Signatures of medium flow imprinted on QCD jets

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We have investigated the effects of medium flow on QCD jets. The motivation for this study is the paradigm of using QCD jets in nucleus-nucleus collisions as probes of the Quark-Gluon Plasma (QGP) formed in these collisions at high energies. In many state-of-the-art calculations the QGP background is modeled in a simplistic way with a medium that is static and at most has a temperature profile changing as a function of time. More realistic descriptions of QGP using relativistic fluid dynamics, even including event-by-event fluctuations, reveal a complex pattern of collective behavior of QGP described by a flow field.

We have used the JETSCAPE event generator [1], and specifically the shower Monte Carlo codes MATTER (for large virtuality partons) and LBT (for low virtuality partons) to study the effect of transverse flow systematically. Transverse here refers to a flow field that is tranverse to the axis of the jet, i.e. coming "from the side" from the point of view of the jet shower partons. Such a scenario would, e.g., be realized for a jet at forward or backward rapidity being exposed to the global longitudinal flow in system of colliding nuclei. Another possible scenario is a jet emitted tangentially and experiencing the global radial flow. In both of these cases the flow is then transverse to the direction of the jet.

In JETSCAPE flow is incorporated in jet quenching by boosting a quark or gluon into the local rest frame of its ambient medium, applying well established MATTER or LBT processes in that frame, and boosting all final particles back into the lab frame. For a systematic study we use a QGP "brick" medium in which temperature, size and the transverse flow speed can be varied. We find that transverse flow affects soft and semi-hard particles in the shower, by imparting momentum in the direction of the flow. In other words, momentum kicks from the ambient medium exhibit a preferred direction. This motivates our suggestion to analyze the azimuthal structure of jets.

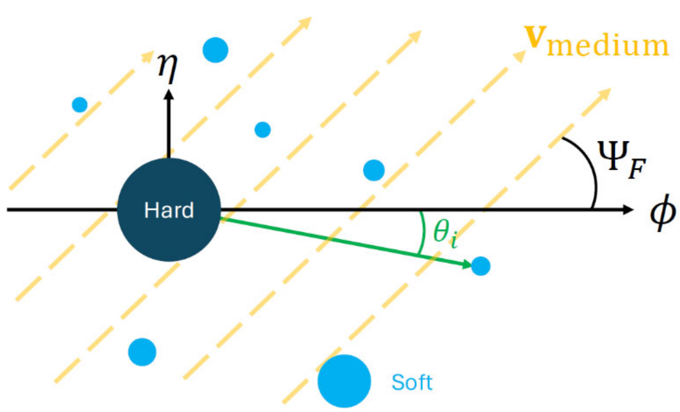

Fig. 1. A sketch of situation analyzed in this work. A jet has been reclustered into small-radius subjets. Using the hardest subjet as a reference, we investigate the azimuthal distribution of softer subjets in the $\boldsymbol{\eta-\phi}$-plane. The ambient medium provides a background flow given by velocity $\mathbf{v}_{\mathbf{medium}}$.

Concretely, we recluster jets into subjets with small jet radius, here R=0.1, and identify the hardest sub jet as a reference, see Fig. 1. We then analyze the q-vectors [2] of softer subjets in a suitable range, here 2-10 GeV, jet-by-jet. The q-vectors for n=1 and 2, which are sensitive to dipole and quadrupole deformations, are of particular interest. As a second step, one can define an analogue to an "event plane" for the jet deformations given by an angle ψ_n [2]. The angle indicates the preferred direction for the dipole and quadrupole deformations, which we expect to be given by the direction of the flow vector. Fig. 2 shows that this is indeed the case. We confirm that both dipole and quadrupole deformations exist when transverse flow is present, and that their direction is aligned well with the direction of the flow velocity vector. The correlation between deformation and flow angle grows with the size of the flow velocity. This discovery could open a path to determining medium flow patterns using jets as probes.

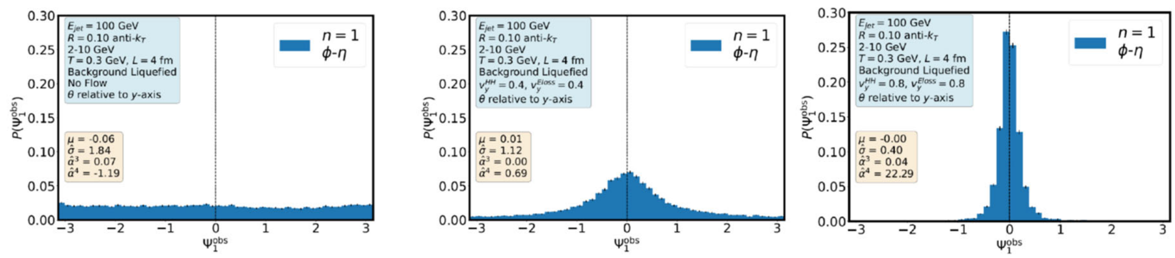

Fig. 2. Distribution of "event plane" angles ψ_1 for dipole deformations of jets computed from the q_1-vectors for three different transverse flow velocities: 0, 0.4 and 0.8 (left to right). There is no preferred direction without flow, and a strong correlation with flow, growing with the flow velocity. The flow angle is set to ψ=0 for simplicity.

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[1] The JETSCAPE 3.6x and XSCAPE 1.2.x packages, https://github.com/JETSCAPE

[2] A.M. Poskanzer and S.A. Voloshin, Methods for analyzing anisotropic flow in relativistic nuclear collisions. Phys. Rev. C **58**, 1671 (1998).

[3] A. Sengupta and R.J. Fries, Deformation of Jets Induced by Ambient Medium Flow, arXiv:2505.14928