A Resonance Structure in the $\gamma\gamma$ Invariant Mass Spectrum in pC- and dC-Interactions

The plan of the report

- The experimental results.
- Data simulation.
- Possible mechanisms of the observed effect.
- Conclusion.
Abstract

- Firstly a resonant structure was observed in the invariant mass spectrum of two photons at $M_{\gamma\gamma} = 360 \pm 7 \pm 9\text{MeV}$ in dC-interactions at momentum 2.75 GeV/c per nucleon.
- Estimates of width and production cross section are: $\Gamma = 49.5 \pm 18.6\text{MeV}$ and $\sigma_{\gamma\gamma} = 98 \pm 24 \pm 93-67\text{\mu b}$.
- The collected statistics amount $2339 \pm 340$ events of $1.5*10^6$ triggered interactions of a total quantity $10^{12}$ of dC-interactions.
- This resonant structure wasn’t observed in pC-interactions at 5.5 GeV/c.
PHOTON-2 setup on internal beams of the NUCLotron
PHOTON-2 setup on internal beams of the NUCLOTRON
Selection criteria to background subtraction

1) the number of photons in an event, $N_{\gamma} = 2$
2) the energies of photons, $E_{\gamma} \geq 100$ MeV
3) the summed energy in real and random events $\leq 1.5$ GeV
Invariant mass distributions of γγ pairs satisfying the criteria (1) – (3) without (upper panel) and with (bottom panel) the background subtraction. The curves are the Gaussian approximation of experimental points.
Check of the observed effect

The dominant part of background comes from the $\pi^0 \rightarrow \gamma\gamma$ 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 $M_{\gamma\gamma}$. (sl. №24)

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 (sl. №25 27)
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 and their energy selection level: both maxima survive and located practically at the same values of $M_{\gamma\gamma}$. (sl. №28, 29)

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

5. Investigations of systematic errors. (sl. №30)

6. Similar analysis within the wavelet method. (sl. №31)

7. Comparisons with another experiments. (sl. №32-34)

8. Model simulation under the experimental conditions (see below).
Distribution of the opening angle of $\gamma\gamma$ pairs in dC collisions for the two selections of $(E_{1\gamma} + E_{2\gamma})$. 

![Graph showing distribution of opening angles for different energy ranges](image)
Data simulation

- To simulate pC- and dC- reactions we used a two-phases transport code [K.K. Gudima et al. LANL Report LA-UR-01-6804, Los Alamos, 2001]

- The following γ-decay channels are taken into account:
  - the direct decays of π⁰, η, η' hadrons into two γ’s;
  - ω → π⁰γ;
  - Δ → γγ;
  - the Dalitz decays of η → ππγ, η → γee, π⁰ → γee;
  - η' → ρ⁰γ, Σ → Λγ,
  - the πN and NN-bremsstrahlung.
The calculated $\gamma \gamma$ invariant mass distribution in pC and dC collisions for selected events with $N_{\gamma} = 2$. 

![Graphs showing $\gamma \gamma$ invariant mass distributions for pC and dC collisions with different decay channels.](image_url)
The invariant mass distributions of $\gamma \gamma$ pairs from the dC (left) and pC (right) reactions after background subtraction.
Invariant mass distributions of $\gamma\gamma$ pairs from the pC and dC reactions after background subtraction. Both experimental (circles) and simulated (triangles) points are obtained under the same conditions. The contribution of photons from the R decay is shown by the solid line.
New preliminary results

The invariant mass distributions of $\gamma\gamma$ pairs from the dCu reaction after background subtraction.
The invariant mass distributions of $\pi^0\pi^0$ pairs from the dC (left) and pC (right) reactions after background subtraction. Normalization of the backgrounds by the total numbers of pairs in the spectra.

PRELIMINARY
Dibaryon mechanism (I)

Recently the idea of nontrivial dibaryon state becomes more attractive. The proposed mechanism $NN \rightarrow d^* \rightarrow NN\gamma\gamma$ proceeds through a sequential emission of two photons: one is caused by production of the decoupled baryon resonance $d^*$, second is its subsequent decay.

Dibaryon mechanism (II)

Very attractive candidate for its realization might be a model of the intermediate $\sigma$-dressed dibaryon. In this model the short-range $NN$-interaction is described with the s-channel $\sigma$ exchange associated with the intermediate dibaryon production treated as a $\sigma$-dressed six-quark bag. As the result we have decrease of the assumed $\sigma$- mass, it is estimated $M\sigma \sim 350$ - $380$ MeV. Therefore it should enhance the near-threshold pion and double-pion production. [V.I.Kukulin et al. J.Phys.G30(2004)287, 30(2004),309]

This mechanism is now under investigation.
Concluding remarks

1. Following a experiment at the JINR Nuclotron the resonans-like enhancement was observed in two-gamma spectrum in dC-interactions (2.75 GeV/c per nucleon). Estimates of its characteristics are:
   \[ M_{\gamma\gamma} = 360 \pm 7 \text{ MeV}, \quad \Gamma = 49 \pm 19 \text{ MeV}, \quad \sigma_{\gamma\gamma} \sim 98 \mu \text{b} \]

2. A structure like this was not observed in the M_{\gamma\gamma} spectrum from pC (5.5 GeV/c) interactions while the \( \eta \) meson was clearly seen in both the cases.
Concluding remarks

3. To understand the nature of the observed effect were attempted some dynamic mechanisms:
   - production of the hypothetic $R$ resonance in $\pi\pi\pi$ interactions during the evolution of the nuclear collision;
   - formation of the $R$ resonance with participation of photons from the $\Delta$ decay;
   - the $\pi^0\pi^0$ interaction effect in the $3\pi^0$ channel of the $\eta$ decay;
   - a particular decoupled dibaryon mechanism.
Concluding remarks, outlook

4. The dibaryon mechanism is discussing as a possible explanation of observed enhancement. In this way it can be considered as $\sigma$-meson.

5. From the experimental side: 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. 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 resonance-like structure which could be a test of the $R$ production mechanism.
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Thank you for attention!
Invariant mass distributions of $\gamma \gamma$ pairs in two different runs of measurement under condition $E_\gamma \geq 50$ MeV: with the empty target (dashed histogram) and with the internal carbon target (solid histogram) in the reaction $dC = \gamma + \gamma + X$ at 2.75 GeV/c per nucleon.
Charged particles contribution

- All counts of pairs
- Backgrounds

\[ N \text{ without sep.} / N \text{ with S1xS2} \]

\[ M_{\gamma\gamma}, \text{ MeV} \]

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Charged particles contribution after background subtraction

Ratio (All pairs) / Ratio (Backgr.)

Ratio (All pairs) / Ratio (Backgr.)

\( M_{\gamma}, \text{ MeV} \)

0,80 0,85 0,90 0,95 1,00 1,05 1,10 1,15 1,20
0 200 400 600 800
Invariant mass distributions of $\gamma\gamma$ pairs satisfying the criteria (1) – (2) after background subtraction in the reaction $dC = \gamma + \gamma + X$ at 2.75 GeV/c per nucleon for two different beam intensities: 503 events/cycle (a) and 85 events/cycle.
The invariant mass distributions of two photons for the opening angles $0.55 < \cos (\Theta_{\gamma\gamma}) < 0.65$ (left) and $0.65 < \cos (\Theta_{\gamma\gamma}) < 0.75$ (right) under the selection criteria (1) – (2).
Invariant mass distributions of $\gamma\gamma$ pairs satisfying the criteria (1) – (2) after background subtraction in the reaction $dC = \gamma + \gamma + X$ at 2.75 GeV/c per nucleon for two energy selection levels.
$N_{\gamma} = 3$
$N_{\gamma}=3$: 1$\gamma$ in the L.Arm, 2$\gamma$ in the R.Arm +

2$\gamma$ in the L.Arm, 1$\gamma$ in the R.Arm
The invariant mass distribution of $\gamma\gamma$ pairs and the biparametric distribution of the GW of the 8-th order for dC (left) and pC (right) interactions. The distribution is obtained with an additional condition for photon energies $E_{\gamma 1}/E_{\gamma 2} > 0.8$ and binning in 2MeV.
Results of the invariant-mass analysis of photon pairs (TAPS). The upper frame shows
the invariant-mass spectrum which corresponds to the $\eta$ trigger in the experiment
$^{58}$Ni+$^{58}$Ni at 1.9 AGeV. The combinatorial background (dotted line) was determined
by event mixing. The lower frame shows the invariant-mass distribution after
background subtraction and demonstrates the quality of the background determination.
Comparison with experiments on the “TAPS”

<table>
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<tr>
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<th>TAPS</th>
<th>PHOTON-2</th>
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<tbody>
<tr>
<td>Opening angles</td>
<td>65°-102°</td>
<td>42°-66°</td>
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<tr>
<td>η energies (GeV)</td>
<td>&gt; 0.70</td>
<td>&gt; 1.01</td>
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<td>Mean values</td>
<td>0.85</td>
<td>1.21</td>
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<td>O.R. energies</td>
<td>&gt; 0.457</td>
<td>&gt; 0.652</td>
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<tr>
<td>Mean values</td>
<td>0.552</td>
<td>0.782</td>
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<td>Total cr. sect. (b)</td>
<td>2.021</td>
<td>0.612</td>
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<td>Arm’s area (m²)</td>
<td>0.578</td>
<td>0.424</td>
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<td>Arm’s solid angle (sr)</td>
<td>0.257</td>
<td>0.047</td>
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<tr>
<td>En.res. σ/E (m.v.,%)</td>
<td>3.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Sig./B. in 300-420:</td>
<td>~ 0.0014 a</td>
<td>0.027</td>
</tr>
</tbody>
</table>

(<0.004)

a Sig. ~ \sqrt{6 \cdot 10^5}
Necessary statistics for same observation in the experiment on TAPS

\[ \sim 3 \cdot 10^{12} \cdot \left( \frac{\Delta \Omega_{\text{PHOTON}}}{\Delta \Omega_{\text{TAPS}}} \right)^2 \cdot \left( \frac{\Delta M_{\text{PHOTON}}}{\Delta M_{\text{TAPS}}} \right)^2 \cdot \left( \frac{(S/B)_{\text{PHOTON}}}{(S/B)_{\text{TAPS}}} \right)^2 \]

\[ S/B = 0.0014 \]

\[ \sim 3 \cdot 10^{12} \cdot \left( \frac{0.047}{0.257} \right)^2 \cdot \left( \frac{3.0}{6.1} \right)^2 \cdot \left( \frac{0.027}{0.0014} \right)^2 \]

\[ = 9 \cdot 10^{12} \text{ interactions,} \]

\[ S/B < 0.004 : \]

\[ > 1.1 \cdot 10^{12} \text{ interactions.} \]

\[ N_{\text{cycle}} > \frac{(1.1 \cdot 10^{12})}{(5 \cdot 10^6 \cdot \omega)} = \]

\[ = 4 \, 500 \, 000 \text{ accelerator cycles,} \]

\[ \omega = \rho x \cdot \frac{N_A}{A} \cdot \sigma(CC) = 0.049, \quad \rho x = 0.487 \text{ g/cm}^2 \]

For indication (+3 st.err.) : > 550 000 acceler. cycles
Invariant mass distributions of $\gamma\gamma$ pairs satisfying the criteria (1) – (2) after background subtraction in the reaction $dC = \gamma + \gamma + X$ at 2.75 GeV/c per nucleon. Normalization of the background by the total number of pairs in the spectrum.
Блок-схема электронной аппаратуры
Invariant mass distributions of γγ pairs from the dC reaction. The top shaded histograms show the background contribution. The bottom histograms are invariant spectra after the background subtraction.
Распределение по инвариантной массе пар γ-квантов до и после вычитания фона: моделированные данные в реальных условиях эксперимента, без включения резонанса.
Energy distribution of $\gamma$-quanta in the dC reaction

d + C $\rightarrow \gamma + \gamma + x,$
$T_d = 2.0 \ \text{GeV/n}$
Without $300 < E_\gamma < 450$ MeV
Without $300 < E < 450$ MeV

Counts / 30 MeV

$M_{\gamma\gamma}$, MeV
Спектр эффективных масс пар γ-квантов за вычетом фона в реакции \( d + C \rightarrow \gamma + \gamma + x \), \( E_d = 1.98 \text{ ГэВ/н} \), \( E_\gamma > 100 \text{ МэВ} \). \( D_i = 50 \text{ мВ} \)
$d + Cu \rightarrow \gamma + \gamma + \ldots$

$T_d = 3.0 \text{ GeV / Nucleon}$