PROCEEDINGS OF SCIENCE

Double-scattering mechanism of production of two ρ^0 mesons in ultraperipheral, ultrarelativistic heavy ion collisions

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We study, for the first time, differential distributions for two ρ^0 meson production in exclusive ultraperipheral, ultrarelativistic heavy ion collisions via a double-scattering mechanism. The calculations are done in the impact parameter space. The cross section for $\gamma A \to \rho^0 A$ is parametrized based on an existing model. Smearing of ρ^0 masses is taken into account. The results of calculations for single and double-ρ^0 production are compared to experimental data at the RHIC and LHC energies. The mechanism considered gives a significant contribution to the $AA \to AA\pi^+\pi^-\pi^+\pi^-$ reaction. Some observables related to charged pions are presented too. We compare results of our calculations with the STAR collaboration results for four charged pion production.

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1. Introduction

The exclusive production of simple final states in ultraperipheral collisions (UPC) of heavy ions is a special class of nuclear reactions [1]. At ultrarelativistic energies we can define two categories of the underlying reaction mechanisms. First one is the photon-photon fusion [2] and another one is double photoproduction of vector mesons [3].

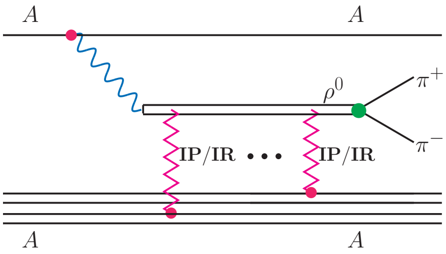

Figure 1: Single vector meson production by photon-Pomeron (or Pomeron-photon) fusion.

In Fig. 1 we show generic diagram of single nuclear ρ^0 production (and its decay into $\pi^+\pi^-$ state) via γ-Pomeron or Pomeron-γ exchange mechanism in UPC of heavy ion. Photon emitted from a nucleus fluctuates into hadronic or quark-antiquark components which rescatters in the second nucleus and converts into a simple final state.

We study, for the first time, differential distributions for exclusive production of two $\rho^0(770)$ mesons (Fig. 2) and its decay into four charged pions in double scattering (DS) processes. The results will be compared with the contribution of two-photon mechanism (Fig. 3). The analysis include a smearing of ρ^0 mass ($\Gamma \sim 0.15$ GeV) using a parametrization of the ALICE Collaboration [4].

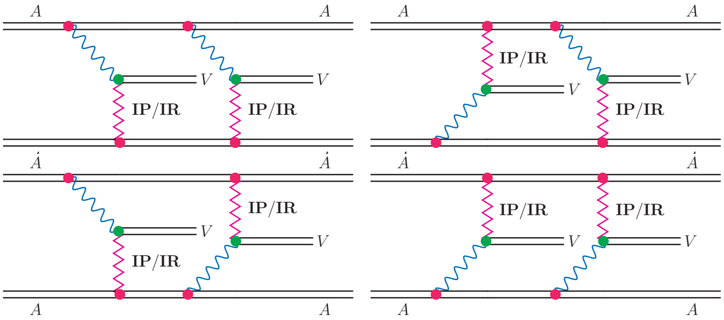

Figure 2: Double vector meson production by photon-Pomeron (or Pomeron-photon) fusion.

2. Formalism

In our approach the cross section for single-vector-meson production (Fig. 1) depends on the impact parameter b (distance between two colliding nuclei) and on the ρ^0 meson rapidity y

$$\frac{d\sigma_{AA\to AA\rho^0}}{d^2b\,dy} = \frac{dP_{\gamma I\!P}(b,y)}{dy} + \frac{dP_{I\!P\gamma}(b,y)}{dy} \,, \tag{2.1}$$

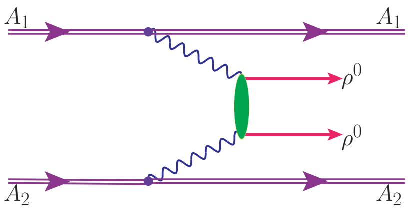

Figure 3: Double ρ^0 production in $\gamma\gamma$ fusion.

where $P_{\gamma I\!P/I\!P\gamma}(b,y)$ expresses the probability density for producing a vector meson at rapidity y for fixed impact parameter b of the heavy ion collision. Each probability is the convolution of a flux of equivalent photon and the $\gamma A \to \rho^0 A$ cross section:

$$P_{\gamma I\!P/\gamma I\!P}(b,y) = \omega_{1/2}\, N(\omega_{1/2},b)\, \sigma_{\gamma A_{2/1}\to\rho^0 A_{2/1}} \; . \tag{2.2}$$

Photon flux $N(\omega_{1/2},b)$ depends on the energy of photon and on impact parameter b (heavy ion – heavy ion distance). Generally photon flux is expressed through nuclear form factor $F(q)$ which is related to charge distribution in the nucleus. Details of different types of form factors and their application into nuclear calculation one can be found in Refs. [2, 5, 6, 7]. To calculate the $\sigma_{\gamma A_{2/1}\to\rho^0 A_{2/1}}$ cross section we use a sequence of equations which are presented in [8]. Constants for the underlying $\sigma_{\gamma p\to\rho^0 p}$ cross section are obtained from a fit to HERA data [9]. The $\sigma_{\rho^0 A}$ total cross section are calculated using classical mechanics formula

$$\sigma_{\rho^0 A} = \int \mathrm{d}^2\mathbf{r}\left(1-\exp\left(-\sigma_{\rho^0 p}\, T_A(\mathbf{r})\right)\right) \tag{2.3}$$

or quantum mechanical Glauber formula

$$\sigma_{\rho^0 A} = 2\int \mathrm{d}^2\mathbf{r}\left(1-\exp\left(-\frac{1}{2}\sigma_{\rho^0 p}\, T_A(\mathbf{r})\right)\right) \; , \tag{2.4}$$

where $T_A(\mathbf{r})$ is nuclear thickness function and r is distance between photon emitted from first/second nucleus and middle of second/first one.

Having a formalism for the calculation of single-vector-meson production, one can use this formula to calculate cross section for double-scattering mechanisms of two-vector-meson production in ultrarelativistic, ultraperipheral collisions of heavy ions. The cross section for the double ρ^0 photoproduction is expressed with the help of probability density of single ρ^0 meson production

$$\frac{\mathrm{d}\sigma_{AA\to AA\rho^0\rho^0}}{\mathrm{d}y_1\mathrm{d}y_2} = \frac{1}{2}\int \mathrm{d}^2b\left[\left(\frac{\mathrm{d}P_{\gamma I\!P}(b,y_1)}{\mathrm{d}y_1}+\frac{\mathrm{d}P_{I\!P\gamma}(b,y_1)}{\mathrm{d}y_1}\right)\times\left(\frac{\mathrm{d}P_{\gamma I\!P}(b,y_2)}{\mathrm{d}y_2}+\frac{\mathrm{d}P_{I\!P\gamma}(b,y_2)}{\mathrm{d}y_2}\right)\right] \; . \tag{2.5}$$

Here we take into account four combinations of $\gamma I\!P$ exchanges: $\gamma I\!P - \gamma I\!P$, $\gamma I\!P - I\!P\gamma$, $I\!P\gamma - I\!P\gamma$ and $I\!P\gamma - \gamma I\!P$ (see Fig. 2).

We are a first group which can calculate not only total cross section for double-vector-meson production but also some differential distributions, e.g. two-dimensional distributions in rapidities of both vector mesons or in $\rho^0\rho^0$ invariant mass. Knowing that the produced ρ^0 mesons decay, with almost 100% probability, into charged pions, and including a smearing of the ρ^0 masses in our calculation, we can compare our predictions with experimental data for $AA \to AA\pi^+\pi^-\pi^+\pi^-$ processes.

3. Results

Fig. 4 shows a comparison of cross section for coherent ρ^0 production measured by the STAR [10] (left panel) and ALICE [4] (right panel) Collaborations for different theoretical models ([8, 11, 12]). One can observe that calculations for classical mechanics rescattering (Eq. 2.3) better (than in quantum approach (Eq. 2.4)) describe both STAR and ALICE experimental data although we see no deep theoretical reasons for this fact. Our results (blue lines) relatively well describe the STAR and ALICE experimental data for the single vector meson photoproduction in ultrarelativistic heavy ion collisions (UPC). This fact is very important for calculation of the cross section for double-scattering mechanism.

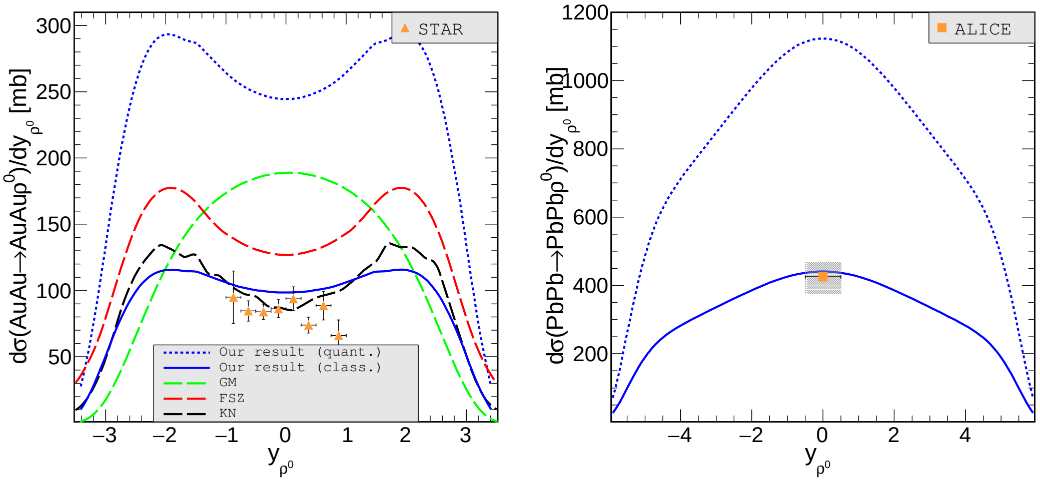

Figure 4: Distribution in ρ^0 meson rapidity for single-ρ^0 production for gold-gold collisions at RHIC energy (left panel) and for lead-lead collisions at LHC energy (right panel).

Fig. 5 shows differential cross section as a function of one ρ^0 meson and a comparison of the results of the double-scattering and the $\gamma\gamma$ fusion mechanisms at RHIC (left panel) and at LHC (right panel) energy. The cross section for exclusive $\rho^0\rho^0$ production in the $\gamma\gamma$ fusion approach is closely explained in Ref. [2]. There the elementary cross section ($\gamma\gamma \to \rho^0\rho^0$) is divided into two parts: low-energy component ($W_{\gamma\gamma} = (1-2)$ GeV) of not completely understood origin and the VDM-Regge parametrization ($W_{\gamma\gamma} > 2$ GeV) [2]. In Fig. 5 one can observe a clear dominance of the DS component over the $\gamma\gamma$ component. The distribution for the center of mass energy $\sqrt{s_{NN}} = 5.5$ TeV is much broader than that for $\sqrt{s_{NN}} = 200$ GeV. At the LHC energy the higher values of two-meson invariant mass becomes more important what corresponds to larger values of particle rapidity. Therefore the high-energy component of the elementary cross section dominates at the LHC energy. Somewhat surprising at this energy is the fact that the VDM-Regge component is about three orders of magnitude larger than the low-energy component which is opposite to the case of the RHIC energy. Both at the RHIC and LHC energy, the contributions coming from the double-scattering mechanism is one order of magnitude larger than that from the $\gamma\gamma$ fusion.

The left panel of Fig. 6 shows four-pion invariant mass distribution for double-scattering, low-energy bump and high-energy VDM-Regge $\gamma\gamma$ fusion mechanism for the limited acceptance of the

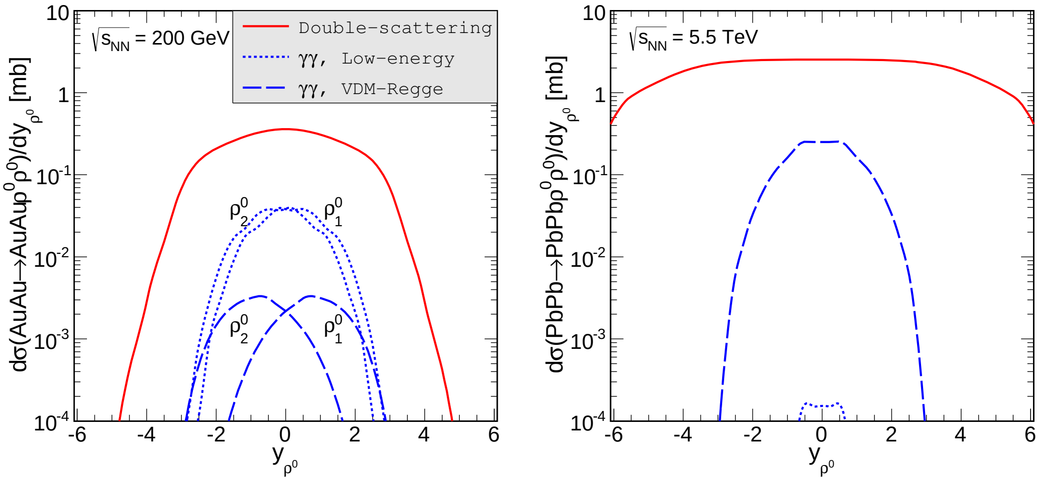

Figure 5: Rapidity distribution of one of the ρ^0 meson produced in the double-scattering mechanism and in the $\gamma\gamma$ fusion at the RHIC (left panel) and at the LHC (right panel) energy.

STAR experiment ($|\eta_\pi| < 1$) [13]. The double-scattering contribution accounts only for 20% of the cross section measured by the STAR Collaboration. The dash-dotted line represents a fit of the STAR Collaboration. Probably the production of the $\rho^0(1450)$ and $\rho^0(1700)$ resonances and their subsequent decay into the four-pion final state is the dominant effect for the limited STAR acceptance. Both, the production mechanism of $\rho^0(1450)$ and $\rho^0(1700)$ and their decay into four charged pions are not yet understood. A model for production of the resonances and their decay has to be study in the future. The right panel of Fig. 6 shows four-pion invariant mass distribution for double-scattering mechanism for the limited range of pion pseudorapidity at the LHC energy. The ALICE group collected the data for four-charged-pion production with the limitation $|\eta_\pi| < 1.2$, but we cannot compare our results with the ALICE data, because those data are not absolutely normalized.

4. Conclusions

We have studied two-ρ^0 as well as four-pion production in exclusive ultrarelativistic heavy ion UPC, concentrating on the double-scattering mechanism of single-ρ^0 production. The produced two ρ^0 mesons give large contribution to exclusive production of the $\pi^+\pi^-\pi^+\pi^-$ final state. We have compared contribution of four-pion production via $\rho^0\rho^0$ production (double scattering and $\gamma\gamma$ fusion) with experimental STAR data. The theoretical predictions have similar shape as the distribution measured by the STAR Collaboration, but exhaust only about 20% of the measured cross section. The missing contribution can come from excited states of $\rho^0(770)$ and their decay into four charged pions. We have discussed also a possibility of identifying the double scattering mechanism at the LHC.

In our calculation we have applied the smearing of ρ^0 meson masses by using the ALICE parametrization [4] which is the most appropriate for the LHC data (comparison of results for

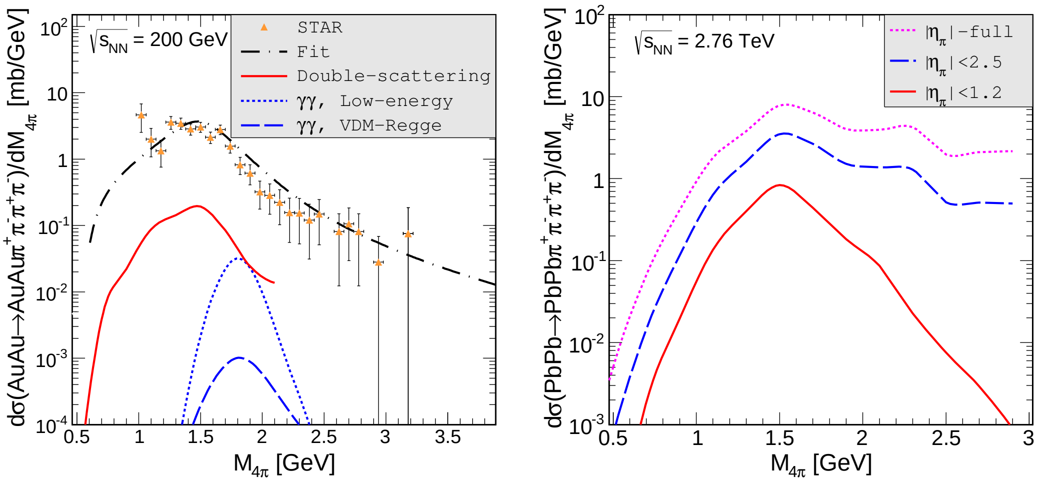

Figure 6: Four-pion invariant mass distribution for the limited acceptance of the STAR experiment (left panel) and for the limited range of pion pseudorapidity at the LHC energy (right panel).

ZEUS, STAR and ALICE parameters for relativistic Breit-Wigner and continuum amplitudes can be found in [7]).

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