

Calibration of the new composite “clover” detector as a Compton polarimeter for the EUROGAM array

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Abstract

The application of a composite Ge detector to the measurement of the linear polarisation of γ -rays has been investigated. The polarisation sensitivity of this device has been determined over the energy range 197–1368 keV. Comparison to a previous design of a similar detector has been made.

1. Introduction

Linear polarisation measurements are often useful in determining the electric or magnetic character of γ -radiations. By combining this information with angular distribution measurements, assignments of spins and parities of nuclear states can be determined. Such measurements can be performed by the use of a segmented detector acting as a Compton polarimeter which is sensitive to the polarisation of the γ -radiation. The polarisation sensitivity of segmented Ge detectors has already been determined over a wide range of γ -ray energies [1].

The aim of this paper is to determine the polarisation sensitivity of the new EUROGAM segmented Ge detector [2], the so called “clover” detector, acting as a Compton polarimeter. Twenty four such counters will be mounted at 75° and 105° relative to the beam axis on the European gamma-ray spectrometer EUROGAM phase II together with thirty tapered coaxial Ge detectors of large volume [3] placed at forward and backward angles. The large photopeak efficiency (about 8.2% at 1.33 MeV) and selectivity of the full array coupled to the good polarisation sensitivity of each of the 24 clover detectors mounted on EUROGAM, will enable linear polarisation measurements of weak intensity transitions to be made.

2. The clover detector

The clover detector was developed in a joint CRN-Intertechnique, Strasbourg project [2]. This detector shown in Fig. 1 contains four separate coaxial n-type germanium crystals packed together in a four-leaf clover arrangement (crystal spacing ≈ 0.2 mm apart). A common high voltage is applied to each crystal to the inner contacts and signals are obtained via AC-coupling.

The energy resolution (FWHM) of each crystal is about 2.1 keV at 1.33 MeV and 1 keV at 122 keV. The photopeak efficiency (ϵ_s) for each crystal is about 21% measured in singles relative to a 7.62 cm $\times$ 7.62 cm NaI detector at 25 cm from the source. In add-back mode, where the signals from each firing element are summed to give a single signal from the whole detector, the efficiency (ϵ_s) is about 125%.

3. Theoretical background

The intensity J of a γ -ray detected at an angle θ relative to the beam axis varies with the electric or magnetic nature of the transition and its multipolarity. The degree of linear polarisation depends upon the angle ψ between the electric vector E of the radiation and the reaction plane containing the angle θ . The linear polarisation $P(\theta)$ of a γ -ray is defined as the difference between the intensities of the radiations presenting an electric vector parallel to the reaction plane ($\psi = 0^\circ$) and those with an

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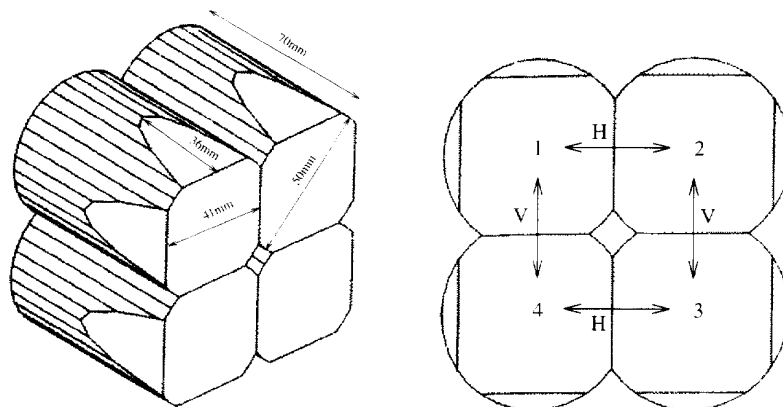


Fig. 1. The clover detector.

electric vector perpendicular to that plane ($\psi = 90^\circ$) [4]. $P(\theta)$ is normalised to the total intensity and written as:

$$P(\theta) = \frac{J(\theta, \psi = 0^\circ) - J(\theta, \psi = 90^\circ)}{J(\theta, \psi = 0^\circ) + J(\theta, \psi = 90^\circ)}. \quad (1)$$

The general principle of the Compton polarimeter is that the probability of Compton scattering of incident γ -radiation through an angle ξ depends upon the angle between the scattering plane containing ξ and the plane normal to the electric vector E of the radiation.

Experimentally, one measures the number of counts in perpendicular and parallel segments (see Fig. 1), and then constructs an experimental asymmetry (A):

$$A = \frac{a(E_\gamma) N_\perp - N_\parallel}{a(E_\gamma) N_\perp + N_\parallel}. \quad (2)$$

In this expression, N is the number of counts either in the reaction plane ($N_\parallel$) or perpendicular to it ($N_\perp$). The value $a(E_\gamma)$ is a scaling factor which corresponds to the ratio of the horizontal versus vertical coincidence count rates measured without polarisation at $\theta = 0^\circ$. It is a function of γ -ray energy.

The two equations are linked by the *polarisation sensitivity* Q of the detector, given by:

$$Q = \frac{A}{P}, \quad (3)$$

where Q is a function i) of the incident γ -ray energy and ii) of the geometry of the experimental setup (distance to the target and internal geometry of the polarimeter).

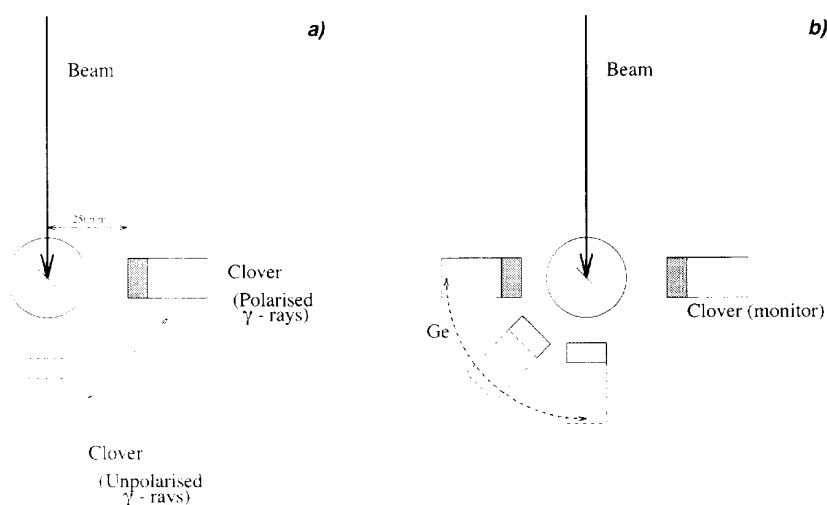


Fig. 2. Experimental setup used. (a) Polarisation measurements. (b) Angular distribution measurements.

4. Experimental measurements

The clover detector acting as a polarimeter utilises the Compton scattering between adjacent segments. These events can be separated according to whether the line through the adjacent segments is either parallel to the reaction plane ($N_{\parallel}$) or perpendicular to it ($N_{\perp}$). Experimentally, the polarisation sensitivity of the detector is obtained in two steps:

- by measuring at 90° the asymmetry A between parallel and perpendicular coincidence rates.
- by calculating the polarisation P of the γ -ray of interest via the measurement of their angular distributions.

Four previously used reactions [1,5–7] were chosen to generate polarised γ -rays (see Table 1). Their energy varies from 197 to 1368 keV which allows calibration of the polarisation sensitivity of the clover detector over a wide energy range. Beams were supplied by the Strasbourg HV-EC CN Van de Graaff accelerator.

Two experimental configurations were used for each reaction (Fig. 2). In the first configuration, the clover detector was situated first at $\theta = 90^{\circ}$ relative to the beam axis, to measure the coincidence asymmetry. The clover was then moved to the $\theta = 0^{\circ}$ position where $P = 0$ so that the relative counting efficiency $a(E_{\gamma})$ could be determined.

In the second configuration, a 70% efficient germanium coaxial detector was placed successively at 5 angles relative to the beam axis (90° , 60° , 45° , 30° , 0°) to measure the angular distribution of the γ -rays. The clover detector was situated at 90° for normalisation purposes.

Table 1

Reactions used to generate polarised γ -rays

Target	J	E_{γ} [keV]	E_p [MeV]	Ref.
^{19}F	$\frac{5}{2}^{+}$	197	2.42	[5]
$^{107,109}\text{Ag}$	$\frac{5}{2}^{-}$	415/423	2.54	[6]
^{56}Fe	2^{+}	845	3.0	[1]
^{24}Mg	2^{+}	1368	2.49	[7]

Energy and timing signals were taken from the clover and coaxial detector (Fig. 3). The energy signals were digitised into 2k ADCs and the timing signals coupled to constant-fraction discriminators with thresholds set just above the noise. The width of their output logic pulses set to 150 ns were used to generate two triggers for the clover detector channels. All the electronics setup has been built using classical NIM coincidence units. The first trigger was generated for any pair of clover elements firing (AND trigger in Fig. 3). This was used in the first configuration (polarisation setup) to trigger the storage of event-by-event data on tape and to monitor online spectra in add-back mode. The second trigger (OR trigger in Fig. 3) was generated by one or more elements firing. This was used in the second configuration (angular distribution setup) in which the energies from each clover segment firing were summed online before being placed into a spectrum. The germanium coaxial counter was used in singles mode and was triggered by itself.

The data set was stored by a Hewlett-Packard 1000 online computer.

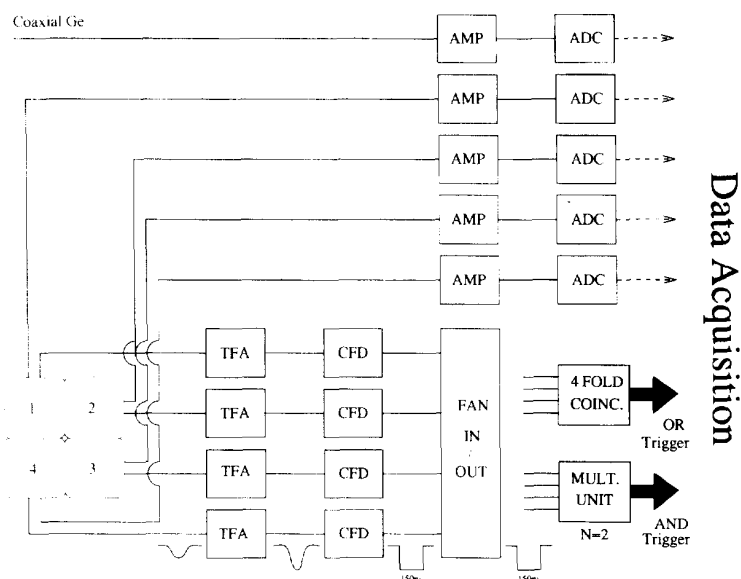


Fig. 3. Block diagram of the electronics used. TFA — timing filter amplifier; CFD — constant fraction discriminator; AMP — amplifier; ADC — analogue to digital converter.

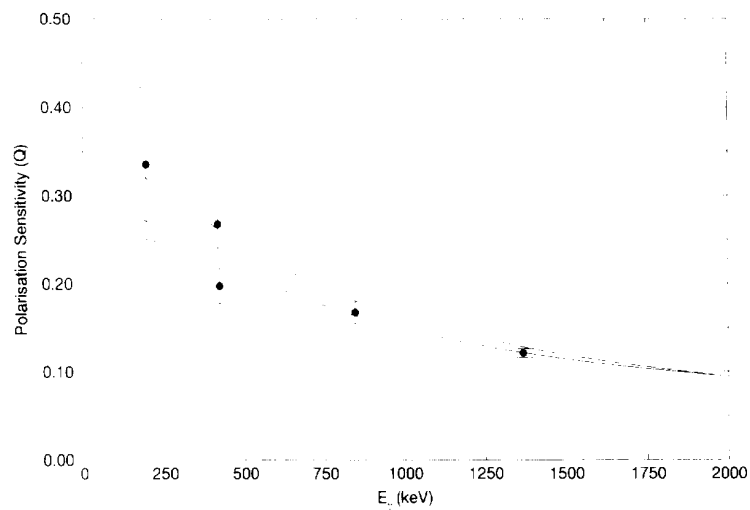


Fig. 4. Polarisation sensitivity of the clover detector. The solid line is the fit to present data (data points have error bars). The dashed line is the fit obtained in configuration (c) of the segmented detector in Ref. [1].

5. Data analysis and results

All cases of horizontal events (coincidences between segments 1 and 2, 3 and 4) and vertical events (coincidences between segments 2 and 3, 1 and 4) were considered (see Fig. 1). The energies deposited in each segment were summed and the total energy was placed in a horizontal or vertical spectrum depending on the pair of crystals firing. The photopeak counts thus gave $N_{\perp}$ and $N_{\parallel}$ (Eq. (2)). The normalisation factor $a(E_{\gamma})$ was obtained

using the spectra of unpolarised γ -rays (clover detector at 0°).

For the intensity angular distribution measurements, the number of counts in the claxial detector photopeak were taken, after normalising to the number of counts in the clover photopeak obtained in add-back mode. The angular distributions were then fitted using the program “STAG” [8] by varying the populations of the magnetic substates of the initial state for each transition. The values of the substate populations obtained in the fit are used to calcu-

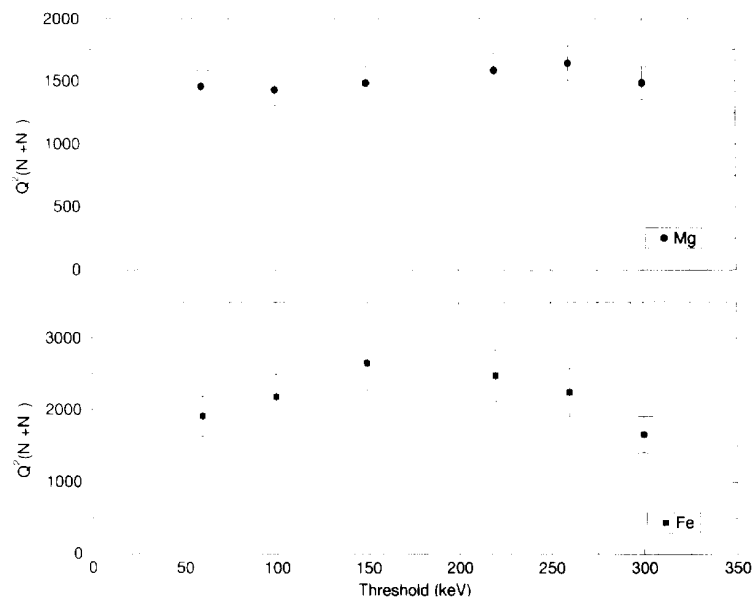


Fig. 5. Effects of energy thresholds on the figure of merit function.

Table 2

Normalised angular distribution coefficients, deduced γ -ray polarisation, measured asymmetries and calculated polarisation sensitivity of the clover detector

Target	E_γ [keV]	J_i	J_f	a_2	a_4	P	A	Q
^{19}F	197	$\frac{1}{2}^+$	$\frac{1}{2}^+$	0.15 (4)	−0.02 (4)	0.23 (6)	0.077 (8)	0.34 (9)
^{109}Ag	415	$\frac{1}{2}^+$	$\frac{1}{2}^+$	0.232 (13)	−0.02 (3)	0.39 (4)	0.103 (4)	0.27 (3)
^{107}Ag	423	$\frac{1}{2}^+$	$\frac{1}{2}^+$	0.27 (3)	−0.03 (3)	0.45 (4)	0.089 (4)	0.20 (2)
^{56}Fe	845	2^+	0^+	0.32 (3)	−0.08 (4)	0.53 (3)	0.089 (4)	0.167 (12)
^{24}Mg	1368	2^+	0^+	0.550 (3)	−0.43 (2)	0.99 (4)	0.121 (3)	0.121 (5)

late the linear polarisation of the emitted γ -ray. A finite solid angle correction [9] was also made.

The results of fitting the angular distributions are shown in Table 2 as well as the deduced values of the linear polarisation for the γ -ray transitions of interest. The asymmetry data measured with the clover detector used as a Compton polarimeter is also summarised in Table 2, along with the polarisation sensitivity of the detector. The values of Q are shown in Fig. 4 where the performance of the clover detector is compared to the polarisation sensitivity of an electrically segmented coaxial p-type detector [1]. As the latter counter is subdivided into eight segments, different coincidence configurations may be chosen. In Fig. 4, the plotted results for a configuration similar to the four-leaf clover geometry is shown (configuration (c) of Ref. [1]), where the segments are coupled by pairs. The response of both detectors are quite similar.

The plotted lines in Fig. 4 are fits from the Klein–Nishina expression for the scattering cross-section from a point scatterer to point absorbers placed at $\psi = 0^\circ$ and $\psi = 90^\circ$, and the kinematic equation of Compton scattering at $\xi = 90^\circ$ for the function $Q'(E)$. The values of Q were fitted using a function:

$$Q(E) = Q'(E)(CE + B). \quad (4)$$

B and C were determined by a linear least squares fit; $B = 0.29 \pm 0.03$, $C = 0.0 \pm 0.003$ (E expressed in MeV). This shows that the polarisation sensitivity is reduced when replacing with detectors of finite size, and is independent of energy.

The effects of applying energy thresholds were also studied for the reactions using the ^{24}Mg and ^{56}Fe targets. The application off-line of energy thresholds on each element restricts the range of ξ and ψ in the Compton scattering between neighbouring sectors. The corresponding loss in statistics is compensated by a better definition of the electric vector orientation relative to the reaction plane leading to a gain in polarisation sensitivity.

Let us define a figure of merit function for polarimeters as:

$$F = Q^2(N_{\perp} + N_{\parallel}). \quad (5)$$

F in Eq. (5) is similar to the definition of the figure of merit given in Ref. [1]. Fig. 5 shows F as a function of

threshold. The variation is small except when the threshold is large compared to the incident γ -ray energy. A value of 60 keV was used for the calibration of the detector to ensure adequate statistics for all reactions and a good polarisation sensitivity.

6. Conclusions

The clover detector gives good energy resolutions and timing performances and has excellent photopeak efficiency both for the individual crystals and the segmented detector as a whole. It has similar polarisation sensitivity characteristics to that of the segmented detector described by Simpson et al. [1] and this sensitivity scales in a simple way to that of an ideal polarimeter with point scatterers and absorbers. Such clover detectors, 24 in total, will be used in the EUROGAM phase II sited at angles of 75° and 105° in the array. Here it should be possible to measure the linear polarisation of weak transitions (e.g. superdeformed transitions), by summing the statistics of all the clover detectors to improve efficiency.

References

- [1] J. Simpson, P.A. Butler and L.P. Ekström, Nucl. Instr. and Meth. 204 (1983) 463.
- [2] G. Duchêne et al., Proc. Workshop on Large Gamma-Ray Detector Arrays, Chalk River, Canada, May 1992, AECL 10613 (1992) to be published.
- [3] C.W. Beausang et al., Nucl. Instr. and Meth. A 313 (1992) 37.
- [4] A.M. Hoogenboom, P.M. Endt and M. Suffert, Physica 25 (1959) 659.
- [5] F.A. Beck, Ann. Phys. (Paris) 1 (1966) 503.
- [6] R. Bass, S. Brinkmann, C. von Charzewski and H. Hanle, Nucl. Instr. and Meth. 104 (1972) 33.
- [7] P.A. Butler, P.E. Carr, L.L. Gadeken, A.N. James, P.J. Nolan, J.F. Sharpey-Shafer, P.J. Twin and D.A. Viggars, Nucl. Instr. and Meth. 108 (1973) 497.
- [8] P.A. Butler, Ph.D. Thesis, University of Liverpool (1974).
- [9] D.C. Camp and A.L. Van Lehn, Nucl. Instr. and Meth. 76 (1969) 192.