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Differences in High Energy Hadronic Interaction Models for Air Shower Measurements in the 100 GeV-100 TeV Range

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The predictions of hadronic interaction models for cosmic-ray induced air showers contain inherent uncertainties due limits of the accelerator data and theoretical understanding in the required energy and rapidity regime. Model uncertainties are typically evaluated in the range appropriate for cosmic-ray air shower arrays (10^{15}-10^{20} eV), however the performance of the models for gamma-ray observatories is becoming more and more important. We assess the model differences on the gross behaviour of the predictions in the energy (0.1-100 TeV) and altitude ranges most appropriate for detection by current ground-based gamma-ray observatories. We go on to investigate the particle production at the first interaction point to extrapolate how the differences in micro-physics of the models may compound into differences in the gross air shower behaviour.

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1. Summary

The details of this study has been recently accepted for publication in Phys. Rev. D.[1], here we will briefly summarise the main results. We studied simulated protons showers in the energy range of 0.1–100 TeV, the typical range where they are the dominant background contribution for ground-based gamma-ray astronomy. In our study we varied the latest hadronic interaction models, EPOS-LHC [2], SYBILL 2.3c[3], QGSJetII-04 [4], UrQMD [5], available in the CORSIKA air shower simulation package [6]. We compared the average behaviour of the lateral distribution functions of the muons, the electromagnetic particles (electrons, positrons and gamma-rays), and the Cherenkov-light between the different interaction models. Good agreement ($< 10\%$) was found above 10 TeV primary energy. At lower energy, most prominent at 100 GeV, we found significant deviations between the predictions for the lateral distribution functions for the different models.

Dedicated runs are proposed at LHC in order to resolve the discrepancies between the models and (ultra-)high-energy cosmic ray observations (see at this conference [7]). At the low-energy regime that we focus on, it needs to be evaluated if data is already available against which the models can be tuned or if a dedicated experiment is needed.

2. First interaction in more detail

The differences observed for 100 GeV protons air showers most be due to first interaction since at 80 GeV the switch is made to the common lower-interaction model UrQMD. To investigate the first interaction, we forced an interaction with a nitrogen atom and evaluated the particles 1 cm below the interaction point. From this interaction we calculated properties of the initial phase of the shower. In Figure 1 we show the average distribution of the the total transverse moment,p_T and

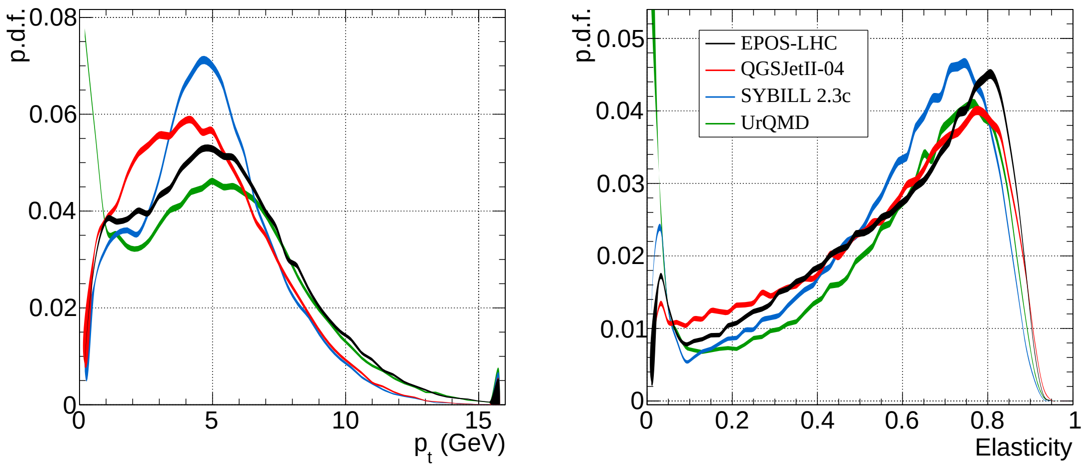

Figure 1: Comparison of the different hadronic interaction models just after the interaction of a 100 GeV proton with a nitrogen atom. The total transverse momentum, p_T is shown in the left on the right we show the elasticity.

the elasticity κ of produced particles. The elasticity we define as

$$\kappa = 1 - \frac{E_L}{E_p}, \tag{2.1}$$

where E_L is the leading particle that took got the most energy in the shower, and E_p is the energy of the primary proton (100 GeV in this case). It is clear that there are significant differences between the interaction models, most notable these are:

- UrQMD produces more often interactions with little p_{T} and κ.
- The p_{T}-distributions differ significantly around 5 GeV region, with QGSJetII-04 having a broader distribution peaking at slightly lower energy.
- For elasticity we see that EPOS-LHC distribution peaks at the highest values, *i.e.* sharing the energy over the most particles.

Which of these differences are causing the overall difference in air shower parameters will be part of a follow-up study.

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