Istituto Nazionale di Fisica Nucleare

ISTITUTO NAZIONALE DI FISICA NUCLEARE

CVI REPORT 2020

INFN SCIENTIFIC PRODUCTIVITY AND ITS SOCIO-ECONOMIC AND INTER-DISCIPLINARY IMPACT

1. INTRODUCTION 4
1.1 INF Strategic Vision 5
2. HIGHLIGHTS FROM THE SCIENTIFIC COMMITTEES 9
2.1 Particle Physics at Accelerators 9
2.2 Astroparticle Physics 19
2.3 Nuclear Physics 24
2.4 Theoretical Physics 33
2.5 Technological and inter-disciplinary research 42
3. THE CTS (COMITATO TECNICO SCIENTIFICO) 45
4. INFN NATIONAL LABORATORIES 46
4.1 LNF Laboratori Nazionali di Frascati 46
4.1.1 Facilities 46
4.1.2 Organization and staff resources 46
4.1.3 Research activity 47
4.1.4 Technology transfer and outreach 56
4.2 LNS Laboratori Nazionali del Sud 59
4.2.1 Scientific Strategy, priorities and goals 59
4.2.2 Scientific and technical progress 61
4.2.3 Activities on External Funds 65
4.2.4 Technology transfer and outreach 65
4.3 LNL Laboratori Nazionali di Legnaro 67
4.3.1 Facilities 67
4.3.2 Scientific strategy, priorities and goals 69
4.3.3 Organization and staff resources 71
4.3.4 Scientific and technical progress 72
4.3.5 Technological transfer and Outreach 77
4.4 LNGS-Laboratori Nazionali del Gran Sasso 81
5 SCIENTIFIC PRODUCTIVITY 82
5.1 Overall scientific production 82
5.2 International framework 85
6. PERSONNEL BALANCE: INCLUSIVENESS, WELL-BEING AND DIVERSITY INSIDE INFN THROUGH A GENDER PERSPECTIVE 87
6.1 Statistical analysis of the INFN personnel under a gender and generational perspective 87
6.2 INFN Affirmative Action Plan 91
6.3 Organizational wellbeing and related activities 93
7 THIRD MISSION AND INFN 94
7.1 The Communication Office 95
7.2 Public engagement activities 101
7.2 Commissione Coordinamento attività Terza Missione - CC3M 103
7.4 Knowledge and Technology Transfer 112
8 EXTERNAL COLLABORATIONS AND FUND RAISING 116
8.1 National competitive funding programmes 116
8.2 The Horizon 2020 Framework Programme 118
8.3 Current organization of External Fund Raising Support Group (DFE) 122
9. ENGAGEMENT IN HIGHER EDUCATION 123
9.1 Students and Graduate training 123
9.2 Post-graduate training 125
APPENDIX A: DETAILED LNF MAP 126
APPENDIX B: LNS ACCELERATORS OPERATION TIME (9MONTHS/YEAR) 127

APPENDIX C: LNL ACCELERATORS OPERATIONS IN 2019 .... **128**
APPENDIX D: LNL ORGANIZATIONAL CHART **129**
APPENDIX E: EXPERIMENTS AT LNL IN 2019 .... **130**
APPENDIX F: RECOMMENDATIONS FROM THE CVI REPORT 2019 .... **131**

1. Introduction

In order to face the new challenges that any research organization in Europe (and outside) is facing in recent years due to changing attitudes towards applied and basic research as well as to an Italian national budget allocated to research shrinking over the last years, INFN has experienced strong changes. In this context, the evaluation process, and data collection and analysis is used as an additional tool in the attempt to measure the outcome of the research and to (in some cases) redirect resources to the best players.

Something about the Covid here...

INFN has always been focussed in tracking its research programmes, thanks to several bodies which perform *ex-ante, in-itinere* and *ex-post* evaluation of experiments and initiatives: the Executive Board, the Board of Directors (CD), the Scientific Committees and Scientific and Technical Committee (CTS) are the bodies in charge of these fundamental tasks. Since 1997 INFN has a CVI and a Gruppo di Lavoro sulla Valutazione (GLV), that prepares this annual Report. The members of the GLV, three for each individual INFN research area plus the CSN Chairs, are listed in the following Table. Marco Pallavicini and Marco Ciuchini are INFN Executive Board members that oversee the GLV.

Research Line	GLV	CSN Chair
Subnuclear Physics (CSN1)	Clara Troncon, Cristina Biino, Monica Pepe	Roberto Tenchini
Astroparticle Physics (CSN2)	Giuseppe Ruoso, Rossella Caruso, Walter Bonivento	Oliviero Cremonesi
Nuclear Physics (CSN3)	Paolo Pedroni, Alessandra Fantoni, Adriana Nannini	Rosario Nania
Theoretical Physics (CSN4)	Luciano Canton, Francesco Murgia, Nazario Tantalo	Fulvio Piccinini
Technological & Interdisciplinary (CSN5)	Luca Tomassetti, Alessandra Retico, Andrea Fabbri	Valter Bonvicini

The overall situation is presented every year to this Committee (CVI), which has the specific mandate to review the quality of INFN activities as a whole. CVI is a reference for the Ministry of University and Research (MUR). In recent years, with the launch of the National exercise to evaluate the quality of research (VQR) a good fraction of the work of the INFN GLV has been devoted to this exercise. In the past, the excellent INFN evaluation in previous VQRs (2004-2010 and 2011-2014) was worth very important additional resources in terms of both research funds and a large number of new researcher positions. A new evaluation, VQR(2015-2019), has been started earlier in January 2020. Results were expected as og July 31th, 2021, however due to the Covid-19 pandemic the final deadline has been postponed to March 2022.

As usual, this report opens with an overview of recent INFN scientific and technological highlights, selected by the Chairs of the National Scientific Committees (CSNs) in Section 2. A very brief CTS summary will follow in Section 3. This year's overarching theme will consist of an overview of INFN's projects with respect to Quantum Computing. We will have status reports on the Technopole project, Technological Transfer and how INFN has coped with the Covid-19 emergency: this last topic will also include a session dedicated to possible research projects on Covid-19 which involve INFN. These activities are not described in this report but will be assessed in depth at the

CVI October meeting.

Sections 4 deals with the reports of the four National Laboratories. The scientific productivity is then addressed in Section 5 which also provides some parameters for international comparison. The following Section 6 deals with gender and human resources. INFN activities in the Third Mission are addressed in Section 7 while Section 8 provides an update on INFN participation to European initiatives and bodies and the situation in terms of fund-raising in competitive calls. Section 9 summarizes the role played by INFN in Higher Education.

This Report is prepared by the Working Group on Research Evaluation (GLVs, Conveners underlined in the inset) coordinated by Pasquale Lubrano, with the advice of the Chairpersons of the INFN CNS's and in close connection with the INFN Executive Board. As in previous reports you will notice that there is often overlap in between Sections, due to overlapping topics being treated by different rapporteurs: this bias can be removed only by a somewhat invasive editing and therefore, at least for this year, it was decided to leave the overlapping as it is.

1.1 INF Strategic Vision

The past year has been difficult and challenging. We had to face a change in the Government, three different Ministers of Research have been in charge in this period and since spring 2020 we had the Covid-19 outbreak.

In July 2019 we had a change of Government in Italy, with the consequent change of the Minister of Research and Education. In January 2020 a further reorganization within the Government lead to the creation of a Ministry exclusively dedicated to Research and University, separated from the Ministry for Education. The new organization, certainly more efficient and focused on research needs, has brought a new Minister (Prof. G. Manfredi) but also some delays due to the time needed to set up the organizational structure of the new ministry from scratch.

Over the past year, INFN has changed its management team. The Executive Board is now composed as follows: dr. Chiara Meroni (vice president) who supervises research in subnuclear physics (HEP), dr. Diego Bettoni (vice president) for nuclear physics, prof. Marco Pallavicini for astroparticle physics, dr. Marco Ciuchini for theoretical physics and dr. Pier Luigi Campana (representative of the Ministry) for Technological and inter-disciplinary research.
Moreover, from September 2020 INFN has a new General Director, dr. Nando Minnella, and has also hired a new administrative manager to coordinate the research area, dr. A. Sequi.
Finally, form August 2020, Fabio Bossi is the new director of the Frascati National Laboratories, while from next October Ezio Previtali will be the new director of the National Laboratories of Gran Sasso.

As already discussed in the previous year reports, budget is a source of concern. The average budget per year needed by INFN for its standard research activities lies between 260 and 270 M€. About half this budget is for salaries and the rest is for research and operations, while the budget for the upgrade of infrastructures or the construction of new ones comes from a different dedicated pot. In 2018 the INFN baseline budget was reduced to 247 M€, due to abolition of the premium quota based and the end of a special funding program from the government. This fact was bringing INFN on a critical path, also because of the increase of the part dedicated to salaries, due to the "stabilization process" and the opening of 73 new positions.

After a long discussion process, we convinced the Research and Education Ministry to increase the INFN 2019 baseline budget to 270 M€, however, due to the government change, this is not yet formally approved. We hope to secure the situation in the next weeks.

In 2020, despite a reduction of about 20 M€ of the overall Ministry budget for Research Institutions, the INFN budget remained constant, while 2021 could be critical.
In parallel in the last two years INFN submitted to the Ministry some projects on the upgrade/renewal of its research infrastructures, for an overall budget of about 650 M€ in the next 15 years. In 2019, the following projects have been approved:

- EuPraxia, which is an upgrade of the existing SPARC FEL of the Frascati Laboratory (LNF) based on advanced acceleration schemes, in the form of high-gradient X-band elements and hopefully with plasma wave accelerated electrons. The overall budget foreseen is 107 M€ in 12 years. The formalization of the approval process is expected in the next weeks.
- Supercomputing Centre in Bologna-Tecnopolo: This project prepared together to the CINECA supercomputing Consortium foresees the preparation of a new big computing infrastructure in the Bologna-Tecnopolo area, which will host the new HPC pre-exascale machine of CINECA and the INFN Tier-1 centre. The overall budget foreseen is 120 M€ in 6 years. The formalization of the approval process is expected in the next weeks.

In 2020 five INFN project on research infrastructures, for a total amount of 330 M€, are currently under scrutiny and the results of this process are expected by the end of the year.

Finally, INFN is currently working in close contact with the Ministry of Research to verify the possibility of exploiting the recovery funds allocated by the European Commission, following the emergency due to COVID-19, for large research projects such as the study and the development of high temperature superconducting magnets and the Einstein telescope, the interferometer for the detection of gravitational waves planned in Sardinia. At the end of 2019, the INFN personnel with permanent positions were 2019, with an increase of about 13% compared to two years earlier. This increase was mainly due to the so called "stabilization process" and the extraordinary recruitment programs for young researchers promoted by the Ministry. In 2020 the INFN policy for the personnel foresees mainly the replacement of turn-over positions and some career advancements for staff with permanent positions.

In 2021 the Government has foreseen a new extraordinary recruitment plan for young researchers and engineers, which will be finalized in the coming weeks. On a preliminary basis, about 200 positions are planned for INFN, to be filled in the next two or three years. This will lead to a further increase of our permanent staff.

The discussion of the strategy for assigning these positions has just begun. Since INFN had already planned to finalize the "stabilization process" in 2021, with the recruitment of 55 researchers and engineers, we are thinking to open these positions as part of the government's extraordinary recruitment plan. Between thirty and fifty positions could then be reserved to cover the turn-over of engineers in the coming years and for some interventions aimed at resolving critical issues in some structures (such as national laboratories, computing centers and the Central Administration). The remaining positions (about one hundred) could be allocated to two extraordinary calls for the recruitment of young researchers to be held at a distance of two years from each other.

Regarding research infrastructures, in 2020 the Ministry of Research has ESFRI (The European Strategic Forum for Research Infrastructures) two Italian-led projects, proposed by INFN:

- Einstein Telescope, the next generation gravitational wave observatory to be built in Europe. There are currently two possible sites, one in Sardinia at the Sos Enattos mine and the other at the end between Belgium and the Netherlands.
- EUPRAXIA a compact plasma accelerator facility with superior beam quality to be installed at the Frascati National Laboratories.
- Starting from 2019 the Ministry of Research has approved the following four PON Projects (Programma Operativo Nazionale) to strengthen INFN research infrastructures located in Italian convergence regions (with lower economic development):
- FARO2030 - Gran Sasso Laboratory (LNGS) infrastructure strengthening for the observation of rare decays. The overall budget approved from PON (Operative National Program) for strengthening research infrastructtures, is 18.4 M€ in 3 years.
- IBISCO – Big Data and scientific computing infrastructure strengthening in southern part of Italy. The overall budget approved from PON program is 11.9 M€ in 3 years.
- PACK – Strengthening of the KM3net underwater research infrastructure. The overall budget approved from PON program is 16.4 M€ in 3 years.
- POTLNS - Strengthening of the National Laboratory of South (LNS) research infrastructure foe the production of high intensity low energy ion beams. The overall budget approved from PON program is 19.3 M€ in 3 years.

A key point activity of the last two years has been the definition of European Particle Physics Strategy, where INFN played a key role participating to all the discussion panels (for example the Physics Preparatory Group and the European Strategy Group) and contributing to the preparation of all the documents. After a long debate the European Particle Physics Strategy was unanimously approved by the CERN Council in June 2020.

INFN faced very actively the Covid-19 outbreak, since its beginning in February 2020. As a first action a Covid-19 Crisis Unit was established. Composed by 7 people with skills in matter of health, management, human resources, legal affairs, communication, the Unit met every day and, with the employee health as a priority, was supporting INFN national and local Management, in particular:

- monitoring the evolution of the pandemic diffusion on the national territory
- suggesting measures and making recommendations to be aligned with the Governmental and local Institutions provisions, and to avoid spread at the workplace
- developing response scenarios, suggesting measures and making recommendations for the modalities of the work activities during the Phase 1 of the emergency, in the case of contamination at the workplace, and for the Phase 2 restart
- preparing and managing the public and internal communication

During the Italian lockdown period, from March 10th to May 4th, INFN has decided to keep its main structures open to provide a message and its contribution to the Country, for continuing to process new orders and payments. About the 95% of the staff was in smart working. Barely the people in charge for the maintenance of safety, technical and computing infrastructures were allowed to enter the workplace. LNGS experiments were kept in data taking, accelerators were turned off and all the travel outside Italy were stopped as well as most in Italy.

Since May 4th, INFN faced the phase 2, restarting some of the activities and increasing the staff at the workplace. At the end of July about the 60% of the staff was still in smart working and we were slowly trying to approach normal work conditions.

Since September INFN, following the indications of the Government, is putting in place a plan to bring back at the workplace about 70% of the personnel.

INFN made its competences and resources promptly available to the covid-19 pandemic contrast (across its network), in particular:

- Protein folding simulation to identify molecules that can interfere with the replication process of the SARS-COV2 virus;
- Design, develop, build and certify a safe, efficient and quick-to-market ventilator, characterized by a simple and open access design (MVM);
- Investigation of the virus replication inhibition by using metal nanoparticles (MeNPs);
- CovidStat public website of statistical analysis of the data about the pandemic diffusion, with synoptic tables and maps navigable interactively;
- Laboratory to test functional qualities of fabrics for the manufacture of masks and PPEs
- Radiogenic source to be used for the sterilization of surfaces;
- Study of possible relationships between the concentration of atmospheric pollutants, meteorological parameters and the biological component of the atmospheric aerosol;
- Possible optimizations of the clinical choice and use of ventilator systems via AI, and study of predictive models based on machine learning to support the diagnosis or prediction of prognosis;
- Use of INFN Cloud open source platform, for simulation and medical and bioinformatics analysis applications for the appropriate treatment of sensitive data.

During the outbreak INFN put in place several communication activities for schools, the large public and the INFN community. Initially schools had difficulty adapting to distance learning. INFN promptly plan and implemented initiatives to support schools and students in their activities, for instance:

- Facebook live events on the main themes of physics research and virtual activities for schools (e.g. Art&Science project);
- A web platform to share didactic, in-depth or popular materials, realized together with other scientific Institutions.

To effectively communicate to the INFN community a dedicated web page, continuously updated, was set up together to the availability of the Covid-19 Crisis Unit to answer to questions and requests of help of the INFN Community. Moreover, Institutional Communications of the INFN Presidency were organized to outline the measures for the contrast of the pandemic diffusion, and to support the INFN Community itself. Finally, it was created an online Team space (Insieme@Distanza) for socialization initiatives, informal dialogue, sharing experiences and staying in touch despite the distance.

2. Highlights from the Scientific Committees

The INFN main mission is to study the basic constituents of matter, and to conduct theoretical and experimental research in the fields of subnuclear, nuclear, and astroparticle physics, in close collaboration with the academic world. Parallel and growing effort in third mission activities has become more and more important in the daily life of INFN researchers.

All the scientific activities carried forward by the scientific committees are developed in close connection with the academic world and other scientific institutions both in Italy and abroad. For all of them, the variety and quality of the research carried out are proven by the number of papers, citations and talks at international conferences. Web pages of the Scientific Committees can be accessed directly from the main INFN web page (www.infn.it).

2.1 Particle Physics at Accelerators

The Commissione Scientifica Nazionale 1 (CSN1) is in charge of evaluating, monitoring and supporting experiments and projects related to particle physics at accelerators. Experiments and R&D activities at present and future accelerators are selected by focusing on their potential value in terms of physics return. The main requirements for supporting experiments and projects are having a high scientific profile and being recognized as timely activities by the worldwide scientific community. In addition, CSN1 pays particular attention to new detector, trigger, computing and accelerator technologies, in close synergy with CSN5.

CSN1 Sector	FTE	Budget
Physics at hadron colliders (LHC)	60.5	59.6
Flavor Physics (including LHCb)	25.9	24.3
Charged Lepton Physics	8.9	12.7
Proton Structure	3.5	2.8
R&D for Future Accelerators	1.2	0.6

Table 2.1 - CSN1 Sectors, FTE and budget (%): year 2019

Physicists, engineers and doctoral students contribute to several active lines of research whose composition and budget are summarized in Table 2.1. The total number of FTE assigned to the CSN1 in 2019, mainly for the construction, operation and data analysis of the experiments was 835, to be incremented by about other 35 contributing to new frontier detectors, electronics and computing developments assigned to CSN5 or with other external grants. The overall budget for 2019 was over 20 M€, with additional 900 k€ coming from European RISE funds and ~ 1 M€ coming from other competitive funds (mostly EU ERC and regional projects).

In 2019 CSN1 has supported experiments at CERN, FERMILAB, IHEP, LNF, KEK and PSI; these experiments have explored fundamental physics at the forefront of High Energy Physics research, producing a total of 562 publications over the year. By far the most important CSN1 commitments, human and resource-wise, are currently within the LHC experiments. More than 500 INFN supported physicists, and about 100 engineers participate with significant and visible roles in the ATLAS, CMS, LHCb, LHCf and TOTEM collaborations, and they are deeply involved in the construction, maintenance, and operation of the experiments, as well as in the associated analysis work and studies for future upgrades. The outstanding Italian contribution to the LHC program is recognized within the international collaborations with many managerial roles. In 2019 the Spokepersons of two of the major experiments, CMS and LHCb, were from INFN.

In 2019 **LHC** started the second long shutdown (LS2) after delivering during four years at a center-of-mass energy of 13 TeV (Run 2, 2015-2018) an integrated luminosity of 156 fb^{-1} and 163 fb^{-1}, respectively, to the general-purpose hadron collider experiments **ATLAS** and **CMS**. The record peak luminosity exceeded 2×10^{34} $cm^{-2}s^{-1}$ and the average number of interactions per crossing in pp collisions was about 36 in the last two years. The data taking efficiency of the two experiments over the entire Run 2 period was high (94% and 92%, respectively), and the fraction of data certified as good quality after offline reconstruction typically about 93%. In 2019 data was smoothly reprocessed by the computing system of the two experiments for the so-called “legacy datasets”. The key indicators of computing activities, in particular for the INFN Tier-1 and Tier-2 centres, were all in line with expectations from previous running periods. The production of large Monte Carlo samples remained the largest resource consumer for both experiments, with a substantial fraction of the simulated data dedicated at detector studies for the Phase 2 (HL-LHC) upgrades.

Since the start of LS2, the ATLAS and CMS detectors has been undergoing an intense programme of maintenance and consolidation. Data-taking activities in 2019 have been limited to standalone runs of individual systems and cosmic data-taking. The main goal of these standalone runs was to follow the maintenance work carried out on the detectors, and to qualify replaced or newly installed components, in order to re-establish the full data-taking chain including data reconstruction before the start of Run 3.

Some highlights of the ATLAS LS2 achievements in 2019 include the mounting of two complete sectors on a support disc of the Muon New Small Wheel, the Liquid-Argon calorimeter’s installation and commissioning campaign for maintenance and upgrade of electronics and the replacement of Tile-calorimeter front-end-cooling connectors with a new, more radiation-tolerant variant. For what concerns CMS the first layer of the pixel detector has been replaced with a new version including a DC-DC converter with radiation hardness adequate for Run 3. In addition a significant effort took place to anticipate the Phase-2 Muon upgrade program. This work included the installation of improved CSC on-detector electronics, the new GEM-based GE1/1 stations (both to be operational already during Run 3), and the installation of services for the future GEM detectors GE2/1 and RPC RE3/1, RE4/1. Furthermore, an extensive repair campaign of leaks in the RPC chambers was ongoing as part of the overall strategy to reduce greenhouse gas (GHG) emissions.

Concerning Phase 2 upgrade activities, during 2019 the main Phase 2 MoUs have been finalized and sent out for signature to the funding agencies, including INFN. Considerable progress has been made on the detailed definition of the many projects, however R&D is still going on and funded by CSN1 in several areas: it is expected to continue until early 2021. A systematic review of the proposed Phase 2 activities, which require infrastructures, manpower and R&Ds, has been pursued by CSN1 referees with the objective of staying efficiently and effectively within the total envelop budget of 64 M€ secured by INFN management. This budget includes up to 45 M€ CORE contribution to the approved Money Matrix of ATLAS and CMS, complemented by an additional 8 M€ contingency, additional human resources dedicated to the Phase 2 construction, infrastructure and final R&D. To be noted that no additional budget has been discussed or secured to cover computing costs for HL-LHC phase neither at CERN or by INFN.

The physics analysis efforts of the ATLAS and CMS collaborations in year 2019 have been mainly focused towards exploiting the full Run-2 proton-proton collision dataset. Recent new results for the ATLAS Collaboration include searches extending the territory explored for new physics, like a search for gluinos in events with many jets and a search for a heavy Higgs decaying to a pair of tau leptons and measurements in key processes of the Standard Model, like a new full Run 2 measurements of Higgs-boson differential cross sections in the $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ decay modes, and the observation of the charge asymmetry in top-quark production at the level of 4 σ, or the observation of the electroweak production of two jets in association with two Z bosons with a statistical significance of 5.5 σ, which set the reach of a new milestone in the study of electroweak symmetry breaking (Figure 2.1, left panel). In 2019, CMS has published the most precise measurements of the Higgs boson mass. From the 4-lepton and diphoton channels and their combination (which includes the Run 1 statistics) a total uncertainty on the Higgs mass of just 150 MeV was achieved. The top-antitop-Higgs associate production (ttH) has been observed in a single Higgs decay mode with a significance of 6.6σ (Figure 2.1, right panel). Important results have also been obtained in flavour physics, with an updated measurement of the $B_{s,d} \rightarrow \mu\mu$ branching fractions, and the observation of excited B_c states. In this realm, CMS has made a special effort by parking non-prompt-reconstructed data especially dedicated to B physics. For the exotic searches, it is worth mentioning the complete scan of the dimuon invariant mass spectrum between 11 GeV and 5 TeV. The ATLAS and CMS Collaborations are making a significant effort to combine their results in a consistent way, this is particularly evident for Higgs boson, top quark and electroweak physics as well for dark matter searches, where a number of results on combinations of measurements appeared, in collaboration with the theory community. The INFN groups are at the forefront of all above-mentioned physics activities.

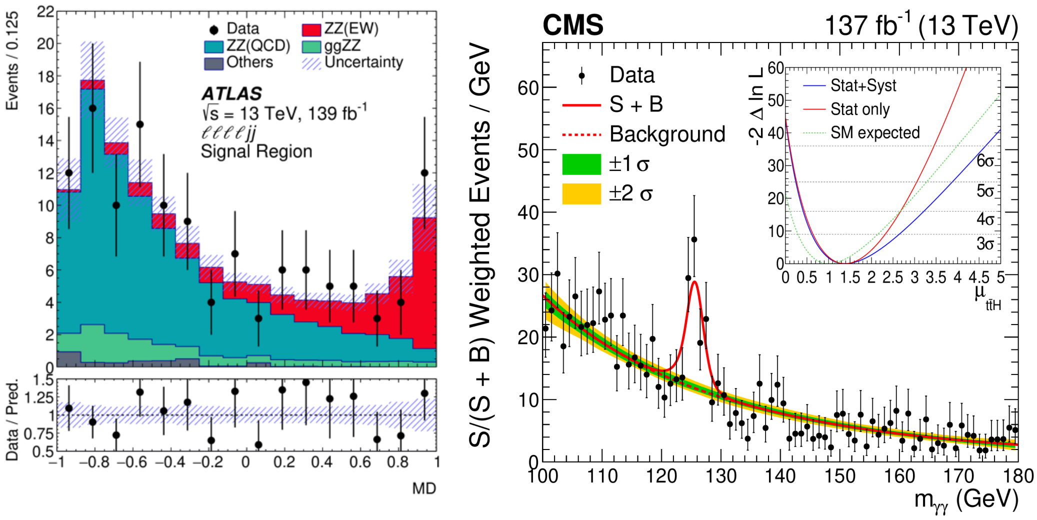


Figure 2.1 - (left panel) Observed and predicted multivariate discriminant distributions after the statistical fit in the signal region for the four-lepton channel in the search for the electroweak production of two jets in association with two Z bosons. (ATLAS Collaboration/CERN), (right panel) invariant mass distribution for the selected events related to the ttH observation in the $H \rightarrow \gamma\gamma$ channel (CMS Collaboration/CERN).

The **TOTEM** experiment at LHC, placed in the same interaction point as CMS, is progressing with its integration with the larger experiment. The TOTEM Collaboration completed a publication on the pp cross section at 13 TeV and, at the same centre-of-mass energy, also on the ρ parameter in the Coulomb-Nuclear Interference region. The increase of the ratio between the elastic and total cross-sections is confirmed, along with the presence of a dip, in the differential elastic cross-section, which position decreases with the energy. The absence of structures at higher t is confirmed. Moreover thanks to the higher statistics collected with a special run at β^*=2500 m, for the first time at LHC, the total cross-section has been measured using QED parameters with three different approaches, obtaining a final value of 110.5±2.4 mb at 13 TeV. The results obtained at 13 TeV show that none of the usual models can simultaneously fit the energy dependence of the total cross section and the ρ parameter while models including an "odderon" exchange better fit both quantities. Activities related to LS2 include the consolidation of the roman pot infrastructure, including a relocation of some stations and the improvement of the movement software and actuators. Moreover the TDR of a new inelastic telescope, T2, has been approved by LHCC and prototype tests were performed before starting the construction. In parallel, the construction of a new diamond based timing detector station, for the common CMS PPS project, started.

The **LHCf** experiment, aimed at studying hadron cascades to better understand cosmic-rays interactions in the Earth's atmosphere, has so far been operated for dedicated low luminosity runs both at the LHC and RHIC hadron colliders, in such a way to exploit different collision energies and different types of colliding particles. In 2019 the proposal for new special LHCf runs in p+p and p+O collisions during the LHC Run 3 has been approved and supported by the LHCC and CERN Research Board. The main efforts of the collaboration were focused in two main directions: the upgrade of the DAQ system of the Arm2 detector, in view of Run 3 and the analysis of data collected in the previous runs. The hardware activity was dedicated to the procurement and test of the new DAQ PC and to the design of custom electronic boards based on commercial components implementing the GBit Ethernet communication protocol, thus freeing the experiment from the use of very specific electronic devices and protocols. The first boards have been already produced and successfully tested while the remaining ones are in the prototyping phase. Concerning data analysis, during 2019 the collaboration was committed to finalize the results for neutron production in pp collision at 13 TeV total energy at LHC, for the study of asymmetries in π^0 production in pp collisions at 510 GeV with polarized beams at RHIC and for single photon production in pp collision at 13 TeV at LHC exploiting the LHCf/ATLAS common data sets.

The **LHCb** experiment is dedicated to the study of **flavor physics** in the **heavy-quark sector**, exploiting the large cross section of charm and beauty production in LHC pp collisions. The experiment completed its last data taking in 2018, and the collaboration is now focusing on the installation of the upgraded detector to resume operation in the LHC Run 3 with an increased instantaneous luminosity of 2×10^{33} $cm^{-2}s^{-1}$. The upgrade effort notably includes sub-detectors funded by INFN, namely the muon system, the upstream tracker, the RICH system and the novel SMOG2 system – a storage cell for injecting different gases upstream of the VELO detector that is expected to widen significantly the physics reach of the fixed-target programme of the experiment.
The LHCb Run 1 + Run 2 datasets comprise pp, pPb, and PbPb collision data at various center-of-mass energies, as well as pA (A = He, Ne, Ar) collisions in fixed target mode, using a pre-SMOG2 gas-injection system. Physics highlights from 2019 include several new measurements, briefly mentioned in the following.

The time-integrated CP-asymmetry difference of $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays, ΔA_{CP}, has been measured at the 10^{-3} level using the full Run 1 + Run 2 statistics, leading to the first observation of CP violation in the charm sector. The result is consistent with the Standard Model expectations, which lie in the range 10^{-4}–10^{-3}. In the coming decade, further measurements with charmed particles will help clarify the physics picture further and establish whether any new physics effect is at play. Although the existence of direct CP violation in the charm system has been established, mixing-induced CP-violation in charm decays still remains an open question. In the Standard Model it is predicted to be much smaller, at the 10^{-5} level, but subject to smaller theoretical uncertainties than direct CP violation, thus resulting in a more sensitive probe for new physics. LHCb performed the most precise measurement of the time-dependent *CP* asymmetry A_Γ in *D*-meson decays, achieving a precision at the 10^{-4} level, starting to approach the precision needed to measure the Standard Model value.

Along with *CP*-violating phases, measurements of the sides of the CKM triangle are also of great interest in order to probe the overall consistency of the Standard Model. Since several years there has been a tension between inclusive and exclusive measurements of the magnitude of the V_{cb} CKM matrix element. LHCb has made the first measurement of $|V_{cb}|$ at a hadron collider, as well as the first ever with B_s^0 decays, using an exclusive method with the final states $B_s^0 \rightarrow D_s^- \mu^+ \nu$ and $B_s^0 \rightarrow D_s^{*-} \mu^+ \nu$. Further highlights comprise the update of the angular analysis of the $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ decay, a test of lepton-flavor universality with baryon decays, using $\Lambda^0_b \rightarrow pK^- l^+ l^-$ for $l = \mu$, e, and the observation of several new heavy-quark resonances.

In the first part of 2020, LHCb also completed an analysis that has led to the first observation of a tetraquark state composed of two charm and two anticharm quarks (Figure 2.2). By studying the J/ψ-pair invariant mass spectrum, a narrow structure at about 6.9 GeV/c^2 has been observed, matching the lineshape of a new resonance, along with the presence of a broader structure closer to the di-J/ψ mass threshold. The global significance of the new state has been determined to be larger than 5σ.

The flavor physics programme of the **Belle II** experiment at KEK has started, this program is largely complementary with LHCb. In 2019 and during the first months of 2020 the radiation monitoring and beam abort system of Belle II has been tuned. The system worked nicely and it was used extensively and in close connection with SuperKEKB teams in order to optimize luminosity

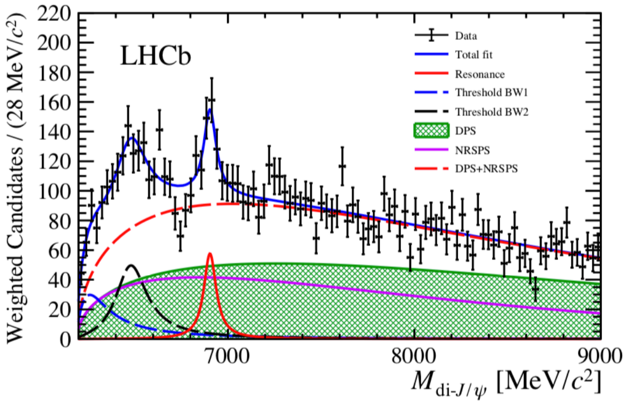


Figure 2.2 - Invariant-mass spectrum of di-J/ψ candidates showing the presence of a narrow structure at 6.9 GeV/c^2 and of a broader structure closer to the threshold.

and background. The Belle II outer detectors have been integrated in the Global Trigger. In particular, the situation of both KLM and TOP detectors drastically improved from 2018. INFN gave relevant contribution to both the debugging phase and the study of KLM efficiency and muon identification and trigger integration. During 2019 the second commissioning phase of the SuperKEKB accelerator has been carried out. Collisions started in 2020 and the optics allowed to reach 5.5 10^{33} $cm^{-2}s^{-1}$ soon after. The Crab waist scheme and continuous injection have been successfully implemented at SuperKEKB; after mitigation of the machine background the accelerator reached 2.4 10^{34} $cm^{-2}s^{-1}$ (setting the luminosity world record) thus allowing 63 fb^{-1} to be collected by the experiment at the time of writing. One important result of this initial phase is the measurement of the decays of Z' into invisible plus μ+ μ- or plus lepton flavour violating channels.

The **strange sector (Kaon physics)** represents an important component of **flavor physics**, in this realm CSN1 supports the **NA62** fixed target experiment at CERN and the **KLOE** experiment at DAPHNE in Frascati.

During 2019 NA62 has continued analyzing data collected in its Run I (2016-2018) achieving significant progress on both the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis and on several other rare kaon and exotic processes. The world-best signal event sensitivity for the BR ($K^+ \to \pi^+ \nu\bar{\nu}$) has been achieved by NA62 with 2017 data, and two candidate events for the ultrarare decay have been found, resulting in the best limit so far on the decay width, thus excluding part of the allowed parameter space for BSM models. Analysis of 2018 data has started and both the effect of the new collimator installed in 2018 and of new data analysis strategies were expected to lead to a further significant increase in signal sensitivity. Indeed, very recently (ICHEP 2020), the collaboration has presented first significant experimental evidence, 3.5 standard deviation significance, for this signal mode.

In the meanwhile, the collaboration has designed an improved system of upstream detectors, including a fourth GTK station and a system of additional veto counters to drastically reduce the dominant background due to the K upstream decays. They are going to be built and installed in 2020, ready for the next data taking foreseen in 2021. The collaboration is progressing also in analyses of numerous other rare and/or forbidden kaon decays and in the search for exotics processes; a new result on the search for lepton number violating decays $K^+ \to \pi^+ ll$ has been published in 2019 improving by a factor of three the previously published best limits.
INFN keeps its leading role in the experiment, with important responsibilities also on the upgrade of the detector (GTK) and key roles on data analysis.

The KLOE-2 experiment successfully concluded its data-taking campaign at DAΦNE in Frascati in March 2018, acquiring a total integrated luminosity of 5.5 fb^{-1} and exceeding its target luminosity by 10%. Including the 2.5 fb^{-1} previously collected by KLOE, an integrated luminosity of around 8 fb^{-1} was acquired, corresponding to ~24 billions of ϕ-mesons produced and representing the largest ever data sample collected at the peak of the ϕ(1020) resonance.
The KLOE-2 collaboration is presently focused on the analysis of the data collected, mainly concerning the tests of the fundamental discrete symmetries with entangled pairs of K mesons, rare kaon and η decays, searches of Dark Force mediators, and the study of the π^0 production in γγ collisions by exploiting the taggers for scattered electrons installed for the KLOE-2 data-taking.
The latest results achieved during 2019 and the beginning of 2020 are: i) the first measurement ever obtained of the branching ratio of the $K_{S\mu3}$ decay, with 2.4% statistical and 3.7% systematic uncertainties; the result is in agreement with the branching ratio expected assuming universality of the kaon-lepton coupling, and can be used for a determination of the V_{us} element of the CKM matrix which is in agreement with the values obtained from the other kaon semileptonic decays; ii) the best upper limit of the P and CP violating decay $\eta \to \pi^+\pi^-$ based on 1.7 fb^{-1} of the KLOE data set; the result improves by a factor of three the previous best limit also obtained by the KLOE Collaboration.

The BES-III experiment at BEPCII in Beijing, PRC, plays a unique role in the tau lepton and charm quark energy region (2 – 4.6 GeV) with many results in **hadron spectroscopy and flavour physics**. In 2019 BESIII collected 3.7 fb^{-1} in the range between 4.6 – 4.7 GeV. The recent upgrade of the machine allowed this higher centre-of-mass energy to be reached, exploring a new energy range. BEPCII switched to top-up mode on Dec.31, 2019 with an increase in the integrated luminosity of about 30%. The INFN community has performed the commissioning of 2/3 of the CGEM-IT at the IHEP laboratory, utilizing cosmic rays with remote control. The BESIII collaboration has reported the most precise measurements to date of the relative strong-phase parameters between D^0 and D^0bar in the decays to $K\_{S,L}\pi^+\pi^-$. Crucial inputs for a variety of CP-violation studies can be determined through the analysis of pairs of quantum-entangled neutral D mesons, which are produced in the decay of the ψ(3770) resonance. In particular the strong-phase parameters provide key inputs in the determination of some of the fundamental parameters in the standard model (SM) of particle physics, like the γ CKM phase angle improving its determination uncertainty by a factor of three. Furthermore a preliminary measurement of time-like neutron form-factor via $e^+ e^-$ -> nnbar has been performed. The electromagnetic form factors are useful to test our understanding of the strong interaction, being the simplest structure observables. The results show improved statistical precision by more than a factor of 60 and initiate a new era where the accuracy of neutron form factor data from annihilation in the time-like regime is similar to that of the electron scattering data. Among many others, we mention the results of the study of open-charm decays and radiative transitions of the X(3872). The process X(3872) → D^{*0} D^0bar +c.c. was observed and evidence for X(3872) → γJ/ψ was found with statistical significances of 7.4σ and 3.5σ, respectively. The measurement, taking into account model predictions, suggests that the X(3872) state is more likely to be a molecule or a mixture of molecule and charmonium, than a pure charmonium state.

An important component of CSN1 research activities concerns the investigation of rare processes and properties related to **charged leptons**. In this sector we have two experiments in preparation related to a possible charged lepton flavor violation (CLFV) coupling leading to a μeγ vertex (**MEG II** and **MU2E**), the **E989** at Fermilab dedicated to a precise determination of the muon anomaly, and the **MUonE** experiment dedicated to muon-electron elastic scattering. In addition, a possible rare process of positron-electron annihilation into a γ and a dark photon is being investigated by the **PADME** experiment in Frascati.

All the components of the MEG II experiment are in operation since 2018 despite the limited (10%) available number of readout channels. The experiment will be completely equipped with the readout electronics at the beginning of 2021. The engineering run foreseen for autumn 2020 will be fundamental to comprehend and reduce the observed wire instabilities in the drift chamber. Physics data taking is foreseen to start in 2021 with the full apparatus in search of lepton flavor violations $\mu^+ \rightarrow e^+\gamma$, aiming at improving the precision on the branching fraction by one order of magnitude.

The Mu2e experiment at FNAL plans to improve by four orders of magnitude the sensitivity reach of the previous best experiment at PSI (MEG-I). In the last two years, Mu2e has well progressed in constructing its apparatus, succeeding to build a good fraction of the two large magnets (Production and Detector solenoids) needed for producing the muon beam and hosting the detection systems. INFN has followed up the construction of the Transport Solenoid (TS), used for transporting and selecting the negative muons, that has been completed at ASG Superconducting in Genova. All assembled modules have been shipped to FNAL where they were cold-test qualified. The upstream side of the TS (TSU) has been assembled over its cryostat, while the downstream section (TSD) is 85% completed. INFN has also a responsibility role for the design, assembly and commissioning of the un-doped CsI crystal calorimeter. At the end of 2019, the contract with St. Gobain (France) for the production of the remaining 330 crystals has been ended and the production assigned to the SICCAS company (China). 240 out of 330 crystals have been already delivered and successfully tested. The irradiation campaign for the Analog and Digital electronics was completed in 2019 and the production of 3500 preamplifier boards is now under way after a successful Construction Readiness Review in November 2019. A vertical slice test with the new prototypes of radiation-hard Analog and Digital electronics is under way to provide green light also for the production of the digital part. All tenders for the realization of the large mechanical pieces have been assigned and all parts are under construction. The calorimeter assembly operation, planned for fall 2020, is now scheduled for beginning of 2021.

The Muon g-2 experiment at Fermilab (E989) completed its second physics run, Run 2, in July 2019 collecting twice the statistics accumulated at BNL. The main improvements with respect to Run1 were: stability of run conditions; magnetic field uniformity about 2x better; improved systematics (i.e. electrostatic quadrupoles). The number of positrons above threshold was ~500/fill (CTAGS), the uptime was more than 90% and the average statistics collected for "good" day corresponded to about 3% of the previous BNL experiment. During the 2019 summer shutdown there was some activity to prepare for Run 3, mostly focused to the Hall and Laser Hut Cooling (mechanical, electrical, controls) and kickers (increase the HV set-point). The third physics run, Run 3, started around the end of November 2019 with some improvements compared to the previous run: thermal control of the experimental room and of the laser hut at ±1 C; small modifications of the apparatus (for example improved cables of the kicker HV), and shows an increase uptime (~ 94%) and a smooth data taking. Some machine time was dedicated to systematics studies.

As far as the analysis is concerned the collaboration is moving towards the publication of Run 1 data with a statistical error comparable to the BNL experiment. In February 2020 the software offset of the whole Run1 dataset was removed, showing good consistency amongst the different un-blinded analyses. INFN personnel have led one of these analyses.

The PADME collaboration at the Beam Test Facility (BTF) of the Frascati Linac has completed the data acquisition for Run 1 at the end of February 2019 collecting ~5×10^{12} positrons on target (POT) with an average of 1×10^{11} POT/day using mostly secondary beam. The study of the Run 1 data set revealed a high level of beam related background, the origin of which was studied with MC simulations. It was established that the origin of the background was the beam halo originated by the BTF secondary production target, and by the presence of a Be window separating LINAC from PADME vacuum. Beam tests performed in July 2019 revealed that primary positron beam has a much lower background level. Test with different position of the Be window failed. The Be window subsequently broke during the vacuum pumping and the area was closed to avoid possible contamination. Data analysis of Run 1 allowed the detector performance to be validated; clean samples of ee->γγ have been extracted. The Run 2 is expected to take place in 2020.

In June 2019 a Letter of Intent has been submitted to the SPSC, proposing an experiment to measure the running of α in a direct way in μe→μe scattering (**MUonE**). Several INFN researchers, together with other international collaborators, signed the proposal. The experiment is based on a series of independent target and tracking modules, utilizing silicon sensors, with the purpose of measuring the muon and electron scattering angles for 150 GeV muons impinging on low-Z targets (Be or C). The aim is to measure the running of the fine structure constant in a q^2 region of interest for g-2 experiments, providing an independent and direct measurement of one of the most uncertain parameters for the determination of the muon anomaly. The SPSC has recently approved a test of the experiment for the end of 2021; CSN1 is supporting the preparation of this test, together with international partners.

The **COMPASS** experiment at the M2 beam line of the SPS at CERN plays a leading role in the investigation of the **nucleon structure** and in the **hadron spectroscopy**. In the last year the activity of the COMPASS experiment was mainly focused on the preparation of the apparatus for the incoming physics run in 2021 with polarised muons on a transversely polarised deuteron target. Major progress was also made in the analysis of data for both hadron spectroscopy and the structure of the nucleon. The analysis on the triangle singularity as the origin of the a1(1420) has been completed on the large data sets on diffractive dissociation reactions and the paper has been accepted by PRL. Results from SIDIS (semi-inclusive deep inelastic scattering) data, on the multiplicity ratios for identified hadrons, extended to the high z kinematic region, are being published on PLB: they indicate that the range of applicability of pQCD formalism in SIDIS should be revised. The study of the exclusive vector meson (VM) contribution to the SIDIS hadron sample has been finalized, finding important effect and the correction for the azimuthal asymmetries; the corresponding paper has been sent for publication at the end of 2019. The extraction of p_T weighted Sivers asymmetry (published on PLB in 2019) allowed a point-by-point extraction of the first moments of the Sivers functions and a model independent comparison with the result obtained in the Drell-Yan experiment. Concerning the DY data, after updating the published results for the Sivers TMD PDFs and all DY Transverse Spin Asymmetries (TSAs), including virtual photon transverse momentum qT -weighted ones, progress was made on the extraction of TSAs from the J/Ψ mass range, with preliminary results for the twist-2 TSAs. Exclusive π^0 production cross section results have been published on PLB, providing important input for modeling Generalised Parton Distributions. Moreover an updated proposal for new measurements using the COMPASS apparatus and the M2 beam line has been submitted to SPSC in September 2019, including proton radius measurement, Drell-Yan process, antiproton production cross-section measurement.

An important component of the CSN1 activities concerns **preparation for the future of the field and related R&D**. Regarding applications in the near-term future (i.e. on the timescale of the HL-LHC run) we have supported the experimental program of **UA9**, aimed at using bent silicon crystals to manipulate particle beams. Once demonstrated the beam collimation in LHC, a big effort was devoted to optimize crystal characterization to deliver and validate a full batch to be devoted to ion beam collimation for HL-LHC. The first tests with heavy ion beam in LHC were successful.
Furthermore, the crystal collimation at LHC was successfully tested in operation with significant background suppression in the TOTEM experiment. Two INFN-CERN agreements have been signed: one for the construction of collimation crystals for LHC (INFN Ferrara) and the other for roman-pots production for the SPS (LNF). A new MoU for the continuation of UA9 is currently under discussion.

CSN1 is actively contributing to the CERN collaborations devoted to different crucial developments on detectors and electronics: RD51 (presently with INFN Spokesperson) on MultiPatternGasDetector (MPGD), RD50 on silicon sensors and RD53 on pixel font-end ASIC readout design.

The **SHiP** Collaboration completed the Comprehensive Design Study, with a document submitted to the SPS committee at the end of 2019. Several tests of sub-detector configurations were performed in 2019 at DESY. A prototype of the surrounding background tagger based on liquid-scintillator viewed by wave-length-shifting optical modules was exposed to address questions about mechanics and materials used. A prototype of the electromagnetic calorimeter, based on scintillator with additional high-resolution layers for the measurement of shower directions, was also tested. The combination of emulsion detectors and SciFi planes was tested in order to evaluate the performance in the electron energy measurement through a calorimetric technique. The design of the Magnet of the Scattering and Neutrino Detector (SND), capable of providing a 1.2 T field in a ~10 m^3 region at a temperature lower than 18°C, was finalised and published at the beginning of 2020. Results of the muon flux measurement at SPS with a SHiP-like target were published. The data analysis of the SHiP-charm exposure performed in 2018 required the development of new algorithms in order to reconstruct interaction vertices in a high-density environment. It was possible to retrieve the proton interaction component and the results are being published. The SHiP Collaboration submitted in February 2020 the proposal for a detector to be installed in the TI18 tunnel to measure for the first time the cross-section of neutrinos produced in pp collisions at the LHC. The detector, called SND, combines the nuclear emulsion technique with electronic detectors to identify all the three neutrino flavours.

Beyond the near-term projects just described, an intense activity is supported by the CSN1 to prepare the future of the field, both contributing to international efforts and discussing commitments in dedicated meetings and events. Several working groups were established at international level to prepare the input to the European Strategy for Particle Physics (ESPP) and to write the related documents, which were submitted in December 2018 with substantial INFN participation. The involvement of the INFN personnel continued during the works, which took place to develop the ESPP update, in particular in preparation, during and after the Granada Open Symposium (May 2019).

Several INFN studies were used as input to the four volumes of the FCC CDR, describing the physics potential of new colliders that could be installed in a new circular tunnel of 100 km length (FCC-ee, FCC-hh, FCC-eh), or in the current LHC tunnel (HE-LHC). INFN researchers have been mainly contributing to physics, detectors and MDI (Machine Detector Interface) studies for a future large e^+e^- circular collider (FCC-ee at CERN, or its Chinese counterpart CepC), aimed at taking data at the Z pole, at and above the WW production threshold, above the HZ production threshold (as a Higgs factory) and at the top-antitop production threshold. These studies included test beams and R&D on detectors, which lead the design of a conceptual apparatus (IDEA), with suitable technologies to operate efficiently at FCC-ee or CepC. Contributions were also submitted to the working groups on future hadron machines, such as HE-LHC or FCC-hh, taking advantage of the experience gained by INFN groups in the LHC experiments and in the preparation studies for HL-LHC.

Another area of substantial activity by INFN researchers concerns the proposal of a muon source for a future Muon Collider, exploiting the muon pair production at threshold by an intense positron beam impinging on electrons at rest in a light target (LEMMA option), with the advantage of minimizing emittance and avoiding cooling needed for proton-driver-generated muons beam (MAP option). In addition beam background induced on detector and neutrinos radiation hazard is expected to be lower with the LEMMA option. The LEMMA team had provided dedicated simulation studies on muon source (positron beam and target). Beam tests took place at CERN (2017 and 2018) to measure cross section and emittance, with different targets. A new design of the muon production target was developed and presented in 2019 at the Granada Symposium. Recently, as a result of the ESSP discussions, a CERN international working group was set-up to evaluate the muon collider options and their feasibility, with the intention to propose a demonstrator on a time scale of a few years.

CSN1 is paying special attention to education and training of young physicists and to this extent has setup a specific postdocs program with over than a 1 M€/year to support 20-25 people permanently at CERN mainly working at LHC. Dedicated fellowships have been established for development on scientific computing crucial items thanks to external funds, aiming at a regular program of 6 biannual grant/year (~ 0.5 M€/year). Moreover it has been established, and very well received, a dedicated grant for up to 12 undergraduates/year (~ 0.15 M€/year) to acquaint international laboratory experience during the fourth year of undergraduate studies.

2.2 Astroparticle Physics

The area of Astroparticle and Fundamental Physics is coordinated by the Second National Scientific Committee (CSN2).

Astroparticle Physics is one of the institutional research areas of the INFN, aiming at investigating the physical properties of particle and fields in a way that is complementary to the studies carried out at particle accelerators. The understanding of the properties of neutrinos, the direct detection of gravitational waves and their use to study unique physics systems such as black holes and neutron stars, the identification of the constituents of dark matter, the explanation for the absence of antimatter in the Universe, the study of the composition and spectrum of cosmic radiation, the search of new physics at atomic or nuclear scale, and the study of subtle effects predicted by General Relativity are some of the research fields supported by the CSN2.

CSN2 experiments exploit non-accelerator techniques and infrastructures, with neutrino beams or man-made neutrino sources such as reactors or artificial sources. They span from table-top experiments which carry out high precision experiments, to orbiting satellites and huge ground-based installations which measure the flux of particles produced by astrophysical sources.

CSN2 experiments are based in natural environments (e.g. space, stratospheric baloons, deep sea, deserts, mountains) as well as nuclear physics laboratories (FNAL, KEK, CERN) and underground installations (LNGS, SURF, KAMIOKA) where the signal to background ratio reaches the sensitivities to observe extremely rare processes. Since a couple of decades, a significant fraction of the activity of CSN2 is performed in space in close cooperation with the Italian Space Agency (ASI).

A significant number of small and/or medium size proposals has been submitted in 2019. Part of them were approved with a tight time profile (NUCLEUS, Ptolemy, COSINUS, VMBCERN, LiteBIRD, CYGNO and SPB2) and will be strictly monitored by CSN2.

Aa already outlined in previous reports, CSN2 activities are divided into four scientific lines:

- **Neutrino Physics**, including experiments studying solar (e.g. BOREXino at LNGS) or galactic supernovae (LVD at LNGS) neutrinos or using artificial neutrino beams (ICARUS-SBL in USA, T2K in Japan, JUNO in China, DUNE in USA). Experiments on fundamental neutrino properties (CUORE, GERDA, CUPID at LNGS) and on direct measurement of neutrino mass (HOLMES, Ptolemy) are also included in this line.

- **Radiation from the Universe**, including large ground-based experiments studying cosmic gamma rays (MAGIC at the Canary Islands and the future CTA), or cosmic rays in the very high energy sector (AUGER in Argentina), or neutrino astronomy (KM3Net deep in the Mediterranean Sea). This line includes also space-born experiments, dedicated to gamma rays (FERMI), X-rays polarization (IXPE), and antimatter and dark matter (AMS-02 and DAMPE). CSN2 participates also in projects devoted to the study of Cosmic Microwave Background Radiation (LSPE and QUBIC) and of dark energy (EUCLID). The e-Astrogam project was not selected for Phase A by ESA so it will not continue. The participation to a low energy X ray mission approved by ASI is presently under discussion.

- **Dark Universe** studies are mostly performed at LNGS. This sector includes experiments for dark matter (DAMA, XENON, CRESST, DarkSide and COSINUS). The possible extension of a search of axions (QUAX) is being considered.

- **Gravitational Waves** (GW) experiments include VIRGO-Adv, the continuously upgraded interferometer in Cascina, and LISA the future space interferometer. An Italian site for the third generation of ground-based GW interferometers (ET or Einstein telescope) is being supported by INFN in Sardinia. General relativity tests in conditions of weak field (MOONLIGHT, SATOR_G, and G-GRANSASSO) can provide important complementary measurements to GW, while experiments made with cold atoms (SUPREMO, HUMOR, FISH) exploit quantum technologies to carry out tests of fundamental physics.

INFN groups play leading roles in many of the above-mentioned experiments and have worldwide visibility. In 2019, the research activity of the CSN2 was organized in 42 experimental initiatives: Table 2.2 summarizes the budget and FTE sharing among the 4 lines, while Table 2.3 lists some CSN2 gender statistics.

Highlights from 2019

The year 2019 has been characterized by a number of experiments in full operation which have produced a rich harvest of results. Significant progress has been recorded also for a number of projects under construction, upgrade or design.

VIRGO-Adv completed the upgrade of the detector and started the O3 run in April 2019. The first exciting results were not long in coming with additional observations of BBH mergers and a long series of surprising observations. Run O3 collected data for over 11 months, with 56 public alerts, 2 articles published and dozens in preparation. The combination of the first observed LIGO-Virgo signal (GW170817) with the observations of 33 radio-telescopes from around the world, allowed to get a picture of the relativistic beam emitted in the merger event, a real success of the multi-messenger approach. While run O3 was ongoing, the Virgo collaboration has already started the preparation of the next run (O4) and of the upgrade for phase 2.

CSN2 Area	FTE	Budget
1. Neutrino Physics	18%	32%
2. Radiation from the Universe	37%	33%
3. The Dark Universe	18%	21%
4. Gravitational Waves, Gravity and Quantum Mechanics	27%	13%

Table 2.2 - Budget and personnel by scientific line in CSN 2 (in %). The budget column is not normalized to 100% because it does not include general expenses ("Dotazioni").

	Male	Female
National Coordinators of CSN2 Expts	71	29
Local Coordinators of CSN2 Expts	79	21
CSN2 coordinators in INFN Units	81	19
FTE of CSN2 INFN staff	82	18
FTE of CSN2 University staff	80	20
Talks at conferences of CSN2	68	32
INFN Ph.D. Thesis in CSN2	75	25

Table 2.3 - Gender statistics in CSN2 (%)

EINSTEIN TELESCOPE, INFN is working hard to support the candidature of Sardinia as the site for the future third generation ground based gravitational wave detector. To this end (and to support VIRGO-Adv upgrades), dedicated funds have been allocated by MIUR. On the other hand, a prototype of the ARCHIMEDES experiment has been prepared along 2019 and installed in the surface laboratory of Sos Enattos in spring 2020. Preliminary surface measurements have demonstrated that this is a really a quiet place, ideal for a GW observatory.

MAGIC, the long-standing pair of Cherenkov telescopes based at La Palma in the Canary Islands remains a reference for ground based gamma measurements and recorded, for the first time ever, GRB gammas with an energy of the order of TeV.

CTA, the international effort to build the next generation ground-based network of Cerenkov detectors, has installed the first large size telescope (LST1) and has inaugurated the newly developed medium size Schwarzschild-Couder telescope in January 2019, with an important contribution of the INFN groups (Figure 2.3). The commissioning campaign immediately started and first signal from the Crab nebula was finally observed in February 2020.

Figure 2.3 - The Schwarzschild-Couder Prototype Telescope

AMS02, FERMI, DAMPE and HERD - AMS02 is running smoothly. The refurbishment of the cooling system of the AMS2 tracker, was successfully completed at the end of 2019 after a series of EVA's carried out by the astronaut Parmitano outside the ISS. AMS2 has thus began a new phase of observations. Fermi continue to represent a reference for gamma observations from the space, accumulating an increasing list of successful results. Its operation has been so far extended until 2023. DAMPE (DArk Matter Particle Explorer), in orbit around the Earth since December 2015, measured the flux of cosmic protons up to very high energies, of the order of 100 TeV. The INFN participation to HERD on the Chinese Space Station (CSS) has been discussed with ASI. Issues related with the withdrawal of the Italian CSS module appear to be finally solved.

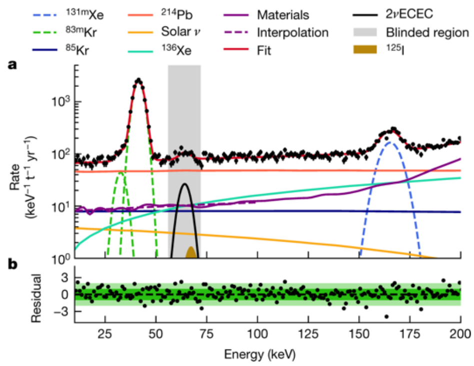
T2K reported in September 2019 a 3σ level indication for CP violation in the lepton sector. The Italian groups are strongly committed to the near detector upgrade, with activities that have continued at the neutrino platform at CERN.

JUNO - The production of the scintillator distillation plants and most of the electronics progressed regularly. The delivery to the Chinese site is expected by the end of 2020. The Italian groups are strongly supporting the realization of a near detector, which would reduce systematics and could represent an important opportunity for FBK. A proposal has been prepared to be discussed in 2020.

ICARUS was successfully installed at FNAL. The filling operations with liquid argon started at the beginning of 2020. The installation of the muon veto will follow after the commissioning of the detector

DUNE – After the signature of the agreement between INFN and DOE about the use of the KLOE magnet and calorimeter as part of the DUNE Near Detector at Fermilab, the INFN groups are preparing to start the effort in 2021.

XENON - XENON-1T detected the longest radioactive decay ever observed in a direct measurement: the double electron capture (2νECEC) of ^{124}Xe (Figure 2.4). The preparation of XENON-nT has continued at tight pace at LNGS. In February 2020, i.e. just few days before the closedown imposed by the covid-19 pandemic, the XENON-nT detector was installed underground. The commissioning of the detector restarted in June and is expected to finish by the end of 2020.



DarkSide20T, which will search for dark matter at LNGS using argon depleted in the radioactive ^{39}Ar isotope, has finalized the design of the setup and submitted a TDR by the end of the year. Argon will be extracted in Colorado (Urania) and purified in Sardinia (ARIA). The conceptual design of the Urania plant evolved during 2019 and was finally approved in February. The design of the cryostat has evolved at CERN, based on the ProtoDUNE model. The corresponding final agreement has been recently signed. The technology to produce low-radioactivity silicon photomultipliers (SiPM) has been perfected and the production of the first Photon Detector Units (PDUs) with FBK SiPMs, started. The tender for the construction of the NOA's clean room was also started.

Figure 2.4 - The XENON-1T spectrum in the ROI for 124Xe 2νDBD. The exposure is 177.7 d in the 1.5-t inner fiducial mass. a, The data are described by a simultaneous fit of Monte Carlo-generated background spectra; b, The residuals between the data and the fit, are shown in green (light green). [Nature 568 (2019) 7753, 532-535]

GERDA completed the data taking of phase 2 getting a record limit on the ^{76}Ge half-life of 1.8×10^{26} yr and reaching and maintaining a noteworthy "zero background" condition (Figure 2.5). Its infrastructure has passed to LEGEND-200 in February 2020. The upgrade of the detector as well as the refurbishing of the infrastructure have started.

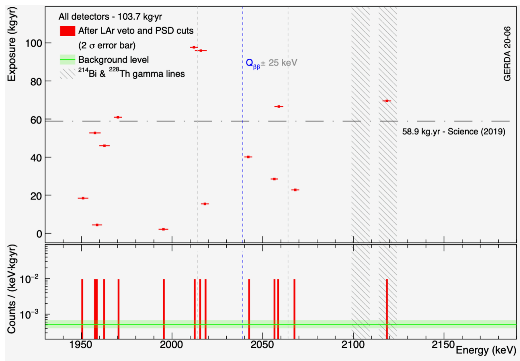


Figure 1.5 -The final GERDA unblinded spectrum (103.7 kg·y) in the ROI (1930-2190 keV). Counts before and after cuts are indicated as dots and solid lines respectively. In total 5 cts are observed in blinded ROI and no counts within ± 2σ of Qββ. Known γ lines are shown in (light) grey. [Neutrino 2020]

CUORE is continuing undisturbed taking data since April 2019. It has recently reached an exposure larger than 1000 kg y. The detector is performing well and new physics results on neutrino-less double beta (NDBD) of ^{130}Te have been presented at the TAUP conference in September, ranking CUORE among the most sensitive experiments. Based on the promising results of CUPID R&D a CDR for a full-scale bolometric experiment with active background suppression has been submitted during the Summer. The anticipated CUPID sensitivity compares to the world leading NDBD experiments

BOREXINO is continuing its long-standing data taking. After a huge effort aimed to stabilize the temperature of the scintillator, it has finally reached the sensitivity to observe the CNO neutrinos emitted by the sun. The rumors circulated in 2019 about a possible observation of these neutrinos have been finally confirmed in 2020 and were presented at the Neutrino 2020 (Figure 2.6), where they were mentioned as one of the most relevant presented results. Unfortunately, as anticipated in previous reports, the decommissioning of Borexino is expected by the end of 2020 and will probably prevent the necessary in-depth analysis of the

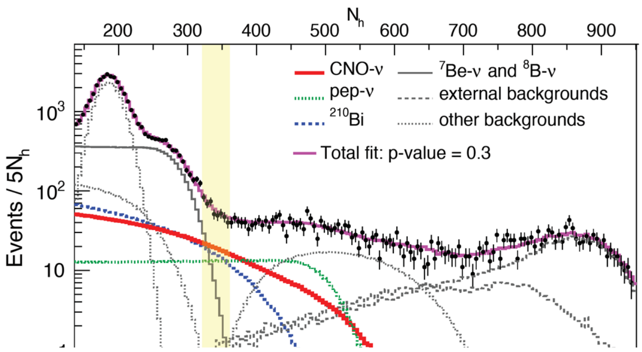


Figure 2.6 - Energy distribution of Borexino events (black points) and spectral (magenta). CNO-, 210Bi , and pep- are highlighted in solid red, dashed blue, and dotted green, respectively. [Neutrino 2020 and arXiv: 2006.15115]

measurement that could lead to the first precise measurement of the solar CNO neutrino flux. Borexino is therefore currently running a real race against time to improve this important measurement.

KM3Net aims at identifying the flux of High Energy Neutrinos originated in Astrophysical sources, with a network of deep-sea Cherenkov telescopes deployed in the Mediterranean Sea. With a total of only 7 strings installed at the two ORCA and ARCA sites, the technical progress towards a complete deployment of the strings is carefully and continuously monitored. The refurbishment of the Capo Passero marine station continued during 2019 together with the preparation of a new junction box and a second main electro-optical cable. Their installation is expected in Fall 2020 together with a new set of strings.

AUGER in Argentina is continuing the study of ultra-energy cosmic rays and is working on the detector upgrade aimed at improving the muon identification capabilities. The completion of the upgrade is anticipated in 2020.

DARKSIDE has published resulta obtained with data recorded with the 50 kg detector, scintillator veto and depleted Ar, after the very good results obtained with natural argon. They obtained important limits on both light dark matter and standard WIMPS. A lot of progress has been accomplished in the design of the Darkside-20t detector. The ARIA distillation column in Sardinia has been commissioned for the first time in August 2019 with encouraging preliminary results. A lot of work is in progress to review the Darkside-20t budget. The INFN President and GE has asked CSN2 to overview the budget and oversee on its management (DarkSide budget management is more complex than usual, because the money comes from several different sources with different contraints and accounting schemes). A group of 6 referees is working with the collaboration and the INFN management to take control of the whole budget. A new project manager has also been appointed by the collaboration.

2.3 Nuclear Physics

The CSN3 deals with experiments aiming to better understand the properties and characteristics of nuclei spanning all of the nuclides map, the nuclear fundamental processes, the primordial Quark-Gluon plasma and the nuclear reactions important for the understanding of the astrophysical processes and for applications. This is achieved with experiments working in different laboratories in the world (CERN, GSI, GANIL…), but with a special attention to the facilities in INFN laboratories (Catania LNS, Frascati LNF, Gran Sasso LNGS and Legnaro LNL) and the CIRCE one in Caserta. The experiments deal with different types of beams (with stable or radioactive projectiles), from very low (keV) to very high (TeV) energies. Few experiments focus on more interdisciplinary studies, including biomedicine applications or fundamental aspects of the standard model with matter/antimatter or quantum physics. More details can be found in the new web site https://web.infn.it/csn3/index.php/en/.

The COVID emergency, early 2020, affected the experimental program, but Italian laboratories remained active, although in reduced mode, and first beams could be delivered to experiments already in June. Data analysis, simulations, engineering work, software developments and many activities possible online continued and interesting results were published. In summer 2020 **LNS** started the upgrade of the Superconductive Cyclotron and the experimental infrastructure (including the Fragment Separator FRIBs), while at **LNL** the **SPES** project is progressing with the cyclotron tests, the definition of the beams facilities and experiments (AGATA will be installed at the end of 2021). The **LUNA-MV** accelerator has been successfully tested in the factory, but there are still few pending issues with the local authorities concerning the installation. The **NUMEN** and **PANDORA** TDRs have been completed with an important part dedicated to the Project Management: both projects are starting the construction phase that will last 3-4 years. **PANDORA,** in particular, after an intense work on physics possibilities, is now aiming to become an INFN facility and will soon request approval from the appropriate boards (CTS and MAC). Few groups are investigating the participation to experiments at **FAIR** in the next years. On the longer term and very high energy regime, several Italian groups are starting their involvement in the newly approved **EIC** project, while the **ALICE** experiment is working on the upgrade of the inner vertex detector foreseen by 2025. In the recent *Report 2020 of the European Strategy Group for Particle Physics* there are recommendations to pursue the **EIC** project as well as reinforce the heavy ion program at HL-LHC; strong collaboration and synergies with NUPECC are also supported and there are special mentions also to experiments and facilities where CSN3 groups are already involved.

Following the NUPPEC research structure, the CSN3 this year has been re-organized into six main research lines, that however have strong interconnections: Quarks and Hadron Dynamics, Phase Transition in Hadronic Matter, Nuclear Structure and Reactions, Nuclear Astrophysics, Symmetries and Fundamental Interactions and Application and Societal Benefits. In the following, a brief outline of their specific goals and achievements is reported.

Quarks and Hadron Dynamics

Experiments gathered in this line study the dynamics of quarks inside hadrons and nuclei for the purpose of understanding strong interaction in the regime where the coupling constant is large. These studies may answer fundamental questions such as what the origin of the hadron mass and spin is. They allow to study quarks confinement and search for effects beyond what predicted by QCD. Participants to these experiments are involved in research programs in several international laboratories, some of which are providing complementary measurements, like hypernuclei produced by electrons and hadrons in **JLAB12** and **ULYSSES** or chiral symmetry breaking studied in kaonic atoms and polarized electron scattering in **KAONNIS** and **JLAB12**. Other experiments cover different kinematic regions or have different detector capabilities, like **MAMBO** and **EIC**.

JLAB12 at Jefferson Lab includes a broad range of high statistics, high precision experiments that make use of the intense and high polarization electron beam produced by the CEBAF accelerator. The facility has been upgraded to 12 GeV to continue with renovated potential the study of the 3D imaging of the nucleon, hadron spectroscopy in the light quark sector, nuclear and hyper-nuclear dynamics and search for physics beyond the standard model. Italian groups have contributed both to the development of the physics program and to the construction of key instrumentation for both the experimental Halls A and to B.

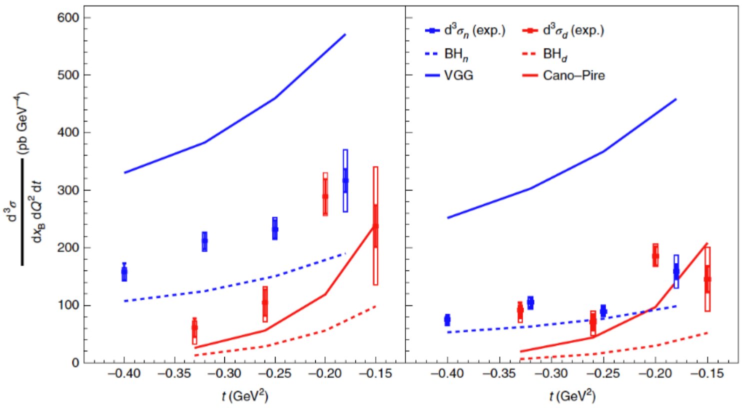


Figure 2.7 - The blue (red) points correspond to the en → enγ (ed → edγ) experimental cross-sections $d^3\sigma_n(d)/dQ^2\, dx_B\, dt$ for beam energy E = 4.45 GeV (left) and 5.55 GeV (right). Comparison with model expectations are also shown. Nature Physics VOL 16 | February 2020 | 191–198

In 2019-2020, data taking at 12 GeV has continued for several scattering experiments over various targets, from Hydrogen up to Lead. In parallel analysis of data collected in the 6 GeV period continued with high impact results. Among the recent works, a study of deeply virtual Compton scattering off the neutron, allowed to access u and d quark flavor contribution to the parton orbital angular momentum (Figure 2.7).

MAMBO has continued data taking at both Mainz (A2@MAMI) and Bonn (BGOOD@ELSA) in photoproduction on nucleons and nuclei. The main science goal is the investigation of nucleon resonances by meson photoproduction. Among other results in 2019 deuteron photodisintegration has shown hints of the d*(2380) hexaquark, linked to high neutron polarization [Phys. Rev. Lett. 124, 132001 – March 2020].

EIC_NET networking activity unites all Italian scientists interested in the US Electron-Ion Collider (EIC) recently approved by US DOE in the Brookhaven National Laboratory. An EoI is being prepared concentrating on possible Italian contributions to PID with Cherenkov detectors, Vertexing with Silicon detector, Triggerless DAQ with streaming readout and theoretical/simulation studies. There is a strong contribution from Italian scientists to the Yellow Paper expected by the end of 2020. The project is presently profiting of strong synergies with JLAB12, ALICE and COMPASS groups.

KAONNIS at INFN-LNF is studying kaonic atoms and low energy kaon-nuclei scattering using SIDDHARTINO and SIDDHARTA-2 detectors at DAFNE. K-^4He and K-^2H X-ray spectroscopy measurements, presently in preparation, will be followed by Li, Be and B kaonic atoms. First data have been taken until February 2020 for calibrations both for the machine and for the experiment. A new running period is foreseen in autumn 2020. A proposal for a long-term operation within the DAFNE collider is under investigation.

ULYSSES at J-PARC studies γ transitions in light hypernuclei (published $^4He_\Lambda$ and $^{19}F_\Lambda$, planned $^4H_\Lambda$ and $^7Li_\Lambda$) and searching for Ξ hypernuclei ($^{12}Be_\Xi$). A new proposal on $^3H_\Lambda$ and $^4H_\Lambda$

lifetimes is under development.

Phase Transition in Hadronic Matter

Currently **ALICE** is the only running experiment financed by the INFN within this research line. An activity of networking and R&D of a new experiment at the CERN SPS, **NA60+**, (see http://cds.cern.ch/record/2673280 submitted to SPSC) started in 2020. With precision measurements of thermal dimuons and charm, **NA60+** aims to investigate the phase transition between hadronic matter and QGP in the region of the QCD phase diagram corresponding to finite baryon-chemical potential around a possible critical point that has been little explored so far.

ALICE is a general-purpose heavy-ion experiment designed to study the physics of strongly interacting matter and the quark-gluon plasma in nucleus-nucleus collisions at the Large Hadron Collider (LHC). The Italian contribution remains compelling, with responsibilities at the highest level in the management, conduction of projects and detectors and physical analyses. The originally approved physics program of ALICE has been accomplished with the last successful ion run of the LHC in November 2018, before the start of the Long Shutdown 2 (LS2) of LHC.

In the following, few highlights from the several recent physics results are reported:

- **ALICE** has measured Λ_c/D^0, $\Sigma_c^{0,+,++}/D^0$ and $\Xi_c^{0,+}/D^0$ ratios in order to study the baryon-to-meson behavior in the charm sector. These ratios are sensitive to the hadronization process that can occur at different transferred energy regimes. A moderate enhancement of the Λ_c/D^0 ratio was observed at intermediate p_T going from pp to Pb-Pb. This result is compatible with models that include recombination in the QGP but still not conclusive to discriminate alternative hadronization processes. $\Sigma_c^{0,+,++}/D^0$ and $\Xi_c^{0,+}/D^0$ have been measured so far in pp collisions. The ratios show a significant modification of the fragmentation process driven by multiplicity, which differs a lot from the measurement obtained in e^+e^- collisions, indicating a very different fragmentation in the two systems. The measurement in pp collisions can be described both by PYTHIA, including color reconnection, and by statistical hadronization models, but both models fail in the description of Ξ_c. All these measurements will improve with future Run3 data, when more precise measurements will be feasible.

- The first measurement of J/ψ polarization in Pb-Pb at the LHC has been recently published [arXiv:2005.11128 [nucl-ex]]. The polarization of J/ψ was measured in pp collisions and found to be compatible with zero. In Pb-Pb collisions, the polarization could be modified in presence of a regeneration contribution, due to feed-down from $\Psi(2s)$ and χ_c, for which no predictions are available. A 2σ effect of non-zero polarization has been measured at low p_T ($2 < p_T < 4$ GeV/c). For the first time, results of the polarization of $\Upsilon(1S)$ were obtained. Within the large uncertainties of the measurement the obtained values are compatible with the absence of polarization.

- The investigation of hyperon-nucleon interactions is very relevant for understanding the high-density cores of neutron stars. A way to study such an interaction is via the measurement of $^{3}{}_{\Lambda}H$ lifetime, since it is directly connected to the structure of the hypernucleus and hence to the Λ-nucleus interaction. A precise measurement of the $^{3}{}_{\Lambda}H$ lifetime has been obtained analyzing the data from 2018 data taking and exploited using Machine Learning techniques. The obtained result ($\tau = 254 \pm 15(stat.) \pm 17(syst.)$ ps) is the most precise available measurement and it is better than the average of all existing experiments (Figure 2.8). It is compatible within 1σ with the free Λ lifetime, confirming that the hypertriton is a weakly bound state of a deuteron and a Λ.

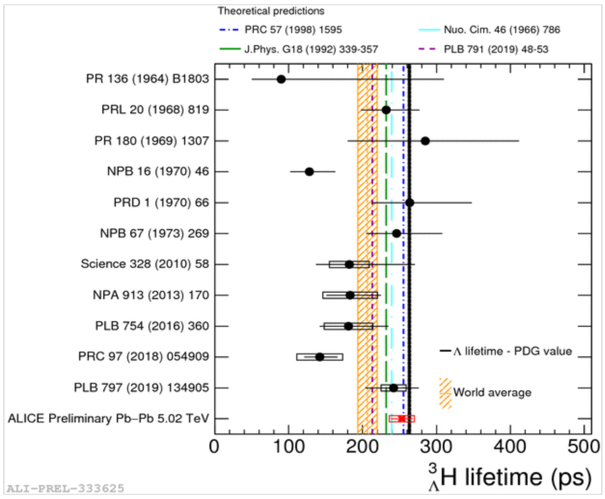


Figure 2.8 - Alice measurement of $^{3}{}_{\Lambda}H$ lifetime compared with previous measurements, Phys. Lett. B B797 134905

While the analyses of the LHC Run2 are being finalized, the Collaboration is preparing for the next LHC runs (Run3 and Run4) with the installation and commissioning of its upgraded detectors. The upgrade will make ALICE able to collect Pb-Pb collisions at a rate of 50 kHz, thus providing an accumulated sample of 10 nb^{-1} "on tape". The upgraded apparatus should be commissioned by summer 2021 and will allow a precise characterization of the QGP by addressing specific questions related to the measurement of heavy flavor hadrons, quarkonia, and low-mass di-leptons at low transverse momenta, together with novel measurements of jets and their constituents and the production of light (hyper-) nuclei. The Italian groups are deeply involved in this program: on the new, high-resolution, low material and fast readout Inner Tracking System (ITS) and on the upgrade of the read-out electronics for the Time Of Flight detector (TOF), Muon Spectrometer and the Zero Degree Calorimeter (ZDC).

Nuclear Structure and Reaction Mechanisms

This scientific line is mainly devoted to the study of the nuclear structure of exotic nuclei and the investigation of reaction mechanisms involved in heavy-ion collisions in the energy range 5-50 MeV/nucleon.

In 2020 the experiments belonging to this line are **GAMMA, NEWCHIM, NUCLEX, PRISMA-FIDES, NUMEN_GR3** and the new experiment **FORTE** (which absorbed about half of the **EXOTIC** collaboration, the other half being part of the **ASFIN** collaboration). A lot of experimental activity is performed in the national laboratories (LNL and LNS), but also the activity in European (GANIL, ISOLDE, GSI, ILL) and extra-European laboratories (TRIUMF, RIKEN, Jyvaskyla, OSAKA) is important.

The study of the ***nuclear structure*** far from the stability valley is the main topic of the **GAMMA** experiment, to be mainly carried out by means of gamma-ray spectroscopy of exotic nuclei produced in nuclear reactions with stable and radioactive ion beams. Many devices are used by the collaboration; the most important are the Advanced Gamma Tracking Array AGATA (at present in GANIL, but moving to LNL in 2021) and the Italian γ-ray spectrometer GALILEO at LNL, both of them coupled to many different complementary detectors.

The main results recently obtained are:

- A first indication of an octupole phonon (a wave-like mode in classical mechanics) at high spin was found in ^{207}Pb, populated by multinucleon transfer processes, via a challenging sub-nanosecond lifetime measurement with AGATA coupled to the magnetic spectrometer VAMOS++ at GANIL. Realistic shell-model calculation points to contributions of octupole (E3) strength from a double-octupole-phonon and a single-phonon coupled to a single particle, all adding coherently [Phys. Lett. B797, 134797 (2019)].
- The development of a new experimental approach for short lifetime measurements using complex (deep-inelastic) reactions in order to test the predictive power of *ab initio* nuclear structure theory in light systems (e.g., ^{20}O and ^{16}C), and the importance of the three-body term of the nuclear interactions, as shown in Figure 2.9. The requested sensitivity could only be reached thanks to the excellent performances of AGATA, coupled to the PARIS scintillator array and to the VAMOS++ magnetic spectrometer. The new method will be essential for studies of exotic nuclei with SPES-type beams [Phys. Rev. C101, 021303(R) (2020)].

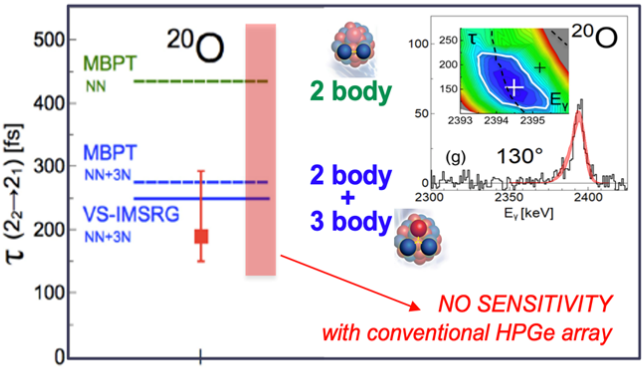


Figure 2.9 - Experimental partial lifetime of ^{20}O compared to some theoretical models.

- The observation of a multifaceted scenario of high-spin rotations in a quantum object, the nucleus ^{130}Ba, at LNL employing the GALILEO spectrometer, coupled to the EUCLIDES and NWALL arrays for charge particle and neutron detection. With the new results, ^{130}Ba presents one of the best and most complete set of collective excitations that a nucleus can manifest at medium and high spins, revealing a surprisingly diversity of shapes and rotations [Phys. Lett. B795, 241 (2019)].

Nuclear dynamics studies investigated the behavior of nuclear matter far from normal conditions and focused on the ***reaction mechanisms*** and on the isospin dynamics obtaining the following major results:

- The decay of the compound nucleus of ^{24}Mg (populated with the reaction ^{12}C+^{12}C @ 95 MeV) into six α particles was studied with the GARFIELD+RCo set-up at LNL. The data analysis evidenced that the decay preferentially proceeds through intermediate doorway states involving excited states of ^{12}C and ^{8}Be, i.e. through a sequential emission, while the simultaneous break-up process is negligible [**NUCLEX** - Phys. Rev. C 99-5, 054610 (2019)].
- The decay of ^{16}O* Quasi-Projectile (QP) in four α particles was investigated, comparing the experimental branching ratios associated to the different evaporation channels to the predictions of a code based on the statistical model (Hauser-Feshbach). Some discrepancies are observed, mainly in the population of the Hoyle state [**NUCLEX** - Journal of Phys. G – Nucl. and Part. Phys., 46-12, 125101 (2019).
- Data analysis is being carried out for the reactions ^{54}Fe+^{92}Mo and ^{206}Pb+^{116}Sn performed with the magnetic spectrometer **PRISMA** at LNL. This will allow to extract information on the properties of nucleon-nucleon correlations in multinucleon transfer processes.
- Fusion excitation functions for the ^{58}Ni+^{64}Ni and ^{24}Mg+^{12}C systems were measured well below the Coulomb barrier by using an electrostatic deflector followed by the time-of-flight (TOF) set-up PISOLO at LNL. No evidence of fusion hindrance was found for the first system, possibly because of the availability of many states with positive Q-value after the transfer [**PRISMA-FIDES** - Phys. Rev. C 100, 044619 (2019)]. Experimental data for the second system provided

the first convincing evidence of a S factor maximum vs energy in a medium-light system with a positive fusion Q value, indicating the presence of fusion hindrance [**PRISMA-FIDES** - Phys. Rev. C 101, 044608 (2020)].

- The different timescales of fusion-fission and quasi-elastic processes near the Coulomb barrier were investigated through the angular momentum transfer as measured via γ-ray multiplicities. The results, obtained for the $^{32}S+^{197}Au$ reaction at the ALTO facility (IPN Orsay) using the double-arm TOF spectrometer CORSET coupled to ORGAM and PARIS γ-detectors, suggest that the γ-ray probe can play a very important role in disentangling fusion-fission and quasi-fission in the regions of the mass-TKE matrix where they overlap [**FORTE** - Phys. Rev. C 101, 064612 (2020) - Editors' Suggestion].
- The effect of the isospin degree of freedom on the reaction mechanisms was evidenced in the study of the reactions $^{78}Kr+^{40}Ca$ and $^{86}Kr+^{48}Ca$ @ 10 MeV/nucleon with the CHIMERA array at LNS. In particular, a slightly higher fusion-evaporation cross section and a strongly pronounced probability of fission-like processes were measured in the neutron poor system [**NEWCHIM** - Eur. Phys. J. A (2019) 55: 22].
- No experimental evidence of α condensation was found in the different reaction channels populated with the system $^{12}C(^{16}O, ^{28}Si^{*})$ investigated at LNS by means of the CHIMERA array coupled to the correlation set-up FARCOS, whose construction was ended in 2020. The reaction mechanism can be described by a hybrid model including sequential decay and multiparticle breakup [**NEWCHIM** - Phys. Rev. C 100, 034320 (2019)];
- The comparison of the main properties of the Quasi-Projectile (QP) in peripheral collisions at Fermi energy with the prediction of the quantum molecular model AMD demonstrated the validity of such an approach also for the description of peripheral collisions [**NUCLEX** - Phys. Rev. C 99, 064616 (2019)];
- In 2019 twelve blocks of the FAZIA detector were coupled to INDRA at GANIL within the **NUCLEX** collaboration and the first data taking on Ni systems at 32 and 52 MeV/nucleon devoted to the study of the symmetry energy and its density dependence was successfully performed.

In this energy range there is also the **NUMEN_GR3** research activity which is devoted to the study of Double Charge Exchange (DCE) reactions as a tool to extract information on nuclear matrix elements which are a fundamental issue in the study of neutrino-less double beta decay. In order to carry out the envisaged goals the collaboration is completing the R&D program for the upgrade of the MAGNEX spectrometer. Important developments have also been done to provide a theoretical description of DCE processes [Phys. Rev. C 98, 061601(R) (2018)] and to support the experimental results achieved in the present configuration. The experiment is now ready for the construction phase and the collaboration is finalizing the TDR which includes all technical details on the foreseen upgrades.

Nuclear Astrophysics

The synergies of the different and complementary research activities of the nuclear astrophysics community (**ASFIN**, **ERNA**, **LUNA**, **n_TOF** and **PANDORA**) are particularly strong. Few examples are the primordial nucleosynthesis of Be and Li, the carbon fusion reactions in the advanced stages of stellar evolution and the proton and the neutron capture reactions for the nucleosynthesis of low mass stars. In particular, in the field of primordial nucleosynthesis, **ERNA 2** has measured the $^{7}Be(p,p)^{7}Be$ scattering and **ASFIN2** has studied the cross section of the reaction $^{7}Be(n,\alpha)^{4}He$ via the Trojan Horse Method at LNL EXOTIC facility, succeeding to apply THM to the study of neutron capture reactions with RIBs [ApJ 879, 3 (2019)].

Concerning the study of the $^{12}C + ^{12}C$ reaction, in November 2019 the **ASFIN2** collaboration carried out a second experiment for a further investigation of the reaction whose first result raised considerable debate in the international scientific community (as also requested in the CVI report 2019). At the same time the **ERNA** and **LUNA** groups have been working together on a possible use of the GASTLY detectors, using Ar, for an underground cross section measurement at **LUNA MV** facility. Unfortunately, although the new accelerator has been successfully tested at the factory with better performances (stability and maximum achieved current) than requested, the actual installation at LNGS is still waiting for approval from the local authorities on safety issues.

Remaining in the framework of ultra-low background conditions at the LNGS, it should be highlighted the direct cross section measurements of proton capture reactions of ^{18}O: the $^{18}O(p,\alpha)^{15}N$ [PLB, 790 (2019)] and $^{18}O(p,\gamma)^{19}F$ [PLB, 797, 134900 (2019)]. These reactions are important as closing and opening channels of the CNO cycle for stellar H-burning.

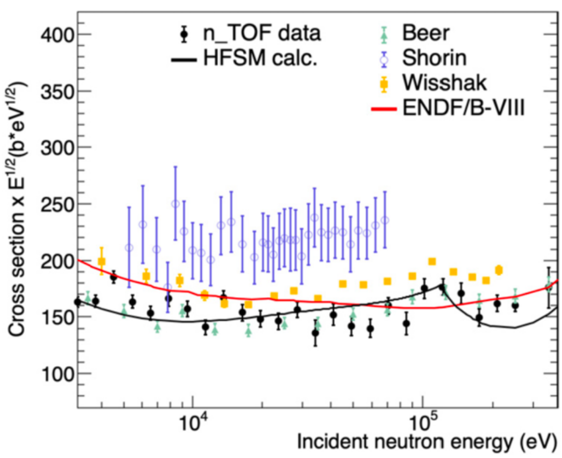


Figure 2.10 - $^{154}Gd(n,\gamma)$ cross section by n_TOF compared to previous measurements (symbols) and evaluation (continuous line).

Taking advantage of the CERN LS3, the new spallation target of the **n_TOF** facility was installed and it has started the construction of the NEAR station for activation measurements on rare and short-lived isotopes (produced at CERN ISOLDE or PSI). Moreover, in the framework of neutron-capture reactions, **n_TOF** published the measurements of the $^{70}Ge(n,\gamma)$ [PRC, 100, 045804 (2019)] and of the $^{154}Gd(n,\gamma)$ [PLB 80, 135 (2020), see Figure 2.10], being the last one very important for s-process nucleosynthesis.

The **PANDORA** experiment aims at a direct measurement of decay time of several isotopes in a plasma environment. The collaboration is presently expanding toward new groups and has finalized the TDR, being now ready for the construction phase. In particular, recent studies have proved the possibility of using the apparatus for plasma opacity measurements in conditions similar to kilonovae ejecta or as a new ion and radiation sources for science and technology. This motivated the request to INFN to upgrade the experiment to a new multipurpose facility at LNS.

Symmetries and Fundamental Interactions

Here are grouped the two experiments working at the antiproton facility at CERN (**AEGIS** and **ASACUSA**), **JEDI** that aims at the search of the Electric Dipole Moment (EDM) of light nuclei (p,d,^{3}He), **FAMU** for the measurement of the proton radius and **VIP** for the study of possible Pauli principle violations. All of them study fundamental properties of matter or antimatter allowing precision tests of the Standard Model.

AEGIS: after the observation of anti-hydrogen atoms with pulsed laser (CERN-SPSC-2019-007 / SPSC-SR-246), the upgrade program foresees a new positron-positronium converter for the antiproton factory that was successfully tested and produced Ps at 300 K temperature (i.e. velocity around $4x10^4$ m/s): this temperature will increase the Ps* -antiproton cross section with high benefit in future antihydrogen formation.

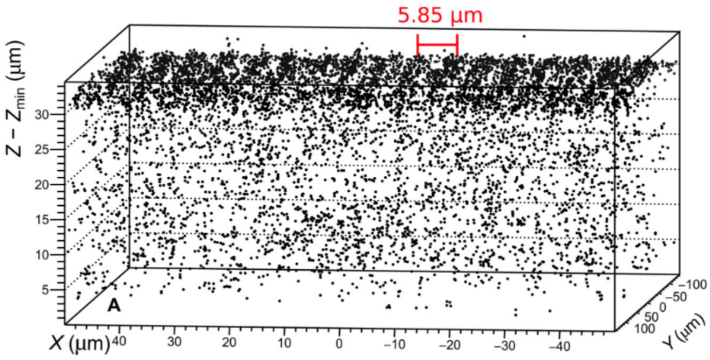


Figure 2.11 - Three-dimensional distribution of the reconstructed points of incidence on nuclear emulsion. A hint of the periodic fringes is appreciable (Science Advances 03 May 2019: Vol. 5, no. 5, eaav7610).

ASACUSA has demonstrated antimatter interferometry with positrons for the first time (Figure 2.11). Using nuclear emulsions, high-contrast periodic fringes were detected in the range of 8 to 16 keV, proving the quantum-mechanical origin of the periodic pattern. Therefore, the observation of interference of matter waves (at the heart of quantum physics) has been extended from electrons and molecules to antimatter.

JEDI at COSY is improving beam polarization lifetime and monitoring to search for EDM of the deuteron. R&D of a dedicated, electrostatic storage ring allows to foresee precise measurements on the proton and He-3 in next decade.

The **FAMU** experiment aims at measuring the Zemach radius of proton, by means of the hyperfine splitting of the muonic hydrogen ground state. It requires a muon beam (provided by RAL) and a hydrogen gas target to form the muonic hydrogen atoms. The experiment is ending the building phase that incorporates the detection system (scintillator array and HPGe), the laser set-up and the cryogenic target. The experiment is ready for the commissioning.

Finally, we recall the results achieved by **VIP** in its investigation of the validity limits of the Pauli principle and of quantum gravity models. Indeed the last year data analysis allows to set the new upper limit of the rate of the Continuous Spontaneous Localization model at $5.2 \cdot 10^{-13}$ and the lower limit on the scale parameter of the Diosi-Penrose model at $5.4 \cdot 10^{-11}$ (papers have been submitted).

Application and Societal Benefits.

Two experiments perform measurements of relevance for practical application and social benefits.

The **TORIO_229**, aiming to measure the energy of ^{229m}Th directly in its IC decay, identified ThF4 crystal as the best candidate for nuclear clock based on gamma decay of ^{229m}Th (PRR 1, 033005, (2019)). New measurement on gamma decay of ^{229m}Th inside ThF4 was proposed and now under construction.

FOOT studies cross section of different projectiles and targets useful for application in hadron therapy. The complete prototype of the calorimeter unit has been successfully tested. Moreover, important results have been achieved in the R&D of the entire project. A test at GSI with Oxygen beam of 200-400 MeV/u allowed to measure with the emulsion setup the light fragments (Z<=3) production on graphite and polyethylene targets (of interest for radioprotection in space). The construction of the electronic setup was completed and will be optimized for the measurement of the heavier fragments produced by 200-400 MeV/u carbon and oxygen beams (of special interest in hadron therapy).

2.4 Theoretical Physics

The INFN research activities in theoretical physics are coordinated by the CSN4. These activities are developed in close connection with the academic world and other scientific institutions both in Italy and abroad. The numbers of papers, citations and talks prove the variety and quality of the research carried on within the CSN4. A large portion of the theoretical investigations is deeply entangled with the experimental research of INFN in particle, nuclear and astroparticle physics. Due to the broad spectrum of topics, the CSN4 activities are organized in six areas covering the most important subjects in theoretical high-energy physics. These areas, called "Linee Scientifiche" (LS), are the following:

- LS1: String and Field Theory.
- LS2: Particle Phenomenology.
- LS3: Hadron and Nuclear Physics.
- LS4: Mathematical Methods.
- LS5: Astroparticle Physics and Cosmology.
- LS6: Statistical and Applied Field Theory.

CSN4 Sector	FTE	Bdgt
LS1: String and Field Theory	29%	361
LS2: Particle Phenomenology	16%	203
LS3: Nuclear and Hadronic Physics	8%	118
LS4: Mathematical Methods	12%	145
LS5: Astroparticle and Cosmology	20%	244
LS6: Statistical and Applied Field Theory	12%	99

Table 2.4 - FTE composition and budget distribution in k€.

In the reference period, more than 1000 physicists - including PhD students and post-docs - corresponding to about 1073 FTE's, were involved in the CSN4 research activities. It is worth mentioning the newly hired ten permanent staff researchers, selected through a national competition, which increase by about 10% the number of research staff. During 2019 the theoretical community has been organized in 35 research projects called "Iniziative Specifiche" (IS), aimed at fostering scientific collaboration and synergies among different research units. Periodically, typically every three years, each IS is evaluated by two independent external referees employed by foreign research institutes and the results of this evaluation process is used to distribute the financial resources and the post-doctoral fellowships of the CSN4. At the time of writing the process of evaluation of the new IS proposals is ongoing. The composition in terms of FTE's and budget of CSN4 in 2019 is shown in Table 2.4. The figures in the budget column refer only to travel funds since these are the only ones that the CSN4 assigns to the various IS. The distribution of roles and activities by gender are summarized in Table 2.5.

	Male	Fem.
National Coordinators IS	86%	14%
Local Coordinators IS	85%	15%
Coordinators in INFN Units	89	11
INFN FTEs	86	14
FTE from University	86	14

Table 2.5 - Gender distribution in CSN4

The CSN4 is currently present in all INFN Units including the TIFPA centre in Trento, in three of the four National Laboratories (with the exception of LNL), and in three "Gruppi Collegati" (Parma, Salerno and Cosenza, linked to the Milano Bicocca and Napoli Units and to the Frascati National Laboratory, respectively).

In 2019 physicists of the CSN4 published 1642 papers, corresponding to 1.53 paper per FTE with an average Impact Factor of about 4.41 per paper and an average number of 3.32 citations per paper. International collaborations were strongly supported (the internationalization index is 0.75);

indeed, a large portion of the full CSN4 budget was used to support exchanges with foreign institutions and international collaborations.

We now comment briefly on some recent scientific activities within the CSN4 with focus on those directly connected with the experimental activities of INFN, i.e. particle and astroparticle physics, cosmology and gravitational waves, nuclear and hadronic physics.

The following main directions in **Particle and Astro-Particle Physics** can be highlighted:

1) *Precision Standard Model (SM) Physics at the LHC*.

After the discovery of the Higgs boson and the missing evidence of new resonances, the LHC has been pushed to a precision machine and New Physics signals could be detected through small departures from SM predictions of kinematical distributions. Therefore, it is of utmost importance to look for the most accurate predictions for SM processes in a fully differential way. In this field several groups are very active on many of the relevant ingredients of the simulation of a high-energy proton-proton collision at large momentum transfer: from the determination of parton distribution functions and their uncertainties, the calculation of the scattering amplitudes, to the study of final state jet substructure by means of advanced algorithms (using also machine-learning techniques). It is worth mentioning the NNPDF collaboration, which provides one among the most used (and constantly updated) sets of parton distribution functions as well as the Monte Carlo frameworks POWHEG-BOX and aMG5_MC@NLO, which are the baseline Monte Carlo generators for most simulations by LHC experiments and are also widely used by the international theoretical community to perform phenomenological studies. These generators have a theoretical precision at the level of one-loop (in the strong as well in the electroweak coupling) matched to resummed leading logarithms for almost all processes measured at the LHC.

The most relevant channels under study have been: single Higgs boson, top-quark pair, Drell-Yan processes, diboson production and vector boson scattering. Progress towards higher precision level can be obtained by means of improvements in the calculations of perturbative scattering amplitudes, in the resummation of subleading logarithms and in the matching schemes to avoid double counting between the fixed order and the resummation.

In the field of perturbative calculation techniques, new results have been obtained for the building blocks of scattering amplitudes at two-loop precision and/or including resummation of specific classes of logarithms in Quantum Chromodynamics for the production of important final states, like for instance a top quark pair. The interplay between higher order corrections due to different interactions, e.g. QCD and QED or QCD and electroweak interactions, have been studied for several relevant processes. Special attention has been devoted to the Higgs boson production and decay modes, with important contributions to the thre-loop accuracy (N3LO) in QCD for single Higgs production and Higgs production in Vector Boson Fusion at NNLO in QCD.

The less tested sector of the SM remains the Higgs system and its self-interactions, which can be probed with the future high-luminosity phase HL-LHC. On this subject, several phenomenological studies on double-Higgs production (with several possible decay channels) have been performed with the aim of studying possible future limits at the HL-LHC to the Higgs self-coupling, compared to indirect limits through loop effects in single Higgs production.

It is worth mentioning that several members of CSN4 acted as consultant expert for the CERN LHC experiments and participated, with coordination roles, to LHC topical physics Working Groups.

2) <u>*Physics Beyond the Standard Model (BSM) and Dark Matter (DM)*</u>

After the Higgs boson discovery and the apparent lack of evidence of BSM particle production at the LHC, a significant change of paradigm has taken place in the theoretical work connected to BSM physics. While, historically, the field of model building has been driven by the idea of naturalness of the electroweak scale, motivating constructions such as SuperSymmetry and composite Higgs scenarios (with dark matter, DM,particle candidates as a bonus of the models), a consistent fraction of the theoretical community started to focus on more compelling problems of the SM, related to its striking difficulties with the most basic features of the Universe: dark matter, dark energy, the asymmetry between matter and antimatter, inflation to explain the initial conditions of the Universe. In view of the above considerations, a strong connection between particle and astroparticle physics emerged in the theoretical activities of CSN4. All possible scenarios about the nature of DM have been investigated and studied, from "traditional" Weakly Interacting Massive Particles, to light DM in the form of axions and axion-like particles (ALP's) as well as primordial black holes. In particular, several new models of DM have been investigated, together with the studies on possible experimental direct and indirect signatures at present and future colliders as well as satellite experiments or ground-based telescopes. Models for baryogenesis and the corresponding predicted first-order phase transitions in the early Universe have been studied together with possible signatures through the stochastic background of gravitational waves.

Concerning the quest for BSM physics at the LHC, the lack of evidence of new TeV-scale particles sets the Effective Field Theory approach to New Physics as the natural framework for parameterizing discrepancies from the SM in a model-independent way. In this approach the SM is extended by systematically including the higher dimensional operators in inverse powers of the New Physics scale. Important contribution have been given to the systematic development of the SMEFT (SM with addition of six-dimensional operators), its implementation in simulation tools and in phenomenological studies focused on differential observables able to improve the sensitivity with respect to the Wilson coefficients of the dim-6 operators. In order to optimize the sensitivities, analysis strategies based on machine learning techniques have been investigated. The EFT approach cannot be applied in scenarios where the SM is extended by including new light particles, like ALP's and dark photons. These scenarios received recently increasing attention and many phenomenological studies have been performed to test the possible sensitivity at various experiments, such as, for instance, BES-III, Belle2, NA62, PADME at LNF and beam dump experiments.

Many efforts have been put to the development of specific extensions of the SM and their comparison with LHC data. To this aim, it is worth mentioning the first public release of the computer code HEPfit, which allows to perform global analysis of electroweak and flavour data within the SM and in several extensions of it.

3) <u>*Flavour Physics*</u>

Several groups contributed to the study of problems related to the flavour structure of the SM and its connection to New Physics. In fact, even if the fermionic masses, with the exception of the top-quark, are well below the electroweak scale, the flavour changing decay processes allow stringent constraints on NP because of some suppression appearing in the SM, for instance because the involved Cabibbo-Kobayashi-Maskawa matrix elements are small or because the tree-level SM prediction is forbidden, as it is the case for flavour-changing neutral current transitions. Recent LHC measurements in charged-current and neutral-current semileptonic B meson decays pointed out anomalies compatible with the violation of the lepton flavour universality. Several studies have been devoted in 2019 to global analysis of the most recent LHCb data in the EFT framework as well as in particular models (involving mainly leptoquarks or new vector bosons Z'), investigating the implications of the derived bounds on NP model building. A common problem affecting the study of several observables related to flavour physics is the large uncertainty associated with non-perturbative matrix elements contained in decay constants and form factors. On this item, ab initio calculations based on Lattice QCD methods give very important information. Different groups of CSN4 have a long tradition in this field and also in 2019 contributed to the improvements in this field with new calculations of masses and decay rates.

The experimental searches at flavour factories and subsequently at LHC and BES-III have found evidence for a number of exotic hadrons above the D meson pair threshold, named XYZ hadrons, not fitting the quark-antiquark scheme of mesons. Some of them are certainly composed of two quarks and two antiquarks. More recently, also pentaquarks states have been discovered at LHCb. Important theoretical work on the understanding of the structure, decay channels and production cross sections of these exotic states has been performed during the last year by different groups, following research lines started soon after the discovery of the X(3872) meson in 2003.

4) Anomalous magnetic moment of the muon

The muon g-2 discrepancy is at present one of the most intriguing hints of New Physics emerged so far in particle physics. In the near future the experimental precision in its measurement will be significantly improved, and for this reason considerable effort is being devoted to reducing the theoretical uncertainty in the SM prediction, currently dominated by the hadronic corrections. Recently, a novel experiment (MuonE, under review at CERN) has been proposed by an INFN team (with a synergic action of theorists and experimentalists of CSN1) to infer the hadronic contribution to the photon vacuum polarization through the measurement of elastic scattering of high-energy muons on atomic electrons. For this new approach to be competitive with more conventional ones, theoretical predictions for electron-muon scattering should be calculated at the highest available precision. The complete NLO corrections in the SM and first NNLO contributions have been computed in 2019. An alternative approach is the ab initio (on the lattice) calculation of the hadronic corrections to the muon g-2. First important results have been obtained during 2019 regarding the electromagnetic and strong isospin corrections as well as on new promising Monte Carlo techniques, like multi-level Monte Carlo integration, able to improve the numerical convergence of the simulations.

5) *Future colliders*

It is worth mentioning that in the framework of the European Strategy Particle Physics Update 2020, several groups within CSN4 started new activities focused on the study of the potential offered by future high energy e^+e^- and hadronic machines. The investigations have been mainly focused on future projections for precision as well as discovery physics in view of presently available and conceivable models. Also, first developments of improved simulation tools have been considered, in view of the very high precision of next-generation colliders.

The above-mentioned activities originated mainly within the international working groups of HL/HE-LHC and FCC, where several members of CSN4 have contributed also at design and coordination levels. At the national level, a strong synergy between physicists from CSN4 and CSN1 has been established.

6) Neutrinos

During last years the field of neutrino physics has seen the emergence of a 3-neutrino mass mixing framework, which enters the era of leptonic CP-violation and mass-ordering searches. The activities of the members of CSN4 in 2019 have been focused on the following items:

- analysis of possible indications about the neutrino CP violating phase from global data analyses;
- investigation of the neutrino mass hierarchy sensitivity with reactor and atmospheric neutrinos;
- phenomenology of sterile neutrino and nonstandard interactions in long-baseline accelerator searches;
- supernova neutrinos: study of nonlinear oscillations associated to neutrino self-interactions;
- study of Earth models in the context of geoneutrinos;
- constraints on axial coupling in neutrinoless double decay from forbidden beta decays;
- study of signatures and constraints on heavy sterile neutrinos from core-collapse supernovae.

Some members of CSN4 have organized several international Workshop/Conferences held in Italy and abroad.

7) Gravitational waves

After the discovery of Gravitational Waves (GW), the related theoretical activities of CSN4 witnessed a relevant boost and development, in particular during 2019. Among these activities, we highlight few selected topics. The first one is the modelling of GW sources via numerical methods. In fact, full General Relativity (GR) simulations of compact object binaries are necessary, in order to compute the GW and electromagnetic signals produced during and after the merger. When neutron stars are present, the GW and electromagnetic emissions are strongly affected by the still unknown Equation of State (EoS) of neutron star matter, by the magnetic field strength and configuration, and by neutrino emission. It is worth mentioning the development of a new computer code (Spritz) able to perform general relativistic magnetohydrodynamics simulations with neutrino emission. A second important topic is related to the use of theoretical models to possibly extract information on the EoS in the inner core of neutron stars. For example, the late-time inspiral signal of a neutron star-neutron star binary coalescence contains information on the neutron star tidal deformability, whereas the frequencies of the post-merger signals depend on the stellar compactness. These properties carry the imprint of the EoS. A third important topics investigated recently by CSN4 teams is the study of strong-field phenomena in modified gravity theories. It is worth mentioning the development of fully General Relativity simulations of Black Hole-Black Hole binary mergers in modified gravity theories.

Some of the physicists involved in these studies are also active members of experimental collaborations such as Virgo, ET, LISA and the Event Horizon Telescope.

8) Cosmology

In the past two decades we have witnessed impressive progress in cosmology, thanks to the wealth of data from experiments like Planck, that released its legacy data in 2018, the multi-wavelength surveys that mapped the large-scale structure of the Universe with unprecedented precision, like SDSS-BOSS, and a number of probes of cosmic expansion, such as that provided by SN-Ia. Even though most of the data can be interpreted in terms of the ``standard'' Lambda-Cold Dark Matter (ΛCDM) model, recently, some tensions appeared between different observations that might point to a necessary revision of the model. Moreover, even if phenomenologically successful, the ΛCDM model is unsatisfactory from the point of view of fundamental physics, as the very nature of dark matter and dark energy, as well as the details of the early phase of inflationary expansion, are still unknown. The activity of the CSN4 members on cosmology has been focused on models of inflation in the early Universe (in particular the imprint of primordial gravitational waves on Cosmic Microwave Background properties); the nature of dark matter and dark energy; the properties of neutrinos and other relics; the viability of modified gravity/alternative dark energy models and global analysis of cosmological observations as a probe of New Physics. Several studies have been performed with the development of numerical codes allowing improved N-body simulations. Advanced machine learning techniques have been used in many analyses involving large experimental data sets.

Several members of CSN4 participated in the activities of the experimental Collaborations in which INFN is involved (for example, ET, Euclid, LISA, LiteBIRD, LSPE, PLANCK...) with coordination roles of internal working groups.

The activities related to astroparticle physics, cosmology and gravitational waves establish a strong synergy between CSN4 and CSN2.

9) String and Field theory

In the quest for a unified quantum theory of all fundamental interactions, including gravity, String Theory has emerged as a natural framework to incorporate gravity with quantum physics, where Italian theoretical physicists give continuously important contributions to several topics, ranging from formal developments to the study of black hole physics and, more generally, to the study of non-perturbative effects in Quantum Field Theory. The understanding of the non-perturbative dynamical properties provides the key for solving different challenging problems in physics, from Quantum Chromodynamics in the strong coupling regime to high-temperature superconductivity.

10) Hadronic and nuclear physics

The research activity has been mainly focused on the following subjects:

1. exploration of the 3-dimensional structure of the nucleons, through the study of the Transverse Momentum Dependent (TMD) parton distribution, Generalized Parton Distributions (GPD) and related form factors. Members of CSN4 obtained the first determination of quark TMDs and GPDs in nucleons and nuclei, and several phenomenological studies have been performed using inclusive as well as exclusive scattering processes. The activity has been also focused on the estimate of the effects of transverse degrees of freedom on high-energy observables, like the mass of the W boson at the LHC;
2. theoretical and phenomenological study of the properties of strongly interacting matter at extreme conditions of high temperature and density. On the one side, members of CSN4 studied the thermodynamic and transport properties of strongly interacting matter from first principles by means of lattice QCD. On the other side the Quark Gluon Plasma phase is studied experimentally through ultrarelativistic heavy ion collisions. The focus of the national theoretical community has been the developments of the theoretical tools necessary to perform realistic simulations of the dynamics of heavy ion collisions. In particular the main topics of interest have been the study of quantum effects in relativistic hydrodynamics such as collective polarization and local parity violation, non-equilibrium dynamics and electromagnetic field in the early stage of the collision, dynamics of heavy quarks and in-medium hadronization. The phenomenology is mainly devoted to the interpretation of the measurements performed in experiments of heavy ion collisions at various facilities such as LHC, RHIC, FAIR and NICA;
3. structure and dynamics of few-body systems, including the structure properties of light nuclei and hyper-nuclei, as well as the study of hadronic reactions of interest for astroparticle physics.

Several members of CSN4 are involved with the activities at JLAB (USA). It is worth mentioning the participation to the Working Groups of planned future facilities like the Electron Ion Collider project and the LHCspin project, with leading coordination roles. The theoretical activities on hadronic and nuclear physics establish a strong synergy between CSN4 and CSN3. It is worth mentioning the work on nuclear matrix elements and transport equations, of interest for the NUMEN experiment at LNS, as well as the theoretical work in support of the production of innovative radionuclides and radiolabeled compounds for advanced medical therapies and diagnostics.

GGI

Since its birth, the Galileo Galilei Institute for Theoretical Physics in Arcetri (GGI) has achieved an impressive record of high-level activities and by now is counted among the leading international institutes for the organization of long-term workshops. On February 15th, 2018 the GGI has been established as a National Centre for Advanced Studies of INFN. There is a strong connection and sinergy between GGI and CSN4, which supports partially the GGI activities, with particular reference to the schools for PhD students. The activities carried on at GGI during 2019 and early 2020 include:

- three long-term workshops:
    - String Theory from a Worldsheet Perspective
    - Breakdown of Ergodicity in Isolated Quantum Systems: From Glassiness to Localization
    - Next Frontiers in the Search for Dark Matter
- four schools (see the next paragraph on training)
- several satellite meetings and focus or training weeks related to the long-term workshops and a few conferences.

The details about these activities can be found at http://www.ggi.fi.infn.it/.

Since 2015 the GGI has been using a five-year grant of about 0.7 M$ funded by the Simons Foundation (US) to support extended visits of eminent scientists at the GGI and the participation of PhD students in the GGI schools.

It is worth mentioning that, with the transformation of the GGI into a National Centre for Advanced Studies, INFN established the **GALILEO GALILEI MEDAL**, a prize in honour of Galileo Galilei, the founding father of modern physics, awarded every two years, starting in 2019. The recipient(s) of the prize can be one or more (not more than three) scientists who, during the 25 years preceding the award, gave outstanding and seminal contributions to one of the areas of Theoretical Physics that are of interest for INFN. The Medal is awarded without restriction of nationality, gender or religion, with the only exception of Nobel Laureates and Fields Medalists. The recipient(s) of the Medal are identified by a Selection Committee, appointed by the INFN President in consultation with the GGI Director, the President of CSN4 and the INFN Executive Board.

On February 15th, 2019, the award of the first Galileo Galilei Medal to Prof. Juan M. Maldacena has been announced, with the following motivation: ``For pathbreaking ideas in theoretical physics, and especially for the discovery of duality between gravity and ordinary quantum field theory, with far-reaching implications''. The award ceremony took place on May 2nd, 2019 at the Villa il Gioiello in Arcetri.

TRAINING

A traditional activity of the CSN4 physicists is the training of young researchers and students. This is reflected in the large number of publications involving Post-Docs and Graduate Students. Since 2005, the CSN4 awards the Sergio Fubini Prize (which in 2007 became an official INFN award) to the best three doctoral theses in theoretical physics of the year. In 2019 the Fubini Prize was awarded to three Ph.D. theses on the following topics:

- Top-mass observables: all-orders behaviour, renormalons and NLO+Parton Shower effects;
- Unveiling Universe's cosmic messengers;
- Non-equilibrium quantum states of matter.

Two of the winners were women.

As in previous years, in 2019/20 the CSN4 has sponsored a series of Ph.D. student schools at the Galileo Galilei Institute in Florence with the aim of gathering students from different Italian and foreign universities and offering them high-level training and pedagogical courses in various areas of theoretical physics. Because of the corona virus emergency, only four schools took place:

1. LACES 2019 (Advanced Lectures on String and Field Theory), 3 weeks, 70 hours of lectures, with 66 students;
2. GGI Lectures on the Theory of Fundamental Interactions, 3 weeks, 56 hours of lectures, with 58 students;
3. Statistical Field Theories, 2 weeks, 38 hours of lectures, with 56 students;
4. Frontiers in Nuclear and Hadronic Physics, 2 weeks, 40 hours of lectures, with 56 students;

while the school ``Theoretical Aspects of Astroparticle Physics, Cosmology and Gravitation'' (at its second edition) has been postponed.

Post-doctoral program

Every year INFN runs a post-doctoral program, with a number of fellowships for theoretical physics, dedicated to young foreign researcher. The number of positions in theoretical physics has been increased from an average of 12/year to 14/year during last few years. CSN4, through its internal referees, coordinates the allocation of the theoretical positions to various teams in INFN Units, taking into account of the external reviews of the IS which the groups belong to and of the local needs discussed with the national coordinators of the IS. This mechanism is quite effective in optimizing the distribution of resources, even if the number is on the low side when comparing with similar research institutions in other countries. The program, since several years, is attracting a large number of applications (an average of more than 40 applications for each position). In 2018 and 2019 the number of fellowships coordinated by CSN4 has been reduced to 7 and 6, respectively, because of the funding of the Fellini international mobility fellowship program for experienced researchers, co-financed by the European Commission through the MSC COFUND Action. Both calls have been extremely successful for INFN theoretical physics, with about 60% of the fellowships assigned to theoretical fellows, obtaining 9 three-year positions out of 15 for each call. The only weak point is that, within the Fellini scheme, there has been no planning for the allocation of the fellowships, generating some unbalanced distribution of resources.

A separate issue is related with computational physics, where INFN has a long historical tradition of excellence. In 2019 Italy has been selected as host of one of the pre-exascale supercomputers within the EuroHPC European project, where INFN is involved together with CINECA and SISSA. Given the size of the project, it would be very important for CSN4 to access a funding scheme of fellowships for young researchers in the field of computational physics. In the recent past, between 2016 and 2019, CSN4 took advantage from about 20 dedicated fellowships funded within the national ministerial scheme HPC_HTC.

2.5 Technological and inter-disciplinary research

CSN5 coordinates technological research and promotes the development of instruments, methods and technologies for fundamental physics, as well as their application also in other scientific fields.

INFN is a firm point of reference, in Italy and worldwide, for the production of today's particle accelerators and for the development of next-generation prototypes. These are used not only in fundamental physics research projects, but also in other areas of research and economic and social life. Another branch of activity involves the development of radiation detectors, electronics and computer systems in close collaboration with other centers and as part of inter-disciplinary research projects. All these technologies have significant social and economic impacts, for instance in the fields of medical imaging, in cancer therapy and in the protection of the cultural and environmental heritage. A significant impact has come from the development of radiotherapy treatment plans with protons and ions (hadron therapy).

The activity coordinated by CSN5 is organized in three sectors covering the most important fields of research in experimental physics. They are:

- Detectors, Electronics and Computing
- Accelerators and Related Technologies
- Interdisciplinary Physics

CSN5 Sector	FTE	Budget (%)
Detectors, Electronics and Computing	156	39
Accelerators and Related	113	25
Interdisciplinary Physics	226	36

Table 2.6 - FTE and Budget of the three CSN5 scientific lines

The FTE and budget of the three CSN5 lines are listed in Table 2.6, while some gender statistics are summarized in Table 2.7.

CSN5 gender statistics	Male (%)	Female (%)
National Coordinators of CSN5 Expts	82	18
Local Coordinators of CSN5 Expts	78	22
CNS5 members	70	30
INFN Ph.D. Thesis in CSN5	68	32

Table 2.7 - CSN5 gender statistics

This activity is carried on in close connection with the academic world and with other scientific institutions, both in Italy and abroad. The variety and quality of the research carried on by CSN5 are proven by the number of papers, citations and talks at international conferences.

In the reference period, the CSN5 activity involved about 1300 physicists corresponding to about 500 FTEs. In 2019, the CSN5 physicists have published 517 papers (to be compared with 336 papers in 2018), with an average Impact Factor of about 3 per paper. The Intellectual Property of INFN is about 0.5/paper. During 2019, 421 talks have been presented at International (379) and National (42) Conferences. In 2019, CSN5 activities were present in all INFN Units/Laboratories.

Several CSN5 projects receive additional resources from External Funds: in 2019 the funding from external sources amounts to roughly 9M€.

Since 2013 the CSN5 has introduced a new funding scheme, which includes (besides “standard experiments”) also “Calls for proposals”. The aim of this new funding scheme is to enhance both the aggregation of the scientific community and the excellence of the proposals. Besides that, the “Calls” are also an effective instrument for CSN5 to address resources on strategic items. They have a budget of the order of 1 M€/project and are subject to more stringent requirements than standard experiments: for instance, approved projects must apply to ERCs and are subject to more frequent status reports.

In the period under consideration, researchers of the CSN5 obtained several interesting scientific results that are worth mentioning in this report. The highlights for 2019 are:

RSD. RSD (Resistive ac-coupled Silicon Detectors) is a grant for young researchers devoted to the development of fast silicon detectors with 100% fill-factor for 4D particle tracking. The devices are silicon detectors based on the internal multiplication (LGAD, Low Gain Avalanche Detectors) concept, but without any segmentation, thus achieving potentially **100% fill-factor** through the **Resistive AC-Coupled** readout principle. In 2019, the first batch of devices (produced at FBK, Trento, Italy, and consisting of 300 x 300, 200 x 200, 100 x100 and 50 x 50 μm^2 pixels with different gains) was tested with an IR laser (Transient Current Technique), with a radioactive ^{90}Sr β-source and on particle beams, demonstrating a position resolution of 2.5 µm and a time resolution of about 14 ps. These results are currently the best achieved with this type of technology and are considered extremely promising in view of the realization of 4D tracking detectors for future High Energy Physics experiments.

NEPTUNE. The call NEPTUNE (Nuclear process-driven Enhancement of Proton Therapy UNraVeled) aims at studying and understanding the observed enhancement in proton therapy effectiveness for irradiations occurring in the presence of ^{11}B atoms, due to the reaction $p + {}^{11}B \rightarrow 3\alpha$ (up to 4 MeV). The main objectives of NEPTUNE will be the consolidation of these results, extending them to include another nuclear reaction between protons and ^{19}F and focusing on understanding all the physical and biological mechanisms involved. A physical characterization of the radiation field will be performed with tissue-equivalent detectors of various types, all based on micro and nanodosimetric techniques. At the same time, biological measurements will be performed for different cell lines using several endpoints. New biological approaches will be considered to study the problem from different points of views, which could reveal mechanisms not yet considered. All experimental data will be compared with predictions from analytical and Monte Carlo models. The project is divided into four main Working Packages: WP1, modelling; WP2: imaging and quantification; WP3: microdosimetry and WP4: radiobiology. An additional group (WP5) coordinates all the foreseen experimental activities.

During 2019, several important results were achieved:

- Implementation of MC simulations (Geant4) for $p + {}^{11}B$ and $p + {}^{19}F$ nuclear reaction spectra generated in the experimental setup (WP1);
- Microdosimetric spectra from the measurement at LNS with the already available detectors (WP3);

- Corroboration of proton biological enhancement by p-B in previously tested cell systems (MCF-10 and DU145 cells) (WP4);
- Preliminary results on enhancement of proton beam effectiveness by p-B and p-F on PANC-1 and BJ cells. Testing carrier concentrations from WP2 (WP4).

PHOS4BRAIN. The PHOS4BRAIN experiment is devoted to the design, development and realization of radiation tolerant, low power, high speed links for High Energy Physics Experiments based on wireless optical communication and Silicon Photonics.

In 2018 and 2019 the collaboration designed and tested the Driver, Mach-Zehnder Modulator (MZM) and Serializer chip prototypes in 65 nm technology. The chips were tested at the bench and in a radiation field, with excellent results. The irradiation tests demonstrated that the Serializer can withstand up to more than 1 Grad. A version of the driver in 28 nm technology, foreseen to work at 25 Gb/s, has been designed. The design of photonic chip prototype, which includes three different types of modulators (MZM, EAM – Electron Absorption Modulator, and RM – Ring Modulator) has been completed and submitted to the foundry in July 2020.

AIM. The AIM (Artificial Intelligence in Medicine) experiment is devoted to the development of new Radiomics and Machine Learning techniques for medical diagnostics and treatment (RX, PET, MRI, US, ...). The experiment is organized in several work packages and has a very ambitious program, focusing on three main objectives: Multicenter Data Harmonization (with applications mainly to the reliability improvement of multi-center studies in neuroimaging and mammography), Quantification (with applications mainly to precise quantification of radiotracer uptakes in PET and to quantitative MRI methods) and Predictive Models (for Radiomics and Dosiomics in Oncology, ML and DL for disease diagnostics). All three main objectives are pursued with advanced AI methods: image processing, data filtering, feature extraction, pattern recognition, Machine Learning, Deep Learning, etc. Recently, a dedicated Working Group on COVID-19 has been formed, to study and apply radiomics techniques and methods on lung CT analysis. Quantitative information on the amount of GG (Ground Glass) opacities and their distribution, possibly combined with clinical and epidemiological patient's information, may be relevant to set up predictive models for patients' stratification, prognosis prediction, etc. Even only pure quantification modules, once properly validated, could be valuable tools for clinicians to set up large-scale population studies.

3. The CTS (Comitato Tecnico Scientifico)

The CTS is the consulting board with the mission defined by art. 4 subsection 2 of INFN statute[1], i.e. to provide "*Opinions on the developments of the scientific lines provided by the CSNs and that one of fairness on the initiatives with a relevant economic impact provided by the CTS are acquired by the Board of Directors in order to evaluate the Triennial Plan of Activity and the Ten-Year Document of Strategic Vision"*[2].

In 2017-2018 the composition of CTS has changed: Dr. Franco Bedeschi has taken over the task of chairing the Committee from Dr. Giuseppe Battistoni (appointed Director of the TIFPA). The composition of the Committee is therefore: Dr. Franco Bedeschi (INFN Pisa, chairman), Prof. Laura Fabbietti (Technische Universität München), Prof. C. Campagnari, (Univ. Of California), Prof. F. Linde (NIKHEF) and Dr. M. Nessi (CERN).

The CTS committee has reviewed the implementation of the LUNA-MV project in the LNGS. Since the scientific and technical aspects of LUNA-MV have already been extensively reviewed by CSN3, the Scientific Committee of LNGS and the INFN MAC with positive recommendations, we have confined our review to the need to configure LUNA-MV as a LNGS facility, and to the implications that this choice would have on the laboratory and INFN.

[1] "*During planning of major (with respect to economic impact) initiatives, the Institute profits of the fairness opinion of the Comitato Tecnico Scientifico."*
[2] Subsection 3 and art. 18 of INFN statute.

4. INFN National Laboratories

4.1 LNF Laboratori Nazionali di Frascati

The Frascati National Laboratory (LNF) has been the first among the INFN National Laboratories and is still the largest for number of employees. Since its foundation, it has been devoted to two main activities: the development, construction and operation of accelerators; the design and construction of forefront detectors for particle, nuclear and astroparticle experiments.
The LNF stands over an area of 135.000 sqm. Of these, 56.000 are indoor and include offices, laboratories and service areas. A detailed map of LNF can be seen in Appendix A.

4.1.1 Facilities

The LNF hosts the following research infrastructures:

- DAFNE, a e^+e^- collider unique in Europe, operated at the center of mass energy of the Φ meson peak, able to deliver instantaneous luminosities ~ 2 x 10^{32} cm^{-2} s^{-1};
- a synchrotron light laboratory, DAFNE-Light, housing seven synchrotron radiation lines in the soft-X and infrared range, extracted from the electron ring of DAFNE;
- a Beam Test Facility, BTF, an area equipped for detector and beam diagnostic tests, where two beam lines that provide electrons, positrons and photons of variable intensity and energy are available;
- SPARC_LAB, a complex hosting a linear electron accelerator able to drive a FEL, and a laser of power ~ 200 TW. The SPARC_LAB is an infrastructure for R&D on new techniques of particle acceleration and for interdisciplinary studies, including PWFA and LWFA experiments, TeraHertz radiation and a Compton source;
- SCF_LAB, a certified laboratory for the design, modelling and characterization of laser ranging equipment. The laboratory procedures are approved by the International Laser Ranging Service;
- COLD, a cryogenic laboratory for the development of ultra-sensitive photon detectors equipped with a complete set of cryogenic facilities for measurements down to mK temperatures;
- RF X-BAND TEST STAND, a new infrastructure under completion to test X-band accelerating structures to gradients up to 100 MV/m, built in collaboration with CERN and part of the LATINO project. It will be available for external companies operating in the compact linac field and for the remaining time will be used for tests of CLIC, EuPRAXIA@SPARC_LAB and XLS accelerating structures;
- large assembly halls with several clean rooms (for a total surface of about 480 sqm) equipped with special tools for designing and building large experimental equipments.

Furthermore, LNF hosts a mechanical workshop, an electronic service, a powerful and modern computing centre and a medical physics service unique in INFN.

4.1.2 Organization and staff resources

The LNF, including also the joint group of the Cosenza University, features 291 units of permanent employed personnel, 24 with fixed term contract and 170 units of associated collaborators.

Among this last category, there are masters and PhD students, young post-Docs, and employees of other scientific institutions (Universities and other Research Centres) from Italy and abroad. Table 1 summarizes the distributions on the different profiles of employees.

	Permanent Staff	Fixed term Staff	Tot.
Researchers	73	4	77
Engineers	55	7	62
Admin staff	34	4	38
Technicians	129	9	138
Tot.	291	24	315

Table 4.1 - LNF personnel at December 2019

During 2019, LNF hosted 254 external users, 32% of which from foreign countries. These are researchers of Italian and foreign institutions taking part to the internal LNF research activities, and users of LNF facilities: DAFNE, the synchrotron light lines and the BTF.

The LNF is organized into three distinct divisions: Research, Accelerator, and Technical, plus some general services which report directly to the Director. The Research Division consists of 65 researchers, 25 engineers, 51 technicians and 10 units of administrative personnel. In total 151 staff members (11 with a fixed term contract). They are involved in the local activities as well as in projects taking place at the major laboratories of particle and nuclear physics all over the world. The Accelerator Division consists of 12 researchers, 32 engineers, 42 technicians and 3 units of administrative personnel. In total 89 staff members (6 have a fixed term contract). The main local activities are the operation of the DAFNE-BTF complex and of the SPARC_LAB. The Technical Division supports research and accelerator activities, also overseeing the functioning and maintenance of the whole laboratory. It consists of 6 engineers, 29 technicians and 3 units of administrative personnel, for a total of 38 members (4 with a fixed term contract). The general services that report directly to the Director are:

- Directorate service, consisting of 2 technicians plus 1 administrative;
- Personnel service, consisting of 3 technicians and 4 administrative employees (1 has a fixed term contract);
- Administration service, consisting of 14 administrative employees;
- Prevention and Protection service, consisting of 2 engineers, 3 technicians, and 1 administrative employee (1 has a fixed term contract);
- Medical service, consisting of 1 engineer, and 5 technicians (1 has a fixed term contract).

This structure is graphically illustrated here: http://user.lnf.infn.it/wp-content/uploads/2018/04/Organigramma_rev_1marzo_english.pdf.

The number of staff members with a fixed term contract has considerably decreased thanks to a hiring-by-law procedure that took place in October 2018. A second round of hiring-by-law is presently ongoing.

4.1.3 Research activity

The research program of LNF has always been mainly focused on high energy physics, accelerator operation and development, and interdisciplinary research equally balanced between internal activities, carried out on site, and external ones taking place in the major laboratories all over the world.

Accelerators operation

The scientific staff of the **SPARC_LAB** facility is fully committed to the experimental studies on plasma acceleration. The goal is to produce a plasma accelerated beam whose quality in terms of emittance, energy spread, dimensions and charge matches the requirements of a FEL radiation source. The experimental demonstration of this result, that has been already predicted theoretically by simulations codes, is a fundamental milestone along the process of the future LNF infrastructure EuPRAXIA@SPARC_LAB construction.

The SPARC_LAB experimental program addressing the **EuPRAXIA@SPARC_LAB** issues includes the plasma de-chirper study, a better understanding of the drive-witness bunch parameters, their global optimization and characterization, the PMQ-plasma lens comparison, the shaping of the drive bunch to reach higher transformer ratio, and the drive/witness bunch separation before the FEL undulator using plasma lenses. In the last year promising experimental results have been obtained. In particular, the witness bunch acceleration has been demonstrated to be stable and reproducible, with a good beam quality especially concerning the energy spread. The accelerating gradient has been limited to ≈ 150 MV/m to allow for a larger longitudinal separation between driver and witness bunches. The experimental activity is progressing with the maximum support of the Laboratory at the highest priority, to improve the performance in terms of beam emittance, accelerating gradient and accelerated beam transport. The final goal is to transport the accelerated beam to a sequence of six variable-gap undulators already in place along the beam line, to measure and demonstrate the coherent emission of FEL radiation that would ultimately validate the scientific program of EuPRAXIA@SPARC_LAB.

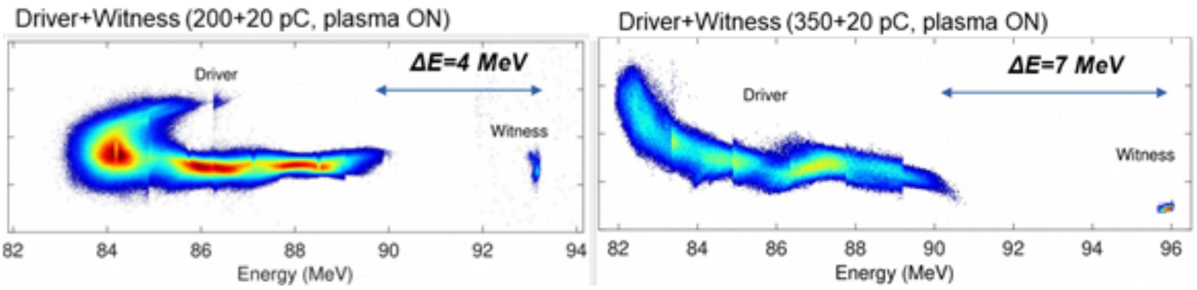


Figure 4.1 - PWFA accelerated witness beam images after the spectrometer measured at SPARC_LAB

EuPRAXIA@SPARC_LAB has been proposed and approved by the Italian Government as a new national infrastructure having the explicit ambition of becoming the particle driven plasma acceleration (PWFA) pillar of the European strategy on the plasma acceleration as defined in the EuPRAXIA European H2020 Design Study completed and delivered in 2019. The Conceptual Design Report of the EuPRAXIA@SPARC_LAB project has been delivered in May 2018 and submitted for evaluation to an International Review Committee, appointed by the INFN management, which gave green light advancing the project to the next phase, the preparation of a Technical Design Report. In the last 12 months, the project has progressed under various aspects:

- The executive design of the new building that will host the facility is ongoing, with the scientific and technical staff of LNF strongly committed in supporting the external engineering company Mytos in charge for this task;
- The Organization Breakdown Structure (OBS) and Work Breakdown Structure (WBS) documents have been presented to the LNF staff and will be announced to the entire collaboration in the fall of 2020;

- The submission of the facility to the ESFRI call, whose deadline has been delayed because of the Covid19 crisis, is now ready. The call is intended to insert the new proposal in the list of the recognized strategic European facilities, a very important award that facilitates the setting-up of international collaborations and the access to EU funding.

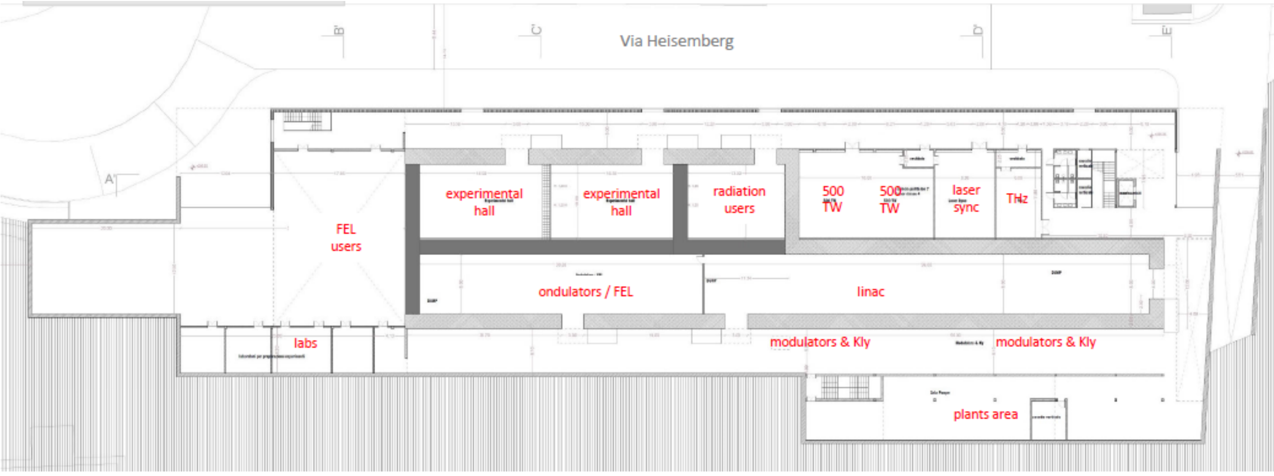


Figure 4.2 - Sketch of the EuPRAXIA@SPARC_LAB building under design

Concerning the **DAFNE/BTF** complex, the operational plans have been strongly affected by two major events: the breaking of a Beryllium window placed just in front of the PADME detector, which occurred on July 25th 2019, and the shutdown of the LNF accelerators from March 12th to July 1st 2020 imposed by the Covid19 pandemic. The Beryllium accident happened during a repositioning operation of the window from the original position upstream the last BTF1 dipole, to a new location downstream the dipole, in front of the PADME detector. This operation was planned with the purpose of reducing the background in the detector caused by off-energy/off-track positrons in the beam. After being mechanically installed, during pre-vacuum pumping the Be window collapsed. The failure was probably caused by a fabrication defect. The BTF1 area was declared off-limits until environmental measurements had shown the absence of Be contamination in the hall, while a significant contamination was detected in all the vacuum chamber elements upstream the window up to the nearest closed vacuum valve located in the DAFNE linac tunnel. No contamination instead was observed in the upstream chamber and in the PADME detector. A recovery plan was elaborated, based on a combination of cleaning and rebuilding of the original parts. The final reassembly of the line and a new PADME run were scheduled for April 2020, but the Covid19 pandemic restrictions forced a shift of the plan. The new line was reassembled and the UHV conditions restored during June 2020, and in July 2020 the data taking of PADME has been resumed. Beryllium windows have been excluded from the new layout, being replaced by special Mylar windows designed by LNF vacuum experts and realized under their supervision.

As a consequence of both the Beryllium window accident and the Covid19 pandemic restrictions, the preparation of the BTF beamline 2 has been delayed. According to the new schedule the final installation will be completed by the end of 2020, and the first call for experiments will take place in spring 2021.

The DAFNE collider commissioning for the SIDDHARTA-2 experiment has been resumed in September 2019 and, except for a few stops imposed by hardware failures, it has continued till the Covid19 shutdown. During this period the performance of the collider has considerably improved. In particular the betatron coupling of both beams has been corrected to < 1 % by rotating a set of electromagnetic quads near the interaction region, a low-beta collision optics has been implemented in place of the commissioning "detuned" one, the crab-waist betatron conditions have been restored by means of a fine longitudinal repositioning of the permanent focusing quadrupole magnets.

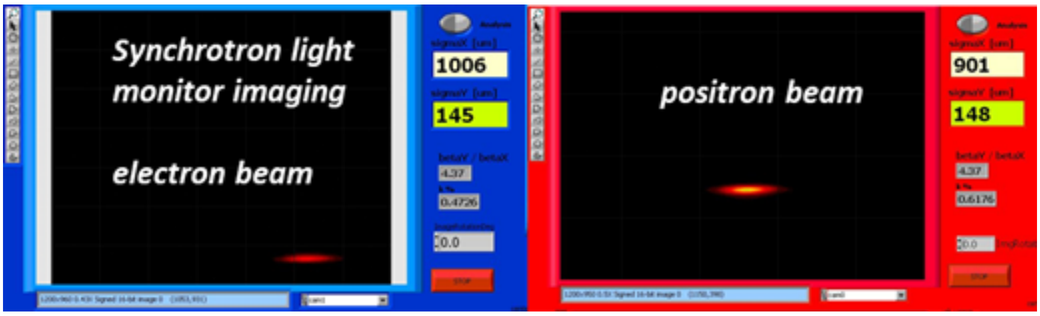


Figure 4.3 - Synchrotron light monitor images of coupling-corrected DAFNE beams

As a result, a 5.4 µm vertical dimension of the beams at the IP has been measured with a luminosity beam-beam scan, a value in line with the best DAFNE performances ever. A maximum luminosity in excess of $\approx 5{\cdot}10^{31}cm^{-2}s^{-1}$ has been estimated by the geometrical parameters of the beams, and it has been confirmed by independent measurements performed by the CCAL-T luminometer, based on Bhabha scattering at small angles and still under commissioning, and by the Kaons counting rate provided by the SIDDHARTINO detector.

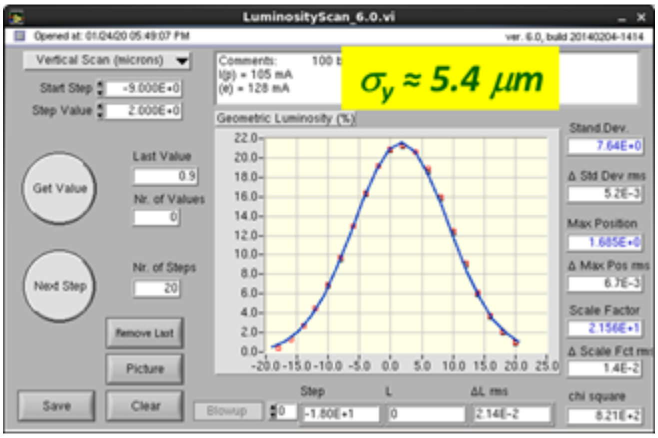


Figure 4.4 - Luminosity vertical beam-beam scan estimating the beam vertical dimensions at IP

As of February 2020, both collider and experiment were ready to start the data taking required to preliminarily evaluate the detector performances and to measure and optimize the signal-to-background ratio. The program has been stopped initially by a heavy hardware fault in the linac requiring the replacement of the klystron C twice, then by the Covid19 containment measures. Some others major or recurring faults limited the collider uptime, such as a linac cathode substitution, and the water leaks in the ring wiggler magnets caused by breakings of the cooling pipe hoses. The DAFNE/SIDDHARTHA-2 run restart is scheduled for late October 2020, when the presently ongoing PADME run will be completed.

<u>On-site fundamental research</u>

The main research activities carried out on site during 2019 have been:

- The recommissioning of DAFNE for the SIDDHARTA-2 run;
- The data taking for the PADME experiment.

The goal of **SIDDHARTA-2** is to perform high precision measurements of X-ray transitions in kaonic atoms in order to deduce antikaon-nucleon scattering lengths. This is possible exploiting the low energy negative kaons from the decay of the Φ resonance produced by DAFNE. In 2009 its predecessor SIDDHARTA performed the most precise measurements of the transition to the 1*s* level of kaonic hydrogen and the first exploratory study of that of kaonic deuterium. Moreover, the kaonic He4 and He3 transitions to the 2*p* level were also measured in gas for the first time. A major upgrade of the existing detector has been performed with the aim to measure transition lines of kaonic deuterium, starting in the fall of 2019. It consisted in an optimization of the trigger system, also implementing a new active shielding, increasing the target density, and using new SDD detectors with a larger active surface and operated at lower temperature to improve the signal/noise ratio.

After the shutdown of the KLOE2 experiment (April 2018) the DAFNE interaction point 1 (IP1) was refurbished to host SIDDHARTA-2. A new vacuum chamber was installed, equipped with new permanent quadrupole focusing magnets and dedicated luminometers. A sub-set of the new apparatus was installed on the DAFNE IP1 in spring 2019. It consisted of 8 SDDs, out of the 48 that constitute the complete setup, the whole new veto and luminosity monitor systems, and the target filled with gaseous He4 (SIDDHARTINO).

Electron and positron beams were circulated in the rings, and the commissioning started. Unfortunately, DAFNE operations were not optimal and it was not possible, within the year, to reach a level of background acceptable for the experiment. In 2020, the lockdown has forced to stop all the LNF accelerators. When in May 2020 experimental activities in the lab were resumed, it was decided to switch on only the DAFNE linac, to allow the commissioning of BTF line 2 and the PADME data taking, and the SPARC_LAB complex. The restart of DAFNE will be reconsidered in Autumn 2020 after a complete survey of the beam-lines of the collider. The SIDDHARTA-2 data taking will take place during year 2021 with the goal of collecting an integrated luminosity of 800 pb^{-1}.

SIDDHARTA-2 is an international collaboration that involves ~ 40 researchers from LNF, INFN and Politecnico Milano, Vienna SMI (Austria), IFIN-HH Bucarest (Romania), TU Munich (Germany), Univ. Zagreb (Croatia), RIKEN (Japan), Univ. Tokyo (Japan), Tohoku Univ. (Japan), Victoria Univ. (Canada), Jagellonian Univ. Cracow (Poland).

The primary goal of the **PADME** experiment is to search for dark photons produced in the annihilation process of the positron beam of the DAFNE linac with the electrons of a thin carbon target, then identified using a missing mass technique. The international collaboration is composed by ~40 researchers from LNF, INFN Rome and Lecce, Sofia University (Bulgaria), Debrecen Atomki Institute (Hungary), Cornell and William & Mary College (USA).

The aim of PADME is to collect 5×10^{13} positrons on target (POT) in order to reach sensitivities down to 10^{-4} on the dark photon-electron coupling constant for masses below ~ 27 MeV/c^2. The experiment is the result of a strong synergy between the Research and the Accelerator divisions. In fact, its ultimate sensitivity is strongly dependent on to the DAFNE linac performance. Crucial parameters are the beam spread (both in energy and space) and the beam pulse duration. During DAFNE operation, the linac beam is set up to provide pulses at 510 MeV with a maximum length of 10 ns at a repetition rate up to 50 Hz. This is not ideal for PADME that, to lower pile-up, requires to stretch the positron bunches up to hundreds of ns, that is the present limit of the linac RF system. This is also the reason why PADME cannot take data in parasitic mode when the collider is in operation for the SIDDHARTA-2 experiment.

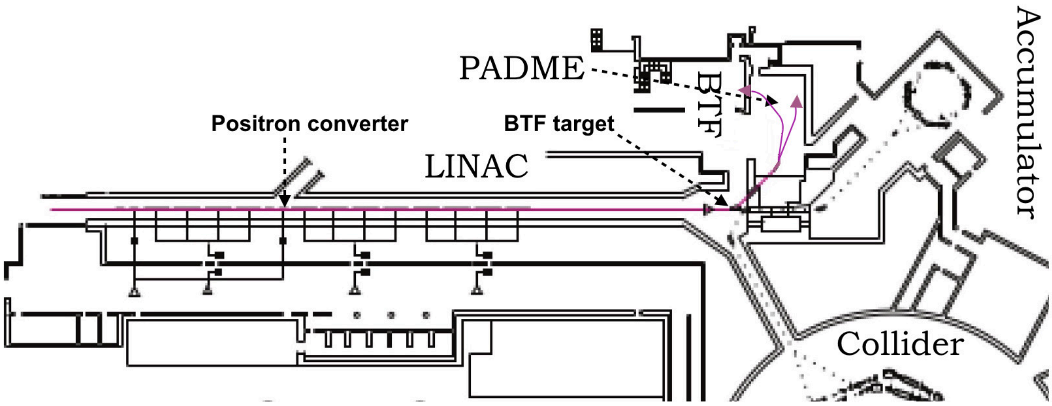


Figure 4.5 - Layout of the LNF LINAC. Positron converter and BTF target are pointed out (see text for more details).

PADME commissioning data taking (taking place from November 2018 to February 2019 during SIDDHARTA-2 installation on DAFNE IP1) was carried on BTF line 1 (BTF1), that since October 2018 is exclusively dedicated to the experiment.

Positrons can either be accelerated up to 550 MeV after being generated in the linac on a W-Re converter of 2 X_0 (Positron converter) located after the first electron accelerating sections (primary positron beam), or can be produced by a primary electron beam of 750 MeV hitting a Cu converter of selectable X_0 (1.7, 2, or 2.3) (BTF target) located before a 1 m thick concrete wall that separate the linac from the BTF experimental hall (secondary positron beam). An energy selection system, and some collimators on the BTF transfer-line, define momentum, spot size, and intensity.
Figure 2 shows a sketch of the linac layout and of the BTF beam lines.

Most of the data collected during this first run were recorder with the positrons produced at BTF target, while for a few days, at the end of February 2019, they were collected with the primary positron beam. The analysis of the data showed that the level of background induced by the beam in the detector was extremely high, in particular for the data set collected with the secondary beam. Therefore, another four-weeks technical run was planned for July 2019, to optimize the beam setup before starting physics data taking in Autumn. Due to problems to the air conditioning system of the BTF hall and the breaking of a Be-window separating the accelerator vacuum from that of the experiment, the program was cancelled and the PADME data taking was postponed to 2020.

Besides PADME and SIDDHARTA-2, other on-site research activities were also carried out. During 2019 experiments at the **DAFNE-Light laboratory** were mostly performed using conventional light sources, while the DAFNE synchrotron radiation beam was used only for a few tests. Access to the facility was granted to about 45 experimental teams, coming from Italian and European Universities and Research Institutions. As for the previous years, two calls for proposals were opened in June and in October and the beamtime was given to experimental proposals submitted by European users within the EU CALIPSOplus Transnational Access program. A detailed description of the activities at DAFNE-Light can be found at the address http://www.lnf.infn.it/rapatt/2019/dafnel.pdf.

A new initiative involving ASI-Matera and INFN-Frascati was established in 2019. The project, named **Joint-Lab ASI-INFN**, will start operations in late 2021 / beginning 2022 with a duration of 5 years (2025/2026). Its purpose is to carry out activities in the field of advanced laser systems for space applications, based on laser retroreflectors and precision laser tracking of spatial objects in the solar system (Earth satellites, the Moon, Mars etc..). In this context, specialized and unique technical-scientific skills were developed for ASI at the Space Geodesy Centre (CGS) of Matera and for INFN at LNF, within the SCF_Lab research group. The project will exploit also a new

LNF infrastructure: the SCF_Lab2 in preparation to be fully operational in 2021. Once completed, the SCF_Lab2 will double the research capabilities of the existing SCF_Lab, to satisfy the growing requests of national and international collaborations with ASI, ESA and NASA. The SCF_Lab2 will host one of two OGSE (Optical Ground Support Equipment) facilities that currently are located within the SCF_Lab. The realization of this new infrastructure can count on the funding of the ASI-INFN Project dedicated to the ASI space mission LARES-2. The latter is an effective point-like test mass for studies of general relativity and space geodesy, and it is the first satellite entirely build by INFN. LARES-2 will be delivered to ASI by the end of 2020 and will be launched by ESA with the qualification (maiden) flight of the new European rocket, the Vega C.

COLD (CryOgenic Laboratory for Detectors), a new laboratory for cryogenic detector development installed in Bld.8, has become the LNF cryogenic facility. The experimental activity includes R&D on ultra-sensitive photon detectors in the range 10 – 100 GHz, mainly devoted to the search for Axions. Novel superconducting resonant cavities operating at 10-20 GHz at one side, and development of Josephson Junction devices for 50-100 GHz microwave photons on the other side, are the devices under study, with the aim of reaching the single photon detection capability. Superconductivity implies operations at very low temperature. Thus, the lab (fig. 7) is equipped with a complete set of cryogenic facilities for measurements down to the mK range. A big-size cryogen-free cryostat from Leiden Cryogenics (CF-CS110 model) was delivered and tested at the end of 2019. It is capable of cooling large devices (up to 500mm diam x 500mm heights) at T below 10 mK, using a continuous-operation dilution refrigerator, with a cooling power of 1 mW @ 120 mK, and a 1.5 W @4.2 K Pulse Tube Cryocooler. This type of refrigerator (fig. 8) allows for long-term experimental runs with virtual 100% duty-cycle. The cryostat is equipped with several coaxial RF feedthroughs and is prepared to host a 9 T superconducting magnet, for application where high-fields are required. The installation of one of these magnets is planned for early 2021.

Figure 4.6 - A view of the COLD lab

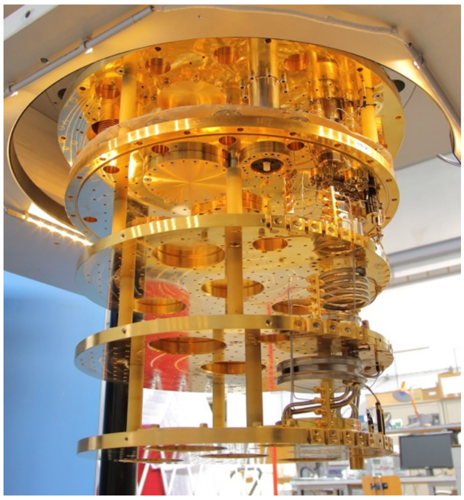


Figure 4.7 - Cold side of the CF-CS110 refrigerator

The laboratory is also equipped with a small-size liquid Helium cryostat with a plastic dilution refrigerator (Leiden Cryogenics MCK50-100), property of CNR-IFN, for DC characterization of small devices down to 40 mK. Another Oxford Instruments Liquid Helium cryostat with a superconducting magnet is devoted to measurements at T = 4 K and B up to 5 T.

The availability of large assembly halls, clean-rooms and technical support makes LNF a hub for many INFN enterprise. In 2019 at LNF premises was ongoing the construction of the modules for the **Cosmic Ray Tagger (CRT) of the Fermilab neutrino program**. The Short Baseline Neutrino (SBn) experiment at Fermilab aims to discover the existence of a sterile neutrino at the eV scale. The SBn will observe neutrino interactions using 3 liquid-Ar TPCs installed along the Booster neutrino

Beam line (BnB) located few meters underground. The shallow depth of the detectors makes them exposed to a sizable flux of cosmic muons, and the electrons, and positrons from the secondary showers could be misidentified as part of neutrino interactions. In order to mitigate this cosmic induced background, SBn near and far detectors are surrounded by external cosmic ray taggers allowing the identification of cosmic muons entering the TPCs. The construction and testing of the top CRT of the ICARUS-t600 TPC was carried out at LNF. Covering a surface of about 426 m^2 the detector is segmented in 123 modules (84 horizontal + 39 vertical). At LNF over 40 people, including physicists, technicians and engineers from the INFN sections of Bologna, Genova, Lecce, LNF, LNS, Milano, Milano Bicocca, Padova, and from CERN, contributed by weekly shifts to the construction and test of 125 CRT modules. All of them are now in stock in a container at LNF waiting to be shipped to Fermilab. Before the Covid-19 pandemic, their installation, commissioning and integration in the SBn DAQ system was foreseen by the end of 2020.

Fundamental research at external laboratories

On December the 3rd 2018 the LHC entered in the Long-Shutdown 2 (LS2) phase, to enable major upgrades and renovations both of the machine complex and of the experimental detectors. All the LHC experiments are upgrading important parts of their detectors. Almost the entire LHCb experiment is being replaced with faster detector components that enable to record events at full proton-proton rate. Similarly, ALICE decided to upgrade the technology of its tracking detectors. ATLAS and CMS undergo improvements and start to prepare for the big experiments' upgrade for the High Luminosity (Hi-Lumi) phase which will start operation after 2025. This is a very ambitious project that will increase the LHC luminosity by a factor 10 beyond its design value. LNF researchers are involved in all the LHC experiments, and thanks to the infrastructures available on-site, are contributing in fundamental way to this process.

The realization of the staves of Outer Barrel (OB) of the new **ALICE** Inner Tracking System (ITS), based on silicon-pixels, relies on the work done in 4 sites: Daresbury (UK), Nikhef (NL), INFN-Torino and INFN-Frascati. At LNF the stave mass production started in February 2018 and was fully completed by the end of 2019. The existing infrastructure hosted in Bldg. 27 was completely reorganized to cope with the assembly and the manipulation of a large quantity of fragile and low-thickness (100µm) silicon sensors with unprotected wire bonds. The production rate at LNF reached a sustained rate of 1 stave/week between the end of 2018 and June 2019 while the final production yield reached 97% (fraction of detector grade modules) for 29 produced staves (27 nominal staves + 2 spares). The ALICE-LNF group also developed a recovery procedure for damaged staves. Since a stave is composed by 2 halves, a tool was engineered at LNF to detach the already glued half-stave from the support to reuse the detector grade parts in a new one. Since the end of the mass production, the group is committed on the ITS surface commissioning (assigned quota of commissioning shifts was fulfilled for 2019) and preparing for the installation of the detector in the ALICE cavern.

ATLAS Small Wheels (SW), detecting the muons passing through the inner part of the detector, have to be changed for Run 3, foreseen to start in 2021, in order to cope with the increasing luminosity of the accelerator. New SW (NSW), combining small-strip Thin Gap Chambers (sTGC) and MicroMegas (MM), are under construction at different institutes and industries in Germany, France, Russia, Greece, CERN. INFN is responsible for the lower part of the small wedges, and LNF is deeply involved in the construction and test operations of MicroMegas modules. In Frascati the final assembly of the quadruplets is performed, and the modules are tested and characterized in a cosmic ray stand. The chambers production started at LNF at the end of 2017 and will last 2020-2021. The LNF ATLAS group plays a central role in the SM1 chamber production performing both the final assembly in properly equipped clean rooms and the quality assurance and quality check tests to validate each chamber before its shipment to CERN. Those tests comprise verifications of the chamber' planarity (required to be < 100 μm), gas leak and alignment checks between the panels composing the quadruplet. In the end, a final validation is performed switching on the high voltage to study the performances in terms of efficiency in cosmic ray detection. Actually, the chamber produced at LNF are those better performing. Therefore, the collaboration decided to adopt in all the production sites the tools and the procedures developed by INFN.

The **CMS** collaboration is also upgrading its muon detector. The CMS Frascati group has a crucial role in the construction of the new muon-chambers based on GEM technology being in charge for supervising the production in all the assembly sites (INFN Bari, Florida Institute of Technology and CERN). Frascati itself is a production site: in the LNF CMS lab the chambers are assembled and tested under several quality control setups, required to accept them for the final installation in the experiment. The CMS Frascati Group has also the responsibility of the installation and operation of a network of Fiber Bragg Grating (FBG) optoelectronics temperature sensors mounted in each chamber. The FBG sensors will provide a detailed map of the temperature gradient in the region, and online monitoring.

The **LHCb** Frascati group is deeply involved in several activities related to the experiment upgrade. The LNF electronic team (LNF-SEA) is producing, testing and commissioning the new muon system off-detector electronics (nODE) which has been redesigned to be compliant with the 40 MHz readout speed of the detector. The 24 nODE of the pre-production have been assembled and tested. At the end of 2019 the 166 boards full production started, and the test is ongoing as they arrive at LNF. In parallel the LNF-SEA team put in place the full acquisition chain (the so called "miniDAQ") needed for the final test of all the boards. Since the new ODE board requires to review the architecture of the Electronic Control System (ECS) completely, the first full connectivity test has been performed at CERN on one of the M4 station quadrants using a preliminary version of the nSYNC libraries. In the meantime, the development of the full new libraries is ongoing under the Frascati responsibility in close touch with the commissioning team at CERN. As soon as the new ECS will be ready, the systematic test of the muon system connectivity will start as the stations will be equipped with the new nSB and nODE boards.
Another activity under the coordination of the LNF-LHCb group is the SMOG2 project. This is the first internal fixed gas target for the LHC and will be part of LHCb. After an intense R&D phase the TDR has been finalized and approved by the LHCC and, at present, the system is under construction.

Concerning the LHCb muon system needed for Hi-Lumi LHC phase, an intense R&D is undergoing to develop and test new generation Micro Pattern Gaseous Detectors (MPGD) which are suitable for rates as high as several MHz/cm^2. In particular, the Frascati Detector Development Group (DDG) is the driving force in the development of micro-Rwell detectors. After a finalization of the resistive stage in order to allow the detector to stand particles rate of the order of MHz/cm^2, the characterization of this technology has been focused on the stability response under irradiation. Some 10×10 cm^2 μ-RWELLs have been operated under X-ray flux for long time integrating 180 mC/cm^2, with the final goal of integrating the 2 C/cm^2 expected after 10 years of operations in the most irradiated region of the LHCb muon detector. For a complete validation of the technology and the adoption in LHCb, further tests are in preparation.

New activities were started, in 2019, in the astroparticle physics line at LNF.

CYGNO is the project to realize a directional Dark Matter detector based on single phase gas-only TPCs, part of an international proto-collaboration (CYGNUS-TPC) that aims at realizing a network of observatory in underground laboratories. The LNF group is in charge of designing and constructing the final detector and all the R&D prototypes, gas studies and GEM developments. Moreover, LNF is the site where all the tests are ongoing. The former LHCb clean-room, in Bd. 28, has been refurbished and assigned to the new group for the needs of the experiment. Once ready the detector will be installed at LNGS.

QUAX (QUest for AXions) is an experiment searching for galactic Axions in a mass range around 40 μeV with a cryogenic resonant cavity resonating at a frequency of about 10 GHz. The first QUAX haloscope is operated at the LNL and a second one is in preparation at LNF. A large effort has been put by the group working at the COLD lab in developing resonant cavities able to operate in a magnetic field of several tesla with a high-quality factor, up to 10^6. The same group in 2019 completed the Conceptual Design Report of KLASH (KLoe magnet for Axion SearcH) a "haloscope" composed of a large resonant cavity at cryogenic temperatures for the search of galactic axions to be inserted inside the KLOE magnet. KLASH could potentially discover Dark Matter particles such as galactic Axions, Dark Photons or other light bosons with a mass of about 1 μeV. The CDR summarizes the motivation and physics reach and contains a detailed study of the mechanical and cryogenic system, electromagnetic properties and of the low-noise electronics and signal acquisition. Since the KLOE magnet and e.m. calorimeter have now become part of the Fermilab neutrino program, the cryostat can eventually be readapted to be hosted in the bore of the FINUDA magnet.

For more details on the described activities, or to get information on others non-explicitly reported in this document, the reader can refer to the **LNF 2019 annual report** available online at this address: http://library.lnf.infn.it/rapporto-di-attivita-2019/.

4.1.4 Technology transfer and outreach

The most relevant activity in thecnology transfer has been the **LATINO** (Laboratory in Advanced Technologies for INnOvation) project. Started at the end of 2018. The project is worth 2.6 M€, 2/3 of which funded through the call "Open Research Infrastructure" of the Regione Lazio, within POR FESR 2014-2020, aiming at the reindustrialization of the local area. The main goal of the project is to promote the access to LNF technologies and their exploitation in areas other than nuclear and particle physics research. For this purpose, four laboratories are under creation: Radio Frequency, Vacuum and Thermal Treatments, Magnetic Measurements, and Mechanical Integration. The planned roadmap of the project is organized in two main steps: a first phase (duration 24 months) devoted to the creation of the infrastructure, followed by the operational phase in which the new-born facility will start performing its activities.

In 2019, a Laboratory project was approved in a second Regione Lazio call on the National Large Research Infrastructures, submitting the **SABINA** (Source of Advanced Beam Imaging for Novel Applications) proposal. The main goal of the project is the consolidation of the technological plants of SPARC_LAB. More specifically, using 4.5M€ of co-funding, the upgrade of the instrumentation and the implementation of two user lines (a power laser and a THz radiation line) will be realized. Several applicative fallouts are foreseeable within these two facilities, such as irradiation tests of samples for aerospace, investigation in physics, chemistry, biology, cultural heritage and material science.

The Laboratory has also participated to a third Regione Lazio fund call named "Strategic Projects" for industrial innovation, with the **eRAD** proposal, in collaboration with the Italian Space Agency (ASI) and the IMT company. The project is based on the use of BTF lines for irradiation with very low energy electron beams of electronics and devices to be used in aerospace applications. The results of these tests will be compared with the measurements carried out with photons, in order to define radiation resistance threshold and parameters. In-depth knowledge of both the space radiation environment and the mechanisms of radiation induced damage is fundamental for the development of an appropriate procedure for the qualification of the electronics components to be used in space environment. The eRAD project was approved for a value of 1.1M€, 75% of which will be financed by Regione Lazio.

Concerning cultural heritage, the main LNF centre for this activity is the **SINBAD IR** beamline located in the DAFNE_Light laboratory. Dedicated to FTIR (Fourier Transform InfraRed) micro imaging and spectroscopy, it was upgraded with new tools and instrumentation: new imaging systems, a UV lamp a MicrostatN cryostat for Hyperion 300 microscope, to perform reflection and transmission analyses at low temperature (77 K). A new laboratory for sample preparation was also installed, dedicated to cultural heritage diagnostics and biological samples analysis. The infrastructure is part of the INFN CHNet project, of the District Technology of Culture (DTC) supported by the Regione Lazio, and of the ADAMO project (Analysis technologies, Diagnostics And MOnitoring for the Preservation and Restoration of Cultural Property) aimed at transferring technologies from the DTC partners (ENEA, Roma Sapienza, Roma Tor Vergata, Roma Tre, Tuscia University, CNR and INFN) to industries (http://progettoadamo.enea.it/).

In 2019 a project called **TASTE** (Transportable and Agile Spectrometer for metal Trace in Edible liquids) proposed by an LNF researcher was awarded one of the grants of the INFN Research for Innovation (R4I) call. The project aims at constructing a transportable X-ray spectrometer for daily checks of quality and authenticity on edible liquids, studying the concentration of metals, their molecular forms and oxidation states. This kind of tests, important for instance in wine and olive oil production process, can be currently realized only in specialized centers. The markets of Italian wine and olive oil can be, roughly esteemed, around 3 billion euro, each: a large use of this new spectrometer could become a true “case study” for the application of scientific research to traditional production.

The LNF accelerator division started a collaboration with a US private firm and Yale University to extend the wavelength range of a FEL light source further into the X-ray region where no FELs are yet available. The **CompactLight XLS** collaboration aims at developing the technical design for the realization of a high-power Ka-band RF system.

During 2019 two innovative devices developed by LNF researchers started the patenting process:

- a collimator for neutrons
- a wearable neutron dosimeter

More details about these patents can be obtained from the central INFN Technology Transfer office in charge to follow patenting process.

The Education and Public Outreach Service (EPOS) of LNF since 20 years fosters the scientific literacy through a wide programme of initiatives addressed to students, teachers and general public to bridge science and society, either inside or outside the LNF site. Its main mission is to engage the public with science, inform about the latest issues in research conducted by INFN-LNF and the collaborations, enhance the valorisation of scientific heritage and building network with the society.

In 2019 great attention has been put in communication aspects on web and social media. At present LNF is active on Facebook, Twitter, Instagram and YouTube. Great attention has also been devoted to the realization of outreach material such as multimedia, graphics and photos, without neglecting the traditional program that consists in organizing public events, Lab visits, students and teachers’ programmes.

Considering only the events taking place "on site", thanks to the variety of the outreach offer, during 2019 LNF could get in contact with approximately 7.000 people. This number includes mainly students, from primary school up to university, but also general public.

LNF dedicates great attention also to orientation – in terms of both university and job – toward STEM careers. In this respect, under the umbrella of the United Nations General Assembly that declared the 11th of February the International Day of Women and Girls in Science, a special science matinée was organized in which scientist women talked about their experiences and careers to 200 students in their last High School year.

During the year it is possible to visit the Bruno Touschek Visitor Centre, the outreach hub dedicated to the history of LNF. The visits are guided by LNF researchers who present the exhibition and interact with people answering their questions. This visit can be included inside a longer itinerary which includes the DAFNE control room and the KLOE experimental site. In total 1811 people visited LNF during 2019

EVENTS 2019	PARTICIPANTS
Visits for kids, high school and university students	800
OpenLabs for the general public	2000
Seminars and Public Lectures	300
IDF and IDFM ("Incontri di Fisica") for high school teachers	203
Stages for high school students	338
"Matinées di scienza" for high school students	350
International Day of Women and Girls in Science	200
Aspettando il Giro d'Italia (Waiting for "Giro d'Italia")	220
"European Researchers' Night"	720
Visits University - Associations	743
Visitor Centre guided tours	1098

Table 4.2 - Overview of outreach events organized at LNF during 2019.

On April 12th LNF joined "Frascati in Pink - Science stage" a special public event organized together with the research centres of the Frascati area in the Il Giro d'Italia framework, that in 2019 stopped in Frascati. LNF proposed guided tours to the main experimental apparata and the Visitor Centre. On this occasion about 220 people visited LNF.

4.2 LNS Laboratori Nazionali del Sud

At the Laboratori Nazionali del Sud (LNS) research activities are mainly oriented towards Nuclear Physics and Nuclear and Particle Astrophysics, Applications of Nuclear Physics to Medicine and Cultural Heritage, development of acceleration systems and ion sources. The LNS are also an advanced technological pole for development of different types of instrumentation. The present document is an update version with respect to what published in last year's report and, therefore, does not contain the general description of LNS. The Organization chart of the LNS is available at https://www.lns.infn.it/en/about-us/organization-chart.html. The overall number of associated personnel units (not INFN staff) is 89. A summary of the beams delivered in 2018 can be found in the table in Appendix B.

4.2.1 Scientific Strategy, priorities and goals

UPGRADE OF THE LNS

As already reported, the LNS upgrade includes improvements of the Superconducting Cyclotron, the installation of the new fragment separator FRAISE for production of in-flight radioactive beams, and the upgrade of the experimental apparatus MAGNEX for the experiment NUMEN.

The goal of the project is to accelerate and deliver high intensity light ion beams with power of several kW and intensity up to 10^{14} pps. To do that, extraction by stripping will be implemented in the Superconducting Cyclotron in addition to the present electrostatic extraction mode. Moreover, the new fragment separator FRAISE will be able to handle intense primary beams that will produce intense and high-quality radioactive beams. Finally, the MAGNEX spectrometer will itself be able to work with intense stable beams, necessary for the investigation of rare processes related to the neutrino physics.

The conceptual study of the project was accomplished few years ago aiming at verifying the feasibility of extraction by stripping and at analyzing many technological aspects involved in the design and realization. In 2018, a call for funding of the upgrade of research infrastructures was published by the MIUR in the framework of the PON (Programma Operativo Nazionale, Research and Innovation 2014-2020, www.miur.gov.it). LNS is one of the 18 selected research infrastructures, that were funded since June 2019. The estimated cost is 19.3 M€ (maximum allowed 20 M€). The project duration is 32 months with a possible extension of 4 additional months.

Currently, by intensively using rigorousness Project Management best practices, the operative phase of the project has been started. All the activities have been scheduled and the tasks have been assigned to the various Divisions of the Lab. The first year of the project has been devoted to preparation of the Technical Specification for tendering and for tendering itself. On June 2020, the scientific activities with accelerated beams have been suspended in order to guarantee the required time allowance for the preparation of the whole Lab to the upgrade. Despite the COVID emergency and the lockdown, at the moment 60% of the budget available for the project has been contracted and this percentage is scheduled to grow to 90% within November 2020. The remaining two years shall be used for supplies management and installation of the renewed and upgraded systems.

The upgrade project represents a very promising scientific upgrade for LNS, in Nuclear Physics, in Applications and in R&D frameworks, in which the research infrastructure already plays an international key role. The new intensities will open new frontiers in the research activities with both stable and unstable beams. The NUMEN project has been a driving physical case and is one of the most challenging experiment over the world scientific community for the determination of the nuclear matrix elements (NME) of double beta decays. Only the combination of an increase in beam intensity of one order of magnitude or more and the upgrade of the magnetic spectrometer MAGNEX can allow to access the NME by double charge exchange reactions including those with ^{76}Ge of direct interest for GERDA experiment in CSN2. Hence the scope of NUMEN extends to the physics beyond the Standard Model (see CSN3 description below). However, the new beams will also improve the studies on EOS and on exotic clustering phenomena performed by the CHIMERA collaboration and by the theoretical group of LNS. The increased beam intensity will allow to access new exclusive observables for the determination of the EOS for nuclear matter with large neutron content that is of interest for the advancement in the knowledge of the structure of exotic nuclei around the drip-line and for the neutron star physics including the oscillation dynamics affecting the gravitational waves emission.

The Asfin group, leader in the application of indirect methods for nuclear astrophysics, will also benefit from the higher intensities of exotics beams for the study of nuclear reactions involved in very specific astrophysics phenomena like hot CNO cycles, asymptotic giant branch (AGB) stars, x-ray bursts. The expected experimental activity at LNS will be complementary to the one with the SPES facility, establishing a strong point in Nuclear Astrophysics for the whole INFN.

LNS is equipped with a multidisciplinary beamline where several international groups perform innovative experiments for different kinds of application, from radiation damage study to irradiation of biological sample and of electronics devices. The new intensities will open new perspectives for irradiation of samples under extreme conditions, for high dose-rate measurements and for mimicking of laser-driven accelerated beams or high-pulsed beam from modern accelerators.

PANDORA

PANDORA completed its feasibility study phase (supported by CSN5, and hereinafter mentioned as simply “FS”), which started in 2017 until December 2019. Meanwhile, the full-scale experiment has been presented for funding at the meeting of CSN3 in June 2019. More than 120 isotopes of astrophysical and nuclear physics interest were found. Hence, in perspective, PANDORA can become a very big facility allowing systematic investigation of beta-decays in plasmas.

A total budget of around 3.75 M€ has been estimated (excluding manpower), which is mainly due to magnetic trap costs (around 1 M€) and detectors array (around 1.2 M€). The remaining costs are due to ancillaries (mechanics, vacuum, etc.), isotopes costs and travel expenses.

For more info, the PANDORA’s “white-book” please refer to the published version on the European Physical Journal – A [D. Mascali et al. Eur. Phys. J. A (2017) 53: 145, DOI: 10.1140/epja/i2017-12335-1], while the advanced draft of TDR is available at https://istnazfisnucl-my.sharepoint.com/:b:/g/personal/vincenzabonanno_infn_it/ETHoO4w46ntAhya2t_9LxRQBVVrLSx1G7y53Wqm8Yn2ahw?e=6gWLwA

PACK

A further expansion of the KM3NeT research infrastructure has been funded in 2019 by the Italian Ministry of Research (MUR) through a project named PACK (Potenziamento Appulo-Campano di KM3NeT) within the framework of the 2013-2020 PON. The attributed funding of 19

M€ will cover the construction and installation of 28 KM3NeT-ARCA detection units as well as the expansion and strengthening of the Naples, Caserta and Bari integration sites in view of a further increase of the detection units production rate that will be needed for the completion of the KM3NeT-ARCA detector.

4.2.2 Scientific and technical progress

LNS is involved in several experiments of CSN2, CSN3, CSN5, as well as many IS of CSN4 that are mainly related to the NUMEN, NEWCHIM and ASFIN2 experimental activities described below. Here we will briefly update the Committee with respect to what summarized in previous reports.

KM3NeT

Netherland, Italy, France, Greece, Spain, German and Romania created a working group done by Research Minister and scientific representatives for ERIC constitution. Work is in progress and in 2021 ERIC has to be realized.

An important result is the start of an EC support action for a KM3NeT legal entity within the framework of H2020. The KM3NeT ARCA seafloor network was subjected to a full critical design review, in order to highlight the critical aspect of the project. This process ended in a complete redesign of the Junction Box; the new high-reliability version of the Junction Box will be ready for installation in spring 2021. In the meantime, since January 2019, one detection unit has been successfully operated using a temporary Junction Box.

The completion of the full KM3NeT-ARCA detector requires a second main electro-optical cable that is currently being constructed and installed by Alcatel Submarine Networks. together with its power feeding system and deep-sea voltage converters. This second cable will be installed between end 2020 and summer 2021.

Data taking has been on hold since November 2019 and will be resumed in October 2020 to allow the refurbishment of the Portopalo shore station infrastructure. This major building upgrade is needed to host the power feeding and data taking equipment for the full KM3NeT-ARCA detector.
The KM3NeT-ORCA detector is presently operating in a six-string configuration since more than six months.

Data analysis and Monte Carlo simulation activities are carried on for the ARCA/ORCA data sets. First results of a combined ARCA/ORCA analysis of the atmospheric muon flux have been published, showing an excellent agreement with theoretical expectations over a seawater depth range of 2200-3400 m.

DarkSide

The ReD (Recoils Directionality) program aims to scrutinize for a possible directional sensitivity of a LAr TPC, which would be a key asset for dark matter searches, and to characterize the response of the detector to very low-energy nuclear recoils. ReD operates a miniaturized dual-phase LAr TPC which has the same design and the same readout as the future DarkSide-20k experiment, and hence provides a significant early testbench of the system.

The ReD TPC with its cryogenic system was re-installed at LNS on the dedicated beamline of the TANDEM accelerator in December 2019, after a period of detailed characterization at INFN-Naples. After a short test beam, the main two-week physics run with the TANDEM beam was performed in February 2020. Data are being analysed to confirm or constrain the directional sensitivity.

After the beam run performed in February 2020, the ReD scientific program in Catania will focus on the characterization of the TPC response to very low-energy nuclear recoils (below a few keV). Due to the civil works related to the upgrade of the LNS accelerators, the system is going to be dismounted and re-installed in the nearby Physics Department of the University of Catania. An intense ^{252}Cf neutron source will be used to irradiate the TPC and to induce nuclear recoils, whose energy and direction can be determined by detecting the scattered neutrons in a dedicated neutron spectrometer. Fission events from the source are tagged, thus allowing the time-of-flight neutron spectroscopy, by a near BaF detector. Data taking with the ^{252}Cf source is expected to take place in early 2021.

NUMEN research activity is devoted to the study of double charge exchange reactions as a tool to extract information on nuclear matrix elements which are a fundamental issue in the study of neutrino-less double beta decay. The study of few selected test cases of double charge exchange reaction using the beam of the LNS superconductive cyclotron has demonstrated the feasibility of this kind of experiments even if the cross section is extremely low (few nanobarn), for instance double charge exchange reactions on ^{48}Ti, ^{76}Ge, ^{76}Se, ^{116}Cd, ^{116}Sn, ^{130}Te using ^{20}Ne and/or ^{18}O beams. An important theoretical development to support the experimental results has shown that double charge exchange reaction cross-sections can be reproduced by calculations and that, even more important, the contribution to the cross-section from multi-nucleon transfer is negligible. In 2019 the LNS theory group has published the first theoretical work that presenting the theory for heavy ion double charge exchange reactions shows the first comparison to experimental results at LNS: J. Bellone et al. P*hys.Lett. B* 807 (2020) 135528; also, a pivotal work by Lenske et al. [Prog. Part. Nucl. Phys. 109 (2019) 103713] showed the similar diagrammatic structure of Majorana double charge exchange reactions and neutrinoless double beta decay.

The collaboration will complete the data analysis of the experiments on double charge exchange reactions completed during NUMEN phase 2. The possibility to determine the nuclear matrix elements for systems, such as ^{76}Ge, used to establish the occurrence and the half-lives associated with the neutrino-less double beta decay will make it available alternative measurements of neutrino masses.

NEWCHIM activities are mainly focused on the study of the density dependence of the symmetry term in the EOS (equation of state) and on the influence of isospin degree of freedom on the reaction dynamics. Experiments performed with CHIMERA using intermediate energy heavy ion collisions have shown the influence of isospin degree of freedom in the competition between fusion and fission and its role in the IMF emission, by studying ^{124}Xe+^{64}Zn,^{64}Ni reactions at 35 AMeV. The CHIMERA detector has proved also extremely performing in the study of nuclear clustering, in particular in the case of the Hoyle state, through which carbon synthesis takes place in stars. The possibility to perform coincident detection of charged fragments and gamma rays (in particular , the investigation of fourfold γ-γ-α-^{12}C coincidences) makes it possible to perform high precision studies of cluster configurations and branching ratios, also in the case of radioactive nuclei.

The activities are focused on continuation of experimental activity on the competition between dynamical and statistical emission of IMF and light charged particles, on clustering in light nuclei, on the pygmy resonance and on fusion barriers, especially at GSI (through the participation to R^{3}B/NeuLAND experiments), after LNS shutdown for upgrade, and at SPES in the next future.

All these new devices represent an important development for the LNS future activities after the CS upgrade. It is worth noting that NUMEN is one of the leading scientific cases of the POTLNS project (PON Research and Innovation 2014-2020), started in 2019, for the enhancement of the LNS research infrastructure.

N_ToF activities are focused on the measurement of neutron-induced reaction cross-section. The study of such reactions is of large importance in stellar nucleosynthesis and in applications of nuclear technology, including the transmutation of nuclear waste, accelerator driven systems and nuclear fuel cycle investigations. The parallel studies in nuclear astrophysics and applied physics produced the two most important results achieved in 2019 by the collaboration. Regarding nuclear astrophysics, N_ToF measured the ^{140}Ce(n,γ)^{141}Ce cross section, main ^{140}Ce destruction channel, whose abundance is presently not reproduced by astrophysical models. Regarding applied physics, the collaboration has measured the ^{235}U(n,f) reaction, a neutron cross section standard, with 1-2% accuracy over a broad energy range. This last result has seen a primary role by LNS researchers.

The collaboration future plans cover detector developments, neutron monitors as well as new physics. New detectors will include the proton recoil telescope and the segmented annular detector for (n, charged particles) reaction measurements, using PSA for particle identification. A new neutron monitor using uranium target will be studied. New measurements focusing at pinpointing the role of fission in the r-process will be proposed, as well as studies on neutron poisons for safety considerations in fission reactors will be performed, in the field of applications. In addition, an important foreseen development concerns the installation of a new experimental hall, close to the neutron spallation source, to be used for neutron activation measurements using high neutron fluxes.

ASFIN2 activities are focused on the measurement, primarily through indirect methods like the THM and the ANC, of reaction cross section of astrophysical interest, using both stable and unstable beams. The use of indirect methods makes it possible to experimentally cover the energy range of astrophysical interest with high statistics, no electron screening or need of extrapolation, small systematic errors due to the use of thick target and thank to the background, we have a minor model dependence. The variety of experimental techniques used by ASFIN2 to carry out measurement under conditions as close as possible to the astrophysical ones is apparent when reviewing the most important achievements in 2019. Regarding the THM measurements, these include the indirect study of the ^{7}Be(n,α)^{4}He using THM, having a significative impact on models of Big Bang nucleosynthesis and, in particular, on primordial lithium abundance determination. A second result also involves reactions induced by neutrons, the ^{10}B(n,□)^{7}Li reaction, of interest for applied physics and future fusion reactors. The two measurements were carried out at LNF (using the EXOTIC facility) and LNS, respectively. The other two collaboration highlights for 2019 are measurements using different approaches. In the case of the ^{7}Li(γ,α)^{3}H reaction, we used a monochromatic gamma beam produced by the HIGS facility at Duke University to investigate photon-induced lithium depletion, an alternative primordial lithium destruction channel.

They investigated the ^{15}N(α,α)^{15}N elastic scattering to perform ^{19}F spectroscopy using the thick-target inverse kinematics approach at LNS; ^{19}F and its mirror nucleus ^{19}Ne are involved in many astrophysical scenarios, from AGB stars to classical novae, so their spectroscopy plays a pivotal role in astrophysics.

MC-INFN

The most important results of the last months were:

- Coordination of the working group of the Geant4 Collaboration devoted to the “Advanced examples”, released with Geant4.
- Development, debug and maintenance of the advanced examples in charge to the LNS group and specifically Hadrontherapy.
- Improvement, validation and maintenance of low-energy electromagnetic physics models within Geant4.
- Participation and support to one ongoing project related to the "Progetto Giovani" of CSN5: PRAGUE project dedicated to the realisation of a new detector concept for relative dosimetry of laser-accelerated beams based on Silicon Carbide.

During 2019 new models for the calculation of LET (Linear Energy Transfer) for proton and ion beams were published by the collaboration and they will become public during 2020.

The Geant4 toolkit is in a mature stage of its life: the plan for the future is to continue to maintain, develop and debug the models and the advanced examples that are in charge to the LNS group, with particular focus on medical and inter-disciplinary applications. Geant4 will likely continue the two-release-per-year policy for the next few years, aiming to improve the physics and computing performance (CPU, multi-threading, memory footprint) of the toolkit.

MICADO

A key activity on nuclear safety, the MICADO Project (Measurement and Instrumentation for Cleaning and Decommissioning Operations), also started in 2019 under Horizon2020 programme and with the collaboration of seven industries and Institutions; MICADO is aimed to standardize the management of radioactive waste, starting from their non-destructive characterization to transport, storage and real-time monitoring.

PRAGUE

PRAGUE is a “Young Grant” of the INFN V Committee and one INFN researcher (Dr Giada Petringa) won the 2019 edition. The activity of the grant will start in 2020. Dr Petringa also won a Marie Curie Global fellow on the same project idea. The aim of PRAGUE (Proton RAnGe measure Using silicon carbidE) project is to design and construct a detector, based on a new generation of Silicon Carbide (or SiC) devices, to measure proton depth dose distributions in real-time and with high spatial resolution (order of 10 μm). The extreme radiation hardness of such devices and the independence of their response with the proton beam energy, makes them capable to operate with conventional clinical hadrontherapy beams as well as laser-driven ion beams, where extremely high dose rates are delivered. The detector will be composed by a stack of new generation, large area (15 mm^2) SiC devices with an active thickness of 10 μm.

These extremely small sensitive thickness can be achieved thanks to a new original technique, based on an electrochemical attach, developed at IMM-CNR (Institute for Microelectronics and Microsystem - Consiglio Nazionale delle Ricerche). PRAGUE has the potential to radically change the panorama of the current research in relative dosimetry with extreme intense dose rate. At today, in fact, a real-time solid-state detector to measure depth-dose distributions curves (energy independence) with such spatial resolution and radiation-hardness characteristics doesn’t exist. The developed technology will allow obtaining dose information shot-to-shot in the biological sample with a precision of the order of 3% as required by international protocols for the patient treatments (IAEA TRS-398).

4.2.3 Activities on External Funds

AISHa

The AISHa ion source (Advanced Ion Source for Hadrontherapy) has been realized within the framework of the PO FESR 2007-2013 program of Sicilian Government and a pool of Sicilian small enterprises was associated with INFN for the realization of this new source. It was designed taking into account the typical requirements of hospital facilities, in order to provide highly charged ion beams with low ripple, high stability and high reproducibility. The technical design choices have been addressed to minimize the mean time between failures together with fast and easy maintenance operations. After the successful commissioning it was realized that some changes to its mechanical design could allow a further improvement of performances and they were completed in 2019, so that this “hybrid magnet ECR ion source” represents now the state of art of the injectors for hospital facilities. The source commissioning at 18 GHz in terms of beam currents and emittance of several ion species (He, C, O, Ar) was repeated in 2019 with the main focus on C4+ optimization (0.5 emA C4+) used for hadrontherapy facilities, but also the performance for O6+ (1.2 emA) and O7+ (0.4 emA) are relevant.

A copy of the AISHa source will be carried out within the framework of the PO FESR 2014-2020 program of Lombardy Region (INSPIRIT project) that will start in February 2020.

ESS: European Spallation Source

The construction of the first elements of the ESS Linear accelerator (proton source and LEBT) has been carried out at INFN-LNS in 2017 and the installation in Lund was performed at the beginning of 2018 according to the schedule. The coupling to the facilities in Lund was completed at the end of the summer 2018 and the beam requirements have been verified immediately after.

The procurement of the components for the second source continued in 2019 and its assembly was completed before the fall of the year. The source will be delivered to ESS in February 2020. INFN-LNS personnel have significantly contributed also to the progress of the construction of the other components provided by INFN as in-kind contribution to ESS, i.e. the above mentioned Drift Tube Linac (DTL) and the Medium Beta Superconducting Cavities (provided by INFN-Milano, LASA) and cooperated with Elettra Sincrotrone Trieste for other components of the Linac (e.g. power supplies).

4.2.4 Technology transfer and outreach

In 2019 the Technological Transfer activities at LNS have been performed in the framework of seven different contract. Moreover, a patent has been deposited.

An agreement with DE.TEC.TOR. s.r.l. for carrying out cooperative research aiming to develop and commercialize an innovative on-line lateral dose-measuring system to be applied on daily quality assurance performed in the hadrontherapy centers. The core of such agreement regards the analysis software and imaging processing to check the main parameters to treat patients.

An agreement with Best Cyclotron for carrying out cooperative research aiming to develop and commercialize a proton beamline for the treatment of the ocular melanoma was signed. The collaboration includes the study and realization of each element of the beamline devoted to checking online the delivered dose on the patient, modulate the beam in energy and obtain a uniform dose distribution.

In the framework of the ASI Supported Irradiation Facilities project (ASIF), five contracts for the supply of accelerated ion beams have been stipulated. The INFN-LNS Superconductive Cyclotron provided 10 Beam Time Units (BTU) of ion species range between protons and heavy ions (20Ne, 40Ar, 84Kr) accelerated to energy range between 20 and 62 MeV, according to users requirements and complying with the 25100 - European Space Agency (ESA) standard about radiation hardness tests of devices to be used for space purposes.

An application for a patent regarding a Silicon Carbide ionizing radiation detector" (n° PCT/IB2019/055491) has been deposited.

In July 2019 the Visitor Center was inaugurated. It will allow, by means of high-quality texts, images, videos and interactive spaces, to increase the already intense public engagement activity of the LNS that reaches over 3000 people, mostly students in secondary and tertiary education, offering an exposure of the current fields of investigation of the laboratories.

The new edition of the Joint Master Degrees (Erasmus Mundus) was approved and financed (December 2019) which includes the participation of the LNS as an associated partner in the training project for the next five years, as part of the Master's Degree in Physics of the Department of Physics and Astronomy "Ettore Majorana" of the University of Catania in a consortium of 8 partner universities in Spain, France and Italy (Catania and Padova), with the participation of several research institutions/companies as associated partners in Spain, France, Italy, Germany and Switzerland (CERN).

As in the past LNS has engaged in numerous outreach activities, they are summarized in the following Table 4.6.

Event	Number of participants
XXVI Settimana della Cultura Scientifica	2300
European Night of Researcg	1000
Famelab	220
Local School visits	370
Alternanza Scuola Lavoro	26

Table 4.6 - Some of LNS outreach activities

4.3 LNL Laboratori Nazionali di Legnaro

The Legnaro National Laboratories (LNL) is one of the four National Laboratories of INFN and it is mainly dedicated to research in nuclear physics and astrophysics, with a strong development in high level technology relevant to all INFN disciplines. The main topics studied in LNL are:

- Study of nuclear structure and properties of nuclear matter; study of reaction dynamics through heavy ion collision at low and intermediate energy collision; study of nuclear processes relevant for stellar evolution;
- High level Technology: study, development and construction of accelerators and accelerator components and high performing nuclear radiation detectors;
- Application of Nuclear technologies in different fields: study, development and production of novel radioisotopes for nuclear medicine; microanalysis, using nuclear techniques, with applications to materials and environmental sciences as well as cultural heritage; radiobiology, micro and nano-dosimetry; development of novel methods of surface treatment; radiation damage studies.

4.3.1 Facilities

At LNL the following accelerators are available:

- The TANDEM-ALPI-PIAVE complex (TAP), consisting of an electrostatic Tandem accelerator with a maximum voltage of 15 MV, and two superconducting LINACs (ALPI and PIAVE), mainly dedicated to nuclear physics and nuclear astrophysics experiments.
- Two small electrostatic accelerators, the CN and AN2000, dedicated mainly to applications of nuclear physics to environment, material science and cultural heritage. However, very specific and precise experiments on nuclear astrophysics and dark matter search are also performed.
- A high-current Cyclotron B70 dedicated both to nuclear physics with exotic beams and to research and production of radioisotope for nuclear medicine.

These accelerators provide beams for nuclear and applied physics experiments and serve a large international user community (see the LNL accelerator operations table in Appendix C). In the following we outline a brief summary of activities at the TAP accelerator complex.

TANDEM

At the beginning of 2019, the Tandem maximum reachable voltage was only 12 MV with unstable operation. A deep maintenance was started on February till November 2019 covering different accelerator critical aspects:

- insulating gas purification and upgrade of the system to limit SF6 pollution probability
- deep revision of Laddertron mechanics
- electrostatic design improvement
- new wheels alignment.

After maintenance, the Tandem operational voltage was increased to 14 MV in December 2019. A recent opening in June 2020, confirmed the good results obtained with the previous maintenance and revealed additional issues on laddertron stretching and on excessive presence of dust inside tank. A new maintenance is underway to solve it.

Regarding Tandem negative ions injectors, the reliability of the vacuum control system and safety system was improved. A new reservoir for cesium has been designed and built at LNL mechanical workshop. This system will allow safer heating and cooling cycles of the reservoir, limiting the possibility of obstructions of the duct feeding cesium into the ion source due to condensed metal. Tests are scheduled in September 2020.

PIAVE-ALPI

The first part of the year was used to finalize installation and alignment of the new ALPI quadrupoles and to complete the PIAVE quarter-wave cryomodules installation into ALPI low beta section. Even if cavities performances were not degraded, the operational accelerating fields for these two cryostats were underperforming after installation.

A new buncher (HEB0) was also installed, and successfully tested, next to PIAVE SRFQ to smoothly adapt the beam longitudinal parameters to ALPI injection.

The vacuum system for both new cryostats in ALPI and the new buncher in PIAVE was installed and for this, different activities were completed:

- the laying of the signal and communication cables
- the modification of the supervision software to accommodate the two new cryostats in the control layout
- the restoration of the fore-vacuum line
- the rebuilding and calibration of the helium gas distribution line for the He-Conditioning cycles
- the rebuilding of the nitrogen distribution line for venting the cryostats.

In the meantime, a fault on the fast tuner device of SRFQ2 was fixed without removing the cryostat.

The PIAVE-ALPI operation restarted in April and the accelerator complex worked to guarantee beam on target from June 2019 to August 2019. The operation highlighted some frequency instabilities on the low beta branch. Six over sixteen low beta cavities could not be controlled when mechanical vibration correction was needed. The medium beta branch worked as expected except for minor issues.

A new control system software, a new HW interface with RF amplifiers and new motion controllers for tuners and couplers were developed and started to replace the old ones; they were installed on HEB0 and on the whole low beta section (CR01÷CR06). Replacement of the remaining parts for the medium and high energy branch, together with new digital LLRF controller's installation is foreseen within 2021.

The period 2019-2020 saw a deep refurbishment of the PIAVE injector. New features were added to the control system, thus improving in general the reliability of the ion source and the safety of the equipment. An important upgrade regarded the microwave circuit that will allow injection of two different frequencies to create ECR plasma, with the purpose of improving performances. All the components have been purchased and first tests are expected by the end of 2020.

AN2000 & CN

In 2019 the AN2000 and CN provided 1797 hours of beam on target.The AN2000 accelerator worked in a regular manner with minor issues for most of the year, giving 873 hours of beam to the experiments. The CN accelerator guaranteed 924 hours of beam on target and 364 hours of test and conditioning. A long maintenance at the beginning of 2019 and a shorter availability of technical personnel were the main causes of the slight decrease in the CN beam hours in comparison with the previous year. Since late March, the accelerator started working regularly, providing beam to experiments. In late spring, the new CITECT supervisory system, on an update platform Win10 based, was installed in the CN console.

B70 Cyclotron

The cyclotron was in shutdown mode for the entire year to allow the completion of the bunker. The first months of 2020 were used to restart the cyclotron systems and a 950 µA beam was successfully accelerated up to 1 MeV in June (Fig. 1.2).

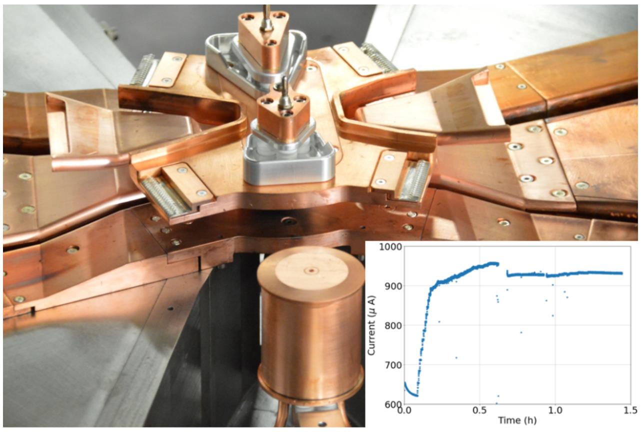


Fig. 1.2: Cyclotron extraction: 950 µA current accelerated up to 1 MeV in June 2020.

4.3.2 Scientific strategy, priorities and goals

Since the very beginning of its history, the Legnaro National Laboratory has been internationally recognized for its dual nature being a center where both fundamental and applied science were well represented, as well as its high-level technological activities. LNL scientific strategy is based on a continuum research of upgrading knowledge and infrastructures to be at the state of the art in all activities which were developed during the years, strengthening the bound between basic science and applications and creating all possible synergies which help in creating a modern future to the scientific community.

SPES: The latest most important initiative of Legnaro is the SPES project (Selective Production of Exotic Species), a second generation ISOL facility (Isotope Separation On Line) on which the short- and long-term strategy of the lab is centered. It is an interdisciplinary project, ranging over nuclear physics, nuclear medicine and materials science. SPES will provide a Radioactive Ion Beam facility for the study of neutron rich unstable nuclei of interest to nuclear and astronuclear physics research. At the same time, it will host a laboratory for research and production of radioisotopes to be applied in nuclear medicine.

SPES is based on a dual-exit high-current Cyclotron, with proton beam energy ranging between 35 MeV and 70 MeV and a maximum beam intensity of 0.75 µA. The Cyclotron B70 is the proton driver which supply an ISOL system with a UCx Direct Target able to sustain a power of 10 kW and produce neutron rich ions at intensities one order of magnitude higher than existing facilities. The second exit may be used for applied physics: radioisotope production for medicine and, eventually, creation of an intense neutron flux for material study.

The layout of the facility is shown in Fig. 1. The proton beam can be sent to two ISOL target caves (ISOL1 and ISOL2), three caves for radioisotopes production (RIFAC) and developments (RILAB) and an area for neutron production and material study.

Fig. 1.3: Layout of the SPES facility: on the right the cyclotron building and irradiation bunkers

The SPES facility is based on a very peculiar physics program, where the exotic beams produced at the ISOL target production system will be re-accelerated by the ALPI superconductive LINAC, which allows reaching beam energies in the range of 10 MeV/n for masses A≈130. At these energies, a huge number of interesting nuclear reactions with radioactive beams are possible. Moreover, as a first delivery of exotic beams to the users, an area with non-reaccelerated beams will also be instrumented (the so-called Low Energy SPES area, delivering 20 – 40 KeV exotic beams, expected in 2022).

SPES was also designed to study the production of innovative radionuclides for medicine which may show unprecedented biological properties. Non-standard radionuclides production is a fundamental opportunity for nuclear medicine in order to identify new radiopharmaceuticals classes for diagnostic and therapeutic applications.
Two projects are active at LNL:

- LARAMED, to study innovative radioisotope production by standard methods, that is exploiting the cyclotron proton beam for nuclear reaction on specific targets, studying cross sections, new target technologies and new radio-chemical separation methods. With reference to Fig. 1, the RILAB bunker will be dedicated to research in the field of radioisotopes (cross section measurements, high-power target tests etc.), whereas RIFAC is designed for jointly operation by INFN and a private partner for the production of radioisotopes such as ^{64}Cu, ^{67}Cu, ^{82}Sr, ^{68}Ge etc.
- ISOLPHARM, which is based on a different technique at variance with LARAMED and will exploit the ISOL technique to produce a large variety of carrier free radioisotopes with high radionuclidic purity (INFN international patent).

The layout of SPES was designed in such a way to operate two targets at the same time distributing the beam according to a schedule that minimizes radiation problems. It should be considered that the activation of materials at a beam power of 20-30 kW do not allow to operate the same target for long time. Considering a shift of two weeks with 2 days for beam preparation, 12 days of beam on target and 7 shifts for maintenance, we can offer about 5000 hours per year of beam dedicated to the ISOL targets and 5000 for applications.

For SPES the short-term goals are: (i) the completion of the 1^+ beam line in 2022 with experiments (non-reaccelerated beams) starting at the end of 2022 and (ii) signing the collaboration agreement with the private partner, start of research and test production of radioisotopes. The contracts for the supply of beam and the lease of lab space to BEST Theratronics are under revision due to new Italian laws and procedure needed.

The long-term goals are the operation of the full facility: experiments with reaccelerated beam, continued research in the field of innovative radioisotopes, commercial production of innovative radioisotopes. To this end reaccelerated beams will be ready within 2023, allowing to start experiments with low mass separation, whereas the HRMS (High-Resolution Mass Separator) will be completed in 2023, thus allowing the exploitation of the full power of the facility in the following years.

In the transition years towards the full operation of SPES the current machines (TAP complex, CN, AN2000) will continue to operate. However, two one-year stops of the TAP complex in two stages were scheduled to accommodate the installations for SPES. The first one was carried out successfully between Spring 2018 and Spring 2019. The second one is programmed for next year, starting in February 2021. Of course, the COVID-19 emergency has brought to some delay due to the lockdown period, even though we have tried to minimize the effects, trying to ameliorate the organization and giving priority to relevant tenders aiming at getting the Cyclotron beam on target by 2022.

In the field of accelerator technologies, the main commitments of the Lab are the construction and test of the DTL (Drift Tube Linac) for the European Spallation Source (ESS) in Lund (Sweden) and the conclusion of IFMIF RFQ commissioning in Rokkasho (Japan). Another important activity in the context of the MUNES project (development of a multidisciplinary neutron source) is the construction of a high-intensity LINAC. In view of significant activities which are taking place in the field of accelerator technologies LNL is planning to build a dedicated laboratory (LATA).

4.3.3 Organization and staff resources

The Laboratory is organized in the three traditional divisions of INFN laboratories (Research, Accelerator, Technical). In addition, a number of services refer directly to the director. The present organizational chart of LNL is shown in Appendix D.

Divisions, Services, Equipment & General Expenses (including Electric Power)	8218
CSN funding	1241
External Funds	36071
Total	45530

Table 4.7 - LNL operating budget (k€) in 2019

The organizational structure of the lab is currently being reviewed, in view of SPES entering its operating phase, and will be finalized by the end of 2020. A renewal of the managing responsibility has been performed at the beginning of the year and it is now in the phase of assessment. In particular new Managers have been assigned to the three Divisions (Research, Accelerators and Technical Divisions).

Another important change will involve the part dedicated to Safety and Radioprotection which will have to be enlarged and re-organized for SPES operation. Possibly the new organization will be submitted to INFN management within the end of the year.

At the end of 2019 the lab counted 145 employees, of which 114 with indefinite positions and 31 with fixed term positions. The staff situation of LNL is summarized in table 3.2.

Table 3.2: 2017 LNL personnel (TI+TD summed)

Technical staff	Admin staff	Researchers	Technologists	**Tot.**
64 (50+14)	20 (16+4)	17 (16+1)	44 (32+12)	**145** (114 TI+ 31TD)

The total number of staff members has been almost constant during the last 10 years: fixed term staff members have been almost constantly around 20-25%. The activity of the Lab has significantly grown lately especially because of the SPES project, which is very demanding in terms of human resources and new competences: many key positions in the Lab and in SPES are still occupied by fixed term staff members and postdocs. In the first few months of 2021, 6 out of the 31 temporary staff should be converted to indefinite position owing to the italian hiring by law programme. We expect, however, new indefinite positions well in excess with respect to the simple replacement of retirements. To operate the upgraded Laboratory, comprehensive of the joint venture with the private company, quite a large number of new staff members would be needed. A plan is under discussion with the INFN management. Important figures are still missing in the Technical Division (especially in the Technical Plants management) and in the Safety and Radioprotection Division.

4.3.4 Scientific and technical progress

As previously outlined, a second proton beam exit will be available in SPES and used for applied physics: it will be mainly dedicated to radioisotope production for medicine. A contract between INFN and the BEST company for the use of the cyclotron to produce radioisotopes for commercial use, has started and it is under finalization. A further project devoted to applications is under design to build a neutron facility (NEPIR) for material studies.

After the commissioning in 2017, the cyclotron was operated up to the end of March 2018. It was then stopped, waiting for the authorization prescription to be fulfilled and to allow, in the meanwhile, the cyclotron maintenance and the completion of several infrastructures. During this period the cooling down and transfer of the beam dump was performed, which allowed to get back the ISOL_1 bunker empty and available to finish construction of the building. All further installations of the ISOL system were therefore rescheduled.

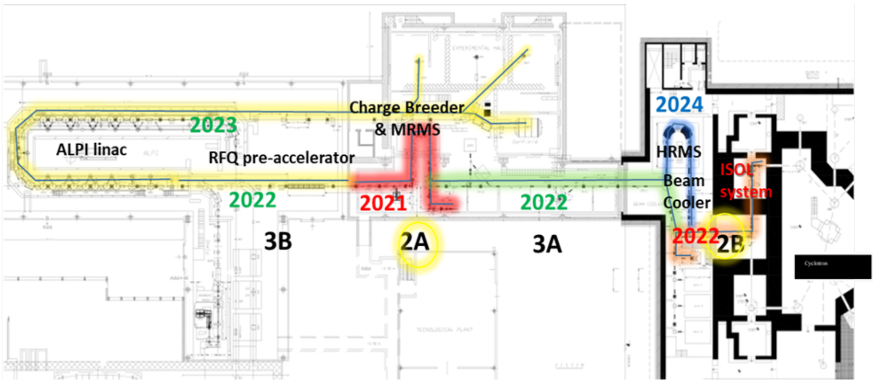
In the following the main activities performed during 2019 are presented:

- Two additional beam lines for the cyclotron were purchased and are being installed: one towards the ISOL2 bunker and a second one towards RILAB, the LARAMED bunker.
- The ISOL1 and ISOL2 bunkers were finally finished as far as the surface and floor paintings to be compatible with the radioprotection prescriptions and they are now ready for the completion of the plants needed for the target system installations.

Fig. 4.1 SPES ISOL1 bunker painting finishing

- The ISOL2 bunker will be temporarily assigned to the BEST company to start the production of some radioisotopes for commercial use in the framework of the INFN-BEST contract. The final dedicated area for this activity will be the RIFAC bunker in the backward part of the building, which is not yet finished and authorized for operation and it is in second priority.
- During 2019 the additional area for LARAMED cross-section measurement was completed as far as the shielding delimitation and it is, at present, in the finishing stage (walls and floor paintings).

Fig 4.2: Installation phases @Spes



- The installation of the ISOL facility according to different phases continued. After the phase 1 completed in 2017, the phase 2, the installation of the ISOL system (phase 2B) and the Charge Breeder (CB) with MRMS mass separator (phase 2A) have started. In particular, the completion of phase 2B will allow exotic beam characterization and RIBs production for non-reaccelerated physics experiments. All elements have been delivered and will be installed just after the finishing of the 1^+ area.

The radiation hard ISOL front-end has been completed and installed off-line, where the hardware commissioning and the high temperature test has started this year. The control system was implemented by EPICS and used for both the ISOL and CB ion sources.

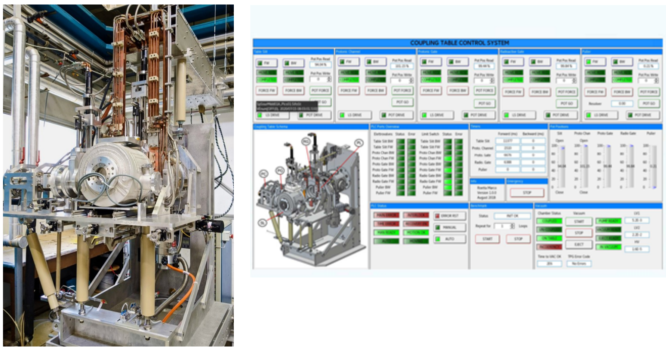
The Charge Breeder (CB) and the following Medium Resolution Mass Separator (MRMS) have been installed in 2018 together with the 1^+ ion source. In 2019 the MRMS high voltage platform was commissioned at the nominal voltage of 130kV and the commissioning of the 1^+ ion source started. A first beam of hundreds of nA of Cs^+ with an excellent stability, thanks to a software routine developed ad-hoc, was extracted in November 2019 using a surface ionization source.

Phase 3 is the installation of the beam transport line from ISOL to CB and the injection into ALPI by the RFQ pre-accelerator. The construction of the main components of the RFQ pre-accelerator has finished. The full set of electrodes (24) and tanks (6) was produced. The structure support, tuners, and couplers are being procured. The copper sputtering of the tanks will be performed in 2020 in synergy with the ESS project. RFQ tuning and commissioning are expected in late 2021. RFQ operation is expected in 2022.

The design of the High-Resolution Mass Separator (HRMS) underwent the critical design review by an international committee in 2018 and the project was updated. The procurement of the main components, dipoles and high voltage platform are waiting for the return of experience with similar configuration and components from the MRMS commissioning in the next months.

a) Experiments with the TAP complex

Fig. 2 - The radiation hard ISOL front-end under commissioning



In 2019 the accelerators in operation at LNL (**AN2000, CN, TANDEM, ALPI, PIAVE**) have provided a total of 2814 beam hours, to a community of about 250 scientists, half of them coming from abroad. The Tandem-ALPI-PIAVE accelerator complex delivered heavy-ion beams for a total amount of 1017 hours (528 hours, corresponding to 22 days, of effective beam on target for experiments, 489 hours for beam preparation and transport and 32 hours for radiation protection tests). A complete list of experiments running at the various LNL accelerators can be found in Appendix D.

The main experimental activities with stable beams delivered by the Tandem-ALPI-PIAVE accelerator complex concerned:

- the continuation of γ–ray spectroscopy studies with the array GALILEO Phase-I coupled to complementary devices for the detection of light charged particles, such as the EUCLIDES and SPIDER set-ups, or to the plunger device for lifetime measurements. Seven GALILEO Triple Clusters were mounted and tested at GSI. One of the mounted detectors was transported to LNL for tests and developments of firmware and read-out code;
- the continuation of the R&D activity on segmented high-purity germanium (HPGe) detectors. In particular, the process technology known as pulsed laser melting (PLM) was applied to the production of n^+ and p^+ contacts. A small p-type HPGe detector was produced allowing to validate the feasibility of the process;
- measurements of fusion excitation function for the system $^{24}Mg+^{12}C$ with the PISOLO set-up consisting of an electrostatic deflector followed by a time-of-flight spectrometer;
- the completion of the in-beam tests of the fast ionization chamber designed to be used for measuring fusion excitation functions, up to energies well below the Coulomb barrier, at 0° with SPES exotic beams. The detector was tested up to counting rates of the order of 10 kHz by using a new front-end based on digital electronics;

- the completion of the in-beam commissioning of the new digital trigger and front-end of the GARFIELD apparatus;
- radiation damage studies performed at the irradiation facility SIRAD.

It is worth mentioning that:

- the first data takings of the Active Target for SPES (ATS) at Laboratori Nazionali del Sud was completed. ATS will be moved to LNL in the second semester of 2020 to be installed in the third experimental Hall of the Tandem-ALPI-PIAVE accelerator complex;
- in second half of 2021 AGATA will be moved to LNL to be coupled to the magnetic spectrometer PRISMA for a long campaign with stable and radioactive beams. The laboratory is working in order to be ready for the AGATA arrival, with infrastructures to be renewed as far as the experimental area where the spectrometer will be installed and a new performant DATA center design is in progress with the aim of supporting the AGATA acquisition system and Data recording.

LNL has recorded a steady demand of beam time for experiments measuring cross sections at low energy for nuclear astrophysics and for detector tests using pulsed beams from the CN and the ion micro-probe at the AN2000. In general, there has been an increasing interest in experiments using low energy beams and, in particular, the ion micro-probe of the AN2000 in projects funded by the INFN Scientific Committees V and III.

The experimental activity at the AN2000 and CN accelerators in the framework of interdisciplinary and applied physics was carried out in 2019 for a total of about 924 beam hours at the CN (11 experiments) and 873 beam hours at the AN2000 (14 experiments).

The main activities at CN and AN2000 accelerators in 2019 concerned:

- interdisciplinary physics (radiation biology, biosensors, micro-dosimetry, study of novel neutron detectors based on innovative materials, single ion irradiation for quantum technologies and HPGe, Si and diamond detector characterization).
- neutron physics and nuclear astrophysics at the CN and at the AN2000 with the setting up of a new channel dedicated to the measurement of angular correlations in electron-positron pairs for the study of anomalies in internal pair production;
- nuclear physics at the CN with the OSCAR apparatus for the study of the one-proton spectroscopic factors of bound and particle-unbound states in ^{33}Cl via the ^{32}S(^{3}He,d)^{33}Cl transfer reaction at 10.4 MeV.
- Ion Beam Analysis with Nuclear Reactions (NRA), Elastic Backscattering (EBS), Elastic Recoil Detection Analysis (ERDA), PIXE, PIGE, ion Channeling.

b) Astroparticle physics

The lab has also a long tradition of experiments in the INFN line of Astroparticle, Neutrino and Quantum Physics. This is mainly due to the availability on site of liquid Helium, which is crucial for apparatuses working at low temperature, but also for the presence of high level technological infrastructures that can provide special services to large scale apparatuses:

- the experiment QUAX is an R&D study for the development of a dark matter detector based on magnetized samples kept at ultra-low temperature. During 2019 the QUAX collaboration performed in Legnaro the first run with a complete prototype, taking advantage of the efficient Cryogenic Service of the Lab. Results have been published in Physical Review Letters. The collaboration is now planning the realization of a full scale detector based on strong magnetic field sources and ultra-low noise microwave receivers working inside a dilution refrigerator system, with the scope of a multi-year dark matter search campaign.

- the technological know-how on material purification and cleaning of the Material Science and Technology Service of LNL has proved to be crucial for the realization of large scale apparatuses hosted at the Laboratori Nazionali del Gran Sasso. After the successful cleaning of main parts of the experiment CUORE in the past years, a Legnaro group continues its collaboration with the CUPID experiment to provide material cleaning and high quality coatings, and from 2019 also joined the experiment DARKSIDE for the ultra-cleaning of parts of the final large detector.
- a small group of Legnaro is working with the development of the new TPC for the T2K experiment in Japan, and collaborated in the recent result regarding the matter-antimatter symmetry-violating phase in neutrino oscillations by T2K.

c) Accelerators

The LNL accelerator group participates to two international accelerator projects, with the responsibility in both cases of an important Italian in-kind contribution: the realization of the RFQ of the IFMIF prototype accelerator (within the Broader Approach to nuclear fusion) and the realization of the DTL of the European Spallation Source.

- IFMIF-DONES

  In July 2019, at the international Broader Approach site in Rokkasho (Japan) the full current deuteron beam, about 125 mA in pulsed mode, was accelerated by the INFN RFQ (Fig. 4.5) at 5 MeV. This result demonstrated the main beam performances, like the final energy and beam transmission (above 90%). The installation of the RFQ accelerator, built in collaboration with other INFN sections (Padova, Torino and Bologna), was completed in 2017. Since then, INFN staff with specific competences in beam physics, radio frequency, beam instrumentation and computer controls, played a key role in the achievement of beam performances, by gradual and continuous beam tests.

  In March 2020, the European Union (Euratom) and Japan signed the agreement of a four-year extension of the activity of the BA. It was decided the continuation of the development activity of the IFMIF accelerator prototype in Rokkasho. This phase includes the gradual increase of the duty cycle, up to the achievement of the continuous 125 mA deuteron beam. INFN participation to this program, with a key role in the beam physics tests and possible participation with dedicated F4E funding to specific new hardware development, is very important for many different fields of application.

  On a longer term, INFN is participating to the preparatory phase of DONES, the European proposal for a neutron source to test the materials for the fusion reactor DEMO. The project DONES-PreP (870186), funded by the European Commission, started in November 2019.

Fig 4.5: IFMIF RFQ under commissioning in Rokkasho

- ESS

  The DTL for ESS, the Alvarez kind structure with permanent quadrupoles accelerating beam from 3.5 to 90 MeV, is developed in collaboration with INFN-Torino. Construction of the main components in the (mainly Italian) industry, together with the construction of critical elements and quality tests in INFN structures, are proceeding with a very intensive schedule. In particular, the construction of the tank modules at Cinel Srl, their copper plating at CERN and partially at GSI and the construction and test of the drift tubes at INFN are going on in parallel for all the five DTL tanks. The very delicate assembly of the tanks is done by INFN staff at Lund in a dedicated workshop in the klystron gallery.

In March 2020, at the start of the lock-down, elements of tank 1 were almost all assembled (Fig. 4.6). Due to Covid-19 restriction mainly in international travels, this work will restart not before September 2020. At a more general level INFN and ESS-ERIC managements are in constant collaboration to mitigate the risks related to the pandemic.

Fig 4.6: ESS DTL under assembly in Lund

All activities related to international projects such as IFMIF and ESS but also to national projects such as MUNES need infrastructures. The executive project of a new test laboratory to be built in Legnaro (LATA) is completed and the construction of the laboratory is ready to be launched. LATA will be a test facility for various accelerator components (ESS, IFMIF-DONES, MUNES, etc.). Waiting for this urgent realization, many crucial R&D activities for high intensity ion sources and high-power solid-state amplifiers are temporary hosted in the third experimental hall of LNL.

4.3.5 Technological transfer and Outreach

a) Technological transfer

The Legnaro National Laboratories carry out a significant program of technology transfer (TT), especially in the field of surface treatments. This is possible thanks to an infrastructure which was set up during the construction phase of the superconducting LINAC ALPI, with the purpose to manufacture over 50 Quarter-Wave Resonators (QWR) with thin Nb films to be deposited on Cu cavities. In the framework of the Service *Material Science and Technology for Nuclear Physics* of the LNL Research Division, this unique infrastructure has developed particular competences within the manufacturing of superconducting cavities for accelerators; among which:

- superconductivity;
- ultra high-vacuum;
- the study of plasma;
- material science;

- the PVD techniques for the deposition of thin films (it is possible to interface the properties of hardness of the deposition with the one of toughness and low cost of the substrate, as it happens, industrially, for the cathodic arc deposition on cutting tools);
- the chemical and electrochemical polishing of surfaces (during the manufacturing phase, any mechanical component is normally subjected to traditional mechanical deburring, after shearing, coining, micro-casting or pressure die-casting processes. However, for some advanced materials, the mechanical operations can be difficult as well as expensive, while the electrolytic polishing can guarantee higher finishing, at lower costs);
- mini-dosimetry mainly related to medical application like mini-Tissue Equivalent Proportional Counters.

All these skills have been proved to be essential, even in different fields of interest for INFN, as, for example, the surface treatments of the Cu components for the cryogenic underground detector of the CUORE experiment, for which the Service has carried out the polishing of over 5000 pieces, each with more than 60 treatments, in sequence, for a total amount of 300.000 operations.

Supported by a training educational instrument, the Master in Surface Treatments for Industrial Applications is organized jointly by INFN and the University of Padua and has reached its 17th edition. In this context INFN has contributed to train super specialists who learn the most advanced surface polishing technologies and subsequently apply them to diverse fields such as the advanced manufacturing of Titanium cardiac valves, dental implants, surgical prothesis, components for ultralight carriages, new technologies for jewels and glasses, low-friction hard and ultra hard coatings for mechanical manufacturing.

Students attending this Master learn how to deal with complicated technological issues, typical of particles accelerators and develop an expertise which can then be used to face problems of industrial consulting. The success of this strategy can be gauged from the following two parameters:

1) a 97% of the employability within the same scientific disciplinary sector for the students who graduate;

2) the amount of requests for industrial consulting (that are received by the LNL without any advertising).

In 2019, several contracts were activated aiming to the transfer of INFN developed technologies to industrial companies. It is worthwhile to mention the work done with Rolleng srl, for example, which began in 2018 and, after the delivery of a prototype plant for the deposition of thin film, the research activities continued in 2019 with another collaboration agreement. Further collaboration contracts have been activated for example with Cinel srl for the study of innovative processes and materials.

The development and supply of prototypes of microdosimeters have continued, both through foreign university collaborations and companies interested in the activities. As a confirmation of the TT activity and the attention given to IP, during 2019 the number of signed Non-Disclosure Agreements (NDA) with various companies (such as Comecer spa, Gamma Vet, CNR ISTEC, Mami, Seamthesis, Surface Technological Abrasives, Innova Partners, etc.) has increased.
Two patents have also been filed:

- Electrically and Mechanically Modular Electrostatic Accelerator with Optical Power Supply
- Spin HYbrid Parallel magnetometer (SHYP).

During 2019 further R&D activities, on the most interesting radionuclides having potential medical interest, under the spotlight at international level, have been carried out. The dedicated, closed-loop new technology developed at LNL, aimed at the alternative, cyclotron-based production of the well-established radionuclide already playing a key role in nuclear medicine, such as Tc99m (the most used in the world for imaging investigations), has been completed in 2018 (main info already reported in the 2018 CVI report). This effort, started after two production world crisis in 2008 and 2010, aims at proposing a breakthrough in the routine production of this vital radionuclide, which may be implemented in any hospital housing a medical cyclotron. Among several requests received from foreign research institutes interested about the technology, a dedicated meeting held at LNL has been organized with representatives of the Nuclear Science Research Institute (NSRI) of the King Abdulaziz City for Science and Technology (KACST), the most important research institute in Saudi Arabia. This process has been driven with the close collaboration of the INFN Technology Transfer Committee (TTC). A proposal has been prepared by INFN, comprising both a **Contract for the Provision of Services** (i.e. the *Training Program)* and the **Licence Contract for the use and exploitation of the Know-how** (*i.e. the* use and exploitation by NSRI of the INFN's know-how).

On the other hand, further advances have been obtained on the investigation of the emerging radionuclides, so-called "theranostic", which are the new frontier in Nuclear Medicine (NM), showing a high potential for both imaging and therapy, like, e.g. Cu64/Cu67, Sc47, up to the frontier of multi-modal imaging (MMI), exploiting the unique paramagnetic properties of Mn52/51 radionuclides. Dedicated research lines have been approved by the CSN5 of INFN to carry out the activities. Moreover, R&D efforts on technological aspects aimed at exploring new target preparation techniques for excitation function measurements, as well as massive radionuclides production, have also been pursued, in collaboration with other INFN departments.

In addition, a fundamental step for INFN activities in this new field, will be the completion of the LARAMED facility, i.e. the LAboratory of RAdionuclides for MEDicine at LNL, now under construction, and of the ISOLPHARM facility, with the aim to become a reference at national and international level.

b) Outreach

LNL staff members have been involved in several outreach activities, mainly addressed to students, teachers and general public. Many of these activities are coordinated by the Third Mission Coordination Committee (CC3M).

The local project MisuraCC3M@LNL started on November 19^{th}, 2019. Twelve students from the high schools "IIS Scalcerle" and "LS Fermi" in Padua carried out an experiment addressed to the elemental analysis of thin films with the Rutherford Backscattering technique at AN2000 accelerator. In December, two groups from another high school "LS Don Bosco" in Padua performed measurements related to superconductivity and plasma.

LNL joined the national project "INFN_Kids CC3M" in which practical activities and seminars are organized in primary schools.

Further outreach and public engagement activities include also Masterclass and World-Wide Data Day (W2D2), where high school students analyse data collected by the Compact Muon Solenoid experiment at CERN Large Hadron Collider

LNL staff members contribute to a project selected by the CC3M, within the "Physics Involving People" programme to realize a movie about future accelerators, in collaboration with 14 INFN units ("What Next? Future explained by young people", leader INFN Ferrara).

In 2019, 4200 people visited LNL (more than usual number) while in 2020, limited to January and February due to the COVID-19 pandemic, we had only 620 visitors. They were mainly students from Italian high schools and Universities and colleagues coming for events and seminars.

LNL has also two open days on Saturdays to host generic public coming from neighbor towns (around 200 people per event). Around 15 guides from LNL researcher and technologist staff accompany guests through a three-hour guided tour of the laboratories, including accelerators and experimental set-ups.

In June 2019, thirty-three students coming from twenty-six schools distributed in four Italian regions stayed for two weeks (80 hours) at LNL. They performed a residential stage with a final oral public presentation on 12 different topics. Tutors were extremely satisfied about the preparation level of the students.

In collaboration with INFN Torino and the Cultural Heritage network, LNL hosted students from high school as special assistants to experiments of the ALCHIMIA group. They regularly measure with micro-beam at AN2000 accelerator by using lapislazzulo as a target.

LNL researchers gave more than 20 lectures of 100 minutes in high schools of the Veneto region. The topics of the seminars covered several research fields such as nuclear physics, radiobiology, cultural heritage, environment, health, mechanics, electronics and informatics.

As usual, INFN LNL shows some key elements about SPES project and Segre's chart during the European Research Night on the last Friday of September. The four corners of the gazebo are dedicated to the accelerators, nuclear physics, interdisciplinary physics, and technology.

4.4 LNGS-Laboratori Nazionali del Gran Sasso

5 Scientific productivity

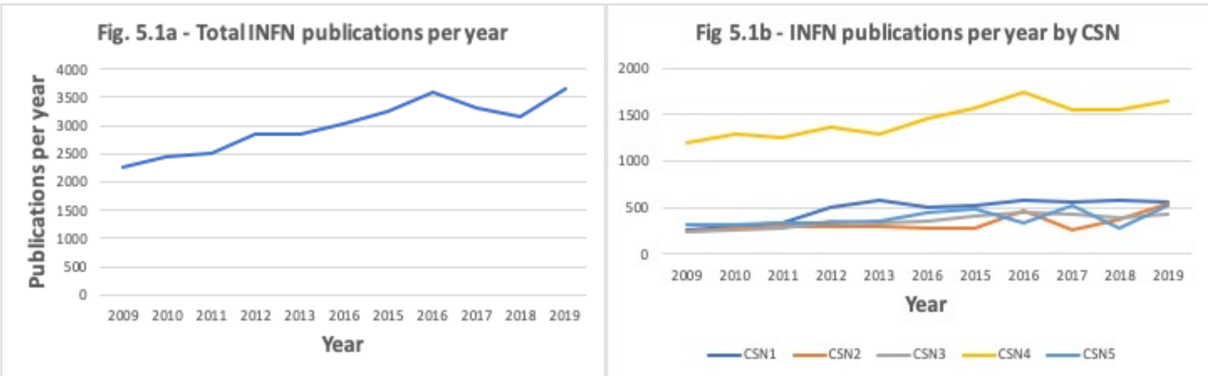
Within the goals of fundamental research in INFN activities there is definitely the increase of scientific knowledge, by improving our understanding of the basic constituents and fundamental laws of Nature and by developing the required technological instruments. The accountability of this process puts a natural emphasis on scientific publications on international journals as one of the main results. For the purpose of this report, however, several other indicators have been considered in order to highlight the INFN personnel contribution.

The main source for bibliometric information has been for a long time ISI, the Institute for Scientific Information owned by Thomson, http://isiknowledge.com (accessible upon subscription). Other sources for bibliometric analysis have recently gained more momentum on the scene, e.g. SCOPUS by Elsevier B.V. http://www.scopus.com (itself accessible upon subscription). INFN has subscribed to both databases and they will be used to prepare data for the incoming VQR(2015-2019) however the results presented in this report are mainly based on ISI, unless otherwise indicated. As mentioned in last year report, the GLV created a task force in order to redesign the publication database of INFN to include SCOPUS data: after an initial phase dedicated to the overall design a working prototype exist.

As for non-journals, more informal ways of disseminating information, we are aware that those ways are also used, however, in order to have a standardized way of measurement- we record only ISI publications as we believe that they represent a reasonable proxy of scientific productivity in our field.

5.1 Overall scientific production

Figure 5.1, as in previous years, presents the update on the overall production, for the INFN Scientific Lines, for the last ten years.



The total publication yield (5.1a) has been steadily growing in the last few years: as usual the most prolific INFN Scientific Line, in terms of publications yield, is the CSN4 (5.1b).

Overall in the last few years ATLAS, CMS and LHCb were the first three contributors in terms of papers to the CSN1 productivity. This effect is also visible in Figure 5.1b where the number of publications per FTE in CSN1 has nearly doubled since the LHC has come into operations.

The recent important discoveries in the Gravitational sector boosted the number of publications of CSN2 and CSN4. This effect is more pronounced for the CSN2 in 2019, since this year has seen the first data-taking campaign of the Virgo and Ligo upgraded detectors (although the run that was cut short because of the Covid-19 pandemic).

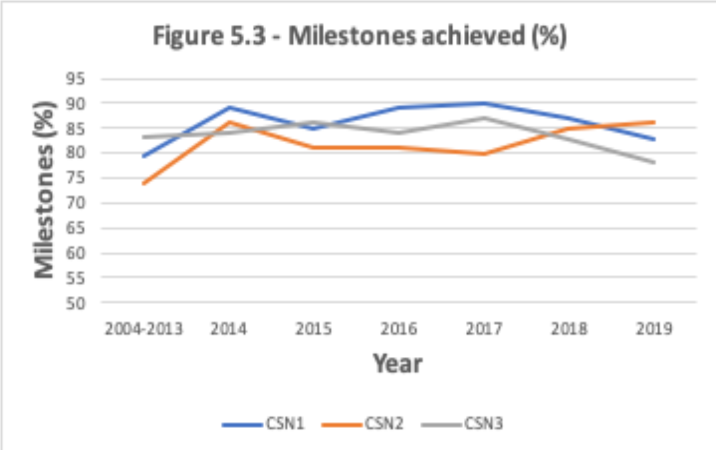
The number of publications is just one of the useful elements in the evaluation of scientific productivity. Indicators like Impact Factor, or the related citation analysis, are often used to measure the quality of the work done. This has been the case, so far, for the last two VQR. Figure 5.2 summarizes some publication indicators, including the average Impact factors, for the INFN research lines.

The fraction of INFN Authors, Figure 5.2a, mirrors the degree of internationalization of the corresponding Collaborations: this is especially evident for the sub-nuclear line (CSN1). The number of scientists authoring INFN papers follows the trend of previous years: the number of publications per Full Time Equivalent (FTE), Figure 5.2d, is as expected very good for CSN4.

The Impact Factor indicators, Figure 5.2b, have been relatively stable over time. However, in 2019, there is a significant drop in the average Impact Factors of the CSN1, CSN2 and CSN3 publications. This is essentially due to a reduction of the overall IF of some journals (NIM, Euro Phys J. C, Phys. Rev. Lett., Phys. Rev., Nature Phys...). As always, one should keep in mind that the Impact Factor qualifies a journal in its entireness, and it is not *per se* a measurement of the quality of a single paper. On the other hand, the average IF of CSN5 for 2018 and 2019 is significantly higher than the average value of previous years: the GLV is trying to understand if this effect is due to a specific line of research of CSN or if it is spread over all of them.

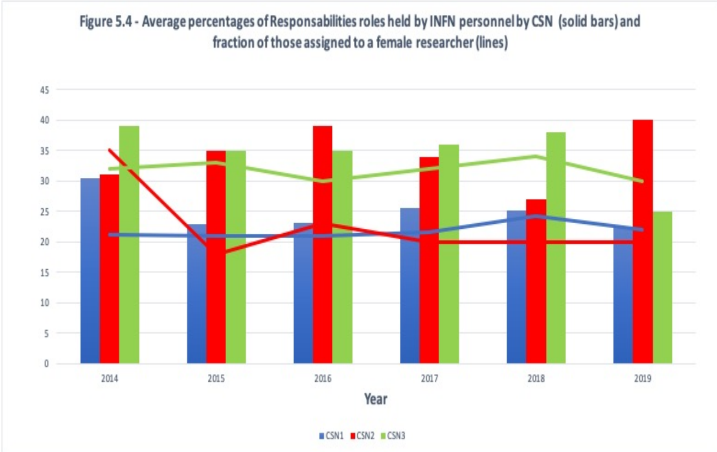
INFN researchers by CSN distributions are shown in Figure 5.2c: both CSN2 and CSN4 have substantially increased the number of full time equivalent (it should be noted that this is mainly due to associated personnel from Universities and other research institutions).

As it is customary for INFN, the objectives to be achieved during the incoming year are yearly formulated by each experiment along with the funding requests. To help researchers and executives trace the status, and apply corrective actions when needed, a set of milestones is then agreed between experiments and their referees. In Figure 5.3 the corresponding performance figures are given for the large experimental CSNs: a very good share of the milestones is met every year.



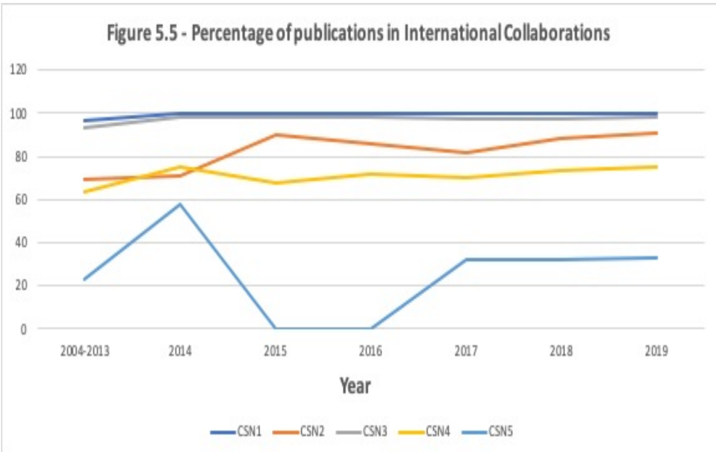
Given the high international level of the activities described above, another indicator of the relevance of INFN work inside the Collaborations is the share of Leadership roles attained by INFN scientists. While there are a few studies about scientific collaborations, in order to really understand the different structures and the real leadership roles of such complex entities, a full network analysis would be needed. In 2014 the GLV, with the help of the Collaborations, studied the different layout of the management structures, and decided the appropriate sets of management roles to be counted (depending upon the specific scientific area, the size of the group etc.), since then the numbers are homogenous. In 2019 we have, repeating the analysis from 2014 onwards, counting the percentage of the management roles (rather than the absolute number, which may also vary from one experiment to the other) held by INFN personnel.

Figure 5.4 shows the average percentage of management roles held by INFN personnel in the CSN lines with major experiments (solid bars). The fraction of these roles assigned to female researchers is shown by the colored lines: in major experiments roughly 30% of management roles are assigned to INFN and about 30% of these are occupied by females. The fraction of management roles is rather high, always exceeding the corresponding INFN funding fraction of the experiments, which is a fair demonstration of the high scientific role played by the Institute in International Collaborations and an acknowledgment to the researchers’ management capacity.



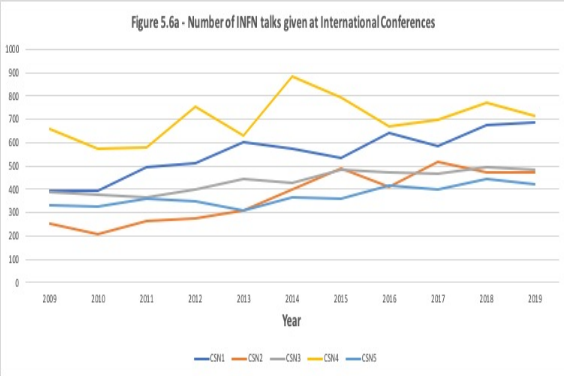
5.2 International framework

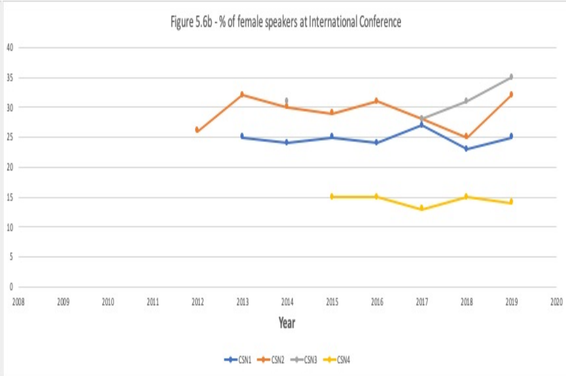
As it was shown in previous reports, in the comparison of INFN with respect to several representative European Countries, the Italian production in nuclear, sub-nuclear and astro-particle physics (experimental and theoretical) is at the same level, in both quantitative and qualitative terms. This also stems naturally from the fact that INFN research is mostly operating in an international framework, achieving, as we have seen, also a good position in the corresponding leadership roles. Figure 5.5 provides a snapshot of the situation. The different values across the CSNs reflect the different sociological (and financial) fabric of each research line.



CSN1 and CSN3 are striking examples, for almost all of the publications are done in collaboration with colleagues from foreign institutions. The measurement of internalization of research has not been recently used in the most recent VQR (contrarily to the previous one), however we believe it is still good to look at this index.

Moving from publications to people, researchers, especially in large Collaborations and especially if young, gain a major visibility through presentations at Conferences. In large experiments the policy is indeed to allow them to be on the forefront in many scientific events, hence the total number of presentations to Conferences is both a measure of the vitality of the whole community and in particular of its younger component. In Figure 5.6 the situation is summarised for all CSNs and compared to previous years: once again one can note a very good pattern, showing that INFN researchers are very active in communicating to peers their scientific achievements. The information on the gender (Figure 5.6b) is, unfortunately, difficult to extract (this information is usually not by the conferences themselves) and we have been unable to do so in some cases.





However, competition in large international collaborations is very hard and may not be easy to have a fair share of presentations at the most important Conferences and Workshop in the INFN research fields. An analysis has been performed for the three major experimental lines by choosing a representative set of conferences for each CSN and the percentage of talks given by INFN researchers has been compared to those of some European countries (and USA and Japan as external references): the outcome is presented in Table 5.1 where we show the result for 2019 and (in between parenthesis) the average of the previous years.

	Italy	Germany	France	UK	USA	Japan
CSN1	**16,2**(12.3)	**9.7**(13,8)	**6,3**(6.1)	**9**(9.3)	**18.8** (24,8)	**3.2**(3.2)
CSN2	**9.4**(10.6)	**11,2**(10.1)	**4,7**(6.9)	**6,3**(4.5)	**22,3**(31,9)	**9,7**(7.8)
CSN3	**10**(11,2)	**16**(16,8)	**5(6,8)**	**5**(3)	**21**(26)	6(5)

Table 5.1 - Comparison of the percentage of talks at a set of International Conferences in 2019, in between parenthesis the average for 2007-2018.

6. Personnel balance: inclusiveness, well-being and diversity inside INFN through a gender perspective

For the European Commission the gender equality achievement continues to be an issue especially, in research and innovation, and requires the collaboration of Member States and Research Organizations. Given the peculiarities of the research sector, specific actions are needed to overcome persisting gender gap. Gender equality should be pursued via the following objectives: gender equality in scientific careers, gender balance in decision making, and integration of the gender dimension into the content of research and innovation. In this section we will present a statistical analysis of the INFN personnel and a comparison of the current status with 2003 data. This comparison shows a dramatic ageing of the INFN personnel, an evident decrease of the young women, a strong difficulty in hiring and in promoting female researchers and technologists, a small improvement in the fraction of female researchers at the first (top) level, that anyhow reach this position later than their male colleagues. Results on organizational wellbeing activities and realization of INFN Affirmative Action Plan will also be presented.

6.1 Statistical analysis of the INFN personnel under a gender and generational perspective

The presented statistical data are updated to 31 December 2019 and have been provided by the INFN Administration. INFN employs 2011 people in permanent positions plus 181 people with fixed-term contracts. Table 6.1 reports the number of men and women for each category and professional level for permanent positions only; for each category and gender, the fraction of employees in a given level is also reported in parentheses.

Category/ Level	Researchers		Technologists		Category/ Level	Administrative staff		Technicians	
	Men	Women	Men	Women		Men	Women	Men	Women
I	102(19%)	21(14%)	47(17%)	3(4.5%)	Dir. I	-	-		
II	185(35%)	54(36%)	81(29%)	17(25%)	Dir. II	-	2(0.8%)		
III	239(45%)	74(50%)	153(54%)	47(70%)	IV	7 (11%)	19 (8%)	254 (41%)	15 (31%)
					V	25 (38%)	122 (49%)	158 (25%)	12 (24%)
					VI	12 (18%)	42(17%)	157 (25%)	10 (20%)
					VII	15 (23%)	58 (23%)	10 (2%)	0
					VIII	7 (11%)	8(3%)	43 (7%)	12(24%)
Total per gender	526(78%)	149(22%)	281(81%)	67(19%)		66(21%)	251(79%)	622 (93%)	49(7%)
Total per category	675 (33,6%)		348 (17,3%)			317 (15,7%)		671(33,4%)	

Table 6.1- Distribution of INFN personnel with indefinite contracts for each category, and professional level, updated to 31-12-2019. For each category and gender, the fraction of employees in a given professional level is also reported in parentheses. The second last line reports in parentheses the percentage of men and women in the category. In the last line the number of employees in a given category and their percentage respect to the total are reported.

Women are about 25.7% of the INFN staff with a permanent contract, and 15.6% excluding administrative personnel, the only category where they are not underrepresented. Comparing the personnel distributions in 2003 and 2019, only a small increase of women is observed for the researchers (from 18% to 22%) and technologists (from 16% to 18%). Women fraction is stable for the technicians and decreasing for administrate staff (from 82.4% to 79%).

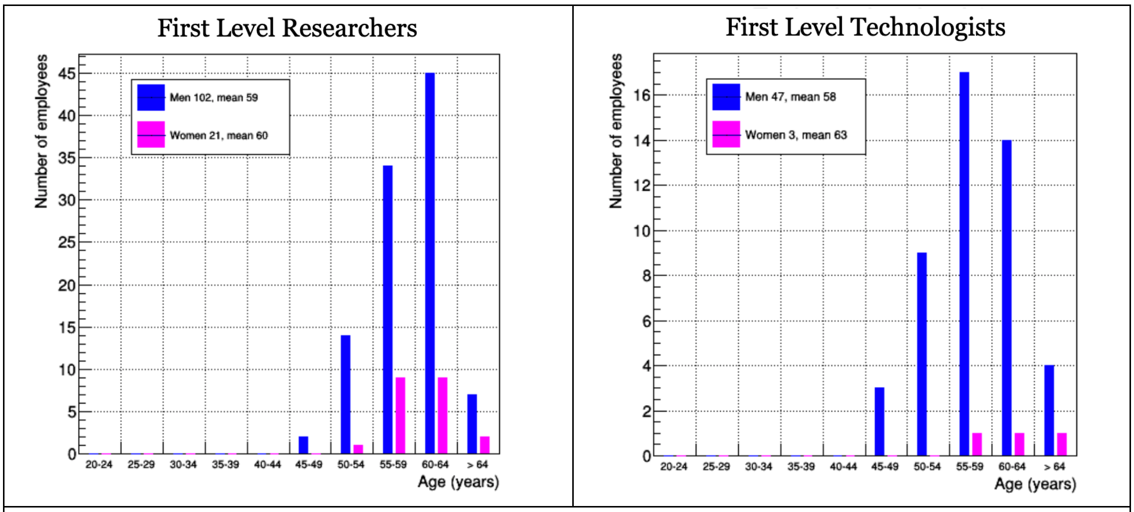


Figure 6.1 – Age distributions of researchers and technologists at first (top) career level - women (red), men (blue) (data updated at 31-12-2019).

Vertical segregation. Women at the first level are 24: 21 researchers and 3 technologists. The probability to achieve the highest professional level is larger for a man than for a woman, as can be seen from Table 6.1. While 19.4% of the male researchers have achieved the highest professional level, the percentage of women is limited to 14.1%. A larger discrepancy is observed for the technologists: only 4.5% of the women employed as technologist (3 in total) are at the first level, versus 17% of the men. A large fraction (70%) of the female technologists are at the entry level. In the last recruitment procedure for top level career transition, no woman has been promoted to first level technologist, versus 12 men. Furthermore, female researchers and technologists in the top level are older than their male colleagues and have a lower seniority in the level (see Fig. 6.1).

The different distribution in the levels between administrative staff (around 8% in the IV level) and technicians (around 41% in the IV level) is due to an asymmetry in- the national contract: an academic degree is required to achieve the IV wage level for the administrative staff but not for technicians. This "difference" can be seen as an example of indirect discrimination. In 2015 the CUG notified this problem to the trade union representatives, as it is a consequence of the application of the National Collective Contract.

Between technicians only 7% are women, this is slightly better than 2017 when the fraction of women was 5.6%. However, recent enrollment procedures hired women at the lowest career level (VIII-level operator). Recently, in the technician role 42 people (12 women and 30 men) and 46 people (1 woman and 45 men) have been hired as VIII-level operator and as VI-level collaborator, respectively. All the technicians with a fixed-term contract are at the VI level. They are 42 and only one woman is present. In summary, recently hired female technicians are concentrated in the lowest career level and in the near future the percentage of female technicians is expected to be further reduced

Increasing ageing of the INFN personnel. Despite of the recent recruitments, the INFN personnel is ageing, as shown in Fig 6.2 for the different categories and sex. The mean age of the staff people is more than 50 years (52 for researchers and technicians, 51 for administrative and 50 for technologists). Only 10% of the personnel is younger than 40 years. Women below the age of 45 years are almost 2/3 with respect to 2003 (40 as opposed to 63 in 2003), male researchers are 131 while they were 215. The number of "young" female researchers is so low that in many INFN strutcures there aren't any.

Recruitment procedures are only apparently neutral. In the last recruitment selections for entry level researchers, the success rate of women was lower than the success rate of men. In theoretical physics, in the last 10 years **only 2 women** were enrolled, corresponding to 6.4% of the winners despite the fact that about 20% of the PhDs in CSN4 (national committee for theoretical physics) are women. In the last competitions for experimental physics (in 2016 and 2018), women won only 16.5% of the positions although the fraction of women in postdoctoral positions in INFN experiments spreads between 30% and 40%. In 2018, INFN hired 169 people using stabilization procedures: 54 administrative staff (43W/11M), 42 technicians (3W/39M), 20 researchers (8W/12M), 52 technologists (14W/38M). For administrative staff 20% of hired people are males, while 7% of the hired technicians are females.

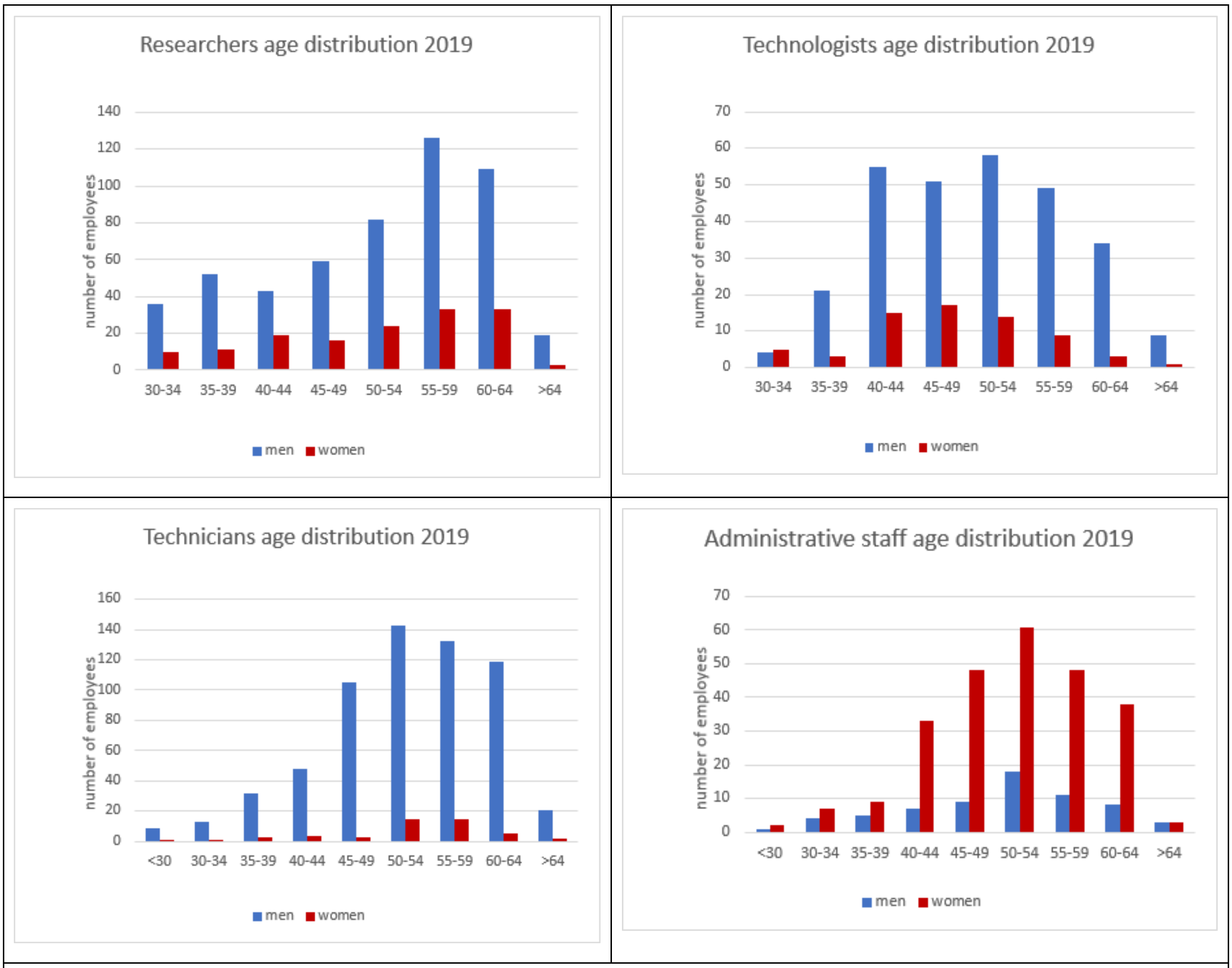


Figure 6.2 – Gender and worker category age distributions - women (red), men (blue)(data updated at 31/12/2019*)*

It should be noted that women have a larger probability (40%) of being hired-by-law as a result of a stabilization programme rather than being hired thru a competitive procedure (14.7%).

Women are fully contributing to the scientific life of the INFN as well as fully covering scientific responsibilities. In Table 6.2 the fraction of women/total for the five National Scientific Committees is reported; data are taken from the 2019 scientific database. The presence of women is not uniform across the different INFN lines: women are well represented in CSN1, CNS2, CNS3, and CNS5 (particles, astrophysics, nuclear physics, and technological applications, respectively) but not in CNS4 (theoretical physics). With respect to previous years, in 2019 the presence of women covering scientific responsibility in CSN1 decreased. The scientific production of women, estimated by the number of PhD thesis and number of conference presentations, is relevant and the number of women covering scientific responsibilities, as convener or local and national group leader, is larger or at least equal to their FTE (Full Time Equivalent) fraction in the different committees.

2019	CSN1(%)	CSN2 (%)	CSN3(%)	CSN4(%)	CSN5(%)
Coordinators	10	20	43	11	28
Nazional Resp.	6	25	26	19	18
Local Resp.	26	23	29	14	22
FTE(1.INFN)	23	18	29	15	20
FTE(Univ.)	19	20	26	14	28
FTE(post-doc)	31	30	40	10	31
Talks	25	32	37	14	36
PhD Thesis	13	25	37	19	29

Tab. 6.2 - Fraction of women/total in the five National Scientific Committees in 2019.

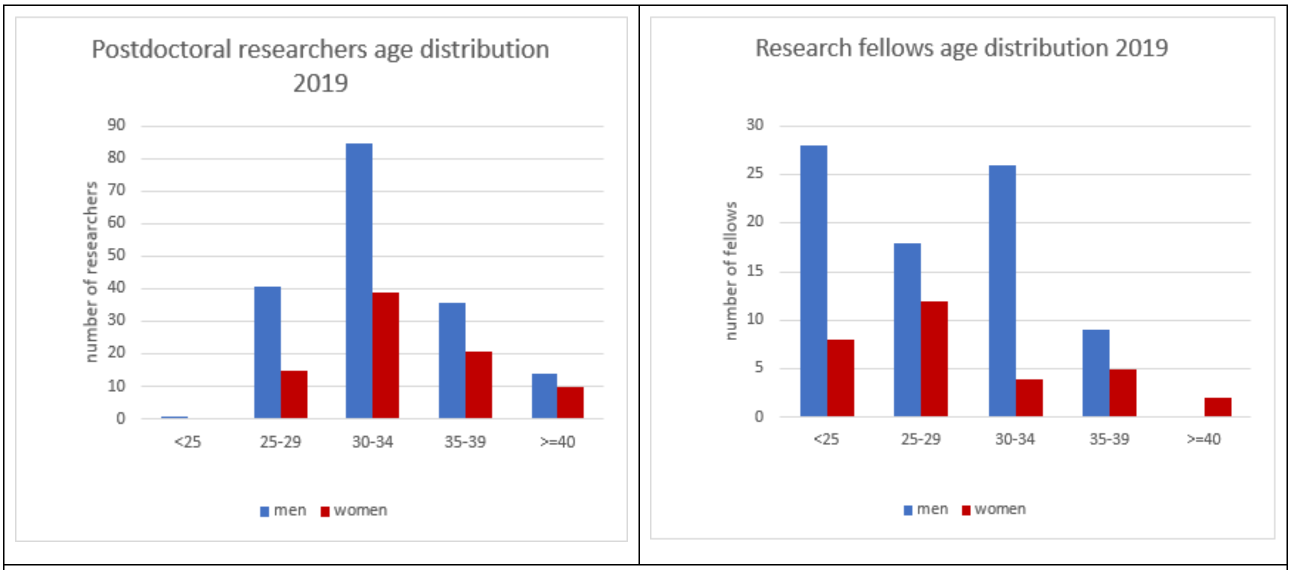


Figure 6.3 – Age distributions for postdoctoral researcher and research fellow - women (red), men (blue) (data updated at 31/12/2019).

Postdoctoral researchers and research fellows. A large contribution to INFN activities is given by 262 Postdoctoral researchers and 112 research fellows, which represent 36.6% of the researcher and technologist personnel. In Fig.6.3 the post-doctoral researcher and research fellow age distributions are shown. It should be noted that:

- 9% of the post-doc is over 40 years old. This is an indication that very experienced post-doctoral researchers have difficulties in finding a permanent position in research. For 40-year-old people better positions should be available, as suggested by the "Code of conduct for the recruitment of researcher", the post-doctoral status should be temporary, and should give the opportunity to obtain a long term position.

- 41.1% (35 men and 11 women) of the research fellows are over 30 years old. In Italy, people with a research fellowship have less economical protection during pregnancy and illness. It would be extremely important to improve the protection level of these categories, INFN management is monitoring this situation.

6.2 INFN Affirmative Action Plan

In July 2019 INFN Board of Directors approved the 6th Affirmative Action Plan[3]. Here we report a brief balance of the just completed 5th Affirmative Action Plan[4] which pursued the following general objectives.

Increasing transparency in decision-making processes and information flow. Despite some progresses, improvements are still required. In 2016 the EU "Minerva" code for recruitment procedures of researchers was adopted by INFN. In 2018 new "Staff Recruitment Guidelines" were approved where criteria for candidate selection are clearly specified. Some changes in the evaluation criteria were implemented at the end of 2019. In Italy career transitions and hiring of researchers are regulated by national public competitions: technicians, technologists and administrative staff are hired on a local competition basis. For researchers and technologists, INFN has two promotion levels:

- from level III (researcher) to II (first researcher, equivalent to University associate professor): the assessment consists of an evaluation of the scientific production of the individual and an interview with the selection committee. This takes considerable time because there could be approx. 250 for a single position. In the last call, for instance, they had about 20 open positions.

  In order to evaluate the scientific production of the candidates, the committee assesses an exhaustive list of aspects that make up a curriculum of scientists. A pre-selection of 80-100 candidates are invited to an interview. In the end, the overall classification is a sum of how they performed in the scientific research assessment and the oral examination.
- from level II to I (director of research, equivalent to University full professor): the procedure is similar to the previous one, but without the interview. The candidates are evaluated against a set of criteria. The scores assigned to each criterion are aggregated to a number and the candidates are ranked accordingly. The individual with the highest rank is selected.

The new "Staff Recruitment Guidelines" were recently tested against an almost complete set of national competitions (hiring of about 150 new researcher and technologists, career transitions of researchers and technologists at both levels). An ex-post analysis of the critical issues involved in these selections gave useful indications to be implemented in the next round of hiring/promotion competitions. It should be stressed that there is a large fraction of senior researcher with high international standard and large seniority that have difficulties in successfully go through the career transition process.

Scientific communication has been largely improved in these last years with the newsletters. A similar transmission for administrative news needs to be implemented.

---

[3] https://web.infn.it/CUG/images/alfresco/Ptap/20190726_del_cd_15215.pdf
[4] https://web.infn.it/CUG/images/alfresco/Ptap/20150331_del_cd_13635.pdf

Removing unconscious bias from institutional procedures. A new “Employees Recruitment Guidelines”, approved in January 2018, introduced an article on Gender Equality: the selection boards have the duty to go through a brief document, prepared by the CUG, informing about the existence of unconscious bias and suggesting some actions. Unfortunately results of the first competitions in which this novelty was introduced did not show any improvement with respect to the past. The “Employees Recruitment Guidelines” have been revised in the last months of 2019. CUG is observing that the Italian law aiming at equal opportunity in recruitment and career procedures for public administration (in the case of equal preparation between a female and a male candidate, man should not be preferred) is still unapplied.

Promoting excellence through diversity. Differential access to managerial positions creates and supports inequality. In these last years a very small increase, still far from an equal access rate, to management positions and to first level researchers for women have been observed, Furthermore as already discussed the low success rate of women in the recruitment process prevents to reach gender equality in INFN.

Taking into account these unresolved issues the new INFN Affirmative Action Plan has a specific area: “Equal opportunity and equality in recruitment, promotion and in decision making bodies for all roles and levels” with the following objectives: “Promoting excellence through diversity” and “ Removing apparently neutral institutional procedure that have a negative effect on the women career opportunities”. In particular, INFN would assure that in recruitment and career progressions the success rate should be independent from the candidate gender. Furthermore, the presence of women in institutional committees and in management should be 50% and 40%, respectively, as indicated by EU Committee in Horizon 2020.

In 2018 during a workshop at CERN public sentences against gender equality expressed by a associate professor to INFN stimulated considerable discussions within INFN and in the whole scientific community. The position expressed by this professor and the following discussions demonstrated how gender equality is not yet universally accepted within the scientific community. INFN took action by disciplining the offender.

Improve research through the integration of the gender perspective. Health and safety aspects should be estimated paying attention to gender, age, country of origin and specific risks related to the contract type. A training course on these topics was organized in March 2019 for people working on Health and Safety. Many outreach scientific activities have begun to include seminars, programs, and laboratories on gender issues. Some are integrated into school-job alternation paths and masterclasses. A specific training on bias is strongly recommended for all the people involved in the outreach activities to avoid “stereotypes”.

Enhancement of human resource in the working environment. Telework and Smart Working are instruments to improve the balance between private and work life for male and female workers. In 2019 73 positions (41 men and 32 women, corresponding to 3.5% of the personnel) were assigned, while in 2020 43 positions have been assigned corresponding to 2% of the personnel.

In 2019 the “Smart Working Guidelines" have been approved. At most 10% of technicians and administrative staff would be allowed to benefit from this institute, for an initial period of 2 years. During the COVID-19 emergency lockdown for in March-May 2020 all the technical and administrative staff have worked remotely and now they continue to do so on a part-time basis.

In 2019 there was a large activity for the preparation of new guidelines for the welfare benefits. Staff members have been contacted for a survey organized from the CUG

6.3 Organizational wellbeing and related activities

In order to better adapt to the INFN work organization the project “Circles of organizational listening” has been evaluated and optimized in a new structure now called “Smart-Lab”. There is the plan to extend this initiative to all the INFN structures: after the initial five in 2018-2019, eleven should be begin in 2020.

At the end of 2019 the working group organized by the INFN Health and Environment Service in collaboration with the CUG suggested to INFN to commit to a research team of the Department of Psychology of the Turin University a survey on organizational wellbeing and work-related stress.

7 Third Mission and INFN

As an Institution working on cutting-edge scientific issues, INFN has a significant impact on the progress of knowledge, on technological development and on the economy of the country. Aware of this role, and of the fact that it is the duty of a public body to share its activities and the results that derive from them with society, the Institute is increasingly committed to communication and to what today is called the Third Mission (3M): i.e. technology transfer (TT), advanced training and the dissemination of scientific culture (public engagement, PE).

INFN plays an important role in the communication of physics at the international, national and local level, promoting, designing and implementing initiatives for the dissemination and promotion of scientific culture, both for the general public and for specific targets. In addition to traditional initiatives, it studies and experiments new forms of communication, emphasising the fundamental relationship between physics and other areas of knowledge. The Institute also contributes a lot to the training of high school students through scholarships, internships, teacher training and school-work projects.

Moreover, INFN promotes technology transfer activities and supports the exploitation of innovative technologies by identifying, supporting and protecting them with appropriate tools, and by seeking industrial partners: all this to facilitate their maturity and introduction in the production and therefore social contexts. INFN is engaged in all these activities to make the most of the role of physics in the production of culture, in helping plan the future of societies and in training the citizens of tomorrow.

The INFN communication strategy is defined jointly by the Management and the Communications Office (CO), that is strategically located in the INFN Headquarters. The communication strategy is then shared and implemented in close collaboration with the CC3M, the Third Mission Coordination Committee, that coordinates, supports and enhances public engagement local activities with national impact, taking a pro-active role towards the new challenges facing the Institute. INFN personnel do engage in such activities since long time and increasingly, so that the INFN Board of Directors approved the new Rules for Competitive Exam recognizing up to 10% of the total score to candidates engaged in 3M activities. Due to the recent requirements by ANVUR[5] of evaluation of social impact (VQR 2011-2014 and its follow-up), recording of activities has improved[6]. The breadth of the activities (from lifelong learning-LLL to stage for students) suggests that a sizeable fraction of INFN personnel is involved in 3M activities. While TT occurs mostly as by-product of research, LLL and outreach needs recording of people involved while they are being done, and this is one of the area where CC3M is taking action.
In the following we describe the Communication Office and its activities, then the broad spectrum of LLL and Public Engagement activities (both supported by CC3M and at local level) with a short focus on the outreach activities performed during the peak of the COVID19 emergency phase by the Communication Office, and/or organized by CC3M. Finally, we discuss the Technology Transfer strategy, and its fulfilment.

[5] ANVUR is the Italian national agency for the evaluation of university and research.
[6] INFN started recording knowledge transfer activities back in 2005.

7.1 The Communication Office

The INFN Communications Office is the central actor of the public image of INFN. In collaboration with the INFN President and Executive Board it defines the overall communication strategy and the projects and actions to be implemented: it is responsible for planning, coordinating and implementing the INFN communication strategy at national and international level.

The CO represents INFN in the international communication networks and, thanks to the professional, editorial and graphic, competences of its staff, it manages institutional communication, press office activities, media relations, graphic and video material production, editorial products, the institutional magazine and the monthly newsletter, internal training, and the central national activities of public engagement, such as large exhibitions and big public events, for instance, and it gives support to the CC3M and local communication activities, when needed.

The aim of INFN communication efforts is to raise the interest of Italian media and public, the awareness and knowledge of basic research in physics and of its technological applications in society. The CO acts as a reliable and prompt source of information for the media, so much that INFN has become a point of reference for Italian journalists, whose queries not only concerns its specific field of research, but also topics related to more general scientific contexts. The INFN is considered a reliable and authoritative source of scientific information.

Strategical messages. There are two main aspects on which the CO has strategically aimed to characterize the image of INFN: an authority within the scientific community with regards to research, and expert in maintaining high level managerial roles along with in effectively managing complex infrastructures and large projects. Additionally, it represents an important potential for the country from the scientific, technological, economic and cultural point of view. The message is that INFN represents an 'Italian scientific excellence', valuing the production of scientific knowledge, the technological and economic impact, and the role in the context of culture in a broad sense: from our view of the world to science as a venue for dialogue and intercultural exchange.

Community training. Given the increasingly involvement of the research community in scientific dissemination, as we said before, it has become paramount to provide it with tools to be as autonomous as possible in the organization of local events, in the management of relations with the media and enhanced effectiveness when communicating with the public. The CO meet this need by organizing internal training sessions with focus on public engagement, media training, event management and social media, reaching a total of 60-80 participants per year. The courses are part of the INFN National Training Plan and received very good results in post-evaluation surveys conducted last year. From their first edition in 2015, the sessions organized by the CO have seen a significant increase in requests for participation. In 2018, in order to offer a training program consistent with the training needs and expectations of the INFN community, the CO carried out an evaluation through an online survey. The results were integrated in the planning of the following years. In 2019 the CO organized 4 curses focused on events (programming and management), public engagement (empowering formal and informal communication) and social media.

Support to CC3M initiatives and local communication. The CO collaborates and/or provides help, with its competences in design and realization, to the communication activities supported by CC3M or promoted by the local Units (Divisions and National Laboratories). In relation to the INFN units spread all over the national territory, the CO aims at providing guidelines and suggestions, and at providing tools to promote an overall picture and a corporate identity of the Institute while, at the same time, seeking to preserve the originality and the authorship of the single projects. The CO can give support to local Units in the development of their main communication projects, not only from the editorial and contents point of view, but also in graphics and design. In addition, the CO produces editorial and graphical products for the INFN offices and committees.

Press activities. In 2019 INFN published more than 100 press releases and news, and was cited about 8700 times by the press and on the web, and 300 times on radio and TV. Here below the trend of the press office activities outputs during the last years (Figure 7.1):

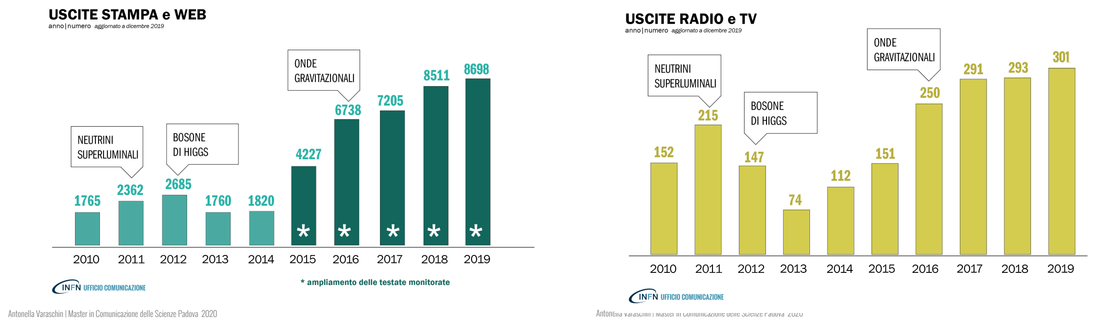


Figure 7.1 - Press Office outputs, years 2010-2019

Asimmetrie. The CO oversees the publication of the INFN institutional half-yearly magazine Asimmetrie. Each issue is a monograph focused on one of the subjects of frontier physics being researched by INFN. With a circulation of 20,000 copies, Asimmetrie has 16,000 private subscribers, while the remaining copies are distributed by INFN Units to visitors and high school teachers and students, who are the main target readership of Asimmetrie. Authors of the articles are INFN researchers, with the CO and the scientific board also involved in the editing process. Asimmetrie is also available online on the website www.asimmetrie.it, and on an App for mobile phones. The magazine has a free subscription on the website. In 2019 the themes of Asimmetrie have been Elements (in April) and Data (in October).

Monthly newsletter. The CO publishes a monthly newsletter in Italian and in English. The main readership is INFN personnel, EU representatives, Italian politicians at the national and European level, national and international stakeholders, policy makers, and scientists of foreign physics laboratories in Europe and all over the world, with whom INFN collaborates. The main goal of the newsletter is to present INFN research and its technological applications, outlining international results, projects and people involved.

Institutional communication channels. The CO manages and updates the official and institutional website of INFN www.infn.it and the website of Asimmetrie www.asimmetrie.it. The CO also manages the INFN presence on social media: it is responsible for the INFN and Asimmetrie Facebook pages and Twitter and Instagram profiles.

The CO programs and follows a strategic plan for each social media account. This strategy gives good results in terms of increasing number of followers and outreach of the pages (e.g. INFN Facebook page likes increase steadily). In 2019, the CO also joined several international Social Media Campaigns, such as #Web30, #DarkMatterDay, #WomenInScience, #SpaceWalkforAMS and #03ishere and organized some of its own, like #UomoVirtuale and #CosmoNelBicchiere to communicate on social media some concepts related to the INFN exhibitions "Uomo Virtuale" and "Il Cosmo nel bicchiere". The CO upkept the Facebook lives and live tweeting events.

The CO also runs a Youtube channel, with more 3,200 followers, where all the audio and video materials are available for journalists, students and the public at large. In 2019, 24 original videos were uploaded to the channel. The CO gives technical and graphic support to the website scienzapertutti.lnf.infn.it dedicated to science education and updated by an editorial board composed of INFN researchers.

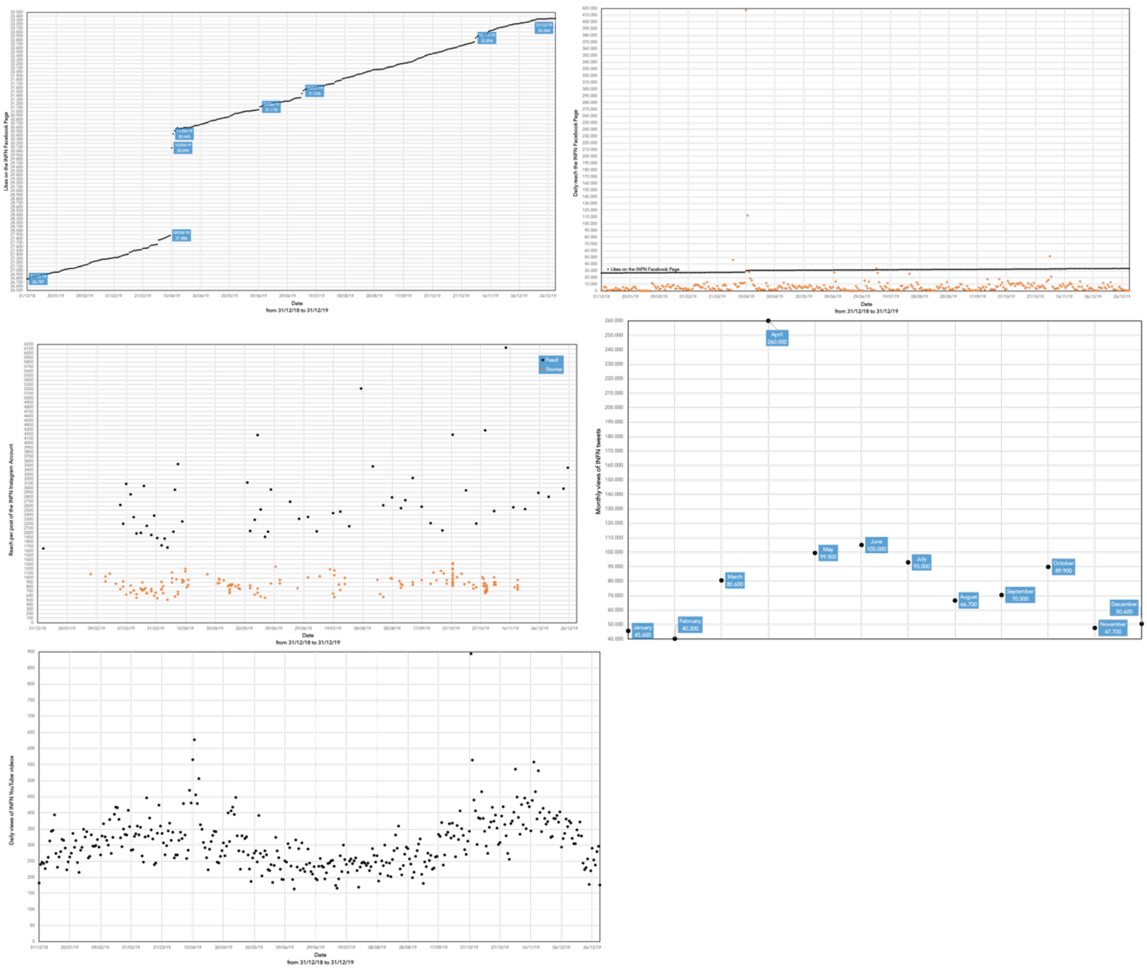


Figure 7.2 The graph on the top left shows the increase in the number of "likes" to the INFN Facebook Page through 2019 and next to it there is a graph describing the daily reach of the page (orange) compared to the numbers of "likes of the page (black). The figure in the centre, on the left, shows the reach of the posts published on the INFN Instagram account (@infn_insights, in orange is the reach of stories and in black the reach of posts published in the feed). On the right, the monthly views of INFN tweets are shown and, at the bottom, the daily views of the videos on the INFN Youtube Channel (Infn Comunicazione) are indicated.

As a key part of the implementation of its communication strategy, the CO conceives, designs and organizes scientific dissemination events, shows, exhibitions and interactive settings in collaboration with artists, computer experts and scientists, suitable for theatres, museums and scientific or cultural festivals.

EXHIBITIONS

The INFN main effort in public exhibitions was characterized also in 2019 by emphasizing and reinforcing the dialogue between science and art, following the strategic objective and theme of the INFN communication that physics is culture.
In particular, INFN CO design and coordinated the realization of a new edition of ***Virtual Mankind. Boby, Mind and Cyborg***, in Turin. A large exhibition that told the story of the exploration of the human body thanks to the eyes of science and technology: a virtual path of 1000 square meters

animated by educational-interactive installations and exhibits that combined science, multimedia and video-art. The human body as you've never seen it before: decomposed, analysed, studied, and reconstructed thanks to technological eyes, virtual shots and bionic prostheses that make up a new body. Virtual Mankind was a scientific and technological itinerary starting from the beginning of the Twentieth century, with the discovery of X-rays, to the future with the new frontiers of imaging and robotics. In order to effectively promote the exhibition and its collateral public events, especially during the summer period, when there is no school audience, the CO decided, in a coordinated way with the CC3M that supported the initiative, to enhance local communication.

In 2019 INFN took also part in the curatorship of the artistic and scientific exhibition ***Sublime Anatomies***, in Rome. An exhibition on the revelation of the sublime in the human body, between past and present and at the intersection of artistic practices and scientific enterprises. A centuries-old and spectacular history of the observation of the body that primarily involves the senses - first of all sight and touch - but also scientific tools and technologies. The exhibition hosted works, artifacts and documents of extraordinary historical importance that, between art and science, told the evolution of human anatomy in close dialogue with contemporary artistic research on the materiality of the body.

Moreover, an important achievement for INFN public image was the opening of the **visitor centre of the Southern National Laboratories**, an initiative also promoted by the CC3M. The CO has coordinated the design of the visitor centre in collaboration with the local group. The new visitor center is a multimedia center, of 400 square meters, in which the public, through a path of exhibits and interactive installations, will be able to venture into a scientific story that ranges from nuclear physics, to astroparticle physics, from particle accelerators to interdisciplinary research, with the important repercussions in the field of cultural heritage and medicine. All activities that see the LNS protagonists on the international scene. Among the exhibits that visitors can experience, there is an immersive environment and an optical module of the KM3NeT experiment. Visitors can also enter the heart of a star tens of times larger than our sun to observe the phases of its life. And discover the image of our galaxy reconstructed at different frequencies of the electromagnetic spectrum and on the basis of the information that other cosmic messengers, such as gravitational waves and neutrinos, are able to bring to us from the depths of space. The public can discover how the composition of a work of art is reconstructed, and understand the profound link between research on the fundamental structure of matter and the development of new technologies with applications in the medical field for diagnosis and therapy (Figure 7.3).

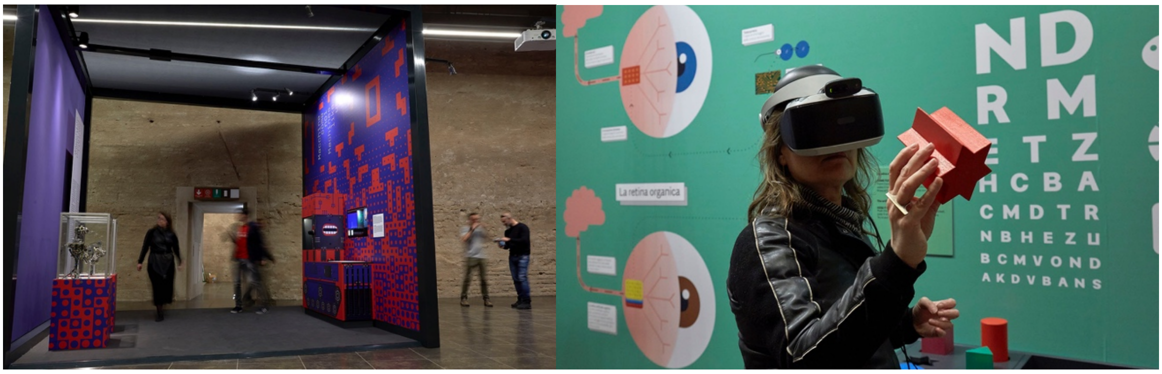


Figure 7.3 Augmented reality in LNS Visitors' Center

In 2019 the CO also experienced a fruitful initiative in collaboration with ISIA in Rome, a public university in design. Starting from a workshop held by the CO on the main research topics of INFN, and working then together with the young ISIA's students, a new photographic communication project has been developed, that became an exhibition and the 2020 INFN calendar.

2019 EXHIBITIONS in details:

- *The Cosmos in a Glass*, Rome, National Geographic Festival delle Scienze, April 8-14, and Genoa, Festival della Scienza, October 24 – November 4. What happens to mix the images of our daily life with those of the phenomena of physics and cosmic evolution? Can a donut with icing become a black hole? Or a liquorice wheel a gravitational wave? The exhibition aims to explore new languages and communication tools in the public narration of the themes of contemporary physics and it is the result of the research of a group of design students starting from the workshop "The visual imaginary of contemporary physics" organized by ISIA ROME and INFN in December 2018.

- *Virtual Mankind. Body, Mind and Cyborg*, Turin, Mastio della Cittadella, May 4 – October 13. An exhibition curated by INFN and created in collaboration with IIT - Italian Institute of Technology and with the support of the Compagnia di San Paolo, the contribution of the Piedmont Region and the Palazzo Blu Foundation and with the support of CentroScienza Onlus Association. Scientific partners were: Polytechnic of Turin, NICO Neuroscience Institute Cavalieri Ottolenghi, NIT Neuroscience Institute Turin of the University of Turin, INN-National Institute of Neuroscience, the La Venaria Reale Conservation and Restoration Center Foundation and the Regional Museum of Natural Sciences of the Region Piedmont. (15.000 visitors, of which 30% students – 3.000 students took part to the educational workshops – about 2.000 people attended the collateral public events)

- *Sublime Anatomies*, Rome, Palazzo delle Esposizioni, October 22, 2019 – January 6, 2020. The INFN contribution to the curatorship of the exhibition was focused on the imaging technologies developed from science to medicine.

PUBLIC EVENTS

As a laboratory for unconventional scientific communication, the experimentation of different ways of communicating science have led the INFN Communications Office to carry out, in the last decade, innovative formats for public events, in which performing arts intertwine with the narrative of science. Since the structure of the story is intrinsically connected with the process of knowledge building, the basic idea for these events relies on the belief that the use of narratives and art can help unveil invisible connections in the interpretation of reality and unexpected scenarios for the acquisition of knowledge. If conceived appropriately and well verified in their contents, these communication formats prove to be valid communications tools to involve different audiences of non-experts, also giving rise to unexpected insights on the ideas of physics and the way research evolves.

As a major commitment, 2019 was the third of the INFN three years of agreement with the *Musica per Roma* Foundation, together with ASI (Italian Space Agency), to co-organize the annual National Geographic Science Festival in Rome. The participation of INFN to the main Science Festivals organized in Italy was also an opportunity to create and produce new events involving artists and scientists in original dialogues, to communicating science in an engaging and coherent way. At the same time, the INFN CO has started to share its experience in the design of public events with some theatres in Italy. Cosmic Tale, a conference-show on the evolution of the universe, designed in 2016, saw in 2019 the renewal of its format. Aimed at a large audience, the dialogue on cosmology and contemporary physics intertwines with performing arts a visual narration. Four reruns - attended by 2800 people - were held in 2019. In the same year, a new conference-show format has been launched and staged on several occasions: “The Universe in a box” is a monologue held by a scientist with the

Figure 7.4. Snapshot from two events

contributions of videos and live music, without any contribution of external moderators (Figure 7.4).

2019 EVENTS in details:

- *Cosmic Tale*, Correggio (Reggio Emilia), Teatro Asioli, January 11, 2019 (1200 people on site), with the participation of the physicists Fernando Ferroni, Antonio Masiero, Viviana Fafone, and the anchorperson Neri Marcorè.
- *On Art and Science*, Milano, Museo della Scienza e delle Tecnologia Leonardo da Vinci, January 16, 2019 with the participation of the art expert Philippe Daverio, the physicist Fernando Ferroni, the actress Lella Costa (900 persone on site + web streaming)
- *Cosmic Tale*, Baveno (Verbania), San Raffaele Retreat, March 14-16, 2019, (400 people on site), with the participation of the physicists Fernando Ferroni, Antonio Masiero, Viviana Fafone, and the anchorperson Neri Marcorè.
- *Cosmic Tale*, Boretto, Teatro del Fiume (Reggio Emilia), April 5, 2019 (1000 people on site), with the participation of the physicists Fernando Ferroni, Antonio Masiero, Viviana Fafone, and the anchorperson Neri Marcorè.
- *Physicists, feminine plural*, April 10, 2019, Roma, Auditorium parco della Musica, Festival delle Scienze di Roma, (700 people on site + web streaming), with the participation of the physicists Elisabetta Baracchini, Chiara Mariotti, Viviana Fafone, and the anchorperson Serena Dandini.
- *Space to Time*, April 12, 2019, Roma Auditorium Parco della Musica, Festival delle Scienze di Roma, (1200 people on site + web streaming), with the participation of the physicists Fernando Ferroni, Antonio Masiero, Giuliana Fiorillo, and the anchorperson Neri Marcorè.
- *Singularities, Big Bang and Black holes*, September 14, 2019, Sassuolo, Festival della Filosofia (2000 people on site), with the participation of the physicists Mariafelicia De Laurentis, Massimo Pietroni, and journalist Marco Cattaneo.
- *The Universe in a box*, August 31, 2019, Isola Polvese, Festival Isola di Einstein (150 people on site), a monologue on the universe with the participation of the physicist Fernando Ferroni, and the music Trio “La Banda dell’Uku”.
- *The Universe in a box*, October 31, 2019, Genova, Teatro della Tosse, Festival della Scienza di Genova (400 people on site), a monologue on the universe with the participation of the physicist Antonio Zoccoli, and the music Trio “La Banda dell’Uku”.
- *The Universe in a box*, November 22, 2019, Napoli, Città della Scienza, Festival Futuro Remoto (400 people on site), a monologue on the universe with the participation of the physicist Antonio Zoccoli, and the Trio “La Banda dell’Uku”.
- *Music images the human body. Jazz dialogue between art and science*, December 20, Rome, Palazzo delle Esposizioni, (about 200 people on site) a concert-narration about the human body, and the

technologies used to explore and study it. With the participation of the physicist Diego Bettoni, the video-artist Paolo Scoppola, and Danilo Rea at the piano.

The CO is also involved in **international dissemination projects**. For instance, it coordinates at national level the CERN Masterclasses which are managed at local level by INFN Units, and it promotes in Italy CERN's *Beamline for Schools* competition.

The CO represents Italy in the following **international networks on communication**:

- EPPCN (European Particle Physics Communication Network), established with the aim of strengthening communication on particle physics and on LHC in particular;
- IPPOG, the International Particle Physics Outreach Group that promotes the outreach activities of particle physics institutes and laboratories;
- InterActions, a communication resource from the world's particle physics laboratories, which provides press releases, news, images and documentation material about experiments, infrastructure, laboratories.

The CO contributes to the organization of the **Erice International School of Scientific Journalism** held every year in Erice by the Majorana Centre. The 2019 title was *Big projects for science and knowledge*.
Moreover, it contributes to the didactic activities of masters in scientific communication organised by Universities.

7.2 Public engagement activities

INFN have a long record in *PE*, mostly as outreach activities. Thanks to the Communication Office, and since 2016 to the CC3M (Commissione Coordinamento Terza Missione), a growing number of structured local and national activities have been pursued. Moreover, within the research community, there is an increasing awareness of the need to move from a top-down approach in dissemination towards a more cooperative attitude with the social players.
Since 2005 the Institute created a central database (managed by the GLV) where events can be recorded by local units, providing a dataset helpful to understand the different aspects of engagement being pursued (see Table 7.1 for a statistic of public events since 2012). In recent years the database reports also detail about the target, and the impact of the activities. Before discussing some figures, it is important to recall that we document only *institutional* (i.e. established at local or national levels)

efforts.

	2015	2016	2017	2018	2019
Bari	-	80	140	-	96
Bologna	78	120	120	120	120
Cagliari	50	120	160	120	120
Catania	100	-	-	-	-
Ferrara	60	152	150	160	180
Firenze	160	142	150	126	161
Genova	180	150	150	250	250
Lecce	70	70	80	60	60
LNF	57	55	52	44	38
Milano	83	140	90	90	90
Padova	620	700	450	200	200
Perugia	82	83	100	75	80
Pisa	89	200	190	90	90
Pavia	-	60	-	60	60
Roma1	80	76	80	-	-
Roma2	50	-	100	-	80
Roma3	??	??	35	??	90
Torino	80	80	80	80	80
Trieste	[illegible]	[illegible]	[illegible]	180	190

19

Activities are split into four categories according to the different targets: school pupils and teachers, university students, public at large, research-related (for specialists). The distribution of activities aimed to schools and general public looks similar (Figure 7.5) for both National labs and local Sections. Approximately 65 (69) % of outreach activities of Sections (Laboratories) are meant for (mostly) high schools. The dominance of school-related events with respect to the ones aimed to the general public testimonies the effort that INFN dedicates to this target. A data quality check shows that events for University students and specialists are not accurately recorded, therefore related numbers can be considered as *lower limits*, and will not be discussed further.

	2012	2013	2014	2015	2016	2017	2018	2019
Lab. Nazionali	87	196	181	266	232	141	211	167
Sezioni	135	149	141	181	346	441	440	640
Uff.Com	9	11	23	7	7	17	25	33
Gr. Collegati	N.P.	N.P.	N.P.	N.P.	0	1	3	4
CNAF+GGI+ GSSI+ TIFPA	N.P.	N.P.	N.P.	0	4	1	6	10
INFN-TOT.	**231**	**356**	**345**	**454**	**589**	**601**	**685**	**854**

Table 7.1. Public events (schools and general public), Years 2012-2019, by structures

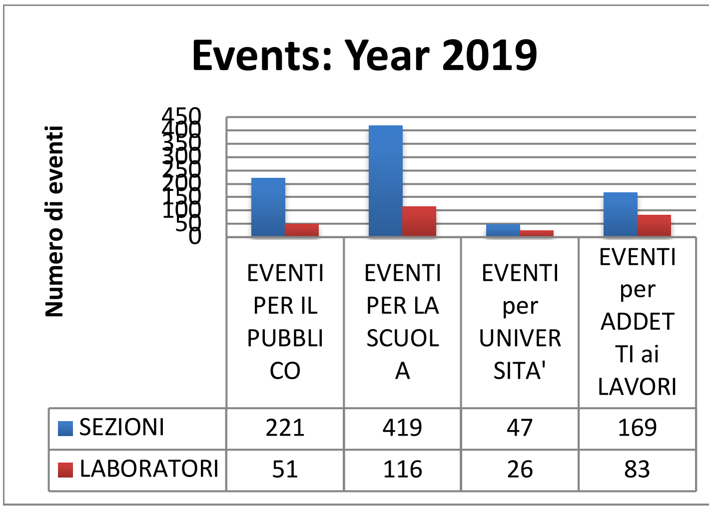


Figure 7.5: Sections and national labs, 2019. The total does not include activities pursued by Comm. Office and Gruppi Collegati

As earlier mentioned, recently we started a better recording of the impact (at least in quantitative terms). Looking at activities for schools (almost always high schools), we can see –for example- that in the "*Alternanza Scuola Lavoro*" area, about 1,600 pupils were involved, while more than 9,000 participated to dedicated seminars. Overall (summing the different categories of visits, stages, *Alternanza Scuola Lavoro*, seminars, etc.) the database describes activities directly involving more than 38,000 high school students in 2019. This large figure is due to a combination of well-established initiatives (like for example the IPPOG Masterclasses, the International Cosmic Day, Womens' Day in Physics, etc.), to co-organization (with local Physics Departments for example) of an array of activities (many *hands-on)* for high-school pupils, and to a continuous work with schools and local communities. As an example Table 7.2 reports the number of participants to the IPPOG Masterclasses over the last five years.

An analysis of activities for the general public shows a number of non-conventional events, like science-café', theatre plays etc. They complement more traditional ones like exhibitions (almost always centrally produced by the Communication Office), guided tours, seminars, as well as some broadcasting in collaboration with local and national TV channels. Over the years the European Researchers' Night (ERN) has become a traditional date, providing our Sections with an opportunity to create an "Open Day" of large attendance with limited means. ERN is an example of how one can reach a broader (and different) public by working in collaboration with other research institutions and Universities. Overall our records show that (not including exhibitions) in 2019 more than 100,000 people took part in events organized by, or with participation of, INFN. While the figure is large, it should be taken with some caution as in several cases (for example during the ERN), it is difficult to estimate the actual impact of our presence.

7.2 Commissione Coordinamento attività Terza Missione - CC3M

This Commission, created in 2016, was described in previous CVI reports, and in this section, after a short recap, we will go only through what is relevant for 2019.
We recall some strategic goals of CC3M to be pursued:

- Differentiate/widen our target groups, extend our high-school activities beyond Licei;
- Provide each National lab with an appropriate visitor center;
- Increase Lifelong Learning activities[7].

CC3M also created a formal way to select, finance and evaluate old and new projects, this aspect is thoroughly described separately.

The first goal (targeting different publics) can be reached in many ways. The Commission encourages INFN personnel to partner with other subjects, to participate in initiatives originated by other subjects, and to find new ways of bringing physics to students and the general public. INFN, with the visibility of its research, is very well placed, and carries a responsibility to do it well.

Proponents are encouraged to seek for funding from local governments, cultural organizations, industrial firms etc. This action is not simply a way to get extra financial support, but also as a way to raise awareness of INFN activities in and out of research. Over the years

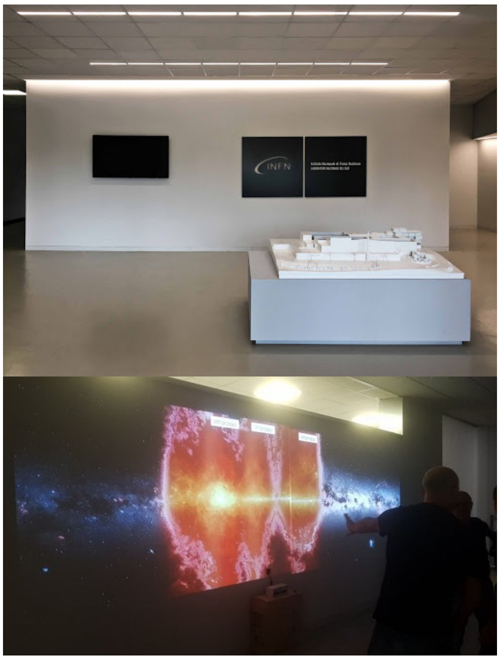


Figure 7.6. The new LNS Visitor Center

[7] In VQR 2011-2014, the evaluation of INFN Lifelong Learning activities reported a limited use of its capabilities, and a limited involvement of its personnel.

this effort obtained some results, although we still do not record a success in participation to EU calls. An important instrument to extend our influence is to relate with local organizations interested in knowledge transfer to firms, and to society. In this perspective INFN participates in national networks active in TM: NetVal (www.netval.it, a well-established network of TT offices of Research institutions and Universities), and APENET (http://www.apenetwork.it, network for Public Engagement of Universities and Research institution). APENET was founded in Spring 2018, and by 2019 it consolidated memberships, that now comprises more than 50 Universities and research institutions.

CVI suggested, since several years, that each National Lab should have an appropriate Visitor Center. While CC3M does not act directly, it encourages (and support whenever possible) the creation of VC, with the help of the Communication Office that brings in the appropriate know-how. LNF Visitor Center opened in 2018, and CC3M financed some upgrade of its exhbits in 2019. In July 2019 the inauguration of the LNS Visitors' Center in Catania was the conclusion of a year-long effort that included also civil constructions. It is now the new, evocative entrance to LNS for all visitors, that experience the depth of the research being done at the lab as well as its broad spectrum, and its impact on science and society. In Legnaro, besides the Visitor Center (opened in late 2016), CC3M is supporting the creation of a visitors' path that includes the search for gravitational waves (using the *Auriga* resonant bar detector as one of the focus), and the development of a *virtual reality* tour of its cyclotron. In 2019 we financially supported both projects. The transformation of *Auriga* into an exhibit is part of a larger project of supporting GW outreach activities.

Organization of the Commission Activities

As 2018 was the first year in which the network of local representatives became operative, CC3M set a way to support/finance old and new activities, at the same time exploiting this new asset. Therefore, the Commission through 2018 developed a procedure to evaluate new proposals (to be financed in 2019), and to set a common way to "measure" their impact. The 2019 budget was mostly allocated to activities discussed, and approved following procedures similar to what done by the National Scientific Commissions: in June-July proposals are submitted, then their approval and financing is discussed in a national meeting in early October by representatives, proponents, and referees. Proponents and referees were instructed on the strategic priorities of the Institute, with a special stress on involving different partners. Finally, the CC3M, based on its budget (set to 300KE), funds the accepted activities. Only a fraction of the budget (for 2019 it was 80%) is assigned in this phase, in order to have the chance to pursue new ideas/activities whenever possible. For 2019 two projects did not get approval to go beyond proposal stage, and two were asked to better organize their ideas for a later time.

Each proposal has at least two referees, and is required to:

- to introduce ways to measure its impact/effectiveness already in the design phase;
- have a national leader, and a contact for the Communication Office;
- a minimum of 0.1 FTE (at national level) for each supported initiative. Minimum fraction for a participant is 0.05. Currently we admit that participants are listed with 0 FTE;
- provide an ex-post evaluation to understand its results.

The last point is innovative. Unlike research project, that are essentially evaluated by their output in terms of papers/results obtained, TM activities often have goals that are very different one another, and must be "measured" to understand whether they were effective or not. In order to standardize (at some level) the Milestones to be set, we approved the use of a methodology borrowed from a US DoE management scheme. We set indications that milestones should follow what is shown in figure 7.7: clear goals and metrics, timely and measurable targets. This approach allows both a clear recording of the expected (and obtained) impact, and an easy self-assessment by proponents of the success of the activity.

In this process a crucial role is played by the network of representatives from local units. As outlined in 2018 report to CVI, it is a cornerstone in the process of improving TM in INFN with a dual role: on one side as a place where information is exchanged, good practices and ideas are shared across structures, and new groups are created; on the other side provides a feedback on ongoing/new ideas being pursued at local level.

In order to strengthen the awareness of the general goals, during general meetings of the network of representatives, some keynote seminars are organized. They address relevant topics (for example by UTT personnel on the issue of copyright, or on new strategies for introducing youngsters to science etc.). In 2019 CC3M dedicated a full two-days training course by the Communication Office to local representatives. The theme was "Organizing an Event", with the aim to provide them with basics on how to handle and organize all aspects of different events, including a short checklist on "what to do". Presentation from this course, as well as other material relevant to the Commission's work, and that can be useful to representatives, is collected in the official INFN AlFresco repository.

Outreach Initiatives supported by CC3M in 2019

In this section we provide a short description of the main initiatives centrally supported by CC3M:

- *Art&Science across Italy: i colori del bosone di Higgs*. After the successful first edition (2016-2018), CC3M supported A&S second edition (2018-2020). This time the initiative is not backed by a European project, therefore is fully supported by INFN. The new edition has a larger participation, with eleven cities and ten sections, with ten exhibitions of the students' artworks. In 2019 three exhibitions (Milan, Genova, Venice) were held, while 2020 situation has been affected by the COVID19 emergency.
- *Asimov*: literary award to scientific popularization. Started as GSSI-INFN activity across three regions, in 2019 involved 92 schools, and 1727 pupils in eleven regions. It is a two-step award. First a scientific committee (rather wide, made by researchers and teachers), selects five

OBJECTIVE	METRIC	HOW MEASURED?	WHEN?
Goal 1. Educate and motivate homeowners in a particular neighborhood/ demographic on program offerings.			
Reach 20,000 homeowners with information about rebates and financial incentives; get X% of them to follow up within Y weeks of outreach	• Number of homeowners reached through outreach • Increase in customer calls or website hits that are a result of homeowner outreach	• Track calls to call center from people who were targeted with outreach • Ask website visitors how they heard about the program offering	• Start tracking within three weeks of outreach • Tally ongoing results quarterly
Goal 2. Build credibility for the program and its offerings through partners the community trusts.			
Recruit five partner organizations to actively promote program offerings (or support specific campaigns or outreach events) with their constituents in the program's first year.	• Number of partners committed to join • Number of partners committed to join • Response rate on materials distributed by partners • Leads generated by partner events	• Sum of organizations that have agreed to partner • Sum of organizations that fulfill agreement • Calculate the rate of return on partner materials or follow-up from partner outreach efforts	• Assess quarterly for the first year or two, then annually • After any partner outreach effort or event
Goal 3. Demonstrate the benefits of home energy improvements to create demand for home energy assessments and upgrades.			
Hold 30 events in upgraded homes in the program's first year, with a call to action to sign up for a home energy assessment.	• Number of satisfied customers willing to host home upgrade demonstrations • Number of event attendees • Number of participants signing up for an assessment after events • Conversion rate of assessment to upgrade	• Sum of owners of upgraded homes willing to host events • Sum of attendees per event • Sum of assessments resulting from event referrals; Divide by number of events • Divide total upgrades from event attendees by assessment from event attendees	• Assess after each event • Monitor quarterly

Source: U.S. Department of Energy, 2014.

Share your evaluation plan with partners

Figure 7.7. Scheme used to set milestones for CC3M financed activities

books. Then the final jury is made by HS students all over Italy that reviews the five books and chose the winner. Thanks to the partnership with ALI (Associazione Librai Italiani) the winner was announced in a national event during Salone del Libro di Torino, giving the award (and INFN) an additional exposure to a large public.

- *Genova Science Festival* (FdS), it is the largest science fair in Italy and the second one (for number of visitors, first for number of activities) in Europe. Our support is twofold: on one side a direct contribution to the FdS organization, on the other we encourage our researcher to propose activities to FdS, and financially support the chosen ones. In 2019 two proposals by INFN researchers were chosen (one was later cancelled due to personal problems of the proponents).
- ***IN**ternational **S**chool on modern **P**h**Y**sics and **RE**search* (INSPYRE,) is aimed to HS students from Italy and abroad, that spend a stage one week long at LNF, exposed to a mixture of didactic labs and lectures on different modern physics topics. The ninth edition in 2019 hosted almost 90 students (http://edu.lnf.infn.it/inspyre-2019/), half from abroad. INSPYRE is also funded by COST action "Quantum Technologies in Space".
- *Lab2Go* (https://web.infn.it/lab2go/), started as a way to overhaul, and share physics experiments in Rome-area high school laboratories. The idea is to help schools in bringing school laboratories and experiments back to life, and then help them in creating a network to share educational experiences among different schools. We are supporting this initiative as can be a general prototype, and it is potentially replicable elsewhere. It was originally linked to the *Alternanza Scuola-Lavoro* MIUR project. *ASL* was modified in late 2018, becoming *Percorsi per le Competenze Trasversali e per l'Orientamento (PCTO)* and Lab2Go adapted to the changes. In 2019 a protocol to exchange experiments between schools was tested for the first time, and INFN Sezione di Napoli joined the three Roman Sections.
- *IPPOG Masterclasses of Physics*. Started in 2005 during the World Year of Physics, is the oldest continuous outreach activity. By far it is the best known INFN outreach activity, and became a traditional date. It obtains wide media coverage, as we host about 2000 students in 21 different cities, to be *scientists for a day*.
  Six groups participating in the FERMI-LAT research program, organized a similar activity using Fermi data, with good results. In both cases CC3M support is limited to centrally providing gadgets for participants, as all other expenses to host large groups of pupils (typically 30 per each day) are covered locally (in several cases by external funds).
- *Outreach with Cosmic Rays Activities* (OCRA). This national initiative was started top-down by the CC3M in late 2018. Every year several units participate in the International Cosmic Day-ICD (coordinated by DESY, https://icd.desy.de/)[8], each one with its own equipment, and without any coordination. Realizing that, besides the ICD, there are a number of stages, exhibitions etc. using CR as a popularization tool, we asked proponents of the ICD to coordinate in a joint initiative. In this way, with a top-down approach, OCRA was created.
  Main goal for 2019 was to equip each group participating in the ICD with appropriate detectors suitable for didactic use, and adequate to the ICD requirements (measurements must be hands on, and performed in the morning of the ICD). Moreover, we tried to test the capability to develop a collaborative effort, by financing a "Cosmic Ray Cube". This is carbon copy of a detector developed at LNGS, and installed at the Lab, as well as in Toledo Metro Station (Naples). CRC was completed in late 2019, on time for the ICD (November 6), but it was essentially the result of the work of a single OCRA sub-group.
  In 2019 almost 1000 pupils (40% women) from 102 schools participated to the ICD in 20 different locations. 60% of participants provided feedback through a survey, that showed a

[8] Students are hosted in a laboratory where, after an introduction to cosmic rays and detectors, perform some cosmic ray flux measurements. Results are then compared via teleconference among the different groups.

good appreciation of the format in all places. OCRA supported a stage at LNGS for the winners of a competition related to the ICD 2018. Thirty students and five teachers from fifteen schools spent three days at LNGS, measuring – together with our researchers- the cosmic ray flux as a function of altitude (figure 7.8). A paper reporting the experience is being prepared for an appropriate journal.
OCRA is the first attempt by CC3M to build a collaboration with a top-down approach, by collapsing together different experiences. The COVID19 emergency impacted the process, as discussed in a separate section.

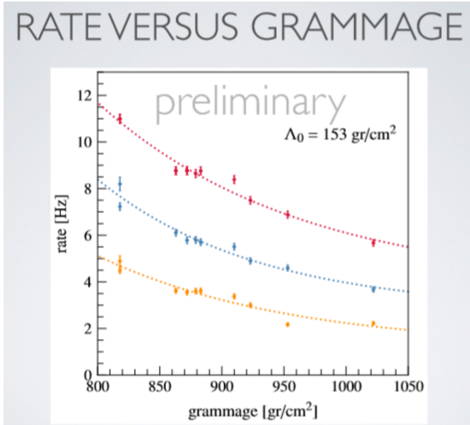


Figure 7.8. OCRA stage 2019: measured flux as a function of grammage; different curves refer to different concidence multiplicity

- *Pint of Science* (PoS, https://pintofscience.it/). Since several years INFN is partner of the Italian edition of this international initiative, aimed to bring science to a wider audience by bringing speakers in pubs (at least three per city). Each pub must host three nights (with different topics), but INFN –as partner- has a 5' slot to introduce itself once per pub, plus (many times) our researchers contribute as speaker.
- *RadioLab.* Hands-on lab activity aimed to HS students that use simple professional detectors to measure Radon concentration in their houses, schools etc. It started during WYP 2005, and continued in several INFN units and Physics Departments spread all over Italy. INFN supported it since the beginning. RadioLab has a good score in terms of schools and students (in 2019 about 1000 pupils and 60 teachers from 62 schools and nine INFN units involved). Six public activities (outside) schools were held (in most cases within Science Fairs and open days), to raise awareness of the radon problem in the population at large, reaching about 10,000 people. There is the possibility to start a citizen science initiative related to RadioLab given the widespread presence of this radioactive gas across the country. As an intermediate step, the group is concentrating on an update (in progress) of its web site, and on producing a brochure to be distributed in public events. Also, thanks to some specific aspects (mixture of hands-on activities, precise measurements, and wide interest of the topic), the group held a "masterclass" in Cagliari during the Womens' in Science Day, and a dedicated hands-on laboratory during the Turin Book Festival (see below).
- *Turin Book Festival* (SALTO); this is the largest book fair in Italy, with about 150,000 visitors in five days. This fair is reserved to publishers and INFN, with *Asimmetrie,* qualifies, and participates since 2018. The 2019 was a good success, and also an opportunity to build several events with a synergic approach. During SALTO19, INFN organized initiatives by OCRA and RadioLab aimed to high school students, one for primary school pupils (by LNF researchers), a presentation of the Asimov Award, and SxT installed a small sub-stand to advertise its website and newsletter. We estimate that more than 5000 people visited the INFN stand, with an impact on a public which is unlikely to be reached otherwise by our activities.
- *Science for Everybody* (Scienza per Tutti, SxT). This web site started in 2002 and was restructured in 2012. As it was the subject of a separate focus in last year's report, we just provide an update. The website itself stabilized at about 3,000 clicks/day during 2019. More interestingly the three milestones set for the year were related to moving from "virtual" to "real". One was an online contest, the second one a participation to Science fairs, and the third transformation of a card-based game (tested in Turin Book Festival) into a more practical App for smartphone. Only the latter was not met due to the bankruptcy of the software house that got the contract.

CC3M also supports some smaller projects. For example, the participation to the European

Researchers Night, as well as some upgrades of exhibits used at LNF and LNL during stages for high school students. In 2018 we started the production of a cartoon aimed to high school students, and devoted to the discovery of gravitational waves. It finally went in print in April 2019, as a supplement to *Asimmetrie*. As for GW, we also supported the transformation of *Auriga* bar into an exhibit (work still in progress), and the crafting of several infographics of INFN ownership to be able to update them whenever needed.

Lifelong Learning Activities

As already mentioned, this is an area where INFN can improve its contribution to society. An area where we can immediately have an impact, is refresher for School Teachers (mandatory since several years). Since 2001 LNF yearly organizes the IdF (Incontri di Fisica), largely based on lectures, for about 150 participants. A few years ago, LNF educational group started the IdFM (Incontri di Fisica Moderna), a refresher program for about 20 teachers from surrounding, based on a mix of lectures and lab experience. By now they are well established initiatives, one (IdF) also structured together with a telematics University. Both IdF and IdFM will be strengthened by the LNF didactic lab being built. CC3M supported with ad-hoc financing, the purchase of some equipment to equip it. In other structures we had scattered experiences, mostly originating from request coming from local government (aimed to unemployed relocation) or other subjects (teachers' and SME associations etc.), but no other stable program. INFN score in VQR 2011-2014 was based on this situation and, besides the already mentioned LNF activities, only LNGS, with its participation to Regional initiatives, contributed to our final result. One of the CC3M goal is to increase the number of people and structures involved, and to raise awareness, within INFN, of the contribution we can provide to society's needs.

The Commission started by supporting refresher courses for teachers[9] in 2018. Reason is twofold: we had previous experience and constitutes an effective (albeit indirect) way to reach out High School students. In this frame CC3M financed *AggiornaMenti*, and *Programma INFN per Docenti (PID)*; both activities (as well as the already mentioned LNF courses) are recognized by Italian Ministry for Education as valid refresher course.

AggiornaMenti is aimed to Middle School (Junior High) science teachers. This is important as, in Italy, physics in Middle School is taught within the wider "science" category by teachers with (usually) background in biology or agriculture, with little physics lab experience. In six classes (one every two weeks), physics topics (fluids, sounds, electromagnetism etc.) are presented, using hands-on, low-cost, lab-based activities. The format is based on a successful experience made by Turin colleagues in 2016-2017 and was reproduced in several sections with a good turnout[10]. Overall (in 2018-2019), courses were held in 8 units, with 90 attendees[11] and 45 researchers involved. The feedback from participants was excellent, with suggestions to broaden the coverage of topics, for example including mechanics. The 2019-2020 activities started well, with nine Sections and one National Lab (LNF) with scheduled courses. About half of them was able to finish classes before the COVID19 emergency cancelled all in-presence activities.

Programma INFN per Docenti (PID, https://pid.web.roma2.infn.it/), is a refresher for High School teachers. It is residential[12] as participants spend a full week (five working days) in National Labs, alternating lectures to lab activities, in order to provide both a refresher in modern physics *and* ideas to introduce it in classes. INFN national labs offer a unique opportunity as each one has its own specific area of research, and as there are many ongoing interdisciplinary activities. Our aim, besides providing a high-quality course, and introduce our topics of interest, is to enhance National Lab

[9] As it is mandatory for Italian teachers to participate in refresher, this gives us an opportunity to reach them, and directly bring them closer to our themes.
[10] The program was discussed and launched at the 2017 CC3M Workshop described in a previous CVI Report.
[11] We estimate ach Middle School teacher impacts on (at least) about 60 students/year.
[12] INFN covers lodging expenses, while meals and travel are on participants as for the similar ITP course at CERN.

visibility both locally and at national level creating a network of teachers active in popularization of physics and familiar with these Labs. First feedbacks are positive, and in principle this initiative can be replicated beyond National Labs (for example LABEC, TIFPA, EGO etc.), depending upon resources availability. After the two prototype courses held in 2018-2019 (Legnaro and Catania) with thirty participants each[13], for School Year 2019-2020 we added Gran Sasso. We received more than 250 applications for a total of 90 available positions for the three (LNGS, LNL, LNS) courses that should have taken place. The Gran Sasso edition was successfully held in late October. One of its goals was to strengthen links between the Lab and local communities, by selecting a fraction of participants from Abruzzo region. In order to evaluate the effectiveness of the program, all participants are surveyed at the end of the week (for a quick feedback on lectures, lecturer and satisfaction), and at the end of the year (to estimate the impact of the course on their didactic activity and on new/reinforced links to INFN Labs). Figure 7.9 shows some responses concerning the LNGS edition. Unfortunately, due to the COVID emergency, the survey at the end of the year, which was done for the 2018-2019 edition, was not conducted. In 2020 we held the LNL edition, while the LNS course was cancelled due to COVID19 lockdown.

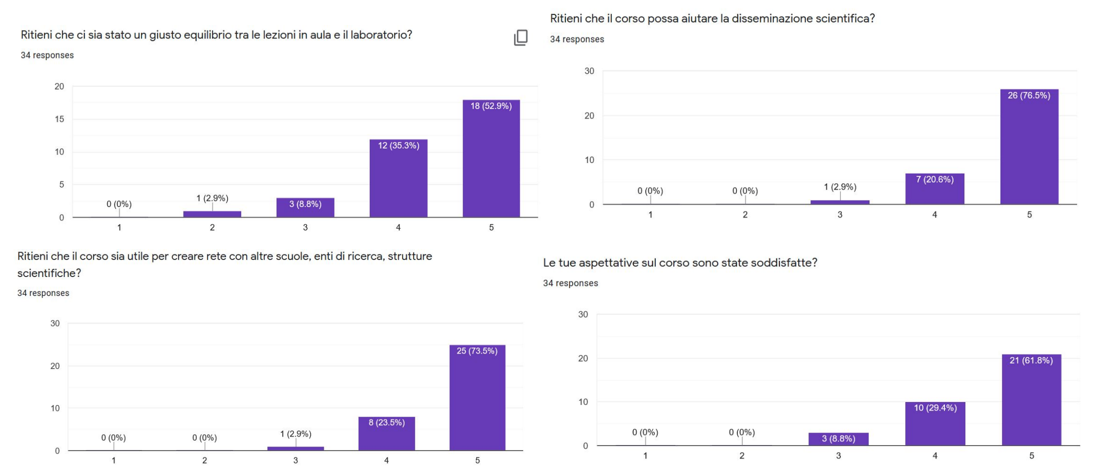


Figure 7.9. Participants' feedback on some aspects of LNGS course

Based on PID experience, in 2019 LNL held a similar refresher course for teachers of the Veneto Region, and Roma2 Section organized a refresher together with the Tor Vergata University. In both cases they were not residential, nevertheless obtained an excellent approval rate.
Overall in 2019 INFN organized 25 refreshers courses, involving 15 local units (including National laboratories).

Focus on reaction to Covid-19 Emergency

The general lockdown of Italy, due to COVID19 emergency, hit outreach initiatives towards school and public, like everything else. There was a concrete risk of stopping all enterprises as most (if not almost all) of them were supposed to be delivered in presence. For example, all of the IPPOG Masterclasses were cancelled just before being held, and the Art&Science exhibitions in Pisa was shut down one day after inauguration. The situation could develop into a cancellation of any outreach for a long time.

When the lockdown was declared, it was immediately clear that schools could be in difficulty in the drastic transition from teaching in person to teaching at distance, and an attempt was made to understand how INFN could be of support to teachers and pupils. The Communications Office reacted

[13] Maximum number of participants is set by the number of people that can simultaneously work hands-on in a lab.

promptly and created a series of interactive Facebook Live events (*Particle Land)* with INFN researchers, set an example of positive response. *Particle Land* started with a first Facebook Live event recorded from the INFN Frascati National Laboratories on March 5, before the general lockdown, and then switched to be live streamed from the researchers' home. Sixteen additional events, on different themes, were recorded from March 13 until June 3. The Particle Land videos reached up to 11.000 views (with a peak of 1.000 people online). In figure 7.10 we show the visualization of our videos during the *Particle Land* period, compared to previous months. Improvement is clear.

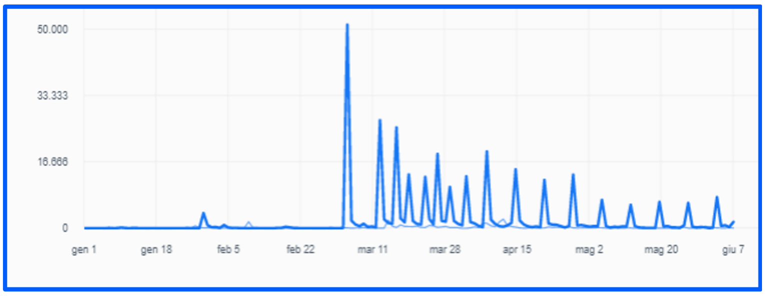


Figure 7.10 Minutes of visualization of INFN videos.
Period Jan.1-June 7 2020. *Particle Land* started on March 5.

Right after the general lockdown, we organized a few meetings of CC3M to reorganize our initiatives and answer society needs. In collaboration with teachers in our networks, it was decided to focus on activities for students. The rationale was that, while teachers were heavily involved in DaD (Digital didactic from remote) with little time for anything else, students of middle and high schools needed additional material for their assignment, and to fill in their schedule.

At first we started with a small group of people, working on the SxT (scienzapertutti) web site. SxT was already well known, and used by students as a place where they could find material for their homework. The first action was to clean an update the "Q&A" section, as several answers were obsolete (mainly the ones related to gravitational waves). In parallel we created a "COVID19 emergency" specific section: "A Scuola Con Voi" (ASCV, At School With You), in which we collected INFN material already existing on our platforms (for example as You Tube recordings), and produced texts/videos to complement/integrate as needed. ASCV is made of several paths: Elementary Particles, Gravitational Waves, Cosmic Rays, Relativity, Cosmology, and Particle Accelerators. Its aim is more pedagogical than the typical outreach, therefore we added exercises at different levels (to be used by pupils and teachers in preparation for the final examination). Most of the material went online during March/early April, and the number of visits/days went up from 3000 clicks/day to a stable 4,600 clicks/day (already 4,400 by April 8) (see figure 7.11).

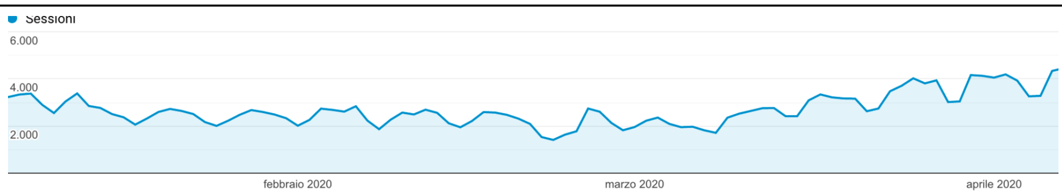


Figure 7.11. Sxt website: clicks/day, Jan.1-April 8 2020. Font: google analytics

As a side project, the INFN Fermi LAT Group developed its "Fermi Masterclass" into an online activity that can be used in different ways. Besides the physics aspects of the Gamma Astronomy, there are hands-on exercises on relativity and cosmic ray physics using *python* code. Programming in *pythons* can be, in turn, an exercise by itself. This was also signalled in the "*Italia Digitale"* initiative.

INFN does not have –as yet- activities specifically addressed to Middle School pupils, but we transformed several *Aggiornamenti* classes (aimed to their teachers), into Facebook/YouTube streaming for students. The philosophy of *Aggiornamenti:* hands-on activities, with cheap and safe material available at home, was indeed well suited for the lockdown period. There was a good response by various colleagues in producing adequate material. Although the series started only on April 8, we had more than 2,600 visualizations of the videos that now constitutes a channel by itself, advertised on social media as “Home Made Physics”.

After an initial phase, in which the other activities supported by CC3M were stopped, the Commission held a general meeting with all representatives in early April, in which we exchanged experiences, and options on how we could resume/transfor our work from remote. This discussion produced a response in essentially all initiatives, so for example, *Lab2Go* was transformed in an “@Home” activity, formally structured and recognized by participating High Schools. In a similar way *RadioLab* exploited existing data to perform remote analysis, *Art&Science* exhibitions moved to online etc.
A special approach was taken by *Inspyre* that had to cancel the stage for almost 100 students, and transformed itself into an online week-long series of lectures followed online by more than 170 students across Europe. LNF, after the success of this experience, created a whole month (April-May) of online conferences aimed to the general public (*Researchers@Home*), with a peak of more than 600 simultaneous participants, and almost 26,000 visualizations.
During Phase-II of the COVID19 emergency (i.e. after the end of the lockdown), we shifted towards producing material for the high-school end-of cycle test (dubbed “Maturità”). The special format of the test for 2020 was announced by the Ministry rather late (in mid-May, with exam to be held in mid-June), and the OCRA collaboration decided to produce a whole set of virtual laboratories (besides the already mentioned Fermi online Masterclasses) to be used by teachers and students in preparation for the orals. Their website now proposes a variety of exercises (in excel or python language) usable to understand special relativity, particle physics etc. by exploiting data collected from different apparatus (Cosmic Ray Cube in Toledo Metro Station, Fermi-LAT observatory in space, Auger in Argentina, etc.).
We cannot go through all initiative taken, but we would like we mention a spin-off of *Art&Science* aimed to primary school pupils: *Art&Science* kids. With the goal to bring science to the youngest, A&S created a contest started in March 2020 (during the lockdown), with a combination of YouTube streaming, online material, and social media publicity. There were three stages, with different themes and 242 drawings were made by pupils of 24 schools from 18 cities. Some of them are online on the website (https://artandscience.infn.it/edizione/edizione-kids/). The participation to this initiative was surprisingly high, as students from Primary Schools are not a usual target of our activities; more than 120 students were connected to the first interactive live YouTube event and a media of 80 students (among who also younger than those from primary schools) took part to the three events. The initiative will be certainly replicated, as that of the youngest students is one of the public we want to address.

Overall the first phase of the COVID19 emergency provided us with some positive feedbacks. First of all, there was reaction to the idea of “everything closes”, by using a combination of ingenuity, perseverance, and collaborative effort. Second, we acquired some technical expertise, and hands-on experience, in the area of virtual/streaming/remote activities that, before the COVID19 emergency, was limited –among us- to a few people[14]. This will certainly come to be handy in the future. Third, some of the activities discussed here, were part of INFN contribution to the MIUR initiative (managed by INDIRE, the Italian Educational Research Institute), of “*Portiamo la ricerca a Scuola!*”. This is a portal where online materials by all Italian research institutions are collected. The Institute participation was led by the Communication Office, and created a loosely connected network with other Research Organizations, another positive outcome. A series of live webinar hosting our

[14] Besides the case of OCRA (already discussed), for example, ASIMOV moved its Regional and final award ceremony, into virtual events locally organized, with a large participation of the public, and good media coverage.

researchers were also organized in collaboration with INDIRE, though the same portal. This collaboration with INDIRE and other Communication Offices was also the occasion to reorganize the INFN Communication Off YouTube Channel in order to make it useful both as a materials resource and as a live communication channel with ever new events, video interviews and comments at the intersection among science and other disciplines. A live event designed for Science Festivals and theatres (*The Universe in a Box*) was transformed on this occasion in a web event made of ten episodes, for the YouTube and Facebook channels. This made the INFN Communication Office YouTube channel subscribers increasing from 1200 to 3000 in one month.

7.4 Knowledge and Technology Transfer

The role of the KTT (Knowledge and Technology Transfer) is today globally recognized as one of the main instruments to increase the innovativeness and competitiveness of the economic community on the national and international market. More specifically, Research Organization, like INFN, play a crucial role in interconnecting the various fields of scientific researches to industrial and social innovation.

KTT processes and activities have always received high attention from INFN also in direct connection with its institutional research programs. Indeed, INFN structures and laboratories are constantly involved in generating new knowledge, both with respect to tangible technology and to intangible knowledge and assets, making the KTT process an intrinsic part of the INFN activities.

INFN is developing many KTT processes to became more efficient in supporting the innovation at local and national level. A specific management structure was organized during the last few years in order to be more efficient in scouting of new and frontier technologies and to implement a strategical plan in connection with other economical stakeholder strictly connected with INFN activities. The Comitato Nazionale per il Trasferimento Tecnologico (CNTT), the Technology Transfer Service (STT) and the Local Referents (LR) network are the committees that directly manage the coordination of the KTT activities, the managing of the Intelletual Properties (IP) and all the actions related to the scouting of ideas and the interconnection of INFN activities at local level. LR network is the fundamental instrument to connect and coordinate the INFN activities distributed through the Italian territory. New rules, guidelines and information tools were prepared in order to maximize the KTT INFN impacts on economical stakeholders and, more in general, with the Italian market.

The CNTT is also working to collect all the necessary information from the internal network to promote the INFN expertise in direct interaction with enterprises and in general with all the actors involved in innovation developments (companies, financial investor, etc.). A better internal communication and the definition of all the entry point for external partners on the technology transfer webpage (https://web.infn.it/TechTransfer/index.php/it/) was implemented. A global mapping of the INFN innovation capabilities was done and it now possible to have a direct access, for the external enterprises and investors, to all the technological portfolio of the institution. Future actions are now under development to better promote the TT activities and to inform external partners and collaborators on the various INFN TT programs.

Great care was devoted to organize, collect and valorize the cutting edge technology developped by INFN. The implementaion of a complete IP management was one of the main efforts made by CNTT during the last few years and impressive results were achieved as reported in Table 7.1. The definition of a renewed KTT strategy generates a net increase in the identification of the internally produced IP. Due to peculiar aspects connected with the IP generated by INFN, starting from the beginning of 2020 a patent authorized representative was hired. This is definitely an important asset allocated for STT that is now more efficient especially in the interaction with the research community that needs specialized support in the definition of the more important IP aspects.

The net increase in the IP protection indicated in the Table 7.1 could be considered as direct consequence of the training program developed by CNTT to increase awareness of the INFN researchers towards a more efficient approach to protect IP Rights. At the same time the increased support received by INFN researcher from the STT and RL strongly helps the finalization of the IP protection processes.

Metric	2011	2012	2013	2014	2015	2016	2017	2018	2019
Invention disclosures	5	7	20	24	21	10	23	14	11
Confidentiality Agreement	N/A	N/A	N/A	N/A	11	16	9	22	24
Priority applications filed (in Italy)	1	7	10	11	10	5	5	11	4
Patents application filed	1	7	15	19	25	14	10	24	25
Patents (both applications and patents issued) active at 31.12	5	10	20	59	63	71	81	103	122

Table 7.1. *Intellectual property management*

Also a great improvement in the license processes was obtained as shown in table 7.2, demonstrating that the INFN collaborations with enterprises were strengthened. This very important result is directly related with the great effort devoted to promote the INFN as very innovative Public

Metric	2011	2012	2013	2014	2015	2016	2017	2018
Licenses/options active at 31.12	3	3	6	6	10	14	17	14
Licenses granted to Italian enterprises	1	1	3	3	6	11	12	10
Licenses granted to EU enterprises	2	2	3	3	3	2	2	1
Licenses generating revenues in the year	0	2	3	3	4	9	5	6
Licenses linked to a patent	3	3	3	3	2	1	2	5

Table 7.2 *Licensing. Trend shows a stable growing of licensing.*

Research Institution, also confirmed by the excellent evaluation we received by many enterprises that collaborated with INFN during the R&D activities for fundamental physics experiment construction.

It is interesting to note that in table 7.2 the licenses capabilities of INFN had impact on various typology and also patents were acquired by enterprises to increase their business. We are defining a strategical approach that will guide future investments to optimize the patent selection and to strongly promote the IP produced by INFN at the international level.

The Proof of Concept program named R4I (Research for Innovation) was implemented to support research projects to became a real innovative products. The developed framework to analize and support new technologies proposed by INFN research groups was implemented in order to allow a direct link from basic research to the market, focusing the project in order to fullfill the market costraints. Analizing three year of R4I program we could evaluate the great and important impact that was obtained by such innovative program:

- Large part of the developed technologies were acquired by external company to generate products for the market
- New IP was generated and new applications not directly connected with INFN core activities were released
- Two Spinoff companies were recognised and financially supported by private investors.

INFN considers the R4I program a great success that allows a real KTT from foundamental reseach to innovative industrial products.

After the approval of the rules for INFN Spinoff in the 2017, some requests were sent to the CNTT. The adopted scheme was established to help new enterprises in establishing well suited technologies with a suitable business approach. We have actually approved two INFN Spinoff:

- Sibylla Biotech, a company that aims at developing biological numerical models able to efficiently study the protein evolution. This approach will strongly help in identify suitable drugs for specific human disease. During the COVID19 crisis, Sibylla Biotech with the support of the powerful computational infrastructure of INFN was able to reconstruct the

full sequence of the ACE2 protein that introduce the virus inside the human cells. This was an impressive result that no one in the world was able to reproduce and allow to identify few possible drugs to minimize the virus impact on patients: the studies are progressing with very interesting results. Sibylla Biotech was funded by a private venture capital company with few millions of euros to completely implements the adopted technology
- Dorian is a new company that uses the developed INFN research activities in the field of medical imaging to study brain disease, more specifically applied to Alzheimer disease. The implemented approach allows an advance screening of the population before the disease occurrence. Implemented analytical method was tested with great success on many specific clinical chases helping the identification of the specific brain disease. Dorian submitted few original patents and it is actually discussing the funds support from some investors.

The R2I program was dedicated to more mature technologies (i.e. technology that were patented or based on well controlled INFN know how), in collaboration with CERN, INFN organized a network to support startup enterprises that would like to adopt INFN and CERN technologies in Italy. Few companies were interested on well identified technology and with the help of selected incubators a KTT process was established. The evolution of the program is now under revision from INFN and CERN in order to better finalize the R2I activities.

To establish the real impact of INFN technology a survey analysis INFN partner companies was completed, demonstrating that collaboration with INFN has a positive impact on companies, above all on the intangible assets side. The main impact is on companies' image improvement, and in the acquisition of technical competencies. These results are extensively described in the article written by M. Dal Molin and E. Previtali published in the *Journal of Public Procurement* in September 2019.

In collaboration with M. Florio and P. Castelnovo of the University of Milano, a three-fold detailed analysis has been conducted on surveyed companies: i) a multiple case studies, ii) an econometric analysis and iii) a Bayesian Network analysis. Two relevant results emerged:

- a positive correlation exists between incremental sales volume and business development and acquisition of new clients, development of new products, improvement of market knowledge, improvement of company's reputation and image, acquisition of technical competencies and creation of new partnerships;
- the Bayesian network analysis shows that: i) a contractual relationship labelled as PPI favors the acquisition of technical knowledge, while the impact on the market does not depend from the type of procurement relationship; ii) the development of new products, as well as the acquisition of managerial competencies favor the business development of the company; iii) the acquisition of new clients is linked to the increase in revenues and iv) the fact that the business development favors both social impact and revenues' increase.

These results are confirmed by the case studies and are extensively described in an article submitted to *Technological Forecasting and Social Change*, written by P. Castelnovo and M. Dal Molin.

In collaboration with A. Piccaluga and D. Scarrà of the Scuola di Studi Superiori Sant'Anna di Pisa - School of Management, a qualitative study has been conducted, and 13 companies have been interviewed by using a structured protocol. Concerning the KTT process, the analysis demonstrated that having a frequent and close collaboration with the INFN is a powerful mechanism to transfer knowledge, technologies and technical capabilities. The overall major benefits are clearly visible with companies that have had a procurement relationship focused on customizing existing products or developing new ones. Positive impact, in fact, vary from innovation impact, market penetration, improved reputation and economic impact. The collaboration with INFN also leads to organizational innovation: due to the specific “time-requirements” asked by researchers, supplier company may adopt organizational innovation properly to answer to researchers’ time needs.

These findings have been presented to the *R&D Management Conference* in Paris and the related article, written by M. Dal Molin, D. Scarrà and V. Valsecchi was submitted to *The Journal of Technology Transfer*.

8 External Collaborations and Fund Raising

8.1 National competitive funding programmes

The European Strutcural and Investment Funds (ESIF) are the main financial instrument through which the European Union intends to reduce the economic and social gap in between the different regions and the backwardness of the less developed areas.

The ESIF mainly focus on 5 areas:

- research and innovation
- digital technologies
- supporting the low-carbon economy
- sustainable management of natural resources
- small businesses

The resources provided by these funds are distributed according to a seven-year programming; the negotiation process for the period 2021 - 2027 is currently underway.

The UE Cohesion Policy makes use of the ESIF funds and national and regional co-financing resources and provides the framework for the implementation of the Europe 2020 strategy which aims at smart, sustainable and inclusive growth in Europe.

The 2014-2020 programming has allocated more than 46.4 billion ESIF and Territorial Cooperation Funds to Italy. To these resources are added the national co-financing share and the resources allocated to complementary programmes, with a total budget for Cohesion Policy in Italy of more than 140 billion Euros.

The Operational Programmes are divided into two types:

- National Operational Programmes, managed by Central Administrations (in Italy by the Territorial Cohesion Agency and Ministries);
- the Regional Operational Programmes, managed by the Regional Administrations.

The National Operational Programmes provide for interventions and actions on transversal themes. The National Operational Programmes Research and Innovation is, for example, a multi-fund programme managed by the MUR that aims at strengthening research, technological development and innovation in the eight less developed and transition regions.

The Regional Operational Programmes, on the other hand, act on the priorities identified by the Regional Administrations in each Region and have as beneficiaries and recipients the territorial actors.

The INFN action can be defined as incisive on both types of Programmes, thanks to a professional, attentive and assiduous response to the Calls for Proposals of the various Ministries and of almost all the Regions and Autonomous Provinces. In June 2019, INFN signed the deeds of obligation for the start-up of the major projects for the strengthening of its Research Infrastructures, the projects are now being implemented for a value of almost 70 million Euros; at the end of 2019, the MIUR, with resources from the Development and Cohesion Fund (FSC), issued a related call for proposals for the strengthening of the human capital of the enhanced IR, INFN will activate, within the very first months of 2021, contracts for fellowships and research grants for a three-year period and for a total value of almost 5 million Euros.

The Institute is presently involved in a relevant commitment on two large research and technology transfer projects to be realised in the regions of Abruzzo and Sardinia with both public and private funding (projects ReSTART and Darkside-20k as described in CSN2 section).

During 2019, thanks to the CALL HUB of Regione Lombardia, two INFN projects have been financed: Pignoletto, full project value € 5,822,049.92 and INSpIRIT, full project value € 7,337,760 (Units of Milano Bicocca and Pavia).

Other active projects, on the various types of financing, can be found at the following link https://dbprogetti.dsi.infn.it/dbprogetti/listaProgettiFE

In the Smart Specialization Strategy, intended as a path in progress for the entire programming period, there is a constant participation of the Institute which, since 2019, has been a national stakeholder for the Strategy itself in the meetings promoted by the Territorial Cohesion Agency. In collaboration with the Agency for Territorial Cohesion an Agreement of Collaboration, aimed at strengthening regional and national innovative systems and developing collaborative activities between the research system and the industry system in line with the objectives of cohesion policy and with reference to research, technological development and innovation, is active.

With reference to the MIUR FISR 2018-2019 call for proposals, aimed at acquiring and selecting research projects of particular strategic importance, consistent with the National Research Programme 2015/2020 and addressed to the public actors of the national research system, the Institute has applied for 20 Projects referring to the different areas of the PNR (with particular focus on Health) and for a total value of € 25,244,912.

During 2019, the DFE took part in the work for the programming of the Cohesion Policy in Italy for the period 2021-2027, in the partnership debate organized at national level by the Department for Cohesion Policies of the Presidency of the Council. This action defined the perimeter, the modalities and the intensity of the intervention of the Cohesion Policy 2021 - 2027 and which will lead to the adoption of the Partnership Agreement between our Country and the European Commission. The INFN has contributed to the activities for Police Objective 1 with a specific document.

The complementarity of Community resources on a few priority themes needs a deep reflection on the development strategy that the Regions intend to implement and the Institute is actively involved in this process, both at central and peripheral level, with particular attention to Policy Objective 1 "A smarter Europe".

The new Community Programming cycle 2021 - 2027 is based on a smaller and more flexible set of objectives, which have been reduced from the 11 themes of the programming cycle 2014 - 2020 to the following 5 Policy Objectives and within which the Regions must identify their priorities, according to the different specific Objectives in which they are declined:

- PO 1 a smarter Europe through innovation, digitisation, economic transformation and support to SMEs;

- PO 2 a greener and carbon-free Europe through the implementation of the Paris agreement and investments in energy transition, renewable energies and the fight against climate change;
- PO 3 a more connected Europe with strategic transport and digital networks:
- PO 4 a more social Europe, achieving concrete results on the European pillar of social rights and supporting quality employment, education, skills, social inclusion and equitable access to health care;
- PO 5 a Europe closer to citizens through support for locally managed development strategies and sustainable urban development across the EU.

Other elements of innovation are greater openness to public debate, strengthening the integration of regional, EU and national policy, aiming at the highest possible concentration of resources.

In 2019 the eight Italian Competence Centres, promoted by the Italian Ministry of Economic Development and with the task of encouraging innovative activities by promoting the sharing of structures and the exchange of knowledge and skills between research and businesses, were also launched. The Competence Centres operate throughout Italy and have a technological connotation of specialization by "themes". The INFN, together with other public and private Institutions, participates in two of them:

- BI-REX with focus on BigData, IoT, Dimensional Control; equipped with a pilot line on Digital Capability Center, based in Bologna;
- SMACT, the Triveneto competence centre, focused on agri-food, clothing, furnishing and automation.

With its participation in BI-REX and SMACT, INFN further strengthens its commitment to making available to Italian companies the technological know-how developed with the frontier activities carried out in the field of research in fundamental physics and in the management and development of the enormous wealth of digital information collected from the distributed sensor networks, which underlie the industrial revolution in progress.

Further details can be found at https://home.infn.it/en/media-outreach/news/3454-competence-centre-partono-bi-rex-e-smact-2

At a national and regional level, INFN expresses relevant design skills with a high number of projects in collaboration with Universities, other Research Institutions and Companies, this confirms and gives value to the widespread network of relations of the Institute.

8.2 The Horizon 2020 Framework Programme

Horizon 2020 (H2020) is the Framework Program (FP) for research and innovation of the European Commission, with nearly €80 billion of funding available over 7 years (2014 to 2020). H2020 is part of the larger strategy Europe 2020, the European Union's long-term global design, which recognizes the challenges Europe is facing and proposes to address them properly: low growth, insufficient innovation and a diverse set of environmental and social challenges. Science and innovation are key factors that will help Europe to progress. And one of the main goal of H2020 is to bridge the gap between science, research and innovation communities and society at large by fostering more inclusive, anticipatory, open and responsive research and innovation systems.

H2020 sets out three strategic objectives: enhance and disseminate the excellence of basic research; maximize competitiveness and the impact on the production system; address major societal challenges; and is structured around three pillars that link directly to these objectives: Excellent Science, Industrial Leadership and Societal Challenges pillars.

Given the Mission of our Institute, it is clear that the first pillar ("Excellent Science") is what is easily able to attract INFN researchers' interests, more than the other two pillars ("Industrial Leadership" and "Societal Challenges"). However, the background of INFN is also full of success stories related to industrial cooperation (for example in the construction of the LHC detectors or computing infrastructures), and to positive spin-offs in production of public goods (for example in the areas of health, cultural heritage restoration and conservation, security, etc.).
The identification of large INFN infrastructure (e.g. the National Laboratories, CNAF, Tier1) as international structures, makes INFN a prime candidate for research infrastructure and *e-infrastructure* projects.

So far, in H2020, the Institute received about 58.6 M€ with 108 EU granted projects involving INFN, and 25 of those are coordinated by INFN teams. The INFN overall success rate in H2020, at present, is 17%, which is higher than the average success rate in H2020 of about 12%.
The total number of INFN granted projects for the different H2020 programmes is summarized in Table 9.1.

H2020 Sub -programme	*INFN granted projects*
European Research Council (ERC)	13
Marie Sklodowska Curie Actions (MSCA)	34
Future Emerging Technologies (FET)	11
Research Infrastructures (RI)	36
EIC- Fast Track to Innovation	1
Leadership in Enabling and Industrial Technologies (LEIT) - ICT	2
Societal Challenge 1 - Health	1
Societal Challenge 6 – Inclusive Society	1
Societal Challenge 7 - Security	1
Science with and for Society	1
Spreading excellence and widening participation	1
EURATOM	2
Joint Undetaking EuroHPC	1
Joint Undertaking Innovative Medicine Initiatives 2 (IMI2)	2
ERASMUS +	1
Research Funds for Coal and Steel (RFCS)	1

Table 8.1 - Number of european projects involving INFN by H2020 sub-programme and other programmes (2014-now).

Some considerations on the performance, focusing only on the last year (2019-2020), can be found in the following.

As expected, there was a strong participation to calls under the H2020 Excellent Science pillar and INFN improved the already good performances of the previous years.

For the MSCA (Marie Skłodowska Curie Actions), the Institute has 2 new granted projects in the action RISE (Research and Innovation Staff Exchange), both as Project Coordinator, and 3 granted projects in the action NIGHT 2020 (European Researchers Night 2020).

In the field of the action COFUND, in 2017 INFN obtained a major accomplishment, winning for the first time, a mono-beneficiary project co-financed by the EU Commission with 3.1M€, for the implementation of an innovative Fellowship Program, which will run for 5 years. In particular, the

Program is oriented to the mobility of researchers, with expected long stay (up to 1 year) in other national and international institutions, businesses and technological centers, industries. The Program offers 3 years fellowships to a total of 30 fellows.
The first call for proposal for the COFUND Fellowship Programme opened in June 2018, received 210 applications from candidates of 32 different nationalities. A second call for proposal opened in June 2019 received 231 application from candidates of 47 different nationalities.
The high number of application and nationalities shows the international attractivity of INFN and its COFUND Programme.

In the realm of the European Research Council (ERC), in the last year, INFN earned 1 Starting Grants, confirming the capacity to successfully apply to these very competitive calls. The evaluation process for the ERC Consolidator and Advanced is still on-going, so consideration on the INFN performances cannot be provided yet.

A very successful result was obtained in the Future and Emerging Technology (FET). INFN obtained 1 granted projects, CleanHME - Clean Energy from Hydrogen-Metal Systems, in the FET-PROACTIVE call and 1 approved project for the Third Phase of the H2020 FET FLAGSHIP Human Brain Project.

"Research Infrastructures and e-infrastructures" remains the area where INFN successfully presents many proposals, in particular in fields that are closest to its institutional activities.
The Institute's performance is well in line with expectations, with 4 new projects:

- FCCIS - Future Circular Collider Innovation Study
- IMPULSE - Integrated Management and reliable oPerations for User-based Laser Scientific Excellence
- AHEAD2020 - Integrated Activities for the High Energy Astrophysics Domain
- CREMLINplus- Connecting Russian and European Measures for Large-scale Research Infrastructures

selected for funding in the last year and a success rate on this specific programme confirmed to be about 50%.

A specific challenge was to enhance the low participation and success rates into in other H2020 pillars sub-programmes and other EU Initiatives of potential interest to INFN. It is important to point out that the quality of INFN research was not an issue. In these areas the change in nature and focus of R&I and the trend toward more application-oriented and interdisciplinary R&I of H2020 seems to have had an adverse effect on the competitiveness of submitted proposals.
Moreover, the difficulty to identify relevant calls for the Institute and, sometimes, the lack of critical mass or skills into properly writing of a proposal could be also considered as barriers for successful applications.

Following these considerations, the Institute started to put more effort into trying to increase the participation in other programmes and the quality of the proposals.

In the last year, we managed to increase our participation and performance on the H2020 sub-programmes other than the ones in the “Excellent Science” pillar and other EU programmes and Joint Undertaking (JU) European Initiative.
INFN obtained the following granted projects:

- IoTwins - Distributed Digital Twins for industrial SMEs: a big-data platform, in the ICT programme;
- LPT - Laser based Proton Therapy sysLPT – Laser based Proton Therapy system,

Harnessing High Intensity Lasers Physics for Cancer Treatment Proton Therapy in the European Innovation Council – Fast Track to Innovation programme
- EXSCALATE4CoV - EXaSCale smArt pLatform Against paThogEns for Corona Virus in the Societal Challenge Health Programme;
- 4CH- Competence Centre for the Conservation of Cultural Heritage in the Societal Challenge Inclusive, innovative and reflective Society programme. INFN is the Project EU Coordinator;
- DarkWave - Novel technologies for dark matter search and frontier astroparticle physics experiments in the Spreading Excellence and Widening Participation programme
- RED-SEA- Network Solution for Exascale Architectures in the JU EuroHPC
- HARMONY PLUS - Healthcare alliance for resourceful medicines offensive against neoplasms in hematology in the JU Innovative Medicine Initiatives 2 (IMI2)
- BLEMAB - BLast furnace stack density Estimation through on-line Muons ABsorption measurements in the Research Funds for Coal and Steel (RFCS) Programme

Regarding other EU initiative, at the end of 2018, INFN joined the QuantERA ERANET consortium as one of the Italian Funding Agency for the QuantERA transnational call in quantum technologies 2019. Response of INFN researchers in applying to this call was very high and with proposal of very high quality. And INFN obtained very successful results. Among the 12 proposals recommended for funding after the evaluation, 5 of them involve INFN teams. In 2 out of the 5 projects, INFN is the Coordinator Institute.

A mention deserves also the fact that other 5 INFN projects were ranked above the quality threshold, but there was no sufficient budget available for funding. Based on these very successful results, INFN decided to confirm its participation as Italian Funding Agency for the QuantERA 2 ERANET. The QuantERA 2 Consortium applied to the dedicates H2020 call for funding and approval of the ERANET by the European Commission. INFN will be leader of the Working Package dedicated to the cooperation with the Quantum Technologies (QT) EU Flagship and other stakeholders in QT, exploring the possibility of additional joint funding activities, spreading research excellence across the European Research Area and mapping public policies in QT research funding. The proposal for QuantERA 2 is under evaluation by the European Commission. The project will officially begin most probably by mid-2020.

In 2019 INFN also joined the ChistERA ERANET, a pathfinder programme for European coordinated research on future and emerging information and communication technologies, as Italian Funding Agency for the transnational call on Explainable Machine Learning-based Artificial Intelligence. Evaluation on the submitted projects is still on going, so it is not yet possible to make considerations on the results.

The H2020 Programme is very close to end but many projects are still under evaluation so there will be still good opportunities for INFN to succeed and to increase more its performances on the Programme.

A final consideration regards the process for the preparation of the next EU Framework Programmes (2021-2027), which started in 2018. During the last year INFN increased its active participation to national and international discussions and consultations on the EU Programmes preparation process, in particular for the next R&I Programme, Horizon Europe and for the Digital Europe Programme - focused on digital technologies, supercomputing, artificial intelligence - through contributions at the on-going discussion, together with main EU stakeholders and the Italian and EU institutions, answers to national and EU consultations and high-level networking.

8.3 Current organization of External Fund Raising Support Group (DFE)

INFN is organized with a dedicated internal Fund Rising support service since 2008. Organization and targets of this service have been changed since then to accomplish an ever-growing strategic role of External Funds in the research activities of our organization. Together with setting the infrastructure, INFN management tried to drive a cultural change, creating more awareness (within our community) about the potential of our activity, and the way to describe our research objectives, in terms of projects. The cornerstone of this translational work is an educational program with the objective to inform about the different funding instruments in H2020, and to assist researchers to structure their projects in the most appropriate way.

To optimize its relations with the European Commission and with other public and private stakeholders that spin around it, INFN also opened an Office in Brussels with a staff permanently in residence.

The last reorganization of the External Funds service has been set up in december 2018 with the creation of the External Fund Division of the INFN Central Administration. Characteristics of the new Division are:

- a new structure organized with offices with well defined tasks, offices and a new director;
- definition, acquisition and development of new management software tools;
- increase of human resources assigned to external funds division activities with the recruitment of personnel with consolidated experience in the field of international/national/regional grant application design, scouting of the competences, and cooperation with the authorities in the calls definition;
- organized information flow with and from the relevant stakeholders (scientists, financial officers, external offices, etc.);
- particular attention in the organization of personnel permanent training in the field of scientific fund raising and fund management.

Currently the External Funds Division (DFE) is organized with 4 areas dedicated to:

1. Pre-award National Support;
2. Pre-award International Support;
3. Financial Management Support;
4. Norms and IT Support.

Within these areas are currently employed 12 full time staff (plus 2 positions already assigned, the selection to be completed within the next 2 months), and 7 collaborators, full time staff in various Infn Units, who work for part of their time with the DFE and who are a natural link between the local Infn Units and the DFE.

9. Engagement in Higher Education

9.1 Students and Graduate training

The training of graduate students and young researchers is one of the missions of INFN and great efforts and resourses are devoted to it. A large number of INFN researchers supervise high-level training activities, with the involvement of both INFN staff and University staff associated to INFN research projects for science and technology. A first indicator is represented by the number of students trained during their thesis work in the INFN labs located either in the INFN national laboratories, centers, or in the Sezioni placed in University buildings. These theses have been completed in connection with INFN scientific activities, either experimental or theoretical, associated with the different Scientific Commissions. Table 9.1 illustrates the number of theses denoted Bachelor ("Laurea"), Master ("Magistralis"), and Doctorate ("Dottorato di Ricerca"), respectively, completed in 2019 in Italian Universities or higher educational centers and related to projects supported by INFN. The theses are subdivided into the different Scientific Commissions. The 2nd- level degree is most important for the training of Highly Qualified personnel in the specific fields related to the INFN activities, before the students eventually enroll further into doctorate (Ph.D.) programs. The figures in parenthesis refer to the previous year (2018). The grand total of thesis completed in 2019 is sitill increasing with respect to previous years, as shown in Figure 9.1

	CSN1	CSN2	CSN3	CSN4	CSN5	TOTAL
Bachelor	**57**	**37**	**42**	**127**	**34**	**297** (252)
Master	**63**	**56**	**39**	**145**	**61**	**364** (371)
Doctorate	**30**	**20**	**19**	**61**	**25**	**155** (143)
Total	**150** (127)	**113** (90)	**100 (91)**	**333**(346)	**120**(112)	**816** (766)

Table 9.1 - Number of students that completed their University Theses in INFN research programs in 2019. In parenthesis a comparison with the numbers of 2018.

The volume of training students that complete their thesis work at INFN structures is compared in Table 9.2 with the corresponding total number of theses completed in physics courses in all Italian Universities. This last information is provided every year in the on-line database by the Ministry of Education, University and Research (MIUR).

The comparison shows that more that one thesis out of three in physics is supervised in INFN Labs, centers or structures, or within research projects co-founded by INFN. The data by MIUR have a delay of one year with respect to the data collected by INFN and for this reason in Tab. 9.2 the most recent data given by MIUR refer to 2018 for all the II-

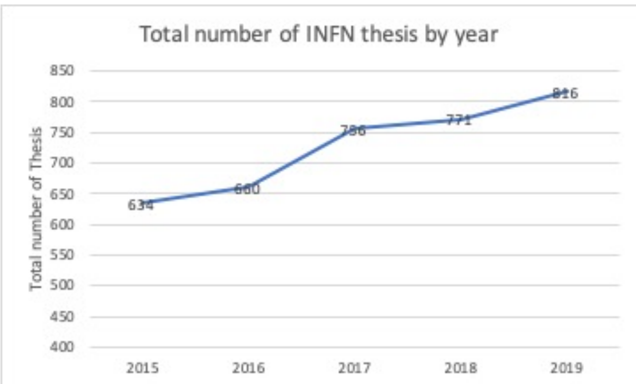


Figure 9.1 - Total number of INFN Thesis (Bachelor, Master, Doctorate) by year.

level theses (left hand side of the table), and for the Ph.D theses (right hand side).

Year	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**
INFN	371	333	287	278	327	298	372	386	143	155	134	129	133	153	173	174
Physics (Italy)	1009	1010	1012	984	1023	978	821	848	405	420	401	428	452	449	438	398

Table 9.2 - Comparison of theses carried out within INFN activities, with respect to previous years and with respect the total in Physics (data from MIUR, Ufficio Statistica).

The Institute provides also fellowships to students at various levels of their careers, and we focus here in particular to the higher-level positions, the doctoral and post-doctoral fellowships (see Table 9.3). Typically, the Ph. D fellowships are for three years, and the post-doctoral fellowships for foreigners are issued to attract highly qualified young researchers from all over the world, to do experimental and theoretical research in INFN structures for two years.

In 2019, as was for the year before, 15 post-doctoral fellowships (of a total of 34) have been made particularly attractive (in terms of salary, benefits and contract extension to 3 years) to stimulate the incoming mobility of excellence young scientists. This special training project, named FELLINI, is an international incoming mobility fellowship programme for experienced researchers which is co-financed by the European Commission through the Marie Sklodowska-Curie COFUND Action. The remaining post-doctoral fellowships (Assegni di Ricerca) are 190. These fellowships are issued directly by the Institute and may be co-funded also by other institutions. In addition, INFN also subsidizes indirectly University Fellowships with the same co-funding scheme.

INFN participates in the management of the Doctoral School in Accelerator Physics, in collaboration with the University of Rome “La Sapienza”, and subsidized additional 6 Ph.D Fellowships in this field. This doctoral school plays a key role in training and fostering young scientist in this strategic sector for INFN.

INFN fosters excellence also by awarding annual prizes to the best PhD theses. The selections of the two best PhD theses are done within each national scientific committe. The awards are named after eminent Italian scientists of the past (Conversi for experimental physics at accelerators, Rossi for astro-particle physics, Villi for nuclear physics, Fubini for theoretical physics, Resmini for instrumentation development, Giulia Vita Finzi for scientific computing).

INFN FELLOWSHIPS	#
Ph.D Fellowships	61
Post-Doc (Incoming mobility)	34
INFN Post-Doc also for Italians	190

Table 9.3 -Number of fellowships and Post-Doc positions by INFN in 2019.

9.2 Post-graduate training

Concerning the activity for post-graduate education, INFN organizes schools at various levels for training students, young researchers and highly qualified personnel. Many INFN scientists and technologists are involved in the organization of schools, in teaching university courses (doctorate, masters etc.) and in a variety of training activities. Some of the schools organized by INFN staff members are listed in table 9.4.

Name of school	Location
XI Edition Efficient Scientific Computing Bertinoro	Bertinoro (INFN-PD-BO)
Laces 2019 - Lezioni Avanzate di Campi E Stringhe	GGI Arcetri (FI)
SFT 2019 - Lectures on Statistical Field Theories	GGI Arcetri (FI)
GGI lectures on the theory of fundamental interactions 2019	GGI Arcetri (FI)
Frontiers in Nuclear and Hadronic Physics 2019	GGI Arcetri (FI)
Theoretical Aspects of Astroparticle Physics, Cosmology and Gravitation 2019	GGI Arcetri (FI)
SOSC 2019 Third International School on Open Science Cloud	Bologna (INFN-CNAF-PG)
ComplexityErice2019	Erice (INFN-CT)
Summer School in Nuclear Physics and Technologies	Ferrara (INFN-FE)
XVI Seminar on Software for Nuclear, Subnuclear and Applied Physics	Alghero (INFN-CA)
VIII International Course "Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics"	Legnaro (INFN-PD-LNL)
Rewriting nuclear physics textbooks: one more step forward	Pisa (INFN-PI)

Table 9.4 - List of some of the schools organized (or co-organized) by INFN for students, young researchers and professionals, in 2019. The total number of participants is approximately 600.

APPENDIX A: **Detailed LNF MAP**

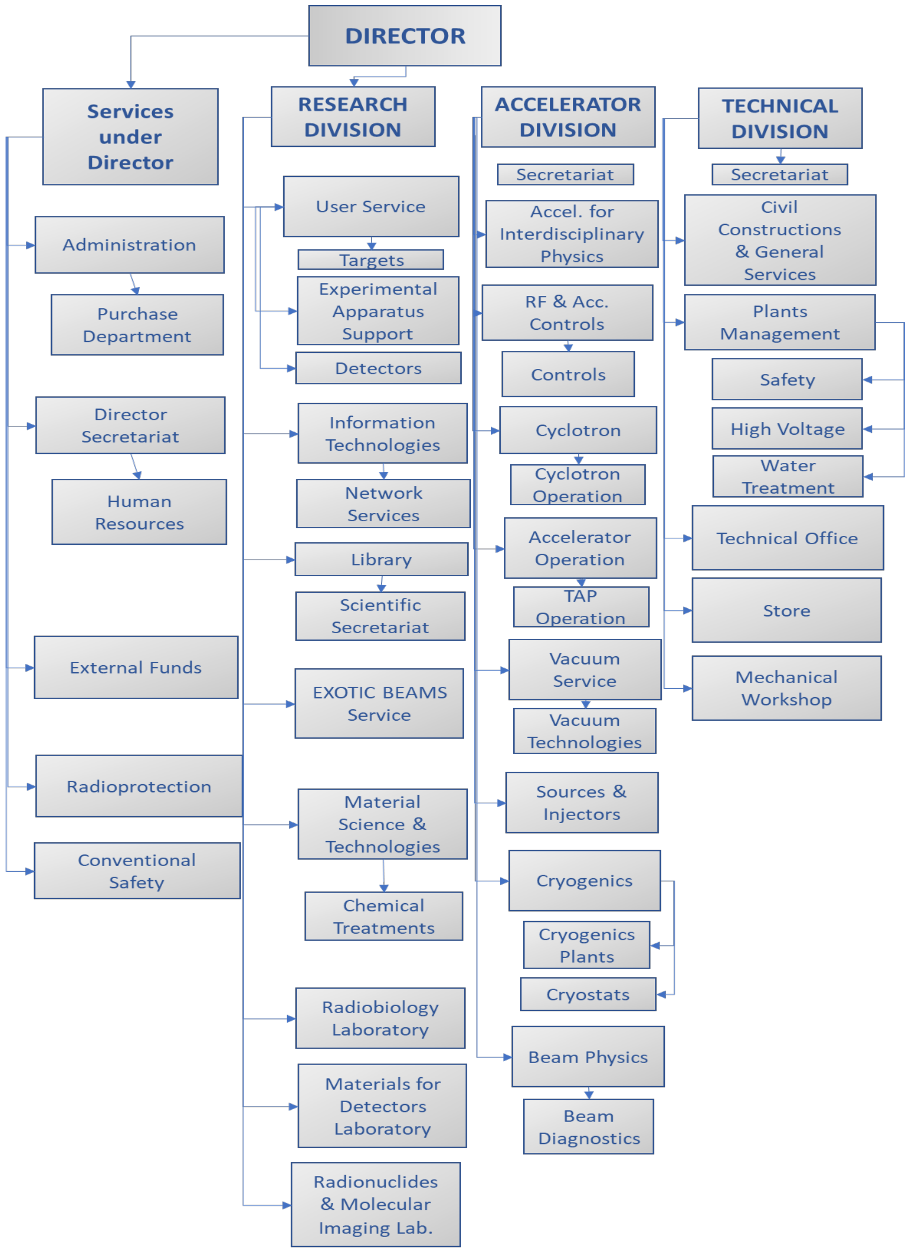
APPENDIX B: LNS Accelerators operation time (9months/year)

Superconducting Cyclotron yearly capability		
Total hours scheduled for operation	(hrs)	5830
Total hours scheduled for user-op	(hrs)	3945
Total hours realised for user-op	(hrs)	3850
Total down-time for user-op	(hrs)	100
Users Efficiency	(%)	98
Number of user groups	(n)	31
Total hours scheduled for Physics	(hrs)	1790
Total hours realised for Physics	(hrs)	1790
Total down-time for Physics	(hrs)	0
Efficiency for Physics	(%)	100
Number of physics groups	(n)	6
Tandem yearly capability		
Total hours scheduled for operation	(hrs)	4050
Total hours scheduled for user-op	(hrs)	2690
Total hours realised for user-op	(hrs)	2690
Total down-time for user-op	(hrs)	0
Users Efficiency	(%)	100
Number of user groups	(n)	11
Total hours scheduled for Physics	(hrs)	2150
Total hours realised for Physics	(hrs)	2150
Total down-time for Physics	(hrs)	0
Efficiency for Physics	(%)	100
Number of physics groups	(n)	7

APPENDIX C: LNL Accelerators operations in 2019

INFN-LNL Accelerators Operation		TAP	CN	AN2000
Year 2019	**Unit**	**Num.**	**Num.**	**Num.**
Total hours requested for user-op	h	5472	1392	912
Total hours scheduled for user-op	h	1172	1392	912
Total hours provided for user-op	**h**	**1017**	**924**	**873**
Total down-time for user-op	h	155	468	39
Users Efficiency	%	87	66	96
Number of user groups	#	7	11	14
Number of user groups (Basic Nuclear Physics)	#	5	2	0
Number of user groups (Applied Nuclear Physics)	#	2	9	14
Total hours requested for Basic Nuclear Physics	h	5016	320	0
Total hours scheduled for Basic Nuclear Physics	h	1052	320	0
Total hours provided for Basic Nuclear Physics	**h**	**993**	**76**	**0**
Total down-time for Basic Nuclear Physics	h	59	244	0
Efficiency for Basic Nuclear Physics	%	94	24	-
Total hours requested for Applied Nuclear Physics	h	456	1072	912
Total hours scheduled for Applied Nuclear Physics	h	120	1072	912
Total hours provided for Applied Nuclear Physics	**h**	**24**	**848**	**873**
Total down-time for Applied Nuclear Physics	h	96	224	39
Efficiency for Applied Nuclear Physics	%	20	79	96

APPENDIX D: LNL Organizational Chart



APPENDIX E: Experiments at LNL in 2019

Approved experiments at the Tandem-ALPI-PIAVE in 2019

n.	Acronym	Title	Spokesperson	Institution	Accelerator	Scientific group
PAC09	**CoulexXe**	Shapes of 0^+ States and Collectivity in ^{130}Xe for Studies of ^{130}Te ββ-decay	Napiorkowski Pawel	Heavy Ion Laboratory, University of Warsaw	PIAVE+ ALPI	**III**
PAC 12	**FastICtest**	A Fast Ionization chamber for the Z-identification for the future transfer …	Colucci Giulia	University of Padova	Tandem-XTU	**III**
PAC13	**i-GEAR**	Cataclysmic binary systems: studying the astrophysical ^{34}Cl(p,gamma)^{35}Ar …	HadynskaKlek Katarzyna	Heavy Ion Laboratory, University of Warsaw	PIAVE+ ALPI	**III**
PAC14	**ISO-LIGHT**	Isospin and clustering effects in the decay of light excited nuclei formed in central reactions	Bruno Mauro	University of Bologna	PIAVE+ ALPI	**III**
PAC22	**SmMg4nW**	Lifetime measurement of 2^+_1 states of W isotopes	Werner Volker	Technische Universität Darmstadt	PIAVE+ ALPI	**III**

Approved experiments carried out at the CN accelerator in 2019

Acronym	Title	Spokesperson	Institution	Scientific group
QDSN	Quantification of Doping processes in Nano-Structures	De Salvador Davide	UNIPD DFA and INFN LNL	V
BELINA	measurement of Maxwell-Boltzmann neutron spectra at kT=30 keV	Mastinu Pierfrancesco	INFN-LNL	III
ETHICSRADIUM	Pre-clinical experimental and theoretical studies to improve treatment and protection by charged particles: radiobiology of targeted radionuclide therapy and hadrontherapy-generated light fragments	Manti Lorenzo	University of Naples Federico II	V
n-TOF	Measurement of the 7Li(p,n)7Be reaction cross section in the double value energy region	Martin Hernandez Guido	CEADEN	III
RADAR	RADiationhARdness and property modulation of superconducting and oxide materials by means of proton and light-ion irradiations	Gozzelino Laura	Politecnico di Torino DISAT and INFN Sez Torino Italy	V
RREACT	Radiation Effects on Innovative Electronic and Optoelectronic Devices	Gerardin Simone	DEI Padova University and INFN PD	V
ARCHIMEDE-CN	ARCHItects of Materials and Enhanced Devices	Rigato Valentino	INFN LNL	V
DiaFab	Diamond microfabrication with ion beam lithography	Picollo Federico	INFN section of Torino University of Torino	V
GRIT-PSA	In-beam commissioning of the new DSSD TRACE detectors	Duenas Jose	University of Huelva	V
UNIPI-CR39	Proton irradiation of CR39 dosemeters	Ciolini Riccardo	University of Pisa	V
BEAT-PRO	Novelrecoilprotonspectrometer	Silva Bortolussi	University of Pavia	V

Approved experiments carried out at the AN2000 accelerator in 2019

Acronym	Title	Spokesperson	Institution	Scientific group
ALCHIMIA	Analysis of Light and CHarge Induced by Micro Ion beAms	Re Alessandro	University of Torino and INFN Torino	V
ASIDI	Advances in Single Ion Deterministic Irradiation	RIGATO Valentino	INFN-LNL	V
COMIBEAT-CIEMAT	Contaminant Migration in radioactive waste repositories by Ion Beam Techniques	ALONSO URSULA	CIEMAT	V
DiaFab	Diamond microfabrication with ion beam lithography	Picollo Federico	University of Torino and INFN section of Torino	V
E-PLATE	Electrostatic Powder pLating for Accelerator TargEts	Skliarova Hanna	INFN-LNL	V
GEO-PD	Migmatitic xenoliths from the Euganean Hills (northern Italy): protolith of the Permian magmatism in the southern eastern Alps	Mazzoli Claudio	University of Padova	V
HCCC	Halo Collimation through Channeling in Crystals HCCC	De Salvador Davide	UNIPD Physics and Astronomy Dept and INFN LNL	V
LTUSS	Nanomaterials for Energy	Vomiero Alberto	Lulea University of Technology	V
MEDEA	Sources and dynamics of the MEDitErranean Aerosol in two distinct locations of southern Europe	Tositti Laura	Universita di Bologna	V
QDSN	Quantification of Doping processes in Nano-Structures	De Salvador Davide	UNIPD DFA and INFN LNL	V

APPENDIX F: Recommendations from the CVI report 2019

CA-1. Adopt a multi-year (three years) budgetary plan.
CA-2. Start the survey on service satisfaction of Administrative services, and use it in a quality assurance PCDA frame.

CSN1-1. Closely watch the schedule of LHC Phase I upgrade projects. Push for critical reviews and realistic schedules. Try to mitigate the impact of delays on the construction of the coming Phase II projects.
CSN1-2. Further develop good indicators to quantify INFN contributions to large international experiments and put them in context of relevant examples.

CSN2.1 INFN/LNGS should require a full-blown technical design report (TDR) for DarkSide20 and conduct a scientific/technical review of the TDR. This review should be followed by a full-fledged cost and schedule review.
CSN2.2 INFN should start an organized process of down-selecting the new initiatives in CSN2.

CSN3-1: Support travelling experimental setups to maximize capabilities of Italian National Labs, e.g., give high priority to AGATA@LNL experiments starting in 2021.
CSN3-2: Support the PANDORA project at LNS since it will add a unique research capability, and define a local operating group including experimental nuclear (astro) physicists.

CSN4-1. There are currently about 35 IS. The CVI report for 2020 should focus on the changes instituted in the IS programme and the rationale for those changes.
CSN4-2. The INFN should present bibliometric information for the associatesand employees separately. *CSN5.1.* Describe the criteria used to allocate resources among the three active CSN5 programs: Standard proposals, Calls for Proposals, and Grants for Young Researchers.

CSN5.2. Review and explain the criteria developed to evaluate the success of the two newer funding schemes: “Calls for Proposals: and “Grants for Young Researchers.”

TT.1. INFN should consider launching a medium-term comprehensive review of its Knowledge and Technology Transfer activities that would lead to a final report in 2021. Proper attention should be given to TT for both economic and social purposes.

CH.1. Explore opportunities for the management of IP of instrumentation, with the Technology Transfer organization in INFN (National committee, Technology Transfer Service, and Local Referents).

LNF-1. INFN should give strong support to EuPRAXIA and EuPRAXIA@SPARC_LAB

LNS-1: Communicate a detailed shutdown-plan as soon as possible to staff and users.

LNS-2: Define a local PANDORA group that operates the device on a day-to-day basis.

LNGS-1. We strongly support the LNGS requirement that DAMA/LIBRA sustain a formal review of a CDR and TDR for it to continue.

LNGS-2. (Repeated from 2018) The laboratory should set up a stepwise “gateway” process for approving and supporting proposed new experiments and upgrades, going beyond assessment of the physics potential to make sure the safety issues and impact on LNGS resources are understood and covered.

LNL-1: Include funding for the dual-energy upgrade of the cyclotron in the upcoming budget plans to enable experiments at both ports with different energies and maximize the research output.

LNL-2: Provide an updated SPES schedule in midterm report and develop a plan how to move technical personnel temporarily to ensure a timely SPES completion and operation of AGATA at LNL starting in Q2/2021.

ET 1. We encourage the INFN to facilitate the full qualification of the Sardinian site for the Einstein Telescope.