Investigation of Mach cones and the corresponding two-particle correlations in a microscopic transport model

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Abstract. We investigate the evolution Mach cones in ultra-relativistic heavy-ion collisions within a microscopic transport model. Using smooth initial conditions and central collisions the jet-medium interaction is studied using highly-energetic jets and various values of the shear viscosity over entropy density ratio, η/s, of the matter. We observe the formation of Mach cones for small shear viscosity over entropy density ratio, η/s, while for larger values of η/s the characteristic structures smear out and eventually vanish. We extract the final azimuthal two-particle correlation from the final gluon distribution. A double-peak structure shows up if, in a single event, the jet propagates in the direction opposite to the radial flow. This indicates that the contribution from the head shock and from the diffusion wake is superimposed by the radial flow and the contribution of the Mach-cone wings can show up. Considering the superposition of many different jet paths in a central heavy-ion collision, a double-peak structure also appears. The double-peak structure then originates mostly from a superposition of deflected jet-induced Mach cones with the contribution originating from head shock and diffusion wake. A large value of the shear viscosity over entropy density ratio destroys the double-peak structure for any scenario.

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 complete suppression of the away-side jet, whereas for lower p_T a double peak structure is observed in the two-particle correlation function [1]. One possible origin of these structures were 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, 4, 5, 6, 7, 8, 9]. Although today the most promising explanation for this phenomenon is due to fluctuating initial conditions [10], we address here the question whether the jet-induced Mach cones can still be considered as possible candidates.

In a previous work [11] we demonstrated in BAMPS the transition of Mach cones from perfect fluid limit to the highly viscous regime by adjusting the shear viscosity over entropy density ratio η/s. For this purpose we used a simplified setup of a static box in order to investigate the pure

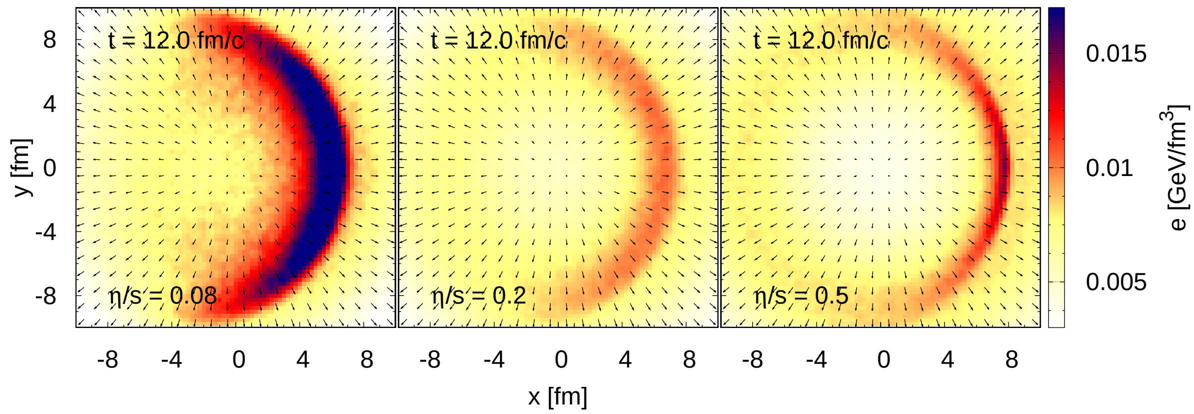

Figure 1. Preliminary results. Shape of a Mach cone in a single event in central ultrarelativistic heavy-ion collisions within BAMPS. We show a snapshot at $t = 12$ fm/c for different values of the shear viscosity over entropy density ratio, η/s. The initial jet energy is $E_{\text{jet}} = 20$ GeV. Depicted is the LRF energy density within a specific range. As an overlay we show the velocity profile as arrows with a scaled length arrow.

evolution of a Mach cone. Using two different source terms with an infinite energy reservoir we have shown, that the double peak structure in extracted two-particle correlations appears only, if the source deposits only energy, but no momentum. However, this only holds if in addition the energy deposition is large enough. Furthermore, a finite shear viscosity over entropy density ratio η/s can destroy this double peak structure.

Although this source term with only energy but no momentum deposition was able to explain under some circumstances the double peak structure in extracted two-particle correlations, the physical motivation for this source term is weak, since its properties does not fit in the usual picture of a jet assumed in heavy-ion collisions. Therefore, the origin of such a double peak structure observed in heavy-ion collision is most probably not the source alone, but maybe medium effect, such as the expansion of the medium. Furthermore, due to the infinite energy in our previous setups, the source never stopped, which also may have an effect of the final results.

In this proceeding we demonstrate first preliminary results using a more realistic setup in order to describe the evolution of jet-induced Mach cones in relativistic collisions of heavy-ions using the microscopic transport model BAMPS. For this purpose we use smoothed Glauber initial conditions for binary collisions only in the transverse direction [12]. For this study we want to focus on the impact of the longitudinal and radial flow on the jet only and thus we neglect additional effects like local density fluctuations. Moreover, we consider only central $Au + Au$ collisions ($b = 0$ fm) at RHIC energies, which results in neglecting effects originating from elliptic flow, v_2, or higher harmonics. We further study the influence of the shear viscosity over entropy density ratio, η/s, on the final results. We use only binary collisions with an isotropic angle distribution. The jet is initialized at midrapidity with $E_{\text{jet}} = 20$ GeV and looses its energy only via binary scatterings.

Since the microscopic transport model BAMPS has no effective hadronization process implemented yet, the final particle distribution is obtained by stopping the simulation at a certain time and extracting the hydrodynamic quantities as well as the two-particle correlations from the final gluon-momentum distribution.

In Fig. 1 we discuss our first scenario of a single jet event a central heavy-ion collision. The initial position of the jet is at $x = -4$ fm and $y = 0$ fm with initially only momentum in x-direction. We perform calculations with different values of the shear viscosity over entropy

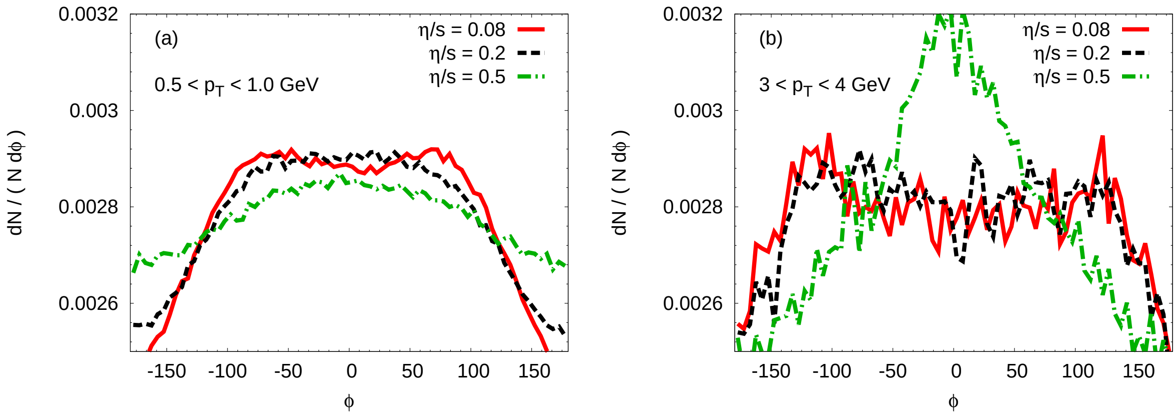

Figure 2. Preliminary results. Two-particle correlations, $\mathrm{d}N/(N\mathrm{d}\phi)$, extracted from BAMPS calculations using several values of η/s in a single event. The results are shown for several regions of p_T and at fixed time $t = 12$ fm/c.

density ratio which reflect possible strengths for the medium interactions expected in HIC. Depicted is the LRF energy density within a specific range. As an overlay we show the velocity profile as arrows with a scaled length arrow. We show a snapshot at $t = 12$ fm/c (Note that the energy density is obviously lower than the expected energy density for deconfined matter. The further evolution when the decondined matter should have already hadronized when the critical energy density is reached does not affect ponderable our final conclusions taken from these calculations). We clearly observe the development of a shock wave in form of Mach cone for a small value of the shear viscosity over entropy density ratio, $\eta/s = 0.08$. However, the shock front is strongly curved, which is due to the strong jet quenching. Increasing the value of η/s results into a smearing out of the profile, while for $\eta/s = 0.5$ the Mach cone structure is very diffuse and vanishes. The vanishing Mach cone structure is analogous to the work done in [11].

As demonstrated in [11] the strong contribution of head shock and diffusion wake in a static box scenario prevents the observation of a double-peak structure originating from the Mach cone wings. However, in this scenario shown in Fig. 1 of a single event, the initial jet propagates in opposite direction to the radial flow of the expanding medium in the heavy-ion collision. This interplay of the medium with the jet strongly affects the final distribution of particles and is the strongest for small values of the shear viscosity. Thus, the contribution of head shock and diffusion wake is reduced.

For this purpose we inspect the extracted normalized azimuthal particle distribution, $\mathrm{d}N/(N\mathrm{d}\phi)$, in Fig. 2. Using different cuts in p_T we demonstrate that a double-peak structure develops for several regions of p_T, and a rather small value for the shear viscosity over entropy density ratio, η/s. For $\eta/s = 0.08$ and $0.5 < p_T < 1$ GeV, as shown in the left panel of Fig. 2, a double-peak structure is observable. We assume that the contribution of head shock and diffusion wake is indeed compensated by the radial flow and the contribution from the Mach cone wings show up. The appearing peaks are approximately at $\phi \approx \pm 70^\circ$. However, for larger transverse momentum, i.e., $3 < p_T < 4$ GeV, and for $\eta/s = 0.08$ and 0.2 again a double-peak structure appears but the peaks move to approximately at $\phi \approx \pm 120^\circ$. In this case we suggest that this contribution comes from the region of the diffusion wake, where matter flows into the region of lower pressure and energy density. Finally, the head-shock contribution for $\eta/s = 0.5$ is very strong and not reduced by the radial flow.

In Fig. 3 we show the results, where we average over all possible jets with randomly chosen

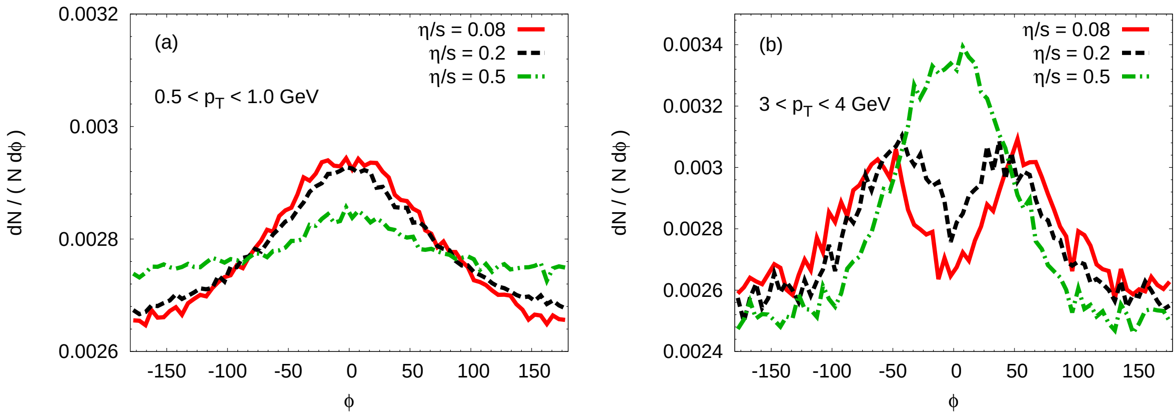

Figure 3. Preliminary results. Two-particle correlations, $\mathrm{d}N/(N\mathrm{d}\phi)$, extracted from BAMPS calculations using several values of η/s. In this scenario we average over several jet paths, i.e., we consider many different events. The results are shown for several regions of p_T and at fixed time $t = 12$ fm/c.

starting positions. In contrast to the above scenario for a single event this scenario gets closest to the experimental situation as many different events are considered. In the left panel of Fig. 3 we show the normalized azimuthal particle distribution for $p_T = 0.5 - 1$ GeV. We do observe a double-peak structure for any value of the shear viscosity over entropy density ratio, η/s. In contrast, for $p_T = 3 - 4$ GeV, as demonstrated in the right panel of Fig. 3, a double-peak structure appears for sufficiently low $\eta/s = 0.08 - 0.2$. The peaks are approximately at $\phi \approx 50°$. In this scenario the double-peak structure originates mostly from a superposition of deflected jet-induced Mach cones with the contribution originating from head shock and diffusion wake [13].

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