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CROSS-TALK STUDIES BETWEEN FCC-hh EXPERIMENTAL INTERACTION REGIONS*

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Abstract

Debris from 50 TeV proton-proton collisions at the main interaction point in the FCC-hh may contribute to the background in the subsequent detector. This cross-talk is of possible concern for the FCC-hh due to the high luminosity and energy of the collider. DPMJET-III is used as a collision debris generator in order to assess the muon cross-talk contribution. An analytical calculation of muon range in rock is performed. This is followed by a full Monte Carlo simulation using FLUKA, where the accelerator tunnel has been modelled. The muon cross talk between the adjacent interaction points is assessed and its implications for FCC-hh design are discussed.

INTRODUCTION

The Future Circular Collider (FCC-hh) aims to accelerate and collide two counter rotating 50 TeV proton beams at two major and two minor experimental interaction regions (EIRs) [1]. The FCC-hh layout [2] is shown in Fig. 1. The nominal and ultimate luminosities of the FCC-hh are $5 \cdot 10^{34}$ $cm^{-2}s^{-1}$ and $20 \cdot 10^{34}$ $cm^{-2}s^{-1}$ respectively. Given this high proton energy and luminosity, collision debris must be properly handled. The impact on the detector and accelerator magnets is discussed in [3–5], in this paper we assess the cross-talk, *i.e.* the effect on the downstream detector from the collision debris, located 5.4 km away. The debris comprises mostly of photons, pions, protons, other charged hadrons, and muons, in order of abundance. Photons are ignored for cross-talk studies as they will not reach the next detector. The number of pions produced is significant, however together with other charged hadrons these do not have the required rigidity to be transported in the accelerator, and are therefore lost almost immediately in aperture restrictions. Protons are of concern, many are transported by the accelerator and can be lost in magnets —this is discussed in [6]. In this contribution we focus on muons, which are of particular interest in cross-talk studies because of their large mean free path, as they can travel kilometres through dense materials. Using the upgraded version of the DPMJET-III [7–9] event generator within FLUKA [10, 11], we simulate the proton collisions at Interaction Point A (IPA), with vertical crossing. The muon distribution given from 10^6 pp collision events is shown in Fig. 2 at intervals downstream of the interaction point. Figure 3 shows the FLUKA model of the tunnel from IPA to IPB.

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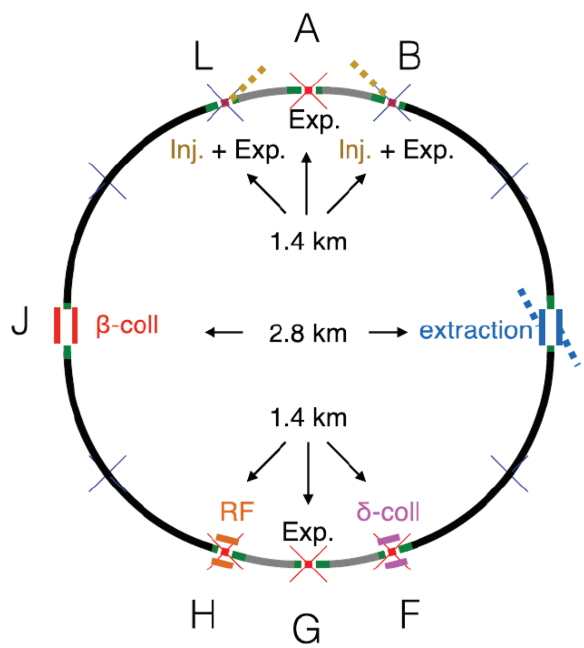

Figure 1: FCC layout [2]. The main EIR are located at A & G, and the low luminosity ones at L & B.

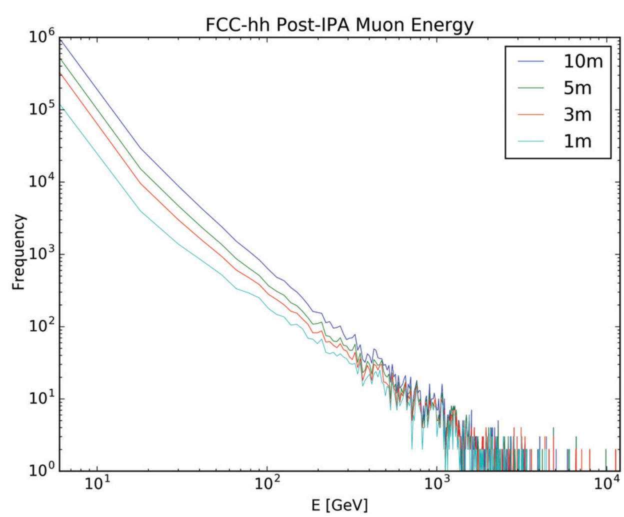

Figure 2: Muon energy distribution at intervals downstream of IPA, generated using DPMJET-III in FLUKA, with no detector or accelerator model.

THEORETICAL RANGE IN STANDARD ROCK

Muons lose energy in several separable ways; ionisation, bremsstrahlung, production of electron-positron pairs, and

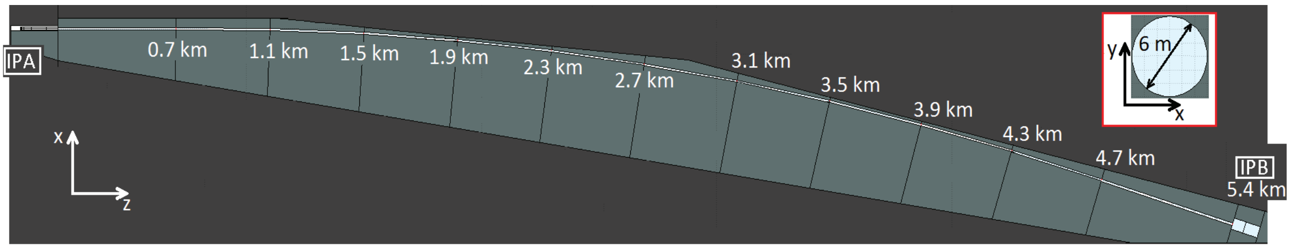

Figure 3: Cross section of the FLUKA FCC-hh tunnel model. The distance from IPA to each point along the tunnel central line in indicated. IPB is located 5.4 km away from IPA.

through photo-nuclear and photo-nucleon interactions. This is summarised in Eq. (1) [12]:

$$\left\langle \frac{-dE}{dx} \right\rangle = a(E) + b(E)E, \tag{1}$$

where $a(E)$ is the ionisation contribution, and $b(E) = b_b(E) + b_p(E) + b_n(E)$ is the sum of the contributions of bremsstrahlung, pair production, and photo-nuclear/nucleon interactions [13]. In the continuous slowing down approximation the range is given by

$$R(E) = \int_{E_0}^{E} (a(E') + b(E')E')^{-1} dE'. \tag{2}$$

At high energy a and b are constant, and this becomes

$$R(E) \approx \frac{1}{b} ln \left(1 + \frac{E}{E_c}\right), \tag{3}$$

where the electronic and radiative losses are equal at the critical energy E_c. We use this approach to calculate the theoretical range of muons in standard rock, which has a specific gravity of 2.65 g/cm^3 and $\langle \frac{Z}{A} \rangle = 0.5$, and in which the muon critical energy is 693 GeV. The result of this calculation is shown in Fig. 4, which gives a maximum range of 3200 m for collision debris muons in the FCC-hh through standard rock. We note that this calculation does not include interactions of collision debris with the detector, which is included in the next section.

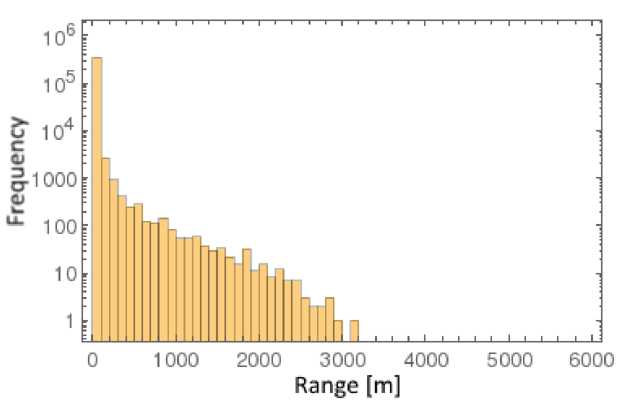

Figure 4: Theoretical range of muons in rock.

In order to verify the range of muons that will be propagated and may arrive to the EIR in L and B, a FLUKA model of the FCC tunnel section between IPA and IPB was developed. The horizontal cross section of this model is shown in Fig. 3. The tunnel consists of 12 cylinders with a diameter of 6 m that approximate its design shape [14].

SIMULATION

A total of $5 \cdot 10^4$ pp collisions were simulated using DPMJET-III in FLUKA with a complete FLUKA model of the detector [15], in order to generate the initial muon distribution, which is shown in Fig. 5.

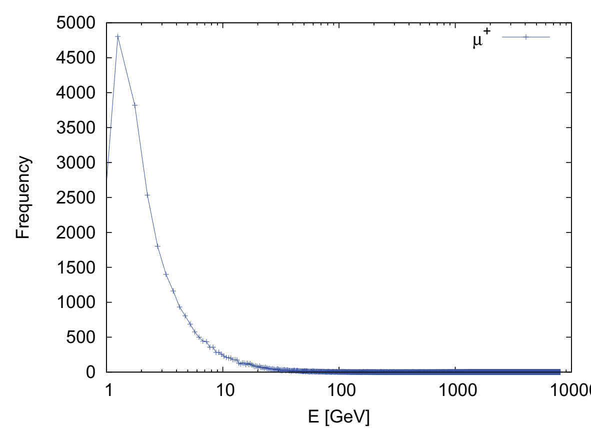

Figure 5: Energy spectrum of the initial muon distribution.

The muons were then scored at the end of the detector (s=40 m) so that they could be propagated in the second stage. Figure 6 shows the phase space distribution of the 30,000 muons scored.

The muons were tracked through the tunnel model shown in Fig. 3 using a total of 10^9 histories. The muon energy distributions at different points along the tunnel are shown in Fig. 7.

An example of the particles tracks are shown in Fig. 8. Less than 10 muons were detected at 2.3 km while none travelled beyond 2.7 km. From these results we may conclude that muon cross-talk does not seem to be an issue in the FCC-hh, as no muons reach the subsequent detector. Some muons have the energy required to travel hundreds of meters, but the curvature of the tunnel combined with the large distance between the adjacent interaction points results in a low probability of a muon reaching the next detector. Further studies will be performed to improve upon the statistics of

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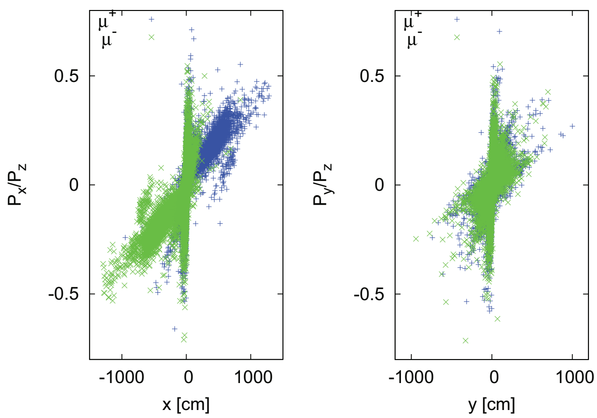

Figure 6: Horizontal and vertical muon phase space at s = 40 m.

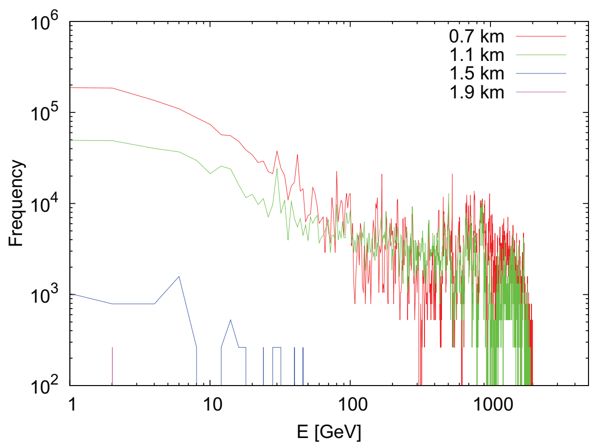

Figure 7: Muon distribution along the tunnel.

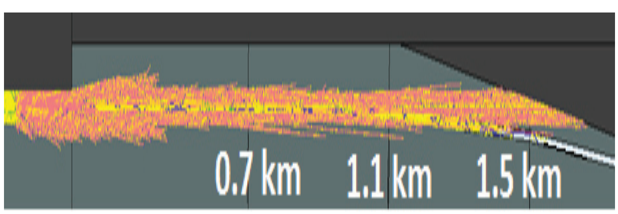

Figure 8: Some muon tracks as a result of the simulation. The distance from IPA is indicated.

the muons reaching IPB, as well as the probability of the muons reflecting off of the tunnel rock.

CONCLUSION

DPMJET-III within FLUKA has been used to generate 50 TeV *pp* collision debris for FCC-hh cross-talk studies. The muon range has been theoretically estimated to be less than 3.2 km through standard rock, whereas the linear distance between IPA and IPB (or IPL) is around 5 km. This theoretical calculation used only the raw collision debris muons. In order to verify this calculation FLUKA studies have been performed using the detector model to generate a more realistic muon distribution. These muons have been tracked in FLUKA taking into account the accelerator tunnel and the rock between IPA and IPB. It was found that no muons travel further than 2.7 km downstream of IPA. Thus we conclude that muon cross-talk is not an issue for the FCC-hh.

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