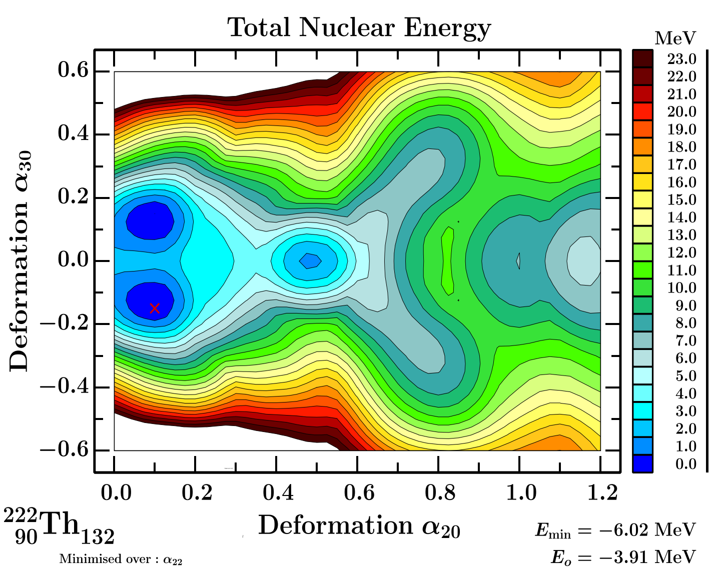
EURO-LABS Newsletter

ISSUE No.2 | JULY 2024

The Students of the ATSOA school at CERN June 2-7, 2024



Contour plot of the energy of ^{222}Th as function of quadrupole and octupole deformation parameters.

EDITORIAL

M.J.G. BORGE, CSIC
B. PEZZOTTA, INFN

HIGHLIGHTS

- **ATSOA** (Advanced Training School on Operation of Accelerators): CERN, June 2024

UPCOMING EVENTS:

- Advanced Training: Open Science and Data Management school in November 2024 in Germany
- **TAM MEETING**: CERN, October 28th - 30th 2024

CONTENT

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101057511.

EDITORIAL

M.J.G. Borge and B. Pezzotta
For the EURO-LABS Team

Dear readers,

The second edition of the EURO-LABS Newsletters continues providing news about interesting activities from EURO-LABS. In this issue the topics range from a new platform for theoretical tools (Theo4Exp), the commissioning of a new accelerator machine learning toolkit and a detector development for LHC, to FAIR data and some recent physics highlights, and apart from news on recent and upcoming events.

In recent years, the nuclear scientific community has increasingly embraced open science principles, including open access publications, and enhanced accessibility to experimental data and codes. One such significant advancement is the Theo4Exp virtual access facility, which aims to democratize access to advanced nuclear structure and reaction calculations to facilitate global collaboration and innovation in nuclear research.

Low Gain Avalanche Detectors (LGADs) are an innovative type of particle sensor with internal gain, poised to play a crucial role in the timing detectors for ATLAS and CMS experiments at the High Luminosity Large Hadron Collider (HL-LHC). These sensors, with time resolutions below 50 picoseconds are essential for resolving the high pile-up conditions expected with the coming increase in intensity at HL-LHC and also for precise time measurements. Ongoing advancements in LGAD technology focus on enhancing radiation hardness and improving sensor fill factors, ensuring their robust performance in the demanding HL-LHC environment.

Maximizing operational efficiency in accelerator laboratories is crucial to ensure optimal use of beam time for experiments. To this aim, a new machine learning toolkit called the Generic Optimization Framework and Front-End (Geoff) has been developed at CERN. Geoff is designed to integrate a wide range of optimization algorithms without the limitations of previous systems, leveraging the extensive Python ecosystem for flexibility and ease of use. Geoff's success at both CERN and GSI highlights its potential to become a standard.

The Fireball collaboration, led by Prof. Gianluca Gregori from the University of Oxford, has successfully recreated astrophysical jets of matter and antimatter at CERN's HiRadMat facility. This groundbreaking experiment aims to replicate the relativistic jets observed in black holes and neutron stars, which are believed to contain plasmas of electron-positron pairs. Utilizing high-intensity proton beams from CERN's Super Proton Synchrotron, the team generated over ten trillion electron-positron pairs, surpassing previous efforts and achieving the necessary conditions to sustain a plasma. These laboratory experiments provide crucial insights into the microphysics of astrophysical jets, bridging the gap

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EDITORIAL

between astronomical observations and computer simulations.

Proton therapy, a cutting-edge cancer treatment that uses proton beams instead of X-rays, offers unparalleled precision in targeting tumors, particularly in sensitive areas like the brain and spinal cord. To enhance the accuracy of this therapy, a Spanish research collaboration has developed a new proton CT scanner. This innovative scanner, characterized at the CCB proton therapy centre in Krakow used Double-Sided Silicon-Strip Detectors (DSSD) and a scintillator calorimeter to produce high-quality images and accurate proton relative stopping power (RSP) maps. The advanced imaging capabilities of this scanner prototype promise to improve treatment planning and outcomes for proton therapy patients.

The INFN Legnaro National Laboratories (LNL) have embarked on a significant milestone with the restarting of their cyclotron, a crucial component of the Selective Production of Exotic Species (SPES) project. This state-of-the-art cyclotron, capable of accelerating protons to 70 MeV with currents up to 750 µA, serves as the primary beam source for producing radioisotopes used in various experiments. In the last months of 2023, LNL initiated the re-commissioning of the cyclotron, a complex process that involved meticulous inspection and maintenance of all components, retuning of RF amplifiers, conditioning of the resonant cavities, and upgrading the control system to ensure safe operation.

The Advanced Training School on Operation of Accelerators (ATSOA) took place at CERN in Geneva, Switzerland, from June 3rd -7th , 2024. This intensive program selected eighteen students to engage in hands-on activities across three key facilities: CLEAR (accelerating electrons), PSBooster (accelerating protons), and ISOLDE (accelerating heavy ions). The course included introductory lessons on CERN accelerators, high-energy electron beams, and accelerator and beam dynamics. This was followed by practical sessions, to gain gaining direct experience in operating and optimizing accelerator systems. These activities provided valuable insights and essential skills and knowledge to the participants for their future careers in particle physics.

Exciting events are on the horizon for the European scientific community.

With the goal of catalyzing the future of Science with collaboration and Open Access, The EURO-LABS Advanced Training on Open Science and Data Management will be held from November 24th -29th , 2024, at Castle Ebernburg, Germany.

Maria J.G. Borge and Barbara Pezzotta
For the EURO-LABS team

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EURO-LABS THIRD ANNUAL MEETING

The 3rd Annual Meeting of the EURO-LABS will take place at **CERN from October 28th to 30th, 2024.**

The event will feature updates on the project's status, activities, progress on service improvements, as well as highlights from user experiments conducted at participating facilities.

Information on the event is available at https://indico.cern.ch/e/euro-labs-tam and EURO-LABS - Annual Meetings

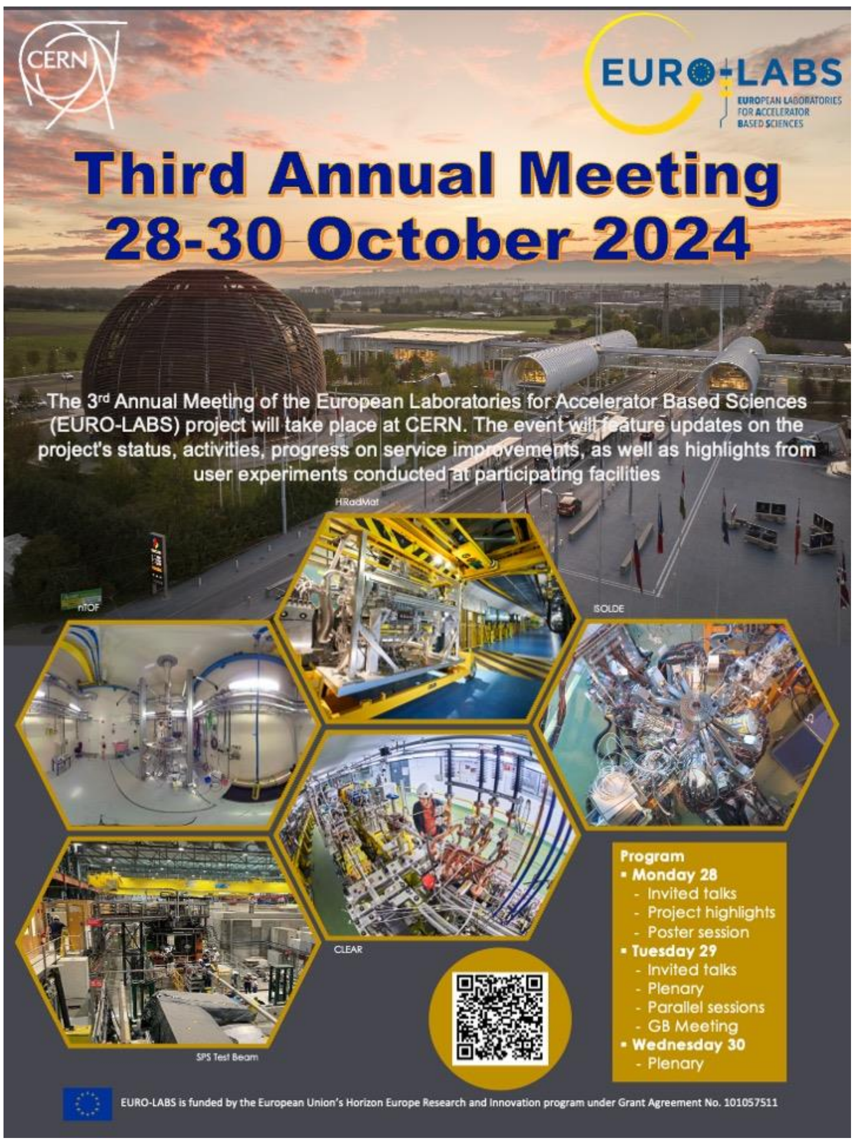

Figure 1: EURO-LABS 3rd Annual Meeting announcement

EURO-LABS Advanced training: Open science and data management | 24TH -29TH November 2024

Open Science is the practice of making scientific research output openly available in the form of data, software, publications, hardware and infrastructure. This promotes transparency, collaboration, and reproducibility in research, as well as wider access to knowledge for the public and to researchers.

Open Science represents an opportunity for the society at large and in particular for the physics community to improve the management and use of the large data sets produced in accelerator facilities around Europe and foster new collaborations. As a goal towards Open Science physics, the development of suited data workflow that could be shared among the physics European facilities would represent a major step forward. The data produced in these facilities should follow the F.A.I.R. principles (Findable, Accessible, Interoperable and Reusable) to ensure long term storage and possible future use by the community. The goal of the Advanced Training course is to convey basic principles and to demonstrate commonly used tools to achieve this goal successfully.
The Advanced Training will take place at castle Ebernburg (Germany) in the week 24.-29. November 2024.
The training will include lectures from experts. A visit is planned to visit the GSI Helmholtzzentrum für Schwerionenforschung and FAIR (Facility for Antiproton and Ion Research, presently under construction) in Darmstadt. This will give the participants an opportunity to see the accelerator facility as well as the FAIR construction site, to experience the “insides” of a large nuclear physics infrastructure.

List of confirmed lecturers and topics:

- Antoine Lemasson (CNRS - GANIL) – Introduction to Open Science
- Florian Uhlig (GSI) – Tools for sustainable programming
- Ozlem Ozkan (Helmholtz Metadata Collaboration) – Metadata for beginners
- Johan Messchendorp (FAIR) – European infrastructures for Open Science
- Clemens Lange (PSI) – Open Science in HEP
- Adrien Matta (LPC Caen - CNRS) and Jérémie Dudouet (IP2I Lyon - CNRS) – Hands-on data challenges
- Kathrin Göbel (GSI) – Open technology transfer
- Local organizers: Andrew Mistry (GSI/FAIR), Christine Hornung (GSI), Gerhard Burau (HGS-HIRe)

Application deadline: 29/09/2024

Information and registration:
Email: euro-labs-school@gsi.de
Website: https://indico.gsi.de/event/19808/

Venue and travel: Castle Ebernburg (https://ebernburg.de/) in Bad Kreuznach close to Frankfurt am Main, Germany, and can be reached by train

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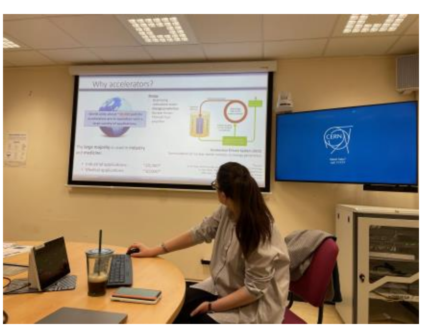
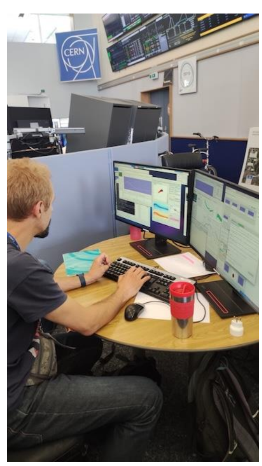
ATSOA (Advanced Training School on Operation of Accelerators)

The advanced training school took place at CERN, Geneva, Switzerland, June 3rd – 7th, 2024 https://indico.cern.ch/event/1357293/. Eighteen students were selected to realize hands-on activities in three facilities at CERN: CLEAR (accelerating electrons), PSBooster (accelerating protons) and ISOLDE (accelerating heavy ions).

The course had introductory lessons on Monday and Wednesday morning. It started with an overview of the CERN accelerators given by the local organizer Ilias Efthymiopoulos followed by an introduction to the High-energy electron beams and the CLEAR facility given by its leader Roberto Corsini. Subsequently a very didactic and complete introduction to accelerator and beam dynamics was developed by Foteini Asvesta. In the post lunch session, the students organized themselves in three groups of six trainees spreading out in the three different facilities. The hands-on activitieswere coordinated by Roberto Corsini and Pierre Korysko for CLEAR, Alberto Rodríguez and Miguel Lozano for ISOLDE and Foteini Asvestas and Tirsi Prebibaj for the PSbooster. The introduction on accelerators and beam design simulation and tracking were done Wednesday morning and given by Foteini Asvestas and Tirsi Prebibaj, respectively. Friday afternoon the students gave presentation about their interest and their take home message.

The hands-on session at CLEAR started with a visit of the accelerator tunnel, the klystron gallery, the CLIC showroom and the CLEAR control room. The students then worked together to start the electron beam following the instructions given by Pierre Korysko. The first step was to check that all the tools for controls were open and all magnets were powered. The students had to open the vacuum valve and the laser shutter to generate electrons and transport them in the accelerating structures. The next step was to start the CLEAR klystrons and optimize their





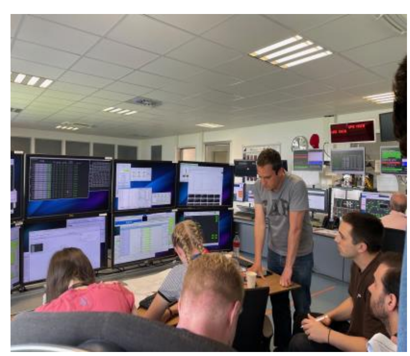


Figure 2: (Left) Foteini giving the introductory course. (Center) Student at CCC. (Right)Students at the ISOLDE control room.

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ATSOA (Advanced Training School on Operation of Accelerators)

phases to obtain the nominal energy for the CLEAR electrons. When the students were comfortable with the tools, they successfully achieved a list of actions including transport and alignment of the beam from the electron gun, measure the beam energy with the spectrometer line, thus operating the accelerator from start to finish.

Each team was assigned a workstation and supervised by Tirsi and Foteini. The students were introduced to the basic operational applications and how to control and measure the beam intensity, beam emittance and the injection system (injection bump, foil crossing). Once the basics were mastered, students were given a series of progressively challenging tasks: Generate a beam with specific characteristics (intensity, emittances), optimization of the tunes throughout the PSB cycle. Bunching and debunking the beam by adjusting the RF settings,…etc. Additionally, students were encouraged to investigate other beam dynamics effects based on their interest. All activities were logged in the PSB logbook.

The training at ISOLDE began with an overview of the facility. The basic working principles were introduced, including explanations of the production of very short-lived isotope and ionization techniques, as well as the separation and post-acceleration of Radioactive Ion Beams (RIBs).

This introductory presentation was followed by a tour of the facility. During this time, various accelerator technologies were introduced, including those used in magnets , power converters, vacuum systems, beam instrumentation, and both room-temperature and superconducting radiofrequency systems. The final part of the training focused on beam operations of the post-accelerator. After a brief introduction to the CERN control system and ISOLDE-specific software LINAC applications, students had the opportunity to work with a stable beam produced in the REX-EBIS charge breeder. They restored the post-accelerator setup for a 3.2 MeV/u 20Ne8+ beam that had been previously prepared. Additionally, they scaled part of the machine to beams with different A/q ratios, measured the A/q spectrum out of the REX-EBIS charge breeder, and measured the beam transmission through the RFQ for different power levels.

The hands-on experience provided the students with practical insights into accelerator operations and enhanced their understanding of the underlying principles and was greatly appreciated by the participants. Due to the great success of the at CERN, a similar program will also run next year, stay tuned!

Figure 3: The Students of the ATSOA school at CERN June 2-7, 2024

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Theo4Exp: a theory service provided by EURO-LABS

Manuela Rodríguez-Gallardo, Gianluca Colò and Jerzy Dudek, on behalf of the Theo4Exp team

In the last few years, the nuclear scientific community has been moving towards open science: open access publications, accessibility to experimental data and codes, etc. In this context, the creation of user-friendly platforms, in which non-expert users can perform calculations using well-established theory codes, represents a significant and long-awaited advancement. The new virtual access facility **Theo4Exp**, created as part of the EURO-LABS, addresses this need, by providing a variety of easily accessible computer codes for low energy nuclear structure and reactions, to researchers worldwide. The use of these codes is made simple by the adoption of clear interfaces and the implementation of graphical tools. Results can be easily transmitted, exchanged and compared. It is expected that the new service will create a virtuous circle of increased collaboration between theorists and experimentalists, leading to innovative experiments and facilitating their interpretation.

EURO-LABS has funded and provided the appropriate framework and dedicated personnel to create this virtual access service. Open to users since February 1st 2024, Theo4Exp is composed of three installations: one for reaction calculations, Reaction4Exp, and two dedicated to structure calculations, MeanField4Exp and Structure4Exp. The Theo4Exp portal can be found at the main web site: https://institucional.us.es/theo4exp Users are granted access to each installation via the application: https://iam-eurolabs.ijclab.in2p3.fr developed within the EURO-LABS project, either by providing their institution credentials (if they belong to eduGAIN network) or thier ORCID identification.

MeanField4Exp

The MeanField4Exp installation is based on the numerical applications [1-3] of the realistic phenomenological mean field approach, developed by J. Dudek and collaborators at the University of Strasbourg. The functioning of the MeanField4Exp service benefits from the integration of advanced methods of nuclear structure theory and quantum mechanics with advanced mathematical tools. These include inverse problem theory and Monte Carlo simulations for parameter optimization, group and group representation theories to handle symmetry issues, and graph theory for studying shape transitions, such as nuclear fission. The service provides access to advanced codes as well as to a comprehensive database containing pre-calculated results. The codes have been implemented by Irene Dedes and Abdelghafar Gaamouci at the Institute of Nuclear Physics (IFJ) of the Polish Academy of Sciences in Krakow.

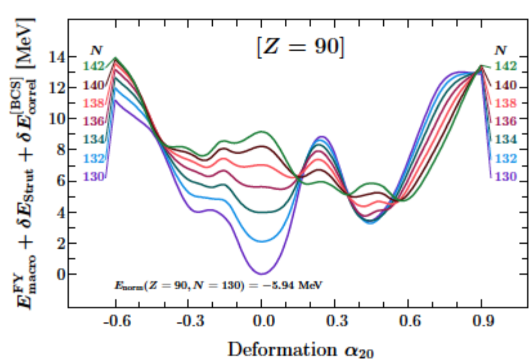

Figure 4: Comparison of the total energy of selected isotopes of thorium as a function of the quadrupole deformation.

Theo4Exp: a theory service provided by EURO-LABS

Users can produce diagrams of nucleonic energy levels or total nuclear energies as functions of various deformation parameters. Potential energy maps allow studying shape coexistence and evolution as functions of proton and neutron numbers, as well as of angular momentum, addressing Jacobi and Poincaré shape transitions. Figure 4 illustrates the energy of selected isotopes of Thorium as a function of quadrupole deformation, whereas Figure 5 displays a contour map of the energy of 222Th as a function of the quadrupole and octupole deformation parameters. . Important extensions to the capabilities of the current system are underway.

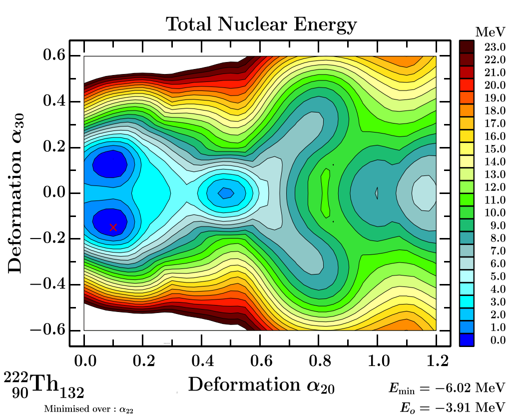

Figure 5: Contour plot of the energy of ^{222}Th as function of quadrupole and octupole deformation parameters.

Reaction4Exp

The installation Reaction4Exp, hosted at Universidad de Sevilla (Spain) and implemented by Carla T. Muñoz-Chimbo, provides codes for the calculations of observables measured in various types of direct reactions, including presently elastic, Coulomb breakup, and inelastic scattering.

The results of the calculations are presented both in text format as well as displayed graphically and can be downloaded. Very soon calculations of double-folding potentials from nuclear density distributions and transfer reactions will be implemented.

Coulomb breakup is calculated in a semi-classical formalism, the Equivalent Photon Model (EPM) [4], and makes use of the EPM code [5] developed by José A. Lay-Valera at the University of Seville. This program provides differential Coulomb breakup cross sections using externally provided transition probabilities, as a function of both angle and energy. Elastic scattering calculations are performed using the Optical Model (OM) formalism, The code provides angular distributions for the reaction considered at a given energy in the laboratory frame. It is also possible to obtain the classical trajectories and deflection function as a function of the impact parameter, using a code developed by Mario Gómez-Ramos at the University of Seville.

The inelastic scattering code provides cross-sections for the population of the excited states of the projectile or the target, making use of transition probabilities obtained from a collective model. It is based on the Coupled-Channels (CC) formalism and the cross sections can also be computed in first order using the Distorted Wave Born Approximation (DWBA). An example of inelastic scattering results, as displayed in the installation, is shown in Fig. 6.

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Theo4Exp: a theory service provided by EURO-LABS

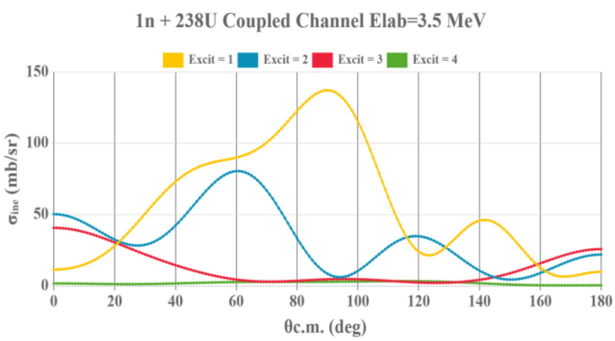

Figure 6: Differential cross sections for the inelastic excitation to the lowest excited states of ^{238}U in the reaction n+^{238}U at 3.5 MeV.

The OM, CC and DWBA calculations are performed using the code FRESCO [6] (www.fresco.org.uk), that was developed by Ian J. Thompson, currently at Lawrence Livermore National Laboratory (LLNL, USA).

Structure4Exp

The installation Structure4Exp, hosted at the University of Milan (Italy), and set up by Dr Imane Moumene, offers two types of codes. The first category includes two codes that are designed for the calculation of basic spectroscopic properties of spherical nuclei throughout the Segrè chart. Ground state properties like masses and radii, as well as vibrational excited states, are provided. For each excited state, the codes give the transition strengths associated with usual isoscalar, isovector and electromagnetic operators. One can visualize how this strength is distributed among giant resonances and low-lying vibrational states.

One of these two codes is based on self-consistent Hartree-Fock (HF) plus Random Phase Approximation (RPA), developed by Gianluca Colò and co-workers [7]. This is suitable for double-magic nuclei, or for nuclei with closed sub-shells both for neutrons and protons. Fig. 7 shows an example of the results given by the code, in the case of the isovector dipole strength of 132Sn. The other code is based on HF+Bardeen-Cooper-Schrieffer (HF+BCS) plus Quasiparticle RPA (QRPA), and has been developed by Gianluca Colò and Xavier Roca-Maza [8]. Both codes employ a Skyrme-type effective force.

The installation also offers the possibility to run the shell-model code KSHELL [9]. This has been developed by N. Shimizu and collaborators at the Centre for Computational Sciences of the University of Tsukuba. The code has been implemented with the help of Giovanni Di Gregorio (Caserta University and INFN Napoli) and Angela Gargano (INFN Napoli). Calculations can be performed in different valence spaces, with a selection of appropriate interactions. Users can specify the energy levels to be determined, and the program provides energy, occupation numbers, main contributing configurations, and, if requested, E2 and M1 electromagnetic transition values. One can compare in several cases the QRPA and shell-model results.

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Theo4Exp: a theory service provided by EURO-LABS

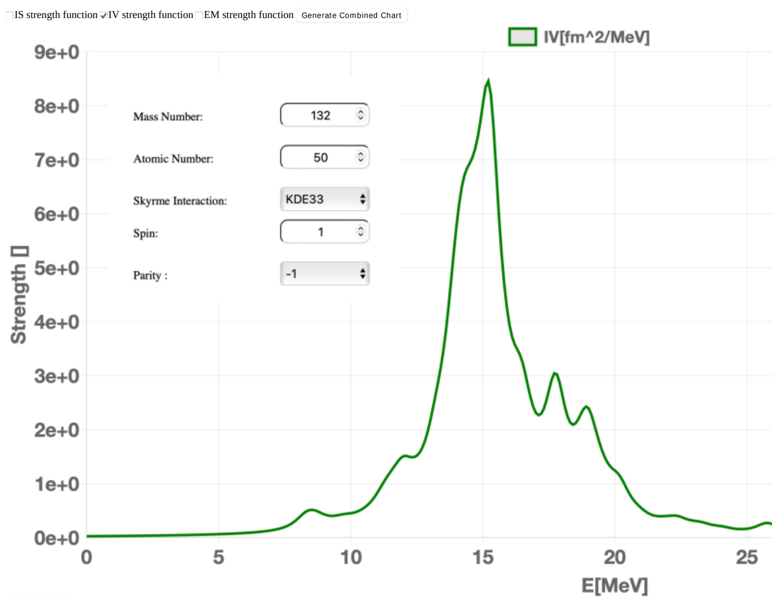

Figure 7: Example of a result, in the case of the isovector dipole strength calculated in RPA using the Skyrme force KDE033 in 132Sn. The inset shows the input mask that the user has to fill.

Conclusions and Outlook

Theo4Exp Virtual Access facility has been running for few months and continues to evolve. Expert help is available if required. There is already a lot of interest from the community. New services are planned to be offered and we also envision ways to interact with the users' community. In this context, an open hands-on workshop in ECT* for experimentalists and, in general for non-expert users, is envisaged for next year.

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Restarting the LNL Cyclotron: The Beating Heart of the SPES Project Comes to Life Again

Faical Azaiez on behalf of the SPES team

One of the key components of the SPES (Selective Production of Exotic Species) project of the INFN Legnaro National Laboratories (LNL) is the cyclotron capable of accelerating protons up to the energy of 70 MeV with a current of up to 750 □A, these protons constitute the primary beam for the production of the radioisotopes necessary for the experiments.

After the initial commissioning and the production of high power accelerated proton beams in 2018, a long shut down period followed until 2021 when an internal proton beam was produced. Since then, LNL was busy upgrading the SPES building and infrastructures. Finally towards the last two months of 2023, the operation of restarting and re-commissioning of the cyclotron was started. Due to the long shutdown the re-commissioning and testing of all the functions of the cyclotron and the beam lines, a suite of complex systems, needed to be carefully checked. The inspection and maintenance of all components, the retuning of the RF-amplifiers, the conditioning of the radio frequency resonant cavities, the recommissioning of the ion source and the upgrade of the control system for completely safe operation were carried out. The activities involved all the LNL divisions, and thanks to dynamic and organized work, this enthusiastic and professional staff managed to resolve the critical issues inevitably created due to the long shutdown, sharing their skills and experience.

After this successful startup of the cyclotron, in particular, a new beam line was used to irradiate various targets at energies of 35, 50 and 70 MeV, operating at a relatively low current: 100 nA, well below the nominal design value of current for which the cyclotron is designed, demonstrating its versatility. Figure 8 shows the cyclotron, beamline and target area. In the inset of Figure 8, it is shown the spectrum of Zn irradiated with protons at 50 MeV for the production of the radionuclide ^{67}Cu, important for nuclear medicine applications.

The completion of this first phase of SPES demonstrates that the new phased approach to the project implementation and the complete dedication of all LNL divisions and services, is key for a timely delivery of the project. This first phase will be successively followed by:

- Commissioning of the ISOL low-energy radioactive beams
- Implementation of a facility for the production of radionuclides for medicine
- Completion of the ADIGE new injector and RFQ for ALPI (replacing PIAVE)
- Commissioning of post-accelerated radioactive beam facility

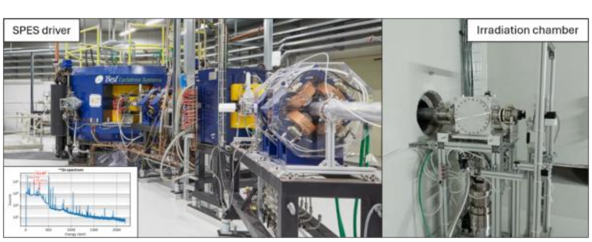

Figure 8: (Left) Photograph of the cyclotron and the new commissioned beam line. (Right) shows the target system installed at the end of the beam line in a different vault. The inset shows the off-line γ decay spectrum after irradiation of the Zn target .

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A new proton CT scanner based on DSSD and scintillators

E. Nácher

Proton therapy is a technique that employs proton beams instead of X-rays for cancer treatment. It has emerged as the most promising method for targeting localized tumours in delicate areas surrounded by highly sensitive tissues, such as the brain and spinal cord. The key advantage of proton therapy over traditional X-ray radiation therapy is its precision, which is essential for minimizing radiation exposure to healthy tissues.

For the optimum application of proton therapy, an effective treatment plan must be designed prior to treatment delivery. This involves using medical images of the patient and state-of-the-art simulation codes to calculate the dose distribution resulting from a proposed beam delivery. Therefore, the treatment plan depends on accurate images of the patient, typically acquired using X-ray computed tomography (CT). Since the treatment involves proton beams passing through the human body, the X-ray CT images must be translated into proton Relative Stopping Power (RSP) maps for the accurate calculation of the proton ranges and delivered dose, which is critical for the treatment plan. In this conversion, uncertainties are propagated to the RSP maps and, consequently, to the proton-range in the body. The most accurate method to produce RSP maps reducing the uncertainties in the position of the proton Bragg peak during the treatment, is to take the images directly with proton beams rather than X-rays, the so-called proton CT images.

Proton CT imaging relies on the use of a proton scanner including a particle tracker, to define the trajectories followed by the protons in the body, and a calorimeter, to measure the energy deposited by those protons along their trajectory within the patient. One such scanners has been designed by a Spanish team from two research centres of the Spanish Research Council CSIC, namely the IEM and IFIC, and one from the University Complutense of Madrid. All the measurements, from the first 2D radiographies to the latest 3D tomographic images, have been carried out at the CCB proton therapy centre in Krakow (IFJ-PAN, Poland), with the support of the EURO-LABS funds.

The experimental setup for evaluating the new proton-CT scanner is illustrated in Fig. 9. The left side of the figure is a photograph of the proton cyclotron, a schematic of the proton beam scattering off a 25-µm titanium (Ti) target, and the actual proton scanner apparatus. The image on the right displays a cylindrical phantom surrounded by two Double-Sided Silicon-Strip Detectors (DSSD), which serve as proton tracker. Adjacent to the tracker, on the right, is a LaBr3-LaCl3 phoswich calorimeter to measure the residual energy of the protons. In practice, the proton scanner was positioned at an angle of 12.5° relative to the original beam direction. The selection of the Ti scatterer and the specific measurement angle was made to generate a fan beam, thereby reducing the intensity impacting the detectors. This approach minimizes radiation damage and ensures the counting rates remain within manageable levels for the acquisition system.

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A new proton CT scanner based on DSSD and scintillators

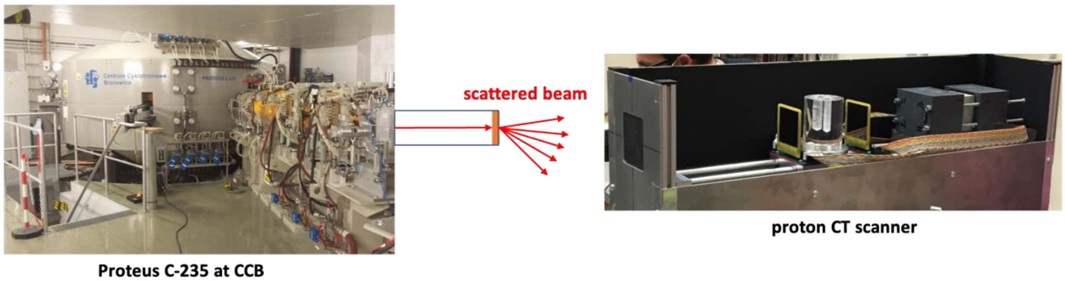

Figure 9: Experimental setup at the CCB facility in Krakow (Poland). (Left) Photograph of the Proteus C-235 cyclotron and the beam line to the experimental hall. The 100-110 MeV proton beam was scattered in a 25-µm-thick Titanium target. (Right) Photograph of the proton scanner at the experimental hall, placed at 12.5 degrees with respect to the incident beam direction.

Using this setup by irradiating various PMMA phantom geometries placed on a rotating platform, which allowed for multiple projections relavant images were obtained. This analysis is part of the thesis work of Amanda Nerio. Some phantoms were designed to evaluate the scanner's spatial resolution (Derenzo-like geometry), while others were filled with different materials to assess the setup and the image reconstruction ability to produce accurate RSP maps. Fig. 10 showcases the quality of the images produced using 100 MeV proton beams with the proton-CT scanner.

The images display the total projection of the tomographic image on the horizontal plane for both phantoms. In the upper row, the 3-mm diameter holes are clearly separated and well-defined. The lower row illustrates distinct regions corresponding to PMMA, ethanol, and water. The final RSP values obtained from these images were in excellent agreement with those reported in previous studies. For a full report on the first tests of this new proton-CT scanner, the reader is referred to our recent publication.

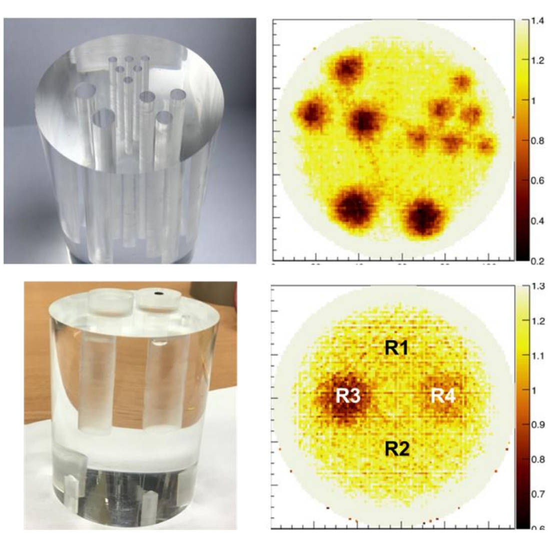

Figure 10: Upper row: picture of the PMMA Derenzo-like phantom (left) and projection of the reconstructed tomographic image (right). Lower row: phantom with PMMA and two inserts with different liquids, namely ethanol and water (left), and the reconstructed tomographic image (right).

References

[1] E. Nácher, J.A. Briz, A. Nerio et al., Eur. Phys. J. Plus (2024) 139: 404.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101057511.

New machine learning toolkit enhances acceleration operation at GSI

S. Appel and Nico Madysa

Accelerator laboratories around the world have a vested interest in maximizing their physics time, i.e. the time in which the produced beams can be used in experiments and the facility is not down for maintenance or repairs.

While many different techniques have been developed in the past – from classical black-box optimization algorithms like Nelder–Mead or COBYLA, to Reinforcement Learning (RL) and more modern approaches like Bayesian Optimization (BO) – attempts to integrate these into a laboratory's controls system have so far fallen short due to various reasons like :

• Focusing on only a select few algorithms,
• Limiting to the kinds of problems that can be solved,
• Failing to fulfil the often-strict reliability requirements that come with a control room.

The Geoff Toolkit

A new approach was taken at CERN in 2020. Development on a new framework for machine learning and automated accelerator controls was started. This project would eventually be called the Generic Optimization Framework and Front-End, "Geoff"[1].

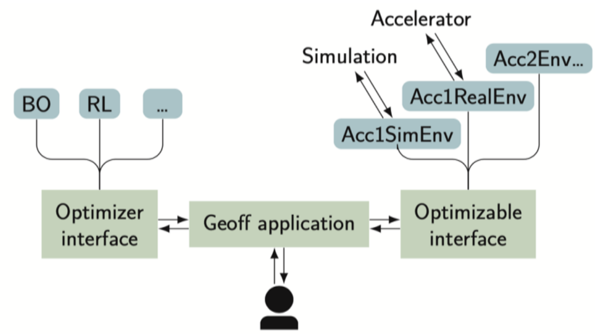

Figure 11: Schematic of the architecture of Geoff. The GUI application exposes interfaces on both sides of the optimizer

Unlike previous approaches, this one was meant to put as few restrictions as possible on the kind of optimization problems users could submit Geoff. As long as it could be written in a programming language like Python, it should be usable by the framework.

At the same time, with the world of RL still being very much in flux with new algorithms being published regularly, it did not make sense to commit to any fixed set of algorithms. Instead, a reasonably loose interface was defined that would accommodate as many algorithms as possible, and wrappers to integrate a wide number of existing algorithms. When a GUI application was added that lets users combine any optimization algorithm with any existing optimization problem, this resulted in the architecture that is shown in Figure 11.

[1] The pronunciation is often "Jeff" or "Joff", but "Jee-off" has also been observed.

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Unlike similar frameworks, Geoff leverages the full capabilities of the Python ecosystem as :

• Most ML research uses Python these days, even the latest and most modern algorithms are available;

• Optimization problems can easily define as full Python packages, they can also depend on other packages and grow to near arbitrary complexity;

Python is considered easy to learn, it is usually not difficult for machine experts at accelerator laboratories to introduce it themselves to the framework.

• An extensive documentation manual with tutorials and complete references answer any question a user might have.

At the GSI Helmholtz centre for Heavy-Ion Research, a new laboratory is currently under construction (Facility for Anti-Proton and Ion Research (FAIR)). It is an international centre to drive the forefront of heavy-ion and antimatter research.

Its complexity will require an extremely high level of automation to maximize available time for experiments within acceptable bounds. Real-World Applications at GSI.

At CERN, Geoff has been instrumental in optimizing various aspects of accelerator operation. Its integration has been seamless, often requiring only a few hours to adapt to new accelerators and optimization tasks. This rapid deployment capability has proven beneficial in maintaining high levels of operational efficiency.

GSI has utilized Geoff to address specific challenges such as minimizing beam loss during the Multi-Turn Injection (MTI) process into the SIS18 synchrotron. By optimizing five injection parameters and four steering elements in the transfer channel, Geoff managed to reduce beam loss from 35% after manual tuning to 20% through in about 15 minutes. Manual adjustment by operators can often take up to 2 hours.

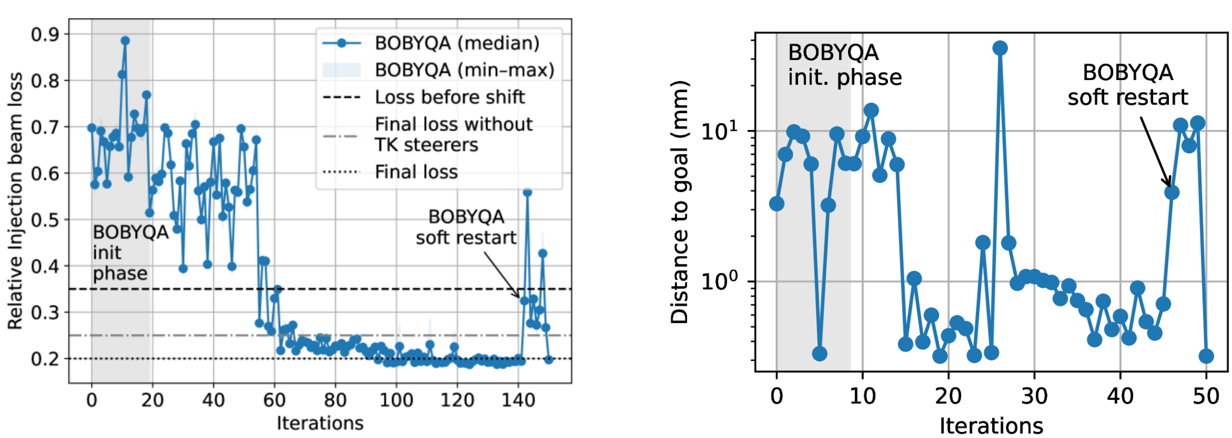

Figure 12: (Left)Results of automatic minimization of beam loss via BOBYQA using SIS18 injection parameters and steerers at GSI. The grey area marks the initialization phase.(Right) Results of beam steering via BOBYQA using four steerers and two profile grids at the GSI fragment separator.

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The optimization algorithms BOBYQA maintains a quadratic model of the objective function, which must be initialized (mark as gray area in Figure 12) with $N \geq 2n+1$ evaluations, where $n = 9$ is the number of optimization parameters. In addition, the algorithm BOBYQA has the included option called “soft restarts” to escape potential local minima.

Moreover, GSI applied Geoff to the optimization of the FRagment Separator (FRS) setup (a key tool for the production of exotic short lived beams), a task that traditionally takes ~ two to three days at the start of each physics experiment. The optimization process involved automatic beam steering to align the beam with a target point on profile grids, achieving convergence in fewer than 20 iterations. Profile grids are used to measure the transverse 2D intensity distribution of the beam, which are used to calculate the beam angle and beam position at the target. Since numerical optimizers generally only work with scalar functions, these observables must be combined into a single variable as the misplacement or distance to the target.

In June, the toolkit has been further expanded to include also experimental detectors for further downstream optimization.

Future Prospects

The success of Geoff at both CERN and GSI underscores its potential to become a standard tool in accelerator optimization. The toolkit's ability to handle complex optimization tasks with minimal manual intervention due to enhances operational efficiency. As development continues, Geoff is expected to further integrate advanced ML techniques and expand its applicability to other research facilities like the one at CEA (France).

For more information and to access the toolkit, please visit the public documentation page or the project page on CERN’s Gitlab website.
https://gitlab.cern.ch/geoff/geoff-app/ and https://cernml-coi.docs.cern.ch/index.html

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Astrophysical Jet recreation at the HiRadMaT Facility

The Fireball collaboration has used CERN's HiRadMat facility to produce an analogue of the jets of matter and antimatter that stream out of some black holes and neutron stars. The multi-national collaboration is led by Prof. Gianluca Gregory of University of Oxford, UK. The first series of experiments conducted in 2023 were funded by EURO-LABS. The experiment will continue with an improved setup in 2024, also supported by EURO-LAB. The text below was partially extracted from the news published at CERN [1], based on a recent publication in Nature Communications [2].

HiRadMat (High-Radiation to Materials) is a user's facility at Super Proton Synchrotron SPS (CERN), designed to provide high-intensity pulsed beams to an irradiation area where material samples as well as accelerator component assemblies can be tested. High-intensity proton beam pulses are extracted from the SPS towards HiRadMat. Within the SPS up to ~3.5·1013 protons per pulse are accelerated to a momentum of 440 GeV/c and extracted to focal spots as small as ~0.5 mm2 (smaller beam spots down to ~0.25 mm2 are also available upon request), with a pulse length of up to 7.95 µs and a maximum pulse energy of up to 2.4 MJ. In addition to protons, 208Pb ion beams with a momentum of 173.5 GeV/nucleon, a pulse length of up to 5.2 µs and a total pulse energy of up to 21 kJ can be also used. Upon discussion with the SPS operators beam parameters can be tuned to match the needs of each experiment.

In the heart of an active galaxy one finds a supermassive black hole gobbling up material from its surroundings. In about one out of ten of such galaxies, the black hole will also shoot out jets of matter close to the speed of light. Such relativistic black hole jets are thought to contain, among other components, a plasma of pairs of electrons and positrons. Electron–positron plasmas are thought to play a fundamental role in astrophysical jets, but computer simulations of these plasmas and jets have never been tested in the laboratory.

Relativistic beams of electron–positron pairs can be created in several ways at different types of laboratories, including high-power laser facilities. However, none of the existing ways can produce the number of electron–positron pairs that is required to sustain a plasma. Without sustaining a plasma, researchers cannot investigate how these analogues of black hole jets change as they move through a laboratory equivalent of the interstellar medium. This investigation is key to explaining observations from ground- and space-based telescopes.The Fireball collaboration, found a way to meet these requirements at CERN's HiRadMat facility. Their approach involved extracting within a mere nanosecond a whopping three hundred billion protons from the SPS and firing them onto a target of graphite and tantalum, in which a cascade of particle interactions generates huge numbers of electron–positron pairs.

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By measuring the resulting relativistic electron–positron beam with a set of instruments, and comparing the result with sophisticated computer simulations, the Fireball collaboration showed that the number of electron–positron pairs in the beam – more than ten trillion – is ten to hundred times greater than previously achieved, exceeding for the first time the number needed to sustain the plasma state.

“The basic idea of these experiments is to reproduce in the laboratory the microphysics of astrophysical phenomena such as jets from black holes and neutron stars. What is known about these phenomena comes almost exclusively from astronomical observations and computer simulations, but telescopes cannot really probe the microphysics and the simulations. Laboratory experiments as the one reported here are a bridge between these two approaches

The recent result published in Nature Com [2] is the first from a series of experiments that the Fireball collaboration is carrying out at HiRadMat. The Fireball collaboration will continue their plasma pursuits at HiRadMat , where these powerful jets propagate through a meter-long plasma to observe how the interaction between them generates magnetic fields that speed up the particles in the jets – one the greatest puzzles in high-energy astrophysics. The Fireball experiments are one of the latest additions to HiRadMat’s portfolio.

References

[1] CERN newsletter: https://home.cern/news/news/physics/bringing-black-hole-jets-down-earth.
[2] C.D. Arrowsmith et al., Nature Com. https://doi.org/10.1038/s41467-024-49346-2

Figure 13: Partial view of the HiRadMat Facility at SPS at CERN

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101057511.

Low Gain Avalanche Detectors in EURO-LABS

Bojan Hiti (JSI, Ljubljana, Slovenia)

LGAD – Low Gain Avalanche Detectors – are a novel type of particle sensors with internal gain, whose most prominent use will be in timing detectors in ATLAS and CMS experiments at the High Luminosity LHC (HL-LHC). The high luminosity will result in extremely high pile-up, which will be resolved with the help of the precise measurement of the time of arrival of collision products. The required time resolution, below 50 ps, will be achieved using LGAD as the sensor technology.
LGAD operate on similar principles as avalanche photodiodes – charge carriers generated by traversing particles get multiplied in the sensor and increase the available signal. However, unlike avalanche photodiodes, where a full-scale avalanche is developed, LGADs operate in the linear regime with the gain factor typically below 50, hence the name Low Gain.

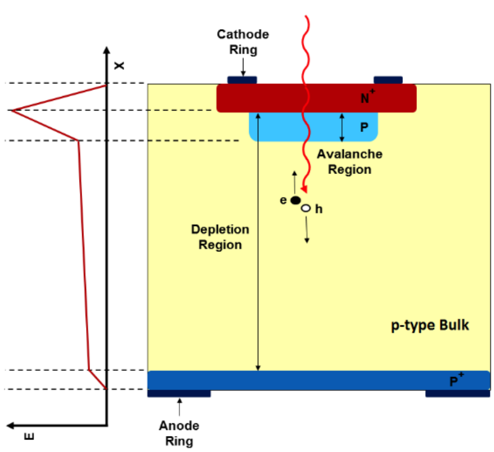

Figure 14: Schematics of an LGAD with illustration of the electric field, which peaks in the gain layer to provide charge multiplication.

The LGAD structure is similar to standard pad diodes, see Figure 14. Silicon LGADs are manufactured on high-resistivity p-type substrate with an additional highly doped thin p+ layer – called multiplication or gain layer – implanted directly under the n-type readout electrode. The gain layer has a typical thickness of 1 μm and a doping concentration much higher than the substrate, albeit still less than the readout electrodes. Depletion of the gain layer requires significant voltage, corresponding to a large electric field, which enables charge multiplication by impact ionization. This is the gain mechanism of the LGAD.

LGAD provide an excellent signal-to-noise ratio (S/N) for minimal ionizing particle (MIP) signals, which is a requirement for a good time resolution. One of the terms that determines the detector time resolution is the so-called electronic jitter contribution, which scales as approximately as t_rise/(S/N), where t_rise is the signal rise time. To achieve fast signals with short rise times, LGAD need a thin active volume with a typical thickness of 50 μm. Such devices can achieve MIP time resolution down to 30 ps, which is ultimately limited by the event-to-event variations in the spatial distribution of the deposited charge carriers (so called Landau fluctuations). These distort the shape of induced signals and lead to a nonreducible term in the time resolution

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LGAD radiation hardness is an important aspect for applications at the HL-LHC, where sensors will have to withstand fluences up to 2.5 × 1015 neq/cm^2, which is comparable to fluences for innermost pixel layers in current trackers. The critical issue is the degradation of the gain layer, which comes from the deactivation of boron dopants via radiation induced microscopic defects. This process is called acceptor removal and results in reduction of the effective doping concentration of the gain layer, leading to smaller multiplication factors. This loss can be partially compensated by increasing the bias voltage on the sensor, but the maximal operating voltage is limited by destructive single event breakdown discharges, which occur when the average electric field in silicon exceeds 12 V/µm. Detailed studies of the single event breakdown properties have been conducted in test beam campaigns organized in the scope of EURO-LABS as it is illustrated in Figure 15.

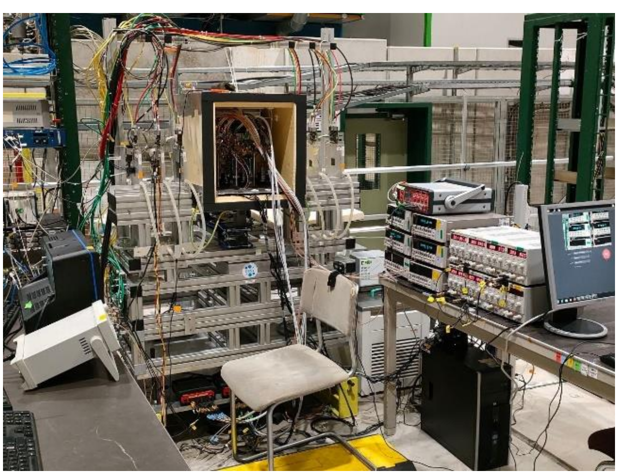

Figure 15: LGAD in a test beam setup at CERN SPS H6 beam line during a EURO-LABS campaign.

Future areas of LGAD development include improvements of radiation hardness, sensor fill factor and suitability for detection of less penetrating radiation. Radiation hardness can be improved by targeted introduction of additional defects (defect engineering) to reduce the acceptor removal rate by shielding the implanted boron. The fill factor is related to the spacing between adjacent gain layers, which is required for electrical inter-pixel insulation, but results in an inactive volume with no gain. In current designs the inactive width is approximately 100 µm and the future target is to reduce it below 10 µm, using either physical gaps (trenches) between pixels or continuous gain layer design with electrode segmentation on the opposite (back) side of the sensor. The latter designs are also suitable for detection of soft X-rays, which penetrate only a very shallow region on the sensor surface. These avenues will among others be explored in the scope of the recently formed DRD3 (Detector R&D) collaboration at CERN.

Development of the LGAD technology over the last decade greatly benefited from the research infrastructure supported by EURO-LABS. Optimization of the sensor radiation hardness was enabled by extensive irradiation campaigns at proton and neutron irradiation facilities and subsequent design iterations. Key device characterization was conducted at high energy test beams at CERN and DESY, where timing performance and charge collection efficiency was determined and single event breakdowns were discovered.

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