Photon and π^0 pairs production in proton-nucleus and deuteron-nucleus interactions. Results of experiments on internal beams of the Nuclotron

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Abstract. The results of experiments on photon and π^0 pairs production in interactions of 5.5 GeV/c protons, 2.75 and 3.83 GeV/c per nucleon deuterons with carbon and copper nuclei are presented. As previously reported (see. [1] and references therein), 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 $dC \to \gamma + \gamma + X$ at momentum 2.75 GeV/c per nucleon. Here are some results of testing the signal and results of statistical analysis of the experimental data which allow to explain the lack of appearance of the signal in other experiments [2, 3] and make predictions for possible appearances of the signal in upcoming experiments.

1 Introduction

This paper is an extension of the research begun earlier (see. [1] and references therein). The first results on π^0 pairs production in interactions of 3.83 GeV/c per nucleon deuterons with copper nuclei are obtained. Also here are results of further verification of the signal detected in the spectrum of the invariant mass of photon pairs in the reaction $d + C \to \gamma + \gamma + X$ at 2.75 GeV/c per nucleon and results of statistical analysis of the experimental data: the possible influence of the internal beam characteristics on the properties of the events detected in different time intervals of the accelerator cycles and appearances of the signal in different parts of the collected statistics. These results allow to explain the lack of appearance of the signal in other experiments [2, 3] and make predictions for possible appearances of the signal in upcoming experiments.

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2 π^0 pairs production in deuteron-copper interactions

Results of an analysis of the d(2.0 GeV/n)+C and p(4.6 GeV)+C events with 4 or more detected photons, are given in [1, 4]. Further analysis of the data for d(3.0 GeV/n)+Cu interactions obtained at lower thresholds of the discriminators (the discriminator thresholds were chosen to be 0.4 and 0.35 GeV for d + C and d + Cu reactions, respectively), shows that the structure, which observed in the d(2.0 GeV/n)+C and p(4.6 GeV)+C reactions after the background subtraction, is also observed in the d(3.0 GeV/n)+Cu reaction (see. figure 1).

3 Photon pair production

Below are the results of testing the signal detected in the spectrum of the invariant mass of photon pairs in the reaction $d + C \to \gamma + \gamma + X$ at 2.75 GeV/c per nucleon [5].

3.1 Another selection criteria

Another method to decrease the influence of possible violations of the energy-momentum conservation laws on the mixing-event background, is a restriction of energies of individual photons (instead of restriction of the sum of their energies [1, 5]). For a background suppression and minimization of systematical errors due to violation of conservation laws the following selection criteria were used:

(1b) the number of photons in an event, $N_\gamma \leq 3$ (the events of each type (one of the photons in the left arm and two on the right, etc.) were analysed separately, the results were summarized);

(2b) the energies of photons, $100 < E_\gamma < 750$ MeV;

The results of this analysis are given in figure 2.

3.2 The accuracy of the combinatorial background

To verify the accuracy of the combinatorial background we have used the method of "miscalibration" of modules of the γ-spectrometer by introduction of chaotic coefficients in the energy scale in each module of the spectrometer. The results are shown in figure 3.

3.3 Data simulation

In order to verify the experimental method of allocation of the observed signal there were simulations of studied reactions performed with accurate experimental measurement conditions, including the set of corresponding event class (see [5]). As the first step, any sources of the signal were not included in the model (see figure 4, left).

Then we have included the additional channel of two-γ creation by two-pion interaction with the observable structure formation. We assume that the resonance can be created by $\pi\pi$ interactions if the invariant mass of the pions obeys Breight-Wigner distribution with the observed parameters (see figure 4, right).

4 Statistical analysis of the experimental data

4.1 Different parts of the accelerator cycles

The purpose of this analysis is to investigate the possible influence of the internal beam characteristics on the properties of the events detected in different time intervals of the accelerator cycles. For this

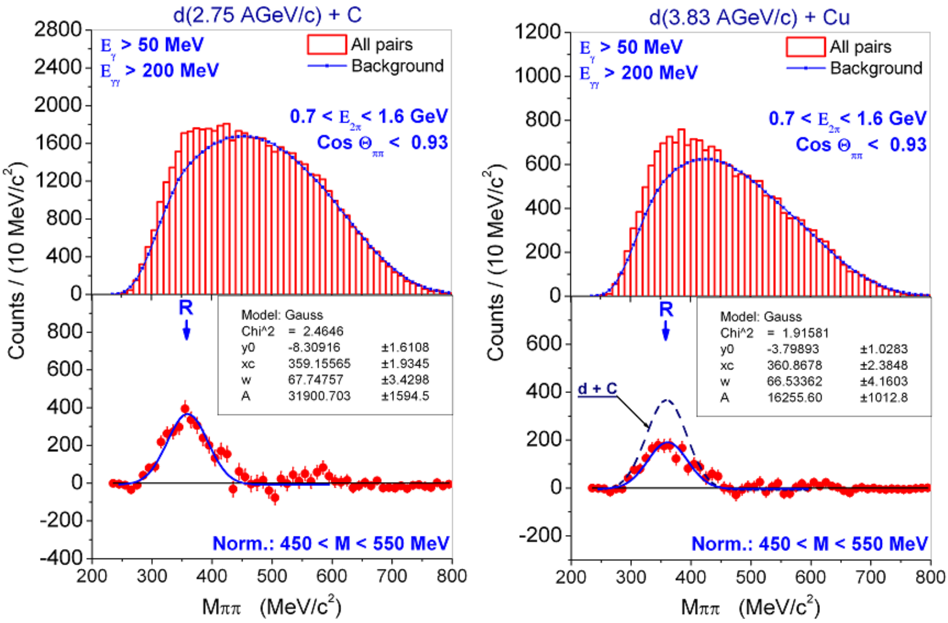

Figure 1. The invariant mass distributions of $\pi^0\pi^0$ pairs without (upper panels) and with (bottom panels) the background subtraction for the reactions $d+C$ at 2.75 GeV/c per nucleon [4] (left figure) and $d+Cu$ at 3.83 GeV/c per nucleon (right figure). The backgrounds are normalized to pair numbers in the interval: $450 < M_{\pi\pi} < 550$ MeV/c^2.

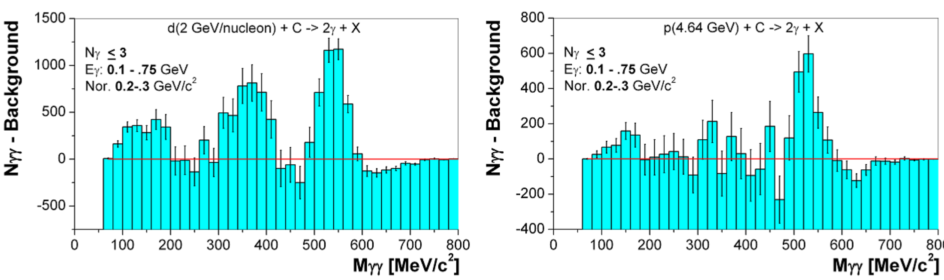

Figure 2. The invariant mass distributions (per 20 MeV/c^2) of $\gamma\gamma$ pairs satisfying criteria (1b)-(2b) in the reactions $d(2\ GeV/n)+C \rightarrow \gamma+\gamma+X$ (left figure) and $p(4.6\ GeV)+C \rightarrow \gamma+\gamma+X$ (right figure) after the background subtraction. The backgrounds are normalized to pair numbers in the interval: $200 < M_{\gamma\gamma} < 300$ MeV/c^2.

analysis we have used the data obtained on an internal beam of deuterons with momentum 2.75 GeV/c per nucleon [5]. The internal target consists of carbon wires with the diameter of 8 microns mounted in a rotatable frame. The overall construction is located in the vacuum shell of the accelerator. The duration of the irradiation cycle is 1 s. For the analysis, the data collected at the maximum beam intensity ($\sim 10^9$ per pulse), were selected (about 2/3 of all the data in the reaction d(2.0 GeV/n)+C [5]). The results of this analysis are shown in figures 5, 6.

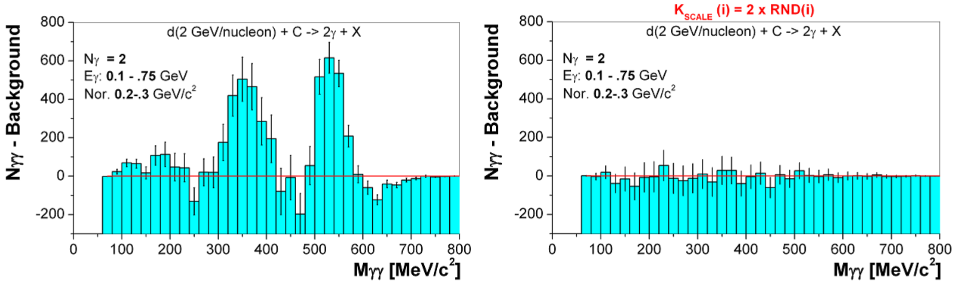

Figure 3. Invariant mass distributions (per 20 MeV/c^2) of $\gamma\gamma$ pairs in the reactions $d(2\ GeV/n) + C \to \gamma + \gamma + X$ after the background subtraction, at the number of photons in an event, $N_\gamma = 2$ and at the energies of photons, $100 < E_\gamma < 750$ MeV (left figure), and the same but after a "miscalibration" of the modules by the introduction of chaotic coefficients in the range $0 \div 2$: $E_i \to E_i \cdot 2 \cdot RND(i)$, (where E_i is the energy in the i-th module, $RND(i)$ are random numbers) (right figure). Here, the average of results obtained after the introduction of 6 different sets of random numbers is shown. The backgrounds are normalized to pair numbers in the interval: $200 < M_{\gamma\gamma} < 300$ MeV/c^2.

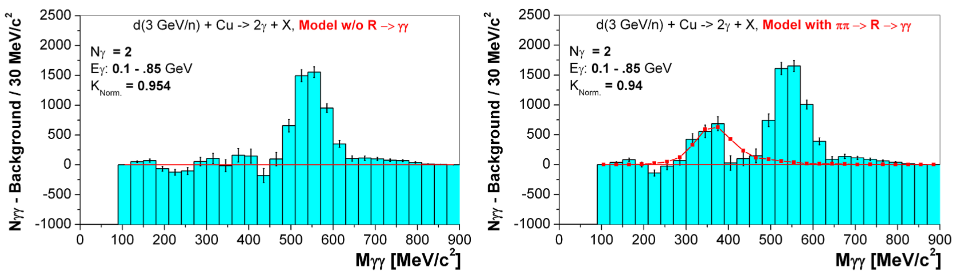

Figure 4. Invariant mass distributions of $\gamma\gamma$ pairs from the $d(3\ GeV/n)$+Cu reaction after the background subtraction, at the number of photons in an event, $N_\gamma = 2$ and at the energies of photons, $100 < E_\gamma < 850$ MeV, without (left figure) and with the reaction $\pi + \pi \to R \to \gamma + \gamma$ (right figure), under the real experimental conditions. The spectra are the result of processing the simulated data with the method which was applied to the experimental data. The contribution of photon pairs from the resonance decay (selected with the help of labels of photons applied in the model) is shown by the solid line. The auxiliary factors K_{Norm} of the backgrounds normalization (see the text, 4.2) are given in the figures.

4.2 Different parts of the collected statistics

The purpose of this analysis is to show different appearances of the signal at low (for a given signal-to-background ratio) statistics. In particular, this allows to explain the lack of appearance of the signal in other experiments [2, 3] and make predictions for possible appearances of the signal in upcoming experiments.

To create conditions, in terms of statistics similar to those of the experiment on TAPS [2] (see also our analysis of this experiment in [5]), we divided the statistics recorded in the reaction d(2.0 GeV/n)+C into 19 parts. Each part was analysed separately, under the conditions shown in figure 3. The spectrum in figure 3 contains a total of 189864 selected ($N_\gamma = 2$) events. The number of pairs after the background subtraction in the range of 300-420 MeV/c^2 (in the vicinity of the resonance

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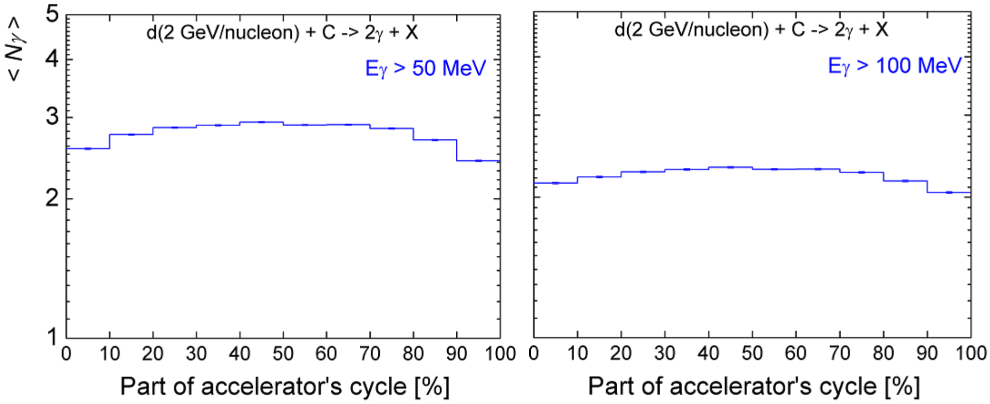

Figure 5. The mean number of detected photons in an event, recorded in different intervals of accelerator cycle, with a minimum energy of photons, $E_{\gamma min}$ = 50 MeV (left) and $E_{\gamma min}$ = 100 MeV (right).

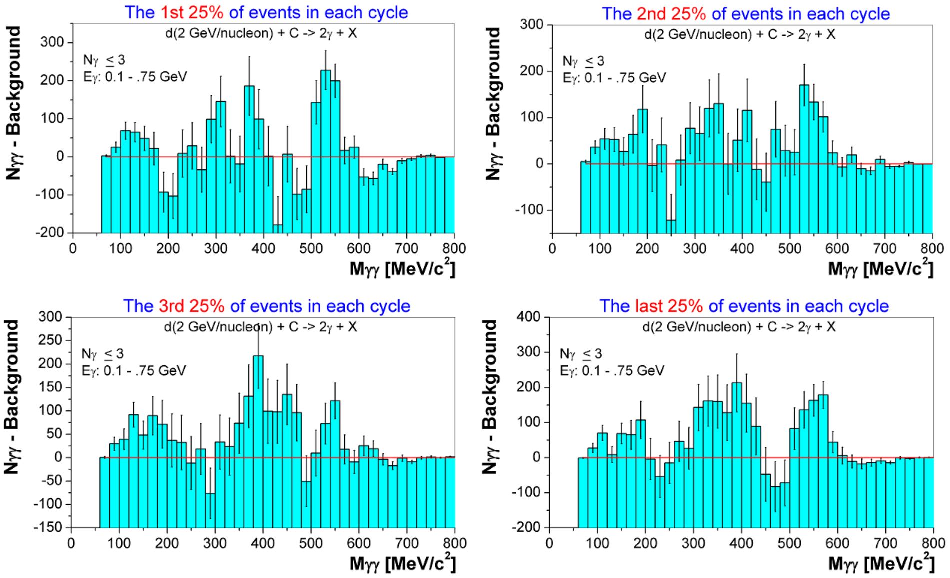

Figure 6. The invariant mass distributions of $\gamma\gamma$ pairs satisfying criteria (1b)-(2b) in the reactions $d(2\ GeV/n) + C \rightarrow \gamma + \gamma + X$ after the background subtraction, in the events recorded in different intervals of accelerator cycle. The backgrounds are normalized to pair numbers in the interval: $200 < M_{\gamma\gamma} < 300$ MeV/c^2.

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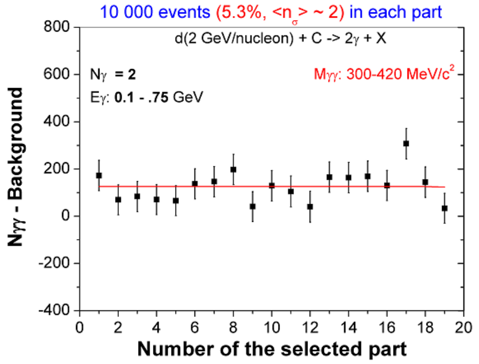

Figure 7. The number of pairs after the background subtraction in the range of 300-420 MeV/c^2 (in the vicinity of the resonance mass) for different parts of the statistics in the reaction $d(2\ GeV/n) + C \rightarrow \gamma + \gamma + X$, under the conditions: the number of photons in an event, $N_\gamma = 2$; the energies of photons, $100 < E_\gamma < 750$ MeV (see figure 3, left figure).

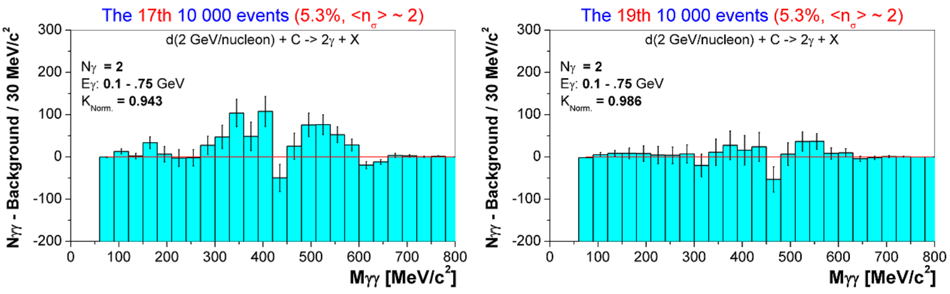

Figure 8. Invariant mass distributions (per 20 MeV/c^2) of $\gamma\gamma$ pairs in the reaction $d(2\ GeV/n) + C \rightarrow \gamma + \gamma + X$ after the background subtraction, under the same conditions as in figure 3, for different parts of the statistics collected in this experiment. The auxiliary normalization factors K_{Norm} (see the text) are given in the figures.

mass), is 2386 ± 280. Thus, the expected average number of pairs after the background subtraction in the above indicated range, for the each part is 126 ± 64, i.e. 2 standard deviations. In our experiment, each of these spectra is a result of $\sim 10^{11}$ d(2.0 GeV/n)+C interactions. Some results of this analysis are shown in figures 7, 8. The background normalization was carried out in two steps. First, the background is normalized to the total pair number. Naturally that at the event mixing the resonance maxima are not reproduced disturbing the overall normalization. At the second step this shortcoming of the background estimate is corrected by an auxiliary factor obtained by iterating treatment of the resonances contribution to the spectrum (in applying this method to the total spectrum (see figure 3) gives a result, which almost coincides with the result obtained after the normalization of the background to the number of pairs in the range 200-300 MeV/c^2).

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