Studies on the definition of inelastic Non-Single Diffractive events

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Abstract

An event selection has been performed in order to retain large fraction of inelastic non-single diffractive (NSD) events, and reject all elastic and most single-diffractive (SD) events. Efficiencies for SD, double diffractive (DD), non-diffractive (ND) and NSD events after the selection criteria are shown. Comparison between results for the PYTHIA 8 and PYTHIA 6 event generators are performed. Also the results are compared with experimental data.

Contents

1 Introduction

Hadronic processes can be classified as being either soft or hard. Soft processes, that dominate scattering cross sections, are characterized by an energy scale of the order of the hadron size ($1fm \approx 200MeV$). The hard processes are described by perturbative QCD. However, perturbative QCD is not a good way to describe soft processes, because for this sector the coupling constant gets large enough to make the higher order terms non-negligible, thus making the process non-perturbative.

Soft interactions are presumed to be mediated by a colour singlet exchange carrying the vacuum quantum numbers, usually referred as Pomeron ($I\!P$) exchange. In QCD, the Pomeron is regarded as a colourless and flavourless multiple gluon or a glueball.

In proton-proton scattering, interactions are classified by the characteristics of the final states. Interactions can be either elastic or inelastic. In elastic scattering ($p_1 + p_2 \rightarrow p_1\acute{} + p_2\acute{}$), the final and initial state particles are identical, and both protons emerge intact without the production of other particles (figure 1a). Elastic scattering can be achieved via the exchange of a glueball-like Pomeron.

When two hadrons approach each other, they may exchange a colour octet gluon, making each hadronic cluster a colour octet. As they move apart they exchange another gluon to become colourless. However, the final state needs not to be identical to the initial state. In this case the processes are called inelastic.

An inelastic collision is called diffractive when no internal quantum numbers are exchanged between the colliding particles. Diffraction occurs when the exchanged Pomeron interacts with the proton to produce a system of particles, referred to as diffractive system. In diffractive scattering, the energy transfer between the two interacting protons remains small, but one or both protons dissociate into multi-particle final states with the same quantum numbers of the colliding protons.

If only one of the protons dissociates then the interaction is Single Diffractive (SD) ($p_1 + p_2 \rightarrow p_1' + X$ or $p_1 + p_2 \rightarrow X + p_2'$) as shown in figure 1b. If both colliding protons dissociate, then is Double Diffractive (DD) ($p_1 + p_2 \rightarrow X_1 + X_2$) (figure 1c). If two Pomerons are exchanged, become possible a Central Diffraction (CD), in which both protons remain intact and are seen in the final state ($p_1 + p_2 \rightarrow p_1' + X + p_2'$) (figure 1d). In Non-Diffractive (ND) interactions there is an exchange of colour charge and subsequently more hadrons are produced (figure 1e).

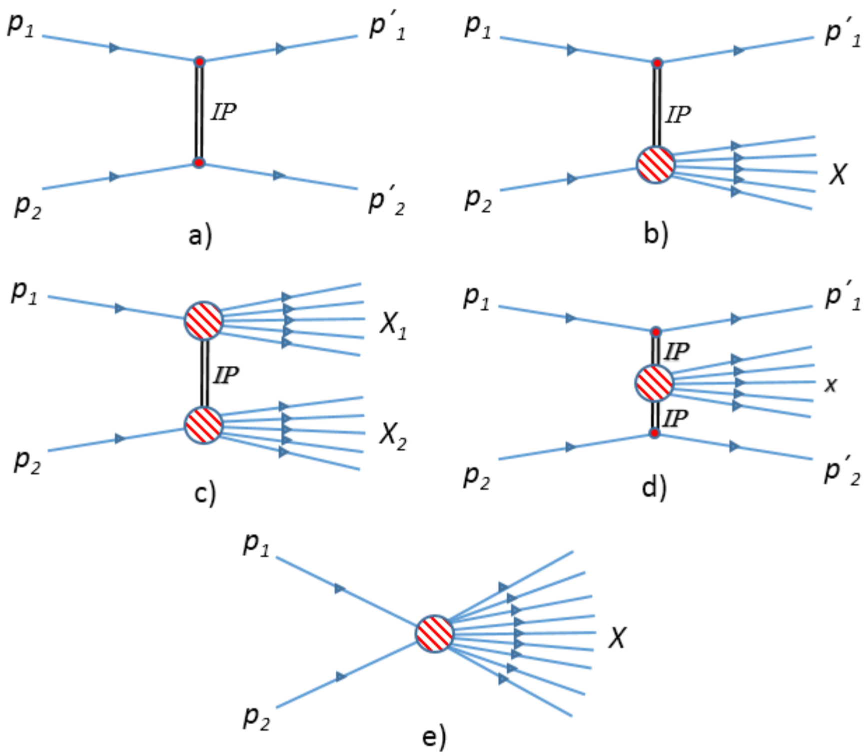

Figure 1: Schematic diagrams of a) elastic scattering, diffractive processes with b) single diffractive dissociation (SD), c) double diffractive dissociation (DD), d) central diffractive dissociation (CD); and non-diffractive processes e).

The total pp cross section is given by the expression:

$$\sigma_{tot} = \sigma_{el} + \sigma_{inel} = \sigma_{el} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD} + \sigma_{ND} \tag{1}$$

The goal of this investigation is to look for a definition of inelastic non-single diffractive events (NSD) that does not depend on the Monte Carlo generator. The event selection was therefore designed to retain a large fraction of inelastic double diffractive (DD) and non-diffractive (ND) events, while rejecting all elastic and most single-diffractive dissociation (SD) events.

2 Experimental Data

The data for this study were obtained for an integrated luminosity of 1.1 μb^{-1} recorded with the Compact Muon Solenoid (CMS) experiment.

2.1 CMS_2011_S8884919 routine

In order to compare the results of the present work with the experimental data, the CMS_2011_S8884919 routine was used inside the RIVET machinery. Rivet is a powerful tool to obtain predictions from a Monte Carlo generator. In the considered routine, measurements of primary charged hadron multiplicity distributions are presented for inelastic non-single-diffractive events (NSD) in proton-proton collisions at center of mass energies of $\sqrt{s} = 0.9$, 2.36 and 7 TeV, in five pseudorapidity ranges from $\mid \eta \mid < 0.5$ to $\mid \eta \mid < 2.4$. Also the average transverse momentum as a function of the multiplicity is presented.

For the simulation of NSD events we generate DD and ND processes. We also simulate multi-parton interactions (MPI) and parton showers and we used the Monash 2013 tune. The comparison with the data is shown in figure 2.

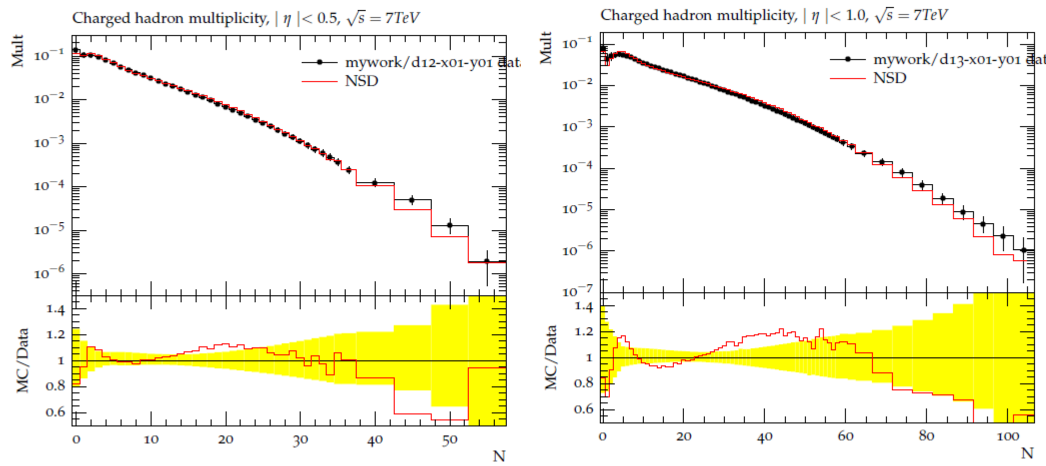

Figure 2: MC and data comparison of charged hadron multiplicity in two pseudorapidity (η) ranges.

For the present work we selected the Monash 2013 tune by Peter Skands. In figure 3, a comparison between this tune and the 4C tune is shown.

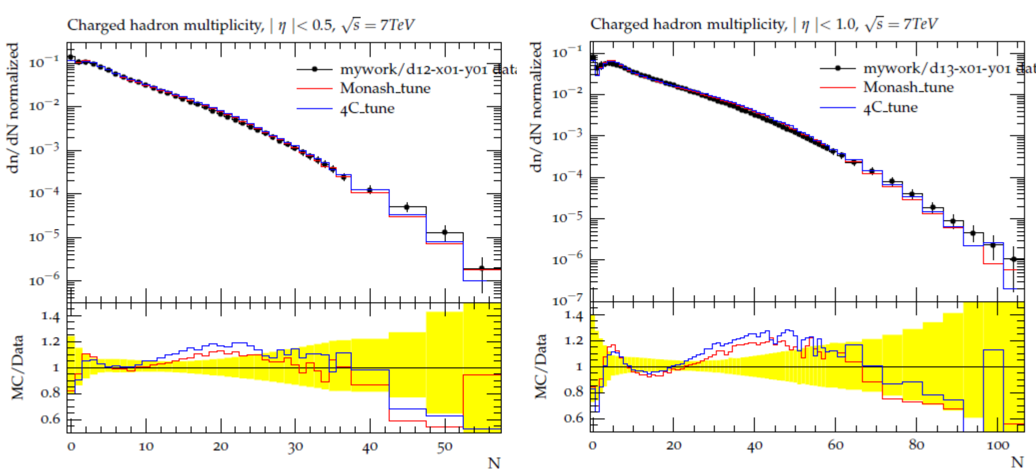

Figure 3: Comparison between predictions obtained with the Monash tune, the 4C tune and the experimental data in two pseudorapidity ranges.

2.2 Multiparton Interactions (MPI)

Due to the composite nature of hadrons, it is possible to have multiple parton scatterings, events in which two or more distinct parton interactions occur simultaneously in a single hadron-hadron collision. We compared results with and without the simulation of MPI (figure 4).

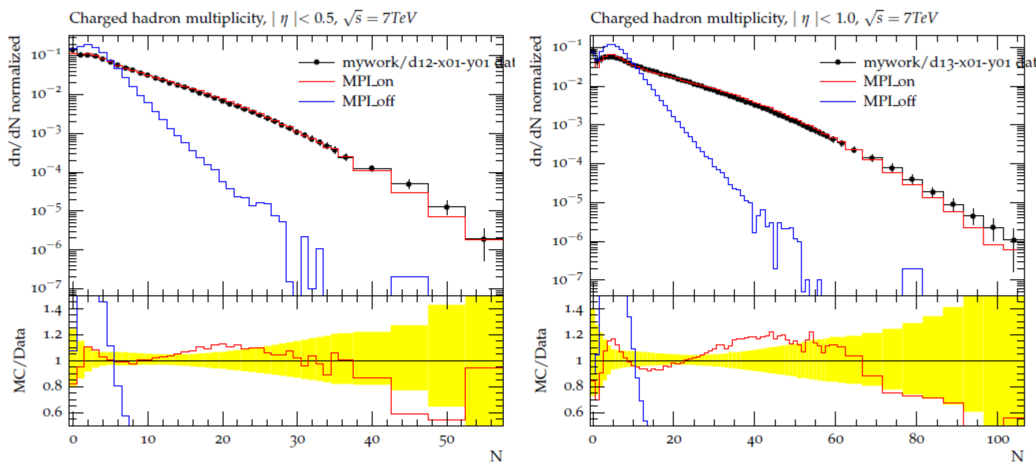

Figure 4: Comparison between data and predictions with and without the simulation of MPI in two pseudorapidity ranges.

From figure 4 we can infer that MPI are important in order to reproduce the experimental data. This is due to the fact that if we suppress MPI then we reduce the number of charged hadrons in the final state.

3 Event Selection

The steel/quartz-fibre forward calorimeter (HF) covers the region $2.9 <| \eta |< 5.2$. In order to keep the inelastic non-single diffractive events rejecting elastic and SD events, any charged hadron hit in the $-5.2 < \eta < -2.9$ region, coinciding with a hit in the $2.9 < \eta < 5.2$ region of the HF calorimeter is accepted. Restrictions in the energy deposited in the HF calorimeter and in the product mass in the pseudorapidity range $-5 < \eta < 5$ were also investigated (next section).

4 Observables

We studied soft QCD processes looking at charged hadrons coming from pp collisions at a center of mass energy $\sqrt{s} = 7TeV$. In figure 5a) we show the $dn/d\eta$ distribution for each type of process. The asymmetry for the SD events comes from the consideration of only one type of SD $AB \to XB$. Also we show the $dn/dp_\perp$ distributions, and the dn/dE distributions for $\eta < 0$ and $\eta > 0$ regions.

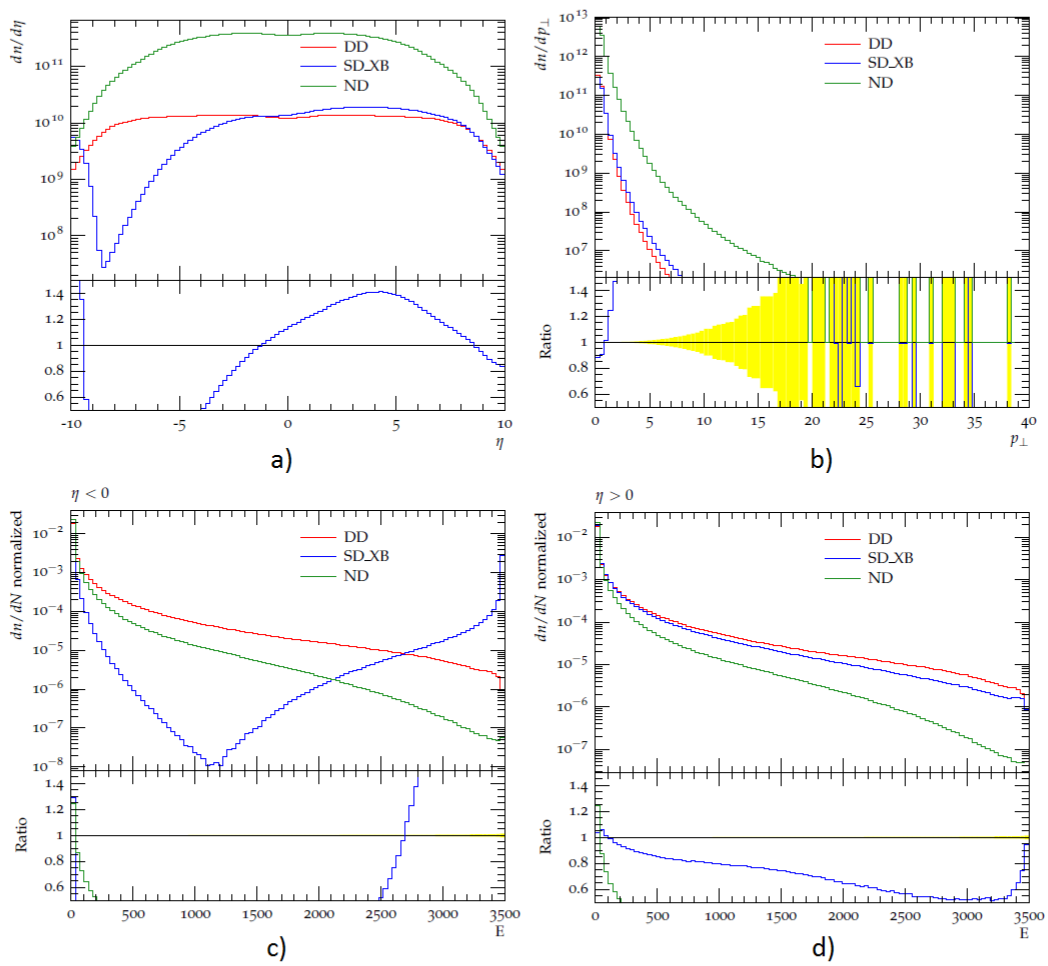

Figure 5: a) $dn/d\eta$, b) $dn/dp_\perp$, c) dn/dE ($\eta < 0$) and d) dn/dE ($\eta > 0$) distributions considering SD ($AB \to XB$), DD and ND events.

In the case of the dn/dE distribution in the region $\eta < 0$ for SD events we note two main regions. The contributions for $E \gtrsim 1200 GeV$ is mainly due to the non-dissociated protons from the SD interaction. We checked this by looking at the particle Id in this region and looking at dn/dE distribution for $\eta < 0$ excluding the very forward region $\eta < -8$. At $E \lesssim 1200 GeV$ contributes low energy hadrons from the dissociated proton.

4.1 Mass distribution of the dissociated system.

We investigated the dn/dM_X distribution of the dissociated mass in the η range $-5 < \eta < 5$, which is the range that it can be reached experimentally. The figure 6 shows the mass of the system composed by all hadrons that go in the range $-5 < \eta < 5$.

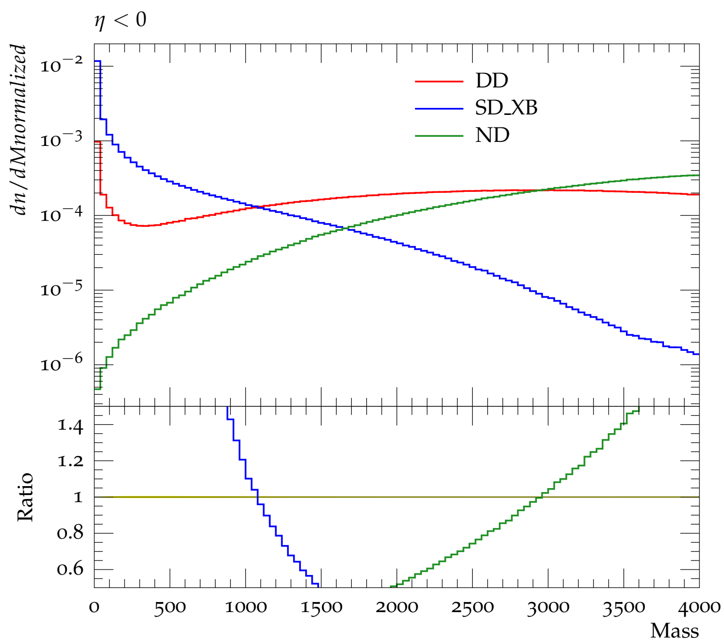

Figure 6: dn/dM distribution in $-5\eta < 5$ considering SD ($AB \to XB$), DD and ND events.

By looking at the behaviour of these curves we could apply cuts in the low mass region to reject SD events and select DD and ND events but this is quite dangerous. If we apply such cuts we restrict the possibility of production of certain particles.

4.2 Charged hadrons energy distribution in the HF zone.

The distributions of the energy deposited by charged hadrons in the $\eta < 0$ region of the HF calorimeter for SD (considering both, AB->AX, AB->XB), DD and ND are shown in the figure 7. We analysed only the region $-5.2 < \eta < -2.9$. The positive η region is symmetric with respect to the negative η region.

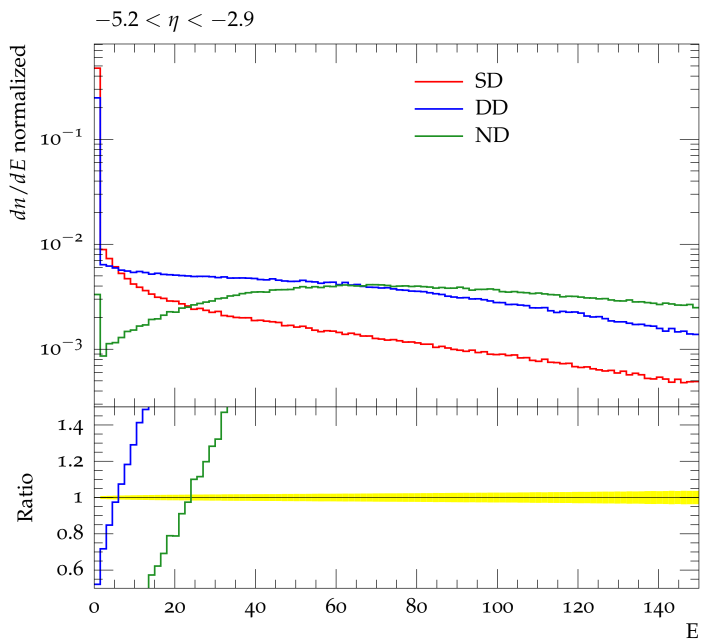

Figure 7: Distribution of energy deposited in $-5.2 < \eta < -2.9$ considering SD (considering both, AB->AX, AB->XB), DD and ND events.

From this figure we see that the different behaviour of SD, DD and ND at low energies allows us to use this energy deposition for the event selection. We apply cuts in the low energy region. In order to reject SD and select NSD events we required hits in both sides of the HF calorimeter and energy deposited in each side of the HF calorimeter larger than a minimum energy E_{min}. The analysis of this minimum energy is made in the next section.

5 Selection efficiency and stability

The selection criteria are expected to have high efficiency for the NSD part of the pp cross-section, while rejecting a large fraction of SD events. The efficiency of the event selection for the different processes was determined using simulated events obtained from PYTHIA 8 and PYTHIA 6. We compare these two predictions from Monte Carlo generators in order to check the stability of the selection criteria. We show the results for different E_{min} values for PYTHIA 8 and PYTHIA 6 event generators.

PYTHIA 8

E_{min}(GeV)	SD	DD	ND	NSD
5	25.8%	33.3%	98.4%	89.9%
10	23.5%	29.9%	96.6%	87.0%
20	19.5%	23.0%	91.6%	82.1%
25	17.8%	20.0%	89.2%	79.6%
30	16.3%	17.3%	86.1%	76.9%
40	13.4%	13.0%	79.8%	70.9%
50	11.0%	9.8%	74.2%	64.9%

Table 1: Efficiencies for SD, DD, ND and NSD processes obtained from the PYTHIA 8 event generator after the selection.

PYTHIA 6

E_{min}(GeV)	SD	DD	ND	NSD
5	24.1%	33.7%	95.0%	84.7%
10	19.4%	26.1%	92.8%	81.4%
20	12.7%	15.7%	87.6%	75.5%
25	10.3%	12.2%	84.7%	72.5%
30	8.2%	9.5%	81.5%	69.7%
40	5.4%	5.7%	74.6%	63.4%
50	3.5%	3.3%	68.3%	57.8%

Table 2: Efficiencies for SD, DD, ND and NSD processes obtained from the PYTHIA 6 event generator after the selection.

In Figure 8 we can see the dependence on the considered generator and how the efficiency changes as a function of E_{min}.

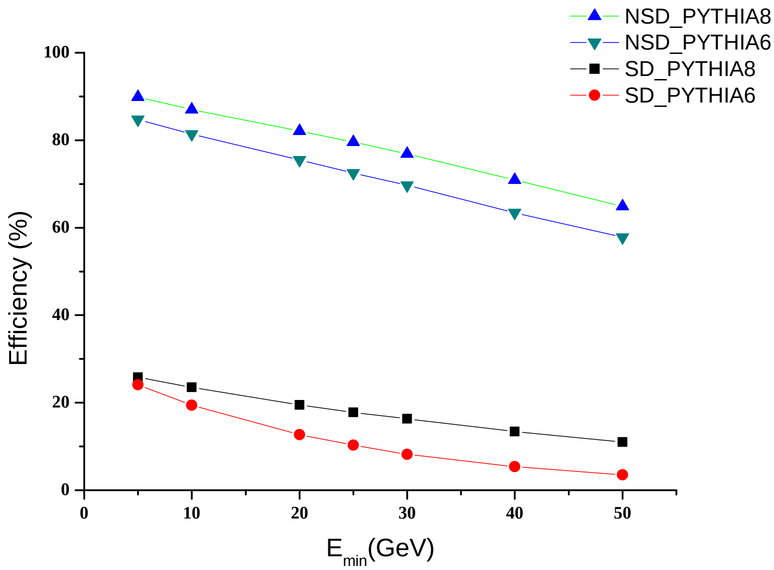

Figure 8: Efficiency vs E_{min} for SD and NSD events in PYTHIA 8 and PYTHIA 6 event generators.

The slope for the NSD events is similar for both generators. Also we can see that the behaviour differs for SD events at low E_{min} which is interesting. This can be explained by taking into account that in PYTHIA 6 the contribution of high mass diffractive systems is not consider, while it is included in the PYTHIA 8 event generator. A separation between the SD curves can be observed (the same for NSD).

6 Comparison with the experimental data

In figure 9 we show the comparison of the experimental data and the NSD events chosen in the event generator with the event selection for two E_{min} values (without modifying the event generator), in some η ranges.

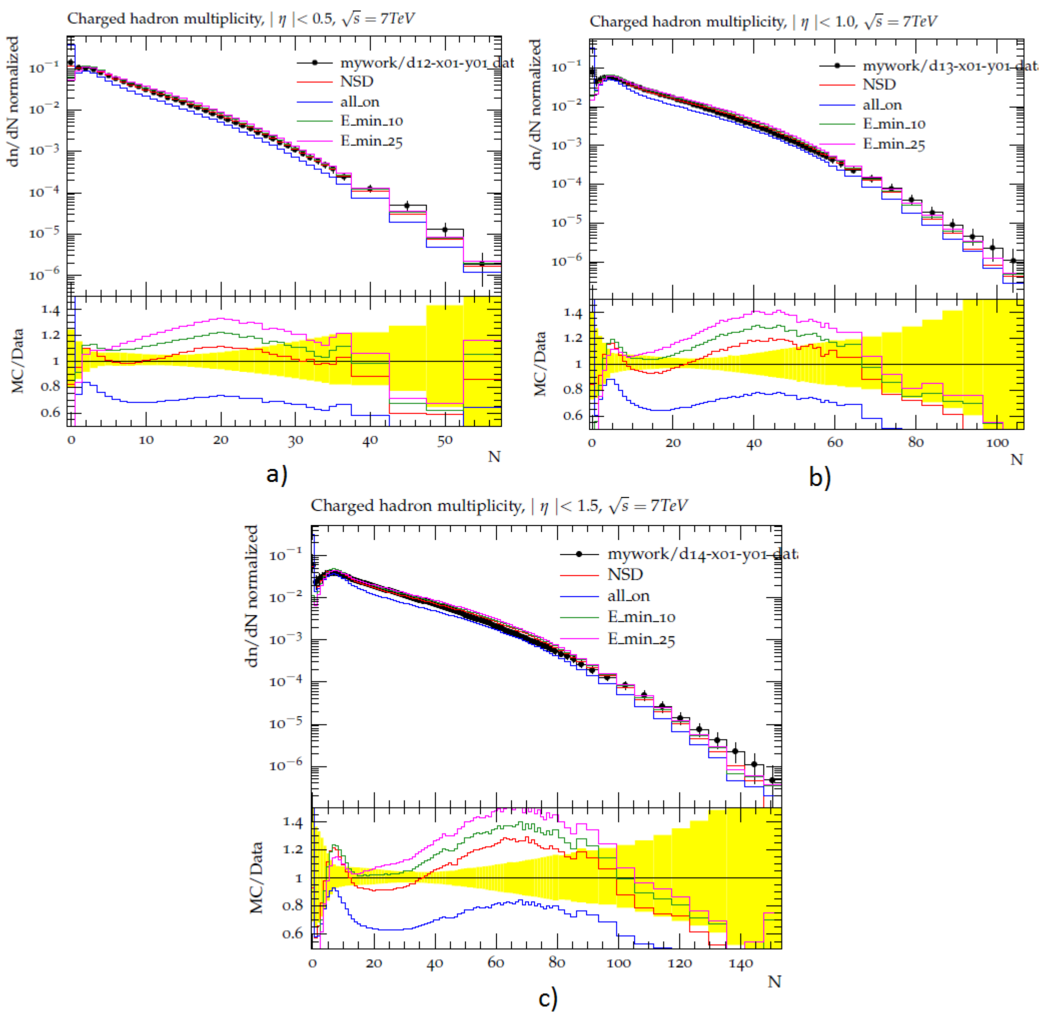

Figure 9: Multiplicity comparison of the experimental data and the NSD events chosen in the generator, with the event selection for 10GeV and 25GeV of E_{min}.

As we can see, the event selection for $E_{min} = 10GeV$ behaves closer $E_{min} = 25GeV$ to the experiment. This means that for this E_{min} value we are rejecting SD and select NSD events with a good efficiency. Also we notice that this selection is closer to the NSD selected in the generators.

7 Conclusions

During the investigations we arrived to some conclusions about SD and NSD events behaviour, and the event selection process. These are:

- The event selection shows that SD and NSD efficiencies depend on the minimum energy deposited.
- Efficiencies are different for PYTHIA 6 and PYTHIA 8 events generators.
- The event selection for $E_{min} = 10 GeV$ shows better agreement with data.

8 Acknowledgements

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