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Exclusive production of two and four pions in ultraperipheral, ultrarelativistic collisions

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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 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 distributions simultaneously for $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ at all experimentally available energies.

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1. Introduction

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 reliable nuclear cross sections. Here we consider $PbPb \to PbPb\pi^+\pi^-$ and $PbPb \to PbPb\pi^0\pi^0$ reactions. To calculate nuclear cross section, we have to take into account the correct form of the elementary cross section for $\gamma\gamma \to \pi\pi$ reactions at low, intermediate and high sub-energies.

2. Elementary cross section

The $\gamma\gamma \to \pi\pi$ reaction is rather complicated. We have tried 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. In Fig. 1 we show our model results (left and middle panel) 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. In the right side of Fig. 1 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 Brodsky-Lepage pQCD [7] and the handbag mechanism proposed by Diehl, Kroll and Vogt [8]), describes the experimental data measured by the Belle Collaboration.

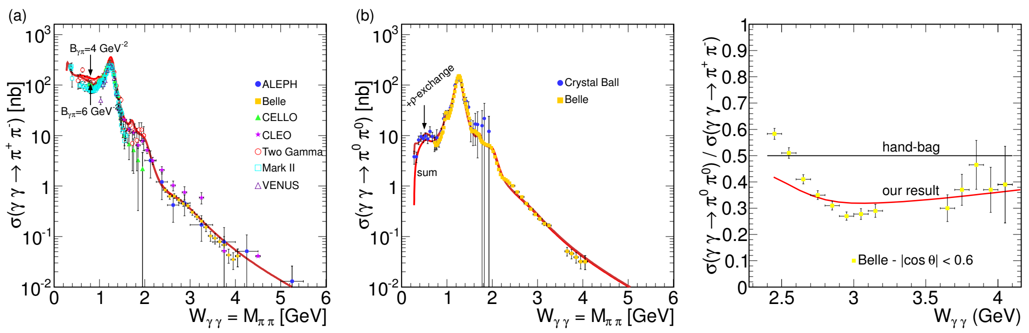

Figure 1: Results of our fit: $\gamma\gamma \to \pi^+\pi^-$ ($|\cos\theta| < 0.6$) (left panel) and $\gamma\gamma \to \pi^0\pi^0$ ($|\cos\theta| < 0.8$) (middle panel). The right panel: the ratio of the $\gamma\gamma \to \pi^0\pi^0$ and $\gamma\gamma \to \pi^+\pi^-$ cross sections as a function of $\sqrt{s_{\gamma\gamma}}$.

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 ultraperipheral 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].

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Fig. 2 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.

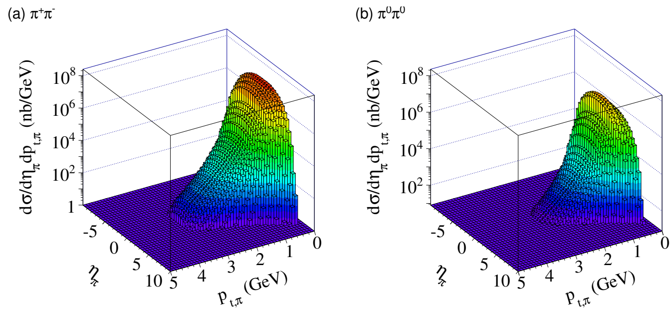

Figure 2: $\frac{d\sigma}{d\eta_\pi dp_{t,\pi}}$ for the ^{208}Pb^{208}Pb$\to$^{208}Pb^{208}Pb$\pi^+\pi^-$ reaction (left panel) and for the ^{208}Pb^{208}Pb$\to$^{208}Pb^{208}Pb$\pi^0\pi^0$ reaction (right panel) at the LHC energy.

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 include 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 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 $AA\to A\rho^0A$ reaction is very large [9].

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