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PHENIX results on J/ψ from small systems

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Charmonium is considered a valuable probe to study the medium produced in collisions involving nuclei and/or nucleons. With the recent observations of collective behavior of produced particles in small system collisions, measurements of the modification of charmonium in these systems have become increasingly relevant. In this talk we will present the PHENIX results of J/ψ measurements at forward and backward rapidities ($1.2 < |y| < 2.2$) in p+Al, p+Au, and ^{3}He+Au at a collision energy of $\sqrt{s_{NN}} = 200$ GeV. These data complement previously published d+Au data, and comprise the most extensive study to date of J/ψ in small systems including system size, centrality, transverse momentum and rapidity dependencies. The observed modifications of J/ψ production depends strongly on target size but is very similar for different projectiles. These proceedings show the conclusion of this experimental effort and discuss the implication on the current understanding of charmonia interaction with nuclear media.

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1. Introduction

The production of charmonium not only in heavy-ion collisions but in asymmetric collisions between p/d and heavy-ion is strongly modified relative to that in p+p collisions. The effects causing the modification in p/d+A collisions are called cold-nuclear-matter (CNM) effects including modification of parton distribution functions (PDF), initial state parton energy loss, breakup of charmonium, and transverse momentum broadening. It is essential to have differential measurements in rapidity (y), transverse momentum (p_T), centrality, and multiplicity to study these effects more precisely. By the virtue of the collision species versatility at Relativistic Heavy Ion Collider, PHENIX collected data of various asymmetric collisions such as p+Al, p+Au, d+Au, and ^{3}He+Au in 2014–2016. In these collision systems, we can study nuclear effects in different projectile/target sizes, which is also related to the number of produced particles.

2. Data analysis

J/ψ decaying to a muon pair can be measured with the PHENIX muon spectrometers at forward and backward rapidity ($1.2 < |y| < 2.2$). The forward silicon vertex tracker located in front of the absorber material can help to improve the mass resolution by measuring direction of particles precisely before suffering from multiple scatterings inside the absorber. For this analysis of inclusive J/ψ, reconstructed muons in the muon arm are not required to be associated with reconstructed FVTX tracks not to lose dimuon candidates due to matching inefficiency between muon and FVTX tracks.

Unlike-sign dimuon candidates are selected with a set of quality cuts and the remaining combinatorial and correlated background are estimated using like-sign dimuons and previous PHENIX measurements of muon pairs from heavy-flavor decays [1]. The raw J/ψ counts are extracted in a fit procedure, and the crystal-ball function is used for the J/ψ signal shape. The extracted J/ψ counts are corrected with an acceptance and efficiency calculated from a GEANT4-based full detector simulation considering detector inefficiency and background hits. More details on the analysis procedure can be found in [2].

3. Results

To study nuclear effects on the inclusive J/ψ production, the nuclear modification factor R_{AB} is calculated, and it is defined as

$$R_{AB} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{d^2N^{AB}/dydp_T}{d^2N^{pp}/dydp_T},$$

where $d^2N^{AB}/dydp_T$ and $d^2N^{pp}/dydp_T$ are the J/ψ invariant yields for a certain centrality bin of A+B collisions and p+p collisions, and $\langle N_{\mathrm{coll}} \rangle$ is the number of binary collisions for that centrality bin.

Figure 1 shows the nuclear modification factor as a function of rapidity for the integrated centrality of p+Al, p+Au, and ^{3}He+Au collisions. In p+Al collisions, there is little modification both at forward (projectile going direction) and backward (target going direction) rapidity, whereas a

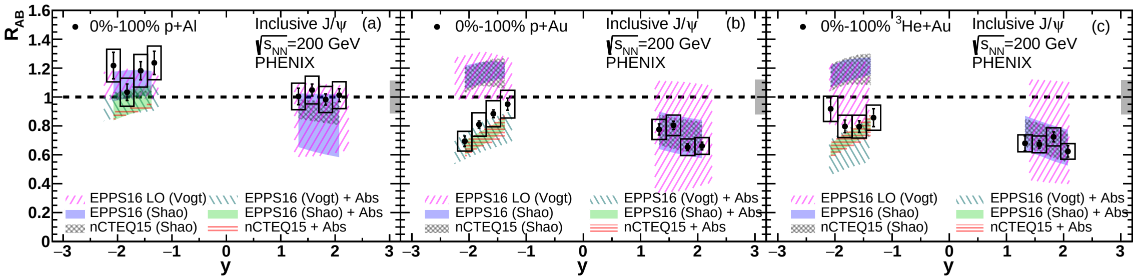

Figure 1: Nuclear modification factor of inclusive J/ψ as a function of rapidity for 0%–100% p+Al, p+Au, and ^{3}He+Au collisions. The figure is from Ref. [2].

suppression is observed in p+Au and ^{3}He+Au collisions at both rapidity regions. In the comparison of R_{AB} in three different collisions, a clear difference is seen in different targets at both rapidity regions. The R_{AB} data are compared with theoretical calculations based on nuclear PDFs, and it shows a good agreement at forward rapidity indicating the modification of nuclear PDF is likely the main effect on the J/ψ modification. The nuclear PDF models estimate a small enhancement at backward rapidity in p+Au and ^{3}He+Au collisions, whereas the data show a suppression which can be described by incorporating nuclear absorption.

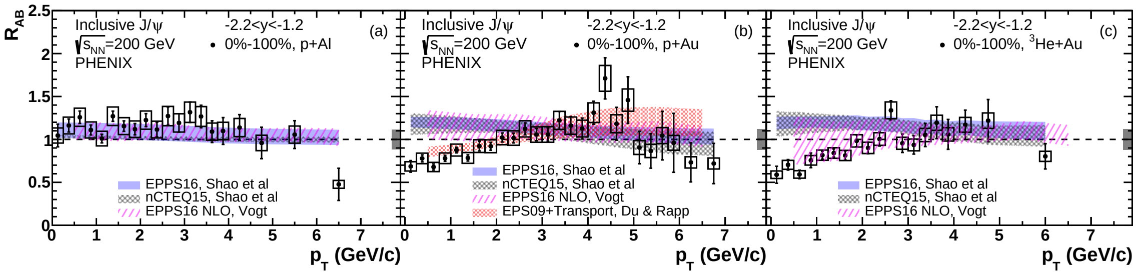

Figure 2: Nuclear modification factor of inclusive J/ψ as a function of p_T at backward rapidity (Al/Au-going direction) in 0%–100% p+Al, p+Au, and ^{3}He+Au collisions. The figure is from Ref. [2].

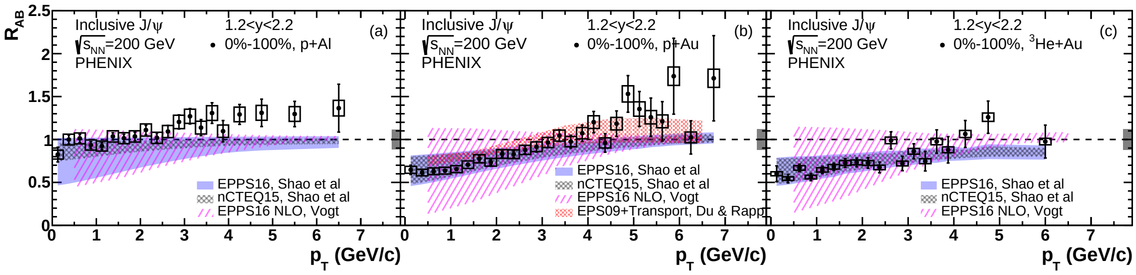

Figure 3: Nuclear modification factor of inclusive J/ψ as a function of p_T at forward rapidity (p/^{3}He-going direction) in 0%–100% p+Al, p+Au, and ^{3}He+Au collisions. The figure is from Ref. [2].

Figures 2 and 3 show the R_{AB} of inclusive J/ψ as a function of p_T at backward and forward rapidity in the integrated centrality of p+Al, p+Au, and ^{3}He+Au collisions. Similarly with the rapidity dependent R_{AB} shown in Fig. 1, there is little modification in p+Al collisions at both forward and backward rapidity. In p+Au and ^{3}He+Au collisions, a suppression is observed at

$p_T < 3$ GeV/c, and the magnitude of suppression is comparable between two collision systems. These p_T-dependent R_{AB} data are also compared to calculations based on nuclear PDFs. The calculations agree with the data at forward rapidity, but the suppression at backward rapidity in p+Au and ^{3}He+Au collisions is not explained by the modification of nuclear PDF. Another theory prediction adapting transport models in small collision systems successfully describe the suppression at backward rapidity in p+Au collisions.

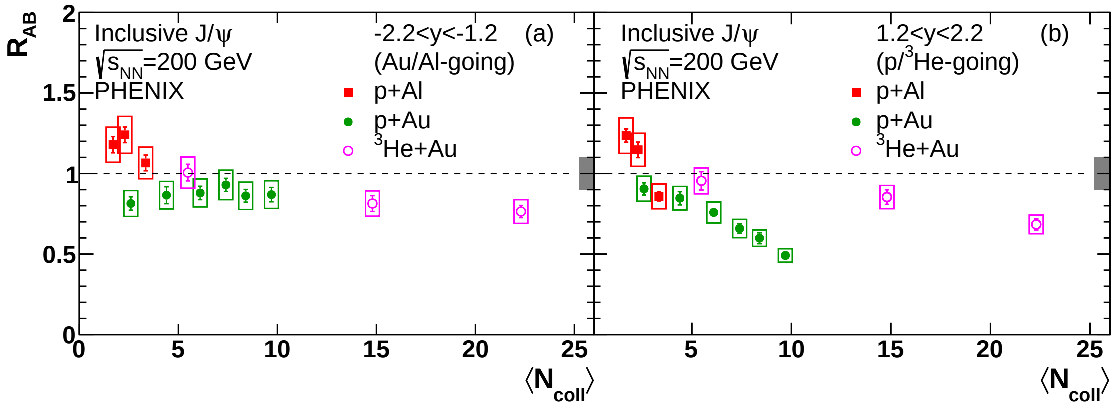

Figure 4: Nuclear modification factor of inclusive J/ψ as a function of $\langle N_{\text{coll}}\rangle$ at backward (left) and forward (right) rapidity in 0%–100% p+Al, p+Au, and ^{3}He+Au collisions. The figure is from Ref. [2].

Because the magnitude of CNM effects can be related to the collision impact parameter and/or the number of produced particles, it is useful to have differential measurements in centrality. Figure 4 show the R_{AB} of inclusive J/ψ as a function of $\langle N_{\text{coll}}\rangle$ at backward (Au/Al-going direction) and forward ($p/^3$He-going direction) rapidity. At backward rapidity, there is no strong centrality dependence in R_{AB} of each collision system, although the modification in p+Al and $p/^3$He+Au is different. However, there is a clear centrality dependence at forward rapidity, and the modification becomes stronger in central collisions for all systems indicating that the modification of nuclear PDF varies with the collision impact parameter.

4. Summary

PHENIX has measured the nuclear modification factor of inclusive J/ψ at forward and backward rapidity in p+Al, p+Au, and ^{3}He+Au collisions. There is little modification in p+Al collision, whereas a suppression is observed in $p/^3$He+Au at both forward and backward rapidity. The modification at forward rapidity is consistent with the calculations considering the modification of nuclear PDF, and additional effect from nuclear breakup is necessary to describe the suppression at backward rapidity.

References

[1] PHENIX collaboration, Phys. Rev. D 99, 072003 (2019).

[2] PHENIX Collaboration, Phys. Review C 102, 014902 (2020).