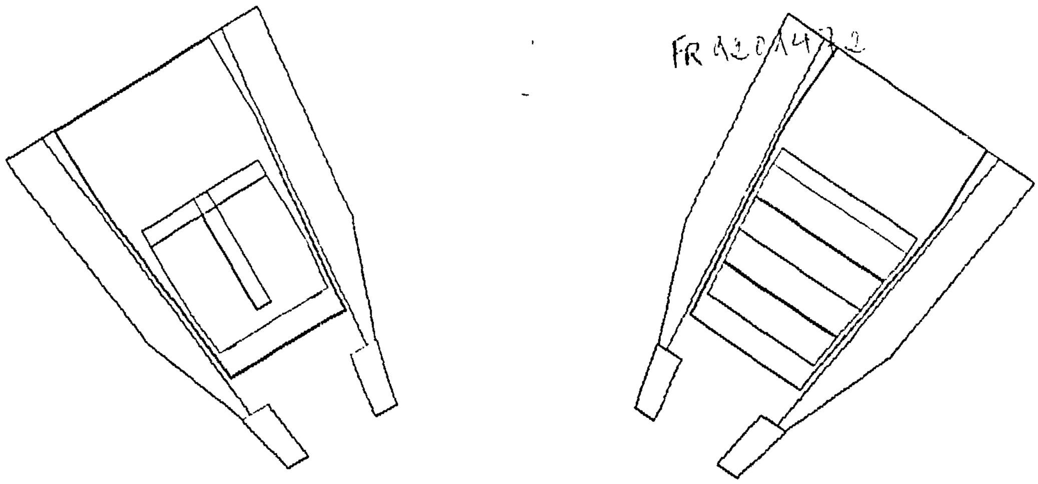
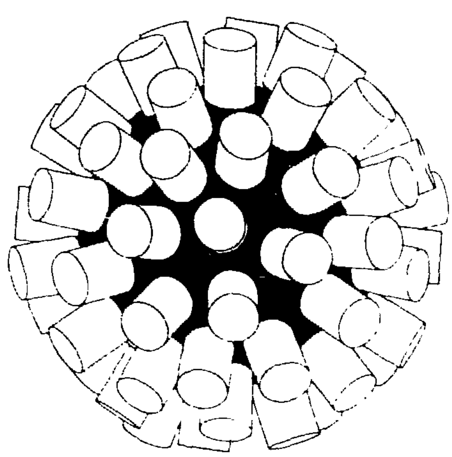


EUROGAM



CRN-EUR-1

BALLISTIC DEFICIT CORRECTION

G.Duchêne, M.Moszynski, D.Curien

Janvier 1991

CENTRE DE RECHERCHES NUCLEAIRES
STRASBOURG

IN_2P_3
CNRS

UNIVERSITE
LOUIS PASTEUR

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The EUROGAM data-acquisition has to handle a large number of events/s. Typical in-beam experiments using heavy-ion fusion reactions assume the production of about 50 000 compound nuclei per second deexciting via particule and γ-ray emissions. The very powerful γ-ray detection of EUROGAM is expected to produce high-fold event rates as large as 10^4 events/s. Such high count rates introduce, in a common dead time mode, large dead times for the whole system associated with the processing of the pulse, its digitization and its readout (from the preamplifier pulse up to the readout of the information).

In order to minimize the dead time the shaping time constant τ, usually about 3 μs for large volume Ge detectors has to be reduced. Smaller shaping times, however, will adversely affect the energy resolution due to ballistic deficit. One possible solution is to operate the linear amplifier, with a somewhat smaller shaping time constant (in the present case we choose τ = 1.5 μs), in combination with a ballistic deficit compensator.

The ballistic deficit can be corrected in different ways using a Gated Integrator (ORTEC 973 or INTERTECHNIQUE 7201 modules), a hardware correction (ORTEC 675 or TENNELEC TC245 modules) or even a software correction. In this paper we present a comparative study of the software and hardware corrections as well as gated integration.

I. SOFTWARE CORRECTION :

Using the Hinshaw method [1] as a guide, we have stored on tape, for each event analysed, the unipolar pulse, the bipolar pulse and the time between the beginning of the rise of the bipolar pulse and the cross-over time. The aim of this work is to apply a general correction, event by event, leading to an energy resolution at least as good as the resolution obtained using a shaping time constant of 1 μs with additional hardware correction.

Unipolar-bipolar diagram :

The diagonal in the unipolar-bipolar spectrum (Fig.1) corresponds to short rise time preamplifier-pulses leading to good charge collection in both unipolar and bipolar channels. The peaks related to the full energy detection appear as tails whose slopes are different from the diagonal (Fig.2). These tails are due to ballistic deficit. Since the rise time of the preamplifier-pulses increases with ballistic deficit and since the bipolar integration is less efficient as compared to the unipolar one, the pulse heights of both signals are different and the slopes of the tails are smaller than 1 (about 0.5 see Table I). Figure 2 shows the tails measured at 1408 keV and 122 keV. It is clear from this figure that ballistic deficit is also observed at low energies (122 keV) with a contribution at least as large as the noise contribution. Ballistic deficit increases with increasing γ-ray energy.

We have applied different type of software corrections, linear and quadratic. The best results have been obtained using a linear correction in two different ways.

Let us take a given event having the (X,Y) coordinates in the unipolar-bipolar diagram. In the first method, we project the (X,Y) point on the diagonal, parallel to a slope P_1. This crossing point determines the rotation axis which allows one to tilt the tail parallel to the bipolar axis leading to a good energy resolution $E_{1/2}$ after projection on the unipolar axis (Fig.2, bottom). The slope P_1 is determined empirically to get the best FWHM at each ^{152}Eu source energy. The expected energy resolution is shown in Figure 2 (bottom).

In the second method, equivalent to the Hinshaw method, we calculate for each event (X,Y) the quantity $\Delta = Y - X$ (see Figure 3) which corresponds to the difference between the unipolar and the bipolar pulse heights. This difference, which is not the real deficit, is multiplied by a slope P_2 and added to the unipolar pulse height. P_2 is determined empirically and varies with the γ-ray energy. We then get :

$$Y_{New} = Y + P_2 . \Delta$$

The projection on the unipolar axis gives the final energy resolution.

Table II summarizes the energy resolutions $E_{1/2}$ (FWHM) measured with a large volume Ge detector (GV8) using a ^{152}Eu source and shaping time constants of 6 and 1 μs. The values of $E_{1/2}$ measured at 1 μs with the INTERTECHNIQUE 7201 Gated Integrator (GI) and those obtained using the software correction are also given. This table shows that both software correction methods lead to similar results :

- the energy resolution $E_{1/2}$ at energies larger than 1 MeV is reasonable. It is about 20 % larger than the $E_{1/2}$ values obtained with 6 μs shaping time constant.

- the correction at low energy (≃ 100 keV) seems to be inefficient

- the empirical slope P in the software method varies in a logarithmic way with the energy of the detected γ rays :

$$P(E_\gamma) = a \ln(E_\gamma) + b \qquad \text{(Table II)}$$

Similar studies have also been performed by M.P.Carpenter et al. at Argonne National Laboratory [2]. Using a large volume Ge detector (≃ 80 %) with 2.25 keV energy resolution for the 1332 keV - ^{60}Co line at 6 μs shaping time constant, they were able to improve the poor energy resolution observed at 1 μs shaping time (4.37 keV) to 2.65 keV applying the Hinshaw software correction method. These results compare fairly well to our measurements for the 1408 keV-^{152}Eu line (see Table II).

But in all cases, low or high energies, the Gated Integrator leads to the best energy resolution and introduces corrections even at low γ–ray energy.

Using the $E_{1/2}$ values presented in Table II, the square root of the difference between the square of the energy resolution obtained with a shaping time constant of 6 μs and the square of the energy resolution obtained at 1 μs with a Gated Intregrator (GI) is independent of the γ-ray energy and is of the order of 1 keV (see Table III and the corresponding expressions). This can be understood as additional electronic noise, σ_{UNI}, due to the use of a shorter shaping time constant. The square root of the difference between the $E^2_{1/2}$ values measured at 1 μs with a GI after software correction shows an additional noise, σ_{BIP}, again of about 1 keV. This noise component could be interpreted as the one added by the bipolar pulse used to correct for ballistic deficit. Thus the Hinshaw method replaces at low energy the ballistic deficit of the unipolar channel by the bipolar noise leading to an energy resolution roughly independent of the correction. This is confirmed in Figure 4 which shows the 122 keV peak in the unipolar-bipolar diagram after correction. The tail has disappeared and is replaced by a point much wider than the transversal thickness of the tail before correction (expected FWHM in Figure 2).

The time information presents two components (see Fig.5), a well defined peak at low energy disappearing with increasing energy and a very small bump at 150 keV, growing with energy (see inserts a), b) and c)). This strange behavior of the time parameter, which seems to issue from the electronics, leads us to work only with the bipolar and unipolar pulses.

II. HARDWARE CORRECTION :

1. Comparison of ORTEC (973) and INTERTECHNIQUE (7201) Gated Integrators.

Using a large volume detector (GV7), we have tested the Gated Integrators of ORTEC and INTERTECHNIQUE by varying the experimental conditions : low counting rate (about 1500 c/s), high counting rate (≈ 30 kc/s), low (122 keV of ^{152}Eu) and "high" (1332 keV of ^{60}Co) energies. Both modules were placed in an empty NIM crate providing sufficient cooling of the electronics. Table IV summarizes the data obtained using a Gaussian shaping of the amplified pulses. As the INTERTECHNIQUE Gated Integrator 7201 does not include an amplifier, the pulses were first amplified by the INTERTECHNIQUE 7200 amplifier.

The data show that both modules are comparable at low and high rates except at low energies where the INTERTECHNIQUE module seems to be slightly better. Energy resolutions are constant as a function of the count rate within the error bars.

New tests using the same modules in a different environment (3 NIM crates, on top of each other, filled with modules) giving rise to poor cooling showed a much worse behavior for the ORTEC module. The deteriorated energy resolution (+ 0,3 keV at 1332 keV) as compared to the INTERTECHNIQUE 7201 was moreover very sensitive to the counting rate. Finally, after a few days, the resolution obtained with the ORTEC module deteriorated completely. We have to mention that there were no problems of low bias on the NIM crate. Placed in a good environment the same ORTEC module again worked perfectly. We would like to emphasize that the sensitivity of the ORTEC 973 Gated Integrator to heating could be particular to the tested module.

2. Hardware ballistic deficit correction :

We have compared the response of different modules to the ballistic deficit observed in large volume Ge detectors at 1 μs shaping time constant. For that purpose we have tested, i) the ORTEC amplifier 672 connected to the Resolution Enhancer 675 or to the INTERTECHNIQUE Gated Integrator 7201 (GI), ii) the TENNELEC TC245 with or without Ballistic Deficit Correction (BDC) or connected to the INTERTECHNIQUE GI and iii) the INTERTECHNIQUE amplifier 7200 connected to the GI or used for software correction. All the data are presented in Table V. Note that all the hardware correction mesurements have been done with a 75 % efficiency counter (EGC 60 No 7745) whereas the software analyses (done before the hardware measurements) were performed with a different large volume detector (GV8). The names and functions of the different modules used are the following:

ORTEC 672	: Amplifier
ORTEC 675	: Resolution Enhancer
INTERTECHNIQUE 7200	: Amplifier
INTERTECHNIQUE 7201	: Gated Integrator
TENNELEC TC245	:- Amplifier on the UNI Output - "Hinshaw corrector" on the PUR Output, BDC (Ballistic Deficit Correction) switched on.

The first column of Table V corresponds to measurements using a 6μs shaping time constant (τ) to test, for a given detector, the quality of the amplifiers (672 of ORTEC, UNI TC245 of TENNELEC and UNI 7200 of INTERTECHNIQUE). The ORTEC module seems to provide a slightly better energy resolution at low energy as compared to TENNELEC module, but both are equally good at higher energies. The data obtained with the INTERTECHNIQUE 7200 amplifier show the good energy resolution of detector GV8. Those data are not comparable to the previous values as the latter were obtained from a different detector (EGC 60 No 7745).

The second column shows the energy resolution obtained in ^{152}Eu using $\tau = 1$ μs. $E_{1/2}$ is always larger than 5 keV at high energy and larger than 1.5 keV at low energy. The former is mainly due to ballistic deficit and the latter to both ballistic deficit and noise contribution.

The $E_{1/2}$ values obtained at $\tau = 1$ μs after correction are summarized in column 3. They show that the energy resolution at low energy is practically not modified as compared to 1 μs without correction (2nd column). However at higher energies there is a large improvement of the energy resolution. The quantity ΔE is defined as the difference between the energy resolutions measured at 1408 keV with $\tau = 6$ μs and $\tau = 1$ μs + correction, divided by the resolution obtained at 6μs and multiplied by 100. It corresponds to the percentage of degradation of the energy resolution due to the use of a short shaping time constant. It shows that the energy resolution is never as good as the values obtained at $\tau = 6\mu$s.

Comparing ΔE obtained from different modules we find that : TC245 seems to be the best, ORTEC 675 the worst and the software correction is in between.

In all cases the Gated Integrator (GI : INTERTECHNIQUE 7201) used with the different amplifiers led to the best results at high as well as low energies (fourth column, Table V). The deterioration of the energy resolution for 1 MeV γ-rays is only about 10 %. But we have to note that the tests performed by J.C.Lisle et al [3] at Manchester in May and in summer 1990 show that the three modules, ORTEC 675 (RE), TENNELEC TC245 and ORTEC 973 (GI) are nearly equivalent, with TC245 being slightly better at τ = 1μs. The EUROGAM Ge prototypes from ORTEC which show better uncorrected energy resolutions at τ = 1 μs as compared to GV8, were used for the tests. By lowering the high-voltage from -4000 V to -3000 V, the energy resolution at τ = 1 μs increased from $\approx$ 3.5 keV to $\approx$ 5 keV, an effect due to an increase of ballistic deficit [4]. In this case results similar to ours were found. Therefore the differences between those tests and our tests could be explained by a difference in the quality of the Ge crystals (very low depletion voltage of ORTEC crystals).

The fifth column of Table V shows the FWHM measured at 2 μs shaping time constant with correction. The ORTEC Resolution Enhancer 675 is by far the best module and leads to results comparable to τ = 6 μs for 1408 keV. However a shaping time constant of 2 μs introduces a too long analysis time of the pulses, increasing dead time in a dramatic way for EUROGAM electronics which is not acceptable.

III. CONCLUSIONS

We have demonstrated that both software and hardware methods are not able to correct ballistic deficit at low energy using a shaping time constant τ = 1 μs.

For higher energies (about 1 MeV) the TENNELEC module TC245 gives better results than the ORTEC Resolution Enhancer 675 or the software correction. In all cases, **the Gated Integrator is the best solution at** τ = 1 μs from both points of view : **energy resolution and time adjustment of the electronic set up.** We have seen that the Gated Integrators of ORTEC and INTERTECHNIQUE are equivalent in a good environment. The heating problems observed with the ORTEC 973 module and the simplicity of the electronic circuit of the INTERTECHNIQUE 7201 module , would favour the choice of the INTERTECHNIQUE 7201 unit to apply the ballistic deficit correction in Eurogam Phase I (at Daresbury).

N.B. . The energy resolutions have been measured for all energies with the same calibration of 1/3 keV/ch. This leads to slightly degradated energy resolutions at low energy.

Acknowledgement :

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[4] J.N.Mo, private communication

E_γ (keV)	122	778	1408
GV8	0.572	0.513	0.522
GV1	0.461	0.525	0.521
GV14	0.598	0.455	0.514

Table I : Natural slopes of the tails in the unipolar-bipolar plan for different energies corresponding to ballistic deficit.

E_γ(keV)		122	244	344	778	964	1112	1408
6 μs		1.04	1.15	1.25	1.62	1.77	1.85	2.15
1 μs		1.66	1.98	2.29	3.52	4.21	4.72	5.6
1 μs + G.I.		1.41	1.50	1.60	1.97	2.07	2.12	2.38
1 μs + soft	Hinshaw method	1.60	1.74	1.86	2.22	2.24	2.34	2.56
	project. method	1.63 *1.63*	1.78 *1.78*	1.90 *1.91*	2.25 *2.30*	2.31 *2.33*	2.38 *2.38*	2.61 *2.61*

Table II : Energy resolutions in keV measured with GV8 on a wide energy range using shaping time constants of *6 μs* and *1 μs without correction*, of **1 μs** using a Gated Integrator or a software correction. In italics, the $E_{1/2}$ values calculated using the logarithmic function for the slopes P deduced empirically from the projection software method : a = 0.0978 and b = -0.219.

	122	244	344	778	964	1112	1408
$\sigma_{UNI} = \sqrt{(1\mu s + GI)^2 - (6\mu s)^2}$	0.95	0.96	1.00	1.12	1.07	1.04	1.02
$\sigma_{BIP} = \sqrt{(1\mu s + soft)^2 - (1\mu s + GI)^2}$	0.82	0.96	1.02	1.09	1.03	1.08	1.07

Table III : Additionnal noises due to the use of a shaping time constant of $1\mu s$ with i) a Gated Integrator (σ_{UNI}) and ii) unipolar and bipolar pulses for software correction (σ_{BIP})

$$E_{1/2}^{6\mu s} = [\sigma_0^2 + F.E_\gamma]^{1/2}$$

$$E_{1/2}^{1\mu s+GI} \approx [\sigma_0^2 + \sigma_{U\,NI}^2(1\mu s) + F.E_\gamma]^{1/2}$$

$$E_{1/2}^{1\mu s+soft} \approx [\sigma_0^2 + \sigma_{U\,NI}^2(1\mu s) + \sigma_{BIP}^2(1\mu s) + F.E_\gamma]^{1/2}$$

	Low Rate (≃ 1,5 Kc/sec)		High rate (≃ 30 Kc/sec)	
E_γ(keV)	122	1332	122	1332
6 μs (7200)	1.28	2.06	–	–
1 μs (7200)	1.93	5.28	–	–
1 μs + GI (7200) + (7201)	1.67	2.47	1.63	2.50
GI (5 μs) (ORTEC 973)	1.77	2.47	1.68	2.53

Table IV : Comparison of the performances of both ORTEC 973 and INTERTECHNIQUE 7201 Gated Integrators obtained with the detector GV7

Detector	Method		6 μs	1 μs	1 μs + corr.	1 μs + GI	2 μs + corr.
EGC 60	ORTEC	E_γ (keV)	Amp.	Amp.	Amp. + 675	Amp. + 7201	Amp. + 675
		1408 ΔE(%)	2.36	5.55	2.95 *25*	2.57 *9*	2.37
		122	1.36	1.88	1.88	1.59	1.49
N° 7745	TENNELEC	E_γ (keV)	Amp.	Amp.	Amp. + BDC	Amp. + 7201	Amp. + BDC
		1408 ΔE (%)	2.35	5.1	2.7 *15*	2.6 *9.5*	2.6
		122	1.42	1.83	1.85	1.65	1.65
GV8	SOFTWARE	E_γ (keV)	Amp.	Amp.	Amp. + soft	Amp. + 7201	
		1408 ΔE (%)	2.15	5.6	2.61 *21*	2.38 *11*	
		122	1.04	1.66	1.63	1.41	

Table V : Energy resolution obtained at 6 μs shaping time constant, at 1 μs s.t.c. and at 1 μs plus ballistic deficit correction. The correction has been applied in hardware (ORTEC Resolution Enhancer 675, TENNELEC TC245 BDC switched on, INTERTECHNIQUE Gated Integrator 7201) or in software (projection and Hinshaw methods).
E_γ (FWHM) is given in keV at 1408 keV and 122 keV. ΔE in percent corresponds to the deterioration of the energy resolution compared to values obtained at 6 μs s.t.c.

Figure captions

Fig.1 : Region of the unipolar-bipolar plan ranging from 0 to 210 keV on both axis obtained using GV8, an annealed large volume Ge detector. The diagonal and the tails presenting different slopes are clearly seen.

Fig.2 : Regions of the unipolar-bipolar plan ranging from 100 to 140 keV (top) and from 1370 to 1450 keV (bottom) respectively. The ballistic deficit characterised by a tail exists at all energies even below 500 keV (top). The best energy resolution we can expect after correction with a shaping time constant of 1 μs is also shown and corresponds to the transversal thickness of the tail. The correction consists to tilt the tail parallel to the bipolar axis (angle α).

Fig.3 : Schematic view of the Hinshaw software correction. As the calculated difference Δ multiplied by the natural slope P of the tail is a too small correction at high energy, the empirical slope P_2 has to be larger than P.

Fig.4 : Region of the unipolar-bipolar plan (after correction) ranging from 100 to 140 keV. The addition of the extra noise of the bipolar pulse leads to a poor final energy resolution.

Fig.5 : Unipolar-time plan showing two opposite components : a well defined peak at low energy vanishing at about 700 keV and a wide bump appearing at energies larger than 150 keV and dominating at 1 MeV. The inserts a), b) and c) correspond to the projections on the time axis of energy slices centered respectively on the 122, 344 and 1112 keV full energy peaks.

Fig.1

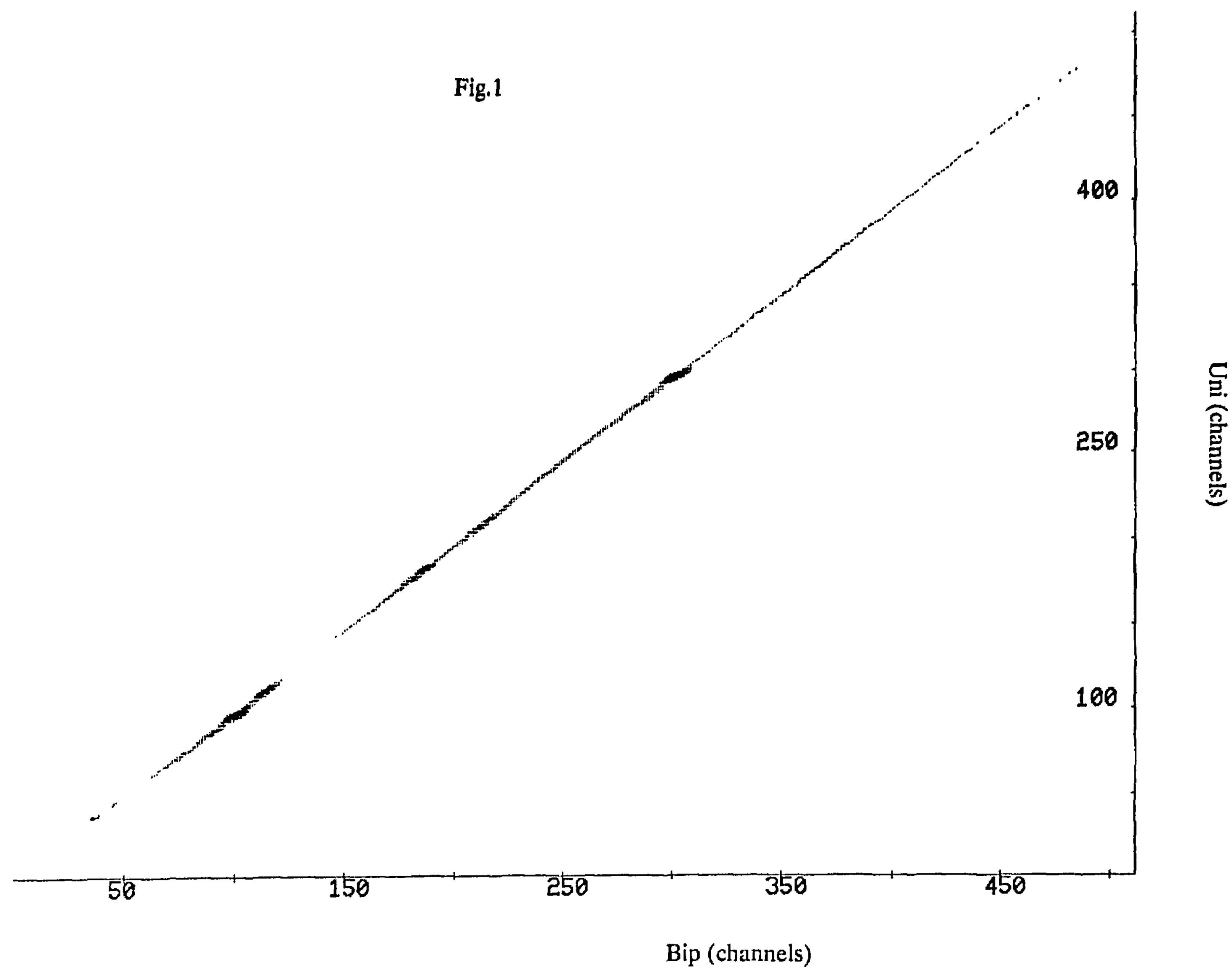


Fig.2

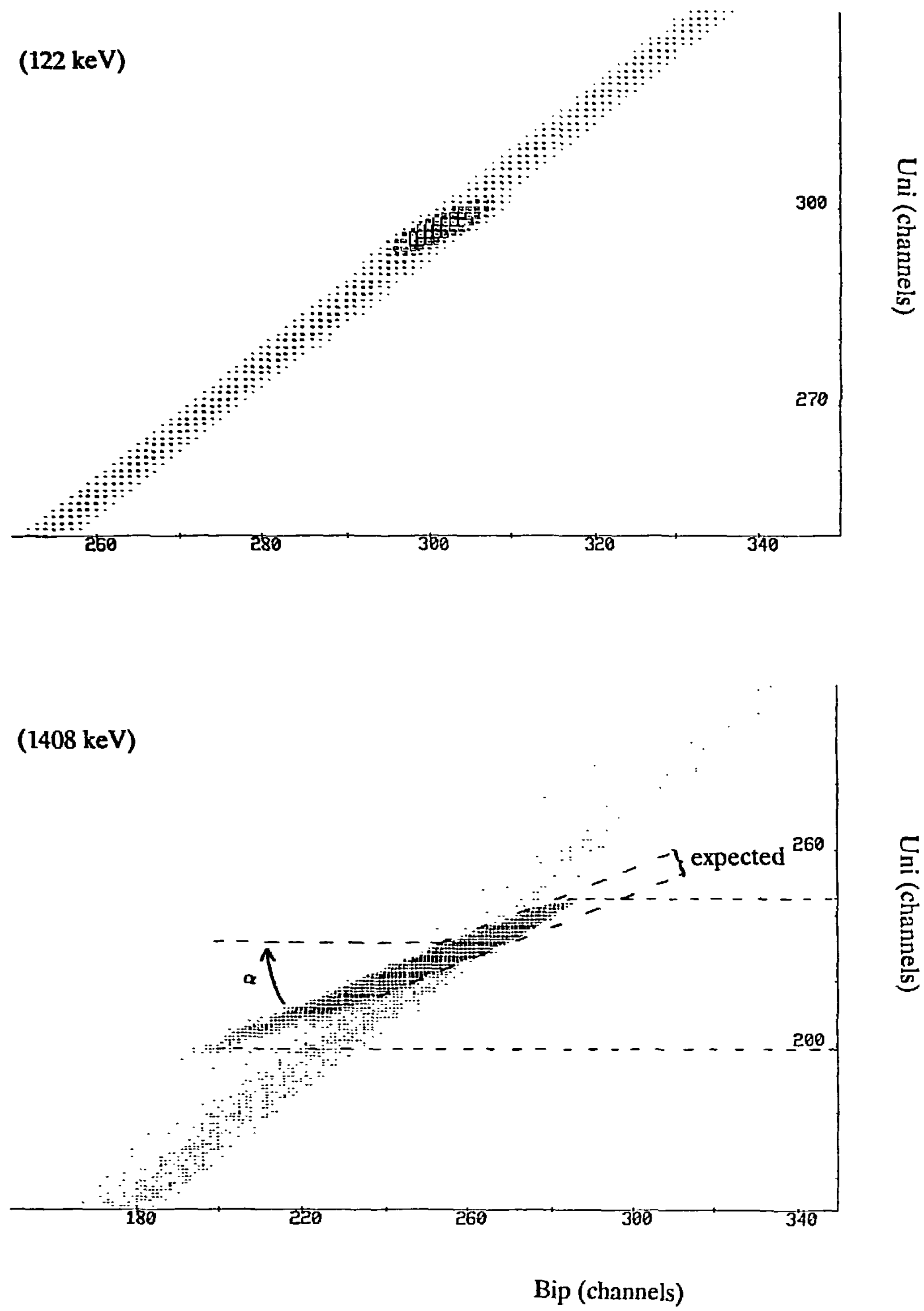

(122 keV)
Uni (channels)
300
270
260
280
300
320
340
(1408 keV)
expected
260
Uni (channels)
200
α
180
220
260
300
340
Bip (channels)

Fig.3

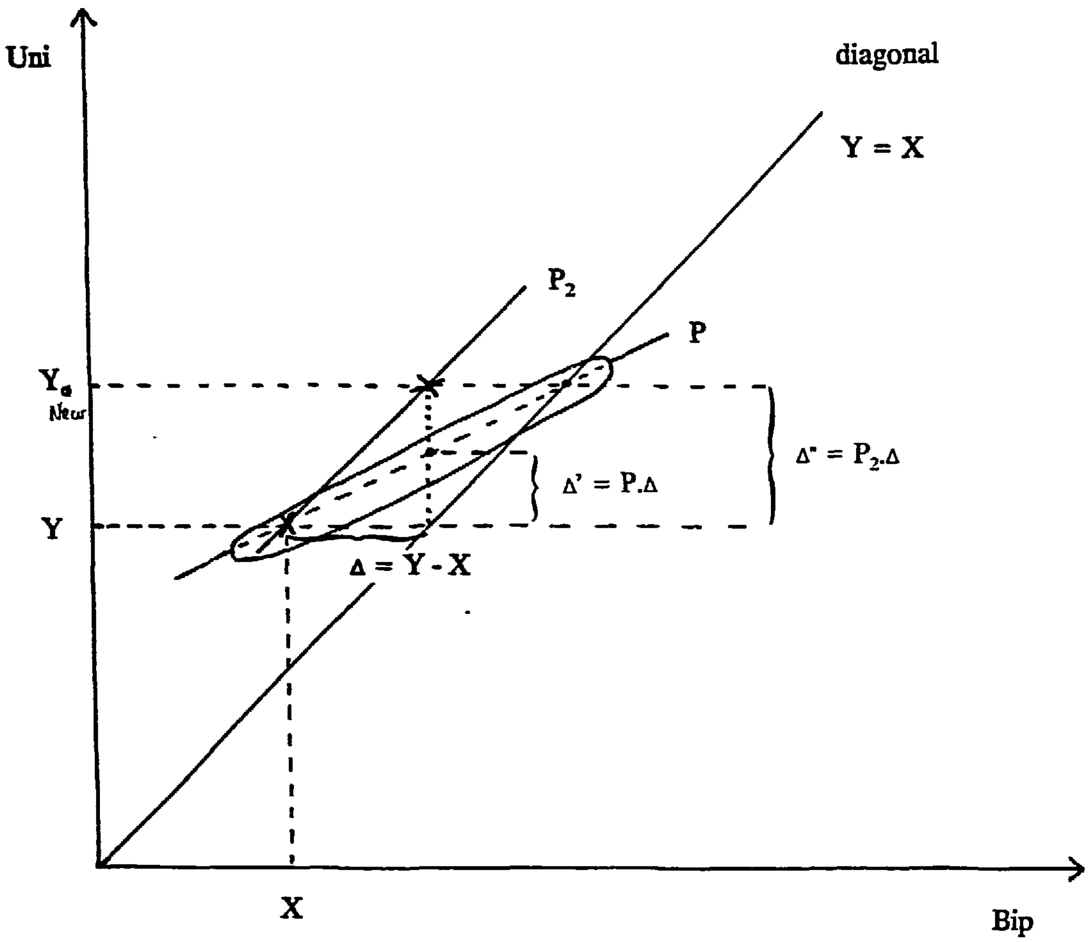


Fig.4

(122 keV)

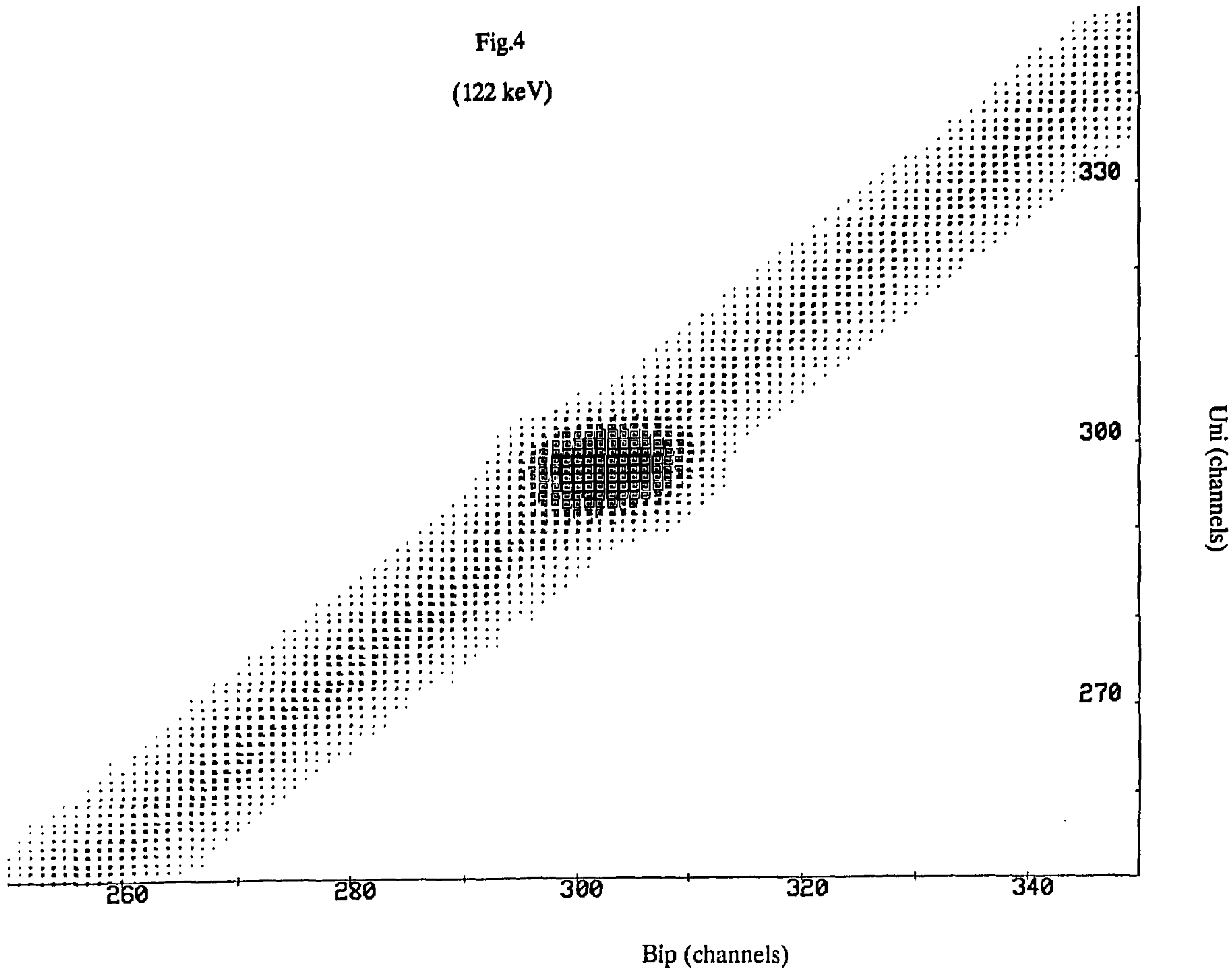
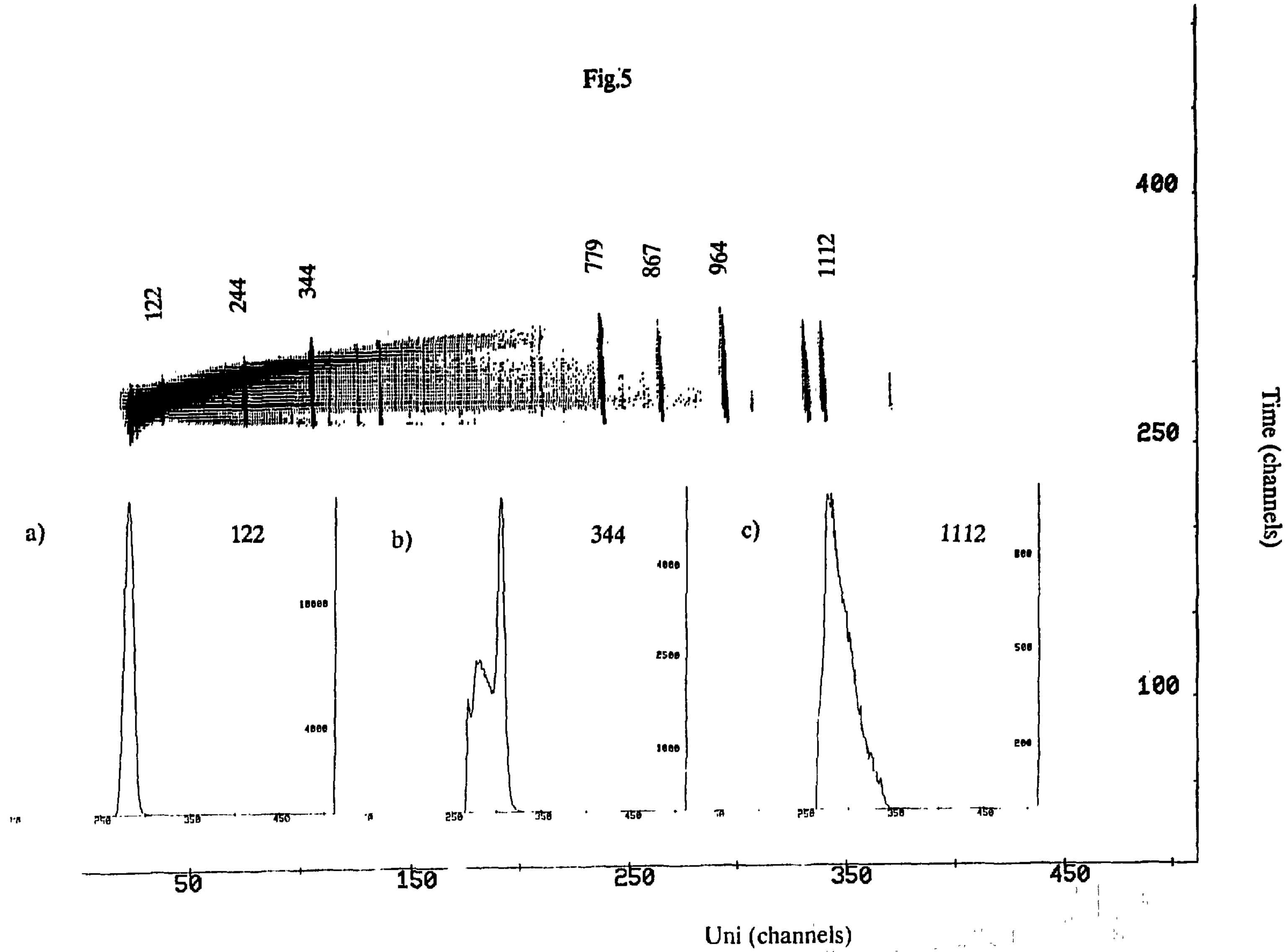


Fig.5



122
244
344
779
867
964
1112
a)
122
b)
344
c)
1112
400
250
100
Time (channels)
50
150
250
350
450
Uni (channels)