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Crosstalk corrections for improved energy resolution with highly segmented HPGe-detectors

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ABSTRACT

Crosstalk effects of 36-fold segmented, large volume AGATA HPGe detectors cause shifts in the γ-ray energy measured by the inner core and outer segments as function of segment multiplicity. The positions of the segment sum energy peaks vary approximately linearly with increasing segment multiplicity. The resolution of these peaks deteriorates also linearly as a function of segment multiplicity. Based on single event treatment, two methods were developed in the AGATA Collaboration to correct for the crosstalk induced effects by employing a linear transformation. The matrix elements are deduced from coincidence measurements of γ-rays of various energies as recorded with digital electronics. A very efficient way to determine the matrix elements is obtained by measuring the base line shifts of untriggered segments using γ-ray detection events in which energy is deposited in a single segment. A second approach is based on measuring segment energy values for γ-ray interaction events in which energy is deposited in only two segments. After performing crosstalk corrections, the investigated detector shows a good fit between the core energy and the segment sum energy at all multiplicities and an improved energy resolution of the segment sum energy peaks. The corrected core energy resolution equals the segment sum energy resolution which is superior at all folds compared to the individual uncorrected energy resolutions. This is achieved by combining the two independent energy measurements with the core contact on the one hand and the segment contacts on the other hand.

1. Introduction

For several new applications in γ-ray detection the outer contact of encapsulated, tapered, regular or irregular shaped, closed ended HPGe detector crystals are highly segmented [1]. Especially the next generation of γ-ray spectrometers like AGATA [2] and GRETA [3] is based on this detector type and will provide the best design parameters to achieve simultaneously the following goals: the very high intrinsic energy resolution from HPGe for γ-rays is maintained for the core signals as well as for all the additional segment signals from the outside contacts. The typical combination of hexagonal (and pentagonal) shapes of long crystals allows the geometrical arrangements in highly symmetric polyhedrons which guarantee highest solid angle coverage of nearly 4π. The position sensitivity is obtained from the pulse shape information of all direct and transient signals from the segments and the core contacts. Pulse shape analysis methods together with the novel γ-ray tracking technique are employed for reconstruction of the individual interaction points of the γ-rays within the active Ge material [4–6].

The tracking technology allows to boost the efficiency of such state of the art spectrometers over present devices. A gain of several orders of magnitude is possible in multiple γ coincidence mode. The reason for this is exemplified in Fig. 1. Three γ-rays are shown to be detected in coincidence in two neighboring detectors of a segmented germanium shell. In a traditional gamma spectrometer, all three γ-rays would add to the Compton background. Using anti-Compton shields, one would have to reject at least parts of these γ-rays. The high segmentation in combination with the new tracking technology allows to recover

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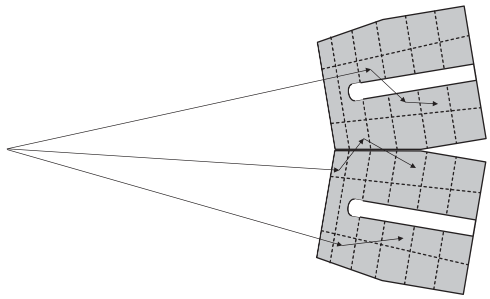

Fig. 1. Schematic drawing illustrating the basic principle and efficiency gain in segmented detector arrays over standard technology: in a traditional γ-spectrometer, all three γ-rays would add to the Compton background or would be rejected if anti-Compton shields were used. The new tracking technology allows to recover such events in the photopeak by identifying the individual interaction points and reconstruction of the scattering path of individual γ-rays.

such γ-rays in the photopeak. Evidently, as prerequisite, a good add-back resolution of the segment energies is assumed.

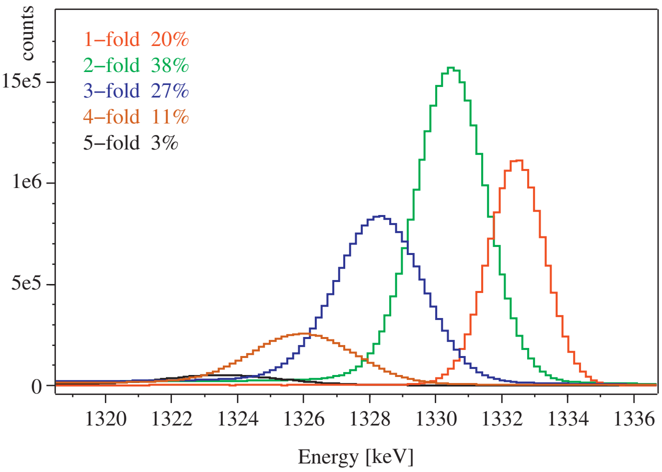

Fig. 2. Segment sum energy peaks for the $E_\gamma = 1332.5$ keV transition from a ^{60}Co source are shown as a function of increasing segment fold. The calibration was performed for onefold events. For fold values from 1 to 5 the peak position is shifting by 2.32 keV per fold unit and the energy resolution is decreasing typically by 0.5 keV (Full Width Half Maximum) per fold unit. The measurements were performed with the AGATA detector crystal S001 in a single test cryostat.

2. Motivation

Unsegmented HPGe detectors provide an outstanding energy resolution for γ-ray detection. However, in highly segmented detectors, this quality is not readily obtained for the additional segment energies due to the mutual influence of the involved detector channels. The main advantage of the novel highly segmented detector type is the additional pulse shape and energy information from the segmented outer contacts which allows a refined analysis of the γ-ray energy deposition within the HPGe detector volume by including the distribution of the energy into the available 36 detector segments. In a real experiment the number of segments firing depends strongly on the γ-ray energy of the individual event.

One experimental challenge in the operation of these detectors is the crosstalk between all the segment signals and the core signals which are all coupled via the capacitances of the bulk Ge material creating an electronic network. An intrinsic property of the highly segmented Ge detectors is the influence of this coupling on the pulse shapes and the observable energy signal. The primary and most severe consequence of this electronic coupling or crosstalk between all channels is a shift in the measurable γ-ray peak energies and the degraded energy resolution (see Ref. [7]). Both effects are linearly dependent on the multiplicity of firing segments or the segment fold. These properties result from the intrinsic properties given by the detector design.

With transitions from γ-ray sources, e.g. ^{60}Co and $E_\gamma = 1332.5$ keV the segment multiplicity dependence of the measured energy in a large volume AGATA detector was examined for segment folds up to seven. The segmented detector allows the analysis of the energy measurement by using either the information from the central core contact or the sum of the energies provided by the individual segments. The comparison of the measured energies shows clear differences between the core and the segment sum energies as a function of the segment multiplicity. An investigation of the peak position of the $E_\gamma = 1332.5$ keV line yielded a considerable shift of the segment sum energy peak position of more than 2 keV per fold to lower energy values (see Fig. 2). The corresponding Full Width Half Maximum (FWHM) values of the energy peaks is deteriorated by 0.5 keV per fold unit.

The results related to the segment sum energy are caused by the inherent crosstalk properties of the segmented Ge detectors. A detailed quantitative description of this behavior is obtained by employing an electronic model of the Ge detector and its first preamplification stage as reported in Ref. [8]. Therein the emphasis was given to the basic detector properties and a detailed modeling in order to describe especially the dependency of the segment sum energy in twofold events and its various segment combinations.

In this present paper a new method is described to eliminate the unwanted energy shifts and peak broadening in highly segmented HPGe detectors. The method allows to retrieve the intrinsic high energy resolution for all energy signals independent on the segment multiplicity. The basic idea is to transform a vector of recorded energy information from all signals linearly into a corrected vector of energy information. The matrix elements of the transformation are deduced in two different ways from measurements with standard γ-ray calibration sources. The procedure does not take considerably longer than a standard calibration measurement. The result of the correction method shows aligned segment sum energy peaks independent of the segment fold. The energy resolution of the corrected segment energy peaks is enhanced for the new 36-fold segmented AGATA detectors.

After a first analogue pre-amplification stage the signal is immediately digitized. Further signal processing in highly segmented detectors is done by modern Field Programmable Gate Arrays (FPGAs) and Digital Signal Processors (DSP) as main part of the subsequent digital electronics. Therefore it is desirable to use a fast and effective correction method which is executed on an event-by-event basis and can be implemented as an algorithm into the online software of the data acquisition system. At this preparatory stage of the development, our crosstalk correction was performed off-line on an event-by-event basis.

3. Experimental setup

Most of the data was taken from an encapsulated, tapered, semi-hexagonal cut, symmetric AGATA detector (S001) at IKP,