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

Chen Zhong for the STAR Collaboration
Shanghai Institute of Applied Physics, CAS, Shanghai 201800, P. R. China
E-mail: zhongchen@sinap.ac.cn

Abstract.
Charm production from the direct reconstruction of $D^0 (D^0 \rightarrow K\pi$ 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 analyzed. The transverse momentum ($p_T$) spectra and the nuclear modification factors for $D^0$ and for leptons from heavy flavor decays is presented. Scaling of charm cross-section with number of binary collisions at $\sqrt{s_{NN}} = 200$ GeV from d+Au to Au+Au collisions is reported.

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-flavor quarks are produced exclusively at initial impact [2]. Due to the heavy mass of charm quarks, charmed hadrons might freeze out earlier than light flavor hadrons. Charm energy loss, highly sensitive to the properties of 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]. 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 charges particles, covers $\pi/30$ rad in azimuth and -1<$\eta$<0 in pseudorapidity at a radius of $\sim 220$ cm from the beam pipe [5]. About 7.8 million Au+Au events with 0-80% centrality and 15 million top 12%
Charm cross-section measurements at STAR

2

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 from 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 Fig. 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 $0.008<m^2<0.014$. 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 Fig. 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 $\pi/K$ 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 $\pi/K$ (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 Fig. 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 panel of Fig. 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. The $R_{AuAu/dAu}$ 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]. Those are shown as open squares and crosses, respectively. Considering the extrapolation of the d+Au fit to lower momenta, muons seen 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 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 Fig. 3 the charm cross-section extracted from a combination of the three measurements is shown as a function of $N_{bin}$. It is $1.33 \pm 0.06 \text{(stat.)} \pm 0.18 \text{(sys.)}$ mb in 0-12% and $1.26 \pm 0.09 \pm 0.23$ mb in 0-80% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ 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 Fig. 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 $\sqrt{s_{NN}} = 200$ GeV from STAR experiment. The $R_{AA/Au}$ 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 number of binary collisions scaling, which is a signature of charm production at the initial stage.

The author wishes to thank NSFC 10610285 and KJCX2-YW-A14 for contributing to the local expenses.

References

[1] Cacciari M., Nason P. and Vogt R., Phys. Rev. Lett. 95, 2005 122001
[2] Liu H.D. et al., Phys. Lett. B 639, 2006 441-446 e-print Arxiv: nucl-ex/0601030
[3] Ackermann K.H. et al., Nucl. Instrum. Meth. A 499, 2003 624
[4] Anderson M. et al., Nucl. Instrum. Meth. A 499, 2003 659
[5] STAR Collaboration, Adams J. et al., Phys. Lett. B 616, 2005 8-16
[6] Xu Z., Zhang H., Zhang Y.F., proceedings of SQM06 Conference, March 2006, LA, USA; e-print arXiv: nucl-ex/0607031, nucl-ex/0607011, nucl-ex/0607015
[7] Particle Data Group, Eidelman S. et al., Phys. Lett. B 592, 2004 48
[8] X.N. Wang and and Gyulassy M. Phys. Rev. D 44, 1991 3501-3516
[9] STAR Collaboration, Adams J. et al., Phys. Rev. Lett. 94, 2005 062301
[10] STAR Collaboration, Adams J. et al., Phys. Rev. Lett. 97, 2006 152301
[11] Adil A. and Vitex I. e-print arXiv: hep-ph/0611111
[12] Rapp. R. and Hees H. van e-print arXiv: hep-ph/0606117