ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPR53

H- SOURCE CHARACTERIZATION AND TRANSFER LINE STUDIES WITH REALISTIC EM FIELDS IN THE ELENA DECELERATOR AT CERN

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Abstract

A local H- /p source is operated at the CERN Extra Low ENergy Antiproton (ELENA) decelerator for commissioning the ring and subsequent electrostatic transfer lines toward the experiments. For proper optics characterization, it is important to have a detailed knowledge of the H- beam parameters at the source. Phase space tomography techniques were applied to reconstruct the beam distribution at the measurement point, which was then tracked backward to the H- source using symplectic field maps to calculate the beam matrix. Due to the presence of an ion switch a highly non-linear behavior with significant deviation from the linear model was observed. The SIMPA tracking code allows EM fields in the transfer line to be treated continuously and as a whole.

INTRODUCTION

The Antiproton Decelerator (AD) has been extended with a new ring called ELENA [1] to decelerate the beam to 100 keV following ejection from the AD at 5.3 MeV. For the commissioning of ELENA a local 100 keV H- source was provided by Julich. The source can also be used in proton mode, although this ability was not exploited. Initially foreseen as a temporary aid for commissioning, the source became an important part of daily operations. After the commissioning, the source was extensively utilized by the experiments for testing and setup purposes and by the operation team to conduct various studies. This study aimed to characterize the beam of the Julich H- source to improve the ELENA intensity and determine key parameters.

The transfer line between the source and the ELENA ring consists of mostly electrostatic elements. The transfer line from the AD ring to ELENA has a common part with the H- injection line. There is an electrostatic ion switch at the junction of the two lines, selecting between $\overline{P}$ and H- injection. The presence of the ion switch makes the modeling of the line non-trivial. The usual kick codes, like MAD-X, can not accurately handle the non-linear effects introduced by the ion switch. The H- line has very limited instrumentation. Since the source was measured before installation, several parameters have been optimized during commissioning to maximise the intensity injected into ELENA. The source was characterized without removing it from the line or opening the vacuum.

THE METHOD

A fluorescent screen, LNR.BTV118, in the ELENA ring after the injection septum was used for observing the injected beam. The voltage of the last quadrupole in the line was

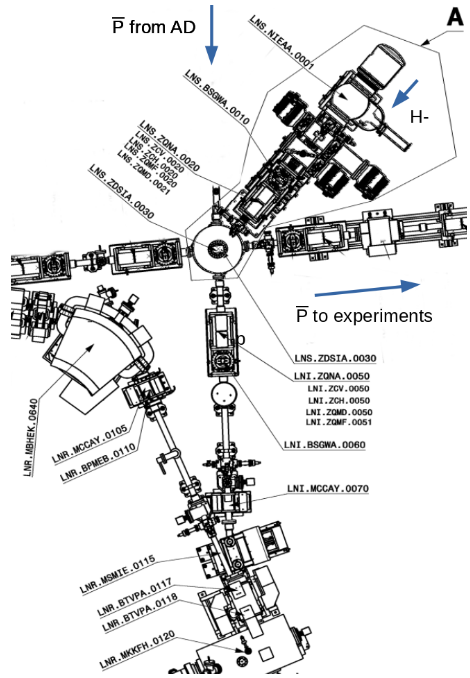

Figure 1: Layout of the H- transfer line with the source indicated in the region with the letter **A**. The ion switch is the element LNI.ZDSIA.0030. The elements between the ion switch and the ELENA ring are shared between the $\overline{P}$ injection line and the H- line.

scanned with a script automatically saving the images of the BTV for each scan. These images showed highly non-linear behavior, meaning that the usual Gaussian approximation for the transverse beam distribution could not be used. Instead a phase space tomography method [2] was applied to reconstruct the 4D phase space distribution at the entry of the quadrupole scanned. The dispersion of the line has not been taken into account for the tomography. Once the beam distribution was obtained from the tomography, the beam was backtracked to the source, and the beam matrix was calculated. This procedure works only if there are no losses in the transfer line. If losses are present, the beam matrix of the backtracked distribution does not characterize the full beam at the source, but only the part of the beam that survived the transfer to the screen. Therefore it was important to accurately model not only the beam transport but also the aperture limitations in the line to identify where beam losses occurred. The SIMPA [3–6] code was used for beam tracking. This code has the special feature that it models the field of the line as a whole. This means that all the fringe fields are naturally included in the model. It can handle arbitrary fields with high precision and is symplectic.

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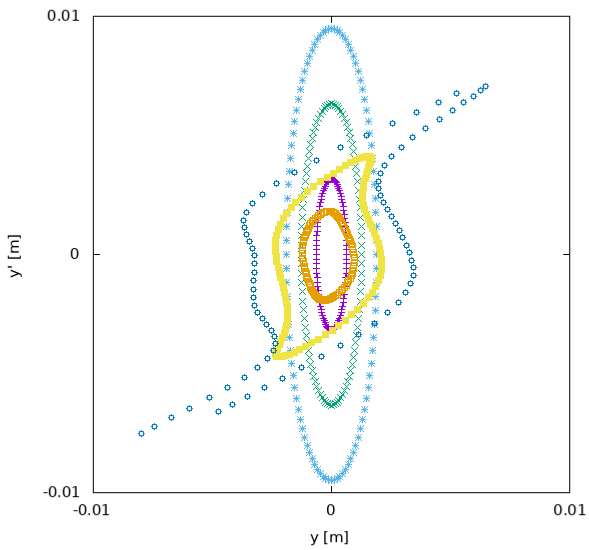

Figure 2: Non-linear behavior of the H- transfer line. Distortion of the initial $1\sigma, 2\sigma$, and 3σ vertical phase space ellipses during the transfer from the source to the BTV 118. Similar distortion was obtained in the horizontal plane.

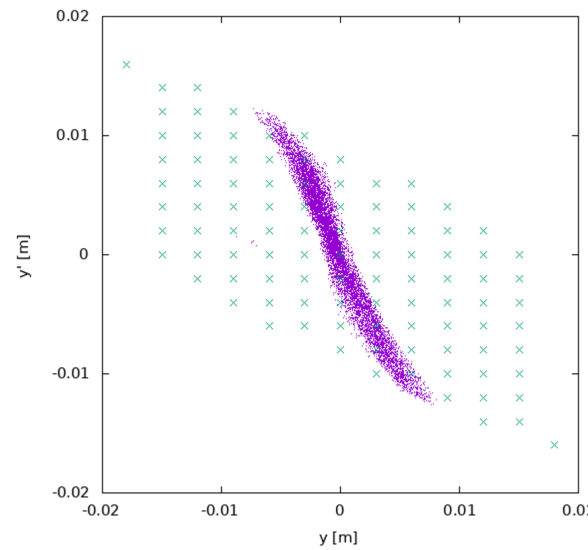

Figure 3: Reconstructed beam and grid data at the H- source with the initial 2023 settings of the line. The violet dots represent 10^4 particles sampled from the beam distribution obtained from phase-space tomography at the entry of the last quadrupole LNI.ZQMF51 and tracked backward to the source. The green crosses are the phase space coordinates of particles from a regular grid beam that survived the forward tracking to the BTV118.

A detailed description of the SIMPA algorithm can be found in the references [3–5] .

A rather non-linear behavior of the line was expected due to the presence of the ion switch. This has a nominal voltage of 26.2 kV which is comparable to the 100 kV beam energy. At the entry and the exit of the ion switch the beam energy changes significantly and this energy change is dependent on the particle position. Modeling these effects with MAD-X is difficult, but with SIMPA the ion switch is no different from any other element as in SIMPA all fields are handled with the same procedure.

RESULTS

To see how non-linearity affects the beam, three ellipses were tracked using SIMPA with $1\sigma, 2\sigma$ and 3σ magnitudes of the phase space variables from the H- source to the BTV 118. Figure 2 shows the regular initial and the final distorted phase space ellipses after tracking.

To know if losses occurred in the transfer line a wide grid in phase space was tracked forward from the source, and to have an idea of the maximum phase space that can be transported. The result of the quadrupole scan was processed with the phase space tomography software and a distribution obtained at the entry of the quadrupole LNI.ZQMF51. The particles from this distribution were then tracked backward to the source with SIMPA. As the displayed vertical phase space data in Fig. 3 shows, the edge of the beam distribution coincides well with the edge of the grid. This indicates that the aperture model in SIMPA is accurate but also that the beam size is limited by the transfer line. The beam measured during the initial 2023 quadrupole scan is not the entire beam distribution of the source, but only the part which was transported to the screen. It also shows that the limitation of the transfer line is in the angle coordinates. A similar angle-limited result was obtained in the horizontal plane.

The location of the losses was identified from the SIMPA tracking, which revealed avenues for improvement. Changing the voltage of the first two quadrupoles located inside the source, from 1500 V to 0 V, increased the angular acceptance of the transfer line. Using the new settings the quadrupole scan and the reconstruction procedure were repeated, and the new distribution backtracked to the source. This second scan was done in 2024. The grid forward tracking with the new settings was also repeated. The results with the new line settings are displayed in Fig. 4. The line transmitted 34 % more particles with the new settings. The optics with the new settings are displayed in Fig. 5. The initial conditions of the H- line were obtained from the sigma matrix of the backtracked distribution. These parameters are displayed in Table 1.

CONCLUSIONS

The beam parameters of the H- source have been reconstructed from quadrupole scans using beam tomography. The distribution obtained was backtracked to the source using realistic field maps allowing the beam matrix to be calculated. The procedure was repeated with a different setting of the transfer line to address the losses observed in the

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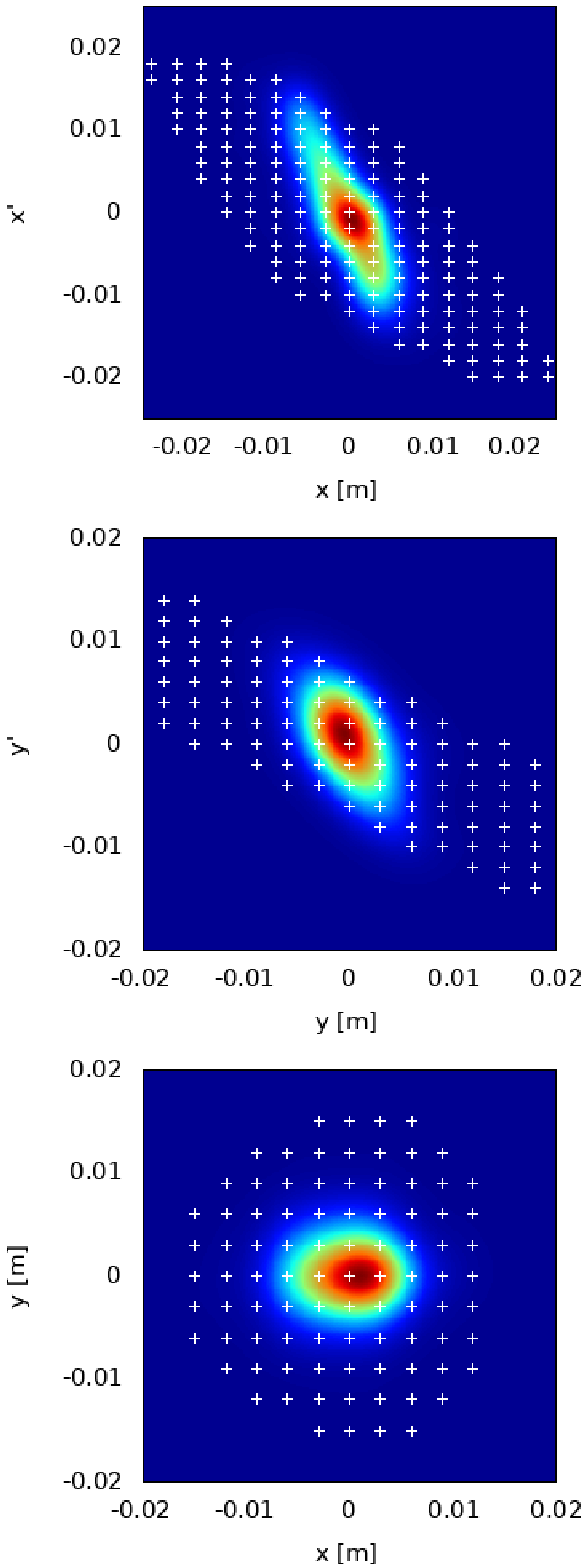

Figure 4: Result of the phase-space grid forward tracking displayed together with the beam reconstructed from the 2024 data at the H- source.

Table 1: Beam parameters obtained from the 2024 measurement reconstruction backtracked to the H- source

Parameter Name	**Value**
Horizontal RMS Emittane (1σ)	11.04 [µm]
Horizontal beta	1.12 [m]
Horizontal alpha	1.77
Vertical RMS Emittane (1σ)	6.62 [µm]
Vertical beta	1.06 [m]
Vertical alpha	1.07

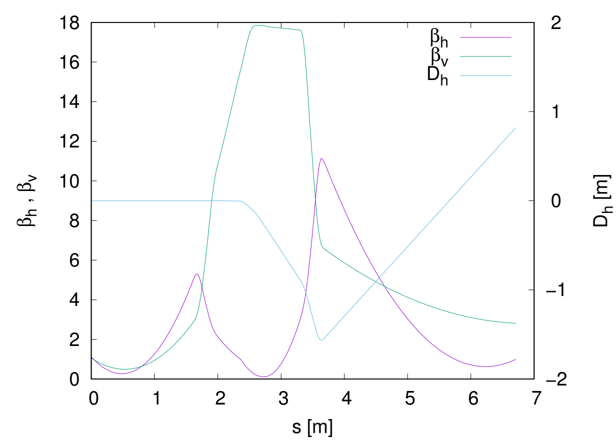

Figure 5: Optics of the H- line with the 2024 settings.

first iteration. The new settings resulted in a 34 % increase in the transmission.

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