An automatic energy-calibration method for segmented germanium detectors

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Abstract

An automatic gain-matching method has been developed for the energy calibrations of the 32 segments of a large-volume Germanium detector. The method calibrates the small-volume segments relative to the central contact, which collects the charge from the total germanium crystal volume and can be efficiently calibrated with known sources. The method presented here can employ photons of arbitrary energy. With the use of in-beam gamma-rays for segment calibrations it presents an efficient way to perform continuous energy calibrations in experiments.

Key words: germanium detectors; segmented detectors; gain matching

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1 Introduction

Segmented large-volume high-purity germanium detectors have become commercially available [1–5] and are increasingly being used in nuclear physics experiments to measure the energies and the interaction points of gamma-rays with typical energies of 0.1 - 5 MeV. In a typical application, the charge from the whole crystal volume is collected with the central contact and the segment contacts collect the charge from the individual segments, which are sensitive to only a fraction of the volume of the whole crystal. The energy calibration of a highly segmented detector presents the user with two challenges. The number of channels to be calibrated necessitates an automated procedure while the small volume of the segments drastically reduces the probability of detecting the full energy of a photon in any one segment (particularly for energies larger than 500 keV).

In this paper we present an automated energy calibration method for multi-segment detectors. The segments are calibrated relative to the central contact. The method presented here can make use of both full energy and partial-energy depositions in any one segment and the energies of the photons do not need to be known. An application of this method to the calibration of a 32-fold segmented high-purity Germanium detector [5] is also discussed.

2 Implementation of the automatic energy-calibration method

For segmented germanium detectors the central contact can be efficiently calibrated with full-energy peaks detected from known gamma-ray sources. The charge collected on the central contact represents the sum of those present on the individual segments. In terms of deposited energy, the central contact measures the total energy deposited in the whole crystal, which equals the sum of the energies measured in the individual segments. For events in which only one segment registers energy, the energy deposited in this segment equals the energy measured by the central contact. We use the class of events with segment multiplicity one (*i.e.* one segment and the central contact register an energy) to calibrate each segment with respect to the central contact. This method makes use of events in which the full energy and events in which part of the photon's energy is deposited in the crystal. The method can be fully automated and can use gamma-rays of known and unknown energies from sources, background, or in-beam events.

Calibrating a segment involves parameterizing a data set (x_i, y_i) with segment multiplicity one, where x_i denotes a channel number corresponding to the (uncalibrated) energy signal measured in the i^{th} segment and y^i denotes the energy determined by the central contact. An example of such a data set for one segment of a 32-fold segmented germanium detector [5] is shown in Fig. 1, where two single-stage 16-channel shaping amplifiers (NSCL design) and two

16-channel ADCs (Philips Scientific 7164H) were used for processing the 32-segment signals, whereas one amplifier (EG&G Ortec 572) and one channel of the ADC (EG&G Ortec 413A) processed the central-contact. Since the electronics for the segments is not optimal, especially in terms of linearity, we choose a quadratic parametrization for the data set (x_i, y_i):

$$y_i = a + bx_i + cx_i^2 \tag{1}$$

The coefficients a, b, and c are determined by minimizing χ^2 defined as

$$\chi^2 = \sum(\Delta y_i)^2 = \sum(y_i - a - bx_i - cx_i^2)^2 \tag{2}$$

There are several different techniques available for finding this minimum (see e.g. the discussion in [6]). If a continously improving on-line calibration is desired, an approach which does not require a complete data set to perform the minimization can be advantageous. However, it should be pointed out that any such solution (which does not involve saving all the data and doing the calculation at the end) will require special care with numerical precision. A possible implementation is given in the appendix.

The distribution of the data points plays an important role in the convergence of the gain-matching procedure. The more evenly the data points are scattered over the whole region of interest, the faster the procedure converges. Therefore a better convergence can be achieved by selecting an appropriate region or weighting the data points properly. In the case of germanium detectors, it is advantageous to separately deal with the low-energy region where the detector is most efficient and where the data points would dominate the fitting compared to the high-energy data points.

3 Results for a 32-fold segmented Germanium detector

Figure 1 shows the calibration curve derived for one segment. The whole energy range was divided into three regions for separate gain matching. Fig. 2 illustrates the quality of the gain-matching procedure. For events with multiplicity one, the central-contact spectrum for one segmented Ge detector is compared to the summed spectrum of all gain-matched segments of this detector.

A traditional calibration using the full-energy peaks in a segment spectrum has been performed for comparison. The result from the gain-matching procedure with various number of data points was compared to this traditional calibration. An energy region between 150 keV and 1600 keV was chosen for the gain matching. As shown in Fig. 3, with only 30 data points used for the gain matching, an average difference of 4.5 keV between the result from the traditional calibration and that from the gain matching was achieved; with 200 data points available, however, the gain matching converged to the traditional calibration with an average difference of less than 1 keV.

If a linear parametrization is chosen in equation 1, we were unable to obtain a calibration with deviations of less than 5 keV for the high- and low-energy regions.

4 Summary

An automatic method has been developed for the energy calibration of segments of a segmented detector. This method can also be applied to other types of segmented detectors, such as segmented silicon detectors, where the energies deposited in individual segments, as well as the total energy in the whole detector, are available. The procedure does not require gamma-rays of known energy, which allows the use of full-energy and Compton-scattered photons from in-beam events or sources.

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5 Appendix

The minimum value of χ^2 in equation 1 can be determined by setting the derivatives of χ^2 with respect to each of the coefficients equal to zero. We can write the optimum values for the coefficients a, b, and c in terms of determinants

$$a = \frac{1}{\Delta} \begin{vmatrix} \Sigma y_i & \Sigma x_i & \Sigma x_i^2 \\ \Sigma x_i y_i & \Sigma x_i^2 & \Sigma x_i^3 \\ \Sigma x_i^2 y_i & \Sigma x_i^3 & \Sigma x_i^4 \end{vmatrix} \tag{3-a}$$

$$b = \frac{1}{\Delta} \begin{vmatrix} 1 & \Sigma y_i & \Sigma x_i^2 \\ \Sigma x_i & \Sigma x_i y_i & \Sigma x_i^3 \\ \Sigma x_i^2 & \Sigma x_i^2 y_i & \Sigma x_i^4 \end{vmatrix} \tag{3-b}$$

$$c = \frac{1}{\Delta} \begin{vmatrix} 1 & \Sigma x_i & \Sigma y_i \\ \Sigma x_i & \Sigma x_i^2 & \Sigma x_i y_i \\ \Sigma x_i^2 & \Sigma x_i^3 & \Sigma x_i^2 y_i \end{vmatrix} \tag{3-c}$$

where

$$\Delta = \begin{vmatrix} 1 & \Sigma y_i & \Sigma x_i^2 \\ \Sigma x_i & \Sigma x_i^2 & \Sigma x_i^3 \\ \Sigma x_i^2 & \Sigma x_i^3 & \Sigma x_i^4 \end{vmatrix} \tag{3-d}$$

The sums in equation (3) extend over all data sets of events with segment multiplicity one for the segment in question. An implementation issue arises for these intermediate summing variables: their values are too large to be held in any of the highest precision variables available in a standard C/C++ library. Instead, a C++-based computation package MPFUN++ [7] is used, which performs multi-precision floating-point arithmetic with arbitrary precision.

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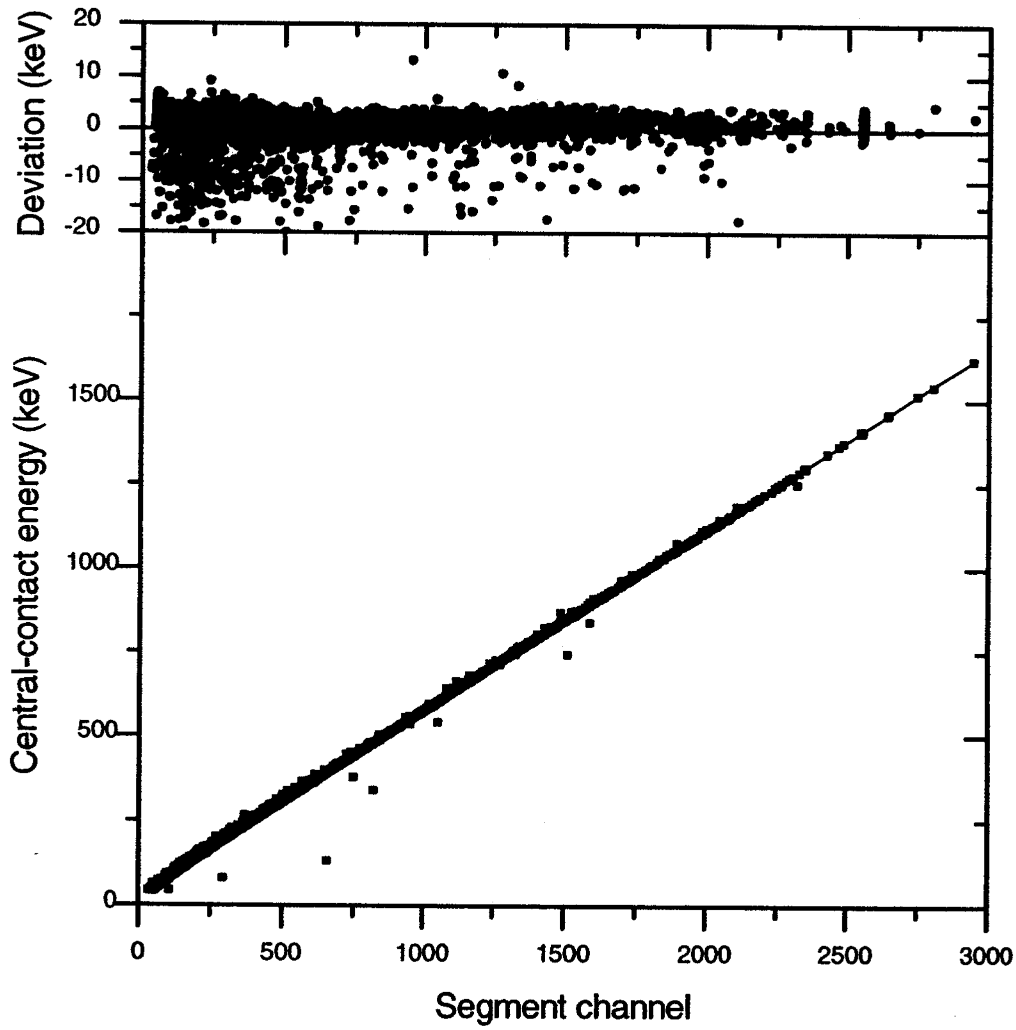
Fig. 1. Lower panel: the (calibrated) energy measured by the central contact for events with segment multiplicity one versus the (uncalibrated) energy signal measured by one segment of a 32-fold segmented germanium detector. Gamma-rays from a ^{152}Eu source were used to generate the events. The solid line shows the result of the quadratic parameterization described in equation (1). Upper panel: the deviation of the calibrated segment energy from the measured central-contact energy.

Fig. 2. The energy-sum spectrum for all gain-matched segments of a 32-fold segmented germanium detector (lower panel), compared to the energy measured in the central contact (upper panel). A ^{152}Eu gamma-ray source was used for the measurement. The energy resolutions are indicated by the labels on the top of the 1408 keV line.

Fig. 3. The root-mean-squared (*rms*) deviation of the gain-matched segment energies, relative to a traditional calibration, versus the number of data points available for the gain-matching procedure.



Deviation (keV)
20
10
0
-10
-20
Central-contact energy (keV)
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
Segment channel

Fig. 1

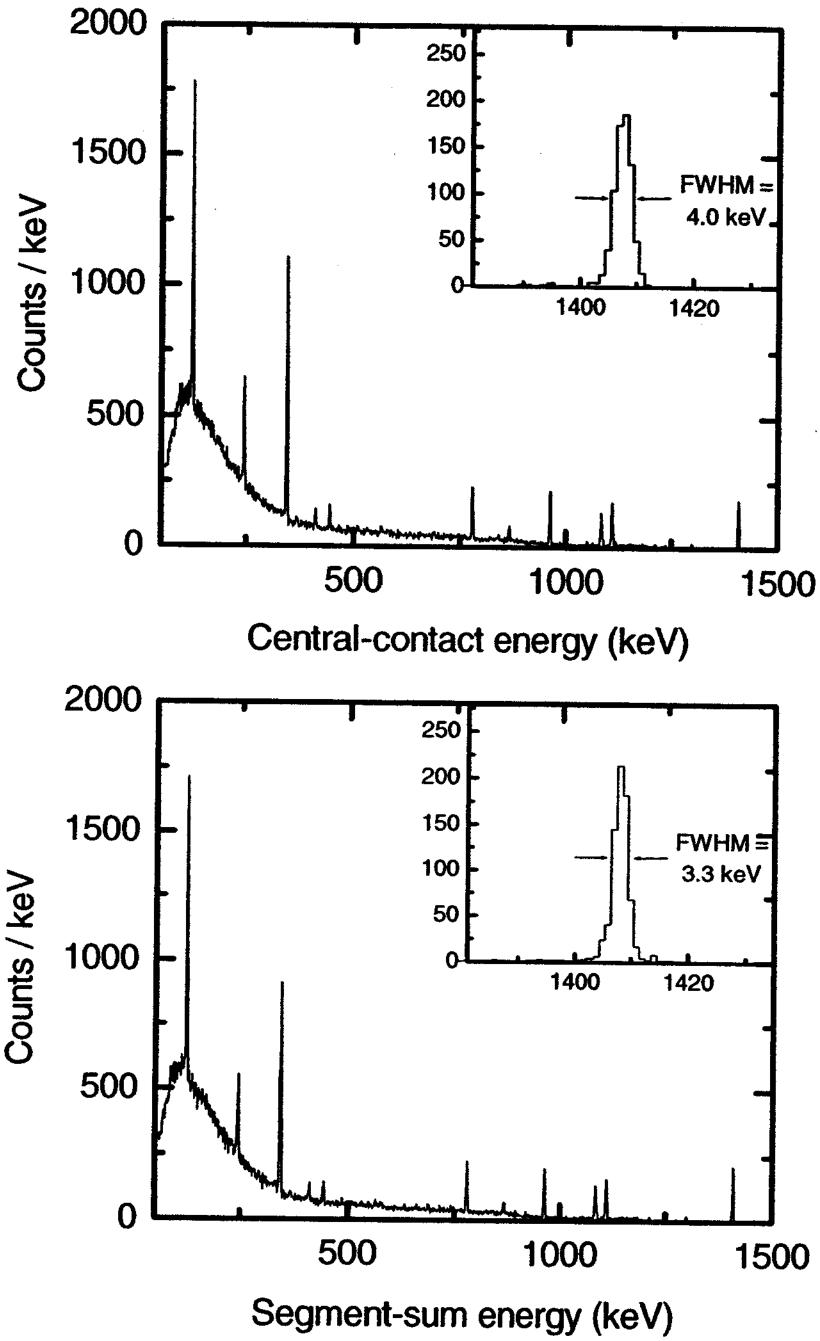

2000
1500
1000
500
0
Counts / keV
250
200
150
100
50
0
1400
1420
FWHM =
4.0 keV
500
1000
1500
Central-contact energy (keV)
2000
1500
1000
500
0
Counts / keV
250
200
150
100
50
0
1400
1420
FWHM =
3.3 keV
500
1000
1500
Segment-sum energy (keV)

Fig. 2

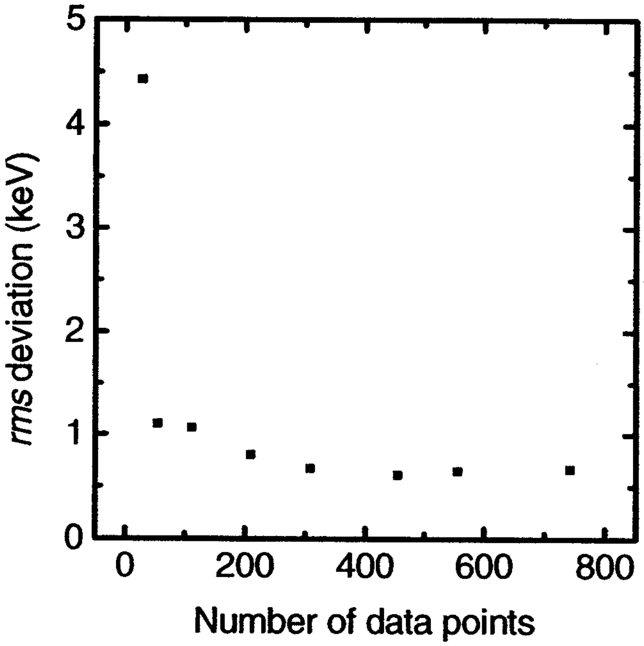

rms deviation (keV)
5
4
3
2
1
0
0
200
400
600
800
Number of data points

Fig. 3