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EURO-LABS

EUROpean Laboratories for Accelerator Based Science

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DELIVERABLE REPORT

REPORT ON THE USAGE OF ACCESS UNITS FOR HEP DETECTOR R&D

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Abstract:

WP4 provides Transnational Access for detector R&D at eleven research infrastructures (RIs): three providing Test Beam (Task 4.1) access, two Detector Characterization (Task 4.2) and six Irradiations (Task 4.3). The overall Access Units (AU) delivery at close to the final point is superb, with the total pledged amount of AUs exceeded by more than 60%. Detailed analysis by RI reveals substantial differences, but only three of eleven RIs are expected to fall behind their pledge at the end of the project. Two of these still delivered more than 2/3 of AUs, while the third just remained at 1/3 of their pledge.

This report also covers the duplicate deliverable D4.3: *Report on the usage of Access Units for Irradiations* (Task4.3).

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

The EUROpean Laboratories for Accelerator Based Science (EURO-LABS) project has received funding from the Horizon Europe programme dedicated to Research Infrastructure (RI) services advancing frontier knowledge under Grant Agreement no. 101057511. EURO-LABS began in September 2022 and will run for 4 years.

Delivery Slip

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Executive summary

WP4 provides Transnational Access for detector R&D at eleven research infrastructures (RIs): three providing test beam access, two detector characterization and six irradiations. The overall Access Units (AU) delivery at close to the final point is superb, with the total pledged amount of AUs exceeded by more than 60%. Detailed analysis by RI reveals substantial differences, but only three of eleven RIs are expected to fall behind their pledge at the end of the project. Two of these still delivered more than 2/3 of AUs, while the third just remained at 1/3 of their pledge.

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, re-analyzing in test-beams, and possibly evaluating their performance in special characterization facilities. This is followed up 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 three RIs offering test beams in WP4.1 are:

- 4.1.1: CERN PS and SPS test beams
- 4.1.2: DESY-II Test beam Facility
- 4.1.3: PSI PiM1 and UCN test beams

The two RIs offering detector characterization in WP4.2 are:

- 4.2.1: RBI-AF, Croatia
- 4.2.2: ITAINNOVA EMC Lab, Spain

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 description and characteristics of individual RIs is provided in the Milestone reports MS21, MS22 and MS23 and will not be repeated here.

The report details the AU usage at the WP4 RIs throughout the project. The introduction is followed by an assessment of the AU usage, then by short reports on major achievements from the eleven RIs. An analysis of their overall performance, focussing on AU delivery concludes the report.

2. ASSESSMENT OF AU USAGE

The usage of AUs at the eleven RIs of WP4 the project (Sep 22 – Aug 26) is summarized in Table 1. While for most of RIs the figures can be considered final, for some of them they contain estimates for the last month of the project. The final figures will be provided in the Final Report in October.

WP4	Research Infrastr.	AU M48 estimate	AU pledged	% of pledge
WP 4.1.1	CERN PS-SPS	23264	8736	266.3%
WP 4.1.2	DESY TB	9312	8640	107.8%
WP 4.1.3	PSI TB	8028	5376	149.3%
WP 4.2.1	RBI	507	504	100.6%
WP 4.2.2	ITAINNOVA	390	550	70.9%
WP 4.3.1	CERN-IRRAD	4567	4000	114.2%
WP 4.3.2	CERN-GIF++	6792	4060	167.3%
WP 4.3.3	JSI	700	700	100.0%
WP 4.3.4	IFJ-PAN	792	800	99.0%
WP 4.3.5	UCL	65	100	65.0%
WP 4.3.6	UoB	101	300	33.7%
WP4 all	Overall	54518	33766	161.5%

Table 1: Usage of AUs at the eleven RIs of WP4. The AUs estimated to be delivered by end of the project, the AUs pledged for the duration of the project and the accomplished percentage of the pledge are provided by RI and for all RIs of WP4.

The overall AU pledge across WP4 is thus exceeded by 60%. There is a clear three-tier division of RIs: the 1st tier (CERN PS-SPS, PSI TB, CERN GIF++) providing excess AU delivery by 50% or more, the 2nd tier (DESY TB, RBI, CERN IRRAD, JSI, IFJ-PAN) within 15% of the target and the 3rd tier (ITAinnova, UCL, UoB) delivering less than 85% of their pledge. It is to be noted, that by the submitted addendum to the Grant Agreement, ITAinnova's initial pledge of 800 AU has been reduced to 550, and the resources re-distributed as a corrective action.

The notable excess of the CERN-based RIs can to a large extent be traced back to the change of Long Shutdown (LS)3 schedule. At the project start, the CERN accelerator complex was scheduled to stop in 2025 for the installation of the High-Luminosity LHC (HL-LHC) upgrade. With the accumulated delays, the schedule was adjusted, providing an additional year of exploitation for EURO-LABS activities.

PSI did remarkably well, given their rather late start due to Swiss funding delay and the fact, that the 2026 test-beam season for them starts after the end of EURO-LABS.

Individually by RIs, CERN has already surpassed their full pledge of AU. On the other hand, it can be expected that the test-beams at CERN will not be available in 2026, so this advancement of AU usage is appreciated.

UCLouvain, that had a start-up with no AU delivery at project half-mark, has nearly caught up. Given their unique Heavy Ion Facility for electronics radiation testing, such turnout is still disappointing. All the more, since several targeted attempts were made to raise awareness among the user community.

ITTAinnova is a rather specific RI, targeted at system aspects of detector performance. There, the lower demand than anticipated could to a large extent be blamed on problems and delays in detector construction for the HL-LHC upgrades.

UoB suffered from their MC40 cyclotron failures, and then their priority turned to QA for the HL-LHC tracker upgrade, where they had a major commitment. As their funding is UK-internal, no corrective action to re-distribute their resources could be taken.

3. REPORTS FROM RI'S

Following are the 11 reports from individual RIs highlighting major achievements of user projects at the respective facilities. Note that the Figure and Reference labels are internal to the (sub-)chapters.

3.1. CERN

Three campaigns were chosen among the 76 projects executed at the CERN PS&SPS test-beams: The ATLAS High-Granularity Timing Detector, the CERN DRD3 Collaboration (Solid State Detectors) and ALICE ITS3 tracker upgrade.

The High-Granularity Timing Detector (HGTD)

The High-Granularity Timing Detector (HGTD) is a key element of the ATLAS Phase-II upgrade for the HL-LHC. Based on Low Gain Avalanche Detector (LGAD) silicon sensors, the HGTD will provide a time resolution of 30–50 ps per track in the forward region ($2.4 < |\eta| < 4.0$), enabling the separation of the up to ~200 simultaneous proton–proton interactions per bunch crossing expected at the HL-LHC and providing a precise luminosity measurement. With about 3.6 million readout channels, it is one of the first large-scale LGAD systems ever built.

The role of test beams and of EURO-LABS support

Beam tests are the backbone of the HGTD R&D and qualification programme: only in-beam measurements can establish the time resolution, efficiency, and collected charge of sensors and front-end ASICs before and after irradiation to HL-LHC fluences. More than 20 test-beam campaigns have been carried out by the HGTD collaboration over the last three years, primarily at the CERN SPS with 120 GeV pions, using a beam telescope (with six MIMOSA planes), MCP-PMT time references, and a cooling box to operate devices under test at their operational temperature of -30° C (Fig. 1).
EURO-LABS provided travel support for two students (one master and one doctoral student) to participate in the May 2023 beam-test campaign. During this campaign the last R&D LGAD sensor prototypes were evaluated, and work began on improving the experimental setup in preparation for the systematic testing of pre-production sensors and ALTIROC ASICS.

Impact on users and scientific output
One of the two students completed her PhD thesis: *V. Gautam, "New Silicon Devices with Charge Multiplication for the ATLAS Upgrade and Medical Applications"* (July 2024; advisors: S. Grinstein, L. Castillo García, S. Terzo). The measurements performed during the May campaign were instrumental in finalizing the pre-production sensor design and in successfully conducting the subsequent extensive test-beam campaigns on pre-production devices, documented in "Beam-test evaluation of pre-production Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector" (arXiv:2512.01855). These results validate the performance of the HGTD sensor pre-production: the LGADs meet the HGTD requirements on charge collection, hit efficiency, and time resolution: remaining below the 50 ps-per-hit end-of-lifetime benchmark, and reaching down to ~35 ps at any fluence, even after neutron irradiation to the maximum expected HL-LHC fluence of 2.5×10^{15} n_{eq}/cm^2, supporting their deployment in the final detector.

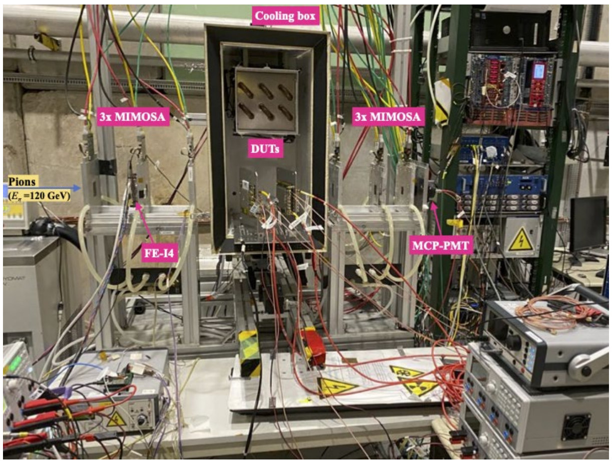

Figure 1: HGTD test-beam setup at the CERN SPS: beam telescope (3+3 MIMOSA planes, FE-I4), cooling box hosting the LGAD devices under test, and MCP-PMT time reference, in a 120 GeV pion beam.

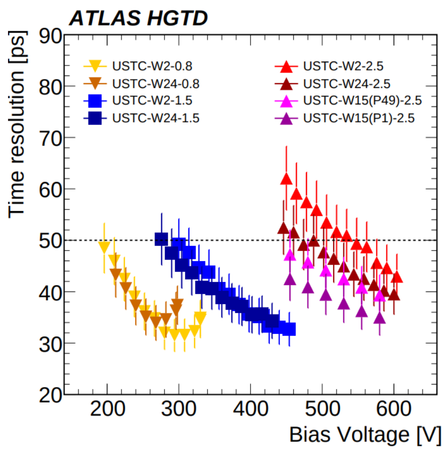

Figure 2: Time resolution as a function of bias voltage for irradiated pre-production LGAD sensors, measured in beam tests (arXiv:2512.01855).

The CERN DRD3 Collaboration – Solid State Detectors
During the 2025 and 2026 run periods at the CERN Super Proton Synchrotron (SPS) H6B beamline, the DRD3 collaboration successfully coordinated several multi-user DRD3 test-beam campaigns. These efforts advanced detector R&D for next-generation particle physics experiments, focusing heavily on 4D tracking concepts (simultaneous ultra-fast timing and precision spatial resolution).

Sharing infrastructure between the different users (main and parasitic), the DRD3 test-beam program maximized beam utilization efficiency and significantly increased scientific data yield across international research groups.

2025-2026 major infrastructure milestones:

- Deployment and optimization of the standardized AIDAinnova environmental infrastructure (including the telescope, coldbox, and chiller system) [1]. In early 2025, user groups frequently swapped out custom cooling setups, inducing operational downtime. DRD3 successfully transitioned users towards a unified AIDAinnova coldbox and chiller infrastructure in the H6B line.
- Following a complete dismantlement of the AIDA telescope at the end of 2025 (main tracking device for test-beams), the DRD3 team rebuilt a functional 5-plane tracking telescope in March 2026 using stored components.
-

2025-2026 major collaboration milestones

To extract the highest possible scientific value from SPS beam time allocation, DRD3 implemented a "multi-user matrix" during the 2025 and 2026 runs:

- Rather than allocating beam sequentially, groups actively merged hardware inside the coldbox common infrastructure, doubling data collection efficiency for those sensors over the baseline run window.
- Parasitic Data Streams: Multiple "parasitic" experiments such as the CMS-ETL ETROC setup and the Mini-Cactus timing arrays were nested downstream behind the primary telescope on dedicated high load capacity 2D tables. This permitted continuous, non-intrusive data acquisition parallel to the main user schedule.
- Data Acquisition (DAQ): In mid-2026, a comprehensive software and readout upgrade was deployed across the shared DUT (Dectector Under Test) DAQ framework. This update significantly increased global data-taking rates and exceeded original data accumulation projections.

Thanks to excellent organization, combined with the aforementioned improvement in data acquisition efficiency, more than 15 institutes from 9 different countries were able to make the best use of the beam time made available through the EURO-LABS transnational access. Some scientific highlights obtained in the framework of the DRD3 collaboration are reported below.

Highlighted Scientific Deliverables

The collaborative framework produced excellent quality data:

- The Mini-Cactus / Monolithic CMOS Project: Utilizing both standalone DESY table tracks and integrated telescope runs, the Cactus team successfully validated monolithic CMOS timing chips ("Cactus"). An exemplary result is shown in Figure 1. The test beam campaigns confirmed high timing resolution performance alongside steady data streams under varying beam conditions.

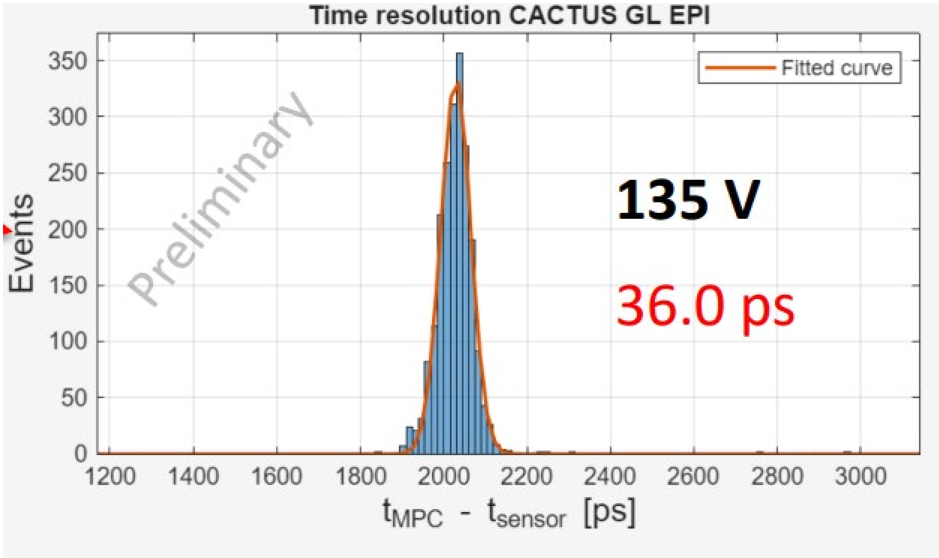

Figure 3: Time resolution of a 30 um thick epitaxial Cactus sensor with gain layer [2].

- Trench-Isolated LGADs (TI-LGADs): the campaigns achieved excellent spatial homogeneity and timing resolution measurements on both non-irradiated and highly irradiated sensors. These results verified that the fine-pitched pixel terminations achieved via trench isolation maintain signal-to-noise performance under intense particle environments. This is shown in Figure 4.

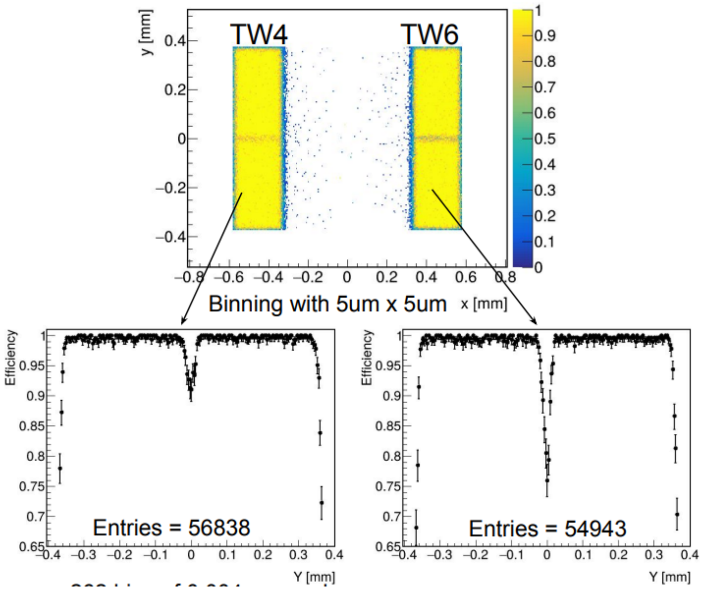

Figure 4: Vertical slice (top) and Efficiency map (bottom) showing the performance of 2 devices with different isolation trench width [3].

- DC-coupled and AC-coupled Resistive Silicon Detectors (DCRSD and RSD2): the data acquisition in the DRD3 SPS test beams proved the exceptionality of the resistive readout concept combined with LGAD substrate. The results surpassed the spatial resolution per unit pitch of the state-of-the-art detectors (down to circa 3% of the pitch), achieving at the same time the remarkable time resolution typical of LGADs, i.e., some tens of picoseconds [4].

Thanks to the presence of high energy particles, it was also possible to compare the performance of both the AC-coupled version against the one of the DC-coupled versions in the same conditions (see Fig. 5), leading to important insights for the next generation of this type of silicon sensors [5].

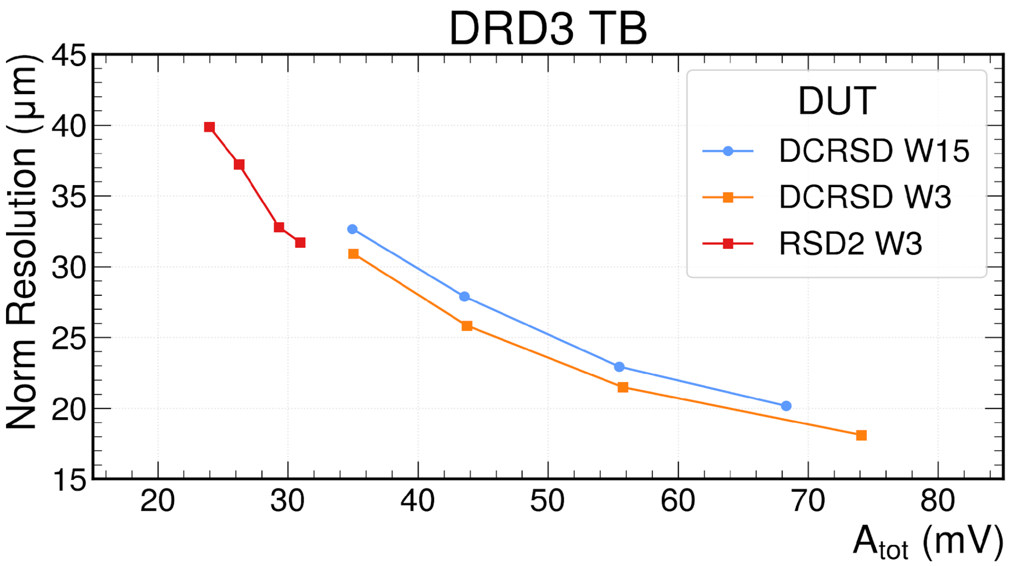

Figure 5: Spatial resolution comparison between AC-coupled (RSD2) and DC-coupled RSD performed for the first time in a test beam environment [5].

References:
[1] AIDAinnova WP3: Test beam and DAQ infrastructure objectives and deliverables, https://aidainnova.web.cern.ch/wp3
[2] S. Terzo *et al.*, 5th DRD3 week on Solid State Detectors R&D Bucharest, Romania 1st July 2026 https://indico.cern.ch/event/1634258/contributions/7135253/attachments/3306048/5915261/terzo_DRD3_Cactus.pdf
[3] A. Gonzalez *et al.,* 21st Trento Workshop on Advanced Silicon Radiation Detectors, 17th February 2026 https://indico.cern.ch/event/1586892/contributions/6846196/attachments/3221260/5740272/Trento26-Antonio.pdf
[4] R. Arcidiacono *et al.*, 5th DRD3 week on Solid State Detectors R&D, 30 June 2026 – Bucharest. https://indico.cern.ch/event/1634258/contributions/7136746/attachments/3305125/5913506/DCRSD-status-DRD3.pdf
[5] L. Menzio *et al.*, 21st Trento Workshop on Advanced Silicon Radiation Detectors, 17th February 2026 https://indico.cern.ch/event/1586892/contributions/6846205/attachments/3222919/5743894/DCRSD_vs_RSD2_TREDI2026.pdf

ALICE ITS3

ALICE's current Inner Tracking System (ITS), installed for the ongoing LHC run, is the world's largest pixel detector to date, with 10m^2 of active silicon area and nearly 13 billion pixels. The new Inner Tracking System, ITS3, builds on the successful use of monolithic active pixel sensors and takes this concept to the next level.

The ITS3 sensors are 50 µm thick and as large as 26×10 cm^2. To achieve this, a novel stitching technology was used to connect individual sensors together into a large structure. These sensors can now be bent around the beampipe in a truly cylindrical shape. The first layer will be placed only 2 mm from the beampipe and 19 mm from the interaction point. It can now be cooled by air instead of water and has a much lighter support structure, significantly reducing the materials and their effect on the particle trajectories seen in the detector.

The ALICE ITS3 project benefited of support from EURO-LABS during the testing, at the CERN SPS North Area H6 beamline facility, of several MAPS (Monolithic Active Pixel Sensor) prototypes. Analogue test structures were fabricated using the Tower Partners Semiconductor Co. CMOS 65 nm ISC process. The purpose was to characterize and qualify this process and to optimize the sensor for the next generation of Monolithic Active Pixels Sensors for high-energy physics. The technology was explored in several variants which differed by: doping levels, pixel geometries and pixel pitches (10–25 µm). The results, shown in Fig. 1, not only demonstrate the feasibility of using this technology for particle detection but also serve as a reference for future applications and optimizations. The pixel geometries tested are shown in Fig. 7

Detection efficiency vs. Threshold for different pixel pitch

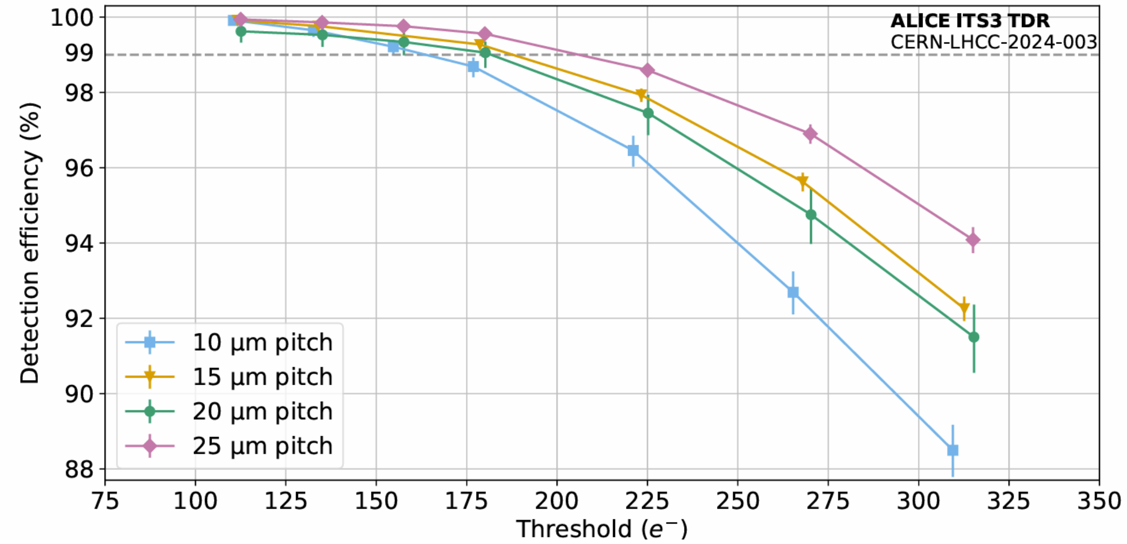

Figure 6: The detector efficiency for different pitch of the pixels.

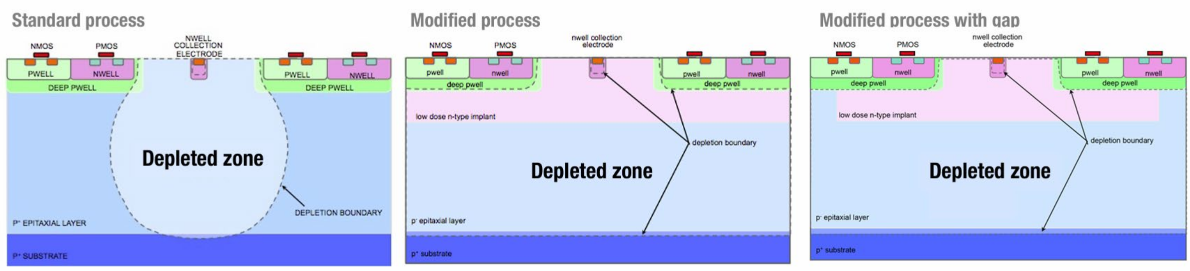

Figure 7: The three different pixel geometries tested at the CERN SPS

The APTS silicon die is shown in Fig. 8.

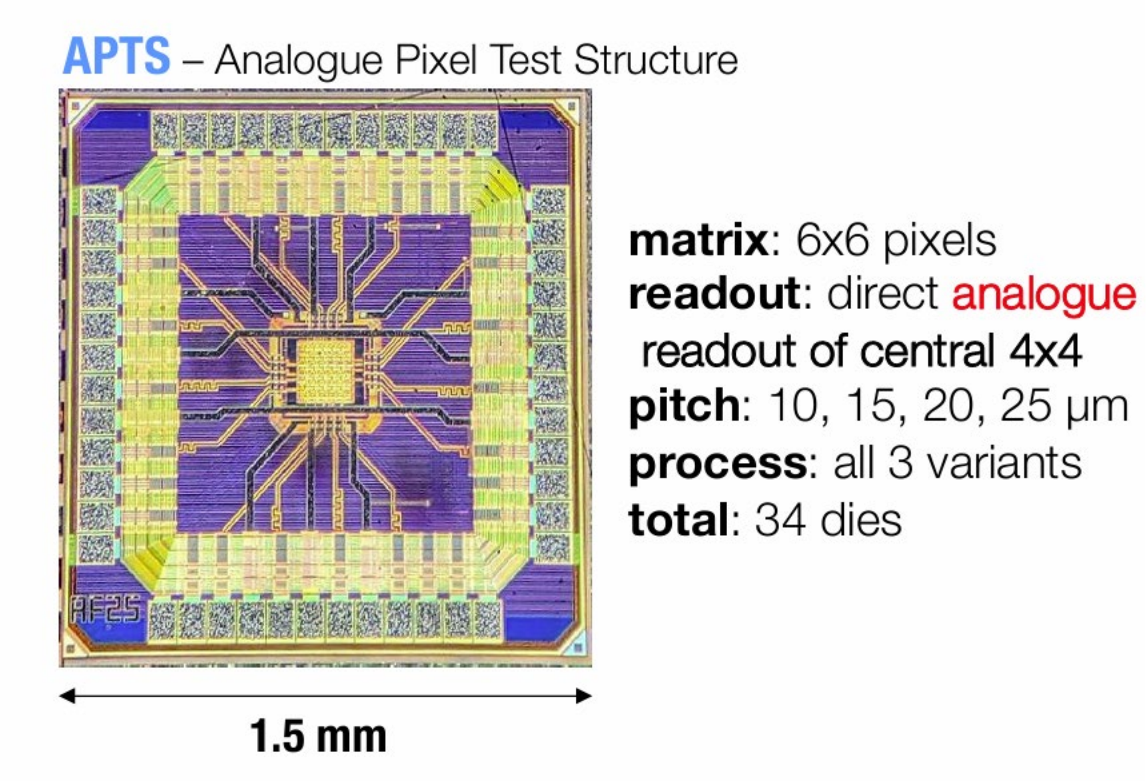

Figure 8: The die of the Analogue Pixel test structure.

In addition to the APTS SF (Source Follower), with direct analogue readout, a version with Operational Amplifier readout (APTS OP), optimised for timing performance was also tested.

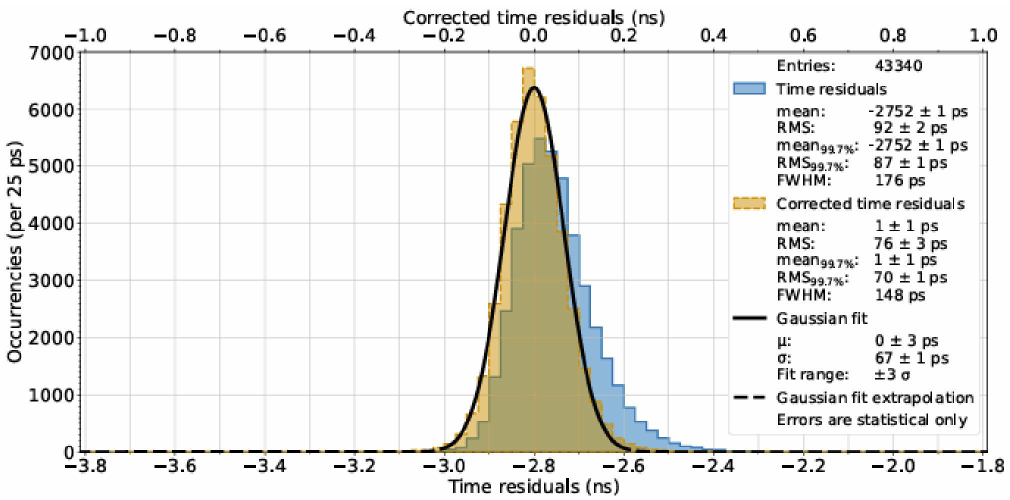

Figure 10: Time residuals measured for the modified with gap process DUT operated at $V_{\mathrm{sub}}=-4.8\,\mathrm{V}$, before (blue distribution, bottom horizontal axis) and after (orange distribution, top horizontal axis) time walk-like correction. The latter distribution is fitted with a Gaussian function on a range of $\pm\,3\sigma$ (black solid line, dashed line for points outside the fit range).

Figure 9 :Example of time residuals obtained with the APTS OP prototype.

All measurements were performed using telescope(s) based on the ALPIDE MAPS pixel chip developed for the ALICE ITS2 detector.
Typically 6 ALPIDEs (30 mm x 15 mm size, 25um pixel pitch) were used as reference planes, with the DUT placed in the middle.
Tracking was performed using the Corryvreckan package.

An example of the response for different of cluster size and spatial resolution as a function of threshold is shown in Fig. 10.

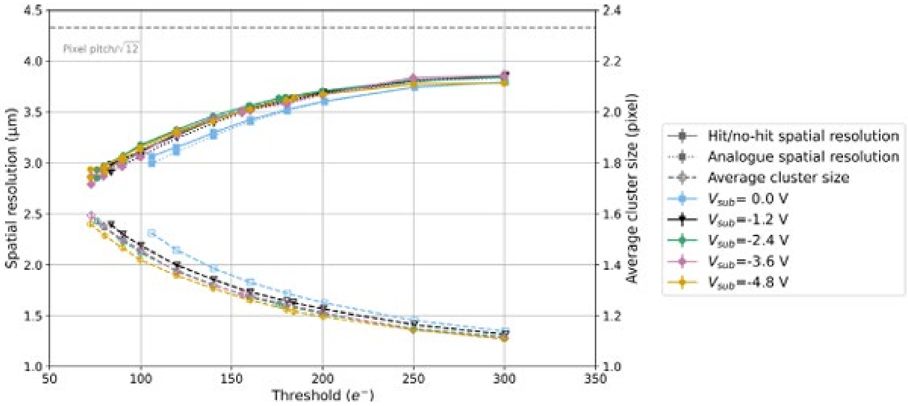

Figure 10: *Example of cluster size and spatial resolution vs. threshold for different bias voltages*

The excellent beam quality (intensity, stability and spot size) as well as the support of the CERN technical services were instrumental to the success of the measurements.

3.2. DESY

During the entire project, the DESY II Test Beam facility provided transnational access to 42 TA project groups, with a total of 194 users benefiting from this programme and conducting high-impact research at the DESY infrastructure.
This section provides an overview of a few selected highlights from the DESY Transnational Access (TA) programme, featuring several particularly interesting measurement campaigns conducted in this framework.

EURO_LABs2023-05 ATLAS-ITk-Strips (13.03.2023-27.03.2023)
Jiri Kroll jiri.kroll@cern.ch/ Czech Republic
This project has tested several modules developed for ATLAS ITk silicon-strip detector, which is an upgrade of the existing tracking system for the High-Luminosity Upgrade of the LHC (HL-LHC) at CERN. The results allowed to validate the detector design and ensure performance at the end of lifetime. The main goal of this project was to ensure that several module types developed for the ITk strip detector will perform well across the lifetime of the ATLAS experiment during the HL-LHC.

Test beam campaign, which took place in beam line TB22 of the DESY II Test Beam Facility in March 2023, served for testing of unirradiated R4 end-cap module and three modules built from irradiated sensors and unirradiated readout electronics, particularly two long-strip barrel modules and one R4 end-cap module. The unirradiated end-cap module of the R4 type was tested both in room temperature as well as cooled down to temperatures well below -40 ˚C. Investigation of the module at two very different temperatures provides us a unique chance to study the evolution of critical detection quantities, such as detection efficiency, noise occupancy, or spatial resolution, with changing environmental conditions. Both long-strip barrel modules included a sensor irradiated by neutrons (5.5E14 n_{eq}/cm^2). In the first case, the readout electronics was glued to the sensor using True Blue glue, while for the second module the collaboration used the SE4445 glue type. The last tested module was the R4 endcap module with the sensor irradiated by gamma particles (66 Mrad) and neutrons (8.5 $x10^{14}$ n_{eq}/cm^2). For the LS module glued with True Blue and the irradiated R4 module we have successfully found the interval of charge thresholds, for which the detection efficiency is still higher than 99%, while the noise occupancy is already below 0.1%.

Publications and presentations:

The results were presented by Geetika Jain (TRIUMF) during the 11th Beam Telescopes and Test Beam Workshop (DESY Hamburg, Germany, April 17-21, 2023) and represented a critical material for the ITk Strip Barrel Module Production Readiness Review (CERN, May 9-10, 2023), which successful passing basically started the mass production of ITk strip barrel modules.

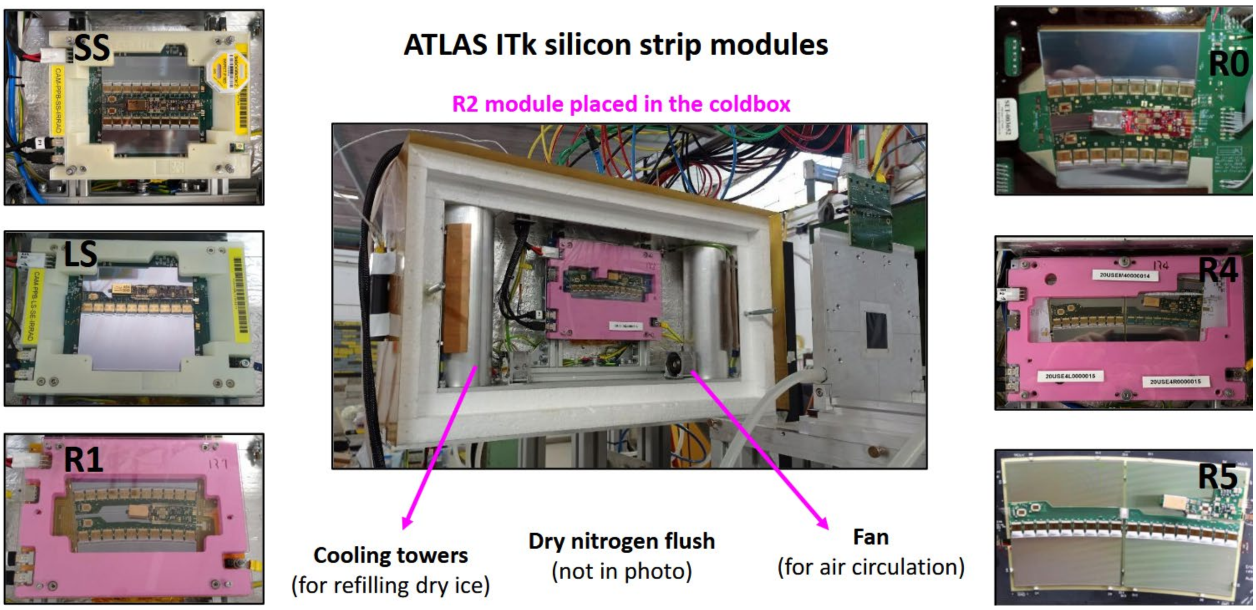

Figure 1: The ATLAS ITk strip modules

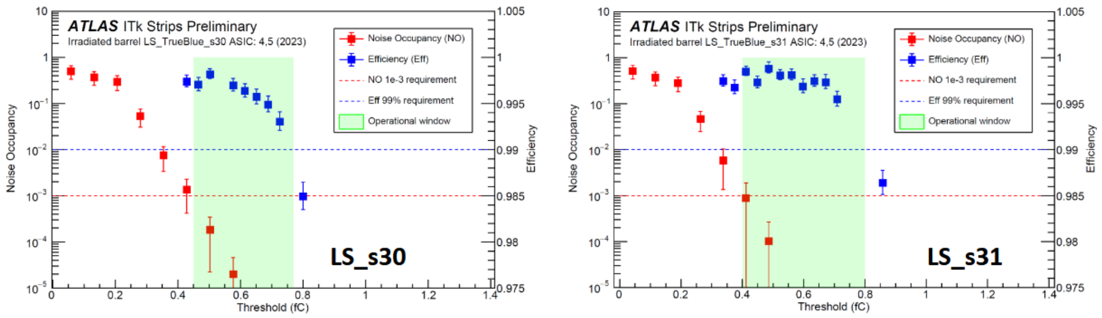

Figure 2: The wide operating window for two strip segments (shaded in green)

Since early 2022, Armenia has been an associated country to the EU Horizon Europe programme and therefore eligible to participate in the TA programme. Shortly after the association came into force, we already had the first user from this new associated country, which demonstrates that our efforts to present the DESY TA programme with increasing its visibility were successful.

Ashort highlight of the first TA project conducted within the TA programme by the Armenian research group is given below.
EURO_LABs2024-15
Study of parametric Cherenkov and X-ray transition radiation from a relativistic electron passing a plate with a periodic structure (27.05.2024-02.06.2024)/ GENERIC R&D
Vahan Kocharyan/Armenia
Spatially periodic structure could facilitate supplementary mechanisms of radiation from a moving charged particle to occur in addition to well-known Cerenkov and transition radiation. In this test beam campaign, numerous studies in this area were carried out, which particularly have shown that the spectral-angular distribution of the radiation of an electron flying through a plate, can be controlled by creating a periodic structure in the plate, in particularly by using high-frequency acoustic fields. The purpose of this project was to experimentally study these phenomena on the DESY II Test Beam Facility.
The main goals of the project were the following: 1) observation of the quasi-monochromatic lines in the spectra; 2) investigations of the connection between frequencies of monochromatic lines and parameters of the acoustic field.
Resonant transition radiation (RTR) with energies ranging from 8 to 200 keV were observed from stacks of thin aluminium foils (thickness a = 10 μm) separated by layers of either air (conventional layered radiator) or Teflon (both materials with $\varepsilon_1, \varepsilon_2 \neq 1$) (thickness b = 100 μm). The period of both radiators was fixed (d = a + b = 110 μm). It was shown that the spectrum is monochromatic even for the energy range where maxima with all diffraction orders are absent. RTR spectral measurements from the radiator with layers made from Teflon have shown sufficient suppression of the TR yield that is caused by the small difference between ωp for two materials forming the radiator. The study of the dependence of the spectral TR distribution on the observation angle indicated periodic changes of intensity.

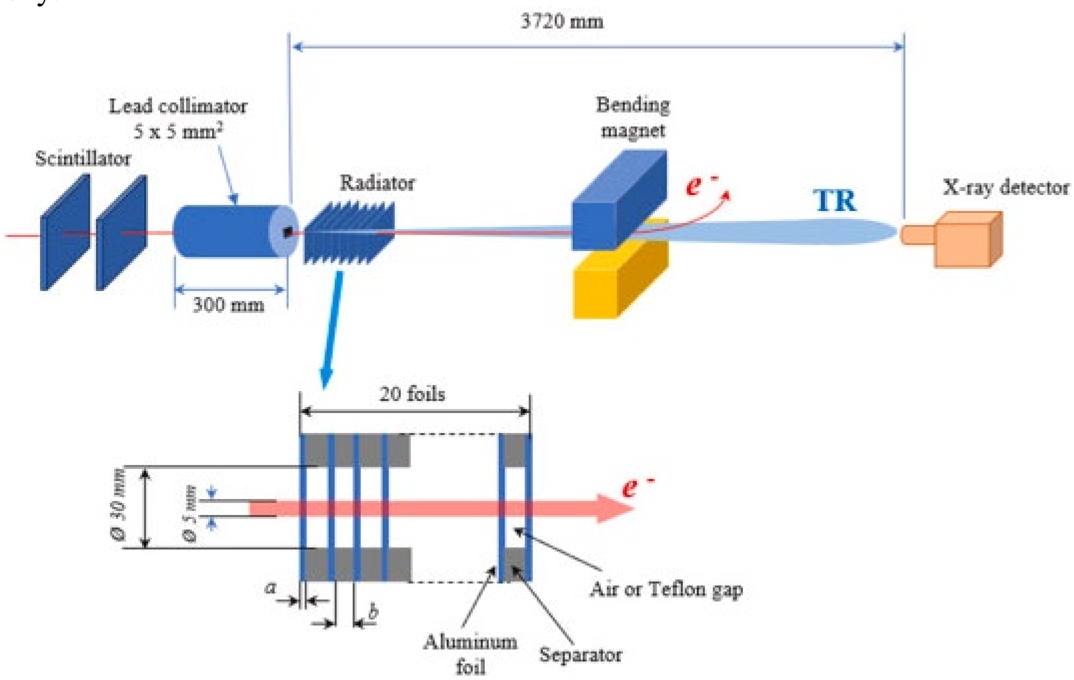

Figure 3. Experimental layout and design of radiators.

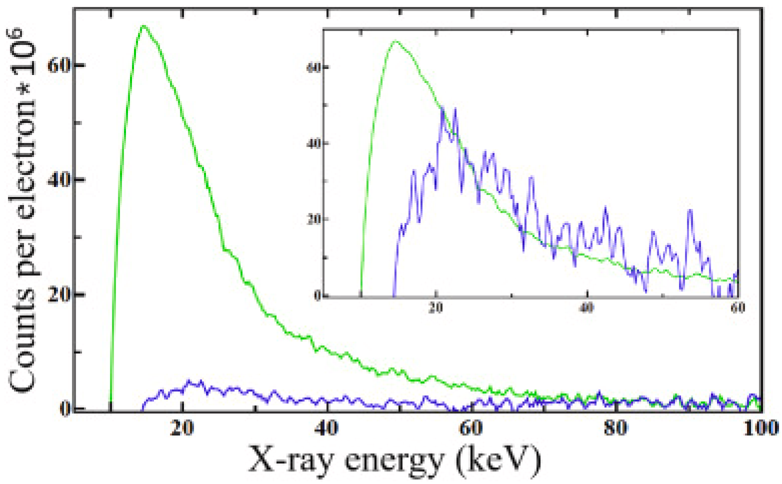

Figure 4. Cleared experimental spectra for the radiator no. 1 with air gaps (green curve) and radiator no. 2 with Teflon infilled gaps (blue curve). In zoomed part (0–60 keV region) the blue curve multiplied by 10.

The results of this TA project were presented at several international conferences and published in *Nuclear Instruments and Methods in Physics Research A* (Volume 1075, June 2025, Article 170418 "*Observation of X-ray transition radiation from a relativistic electron passing a stack of plates*").

R&D activities related to the Belle II Vertex Detector upgrade, in particular the development towards the fully pixelated MAPS-based VTX system for SuperKEKB, have also benefited from the transnational Access programme. The opportunity to perform dedicated measurements and detector studies within this framework has supported key aspects of the ongoing upgrade efforts:
EURO_LABs2024-18
Belle II Vertex Detector Upgrade (15.07.2024-21.07.2024)
Carlos Marinas / IFIC- (CSIC/UV)
The applicant groups developed a monolithic pixel sensor targeting the upgrade of the vertex detector Belle II experiment at the SuperKEKB collider (Japan). The DESY beam infrastructure was used to test the response of irradiated TJ-Monopix2 chips to 6 GeV impinging electrons. The feedback from the beam test was crucial to validate the performance of the first tailored CMOS chip towards Belle II vertex detector upgrade.

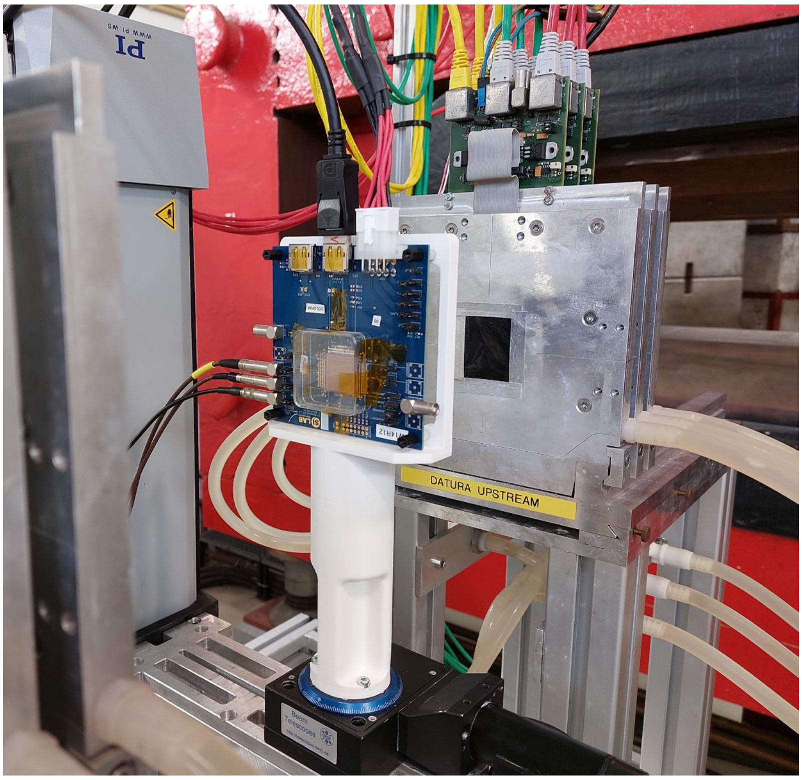

Figure 5 The TJ-Monopix2 chip mounted inside the beam telescope at the DESY Test beam

Determination of the efficiency and resolution of irradiated TJ-Monopix2 chips (X-rays, protons) to the total levels expected at Belle II was the main goal of this measurement camping. The test beam campaign evaluated TJ-Monopix2 irradiated samples (TID up to 1 MGy, NIEL up to 5 × 10^{14} neq/cm²). At high TID levels, both DC and AC coupled front-ends achieved 99.9% efficiency, while at high NIEL fluences, performance slightly degraded due to increased leakage current and temperature effects. The DC cascode maintained >99.5% efficiency with ~3% masked pixels, while the AC cascode reached 98.5%. Above 40°C, threshold and noise increased, reducing efficiency. These preliminary results on temperature effects suggested further investigation; the next test beam was planned to explore a wider range of temperatures and fluences to fully characterize sensor performance.

Since Ukraine is also an associated country to the EU Horizon Europe programme, we were pleased to offer our Ukrainian colleagues, even in these difficult times, the opportunity to benefit from the TA and remain involved in scientific research. They were able to carry out their project within the TA framework, with selected results presented here.

EURO_LABs2025-24
X-ray transition radiation by high-energy electrons in external magnetic field (16.06.2025-22.06.2025)
Sergii Trofymenko /Ukraine (GENERIC R&D)

X-ray transition radiation (XTR) of high-energy particles in thin foils has been extensively studied both theoretically and experimentally and is a nice tool for detecting and separating high-energy particles. XTR is formed on a certain distance along the particle velocity after its passage through the

target, known as formation length. If the particle deflects to a sufficiently large angle within the formation length under the impact of external magnetic field, the formation of XTR can be violated and its characteristics modified. Such an effect has never been investigated for XTR. The aim of this project was to experimentally investigate the influence of external magnetic field on XTR spectrum under conditions which can be realised at the DESY II Test Beam Facility.
The main goal of the project was to perform the first experimental observation and investigation of the influence of the external magnetic field on the spectral properties of XTR by high-energy electrons. For sufficiently high electron energies and small detector acceptance angles it is expected to observe the effect of XTR suppression, which can be considered as some analogue of the Landau-Pomeranchuk-Migdal effect of the Bremsstrahlung suppression.
A series of measurements of the X-ray spectra produced by multi-GeV electrons deflected in the field of a dipole magnet has been carried out at the TB21 facility. The absolute values of the X-ray synchrotron radiation spectra for 4 and 5 GeV electrons were obtained, allowing additional verification of synchrotron radiation theory in the X-ray range—both for the spectral shape and the absolute values of the spectral density. To investigate the influence of interference between transition and synchrotron radiation on X-ray spectra produced in a target placed in an external magnetic field, a thin multi-foil target was constructed and tested. An optimal detector position was determined for this measurement, and a series of preliminary measurements of radiation spectra were carried out.
The results were presented at several international conferences and were followed by further theoretical research based on the experimental findings.

3.3. PSI

The EURO-LABS project in Switzerland could only be started in 2023 as the funds for TA support needed to be confirmed by SERI, the Swiss State Secretariat for Education, Research and Innovation. The first 4.5 months of the beam period in 2023 were dedicated to a physics experiment, MUSE. Test beams were scheduled for the time after October. Only 2 teams doing test beams applied for TA support: COMET and a group from Mainz and Heidelberg.
The COMET experiment will search for the muon-to-electron conversion process at J-PARC, Japan. This project will primarily involve negative pions, muons, and electrons with a momentum of <200 MeV/c. The primary objective of the test beam was to scrutinize the secondary particles emanating from tungsten blocks, subjected to pions and muons. This analysis was facilitated by a set of plastic scintillating counters. Both tested detectors will contribute to the particle-type identification of these secondary particles.
The group consisted of 12 scientists from Japan, France, and the UK. Five of them -- all PhD students -- were supported in the framework of the EURO-LABS project.
The 2nd group supported tested a very compact spectrometer consisting of a four-layer pixel detector and a strong permanent neodymium dipole magnet. This setup serves as a demonstrator for a "photon tracker", where the conversion electron positron pair is tracked in double layers of pixel detectors. The pixel tracker is based on MuPix sensors developed for the Mu3e experiment. The project was granted two weeks of beam time. Four undergrad-students form the Universities of Heidelberg and Mainz obtained TA support.
In 2024 the schedule is similar to 2023. The PiM1 beam line is dedicated to the MUSE experiment up to mid-August and from the 2nd half of October. Test beams are only scheduled for the time in-between. However, three groups have applied for TA and have been supported.
In 2025 the beam schedule was again in favour of the MUSE-experiment, leaving space for only 2 supported test beam campaigns. As highlight one can mention the PIONEER-experiment (a next generation rare pion decay experiment) which tested prototype crystals for their proposed LYSO-

calorimeter (see Fig. 1). They proved that with this technology the requirements of the PIONEER-experiment can be met which triggered the experiment's base line decision for this calorimeter technology.

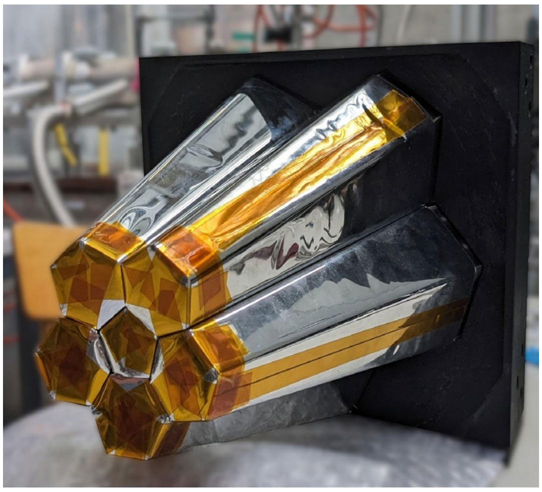

Figure 1: Set of six LYSO crystals used in the PiM1 test beam area.

In 2026 the period in which PiM1 is available for device testing starts in September which is after the termination of EUROLABS. Although there were several projects which would have profited from TA-support, they cannot not be funded anymore.

Fig.2: Team during the preparation of the test beam measurements. Six of the seven persons receiving TA support, are in the picture (all PhD students and postdocs).

The Ultra Cold Neutron (UCN) West-2 beam line is a dedicated beamline for testing UCN equipment and detectors. However, dedicated detector tests were carried out at all beamlines. At beamline West-1, detector tests for the tSPECT experiment were carried out, with explicit testing of important monitoring counters at specific beamline positions, and UCN counters for high efficiency UCN counting with low or close to zero Fermi potential. On UCN beamline south spin polarized UCNs can be provided and several detector tests of scintillation counters based on CF_4 gas at various pressures were carried out. In addition, spin polarized UCN detector tests, characterizations and optimizations were performed. These detectors are very important for fundamental physics experiments, most prominently the search for a neutron electric dipole moment. Many detector testing projects could be supported.
Despite the limitations in the first and final year EURO-LABS was very successful at PSI. In total 64 users received TA-support for a total of 659 days.

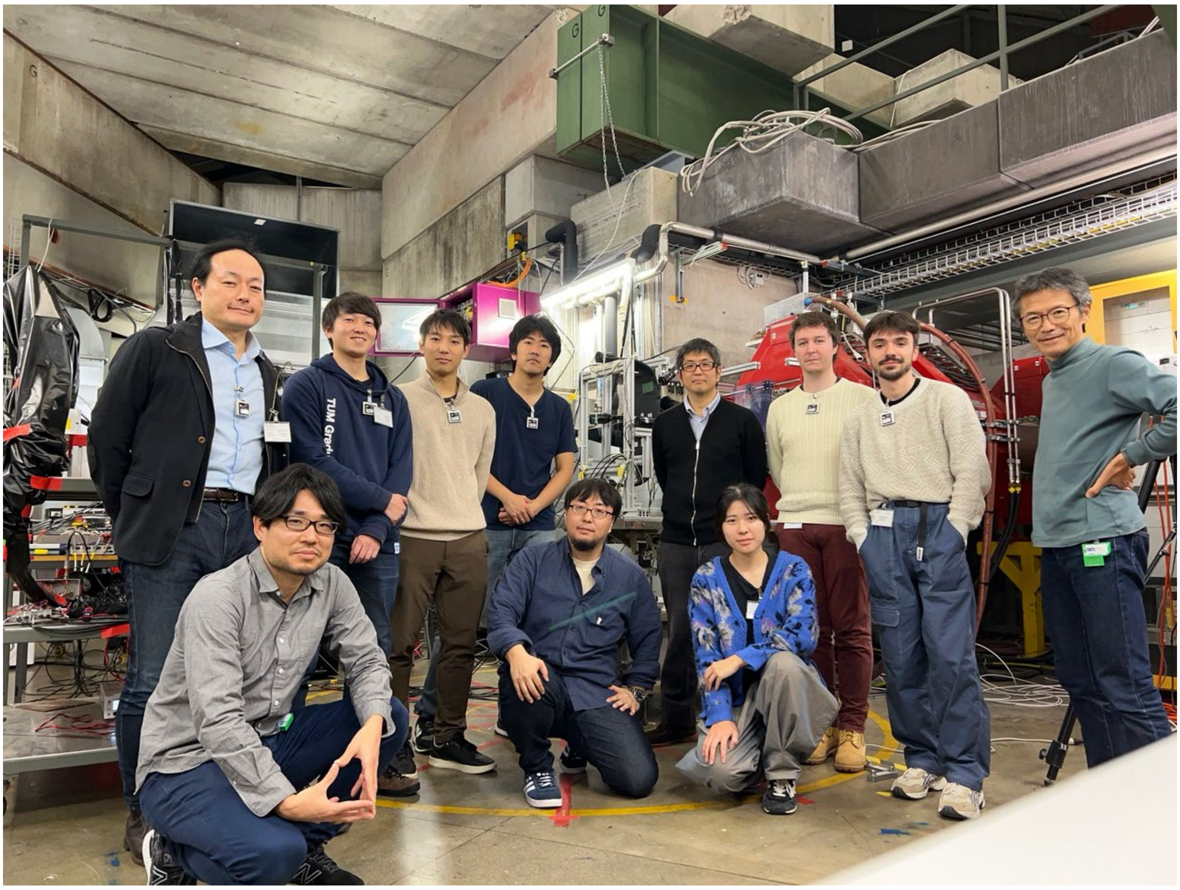

Figure 1: Members of the COMET test beam team at the PiM1 line in PSI, their set-up in the background.

3.4. RBI

The Ruđer Bošković Institute Tandem Accelerator Facility (RBI-AF) has been used by TA users for detector characterization. During the project lifetime 12 TA user projects have been approved, as initially planned. Until May 2026, 11 projects were implemented and the remaining one is scheduled for June 2026. For their studies, the users have had on disposal two ion microprobes and other end station depending on the actual objectives of the proposed work.

Most users used in vacuum and in-air Ion Beam Induced Charge (IBIC) imaging of charge collection properties to study novel solid-state detectors, based on silicon, silicon carbide and diamond, using protons of up to 10 MeV with micrometre spatial resolution as a probe. Some users used time resolved IBIC (lateral and frontal IBIC), and in some experiments the users used ion beams to perform real-time controlled damaging of small detector areas to study sensitivity and detector response to various radiation levels. Several projects were focused on the analysis of novel materials for detector and related technologies (one investigated power devices). In particular, the users investigated various detectors and (potential) detector materials for the range of applications, such as:

- TA1) Novel ultra-thin SiC radiation detector for ion beam detection (SenSiC GmbH, Villigen, Switzerland and INFN, Torino, Italy)
- TA2) Large area single pad SiC detector for particle identification (INFN-LNS, Catania, Italy)
- TA3) Si based SiTeK Position Sensing Detector (University of Torino, Italy)
- TA4) Study of Li channelling implantation in single crystal SiC and diamond of importance for detector technology (National Technical University of Athens, Greece, and Vinca Institute, Serbia)
- TA5) High temperature implantation of group IV elements into diamond for the color center creation process in diamond (Institute of Quantum Optics, Ulm, Germany)
- TA6) Adaptation of Fluorescence Nuclear Track Detectors (FNTDs) for fast neutron dosimetry (German Cancer Research Center, Heidelberg, Germany)
- TA7) Characterization of cathode materials of energy storage devices (University of Salerno, Italy)
- TA8) Study of commercial diamond crystals intended for detector fabrication (National Technical University of Athens, Greece)
- TA9) Investigation of avalanche mechanisms in diamond electronic structures to support the development of high-field diamond detectors and power devices (CEA LIST, France)
- TA10) Characterization of evaporated foils used for MPC detector triggering (NCRS Demokritos and National Technical University of Athens, Greece)
- TA11&12) Investigation of the SP@M instrument based on the thick Si detectors to study the detector response and to validate the pulse discrimination algorithms to measure the electrons and protons around Mars for the planned ESA M-MATISSE mission (Institute of Research in Astrophysics and Planetology, Toulouse, France)

Two examples are shown to illustrate the results obtained by the users after the first two experiments performed at the RBI-AF. These two examples are selected since the authors have had enough time to perform full analysis of experimental results and publish the related research articles.

TA1) A sub-micrometre ultrathin silicon carbide sensor has been tested for operation as an in-beam counter of transmitted ions (Figure 1). The SiC sensor signals, when compared to a Passivated Implanted Planar Silicon detector signal, exhibited a 96.5% ion detection confidence, demonstrating that the membrane sensors can be utilized for high-fidelity ion counting. Furthermore, the angular straggling of transmitted ions due to the interaction with the SiC sensor was assessed, employing the scanning knife-edge method of a focused ion microbeam. The lateral dimension of the ion beam with and without the membrane sensor was compared to the SRIM calculations. The results were used to discuss the potential of such experimental geometry in deterministic ion-implantation schemes as well as other applications.

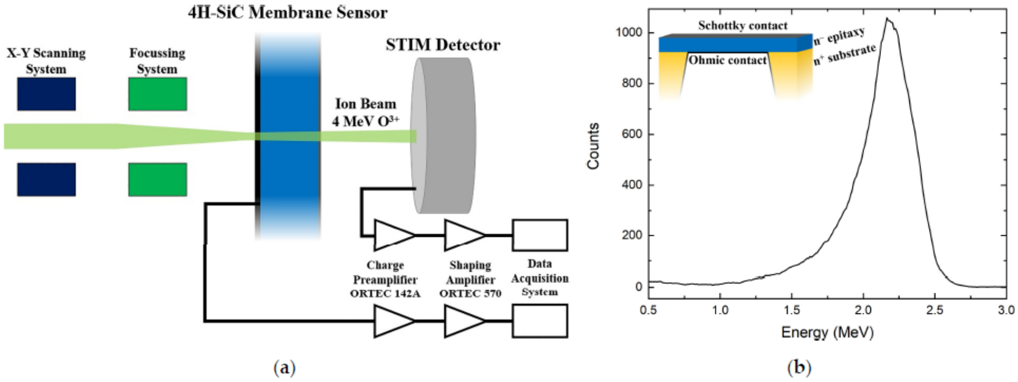

*Figure. 1: (**a**) Schematic of the experimental setup for the calculation of the sensor thickness and counting measurements; (**b**) energy spectrum obtained by the STIM detector used for the determination of the SiC sensor thickness. In the insert, a schematic cross-section of the SiC sensor is shown. (Figure taken from Sangregorio et al. [Ref. 1].*

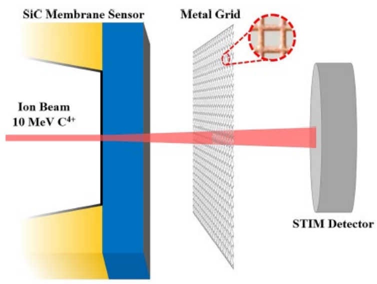

Figure 2: Schematic representation of the experimental setup used for the lateral straggling determination (Figure taken from Sangregorio et al. – Ref. 1).

<u>TA 2)</u> In this work large area, p–n junction, silicon carbide (SiC) detectors (Figure 3), designed to be used to construct the new particle identification system of the focal plane detector of the MAGNEX magnetic spectrometer foreseeing the NUMEN experimental campaigns, were characterized in terms of the charge collection efficiency (CCE) both in the inner areas and along the perimeter.

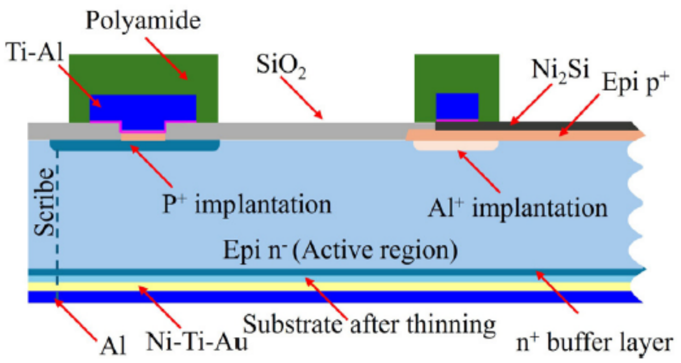

Figure 3: Sketch of the sectional view illustrating the internal structure of the SiC device – not to scale. (Figure taken from Spatafora et al. – Ref. 2).

Ion beam induced charge technique with a proton microprobe was used for obtaining a 3D characterization of the CCE(Charge Collection Efficiency) of the SiC detectors. The technique was used to draw the CCE profile with accuracy as low as 10 µm along the surface area and to explore a possible dependence on the depth of the detectors by exploring a range of proton incident energies from 1.26 to 3.92 MeV. In the inner area a good uniformity in the signal collection was found, whereas an anomalous behaviour was observed in two of the four edges (Figure 4).

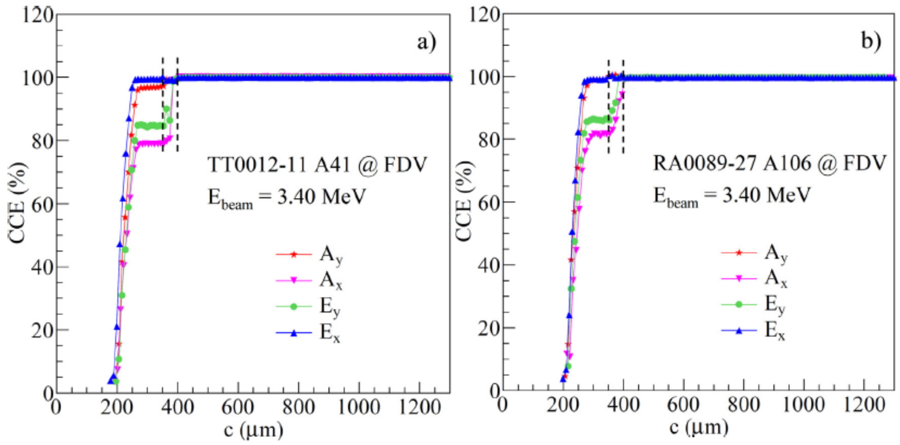

Figure. 4: Comparison between the CCE profiles measured at 3.4 MeV proton energy on the four edges of two SiC devices (shown on a and b panels). In two of the four edges a drop of the CCE down to about 80% is found in the region 250 – 350 µm. (Figure taken from Spatafora et al. – Ref. 2).

The obtained results suggest the necessity to improve the wafer cutting techniques together with a recast of the edge structures. Guided from the results of this paper, a new production of SiC detectors was recently started with further improvements on the cutting techniques (e.g. grinding wheel) and widening of the edge structure. The results of this experiment have been published by Spatafora *et al.* (Ref 2).

Ref. 1: E. Sangregorio *et al.*, Materials 16 (2023) 7692 (DOI: 10.3390/ma16247692)
Ref. 2: A. Spatafora *et al.*, NIM **A1084** (2026) 171254. (DOI:10.1016/j.nima.2025.171254)

3.5. ITAINNOVA

Within the EURO-LABS framework, the ElectroMagnetic Compatibility (EMC) laboratory at ITA performs both standard and advanced EMC testing to evaluate electromagnetic emissions and susceptibility in detector electronics. These tests provide detailed insight into noise coupling mechanisms and system response, enabling the characterization of front-end electronics under realistic operating conditions. The measurements are particularly relevant for assessing grounding strategies, identifying sensitive regions, and analysing the frequency response of detectors to conducted and radiated noise. In addition, the laboratory supports the optimization of filter designs and the definition of noise emission requirements for power supplies, contributing to the robust design of high-performance detector systems. During the project, a wide range of systems has been characterized, including electronics for pixel detectors, Micromegas-based detectors, and timing detectors.

ARC4IAXO Micromegas EMC Characterization

This work addresses the EMC characterization of the data acquisition (DAQ) system for Micromegas detectors developed within the IAXO (International Axion Observatory) experiment, with a progressive approach covering both subsystem and full-system integration. In the first stage (EURO-LABS-TA-EMC-2024-002), the focus is placed on the standalone evaluation of the ARC-based DAQ modules, incorporating AGET and STAGE ASICs, to assess their susceptibility to conducted electromagnetic interference and to optimize grounding, shielding, and operating conditions. In the second stage (EURO-LABS-TA-EMC-2024-003), the study is extended to the complete signal chain, including the Micromegas detectors and the dedicated RadioPure flat cables ("Limandes") used for interconnection. This phase specifically investigates the impact of sensor and mechanical constraints on noise coupling and overall system performance.

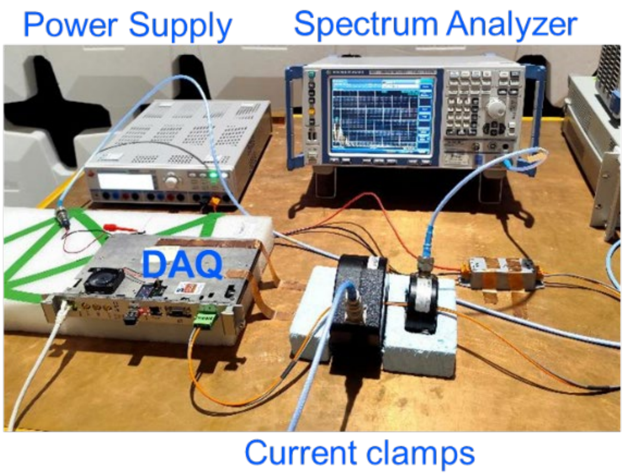

Figure 1:Test set up for ARC-based DAQ modules.

Figure 2:Test set up for IAXO ARC-based full system test

During the first set of tests, a detailed characterization of the ARC-based DAQ system was performed. The frequency response of the Front End of AGET ASIC, as well as its noise response and gain behaviour, were evaluated for different shaping times and gain settings. These measurements enabled the identification of optimal AGET-ASIC configuration parameters that provide a more robust response against noise. This parameter optimization process is illustrated in Figure 2, which shows the gain characterization of the analogue front-end conditioning stage under multiple configuration conditions

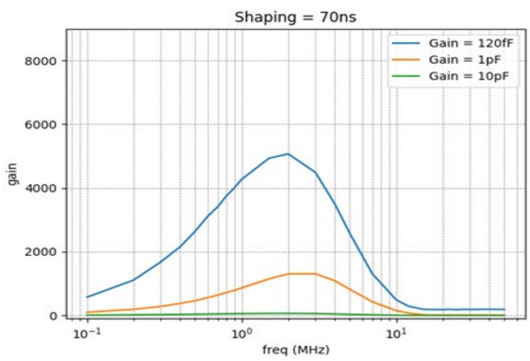

Fig. 3: Gain response of the ARC-based DAQ for a shaping time of 70 ms

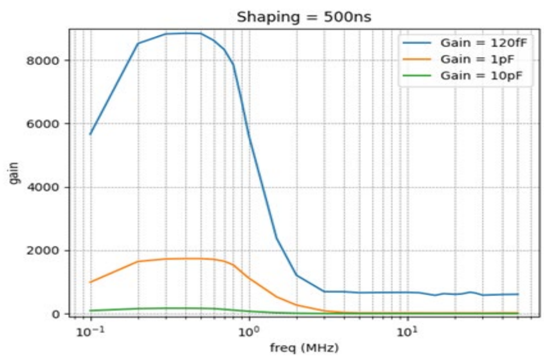

Fig. 4: Gain response of the ARC-based DAQ for a shaping time of 500 ms

During the second test campaign, the full detector system, including the remaining components and interconnections, was evaluated. The results clearly show a significant impact of the sensor connections on the overall noise susceptibility, as illustrated in Fig 4. In particular, the measurements highlight the importance of the interconnection scheme as a critical path for noise coupling. Additionally, the introduction of filters in the Micromegas bias lines proved to be essential for improving the robustness of the detector against conducted electromagnetic noise, as shown in Fig.5.

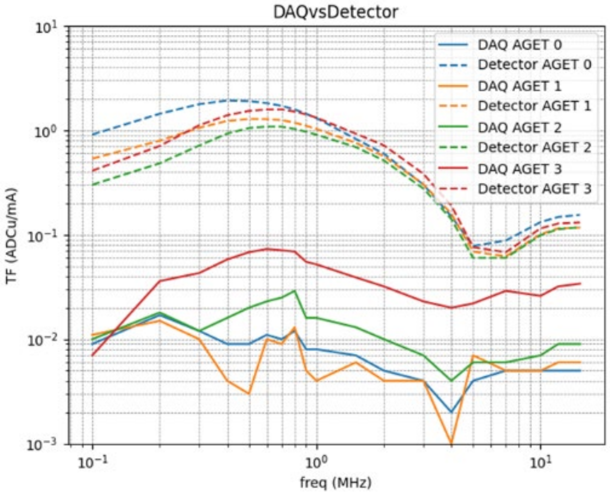

Fig. 5:CM TF on power lines of ARC based IAXO FEE with and without micromegas connection

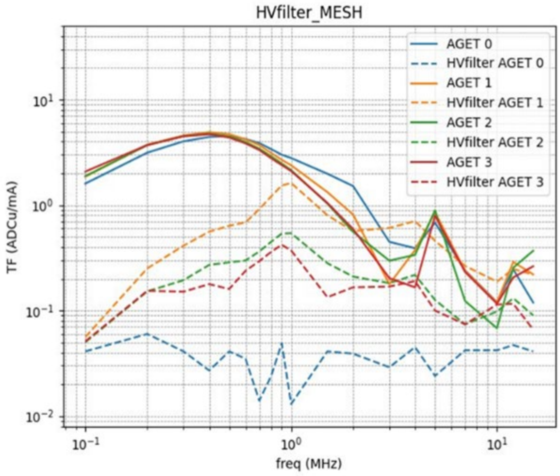

Fig. 6:CM TF on HV lines of ARC based IAXO FEE with and without HV CM filter

The combined results provided the IRFU-CEA group at the University of Paris-Saclay, as well as the IAXO community, with valuable insights into the EMI/EMC behaviour of the detector's readout architecture. These test results provided an in-depth understanding of noise coupling mechanisms and served as the basis for introducing specific improvements to the design of interconnections, grounding schemes, and noise mitigation strategies. It is the first time that this type of test has been performed in a astroparticle physics experiment.

ETROC2 EMC Characterization

The objective of this project is to perform a comprehensive EMC and noise susceptibility characterization of the ETROC2 timing ASIC, developed for the CMS Endcap Timing Layer (ETL), under realistic operating conditions. Given the stringent timing requirements at the picosecond level, the study aims to evaluate the impact of electromagnetic disturbances on key performance parameters such as timing resolution, jitter, and data integrity. The test campaign at the ITA EMC laboratory focused on evaluating the susceptibility of the ETROC2 timing ASIC to conducted electromagnetic noise. The noise was injected into different coupling ports of the ETROC test board, covering a range from 100 kHz to 100 MHz.

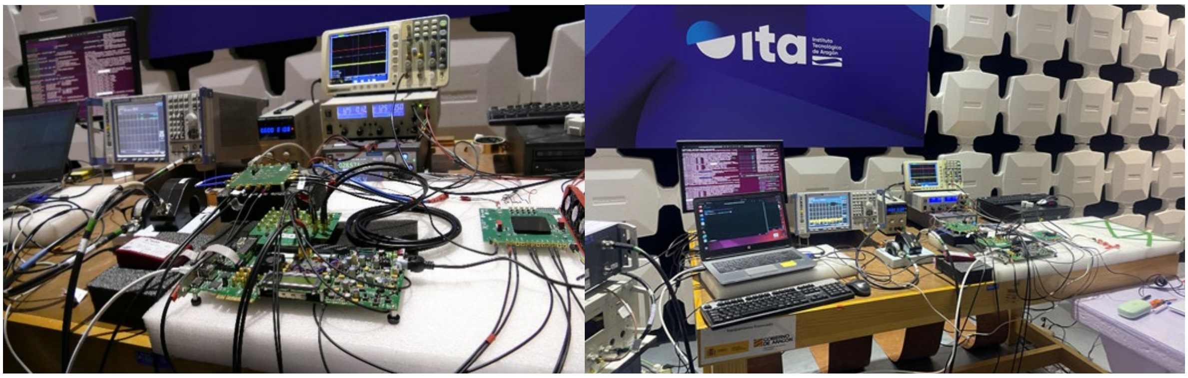

Figure 7: Test set up for IAXO ARC-based full system test

The preliminary results show a clear dependence of the noise response on the injection point, with the power supply lines (VDDA, VDDD) and clock inputs identified as the most critical coupling paths. An increase in noise width and baseline fluctuations is observed as a function of both the amplitude and frequency of the injected noise, confirming the sensitivity of the analogue front-end to conducted noise. Additionally, the power distribution network exhibits measurable noise propagation effects, which may impact supply stability and PLL locking conditions. Figures 8 illustrate the dispersion of noise across all ETROC channels as a function of frequency.

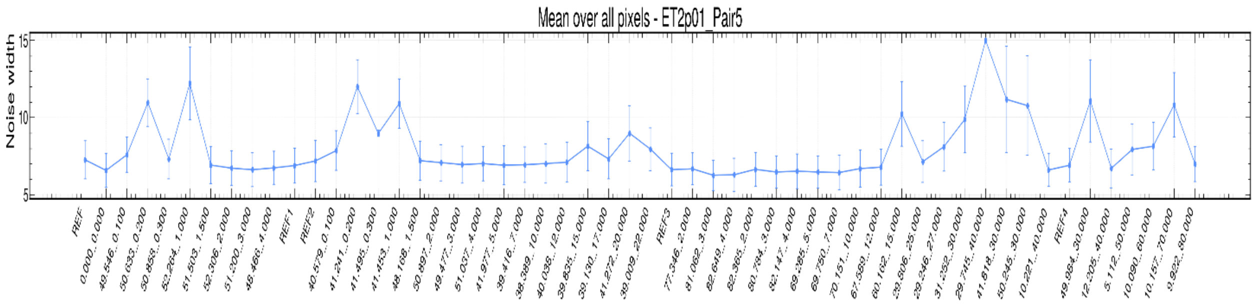

Figure 8: Noise variation per frequency in all ETROC2 channels

These results underline the importance of power integrity, filtering, and grounding strategies to preserve timing performance, and provide quantitative insight into how electromagnetic disturbances can degrade signal quality and increase jitter in high-precision timing ASICs.

3.6. CERN IRRAD

The proton irradiation facility (IRRAD) at the Proton Synchrotron (PS) East Area (EA) at CERN 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 facility is operated by Detector Technologies (DT) group in the Experimental Physics department (EP-DT) and part of a more complex infrastructure in the CERN East Area serving radiation tests. The IRRAD facility exploits the 24 GeV/c PS proton beam for irradiation experiments and was for the last four years heavily loaded with irradiation experiments serving the qualification and testing of materials and components for the upcoming HL-LHC upgrade. Next to this rich and demanding program, part of the available beam time could be made accessible through the EURO-LABS transnational access program to more generic radiation testing experiments and users outside the HL-LHC community. Two highlights of such experiments are given below that would have been difficult to implement without EURO-LABS but are of high scientific value to the HEP detector development community. The first one is targeting very high fluences in perspective of detectors for future hadron accelerators and as such required a significant number of access units. The second one is targeting a comparison of various radiation sources and facilities and, as such, not only profited from the access to the IRRAD facility but also from the access to other facilities within the EURO-LABS TA program.

Characterization of thick LGAD sensors after irradiation to very high particle fluences

The aim of the project is to measure the properties of Silicon sensors after exposure to hadron fluences above 10^{16} n_{eq}/cm^2 with the ultimate goal to design sensors capable of operating in extreme fluence regimes at 10^{17} n_{eq}/cm^2 and above. Within the irradiation project at CERN 24 sensors of different thickness and 6 test structures have been irradiated to 3 different fluences with 24 GeV/c protons. The fluences, expressed in terms of 1 MeV equivalent neutrons (n_{eq}), are 10^{16}, $5x10^{16}$ and $10^{17} n_{eq}/cm^2$.The irradiated sensors are from the EXFLU1 (EXtreme FLUence) production made by FBK [1] and comprise thin sensors, with an active thickness ranging from 15 to 45 µm, as well as compensated LGAD (Low Gain Avalanche Diodes), a new design of the gain implant that exploits the compensation of p-type (Boron) and n-type (Phosphorus) atoms to enhance the radiation tolerance of LGAD sensors. The concept of this design is shown in Figure 1. In the given example, the boron and phosphorous concentrations have a ratio of 5 to 4 and are thus resulting in an active doping level that corresponds to 1/5 of the implanted boron. The idea is to preserve an active doping level after irradiation even if large fractions of the initial implant have been rendered non-active by radiation damage.

The irradiation campaign at CERN is part of a larger campaign that aims to compare the results from different radiation sources with a similar level of equivalent fluence. In particular, results with protons will be compared with those already presented in [2] and shown in *Figure 2*. It is observed that in thin LGAD sensors with a standard gain-implant design, charge multiplication is strongly suppressed at fluences above $5x10^{15}$ n_{eq}/cm^2. The irradiation campaign at CERN IRRAD has enabled further data collection to optimise the compensated LGAD design. This study is still ongoing within the framework of working group 3 – Radiation Damage Characterization – of the DRD3 collaboration, and the results will be part of the DRD3 project CERN-DRD3-PROJECT- 2024-005 [3], aiming among others to perform post- irradiation electrical and structural characterisation, modelling, and parametrisation of very highly irradiated silicon sensors.

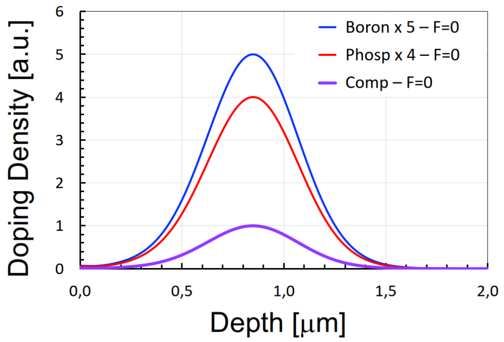

Figure 1: Sketch of the gain implant profile of the deep gain layer of a compensated LGAD.

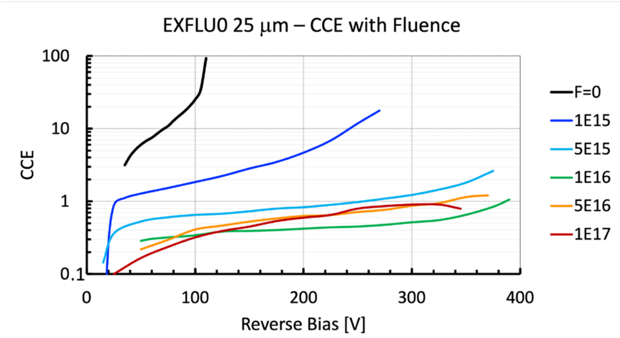

Figure 2: Charge amplification of 25 µm thick LGAD sensors before and after irradiation up to the extreme fluence of 10^{17} n_{eq}/cm^2.

HADES - HArdness factor and DEfect studies in Silicon

The HADES project (HArdness factor and DEfect studies in Silicon) aims to provide a comprehensive dataset on particle-dependent radiation damage in silicon detectors across a broad range of particles and energies, spanning from the keV to the multi-GeV regime, including neutron, electron, proton, and gamma radiation. By combining results obtained on irradiations performed at multiple facilities, employing silicon diodes of identical design, and applying standardized characterization procedures, the project ensures methodological consistency and enables cross-comparison of results. A wide range of complementary measurement techniques (including current–voltage (IV), capacitance–voltage (CV), deep-level transient spectroscopy (DLTS), and thermally stimulated current (TSC)) provides access to both macroscopic device properties and microscopic defect characteristics. By correlating defect-level information with detector performance, the project addresses known limitations of the Non-Ionizing Energy Loss (NIE) hypothesis, in particular improving the understanding of the distinct effects of point defects and defect clusters. Another central objective is the consolidation and extension of hardness factors within the NIEL scaling framework. Using leakage current as a robust damage indicator, HADES aims to reduce existing uncertainties and improve the reliability of radiation damage predictions relevant for environments such as the LHC. Overall, HADES seeks to develop an improved modelling approach beyond traditional NIEL scaling by incorporating the nature of radiation-induced defects. In combination with detailed simulations, this approach enhances the predictive power for silicon detector performance in complex radiation environments.

Irradiations for this project have been performed at several irradiation facilities, including facilities participating in EURO-LABS. In particular 24 GeV/c and 12 GeV/c proton irradiations at CERN IRRAD, 11, 16 and 24 MeV proton irradiations at the MC40 Cyclotron in Birmingham, 18, 40 and 60 MeV proton irradiations at AIC-144 IFJ PAN, Krakow and 41 and 62 MeV proton irradiations at UCLouvain-CRC as well as neutron irradiations at the JSI TRIGA reactor and in a neutron field with a spectrum around 20 MeV at the UCLouvain. A full list of the used facilities, including facilities not participating in EURO-LABS, is given in [5]. Figure 3 shows exemplary a comparison of the majority carrier traps in p-type silicon diodes after exposure to 24 GeV/c protons and reactor neutrons and Figure 4 gives an overview of existing hardness factors for monoenergetic proton sources (see [4] for details and references) including the newly obtained results for 12 GeV/c protons at the IRRAD facility. In this case the hardness factor is obtained from comparing the radiation induced leakage current per particle versus the leakage resulting from 1 MeV neutrons (see [4] for details). The samples for other facilities mentioned above are still under investigation. The point at 12 GeV/c is of particular interest, as it is a new beam setting to the IRRAD infrastructure that required a particular machine tuning and has so far not been measured in this way before.

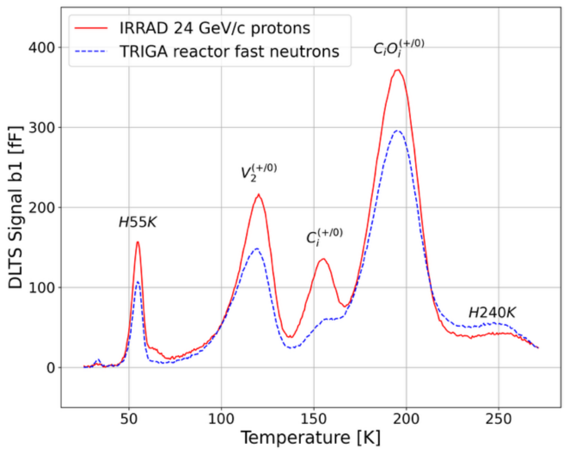

Figure 3: Deep-level transient spectroscopy *(DLTS) spectra of proton and neutron irradiated silicon diodes after exposure to the same neutron equivalent particle fluence ($2x10^{11}$ n_{eq}/cm^2). DLTS settings: T_W = 20 ms, U_R=10 V, U_P=0.6 V, t_p=100 ms.*

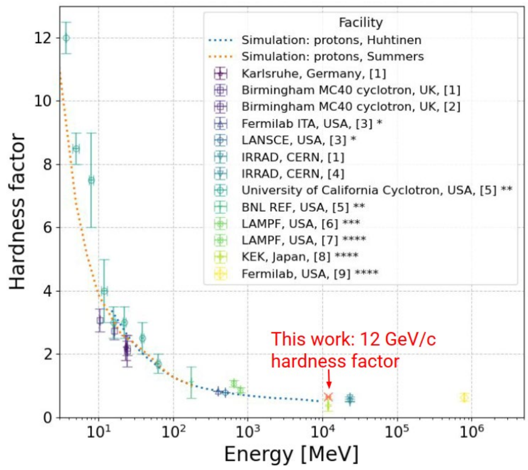

Figure 4: Hardness factors for various monoenergetic proton sources. The data are obtained from the measurement of the radiation induced increase of leakage current in silicon diodes.

3.7. 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 (North Area, Prevéssin site).
It is a unique place for detector R&D, where a strong gamma source and a muon/pion particle beam are simultaneously available. Together with the IRRAD in the East Area (Meyrin site), the 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.
The irradiator (^{137}Cs, 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 m^2. The two gamma fields (<= 2Gy/h) enable ageing studies and provide radiation background similar to the future working conditions inside the LHC large experiments.
In 2025 the facility underwent a major upgrade, with the extension of the bunker (Fig. 1).

OLD LAYOUT **NEW LAYOUT**

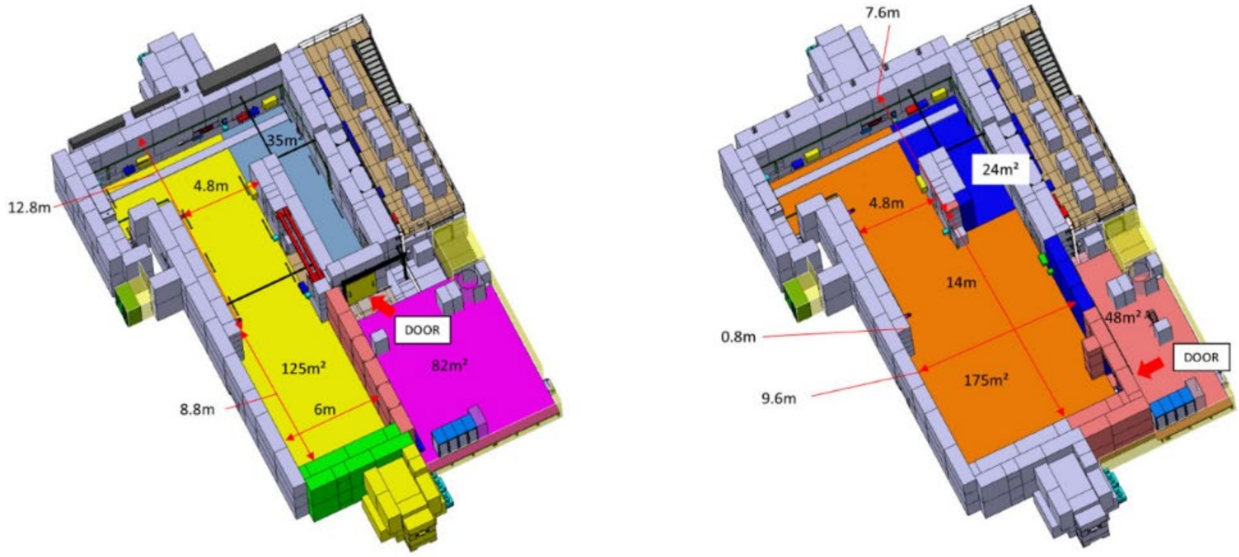

Figure 1: GIF++layout before and after the 2025 upgrade

The muon (or pion) beam, available during dedicated time slots (typically 3 x 2 weeks/year, 2 x 2 in 2026 due to the shorter running period of the SPS, before LS3) is used to investigate and validate the detectors performance and behavior under these expected conditions.

The new layout allows for a better exploitation of the beam, in particular the complete scan of large (> 1m^2) detector.

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 gas area has also been extended in order to host and support the still increasing number of users.

The facility is intensively exploited by a large collaboration, mainly composed by users belonging to the LHC experiments. On average, more than 7 setups run continuously in parallel during the year, with a peak of 15 in July 2026, during the last test beam before the Long Shutdown 3 (LS3).

During LS3, the North Area will undergo a major renovation and consolidation campaign and beam is expected to be back only mid-2029, but GIF++ will continue to run in irradiation mode-only.

The main detector R&D programme remains the upcoming upgrade of the LHC experiments in view of the High Luminosity LHC phase (HI-LUMI 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 requires, with few exceptions, long-term, even years, irradiation and scientists involved spend a large fraction (> 50%) of their working time at CERN or are permanently based at CERN. Shown in figure 2 is an experiment setup at GIF++, taken in July 2026, just before the start of the test beam period.

Figure 2: Pictures of an experiment at GIF++, taken in July 2026, just before the start of the test beam period

3.8. JSI

Radiation damage remains a major challenge for the use of silicon detectors in charged-particle tracking at high-energy physics experiments. A key performance-degrading mechanism is the displacement of silicon atoms by neutrons, protons, or other high-energy particles. This displacement damage scales with particle fluence and is typically expressed in terms of the equivalent fluence (Φ_{eq}) of 1 MeV neutrons that would produce the same effect as the irradiating particles. Silicon detectors in the innermost layers of experiments at the High Luminosity Large Hadron Collider (HL-LHC) will need to withstand fluences of up to $\Phi_{eq} = 2\times10^{16}$ cm^{-2}. Achieving such radiation hardness has required decades of research, including extensive irradiation campaigns using various particle sources. Neutrons play a particularly important role in displacement damage in silicon in particle physics environments. The Ljubljana TRIGA reactor is a key facility for studying radiation effects in particle detectors.

EURO-LABS is providing Transnational Access (TA) for irradiations under WP4. Up to now 63 irradiation projects have been approved by the user selection panel and most of them already carried out.

EURO-LABS has contributed significantly to the final stages of development of tracking detectors currently in production for the HL-LHC. Particular emphasis has been placed on improving of radiation hardness of Low Gain Avalanche Diodes (LGADs), which provide precise timing information in addition to spatial tracking. These devices will significantly extend the scientific reach of HL-LHC experiments by improving vertex reconstruction and tracking performance in high-pileup environments. Good timing resolution will also be one of basic requirements in experiments at future colliders [1,2].

Several projects have also focused on radiation testing of photon detectors being developed for upgrades of the LHCb experiment, where radiation damage is expected to become relevant even in previously unaffected detector regions [3,4].

Large irradiation campaigns within EURO-LABS have enabled continued studies of silicon detector properties at fluences approaching and exceeding HL-LHC levels. Despite decades of research, important open questions remain, driven in part by ever-increasing radiation levels. In particular, understanding the acceptor removal phenomenon is crucial, as many modern detector concepts rely on controlled internal gain to achieve high timing resolution.

A significant fraction of the projects has focused on the development of detectors for future experiments. Emphasis has been placed on resistive sheet AC coupled LGADs (AC-LGAD) technology, which aims to eliminate the dead regions present in standard LGADs due to inter-pad insulation structures [5,6].

Variants of detectors with gain such as nLGADs are being developed for the detection of low-penetrating protons, soft X-rays, and UV photons, with growing interest in imaging applications at synchrotron light sources. In applications involving low-energy protons, displacement damage remains an important consideration and must be carefully studied. [7]

Several projects have also addressed the irradiation of various monolithic CMOS detectors including projects following a broader trend toward fully monolithic designs with sensing elements with gain. EURO-LABS has played an important role in supporting these developments through TA to irradiations in the reactor [8].

In addition, several studies have investigated wide-bandgap materials, particularly silicon carbide (SiC), which is widely used in high-power electronics and has seen significant improvements in material quality. Recently, SiC-based devices with gain (LGAD-like structures) have been demonstrated. However, radiation studies, including those supported by EURO-LABS, indicate that radiation hardness in terms of Charge Collection Efficiency (CCE) remains inferior to that of silicon. Nevertheless, the inherent advantages of wide-bandgap materials—such as higher breakdown fields and lower leakage currents—may outweigh the reduced CCE in certain applications, justifying continued research [9].

The TRIGA reactor offers a unique capability for neutron irradiations over a wide range of fluences spanning many orders of magnitude. Electronic circuits containing commercial off-the-shelf (COTS) components have been tested at fluences as low as $\Phi_{eq} = 10^{12}$ cm^{-2}. Silicon devices were irradiated with only e $\Phi_{eq} = 10^{8}$ cm^{-2} in a specialized study. At the other extreme, irradiations up to $\Phi_{eq} = 10^{18}$ cm^{-2} have been carried out [10].

In collaboration with DRD3, EURO-LABS organized two irradiation campaigns at extreme fluences to accelerate the development of detectors for operation in harsh radiation environments, such as those expected at future hadron colliders or in fusion reactors. Such irradiations would not have been possible without EURO-LABS support.

The highest neutron flux at the JSI reactor reaches $\Phi_{eq} = 6.7\times10^{12}$ cm^{-2} s^{-1} in the core centre. Achieving $\Phi_{eq} = 1\times10^{18}$ cm^{-2} requires at least 40 hours of irradiation, corresponding to approximately five full shifts of continuous reactor operation for a single container. Due to the reactor's tight schedule, such long irradiations must be carefully planned and cannot be performed frequently.

For the 2024 campaign, samples were provided by 12 groups, and for 2025 by 10 groups, involving collaborations with institutions across Europe, the USA, and China. The samples included structures made of Si, SiC, ZnTe, GaN, and diamond. Only small, bare sensor samples were accepted to fit into the irradiation containers and to minimize activation. Nevertheless, the long irradiation times resulted in significant activation, requiring special handling and extended cooling periods. Most samples, however, were distributed to testing sites within three months after irradiation. These campaigns provided valuable experience in both irradiation procedures and post-irradiation handling at extreme fluences.

Results from irradiated samples have been presented at several conferences, with some already published in peer-reviewed journals. Notable studies at extreme fluences include measurements of carrier recombination lifetime and diffusion coefficients in GaN as a function of fluence up to $\Phi\_eq = 10^{18}$ cm^{-2}, as well as measurements of low-field mobility in silicon at similar fluences. Data on fundamental semiconductor parameters at such extreme radiation levels remain scarce but are essential for realistic detector modelling in future high-radiation environments in hadron colliders.
Among the irradiated silicon devices were trench 3D detectors, in which electrodes are formed within columns etched through the silicon bulk. Unlike planar detectors, 3D architectures allow the electrode spacing to be decoupled from the wafer thickness, which is advantageous under high radiation damage conditions where charge carrier trapping times are very short. As shown in Figure 1, the charge collection distributions measured before and after irradiation to $\Phi\_eq = 1\times10^{17}$ cm^{-2} are nearly identical—a remarkable result. Test-beam measurements further confirm high minimum-ionizing-particle (MIP) detection efficiency even after irradiation to extreme fluences.
Transient Current Technique (TCT) measurements of trench 3D detectors have demonstrated measurable responses even after irradiation to $\Phi\_eq = 5\times10^{17}$ cm^{-2} and 1×10^{18} cm^{-2}. These results represent promising initial steps toward the development of detectors suitable for future hadron collider environments.

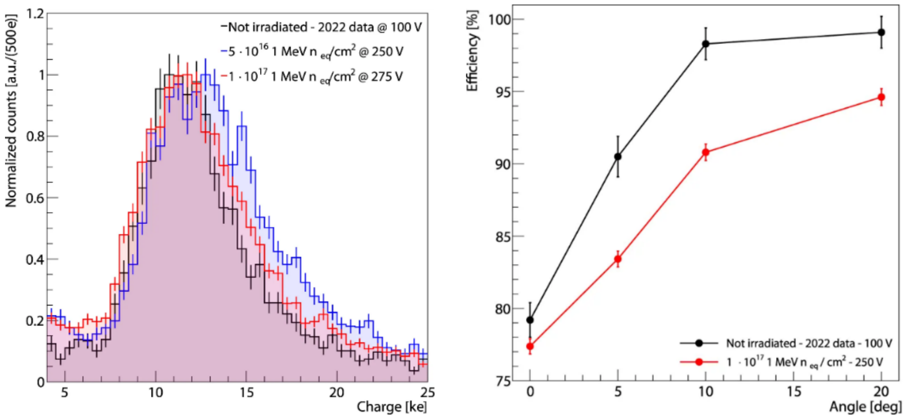

Fig. 1: Distribution of collected charge from MIP passage (left) and efficiency vs. tilt angle (right) measured in test beam with trench 3D detector irradiated up to 1×10^{17} *n/cm2 from [1].*

References:
[1] M. Ferrero *et al.,* Compensated LGAD — an innovative design of thin silicon sensors for very high fluences, 2025 JINST 20 C07023, https://doi.org/10.1088/1748-0221/20/07/C07023
[2] A. Fondacci *et al.,* Compensated LGAD optimisation through van der Pauw test structures, NIMA 1080 (2025) 170800. https://doi.org/10.1016/j.nima.2025.170800
[3] E. Curras-Rivera , G. Haefeli and F. Ronchetti, Cryogenic operation of neutron-irradiated silicon photomultiplier arrays up to 1×10^{14} neq/cm2. https://doi.org/10.48550/arXiv.2603.25478
[4] F. Asdessa et al., Optimization of LYSO crystals and SiPM parameters for the CMS MIP timing detector, 2024 JINST 19 P12020. https://doi.org/10.1088/1748-0221/19/12/P12020
[5] U. Elcibul *et al.*, Irradiation studies of the Resistive AC-coupled Silicon Detector (RSD/AC-LGAD), NIMA 1080 (2025) 170705. https://doi.org/10.1016/j.nima.2025.170705
[6] S. Stage *et al.*, Performance of neutron and proton irradiated AC-LGAD sensors, NIM A 1082 (2026) 171012. https://doi.org/10.1016/j.nima.2025.171012
[7] V. Kraus *et al.*, "Studies on the effect of low-fluence proton and neutron irradiation on n-type LGADs", NIMA 1083 (2026) 171138. https://doi.org/10.1016/j.nima.2025.171138
[8] B. Pilsl *et al.*, Enhancing radiation hardness and granularity in HV-CMOS: The RD50-MPW4 sensor, NIMA 1080 (2025) 170752. https://doi.org/10.1016/j.nima.2025.170752

[9] A. Gsponer *et al.*, Silicon Carbide Detector Development for HEP and Medical Applications , Presented at TREDI 2025, https://indico.cern.ch/event/1455346/contributions/6323070/attachments/3008026/5302852/TREDI_SiC_Gsponer_presented.pdf
[10] L. Poley *et al.*, Curing early breakdown in silicon strip sensors with radiation, NIMA 1064(2024) 169405. https://doi.org/10.1016/j.nima.2024.169405
[11] C. Scharf *et al.*, Current and low-field carrier mobility in silicon sensors irradiated to extreme fluences, 21st "Trento" Workshop on Advanced Silicon Radiation Detectors, https://indico.cern.ch/event/1586892/contributions/6846244/attachments/3221263/5740277/TREDI_2026_poster_extreme_fluences_fin.pdf
[12] A. Lampis *et al.,* Characterisation of 3D trench silicon pixel sensors irradiated at 1e17 1 MeV neq/cm−2, Front. Phys., Sec. Radiation Detectors and Imaging, Volume 12, 2024, https://doi.org/10.3389/fphy.2024.1497267

3.9. IFJ-PAN

The AIC-144 cyclotron facility provides 60 MeV proton beams with intensities of up to 100 nA in two experimental areas: (a) a former proton therapy eye-treatment room, equipped for precise positioning and clinical-quality irradiation with beam diameters of up to 40 mm; and (b) an experimental hall featuring an irradiation line with a 2D scanner (EURO-LABS service improvement), enabling the exposure of larger samples up to 400 mm × 400 mm. The facility operates as a user-oriented platform, supporting experiments in detector physics, medical physics, the space and aerospace industries, and radiobiology. The irradiation stations are equipped with a comprehensive range of dosimetry instruments and are metrologically linked to the Secondary Standard Dosimetry Laboratory in Warsaw.

Testing Commercial Off-The-Shelf *(COTS) electronics - the susceptibility of the central router to radiation faults*

This work was to radiation test of a Network On Chip (NoC) with star topology with the purpose of evaluating the susceptibility of the central router to radiation faults. The work was jointly performed by the Interdisciplinary Centre for Security Reliability and Trust (SnT), University of Luxembourg and the Department of Radiation Research and Proton Radiotherapy Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland.

Systems deployed in space must operate reliably in a radiation-rich environment. Traditionally, this has been addressed through shielding and the use of expensive space-grade Application-Specific Integrated Circuits (ASICs). However, to reduce costs and leverage the performance and energy efficiency of modern semiconductor technologies, COTS computing systems—particularly FPGA-based platforms—are increasingly being considered as alternatives. One such development is the Self-protecting Hybrid ARChitectureS (SHARCS) framework—a hardware-software approach designed to provide fault tolerance in distributed computing clusters, with a particular focus on radiation-induced faults. It was designed at the Interdisciplinary Centre for Security, Reliability and Trust (SnT) at the University of Luxembourg.

The aim of this experiment performed at the AIC-144 cyclotron using 58 MeV proton beam was to assess the robustness and fault tolerance of a computing cluster built from commercially available off-the-shelf (COTS) processors intended for operation in space. In particular, the study evaluates the system's ability to withstand faults, errors, and crashes caused by radiation-induced Single Event Upsets (SEUs) and Single Event Functional Interrupts (SEFIs). The experiment utilized a custom-designed computing cluster composed of Compute Modules arranged in a planar configuration, enabling uniform irradiation of all system components. The selected modules were COTS devices originally designed for industrial and automotive applications. Prior testing at the IFJ facility demonstrated that these components exhibit suitable semiconductor properties for Low Earth Orbit (LEO), specifically showing no latch-up events under proton irradiation up to 58 MeV.

To evaluate SHARCS in practice, selected compute modules were deployed in a clustered configuration, allowing observation of system-wide behaviour, fault mitigation strategies, and the implications of architectural design decisions. A dedicated test platform, the SHARCS Compute Cluster MVP (SHARCS-CC-MVP), was developed for this purpose. The objectives of the irradiation campaign were to observe cluster behaviour under radiation exposure, evaluate the effectiveness of fault-tolerance mechanisms, ensure consistency across distributed nodes, assess the system's ability to continue operation despite random faults and finally evaluate the system's ability to recover faulty compute modules at runtime.

The cluster was irradiated with proton flux at the level of 5.0×10^5 p/cm²/s, with gradual increase up to approximately 1.0×10^7 p/cm²/s. In order to irradiate of all four compute modules and the voting integrated circuits a wide 12 cm diameter beam was used. The irradiations were performed in two sessions of between 18 and 20 minutes, keeping the beam energy constant during that particular session. Starting with 20 MeV, the beam energy were gradually increased to 30, 40, and 50 MeV, and the maximum of 58 MeV. Whenever a failure was detected during a session that the system could not work through, we stopped the beam, rebooted the entire system, and resumed the test.

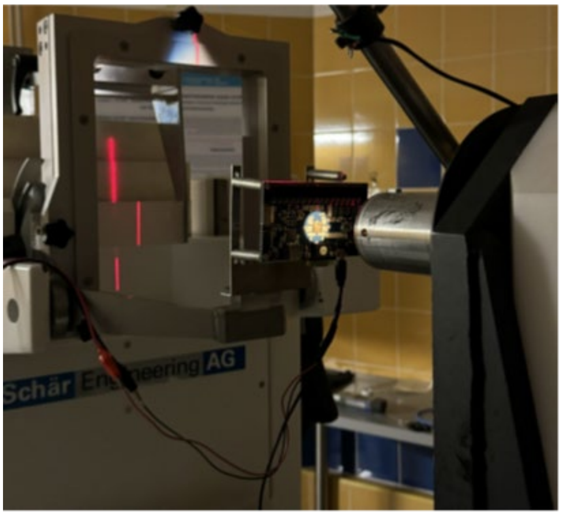

Fig. 1: Experimental setup under proton beam at the irradiation station of AIC-144

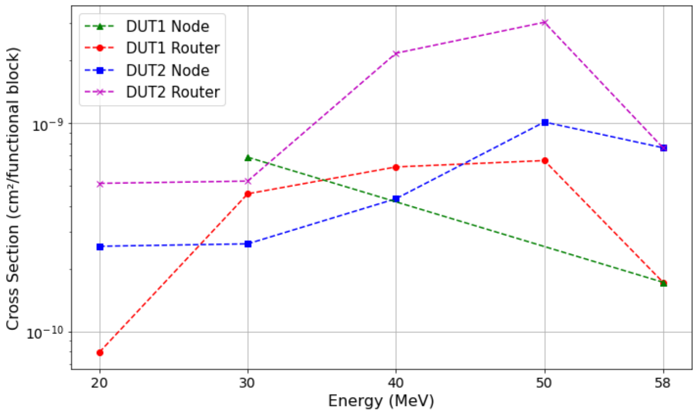

Fig. 2: Cross section of functional block over different proton energy levels

Proton beam radiation test was performed on a FPGA board: the Basys-3 with its Arty-7 FPGA chip. A soft core and soft NoC implementation in two variants with four nodes connected in a star topology. In the first, no additional protection was applied at the node level, while in the second, proactive rejuvenation and consensus on the node to rejuvenate were introduced to counter node-level radiation faults and, in particular, to remove resident radiation effects from nodes. While periodic proactive rejuvenation proved effective in allowing more messages to be delivered successfully, the unprotected router and a single point of failure were identified. From all failures observed 77% of them contributed to situations where the router delivered wrong messages to incorrect destinations or caused the system to crash, which required a total reset of the FPGA. To guide the research towards more resilient networks on a chip, we highlight possible directions for future research and discuss the implications of some of these solutions. The results of the work were published in: 2024 24th European Conference on Radiation and Its Effects on Components and Systems (RADECS) [1].

Testing SiPM readout system for X- and gamma-ray detectors in POLAR-2 mission

This experiment was performed by international collaboration under the leadership of Xin Wu from the Department of Particle Physics, University Geneva. [2].
Gamma-Ray Bursts are one of the biggest mysteries of modern astrophysics. These are the most energetic astrophysical events in the Universe known to man, emitting energies up to 10^{51} J. This emission is studied within the POLAR experiment by means of by polarization measurements performed by dedicated polarimeters POLAR (50-500 keV) and GAP (50-300 keV) installed on a satellite. The new version of the polarimeter will be installed on the China Space Station for a mission of at least 2 years. Since the polarimeter will be exposed to galactic cosmic-rays, solar cosmic-rays and trapped charged particles it has to be tested in adequate radiation field. POLAR 2 consists of 100 modules facing deep space with a half -sky filed of views. Each detector module consists of a target of 64 plastic scintillators which are read out by silicon photomultipliers (SiPM). These SiPMs are using the module of front electronics which was designed using commercial off-the-shelf (COTS) components. One of the main concerns when using these components is their radiation resilience.
Among all components used, only the Citiroc 1A ASICs are at TRL 8, indicating a high level of radiation tolerance. The radiation tolerance of the IGLOO FPGA, the DC/DC converter used to power the SiPMs, and the ADCs has not been established. Of particular concern was the DC/DC converter: initially, the C11204-01 model by Hamamatsu, specifically designed for powering SiPMs, was considered. However, it failed a basic proton irradiation test, leading to its replacement with the T3482 DC/DC converter in the current design.
The objective of the experiment was to test performance of the front-end electronics (FEL) of the polarimeter to doses equating to 2-10 years of exposure in space. Theses doses, delivered incrementally to different elements of the FEL should allow for testing components for failures and operational performance. To assess the radiation tolerance of the complete system, it was subjected to wide-beam proton irradiation tests at the Instytut Fizyki Jądrowej (IFJ) in Kraków, Poland, using a 58 MeV proton beam. A brass collimator was used to shape a 40 mm diameter beam into a 25 mm square field, allowing irradiation of the central rigid part of the readout in six steps. Six regions were irradiated sequentially to cover the full sensitive area (see Figure 2).

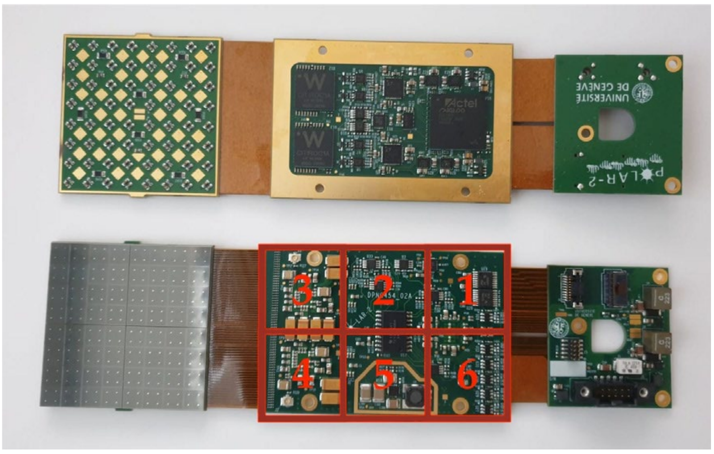

Figure 3: Top and bottom view of the electronics showing the 6 irradiated areas.

The system was exposed to three doses of 0.17 Gy and a fourth dose of 0.25 Gy. Based on simulations of the POLAR-2 detector, this corresponds to approximately 11 years in low Earth orbit. Data acquisition runs performed between irradiation steps showed no degradation in performance or increase in power consumption. The estimate of 11 years in space is based on POLAR-2 simulations and cannot be directly generalized to other missions. In POLAR-2, the electronics are shielded by several millimetres of aluminium. Nevertheless, the results indicate that all components in the readout are tolerant to radiation levels equivalent to several years in low Earth orbit. The results of the experiment were published in [2].

[1] G. L. Da Costa et al., "Assessment of Router Failures Under Proton Beam Radiation," 2024 24th European Conference on Radiation and Its Effects on Components and Systems (RADECS), Maspalomas, Spain, 2024, pp. 1-7, doi: 10.1109/RADECS61970.2024.11298585.
[2] M. Kole et al Nuclear Instruments and Methods in Physics Research A 1080 (2025) 170782, https://doi.org/10.1016/j.nima.2025.170782

3.10. UCLOUVAIN

UCLouvain offers a series of facilities at the Centre de Ressources du Cyclotron (CRC) .
It consists of 4 facilities:

- Heavy Ion Facility (HIF).
- Light Ion Facility (LIF)
- Neutron Iradiation Facility (NIF)
- Gamma Irradiation (GIF)

The first three are set around the CYCLONE, a research cyclotron in which the first radioactive beam was accelerated. They are used mainly for the study of Single Event Effects (SEE) in electronic components, HIF and LIF, but also for TID studies, LIF and NIF. Most of the EURO-LABS projects have used HIF (four projects) and two projects ask for irradiation at LIF.
The 4th one is a high intensity Co60 source is also proposed for long TID studies. EURO-LABS has not used this facility.
The start of the project was quite disappointing: during almost two years, just one proposal was received, as if the EURO-LABS community was not interested in this kind of tests, despite the efforts of the CRC and the WP manager to target audiences. After the second year, a larger community was targeted, and we started to get proposals at a reasonable rate. It’s quite striking because the facility is highly demanded in the SEE test in Europe.
In the following, two scientific projects, one at HIF and one at LIF, are presented. The beam was delivered to these projects quite late (less than one year) and there is, to our knowledge, still no results communicated.

Ion Beam Radiation Testing of the FastRICH ASIC
User Group Leader: Dr. Florin Maciuc, IFIN-HH / LHCb Collaboration
The FastRICH chip is a new front-end readout ASIC developed jointly by CERN's Microelectronics section and the University of Barcelona, designed to meet the demanding requirements of the Ring Imaging Cherenkov (RICH) detectors in the LHCb experiment at CERN. Fabricated in 65 nm CMOS technology and conceived to operate well into the 2040s under the harsh radiation conditions of the High-Luminosity LHC, the chip must demonstrate robust radiation tolerance before it can be approved for large-scale deployment during the LHC Long Shutdown 3.
The first major scientific highlight of this project is the systematic mapping of Single Event Effect (SEE) cross-sections in the FastRICH chip as a function of Linear Energy Transfer (LET). By exploiting the wide ion cocktail available at the CRC Heavy Ion Facility — covering species from Carbon to Xenon and extending the effective LET range through sample tilting — the team was able to trace for the first time the full Weibull-curve behaviour of Single Event Upsets and Single Event Latchups in this device. This quantitative characterisation had never been carried out on this chip

before and provides the LHCb community with the data needed to validate the radiation-hardness design choices made at the 65 nm node.

A second highlight relates to the operational realism of the test conditions. The chip was kept fully active throughout irradiation, running at parameters representative of its future LHCb deployment: realistic data-stream rates, live reconfiguration, and power cycling between irradiation steps. This approach revealed the interplay between configuration-register upsets and transient effects in the data stream — information that purely passive or low-rate tests would have missed. The group was also able to check in real time whether chip resets or power cycles could recover radiation-induced errors, directly informing the fault-recovery strategies that will be implemented in the LHCb readout firmware. The results of both test sessions are being prepared for publication and will be presented within the LHCb collaboration and at international detector instrumentation conferences.

Radiation Damage Studies of Silicon Detectors

User Group Leader: Michael Moll / Marie Muehlnikel, CERN Solid State Detector Lab

Silicon particle detectors operating in high-radiation environments such as the LHC experiments degrade over time as energetic particles displace atoms in the crystal lattice. These displacement defects alter the leakage current, the effective doping concentration, and the charge collection efficiency of the device, ultimately limiting its useful lifetime. A widely used framework to compare radiation damage induced by different particle types and energies is the Non-Ionizing Energy Loss (NIEL) scaling hypothesis, which predicts that damage scales with a single hardness factor regardless of the particle species. Recent experimental evidence, however, suggests that this hypothesis breaks down for materials with varying resistivity or impurity concentrations, pointing to a gap in the current understanding of microscopic damage mechanisms.

The first scientific highlight of this project is a comprehensive, cross-facility calibration of hardness factors for proton and neutron irradiation of silicon PIN diodes. By irradiating samples with protons at two distinct energies at the CRC and combining these with neutron irradiation data obtained at a complementary facility, the team is assembling a coherent, internally consistent dataset that spans a broad range of damage levels. The deliberate choice of well-controlled silicon PIN diodes as a common reference material is key: it allows the group to isolate genuine deviations from NIEL scaling from artefacts arising from differences in sensor geometry or processing, laying the groundwork for more reliable damage prediction models for future detector generations.

A second highlight is the depth of post-irradiation characterisation planned at CERN. Beyond standard electrical measurements, the irradiated diodes will be analysed using Transient Current Technique (TCT), Deep Level Transient Spectroscopy (DLTS), and Thermally Stimulated Current (TSC) measurements. This combination of techniques gives access to the identity, concentration, and annealing kinetics of individual radiation-induced defects, connecting macroscopic performance degradation back to specific microscopic damage centres. Understanding which defects are responsible for the observed deviations from NIEL scaling is a prerequisite for defect engineering strategies — deliberate introduction of impurities during crystal growth — that could substantially improve the radiation tolerance of future silicon detectors, with applications ranging from LHC tracking detectors to CMOS imaging sensors and dark matter detection experiments.

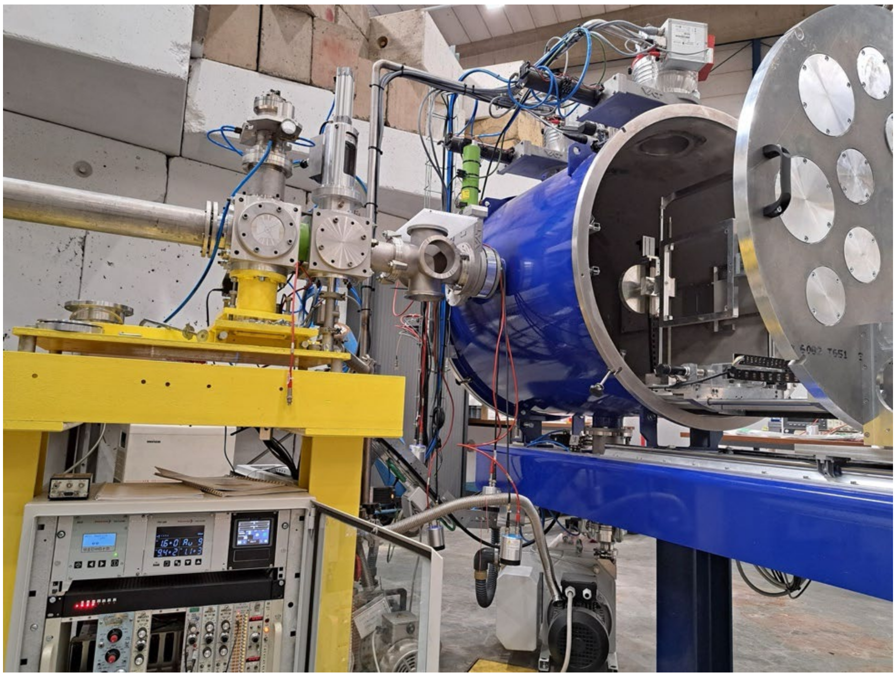

Figure 1:The end of the HIF beam line with the newly installed test chamber

3.11. UOB

The following includes a brief summary of some of the more noteworthy TA projects conducted at the UoB MC40 cyclotron facility:

Annealing studies of proton-irradiated silicon diodes for the CMS HGCAL project (EURO-LABS-2024-UOB-002)

From previous studies using 6" n-type silicon wafers it is well known that protons and neutrons cause different radiation damage. In the context of the CMS HGCAL project, recent studies with neutron-irradiated samples of 8" p-type silicon wafers resulted in significant deviations from the annealing behaviour expectations for neutron damage. This study aimed to investigated whether similar deviations also occur after proton irradiation. The aim of the project is to compare the proton and neutron irradiated samples to investigate the differences in annealing behaviour in terms of the types of defects that are predominantly created during irradiation of the substrate. The measurements were conducted in the same setup using the same production of sensors to keep the comparability as high as possible, as outlined in *JINST* 21 (2026) 03, P03034. The samples were proton irradiated at the UoB MC40 cyclotron to the target fluences successfully and initial comparisons between proton and neutron irradiated samples, before annealing, have been undertaken. The project is now undertaking a comprehensive study of the long-term annealing behaviour, the results of which will be prepared for publication once the study has concluded.

Studying the temperature stability of Silicon Photonics devices during proton irradiation (EURO-LABS-2025-UOB-001)

Silicon photonics (SiPh) ring modulators are highly sensitive to temperature variations, affecting both their basic operation and their response to radiation damage. Therefore, temperature control and stability are crucial for successful irradiation tests. The UoB proton facility can provide high proton fluxes, allowing the limits of SiPh radiation tolerance to be investigated. However, this high flux also causes significant energy deposition into the samples and substrates. This project studied approaches to optimise sample preparation, test board design, and cooling methods in order to maintain temperature stability of SiPh samples during irradiation. A dedicated test board with eight sample locations and 20 temperature sensors was developed and used to monitor temperature stability during irradiation, as shown in Figure 1. The findings, an example of which is shown in Figure 2, will provide valuable insights into achieving sufficient temperature stability in future radiation tests of SiPh components at UoB and other proton irradiation facilities.

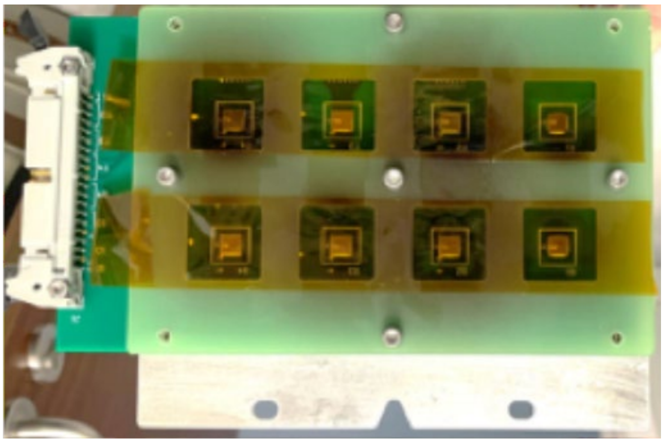

Figure 2: *Dedicated test frame developed for assessment of temperature stability of SiPh devices during proton irradiation.*

Figure 3: *Time evolution of temperature measured on the test frame during irradiation.*

Measurement of proton hardness factors in silicon at MeV-scale beam energies (EURO-LABS-2025-UOB-002)

Silicon detectors used in high-radiation environments such as the LHC experiments suffer from performance degradation due to radiation-induced displacement damage in the silicon crystal lattice. This damage affects key detector properties including leakage current, charge collection, and depletion voltage. To compare and quantify these effects across different radiation environments, the Non-Ionizing Energy Loss (NIEL) scaling hypothesis is commonly used. However, recent studies have shown that NIEL scaling does not fully capture all damage mechanisms, particularly for materials with varying resistivity or impurity levels. This project aimed to refine the understanding of radiation damage in silicon detectors by consolidating and expanding the available experimental data on *hardness factors* which quantify the relationship between radiation type and induced damage, across multiple radiation facilities. A key outcome will be the development of standardized silicon dosimeters for consistent hardness factor evaluations. Ultimately, the findings may lead to improved damage prediction models and inspire new strategies for radiation hardness, such as defect engineering, with broader applications including CMOS electronics and dark matter detection. This TA project was notable in that it made use of two of the facility's key auxiliary capabilities, namely the ability to vary the beam energy and provide high precision dosimetry. Samples were irradiated at three beam energies: 27 MeV, 20 MeV and 15 MeV and a detailed understanding of the beam energy at the samples, based on Geant4 simulates (described in *JINST* 20 (2025) 01, P01024) was shared with the team, as shown in Figure 3. Furthermore, high precision dosimetry was delivered at a level of around 5-10%, based on careful analysis of activation foils and technical information on its associated systematic uncertainties was shared with the team to facilitate their data analysis on the measurement of the hardness factors.

Figure 4: *A simulation of the energy profile of the UoB MC40 proton beam as it passes through the irradiation setup. Given the low beam energy, significant energy loss is experienced and the beam energy incident on the dosimetry foil and samples are notably lower than that of the primary beam. Image from* JINST *20 (2025) 01, P01024.*

Post-irradiation characterisation of detector modules from the ATLAS High Granularity Timing Detector upgrade (EURO-LABS-2026-UOB-002)

The High Granularity Timing Detector (HGTD) is a critical component of the ATLAS Phase-II upgrade, designed to mitigate the effects of extreme pile-up by providing a time resolution of approximately 30-50 ps per track. To ensure the operational stability of the detector throughout the High Luminosity LHC (HL-LHC) lifetime, it is imperative to validate the integrated performance of the final sensor-ASIC assembly under realistic end-of-life radiation conditions. An irradiation campaign at the UoB MC40 cyclotron was planned to evaluate the radiation hardness and operational stability of the HGTD modules. These modules, comprising Low Gain Avalanche Detectors (LGAD) bump-bonded to the ALTIROC front-end ASIC, are designed to provide high-precision timing (<70 ps) necessary to mitigate pile-up effects at the HL-LHC. A total of three modules were irradiated to neutron-equivalent fluences of 2.5x1015 neq/cm2 to simulate the most extreme conditions expected, and one module will be irradiated to an intermediate fluence of 1x1015neq/cm2. The post-irradiation characterisation will focus on the hit efficiency and time resolution despite radiation-induced gain degradation in the LGADs and potential noise increases in the ALTIROC electronics. These results will be compared against pre-irradiation benchmarks to validate the final module design. This project is particularly notable in that it was the first to make use of the facility's service improvement involving an upgrade to the sample scanning system, allowing the large area samples, around 2 cm x 4 cm, as shown in Figure 4, to be each irradiated in one day of operations. This had a significant advantage over the previous system in that it mitigated potential difficulties associated with sample handing and environmental exposure inherent in irradiations which span multiple runs.

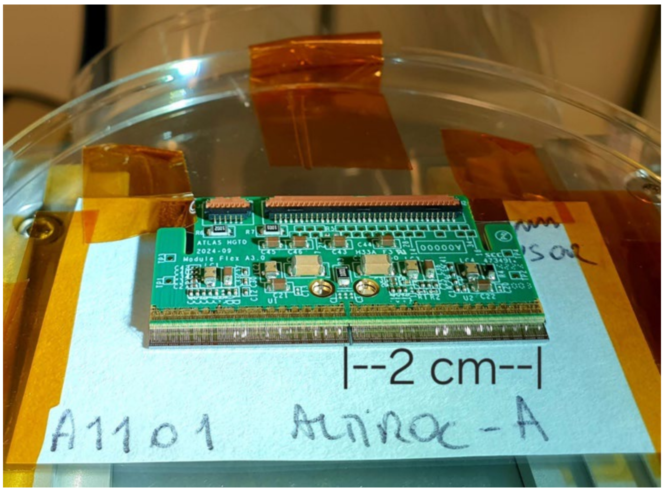

Figure 5: A photograph of one of the ATLAS HGTD modules irradiated at the UoB MC40 cyclotron, labelled for scale.

4. ANALYSIS

In the four years of EURO-LABS 286 projects with nearly 1100 users were carried out for Detector R&D, benefiting from the TA provided. While the number of projects is indicative of the TA usage, the number of users should be evaluated with care. The TA was namely provided in two modalities: *physical* and *remote* access. With *physical* access, users visited the RI to carry out their experiments, and user support was available. For *remote* access, typical for irradiations, samples were sent to the RIs, irradiated and sent back to the users after checking the activity and allowing for the appropriate cool-off period. Naturally, users' incentive to register was more pronounced for the physical access; applications for remote access had a reduced number of users, in some cases only the PI of the project. Table 1 lists the number of projects and number of users in the 11 RIs of WP4.

WP4	Research Infrastructure	Projects	Users
WP 4.1.1	CERN-PS-SPS	76	370
WP 4.1.2	DESY TB	42	194
WP 4.1.3	PSI TB	20	64
WP 4.2.1	RBI	12	25
WP 4.2.2	ITAINNOVA	5	6
WP 4.3.1	CERN-IRRAD	18	57
WP 4.3.2	CERN-GIF++	12	72
WP 4.3.3	JSI	65	197
WP 4.3.4	IFJ-PAN	19	64
WP 4.3.5	UCL	6	18
WP 4.3.6	UoB	11	27
WP4 all	Overall	286	1094

Table 1: Number of projects and number of users in WP4 during the 4 years of TA in EURO-LABS

A diversity analysis has been conducted for the first two years in MS21-23, and as the deliverable D5.2 "*EURO-LABS users' diversity final report*" in December 2025. The interested reader is thus referred to these documents. The final diversity analysis of all the completed projects in WP4 will be provided in the Final Report end of October.

ANNEX: GLOSSARY

Acronym	Definition
RI	Research Infrastructure
TA	Transnational Access
AU	Access Unit, usually equal to a beam hour
SERI	Swiss State Secretariat for Education, Research and Innovation
CHRISP	Swiss Research Infrastructure for Particle Physics
PSI	Paul Scherer Institut
DESY	Deutsches Elektronen Synchrotron
ECR	Early Career Researcher
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