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BEAM-INDUCED BACKGROUND SIMULATIONS FOR THE CMS EXPERIMENT AT THE LHC

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Abstract

Beam-induced background (BIB) comes from interactions of the beam and beam halo particles with either the residual gas in the vacuum chamber of accelerator or the collimators that define the beam aperture. Beam-induced processes can potentially be a significant source of background for physics analyses at the Large Hadron Collider (LHC).

This contribution describes the simulation software environment used for this part of the Compact Muon Solenoid (CMS) experiment activity and recent beam-induced background simulation results for the Phase-2 CMS operation design.

INTRODUCTION

The LHC [1] will be upgraded to enable baseline operation for the High Luminosity LHC (HL-LHC) [2] period (Phase-2) at an instantaneous luminosity of 5×10^{34} cm^{-2} s^{-1}. The accelerator will operate at energy of 7 TeV per beam and a distance between bunches of 25 ns. This will allow to the CMS experiment [3] to collect integrated luminosity order 300 fb^{-1} per year and up to 3000 fb^{-1} during the HL-LHC projected lifetime of ten years, assuming machine efficiency is around 50%. The consideration of the radiation effects is a key to the overall success of the CMS experiment.

The Beam Radiation Instrumentation and Luminosity (BRIL) Project is responsible for the simulation and monitoring of the BIB in the CMS. The collaboration needs to understand and take into account all sources of the BIB and kinematic parameters of BIB particles entering the experimental cavern from the LHC tunnel.

BIB FORMATION ANF EFFECT

BIB comes from interactions of the beam or beam halo particles either with the residual gas in the beam pipe or with the collimators that define the beam aperture. We can divide BIB into three different types based on their origin.

The first one is the local inelastic beam-gas interactions (LBG). This is the dominant source of BIB in the CMS near-beam region. The main locations of inelastic beam gas collisions are the superconducting parts of the beam pipe in the Long Straight Section 5 (LSS5). Cold sections have a relatively high rate of the residual gas pressure compared to warm ones. The most important is the final focus triplet cryostat just upstream of the CMS hall.

The second source is the distant Beam Halo (BH). BH particles are produced when off-orbit components of the beam scrape one of the collimators in the cleaning sections of the LHC, and the resulting collision products are absorbed downstream by the tertiary collimators (TCT), which are about 150 m upstream of the interaction point 5 (IP5). The products of hadronic and electromagnetic showers started in the TCT can reach the CMS cavern.

The third source is the distant elastic beam gas interactions (DBG) that occur anywhere around the ring. Elastically scattered particles can make several turns before they hit a collimator. When they interact with the TCT, they can produce particle showers similar to those produced by the BH.

In the HL-LHC time the BIB will differ in several aspects from what is currently experienced at the LHC. The cold section of the final focus triplet will be extended and thus a longer degraded vacuum section is expected there. The higher luminosity and the beam current will also amplify the degradation of the vacuum in the beam pipe in the forward regions of the CMS. In addition, the aperture of the final focus triplet and the Target Absorber Secondaries collimator (TAS) will be larger, and this will allow more BIB particles to enter the CMS cavern at a low radius. Most of the BIB particles that enters the CMS inner tracker volume is originating from interactions of the previous generations of the BIB particles with the beam pipe material. Thus, compared to the current conditions, where the beam pipe in the CMS is partially sheltered from background particles by the TAS, highly energetic BIB particles will be able to travel through the TAS aperture and interact with the beam pipe in the central part of the detector, resulting in a higher level of background.

Low-radius BIB mainly affects pixel and strip trackers in CMS, where it induces spurious hits in detectors, increasing dead time and adversely affecting track reconstruction. The main impact arises when a muon produced in a decay of mesons created by the interaction of the beam or beam halo particles upstream of the detector interacts with the CMS detector and produces an energy deposition that can mimic the signatures of particles originating from central collisions in the IP5, also introducing a large imbalance in the measured total transverse momentum.

The rate of BIB events was typically a few Hz during Phase-1 Run 2 data taking.

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SIMULATION SOFTWARE

The Beam Radiation Instrumentation and Luminosity (BRIL) project of CMS is responsible for maintaining and improving the radiation simulation infrastructure of the CMS experiment. This software infrastructure is used by the BRIL to estimate the radiation levels in the CMS detector and experimental cavern.

Simulations are performed by the BRIL Radiation Simulation group (RadSim) using specialized software based on a complex dynamic model of the CMS experiment, its infrastructure and interface with the LHC. RadSim uses two Monte Carlo (MC) simulation packages, FLUKA [4, 5] and MARS [6], to transport particles through the CMS and to calculate radiation levels in the detectors and the CMS cavern.

It is also important to estimate the BIB radiation relative to the Collision Induced Background (CIB) at locations of various radiation detectors, which are operated by the BRIL project and are used to monitor the BIB rate and luminosity during the LHC operation [7].

BIB simulation uses an external set of input data. For LBG input source at the interface plane between LHC and CMS cavern can be calculated with FLUKA or MARS using residual gas profiles in the LSS5 beam pipe, preliminary simulated by the LHC Vacuum Group.

For DBG source should be calculated in two steps. Elastic beam-gas interactions along the cold LHC ring and the intermediate source at TCT are calculated using the STRUCT tracking code [8], and then the particle transport from TCT to the entrance of the CMS was simulated using MARS [9].

For BH source was also prepared in two steps. Intermediate source – hits map at the TCT - was determined using the SixTrack tracking code [10], and the particle transport to the CMS was simulated using FLUKA code [11].

Actual geometry models of the CMS and LSS5 are important parts of the simulation soft. There are include description of the CMS sub-detectors, LHC elements (vacuum chambers, vacuum equipment, interface of experiment with accelerator, magnetic elements in the LSS5), experimental cavern with CMS infrastructure. Magnetic structure description should include not only field in magnet apertures, but also field inside material of magnets and scattered field around it. It should provide correct description of trajectories of the charged products of cascades, initiated in the SS5.

SIMULATION AND RESULTS

The BIB particles transport simulation through the CMS detector was performed with CERN FLUKA v.4-1.1 and CMS FLUKA Model v.6.0, that represents the CMS Phase-2 configuration. In the Fig. 1 MC estimation of the flux of all charged particles produced by proton-proton collisions in the CMS experimental cavern is shown.

Two most modern BIB source files for HL-LHC were used, for BH and LBG. BIB particles are coming from the right side starting from interface plane at Z = 22.6 m. In Fig. 2 and Fig. 3 results of the simulations are shown for the same particle type and scale as in Fig. 1. Background from proton-proton collisions (CIB) dominates over the BIB, and the outgoing BIB particles (at negative Z side) cannot be distinguished from CIB ones. But the incoming BIB particles are in antiphase with the outgoing CIB, and at some locations can be clearly separated from CIB and measured. Such measurements are used for the control of the LHC beam conditions and beam abort signal elaboration if it is necessary for detector safety.

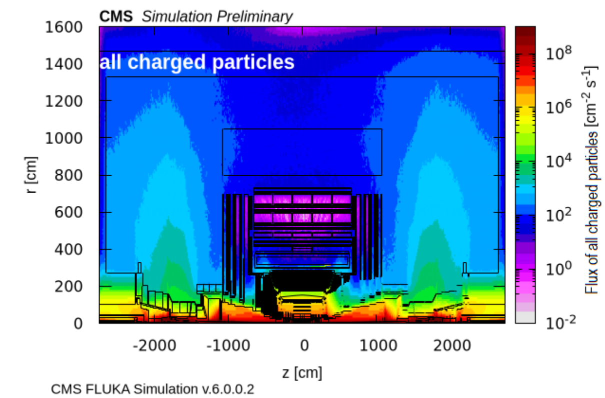

Figure 1: MC estimation of the flux of all charged particles in the CMS detectors and cavern at nominal HL-LHC luminosity 5×10^{34} cm^{-2}s^{-1}.

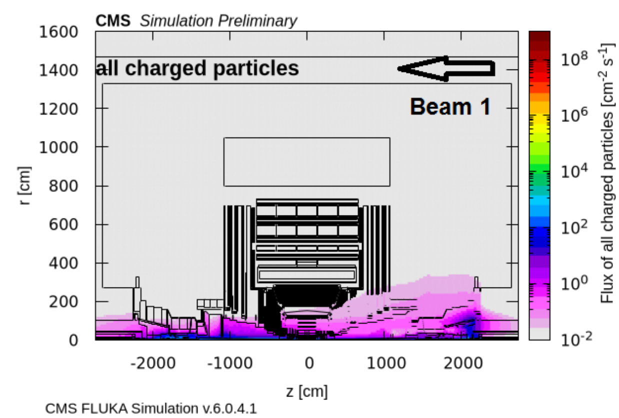

Figure 2: MC estimation of the flux of all charged particles in the CMS detectors and cavern from BH BIB source.

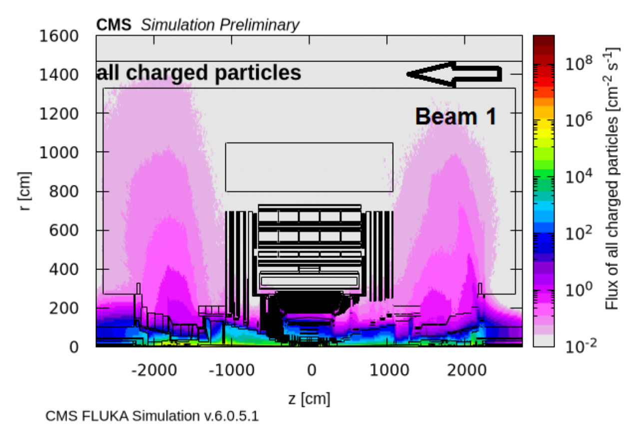

Figure 3: The same as for Fig. 2, but for LBG BIB source.

In Fig. 4 and Fig. 5 the flux of muons is presented for the same two BIB sources. The flux of BH initiated muons at

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small radius is much less intense than the flux from LBG, but BH source can give perceptible contribution to the total BIB at radius greater than 1 m.

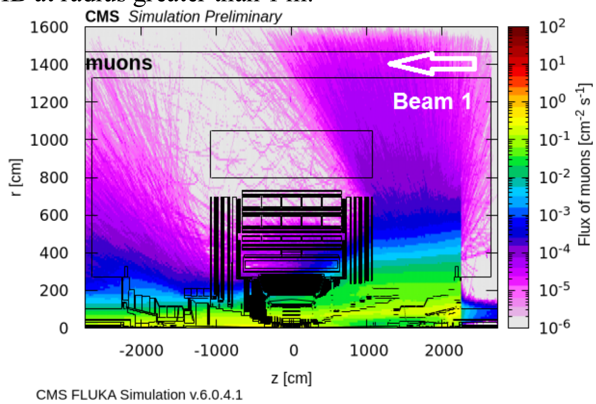

Figure 4: MC estimation of the flux of muons in the CMS detectors and cavern from BH BIB source.

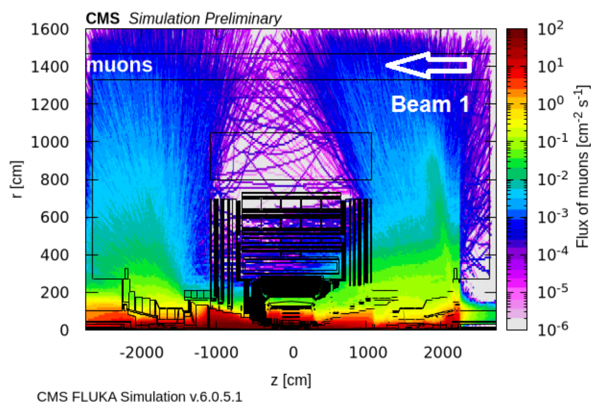

Figure 5: The same as for Fig.4, but for LBG BIB source.

In Fig. 6 and Fig. 7 radial distributions of the flux of all charged particles of BIB are presented for locations of the BRIL near beam detectors, designed to control BIB intensity and beam conditions. BCML is a Beam Condition Monitor that includes two pairs of stations located at different distance from IP (Z = 0). While the rates of the incoming background are relatively low, the outgoing background particles interact with detector material inside CMS and the central beam pipe (both cylindrically shaped central and conically shaped sections) and thus produces showers that generate much larger numbers of hits in the detector. However, unless bunches are noncolliding, these showers are fully superimposed over the collision products and thus are not distinguishable in the data.

TEPX D4R1 (part of the CMS end cap pixel detector) and FBCM (Fast Beam Condition Monitor) will also be used for measuring of the BIB intensity and distribution at the HL-LHC.

CONCLUSION

The software and approaches used by the CMS BRIL RadSim group for BIB simulations in the CMS experiment at HL-LHC are presented in this report. The first data of BIB simulation for modern version of the CMS Phase-2 FLUKA Model v.6.0 are presented.

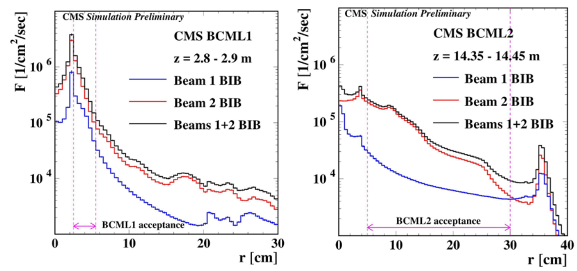

Figure 6: MC estimation of the radial distribution of the flux of all charged particles of BIB in CMS BCML1 (left) and BCML2 (right) detectors per one second of HL-LHC operation.

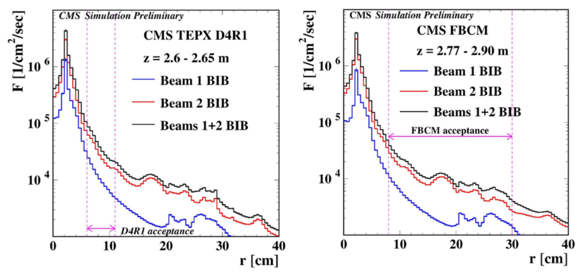

Figure 7: The same as for Fig. 6, but for CMS TEPX D4R1 (left) and FBCM (right) detectors.

ACKNOWLEDGMENTS

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