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Influence of the Nucleon Hard Partons Distribution on J/Ψ Suppression in a GMC Framework *

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In a Glauber Monte Carlo framework, taking into account the transverse spatial distribution of hard partons in the nucleon, we analyze the nuclear modification factor $R_{d\,\mathrm{Au}}$ for J/ψ in d+Au collisions with EPS09 shadowing parametrization. After the influence of nucleon hard partons distribution is considered, a clearly upward correction is revealed for the dependence of $R_{d\,\mathrm{Au}}$ on N_{coll} in peripheral d+Au collisions, however, an unconspicuous correction is shown for the results versus p_T. The theoretical results are in good agreement with the experimental data from PHENIX.

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Since J/ψ production is sensitive to both cold nuclear matter (CNM) and quark-gluon plasma (hot-dense matter),[1] the normal suppression in the CNM should be subtracted in any interpretation of charmonium production in heavy ion collisions. The Glauber Monte Carlo (GMC) approach,[2−6] which can simulate experimentally observable quantities and analyze real data, is an ideal tool for studying the CNM effects provided in deuteron-gold (d+Au) collisions.[7] In the framework of the GMC, only the essential J/ψ production process,[8] $g + g \to c\bar{c}$, is considered. Thus, the subprocess cross section can be obtained by extracting from the proton-proton (p+p) experimental data[9] and given as the Monte Carlo inputs of rapidity (y) and transverse momentum (p_T).[3,4] The shadowing and normal nuclear absorption effects, which are two dominant CNM effects at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) energies, can also be considered properly in the GMC framework. Since shadowing should depend on the spatial position of the interaction parton within the nucleus, the inhomogeneous shadowing effect[10,11] should also be taken into account. In this study, the latest shadowing parametrization EPS09 (Eskola, Paukkunen and Salgado)[12] is used.

At ultra-high energy domain, the mechanism of inelastic hadronic collisions is dominated by the contribution from small-x gluons and the influence of the transverse spatial distribution of hard partons in the nucleon become important.[13,14] Unfortunately, compared with the longitudinal momentum distribution of partons in the nucleon, the measurements of the transverse spatial distribution of partons are rather limited.[15] In this Letter, two kinds of hard partons distributions in the nucleon are used. One is the assumption that the hard partons are uniformly distributed in a hard sphere nucleon, the other is derived from fits to J/ψ photo-production data at HERA and FNAL.[13,15] The corresponding results with both of them will be given in the following.

In the Glauber Monte Carlo framework,[2−4] the J/ψ production in nucleus-nucleus ($A + B$) collisions can be simply written as

$$\begin{aligned}\frac{dN^{J/\psi}_{A+B}}{d^2\boldsymbol{b}dp_T} &= \frac{1}{N_r}\sum_{i=1}^{N_r}\sigma^{\mathrm{in}}_{\mathrm{nn}}F^A_g(x_{1i},Q^2,\boldsymbol{b}_{Ai},z_{Ai})\\ &\times F^B_g(x_{2i},Q^2,|\boldsymbol{b}-\boldsymbol{b}_{Ai}|,z_{Bi})S_A(\boldsymbol{b}_{Ai},z_{Ai})\\ &\times S_B(|\boldsymbol{b}-\boldsymbol{b}_{Ai}|,z_{Bi})\frac{dN^{J/\psi}_{\mathrm{p+p}}}{dp_T},\end{aligned} \tag{1}$$

where

$$x_1 = \frac{m_T}{\sqrt{s}}e^{y}, \quad x_2 = \frac{m_T}{\sqrt{s}}e^{-y},$$

with the transverse mass of J/ψ, $m_T = Q = \sqrt{(2m_c)^2 + p_T^2}$. The charm quark mass $m_c = 1.2\,\mathrm{GeV}$ and the center of mass energy per nucleon pair $\sqrt{s} = 200\,\mathrm{GeV}$ at RHIC energies, $\sigma^{\mathrm{in}}_{\mathrm{nn}}$ is the inelastic cross section, N_r is the total number of Monte Carlo random point, and b is the nucleus-nucleus impact parameter.[16] The probability density function for y and p_T, which are extracted from p+p data taken from PHENIX,[9] are given by the double Gaussian form and $C_1 \times (1 + (p_T/C_2)^2)^{-6}$ form,[9,17] respectively.

In Eq. (1), the factor $F^A_g(x_1, Q^2, \boldsymbol{b}_A, z_A)$ can be given by[10,11]

$$F^A_g(x_1,Q^2,\boldsymbol{b}_A,z_A) = \rho_A(\boldsymbol{b}_A,z_A)R^A_g(\boldsymbol{b}_A,x_1,Q^2), \tag{2}$$

where $\boldsymbol{b}_A$ and z_A are the transverse and longitudinal location of the parton in nucleus A. If we assume that shadowing is proportional to the parton path through the nucleus,[10,18] then the inhomogeneous shadowing

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ratio

$$R_g^A(\boldsymbol{b}_A, x_1, Q^2) = 1 + N_\rho (R_g(x_1, Q^2) - 1) \frac{T_A(\boldsymbol{b}_A)}{T_A(0)}, \quad (3)$$

where $T_A(\boldsymbol{b}_A)$ is the nuclear thickness function at $\boldsymbol{b}_A$, and $R_g(x_1, Q^2)$ is the homogeneous shadowing ratio[19] taken from the EPS09 shadowing parametrization.[12] The nucleon density in the nucleus, $\rho_{A(B)}$, is assumed to be a Woods–Saxon distribution[20] for gold (Au) and a Húlthen form[21,22] for deuteron (d). The unitary factor N_ρ is chosen so that $\int d^2\boldsymbol{b}_A dz_A \rho_A(\boldsymbol{b}_A, z_A) R_g^A = R_g(x_1, Q^2)$.

The survival probability

$$S_A(\boldsymbol{b}_A, z_A) = \exp\{-N_{\rm tr}^{J/\psi - N}(\boldsymbol{b}_A, z_A)\}, \quad (4)$$

where the number of $c\bar{c}$ colliding with the remaining nucleons in nucleus A,[4] $N_{\rm tr}^{J/\psi-N} = \frac{1}{N_r'} \sum_{i'}^{N_r'} \sigma_{\rm abs} \times \rho_A(\boldsymbol{b}_A, z'_{{\rm Au}i'})$, with $z'_{Ai'} > z_A$. The absorption cross section $\sigma_{\rm abs}$ is taken as 3.1 mb by a global χ^2 analysis with the experimental data from PHENIX.[4,7] Both the shadowing and nuclear absorption effects are ignored for deuteron.

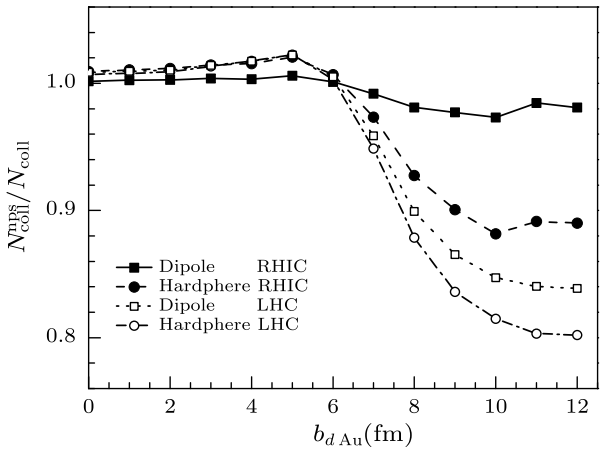

Fig. 1. The ratios of $N_{\rm coll}^{\rm nps}$ to $N_{\rm coll}$ for d+Au collisions at RHIC and LHC energies.

Now let us consider the influence of the transverse spatial distribution of hard partons in the nucleon. Two kinds of nucleon hard parton transverse distributions are used in this study. The first is assumed that the hard partons are uniformly distributed in a hard-sphere nucleon, then the distribution function of hard partons in the transverse plane will be given by

$$F_1(b_n) = 3/(2\pi r_n^3)\sqrt{r_n^2 - b_n^2}\,\theta(r_n - b_n), \quad (5)$$

where the nucleon radius $r_n = \sqrt{\sigma_{\rm nn}^{\rm in}/\pi}/2$, and the inelastic cross section $\sigma_{\rm nn}^{\rm in} = 42$ mb (RHIC energies), 72 mb (LHC energies). The second is derived from the J/ψ photo-production data and described by a dipole form[13]

$$F_2(b_n) = m_g^2/(4\pi)(m_g b_n) K_1(m_g b_n), \quad (6)$$

where K_1 denotes the modified Bessel function[23] and the mass parameter $m_g^2 \sim 1.1\,{\rm GeV}^2$.

In the GMC framework, the number of binary nucleon-nucleon (n+n) collisions, $N_{\rm coll}$, is always simply given by[2]

$$N_{\rm coll}(b) = \sum_{i\in A, j\in B} \theta(|\boldsymbol{b}_{Ai} - \boldsymbol{b}_{Bj}| - d_{\rm max}), \quad (7)$$

where $d_{\rm max} = \sqrt{\sigma_{\rm nn}^{\rm in}/\pi}$. If we consider the nucleon hard partons transverse spatial distribution, the number of binary n+n collisions will be correspondingly written as[22,24]

$$N_{\rm coll}^{\rm nps}(b) = \sum_{i\in A, j\in B} t_{\rm nps}(\boldsymbol{b}_{Ai} - \boldsymbol{b}_{Bj}) \sigma_{\rm nn}^{\rm in}, \quad (8)$$

where the normalized overlap function for n+n collision, $t_{\rm nps}$, can be given by the convolution of collision nucleon hard parton transverse distribution function. The ratios of $N_{\rm coll}^{\rm nps}$ to $N_{\rm coll}$ calculated for d+ Au collisions are given in Fig. 1. In peripheral collision domain ($b_{d\,\rm Au} > 6$ fm), the ratios are less than 1 and a clearly downward trend can be seen. For the magnitude of the bias is sensitive to width of the n+n overlap function, the bias is larger at LHC energies compared with RHIC energies.

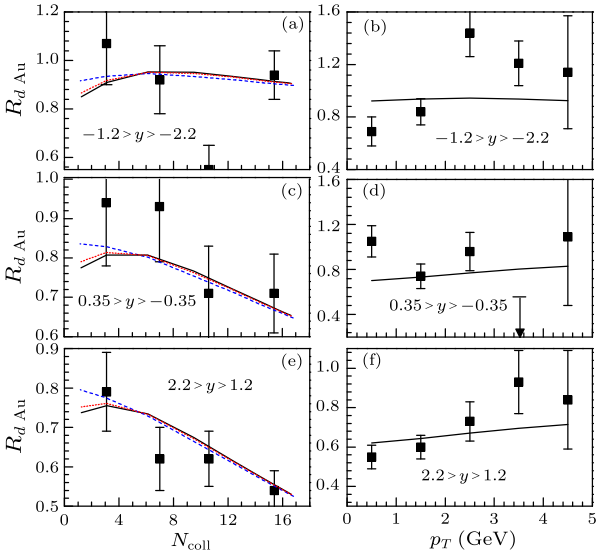

Fig. 2. The $R_{d\,\rm Au}$ ratios versus $N_{\rm coll}$ (left) and p_T (right) at RHIC energies for three rapidity ranges: $-2.2 < y < -1.2$ (a,b), $|y| < 0.35$ (c,d), $1.2 < y < 2.2$ (e,f). The curves are without considering the nucleon hard partons distribution (solid), and with hard-sphere (dashed) or dipole (dotted) nucleon hard partons distribution. The experimental data come from PHENIX.[7]

In order to compare with the experimental data from PHENIX, we introduce the nuclear modification factor:

$$R_{d\,\rm Au}(b) = \frac{\langle dN_{d+\rm Au}^{J/\psi}/d^2\boldsymbol{b}dp_T\rangle_{p_T}}{N_{\rm coll}(b)\langle dN_{\rm p+p}^{J/\psi}/dp_T\rangle}. \quad (9)$$

The J/ψ ratios $R_{d\,\mathrm{Au}}$ versus N_{coll} (left) and p_T (right) are shown in Fig. 2. From top to bottom, the results are for three rapidity regions: backward ($-2.2 < y < -1.2$), central ($|y| < 0.35$) and forward ($1.2 < y < 2.2$). The solid curves are the results without considering the nucleon hard partons distribution. The dashed and dotted curves are the results with hard-sphere and dipole nucleon hard partons transverse distribution, respectively. In the left side of Fig. 2, a clearly upward correction is shown at small N_{coll} for the ratios shown in Fig. 1 is less than 1 as $b_{d\,\mathrm{Au}} > 6$ fm. It is shown that the theoretical results considering the nucleon hard partons distribution are in good agreement with the experimental data from PHENIX.[7] In the right side, there is not any obvious correction for the ratios versus p_T. The reason is that the nuclear modification factor versus p_T will be changed into

$$R_{d\,\mathrm{Au}}(p_T) = \frac{\langle dN^{J/\psi}_{d+\mathrm{Au}}/d^2\boldsymbol{b}dp_T\rangle_{\boldsymbol{b}}}{\langle N_{\mathrm{coll}}(b)\rangle dN^{J/\psi}_{\mathrm{p+p}}/dp_T}, \qquad (10)$$

and the average number of inelastic n+n collisions at RHIC energies, $\langle N_{\mathrm{coll}}(b)\rangle \sim 1654$, for all of the methods mentioned above.

In summary, we have considered the influence of nucleon hard partons distribution on the nuclear modification factor for J/ψ in d+Au collisions in the GMC framework. A visible correction can be seen for the ratios versus N_{coll} and the theoretical results considering the hard parton distribution are in good agreement with the experimental data from PHENIX.[7] Since the bias shown in Fig. 1 is much larger at LHC energies than RHIC energies with the same n+n overlap function, the influence of nucleon hard parton distribution must also be properly considered at LHC energies.

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