Resonance structure in the $\gamma\gamma$ invariant mass spectrum in pC, dC and dCu interactions

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Along with π^0 and η mesons, a resonance structure in the invariant mass spectrum of two photons at $M_{\gamma\gamma} = 360 \pm 7 \pm 9$ MeV is observed in dC interactions at momentum 2.75 GeV/c per nucleon. This resonance structure is not observed in pC collisions at the beam momentum 5.5 GeV/c. The result obtained in the reaction dC is confirmed by the second experiment carried out on the deuteron beam at momentum 3.83 GeV/c per nucleon with a copper target. Some other checks of the observed effect are presented.

1. INTRODUCTION

Dynamics of the near-threshold production of lightest mesons and their interaction, especially $\pi\pi$ interaction, are of lasting interest. Two-photons decay of light mesons represents an important source of information. In particular, the $\gamma\gamma$ decay of light scalar mesons has been considered as a possible tool to deduce their nature. In this work the resonance struc-

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ture with mass $M_{\gamma\gamma} = 360 \pm 7 \pm 9$ is described. A nature and possible mechanisms of the observed effect are discussed.

2. EXPERIMENT

The data acquisition of production of neutral mesons and γ-quanta in pC and dC interactions has been carried out with internal beams of the JINR Nuclotron [1, 2].

The presented data concern reactions induced by deuterons with a momenta 2.75 and 3.83 GeV/c per nucleon and of protons with 5.5 GeV/c. Typical deuteron and proton fluxes were about 10^9 and 2×10^8 per pulse, respectively. The electromagnetic lead glass calorimeter PHOTON-2 was used to measure both the energies and emission angles of photons. The experimental setup is schematically represented in Fig. 1. The PHOTON-2 setup includes 32 γ-spectrometers of lead glass [3–5]. The modules of the γ-spectrometer are assembled into two arms of 16 units. These modules in each arm are divided into two groups of 8 units. The output signals in each group are summed up linearly and after discrimination by amplitude are used in fast triggering. In this experiment, the discriminator thresholds were at the level of 0.4 GeV. Triggering takes place when there is a coincidence of signals from two or more groups from different arms.

3. EVENT SELECTION

The so-called event mixing method was used to estimate the combinatorial background: combinations of γ-quanta were sampled randomly from different events. For the general sampling and combinatorial background one, the same following selection criteria were used: 1) the number of γ-quanta in an event, $N_\gamma = 2$; 2) the energies of γ-quanta, $E_\gamma \geq 100$ MeV; 3) the summed energy in real and random events ≤ 1.5 GeV.

The invariant mass distributions before and after background substraction are shown at Figs. 2 and 3.

4. CHECK OF THE OBSERVED EFFECT

The dominant part of background comes from the $\pi^0 \to \gamma\gamma$ decay. Other sources of background are charged particles as well as neutrons and particles from a general background in the accelerator hall.

1. The contribution of the general background in the experimental hall was estimated from the measurements with empty target: this source contributes less than 1% and is quite smoothly distributed with respect to $M_{\gamma\gamma}$.

2. Contributions of the given sources were estimated by special measurements with and without veto-detectors S1 and S2 and by comparison of data obtained at different beam intensities. The total contribution of above sources is less than 10% and becomes negligible ($< 1\%$) after subtraction of event mixing background.

3. To elucidate the nature of the detected enhancement , we investigate the dependence of its position and width on:

the opening angle of two photons; their energy selection level; ratio of their energies, the number of detected photons (the energy of 3rd photon).

4. Pair distributions over the opening angle $\Theta_{\gamma\gamma}$ for different intervals of the sum of two-photon energy.

5. Investigations of systematic errors.

6. Similar analysis within the wavelet method.

7. Comparisons with another experiments [11–13]. In particularly, as described in [13], three differing branches of splittings of nuclei of tungsten by protons with energy of 1 GeV testify to presence of three discrete values of energy of excitation of the residual nucleus (thus the energy of excitation reserved in a residual nucleus, can be in an interval of 325–343 MeV). This experimental fact allows to conclude that there is a possibility of absorption of both particles of disintegration in a nucleus, and also possibility of absorption of one and emission another and, at last, possibility of emission of both particles of disintegration. Such scheme well corresponds to the mechanism of connection of σ-meson formation with three versions of nuclear splittings.

8. Model simulation without and with (see Fig. 4) $R \to \gamma\gamma$ under the experimental conditions.

5. DATA SIMULATION

To simulate pC, dC, and dCu reactions under question we use a transport code on the base Dubna cascade model [6] with upgrade elementary cross sections involved and with including experimental conditions.

The following γ-decay channels are taken into account: the direct decays of π^0, η, η' hadrons into two γ's, $\omega \to \pi^0\gamma$, $\Delta \to N\gamma$ and the Dalitz decay of $\eta \to \pi^+\pi^-\gamma$, $\eta \to \gamma e^+ + e^-$ and $\pi^0 \to \gamma e^+ + e^-$, the $\eta' \to \rho^0 + \gamma$, the $\Sigma \to \Lambda + \gamma$, the πN and NN bremsstrahlung. Furthermore the mechanism of $\eta \to 3\pi^0$-decay [7] was checked. We simulated two channels of it: the direct decay into two photons $\eta \to 2\gamma$ and $\eta \to 3\pi^0$ which then decay into photons. Then the dibaryon mechanism of the two-photon emission [8] has been studied. The proposed mechanism $NN \to d_1^\star\gamma \to NN\gamma\gamma$ proceeds trough a sequential emission of two photons, one of which is caused by production of the decoupled baryon resonance $d_1^\star$ and the other is its subsequent decay.

These models reproduce quite accurately the observed η peak in the invariant mass distribution of γ pairs but there is no enhancement in the region, where experimental data exhibit a resonance-like structure. Therefore we have included the additional channel of two-γ creation by two-pions interaction with the observable structure formation (which will be called below an R-resonance). We assume that R-resonant can be created by $\pi\pi$-interactions if the invariant mass of two pions obeys to Breight-Wigner distribution with observed parameters and both γ-quanta satisfy experimental condition. The two photons invariant mass spectra and its comparisons with the experiment are given in [14].

Another more candidate for realization of dibarion mechanism may be a model of the intermediate σ-dressed dibaryon [9, 10]. This mechanism is now under investigation.

6. CONCLUSION

Thus, based on a thorough analysis of experimental data measured at the JINR Nuclotron and record statistics of 2339 ± 340 events of 1.5×10^6 triggered interactions of a total number 2×10^{12} of dC interactions there was observed a resonance-like enhancement at the mass $M_{\gamma\gamma} = 360 \pm 7 \pm 9$ MeV, width $\Gamma = 63.7 \pm 17.8$ MeV, and preliminary production cross section $\sigma_{\gamma\gamma} \sim 98$ μb in the invariant mass spectrum of two photons produced in dC interactions at momentum of incident deuterons 2.75 GeV/c per nucleon. The collected statistics amount to 2339 ± 340 events of 1.5×10^6 triggered interactions of a total number $\sim 10^{12}$ of dC-interactions. A structure like this was not observed in the $M_{\gamma\gamma}$ spectrum from pC (5.5 GeV/c) interactions while the η meson is clearly seen in both the cases. The result obtained in the reaction dC is confirmed by the second experiment carried out on the deuteron beam at momentum 3.83 GeV/c per nucleon with a copper target: $M_{\gamma\gamma} = 382 \pm 13$ MeV, $\Gamma = 62.0 \pm 37.2$ MeV and $\sigma_{\gamma\gamma} = 273 \pm 75^{+320}_{-96}$ μb.

To understand the origin of the observed structure, several dynamic mechanisms were attempted: production of the hypothetic R resonance in $\pi\pi$ interactions during the evolution of the nuclear collision, formation of the R resonance with participation of photons from the Δ decay, the $\pi^0\pi^0$ interaction effect in the $3\pi^0$ channel of the η decay, a particular decoupled dibaryon mechanism. Unfortunately, none of these mechanisms is able to explain the measured value of the resonance-like enhancement, though they contribute to the invariant mass region in question.

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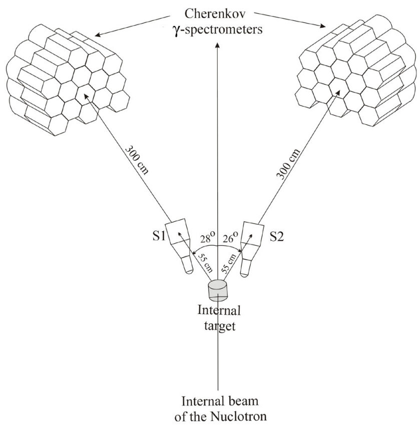

Figure 1. The schematic drawing of the experimental PHOTON-2 setup. The S_1 and S_2 are scintillation counters.

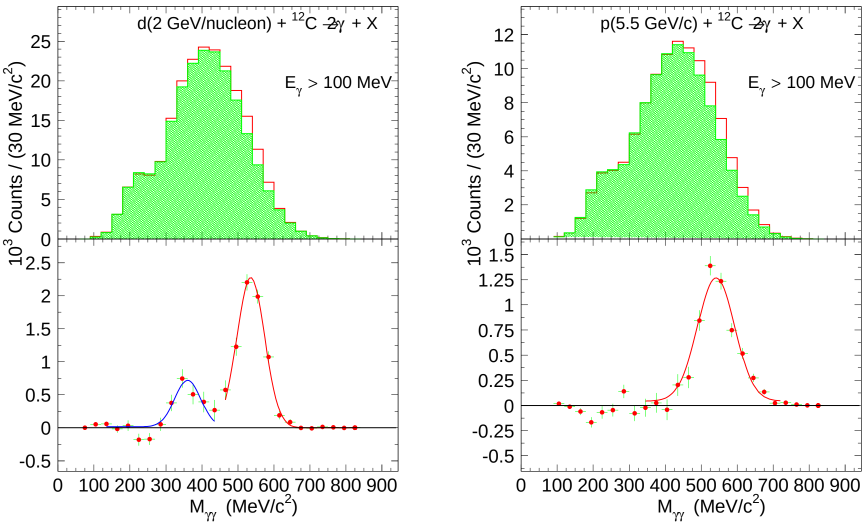

Figure 2. Invariant mass distributions of $\gamma\gamma$ pairs satisfying criteria 1)–3) without (upper panel) and with (bottom panel) the background subtraction. The left and right figures are obtained for the reaction dC-collision at 2.75 GeV/c per nucleon and pC- collision at 5.5 GeV/c, respectively. The curves are the Gaussian approximation of experimental points.

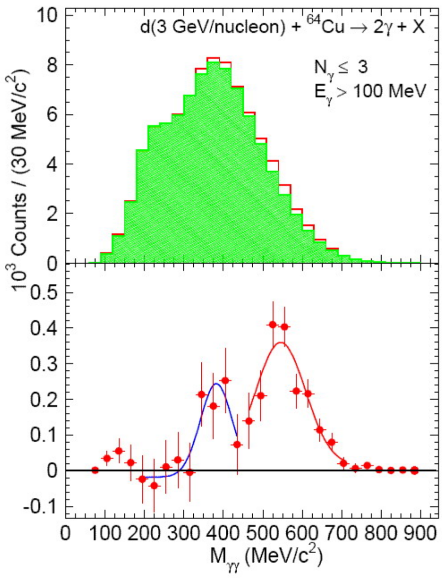

Figure 3. Invariant mass distributions of $\gamma\gamma$ pairs satisfying the criteria: $N_\gamma \leq 3$, $E_\gamma \geq 100$ MeV, the summed energy in real and random events ≤ 1.7 GeV for the reaction dCu at 3.83 GeV$/c$ per nucleon.

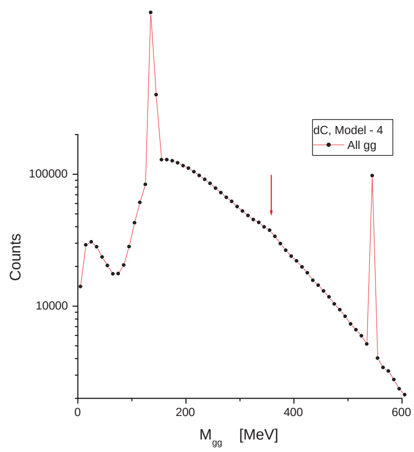

Figure 4. Invariant mass distribution in $d\mathrm{C} \to \gamma\gamma X$ in the described model with including the $\pi\pi \to R \to \gamma\gamma$ channel.

FIGURE CAPTIONS

Fig. 1: The schematic drawing of the experimental PHOTON-2 setup. The S_1 and S_2 are scintillation counters.

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