Automated Determination of Segment Positions in a High-Purity Thirty-Two Fold Segmented Germanium Detector

K.L. Miller [a,b,*], T. Glasmacher [a,b], C. Campbell [c], L. Morris [a],
W.F. Mueller [a], E. Strahler [b]

[a] *National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824*

[b] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824*

[c] *Department of Physics and Astronomy, Western Kentucky University, Bowling Green, KY, 42102*

Abstract

An automated system for determining detector segment positions in a high-purity thirty-two fold segmented germanium detector has been developed. To determine segment positions as they would appear in an experiment, positions must be measured while the thirty-two-fold segmented germanium crystal is kept at liquid nitrogen temperatures. A collimated ^{57}Co gamma-ray source is moved around the surface of the detector cryostat, and the response of the germanium crystal is measured. Motion of the source is driven by two Slo-Syn motors and BEI incremental optical encoders, which are controlled through LabVIEW programming and a National Instruments PCStep board. The collected data is analyzed to determine the position of the center of each of the thirty-two segments.

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1 Introduction

An array of eighteen thirty-two-fold segmented germanium detectors (MSU detectors) has been implemented at the National Superconducting Cyclotron Laboratory (NSCL) for use in intermediate-energy experiments with exotic beams [1]. High-purity segmented germanium detectors which have now become available [2,3] will provide better energy resolution in gamma-ray detection experiments with fast exotic beams than scintillation detectors such as the MSU NaI(Tl) array [4]. To take advantage of the good intrinsic energy resolution of the germanium detectors, however, the position of the first gamma-ray interaction within the germanium crystal must be determined. Gamma-rays produced in experiments with intermediate-energy beams ($v_{lab}/c \approx 0.2 - 0.5$) are considerably Doppler-shifted. The energy E_γ^{pro} of the emitted photon in the projectile frame of the exotic beam particle may be reconstructed from the energy of the photon observed in the laboratory E_γ^{lab}, if the photon emission angle θ_{lab} with respect to the scattered beam particle is known:

$$E_\gamma^{pro} = \frac{E_\gamma^{lab}(1 - \beta\cos(\theta_{lab}))}{\sqrt{1-\beta^2}}, \; \beta = \frac{v_{lab}}{c} \qquad (1)$$

The segmentation of the outer contacts of the MSU detectors, shown in Fig. 1, currently allows for a determination of the angle of emission θ_{lab} of the gamma

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* Corresponding author. Tel.: +1 517 333-6401; fax: +1 517 353-5967; e-mail: kmiller@nscl.msu.edu.

ray by locating the interaction points of the gamma rays within the germanium crystal to a precision of one centimeter, if the locations of the segments have been well determined. In the future, this position resolution will be further improved through the analysis of the digitized pulse shapes for all segments on each germanium detector. Simulations of pulse-shape analysis in segmented germanium detectors indicate that a position resolution of one to three millimeters appears possible [3,5]. The validity of these simulations has been confirmed in a first measurement [6]. The determination of the first interaction point of a gamma ray from the set of interaction points will rely on accurate and fast tracking algorithms, which are currently being developed [7]. In order for the avenue of gamma-ray energy tracking using pulse-shape analysis to be explored with the MSU detectors, uncertainty in the physical position of the segments must be reduced to less than one millimeter.

While the energy resolution of the MSU germanium detector array is dependent on the opening angle of the germanium detectors and thus on the achievable position resolution, other experimental factors also contribute. The uncertainty in the position and angle of the incoming beam, velocity change in the target, and uncertainty in the measured position of the outgoing particle also must be accounted for. If the position resolution in the segmented germanium detectors is reduced to three millimeters through the use of pulse-shape analysis, the energy resolution of the MSU germanium detector array at a distance of forty centimeters from the target may be reduced to one percent at 1332 keV. For a Coulomb excitation experiment at the NSCL where a beam of ^{32}Mg with a total energy of 3.2 GeV impinges on a 200 mg/cm^2 ^{197}Au target, such an energy resolution may be achieved if the position of the incoming beam is determined to within five millimeters and the angle of the outgoing beam particle is measured to within 0.3 degrees. Such measurements will be possible at the NSCL using a series of parallel-plate avalanche counter beam tracking detectors [8] to track the position of the incoming beam, and a high-resolution heavy-ion spectrograph such as the S800 [9] to measure the position of scattered beam particles.

In addition to an accurate determination of the first interaction point of a gamma ray within a germanium detector segment, determination of the angle of gamma ray emission requires knowledge of the position of the thirty-two segments within each detector, and the position of each detector with respect to the target. The position of each detector is measured for each experimental configuration. The position of each segment within the germanium crystal must be measured as it would appear in an experiment, when the detector is cooled to liquid nitrogen temperatures. This presents two difficulties: the germanium crystal must be inside the cryostat and under vacuum, preventing a direct measurement of segment positions; and the crystal is attached to a cooling rod, which contracts and expands a few millimeters as the temperature of the detector changes from room temperature to liquid nitrogen temperature.

We have developed and implemented a system for determining segment positions in a cooled MSU thirty-two fold segmented germanium detector.

2 Mechanical Setup and Data Acquisition

The test stand used to automatically determine the segment positions is shown in Fig. 2. The detector is positioned such that the cylindrical cryostat containing the germanium crystal is centered within a movable ring. Centering of the cryostat is accomplished through the apparatus' four adjustable legs. A ^{57}Co source, three millimeters in diameter, is mounted in a copper collimator affixed to the movable ring. The collimator is 2.5 centimeters thick and approximately 20 square centimeters in area, with a one millimeter diameter hole in the center. The source is placed over the one millimeter hole, allowing the copper block to act as a collimator for the 122 keV gamma-rays emitted from the decay of ^{57}Co. A low-energy gamma-ray source was chosen to minimize Compton scattering within the detector segments, so that only full-energy peaks in the germanium crystal are detected. The ring on which the copper block is mounted allows the gamma-ray source to move 360 degrees around the cryostat, and up to 41 centimeters linearly. This allows the source to move to any position around the surface of the cryostat, excluding the front and back faces of the cylinder. The motion of the source is driven by two synchronous stepping motors (Slo-Syn M063-LE09), one each for the linear and circular axes of motion. To better control the position of the source, an incremental optical encoder (BEI L25) is connected to each axis. The direction and magnitude of motion is controlled by LabVIEW programming and ValueMotion software, through a National Instruments PCStep four-axis closed-loop stepper board.

The goal of the automated position determination is a measurement of the linear and angular centers of each segment. The center of a segment is defined as the source position at which the number of 122 keV gamma-rays detected by that segment is greatest. Linear positions are measured with respect to the front face of the cryostat, the position of which is determined by a convergent laser sensor (PicoDot PD45VP6C100). Angular positions are measured with respect to the initial position of the source, which is determined by the activation of an optical switch.

The source is moved to one hundred positions along the length of the cryostat, and to one hundred angular positions at each linear position. The number of positions was chosen to place the source of gamma rays directly over each segment for at least ten positions linearly, and twenty-five positions around the cryostat circumference. The mechanical motion of the source and data acquisition are controlled by one LabVIEW program. At each position, data for 10,000 gamma-ray events in the germanium crystal passes through a series of electronics prior to digitization by two sixteen-channel twelve-bit ADCs (National Instruments PC-MIO-16E-4). The trigger for data acquisition is provided by the central contact of the germanium detector, which provides a signal when any of the thirty-two segments register a gamma-ray interaction. The central contact signal is amplified in a timing filter amplifier (Ortec 454) and then discriminated in a Tennelec 455 constant fraction discriminator. The output of the discriminator is delayed before it is passed to the ADCs as the event trigger. The energy signals from each of the thirty-two segments are amplified in quad shaping amplifiers manufactured at MSU, and the peak amplitude is held in an ASCOM NIM stretcher before digitization. At each source position, the digitized energy signals for each segment as well as the angular and linear position of the source are saved in a 665 KB binary data file.

A total number of 10,000 gamma-ray events for each position was chosen in order to assure 900 to 1,000 counts in the 122 keV photopeak at the center of each segment. As the central contact provides a trigger when any segment registers an interaction, background gamma-ray events in other segments as well as inelastic scattering to neighboring segments makes the large number of total events necessary to achieve the goal of 1,000 photopeak events in each segment of interest. Each of the 10,000 gamma-ray events takes approximately six milliseconds to be processed through the electronics, LabVIEW, and written to disk. This results in a data collection rate of approximately 150–200 Hz, for a total scanning time of seven days for 10,000 positions. The deadtime of the data acquisition is dominated by the LabVIEW processing time, requiring that data be collected for a fixed number of gamma-ray events rather than a fixed amount of time.

3 Data Analysis

To determine the linear and angular center positions of each segment, the collected data is analyzed using a combination of Tcl and C programming. For each of the 10,000 positions of the ^{57}Co source, an energy spectrum is generated for all thirty-two segments. An energy spectrum for one segment is shown in Fig. 3. The center of the 122 keV photopeak is determined for each position, and the number of counts in a range of channels around the center is integrated. For each segment, at each fixed linear position, a graph of total counts under the photopeak versus angular position is created. An example for the F segments is shown in Fig. 4(a). The tails on the total counts versus position curves are due to incomplete collimation of the 122 keV gamma ray in the copper collimator.

From the graph of counts versus angular position, the angular center position is determined, defined as the centroid of the curve for each segment. A weighted average method is used to calculate the centroid of each curve. This process is repeated for each of the one hundred linear positions. Multiple curves for a segment will result in multiple centroids for that segment. The centroids are averaged to produce the final angular center position for each segment. The procedure is then repeated for each of the one hundred angular positions, resulting in linear and angular center positions for each of the thirty-two segments.

4 Results and Performance

Eleven of eighteen MSU segmented germanium detectors have been successfully scanned and analyzed. The automation of the data acquisition process has allowed the positions of each segment to be determined with better accuracy than the two millimeters specified by the manufacturer. The errors in the linear segment positions determined using this method were 0.28 mm for the A segments, 0.23 mm for the B through G segments, and 0.43 mm for the H segments. The reason for the larger errors for the A and H segments' center positions is apparent from Fig. 4(b). The ^{57}Co source begins at the front face of the cryostat, at the edge of the A segments. Thus one tail of the curve for the A segments is largely missing. A similar discrepancy is obvious in the H segments. In this case, the copper block containing the ^{57}Co source cannot travel past the edge of the H segments due to the presence of the detector's cooling arm. For the angular segment positions, the errors for all segments are 0.28 degrees.

In addition to the more accurate determination of the segment positions, other characteristics of the crystal position and outer contact segmentation were observed as a result of these measurements. From Fig. 5, it can be seen that the germanium crystal is centered within the detector cryostat and is not tilted in any direction. Secondly, the segments are equally spaced with respect to one another, both in linear and angular position. Lastly, all eleven detectors scanned so far show very similar linear and angular positions. Thus the manufacturer has been consistent in the placement of the germanium crystal and position of segments in the first eleven detectors.

5 Acknowledgments

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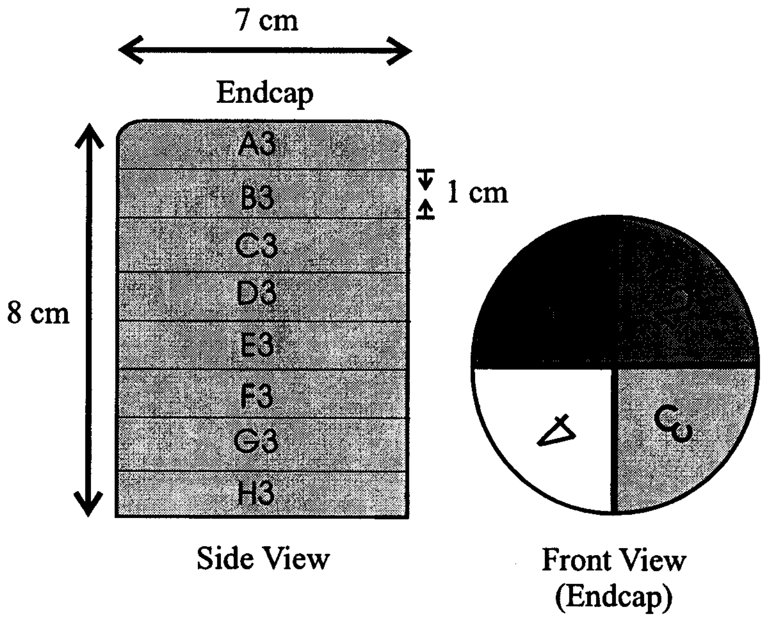

Fig. 1. Schematic of electronic segmentation of the germanium crystal.

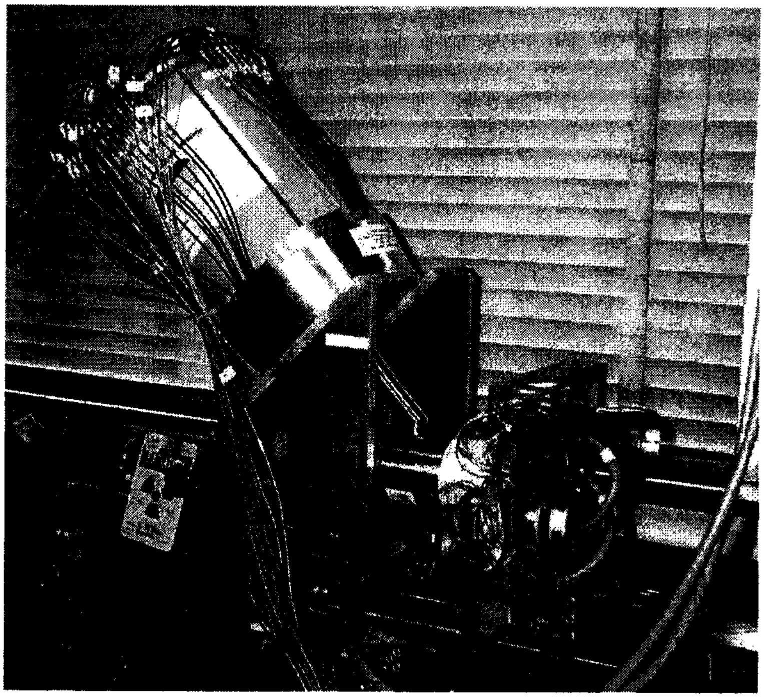

Fig. 2. MSU segmented germanium detector mounted in the test stand.

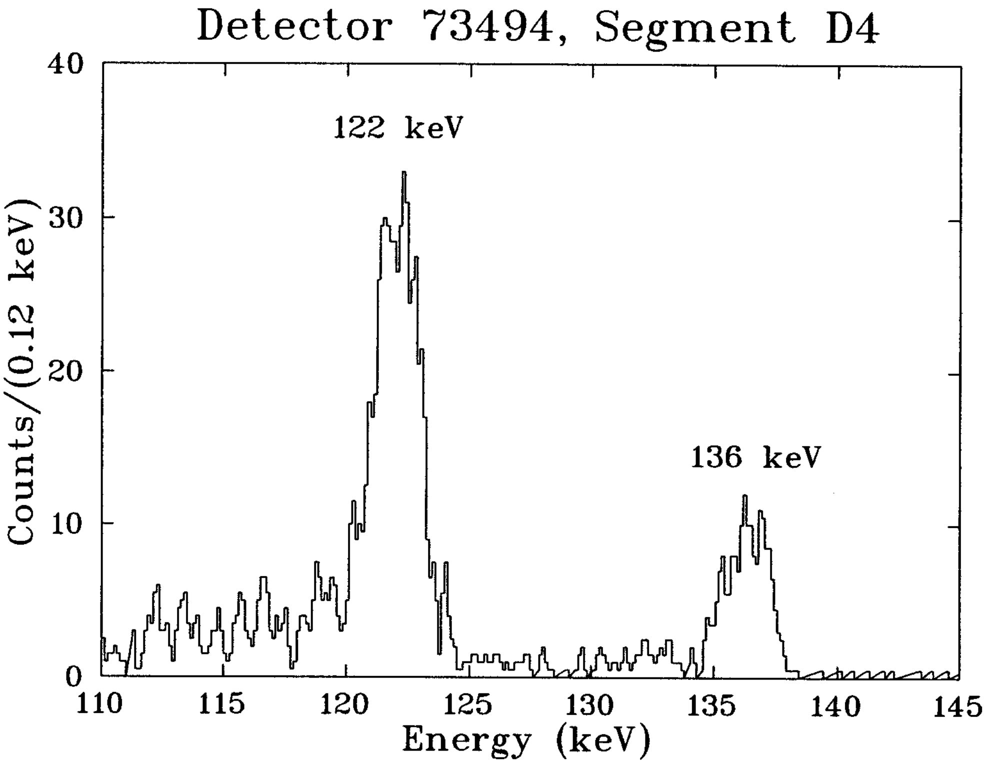

Fig. 3. Typical energy spectrum for one detector segment. The ^{57}Co source is positioned close to the center of segment D4. The 122 keV and 136 keV lines from the decay of ^{57}Co are visible. The intrinsic energy resolution of one segment is less than 2 keV at 1332 keV. The observed resolution is due to the use of the MSU quad shaping amplifiers which were not designed for high-resolution spectroscopy. The resulting resolution shown here is sufficient for the present application.

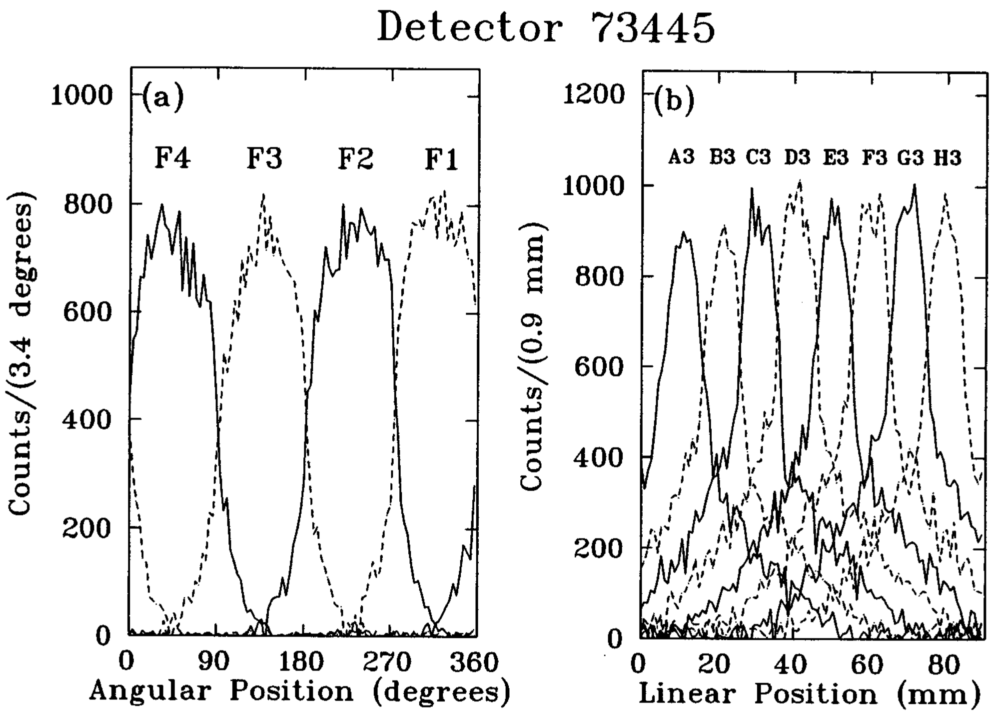

Fig. 4. Number of counts under the 122 keV photopeak versus angular (a) and linear (b) source positions for detector 73445. The centroid of each curve, determined using a weighted average method, specifies the center position of the corresponding segment.

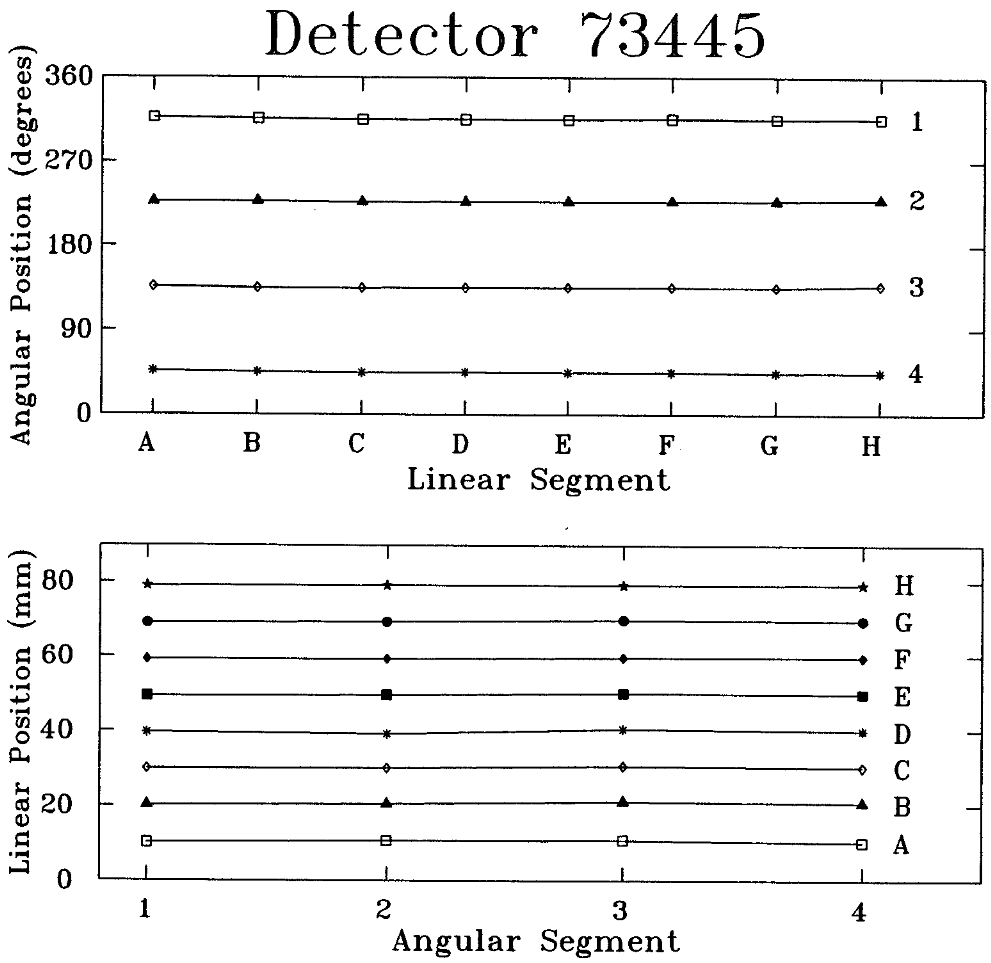

Fig. 5. Angular and linear center positions for the thirty-two segments of detector 73445. Error bars for both linear and angular positions are smaller than the plotting symbol.