Open Bottom Production in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR Experiment

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In these proceedings, we present measurements of open bottom hadron production through multiple decay channels in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the STAR experiment. Namely, measurements of nuclear modification factors for electrons, J/ψ , and D^0 from open bottom hadron decays are shown. The decay products are topologically identified utilizing the Heavy Flavor Tracker, a silicon vertex detector installed at STAR during the period of 2014 - 2016. It enables precise reconstruction of displaced decay vertices. The results show large suppression for non-prompt J/ψ and non-prompt D^0 at high transverse momenta, and indicate less suppression for electrons from bottom hadron decays than for those from charm hadron decays at $\sim 2\sigma$ significance level.

Keywords: Open bottom production; nuclear modification factors; non-prompt J/ψ ; non-prompt D^0 ; electrons from bottom hadron decays; quark-gluon plasma.

1. Introduction

Heavy quarks are predominantly produced at early stages of the relativistic heavy-ion collisions before the creation of the deconfined Quantum Chromodynamics (QCD) medium, known as the Quark-Gluon Plasma (QGP). They subsequently traverse the created system throughout its evolution, and thus are suggested as an excellent probe for studying the properties of the QGP. By comparing the yields of heavy-flavor hadron decay electrons at large transverse momenta (p_T) in Au+Au collisions with those in p+p collisions at $\sqrt{s_{NN}} = 200$ GeV, a significant suppression has been observed.¹ This suppression is believed to be caused by the energy loss of heavy flavor quarks through interactions with the QGP, which is expected to be different for bottom and charm quarks because of their different masses.² Separate measurements of open bottom and charm hadron production in Au+Au collisions are crucial to test the mass hierarchy of the parton energy loss in the QGP. In these

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proceedings, we focus on measurements of electrons, J/ψ , and D^0 from open bottom hadron decays in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the STAR experiment.

2. Experiment

The STAR experiment uses three main detectors, the Time Projection Chamber (TPC), the Time Of Flight (TOF) detector, and the Barrel Electromagnetic Calorimeter (BEMC), to reconstruct charged tracks and perform particle identification (PID). All of these three detectors cover the full azimuth within pseudo-rapidity range of $|\eta| < 1$. The TPC provides tracking, momentum determination and PID via measuring ionization energy loss. The BEMC can trigger on and identify high- p_T electrons using the energy to momentum ratio and shower shape. The TOF provides PID capability through measured time-of-flight. Electrons are identified using the TPC combined with the TOF at low p_T and with the BEMC at high p_T . Hadrons are identified using the TPC as well as the TOF but only when a track is matched to a TOF hit.

The Heavy Flavor Tracker (HFT) was installed at STAR and participated in data taking from 2014 to 2016. It is composed of three sub-detectors: the silicon PiXeL detector (PXL), the Intermediate Silicon Tracker (IST) and the Silicon Strip Detector (SSD). It provides an excellent track pointing resolution for precise measurements of displaced vertices.³ Its resolution is less than $30 \mu m$ for charged particles with $p_T > 1.5$ GeV/c. Therefore, the HFT is used to identify particles from charm and bottom hadron decays by taking advantage of their different decay lengths.

3. Analysis

3.1. Bottom decay electrons

The distance of the closest approach (DCA) to the collision primary vertex is used to separate the bottom hadron decay electrons ($B \rightarrow e$) from charm hadron decay electrons ($D \rightarrow e$). The measured DCA distribution in the transverse plane (DCA_{XY}) for inclusive electrons (black circles) is shown in the upper panel of Fig. 1, along with the template fit including $B \rightarrow e$ (red line), $D \rightarrow e$ (green line), background from photonic electrons (black line), and hadron contamination (pink line). The templates for $B \rightarrow e$ and $D \rightarrow e$ are obtained from a data-driven simulation coupled with a EvtGen⁴ decayer ($D^0, D^\pm, B^0$ and $B^\pm$). The DCA_{XY} distribution for $B \rightarrow e$ is broader than that for $D \rightarrow e$ on account 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 data corrected for the electron reconstruction efficiency extracted from embedding based on HIJING⁵ simulations. 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 lower panel of Fig. 1 shows the ratio between data to the combined

template fit, which agrees with data quite well. Using these results, the fraction of $B \rightarrow e$ to open heavy flavor hadron decay electrons is obtained, which is shown as red circles in Fig. 2, along with that in p+p collisions (blue circles).⁶ An enhancement of the fraction of $B \rightarrow e$ is observed in Au+Au collisions compared to p+p collisions.

Fig. 1. *Top* : The DCA_{XY} distribution for inclusive electrons with a template fit including $B \rightarrow e$, $D \rightarrow e$, and background electrons. *Bottom* : Ratio of data to the fitted template.

Fig. 2. The fraction of $B \rightarrow e$ to open heavy flavor hadron decay electrons in 200 GeV p+p and Au+Au collisions.

Fig. 3. *Left* : R_{AA} as a function of p_T for open heavy flavor hadron decay electrons. *Right* : $R_{AA}^{B \rightarrow e}$ and $R_{AA}^{D \rightarrow e}$ as a function of p_T .

The R_{AA} of $B \rightarrow e$ and $D \rightarrow e$ are obtained using:

$$R_{AA}^{B \rightarrow e} = \frac{f_{Au+Au}^{B \rightarrow e}(data)}{f_{p+p}^{B \rightarrow e}(data)} R_{AA}^{HF_e}(data), \quad R_{AA}^{D \rightarrow e} = \frac{1 - f_{Au+Au}^{B \rightarrow e}(data)}{1 - f_{p+p}^{B \rightarrow e}(data)} R_{AA}^{HF_e}(data), \quad (1)$$

where $f^{B \rightarrow e}$ is the fraction of $B \rightarrow e$ in Au+Au or p+p collisions, and $R_{AA}^{HF_e}$ the R_{AA} of open heavy flavor hadron decay electrons, which is obtained by taking a ratio of decay electron yield in Au+Au collisions to that in p+p collisions normalized by the number of binary nucleon-nucleon collisions (N_{coll}). In Fig. 3, the left panel shows

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the $R_{AA}^{HF_e}$ while the right one shows $R_{AA}^{B \rightarrow e}$ and $R_{AA}^{D \rightarrow e}$, along with a comparison to the DUKE model calculation for $B \rightarrow e$ (red line) and $D \rightarrow e$ (blue line)⁷ in 0-80% central Au+Au collisions. The $R_{AA}^{D \rightarrow e}$ is less than $R_{AA}^{B \rightarrow e}$, which is qualitatively described by the DUKE model calculation.⁷

3.2. Non-prompt J/ψ

The pseudo-proper decay length $l_{J/\psi}$ is used to separate non-prompt and prompt J/ψ , and is defined as:

$$l_{J/\psi} = \frac{\vec{L} \cdot \hat{p}}{|\vec{p}|/c} \cdot M_{J/\psi}, \quad (2)$$

where $\vec{L}$ is B hadron flight path, $\vec{p}$ the J/ψ momentum, and $M_{J/\psi}$ the J/ψ mass. The $l_{J/\psi}$ distribution for inclusive J/ψ is shown in the left panel of Fig. 4, along with the template fit for non-prompt (red shadow) and prompt (purple shadow) J/ψ . The template for prompt J/ψ is from the FONLL calculation combined with a data-driven simulation of detector effects. For the non-prompt J/ψ the template is obtained by decaying B-hadrons ($B^0, B^\pm$) from FONLL into J/ψ via PYTHIA and taking into account detector effects. The fraction of non-prompt J/ψ extracted from the template fit is shown in the middle panel of Fig. 4, and is compared with the CEM+FONLL calculation^{8,9} for 200 GeV p+p collisions (gray band).

Fig. 4. *Left* : The $l_{J/\psi}$ distribution for inclusive J/ψ fitted with templates for non-prompt and prompt J/ψ . *Middle* : fraction of non-prompt J/ψ as a function of p_T (red circles). *Right* : R_{AA} of non-prompt J/ψ as a function of p_T (red circles).

The R_{AA} of non-prompt J/ψ is calculated as:

$$R_{AA}^{B \rightarrow J/\psi} = \frac{f_{Au+Au}^{B \rightarrow J/\psi}(data)}{f_{p+p}^{B \rightarrow J/\psi}(theory)} R_{AA}^{inc.J/\psi}(data), \quad (3)$$

where $f_{p+p}^{B \rightarrow J/\psi}$ is the fraction of non-prompt J/ψ in Au+Au or p+p collisions and $R_{AA}^{inc.J/\psi}$ is the R_{AA} of inclusive J/ψ .¹⁰ The right panel of Fig. 4 shows the R_{AA} of non-prompt J/ψ , together with a comparison to that of inclusive D^0 (blue circles)¹¹

and the DUKE model calculation⁷ (red line) in 0-80% centrality of 200 GeV Au+Au collisions. A strong suppression is observed for non-prompt J/ ψ at high p_T and is similar to that of D^0 mesons.

3.3. Non-prompt D^0

The DCA distribution is used to distinguish non-prompt D^0 from the prompt ones. The left panel of Fig. 5 shows the DCA distribution of inclusive D^0 , along with the template fit of non-prompt (green line) and prompt (blue line) D^0 . The templates for non-prompt and prompt D^0 are obtained using the same method as for the non-prompt and prompt J/ ψ . The extracted fractions of non-prompt D^0 in different centralities of 200 GeV Au+Au collisions are presented in the middle panel of Fig. 5. The non-prompt D^0 fractions in p+p collisions are also shown, which are obtained by taking a ratio of non-prompt D^0 yield from FONLL calculation⁹ to the inclusive D^0 yield either from the FONLL calculation⁹ (green shadow) or from the STAR published data¹² (yellow shadow).

Fig. 5. *Left* : The DCA distribution of inclusive D^0 with a template fit including non-prompt and prompt D^0 . *Middle* : fraction of non-prompt D^0 as a function of p_T in different centralities compared to that for p+p collisions. *Right* : R_{AA} of non-prompt and inclusive D^0 as a function of p_T .

Since non-prompt D^0 in 200 GeV p+p collisions has not been measured, the R_{AA} of non-prompt D^0 is obtained utilizing FONLL calculations:

$$R_{AA}^{B \rightarrow D^0} = \frac{1}{\langle N_{coll} \rangle} \frac{f_{Au+Au}^{B \rightarrow D^0} \times dN_{Au+Au}^{inc.D^0}/dp_T}{dN_{FONLL}^{B \rightarrow D^0}/dp_T}, \quad (4)$$

where $f_{Au+Au}^{B \rightarrow D^0}$ is the fraction of non-prompt D^0 in Au+Au collisions, $dN_{Au+Au}^{inc.D^0}/dp_T$ the inclusive D^0 yield measured by STAR in Au+Au collisions¹³ and $dN_{FONLL}^{B \rightarrow D^0}/dp_T$ the non-prompt D^0 yield from the FONLL calculation for p+p collisions. The right panel of Fig. 5 shows the R_{AA} of non-prompt (red circles) and inclusive D^0 (blue circles)¹¹, along with a comparison to the DUKE model calculation.⁷ The non-prompt D^0 is measured in 0-20% centrality while the inclusive D^0 and the model calculation are for 0-10% centrality. A strong suppression of non-prompt D^0 is

observed at high p_T and there is a hint of less suppression for non-prompt D^0 compared to prompt ones at $4 < p_T < 6.5$ GeV/c.

4. Summary and Outlook

In these proceedings, we present the STAR results of measurements of bottom hadron production via electron, J/ψ , and D^0 decay channels in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. For R_{AA} of non-prompt J/ψ and D^0 , a strong suppression is observed at high p_T . For the electron channel, there is less suppression for electrons from B-hadron decays compared to those from D-hadron decays, which is consistent with the theoretical prediction that bottom quarks should lose less energy than charm quarks due to their larger mass. The presented results for electron and D^0 are from 2014 data and J/ψ from 2014 and 2016 data. In 2016, there were a factor of ~ 2 more minimum-bias and ~ 5 more high- p_T electron triggered events in 200 GeV Au+Au collisions events recorded by the STAR experiment, which can be used to further improve the precision of the measurements for electrons and D^0 from B-hadron decays.

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