

## DOUBLE SCATTERING PRODUCTION OF TWO $\rho^0$ MESONS IN UPC\*

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We review our recent results for double-scattering mechanism in the exclusive  $AA \rightarrow AA\rho^0\rho^0$  reaction in ultrarelativistic ultraperipheral heavy-ion collisions. The cross section for single and double- $\rho^0$  production is calculated in the impact parameter space equivalent photon approximation. We compare the results of our calculation with the STAR and ALICE collaborations results on one  $\rho^0(770)$  meson and four-charged-pion production.

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### 1. Introduction

The exclusive production of simple final states in ultrarelativistic UPC of heavy ions is a special class of nuclear reactions [1]. At high energies and due to large charges of colliding nuclei (gold-gold or lead-lead collisions), there are two categories of the underlying reaction mechanisms. First is the photon-photon fusion [2] and the second is double photoproduction [3].

We evaluated for the first time differential distributions for exclusive production of two  $\rho^0(770)$  mesons (four charged pions) in the double scattering (photon-Pomeron) process [3] for RHIC and LHC. The results will be compared with the contribution of two-photon mechanism. The analysis includes a smearing of  $\rho^0$  mass using a parametrization of the ALICE Collaboration [4].

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### 2. Single-scattering mechanism

Figure 1 illustrates a single  $\rho^0$  production mechanism (and its decay into  $\pi^+\pi^-$  state) in UPC of heavy ions. Photon emitted from a nucleus fluctuates into hadronic or quark–antiquark components and converts into an on-shell meson. The cross section for this mechanism can be written differentially in the impact parameter  $b$  (distance between two colliding nuclei) and in the vector meson rapidity  $y$

$$\frac{d\sigma_{AA\rightarrow AA\rho^0}}{d^2b dy} = \frac{dP_{\gamma\mathbb{P}}(b, y)}{dy} + \frac{dP_{\mathbb{P}\gamma}(b, y)}{dy}. \tag{1}$$

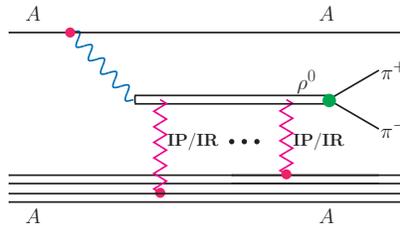


Fig. 1. Single vector meson production by photon–Pomeron (or Pomeron–photon) fusion.

$P_{\gamma\mathbb{P}/\gamma\mathbb{P}}(b, y)$  is 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 the  $\gamma A \rightarrow \rho^0 A$  cross section and a flux of equivalent photon

$$P_{\gamma\mathbb{P}/\gamma\mathbb{P}}(b, y) = \omega_{1/2} N(\omega_{1/2}, b) \sigma_{\gamma A_{2/1} \rightarrow \rho^0 A_{2/1}}, \tag{2}$$

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

$$\sigma_{\rho^0 A} = \int d^2\mathbf{r} (1 - \exp(-\sigma_{\rho^0 p} T_A(\mathbf{r}))) \tag{3}$$

or the quantum mechanical Glauber formula

$$\sigma_{\rho^0 A} = 2 \int d^2\mathbf{r} (1 - \exp(-\frac{1}{2}\sigma_{\rho^0 p} T_A(\mathbf{r}))) , \tag{4}$$

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

Returning to formula for single vector meson production (Eq. (1)), this expression depends on the running  $\rho^0$  meson mass. In our calculation, we use the ALICE parametrization [4] which is the most appropriate for the LHC data (a comparison of the ZEUS, STAR and ALICE parameters for relativistic Breit–Wigner and continuum amplitudes was shown during a talk at the EDS Blois workshop and can be found in [9]).

Figure 2 shows the comparison of cross section for coherent  $\rho^0$  production measured by the STAR [10] (left panel) and ALICE [4] (right panel) collaborations for different theoretical models [7, 11, 12]. In addition, one can observe that calculations for classical rescattering (Eq. (3)) better (than in quantum approach (Eq. (4))) describe both the STAR and ALICE experimental data. Our results relatively well describe the STAR and ALICE experimental data for the single vector meson photoproduction in heavy ion UPC. This fact is important for calculation of cross section for double-scattering mechanism which is discussed in the next section.

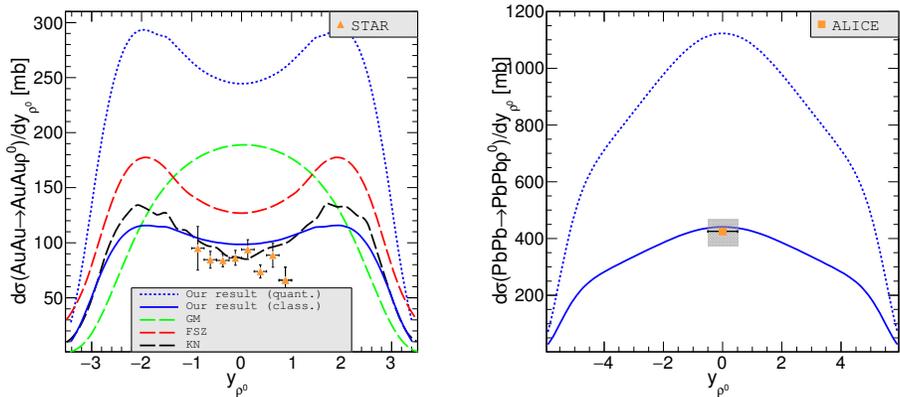


Fig. 2. Rapidity distribution of  $\rho^0$  meson with the smeared mass of the meson for gold–gold collisions at the RHIC energy (left panel) and for lead–lead collisions at the LHC energy (right panel).

### 3. Double $\rho^0$ production

Figure 3 shows diagrams for production of pairs of vector mesons by two-photon-induced subprocess in heavy ion collision (left panel) and for the double-scattering mechanism (in fact, we take into account four different combinations of  $\gamma\mathbb{P}$  exchanges:  $\gamma\mathbb{P}\text{--}\gamma\mathbb{P}$ ,  $\gamma\mathbb{P}\text{--}\mathbb{P}\gamma$ ,  $\mathbb{P}\gamma\text{--}\mathbb{P}\gamma$  and  $\mathbb{P}\gamma\text{--}\gamma\mathbb{P}$ ).

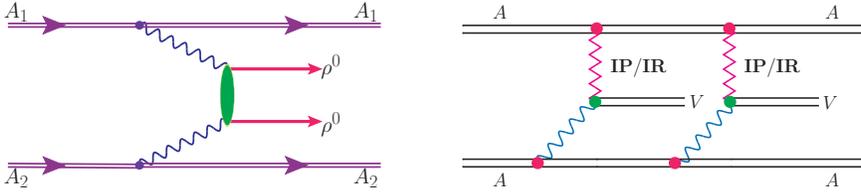


Fig. 3. Double  $\rho^0$  production for  $\gamma\gamma$  fusion (left panel) and for double-scattering mechanism (right panel).

The cross section for exclusive  $\rho^0\rho^0$  production via  $\gamma\gamma$  fusion is closely explained in Ref. [2]. There, the elementary cross section ( $\gamma\gamma \rightarrow \rho^0\rho^0$ ) is divided into two parts: a low-energy component ( $W_{\gamma\gamma} = (1-2)$  GeV) and a VDM-Regge parametrization ( $W_{\gamma\gamma} > 2$  GeV) [2]. The cross section for the double  $\rho^0$  photoproduction is expressed with the help of probability density of single  $\rho^0$  meson production as

$$\frac{d\sigma_{AA \rightarrow AA\rho^0\rho^0}}{dy_1 dy_2} = \frac{1}{2} \int \left( \frac{dP_{\gamma\mathbb{P}}(b, y_1)}{dy_1} + \frac{dP_{\mathbb{P}\gamma}(b, y_1)}{dy_1} \right) \times \left( \frac{dP_{\gamma\mathbb{P}}(b, y_2)}{dy_2} + \frac{dP_{\mathbb{P}\gamma}(b, y_2)}{dy_2} \right) d^2b. \quad (5)$$

The factor  $\frac{1}{2}$  appears due to identity of mesons in the outgoing channel.

Figure 4 shows differential cross section as a function of one  $\rho^0$  meson rapidity and a comparison of the double-scattering and  $\gamma\gamma$  fusion mechanisms at the RHIC (left panel) and at the LHC (right panel) energy. One can observe a clear dominance of the DS component over the  $\gamma\gamma$  component. The

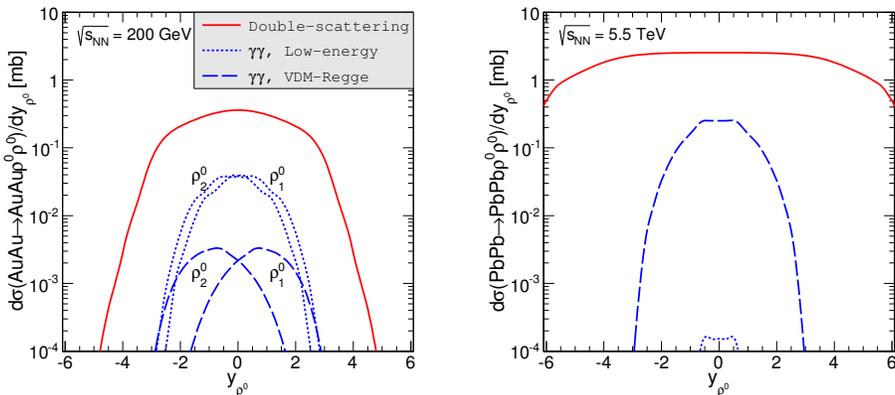


Fig. 4. Rapidity distribution of one of the  $\rho^0$  meson produced in the double-scattering mechanism and in the  $\gamma\gamma$  fusion at the RHIC (left panel) and at the LHC (right panel) energy.

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 which corresponds to larger values of particle rapidity. Thus, the high-energy component of the elementary cross section dominates at the LHC energy. Somewhat surprisingly at this energy, 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  $\gamma\gamma$  fusion is one order of magnitude smaller than that from the double-scattering mechanism.

The left panel of Fig. 5 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 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 fully understood. A model for production of the resonances and their decay has to be worked out in the future. The right panel of Fig. 5 shows four-pion invariant mass distribution for double-scattering mechanism for the limited range of pion pseudorapidity. The ALICE group collected the data for four-charged-pion production with the limitation  $|\eta_\pi| < 1.2$ . We cannot compare this distribution with the ALICE data, because those data points are not yet absolutely normalized.

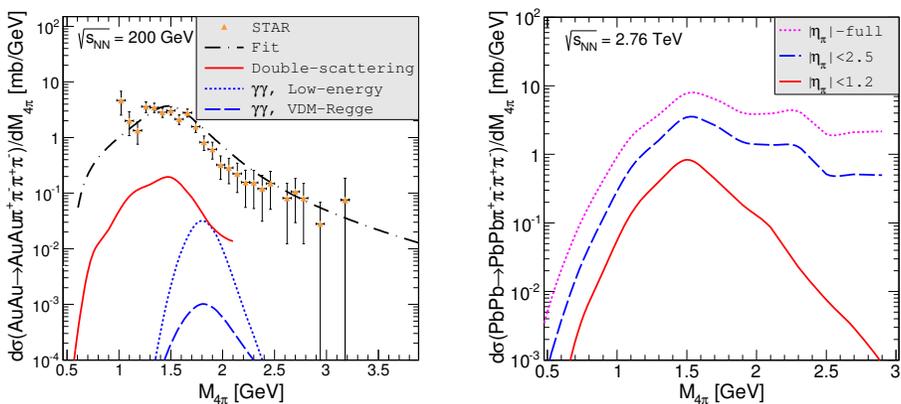


Fig. 5. Four-pion invariant mass distribution for the limited acceptance of the STAR experiment (left panel) and for the limited range of pion pseudorapidity at the LHC energy (right panel).

#### 4. Conclusion

We have studied two- $\rho^0$  as well as four-pion production in exclusive ultrarelativistic heavy ion UPC, concentrating on the double-scattering mechanism of single- $\rho^0$  production. The produced  $\rho^0$  mesons decay, with almost 100% probability, into charged pions, giving 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 the experimental STAR Collaboration data. The theoretical predictions have a similar shape to the distribution measured by the STAR Collaboration, but exhaust only about 20% of the measured cross section. The missing contribution can come from decays of excited states of  $\rho^0(770)$  into four-charged pions. In addition, predictions for the LHC have been shown.

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