École Joliot-Curie 2015

''Instrumentation, detection and simulation in modern nuclear physics''

Nuclear Structure studies using *Advanced-GAmma-Tracking* techniques

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AGATA ADVANCED GAMMA TRACKING ARRAY

World-wide projects for γ-ray spectroscopy

Use highly segmented
Ge detectors
+ digital electronics to
reconstruct the path of γ rays
in the detector medium

GRETA
(Gamma-Ray
Energy Tracking
Array)

AGATA (Advanced-Gamma-Tracking Array)

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Use highly segmented
Ge detectors
+ digital electronics to
reconstruct the path of γ rays
in the detector medium

GRETA
(Gamma-Ray Energy Tracking Array)

AGATA (Advanced-Gamma-Tracking Array)

Grand Accelerateur National d'Ions Lourdes (GANIL) France (2014 – at present)

GSI, Germany (2012-2014)
@ fragment separator

Legnaro National Lab. (2009-2012)
Demostrator phase

Outline

PART 1 (September 28th 2015)

General Introduction: Physics Motivation

1. Nuclear structure and γ-ray spectroscopy
2. Structure of neutron-rich fission fragments

γ-ray tracking: Motivation and Concept

1. In-beam γ-ray detection: requirements
2. From conventional germanium detector arrays to γ-ray tracking
3. γ-ray tracking (''philosophy'', approximations, open questions)

Pulse Shape Analysis (PSA)

1. Principle
2. Position resolution and Compton imaging

(be aware … personal ☺ selection of topics!)

Outline

PART 2 (September 29^{th} 2015)

Pulse Shape Analysis (PSA)

1. Signal bases calculation
2. Signal decomposition

Some results from Ge position sensitive mode operation and γ-ray tracking

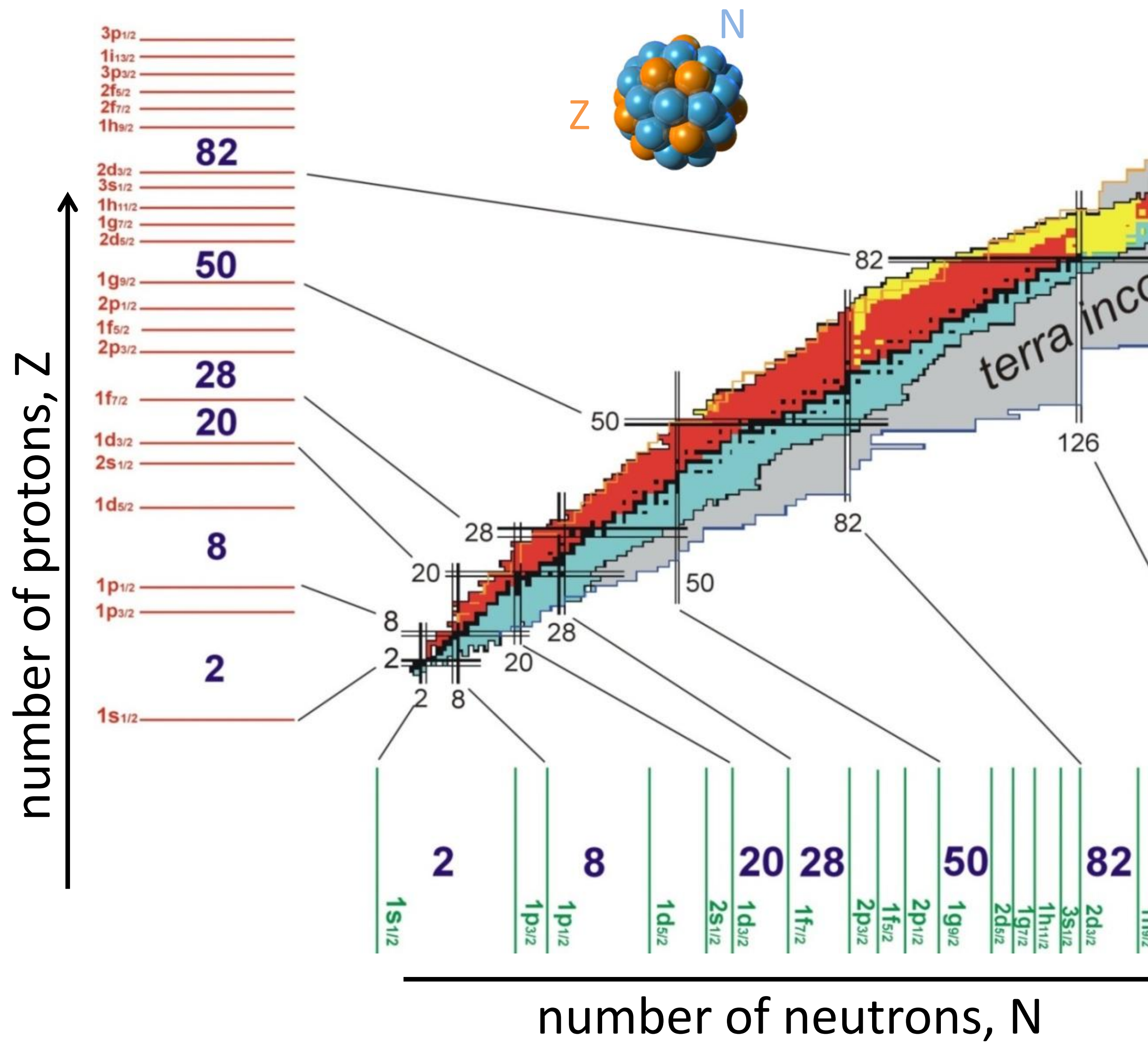
The AGATA array of segmented HPGe detectors

1. Implementation of Pulse Shape Analysis and Tracking concepts
2. The AGATA detectors and preamplifiers
3. The structure of electronics and data acquisition
4. Digital signal processing (at high counting rate)
5. (AGATA data processing)

AGATA+VAMOS (magnetic spectrometer) at GANIL

(be aware … personal ☺ selection of topics!)

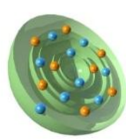
The Atomic Nucleus



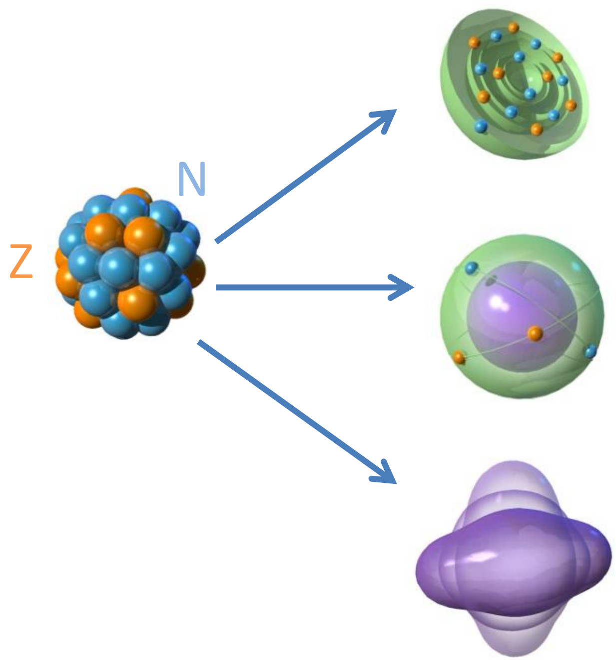
NOBEL PRIZE 1963

Maria Goeppert Mayer
1906 - 1972
*PR*75, 1969 (1949)
J. Hans D. Jensen
(1907 – 1973)
PR75, 1766 (1949)

The Nuclear Shell Model



Nuclear Excitations



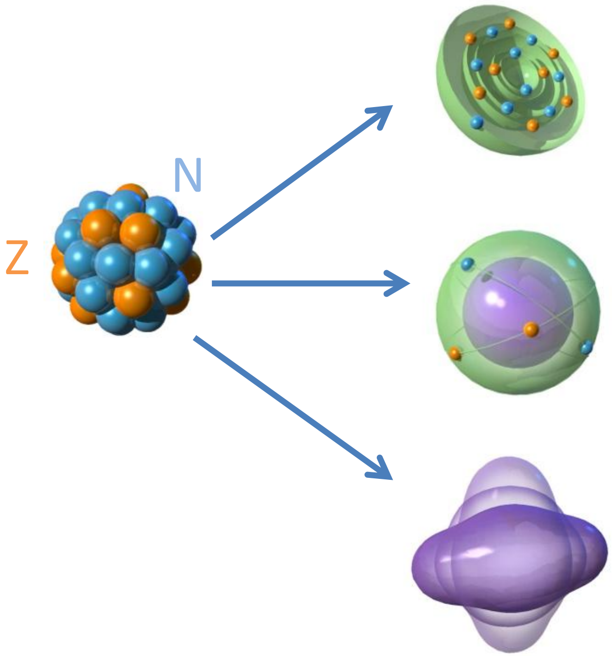
Shell Model

Cooper Pairs

Collective Excitations

Need to tune model parameters collecting nuclear experimental information

Nuclear Excitations



Shell Model

Cooper Pairs

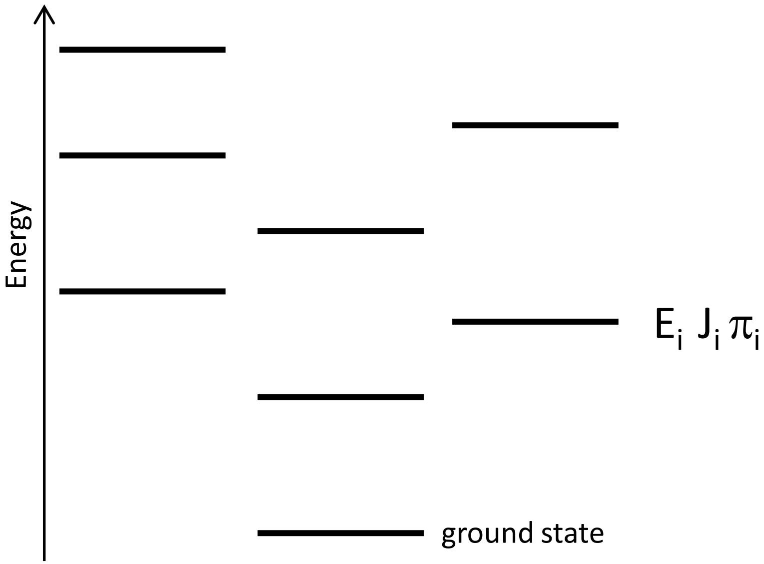
Collective Excitations

Need to tune model parameters collecting nuclear experimental information

Test of nucleon-nucleon interaction
by comparing the experimental results to model prediction

What is the effective nucleon-nucleon interaction?
What are the limits of existence for bound nuclei (*driplines*) ?

The Structure of the Nucleus



- ✓ systematics (e.g. shape transitions)
- ✓ benchmarks for nuclear models (e.g. Nuclear Shell Model)

Observables:

✓energy levels (E_i)

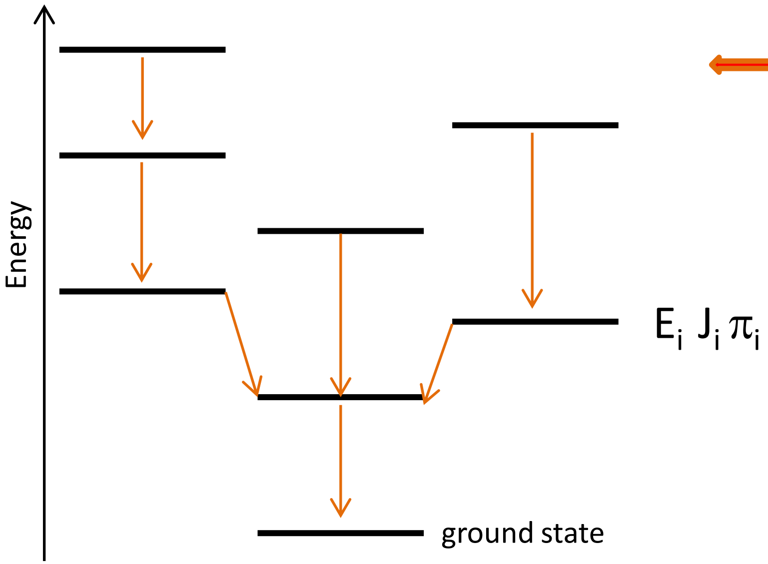
✓spin (J_i)

✓parity (π_i)

✓lifetime (transition probabilities) (τ_i)

✓nuclear moments (g-factors)

The Structure of the Nucleus



populate in excited state(s) and observe γ ray de-excitation radiation

γ ray spectroscopy is an approach for the study of nuclear structure

- ✓ systematics (e.g. shape transitions)
- ✓ benchmarks for nuclear models (e.g. Nuclear Shell Model)

Observables:

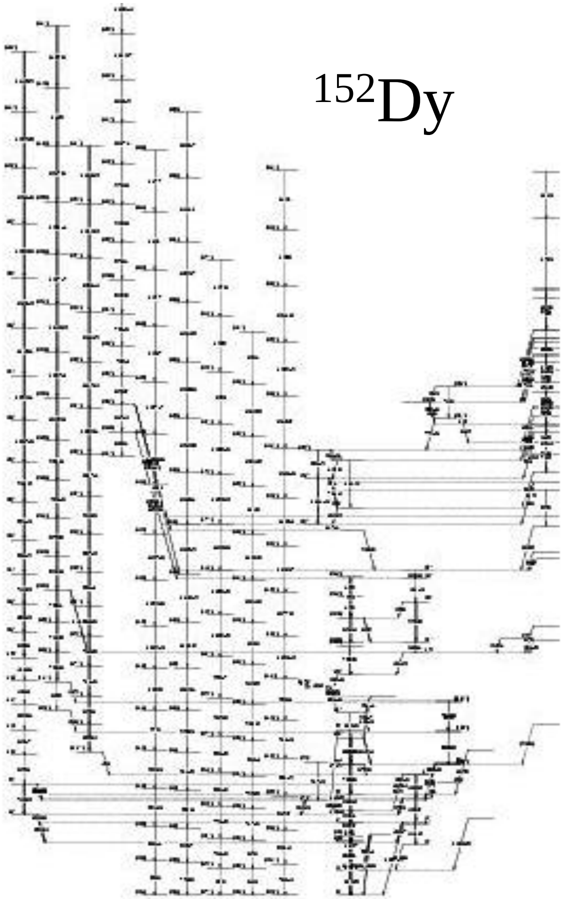
- ✓energy levels (E_i)
- ✓spin (J_i)
- ✓parity (π_i)
- ✓lifetime (transition probabilities) (τ_i)
- ✓nuclear moments (g-factors)

Measuring γ-ray:

- ✓energy
- ✓angular distribution
- ✓linear polarization
- ✓energy Doppler shift (for example)
- ✓angular distribution vs t

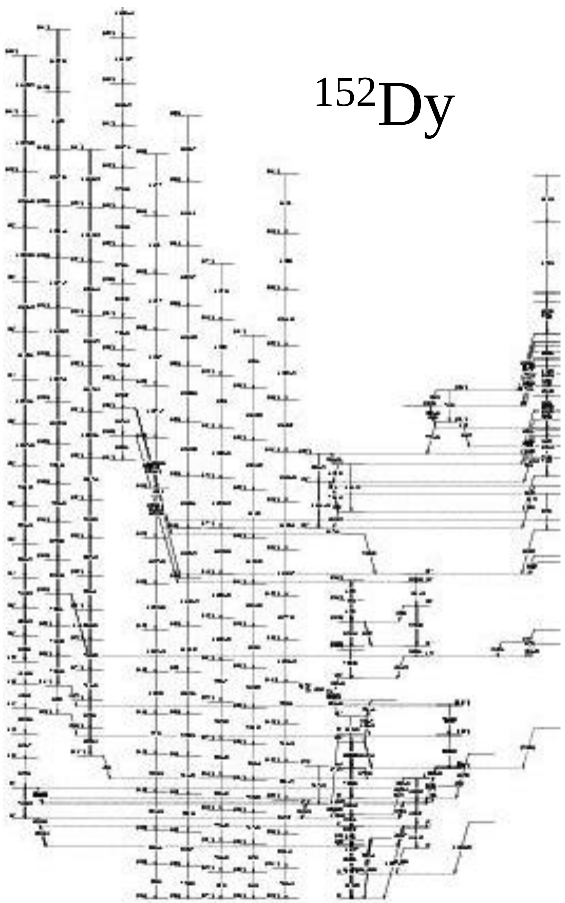
Level schemes vs Energy spectra

What we want ...

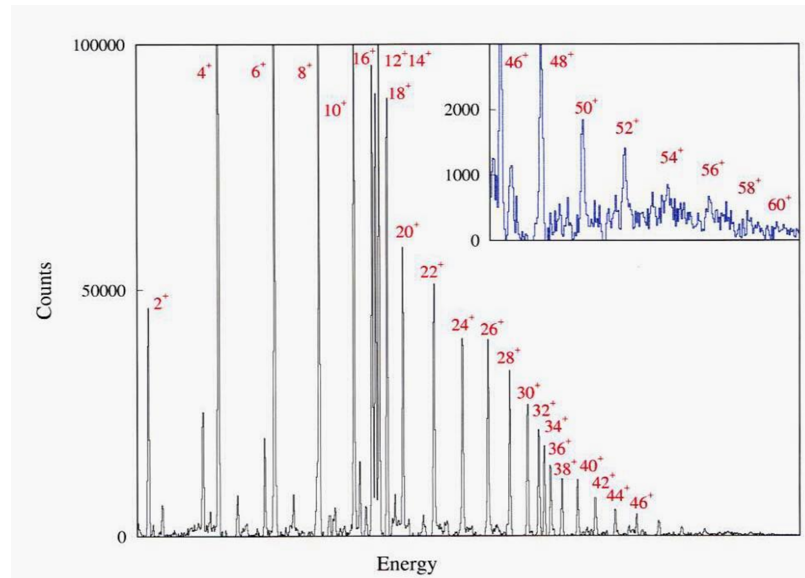


Level schemes vs Energy spectra

What we want ...



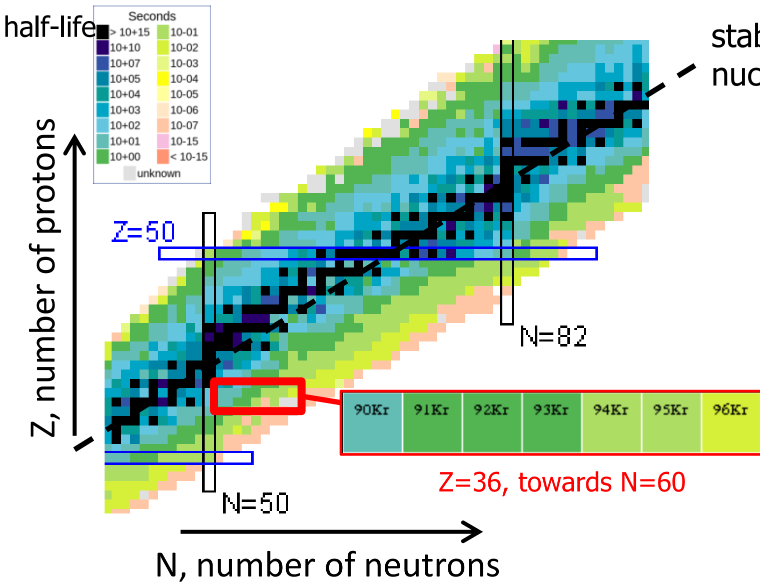
What we get ...



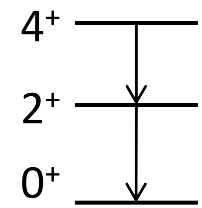
"Allegoria della pazienza"
G. Vasari

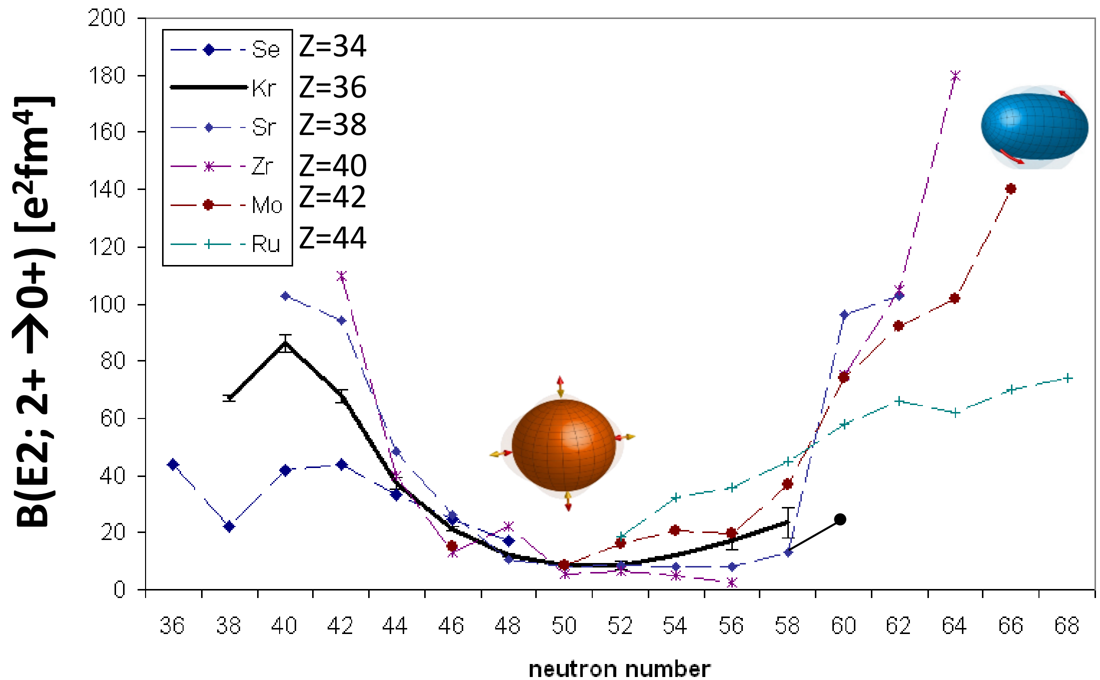
Analysis of complex spectra
with many lines close in energy

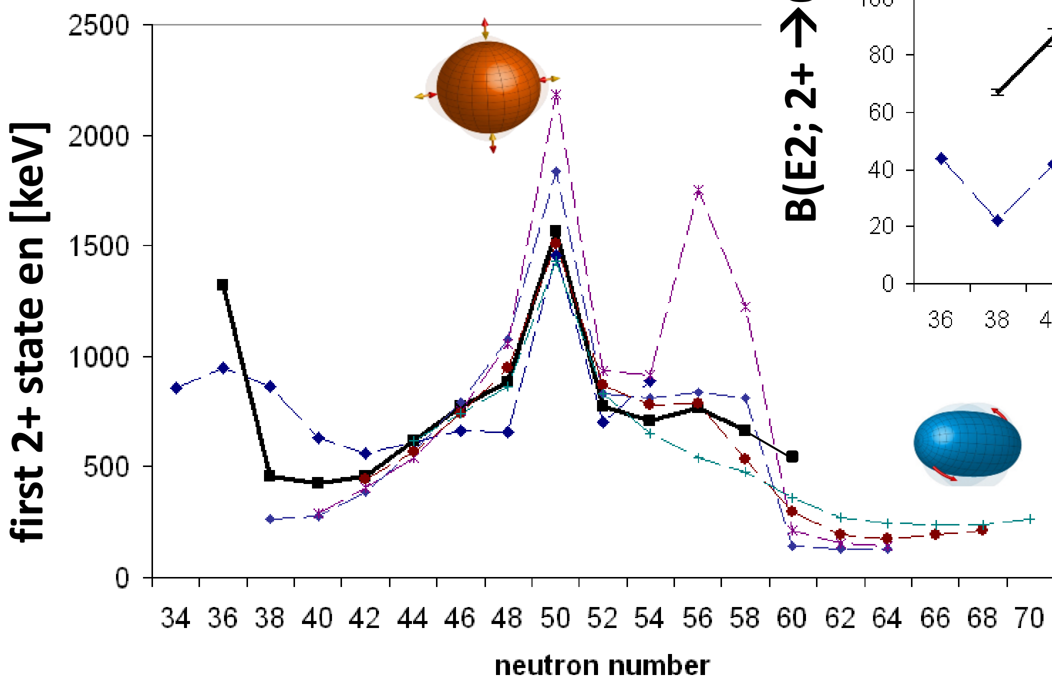
Nuclear deformation in the A~100 region



Nuclear shape evolution in the neutron-rich Kr isotopes



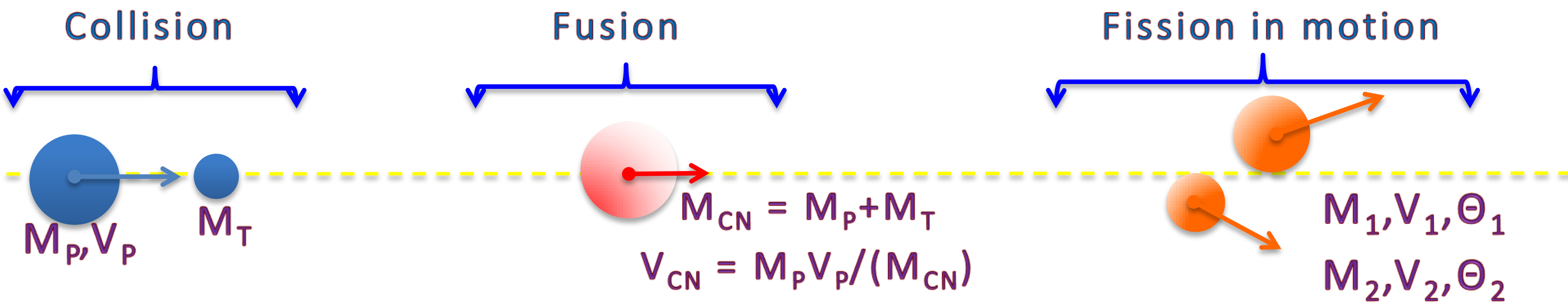




M. Albers et al., Phys. Rev. Lett. 108, 062701, "Evidence of a smooth onset of deformation in the neutron-rich Kr isotopes"

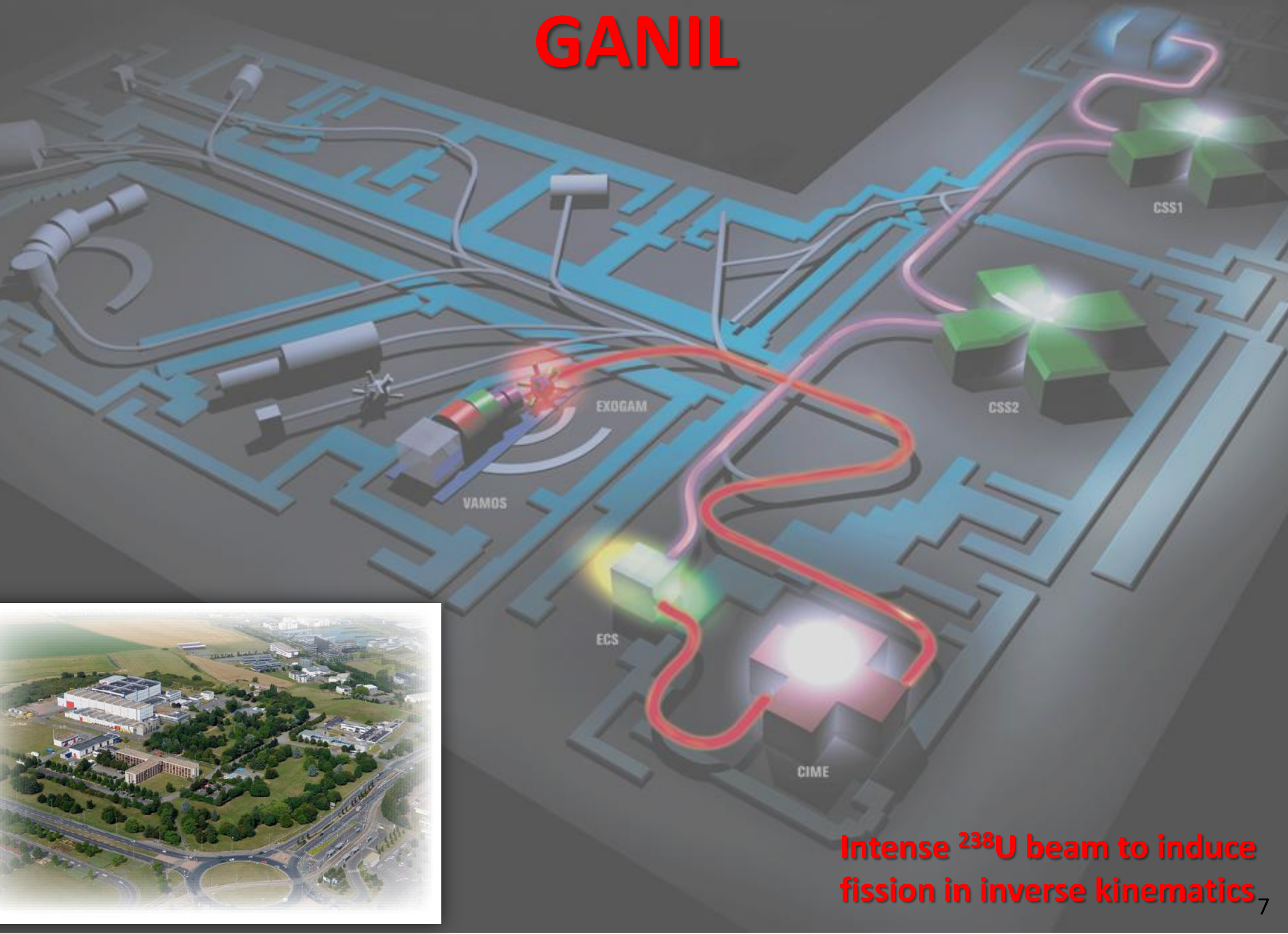
γ-ray spectroscopy of neutron-rich isotopically-identified fission fragments

$^{238}U + ^{9}Be$



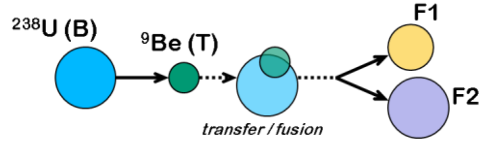
Gamma ray detector + mass spectrometer

GANIL

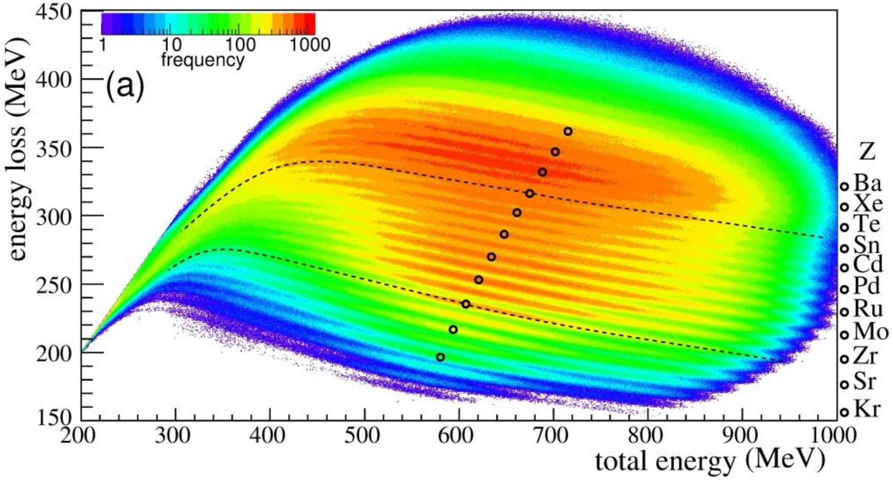


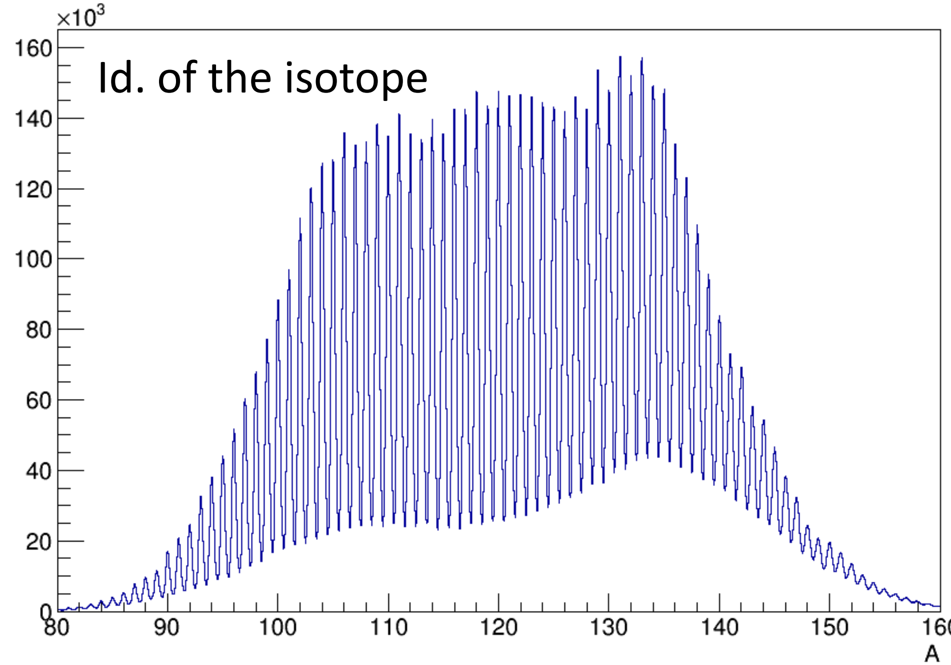
Intense ^{238}U beam to induce fission in inverse kinematics

^{238}U beam (@ 6.2 MeV/A) on ^{9}Be target

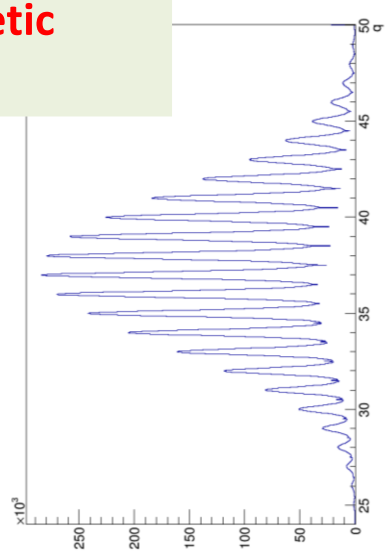


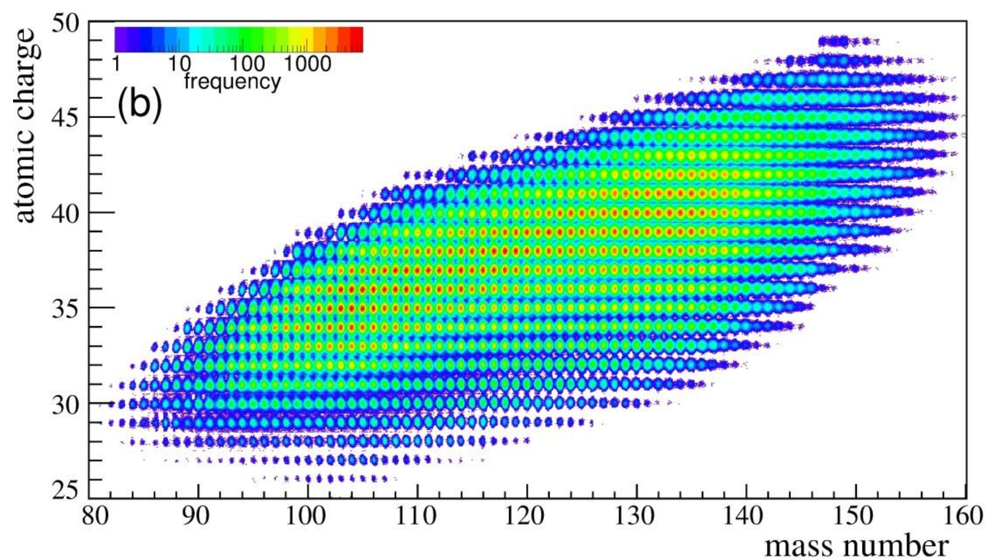
Id. of the element





Isotopic identification event-by-event in the magnetic spectrometer

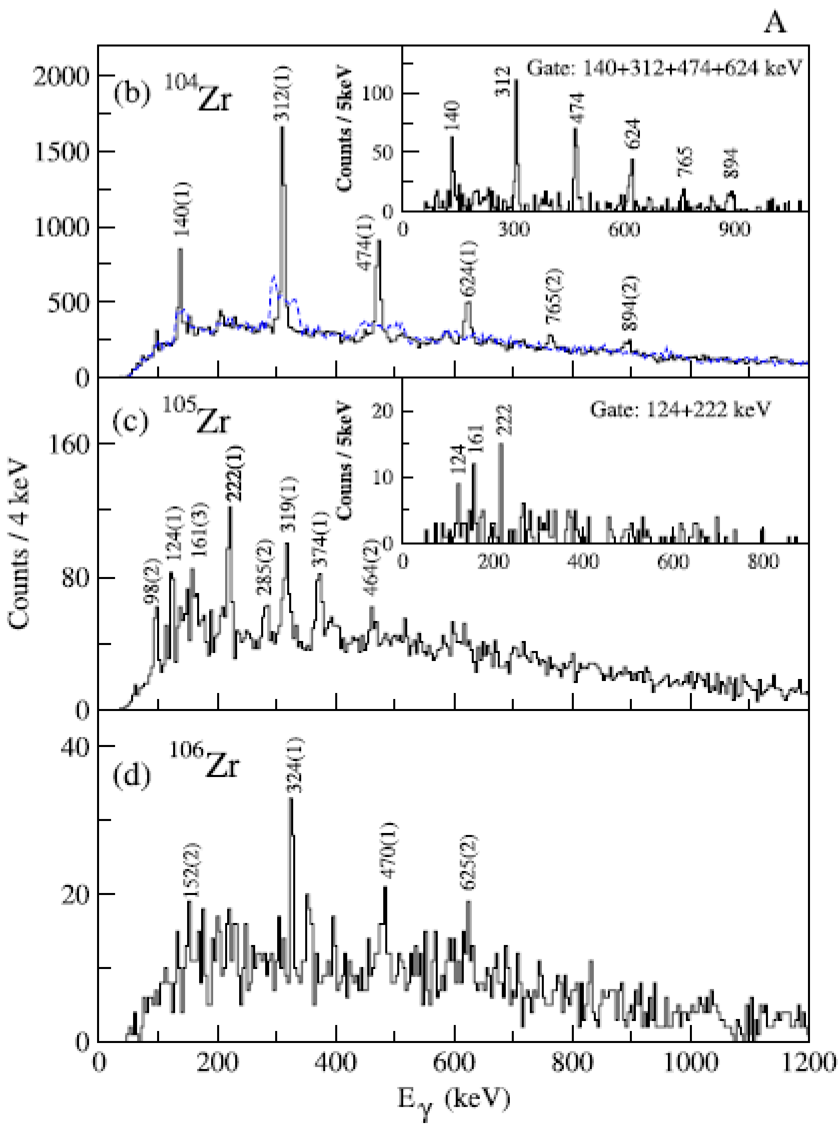


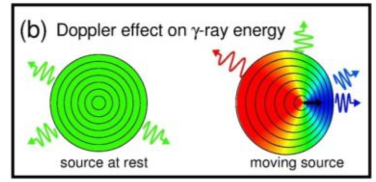


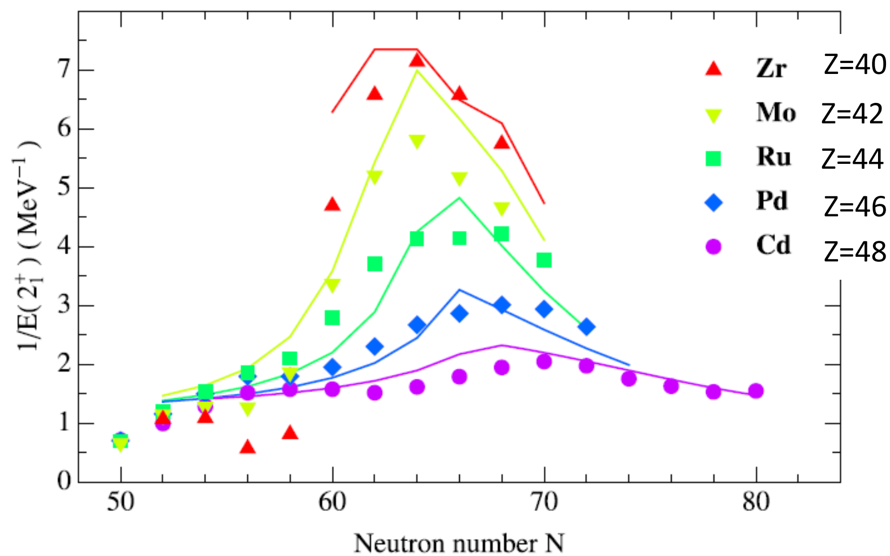
A. Navin et al.,
*Phys. Lett. B **278**, 136 (2014)*

Courtesy of M. Rejmund

Collectivity in neutron-rich Zr nuclei







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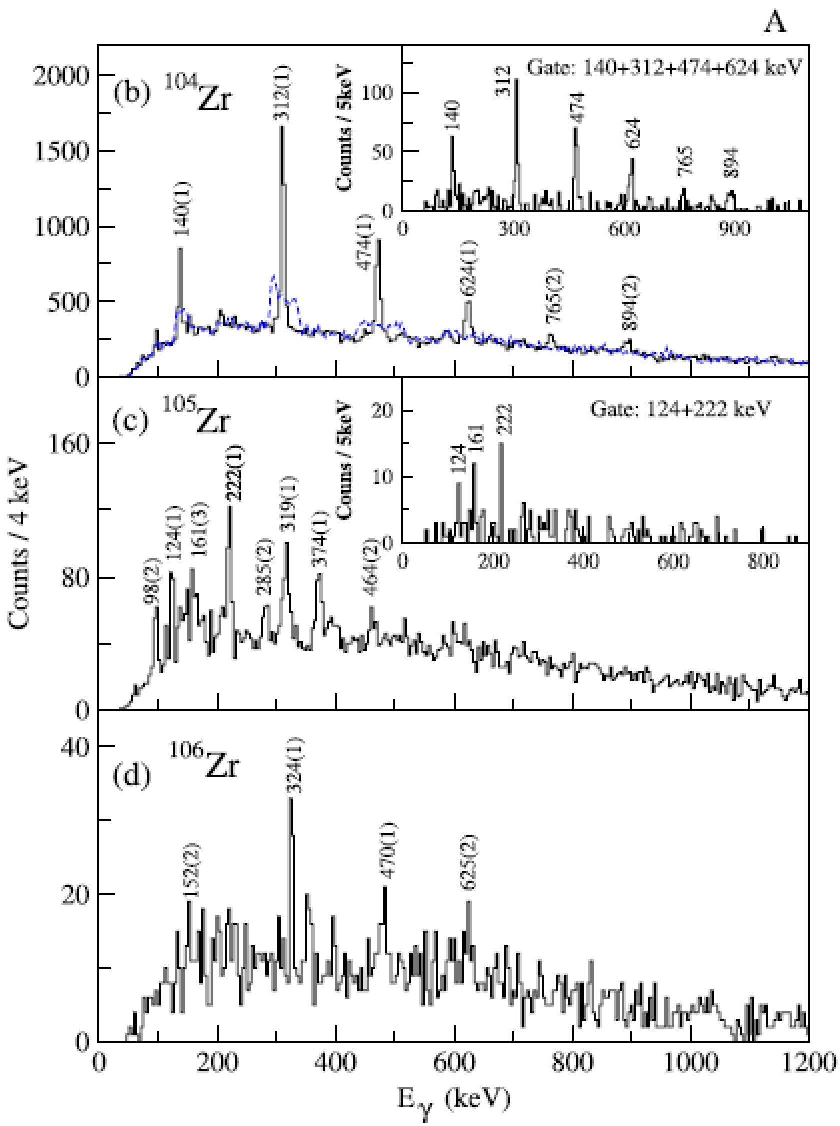
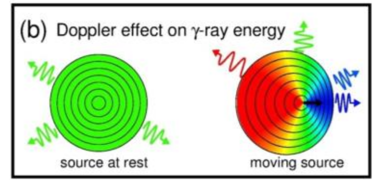
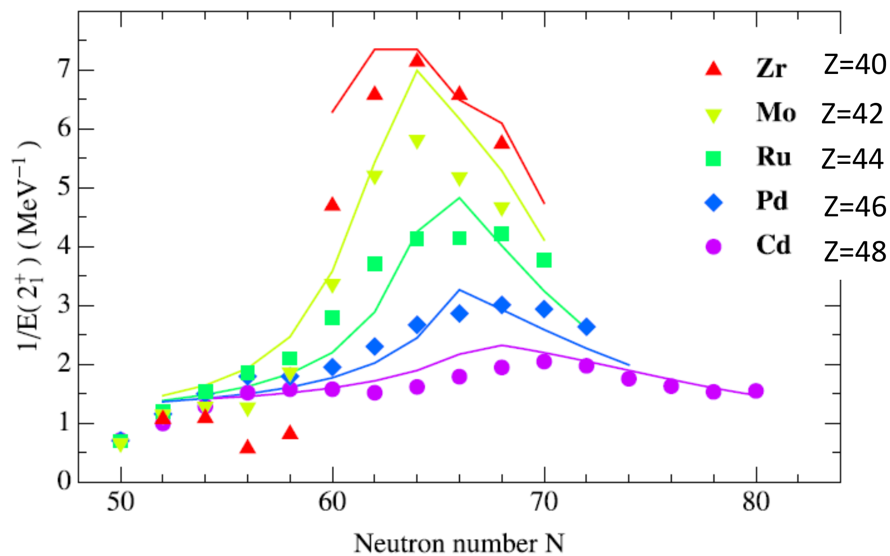




How we can do better?

- ✓ Low energy gamma rays
- ✓ Resolution (EXOGAM: 8 keV at 1.2 MeV)
- ✓ Gamma linear polarization measurements
- ✓ ...



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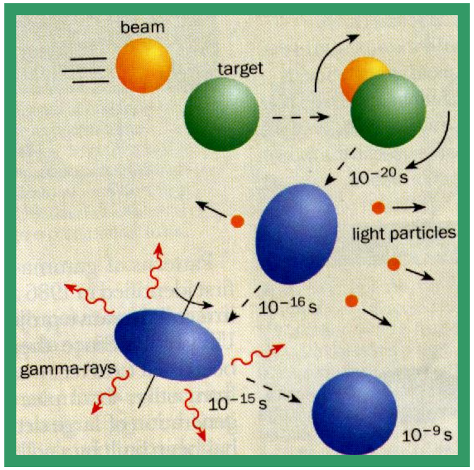
In-beam γ-ray spectroscopy: requirements



Energy resolution (E_γ ~10 keV -10 MeV),
in order to disentangle complex spectra
→ germanium detectors

Peak to Total ratio (large continuous Compton background),
in order to maximize "good events"
→ Compton background suppression

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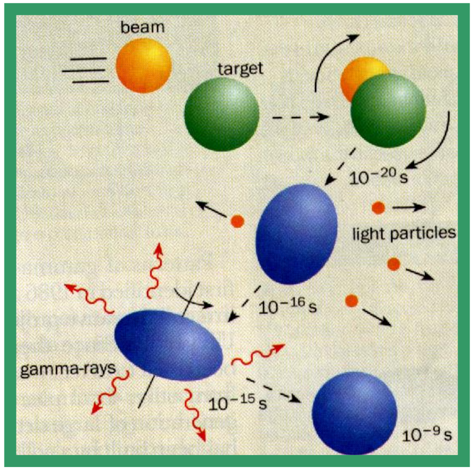

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energy resolution dominated by Doppler broadening if the velocity vector and the emission angle of the γ-ray are not well known (β ~ 5-10%, up to 50%)

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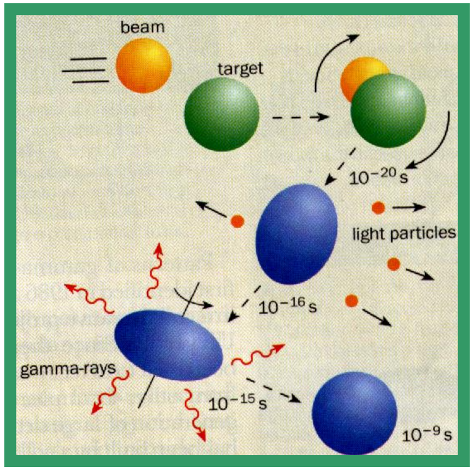

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Good solid angle coverage (ideally 4π), in order to maximize efficiency

Good granularity ,
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Avoid dead materials that could absorb radiation (→preserve low energies)

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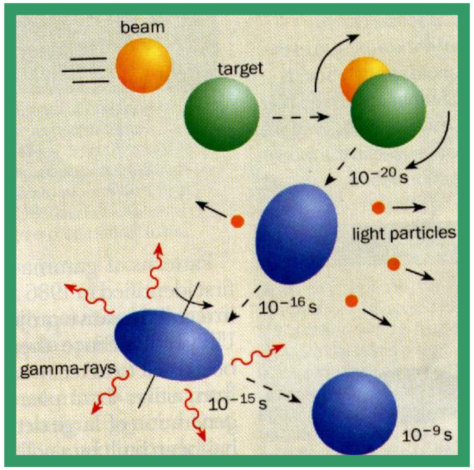

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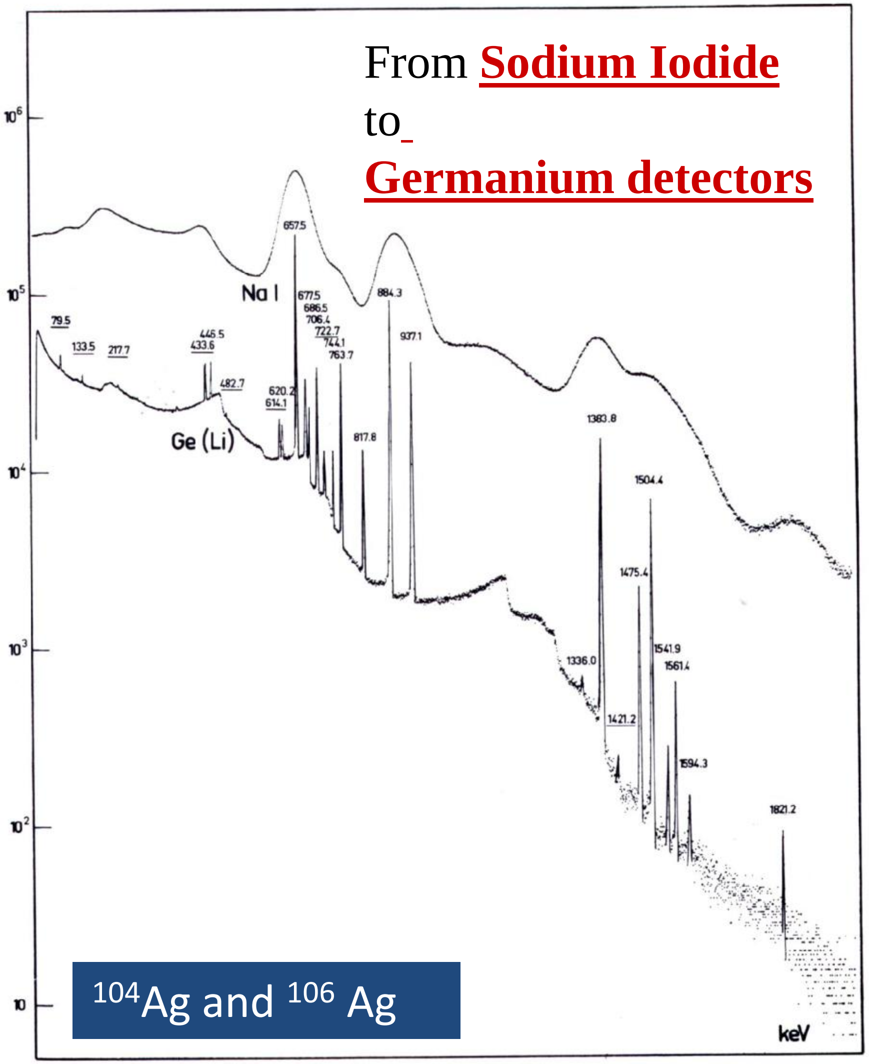
Avoid dead materials that could absorb radiation (→preserve low energies)

High counting rate capability (frequently background much stronger than channel of interest)

Time resolution (prompt events selection, lifetimes)

Energy resolution



Response function = differential spectrum obtained with a detector when hit by monochromatic radiation

60's → Use of Ge(Li) detectors marks the beginning of high-resolution in-beam γ-ray spectroscopy

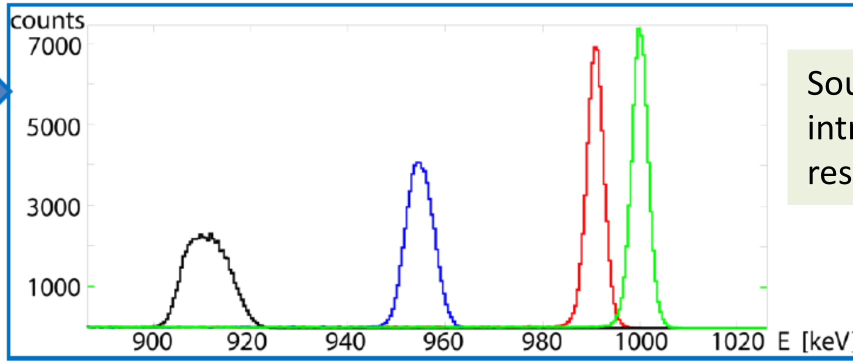
70's → Only few detectors , operated in γ–γ coincidence. Development of the HP-Ge detector.

Use of Germanium detectors = breakthrough in nuclear structure

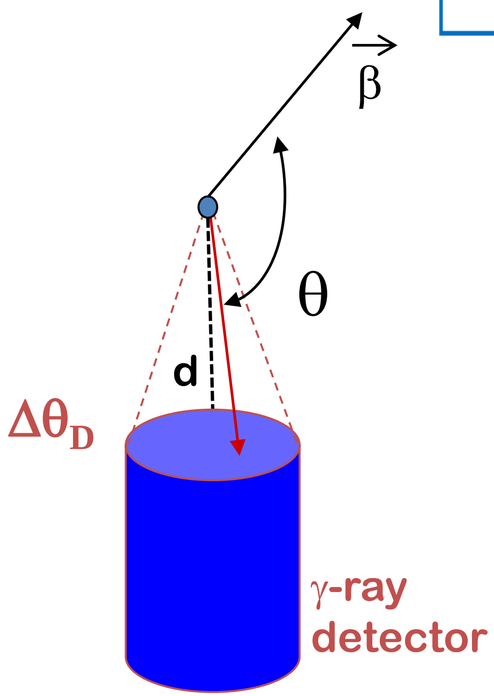
FWHM = 2 keV at 1.3 MeV

Doppler broadening: effective energy resolution

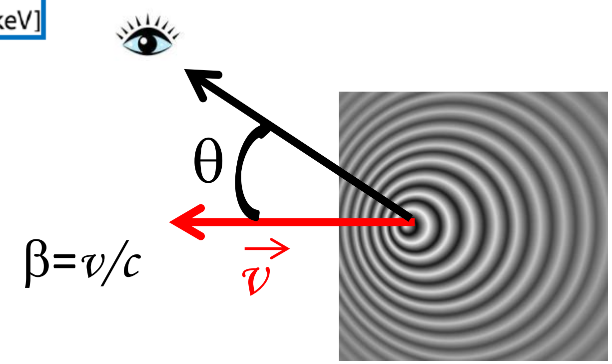
E_0=1MeV
β=0, 0.01, 0.05, 0.10
(fixed direction)
$\theta = 158\ deg$



Source at rest → intrinsic energy resolution



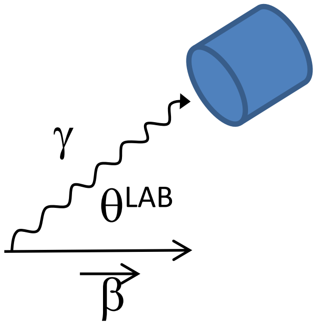
$$E_{\gamma}^{Lab}(\theta) = E_{\gamma}^{CM}\frac{\sqrt{1-\beta^2}}{1-\beta\cdot\cos\theta}$$



Efficiency vs Resolution:

Small d	⟷	**Large Ω**	⟷	**High eff**	⟷	**Poor FWHM**
Large d		**Small Ω**		**Low eff**		**Good FWHM**

Doppler broadening: effective energy resolution



E_γ	1 MeV	
ΔE_{lab}	$\sqrt{(1.2+0.003 * E_{lab})}$	
$\beta(\%)$	5±0.01	20±0.005
$\Delta\Theta$(deg)	8	2

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

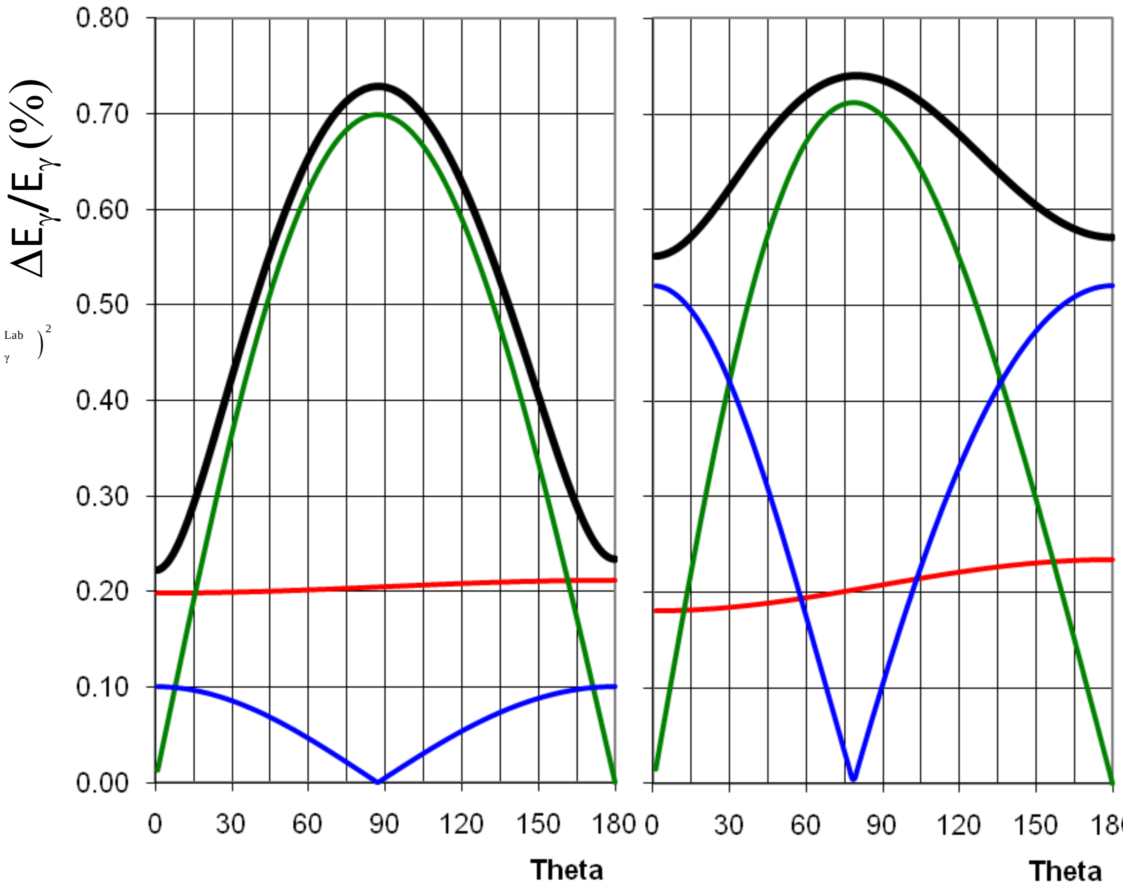
$$E_\gamma^{CM} = E_\gamma^{Lab} \frac{1-\beta \cdot \cos\theta^{Lab}}{\sqrt{1-\beta^2}}$$

$$\left(\Delta E_\gamma^{CM}\right)^2 = \left(\frac{\partial E_\gamma^{CM}}{\partial \theta^{Lab}}\right)^2 \left(\Delta\theta^{Lab}\right)^2 + \left(\frac{\partial E_\gamma^{CM}}{\partial \beta}\right)^2 \left(\Delta\beta\right)^2 + \left(\frac{\partial E_\gamma^{CM}}{\partial E_\gamma^{Lab}}\right)^2 \left(\Delta E_\gamma^{Lab}\right)^2$$

$$\left(\frac{\Delta E_\gamma^{CM}}{E_\gamma^{CM}}\right)^2 = \left(\frac{\beta \cdot \sin\theta^{Lab}}{1-\beta \cdot \cos\theta^{Lab}}\right)^2 \left(\Delta\theta\right)^2 +$$ Opening

$$\left(\frac{\beta - \cos\theta^{Lab}}{\left(1-\beta^2\right)\left(1-\beta \cdot \cos\theta^{Lab}\right)}\right)^2 \left(\Delta\beta\right)^2 +$$ Recoil

$$\left(\frac{\Delta E_\gamma^{Lab}}{E_\gamma^{Lab}}\right)^2$$ Intrinsic

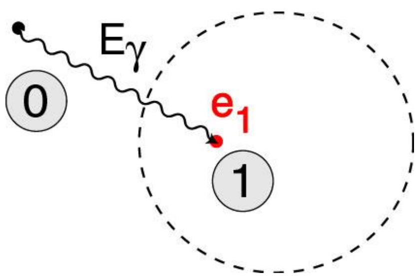


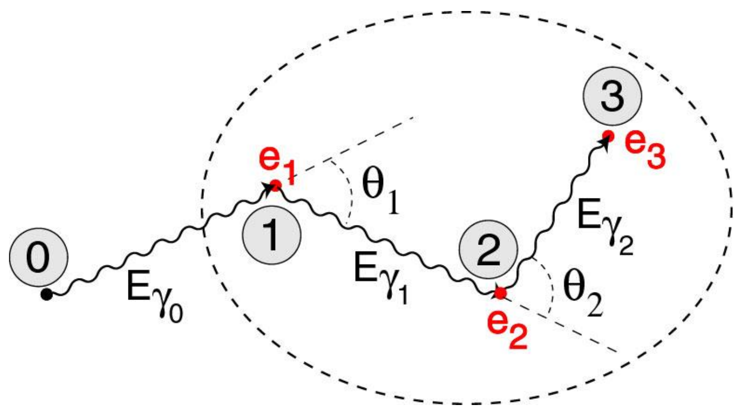
Photon interaction with matter

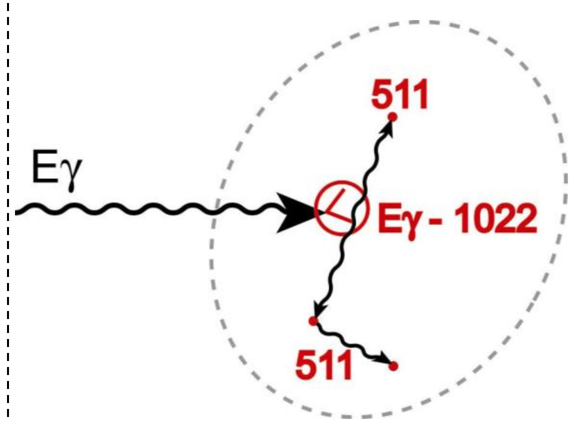
~ 100 keV | ~1 MeV | ~ 10 MeV

γ ray energy →

Photoelectric	Compton Scattering	Pair Production







$$E_{e1} = E_\gamma - E_b$$

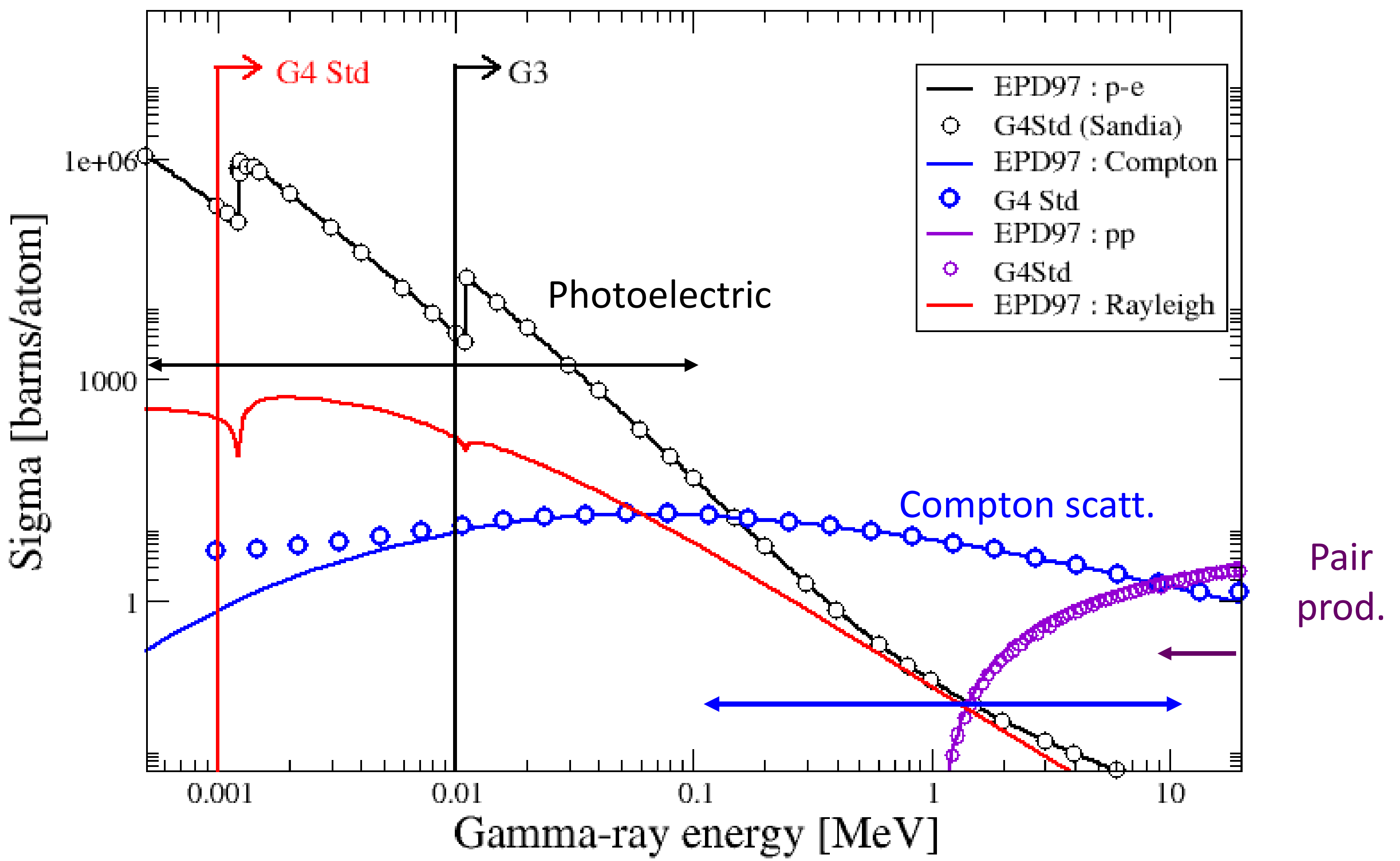
$$\sigma \propto \frac{z^n}{E_\gamma^{3.5}}, \quad n \approx 4 \div 5$$

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

$$(E_\gamma > 2m_e c^2)$$

$$\sigma \propto Z^2$$

Cross Sections in Germanium

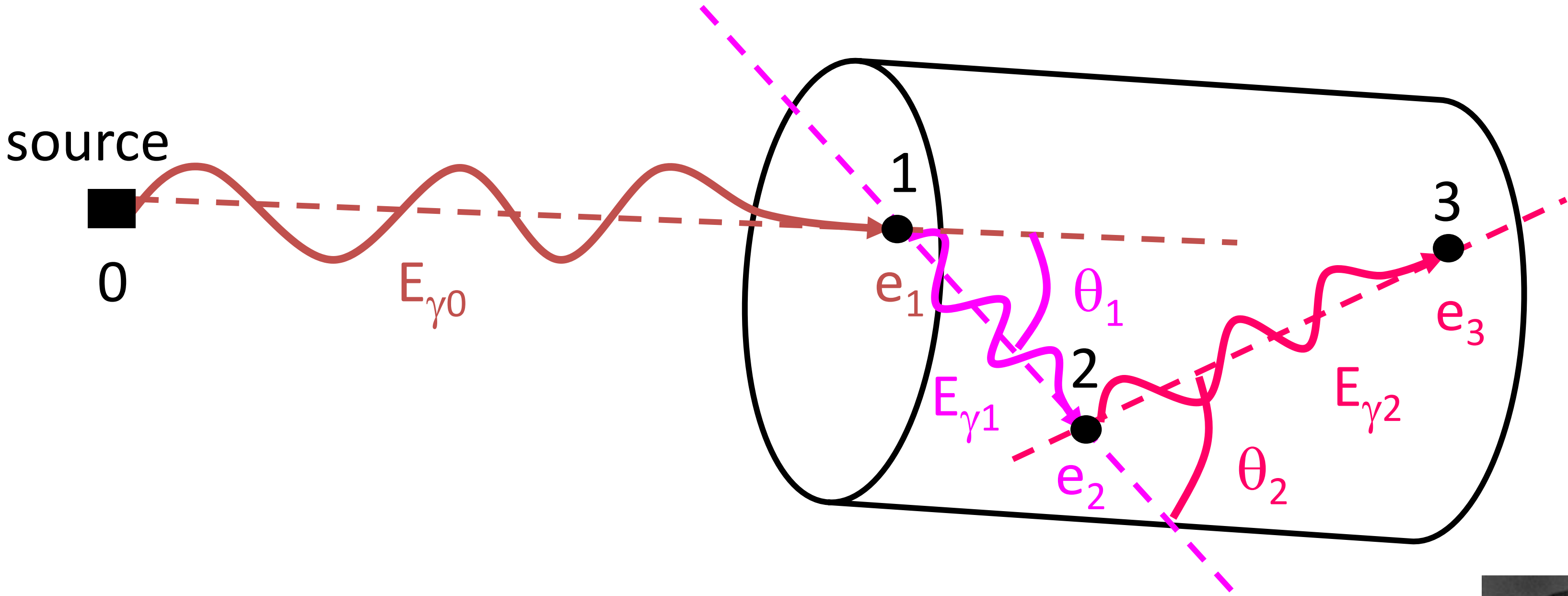


Mean free path: $\lambda(E) = M_A/(N_{AV}.\rho) \cdot 1/\Sigma\sigma_E$

λ(10 keV) ~ 55 µm λ(100 keV) ~ 0.3 cm λ(200 keV) ~ 1.1 cm

λ(500 keV) ~ 2.3 cm λ(1 MeV) ~ 3.3 cm

Compton Scattering (1)



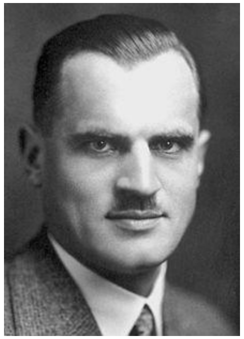
assuming that the e⁻ is at rest,
from conservation of energy and momentum:

$$E_{\gamma i} = \frac{E_{\gamma\, i-1}}{1 + \frac{E_{\gamma\, i-1}}{m_0 c^2}(1 - \cos\theta_i)}$$

Energy of scattered γ

$$e_i = E_{\gamma\, i-1} - E_{\gamma\, i}$$

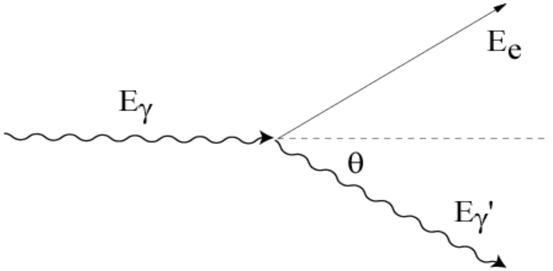
Energy of scattered e^-



Arthur Holly Compton
Nobel prize 1927

Compton Scattering (2)

The angular distribution of the scattered photon is described by the Klein-Nishina formula:

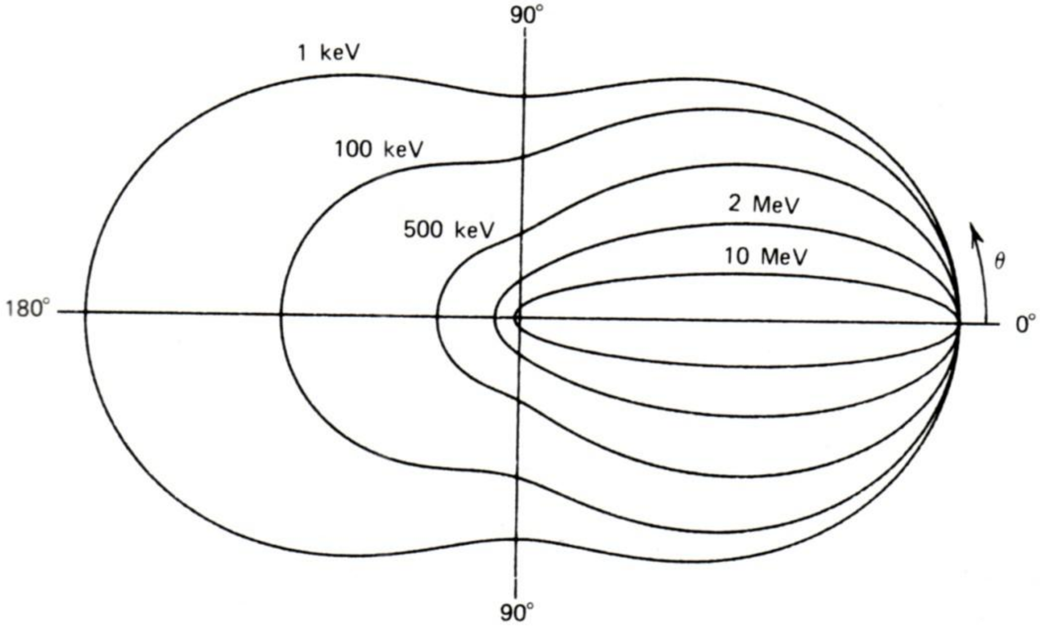


$$\frac{d\sigma}{d\Omega} = z r_e^2 \left(\frac{1}{1+\alpha(1-\cos\theta)}\right)^2 \left(\frac{1+\cos^2\theta}{2}\right)\left(1+\frac{\alpha^2(1-\cos\theta)^2}{(1+\cos^2\theta)[1+\alpha(1-\cos\theta)]}\right)$$

$\alpha = E_\gamma / m_e c^2$

and r_e is the classical electron radius

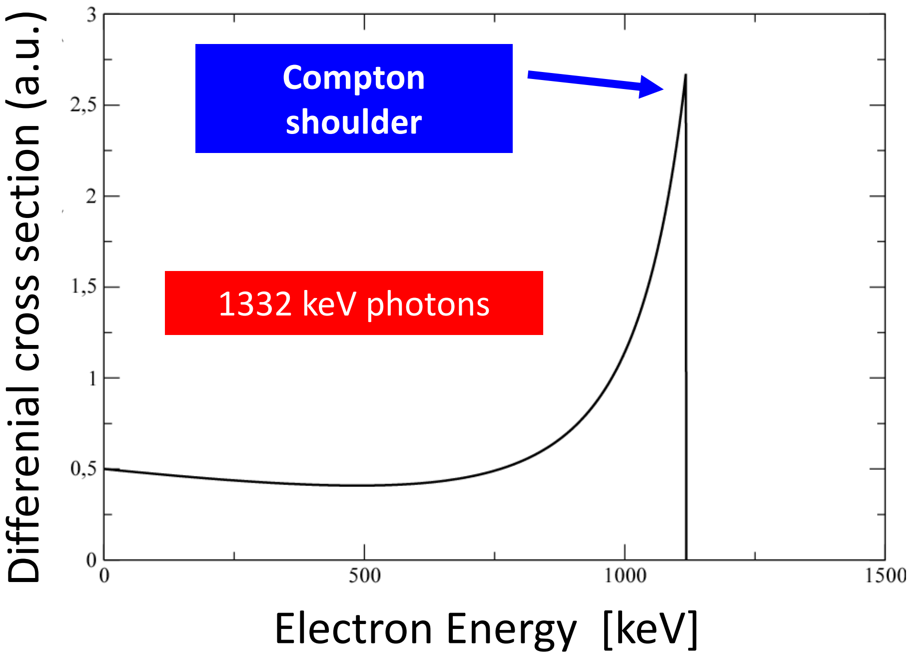
For E_γ > few 100 keVs the angular distribution is highly anisotropical and peaked to small forward angles. It strongly ``focuses'' with the increasing photon energy.



Continuum Compton

The spectrum of the scattered electrons can be deduced from the Klein-Nishina formula:

$$\frac{dN}{dE_e} \propto \left(\frac{1+f^2(E_e)}{2}\right)\left[1+\frac{1}{1+f^2(E_e)}\frac{E_e^2}{E_\gamma(E_\gamma-E_e)}\right] \qquad f(E_e)=1-\frac{m_e c^2}{E_\gamma}\frac{E_e}{E_\gamma-E_e}$$

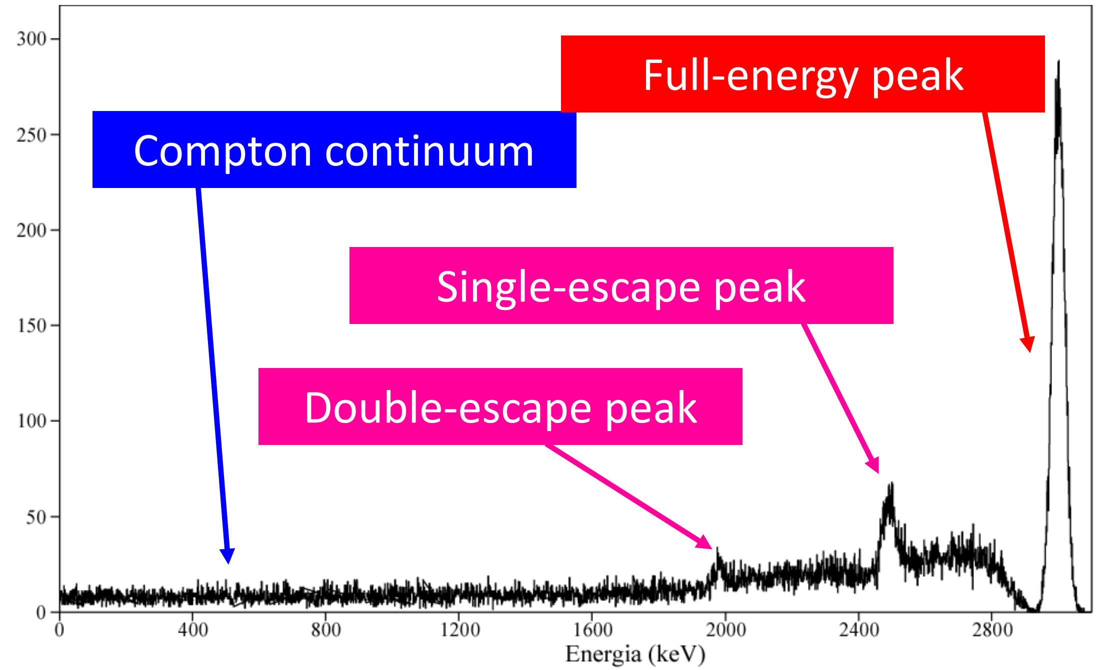


Since the actual energy deposition is performed by the electrons, photons interacting via Compton scattering will produce a continuum.

Corrections are needed since electrons are not free, rather bound in materials, producing a smoothening of the actual spectrum

(Compton profile)

Shape of the γ spectrum for a typical size Ge detector



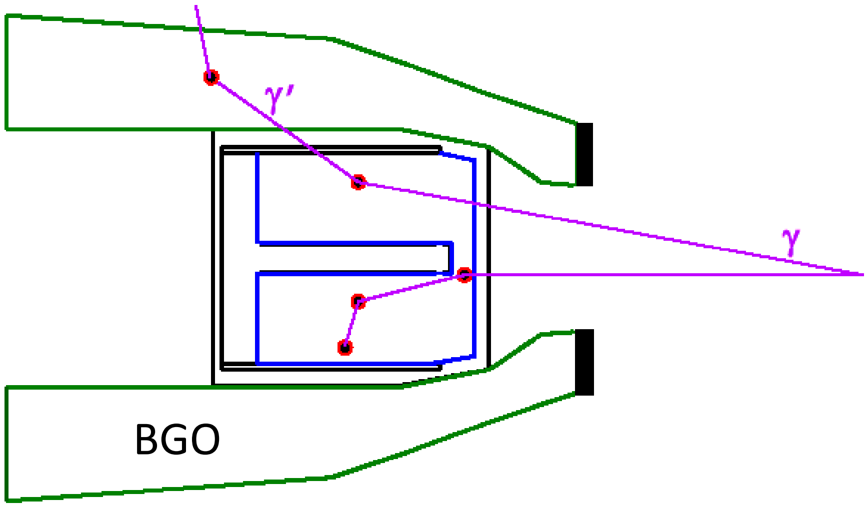
E_{γ}=3 MeV

HPGe detector used with the GASP array

(LNL)

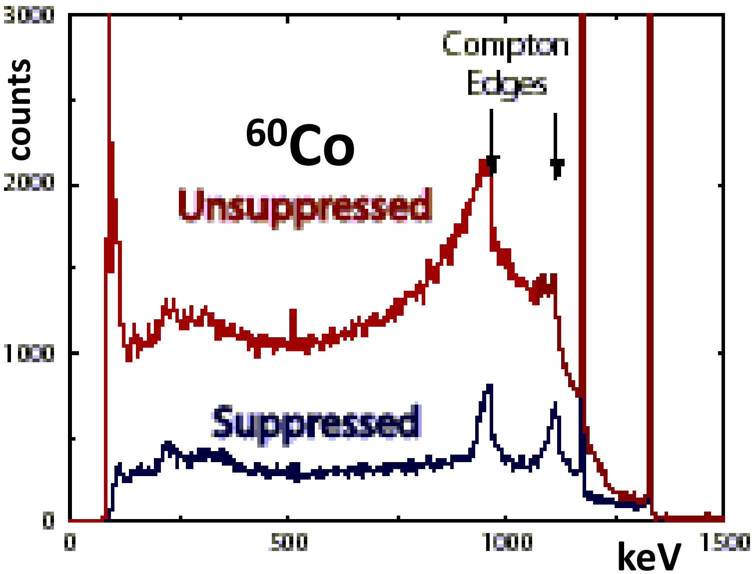
High probability that the incoming photons are only partially absorbed. Response function: full-energy peak, continuum generated by photons which underwent Compton scattering and, if the photon energy is larger than 1.022 MeV, peaks due to the missed detection of one or both the annihilation photons (single and double escape peaks).

Escape-suppressed Ge detectors (Compton suppression)



The cross section for Compton scattering in germanium implies quite a large continuous background in the resulting spectra

For large-volume Ge crystals the Anticompton shield (AC) improves the PeakToTotal ratio (P/T) from ~20% to ~60%

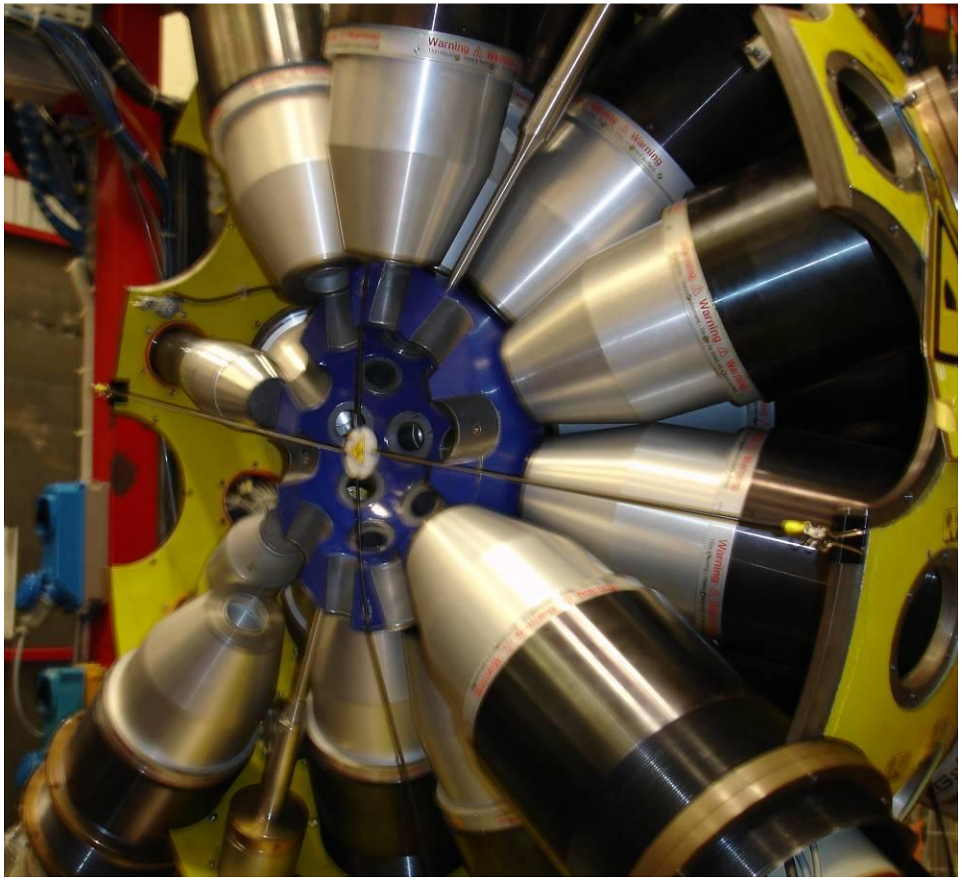


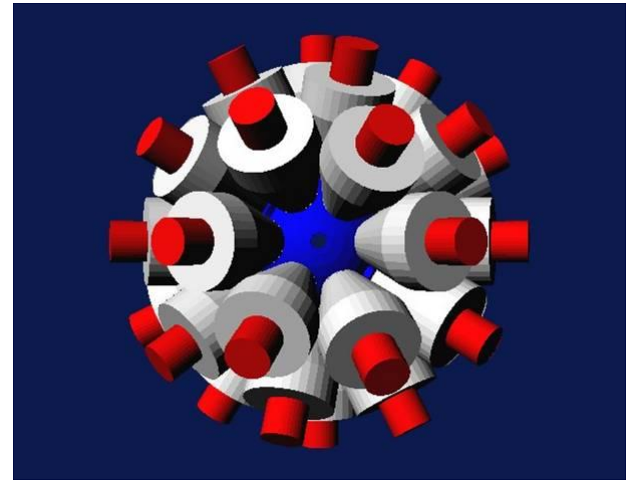
γ1 \ γ2	P	B
P	PP	PB
B	BP	BB

In a γ–γ measurement, the fraction of useful peak-peak coincidence events grows from 4 % to 36%

For high fold (F) coincidences the fraction of useful coincidences is P/T^{F}

GASP @ Legnaro Nat. Lab.





- 40 HPGe + AC (config. II)
  - $d_{target\text{-}det.}$ = 22 cm
  - ε_{ph}~ 5.8% @ 1332.5 keV
- Pb collimator (6 cm thick)
  - inner space R_{int} = 15 cm

Lifetime measurements with Doppler Shift Techniques

7 rings @	35°,	60°,	72°,	90°,	108°,	120°,	145°
	6	6	4	8	4	6	6

C. Rossi-Alvarez, Nucl. Phys. News Europe 2 (1993) 10

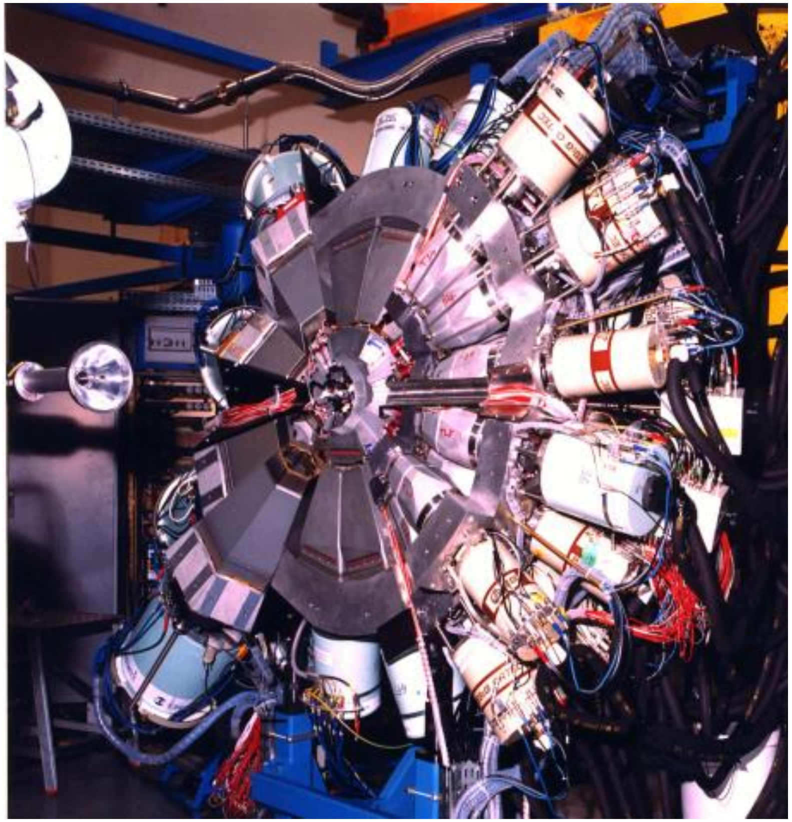
D. Bazzacco, in: Proc. Conf. On Physics from Large g-ray detector arrays, 1992, p. 376

GAMMASPHERE

EUROBALL

up to 110 Compton-Suppressed Ge detectors

I.Y. Lee, NPA 520 (1990) 641



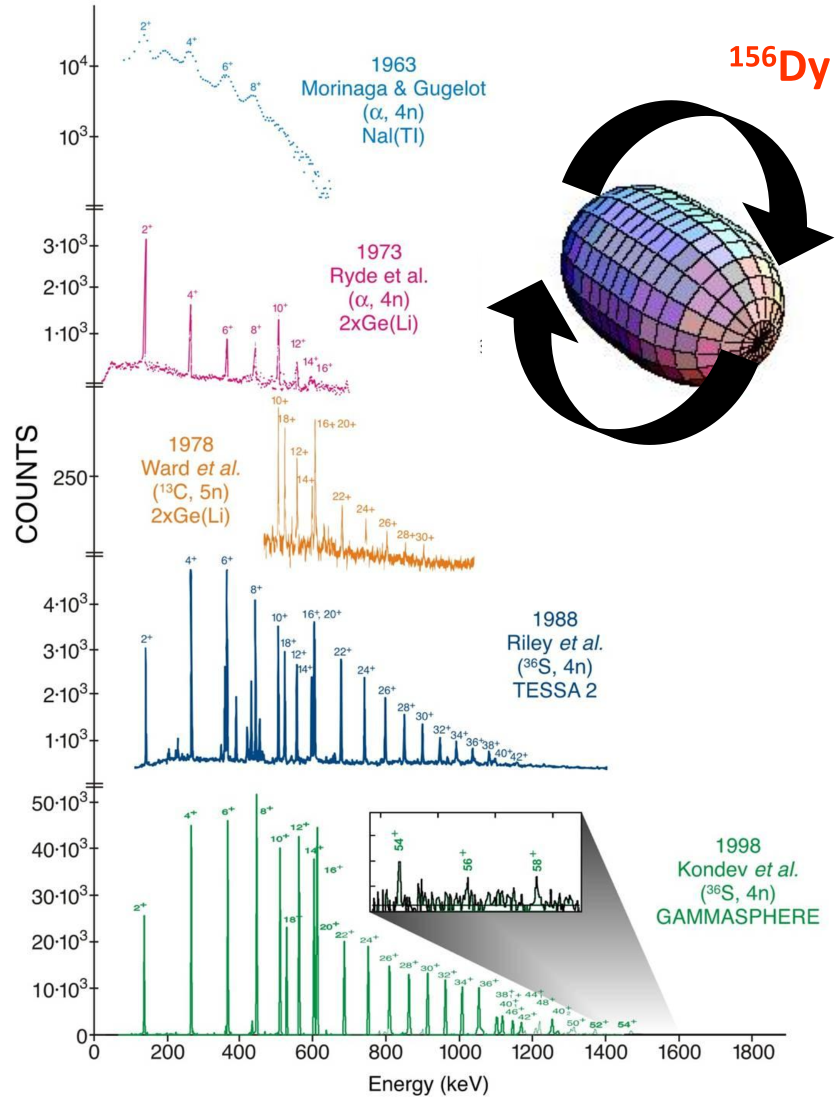
15 Clusters (7-Ge); 26 Clovers (4-Ge); 30 single Ge
71 CS-systems
239 Ge crystals

Efficiency	ε_p ~ 10 — 5 %
Peak/Total	PT ~ 55 — 40 %
	(M_γ=1 — M_γ=30)

Solid angle covered by Ge ➔ 40-50 %

Spectroscopic history of ^{156}Dy

The “spectroscopic history” of ^{156}Dy is a notable example of how the progress with the acceleration and detection techniques leads to better insight on the nuclear structure.



The nucleus is always full of surprises

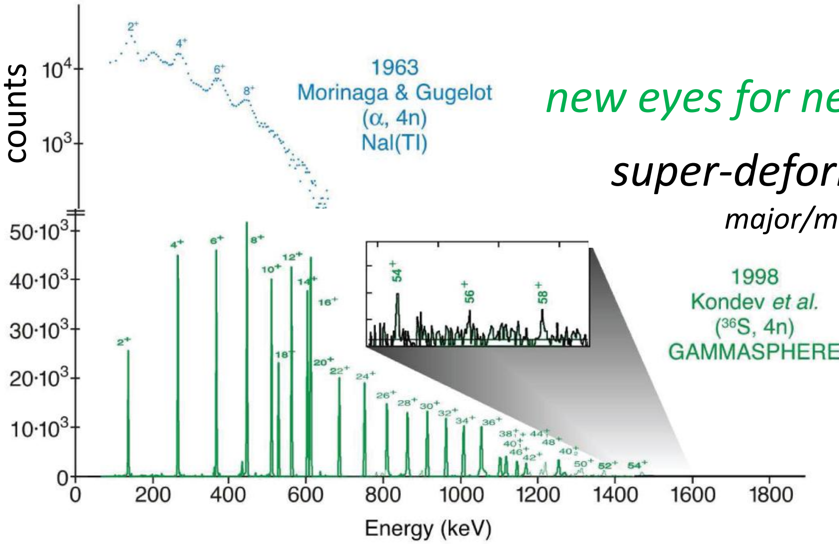
Instrumentation advances ⇔ New Science

Advances in γ-ray spectroscopy: sensitivity vs year

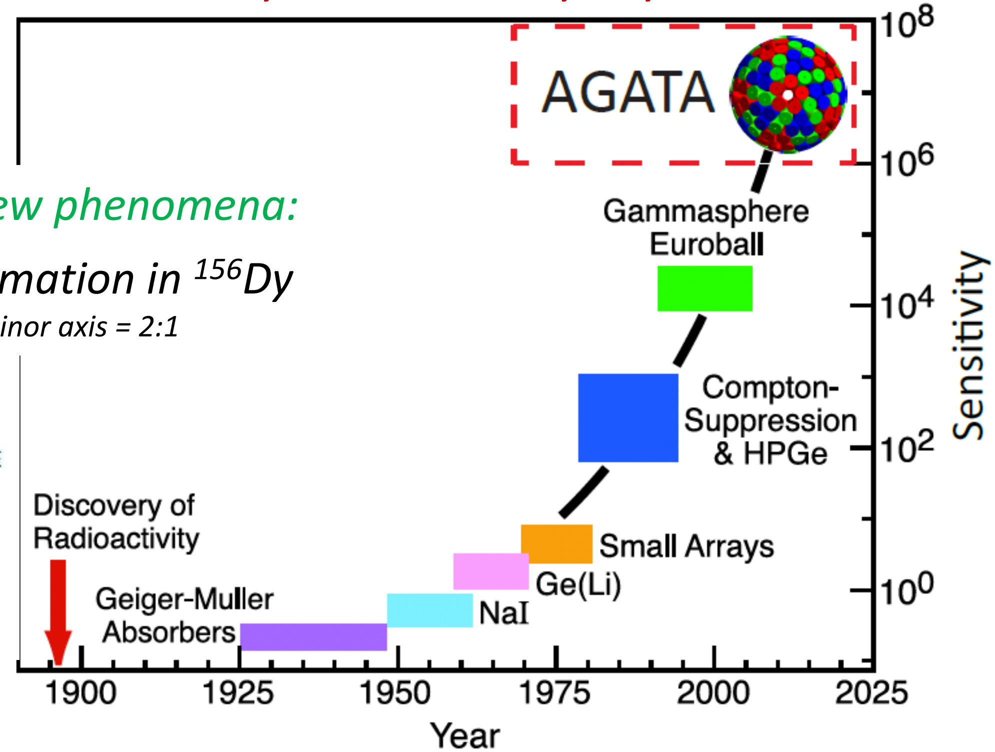
new eyes for new phenomena:

super-deformation in ^{156}Dy

major/minor axis = 2:1



Ge detector system sensitivity vs year



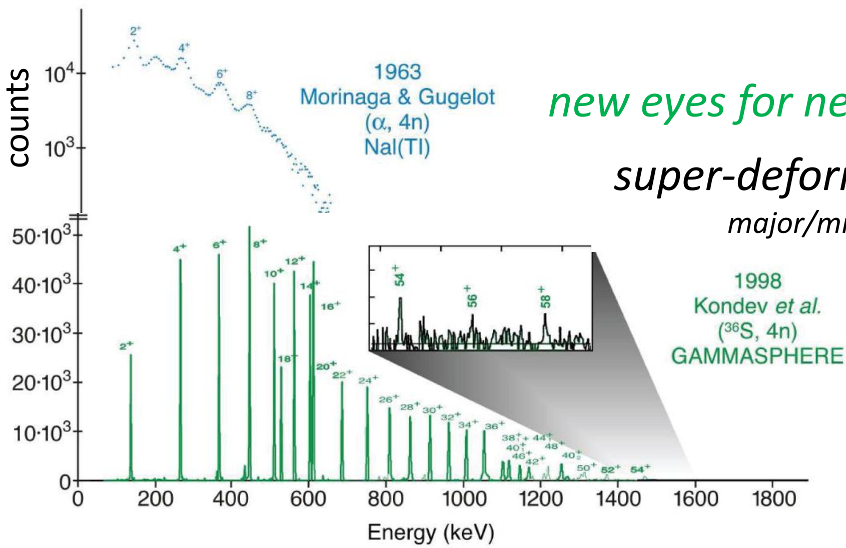
Sensitivity =
inverse of the weakest channel reaction cross-section that can be measured over total cross section

Advances in γ-ray spectroscopy: sensitivity vs year

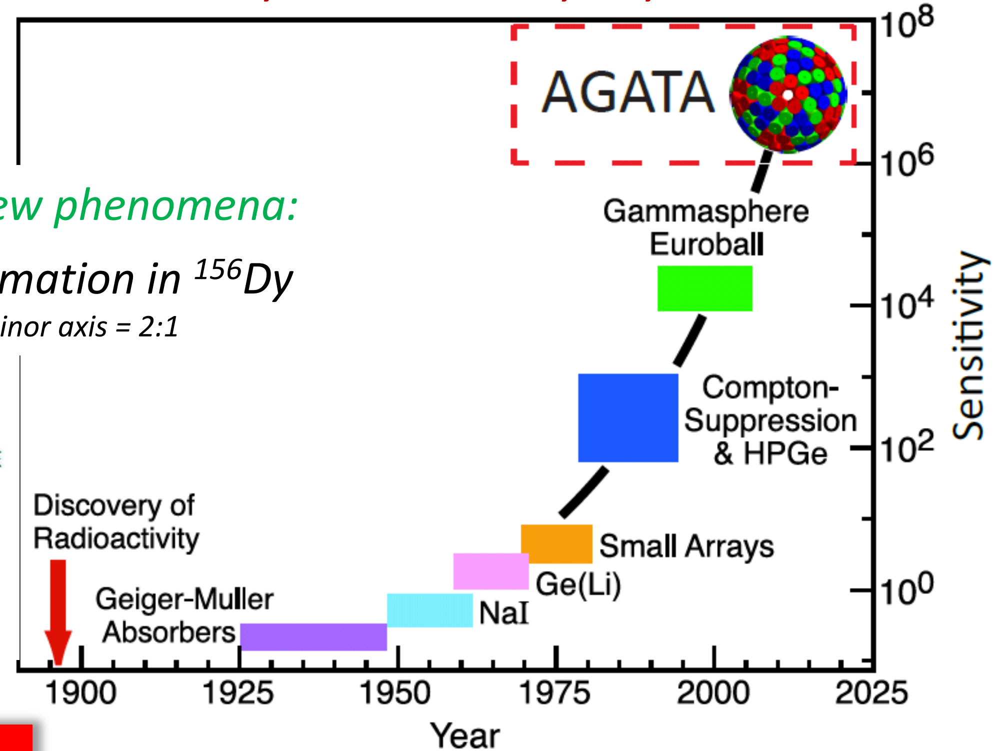
new eyes for new phenomena:

super-deformation in ^{156}Dy

major/minor axis = 2:1



Ge detector system sensitivity vs year

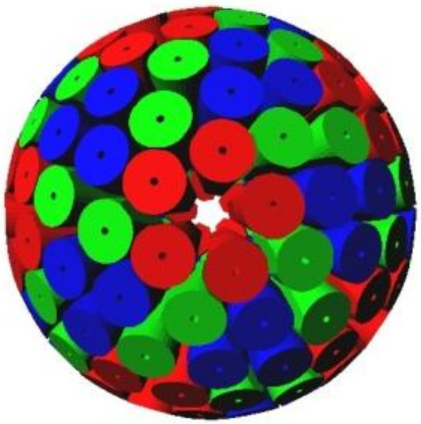


AGATA (EU) and GRETA (US) will allow unprecedented gamma detection sensitivity, by using the germanium detectors in *position sensitive mode* (Pulse Shape Analysis and Tracking)

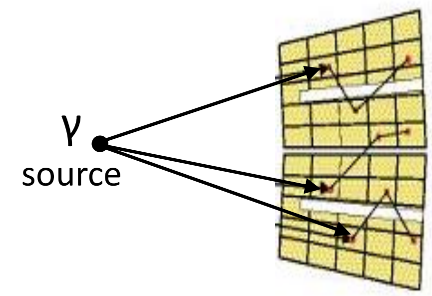
Sensitivity =
inverse of the weakest channel reaction cross-section that can be measured over total cross section

The γ-ray spectroscopy dream

Cover the whole detection solid angle by germanium and track the path of the g rays inside the detector medium



- segmented detectors
- digital electronics
- timestamping of events
- analysis of pulse shapes
- tracking of γ-rays



4 time more efficient than standard arrays, also for high γ multiplicity
(28 % M_γ=30)

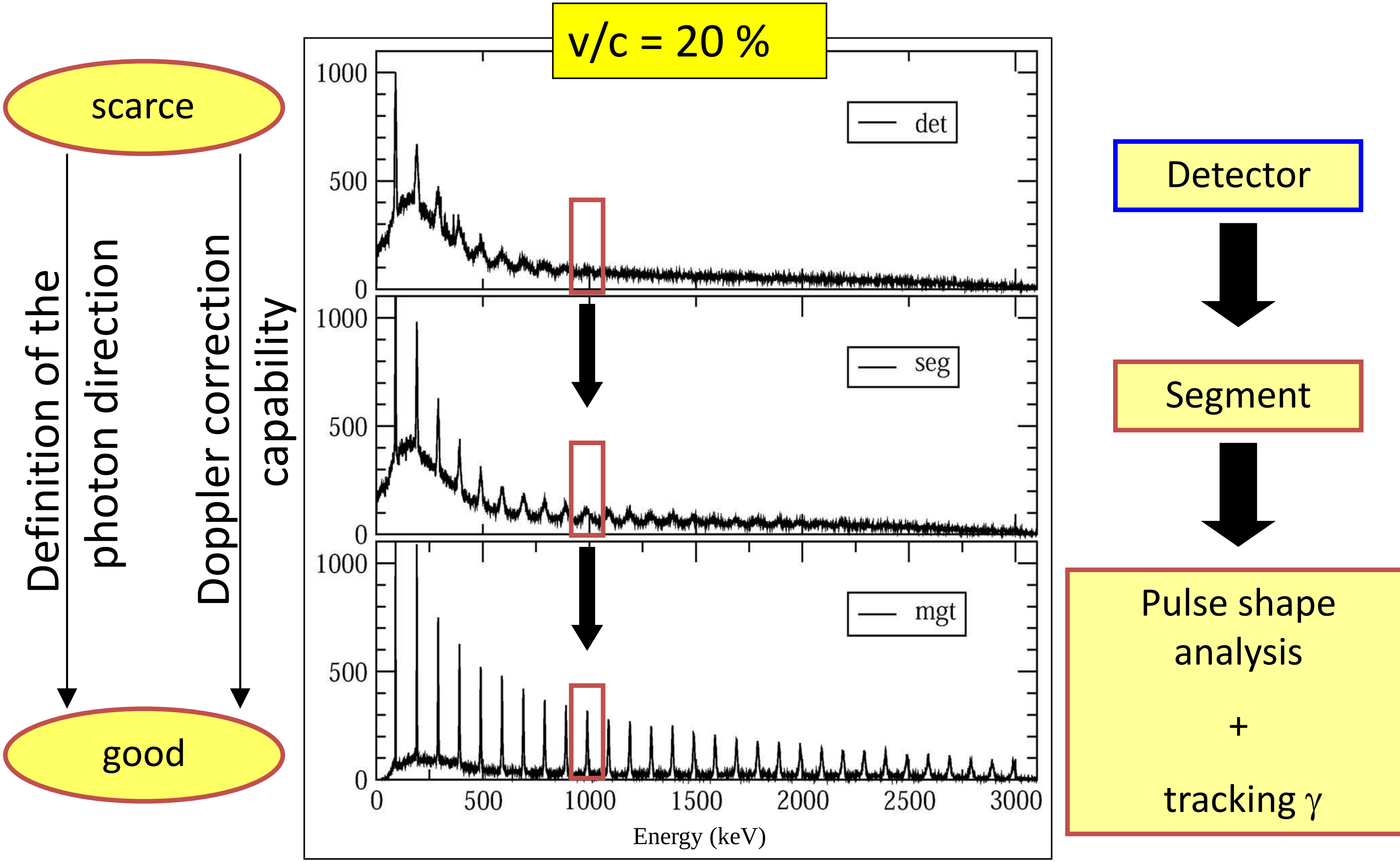
High count rate capabilities
(100s KHz)

→ Study of nuclei in extreme conditions of angular momentum and neutron/proton asymmetry

"continuous" angular distributions of the γ interaction points (θ~1°)

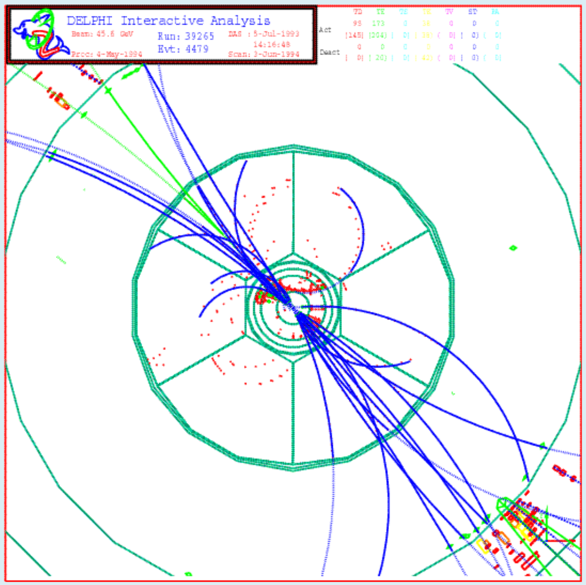
→ "perfect" Doppler correction
(6 keV @ 1 MeV, β=50%)
new accuracy and sensitivity for
nuclear level lifetimes
γ linear polarization

Position resolution used to limit Doppler broadening of gammas emitted in flight -- Benefits of the γ-ray tracking



Tracking of radiation

in High Energy Physics

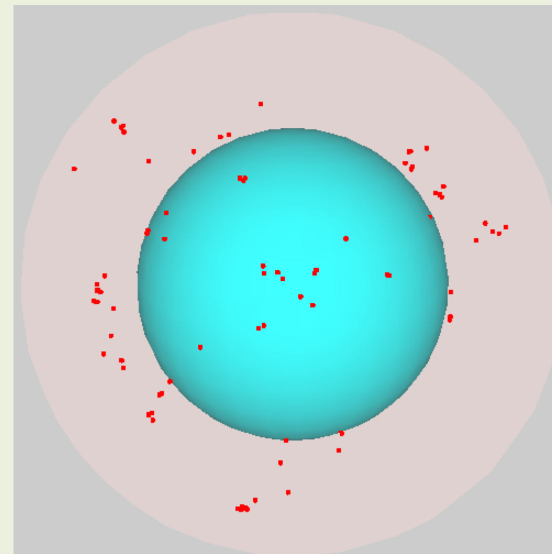


"continuous tracks" from very energetic particles

huge detectors for "one" experiment

Physics 🡐 the study of "complete" events

in Nuclear Spectroscopy



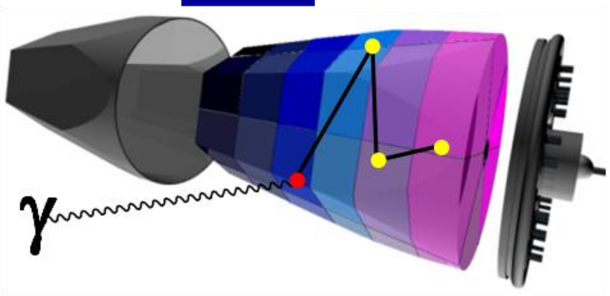
"many" low energy (0.01 -- 10 MeV) neutral transitions with low density of energy deposition

"general-purpose" detectors for a large variety of experiments

Physics 🡐 large number of incomplete events

Position-sensitive operation mode and γ-ray tracking

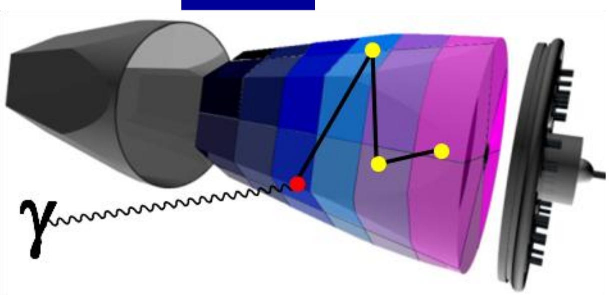
highly segmented HPGe detectors



Event by event:
how many gammas,
for each gamma: energy,
first interaction point, path

Position-sensitive operation mode and γ-ray tracking

highly segmented HPGe detectors



digital electronics to record sampled waveforms

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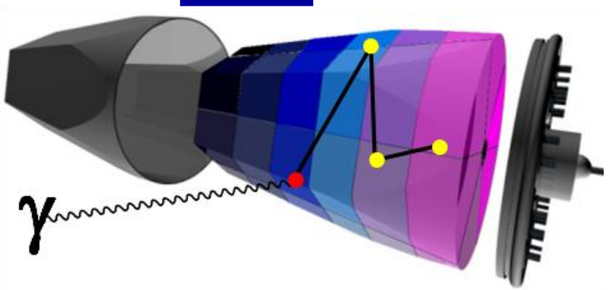
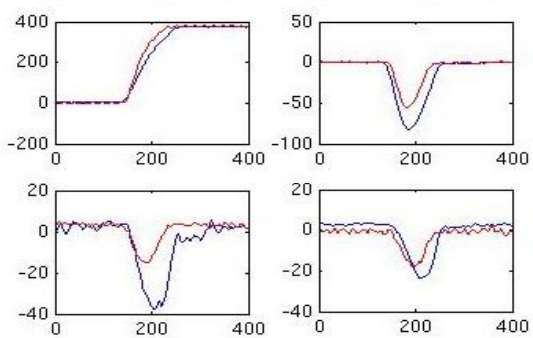


digital electronics to record sampled waveforms

Pulse Shape Analysis of the recorded waves



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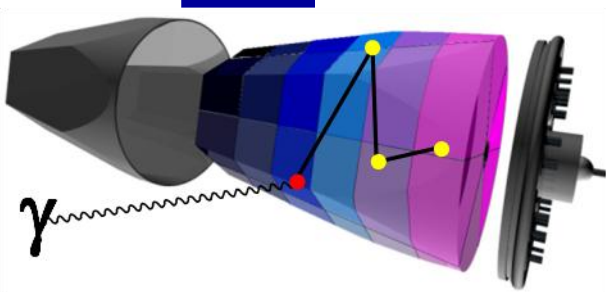

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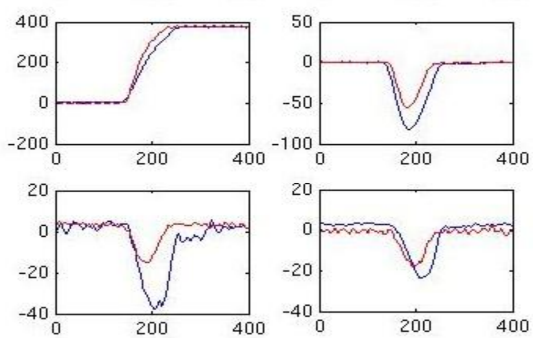
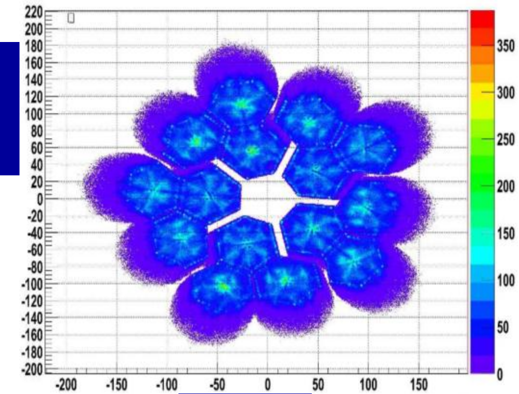


Identified interaction points (hits)

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



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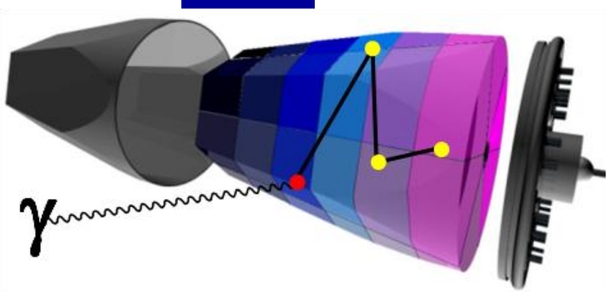
highly segmented HPGe detectors



digital electronics to record sampled waveforms

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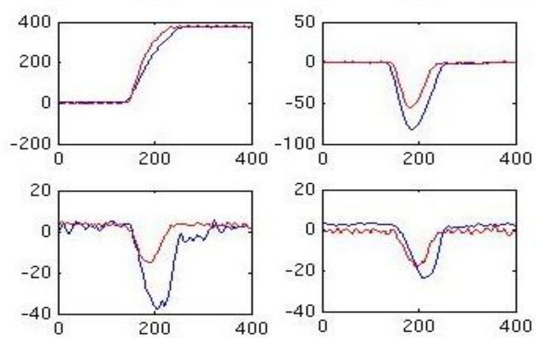

Identified interaction points (hits)

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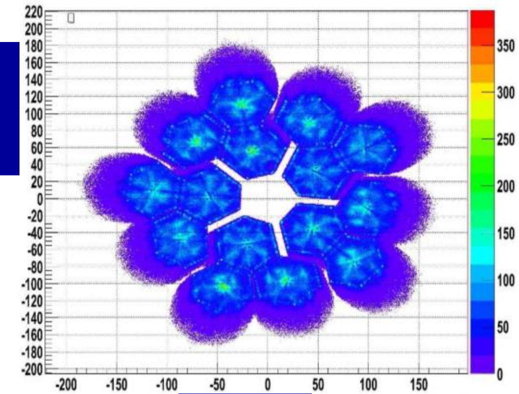
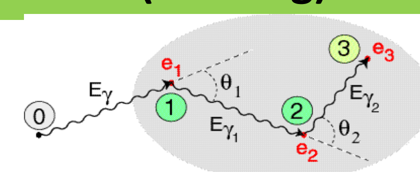


reconstruction of γ-rays from the hits (tracking)

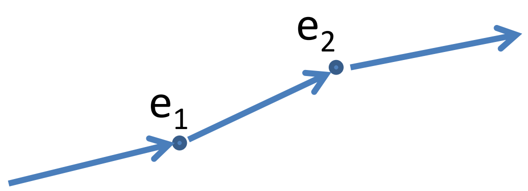


Event by event:
how many gammas,
for each gamma: energy,
first interaction point, path

Aim of gamma-ray tracking

deposited energies and the positions
of all the interactions points
of an event in the detector

e_1, x_1, y_1,z_1
e_2, x_2, y_2,z_2
....
e_n, x_n, y_n,z_n



reconstruct individual photon trajectories
and write out photon energies,
incident and scattering directions

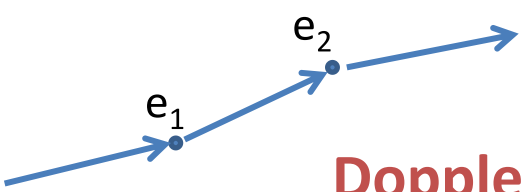
E_1, $(\theta,\phi)_{inc,1}$,$(\theta,\phi)_{sc,1}$. ...
E_2, $(\theta,\phi)_{inc,2}$,$(\theta,\phi)_{sc,2}$. ...
....
E_i, $(\theta,\phi)_{inc,i}$,$(\theta,\phi)_{sc,i}$

discard events corresponding to
incomplete energy release

Aim of gamma-ray tracking

deposited energies and the positions
of all the interactions points
of an event in the detector

e_1, x_1, y_1, z_1
e_2, x_2, y_2, z_2
....
e_n, x_n, y_n, z_n



reconstruct individual photon trajectories
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$E_1, (\theta,\phi)_{inc,1}, (\theta,\phi)_{sc,1}. \ldots$
$E_2, (\theta,\phi)_{inc,2}, (\theta,\phi)_{sc,2}. \ldots$
....
$E_i, (\theta,\phi)_{inc,i}, (\theta,\phi)_{sc,i}$

Doppler correction

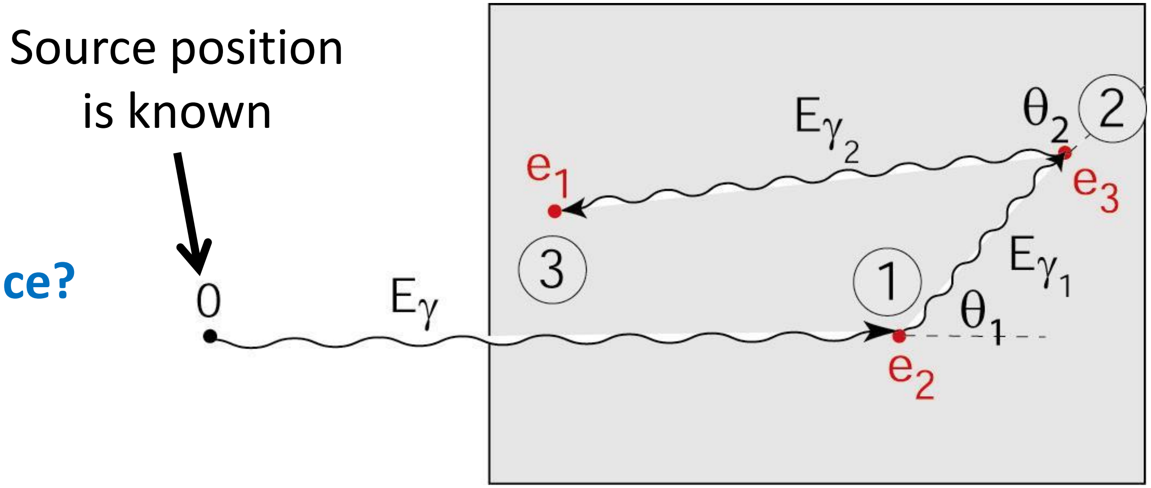
Linear Polarization

discard events corresponding to
incomplete energy release

Tracking of Compton Scattered Events

Questions :

1) **Is the event complete?**
2) **What is the right sequence?**

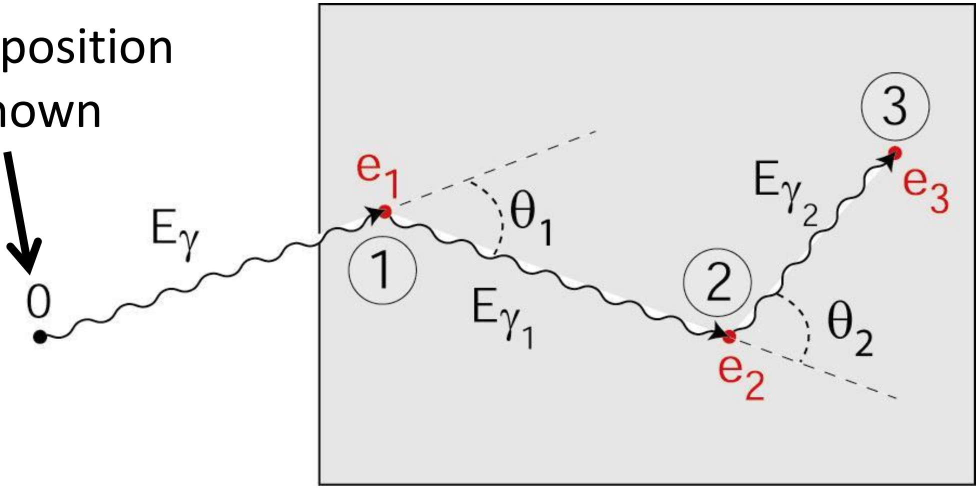


Tracking of Compton Scattered Events

Questions :

1) **Is the event complete?**
2) **What is the right sequence?**

Source position is known



Tracking of Compton Scattered Events

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1) **Is the event complete?**
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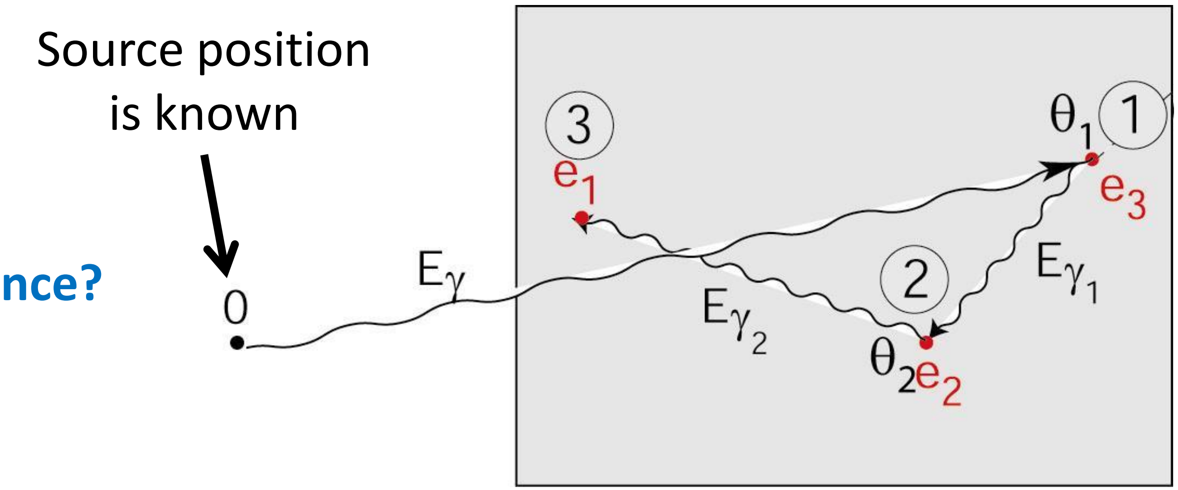


From energy deposition + incident energy

$$E_{\gamma}^{E} = \sum_{i=n}^{N-1} e_i \qquad E_{\gamma'}^{E} = \sum_{i=n+1}^{N-1} e_i$$

From source + interaction positions

$$\cos\theta^{P} = \frac{\overrightarrow{01} \cdot \overrightarrow{12}}{\left|\overrightarrow{01}\right| \cdot \left|\overrightarrow{12}\right|} \Rightarrow E_{\gamma'}^{P} = \frac{E_{\gamma}^{E}}{1 + \frac{E_{\gamma}^{E}}{m_0 c^2}\left(1 - \cos\theta^{P}\right)}$$

Track order = permutation with best χ^2

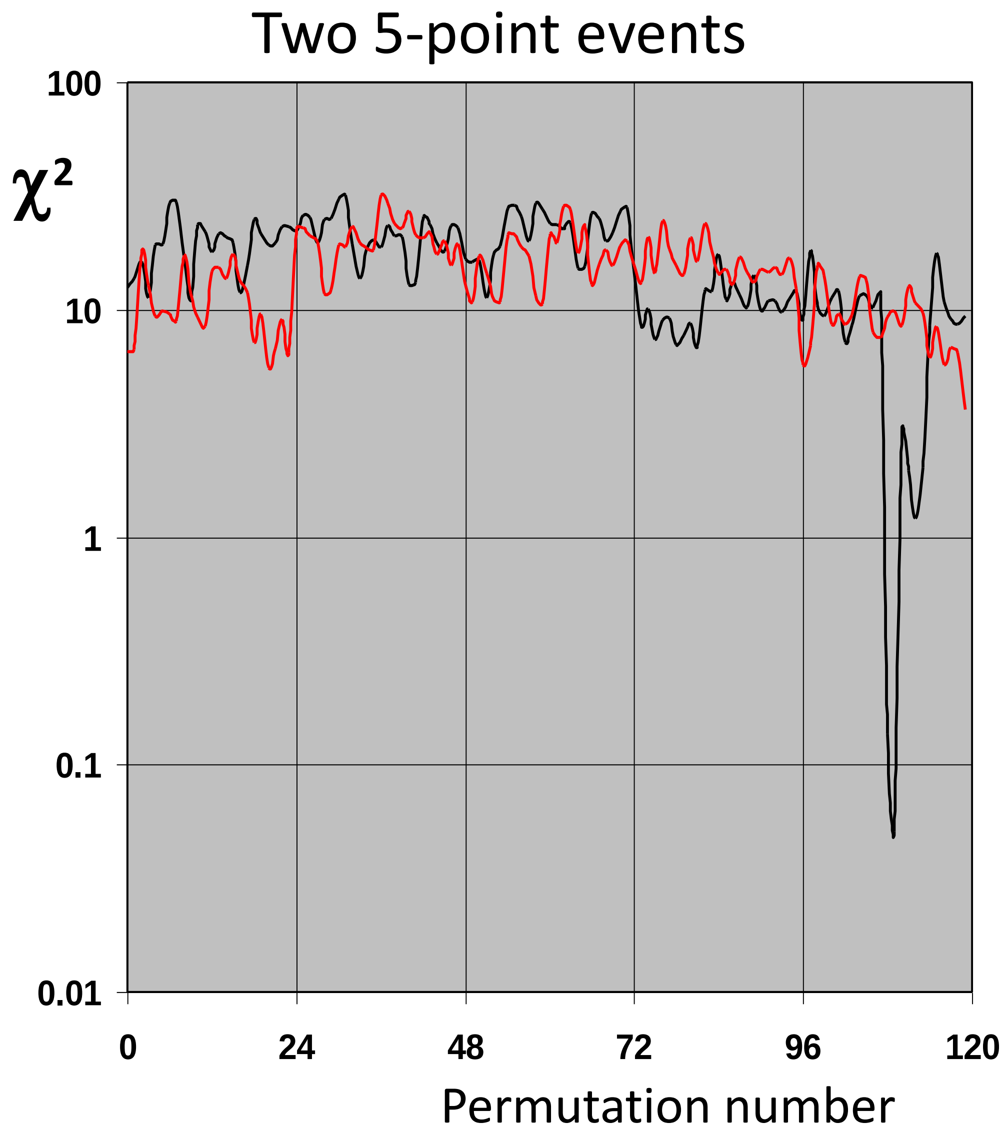
$$\chi_n^2 = \left(\frac{E_{\gamma'}^{E} - E_{\gamma'}^{P}}{\sigma}\right)^2 \Rightarrow \chi^2 \approx \sum_{n=1}^{N-1} \chi_n^2$$

Tracking of Compton Scattered Events

Find χ^2 for the N! permutations of the interaction points

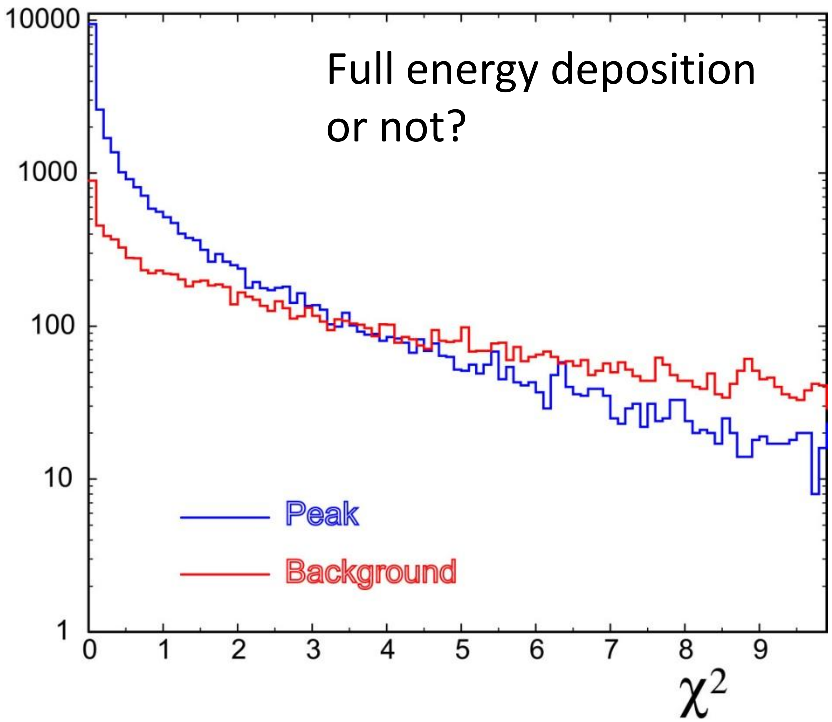
Fit parameter is the permutation number

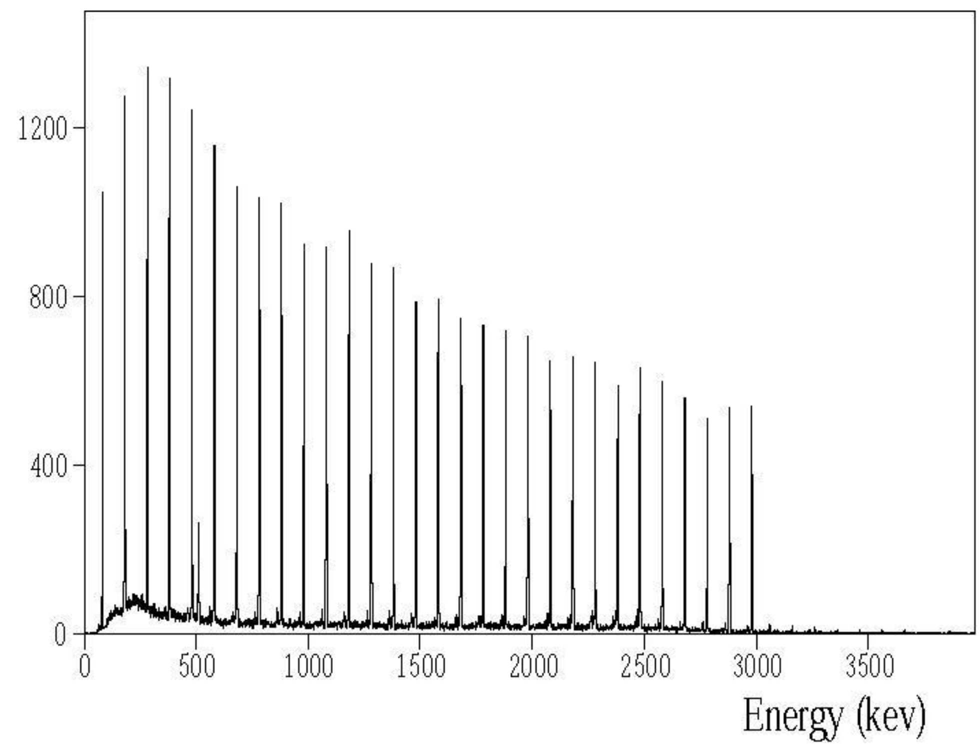
Accept the best permutation if its χ^2 is below a predefined value



Identification is not 100% sure

➔spectra will always contain background

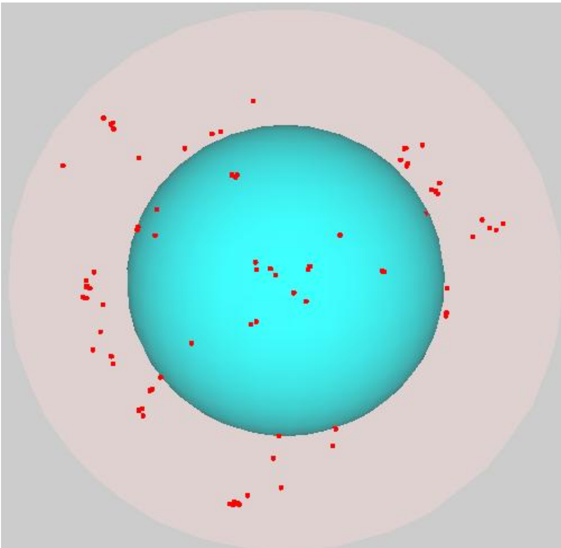


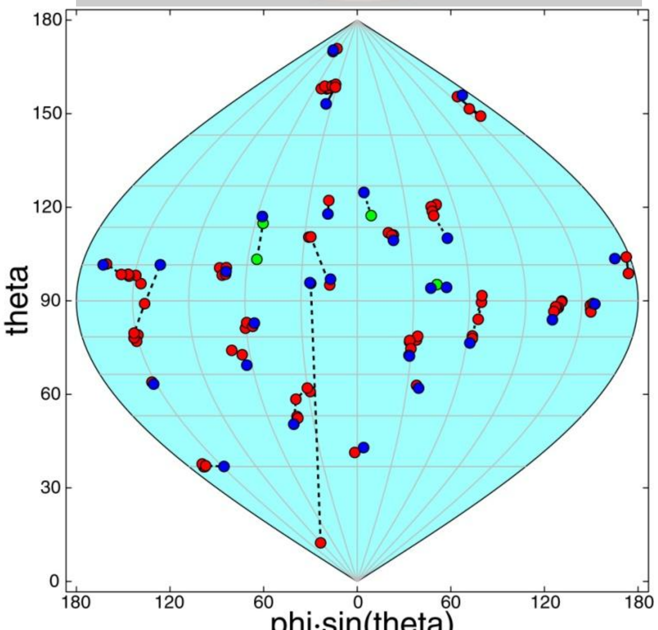


The acceptance value determines the quality (P/T ratio) of the spectrum

Often we use the **R = Efficiency•PT** to qualify the reconstructed spectra

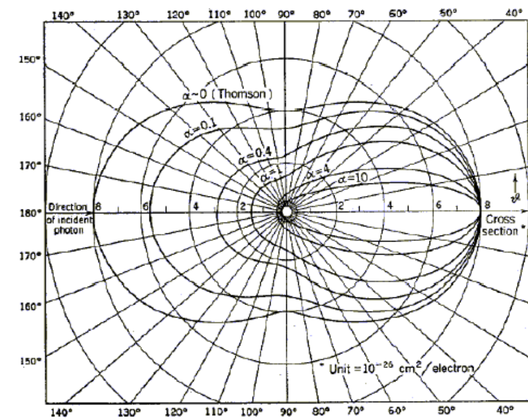
Reconstruction of multi-gamma events





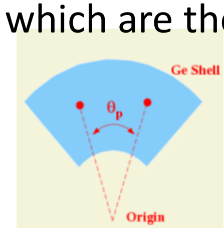
- Analysis of all partitions of measured hits is not feasible:
  Huge computational problem
  (~10^{23} partitions for 30 points)
  Figure of merit is ambiguous → the total figure of merit of the "true" partition not necessarily the minimum

- Forward peaking of Compton scattering cross-section implies that the hits of one gamma tend to be localized along the emission direction



$$\frac{d\sigma_{KN}}{d\Omega} = Z\frac{r_0^2}{2}\left(\frac{E'}{E}\right)^2\left[\frac{E'}{E}+\frac{E}{E'}-\sin^2\theta\right]$$

- The most used algorithm (G.Schmid et al. NIMA 430 1999, GRETA) starts by identifying **clusters** of points which are then analyzed as individual candidates gammas



Forward tracking implemented for AGATA

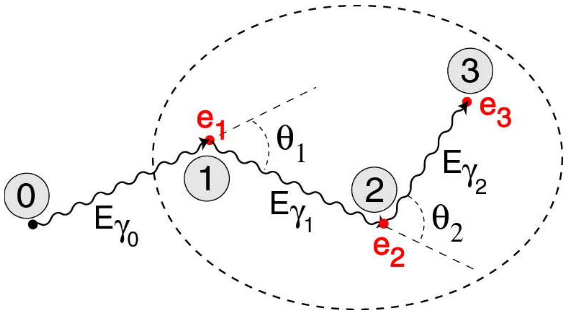
(D.Bazzacco, Padova - A. Lopez-Martens, Orsay [NIMA 533 (2004) 454])

1. Create cluster pool => for each cluster, $E_{\gamma 0} = \sum$ depositions in the cluster

Forward tracking implemented for AGATA

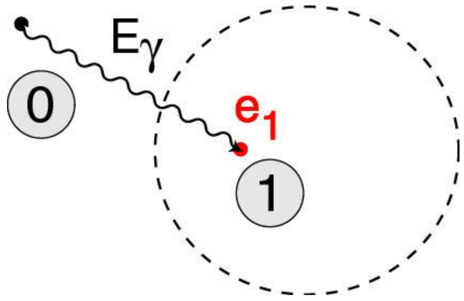
(D.Bazzacco, Padova - A. Lopez-Martens, Orsay [NIMA 533 (2004) 454])

1. Create cluster pool => for each cluster, $E_{\gamma 0} = \sum$ depositions in the cluster
2. Find most probable sequence of interaction points, test the 3 mechanisms
   1. do the interaction points satisfy the **Compton** scattering rules ?



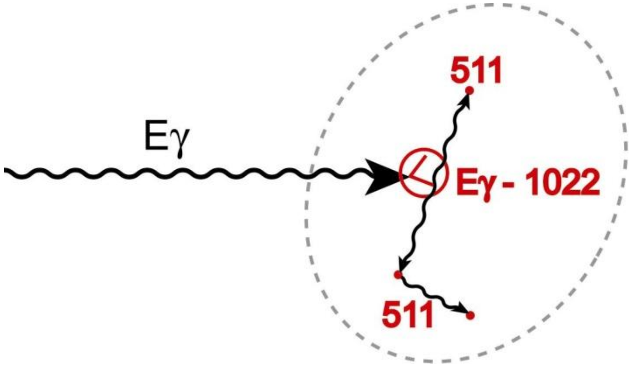
$$\chi^2 \approx \sum_{n=1}^{N-1} W_n \cdot \left(\frac{E_{\gamma'} - E_{\gamma'}^{Pos}}{E_\gamma} \right)_n^2$$

   2. does the interaction satisfy **photoelectric** conditions (e_1,depth,distance to other points) ?



   3. do the interaction points correspond to a **pair production** event ?

$$E_{1st} = E_\gamma - 2\, m_e c^2$$



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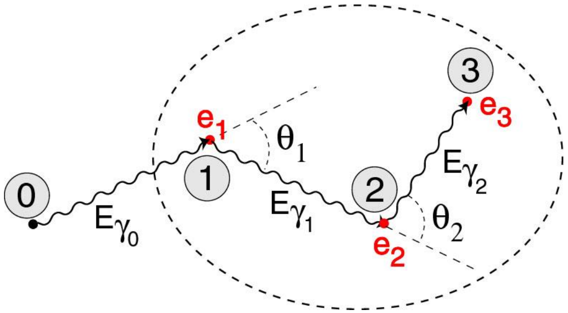

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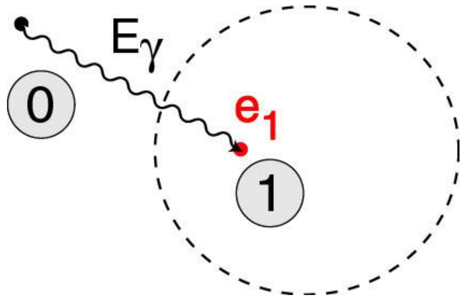

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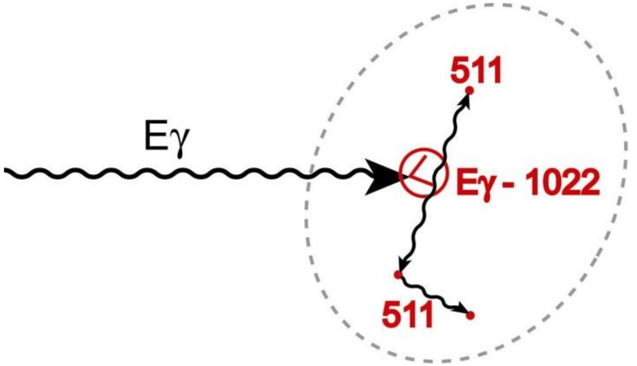
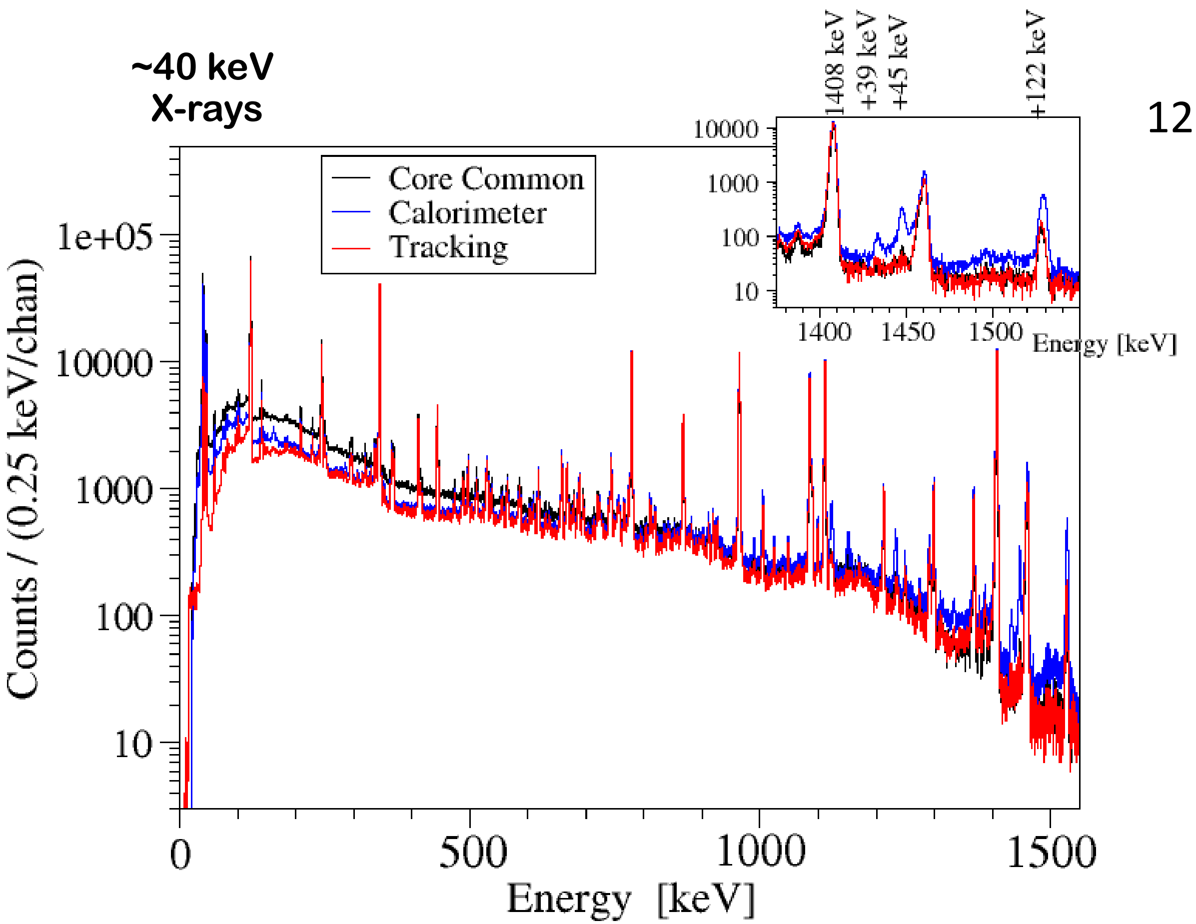


   3. do the interaction points correspond to a **pair production** event ?

$$E_{1st} = E_\gamma - 2\, m_e c^2$$

3. Select clusters based on χ^2

Examples of tracked source spectra

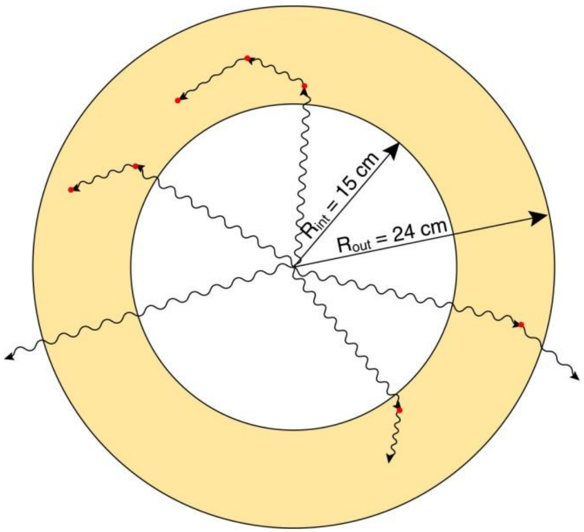


^{152}Eu

12 AGATA detectors

Performance of the Germanium Shell

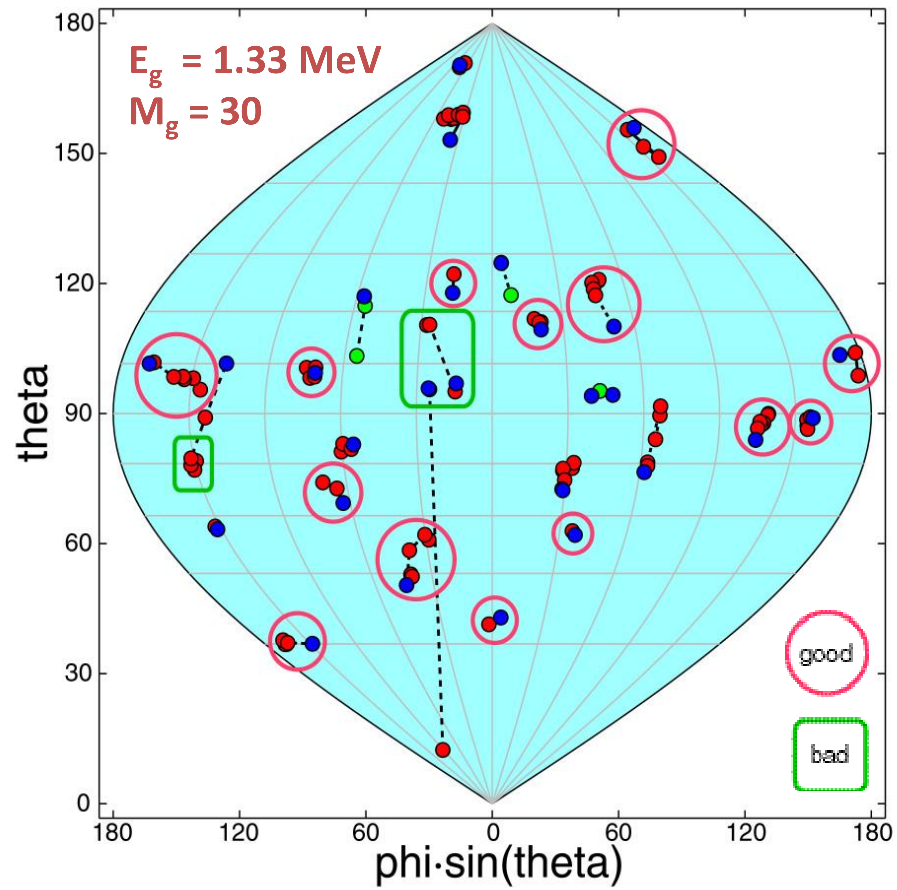
Idealized configuration to determine maximum attainable performance.



1.33 MeV	$M_\gamma = 1$	$M_\gamma = 30$
ε_{ph} (%)	65	36
P/T(%)	85	60

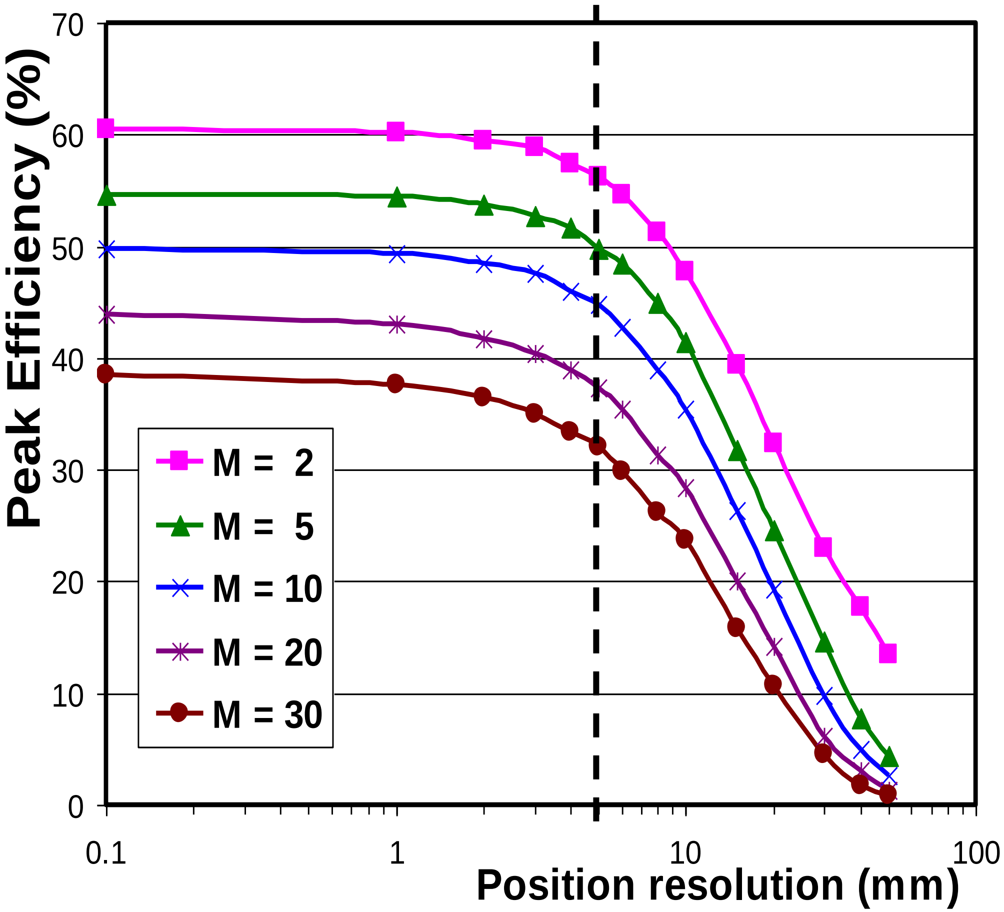
Reconstruction by Cluster-Tracking
Packing Distance: 5 mm
Position Resolution: 5 mm (at 100 keV)

A high multiplicity event



27 gammas detected -- 23 in photopeak
16 reconstructed -- 14 in photopeak

Efficiency of Standard Ge Shell vs. Position Resolution and γ Multiplicity



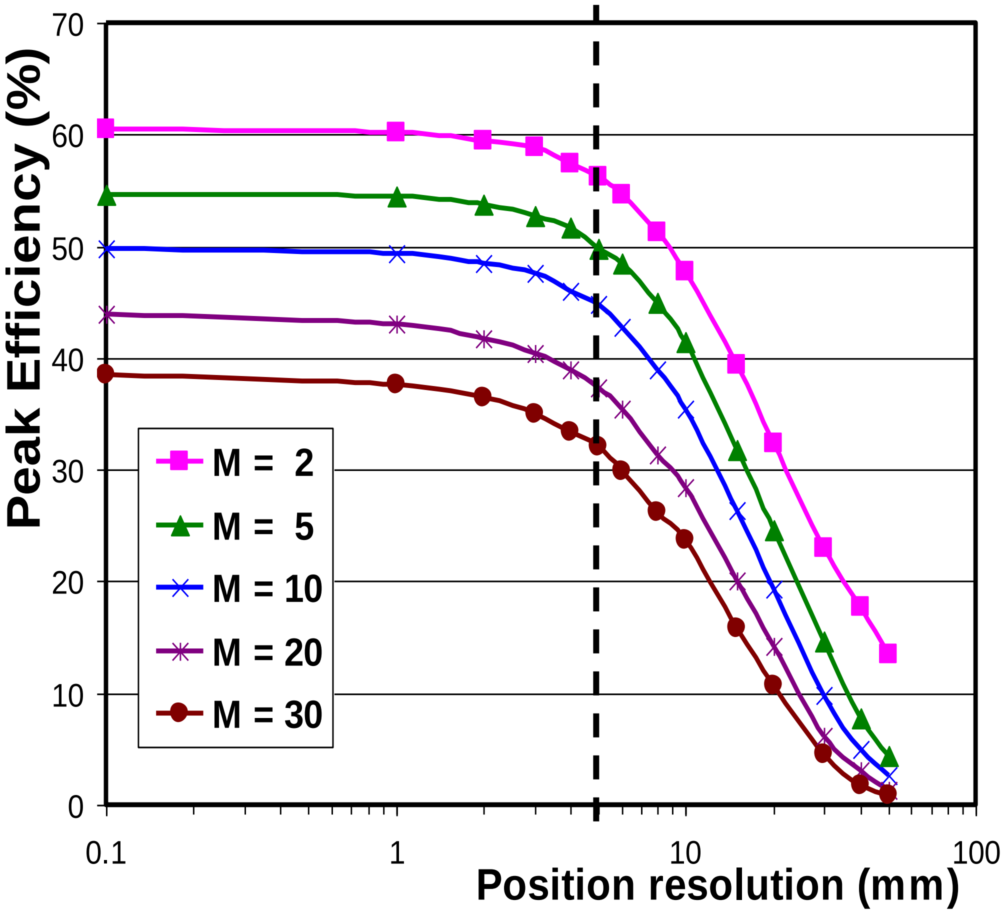
The biggest losses are due to multiplicity (mixing of points) not to bad position resolution

5 mm is the standard "realistic" packing and smearing assumption

If positions inside segments are not known, performance is a factor 2 worse

Standard shell; E_γ = 1.33 MeV; Packing=Smearing; Energy independent smearing

Efficiency of Standard Ge Shell vs. Position Resolution and γ Multiplicity



Standard shell; E_γ = 1.33 MeV; Packing=Smearing; Energy independent smearing

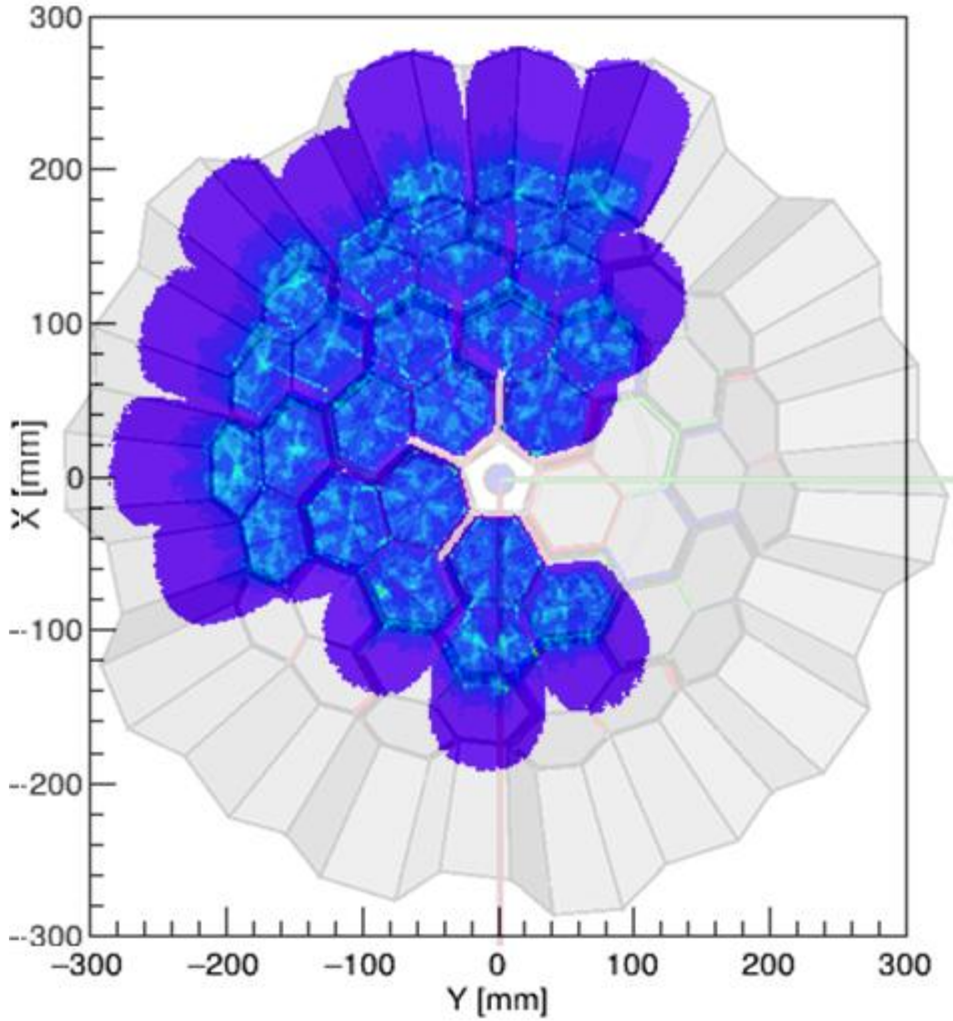
The biggest losses are due to multiplicity (mixing of points) not to bad position resolution

5 mm is the standard "realistic" packing and smearing assumption

If positions inside segments are not known, performance is a factor 2 worse

Sub-segment position resolution is needed

Pulse Shape Analysis (PSA)



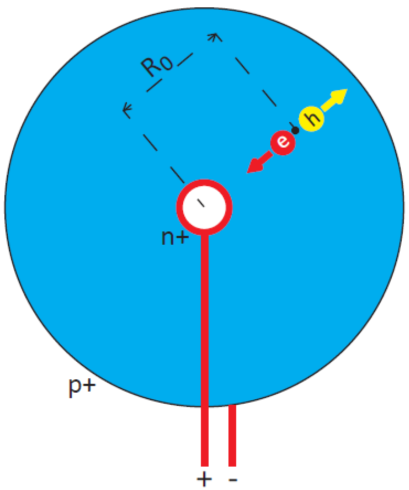
8 AGATA Triple Clusters
(24 detectors)
@ GANIL
"captured" during an
experiment

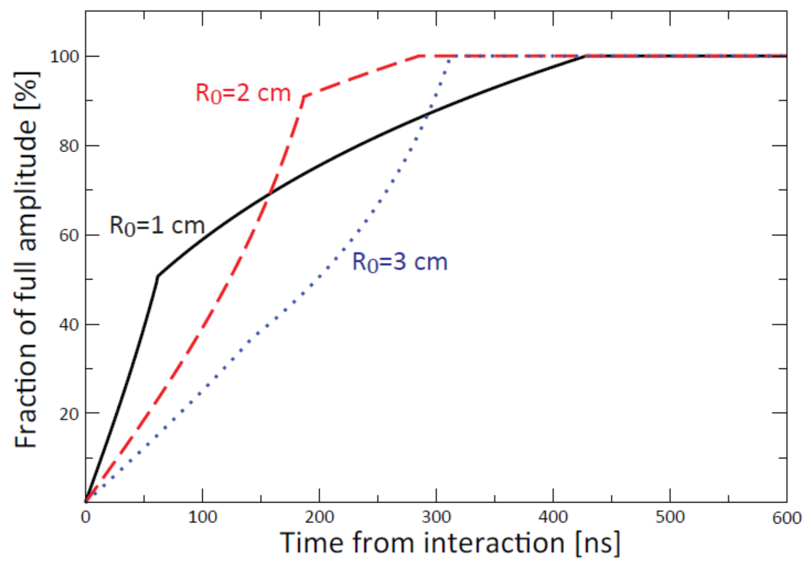
Reconstruction of the
interaction points
(hits)

Pulse shapes in a coaxial Ge detector

Reverse bias (-HV on p^+ contact) depletes bulk and generates high electric filed

Radiation ➔ carriers in the bulk, swept out by electric field ➔ signal



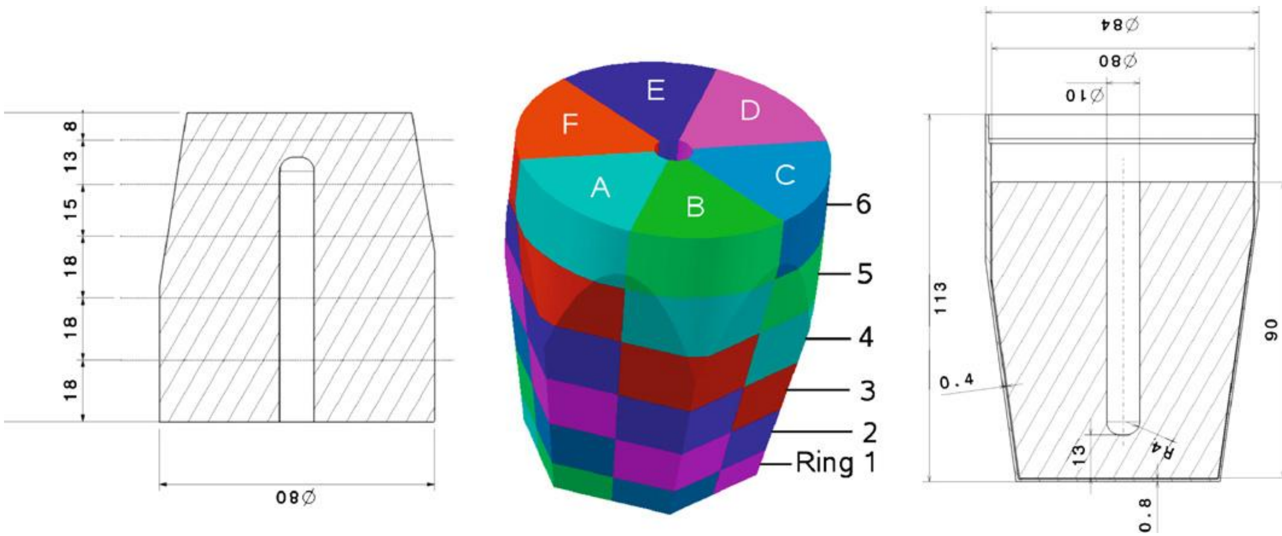


On “true” coaxial detectors, the shape depends on initial radius

Segmented detectors

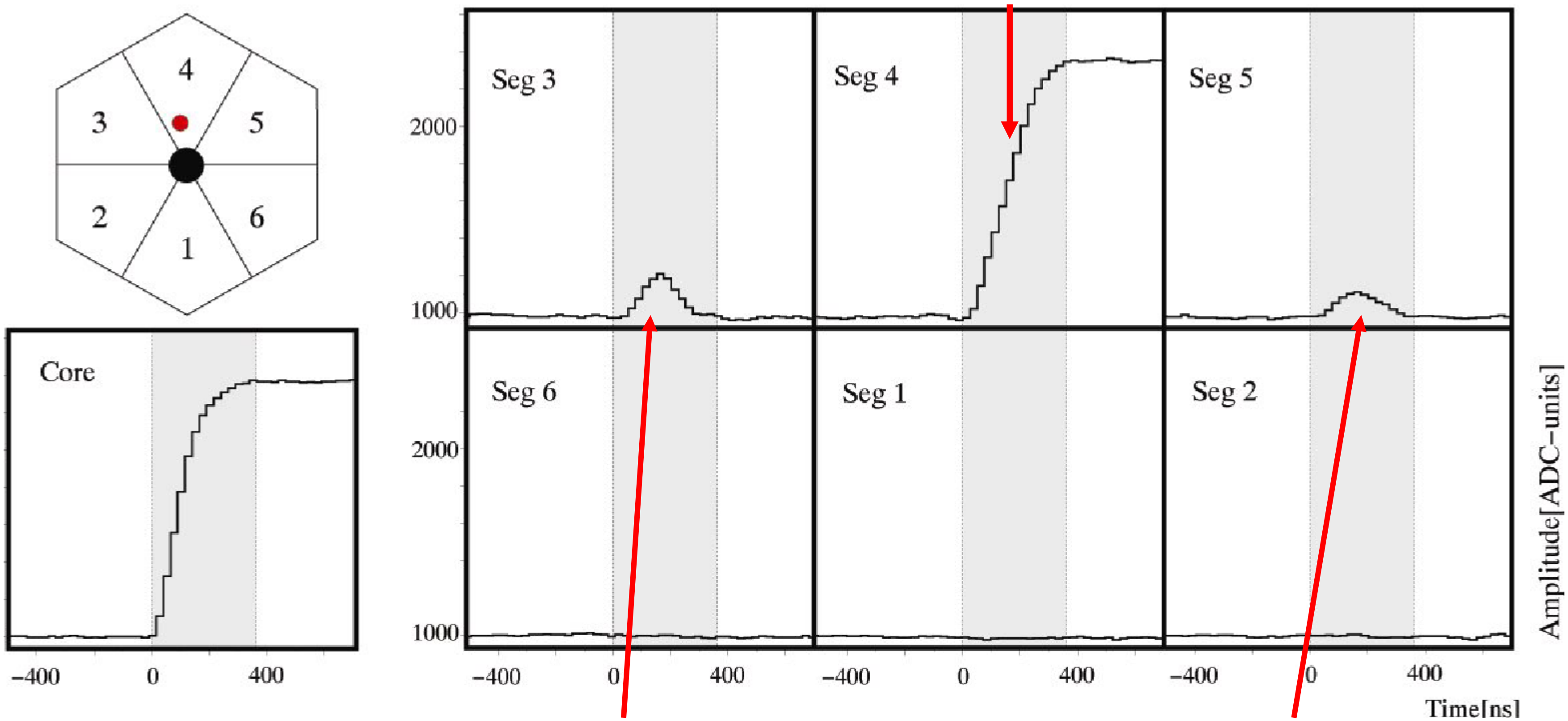
- When one of the electrodes is (electrically) segmented, the motion of charges within one segment induces a transient signal also in the neighboring electrodes
- Contrary to the segment where the interaction takes place (the charge is released), the total collected charge in the neighboring electrodes is null
- The amplitude of the induced transient signals provides a convenient way to locate the interaction with sub-segment precision

Segmentation of an AGATA detector



Pulse Shape Analysis concept

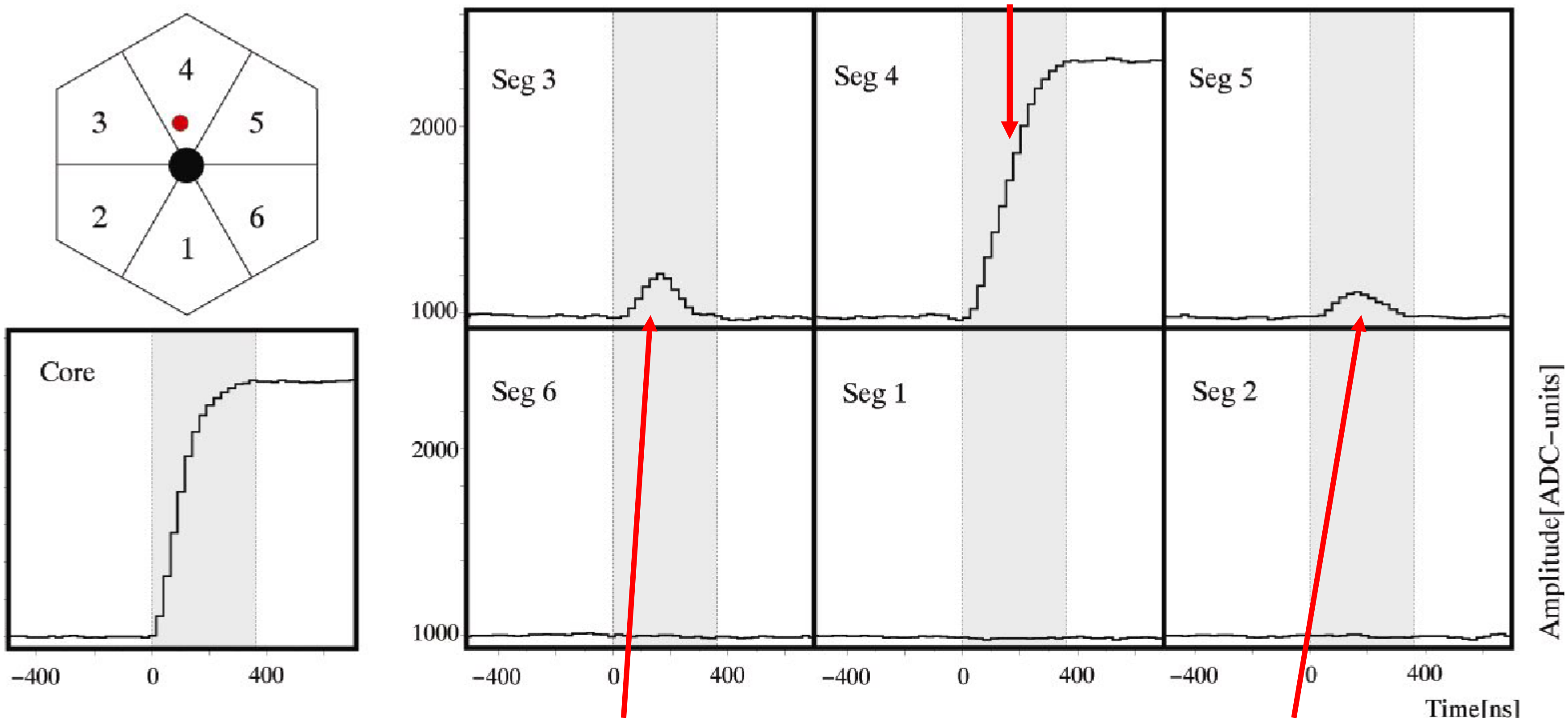
Interaction occurred in segment 4
(net charge signal)



Interaction is closer to segment 3 (larger amplitude than segment 5)

Pulse Shape Analysis concept

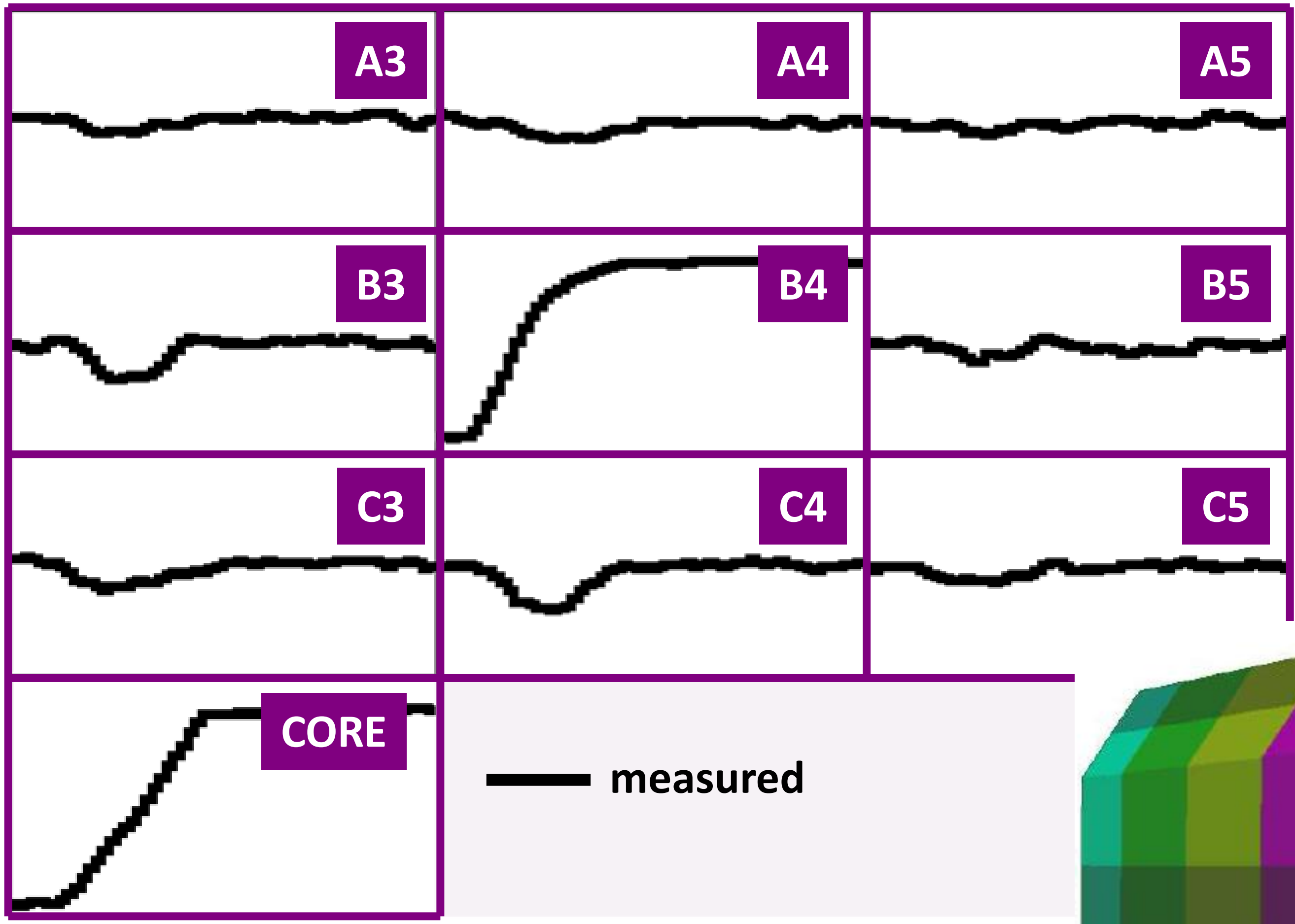
Interaction occurred in segment 4
(net charge signal)

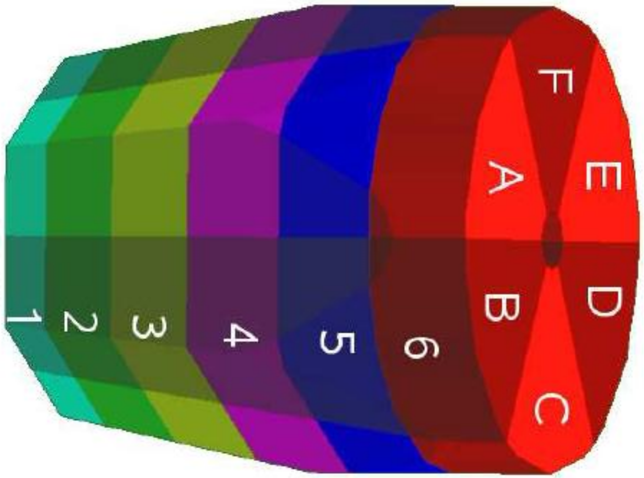


Interaction is closer to segment 3 (larger amplitude than segment 5)

Sub-segment precision … but not enough to efficiently perform tracking!
➔ Pulse Shape Analysis

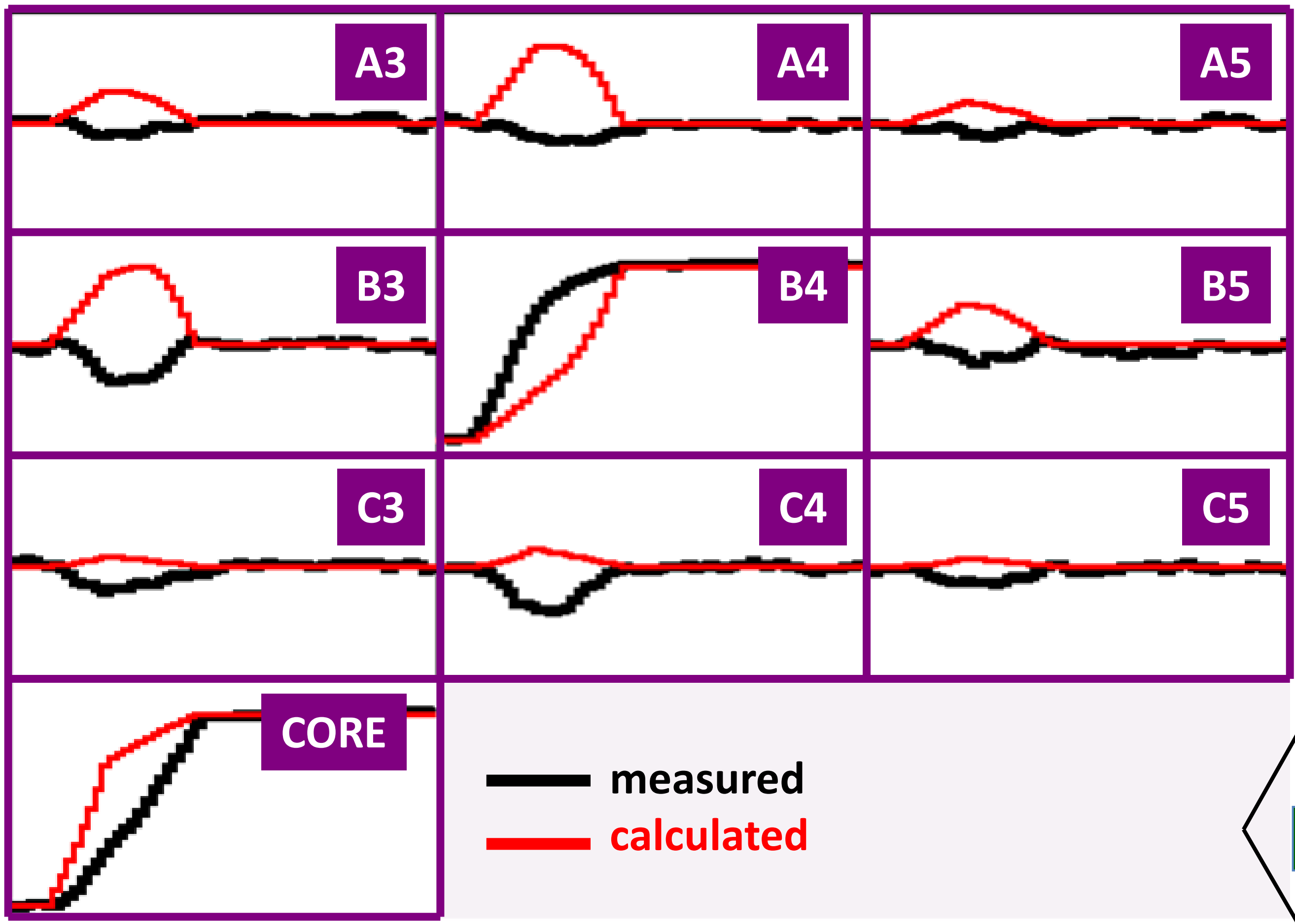
Pulse Shape Analysis concept



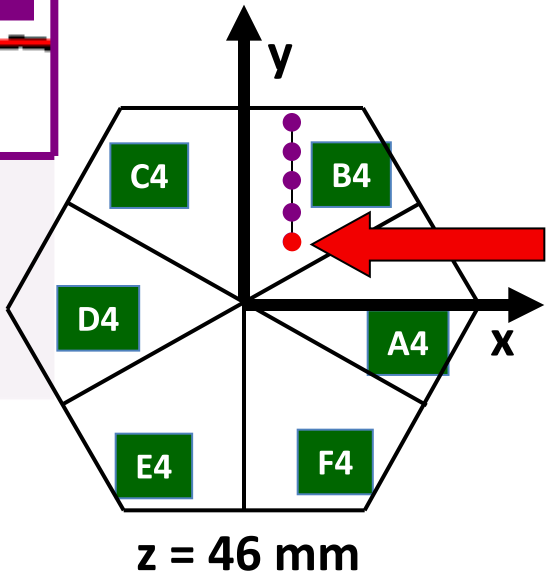


791 keV deposited in segment B4

Pulse Shape Analysis concept

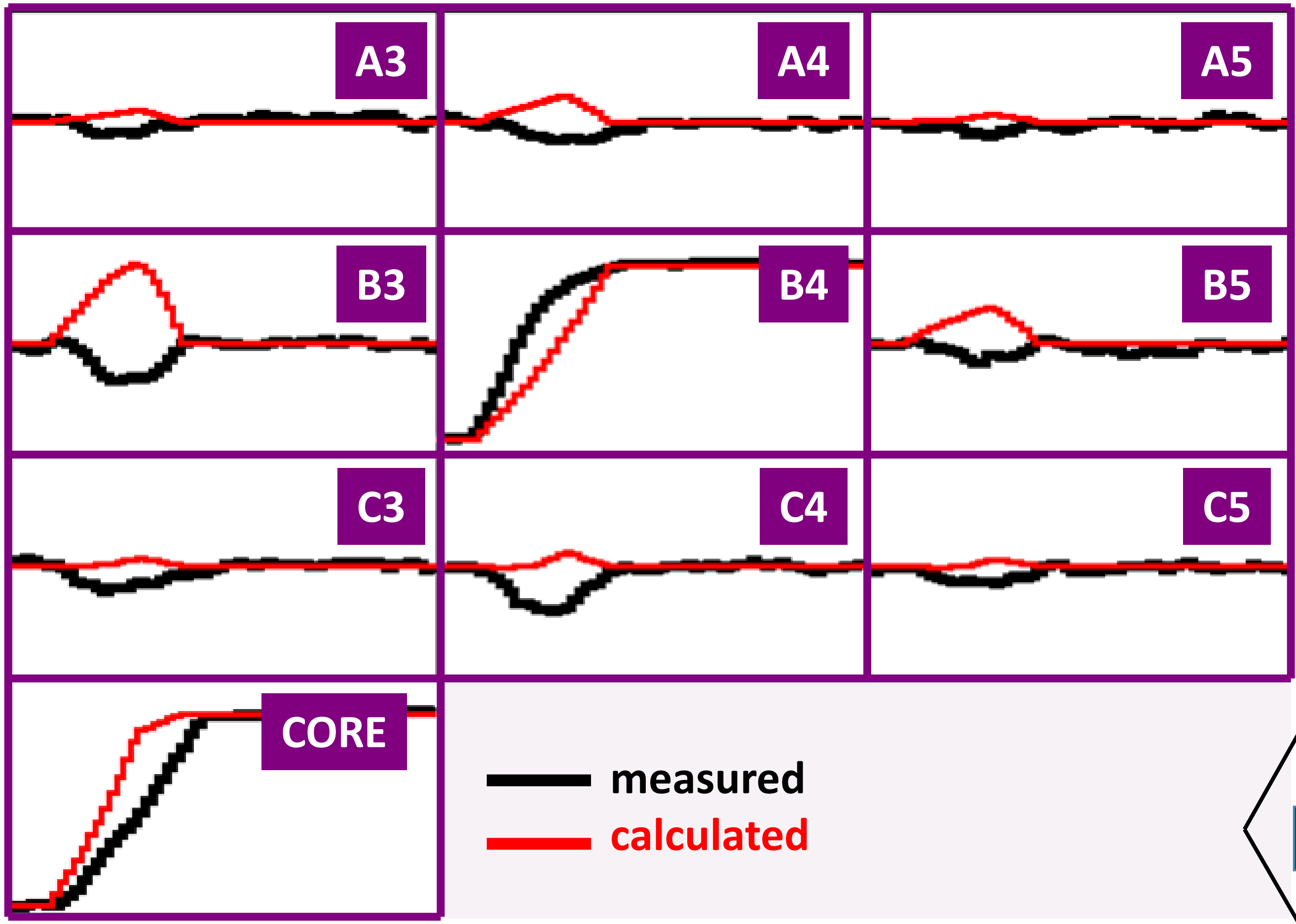


(10,10,46)



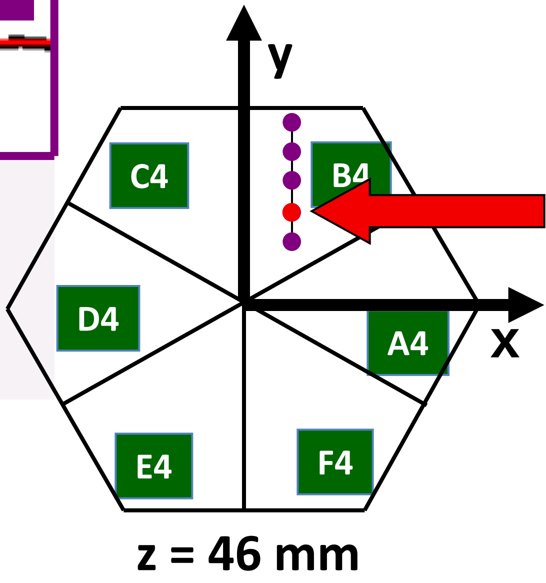
791 keV deposited in segment B4

Pulse Shape Analysis concept

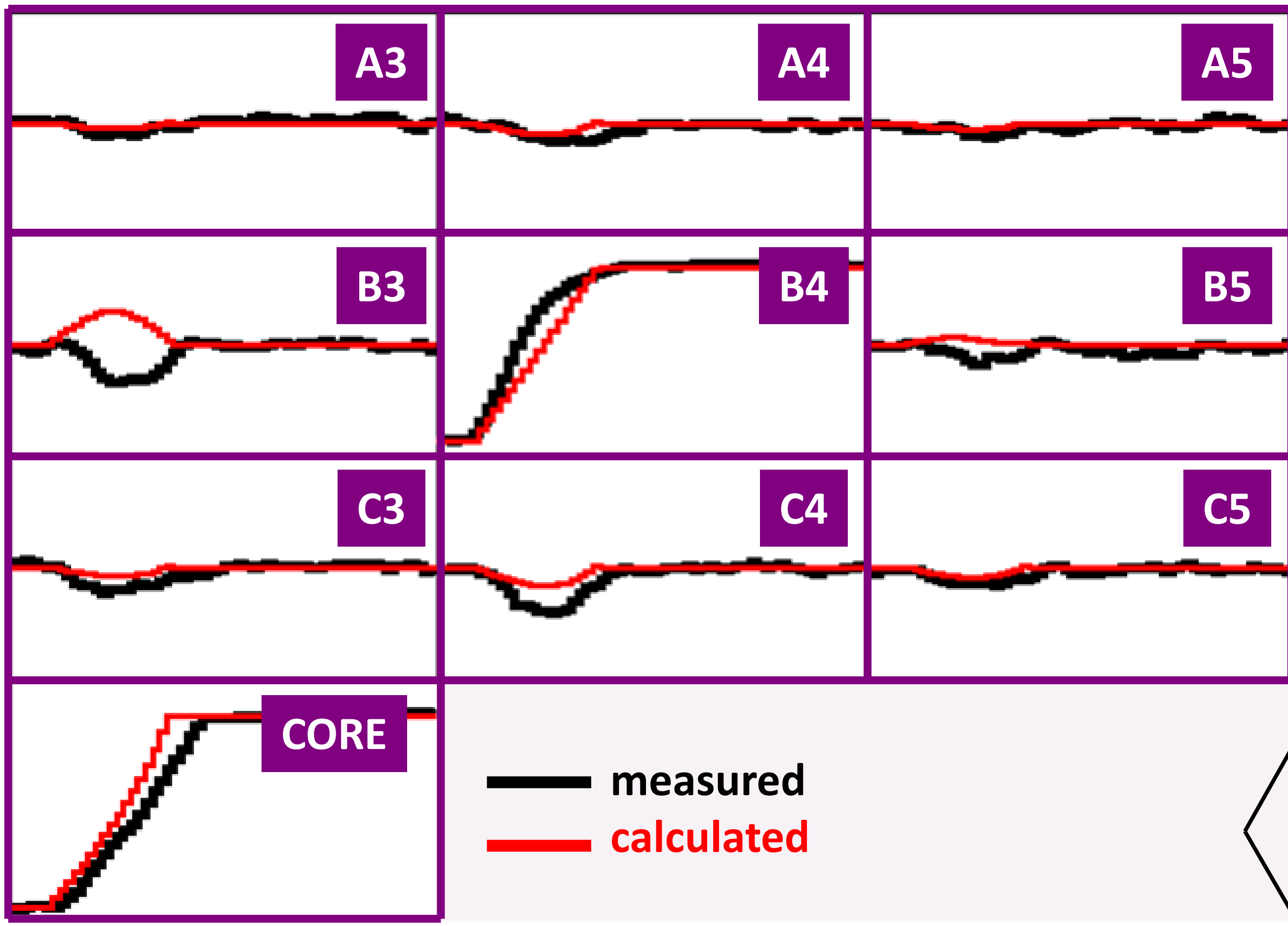


791 keV deposited in segment B4

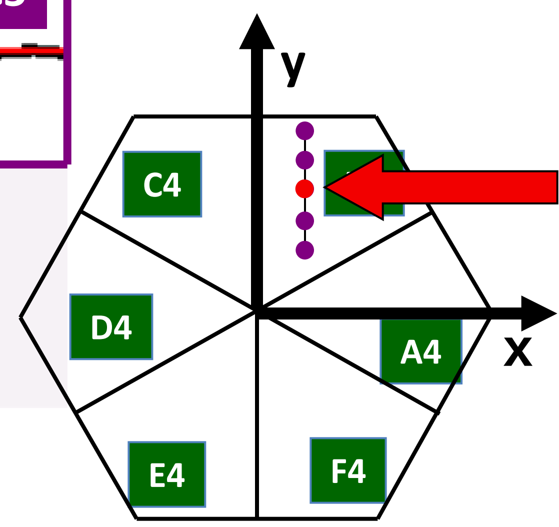
(10,15,46)



Pulse Shape Analysis concept



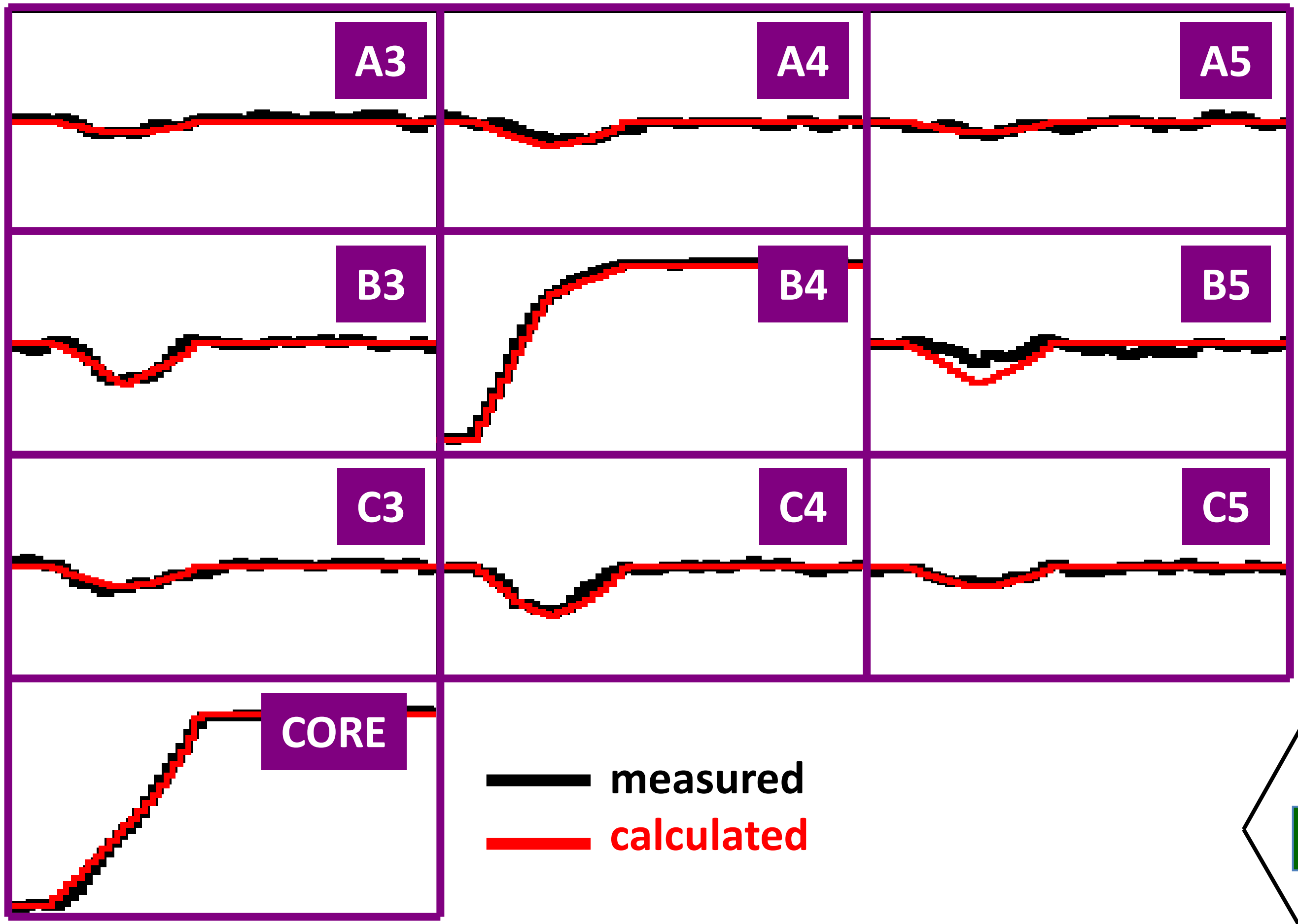
(10,20,46)



z = 46 mm

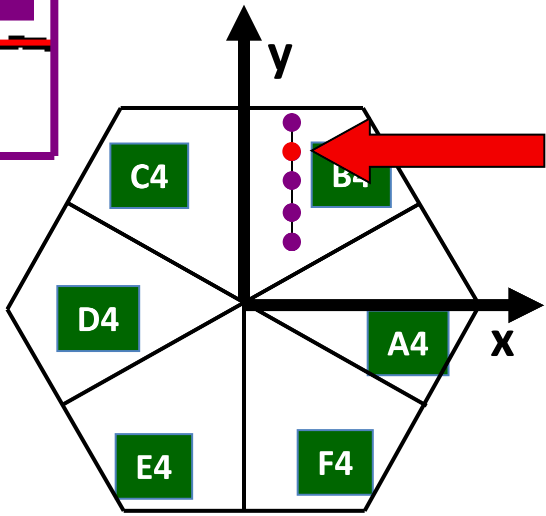
791 keV deposited in segment B4

Pulse Shape Analysis concept



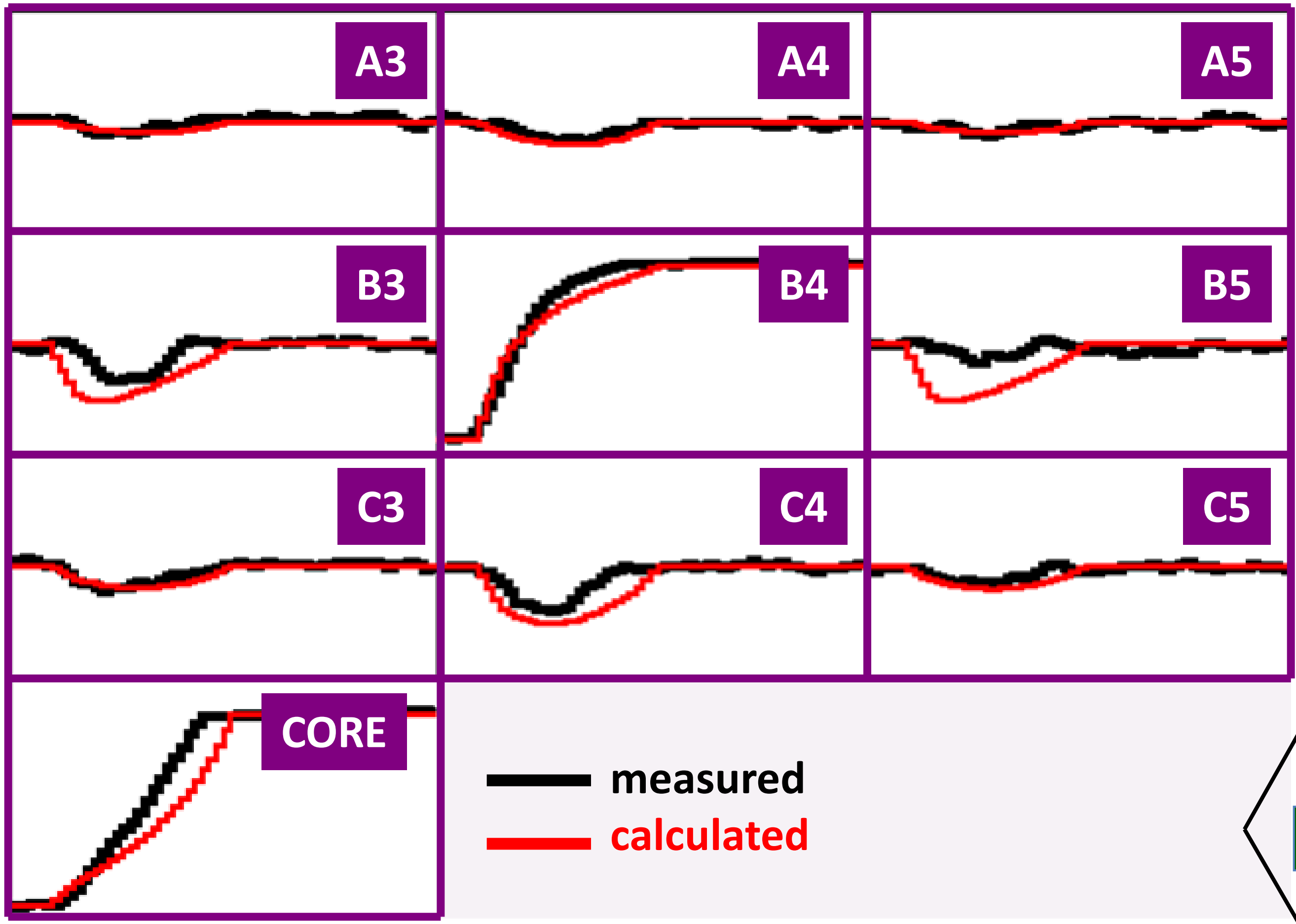
791 keV deposited in segment B4

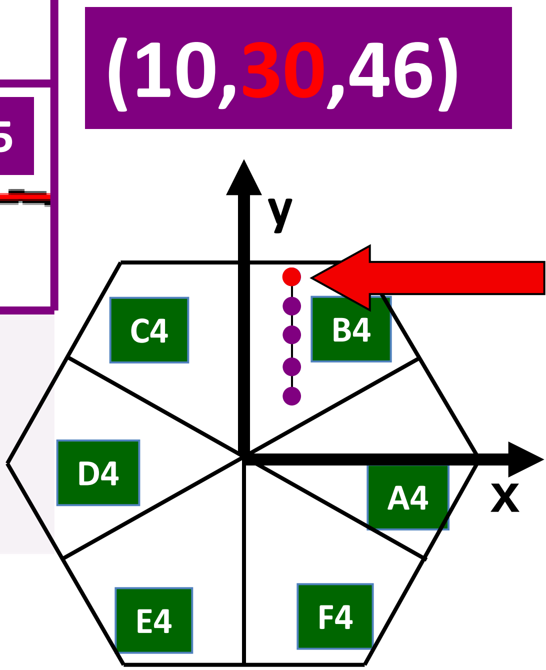
(10,25,46)



z = 46 mm

Pulse Shape Analysis concept

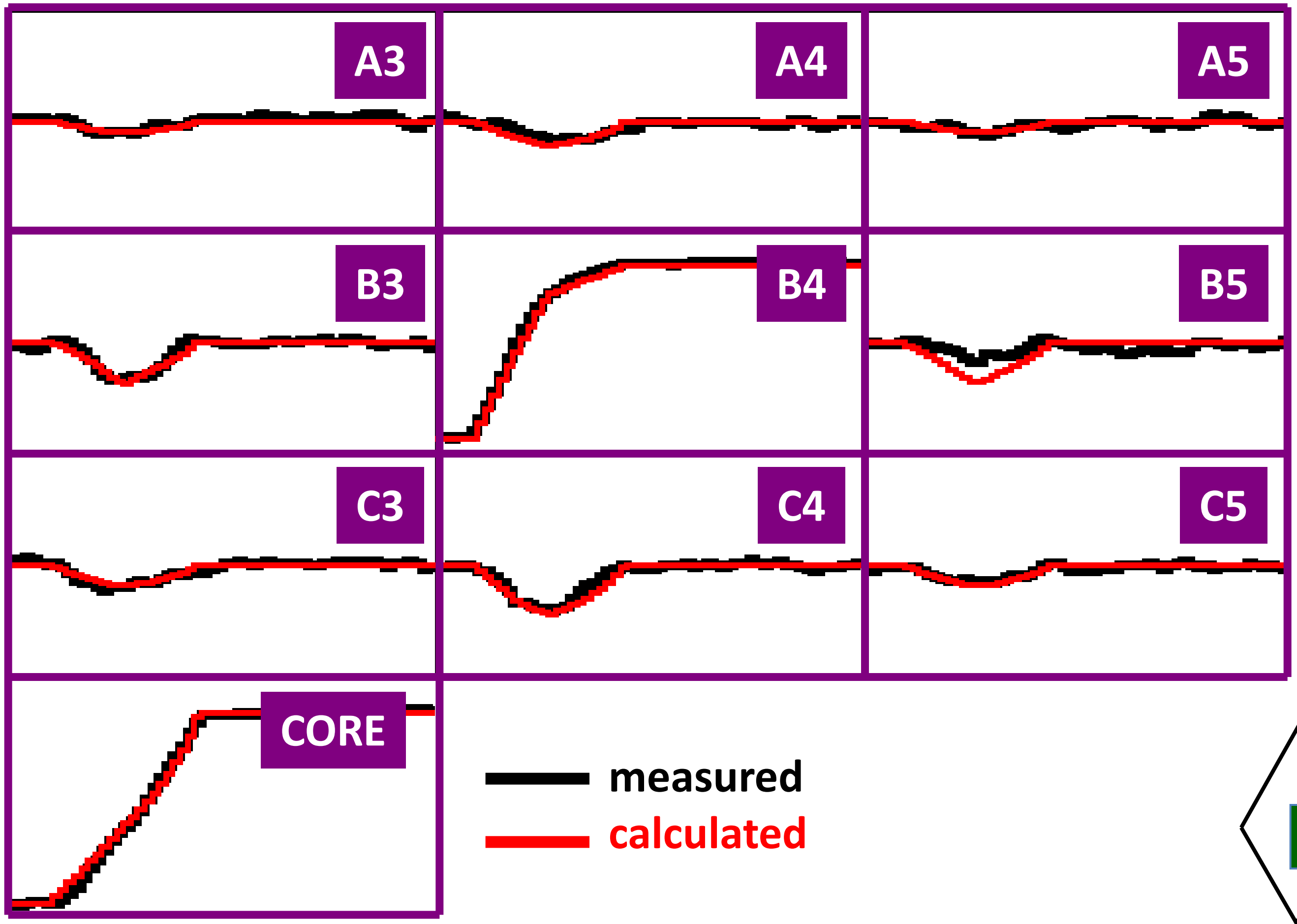




791 keV deposited in segment B4

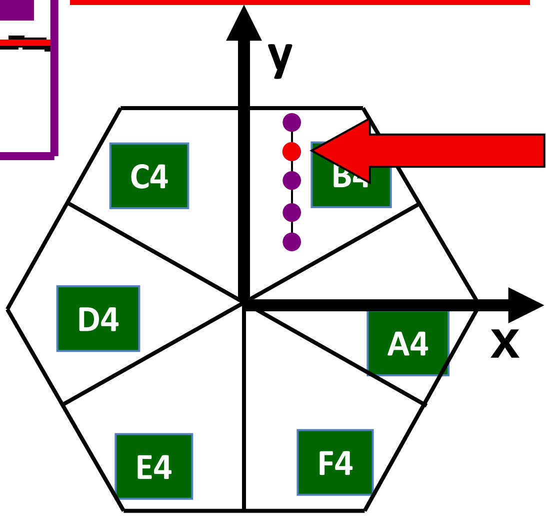
z = 46 mm

Pulse Shape Analysis concept



Result of
Grid Search
Algorithm

(10,25,46)



z = 46 mm

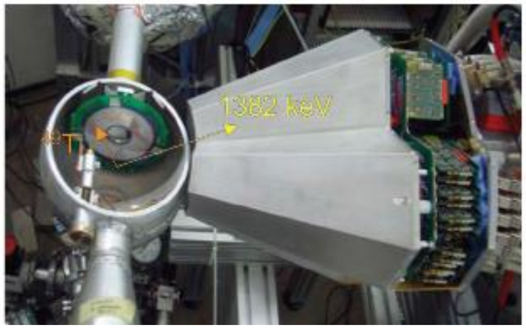
791 keV deposited in segment B4

Position resolution of AGATA

Method = Doppler correction capability
in an in-beam experiment

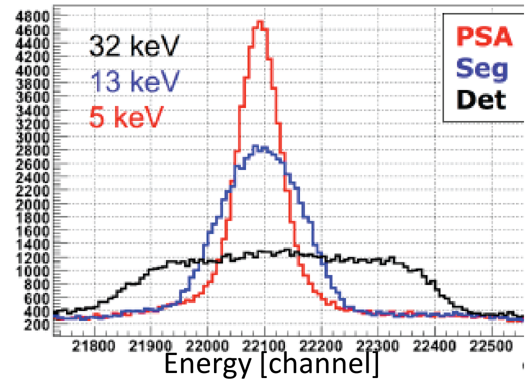
F. Recchia et al., NIMA 604 (2009) 555

P-A. Soederstroem et al., NIMA 638 (2011) 96



REACTION CHANNEL: $^{48}Ti(d,p)^{49}Ti$

beam	^{48}Ti	100 MeV
target	$^{48}Ti + ^{2}H$	220 μg/cm²
Si detector	thickness	300 μm
	segmentation	32 rings, 64 sectors
AGATA triple symmetric cluster		



F. Recchia et al., NIMA 604 (2009) 555

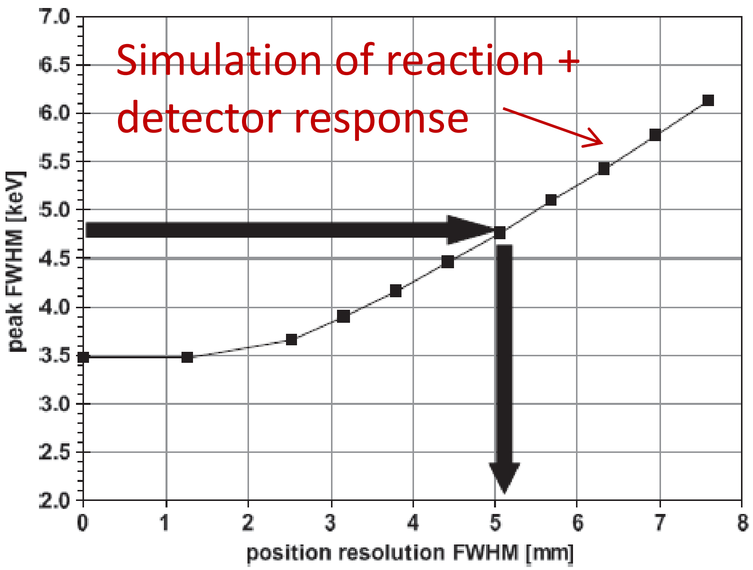
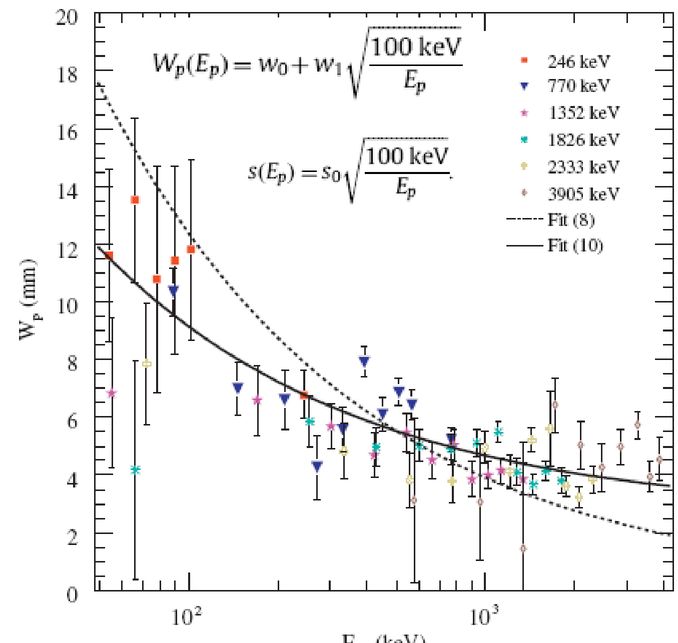


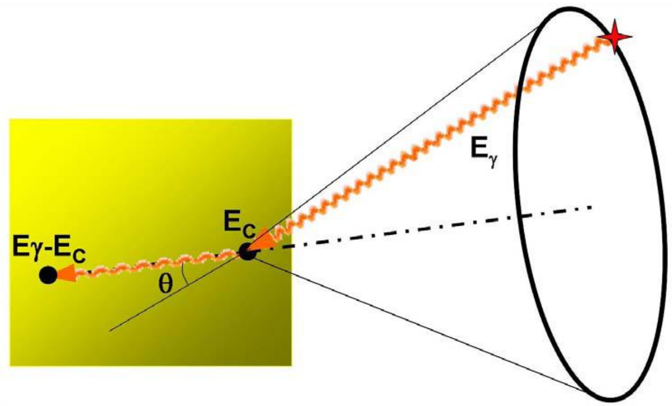
Fig. 10. Width of the simulated 1382 keV peak as a function of the position smearing for the full triple cluster. Individual crystal energy resolution have been considered. All of the segment multiplicities are taken into account. The horizontal arrow indicates the experimental width.



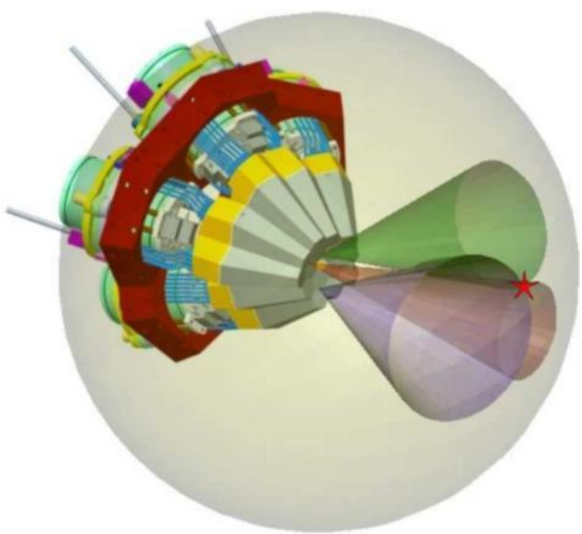
P-A. Soederstroem et al., NIMA 638 (2011) 96

Imaging of E_γ=1332 keV gamma rays

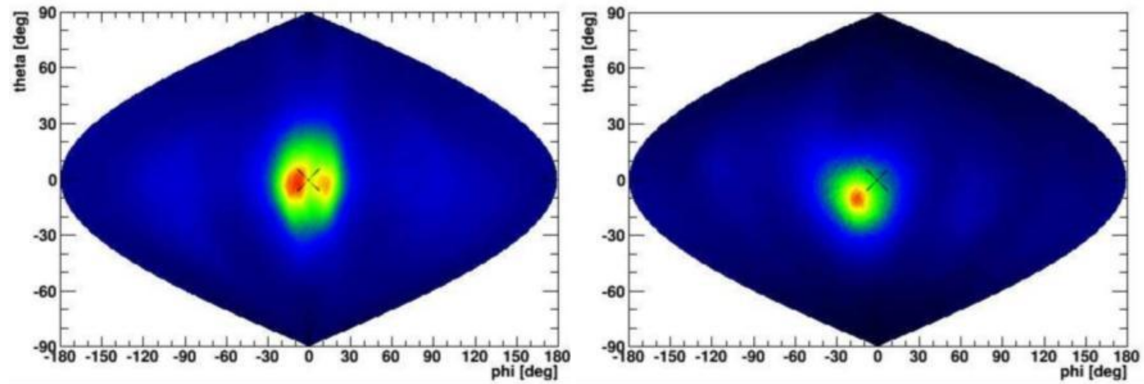
AGATA used as a big and exspensive Compton Camera



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



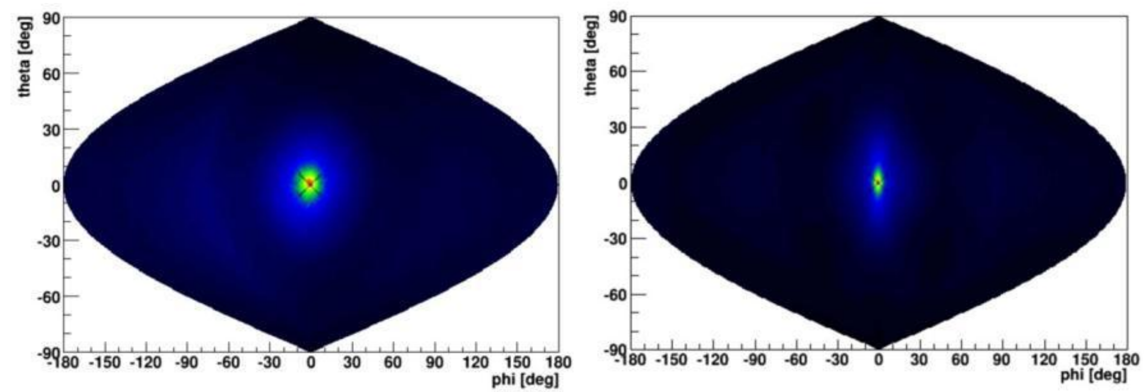
Far Field Backprojection



All 9 detectors

One detector

Near Field Backprojection



All 9 detectors

One detector

Source at 51 cm ➔ Dx ~Dy ~2 mm Dz ~2 cm

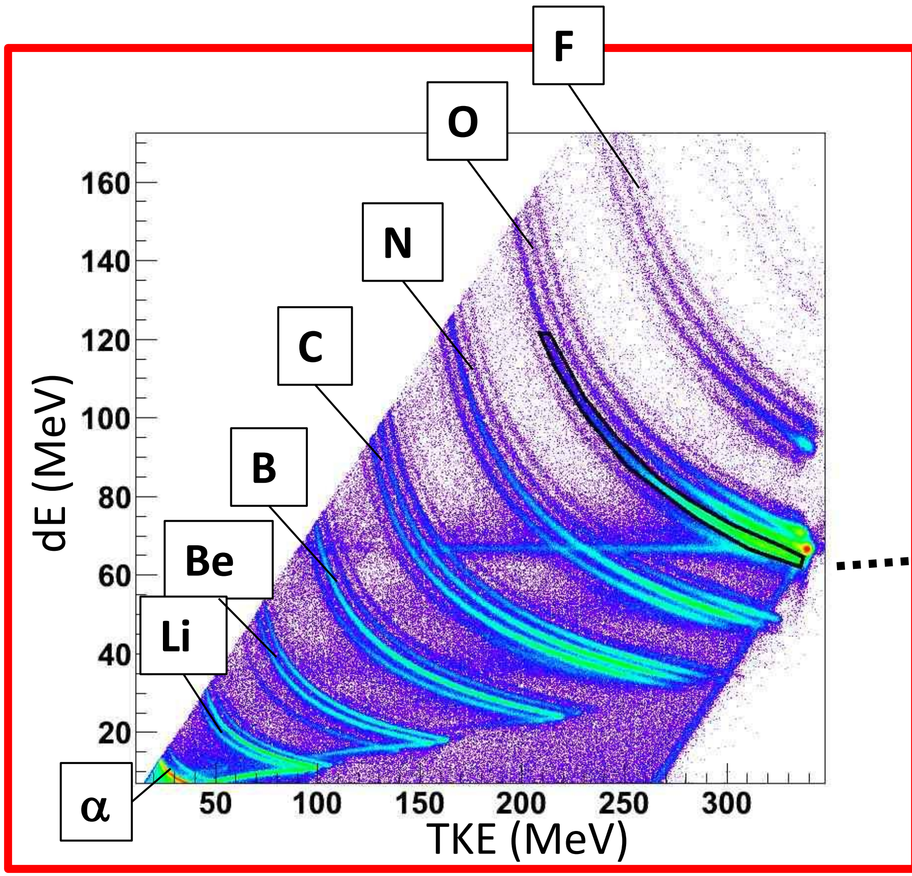
F. Recchia et al., NIMA 604 (2009) 60

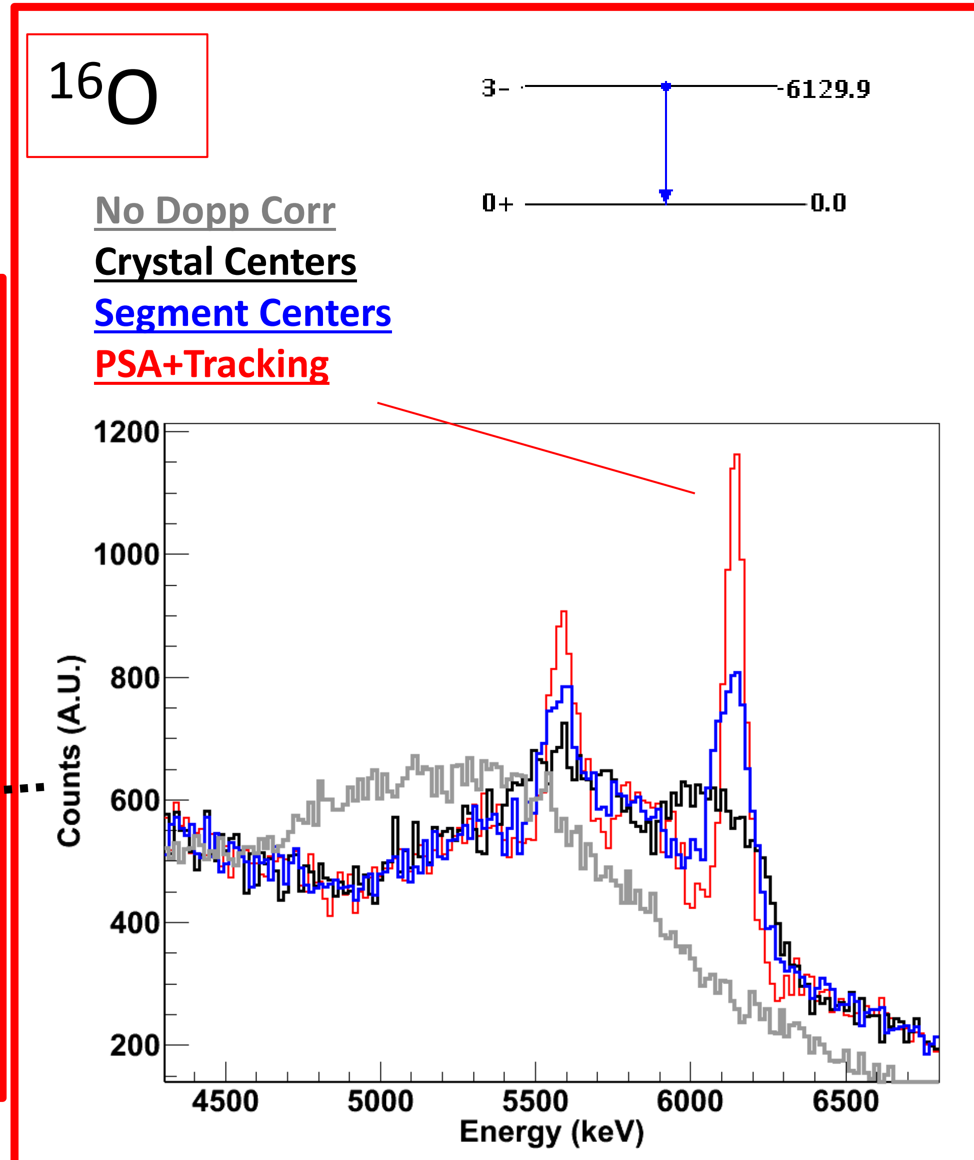
Doppler correction capabilities

AGATA Demonstrator at LNL

Inelastic scattering

^{17}O @ 20 MeV/u on ^{208}Pb





F.Crespi, Milano

Outline

PART 2 (September 29th 2015)

Pulse Shape Analysis (PSA)

1. Signal bases calculation
2. Signal decomposition

Some results from Ge position sensitive mode operation and γ-ray tracking

The AGATA array of segmented HPGe detectors

1. Implementation of Pulse Shape Analysis and Tracking concepts
2. The AGATA detectors and preamplifiers
3. The structure of electronics and data acquisition
4. Digital signal processing (at high counting rate)
5. (AGATA data processing)

AGATA+VAMOS (magnetic spectrometer) at GANIL

(be aware … personal ☺ selection of topics!)