Peripheral heavy ion collisions as a probe of the nuclear gluon distribution

V.P. Gonçalves [1,†] and C. A. Bertulani [2,⋆]

[1] *Instituto de Física e Matemática, Universidade Federal de Pelotas*
Caixa Postal 354, CEP 96010-090, Pelotas, RS, BRAZIL

[2] *Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824-1321 - USA*

Abstract

At high energies a quark-gluon plasma is expected to be formed in heavy ion collisions at RHIC and LHC. The theoretical description of these processes is directly associated to a complete knowledge of the details of medium effects in the nuclear gluon distribution. In this paper we analyze the possibility to constraint the behavior of this distribution considering peripheral heavy ion collisions. We reanalyze the photoproduction of heavy quarks for the deduction of the in-medium gluon distribution using three current parameterizations for this parton distribution. Moreover, we show that the elastic photoproduction of vector mesons is a potential process to probe the nuclear gluon distribution.

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† E-mail: barros@ufpel.tche.br

⋆ E-mail: bertulani@nscl.msu.edu

I. INTRODUCTION

One of main predictions of QCD is the transition from the confined/chirally broken phase to the deconfined/chirally symmetric state of quasi-free quarks and gluons, the so-called quark-gluon plasma (QGP). Recently the heavy ion collisions have provided strong evidence for the formation of a QGP [1], with the first results of RHIC marking the beginning of a collider era in the experiments with relativistic heavy ions, as well as the era of detailed studies of the characteristics of the QGP. Currently, distinct models associated to different assumptions describe reasonably the experimental data [2], with the main uncertainty present in these analysis directly connected with the poor knowledge of the initial conditions of the heavy ion collisions. Theoretically, the early evolution of these nuclear collisions is governed by the dominant role of gluons [3], due to their large interaction probability and the large gluonic component in the initial nuclear wave functions. This leads to a "hot gluon scenario", in which the large number of initially produced energetic partons create a high temperature, high density plasma of predominantly hot gluons and a considerably number of quarks. Such extreme condition is expected to significantly influence QGP signals and should modify the hard probes produced at early times of the heavy ion collision. Consequently, a systematic measurement of the nuclear gluon distribution is of fundamental interest in understanding of the parton structure of nuclei and to determine the initial conditions of the QGP. Other important motivation for the determination of the nuclear gluon distributions is that the high density effects expected to occur in the high energy limit of QCD should be manifest in the modification of the gluon dynamics.

At small x and/or large A we expect the transition of the regime described by the linear dynamics (DGLAP, BFKL) (For a review, see e.g. Ref. [4]), where only the parton emissions are considered, to a new regime where the physical process of recombination of partons becomes important in the parton cascade and the evolution is given by a nonlinear evolution equation. In this regime a Color Glass Condensate (CGC) is expected to be formed [5], being characterized by the limitation on the maximum phase-space parton density that can be reached in the hadron/nuclear wavefunction (parton saturation) and very high values of the QCD field strength $F_{\mu\nu} \approx 1/\sqrt{\alpha_s}$ [6]. In this case, the number of gluons per unit phase space volume practically saturates and at large densities grows only very slowly (logarithmically) as a function of the energy [7]. This implies a large modification of the gluon distribution if compared with the predictions of the linear dynamics, which is amplified in nuclear processes [8–11].

Other medium effects are also expected to be present in the nuclear gluon distribution at large values of x: the antishadowing ($0.1 < x < 0.3$), the EMC effect ($0.3 < x < 0.7$) and the Fermi motion ($x > 0.7$) [12,13]. The presence of these effects is induced from the experimental data for the nuclear structure function which determines the behavior of the nuclear quark distributions and the use of the momentum sum rule as constraint. Experimentally, the behavior of the nuclear gluon distribution is indirectly determined in the lepton-nucleus processes in a small kinematic range of the fixed target experiments, with the behavior at small x (high energy) completely undefined. This situation should be improved in the future with the electron-nucleus colliders at HERA and RHIC [14,15], which probably could determine whether parton distributions saturate. However, until these colliders become reality we need to consider alternative searches in the current accelerators which allow us to constraint the nuclear gluon distribution. Here, we analyze the possibility of using peripheral heavy ion collisions as a photonuclear collider and therefore to determine the behavior of the gluon distribution.

In ultra-peripheral relativistic heavy-ion collisions the ions do not interact directly with each other and move essentially undisturbed along the beam direction. The only possible interaction is due to the long range electromagnetic interaction and diffractive processes [For a review see, e. g. Ref. [16]]. Due to the coherent action of all the protons in the nucleus, the electromagnetic field is very strong and the resulting flux of equivalent photons is large. A photon stemming from the electromagnetic field of one of the two colliding nuclei can penetrate into the other nucleus and interact with one or more of its hadrons, giving rise to photon-nucleus collisions to an energy region hitherto unexplored experimentally. For example, the interaction of quasireal photons with protons has been studied extensively at the electron-proton collider at HERA, with $\sqrt{s} = 300$ GeV. The obtained γp center of mass energies extends up to $W_{\gamma p} \approx 200$ GeV, an order of magnitude larger than those reached by fixed target experiments. Due to the larger number of photons coming from one of the colliding nuclei in heavy ion collisions similar and more detailed studies will be possible in these collisions, with $W_{\gamma N}$ reaching 950 GeV for the Large Hadron Collider (LHC) operating in its heavy ion mode.

When a very hard photon from one equivalent swarm of photons penetrates the other nucleus it is able to resolve the partonic structure of the nucleus and to interact with the quarks and gluons. One of the basic process which can occur in the high energy limit is the photon-gluon fusion leading to the production of a quark pair. The main characteristic of this process is that the cross section is directly proportional to the nuclear gluon distribution. The analysis of this process in peripheral heavy ion collisions has been proposed many years ago [17] and improved in the Refs. [18,19] [For a review, see Ref. [20]]. Here we reanalyze the charm photoproduction as a way to estimate the medium effects in xG_A in the full kinematic region. We consider as input three distinct parameterizations of the nuclear gluon distribution. First, we consider the possibility that the nuclear gluon distribution is not modified by medium effects, i.e., $xG_A(x,Q^2) = A \times xG_N(x,Q^2)$, with the nucleon gluon distribution (xG_N) given by the GRV parameterization [21]. Moreover, we consider that $xG_A(x,Q^2) = R_G \times xG_N(x,Q^2)$, where R_G parameterizes the medium effects as proposed by Eskola, Kolhinen and Salgado (EKS) [22]. The main shortcoming of these parameterizations is that these are based on the DGLAP evolution equations which are not valid in the small x regime, where the parton saturation effects should be considered. In order to analyze the sensitivity of peripheral heavy ion collisions to these effects we consider as input the parameterization proposed by Ayala Filho and Gonçalves (AG) [23] which improves the EKS parameterization to include the high density effects. In this paper we analyze the mass and rapidity distributions of the cross sections for peripheral Pb + Pb collisions at LHC energies, where the experimental analysis of this process should be possible. We conclude that the distinction between the EKS and AG predictions for the mass distribution is a factor 1.25 in the small mass region. For the rapidity distribution the difference between the predictions is larger, which should allow to discriminate between the results.

One shortcoming of the analysis of photoproduction of heavy quarks in peripheral heavy ion collisions to constraint the nuclear gluon distribution is the linear dependence of the cross section with this distribution. This implies that only experimental data with a large statistics and small error will allow to discriminate the medium effects in the nuclear gluon distribution. Consequently, it is very important to analyze other possible processes which have a stronger dependence in xG_A. Here we propose the study of the elastic photoproduction of vector mesons in peripheral heavy ion collisions as a probe of the behavior of the nuclear gluon distribution. This process has been largely studied in *ep* collisions at HERA, with the perturbative QCD predictions describing successfully the experimental data [4], considering a quadratic dependence of the cross section with the nucleon gluon distribution. We extend the formalism used in *ep* collisions to peripheral heavy ion collisions, obtaining that the cross section is proportional to the nuclear gluon distribution squared, which amplifies the distinctions associated to medium effects and implies large differences in the rapidity distribution. Considering the three distinct parameterizations for the nuclear gluon distribution described above, we calculate the total cross section for this process and rapidity distributions for RHIC and LHC energies. Our results indicate that this process could be used to probe the nuclear gluon distribution in all kinematic regions, i.e., this process will be able to estimate the magnitude of the EMC, antishadowing and high density effects.

This paper is organized as follows. In next section we present a brief review of the peripheral heavy ion collisions and the main formulae to describe the photonuclear process in these collisions. We analyze the photoproduction of heavy quarks in peripheral heavy ion collisions and present our predictions for the mass and rapidity distributions. Moreover, we briefly discuss the contribution of the resolved component of the photon for the photoproduction of charm quarks. In Section 3 we consider the elastic photoproduction of vector mesons and analyze the total cross sections and rapidity distributions for RHIC and

LHC energies. We also present a comparison between this process and the photoproduction of heavy quarks, which demonstrates that the elastic photoproduction of vector mesons in peripheral heavy ion collisions is a potential process to probe the nuclear gluon distribution. Finally, in Section 4, we present our main conclusions.

II. PHOTOPRODUCTION OF HEAVY QUARKS

At high energies the dominant process occurring when the photon probes the structure of the nucleus is the photon-gluon fusion producing a quark pair. For heavy quarks the photoproduction can be described using perturbative QCD, with the cross section given in terms of the convolution between the elementary cross section for the sub-process $\gamma g \rightarrow Q\overline{Q}$ and the probability of finding a gluon inside the nucleus, i.e., the nuclear gluon distribution. Basically, the cross section for $c\overline{c}$ photoproduction is given by

$$\sigma_{\gamma g \rightarrow c\overline{c}}(s) = \int_{2m_c}^{\sqrt{s}} dM_{c\overline{c}} \frac{d\sigma_{c\overline{c}}}{dM_{c\overline{c}}} \, g_A(x,\mu) \;, \tag{1}$$

where $d\sigma_{c\overline{c}}/dM_{c\overline{c}}$ is calculable perturbatively, $M_{c\overline{c}}$ is the invariant mass of the $c\overline{c}$ pair with $M^2_{c\overline{c}} = \hat{s} = xs$, s is the squared CM energy of the γA system, $g_A(x,\mu)$ is the gluon density inside the nuclear medium, μ is the factorization scale ($\mu = \sqrt{M^2_{c\overline{c}}}$), and m_c is the charm quark mass (In this paper we assume that $m_c = 1.45$ GeV). Moreover, the differential cross section is [24]

$$\frac{d\sigma_{\gamma g \rightarrow c\overline{c}}}{dM_{c\overline{c}}} = \frac{4\pi\alpha\alpha_s e_c^2}{M^2_{c\overline{c}}}\left[(1+\epsilon+\frac{1}{2}\epsilon^2)\ln(\frac{1+\sqrt{1-\epsilon}}{1-\sqrt{1-\epsilon}}) - (1+\epsilon)\sqrt{1-\epsilon}\right] \;, \tag{2}$$

where e_c is the charm charge and $\epsilon = 4m_c^2/M^2_{c\overline{c}}$. From the above expression, we verify that the cross section is directly proportional to the nuclear gluon distribution, which implies the possibility to constraint its behavior from experimental results for photoproduction of heavy quarks.

Throughout this publication we use the Born expression for the elementary photon-gluon cross section [Eq. (2)]. QCD corrections to the Born cross section will not be considered here, although these corrections modify the normalization of the cross section by a factor of two. This is justified by the fact that we are interested in the relative difference between the predictions of the distinct nuclear gluon distributions, which should be not modified by the next-to-leading-order corrections.

In Fig. 1 we present the energy dependence of the photoproduction cross section. We focus our analysis on charm photoproduction instead of bottom photoproduction, since in this process smaller values of x are probed. We verify that different nuclear gluon distributions imply distinct behaviors for the cross section, with the difference between the predictions increasing with the energy. This is associated to the fact that at high energies we are probing the small x behavior of xG_A, since $x \propto M_{c\bar{c}}/s$, where $M_{c\bar{c}}$ is the invariant mass of the photon-gluon system. Currently, only the region of small center of mass energy has been analyzed by the fixed target electron-nucleus experiments, not allowing a good constraint on medium effects present in the nuclear gluon distribution. Such situation should be improved in the future with electron-nucleus colliders at HERA and RHIC [12,15].

Another possibility to study photoproduction of heavy quarks at large center of mass energies is to consider peripheral heavy ion collisions [17–19]. In this process the large number of photons coming from one of the colliding nuclei in heavy ion collisions will allow to study photoproduction, with $W_{\gamma N}$ reaching 950 GeV for the LHC. To determine the photoproduction of heavy quarks in peripheral heavy ion collisions the elementary photon-gluon cross section has to be convoluted with the photon energy distribution and the gluon distribution inside the nucleus:

$$\sigma(AA \rightarrow XXQ\overline{Q}) = n(\omega) \otimes \sigma_{\gamma g \rightarrow Q\overline{Q}} \otimes xG_A(x, Q^2) \ . \tag{3}$$

where the photon energy distribution $n(\omega)$ is calculated within the equivalent photon or Fermi-Weizsäcker-Williams (FWW) approximation. In this approximation [16] the cross section for a photonuclear reaction in a relativistic heavy ion collision is given by

$$\sigma = \int \frac{d\omega}{\omega} n(\omega)\, \sigma_{\gamma A}(\omega) \ , \tag{4}$$

where $\sigma_{\gamma A}$ is the on-shell elementary photonuclear cross section. The appropriate number of equivalent photons, $n(\omega)$, including nuclear absorption at small impact parameters, b, is given by [25]

$$n(\omega) = \frac{2Z^2\alpha\omega^2}{\pi\gamma^2}\int_0^\infty db\, b\, \left[K_1^2(\xi) + K_0^2(\xi)/\gamma^2\right] \exp\left\{-\sigma_{NN}\int_{-\infty}^{\infty} dz' \int d^3r\rho(r)\rho(|\mathbf{r}' - \mathbf{r}|)\right\}\ , \quad (5)$$

where $\mathbf{r}' = (b, 0, z')$, $\xi = \omega b/\gamma$, σ_{NN} is the nucleon-nucleon cross section (we use $\sigma_{NN} = 40$ mb), and $\rho(r)$ is the nuclear density. For Pb we use a Woods-Saxon density distribution

$$\rho(r) = \frac{\rho_0}{1 + \exp\left[(r-c)/a\right]}\ , \quad (6)$$

with parameters $c = 6.63$ fm, $a = 0.549$ fm, and $\rho_0 = 0.16$ fm^{-3}. For $b \ll 2c$ the exponential function in Eq. (5) can be replaced by zero, i.e., for central, or almost central collisions, the nuclei will surely fragment and the coherent exchange of virtual photons among them is not part of the main physics involved.

Before we present our results, it is interesting for our studies to determine the values of x which will be probe in peripheral heavy ion collisions. The Bjorken x variable is given by $x = (M/2p)e^{-y}$, where M is the invariant mass of the photon-gluon system and y the center of momentum rapidity. For Pb + Pb collisions at LHC energies the nucleon momentum is equal to $p = 3000$ GeV; hence $x = (M/6000\,\mathrm{GeV})e^{-y}$. Therefore, the region of small mass and large rapidities probes directly the small x behavior of the nuclear gluon distribution. This demonstrates that peripheral heavy ion collisions at LHC represents a very good tool to determine the behavior of the gluon distribution in a nuclear medium, and in particular the low x regime. Conversely, the region of large mass and small rapidities is directly associated to the region where the EMC and antishadowing effects are expected to be present. Similarly, for RHIC energies ($p = 100$ GeV) the cross section will probe the region of medium and large values of x ($x > 10^{-2}$). For this kinematical region, the EKS and AG parameterizations are identical, which implies that the photoproduction of heavy quarks in peripheral heavy ion collisions at RHIC does not allows to constraint the high density effects. However, the study of this process at RHIC will be very interesting to determine the presence or not of the antishadowing and EMC effect in the nuclear gluon distribution.

Here we restrict our considerations to peripheral Pb + Pb collisions at LHC energies, with the Lorentz contraction factor set equal to $\gamma = 3000$, in the lab system. At the reference system of one of the nuclei, the appropriate Lorentz factor is $\gamma_c = 2\gamma^2 - 1$. In this paper we assume that we know from which nucleus the gluon originates, although in practice we cannot distinguish to which nucleus the gluon belongs. Our calculations assume that the photon is in the field of the nucleus coming from negative rapidity. If the photon is emitted by the target instead of the projectile, the resulting rapidity distribution will be a mirror image of our distributions around $y = 0$, implying that the total rapidity distribution is the sum of the curves shown in our figures with its mirror images when both nuclei emit photons.

In Fig. 2 we present our results for the mass distribution in photoproduction of charm quarks in peripheral heavy ion collisions. We can see that the main difference between the predictions occur at small values of M, which is associated to the small x region. Basically, we have that the predictions of the EKS parameterization are a factor 1.25 larger than the AG prediction in this region, while the prediction of Glück, Reya and Vogt (GRV) is a factor 2.4 larger. This result is consistent with the fact that the main differences between the parameterizations of the nuclear gluon distribution occur at small x [23]. The difference between the predictions diminishes with the growth of the invariant mass, which implies that this distribution is not a good quantity to estimate the nuclear effects for medium and large x.

A better distribution to discriminate the behavior of the nuclear gluon distribution is the rapidity distribution, which is directly associated to the Bjorken x variable, as discussed above. The rapidity distribution is calculated considering that $d\sigma/dy = \omega d\sigma/d\omega$. In Fig. 3 we present our results for the rapidity distribution considering the three parameterizations of xG_A as input. We have that the region of small rapidities probes the region of large x, while for large y we directly discriminate the different predictions of xG_A for small x. Our results are coherent with this picture: as at large x the EKS and AG predictions are identical, this region allows to estimate $R_G = xG_A/(AxG_N)$ in the region of the antishadowing and

EMC effects; at large y the large difference between the parameterizations implies large modifications in the rapidity distribution, which should allow a clean experimental analysis.

A comment is in order here. In hard photon-hadron interactions the photon can behave as a pointlike particle in the so-called direct photon processes or it can act as a source of partons, which then scatter against partons in the hadron, in the resolved photon processes (For a recent review see Ref. [26]). Resolved interactions stem from the photon fluctuation to a quark-antiquark state or a more complex partonic state, which are embedded in the definition of the photon structure functions. Recently, the process of jet production in photoproduction has been search of studies of the partonic structure of the photon (See e.g. [4]), and the contribution of the resolved photon for the photoproduction of charm has been estimated [27]. Basically, these studies shown that the partonic structure of the photon is particularly important in some kinematic regions (for example, the region of large transverse momentum of the charm pair [27]). Consequently, it is important to analyze if this contribution modifies, for instance, our results for the rapidity distribution, which is strongly dependent of nuclear gluon distribution. In leading order, beyond the process of photon-gluon fusion considered above, charm production can occur also in resolved photon interactions, mainly through the process $gg \rightarrow c\overline{c}$. Therefore, we need to add in Eq. (3) the resolved contribution given by

$$\sigma_{res}(AA \rightarrow XXQ\overline{Q}) = n(\omega) \otimes x_\gamma G_\gamma(x_\gamma, Q^2) \otimes \sigma_{gg\rightarrow Q\overline{Q}} \otimes xG_A(x, Q^2) \ , \tag{7}$$

where x_γ denote the fraction of the photon momentum carried by its gluon component $x_\gamma G_\gamma$ and $\sigma_{gg\rightarrow Q\overline{Q}}$ the heavy quark production cross section first calculated in Ref. [28]. Since the resolved contribution should be the same for the three nuclear parton distributions, we only present in Fig. 4 the results obtained using the GRV parameterization for the nucleon. For the photon distribution we use the GRV photon parameterization [29], which predicts a strong growth of the photon gluon distribution at small x_γ. We can see that though this contribution be important in the photoproduction of heavy quarks, as shown in Ref. [27], it is small in the rapidity distribution of charm quarks produced in peripheral heavy ion collisions. Therefore, we believe that the inclusion of the resolved component of the photon does not is not relevant for the use of this process as a probe of the nuclear gluon distribution. Nevertheless, this subject deserves a further more detailed study.

Before to conclude this section it is important to salient that the potentiality of the photoproduction of quarks to probe the high density effects have been recently emphasized in Ref. [30], where the color glass condensate formalism was used to estimate the cross section and transverse momentum spectrum. The authors have verified that the cross section is sensitive to the saturation scale which characterizes the colored glass. Our results corroborate the conclusion that this process is sensitive to the high density effects and the agreement between the predictions is expected in the kinematic region in which the transverse momentum of the pair k_t is larger than the saturation scale Q_s. For $k_t < Q_s$ the collinear factorization used in this paper to calculate the cross sections must be generalized, similarly to Ref. [30].

III. ELASTIC PHOTOPRODUCTION OF VECTOR MESONS

The production of vector mesons at HERA has become a rich field of experimental and theoretical research [For a recent review see, e.g. Ref. [31]], mainly related with the question of whether perturbative QCD (pQCD) can provide an accurate description of the elastic photoproduction processes. At high energies the elastic photoproduction of vector mesons is a two-stage process: at first the photon fluctuates into the vector meson which then interacts with the target. For light vector mesons the latter process occurs similarly to the soft hadron-hadron interactions and can be interpreted within Regge phenomenology [32]. However, at large mass of the vector meson, for instance the mass of the J/Ψ meson, the process is hard and pQCD can be applied [33]. In this case the lifetime of the quark-antiquark fluctuation is large compared with the typical interaction time scale and the formation of the vector meson only occur after the interaction with the target. In pQCD the interaction of the $q\bar{q}$ pair is described by the exchange of a color singlet system of gluons (two gluons to leading order) and, contrary to the Regge approach, a steep rise of the vector meson cross section is predicted, driven by the gluon distribution in the proton. Measurements of the elastic photoproduction of J/Ψ mesons in ep processes has been obtained by the H1 and ZEUS collaborations for values of center of mass energy below 300 GeV, demonstrating the steep rise of the cross section predicted by pQCD. This result motivates the extension of the pQCD approach used in electron-proton collisions to photonuclear processes.

The procedure for calculating the forward differential cross section for photoproduction of a heavy vector meson in the color dipole approximation is straightforward. The calculation was performed some years ago to leading logarithmic approximation, assuming the produced vector-meson quarkonium system to be nonrelativistic [33] and improved in distinct aspects [34]. To lowest order the $\gamma A \rightarrow J/\Psi A$ amplitude can be factorized into the product of the $\gamma \rightarrow c\bar{c}$ transition, the scattering of the $c\bar{c}$ system on the nucleus via (colorless) two-gluon exchange, and finally the formation of the J/Ψ from the outgoing $c\bar{c}$ pair. The heavy meson mass $M_{J/\Psi}$ ensures that pQCD can be applied to photoproduction. The contribution of pQCD to the imaginary part of the $t = 0$ differential cross section of photoproduction of heavy vector mesons is given by [33]

$$\frac{d\sigma(\gamma A \rightarrow J/\Psi A)}{dt}|_{t=0} = \frac{\pi^3 \Gamma_{ee} M_{J/\Psi}^3}{48\alpha} \frac{\alpha_s^2(\overline{Q}^2)}{\overline{Q}^8} \times [xG_A(x, \overline{Q}^2)]^2 \,, \tag{8}$$

where xG_A is the nuclear gluon distribution, $x = 4\overline{Q}^2/W^2$ with W the center of mass energy and $\overline{Q}^2 = M_{J/\Psi}^2/4$. Moreover, Γ_{ee} is the leptonic decay width of the vector meson. The total cross section is obtained by integrating over the momentum transfer t,

$$\sigma(\gamma A \rightarrow J/\Psi A) = \frac{d\sigma(\gamma A \rightarrow J/\Psi A)}{dt}|_{t=0} \int_{t_{min}}^{\infty} dt \, |F(t)|^2 \,, \tag{9}$$

where $t_{min} = (M_{J/\Psi}^2/2\omega)^2$ and $F(t) = \int d^3r \; \rho(r) \; \exp(i\mathbf{q}\cdot\mathbf{r})$ is the nuclear form factor for the distribution given by Eq. (6).

A comment is in order here. Although some improvements of the expression (8) have been proposed in the literature [34], these modifications do not change the quadratic dependence on xG_A. As our goal in this paper is to analyze the use of this process to constraint the nuclear gluon distribution, we will restrict ourselves to the use of Eq. (8) in our studies.

The main characteristic of the elastic photoproduction of vector mesons is the quadratic dependence on the gluon distribution, which makes it an excellent probe of the behavior of this distribution. In Fig. 5 we show the energy dependence of the differential cross section [Eq. (8)], considering the three distinct nuclear gluon distributions discussed above. We have obtained larger differences between the predictions than obtained in photoproduction of heavy quarks, mainly at large values of energy. This result motivates experimental analysis of elastic J/Ψ photoproduction in photonuclear processes at high energies. Although the future electron ion colliders (HERA-A and eRHIC) should probe this kinematic region, here we show that this can also be done with peripheral heavy ion collisions.

Following similar steps used in photoproduction of heavy quarks, photons coming from one of the colliding nuclei may interact with the other. For elastic photoproduction of J/Ψ we consider that this photon decays into a $c\bar{c}$ pair which interacts with the nuclei by the two gluon exchange. After the interaction, this pair becomes the heavy quarkonium state. Consequently, the total cross section for J/Ψ production in peripheral heavy ion collisions is obtained by integrating the photonuclear cross section [Eq. (9)] over the photon spectrum [Eq. (5)], resulting

$$\sigma(AA \to AAJ/\Psi) = \int \frac{d\omega}{\omega}\, n(\omega) \frac{d\sigma(\gamma A \to J/\Psi A)}{dt}|_{t=0} \int_{t_{min}}^{\infty} dt\, |F(t)|^2 \,. \qquad (10)$$

In table 1 we present our predictions for the total cross section considering as input the distinct nuclear gluon distributions and LHC energies. We salient that although these number will be modified by the inclusion of higher order corrections for the cross section [34], the difference between the predictions should not be altered. We verify that due to the large number of equivalent photons and the large center of mass energies of the photon-nucleus system, the cross section for this process is large, which allows an experimental verification of our predictions. Also, in peripheral heavy ion collisions the multiplicity is small what might simplify the experimental analysis. Moreover, the difference between the predictions is significant. For RHIC energies, the cross section for this process is small and probably an experimental determination will be very hard.

In Figs. 6 and 7 we present our predictions for the rapidity distribution for J/Ψ production at RHIC and LHC energies. In this case, the final state rapidity is determined by

$$y = \frac{1}{2}\ln\frac{\omega}{\sqrt{|t_{min}|}} = \ln\frac{2\omega}{M_{J/\Psi}} \ . \tag{11}$$

Similarly to the heavy quark photoproduction, the large y region probes the behavior of xG_A at small x, while the region of small y probes medium values of x. We conclude that the rapidity distribution for elastic production of J/Ψ at RHIC allows to discriminate between the GRV and EKS prediction, with the AG prediction being almost identical to the latter. For LHC we have a large difference between the distributions, mainly in magnitude, which will allow to estimate the magnitude of the EMC, antishadowing and high density effects.

Finally, in Fig. 8 we compare the photoproduction of heavy quarks and the elastic photoproduction of J/Ψ in peripheral heavy ion collisions as a possible process to constraint the behavior of the nuclear gluon distribution. We present the rapidity distribution of the ratio

$$R[EKS/AG] \equiv \frac{d\sigma}{dy}[EKS]/\frac{d\sigma}{dy}[AG] \ , \tag{12}$$

where we consider the EKS and AG parameterizations as inputs of the rapidity distributions. We confirm that the analysis of the elastic photoproduction of J/Ψ at medium and large rapidities is a potential process to determinate the presence and estimate the magnitude of the high density effects.

IV. CONCLUSIONS

A systematic determination of gluon distribution is of fundamental interest in understanding the parton structure of nuclei. The nuclear gluon distribution is also of central importance in the field of minijet production that determines the total entropy produced at RHIC and higher energies. At the moment the behavior of this distribution is completely undetermined by the fixed target experiments, with a possible improvement in the future electron-nucleus colliders. However, as the date of construction and start of operation of these colliders is still in debate, we need to obtain alternative searches to estimate the medium effects in the nuclear gluon distribution. In this paper we have studied the possibility of using peripheral heavy ion collisions to constraint the behavior of xG_A. In these collisions the high flux of quasi-real photons from one of the nucleus provides a copious source of photoproduced reactions and large values for the cross sections are obtained. Initially, we have reanalyzed the photoproduction of heavy quarks in peripheral heavy ion collisions considering three possible parameterizations of xG_A which estimate the medium effects differently. Our results for the mass and rapidity distribution shown that at LHC energies this process is sensitive to the medium effects. However, as this process is linearly proportional to xG_A the differences are not large, which implies that only experimental measurements with large statistics will allow to discriminate between the behaviors. To improve this situation, in this paper we propose, for the first time, the study of the elastic photoproduction of vector mesons in peripheral heavy ion collisions as a potential process to probe the medium effects. As the cross section for the elastic vector meson production depends (quadratically) on the gluon distribution, it gives a unique opportunity to study the low x behavior of the gluons inside the nucleus. Our results demonstrate that the study of photoproduction of vector mesons determines the behavior of the nuclear gluon distribution in the full kinematic region, with the rapidity distribution allowing for the first time to estimate the EMC, antishadowing and high density effects.

We expect that our results contribute to motivate the studies of peripheral heavy ion collisions at RHIC and LHC since, as discussed in the introduction, the determination of the medium effects is fundamental for the derivation of reliable predictions of the initial conditions of the quark gluon plasma and its signatures.

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REFERENCES

[1] See, e.g., U. Heinz, Nuc. Phys. A **685**, 414 (2000).

[2] K. J. Eskola, Proceedings "Quark Matter 2001", Nuc. Phys. A (in press), hep-ph/0104058.

[3] See, e.g., K. Geiger., Phys. Rep. **258**, 237 (1995); X.-N Wang. Phys. Rep. **280**, 287 (1997).

[4] H. Abramowicz and A. C. Caldwell, Rev. Mod. Phys. **71**, 1275 (1999).

[5] E. Iancu, A. Leonidov and L. McLerran, Nuc. Phys. A **692**, 583 (2001).

[6] A. H. Mueller, Nucl. Phys. B **558**, 285 (1999).

[7] M. B. Gay Ducati and V. P. Gonçalves, Phys. Lett. B **502**, 92 (2001).

[8] A. L. Ayala, M. B. Gay Ducati and E. M. Levin. Nucl. Phys. **B493**, 305 (1997).

[9] E. Gotsman, E. Levin, U. Maor, L. McLerran and K. Tuchin, Nuc. Phys. A **683**, 383 (2000).

[10] M. B. Gay Ducati and V. P. Gonçalves, Phys. Lett. B **466**, 375 (1999).

[11] V. P. Gonçalves, Phys. Lett. B **495**, 303 (2000).

[12] M. Arneodo, Phys. Rep. **240**, 301 (1994).

[13] G. Piller and W. Weise, Phys. Rep. **330**, 1 (2000).

[14] M. Arneodo *et al.*, *Future Physics at HERA*. Proceedings of the Workshop 1995/1996. Edited by G. Ingelman *et al.*. hep-ph/9610423.

[15] R. Venugopalan, hep-ph/0102087.

[16] C. A. Bertulani and G. Baur, Phys. Rep. **163**, 299 (1988).

[17] Ch. Hofmann, G. Soff, A. Schafer and W. Greiner, Phys. Lett. B **262**, 210 (1991).

[18] N. Baron and G. Baur, Phys. Rev. C **48**, 1999 (1993).

[19] M. Greiner, M. Vidovic, Ch. Hofman, A. Schafer and G. Soff, Phys. Rev. C **51**, 911 (1995).

[20] F. Krauss, M. Greiner and G. Soff, Prog. Part. Nucl. Phys. **39**, 503 (1997).

[21] M. Glück, E. Reya and A. Vogt, Z. Phys. C **67**, 433 (1995).

[22] K. J. Eskola, V. J. Kolhinen and C. A. Salgado, Eur. Phys. J. C **9** , 61 (1999); K.J. Eskola, V. J. Kolhinen and P. V. Ruuskanen, Nucl. Phys. B **535**, 351 (1998).

[23] A.L. Ayala and V. P. Gonçalves, Eur. Phys. J. C **20**, 343 (2001).

[24] M. Glück and E. Reya, Phys. Lett. **79**, 453 (1978).

[25] C.A. Bertulani and A. Nathan, Nucl. Phys. A **554**, 158 (1993).

[26] R. Nisius, Phys. Rep. **332**, 165 (2000).

[27] S. Frixione et al., Phys. Lett. B **348**, 633 (1995); Nucl. Phys. B **454**, 3 (1995).

[28] B. L. Combridge, Nucl. Phys. B **151**, 429 (1979).

[29] M. Glück, E. Reya and A. Vogt, Phys. Rev. D **45**, 3986 (1992)

[30] F. Gelis and A. Peshier, Nuc. Phys. A (in press), hep-ph/0107142.

[31] B. Naroska, hep-ex/0110023.

[32] A. Donnachie and P. V. Landshoff, Nuc. Phys. B **244**, 322 (1984).

[33] M. G. Ryskin, Z. Phys. C **57**, 89 (1993); S. J. Brodsky, L. Frankfurt, J. F. Gunion, A. H. Mueller and M. Strikman, Phys. Rev. D **50**, 3134 (1994); M. G. Ryskin, R. G. Roberts, A. D. Martin and E. M. Levin, Z. Phys. C **76**, 231 (1997); L. Frankfurt, W. Koepf and M. Strikman, Phys. Rev. D, 512 **57**, 512 (1998).

[34] L. Frankfurt, M. McDermott and M. Strikman, JHEP **03**, 045 (2001); K. Susuki, A.

Hayashigaki, K. Itakura, J. Alam and T. Hatsuda, Phys. Rev. D **62**, 031501 (2000).

TABLES

Gluon Distribution	LHC
GRV	6.584 mb
EKS	2.452 mb
AG	0.893 mb

TABLE I. The total cross section $\sigma(AA \rightarrow AAJ/\Psi)$ for different nuclear gluon distributions. Results for LHC.

FIGURES

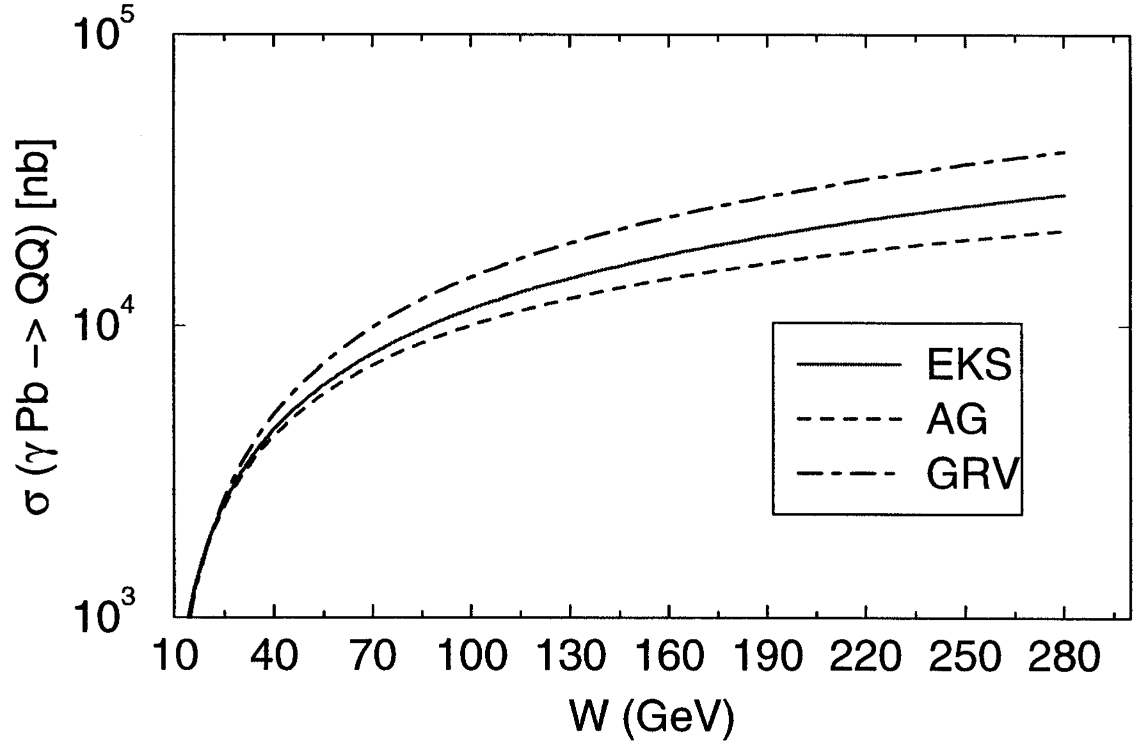

FIG. 1. Energy dependence of the photoproduction of heavy quarks for distinct nuclear gluon distributions ($A = 208$).

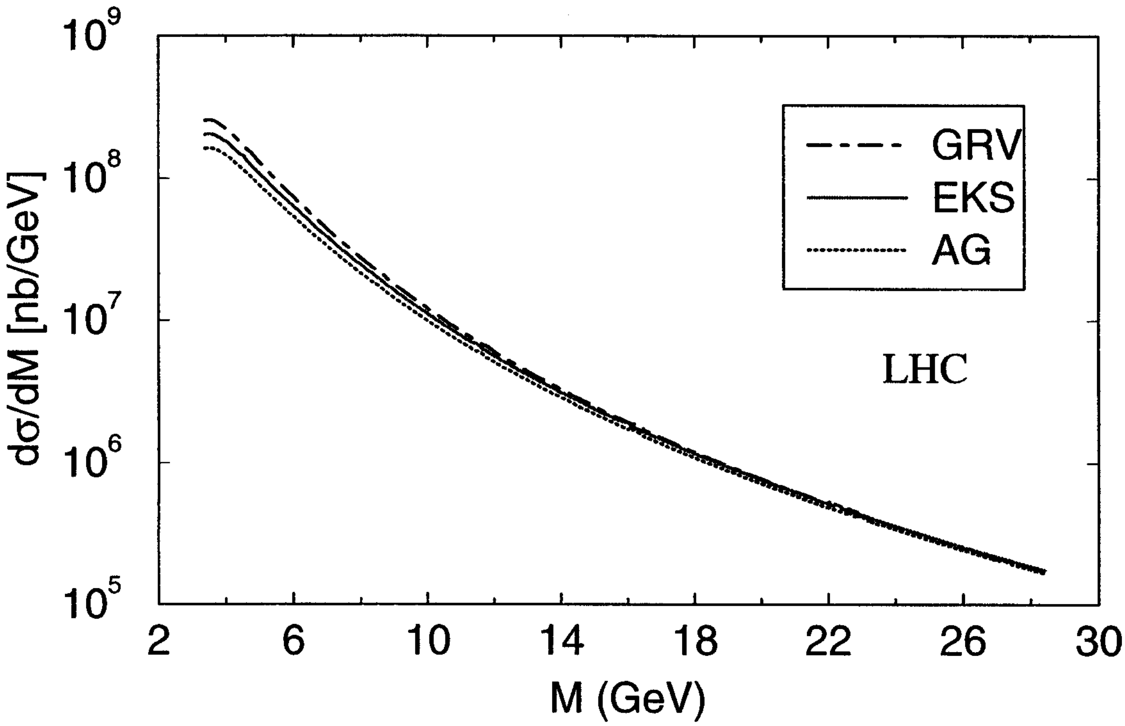

FIG. 2. Differential cross section for $c\bar{c}$ production versus the invariant mass $M = M_{c\bar{c}}$. The photon-gluon fusion in the heavy-ion collision system ^{208}Pb + ^{208}Pb at LHC energy is considered.

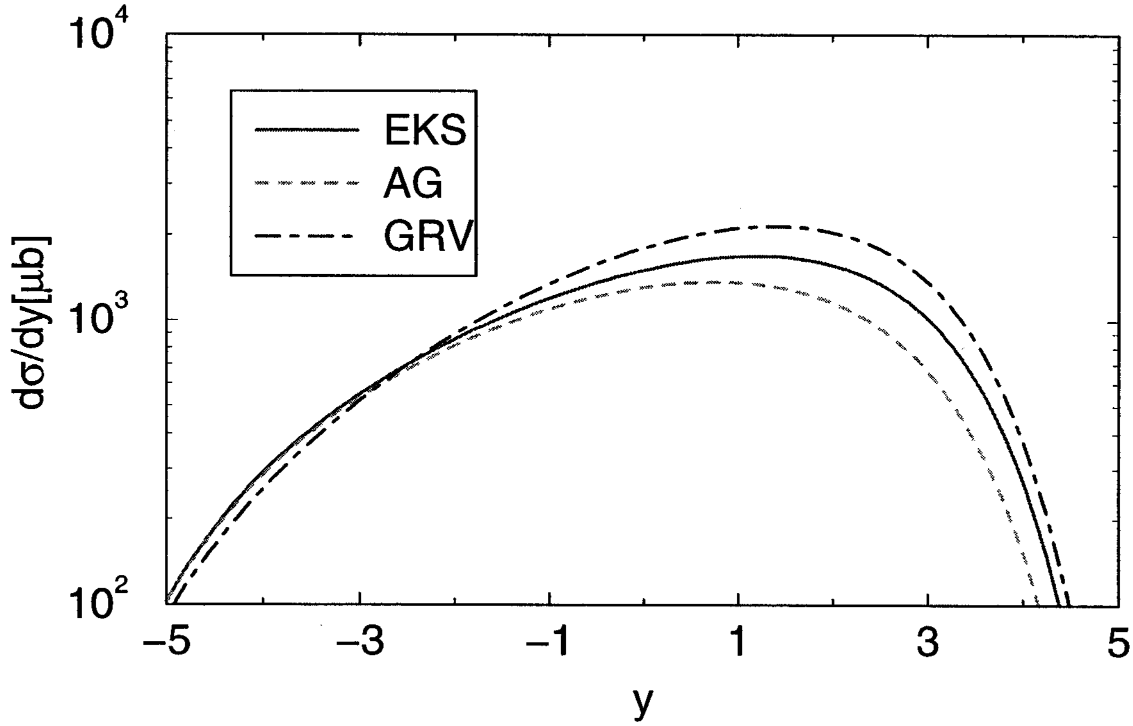

FIG. 3. Rapidity distribution for the photoproduction of charm quarks in ^{208}Pb + ^{208}Pb collisions at LHC.

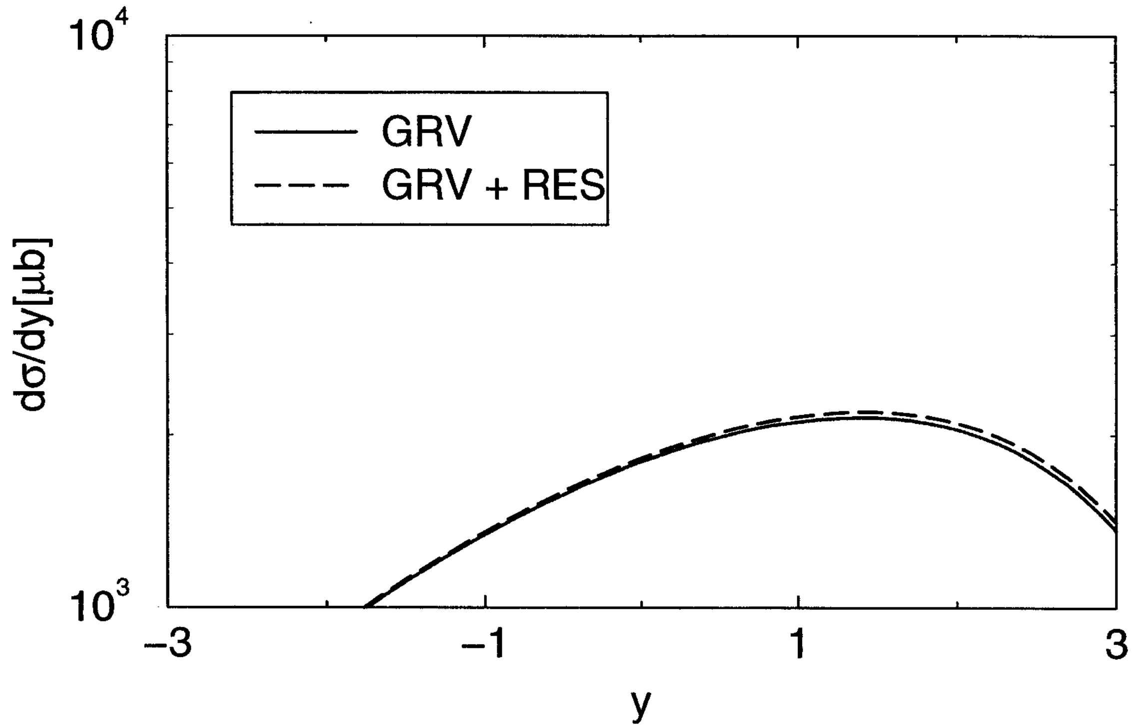

FIG. 4. Rapidity distribution for the photoproduction of charm quarks in ^{208}Pb + ^{208}Pb collisions at LHC with (GRV+RES) and without (GRV) the inclusion of the resolved contribution.

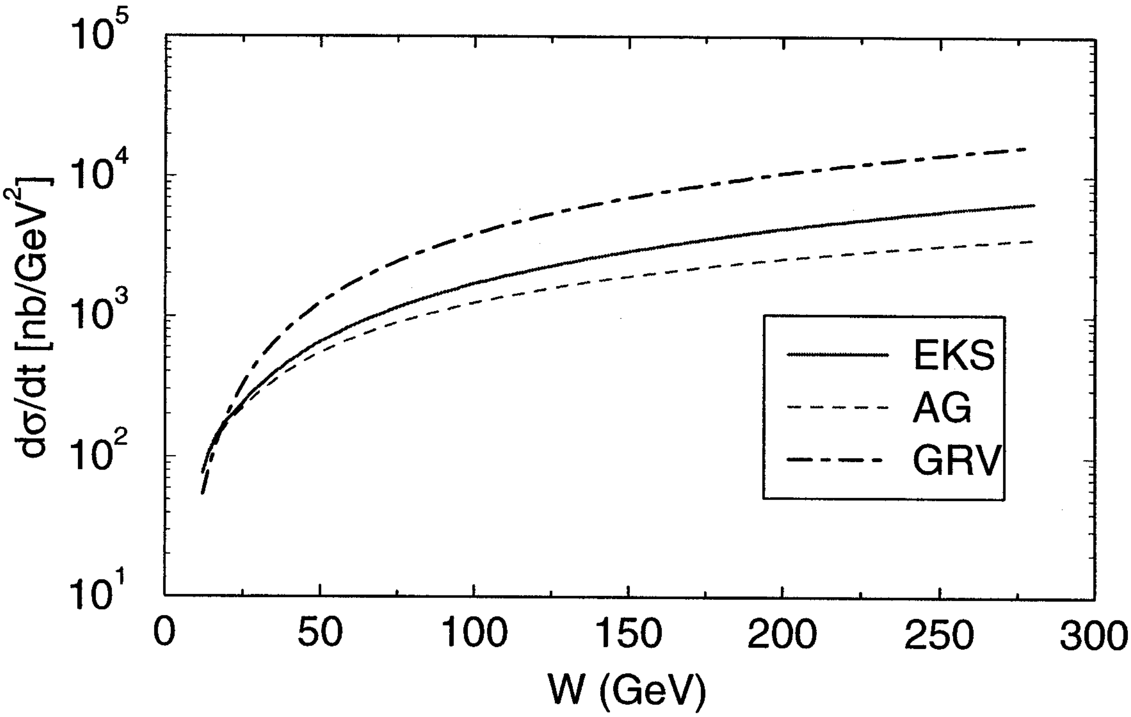

FIG. 5. Energy dependence of the elastic photoproduction of J/Ψ for distinct nuclear gluon distributions ($A = 208$).

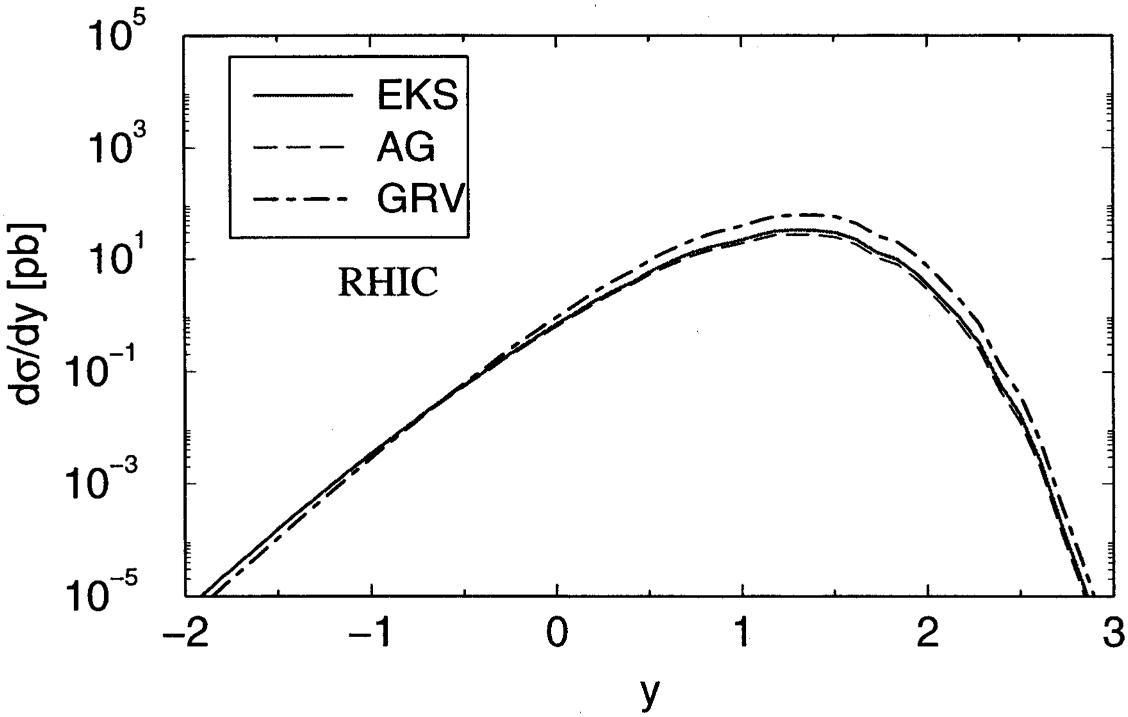

FIG. 6. The rapidity distribution for elastic photoproduction of J/Ψ at RHIC, considering distinct nuclear gluon distributions ($A = 208$).

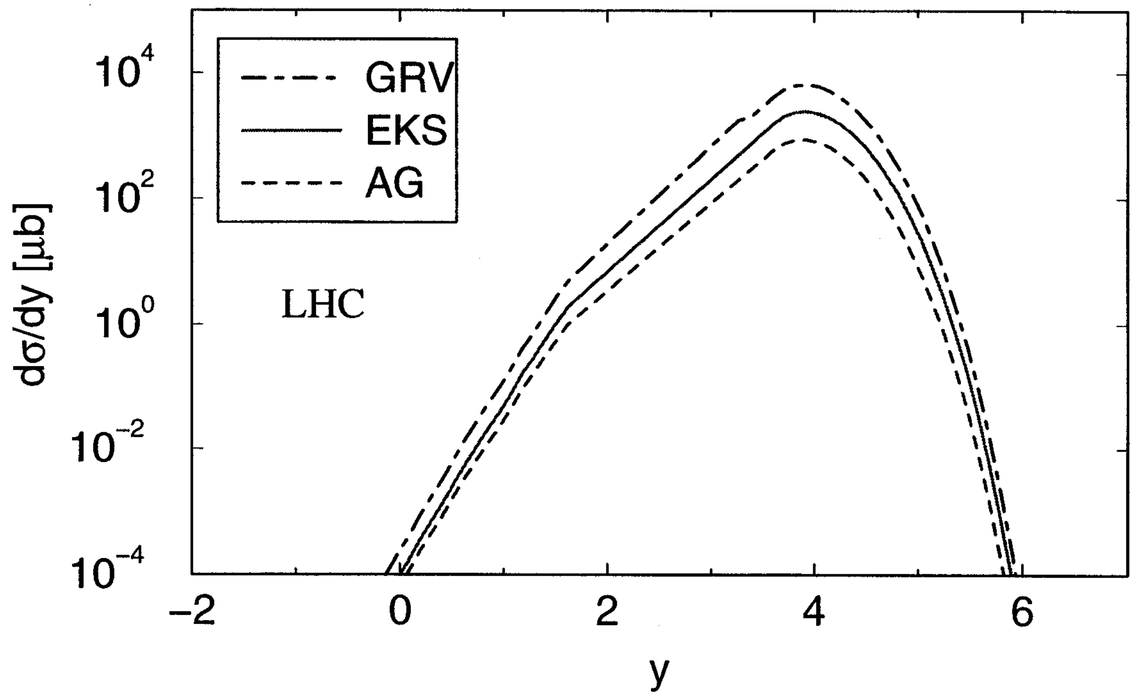

FIG. 7. The rapidity distribution for elastic photoproduction of J/Ψ at LHC considering distinct nuclear gluon distributions ($A = 208$).

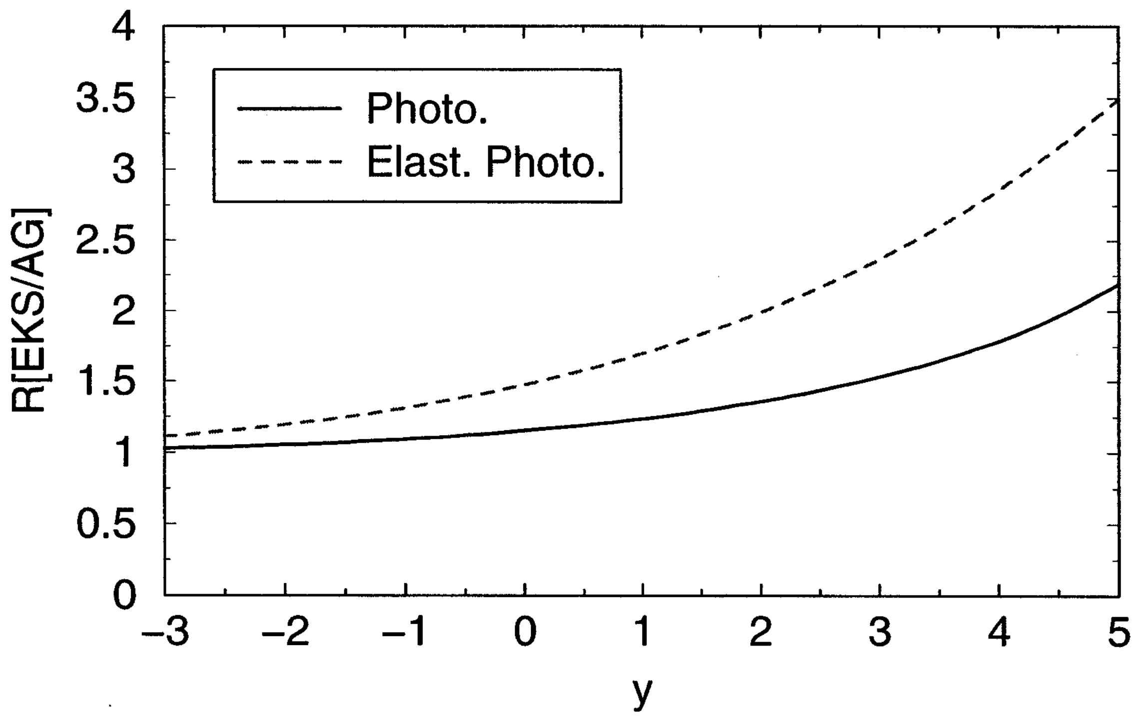

FIG. 8. Rapidity behavior of the ratio between the EKS and AG predictions for photoproduction of charm quarks and elastic photoproduction of J/Ψ.