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Current status and further improvements of a multi-phase transport (AMPT) model

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Abstract : The AMPT model is a multi-phase transport model that is constructed specifically for the study of the quark-gluon plasma created in high energy heavy ion collisions such as those at RHIC and LHC. It contains the initial conditions, an explicit partonic phase, descriptions of the bulk hadronization of a partonic matter into a hadronic matter, and a hadronic phase. The AMPT model has been applied to study many observables at RHIC. The current status of the AMPT model is reviewed first. Then we discuss areas for further improvements, including updating parton distribution functions for heavy nuclei and improving the bulk hadronization of partonic matter.

Keywords : Particle production, transport calculation

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1. Introduction

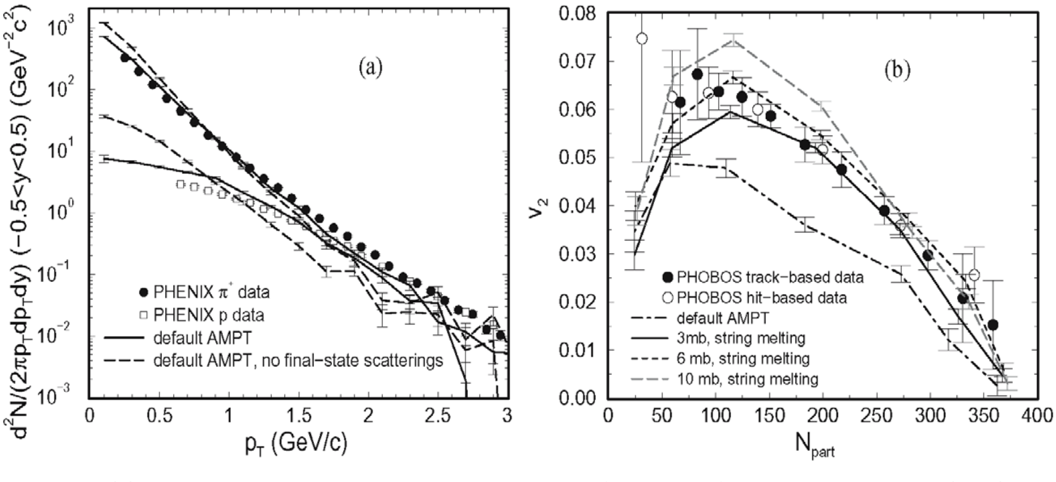
A high density matter that is many times the density of cold nuclear matter has been created in Au+Au collisions at RHIC. The thermalization of the dense matter is very strong, as shown by the large magnitudes of the elliptic flow, for example. Partonic as well as hadronic degrees of freedom are involved in the evolution of the dense matter. Initially the matter is expected to consist of mostly gluon fields. On the other hand, the scaling of elliptic flows with the valance quark number suggests that, at least near hadronization, quarks are the main degrees of freedom. Comparisons between the theoretical results and the extensive data from RHIC and the upcoming LHC enable us to study the properties of the dense matter created in these collisions.

Monte Carlo transport models are useful tools to study the dynamics of heavy ion collisions as they can address non-equilibrium as well as equilibrium processes in principle. A multi-phase transport model is constructed specifically for the study of the quark-gluon plasma created in high energy heavy ion collisions at RHIC and LHC, as it contains an explicit partonic phase in a parton cascade as well as descriptions of the bulk hadronization of a partonic matter into a hadronic matter. After partons convert to hadrons, hadrons continue to interact in a hadron cascade until chemical and thermal freeze-outs.

2. Current status of the AMPT model

The first public release of the AMPT model, version 1.11 for the model with the default Lund string fragmentation (named the default model), and version 2.11 for the model with string melting and quark coalescence (named the string melting model), have been described in detail [1] and made available at http://karman.physics.purdue.edu/OSCAR-old/models/list.html and http://personal.ecu.edu.linz/ampt. Newer versions of the AMPT model and documentation on the corresponding changes can also be found at these websites.

The AMPT model uses the Heavy Ion Jet INteraction Generator (HIJING) model as the initial conditions for energy production from the two colliding nuclei. In the default model (v1.11) only minijet partons are in partonic degrees of freedom and enter the parton cascade while the rest of the energy resides in strings and stays idle during the parton cascade. On the other hand, the string melting model (v2.11) converts those strings initially in the overlap region of the heavy ion collisions into partons because the initial energy densities there are much greater than 1 GeV/fm^3. Therefore all the energy produced in the overlap region takes part in the parton cascade, leading to much bigger partonic effects on certain observables such as the elliptic flow [2]. At the end of the parton cascade, the AMPT model uses either the Lund string fragmentation model (v1.11) or a quark coalescence model [2] (v2.11) for hadronization. Hadron cascade then follows until chemical and thermal freeze-outs are sufficiently reached. In practice, the hadron cascade is terminated at a



Fligure 1. (a) Transverse momentum spectra at mid-rapidity from the default AMPT model with (solid) and without (dashed) final-state interactions in central Au+Au collisions at 200 AGeV. (b) Centrality dependence of charged hadron elliptic flow in Au+Au collisions at 200 AGeV. Results from the AMPT model with different partonic dynamics are compared with the PHOBOS data.

cut-off time after which the observable of interest changes little. In central Au+Au collisions at RHIC energies, the default cut-off time of 30 fm/c is used for the study of particle rapidity distributions and the momentum spectra at mid-rapidity. However, a cut-off time of 200 fm/c has been used for the study of particle interferometry at mid-rapidity where the information of the last interactions is needed. It also takes a much longer time to reach hadron freeze-out at LHC due to the longer lifetime of the dense matter and the larger rapidity width, as can be seen from Fig. 2(b).

The AMPT model has been used to study many aspects of heavy ion collisions at RHIC, such as particle yields and momentum spectra [3], elliptic flow [2], two-meson interferometry [4, 5], flow of charm hadrons [6], and J/ψ productions [7]. For example, Fig. 1(a) shows the importance of final-state interactions, which significantly change the transverse momentum spectra of protons and bring the spectra close to the RHIC data. Fig. 1(b) shows that the large observed elliptic flows cannot be generated by hadronic interactions alone but can be accounted for by partonic interactions. It also shows that v_2 continues to increase significantly with the parton cross section, suggesting that the dense matter at mid-rapidity in Au+Au collisions at RHIC has not reached complete thermal equilibrium.

3. Further improvements

In order to reliably predict particle yields and describe the space-time evolution of heavy ion collisions, especially at LHC energies, the AMPT model is in urgent need for up-to-date parton distribution functions (PDFs) and their nuclear modifications, particularly at small-x. For example, at the top LHC energy a pair of 2 GeV back-to-back minijets at

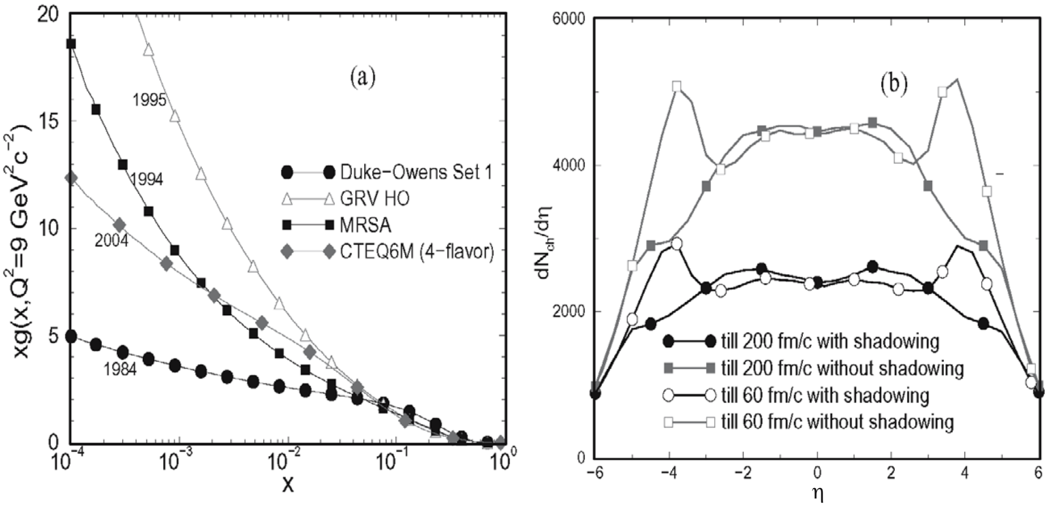


Figure 2. (a) Gluon distribution functions multiplied by the Bjorken-x at Q^2 = 9 GeV^2/c^2 for four parameterizations. The year of the publication of each parameterization is also given. (b) The default AMPT model with (circles) and without (squares) nuclear shadowing for central Pb+Pb collisions at 5.5 ATeV. Results with hadron cascade cut-off times of both 60 fm/c and 200 fm/c are shown.

mid-rapidity corresponds to initial partons at x ~ 0.0007, compared to x ~ 0.02 at RHIC. As a result, predictions from the AMPT model for heavy ion collisions at LHC energies suffer from significant uncertainties due to the old Duke-Owens PDFs currently implemented that severely underestimate parton distributions at small-x, as shown in Fig. 2(a). In addition, nuclear effects on parton PDFs are important at LHC. Figure 2(b) shows that, for central Pb+Pb collisions at 5.5 ATeV, including the nuclear shadowing effect decreases the default AMPT model prediction on $dN_{ch}/d\eta(\eta=0)$ from ~ 4500 to ~ 2500.

The description of quark coalescence for bulk hadronization in the AMPT model also needs to be improved. The current existence of two versions of the AMPT model (default and string melting) underlines the need for this improvement. Although the string melting model is more consistent with QCD expectations and has successes in describing the large elliptic flow [2] as well as the two-pion interferometry at RHIC [4], it does not work as well as the default model in describing the hadron spectra, and it even produces an artificial peak around mid-rapidity for protons and anti-protons [1]. Part of the reason is that the quark coalescence process in the AMPT model only starts after all parton interactions are complete, whereas it is more reasonable to start the quark coalescence at the density corresponding to the QCD phase transition. This also leads to an unwanted dependence of the effective equation of state in the model on the parton cross section [8] because, for example, the average parton density at parton freeze-out is lower for a larger parton cross section. Now we know more about the quark coalescence model [9] since our first implementation [2], so improving the quark coalescence description in the AMPT model is very much needed.

4. Summary

The AMPT model has been constructed for and applied to the study of the quark-gluon plasma created in heavy ion collisions at RHIC and LHC. It has demonstrated the importance of final state interactions in particle momentum spectra, the essential role of partonic interactions in the elliptic flow, and reasonable agreements with the radius parameters from the pion interferometry data at RHIC. In order to apply the AMPT model to LHC energies and better understand heavy ion collisions at RHIC, there is an urgent need to improve the model with up-to-date parton distribution functions for heavy nuclei and a better description of the quark coalescence process for the bulk hadronization of the partonic matter. This will allow the improved AMPT model to serve as a powerful transport tool for heavy ion studies at RHIC and LHC.

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