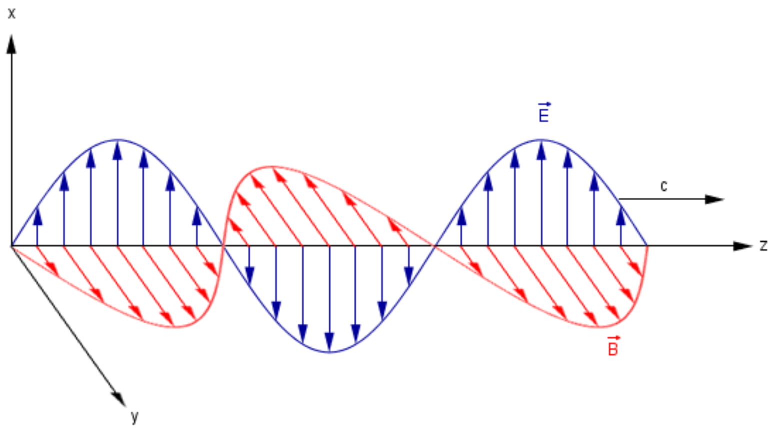
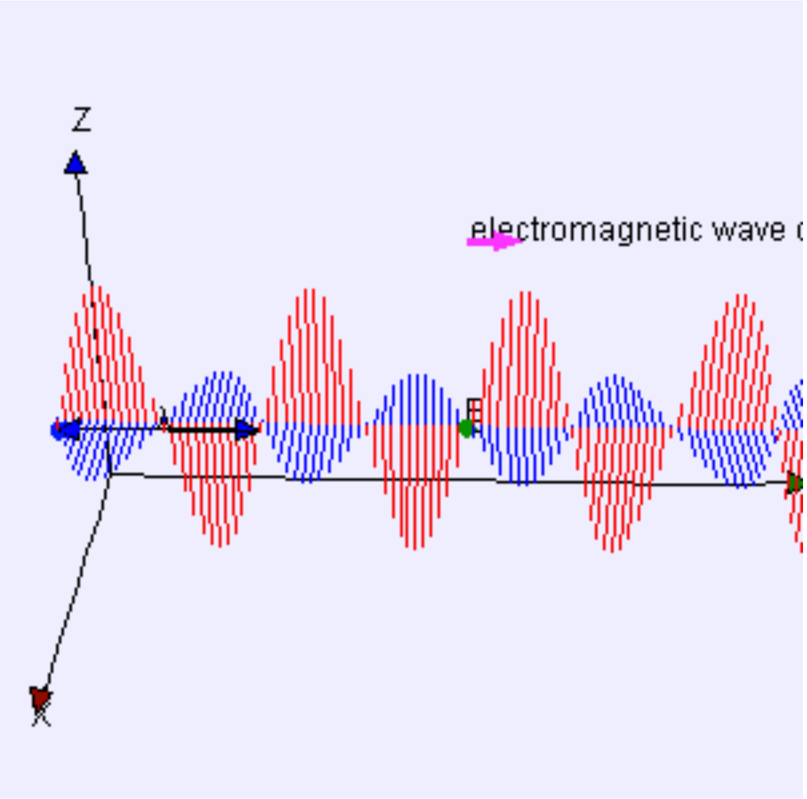
Parity determination via Polarization

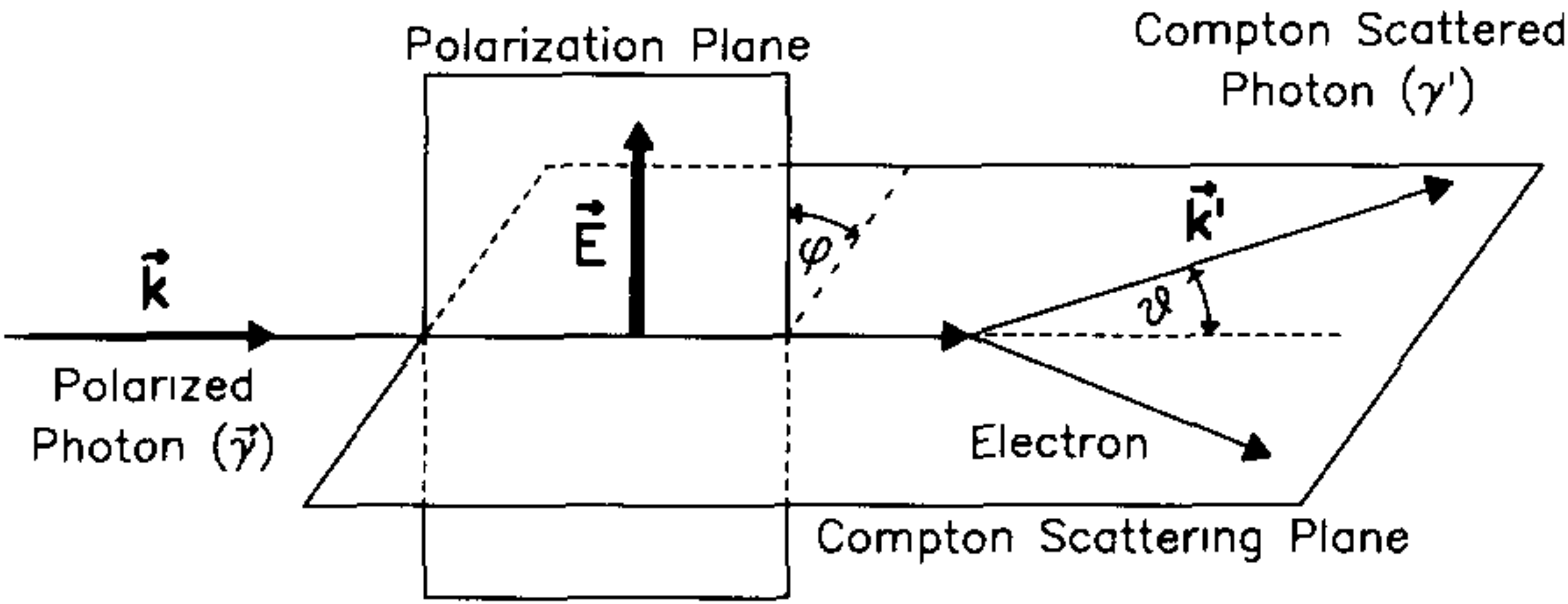
Electromagnetic waves are polarised:





The polarisation has an effect on the Compton Scattering!

Some definitions



This and most of the following slides are based on
B. Schlitt, RDH, et al, NIMA337 (1994) 416-426

Klein-Nishina Formula

The scattered gamma-ray has energy

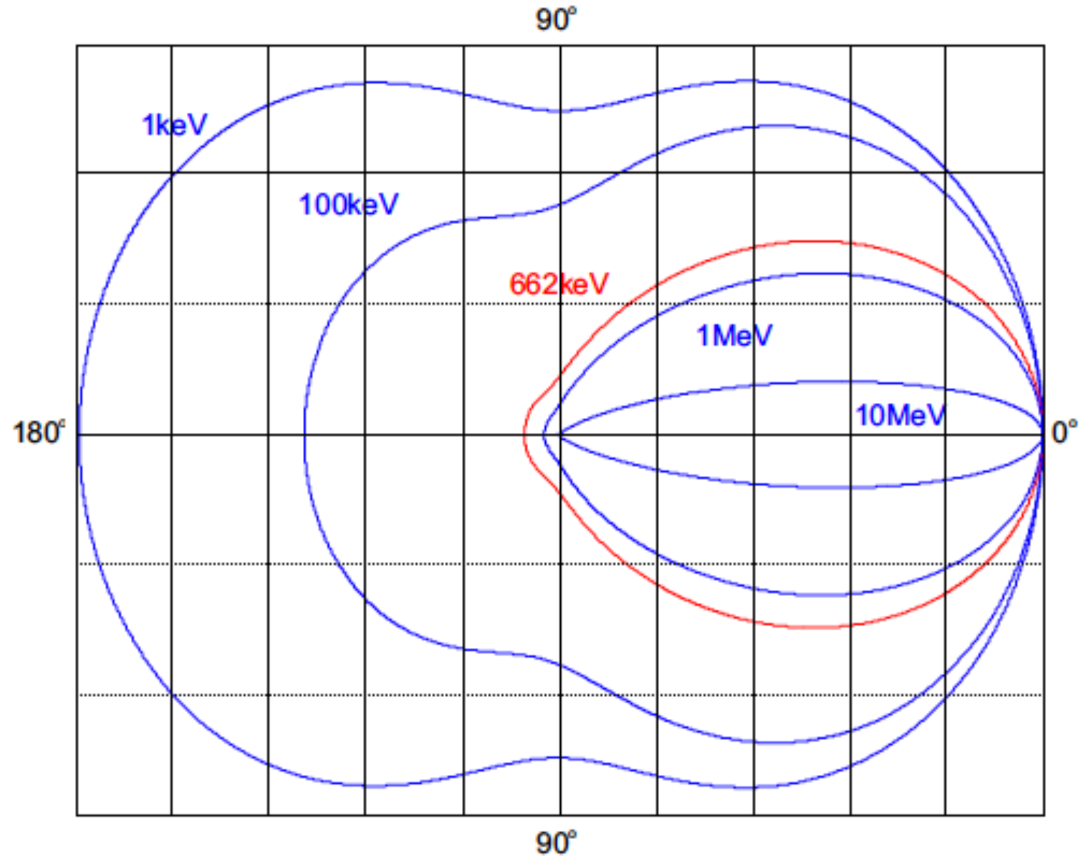
$$E'_\gamma = \frac{E_\gamma}{1+\frac{E_\gamma}{m_0 c^2}(1-\cos\vartheta)}$$

The differential cross section then becomes:

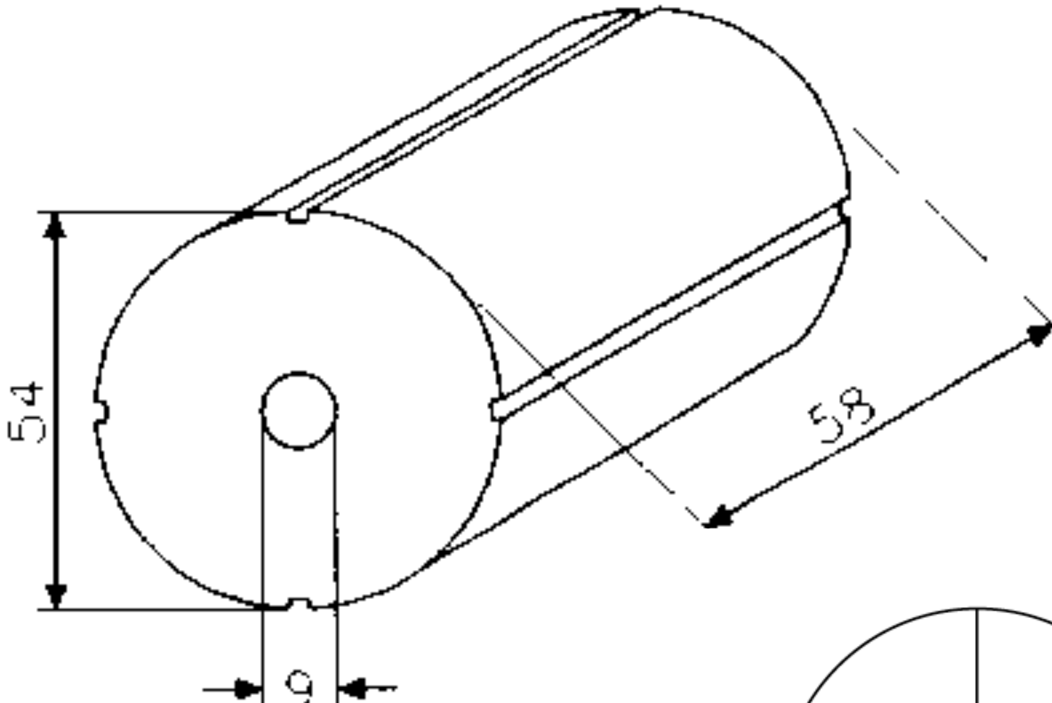
$$\frac{d\sigma}{d\Omega} = \frac{e^4}{2m_0^2 c^4}\frac{E'^2_\gamma}{E_\gamma}\left(\frac{E'_\gamma}{E_\gamma}+\frac{E_\gamma}{E'_\gamma}-2\sin^2\vartheta\cos^2\varphi\right)$$

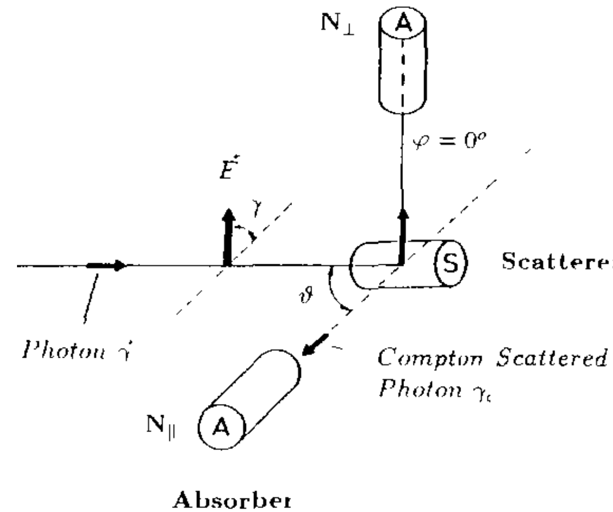
$r_0 = \frac{e^2}{m_0 c^2}$ is the classical electron radius. Note that E'_γ depends on ϑ !

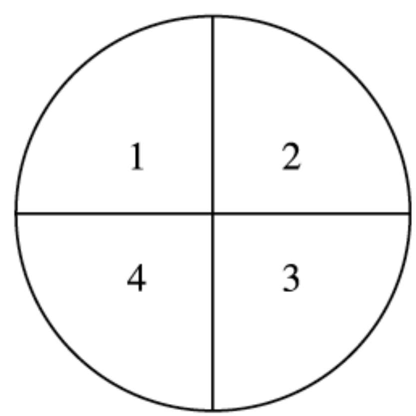
Klein-Nishina Formula

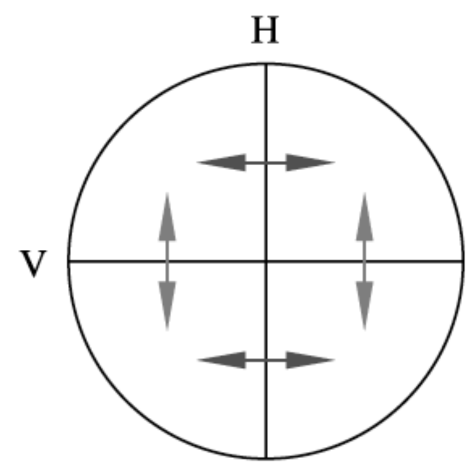


Compton Polarimeter





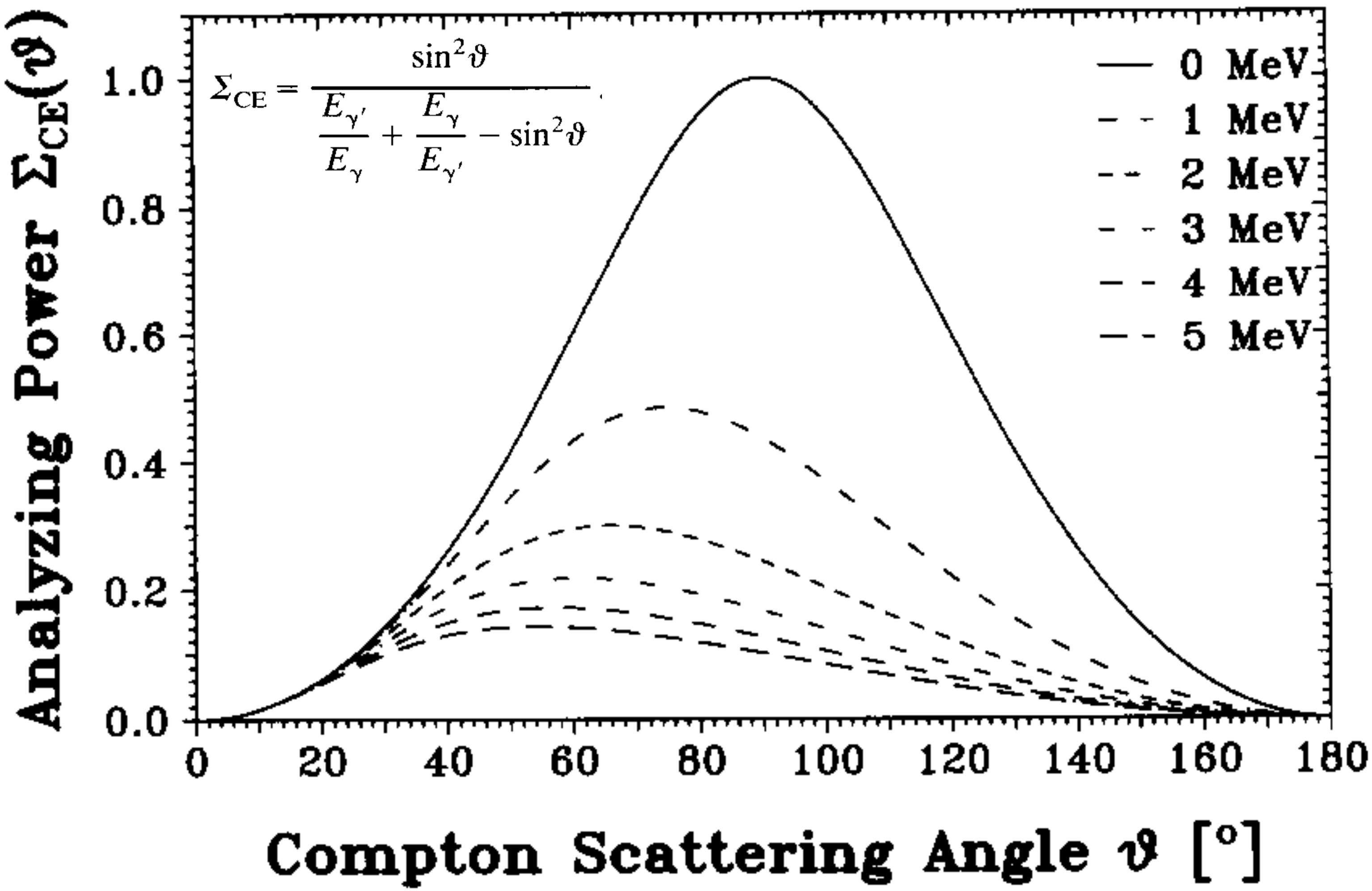




B. Schlitt, RDH, et al, NIMA337 (1994) 416-426

Analysing Power

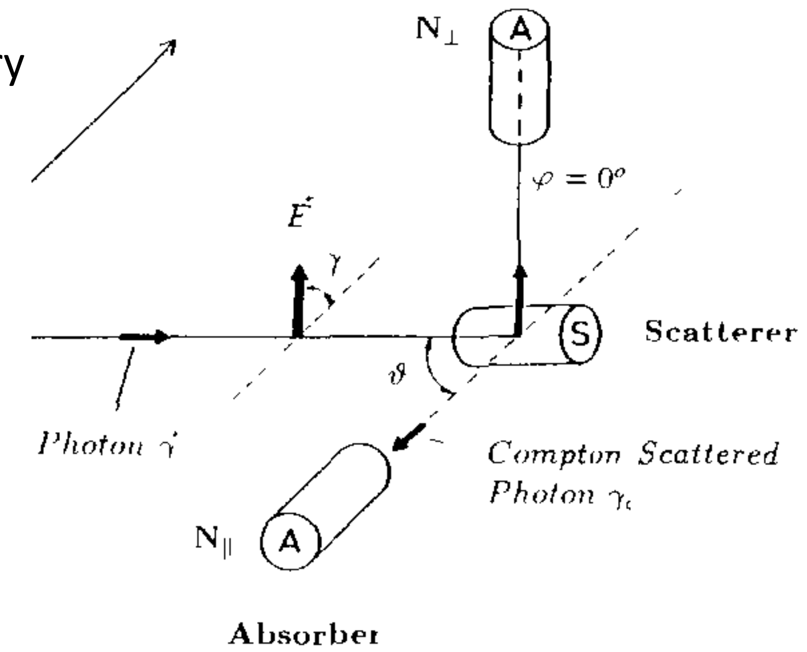
B. Schlitt, RDH, et al, NIMA337 (1994) 416-426



Analysing Power II

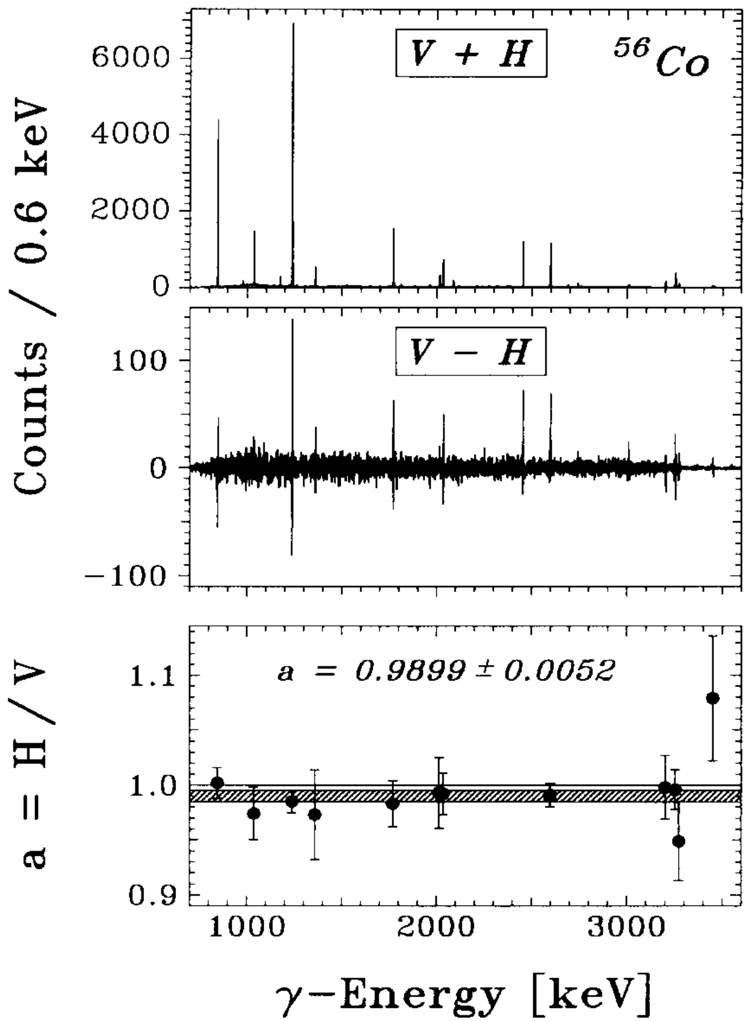
From Klein-Nishina and the observed asymmetry

$$\varepsilon = \frac{aN_\perp - N_\parallel}{aN_\perp + N_\parallel}$$



$$\Sigma_{\mathrm{CE}} = \frac{\dfrac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\vartheta, \varphi = 90^\circ) - \dfrac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\vartheta, \varphi = 0^\circ)}{\dfrac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\vartheta, \varphi = 90^\circ) + \dfrac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\vartheta, \varphi = 0^\circ)},$$

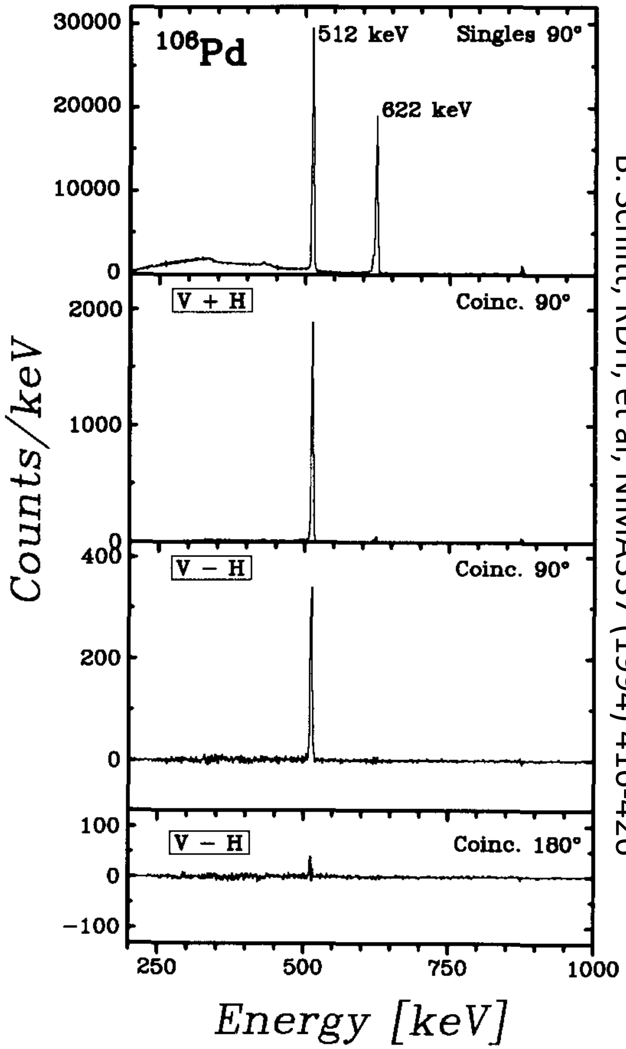
Apparative asymmetry



- ^{56}Co source gives unpolarised gamma rays, thus we can use it to extract the apparative asymmetry *a*

B. Schlitt, RDH, et al, NIMA337 (1994) 416-426

Sample Spectra

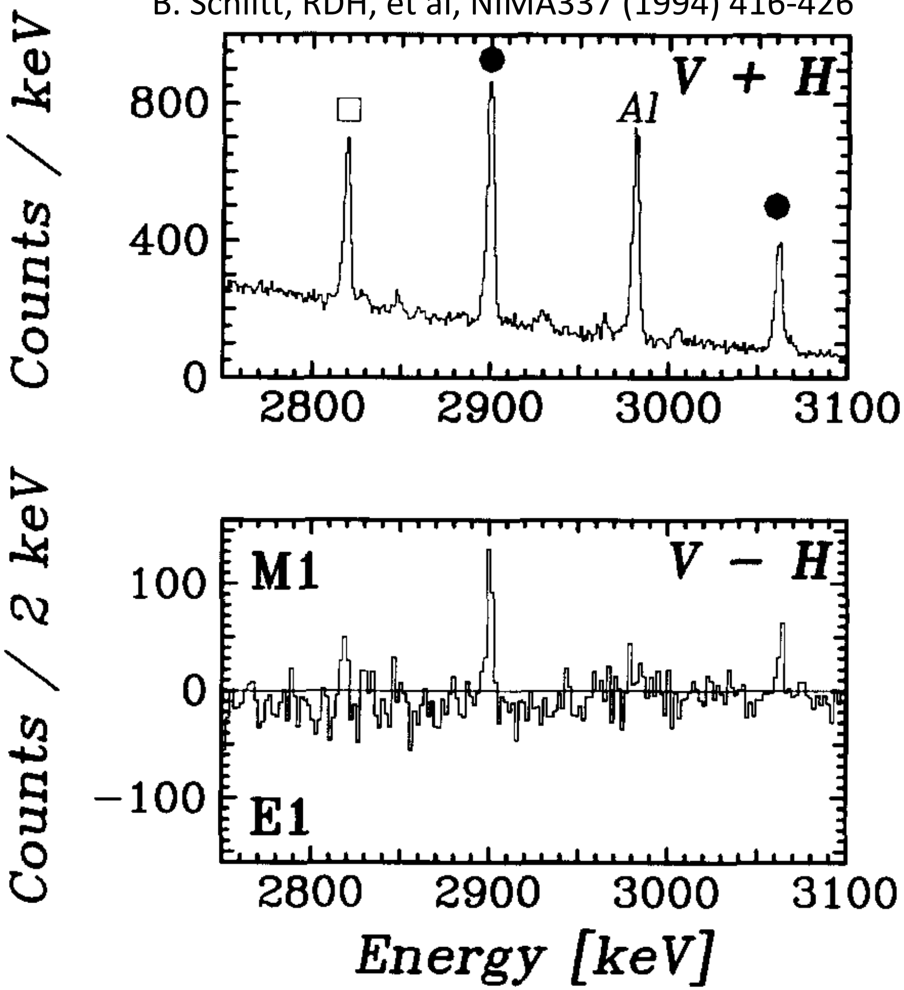


B. Schlitt, RDH, et al, NIMA337 (1994) 416-426

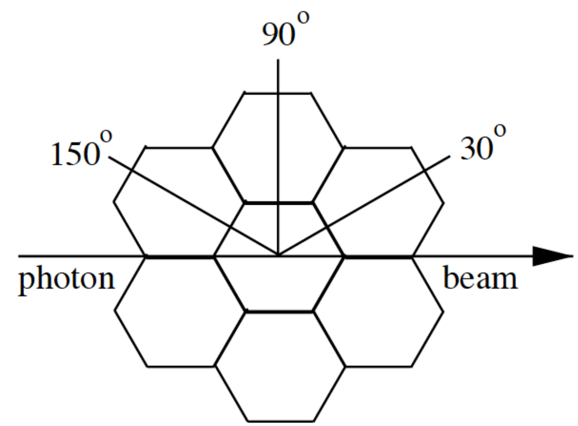
- Singles
- Sum
- Difference at 90°
- Difference at 180°

Application to ^{162}Dy

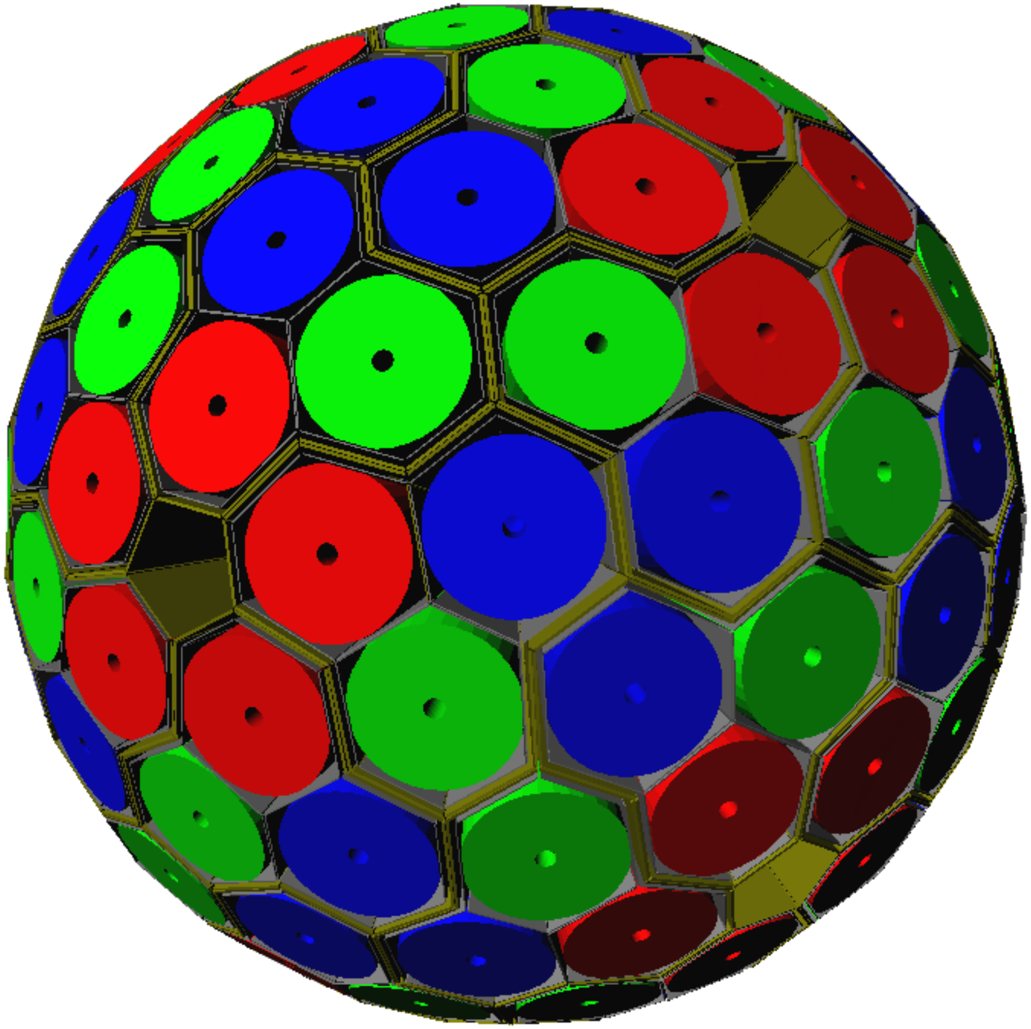
B. Schlitt, RDH, et al, NIMA337 (1994) 416-426



- The concept is easily extended to different geometries, e.g. Cluster detectors.

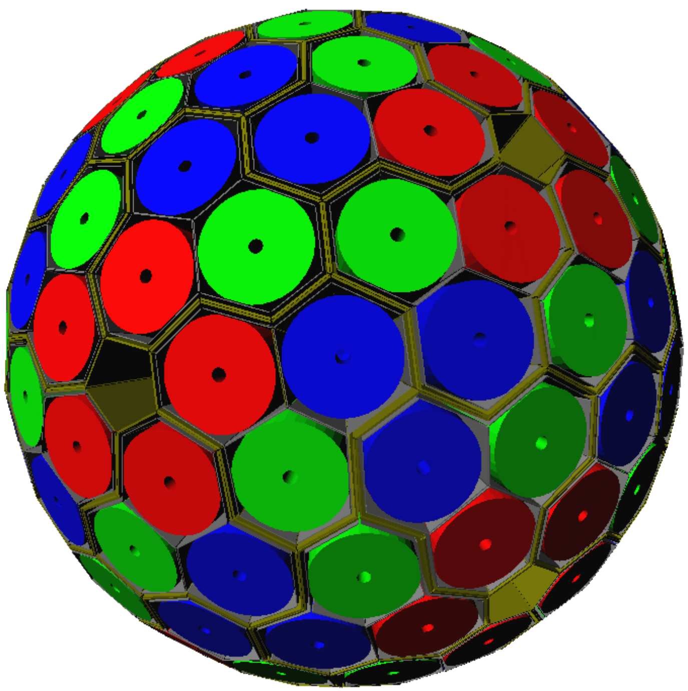


Gamma Ray Tracking



AGATA
(Advanced GAmma Tracking Array)

4π γ-array for Nuclear Physics Experiments at European accelerators providing radioactive and high-intensity stable beams



Main features of AGATA

Efficiency: 43% (M_γ=1) 28% (M_γ=30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

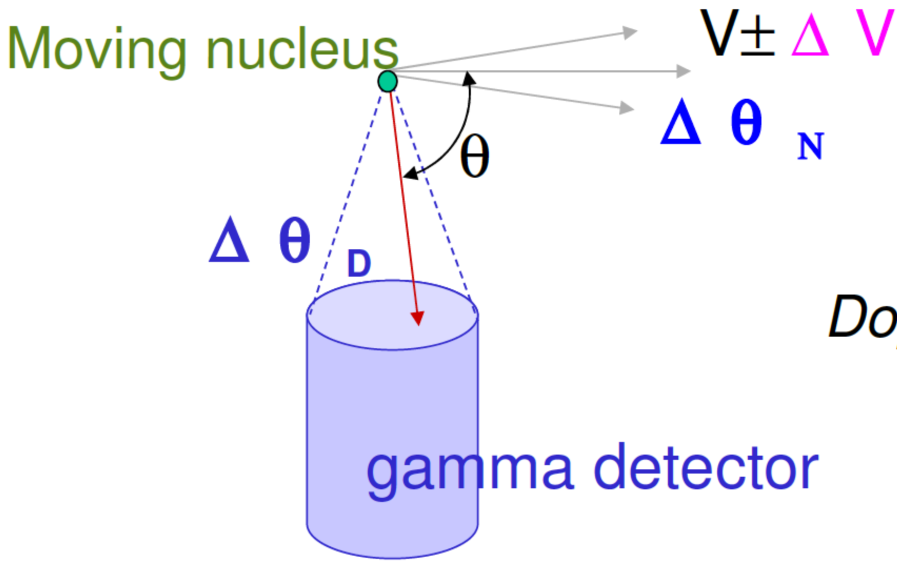
Peak/Total: 58% (M_γ=1) 49% (M_γ=30)
today ~55% 40%

Angular Resolution: ~1° →
FWHM (1 MeV, v/c=50%) ~ 6 keV !!!
today ~40 keV

Rates: 3 MHz (M_γ=1) 300 kHz (M_γ=30)
today 1 MHz 20 kHz

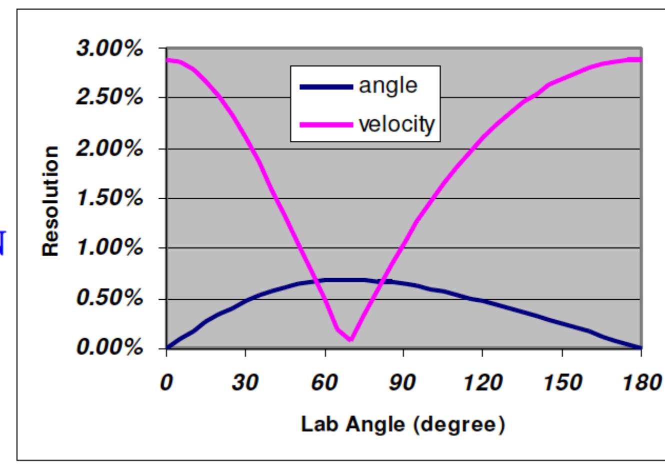
- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

Doppler Broadening



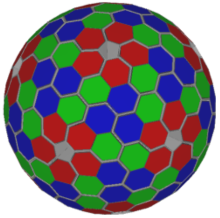
Doppler shift $$E_\gamma = E_\gamma^0 \frac{\sqrt{1-\frac{V^2}{c^2}}}{1-\frac{V}{c}\cos\theta}$$

Broadening of detected gamma energy from
- Spread in speed of recoil ΔV
- Distribution in the direction of recoil $\Delta\theta_N$
- Detector opening angle $\Delta\theta_D$

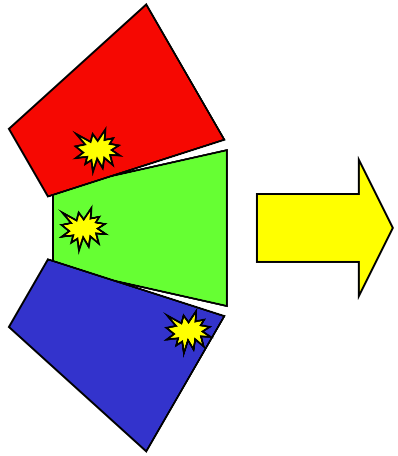


Taken from D. Radford

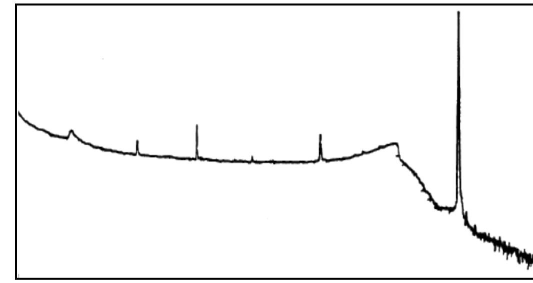
The Concept



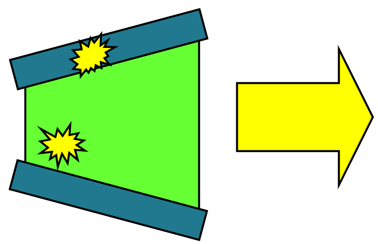
Without Compton suppression shields

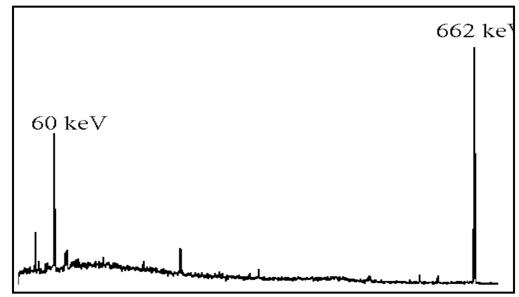


Compton continuum.
=> Large peak to total ratio



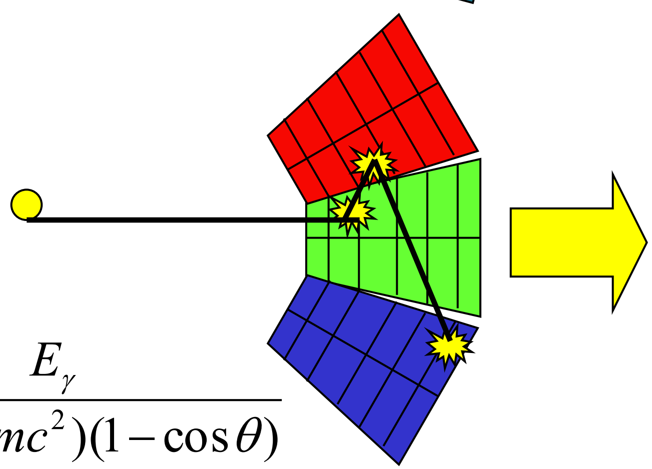
With BGO shielding





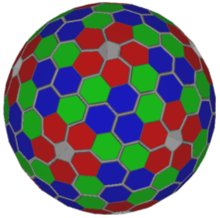
Less solid angle coverage
=> Big drop in efficiency

With highly segmented detectors



$$E_\gamma' = \frac{E_\gamma}{1+(E_\gamma/mc^2)(1-\cos\theta)}$$

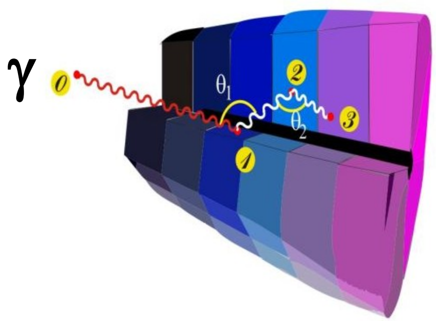
Path of γ-ray reconstructed to form full energy event
=> Compton continuum reduced
=> Excellent efficiency ~50% @1MeV
=> Greatly improved angular resolution (~1^0) to reduce Doppler effects



Ingredients of γ-Tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

3

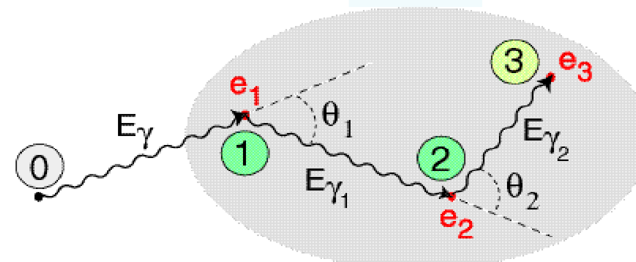
Pulse Shape Analysis to decompose recorded waves

Identified interaction

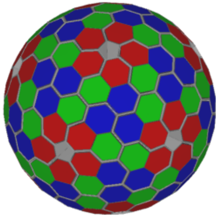
$(x,y,z,E,t)_i$

4

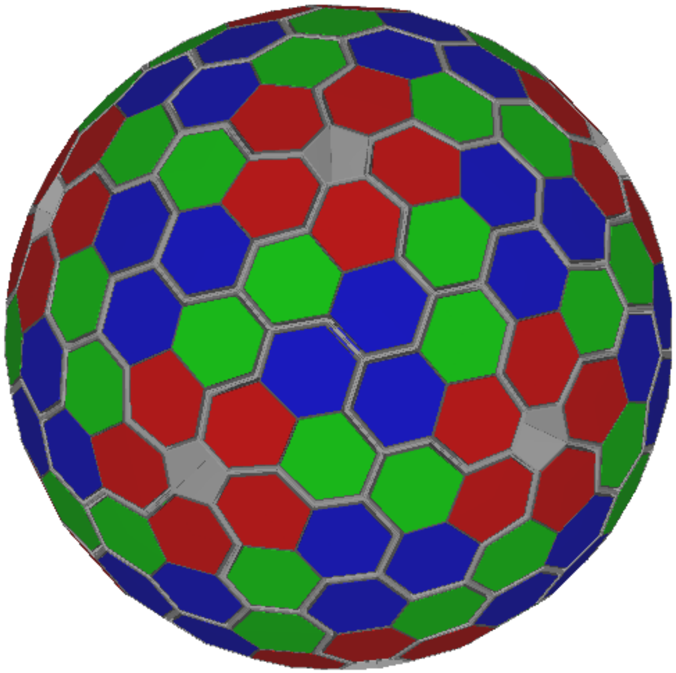
Reconstruction of tracks e.g. by evaluation of permutations of interaction points

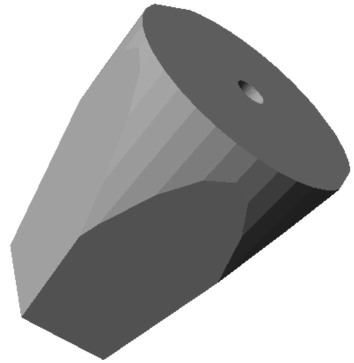


reconstructed γ-rays



AGATA





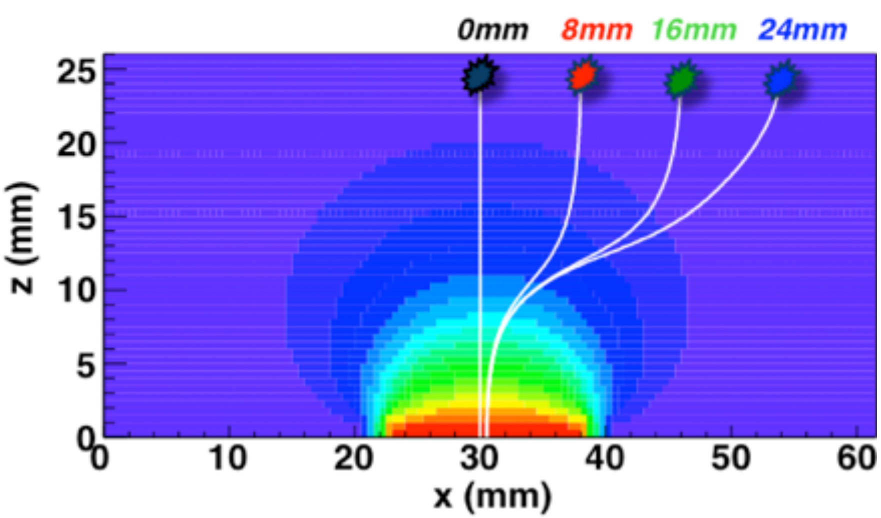
Ge crystals size:
length 90 mm
diameter 80 mm

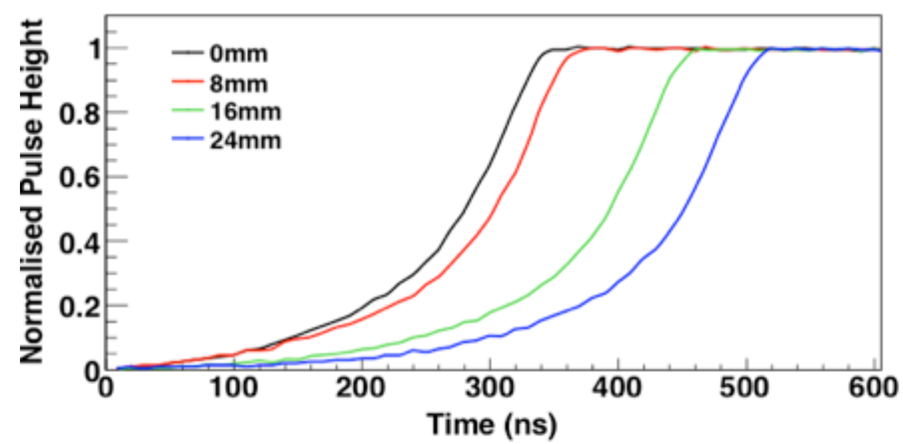
180 hexagonal crystals 3 shapes
60 triple-clusters all equal
Inner radius (Ge) 22 cm
Amount of germanium 310 kg
Solid angle coverage 80 %
Singles rate ~50 kHz
6480 segments

Efficiency: 40% (M_γ=1) 25% (M_γ=30)
Peak/Total: 65% (M_γ=1) 50% (M_γ=30)

Pulse Shape Analysis

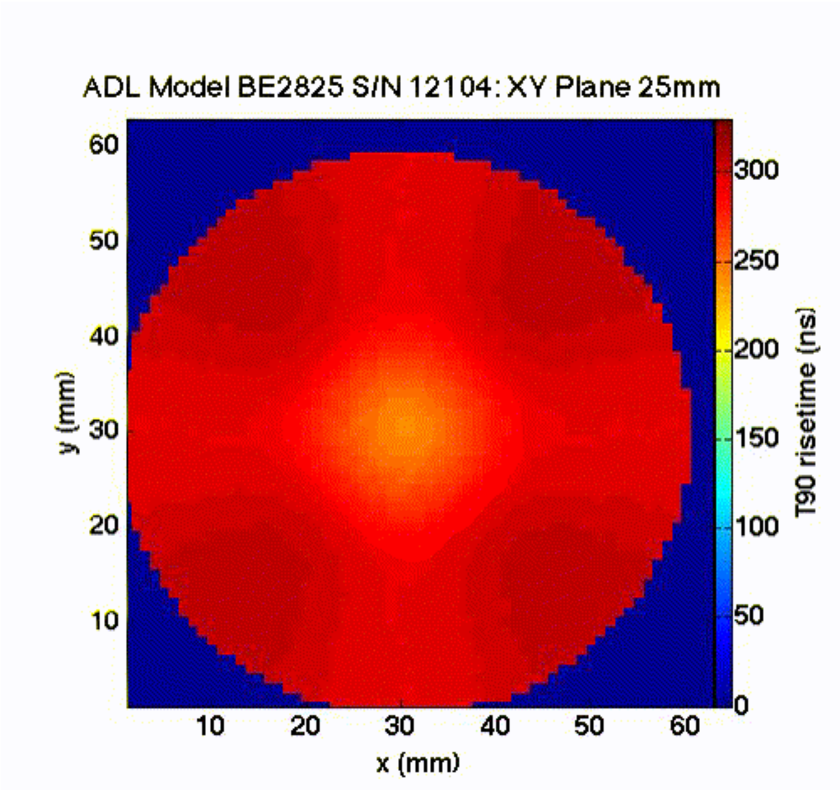
- Shape of the generated signal as a function of time is dependent on the position of the interaction within the depth of the detector, which charge carrier provides the pulse, and its mobility within the detector
- Therefore, information can be gained on interaction position

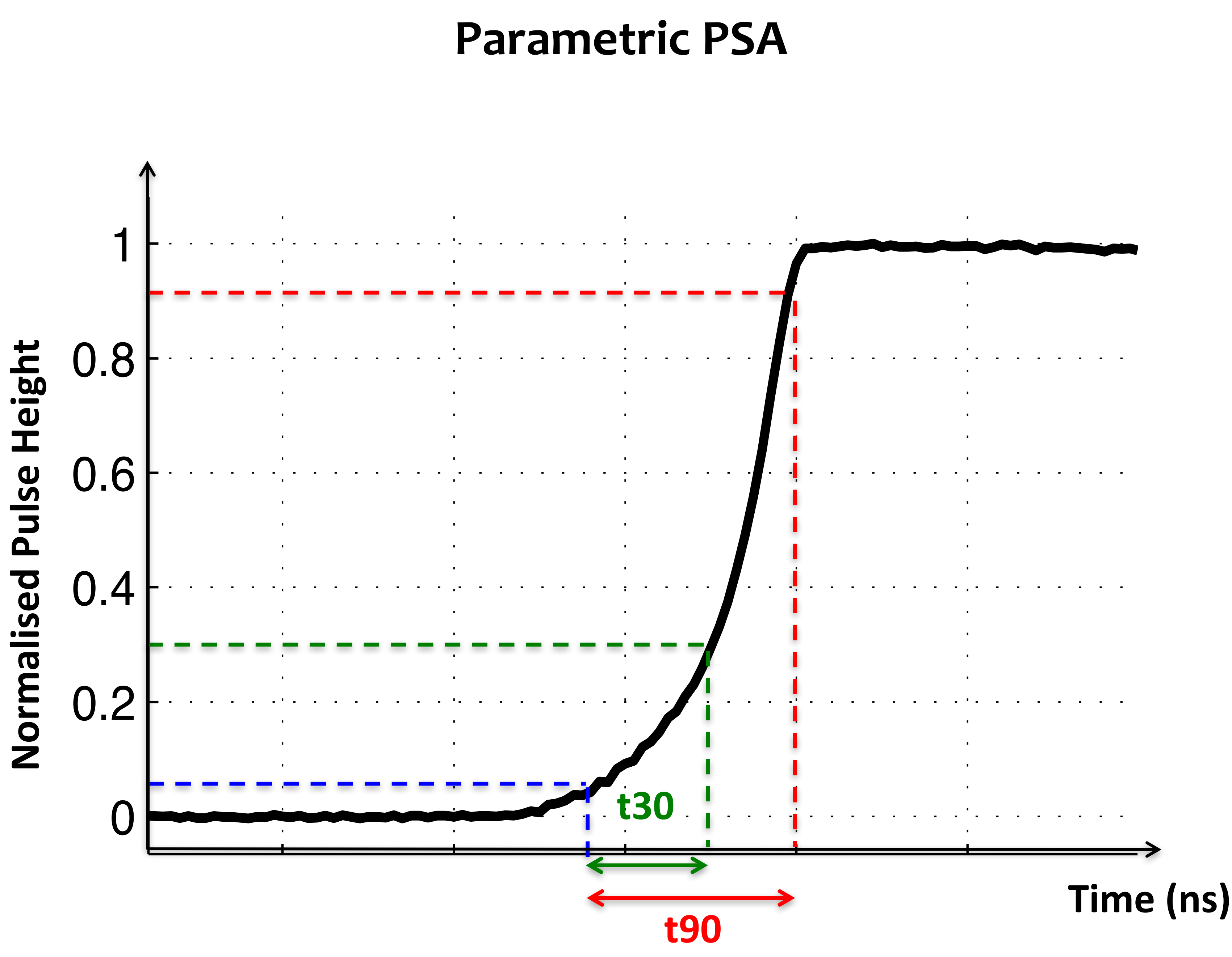




Parametric PSA

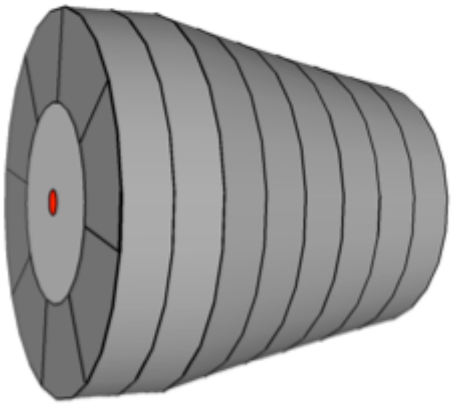
- Charge collection time for the “real charge” pulse varies according to the distance the charge carriers have to travel to the electrodes
- Rise time parameters, e.g. t30 and t90 can be used (e.g. t30=T30-T10 and t90=T90-T10)
- For planar detectors, with uniform electric field, gives information on the depth. For non-planar, can also give additional information, e.g. BEGe detectors give some radial information

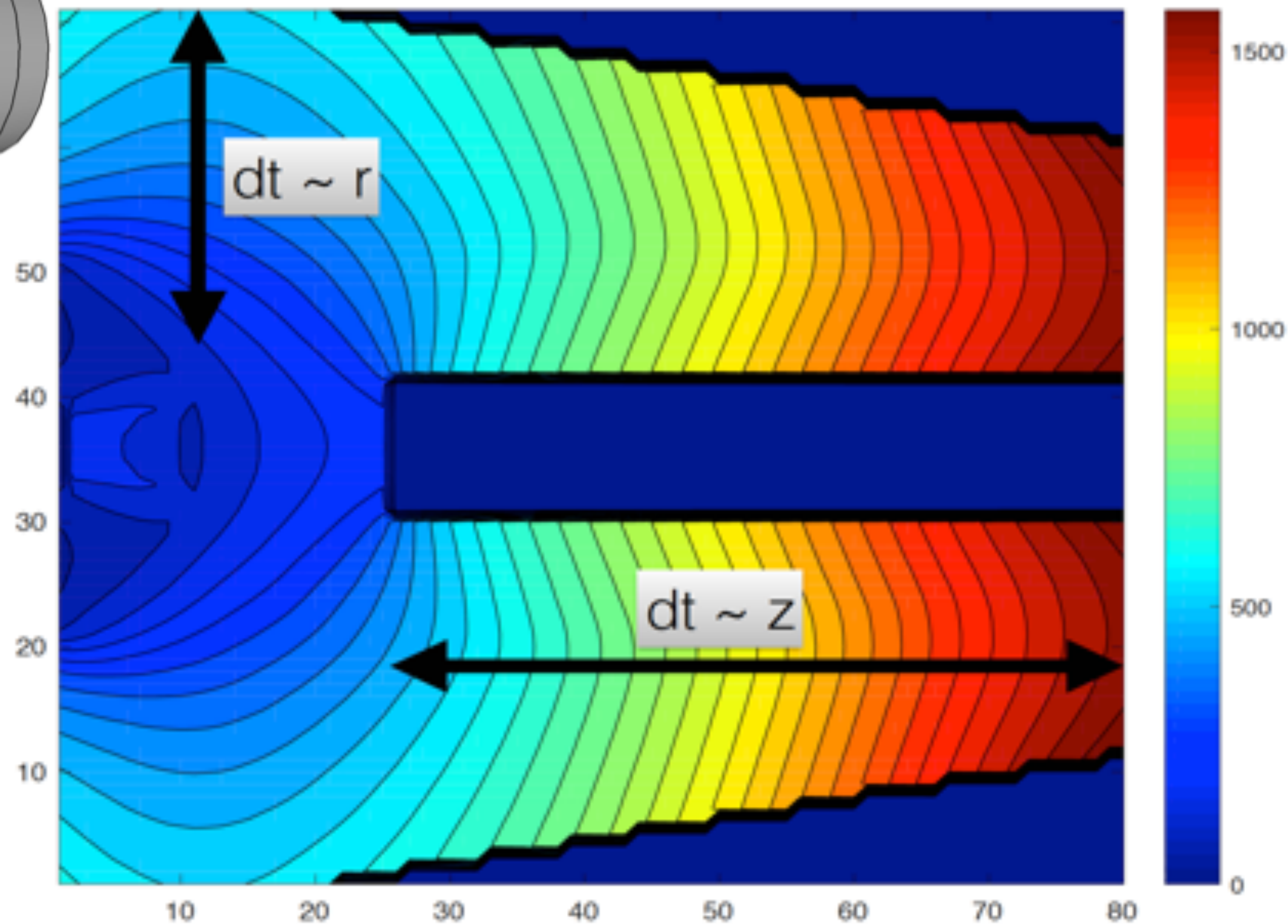


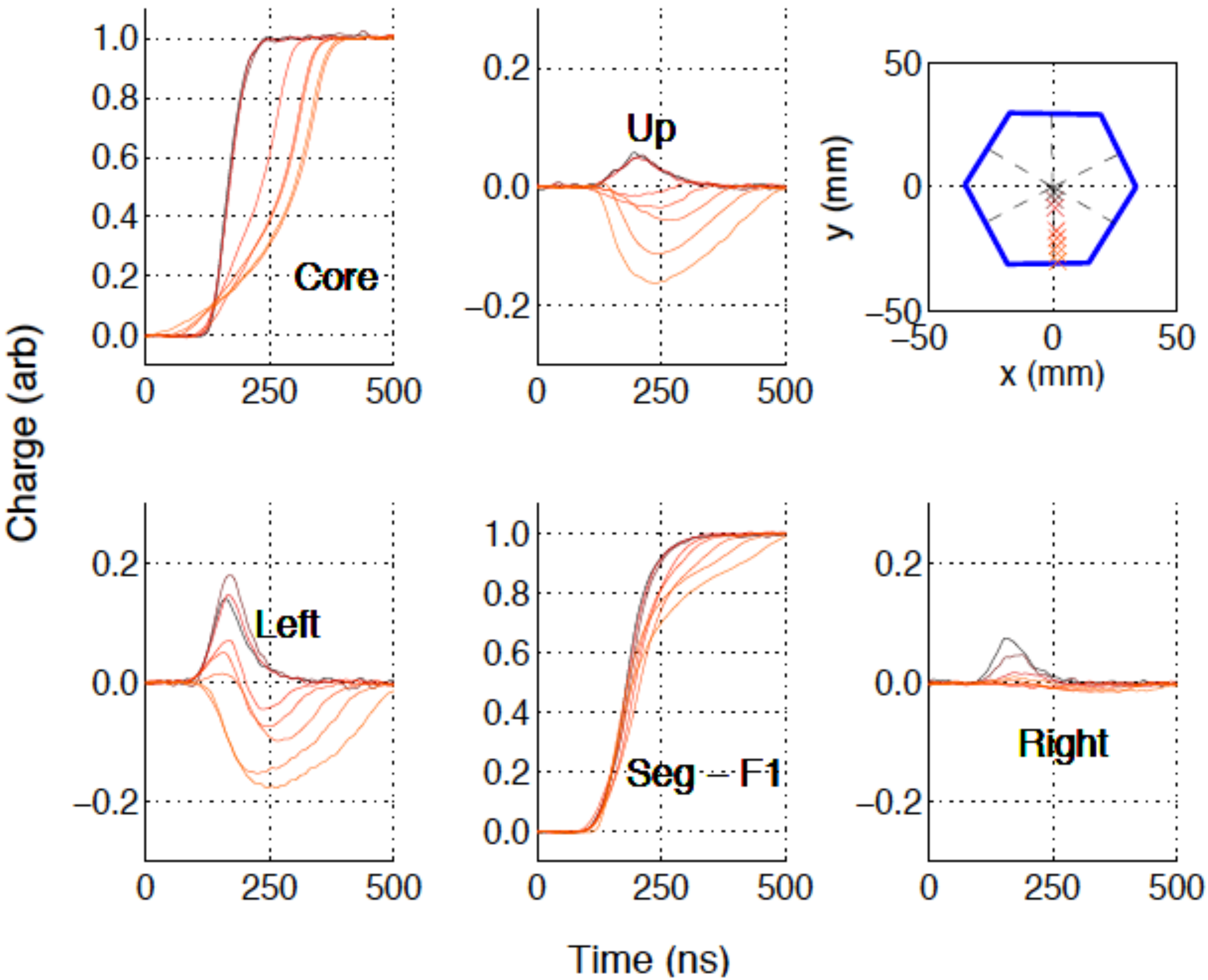


Parametric PSA
Normalised Pulse Height
1
0.8
0.6
0.4
0.2
0
t30
t90
Time (ns)

Parametric PSA





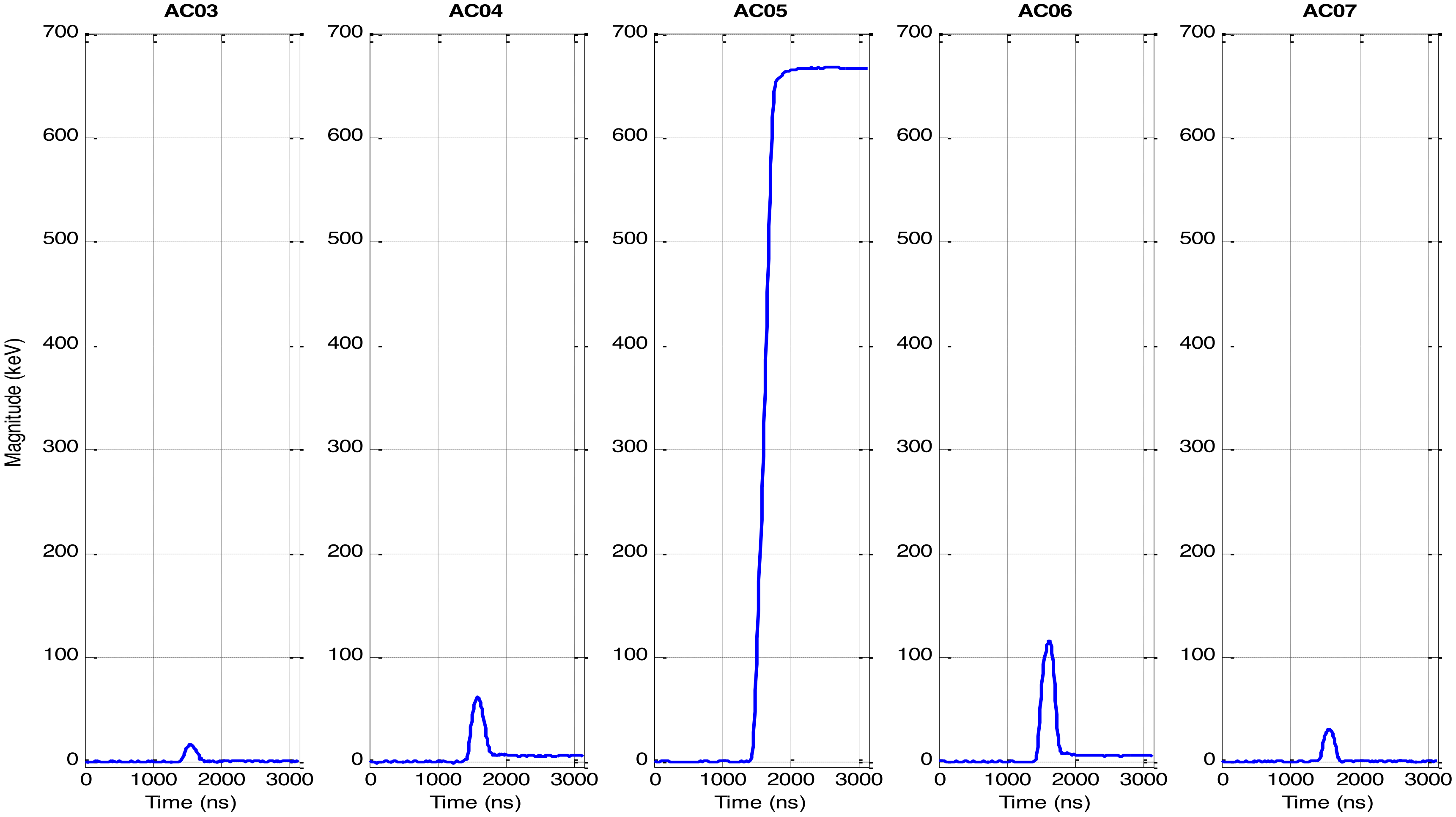


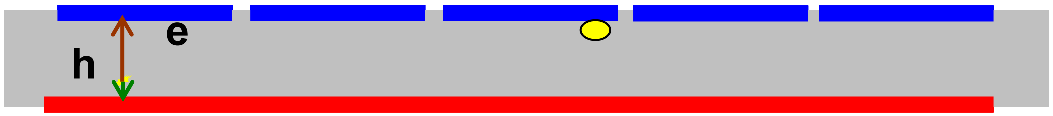
Charge (arb)
Core
Up
Left
Seg – F1
Right
y (mm)
x (mm)
Time (ns)
0
250
500
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
50
0
−50

Parametric PSA

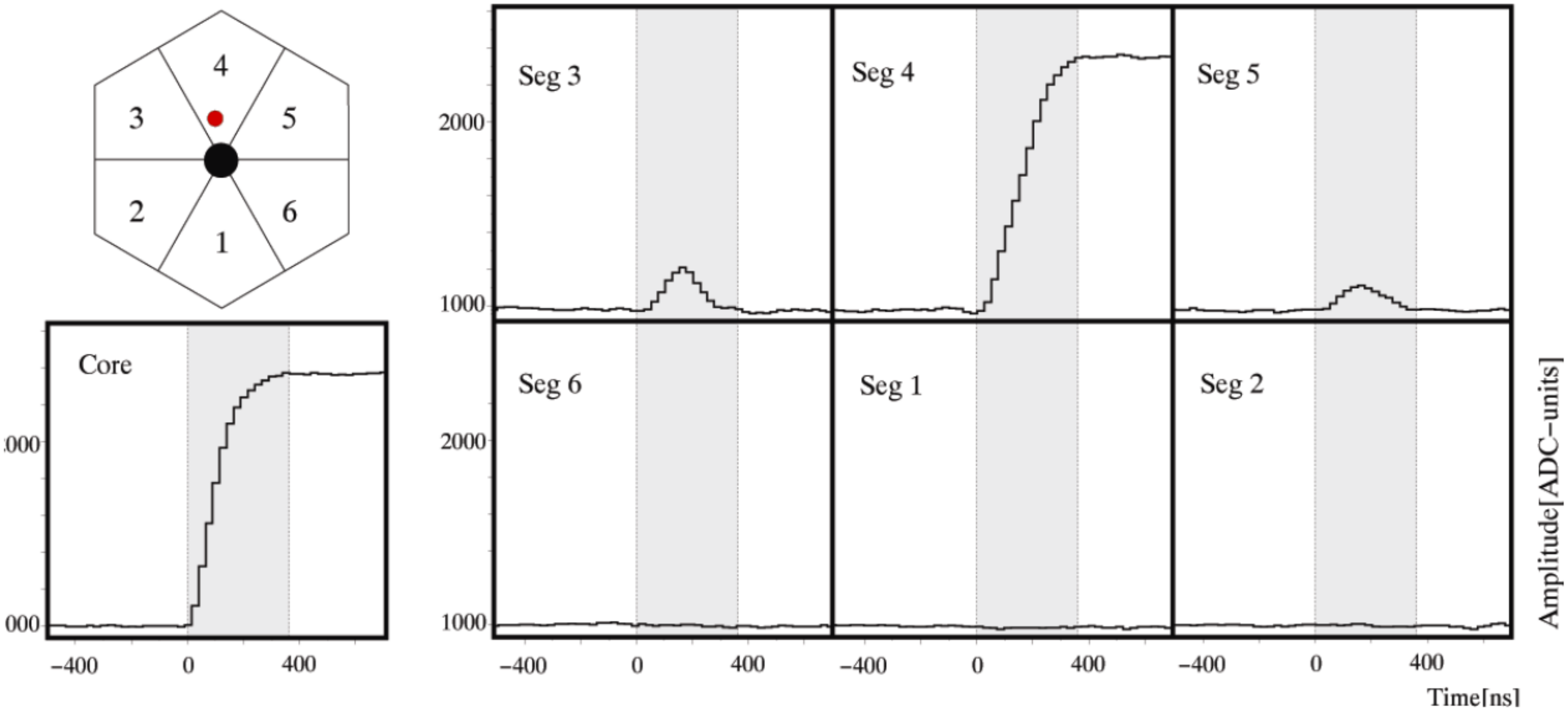
- Image charges are induced in the electrodes which neighbour the “sensing” electrode, due to the movement of the charge carriers
- The net image charge signal is zero because the sum of the image charges is equal and opposite in opposite electrodes
- The magnitude of the image charges in the strips (segments) either side of the sensing electrode depends on the position of interaction within the sensing electrode
- If the interaction occurs closer to one neighbouring strip than the other, the relative image charge size is larger
- In PSA, image charge size is calculated and compared, for (x-y) info

Parametric PSA



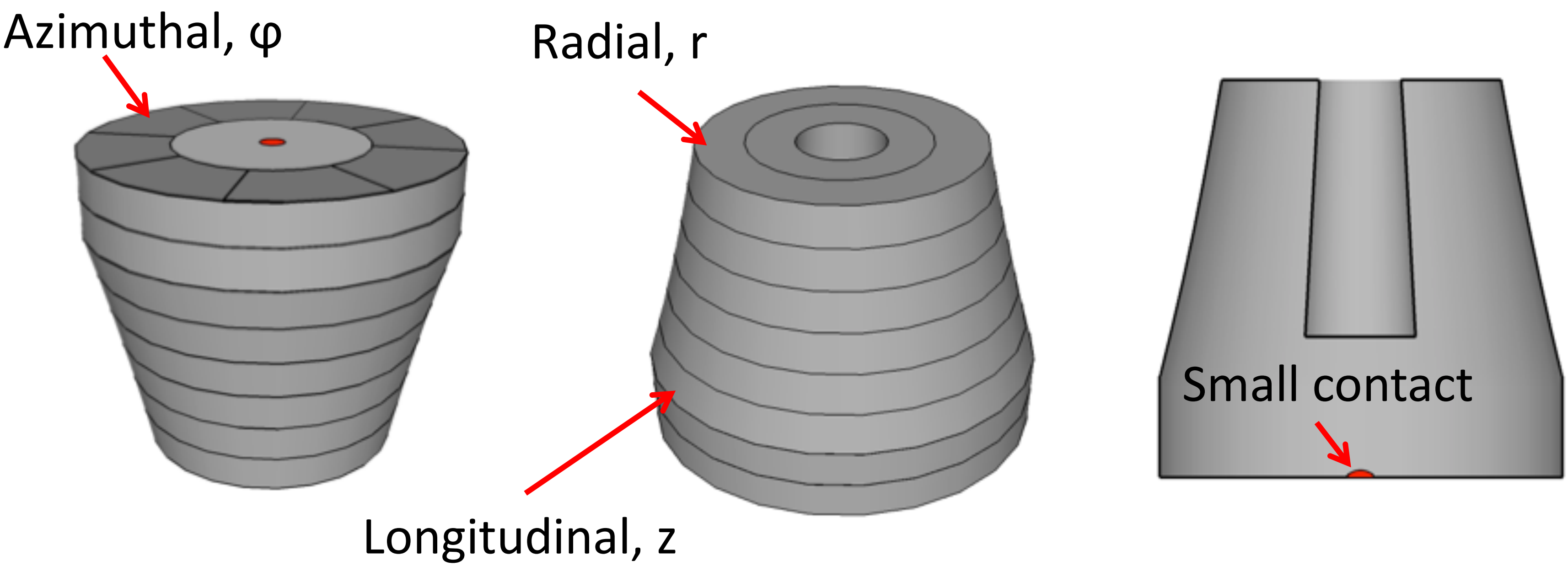


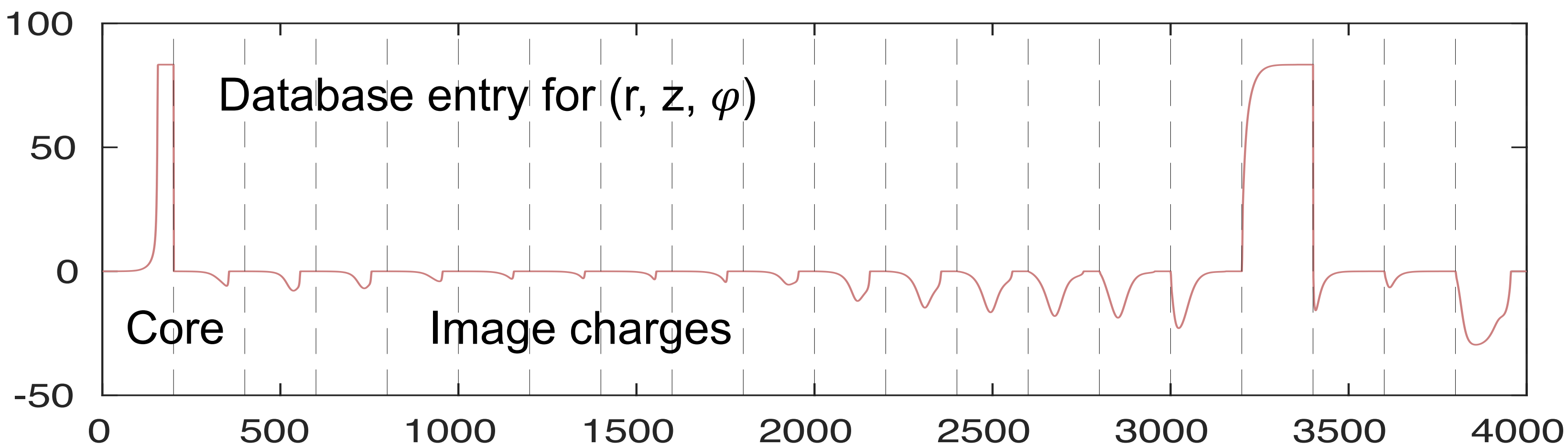
AGATA



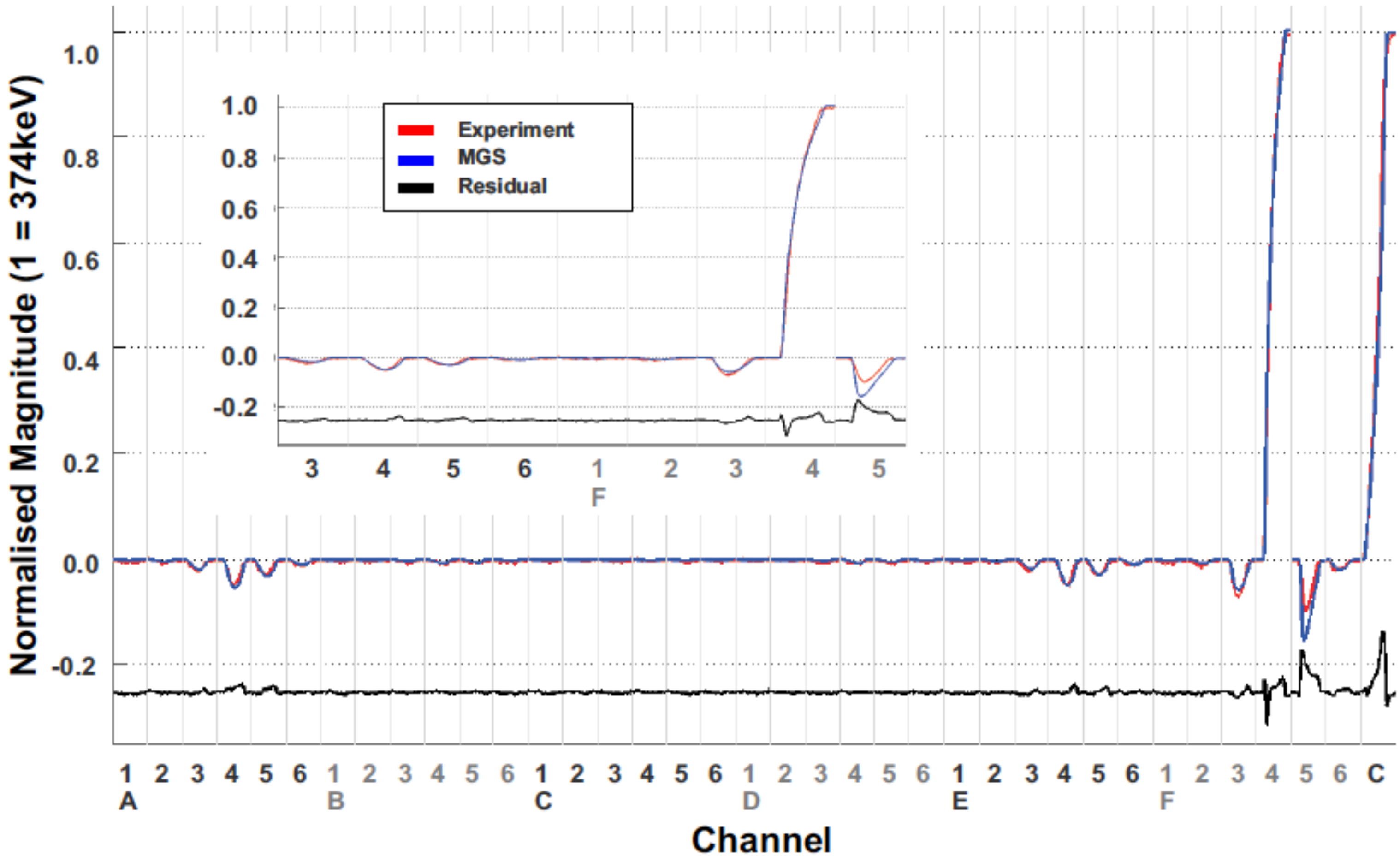
J. Gerl and W. Korten (editors), Technical Proposal for an Advanced Gamma Tracking Array for the European Gamma Spectroscopy Community (2001).

Parametric PSA





AGATA Database



Zone 3, x = 18.1±0.9mm, y = -29.4±0.9mm, z = 48.8±0.3mm.

From M. Dimmock, PhD Liverpool, 2008

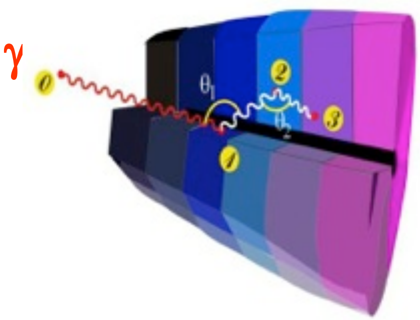
Database PSA

- Generation of a database containing signals for variation interaction positions within detector
- Signals generated through experimental measurements or models
- Experimental generation is lengthy and results are unique per detector
- Vary according to detector geometry, crystallographic axis, impurity concentration
- Algorithms used to match observed signals in-situ with those from database

Gamma-ray Tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process signals

3

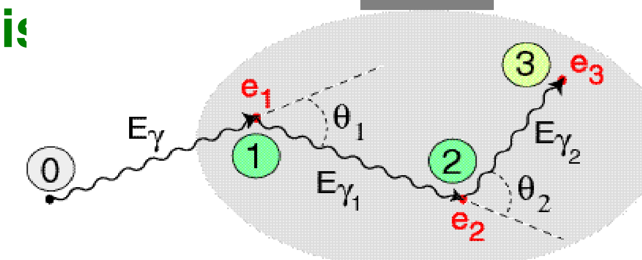
Pulse Shape Analysis to decompose recorded waves

Identified interaction points

$(x,y,z,E,t)_i$

4

Evaluation of permutations of interaction points



Reconstructed γ-rays

220 MeV ^{56}Fe → ^{197}Au

ATC1 + DANTE