# Outline: Characterization of segmented Ge detectors

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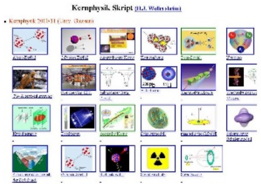
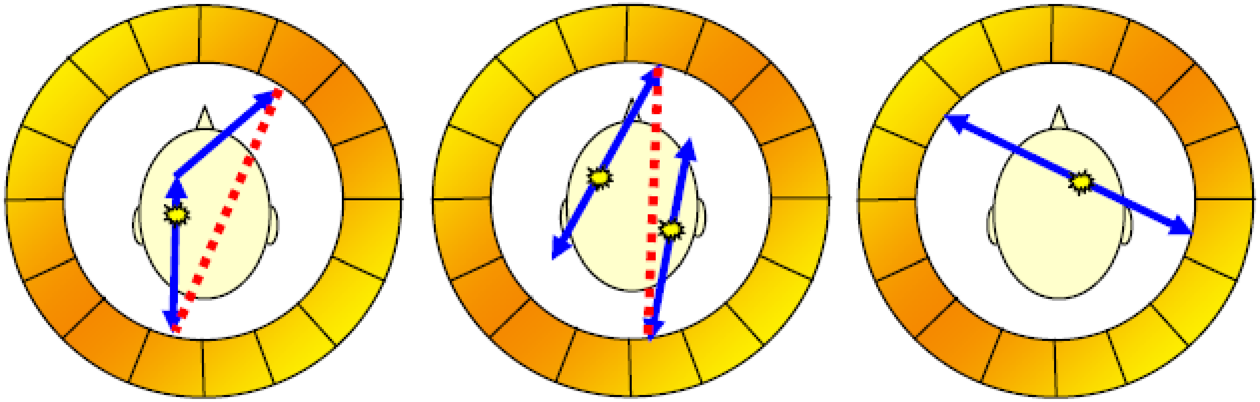
web-page: https://web-docs.gsi.de/~wolle/ and click on



1. γ-ray camera
2. moving γ-ray source and Ge detector
3. scanner at GSI for segmented detectors

# The motivation behind the project



Scattered Coincidence

Random Coincidence

True Coincidence

- Existing technology relies on BGO scintillator technology

  - Limited position resolution
  - High patient dose requirement.
  - Poor energy resolution only accept photopeak events.
  - Will not function in large magnetic field

- SPECT applications utilizing Compton Camera techniques.

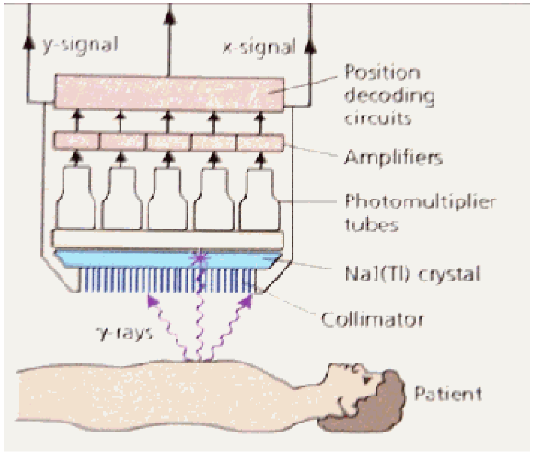
# Which γ-ray camera to be used?

***Requirements:***

- Excellent resolution Δx = 2 mm
- Large field of view (**FOV**) = 8x9 cm$^2$

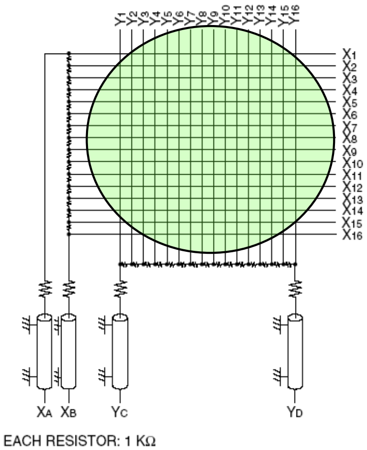
- Large FOV of ~20 cm diam.
- Low spatial resolution 0.5-1 cm

www.siemens.de

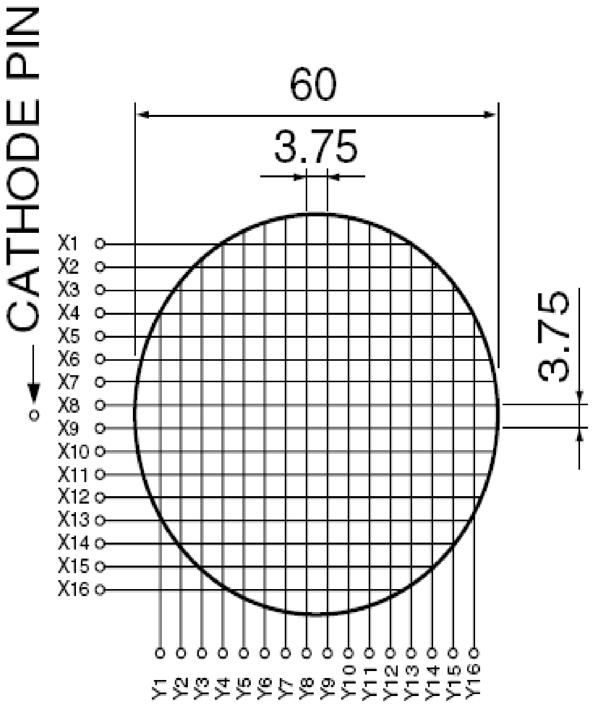



- Small FOV of 3-4 cm diam.
- High spatial resolution 2-3 mm

Gem-imaging.com



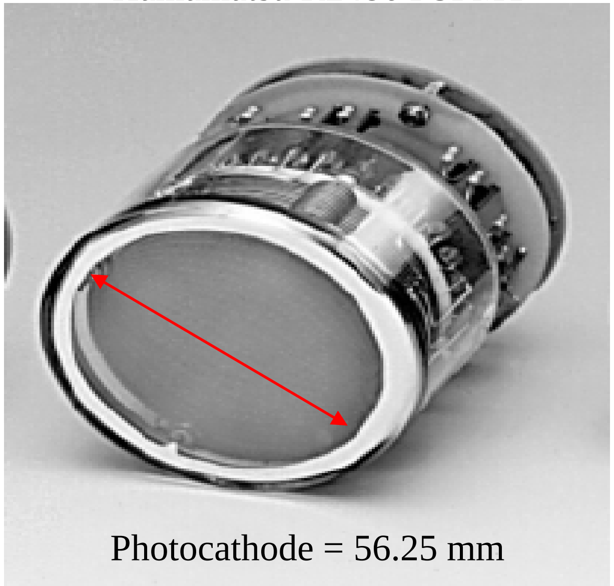

**16 wires in X axis and 16 wires in Y axis**




ANODE PATTERN
(TOP VIEW)

C.Domingo Pardo, N. Goel, et.al., IEEE, Vol.28, Dec. 2009

Hamamatsu R2486 PSPMT




LYSO
scintillator

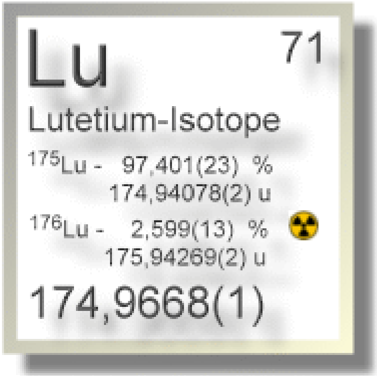
$Lu_{2(1-x)}Y_{2x}SiO_5$

d = 76 mm
t = 3 mm
$\rho = 7.4\ g/cm^3$

Lutetium–yttrium
oxyorthosilicate

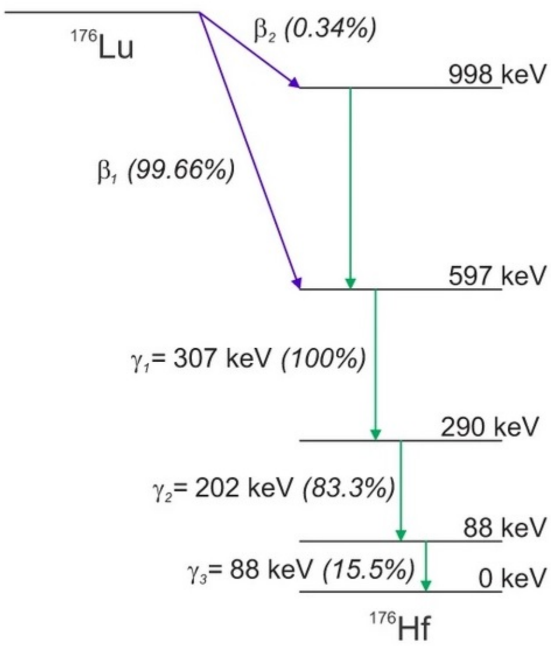
# Intrinsic activity of LYSO

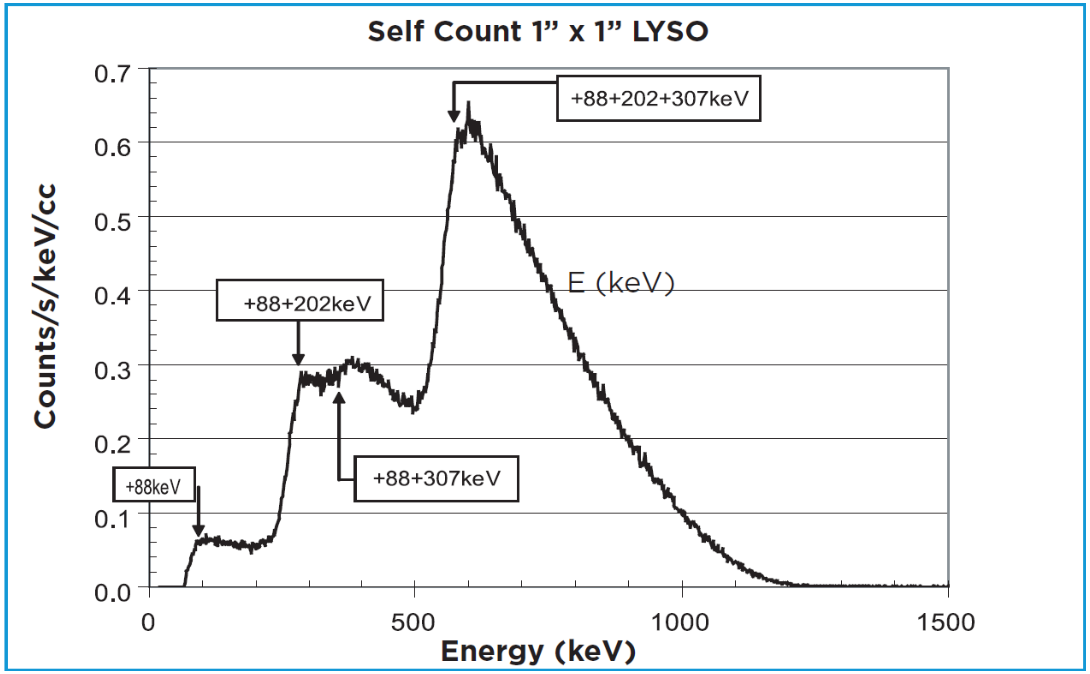
LYSO: $Lu_{1.8}Y_{0.2}SiO_5$:Ce




scintillating properties:

high density (7.1 g/cm³)
fast decay time (40 ns)
very high light output (~ 27600 ph/MeV)

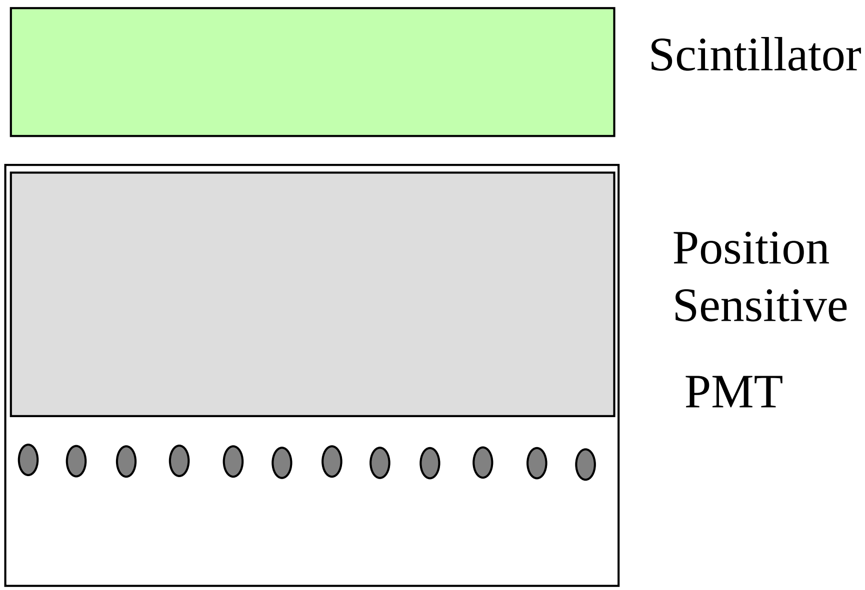


# Which γ-ray camera to be used?

***Requirements:***

- Excellent resolution $\Delta x$ = 2 mm
- Large field of view (FOV) = 8x9 $cm^2$

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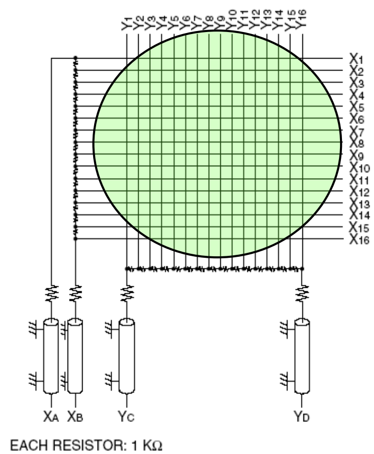


Gem-imaging.com

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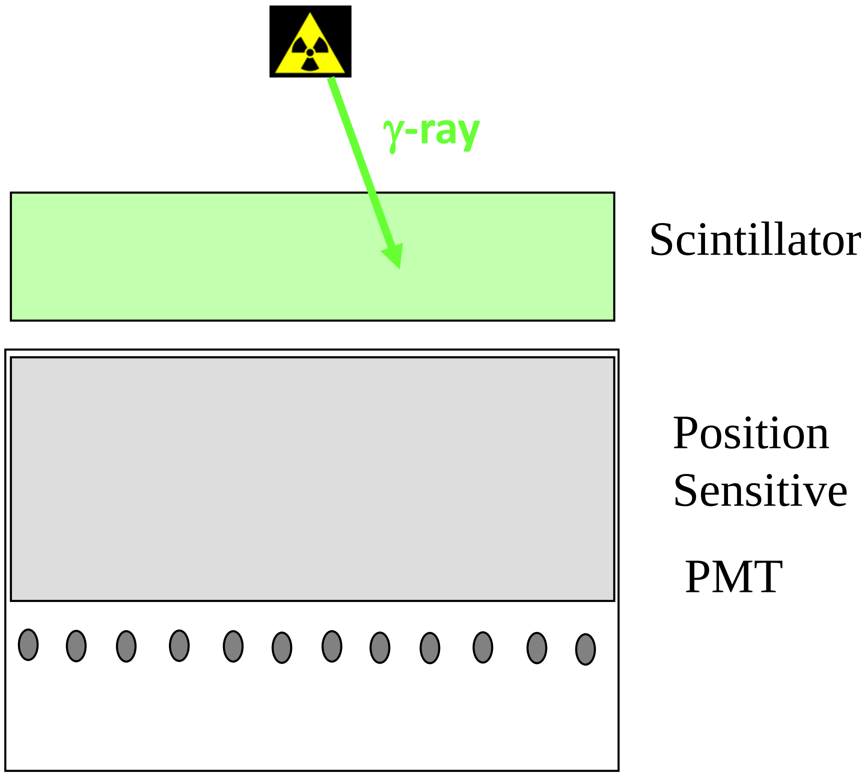


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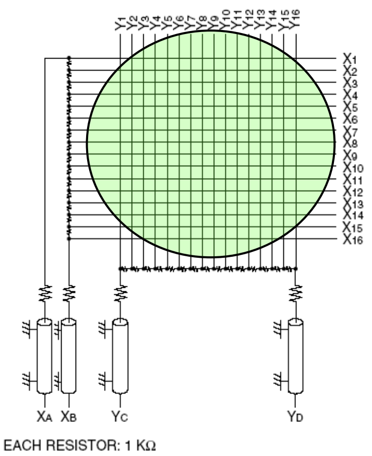


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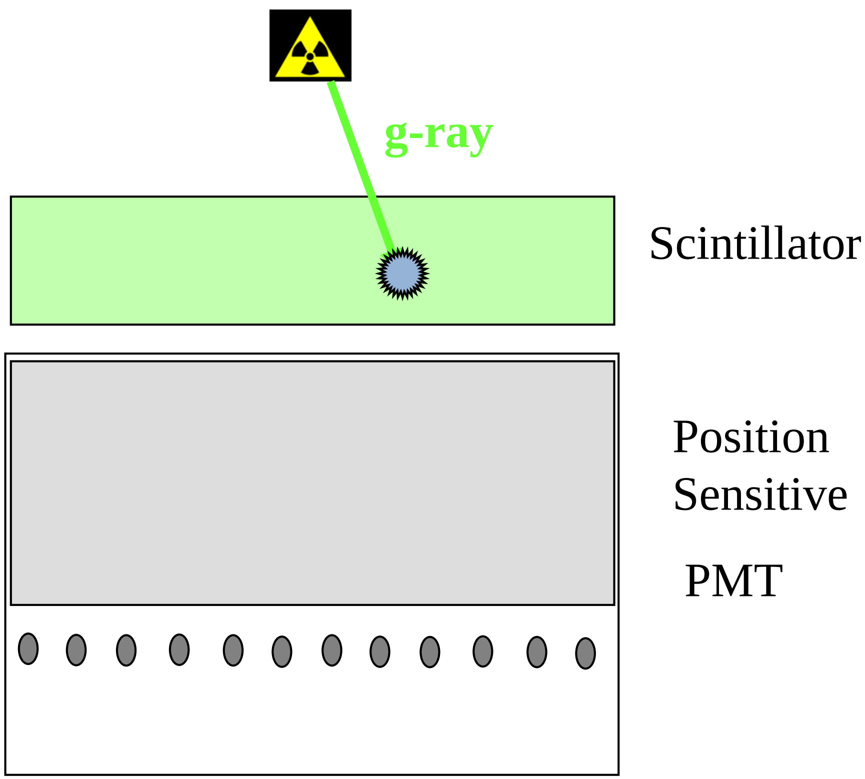


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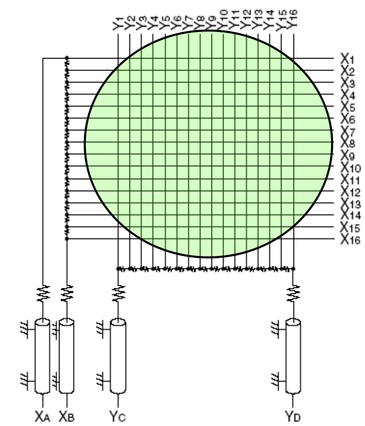


Gem-imaging.com

# Which γ-ray camera to be used?

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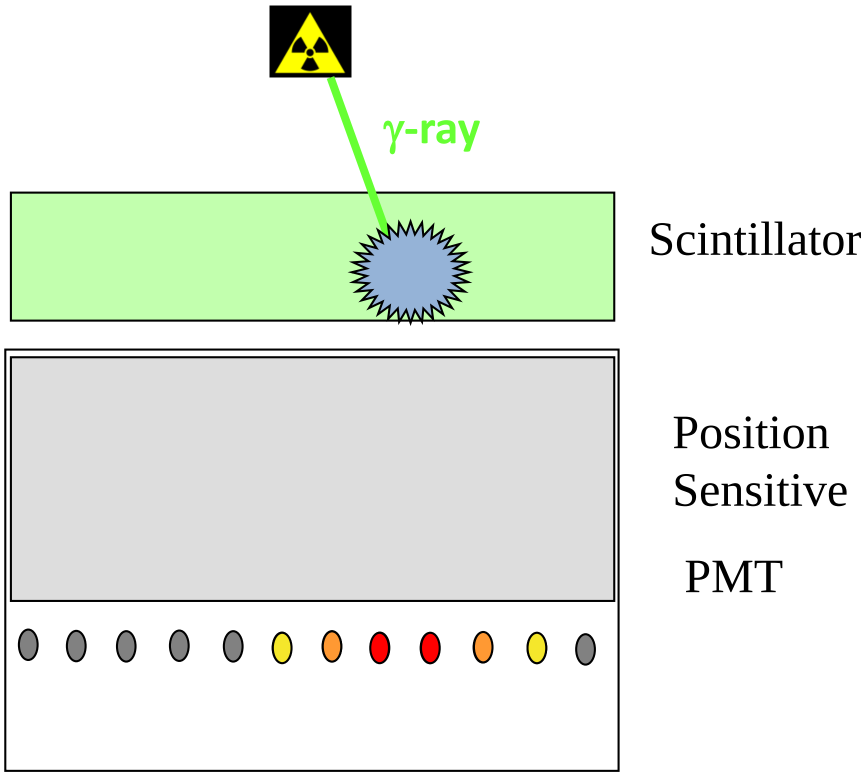


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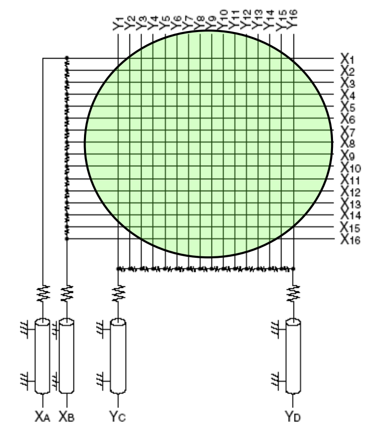


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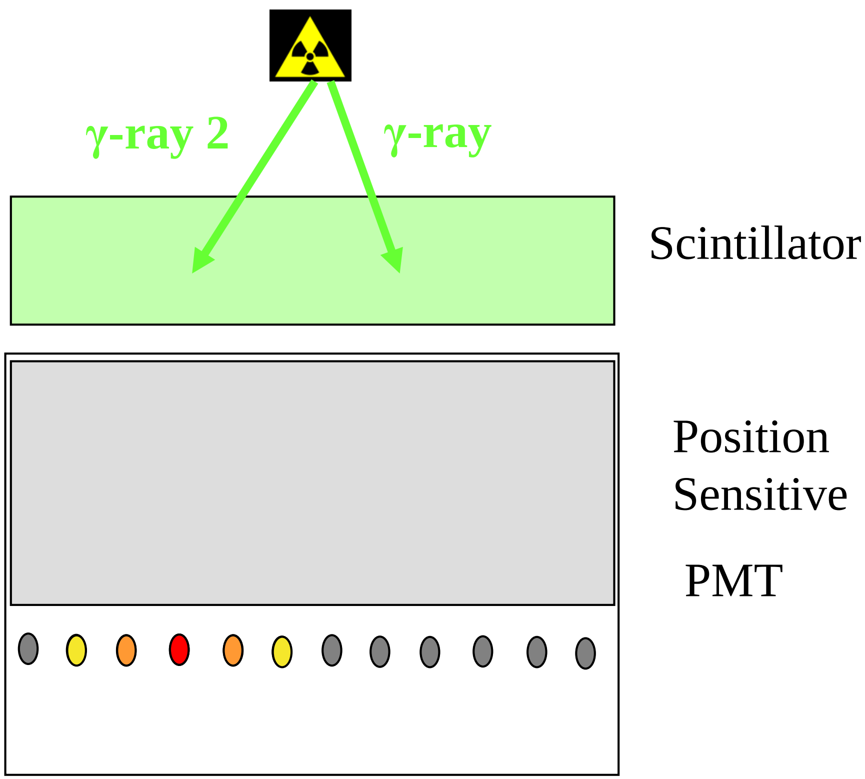


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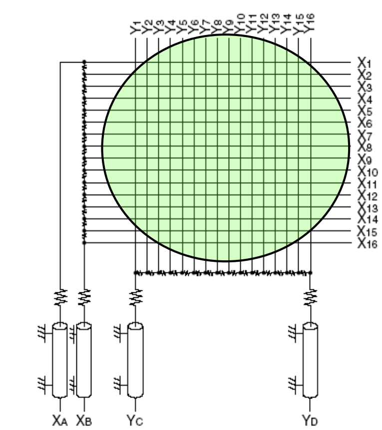


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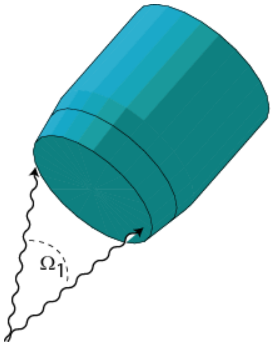
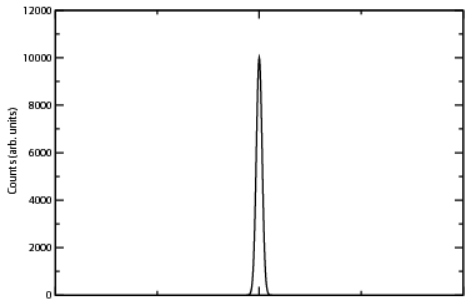
# Efficiency versus resolution

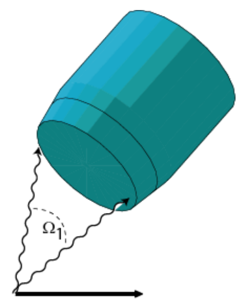


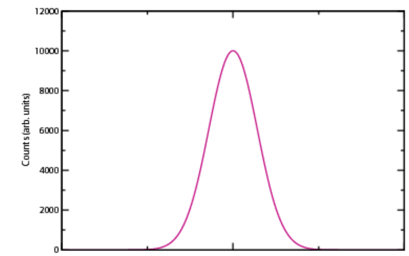




With a source at rest, the intrinsic resolution of the detector can be reached;

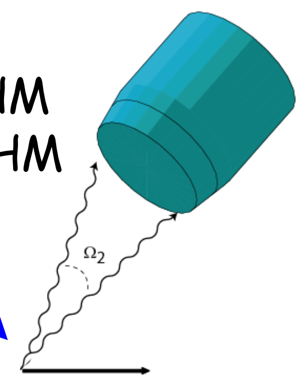
efficiency decreases with the increasing detector-source distance.

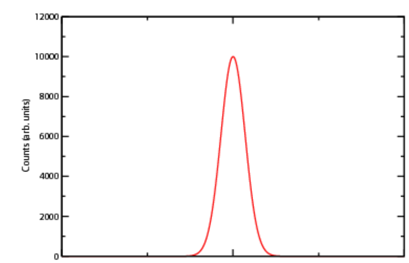
With a moving source also the effective energy resolution depends on the detector-source distance (Doppler effect)




| | | | | | | |
|---|---|---|---|---|---|---|
| Small *d* | ⟺ | Large Ω | ⟺ | High ε | ⟺ | Poor FWHM |
| Large *d* | | Small Ω | | Low ε | | Good FWHM |



# Doppler broadening and position resolution

REMINDER

$$E_{\gamma 0} = E_\gamma \frac{1-\beta\cdot\cos\vartheta_\gamma}{\sqrt{1-\beta^2}} \qquad \left(\beta, \vartheta_p = 0^0, \vartheta_\gamma \text{ and } E_\gamma \text{ in lab} - \text{frame}\right)$$

$$\left(\frac{\Delta E_{\gamma 0}}{E_{\gamma 0}}\right)^2 = \left(\frac{\beta\cdot\sin\vartheta_\gamma}{1-\beta\cdot\cos\vartheta_\gamma}\right)^2 (\Delta\vartheta_\gamma)^2 + \left(\frac{\beta-\cos\vartheta_\gamma}{(1-\beta^2)\cdot(1-\beta\cdot\cos\vartheta_\gamma)}\right)^2 (\Delta\beta)^2 + \left(\frac{1}{E_\gamma}\right)^2 (\Delta E_\gamma)^2$$

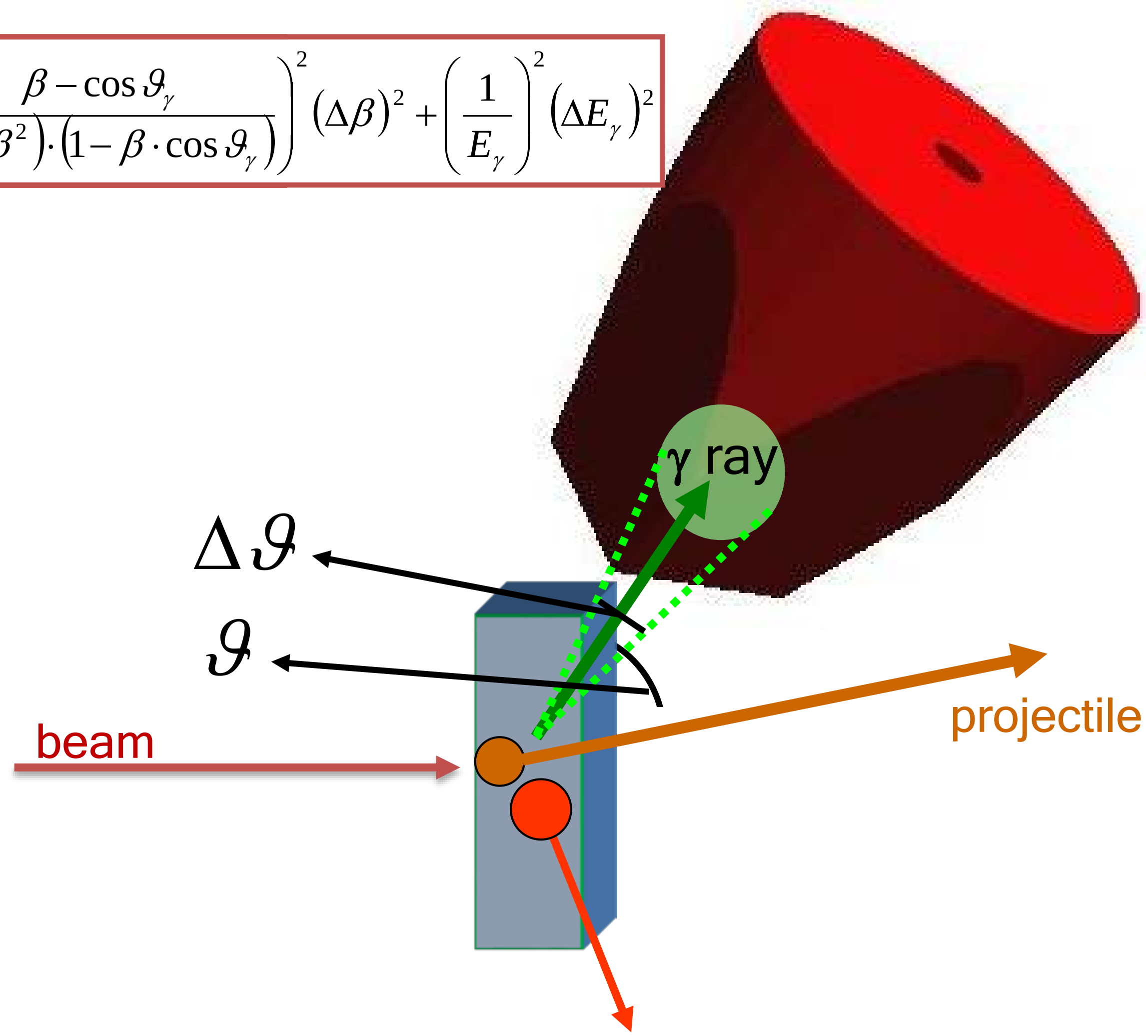
Position resolution

↓

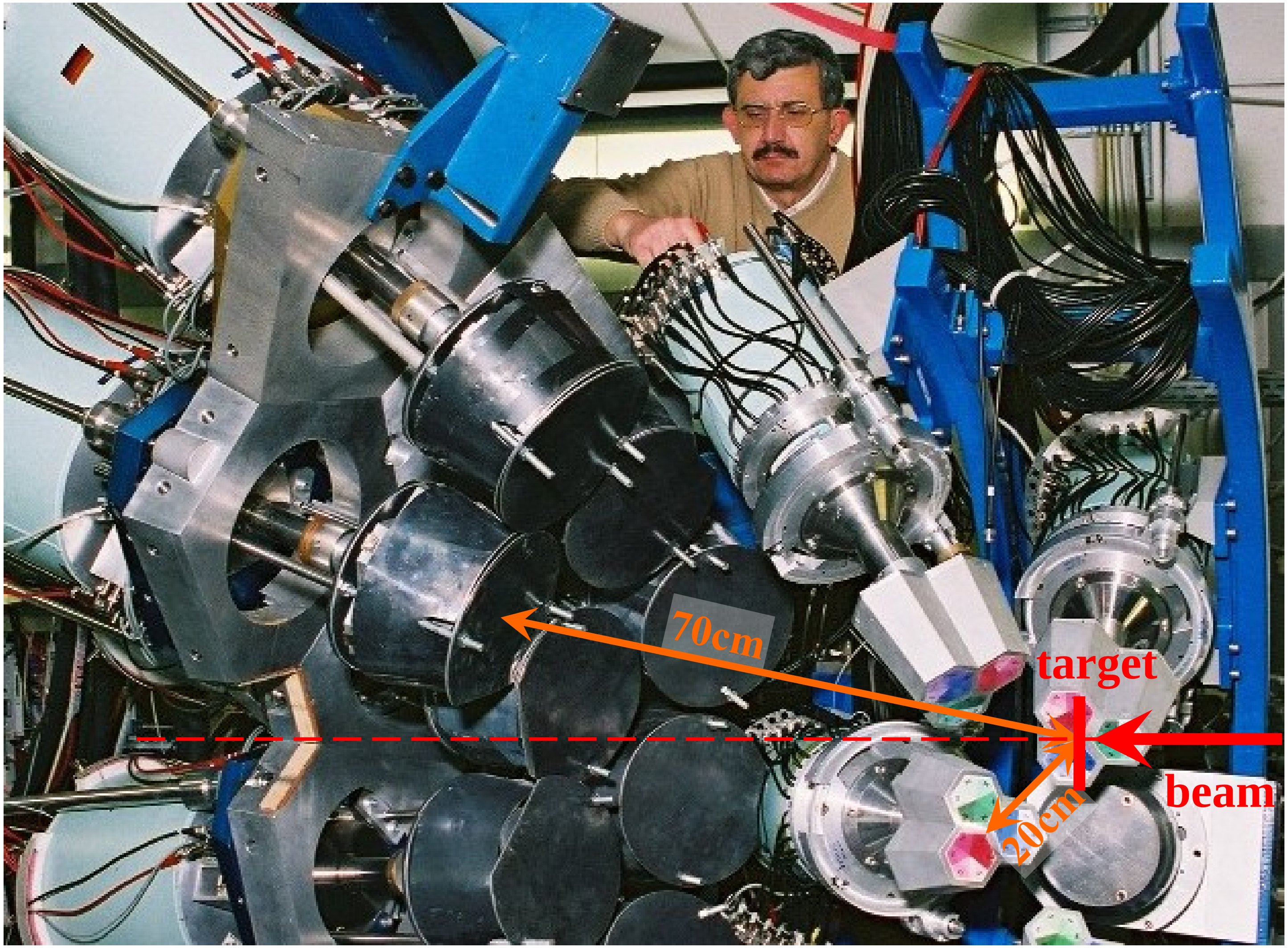
Angular resolution

↓

Energy resolution

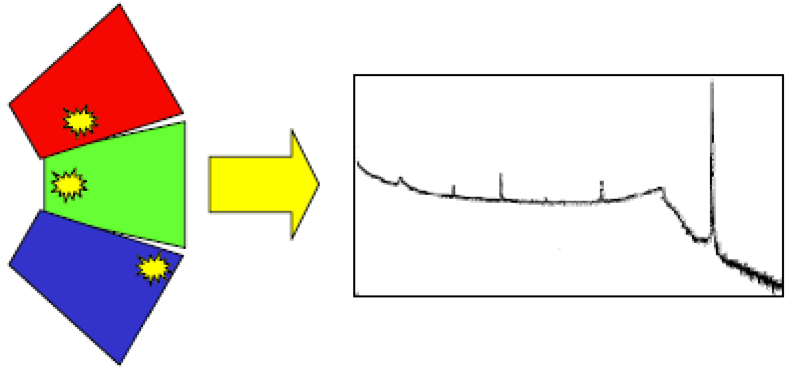


# Segmented detectors



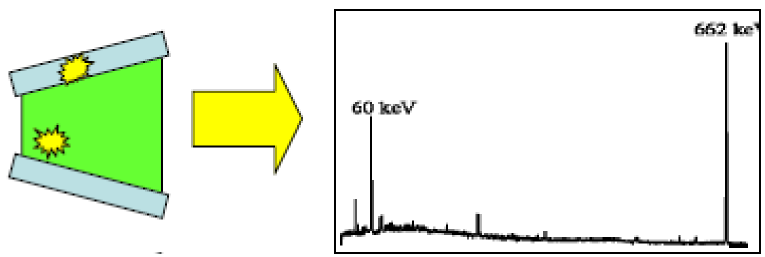
# Gamma-ray tracking – the concept

without Compton suppression shield



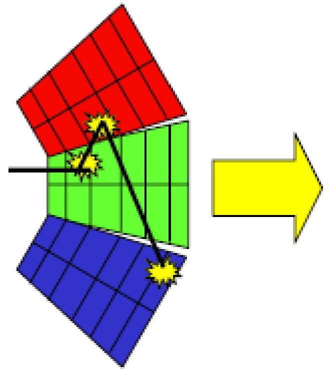
Compton continuum → small peak to total ratio

with BGO shielding




Less solid angle coverage → big drop in efficiency

with highly segmented detectors



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

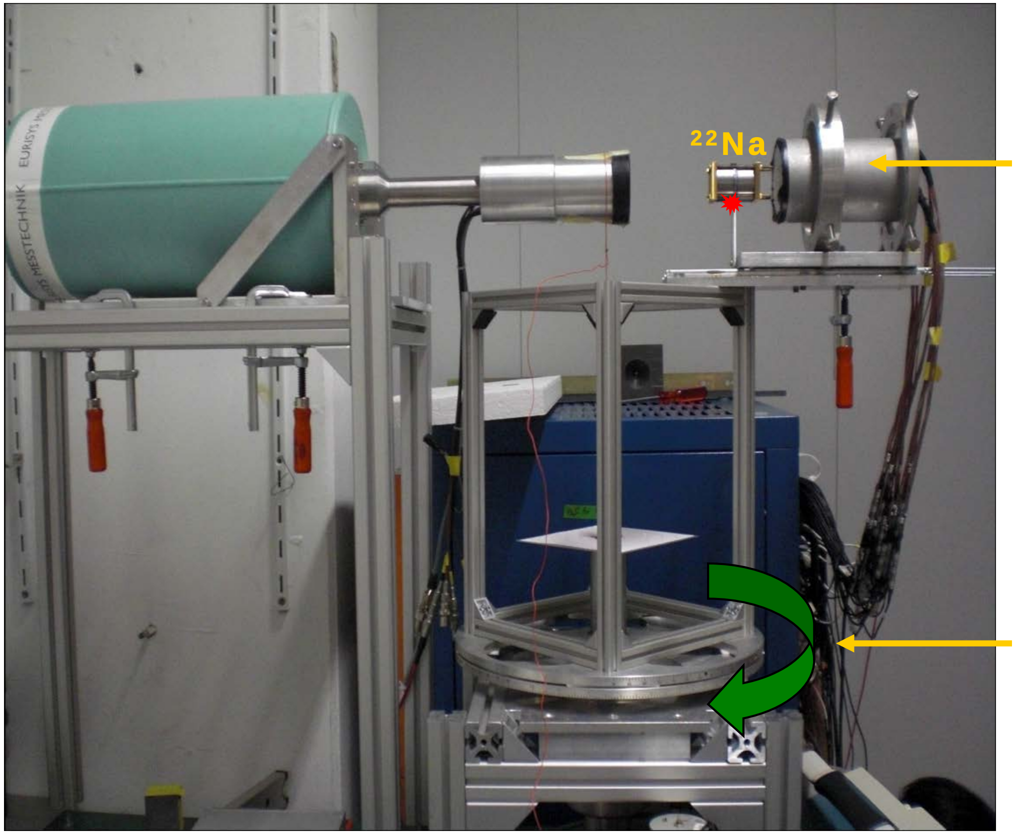
Path of γ-ray reconstructed to form full energy event

→ Compton continuum reduced

→ Excellent efficiency ~50% @ 1 MeV

→ Greatly improved angular resolution (~1%) to reduce Doppler effect.

# Scanner at GSI




**Position sensitive detector**

Characteristics:

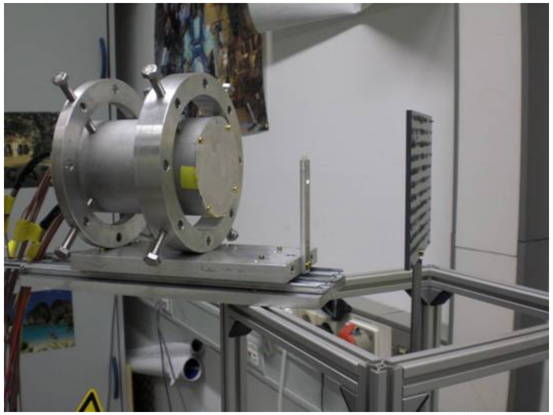
- Faster
- Precision: 1-2 mm
- Imaging capability

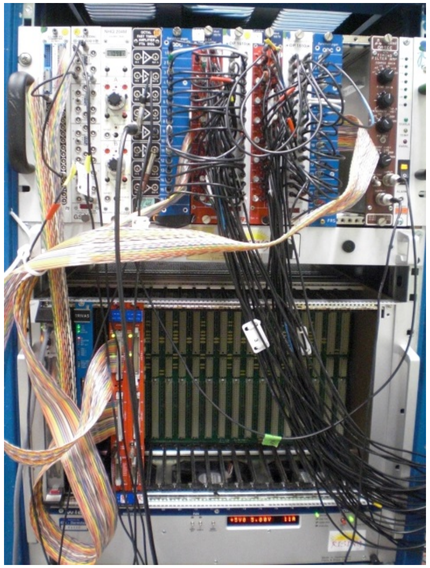
**Rotating table**

Requirements:
1. Position sensitive detector
   - Excellent Δx/x
   - Large field of view
2. Method to compare the pulses

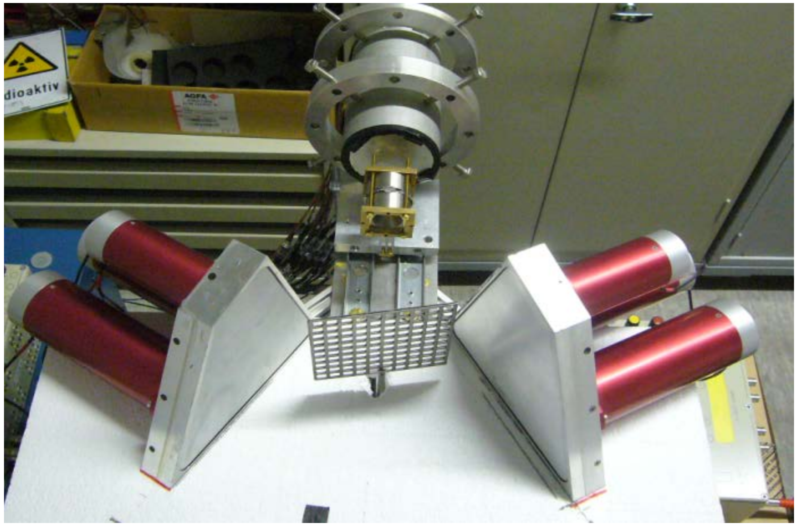
# Position calibration

- Determine: $X_r(x_m,y_m)$, $Y_r(x_m,y_m)$



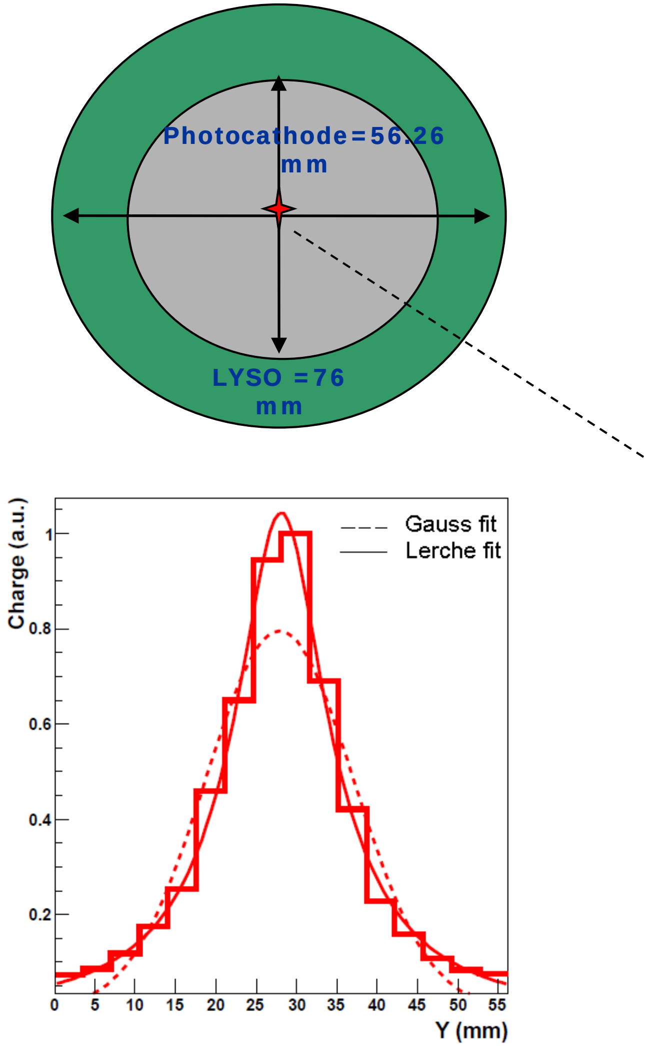


Gamma-ray scattering technique

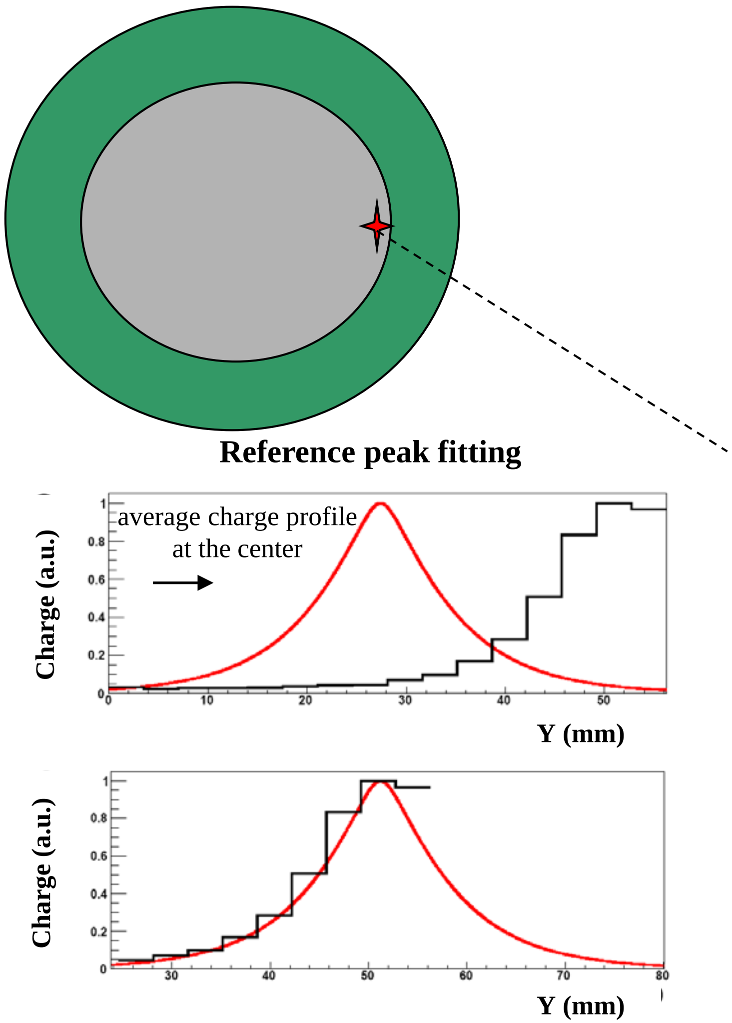


# Position reconstruction

**Central Interaction**




**Peripheral Interaction**

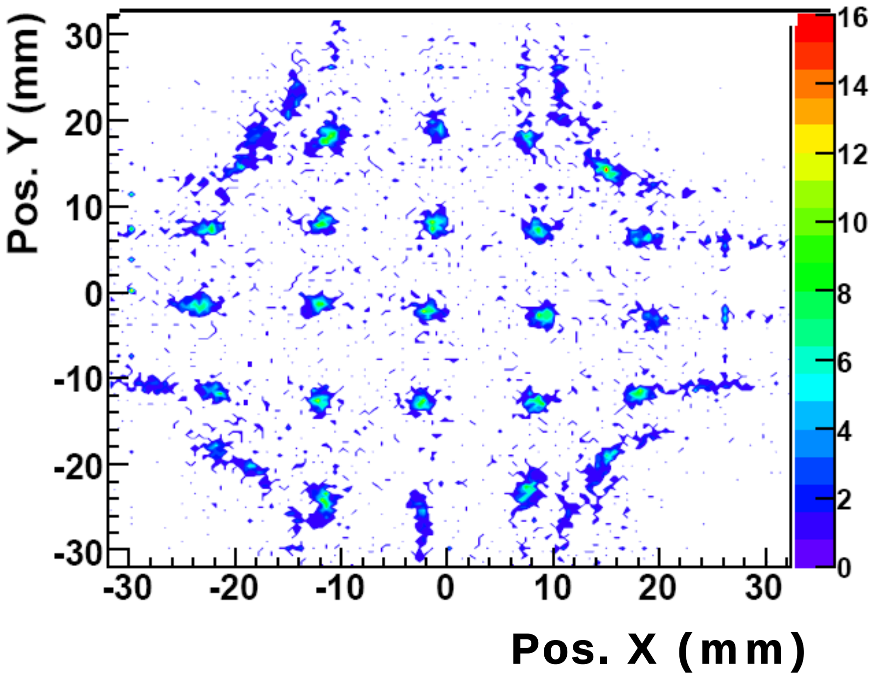



C. Domingo Pardo, N.Goel, et.al., IEEE, Dec. 2009 Volume: 28 Issue 12

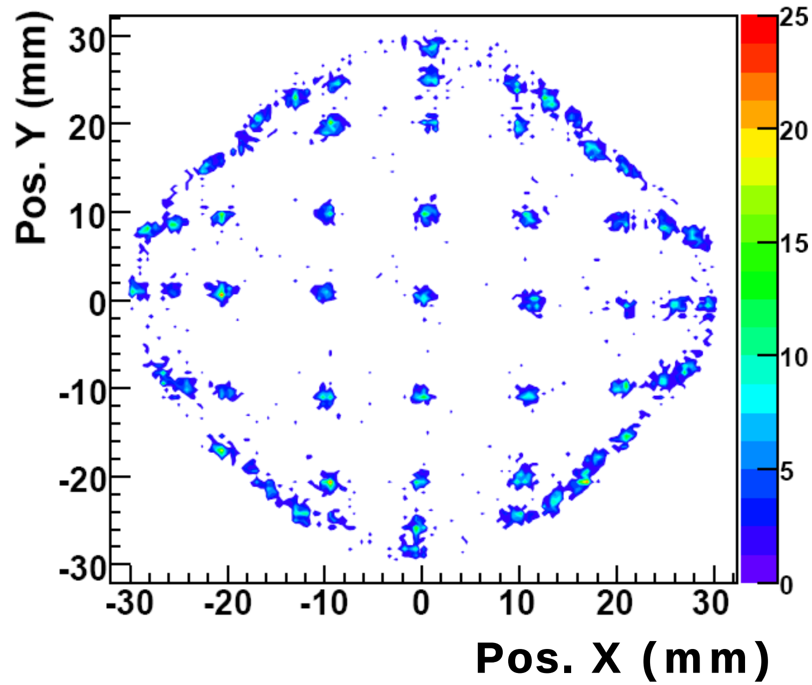
C.W.Lerche, et.al., NIM A, Vol 537, pp. 326-330, Jan. 2005

# Position reconstruction

Gaussian fitting




Reference peak fitting



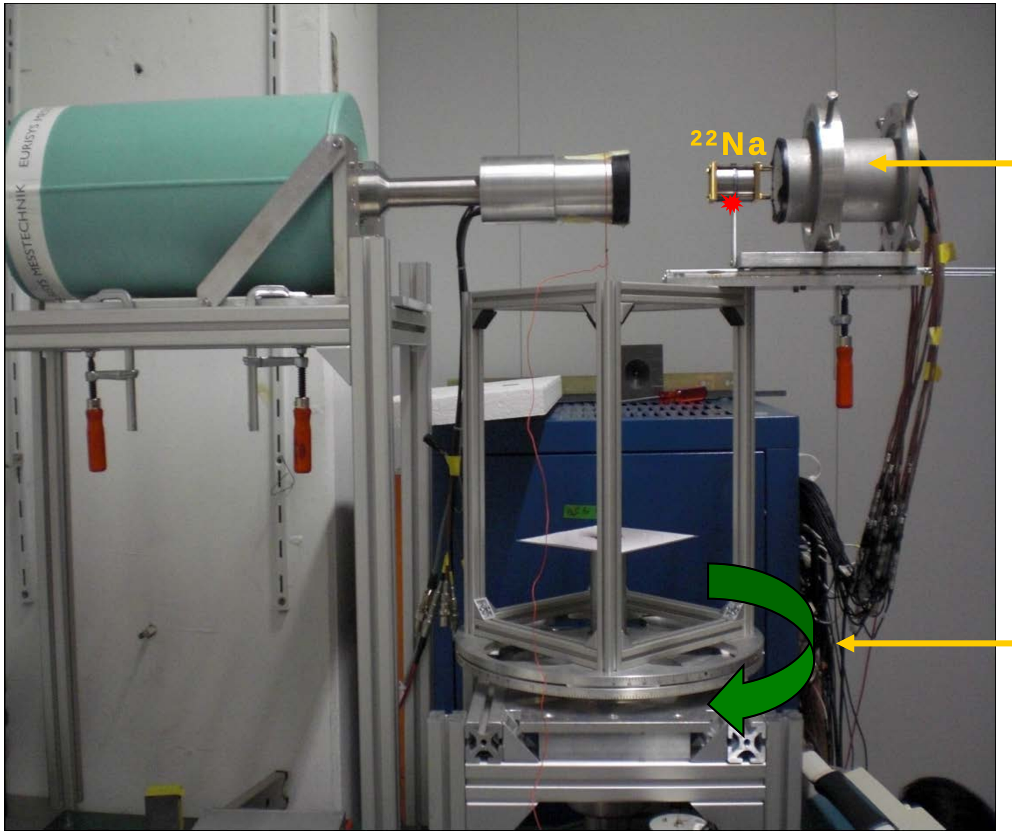

Gaussian fitting works relatively well
in the central region

Linear for 50 mm

Field of view = 28 $cm^2$

Average spatial resolution in X and Y ~ 1mm

# Scanner at GSI




**Position sensitive detector**

Characteristics:

- Faster
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- Imaging capability

**Rotating table**

Requirements:
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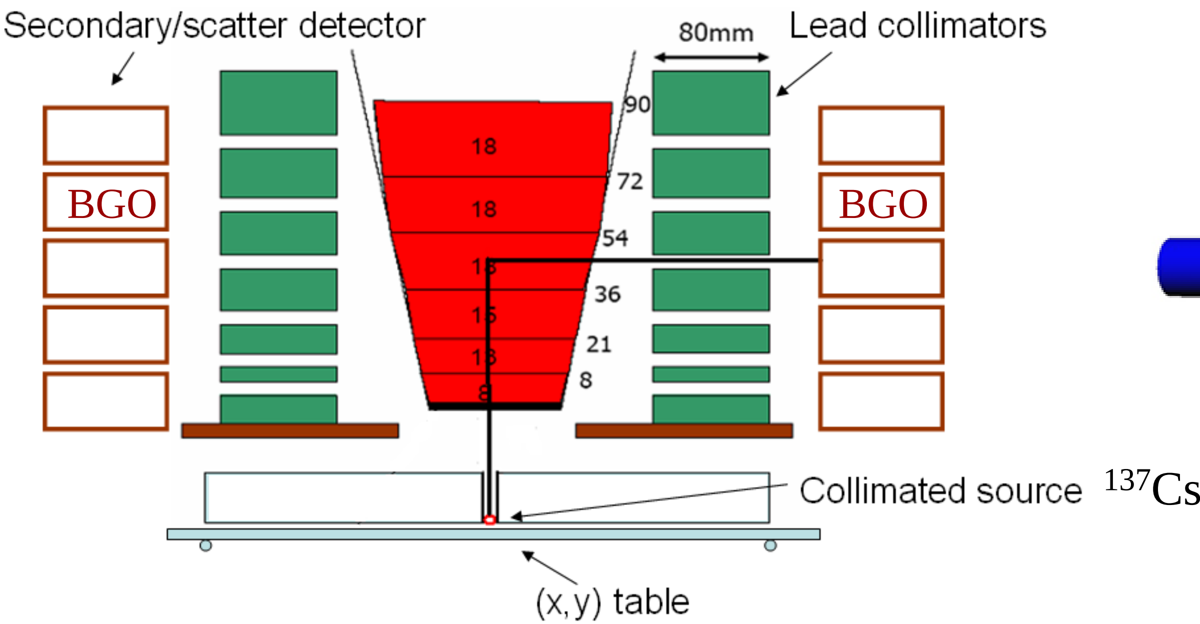
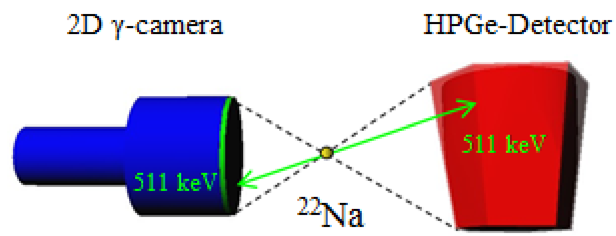
# Superiority over conventional scanner

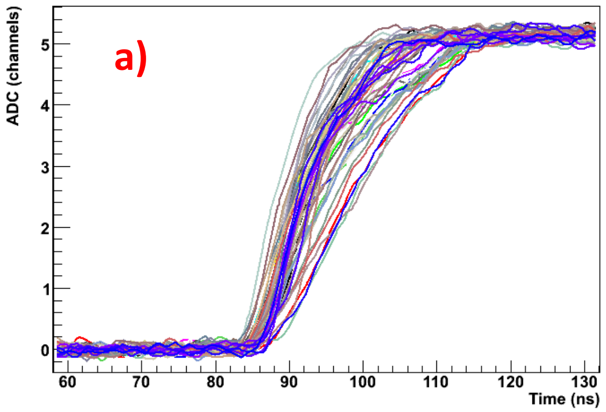
coincidence between the Germanium and BGO detectors for
90 degree Compton scattered events for depth determination

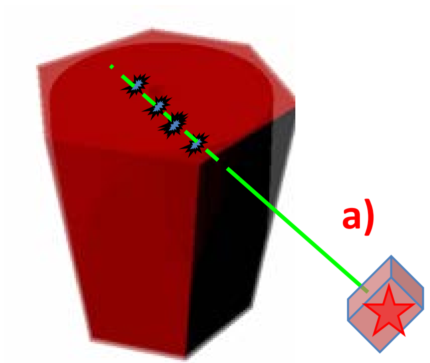



Advantage over conventional scanner: Full detector can be scanned in one measurement
10 times faster than a conventional scanner
Accuracy of simulations can be checked for complex regions of electric field

# Scanner based on pulse shape comparison scan



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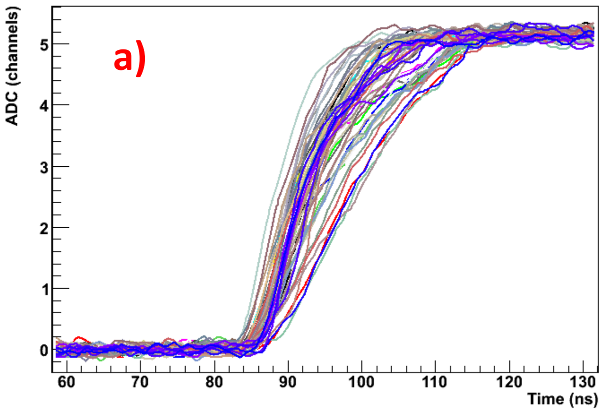
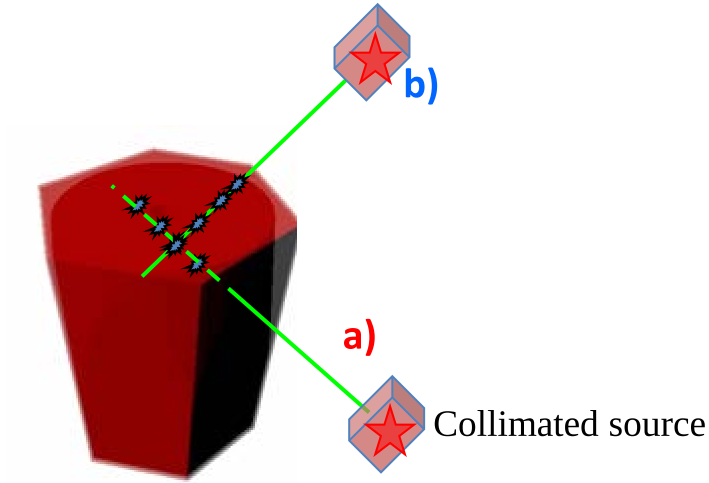
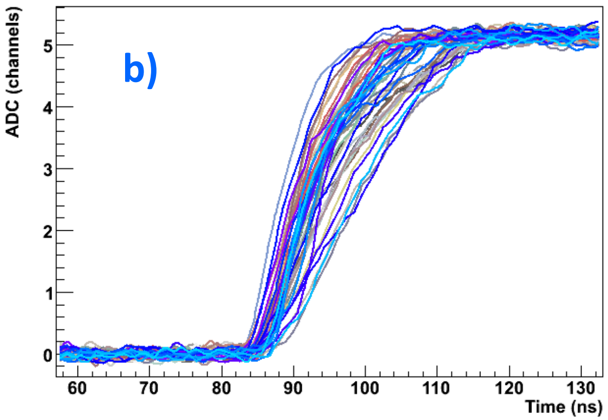
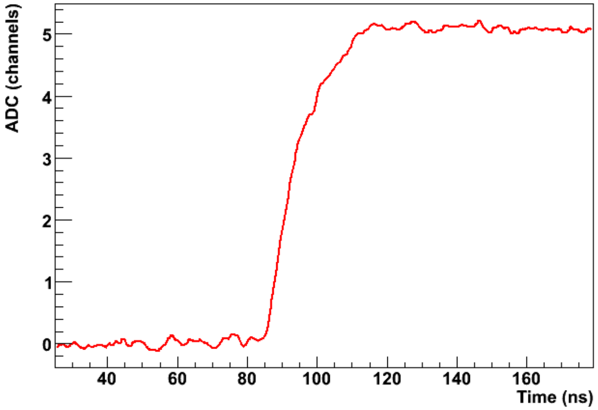



Geometric crossing point: **x,y,z**

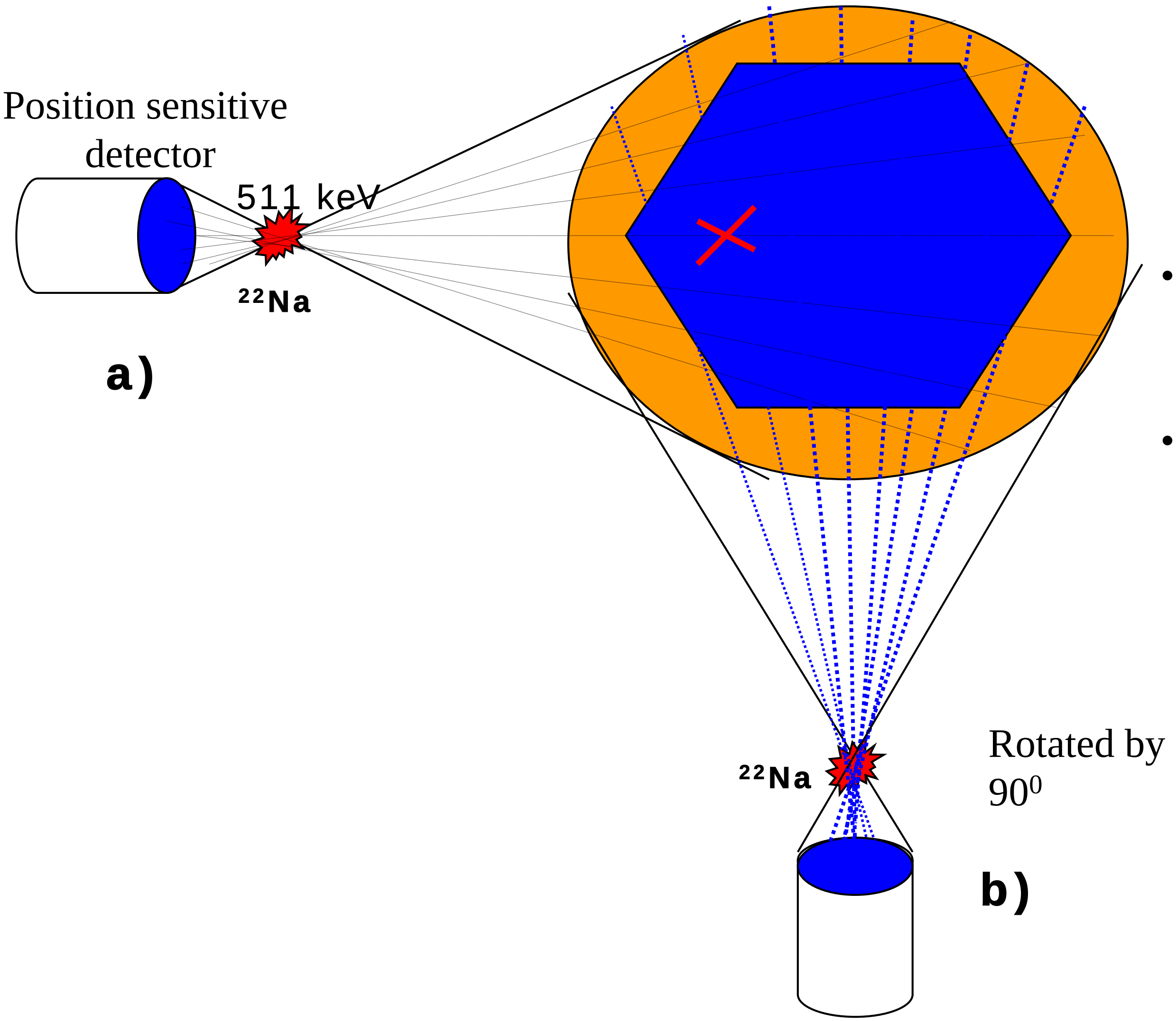



Common pulse out of data sets (a) & (b)




F.C.L. Crespi, et al. NIM A 593 (2008), 440

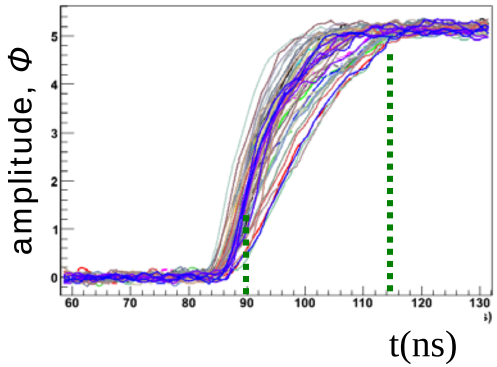
# Pulse shape comparison scan method based on a position sensitive detector



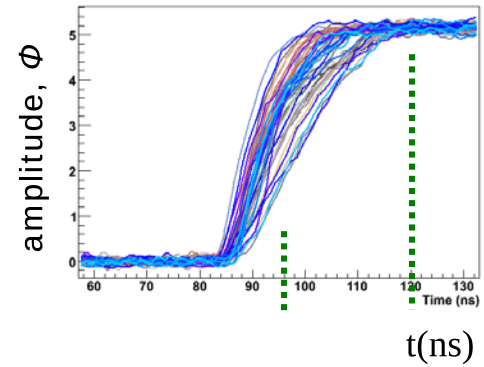

- Recording pulse shapes for positions (a) and (b)
- Identical signals at the crossing point.

# $\chi^2$ minimization method

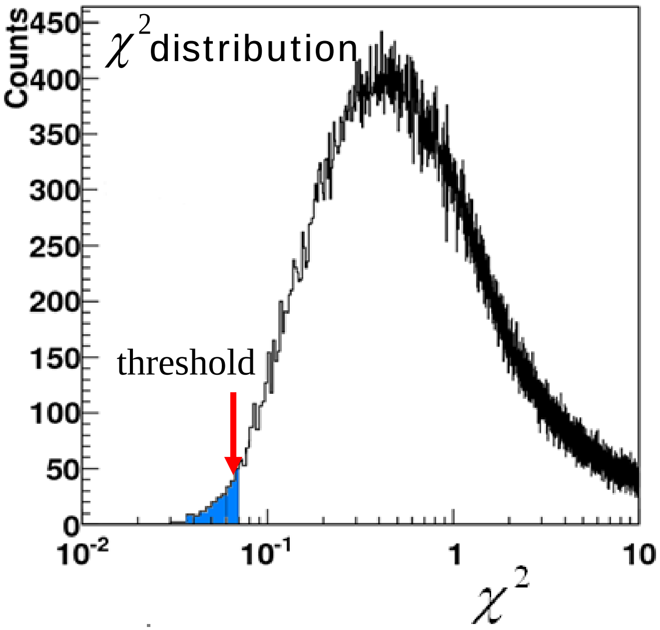
0° measurement



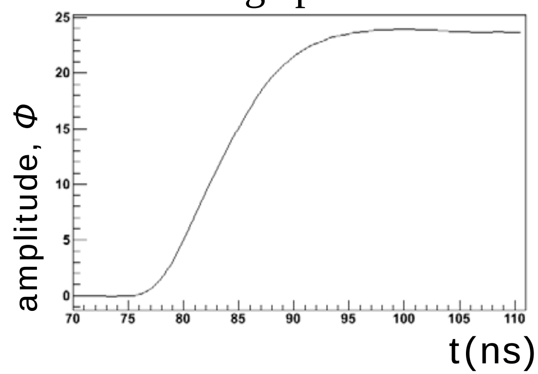

90° measurement




$$\chi^2 = \sum_t \left(\phi_t^{0^\circ} - \phi_t^{90^\circ}\right)^2$$

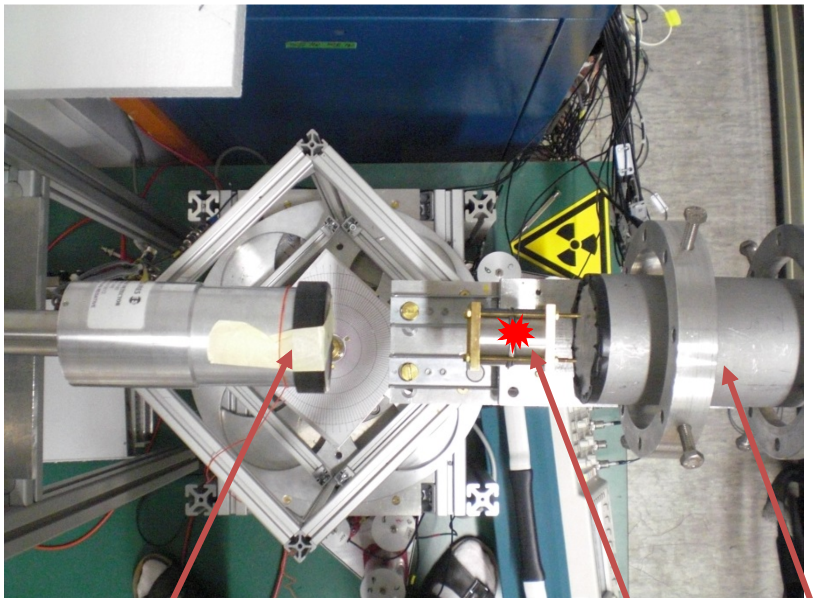



Average pulse

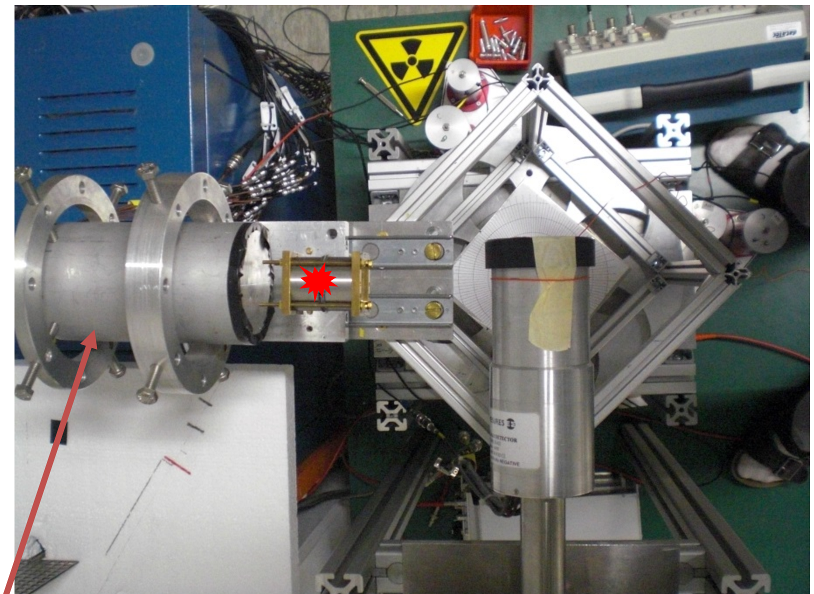


# Characterization of planar HPGe detector

Front view



Side view



Planar Ge

$^{22}$Na

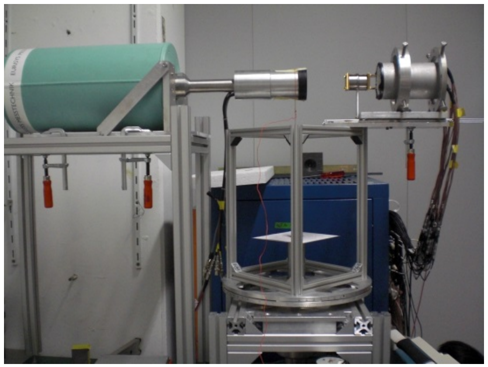
Position sensitive detector

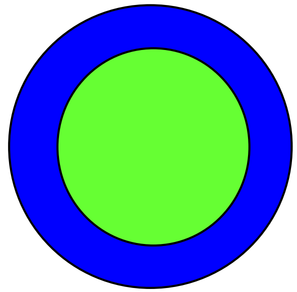
d = 4 cm

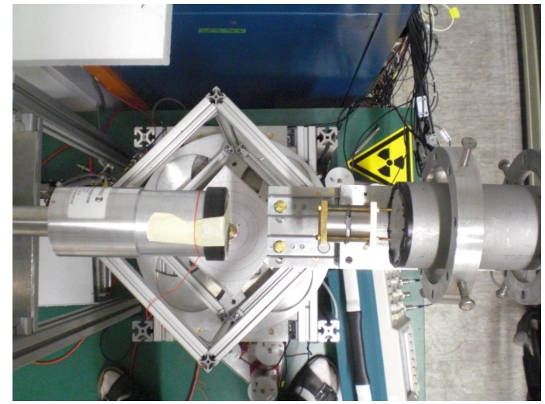
t = 2 cm

# Detector scan

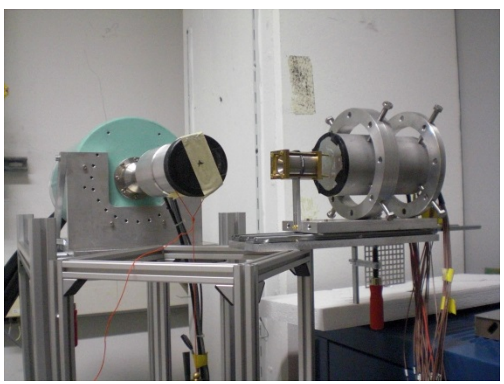
Front view (0 deg):

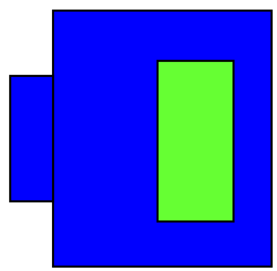


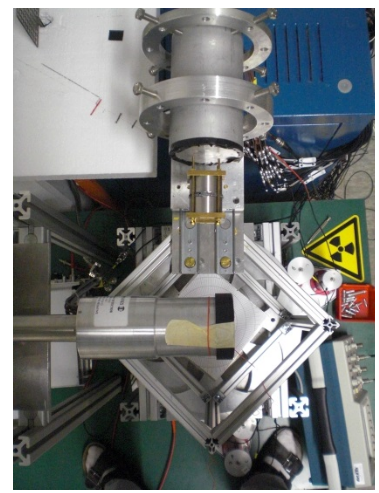




Side view (90 deg):

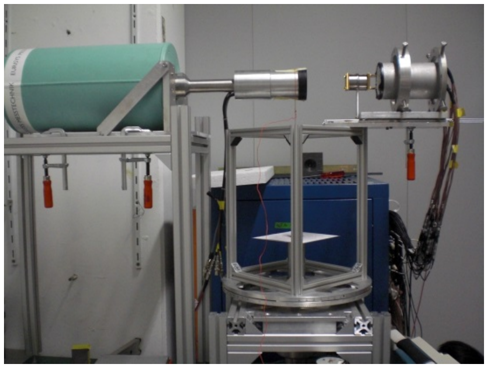


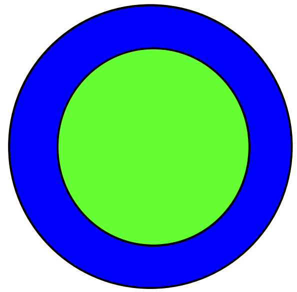


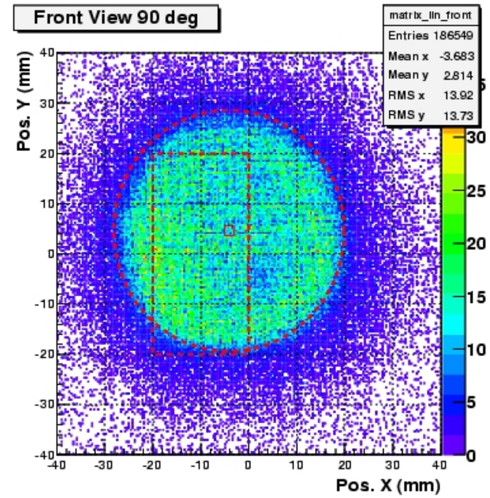


# Detector scan

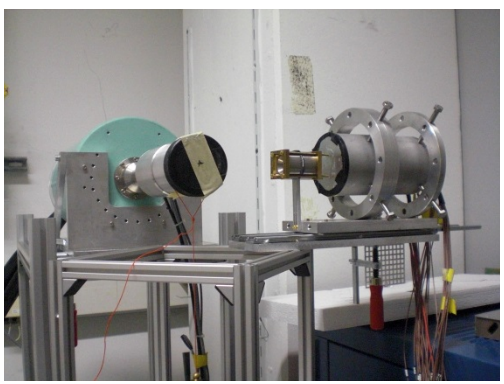
Front view (0 deg):

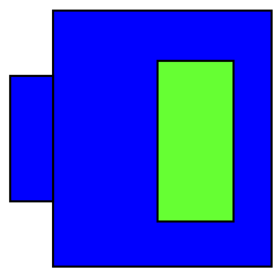


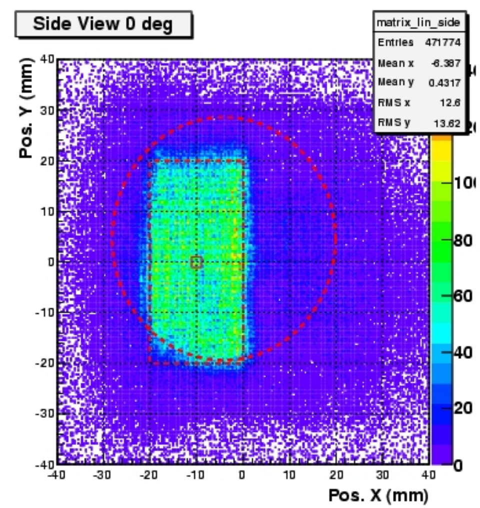




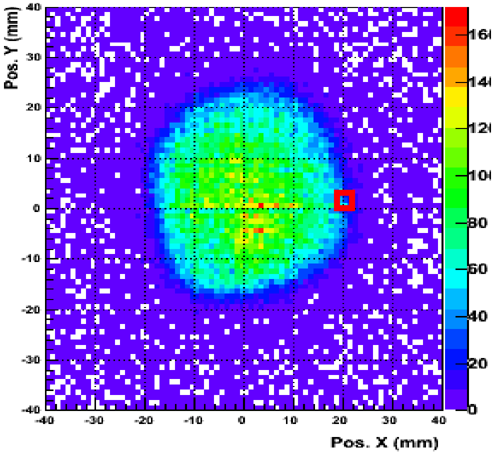

Side view (90 deg):

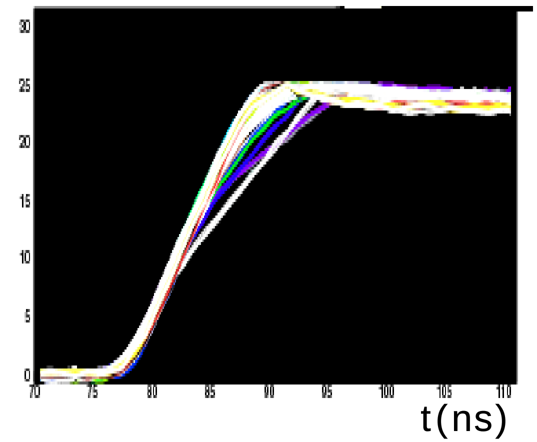


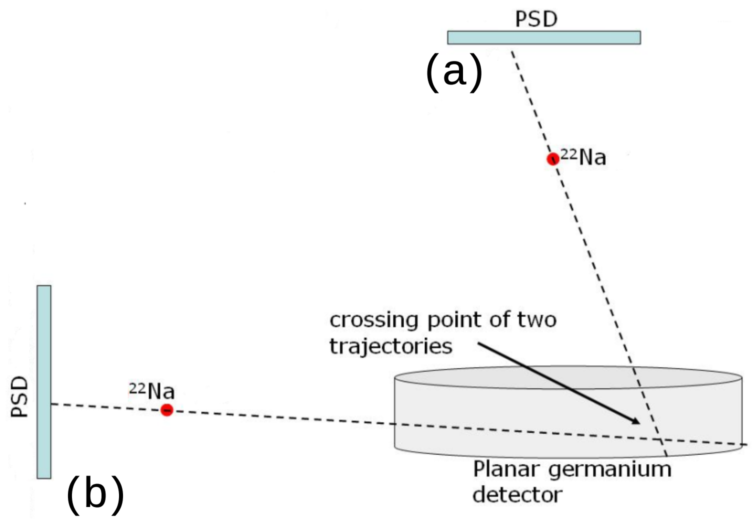


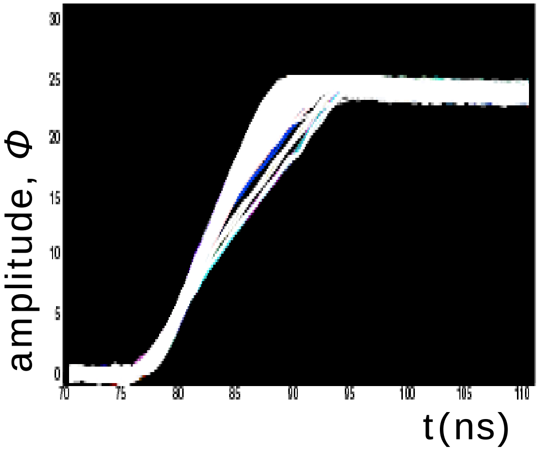


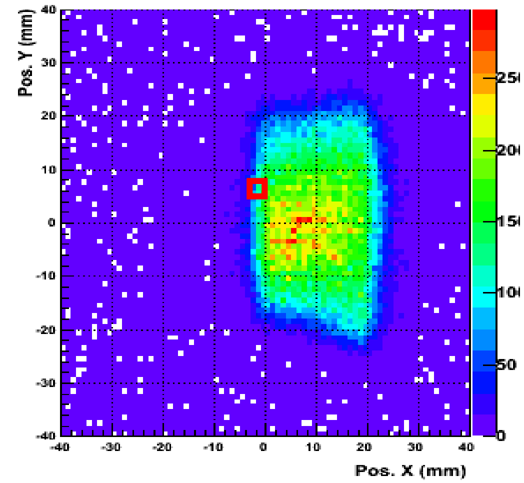
Intensity distribution for photopeak events



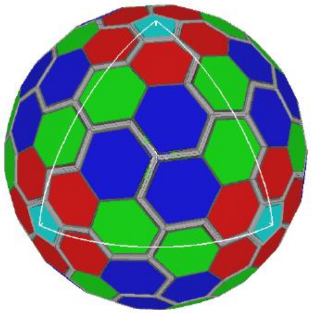



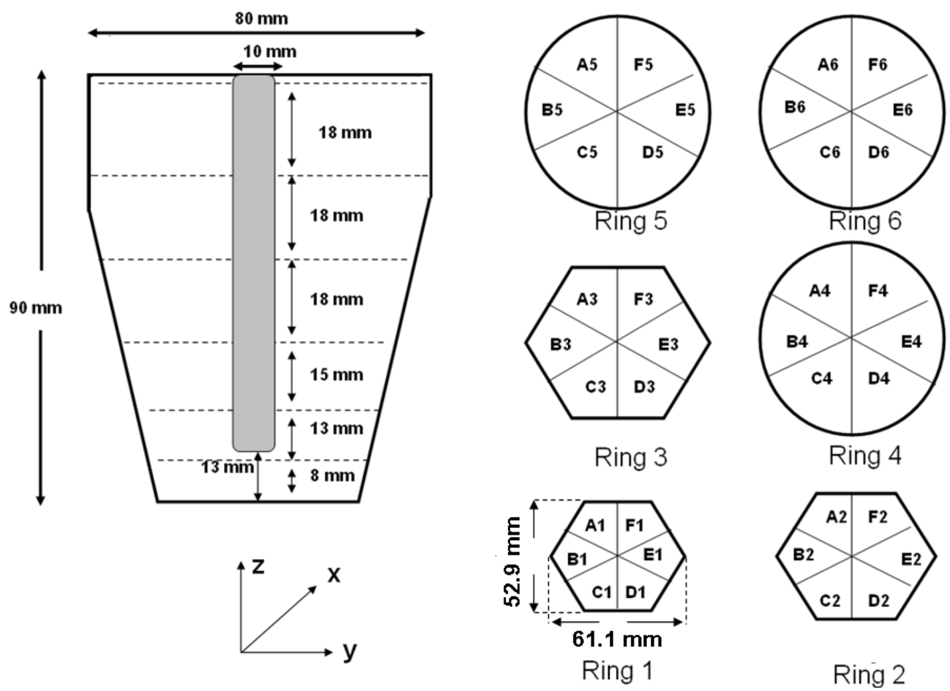



# AGATA: Advanced Gamma Tracking Array

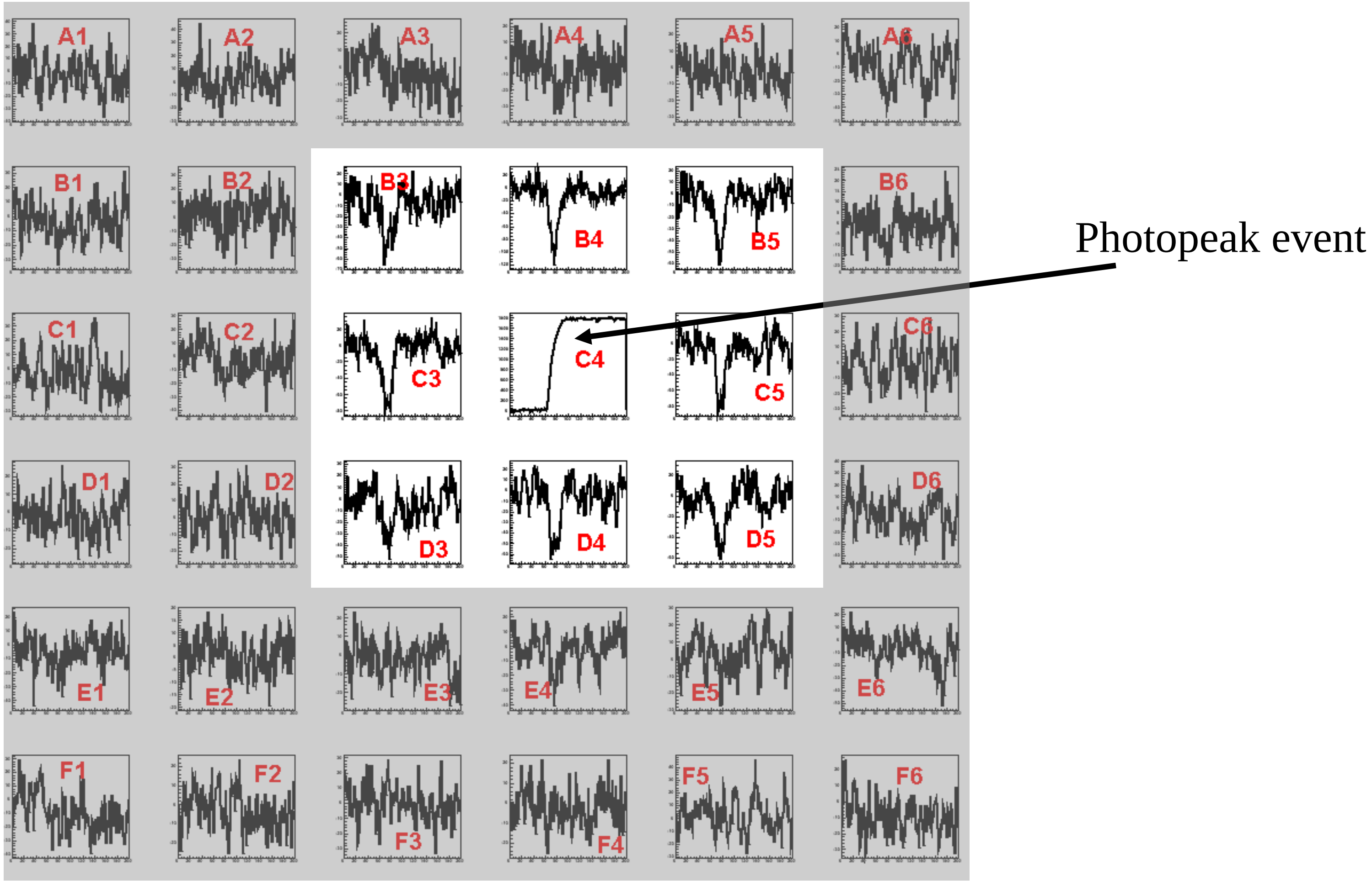
- $4\pi$ array of germanium crystals
- 180 segmented crystals arranged around the reaction target
- 3D sensitivity





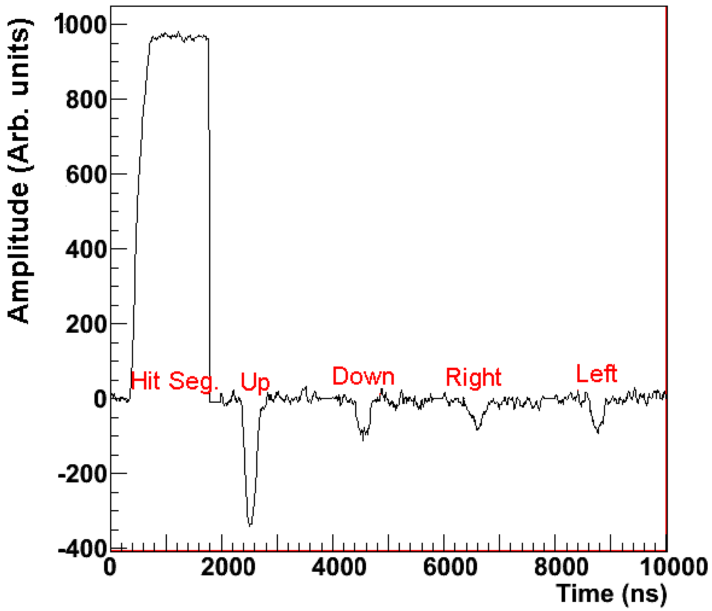

**Symmetric AGATA prototype crystal**

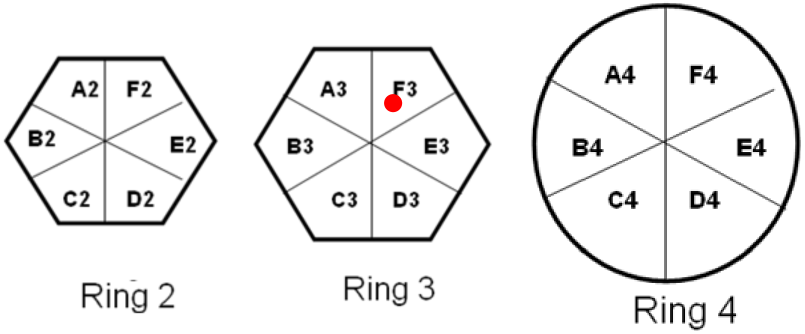
# Signal shapes from all 36 segments




Most significant transient charge signals are from the direct neighbouring segments

# Combined trace for pulse shape comparison



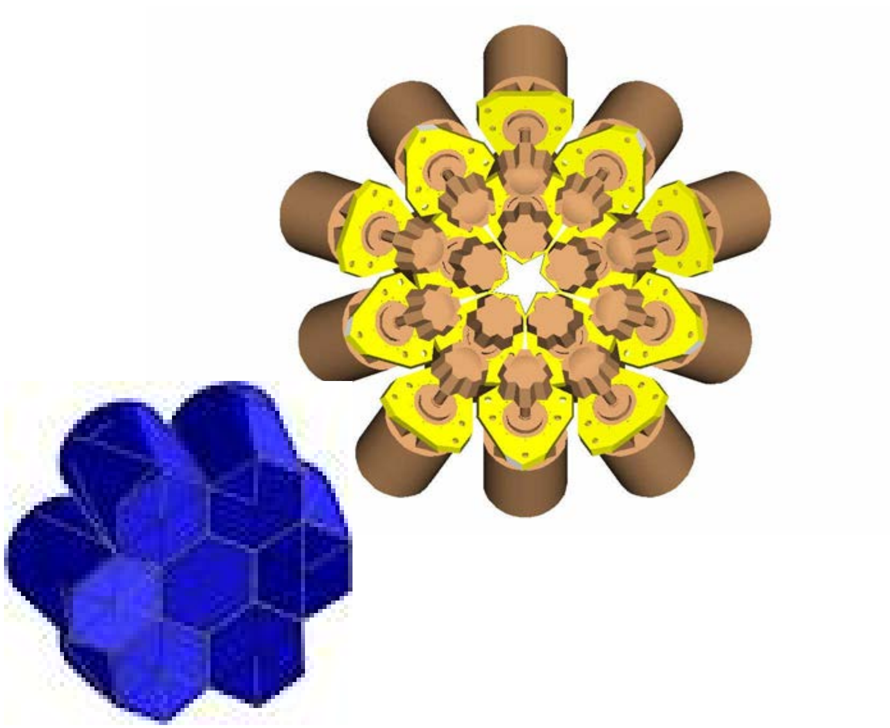




Direct neighbours of segment F3

We have the method, the device and the detector ready, lets do the scan of AGATA!

# Gamma detector array

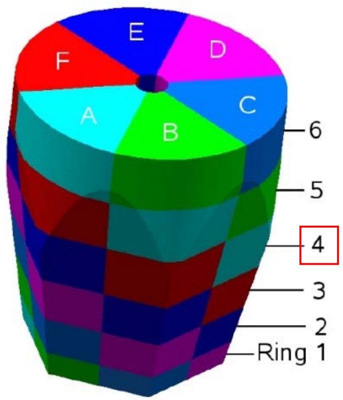
## EUROBALL Cluster Detectors



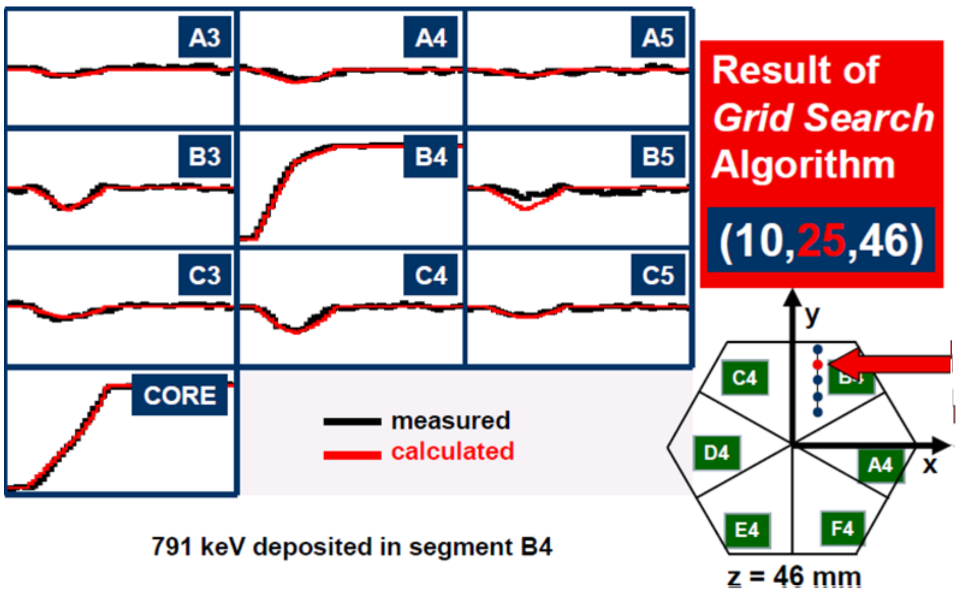
15 EUROBALL det.

photopeak eff. 2.8%

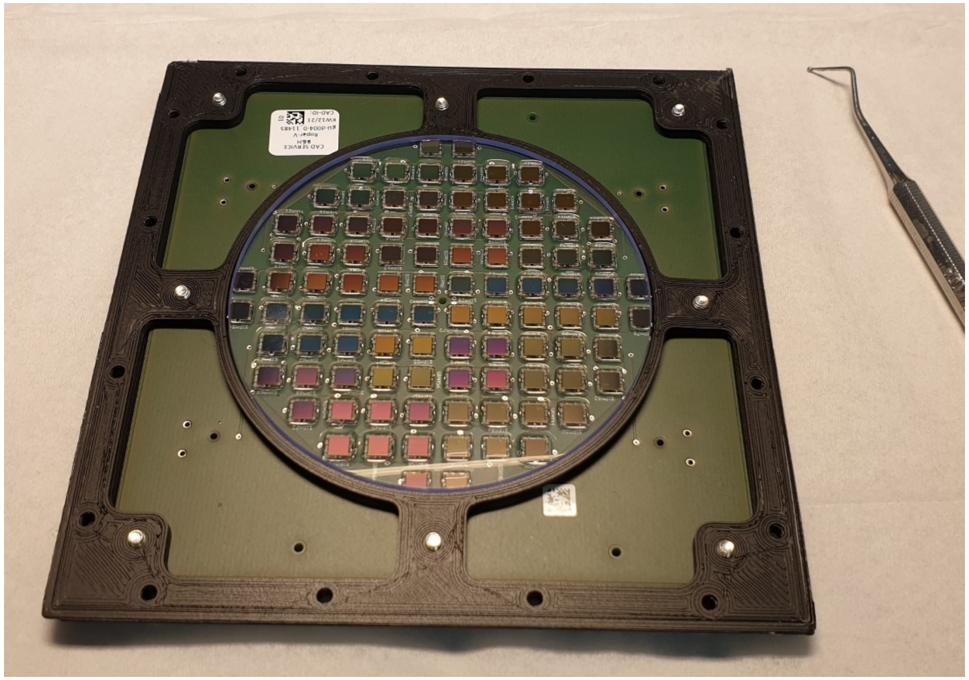
## PRESPEC - AGATA



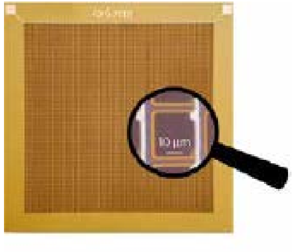

**Signals from 36 segments + core** are measured as a function of time (γ-ray interaction point)



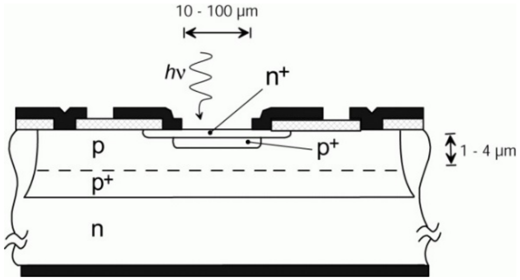
# New scanner at GSI



LYSO & SIPM (Silicon Photomultiplier Sensors, series C, 3mm)



3x3 mm




single-photon avalanche diode

## Advantages:

High detection probability

## Disadvantages:

Dark current (temperature)

www.onsemi.com/products/sensors/photodetectors-sipm-spad/silicon-photomultipliers-sipm/c-series-sipm