Effect of the jet production on pseudorapidity, transverse momentum and transverse mass distributions of charged particles produced in pp-collisions at Tevatron energy [*]

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Abstract: We investigate the effects of jet production on the following parameters: pseudorapidity, transverse momentum and transverse mass distributions of secondary charged particles produced in pp-collisions at 1.8 TeV, using the HIJING code. These distributions are analyzed for the whole range and for six selected regions of the polar angle as a function of the different number of jets. The obtained simulation results for these parameters are interpreted and discussed in connection to the increase observed in the multiplicity of secondary charged particles as a result of its multi-jet dependence, and are also discussed in comparison with the experimental results from the CDF Collaboration.

Key words: jet production, charged particles in pp-interactions, HIJING, pseudorapidity, transverse momentum, transverse mass

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1   Introduction

Jet quenching [1, 2] in high energy hadronic collisions at ultrarelativistic energies is considered one piece of experimental evidence for the formation of quark-gluon plasma (QGP), a new state of strongly interacting matter formed under critical conditions of high density and high temperature. Jet quenching is the result of the energy loss by jets at the partonic level interaction [3]. In order to study jet production or jet suppression and its effects on the different parameters of the charged particles produced in high energy collisions, it is useful to know the jet dependence of parameters like charged particles multiplicity, pseudorapidity and transverse momenta etc. in pp collisions. Here we present an investigation of the jet dependence of the pseudorapidity, transverse momentum and transverse mass distributions of charged particles produced in pp interactions at 1.8 TeV energy using the Heavy Ion Jet Interaction Generator (HIJING) Monte Carlo model [4–6]. The HIJING Monte Carlo model is basically designed to simulate multiple jets and particle production in hadron-hadron (pp), hadron-nucleus (pA) and nucleus-nucleus (AA) interactions at collider

energies. There are some special parameters in HIJING, like energy, frame (lab or centre of mass), types of the colliding nuclei, their impact parameter and some other parameters regarding the production of jets and other particles, which users have to specify or change. In particular, HIJING reproduces many inclusive spectra two particle correlations, and can explain the observed flavor and multiplicity dependence of the average transverse momentum. The concept of jets and their association with hard parton scattering has been well established in hadronic interactions and they have been proven to play a major role in every aspect of pp collisions at high (SPS and Tevatron) energies. At the hadron-hadron level of interaction, HIJING also made an important effort to address the interplay between low transverse momentum ($p_{\rm T}$) non-perturbative physics and the hard perturbative quantum chromodynamics (pQCD) processes. This Monte Carlo model has been tested extensively against data on pp interactions over a wide range of collider energies. More details about HIJING can be found in Refs. [4–6].

This study is a continuation and confirmation of the HIJING code results on the influence of the jets on

charged particle multiplicities (N_{ch}) in pp collisions at 1.8 TeV [7], where we presented and discussed the increase observed in N_{ch} as a function of the different number of jets for charged particles distributions in full phase space (whole polar angle rage) and for six different regions of the polar angle θ (R1: $\theta=0°$–$2°$, R2: $\theta=2°$–$4°$, R3: $\theta=4°$–$6°$, R4: $\theta=6°$–$10°$, R5: $\theta=10°$–$30°$ and R6: $\theta=30°$–$90°$). The reason for selection of these angular intervals R1–R6 was the statistical reliability of the data. We chose this selection of the polar angle regions from analyses of the angular distributions of the secondary charged particles. The results of distributions of N_{ch} for zero and multi-jet events were found to be inconsistent with the experimental multiplicity distributions (MDs) of charged particles interpreted by fitting with the Pascal (negative binomial) distributions [8].

In the present work we present a study of the effects of jet production on pseudorapidity (η), transverse momentum (p_{T}) and transverse mass (m_{T}) distributions of secondary charged particles for the whole polar angle range and also for six selected regions of polar angle R1 to R6, where R1 to R6 are defined as above. The relation that defines the pseudorapidity is

$$\eta=-\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

where θ is the polar angle with the beam axis. The transverse momentum is defined by $p_{\text{T}}=\sqrt{p_x^2+p_y^2}$ or $p_{\text{T}}=p\sin\theta$. The total momentum is given by $p^2=p_x^2+p_y^2+p_z^2$ with p_z the longitudinal momentum parallel to the beam (z) axis. The transverse mass is defined by the relation $m_{\text{T}}=\sqrt{m^2+p_{\text{T}}^2}$. Here, we have studied the results for pseudorapidity, transverse momentum and transverse mass distributions of secondary charged particles for the whole polar angle range and for six regions in comparison with the reported results for the change (increase) in multiplicity of N_{ch} in multi-jet events [7]. Moreover, these results are discussed in connection with the experimental results for pseudorapidity distributions of charged particles from the Collider Detector at Fermilab (CDF Collaboration) [9].

2   Simulation results for pp interactions at 1.8 TeV

We have analyzed $\eta-$, p_{T}- and m_{T}-distributions of the secondary charged particles produced in pp collisions at 1.8 TeV centre of mass energy. The Dubna version of the HIJING code (modified by Uzhinsky [10, 11]) is used for simulation of 100000 events. These distributions of secondary charged particles, including protons, charged π ($\pi^{\pm}$) and charged K-mesons ($K^{\pm}$-meson) are considered. These distributions are considered for different numbers of jets (N_{jet}) for the whole range of the polar angle as well as in its different regions. The number of

jets was $N_{\text{jet}}=D$, i.e. the default value of jets (maximum number) taken from the HIJING model, 0, 1 and 2 (and labeled as D, 0, 1 and 2 respectively). (In the HIJING model, the parameter for the number of jets has default value D, which is the maximum number of jet production; it can be turned off i.e. 0 jets and can be fixed to any number 1, 2, and so on. For the particular case considered here since the distributions of η, p_{T} and m_{T} for simulation results shown below for $N_{\text{jet}}=D$ are same as for $N_{\text{jet}}=1$ so we can say that default value of N_{jet} is 1.) Different angular regions were selected for six ranges of the polar angle theta θ (in degrees) from R1 to R6.

2.1   Pseudorapidity distributions

The full phase space η-distribution of charged particles produced in pp collisions at 1.8 TeV, as a function of the number of jets $N_{\text{jet}}=D$, 0, 1 and 2, superimposed with the η-distribution for $|\eta|\leqslant3.5$ from CDF [9] at 1.8 TeV, is shown in Fig. 1. This figure shows some plateaus in the central pseudorapidity regions. The existence of plateaus in rapidity or pseudorapidity is very important for theoretical estimation. For example, J. D. Bjorken described the space-time evolution of the hadronic matter produced in the central rapidity region in extreme nucleus-nucleus collisions [12]. He found that quark-gluon plasma is produced at a temperature of the order of 200 MeV, which was in agreement with previous measurements [13]. The author also commented that the description relies on the existence of a flat central plateau and on the applicability of hydrodynamics. Here in Fig. 1, one can see that with increasing the number of jets, the width of the distribution/plateaus is decreased and the pseudorapidity density in the central area is increased.

In Fig. 2 the data are presented for the corrected η distributions (corrected for geometric and kinematic
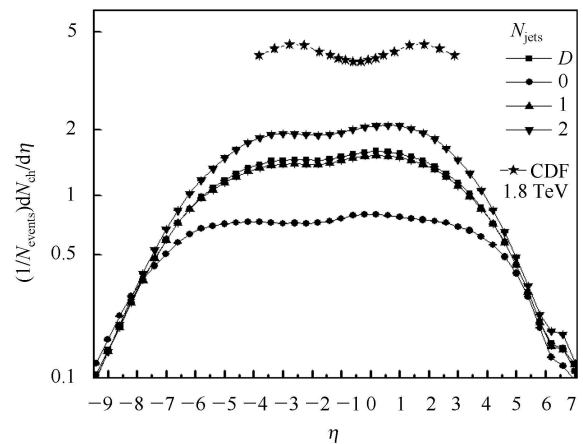

Fig. 1. η-distribution of charged particles for $N_{\text{jet}}=D$, 0, 1 and 2 for the whole range of polar angle, superimposed with the η-distribution for $|\eta|\leqslant3.5$ from CDF [9] at 1.8 TeV.

acceptance, tracking efficiency etc.) of charged particles produced in proton-antiproton collisions at $\sqrt{s}$=1800 and 630 GeV from the Collider Detector at Fermilab [9]. A measurement from the CERN SPS collider performed by UA5 at $\sqrt{s}$=546 GeV is also shown in this figure. A qualitative comparison of these data with those from Fig. 1 for the pseudorapidity region $|\eta|\leqslant 3.5$ demonstrates that as the η spectra for CDF data are much higher than those for the HIJING (N_{jet}=2) data, this increase in pseudorapidity density is due to multi-jet events.
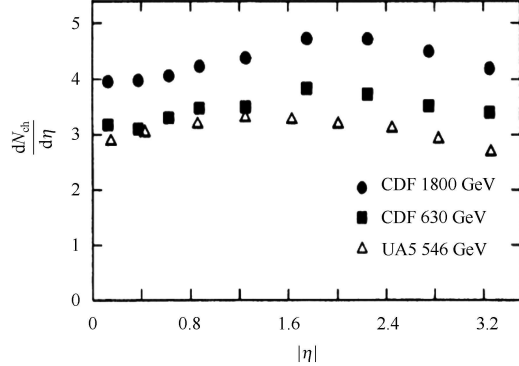

Fig. 2. The pseudorapidity density measured by the CDF Collaboration at 1800 and 630 GeV, and by the UA5 Collaboration at 546 GeV [9].

Figure 3 (a) to (f) demonstrates the η-distribution of secondary charged particles produced in pp collisions at 1.8 TeV as a function of N_{jet}=D, 0, 1 and 2, for the six regions of polar angle R1 to R6 respectively. One can observe the following.
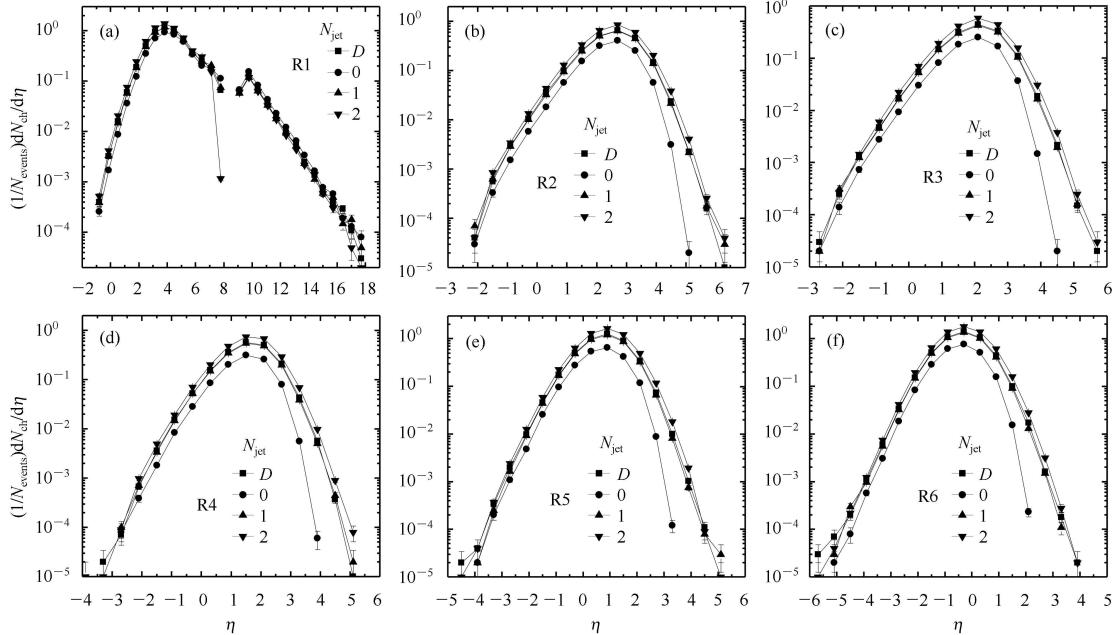
1) For particles with polar angle less than 2 degrees (R1) the η-distributions do not depend on N_{jet}. However, two regions (peaks) are observed for the η-distribution of the particles separated by a sharp drop at η=8; especially for the case N_{jet}=2, there is a very sharp transition from the first region to the second. This effect is connected with kinematics (θ-η correlation) because the probability of contribution to the second area (η>8) is very low due to the θ-η correlation (particles with η>8 have $\theta\sim 0$, i.e. they are mainly leading particles, particles with energies very close to the projectile energies).

2) For particles with the polar angle greater than 2 degrees, the width and height of the distributions increase with N_{jet}.

It is also observed in this figure that the pseudorapidity spectra for N_{jet}=2 are systematically higher than those for N_{jet}=0 for all the regions R1-R6, which shows that 2 (multi)-jet events lead to an increase in the pseudorapidity density.

2.2 Transverse momentum distributions

In Fig. 4 and Fig. 5((a) to (f)), the transverse momentum p_{T} distributions of secondary charged particles produced in pp interactions at 1.8 TeV as a function of the number of jets N_{jet}=D, 0, 1 and 2, are presented, for the whole range and for the six selected regions (R1 to R6) of the polar angle. We can see that with increasing the number of jets from 0 to 1, 2 or with the default values of jets the transverse momentum is increased as the jets or multi-jet events contain high p_{T} particles.

Fig. 3. η-distributions of charged particles for N_{jet}=D, 0, 1 and 2 in the angular regions: (a) R1 θ=0°–2° (b) R2 θ=2°–4° (c) R3 θ=4°–6° (d) R4 θ=6°–10° (e) R5 θ=10°–30° (f) R6 θ=30°–90°.
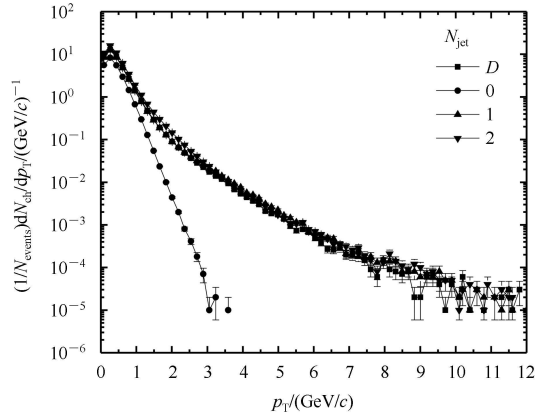
Fig. 4. p_T distribution of charged particles for $N_{jet} = D$, 0, 1 and 2 for the whole range of polar angles.

The shape of the distributions in the case of $N_{jet} \geqslant 1$ is different in two areas of p_T: $p_T < 2$ GeV/c and $p_T > 2$ GeV/c. The slopes of the distributions in the first area are very close to those of the events with $N_{jet} = 0$ (slopes of the p_T distributions for the whole θ-range and for regions R1–R6 are shown in Fig. 6). So we could say that particles with $p_T < 2$ GeV/c are produced by the same dynamics in events with different N_{jet}, i.e. there is no jet dependence in the $p_T < 2$ GeV/c region (or zero-jet events have no contribution to the $p_T > 2$ GeV/c region). The particles with $p_T > 2$ GeV/c are those produced by some special dynamics, different from the particles produced with $p_T < 2$ GeV/c; namely, the jet dynamics (production and hadronization of the jets) from the HIJING code. In our previous study [7] we also observed two

regions for the multiplicity distribution of charged particles. We concluded that the high multiplicity regions in the N_{ch}-distribution correspond to the multi-jet events. The results were in good agreement with those discussed by Ugoccioni and Giovannini [8].

Figure 5 ((a) to (f)) demonstrates how the increase in values of the p_T spectra depends on the polar angle of the produced charged particles (as $p_T = p\sin\theta$). This shows the dependence of the variation in the p_T spectra with respect to the polar angle (the angular regions R1-R6) and its dependence on N_{jets}.

In Figure 6 ((a) and (b)), plots are shown for the slopes of the p_T spectra for the whole range and selected six regions R1–R6 of the polar angle for $p_T < 2$ GeV/c and for 2 GeV/$c < p_T < 3$ GeV/c as a function of N_{jets}. This supports the analysis described above for the p_T spectra.

2.3 Transverse mass distributions

We now consider the transverse mass m_T distributions of secondary charged particles produced in pp interactions at 1.8 TeV as a function of the number of jets $N_{jet} = D$, 0, 1 and 2, for the whole range and the six selected regions (R1 to R6) of the polar angle. It is well known that the m_T distributions are more sensitive to the temperature of the systems. Fig. 7 shows the m_T distributions of secondary charged particles produced in pp interactions at 1.8 TeV for $N_{jet} = D$, 0, 1 and 2 for the whole polar angle range. With increasing the number of jets from 0 to 1, 2 or the default value of jets, an increase in the transverse mass is observed and here the increase
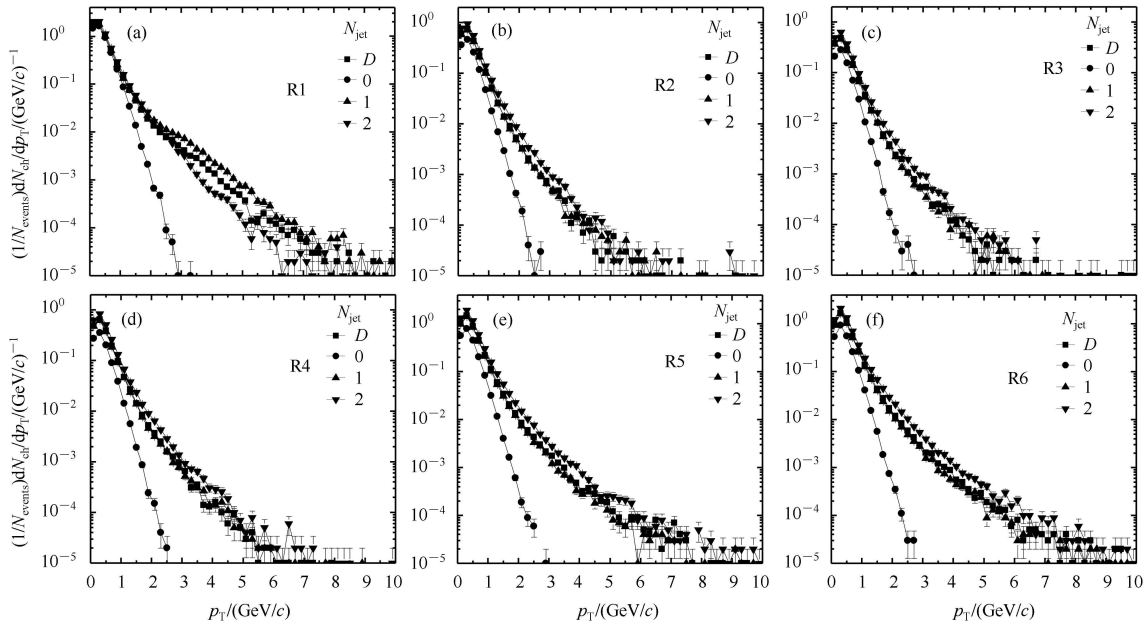

Fig. 5. p_T distributions of charged particles for $N_{jet} = D$, 0, 1 and 2 in the angular regions: (a) R1 $\theta = 0°–2°$ (b) R2 $\theta = 2°–4°$ (c) R3 $\theta = 4°–6°$ (d) R4 $\theta = 6°–10°$ (e) R5 $\theta = 10°–30°$ (f) R6 $\theta = 30°–90°$.
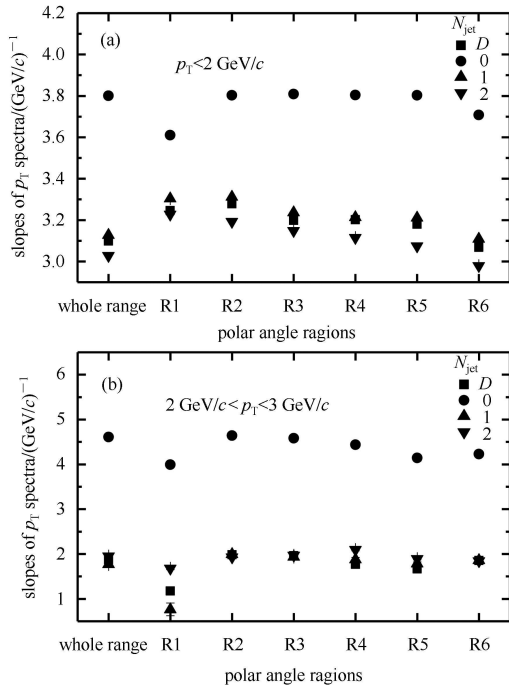
Fig. 6.   Slopes of the p_T spectra for the whole range and selected regions R1–R6 of the polar angle, (a) for $p_T < 2$ GeV/c and (b) for 2 GeV/c < $p_T < 3$ GeV/c.

in the case of multi-jet events is more than for the transverse momentum distributions as transverse mass is $m_T = \sqrt{m^2 + p_T^2}$.

Transverse mass distributions of secondary charged particles for pp collisions at 1.8 TeV, for the six selected

regions (R1–R6) of polar angle, are shown in Fig. 8 (a) to (f) respectively. An increase in m_T similar to that in p_T is observed in all regions except for the angular region R1 $\theta = 0°–2°$, where multi-jet events have a higher increment for m_T which may be due to the elastic scattering events in pp interactions. The region R1 may also be affected by the leading particle effect [14–16] with particles containing high longitudinal and low transverse momentum, as was observed in our previous study in the case of N_{ch} distribution for the same polar angle region and also in the low N_{ch} region for multiplicity distributions for full phase space [7]. We can see that the slopes of the distributions depend on the polar angle of the particles and the number of jets for the high p_T particles ($p_T > 2$ GeV/c).
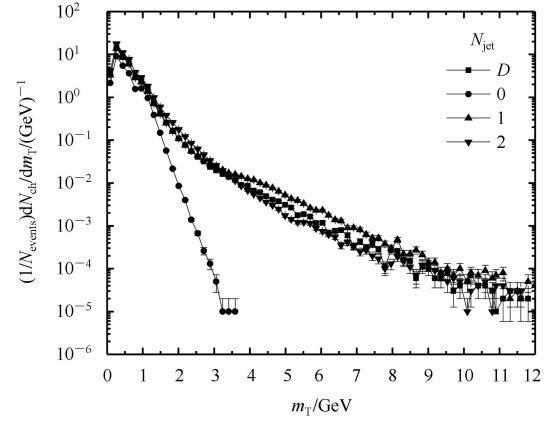

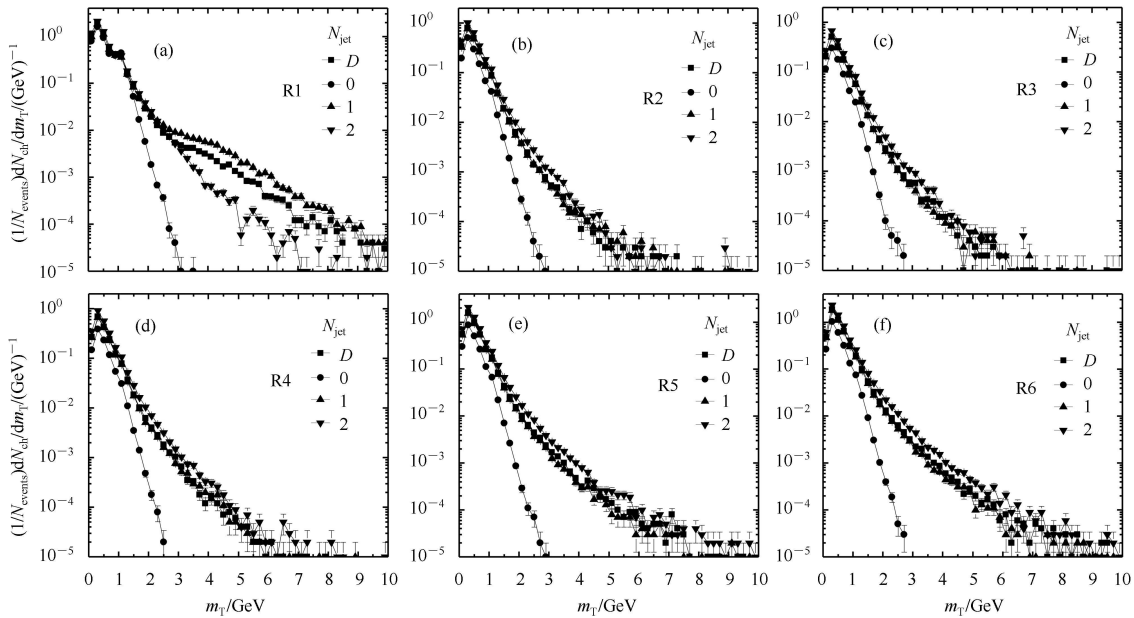Fig. 7. m_T distribution of charged particles for $N_{jet} = D$, 0, 1 and 2 for the whole range of polar angles.

Fig. 8. m_T distributions of charged particles for $N_{jet} = D$, 0, 1 and 2 in the angular regions: (a) R1 $\theta = 0°–2°$ (b) R2 $\theta = 2°–4°$ (c) R3 $\theta = 4°–6°$ (d) R4 $\theta = 6°–10°$ (e) R5 $\theta = 10°–30°$ (f) R6 $\theta = 30°–90°$.
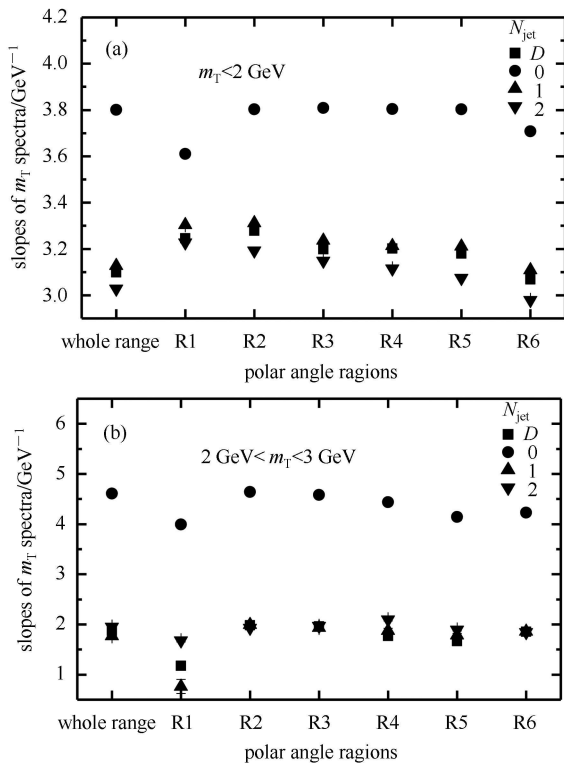
Fig. 9. Slopes of the m_T spectra for the whole range and selected regions R1–R6 of the polar angle, (a) for $m_T < 2$ GeV and (b) for 2 GeV$< m_T < 3$ GeV.

Figure 9 ((a) and (b)) shows the plots of slopes of the m_T spectra for the whole range and selected six regions R1–R6 of polar angles for $m_T < 2$ GeV and for 2 GeV$< m_T < 3$ GeV as a function of the number of jets. Very similar behavior to Fig. 6 is seen here. Event selection with $N_{jet}=0$ affects the m_T distribution only up to $m_T \sim 3$ GeV, as for $m_T > 3$ GeV events with $N_{jet} > 0$ are contributing.

3   Conclusion

We studied the effects of jet production on the pseudorapidity, transverse momentum and transverse mass distributions of secondary charged particles produced in pp collisions at 1.8 TeV in the CDF experiment, using the HIJING code. These distributions were analyzed for the whole range and for six selected regions of the polar angle as a function of the different number of jets.

Some plateaus are observed in the central area of pseudorapidity. The existence of these plateaus is very important for the applicability of hydrodynamics. With increasing the number of jets the widths of the distributions decreased and the pseudorapidity density in the central area increased.

It was observed that with increasing the number of jets from 0 to 1, 2 or the default value of jets, the transverse momentum increased as the jets or multi-jet events contain high p_T particles.

The behavior of the p_T - distributions in the case of $N_{jet} \geqslant 1$ is different in two areas of p_T: $p_T < 2$ GeV$/c$ and $p_T > 2$ GeV$/c$. The slopes of the distribution in the first area are very close to that for events with $N_{jet}=0$. We can therefore say that particles with $p_T < 2$ GeV$/c$ are produced by the same dynamics in events with different N_{jet}. The particles with $p_T > 2$ GeV$/c$ are those produced by some special dynamics, different from the particles with $p_T < 2$ GeV$/c$. We may conclude that along with the multi-jet events, zero-jet events affect the p_T spectra only up to 3 GeV$/c$ and for $p_T > 3$GeV$/c$ only the multi-jet events contribute. This is caused by the jet dynamics (production and hadronization of the jets) from the HIJING code. We also observed, in a previous study, similar results for the multiplicity distribution of charged particles. We concluded that the high multiplicity regions in the N_{ch} distribution correspond to multi-jet events.

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