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Monte Carlo simulations of the radiation environment for the CMS Experiment

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Abstract

Monte Carlo radiation transport codes are used by the CMS Beam Radiation Instrumentation and Luminosity (BRIL) project to estimate the radiation levels due to proton-proton collisions and machine induced background. Results are used by the CMS collaboration for various applications: comparison with detector hit rates, pile-up studies, predictions of radiation damage based on various models (Dose, NIEL, DPA), shielding design, estimations of residual dose environment. Simulation parameters, and the maintenance of the input files are summarised, and key results are presented. Furthermore, an overview of additional programs developed by the BRIL project to meet the specific needs of CMS community is given.

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Monte Carlo simulations of the radiation environment for the CMS Experiment

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Abstract

Monte Carlo radiation transport codes are used by the CMS Beam Radiation Instrumentation and Luminosity (BRIL) project to estimate the radiation levels due to proton-proton collisions and machine induced background. Results are used by the CMS collaboration for various applications: comparison with detector hit rates, pile-up studies, predictions of radiation damage based on various models (Dose, NIEL, DPA), shielding design, estimations of residual dose environment. Simulation parameters, and the maintenance of the input files are summarised, and key results are presented. Furthermore, an overview of additional programs developed by the BRIL project to meet the specific needs of CMS community is given.

Keywords: Radiation, Simulation, FLUKA, MARS, CMS, Radiation Levels
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1. Introduction

This paper summarises the work performed by the CMS Beam Radiation Instrumentation and Luminosity (BRIL) project in collaboration with the CERN Radiation Protection (DGS/RP) group to make estimates of the radiation levels at CMS for LHC Run II using the Monte Carlo particle transport codes FLUKA [1, 2] and MARS [3]. Predictions of the radiation levels are important to determine the detector performance, longevity of materials and expected dose to personnel.

2. The CMS FLUKA and MARS Models

The latest FLUKA and MARS geometry models for Run II include a representation of the cavern, beamline components and the CMS detector. Upgrades installed during the first LHC long shutdown, including the newly installed central beampipe and fourth muon endcap disk, have been implemented. The latest FLUKA model also includes general improvements, such as the introduction of phi-asymmetric cavern elements, better modelling of gaps in the forward rotating shielding, and a detailed model of the tracker. A version scheme [4] has been recently introduced for the CMS FLUKA models, where a new tag is given for every change to the input files that would influence a result. This includes the simulation parameters and geometry updates.

3. Prompt Radiation

Prompt radiation from collisions or the LHC machine induced background, is simulated through the CMS cavern to determine the absorbed dose and particle fluxes over the CMS cavern and the particle spectra in specific regions.

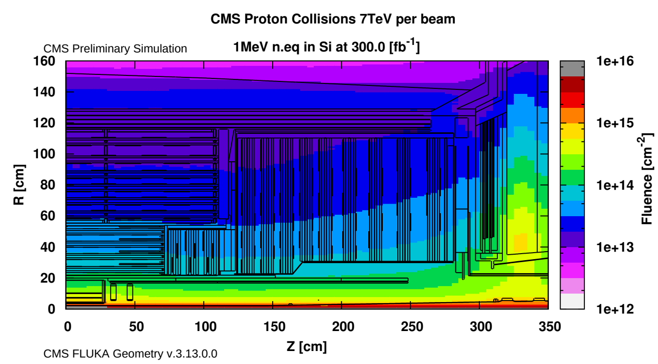

Figure 1: Estimation of the expected 1 MeV neutron equivalent fluence in silicon in the tracker region for a total integrated luminosity of 300 fb^{-1}, Collisions from 7 TeV proton beams were simulated.

3.1. Proton-Proton Collisions

The event generator DPMJET-III [5] is currently used in both FLUKA and MARS simulations as a collision source. Example applications of data from collision induced radiation simulations include the estimation of background rates on the muon detectors, the prediction of radiation damage to the pixel and strip tracker based on 1 MeV n-eq fluence in silicon [6], the prediction of radiation damage to detector parts based on dose (e.g. optical fibers in the HF detector), and estimates of radiation levels in the cavern to optimize shielding elements. Figure 1 shows the latest estimate of the 1 MeV n-eq fluence in silicon based on simulations with a recently updated model of the tracker.

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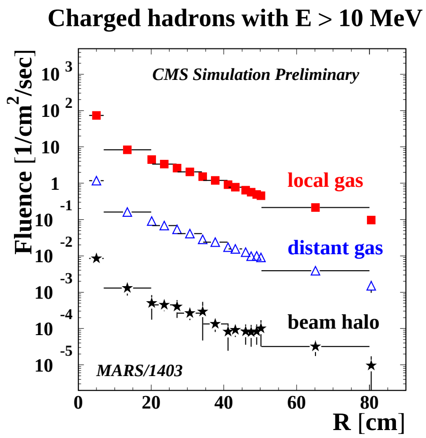

Figure 2: Monte Carlo estimates of the MIB flux for nominal Run II LHC conditions ($L = 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 7 TeV per beam) at Z = 1.8 m from IP5.

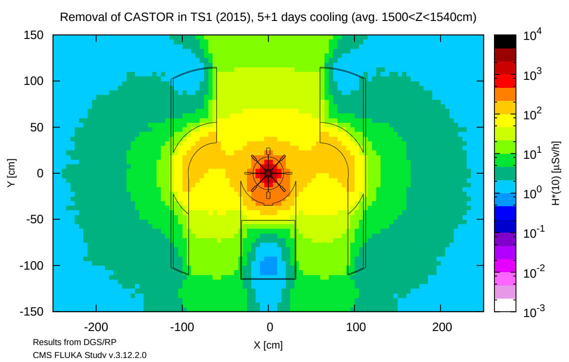

Figure 3: Residual ambient dose equivalent rates, H*(10), across the CASTOR detector after 6 days cooling in TS1. Results are based on 1 fb^{-1} before TS1, at 75% of peak luminosity $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Collisions from 6.5 TeV proton beams are simulated and an 80 mb inelastic cross section is assumed.

3.2. Machine Induced Background (MIB)

Data from MIB simulations are used to make predictions of background rates in various subdetectors. In particular, it is important to estimate the MIB radiation relative to the collision radiation at the location of various radiation detectors, which are operated by the BRIL project, and used to monitor the MIB and luminosity during operation [7]. Figure 2 shows the predicted charged hadron fluxes due to MIB from one beam (LHC beam 2) in the BRIL BCM1 detector region for nominal Run II conditions. The particle transport through CMS was simulated with MARS. For inelastic local (LHC straight section 5) gas interactions, the radiation source was calculated with MARS and residual gas profiles from [8] were used. For elastic distant gas interactions along the cold LHC ring, the source at the TCT (target collimator tertiary) was calculated by the STRUCT code and particle transport to CMS was simulated with MARS. For Beam Halo interactions, the source at the TCT was determined with SixTrack and the particle transport to CMS simulated with FLUKA. Normalizations for hits on the TCT are based on [9].

4. Residual Radiation Levels

Estimates of the residual radiation are an important part of the planning process for interventions in the CMS cavern. Activation simulations have been performed with FLUKA for several LHC Run II scenarios, and for both closed and open CMS configurations [10]. An example application is the comparison of the predicted residual ambient dose equivalent rates considering various planning scenarios for CASTOR (a forward electromagnetic and hadronic quartz calorimeter of the CMS experiment), removal and re-installation in 2015. Figure 3 shows the rates across the CASTOR detector made using FLUKA and SESAME (see section 5), with open rotating shielding and open collars after 6 days cooling in technical stop one (TS1).

5. Simulation Tools Developed by the BRIL Project

Two tools have been developed to allow CMS users to independently obtain results with CMS FLUKA models: A Python based web ‘plotting tool’, which enables CMS members to access BRIL simulation data and generate their own 2D flux maps according to a specified region, particle type, and simulation parameter, and FOCUS, a tool which allows users not familiar with FLUKA to perform simulations of proton-proton collisions and output a greater variety of data (e.g. particle type, time of arrival, coordinate, momentum) at a user-specified boundary. Furthermore, for experienced FLUKA users performing activation studies, the SESAME [11] tool has been developed. SESAME enables the separation of prompt and decay simulation steps and the transformation of the geometry model in-between, which includes the ability to rotate, translate, remove and add components. This is particularly useful for estimates of residual radiation with an open CMS configuration.

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