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Research

THE EXOGAM2 CALIBRATION USING THE NEWLY DEVELOPED NUMEXO2 DIGITAL ELECTRONIC

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ABSTRACT

In this study, the calibration process of the EXOGAM2 conventional gamma detector system with the newly developed digital electronic device, namely NUMEXO2, will be presented. This experimental study was performed at the GANIL (Grand Accélérateur National d'Ions Lourds) nuclear research center in France. The energy calibration of the EXOGAM2 detector system with the newly developed NUMEXO2 digital electronic device was conducted using both low and high gamma energy levels of a ^{152}Eu radioactive source. This calibration was carried out for two EXOGAM2 detectors, and the energy resolution of each crystal in the EXOGAM2 system was determined.

The energy resolution of each crystal was found to be reasonable energy resolution values of the EXOGAM2 detectors. Therefore, the use of the digital electronic device NUMEXO2 did not affect the energy resolution of the detectors, but it did enable us to acquire data at a high counting rate.

Keywords: EXOGAM2, NUMEXO2, Digital electronic, Calibration

1. INTRODUCTION

The aim of this study is to demonstrate the design, performance verification and efficiency of a digital electronic system, namely NUMEXO2, with an EXOGAM2 (EXOtic GAMma array) detector located at GANIL, France [1,2]. Gamma-ray spectroscopy is the most widely used technique for observing nuclear characteristics, providing insights into the behavior and structure of nuclei.

A detector system can be used to distinguish a new radioisotope by analyzing the properties of the gamma rays spectrum and determining the levels of gamma energy. Over the past year, significant advancements have been made in detector systems through the integration of novel technologies. As a result, the conventional analog electronics of these systems have been replaced with digital electronics. There are several reasons behind this transition to digital electronics, including the ability to handle high counting rates, facilitate complex data sets, and improve overall performance without compromising the energy resolution of the detectors.

Nuclear structural physics is currently focused on revealing the properties of new exotic nuclei. Previously very competent devices such as high purity germanium (HP-Ge) systems EUROBALL [3], GAMMASPHERE [4], MINIBALL [5], and EXOGAM [4] were commonly used. In recent years, AGATA [6], GRETINA [7], JUROGAM II [8], and EXOGAM2 [2], coupled with the newly developed digital electronic system NUMEXO2, have been employed to detect of gamma rays emitted from nuclear reactions. In addition, the Neutron Shell and Neutron Wall used to use as neutron detectors [9, 10, 11], while the newer arrays are coupled with the NEDA [12,13] neutron detector array and ancillary charged particle detector arrays such as DIAMANT [14]. Both NEDA and DIAMANT also utilize the digital electronic system NUMEXO2.

Semiconductor types of Germanium (Ge) detectors were developed in the 1970s and 1980s, focusing on volume and purity [15–17]. Significant advancements in highly segmented Ge detectors have greatly improved their efficiency and energy resolution. The capacity to categorize between two gamma rays with closely spaced energies necessitates high energy resolution detectors. As a result, HPGe detectors such as AGATA, GRETINA, and EXOGAM2 are renowned for their superior energy resolution. Achieving excellent energy resolution relies on both the electronics and type of detector. Energy resolution is usually determined using a metric known as full width at half maximum (FWHM), which quantifies the distribution at half width of the peak.

Figure 1 shows the peak or pulse shape, the energy resolution is described by the formula FWHM=2.35σ, where σ represents the standard deviation of the Gaussian shape. The lower the FWHM value, the higher the sensitivity level of the detector, allowing the separation of closely related gamma energies..

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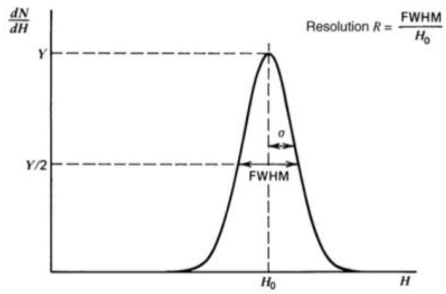

Figure 1. Detector response function in Gaussian form.

The main objective of the EXOGAM design was to optimize the efficiency of the light peaks, in other words to maximize the total efficiency of the light peaks while maintaining the quality of the spectra. Searching for new exotic nuclei also requires experiments with exotic beams, which is a highly challenging process to achieve a high signal-to-noise ratio and good resolution [18]. Instead of an analog system a digital electronic system should be used, resulting in the production of a new digital electronic system for EXOGAM, from now on referred to as EXOGAM2.

EXOGAM2 comprises an array of high-resolution germanium detectors positioned in close proximity to the target point. These detectors have been strategically organized to achieve a high photo-peak efficiency of 20% at 1.3 MeV gamma rays [19]. Each germanium detector is surrounded by an escape suppression shield typically made of bismuth germanate (BGO).

This suppression shield enhances the quality of the spectrum. The high-purity germanium detectors used in EXOGAM are coaxial n-type HPGe crystals. Additionally, each of the four germanium crystals constitutes a segmented CLOVER detector placed within the same cryostat.

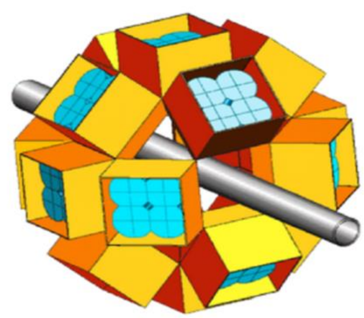

Figure 2. EXOGAM detector array design [2].

2. MATERIAL AND METHOD

CLOVER detectors that have been segmented make up the EXOGAM2 design. Electronic segmentation has separated each Germanium crystal into four areas and placed them all in the same cryostat (Figure 3). This segmentation is a crucial requirement in order to have a large volume and to more accurately pinpoint the gamma ray impact point in the detector. Additionally, the segmentation design's closed-packed and effective construction aid in reducing Doppler broadening. A high level of granularity is required to maintain reasonable resolution and accommodate the Doppler broadening of the gamma-ray peaks [20]. Segmentation is consequently used to achieve granularity. In the Clover detector, each Germanium crystal includes an interior contact and four exterior contacts that are situated at each crystal's corners. These contacts make it possible to describe the location of the event (right side in Figure 3)

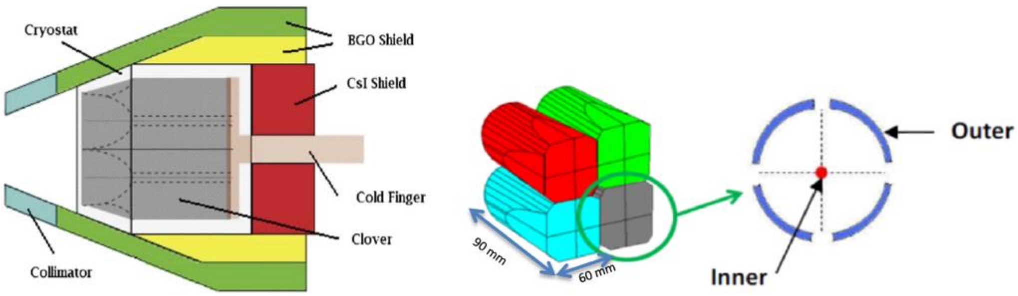

Figure 3. Left: Detail of the segmented CLOVER Ge detector crystal. Right: Zoom-in on segmented crystals.

Electronic detection systems significantly affect the quality of test data. New engineering matrix structures use high-speed analog-to-digital (A/D) devices, high-speed optical data transfers, and reconfigurable logic devices in the front electronics to add channels and complex processing algorithms [21]. Therefore, NUMEXO2 provides a common solution for more detection systems, reducing time and resources.

NUMEXO2 [22] serves as the central component within the NEDA front-end electronics. Collaboratively developed with GANIL, the NUMEXO2 digitizer and pre-processing system offer a unified solution for various detection systems, ultimately streamlining time and resource allocation. The primary functions of the digitizer encompass A/D conversion, data pre-processing, interfacing with the Global Trigger System GTS system, and managing communication links for up to 16 channels. This system comprises a motherboard and a quartet of FADC mezzanines, each responsible for A/D conversion in four channels. The NUMEXO2 digital electronics can capture 14-bit data at 200 Msps (Megasamples per second) and has a data transfer rate of 100–200 MHz. NUMEXO2's adaptability is achieved through its utilization of Field-Programmable Gate Arrays FPGAs, simplifying the design of firmware algorithms. Specifically, NUMEXO2 incorporates two high-performance FPGAs, namely a Virtex-6 and a Virtex-5 by Xilinx. Figure 4 provides an overview of the central NUMEXO2 block diagram, featuring the FPGAs, Flash Analog Digital Converter FADC mezzanine components, and communication links [22].

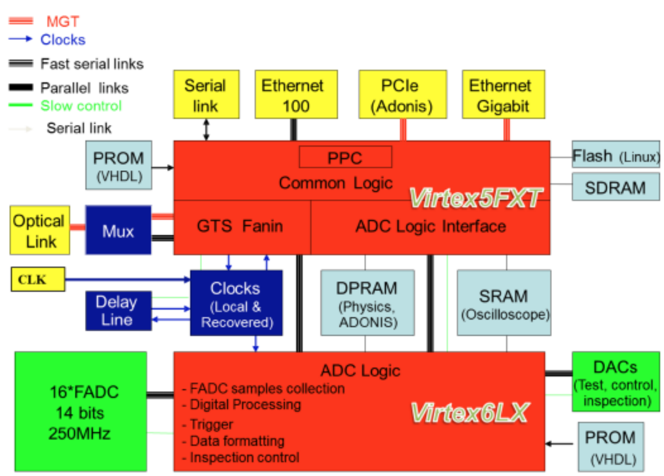

Figure 4. NUMEXO2 general block diagram [20].

3. RESULTS AND DISCUSSION

A general requirement for scientific data processing is to detect signal peaks and measure the peak heights to obtain information about the properties of the peaks, which in turn provides information about the underlying physical system. The energy spectrum of gamma rays is obtained from the detectors, and the peaks in this spectrum are then detected and analyzed. The task is to identify the peaks and measure their locations, widths, and heights. The calibration process is critical for accurately associating energies with peak locations in the spectrum.

3.1 Calibration Procedure

In this study, we used a ^{152}Eu radioactive source for the calibration of the EXOGAM2 detectors. This source emits gamma rays at two distinct energy levels: 344. 785 keV and 1408 keV. These well-known gamma lines were employed to calibrate the detectors. The calibration coefficients were derived by fitting the energy peaks corresponding to these gamma lines and using the coefficients of the line equation. The energy calibration was performed for two EXOGAM2 detectors, for 8 HpGe crystals. The third degree of the equation $E_{i=} \sum_n a_n c_i^n$ was used to calibrate the EXOGAM2 detectors.

3.2 Peak Fitting Process

The peak fitting process was conducted using the ROOT program, a widely used tool in nuclear physics. ROOT provides a versatile environment for data analysis, offering tools for fitting energy spectra, which contain intense low and high-energy peaks. By fitting the energy peaks, we were able to determine the mean energy values for each crystal. Aligning these mean energy values with the reference energies from the ^{152}Eu radioactive source ensured that each gamma energy was correctly positioned.

For each crystal, correction coefficient values constructed using the mean energy values obtained from the peak fitting method to align them with the known energies of ^{152}Eu. Therefore, the data was prepared for analysis to obtain the energy resolution for EXOGAM2 with newly developed NUMEXO2 electronic.

3.3 Energy Resolution Analysis

The energy resolution of each crystal in the EXOGAM2 system was determined based on the FWHM of energy peaks. The FWHM is a standard metric used to quantify the distribution at half width of the peak. The lower the FWHM value, the higher the sensitivity level of the detector, allowing the separation of closely related gamma energies.

The energy resolution values for each crystal were calculated at both the low-energy peak (344.785 keV) and the high-energy peak (1408 keV) from the ^{152}Eu source. Figure 5 shows measured FWHM values as an example for the second crystal of EXOGAM2 for ^{152}Eu energies at 344.785 keV and 1408 keV.

The values for all the crystals for EXOGAM were obtained using the ROOT software, and the results are summarized in Table 1 [23].

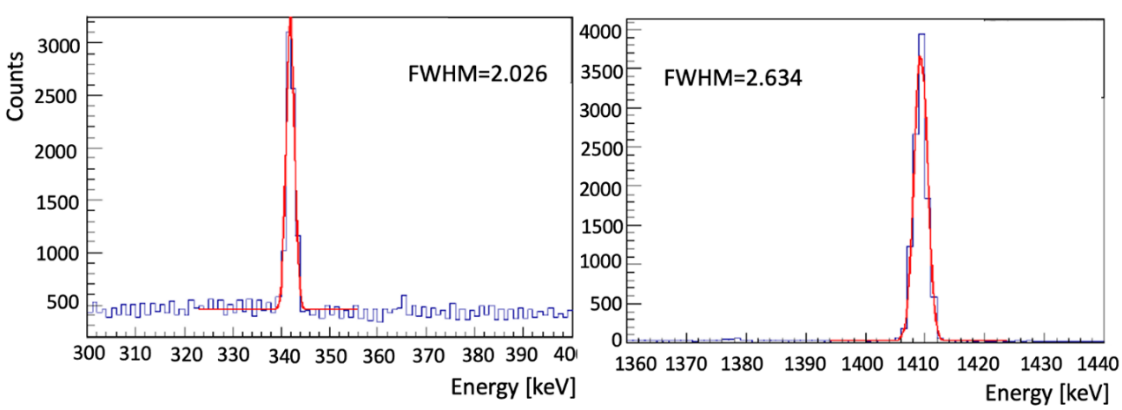

Figure 5. Examples of peak fitting from the radioactive ^{152}Eu calibration source are shown in the left (344.785 keV) and right (1408 keV) panels [23].

Table 1: Energy resolution values for each crystal in the EXOGAM2 system at 344.785 keV and 1408 keV [23].

Crystal Name	Energy resolution for the low energy region-344.785 keV (FWHM)	Energy resolution for the high energy region-1408 keV (FWHM)
1.EXOGAM2-1	2.087	2.684
1.EXOGAM2-2	2.026	2.634
1.EXOGAM2-3	2.004	2.573
1.EXOGAM2-4	3.168	2.938
2.EXOGAM2-1	2.411	2.670
2.EXOGAM2-2	2.409	2.677
2.EXOGAM2-3	2.813	3.410
2.EXOGAM2-4	2.616	4.051

FWHM values for all the crystals of EXOGAM2 shows the energy resolution of EXOGAM2 with NUMEXO2 digitizer determines how accurately it can measure the energy of these gamma rays. Moreover, how distinguish between gamma rays with very close energy levels, providing more precise information about the source. Therefore, the energy resolution which are obtained from the calculation of FWHM are listed in Table 1 for relatively low and high energies of ^{152}Eu. The results indicate that the energy resolution deteriorates as the energy value increases, which is a characteristic property of high-energy efficient detectors. However, certain crystals showed unexpected results, which may require further investigation.

4. CONCLUSION

In this study, we presented the calibration process of the EXOGAM2 conventional gamma detector system using the newly developed NUMEXO2 digital electronic device. Calibration was performed with a ^{152}Eu radioactive source emitting gamma rays at two distinct energy levels. Calibration coefficients were derived from the line equation coefficients obtained by fitting the energy peaks corresponding to these gamma lines.

The energy resolution of each crystal in the EXOGAM2 system was determined based on the FWHM of energy peaks. The results indicated that the energy resolution values for the low-energy branch exhibited reasonable results. However, for high energies, the resolution was not as favorable as for low energies. Notably, the resolution of the 4th, 7th, and 8th crystals at both low and high energy levels displayed unexpected outcomes, necessitating further examination in future experiments with this detector.

Nevertheless, these findings suggest that the use of the NUMEXO2 digital electronic device did not negatively impact the energy resolution of the detectors.

Overall, integrating the NUMEXO2 digital electronic device into the EXOGAM2 detector system facilitates efficient data acquisition at high counting rates, making it a valuable tool for nuclear physics experiments. Further investigations and refinements may be necessary to address unexpected results in certain crystals and optimize the system for specific research objectives.

SIMILARITY RATE: 11 %

CONFLICT of INTEREST

The authors declared that they have no known conflict of interest.

REFERENCES

[1] FJ Egea Canet et al. A new front-end high-resolution sampling board for the new generation electronics of EXOGAM2 and NEDA detectors. IEEE Transactions on Nuclear Science, 62(3):1056–1062, 2015.

[2] G. de France. Exogam detectors. [Online]. Available: http://pro.ganilspiral2. eu/laboratory/detectors/exogam/exogam-detectors.

[3] G De Angelis, A Bracco, and D Curien. The EUROBALL gamma ray detector array. Europhysics news, 34(5):181–185, 2003.

[4] FS Goulding, DA Landis, N Madden, M Maier, and H Yaver. Gammasphere. Overview of detector and signal processing system. In Nuclear Science Symposium and Medical Imaging Conference Record, 1995., 1995 IEEE, volume 1, pages 432–436. IEEE, 1995.

[5] J Eberth, G Pascovici, HG Thomas, N Warr, D Weißhaar, D Habs, P Reiter, P Thirolf, D Schwalm, C Gund, et al. Miniball: A gamma-ray spectrometer with position sensitive ge detectors for nuclear structure studies at rex-isolde. In AIP Conference Proceedings, volume 656, pages 349–356. AIP, 2003.

[6] S Akkoyun, Alejandro Algora, B Alikhani, F Ameil, G De Angelis, L Arnold, A Astier, Ayse Atac¸, Y Aubert, C Aufranc, et al. Agata advanced gamma tracking array. Nuclear Instruments and Methods in Physics Research Section A: Accelerators,Spectrometers, Detectors and Associated Equipment, 668:26–58, 2012.

[7] CW Beausang. Greta: the gamma-ray energy-tracking array. status of the development and physics opportunities. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 204:666–670, 2003.

[8] PT Greenlees. on behalf of the jurogam and great collabs. Nucl. Phys. A, 787:507c, 2007.

[9] DG Sarantites, W Reviol, CJ Chiara, RJ Charity, LG Sobotka, M Devlin, M Furlotti, OL Pechenaya, J Elson, P Hausladen, et al. Neutron shell: a high efficiency array of neutron detectors for gamma-ray spectroscopic studies with gammasphere. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 530(3):473–492, 2004.

[10] J. Nyberg. Neutron wall. [Online]. Available: http://egpworkshop.in2p3.fr/docs/Talks-Mardi/nwall-jn.pdf., 27-30 May 2008.

[11] O Skeppstedt, HA Roth, L Lindstr¨om, R Wadsworth, I Hibbert, N Kelsall, D Jenkins, H Grawe, M G´orska, M Moszynski, et al. The EUROBALL neutron wall–design and performance tests of neutron detectors. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 421(3):531–541, 1999.

[12] J.J. Valiente-Dobon. Neda - neutron detector array. [Online]. Available: http://www.mi.infn.it/WSBormio-Milano2012/Doc/TALK/Dobon-Bormio12-web.pdf., 22-25 February 2012.

[13] G Jaworski, M Palacz, Johan Nyberg, G De Angelis, G De France, A Di Nitto, J Egea, MN Erduran, S Ertürk, E Farnea, et al. Monte carlo simulation of a single detector unit for the neutron detector array NEDA. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 673:64–72, 2012.

[14] BM Nyako et al. Performance of the diamant detector at ganil and plans for improvements.ATOMKI laboratory: for the DIAMANT collaboration,(unpublished), 2007.

[15] RD Baertsch and RN Hall. Gamma ray detectors made from high purity germanium. IEEE Transactions on Nuclear Science, 17(3):235–240, 1970.

[16] WL Hansen. High-purity germanium crystal growing. Nuclear Instruments and Methods, 94(2):377–380, 1971.

[17] J Llacer. Planar and coaxial high purity germanium radiation detectors. Nuclear Instruments and Methods, 98(2):259–268, 1972.

[18] F Azaiez. Exogam: gamma ray spectrometer for radioactive beams. Nuclear Physics A, 654(1):1003c–1008c, 1999.

[19] J Simpson, F Azaiez, G De France, J Fouan, J Gerl, R Julin, W Korten, PJ Nolan, BM Nyako, G Sletten, et al. The exogam array: a radioactive beam gamma-ray spectrometer. Acta Physica Hungarica, New Series, Heavy Ion Physics, 11:159–188, 2000.

[20] Glenn F Knoll. Radiation detection and measurement. John Wiley & Sons, 2010.

[21] FJ Egea Canet et al. A new front-end high-resolution sampling board for the new generation electronics of EXOGAM2 and NEDA detectors. IEEE Transactions on Nuclear Science, 62(3):1056–1062, 2015.

[22] M Tripon. EXOGAM2 technical specifications, 2012.

[23] Şahin Elif, "Adaptation Of Digital Electronic Into Detector Systems NUMEXO2 In Exotic Nuclei Research", Master Thesis, İzmir Institute of Technology, 2017.