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Abstract

Mini-jet and particle production are studied in the framework of HIJING Monte Carlo model which can describe pp and $p\bar{p}$ collisions well from ISR to Fermilab Tevatron energies. Mini-jets are shown to have eminent contributions to particle production in ultra-relativistic heavy ion collisions. However, parton shadowing and jet quenching also have important effects and can be studied by single particle distributions.

MINI-JET AND PARTICLE PRODUCTION IN ULTRA-RELATIVISTIC HEAVY ION COLLISIONS*

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ABSTRACT

Mini-jet and particle production are studied in the framework of HIJING Monte Carlo model which can describe pp and $p\bar{p}$ collisions well from ISR to Fermilab Tevatron energies. Mini-jets are shown to have eminent contributions to particle production in ultra-relativistic heavy ion collisions. However, parton shadowing and jet quenching also have important effects and can be studied by single particle distributions.

INTRODUCTION

In ultra-relativistic heavy ion collisions, the background due to nonequilibrium processes must be understood in order to recognize the new physics of the formation of a quark-gluon plasma (QGP)[1]. At energies of $\sqrt{s} \gtrsim 200$ GeV/n, nuclear effects on mini-jet productions and some rare high P_T QCD processes must also be studied to test the proposed signatures and probes of ultra-dense matter such as jet quenching[2]. Therefore, we have developed a new Monte Carlo model HIJING (Heavy Ion Jet INter-action Generator)[3] to address a wide range of phenomenological problems involving nuclear collisions. The main features of HIJING include: (1) Soft beam jets modelled by quark-diquark strings with gluon kinks in the spirit of Lund FRITIOF model[4]. In addition, multiple low P_T kicks to the end point quarks or diquarks are taken into account. (2) Exact Glauber nuclear geometry, as in the ATTILA event generator[6], is used to calculate the impact parameter dependence of the number of inelastic processes. (3) Multiple mini-jet productions with initial and final state radiation is included along the lines of the PYTHIA model[5]. In our treatment, an eikonal formalism is used to calculate the number of of mini-jets per inelastic pp collision, consistent with the energy variation of the total cross section. (4) The influence of local, impact parameter dependent, nuclear shadowing of the parton structure function is approximated by an empirical parametrization. (5) Rare events with high P_T can be triggered with the associated enhancement of multiple mini-jet and soft background. (6) A simple model for

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jet quenching is assumed to enable the study of the dependence of moderate and high P_T observables on the energy loss dE/dx of partons in the dense matter.

The emphasis in HIJING on the role of multiple mini-jets is motivated by previous estimates[7] that up to 50% (80%) of the transverse energy per unit rapidity may arise in nuclear collisions at RHIC (LHC) energies from semi-hard processes with $P_T \gtrsim 2$ GeV/c. While not resolvable as distinct jets, they are found very important to particle production in pp, $p\bar{p}$ collisions at collider energies[8] and are expected to result in a variety of correlations among observables such as high p_T and strangeness enhancement that compete with the expected signatures of a QGP in ultra-relativistic nuclear collisions. Therefore, it is especially important to calculate these background processes as reliably as possible.

$N + N$ COLLISIONS

Since HIJING is based on a particular model of high energy $p+p$ inelastic collisions, the model and its parameters have to be constrained with the existing $p+p$ and $p+\bar{p}$ data. The cross section and probability of multiple mini-jet productions can be calculated in the eikonal formalism as

$$\sigma_{in} = \pi \int_0^\infty db^2 [1 - e^{-(\sigma_{soft} + \sigma_{jet})A(b,s)}], \tag{1}$$

$$G_0 = \frac{\pi}{\sigma_{in}} \int_0^\infty db^2 [1 - e^{-\sigma_{soft}A(b,s)}] e^{-\sigma_{jet}A(b,s)}, \tag{2}$$

$$G_j = \frac{\pi}{\sigma_{in}} \int_0^\infty db^2 \frac{[\sigma_{jet}A(b,s)]^j}{j!} e^{-\sigma_{jet}(b,s)}, \tag{3}$$

where $A(b,s)$ is the partonic overlap function between two nucleons at impact parameter b, σ_{jet} is the total inclusive jet cross section with $P_T \geq P_0$ and σ_{soft} is the corresponding inclusive cross section for soft processes. We regard P_0 as a model dependent phenomenological parameter. We have fixed it to 2 GeV/c by achieving the correct energy dependence of cross sections with a particular assumption about σ_{soft}. In our model σ_{soft} is related to the geometrical size of hadrons to account for geometrical scaling at low energies[8]. It is the assumption that σ_{soft} tends to a constant as a function of energy that leads us to the choice of $P_0 = 2$ GeV/c and $\sigma_{soft} = 57$ mb at high energies. Fortunately, this P_0 scale turns out to be sufficiently large that PQCD can be reasonably applied for $P_T > P_0$. HIJING uses the above equations to determine the interaction cross section and the number of mini-jet productions. Then PYTHIA subroutines are used to generate the kinetic variables of the scattered partons. The beam jets are modelled by two string excitation as in other models[4,5,9,10] with soft gluon radiations[4]. Gluons from hard processes are regarded as kinks on the beam strings and Lund JETSET 7.2 fragmentation scheme[11] is employed to describe the hadronization. We have found that HIJING can describe $p + p$, $p + A$ and $A + B$ for

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$\sqrt{s} \geq 5$ GeV well[3]. We will only discuss the results at collider energies here.

Shown in Fig. 1, are the calculated (histograms) pseudo-rapidity distributions of charged particles in non-single-diffractive events from $p + p$ at $\sqrt{s} = 53$ GeV to $p + \bar{p}$ collisions at $\sqrt{s} = 1800$ GeV. HIJING reproduces the experimental data[12,13] well. The increase of central rapidity density is mainly due to multiple mini-jet productions. We have tested that mini-jet production is virtually negligible at ISR energies and the central density $dn/d\eta(\eta = 0)$ is essentially independent of the colliding energy without jet production. A more convincing indication for the importance of jet production is seen in the p_T distribution of produced particles as shown in Fig. 2. Instead of being nearly an exponential function of p_T at low energies, both HIJING (histograms) and experimental data[14,15,16] show the build-up of a power-law tail with increasing energies which is characteristic of PQCD. The effect of multiple mini-jet production is also reflected in the multiplicity distributions and the underlying event structure as illustrated in Fig. 3. As shown in the figure, the low multiplicity events are dominated by events with no jet production (dot-dashed histograms) while the contributions from those with one (dashed histograms) and two or more than two (dotted histograms) jet productions are most important in high multiplicity events.
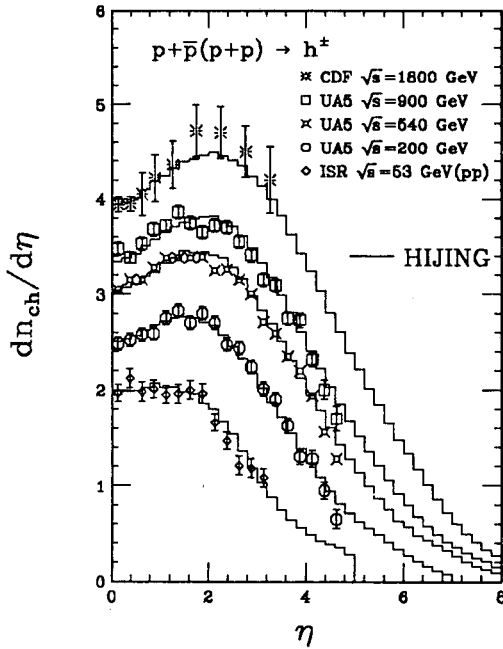

Fig. 1 Pseudo-rapidity distributions of charged particles in $p + \bar{p}$ $(p + p)$ collisions. Histograms are HIJING calculation and data are from Ref. [12,13].
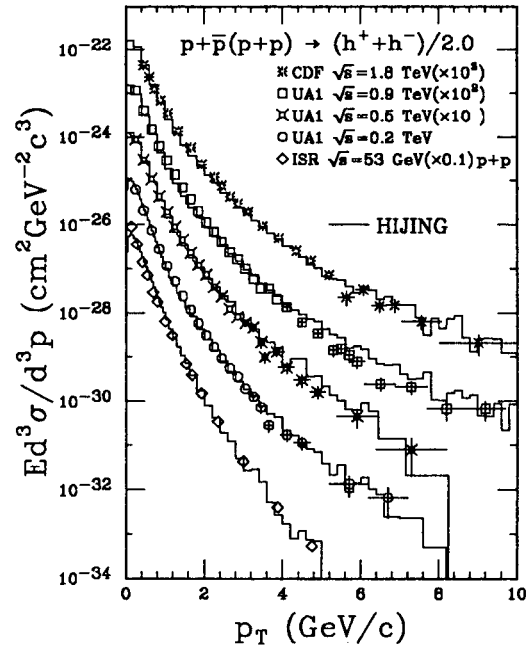
Fig. 2 Inclusive cross sections of charged particles in $p + \bar{p}$ $(p + p)$ collisions as a function of p_T. Histograms are HIJING calculation and data are from Ref. [14,15,16].
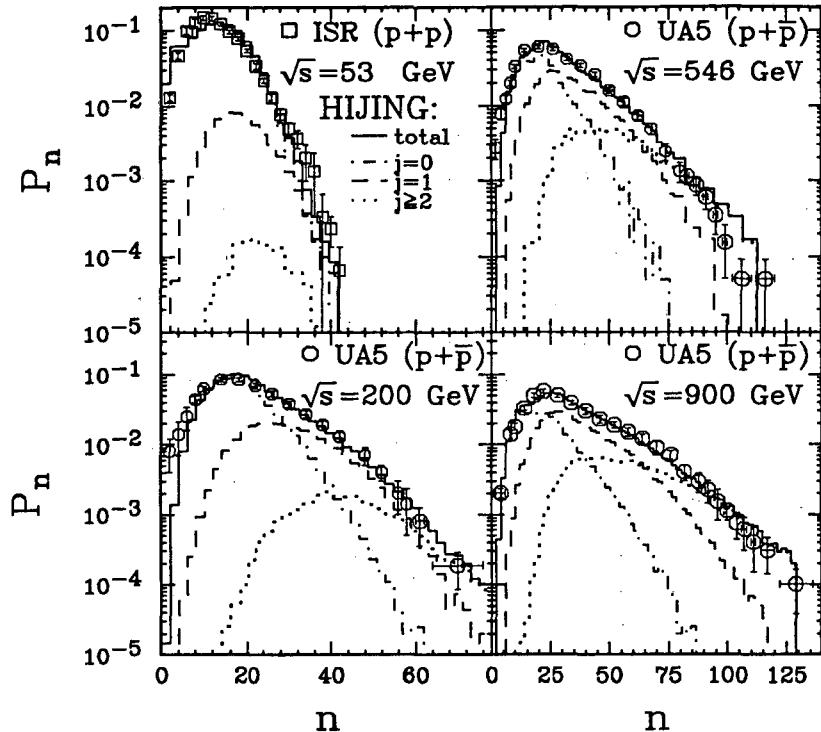
Fig. 3 Multiplicity distributions of charged particles in $p+\bar{p}$ $(p+p)$ collisions. Data are from Ref. [17,18] and histograms are HIJING results. The number j indicates the number of jet productions in different contributing events.

$A+A$ COLLISIONS

We adopt a multiple collision ansatz in HIJING where a $A+A$ collision is decomposed into binary $N+N$ collisions involving in general excited or wounded nucleons and sometimes a hard scattering. Wounded nucleons are assumed to be $q-qq$ strings that decay on a slow time scale compared to the collision time of the nuclei. We use the three parameter Wood-Saxon nuclear density to generate the coordinates of nucleons. For each binary collisions we can calculate the corresponding impact parameter and use Eqs. 1-3 to determine the interaction cross section and the number of mini-jet productions. The nuclear shadowing of parton structure function and its impact-parameter dependence are taken into account both in the calculation of inclusive jet cross section and the generation of kinetic variables of scattered partons. We use an effective nuclear parton structure function parametrized according to experimental data[19] and assume the same shadowing for gluons and quarks. We also include a simple model for jet quenching in HIJING. The interaction of a jet with the excited medium in central rapidity region is determined by its mean free path λ_s and its energy loss dE/dx due

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to the interaction. We assume that the energy loss of a quark has a value of the string tension

$$dE/dx = \kappa \approx 1 \text{ GeV/fm}. \tag{4}$$

and the lost energy is carried away by a collinearly split gluon.

We plot in Fig. 4 the central pseudo-rapidity density of charged particles in central $A + A$ collisions at $\sqrt{s} = 200$ GeV as a function of the atomic number A of the nuclei. When there is no mini-jet productions, $dn/d\eta(\eta = 0)$ is nearly linear to A, because soft particle production should be proportional to the number of participants plus some small contribution from multiple binary collisions. When mini-jets are included we would naively expect that $dn/d\eta(\eta = 0)$ is to build up a large component proportional to $A^{4/3}$ and this is exactly what we get as shown in the figure. However, with nuclear shadowing this component is greatly reduced for heavy nuclei. Our calculations show that the number of mini-jet productions is reduced by more than a half in $Au + Au$ due to parton shadowing. Jet quenching only has a slight effect on $dn/d\eta(\eta = 0)$ but will have an important influence over the p_T distributions of charged particles. In Fig. 5 we plot the ratio

$$R^{AA}(p_T) = \frac{d^2 n_{ch}^{AA}/dp_T^2/d\eta}{d^2 n_{ch}^{pp}/dp_T^2/d\eta} \tag{5}$$

of the inclusive p_T spectrum of charged particles in central $Au + Au$ collisions to that of $p + p$. At large p_T where PQCD hard processes dominate, this ratio should be the number of binary collisions in $A + A$. However, we see that shadowing reduces this
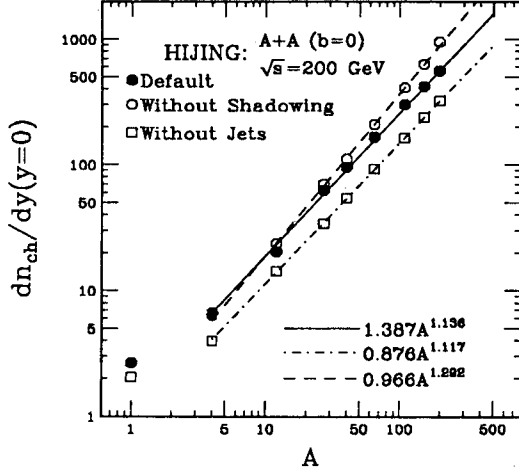
Fig. 4 The central rapidity density of charged particles in central $A + A$ collisions as a functions of A. The points are HIJING calculation and lines are parametrization.
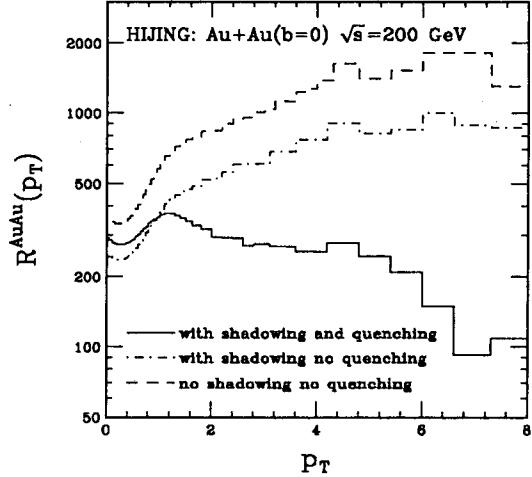
Fig. 5 The ratio of p_T distributions of charged particles in central $Au + Au$ to that in $p + p$.

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number by a large amount and jet quenching suppresses even more the particles with high p_T. We find that the effect of jet quenching on single particle p_T distribution is most important for $2 \lesssim p_T \lesssim 10$ GeV/c. Since jet quenching is due to the interaction with the excited matter in central region in the transverse direction, it should be absent in $p + A$ collisions. Therefore by studying the same quantity $R^{pA}(p_T)$ in $p + A$ at the same energy we could determine the shadowing effect on single particle production and thus disentangle jet quenching effect from the complex system in $A + A$ collisions. It is for this kind of purpose that we could use HIJING to study mini-jet and particle production in ultra-relativistic nuclear collisions.

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