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Scaling of the charm cross-section and modification of charm p_T spectra at RHIC

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Abstract

Charm production from the direct reconstruction of D^0 ($D^0 \rightarrow K\pi p_T$ up to 2 GeV/ c) and indirect lepton measurements via charm semileptonic decays ($c \rightarrow e + X$ at $0.9 < p_T < 5.0$ GeV/ c and $c \rightarrow \mu + X$ at $0.17 < p_T < 0.25$ GeV/ c) at $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions are analysed. The transverse momentum (p_T) spectra and the nuclear modification factors for D^0 and for leptons from heavy flavour decays are presented. The scaling of charm cross-section with a number of binary collisions at $\sqrt{s_{NN}} = 200$ GeV from d+Au to Au+Au collisions is reported.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

In relativistic heavy-ion collisions, charm quarks are believed to be produced at early stages via initial gluon fusion and their production cross-section can be evaluated by pQCD [1]. Study of the binary collision (N_{bin}) scaling properties of the charm total cross-section in p+p, d+Au to Au+Au collisions can test if heavy-flavour quarks are produced exclusively at the initial impact [2]. Due to the heavy mass of charm quarks, charmed hadrons might freeze out earlier than light flavour hadrons. Charm energy loss, highly sensitive to the properties of the medium, can be inferred by studying the nuclear modification factor of its semileptonic decayed electron.

2. Experiment and analysis

The data used for this analysis were taken with the time projection chamber (TPC) and the time-of-flight (TOF) detectors in the STAR [3] experiment during the $\sqrt{s_{NN}} = 200$ GeV Au+Au run in 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 [4].

¹ A list of members of the STAR Collaboration is given at the end of this issue.

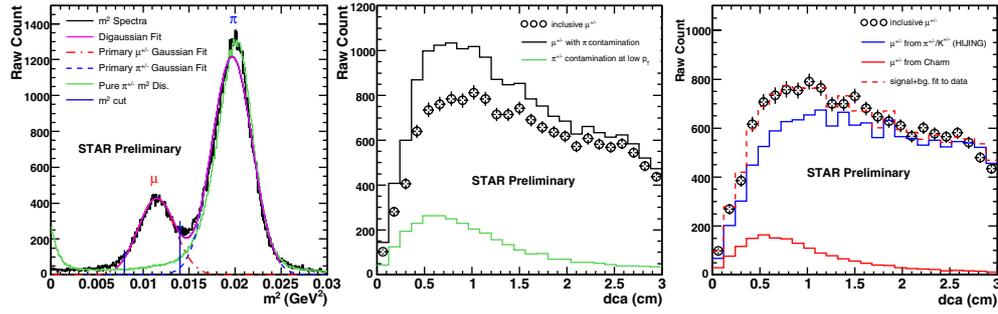


Figure 1. Left panel: particle mass-squared distribution ($m^2 = (p/(\beta\gamma))^2$). The muon and pion peaks are clearly visible. Middle panel: procedure to remove the residual pion background. Right panel: DCA distributions of muons from charm decays and from weak π/K decays (from HIJING simulation.)

In this study the measurements of the ionization energy loss (dE/dx) of charged tracks in the TPC gas is used to identify pions, kaons, electrons and muons. The TOF, which measures the velocity of charged particles, covers $\pi/30$ rad in azimuth and $-1 < \eta < 0$ in pseudorapidity at a radius of ~ 220 cm from the beam pipe [5]. About 7.8 million Au+Au events with 0–80% centrality and 15 million top 12% central Au+Au collision events were used in the analysis.

For the hadronic decay mode, reconstruction of $D^0 \rightarrow K^-\pi^+$ ($\bar{D}^0 \rightarrow K^+\pi^-$) (branching ratio of 3.8%) was carried out. An alternative method to study charm production is through the measurement of semileptonic electrons/muons decays of charmed hadrons ($c \rightarrow e/\mu + X$ with a branching ratio of 6.87%/6.5%) [2, 6, 7]. Lepton identification was carried out using the STAR TPC in conjunction with TOF. The single muon measurements benefit from the absence of Dalitz decays and photon conversions present in the electron channel. We have carried out muon measurements in the p_T region $0.17 < p_T < 0.25$ GeV/ c in both 0–80% and top 12% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

The left panel of figure 1 shows the $m^2 = (p/(\beta\gamma))^2$ distribution from TOF after TPC dE/dx selections. A clear muon peak is observed within a mass window of $0.008 < m^2 < 0.014$ GeV^2 . We also see some residual pion background in the mass range. The residual pions are removed statistically by studying the distance of closest approach (DCA) of the tracks from the collision vertex within the above mass range. The method and the resultant inclusive muon DCA distribution (open circles) are shown in the middle panel of figure 1. The right panel illustrates the procedure to obtain muon yields from charm semileptonic decays from inclusive muon DCA distribution. This is done statistically by removing the contribution of muons from π/K weak decays. We obtain the $\pi/K \rightarrow \mu$ DCA distributions from HIJING [8] simulations using the full STAR Detector configuration. We then use DCA of muons from primary particles and those coming from weak decays of π/K (HIJING simulation) to fit the inclusive muons DCA spectra. This is used to get the raw yields of muons from charm semileptonic decays.

3. Results

The left panel of figure 2 shows invariant yields for D^0 (stars) and electrons/muons from charm semileptonic decays as a function of p_T . A power-law function was used to fit the D^0 spectrum combined with the lepton spectra from charmed hadron semileptonic decays. All three measurements together stringently constrain the charm cross-section at RHIC. The right

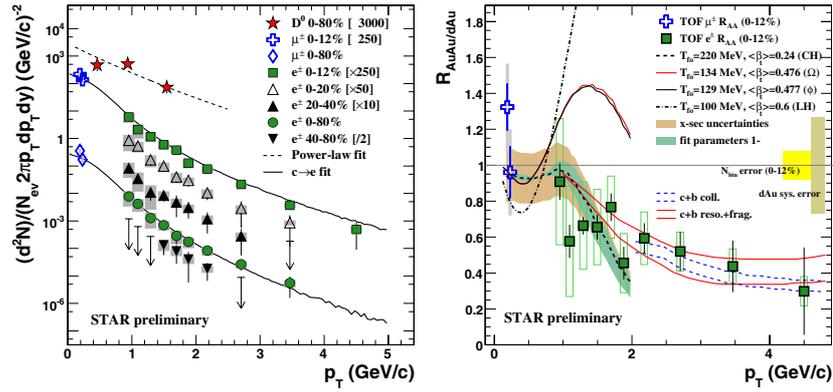


Figure 2. Left panel: the p_T spectra of D^0 and electron/muon from charm semileptonic decays in Au+Au collisions. The dashed and solid curves are power-law combined fit for D^0 and decayed leptons, respectively. Right panel: nuclear modification factor ($R_{AuAu/dAu}$) of electron and muon as a function of p_T . Low p_T muon $R_{AuAu/dAu}$ is consistent with number of binary scaling, and intermediate p_T electron $R_{AuAu/dAu}$ show a strong suppression.

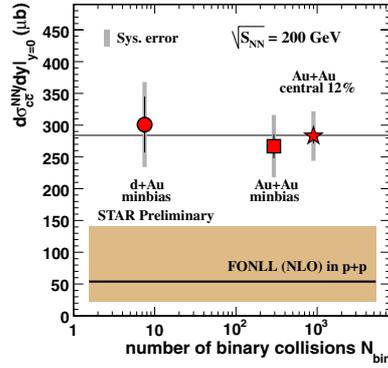


Figure 3. Charm cross-section at mid-rapidity as a function of a number of binary collisions (N_{bin}) in d+Au, 0–80% and 0–12% central Au+Au collisions.

panel of figure 2 shows the nuclear modification factors ($R_{AuAu/dAu}$) as a function of p_T for various collision centralities which can give insight into the particle production mechanism. $R_{AuAu/dAu}$ for non-photonic electron and muon production are derived by using the N_{bin} -scaled p_T spectra in central Au+Au collisions divided by the N_{bin} scaled decayed electron spectra from a combined fit in d+Au collisions [6, 9]. These are shown as open squares and crosses, respectively. Considering the extrapolation of the d+Au fit to lower momenta, muons seem to follow a N_{bin} collision scaling within the systematical uncertainties. The non-photonic electron $R_{AuAu/dAu}$ is suppressed as strongly as that of light hadrons [10], which indicates that charmed hadrons experience energy loss in the medium. Model calculations [11, 12] with a different mechanism considering in-medium charm resonances or charm diffusion and collisional dissociation of heavy mesons, respectively, can reasonably describe the $R_{AuAu/dAu}$ for non-photonic electrons. A blast-wave parameterization that assumes early kinetic freeze-out of charmed hadrons (dashed curve) describes the $R_{AuAu/dAu}$ distribution better than those with the late freeze-out assumption (black/red dotted curves).

In figure 3, the charm cross-section extracted from a combination of the three measurements is shown as a function of N_{bin} . It is 1.33 ± 0.06 (stat.) ± 0.18 (sys.) mb in 0–12% and $1.26 \pm 0.09 \pm 0.23$ mb in 0–80% central Au+Au collisions at $\sqrt{s_{\text{NN}}} = 200$ GeV. Within errors the charm cross-section is found to follow binary collisions scaling. This supports the conjecture of charm quarks being produced at early stages in RHIC. The prediction from a recent pQCD calculation (FONLL) for p+p collisions is depicted by the band in figure 3 [1]. It underestimates the observed cross-section by a factor of 5.

4. Conclusions

We have reported the first measurement of single muon yields from charm semileptonic decays at low p_T in Au+Au collisions at $\sqrt{s_{\text{NN}}} = 200$ GeV from the STAR experiment. $R_{\text{AuAu/dAu}}$ of the low p_T muons show N_{bin} scaling and those for non-photonic electron show strong suppression at intermediate p_T . 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 charm cross-sections 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 a number of binary collisions scaling, which is a signature of charm production at the initial stage.

Acknowledgments

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