BEAM DYNAMICS STUDIES OF THE ELENA ELECTROSTATIC TRANSFER LINES IN THE PRESENCE OF MAGNETIC STRAY FIELDS

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Abstract

The ELENA (Extra Low ENergy Antiproton) [1] ring at CERN will further decelerate antiprotons produced at the AD (Antiproton Decelerator) facility from a kinetic energy of 5.3 MeV to 100 keV. The antiprotons will be distributed through a network of electrostatic transfer lines to several experiments, which will replace the existing magnetic transfer lines. The existing experiments and limited space in the AD hall forces the new transfer lines into close proximity to the high-field solenoids used by some experiments to trap the antiprotons. The stray fields from the experimental magnets are known to perturb beam delivery and are a concern for operation at the decreased beam rigidity provided by ELENA, which, however, can be mitigated by a fairly large number of correctors and generally low beta functions along the transfer lines. A study was carried out to investigate the influence of stray magnetic fields on the beam, including different operational scenarios. The analytical model of the fields used for simulation will be discussed. Furthermore, trajectory correction algorithms using MADX optic model of the lines have been investigated. The results of these studies as well as specifications of acceptable stray field limits and field attenuation requirements will be presented.

INTRODUCTION

The antiproton beam, composed of four bunches at a kinetic energy of 100 keV, can be extracted at once from the ELENA ring and single bunches from this bunch train will then be deflected into the respective experimental lines by fast deflectors. The electrostatic quadrupoles in the lines are common to several experiments and therefore have a unique optics setting. Only the quadrupoles that are active for a single experiment can be used for operational tuning after the setting up of the common sections is completed. The same applies to the trajectory correction. In the scope of this publication, the influence of stray fields originating from experimental magnets on the longest line delivering beam to the ALPHA experiment has been investigated. An overview of the ELENA ring and its transfer lines is shown in Fig. 1.

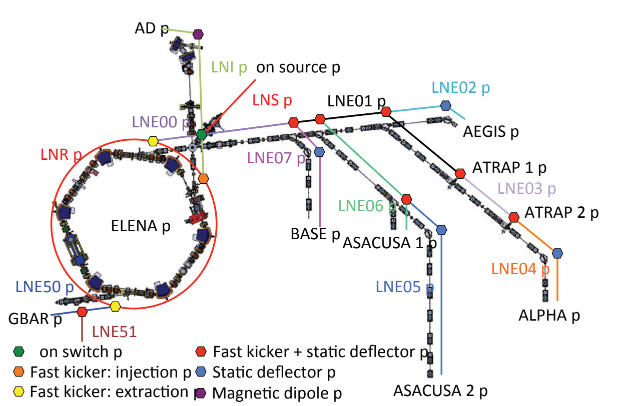

Figure 1: Layout of the ELENA ring and its transfer lines. [2]

MODELING SOLENOID FIELDS

In order to model the magnetic fields of the experiments' solenoids inside the AD hall, an analytic description of the magnetic field based on currents loops in Cartesian coordinates was chosen [3]. In total, five magnets were simulated in the scope of this study: Two magnets from the AEḡIS experiment and three from the vertical experiments ATRAP 1 and ATRAP 2. Their parameters are summarized in Table 1. The absolute value of the stray magnetic field, as well as the location of the transfer line from the ELENA ring to the ALPHA experiment is shown in Fig. 2.

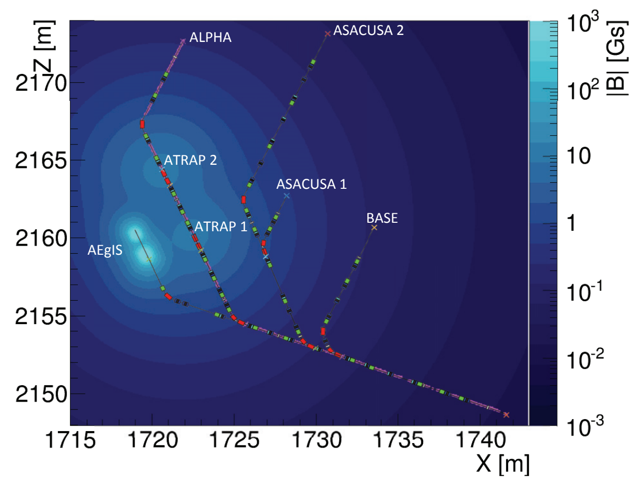

Figure 2: $\left|\vec{B}\right|$ in the AD hall at beam level and the beam transfer lines LNE00-07.

EFFECT ON ANTIPROTON BEAM

The initial beam line design was implemented in MADX [2,4]. In order to simulate the influence of the magnetic stray fields on the beam, the integrated transversal field components along the transfer line (see Fig. 3, top) were translated into horizontal and vertical kicks. Those kicks were applied at a resolution of every 10 cm, where possible, in between existing equipment. The influence of the magnetic stray fields on the beam trajectory along the transfer line is presented in Fig. 3 (bottom). The horizontal black lines indicate the available aperture.

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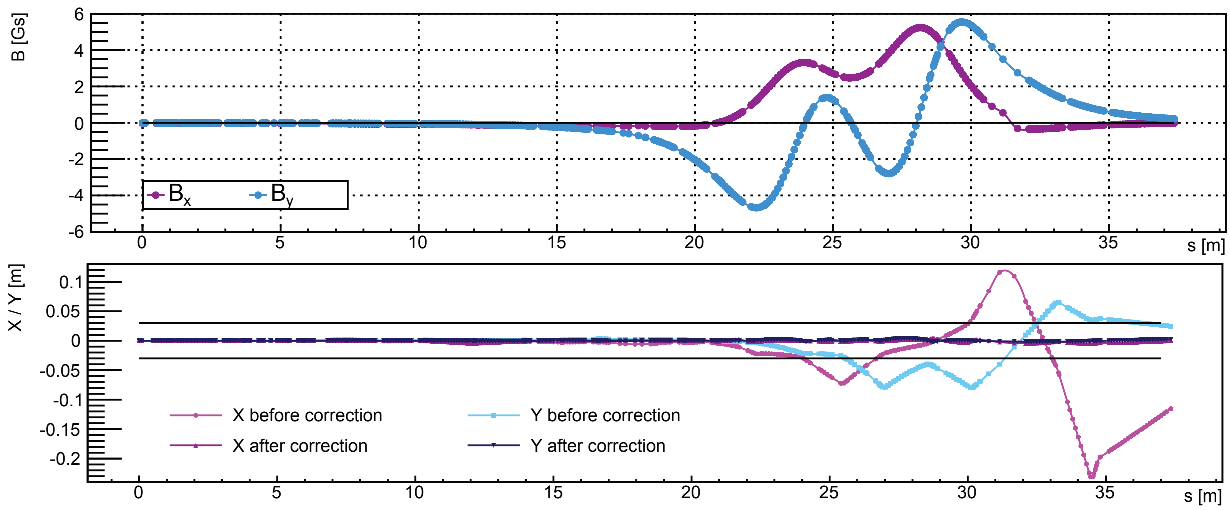

Figure 3: Transversal magnetic field components from all five magnets in the beam frame (top) and the trajectory before and after correction from ELENA ring to the ALPHA experiment (bottom).

Table 1: Magnet Parameters Used for Simulation

Magnet	Field	Length	Radius
AEḡIS 1	4.46 T	1.290 m	0.100 m
AEḡIS 2	1 T	1.290 m	0.130 m
ATRAP 1	5 T	0.457 m	0.174 m
ATRAP 2	1 T	1.524 m	0.301 m
ATRAP 2 PBAR	2 T	0.250 m	0.130 m

Correction Technique

As the computed, disturbed trajectory in Fig. 3 (bottom) clearly exceeds the aperture limitations of ±30 mm in the electrostatic quadrupoles, correction is necessary. In total, 21 horizontal and 21 vertical correctors are available. In this simulation, the MADX MICADO technique was used to correct in both transversal planes, aiming to limit the RMS values along the line to 10^{-5} m. The correction algorithm, number and strength of available correctors are not sufficient to reduce the RMS of the trajectory to that target value at the nominal magnetic field strength. However, as measured at the beam position monitors, an RMS along the line of 1 mm can be achieved. The minimum available aperture in that case is 4.7 σ (vs 5.6 σ nominal) horizontally and 8.9 σ (vs 9.0 σ) vertically.

Attenuation Studies

A study was carried out to understand to what extent individual experiments can ramp down their magnets without affecting the others and without requiring time consuming re-correction of the trajectory. Therefore, the option of local magnetic shielding close to the beam line was studied. All magnetic fields were successively scaled by attenuation factors ranging from 1 to 1000. For each factor the trajectory was corrected and was found to reach the 10^{-5} m RMS target at an attenuation factor of ≥ 50. In that case, the required corrector strengths do not exceed 0.4 mrad, which is well below the operational maximum of 20 mrad. The horizontal (X) and vertical (Y) RMS of the trajectory along the line before and after correction for the various attenuation levels is shown in Fig. 4. To avoid biasing the result from the

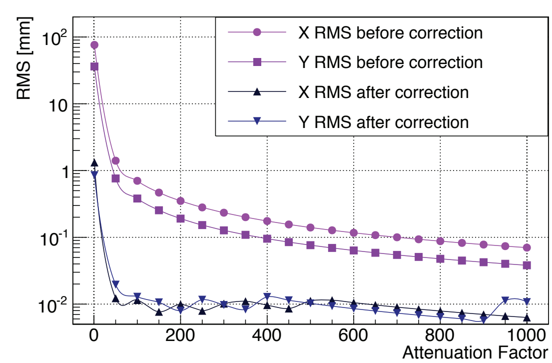

Figure 4: X and Y RMS measured on beam position monitors at $s > 15$ m before and after correction.

almost field free region in the first 15 m of the line, the beam position monitor readings from this section of transfer line were omitted.

This correction scheme applies for all considered magnets in operation at full strength. Due to, e.g. scheduled interventions or operational changes, the number of powered magnets could change. Therefore, a series of studies was carried out, switching off different magnets at a time, while keeping the applied corrector settings fixed. Here, four basic scenarios were investigated:

1. ATRAP 1 magnet ramped down and turned off;
2. ATRAP 2 PBAR magnet ramped down and turned off;
3. both ATRAP 2 and ATRAP 2 PBAR magnets ramped down and turned off;

4. both AEḡIS magnets ramped down and turned off.

Table 2: Integrated Magnetic Field Contributions from Simulated Magnets in Beam Frame
*Sum of individual absolute contributions.

Magnets	$\int B_x \mathrm{d}s$ [Gs m]	$\int B_y \mathrm{d}s$ [Gs m]	$\int \lvert B_x \rvert \mathrm{d}s$ [Gs m]	$\int \lvert B_y \rvert \mathrm{d}s$ [Gs m]
AEḡIS	-0.21	2.51e-6	5.46	0.19e-3
ATRAP 1	12.47	0.41	13.65	27.79
ATRAP 2	11.75	0.26	15.25	28.92
ATRAP 2 PBAR	2.58	0.10	3.10	6.07
Total	26.59	0.77	37.46*	62.78*

The integrated transversal magnetic field components of these configurations along the studied transfer line are shown in Table 2. These have to be seen in relation to the low magnetic rigidity of the passing antiproton beam of 457 Gs m [1]. The resulting X and Y RMS values are shown in Fig. 5. The AEḡIS magnet is at the same height as the passing line, so it only effects the vertical (Y) component of the trajectory. The biggest influence in both planes comes from the ATRAP 1 magnet. In order to achieve an RMS along the line of 10^{-4} m, which we would assume as negligible and similar to the expected shot-to-shot jitter, an attenuation of the fields by at least a factor 800 would be necessary. Otherwise, the trajectory would have to be re-steered and the corrector strengths would have to be re-adjusted.

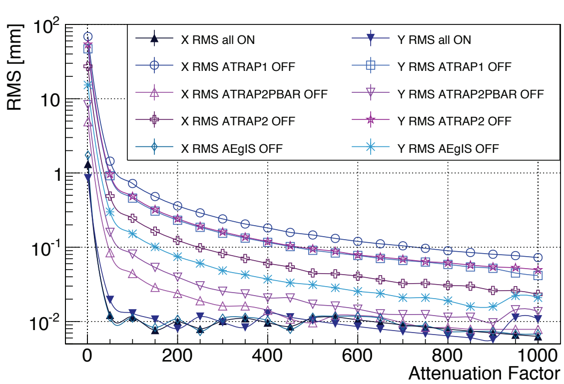

Figure 5: X and Y RMS measured on beam position monitors at $s > 15$ m for various magnet settings using the corrector settings from Fig. 4.

However, the RMS of the beam trajectory is not the only concern of the beam delivery to the ALPHA experiment. Aperture restrictions and the transversal displacement of the focal point also have to be considered. While the aperture loss is negligible after a field attenuation of 50, Fig. 6 shows that an attenuation factor of 200 is necessary to displace the position of the focal point by less than 1 mm. At an attenuation factor of 1000, the displacement is less than 0.1 mm and negligible.

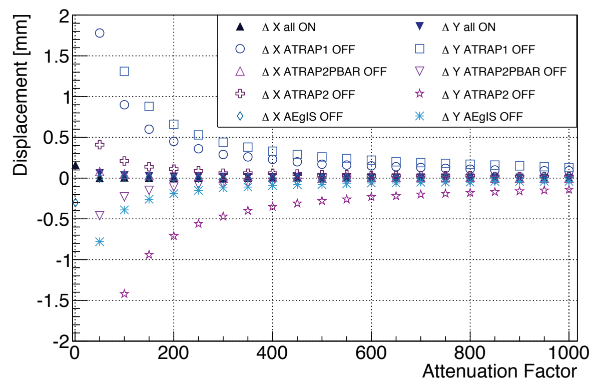

Figure 6: X and Y displacement at the ALPHA focus point for various magnet settings using the corrector settings from Fig. 4.

CONCLUSION AND OUTLOOK

First order effects of the influence of magnetic stray fields from the experimental solenoids on the passing antiproton beam have been investigated. The study assumed unshielded solenoids modelled analytically as a single current loop in an open space and neglected any shielding or magnetic material in the hall, which could perturb the fields. The trajectory can be corrected without attenuation and minimal loss in acceptance, although the corrector strengths will be relatively high. Considering changes to the powering configuration of the experimental magnets, a field attenuation by a factor 800 would be necessary to achieve the required RMS along the line, to limit the aperture loss and to minimise the beam displacement at the ALPHA experiment without retuning the correctors. In both cases the required corrector strengths are well within specifications.

To improve this study, a simulation of long magnets consisting of multiple current loops will be conducted. Nevertheless, we propose to conduct an in-situ magnetic field measurement along the line in the future to verify and complement these simulation results.

ACKNOWLEDGEMENT

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