# COMMISSIONING OF THE LEBT OF PIAVE AND THE ALICE ION SOURCE EMITTANCE MEASUREMENT

A. Pisent, M. Cavenago, P. Bezzon, S.Canella, F. Cervellera, M. Comunian, A. Facco, A. Lombardi, M. Poggi, INFN-LNL, Legnaro, Italy; T.Kulevoy, ITEP, Moscow, Russia

*Abstract*

The relatively long low energy beam transport (LEBT) line joining the ion source high voltage platform and the first superconductive RFQ PIAVE is described, summarising design choice and describing related beam experiments; PIAVE will inject beams into the ALPI linac. In particular, the beam line has to cope with fluctuation in platform voltage (against which was made achromatic ) and the ion source noise, and has to match the beam to RFQ acceptance. The beam line is formed by a slanted U-bend, on a rigid 7 m long frame, followed by a long straight path where four large aperture quadruple doublets and a buncher allow the to prepare the RFQ nominal beam conditions. A beam emittance detector is placed at RFQ location, to monitor both the ion source operation, its apparent emittance and the beam line behaviour, so to ensure the transverse matching to RFQ acceptance. First experimental result and operating experience with argon and xenon test beams are described, showing a good emittance and excellent transmission.

## 1 INTRODUCTION

The positive ion beam, which is produced and preaccelerated by the ECR source Alice, will be injected into the new linac, named PIAVE, and then by the existing linac ALPI, so to bring ions up to uranium above the nucleus-nucleus barrier. The ion source is mounted on a high voltage platform tested up to 350 kV and intended for stable operation with a voltage $V_p$ up to 315 kV, so that the ion source voltage $V_s$ can be fixed to a convenient $V_s = 11$ kV, and $V_p$ can be adjusted to match the RFQ input speed which was chosen as $\beta = 0.0089$, corresponding to an ion energy of 37.1 keV/u. More details about Alice and the PIAVE superconducting RFQ development can be found in refs [1, 2].

In this paper we report about the commissioning of the Low Energy Transport Line (LEBT) linking the ion source to the superconducting RFQ. In the line both the longitudinal and the transverse matching to the RFQ is prepared, by means of a three harmonic buncher and a set of magnetic quadrupoles. We have mounted a fast Faraday Cup PM6 and a emittance measurement box at the place of the RFQ location (see fig. 1), in order to have a direct measurement of bunch length and beam characteristics (emittance and Twiss parameters) under various conditions.

We verified the good transmission of several ion species (namely $Ar^{6+}$, $Ar^{8+}$, $Ar^{9+}$ and $^{129}Xe^{14+}$, $^{129}Xe^{17+}$, $^{129}Xe^{18+}$) and their emittance, as shown in section 3. For the sake of comparison and simplicity, for all the ions we set the platform voltage at $V_p = 240$ kV (nominally), which is about the correct value for $^{129}Xe^{18+}$ injection.

The test of the bunching system will follow.

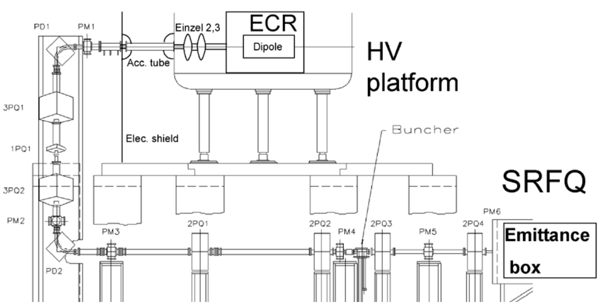


Figure 1: Layout of the beamline and of the ECR platform

## 2 GENERAL LAYOUT DESCRIPTION

The LEBT from ion source to RFQ is constituted by four straight lines (and three bends of about 90 degrees): the extraction line from the source (perpendicular to fig. 1 sheet), the acceleration tube line, the descent to a lower floor and the line on PIAVE beam axis.

In the beam extraction line [3] we have a matching einzel lens E1 and the extraction optics, which is discussed elsewhere [4]. The accelerating line is formed by two einzel lenses, the accelerating tube and an electrostatic triplet; steerer magnets are located at the line ends (see Ref. [1] ); lenses and triplet give redundant flexibility to match different source over platform voltage ratio $V_s/V_p$.

The achromatic almost vertical line ($18^0$ inclination) guarantees the beam transfer between the accelerating column axis and the RFQ axis, with two dipoles, two triplets and a singlet. The whole line is mounted on a common girder and was prealigned from the company. The achromaticity allows to cope with platform voltage $V_p$ fluctuation, and to install a low frequency buncher on the platform.

The beam is therefore reduced to a small spot in the buncher by means of two doublets, and matched to a smaller spot at the RFQ input by means of two similar lenses. The quadrupoles of the LEBT are characterised by a large bore aperture (120 mm diameter) and short effective length. The main difficulties in these elements came from the multipole component in fringe field (multipole components below 0.8 % in 85% of quadrupole aperture have been obtained with a mechanical correction after preliminary measurements).

Other main components of the line are the three-harmonic buncher [5] and the beam diagnostics (five Beam Profile Monitors PM1-5, three Faraday cups with electron suppression FC1,FC3 and FC5, respectively attached to PM1,PM3,PM5). PM1 is 0.8 m after the accelerating tube, PM5 is about 2 m before the emittance box. The line has been assembled during last year, so to allow the necessary time for LEBT commissioning, before RFQ installation. Beamline terminates on a isolated flange FC, which was used as an additional Faraday cup with a 50 V electron suppression. Beam current can be also be measured on the platform at the Faraday named FC/E6 , with a 60 V electron suppression).

The beam transverse emittance measurement (BTEM) box has been developed and built for the precise measurement of beam characteristics during commissioning. The emittance measurement is performed using a slit and a grid at fixed distance, moved together by a stepping motor for each plane, either the horizontal or the vertical, at a time. From the hardware point of view, the BTEM system uses the same beam profile monitor front-end electronics of the ALPI beam line, except for the current to voltage conversion gains. Due to the foreseen current from the ECR source injecting the line, the conversion gain are four instead of two: from 1 volt at 1 nA to 1 volt at 1 $\mu$A.

The ADC conversion is synchronised with the step by step movement and also the whole acquisition system is based on the ALPI beam profile monitor system. The measurement plane , the step number, the initial and final position can be selected by the user; data analysis and graphic representation of the transverse emittance is done offline. The beam profile monitor ”wires” are actually little bars of tungsten, 0.4 mm thick, we have 77 bars (spaced by 0.6 mm) for each plane. The distance between the slit and the beam profile monitor plane is 300 mm, so an angular accuracy of 3 mrad is reached. The whole angular divergence covered is 231 mrad. The slits are made by tungsten with a 100 $\mu$m wide aperture and they are sticked to a piece of copper to dissipate the generated beam heat.

## 3 PLATFORM AND BEAMLINE OPERATION

A first part of the commissioning, made with $Ar^{8+}$ and $Ar^{6+}$ was devoted to: 1) understand how to use steerers in the platform and immediately following; 2) debug hardware; 3) validate a beam transport optimisation procedure. We find out that only the steerer on the platform need to used, even if the current necessary is not simply proportional to ion rigidity, as expected, but tend to be constant; the vertical steerer after the tube need not to be used up to now [1].

Accidental deflection $\theta_y$ due to residual magnetic field may be simply estimated from the field integral

$$\theta_y = \frac{\sqrt{qe}\int B_x dz}{\sqrt{2m_p A(V_p+V_s)}}$$

where $A$ is the nucleon number and $q$ the charge number; $m_p$ and $e$ are respectively the mass and charge of a proton; $z$ is the beam axis and $x$ is horizontal. From measures of residual magnetic field of accelerating tube (dark currents are magnetically suppressed in a satisfactorily way) we estimate $\int B_x \ll 50$ G cm; similarly from earth magnetic field $|\int B_x dz| < 100$ G cm, which shows $|\theta_y| < 1$ mrad, which may be easily corrected by bending magnet PD1. Similar consideration applies to the final focus line.

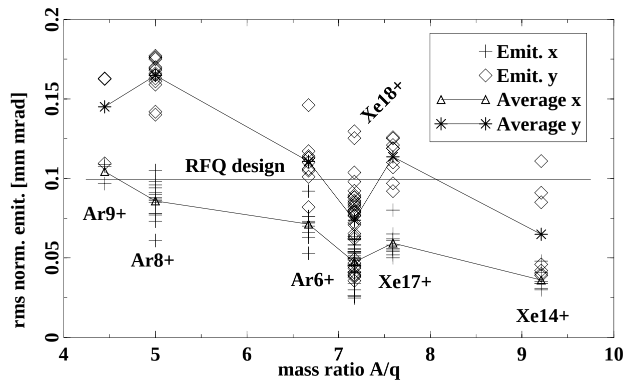


Figure 2: Summary of measured rms emittance vs. the mass ratio $A/q$

The simpler optimisation procedure relies on using a moderately large $Ar^{8+}$ beam; the beam is approximately centered on PM1 by using platform steerer and lenses are adjusted around their theorical or empirical value 7.5 kV observing beam rms spot size $\sigma = \sqrt{<x^2+y^2>/2}$; then beam is centered on the next profile monitor PM2 by PD1 only, with triplet off at a first time. Triplet 3PQ1 and 3PQ2 are then adjusted, checking beam on PM2. Other elements are similarly adjusted. This step by step optimisation gives more than 50 % of beam on Faraday cup FC5, but is sensitive to any detector misalignment. Later a finer tuning of each setting at time (starting again from the platform steerer) allow us reach typically 93 % transmission; this phase is called global optimisation (see table 1).

As an alternate tuning strategy, the theorical value is clearly sensitive (at the $10^{-3} - 10^{-2}$ level) to errors in element and model construction and voltage data, but can be satisfactorily used as a starting point for global optimisation. As third and faster method, optimal values for $Ar^{8+}$ can be scaled to ion of interest, which gives at least dipole value accurate within $10^{-3}$, and global optimisation may be performed easily.

## 4 EMITTANCE MEASUREMENT

In table 1 we list the beam currents ($I_1$ measured at FC1, $I_5$ at FC5) and the average emittance measured, while in Fig. 2 we plot the measured emittance as a function of mass over charge ratio $A/q$. For each beam the emittance has been measured for many different settings of the last two doublets.

Table 1: Beam properties: beam size $\sigma$ in mm, current $I_1$ and $I_5$ in nA, normalised rms emittance $\epsilon$ in mm mrad

| **Ion** | $I_1$ | $\sigma$ | $I_5$ | $\epsilon_x$ | $\epsilon_y$ |
|---|---|---|---|---|---|
| $Ar^{6+}$ | 2760 | 3.1 | 2600 | $0.100 \pm 0.0067$ | $0.140 \pm 0.031$ |
| $Ar^{8+}$ | 1320 | 3.4 | 1210 | $0.086 \pm 0.011$ | $0.160 \pm 0.011$ |
| $Ar^{9+}$ | 720 | 3.7 | 630 | $0.071 \pm 0.010$ | $0.110 \pm 0.016$ |
| $^{129}Xe^{14+}$ | 120 | 3.0 | 110 | $0.047 \pm 0.011$ | $0.074 \pm 0.024$ |
| $^{129}Xe^{17+}$ | 270 | 6.3 | 238 | $0.059 \pm 0.0086$ | $0.110 \pm 0.012$ |
| $^{129}Xe^{18+}$ | 410 | 3.9 | 380 | $0.036 \pm 0.0063$ | $0.065 \pm 0.030$ |

The beam is transported from FC1 (immediately after the accelerating column) to the emittance box (FC in the final flange) with a typical transmission of 95%. The quadrupole values in the last part of the line (2PQ1, 2PQ2, 2PQ3, 2PQ4) agree within few percent with nominal optics [6] and calibrations done at the company.

Our optics is very reproducible, and scales correctly with beam rigidity, so that the change of ion kind is a rather fast operation.

The measured horizontal emittance are within the nominal RFQ emittance ($\epsilon_{RMS}$ =0.1 mm mrad, normalised), while the vertical ones are somewhat above only for light ions. Some beam halos in $x$ direction is indeed necessarily cut at the beam selection slit of the ECR platform (12 mm wide in $x$, 24 mm wide in $y$). Moreover we remind that the vertical plane is (approximately) the bending plane, so that some contribution to the emittance may come from the non-optimal setting of the optics of the vertical part of the line.

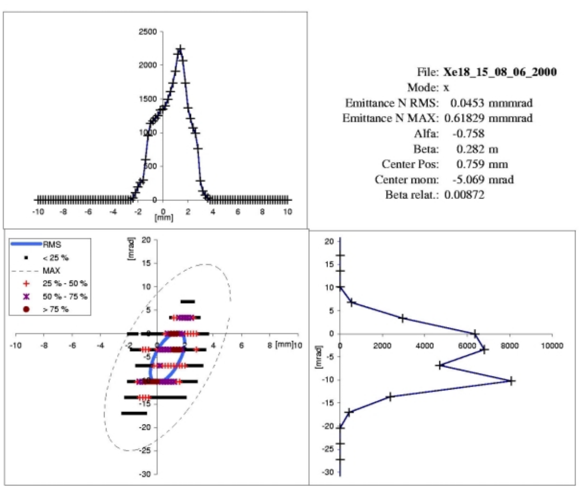


Figure 3: Data (relative uncalibrated currents) taken from emittance box for phase space $xx'$ for a $^{129}Xe^{18}$ beam at a current $I_5 = 136$ nA; rms emittance ellipse shown in solid line; maximum emittance in dashed line. Current profiles in $x$ or $x'$ also shown

The normalised emittance as a function of mass over charge ratio has the trend $q/A$ foreseen by the theory [7]. In figs. 3 and 4 we show a typical emittance measurement

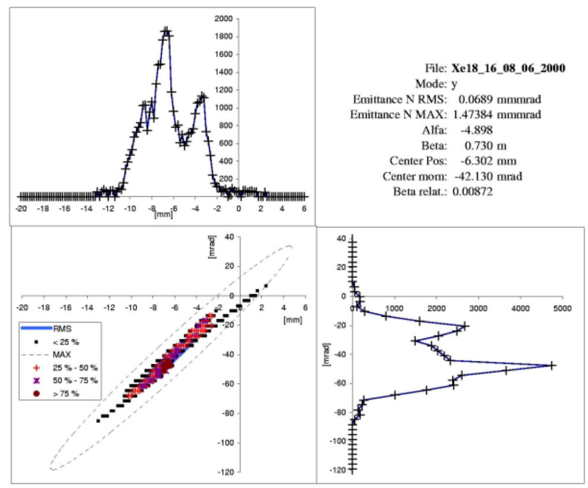


Figure 4: As for fig 3, but for $yy'$ phase space

for 136 nA of $^{129}Xe^{+18}$. Both horizontal and vertical plots are shown. The residual misalignment is due to the lack of some dipole steerers in the final beam line, which will be soon installed. Systematic measurements to gain experience on the focusing nominal condition and the tests of the bunching system are foreseen.

## REFERENCES

[1] M.Cavenago, T. Kulevoy, S. Petrenko, " Operation of the LNL ECR ion source", these proceedings.

[2] G. Bisoffi et al. "First Results with the Full Niobium Superconducting RFQ Resonator at INFN-LNL" this conference.

[3] W. Krauss-Vogt, H. Beuscher, H. Hagedorn, J. Reich, P. Wucherer, "Emittance and matching of ECR sources", *Nucl. Instr. Meth*, **A268**, 5 (1988).

[4] M.Cavenago "Selection of charge for the ECR Alice without forming a waist"; *Nucl. Instr. Meth*, **A328**, p. 266-9 (1993).

[5] A. Facco et al. "Status of the Non-RFQ Resonators of the PIAVE Heavy Ion Linac" this conference.

[6] A. Pisent M.Comunian "Complete simulation of the heavy ion linac PIAVE" PAC 97 conference, IEEE conference proceedings (1998) p. 1132-35.

[7] R.Geller, *Electron Cyclotron Resonance Ion Sources and ECR Plasmas*, Institute of Physics Publ.,Bristol,1996.