SIMULATIONS AND MEASUREMENTS OF PHYSICS DEBRIS LOSSES AT THE 4 TeV LHC*

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Abstract

At the Large Hadron Collider (LHC), dedicated physics debris collimators protect the machine from the collision products at the high-luminosity experiments. These collimators reduce the risk of quenches by stopping physics debris losses. Several measurements have been performed at 4 TeV, with peak luminosity values up to $4 \cdot 10^{33}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ to address the need of these devices and optimize their settings. In this paper, the measurement results are presented and compared with SixTrack simulations of beam losses in IR1 and IR5 for the same conditions.

INTRODUCTION

Installed downstream of the LHC high-luminosity experiments for both beams, the long absorbers for physics debris, usually referred to as *TCLs*, are collimators made of two 1 m-long copper jaws [1]. Their goal is to intercept secondary particles and scattered protons coming from the IPs, having undergone collisions hence displaying extra kicks and momentum offset. They prevent these particles from being lost in the cold magnets of the straight section (mainly Q5 and Q6) and the Dispersion Suppressor (DS).

During LHC operation in 2012, the TCLs were kept at a setting of 10 units of betatronic standard deviation (called σ) and proved to be very effective. Dedicated tests were performed to study their effect during collisions, in the range from $10\,\sigma$ to a "TCL out" setting of $60\,\sigma$ (3.6 to 21.6 mm) at different luminosities. These data enable a beam–based optimisation of the TCL settings, and provide an important reference for benchmarking simulation codes like the particle tracking code SixTrack [2].

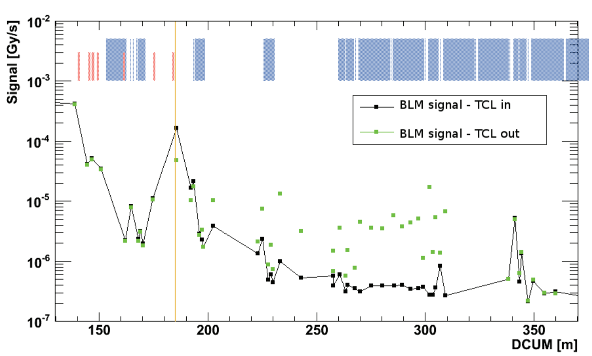

Figure 1: BLM signals on the right side of IP1 (s = 0 m) for "TCL in" (black) and "out" (green) with a luminosity of $\simeq 4 \cdot 10^{33}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$. Layout elements are illustrated by red and blue boxes. The TCL sits at s=184 m (orange line).

RESULTS OF TCL SCANS

The first observations of the TCL scans can be seen on a measured loss map: the signal of the Beam Loss Monitors (BLMs) at their different longitudinal positions s. BLMs are ionisation chambers located outside the LHC cryostat or on the collimator tanks, detecting secondary shower particles. Measurements were performed on the 4^{th} of July 2012. Each TCL was moved from the nominal setting of $10\,\sigma$ to $60\,\sigma$. The losses on the right of IR1 are given in Fig. 1. The decrease in losses downstream (up to 120 m) shows the actual protection provided by the TCL.

The duration over which the TCL jaws are moved, around 15 min, is quite long with respect to the variation of the luminosity in the LHC. The signal measured by the BLMs is expected to be proportional to the decrease in luminosity. The signals are normalized by the instantaneous luminosity to identify the specific TCL contribution.

In order to evaluate the cleaning provided by the collimator, the ratio of the normalised signal when it is *in* ($10\,\sigma$) over the normalised signal when it is *out* ($60\,\sigma$) was calculated. The results for the four TCLs are shown in Fig. 2. With the TCL in, the losses at the TCL increase by a factor $\simeq 4$; the losses downstream are decreased by a factor down to 0.02 at the most affected location.

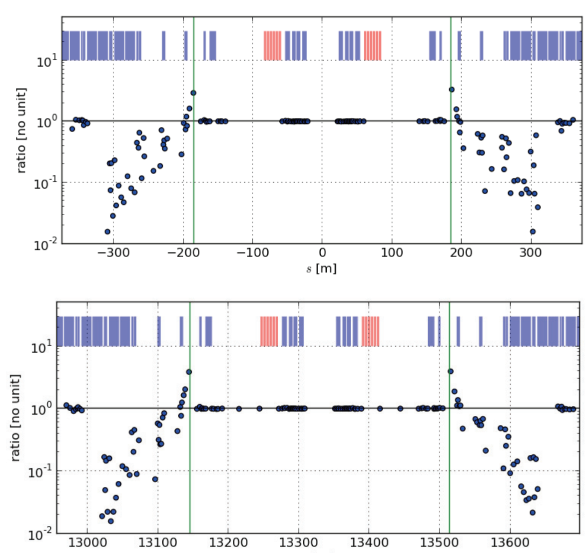

Figure 2: Ratio of the luminosity-normalised losses for TCL at $10\,\sigma$ over $60\,\sigma$ (Fig. 1) in IR1 (top) and IR5 (bottom). TCL positions are given by the green lines.

* Research supported by FP7 HiLumi LHC – Grant agreement 284404
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ISBN 978-3-95450-122-9

In Fig. 3, the losses at the quadrupoles Q5 to Q8 measured during the TCL scan are given as a function of half-gap. The curves are normalized to their maximum values, for TCL out. They don't reach zero for elements closer to the IP because of external BLM background signal. Each loss location shows a characteristic evolution. When the TCL moves out, the signal starts rising the furthest away from the TCL (Fig. 3, red curve). When the TCL opens more, the signal at closer BLMs start rising as well (Fig. 3, green curve); this behaviour can be qualitatively explained by the dispersion and momentum spread. The maximum setting for the same cleaning at different loss locations can be read from these plots. Fig. 3 centre (right of IP1) shows that this TCL could be set at 15 σ without losing any cleaning. It must be noted that, even though the layouts are symmetric for both sides of IP1 (Fig. 3, top and centre), there are differences in the BLM signals, especially in the setting for which they start rising.

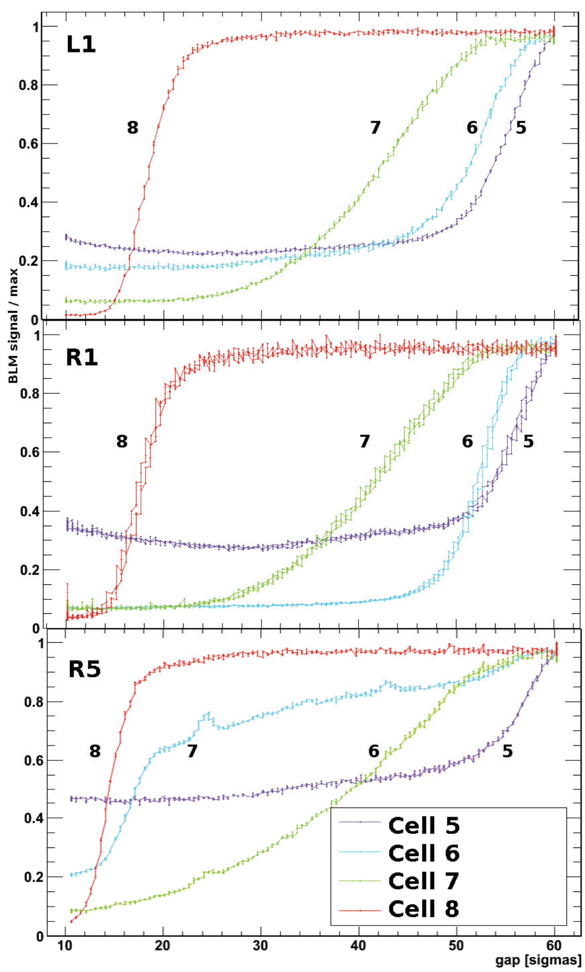

Figure 3: Measured losses normalised by luminosity at Q4 to Q8 magnets vesus TCL half-gap, normalized by maximum value for TCL out. Top: Left of IP1, centre: right of IP1, bottom: right of IP5.

PRELIMINARY SIMULATIONS

The collimation simulations were performed with the particle tracking code SixTrack [2]. The initial particle distribution was generated from the products of proton collisions simulated by the particle-matter interaction code FLUKA [3, 4]. Cuts were applied to select the protons (with extra kicks and momentum offsets) that are relevant for losses in the matching section and DS.

Settings between 10 σ and 60 σ were simulated with 5 σ steps. An example of the results for 10 σ and 60 σ is given in Fig. 4. For each simulated setting, the secondary showers detected by the BLMs were approximated by summing up the protons lost on aperture over 10 m upstream the position of each selected BLM. This is shown in Fig. 5 where the results of the TCL scan is given. The results are normalized to the maximum losses for TCL out, as in Fig. 3. For the Q8 case, the losses are also integrated over 5 m. The losses simulated at the BLM of a DS dipole in cell 8, calculated in a similar way, are given in Fig. 6 together with the measured signal. This is a first attempt to compare the results of these complex simulations against the measurement results, in absence of detailed energy deposition studies of BLM response.

Simulations show a good qualitative agreement with measurements, considering their uncertainty illustrated by Fig. 3. For example, the fact that the Q5 protection is main-

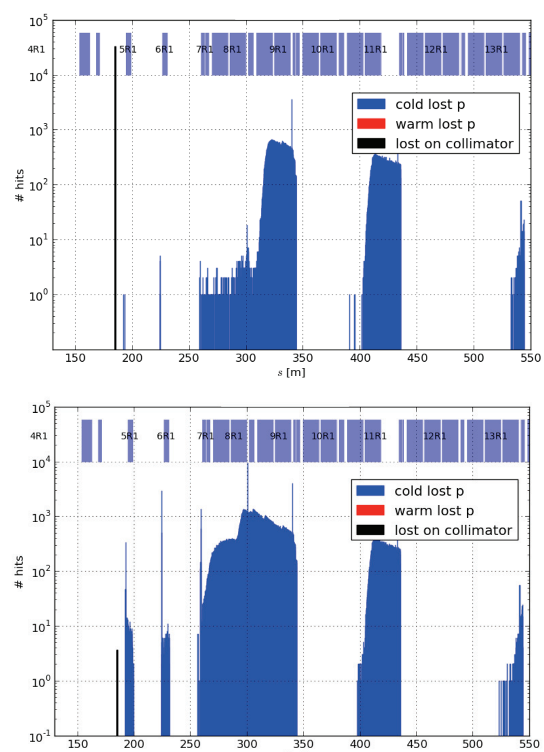

Figure 4: Losses simulated by SixTrack for the losses downstream TCL.5R1.B1 (at 184 m). Top: TCL set at 10 σ, bottom: 60 σ. The initial distribution had $1.77 \cdot 10^6$ particles, corresponding to 10^7 p-p interactions.

ISBN 978-3-95450-122-9

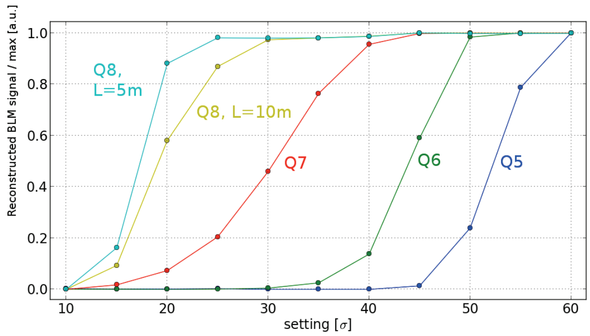

Figure 5: Simulated losses summed on 10 m in front of the position of each selected BLM. A different summing length of 5 m has been added for the BLM of Q8, to show the effect of the summing length.

tained for settings up to about $50\,\sigma$ is well reproduced in simulations. This comparison is carried out for the normalized signals; quantitative comparisons require information on the energy deposited to the different BLMs. It should be noted that a difference was found between measurements and simulations of the losses at the TCL itself. Simulated losses vanish above about $40\,\sigma$ whereas measurements indicate decreasing losses up to $60\,\sigma$. The effects of the chosen cuts of the debris distributions is under investigation.

The ratio of the losses with the "TCL in" over the losses with the "TCL out" was calculated for the simulations, as shown in Fig. 7. Taking simply the ratio of protons hitting the cold aperture, the reduction factor up to the Q8 is overestimated by a factor $\simeq 10$. The behaviour at the Q9 is well reproduced. This can be explained by the nature of the measurements [5]. Several sources of errors in these simulations could explain this discrepancy: 1) the BLMs detect the secondary showers (outside the cryostat) created by the primary particles lost on the beam pipe; 2) the longitudinal range over which protons lost in aperture affect a specific BLM; and 3) the BLM backgrounds are not accounted for in simulations. These aspects are under investigation.

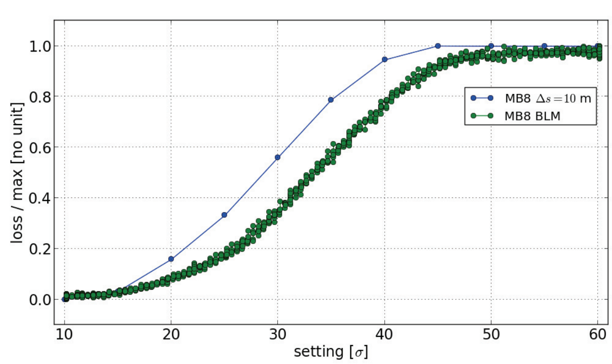

Figure 6: BLM signal and simulated losses summed over 10 m in front of the BLM position versus gap, for the main dipole of cell 8.

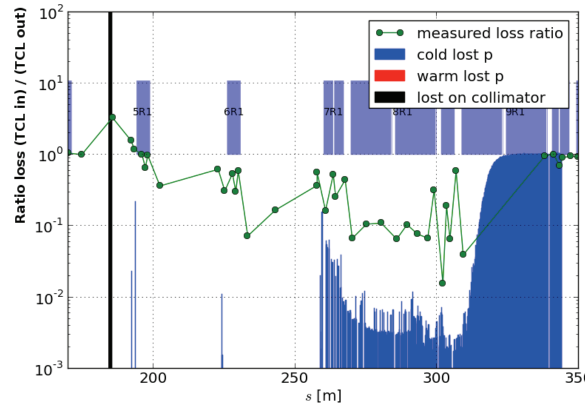

Figure 7: Ratio of the simulated losses for the case "TCL in" ($10\,\sigma$, Fig. 4 top) over the case "TCL out" ($60\,\sigma$, Fig. 4 bottom), for the range of s for which the SixTrack simulations are meaningful. The black line represents the TCL.5R1.B1. The green curve represents the ratio for the measurements in the LHC, as shown in Fig. 2.

CONCLUSIONS

In conclusion, the results of measurements of physics debris collimator cleaning for different collimator gaps were reported. Measurements performed at the LHC at 4 TeV were summarized. The measurements were compared against preliminary results of tracking simulations. The resulting loss pattern of primary protons, simulated with SixTrack, is consistent with the observed BLM signals during a TCL scan in the LHC. The elements closer to the collimator (Q5 and Q6) would be protected even for large values of the setting, whereas further elements in cell 9 need much tighter setting to be protected. This is due to the dominating effect in the IP debris: the momentum offset.

Further work includes gathering results from other LHC measurements, in order to evaluate the uncertainty on the settings due to BLM signal, and reproducing BLM signal more accurately from the simulated losses in 10 cm bins.

ACKNOWLEDGEMENTS

The author whishes to thank L. Lari, D. Mirarchi, B. Salvachua, G. Valentino, the whole collimation team and the operation team for providing data and input.

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