Transition From Ideal To Viscous Mach Cones In A Partonic Transport Model

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Abstract.

Using a partonic transport model we investigate the evolution of conical structures in ultrarelativistic matter. Using two different source terms and varying the transport properties of the matter we study the formation of Mach Cones. Furthermore, in an additional study we extract the two-particle correlations from the numerical calculations and compare them to an analytical approximation. The influence of the viscosity to the shape of Mach Cones and the corresponding two-particle correlations is studied by adjusting the cross section of the medium.

1. Introduction

In relativistic heavy-ion collisions at the relativistic heavy-ion collider (RHIC) and the Large Hadron Collider (LHC) a new state of matter, the Quark-Gluon Plasma (QGP), is supposed to be created. In these collisions highly energetic partons propagate through the hot and dense medium and rapidly lose their energy and momentum as the energy is deposited in the medium. Measurements of two- and three-particle correlations in heavy-ion collisions show a under certain circumstances a suppression of the away-side jet, whereas for lower p_T a double peak structure is observed in the two-particle correlation function. A promising origin of these structures was assumed to be the interaction of fast and high-energetic partons with the soft matter which generates collective motion of the medium in form of Mach cones [2].

For this purpose we investigate the propagation and formation of Mach cones in the partonic transport model BAMPS (Boltzmann Approach of MultiParton Scatterings) [4] in the limit of vanishing mass and very small shear viscosity over entropy density ratio η/s of the matter. Two different scenarios for the jet are used. By adjusting η/s the influence of the viscosity on the profile of the Mach cone and the corresponding two-particle correlation is studied for the first time. The results presented here are based on a recent publication [5].

2. Shock Waves and Mach cones

Shock waves are phenomena which have their origin in the collective motion of matter. In a simplified one-dimensional setup shock waves have already been studied within the framework of BAMPS for the perfect fluid limit [6, 7]. Furthermore BAMPS calculations have demonstrated

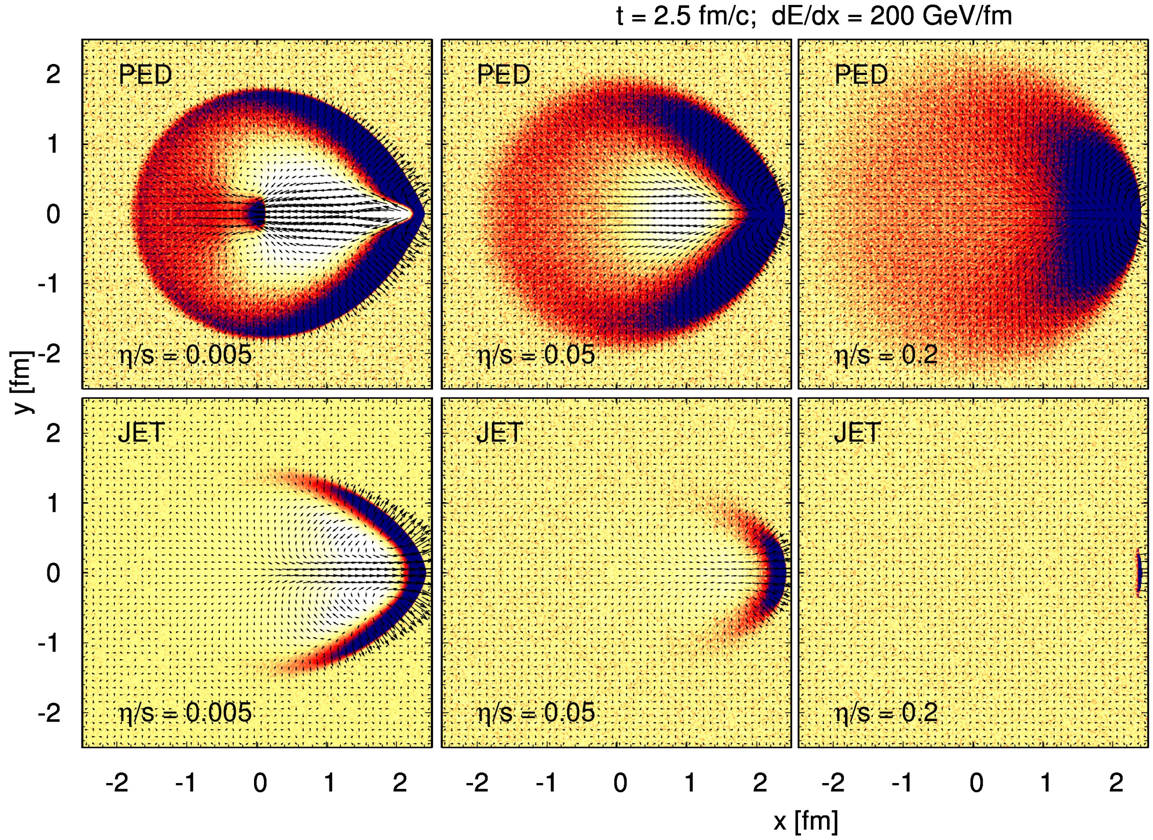

Figure 1. (Color online) Transition from ideal to viscous Mach cones. Shape of a Mach cone shown for different jet scenarios and different viscosity over entropy density ratios, $\eta/s = 0.005$, 0.05 and 0.5. The energy deposition is $dE/dx = 200$ GeV/fm. The upper panel shows the pure energy deposition scenario (PED); the lower panel shows the propagation of a highly energetic jet (JET) depositing energy and momentum in x-direction. Depicted are the LRF energy density within a specific range; as an overlay we show the velocity profile with a scaled arrow length. The results are a snapshot of the evolution at $t = 2.5$ fm/c.

that the shock profile is smeared out when viscosity is large. It was also found that a clear observation of the shock within the short time available in HIC requires a small viscosity.

In the following we study the evolution of "Mach cone"-like structures with different scenarios of the jet-medium interaction by using the parton cascade BAMPS. We focus on investigation of Mach cone evolution in absence of any other effects - i.e. we neglect such effects as initial fluctuations or expansion, which are however relevant in HIC. We use a static box with $T_{\rm med} = 400$ MeV and binary collisions with an isotropic cross section. Furthermore, we keep the mean free path $\lambda_{\rm mfp}$ of the medium particles constant in all spatial cells by adjusting the cross section according to $\sigma = 1/(n\lambda_{\rm mfp})$, where n is the particle density. The related shear viscosity for isotropic binary collisions is given by $\eta = 0.4\, e\, \lambda_{\rm mfp}$ [8].

The Mach Cones studied here are induced by two different sources. The first of them we refer to as the pure energy deposition scenario (PED) [9]. This is simulated by a moving source depositing momentum end energy isotropically according to the thermal distribution $f(x,p) = \exp(-E/T)$. The second source we refer to as JET. This is simulated by a highly massless particle (jet) which has only momentum in x-direction, i.e. $p_{\rm x} = E_{\rm jet}$. After each

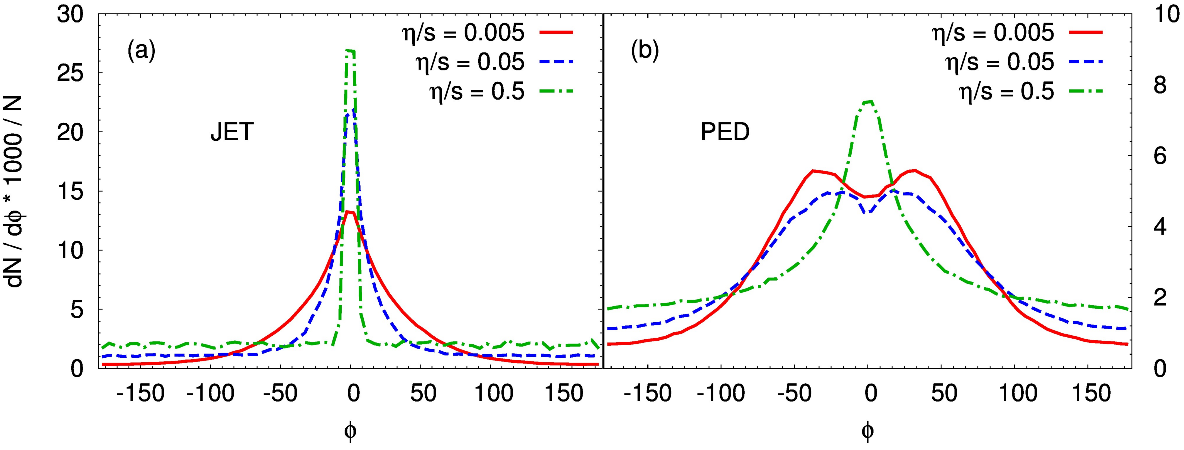

Figure 2. (Color online) Two-particle correlations $dN/(Nd\phi)$ for different viscosities extracted from calculations shown in Fig. 1. The results are shown in the for the JET (a) and PED (b) scenario for $dE/dx = 200$ GeV/fm.

timestep the energy of the jet particle is reset to its initial value. For both scenarios the sources are initialized at $t = 0$ fm/c at the position $x = -0.1$ fm and propagate in x-direction with $v_{\rm source} = 1$, i.e. with the speed of light.

In Fig. 1 we show the Mach Cone structure for both PED scenario (upper panel) and JET scenario (lower panel) with $\eta/s = 0.005$, 0.05 and 0.5 from left to right, respectively. We show a snapshot at $t = 2.5$fm/c. The energy deposition rate is fixed to $dE/dx = 200$ GeV/fm. Although this rather high energy deposition is not expected to be produced by any known energy-loss process in current heavy-ion collisions, this rate is necessary in order to observe possible double-peak structures in corresponding two-particle correlations.

In both scenarios, PED and JET, for $\eta/s = 0.005$ (left panel), we observe a conical structure, but with obvious differences. The PED case with the isotropic energy deposition induces a spherical shock into back region; this structure is missing in the JET scenario because of the high forward peaked momentum deposition. Another difference is that in the JET scenario a clearly visible head shock appears. This in turn is missing in the PED scenario. Furthermore a (anti)-diffusion wake is induced by the JET (PED) scenario.

Adjusting the shear viscosity over entropy density ratio $\eta/s = 0.05 - 0.5$ we observe a smearing out of the Mach cone structure. For a sufficient high $\eta/s = 0.5$ the conical structures in both scenarios disappear. This is true for shock fronts as well as for the (anti-) diffusion wake. The difference between the PED and the JET case is that as η/s increases, in the PED scenario the resulting "Mach cone" solution covers approximately the same spatial region regardless of a value of η/s, while in the JET case the structure is concentrated more and more near the projectile as the viscosity increases.

In Fig. 2 we show the two-particle correlations extracted from BAMPS calculations of the Mach Cones shown in Fig. 1. For the JET scenario (a) and sufficiently small $\eta/s = 0.005$ we observe only a peak in direction of the jet. The typical double peak structure, which has been proposed as a possible signature of the Mach cone in HIC, can only be observed for the PED scenario (b) and small η/s. However, the PED scenario has no correspondence in heavy-ion physics. For the JET scenario, which is a simplified model of jets depositing energy and momentum, a double peak structure never appears. This is due to the strong formation of a head shock and diffusion wake.

3. Summary and Conclusions

In this work we investigated the evolution of Mach cones induced by two different source terms, PED and JET, using a partonic transport model. The studies were performed in a static system, neglecting effects coming from initial fluctuations and expansion. The development of Mach cones is observed in case the viscosity of matter is small enough. In addition, the effects of viscosity of the matter were shown by adjusting the shear viscosity over entropy density ratio η/s from 0.005 to 0.5. A clear and unavoidable smearing out of the profile depending on a finite ratio of shear viscosity to entropy density is clearly visible. Investigating the corresponding two-particle correlations we see that Mach cones can not be connected to double peak structures by any realistic picture of jets in HIC. A further investigation using more realistic jets in an expanding system is under way.

Acknowledgements

The authors are grateful to the Center for the Scientific Computing (CSC) at Frankfurt for the computing resources. A.E. was supported by BMBF. This work was supported by the Helmholtz International Center for FAIR within the framework of the LOEWE program launched by the State of Hesse.

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