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REALISTIC SIMULATIONS OF STRAY FIELD IMPACT ON LOW ENERGY TRANSFER LINES*

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Abstract

Low energy (~100 keV) facilities working with antiprotons, heavy ions, or charged molecules may experience severe beam transport instabilities caused by field imperfections. For example, long (~10 m), unshielded beam lines will not be able to transfer particles due to the natural Earth magnetic field or stray fields from closely located experiments. Currently, only a limited number of simulation codes allow a simplified representation of such field errors, limiting capabilities for beam delivery optimization. In this contribution, a new simulation approach is presented that can provide detailed insight into 4D beam transport. It illustrates the impact of imperfections and stray fields on beam stability and quality through simulations of two antiproton experiments located in the Antimatter Factory at CERN in Geneva, Switzerland. Magnetic field imperfections are examined in two different ways, providing greater flexibility and an opportunity to benchmark all outcomes. Simulation performance is analyzed as a function of the level of detail and efficiency.

INTRODUCTION

The Extra Low ENergy Antiproton ring (ELENA) [1,2] is a small synchrotron recently constructed and commissioned at CERN to decelerate antiprotons with kinetic energy of 5.3 MeV produced by Antiproton Decelerator (AD) down to 100 keV. The lower energy will improve the trapping efficiency by about a factor 10–100 for the experiments which currently receive beam from the AD. Beam transfer lines attached to the ELENA ring are based on electrostatic optics and deflectors, which were a cost-effective solution for extraction system to multiple experiments. They are able to guide the low energy antiproton beam divided into four bunches concurrently. The CAD model of the storage ring and electrostatic beam lines inside the AD hall are shown in Fig. 1.

In order to understand the overall performance of combined system formed by all the beam lines it is important to know the impact from stray fields produced by the joint operation of multiple experiments in the AD-ELENA complex. Most of the present particle traps utilise strong solenoids (~5 T) to confine antiprotons. Due to the absence of magnetic shielding around some of the experimental setups, stray magnetic fields may perturb beam motion in the transverse plane for closely located beam lines.

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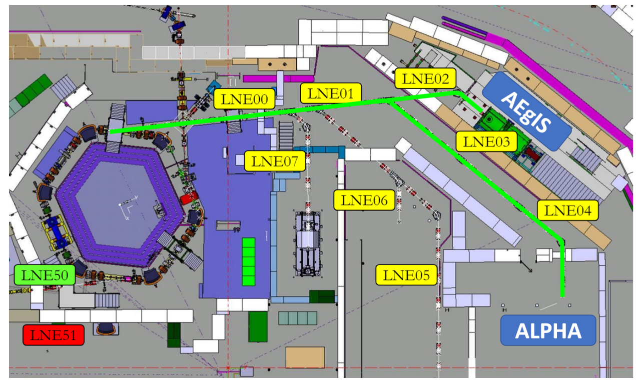

Figure 1: Schematics of part of AD hall with ELENA ring and all electrostatic transfer lines. Beam lines considered in the scope of this paper are highlighted with light green.

In the context of the ELENA transfer lines, preliminary studies were carried out describing the solenoids as a single point source and adopting an analytic approach [3,4]. In this case, the impact of the field components was implemented in the model via horizontal or vertical kicks to a reference particle with 10 cm sampling of the drift space between the existing elements of the optical lattice modelled using the accelerator design code MAD-X [5]. It is worth to mention that a similar method is implemented in beam dynamics code ELEGANT [6], where *STRAY* lattice elements are defined inside the beam line.

To go beyond the current somewhat simplistic model towards a more realistic model, in this paper we present a 3D computation of the stray fields. As an example, we consider the ELENA transfer line to the ALPHA experiment [7], which might be significantly affected by the fields from the two solenoids of the AEgIS experiment [8].

COMPUTATIONAL TOOLS

The beam lines highlighted in Fig. 1 have been implemented in G4beamline [9] by extending previous models [10–12] to include the AEgIS experimental section. It consists of two main coils and 21 low field correction coils. All coils were simulated using CST [13] to include external field coming from the trap, and an additional benchmark has been performed between CST and G4beamline using *coil* and *solenoid* elements. The field generated with these *coils* is computed for a set of infinitely thin current sheets spread evenly radially. The *solenoid* specifies the working current within the coil. Dimensions of the simulation region for the CST case have been chosen in such a way that the

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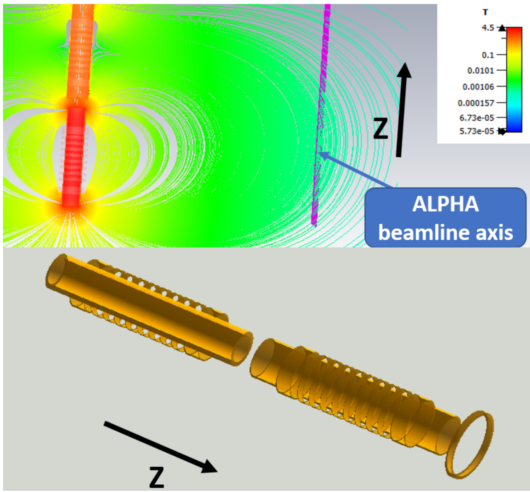

Figure 2: Simulation of AEgIS coils. (Top) CST model of 23 coils with maximum produced field amplitude of 4.5 T. Purple plane indicates relative position of ALPHA transfer line. (Bottom) Geometry of the coils modelled using the code G4beamline.

field components drop below the Earth's natural magnetic field amplitude.

A comparison of both models is shown in Fig. 2. The top part of the image showcases field lines generated within the coils. The neighboring beam line directed towards ALPHA is located at ~3 m from solenoid axis. The bottom image demonstrates geometry of the coils created in G4beamline. To maximize tracking performance only small part of the simulated field was used, a field map of size 0.024x0.024x13 m was exported and implemented into G4beamline simulation in such a way that the antiproton beam is passing through middle of the field. The use of the whole map is not computationally efficient when the fine mesh (2 mm) is used.

STRAY MAGNETIC FIELDS

Impact on the Beam

Knowing the Twiss parameters at the extraction point of the ELENA ring, a 6D beam distribution with a momentum of 13.7 MeV/c has been generated and used as an input. Due to the presence of such fields the beam is deflected immediately after bending towards the ALPHA experiment. Beam trajectories from beam tracking are shown in Fig. 3. Loss of the beam happens due to radial cut-off of maximum possible beam deflection within the line, equal to electrostatic quadrupole aperture (30 mm in radius) and representing the invisible beam pipe.

To benchmark both methods we have tracked a neutral particle through the ALPHA beam line. All field components crossed by such track can be stored using G4beamline. The benchmark of both simulations is shown on Fig. 4. For comparison, it is worth to mention that the absolute value of the Earth's magnetic field in the CERN region has an amplitude of 0.4 Gauss [14].

Passive Shielding

In order to decrease the amplitude of the stray fields we briefly looked into the possibility of blocking these fields using passive shielding. The most effective way to create magnet free region is to surround it with thin shell made of material with high magnetic permeability μ. Common choice is a fully enclosed cylinders or boxes made of mu-metal ($\mu \sim 80000$) or permalloy [15–17]. In principle it might be possible to cover beam pipes in drift section with thin foils made from these materials.

Another option can be light-weight modular shields which will guide magnetic field in required direction. One of preliminary designs is shown in Fig. 5. It consists of two thin cylindrical sectors made of mu-metal. In comparison with unprotected side, the produced field is partially blocked after passing through the structure. The main advantage of the addressed design is easy access to beam pipe elements or particle trap components along with portability and multitasking. Further, we also investigated how distance from the main solenoid axis impacts shielding abilities which is shown in Fig. 6.

As you can see, the shield efficiency increases with the distance due to the fact that smaller portion of the field is able to bypass mu-metal foils.

CONCLUSIONS AND OUTLOOK

The influence of magnetic stray fields from the AEgIS experiment solenoids on the antiprotons passing through neighboring transfer lines have been investigated. In this study we considered unshielded solenoids modelled numerically in G4beamline as well as in CST. The primary obstacles between beam line and experiment are a concrete wall and the stainless steel vacuum vessels which have minimal magnetic shielding effects. We neglected any extra effect coming from additional magnetic material present in the space between solenoids and ALPHA beam line, which could mitigate part of the impact of stray fields. The findings of this study are in close agreement with previous investigations done by J.Jentzsch; thus, the trajectory can be corrected without attenuation and minimal loss in acceptance using electrostatic correctors. We demonstrated the first insight into how the simple passive shielding at different distances from the solenoid might decrease the amplitude of the stray fields. Another way to attenuate these fields can be re-powering of solenoid magnets in high frequency mode where low field time gaps will be large enough to allow bunches pass downstream. To complete this study, in the future we plan in to compare our results with an insitu magnetic field measurements along the line and local Earth magnetic field to verify and complement these simulation results.

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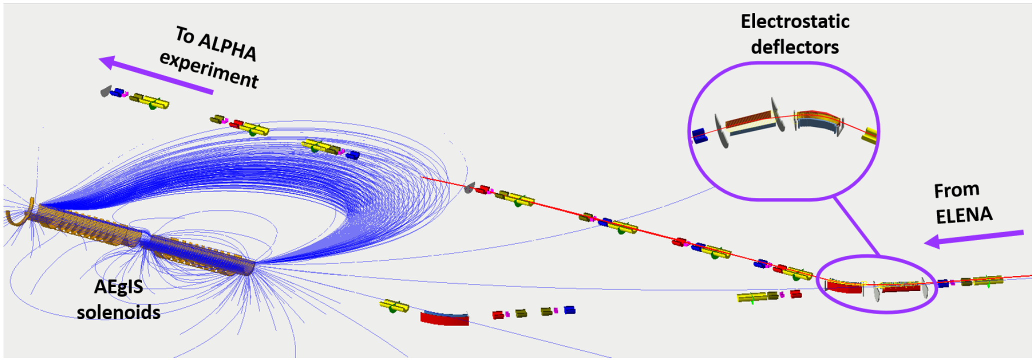

Figure 3: Antiproton deflection and loss within the line due to stray fields (blue lines). Tracking is terminated due to cut-off distance from the reference line equal 30 mm (beam pipe radius).

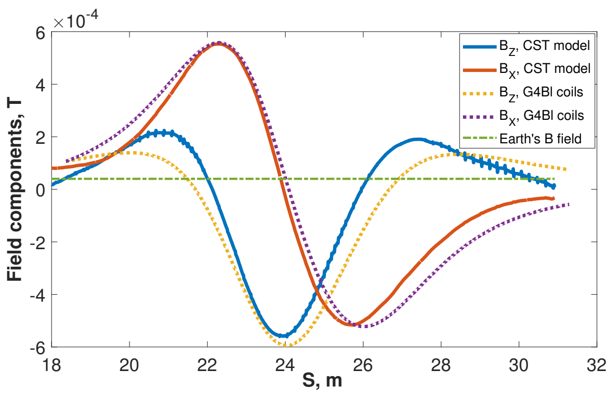

Figure 4: Comparison of two biggest stray field components: B_z along the beam tracking axis and B_x as transverse component.

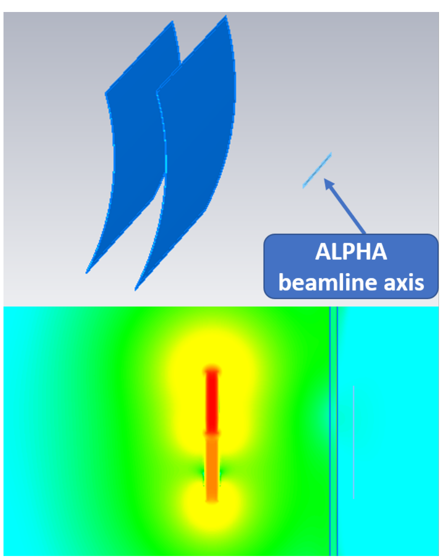

Figure 5: Impact from the passive shielding. (Top) Geometry of two thin sector shields. (Bottom) Field distribution from the solenoid coils when shield is installed on the right side.

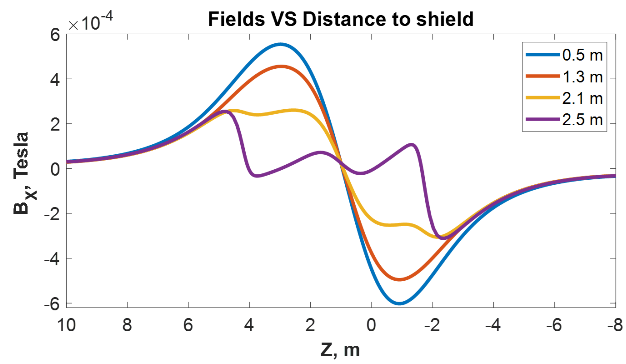

Figure 6: Dependence of transverse magnetic field component B_x (at ALPHA axis) from the distance to the shielding foils.

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