Measurements of Charm and Charmonium Production by PHENIX

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Abstract. The PHENIX Experiment at RHIC has measured charmonium production using dileptons and open heavy flavor production via semileptonic decays in $p+p$, $d+Au$, and $Au+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV. A nuclear dependence affecting J/ψ production in $d+Au$ collisions is observed. For electrons from heavy flavor decay in $Au+Au$ collisions, the transverse momentum spectrum is observed to be strongly modified compared to scaled results from $p+p$ collisions. An initial measurement of the azimuthal anisotropy parameter, v_2, for such electrons is reported.

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INTRODUCTION

The PHENIX Experiment [1, 2] at RHIC has collected $p+p$, $d+Au$, $Cu+Cu$, and $Au+Au$ collision data at $\sqrt{s_{NN}} = 200$ GeV. Measurements of open charm production in $p+p$ collisions can be used to make important tests of pQCD predictions at $\sqrt{s} = 200$ GeV and establish a baseline for total charm production for the heavy ion program [3]. Analogous measurements for $Au+Au$ collisions can be used to study medium modification effects such as charm quark energy loss and collective flow as well as establish a baseline for J/ψ production. Such measurements can also be used to study potential thermal production of charm from a possible Quark Gluon Plasma. The J/ψ production cross section is predicted to be modified by the medium produced in heavy ion collisions. Measurements of open heavy flavor and J/ψ production in $d+Au$ collisions can be used to study modification of the gluon structure function in nuclei.

PHENIX EXPERIMENT

The PHENIX experiment consists of two separate central arms with 90° coverage in azimuth and pseudorapidity coverage of $|\eta| < 0.35$. Two separate muon spectrometers at forward and backward rapidity cover the range $1.2 < |\eta| < 2.4$, with full azimuthal coverage. Electrons are measured in the central arm detectors by matching charged particle tracks to clusters in an electromagnetic calorimeter and rings in a ring imaging Čerenkov detector. Muons are measured in the forward/backward arms using Iarocci

[1] For the full PHENIX Collaboration author list, see Ref. [1].

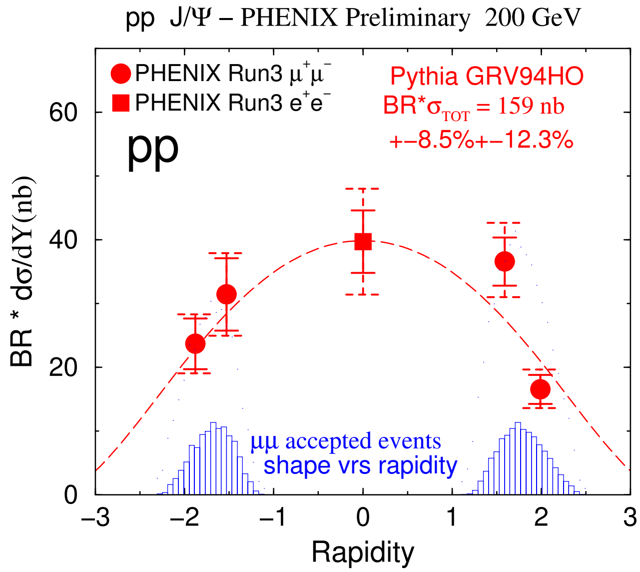

FIGURE 1. J/ψ differential cross section, multiplied by the dilepton branching ratio, versus rapidity for dimuons (circles) and dielectrons (square) [4], compared to a theoretical prediction (curve) from PYTHIA using the GRV94HO parton distribution.

tubes sandwiched between steel absorber planes for identification and cathode strip chambers for momentum measurement. Experimental details are provided in Ref. [2].

J/ψ PRODUCTION

Using $p+p$ collisions at $\sqrt{s} = 200$ GeV, PHENIX has measured the J/ψ differential production cross section at both mid-central and forward/backward rapidities (Fig. 1) using dielectrons and dimuons, respectively. The preliminary value of the measured [4] branching ratio times cross section is 159 nb $\pm$ 8.5% $\pm$ 12.3%. Comparisons have been made to different theoretical predictions [4]. Future runs with increased statistics will be used to discriminate between predictions, extend the measurements to higher transverse momentum, and allow measurement of the J/ψ polarization.

The ratio between the J/ψ differential production cross section in $d+Au$ collisions and the same quantity for $p+p$ collisions scaled by 2×197 has been measured [4]. The ratio (nuclear modification factor) is near unity at backward rapidity and significantly lower at forward rapidity. Such measurements can be used to test theoretical predictions for the modification of the gluon structure function in nuclei (shadowing).

PHENIX has measured the cross section for J/ψ production in $Au+Au$ collisions as a function of centrality [5]. Such measurements provide important tests of theoretical predictions for modification of J/ψ production due to the creation of a possible Quark Gluon Plasma. The present statistics are insufficient to make strong conclusions, although models with strong enhancement appear to be disfavored. Results based on data from subsequent runs with greater statistics as well as different colliding species ($Cu+Cu$) are in preparation.

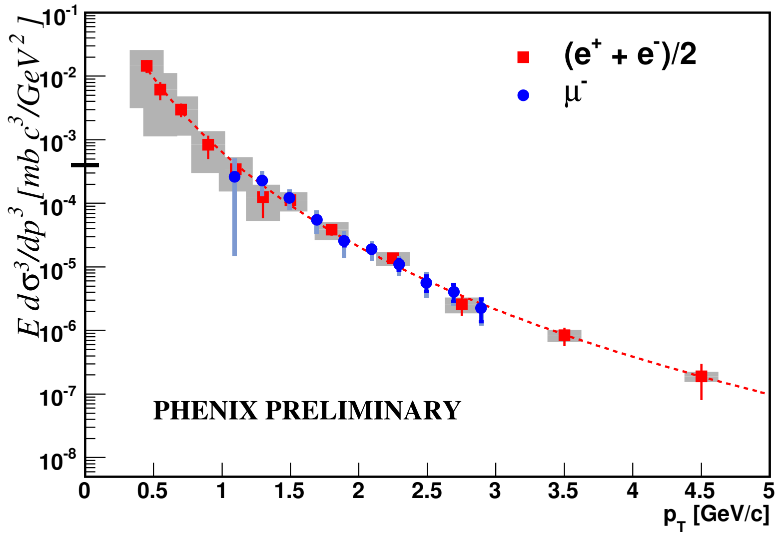

FIGURE 2. Transverse momentum distribution of invariant differential production cross section for negative muons (circles) and the average of electrons and positrons (squares) from heavy flavor decay for $p+p$ collisions at $\sqrt{s} = 200$ GeV. The pseudorapidity interval is centered around $|\eta| = 1.65$ for muons and $\eta = 0$ for electrons and positrons. Systematic errors are indicated as bands. The systematic error associated with overall normalization of the muon data is separately indicated by the horizontal band on the vertical axis. The dashed curve is a power law fit to the electron data points.

OPEN HEAVY FLAVOR PRODUCTION

After appropriate subtraction of physics backgrounds, PHENIX measurements of inclusive single electron and muon production can be used to extract the yield of leptons resulting from the semileptonic decay of heavy quarks, and thereby obtain the cross section for open heavy flavor production.

Hadrons that punch through the absorber of the muon spectrometer and mimic muons and real muons resulting from the decay of light hadrons must be subtracted on a statistical basis from the measured inclusive single muon yield, in order to obtain the signal for muons resulting from heavy flavor decay. Data collected from successive layers in the Muon Identifier are used to measure an effective nuclear absorption length which is used in a Monte Carlo simulation to estimate the punch-through contribution. The measured vertex dependence of the inclusive muon yield is used to obtain the contribution due to the decay in flight of light hadrons. The production cross section for negative single muons from heavy flavor semileptonic decay for $p+p$ collisions at $\sqrt{s} = 200$ GeV is shown in Fig. 2 as a function of transverse momentum.

The contributions of electrons resulting from photonic sources such as photon conversions and Dalitz decays of π^0 and η mesons must be subtracted from the inclusive single electron yield, in order to obtain the signal for non-photonic electrons which primarily results from semileptonic heavy flavor decay [6, 7]. PHENIX has measured the transverse momentum distribution of the cross section for non-photonic single electrons resulting from heavy flavor decay in $p+p$ (Fig. 2), $d+Au$, and $Au+Au$ collisions

[6, 7] at $\sqrt{s_{NN}} = 200$ GeV. Preliminary measurements indicate that in $p+p$ collisions the shape of the transverse momentum distribution of the differential production cross section for these electrons is harder than that of leading-order PYTHIA predictions.

Recent preliminary measurements with increased statistics indicate that the production of electrons from heavy flavor decay in $Au+Au$ collisions is suppressed at high p_T relative to $p+p$ results scaled by the number of binary collisions. The spectral shape is modified by the medium in a pattern which is consistent with theoretical models incorporating quark energy loss.

PHENIX has measured the second harmonic, v_2, of the azimuthal distribution of electrons from heavy flavor decay in $Au+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV as a function of transverse momentum [8]. The measured v_2 is nonzero at 90% confidence level; however, the present uncertainties are too large to draw conclusions concerning flow of the heavy quark. Analysis of a subsequent data set with significantly greater statistics is underway which should provide more detailed information concerning charm flow.

SUMMARY AND CONCLUSIONS

Heavy flavor production has been measured via leptonic decays in $p+p$, $d+Au$, and $Au+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV by the PHENIX Experiment at RHIC. As discussed above, such results have been used to test theoretical predictions concerning topics such as the momentum spectrum of open heavy flavor production, shadowing in nuclei, and modifications of the J/ψ production cross section in heavy ion collisions. Strong modification of the spectra for electrons from heavy flavor decay is observed in $Au+Au$ collisions. An initial measurement of the azimuthal anisotropy, v_2, for electrons from heavy flavor decay has been made. Results with higher statistics and other colliding species are in preparation.

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