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'Soft' and 'Hard' Interactions in Proton-Proton Collisions at LHC Energies

SIDHARTH K PRASAD*[1], SUPRIYA DAS[1], SANJAY K GHOSH[1], PREMOMOY GHOSH[2], SANJIB MUHURI[2], TAPAN K NAYAK[2] and RAJARSHI RAY[1]

[1]*Bose Institute, Centre for Astroparticle Physics and Space Science, Kolkata* 700 091, *India*
[2]*Variable Energy Cyclotron Centre, Kolkata* 700 064, *India*

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We present a study of the properties of 'soft' and 'hard' events using PYTHIA 6.425 (Sjostrand *et al*., 2006) in proton-proton (pp) collisions at centre-of-mass energies ($\sqrt{s}$) 0.63, 0.9, 1.8, 2.76 and 7 TeV. Events are classified into 'soft' and 'hard', based on the presence of a jet. The multiplicity and transverse momentum (p_T) distributions of charged particles at midrapidity are studied for both 'soft' and 'hard' events as a function of $\sqrt{s}$. No significant change in the charged particle multiplicity and p_T distributions are observed with $\sqrt{s}$ for 'soft' events, indicating that the increase in $\sqrt{s}$ mostly contributes to the increase in the fraction of 'hard' events.

Key Words : Soft Hard Interactions; Multiplicity; pt Spectra

Introduction

Non-diffractive proton-proton collisions can be classified into 'soft' and 'hard' (or 'semi-hard') interactions. The hard (or 'semi-hard') interactions involve parton-parton interactions with large momentum transfer which results into hard partons and jets. On the other hand interactions without a jet (or minijet) can be considered as 'soft' interactions. Energy invariance in the properties (e.g. multiplicity, transverse momentum, and mean transverse momentum distributions) of 'soft' events is observed at lower centre-of-mass energies (Acosta *et al*., 2002; Huang *et al*., 2004). Recently, energy invariance in the properties of 'soft' events is predicted also at the LHC energies (Ghosh, 2012). The underlying mechanisms of particle production in hadronic interactions for 'hard' (pQCD based) and 'soft' (phenomenological model based) interactions can be better understood by studying pp interactions by classifying them into 'soft' and 'hard' events. In this work, we investigate the properties of 'soft' and 'hard' interactions using the minimum bias PYTHIA (Sjostrand *et al*., 2006) events in pp collisions at various $\sqrt{s}$ in the range from 0.63 to 7 TeV.

*Author for Correspondence : E-mail: sprasad@cern.ch

Selection of 'Soft' and 'Hard' Events and the Analysis Method

This study is performed using minimum bias events obtained from Monte Carlo (MC) event generator PYTHIA 6.425 (tune Perugia 2011 (Skands, 2010)) in pp collisions at $\sqrt{s}$ = 0.63, 0.9, 1.8, 2.76 and 7 TeV. The total number of events generated for each $\sqrt{s}$ is 0.5 M. The minimum bias events are classified in two classes, (a) 'soft' and (b) 'hard', on the basis of presence of charged jets with transverse momentum (p_T) above a given threshold value. Jets are reconstructed using anti-k_T (Cacciari *et al*., 2008) jet finding algorithm from Fastjet package (Cacciari and Salam, 2006) within $\mid \eta \mid < 1.0$. Charged particles with $p_T >$ 0.15 GeV/c and within $\mid \eta \mid < 1.0$ are the inputs to the jet finding algorithm. In each event the reconstructed jets p_T are then compared to the threshold value, and if any of the jet p_T is found larger than the threshold value, the event is categorized as 'hard' event otherwise it is categorized as 'soft' event. There is no unique value that exists for this threshold, therefore, the analysis is performed for various threshold values such as 1.0, 1.5 and 2.0 GeV/c. The multiplicity and transverse momentum distributions of the charged particles with $p_T > 0.15$ GeV/c and within $\mid \eta \mid < 1$ are obtained for both the classes of events at all $\sqrt{s}$.

Results

Multiplicity Distributions

Fig. 1 shows the multiplicity distributions of charged particles with $p_T > 0.15$ GeV/c and within $\mid \eta \mid < 1.0$, for 'hard'(A), and 'soft' (B, C, D) classes of events in pp collisions at $\sqrt{s}$ = 0.63, 0.9, 1.8, 2.76 and 7 TeV. Plots A and B of Fig. 1 are obtained for threshold value of 1.0 GeV/c whereas C and D are obtained for threshold values of 1.5 and 2.0 GeV/c respectively. It is interesting to note that the shapes and the $\sqrt{s}$ dependence of the multiplicity distributions for 'soft' and 'hard' events are very different. The multiplicity is higher in 'hard' events compared to 'soft' events as expected due to presence of jets. In the case of 'hard' events the multiplicity increases with increase in $\sqrt{s}$, whereas the multiplicity distributions are found to be somewhat invariant with $\sqrt{s}$ for 'soft' events. No significant change in the distribution is observed in the wide range of $\sqrt{s}$ from 0.63 to 7 TeV. The effect of changing the threshold value has a very small effect on this observation, however, the multiplicity slightly increases for higher threshold values.

Transverse Momentum Distributions

Fig. 2 shows the transverse momentum distributions of charged particles within $\mid \eta \mid$ 1.0, for 'hard' (A), and 'soft' (B) events in pp collisions at $\sqrt{s}$ = 0.63, 0.9, 1.8, 2.76 and 7 TeV for threshold value of 2.0 GeV/c. The p_T distributions become harder with increasing $\sqrt{s}$ as expected for 'hard' events, whereas no change in the distributions are observed for 'soft' events.

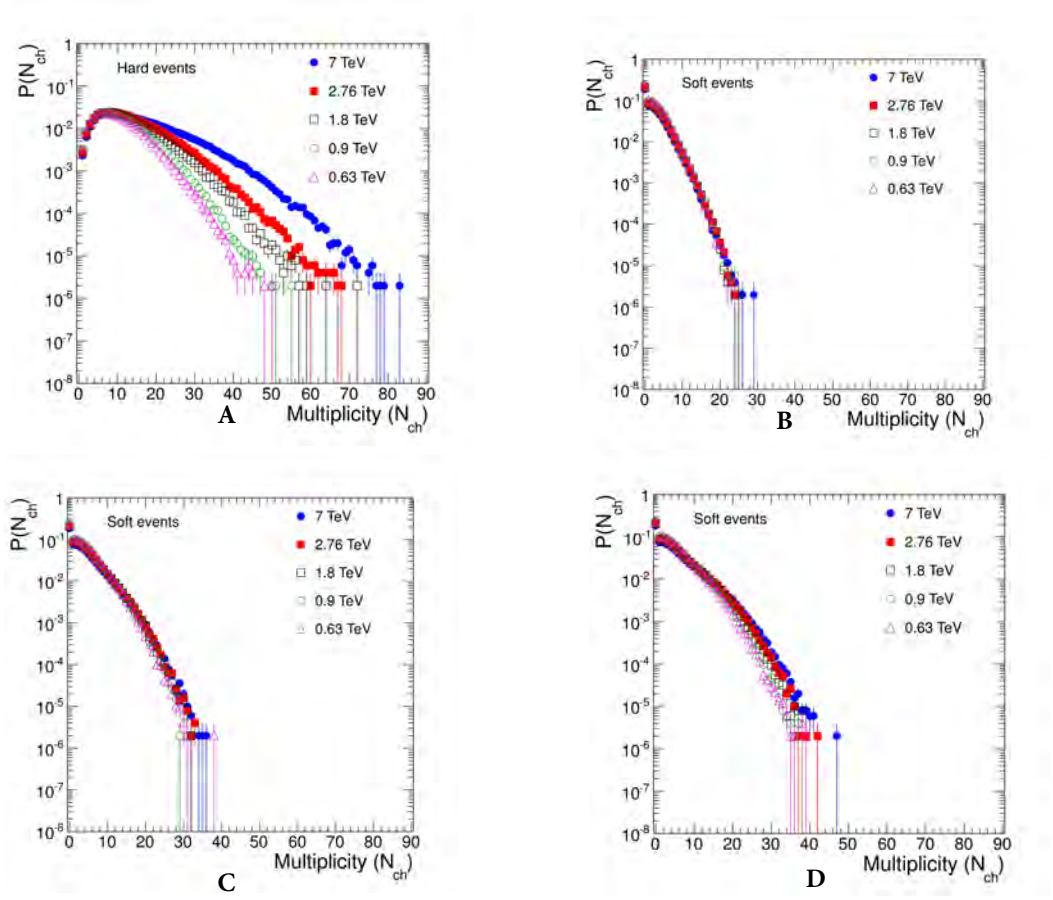

Fig. 1: (Color online) Charged particle multiplicity distributions in pp collisions at $\sqrt{s}$ = 0.63, 0.9, 1.8, 2.76, and 7 TeV for 'hard' (A (threshold = 1 GeV/c)) and 'soft' (B (threshold = 1 GeV/c)), (C (threshold = 1.5 GeV/c)) and (D (threshold = 2 GeV/c)) events obtained using PYTHIA

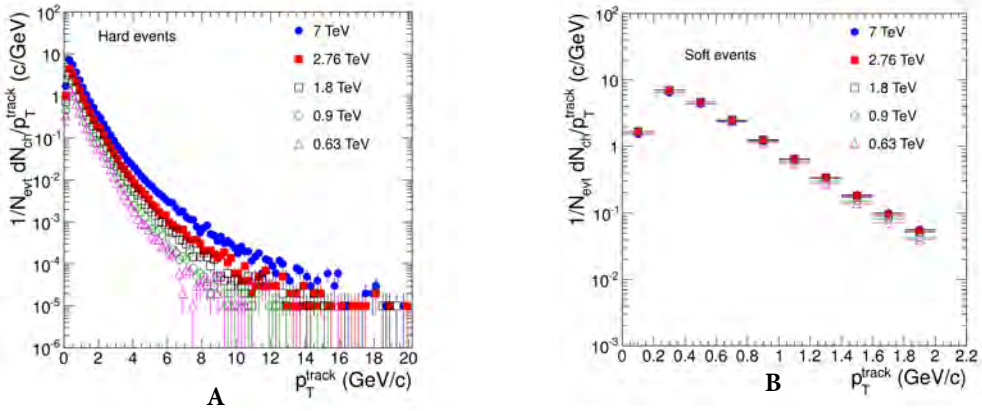

Fig. 2: (Color online) Transverse momentum distributions of charged particles in pp collisions at $\sqrt{s}$ = 0.63, 0.9, 1.8, 2.76, and 7 TeV for 'hard' (A) and 'soft' (B) events with threshold value of 2.0 GeV/c obtained using PYTHIA

Summary and Conclusions

The properties of 'soft' and 'hard' events are studied in pp collisions at $\sqrt{s}$ = 0.63, 0.9, 1.8, 2.76, and 7 TeV using PYTHIA MC event generator. The events are classified into 'soft' and 'hard', based on the presence of charged jets above a threshold on jet p_T of 1, 1.5, and 2 GeV/c. PYTHIA reproduces the invariance properties of the multiplicity and p_T distributions of charged particles at mid rapidity for 'soft' events as observed by the CDF (Acosta *et al*., 2002) and STAR (Huang *et al*., 2004) collaborations. The study is extended to LHC energies and similar properties are observed in PYTHIA. The increase of $\sqrt{s}$ seems to mostly contribute to the increase in the fraction of 'hard' events. In future, we will include more observables, such as mean transverse momentum, particle ratios etc. and extend this study further to understand the effects of color reconnection in the MC event generator and eventually apply to the ALICE data.

References

1. Acosta D *et al*., (CDF Collaboration)(2002) Soft and hard interactions in $p\overline{p}$ collisions at $\sqrt{s}$ = 1800 and 630 GeV *Phys Rev* **D65** 072005
2. Cacciari M and Salam GP (2006) Dispelling the N^3 myth for the kt jet-finder *Phys Lett* **B641** 57
3. Cacciari M, Salam GP and Soyez G (2008) The anti-kt jet clustering algorithm *JHEP* **04** 63
4. Ghosh P (2012) Negative binomial multiplicity distribution in proton-proton collisions in limited pseudorapidity intervals at LHC up to $\sqrt{s}$ = 7 TeV and the clan model *Phys Rev* **D85**, 054017
5. Huang S *et al*., (STAR Collaboration)(2004) Soft and Hard Interactions in proton + proton collisions at $\sqrt{s}$ = 200 GeV arXiv:0403038 [nucl-Ex]
6. Sjostrand T, Mrenna S and Skands PZ (2006) PYTHIA 6.4 physics and manual *JHEP* **05** 026
7. Skands PZ (2010) Tuning Monte Carlo generators: The Perugia tunes *Phys Rev* **D82** 074018.