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Studies of the difference between light and heavy flavor energy loss by reconstructed jets

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Abstract

While the nuclear modification factor R_{AA} of charged hadrons measures jet quenching in terms of the suppression of single inclusive particle spectra, studies employing reconstructed jets additionally allow the investigation of medium modifications to the initial parton shower as a whole and thereby provide information about the angular dependence of jet quenching. Furthermore, due to mass effects the energy loss of jets is expected to be sensitive to the flavor of the shower-initiating parton. For investigating the medium modification of parton showers, we employ the transport approach BAMPS, which numerically solves the (3+1)D Boltzmann equation for gluons, light and heavy quarks based on pQCD cross sections for both $2 \rightarrow 2$ and $2 \leftrightarrow 3$ processes. While employing an improved Gunion-Bertsch matrix element together with a running coupling, BAMPS simulations show a good agreement with data for both R_{AA} and the elliptic flow v_2. We review recent results about the R_{AA} of inclusive and b-tagged reconstructed jets and the modification of its underlying jet shapes.

Keywords:
jet quenching, heavy quarks, reconstructed jets, nuclear modification factor, jet shapes

1. Motivation

Proposed by Bjorken in the early 1980s[1], *jet quenching* became one of the most prominent signals for investigating the properties of the quark-gluon plasma produced in ultra-relativistic heavy-ion collisions. Jet quenching refers to the effect that when energetic partons, produced early in hard nucleon-nucleon collisions, subsequently traverse the hot and dense matter, they lose momentum and the structure of their surrounding quantum-chromodynamical (QCD) parton shower gets modified. The momentum loss of leading partons was measured in both $\sqrt{s}_{\mathrm{RHIC}} = 200$ AGeV Au + Au collisions at the Relativistic Heavy-Ion Collider (RHIC) [2, 3] and in $\sqrt{s}_{\mathrm{LHC}} = 2.76$ ATeV Pb + Pb collisions at the Large Hadron Collider (LHC) [4, 5] by the nuclear modification factor,

$$R_{AA} = \frac{\mathrm{d}^2 N_{\mathrm{AA}}/\mathrm{d}p_T \mathrm{d}y}{N_{\mathrm{bin}}\, \mathrm{d}^2 N_{\mathrm{pp}}/\mathrm{d}p_T \mathrm{d}y}\,, \tag{1}$$

which is defined as the ratio between single inclusive hadron spectra measured in heavy-ion collisions and scaled p + p reference spectra.

Nowadays, the larger collision energies at the LHC allow a reliable discrimination of jets and their underlying background medium and thereby studying jet quenching in terms of reconstructed jets. Jet reconstruction aims to group particles together in order to characterize the initial shower-initiating parton. This allows to not only investigate the momentum loss of the leading parton but also the in-medium modification of its surrounding parton shower. Results about this medium modification of reconstructed jets at LHC show both a momentum asymmetry between the leading and subleading jets [6, 7, 8] together with a strong suppression

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measured by the nuclear modification factor R_{AA} of reconstructed jets [9, 10].

Furthermore, the mass dependence of jet quenching can be studied by heavy-flavor tagged jets—jets that are close in angle to a heavy-flavor parton/hadron—and may provide further information about the underlying energy loss mechanisms. First studies [11, 12, 13] showed a suppression of beauty-tagged (b-tagged) jets that is surprisingly similar to the inclusive jet R_{AA}. In this proceeding we review our recent progress in understanding the medium modification of both light and heavy-flavor jets within the partonic transport approach BAMPS (Boltzmann Approach to Multi-Parton Scatterings) [14]. To this end, we study the R_{AA} of inclusive and b-tagged reconstructed jets in 0-10% Pb + Pb collisions at $\sqrt{s}_{\mathrm{LHC}} = 2.76\,\mathrm{ATeV}$[14]. Furthermore, we discuss the medium modification of jet shapes [15], defined as

$$\rho(r) = \frac{1}{\delta r} \left\langle \frac{\sum_{\text{partons} \in [r_a,\, r_b)} p_T^{\text{parton}}}{p_T^{\text{jet}}} \right\rangle_{\text{jets}} \quad (2)$$

for reconstructed b-tagged jets in LHC collisions and compare them with results for the inclusive jet shapes by CMS [15]. After normalizing the jet shapes between $r \in [0, R = 0.3]$ to unity, $\rho(r)$ represents the fraction of jet momentum in an angle between $r - \delta r/2$ at r and $r + \delta r/2$ to each jet axis.

2. Reconstructed jets within BAMPS

The partonic transport approach BAMPS describes the QGP created in ultra-relativistic heavy-ion collisions by numerically solving the 3+1 D Boltzmann equation,

$$p^\mu \partial_\mu f(\mathbf{x}, t) = C_{22} + C_{2\leftrightarrow 3}\,, \quad (3)$$

for gluons as well as light and heavy quarks by employing a stochastic test-particle Ansatz [16]. While both the gluons and light quarks (flavor u,d,s) are treated as massless particles, the masses of heavy quarks (flavor c,b) are set to $M_c = 1.3\,\mathrm{GeV}$ and $M_b = 4.6\,\mathrm{GeV}$. By evaluating the running of the QCD coupling on a microscopic level, BAMPS considers both elastic and radiative Bremsstrahlung processes: elastic matrix elements that are derived from leading-order pQCD and inelastic matrix elements calculated in an improved Gunion-Bertsch approximation [17] that was recently extended also to massive particles [18]. This procedure allows an equal treatment of massless and massive partons while any potential mass effect results directly from the underlying pQCD matrix element. The important Landau-Pomeranchuk-Migdal effect [19] corresponding to a suppression of coherent gluon emissions is effectively treated via a theta function $\theta(\tau - X_{\mathrm{LPM}}\lambda)$ in the inelastic matrix elements, where τ is the formation time of the emitted gluon, λ is the mean free path of the emitting parton, and the free parameter X_{LPM} is fixed to $X_{\mathrm{LPM}} = 0.3$ by a comparison with the neutral pion R_{AA} data from RHIC [20, 18]. For more details about the BAMPS framework and recent results we refer to Refs. [16, 21, 20, 18].

Reconstructed jets are sensitive to the medium modification of both the leading parton and its surrounding shower. Following previous studies about the momentum imbalance A_J of reconstructed jets [8, 14], we employ the event generator PYTHIA for the initial distribution of parton showers. For the b-tagged jet results we select only events originating from a hard b-quark pair production process. The parton showers are spatially distributed by a Glauber modeling with a Woods-Saxon density profile and after their formation time subsequently evolved within expanding BAMPS simulations of $\sqrt{s}_{\mathrm{LHC}} = 2.76\,\mathrm{ATeV}$ collisions with impact parameter $b = 3.6\,\mathrm{fm}$ corresponding to 0-10% centrality and reconstructed by the anti k_t algorithm as provided in the package FastJet [22].

3. Results

In Fig. 1[14] we present the nuclear modification factor R_{AA} of inclusive (left panel) and b-tagged jets (right panel) as calculated within BAMPS in comparison with the corresponding experimental data from the LHC. The inclusive jet suppression resulting from gluon and light quark jets seems too strong in comparison with data for both employed radii $R = 0.2$ and $R = 0.4$. Since BAMPS simulations for the single hadron R_{AA} shows a realistic energy loss of the leading parton [20], this finding indicates that the radiated gluons are transported too far away from the respective jet axis within BAMPS.

In the right panel of Fig. 1[14] we present our results for the suppression of b-tagged jets. The suppression of b-tagged jets while employing $R = 0.3$ is slightly less than the suppression of inclusive jets, but still compatible with the experimental data. In order to investigate the actual mass effect of the jets during the BAMPS evolution we show by the green line simulations where we initialize a b-quark shower within PYTHIA but consider the beauty quark as massless during the subsequent BAMPS evolution. Since both lines are similar we infer that the different suppression of light and