Gamma Ray Spectrometer For Nuclear Structure Studies With Fast Moving Recoils

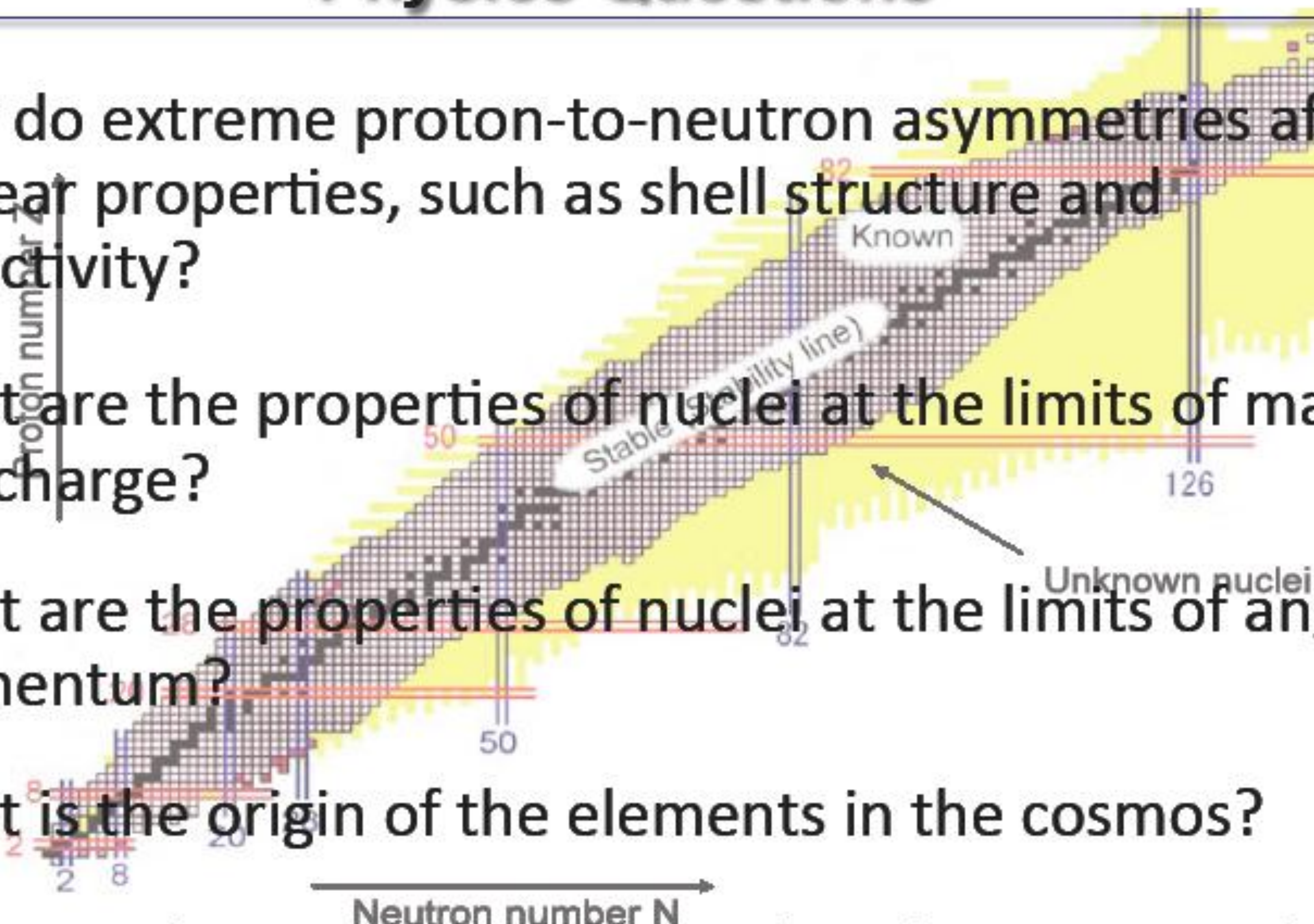
S. S. Ghugre

UGC-DAE Consortium For Scientific Research, Kolkata Centre, Sector III, LB-8, Bidhan Nagar, Kolkata-700 098, INDIA

email: ssg@alpha.iuc.res.in

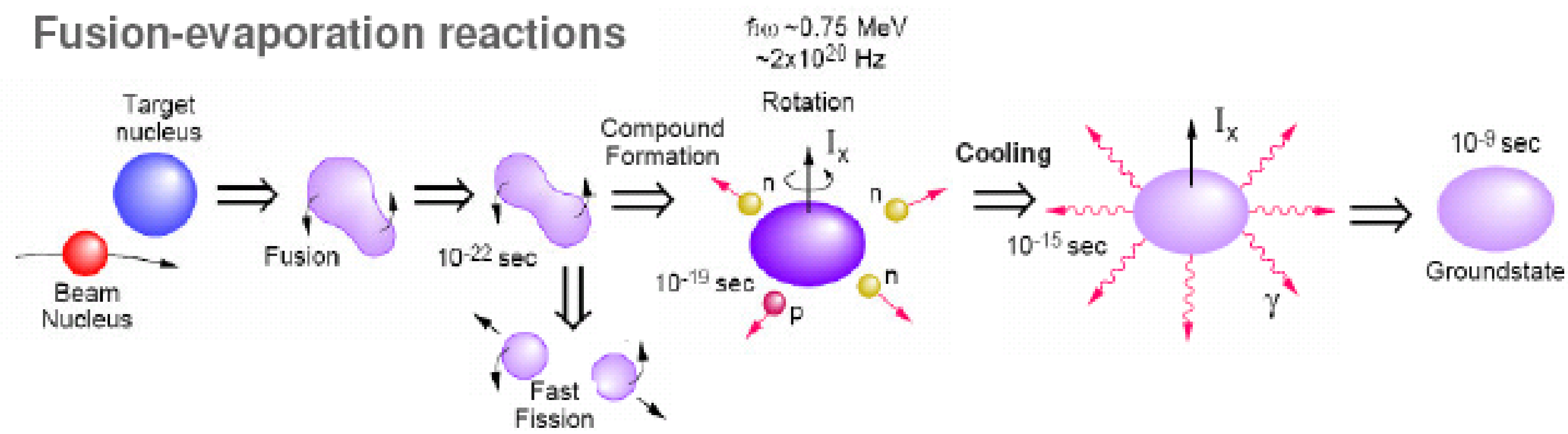
The GEANT simulation have been carried out by SoumenduShekhar Bhattacharjee

Physics Questions



- How do extreme proton-to-neutron asymmetries affect nuclear properties, such as shell structure and collectivity?
- What are the properties of nuclei at the limits of mass and charge?
- What are the properties of nuclei at the limits of angular momentum?
- What is the origin of the elements in the cosmos?
- What are the nuclear reactions that drive stars and stellar explosions?

■In-beam gamma ray spectroscopy (investigations of prompt gammas from nuclear reaction of beam on target) at energies up to (~ 6 Mev/A) has provided us with an intriguing information on “dizzy nuclei”



■Evolution of shell structure with angular momentum (stress of collective motion)

■Impact of deformation on shell structure

■Impact of the occupation of specific orbitals on global properties (nuclear shape,...)

■Evolution of interactions (pairing..) with spin

Most studies at very high spin concentrate on stable or neutron-deficient nuclei, but

- some of the orbitals involved at high spin become yrast as N increases
- some of the phenomena seen at high spin may occur at lower spin in exotic nuclei
- the job is not finished: many open questions remain

Hence we would like to exploit the main ingredients of gamma ray spectroscopy

✓ **Excellent energy resolution**

✓ **Enhanced efficiency**

✓ **Improved peak-to-total**

in our investigations as we charter along the nuclear landscape.

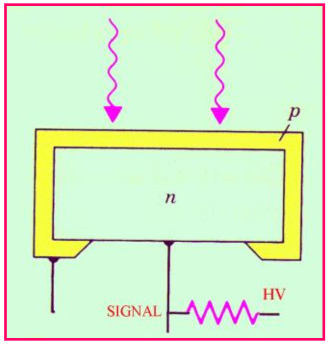
The emitted gamma is generally emitted by moving product.

Hence, velocity and spread (speed and angle) strongly influence the energy resolution.

Velocities of Ejectiles are almost same as that of projectile

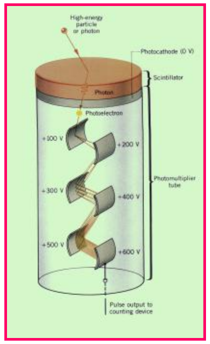
Gamma-rays are Doppler-Shifted

γ-ray detection sytems



Ge semiconductor detector

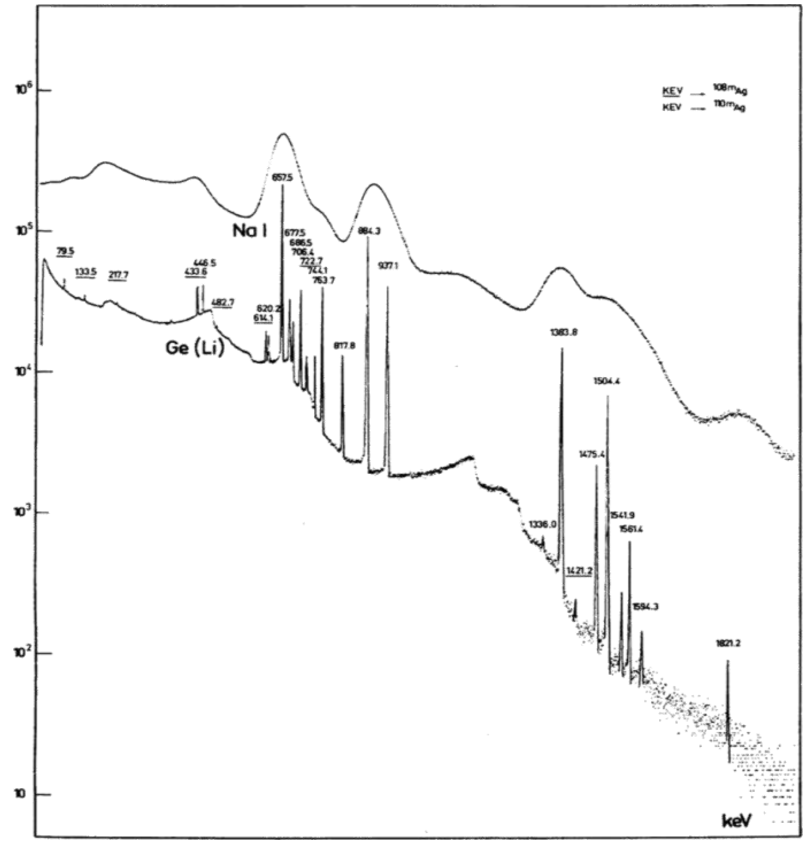
v/s BaF_2 scintillator



- Energy resolution
  Ge 0.2% <<
  BaF_2 (~10%)

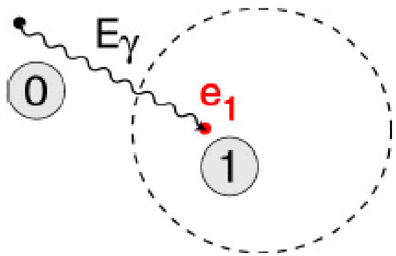
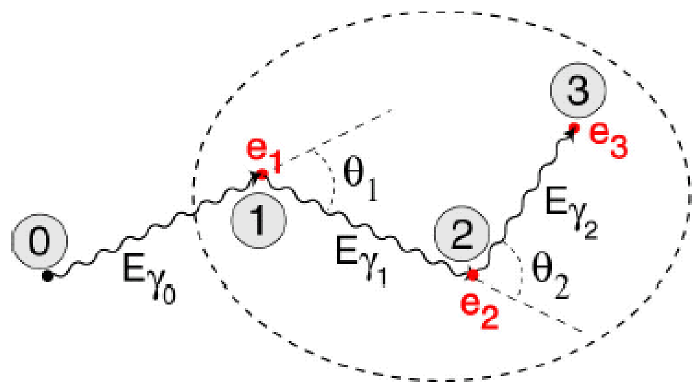
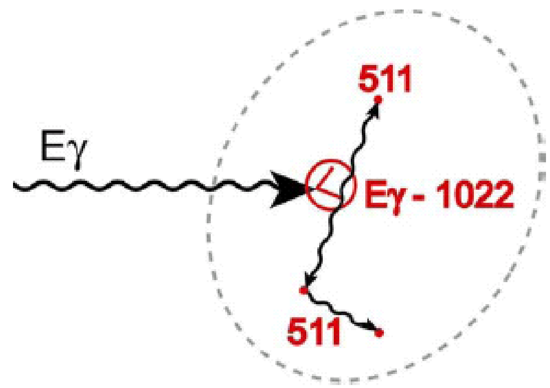
- Efficiency(Eγ)
  BaF_2 > Ge

- Timing ressolution
  BaF_2 (<0.5ns)
  << Ge (~8-12 ns)

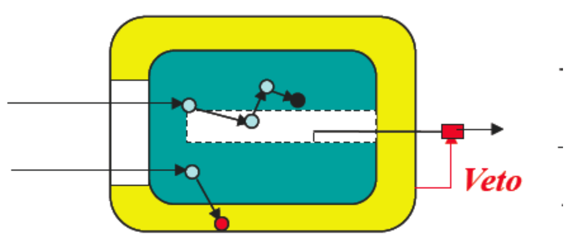


The Three Main Interaction Mechanisms

γ-ray energy →

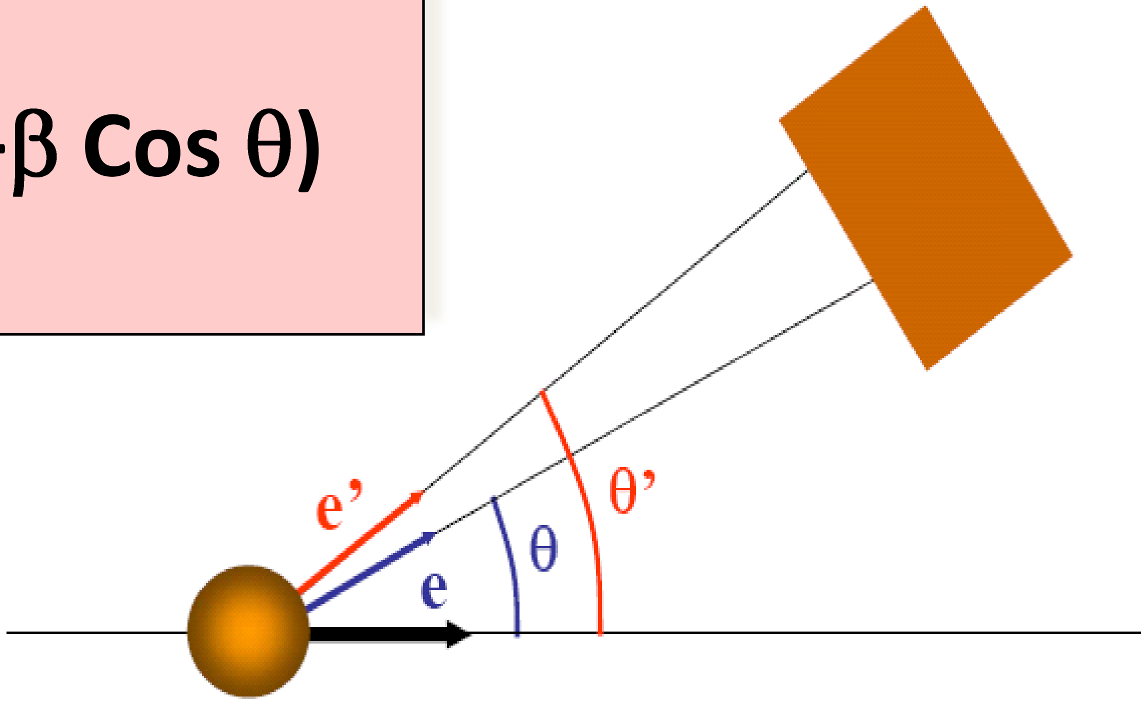
Photoelectric	Compton Scattering	Pair Production
		

Isolated hits	Angle/Energy	Pattern of Hits
Probability of interaction depth	$E_{\gamma'} = \dfrac{E_\gamma}{1+\dfrac{E_\gamma}{m_0c^2}(1-\cos\theta)}$	$E_{1st} = E_\gamma - 2\,mc^2$

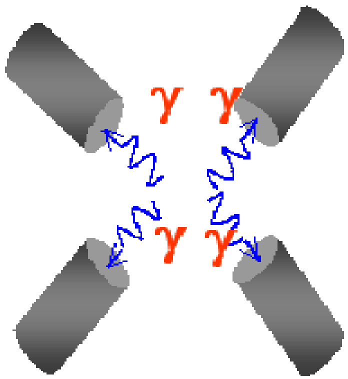


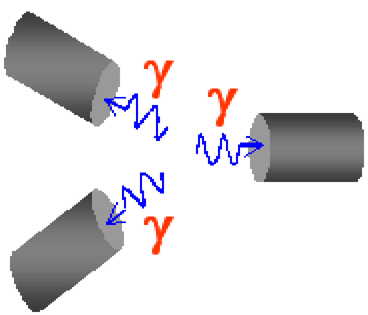
Possibility to increase the detector size ???

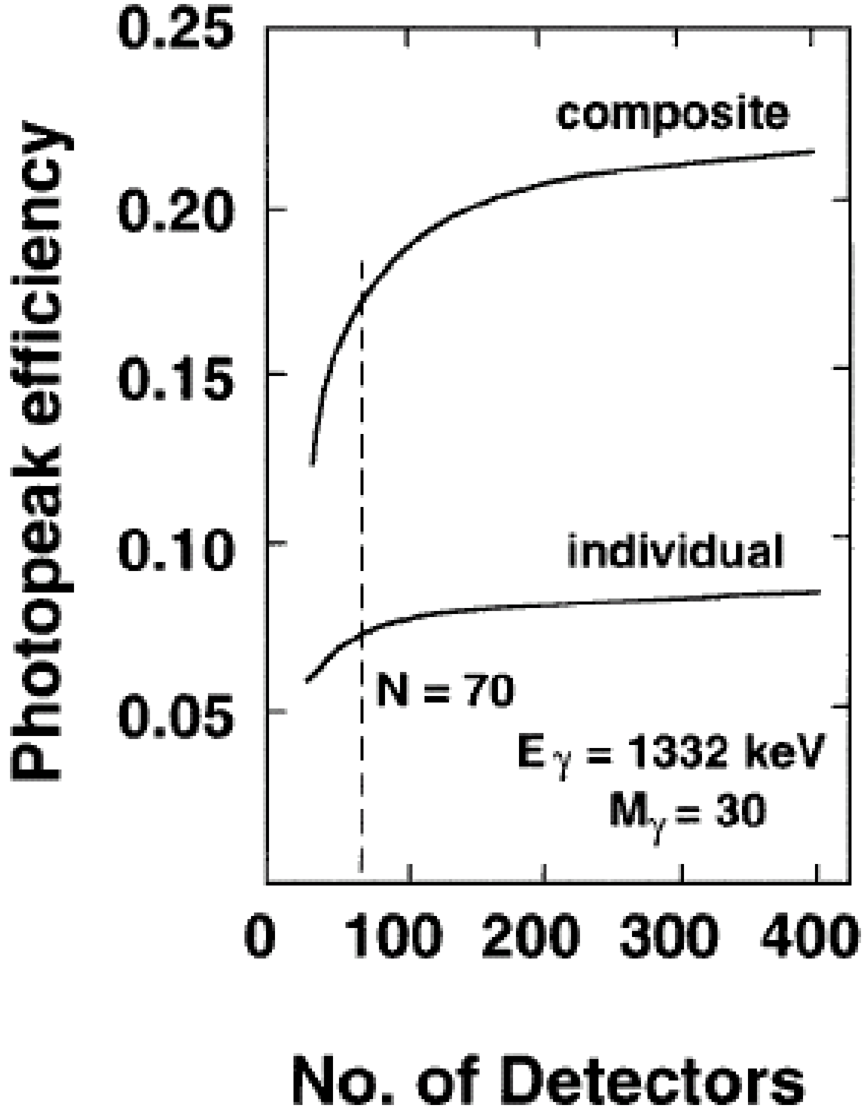
$$E=E_0(1+\beta \cos \theta)$$

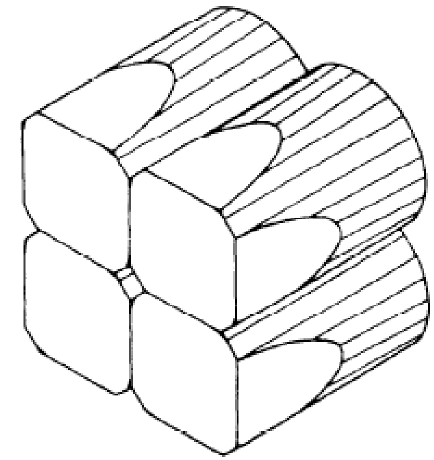


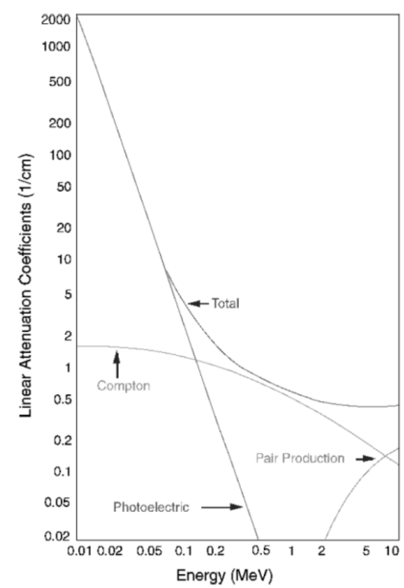
$$\frac{\Delta E_\gamma^{(Doppler)}}{E_\gamma} = 2\frac{v_r}{c}\sin\theta_\gamma \sin\Delta\theta_\gamma$$


γ
γ
γ
γ

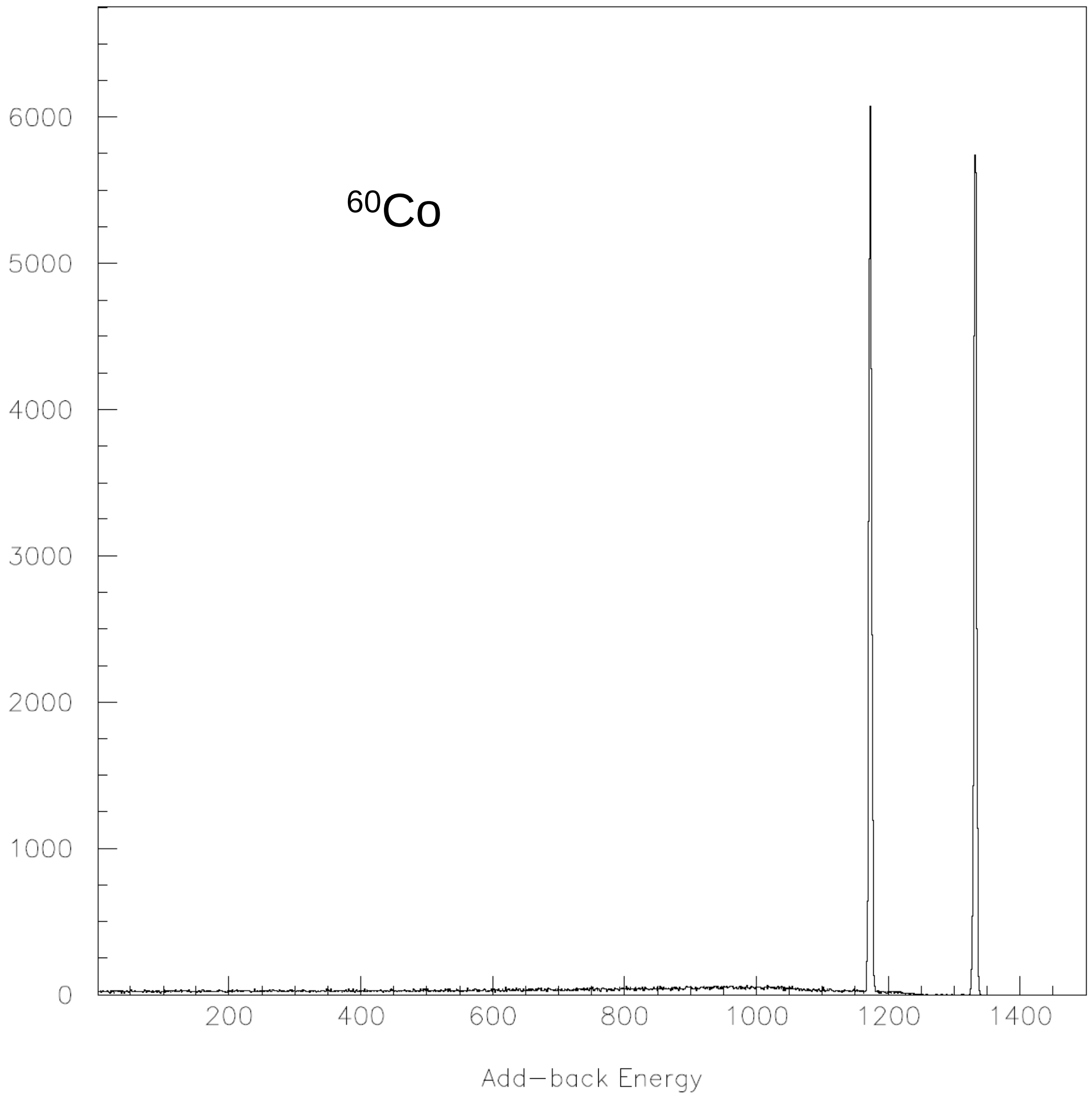

γ
γ
γ

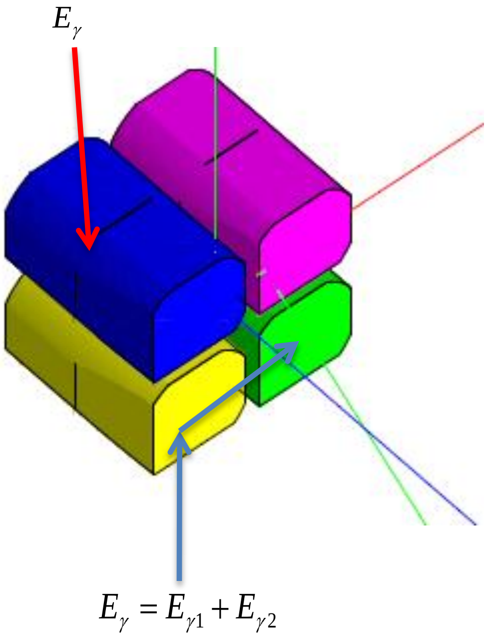

Photopeak efficiency
0.25
0.20
0.15
0.10
0.05
composite
individual
N = 70
Eγ = 1332 keV
Mγ = 30
0
100
200
300
400
No. of Detectors

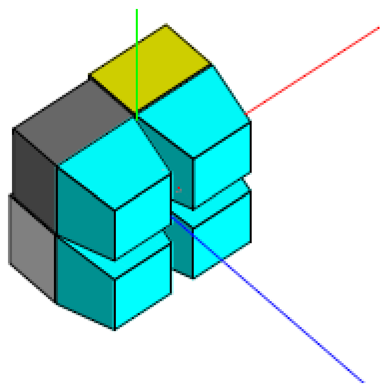


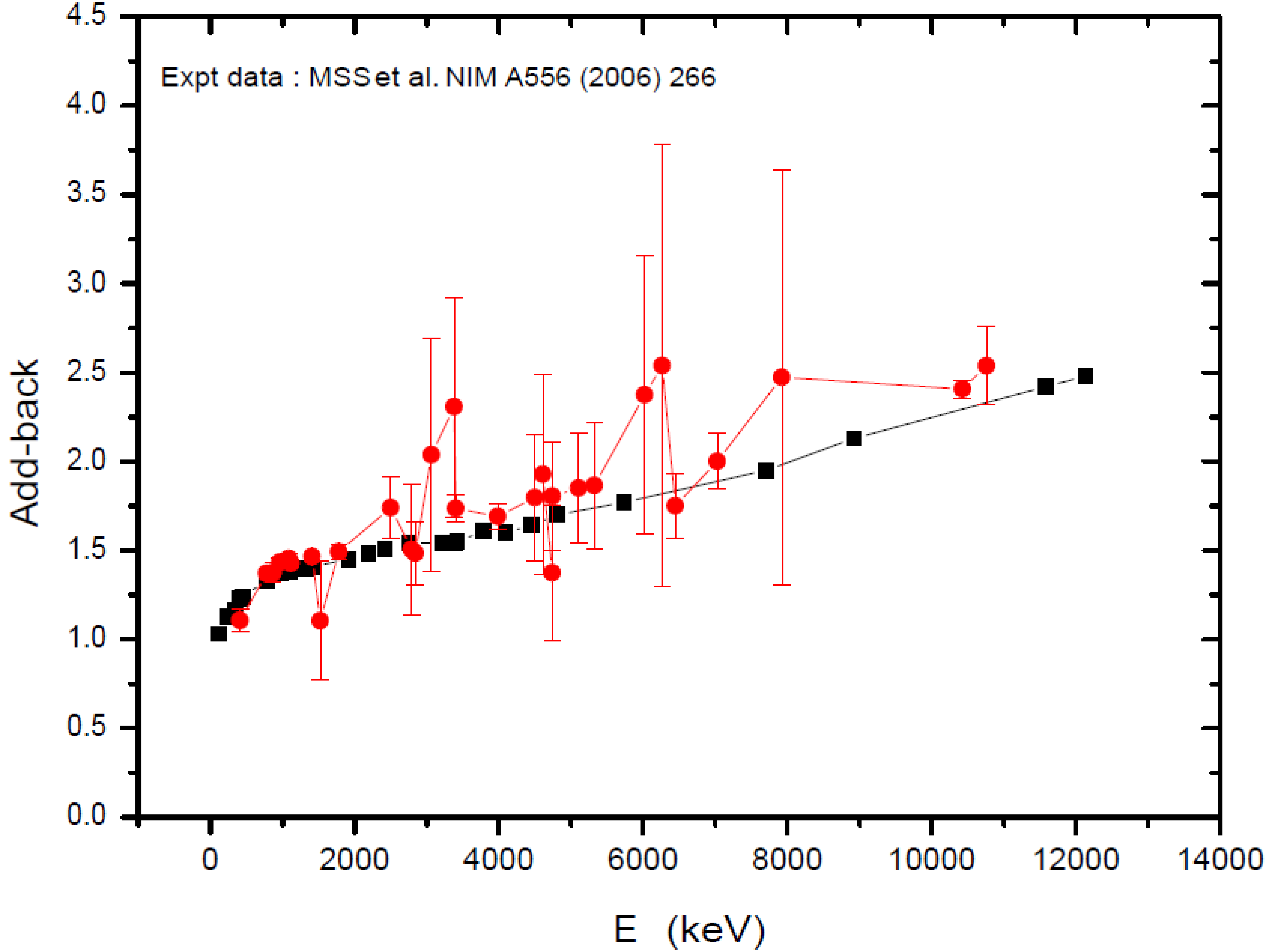

Linear Attenuation Coefficients (1/cm)
2000
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
Total
Compton
Pair Production
Photoelectric
0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10
Energy (MeV)

GEANT4 simulation for INGA Clover



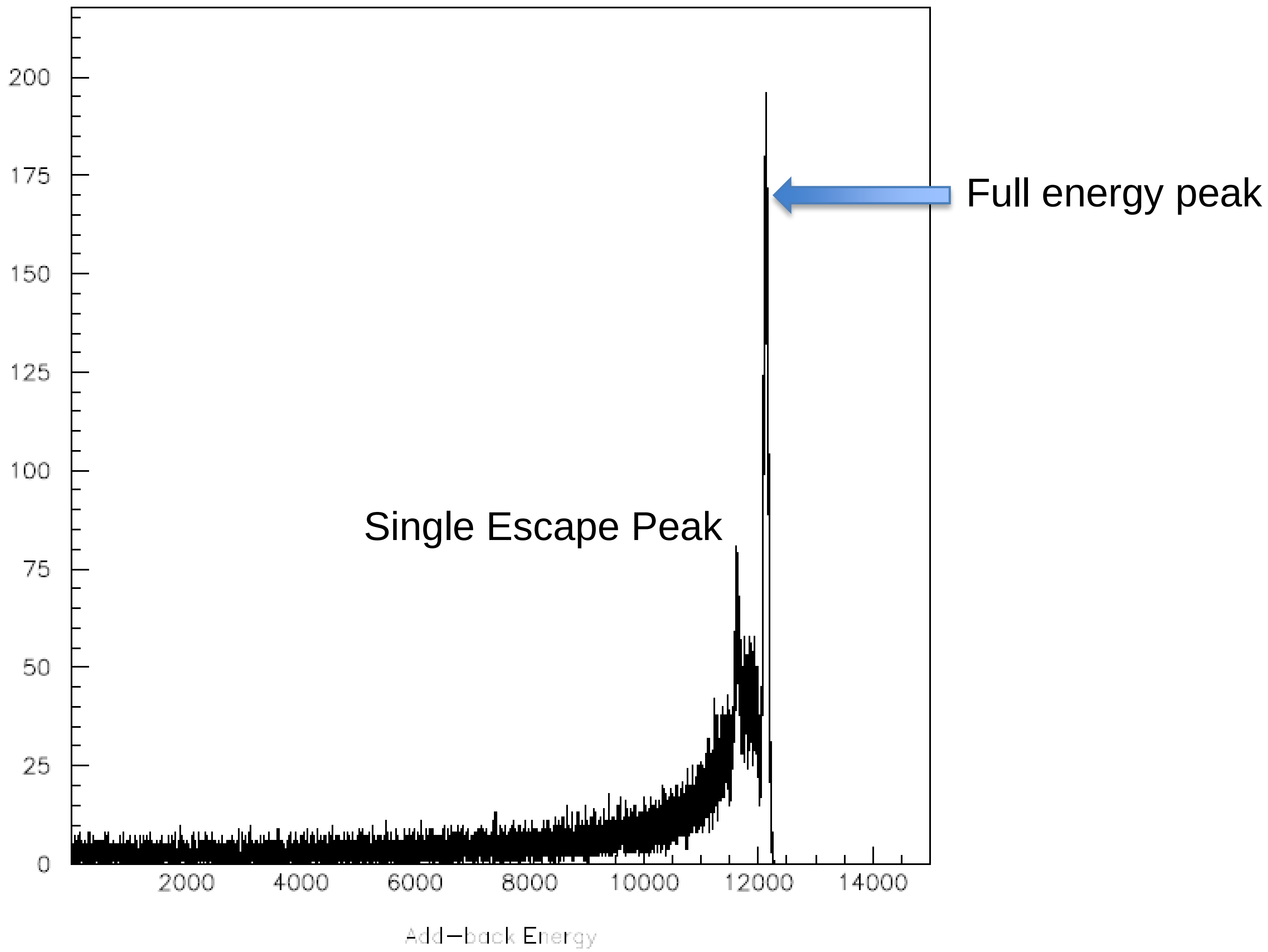




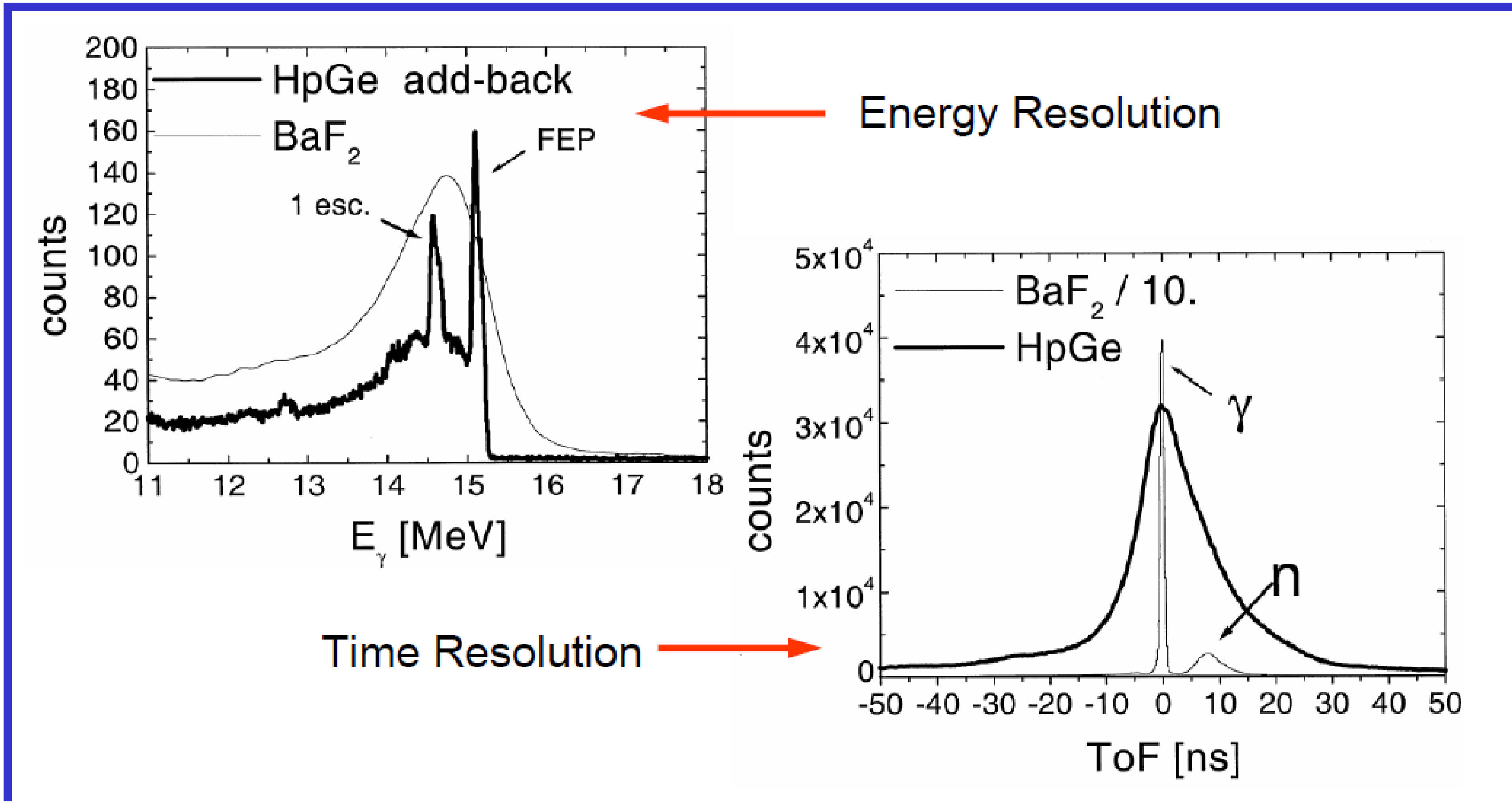


Expt data : MSS et al. NIM A556 (2006) 266
Add-back
E (keV)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
2000
4000
6000
8000
10000
12000
14000

GEANT4 simulation for INGA Clover up to 12 MeV



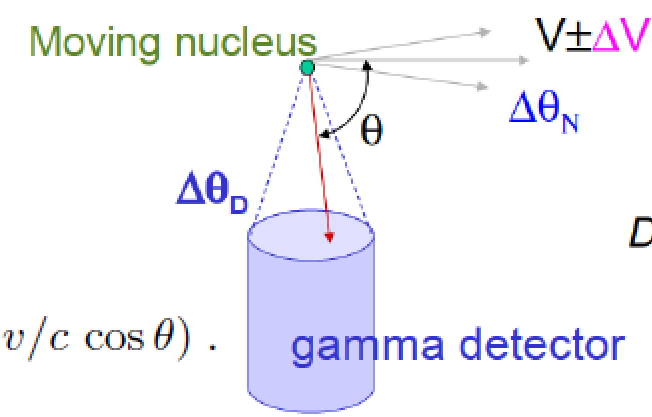
B. Million *et al*. Nucl. Instrum. and Methods **A 452** (2000) 422



Hence the combination of Clover (s) + fast scintillator array could open up exciting avenues

Challenges for fast moving recoils

- The recoil velocities produced are ~ 3-4 % the velocity of light.
- These produce considerable Doppler effects.
- Hence, the angle subtended by each detector should be kept within reasonable limits.
- Higher granularity detectors are required.



$$E_\gamma = E_0(1 + v/c\,\cos\theta)\ .$$

Doppler shift $$E_\gamma = E_\gamma^0 \frac{\sqrt{1-\frac{V^2}{c^2}}}{1-\frac{V}{c}\cos\theta}$$

$$\Delta E_\gamma = E_0 v/c\,\sin\theta\,\Delta\theta\ .$$

Gamma-ray Tracking with Segmented HPGe Detectors

O. Wieland[a], Th. Kröll[b], D. Bazzacco[c], R. Venturelli[c], F. Camera[a], B. Million[a], E. Musso[a], B. Quintana[d], C. A. Ur[e], M. Bellato[c], R. Isocrate[c], Ch. Manea[c], R. Menegazzo[c], P. Pavan[c], C. Rossi Alvarez[c], E.Farnea[c], A. Gadea[e], D. Rosso[e], P. Spolaore[e], A. Pullia[a], G. Casati[f], A. Geraci [f], G. Ripamonti[f], and M. Descovich[g]

Correction of Doppler Broadening

reconstruction of interaction points by a Genetic Algorithm

^{56}Fe → ^{208}Pb
@ 240 MeV
v/c ~ 7 %

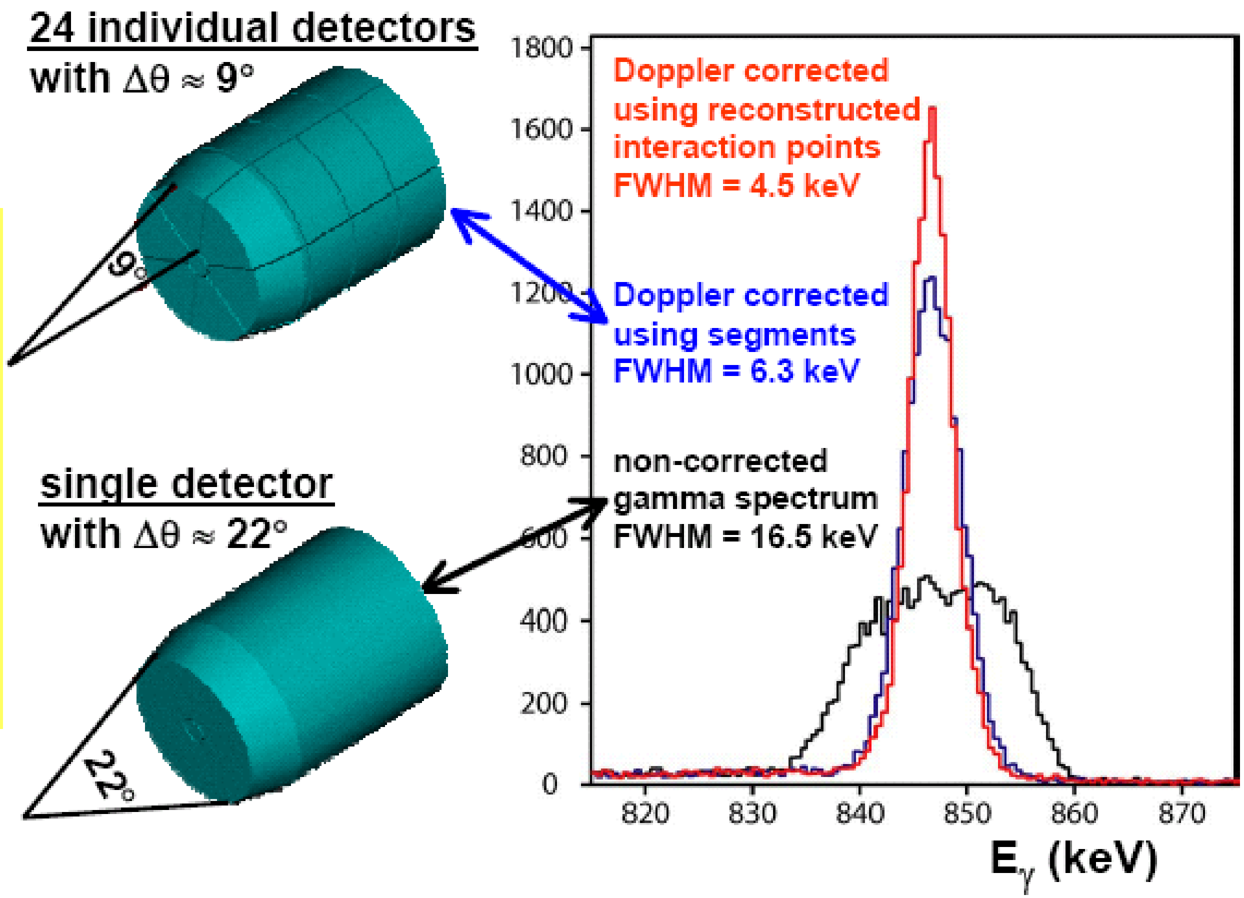
Expected final results:

perfect tracking

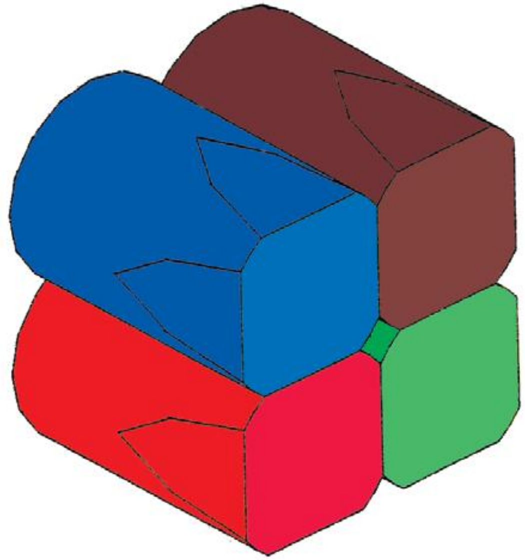
→ 3.4 keV

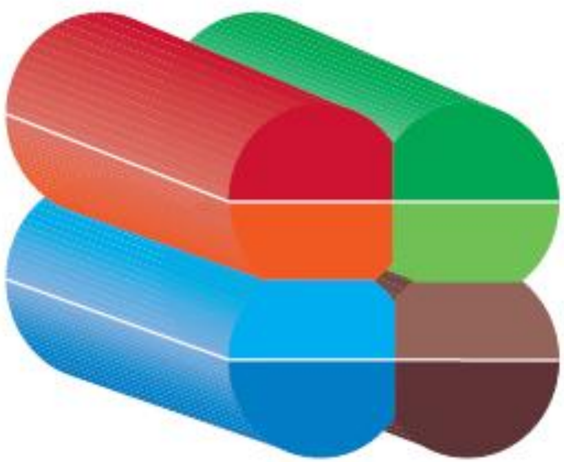
positional error <d> ≈ 5 mm

→ 4.2 keV

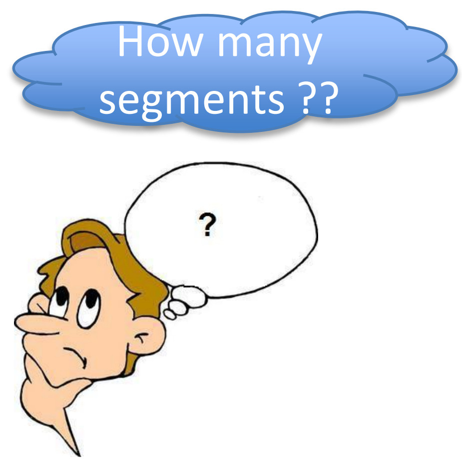


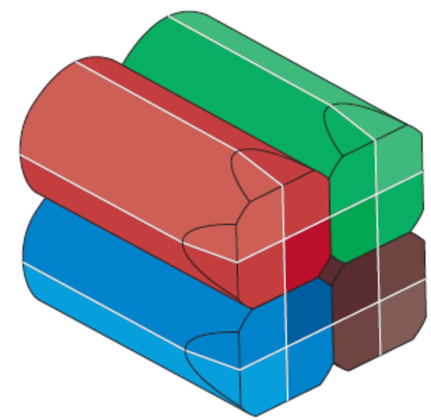
Tapered detectors will perform better as some of the difficult front part is cut away





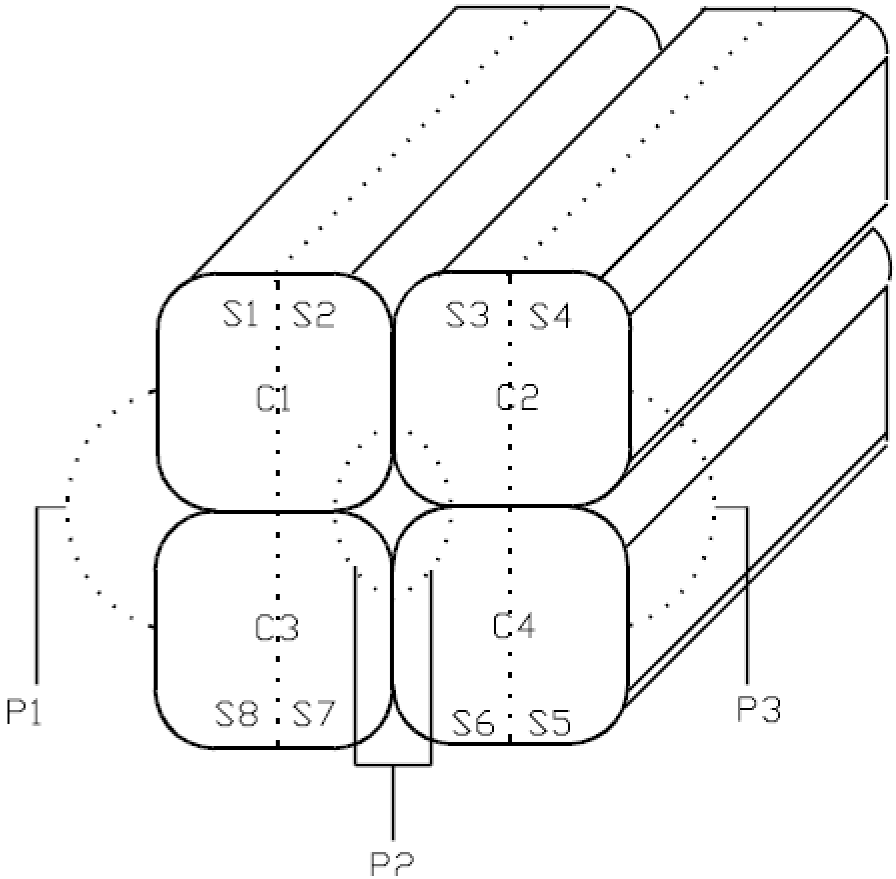
2 FOLD SEGMENTED CLOVER

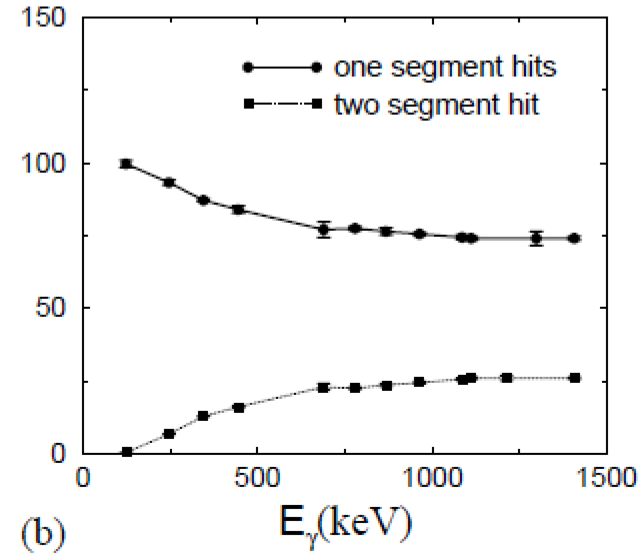




4 FOLD SEGMENTED SUPER CLOVER

Arrangements of 4 detectors 140 mm long



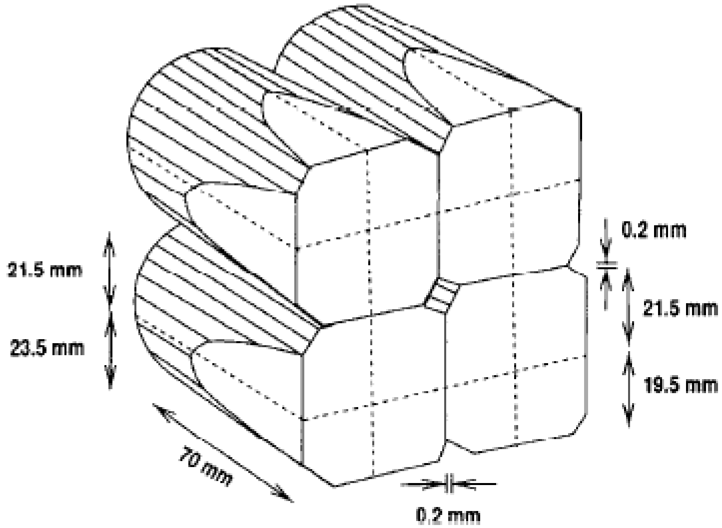


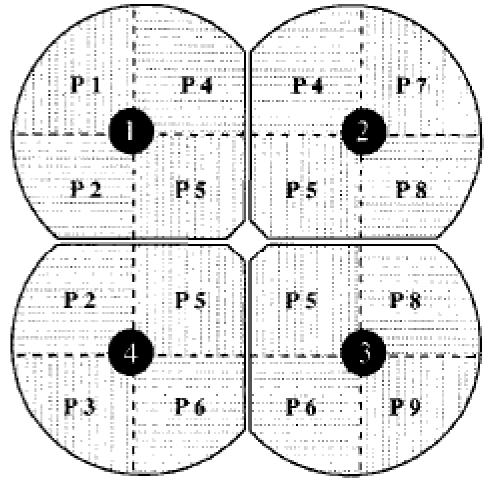
(b)

Fig. 1. Schematic diagram of two-fold segmented Clover. C_i represents the crystal number while S_i represents the segment number. The two segmentation planes and the position signals P1, P2 and P3 taken from the outer contacts are shown in the figure.

B.S. Nara Singh et al. / Nuclear Instruments and Methods in Physics Research A 506 (2003) 238–249

S.L. Shepherd et al. / Nuclear Instruments and Methods in Physics Research A 434 (1999) 373–386

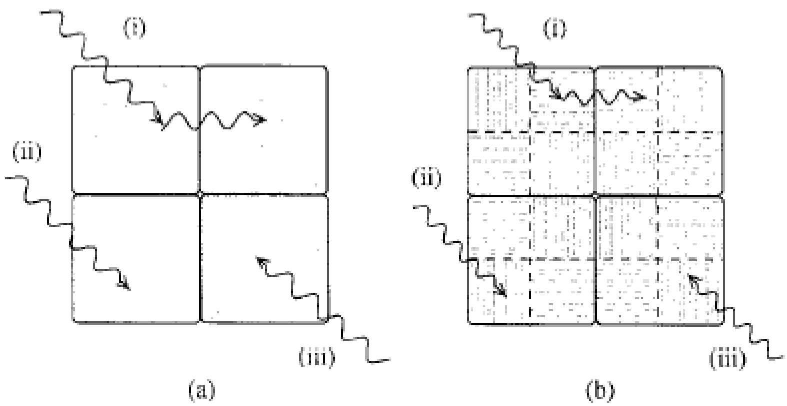




Most gammas hit one or two crystals

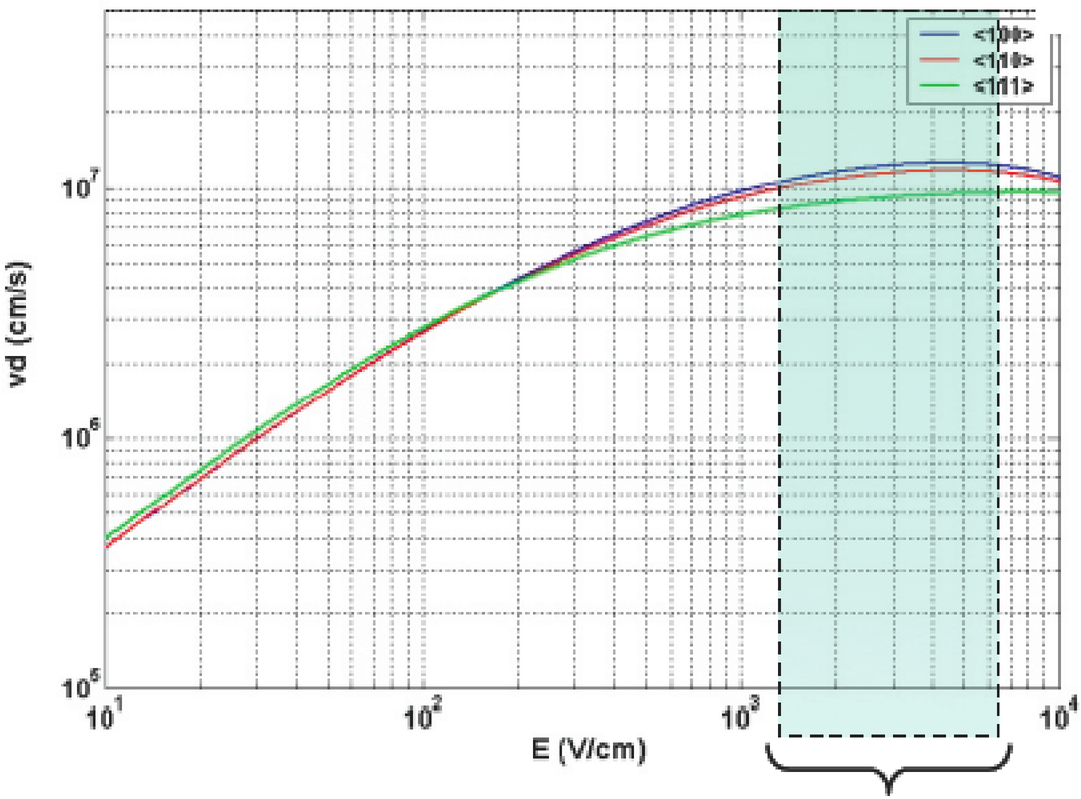
Most hit crystals have one or two hit segments

Most hit segments have one or two interactions

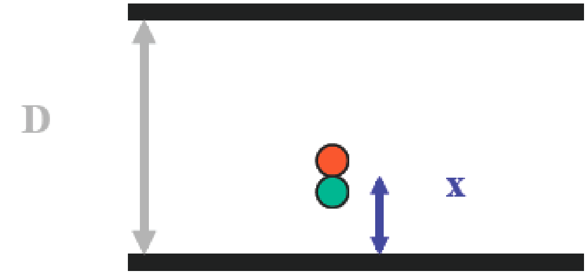


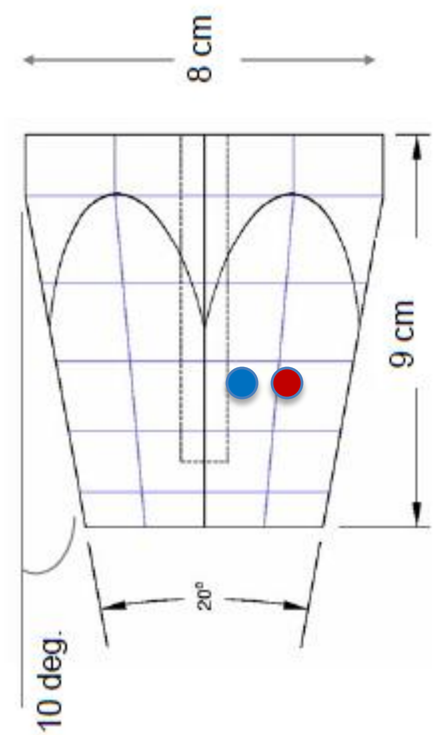
Segmentation is the need of the hour

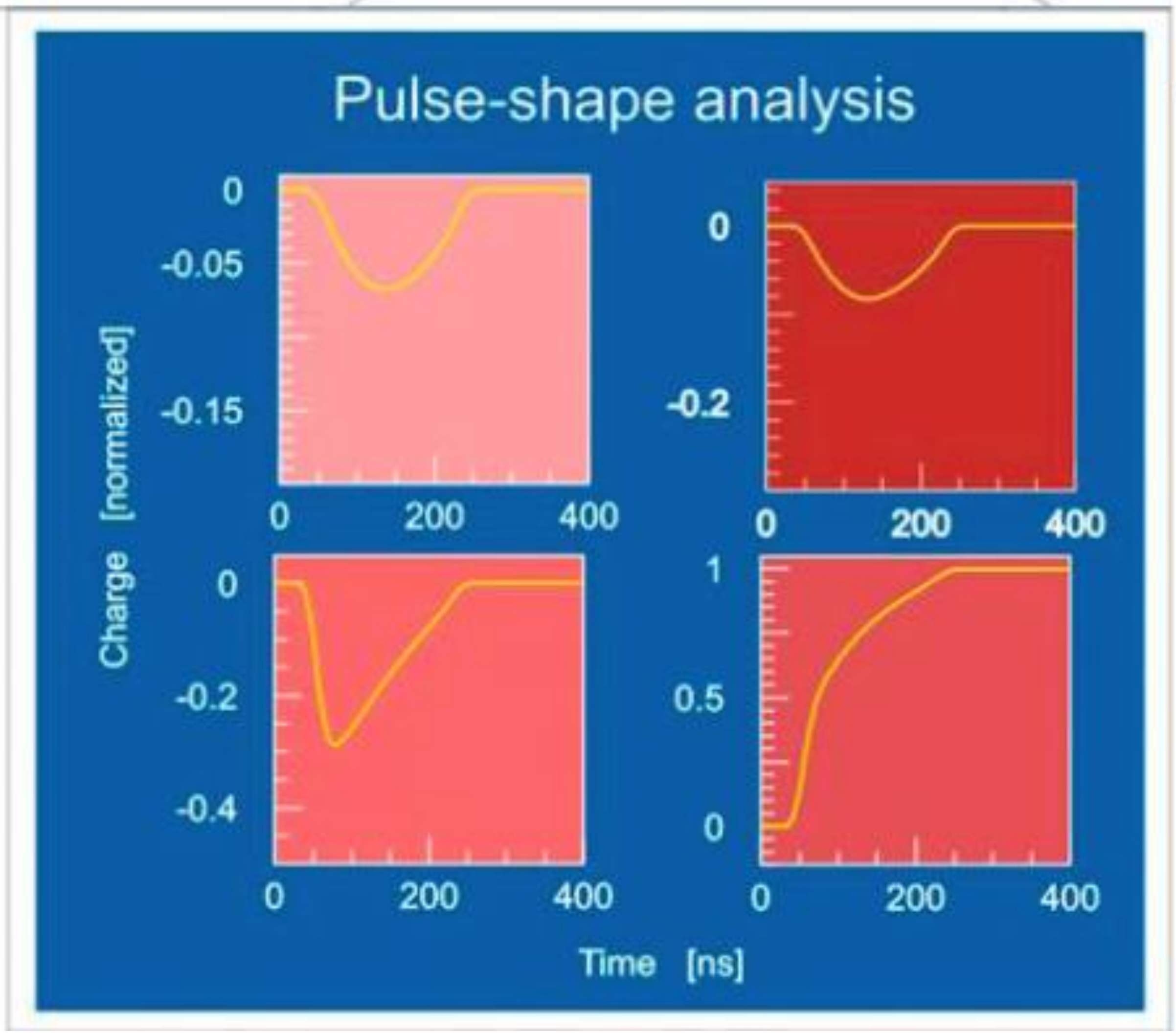
Calculated electron drift velocity



Typical HPGe Operation fields



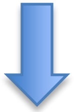




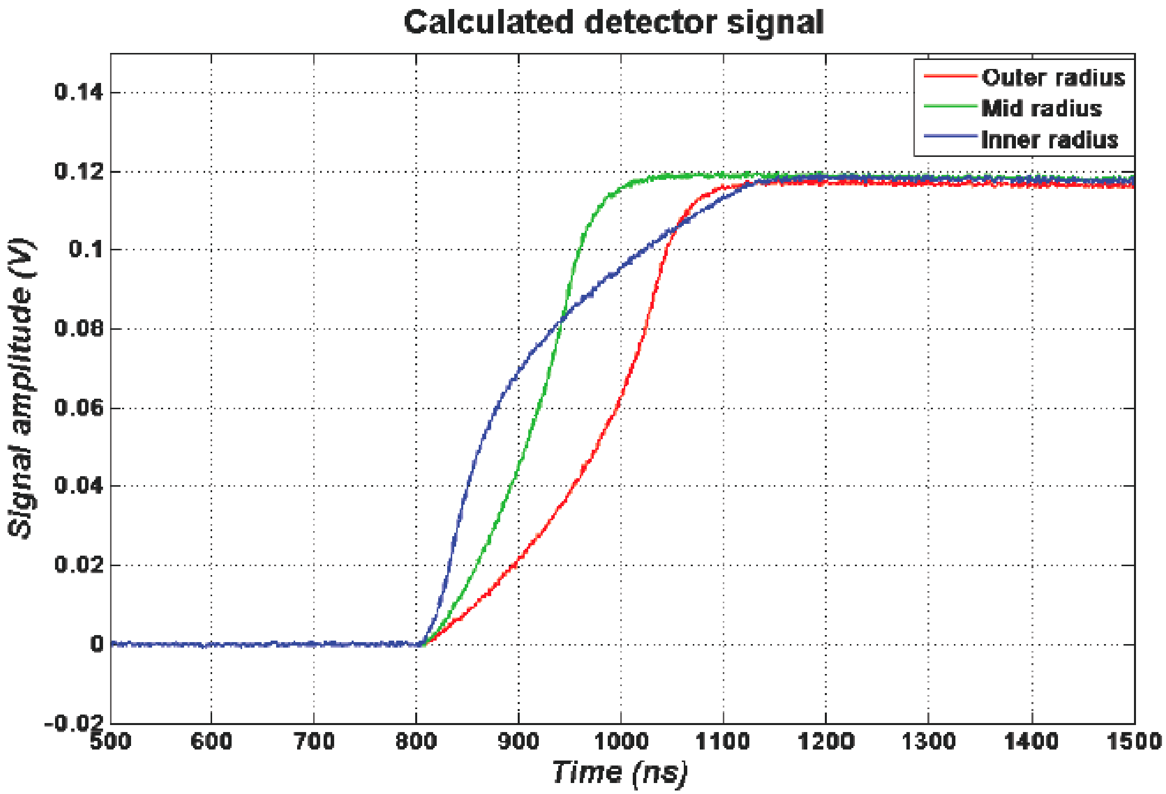
It turns out that the interaction points can be determined by analysing the pulse shapes of the signals induced on the electrodes during charge collection

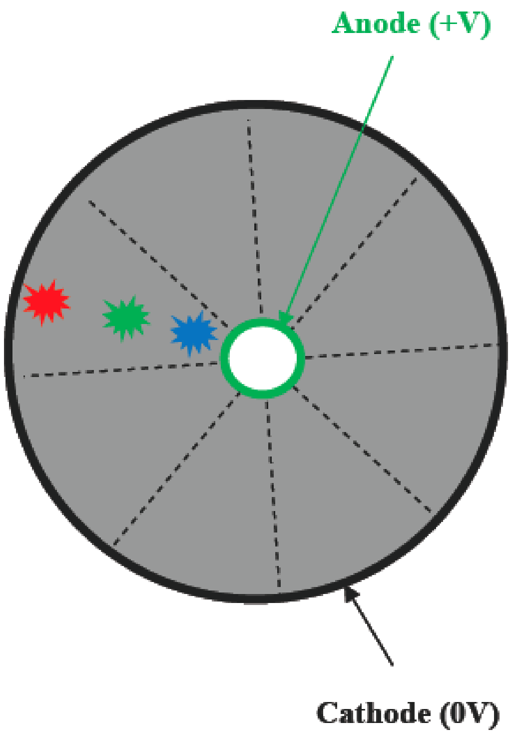
The shape of the signals is determined by the form of the electric potential.

Once the potential is known one can deduce the initial interaction point from the pulse shape.



Doppler correction





From the presentation of ***Augusto O. Macchiavelli, at the "School cum Workshop On Yrast & Near Yrast Spectroscopy"***

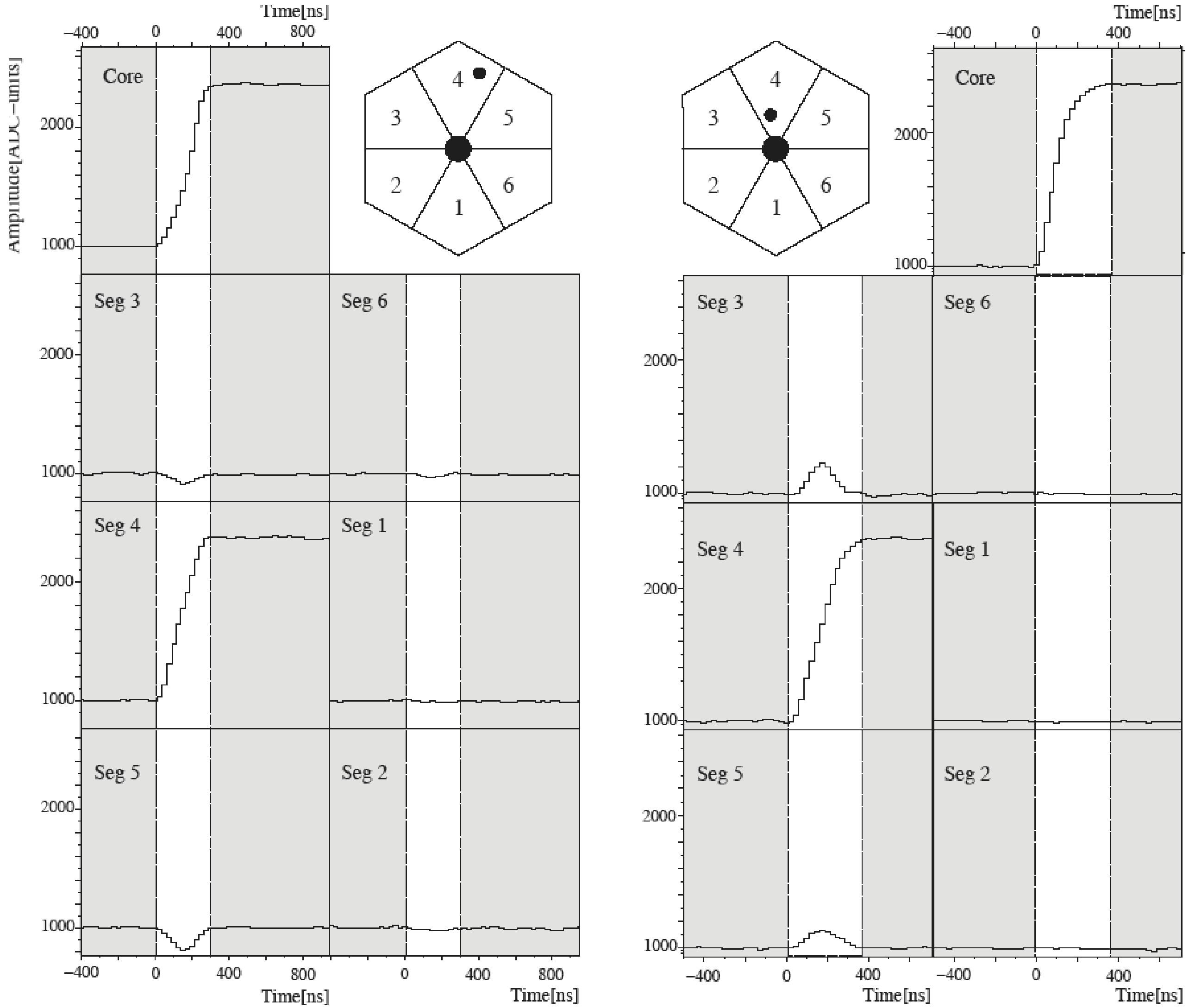
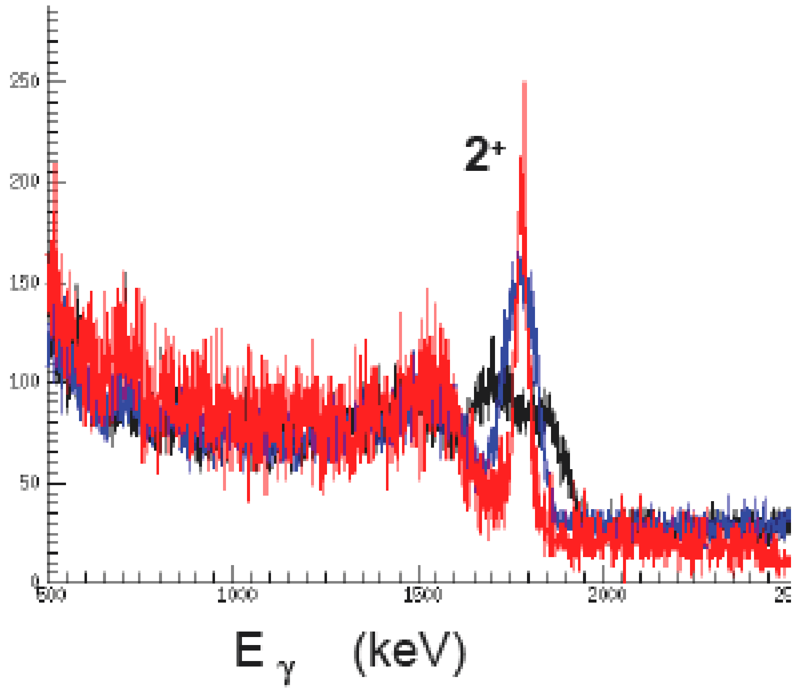


FIGURE 2. Signals for two different interactions. In each case, the interaction takes place in segment 4, but in different places. Note the dependence of the rising edge of the core signal on the radius of the interaction and the asymmetry of the amplitudes of the transient signals induced in the neighbouring segments.

Taken from the reference : "Miniball: A Gamma-Ray Spectrometer With Position-Sensitive Ge Detectors For Nuclear Structure Studies At REX-ISOLDE" J. Eberth, *et al*.



Doppler correction:

Crystal	10%
Segment	5%
Tracking	2%

Hence, further segmentation of the detector is very much essential

Some of the Physics Questions

Basic "facts" of nuclear physics that may not be valid in far-from-stability nuclei

What is the impact on the mean field as reflected in:

- the single particle energies
- the shapes and spatial extensions
- the modes of excitation
- the binding energy, etc.

What is the impact on correlations in the medium as reflected in:

- the effective interactions
- the effective charges
- the transition rates, etc.