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Silicon strip detectors for fission

V.P. Likhachev[a,1,2], J.F. Dias[a,3], M.-L. Yoneama[a,4], M.N. Martins[a,*], J.D.T. Arruda-Neto[a], C.C. Bueno[a,5], V. Perevertailo[b], O. Frolov[b]

[a] *Instituto de Física, Universidade de São Paulo, Caixa Postal 66318, CEP: 05389-970 São Paulo, Brazil*
[b] *Kiev Institute of Microdevices, Kiev, Ukraine*

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Abstract

The performance of a silicon strip detector especially designed for photofission experiments and a particular arrangement for low count rate photofission measurements are presented. Other applications for the same detection system are discussed.

1. Introduction

The study of photofission of actinide nuclei, especially at the region close to the barrier, has provided much interesting information about the fission process. In particular, by investigating the fission fragment angular distributions it was possible to obtain important information about the multi-humped structure of the fission barrier [1]. Moreover, the study of the fission fragment mass, energy and charge distributions revealed important aspects of the dynamical properties of the fissioning system [2]. By measuring both the angular and mass distributions of the fragments it is possible to obtain information about the correlation between the multipolarity of the excitation and the mass division. First experiments in this direction have been carried out by Wilke et al. [3] and Steiper et al. [4] using position sensitive parallel plate avalanche detectors (PPADs).

It is clear that the kind of investigation mentioned above requires accurate measurement of the fission fragment angular, energy and mass distributions together with a precise knowledge of the bombarding photon energy. Current high duty-factor electron accelerators, associated with the tagged photon technique [5,6] and high quality fission fragment detectors constitute a powerful tool for this kind of study. However, the tagged photon technique limits the photon flux to a maximum of about $10^7\ s^{-1}$ [7,8], which appears to be incompatible with measurements involving low cross sections as the ones mentioned above. Moreover, in order to achieve this flux, the photon beam has to be non-collimated. This circumstance leads, especially in the case of low initial electron energy (thus large divergence), to large beam spots on the target.

To take into account the specific needs of this kind of measurement, the detection system should match the following requirements:

- high energy resolution for heavy charged particles;
- good angular resolution;
- high time resolution (comparable to the difference in the time of flight of the particles);
- stability over large periods of time;
- possibility of large illuminated target area;
- detector array as close as possible to the target.

All these requirements, in particular the high energy resolution and good stability over time, could be fulfilled by e.g. position sensitive silicon detector arrangements, which were widely used in the past in high energy physics for precise determination of charged particle coordinates [9-13]. Other possible choices like PPADs [14] and multiwire proportional parallel plate detectors (M3Ps) [15] are not adequate to our particular conditions. Indeed, experiments with low count rates, large illuminated target area, and limited available room for detectors are incompatible with detectors such as PPADs and M3Ps because of the long time-of-flight distances needed for achieving accurate mass determination.

This work presents the development of a detecting system suitable for low energy experiments involving low count rate statistics. This system consists of a new silicon strip detector arranged in an optimized geometry especially chosen to fulfill our purposes. In Section 2 we describe the

* Corresponding author. Address: Universidade de São Paulo, Instituto de Física, Laboratorio do Acelerador Linear, Rua do Matão, Travessa R, no. 187, Butantã, São Paulo-SP, 05508-900 Brazil. Tel.: +55 11 8145599, fax: +55 11 8140503.

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[5] Instituto de Pesquisas Energéticas e Nucleares - IPEN (São Paulo, Brazil).

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Table 1
Main features of the silicon strip detectors

Description	Value
Sensitive area	52×52 mm^2
Thickness	300 μm
Number of Si crystals	2
Number of strips	16
Strip width	2900 μm
Interstrip distance	100 μm
Working voltage	10–100 V
Breakdown voltage	>100 V
Thickness of upper Al contact	0.3 μm
Thickness of lower Al contact	0.3 μm
depth of p^+ layer	0.2 μm

detectors characteristics and the tests carried out. In Section 3 the proposed detection system is discussed and in Section 4 we summarize the main conclusions achieved in this work.

2. The silicon strip detector

2.1. Manufacturing details

In order to accomplish all the requirements of the intended experiments, silicon strip detectors were especially manufactured at Kiev SPA Detector (Ukraine). These detectors use an n–Si substratum with resistivity of 2–5 kΩ cm. The p^+–n junctions were made with implanted boron using planar technology. The beam energy was 15 keV and the implanted dose 5×10^{14} ions/cm^2. Such low ion energies make small depth junctions (0.2 μm) and allow the use of low temperatures for the activation. These characteristics reduce the thickness of the input windows. The n^+ contact on the back side of the detector was made with implanted phosphorus. The phosphorus dose was 5×10^{15} ions/cm^2 at 30 keV. The p^+–n junctions and the detector back side were covered by a thin aluminum layer. The two silicon substrata with their output connectors were mounted on a plastic board. The strips were welded to the board connectors using gold strips. In Table 1 the main features of the silicon strip detectors are summed up.

2.2. Performance

Tests were carried out in order to assess the detector performance in measuring conditions. Initially, we checked the leakage current and depleted depth variations of the detectors as a function of the bias voltage. Table 2 summarizes the results of this study for four detectors. It is seen in this table that for a bias voltage of 20 V the depletion depth is more than 100 μm, which is enough to detect fission fragments. Other important parameters related to the detector performance are discussed in the following subsections.

2.2.1. Energy resolution

The fission fragment spectra of actinide nuclei are known to exhibit a double-humped structure, which is the signature of asymmetric fission. For these nuclei the contribution of symmetric fission is small (for low excitation energies) and corresponds to the valley of the double-humped structure. Therefore, the clear separation between the two humps allows the determination of the mass distribution in terms of light and heavy fragment groups. Thus, the energy resolution and spectrum distortion problems for the detection of fission fragments are very important issues. This means that the detector performance must be designed to minimize the pulse height defect caused by the high energy loss along the ion track. Moreover, the energy resolution of detector and electronics should give a small contribution to the final energy spectrum.

The measurement of ^{252}Cf fission fragments is a standard test to assess the performance of heavy ion spectroscopy detectors. For that purpose, a ^{252}Cf source was placed inside a small reaction chamber together with the silicon strip detectors. The system was evacuated and kept at a pressure of about 10^{-3} Pa. Conventional electronics consisting of preamplifier, amplifier, and ADC, connected

Table 2
Relevant strip parameters obtained for four different strip detectors. Each detector consists of two silicon crystals with 8 strips each. DN: detector number; CN: crystal number

DN	CN		Current [nA]				Depleted depth [μm]			
		Bias (V) ⇒	20	40	60	100	20	40	60	100
1	1		70–100	100–150	100–200	200–300	110	140	165	200
1	2		50–60	70–80	100–150	200	105	140	165	210
2	1		60–80	70–100	100–200	200–300	105	130	160	200
2	2		80–100	100–120	200–300	400–500	105	140	160	210
3	1		80–200	100–250	180–300	300–400	110	145	175	220
3	2		50–130	70–200	160–250	300–500	110	140	165	210
4	1		100–120	130–240	200–400	500–600	110	140	170	210
4	2		10–20	20–30	100	150–200	115	150	175	220

to a personal computer, were used in these tests. In Fig. 1 we present the ^{252}Cf energy spectrum obtained using a single strip of one particular detector. As we can see in this figure, this spectrum exhibits two prominent peaks (due to asymmetric fission) with an intermediate valley (due to symmetric fission). The two peaks correspond to the light (higher channels) and heavy (lower channels) fission fragments. Following the procedure of Weissenberger and collaborators [16], we fitted two Gaussians to the total spectrum and obtained the spectrum shape parameters in order to check the quality of the detector. For instance, the results obtained for the peak to valley ratio for the heavier and lighter fission fragments were 2.1 and 2.8 respectively, while the peak (lighter fragments) to peak (heavier fragments) ratio was about 1.3. The overall agreement of these parameters with the values tabulated by Schmitt and Pleasonton [17] and recently confirmed by Weissenberger et al. [16] are very good, indicating the good quality of the detector.

2.2.2. Time resolution

Is in order to assess the timing features of the detectors, we used a light emitting diode (LED) driven by a fast pulser with adjustable amplitude [8]. With this arrangement we could simulate the passage of alpha particles or fission fragments through the strips by adjusting proper amplitudes in the pulse generator. Since all the strips were illuminated simultaneously, we used the generated signals to simulate coincidence spectra from two strips in different combinations. Fig. 2 presents two coincidence spectra added to appear in a single plot. We used different external delays in each spectrum to set the peaks 4 ns apart. The FWHM of each peak is about 0.4 ns. This width is mainly due to two factors: i) time variation of the emitted light; ii) time resolution of the strip detector [8]. Therefore, the real time resolution of the detector should be less than 0.4 ns.

2.2.3. Strip uniformity

The uniformity of the strips was checked through irradiation of the detector by an ^{241}Am alpha source. The pulse height spectrum was independently measured for each of the 16 strips of a particular detector (bias voltage: 20 V). These spectra were normalized in order to compensate for the change in solid angle from the center to the border strips (up to 12% for extreme strips). Finally these spectra were put together in one single spectrum as depicted in Fig. 3. The strips present different leakage currents and the ones having higher currents appear

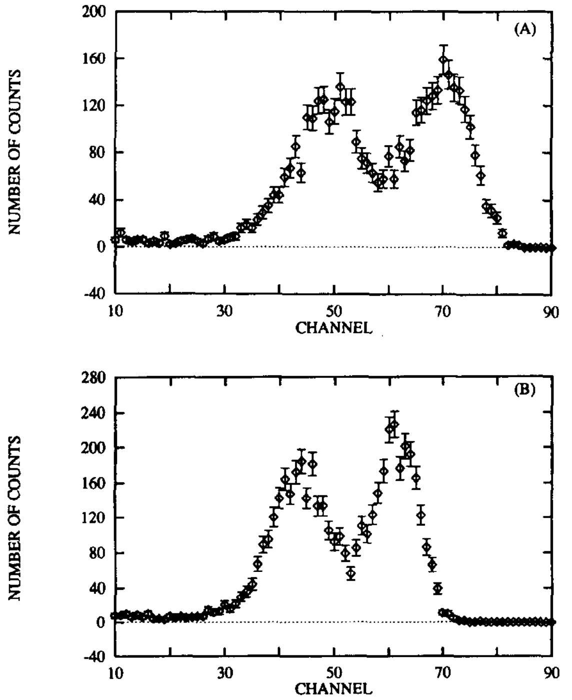

Fig. 1. Pulse height spectra of ^{252}Cf fission fragments detected by a single strip (no. 11) of one particular detector. (A) without encoding system; (B) with encoding system. See text for further information.

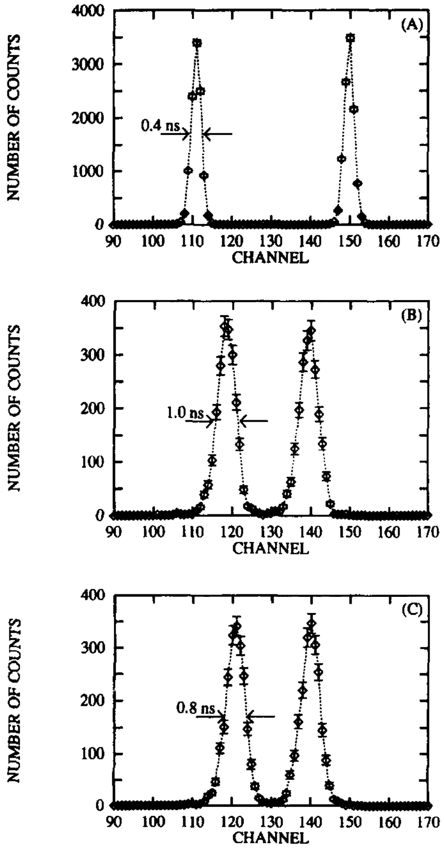

Fig. 2. Time coincidence spectra in three specific cases: LED light flash (A) simulating α particles without encoding system; (B) simulating α particles with the encoding system; and (C) simulating fission fragments with the encoding system. See text for further information.

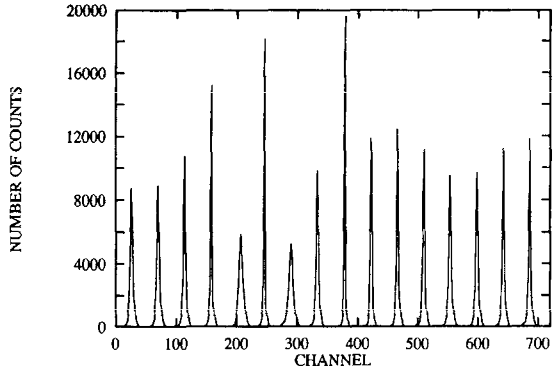

Fig. 3. Pulse height spectra of ^{241}Am alpha source measured by different strips. In order to present the spectra in the same scale, the gain was changed for each strip. The areas under the peaks are the same within ±1.7%.

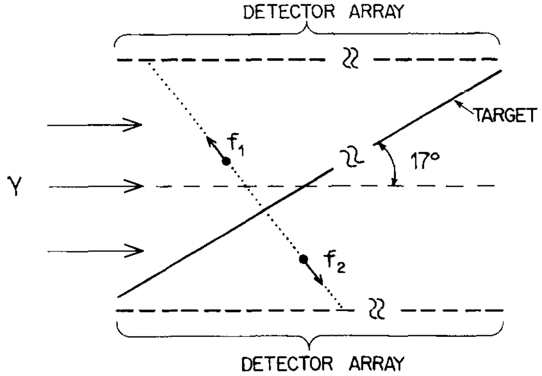

Fig. 5. Schematic drawing depicting the target position and the detector arrays. f_1 and f_2 correspond to fission fragments emitted in opposite directions.

broader than the others, but all the peaks have the same area within 1.7%.

The uniformity along each strip was measured with an ^{241}Am alpha source and a 2 mm movable collimator. Fig. 4 shows the pulse height spectra obtained at four different positions along one single strip. The areas under the peaks are compatible within 5.0%, which shows that the strip response as a function of the incident position of the particle is quite uniform.

3. Detector arrangement

As mentioned before, the silicon strip detectors arrangement will be used in experiments involving i) very low cross sections; and ii) large illuminated target area needing, nevertheless, good angular resolution. The detector arrangement described here was designed for the specific case in which two reaction products are emitted in opposite directions (requiring a thin, self-supported target). For this reason, we opted for a *sandwich* configuration where the

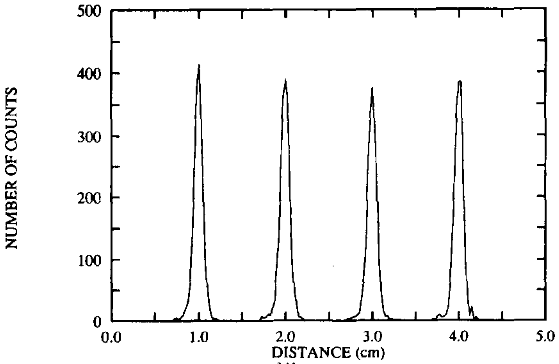

Fig. 4. Pulse height spectra of ^{241}Am alpha source measured in different positions along one of the strips of a particular detector. See text for further information.

target is tilted with respect to the photon beam and lies between two planes of detectors (see Fig. 5). The associated electronics select any pair of opposing strips, thus determining the fission fragment emitted angles. These features will be discussed in the following sub-sections.

3.1. Geometry optimization

The geometry of the detection system was optimized by a Monte Carlo simulation [18]. The photon coordinates on the beam spot and the emission angles θ_1 and φ_1 of one of the fission fragments were randomly generated. The angles of the second fission fragment were then calculated according to the reaction kinematics. Finally, the case where both particles were detected in coincidence by an opposing pair of strips was analyzed. The dependence of the coincidence rate on the beam diameter, on the distance from target to detector planes, and on the target angle with respect to the photon beam direction was also calculated [18]. For a beam diameter of 3 cm, the best target angle with respect to the photon beam direction is about 17°. A schematic drawing of the detector array including the target is shown in Fig. 5. The arrangement consists of two parallel planes of detectors, each of them with two strip detectors (thus having a total of 32 strips, see Table 1). The strips are oriented in a direction perpendicular to the photon beam direction and the distance between the detector planes is 40 mm. This setup covers polar angles $22° < \theta < 158°$. The dependence of the polar angle θ on the azimuthal angle φ (which varies along the strip) was checked for limiting cases (i.e., fragments emitted from the central and border regions of the target at 90° with respect to the photon beam; and fragments hitting far opposing strips). The results show that for $\theta = 90°$ the polar angular resolution is ±4° while for $\theta = 22°$ and 158° the polar angular resolution is ±5°. In these limiting cases the φ acceptance varies from ±50° to ±30° respectively.

3.2. Electronics

The forthcoming experiments will require knowledge of parameters like the energy of both fission products and the polar angle θ, the latter being related to the identification of which pair of strips fired. Therefore, the electronics setup should be conceived to fulfil such requirements.

In order to reduce the number of electronic modules like preamplifiers (PA), analog to digital converters (ADC), time to digital converters (TDC), discriminators (D) and others, we opted for the method of time codification of the strip number based on delay lines. Fig. 6 shows a detailed scheme for one of the detectors.

The common backside output of the detectors provides a signal that is sent to a preamplifier (PA). This PA generates fast and charge sensitive output signals. The charge sensitive signal goes to an ADC (E signal) for energy determination. For the strip identification, two fast signals are used: one of them comes from the PA (T signal) and is sent straight to a discriminator (D) and then to a TDC module (start input). The other one comes from the particular strip which fired. This signal is delayed and, after the PA module, is sent to the TDC (stop input). Actually, all strip outputs are connected to each other by delay lines of 5 ns each, which means that the total delay of a particular strip can be only assigned to that very strip, thus providing its identification. We will refer to this system as the *encoding system*. Note that a further delay line (50 ns) is added in order to allow the identification of the crystal to which that strip belonged (each detector has two crystals with 8 strips each).

Pulses from two detectors observing the same target side are sent to OR modules. Pulses coming from the OR modules are sent to a coincidence/anti-coincidence module. In case two pulses arrive within the time resolution in this module, an AND pulse is generated and sent to the Master Trigger (MT), which is responsible for activating the data acquisition system. Gates are then generated for the ADCs and the bit pattern module (BP). The BP module is used for the identification of the detectors that fired. A pulse is sent to the crate controller (CC) and then the ADCs, TDCs and the BP are read out and transferred to the computer and saved in tape for off-line analysis. The events are saved in an *event by event* mode. In case only one pulse arrives in the coincidence/anti-coincidence module within the time resolution, and $\overline{\text{AND}}$ pulse is generated, which serves as a veto to the TDC. Scalers are used to keep track of the total number of counts.

Finally, it is important to mention that this electronic setup could be easily coupled to a larger setup including the photon tagging electronics.

3.2.1. Performance

Since the encoding system is placed right after the detectors, it is necessary to use high capacitance preamplifiers in order to keep electronic noise at acceptable levels to achieve good time and energy resolutions. The charge-sensitive and high-capacitance preamplifiers (PA) used in this work were manufactured at Kiev Institute of Nuclear Physics. With this PA it is possible to have precise determination of the energy loss in the detector with an open-loop gain of $K = 9000$. The full energy resolution

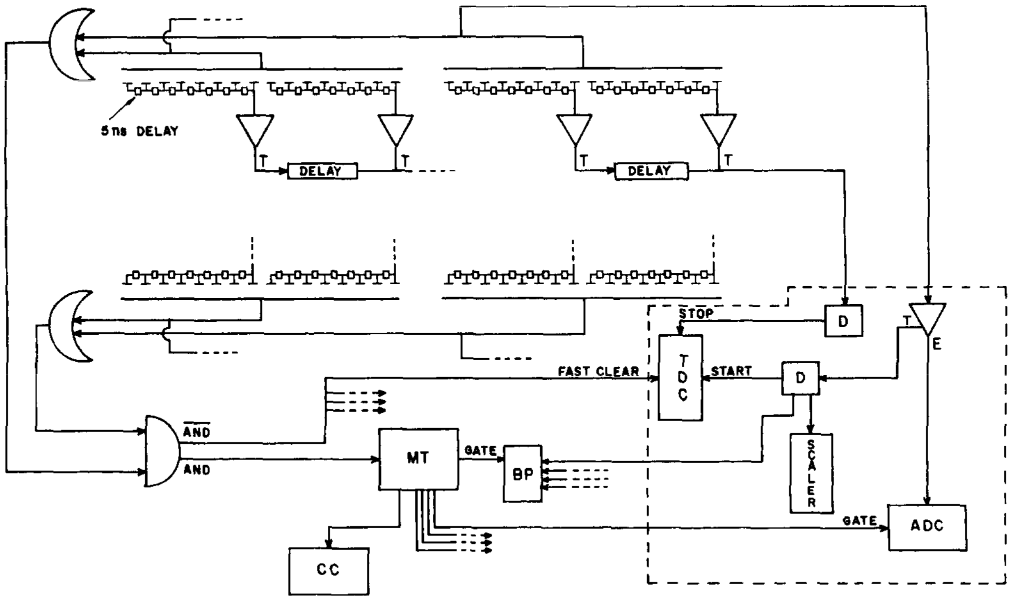

Fig. 6. The electronics setup. PA: preamplifier; D: discriminator; ADC: analog to digital converter; TDC: time to digital converter; CC: crate controller; BP: bit pattern; MT: master trigger. The dashed box depicts the electronics for one detector and is the same for all four detectors used.

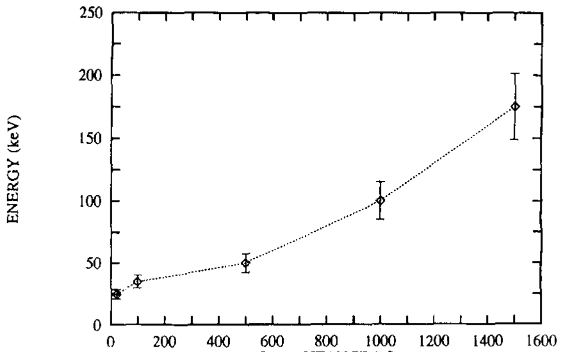

Fig. 7. Equivalent energy of the electronic noise at the fast output channel of the preamplifier as a function of the external capacitance. The dotted lines connecting the points were drawn to guide the eye.

achieved in this case is $R = 2.06\,\text{keV} + 0.018\,\text{keV/pF}$ with an output pulse rise time of $t = 25\,\text{ns} + 0.035\,\text{ns/pF}$ at a feedback capacitance of $C_{fb} = 0.24\,\text{pF}$. The fast output channel used for the timing has a pulse width of about 30 ns.

In the proposed scheme, the value of the external capacitance is limited by the electronic noise of the fast output channel. Fig. 7 shows the electronic noise at the fast output versus the external capacitance. From this figure it can be seen that an encoding system with capacitance of about 700 pF still allows a clear discrimination of the electronic noise from the pulses of interest (fission fragments have energies of, at least, 5 MeV).

In order to assess the effects of the high capacitance (700 pF) on the energy resolution for the detection of fission fragments, tests were carried out using a ^{252}Cf source. The results of these tests are shown in Fig. 1. From this figure, it is clear that the capacitance generated by the encoding system affects the energy resolution, but this effect is small and does not prevent good energy resolution data to be obtained.

The effects of such high capacitances on the time resolution were evaluated by simulating alpha particles and fission fragments with the LED (Fig. 2). In the case of alpha particles, the FWHM is about 1 ns, due to the influence of the increasing electronic noise. However, for the case of fission fragments, the FWHM is 0.8 ns. Here, the influence of the electronic noise is less important because the signal pulse amplitudes are far higher than the noise amplitudes.

4. Final remarks and conclusion

In this paper we report on the working characteristics of a silicon strip detector which is intended to be used in photofission experiments. This detector proved to be suitable for such experiments because of the excellent spectroscopy and time characteristics for heavy ion detection. In particular, a special arrangement (large solid angle and large illuminated target spot) is proposed aiming experiments involving low counting rates.

As a matter of fact, any experiment involving the emission of two charged particles with well defined kinematics can be carried out with the proposed arrangement. Of particular interest is the study of photodisintegration of light nuclei such as lithium isotopes. Indeed, the study of reactions like ^{6}Li(γ, ^{4}He d), ^{6}Li(γ, ^{3}He t) and ^{7}Li(γ, ^{4}He t) are suitable to be investigated with such experimental setup because of the very low cross sections expected for these processes [19]. The study of such reactions at photon energies below 30 MeV could enhance our understanding of the giant resonance process in light nuclei where collective motion of the nucleons is unlikely [20] because of the strong cluster effects in such nuclei.

Finally, this work must be understood in a broad context, aiming the future experiments to be carried out at the 31 MeV cw microtron together with a photon tagging facility under construction in São Paulo.

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