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EURO-LABS

EUROpean Laboratories for Accelerator Based Sciences
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MILESTONE REPORT

A) MORE THAN 30% OF AU DELIVERED IN WP4.3: IRRADIATIONS

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Abstract:

Task 4.3 provides Transnational Access to six research infrastructures (RIs) for irradiations. The facilities are used to expose prototype detectors to different types of irradiations during their R&D phase. The milestone provides a checkpoint of RIs' delivery of Access Units (Aus) at project midterm. The overall usage is acceptable with the 30% goal exceeded by 14%. Detailed analysis by facility reveals substantial differences. Applying proper measures, none of the facilities, however, are expected to fall behind their pledge at the end of the project.

EURO-LABS Consortium, 2024

For more information on EURO-LABS, its partners and contributors please see <https://web.infn.it/EURO-LABS/>

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	Name	Partner	Date
Authored by	M.Mikuž	JSI	18/09/2024
Reviewed by	M.Mikuž [WP Coordinator]	JSI	25/09/2024
Approved by	Navin Alahari [Scientific coordinator]	GANIL	27/09/2024

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Executive summary

Task 4.3 provides Transnational Access to six research infrastructures (RIs) where different types of particles are employed to irradiate prototype detectors during their R&D phase. The M23 milestone provides a checkpoint of RIs' delivery of Access Units (AUs) at project midterm. The overall performance is acceptable with the 30% goal exceeded by 14%. Detailed analysis by facility reveals substantial differences. Applying proper measures, all the six RIs can still be expected to fulfil their commitment at the end of the project.

1. INTRODUCTION

WP4 of EURO-LABS is devoted to support detector R&D via Transnational Access (TA) carried out at 11 RIs in Europe. The typical detector R&D cycle consists of constructing a series of prototypes, testing them in high-energy particle beams, irradiating them and possibly evaluating their performance in special characterization facilities. This is followed by the division of WP4 into tasks: WP4.1 supplies the test beams in 3 RIs, WP4.2 offers detector characterization in 2 RIs and WP4.3 irradiation opportunities in 6 RIs.

The six RIs offering irradiations in WP4.3 are:

- 4.3.1: CERN IRRAD, Switzerland
- 4.3.2: CERN GIF++, Switzerland
- 4.3.3: JSI TRIGA reactor, Slovenia
- 4.3.4: IFJ PAN AIC-144 cyclotron, Poland
- 4.3.5: UCLouvain CRC, Belgium
- 4.3.6: UoB MC40 Cyclotron, United Kingdom

The goal is to cover the wide range of identified particle/ γ - ray sources needed for detector development for later stages of High Luminosity LHC (HL-LHC) upgrades and enable initial research on detectors for the Future Circular Collider (FCC). These RI's include proton, neutron or mixed field sources as well as γ - ray irradiation. Some of these RI's can provide extreme fluences beyond 10^{17} n_{eq}/cm^2 (JSI, IFJ-PAN, UoB) for smaller samples, while others deliver lower fluences of $\sim 10^{15}$ n_{eq}/cm^2 on larger (10×10 cm^2) objects. GIF++ covers irradiation of large-scale objects like muon chambers, while the Heavy Ion Irradiation Facility (HIF) at UCL is widely used for Single Event Effect tests of electronics.

The operational parameters of the irradiation RIs are summarized in the following table:

Infrastructure short name	Sub-task number	Installation name	Source	Particle	Energy (in MeV)	Φ_{Max} part $s^{-1}cm^{-2}$
CERN	4.3.1	IRRAD	PS	Protons,	24000	10^{10}
	4.3.2	GIF++	^{137}Cs	γ - rays	0.662	14 TBq
JSI	4.3.3	TRIGA Mark III	Reactor	Neutrons	<10 (Watt spectrum)	7×10^{12}
IFJ_PAN	4.3.4	AIC-144 Cyclotron	Cyclotron	Protons	10-60	3×10^{11}
UCLouvain	4.3.5	CRC NIF, LIF, HIF	Cyclotron	Neutrons,	<50 (cont.)	7×10^{10}
				Protons, Heavy Ions	10-62 110 Q ² /M	2×10^8 10^4
UoB	4.3.6	MC40 Cyclotron	Cyclotron	Protons	26	1.5×10^{13}

The report details the AU (Access Units) usage at the irradiation facilities in the first two years in the project. The introduction is followed by an overall assessment of the usage, then a short report from the six RIs. An analysis of their performance with an outlook towards the end of the project concludes the report.

2. ASSESSMENT OF AU USAGE

The usage of AUs at the three RIs of WP4.3 during P1 and P2 (Sep 22 – Aug 24) is summarized in Table 1.

WP4.3	Name	Pledge	Delivered	30% goal	Delivered/goal
WP4.3.1	CERN IRRAD	4000	1824	1200	152%
WP4.3.2	CERN GIF++	4060	936	1218	77%
WP4.3.3	JSI	700	237	210	113%
WP4.3.4	IFJ PAN	800	272	240	113%
WP4.3.5	UCLouvain	100	0	30	0%
WP4.3.6	UoB	300	31	90	34%
Total		8060	2760	2418	114%

Table 1: Usage of AUs in the six RIs of WP4.3. The AUs pledged for the duration of the project, the AUs delivered by mid-term, the MS goal of 30% and the accomplished percentage of the goal are given by RI and for the whole task.

The overall milestone goal of 30% across task WP4.3 is thus met. Taking the pro-rata mid-term target of 50%, the task is marginal having delivered 34% of the totally pledged AUs.

Individually by RIs, CERN IRRAD with 47% is at its pro-rata goal. JSI, IFJ-PAN and CERN GIF++ are grouped around the goal with 34, 34 and 23% of the full pledge. They will need to increase their performance substantially to meet the overall goal at the end of the project.

UoB with only 10% is underperforming, while UCLouvain has not yet delivered any AU. Given the relatively small number of pledged AUs (300, 100) delivered to users in 12 and 10 foreseen projects at UoB and UCLouvain the fluctuations are expected to be large. Suitable steps in this direction need to be made to attract users to those facilities. Then, not only at the task level but also individually at all RIs, the committed amount of AUs will be reached.

3. REPORTS FROM RI'S

3.1. CERN IRRAD

The proton irradiation facility (IRRAD) at the Proton Synchrotron (PS) East Area (EA) was built during the Long Shutdown 1 (LS1, 2013-2014) and improved during LS2 (2019-2021) to cope with the increasing needs for radiation tests of the experimental community working for the HL-LHC upgrade and beyond. The IRRAD facility, operated by Detector Technologies (DT) group in the Experimental Physics department (EP-DT). It exploits the 24 GeV/c PS proton beam, and is part of a more complex infrastructure that includes on the EA-T8 beamline the CHARM. This is operated by the Beams (BE) department and the CERN Shielding Benchmark Facility (CSBF test station to benchmark the efficiency of radiation shielding materials). It serves as well as a test bench for developing a high-energy ion beam aiming to provide an optimal tool to reproduce the effects of

galactic cosmic rays (within the HEARTS (High-Energy Accelerators for Radiation Testing and Shielding) EU-funded project fostered by the CERN-ESA collaboration).

The year 2023 has been the second full year of IRRAD operation after LS2, with 27 weeks (189 days) of irradiation. 39 user experiments were executed, involving more than 400 samples. About 60% of the experiments belonged to the CERN LHC experimental users working to complete the Phase II upgrade projects (e.g., ATLAS ITk Pixel/Strips & HGTD, CMS IT & HGCAL, LHCb PicoCal & ECAL, etc.), while the remanet 40% belonged to CERN equipment groups (ATS), as well as to users from EU/R&D/external projects. In 2024 the proton run will last 33 weeks and, so far, 24 experiments are registered and a total of more than 420 samples were submitted for irradiation and are being processed. Figure 1 shows some examples of IRRAD experiments: on the left-hand side, the irradiation of new vacuum window materials (i-FAST -Innovation Fostering in Accelerator Science and Technology -project) to integrate ultra-high fluence levels $>1 \times 10^{17}$ p/cm², while the right-hand side shows an array of Silicon Pixel modules for the ATLAS ITk & CMS IT detectors.



Figure 1: Examples of experiments performed during the run 2023 at the IRRAD Facility. Vacuum window samples (left-hand side) and silicon pixel modules (right-hand side).

Within the EURO-LABS TA framework in the first year from September 2022 to August 2023 a total of 1348 Access Units were provided to 4 selected projects with 15 participating users. Within 2023/24 further 476 Access Units were delivered to two user groups and since the re-start of the accelerator complexes after the winter shutdown five further projects were identified for EURO-LABS TA support and are presently ongoing. All-in-all, the facility is fully committed in 2024 with the EURO-LABS TA access, the ongoing radiation hardness and qualification testing for components and detector elements for the High-Luminosity LHC detectors and accelerator, and various other projects as described above.

3.2. CERN GIF++

The CERN Gamma Irradiation Facility (GIF++) is a joint BE & EP Department facility located on the H4 beamline (SPS, Zone PPE-154) in EHN1 hall (North Area, Prevéssin site).

It is a unique place for detector R&D, where a strong γ - ray source and a muon/pion particle beam are simultaneously available. Together with IRRAD in the East Area (Meyrin site), GIF++ delivers essential services to the HEP community, with the focus on validating and optimizing detector technologies, mainly in view of the High-Luminosity upgrade of LHC and accelerator projects beyond.

A photo of the facility and the arrangement of experiments inside the experimental area is shown in Figure 2. The irradiator (¹³⁷Cs, 14 TBq as of 2014) is operated throughout the year, independently of the SPS and offers two adjustable gamma irradiation zones, with a total floor space of more than 100

m². The two gamma fields ($\leq 2\text{Gy/h}$) enable ageing studies and provide radiation background similar to the future working conditions inside the large LHC experiments.

The muon (or pion) beam, available during dedicated time slots (typically 3 x 2 weeks/year) is used to investigate and validate the detector performance and behaviour under the expected conditions.

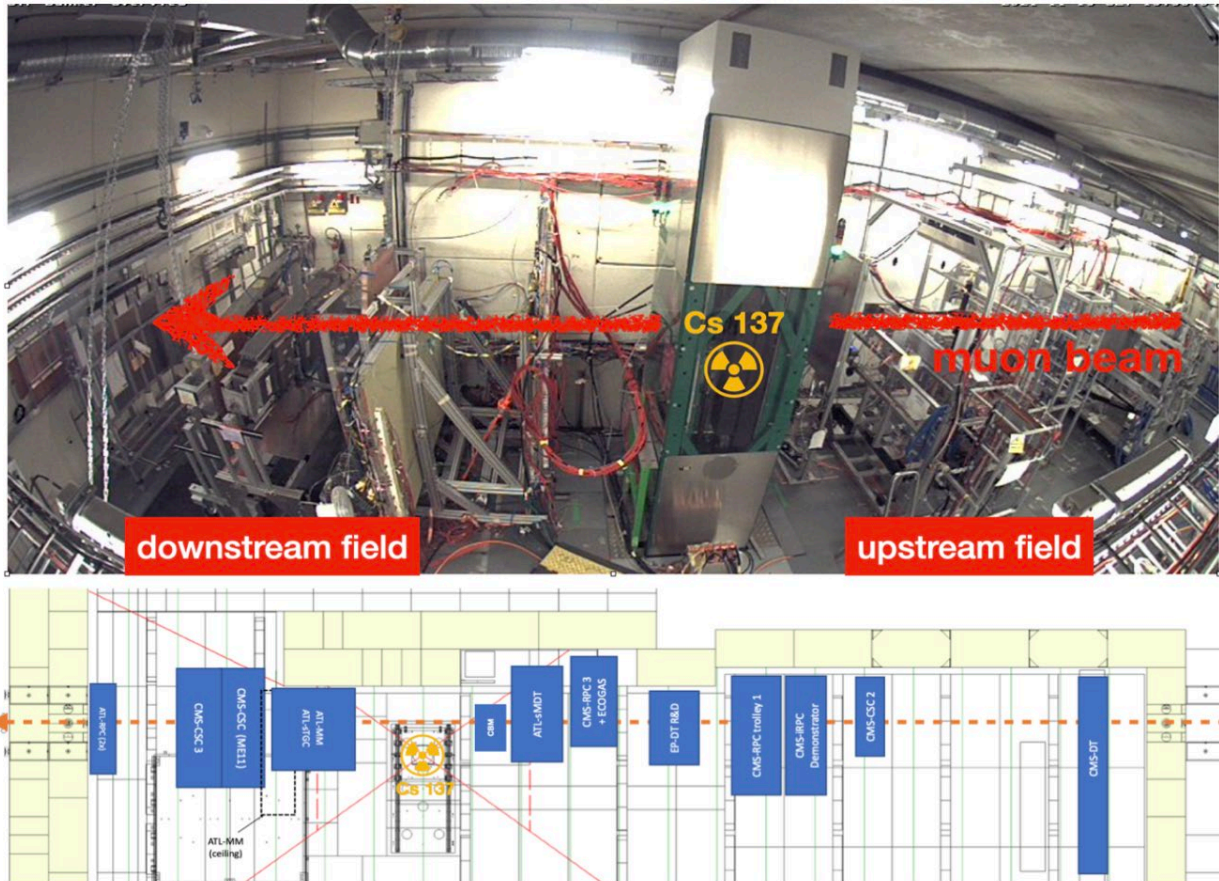


Figure 2: Photo of the GIF++ irradiation bunker. Up to 11 different setups – often composed of multiple chambers – can be hosted along the muon beam, while several other experiments continue to use the irradiator only. The drawing at the bottom describes the experiments in the experimental area and shows the two opening cones of the gamma irradiator (downstream and upstream fields).

The facility is equipped with excellent gas and electronics infrastructures, a unified control/monitoring system, setups for beam and cosmic trigger as well as radiation and environmental conditions monitoring.

The facility is extensively exploited by a large community, mainly composed of users belonging to the CERN LHC experiments. On average, 5 - 6 setups run continuously in parallel during the year, with a peak of 11 setups. In 2024 a campaign to validate the mass production of Resistive Plate Chambers (RPC) for the upgrade of the CMS experiment was started. Discussions are ongoing in order to enlarge the available surface in the bunker and accommodate additional gas systems to cope with the increasing number of user requests.

The main detector R&D programme remains the upcoming upgrade of the LHC experiments in view of the High Luminosity LHC phase (HL-LHC), including long term ageing studies for various gas mixtures. Over the last years the search for environmentally friendly gas mixtures gained momentum and became a driving element of the scientific programme of the facility via the ECOGAS collaboration.

Projects running in the facility require, with a few exceptions, long-term, even years of irradiation and scientists involved spend a large fraction (> 50%) of their working time or are permanently based at CERN.

The situation described above, namely that most of the scientists are deeply involved in the long-term qualification and development work for the HL-LHC, leaves little room for more fundamental scientific studies. This is seen as the reason for the low demand encountered in the first reporting period. Only two projects on the study of environmentally friendly gases were submitted in the EURO-LABS TA framework, approved and executed. More projects are under discussion and projected to be performed in the upcoming reporting period.

3.3. JSI

The reactor facility is used for neutron irradiation aiming at studies of radiation effects in detectors and electronics. Since the start of EURO-LABS, 26 projects were supported with 157 access units (reactor hours) by EURO-LABS TA. Irradiation projects are directed into development of detectors for High Luminosity LHC and developments for future particle physics experiments. Studies include a variety of semiconductor materials – Si, SiC, GaN, diamond and different detector structures such as 3-D detectors, planar PIN diodes and LGADs, CMOS detectors etc.

The TRIGA reactor offers a unique opportunity for irradiation tests with neutrons to fluences spanning over many orders of magnitude. Electronic circuits containing COTS components were tested with 10^{12} n/cm² while 3-D detector structures were irradiated to 10^{17} n/cm².



Figure 3: Insertion of samples into the F19 channel (encircled in red) leading to the reactor core faintly visible at the bottom of the water tank. The sample holder can be seen attached to the fishing rope used to lower it for irradiation and then lift it to a shielded position above the core for initial cool-down.

A special irradiation campaign, worth 80 AUs, up to the extreme radiation fluence of 10^{18} n/cm² has been carried out in August 2024. It is devoted to initiate activities for development of tracking detectors for future hadron colliders, like Future Circular hadron-hadron Collider (FCC-hh). Experience collected with this irradiation will help planning the next irradiation campaigns. We expect it to provide first indications about the direction of detector development for future hadron colliders. Including this extreme fluence campaign a total of 237 AUs were used until the end of August 2024.

3.4. IFJ-PAN

The AIC-144 cyclotron facility offers 60 MeV proton beams with intensity up to 100 nA in two experimental rooms: a) the former proton therapy eye-treatment room with the setup for precise positioning and clinical-quality irradiation with beam diameters up to 40 mm and b) an experimental hall with an irradiation line equipped with 2D scanner (EURO-LABS service improvement), which allows to expose larger elements with sizes up to 400 mm x 400 mm. It is a user facility, which provides beams for experiments in detector physics, medical physics, cosmic industry and radiobiology. The irradiation stations are equipped with all type of dosimetry tools and are metrologically connected to the Secondary Standard Dosimetry Laboratory in Warsaw.

Within the EURO-LABS project, the facility was mainly used to test detectors intended for use in various experiments in physics and in space. Low gain avalanche detectors (LGAD) were tested for on-line measurements of charged particle flux with high speed and spatial precision. Further projects involved electronic modules of the POLAR-2 Gamma-Ray Burst experiment, Double Sided Silicon Strip Detectors (DS-SSD) for nuclear physics experiments, ion detector systems used for the 10 PW laser-nuclear experiments at ELI-NP and others.

Since the start of EURO-LABS 8 projects were supported with 272 access units (cyclotron hours) by EURO-LABS TA.

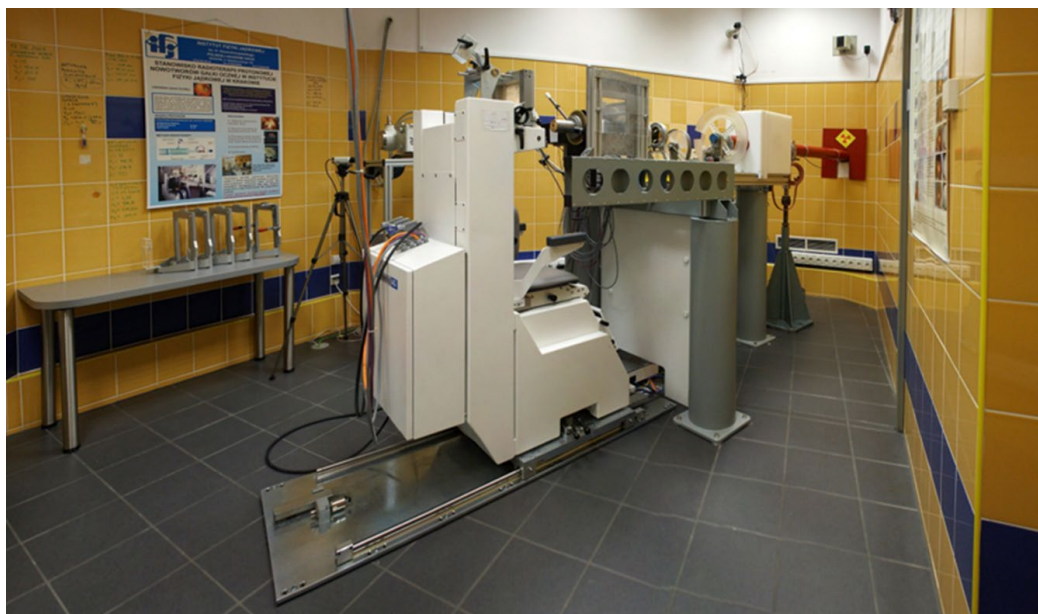


Figure 4: The irradiation room adapted from the proton therapy eye-line installation. The samples for irradiations are mounted and positioned on the movable treatment chair in front of the beam collimator.

3.5. UCLouvain

Cyclotron Research Centre (CRC) is a research unit attached to the Institut de Recherche en Mathématique et Physique (IRMP) at UCLouvain. The facility operates the CYCLONE110 cyclotron, able to accelerate charged ions to kinetic energies up to $110 \times (Q^2/M)$ MeV. Main activities of the centre are industrial applications (membrane production), and irradiation of electronic components. In total, around 2,500 effective hours of beam are delivered to users during 35 weeks of operation. Around 10% of access is devoted to scientific applications, mainly nuclear physics experiments, detector irradiations, rad-hard electronic devices and biomedical applications.

CRC offers 3 irradiation facilities based on CYCLONE110 operation:

- Neutron Irradiation Facility (NIF). Neutrons obtained impinging a 50 MeV deuteron beam on a Be target giving a continuous neutron spectrum up to 50 MeV with a mean energy of 20 MeV. The intensity of the beam can reach a flux of $7.3 \times 10^{10} \text{ n s}^{-1} \text{ cm}^{-2}$, providing a beam diameter ~ 4 cm. The irradiation area can be maintained at constant temperature down to -20°C during irradiation.
- Light Ion Irradiation Facility (LIF). Mono-energetic protons with energies between 20 and 65 MeV. Beam size of ~ 8 cm diameter and maximum flux of $5 \times 10^8 \text{ p s}^{-1} \text{ cm}^{-2}$.
- Heavy Ion Irradiation Facility (HIF). This facility provides a beam of up to $10^4 \text{ ions s}^{-1} \text{ cm}^{-2}$ monoenergetic heavy ions with well-known range and LET. Irradiation area is ~ 25 mm diameter with 10% homogeneity. Various “ion cocktails” can be accelerated allowing an easy and efficient way to change LET. The available cocktails, LET and ranges are described on the facility webpage. This facility is especially devoted to irradiating electronics. DUTs are in vacuum and must not be encapsulated.

All these three facilities are available to EURO-LABS users. Till date, for EURO-LABS TA, we have received just one application, with the irradiation foreseen in spring 2025.



Figure 5: The end of the HIF beam line with the newly installed test chamber

The installation of the new test chamber for HIF in the scope of the UCLouvain service improvement (Fig. 5) has almost been completed. The only piece missing is the installation of a new, scintillator-

based detector to cross-check the ion flux measurement. The material has been procured and it is under test with heavy ions.

3.6. UOB

The MC40 cyclotron at the University of Birmingham has been working as a EURO-LABS Transnational Access facility over the past two years. It has delivered irradiations to four projects, and 11 users in total, out of 12 and 36, respectively, requested on the grant. The projects covered the study of radiation damage to depleted Monolithic Active Pixel Sensors, to the I3T80 technology for the development of DC/DC power regulators, to silicon sensors, including novel Low Gain Avalanche Detectors, and the study of effects of annealing on irradiated silicon sensors. By the end of the reporting period, about 30 AU were delivered, out of 300 requested on the grant. It must be noted that the MC40 cyclotron has been unavailable for approximately 6 months, between August 2022 and January 2023, due to a fire in one of the magnets that then needed replacement. During these two years, work has been ongoing on system improvements to deliver fluences well above 10^{16} n_{eq}/cm². The system is in the advanced stages of development and is approaching a stage where commissioning at the MC40 cyclotron can begin. Full commissioning is expected to be achieved by spring 2025. This improvement will enable the facility to deliver a higher number of AU to projects and to work towards the delivery of the full AU target (300 AU).



Figure 6: Upgraded sample scanning assembly during the laboratory commissioning phase.

4. ANALYSIS AND OUTLOOK

An analysis of the close to 60 projects with 201 users executed during the first two years of EURO-LABS in irradiation RIs of WP4.3 reveals a great diversity of the users involved in experiments carried out within the TA framework. Based on the location of their institute, the 201 users come from 27 countries on three continents including an almost perfect coverage of EU member states. The gender balance with one fifth of female participation (somewhat typical for the field). The proportion of ECRs, especially for the financially supported users, is very high due to intentional preference of funding students and post-docs.

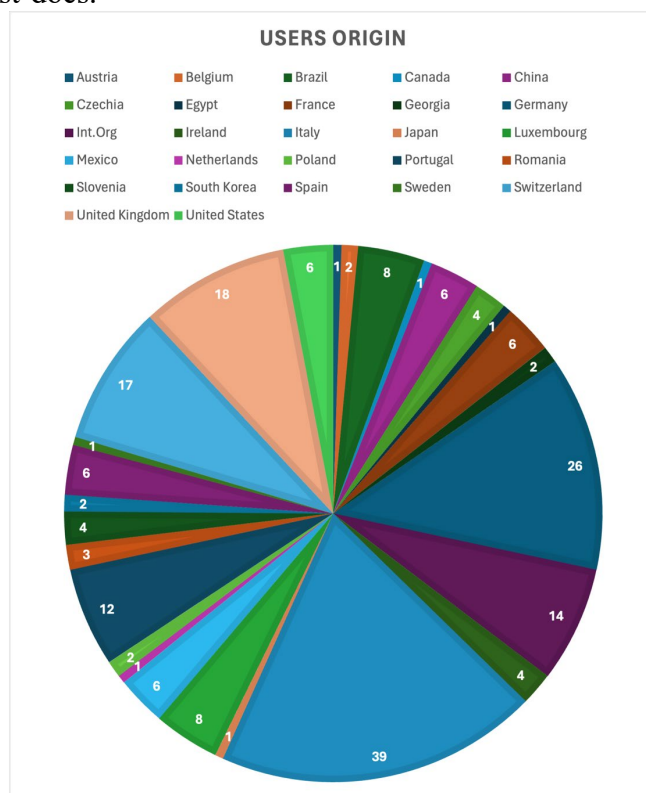


Figure 7: Distribution of TA users in WP4.3 by country in the first two years

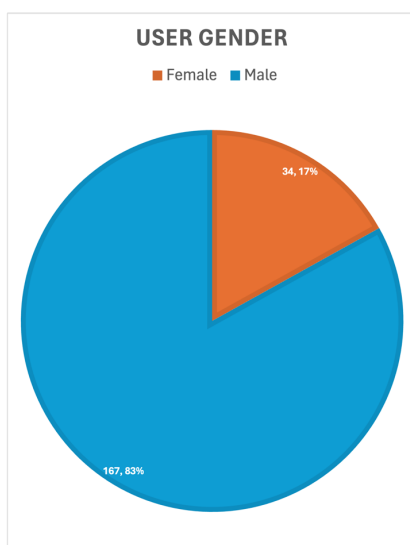


Figure 8: Distribution of TA users in WP4.3 by gender in the first two years

Even with the milestone goal achieved, the relatively low performance in WP4.3 in delivery of AUs when compared to the nominal, pro-rata expectations calls for concerted action to ensure a successful usage of EURO-LABS TA by the end of the project. The temporal decline in user interest can be attributed to two facts:

- The delays in the detector upgrades for the HL-LHC, which are binding potential users to routine QA activities and solving problems that are in conflict with genuine detector R&D.
- The organization of Detector R&D (DRD) collaborations as the implementation of the ECFA Detector R&D Roadmap. That process involved significant effort, effectively reducing the amount of R&D activity.

The construction of the upgrades is bound to last beyond the EURO-LABS project. There are still some modifications that can be regarded as pre-series verification and thus eligible for EURO-LABS support. The major upswing in user demand is though expected to arise from the activity of DRDs. DRD1 (gas detectors) has a large interest in GIF++, DRD3 (solid state) in all RIs (except GIF++) and DRD7 (electronics) in HIF and NIF at UCL (and possibly protons at IFJ-PAN). All the three DRDs were approached, delivering a presentation on EURO-LABS at their respective collaboration workshops. So, it is reasonable to expect an increased user demand for irradiation services, which should allow at task level but also individually at all the six RIs, the pledged amount of AUs to be reached.

ANNEX: GLOSSARY

Acronym	Definition
RI	Research Infrastructure
TA	Transnational Access
AU	Access Unit, usually equal to a beam hour
IRRAD	CERN Proton Irradiation facility
CHARM	Cern High energy AcceleratoR Mixed-field facility
GIF++	CERN Gamma Irradiation Facility
JSI	Jožef Stefan Institute
IFJ-PAN	Nuclear Physics Institute of the Polish Academy of Sciences
UCL	Catholic University of Louvain
UoB	University of Birmingham
DRD	Detector Research and Development
HL-LHC	High Luminosity Large Hadron Collider
ECR	Early Career Researcher