IMPACT ON THE HL-LHC TRIPLET REGION AND EXPERIMENTS FROM ASYNCHRONOUS BEAM DUMPS ON TERTIARY COLLIMATORS*

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Abstract

In the CERN LHC, accidental beam impacts on the tertiary collimators (TCTs) can lead to significant energy deposition in the triplet region and to leakage of the induced particle shower towards the experimental cavern. In this work, carried out in the context of the planned High Luminosity Upgrade of the LHC, severe impacts from asynchronous beam dumps on the horizontal tertiary collimator in cell 4 of the CMS insertion were studied, with half or a full proton bunch impacting on a collimator jaw. The choice of jaw material is shown to be of great importance, with over a factor of 10 increase in peak energy density values in the triplet coils moving from tungsten (Inermet) to molybdenum graphite jaws. Nevertheless, although the quench limit is exceeded in at least one or more triplet magnets in all the evaluated scenarios, values remain well below the damage limit. Yields and energy spectra of particles leaking into the experimental cavern have also been estimated and are presented here.

INTRODUCTION

A misfire of one or more extraction kicker magnets (MKDs) in the LHC, defined as an asynchronous beam dump, can induce a larger betatron oscillation in several proton bunches, potentially causing them to directly hit the tertiary collimators (TCTs) that are placed upstream of the LHC interaction regions (IRs) to protect the triplet aperture [1]. Their jaws are composed of Inermet, a commercial tungsten (95%) alloy which is efficient in absorbing high-energy particles but also, for the same reason, more easily susceptible to damage. In the High Luminosity Upgrade of the LHC (HL-LHC) [2] two sets of TCTs are foreseen on each side of the IRs in cells 4 and 6, each consisting of a horizontal and vertical TCT. In the present study, different impacts on the horizontal TCT in cell 4 of IR5 were studied and their effects on the triplet and D1 were compared when occurring on jaws composed of different materials.

SIMULATION SETUP

The particle tracking calculations were performed with `SixTrack` [3, 4] using HL-LHC optics version 1.2 with β*=15 cm in collision. Two impact scenarios on the inner jaw of the horizontal TCT in cell 4 were studied: an (almost) full bunch impact with 94% of the protons hitting the jaw (242 kJ impacting energy) and a half bunch impact with 53% of the protons hitting the jaw (137 kJ impacting energy). The TCT was set at an opening of 13.3σ (19.6 mm halfgap), the largest at which it still shadows the triplet. It should be noted that only a single bunch was considered, assuming a population of 2.3×10^{11} protons. In reality, an asynchronous beam dump event involves multiple bunches and the TCT may be impacted by different fractions of some of them at different depths. Therefore, the results of this study are not directly scalable to such scenarios.

Minor changes in the triplet-D1 region featured by the latest layout version (1.3) should not affect the results presented in this work. On the other hand, the betatron phase advance from the MKDs to the TCTs has been significantly improved in version 1.3 [5], leading to lower expected losses. In this sense, the present study is to be taken as a conservative scenario.

The `SixTrack` input was loaded in `FLUKA` [6, 7] at the front face of the TCTH4 in order to simulate the impact of the protons on the collimator and the evolution of the secondary particle showers into the triplet area and the experiment. The non-impacting fraction of the bunch was also included in order to verify its transport without interaction through the simulated geometry. All beam-line elements (collimators, magnets etc.) were modelled and placed within a realistic geometry of the surrounding tunnel, as shown in Fig. 1. Their exact positioning, as well as the magnetic settings, are generated automatically based on the optics files [8]. Alignment or magnetic errors were not included in the simulation. Two different material options were considered for the TCT jaws: Inermet and molybdenum graphite, a lighter material and therefore more resistant to beam impacts, but offering weaker protection [9].

The impact on the triplet-D1 magnets was estimated for three different configurations: a half bunch impact on an Inermet collimator jaw and a full and half bunch impact on a molybdenum graphite jaw. Molybdenum graphite is the lightest material under consideration and therefore represents the most pessimistic case in terms of protection. For an Inermet jaw, only the half bunch impact was simulated because it is expected to lead to higher energy deposition in the triplet compared to a full bunch impact [10]; in the latter case, strong local absorption will protect downstream magnets, whereas in the former case a significant part of particles scattered near the jaw surface will escape towards the triplet still carrying significant energy. In addition to studying the radiation impact on the magnets, particles moving towards the experimental cavern were recorded on a scoring plane at 22.6 m from the interaction point (IP) in order to characterise the radiation field. This information was pro-

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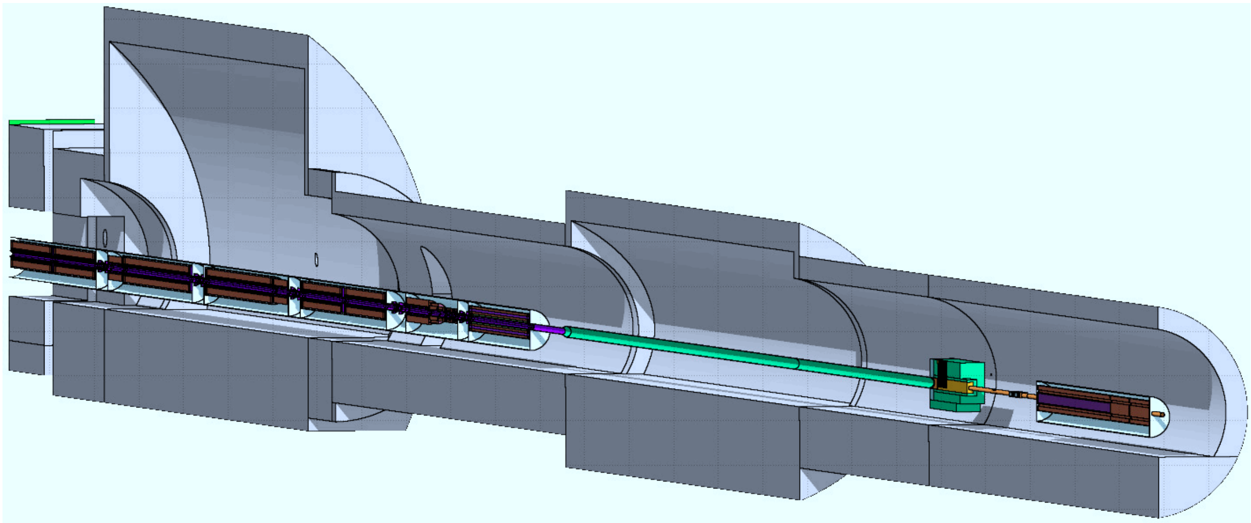

Figure 1: A 3D representation of the simulated geometry generated with Flair [11], the FLUKA graphical user interface. The triplet magnets and D1 can be seen on the left side. The TCTs are located between the TAXN absorber and D2, pictured on the right, and the impacting beam enters from this direction. The cut on the left corresponds to the interface plane at 22.6 m from the IP, where the particles are recorded.

vided to CMS for detailed studies of the impact to the detector, in analogy to previous studies on background [12].

IMPACT ON THE MAGNETS

The energy deposition distribution among the various elements varies between the different scenarios and strongly depends on the choice of collimator material. With Inermet, more than 70% of the impacting energy is deposited in the TCT and its tank as well the surrounding tunnel walls, with only about 6% of the energy being deposited in the triplet-D1 region and less than 5% being carried into the experimental cavern mostly by protons at beam energy. Conversely, the choice of molybdenum graphite implies a local deposition in the TCT area of about 30% of the energy, with up to 40% deposited in the triplet-D1 region and up to 13% leaking towards the experiment. In this case, the contribution of beam energy protons to the last term is not dominant, being complemented by a significantly larger number of other particles, in particular high energy neutrons.

The importance of the choice of material is also apparent in the expected energy density in the coils, whose peak profile is shown in Fig. 2. The maximum values are found in the non-IP face of D1 and drop by about two orders of magnitude moving towards Q1. The peak on Q2B is due to protons at near beam energy, with the different impact parameter in the two impact scenarios leading to the observed difference in its position and shape. Irrespective of the impact scenario, peak energy density values are more than an order of magnitude higher when Inermet is replaced with molybdenum graphite. With a peak value of over 50 mJ/cm^3, the D1 is expected to quench in the case of a half-bunch impact on an Inermet jaw, whereas all magnets will be exposed to potential quenches in the case of molybdenum graphite jaws. In all cases, however, values remain safely below the damage limit, which is estimated to be of the order of 100 J/cm^3.

A similar study has also been performed for the present LHC machine [10]. Important layout differences with respect to HL-LHC include the use of a warm D1 (consisting of six modules) with an elliptical aperture and a shorter triplet with a smaller aperture. The nominal bunch intensity is half than what is foreseen for HL-LHC, leading to a lower total impacting energy on the TCT which reaches 126 kJ for the full bunch impact. Despite these differences, comparable peak energy density values are found in the triplet, exceeding the quench limit for some or all triplet magnets but remaining well below the 100 J/cm^3 damage limit.

RADIATION LEAKAGE TO THE EXPERIMENT

The particles crossing the scoring plane at 22.6 m from the IP consist mainly of photons (75-85% depending on the case), neutrons (10-15%) and protons (0.1-0.5%), with the remainder being dominated by electrons and positrons. Protons are mostly concentrated inside the beam pipe and include a significant component with near nominal (7 TeV) momentum carrying a fraction of the energy crossing the plane that ranges from 10% (33%) for the full (half) bunch impact on molybdenum graphite to 74% for the half bunch impact on Inermet. Photon and neutron fluences also peak inside the beam pipe, but with a distribution covering the entire 2×2 m cross-section of the tunnel at that location. The energy spectra of the photons, neutrons and protons crossing the plane can be seen in Fig. 3. Independently of the particular impact scenario, it is clear that the number of particles leaking towards the experimental cavern also increases by at least a factor of 10 when considering a molybdenum graphite jaw compared to Inermet.

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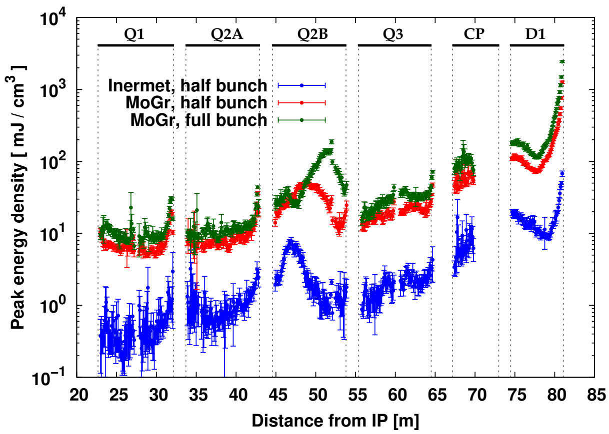

Figure 2: Peak energy density profile in the triplet-D1 inner coils (CP stands for 'Corrector Package') for the three investigated scenarios. Values are normalised to the HL-LHC bunch population of $2.3{\times}10^{11}$ protons.

CONCLUSION

We assessed that, in the case of a beam impact on the horizontal tertiary collimator in cell 4 of IR5 following an asynchronous beam dump, the estimated peak energy density values in the triplet remain well below the damage limit, although quenches are expected in all investigated scenarios. As expected, the choice of molybdenum graphite as jaw material leads to a far higher leakage towards the triplet and beyond, independently of the particular impact scenario, with an increase in peak energy density in the triplet coils and the neutron, photon and proton populations crossing into the experimental cavern of more than an order of magnitude. A third material under consideration (copper-diamond) has an intermediate density and can be expected to yield results that lie between the other two, as has already been confirmed for the present LHC [10]. Further studies will focus on the impact of a proton bunch on the horizontal TCT in cell 6. It is reasonable in this case to expect a significant impact on Q5, while Q4 may also suffer in its MQY version featuring a 70 mm coil aperture as Q5.

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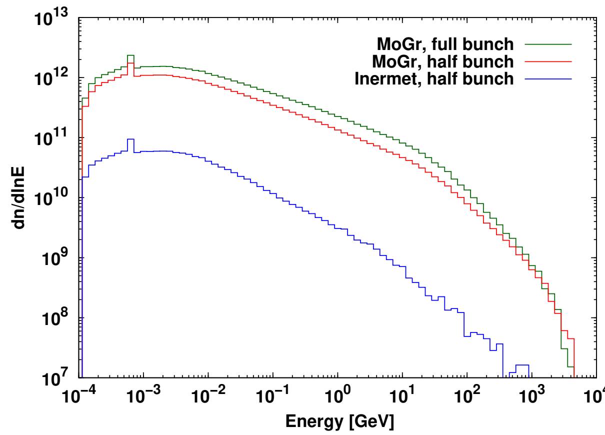
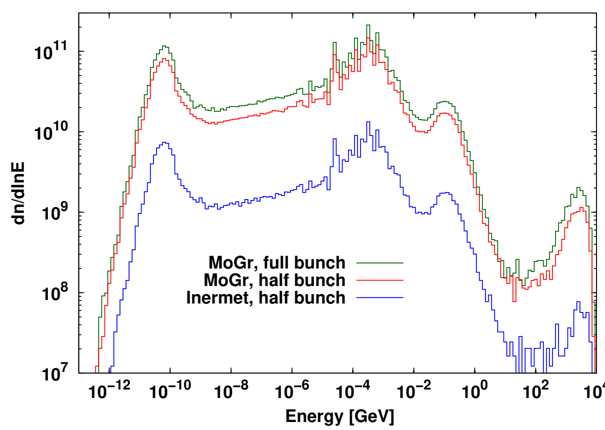


(a)



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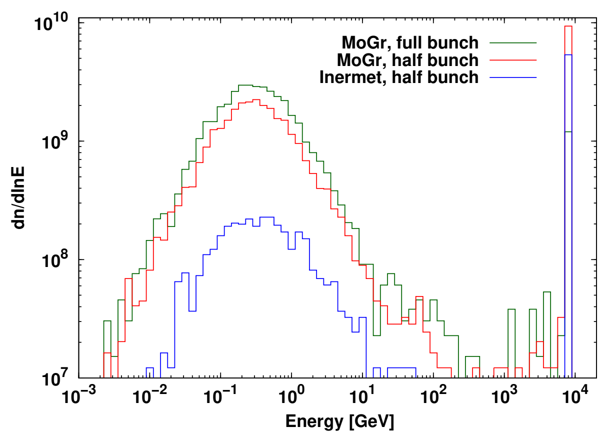

(c)

Figure 3: Energy spectra of (a) photons, (b) neutrons and (c) protons crossing the scoring plane at 22.6 m from the IP, i.e. moving towards the CMS experimental cavern. Values are normalised to the HL-LHC bunch population of $2.3{\times}10^{11}$ protons.

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