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FLUKA SIMULATION OF PARTICLE FLUENCES TO ALICE DUE TO LHC INJECTION KICKER FAILURES

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Abstract

The counter-rotating beams of the LHC are injected in insertion regions which also accommodate the ALICE and LHCb experiments. An assembly of beam absorbers ensures the protection of machine elements in case of injection kicker failures, which can affect either the injected or the stored beam. In the first years of LHC operation, secondary particle showers due to beam impact on the injection beam stopper caused damage to the MOS injectors of the ALICE silicon drift detector as well as high-voltage trips in other ALICE subdetectors. In this study, we present FLUKA [1,2] simulations of particle fluences to the ALICE cavern for injection failures encountered during operation. Two different cases are reported, one where the miskicked beam is fully intercepted and one where the beam grazes the beam stopper.

INTRODUCTION

The LHC accommodates its beam injection systems in the same Insertion Regions (IR2 and IR8) as the ALICE and LHCb experiments [3]. The transfer lines from the SPS join the two rings from the external side, approximately 150 m (IR2) and 160 m (IR8) upstream of the interaction points. A series of five septum magnets (MSI) and four kicker magnets (MKI) forces the injected beam onto the circulating orbit by applying a horizontal deflection of 12 mrad and a vertical deflection of 0.85 mrad, respectively. An assembly of beam absorbers is installed downstream of the MKIs with the purpose to protect machine elements in case of MKI malfunctions or to intercept bunches during the set-up of the injection system. The injection protection system comprises a movable two-sided absorber (TDI) and auxiliary collimators (TCLIA/B), which are complemented by masks (TCDD/TCDDM, TCLIM) in front of downstream magnets. The TDI is located about 70 m downstream of the injection kickers at a vertical phase advance of 90° and 15 m upstream of the recombination dipole (D1).

As anticipated, several MKI failures occurred during the first years of high-intensity operation leading to beam impact on the TDI and TCLIs [4]. During such incidents, particle showers leaking from the protection devices can give rise to considerable energy deposition in neighbouring detectors and magnets. The energy density induced in magnet coils can typically reach several J/cm^3 [4]. In July 2011, two consecutive injection failures, both caused by a MKI switch erratic, resulted in high-voltage trips in several ALICE subdectectors. In addition, one of the two incidents lead to permanent damage to integrated electronic components used to calibrate the drift velocity of the Silicon Drift Detector (SDD). The SDD constitutes the third and fourth layer of the ALICE Inner Tracking system (ITS) at about 15 cm and 24 cm from the beam axis. In this paper we present FLUKA simulations of particle fluences entering the ALICE cavern for the described incidents.

INJECTION KICKER FAILURES

On 28 July 2011, there were two consecutive incidents involving kicker failures in IR2. In the first one, an erratic turn-on of a MKI module was detected by the interlock system and discharged the MKI [5]. A batch of 144 injected bunches fully impacted on the upper jaw of the TDI [6]. Consequently, high-voltage trips occurred in some ALICE subdetectors.

In the second one, 176±4 circulating bunches were miskicked (12.5% of the nominal kick) due to another erratic turn-on which was not detected by the interlock system [5]. 14±2 bunches were swept over the aperture and 162±2 bunches impacted on the TDI at grazing incidence [6]. The shower quenched a series of downstream magnets, including the D1 and inner triplet magnets (Q1, Q2 and Q3). Again several high-voltage trips occurred in the subdetectors, and the ALICE SDD was damaged as described in the introduction.

Figure 1 shows a schematic of the kicked beam in the vertical plane, illustrating the two incidents. Some key figures of the two incidents are summarized in Table 1.

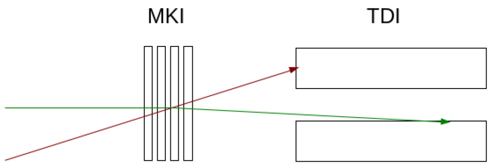

Figure 1: Schematic of the vertical plane illustrating full (injected beam) and grazing (circulating) impact on the TDI.

Table 1: Beam Impact on the TDI Due to Injection Kicker Failures that Occurred on 28 July 2011 in IR2

Impact	Beam	Bunch intensity	No. of bunches
Full	inj.	1.2×10^{11}	144
Grazing	circ.	1.2×10^{11}	162±2

SIMULATION SETUP

The FLUKA geometry of IR2 used in the simulation is shown in Fig. 2. Detailed description of beamline elements and surrounding regions is enabled by a FLUKA utility called LineBuilder [7]. The figure shows the MKIs, TDI, TCDD, magnets, correctors and other elements embedded along the tunnel leading to the ALICE cavern. Figure 3 shows the absorber jaws of TDI, each containing six blocks of boron nitride followed by aluminum and copper blocks.

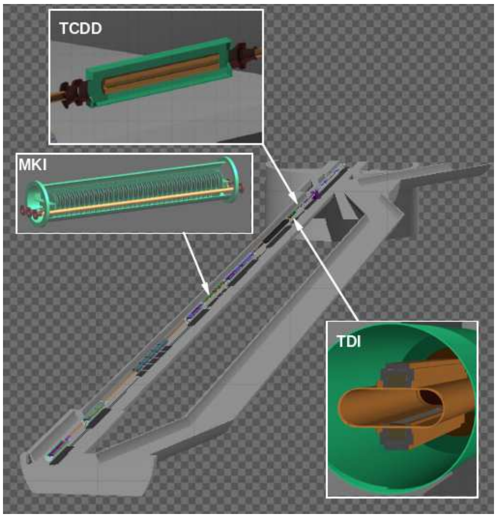

Figure 2: FLUKA geometry of IR2.

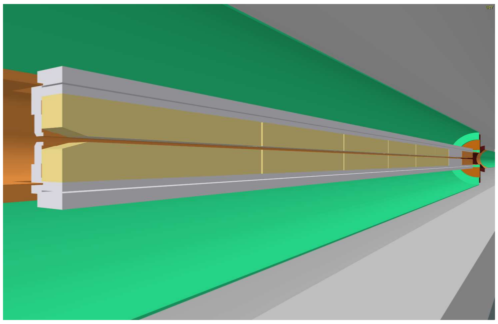

Figure 3: Vertical cross-section of the TDI vacuum tank containing the absorber blocks.

The impact distribution on the front face of the TDI was obtained by tracking particles using MAD-X [6] assuming an emittance of 2 μm·rad. This distribution was used as the source term for the FLUKA simulations. Table 2 shows the average vertical position and angle for both the incidents. At the impact position, the beam has a horizontal angle of -1.5 mrad with respect to the machine axis because the TDI is located between the separation dipoles. As noted in Ref. [4], the impact parameters for grazing impact can only be determined approximately due to uncertainties in the spatial and angular alignment of the TDI relative to the beam. For example, the angular alignment is affected by an uncertainty of ±100 μrad while the orbit position is obtained with an accuracy of ±150 μm.

In all simulations, the kinetic energy threshold was set at 20 MeV for electrons, positrons and neutrons, and at 2 MeV for photons. Particles were scored at a plane 19 m upstream of the interaction point IP2.

Table 2: Vertical Beam Position and Angle of the Kicked Beam

Incident	y (cm)	yp (mrad)
Full impact	3.18	0.3
Grazing impact	-0.77	-0.1

PARTICLE FLUENCES TO ALICE

The calculated particle spectra are shown in Fig. 4 and 5, respectively for full and grazing impact.

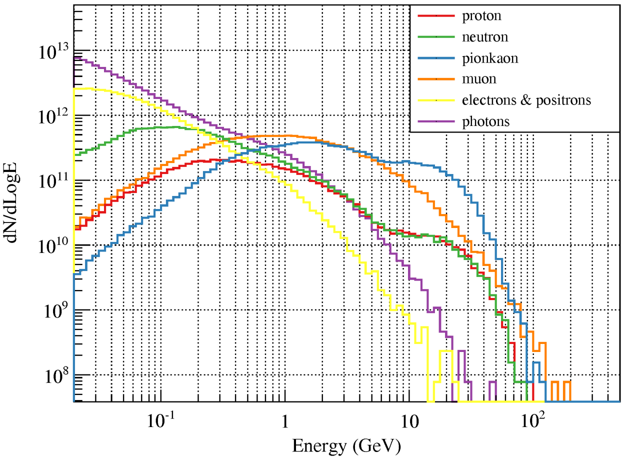

Figure 4: Secondary particle spectra normalized per unit lethargy and per failure event, at the scoring plane for full impact.

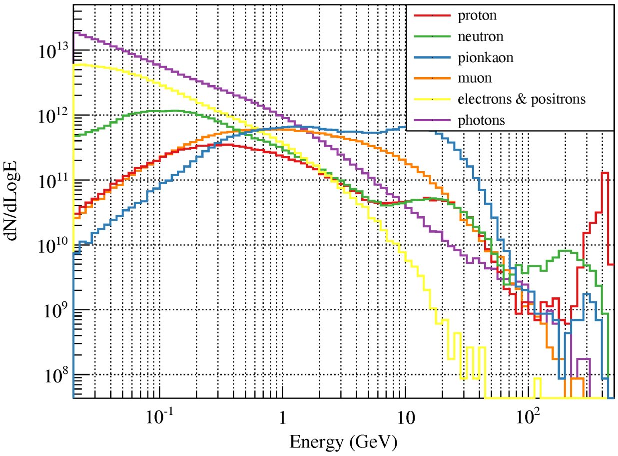

Figure 5: Secondary particle spectra normalized per unit lethargy and per failure event, at the scoring plane for grazing impact.

In case of full impact, showers induced by particles leaking from the downstream face of the TDI jaw form the major component of the observed spectra. In case of grazing impact, particles can also leak from the TDI surface facing

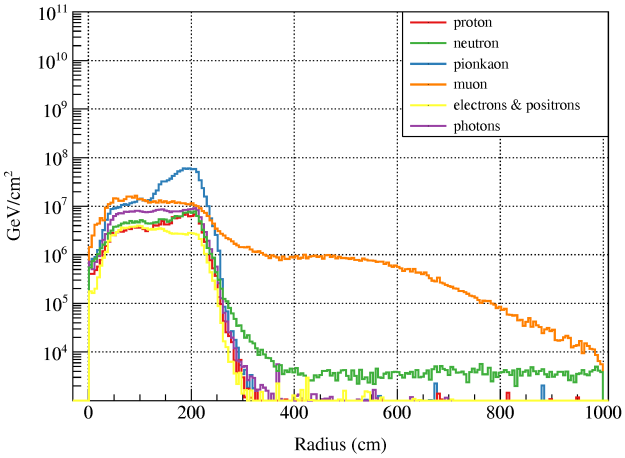

Figure 6: Radial distribution of energy fluence of secondary particles normalized per failure event, at the scoring plane for full impact. Center at machine axis.

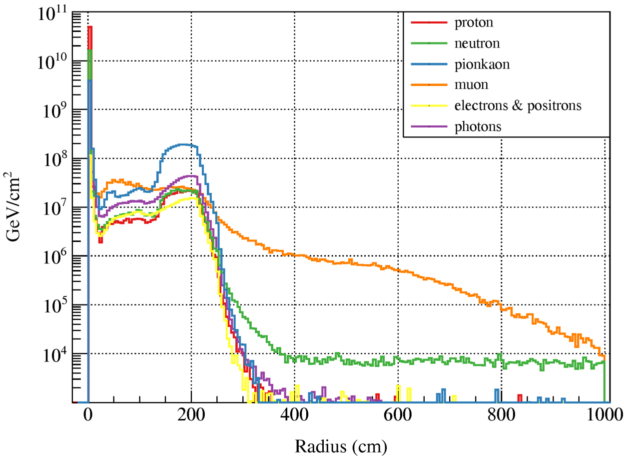

Figure 7: Radial distribution of energy fluence of secondary particles normalized per failure event, at the scoring plane for grazing impact. Center at machine axis.

the beam, hence contributing to the higher energy component (>100 GeV) which becomes negligible in the case of large impact parameters. In addition, the beam traverses less material in case of grazing incidence since the higher-Z blocks (aluminium and copper) at the downstream end of the jaws have an offset of 2mm with respect to the boron nitride blocks. This is to avoid direct beam impact during injection failures and hence extensive heating of these materials.

Figures 6 and 7 show the radial distribution of energy fluence normalized per failure. The fluences sharply decrease at a radius of approximately 2–3m, due to the concrete shielding which encloses the beamline the last 15 m upstream of the scoring plane. Beyond the shielding, radiation is mainly due to muons and to some extent due to neutrons.

For grazing impact, the energy fluences along the beamline axis (at radius = 0 cm) are orders of magnitude higher than for the other case considered, with a significant contribution from single-diffractive protons. At larger radii, the fluences for full and grazing impact differ only by a few factors.

CONCLUSION

Two consecutive injection failures that occurred in IR2 were simulated using FLUKA to estimate particle fluences entering the ALICE cavern. In case of grazing impact on the TDI, large particle fluences are observed within the beam pipe, which are absent in the second case, where the beam impacts on the TDI with a large offset (~3 cm) from the TDI jaw edge. The simulation results will be used to derive particle fluences in detector components and to compare against Beam Condition Monitor (BCM) signals.

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