Influence of the Nucleon Hard Partons Distribution on $J/\Psi$ 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 nucleus, we analyze the nuclear modification factor $R_{dAu}$ for $J/\psi$ 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 $R_{dAu}$ on $N_{\text{coll}}$ in peripheral $d+Au$ collisions, however, an unconspicuous effect 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 $J/\psi$ production is sensitive to both cold nuclear matter (CNM) and quark-gluon plasma (hot dense matter), 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, 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. [1] In the framework of the GMC, only the essential effects should be subtracted in any interpretation of charmonium suppression in $d+Au$ collisions.[2] The corresponding results with both of them will be given in the following.

In the Glauber Monte Carlo framework, the $J/\psi$ production in nucleus-nucleus ($A+B$) collisions can be simply written as

$$dN_{A+B}^{J/\psi} = \int \frac{dN_{p+p}^{J/\psi}}{d^2 b_{T}} \sum_{i=1}^{N_{c}} \frac{e_{\text{in}}^{m_{i}} F_{g}^{A}(x_{1i}, Q_{T}^{2}, b_{Ai}, z_{Ai})}{N_{i}} \times F_{g}^{B}(x_{2i}, Q_{T}^{2}, |b-b_{Ai}|, z_{Bi}) S_{A}(b_{Ai}, z_{Ai}) \times S_{B}(|b-b_{Ai}|, z_{Bi}) \frac{dN_{p+p}^{J/\psi}}{d^2 b_{T}},$$

(1)

where

$$x_{1} = \frac{m_{T}}{m_{c}} e^{y}, \quad x_{2} = \frac{m_{T}}{m_{c}} e^{-y},$$

with the transverse mass of $J/\psi$, $m_{T} = Q = \sqrt{(2m_{c})^{2} + p_{T}^{2}}$. The charm quark mass $m_{c} = 1.2\text{GeV}$ and the center of mass mass per nucleon pair $\sqrt{s} = 200\text{GeV}$ at RHIC energies, $e_{\text{in}}^{m_{i}}$ is the inelastic cross section, $N_{i}$ is the total number of Monte Carlo random point, and $b$ is the nucleus-nucleus impact parameter.[10] The probability density function for $y$ and $p_{T}$, which are extracted from p+p data taken from PHENIX, are given by the double Gaussian form and $C_{1} \times (1 + (p_{T}/C_{2})^{2})^{-6}$ form respectively.

In Eq. (1), the factor $F_{g}^{A}(x_{1}, Q_{T}^{2}, b_{A}, z_{A})$ can be given by

$$F_{g}^{A}(x_{1}, Q_{T}^{2}, b_{A}, z_{A}) = \rho_{A}(b_{A}, z_{A}) R_{g}^{A}(b_{A}, x_{1}, Q_{T}^{2}),$$

(2)

where $b_{A}$ 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, then the inhomogeneous shadowing distributed in a hard sphere nucleon, the other is derived from fits to $J/\psi$ photo-production data at HERA and FNAL.[13,15] The corresponding results with both of them will be given in the following.

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. 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 $J/\psi$ photo-production data at HERA and FNAL.[13,15] The corresponding results with both of them will be given in the following.
where the number of \( c \) for deuteron (d). The unitary factor \( N \) nucleons in nucleus distribution \( \rho \) nucleus, \( \rho \) is taken as 3.1 mb by a global \[12\] and \( \sigma_{\text{nps}} \) from PHENIX.\[14,17\] Both the shadowing and nuclear absorption effects are ignored for deuteron.

\[
S_A(b_A, z_A) = \exp\{-N_{tr}^J/\psi-N(b_A, z_A)\},
\]

where the number of \( c \) colliding with the remaining nucleons in nucleus \( A \), \( N_{tr}^J/\psi-N = \frac{1}{N_A} \sum_i N_i \sigma_{\text{abs}} \times \rho_A(b_A, z'_A) \), with \( z'_A > z_A \). The absorption cross section \( \sigma_{\text{abs}} \) is taken as 3.1 mb by a global \( \chi^2 \) analysis with the experimental data from PHENIX.\[4,7\] The survival probability \( S_A(b_A, z_A) \) is the homogeneous shadowing and nuclear absorption effects are ignored for deuteron.

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

\[
F_1(b_n) = 3/(2\pi r_n^3) \sqrt{r_n^2 - b_n^2} \theta(r_n - b_n),
\]

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

\[
F_2(b_n) = m_d^2/(4\pi)(m_d b_n) K_1(m_d b_n),
\]

where \( K_1 \) denotes the modified Bessel function\[23\] and the mass parameter \( m_d^2 \sim 1.1 \text{GeV}^2 \).

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

\[
N_{\text{coll}}(b) = \sum_{i \in A, j \in B} \theta(|b_{Ai} - b_{Bj}| - d_{\text{max}}),
\]

where \( d_{\text{max}} = \sqrt{\sigma_{\text{nps}}/\pi} \). 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_{\text{coll}}(b) = \sum_{i \in A, j \in B} t_{\text{nps}}(b_{A_i} - b_{B_j}) \sigma_{\text{nps}},
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where the normalized overlap function for n+n collision, \( t_{\text{nps}} \), can be given by the convolution of collision nucleon hard parton transverse distribution function.

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N_{\text{RHIC}}(b) = \sum_{i \in A, j \in B} \theta(|b_{A_i} - b_{B_j}| - d_{\text{max}}),
\]

where the normalized overlap function for n+n collision, \( t_{\text{nps}} \), can be given by the convolution of collision nucleon hard parton transverse distribution function.

The ratios of \( N_{\text{RHIC}}(b) \) to \( N_{\text{coll}}(b) \) for d+Au collisions at RHIC and LHC energies.

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The ratios of \( N_{\text{RHIC}}(b) \) to \( N_{\text{coll}}(b) \) for d+Au collisions are given in Fig. 1. In peripheral collision domain \( b_{\text{dAu}} > 6 \text{fm} \), 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.

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The $J/\psi$ ratios $R_{d\text{Au}}$ versus $N_{\text{coll}}$ (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 $N_{\text{coll}}$ for the ratios shown in Fig. 1 is less than 1 as $b_{d\text{Au}} > 6$ fm. It is shown that the theoretical results considering the nucleon hard partons distribution are in good agreement with the experimental data from PHENIX. 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

$$R_{d\text{Au}}(p_T) = \frac{\langle dN_{J/\psi}/d^2bp_T \rangle_b}{\langle N_{\text{coll}}(b) \rangle dN_{J/\psi}/dp_T}$$

(10)

and the average number of inelastic n+n collisions at RHIC energies, $\langle N_{\text{coll}}(b) \rangle \sim 1654$, 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 $J/\psi$ in $d+\text{Au}$ collisions in the GMC framework. A visible correction can be seen for the ratios versus $N_{\text{coll}}$ and the theoretical results considering the hard parton distribution are in good agreement with the experimental data from PHENIX. 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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