GEOMETRY AND OPTICS OF THE ELECTROSTATIC ELENA TRANSFER LINES

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Abstract

The future ELENA ring at CERN will decelerate the AD anti-proton beam further from 5.3 MeV to 100 keV kinetic energy, to increase the efficiency of anti-proton trapping. At present there are four experiments in the AD hall which will be complemented with the installation of ELENA by additional three experiments and an additional source for commissioning. This paper describes the optimization of the transfer line geometry, ring rotation and source position. The optics of the transfer lines and error studies to define field and alignment tolerances are shown, and the optics particularities of electrostatic elements and their optimization highlighted.

INTRODUCTION

The ELENA transfer lines will transfer the anti-proton beam from the ELENA ring [1, 2] to eight different experiments located in the AD hall. At two extraction points fast electrostatic separators extract the beam into a total of 100 m transfer lines where an additional 7 fast separators are used to distribute them to the different experiments. In addition proton/H$^-$ beams can be injected into the ring for commissioning from a dedicated source via a 4 m long beam line. The installation of the source imposes extra constraints on the optics design and some hardware elements. Due to the low beam energy of 100 keV electrostatic elements will be used.

ELENA PARAMETERS

Table 1 shows the beam parameters and specification values relevant for the injection and extraction systems. These values assume the nominal operation of 4 bunches at extraction.

Table 1: ELENA Beam Parameters

Beam parameters	Injection	Extraction
E_{kin} [MeV]	5.3	0.1
β_{rel}	0.1064	0.0146
Revolution period [μs]	0.958	6.946
Magnetic rigidity [mT.m]	333	46
Electric rigidity [kV]	10670	200
# bunches	1	4
Emittance, h/v [π.mm.mrad]	$<$15/15	6/4
Momentum spread, 95%	1*10^{-3}	2.5*10^{-3}
Total intensity	3*10^7	1.8*10^7

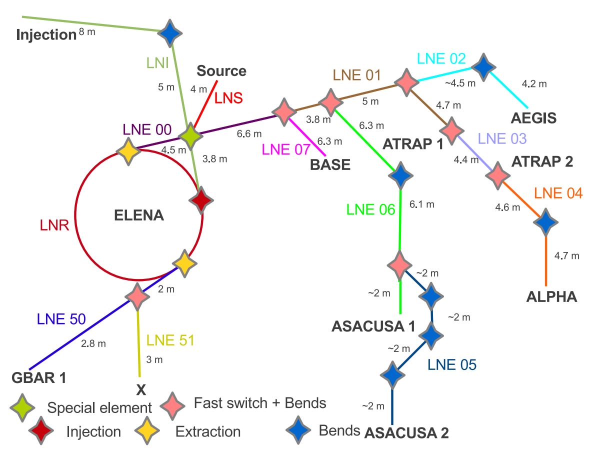

Figure 1: Sketched layout of the ELENA transfer lines. The upper extraction directs the beam to the existing experimental zones, the lower extraction into a zone with new experiments.

GEOMETRY OF THE TRANSFER LINES

Figure 1 shows a schematic view of the transfer lines. About 100 meters of transfer lines will be installed to deliver anti-proton beams to 8 experiments distributed around the AD-hall. Two experiments (GBAR1 and ASACUSA2) will be newly installed, BASE is being installed during the long shutdown 2013-2014 and AEGIS was installed during 2012-2013. The other 4 experiments are already in place since several years. The beam line layout was constrained by the existing experiments and shielding walls. had to be taken into account. A fast deflector (10^o) and a 80° bend will deliver the beam vertically to ATRAP1 and ATRAP2, located about 2 m above the beam line.

During the geometry optimization studies the number of different bending angles was minimized. This resulted in an average bending angle of about 48^o. Small deviations from this angle will be adjusted by redistributing the voltages on the plate. The fast extraction devices [3] will be both used for extraction from ELENA as well for fast switching in the transfer lines.

AN ELECTROSTATIC SWITCHYARD FOR THE ION SOURCE

The ion source (green star at the crossing of the LNI and LNE00 line in Fig. 1) will deliver protons and H$^-$ ions at E_{kin}=100 keV. An electrostatic switchyard (Fig. 2a) is be-

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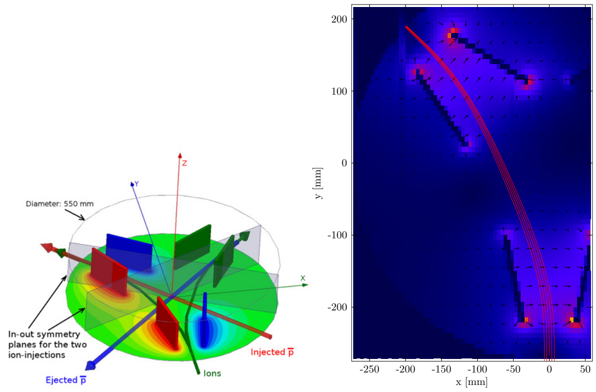

Figure 2: a) 3D model (upper half only) and simulated field of the switchyard. b) Simulated trajectories in the device - arrows and color indicate field strength.

ing designed to deflect these ions by $\pm 53.75°$. Protons can be injected either (i) via the ejection channel with normal polarity of the ELENA ring or (ii) via the injection line with inverted polarity of the ring. The former is of interest e.g. for lattice studies and the latter for cooling tests (in case the life-time of H- is poor). At the same time the free passage of the injected (E_{kin}=5.3 MeV) and ejected (E_{kin}=100 keV) anti-proton beam need to be possible as well.

As for an electrostatic deflector, the device is focusing in the bending plane, and needs two tuneable high-voltage power supplies. A continuous set of $V_{repulsive}$ vs. $V_{attractive}$ voltages results in the required deflection angle (x'_{out}=0). However, in general the output beam can still be offset from the nominal trajectory ($x_{out} \neq 0$). The design is driven by the following considerations:

- Simplicity: use plate electrodes.
- The device should be symmetric not only to its trivial symmetry plane (XY), but also to the mid-plane between its input and output for a given deflection mode (see Fig. 2). This guarantees that the two conditions x'_{out}=0 and x_{out}=0 are simultaneously fulfilled.
- The ion beam should have sufficient distance from the electrodes (30 mm).

The geometry shown in Fig. 2a was found to give satisfactory performance. Trajectories of 100 keV particles in the device are shown in Fig. 2b.

OPTICS OF THE TRANSFER LINES

Table 2 lists the main elements that will be installed in the electrostatic ELENA transfer lines. About 105 electrostatic quadrupoles and 20 bends are used for focusing and bending the anti-proton beam. In addition the part between the north extraction and the source switch will need to switch polarity (occasionally) so that beams from the source can be injected.

The experiments require a beam spot size between 1 to 2 mm. The beam pipe diameter is 200 mm, the aperture width between the electrodes in the quadrupoles and bends is 60 mm. The choice for the diameter in the quadrupoles was a trade-off between the needed aperture and voltage requirements.

Table 2: Electrostatic ELENA Transfer Line Elements

Total length transfer lines [m]	100
Present number of experiments	8
Total number of fast separators	9
Total number of electrostatic quadrupoles	105
Total number of electrostatic bends	20
Total number of dual-plane correctors	44
Total number of dual-plane monitors	44
Total number of longitudinal pick-ups	2

FODO Cell

During the optics design of the ELENA transfer lines a FODO cell structure was implemented wherever possible; this significantly reduces the number of power converter families. In the current design about 80% of the length is occupied by FODO structures. The FODO cell with 1.4 m drift between the quadrupoles is matched to 90° phase advance which results in a potential difference of 1736 V to be applied between the electrodes. The optics and beam size in the FODO cell is shown in Fig. 3.

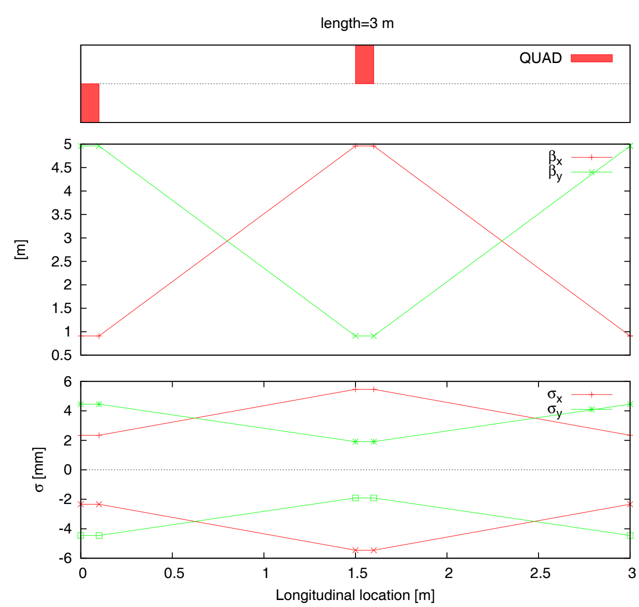

Figure 3: Optics in the FODO cell. The location of the quadrupoles is shown on the top, the beta-functions in the middle and the betatron beam size on the bottom. The dispersion contribution to the beam size is not taken into account.

Matching Section

Two kinds of matching sections are designed for the transfer lines. The first one is for matching the optics pa-

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rameters to the FODO cells; this matching section is composed out of 3 doublet structures. The second one is for matching to the optics parameters at the experiments. This section is composed in most cases out of a triplet and a couple of auxiliary doublet structures, to support the triplet in matching the optics to the required beam size.

Figure 4 shows an example of the final matching section to the AEGIS experiment. The FODO structure is kept until the bend, with an angle of 47.84°. After the bend the final matching section to the AEGIS experiment commences. The spherical electrostatic bends introduce a large focusing effect in both planes, this can be observed in the figure. Both the horizontal and vertical β increase significantly directly after the bend. The largest beam size of 13 mm, in the horizontal plane, is reached between the first and second doublet, this is due to the dispersion and the horizontal β peaking at the same location. The maximum voltage needed in the electrostatic matching quadrupole is about 8.9 kV. The beam sizes at the handover point to the AEGIS experiment are about 1.6 and 1.2 mm, respectively, in the horizontal and vertical plane.

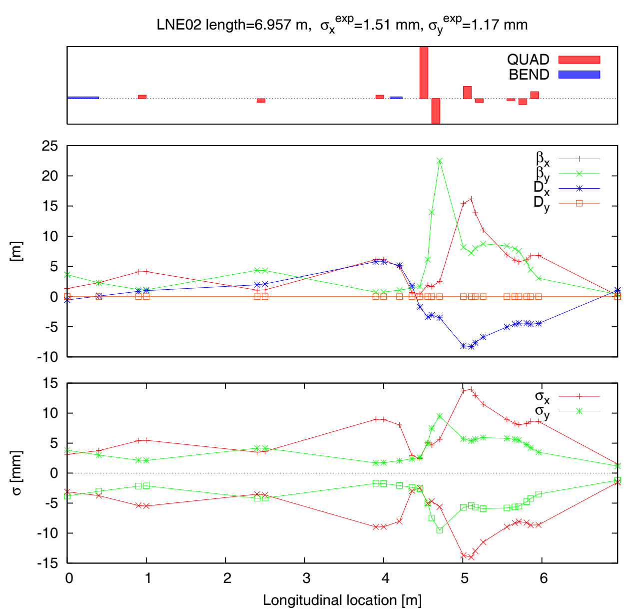

Figure 4: Optics for the final matching section to the AEGIS experiment. The top plot shows the location of the electrostatic bends/fast switches (blue) and quadrupoles (red). The optics functions are shown in the middle plot and the betatron and dispersion beam size for both planes are shown in the bottom plot.

TRAJECTORY CORRECTION AND ERROR STUDIES

Trajectory correction and error studies are an integral part of the design of transfer lines. Not only does it have a direct impact on the number of correctors needed, but it also defines the tolerances on the design of the hardware and alignment.

Trajectory correction studies were conducted for the AEGIS line, for these studies only misalignments of the quadrupoles were assumed with 0.9 mm as the maximum for both planes. No noise was applied to the monitors. Dual-plane correctors were placed at every second quadrupole in the line, in total 9 were installed. Dual-plane monitors are installed beside the correctors, two extra monitors were installed, one near the extraction of the ELENA ring and one just before the AEGIS experiment. Figure 5 shows statistics of the correction studies. With a total of 9 dual-plane correctors installed along the 27 m line it is possible to correct the trajectory to a satisfactory level.

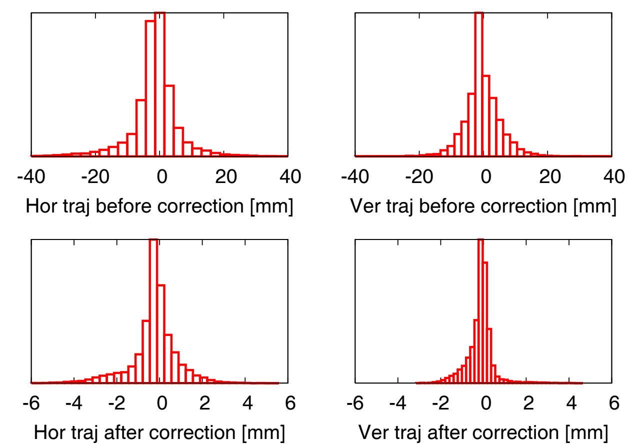

Figure 5: Results of the trajectory correction studies for the transfer line up to the AEGIS experiment. Both planes were studied. The horizontal trajectory before correction (top left), the horizontal trajectory after correction (bottom left), the vertical trajectory before correction (top right) and the vertical trajectory after correction (bottom right). For both planes the trajectory has been corrected to a satisfactory level.

CONCLUSIONS AND OUTLOOK

The design of the ELENA transfer lines is entering the final stage. The geometric layout of the lines meets the constraints of integration in the AD hall. Optics studies show that it is possible to transfer the beam from the extractions to each experiment with sufficient aperture margin and to reach the required beam sizes at the experiments. Preliminary correction studies were conducted for one of the lines and resulted in a well corrected trajectory. The hardware design of the electrostatic quadrupoles, ion switch, fast separators and bending elements has started.

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