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Measurement of single muon yields from charm semileptonic decay at $\sqrt{s_{NN}} = 200$ GeV Au + Au collisions at STAR

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Abstract. We report on the first measurement of single muon from charm semileptonic decays at low transverse momentum (p_T) in $\sqrt{s_{NN}} = 200$ GeV Au + Au collisions. Muon identification was obtained using the STAR time projection chamber in conjunction with a time-of-flight detector. The p_T spectra of electron and muon from charm semileptonic decays are presented. The measured $D \to \mu + X$ at $p_T < 0.25$ GeV/c greatly constrains the charm total cross section. The charm differential cross section $d\sigma_{cc}/dy$ is found to be consistent with the number of binary collision scaling.

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1 Introduction

In relativistic heavy-ion collisions, charm quarks are believed to be produced at early stages via initial gluon fusions. Their production cross section can be evaluated by perturbative QCD. Study of the number of binary collision (N_{bin}) scaling properties of the charm total cross section in the $p + p$, $d +$ Au and Au + Au collision systems, can test if heavy-flavor quarks are produced exclusively at the initial impact. PHENIX and STAR collaborations have made pioneering measurements in charm related physics [1–8]. The low p_T measurements accounts for a large fraction of the total charm cross section. However low p_T reconstruction of charmed hadrons and measurement of single electrons from charm semileptonic decay in relativistic heavy-ion collisions are associated with large systematic and statistical errors. Measurements of the muon yields from charmed hadron semileptonic decay at low p_T is better suited in this respect, due to the absence of Dalitz decays and photon conversions compared to the measurements involving the electron channel. A new method has been proposed to extract the charm total cross section by measuring muons from charmed hadron semileptonic decay at low p_T at RHIC [9]. We present the first measurements of single muon at low p_T in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV in STAR.

2 Experiment and data

The data used for this analysis were taken with the time projection chamber (TPC) and the time of flight (TOF) detectors in the STAR [10] experiment during the $\sqrt{s_{NN}} = 200$ GeV Au + Au run in year 2004. The TPC is the main tracking device in STAR, which provides particle identification within a pseudorapidity coverage of $|\eta| < 1.5$ and full azimuthal coverage [11]. In this study the measurements of the ionization energy loss of charged tracks in the TPC gas is used to identify electron and muon in the region $0.9\ \text{GeV/c} < p_T < 5\ \text{GeV/c}$ and $0.17\ \text{GeV/c} < p_T < 0.25\ \text{GeV/c}$ respectively. The TOF covers $\pi/30$ rad in azimuth and $-1 < \eta = \ln(\tan(\theta/2)) < 0$ in pseudorapidities at a radius of ~ 220 cm from the beam pipe, where θ is the angle of emission relative to the beam pipe direction [12]. The particle identification in TOF uses the velocity of charged particles. About 7.8 million 0%–80% minimum bias Au + Au events and 15 million top 12% central Au + Au collision events were used in the current analysis.

3 Analysis and results

The D^0 mesons have both hadronic and semileptonic decay channels. For the hadronic decay mode, reconstruction of $D^0 \to K^-\pi^+ (\bar{D}^0 \to K^+\pi^-)$ (branching ratio of 3.8%) was carried out. The D^0 invariant yield were obtained from direct reconstruction of kaon-pion pairs after mixed-event background subtraction. More details can be found in [1]. For semileptonic decay, we measure inclusive electrons ($D^0 \to e + X$ with a branching ratio of 6.87%) and muons ($D^0 \to \mu + X$ with a branching ratio of 6.5%) [5, 8, 13].

Inclusive electrons are identified in the intermediate p_T ($0.9 < p_T < 5$ GeV/c) region. The measurements of intermediate p_T electrons from heavy-flavor semileptonic decays have posed challenges to our understanding of par-

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tonic energy loss in the medium [8]. However, it is difficult to directly reconstruct charmed hadrons and single electrons from charm semileptonic decay in Au + Au collisions with high precision at low p_{T}, where the yield accounts for a large fraction of the total charm cross section. The difficulties are due to large combinatorial backgrounds in charmed hadron decay channels, and the overwhelming photon conversions in the detector material, and π^0 Dalitz decays in electron detection. The electrons from charm and other sources are less than a few percents [9].

Inclusive muon can be identified at low p_{T} by using a combination of velocity (β) of charged particles measured in the TOF and their ionization energy loss ($\mathrm{d}E/\mathrm{d}x$) measured in the TPC [11]. The single muon measurement is made for $0.17 < p_{\mathrm{T}} < 0.25\,\mathrm{GeV/c}$ in both 0%–80% minimum bias and top 12% central Au + Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$.

The upper panel of Fig. 1 shows the $m^2 = (p/\beta/\gamma)^2$ distribution from TOF after TPC $\mathrm{d}E/\mathrm{d}x$ selections. A clear muon peak is observed within a mass window of $0.008 < m^2 < 0.014$. The tail of the residual pion background to the muon yields is evaluated by selecting pure pion candidates with a proper $\mathrm{d}E/\mathrm{d}x$ selections, and subtracted statistically from the distribution of the distance of the closest approach (DCA) to the collision vertex. The following procedure is adopted. We obtain the $\pi \to \mu$ DCA distributions from HIJING [14] simulations using a realistic STAR Detector configuration. We then use DCA of muons from primary particles and those coming from weak decays of pions (HIJING simulation) to fit the inclusive muons DCA spectra. This is used to get the raw yields of muons from charm semileptonic decays. Figure 1 bottom panel demonstrates that the single muon from charm semileptonic decays can be extracted from inclusive muon by statistically subtracting the muon decayed from π. This approach can be used at detectors with similar configuration, such as in CDF and ALICE.

Figure 2 shows invariant yield for the directly reconstructed D^0 (stars) spectra and the measured electron and muon spectra from semileptonic decays. High p_{T} electron (circles and squares) suppression causes the charm cross section to pile at lower p_{T}. Our inclusive muons (triangles) measurements at low p_{T} provides constrain to the total charm cross section. The $\langle p_{\mathrm{T}} \rangle$ and n can be derived from a power-law combined fit (dashed curves) to the D^0 p_{T} distributions and decayed lepton spectra, while the freeze-out temperature T_{fo} and flow velocity β_{T} can be derived from a blast-wave model [15] fit (solid curves) to the $D^0 p_{\mathrm{T}}$ distributions and decayed lepton spectra for $p_{\mathrm{T}} < 2\,\mathrm{GeV/c}$ region.

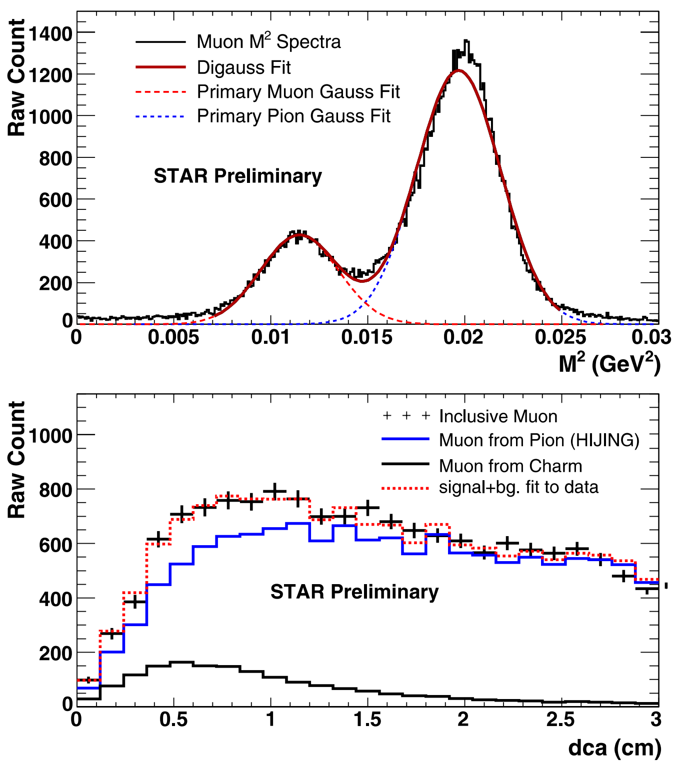

Fig. 1. *Upper panel*: Particle mass squared distribution ($m^2 = (p/\beta/\gamma)^2$) from the TOF after TPC $\mathrm{d}E/\mathrm{d}x$ selections. Clear muon mass peak was seen and the primary pion candidates are shown as the right peak. *Bottom panel*: Primary particle DCA (*red line*) and muon DCA distribution from pion kaon weak decayed background after TPC $\mathrm{d}E/\mathrm{d}x$ and TOF m^2 selections from HIJING simulation through realistic STAR detector configuration (*blue line*)

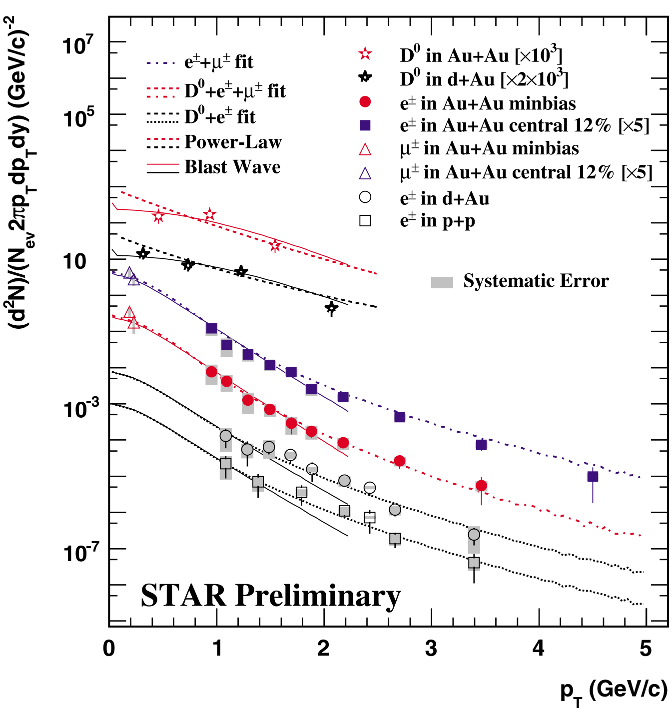

Fig. 2. The p_{T} spectra of reconstructed D^0 from their hadronic decay mode, electron and muon from semileptonic decay mode in Au + Au and d + Au collisions. *Dashed curves* are from the power-law fits to the combined measurements while *solid curves* are the blast-wave fits to the D^0 spectra and combination of muon measurements with non-photonic electron spectra upto $p_{\mathrm{T}} < 2\,\mathrm{GeV/c}$

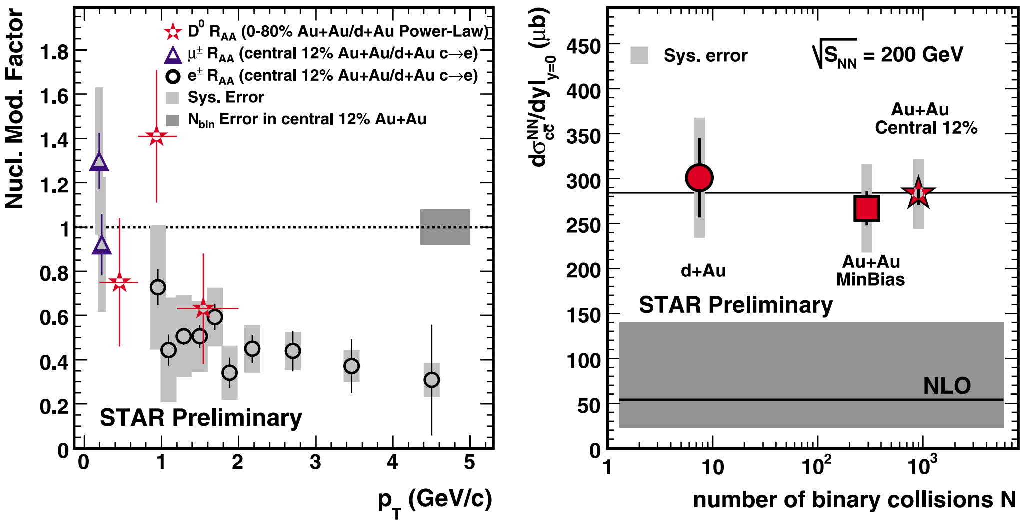

Fig. 3. *Left Panel*: Nuclear modification factor (R_{AA}) of electron and muon as a function of $p_{\rm T}$. Intermediate $p_{\rm T}$ electron R_{AA} show a strong suppression and low $p_{\rm T}$ muon R_{AA} show roughly number of binary scaling. *Right Panel*: Charm cross section at mid-rapidity as a function of number of binary collisions ($N_{\rm bin}$) in $d+$Au, minimum bias and 0%–12% central Au + Au collisions

The nuclear modification factors (R_{AA}) when studied as a function of $p_{\rm T}$ for various collision centrality can give insight into the particle production mechanism. Figure 3 left panel shows the R_{AA} as a function of $p_{\rm T}$ for muon and electron production in central Au + Au collisions to minimum bias at $\sqrt{s_{NN}} = 200$ GeV. The $N_{\rm bin}$ values for the most central (0%–12%) and minbias (0%–80%) Au + Au collisions are 900 and 293 respectively. For the $d+$Au reaction the $N_{\rm bin}$ value is 7.5. The value of R_{AA} of non-photonic electrons decrease from 0.6 to 0.2 within $1 < p_{\rm T} < 5$ GeV/c. This indicates a strong suppression in the production of non-photonic electrons in the $p_{\rm T}$ range studied. The R_{AA} of low $p_{\rm T}$ muons that constrain charm cross section show roughly number of binary collision scaling. In the right panel of Fig. 3 the cross section extracted from a combination of the three measurements is shown as a function of $N_{\rm bin}$. We scale the spectrum by $N_{\rm bin}$ as in the left panel. Charm cross section is found to follow binary scaling.

4 Conclusions

We have reported the first measurements of single muon yields from charm semileptonic decays at low $p_{\rm T}$ in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV from STAR experiment. Muon identification was carried out using the STAR time projection chamber (TPC) in conjunction with a time-of-flight detector (TOF).

The R_{AA} of non-photonic electron show strong suppression at intermediate $p_{\rm T}$, and those for the low $p_{\rm T}$ muons show $N_{\rm bin}$ scaling. Charm cross sections are extracted from a combination of the three measurements covering $\sim 90\%$ of the kinematic range within the detector acceptance. The present measurements of the total charm cross sections in $d+$Au and in different collision centralities for Au + Au collisions are significantly improved over the previous measurements from non-photonic electrons and/or from directly reconstructed charmed hadron with low statistics. The charm cross section is found to follow binary scaling, which is a signature of charm production exclusively at the initial impact. This supports the assumption that hard processes scale with binary interactions among initial nucleons and charm quarks can be used as a probe sensitive to the early dynamical stage of the system.

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