Physics Letters B 710 (2012) 647–653

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Coherent ρ and J/ψ photoproduction in ultraperipheral processes with electromagnetic dissociation of heavy ions at RHIC and LHC

V. Rebyakova [a], M. Strikman [b,*], M. Zhalov [c]

[a] Petersburg State Technical University, St. Petersburg, Russia
[b] Pennsylvania State University, University Park, PA 16802, USA
[c] Petersburg Nuclear Physics Institute, Gatchina, Russia

ARTICLE INFO

Article history:
Received 28 September 2011
Received in revised form 7 February 2012
Accepted 16 March 2012
Available online 19 March 2012
Editor: J.-P. Blaizot

ABSTRACT

We present predictions for the J/ψ and ρ meson production in the heavy ion ultraperipheral collisions (UPC) for the current energy 2.76 TeV at the LHC. Both total cross sections and cross sections with the neutron emission from one or both nuclei are presented. We also perform analysis of the RHIC ρ meson photoproduction data and emphasize importance of these data for testing the current model for nucleus breakup in the UPC.

1. Introduction

Ultraperipheral collisions at the LHC provide a fine probe of the small x dynamics in much cleaner environment than strong proton–proton (nucleus) collisions. They also present an important bridge to the future studies at the e–A colliders. A detailed review of the UPC physics was performed by the UPC study group and reported in [1]. However, all the predictions were presented in [1] for the planned energy of the heavy ion collisions at the LHC of $\sqrt{s_{NN}} = 5.52$ TeV. Hence, it is necessary to update those studies for the current energy $\sqrt{s_{NN}} =$ 2.76 TeV in models, used in [1], as well as to explore long term advantages of having UPC data at two different LHC energies. Also, we have received requests from experimental groups to calculate the quantities which are more readily accessible experimentally – the partial cross sections with electromagnetic dissociation of one or two nuclei with emission of neutrons.

The basic expressions for the cross section of production of vector mesons in ultraperipheral collisions are given in a number of papers, see e.g. [1]:

$$\frac{d\sigma_{A_1A_2\to A_1A_2V}}{dy} = n_{\gamma/A_1}(y)\sigma_{\gamma A_2\to VA_2}(y) + n_{\gamma/A_2}(-y)\sigma_{\gamma A_1\to VA_1}(-y). \quad (1)$$

Here $y = \ln\frac{2\omega_\gamma}{M_V}$ is the rapidity of the produced vector meson, and $n_{\gamma/A}(y)$ is the flux of photons with the energy $\omega_\gamma = \gamma_L q_0$ emitted by one of the nuclei, γ_L is the Lorentz factor for colliding nuclei, and q_0 is the photon momentum in the rest frame of the nucleus emitting the photon.

The characteristic feature of the ultraperipheral collisions is that collisions occur at a rather large impact parameter $\vec{b}$ between interacting nuclei. Hence, the flux of photons, radiated by accelerated ion, can be with reasonable accuracy approximated by the equivalent photon spectrum of the point charge Z, moving with velocity $\beta = p_N/E_N$. To avoid the strong interaction of the colliding ions (which breaks coherence of the process), one has to restrict the impact parameters b of the interaction. One can impose condition $b_{\min} > 2R_A$ and additionally use the Glauber model to describe the geometry of nucleus–nucleus collisions and suppress the strong interactions by the simple factor

$$P_S(b) = \exp\left[-\sigma_{NN}T_{AA}(b)\right], \quad (2)$$

with

$$T_{AA}(b) = \int_0^\infty db' \int_{-\infty}^{\infty} dz\, \rho_A(\vec{b}-\vec{b}', z) \int_{-\infty}^{\infty} \rho_A(\vec{b}', z')\, dz', \quad (3)$$

describing overlap of colliding ions ($\rho_A(\vec{b}, z)$ is the nuclear density normalized by the condition $\int d^2b\, dz\, \rho(\vec{b}, z) = A$). Another important feature of the UPC of heavy ions is a significant probability of the photon exchange with excitation of nuclei accompanied by a subsequent nucleus decay with emission of neutrons [2]. When such photon exchange occurs in the final state of UPC with the vector meson photoproduction, this does not destroy the coherence of photoproduction, and sum over the final state of ions gives the total coherent photoproduction cross section.

Experimental studies performed by the STAR experiment at RHIC using the Zero Degree Calorimeters (ZDC) (most of the

* Corresponding author.
E-mail address: strikman@phys.psu.edu (M. Strikman).

0370-2693
http://dx.doi.org/10.1016/j.physletb.2012.03.041

currently running experiments at RHIC and LHC have ZDCs) have demonstrated that it is possible to select different channels, in particular, coherent photoproduction with excitation of ions in which neutrons are emitted by one or both nuclei. One can distinguish between several channels: $1n1n$ – emission of one neutron by each ion, $XnXn$ – emission of several neutrons, $0n1n$ and $0nXn$ excitation and decay only of one ion. To estimate these partial cross sections, we use the model suggested in [2] where it is shown that coherent photoproduction with additional electromagnetic nucleus excitation can be calculated modifying the flux of photons by impact parameter dependent factors $P^i_C(\vec{b})$ which account for different channels ($i = 0n0n, 0n1n, 1n1n, 0nXn, XnXn$).[1] Hence, the final expression for the photon flux used in our calculations is

$$n^i_{\gamma/A}(\omega_\gamma) = \frac{2\alpha Z^2}{\pi} \int_{b_{\min}}^{\infty} db\, \frac{x^2}{b} \left[K_1^2(x) + \frac{K_0^2(x)}{\gamma_L^2} \right] P_S(b) P^i_C(b), \quad (4)$$

where $x = \frac{\omega_\gamma b}{\gamma_L \beta}$, and K_0, K_1 are the modified Bessel functions.

We provide predictions for the light and heavy vector meson photoproduction with small transverse momenta of vector mesons. The dynamics of production of mesons, built of light quarks, and those, built of heavy quarks, is qualitatively different. Hence, we treat them separately.

2. Production of light vector mesons

Production of ρ meson provides an important check of the modeling of the dynamics of UPC. Indeed, the cross section $\gamma + A \to \rho + A$ is well understood theoretically. Though the Gribov space–time picture of high energy process of hadron–nucleus interaction differs qualitatively from low energy Glauber picture, numerically, the Gribov–Glauber theory which includes inelastic screening effects predicts very small (on the level of few percent) deviations from the Glauber model for hadron–nucleus scattering. An additional element of the theory in the case of the photon projectile is presence of the nondiagonal transitions $\gamma \to \rho' \to \rho$. The generalized vector dominance model combined with Glauber approach describes well the data on ρ production at $E_\gamma \sim 10$ GeV without free parameters [3]. It also predicted [4] reasonably well absolute cross section of the ρ meson photoproduction as measured in the UPC at RHIC for $\sqrt{s_{NN}} = 130$ GeV [5]. For high energy photoproduction off heavy nuclei correction to the standard VDM + Glauber model due to taking into account the nondiagonal transitions is about 10–15%. Since the uncertainty (combined statistical and systematic errors) of the experimental cross sections measured by STAR exceeds this correction by almost factor of two, we use the standard Glauber model formula [6] to calculate the cross section of coherent ρ meson photoproduction in UPC of heavy ions at RHIC and LHC:

$$\sigma_{\gamma A \to \rho A} = \frac{d\sigma_{\gamma N \to \rho N}(t=0)}{dt} \int_{-\infty}^{t_{\min}} dt \times \left| \int_0^\infty d\vec{b}\, e^{i\vec{q}_\perp \cdot \vec{b}} \int_{-\infty}^{\infty} dz\, \varrho(\vec{b}, z) e^{iq_\parallel^{\gamma \to \rho} z} e^{-\frac{\sigma_{\rho N}}{2} \int_z^\infty \varrho(\vec{b}, z')\, dz'} \right|^2. \quad (5)$$

[1] Our thanks to S. Klein and J. Nystrand for kindly providing their code for calculating the probabilities of electromagnetic excitations with subsequent neutron decay.

Table 1
Cross sections of the ρ meson photoproduction in gold–gold UPC at RHIC calculated in the Glauber model. Numbers in brackets present results obtained by the STAR Collaboration from analysis of the experimental data on the gold–gold UPC studies at RHIC using their measurement of the $XnXn$ and $1n1n$ cross sections.

$\sqrt{s_{NN}}$ UPC	62.4 GeV AuAu	130 GeV AuAu	200 GeV AuAu
$\sigma^\rho_{coherent}$, mb	137	520	910
STAR	(190 ± 36)	(460 ± 245)	(530 ± 60)
σ^ρ_{0n0n}, mb	79	354	661
STAR	(120 ± 25)	(370 ± 90)	(39 ± 60)
σ^ρ_{0nXn}, mb	45	132	198
STAR	(59.3 ± 13)	(95 ± 65)	(105 ± 16)
σ^ρ_{XnXn}, mb	13	34	51
STAR	(10.5 ± 2.2)	(28.3 ± 6.3)	(32 ± 4.8)
σ^ρ_{0n1n}, mb	16	46	67
STAR	–	–	–
σ^ρ_{1n1n}, mb	1.4	3.5	4.9
STAR	–	(2.8 ± 0.9)	(2.4 ± 0.5)

Table 2
Comparison of the Glauber model predictions with the results of measurements by STAR for ρ meson photoproduction in gold–gold UPC at $\sqrt{s_{NN}} = 200$ GeV at RHIC.

Energy	Partial cross section, mb	$\sigma(XnXn, \|y\| < 1)$	$\sigma(1n1n, \|y\| < 1)$
$\sqrt{s_{NN}} = 130$ GeV	Glauber model	18.6	1.87
	STAR experiment	14.9 ± 2.0	1.47 ± 0.16
$\sqrt{s_{NN}} = 200$ GeV	Glauber model	25.4	2.4
	STAR experiment	14.5 ± 2.0	1.07 ± 0.16

Table 3
Cross sections of the ρ meson photoproduction in PbPb UPC at LHC calculated in the Glauber model.

$\sqrt{s_{NN}}$ UPC	2760 GeV PbPb	5500 GeV PbPb
$\sigma^\rho_{coherent}$, mb	7023	9706
σ^ρ_{0n0n}, mb	5915	8309
σ^ρ_{0nXn}, mb	847	1057
σ^ρ_{XnXn}, mb	261	340
σ^ρ_{0n1n}, mb	260	306
σ^ρ_{1n1n}, mb	18.5	21

Here $\vec{q}^{\,2}_\perp = t_\perp = t_{\min} - t$, $-t_{\min} = |q_\parallel^{\gamma \to \rho}|^2$ is longitudinal momentum transfer in γ–ρ transition in the target nucleus rest frame. We also use the Donnachie–Landshoff model [7] for the total ρN cross section and forward cross section of coherent ρ photoproduction off the nucleon target. This model describes reasonably well the data for $\gamma p \to p\rho$ at energies up to $W_{\gamma p} \approx 200$–300 GeV studied at HERA but can slightly overestimate the cross section at very high energies due to including contribution of the hard pomeron exchange with large intercept ($\alpha_H(0) = 1.44$) in the soft process of coherent photoproduction of ρ's with small transverse momentum. Note, that we neglect the interesting effect of interference between production by left and right moving photons [8] since it gives a small correction in the cross section integrated over rapidities, and p_t. Our calculations for the ρ meson photoproduction in UPC at RHIC and LHC are presented in Tables 1–3 and Figs. 1–3. In Table 1 and Fig. 1 we compare cross sections obtained in the model described above with results reported by the STAR Collaboration [5,9,10]. It is worth noting that in the STAR experiment only the $(XnXn)$ and $(1n1n)$ channels were measured. The ρ mesons were detected in the rapidity range $-1 < y < 1$ and $p_t < 150$ MeV/c. The numbers reported by experiment for the total cross sections

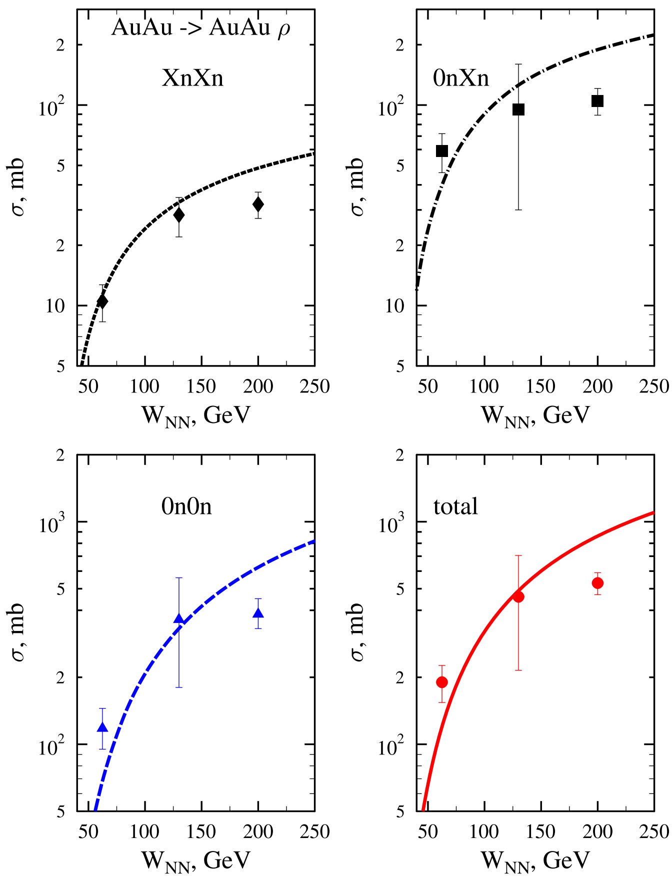

Fig. 1. Comparison of the calculated cross sections for ρ photoproduction in gold–gold UPC with the STAR experimental results.

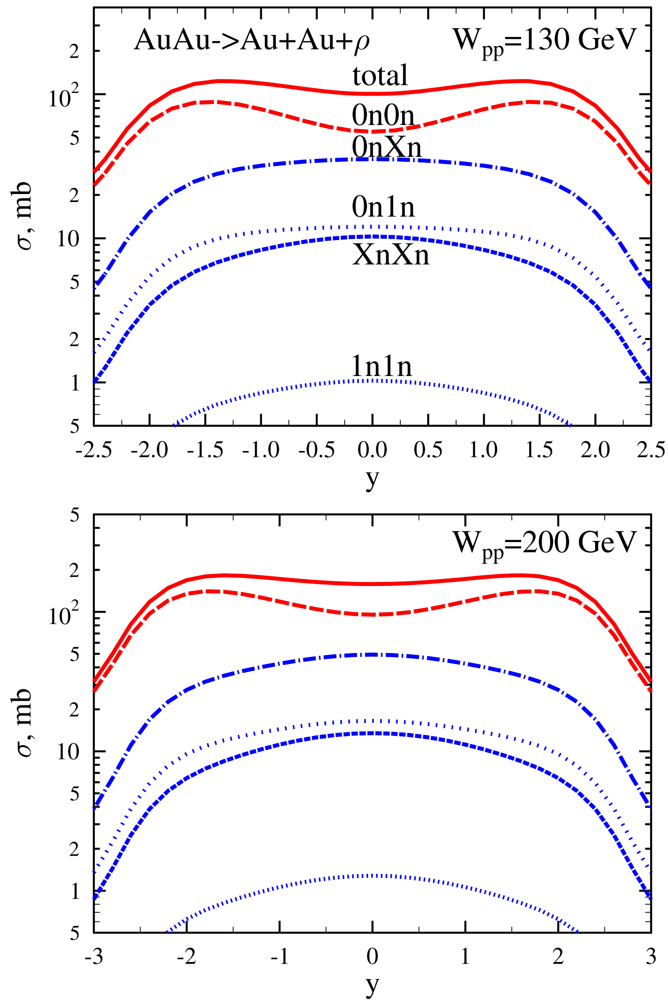

Fig. 2. Calculated rapidity distributions for different channels in ρ photoproduction in gold–gold UPC at RHIC.

of various channels were calculated from the measured two cross sections using the StarLight event generator to extrapolate to the larger $|y|$ and to calculate the ratio of the cross section in different channels.

We find a reasonable agreement at lower energies but a significant discrepancy in all measured partial cross sections at $\sqrt{s_{NN}} = 200$ GeV.

In particular, the data reported [10] do not show an increase of the cross section with increase of energy from $\sqrt{s_{NN}} = 130$ GeV to $\sqrt{s_{NN}} = 200$ GeV expected in **all** theoretical calculations. This is puzzling since the energy dependence of the cross section of ρ photoproduction in UPC of heavy nuclei comes practically solely from the increase of the photon flux which is essentially model independent and, hence, very similar in all calculations. The cross section $\gamma + p \to \rho + p$ is a weak function of energy in the discussed energy interval and $\gamma + A \to \rho + A$ is expected to be even weaker function of the incident energy due to blackness of the interaction with heavy nuclei at small impact parameters.

One can see from Table 2 that the measured cross sections at two energies are practically equal while the calculated ones increase by a factor ≈ 1.3, which coincides with an increase of the average photon flux.

In Fig. 3 we present our predictions for the rapidity distributions of the ρ photoproduction at energies $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.5$ TeV at LHC. The total cross sections are given in Table 3.

Since $d\sigma(\gamma A \to \rho A)/dt\,(t = 0)$ weakly depends on energy, combined studies at several energies and at different rapidities will provide a stringent test of the dynamics of the breakup of nuclei due to e.m. interactions in coherent vector meson photoproduction in the high energy heavy ion UPC.[2]

Note in passing that our cross sections larger than the StarLight results since the StarLight MC code [13] uses expression for the total cross section of hadron–nucleus interaction given by the classical mechanics which in the limit of large total *VN* cross sections and large *A* differs from the Gribov–Glauber model by a factor of about two. Recently one more update of predictions for the total coherent cross sections in heavy ion UPC at RHIC and LHC has been published [14]. The calculations in [14] are based on use of Color Glass Condensate (CGC) ideas and two versions of the color dipole model (IP-SAT [15] and IIM [16]). Comparing to the data of STAR at $\sqrt{s_{NN}} = 200$ GeV the authors found that IP-SAT model gives a larger cross section of ρ photoproduction but the result with IIM model appears to be close to that of the STAR experiment. So, cross section at the LHC energies predicted with this model are considered by the authors as preferable. However, as we show in this Letter, the STAR measurements at $\sqrt{s_{NN}} = 200$ GeV give the cross sections practically equal to cross sections at $\sqrt{s_{NN}} = 130$ GeV, and this disagrees with the energy dependence, dictated by the increase of the photon flux with increase of $\sqrt{s_{NN}}$. As a result, the

[2] It is worth noting that recent ALICE ZDC measurements of neutrons from the electromagnetic dissociation of nuclei in the UPC at $\sqrt{s_{NN}} = 2.76$ TeV [11] are in nice agreement with predictions [12].

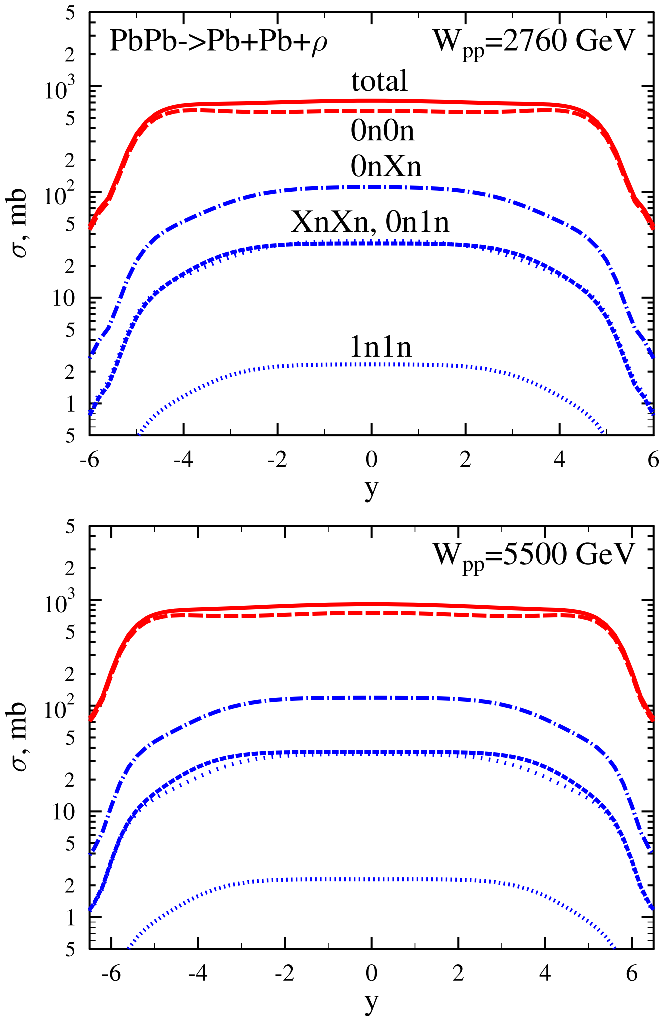

Fig. 3. Calculated rapidity distributions for different channels in ρ photoproduction in lead–lead UPC at LHC.

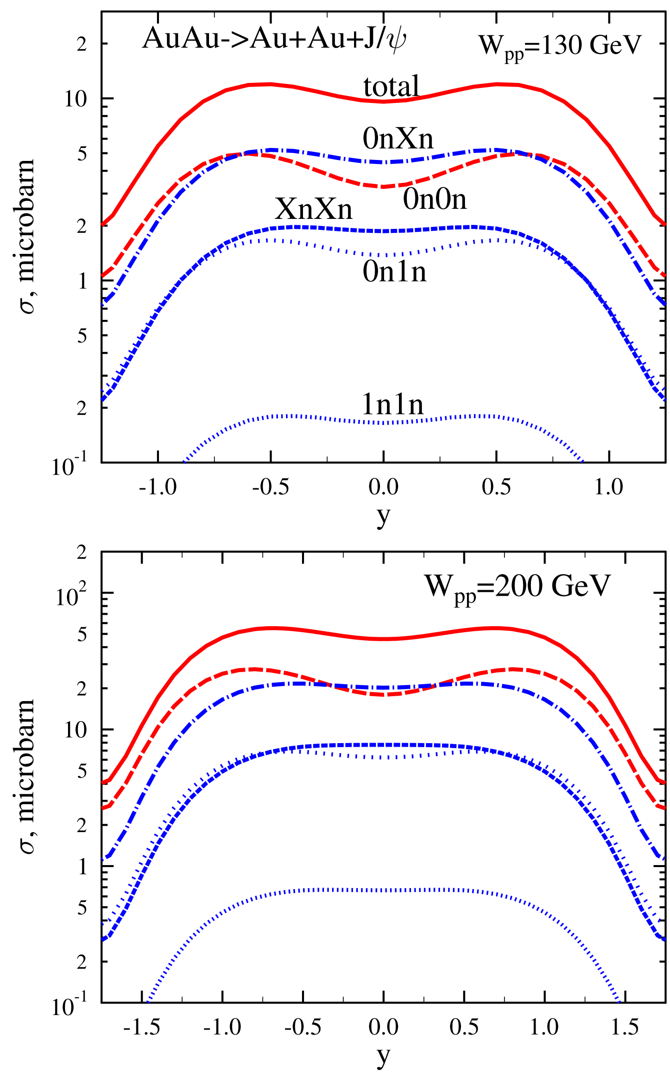

Fig. 4. Calculated rapidity distributions for different channels in J/ψ photoproduction in gold–gold UPC at RHIC.

cross sections of ρ photoproduction in UPC at LHC, predicted in [14], appeared to be smaller than our. Note in passing that the color dipole models are usually used for description of the hard interactions. A rational to apply such a model for the description of the soft process of the ρ meson exclusive photoproduction is not clear, as opposed to the use of the (generalized) vector dominance model which is theoretically well justified in this case.

3. J/ψ production

The coherent production of J/ψ in UPC is one of the direct ways of probing the pattern of the interaction of small color dipoles of average transverse size ~ 0.2–0.25 fm [17]. Due to their small size, the dominant mechanism of coupling of the $c\bar{c}$ to the nucleon is through a two gluon attachment which forms a start of the gluon ladder. In the dipole approximation the cross section of $\gamma + T \to J/\psi + T$ process can be calculated in the leading order of PQCD. In the approximation when the Fermi motion of the quarks in J/ψ is neglected one finds [18,19]

$$\frac{d\sigma_{\gamma T\to J/\psi T}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{em}M^5_{J/\psi}}\left[\alpha_s(\mu^2)xG_T(x,\mu^2)\right]^2. \qquad (6)$$

Here Γ_{ee} is the width of the leptonic decay of J/ψ and $G_T(x,\mu^2)$ is the density of gluons with fraction $x = \frac{M^2_{J/\psi}}{s_{\gamma T}}$ of momentum of the target ($s_{\gamma T}$ is the invariant energy for γ–T scattering), and μ^2 is the scale which we choose to be $\mu^2 = \frac{M^2_{J/\psi}}{4}$. Applying Eq. (6) to the proton and nucleus target, one can write the cross section for the photoproduction of J/ψ off the nucleus in the form

$$\sigma_{\gamma A\to J/\psi A}(\omega) = \frac{d\sigma_{\gamma N\to J/\psi N}(\omega, t_{\min})}{dt}\left[\frac{G_A(x,\mu^2)}{AG_N(x,\mu^2)}\right]^2 \times \int_{-\infty}^{t_{\min}} dt \left|\int d^2b\, dz\, e^{i\vec{q}_\perp\cdot\vec{b}} e^{-q_\parallel z}\rho(\vec{b},z)\right|^2. \qquad (7)$$

The key feature of the photoproduction of the hidden heavy flavor vector mesons off heavy nuclei is the gluon nuclear shadowing which is characterized by the ratio of the nuclear gluon density distribution $G_A(x,\mu^2)$ to the proton gluon distribution $G_N(x,\mu^2)$.

The G_A/G_N ratio can be calculated within the theory of leading twist nuclear shadowing [20] (see [21] for details of the model and references) developed on the base of the Gribov theory of inelastic shadowing, Collins's factorization theorem for hard diffraction and the DGLAP evolution equations. This model uses, as an input, nucleon diffractive parton distribution functions (pdfs) which are available both in the NLO and in LO. In our study we select LO

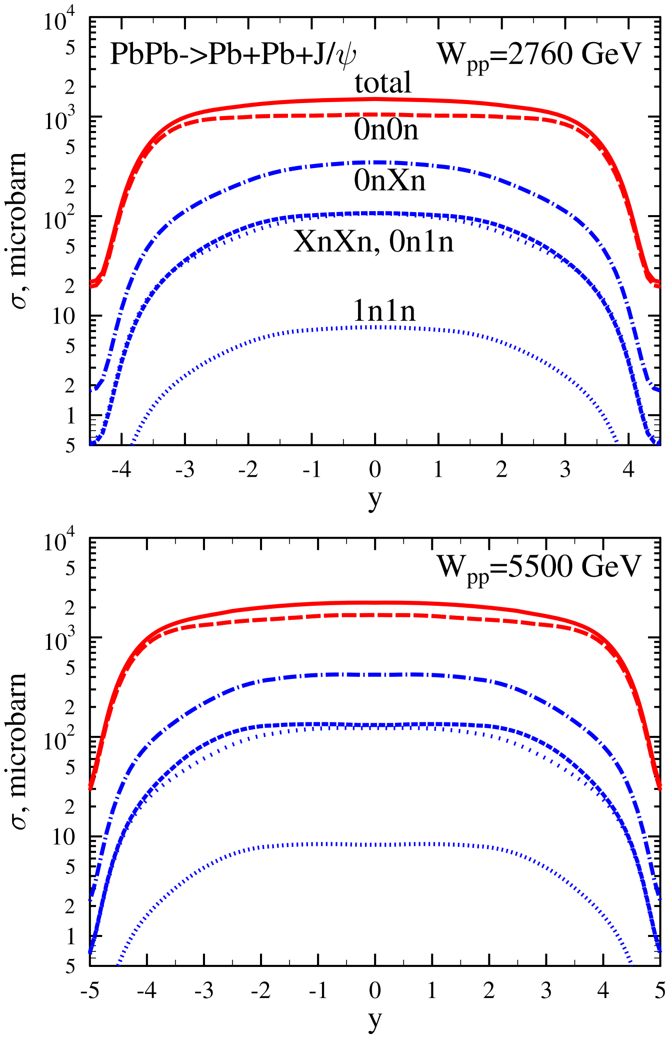

Fig. 5. Calculated rapidity distributions for different channels in J/ψ photoproduction in lead–lead UPC at LHC.

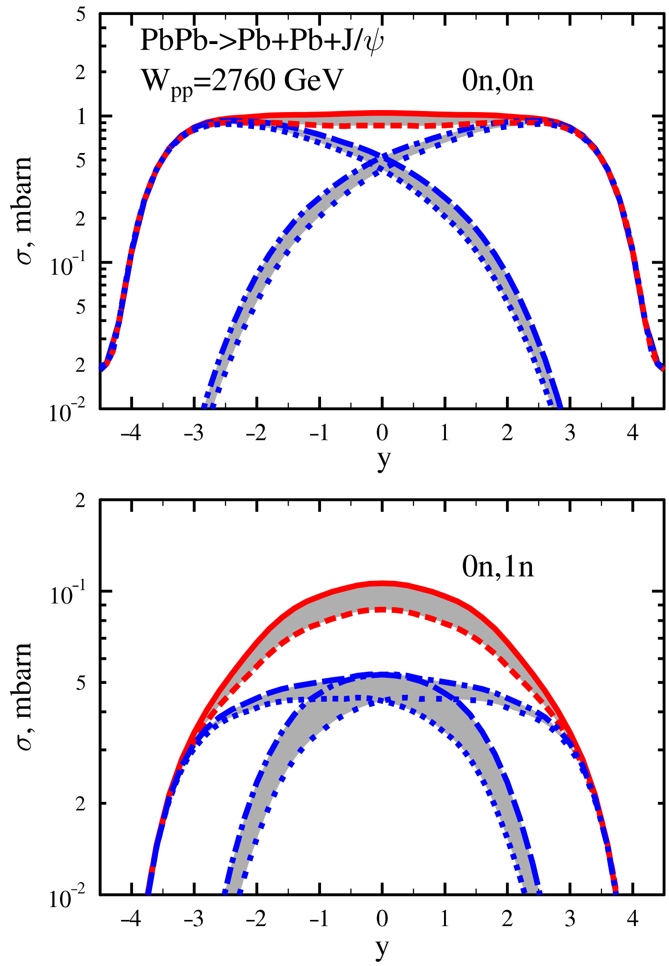

Fig. 6. Calculated rapidity distributions for $(0n0n)$ and $(0n1n)$ channels in J/ψ photoproduction in PbPb UPC at $\sqrt{s_{NN}} = 2.76$ TeV. Shaded area shows uncertainty in accounting for the gluon nuclear shadowing. Left and right curves demonstrate one-side contributions.

nucleon pdfs which give a reasonable description of the energy dependence of the elementary cross section. Also, we use the LO gluon density in proton $G_N(x, \mu^2 = 2.5\ \text{GeV}^2)$, recently found [22] by the Durham–PNPI group in the range $10^{-4} < x < 10^{-2}$ from the fit of cross section, given by Eq. (6), to the HERA experimental data on $\gamma + p \to J/\psi + p$.

The results of calculations are presented in Figs. 4–6 and in Table 4. Since the estimate of shadowing is based on the parton distribution functions determined from the data, there is some uncertainty related to the experimental errors. In Fig. 6 we show how this uncertainty influence our predictions for the cross sections. Besides, there are some model uncertainties in used approach. Since Eq. (6) is valid in the leading order PQCD approximation we find it consistent to use in calculation of the LT gluon shadowing the LO gluon density in proton and LO diffractive pdfs. We compared the gluon shadowing obtained in our calculations with numbers which one can get using other LO gluon distributions. In particular we found that at $x = 0.001$ use of the MRST08LO will result in smaller shadowing by a factor 1.3–1.5 and CTEQ6L by a factor about 1.7. Note, that neither MRST08LO nor CTEQ6L can reproduce the energy dependence of the cross section of J/ψ photoproduction off proton. Also there is an uncertainty related to the choice of the hard scale. We have used $\mu^2 = 2.5\ \text{GeV}^2$ while the increase of this scale up to $\mu^2 = 3.5$–$4\ \text{GeV}^2$ is suggested by some

Table 4
Cross sections of J/ψ photoproduction in gold–gold UPC at RHIC and PbPb UPC at LHC calculated in the leading order LT shadowing model.

$\sqrt{s_{NN}}$	AuAu 130 GeV	AuAu 200 GeV	PbPb 2760 GeV	PbPb 5500 GeV
σ_{tot}, µb	24	137	9281	15 836
σ_{0n0n}, µb	10.1	68	7044	12 376
σ_{0nXn}, µb	10.2	52	1689	2584
σ_{XnXn}, µb	3.7	17	548	876
σ_{0n1n}, µb	3.25	16.8	512	739
σ_{1n1n}, µb	0.35	1.6	39	54

analyses. This would result in a decrease of the shadowing. So, our predictions are an upper end of possible shadowing effect for the J/ψ production within the LT gluon shadowing mechanism.

It is worth noting that up to now the only measurement of the J/ψ photoproduction in the UPC of heavy ions has been performed by the PHENIX Collaboration at $\sqrt{s_{NN}} = 200$ GeV at RHIC [23]. The cross section of $J/\psi + Xn$ production which included both coherent and incoherent events was found to be 76 ± 35 µb at midrapidity of the J/ψ $(y = 0)$. It can be compared with our value 48–50 µb obtained by summing cross sections of the $(0n, Xn)$, (Xn, Xn) channels and our estimate given in [24] for the incoherent process of photoproduction accompanied by neutron decay of the target nucleus in gold–gold UPC at RHIC.

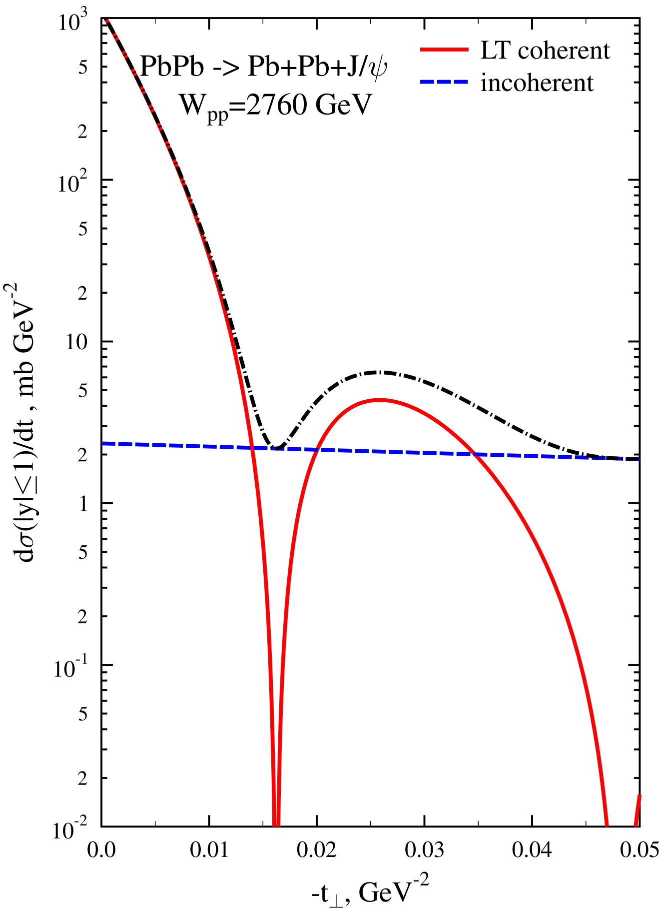

Fig. 7. Distributions on the transverse momentum transfer in coherent and incoherent J/ψ photoproduction in PbPb UPC at $\sqrt{s_{NN}} = 2.76$ TeV.

Our predictions for the cross section of J/ψ photoproduction at LHC are smaller than the ones of StarLight and [14]. This is due to the accounting for the leading twist gluon shadowing which was not included in StarLight. The calculation of [14] included only higher twist shadowing in the color dipole model which is known to be much smaller than the leading twist shadowing in a wide range of x, see [25] for detailed comparison of the shadowing in the leading twist approximation and in the color dipole model.

As we mentioned before, the coherent scattering is determined by the sum of lower and higher energy contributions. This makes it difficult to separate these contributions at any rapidity, except for $y = 0$ where they are equal. One would like to determine the coherent cross section in as wide range of γA energies as possible, with higher energies allowing to probe the gluon density at lower x. For example, in PbPb UPC at $\sqrt{s_{NN}} = 2.76$ TeV and rapidity of produced J/ψ $y \approx 0$, the corresponding $x \approx 10^{-3}$, while, if one could extract contribution due to the higher energy photon to the cross section of production J/ψ with $y \approx 2$, it would be possible to extract gluon density at $x \approx 1.5 \cdot 10^{-4}$. However, due to the rapid drop of the flux of photons with higher energy, this contribution is significantly lower than the cross section from the low energy photons (see Fig. 6) which is determined by the gluon density at $x \approx 10^{-2}$. It was argued in [2] that measurement of the process of photoproduction with additional photon exchange enhances the contribution from the higher energy photons. We would like to emphasize that measuring at the same $\sqrt{s_{NN}}$ for two or more channels at a fixed J/ψ rapidity, for example $(0n1n)$ and $(0n0n)$ or any other channels, one can easily separate high and low energy contributions, provided that the fluxes of photons modified by accounting for the neutron emission are calculated with reasonable accuracy. These fluxes and the whole procedure can be tested by studying the ρ photoproduction in PbPb UPC since the cross section of ρ photoproduction off nuclear target weakly depends on energy and can be calculated in the Glauber model. Also we would like to note that contribution of the incoherent photoproduction in the UPC at LHC to the coherent cross section with detection of neutrons will be very small if one uses the low p_t cut on the transverse momentum of the produced J/ψ (see Fig. 7).

If the measurements are done at two energies $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 5.52$ TeV a simultaneous analysis of two data sets will allow to extend model independent determination of nuclear ratio to x at least a factor of two smaller than in $y = 0$ at $\sqrt{s} = 5.52$ TeV.

4. Conclusions

The studies of the J/ψ production in the heavy ion UPC at the LHC will allow to measure coherent photoproduction cross section down to $x \approx 10^{-4}$ using the channels without nucleus breakup which dominate at the LHC energies. A crosscheck will be possible using channels with dissociation of nuclei. However, this would require sorting out situation with the ρ meson production at the RHIC energies as well as further experimental studies at RHIC and LHC. Further theoretical studies are also necessary.

Note added in proof

After this Letter was put on the archive (arXiv:1109.0737 [hep-ph]) and was accepted for publication in Physics Letters B the STAR Collaboration published [26] the revised version of their results [9] for the ρ photoproduction in UPC AuAu collisions at $\sqrt{s} = 62.4$ GeV. The final values of the cross sections are reduced by a factor 1.5 that with account for the large errors in the values of cross sections at $\sqrt{s} = 130$ GeV somewhat improves the situation with energy dependence of cross section, see Fig. 4 in [26] where the revised data are compared with results of calculations in different models mentioned above and in particular with the calculations of this Letter. Still several questions about consistency of the STAR data and theoretical calculations have to be resolved and the data from LHC will be undoubtedly useful.

Acknowledgements

We would like to thank D.G. d'Enterria, L. Frankfurt, Yu. Gorbunov, V. Guzey, S. Klein, J. Nystrand for the discussions. This work was supported in part by the US DOE Contract Number DE-FG02-93ER40771 and by Program of Fundamental Researches at LHC of Russian Academy of Science.

References

[1] A.J. Baltz, G. Baur, D. d'Enterria, et al., Phys. Rep. 458 (2008) 1.
[2] A.J. Baltz, S.R. Klein, J. Nystrand, Phys. Rev. Lett. 89 (2002) 012301.
[3] L. Frankfurt, M. Strikman, M. Zhalov, Phys. Lett. B 537 (2002) 51.
[4] L. Frankfurt, M. Strikman, M. Zhalov, Phys. Rev. C 67 (2003) 034901.
[5] C. Adler, et al., STAR Collaboration, Phys. Rev. Lett. 89 (2002) 272302.
[6] T.H. Bauer, R.D. Spital, D.R. Yennie, F.M. Pipkin, Rev. Mod. Phys. 50 (1978) 261.
[7] A. Donnachie, P.V. Landshoff, Phys. Lett. B 478 (2000) 146.
[8] S.R. Klein, J. Nystrand, Phys. Rev. Lett. 84 (2000) 2330.
[9] G. Agakishiev, et al., STAR Collaboration, arXiv:1107.4630v1 [nucl-ex].
[10] B.I. Abelev, et al., STAR Collaboration, Phys. Rev. C 77 (2008) 034910.
[11] ALICE Collaboration, arXiv:1107.1985 [nucl-ex].
[12] I.A. Pshenichnov, E.V. Karpechev, A.B. Kurepin, I.N. Mishustin, Phys. Atom. Nucl. 74 (2011) 139.
[13] S. Klein, J. Nystrand, Phys. Rev. C 60 (1999) 014903, http://sourceforge.net/projects/upcstarlight.
[14] V.P. Goncalves, M.V.T. Machado, Phys. Rev. C 84 (2011) 011902.
[15] H. Kowalski, T. Lappi, R. Venugopalan, Phys. Rev. Lett. 100 (2008) 022303.
[16] E. Iancu, K. Itakura, S. Munier, Phys. Lett. B 590 (2004) 199.
[17] L. Frankfurt, M. Strikman, M. Zhalov, Phys. Rev. Lett. 102 (2009) 232001;
L. Frankfurt, V. Guzey, M. Strikman, M. Zhalov, JHEP 0308 (2003) 043;
L. Frankfurt, L. Gerland, M. Strikman, M. Zhalov, Phys. Rev. C 68 (2003) 044602;

L. Frankfurt, M. Strikman, M. Zhalov, Phys. Lett. B 540 (2002) 220.
[18] M.G. Ryskin, Z. Phys. C 57 (1993) 89.
[19] S.J. Brodsky, L. Frankfurt, J.F. Gunion, A.H. Mueller, M. Strikman, Phys. Rev. D 50 (1994) 3134.
[20] L. Frankfurt, M. Strikman, Eur. Phys. J. A 5 (1999) 293.
[21] L. Frankfurt, V. Guzey, M. Strikman, arXiv:1106.2091 [hep-ph].
[22] A.D. Martin, C. Nockles, M.G. Ryskin, T. Teubner, Phys. Lett. B 662 (2008) 252.
[23] D.G. d'Enterria, arXiv:nucl-ex/0601001;
S. Afanasiev, et al., PHENIX Collaboration, Phys. Lett. B 679 (2009) 321.
[24] M. Strikman, M. Tverskoy, M. Zhalov, Phys. Lett. B 626 (2005) 72.
[25] L. Frankfurt, V. Guzey, M. McDermott, M. Strikman, JHEP 0202 (2002) 027.
[26] G. Agakishiev, et al., STAR Collaboration, Phys. Rev. C 85 (2012) 014910.