ATSOA AT CERN: A HANDS ON ACCELERATOR COURSE IN THE EURO-LABS FRAMEWORK*

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Abstract

Beyond providing Transnational Access to major Research Infrastructures (RIs) across Europe, the European Laboratories for Accelerator Sciences (EURO-LABS) programme supports advanced training activities. Within this framework, an Advanced Training School on the Operation of Accelerators (ATSOA) is organised at CERN. The school targets students, young researchers, and professionals in the field of accelerator science, offering them a unique opportunity to participate in a week of hands-on training. Five CERN facilities — CLEAR, AD/ELENA, ISOLDE, PSB and LEIR — are involved in the training, allowing participants to familiarise themselves with different accelerator types and particle species. Under the guidance of experienced instructors, they carry out dedicated experiments designed to illustrate key physics concepts and operational principles that can be applied in their own work. This contribution gives an overview of the past schools and an outlook for future courses.

INTRODUCTION

The European Laboratories for Accelerator Sciences (EURO-LABS) is a network of 33 research and academic institutions across 18 countries, bringing together the communities of nuclear physics, accelerator science, and detector technology for high-energy physics under a single collaborative framework [1]. One of the key pillars of the EURO-LABS mission, beyond providing "Transnational Access to Research Infrastructures", is the support of advanced training activities for the next generation of accelerator scientists.

Within this framework, the Advanced Training School on the Operation of Accelerators (ATSOA) was established and has been held annually at CERN since 2024. The school targets students, early-career researchers, and young professionals in accelerator science, offering a unique week of immersive, hands-on training in a world-class research environment. Selected participants have their travel, accommodation, and subsistence costs fully covered by EURO-LABS.

The first edition, ATSOA 2024 (Fig. 1, left), took place at CERN in June 2024 [2]. Eighteen selected trainees participated in measurement campaigns at three CERN facilities: the Proton Synchrotron Booster (PSB) [3], the Isotope Separator OnLine DEtector (ISOLDE) [4], and the CERN Linear Electron Accelerator for Research (CLEAR) [5]. Topics included accelerator complex operation, control systems, beam characterisation, superconducting cavity phasing, and steering algorithms.

Building on this success, ATSOA 2025 (Fig. 1, middle), was held at CERN in May 2025 [6], expanding the participating facilities to include the Antiproton Decelerator/Extra Low ENergy Antiproton (AD/ELENA) complex [7]. This enabled additional advanced topics such as electron cooling, as well as increasing the number of participants to 22. The programme was further refined based on feedback from the first editions, with an increased hands-on component.

The third edition, ATSOA 2026 (Fig. 1, right), took place at CERN in April 2026 [8]. Due to ongoing upgrades of ISOLDE aimed at improving future operation [9], it was replaced by the Low Energy Ion Ring (LEIR) [10], allowing participants to work with a accelerator Pb ions.

In all editions, the school typically hosted 18–22 participants per year, with approximately four participants per facility, a limitation driven by the available control room space and the hands-on nature of the training. A summary of the demographics of the participant, including age and gender distribution as well as educational background and nationality, is provided in Fig. 2. During the three editions, a steady increase in interest has been observed, reflected both in the growing number of applications and in the overall quality of applicants. This trend highlights the strong demand for hands-on accelerator training within the community, the unique attractiveness of CERN facilities, and further supports the objectives of the EURO-LABS programme in fostering practical, facility-based education.

In the following sections, an overview of the three schools held to date is provided, focusing on the training format and key content highlights. Future prospects for the school are briefly addressed in the final section.

ATSOA SCIENTIFIC PROGRAMME

The ATSOA scientific programme is structured around a combination of common introductory courses and dedicated hands-on training sessions. At the opening of each edition, participants receive an introduction to the CERN

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Figure 1: Posters of the three editions of the Advanced Training School on the Operation of Accelerators.

accelerator complex, the relevant control systems, and the specific facilities involved in that year's school. These common courses establish a common starting point and provide the operational context necessary for the experimental work that follows.

The majority of the programme is devoted to immersive training sessions carried out directly by the participants at the accelerators. The students are divided into small groups that rotate across the facilities during the week, allowing each trainee to gain direct operational experience at different accelerators. Each facility session is designed and conducted by CERN experts, with exercises tailored to illustrate key beam physics concepts and operational principles in a real accelerator environment. The individual facility training modules are described in the following sections.

Training at PSB

The PSB is the first circular accelerator in the CERN proton injector chain, receiving H^- ions from Linac 4 at 160 MeV, which are stripped to protons at injection and accelerated up to 2 GeV. The PSB is composed of four identical superposed rings and delivers proton beams to a wide range of downstream users. Beam performance in the PSB is dominated by the space charge effect, which induces an amplitude

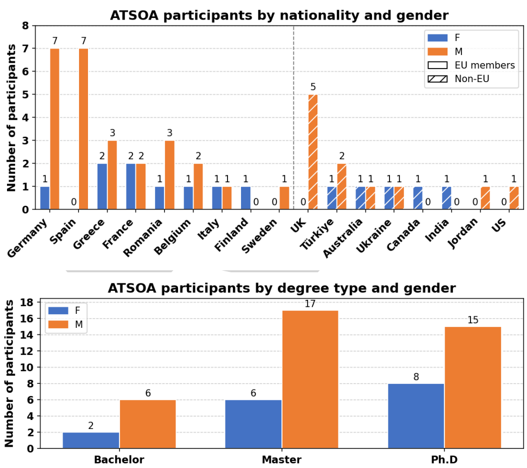

Figure 2: ATSOA participant demographics by gender, country of origin (top) and educational background (bottom).

dependent tune spread and can drive particles onto betatron resonances, causing emittance blow-up and/or losses. As a result, careful management of the working point in the tune diagram is one of the main challenges of the machine.

The PSB training module was conducted from the CERN Control Centre (CCC). Students were introduced to the PSB layout, beam types, operational procedures, and the control system, before undertaking exercises aimed at characterising and understanding the machine's brightness performance. The programme included: setting up the beam manipulating the charge exchange injection; monitoring key beam parameters like intensity, tune, emittances and orbit; and studying the interplay between working point, space charge, and resonances. To complement the machine measurements, students also worked with simulation tools. In particular, they were introduced to the Xsuite [11] code using PSB tracking examples showcasing the effects of space charge. Furthermore, they were introduced to the analytical space charge tune spread estimates using the PySCRDT module [12]. These exercises allowed participants to connect observations at the real machine with underlying beam dynamics models.

Training at ISOLDE

The ISOLDE facility is the radioactive ion beam production facility at CERN, operational since 1967. It receives 1.4 GeV protons from the PSB, which impinge on a production target to generate radioactive isotopes that are ionised, mass-separated, and delivered either directly to low-energy experimental stations or further accelerated through the REX/HIE-ISOLDE post-accelerator to energies up to 9.2 MeV/u (A/q = 4.5).

The ISOLDE training module combined guided hardware visits with hands-on exercises performed from the ISOLDE control room, including: restarting the machine from stand-by; performing a mass-to-charge (A/q) scan with the REX separator to identify the charge-state distribution from the charge breeder; measuring beam transmission through the RFQ as a function of RF and beam parameters; measuring the beam energy at the exit of the superconducting linac using the HIE-ISOLDE diagnostics; rescaling all machine settings to a different A/q ratio to illustrate magnetic rigidity relationships; and returning the machine to stand-by, closing the full operational cycle. Two guided tours of the facility complemented the exercises, covering several areas including the target stations, separators, vacuum systems, cryomodules, and the high-energy experimental stations.

Training at CLEAR

The CLEAR accelerator is a versatile multi-purpose electron linac and experimental beamline operated at CERN as a User Irradiation Facility since 2017, delivering beams in the energy range of 60–220 MeV. CLEAR supports R&D on accelerator components and beam instrumentation, Very High Energy Electron (VHEE) irradiation studies for medical and space electronics applications as well as training opportunities for accelerator scientists.

The training module gave students full hands-on control of the machine throughout its complete operational cycle. Starting from RF start-up and laser injection onto the photocathode, participants measured the beam energy via the VESPER spectrometer line, transported and steered the beam from the gun to the beamline end using steering correctors and position monitors, and quantified beam transmission using Integrating Current Transformers (ICTs). Transverse beam profiles were measured with scintillating screens, and the transverse emittance and Twiss parameters were extracted via quadrupole scans. The longitudinal bunch length was measured with a deflecting cavity. In the in-air experimental area, students converted the Gaussian beam profile into a spatially uniform field using a double-foil scattering system and collimator, then used the CLEAR robotic sample stage to execute a VHEE irradiation run on radiochromic films. As a concluding exercise, students were invited to sculpt the transverse beam profile into creative shapes on a downstream screen, a challenging and instructive demonstration of beam optics sensitivity.

Training at AD/ELENA

The AD and its downstream ring ELENA form the world's only facility providing low-energy antiprotons in a synchrotron, serving six experimental collaborations conducting antimatter studies. Antiprotons with 3.57 GeV/c are produced by directing 26 GeV protons from the PS onto an iridium target, and are decelerated in AD and ELENA down to 100 keV, delivering up to 5×10^7 antiprotons per cycle to four experiments simultaneously. Stochastic and electron cooling are essential ingredients for decelerating the beam while maintaining a small transverse beam size to keep the particles within the machine acceptance.

The training module was conducted using H^- ions from a local source in ELENA. This is routinely used for commissioning and machine development in parallel to normal physics production in the AD/ELENA complex, making it well-suited for a training school without interfering with the ongoing physics programme. Students worked from the AD control room on the final 2-second-long electron-cooling plateau of the ELENA cycle. The experimental programme covered: measurement and correction of transverse betatron tune and coupling; characterisation of the electron cooler performance by observing the evolution of beam emittance as a function of time during the cooling plateau; optimisation of the electron cooler alignment to minimise the final beam emittance.

Training at LEIR

The LEIR is the first circular accelerator in the CERN heavy-ion injector chain. Originally constructed as the Low Energy Antiproton Ring (LEAR) in the 1980s, it was repurposed and recommissioned in 2005 for the CERN heavy-ion programme. Its primary function is to receive long, unbunched pulses of lead ions from LINAC3 at 4.2 MeV/u, accumulate up to eight successive injections via multi-turn phase-space painting, cool the beam with an electron cooler, and accelerate the ions to 72 MeV/u before extraction to the PS. The lattice employs a large dispersion of approximately 10 m at the injection septum to enable efficient momentum and transverse phase-space stacking, and double-harmonic RF operation in Bunch Lengthening Mode to mitigate space charge effects during the phase of bunched beam.

The LEIR training module was introduced at the most recent school, ATSOA 2026, and was conducted from the CCC with a local visit also offered to the participating groups. The students first used a dedicated simulation tool to build intuition for the injection dynamics, then optimised key LEIR parameters: energy spread, betatron tunes, and injection bumps, thus comparing measurements with simulations. The programme also covered electron cooler operation and setup; measurements of tunes; closed orbit; and beam intensity evolution across the multi-injection accumulation cycle.

CONCLUSION AND OUTLOOK

Three editions of the Advanced Training School on the Operation of Accelerators (ATSOA) have been successfully held at CERN under the EURO-LABS framework, in 2024, 2025, and 2026. The school has established itself as a unique opportunity for acquiring hands-on experience at facilities spanning a broad range of accelerator types and particle species. CERN is currently entering a long shutdown period to undergo several upgrades, including the High-Luminosity LHC [13].

For the future, we hope that, given the success of the school and the strong interest it has generated, the programme will resume after the Long Shutdown, following the end of EURO-LABS, and could potentially be established as a regular yearly offer under a new framework, similar to other initiatives at CERN [14]. In this context, it could further develop into a platform for collaborative training between accelerator operation teams from various centres in Europe and worldwide, fostering exchange of expertise and best practices.

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