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CORRELATION OF SECONDARY PARTICLES IN THE REACTION OF DISINTEGRATION OF ^{4}He(γ, pn)d ON THE BEAM OF COHERENT BREMSSTRAHLUNG RADIATION

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In this work there are set experimental data of the reaction ^{4}He(γ,pn)d at the energy of photonic beam of E_γ ÷30-100 MeV, received by the streamer chamber method on the coherent beam of γ-rays. The beam of photons was received in the result of coherent bremsstrahlung radiation (CBR) of electrons from the accelerator LU-2000 on the diamond mono crystal. There are measured energetic and angular correlations of the reaction products. It is shown, that the behavior of angular and energetic distributions, received by the diffusion chamber method on the bremsstrahlung beam of γ-rays with the help of streamer chamber on the coherent beam are the same, that allows us make a conclusion about reliability of identification of events. The presence of the deuterons with high kinetic energy and big angle recession with the proton can be explained by absorption of the γ-rays by three or more correlated nucleons.
KEYWORDS: photons, nucleons, protons, correlations, helium nucleus, streamer chamber, coherent bremsstrahlung radiation

КОРЕЛЯЦІЇ ВТОРИННИХ ЧАСТИНОК В РЕАКЦІЇ РОЗЩЕПЛЮВАННЯ ^{4}He(γ, pn)d НА ПУЧКУ КОГЕРЕНТНОГО ГАЛЬМІВНОГО ВИПРОМІНЮВАННЯ

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У цій роботі приведені експериментальні дані реакції ^{4}He(γ,pn)d при енергії фотонного пучка E_γ ÷30-100 MeV, отримані методом стримерної камери на когерентному пучку γ-квантів. Пучок фотонів виходив в результаті когерентного гальмівного випромінювання (КГВ) електронів від прискорювача ЛП-2000 на монокристалі алмазу. Виміряні енергетичні і кутові кореляції продуктів реакції. Показано, що поведінка кутових і енергетичних розподілів, отриманих методом дифузійної камери на гальмівному пучку γ- квантів і за допомогою стримерної камери на когерентному пучку співпадають, що дозволяє зробити укладення про надійність ідентифікації подій. Наявність дейтронів з високою кінетичною енергією і великим кутом розльоту з протоном може бути пояснена поглинанням γ-квантів трьома і більше корельованими нуклонами.
КЛЮЧОВІ СЛОВА: фотони, нуклони, протони, кореляції, ядро гелію, стримерна камера, когерентне гальмівне випромінювання

КОРРЕЛЯЦИИ ВТОРИЧНЫХ ЧАСТИЦ В РЕАКЦИИ РАСЩЕПЛЕНИЯ ^{4}He(γ, pn)d НА ПУЧКЕ КОГЕРЕНТНОГО ТОРМОЗНОГО ИЗЛУЧЕНИЯ

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В данной работе приведены экспериментальные данные реакции ^{4}He(γ,pn)d при энергии фотонного пучка E_γ ÷30-100 МэВ, полученные методом стримерной камеры на когерентном пучке γ-квантов. Пучок фотонов получался в результате когерентного тормозного излучения (КТИ) электронов от ускорителя ЛУ-2000 на монокристалле алмаза. Измерены энергетические и угловые корреляции продуктов реакции. Показано, что поведение угловых и энергетических распределений, полученных методом диффузионной камеры на тормозном пучке γ-квантов и с помощью стримерной камеры на когерентном пучке совпадают, что позволяет сделать заключение о надежности идентификации событий. Наличие дейтронов с высокой кинетической энергией и большим углом разлета с протоном может быть объяснено поглощением γ-квантов тремя и более коррелированными нуклонами.
КЛЮЧЕВЫЕ СЛОВА: фотоны, нуклоны, протоны, корреляции, ядро гелия, стримерная камера, когерентное тормозное излучение

There is a set experimental fact that on the small distances between nucleons in the nucleus there emerge correlations. The investigation of the nucleon – nucleonic correlations, two-nucleonic correlations in particular, is visual in the reactions of photodisintegration with the exit of the nucleon pairs. For investigation of the mechanism of the absorption of the photons by nuclei there is a reasonable investigation of the (γ,pn) – processes on the few nucleon nuclei, on the ^{4}He nucleus in particular.

Three-body photodisintegration reactions of the helium nucleus ^{4}He (γ,pn)d studied at intermediate energies range from the reaction threshold up to 150 MeV by the diffusion chamber method on the γ-ray bremsstrahlung beam from an electron accelerator with an energy of 300 MeV [1-3]. The study results were interpreted by the authors as an evidence of a significant contribution to this process of the mechanism of photo absorption by pn-pair ^{4}He.

During the investigation of the mechanism of interaction of electromagnetic radiation with light nuclei, in particular, the correlations of the nucleons in the nucleus ^{4}He it is interesting to study this reaction by qualitatively different procedure, using the photon beam, which spectrum differs from the bremsstrahlung. This paper presents new data about the reaction ^{4}He (γ,pn)d, obtained by processing the experimental results on coherent photon beam electron accelerator 2 GeV using the streamer chamber. These angular and energy correlations of secondary particles are compared with those obtained by the method of diffusion chamber on the beam bremsstrahlung γ-rays beam.

The aim of the present work is to conduct investigation by new method, i.e. method of streamer chamber on the coherent bremsstralung beam of γ-rays, received earlier with the help of diffusion chamber of products correlations of photodisintegration reaction ^{4}He(γ,pn), its comparison. The coincidence of the results justifies the reliability of identification of experimental data. Later, more accurate information about the reaction mechanism ^{4}He($\vec{\gamma}$,pn)d , about the relative contribution of one nucleon and mesonic exchange currents can be received from the asymmetry of the products reaction on the polarized beam of γ-rays, received by the same method. Nowadays there is no experimental data about the investigation of the reaction mechanism ^{4}He($\vec{\gamma}$,pn)d on the polarized beam of γ-rays at E_γ up to 150 MeV.

METHODOLOGY OF THE EXPERIMENT

Photon beam was obtained as a result of coherent bremsstrahlung (CB) of electrons from electron accelerator LU-2000 with an energy of 600 MeV and 800 MeV on diamond mono crystal with thickness t_a= 0.3 mm and t_a = 0.14 mm [4]. The position of the first maximum in the CBR spectrum was set at an energy E_γ^{max}= 60 MeV and 80 MeV. In the coordinate system, in which the X-axis coincides with the direction of the photon impulse, and Z-axis – with the direction of the magnetic field and with the axis of photographing, the polarization vector γ-rays beam was placed at an angle of ±45° to Z. In Fig. 1, the solid line shows the spectra of the photon beam CBR, after passing through the streamer chamber.

The events of this reaction were selected and visually identified by the following criteria: two-pronounced stars events were considered throughout the whole chamber volume, the apex of which is within the γ-rays beam, the recession angle between the tracks that do not exceed 160°. The impulses of the particles, forming an angle with the direction of the magnetic field less than 45^0, could not be measured with sufficient accuracy, so these events were not considered. Coordinate measuring tracks was performed with semiautomatic microscopes. Kinematic parameters of the particles were determined by program of geometrical reconstruction of events. Accuracy of determination of impulse of the reaction products (ΔP/P) was 8%, the polar angle – 3°, azimuth angle – 8°.

By visual selection of events to identify the proton and deuteron were taken into account the following: the ionization track, its characteristic change along the track, the angle to the median plane and calculated after processing, the kinematic parameters of the particles. Track method did not allow to determine the amount of emitted neutral particles, and consequently, to reliably calculate the reaction ^{4}He (γ,2p2n) [5]. Dubious events in which the proton and deuteron were difficult to distinguish, were -5% of the events.

Background reactions were excluded in the process of visual selection and analysis of kinematics of the events after the measurement. Two-pronounced stars events processes ^{4}He(γ, p)T, ^{4}He (γ, 2d) were separated from the reaction of interest on the balance of the cross-impulse.

Energy of the incident γ-rays and neutron parameters were calculated by the measured kinematic data of charged particles - the proton and deuteron [6].

If P_x, P_y, P_z - total projections of the proton and deuteron impulses per axis X, Y, Z and E - their total energy, then the energy of the gamma- is determined by the formula:

$$E_\gamma = \frac{m_n^2 + P^2 - (M_я - E)^2}{2(M_я - E + P_x)}, \quad (1)$$

where $P = (P_x^2 + P_y^2 + P_z^2)^{1/2}$, $M_я$ – mass of the target nucleus, m_n – mass of the neutron. Impulse P_n and energy E_n of the neutron were determined by correlations: $P_{nx} = E_\gamma - P_x$, $P_{ny} = - P_y$, $P_{nz} = -P_z$.
Hence:

$$P_n = (P_{nx}^2 + P_{ny}^2 + P_{nz}^2)^{1/2} .$$
$$E_n = (P_n^2 + m_n^2)^{1/2} \quad (2)$$

Thus, in the process of treatment the kinematics of the process was completely restored. In Fig.1 points represent the experimental data of spectrum, obtained using the streamer chamber for the reaction of photodisintegration

$^4He(\gamma,pn)d$ at the photon energies, in mark E_γ^{max} = 60 MeV (a) and 80 MeV (b) with ΔE_γ=5 MeV. The errors are statistical. Solid curve – is a calculated spectrum CBR, dashed - calculated bremsstrahlung spectrum [4].

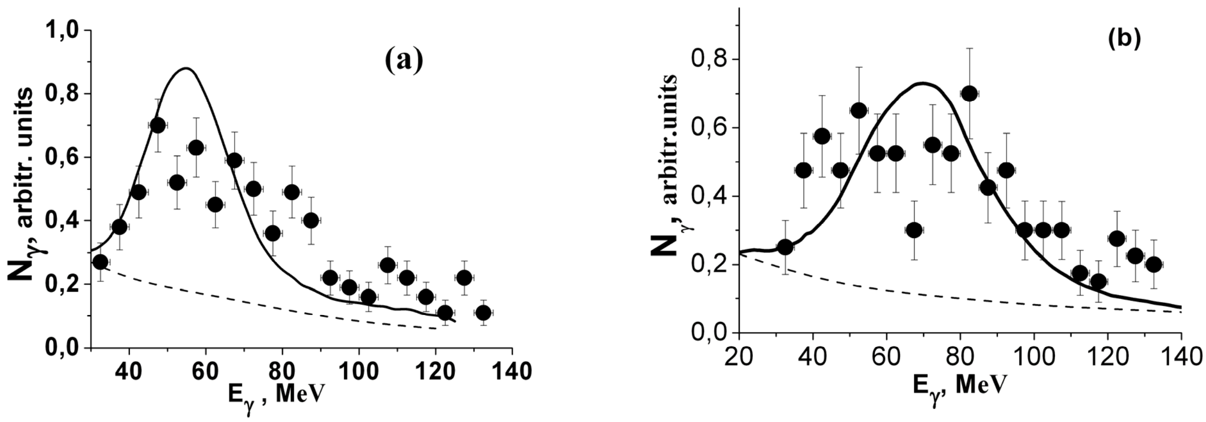

Fig.1 The CBR spectrum of photons

(a) – E_γ^{max} = 60 MeV, (b) – 80 MeV. Experimental points obtained using the streamer chamber for the reaction of photodisintegration $^4He(\gamma,pn)d$. Solid curve – is a calculated spectrum CBR, dashed - calculated bremsstrahlung spectrum [4].

ANGULAR AND ENERGETIC CORRELATIONS

One of the most "sensitive" distributions, allowing to evaluate the role of nucleon correlations in the nucleus, is the distribution of the relative energy of pairs of the reaction products, defined by expression [7]:

$$t_{ik} = \left[T_i + T_k - \frac{(\vec{P}_i + \vec{P}_k)^2}{2(m_i + m_k)} \right] \cdot E_0^{-1}, \quad (3)$$

where T_i , T_k , P_i , P_k, m_i, m_k – kinetic energies, impulses and mass of the secondary particles, E_0 – the sum of kinetic energies of all reaction products.

Fig. 2 shows the distribution of relative energy pairs of products $^4He(\gamma, pn)d$ reaction. Statistical distributions are plotted by the curve, in the calculation of which it was assumed that the correlations are determined by the phase space, the matrix elements of transition from the initial to the final state are constants and interaction in the final state does not affect on the result [7]. Upon receiving of distributions in the energy range (30-60) MeV were used events obtained for the photon beam $E_\gamma^{max} = 60$ MeV, and for distributions in the energy range (60-100) MeV events received for $E_\gamma^{max} = 80$ MeV.

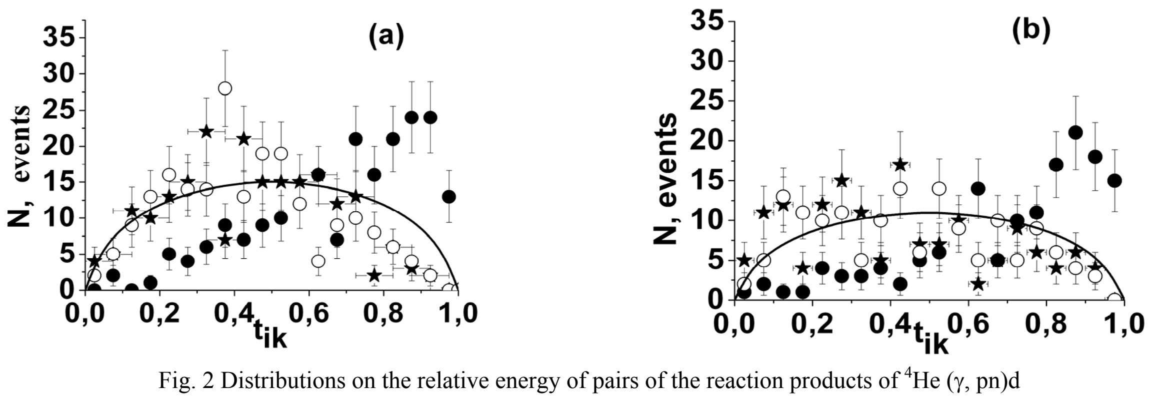

Fig. 2 Distributions on the relative energy of pairs of the reaction products of $^4He(\gamma, pn)d$

(a) – E_γ^{max} = 60 MeV, (b) – 80 MeV, resulting in a beam of coherent bremsstrahlung of photons. Dark circles - pn pairs, sprockets - pd pairs, light circles - nd pairs, curve - statistical distributions [7].

Since experimental data were obtained by summation of events throughout the chamber volume, i.e. summed over all angles, they do not depend on the polarization of the photon beam.

These distributions indicate that the proton-neutron pair takes a significant part of energy, i.e. in the reaction $^4He(\gamma,pn)d$ absorption of γ-rays, that mainly occurs in the correlated proton-neutron pair. Distribution obtained by the diffusion chamber method on a beam of bremsstrahlung photons also indicate a strong correlation of pn-pairs having the maximum possible relative energy, and with increasing E_γ this correlation becomes more clear [3].

When interacting γ-rays with a correlated proton-neutron pair can be expected that the proton and neutron will fly in opposite directions.

The following figures show the experimental data obtained on the coherent bremsstrahlung photon beam by the method of streamer chamber by the number of events depending on the angle recession with a proton and neutron (Fig. 3a,b) and proton and deuteron (Fig. 3c,d) and applied to the data obtained on the bremsstrahlung beam of γ -rays with the help of diffusion chamber. Results are normalized to the same area. Within experimental error data from diffusion and streamer chambers coincide. The curve shows normalized onto the experimental data, theoretical calculations from the streamer chamber [1] in quasideuteron approximation.

For proton - neutron pair there is a noticeable deviation of the experimental data from the theoretical curve, and for proton - deuteron pair the consent of experimental data with the theoretical curve is satisfactory. Such disagreement does not allow to draw conclusions about justice of quasideuteron mechanism for description of the experimentally obtained angular correlations.

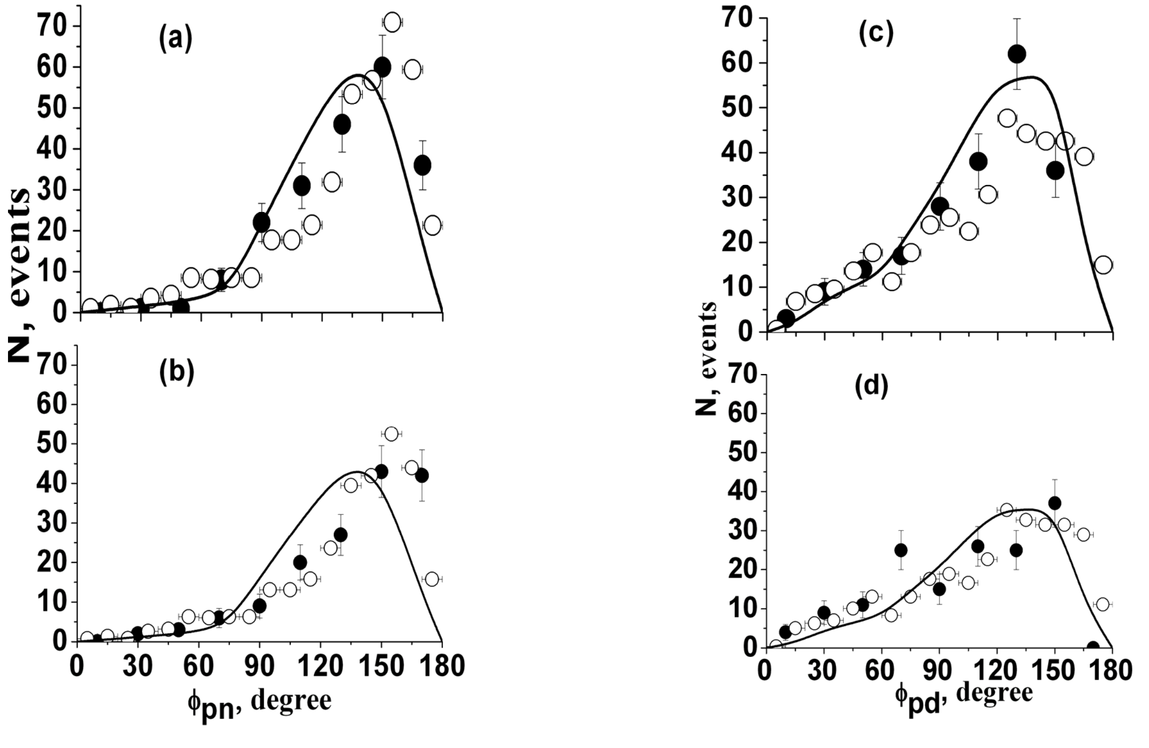

Fig.3 Dependence of the number of events from the angle recession ϕ_{pn} of proton and neutron and ϕ_{pd} for proton and deuteron (a,c) – energy γ-rays (30-60) MeV, (b,d) – (60-100) MeV. Dark circles - data from the streamer chamber, light circles – data from the diffusion chamber [3], curve - theoretical calculations in the pole approximation of the quasideuteron type [1].

Fig.4 shows the dependence of number of events on the kinetic energy of the deuteron for two intervals of energy photon beam (30-60) MeV and (60-100) MeV obtained by coherent bremsstrahlung and bremsstrahlung beams γ-rays. There is providing a comparison with theoretical calculations. Results are normalized to the same area. Within experimental error data from diffusion and streamer chambers agree qualitatively. Theoretical calculations carried out under the assumption that the polar diagrams [1] are most similar to the description of experimental data for the two energy intervals.

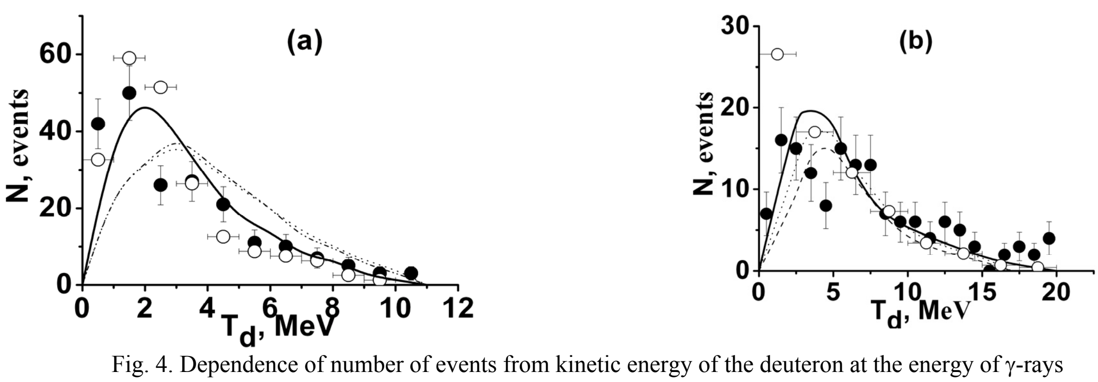

Fig. 4. Dependence of number of events from kinetic energy of the deuteron at the energy of γ-rays (a) - in the range (30-60) MeV, (b) – (60-100) MeV. Dark circles - streamer chamber, light circles - diffusion. Curves - theoretical calculations: solid curve - theoretical calculations for the pole diagram [1]. Dotted and dash-dotted curves – triangle diagrams [2].

It should be expected that during the absorption of γ-rays by the nucleon pair, deuteron is a spectator and should have a much lower kinetic energies than the proton.

In the analysis of experimental data of three-particle photodisintegration of ^{4}He nucleus at energies γ-rays up to 100 MeV [8], obtained on the basis of the diffusion chamber located on the bremsstrahlung beam of γ-rays, there was observed yield of deuterons with high kinetic energies.

Fig. 5 shows the number of events from the kinetic energy of protons and deuterons. The errors are statistical.

As shown in Fig.5 the significant part of the deuterons has a much lower energy than protons. With increasing energy, at the kinetic energies of 7 MeV the number of protons and deuterons coincides. This also coincides with the results obtained in the [8].

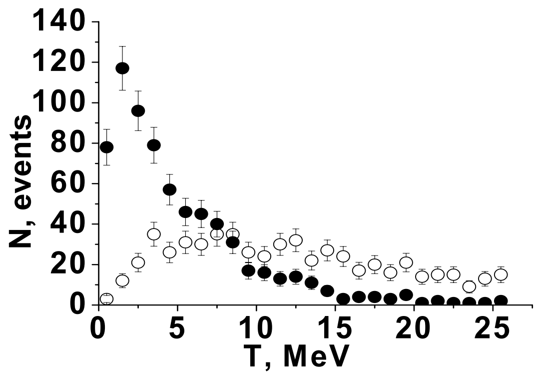

Fig. 5. Dependence of the number of events from the kinetic energy: light circles - protons, dark circles – deuterons

During the study of the reaction ^{4}He(γ,pn)d on the bremsstrahlung beam of γ-rays, there was made a conclusion [3], that the main mechanism of the reaction at photon energies above 50 MeV is the absorption of electromagnetic radiation by the nucleon pair of the nucleus, i.e. quasideuteron mechanism. However, the presence of deuterons with high energy and large angle recession with a proton contradicts this conclusion and may be explained by the absorption of γ-rays by three or more correlated nucleons.

CONCLUSIONS

Streamer chamber method on the coherent bremsstrahlung beam of γ-rays there was investigated photodisintegration reaction ^{4}He with yield of nucleon pairs ^{4}He(γ,pn)d in the energy photons range from 30 MeV to 100 MeV. Identified as the reaction ^{4}He(γ,pn)d ≈ 1000 two-pronounced stars events at energy γ-rays at peak $E_\gamma^{max} = 60$ MeV and $E_\gamma^{max} = 80$ MeV. Energy and angular correlations of reaction products are measured. It is shown that the behavior of the angular and energetic distributions of the experimental data on the bremsstrahlung and coherent beams coincide, that allows us to do a conclusion about reliability of identification of events. Comparison with theoretical predictions does not allow to make a definite conclusion about the reaction mechanism. Availability of deuterons with high kinetic energy and large angle recession with a proton can be explained by the absorption of γ-rays by three or more correlated nucleons.

Currently there is no experimental data on the investigation of the reaction ^{4}He($\vec{\gamma}$,pn)d polarized beam of γ-rays at energies up to 150 MeV. For more information about the mechanism of the reaction type ($\vec{\gamma}$,pn), the relative contribution of one-nucleon and meson exchange currents, one can hope to get during he investigation of asymmetry of the reaction products.

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