Exclusive Photoproduction $J/\psi$ in Peripheral Pb-Pb

M. B. GAY DUCATI1; S. MARTINS2
High Energy Physics Phenomenology Group, GPPAE II - UFRGS, Brazil

Introduction

The ALICE collaboration measured the $J/\psi$ hadroproduction in peripheral collisions Pb-Pb, with $\sqrt{s} = 2.76$ TeV, revealing an excess in the production of the meson in very small transverse momentum ($p_T < 0.3$ GeV/$c$) in the range rapidity $2.5 < y < 4.0$ [1]. Considering the $J/\psi$ excess could be generated from exclusive photo-production, we calculated the $J/\psi$ nuclear photo-production in peripheral collisions from the formalism adopted in the ultraperipheral collisions (UPC), which cross section can be separated in two components: the equivalent photon flux, $N(\omega, b)$, and the photonuclear cross section, $\sigma_{\gamma A \rightarrow A}$. In our approach, the transition from ultraperipheral to peripheral regime is analysed considering three scenarios: (1) direct application of the usual photon flux and of the photonuclear cross section without any change in relation to UPC’s, (2) change only in the photon flux and (3) change in the photon flux and in the photonuclear cross section.

Theoretical Framework

In the ultrarelativistic limit, the exclusive nuclear photoproduction of a vector meson $V^i$ can be written as the convolution between the photon flux, created from one of the nucleons, and the photonuclear cross section, which characterizes the photon-target interaction $\gamma \rightarrow V^i A$. Assuming a photon flux with $b$ dependence impact parameter, the differential cross section in the rapidity $y$ and impact parameter $b$, is given by [2]

$$\frac{d^2\sigma_{\gamma A \rightarrow A V}}{db dy} = \omega N(\omega, b) \sigma_{\gamma A \rightarrow A V}(y - y_0),$$

where $\omega = \frac{dR}{dQ}$ is the photon energy and $M_V$ is the meson mass. In the peripheral collisions the electromagnetic form factor, $F(k^2)$, becomes relevant and, therefore, was adopted the following generic formula for the photon flux [3]

$$N(\omega, b) = \frac{Z^2 N_{\text{had}}}{4\pi} \int d^2k \frac{F(k^2)}{k^2} \langle b(\Delta k^2) \rangle^2,$$

where $Z$ is the nuclear charge, $\gamma = \frac{\sqrt{s}/s}{2m_{\text{hadron}}}$ is the Lorentz factor, $k_L$ is the transverse momentum of the photon and $k^2 = (\omega/\gamma)^2 + k_L^2$. For the lead nucleus, it was used the form factor $F(k^2) = \frac{1}{2\pi} x f_{\omega}(1 - \frac{1}{4\pi} F_{\perp}^2)$, $f_{\omega}$ is the light cone colour dipole formalism, which includes the parton saturation phenomenon and the nuclear shadowing effects [4]. The formalism has already been explored in the last works [5] and, here, we showed only its mean equation.

$$\sigma_{\gamma A \rightarrow A V(y, b)} = \int_{T(b)} d t \int_{\gamma} d \gamma_{\text{dip}} = 2 \pi R_A^2 \int_{T(b)} dt,$$

where $T(b)$ is the nuclear overlap function and $\sigma_{\text{dip}}$ is the dipole cross section. In our calculations, we considered the GBW and CGC dipole models, since they presented a good agreement with the data in the ultraperipheral regime [5]. The form factor is integrated from $t_{\text{min}} = (M_N^2/2x)_{\text{min}}$ to infinity, with $F(k^2)$ as previously defined. The other parameters are detailed in [6]. The application of the equations (2) and (3) inside of (1) constitutes what we named the scenario 1, which produces the results showed in the second row of Table 1.

The Effective Photon Flux

In order to refine our calculation, we modified the photon flux following the similar procedure suggested in [2], which an effective photon flux built in terms of the usual photon flux (eq. 2) with two restrictions: (1) only the photons that reach the geometrical region of the nuclear target will be considered and (2) photons that reach the overlap region will be neglected. Then, the new photon flux can be expressed as [7]

$$N_{\text{eff}}(\omega, b) = \frac{4}{\pi} \int d^2k N(\omega, b) \theta(R_A - b) \theta(b - R_A),$$

where, unlike [2], it was divided by effective area $A_{\text{eff}}(b) = R_A^2 - \pi b^2 (\cos^{-1}(\frac{R_A - b}{R_A}) - \frac{1}{2}(R_A - b))$, instead of the fixed value $R_A^2$. In the Figure 1, was compared the usual photon flux with the effective photon flux to the energy of the photon $\omega = 0.01$ GeV and $\omega = 1$. For $b \leq 4$, the usual photon flux diverges considerably from the effective photon flux going to zero as $b \rightarrow 0$. In the range $1 \leq b \leq 11$, the usual photon flux is bigger than the effective photon flux, mainly on the threshold $b \sim R_A \sim 7$. In the last, as $b \rightarrow \infty$, both models become similar as expected.

![Figure: Comparison between the usual and effective photon flux for the $\omega = 0.01$ GeV and $\omega = 1$ GeV at $\sqrt{s} = 2.76$ TeV.](image)

Rapidity Distribution

Considering the effective photon flux without changing the photonuclear cross section (scenario 2), was calculated the rapidity distribution for the $J/\psi$ production in Pb-Pb collisions in the following centrality classes: 30%-50%, 50%-70% and 70%-90%. Adopting the GBW and CGC dipole models, we performed our analysis at $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 5.02$ TeV as it can be seen in the Figure 2. For $\sqrt{s} = 2.76$ TeV (left), it was observed an increase of the $\sim 12\%$ from 70%-90% to 50%-70% and of the $\sim 13\%$ from 50%-70% to 30%-50%, for the both models, at $y = 0$. Similarly, it was observed an increase of the $\sim 12\%$ from 70%-90% to 50%-70% and $\sim 13\%$ from 50%-70% to 30%-50% at $y = 0$. Therefore, the relative variation between the different centrality classes do not present sensitivity as the increase of the energy.

1. Physics Institute, IF-UFRGS, UFRGS - beatriz.gay@ufrgs.br
2. Physics Institute, IF-UFRGS, UFRGS - sonia.fusca@gmail.com

Conclusion and Discussion

Our estimates for the rapidity distribution and nuclear modification factor were presented for the $J/\psi$ production in the centrality classes 30%-50%, 50%-70% and 70%-90%. In our calculation, we compared the ALICE data with our estimates, obtained from three different approaches. In the simplest approach (scenario 1), it was obtained better agreement with the data only in the more peripheral region, where there is a considerable uncertainty. On the other hand, for the more consistent approach (scenario 3), the result overestimate in the more peripheral region, however, it agrees better with the data in the more central region where the uncertainty is small. Although it is not yet possible to confirm that the exclusive photoproduction is solely responsible by $J/\psi$ excess observed at ALICE, there are indications that it produces the most part of the effect.