COLLIMATION IN THE TRANSFER LINES TO THE LHC

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Abstract

Injection intensities for the LHC are over an order of magnitude above damage level. The TI 2 and TI 8 transfer lines between the SPS and LHC are each about 2.5 km long and comprise many active elements running in pulsed mode. The collimation system in the transfer lines is designed to dilute the beam energy sufficiently in case of accidental beam loss or mis-steered beam. A system using three collimator families spaced by 60 degrees in phase advance, both in the horizontal and the vertical plane has been chosen. We discuss the reasons for this choice, the layout and, the expected performance of the system in terms of maximum amplitudes and energy deposition.

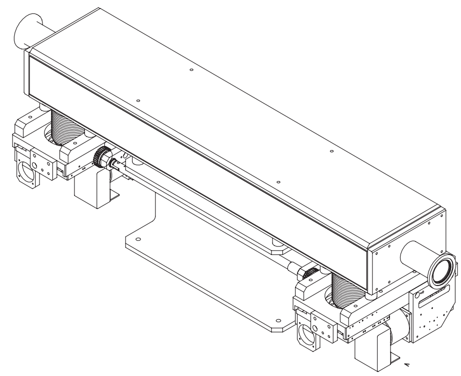

Figure 1: Side view of a transfer line collimator assembly.

INTRODUCTION

Beams will be injected from the SPS into the LHC through the two transfer lines TI 2 and TI 8 [1]. Batches of up to 288 bunches are extracted in 4/11 of an SPS turn or 7.9 μs. The transfer lines are pulsed. Power supplies will be surveyed, but failures, leading to local loss of the injected beams cannot completely be excluded [2]. The damage level for fast losses is around 2.3×10^{12} protons [3]. Reference numbers are summarised in Table 1.

Table 1: Beam parameters for LHC injection.

Proton energy	450 GeV
Normalised emittance	$\epsilon_N = 3.5\,\mu$m
Nominal:	
Protons per injection	3.2×10^{13}
Ultimate:	
Protons per injection	4.9×10^{13}

Collimation in the transfer lines should provide damage protection up to ultimate intensities. This leads to the design goal for the transfer line collimators to provide an attenuation of at least a factor of 4.9×10^{13} / $2.3\times10^{12} \approx 20$ to prevent damage by the injected beam.

The transfer line collimators will be installed towards the end of the transfer lines, to provide a generic, passive protection against failures of upstream elements. They will have each two 1.2 m long flat graphite jaws with motorisation to provide both opening and angle control. Fig. 1 shows a side view of a transfer line collimator assembly.

The role of the transfer line collimators is to dilute the beams in case of rare failures to intensities below the damage level. Regular beam cleaning instead will be done in the SPS prior to extraction using a system of three (horizontal, vertical and 45°) scrapers [4].

We now discuss the choice for three collimator families spaced by 60° in phase advance and compare it with alternative solutions with two and four families. For this we will refer to σ, which is the nominal r.m.s. beam size at injection.

CHOICE FOR THREE 60° PHASES

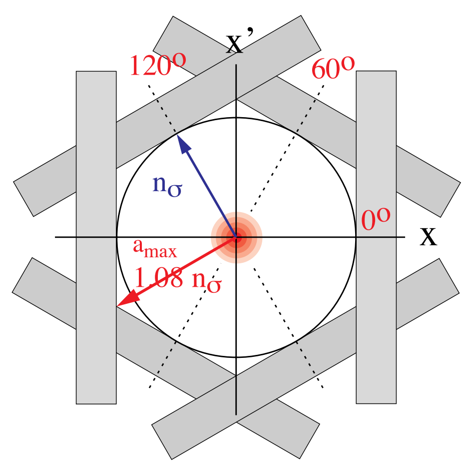

Figure 2: Phase space coverage with 3-phase collimation at $0, 60, 120°$.

Beams in the LHC are largest at injection and the physical aperture is tight, about 7.5 σ [5]. The aperture in the transfer lines and the injection septum at the end of the transfer lines is limited to about 7 σ.

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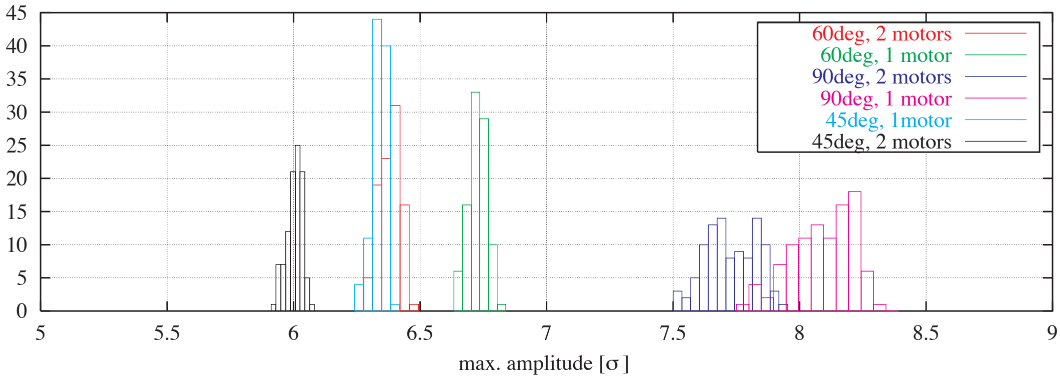

Figure 3: Comparison of the maximum particle amplitudes obtained for the different options.

Collimators at several betatron phases in the horizontal and vertical plane will be needed to guarantee sufficient phase-space coverage to protect the tight aperture at injection. For only two families spaced by 90° in phase advance, the phase space in normalised coordinates x, x' or y, y' would be a square delimited by the jaws set at n_σ. The largest amplitude in this case would be on the diagonal in phase space, $a_{\max} = \sqrt{2} n_\sigma$, or 1.41 larger than the collimator setting. With four collimators spaced by 45°, amplitudes are limited to $a_{\max} = n_\sigma / \cos\frac{45}{2} = 1.08\, n_\sigma$. With three families, spaced by 60° in phase space, the maximum amplitude is $a_{\max} = 1.15\, n_\sigma$, see Fig.2.

Comprehensive Monte Carlo simulations including imperfections, jaw positioning, orbit, β-beat, mismatch from the SPS and kicker ripple have been performed. A comparison of the maximum particle amplitudes for the different options is shown in Fig. 3. The best result was obtained for four families of transfer line collimators spaced by 45°, each equipped with two motors. It turned however out to be very difficult to find sufficient space to place four collimator families both in x and in y. Together with cost and optics flexibility arguments, we chose three collimator families, spaced by 60° in phase space, with two motors per jaw.

According to simulations, the transfer line collimators will have to be set at about $4.5\,\sigma$, to reach the required protection. The effect of all imperfections corresponds roughly to an increase by $1.4\,\sigma$ to $6.0\,\sigma$. The maximum amplitude in phase space is then $6.9\,\sigma$. According to the simulations, this should be sufficient to provide the required passive protection to the injection septum and the cold LHC aperture in the arc.

COLLIMATOR POSITIONS AND OPTICS

Figs. 4 and 5 show the optics parameters and collimator positions in the last 300 to 400 m of the two transfer lines TI 2 and TI 8. The integration of the three families of transfer line collimators into the layout of the transfer lines has been rather difficult, in particular in TI 8 which has little space available. In one case (for the horizontal plane in

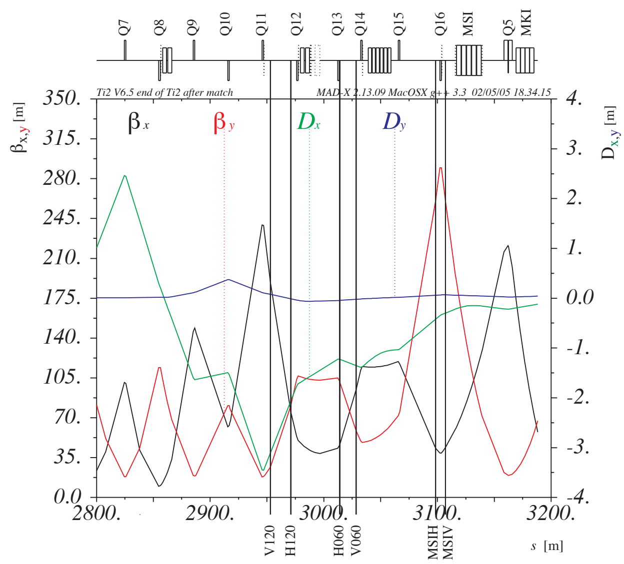

Figure 4: End of TI 2.

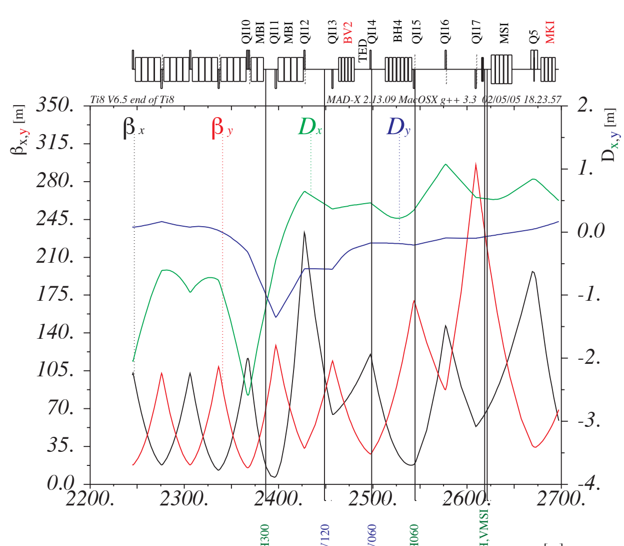

Figure 5: End of TI 8.

TI 8), an alternative position 180° further upstream is used.

The transfer line collimator positions described here have been optimised for the LHC design optics (V6.5). The end part of the transfer lines is used as matching section for optics matching to the LHC. The optics flexibility is discussed in [6].

LOCAL PROTECTION AND HEAT DEPOSITION

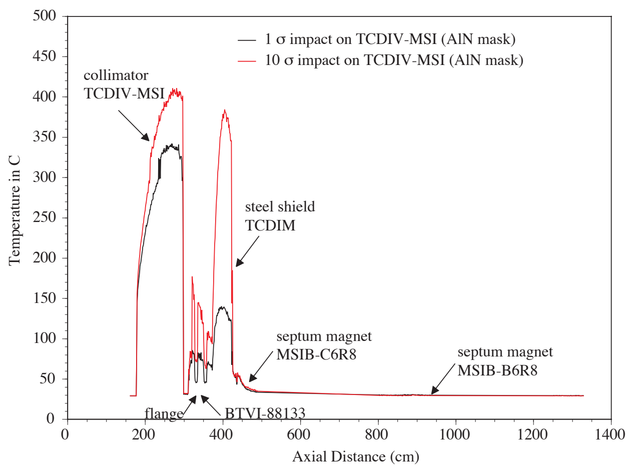

Figure 6: Heat distribution along the beam line in case of beam loss at the transfer line collimator at the septum.

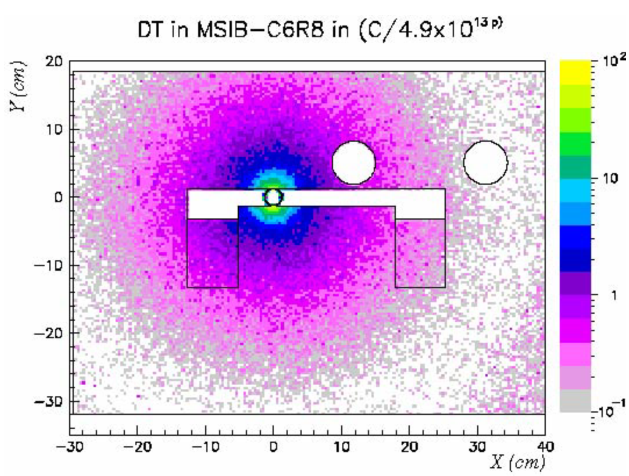

Figure 7: Heat distribution in the injection septum (MSI) in case of local beam loss at the transfer line collimator and in the presence of the shield.

The transfer line collimators are sufficiently robust and long to withstand the impact of a full injected batch of ultimate intensity and to dilute the beam to a safe level for the LHC. The showers escaping the low-Z jaws, however, can lead to significant temperature rise in the transfer line equipment close-by. For this reason, the transfer line collimators are complemented by 50 cm iron shields placed outside the vacuum chamber several meters downstream of the collimators in front of the next element.

The last 300 m of TI 8 have been implemented in FLUKA to check worst-case impact scenarios on the transfer line collimator jaws and the consequences on the downstream equipment. It has been verified that with the iron shields, the temperature rise in the local elements stays below damage level. The shield in front of the last element in the transfer line, the MSI injection septum, needs to be made of a more robust material. An AlN (Aluminium Nitride) mask has been proposed. Fig. 6 shows the temperature distribution along the beam line in case of local beam loss with 1 and 10 σ impact from the edge on the transfer line collimator upstream of the septum. Fig. 7 shows a cross-section of one of the septum magnets with the temperature rise during impact on the septum collimators.

CONCLUSION

Three families of transfer line collimators spaced by 60° in phase advance and positioned towards the end of the transfer lines provide for passive protection against damage at injection into the LHC in case of failures. The mechanical design is similar to that of the secondary LHC collimators. Two motors will be used to be able to adjust the collimators in position and angle. Simulations have shown that a good protection level can be obtained if the transfer line collimators will be set at about 4.5 σ and that the collimators themselves and the upstream material would not be damaged even in case of full beam impact. Design details and the exact positioning are currently being finalised. Further simulations aiming at predictions and optimisation of quench protection for the adjacent LHC equipment and studies on how to match and commission the system for injection into the LHC are planned.

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