

Open charm measurements in $p + p$ collisions at STAR

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Abstract.

In this article, we will present the STAR results of open charm hadron and non-photonic productions at mid-rapidity in $p+p$ collisions at $\sqrt{s} = 200$ and 500 GeV. Open charm mesons are reconstructed directly via hadronic decay channels with daughter particles identified by STAR Time Projection Chamber (TPC) and Time Of Flight (TOF) detectors. Non-photonic electron yields are calculated by subtracting photonic electrons from inclusive electrons identified using TPC and Electromagnetic Calorimeter. These measurements are compared to theoretical model calculations and physics implications will be discussed.

1. Introduction

Heavy quark production at RHIC energies is dominated by initial gluon fusion and can be described by perturbative QCD (pQCD) due to their large mass [1]. The measurement of the charm quark production in $p + p$ collisions provides both pQCD test and baseline for any measurement in Heavy-Ion collisions. The study of heavy quark production in relativistic nuclear collisions follows two different approaches: (i) the direct reconstruction of heavy flavor mesons and (ii) the identification of electrons from semi-leptonic decays of such mesons, the so-called non-photonic electrons.

2. Data Analysis

2.1. The Direct Reconstruction of Open Charm Mesons

Invariant yield of charm quark Y is obtained from fitting the reconstructed invariant mass spectrum of open charm mesons through hadronic decays: $D^0(\bar{D}^0) \rightarrow K^\mp \pi^\pm$ (BR = 3.89%) and $D^{*\pm} \rightarrow D^0(\bar{D}^0)\pi^\pm$ (BR = 67.7%) $\rightarrow K^- \pi^+ \pi^\pm$ (total BR = 2.63%). The Y is calculated then as

$$Y \equiv \frac{d^2 N_{c\bar{c}}}{2\pi p_T dp_T dy} = \frac{1}{N_{\text{trig}}} \frac{N(p_T, y)}{2\pi p_T \Delta p_T \Delta y} \frac{f_{\text{trg}}}{\text{BR} f_{\text{frag}} \epsilon_{\text{rec}}} \quad (1)$$

where N_{trig} is the total number of triggered events used for the analysis. $N(p_T, y)$ is the raw charm hadron signal in each p_T bin within a rapidity window $\Delta y = 2$. BR is the hadronic decay branching ratio for the channel of interest. ϵ_{rec} is the reconstruction efficiency including geometric acceptance, track selection efficiency, PID efficiency, and analysis cut efficiency. f_{frag} represents the the ratio of charm quarks hadronized to open charm mesons. And f_{trg} is the correction factor to account for the bias between the minimum-bias sample used in this analysis and the total Non-single Diffractive (NSD) sample [2]. f_{trg} is found to be 0.65 for D^0 and 0.67 for D^* at $\sqrt{s} = 200$ GeV and 0.6 and 0.59 at $\sqrt{s} = 500$ GeV respectively.

The identification of daughter particles is done in the STAR experiment [3] at mid-rapidity $|y| < 1$ at $\sqrt{s} = 200$ and 500 GeV. The analysis presented herein is done using two datasets; the first one collected in year 2009 ($N_{\text{trig}} \sim 105$ million 200 GeV $p + p$ collisions), and the second one in 2011 ($N_{\text{MB}} \sim 50$ million 500 GeV $p + p$ collisions).

2.2. Identification of electrons from semi-leptonic decays

The invariant cross section for non-photonic electron production is calculated according to

$$E \frac{d^3\sigma}{dp^3} = \frac{1}{\mathcal{L}} \frac{1}{2\pi p_T \Delta p_T \delta y} \frac{N_{\text{npe}}}{\varepsilon_{\text{rec}} \varepsilon_{\text{trig}} \varepsilon_{\text{eid}} \varepsilon_{\text{BBC}}}, \quad (2)$$

where N_{npe} is the nonphotonic electron raw yield, ε_{rec} is the product of the single electron reconstruction efficiency and the correction factor for momentum resolution and finite spectrum bin width, $\varepsilon_{\text{trig}}$ is the high-tower trigger efficiency, ε_{eid} is the electron identification efficiency, \mathcal{L} is the integrated luminosity with the z -position of vertex cuts, and $\varepsilon_{\text{BBC}} = 0.87 \pm 0.08$ is the BBC trigger efficiency.

The analysis of non-photonic electrons consists of three main steps: selection of a clean electron sample; subtraction of electron background arising from conversion and Dalitz decays; and residual corrections of the signal yield. The analysis details and a discussion of the sources of uncertainty can be found in [4]. The main background in this analysis is the substantial flux of photonic electrons from photon conversion in the detector material and Dalitz decay of π^0 and η mesons. These contributions need to be subtracted in order to extract the non-photonic electron yield according to formula

$$N_{\text{npe}} = N_{\text{inc}} \varepsilon_{\text{purity}} - \frac{N_{\text{pho}}}{\varepsilon_{\text{pho}}}, \quad (3)$$

where N_{npe} is the non-photonic electron yield, N_{inc} is the inclusive electron yield, N_{pho} is the photonic electron yield, ε_{pho} is the photonic electron reconstruction efficiency defined as the fraction of the photonic electrons identified through invariant mass reconstruction, and $\varepsilon_{\text{purity}}$ is the purity reflecting hadron contamination in the inclusive electron sample.

3. Results

3.1. The Direct Reconstruction of Heavy Flavor Mesons

Yields $N(p_T, y)$ are calculated in six p_T bins (first two for D^0 , the next four for D^*) in $p + p$ 200 GeV and five p_T bins (first for D^0 , the next four for D^*) in $p + p$ 500 GeV. The charm cross section at mid-rapidity $d\sigma^{c\bar{c}}/dy$ was obtained from the power-law function fit [2] to $d^2\sigma^{c\bar{c}}/(2\pi p_T dp_T dy) = Y \cdot \sigma_{\text{NSD}}$, where Y is calculated according to (1). σ^{NSD} is the total NSD cross section, which is measured at STAR to be 30.0 ± 2.4 mb at $\sqrt{s} = 200$ GeV [5]. In the case of $\sqrt{s} = 500$ GeV, σ^{NSD} is extrapolated from 200 GeV measurement with the help of PYTHIA simulation to be 34 mb.

The charm production cross section at mid-rapidity $\left. \frac{d\sigma_{c\bar{c}}}{dy} \right|_{y=0}$ is $170 \pm 45(\text{stat.})_{-51}^{+37}(\text{sys.}) \mu\text{b}$ at $\sqrt{s} = 200$ GeV and is $217 \pm 86(\text{stat.}) \pm 73(\text{sys.}) \mu\text{b}$ at $\sqrt{s} = 500$ GeV. FONLL predictions for p_T spectra [6] shown in Fig. 1. In order to compare STAR results with other experiments, we extrapolated $\left. \frac{d\sigma_{c\bar{c}}}{dy} \right|_{y=0}$ to $\sigma_{c\bar{c}}^{\text{NN}}$ using PYTHIA simulations with various parameter tunings giving extrapolation factors 4.7 ± 0.7 for 200 GeV and 5.6 ± 0.1 for 500 GeV collisions. The results are depicted in Figure 1 revealing agreement with with NLO prediction [7]. Note that the STAR result at 200 GeV was used in [7] to fit the μ_R and μ_F parameters, so only the STAR result at 500 GeV can be used as a test of this prediction.

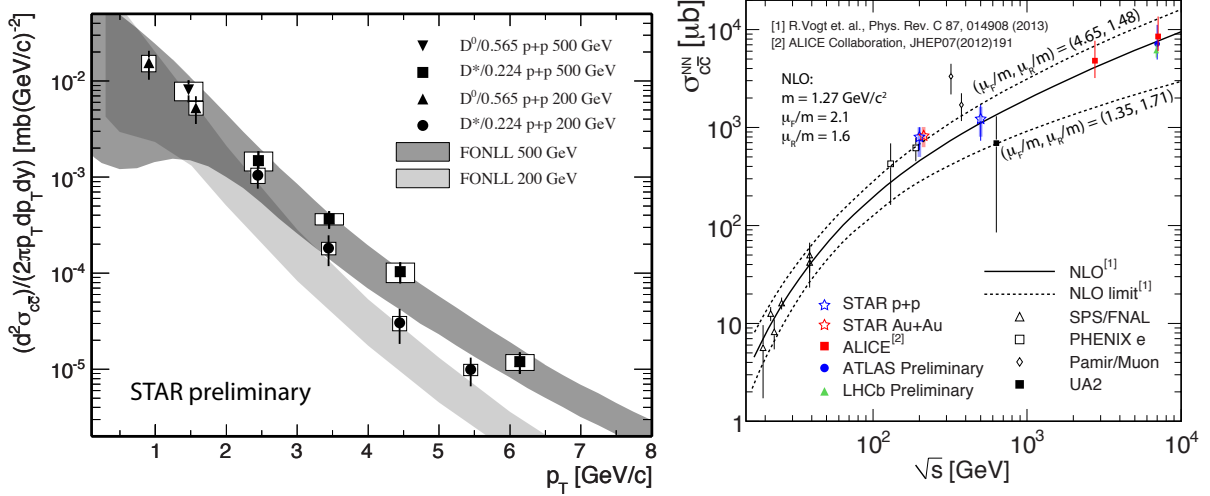


Figure 1. Left Panel: Charm quark production invariant cross section as a function of D meson p_T in 200 and 500 GeV $p+p$ collisions with two FONLL predictions [6] using normalization and factorization scale equal to charm quark mass m_c . Right Panel: Total charm cross section as a function of \sqrt{s}

3.2. Identification of electrons from semi-leptonic decays

Electrons from bottom and charm meson decays are the two dominant components of the non-photonics electrons. Mostly due to the decay kinematics, the azimuthal correlations between the daughter electron and daughter hadron are different for bottom meson decays and charm meson decays. A study of these azimuthal correlations has been carried out on STAR data and is compared with a PYTHIA simulation to obtain the ratio of the bottom electron yield to the heavy-flavor decay electron yield $\frac{e_b}{e_b + e_c}$ [8], where PYTHIA was tuned to reproduce STAR measurements of D mesons p_T spectra [9]. Using the measured $e_b/(e_b + e_c)$ together with the measured non-photonics electron cross section with the electrons from J/Ψ , Υ decay and Drell-Yan processes subtracted, we are able to disentangle these two components. Figure 2 shows the invariant cross section of electrons $\left(\frac{e^+ + e^-}{2}\right)$ from bottom (upper left) and charm (upper right) mesons as a function of p_T and the corresponding FONLL predictions, along with the ratio of each measurement to the FONLL calculations (lower panels).

From the measured spectrum, we determine the integrated cross section of electrons $\left(\frac{e^+ + e^-}{2}\right)$ at $3 \text{ GeV}/c < p_T < 10 \text{ GeV}/c$ from bottom and charm meson decays to be, respectively,

$$\begin{aligned} \left. \frac{d\sigma_{(B \rightarrow e) + (B \rightarrow D \rightarrow e)}}{dy} \right|_{y_e=0} &= 4.0 \pm 0.5(\text{stat}) \pm 1.1(\text{syst})\text{nb} \\ \left. \frac{d\sigma_{D \rightarrow e}}{dy} \right|_{y_e=0} &= 6.2 \pm 0.7(\text{stat}) \pm 1.5(\text{syst})\text{nb} \end{aligned}$$

4. Conclusions

Open charm hadron (D^0, D^{*+}) cross section in $p+p$ minimum bias collisions at $\sqrt{s} = 200$ and 500 GeV at STAR is measured with results:

$d\sigma_{cc}^{\text{NN}}/dy|_{y=0} = 170 \pm 45(\text{stat.})_{-51}^{+37}(\text{sys.}) \mu\text{b}$ at 200 GeV, $217 \pm 86(\text{stat.}) \pm 73(\text{sys.}) \mu\text{b}$ at 500 GeV. The total charm cross section at 500 GeV is within statistical and systematic uncertainties consistent with the latest NLO pQCD prediction.

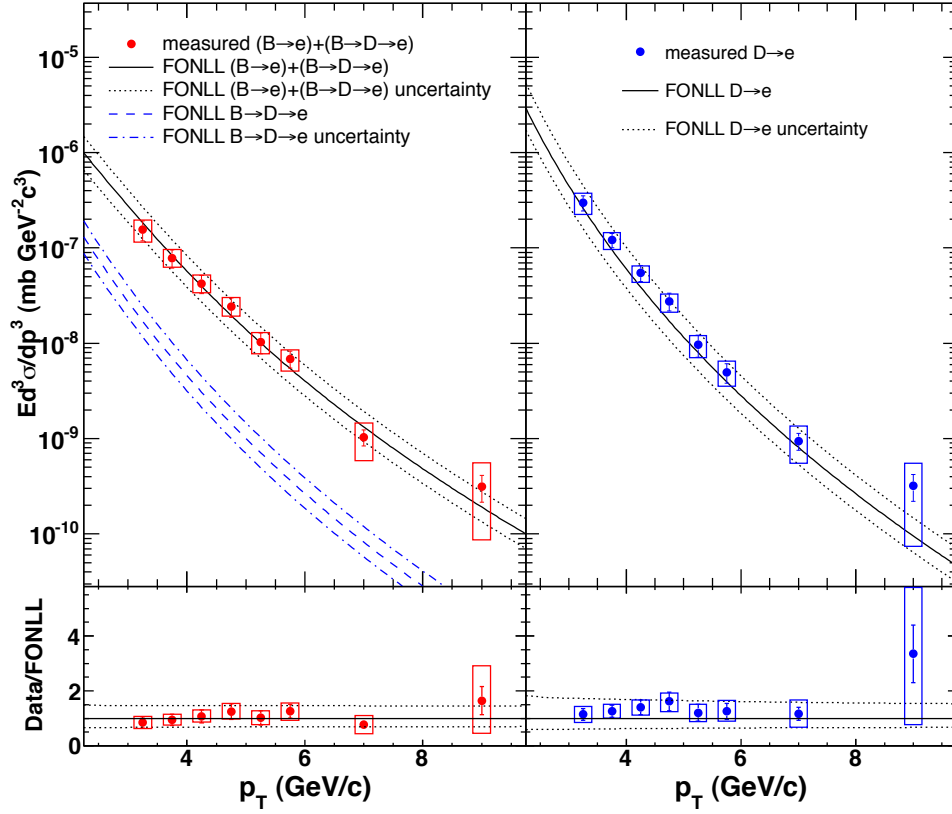


Figure 2. Invariant cross section of electrons from bottom (upper left) and charm meson (upper right) decay, together with the ratio of the corresponding measurements to the FONLL predictions for bottom (lower left) and charm electrons (lower right). The solid circles are experimental measurements. The error bars and the boxes are, respectively, the statistical and systematic uncertainties. The solid and dotted curves are the FONLL predictions and their uncertainties. The dashed and dot-dashed curves are the FONLL prediction for $B \rightarrow D \rightarrow e$.

Acknowledgments

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