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Reconstructed jets in a multi-phase transport model

Guo-Liang Ma

Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China

Abstract

With a framework of a multiphase transport model, we studied various of properties of fully reconstructed jets, including dijet asymmetry, jet shape, jet fragmentation function, jet azimuthal anisotropy, and overall momentum balance of dijet events. Our studies concentrate on the stage evolution of these full jet observables in heavy-ion collisions. We demonstrate that the medium modification effect on these observables mainly arises from strong interactions between jet and partonic matter, with further slight modifications from hadronization and hadronic rescatterings. Our model results provide a dynamical understanding of jet transport process in high-energy heavy-ion collisions.

Keywords: jet energy loss, transport model, QGP

1. Introduction

In sufficiently high-energy heavy-ion collisions, Quantum Chromodynamics (QCD) predicts that hot and dense deconfined matter, commonly referred to as the Quark-Gluon Plasma (QGP), can be formed because of asymptotic freedom [1, 2]. Sufficient experimental evidences from the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC) support a strongly-interacting QGP has been created in the central nucleus-nucleus collisions. Jet is thought as a powerful probe to investigate the properties of formed hot and dense medium, because it has to pass through the medium and loss a significant amount of energy [3]. The jet quenching phenomenon has been originally observed with triggering the leading particles of jets, such as the disappearance of away-side peak in dihadron azimuthal correlation [4] and the suppression of nuclear modification factor [5]. On the other hand, the recent measurements on fully reconstructed jets provide a comprehensive characterization of jet quenching, such as a large dijet asymmetry [6, 7], the medium modifications of jet shape [8] and jet fragmentation function [9], a nonzero elliptic anisotropy of reconstructed jet [10], and overall momentum balance of dijet events [11]. These full jet measurements provide more treasurable information for understanding jet quenching mechanism.

In this work, we take advantage of a hybrid dynamical model, namely a multi-phase transport model (AMPT), to theoretically describe these full jet observables. Since heavy-ion collisions are dynamical evolutions which includes many important evolution stages, our work focuses on not only how these full jet observables are produced but also how they survive from different evolution stages. It hopefully contributes a helpful understanding to the whole jet quenching picture of high-energy heavy-ion collisions.

2. Jet simulations in the AMPT Model

The AMPT model with string melting mechanism is used to simulate jet transport in high-energy heavy-ion collisions [12]. It consists of four main stages of heavy-ion collisions: the initial condition, parton cascade, hadronization, and hadronic rescatterings. In order to increase simulation efficiency, a dijet is triggered in the initial condition based on HIJING model [13], where the high-p_T primary partons can pullulate to jet showers full of lower virtuality partons through initial- and final- state QCD radiations. The jet parton showers are then converted into clusters of on-shell quarks

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and anti-quarks through the string meting mechanism of AMPT model. After the melting process, both a quark and anti-quark plasma and jet quark showers are built up. In the following, Zhang's parton cascade (ZPC) model [14] automatically simulates the elastic partonic interactions between medium partons and jet shower partons with a cross section of 1.5 mb, but without including inelastic parton collisions at present. When all partons freeze out, they are recombined into medium hadrons or jet shower hadrons via a simple coalescence model. The final-state hadronic interactions between jet shower hadrons and hadronic medium can be described by a relativistic transport (ART) model [15]. We finally use the anti-k_t algorithm from the standard Fastjet package to reconstruct full jet observables, with same kinetic cuts as experiments did.

3. Results and Discussions

In order to see how the AMPT model can describe some basic properties of dijet events, Figure 1 presents the comparisons between the CMS experimental data and the AMPT results for Leading jet p_T distribution (Left plot) , dijet relative angle $\Delta\phi_{1,2}$ distribution (Middle plot) , and dijet asymmetry ratio $A_J = (p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$ distribution (Right plot) in central Pb+Pb collisions (0-10%) at 2.76 TeV. From the ratios of AMPT results to experimental data, we can see the AMPT model can give reasonable descriptions to the two distributions within at least a factor of three. But the two properties seems to be independent of whether parton interactions exist (1.5 mb) or not (0 mb). On the other hand, the dijet asymmetry ratio A_J distribution show a good sensitivity to the partonic interactions. We find that the CMS experimental data can be basically described by the AMPT model with a partonic interaction cross section of 1.5 mb, rather than 0 mb. This indicates that partonic interactions is the key to reproduce the observed dijet asymmetry in central Pb+Pb collisions [16].

However, heavy-ion collisions are dynamical evolutions which involve many important evolution stages. As the AMPT model is a hybrid model, it is capable of studying how dijet asymmetry is produced and developed at different evolution stages. Figure 2 presents the dijet asymmetry ratio A_J distributions at different evolution stages from the melting AMPT model. In the initial state, the dijet is produced based on the pQCD calculation in HIJING model, which basically shows a more symmetric p_T balance between leading jet and subleading jet. But the A_J distribution is distorted into an asymmetric one after parton cascade, because jet losses its energy through many elastic collisions when it passes through the formed medium. Ones can experimentally observe such a jet quenching signal, thanks to the fact that the dijet asymmetry A_J distribution can survive from the two following stages of hadronization and hadronic rescatterings [16].

Since jet interacts strongly with the surrounding hot and dense medium, it is interesting to investigate how its shape is modified by these strong interactions, with respect to the p+p case without the hot QCD medium. Figure 3 presents the differential jet shape ratio of most central Pb + Pb collisions (0-10%) to p+p collisions at different evolution stages in the melting AMPT model. In the initial state, two jet shapes are consistent with each other between p+p and Pb+Pb collisions. A large modification appears after the parton cascade process, which shows a suppression at small radius and an enhancement at large radius. It indicates that jet energy is redistributed towards a larger radius via the strong interactions between jet and the partonic medium. The coalescence process can tune the medium modification further, which tends to make the AMPT results much closer to the CMS data. Unfortunately, the final hadronic rescatterings leads to a little larger modification than the experimental data, which could be due to a larger smearing effect of resonance decays in our model [17].

When jet interacts with hot medium, the energies carried by these constitute shower particles should be modified or redistributed. The jet fragmentation function is supposed to measure the distribution of momentum component of charged particle along the jet axis inside the jet cone. Figure 4 presents the jet fragmentation function ratio of most central Pb + Pb collisions (0-10%) to p+p collisions at different evolution stages in the melting AMPT model. We see the ratio is consistent with unity in the initial state, implying no medium modification initially. After parton cascade, we see an enhancement at low ξ and a suppression at intermediate ξ, where ξ reflects the energy fraction carried by charged particle with the relation of $\xi = ln(1/z)$. The enhancement is because the energy loss from jets is more significant than that from leading-like partons, while the suppression is a result of the decrease of associated particles with intermediate p_T. However the shape is dramatically modified by coalescence, while final hadronic rescattering process does not change it very much. Compared to the CMS data, the AMPT result can not fit the data. We argued that it is possibly because of the missing of jet fragmentation which should contribute to jet hadronization as well. We proposed to study such a competition (coalescence vs fragmentation) by comparing the jet fragmentation function between charged pions and protons [18].