Open Charm Production in $\sqrt{s_{NN}}=200$ GeV Au+Au Collisions

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Abstract. We report on the measurement of D meson production from the analysis of their hadronic ($D^0 \rightarrow K\pi$) and semileptonic ($D \rightarrow \mu + X$, $D \rightarrow e + X$) decays in $\sqrt{s_{NN}}=200$ GeV Au+Au collisions. The transverse momentum ($p_T$) spectra and the nuclear modification factors for $D^0$ and for electron/muon‡ from charm semileptonic decays will be presented. The differential cross section $d\sigma/dy$ is found to be consistent with the number of binary scaling. The blast-wave fit suggests that the charm hadron freeze out earlier than other light flavor hadrons.

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1. Introduction

In relativistic heavy-ion collisions, charm quarks are predicted to lose less energy compared to light quarks in the partonic matter due to the “dead-cone” effect [1 2 3]. The $p_T$ distributions and nuclear modification factors of D mesons and of single electrons from charmed hadron decay will be vital to study the physics in relativistic heavy-ion collisions [4]. Charm quarks are believed to be produced at early stages via initial gluon fusion and their production cross section can be evaluated by perturbative QCD [9]. Study of the binary collision ($N_{bin}$) scaling properties for the charm total cross section among p+p, d+Au to Au+Au collisions can test if heavy-flavor quarks are produced exclusively at initial impact [10]. Due to the heavy mass of charm quark, charmed hadrons might freeze out earlier than light flavor hadrons. Their flow velocity might be a good indicator of light flavor thermalization occurring at the partonic level [5 6 7 8].

2. Analysis and Results

The data used for this analysis methods were taken with the STAR experiment during the $\sqrt{s_{NN}}=200$ GeV Au+Au run in 2004. A total of 13.3 and 7.8 million 0-80% minimum

† For the full list of STAR authors and acknowledgements, see appendix ‘Collaboration’ of this volume.
‡ The word “muon” refers to $\mu^+/\mu^-$, “electron” refers to electron/positron throughout these proceedings.
bias Au+Au events were used for the $D^0$ reconstruction and the Time-of-Flight (TOF) single muon/electron analysis, respectively. About 15 million top 12% central Au+Au collision events were also used for TOF single muon and electron analysis.

The $D^0$ mesons ($p_T < 3$ GeV/c) were reconstructed through their decay $D^0 \rightarrow K^-\pi^+$ ($\bar{D}^0 \rightarrow K^+\pi^-$) with a branching ratio of 3.83%. The $D^0$ yields were obtained from the invariant mass distributions of kaon-pion pairs after mixed-event background subtraction. Analysis details can be found in Ref. [11].

Inclusive electrons can be identified up to $p_T = 5$ GeV/c by using a combination of velocity ($\beta$) from the TOF and ionization energy loss ($dE/dx$) measured in the STAR Time Projection Chamber (TPC). To measure the photonic electron spectra, the invariant mass and opening angle of the $e^+e^-$ pairs were constructed from an electron (positron) in the TOF at lower $p_T (< 1.2$ GeV/c) or in the TPC at higher $p_T (1.2 < p_T < 5$ GeV/c) combined with every other positron (electron) candidate reconstructed in the TPC [12, 13]. The non-photonic single electron spectra ($0.9 < p_T < 5$ GeV/c) from charm semileptonic decays can be extracted from the inclusive electron spectra subtracted by photonic background. Detailed analysis can be found in Ref. [11, 13].

However, due to the large combinatorial background in charmed hadronic decay channels and the overwhelming photon conversions in the detector material, we
conducted the measurement of single muon spectra at low $p_T$ ($0.17 < p_T < 0.25 \text{ GeV/c}$) in both 0-80% minimum bias and top 12% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Muon identification was provided by $dE/dx$ from the TPC and velocity from the TOF. Background muons from pion/kaon weak decays were subtracted using the distribution of the distance-of-closest-approach (DCA) to the collision vertex. The single muon raw yield was obtained from the fit to muon DCA distributions by combining the background DCA distributions and the primary particle DCA distributions [10, 14].

The spectra of $D^0$ and muons/electrons from charmed hadron decays are shown in the right panel of Fig. 1. The electron yield relies more on $D^0$ spectrum shape with a wide range of power-law parameters $n$ and $\langle p_T \rangle$ at fixed charm total yield. A factor of 8 variation of electron yield integrated above $p_T$ of 1.0 GeV/c was seen, while muon yield only changes within $\pm 15\%$ [10]. We therefore conducted a measurement of muons at low $p_T$ in order to constrain the charm cross section. The $\langle p_T \rangle$ and $n$ can be derived from a power-law fit to the $D^0$ $p_T$ distributions and decayed lepton spectra shape, while the freeze-out temperature $T_{fo}$ and flow velocity $\beta_T$ can be derived from a blast-wave fit to the $D^0$ $p_T$ distributions and decayed lepton spectra shape ($p_T < 2 \text{ GeV/c}$), see the right panel of Fig. 1. The 1σ contour from the combined blast-wave fit with a quadratic sum of stat. and sys. errors for the spectra shows the lower limit of charm hadron $T_{fo}$ (> 140 MeV) and small but non-zero $\beta_T$ ($0.21 \pm 0.04\text{(stat.)} \pm 0.07\text{(sys.)}$). This result suggests that charm hadron seems to freeze out earlier than other hadrons, see the left panel of Fig. 2.

The charm cross sections at mid-rapidity ($d\sigma/dy$) can be obtained from the average of the two fits by combining the three measurements covering $\sim 90\%$ of the kinematics. They are $301 \pm 44\text{(stat.)} \pm 67\text{(sys.)} \mu b$ in 200 GeV d+Au collisions [11], $267 \pm 19 \pm 49 \mu b$ in 200 GeV 0-80% minimum bias Au+Au collisions and $283 \pm 12 \pm 39 \mu b$ in 200 GeV top 12% central Au+Au collisions. Within error bars, the measured charm differential cross sections are found to be consistent with the number of binary scaling, see the right panel of Fig. 2. In addition, the measured cross sections are larger than the pQCD prediction by a factor of 5 [9]! Note that the systematic errors are the dominant
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ones. In the fitting procedure, the statistical and systematic errors were summed up quadratically.

3. Conclusions

The measurement of charm production from analysis of $D^0 \rightarrow K\pi$, muon, and electron channels in both minimum bias and central Au+Au collisions at RHIC was reported.

The transverse momentum spectra from non-photonic electrons are strongly suppressed at $1 < p_T < 5$ GeV/c in Au+Au collisions relative to that in p+p and d+Au collisions [4]. For electron with $p_T > 2$ GeV/c, corresponding to charm hadron with $p_T > 4$ GeV/c, the suppression is similar to those of light baryon and meson hadrons [16].

Detailed model-dependent analysis of the electron spectra with $p_T \leq 2$ GeV/c suggests that charm hadrons have a different freeze-out pattern from the more copiously produced light hadrons. The blast-wave fits show that charm hadrons seem to freeze out early, and have similar freeze-out temperature as multistrangeness hadrons ($\phi$, $\Omega$) but with smaller collective velocity.

Charm cross sections at mid-rapidity are extracted from a combination of the three measurements covering $\sim 90\%$ of the total yield at mid-rapidity. The 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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