EXPECTED PERFORMANCE OF TOTEM BLMS AT THE LHC

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Abstract

The TOTEM experiment at the LHC will operate down to 10σ from the beam in the forward region of the CMS experiment. The associated beam loss monitors (BLMs) are crucial to monitor the position of the detectors and to provide a rapid identification of abnormal beam conditions for machine protection purposes. In this paper, the response of the TOTEM BLMs is considered for nominal machine operation and the protection thresholds are defined, with calculations made of the expected signal from protons grazing the TOTEM pot as a function of pot distance from the beam, and the BLM signal from proton collisions at the CMS beam interaction point.

INTRODUCTION

The roman pots of the TOTEM experiment [1] are installed in the forward region of IR5 to measure the total cross section and tag diffractive protons coming from the CMS interaction point (IP). The stations, each containing two horizontal and four vertical pots, are located at 147m and 220m from the IP, and will be moved into the beam during stable operation to a distance of closest approach of $10\ \sigma$. Each pot consists of a Silicon detector, located behind a stainless steel window, and thus each pot presents an aperture restriction with a 5 cm long and 200 μm thick stainless steel target to the beam.

The regions of the TOTEM stations are equipped with dedicated beam loss monitors (BLMs), which form part of the machine and detector protection system and monitor beam losses and provide protection against downstream magnet quenches. The BLMs provide active protection, and so are connected to the beam dump system through the beam interlock system (BIS). A beam dump request is issued if the loss in a BLM exceeds a pre-determined threshold, chosen to be less than the magnet quench threshold. The standard BLMs are cylindrical ionization chambers, 60cm in length with a diameter of 9cm. Their response to different particle species is highly non-linear, as shown in figure 1, and in the region of interest for this work (MeV to GeV) the response is dominated by charged hadrons. The placement of the dedicated BLMs in the TOTEM pot regions was discussed in [3] and were chosen to maximise the signal from proton interactions with the pot.

In this paper, an initial study of the expected signal seen in the BLMs will be performed and normalised to the rate of expected protons interactions with the pot, for nominal running conditions at a luminosity of 10^{34} cm^{-2} s^{-1}. The shower simulations performed are similar to those

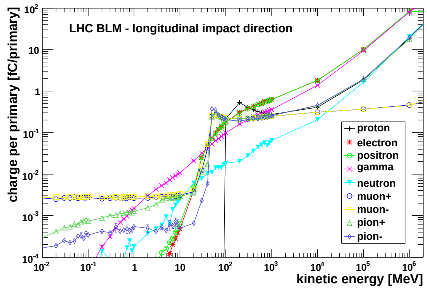

Figure 1: The non-linear response of a LHC BLM to the kinetic energy of various incident particles, courtesy of Markus Stockner [2].

in [3], which computes the shower product distribution downstream of the pots.The normalization of these shower products into the time domain has been performed using a model of the proton loss rate on the horizontal pots, performed with Sixtrack [4], and will be discussed in the next section. To compute the ratio of the pot BLM signal to the flux arising from collisions at the IP, DPMJET [5] and FLUKA [6] simulations were performed to estimate the IP flux and then combined with the pot-induced flux as a function of pot position. Results are shown for the BLMs at 220m in this paper, with 147m BLM results discussed in [7] and the extension to lower luminosity, special running conditions reserved for later work.

PARTICLE RATES INTO THE BLMS

IP proton flux

The rate of particles into the BLMs from IP protons is performed using DPMJET for the IP phase space and a FLUKA model of the LSS for the showering, with the particle fluxes recorded on the surface of a 32cm radius cylinder in the region around the TOTEM pots. The flux is normalised to per IP event (with 10^5 IP events per FLUKA run). The scaling to a rate is performed for nominal luminosity of 10^{34} cm^{-2} s^{-1} and using the total cross section, giving 35 interactions per bunch crossing and a BLM rate proportional to the instantaneous luminosity.

Pot-induced flux

The density of particle flux from the proton collisions with the pot is estimated using the IHEP version of the MARS code [8] model of the LSS and the pot, with the particles recorded on the surface of a 32cm radius cylinder in the region after the pot for a single inelastic pro-

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ton interaction with the pot. The normalisation to a rate requires knowledge of the number of proton interactions with the pot, which will not be known accurately until the LHC is turned on and the proton impacts on the pot can be measured. However, this quantity can be estimated using a simulation of the LHC optics and collimation system.

This calculation is done using SixTrack, with the V6.503 LHC nominal collision optics and the phase one collimation system, and computes the fraction of protons inelastically interacting with the TOTEM pot at variable pot distance from the beam. The interaction point proton phase space was generated using the double pomeron exchange event (DPE) kinematics and cross section, and normalised to an expected proton loss rate of 82×10^6 p s^{-1} for DPE and single diffractive events. The TOTEM horizontal pots are included as two horizontal collimators, with the gap set as required. The loss distribution of the proton sample is shown in figure 2, which shows the loss fraction of the protons as a function of distance around the LHC ring (with 0 corresponding to IP5). The left-hand plot shows the whole ring, with large spikes corresponding to loss in LSS5, the betatron cleaning section in LSS 7 and the momentum cleaning section in LSS3. These locations are the main regions for proton inelastic interactions. The right-hand plot shows a zoom of IR5. In this plot, the principle (middle) peak corresponds to loss on the TCL collimator (positioned at 10σ), with the two loss peaks either side corresponding to the 147m (left) and 220m (right) TOTEM roman pot locations.

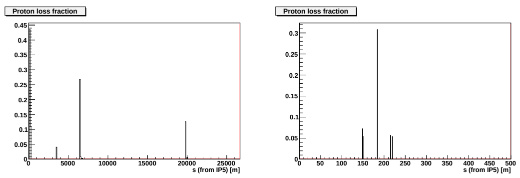

Figure 2: The loss distribution of IP protons for a multi-turn simulation, showing the loss fraction of the protons as a function of distance around the LHC ring for the whole ring (left-hand plot) and the LSS5 region (right-hand plot).

The numerical loss rate (inelastic interactions) on the horizontal pots at 10 σ is calculated to be 9.1×10^6 p s^{-1}, based on an expected loss rate of the IP proton sample of 82×10^6 p s^{-1}. It should be stressed that this is an estimate with many assumptions and model dependencies and the true loss rate on a pot will not be known until beam measurements are made.

The additional contribution from the beam halo itself is expected to be small at pot distances $\geq\ 10\sigma$, due to the pots being in the shadow of the primary and secondary collimators. For example, a Sixtrack simulation of 500k halo particles over 200 turns yielded very few inelastic hits on the TOTEM pots positioned at 10 σ. Therefore the rate in the BLM will receive only a minor correction from halo hits during collision. However this may differ for the case of the TOTEM dedicated high-beta optics and its collimator settings.

SIGNAL IN THE Q6 BLMS

Figure 3 shows the flux of neutrons, protons and charged hadrons arising from proton interactions with the pot as a function of distance from the IP for the region immediately after the 220m station. The plot is normalised for a pot position of 10σ, using the proton inelastic interaction rate from Sixtrack. The shower products reach a peak just after after the inelastic interaction, and the charged hadron flux remains constant in the bare beam pipe region until the beginning of the Q6 cryostat at around 224.5m. The charged hadron flux then peaks again at the start of the cryostat before becoming attenuated by the matter distribution of Q6 (dominated by the coils and the yoke). In contrast to the charged hadrons, the neutron flux remains high in the Q6 cryostat. The distribution of flux is in agreement with [3].

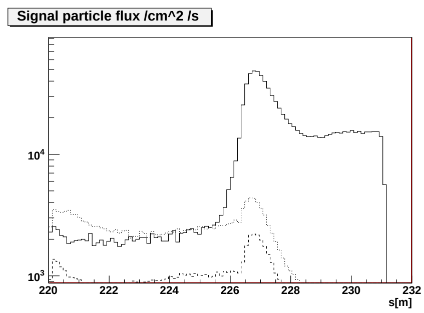

Figure 3: The pot-induced fluxes after the 220m pot station as a function of distance from IP5, showing the neutron flux (solid line), the proton flux (dashed) and the charged hadron flux (dotted).

Figure 4 shows the fluxes of neutrons, protons and charged hadrons arising from IP interactions in the same longitudinal region. This flux shows the same features as the pot-induced flux - an initial peak and plateau in the bare beam pipe region followed by a second peak at the start of the Q6 cryostat. The IP fluxes are more suppressed in the drift region due to screening by upstream matter and is less suppressed in the Q6 cryostat region. This flux is dominated by neutrons, both in the beam pipe and the Q6 cryostat, and the difference in flux between these two regions is more pronounced for the IP flux than the pot-induced flux. The origin of the IP flux suppression in the beam pipe region is screening of the IP source by the distribution of matter immediately upstream, and around, 220m, and this is a feature not seen for the (locally produced) pot-induced flux.

The expected charged hadron flux in a BLM can be estimated by integrating the IP and pot-induced charged hadron fluxes over the longitudinal and azimuthal acceptance of the BLM. This has been done in the left plot of figure 5 for the BLM at 221m (solid line) and the BLM at 226.5m (dashed line) as a function of pot position, and presented as a (signal to background) ratio in the BLM; hence

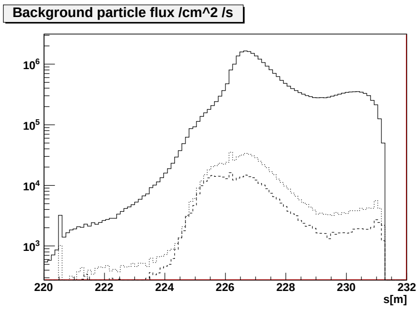

Figure 4: The IP fluxes after the 220m pot station as a function of distance from IP5, showing the neutron flux (solid line), the proton flux (dashed) and the charged hadron flux (dotted).

unity indicates the point a meaningful signal related to the pot position can be observed. The plot shows the BLM at 226.5m does not see flux from the pots over the dominant IP flux rate, while the BLM at 221m sees the pot-induced showers when the pots are placed approximately 30 σ from the beam, and an increasing signal as the pots are placed closer.

The expected current in the BLMs as a function of pot position is shown in the right plot of figure 5, with the 221 m BLM is shown as a solid line and the 226.5 m BLM is shown as the dashed line. The predicted current range is within the 2.5 pA to 1 mA acquisition range of the BLM electronics. The dominance of the IP flux current in the 226.5 m BLM means the current is a weak function of pot position and no significant change of current as a function of pot position is observed. However, the change in current in the 221m BLM a a function of pot position is significant and readily observable. This is consistent with the large pot flux to IP flux ratio observed in this BLM. The experimental measurement of the current in the BLM, when available, can be used to normalise this calculation. The observation that the 226.5m BLM is dominated by the IP flux means the experimentally observed rate of IP background events can be inferred from this BLM (assuming a small halo rate), and hence the true hit rate on the TOTEM pots can be inferred from the subtracted signal of the two BLMs. Such calculations could be attempted when the first data is available.

SUMMARY

In this paper, the expected current in the TOTEM BLMs as a function of pot position has been calculated for nominal running conditions at a luminosity of 10^{34} cm^{-2} s^{-1}. The work is a first look and will be extended later to special running conditions and lower luminosity. The contributions from IP showers and showers originating on the pots are computed using a showering calculation, with FLUKA for the IP flux and MARS for a shower from the pots. In general, it was found that BLMs screened from IP fluxes by distributions of matter immediately upstream and located at an aperture change are able to see the pot charged hadron signal, and BLMs with no such environment has difficulty seeing signal due to the large number of charged hadrons from IP. It was shown the BLM at 221m can see the signal charged hadrons when the 220m pots are approximately 30 σ from the beam, although this number should be considered a first estimate with many model-dependent uncertainties.

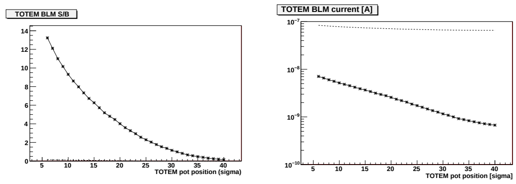

Figure 5: The ratio of pot-induced to IP charged hadrons in the BLMs (left) and the expected current (right) after the 220m TOTEM pot station as a function of pot position. The 221m BLM is shown as a solid line and the 226.5m BLM is shown as the dashed line, with the 226.5m line close to zero on the left plot.

Finally, the BLM response to particle species and energy was used to predict the current in the BLMs as a function of pot position. It was found that the expected currents were within the acquisition range of the BLMs, and a strong change in current with pot position was seen for some of the BLMs. The experimentally observed current in the TOTEM BLMs can be used to normalise the simulations presented in this paper and refine the understanding of the production of IP particle fluxes and hit rates on the pots.

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