Measurements of Open Heavy Flavor Production in Semi-leptonic Decay Channels at the STAR experiment

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Abstract. In these proceedings, we will present the new results of the Non-Photonic Electron (NPE) production from semi-leptonic decays of open heavy flavor hadrons at the STAR experiment. Firstly we will report the updated results on NPE production in p+p collisions at $\sqrt{s} = 200$ GeV with much improved precision and wider kinematic coverage than previous measurements. Secondly we will report measurements of the nuclear modification factor, $R_{AA}$, for NPE production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with this new p+p reference. The NPE $R_{AA}$ shows large suppression at high transverse momenta ($p_T$) in central collisions, which reduces gradually towards more peripheral collisions, and an enhancement at low $p_T$ with large systematic uncertainties from the p+p reference. We will compare NPE $R_{AA}$ to the $R_{AA}$ of charm decayed electrons, $D^0$ mesons and light hadrons in Au+Au collisions as well as to NPE and $D^0$ mesons in central U+U collisions and show that they are all consistent within the uncertainties. Finally we will report the results on measurements of NPE from open bottom hadron decays and discuss the prospect of measuring NPE from open bottom and charm hadron decays separately utilizing the Heavy Flavor Tracker.

1. Introduction

Heavy quarks are predominantly produced in hard scatterings at early stages of high-energy heavy-ion collisions due to their large masses. Studies of interactions between heavy quarks and the Quark-Gluon Plasma (QGP) in various collision geometries, especially for charm and bottom quarks separately, can provide new insights to the properties of QGP. The heavy quark production in p+p collisions provides a baseline to similar measurements in heavy-ion collisions and is expected to be well described by perturbative Quantum Chromodynamics (pQCD) calculations. Thus measurements of heavy quark production in both p+p and Au+Au collisions are crucial. Heavy quark production can be studied via measuring the electrons from semi-leptonic decays of heavy flavor hadrons, also known as Non-Photonic Electrons (NPE). In these proceedings, we focus on the measurements of NPE in p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at the STAR experiment.
2. Analysis

2.1. Track selection and electron identification

STAR 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). The TPC, covering full azimuth within pseudorapidity range of $|\eta| < 1$, provides tracking, momentum determination and PID via measuring ionization energy loss. The BEMC, covering $|\eta| < 1$ and full azimuth, can trigger on and identify high-$p_T$ electrons via the ratio of energy to momentum measurements. The TOF covers $|\eta| < 1$ within full azimuth and provides PID capability through measured time-of-flight. Electrons are identified using the TPC combined with the TOF at low $p_T$ and the BEMC at high $p_T$.

2.2. NPE cross-section extraction

The NPE raw yield is extracted using the equation $N_{NPE} = N_{inc} \times purity - N_{phe}/\epsilon_{phe}$, where $N_{inc}$ is the number of inclusive electron candidates, $purity$ the fraction of real electrons in the inclusive electron sample, $N_{phe}$ the number of photonic electron candidates obtained via selecting the invariant mass of $e^+e^-$ pairs, and $\epsilon_{phe}$ the photonic electron reconstruction efficiency. There are primarily two types of photonic electron background: gamma conversion, $\pi^0$ and $\eta$ Dalitz decays. The final yields of NPE need to be corrected for the detector acceptance and efficiency.

3. NPE measurement in p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

3.1. NPE $p_T$ spectrum

The measured NPE cross-section for p+p collisions at $\sqrt{s} = 200$ GeV from 2012 data (red points) is shown in the upper panel of Fig. 1, along with the previous STAR result from 2005 and 2008 data (black points) [1] and the FONLL (Fixed-Order Next-to-Leading Logarithm) pQCD calculation (blue curves) [2]. The lower panel shows the ratio of data to FONLL calculation. The new measurement extends to both the lower and higher $p_T$ regions compared to the previous STAR measurement with greatly reduced uncertainty and is consistent with the FONLL prediction. Due to the large uncertainties in the gluon density function and the dramatic increase of strong coupling constant towards low $p_T$, pQCD calculations have little predictive power for the charm cross-section at low $p_T$ [3].

![Figure 1: Top : The NPE cross-section in p+p collisions. Bottom : Ratio of data to the pQCD calculation.](image1)

![Figure 2: The NPE invariant yields in different centralities for Au+Au collisions.](image2)
and the scaled FONLL calculation, indicating existence of hot medium effects. From central to peripheral collisions, the difference is getting smaller, which is consistent with the expectation of less QGP effects in peripheral collisions.

3.2. NPE $R_{AA}$

The $R_{AA}$ is obtained by taking the ratio of the NPE yield in Au+Au collisions to that in p+p collisions normalized by $N_{\text{coll}}$. In Fig. 3, there are four panels showing $R_{AA}$ in different centralities. We observe an enhancement at low $p_T$ across all centralities, with large systematic uncertainties from p+p reference, and strong suppression at high $p_T$ in central collisions, which reduces gradually towards peripheral collisions. Different model calculations are compared with our data in the 0-10% centrality. The DGLV model with only radiative energy loss [4] underestimates the suppression of NPE. With the addition of the collisional energy loss, the model calculation agrees with our data. The other models, Collisional dissociation [6], Min He et al. [7, 8], and Gossiaux et al. [5, 9, 10] have some difficulties to describe the data. In low $p_T$, NPE $R_{AA}$ is consistent with $R_{AA}$ for charm decayed electrons ($c\rightarrow e$) (blue line) extracted via decaying $D^0$ mesons [11] according to the measured $p_T$ spectrum which is shown in upper panel of Fig. 5 (black points) into electrons through PYTHIA. As we can see from upper panels of Fig. 5, bottom decayed electrons ($b\rightarrow e$) have larger contribution to NPE when $p_T > 3$ GeV/c. So NPE $R_{AA}$ is not consistent with $R_{AA}$ for $c\rightarrow e$ in high $p_T$.

Figure 3: NPE $R_{AA}$ as a function of $p_T$ in different centralities of Au+Au collisions.

Figure 4: $R_{AA}$ as a function of the number of participating nucleons ($N_{\text{part}}$).

Figure 4 shows $R_{AA}$ as a function of the number of participating nucleons ($N_{\text{part}}$). We compare NPE $R_{AA}$ with $D^0$ and light hadron $R_{AA}$ [12] in different heavy-ion collision systems and find that the suppression of NPE at high $p_T$ in central Au+Au collisions is similar to those of $D^0$ mesons and light hadrons in Au+Au collisions as well as NPE and $D^0$ mesons in central U+U collisions.

3.3. Bottom decayed electron $R_{AA}$

The invariant yields and $R_{AA}$ of $b\rightarrow e$ are shown in upper and lower panels of Fig. 5. The equation $N_{b\rightarrow e} = N_{NPE} - N_{c\rightarrow e}$ is used to extract the invariant yields of $b\rightarrow e$ (blue lines), where $N_{c\rightarrow e}$ is the number of $c\rightarrow e$ (red lines), and $N_{NPE}$ the number of measured NPE (red points). Using the $b\rightarrow e$ FONLL calculation scaled by $N_{\text{coll}}$ as the reference, we can obtain the $R_{AA}$ of $b\rightarrow e$. The difference from Levy and Power-law function fits to the $D^0$ $p_T$ spectrum is taken as the uncertainty. In peripheral collisions, $b\rightarrow e$ $R_{AA}$ is consistent with no suppression. In 0-80% and 0-10% central collisions, $b\rightarrow e$ $R_{AA}$ shows an indication of suppression and is similar to $D^0$ $R_{AA}$ within large uncertainties.
The Heavy Flavor Tracker (HFT) has been installed into STAR and taken data since 2014. It provides excellent track impact parameter resolution [13], enabling separation of NPE from D and B mesons via their different decay lengths.

Figure 5: The invariant yields and $R_{AA}$ of bottom decayed electrons.

4. Summary and Outlook
In these proceedings we present the NPE production cross-section in $p+p$ collisions at $\sqrt{s} = 200$ GeV, which is measured over a broad $p_T$ range 0.3-12 GeV/c with significantly improved precision than previous measurements. The new result confirms the pQCD calculation and provides further constraints on theoretical calculations. Using the new $p+p$ reference, the NPE $R_{AA}$ in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is presented. We observe large suppression at high $p_T$ in central collisions, which is consistent with substantial energy loss of heavy quarks in dense matter, and an enhancement at low $p_T$, which is consistent with charm decayed electron $R_{AA}$, suggesting recombination of charm quarks with light quarks in the medium of strong radial flow. Finally, the perspective for the separation of charm and bottom contributions to NPE in Au+Au collisions with HFT data is given.

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