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DIGITAL METHOD FOR PROCESSING EVENTS OF (γ,np)-REACTIONS ON ^{12}C, ^{14}N, AND ^{16}O NUCLEI, OBTAINED USING BY TRACK 4π-DETECTOR

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To study (γ,np)-reactions on the nuclei of ^{12}C, ^{14}N, and ^{16}O, an algorithm-sequence of specific actions has been developed to obtain physical information about events using digital methods. A set of corresponding graphical applications has been created in the Python programming language, which allows one specialist to perform all procedures to obtain physical information regarding the studied reactions on a computer. An automated method for determining the coordinates of points along the track has been developed, significantly speeding up the process of measuring tracks. A comparison of kinematic parameters obtained by the digital methods and with the help of specialized measuring devices has been made. It has been found that the digital method improves the quality of measurement and reduces the absolute measurement error.

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INTRODUCTION

Photodisintegration reactions at the giant resonance with the emission of two nucleons are a tool for studying nucleon correlations in the nucleus, which are an important component of information about the nuclear structure [1, 2]. Initially, this was considered a good tool for studying short-range correlations. Later, it became clear that several mechanisms play a role in these reactions, and this makes it difficult to obtain information about nucleon correlations. The understanding of the various processes of interaction between γ-quantum and the nucleus has advanced considerably in recent years due to substantial improvements in both the quality of experimental data and the theoretical description of the photoemission process. When a photon is absorbed by a nucleus, various absorption processes and final state interactions create a complex theoretical problem. For nuclei with a few nucleons (e.g., ^{4}He), cross sections can be calculated from basic Feynman diagrams. However, for heavier nuclei than ^{4}He (e.g., ^{12}C, ^{14}N, and ^{16}O), the complexity of the calculation makes this approach intractable. However, the study of such nuclei is important not only to investigate the contributions of nucleons above the s-shell, but also to learn more about how the nuclear environment affects the fundamental nuclear processes.

Earlier, the ^{4}He(γ,np)d reaction was analyzed in [3]. The results given here were obtained by using a diffusion chamber placed in a magnetic field and exposed to a beam of bremsstrahlung photons, their endpoint energy being 150 MeV. The working volume of the chamber was photographed by two 2-lens stereo cameras. The physical information was obtained in several independent stages using special technical devices – stereo microscopes and semi-automatic devices of the PUOS type [4]. This procedure is quite time-consuming, requires a certain number of trained personnel and a lot of time for measuring and reconstructing tracks. In the distribution of ^{4}He(γ,np)d reaction events by deuteron kinetic energy, a peak in the low energy region (~ 90 MeV/c) was found. Within the quasideuteron model, the deuteron is a spectator, so that its kinematical parameters do not carry information about the mechanism of photon absorption by a nucleon pair, but, on leaving the nucleus, this deuteron may interact with the nucleons of the pair. Therefore, data on the deuteron spectrum are needed in analyzing reaction stages. In order to study the nature of the peak, a detailed study of the dependence of the reaction yield on the deuteron pulse at different photon energies was performed and the angular and energy correlations of nucleons at different deuteron pulses were analyzed. The peak parameters were found to be independent of the photon energy. We have explained the reaction yield in the peak region on the basis of the quasideuteron model without taking into account final-state interaction and attributed an increase in the deuteron momentum beyond 100 MeV/c to final-state deuteron-nucleon interaction.

At the next stage of the research, it was decided to obtain experimental data from the (γ,np)-reactions on ^{12}C, ^{14}N, and ^{16}O nuclei. The number of events of (γ,np)-reactions on these nuclei was estimated, and it was determined that the expected value slightly exceeds the number of events of the ^{4}He(γ,np)d reaction, but the values for ^{12}C, ^{14}N, and ^{16}O nuclei are close.

The main problem for measuring the events of such reactions was the geometry of the tracks – a long track for a single-charged particle (proton) with a noticeable curvature and a short track for a multi-charged particle (^{10}B, ^{12}C, and ^{14}N, respectively). In addition, the measurement time for all three reactions by the conventional method (PUOS) is very long, and therefore it was necessary to find a way to reduce it.

1. DIGITAL METHODOLOGY FOR PROCESSING PHOTOGRAPHIC FRAMES FROM A TRACK 4π-DETECTOR

An experimental complex for measuring and analyzing photonuclear reactions with a digital data bank of stereo frames of the corresponding reactions obtained from a 4π-track detector has been created [5]. A set of graphical applications has been developed permitting to reconstruct events and perform a physical analysis of the obtained data. The photographic frames are stored on three separate physical disks and are structured with the maximum necessary information about the experiment session. The digital format of recording information allows for all required procedures for track reconstruction to be performed on a computer with a sufficiently large screen. Optical magnification allows you to more reliably obtain the coordinates of the top of the event and better reconstruct this track.

An algorithm-sequence of specific actions has been developed to obtain physical information about events for the (γ,np)-reactions using digital methods. The procedure for obtaining physical information has been divided into several blocks:

– visual viewing of photo frames, selection of frames with events of the desired reaction;

– measuring the coordinates of points along the track on each stereo frame;

– reconstruction of 3D-parameters of the track;

– identification of the reaction and further physical analysis.

For each of the blocks for the study of (γ,np)-reactions, a set of corresponding graphical applications has been created that allow one specialist to perform all the procedures for obtaining physical information on a computer. Graphical applications have been created in Python [6] on the platform of the Tkinter graphics library, using complementary modules PIL, SciPy, NumPy and Pandas. PIL (Python Imaging Library) is a multifunctional library of image processing that allows one to perform the necessary manipulations with an image as well as accessing to each individual pixel. The created applications have an optional cycle of interaction generated by user actions such as key-in, keystroke, or cursor moving. For each potential event, a function is assigned corresponding to a specific graphical component (widget) that can be placed on the application canvas. The Matplotlib library was used as a tool for visualizing data with two-dimensional graphics.

The general procedures for digitally viewing and selecting events on different nuclei (^{12}C, ^{14}N, ^{16}O) and measuring track coordinates are the same for all target nuclei. Therefore, taking into account minor changes related to the change of service information about the target nucleus and decaying particles, the viewing and measurement blocks are the same for use.

When viewing and selecting events, it was found that the tracks for a multicharged particle (^{10}B, ^{12}C or ^{14}N) are clearly visible on the frame and their length is on average ~ 25 pixels. It was decided to create a fully automated method for obtaining the coordinates of points along the track to expedite the process of measuring the tracks.

In Fig. 1 shows three identical fragments of a photo frame. The white segments emanating from the same vertex (see Fig. 1,a) correspond to a two-track event. It should be noted that there are significant background emissions (light objects in the frame) that can distort the data during image analysis. They arise due to the complex gas structure of the diffusion chamber. However, such background emissions are not systematic and, obviously, the total intensity along the tracks should be higher.

To implement an automatic technique for obtaining the kinematic parameters of reaction particles, we propose an algorithm that scans the intensity of pixels along a circular trajectory of a certain radius (Θ) and determines the average value at each scanning step $I_\Theta = (\sum_1^n I_i)/n$, where n is the number of pixels (radius length) and I_i is the intensity of the i-th pixel. In Fig. 1,b above, for a visual example, dark segments of 50 pixels in length represent the procedure of scanning in a circle. The scan was performed along the clockwise trajectory with a step of 20°. In the real study, the scanning step was 1°.

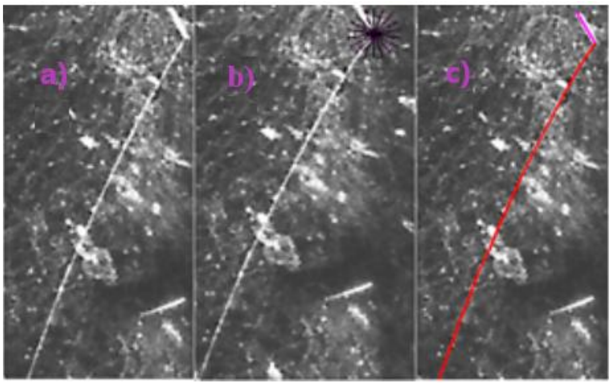

Fig. 1. Digital image processing

For the convenience of data analysis and searching for extremes, we introduced the relative intensity $I^{extr} = I_\Theta / I^{aver}$, where I^{aver} is the average intensity of the circle.

In Fig. 2, the histogram shows the dependence of I^{extr} on the scanning angle in the range from 0 to 360°. There is an irregular structure with several maxima corresponding to the deviation from the background in the scanning area. To automatically determine the position of these maxima, we used the groupby function from the Pandas module, which performs grouping by one or more parameters and determines the inflection points (extremes). The positions of the calculated extremes are shown as solid points. The two maxima in the positive region correspond to the two tracks in Fig. 1,a, and the position of the maximum gives the value of the departure angle of the corresponding track.

Thus, knowing the top of the event, the angles of departure of the tracks, and the average intensity of the I^{aver} in the selected direction, it is possible to calculate the coordinates of points along each track. For this purpose, the procedure of sequential advancement of the scanning segment along the corresponding track was performed. The pixels in the scanning segment were checked for intensity. A sharp change in intensity compared to I^{aver} made it possible to determine the boundary of the track. If all pixels corresponded to the track, the procedure was performed to move the start of the scan to the last point of the scanning segment, and then the procedure of scanning the intensity of pixels along a circular trajectory was performed again to determine the angle of departure of the track and further advancement along the track. This sequence of actions was performed in a loop until the track boundary was determined. This algorithm allows us to take into account the curvature of the track and at each stage of moving along the track it is possible to refine the departure angle.

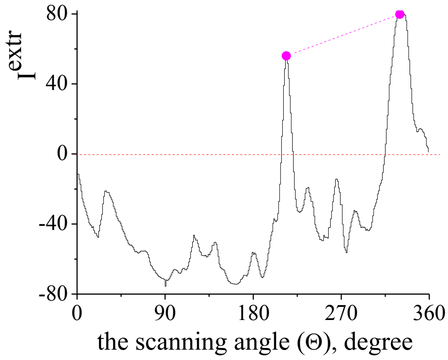

Fig. 2. Dependence of pixel intensity on scanning angle

In Fig. 1,c on the bottom image shows the result of the automatic digitization of all three event tracks. The points describe the trajectory of the tracks well. It should be noted that a long track often has a fuzzy trace with dips and background noise that can distort the data during image analysis. Therefore, a semi-automatic algorithm is also included in the measurement procedure [5].

In Fig. 3 shows the dependence of the number of events on the measurement time. The same number of events on ^{12}C, ^{14}N, and ^{16}O nuclei was selected for analysis. The general appearance of the distributions is the same, and the average time of event measurement is about 60 seconds. This is much faster than when measuring the PUOC.

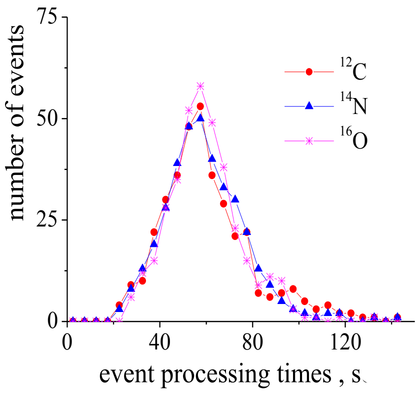

Fig. 3. Event processing times (γ,np) of reactions on ^{12}C (circles), ^{14}N (triangles), and ^{16}O (stars) nuclei

Thus, in most events, it is possible to automatically calculate points along the tracks. Subsequently, the functions of fitting the points with a first- or second-order curve and refining the coordinates corresponding to the middle of the track were performed. After reconstructing the geometry of the event, a numerical matrix of this event is created, in which for each track there are guide cosines l, m, n; the radius of curvature and track length.

2. COMPARISON OF MEASUREMENT RESULTS USING THE DIGITAL AND THE PUOS METHODS

It should be noted that the larger the mass of the target nucleus, the shorter the track of the multicharged particle (^{10}B, ^{12}C, and ^{14}N, respectively). This has always been a significant obstacle to measuring the parameters of such tracks by the PUOS. The digital technique should eliminate this problem. To reconstruct the event, the coordinates of points along each track are measured in all stereo frames. For comparison, the coordinates of the points were obtained by two measurement methods - digital and using the PUOS. The data from the PUOS were converted to the digital coordinate system.

The events corresponding to (γ,np)-reactions on ^{12}C, ^{14}N, and ^{16}O nuclei look the same in the photo frames – a long track with a noticeable curvature for the proton and a short track for a multicharged particle (^{10}B, ^{12}C or ^{14}N). In Fig. 4,a, the closed points for the digital technique and the open points for the PUOS show the results of measurements of such tracks. For the long track, a smoother sequence of points for the digital method is even visually visible.

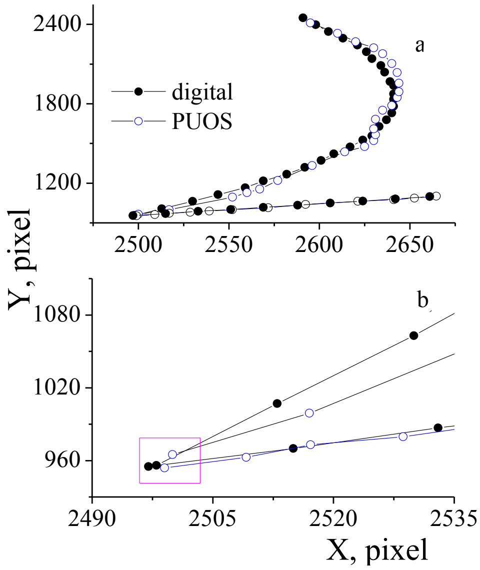

Fig. 4. Coordinate values of points along the tracks during measurements by the digital method (closed points) and using the PSS (open points)

In Fig. 4,b shows the area (rectangle) of the starting points (x_0,y_0) for each track. Using the digital method, we obtained their values (2497.955) for the first and (2498.956) for the second track, and using the PUOS – (2502.965) and (2499.954), respectively. Obviously, the digital method of measuring the starting points gives better results with a much smaller error.

To qualitatively assess the track measurements, we fitted (solid curves in Fig. 5) the points along the track with a second-order polynomial $y= b_0 + b_1·x+ b_2·x^2$ for a long track with a noticeable curvature (see Fig. 5,a) and a first-order polynomial $y= b_0 + b_1·x$ for a short track (see Fig. 5,b). The closed points correspond to the digital method, and the open points – to the use of the PUOS.

The results of fitting the coordinates of the points for the long track: b_1 =-81.0±6.6, b_2 = 0.017±0.001 (digital method) and b_1 = -100.6±13.5, b_2 = 0.021±0.003 (PUOS). For the short track: b_1 = 0.871±0.003 (digital method) and b_1 = 0.869±0.011 (PUOS). Within the measurement error, the data of the two methods are consistent, but attention should be paid to a significantly larger error in the values obtained when using the PUOS for both the long track and the short track.

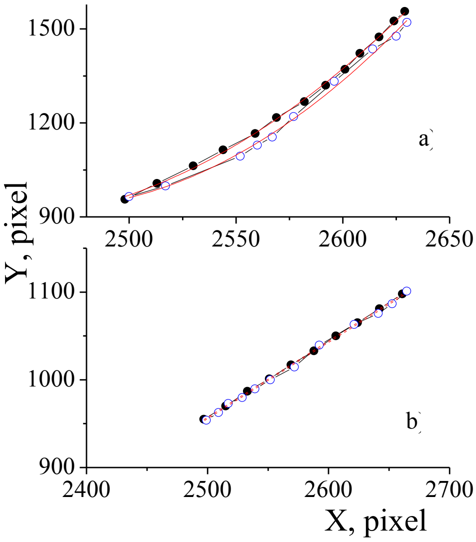

Fig. 5. Fitting the coordinates of track points obtained by the digital method (closed points) and by the PUOS (open points)

The reconstruction of the tracks is performed by mathematically calculating the guide cosines, radius of curvature and track length, taking into account the results of the fitting. Thus, the digital method improves the quality of measurement and reduces the absolute error.

CONCLUSIONS

A digital methodology for selecting and measuring events (γ,np)-reactions on ^{12}C, ^{14}N, and ^{16}O nuclei was created, which allows one specialist to perform all procedures for obtaining physical information on a computer. Python software was developed for each stage of the study to perform procedures for viewing digital images with photonuclear reaction events, selecting events of the reactions under study, and determining the kinematic parameters of each event track. To accelerate the process of measuring tracks, a fully automated method for obtaining the coordinates of points along the track was created.

The kinematic parameters of two tracks (a long track for a single-charge particle and a short track for a multi-charge particle) obtained by the digital method and using specialized measuring devices such as PUOS are compared. It was found that the data of the two methods are consistent, but in the case of using the PUOS, a larger error in the obtained values occurs. The digital method improves the quality of measurement, reduces the absolute measurement error, and significantly speeds up the measurement time.

REFERENCES

1. T.H. Yau, I. MacGregor, J. Ahrens, et al. The angular distribution of the ^{12}C(γ,pn) reaction for $E_γ$=120−150 MeV // *Eur. Phys. J. A.* 1998, v. 1, p. 241-244; https://doi.org/10.1007/s100500050055
2. D.G. Middleton, J.R.M. Annand, C. Barbieri, et al. Knockout of proton-neutron pairs from ^{16}O with electromagnetic probes // *Eur. Phys. J. A.* 2010, v. 43, p. 137-143; https://doi.org/10.1140/epja/i2009-10902-7
3. A.F. Khodyachikh, E.S. Gorbenko, R.T. Murtazin. Investigation of the reaction ^{4}He(γ,pn)d at energies below the meson-production threshold // *Physics of Atomic Nuclei*. 2017, v. 80, N 1, p. 25-31; https://doi.org/10.1134/S1063778817010100
4. Yu.M. Arkatov, P.I. Vatset, V.I. Voloshchuk, et al. *Method for processing stereo photographs from a diffusion camera:* Preprint No. 70-73. Kharkiv: KIPT, 1970.
5. S.N. Afanasiev, I.A. Afanasieva. Digital processing of photos from 4π track detector // *Problems of Atomic Science and Technology. Series “Nuclear Physics Investigations”*. 2022, N 5(141), p. 87-91; https://doi.org/10.46813/2022-141-087
6. Mark Lutz. *Learning Python, 5th Edition Packages*. O'Reilly Media, 2013, 1648 p.

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ЦИФРОВА МЕТОДИКА ОБРОБКИ ПОДІЙ (γ,np)-РЕАКЦІЙ НА ЯДРАХ ^{12}C, ^{14}N ТА ^{16}O, ОТРИМАНИХ ЗА ДОПОМОГОЮ ТРЕКОВОГО 4π-ДЕТЕКТОРА

С.М. Афанасьєв

Для дослідження (γ,np)-реакцій на ядрах ^{12}C, ^{14}N та ^{16}O розроблено алгоритм-послідовність конкретних дій для отримання фізичної інформації щодо подій за допомогою цифрової методики. На мові програмування Python створено набір відповідних графічних застосунків, які дозволяють на комп’ютері одному спеціалісту виконувати всі процедури для отримання фізичної інформації щодо досліджуваних реакцій. Розроблено автоматизовану методику визначення координат точок вздовж трека, що суттєво прискорило процес вимірювання треків. Зроблено порівняння кінематичних параметрів, отриманих цифровою методикою і за допомогою спеціалізованих вимірювальних пристроїв. Виявлено, що цифрова методика поліпшує якість вимірювання і зменшує абсолютну похибку вимірювань.