Measurements of Charm Quark Interaction with the QGP in Heavy-Ion Collisions at STAR

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Abstract. We report the measurements of D^0 transverse momentum (p_T) differential invariant spectra with p_T < 8 GeV/c for 0–10%, 10–40%, and 40–80% centrality classes in isobar collisions (^{96}Ru + ^{96}Ru and ^{96}Zr + ^{96}Zr) at $\sqrt{s_{NN}}$ = 200 GeV with the STAR experiment. The strong suppression of D^0 yield is observed for p_T > 3 GeV/c in the central collisions, demonstrating that charm quarks suffer significant energy loss in the bulk QCD medium. In this proceeding, the measurements of D^0 meson tagged jets at $\sqrt{s_{NN}}$ = 200 GeV in Au+Au collisions are reported as well. We present the nuclear modification factor, R_CP, as a function of $p_\mathrm{T,Jet}$ and z_Jet, and show the ratios of the D^0 radial profile with 1 < p_{T,D^0} < 10 GeV/c. Comparisons to model calculations for D^0 and D^0-tagged jets are also discussed.

1 Introduction

Heavy-flavor quarks, charm and bottom, are dominantly produced in the initial hard scatterings of heavy-ion collisions and experience almost the entire evolution of the Quark–Gluon Plasma (QGP) created in those collisions [1]. They lose energy due to interactions with the medium; hence studying heavy quark in heavy-ion collisions can shed light on the QGP properties. Nuclear modification factor, R_AA, was proposed as an observable to study the interactions of heavy quarks in the medium [2, 3]. Furthermore, measurements of D^0 R_AA in different colliding systems can shed light on the potential collision system dependence of the quark energy loss. The phenomenological Blast-Wave model (BW), which describes the data well [3, 4], can be used to extract parameters related to the collective behavior of light and heavy flavored hadrons in different collision systems.

Studying D^0-tagged jet can provide us an opportunity to investigate the energy loss of heavy-flavor quarks in the QCD medium in more detail, and can be used to extract information about heavy-flavor jet fragmentation [5]. The yield modifcations of D^0-tagged jets as a function of $p_\mathrm{T,Jet}$ and z_Jet, together with the radial profile of the D^0 mesons in these tagged jets can help to constrain the theoretical calculations of parton flavor, parton mass, and system size dependencies of parton interactions with the QGP.

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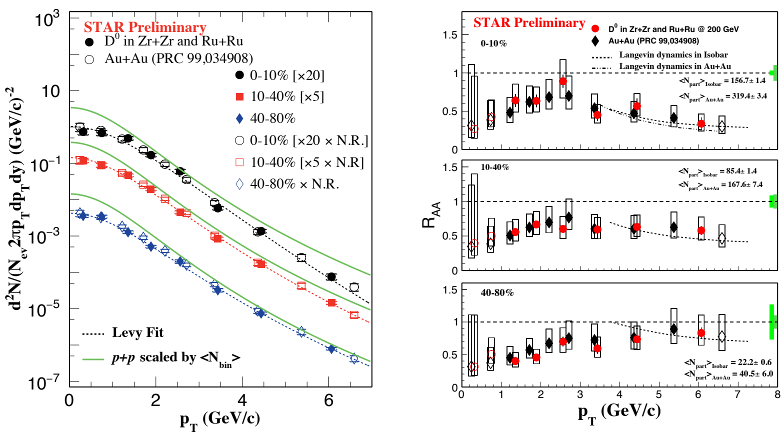

Fig. 1. D^0 invariant yields at mid-rapidity ($|y| < 1$) as a function of p_T for different centrality classes in isobar collisions compared to that of D^0 in Au+Au collisions at the same energy (left). Vertical lines and square brackets on data points indicate statistical and systematic uncertainties, respectively. D^0 R_{AA} within the same centrality are compared between isobar and Au+Au collisions (right). The dashed lines are model curves based on Langevin dynamics.

2 Inclusive D^0 production in Isobar Collisions at 200 GeV

This work uses Minimum Bias (MB) triggered ${}^{96}_{40}$Zr + ${}^{96}_{40}$Zr and ${}^{96}_{44}$Ru + ${}^{96}_{44}$Ru events collected in 2018 by the STAR detector [6] at RHIC. The detector subsystems, the Time-of-Flight detector (TOF) and the Time Projection Chamber (TPC), are used to reconstruct and identify the daughter particles of the D^0-meson. The inclusive D^0 production is measured through its hadronic decay channel $D^0 \to K^-\pi^+$ (or $\bar{D}^0 \to K^+\pi^-$) with a branching ratio of 3.89% [7].

The D^0 p_T-differential spectra at mid-rapidity in isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV are shown in the left panel of Fig.1. The open markers represent the published D^0-meson p_T spectra in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV [3], which are scaled by an additional number of binary collisions, $\langle N_{bin}\rangle$, ratio factor (N.R.) between isobar and Au+Au collisions. The D^0 production cross section follows $\langle N_{bin}\rangle$ scaling within systematic uncertainties between isobar and Au+Au collisions at 200 GeV. For all three centralities in isobar collisions, the Levy fit is performed in the range of $0 < p_T < 8.0$ GeV/c. The right panel of Fig.1 shows D^0 R_{AA} as a function of p_T in 0–10% (central), 10–40% (mid-central), and 40–80% (peripheral) centrality ranges from top to bottom panel, respectively. Compared with peripheral collision, D^0 R_{AA} in the central collisions shows suppression at $p_T > 3$ GeV/c, which demonstrates that charm quarks suffer significant energy loss in the bulk QCD medium. A model based on the Langevin approach calculates heavy-quark propagation in the medium, which doesn't include charm hadrochemistry and shadowing effect, and describes the D^0 R_{AA} suppression at $p_T > 3$ GeV/c in the data [8].

We do a fit to the m_T spectra in isobar collisions to extract an inverse slope parameter, T_{eff}, where $m_T = \sqrt{p_T^2 + m_0^2}$ and m_0 is the D^0 meson mass at rest. The same m_T spectra fit range is used as in the previous analysis [3]. The correlations between T_{eff} and the mass of the various hadrons produced in $\sqrt{s_{NN}}$ = 200 GeV isobar and Au + Au collisions are shown in the left panel of Fig.2. They clearly present two different sets of linear dependencies, suggesting that ϕ, Λ, Ξ, Ω and charm hadrons may acquire less collective behavior [3]. The correlations

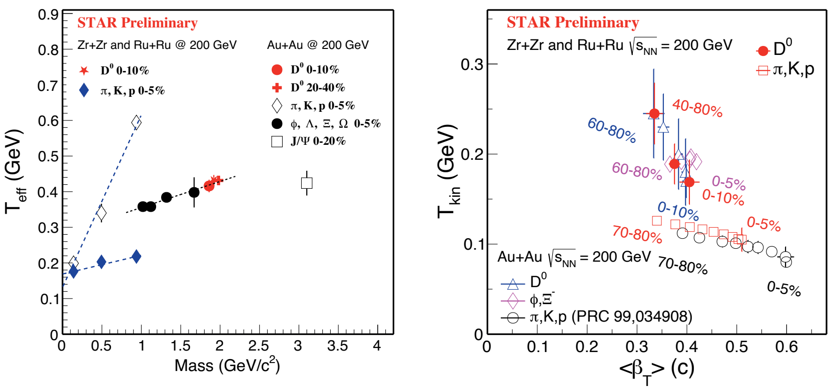

Fig. 2. $\mathrm{T_{eff}}$ obtained from m_{T} spectra fits as a function of the hadron mass in isobar and Au+Au collisions (left). The correlation between $\mathrm{T_{kin}}$ and $\langle\beta_{\mathrm{T}}\rangle$, extracted from the Blast-wave fits for different hadron p_{T} spectra (right).

among different hadrons show that the collective behavior of light hadrons may be dependent on the system size between isobar and Au+Au collisions at the same energy, while there is no significant system dependence for the charm meson within the uncertainty. The BW model is applied to fit the p_{T} spectra in order to extract the kinetic freeze-out temperature, $\mathrm{T_{kin}}$, and the transverse radial flow velocity, $\langle\beta_{\mathrm{T}}\rangle$. The right panel of Fig.2 shows $\mathrm{T_{kin}}$ and $\langle\beta_{\mathrm{T}}\rangle$ of D^0 are consistent within uncertainties for the same centrality, indicating the thermal parameters of D^0 meson weakly depend on system size. On the other hand, we observe collision system dependence for light hadrons, which is consistent with the m_{T} spectra analysis.

3 D^0 Tagged Jets production in Au+Au Collisions at 200 GeV

In this analysis, the MB Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV data, taken in the year 2014, is used. The $_s\mathcal{P}$lot method is used to extract the raw yield of $D^0(\bar{D}^0)$ mesons [9], and the invariant yield of $D^0(\bar{D}^0)$ tagged jets after efficiency correction is obtained for $1 < p_{\mathrm{T},D^0} < 10$ GeV/c, as a function of $p_{\mathrm{T,Jet}}$. The R_{CP} as a function of $p_{\mathrm{T,Jet}}$ with the 40–80% spectrum as the reference for 0–10% and 10–40% centrality are shown in the top and bottom half of the left panel in Fig.3. It shows a hint of suppression of D^0 meson tagged jet yield in central collisions. The LIDO model [10], which considers heavy quark evolution in medium with collisional and radiative energy losses, underestimates R_{CP} of the D^0 tagged jet in central 0–10% collisions. This may be due to the low D^0 p_{T} threshold, which may lead to an important contribution from multiple parton interactions (MPI) which are not included in this model. The p_{T} fraction of the jet carried by $D^0(\bar{D}^0)$ mesons along the jet axis, defined as $\mathrm{z_{Jet}} = \vec{p}_{\mathrm{T,\,Jet}} \cdot \vec{p}_{\mathrm{T},D^0}/p^2_{\mathrm{T,Jet}}$, is related to the jet fragmentation function. The R_{CP} as a function of $\mathrm{z_{Jet}}$, shown in the middle panel of Fig.3, indicates a hint of suppression for hard fragmented charm jets, while soft fragmented jets have R_{CP} consistent with unity within the uncertainties.

The radial profile for $D^0(\bar{D}^0)$ mesons with $1 < p_{\mathrm{T},D^0} < 10$ GeV/c in the tagged jets is obtained as a function of the distance from the jet axis (Δr) in Au+Au collisions, where $\Delta \mathrm{r} = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ is quadratic sum of the differences in pseudorapidity ($\Delta\eta$) and azimuth ($\Delta\phi$) of the $D^0(\bar{D}^0)$ meson with respect to the jet axis in the $\eta - \phi$ plane. The right panel of Fig.3 shows the ratios of the radial profiles for the central and mid-central events to peripheral

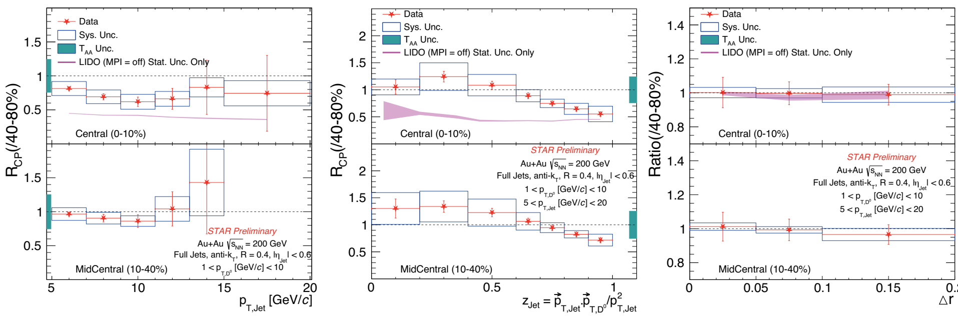

Fig. 3. R_{CP} of $D^0(\bar{D}^0)$ tagged jet as a function of $p_{\mathrm{T,Jet}}$ (left) and $\mathrm{z_{Jet}}$ (middle) for different centrality classes in Au+Au collisions. The bands at unity are uncertainties associated with the nuclear overlap integral, $\mathrm{T_{AA}}$. The ratios of the D^0 radial profile distributions as a function of the distance from the jet axis (Δr) with $1 < p_{\mathrm{T},D^0} < 10$ GeV/c for different centrality classes (right). Theoretical calculations with MPI off are drawn as bands.

events, which are consistent with unity within the uncertainties. The LIDO model (MPI = off) describes the ratio of radial profile in the data.

4 Summary

We report the first measurements of D^0-meson production at mid-rapidity ($|y| < 1$) in isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV with the STAR experiment. The Blast-Wave model is used to fit the D^0 p_{T} spectra, and it is found that the collective behavior obtained by D^0 between isobar and Au+Au collisions at the same energy has no significant system dependence. The strong suppression of D^0 nuclear modification factor is observed for $p_{\mathrm{T}} > 3$ GeV/c in the central isobar collisions, demonstrating that charm quarks suffer significant energy loss in the bulk QCD medium. A hint of D^0 tagged jet suppression in central Au+Au collisions, mainly from hard fragmented jets, is observed. The ratios of $D^0(\bar{D}^0)$ radial profile in its tagged jets of central and mid-central to peripheral collisions are consistent with unity within uncertainty. The LIDO model that does not include multiple parton interactions describes the ratio of radial profile in the data, but underestimates R_{CP}.

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