

RECENT RESULTS OF BEAM EMITTANCE AND TRANSPORT AT ALTO-LEB PLATFORM IJCLAB

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Abstract

The ALTO research platform at the Laboratoire de physique des 2 infinis Irène Joliot Curie (IJCLab) is dedicated to wide-ranging research in nuclear physics, nuclear astrophysics and interdisciplinary activities such as health physics. ALTO-LEB is the low energy beam area of ALTO where neutrons rich exotic nuclei are studied. This paper focuses on the final analysis of beam emittance measurements made at ALTO-LEB dedicated to the characterisation of the ion source. The obtained results were also used to study beam transport along the low-energy beam line, and the outcomes of this study are also presented. Those results are also directly connected to the reliability of ALTO-LEB beam lines initiated at IJCLab in 2018.

EMITTANCE MEASUREMENTS AT ALTO-LEB

A dedicated beam qualification has been done at the ALTO-LEB facility [1] during spring 2023 and 2024. Many results have been already published [2, 3]. Part of these experimental campaigns were dedicated to beam emittance measurements in order to characterise the beam delivered by the target ion source system. The emittance measurements at ALTO-LEB were performed with an Allison scanner based system [4] developed at the CNRS/IPHC Strasbourg laboratory [5]. Emittance was never measured at ALTO-LEB facility before. This facility was constructed step-by-step during the last 20 years. It was therefore a unique opportunity to have the CNRS/IPHC emittance meter.

During the experimental campaign, emittance has been measured at two locations (e.g. Fig. 1). We also measured the beam profile at two locations where EMS beam profilers are available at the installation.

The nominal beam emittance measurement was repeated many times during our campaigns. This measurement was performed approximately 4 meters downstream of the ion production location, as it was not possible to place the device directly in front of the target-ion source system (e.g. Fig. 2).

We present the main result obtained using the new analysis method developed in this context [6, 7] (e.g. Fig. 3).

Horizontal emittance and Twiss parameters are:

- $\epsilon_{rms-x} = 4.2 \pm 2.2 \pi \cdot \text{mm.mrad}$,
- $\alpha_x = -9.7 \pm 5.2 \pi^{-1}$,
- $\beta_x = 19.2 \pm 10.3 \text{ mm.}/(\pi \cdot \text{mrad})$.

Vertical emittance and Twiss parameters are:

- $\epsilon_{rms-y} = 2.0 \pm 0.3 \pi \cdot \text{mm.mrad}$,
- $\alpha_y = -0.7 \pm 0.1 \pi^{-1}$,

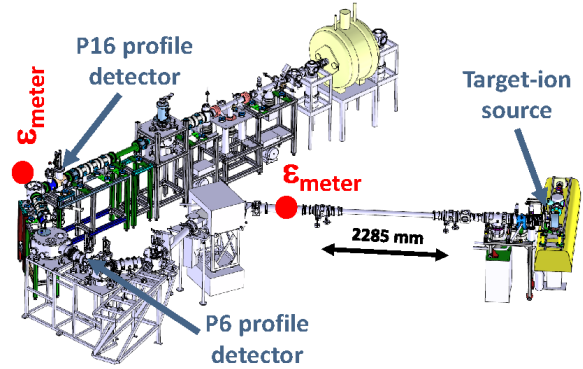


Figure 1: Isometric view of the ALTO-LEB beam lines. Emittance measurements were performed at the locations indicated by red dots. The available beam profilers are labeled P6 and P16. 30 keV and mono-charged ion beam (like stable $^{85}\text{Rb}^{1+}$ produced by surface ionisation) is emitted at the target ion source location.

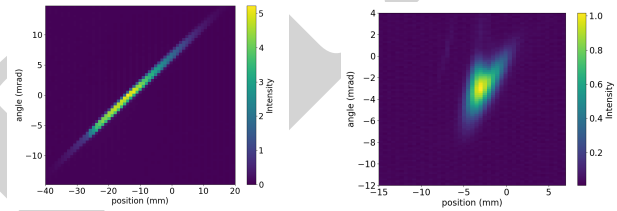


Figure 2: Measured transverse phase-space for the nominal beam at ALTO-LEB. Left: horizontal plane, right: vertical plane.

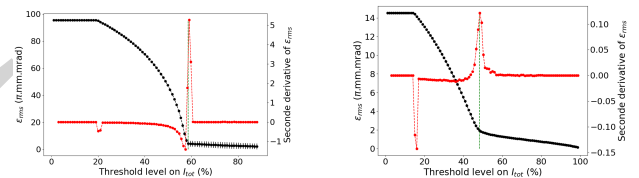


Figure 3: Analysis of the transverse phase-space for the nominal beam at ALTO-LEB. Left: horizontal plane, right: vertical plane.

- $\beta_x = 1.0 \pm 0.1 \text{ mm.}/(\pi \cdot \text{mrad})$.

These measurements were also used to study the beam dynamics in preparation for the commissioning of the new beamline recently developed at ALTO-LEB, which will lead to two new experimental setups.

OPTICAL ELEMENTS STUDIES

The ALTO-LEB beamlines reflect the history of the facility through the changes they have undergone [3]. Optical components were added in stages as new experimental se-

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tups were developed and installed. The transport between these sections has never been rigorously studied and the design of the optical components may vary between sections. To obtain a realistic simulation of the entire beam line up to the new experimental devices, we studied the individual electromagnetic behaviour of each element (quadrupoles, electrostatic deflectors, and one magnetic dipole) using OPERA3D [8] and generated their field maps. (e.g. Fig. 4).

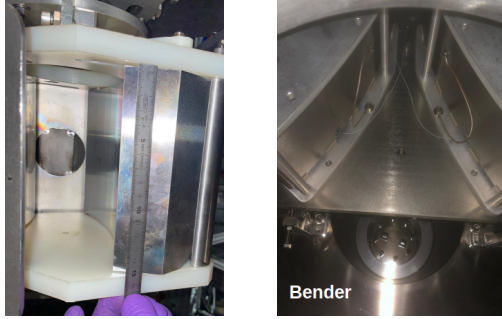


Figure 4: Photos of the 45° electrostatic bender (Left) and the electrostatic 35° kicker-bender used at ALTO-LEB.

All the field maps calculated using OPERA3D were integrated into the TraceWin simulation code [9], and the behaviour of each element was compared with that of the ideal element [10] (e.g. Figs. 5 and 6).

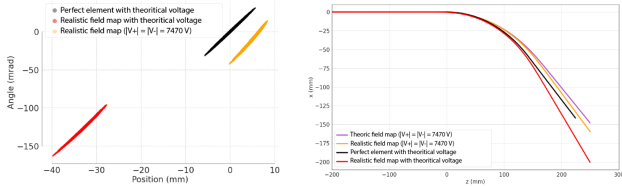


Figure 5: Left figure: Output distribution in the horizontal plane (x, x') following the perfect element (black dots) and the simulated field map (red and yellow dots). Right figure: Comparison of trajectories for an initial particle on the beam axis at $z = -200$ mm before entering the 45° bender (centered at $z = 0$ mm). Perfect element : $\rho = 200$ mm, $\theta = 45^\circ$ and $g = 60$ mm.

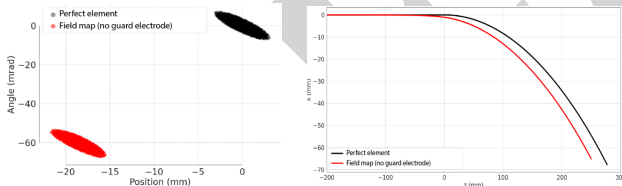


Figure 6: Left figure: Output distribution in the horizontal plane (x, x') following the perfect element (black dots) and the simulated field map (red dots). Right figure: Comparison of trajectories for an initial particle on the beam axis at $z = -200$ mm before entering the bender (centered at $z = 0$ mm). In red, the particle passes through the field map of the 27.5° bender alone; in black, when the element is perfect ($\rho = 600$ mm, $\theta = 27.5^\circ$ and $g = 40$ mm).

Two optical elements in the beamline proved to be problematic: a 45° electrostatic deflector and a two-element

electrostatic assembly for a 35° deflection, known as the kicker-bender. The kicker-bender consists of two parallel plates providing a 7.5° deflection, followed by a 27.5° electrostatic bender. These two examples show that along the ALTO-LEB beam line, some electrostatic beam line element are not design in order to fulfil properly a first order design. These elements show that the beam cannot be properly align. Regarding the other elements, apart from the 60° electrostatic bender, no major issues were observed with the magnetic dipole separator [11] and the electrostatic quadrupoles. Unfortunately the ALTO-LEB beam line don't have sufficient orbit correctors (both horizontal and vertical steerers along the oldest section of the facility), in order to properly correct the strong effects induced by the 45° electrostatic deflector and the 35° electrostatic kicker-bender presented here.

SIMULATED BEAM TRANSPORT

Since the beam line has been reconstructed in TraceWin using the various field maps of the individual elements, and the emittance and Twiss parameters are known at the measurement point upstream of the magnetic dipole separator, we are able to study beam transport along the ALTO-LEB lines (e.g. Figs. 7 and 8).

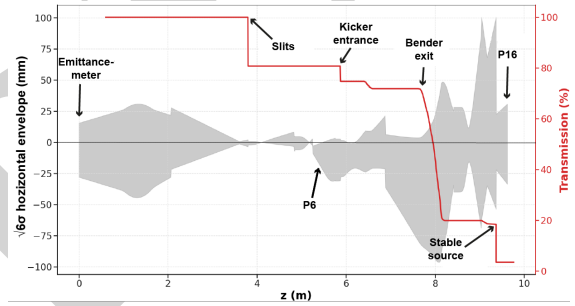


Figure 7: Horizontal beam envelope at $\pm\sqrt{6}\sigma$ of the beam transport from the emittance meter up to the beam profiler P16.

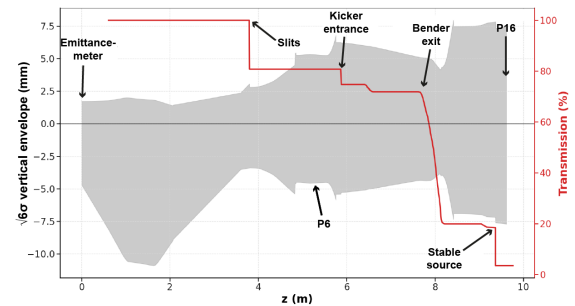


Figure 8: Vertical beam envelope at $\pm\sqrt{6}\sigma$ of the beam transport from the emittance meter up to the beam profiler P16.

Profile measurements recorded during measurement campaigns are used to cross-check and validate the results (e.g. Figs. 9 and 10).

From the beam transport studies, we can observed that in the horizontal plane we have various mis-alignment which

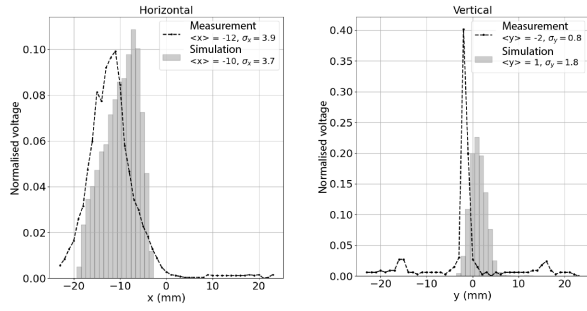


Figure 9: Comparisons between the beam profiles measured at P6 (shown as a black dotted line) and the position histograms obtained from the measured phase space emittance from the emittance meter up to P6. The profiles are normalised so that the area under the curves is one.

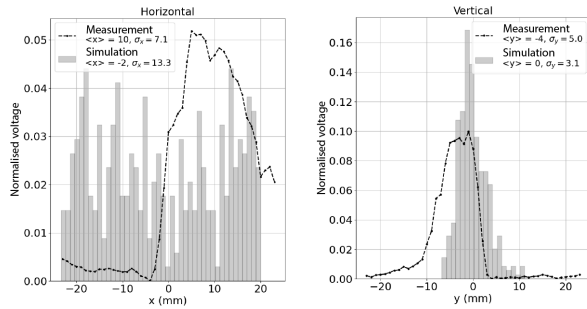


Figure 10: Comparisons between the beam profiles measured at P16 (shown as a black dotted line) and the position histograms obtained from the measured phase space emittance from the emittance meter up to P16. The profiles are normalised so that the area under the curves is one.

can not be correct easily due to strong problems due to the different electrostatic deflectors available along the beam lines (e.g. 45°, 60° and kicker-bender). These deflectors are the main elements responsible to the degradation of the quality of the beam optic along the ALTO-LEB beam lines. The pure calculation and measured profile on the beam profiler P6 are in relatively good agreement both in the horizontal and in the vertical plane. Unfortunately, the beam transport up to the beam profiler P16 show that we are not able to reproduce the measured beam in the horizontal plane instead that we can have a relatively good agreement in the vertical plane. In the case of P6, only alignment issues of the 45° and 60° electrostatic deflectors may be encountered. In contrast, the measurement at P16 accumulates alignment errors from a large number of elements, which explains why we are no longer able to accurately simulate beam transport, particularly in the horizontal plane. These comparisons still allowed us to demonstrate relatively good agreement between the simulation and the measurements. However, the studies also revealed a misalignment of the optical elements in the older sections of the ALTO-LEB transfer line.

CONCLUSION

The ALTO-LEB facility produces neutron-rich exotic beams by combining the Isotope Separation On-Line (ISOL)

technique with photofission. These beams remain highly relevant for fundamental research in nuclear physics. However, the ALTO research platform is aging, and its Low Energy Branch (LEB) was incrementally constructed as new experimental devices were added. As a result, no comprehensive studies of the beam transfer lines have ever been conducted. The age of the ALTO-LEB facility, combined with fragmented archiving, has led to a loss of critical knowledge—particularly regarding older beam optic components. This lack of documentation makes operating ALTO-LEB increasingly complex, despite its undeniable potential.

To address these challenges, we began by characterizing beam parameters as close to the source as possible and then studied their transport through the transfer lines. All optical elements of the lines were simulated using OPERA3D to minimize the knowledge gaps accumulated over the past decade. We compared the field maps extracted from these simulations with their first order theoretical element. With the exception of the optical elements studied in parallel with the electromagnetic design for the DESIR project (located at the end of the line), all other components exhibited significant deviations due to design flaws in many of them. The entire ALTO-LEB beamline was reconstructed using the field maps to ensure maximum fidelity to reality. Particle distributions obtained from emittance analysis allowed us to simulate the beam transport up to the measurement points equipped with beam profile detectors. However, when studying beam transport over longer sections, misalignments of optical elements and uncertainties—such as the exact position of the outer electrode of the 45° electrostatic deflector—prevented accurate beam transport simulations. The new experimental set-ups served by the new beamline presented in this paper will suffer from very low transmission rates due to the difficulties in transporting beams through the upstream lines. Indeed, most elements either have design defects or are ill-suited for their purpose (e.g., kicker-benders).

Making the ALTO-LEB lines more reliable is not possible in the current state of the installation. Instabilities in the source, the lack of understanding of certain multiphysics processes, and the insufficient number of diagnostics along the lines prevent the reproduction of identical beams for each experimental campaign. The loss of knowledge and design flaws in the optical elements make the transfer line highly sensitive, resulting in excessively long setup times.

Despite these vulnerabilities, the ALTO-LEB facility remains a valuable asset in the landscape of low-energy radioactive beam production. It is one of the very few facilities in the world producing radioactive nuclei from fission.

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