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Exclusive electromagnetic production of pion pairs in lead-lead collisions at LHC ⋆

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Abstract. The cross section for $\pi^+\pi^-$ and $\pi^0\pi^0$ meson pairs production in peripheral ultrarelativistic heavy-ion collisions is calculated in the impact parameter space equivalent photon approximation. The cross section is calculated at the energy available at the CERN Large Hadron Collider, $\sqrt{s_{NN}}$ = 3.5 TeV. For the first time the world data for $\gamma\gamma \to \pi\pi$ are described, both for the total cross section and for the angular distribution. This is obtained simultaneously for $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ at all experimentally available energies.

1 Introduction

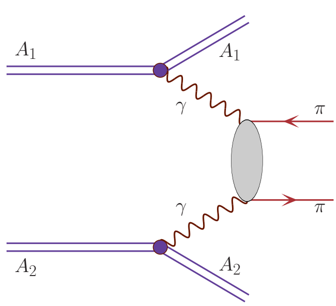

Figure 1. The diagram illustrating the formation of the pion pair. For the LHC the A_1 and A_2 letters denote the ^{208}Pb nuclei.

It is known that ultrarelativistic colliding heavy ions are a source of high-energy $\gamma\gamma$ collisions. Recently we have studied several processes initiated by the photon-photon collisions such as $\rho^0\rho^0$ [1], $\mu^+\mu^-$ [2], $Q\bar{Q}$ [3], $J/\Psi J/\Psi$ [4] and $\pi\pi$ [5, 6]. We have shown there that inclusion of realistic charge form factors, being Fourier transforms of realistic charge distributions, is crucial to estimate

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reliable nuclear cross sections. We consider $PbPb \to PbPb\pi^+\pi^-$ and $PbPb \to PbPb\pi^0\pi^0$ reactions. In figure 1 we show the basic mechanism of the exclusive production of $\pi^+\pi^-$ and $\pi^0\pi^0$ meson pairs. To calculate nuclear cross section, we have to take into account the correct form of the elementary cross section. We discuss $\gamma\gamma \to \pi\pi$ reactions at low, intermediate and high sub-energies.

2 Elementary cross section

The $\gamma\gamma \to \pi\pi$ reaction is rather complicated. Different mechanisms contribute in general. We try to understand both $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ processes simultaneously, starting from the two-pion threshold (W = $2m_\pi$) up to the maximal experimentally available energy $W_{\gamma\gamma} \approx 6$ GeV. We include both soft (figure 2), hard continuum (right panel of figure 3 - pQCD mechanisms proposed by Brodsky and Lepage [7] and the handbag mechanism proposed by Diehl, Kroll and Vogt [8]) as well as s-channel resonances (left panel of figure 3). We show that for a correct description of the low-energy experimental data we have to include also pion-pion rescattering (figure 4), which leads to a coupling between the $\pi^+\pi^-$ and $\pi^0\pi^0$ channels.

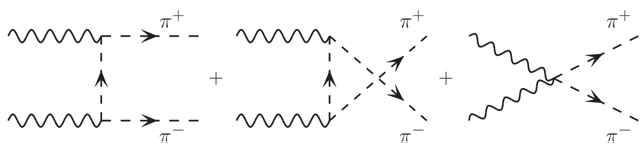

Figure 2. The $\gamma\gamma \to \pi^+\pi^-$ continuum Born terms.

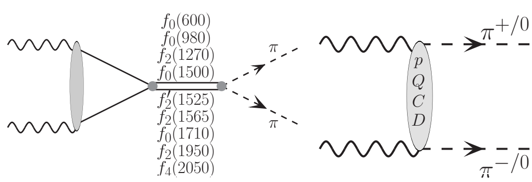

Figure 3. s-channel $\gamma\gamma \to$ resonances $\to \pi^{+/0}\pi^{-/0}$ (left panel) and the Brodsky-Lepage or hand-bag perturbative mechanisms for large-angle $\gamma\gamma \to \pi\pi$ scattering (right panel).

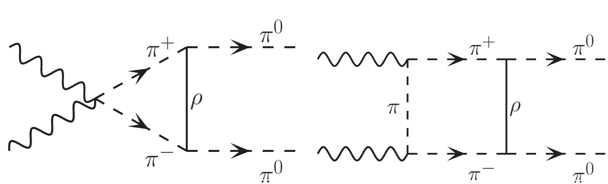

Figure 4. $\gamma\gamma \to \pi^0\pi^0$ in a simple coupled-channel model with $\rho^\pm$ exchange.

In figure 5 we show our model results against world data for $\gamma\gamma \to \pi\pi$. We get a good agreement with all available data for the first time in such a large range of energies. This make our model for photoproduction of pions well suited for the predictions of the cross sections for nucleus-nucleus collisions.

In figure 6 we present a ratio of the neutral and charged pion pair cross sections as a function of $\gamma\gamma$ energy. The upper line represents the handbag model result, which is independent of $z = \cos\theta$ and of the collision energy. Our result, which includes the BL pQCD and handbag contribution, describes the experimental data measured by the Belle Collaboration.

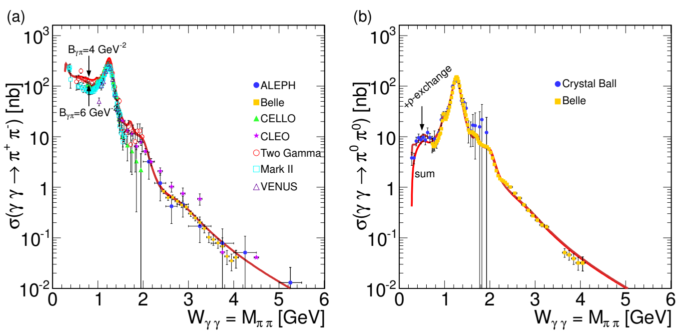

Figure 5. Results of our fit: $\gamma\gamma \to \pi^+\pi^-$ ($|\cos\theta| < 0.6$) (left panel) and $\gamma\gamma \to \pi^0\pi^0$ ($|\cos\theta| < 0.8$) (right panel).

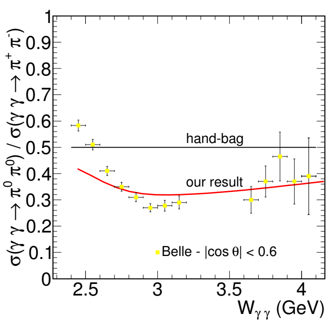

Figure 6. The ratio of the $\gamma\gamma \to \pi^0\pi^0$ and $\gamma\gamma \to \pi^+\pi^-$ cross sections as a function of $W_{\gamma\gamma} = \sqrt{s_{\gamma\gamma}}$.

3 Nuclear cross section

The nuclear cross section has been calculated with the help of b-space equivalent photon approximation (EPA). This approach allows to separate peripheral collisions of nuclei ($b > R_1 + R_2 \approx 14$ fm). A compact formula for calculating the total cross section takes the form:

$$\sigma(AA \to AA\pi\pi; s_{AA}) = \int \hat{\sigma}(\gamma\gamma \to \pi\pi; W_{\gamma\gamma}) S^2_{abs}(\mathbf{b}) N(\omega_1, \mathbf{b}_1) N(\omega_2, \mathbf{b}_2) \frac{W_{\gamma\gamma}}{2} d^2\mathbf{b}_1 d^2\mathbf{b}_2 dW_{\gamma\gamma} dY_{\pi\pi} \; .$$

The details of its derivation can be found in our papers [2, 6].

Table 1. Cross section for different lower cuts on pion transverse momenta at the LHC energy.

$p_{t,min}$ (GeV)	$\pi^+\pi^-$ (mb)	$\pi^0\pi^0$ (mb)
0.2	46.7	8.7
0.5	12.1	5.1
1.0	0.08	0.05

Figure 7 shows two-dimensional distributions in pseudorapidity of charged (left panel) or neutral pion (right panel) and transverse momentum of one of the pions. With larger $p_{t,\pi}$ values, the pseudorapidity distribution becomes somewhat narrower.

In table 1 the total cross sections for $\sqrt{s_{NN}} = 3.5$ TeV are reported for both $\pi^+\pi^-$ and $\pi^0\pi^0$ channels and for different lower cuts on pion transverse momentum.

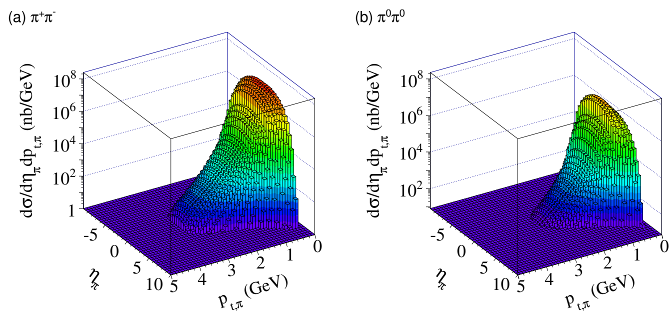

Figure 7. $\frac{d\sigma}{d\eta_\pi dp_{t,\pi}}$ for the ^{208}Pb^{208}Pb$\to^{208}$Pb^{208}Pb$\pi^+\pi^-$ reaction (left panel) and for the ^{208}Pb^{208}Pb$\to^{208}$Pb^{208}Pb$\pi^0\pi^0$ reaction (right panel) at the LHC energy.

4 Conclusions

We have shown that in order to describe the word data for $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ reactions, one should consider several different mechanisms: soft two-pion continuum, several resonanses, pion-pion rescattering, pQCD mechanisms proposed by Brodsky and Lepage, as well as the hand-bag mechanism proposed by Diehl, Kroll and Vogt. The energy-dependent cross sections for these two sub-processes have been used next in EPA in the impact parameter space to calculate for the first time corresponding production rate in ultraperipheral ultrarelativistic heavy-ion reactions. In this calculation we have taken into account realistic charge distributions in colliding nuclei.

The $\gamma\gamma \to \pi^+\pi^-$ sub-process constitutes a background to the exclusive $AA \to A\rho^0(\to \pi^+\pi^-)A$ process, initiated by photon-pomeron or pomeron-photon sub-processes. We have found [9] that only a part of the dipion invariant mass spectrum associated with $\gamma\gamma$-collisions can be potentially visible as the cross section for the $AA \to A\rho^0 A$ reaction is very large.

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