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Jet-induced modifications of the characteristic of the bulk nuclear matter

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Jet–induced modifications of the characteristic of the bulk nuclear matter

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Abstract. We present our studies on jet–induced modifications of the characteristics of bulk nuclear matter. To describe such matter, we use efficient relativistic hydrodynamic simulations in (3+1)-dimension, employing the Graphics Processing Unit (GPU) in the parallel programming framework. We use Cartesian coordinates in the calculations to ensure a high spatial resolution that is constant throughout the evolution of the system. We show our results on how jets modify the hydrodynamics fields and discuss the implications.

1. Simulation setup

The dynamics of the bulk matter is simulated using the ideal relativistic hydrodynamic equations with a source term [1]

$$\partial_\mu T^{\mu\nu} = \partial_\mu \left((e+p)u^\mu u^\nu - p g^{\mu\nu}\right) = S^\nu, \tag{1}$$

where $u = u(x)$ represents a conserved variable, which includes energy, momentum, and charge densities. The source term represents energy deposited by jets in the system, and it is defined as

$$S^\nu(\vec{x}) = \sum_{i=1}^{n_{jet}} \left(-\frac{\mathrm{d}E}{\mathrm{d}t}, -\frac{\mathrm{d}\vec{M}}{\mathrm{d}t}\right) \delta^{(3)}(\vec{x} - \vec{x}_i(t)), \tag{2}$$

where n_{jet} is the number of jets. We implemented several algorithms for solving the problem, including WENO [2] (5^{th} and 7^{th} order) and Musta-Force [3]. We use 7^{th} order WENO, which has proven to have high performance and good quality in test problems with steep gradients. The numerical scheme is integrated over time using the 3^{rd} order Runge-Kutta algorithm.

The energy loss of jets propagating through the bulk nuclear matter is described by using two mechanisms, radiation of gluons and collisions of partons in a dense medium, and is given by

$$\left(-\frac{\mathrm{d}E}{\mathrm{d}x}\right) = \kappa_{rad}\frac{C_R}{C_F}T^3 x + \kappa_{coll}\frac{C_R}{C_F}T^2, \tag{3}$$

where T is local temperature and $\kappa_{rad}, \kappa_{coll}, C_R, C_F$ coefficients depend on jet flavor (quark or gluon) and its energy [4]. In the simulations, we assumed $\kappa_{rad} = 4, \kappa_{coll} = 2.5, C_R/C_F = 1$. We assume that $\frac{\mathrm{d}E}{\mathrm{d}x}$ is small compared to the jet energy, and the jet is not modified by the medium.

The code is written using NVIDIA CUDA programming framework purposed for parallel computing on graphical processing units (GPU). Our implementation [5, 6, 7, 8] speeds up more than two orders of magnitude in comparison to the equivalent CPU execution.

2. Results

We simulated propagation and energy loss $\left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)$ of a high-energy parton through the medium and analyzed the evolution of the system. The initial condidtions were based on ellipsoidal flow [9] with initial simulation time $t_0 = 1$ fm/c.

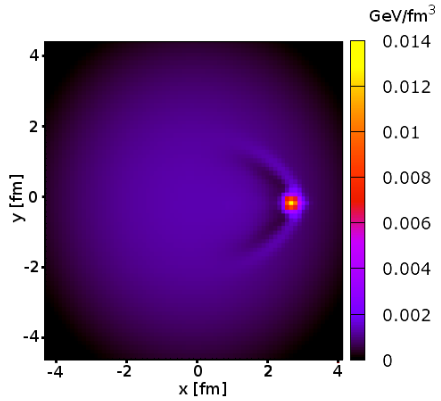

Figure 1. Energy density in plane xy at $z = 0$ after $t = 2.4$ fm/c.

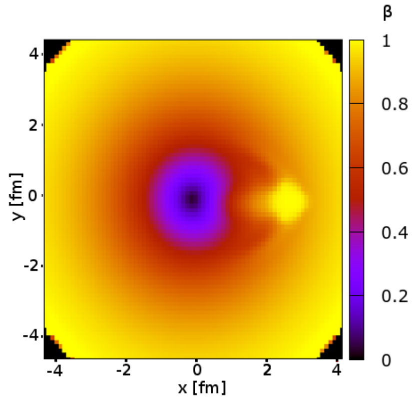

Figure 2. Velocity profile in plane xy at $z = 0$ after $t = 2.4$ fm/c.

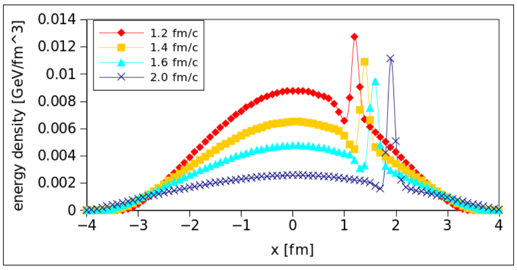

Figure 3. Evolution of the system: energy density 1D sections at $y = z = 0$ at different points of time (from 1.2 fm/c to 2 fm/c after simulation start). Simulation parameters: $\mathrm{d}x = 0.1$ fm, $\mathrm{d}t = 0.02$ fm/c, grid size $256 \times 256 \times 256$, EOS $p = e/3$.

In figures 1 and 2, there is a clean signal of jet propagation in the medium, a Mach cone is visible both in energy and velocity distributions. Figure 3 shows the evolution of energy density with time. There is a clear indication that jet energy loss has a significant impact on the system. The area where the jet interacted with the system has much larger energy density compared to the surrounding matter and the difference increases with time.

In the future, we plan to employ more realistic jet energy loss algorithm and add freeze–out to study the effect on the experimental observables: elliptic flow and higher flow harmonics.

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