

Measurements of Cold Nuclear Matter Effects on J/ψ in the PHENIX Experiment via Deuteron-Gold Collisions

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Abstract. A new calculation of R_{dAu} has been performed using the 2003 d+Au data and the higher-statistics 2005 p+p data. These nuclear modification factors are compared to calculations using nuclear-modified PDFs and a J/ψ breakup cross section is extracted. These values are then used to project the cold nuclear matter effects in Au+Au collisions. Additionally, a more data-driven projection is performed.

1. Introduction

Cold nuclear matter (CNM) effects are those due to being within the nuclear environment, as opposed to a higher-density medium or vacuum. These effects are quite interesting on their own, but are even more important at the Relativistic Heavy Ion Collider (RHIC) as we attempt to observe the Quark-Gluon Plasma (QGP), a state with much higher energy density than normal nuclei. There are several proposed signatures that could indicate the transition to a QGP, and it is essential to understand them in the context of what normally occurs in nuclei.

One such proposed signature is the suppression of J/ψ production in the deconfined medium of the QGP, due to color-charge screening of the $c\bar{c}$ interaction [1]. However, J/ψ production may also be modified due to CNM effects such as nuclear shadowing, gluon saturation, the EMC effect, or absorption/breakup within the nuclear remnants. Therefore it is very important to quantify these contributions.

2. The PHENIX Experiment

In order to study CNM effects at RHIC, deuteron and gold ions are collided at $\sqrt{s_{NN}} = 200$ GeV. This was first done in Run-3 and more recently in Run-8, the latter of which is currently being analyzed. Since the original analysis of the Run-3 data [2], a new p+p dataset was recorded in Run-5 with more than an order-of-magnitude increase in J/ψ statistics over the p+p data from Run-3 [3]. In addition, there have been two years' worth of improvements in the reconstruction software, the J/ψ signal extraction, and our understanding of the detector. Consequently, a new analysis of the Run-3 d+Au data was performed using the same methods as the new p+p reference data so that an apples-to-apples comparison could be done [4]. It should also be noted that the Run-4 Au+Au [5] and Run-5 Cu+Cu [6] R_{AA} results use this same p+p reference data.

The PHENIX rapidity coverage consists mainly of two regions: the Drift Chamber, Pad Chamber, EM Calorimeter and RICH measure $J/\psi \rightarrow e^+e^-$ at mid-rapidity ($|y| < 0.35$), and the Muon Tracker and Muon Identifier measure $J/\psi \rightarrow \mu^+\mu^-$ at forward and backward rapidity ($1.2 < |y| < 2.2$).

3. Nuclear Modification Factor

The nuclear modification factor R_{AA} (Equation 1) quantifies the suppression or enhancement of particle production in collisions of heavier nuclei with respect to p+p collisions, scaled by the appropriate number of binary collisions ($\langle N_{\text{coll}} \rangle$) in the heavier species, as calculated by a Glauber model [7]. Using the Run-3 d+Au and Run-5 p+p data we can construct R_{dAu} as functions of transverse momentum, collision centrality, and rapidity. We will focus on the latter here; for the broader analysis, see [4].

$$R_{\text{dAu}} = \frac{1}{\langle N_{\text{coll}} \rangle} \frac{dN_{J/\psi}^{d+Au}/dy}{dN_{J/\psi}^{p+p}/dy} \quad (1)$$

R_{dAu} as a function of rapidity is plotted as the black points in Figure 1. As can be seen in the Figure, J/ψ production in d+Au collisions is consistent (within the large error bars) with binary-collision-scaled p+p collisions at backward and mid-rapidity, but is suppressed at forward rapidity (in the gold-going direction).

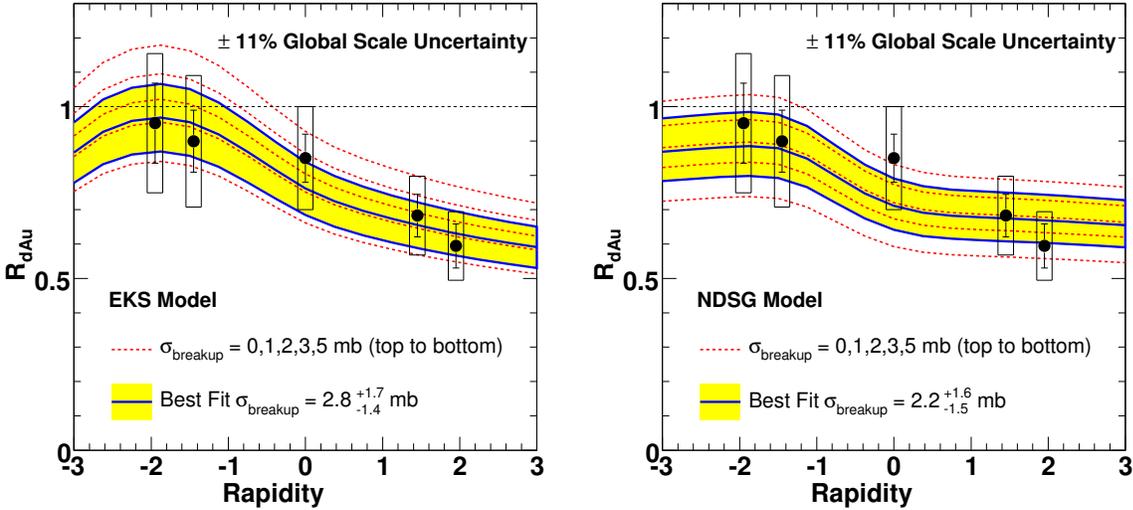


Figure 1. (color online) R_{dAu} data compared to various theoretical curves for different σ_{breakup} values. Also, shown as a band are the range of σ_{breakup} found to be consistent with the data within one standard deviation. The left panel is a comparison for EKS shadowing [8], while the right panel is for NDSG shadowing [9].

It can be useful to compare the measured R_{dAu} to a simple model of CNM effects. By comparing the modification due to available nuclear-modified PDFs with the data, we can extract a breakup cross section (σ_{breakup}) for the J/ψ passing through the nuclear medium. This is found to be $\sigma_{\text{breakup}} = 2.8^{+1.7}_{-1.4}$ mb and $\sigma_{\text{breakup}} = 2.2^{+1.6}_{-1.5}$ mb using the EKS [8] and NDSG [9] nuclear-modified PDFs, respectively. Note that the quoted uncertainties account for all experimental statistical and systematic errors, including the global scale uncertainty.

However, theoretical model uncertainties are not included. For details of how the statistical and systematic errors of the data are accurately accounted for, see [4] and [10].

These values overlap within one standard deviation with the published value of $\sigma_{abs}^{J/\psi} = 4.5 \pm 0.5$ mb from CERN-SPS [11] (within the large uncertainties). It should be noted, however, that the SPS value does not include any nuclear shadowing or anti-shadowing. It has been suggested that the SPS data lies in the anti-shadowing region, causing an enhancement in J/ψ production, which would then have to be balanced by an even larger $\sigma_{abs}^{J/\psi}$ to match the data [12].

4. Projections to Au+Au

To quantify CNM effects in Au+Au collisions, we use the nuclear-modified PDFs (in conjunction with a model of their impact-parameter dependence [13, 14]) and the calculated $\sigma_{breakup}$ to project R_{AA} for Au+Au strictly due to CNM effects. This is shown versus the number of participant nucleons in the Au+Au collision in Figure 2, where the two bands represent the one-standard-deviation uncertainty bands using the two PDFs, and the blue points represent the PHENIX J/ψ R_{AA} measurements from Run-4 [5].

The R_{AA} measured in Run-4 shows statistically-significant suppression at forward rapidity in comparison to the projected suppression due to CNM effects. This is not true, however, in the mid-rapidity case, except perhaps in the most central collisions. There are several things to note here: first, that the large error bands on the CNM projections limit our ability to make any definitive statements, and this will have to be improved in the future; second, that the above calculations are explicitly model-dependent, and there is no easy way to include this in the uncertainty bands; third, the error bands shown in Figure 2 are correlated between the two rapidity regions, as they are due to the same calculation of $\sigma_{breakup}$. Calculations in separate rapidity bins were performed for [4], but are not included here due to the large uncertainties.

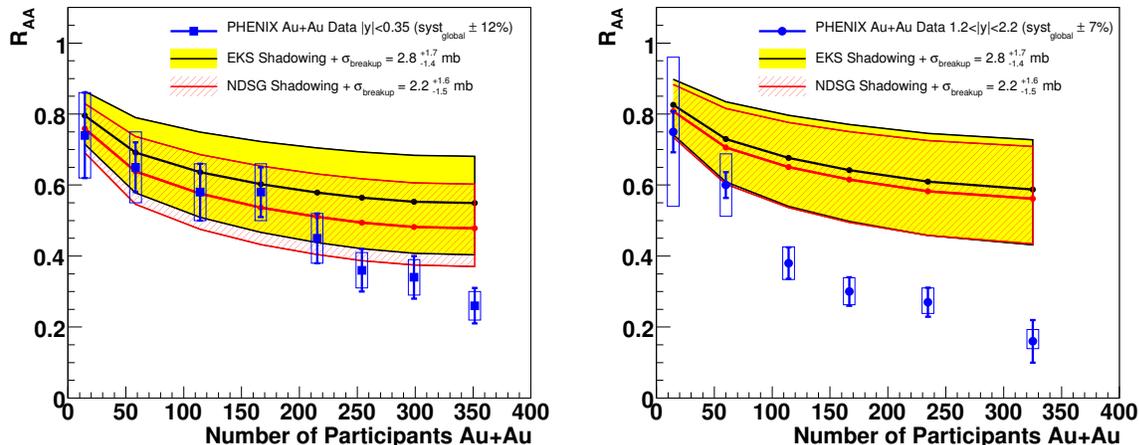


Figure 2. (color online) R_{AA} for Au+Au [5] collisions compared to a band of theoretical curves for the $\sigma_{breakup}$ values found to be consistent with the d + Au data as shown in Figure 1. The left figure includes both EKS shadowing [8] and NDSG shadowing [9] at mid-rapidity. The right figure is the same at forward rapidity.

A less model-dependent approach to the problem is to parametrize the CNM data directly, as proposed in [15]. Instead of invoking nuclear-modified PDFs and breakup cross sections, we start from the assumption that R_{dAu} should approach unity for the most peripheral collisions, and then fit the measured R_{dAu} to a linear function satisfying this condition (convolving this

function with the d+Au centrality distributions for each data point). Other fit functions may be tried, but the results do not vary much due to the imprecision of the current data.

Using the results of the fit we then construct R_{AA} as a function of impact parameter by integrating over the radial distribution of binary collisions for each gold nuclei at a given impact parameter value. As can be seen in Figure 3, the resulting one-standard-deviation bands are qualitatively similar in shape to those shown in Figure 2, but generally have a larger 1σ region and slightly more suppressed most-likely values. It must be noted that, contrary to the previous case, the uncertainty bands here are entirely uncorrelated between rapidities.

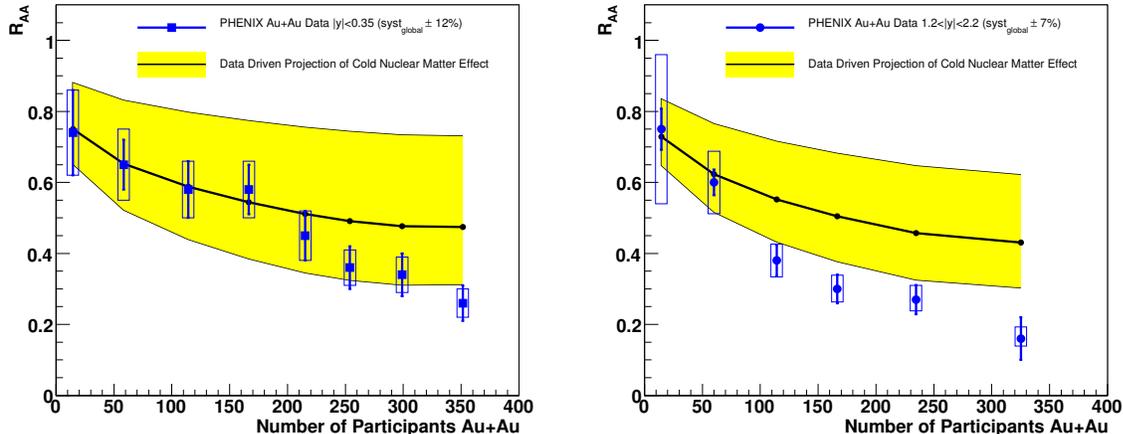


Figure 3. Predictions of the data-driven method constrained by the R_{dAu} as a function of collision centrality for the Au+Au R_{AA} for mid-rapidity (left) and at forward rapidity (right).

5. Summary

We have presented R_{dAu} as a function of rapidity as a quantification of CNM effects in heavy ion collisions. We have also used several techniques to project the CNM effects to R_{AA} for Au+Au collisions.

MGW acknowledges funding from the Division of Nuclear Physics of the U.S. Department of Energy under Grant No. DE-FG02-00ER41152.

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