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Exclusive production of $\pi^+\pi^-$ and $\pi^0\pi^0$ pairs in photon-photon and in ultrarelativistic heavy ion collisions

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Abstract. The $\gamma\gamma \to \pi\pi$ reactions are discussed. To describe those processes, we include dipion continuum, resonances, high-energy pion-pion rescatterings, ρ meson exchange and pQCD Brodsky-Lepage mechanisms. The cross section for the production of pion pairs in photon-photon collisions in peripheral heavy ion collisions is calculated with the help of Equivalent Photon Approximaption (EPA) in the impact parameter space. We show predictions at $\sqrt{s_{NN}} = 3.5$ TeV which could be measured e.g. by the ALICE collaboration at the LHC.

1 Introduction

Due to the large charge of colliding nuclei, ultrarelativistic collisions of heavy ions provide an opportunity to study photon-photon collisions. We focus on the understanding of both $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ processes in the whole energy range of the exprimental data. Different mechanisms may contribute in general. Correct form of the elementary cross section is necessary to calculate the prediction for future nucleus-nucleus experiments.

2 Elementary cross section

The $\gamma\gamma \to \pi\pi$ processes are fairly complicated. So far nobody was able to describe both the production of neutral and charged pions at low and intermediate energies. We discuss those processes starting from kinematical threshold ($W = 2m_\pi$) up to about $W = 6$ GeV.

Fig. 1 shows the cross section function of W. The angular ranges in the figure caption correspond to experimental cuts: $|\cos\theta| < 0.6$ for $\gamma\gamma \to \pi^+\pi^-$ and $|\cos\theta| < 0.8$ for neutral pion production. Several mechanisms are identified. The dashed-dotted lines denote the contribution from resonances (see Fig. 2). We take into account the following scalar: $f_0(600)$, $f_0(980)$, tensor: $f_2(1270)$, $f_2'(1525)$, $f_2(1560)$ as well as one spin-4: $f_4(2050)$ resonances. Our parametrization of the helicity dependent resonant amplitude is a standart relativistic Breit-Wigner distribution with the energy-dependent resonance widths using the spin dependent Blatt-Weisskopf form factor [6].
The solid blue line denotes $\gamma\gamma \to \pi^+\pi^-$ pion exchange Born continuum. The helicity dependent amplitude is a sum of three terms (contact amplitude, t- and u-channel pion exchange amplitude) multiplied by t and u dependent form factor. Finally we use the QED amplitude for the real finite-size pions.
The solid lines describe the high-energy pion-pion rescattering (see Fig. 3), t/u-channel $\rho^\pm$ meson exchange and pQCD Brodsky-Lepage mechanism (Fig. 4). The corresponding formalism of those mechanisms is rather complicated and it will be presented in our forthcoming publication [7]. The pQCD mechanism is very important for large invariant mass of the pion pairs. The details related to

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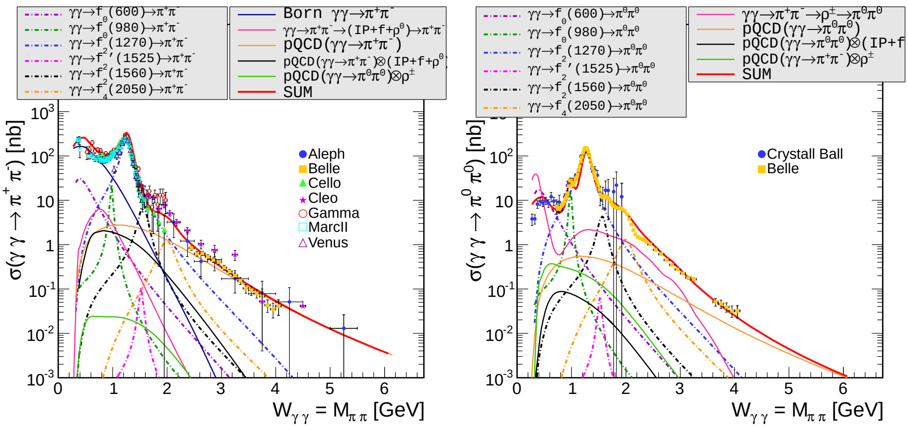

Fig. 1. Energy dependence of the $\gamma\gamma \to \pi^+\pi^-$ (left panel) and the $\gamma\gamma \to \pi^0\pi^0$ (right panel) cross section. Experimental data points have been obtained by different groups.

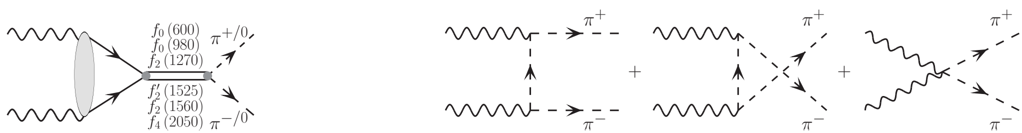

Fig. 2. Feynman diagrams describing the $\gamma\gamma \to$ resonances $\to \pi^{+/0}\pi^{-/0}$ amplitude (left panel) and the Born amplitude for $\gamma\gamma \to \pi^+\pi^-$ (right panel).

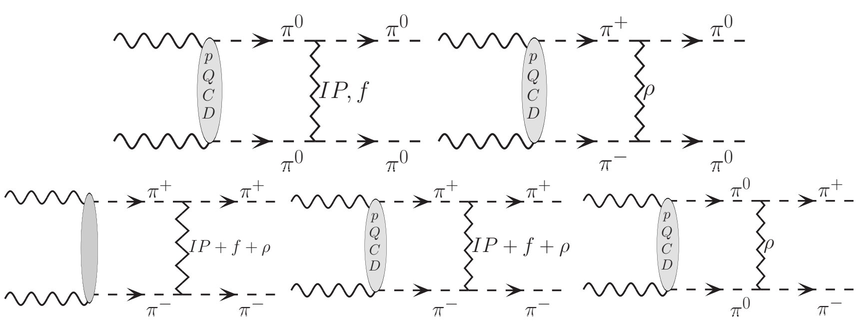

Fig. 3. Pion-pion rescattering.

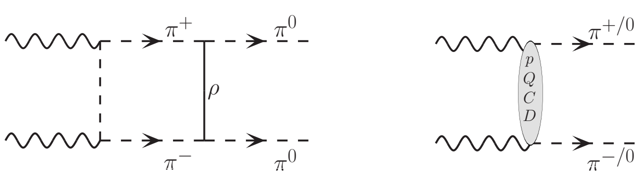

Fig. 4. $\gamma\gamma \to \pi^0\pi^0$ in a simple coupled channel model with $\rho^\pm$ exchange (left panel) and the Brodsky-Lepage perturbative mechanism for $\gamma\gamma \to \pi\pi$ scattering.

this mechanism one can find in our last paper [5]. We can see that processes with the pomeron and reggeon exchange play a crucial role at low energy. In the same region of energy a major contribution to the final result gives $f_0(600)$ s-channel resonance as well as ρ meson exchange (pink solid line - right panel). At arround W $\approx$ 1 GeV we observe a small dip. This comes from interfering of different amplitudes.

3 Nuclear cross section

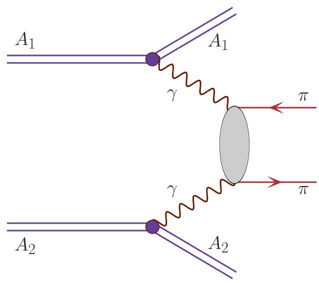

Fig. 5. The Feynman diagram illustrating the formation of the pion pair.

In Fig. 5 we show the basic mechanism of the exclusive electromagnetic pion pair production as a result of the peripheral nuclear collisions. The equivalent photon approximation in the impact parameter space is the best suited approach for applications to the peripheral collisions of nuclei. This approach have been used recently in the calculation of the $\rho^0\rho^0$ pairs [1], $\mu^+\mu^-$ [2], $Q\bar{Q}$ [3], $D\bar{D}$ [4] and for high mass dipions [5]. There one can find the details of the b-space EPA derivation. Below we present a useful and compact formula for calculating the total cross section for $PbPb \to Pb\pi\pi Pb$ process:

$$\sigma(s_{NN}) = \int \hat{\sigma}\left(\gamma\gamma \to \pi\pi; W_{\gamma\gamma}\right)\theta\left(|\mathbf{b}_1 - \mathbf{b}_2| - 2R_A\right) N(\omega_1, \mathbf{b}_1)\, N(\omega_2, \mathbf{b}_1)\, 2\pi b_m\, \mathrm{d}b_m\, \mathrm{d}\bar{b}_x\, \mathrm{d}\bar{b}_y \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma}\mathrm{d}Y \,. \tag{1}$$

This is a convolution of the elementary cross section and photon fluxes. In the EPA approach absorption effect is taken into account by limiting impact parameter $b > R_1 + R_2 \approx 14$ fm.

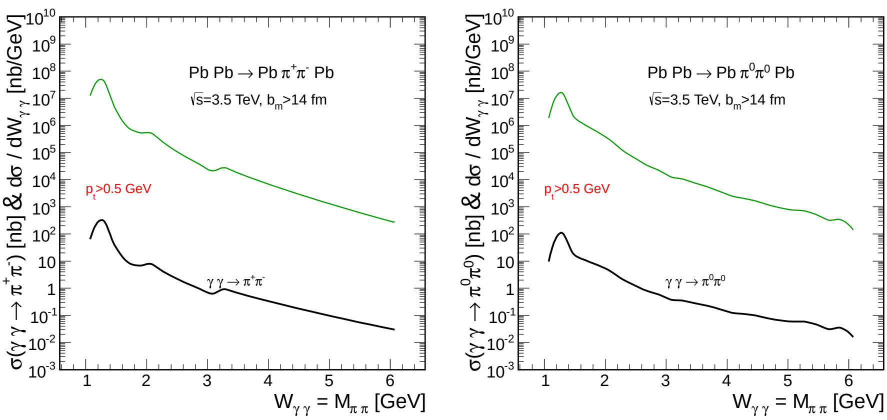

Fig. 6. The nuclear cross section (green lines) as a function of $\gamma\gamma$ subsystem energy for the $PbPb \to Pb\pi^+\pi^- Pb$ (left panel) and for the $PbPb \to Pb\pi^0\pi^0 Pb$ (right panel) reactions calculated with an extra cut-off on pion transverse momentum. The black lines refer to the elementary cross sections.

In Fig. 6, 7 we present the predictions for possible future experiments. We show total (angle-integrated) cross section as a function of $\gamma\gamma$ energy as well as as a function of pion pair rapidity for both charged and neutral pions. We consider lead-lead collisions at energy $\sqrt{s_{NN}} = 3.5$ TeV. In these calculations we have imposed extra cuts on pion transverse momenta ($p_t > 0.5$ GeV). The nuclear cross section is a reflection of the elementary cross section. We have obtained measurable cross sections.

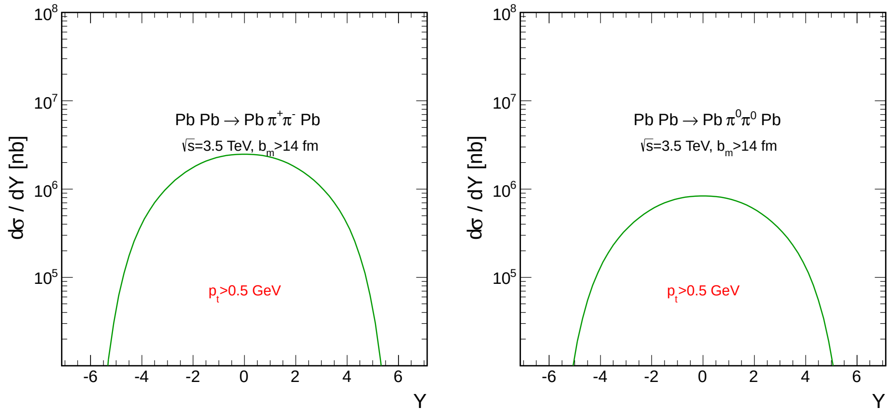

Fig. 7. The nuclear cross section as a function of pion pair rapidity for the $PbPb \to Pb\pi^+\pi^- Pb$ (left panel) and for the $PbPb \to Pb\pi^0\pi^0 Pb$ (right panel) reactions calculated with an extra cut-off on pion transverse momentum.

4 Conclusion

We have discussed a possibility to study the $\gamma\gamma \to \pi\pi$ processes in ultraperipheral ultrarelativistic heavy-ion collisions. First, we have described the experimental data for the $\pi\pi$ production in e^+e^- collisions. To obtain correct description of the data we have taken into account pion exchange for $\pi^+\pi^-$ channel, several resonances, pQCD mechanisms, pion-pion rescatterings both at low and intermediate energies. Next, cross sections for corresponding nuclear collisions was calculated. The cross sections are fairly large. Whether they can be measured requires further studies.

Table 1. The total cross section for the $PbPb \to Pb\pi\pi Pb$ reactions.

Reaction	Extra cut on p_t	Total cross section
$PbPb \to PbPb\pi^+\pi^-$		112 mb
$PbPb \to PbPb\pi^+\pi^-$	$p_t > 0.5$ GeV	14 mb
$PbPb \to PbPb\pi^0\pi^0$		10 mb
$PbPb \to PbPb\pi^0\pi^0$	$p_t > 0.5$ GeV	5mb

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