EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN – ACCELERATOR AND TECHNOLOGY SECTOR

CERN-ATS-2011-139

MACHINE-INDUCED SHOWERS ENTERING THE ATLAS AND CMS DETECTORS IN THE LHC

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Abstract

One source of experimental background in the LHC is showers induced by particles hitting the upstream collimators or particles that have been scattered on the residual gas. We estimate the flux and distribution of particles entering the ATLAS and CMS detectors through FLUKA simulations starting either in the tertiary collimators or with inelastic beam-gas interactions. Comparisons to MARS15 results are also presented. Our results can be used as a source term for further simulations of the machine-induced background in the experimental detectors.

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One source of experimental background in the LHC is showers induced by particles hitting the upstream collimators or particles that have been scattered on the residual gas. We estimate the flux and distribution of particles entering the ATLAS and CMS detectors through FLUKA simulations starting either in the tertiary collimators or with inelastic beam-gas interactions. Comparisons to MARS15 results are also presented. Our results can be used as a source term for further simulations of the machine-induced background in the experimental detectors.

INTRODUCTION

To ensure optimal performance of the LHC experimental detectors, it is important to understand the background, which can come from several sources. In this article we discuss machine-induced background, caused either by nearby beam losses or interactions between beam particles and the residual gas inside the vacuum pipe.

Beam losses outside the experimental interaction regions (IRs) are unavoidable during collider operation. The halo is continuously repopulated and has to be cleaned by the collimation system [1, 2, 3], so that the losses in the cold magnets are kept at a safe level. The collimation system is located in two dedicated insertions (IR3 and IR7) but a small leakage of secondary and tertiary halo is expected to escape. Some particles make it to the experimental IRs, where they are intercepted by tertiary collimators (TCTs) that are installed in order to protect the inner triplet magnets. Some parts of the induced high-energy shower can escape and propagate into the detectors.

Another source of background is beam-gas interactions. Beam protons can scatter elastically or inelastically on residual gas molecules. If an inelastic interaction occurs close to the detector, it causes a shower that could reach the detector. Elastic interactions can scatter protons directly onto the TCTs without passing IR7, which has to be treated separately from the beam-halo losses discussed above. Machine-induced background can also originate from a cross-talk between different IPs.

In this article we focus on beam-halo losses and inelastic beam-gas interactions two LHC experiments: ATLAS in IR1 and CMS in IR5. We compare also to previous results [4, 5]. We simulate the machine-induced showers propagating through the interaction region up to an interface plane between the machine and the detector, which is defined to be at 22.6 m from the interaction point (IP) along the beam direction. The coordinates and momenta of the particles crossing this plane are recorded and can be used as a source term for further simulations of the detector itself. The interface plane extends to 30 m radially, although 99% of the total energy was found within a 2.5 m radius in the simulations.

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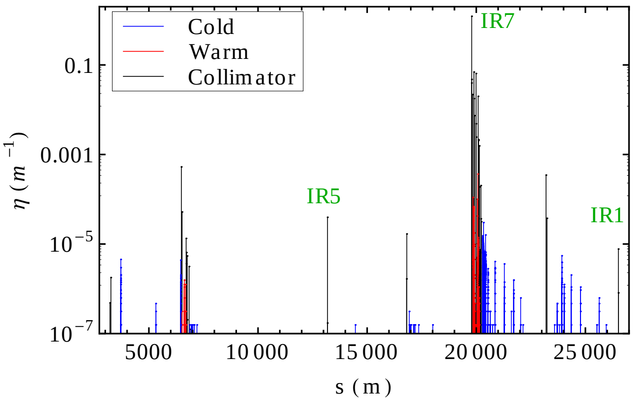

Figure 1: Cleaning inefficiency η (ratio of local losses per metre to the total losses on the TCPs), simulated with SixTrack, for the 2010 LHC running conditions (3.5 TeV, $\beta^* = 3.5$ m). The horizontal TCPs in IR7, beam 1, were hit first by the halo. The leakage to the TCTs in IR1 and IR5 is about 10^{-5}–10^{-4}. The colour codes indicate if the losses occur on a collimatoror in a warm or cold element.

SIMULATIONS OF BEAM-HALO

We use SixTrack [6] to simulate the cleaning of the LHC beam-halo. SixTrack combines optical tracking with a Monte Carlo simulation of the particle-matter interaction in the collimators. The tracking stops either when an inelastic interaction occurs inside a collimator or when the aperture is hit. The starting conditions are an assumed primary halo impact parameter of about 1 μm on the primary collimators (TCPs). Separate simulations are performed for the two beams and for horizontal and vertical halo.

Simulations have been performed earlier for the nominal machine with 7 TeV beams [7], nominal collimator settings, and β^*=0.55 m. Simulations of the machine used in 2010 with 3.5 TeV beams, $\beta^* = 3.5$ m, and relaxed col-

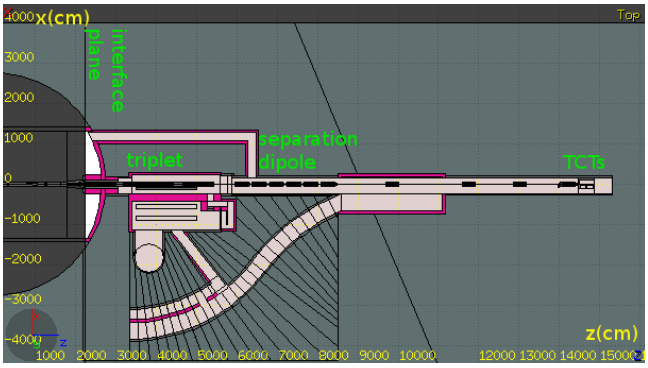

Figure 2: A cross-section of the FLUKA geometry for IR5 in the x-z-plane.

limator settings [8] are presented here. Fig 1 shows the losses around the ring in this scenario.

The inelastic interactions inside the TCTs in IR1 and IR5 were used as starting conditions for a shower simulation with FLUKA [9, 10]. Separate geometries were used for IR1 and IR5, extending from the TCTs to the detector. A full map of the magnetic field, going out to the cryostat, was used both in the inner triplets and in the separation dipole. The geometry of IR5 is shown in Fig. 2. All FLUKA simulations were done without biasing but an energy cut-off at 20 MeV was applied, motivated by the fact that particles with lower energy are not important for background.

Both beams were simulated at IR1 and IR5. Thus four simulations were performed for each studied machine scenario. The FLUKA geometry covers only the right side of IR1 and IR5 but was used also for the simulation of the left side. The error should be minor since the optics and aperture of the incoming beams are identical. There are smaller geometrical differences farther away from the beam line but their influence is considered minor.

The nominal 7 TeV case at IR5 has previously been simulated [4, 5] with MARS15 [11] and has now been repeated with FLUKA with the same source. Fig. 3 shows the energy spectrum and radial energy distribution at the interface plane for some particle types for both codes. All results are normalized to the losses on the TCTs. There is a very good agreement between the two codes in most cases despite independent implementations of both the physics models and the geometry (ranging about 150 m), which we consider an important benchmark. At larger radii, more energy reaches the interface plane in FLUKA than in MARS15. This difference could be caused by geometrical differences. The total energy reaching the interface plane per TCT hit is 5.8 GeV from MARS15 and 5.5 GeV from FLUKA. The muon distribution at low radii is also slightly different.

Because of asymmetries in the betatron phase advance, the TCT impact distribution differs between IRs and beams. Simulations show that if identical starting conditions are used in both geometries, the resuls are almost identical except at large radii where the shielding is different. The difference observed between IR1 and IR5 is thus caused mainly by the impacts on the TCTs. For the 7 TeV case, beam 1 dominates the beam-halo background at IR1 and beam 2 at IR5, where the distance is the shortest between IR7 and the detector.

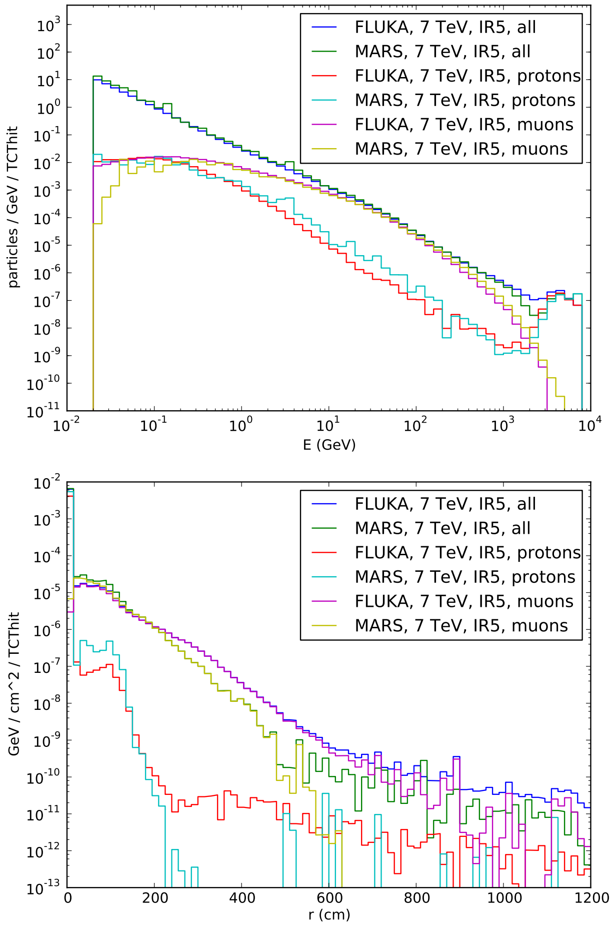

Figure 3: Energy spectrum (top) and radial energy distribution (bottom) for 7 TeV beam-halo at IR5, beam 2, comparing MARS15 results [4, 5] with FLUKA.

For the 3.5 TeV machine, this is different. Since the absorbers in IR7 are retracted to 17.7 σ [8], larger part of the tertiary halo escapes. Because of the phase advance from the secondary collimators, these particles make almost a full turn before they are intercepted by the TCTs in IR1 for beam 2 and IR5 for beam 1. For the 2010 machine, this effect turns out to be dominating.

In Fig. 4 we show some examples of energy spectra from FLUKA for the 2010 machine. The qualitative shapes of the distributions are similar to the 7 TeV simulations, but with different offsets. Between 5 and 13 GeV reaches the interface plane per TCT hit—in most cases this is more than at 7 TeV. This is explained by the different starting conditions. In the 3.5 TeV simulations, the impact parameters are in most cases smaller, meaning that more energy escapes out of the TCTs.

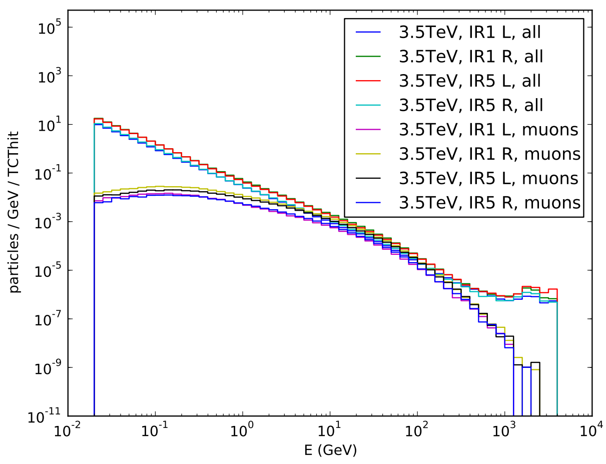

Figure 4: Energy spectrum for 3.5 TeV beam-halo.

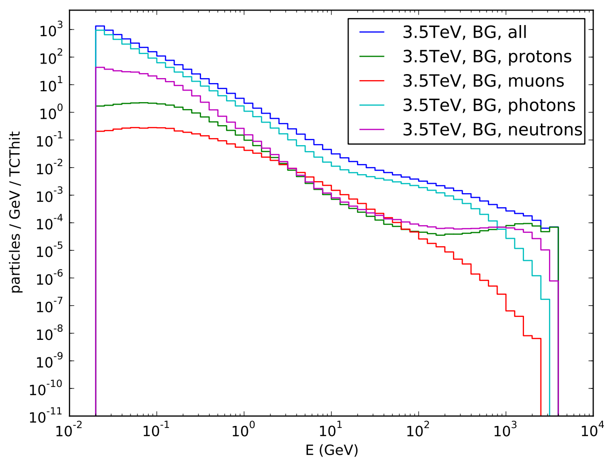

Figure 5: Energy spectrum for 3.5 TeV beam-gas, assuming a homogenous pressure profile and N as rest gas.

SIMULATIONS OF BEAM-GAS

For the beam-gas simulations, we use the same FLUKA geometries (see Fig. 2) as for beam-halo and consider inelastic events occuring somewhere between the interface plane and the TCTs, accounting for events only up $z = 150$ m from the IP. However, it has been shown [4, 5, 12] that events up to $z = 550$ m are contributing and an extension of the FLUKA geometry is ongoing work. The events are sampled with a uniform probability distribution in the longitudinal coordinate along the ideal orbit. This is equivalent to an underlying assumption of a homogeneous pressure profile. This is evidently not found in the machine. However, all correlations are kept between secondaries reaching the interface plane and the initial interaction. Therefore, an arbitrary pressure profile can be reproduced by simple post-processing routines: single events with all resulting secondaries can be sampled with a probability weighted by the local pressure at the position of the initial interaction. With this approach, the FLUKA run does not have to be repeated for different pressure profiles.

In Fig. 5 we show some energy spectra at the interface plane from the simulation of scattering on nitrogen in the 3.5 TeV machine with $\beta^* = 3.5$ m. Only the right side of the IPs was simulated, however, the results should be applicable to the left side as well with good approximation. Results are shown for IP5 but IP1 is identical. Differences between the two appear at large radii (not shown here), likely due to the different geometry of the shielding.

CONCLUSIONS

We have shown simulations of particle fluxes causing background entering ATLAS and CMS from the LHC machine. Two sources were considered—halo protons hitting the tertiary collimators, driving a shower where a small part reaches the detector, and inelastic interaction between beam protons and the residual gas in the vacuum pipe close to the detector. FLUKA was used to simulate the shower in both cases and SixTrack was used to generate the starting distribution of the halo particles. In both cases the FLUKA simulations stop at an interface plane between the machine and the detector, where the coordinates and momenta are written out. The simulation output can be used as a source term for a simulation of the background in the detectors.

The beam-halo simulation was performed both for 3.5 TeV and 7 TeV. The 7 TeV case was compared with an earlier MARS15 simulation. An overall very good agreement was found although small discrepancies were observed in the radial distributions. Our comparison is nevertheless an important validation of the agreement between the codes.

ACKNOWLEDGMENTS

We would like to thank P. Hagen for providing the magnetic field map of the D1 dipole. We are also grateful to N. Baccetta, W. Bell, P. Bhat, S. Gibson and M. Guthoff for helpful discussions.

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