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Measurements of electron production from heavy flavor decays in p+p and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV at STAR

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In these proceedings, we present the analyses of single electrons from semileptonic decays of open heavy flavor hadrons at mid-rapidity in p+p and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The data for Au+Au collisions were taken with the Heavy Flavor Tracker which enables a topological separation of electrons originating from bottom- and charm-hadron decays. We report results on the fraction of bottom-decayed electrons as a function of transverse momentum for Au+Au collisions from the STAR experiment with significantly improved precision compared to previous measurements. At the same time, improved measurements of nuclear modification factors ($R_{\rm AA}$) of bottom- and charm-decayed electrons and a new measurement of the double ratio of $R_{\rm CP}$ between bottom- and charm-decayed electrons are also be presented.

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1. Introduction

Measurements of nuclear modification factors (R_{AA}, R_{CP}) for open Heavy-Flavor (HF) hadrons are essential probes to the quark-gluon plasma (QGP) produced in heavy-ion collisions. Electrons from open heavy flavor hadron decays are an excellent channel to study these hadrons due to their large branching ratios and triggering capabilities. The STAR Heavy Flavor Tracker (HFT) [1] provides an excellent track pointing resolution which allows to separate electrons originating from open charm and bottom hadron decays based on their measured distance of closest approach to the collision vertex. Measurements of the HF electrons (HFE) from charm and bottom hadron decays separately can be used to investigate the mass hierarchy of parton energy loss in the QGP.

2. Experiment and Analysis

The data used in this analysis were recorded for p+p collisions at $\sqrt{s}$ = 200 GeV in 2012 and for Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV in 2014 and 2016 by the STAR experiment. The main detectors used in this analysis are the Time Projection Chamber, the Time Of Flight detector, and the Barrel ElectroMagnetic Calorimeter to reconstruct charged tracks and perform particle identification. The HFT was installed at STAR and participated in data taking from 2014 to 2016. It provides an excellent track pointing resolution, i.e. $< 30\ \mu m$ for charged particles with transverse momenta (p_{T}) above 1.5 GeV/c, for precise reconstruction of displaced vertices [2]. Therefore, the HFT can be used to separate electrons from charm and bottom hadron decays by taking advantage of their different lifetimes.

2.1 Bottom contribution to the HFE production in p+p collisions

The fraction of bottom decayed electrons to the HFE in p+p collisions is measured by azimuthal correlations between HFE and hadrons. We start with the semi-inclusive electron sample to construct correlations with charged hadrons. The semi-inclusive electrons are obtained by removing the background from photon conversions and π^0 and η Dalitz decays from the inclusive electron sample. These photonic electron background are identified through electron-positron pairs of low invariant mass. The correlation signal between HFE and charged hadrons is calculated as following:

$$\Delta\phi_{\mathrm{HFE-h}} = \Delta\phi_{\mathrm{semi-h}} + \Delta\phi_{\mathrm{like-h}} - \Delta\phi_{\mathrm{not\_reco-h}} - (1 - \varepsilon_{\mathrm{purity}}) * \Delta\phi_{\mathrm{hadron-h}} \tag{1}$$

where $\Delta\phi_{\mathrm{like-h}}$ is an estimate of the combinatorial background in the photonic electron reconstruction and used to account for the over-subtraction of photonic electron background. $\Delta\phi_{\mathrm{hadron-h}}$ is the hadron-hadron correlation arising from the hadron contamination, and $(1 - \varepsilon_{purity})$ is the fraction of background hadrons in the inclusive electron sample estimated using a data-drivne method. $\Delta\phi_{\mathrm{not\_reco-h}}$ is the remaining contribution from photonic electrons that are not reconstructed through the invariant mass method. It is calculated as:

$$\Delta\phi_{\mathrm{not\_reco-h}} = (1/\varepsilon_{\gamma} - 1) * \Delta\phi_{\mathrm{reco-h}} \tag{2}$$

where $\Delta\phi_{\mathrm{reco-h}}$ is the correlation between reconstructed photonic electrons and hadrons, and ε_{γ} is the efficiency for the photonic electron reconstruction which can be obtained from simulations.

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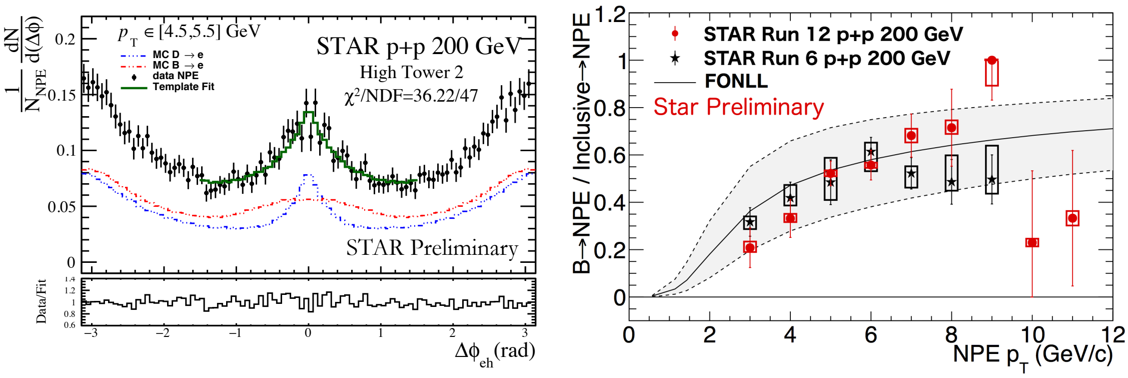

Figure 1: (Color online) Left: HFE-hadron azimuthal correlations from STAR fitted with PYTHIA templates in p+p collisions at $\sqrt{s}$ = 200 GeV. Right: The measured fraction of bottom decayed electrons to the HFE for p+p collisions at $\sqrt{s}$ = 200 GeV. Statistical uncertainties are shown as error bars and systematic ones as brackets.

Left panel in Fig. 1 shows the azimuthal correlation between HFE and charged hadrons. We use PYTHIA 8.135 to generate azimuthal correlations between electrons from bottom and charm hadron decays and charged hadrons [3]. Fitting the experimental data with the HFE-h azimuthal correlations from PYTHIA, we can extract the bottom contribution to the HFE. Right panel shows the extracted bottom fraction f_b, defined as $N(b \to e)/N(b+c \to e)$, as a function of p_{T} (red circles). The preliminary results agree with STAR 2006 p+p results (black stars) [4], and the systematic uncertainties are significantly reduced. We also compare the results with Fixed Order plus Next to Leading Logarithm (FONLL) predictions [5, 6], and find the results are consistent with FONLL calculation within uncertainties.

2.2 Bottom contribution to the HFE production in Au+Au collisions

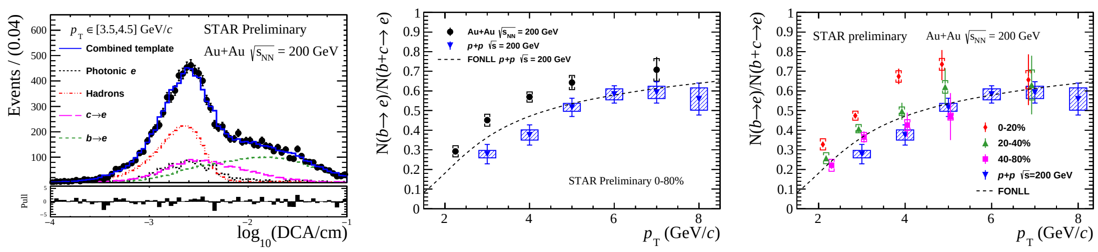

Figure 2: (Color online) Left: Example fit to the log(DCA/cm) distribution in MB $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV Au+Au collisions. Middle: The measured fraction of bottom decayed electrons to the HFE in MB $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV Au+Au collisions. Right: The bottom fraction as a function of p_{T} in different collision centrality categories. In the two right plots the p+p data (from combined published [4] and preliminary data 2.1) and the FONLL predictions [5, 6] (black dashed line) are also shown. Statistical uncertainties are shown as error bars and systematic ones as brackets.

The fraction of bottom decayed electrons to the HFE in Au+Au collisions is extracted with a template fit to the log(DCA/cm) distribution, where the DCA is the 3D distance of closest approach of a candidate electron to the collision vertex. The measured log(DCA/cm) distribution for inclusive electrons is shown in the left panel of Fig. 2, along with the template fit including $b \to e$, $c \to e$, background from photonic electrons, and hadron contamination. Through the template fitting, the bottom fraction is obtained, which is shown in Fig. 2 middle and right panels for minimum bias (MB) and in bins of collision centrality, respectively, for Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The ratio shows a clear enhancement in central and mid-central collisions with respect to the p+p data and the FONLL predictions [5, 6].

3. Bottom and Charm Decayed Electron Nuclear Modification Factors

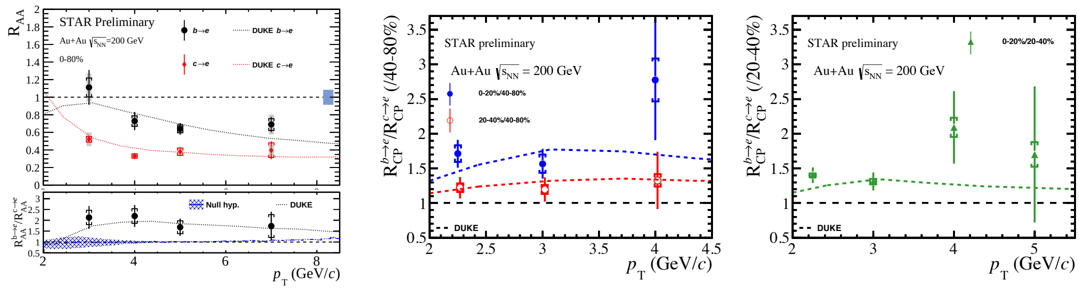

Figure 3: (Color online) Left: The measured $R_{\rm AA}$ for bottom and charm decayed electrons as a function of electron $p_{\rm T}$. Statistical uncertainties on the data are shown as error bars and systematic ones as brackets; the shaded gray boxes show the global uncertainty due to the HF electron $R_{\rm AA}$ measurement. The blue shaded region at $R_{\rm AA}$ = 1 shows the uncertainty on $N_{\rm coll}$. The bottom panel shows the bottom to charm decayed electron $R_{\rm AA}$ ratio. The blue shaded curve shows the null hypothesis described in the text. In both panels, Duke model [7] predictions are shown as the dotted lines. Middle, Right: The measured $R_{\rm CP}$ ratios of bottom decayed electrons to that of charm decayed electrons in $\sqrt{s_{\rm NN}}$ = 200 GeV Au+Au collisions. The error bars show statistical uncertainties and the brackets show systematic ones. The predictions from the Duke model are shown as colored lines.

The $R_{\rm AA}$ of $b \to e$ and $c \to e$ are obtained using:

$$R_{AA}^{b\to e} = \frac{f_b^{AA}}{f_b^{pp}} R_{AA}^{HFE}, R_{AA}^{c\to e} = \frac{1-f_b^{AA}}{1-f_b^{pp}} R_{AA}^{HFE} \tag{3}$$

where f_b^{AA}, f_b^{pp} is the bottom fraction in Au+Au and p+p collisions, respectively, and $R_{\rm AA}$ is the ratio of HFE yield in Au+Au collisions to that in p+p collisions normalized by the number of binary nucleon-nucleon collisions ($N_{\rm coll}$). The obtained $R_{AA}^{b\to e}$, $R_{AA}^{c\to e}$ are shown in left panel of Fig. 3 along with their ratio. The data show the bottom decayed electron $R_{\rm AA}$ is larger than that of charm decayed electrons. A constant fit to the ratio yields 1.92±0.25(stat.)±0.21(syst.), which is above 1 at roughly a 3σ level. A null hypothesis for the ratio (blue shaded curve) is constructed by applying D meson $R_{\rm AA}$ to the $b/c \to e$ simulation, which takes into account the different decay kinematics. The p-value of the data to this curve is 0.014, disfavoring the hypothesis of identical D and B hadron $R_{\rm AA}$.

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We compare to the Duke Langevin transport model [7] shown as the dotted lines in the left panel of Fig. 3, which contains the mass dependence of energy loss and other affects which may influence the measured R_{AA} (e.g., hadronization and initial HF spectra). Within uncertainties the model is able to describe both the absolute values of R_{AA} and their ratio. This compatibility between the data and model shows a good indication that b-quarks lose less energy in the QGP compared to c-quarks.

An additional measurement of the ratios of bottom to charm decayed electron R_{CP} are performed and shown in middle and right panels of Fig. 3. Data show no strong p_{T} dependence. Performing the same constant fits described above, we find R_{CP}(0-20%/40-80%)=1.68±0.15(stat.)±0.12(syst.) and R_{CP} (0-20%/20-40%)=1.38±0.08(stat.)±0.03(syst.). The significances of these measurements deviating from unity are 3.5σ and 4.4σ, respectively.

4. Summary

We measure the charm and bottom decayed electron R_{AA} and find that the bottom decayed electron R_{AA} is larger than the charm decayed electron R_{AA} by roughly a factor of two with a significance of about 3σ. The measured ratios of bottom and charm decayed electron R_{CP} show the same hierarchy with a significance greater than 3.5σ. These observations, combined with the agreement to the model calculation including mass dependence of parton energy loss, are consistent with the mass hierarchy of energy loss in the QGP.

Acknowledgments

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References

[1] G. Contin, L. Greiner, J. Schambach, M. Szelezniak, E. Anderssen, J. Bell et al., *The STAR MAPS-based PiXel detector*, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **907** (2018) 60.

[2] H. Qiu and S. Collaboration, *STAR heavy flavor tracker*, *Nuclear Physics A* **931** (2014) 1141.

[3] T. Sjostrand, P. Eden and C. Friberg, *Comput. Phys. Commun. 135, 238*, .

[4] M. Aggarwal, Z. Ahammed, A. Alakhverdyants, I. Alekseev, J. Alford, B. Anderson et al., *Measurement of the bottom quark contribution to nonphotonic electron production in p+ p collisions at $\sqrt{s}$ = 200 GeV*, *Physical review letters* **105** (2010) 202301.

[5] M. Cacciari, S. Frixione, N. Houdeau, M.L. Mangano, P. Nason and G. Ridolfi, *Theoretical predictions for charm and bottom production at the LHC*, *Journal of High Energy Physics* **2012** (2012) 137.

[6] M. Cacciari, M.L. Mangano and P. Nason, *Gluon PDF constraints from the ratio of forward heavy-quark production at the LHC at $\sqrt{s}$= 7 and 13 TeV*, *The European Physical Journal C* **75** (2015) 610.

[7] S. Cao, G.-Y. Qin and S.A. Bass, *Energy loss, hadronization, and hadronic interactions of heavy flavors in relativistic heavy-ion collisions*, *Physical Review C* **92** (2015) 024907.