ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
2010. Т. 41. ВЫП. 7

RESONANCE STRUCTURE IN THE $\gamma\gamma$ INVARIANT MASS SPECTRUM IN pC AND dC INTERACTIONS

Kh. U. Abraamyan[1,*], *M. I. Baznat*[2], *A. V. Friesen*[1], *K. K. Gudima*[2], *M. A. Kozhin*[1], *S. A. Lebedev*[1,3], *M. A. Nazarenko*[1,4], *S. A. Nikitin*[1], *G. A. Ososkov*[1], *S. G. Reznikov*[1], *A. N. Sissakian*[1], *A. S. Sorin*[1], *V. D. Toneev*[1]

[1]Joint Institute for Nuclear Research, Dubna

[2]Institute of Applied Physics, Kishinev, Moldova

[3]Gesellschaft für Schwerionenforschung, Darmstadt, Germany

[4]Moscow State Institute of Radioengineering, Electronics and Automation, Moscow

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 the reaction $d\mathrm{C} \to \gamma + \gamma + X$ at momentum 2.75 GeV/c per nucleon. Estimates of its width and production cross section are $\Gamma = (63.7 \pm 17.8)$ MeV and $\sigma_{\gamma\gamma} = (98 \pm 24^{+93}_{-67})$ μb, respectively. The collected statistics amount to (2339 ± 340) events of $1.5 \cdot 10^6$ triggered interactions of a total number $\sim 10^{12}$ of dC interactions. This resonance structure is not observed in pC collisions at the beam momentum 5.5 GeV/c. Possible mechanisms of this ABC-like effect are discussed.

PACS: 24.30.-v

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

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 momentum 2.75 GeV/c per nucleon and of protons with 5.5 GeV/c. Typical deuteron and

*E-mail: abraam@sunhe.jinr.ru

proton fluxes were about 10^9 and $2 \cdot 10^8$ 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.

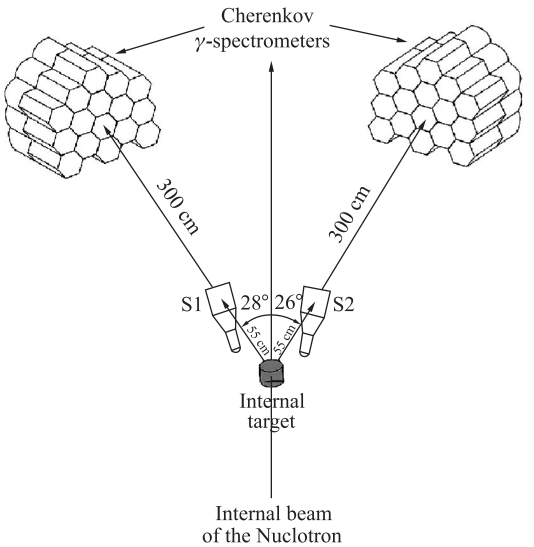

Fig. 1. The schematic drawing of the experimental PHOTON-2 setup. The S1 and S2 are scintillation counters

To calculate experimental hall background the empty-target experiment has been run. Charged particles part of background has been rated by measurement with including to trigger veto-detector and without it and by comparison data from experiments with different beam intensity. The contribution in the total combinatorial spectrum of charged particles, neutrons and particles from a general background in the accelerator hall is less than 10% and becomes negligible ($< 1\%$) after subtraction of event mixing background.

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, $E_\gamma \geqslant 100$ MeV; 3) the summed energy in real and random events $\leqslant 1.5$ GeV.

The invariant mass distribution before and after background subtraction is shown in Fig. 2.

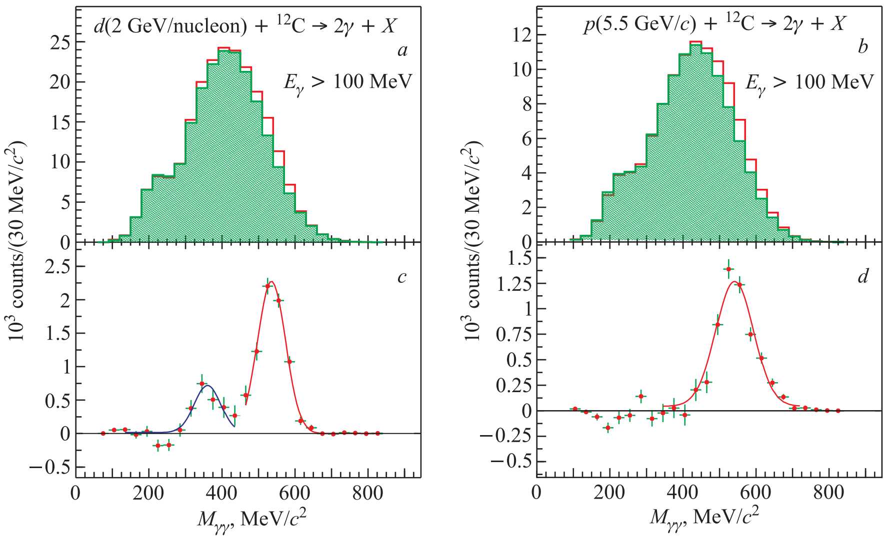

Fig. 2. Invariant mass distributions of $\gamma\gamma$ pairs satisfying criteria 1)–3) and the trigger condition without (a, b) and with (c, d) the background subtraction. The plots a, c and b, d are obtained for the reaction dC collision at 2.75 GeV/c per nucleon and pC collision at 5.5 GeV/c, respectively. The curves are the Gaussian approximation of experimental points

To clarify the nature of the detected structure in dC collision the next points were investigated:

1. The dependence of peak position and width on the opening angle and energies of photons.

2. The opening angle $\theta_{\gamma\gamma}$ distribution of the $\gamma\gamma$ pairs in different intervals of the photon energies sum.

3. The influence of the systematic errors in the event mixing background.

4. The wavelet analysis.

5. The comparisons with model data.

To simulate pC and dC reactions in 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 through 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 resonance can be created by $\pi\pi$ interactions if the invariant mass of two pions obeys the Breight–Wigner distribution with observed parameters and both γ-quanta satisfy experimental condition. The two-photons invariant mass spectrum and its comparison with experiment is shown in Fig. 3.

Another candidate for realization of dibaryon mechanism may be a model of the intermediate σ-dressed dibaryon [9]. In this model the short-range NN in-

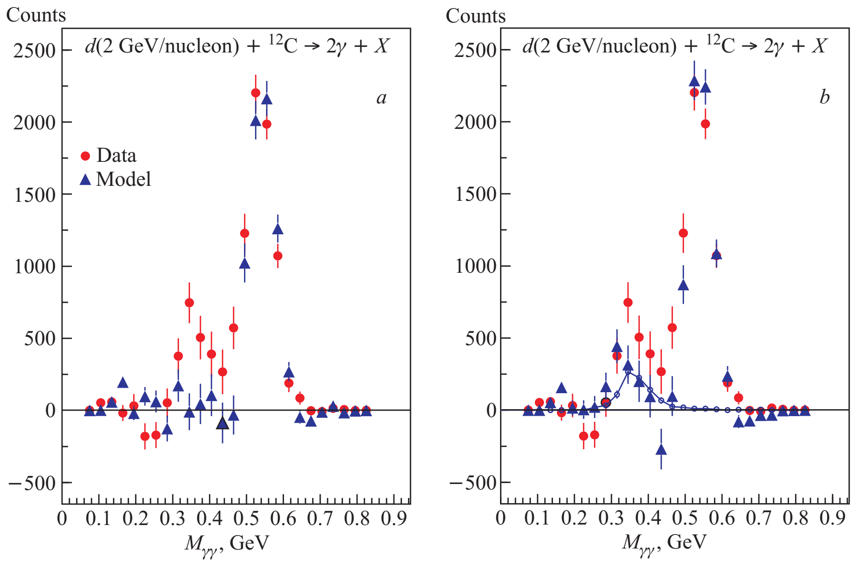

Fig. 3. The comparison of invariant mass distributions after background subtraction in $d\mathrm{C} \to \gamma\gamma X$ with the modeling result without (*a*) and with (*b*) including of the $\pi\pi \to R \to \gamma\gamma$ channel

teraction, described by the standard t-channel σ exchange between two nucleons, is replaced with the respective s-channel σ exchange associated with the intermediate dibaryon production treated as a σ-dressed six-quark bag. The strong scalar σ field arises around the symmetric $6q$ bag, because of the change in the symmetry of six-quark state in the transition from the NN channel to the intermediate dressed-bag state. Due to a strong attraction of the σ meson to quarks, this intensive σ field squeezes the bag and increases its density. The high quark density in the symmetric $6q$ state enhances meson field fluctuations around the multiquark bag and thereby partially restores the chiral symmetry. Therefore, the mass of σ meson gets much lower and has been estimated to be the value $m_\sigma \sim 350{-}380$ MeV. In its turn, it should enhance the near-threshold pion and double-pion production [9, 10]. This mechanism is now under investigation.

Thus, based on a thorough analysis of experimental data measured at the JINR Nuclotron and record statistics of (2339 ± 340) events of $1.5 \cdot 10^6$ triggered interactions of a total number $2 \cdot 10^{12}$ 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. 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 cases.

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.

From the experimental side it is highly desirable to determine more accurately the mass, width and cross section of the observed resonance structure by enlarging the acceptance. To verify the above conclusions new experiments are required to be carried out under conditions appropriate for registration of pairs of two photons within the invariant mass interval of 300–400 MeV. In this respect experiments on proton and Carbon targets with proton and deuteron beams at the same energy per nucleon would be very useful. Some scanning in the beam energy will clarify the possible resonance structure of this effect. By varying the opening angle of the PHOTON-2 spectrometer it is possible to get information about momentum spectra of the produced resonance-like structure which could be a delicate test of the R-production mechanism.

Acknowledgements. We are grateful to A. S. Danagulyan, S. B. Gerasimov, V. D. Kekelidze, A. S. Khrykin, E. E. Kolomeitsev, V. I. Kukulin, A. M. Sirunyan,

O. V. Teryaev, G. A. Vartapetyan for numerous fruitful discussions. We thank S. V. Afanasev, V. V. Arkhipov, A. S. Artemov, A. F. Elishev, A. D. Kovalenko, V. A. Krasnov, A. G. Litvinenko, A. I. Malakhov, G. L. Melkumov, S. N. Plyashkevich and the staff of the Nuclotron for their help in conducting the experiment, as well as B. V. Batyunya, A. V. Belozerov, A. G. Fedunov, V. V. Skokov and V. D. Yudichev for their help in analyzing data.

The work was supported in part by the Russian Foundation for Basic Research, grant 08-02-01003-a and a special program of the Ministry of Education and Science of the Russian Federation, grant RNP.2.1.1.5409.

REFERENCES

1. *Abraamyan Kh. U. et al.* // Proc. of the Intern. Workshop «Relativistic Nuclear Physics: from Hundreds MeV to TeV». Dubna, 2005. P. 228; Workshop Round-Table Discussion «Searching for the Mixed Phase of Strongly Interacting Matter at the JINR Nuclotron», Dubna, 7–9 July, 2005; http://theor.jinr.ru/meetings/2005/roundtable/
2. *Abraamyan Kh. U., Sissakian A. N., Sorin A. S.* Observation of New Resonance Structure in the Invariant Mass Spectrum of Two Gamma-Quanta in *d*C Interactions at Momentum 2.75 GeV/*c* per Nucleon. nucl-ex/0607027.
3. *Abraamyan Kh. U. et al.* // Phys. Lett. B. 1994. V. 323. P. 1; Yad. Fiz. 1996. V. 59. P. 271; 1997. V. 60. P. 2014; 2005. V. 68. P. 1020.
4. *Abraamyan Kh. U. et al.* // PTE. 1989. V. 1. P. 57; 1996. V. 6. P. 5.
5. *Khachaturian M. N.* JINR Commun. E1-85-55. Dubna, 1985; *Astvatsaturov R. G. et al.* // Nucl. Instr. Meth. 1979. V. 163. P. 343.
6. *Gudima K. K., Toneev V. D.* // Nucl. Phys. A. 1983. V. 400. P. 173c.; *Gudima K. K. et al.* // Ibid. V. 401. P. 329.
7. *Brown L. M., Singer P.* // Phys. Rev. Lett. 1962. V. 8. P. 460.
8. *Khrikin A. S. et al.* // Phys. Rev. C. 2001. V. 64. P.034002; Nucl. Phys. A. 2003. V. 721. P. 625c.
9. *Kukulin V. I., Shikhalev M. A.* // Phys. At. Nucl. 2004. V. 67. P. 1536; *Faessler A., Kukulin V. I., Shikhalev M. A.* // Ann. Phys. 2005. V. 320. P. 71; *Kukulin V. I. et al.* // Intern. J. Mod. Phys. E. 2002. V. 11. P. 1.
10. *Kukulin V. I. et al.* // J. Phys. G. 2004. V. 30. P. 287; J. Phys. G. 2004. V. 30. P. 309.