Measurement of D^0 meson tagged jets in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

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Abstract. In this contribution, we report the measurement of D^0 meson tagged jets in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV by the STAR experiment at RHIC. We present the nuclear modification factor R_{CP} as a function of the jet transverse momentum and transverse momentum fraction of the jet, carried by D^0 meson along the jet axis z_{Jet}, and the radial profile of the D^0 meson. These results are compared to theoretical predictions provided by a hybrid transport model. Additionally, we show the raw measurement of several generalized angularities λ_α^κ, which describe the jet substructure. These results may help distinguish between different models describing jet quenching and heavy flavor quark in-medium energy loss.

1 Introduction

The Quark-Gluon Plasma (QGP) produced in heavy-ion collisions can be studied using hard probes, such as c- and b-quarks created at the initial collision stage before the QGP is formed. The heavy quarks lose energy via the radiation of gluons and scattering with other partons present in the QGP. The radiation creates a cone-shaped spray of particles generally called a jet. The presence of the medium broadens the parton shower compared to p+p collisions or peripheral heavy-ion collisions where the creation of the QGP is not expected.

The interaction of quarks with the medium is mass-dependent. This is due to a phenomenon known as the dead-cone effect, predicted by the theory of quantum chromodynamics (QCD) and later observed by ALICE collaboration [1]. The dead-cone effect suppresses the emission of gluons within a cone of angular size m_q/E_q where m_q and E_q are mass and energy of a given quark, respectively.

The broadening of the jets in the medium in Pb+Pb collision to p+p collisions was observed at the LHC. The centrality-dependent modification of the jet shape nuclear modification factor as a function of radial distance from the jet axis reveals the different shower evolution in the presence of the QGP [2]. The other observable characterizing the jet substructure are the so-called generalized jet angularities λ_α^κ where the different choices of κ and α parameters tune the sensitivity of the observable to various jet aspects. These modifications of the jet shape contain information on the mechanism of the energy loss in the medium.

The study of D^0 and $\overline{D}^0$ meson tagged jets, consisting of the related c- and u-quarks in heavy-ion collisions opens a pathway to investigate the aforementioned modifications for the charm quark in the presence of a hot and dense medium.

2 Analysis details

The D^0 and $\overline{D}^0$ meson candidates were reconstructed from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV in central (0-10%), midcentral (10-40%), and peripheral (40-80%) collisions, collected by the STAR experiment at Relativistic Heavy Ion Collider (RHIC) in 2014. The D^0 meson candidates with transverse momentum $1 < p_T < 10$ GeV/c are reconstructed via decay channel $D^0 \rightarrow K^- + \pi^+$ with branching ratio (3.947 ± 0.030) % [3]. The daughter particles were tracked and identified using Time Projection Chamber (TPC), Heavy-Flavor Tracker (HFT), and Time-of-Flight (TOF) detectors. The combinatorial D^0 background contribution is subtracted using a technique called ${}_s\mathcal{P}lot$ [4], which is part of the native class in RooStats. The inclusive D^0 meson tagged jets are reconstructed with C++ software package FastJet [5] employing anti-k_T algorithm with radius $R = 0.4$ within pseudorapidity range $|\eta| < 1 - R$. The neutral particle contribution was measured by the Barrel Electro-Magnetic Calorimeter (BEMC). The relatively soft background contribution and detector resolution effects are treated using the event-by-event background subtraction and Bayesian unfolding.

3 Nuclear modification factor

The nuclear modification factor for central (C) and peripheral (P) collisions as a function of jet transverse momentum $p_{T,\,Jet}$ is expressed as

$$R_{CP}(p_{T,\,Jet}) = \frac{\langle N_{coll}\rangle_P}{\langle N_{coll}\rangle_C} \frac{N_P^{events}}{N_C^{events}} \frac{d^2 N_C/(dp_{T,\,Jet}dy)}{d^2 N_P/(dp_{T,\,Jet}dy)}, \quad (1)$$

where $\langle N_{coll}\rangle$ and N^{events} are the corresponding number of nucleon-nucleon binary collisions and number of events, respectively.

The z_{Jet} observable is related to the fragmentation function in the DGLAP equation [6] and is defined as

$$z_{Jet} = \frac{\vec{p}_{T,\,Jet} \cdot \vec{p}_{T,\,D^0}}{|\vec{p}_{T,\,Jet}|^2}, \quad (2)$$

where $p_{T,\,jet}$ and $p_{T,\,D^0}$ are transverse momenta of the jet and D^0 meson, respectively. The nuclear modification factors R_{CP} as a function of $p_{T,\,Jet}$ and z_{Jet} for central and midcentral collision to the peripheral collision are presented in Fig. 1. The results of $R_{CP}(p_{T,\,Jet})$ show a hint of suppression of D^0-jets transverse momenta in central events. For midcentral collisions, the ratio is consistent with unity, which represents no significant impact of the QGP relatively to peripheral collisions. The second nuclear modification factor $R_{CP}(z_{Jet})$ shows a hint of D^0-jet suppression in central collisions, primarily from hard fragmented jets (high z_{Jet}). The ratios for the soft fragmented jets show no significant modification across both centrality ranges.

The charm quark diffusion can be studied by the radial distribution measurement of the D^0 meson inside the jet defined as

$$\Delta r = \sqrt{(\eta_{Jet} - \eta_{D^0})^2 + (\phi_{Jet} - \phi_{D^0})^2}, \quad (3)$$

where η and ϕ are the pseudorapidity and azimuthal angle, respectively. The measured ratios of per-jet normalized distributions $1/N_{Jet} \cdot \Delta r(p_{T,\,Jet})$ of different centralities are shown in Fig. 2 left. The measured ratios do not reveal any significant modification of them at the top RHIC energy of 200 GeV.

The model predictions in Fig. 1 and 2 left represented by magenta areas are provided by the LIDO model which is a hybrid transport model for the evolution of heavy quarks in

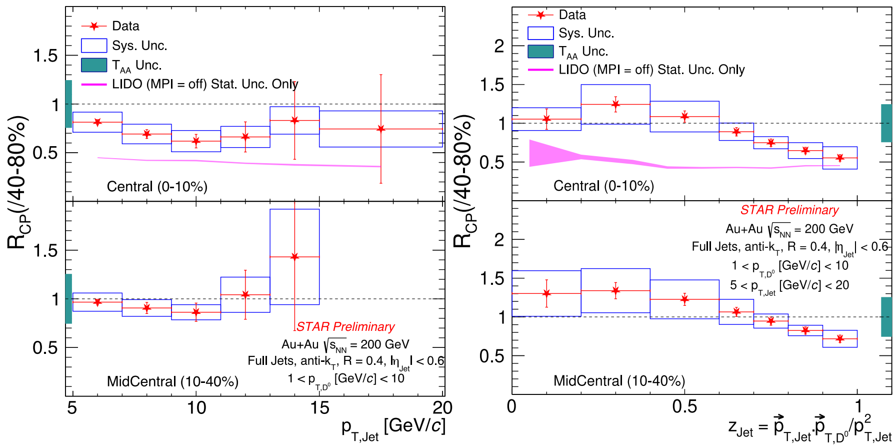

Figure 1. The nuclear modification factor R_{CP} for central (0-10 %) and midcentral (10-40%) collisions relative to peripheral (40-80%) collisions as a function of jet transverse momentum $p_{\mathrm{T,\,Jet}}$ (left) and fragmentation function z_{Jet} (right) for D^0 meson tagged jets in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. The magenta areas represent the LIDO model prediction [7].

a QGP medium [7]. The model slightly underpredicts the yield in central collisions but it is consistent with the yield in peripheral events. This results in the underprediction of R_{CP} as a function of $p_{\mathrm{T,\,Jet}}$ and z_{Jet}. Regarding the Δr distributions, LIDO qualitatively well explains the radial profile trends in both central and peripheral collisions.

4 Generalized angularities

One of the jet substructure observables that can discriminate between quark- and gluon-initiated jets or mass of the initiated parton are generalized angularities that depend on an angular exponent α and an energy weighting factor κ, defined as

$$\lambda_\alpha^\kappa = \sum_{i \in \mathrm{Jet}} \left(\frac{p_{\mathrm{T},i}}{p_{\mathrm{T,\,jet}}} \right)^\kappa \left(\frac{\Delta R_i}{R_{\mathrm{Jet}}} \right)^\alpha , \tag{4}$$

where $p_{\mathrm{T,\,Jet}}$ and R_{Jet} are transverse momentum and jet radius, and $p_{\mathrm{T},i}$ and ΔR_i are transverse momentum and radial distance from the jet axis of the i-th track-based jet constituent (charged particles + D^0 meson), respectively. These observables are infrared and collinear safe only for sets where $\kappa = 1$ and $\alpha > 0$ [8]. In such cases, their distributions for p+p collisions can be calculated using perturbative QCD. For $\kappa = 1$, lower values of α parameter $(0 < \alpha < 1)$ increase sensitivity to mass effects by emphasizing the influence of the dead-cone effect, i.e. contribution of jet constituent particles close to the jet axis. Conversely, higher values of α $(\alpha > 1)$ suppresses the mass effects and increases the sensitivity to Casimir color effects.

In general, several generalized angularities have specific names due to their significance, such as $\lambda_{0.5}^1$ (Les Houches Angularity), which is sensitive to flavor discrimination, λ_1^1 (girth or width), which describes jet constituent broadening, and λ_2^1 (mass or thrust), which relates to the mass-squared at fixed jet energy [8]. The raw data results after background subtraction for the λ_1^1 and λ_3^1 in central collisions are shown in Fig. 2 right. The unphysical results, i.e., $\lambda_{\alpha \geq 1}^1 \notin \langle 0;1 \rangle$, are caused by the jet background fluctuations and detector resolution. To obtain the true distributions, 2D or higher-dimensional unfolding is required, and work on this is currently ongoing.

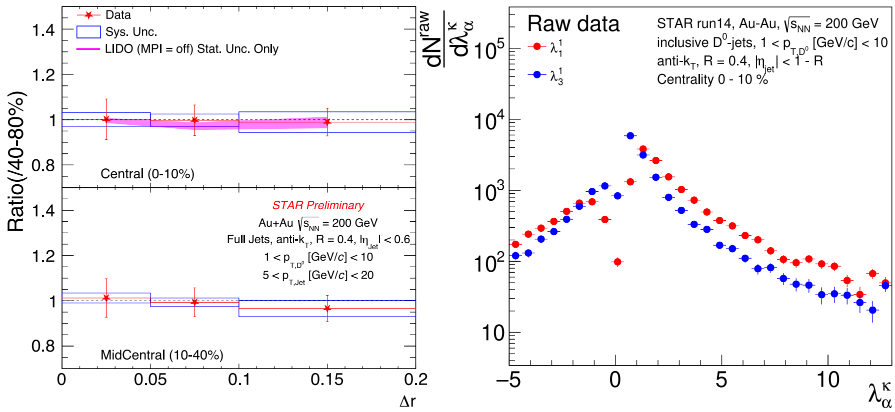

Figure 2. The ratios of the per-jet normalized distributions of radial profiles of D^0 mesons Δr for central (0-10%) and midcentral (10-40%) collisions relative to peripheral (40-80%) collisions (left), and the raw distributions of the generalized angularities λ_1^1 and λ_3^1 for central collisions (right) for D^0 meson tagged jets in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The magenta area represents the LIDO model prediction [7].

5 Summary

We presented results of nuclear modification factors $R_{CP}(p_{T,\,Jet})$ and $R_{CP}(z_{Jet})$ of D^0 meson tagged jets in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. We observe suppression of D^0-jet transverse momenta in central collisions and hard fragmented jets in central and midcentral collisions. Next, we showed the ratios of the per-jet normalized distributions of radial profiles Δr of D^0 mesons, which, within uncertainties, are consistent with unity at $\sqrt{s_{NN}} = 200$ GeV. All three results were compared with the LIDO model. Overall, this model accurately predicts the trends of p_T, z_{Jet}, and Δr distributions, although it underpredicts the yield in the central collisions.

The future work will focus on calculation of D^0-jet angularity modification in central heavy-ion collisions in the form of $R_{CP}(\lambda_\alpha^\kappa)$, to reveal the jet substructure modification in the presence of the QGP medium. In order to draw physical conclusions, unfolding, D^0 meson reconstruction efficiency, and other factors need to be included. This measurement may help to constrain several model predictions focused on the energy loss of partons in the QGP.

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References

[1] ALICE Collaboration, Nature **605**, 440–446 (2022).
[2] CMS Collaboration, Phys. Lett. B **730**, 243-263, (2014).
[3] R. L. Workman et al. (PDG), Prog. Theor. Exp. Phys. **2022**, 083C01 (2022).
[4] M. Pivk, F. R. Le Diberder, Nucl. Instrum. Methods Phys. Res. A **555**, 356-369 (2005).
[5] M. Cacciari, G. P. Salam, G. Soyez, Eur. Phys. J. C **72**, 1896 (2012).
[6] G. Altarelli, G. Parisi, Nucl. Phys. B **126**, 298–318 (1977).
[7] W. Ke, Y. Xu, S. A. Bass, Phys. Rev. C **98**, 064901 (2018).
[8] A. J. Larkoski, J. Thaler, W. J. Waalewijn, High Energ. Phys. **2014**, 129 (2014).