ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRO027

FIRST BEAM BACKGROUND SIMULATION STUDIES AT IR1 FOR HIGH LUMINOSITY LHC*

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Abstract

In the High-Luminosity Large Hadron Collider (HL-LHC) Project, the LHC will be significantly upgraded to produce about an order of magnitude more of integrated luminosity per year than what was achieved in Run I (2011 and 2012 data) in ATLAS at IR1 and CMS at IR5. In the view of a successful machine setup as well as a successful physics programme, beam induced background studies at IR1 were performed to investigate sources of particle fluxes to the experimental area. In particular, as a start of the study, two sources forming important contributions were simulated in detail: the first one considers inelastic interactions from beam particles hitting tertiary collimators, the second one from beam interactions with residual gas-molecules in the vacuum pipe close by the experiment, referred to as beam-halo and local beam-gas, respectively. We present these first HL-LHC background studies based on SixTrack and Fluka simulations, highlighting the simulation setup for the design case in the HL-LHC scenario. Results of particle spectra entering the ATLAS detector region are presented for the latest study version of HL-LHC machine layout (2013).

INTRODUCTION

A major upgrade of the LHC to the High Luminosity (HL) LHC after ten years of operation targets 250 fb^{-1} of integrated luminosity per year, nearly an order magnitude higher than what was achieved in Run I. The upgrade involves in particular new layouts of the experimental insertions of IR1 and IR5, including e.g. larger-aperture magnets, also the optics has been redesigned. The experiments must update in this new configuration estimates of beam induced background events. This paper highlights the first simulation results of such background events in IR1 applying the latest baseline of the HL-LHC machine optics.

BEAM INDUCED BACKGROUND SOURCES

Circulating beams in the LHC are normally accompanied by a beam-halo and intensity losses are unavoidable. In order to safely clean the beam-halo, the LHC has a 3-stage cleaning system. Primary and secondary collimators together with absorbers are placed in IR7 for betatron and in IR3 for momentum cleaning. Tertiary collimators complete the cleaning system and are placed close to the experimental areas to protect in IR1 (and IR5) the inner triplet (last three quadrupoles for final focussing) and reduce background. The HL-LHC upgrade foresees as well an upgrade of the collimation system [1], which however is not included in the present studies but left for future studies when more layout decisions are taken [2].

Two main sources of background in the experimental areas are investigated in detail: beam-halo protons that were not absorbed in the first two cleaning steps but hit the tertiary collimators and local beam-gas collisions in which beam protons collide with residual gas molecules in the beampipe also close to the experiment, up to 140 m upstream the interaction point (IP). This paper considers these inelastic scattering events creating particle showers towards the detector region in IR1 induced by the incoming beam of the right side (B2). Other sources, not discussed in this paper, are beam-gas collisions taking place further away (*global beam-gas*) or protons from a collision at IP5 which were scattered such that they end up in the tertiary collimators of IR1 (or vice versa, so-called *cross-talk*).

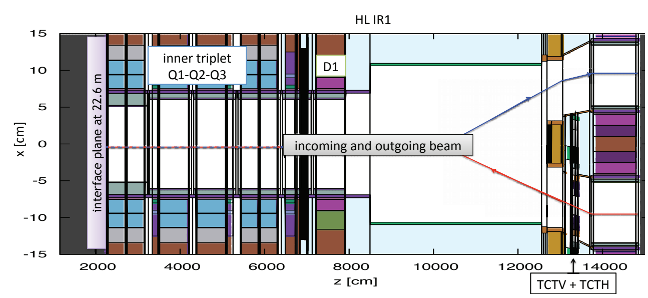

Figure 1: Horizontal cut of the Fluka HL IR1 geometry (same geometry as used in Ref. [5] for energy deposition studies) showing the detector-machine interface plane at 22.6 m and the tertiary collimators TCTV and TCTH at about 132 m on the incoming beam.

SIMULATION SETUP AND SCENARIO

Two simulation tools were used, SixTrack [3] for particle tracking around the machine and Fluka [4] for particle shower generation, both using HL optics, the *achromatic telescopic squeeze – ATS* optics for round beams, version HLLHCv1.0 for a β^* of 15 cm, and nominal LHC collimator settings [6]. The simulations were set up for the nominal HL-LHC scenario, i.e. considering a beam energy of 7 TeV, 2808 bunches, a spacing of 25 ns and $2.2{\times}10^{11}$ protons per bunch.

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In FLUKA, a detector-machine interface plane is defined at 22.6 m away of the IP at which particles showering towards the detector are written out for analysis. A horizontal cut of the geometry at beam height is shown in Fig. 1.

Beam-Halo Shower Simulation

In a two-step simulation, first SIXTRACK is used to perform particle tracking: user defined distributions of halo protons are tracked through a magnetic lattice, and a built-in Monte-Carlo generator simulates the physics process when they interact with a collimator. Escaping protons continue in the lattice until they hit the aperture or undergo an inelastic interaction in a collimator (or a maximum number of turns is reached, for more details of SIXTRACK see also Ref. [6, 7]). The main output are loss maps, locations of intercepted particles in either collimators or the aperture. For this study, losses in the tertiary collimators of IR1, the TCTH and TCTV for vertical and horizontal halo particles, at around 132 m upstream the IP were of interest. In the second step, the simulated particle losses in the tertiary collimators are used in FLUKA to generate inelastic interactions which produce a particle shower streaming to the detector.

Two scenarios are analysed, one for a beam lifetime of 12 min which corresponds to the design parameter of the collimation system, the other for a beam lifetime of 100 h as an indicator of a more optimistic operation case.

Beam-Gas Shower Simulation

Local beam-gas collisions are simulated in FLUKA only employing a gas pressure profile all along the sampling path up to 140 m upstream the IP. The pressure profiles are obtained using the vacuum simulation code VASCO [8] for the most dominant gas molecules H_2, CH_4, CO and CO_2. These are displayed in Fig. 2 for each element. As the vacuum quality varies at the beginning and after machine conditioning[1], the studies were performed for these two scenarios. Due to uncertainties in the simulations, two density levels were simulated for each case as shown in Fig. 2. The more conservative, high pressure levels were chosen for this analysis.

PARTICLE SPECTRA AT THE INTERFACE PLANE IN IR1

Several distributions per particle species were studied. We highlight here some of the most interesting ones for the experiments: the energy distribution of protons, neutrons and muons in Fig. 3 and their radial distribution in Fig. 4.

One can observe distinctive differences in the beam-gas and -halo induced distributions. The single-diffractive peak close to the beam energy in the halo distributions is clearly visible in Fig. 3 (a) while the ones in the beam-gas distributions are more smeared out. Protons and neutrons show in the halo spectra additional features compared to the beam-gas spectra like the energy bump at a round 50 GeV. These

[1] Machine conditioning is performed in dedicated "scrubbing runs" to reduce the secondary electron yield of the inner surface of the beam screen.

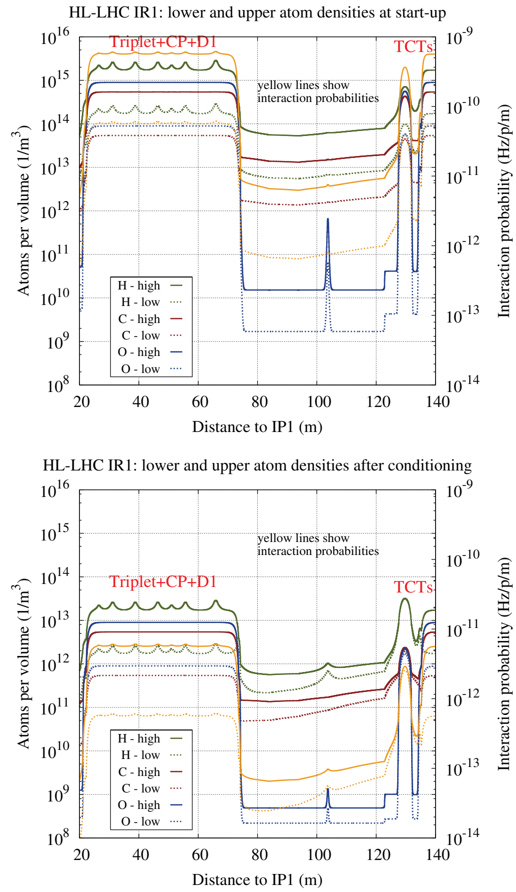

Figure 2: Preliminary density profiles at start-up conditions (top) and after machine conditioning (bottom) for the most common residual atoms over the sampling length. *High* and *low* indicate the uncertainty range due to uncertainties in layout, effective dimensions and pumping speed.

can only arise from geometrical structures which do not affect the beam-gas distribution as evidently as the beam-halos since collisions with gas molecules take place all along the way up to the interface plane. Such a structure is not visible for the muons. We emphasize that the shape of the distributions in Fig. 3 and 4 show layout dependencies, thus this analysis needs to be repeated in a final HL-LHC configuration for an improved background estimate.

From Fig. 3 one can expect most of the background neutrons during machine start-up, while lowest background is possible from halo protons during normal operation. About 100 times more background muons must be expected for very short beam lifetimes and during start-up, compared to the optimistic scenarios of long beam lifetimes and a conditioned machine.

The radial distribution of protons and neutrons in Fig. 4 (a) and (b) show similar features in their spectra, but with about ten times more neutrons. The largest contributions to background can be in the start-up scenario by beam-gas. The rate can be about 4 orders of magnitude smaller for halo losses assuming a long beam lifetime. The combination of Fig. 3 (c) and Fig. 4 (c) implies that both beam-gas scenarios

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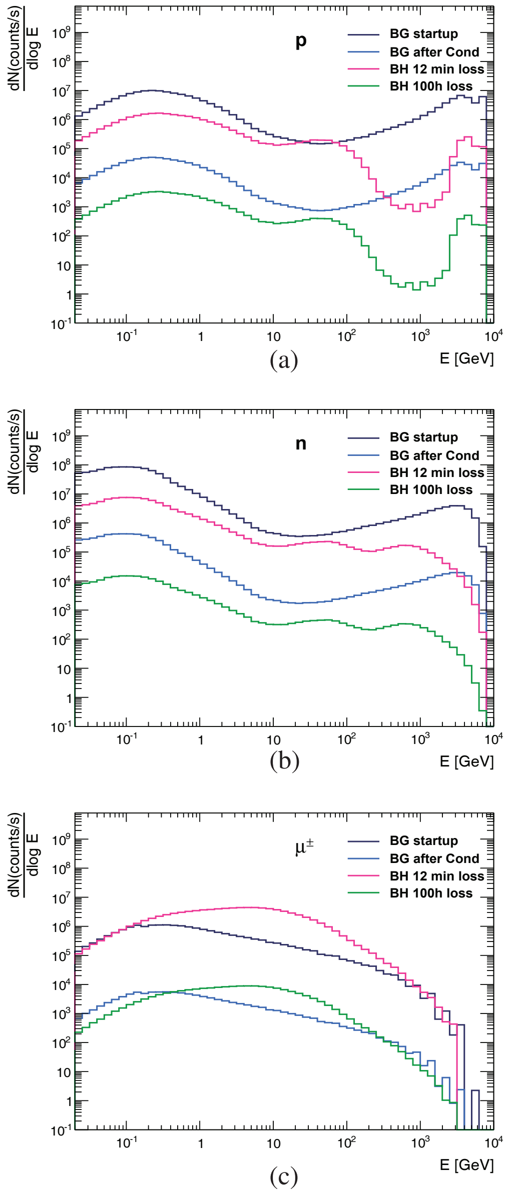

Figure 3: Energy distribution of protons (a), neutrons (b) and muons (c) produced in beam-gas (BG) and beam-halo (BH) events and shown for the different simulation scenarios.

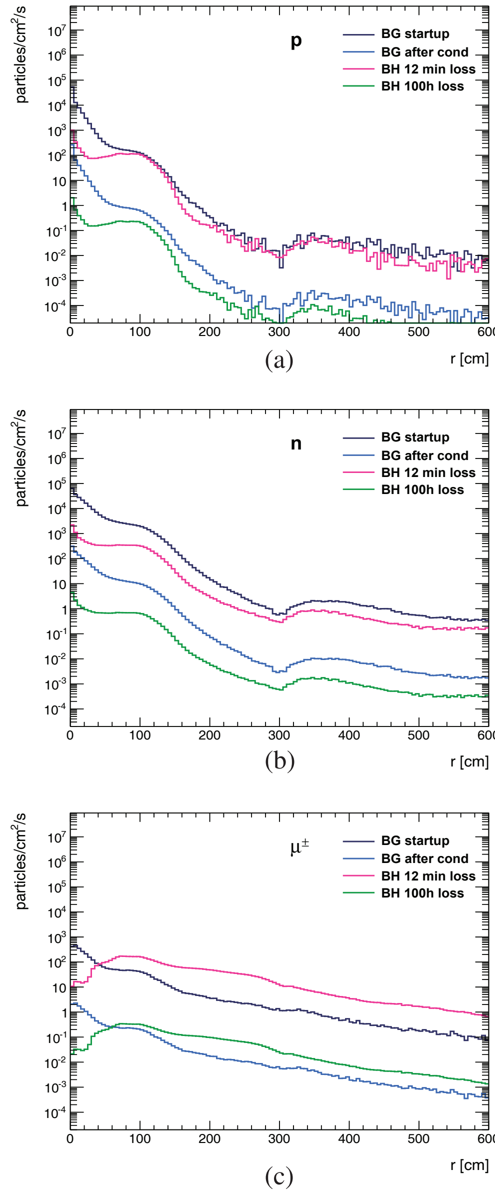

Figure 4: Radial distribution of protons (a), neutrons (b) and muons (c) at the interface plane again for the different BG and BH simulation scenarios.

produce many high energy muons at small radii. Except at high energies, the highest muon is rate caused by halo losses assuming a very short beam lifetime.

CONCLUSION AND OUTLOOK

We presented the first studies of particle spectra at IR1 entering the experimental area from the machine side with an updated geometry for the HL-LHC design case. Four scenarios were investigated, two for beam-gas with a particle density profile at start-up and conditioned machine, two for beam-halo assuming a very short and long beam lifetime. Highest background contributions can be expected from beam-gas at startup, followed by halo losses with short lifetimes. High energy muons are produced in all scenarios with the least contribution at small radii from halo losses with a long lifetime, see Fig. 4. The results also show geometry specific features, thus they need to be renewed once pressure profiles are updated and the machine layout is finalised.

More scenarios are under study changing a few open parameters, e.g. applying flat instead round beam optics or a more relaxed collimator configuration. In addition, one can take into account the HL collimator layout once it is finalised. It includes a new tertiary collimator further upstream [2] and is expected to further reduce background to the experiments. Similar to Ref. [7] it is planned to perform the same set of studies for IR5 and for beam 1.

ACKNOWLEDGMENT

The authors would like to thank S. Redaelli for helpful discussions.

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