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Possible Injection Schemes for the CERN Laser Ion Source into Linac III

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Abstract

A laser ion source is presently under study at CERN in the frame of the LHC heavy ion program. This source is supposed to deliver a high-current beam of $208Pb^{25+}$ via LEBT, RFQ and a dedicated injection line into the CERN ion linac (Linac III). While the design of LEBT and RFQ have been addressed in previous notes, we present in this note possible injection lines from the RFQ to the linac.

Geneva, Switzerland

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1 Introduction

A possible source candidate for the LHC ion program is a Laser Ion Source (LIS), presently under study at CERN. We have studied for the example of this source possible extraction systems [1], possible low-energy beam transport lines (LEBT) [2] as well as a radio-frequency quadrupole (RFQ) [3]. In this note, we address possible injection schemes from the RFQ into the CERN ion linac (Linac III).

We have studied a scheme, where a new ion source (here: LIS) injects into Linac III while keeping the possibility to inject beam from the present ECR source. We present two different scenarios: in the first case, the existing ECR source injects into Linac III through a modified MEBT which houses an additional dipole. The LIS injects via an achromatic line. In the second case, the LIS injects via the straight line, while the ECR source injects via the bent line.

2 Input Beam Parameters

We have used for the simulation of the injection line for the LIS input beam parameters which have been obtained from a simulation of a dedicated LIS RFQ [3]. For the beam coming from the present ECR source, we have used the beam parameters at the exit of the existing RFQ installed in Linac III. Table 1 summarises the beam parameters at the exit of both RFQs, which have been used as input for the simulation of the injection lines.

	new LIS RFQ design	existing Linac III RFQ
α_x	-1.75	1.54
β_x [m/rad]	0.16	0.22
ε_x (r.m.s., norm.) [mm mrad]	0.17[2]	0.082[2]
α_y	1.52	-1.46
β_y [m/rad]	0.14	0.19
ε_y (r.m.s., norm.) [mm mrad]	0.17[2]	0.08[2]
α_l	-0.23	-0.037
β_l [deg/MeV]	28.24	57.61
ε_l (r.m.s.) [MeV deg/u]	0.016	0.0067

2) 1/6 of total emittance for waterbag distribution.

Table 1: Output beam parameters of new LIS RFQ and existing Linac III RFQ.

3 Injection Lines into Linac III

We have designed transfer lines from the RFQ to Linac III which allow to inject beam either from the present ECR source or from the LIS into the linac. Two possibilities of such a switch yard have been studied:

1.) The present ECR source stays in its place. The existing MEBT of Linac III is modified such that it can house an additional dipole. The beam from the LIS RFQ is injected via an achromatic line.

2.) The LIS injects via a straight line into Linac III and the present ECR source injects via an achromatic line.

3.1 Scenario 1: LIS Injection via Achromatic Line; ECR Injection via Straight Line

3.1.1 LIS Injection via Achromatic Line

The bent line, via which the beam from the LIS RFQ is injected into Linac III, is supposed to be achromatic. Further design goals were to match the line to the IH acceptance parameters

and to limit transverse and longitudinal emittance growth.
In its simplest form, an achromatic line consists of two dipole magnets with two quadrupole magnets in between (see e.g. [4]). In our case, where the beam is space-charge dominated, we use two triplets between the dipoles in order to transport the beam without unacceptable transverse and longitudinal emittance growth. The longitudinal matching of this line to the IH acceptance is done by adjusting the voltage of the two buncher cavities before and after the bending magnets. Figure 1 shows the design of the achromatic line as simulated with the envelope code TRACE.

From the simulation program TRACE we obtain the matched values of the quadrupoles and bunchers, but it does not take into consideration non-linearities. To evaluate the beam transport from the RFQ to the IH, we have used the multi-particle tracking code PATH. The figure of merit is the injection efficiency into the IH which is characterised by the following acceptance:
in the horizontal plane α = 1.69, β = 0.94 mm/mrad, ε = 1 π mm mrad (norm.);
in the vertical plane α = 0.47, β = 0.55 mm/mrad, ε = 1 π mm mrad (norm.);
in the longitudinal plane α = -1.28, β = 0.23 mm/mrad, ε = 18.72 deg MeV.
Figures 2, 3 and 4 show the horizontal, vertical and longitudinal phase space at the exit of the achromatic line. We find an injection efficiency into the IH of 87.6% in the horizontal plane, 90.0% in the vertical plane and 65.9% in the longitudinal plane. This yields an overall injection efficiency of 54.7%. The remanent dispersion at the exit of the line is 15 cm.

3.1.2 ECR Injection via Straight Line

The existing MEBT of Linac III needs to be modified to house an additional dipole which is needed to inject the LIS beam. We have used the four quadrupoles from the existing line, but changed their positions and settings. The aperture of the first two quadrupoles is 20 mm, while for quadrupoles 3 and 4 it is 16 mm. Figure 5 shows the original and the modified MEBT of Linac III as simulated with TRACE. In the present MEBT, the aperture of the second quadrupole limits the transverse acceptance to 48.9 mm mrad. For the modified MEBT, we find an acceptance of 33.9 mm mrad. This would mean a reduction of about 30%. Possible ways to improve this are to increase the aperture of quadrupole 3 to 22 mm, which would yield the same acceptance as for the present MEBT. Alternatively, one can permute quadrupoles 1 and 3. In this case the acceptance is limited by the second quadrupole to 40 mm mrad, which means a reduction of the transverse acceptance by 18% with respect to the present MEBT.

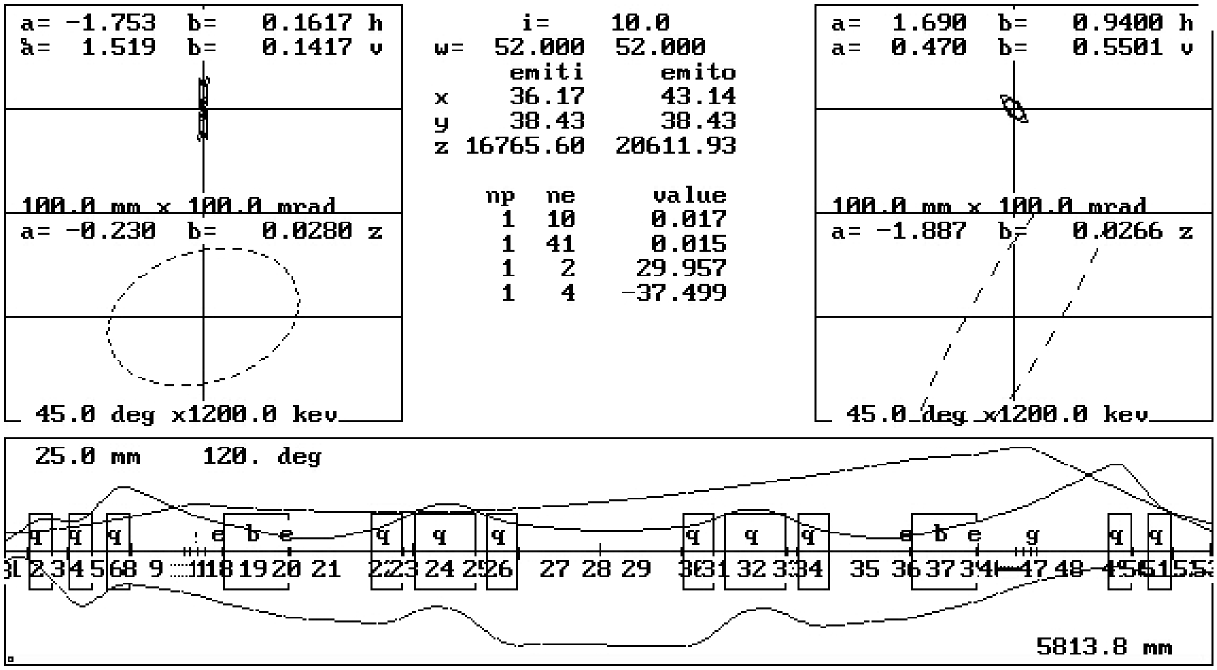

Figure 1: Achromatic line for LIS beam as simulated with TRACE.

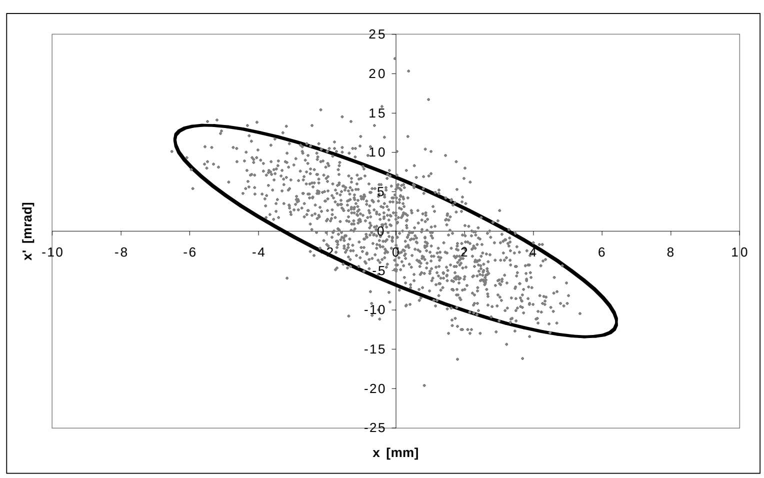

Figure 2: Horizontal phase space at the exit of the achromatic line as simulated with PATH. The solid ellipse indicates the acceptance of the IH, in which 87.6% of the particles are found.

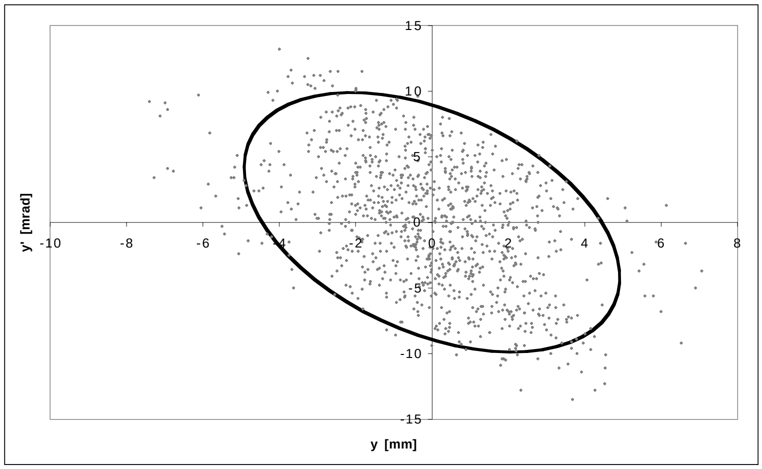

Figure 3: Vertical phase space at the exit of the achromatic line as simulated with PATH. The solid ellipse indicates the acceptance of the IH, in which 90.0% of the particles are found.

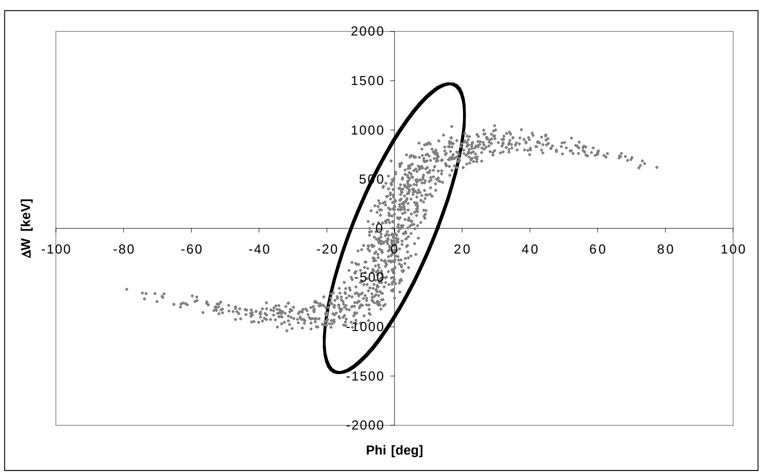

Figure 4: Longitudinal phase space at the exit of the achromatic line as simulated with PATH. The solid ellipse indicates the acceptance of the IH, in which 65.9% of the particles are found.

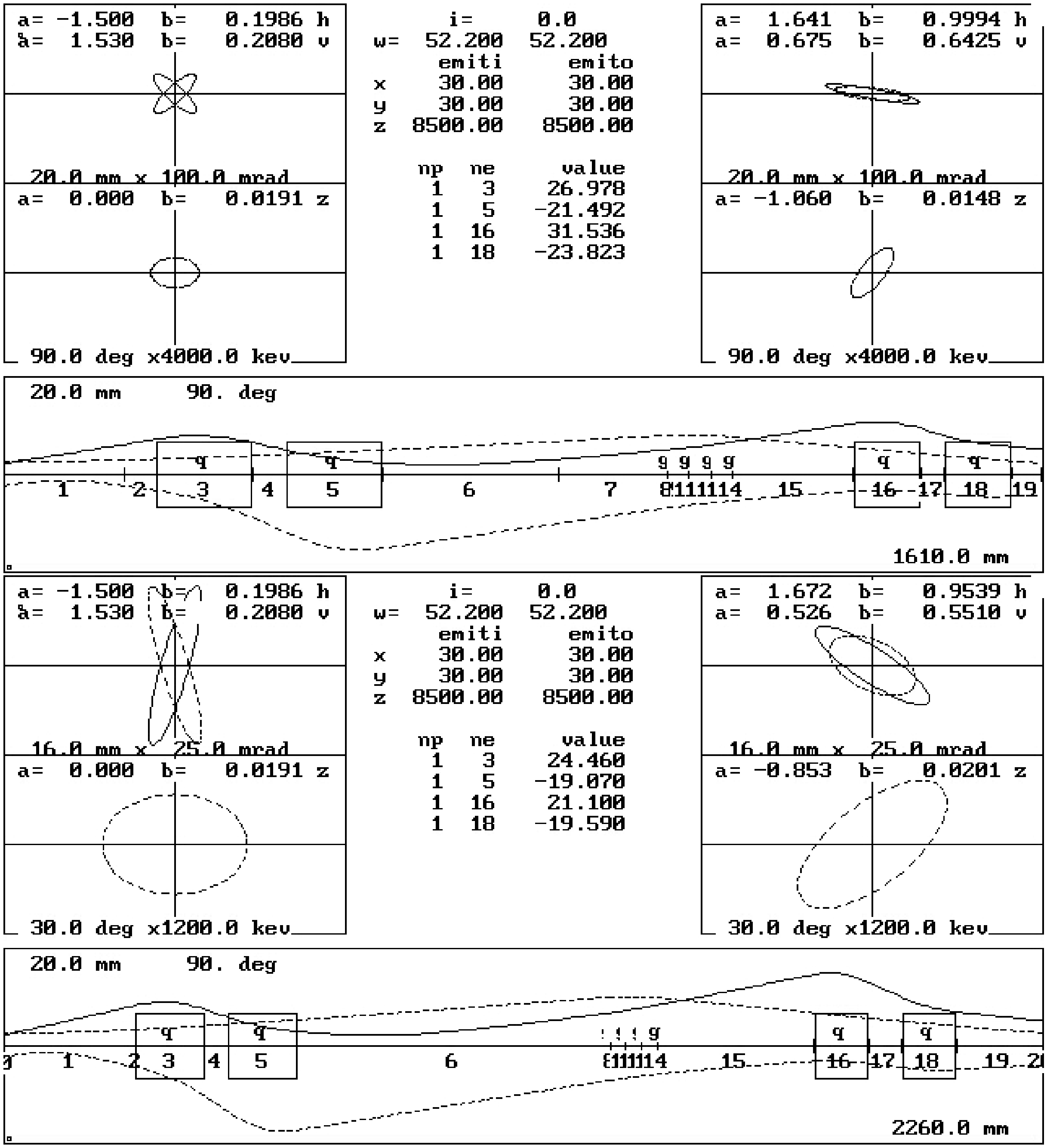

Figure 5: Original (upper Figure) and modified MEBT (lower Figure) of Linac III as simulated with TRACE.

3.2 Scenario 2: LIS Injection via Straight Line; ECR Injection via Achromatic Line

3.2.1 LIS Injection via Straight Line

As an alternative to the scheme reported in Section 3.1, we have studied a scheme where the beam from the LIS RFQ is injected via a straight line directly into Linac III. The present ECR source is in this scenario moved and injects via a bent, achromatic line. Figure 6 shows the straight injection line for the LIS as simulated with TRACE.

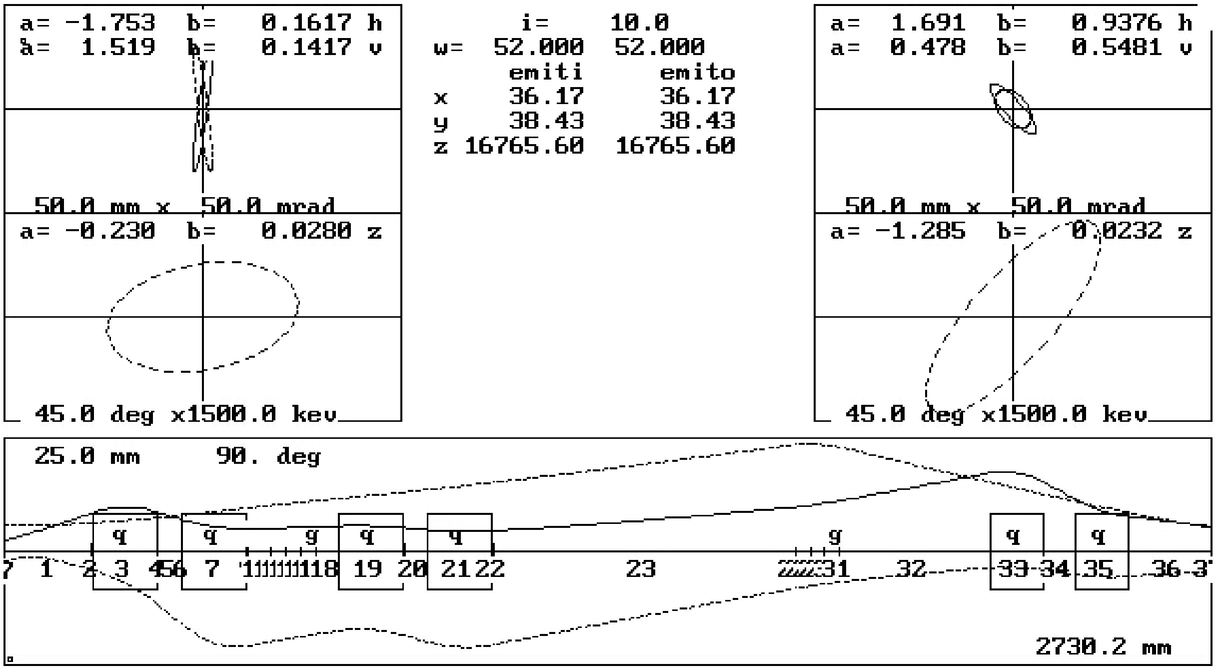

Figure 6: LIS injection via straight line as simulated with TRACE.

Again, this line was simulated using the tracking code PATH. Figures 7, 8 and 9 show the horizontal, vertical and longitudinal phase space at the exit of the straight line. We find an injection efficiency into the IH of 91.3% in the horizontal plane, 94.3% in the vertical plane and 74.3% in the longitudinal plane. This yields an overall injection efficiency of 67.2%. This value is higher than in the case of the bent line because of the total absence of dispersion.

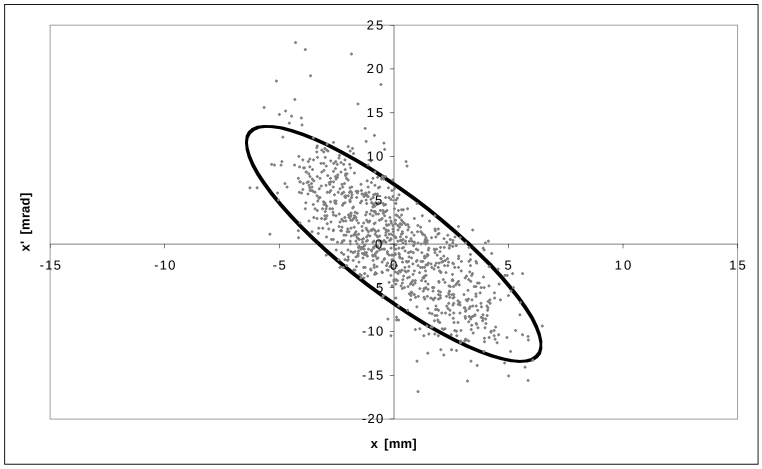

Figure 7: Horizontal phase space at the exit of the straight line as simulated with PATH. The solid ellipse indicates the acceptance of the IH, in which 91.3% of the particles are found.

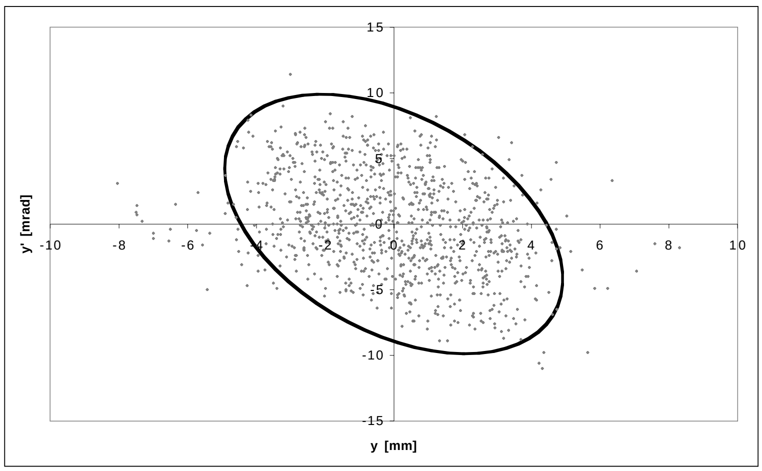

Figure 8: Vertical phase space at the exit of the achromatic line as simulated with PATH. The solid ellipse indicates the acceptance of the IH, in which 94.3% of the particles are found.

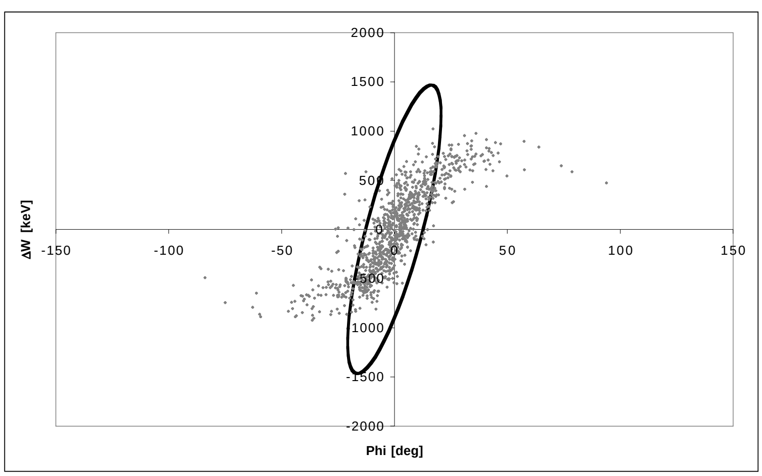

Figure 9: Longitudinal phase space at the exit of the straight line as simulated with PATH. The solid ellipse indicates the acceptance of the IH, in which 74.3% of the particles are found.

3.2.2 ECR Injection via Achromatic Line

The ECR source injects via an achromatic line into Linac III. The lay-out of the line is the same as discussed in Section 3.1.1. Figure 10 shows the simulation of the line with TRACE.

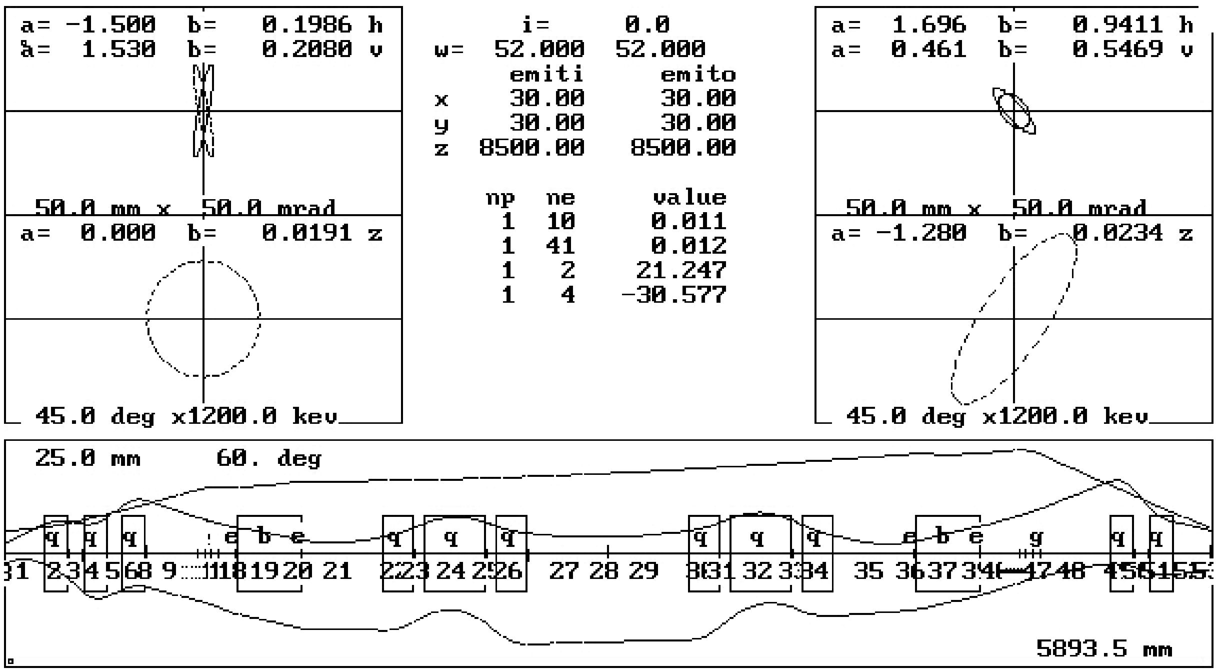

Figure 10: ECR source injecting via achromatic line. Simulation with TRACE.

4 Conclusions

We have studied two possible injection schemes for the beam coming from the CERN laser ion source into the Linac III. The simulations are based on a simulation of the LIS RFQ, which, in turn, is based on assumed beam parameters from the source. A final design of RFQ and injection lines can only be made once the source parameters are experimentally known.

So far we can conclude, that a direct injection of the high-current LIS beam into the IH is preferred with respect to an injection via a bent line. The main limitation for the injection efficiency is found in the longitudinal plane. The longitudinal matching could be improved by moving the position of the second buncher with respect to the IH entry plane. For the simulations reported here, the position of this buncher has been left as it is in the present Linac III MEBT.

References

[1] R. Scrivens, *Extraction Geometry for the Future LIS Plasma*, CERN PS/PP Note 2001-003 (2001).

[2] K. Hanke, S. Heising, R. Scrivens, *Comparison of the Beam Dynamic Solutions for Low Energy Beam Transport Systems for a Laser Ion Source at CERN*, CERN PS/PP Note 2001-004 (2001).

[3] K. Hanke, A. Lombardi, *Preliminary Design of an RFQ for the CERN Laser Ion Source*, CERN PS/PP Note 067 (2002).

[4] H. Wiedemann, *Particle Accelerator Physics*, **Vol. I**, Springer (1993).

[5] Tracking Code PATH, CERN version, documentation in preparation.

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