Segmented Detectors

Lecture: Hans-Jürgen Wollersheim

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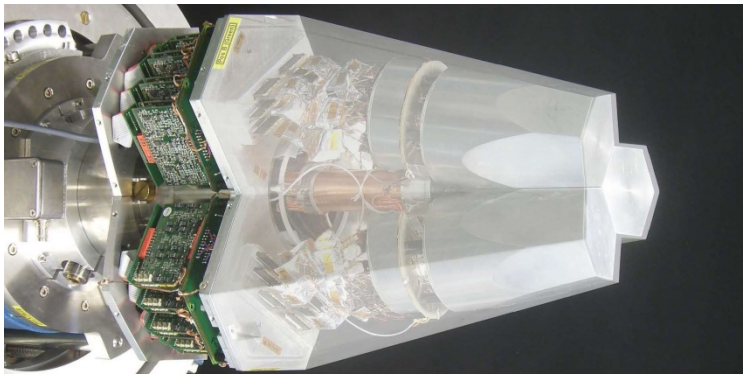
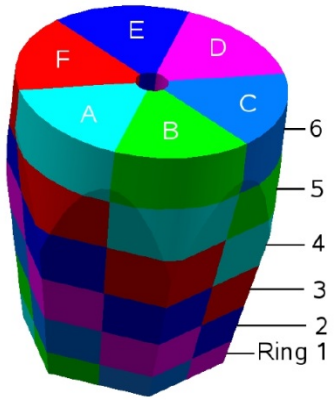
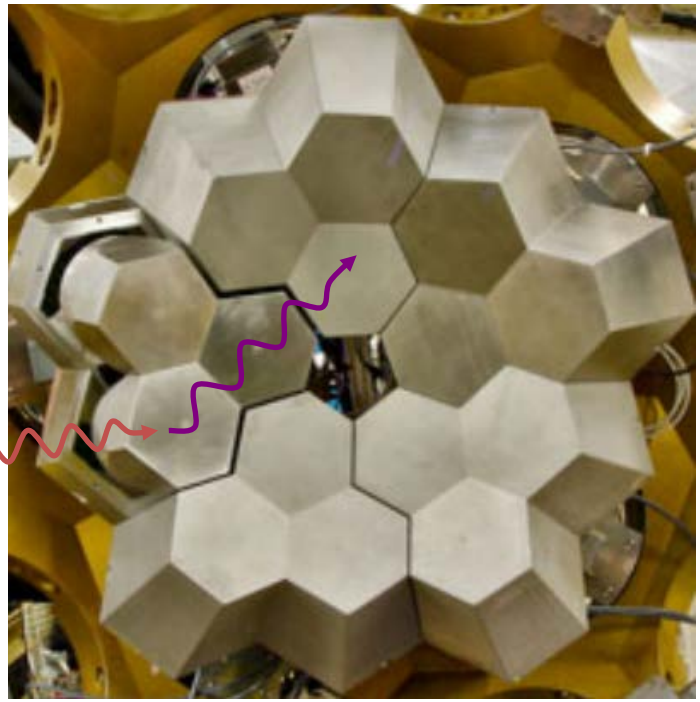




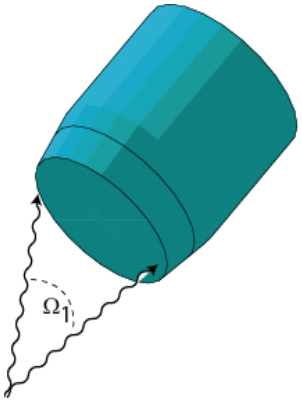
Challenges of γ-ray spectroscopy

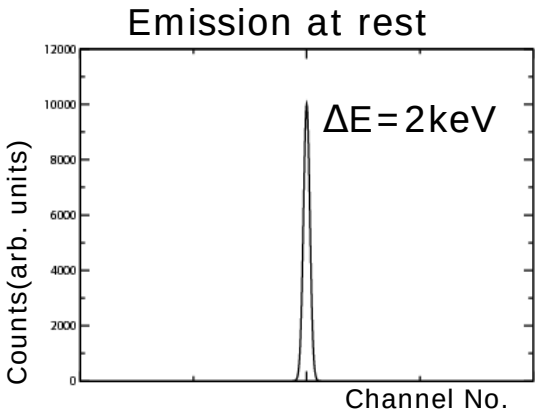
efficiency vs resolution

γ ray



Composite HPGe detectors
in ADD BACK mode

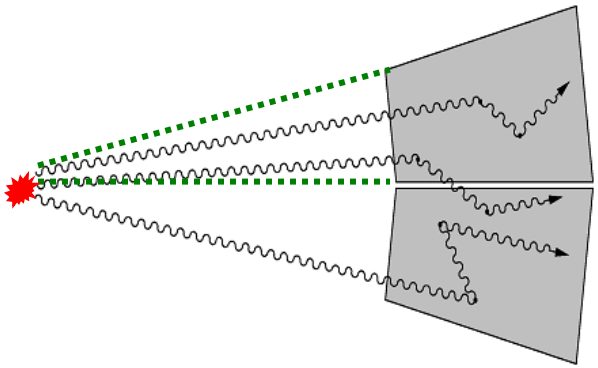


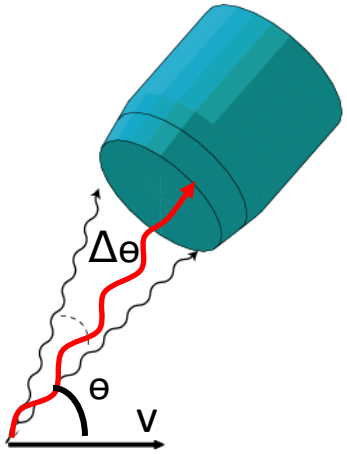


Challenges of γ-ray spectroscopy

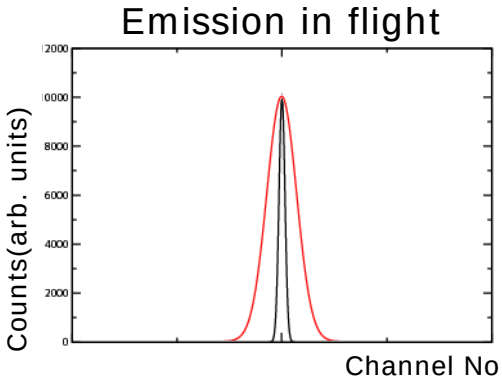
efficiency vs resolution

High M_γ



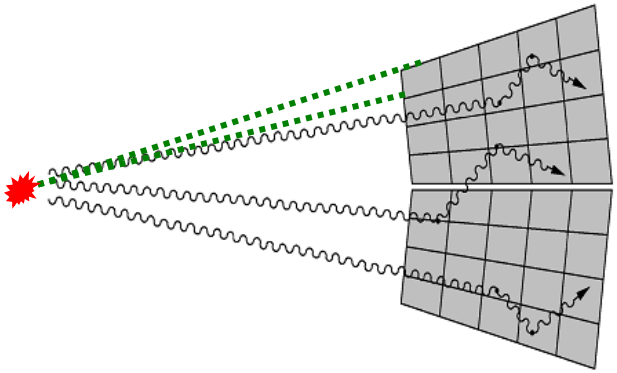


Doppler broadening



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

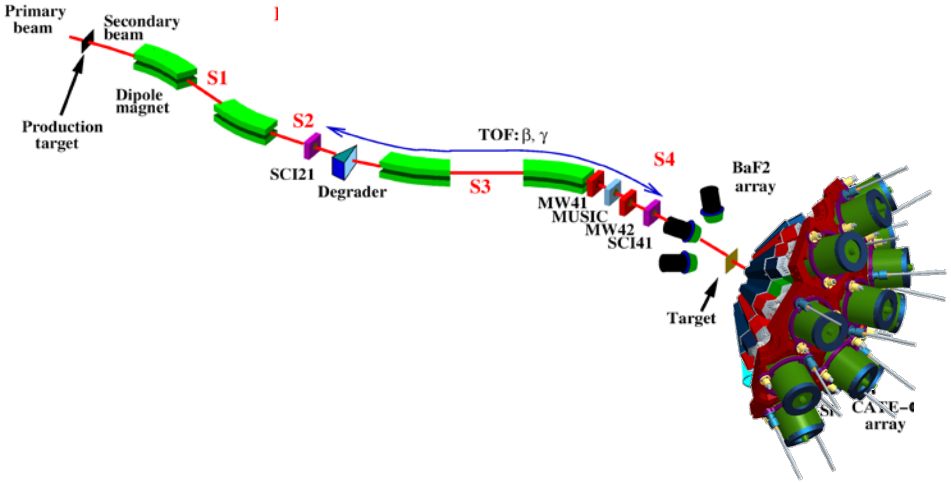
Solution

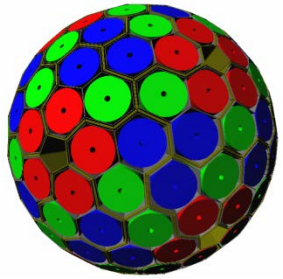


- Segmentation
- Gamma-ray tracking
- Pulse shape analysis
- Doppler correction

γ-ray spectroscopy with 3D position sensitive HPGe detectors

In flight γ-ray spectroscopy → **HISPEC**





Advanced
GAmma
Tracking
Array

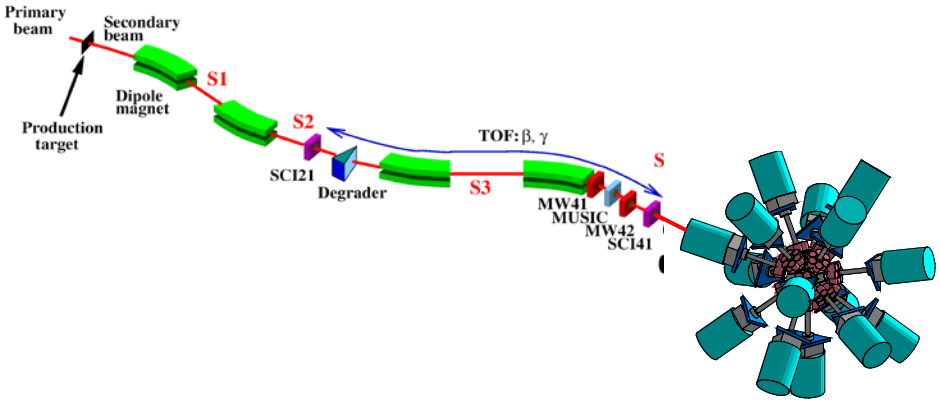
Efficiency: 43% (M_γ =1) 28% (M_γ =30)

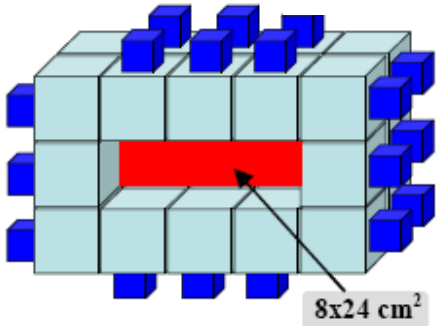
P/T: 58% (M_γ=1) 49% (M_γ=30)

Angular resolution: ~1°

FWHM (1 MeV, v/c=50%) ~ 6 keV

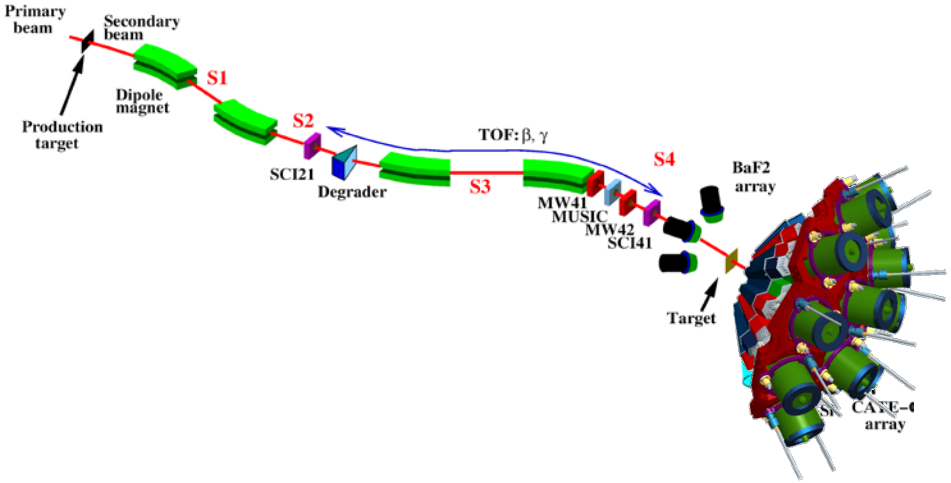
Decay γ–ray spectroscopy after implantation → **DESPEC**

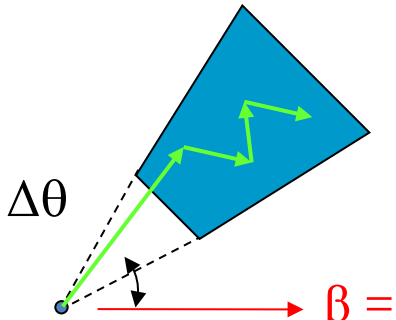




γ-ray spectroscopy with 3D position sensitive HPGe detectors

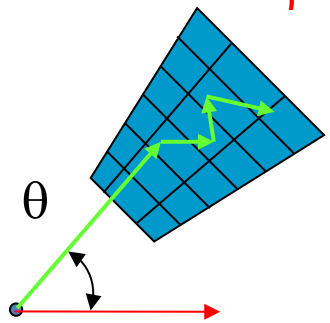
In flight γ-ray spectroscopy





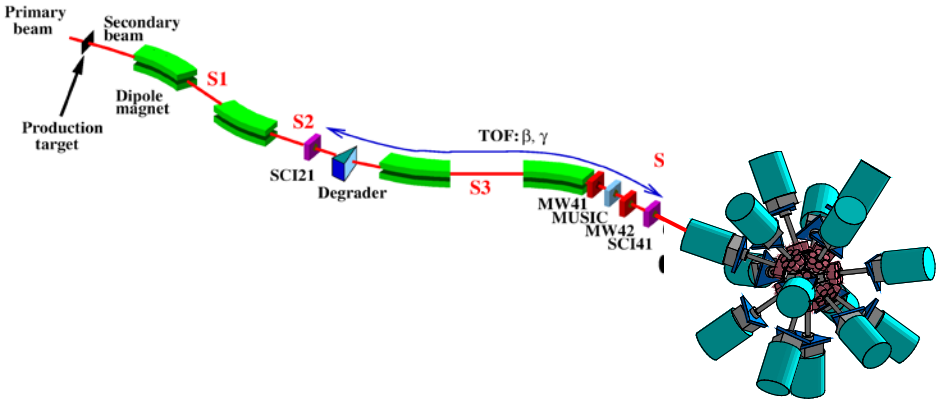
$$E_\gamma = E_\gamma^0 \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

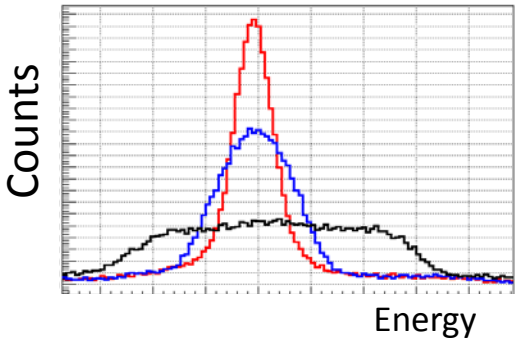
$$\Delta E_\gamma = E_\gamma^0 \, \beta \, \sin\theta \, \Delta\theta$$



Via *tracking* it becomes possible to determine the incident angle and preserve the good energy resolution.

Decay γ–ray spectroscopy after implantation





E_γ = 1.3 MeV

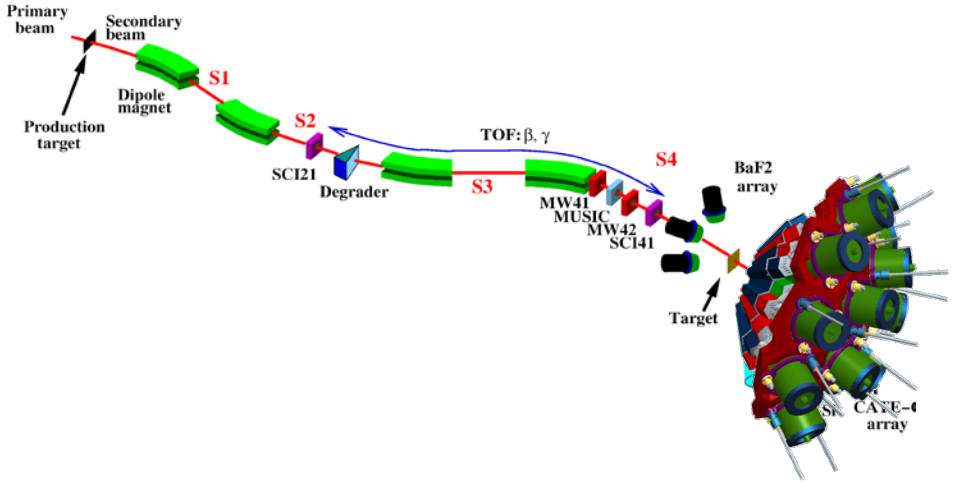
PSA = 5 keV

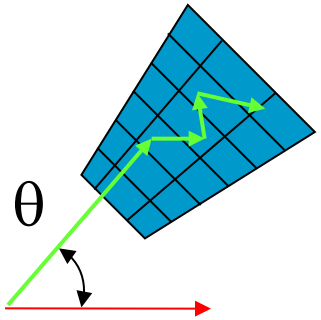
Segment = 12 keV

Detector = 35 keV

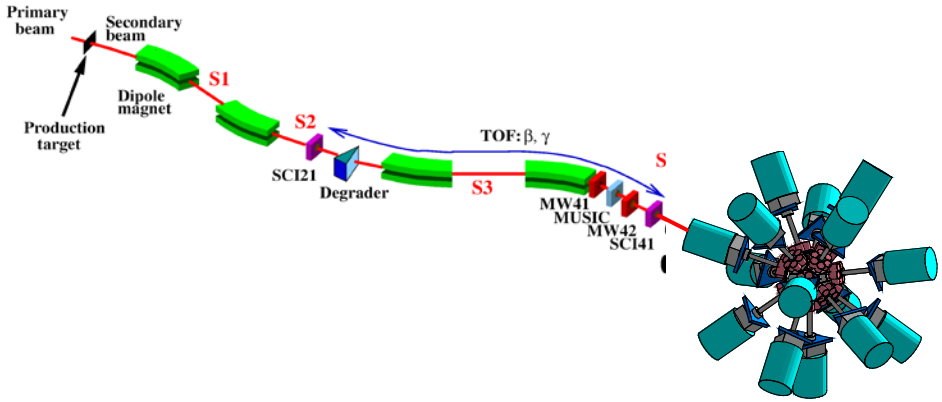
γ-ray spectroscopy with 3D position sensitive HPGe detectors

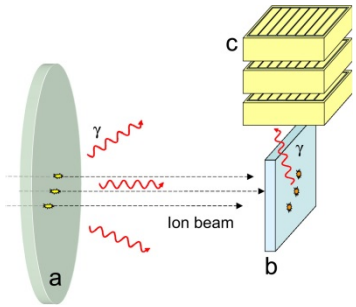
In flight γ-ray spectroscopy



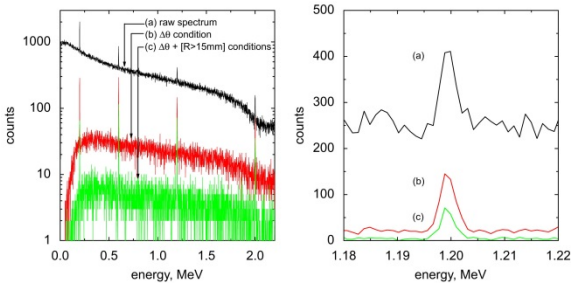


Decay γ–ray spectroscopy after implantation





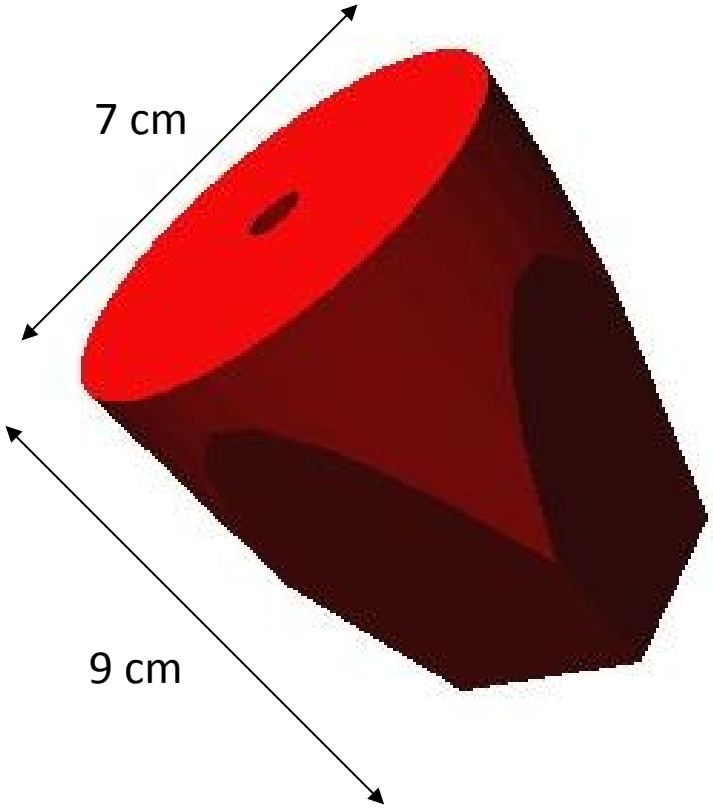
Background suppression and P/T can be improved by applying imaging techniques.



Pushpendra P. Singh & Hans Jürgen Wollersheim (2018)

S. Tashenov, et al. NIMA 586 (2008) 224-228

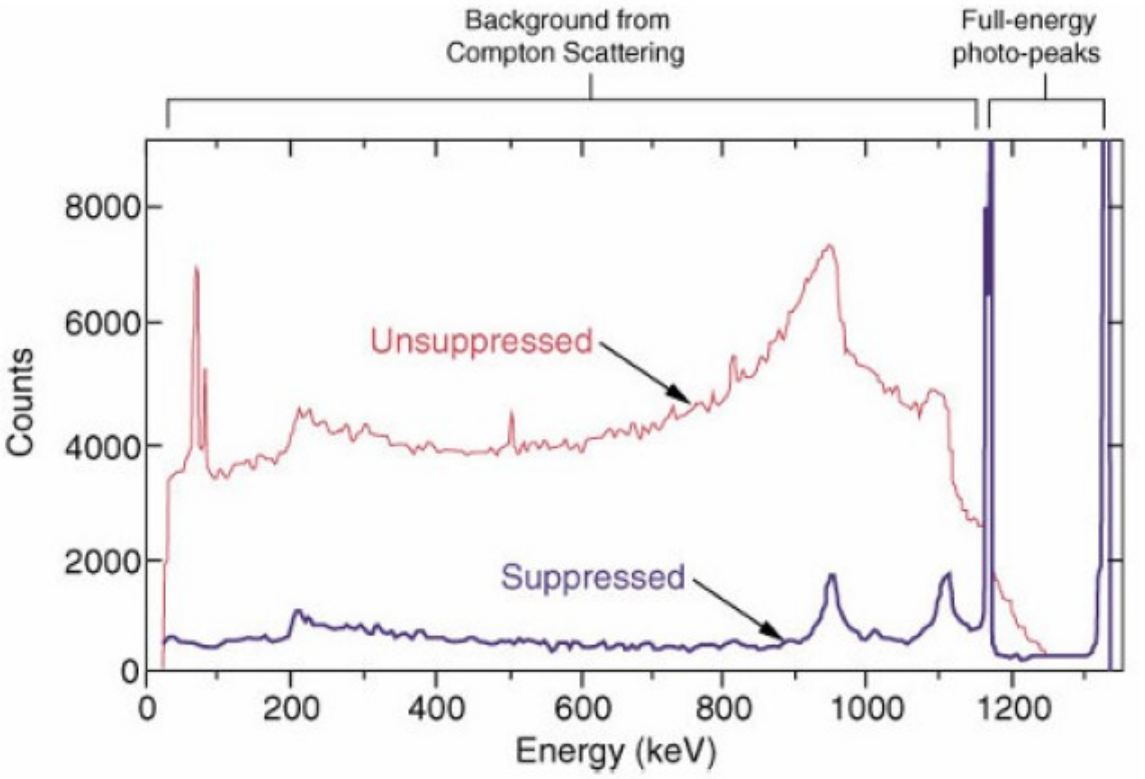
HPGe detector



Compton suppressed Germanium detektor

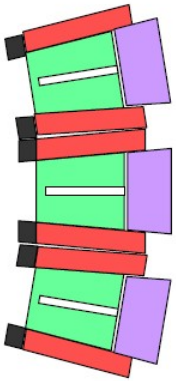
Interaction in a Ge crystal:

- **Photo effect** (low γ-ray energy)
- **Compton scattering** (medium γ-ray energy)
- Pair production e^+e^- (high γ-ray energy)

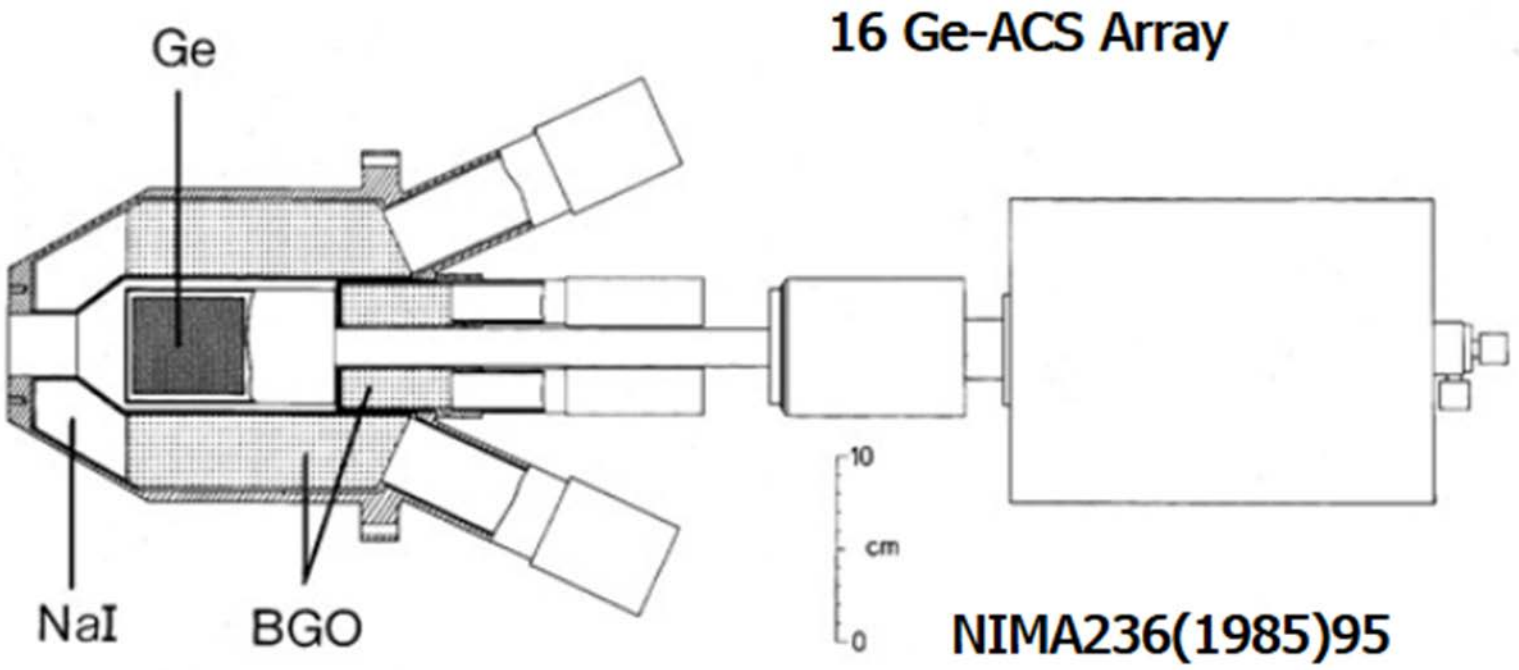


peak-to-total ratio

- unsuppressed
  P/T~0.15
- Compton suppressed
  P/T~0.6

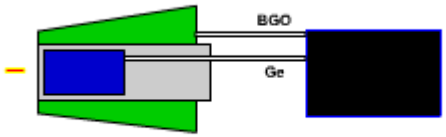


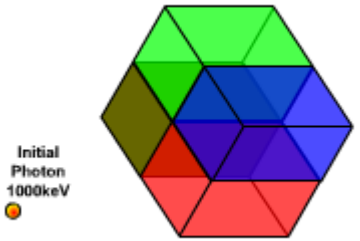
Compton suppressed Germanium detektor

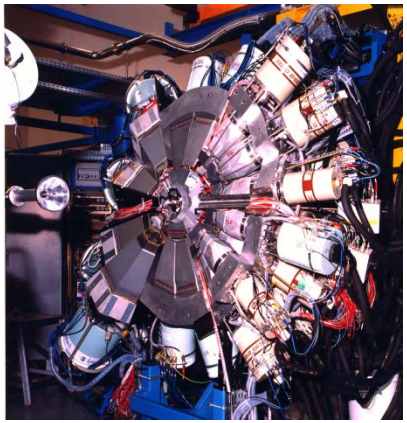


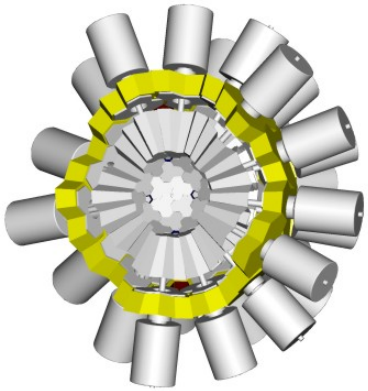
Gamma Arrays based on Compton Suppressed Spectrometers

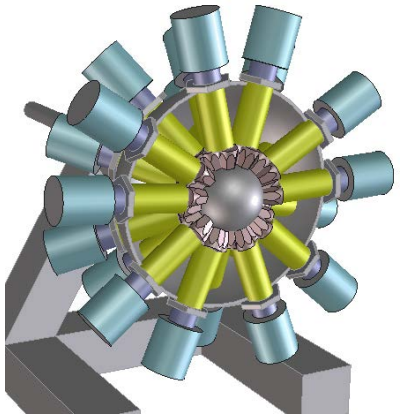
Tracking Arrays based on Position Sensitive Ge Detectors









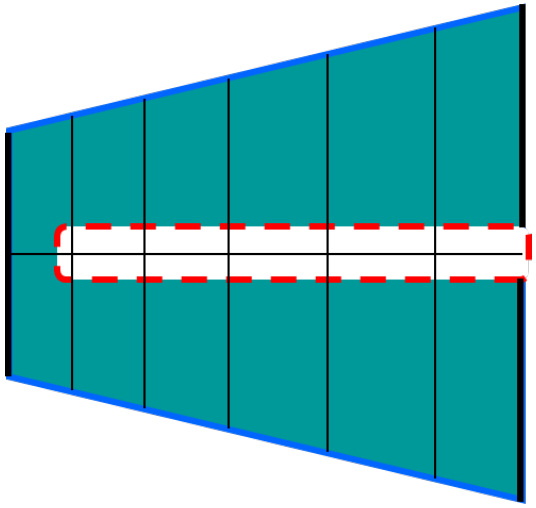


EUROBALL GAMMASPHERE AGATA GRETA

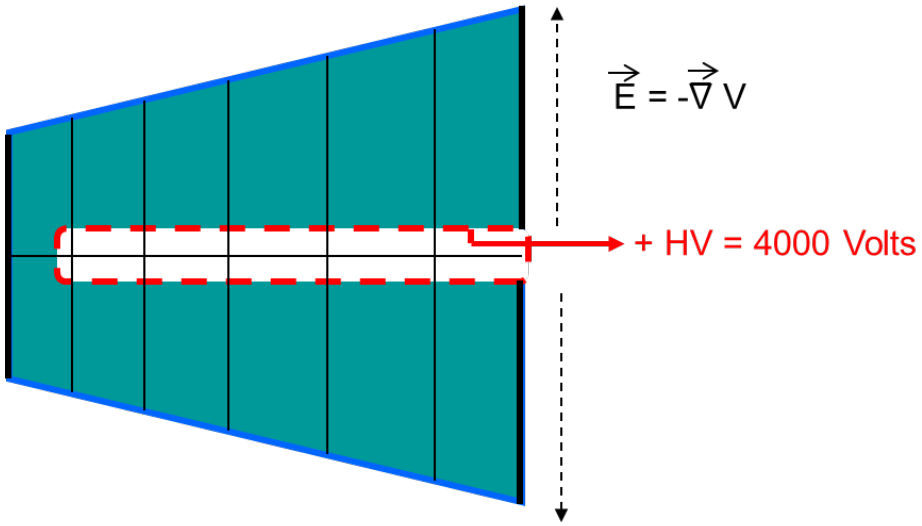
$\varepsilon \sim 10 - 7\ \%$
$(M_\gamma = 1 - M_\gamma = 30)$

$\varepsilon \sim 50 - 25\ \%$
$(M_\gamma = 1 - M_\gamma = 30)$

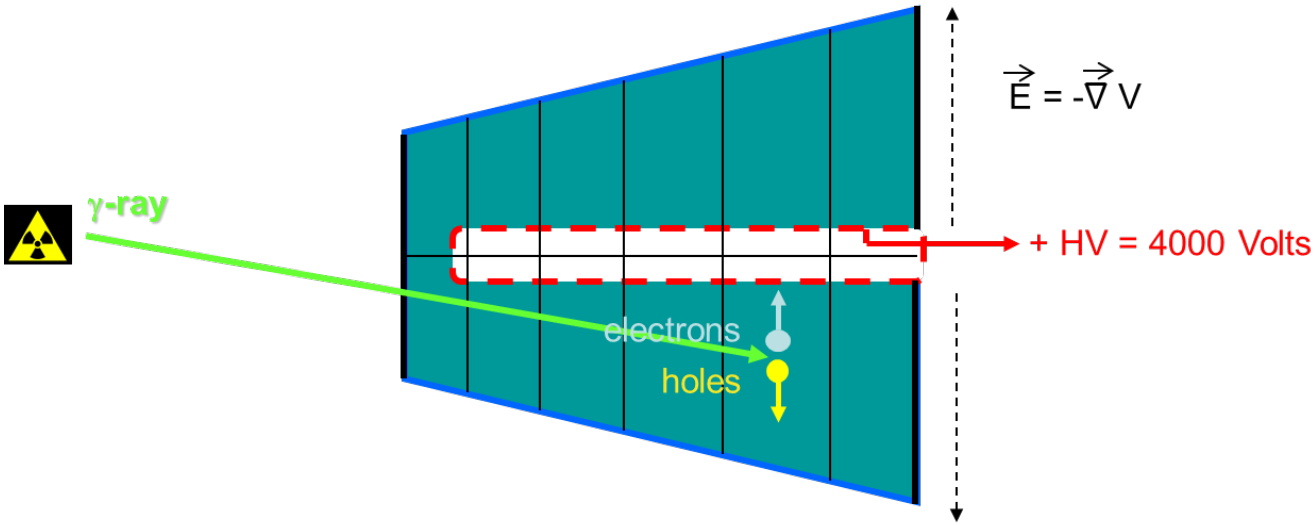
HPGe detector – working principle



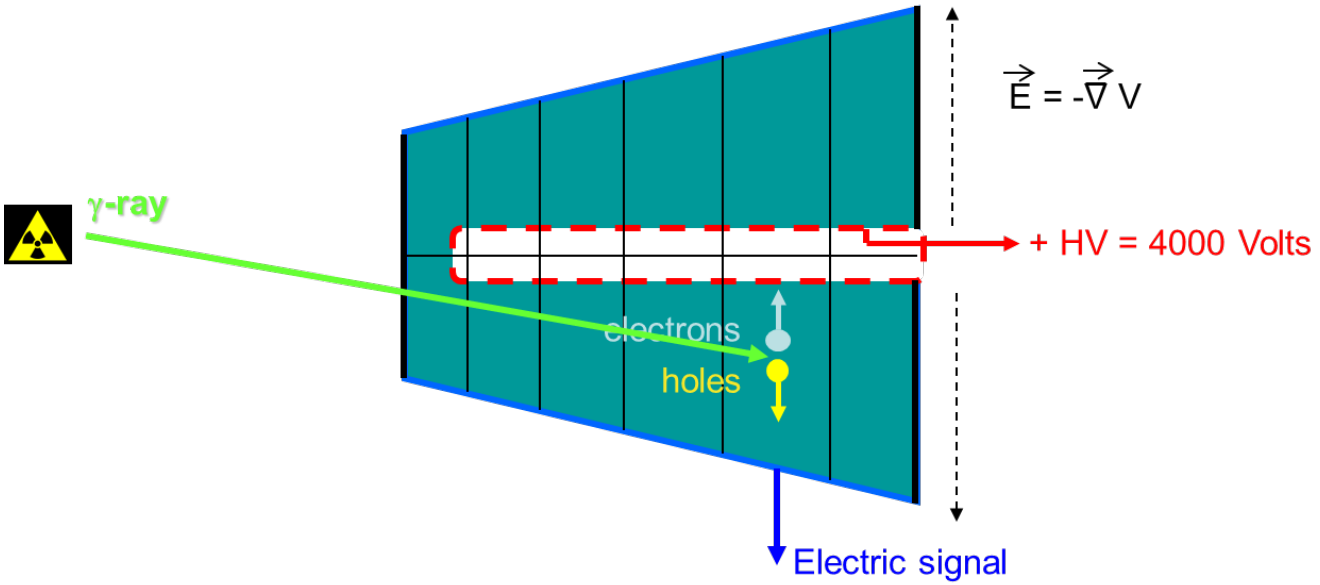
HPGe detector – working principle

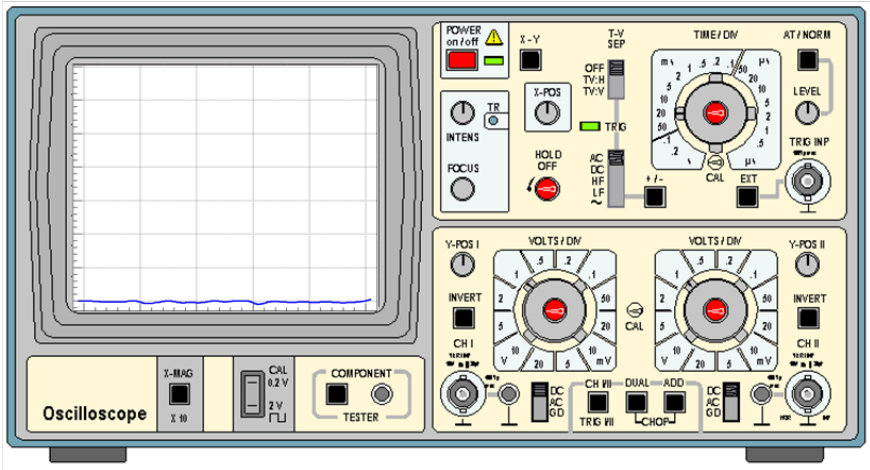


HPGe detector – working principle

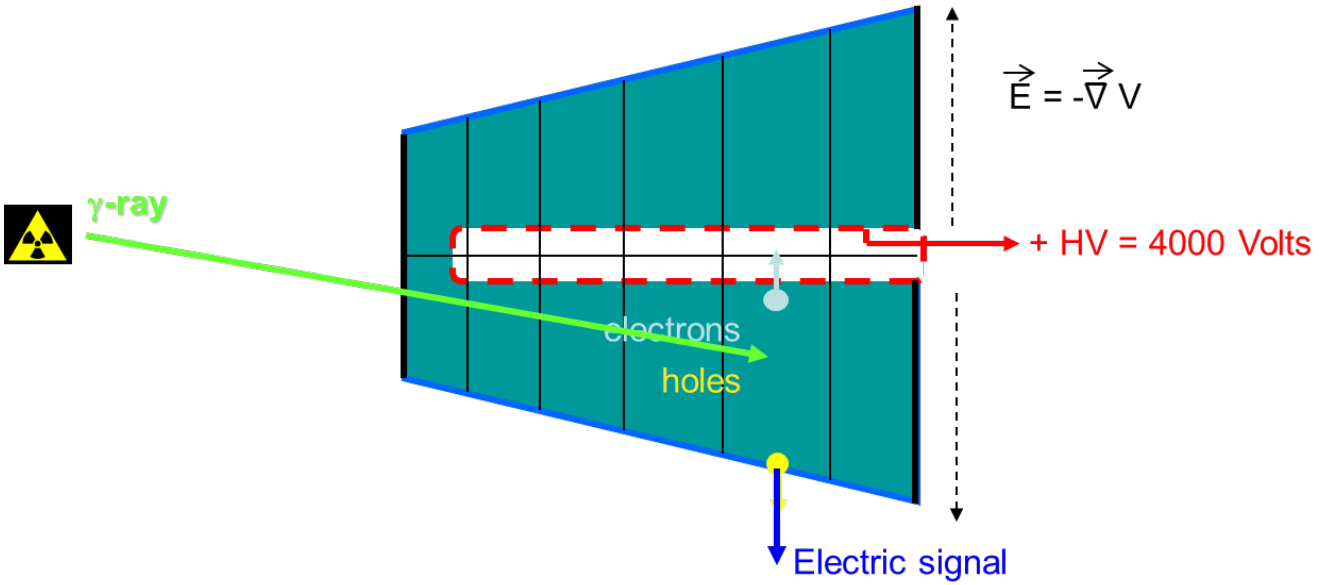


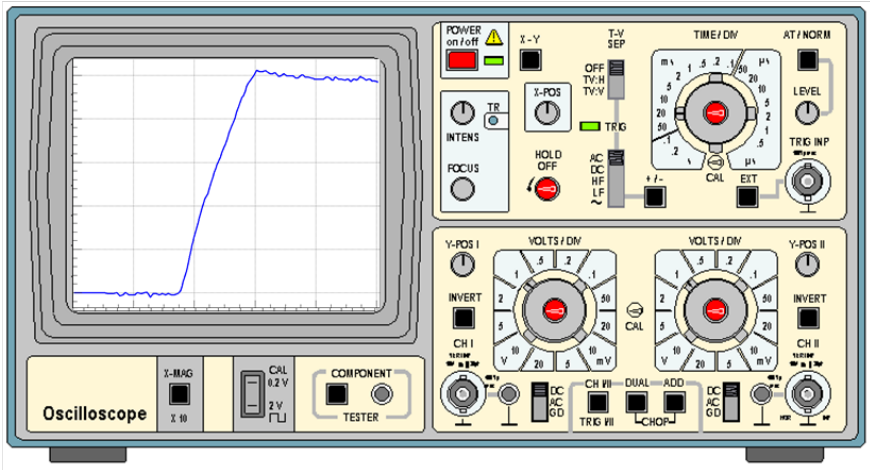
HPGe detector – working principle



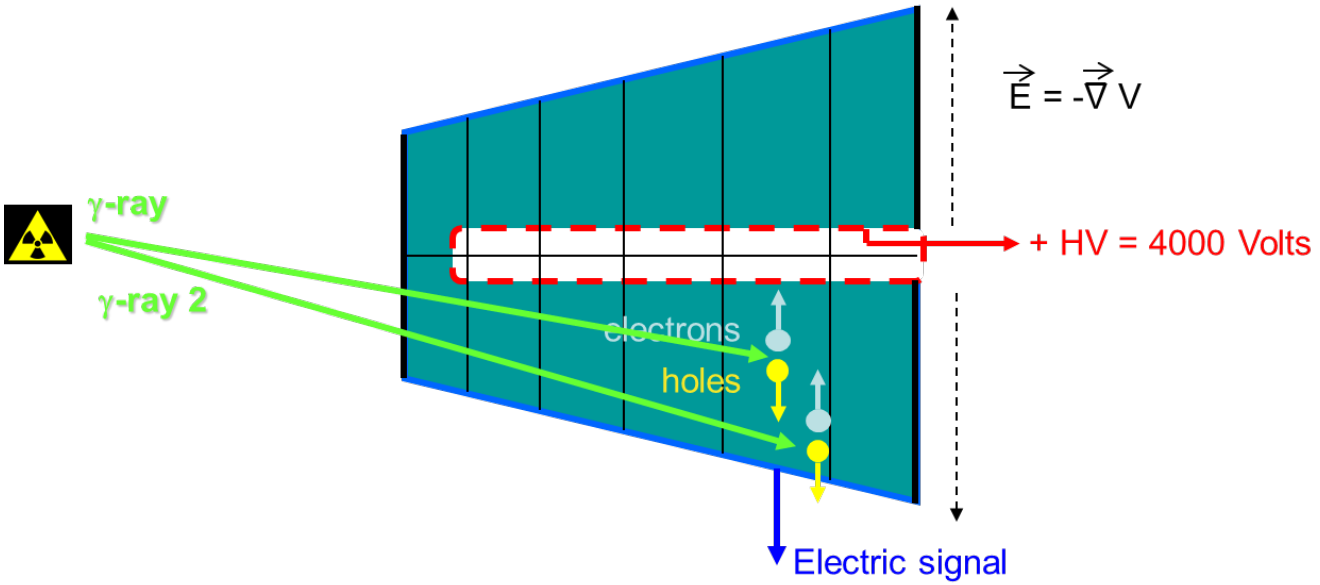


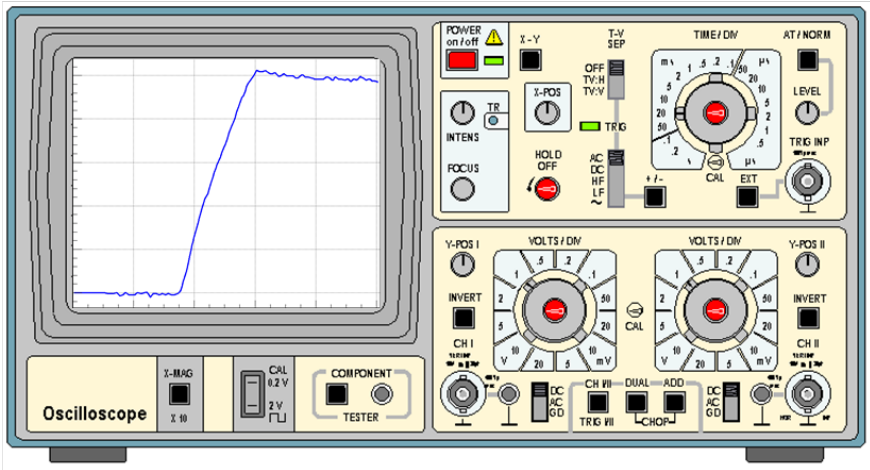
HPGe detector – working principle



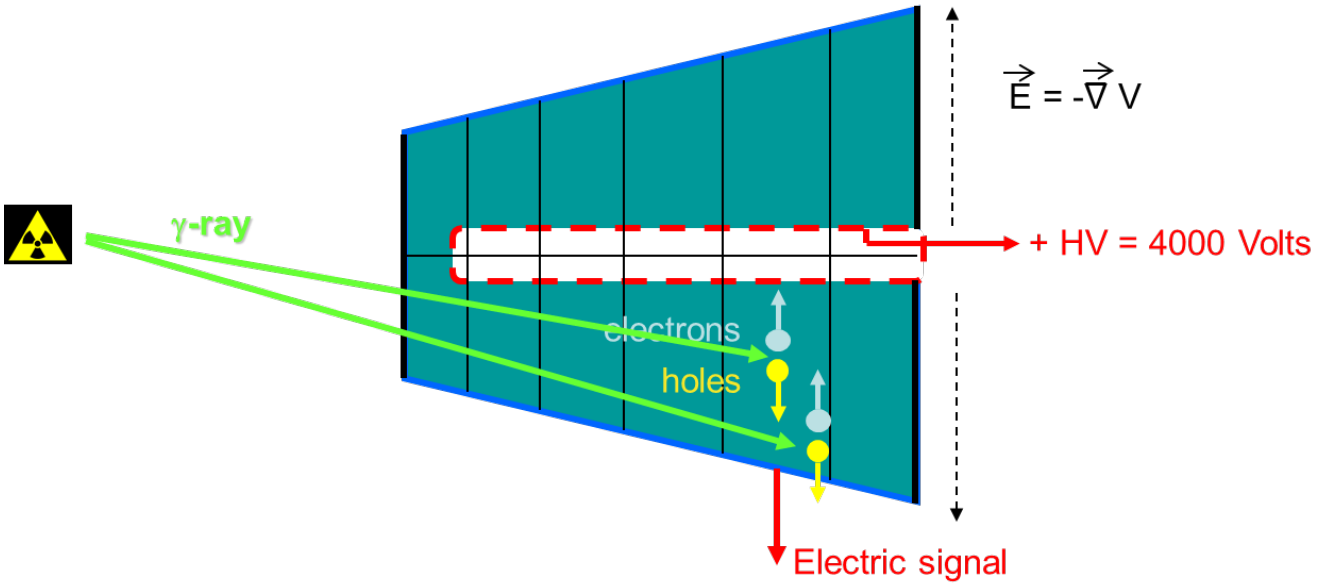


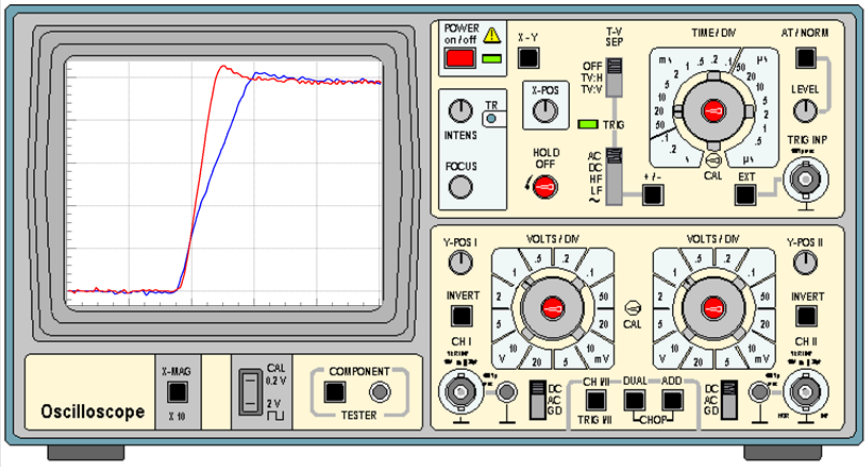
HPGe detector – position sensitivity





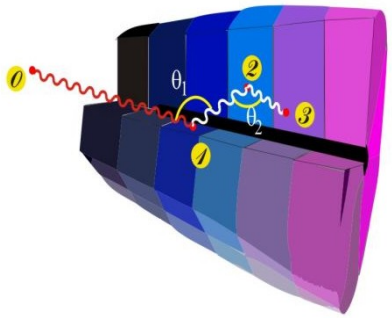
HPGe detector – position sensitivity





Ingredients of γ-ray tracking

Highly segmented HPGe detectors



AGATA:

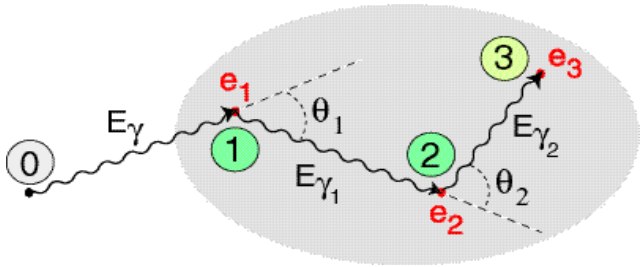
Advanced Gamma Tracking Array

Digital electronics to record and process segment signals

Pulse Shape Analysis to identify the interaction position coordinates

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

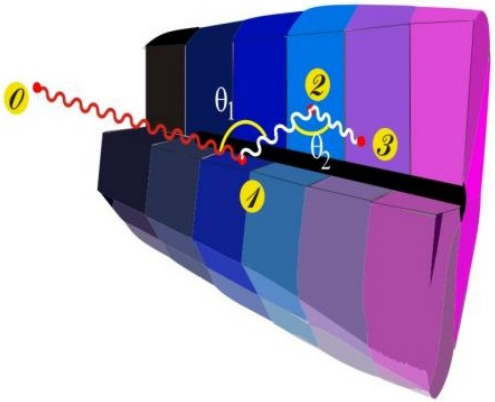
reconstructed γ-rays



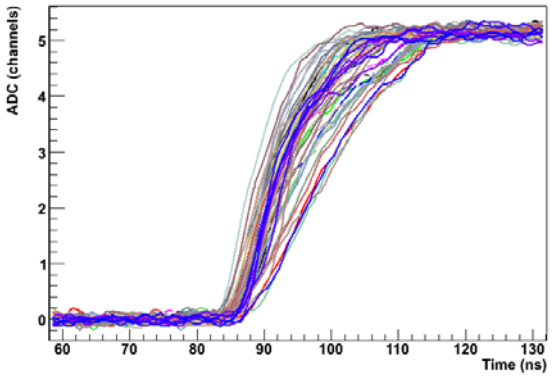
Reconstruction of tracks e.g. by evaluation of permutations of interaction points

Method to characterize the pulse shape of HPGe detectors

Determine a **data-base of pulse shapes** S(x,y,z) which allows one to correlate an arbitrarily measured pulse, with an interaction position inside the detector.



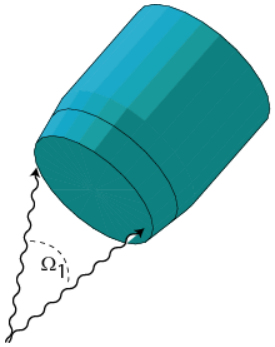
?

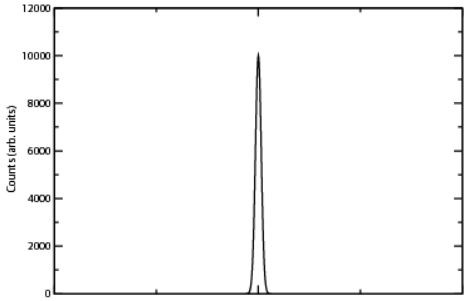


How to do this?

Using PET principle in combination with γ-ray imaging techniques !

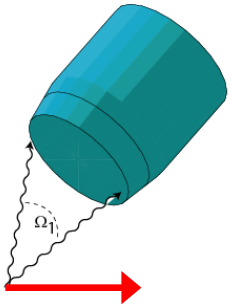
Doppler effect - Efficiency versus energy resolution

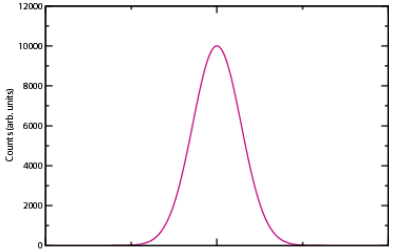




- With a source at rest, the intrinsic resolution of the detector can be reached.
- Efficiency decreases with the increasing detector-source distance.

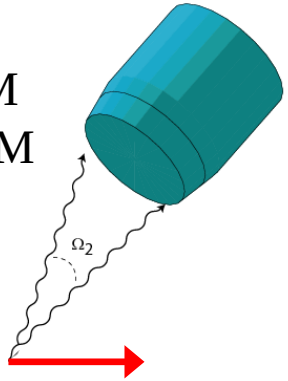
With a moving source also the effective energy resolution depends on the detector-source distance (Doppler effect)

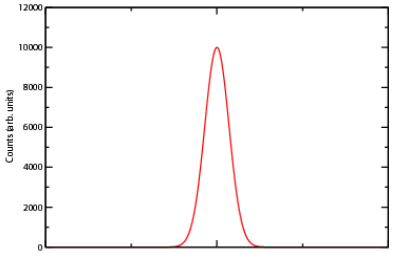




Small *d* ⟷ Large Ω ⟷ High ε ⟷ Poor FWHM

Large *d* ⟷ Small Ω ⟷ Low ε ⟷ Good FWHM





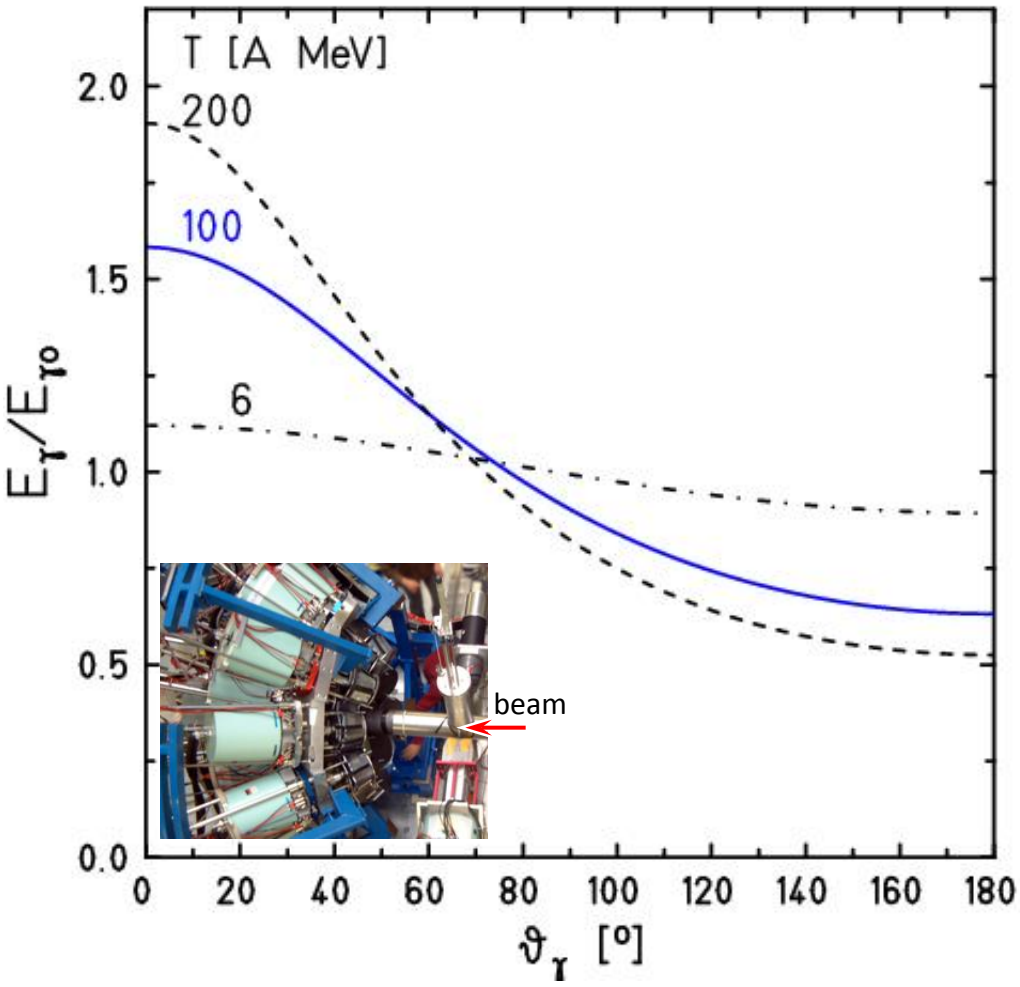
Doppler effect at relativistic energies

$$\frac{E_{\gamma 0}}{E_\gamma} = \frac{1-\beta\cdot\cos\vartheta_\gamma^{lab}}{\sqrt{1-\beta^2}}$$

for $\vartheta_p \cong 0^0$

Lorentz boost:

$$\frac{d\Omega_{rest}}{d\Omega_{lab}} = \left(\frac{E_\gamma}{E_{\gamma 0}}\right)^2$$

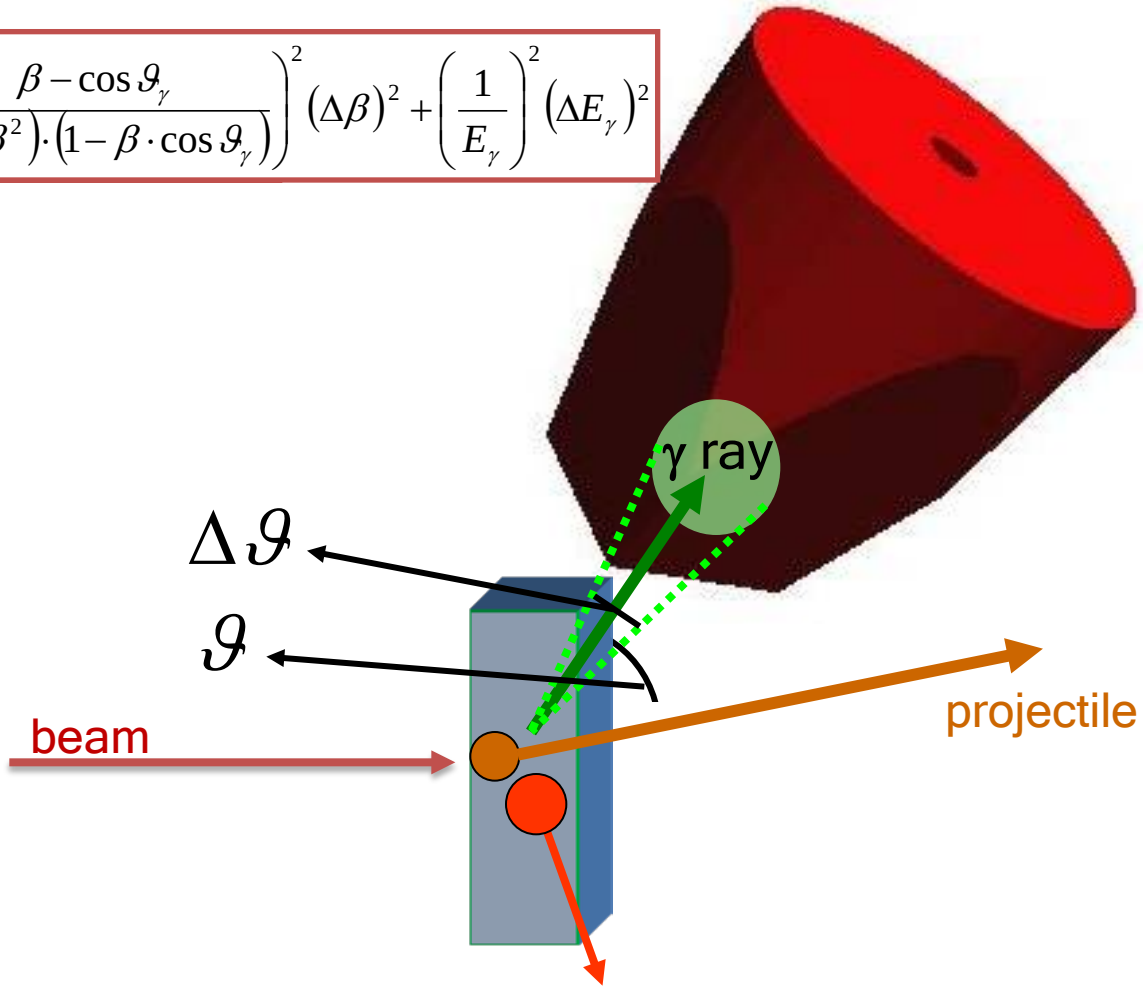


Doppler broadening and position resolution

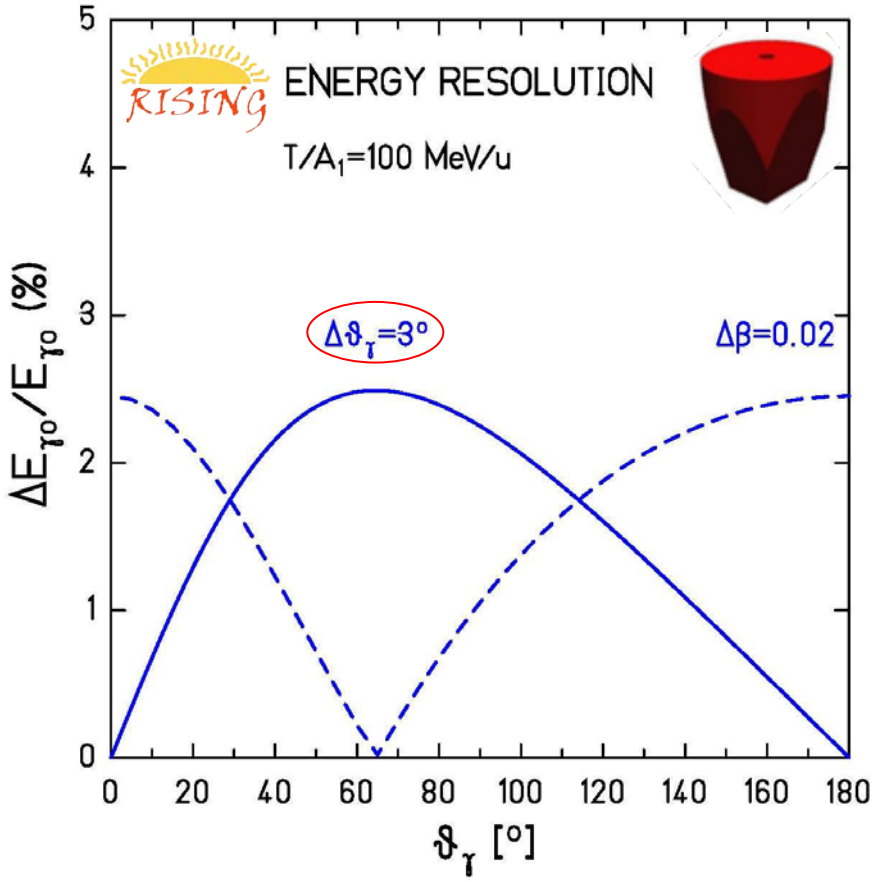
$$E_{\gamma 0} = E_{\gamma}\frac{1-\beta\cdot\cos\vartheta_{\gamma}}{\sqrt{1-\beta^2}} \qquad \left(\beta, \vartheta_p = 0^0, \vartheta_{\gamma} \text{ and } E_{\gamma} \text{ in lab} - \text{frame}\right)$$

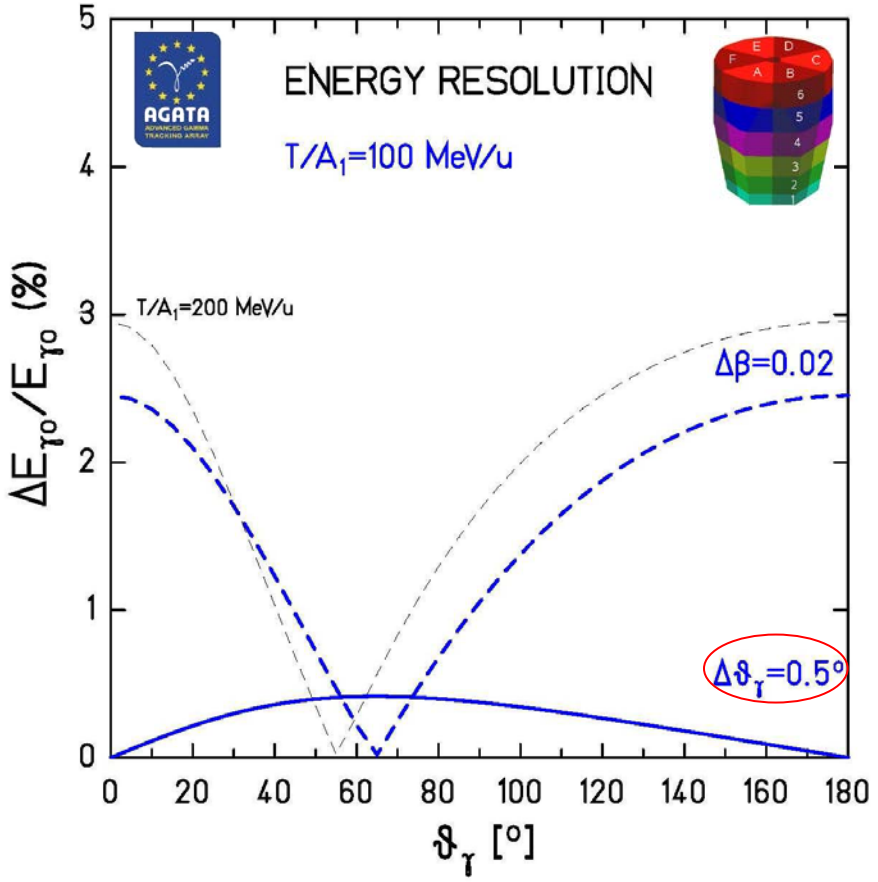
$$\left(\frac{\Delta E_{\gamma 0}}{E_{\gamma 0}}\right)^2 = \left(\frac{\beta\cdot\sin\vartheta_{\gamma}}{1-\beta\cdot\cos\vartheta_{\gamma}}\right)^2(\Delta\vartheta_{\gamma})^2 + \left(\frac{\beta-\cos\vartheta_{\gamma}}{(1-\beta^2)\cdot(1-\beta\cdot\cos\vartheta_{\gamma})}\right)^2(\Delta\beta)^2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

- Position resolution
- Angular resolution
- Energy resolution

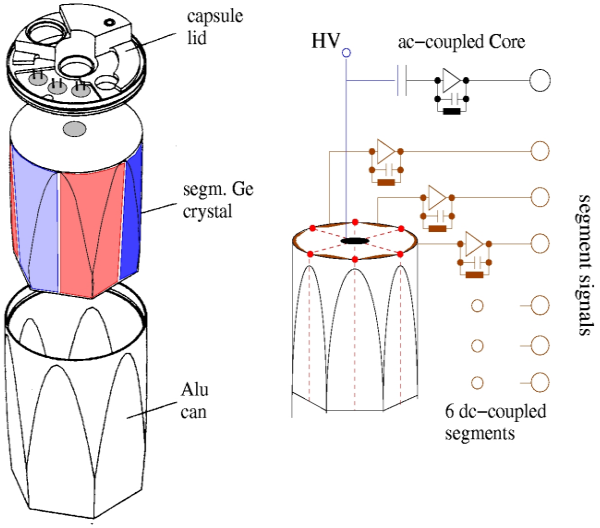


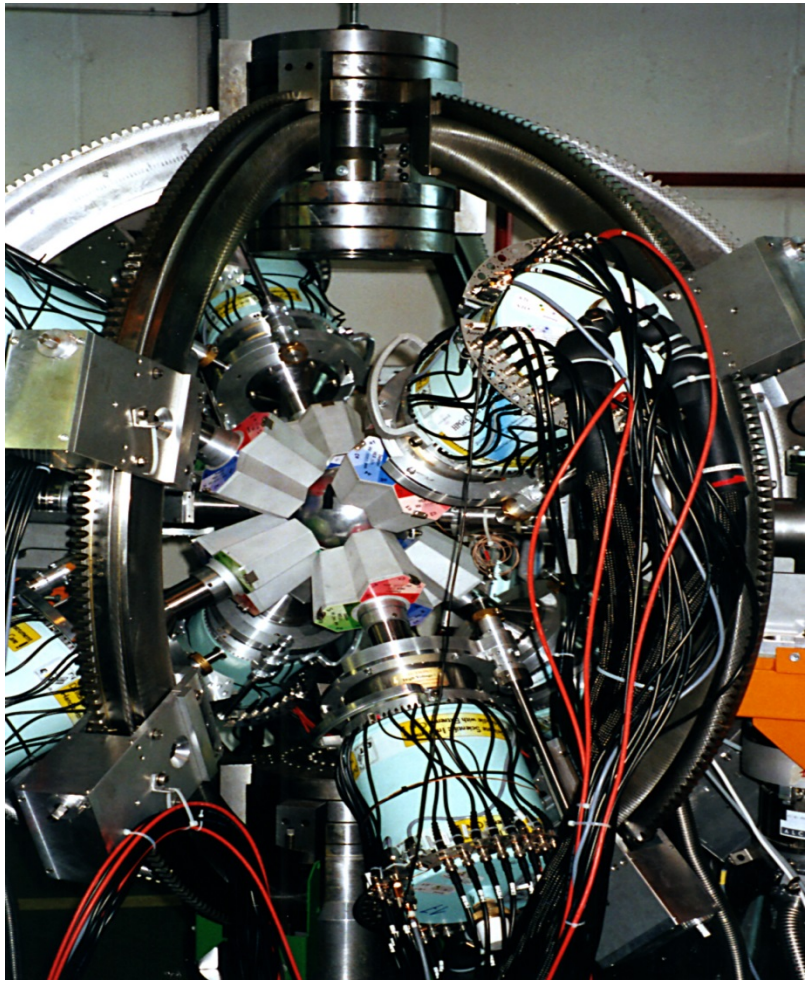
Doppler broadening





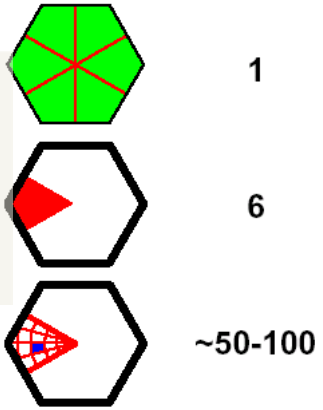
Miniball



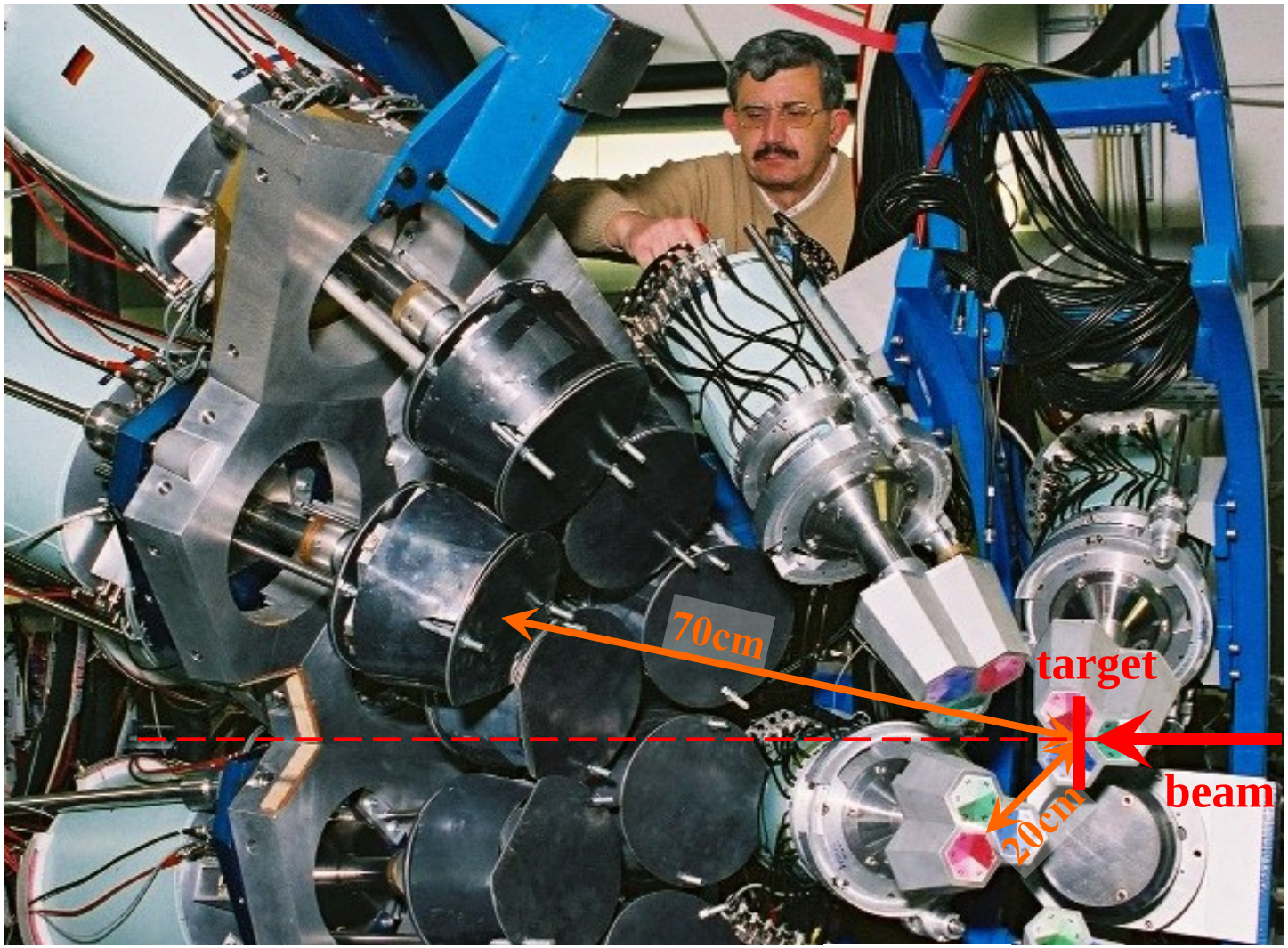


- 8 clusters à 3 6-fold segmented crystals
- total MINIBALL efficiency ~8% at 1.3 MeV
- digital electronics, on-board online pulse shape analysis (PSA) for better position resolution

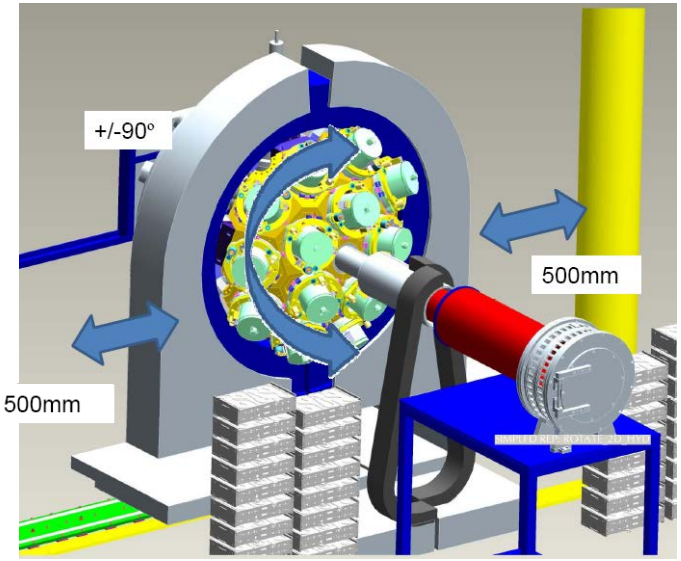
granularity:



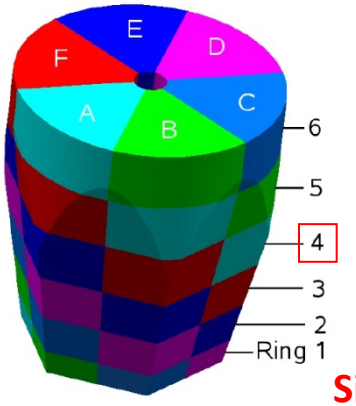
EUROBALL versus MINIBALL detectors



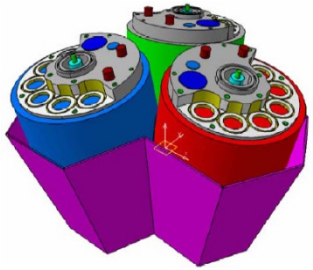
Advanced GAmma Tracking Array

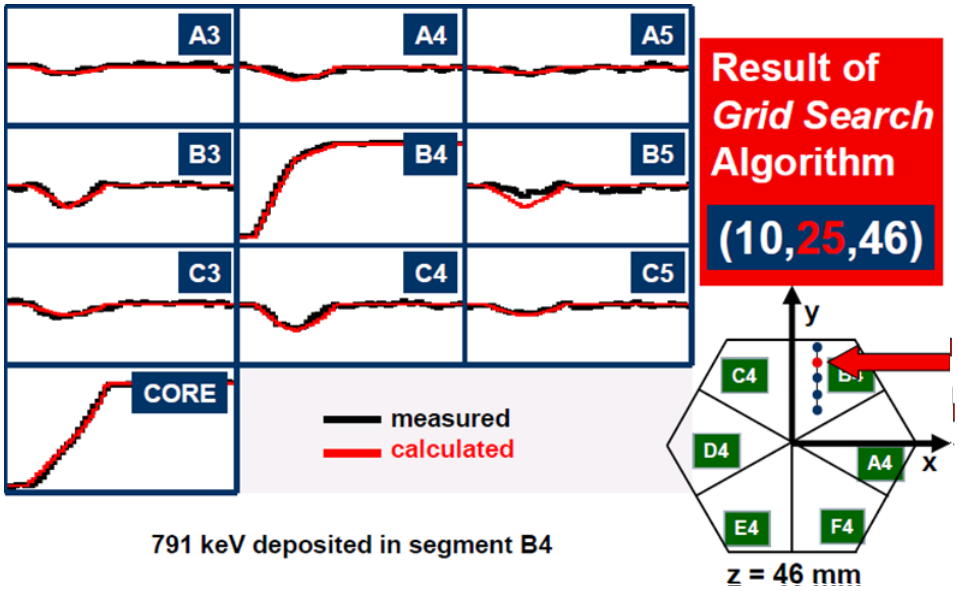


John Strachan

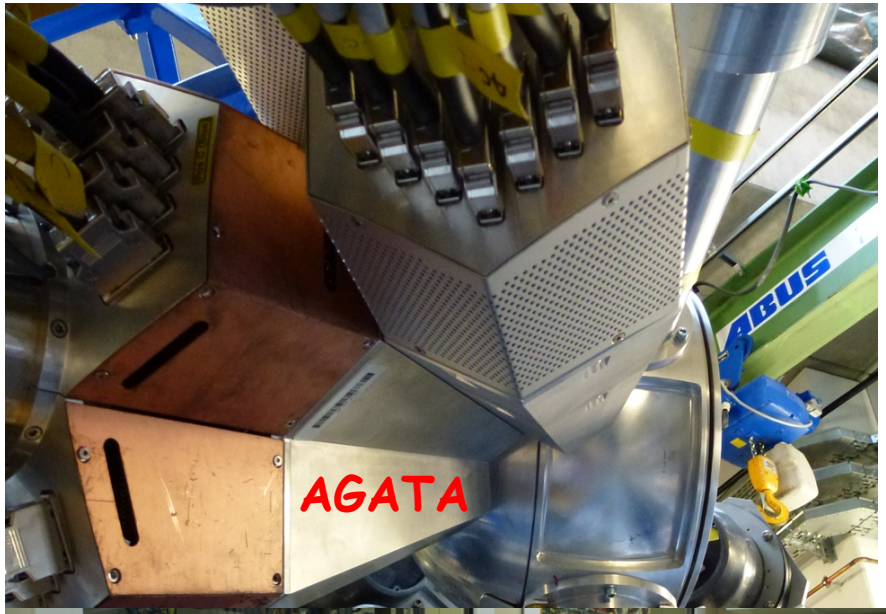


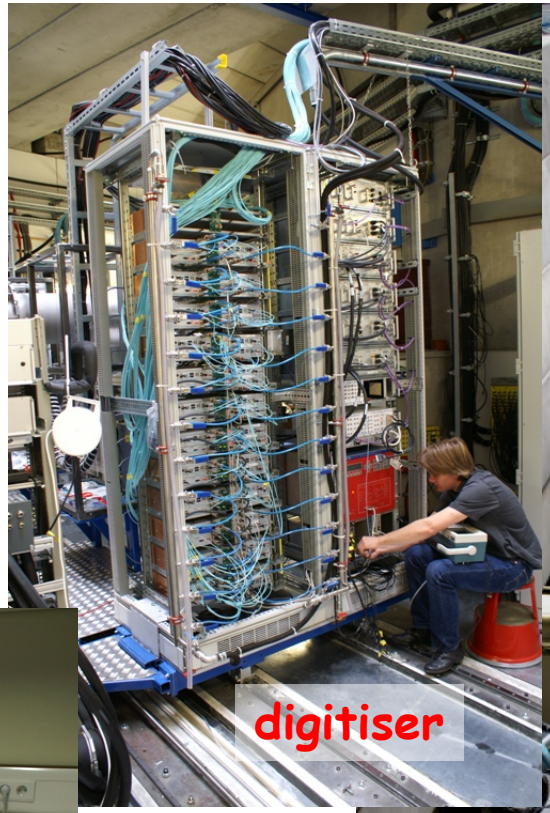
Signals from 36 segments + core are measured as a function of time (γ-ray interaction point)





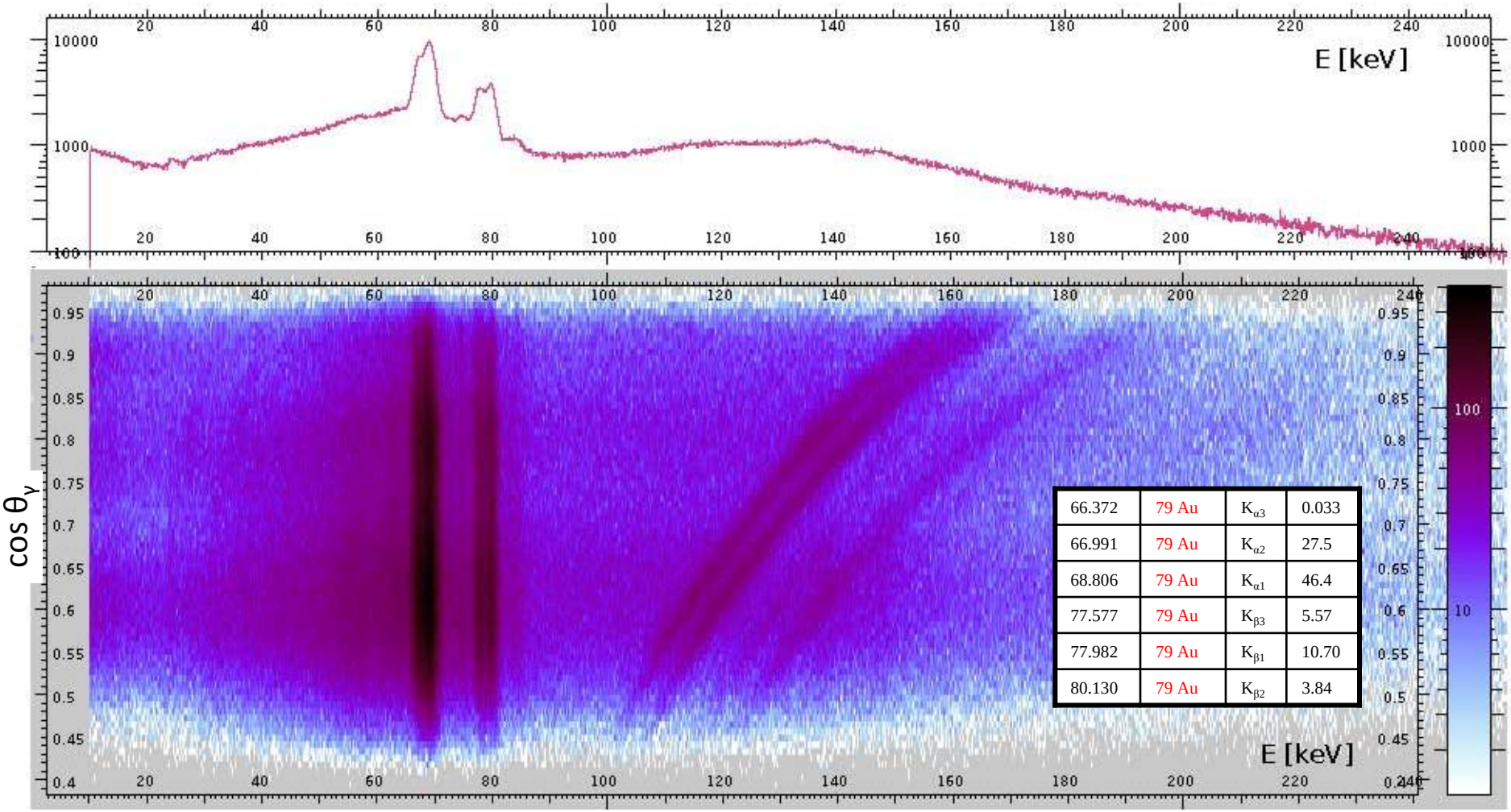
AGATA at PreSPEC



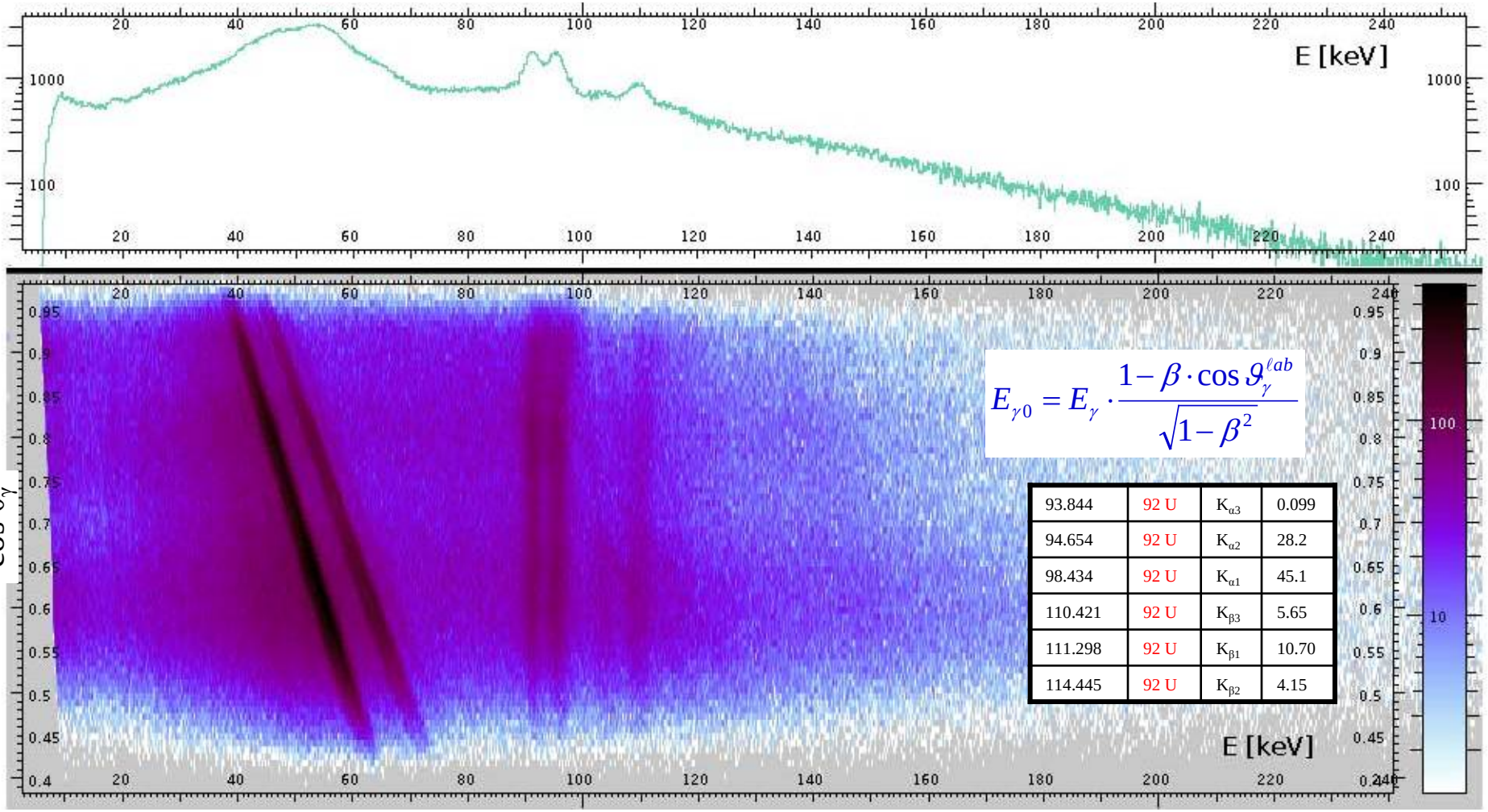


Damian Ralet,
Stephane Pietri

Doppler-shift correction ^{238}U on ^{197}Au at 183 AMeV



Doppler-shift correction ^{238}U on ^{197}Au at 183 AMeV

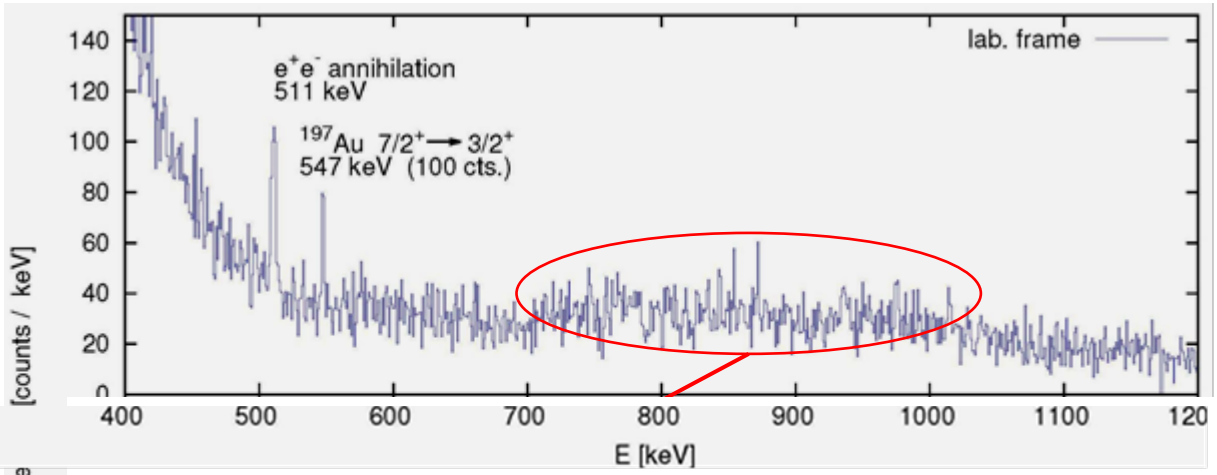


$$E_{\gamma 0} = E_{\gamma} \cdot \frac{1 - \beta \cdot \cos \vartheta_{\gamma}^{\ell ab}}{\sqrt{1 - \beta^2}}$$

93.844	92 U	$K_{\alpha 3}$	0.099
94.654	92 U	$K_{\alpha 2}$	28.2
98.434	92 U	$K_{\alpha 1}$	45.1
110.421	92 U	$K_{\beta 3}$	5.65
111.298	92 U	$K_{\beta 1}$	10.70
114.445	92 U	$K_{\beta 2}$	4.15

Scattering experiment at relativistic energies

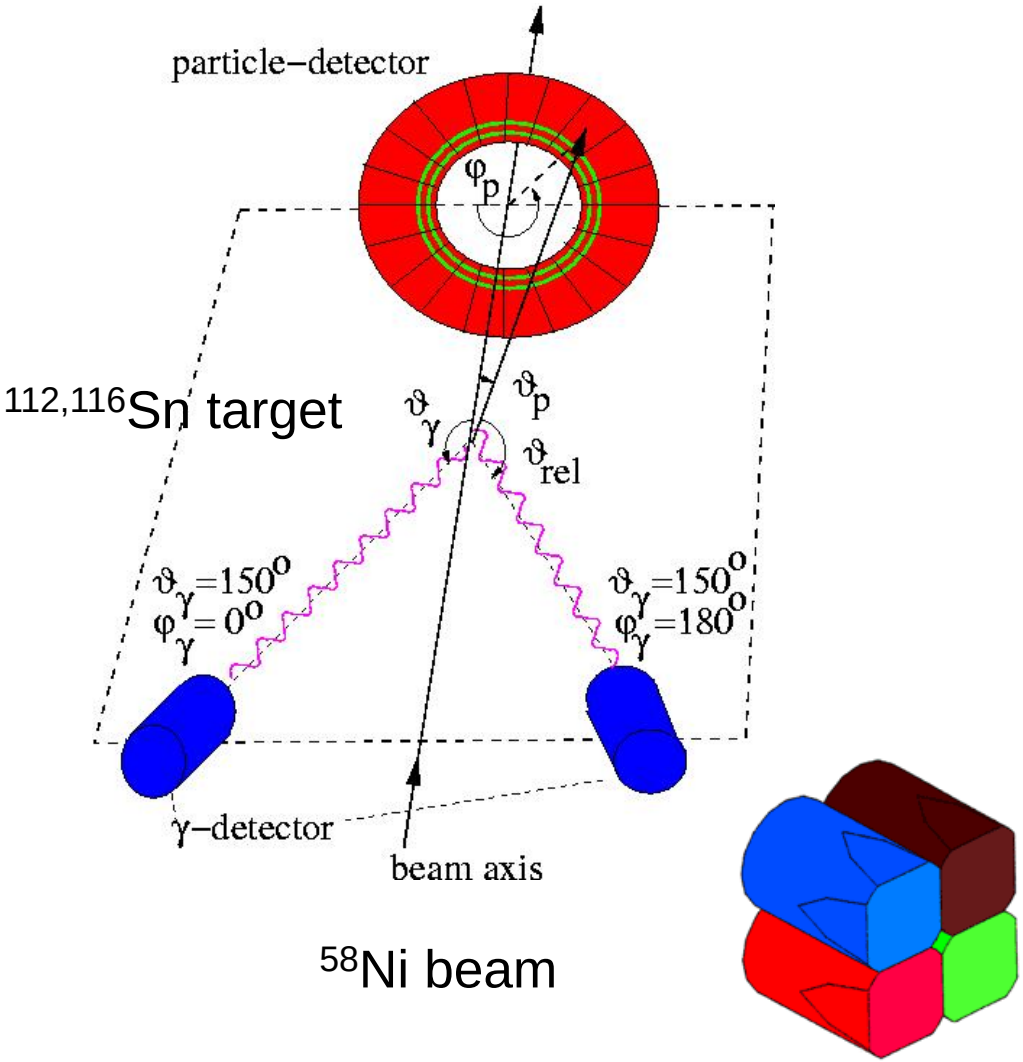
$^{80}Kr \rightarrow {}^{197}Au$, 150 AMeV



Doppler effect

$$\frac{E_{\gamma 0}}{E_{\gamma}} = \frac{1-\beta \cdot \cos \vartheta_{\gamma}^{\ell ab}}{\sqrt{1-\beta^2}}$$

Example - Coulomb excitation experiment at IUAC



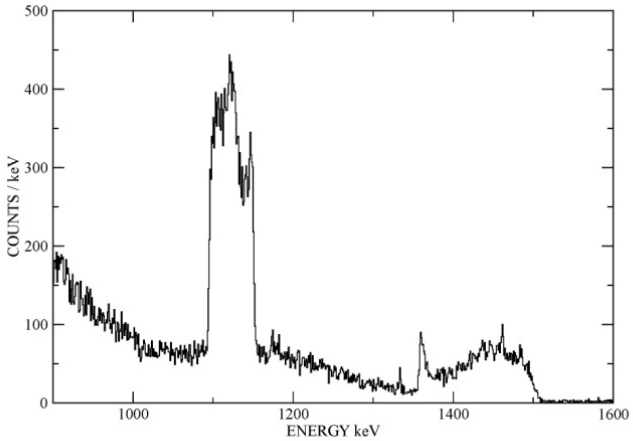
^{58}Ni → Sn at 175MeV

γ-efficiency = 0.005
accelerator duty factor=100%

beam intensity = 0.5pnA
target thickness = 0.2mg/cm^2

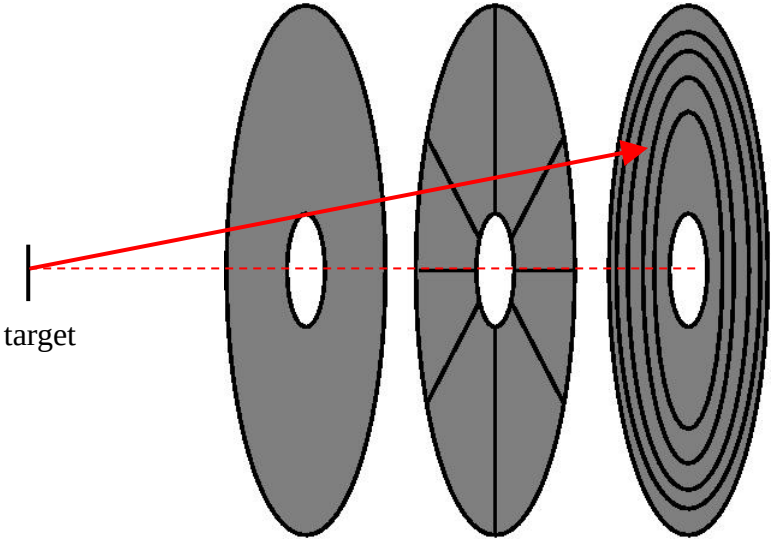
pγ-rate (Sn) = 1/s

Doppler effect depends on $(\vartheta_\gamma, \varphi_\gamma)$ and (ϑ_p, φ_p)

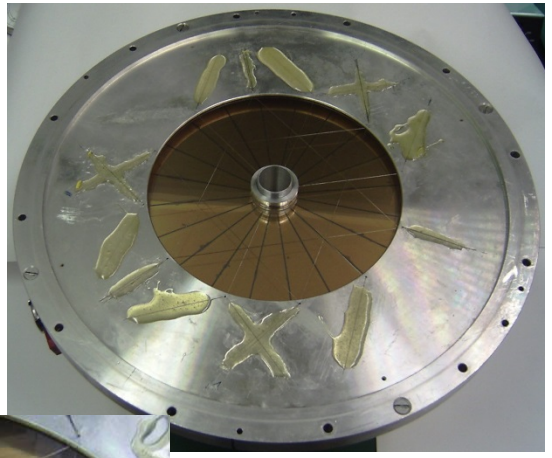


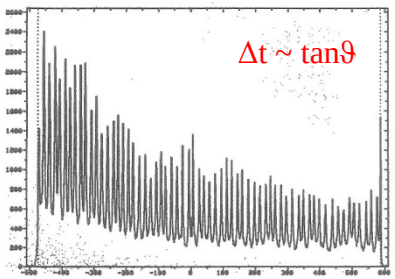
γ-ray spectrum

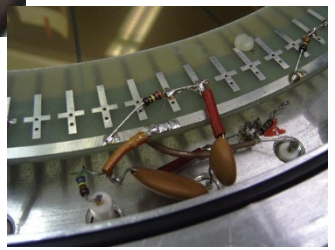
Position sensitive proportional counter



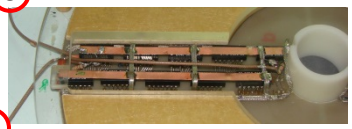
V_0 ~ 500 V
p = 5-10 Torr
~ 3 mm gap anode-cathode







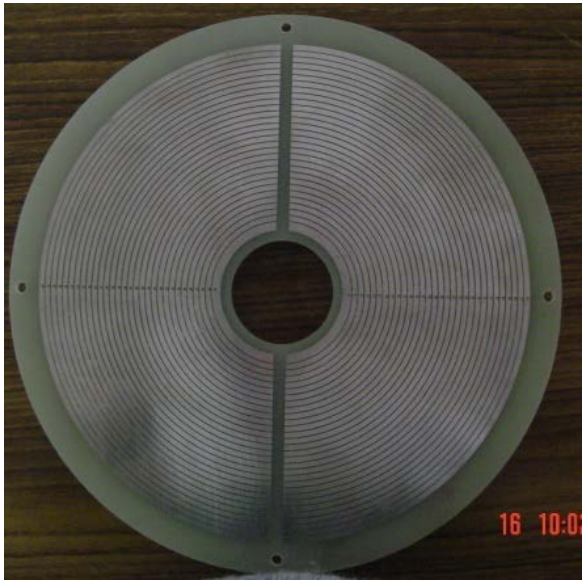
o



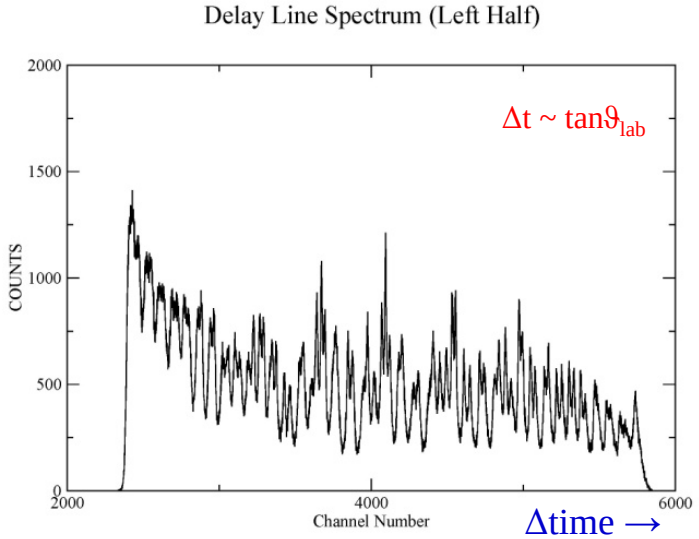
i

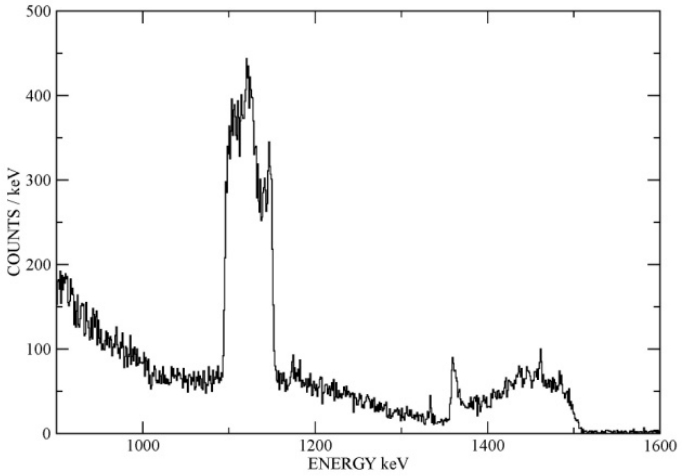
delay line

Position sensitive proportional counter



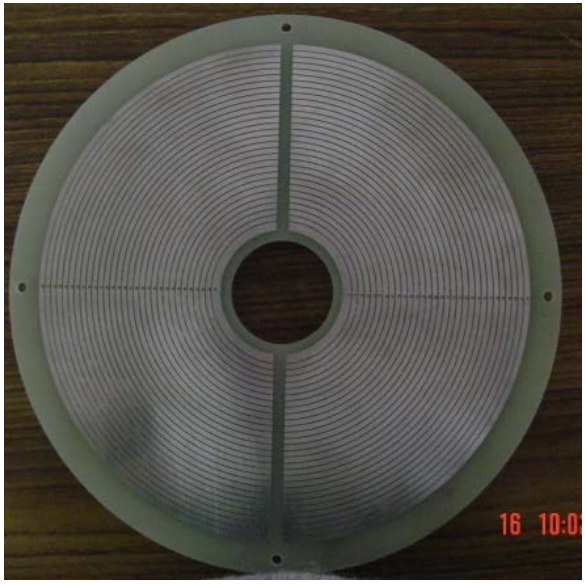
~ tan ϑ_{lab}



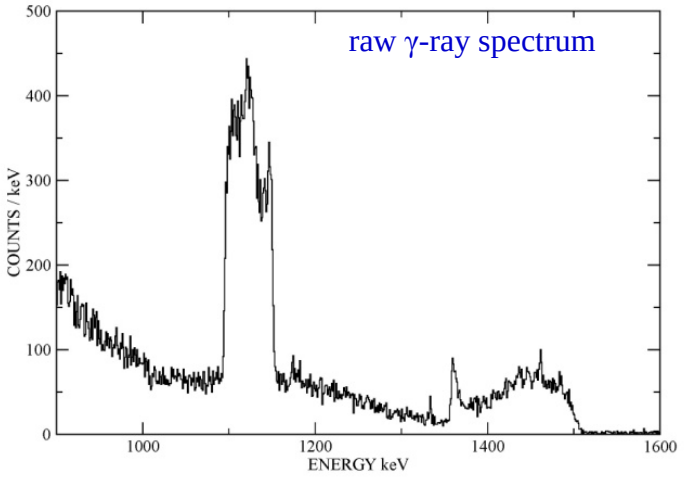


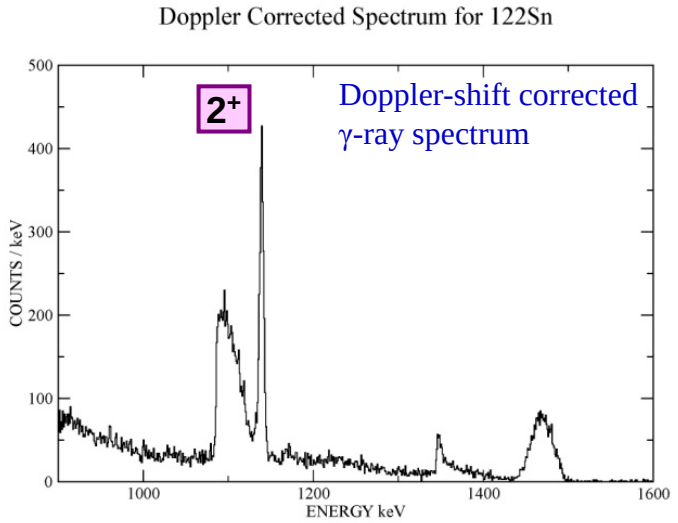
raw γ-ray spectrum

Position sensitive proportional counter

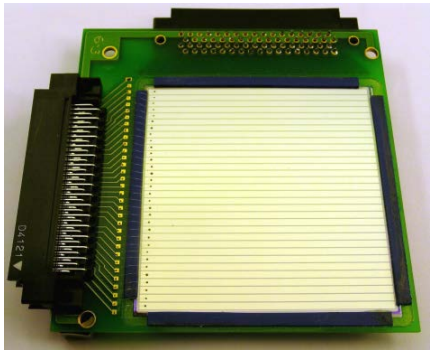


~ tan ϑ_{lab}

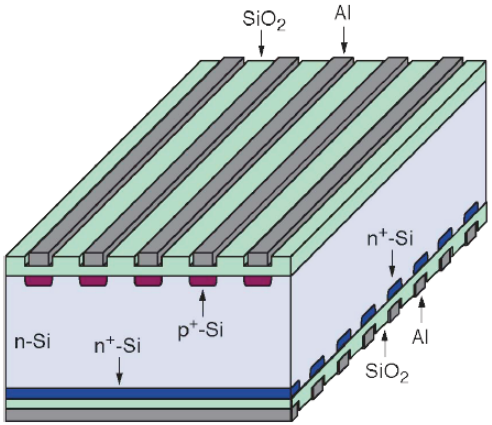


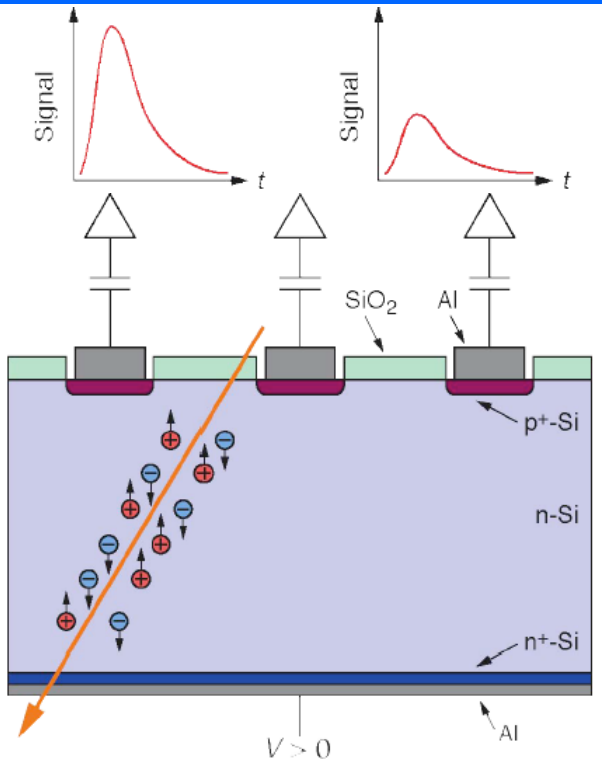


Position resolution – Double Sided Silicon Strip Detector (DSSSD)

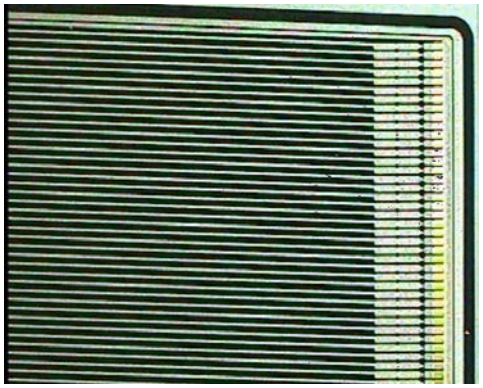


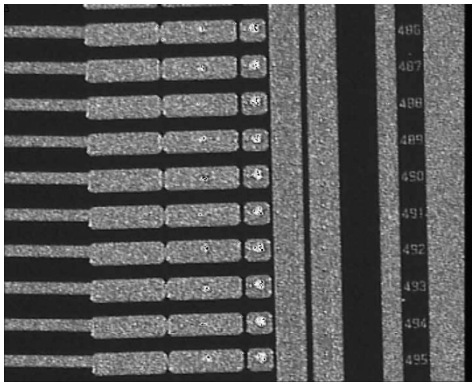
surface of a Microstrip detector



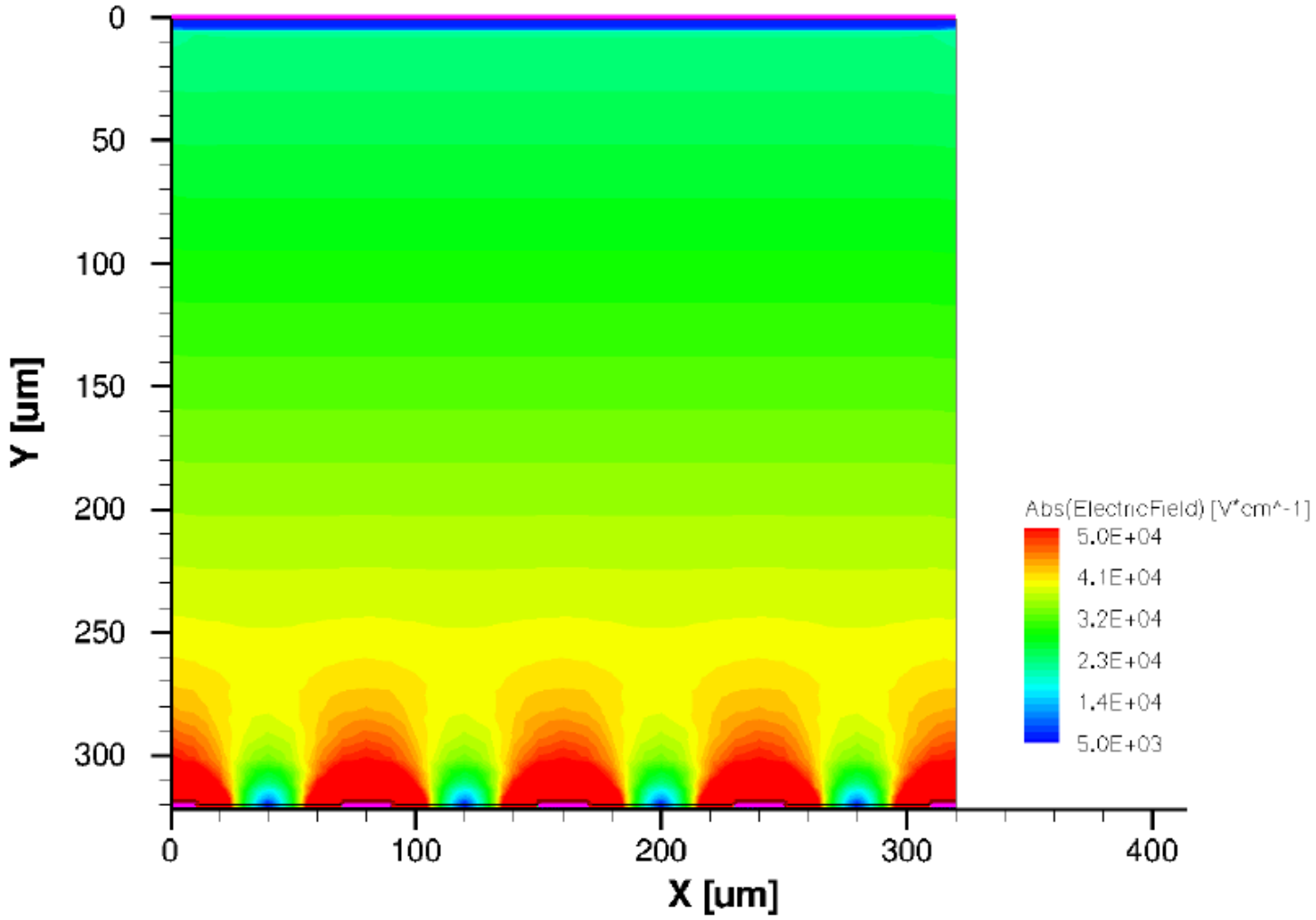


bonding pads





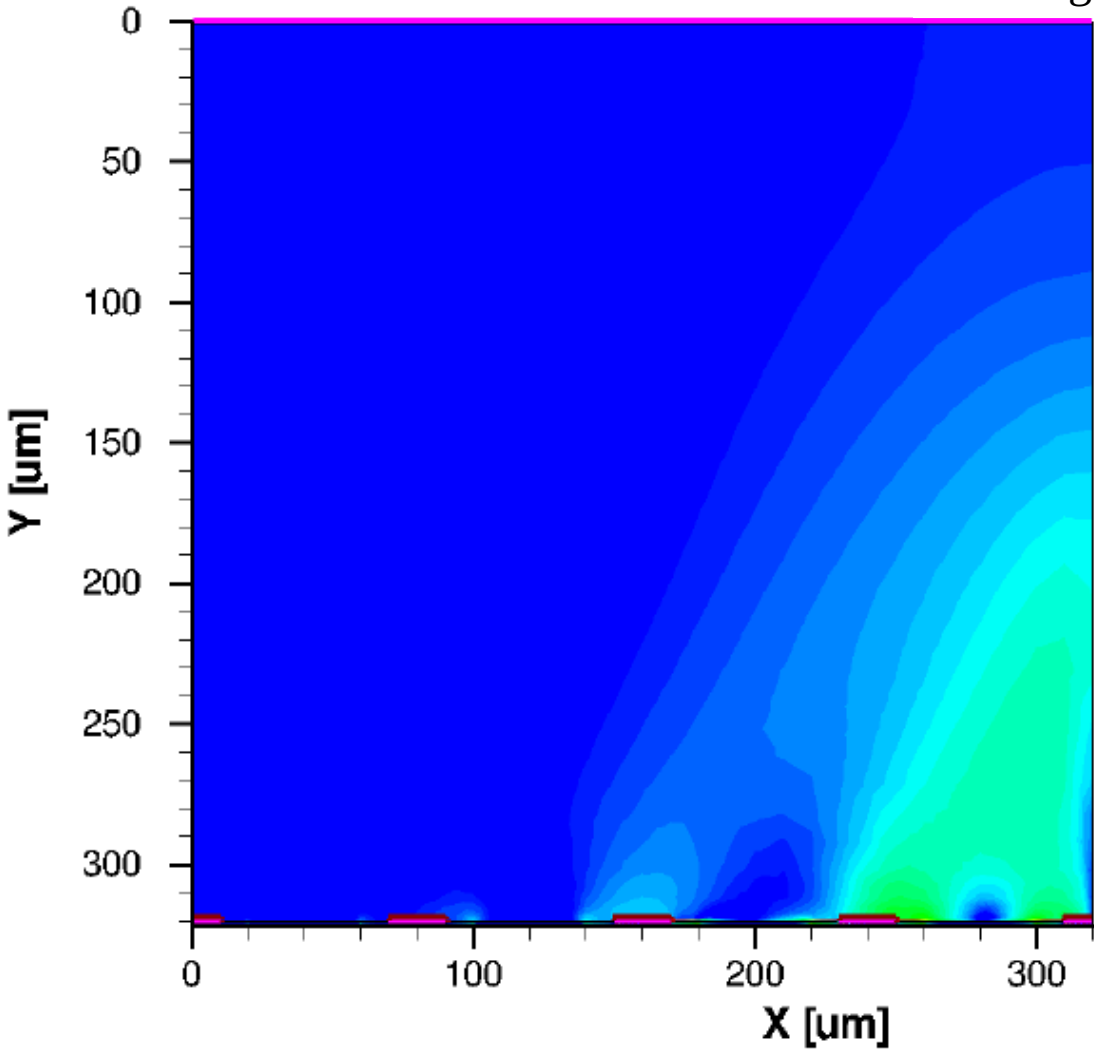
Simulation result – electrical field configuration



Thomas.Eichhorn@kit.edu

Current density

Ionizing particle with 45^0 angle t = 7.0 ns



all electrons are collected

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