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Study on 'soft' and 'hard' interactions in $\bar{p}p$ (pp) collisions using HIJING and PYTHIA *

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This paper presents a study on 'hard' and 'soft' interactions in $\bar{p}p$ (pp) collisions using a phenomenological model of HIJING, the jet-cone reconstruction method is employed to select the 'hard' and 'soft' event sub-samples from minimum bias events. It is found that the HIJING model can reproduce the energy scaling behaviour of mean transverse momentum ($\langle p_{\rm T}\rangle$) distributions of charged hadrons versus multiplicity ($N_{\rm ch}$) in 'soft' events. From the PYTHIA simulation comparing with the HIJING model, the enhancement of the kaon and proton yields from 'hard' interactions comparing with 'soft' interactions is observed to be due to the mini-jets effect. These mechanisms responsible for the increase of charged hadron's $\langle p_{\rm T}\rangle$ are different in 'soft' and 'hard' interactions.

Keywords: mini-jet, HIJING, PYTHIA, soft gluon radiation

PACC: 2000, 2410

1. Introduction

As the energy of hadron–hadron collision increases, the 'hard' interactions will give more significant contribution to the particle productions from more abundant mini-jets,[1] which hence plays an important role in the high energy hadron–hadron or nuclei–nuclei collisions processes, and is a good probe of quark-gluon-plasma.[2] But due to its lower transverse energy and higher background contaminations from 'soft' interactions, the mini-jet is normally difficult to be measured and studied.

Recently, both CDF and STAR collaboration have used the jet-cone reconstruction method to classify the minimum bias $\bar{p}p$ (pp) collisions into 'hard' and 'soft' events and study their properties.[3,4] The main difference between 'soft' and 'hard' events is that the 'hard' event is dominated by 'hard' interactions while 'soft' event is otherwise. In 'soft' events the $\langle p_{\rm T}\rangle$ distributions of charged hadrons as a function of charged multiplicity is observed to exhibit an energy scaling behaviour, it depends only on the charged multiplicity but not the colliding energy, and increases even in low charged multiplicity region.

In this paper, we aim at studying the mini-jet properties in 'hard' interactions by using HIJING[5] and PYTHIA,[6] and we also try to use these models to investigate the interesting experimental results in 'soft' events. Basically, PYTHIA is a kind of string fragmentation model. Since HIJING can more easily trigger jets through jet fragmentation, its Monte Carlo (MC) simulation is more reasonable to fit experimental data. So here we just use PYTHIA to calculate particle ratios as a comparison.

2. The definitions of 'soft' and 'hard' events

The same jet-cone reconstruction method as from CDF and STAR collaboration is adopted for the classification of 'soft' and 'hard' event in $\bar{p}p$ (pp) collisions. The cone is defined with the size of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2} = 0.7$, where η is the pseudo-rapidity ($\eta = -\log(\tan(\theta/2))$) and ϕ is the azimuthal angle. To be considered as a jet, there must be at least two tracks in this cone. The most energetic seed track in the cone is triggered with a transverse momentum ($p_{\rm T}$) more than 1.0 GeV/c, the $p_{\rm T}$ of next more energetic associated track must be at least 0.2 GeV/c. The 'soft' event is defined as one that contains no such jet and all other events are classified as 'hard'. The following studies are done for these minimum bias (MB) events and its 'hard' and 'soft' sub-samples.

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3. $\langle p_T \rangle$ of charged hadrons

In HIJING calculation, we use the same cut conditions as CDF and STAR experiments.[3,4] The $\langle p_T \rangle$ is calculated by the charged hadrons with $p_T > 0.4\,\mathrm{GeV/c}$ at mid-rapidity $|\eta| < 1$. The charged multiplicity is defined as the total number of charged hadrons.

Figure 1 shows the HIJING MC simulation results together with what experimentally observed from CDF and STAR for the 'hard' (a) and 'soft' (b) events at 630 and 200 GeV energies. It is obvious that the $\langle p_T \rangle$ distributions in 'hard' events are higher than that in 'soft' events. These results indicate that the mini-jets are the main source for the different $\langle p_T \rangle$ behaviour between 'soft' and 'hard' events. In Fig.1 (b) the remarkable difference between MC and experimental data could be explained from the contaminations of mini-jets to the 'soft' events, which are hard to be rejected experimentally. Apart from this difference, an interesting energy scaling behaviour of $\langle p_T \rangle$ distributions in 'soft' events is observed from both HIJING model and experiments. The $\langle p_T \rangle$ of charged hadrons changes with charged multiplicity but not the collision energy. The HIJING calculation and experimental measurements also show that for 'soft' events the $\langle p_T \rangle$ distributions of charged hadrons increase in the low multiplicity region.

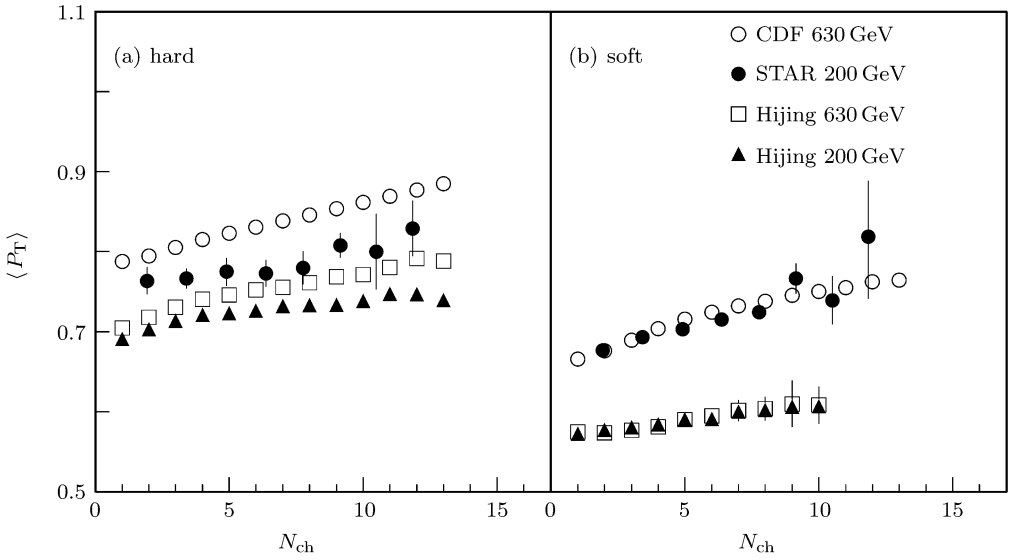


Fig.1. The $\langle p_T \rangle$ distributions of charged hadrons versus the charged multiplicity in 'soft' and 'hard' events in different energies

To reveal the physical mechanism of the increase of $\langle p_T \rangle$ with charged multiplicity in 'soft' events, we use HIJING to produce and separate the so-called ideal 'soft' and 'hard' events. The ideal 'soft' event is defined as the event without 'hard' interactions. It can be seen that in this ideal 'soft' events the $\langle p_T \rangle$ distributions still increase with the multiplicity, as shown in Fig.2. It may indicate that the mini-jets are not the only source of $\langle p_T \rangle$ increasing in hadron–hadron collisions. However, if the soft gluon radiation mechanism in HIJING model is switched off, the $\langle p_T \rangle$ distributions will become to decrease in ideal 'soft' events reversely. Therefore from this study, it seems that the soft gluon radiation before or after soft interaction also plays an important role in the $\langle p_T \rangle$ enhancement of the charged hadrons.

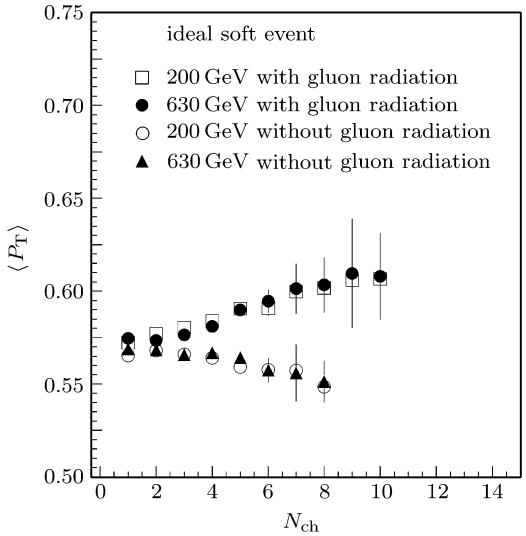


Fig.2. The gluon radiation effect of the $\langle p_T \rangle$ distributions of charged hadrons versus charged multiplicity in ideal 'soft' events

4. K^-/p^- and $\bar{p}/\pi^-$ yield ratio in 'soft' and 'hard' events

The jet fragmentation functions adopted are all from the measurements of electron–position annihilation,[7,8] whether they work for hadron–hadron collisions is questionable.

It is very difficult to measure mini-jets directly in hadron–hadron collisions experiments, but the yield ratios of K^-/π^-, $\bar{p}/\pi^-$ in 'soft' and 'hard' events can be well measured. In order to give a comparison with experimental results, we calculate the K^-/π^-, $\bar{p}/\pi^-$ ratios in 'hard' and 'soft' events at 200 GeV pp collisions using HIJING and PYTHIA models, the results are shown in Fig.3, where the mark points are experimental data.[3] The yields are all calculated within the pseudo-rapidity $|\eta| < 0.2$ region. The $dN_{ch}/d\eta$ is defined as the charged multiplicity in per unit pseudo-rapidity. From Fig.3(a) and Fig.3(b), it can be seen obviously that the K^-/π^-, $\bar{p}/\pi^-$ yield ratios in 'hard' events are higher than those in 'soft' events from HIJING, which is consistent with experimental data. The PYTHIA model gives similar results as those shown in Fig.4.

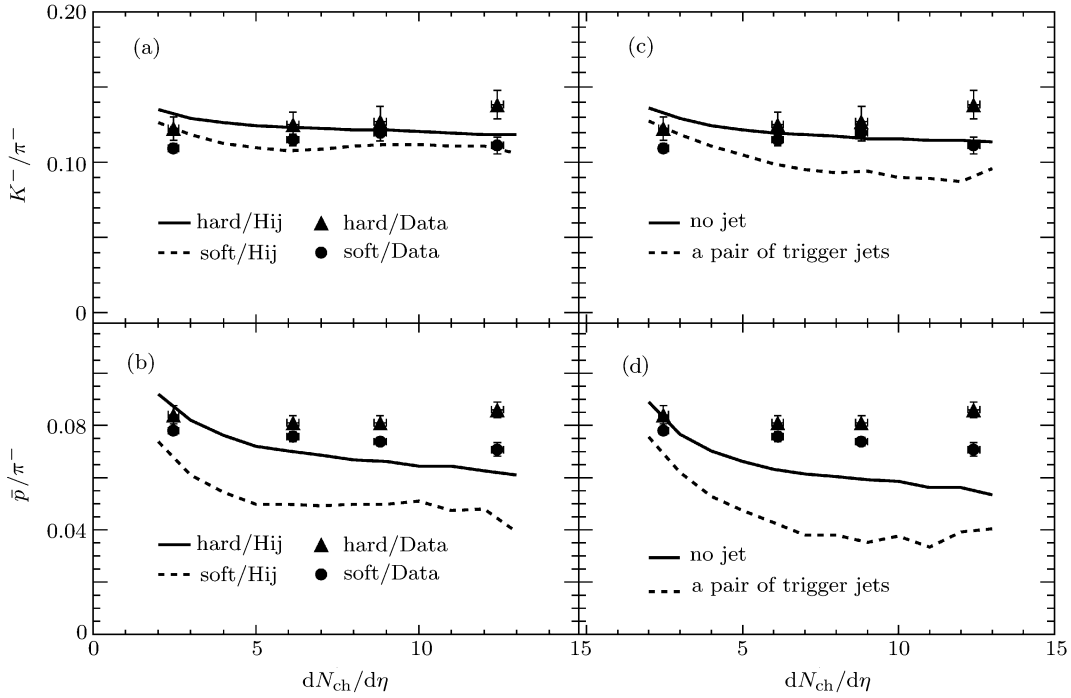


Fig.3. The K^-/π^-,$\bar{p}/\pi^-$ ratios with charged multiplicity in 'soft' and 'hard' events from HIJING.

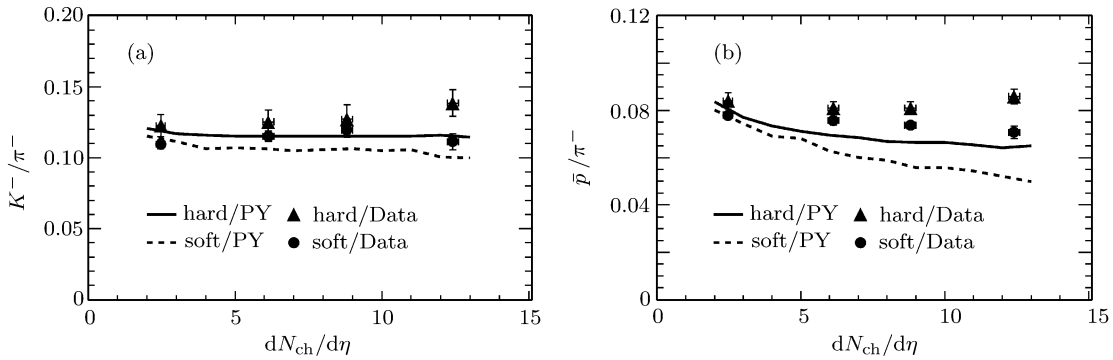


Fig.4. The K^-/π^-, $\bar{p}/\pi^-$ ratios with charged multiplicity in 'soft' and 'hard' events from PYTHIA.

To confirm that the difference between 'soft' and 'hard' events really comes from the effect of mini-jets but not the selection method itself, we generate two special kinds of event samples: there is at least a pair of mini-jets in the first sample and no mini-jet in the second one. The results are shown in the Fig.3(c) and Fig.3(d). It can be seen that the K^-/π^-, $\bar{p}/\pi^-$ ratios with mini-jets contributions are higher than those without mini-jets.

The HIJING model calculation shows that 70% of 'hard' events contain 'hard' interactions and 90% of soft events do not contain hard interactions at the experimental selection condition. Combined with mini-jet event results, we are convinced that the 'soft' and 'hard' event classification can qualitatively reflect the difference of 'hard' and 'soft' interactions, and the kaon and proton yields from mini-jets fragmentation are higher than those from 'soft' interactions. From electron–positron annihilation measurement the $\bar{p}/\pi^-$ yield ratio is about 0.5 in quark fragmentation and 0.8 in gluon fragmentation.[8] So we can confirm that the mini-jets are dominated by gluon jets.

From Figs.3 and 4 we can also see that both HIJING and PYTHIA can not quantitatively describe the K^-/π^-, $\bar{p}/\pi^-$ yield ratios versus N_{ch}, which might be due to other unclear mechanism.

5. Conclusions

We studied the phenomenological properties of 'soft' and 'hard' events in pp and $\bar{p}p$ collisions using the mini-jet method in HIJING model, and found that this model can reproduce the energy scaling behaviour of $\langle p_T \rangle$ distributions of charged hadrons with multiplicity in 'soft' events, which is measured by STAR and CDF experiment. Both HIJING and PYTHIA can describe the difference between K^-/π^-, $\bar{p}/\pi^-$ ratios in 'hard' and 'soft' event qualitatively, and the calculation illustrates that this difference is due to the mini-jets fragmentation. The HIJING model also indicates the increase of $\langle p_T \rangle$ with multiplicity is dominated by soft gluon radiation in 'soft' events and by the mini-jets in 'hard' events respectively.

References

[1] Wang X N and Hwa R C 1989 *Phys. Rev.* D **39** 187
Jacob M 1983 CERN Report No. CERN/TH. 3515
Bopp F W, Aurenche P and Ranft J 1986 *Phys. Rev.* D **33** 1867

[2] Helmut Satz 1984 *Nucl. Phys.* A **418** 447c

[3] Huang S L 2004 nucl-ex/0403038

[4] Acosta D (CDF Collaboration) 2002 *Phys. Rev.* D **65** 072005

[5] Gyulassy Miklos and Wang X N 1994 *Comput. Phys. Commun.* **83** 307

[6] Sjöstrand T 1994 *Comput. Phys. Commun.* **82** 74

[7] Abreu P (DELPHI Collaboration) 1996 *Z. Phys.* C **73** 11

[8] Adams J (ARGUS Collaboration) 2003 nucl-ex/0309012