PROCEEDINGS OF SCIENCE

PoS(High-pT2017)030

Overview of open heavy-flavor production from STAR

Yi Yang (on behalf of the STAR Collaboration)[*]
National Cheng Kung University, Tainan 70101, Taiwan
E-mail: `yiyang@ncku.edu.tw`

We report the results on the open heavy-flavor production measured by the STAR experiment in Au+Au collisions at a center-of-mass energy per nucleon-nucleon pair of 200 GeV at RHIC, including the nuclear modification factors for D^0, electrons from B and D hadron decays, and non-prompt J/ψ and D^0. We also present results on elliptic and triangular azimuthal anisotropies for D^0 as well as the production ratios of $D_s^{\pm}/D^0$ and Λ_c/D^0. These results are compared to various theroretical predictions, providing us valuable information on the properties of the quark-gluon plasma.

12th International Workshop on High-pT Physics in the RHIC/LHC Era
2-5 October, 2017
University of Bergen, Bergen, Norway

---

[*] Speaker.

1. Introduction

Studying the properties of the Quark-Gluon Plasma (QGP), a new phase of matter, provides valuable information for understanding the Quantum Chromodynamics (QCD). Due to their heavy masses, heavy-flavor quarks are mainly produced at the early stages of a collision. Both, quarkonia ($Q\bar{Q}$) and open heavy-flavour hadrons ($Q\bar{q}$, Qqq), then subsequently probe the created system throughout its entire evolution. In particular, the open heavy-flavor states are crucial for understanding the nature of heavy quark-medium interaction (the flavor-dependence of energy loss), the heavy quark collective behavior, and the hadronization in the QGP. The Heavy Flavor Tracker (HFT) at STAR plays an important role in reconstructing the secondary decay vertices, giving us the opportunity to probe the QGP properties using open heavy-flavor hadrons. In this manuscript, we will concentrate on the results for open heavy-flavor hadrons in Au+Au collisions at $\sqrt{s_{\rm NN}} =$ 200 GeV measured by the STAR experiment.

2. Nuclear modification factor measurements for D^0

As shown in Fig. 1, the nuclear modification factors (R_{AA}) of D^0 in different centrality classes are measured in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV and show a strong suppression at high transverse momenta ($p_T > 4$ GeV) in the $0-10\%$ and $10-40\%$ centralities, indicating substantial energy loss of charm quarks in the medium. It is also shown that the data are in qualitative agreement with theoretical predictions [1, 2] incorporating quark energy loss and coalescence in the medium.

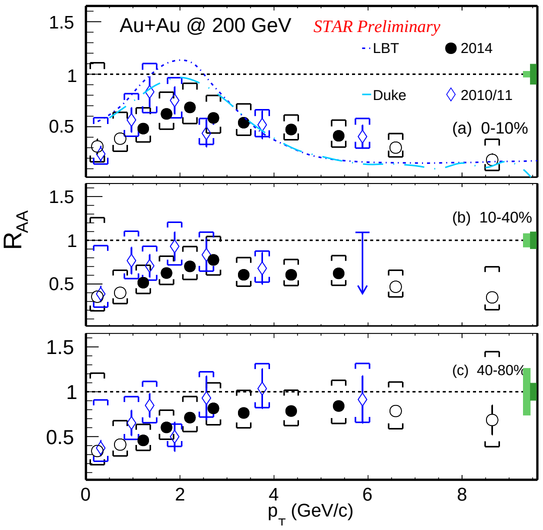
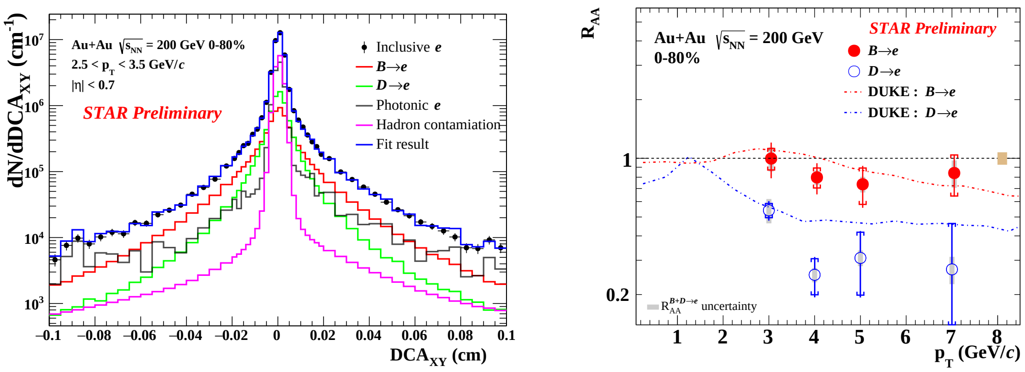


Figure 1: The R_{AA} of D^0 as a function of p_T compared to various theoretical predictions [1, 2].

3. Measurements of e, J/ψ and D^0 from B hadron decays

The HFT at STAR provides an excellent track pointing resolution which allows for distinguishing the electrons from B and D hadron decays via measuring their distances of closest approach (DCA). Figure 2(a) shows the DCA distribution of inclusive electrons extracted from data and fitted with sum of distributions for electrons from different sources obtained from a combination of data and Monte Carlo (MC) simulations. The nuclear modification factors for $B \to e$ and $D \to e$ are calculated using $R_{AA}^{B\to e} = \frac{f_{Au+Au}^{B\to e}}{f_{p+p}^{B\to e}} R_{AA}^{HF_e}$ and $R_{AA}^{D\to e} = \frac{1-f_{Au+Au}^{B\to e}}{1-f_{p+p}^{B\to e}} R_{AA}^{HF_e}$, respectively, where HF_e stands for the electrons from open heavy-flavor hadron decays. The result in Fig. 2(b) shows that electrons from D hadrons exhibit stronger suppression than those from B hadrons, which is consistent with the mass hierarchy of energy loss, i.e. heavier quarks are expected to lose less energy than lighter ones.



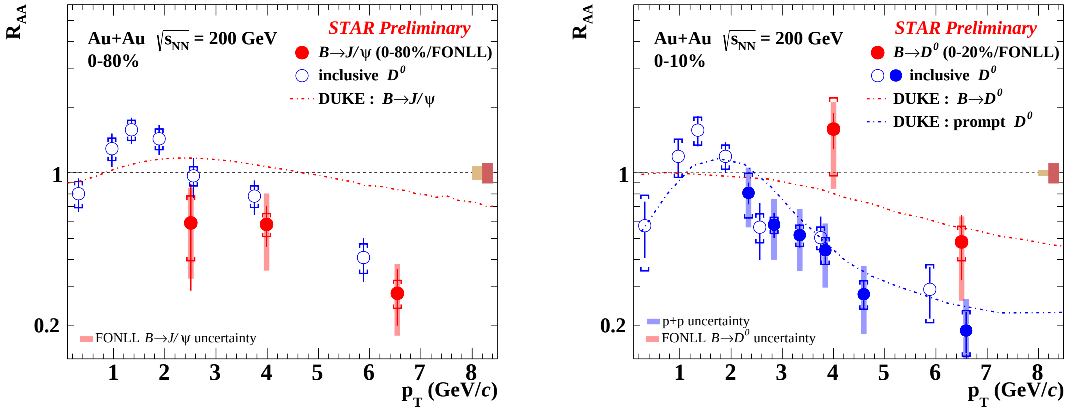
(a) (b)

Figure 2: (a) The DCA distribution of inclusive electrons is fitted by the distributions of electrons from various sources obtained from data and MC. (b) The R_{AA} of electrons from D and B hadron decays as a function of p_T, which is consistent with the mass hierarchy of energy loss.

The HFT also provides the capability to measure the pseudo-proper decay length (l), defined as $l_{J/\psi} = \frac{\vec{L}\cdot\hat{p}}{|\vec{p}|/c} \cdot M_{J/\psi}$, for extracting the non-prompt J/ψ fraction. Figure 3(a) shows that $B \to J/\psi$ is highly suppressed at high-p_T region ($p_T > 5$ GeV/c) and the R_{AA} is consistent with that for the inclusive D^0. On the other hand, for the $B \to D^0$ extracted from the DCA distributions, the result shows less suppression for non-prompt D^0 than that for inclusive D^0, as shown in Fig. 3(b).

4. D^0 elliptic and triangular azimuthal anisotropies

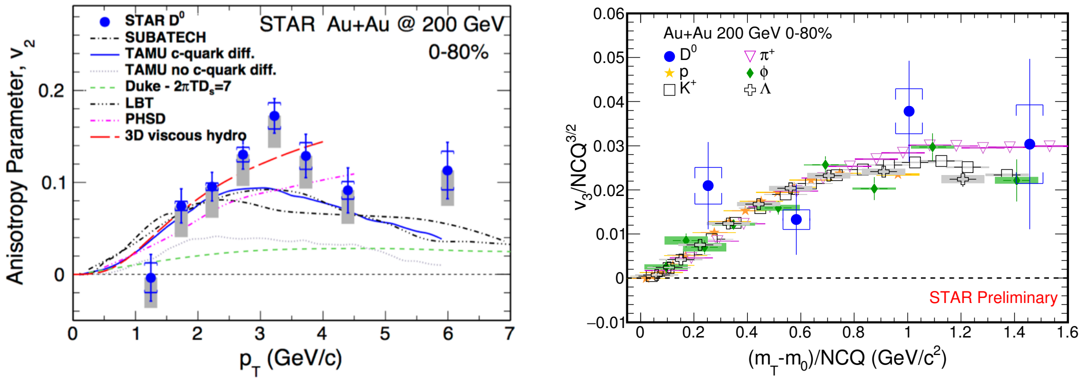
The measurements of elliptic (v_2) and triangular (v_3) azimuthal anisotropies for D^0 meson can shed lights on understanding the bulk properties of the QGP. Figure 4(a) shows a large non-zero D^0 v_2, indicating strong collective motion for charm quarks. The result is compared to various models and in particular, a good agreement is seen for the 3D viscous hydrodynamic model [3] for $p_T < 4$ GeV/c suggesting that charm quarks may have been fully thermalized. Additionally, the data is also consistent with several dynamic models [1, 2, 4, 5, 6] taking into account the charm quark diffusion effect and the resulting diffusion coefficient ($2\pi T \times D_s$) ranges between $2-12$ for T in $T_c - 2T_c$ range. The first D^0 v_3 measured by STAR is shown in Fig. 4(b) and with large non-zero values also indicates strong collective behavior. The result is consistent with the NCQ scaling



(a) (b)

Figure 3: The R_{AA} as a function of p_T for (a) $B \to J/\psi$ and (b) $B \to D^0$, compared to that for inclusive D^0.

($\frac{m_T - m_0}{\mathrm{NCQ}}$, where $m_T = \sqrt{m_0^2 + p_T^2}$, m_0 is the hadron mass and NCQ is the number of constituent quarks) which means that charm quarks may have acquired similar azimuthal anisotropy as light quarks. However, more data is needed to draw a solid conclusion.

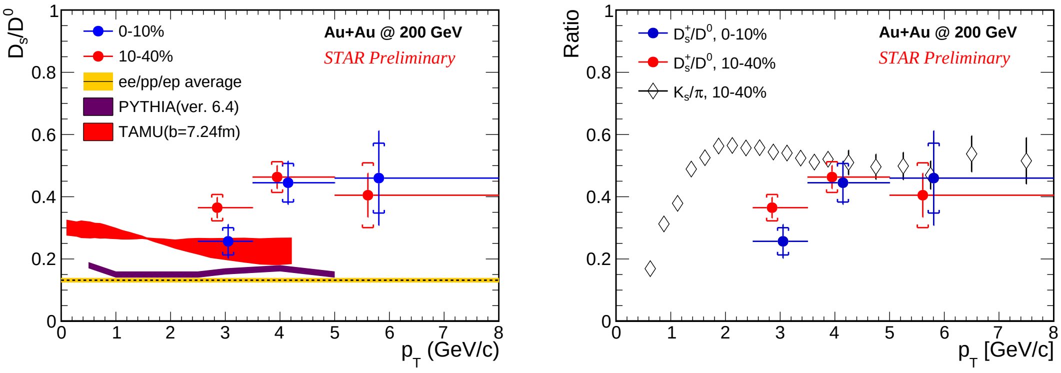


(a) (b)

Figure 4: (a) The D^0 v_2 compared to various theoretical models including a 3D viscous hydrodynamic model and dynamic models [1, 2, 4, 5, 6]. (b) The D^0 $v_3/\mathrm{NCQ}^{3/2}$ as a function of $\frac{m_T - m_0}{\mathrm{NCQ}}$ is consistent with the empirical m_T scaling which means that charm quarks may have acquired similar flow as light quarks.

5. $D_s^{\pm}/D^0$ and Λ_c/D^0 ratios

In Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV, the $D_s^{\pm}$ and $D^{\pm}$ candidates are reconstructed via the $\phi(1020) + \pi^{\pm} \to K^+K^-\pi^{\pm}$ decay channel. Figure 5(a) shows the results of $D_s^{\pm}/D^0$ ratio in different centrality classes as a function of p_T compared to theoretical predictions. There is no obvious centrality dependence and the predictions from PYTHIA and the TAMU model clearly underestimate the data [7]. Figure 5(b) shows the comparison between $D_s^{\pm}/D^0$ and K_s/π (the light mesons). The result shows that they have similar magnitudes at high-p_T, but the ratio is larger for light mesons at low-p_T.



(a) (b)

Figure 5: $D_s^{\pm}/D^0$ ratio as a function of p_T in different centralities compared to (a) theoretical predictions and (b) K_s/π ratio.

For the first time, the Λ_c baryon is reconstructed in heavy-ion collisions through $\Lambda_c^{\pm} \to p^{\pm} + K^{\mp} + \pi^{\pm}$ decay mode. Figure 6 shows the invariant mass of $pK\pi$ system illustrating a Λ_c signal of 5σ significance. The Λ_c/D^0 ratio measured by STAR is $1.3 \pm 0.3(stat.) \pm 0.4(sys.)$ and it is significantly larger than the PYTHIA prediction. On the other hand, the result is consistent with the Ko model (0 - 5%) [8] which includes coalescence and thermalized charm quarks. The magnitude of the enhancement is similar to that observed for light hadrons, as shown in Fig. 7.

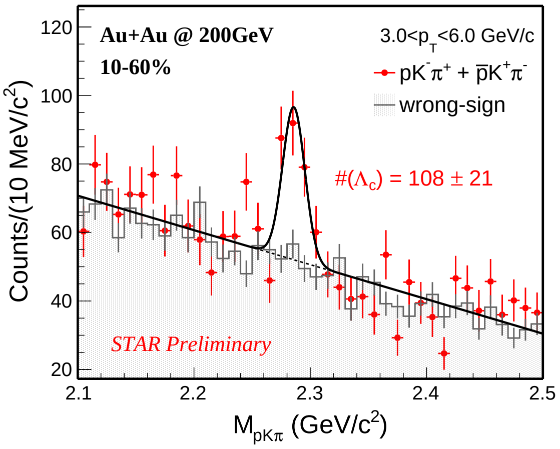


Figure 6: The invariant mass of $\Lambda_c^{\pm} \to p^{\pm} + K^{\mp} + \pi^{\pm}$ in Au+Au collisions at 200 GeV.

6. Conclusion

In these proceedings, we present several results on the open heavy-flavor hadron production

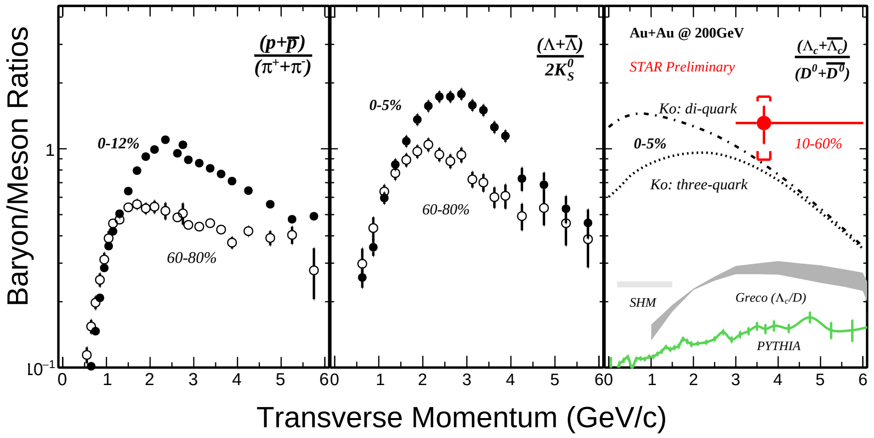


Figure 7: The Λ_c/D^0 ratio as a function of p_T compared to the results for light hadrons and to the Ko model (0 - 5%) including coalescence and thermalized charm quarks [8].

measured by the STAR experiment. In particular, the HFT in STAR provides us with a great opportunity to study B and D hadron productions in heavy-ion collisions to probe the nature of the QGP. Firstly, the R_{AA} of D^0 shows that charm mesons are strongly suppressed at high-p_T due probably to strong interactions between heavy quarks and medium. Electrons from B-hadron decays are less suppressed compared to those from D-hadron decays which is consistent with the mass hierarchy of the parton energy loss. The measurements on v_2 and v_3 for D^0 show strong collective behavior suggesting that the charm quarks may have achieved local equilibrium with the medium. Finally, the enhancements of the $D_s^{\pm}/D^0$ and Λ_c/D^0 ratios suggest that charm quarks may also participate in the coalescence hadronization in the medium.

References

[1] S. Cao, T. Luo, G.-Y. Qin, and X.-N. Wang, Phys. Rev. C **94**, 014909 (2016).

[2] S. Cao, G. Y. Qin and S. A. Bass, Phys. Rev. C **88**, 044907 (2013).

[3] L.-G. Pang, Y. Hatta, X.-N. Wang, and B.-W. Xiao, Phys. Rev. D **91**, 074027 (2015).

[4] M. He, R. J. Fries and R. Rapp, Phys. Rev. C **86**, 014903 (2012).

[5] M. Nahrgang et. al., Phys. Rev. C **91**, 014904 (2015).

[6] H. Berrehrah *et al*, Phys. Rev. C **90**, 051901 (2014).

[7] H. Min *et al*, Phys. Rev. Lett. **110**, 112301 (2013).

[8] Y. Oh, *et al*, Phys. Rev. C **79**, 044905 (2009).