Position Determination of Photon Interactions in Segmented Germanium Detectors

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Abstract:

In order to perform in-beam gamma-ray spectroscopy experiments of rare-isotope beams at the National Superconducting Cyclotron Laboratory (NSCL) of Michigan State University, a new array of 32-fold segmented germanium detectors (SeGA) has been developed and implemented (1). The velocities of secondary exotic beams at the NSCL are typically 0.2 to 0.5c so that the main contribution to the gamma-ray resolution stems from Doppler broadening due to the finite solid angle of the detector. One way to reduce the uncertainty in the gamma-ray emission angle is to use segmented germanium detectors. For a given event in a detector, one or more segments will register a measurable signal. With a single segment event the angle of emission of the gamma ray can be determined to within the physical segment size. For multiple segment hits, the determination of the gamma-ray emission angle is less clear. We report here on an analysis of first-hit probabilities based on the locations and energies deposited in individual segments.

Introduction

We are interested in high-resolution gamma-ray spectroscopy with fast beams. Velocities of the beam ranges from 0.2 to 0.5c as it travels from the cyclotron to the different experimental vaults. When it enters the vault, a target, such as Beryllium, is set-up in the beam line. The beam, which consists of highly focused ions, hits the target and ejects a gamma-ray. The way in which we detect these gamma-rays is by using High Purity Germanium Detectors. The main contribution to the gamma-ray resolution comes from Doppler broadening due to the finite solid angle of the detector. By using the highly segmented Germanium crystals, one is able to reduce the uncertainty of the solid angle. By looking at the first-hit segment, we are able to reduce the uncertainty of the angle even further.

Detectors

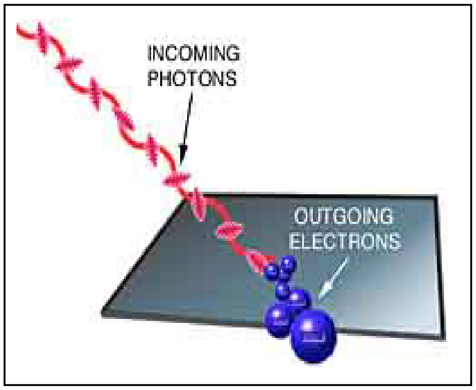
Modern high-resolution gamma-ray resolution detectors consist of a diode made by applying electrical contacts to a single piece of high purity germanium (HPGe). The diode is reserve biased to establish an electric field, which causes the detector element of free charge carriers. When incoming photons interact with the depleted region, a flow of electronics is generated. This flow of electrons establishes a current directly proportional to the energy of the photon. The current is then incorporated by a preamplifier to produce an output pulse, which is analyzed by outside electronics (4).

The SeGA detectors used by the gamma group at Michigan State University are of coaxial design. The coaxial detector element is in the shape of a right circular cylinder with a coaxial hole 10 mm in diameter extending from the rear to within 10-15 mm of the front face. The outer electrode covers the front face and sides of the cylinder and the inner electrode covers the surface of the hole. The outer electrode is a positive ion-implanted contact only a few microns thick. The inner electrode on the other hand is a negative lithium diffused contact about 1 mm thick. The corners are rounded to increase the uniformity and intensity of the electric field where the front face meets the walls of the cylinder (2).

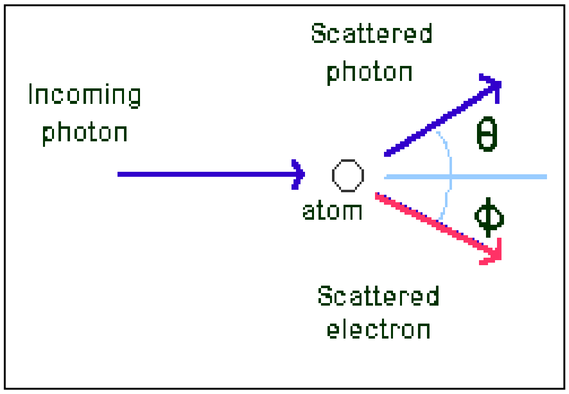
This configuration of the contacts is called the reverse-electrode. In a conventional electrode, the inner contact is positive and a negative outer contact. The reverse electrode has several advantages over the conventional electrode. First, the thin outer contact extends the usable energy range down to about 3 keV in contrast to about 40 keV in the conventional electrode. Secondly, the reverse-electrode detectors can be restored to almost new after large amounts of neutron irradiation. Finally, the conventional electrodes are essentially one large diode in contrast to the 32-individual diodes in the MSU detectors (2).

Question:

When the gamma-ray is emitted from the target, its energy is measured in the laboratory reference frame; the energy in the moving frame causes the solid angle to have an uncertainty associated with it. This uncertainty is based on the direction of the photon in relation to the Germanium crystal. The gamma-ray's direction of emittance will sometimes be towards the detector and sometimes away due to the Doppler effect. We can apply the Doppler effect to gamma rays in the same way as the red shift is applied to galaxies. If a 1 meV gamma-ray were emmited from the target, its energy if it hit the back of the crystal would be 0.7 meV and if it hit in the front would be 1.3 meV. When the gamma-ray is moving toward the detector, its spectra will be forward-shifted. When it is moving away its spectra will be backward-shifted (3). We need to correct this shift by determining the angle the gamma-ray hit the segment.



This is where we take into consideration first-hit probability. We want to find out where the gamma-ray hit and what its energy distribution over the crystal looks like. If the gamma-ray scatters within the crystal, multiple segments will record events. We know which segments had an energy deposition, but we do not the order in which they were deposited. By looking at the energy distribution, we will be able to predict the photon's first interaction point based on the energy deposited. This will then give a



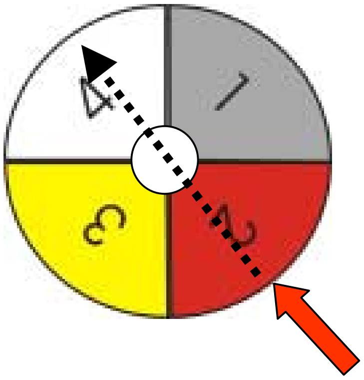
more accurate reference point for the determination of the Doppler reconstruction angle.

However, gamma-rays can interact within the detector crystal in several ways. First, if a gamma-ray hits a segment and its energy is fully absorbed into the crystal, photoelectric absorption has taken place (Figure 2). In this process, the gamma-ray deposits all of its energy into a bound electron in the crystal and an event is recorded. However, this happens only in a small percentage of events. The more common interaction in the crystal is through Compton scattering (Figure 3). The incoming gamma-ray hits an electron and the electron is broken free from the crystal structure. The gamma-ray continues on with less energy then it started with. The photon could then hit another segment in the crystal and continuing scattering until it is absorbed or is ejected from the crystal (3).

Experiment/Method

In this experiment, we concentrated on first-hit probabilities within the segments. To do so, we chose a single quadrant and irradiated the eight individual segments in the center and along the edges. We know which segment was hit first so we could then analyze the energy distribution of the interacting gamma-rays. We hypothesized that the chosen segment and the segment behind it would have the most counts compared to the neighboring segments and the remainder of the crystal.

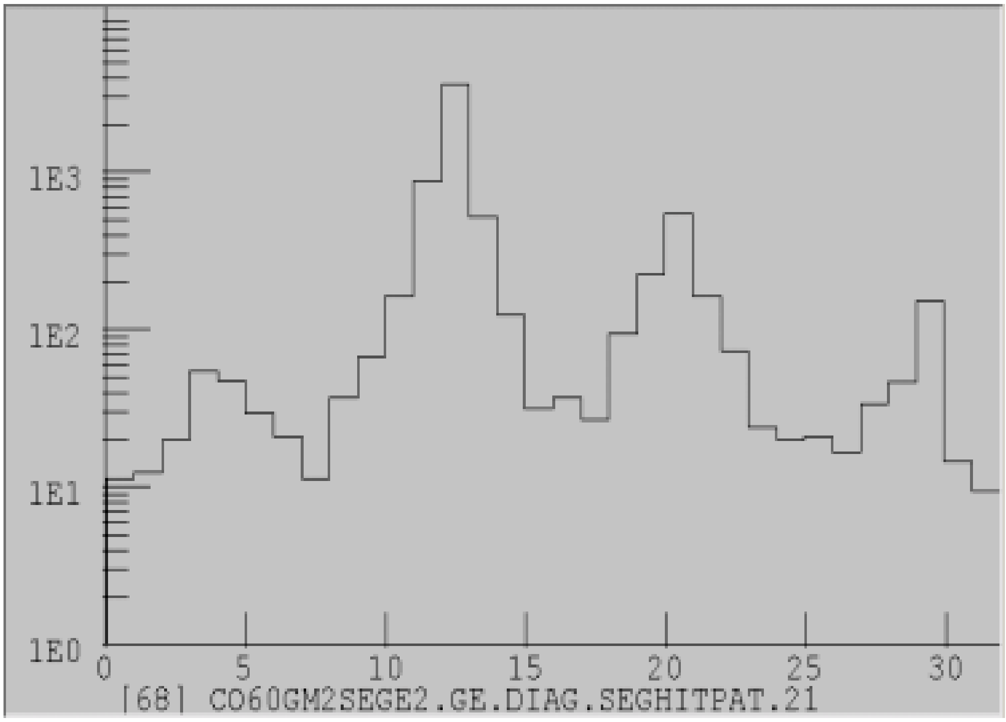
A heavy-metal collimator was used to reduce random gamma-ray emission and to keep it concentrated on the intended segment to be irradiated (Figure 4). The collimator was about 12 cm long and a diameter of about 8 cm. There is a 2mm diameter hole through which gamma-rays are emitted from. In this experiment, a 33 Ci ^{60}Co gamma-ray source was used. At higher energies, the gamma-ray interacts within the crystal, and scatters into more than one segment. A small, removable Banner laser was mounted to the collimator (model number M126E2LDQ). The laser was used for aligning the emission hole with the crystal. The laser needed to be perpendicular to the segment and reflect back into the emission hole, otherwise the gamma-rays would not be fully directed at the segment of interest (Figure 5).



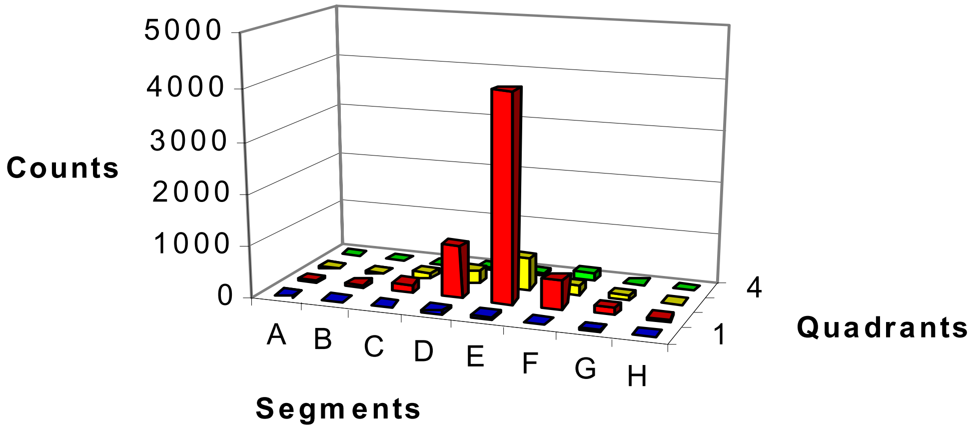
After setting up the collimator, the detector was set-up. The detector was taken out of SeGA and mounted in an aluminum stand. Each segment was tested to make sure there was a signal from the preamps. The detector was then biased to +4000 Volts to create the diode and the rest of the electronics cables were connected to the appropriate modules. The collimator was then used to align the emission hole with the individual segments. The position of the collimator was marked on the wood board for later use with the source.

The laser was then removed and the source was inserted into the collimator. At each of the fifteen source positions, data for 30 minutes of gamma-ray events was taken. The events that occurred in the germanium crystal passed through a series of electronics prior to digitization by two 16-channel 12-bit Analog to Digital Converter (ADCs). The trigger for data acquisition is provided by the central contact of the germanium detector.

Results

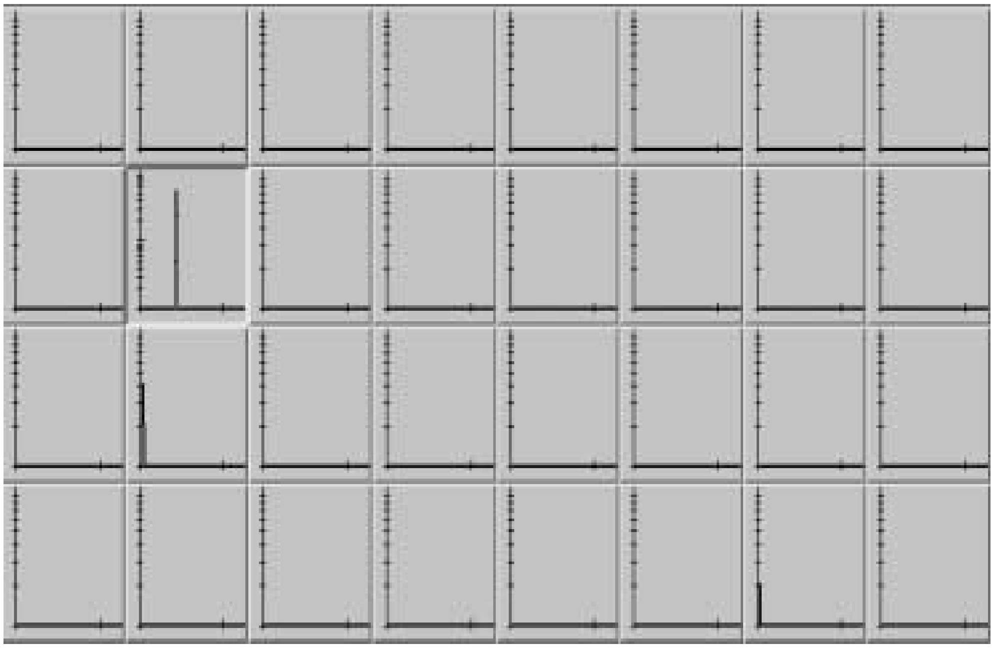


By knowing which segment the gamma-ray hit first, we were able to predict that the segment would have the most energy deposited there. In the analysis, we looked at the segment multiplicity two events and the fully absorbed energy events in the photo peak from the central contact to get a better understanding



of how the gamma-ray interacted in the crystal. We were able to see that the segment irradiated had in fact the most counts. Figure 6 displays the segment hit pattern associated with a run that was done this summer. The events that were recorded were over the entire run length of 30 minuets. Here, segment E2 was irradiated and one can see that it had the most counts. Figure 6 illustrates that there were multiple events happening in the crystal, however, it does not lend to an understandable representation of where the most events happened. Figure 7 is a 2-D version of Figure 6. We can now see quite clearly that E2 had the most interactions and that F2 and D2, the neighboring segments, had considerable events in contrast to the rest of the crystal.

The corresponding segment energy pattern for the segment hit pattern above shows us where the photon hit the crystal and scattered (Figure 8). The X-axis of the graph corresponds to channel number which has an energy associated with it. The Y-Axis corresponds to counts per channel.



However, in the Figure 7, we came across an interesting trend. Quadrant 1 barely had any hits. Due to the fact that there were so few hits, we speculate that the source was not properly aligned. Instead of using the calculated segment positions, the source was aligned using the canister sticker that was not as accurate.

Conclusions/ Future Work

The hypothesis that the first segment hit will have the most energy was shown to have worked in this experiment. Because of this, we now have a slightly better understanding of how a gamma-rays first hit relates to the energy deposited in the crystal. Yet, further testing of this theory still needs to take place to insure accuracy of the prediction.

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