Measurements of electrons from heavy-flavor hadron decays in 27, 54.4, and 200 GeV Au+Au collisions in STAR

Shenghui Zhang (for the STAR Collaboration)[1,2,*]

[1]University of Illinois at Chicago, Chicago, IL 60607, USA
[2]University of Science and Technology of China, Hefei 230026, China

Abstract. In these proceedings, we present the measurements of nuclear modification factors for electrons from open charm ($c{\to}e$) and bottom hadron decays ($b{\to}e$) at mid-rapidity region in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The significance of the difference in nuclear modification factors between $b{\to}e$ and $c{\to}e$ is $\geq 3\sigma$. We also present the measurements of the elliptic flow (v_2) of inclusive heavy-flavor hadron decayed electrons (HFE) in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 27 and 54.4 GeV. The results show non-zero HFE v_2 in 54.4 GeV Au+Au collisions and a hint of smaller HFE v_2 in 27 GeV Au+Au collisions than those at 54.4 and 200 GeV.

1 Introduction

Heavy quarks are predominantly produced at the early stages of the relativistic heavy-ion collisions before the creation of the deconfined Quantum Chromodynamics medium, known as the Quark-Gluon Plasma (QGP). They subsequently traverse the created system throughout its evolution, and thus measurements of heavy-flavor hadron production and elliptic flow (v_2) are unique and indispensable probes of the QGP properties. Studies of the production of electrons from open charm and bottom hadron decays in Au+Au collisions serve as a valuable tool to investigate the mass hierarchy of the parton energy loss. Furthermore, measuring

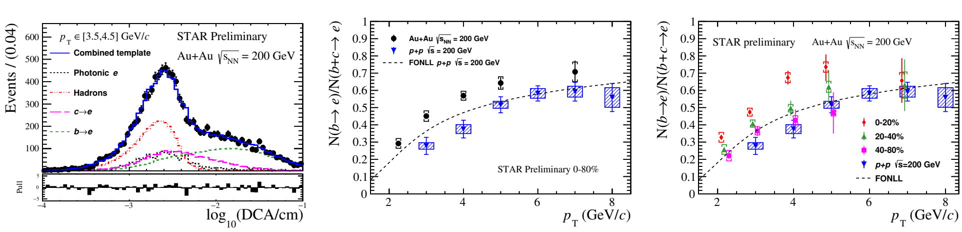

Figure 1. Left: log(DCA/cm) distribution for inclusive electrons with a template fit including $b{\to}e$, $c{\to}e$, and various background sources in 0-80% Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. Middle: the fraction of $b{\to}e$ as a function of $p_{\rm T}$ in 0-80% Au+Au collisions, along with that in p+p collisions and the FONLL prediction. Right: the fraction of $b{\to}e$ as a function of $p_{\rm T}$ in different centralities of Au+Au collisions, along with that in p+p collisions and the FONLL prediction.

*e-mail: zhang08@mail.ustc.edu.cn

v_2 of heavy flavor hadrons and their decay daughters at different collision energies provide important insights into the temperature dependence of the heavy-flavor quark interactions with the QGP. In these proceedings, we present preliminary results on the production of electrons from open charm and bottom hadron decays in $\sqrt{s_{_{\rm NN}}}$ = 200 GeV Au+Au collisions, as well as inclusive heavy-flavor electron (HFE) v_2 in $\sqrt{s_{_{\rm NN}}}$ = 27 and 54.4 GeV Au+Au collisions.

2 Experiment and Analysis

The STAR experiment utilizes the Time Projection Chamber, the Time Of Flight detector, and the Barrel Electromagnetic Calorimeter to reconstruct charged tracks and perform particle identification. Electrons originating from charm and bottom hadron semileptonic decays are topologically separated utilizing the Heavy Flavor Tracker which provides precise identification of displaced vertices [1].

2.1 Nuclear modification factor

The log(DCA/cm) distribution, where the DCA is the 3D distance of closest approach of a candidate electron to the primary vertex, is used to separate the bottom hadron decayed electrons ($b{\to}e$) from charm hadron decayed electrons ($c{\to}e$). Such a distribution for inclusive electrons is shown in the left panel of Fig. 1, along with the template fit including $b{\to}e$, $c{\to}e$, background from photonic electrons, and the hadron contamination. The templates for $b{\to}e$ and $c{\to}e$ are obtained from a fast simulation, taking into account detector effects, coupled with the EvtGen [2] decayer, in which $D^0, D^{\pm}, D_S, \Lambda_c, B^0, B^{\pm}, B_S$, and Λ_b decays are included. The DCA distribution for $b{\to}e$ is broader than that for $c{\to}e$ because of the longer lifetime of B hadrons. The template for photonic electrons, arising from gamma conversions, π^0 and η Dalitz decays, is obtained from simulations, and constrained by the photonic electron fraction. Furthermore, hadrons misidentified as electron candidates need to be accounted for. Their template is obtained from data and the magnitude is constrained by the inclusive electron purity. The fractions of bottom-decayed electrons to the sum of bottom- and charm-decayed electrons, $f^{b\to e} = N(b{\to}e)/N(b+c{\to}e)$, as a function of transverse momentum ($p_{\rm T}$) in different centralities of 200 GeV Au+Au collisions are obtained via the template fitting and shown in the middle and right panels of Fig. 1. The fractions in Au+Au collisions are compared to the results from p+p collisions ([3] and preliminary 2012 STAR data) and the FONLL prediction [5, 6]. An enhancement of the $b{\to}e$ fraction is observed in 0-80% Au+Au collisions compared to that in p+p collisions and FONLL prediction. The enhancement is more significant in central Au+Au collisions and consistent with p+p and FONLL in peripheral collisions.

The nuclear modification factor ($R_{\rm AA}$) of bottom- and charm-decayed electrons are obtained using:

$$R_{\rm AA}^{b\to e} = \frac{f^{b\to e}_{Au+Au}}{f^{b\to e}_{p+p}} R_{\rm AA}^{\rm HFE},\ R_{\rm AA}^{c\to e} = \frac{1-f^{b\to e}_{Au+Au}}{1-f^{b\to e}_{p+p}} R_{\rm AA}^{\rm HFE}, \quad (1)$$

where $f^{b\to e}$ is the fraction of $b{\to}e$ in Au+Au or p+p collisions, and $R_{\rm AA}^{HFE}$ is the $R_{\rm AA}$ of the HFE defined as a ratio of HFE yield in Au+Au collisions to that in p+p collisions normalized by the average number of binary nucleon-nucleon collisions. The left panel of Fig. 2 shows $R_{\rm AA}^{b\to e}$, $R_{\rm AA}^{c\to e}$ and the ratio of $R_{\rm AA}^{b\to e}$ to $R_{\rm AA}^{c\to e}$ in 0-80% Au+Au collisions, along with a comparison to the DUKE transport model calculations that include the mass dependence of the parton energy loss [4]. From a constant fit to the ratio, the $R_{\rm AA}^{b\to e}$ is about 1.92 times larger than $R_{\rm AA}^{c\to e}$ (2.8σ significance), which is qualitatively described by the DUKE model calculation and consistent with the mass hierarchy of parton energy loss. A null hypothesis of no mass dependence for the $R_{AA}^{b\to e}$ to $R_{AA}^{c\to e}$ ratio (blue shaded curve) is constructed by using the D meson R_{AA} [7] to the $c/b\to e$ simulation, which takes into account the different decay kinematics. The p-value of the data to this curve is found to be 0.014, disfavoring the hypothesis of identical charm and bottom hadron R_{AA}.

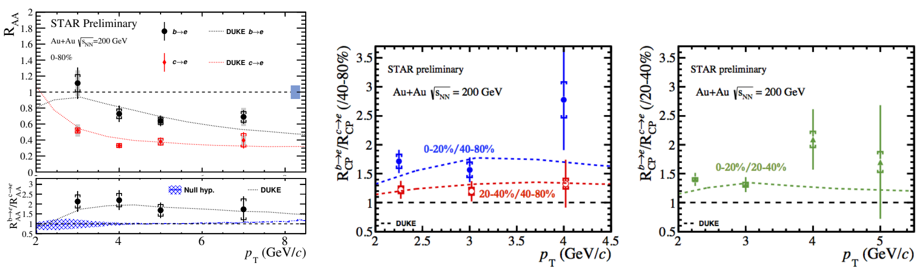

Figure 2. Left: $R_{AA}^{b\to e}$ and $R_{AA}^{c\to e}$ (top) and the $R_{AA}^{b\to e}/R_{AA}^{c\to e}$ ratio (bottom) as a function of p_T in 0-80% Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The blue shaded curve represents the null hypothesis. Middle: the double ratios of $R_{CP}^{b\to e}$ to $R_{CP}^{c\to e}$ (0-20%/40-80% and 20-40%/40-80%) as a function of p_T. Right: the double ratio of $R_{CP}^{b\to e}$ to $R_{CP}^{c\to e}$ (0-20%/20-40%) as a function of p_T. Results are compared to the Duke model calculations.

The double ratio of $R_{CP}^{b\to e}$ to $R_{CP}^{c\to e}$ is obtained as follows:

$$\frac{R_{CP}^{b\to e}}{R_{CP}^{c\to e}} = \frac{f_{central}^{b\to e}}{1 - f_{central}^{b\to e}} \frac{1 - f_{peripheral}^{b\to e}}{f_{peripheral}^{b\to e}}. \tag{2}$$

In the middle and right panels of Fig. 2, the obtained double ratios of $R_{CP}^{b\to e}$ to $R_{CP}^{c\to e}$ are shown for 0-20%/40-80%, 20-40%/40-80% and 0-20%/20-40%, respectively. A constant fit to the double ratios is performed and the R_{CP} ratio values are found to be 1.68±0.15(stat.)±0.12(syst.) and 1.38±0.08(stat.)±0.03(syst.) for 0-20%/40-80% and 0-20%/20-40%, which are significantly different from unity at a 3.5σ and 4.4σ level, respectively.

2.2 Elliptic flow

The inclusive HFE v_2 is measured in $\sqrt{s_{NN}}$ = 27 and 54.4 GeV 0-60% Au+Au collisions in a similar way to STAR published measurements at $\sqrt{s_{NN}}$ = 200, 62.4, and 39 GeV [8]. The

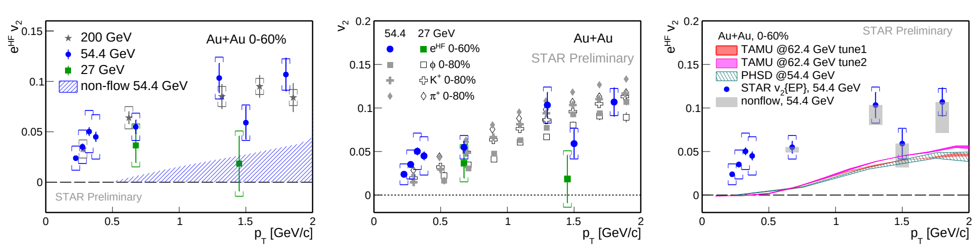

Figure 3. Left: HFE v_2 as a function of p_T in 0–60% centrality of 27 and 54.4 GeV Au+Au collisions compared with that from 200 GeV Au+Au collisions. Middle: HFE v_2 as a function of p_T compared to those of light flavor mesons in 27 and 54.4 GeV Au+Au collisions. Right: HFE v_2 as a function of p_T, compared to TAMU and PHSD calculations in 0–60% centrality of 54.4 GeV Au+Au collisions.

results are shown in left and middle panels of Fig. 3, together with a comparison to the 200 GeV Au+Au results of HFE v_2 and to those of light flavor mesons in 27 and 54.4 GeV Au+Au collisions, respectively. A non-zero v_2 is observed for HFE in 54.4 GeV Au+Au collisions, and is comparable to that at 200 GeV as well as the v_2 of light flavor mesons in 54.4 GeV Au+Au collisions, which indicates strong charm quark interactions with the medium at 54.4 GeV. There is a hint of smaller HFE v_2 in 27 GeV Au+Au collisions compared to those at 54.4 and 200 GeV and those of light flavor mesons in 27 GeV Au+Au collisions. In the right panel of Fig. 3, the HFE v_2 in 54.4 GeV Au+Au collisions is compared to the TAMU [9] and PHSD [10, 11] calculations, in which heavy quarks interact with the strongly coupled medium elastically without gluon radiation process. The TAMU and PHSD predictions are lower than the measured v_2 at low p_{T} and comparable to data at high p_{T} considering the non-flow contribution and uncertainties.

3 Summary

In these proceedings, we present the STAR measurements of R_{AA} and the double ratio of R_{CP} for open charm and bottom hadron decayed electrons in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV. The results indicate less suppression for electrons from bottom hadron decays compared to those from charm hadron decays with a significance larger than 3σ. They are consistent with the mass hierarchy of parton energy loss and the DUKE model calculations. We also present the measurements of HFE v_2 in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 27 and 54.4 GeV. HFE v_2 in 54.4 GeV Au+Au collisions is non-zero and is comparable to the HFE v_2 at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV and v_2 of light flavor mesons in 54.4 GeV Au+Au collisions, indicating that charm quarks interact strongly with the QGP medium in $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV Au+Au collisions. Model calculations are systematically lower than the measured HFE v_2 at low p_{T} and comparable to data at high p_{T}. There is a hint of smaller HFE v_2 in 27 GeV Au+Au collisions than those at 54.4 and 200 GeV.

Acknowledgments

This work was supported in part by Project funded by China Postdoctoral Science Foundation under Grant No. 2019M652177, National Natural Science Foundation of China with Grant No. 11890712 and 12061141008, National Key Research and Development Program of China with Grant No. 2018YFE0205200 and 2018YFE0104700, the Strategic Priority Research Program of CAS with Grant No. XDB34030000.

References

[1] G. Contin et al., Nucl. Instrum. Meth. A **907**, 60 (2018)
[2] D. J. Lange, Nucl. Instrum. Methods Phys. Res. Sect. A Accel. Spectrometers Detect. Assoc. Equip. **462**, 152–155 (2001)
[3] M. M. Aggarwal et al., Phys. Rev. Lett. **105**, 202301 (2010)
[4] S. Cao et al., Phys. Rev. C **92**, 024907 (2015)
[5] M. Cacciari et al., JHEP **1210**, 137 (2012)
[6] M. Cacciari et al., arXiv:1507.06197
[7] J. Adam et al., Phys. Rev. C **99**, 034908 (2019)
[8] L. Adamczyk et al., Phys. Rev. C **95**, 034907 (2017)
[9] M. He et al., Phys. Rev. C **91**, 024904 (2015)
[10] T. Song et al., Phys. Rev. C **92**, 014910 (2015)
[11] T. Song et al., Phys. Rev. C **96**, 014905 (2017)