IMPACT ON MULTIPLICITY OF PARTICLES BY CHANGING MULTIPARTON INTERACTION PARAMETERS IN PYTHIA 8.3 AT LHC ENERGIES*

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The PYTHIA program is a standard tool for the generation of events in high-energy collisions. It comprises a coherent set of physics models describing the evolution from a few-body hard process to a complex multi-particle final state including the multi-parton interaction. The model for soft interactions describing minimum-bias events is based on various parameters whose values are *a priori* unknown and thus need to be constrained by data. This study shows the impact of parameters on the multiplicity of events in proton–proton collisions at the center-of-mass energy 14 TeV and offers insights into which parameters could be optimized for Run 3.

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1. Introduction

Hadrons are complex objects containing three valence quarks and countless gluons and sea quarks. In high-energy proton–proton (*pp*) collisions, the hard scattering of partons is accompanied by additional activity from multiple-parton interactions (MPI). To describe both soft- and hard-scattering interactions, underlying (UE) and minimum-bias events, Monte Carlo event generators, like PYTHIA, are used. Because the majority of interactions in *pp* collisions are soft in nature, the perturbative quantum chromodynamics (pQCD) cannot be used, and hence they are predicted by phenomenological models. The models depend on a number of parameters, and the optimization of those parameters is important in order to provide a reasonable description of measured observables that are sensitive to the data [1]. This study shows the impact of different PYTHIA 8 settings for multiparton interactions on the number of charge particles produced in a *pp* collision.

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2. PYTHIA event generator

The PYTHIA program is a standalone tool for the generation of events in high-energy collisions [2]. It contains a coherent set of physics models for the evolution from a few-body hard-scattering process to a complex multi-particle final state. The main goal of PYTHIA is to simulate particle production in high-energy collisions over the full range of energy scales accessible to the experiments. The event generator in PYTHIA 8.3 is designed in a way to consider hard scattering, hard processes producing a set of short-lived resonances such as W and Z gauge bosons, final- and initial-state radiations, and multiparton interactions [2].

The starting point of the parton-based MPI models is the observation that the t-channel propagators and α_{s} factors appearing in perturbative QCD $2 \to 2$ cross section $\hat{\sigma}$ diverge at low momentum transfers [3]

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}} \propto \frac{\alpha_{\mathrm{s}}^2\left(Q^2\right)}{\hat{t}^{\,2}} \Rightarrow \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}p_{\mathrm{T}}^2} \propto \frac{\alpha_{\mathrm{s}}^2\left(p_{\mathrm{T}}^2\right)}{p_{\mathrm{T}}^4}\,, \tag{1}$$

where α_{s} is the running coupling constant and p_{T} is the transverse momentum. The divergence in Eq. (1) can be regularised by the introduction of the threshold parameter p_{T0} which is added to p_{T}

$$\frac{1}{p_{\mathrm{T}}^4} \to \frac{1}{\left(p_{\mathrm{T}}^2 + p_{\mathrm{T0}}^2\right)^2}\,. \tag{2}$$

With this approach, as $p_{\mathrm{T}} \to 0$, the cross section takes a small but non-zero value that depends on the matter distribution inside the hadron. The parameter p_{T0} is related to $p_{\mathrm{T0}}^{\mathrm{ref}}$ as in Eq. (3)

$$p_{\mathrm{T0}} = p_{\mathrm{T0}}^{\mathrm{ref}} \left(\frac{\sqrt{s}}{\sqrt{s_0}}\right)^{\epsilon}\,, \tag{3}$$

where $\sqrt{s_0}$ is a reference center-of-mass-energy and $p_{\mathrm{T0}}^{\mathrm{ref}}$ is p_{T0} at $\sqrt{s_0}$. The parameter p_{T0} separates the perturbative from the non-perturbative regions and depends on the centre-of-mass energy $\sqrt{s}$. Therefore, the reference value $p_{\mathrm{T0}}^{\mathrm{ref}}$ at the chosen reference value $\sqrt{s_0}$ is set with a power-like dependency on $\sqrt{s}$ with the parameter ϵ.

Due to the lack of interference in the scattering of partons from different hadrons, the description of the inelastic proton–proton collision is based on the concept of factorization of the cross section. It is assumed that the cross section can be computed as a convolution product of perturbative hard scattering cross section of point-like partons and universal factors called parton density functions (PDF) that are assumed to be long-distance non-perturbative quantities [4], Eq. (4) shows the cross section in a proton–proton interaction

$$\mathrm{d}\sigma^{h_1 h_2 \to cd} = \int_0^1 \mathrm{d}x_1 \int_0^1 \mathrm{d}x_2 \sum_{a,b} f_{a/h_1}\left(x_1, Q^2\right) f_{b/h_2}\left(x_2, Q^2\right) \mathrm{d}\sigma^{ab \to cd}\left(Q^2\right) . \tag{4}$$

The total cross section is dependent upon $f_{a/h_1}(x_i)$ which is the parton distribution function (PDF), indicating the probability of finding a parton of type a with the momentum fraction x_i in hadron h_1. This parameter cannot be calculated with perturbative calculations and thus, some models need to be predicted. On the other hand, there is another function in this cross-section equation $\mathrm{d}\sigma^{ab\to cd}$ — the parton level hard scattering cross section which could be calculated by the perturbative QCD [5].

The idea of screening in MPI is derived from modelling of initial states using dipoles in transverse space. A model uses the extended Müller dipole formalism to describe total and diffractive cross sections in pp and $\gamma^* p$ collisions, and the elastic cross section in pp scattering [6]. In this picture, the initial-state dipoles are evolved forward in rapidity, before their collision. As the evolution proceeds, the number of dipoles with small transverse momentum extent grows faster than that of larger dipoles. The dipole size r determines the screening length which appears in the interaction cross section as $p_{\mathrm{T0}}^{\mathrm{ref}} \sim 1/r$. Smaller dipoles imply a large effective cut-off and hence an enhanced amount of screening [6]. The modelling of enhanced screening parameter in PYTHIA is done using Eq. (5)

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}^2} \propto \frac{\alpha_{\mathrm{s}}^2\left(p_{\mathrm{T0}}^2 + p_{\mathrm{T}}^2\right)}{\left(p_{\mathrm{T0}}^2 + p_{\mathrm{T}}^2\right)^2} \to \frac{\alpha_{\mathrm{s}}^2\left(p_{\mathrm{T0}}^2 + p_{\mathrm{T}}^2\right)}{\left(\boldsymbol{n} p_{\mathrm{T0}}^2 + p_{\mathrm{T}}^2\right)^2} , \tag{5}$$

where n could have different values that would correspond to different settings and distributions which is evident from Fig. 2.

3. Results

The production of particles from the MPI model in proton–proton collisions depends on a number of parameters. The most significant are: PT0Ref, ecmpow, enhanceScreening, alphaSvalue, bProfile, and pSet [6]. All these parameters have an impact on the multiplicity of particles. The impact of the parameter $p_{\mathrm{T0}}^{\mathrm{ref}}$ on the multiplicity of particles is shown in Fig. 1, decreasing the value results in higher hadron multiplicities. The strong coupling constant α_{s} also becomes divergent at lower p_{T} and thus it has to be regulated by the cut-off parameter p_{T0}. The distribution shows that higher values of α_{s} result in higher hadron multiplicities which is evident from Fig. 1. The impact of ϵ on hadron production is shown in the bottom part of Fig. 1.

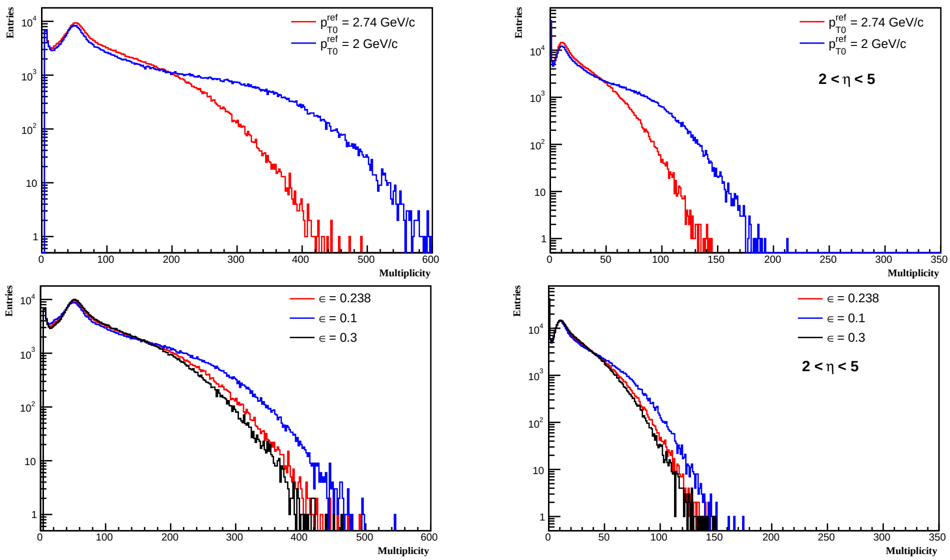

Fig. 1. Impact of parameter $p_{\mathrm{T0}}^{\mathrm{ref}}$ (top) and α_{s} (bottom) on multiplicity distribution. The left plots show the distribution for the entire acceptance, plots on the right represent the LHCb acceptance $2 < \eta < 5$ as an example.

The screening parameter is related to p_{T0} from Eq. (5), where n takes different values corresponding to different settings. Once this value is off, there is no screening dependence, but setting it to 1 means that only MPIs take place in an event, whereas setting it to 2 means also ISR along with MPI are present in an event that would produce screening and decrease hadron production, which is evident from Fig. 2.

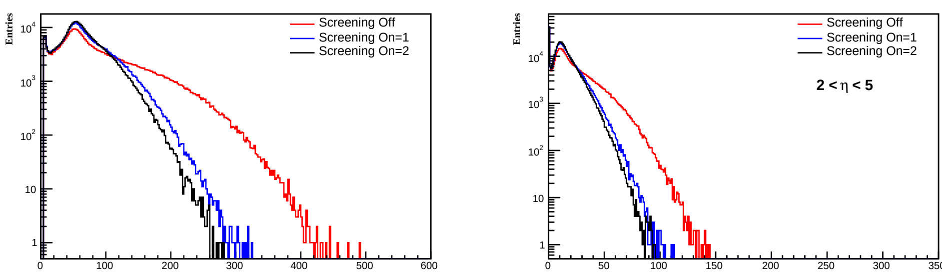

Fig. 2. Impact of screening parameter on multiplicity distribution for three different settings in entire (left) and within the LHCb acceptance (right) η ranges.

The influence of the impact parameter on the multiplicity distribution of particles is shown in Fig. 3. The addition of an impact parameter also leads to a good description of the "Pedestal Effect", where events with a hard scale tend to have more underlying activity; this is as central collisions have a higher chance both of a hard interaction and of more underlying activity [6].

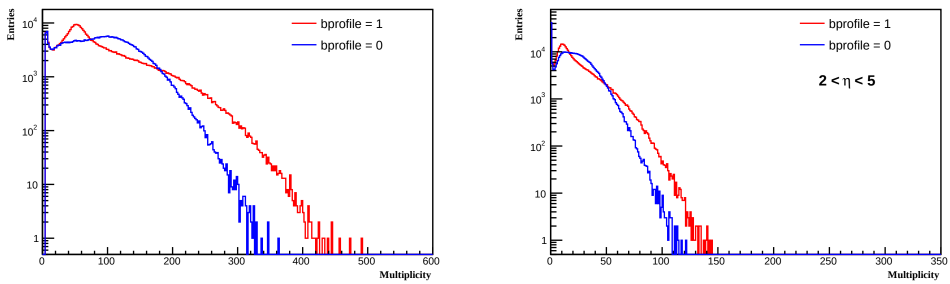

Fig. 3. Influence of impact parameter on multiplicity distribution for two settings in entire (left) and within the LHCb acceptance (right) η ranges.

PYTHIA uses an external library for parton distribution functions (PDF) that are dependent on different sets of parameters which are mentioned earlier and many other parameters the description of which could be found in [7], three settings are mentioned in Fig. 4 which shows the impact of different PDF sets on multiplicity distribution.

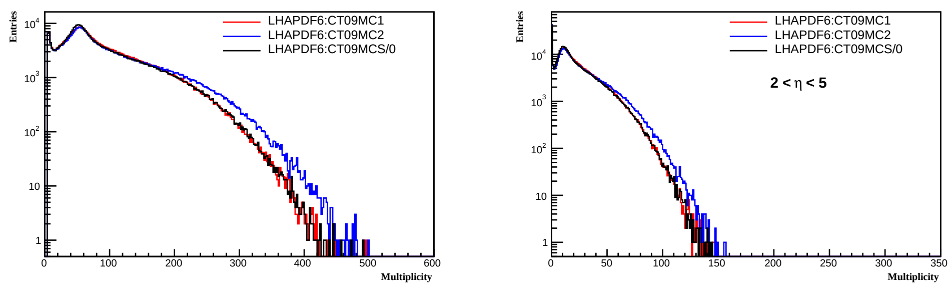

Fig. 4. Impact of different PDF settings on multiplicity distribution for entire (left) and within LHCb acceptance (right) η ranges.

4. Conclusion

The modelling of multiparton interactions in PYTHIA helps in understanding of minimum-bias event distributions. This model is based on a number of parameters that have been investigated *i.e.* $p_{\mathrm{T0}}^{\mathrm{ref}}$, α_{s}, ϵ, screening parameter, impact parameter, and PDF settings where it was found that these parameters do have an impact on the multiplicity of particles. This study would be useful in optimization of these parameters with respect to the data.

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