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An alternative gamma tracking method using the Compton scattering probability

F.A. Beck[1], I. Piqueras[1], E. Pachoud[1,2], G. Duchêne[1,a], O. Dorvaux[1], P. Medina[1], and C. Ring[1]

[1] Institut de Recherches Subatomiques, UMR 7500, CNRS-IN2P3/Université Louis Pasteur, F-67037 Strasbourg Cedex 2, France
[2] Canberra Eurisys, Strasbourg, France

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Abstract. A new gamma tracking method, called probabilistic method and based on the Compton scattering probability of photons in a highly segmented Ge spectrometer, has been evaluated with the GEANT simulation code. This method has been used to calculate the performances of a 4π array composed of planar detectors as their crystal shape allows to realize identical segments of quasi-cubic shape. The tracking algorithm selects the full-absorption events by taking into account only the centre of gravity of the segments hit and the partial energies released in each of them. The results obtained, in terms of photopeak detection efficiency and peak-to-total ratio, are comparable to the ones deduced from the usual tracking methods. The probabilistic algorithm seems also to apply efficiently for other types of detectors as simulation calculations performed on a single stack of planar detector and a single segmented CLOVER detector give nearly the same reconstruction efficiency.

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1 Introduction

Large R&D efforts have been realised all over the world in the last five years trying to develop a new generation of gamma spectrometers based on the tracking of the gamma path in Ge detectors [1,2]. The existing reconstruction algorithms, the forward tracking [3] and the backward tracking [4], are based on the use of the Compton scattering equation. They will be called, in this paper, the "analytic" algorithms. Their performances depend strongly on the precision of the spatial determination of the interaction points of the scattered gamma rays and, consequently, on the quality and reliability of the pulse shape analysis technique. In fact, as each interaction position will not be determined better than within a few millimetres, the analytic methods will finally lead to a reconstruction probability.

Therefore we searched for a tracking method leading to similar performances but in a much simpler way, *e.g.* free of complicated on-line calculations. We will show in this paper how this new method, named "probabilistic" [5], that just requires the knowledge of the centre-of-gravity position of the segments hit and of the energy deposit in each of them, reaches this goal.

[a] e-mail: Gilbert.Duchene@ires.in2p3.fr

2 Performances of a 4π Ge array

As in the probabilistic method the position of the interaction in a segment refers only to the centre-of-gravity of this pixel, we have first assumed that the tracking-algorithm efficiency could be enhanced by the use of identical quasi-cubic segments. The planar detectors seemed to be, as a first approach, the most appropriate choice. The single detection unit is a stack of four large-planar crystals (7.5 cm $\times$ 10 cm, 2 cm thickness) each segmented in 4×4 and grouped in a compact geometry. The 4π array is composed of 72 such detectors arranged in a "castle" geometry. The gamma rays enter in the Ge crystals through the passivated surfaces.

Similarly to the forward-tracking analytic method, the interaction points are grouped in clusters using proximity criteria rather than the cone projection. The cluster evaluation is performed using the characteristics of the Compton scattering probability *versus* energy deposit. Different criteria to constrain the probabilistic algorithm are applied to preferentially select photopeak events [6].

One can observe in table 1 that the performances obtained with the probabilistic method, whose elementary spatial information is the size of the single segments (1.87 cm $\times$ 2.5 cm, 2 cm thickness), are comparable to the ones of the analytic-tracking method in which a subsegment spatial resolution of 5 mm was considered.

Table 1. Comparison of the performances, in terms of photopeak detection efficiency and peak-to-total ratio, of EUROBALL, AGATA and a planar 4π array for $E_\gamma = 1.3$ MeV and for gamma multiplicities 1 and 30.

	$M_\gamma = 1$		$M_\gamma = 30$	
Multidetector	E_p(%)	P/T (%)	E_p(%)	P/T (%)
EUROBALL	9.8	50	6.5	37
AGATA Coax. (analytic method)	40	55	21	45
Planar 4π array (probabilistic method)	37	55	20	38

Table 2. Photopeak detection efficiency, peak-to-total ratio and reconstruction efficiency calculated with the probabilistic-reconstruction method for $E_\gamma = 1.3$ MeV and two detector geometries, a stack of four planar crystals and a CLOVER detector. Note that simul1 (simul2) corresponds to simulation calculations including (not including) events with a single hit.

		Without	With tracking		Reconstr.
		P/T	P/T	$\epsilon_p\omega$	efficiency
Planar	simul1	0.31	0.44	$1.74\ 10^{-3}$	0.90
stack	simul2	0.34	0.81	$1.24\ 10^{-3}$	0.64
CLOVER	simul1	0.32	0.42	$1.68\ 10^{-3}$	0.89
	simul2	0.32	0.82	$1.21\ 10^{-3}$	0.62

The great advantage of the probabilistic method is the high detection efficiency obtained without the complicated and time-consuming on-line pulse shape analysis technique. On the other hand, the Doppler-shift correction, especially for very large recoil velocities, is less effective than in the analytic-tracking methods due to the size of the segments. The values from simulation calculations of in-beam energy resolution are 2.7 keV and 8.8 keV for $E_\gamma = 1.3$ MeV and $v/c = 2\%$ and 10%, respectively. At the latter recoil velocity, the given FWHM is much better than the one observed in EUROBALL. In addition, a fast on-line interaction-position-determination technique especially applicable with planar detectors and based on look-up tables, could be used to ensure a Doppler-broadening correction comparable to the one expected when the pulse shape analysis is used and this even at the largest recoil velocity values ($v/c = 50\%$).

3 CLOVER detector performances

In order to test the possible application of the probabilistic algorithm to other types of detectors, we have performed a first calculation for coaxial detectors which provide also identical quasi-cubic segments. The detector is a non-tapered CLOVER detector composed of four crystals, each segmented in 4 sectors and 4 slices (4×4). The comparative calculation for a stack of planar crystals and for a CLOVER detector indicates that a 4π array based on CLOVER detectors could be a good alternative (see table 2).

Consequently, we will calculate in a near future the performances of a 4π array composed of CLOVER detectors using the probabilistic-reconstruction method. This type of array is also strongly supported by the fact that the CLOVER detectors are particularly reliable detectors in the present EUROBALL campaign of experiments [7] and that a segmented CLOVER detector with 8 segments per crystal (4 sectors and 2 slices) has recently been produced with energy resolutions less than 2 keV per segment [8].

With the experience and knowledge acquired along these first series of calculations, we will also explore the case of detectors with non-identical non-cubic segments: simulation calculations using the probabilistic method will be undertaken for the AGATA coaxial geometry to estimate its possible application also to such array configurations.

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