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Exclusive Photoproduction of J/ψ's in Peripheral AA Collisions

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The rapidity distribution and the nuclear modification factor (R_{AA}) were calculated through the exclusive photoproduction mechanism in the peripheral regime. Using the light-cone color dipole formalism commonly used in the UPC regime, the J/ψ production was investigated considering three scenarios: (1) in the simplest scenario it was considered a photon flux with b-dependence without any geometrical constraint (UPC with b-dependence), (2) an effective photon flux is considered, such that, only the spectators in the target are the ones that interact coherently with the photon and (3) the photonuclear cross section is modified using the same geometrical constraints applied in the scenario 2. The results were compared with the ALICE measurements and shown a better agreement for the scenarios 2 and 3, mainly in the more central regions (30%-50% and 50%-70%) where the dependence with b is more pronounced. Although it is not yet possible to confirm that the exclusive photoproduction is fully responsible for the J/ψ excess observed in ALICE, there are indications that it produces a considerable part of the effect.

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1. Introduction

A significant excess of J/ψ in very small transverse momentum ($p_T < 0.3$ GeV/c) and range rapidity $2.5 < y < 4.0$ was observed by the ALICE collaboration [1] and, after, confirmed by the STAR collaboration [2]. In order to quantify this excess, the light-cone color dipole formalism used in a previous work [3] was extended to the peripheral regime considering three scenarios: (1) a photon flux with b-dependence was used, (2) a geometrical cut is applyed in the photon flux ensuring that only the spectators in the target will interact coherently with the photon and (3) where, for completeness, the same restriction adopted in the scenario 2 to construct the effective photonuclear cross section was applyed. Using these three scenarios, the rapidity distribution and the nuclear modification factor, R_{AA}, were estimated for 30%-50%, 50%-70% and 70%-90% centrality classes.

2. Exclusive Photoproduction in Peripheral Collisions

The differential cross section in the rapidity y and impact parameter b can be written as [4]

$$\frac{d^3\sigma_{AA\to AAV}}{d^2bdy} = \omega N(\omega,b)\sigma_{\gamma A\to VA} + (y\to -y)\,. \tag{2.1}$$

where $\sigma_{\gamma A\to VA}$ is the photonuclear cross section that characterizes the photon-target interaction $\gamma A \to VA$, $\omega = \frac{1}{2}M_V \exp(y)$ is the photon energy in function of the rapidity y and of the mass M_V of the meson, and $N(\omega,b)$ is a photon flux with b-dependence given by [5]

$$N(\omega,b) = \frac{Z^2\alpha_{QED}}{\pi^2\omega}\left|\int_0^\infty dk_\perp k_\perp^2 \frac{F(k^2)}{k^2} J_1(bk_\perp)\right|^2, \tag{2.2}$$

where Z is the nuclear charge, $\gamma = \sqrt{s_{NN}}/(2m_{\text{proton}})$ is the Lorentz factor, $k_\perp$ is the transverse momentum of the photon, $k^2 = (\omega/\gamma)^2 + k_\perp^2$ and the form factor for lead nucleus is given by $F(k) = 4\pi\rho_0\left[\sin\,(kR_A) - kR_A\cos\,(kR_A)\right]/\left[Ak^3\left(1+a^2k^2\right)\right]$ [6], with $a = 0.7$ fm and $\rho_0 = 0.1385$ fm^{-3}. The photonuclear cross section is described in this work in the light cone colour dipole formalism, which includes the partonic saturation phenomenon and the nuclear shadowing effects [7, 8]. The formalism has already been explored in the last works [3] in pp, pA and AA collisions. In this approach, the photon-nuclei forward scattering amplitude can be factorized as

$$\text{Im}\,A(x,t=0) = \int d^2r \int \frac{dz}{4\pi}\left(\psi_V^*\psi_\gamma\right)_T \sigma_{\text{dip}}^{\text{nucleus}}(x,r). \tag{2.3}$$

where $\left(\psi_V^*\psi_\gamma\right)_T$ is the overlap between the photon and the vector meson wave functions (described with more detail in [9]) and $\sigma_{\text{dip}}^{\text{nucleus}}(x,r)$ is obtained using the Glauber-Gribov picture [10], as proposed in [11]

$$\sigma_{\text{dip}}^{\text{nucleus}}(x,r) = 2\int d^2b' \left\{1-\exp\left[-\tfrac{1}{2}T_A(b')\sigma_{\text{dip}}^{\text{proton}}(x,r)\right]\right\}. \tag{2.4}$$

In the Eq. (2.4), $T_A(b)$ is the nuclear overlap function, calculated from Woods-Saxon distribution, and σ_{dip} is the dipole-nucleon cross section, which was calculated in this work using the GBW [12] and CGC [13] dipole models. These two models shown a good agreement with the data in the

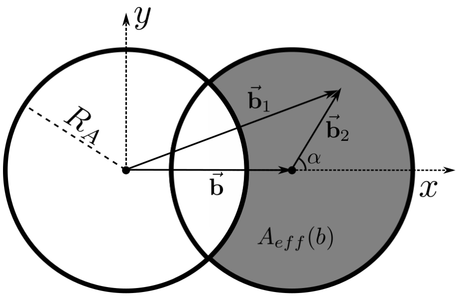

Figure 1: Scheme of the interaction according to scenario 2.

ultraperipheral regime [3]. The combination of the photon flux (2.2) with the photonuclear cross section used in UPC constitute what we named as **scenario 1**.

Scenario 2: To refine our calculations, an effective photon flux was built following a similar procedure showed in [4] where two hypothesis were considered: (1) only the photons that reach the geometrical region of the nuclear target will be considered and (2) the photons that reach the overlap region will be neglected, Figure 1. Then, the new photon flux can be expressed as [14]

$$N^{eff}(\omega,b) = \int N^{usual}(\omega,b_1)\frac{\theta(b_1-R_A)\theta(R_A-b_2)}{A_{eff}(b)}d^2b_2 \tag{2.5}$$

where the effective interaction area is given by $A_{eff}(b) = R_A^2\left[\pi - 2\cos^{-1}\left(\frac{b}{2R_A}\right)\right] + \frac{b}{2}\sqrt{4R_A^2-b^2}$.

Scenario 3: In accordance with the geometrical constraints adopted in the construction of the effective photon flux, an effective photonuclear cross section was constructed applying the $\Theta(b_1 - R_A)$ function into Eq. (2.4), which produces

$$\sigma_{\rm dip}^{\rm nucleus}(x,r) = 2\int d^2b_2\Theta(b_1-R_A)\left\{1-\exp\left[-\frac{1}{2}T_A(b_2)\sigma_{\rm dip}^{\rm proton}(x,r)\right]\right\} \tag{2.6}$$

where, $b_1^2 = b^2 + b_2^2 + 2bb_2\cos(\alpha)$. Considering the effective photon flux and photonuclear cross section, the rapidity distribution was calculated and its results for the three centrality classes (scenario 3) are shown in the Table (1).

3. Main Results

In the Table (1), the average rapidity distribution using the GBW and CGC models is shown for the three scenarios described in the text. In the simplest approach (scenario 1), a good agreement with the ALICE data is reached for 70%-90% centrality class where the b-dependence is weaker. In more central regions, the scenarios 2 and 3 are more suitable.

Average Rapidity Distribution: $d\sigma/dy$

GBW/CGC	30%-50%	50%-70%	70%-90%
Scenario 1	200/170	100/84	60/51
Scenario 2	128/107	98/80	80/67
Scenario 3	73/61	78/66	75/63
ALICE data	$73 \pm 44^{+26}_{-27} \pm 10$	$58 \pm 16^{+8}_{-10} \pm 8$	$59 \pm 11^{+7}_{-10} \pm 8$

Table 1: Comparison between our results obtained from the different scenarios and the ALICE data [1].

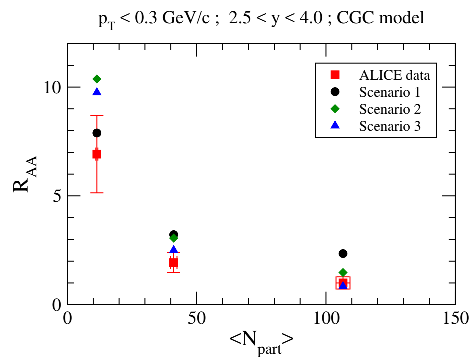

Figure 2: Comparison of the R_{AA} results with the ALICE data for the centrality classes 30%-50%, 50%-70% e 70%-90% [1].

The excess of the J/ψ was also quantified by the nuclear modification factor and calculated from the results presented in the Table (1). Adopting the CGC model, which shows slightly better results than the GBW model, the R_{AA} was calculated for the three scenarios investigated and its results are compared with the ALICE data, Fig. 2. Similarly to the rapidity distribution, the scenario 1 shows better agreement in the more peripheral region while the scenarios 2 and 3 are more suitable for more central collisions where the b-dependence is more relevant. More details about this work can be found in [15]. Although it is not yet possible to confirm that the exclusive photoproduction is fully responsible for the J/ψ excess observed in ALICE, there are indications that it produces a considerable part of the effect.

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