J/ψ Production in $p+p$, $d+Au$, and $Cu+Cu$ Collisions at RHIC

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Abstract. PHENIX results for J/ψ production in $p+p$, $d+Au$, and $Cu+Cu$ collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ are presented.

Keywords: Relativistic heavy ion collisions, Charmonium Production, Deconfinement
PACS: 13.20.Gd, 13.20.Fc, 13.85.Ni, 14.40.Gx, 25.75.Dw, 25.75-q

INTRODUCTION

J/ψ's are an interesting probe of the extremely hot and dense matter produced in heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC). Suppression of J/ψ production in heavy ion collisions (relative to production in $p+p$ collisions scaled by the number of binary nucleon-nucleon collisions (N_{coll}), which is expected for point-like processes), was predicted by Matsui and Satz [1] to be an unambiguous signature for the formation of the quark-gluon plasma due to Debye screening by free color charges. Such a suppression has indeed been observed by the NA50 experiment at CERN [2, 3]. However, interpretation has been made difficult by subsequent work demonstrating numerous mechanisms that can suppress J/ψ formation [4], including initial parton energy loss, shadowing, cold nuclear matter absorption, and co-mover absorption. In addition to these effects, the produced charm quark density at RHIC may allow for J/ψ production via recombination [5, and references therein], thus countering suppression of prompt production. The mechanism leading to the large final-state charm-quark energy loss observed at RHIC [6] may also affect J/ψ production.

Unraveling this rich structure will require measurement of J/ψ production as a function of numerous independent variables. In this paper we present current PHENIX results for J/ψ production at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ versus transverse momentum (p_T), rapidity (y), and system size for light systems ($p+p$, $d+Au$ and $Cu+Cu$).

RESULTS AND SUMMARY

PHENIX [7, and references therein] has measured J/ψ production in $p+p$ [8, 9], $d+Au$ [9], $Cu+Cu$ [10], and $Au+Au$ [10–12] collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$. Measurements at forward and backward rapidity ($1.2 < |y| < 2.2$) are made with the Muon Arm spectrometers ($J/\psi \to \mu^+\mu^-$), measurements at mid-rapidity ($|y| < 0.35$) are made with the Central Arm spectrometers ($J/\psi \to e^+e^-$).

The left panel of Figure 1 shows rapidity distributions for J/ψ production in $p+p$ collisions. This measurement, which goes down to $p_T = 0$, is consistent with predictions of the color octet model (COM) [13], as observed by CDF [14]. Recall that J/ψ polarization at high p_T, predicted by the COM, has not been observed [15]. The right panel of Figure 1 shows the nuclear modification factor ($R_{AB} = \frac{dN^{AB}/dy}{N_{coll}^{AB} dN^{pp}/dy}$) in $d+Au$ collisions, which is expected to be 1 in the absence of nuclear effects. Only cold nuclear matter effects are expected in $d+A$ collisions, and these are seen to be modest. Although these results are consistent with predictions incorporating shadowing and nuclear absorption they do not scale with x_2 (the momentum fraction in the gold nucleus) when comparing with lower energies, as would be expected for shadowing [9, and references therein]. The left panel of Figure 2 shows the nuclear modification factor in $Cu+Cu$ collisions vs. collision centrality (quantified by N_{part}, the number of participants as determined with a Glauber calculation [16]). The suppression increases smoothly to a factor of two for the most central collisions. This suppression is consistent with the suppression observed by NA50 and is reasonably well-reproduced by models incorporating only cold-nuclear matter effects and by models which incorporate nearly complete suppression of initial-state J/ψ's plus subsequent formation via recombination mechanisms [10, and references therein]. Models which successfully reproduced NA50 results overpredict the suppression at RHIC if recombination is not invoked. The right panel of Figure 2 shows the J/ψ rapidity distributions for $p+p$ collisions and $Cu+Cu$ collisions of different centrality. These distributions do not appear to change shape. In particular they do not get significantly narrower as is predicted for current J/ψ recombination models [5]. Satz [17] has recently suggested that the similarity in suppression observed by PHENIX and NA50 is caused by nearly complete melting of J/ψ precursors ($\psi\prime$ and χ_c) while directly produced J/ψ's remain intact. No recombination is invoked in this model.

J/ψ's hold promise as sensitive probes of hot nuclear matter, but the probe requires better calibration. In particular, better measurements in $p+p$ collisions, including polarization measurements, are needed to understand the initial production mechanism; better measurements in $d+Au$ collisions are necessary to understand effects of cold nuclear matter; better measurements of rapidity, p_T, and reaction plane are needed to distinguish between competing final state effects; measurements of other quarkonia states, particularly $\psi\prime$ and χ_c are necessary to understand feeddown contributions.

ACKNOWLEDGMENTS

This work was sponsored by the Division of Nuclear Physics, U.S. Department of Energy, under contract DE-AC05-00OR22725 with UT-Battelle, LLC (Oak Ridge National Laboratory).

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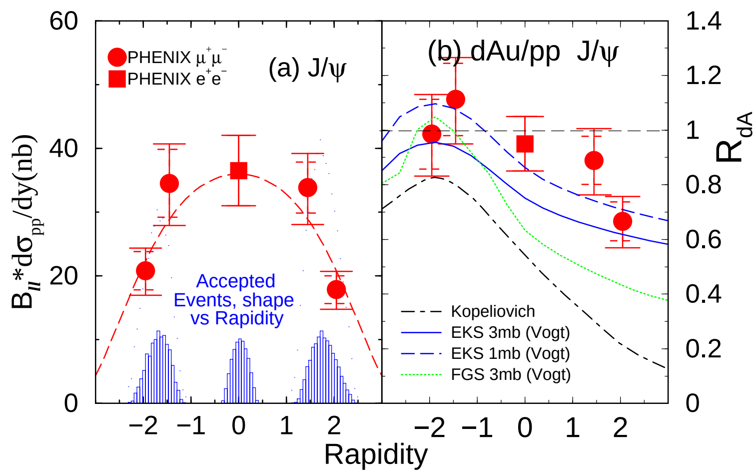

FIGURE 1. Left: Differential J/ψ cross section (times di-lepton branching ratio) vs. y in $p+p$ collisions. Right: Nuclear modification ratio for J/ψ production in $d+Au$ collisions [9, and references therein].

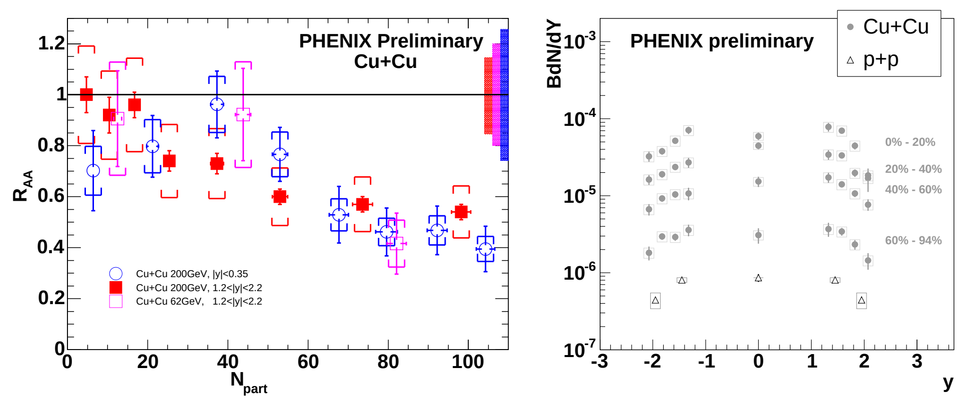

FIGURE 2. Results for $Cu+Cu$ collisions. Left: Nuclear modification factor. Right: Rapidity distributions for indicated centrality selections. Results for $p+p$ collisions are shown for comparison.

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