TRANSITION FROM IDEAL TO VISCOUS MACH CONES IN BAMPS*

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We investigate in a microscopical transport model the evolution of conical structures originating from the supersonic projectile moving through the matter of ultrarelativistic particles. Using different scenarios for the interaction between projectile and matter, and different transport properties of the matter, we study the formation and structure of Mach cones. Furthermore, the two-particle correlations for different viscosities are extracted from the numerical calculations and we compare them to an analytical approximation. In addition, by adjusting the cross section we investigate the influence of the viscosity to the structure of Mach cones.

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1. Introduction

Highly energetic partons propagating through the hot and dense QGP 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 complete suppression of the away-side jet, whereas for lower p_{T} a double peak structure is observed in the two-particle correlation

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function [1]. One possible and promising origin of these structures is assumed to be the interaction of fast partons with the soft matter which generates collective motion of the medium in form of Mach cones [2, 3].

For this purpose we investigate the propagation and formation of Mach cones in the microscopic 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. In addition, by adjusting η/s, the influence of the viscosity on the profile of the Mach cone and the corresponding two-particle correlation is explored for the first time. The results presented 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 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 $T_{\rm med} = 400\,{\rm MeV}$ 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 is 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 is JET. This is simulated by a highly massless particle (jet) which has only momentum in x-direction, *i.e.* $p_x = E_{\rm jet}$. After each 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 $t = 2.5\,\mathrm{fm}/c$. The energy deposition rate is fixed to $dE/dx = 200\,\mathrm{GeV/fm}$. 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.

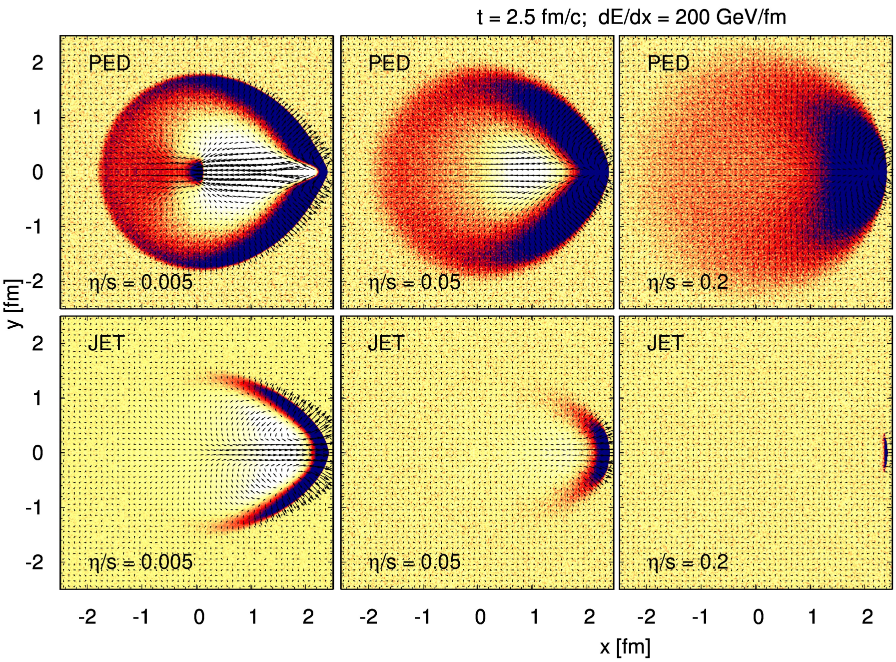

Fig. 1. (Color online) Transition from ideal to viscous Mach cones. Shape of a Mach cone shown for different jet scenarios and different viscosity over entropy density ratios, $\eta/s = 0.005$, 0.05 and 0.5. The energy deposition is $dE/dx = 200\,\mathrm{GeV/fm}$. The upper panel shows the pure energy 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 $t = 2.5\,\mathrm{fm}/c$.

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 structure in both scenarios disappears. 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.

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.

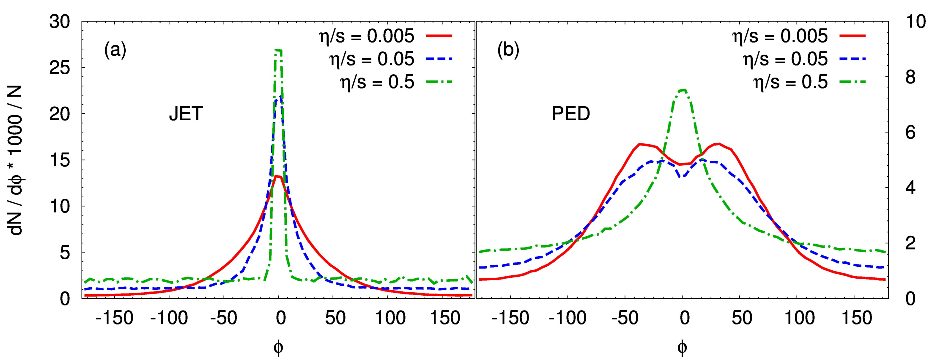

Fig. 2. (Color online) Two-particle correlations $dN/(Nd\phi)$ for different viscosities extracted from calculations shown in Fig. 1. The results are shown for the JET (a) and PED (b) scenario for $dE/dx = 200\,\mathrm{GeV/fm}$.

3. Conclusions

In summary, the evolution of Mach cones induced by two different source terms, PED and JET, were investigated using a microscopic transport model. The development of Mach cones is observed in the 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 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 cannot be connected to double peak structures by any realistic picture of jets in HIC.

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