ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-TUPCO21

LOW ENERGY EXPERIMENTAL BENCH (LEEx-B) AND EMITTANCE-METER DEVELOPMENTS AT IPHC

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Abstract

A low-energy experimental bench called LEEx-B is being developed at IPHC-CNRS of Strasbourg, France. The bench is composed of a Cs^+ ion gun mounted on a HV platform providing beams up to 25 keV. The main objective of this bench is to support the advancement of beam diagnostics, including the ongoing development of the Allison-type emittance-meter. This paper presents the progress of the construction of the LEEx-B and of the beam diagnostics.

INTRODUCTION

Beam diagnostics are key for commissioning, tuning and operating particle accelerators, transfer lines and other beam manipulation systems, providing measurements of beam intensity, energy, position and distribution.

Over the past two decades, major accelerator projects (e.g. LHC, ESS) have pushed technologies to deliver extreme beams for fundamental research, while others, notably in the medical sector, focus on lower energies with highly specific requirements. These advances demand diagnostics of higher precision and reliability, often non-invasive, yet existing tools face clear limitations.

At IPHC-CNRS Strasbourg, the Accelerator Instrumentation Team (EIA) has concentrated its efforts on low-energy accelerators and their applications. With nearly 20 years of expertise in beam diagnostics and control systems, the team develops new-generation instruments and upgrades existing ones. A major achievement is the Allison-type emittance meter [1], first proposed in 1983, of which several versions were realized within projects such as SPIRAL2, MYRRHA, FAIR and soon NEWGAIN [2-4].

To gain autonomy and efficiency in validating its developments - previously dependent on external facilities with strong time and location constraints - the team is now building its own dedicated experimental bench.

THE LOW ENERGY EXPERIMENTAL BENCH

To support the development of beam diagnostics, the EIA team designed a dedicated low-energy experimental bench (LEEx-B). Such a platform enables tests with minimal energy consumption and operating costs, while providing the autonomy needed for systematic validation of new instruments.

Specifications and Equipment

The LEEx-B is intended to validate key aspects of beam diagnostics systems (BDS): accuracy, precision, calibration, sensitivity, compatibility with beam properties, and long-term reliability. These tests ensure robust and trustworthy measurements.

The bench consists of a modular support with a high-voltage platform, a low-energy ion gun based on a surface ionization source, and a beamline section including optics, diagnostics, and a vacuum chamber adaptable for future developments or ion beam experiments (Fig. 1).

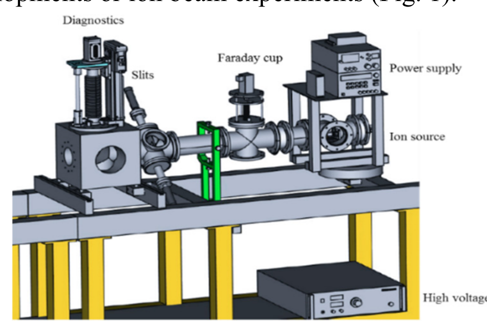

Figure 1: 3D view of the experimental bench.

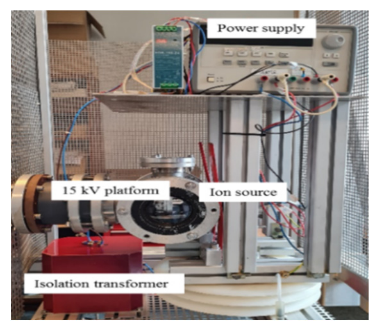

Figure 2: Photograph of the high voltage platform.

The ion source, a HeatWave HWIG-250 [5], can generate a 1 µA, 10 keV Cs^+ beam. It operates under ultra-high vacuum (10^{-6} -10^{-7} mbar) maintained by scroll and turbomolecular pumps, with pressure monitoring by Pirani and Penning gauges. Beam formation relies on a heated Cesium compound pellet, extraction electrode, and focusing optics. The HV platform, powered by a FUG HCN 35 supply and insulated via a dedicated transformer, reaches up to 25 kV (Fig. 2). Safety is ensured through interlocks, light beacons, and secured access to the HV zone. Optical simulations using SIMION [6] were performed to optimize ion transport along the beamline.

Control System

The bench integrates three main components - source, optics, and diagnostics - each with dedicated control. Source: four power channels (heater, source, extraction, focus) are controlled via optical fiber to withstand the HV

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potential. Optics: two electrostatic lenses and an XY steerer, driven by low-voltage power supplies. Diagnostics: two Faraday cups, a wire profiler, and horizontal/vertical Allison-type emittance meters.

Control is organized into two GUIs: one for source and optics, the other for diagnostics, with interlocks ensuring safe operation. Measurements are primarily current-based, acquired with high-sensitivity electrometers and picoammeters. The emittance meters, managed by a compactRIO, provide transverse emittance data and interface with the EPICS environment for integration into accelerator control systems. Figure 3 shows the layout of the command control of the platform.

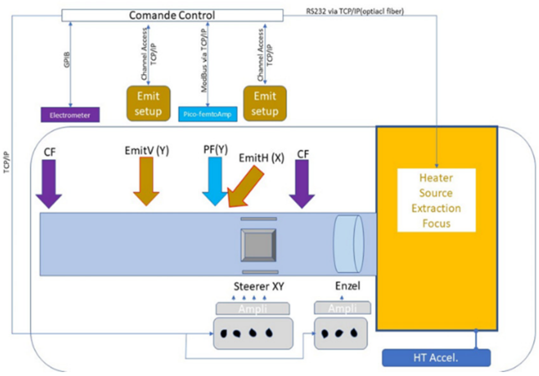

Figure 3: Command control schematic layout.

COMISSIONING OF THE LEEx-B

The source qualification was carried out in two phases. The first test, limited to 3 kV and without isolation transformer, validated the concept of the bench. The second stage, with additional optics and nominal platform voltage (25 kV), enabled full operation.

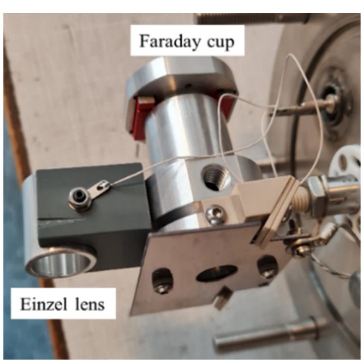

Figure 4: Focusing and current reading.

The HV platform integrates an Agilent E3631E power supply for pellet heating (up to 6 V–5 A) and extraction/focusing voltages (±25 V). Control is done remotely via a private Wi-Fi link. Beam current is measured with a Keithley picoammeter connected to a Faraday cup, followed by an Einzel lens and a second cup 60 cm downstream (Fig. 4). Typical operating values were: platform 3 kV, heater 3.2 V/2.42 A, extraction -25 V, focusing 190 V, yielding ~50 nA.

Beam Profile Measurements

Beam profiles were recorded using a grid profiler under development at IPHC (Fig. 5), consisting of 2 × 16 wires (0.38 mm radius) mounted on a motorized frame, positioned 1.1 m from the source. Tests showed: Increasing Einzel voltage (0-2 kV) focused the beam as expected but revealed a misalignment along the bench (Fig. 6). Increasing source voltage (8-15 kV) broadened the beam profile (Fig. 7).

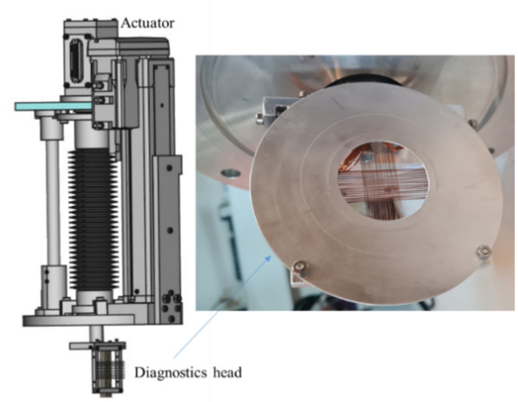

Figure 5: Schematic view of the grid diagnostics (left) and its picture (right).

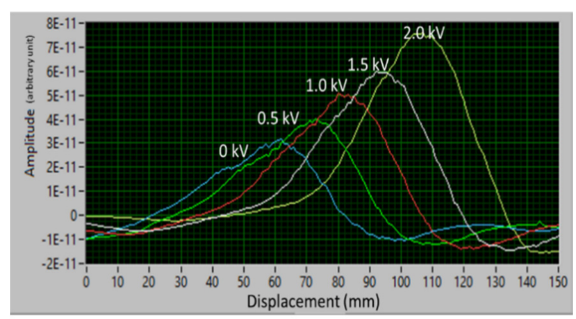

Figure 6: Effect of the voltage of the Einzel lens onto the beam particles (from 0 kV-blue to 2.0 kV-yellow). The source voltage is kept at 3 kV.

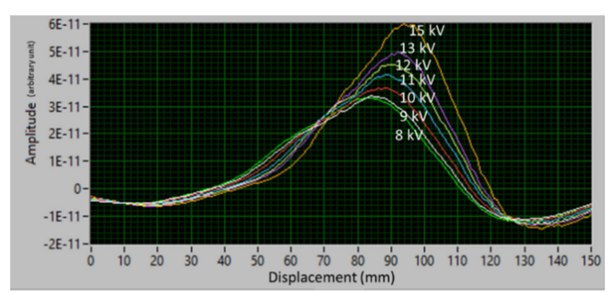

Figure 7: Effect of the voltage of the source onto the beam particles (from 8 kV: green to 15 kV: orange).

Emittance Measurements

Transverse emittances were measured with an Allison-type emittance-meter developed at IPHC (Fig. 8), capable

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of simultaneous position/angle reconstruction for currents from 10 pA to 1 µA. Initial measurements, varying the Einzel lens, again suggested misalignments (Fig. 9).

The device relies on local I/V conversion cards to minimize signal loss and noise. These cards, with four selectable gains (50 nA - 50 µA), are calibrated for accuracy and allow internal current injection for debugging. Once the setup was realigned, the LEEx-B enabled the comparison of several card designs. Figure 10 shows emittance results obtained with one card, indicating improved alignment. The normalized emittance was measured at 0.057 ± 0.026 π·mm·mrad.

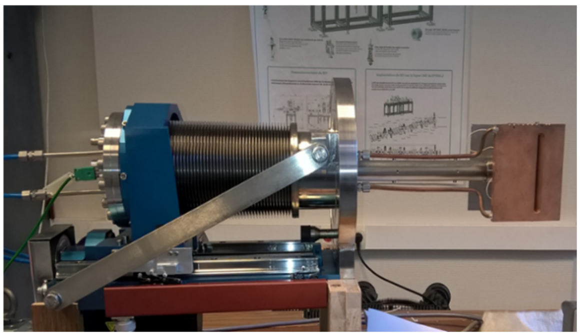

Figure 8: IPHC Emittance-meter.

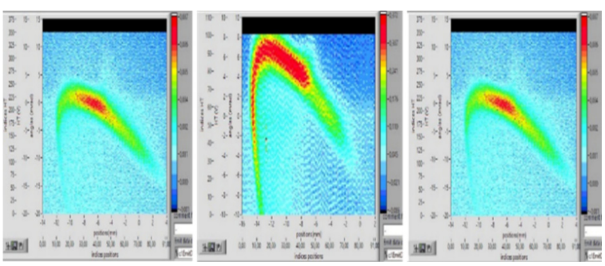

Figure 9: Transverse emittances for different Einzel 1 and 2 settings: 1300 V and 1260 V (left), 1360 V and 1360 V (middle) and 1340 V and 1320 V (right). High voltage platform: 3kV. Extract ion: -25 V. Focus: 190 V. CPU 1, output current: ~30 nA, CPU 2 current: between 15 nA and 24 nA depending on the settings.

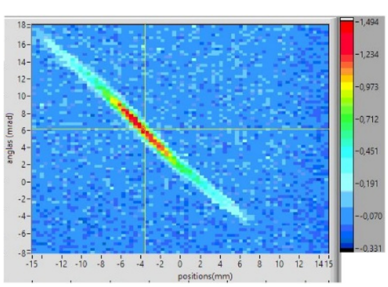

Figure 10: Emittance obtained after re-alignment with one of the I/V cards. Accelerating voltage: 25 kV.

The Allison scanner successfully characterized the source and, for the first time, demonstrated emittance measurements at very low currents (few nA), well below its initial design range. Despite weak acceleration voltages and alignment constraints, transmission efficiency remained acceptable depending on settings.

CONCLUSIONS

The LEEx-B bench provides the IPHC-CNRS team with an autonomous platform for developing and validating beam diagnostics. Commissioning demonstrated stable beam production, successful profile and emittance measurements, and reliable operation of low-current electronics. Importantly, Allison-type scanners were shown to measure emittances at the nA level, confirming their suitability for low-intensity beams. LEEx-B will continue to support innovation in diagnostic development and training.

OUTCOMES

Beyond proving that Allison-type emittance-meters can operate at beam currents as low as a few nA, the platform offers several key outcomes: **Autonomy in diagnostics development**: the EIA team can now design, test, and qualify instruments without relying on external facilities or beamtime slots. **Validation of electronics**: the I/V conversion cards were successfully benchmarked, providing a robust solution for low-current diagnostics. **Training and education**: LEEx-B represents a valuable tool for students and young researchers to gain hands-on experience with particle beams. **Future applications**: the bench can serve as a testbed for new non-invasive diagnostics, optical elements, and control electronics, supporting projects within IPHC and international collaborations.

The next steps will include extending the range of diagnostics tested on the bench, optimizing alignment and beam transport, and exploiting the platform for collaborative R&D in low-energy accelerator physics.

ACKNOWLEDGMENTS

The authors thank the management of IPHC and CNRS-IN2P3 for their support in the realization of this project.

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