Open Charm Yields in 200 GeV p+p and d+Au Collisions at RHIC

Lijuan Ruan† (for the STAR Collaboration‡)
Dept. of Modern Physics, University of Science and Technology of China, Hefei, Anhui, China, 230026; Brookhaven National Laboratory, Upton, NY, 11973, USA

Abstract. Open charm spectra at mid-rapidity from direct reconstruction of $D^0 \rightarrow K\pi$ and indirect electron/positron measurements via charm semileptonic decay in p+p and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are reported. The combined spectra cover open charm transverse momentum range $0.1 < p_T < 6$ GeV/c. The electron spectra show approximate binary scaling between p+p and d+Au collisions. From these two independent analyses, the differential cross section per nucleon-nucleon interaction at mid-rapidity for open charm production at RHIC is $d\sigma_{NN}/dy = 0.31 \pm 0.04 \text{(stat.)} \pm 0.08 \text{(syst.)}$ mb. The next-to-leading-order pQCD calculation underpredicts the charm yields.

The production and spectra of hadrons with heavy flavor are sensitive to initial conditions and the later stage dynamical evolution in high energy nuclear collisions, and may be less affected by the non-perturbative complication in theoretical calculations [1]. Charm production has been proposed as a sensitive measurement of parton distribution function in nucleon and the nuclear shadowing effect by systematically studying p+p, and p+A collisions [2]. The relatively reduced energy loss of heavy quark traversing a Quark-Gluon Plasma will help us distinguish the medium in which the jet loses its energy [3]. A possible enhancement of charmonia ($J/\Psi$) production can be present at RHIC energies [4] due to the coalescence of the copiously produced charm quarks.

Direct and indirect charm production has been measured in hadron-hadron collisions [5, 6, 7]. However, no experimental results are available at $\sqrt{s_{NN}}=200$GeV. Theoretical predictions for this energy region differ significantly [8]. Therefore precise experimental measurement of the baseline charm cross sections at RHIC is necessary. In this paper, we report the recent STAR results on the absolute open charm cross section measurements from direct charmed hadron $D^0$ reconstruction in d+Au collisions and electrons from charm semileptonic decay in both p+p and d+Au collisions at 200 GeV.

1. Analysis methods and results

At STAR, the hadronic channel of $D^0 \rightarrow K^-\pi^+(+c.c.)$ with branching ratio of 3.83% was measure by the Time Projection Chamber (TPC) [9,10] in d+Au collisions. The

† rlj@mail.ustc.edu.cn
‡ For the full author list and acknowledgements see Appendix “Collaborations” in this volume.
Open Charm Yields in 200 GeV \( p + p \) and \( d + Au \) Collisions at RHIC

\( D^0 \) signal was reconstructed using the event-mixing technique which is the same as the one used to identify and measure the \( K^{0*} \) resonance [11]. After the mixed-event background subtraction, the \( D^0 \) signal in \( p_T < 3 \) GeV/c and \( |y| < 1 \) from 15.7 million \( d + Au \) minimum bias events is shown as filled symbols in Fig. 1(a). A linear function was used to reproduce the residual background. After the two-step background subtraction, a gaussian function was used to obtain the \( D^0 \) signal shown as open symbols.

In the 2002-2003 run, a prototype multi-gap resistive plate chamber time-of-flight system (TOFr) [9] was installed with the coverage \(-1 < \eta < 0\) in pseudorapidity. In addition to its capability of hadron identification [12], electrons could be identified at low momentum \( (p_T \leq 3 \) GeV/c) by the combination of velocity \( (\beta) \) from TOFr [9] and the particle ionization energy loss \( (dE/dx) \) from TPC [9]. Fig. 1(b) shows that the electrons are clearly identified as a separate band in the \( dE/dx \) versus momentum \( (p) \) with a selection on \( \beta \) at \( |1/\beta - 1| \leq 0.03 \). At higher \( p_T \) (2–4 GeV/c), negative electrons were also identified directly by TPC since hadrons have lower \( dE/dx \) due to the relativisitic rise of electron \( dE/dx \). Detector acceptance and efficiency corrections were determined from the embedding data [12]. Total inclusive electron spectra from \( p+p \) and \( d+Au \) collisions are shown as symbols in Fig. 2.

\( \gamma \) conversions and \( \pi^0 \) Dalitz decays are the dominant photonic sources for electron background. Such background was mainly constrained at small pair invariant mass and small opening angle. To measure the background, pair invariant mass and opening angle distributions were constructed by first selecting an electron from TOFr and then looping through oppositely charged tracks reconstructed in the TPC [13]. Fig. 1(c) shows an example of the pair invariant mass. Simulations using both HIJING [14] and PYTHIA [15], with GEANT to describe the detector, showed \( \sim 60\% \) efficiency of such background reconstruction for \( p_T \geq 1 \) GeV/c, with negligible \( p_T \) dependence. This value was used
to correct for the photonic electron spectra in data. In this method, more than 95% background has been measured, shown as thick solid lines in Fig. 2. Other contributions (<5%) from decays of $\eta, \omega, \rho, \phi$ and $K$ were determined from simulations. The overall uncertainty of the background is $\sim$20%.

The non-photonic electron spectra, obtained by subtracting the previously described photonic background from the inclusive spectra, are shown as symbols in Fig. 3 (left) for both $p+p$ (triangles) and $d+Au$ (circles) collisions. The $D^0$ invariant yields $d^2N/2\pi p_T dp_T dy$ are calculated and also shown in Fig. 3 (left) as squared symbols as a function of $p_T$. The mid-rapidity yield $dN/dy$ was extracted with an exponential fit to the invariant yield as a function of transverse mass $m_T$, which is $0.028\pm0.004\pm0.007$. Several model studies [1, 15] showed that semi-leptonic decays from open charm are the dominant non-photonic electrons at $1 \leq p_T \leq 4$ GeV/c. We performed a fit with the combined results of $D^0$ and electron distributions in $d+Au$ collisions, assuming that the $D^0$ spectrum follows the power law up to 6 GeV/c. From the fit, we got the yield of $D^0$ at mid-rapidity $dN/dy = 0.030 \pm 0.004 \pm 0.008$ and $d\sigma^{NN}_{cc}/dy= 0.31 \pm 0.04 \pm 0.08$ mb. Thus the total charm-pair cross section $\sigma^{NN}_{cc} = 1.44 \pm 0.20 \pm 0.44$ mb, where a factor of $4.7 \pm 0.7$, estimated by the model simulations [8, 15], was used to convert the $d\sigma/dy$ at mid-rapidity to total cross section. The systematic error is dominated by the background subtraction, $p_T$ coverage for each measurement and overall normalization. The nuclear modification factor was obtained by taking the ratio of the electron spectra in Fig. 3 (left) scaled with the underlying nucleon-nucleon binary collisions. It was measured to be $1.2 \pm 0.2 \pm 0.3$ and is consistent with binary scaling within the errors.

The beam energy dependence of the cross section is shown in Fig. 3 (right). The solid (MSEL=1) and dashed (MSEL=4) lines are PYTHIA calculations with and without high order processes such as flavor excitation etc., respectively. The dot-dashed line is the NLO calculation from [8], which underpredicts our result. Dotted line is the power-law fit of $\sigma^{NN}_{cc} \propto (\sqrt{s})^n$ to the data points. For the total charm production, the power $n \sim 2.2\pm0.5$, while $n \sim 0.5(0.3)$ has been observed for pion (charged multiplicity) productions at lower energy [4, 16].
2. Summary

The charm cross section, $d\sigma_{c\bar{c}}^{NN}/dy = 0.31 \pm 0.04$ (stat.) $\pm 0.08$ (syst.) mb from 200 GeV d+Au collisions has been measured at RHIC. The independent measurements of the reconstructed $D^0$ and single electrons from charm semileptonic decay are consistent. The NLO calculation underpredicts the total cross section at this energy.

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