

POWER DEPOSITION IN LHC MAGNETS WITH AND WITHOUT DISPERSION SUPPRESSOR COLLIMATORS DOWNSTREAM OF THE BETATRON CLEANING INSERTION*

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Abstract

The power deposited in dispersion suppressor (DS) magnets downstream of the LHC betatron cleaning insertion is governed by off-momentum protons which predominantly originate from single-diffractive interactions in primary collimators. With higher beam energy and intensities anticipated in future operation, these clustered proton losses could possibly induce magnet quenches during periods of short beam lifetime. In this paper, we present FLUKA simulations for nominal 7 TeV operation, comparing the existing layout with alternative layouts where selected DS dipoles are substituted by pairs of shorter higher-field magnets and a collimator. Power densities predicted for different collimator settings are compared against present estimates of quench limits. Further, the expected reduction factor due to DS collimators is evaluated.

INTRODUCTION

The LHC accommodates a multi-stage collimation system mainly located in the Insertion Regions IR3 and IR7 which are dedicated to momentum and betatron cleaning, respectively. A potential performance limitation in IR7 arises from off-momentum protons, predominantly originating from single-diffractive interactions in primary collimators, which impact on the magnet beam screen in neighbouring dispersion suppressors (DS) due to the elevated dispersion function. An option presently under study is to substitute selected DS dipoles downstream of IR7 with collimators, called TCLDs, enclosed by shorter higher-field (11T) magnets. Alternative DS layouts based on this option have been proposed recently [1]. In this paper, we present corresponding FLUKA [2] power deposition studies in order to estimate the risk of magnet quenches during periods of short beam lifetime and to quantify the achievable power reduction in coils due to DS collimators. The study compares the existing DS layout with one accommodating 80 cm tungsten collimators in cells 8 and 10, respectively (see Fig. 1). Simulations were performed for the counter-clockwise rotating beam (beam 2), nominal 7 TeV beam optics, and for different collimator settings (relaxed and nominal) as detailed in Table 1.

The simulations were based on a realistic IR7 FLUKA model featuring geometrical characteristics essential for energy deposition studies, including an accurate representation of magnets and collimators. As a first simulation step,

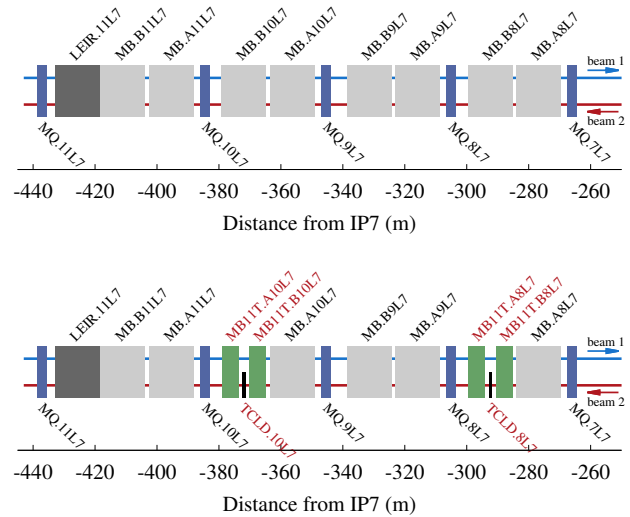


Figure 1: Illustration of the existing DS layout left of IR7 (top), compared to an alternative layout as discussed in Ref. [1] (bottom), where 2 dipoles are replaced by collimators (TCLDs) and higher-field magnets.

Table 1: Collimator Settings Considered in the Simulation Studies. Half gaps are expressed in terms of nominal sigma (3.75 $\mu\text{m}\cdot\text{rad}$ normalized emittance). Values from Ref. [1].

Coll.	IR	Relaxed	Nominal
TCP/TCS/TCLA	IR7	7.0/10.3/13.0	6.0/7.0/10.0
TCLD	DS (IR7)	13.0	10.0
TCSG/TCDQ	IR6	11.0/11.6	7.5/8.0
TCT	IR1/5	13.2	8.3

products of inelastic nuclear interactions, including single-diffractive protons, were generated in IR7 collimators according to the spatial distribution predicted by SixTrack [1]. Secondly, high-energy particles emerging from these collisions or from consecutive showers were transported to the DS, eventually followed by detailed simulations of the energy deposition in DS magnets. In all simulations, losses were assumed to be horizontal only (i.e., primary beam losses on the horizontal primary collimator) which is known to be the worst case for collimation cleaning. All results presented in the following are based on a proton loss rate of $4.5 \times 10^{11} \text{ sec}^{-1}$, which corresponds to a 0.2h beam lifetime for 2808 circulating bunches with a bunch intensity of 1.15×10^{11} protons. One can however also draw first conclusions for the HL-LHC era, where the anticipated stored

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beam intensity (and hence the loss rate for a 0.2 h beam lifetime) is almost double as high.

PROTON IMPACT DISTRIBUTION

The loss location of single-diffractive protons in the DS depends in a distinct way on the relative momentum loss $\Delta p/p$ they experienced in the scattering event, with two dominating loss clusters in cells 9 and 11 [1,3]. Fig. 2 shows results from FLUKA simulations, demonstrating how proton losses are shared between the cells. Protons with a $\Delta p/p$ between $\sim 0.5\%$ and $\sim 2.3\%$ primarily impact on the magnet aperture in cell 11, while protons with a $\Delta p/p$ larger than $\sim 2.3\%$ are mainly lost in cell 9. In presence of DS collimators in cells 8 and 10, a similar separation can be observed for protons intercepted by the collimators, except that a fraction of particles with $\Delta p/p < 2.3\%$ also impacts on the collimator in cell 8 (see Fig. 2). In addition, the collimator in cell 10, and to a lesser extent the one in cell 8, intercepts a fraction of protons with momentum losses $\Delta p/p < 0.5\%$, which would otherwise escape the DS. This confirms the effectiveness of the second collimator for reducing global losses around the ring as already indicated in tracking studies [1].

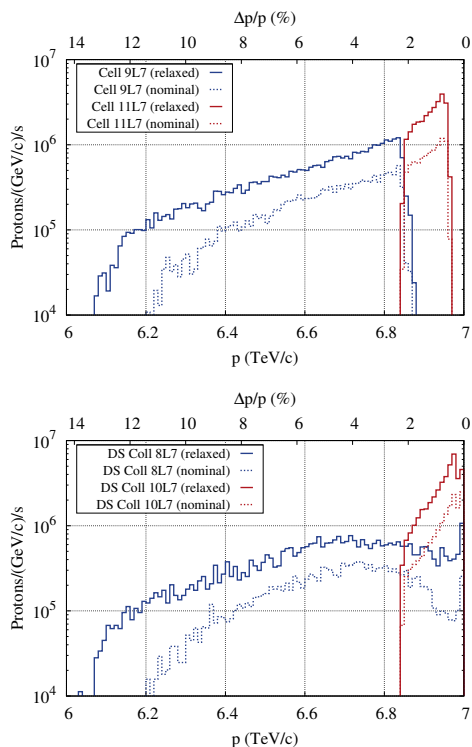


Figure 2: Momentum distribution of protons impacting on the magnet aperture in DS cells 9 and 11 in absence of DS collimators (top) and momentum distribution of protons intercepted by DS collimators installed in cells 8 and 10 (bottom). Spectra are shown for both nominal and relaxed collimator settings, considering only protons which had an interaction in IR7 collimators in the same turn.

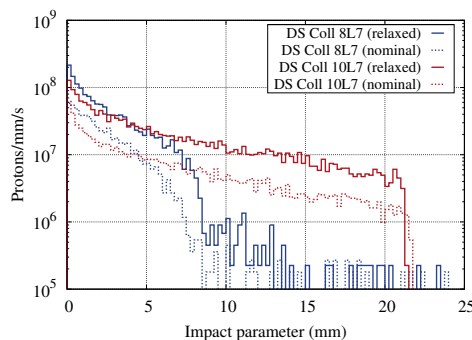


Figure 3: Proton impact parameter distribution on the front face of DS collimators in cells 8 and 10 (left jaw) for nominal and relaxed collimator settings.

Besides the different $\Delta p/p$ distributions, protons intercepted by the two DS collimators also exhibit significant differences in their spatial and angular spread. This is illustrated in Fig. 3, showing the impact parameter distribution on the collimator front face predicted by FLUKA. In particular, the mean impact parameter is found to be more than twice as large for the collimator in cell 10 (~ 5.6 mm) than in cell 8 (~ 2.2 mm).

POWER DEPOSITION IN DS MAGNETS

To illustrate the effect of the DS collimators on the corresponding power deposition in magnets, Fig. 4 presents power density maps in the horizontal plane of DS dipoles for relaxed collimator settings. Compared to the existing DS layout, where the power density pattern follows closely the impact distribution on the magnet aperture, the DS collimators effectively reduce the power deposition in cell 9 and 11, but imply a local power density increase in the 11T dipoles downstream of the collimators due to secondary showers from the collimator jaws. This is also reflected in the peak power density in magnet coils shown in Fig. 5 (power density radially averaged over inner coils). The local increase is particularly visible in cell 8, but is less distinct in cell 10, which can primarily be attributed to the differences in the proton impact distribution on the collimators. Besides the local increase in 11T dipoles, the power density reduction due to DS collimators is smallest towards the end of cell 9 due to remaining losses of protons on the magnet beam screen. These remaining losses eventually cause a similar peak power density in MQ.9 and MB.B9 as in the 11T magnets. Results for nominal collimator settings are qualitatively the same as for relaxed settings.

The maximum (radially averaged) power density deposited in magnet coils in the presence of the collimators is estimated to be $\sim 2\text{--}2.5$ mW/cm³ for relaxed settings, and $\sim 0.5\text{--}1$ mW/cm³ for nominal settings. This is to be compared to a power density of up to $\sim 9/20$ mW/cm³ (nominal/relaxed settings) predicted for the existing DS layout (in MB.A9). Recent estimates of the steady-state quench limit of MB cables (for 7 TeV operation) range from 25 mW/cm³

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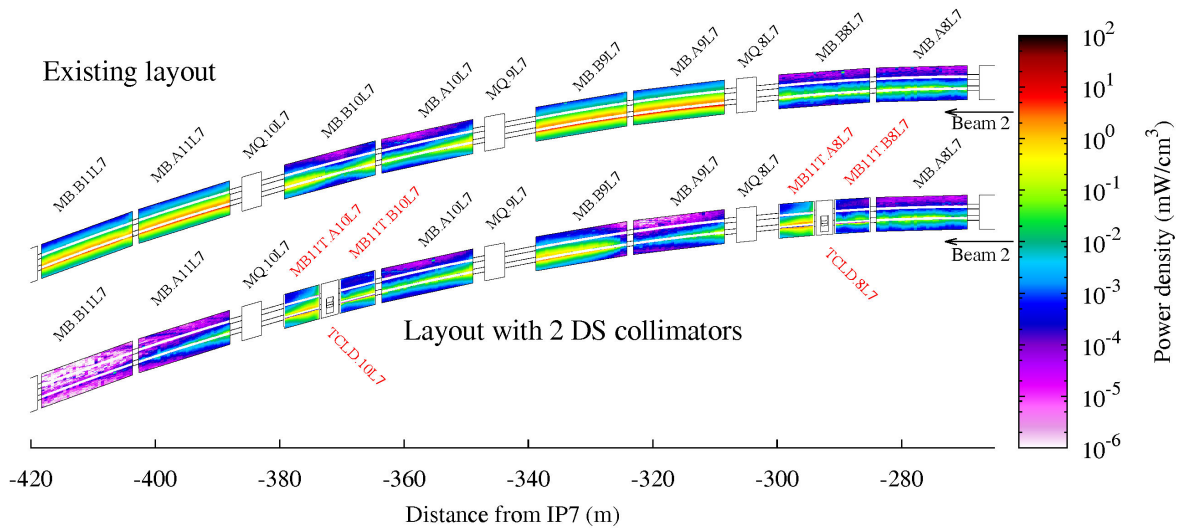


Figure 4: Power density in the horizontal plane of DS dipoles for relaxed collimator settings, comparing the existing with the alternative DS layout. The beam direction is from the right to the left.

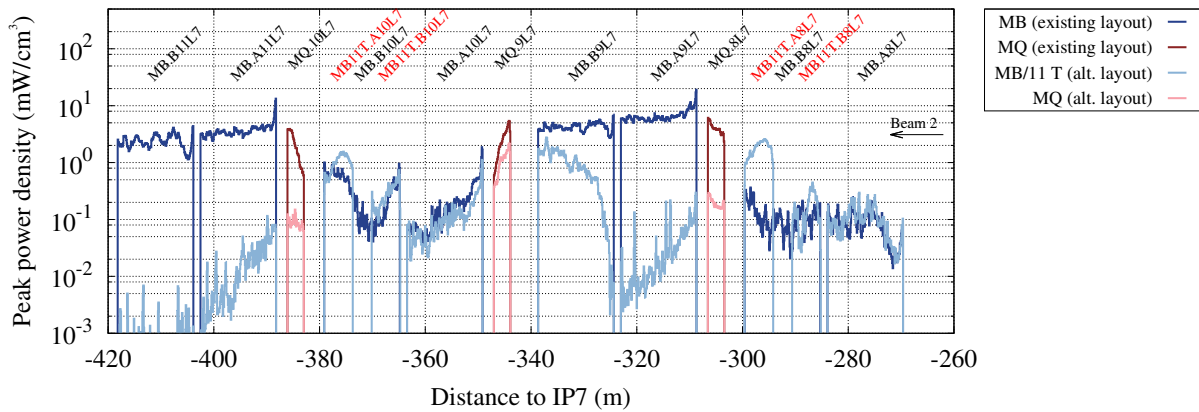


Figure 5: Peak profile of the power density radially averaged over inner coils. Comparison of the existing with the alternative DS layout (relaxed collimator settings). The beam direction is from the right to the left.

[4] to 49 mW/cm^3 [5]. A similar quench limit can be assumed for the MQ (53 mW/cm^3 [4]), while it is higher for the Nb₃Sn-based 11T magnets (around 110 mW/cm^3 according to first estimates [6]). In comparison with these values, the FLUKA results indicate that power densities are several factors lower in presence of DS collimators, while the margin for the existing layout is less pronounced. Efforts to refine the simulation models used in this study are presently ongoing, i.e. to improve relevant details of the IR7 FLUKA geometry, to increase the accuracy of scoring techniques for the bent MB coils, and to address other challenging issues. This includes for example an underestimation of losses in cell 9, as has been shown in a recent comparison of simulated and measured Beam Loss Monitor (BLM) signals [7].

CONCLUSIONS

FLUKA simulations indicate that the peak power density deposited in the coils of DS magnets downstream of IR7 could be reduced by several factors if tungsten colli-

matoms are introduced in cells 8 and 10, despite a local increase downstream of the collimators due to the leakage of secondary showers. For nominal 7 TeV proton operation, the simulations predict that the induced power density lies safely below quench limits in this case, leaving also a sufficient margin for the anticipated intensity increase in the HL-LHC era. The margin to quench limits appears to be less distinct for the existing DS layout. The final decision on the need for DS collimators will be done based on the beam experience in the next LHC run. A possible option could also be the installation of only one collimator in cell 8, which however would leave cell 11 essentially unprotected, hence posing a potential limit for the achievable intensity.

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