THE CLOVER DETECTOR

F.A.Beck, Th.Byrski, D.Curien, G.Duchêne, G.de France,B.Kharraja, L.Wei
Centre de Recherches Nucléaires, IN_2P_3/Université Louis Pasteur - BP 20, 67037 Strasbourg Cedex 2, France

P.Butler, G.Jones, P.Jones
Oliver Lodge Laboratory, University of Liverpool
Oxford Street, p.o. Box 147
LIVERPOOL L69 3BX, U.K.

F.Hannachi
SERC Daresbury Laboratory
Daresbury, Warrington WA4 4 AD, U.K.

The EUROGAM Phase I device is almost running for experiments and new technical developments are in progress for its second phase. For example, a composite Ge detector should enable i) a very large photopeak efficiency with good energy and timing resolutions and ii) the covering, with Ge, of a large portion of 4π-Str. The Clover detector, proposed by the CRN, Strasbourg, is one of this new generation of Ge detectors. It is currently developed in France by the EUROGAM collaboration. The design, the technical characteristics of the counter and the first results of the prototype tests are discussed in this contribution.

1. CLOVER GEOMETRY

The Clover detector consists of four coaxial N-type Ge-detectors, arranged like a four-leaf clover. Each crystal has a square front face with round edges obtained by tapering it on two adjacent faces with an angle of 7.1° starting at around the half of the length (see fig.I a)) and by cutting the two remaining faces parallel to the crystal axis and along its whole length. This enables a close packing of the crystals (Ge-Ge distance of about 0.2mm) and retains most (89 %) of the original crystal volume. For Ge crystals of 50 mm diameter and 70 mm length, the remaining active volume in the Clover detector is about 470 cm^3, 55 % more than the large monolithic coaxial crystals used in EUROGAM Phase I. The crystals are held only by the rear-side which reduces the amount of material around the detector and improves its P/T response. The four crystals are mounted in a common cryostat of tapered rectangular shape. To save space the gap between the tapered edges of the crystals and the inside of the cryostat is as small as 3.5 mm. To enable the close packing of the Ge crystals the outer surfaces of the crystals are at ground whereas the high voltage (common for the 4 crystals) is applied on the inner contacts. Energy and timing signals are obtained for each crystal through AC-coupling..

Beside the reduction of Doppler broadening, other advantages support the Clover detector :

1. its sensitivity to the linear polarisation of the gamma rays,
2. its reduced vulnerability to neutron damage,
3. the good timing particularily for low energy gamma rays.

2. CLOVER PROTOTYPES

Two prototypes built by the company Intertechnique, Strasbourg with Ge crystals of 50 mm diameter are currently being tested at the CRN, Strasbourg and another prototype with 55 mm diameter crystals has been ordered from EG&G Ortec, Oak Ridge. The response of the second Intertechnique prototype is summarized in table I.

The detection of the full energy of a gamma ray in a composite Ge detector made of N segments (crystals) proceeds in two ways :

i) the detection in one of the N segments (M = 1 in table I) called single event,

ii) the detection in several segments (M> 1 in table I) called multiple events.

In the latter case the full energy of the gamma ray is obtained by summing (add-back) the energies deposited in the M segments firing. The add-back factor $F_{a.b.}$ is thus defined as the ratio of the full efficiency in add-back mode over the efficiency in singles :

$$F_{a.b.} = \frac{(\varepsilon_p \omega)_{M=1} + (\varepsilon_p \omega)_{M \geq 1}}{(\varepsilon_p \omega)_{M=1}}$$

For the Clover detector (N = 4) the average photopeak efficiency $(\varepsilon_p \omega)_{ind}$ of the individual crystals at 1.33 MeV is 2.58 x 10^{-4} at 25 cm from the ^{60}Co source, whereas the total photopeak efficiency in add-back mode is 16.1 x 10^{-4} (table I). The latter value corresponds to a large add-back factor of 1.56 and to an increase in efficiency, compared to the detectors of EUROGAM I ($\varepsilon_p \omega \simeq 8.5 \times 10^{-4}$ at 25cm), of nearly 85%. The multiple events (M> 1) are mainly doubles at 1.33 MeV and the P/T response of the bare Clover detector is 0.30 (table I).

	$(\varepsilon_p \omega)_{ind.}$ x10^4	$(\varepsilon_p \omega)_{\Sigma}$ x10^4	M 1	2	3	4	$F_{a.b.}$	$(P/T)_{\Sigma}$
meas.	2.58 (20.7 %)	16.1 (129 %)	100	49.4	6.1	0.3	1.56	0.30
calc.	2.68 (21.5 %)	16.3 (131 %)	100	46.7	5.0	-	1.52	0.29

Table I :*Average individual* $(\varepsilon_p \omega)_{ind}$ *and total* $(\varepsilon_p \omega)_{\Sigma}$ *photopeak efficiencies are given as well as the corresponding relative efficiencies in percent. M is the number of segments in the Clover counter hitted by a 1332 keV gamma ray. The associated values give in % the proportion of doubles (M=2), triples (M=3) and quadruples (M=4) normalized to the singles (M=1).* $F_{a.b.}$ *is the add-back factor. P/T is the peak to total ratio obtained in add-back mode for a* ^{60}Co *source and with a threshold of 100 keV. Table I compares calculated to measured values.*

The energy resolutions of the four crystals shaped and placed in the definitive cryostat are about 2.0 keV at 1.33 MeV and 900 eV at 122 keV. The line shape is symmetric with FWTM/FWHM between 1.85 and 1.90. The energy resolution in add-back mode is excellent : 2.14 keV at 1.33 MeV and almost unaltered at low energy because $F_{a.b.}$ equal 1 up to 120 keV.

The timing response of the individual crystals mesured with a ^{60}Co source in coincidence with a small BaF_2 scintillator is good: the average FWHM is about 5.5 ns and FWTM/FWHM is smaller than 3.0 for a CFD threshold of about 50 keV.

3. SIMULATION CALCULATIONS USING THE CODE GEANT III.

The calculated performances of the Clover counter are compared to the experimental data in table I. The agreement is fairly good. Simulation calculations using the code Geant III have been performed to optimize the geometry of the composite detector and to determine the best procedure for the Doppler broadening correction. The calculations led to the geometry shown in fig.Ia). Concerning Doppler broadening, the energy resolution of the Clover detector after correction, despite the large opening angle of the counter, is predicted to be equivalent to the energy resolution obtained on TESSA3 array with 25 % efficiency Ge counters. More details are given in the contribution "Simulation calculations using the Code Geant III".

4. POLARISATION SENSITIVITY OF THE CLOVER COUNTER

The polarisation sensitivity Q of the Clover detector has been measured using four reactions (see table II) producing strongly polarised gamma-rays of E_2 multipolarity. The scattering asymmetry A of the Clover detector can be written as :

$$A = \frac{a(E_\gamma)N_\perp^c(90^\circ) - N_\parallel^c(90^\circ)}{a(E_\gamma)N_\perp^c(90^\circ) + N_\parallel^c(90^\circ)} \qquad where \qquad a(E_\gamma) = \frac{N_\parallel^c(0^\circ)}{N_\perp^c(0^\circ)}$$

$N^c_{\perp(\parallel)}$ represents the coincidence counting rate between two adjacent crystals located in a plan perpendicular (parallel) to the reaction plan (see fig.Ib). $a(E_\gamma)$ is the relative efficiency of the two adjacent crystals and is measured at 0°. It is a function of the γ-ray energy E_γ.

Target	Level J	E_γ(keV)	E_p(MeV)	Reaction
^{19}F	$5/2^+$	197	2.4	Coulomb Excitation
$^{107,109}Ag$	$5/2^-$	418/423	2.45	Coulomb Excitation
^{56}Fe	2^+	845	3.0	Resonance
^{24}Mg	2^+	1368	2.45	Resonance

Table II : *The reactions used for linear polarisation sensitivity calibration.*

The theoretical polarisation is calculated from the experimental angular distribution of the gamma-rays. For stretched E_2 it is defined by :

$$P_{th} = \frac{3a_2 + \frac{5}{4}a_4}{2 - a_2 + \frac{3}{4}a_4}$$

where a_2 and a_4 are the normalised angular distribution coefficients. The polarisation sensitivity Q is the ratio of the asymmetry over the theoretical polarisation (Q = A/P_{th}). The data obtained are compared in figure II to these published by J.Simpson et al. [1] for a segmented Ge(Li) detector of 17 % total photopeak efficiency at ^{60}Co and to a classical 3 Ge(Li) polarimeter. The Clover detector is about 20 % less sensitive to polarisation then the segmented Ge(Li) and by a factor of 2 compared to the 3 Ge(Li) polarimeter. This is due to the very compact geometry of the Clover (large scattering angle from the scatterer segments to the analyser crystals).

Let us define a figure of merit F as :

$$F = Q^2(\varepsilon_p\omega) \qquad where \qquad (\varepsilon_p\omega)_c = \frac{\mathcal{N}_{\parallel}^c + \mathcal{N}_{\perp}^c}{2} \cdot \frac{(\varepsilon_p\omega)_\Sigma}{N_{Tot}}$$

and N_{Tot} is the total number of counts in the Clover counter measured in add-back mode. For the 1368 keV transition, F (x 10^8) equals about 20 for the 3 Ge(Li) polarimeter, 43(4) for the segmented detector and 102(15) for the Clover detector which shows the importance of the large coincidence probability in this latter counter. As 24 such counters will be placed at 75° or 105° relative to the beam axis in EUROGAM phase II, the polarisation of very weak intensity gamma rays (as in superdeformed band) will be possible.

CONCLUSION

The Clover detector presents good energy and timing resolutions for a high photopeak efficiency. It enables a large correction of the Doppler broadening effect and may be used as a γ-ray polarimeter.

Reference [1] J.Simpson et al., *NIM* **204** (1983) 463

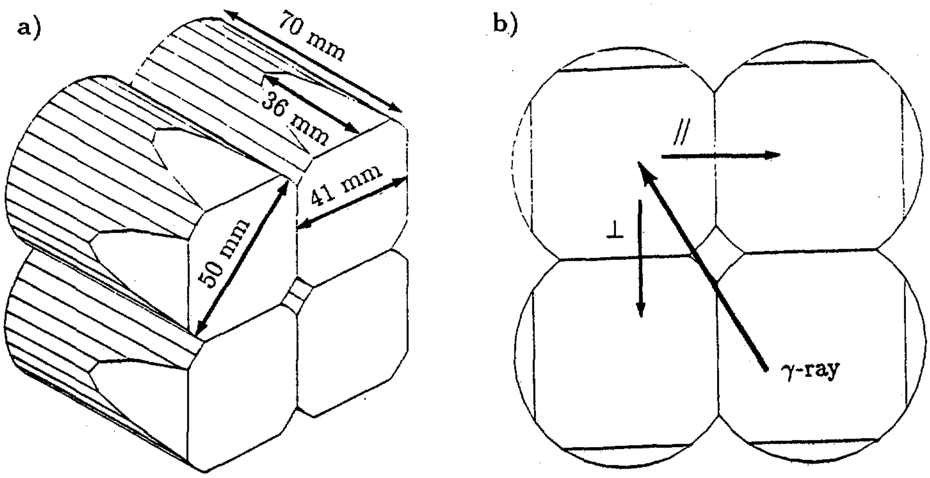

Figure I : *Schematic view of the Clover detector. Crystal sizes are given in a). In b) the upper left crystal is used as a scatterer segment. The vertical (⊥) and horizontal (//) coincidences with the adjacent segments are also shown.*

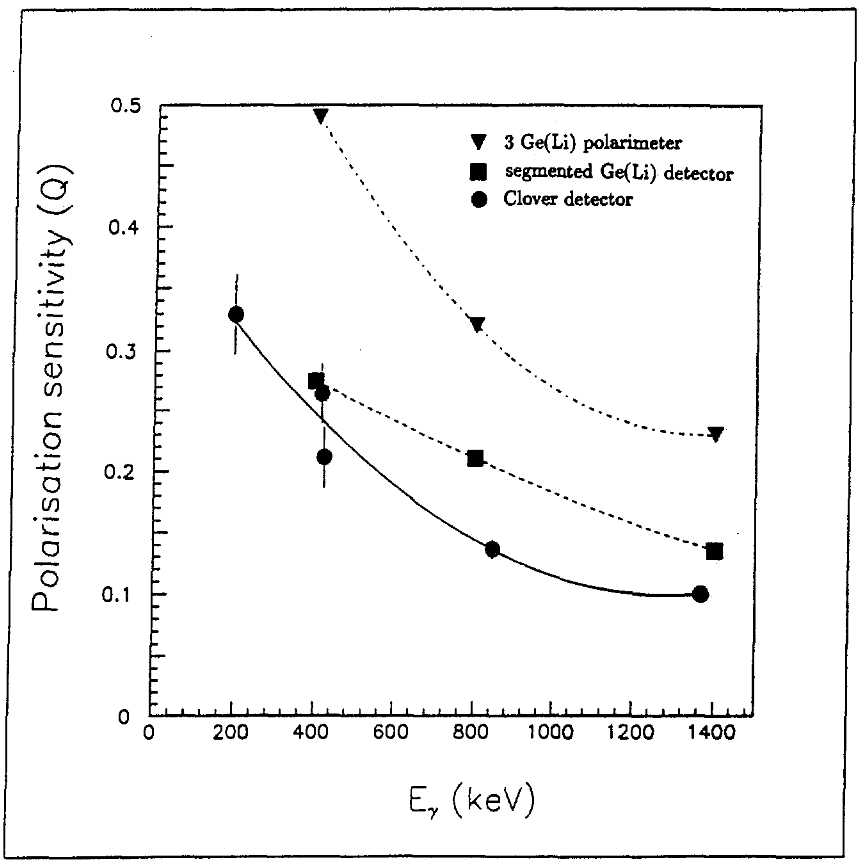

Figure II : *Polarisation sensivity versus γ-ray energy for the Clover counter (cercle), the segmented detector (square) and 3 Ge(Li) polarimeter (triangle).*