A Parton-Hadron Cascade Approach in High-energy Nuclear Collisions
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A parton-hadron cascade model which is the extension of hadronic cascade model incorporating hard partonic scattering based on HIJING is presented to describe the space-time evolution of parton/hadron system produced by ultra-relativistic nuclear collisions. Hadron yield, baryon stopping and transverse momentum distribution are calculated and compared with HIJING and VNI.

1. INTRODUCTION
Event generators based on perturbative QCD (pQCD) are proposed such as HIJING (Heavy Ion Jet Interaction Generator) [1], VNI (Vincent Le Cucurullo Con Giginello) [2], in order to describe ultra-relativistic heavy ion collisions, especially, at collider energies (RHIC/LHC). Although both models reproduce many pp and ¯pp data, there are large discrepancies in AA collisions between these two models, for example, absolute number of produced particles, slope of transverse momentum. The main differences of the modeling between these two models are following: VNI is a Monte Carlo implementation of parton cascade model (PCM) in which the time evolution of heavy ion collision is simulated by the parton cascading. While HIJING assumes the Glauber theory in the description of AA collisions and handles the soft process based on the string model. Namely, the treatment of the multiple parton and hadron interactions is different. Second, the cut-off $p_0$ has to be introduced to avoid divergent QCD cross section for $p_\perp \to 0$ and this value is model dependent. In order to understand particle production mechanism in nuclear collisions, the role of multiple interactions as well as the sensitivity of model parameters should be carefully investigated. Hadronic microscopic transport models such as RQMD [3], ARC [4], QGSM [5] and UrQMD [6] have been successfully applied to nuclear reactions at AGS and SPS energies. Thus, the purpose of this work is to include hard processes into hadronic transport model by using HIJING formalism and study the effect of multi-step interaction on particle spectra at collider energies.

2. PARTON-HADRON CASCADE MODEL
In parton-hadron cascade model (PHC), elementary processes are taken from HIJING; The hard and soft processes are determined by HIJING formalism [8] and PTHIA5.7 [10] is used to generate hard scattering as well as initial and final state radiations. Only on-shell partons produced from hard scattering are propagated. For soft interaction of hadrons, the
Figure 1. The rapidity and transverse momentum distributions of net protons and negative charged particles ($\pi^-, K^-, \bar{p}$) for S + S collision at 200AGeV/c with centrality 20%. Experimental data are taken from NA35.

String excitation is assumed with the same probability for light-cone momentum exchange as DPM type functions at the c.m. energy above 5GeV. At low energy ($\sqrt{s} < 5$GeV), $1/x$ distribution which is the same as FRITIOF \[7\] model is used. If excited mass is larger than 2GeV in baryon case, it is assumed to be excited string like. The strings are assumed to hadronize via quark-antiquark creation using Lund fragmentation subroutine PYSTRF of PYTHIA6.1\[10\]. Therefore, at hh level PHC is essentially the same as HIJING.

For the description of AA collisions, the trajectories of all hadrons as well as partons, including produced particles, are followed explicitly as a function of space and time. Space-time point of produced partons can be simply determined by the uncertainty principle\[9\]. Formation points of hadrons from the fragmentation of string are assumed to be fixed by the average of two constituents formation points\[3\]. Low energy baryon-baryon, baryon-meson and meson-meson rescattering are also included assuming resonance excitation picture in order to treat final state interaction of hadronic gas. Extending the particle table of PYTHIA, baryon and meson resonances are explicitly propagated and they can rescatter. The rescattering among produced partons are not implemented now, however, constituent quarks can scatter with hadrons assuming the additive quark cross section within a formation time. The importance of this quark(diquark)-hadron interaction for the description of baryon stopping at CERN/SPS energies was reported by Frankfurt group \[11,6\].

3. RESULTS

In Fig. 1, I compare the data \[13\] on net proton and negative charged particle rapidity and transverse distributions for S+S collision at 200AGeV/c. PHC improves the HIJING results \[12\] and the agreement is good for both net protons and negative charged particles. At this energy, this model is reduced to the hadronic cascade model if we use the cut off...
Figure 2. The rapidity and transverse momentum distributions of charged particles for S + S collision at RHIC energy (b = 0.0fm). Solid, long dashed and dots histogram represent PHC, HIJING and VNI results respectively.

parameter $p_\perp = 2$GeV, because the probability for hard scattering is very small at this incident energy (average number of hard scattering $\sim 0.1$/event in S + S collision). This model can work also well for the lower energies.

Figure 2 shows the charged particle rapidity and transverse momentum distributions from three different models, VNI, HIJING and present model in S+S collision at RHIC energy. It is seen that absolute particle yield in PHC calculation is not so different from HIJING, however, PHC result for the transverse momentum distribution becomes close to the parton cascade model prediction. The difference between HIJING and PHC results comes mainly from the treatment of multiple collisions of hadrons and quarks.

The baryon stopping problem is one of the important element in nucleus-nucleus collisions. Net proton distributions calculated by various models are compared in Fig. 3. PHC model predicts no baryon free region at midrapidity, while parton cascade model predicts transparency. PHC result is similar to RQMD and UrQMD calculations. It is important to mention that if quark-hadron interaction is switched off, PHC gives the same results as HIJING. Interaction of quarks with hadrons modifies the stopping power as well as transverse momentum shape. What is the important difference between VNI and PHC is that first NN collisions are the scattering of the coherent objects (hadron) in PHC and after the hard scattering, partons are treated as classical particle like VNI, while in VNI, from the beginning, partons are sampled and on-shell as well as virtual partons are evolved in time.

In summary, a microscopic transport model which is the extension of hadronic cascade model based on HIJING is presented. The multi-step interaction in AA collisions changes the prediction for the final hadron distribution. It is interesting to include rescattering between produced partons to investigate thermalization and equilibration of parton system. This may be also useful for the understanding of the discrepancy between models.
Figure 3. The rapidity distributions of net proton for S + S collision at RHIC energy. Solid, long dashed and dots histogram represent PHC, HIJING and VNI results respectively.

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