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BEAM TRANSFER LINE DESIGN TO THE SPS BEAM DUMP FACILITY

Y. Dutheil, J. Bauche, M. Calviani, L.A. Dougherty,
M.A. Fraser, B. Goddard, C. Hessler, J. Kurdej, E. Lopez Sola
CERN, Geneva, Switzerland

Abstract

Studies for the SPS Beam Dump Facility (BDF) are ongoing within the scope of the Physics Beyond Collider project. The BDF is a proposed fixed target facility to be installed in the SPS North Area, to accommodate the SHiP experiment (Search for Hidden Particles), which is most notably aiming at studying hidden sector particles. This experiment requires a high intensity slowly extracted 400 GeV proton beam with 4×10^{13} protons per 1 s spill to achieve 4×10^{19} protons on target per year. The extraction and transport scheme will make use of the first 400 m of the existing North Area extraction line. In this paper, we will present the design of the additional 400 m of transfer line towards BDF branching off from the existing line and discuss the detailed design of the BDF beam line, its components and optics. We present the latest results on the study and design of a new laminated Lambertson splitter magnet to provide fast switching between the current North Area experiments and the BDF. The latest specification of a dilution system used to reduce the local peak power of the beam on the target is also presented.

INTRODUCTION

Despite the recent discovery of the Higgs boson strong evidence points to the *Standard Model* being incomplete. Most notably indirect measurements have established the existence of an excess of matter in galaxies that has not been directly observed or explained. Massive weakly interactive particles might be involved but are hardly reachable by current collider experiments [1].

In the context of the Physics Beyond Collider project a new general purpose fixed target facility (BDF) to search for hidden sector particles is proposed [2]. The SHiP detector requires specific beam characteristics such that the slow extracted proton beam from the SPS at 400 GeV is most suitable. The physics case is built using 2×10^{20} protons on the primary target. Further requirements on the detector and intrinsic limits on the electronics means that the beam needs to be delivered slowly. It was established that an extraction time of 1 s for 4×10^{13} protons per cycles is optimal [3].

The target is designed with these beam characteristics in mind. Particularly challenging is the thermal design to handle large average beam power of 355 kW and up to 2.5 MW during the 1 s spill. Such a high beam power requires not only careful design of the target but also a dilution system to move the beam spot over the target during the spill.

LAYOUT

As the SHiP detector favors a slow extracted beam over 1 s it was decided to accommodate the BDF in the existing complex, called the North Area. Currently, specific Lambertson septa are used to split the beam twice and deliver it simultaneously to three targets. Figure 1 shows the new line branching off the existing North Area complex at the level of the first splitter.

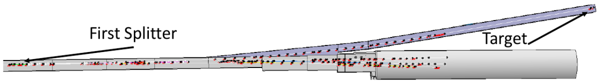

Figure 1: Layout of the North Area lines with the new line branching off at the first splitter in blue.

The constraint at this stage is purely geometrical as the target area and SHiP detector are to be located away from the other existing lines.

BDF TRANSFER LINE DESIGN

The SHiP experiment will take dedicated spills in order to avoid the beam loss intrinsic to splitting with other experiments in the North Area. Thermal and mechanical constraints at the target also require large beam size at the target of 8 mm RMS in both planes. The dispersion in both planes at the target is also canceled by design.

Physically, the constraints are geometrical and economical. The new line needs to branch off at the first splitter while using the same magnets upstream. It also needs to coexist along the existing lines after the first splitter with minimum to no modification of the other lines. Finally, the aim of the design phase is to use as much as possible existing and available equipment in order to minimize the cost.

Figure 2 shows the beam size is maintained small along the line and brought to 8 mm only at the target. The existing part is located between $s = 0$ m and $s = 620$ m. The evolution of the beam size follows a FODO lattice with matching sections at the beginning and at the splitter. The new part of the line transports the beam to the target while satisfying to the aperture requirements of the beam line.

Figure 3 shows the evolution of the dispersion in both planes between the extraction point and the target. In the vertical plane the beam is brought from the level of the SPS tunnel to almost ground level. This involves large accumulated bending angles in the vertical plane hence large values of dispersion. Nevertheless, careful design achieved a perfect cancellation of the dispersion at the target.

Table 1 summarizes the magnets chosen for the design of the new line and their availability. Most of the magnets used are available and in storage at CERN. Only the most specific elements discussed below will need to be designed and built.

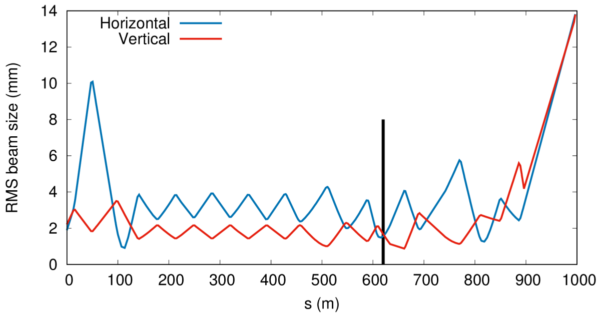

Figure 2: Beam size with a momentum spread of 10^{-4} as a function of longitudinal position in meter from the SPS extraction to the BDF target in the horizontal and vertical plane with the transition between the existing and new parts represented as a black vertical line.

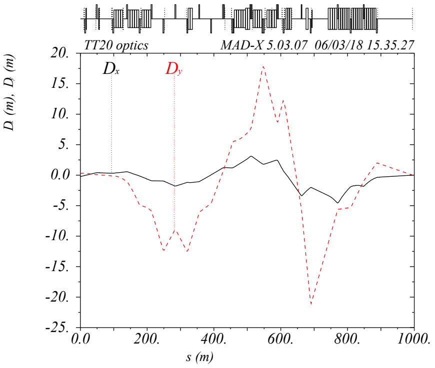

Figure 3: Evolution of the dispersion in both planes as a function of longitudinal position in meter from the SPS extraction to the BDF target.

Table 1: List of Magnets Selected

Quantity	Name	Function
1	QTG	Quadrupole
5	QTL	Quadrupole
5	MBB	Dipole
18	MBN	Dipole
6	MDX	Correctors
3	MSSB	Splitter
2	MPLS	Horizontal diluter
2	MPLV	Vertical diluter

Laminated Splitter

As showed in Fig. 1 the new line branches off at the first splitter in the opposite direction. The BDF will not share simultaneously the beam with the other lines. Instead, consecutive cycles of the SPS will need to accommodate the BDF and existing lines, sequentially. This means the first splitter will need to quickly reverse field between the two cycles. This is not possible with the existing design as it is made of solid, non-laminated iron. A new design of a splitter magnet with laminated core to be able to switch the field within 1 to 2 s is under study. Particularly challenging is the behavior of the laminated core in high radiation environment while maintaining good vacuum level. The Fig. 4 shows the extremity of the splitter with the small field free region in the center of the upper part.

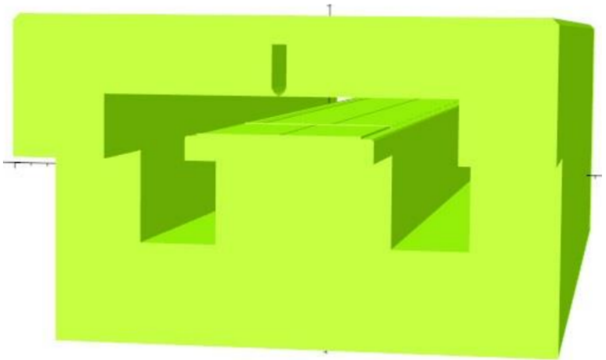

Figure 4: Three dimensional model of the splitter core.

Dilution System

As discussed earlier the increase of the beam size at the target is not sufficient to ensure its survival. The beam needs to be diluted over the target in order to reduce the maximum local density of energy deposition. Table 2 shows the functional specifications of the dilution system. Technical details of the system are still being studied but the specifications are fixed and realistically achievable with conventional technologies.

Table 2: Dilution System Specifications

Parameter	Value
Sweep Pattern	circle
Sweep radius	50 mm
Turns per spill	4
Rise time	62.5 ms
Integrated field per plane	0.7 T m

Correction Scheme

Robust and realistic correction scheme is critical for the design of the transfer line. In particular with the large energy and beam intensities involved.

Static errors, which comprise the alignment of magnets and monitors, as well as systematic field errors, were studied here. Using [4] the following realistic errors were considered:

- to the dipole field of the `RBEND` elements a relative error of $\mathcal{N}\left(0,(2.5\times10^{-4})^2\right)$ truncated at $\pm2\sigma$
- to the quadrupole field of the `QUADRUPOLE` elements a relative error of $\mathcal{N}\left(0,(2.5\times10^{-4})^2\right)$ truncated at $\pm2\sigma$

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- to the tilt around the longitudinal axis of the `RBEND` elements an angle of $\mathcal{N}\left(0, (1.6 \times 10^{-6})^2\right)$ rad truncated at $\pm 4\sigma$
- to the transverse position of the `QUADRUPOLE` elements a vertical and horizontal misalignment of $\mathcal{N}\left(0, (0.2 \times 10^{-3})^2\right)$ m truncated at $\pm 3\sigma$
- to the transverse position of the `MONITOR` elements a vertical and horizontal misalignment of $\mathcal{U}\left(-0.5 \times 10^{-3}, 0.5 \times 10^{-3}\right)$ m
- to the transverse position at the start of the line a vertical and horizontal misalignment of $\mathcal{N}\left(0, (0.5 \times 10^{-3})^2\right)$ m truncated at $\pm 2\sigma$
- to the transverse angles at the start of the line a vertical and horizontal angle of $\mathcal{N}\left(0, (0.05 \times 10^{-3})^2\right)$ rad truncated at $\pm 2\sigma$

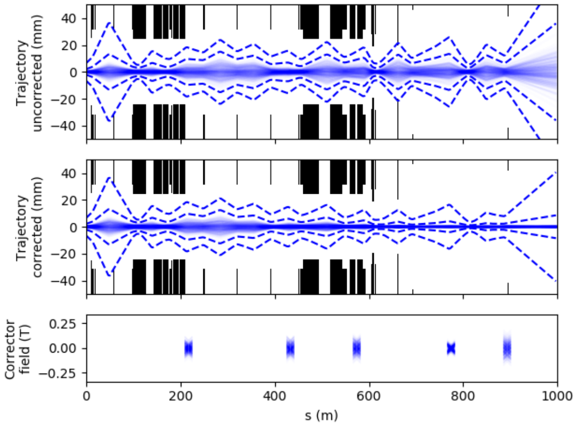

Figure 5: Effect of errors and correction scheme in the horizontal plane.

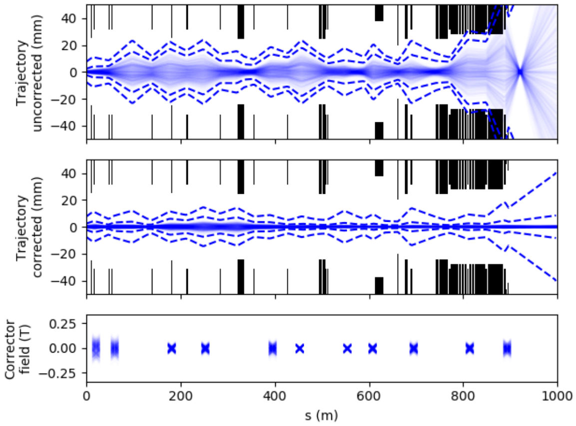

Figure 6: Effect of errors and correction scheme in the vertical plane.

Figures 5 and 6 show the result of the error study and trajectory correction along the line. The upper plots represent the cases before and after correction. The bottom plots show the fields at each corrector used by MADX to correct the orbit.

The blue continuous lines show the trajectories along the line with 400 sets of errors randomly generated by the MADX built-in error module. The trajectory is corrected by the MADX `CORRECT` module in two steps. First all correctors and monitors are used and a first corrected trajectory is generated. Then a second correction only uses the last corrector in each plane to center the trajectory on the last monitor `BTV.BDF.TG`.

The blue dashed lines represent the maximum beam envelopes including trajectory offsets at 1σ and 5σ with usual emittances and a momentum spread of $dp/p = 10^{-4}$. In details those envelopes where z stands for x in the horizontal plane and y in the vertical one, are computed by :

$$\pm Z = z_{max} + N \times \sqrt{\beta_z * \epsilon_z + (D_z \times dp/p)^2} \tag{1}$$

with:

- z_{max} the absolute maximum value of the trajectory
- N the number of *sigma*
- ϵ_z the beam emittance, $\epsilon_x = 3.51 \times 10^{-8}$ m in the horizontal plane and $\epsilon_y = 1.17 \times 10^{-8}$ m in the vertical plane

The correction scheme is proven to work using 6 new position monitors and 5 new dipole correctors.

CONCLUSION

The design of the transfer line for the BDF project is ongoing. The trajectory and optics were frozen with the choice of magnets. The correction scheme chosen will be able to transport the beam to the target within the design constraints with realistic monitor and corrector capabilities. The design also minimizes the resulting cost by making use of existing magnets.

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