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A PULSE SHAPE ANALYSIS ALGORITHM FOR SEGMENTED HPGe DETECTORS*

F.C.L. Crespi

On behalf of the AGATA Collaboration

Universitá di Milano
Istituto Nazionale di Fisica Nucleare Sezione di Milano
via Celoria 16, Milano, Italy

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A simple Pulse Shape Analysis method for the determination of the number of interactions and their radial localization inside one HPGe segmented detector segment is presented. The algorithm processes only the net charge signal using a fast comparison procedure with a basis of reference signals. The efficiency of the algorithm calculated for 600 keV γ-rays ranges between 65 to 95% depending on the complexity of the analyzed event. The algorithm has been applied to real signals acquired during an in-beam test of the MARS 25-fold segmented HPGe detector.

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1. Introduction

High resolution γ-spectroscopy measurements with radioactive beams at relativistic energies have to be performed under critical conditions, especially due to the low beam intensity, the high background radiation and the presence of large Doppler Broadening effects. In this kind of measurements it is therefore required the development of high-purity Ge detectors capable not only to cover the largest fraction of solid angle around the target but also to reconstruct the trajectory of each γ-ray interacting into the array. The AGATA (Advanced GAmma Tracking Array) project [1] is a collaboration between 12 European countries and more than 30 institutions which have been established for the construction of a detector array based on such tracking technologies [2]. One of the critical points in the reconstruction of the

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gamma ray path inside a detector is the localization, within few millimetres, of the gamma-ray interaction position. Since such a precision is far beyond the level that can be reached segmenting the detector electrode [3], this position information has to be obtained through an analysis of the shape of the electronic impulse acquired from the HPGe detector (Pulse Shape Analysis). The final tracking efficiency of the whole array and also its acquisition counting rate performances strongly depend on the performances of the PSA routines [4]. For this reason high-efficiency PSA algorithms that can be applied in real time are needed. A simple PSA method that allows the identification of the number of interactions inside a detector segment and their radial localization will be described. This procedure allows the computing time which is required to analyze one event to scale linearly with the number of interactions that have to be disentangled.

2. Algorithm description and radial sensitivity

The algorithm presented here identifies the number of interactions and their radial localization inside one detector segment. In Fig. 1(a) the calculated current pulse shapes for different radial localization of the interaction points inside a segment of a coaxial cylindrical geometry detector are represented. It can be noticed that there is a clear correspondence between the current pulse maximum position and the radial coordinate of the interaction point.

A second important feature is that, in a small window around its maximum, the shape of the current pulse is determined mainly by the characteristics (x, y, z, E) of only one interaction also in a multiple interaction event (see Fig. 1(b)). This allows to analyze the hits in a sequential way and to limit the comparison between the detector signal and the basis signals in a small window around the maximum.

On the basis of the previously mentioned properties an algorithm, from now on identified as Recursive Subtraction algorithm (RS), can be constructed. The RS algorithm will:

(i) Find the maximum of the current pulse.

(ii) Find within a pre-calculated signal-basis the signal which better reproduces the measured one around the maximum.

(iii) Subtract it from the measured one.

(iv) If the decomposed interactions reach an energy weight of 100%, stop the algorithm, otherwise go back to step *(i)*. The procedure is repeated up to K times, where K is the maximum number of interaction that we expect to find in one segment (usually $K = 2$–3).

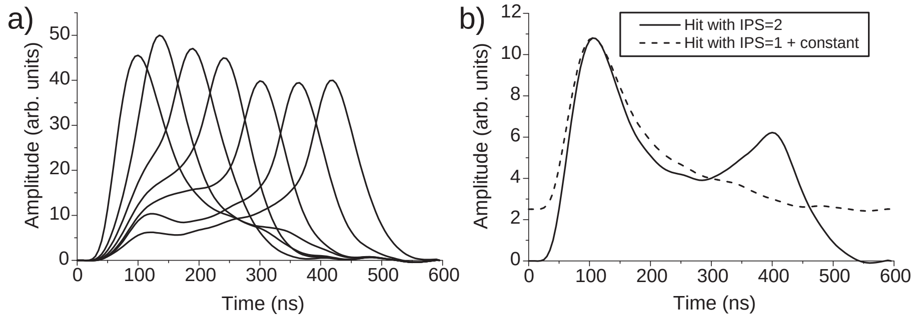

Fig. 1. The current signals calculated for a simple cylindrical 24-fold segmented HPGe detector for different radial coordinates (a). The interaction points associated with the represented set of signals have all the same value of z ($= 0$ cm) and θ ($= 29°$). The radial coordinate starts from $R = 0.6$ cm for the pulse with the rightmost positioned maximum. The following signals (from right to left) correspond to a radial coordinate respectively of $R = 1.0$, 1.5, 2.0, 2.5, 3.0 and 3.5 cm. In the coordinate system used the z axis coincides with the cylindrical crystal symmetry axis and the $z = 0$ plane lies in the middle of the segment. The value of θ coordinate is 0° in the centre of the segment and ±30° respectively at the edges. The current signal produced by an event with two IPs is indicated with the continuous line (b). The first hit has deposited 60% of the total energy at $R = 3.5$ cm, $\theta = 20°$ and $z = 0$. The second IP has been positioned at $R = 0.6$ cm with the same θ and z. With the dotted line the event relative to the first IP plus a constant is plotted.

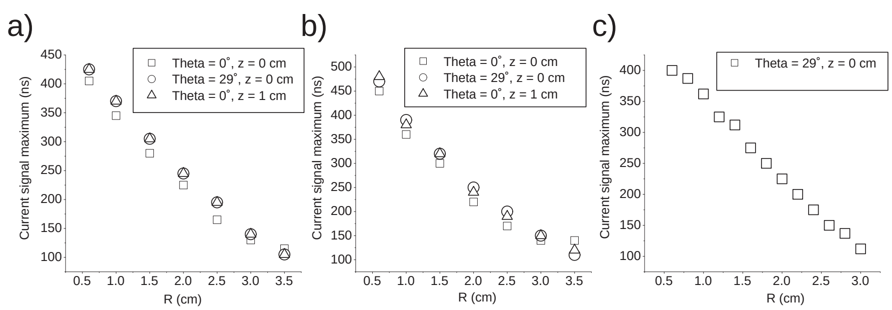

Fig. 2. In the 3 panels the position in time of the current pulse maxima is plotted against the value of the radial coordinate of the associated interaction point. The first set of signals (a) has been analytically extracted for a simple cylindrical 24-fold segmented HPGe detector [5, 6], the second (b) numerically calculated for the 25-fold segmented MARS detector geometry [7], and the third (c) is a set of measured signal acquired during a scan of an AGATA capsule [8, 9].

The radial sensitivity of the algorithm has been tested on four different set of signals, three of them theoretically calculated while one has been measured (see Fig. 2 and 3). In all cases it has been possible to match the current pulse maximum position of the signal with a precise radial localization of the interaction point inside the detector. In Fig. 2, the radial dependence in true coaxial segment or middle positioned segment is shown. Using the MGS [10] calculated basis signals, it has been possible to check the correspondence between the position of current pulse maxima and the spatial localization of the associated Interaction Points (IPs) in all the AGATA geometry crystal. This is shown in Fig. 3, where the interaction points with different position of the current pulse maximum are labelled with different colours. It can be seen that the coloured regions are well separated. Consequently, the measurement of the current pulse maximum position gives information on the localization of the interaction point also in segments that are in the frontal part of the crystal, namely with a geometry very different from a true coaxial one.

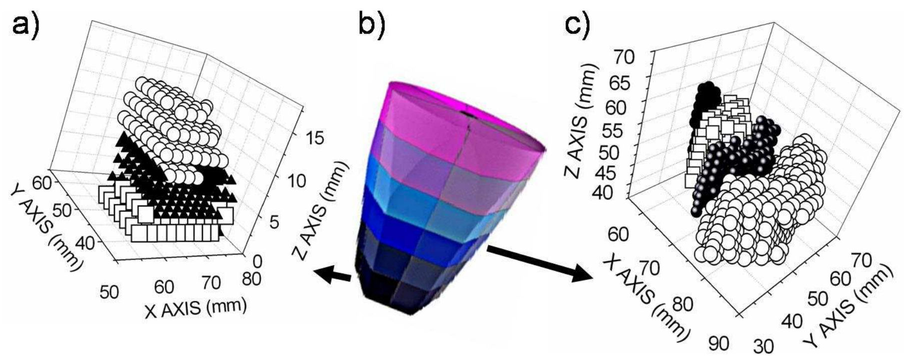

Fig. 3. Representations of the MGS calculated grid for two segments (one in the front end (left panel a) and the other in the back part (right panel c)) of an AGATA geometry 36-fold segmented HPGe detector. A different label is associated to each point of the grid depending on the position of correspondent current pulse maximum.

3. Results of the tests

The RS algorithm has been tested on a dataset of 600 keV simulated events, in which the whole energy has been released inside one segment of the quasi-true coaxial part of the MARS detector. All the analyzed signals have been convolved with the measured response function of the MARS [11] preamplifier and real noise (sampled at the output of a preamplifier of the

MARS detector) has been added. A fifth order low pass filter with all the poles at a frequency of 10 MHz has been applied. The IPs have been randomly distributed inside the segment and their energies have been randomly distributed as well.

A success is defined only when the number of IPs is correctly identified and the radial coordinate of each IP is matched within 5 mm. In all the tests the RS algorithm searches up to three IPs. The set of simulated signals used for the tests is composed by a mixture between events with a different numbers of IPs: 73% of one-IP events, 22% of two-IPs events and the remaining 5% of three-IPs events, as predicted by a GEANT simulation reported in Ref. [11].

The values reported in Table I represent the efficiency results obtained applying the RS algorithm to the described set of signals for different values of the buffer size N. The N parameter is proportional to the CPU power needed, and should be adjusted depending on the experimental data processing rate requirements. In any case, for values of N greater than 50, the improvement in efficiency becomes less significant due to saturation effects (N approaches the number of points in the signal basis grid that are eligible to represent the location of the first decomposed interaction).

TABLE I

The percentage of the events in which the number of IPs has been correctly identified and correctly localized in terms of the radial coordinate. The events, according to the result of GEANT simulations, are composed of 1, 2, or 3 gamma interactions points (IPs) inside the considered MARS detector segment (IPs = 1–3). See text for the description of the algorithm parameters M and N.

	$M = 1$	$M = 2$	$M = 3$
IPs	1–3	1–3	1–3
$N = 1$	72%		
$N = 3$	78%	82%	
$N = 5$	80%	84%	88%
$N = 10$	83%	87%	91%
$N = 50$	85%	88%	93%

Since the algorithm is a pre-process one, we introduced the possibility of sending to the following PSA code more than one solution (M — number of solutions accepted by the following code). Of course by increasing M we increase the probability that the right decomposition is included in the output. As clearly shown in the table the results are extremely encouraging providing a correct signal-decomposition in approximately 80–90% of the events.

The algorithm has been also tested on a set of measured signals acquired during an in-beam test of the MARS segmented detector [10]. In this case the transition of interest was at 847 keV. Only the events in which the whole energy has been released in a segment belonging to the quasi-true coaxial part of the MARS detector have been selected. From the application of the RS algorithm to the experimental signals it has been possible to extract both the interaction numbers and the radial distributions. In Fig. 4 such experimental distributions are compared to the ones resulting from a GEANT simulation of the experiment. While the expected hit distribution is nicely reproduced (see Fig. 4 (a)) the experimental radial localization distribution deviates from the theoretical one in the outer part of the detector, namely for $r > 2$ cm. Since such effect has been also observed analyzing the same set of data using a genetic algorithm [11], a technique totally independent from the RS algorithm, the observed deviation it is not probably due to the reconstruction processes but to a miss-correspondance between the calculated basis and the real signals coming from the detector outer part.

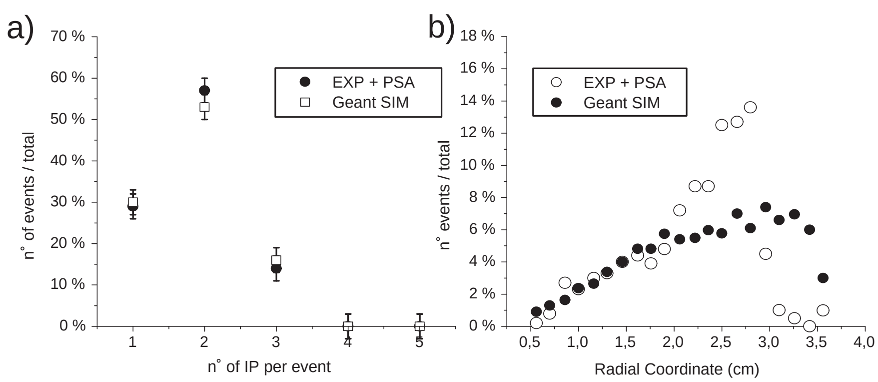

Fig. 4. Comparison between calculated and measured distributions for the number of IPs per event (a) and for the radial localization of the IPs (b).

4. Summary

In this paper a new simple and fast algorithm to extract the number of interaction points and their radial localization is discussed. The algorithm has been tested on simulated events producing very encouraging results in terms of efficiency, furthermore it has been applied on measured signals acquired in real experimental conditions with the 25-fold MARS detector obtaining a reproduction of the figures produced with a GEANT simulation of the experiment. The results of performed tests show that the approximations on which the algorithm is based are generally valid and that it is able to successfully decompose the great majority of the events. In order to check the efficiency of the algorithm on signals from a 36-fold AGATA geometry crystal and also its Doppler correction capabilities further tests on the real data on the AGATA triple symmetric cluster are planned.

REFERENCES

[1] D. Bazzacco, *Nucl. Phys.* **A746**, 248c (2004); AGATA Technical Proposal edited by J. Gerl, W. Korten, September 2001, available at `http://agata.pd.infn.it/info.html`

[2] R. Lieder *et al.*, *Prog. Part. Nucl. Phys.* **46**, 399 (2001).

[3] O. Wieland *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 48, No. 3, June 2001.

[4] G.J. Shmidt *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A430**, 69 (1999).

[5] E. Gatti *et al.*, *Nucl. Instrum. Methods Phys. Res.* **193**, 651 (1982).

[6] P. Pulici, Graduation Thesis: Progetto di nuovi rivelatori di radiazione gamma per la rivelazione della posizione degli eventi, Politecnico di Milano, 2003.

[7] T. Kroell *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A463**, 227 (2001).

[8] `http://ns.ph.liv.ac.uk/imaging-group/projects/agata/agata_working_group.php`

[9] `http://www.csnsm.in2p3.fr/groupes/strucnuc/Agata/database.html`

[10] P. Medina *et al.*, A Simple Method for the Characterization of HPGe Detectors, IMTC 2004, Como, Italy, `http://mgs2005.in2p3.fr/Mgs.php`

[11] M. Nespolo, Ph.D. Thesis: Pulse Shape Analysis with Germanium Detectors: from MARS to AGATA, Universitá degli studi di Padova, 2004.