# A Novel technique for the characterization of a HPGe detector position response based on pulse shape comparison

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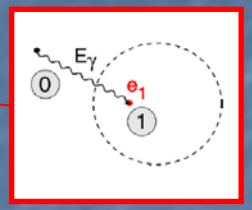
# OUTLINE:

- γ-ray tracking
- Characterization of segmented HPGe detectors
- A Novel technique based on Pulse Shape Comparison

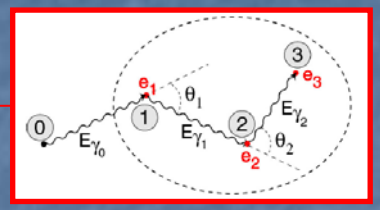
# γ-ray Tracking

- Focus on 0.1 – 10 MeV γ-rays, in this Energy range the relevant Interaction mechanisms of photons in Ge are:

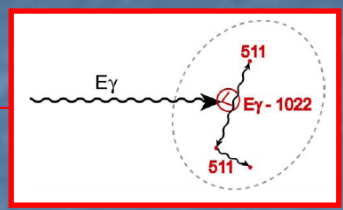
**Photoelectric Effect**




**Compton Scattering**

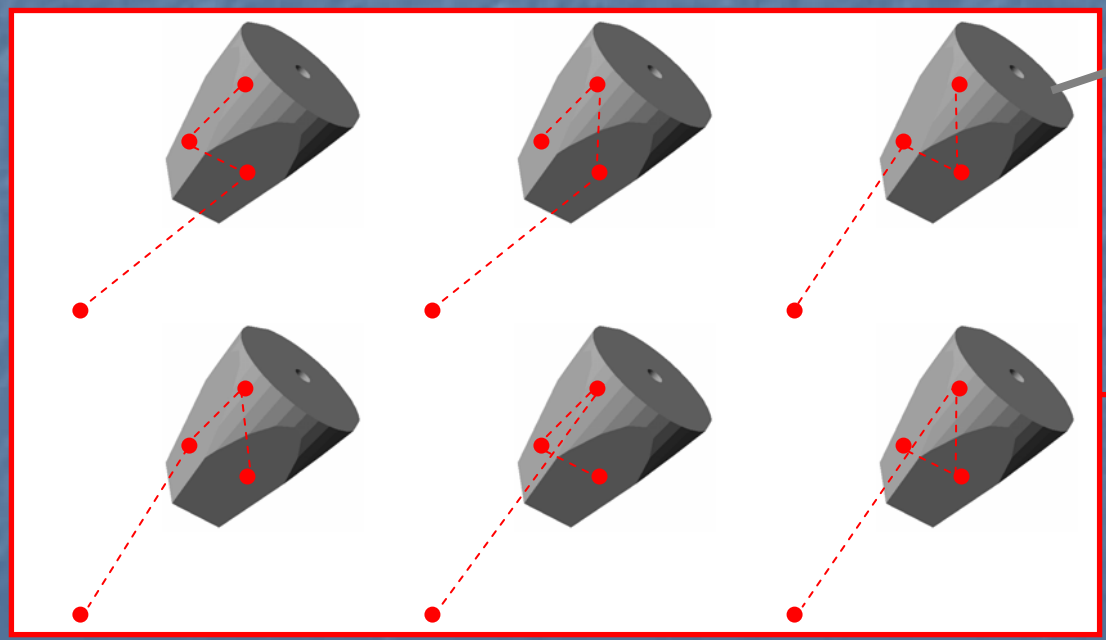



**Pair Production**




- **tracking algorithms** rely on the characteristics of these processes to order the individual interactions into a γ-ray path:

- **Determination of γ-ray emission direction**
- **Rejection of γ -rays escaped from the detector**
- **Separation of different γ-rays contributions**



large volume HPGe crystal for γ spectroscopy
- 90 mm long
- 80 mm diameter (rear part)

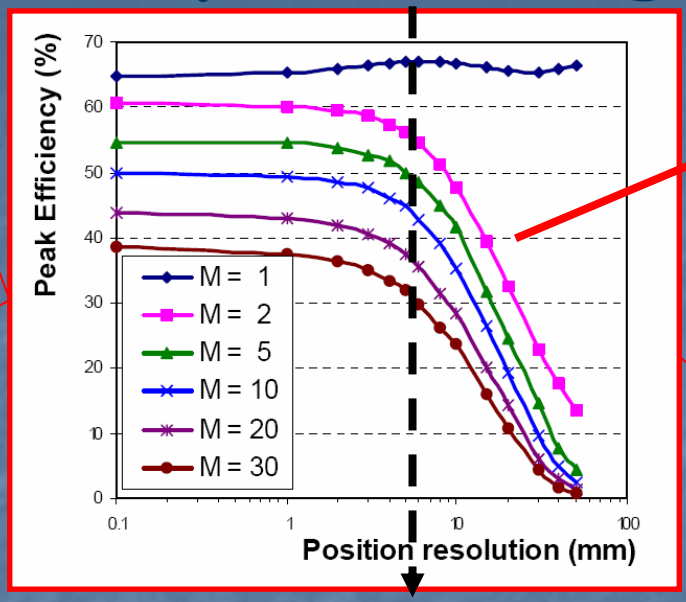
3 interaction points → 3! permutations

$(e_i, x_i, y_i, z_i)$ have to be experimentally determined for each interaction

# γ-ray Tracking

**"M"** = γ multiplicity of the event

As the position resolution worsens, the probability to mix Interaction points belonging to different γ's becomes larger



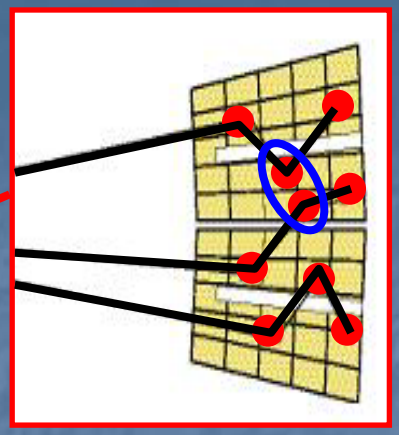
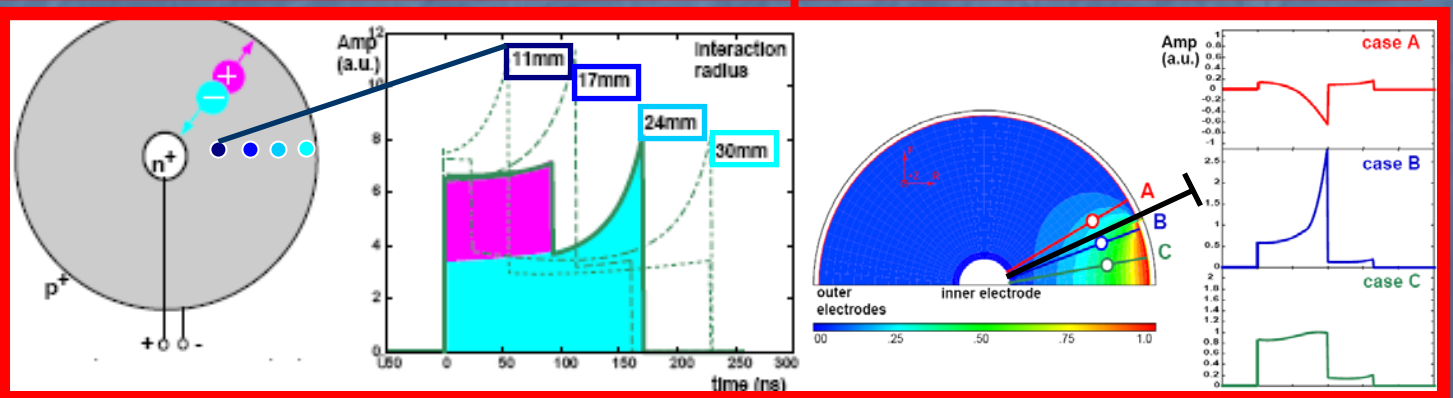



Figure taken from
J. Gerl, W. Korten (Eds.)
AGATA Technical Proposal,
September 2001

**5 mm (FWHM) Position Resolution needed!**

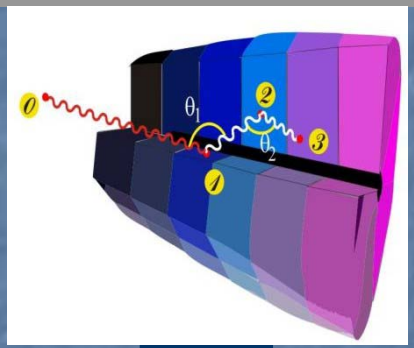
**Detector Segmentation + Current Pulse Shape Position Dependence**



# Ingredients of γ-Tracking

**1**

Highly segmented HPGe detectors




**2**

Digital electronics to record and process segment signals

**3**

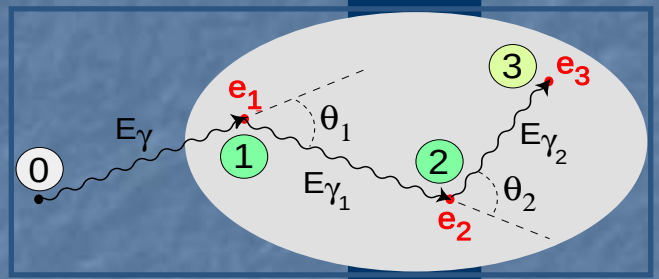
Pulse Shape Analysis to decompose recorded traces

Identified interaction points

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

**4**

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



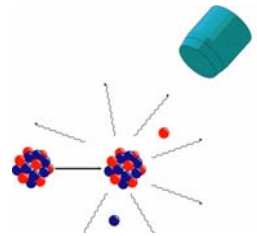

**reconstructed γ-rays**

# Physics Motivation

In-beam γ spectroscopy is the most effective tool for extracting experimental information on the nuclear structure

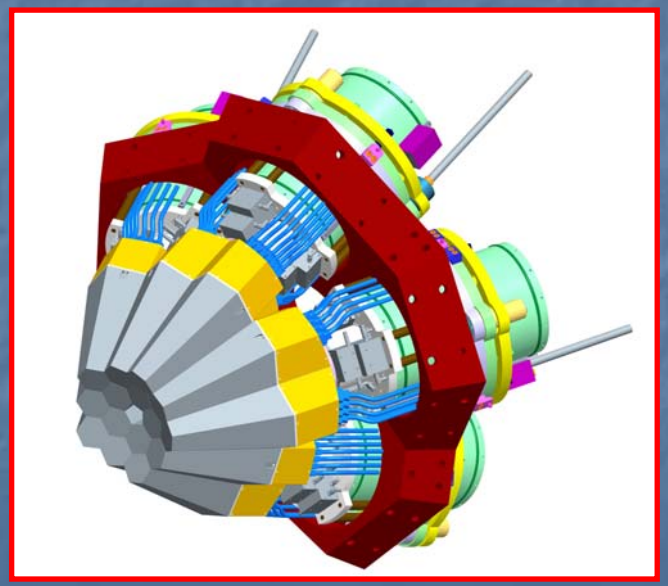
**Experiments with Radioactive Ion Beams:**

- Low intensity
- High background
- Large Doppler broadening
- High γ-ray multiplicities



## The Advanced GAmma-ray Tracking Array (AGATA) Demonstrator

→ on line Pulse Shape Analysis and γ-ray tracking



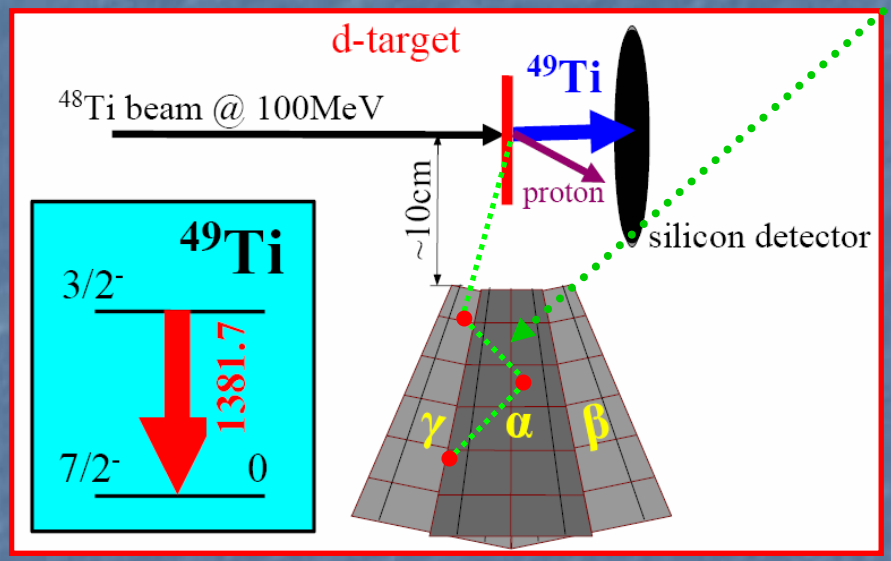
1 symmetric triple-cluster
5 asymmetric triple-clusters
36-fold segmented crystals
Eff. 3 – 8 % @ $M_\gamma = 1$
Eff. 2 – 4 % @ $M_\gamma = 30$

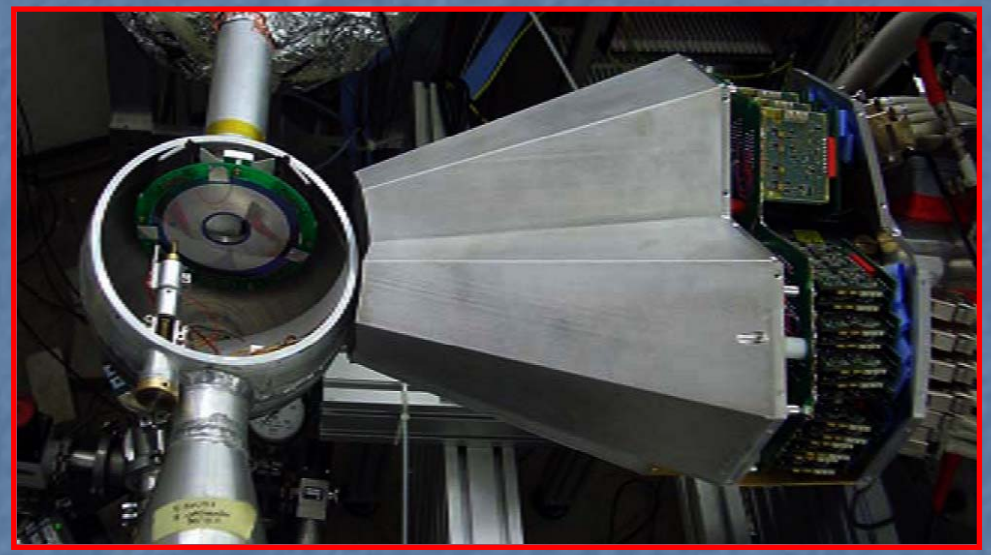
Installation is currently taking place @ LNL, INFN Laboratories

# In beam test of the first triple cluster

performed @ IKP Köln

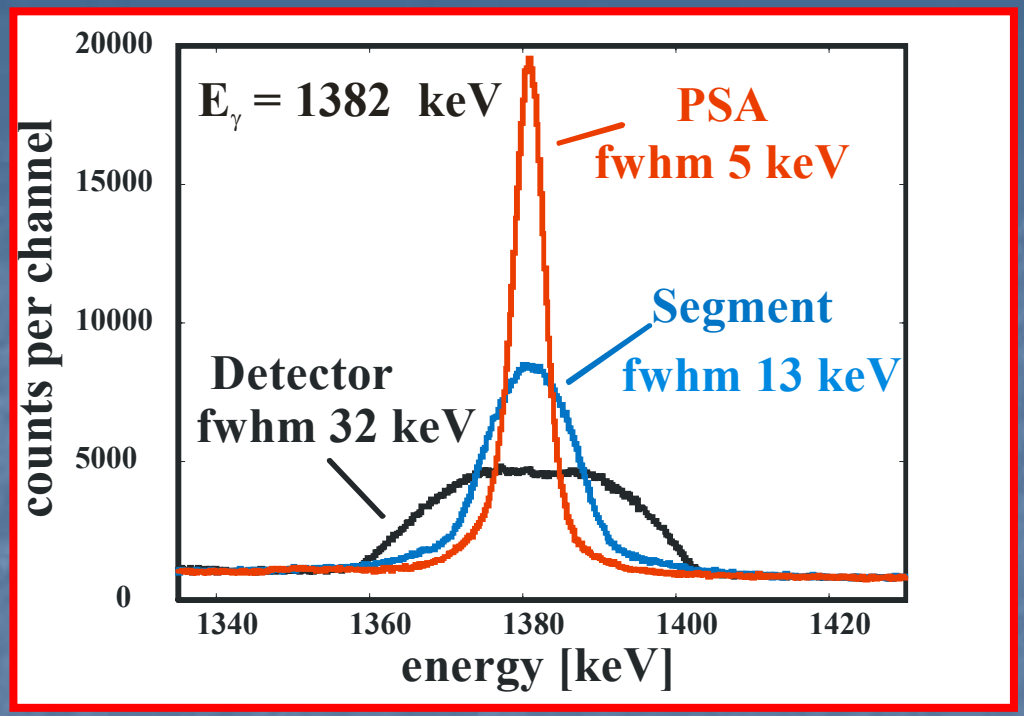
The position resolution obtained with PSA (< 5 mm) is deduced from the Doppler correction capabilities on the photons emitted in-flight following a nuclear reaction



Detector signals digitized using XIA-DGF modules (14 bit, 40 MHz), a digital measured value for the net charge deposited inside each segment is provided as well

Position Information extracted with PSA is then used for Doppler correction of gamma spectra… →




Results obtained with Grid Search PSA algorithm
(R. Venturelli and D. Bazzacco, LNL-INFN(REP) 204 (2005)),
→ **Position resolution ~4.4mm (FWHM)**

# Other PSA methods proposed/under development:

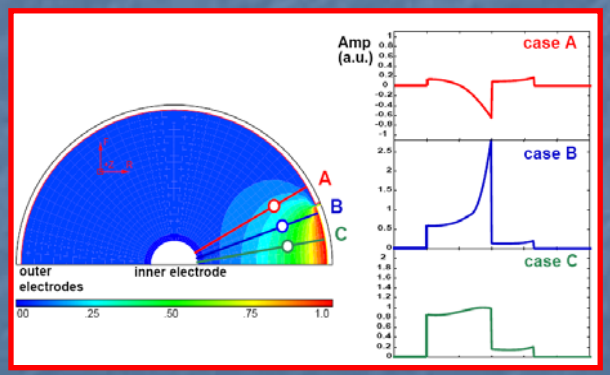
- Genetic algorithms (Th. Kroell, D. Bazzacco NIMA 565 (2006) 691–703)
- Matrix inversion (A. Olariu, P. Desesquelles et al, IEEE TRANS. ON NUCL. SCI., VOL. 53, NO. 3, JUNE 2006 )
- Particle Swarm Optimization (M. Schlarb, MLL annual report 2005 and AGATA week presentations)
- Recursive Subtraction (F.C.L. Crespi et al., Nucl. Instrum. Methods A570 (2007), p. 459 and
  → **poster session!** )

# Detector Characterization and Scanning

- PSA algorithms assume the detector position response to be known a priori ( i.e. in the case of a single interaction event, the detector signal shape must be already determined)

- Experimental extraction ( using standard techniques based on coincidence Measurements) is prevented by the extremely long time needed for a full-volume detector scan

- Detector position response is calculated solving the appropriate electrostatic equations, (different codes developed at this purpose, e.g.: Th. Kröll and D. Bazzacco, Nucl. Instr. and Meth. A 463 (2001); P. Medina, et al., A simple method for the characterization of HPGe detectors, IMTC, Como, Italy, 2004; M. Schlarb presentations at the AGATA week )




$$\vec{v}_{Drift,(e/h)} = \mu_{(e/h)}(\vec{E})\vec{E} = \frac{d\vec{x}(t)}{dt}$$

$$i_{ind}(t) = q\vec{E}_{weighting}(\vec{x}(t)) \cdot \vec{v}(\vec{x}(t))$$

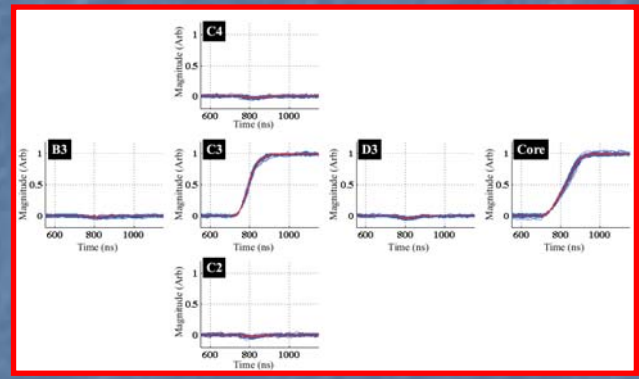
➢ Some critical points in reproducing precisely the detector position response

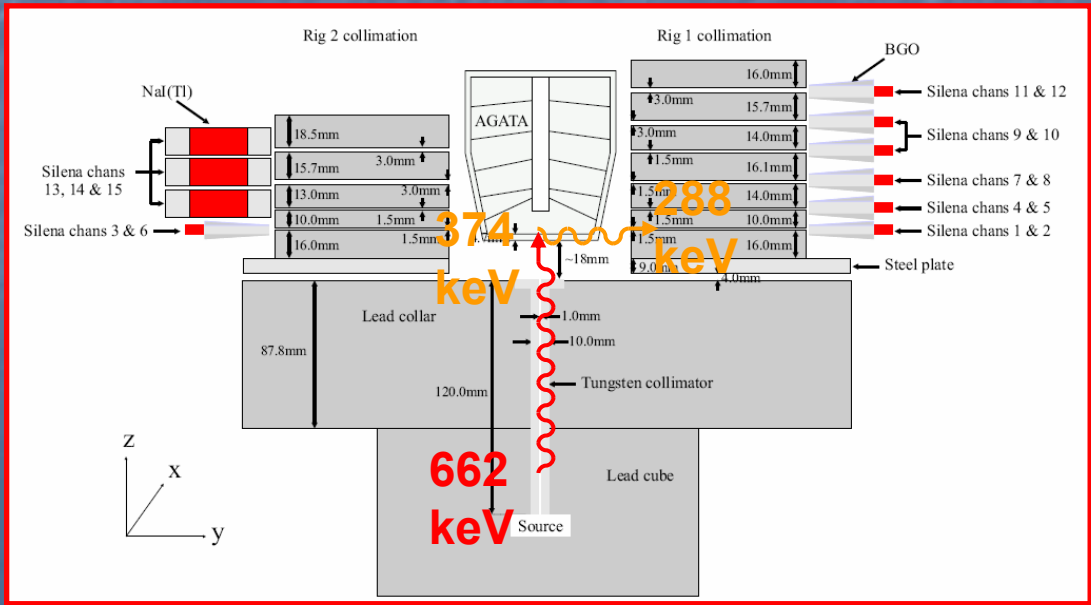
measurements for the characterization of segmented HPGe detectors are presently performed in many laboratories since experimental data are strictly needed to validate the codes…

## Standard Characterization technique: Coincidence scan for 3D position determination (A. Boston et al., NIM B 261 (2007))

- 662 keV pencil beam from a $^{137}Cs$ collimated source hits the front face of the detector
- A secondary collimation system is placed perpendicularly to the injected beam,
- Only photons that interacted in the detector and were scattered through 90° are collected.

*see M. Dimmock, PhD thesis, University of Liverpool, 2008*



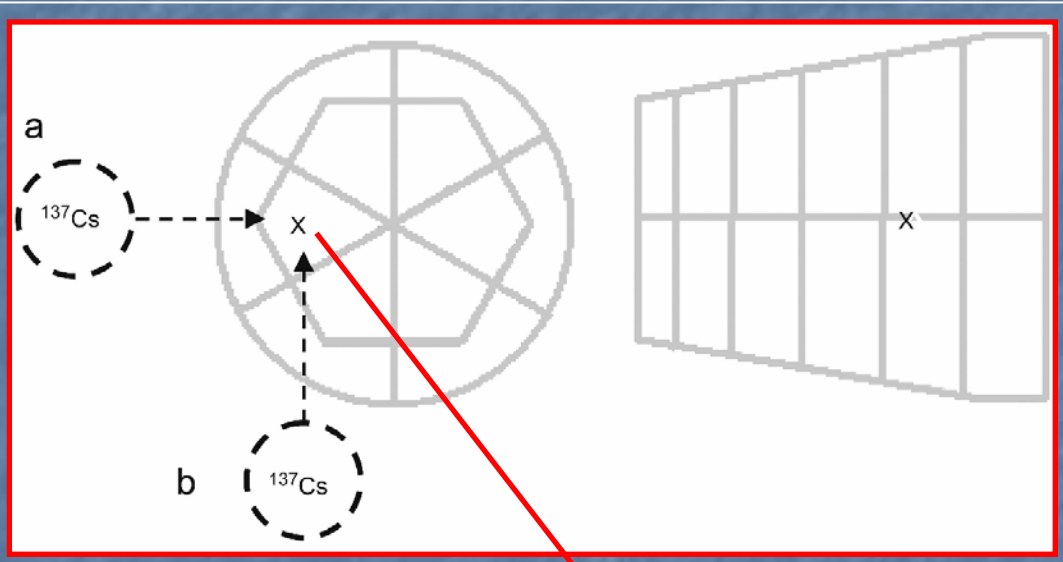




# Pulse Shape Comparison based Scan (PSCS)*: BASIC IDEA

- Only measurements in single mode, characterized by a defined collimation of the gamma ray source (→ large decrease of time consumption, as compared with the standard coincidence techniques)

- **Events of Interest** are selected by means of a specific signal shape comparison procedure

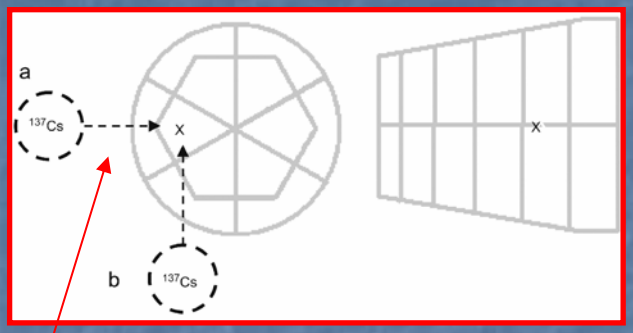
Energy release concentrated in a ( known a priori ) position inside the detector volume




**The pairs of signals that have the SAME SHAPE (i.e. that minimize the $\chi^2$ ) are associated to an energy release concentrated in the point where the 2 collimation lines cross**

*F.C.L. Crespi et al. NIMA 593 (2008)

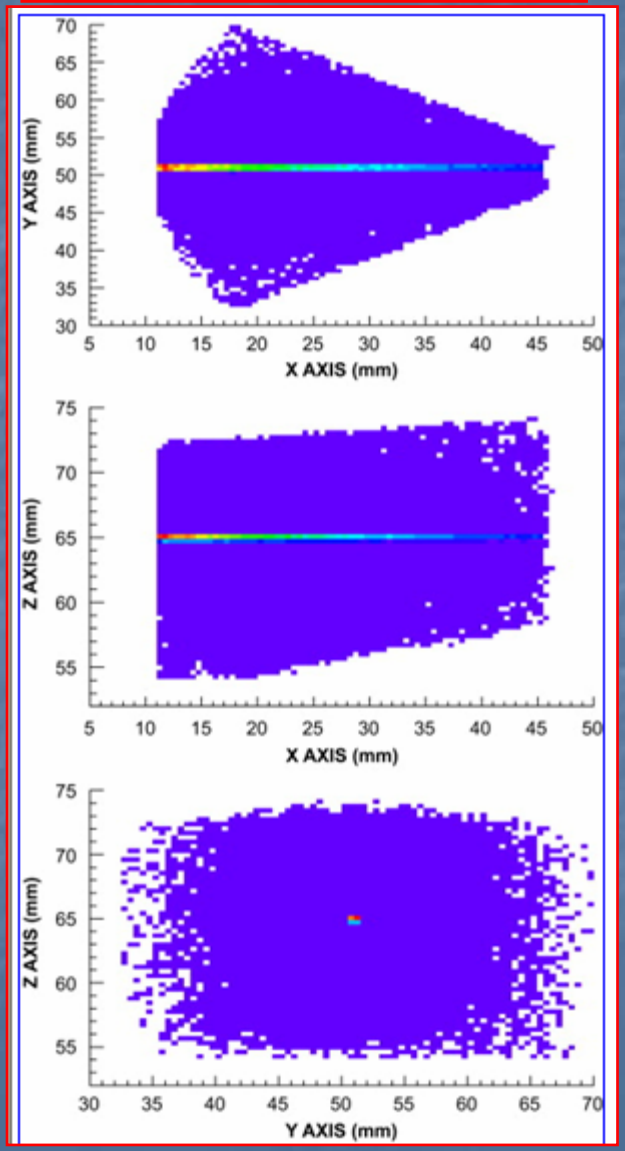
# VALIDATION TEST WITH SIMULATED EVENTS



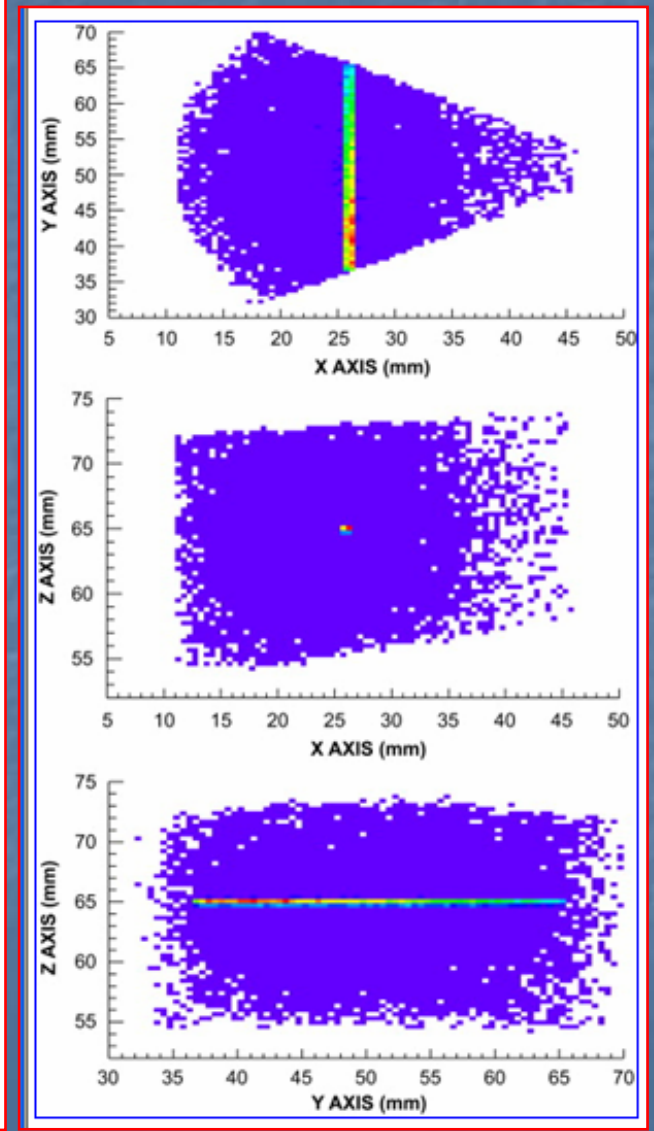

**Simulation**:**
A 662.7 keV γ-ray pencil beam hits a segment of the AGATA detector, in two perpendicular directions **[a)] [b)]**

**Simulation performed using a Geant4 based code
E. Farnea and D. Bazzacco, LNL-INFN(REP) 202 (2004),

*energy release – case (a)*




*energy release – case (b)*

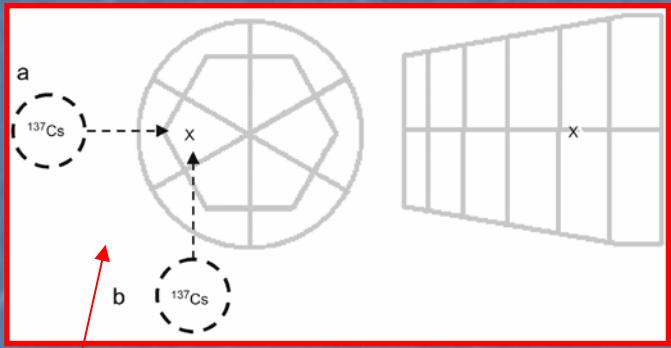


# VALIDATION TEST WITH SIMULATED EVENTS

**PSCS method applied to a simulated** 36-fold segmented HPGe AGATA detector:**
→ calculated pulses are produced using the MGS* code. In the simulation the effect of noise and electronic chain response is taken into account.

*P. Medina, et al., IMTC, Como, Italy, 2004

The more stringent the $\chi^2$ threshold is set
(i.e. the more the signal shapes are similar), the more the energy release is concentrated in the position of interest

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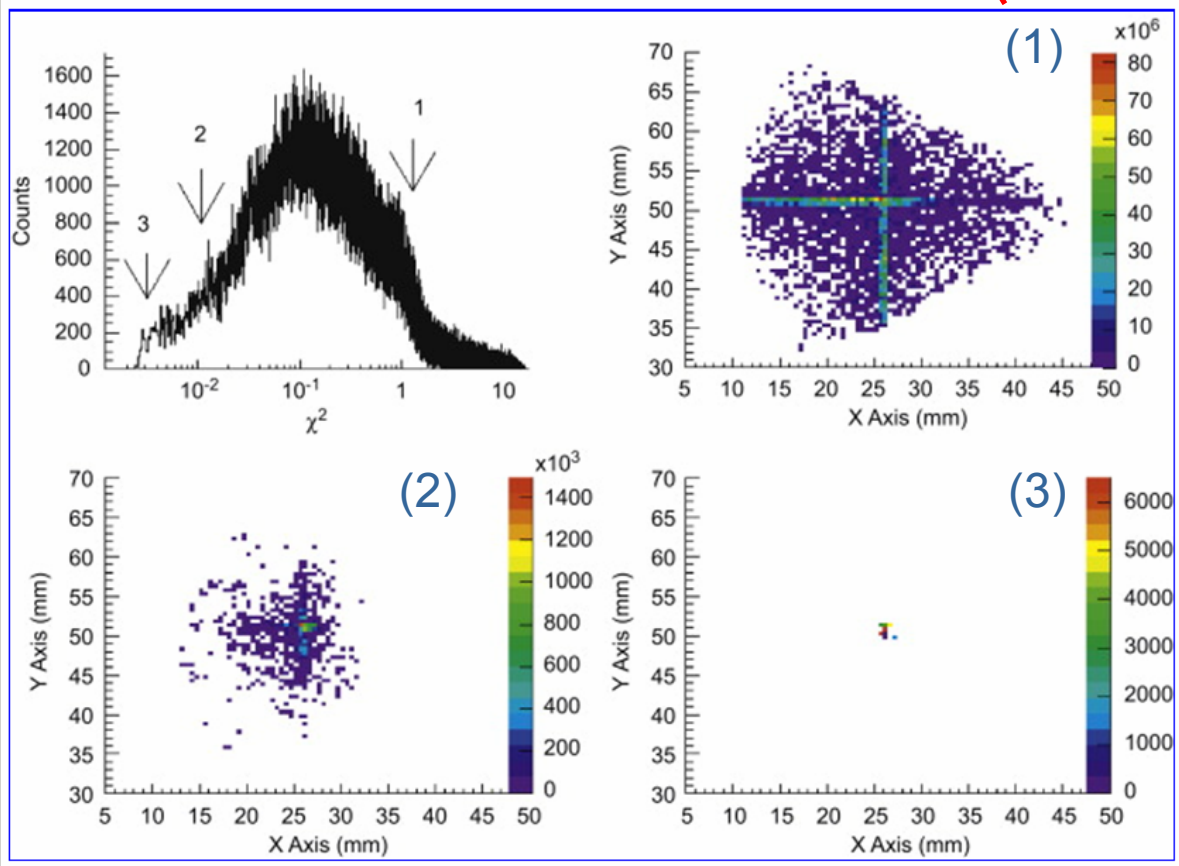
A 662.7 keV γ-ray pencil beam hits a segment of the AGATA detector, in two perpendicular directions [a)] [b)]



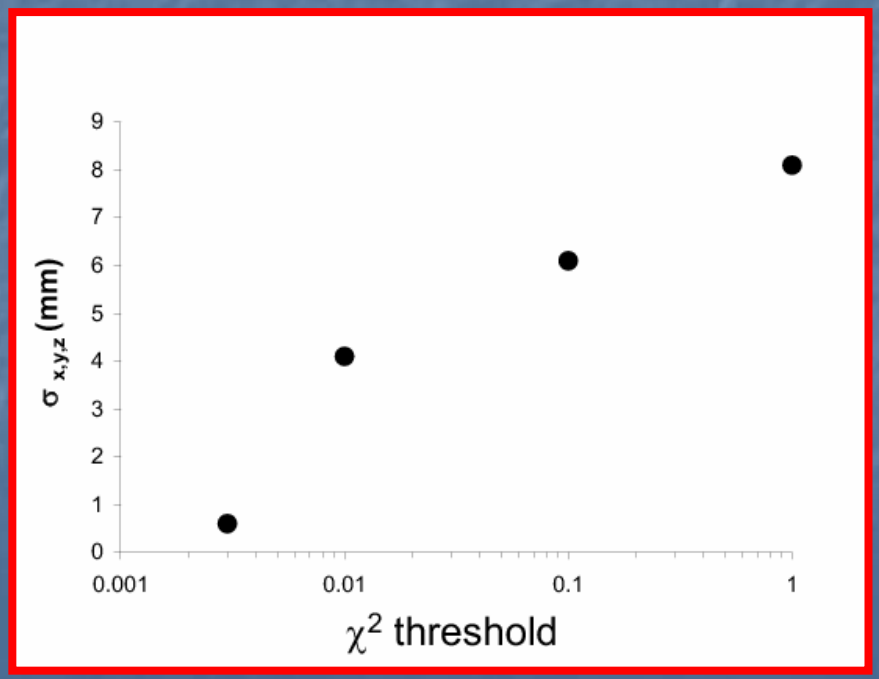

**Simulation performed using a Geant4 based code
E. Farnea and D. Bazzacco, LNL-INFN(REP) 202 (2004),

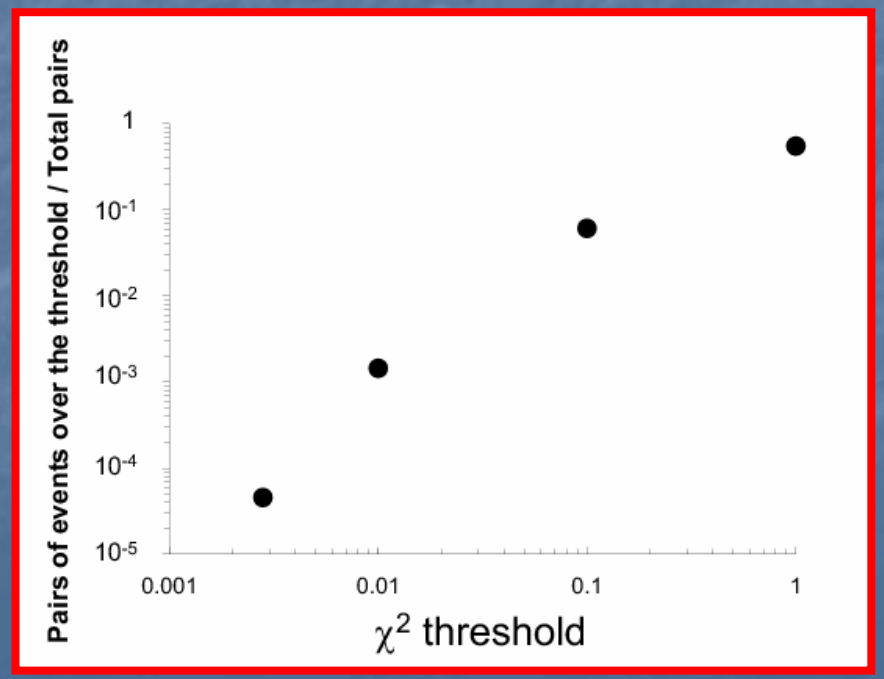
# VALIDATION TEST WITH SIMULATED EVENTS

- All the pairs with a sufficient small $\chi 2$ value are matched with an energy release localized in a region of space of few $mm^3$ around the point in which the two collimation lines cross

- The accuracy of the localization is directly proportional to the $\chi 2$ threshold value

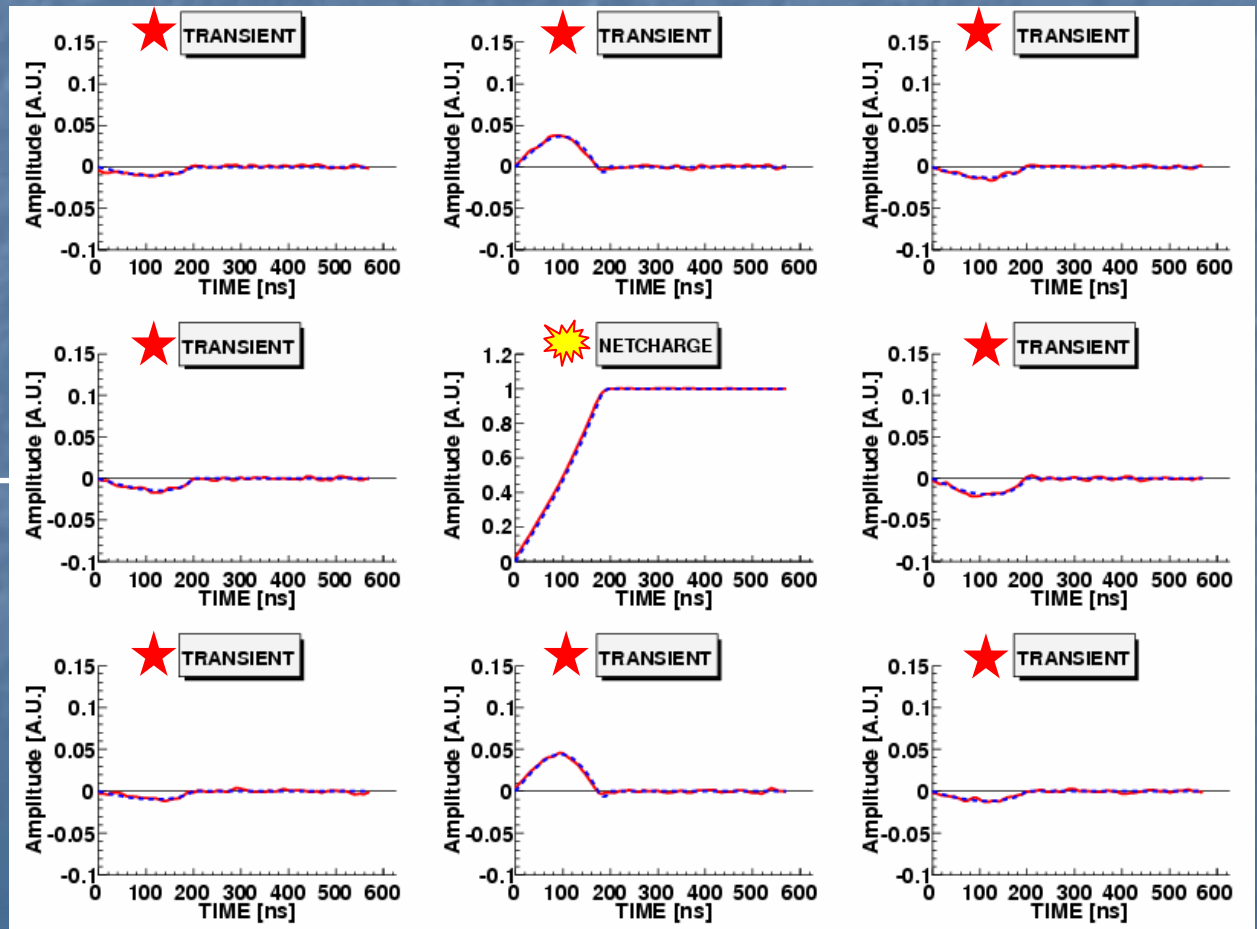
- Considering the signals acquisition rate the estimated time for a full volume scan of a large volume segmented HPGe detector (~240 $cm^3$) is of **less than a week**.



# VALIDATION TEST WITH SIMULATED EVENTS

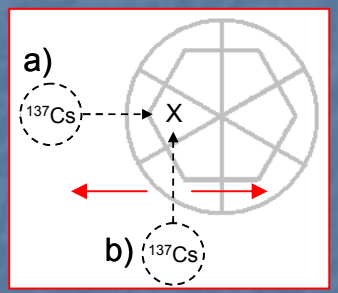
- The signal shape associated to the coordinates of the collimation lines crossing point ( **DOTTED BLUE LINE**) is compared with the signal shapes obtained with the scanning procedure (**SOLID RED LINE**)
- The detector position response is extracted by averaging the signal shape associated to all the event pairs below the most stringent $\chi^2$ threshold



# VALIDATION TEST WITH SIMULATED EVENTS

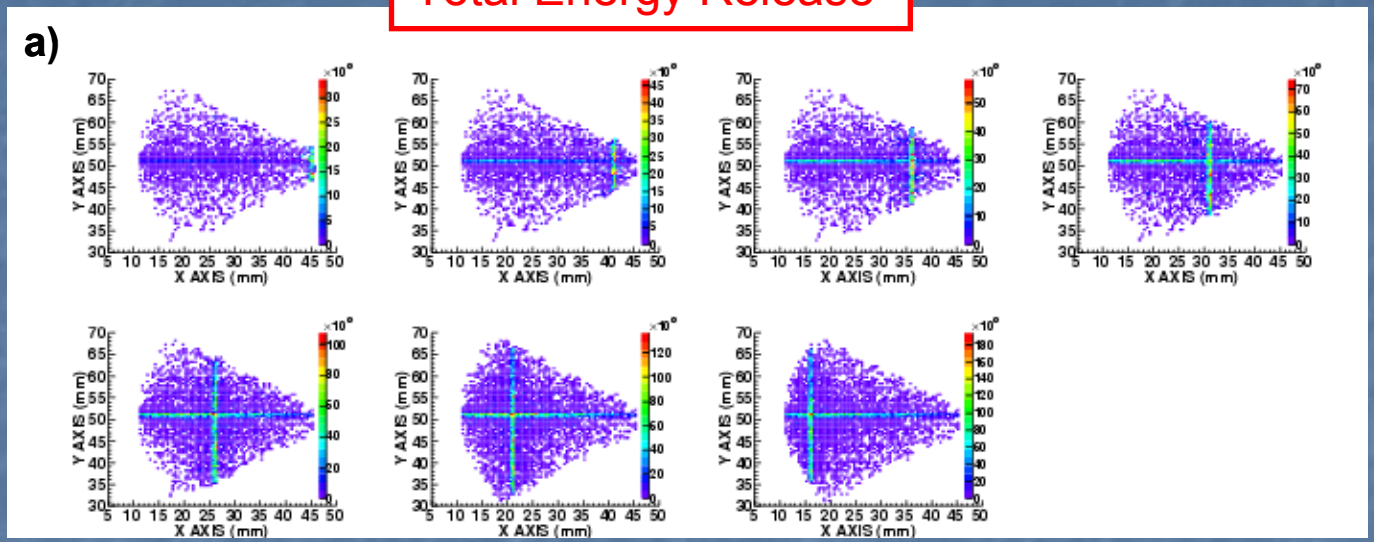
Same technique applied to different positions: the chosen points lie along the radial direction, having a relative distance of 5mm.

position change is made by shifting one collimation line with respect to the other



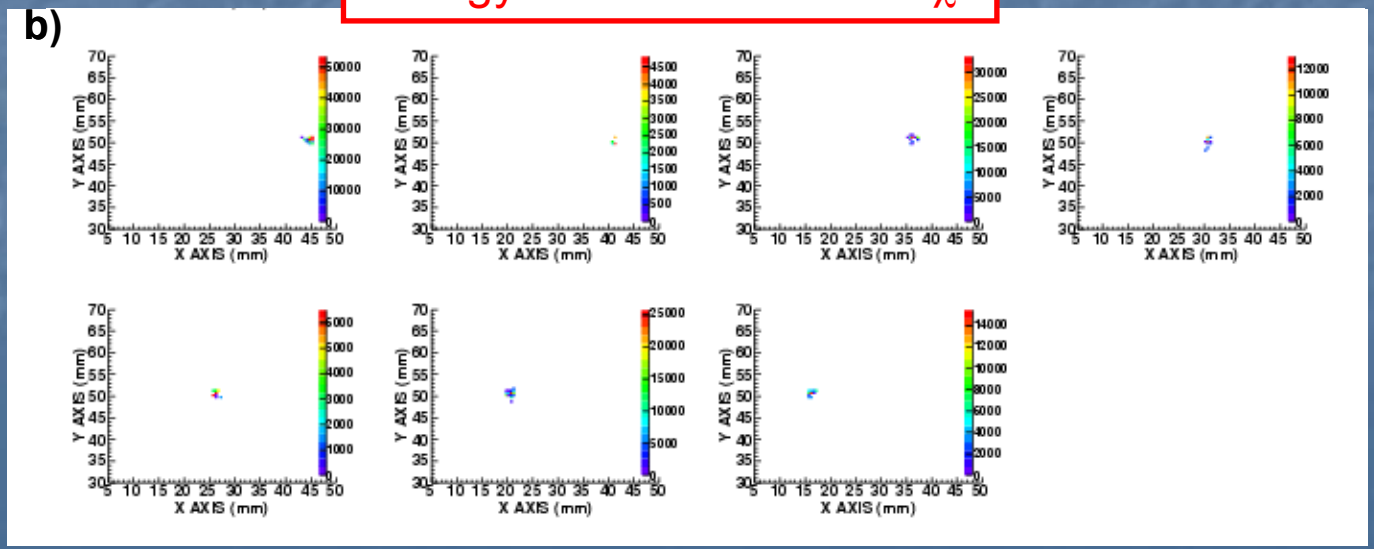

## Total Energy Release

a)

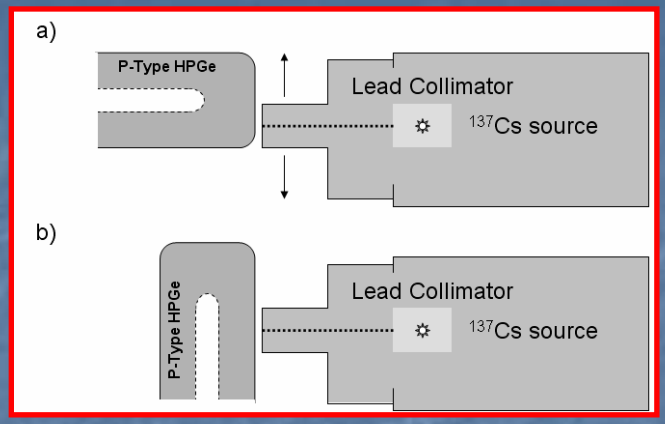



## Energy Release Gated on $\chi^2$

b)



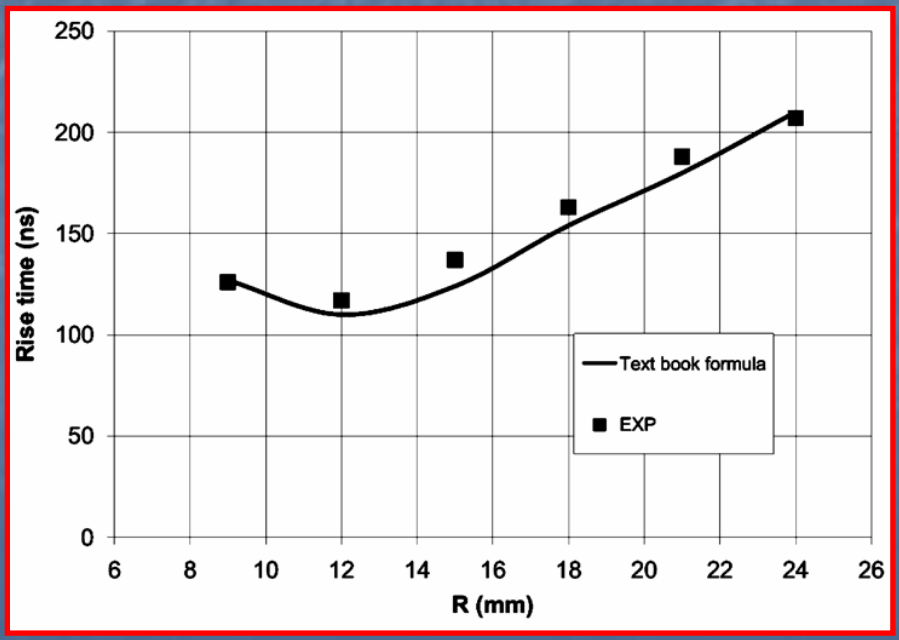
# Application of the PSCS technique for the measurement of the position response of a non-segmented coaxial HPGe detector, along the radial direction*

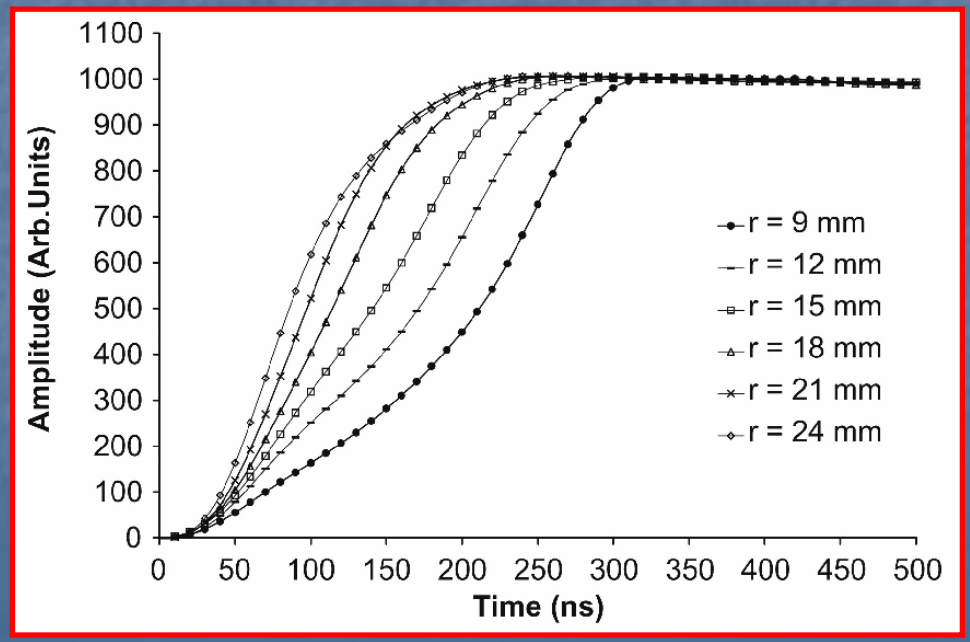



- P-Type HPGe
- 438 MBq $^{137}$Cs collimated source
- collimation line at a distance of 9,12,15,18,21,24 mm from the detector centre
- signal shapes digitised at 100 M Sample/s at the output of the preamplifier
- 60 s per measure

*F.C.L. Crespi et al. NIMA 593 (2008)

***The Rise Time Values of the Averaged Signals reproduce the ones Obtained with simple calculations***



## Conclusions:

- A novel technique for measuring a HPGe detector position response has been presented.
- It has been validated on a 36-fold HPGe AGATA detector using **simulated** events
- It has been applied to scan a non-segmented coaxial HPGe detector along the radial direction:
  - ✓ *The rise time of the signals extracted with the scanning procedure were compared with the calculated ones, resulting in a good agreement.*
- Considering the signals collection rate reached during the mentioned measure the estimated time for the full volume scan of a large volume of highly segmented HPGe detector (240cm$^3$) is of less than a week.

## Perspectives:

- PSCS will be experimentally validated on a 36-fold segmented HPGe AGATA detector, several laboratories are adapting their scanning systems to use pulse shape comparison for decreasing measurement time consumption
- **Tracking and PSA performances will definitely benefit from a measured detector position response**