- Introduction to Pulse Shape Analysis (PSA) -
- Basis Generation -
- Coincidence and Pulse Shape Comparison based Scan (PSCS) -

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Outline

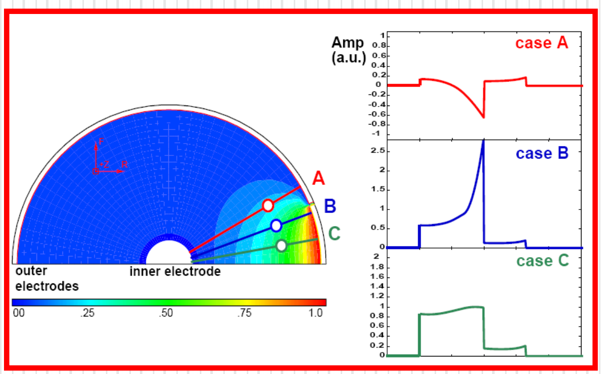
- Detector Characterization and Scanning
- Coincidence Scan Technique
- Pulse Shape Comparison Based Scan (PSCS)
  - *Tests with Geant4 simulations*
  - *Application to standard HPGe detector*
  - *Application to AGATA detectors*
  - *Variant of the PSCS method requiring no collimators*

Coincidence and Pulse Shape Comparison based Scan (PSCS)

- 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.:
  - ***B. Bruyneel et al. NIMA 569 (2006) 764 + NIMA 569 (2006) 774 + NIMA 599 (2009) 196 + NIMA 608 (2009) 99 + NIMA 641 (2011) 92 …**
  - 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, R. Gernhäuser, R. Krücken, Simulation and Real-Time "Analysis of Pulse Shapes from HPGe Detectors, GSI Scientific Report 2008, p. 232.



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

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

- Some critical aspects in reproducing precisely the detector position response

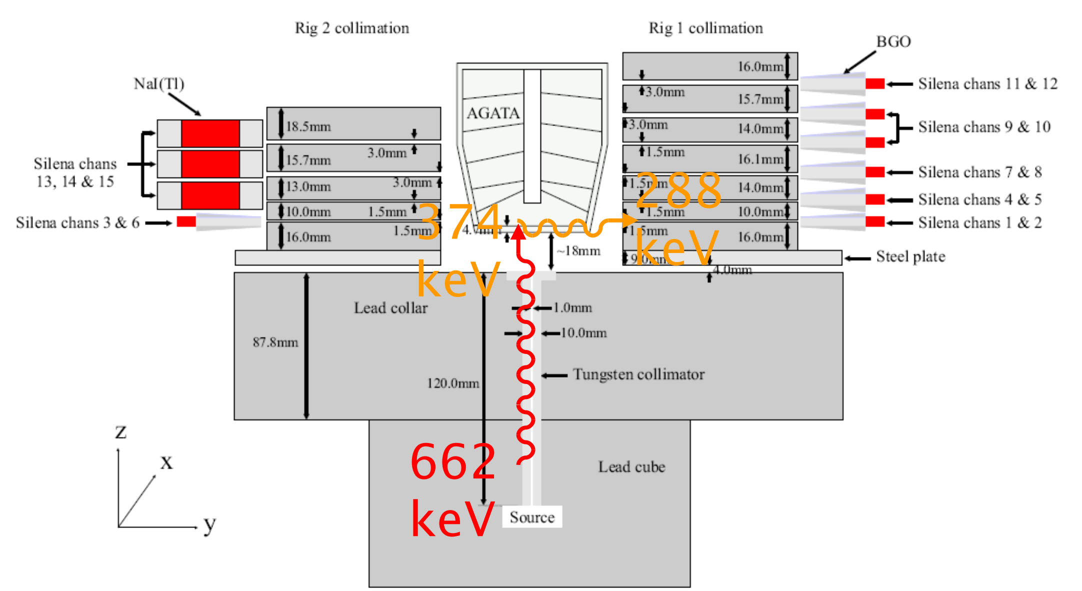
Characterization measurements of segmented HPGe AGATA detectors are fundamental

Coincidence Scan

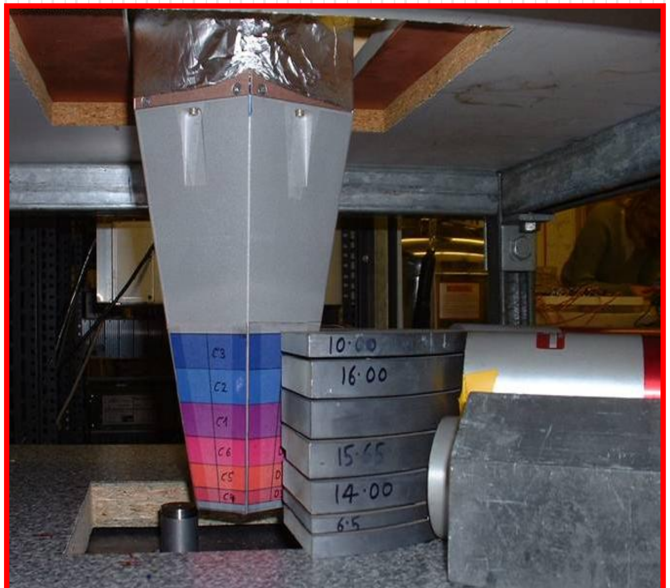
- 662 keV pencil beam from a ^{137}Cs collimated source hits the front face of the detector
- A secondary collimation system is placed perpendicularly to the injected beam,
- Only photons that interacted in the detector and were scattered through 90° are selected.

- A.J. Boston et al., "Gamma-ray tracking: Characterization of the AGATA symmetric prototype detectors", NIMA 261 (2007) 1098
- L. Nelson et al., "Characterisation of an AGATA symmetric prototype detector", NIMA 573 (2007) 153
- M. Dimmock, PhD thesis, University of Liverpool, 2008
- A.J. Boston et al., "Performance of an AGATA asymmetric detector", NIMA 604 (2009) 48

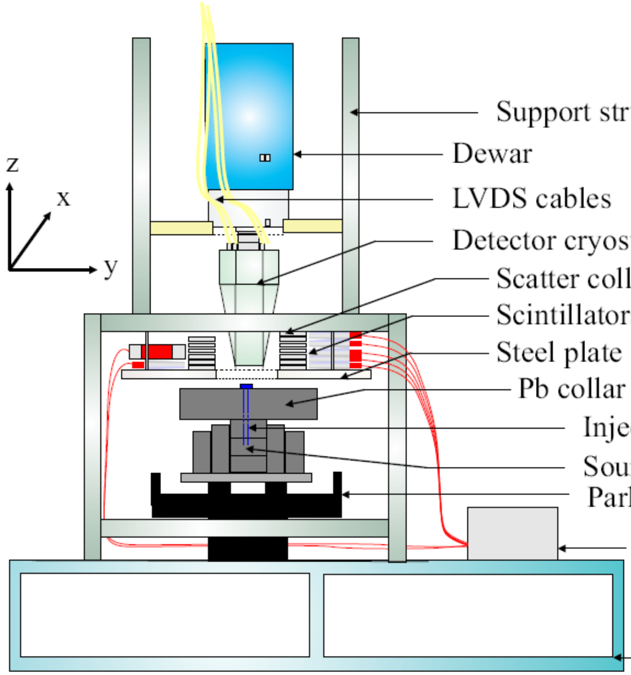
Schematic representation of the AGATA S002 prototype detector mounted on the Liverpool scanning table. The coincidence scatter detectors and scatter collimator dimensions are labelled. There were six collimation depths on rig one and four collimation depths on rig two. The distance from the top of the Tungsten collimator to the front face of the crystal was 23mm.



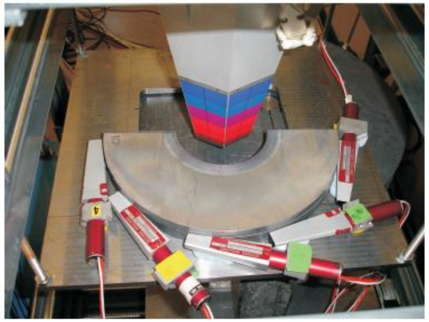
$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_0 c^2}(1 - cos\theta)} = \frac{662}{1 + \frac{662}{511}(1 - 0)} = 288 keV.$$



The AGATA cryostat was suspended in a vertical position above the collimated 137Cs source. When operated in singles and coincidence modes, the source was positioned at various locations beneath the detector. The pulse shape response was measured at each location. The 90o scatter collimators and scatter detectors were only required for the coincidence measurements, however they were positioned prior to the singles scan to ensure that the data sets were comparable.

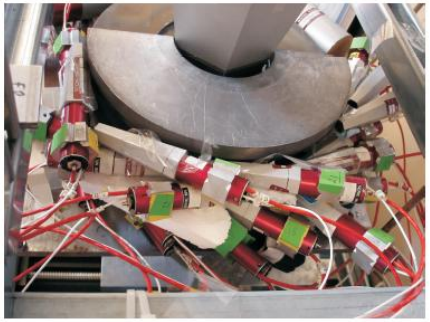


Photographs showing the stages of construction of the scatter collimator rig. The rig was built in two halves. Rig one surrounded sectors A, F and E of the AGATA detector, while rig two surrounded sectors B, C and D. a) lead sheets and five BGO detectors (two banks) for collimation depth one of rig one. b) View showing the sheets of lead that form the six collimation depths of rig one and four collimation depths of rig two. c) Final BGO detector arrangement for rig one. d) Final BGO (depth one) and NaI(Tl) (depths two to four) detector arrangement for rig two.

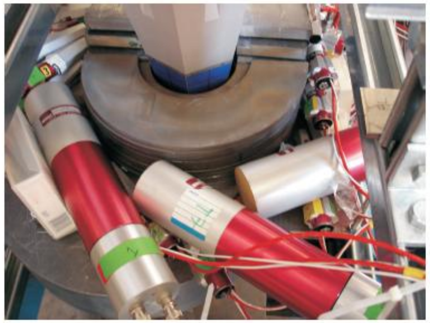


a) Rig1, collimation depth1

b) Rig1 (far) and Rig 2 (near) collimation

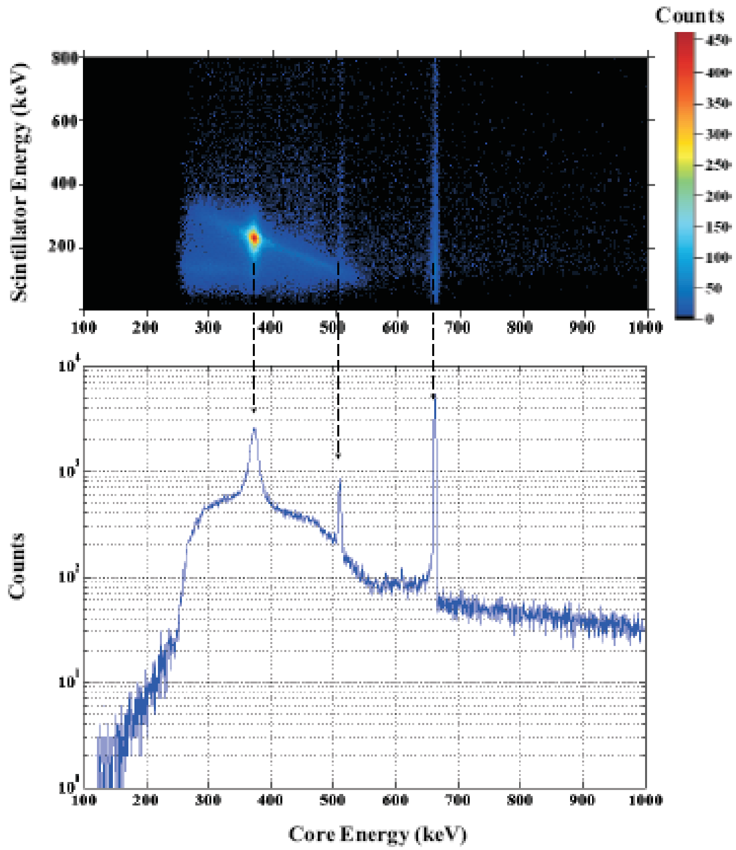


c) Rig 1 BGO detectors

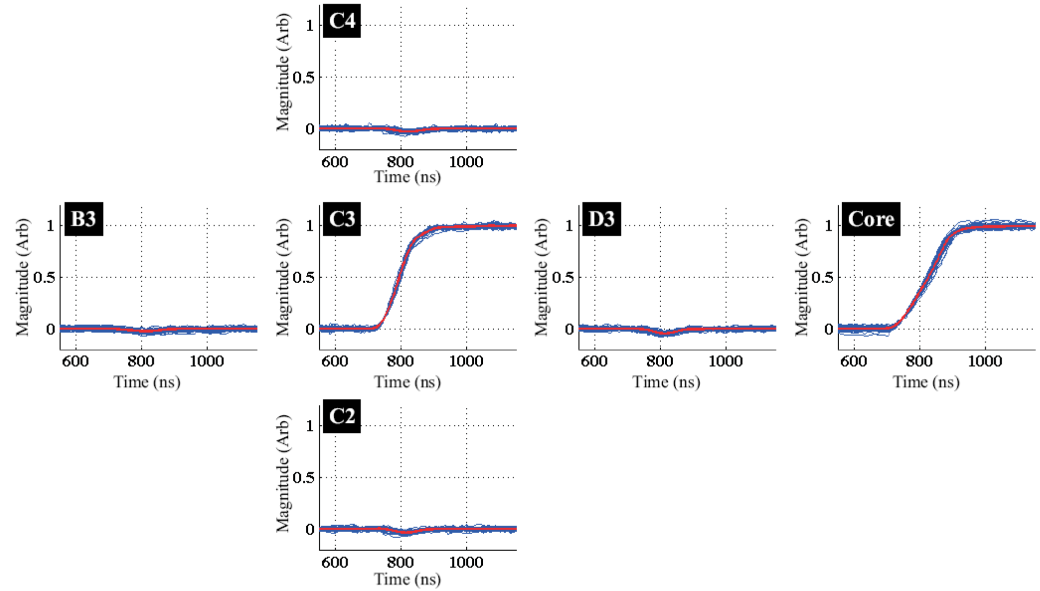


d) Rig 2 NaI(Tl) detectors

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



Matrix of the centre contact energy versus scintillation detector energy for all fold one events that triggered the acquisition. A fold one gate was also applied to the scintillation detector banks. The small circular shaped region of high intensity in the centre of the matrix corresponds to the 90o scatters. The diagonal line that extends through either side of this region corresponds to other scattering angles through which the gamma rays could pass between the collimation gaps. The 662keV photo-peak was the result of random coincidences with photons, emanating from the source, penetrating the lead shielding and interacting in the AGATA detector.



Average (red) and all constituent (blue) pulse shapes for an interaction at x = 78.8mm, y = 49.0mm, z = 33.1mm in segment C3, following the 2 rejection.

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

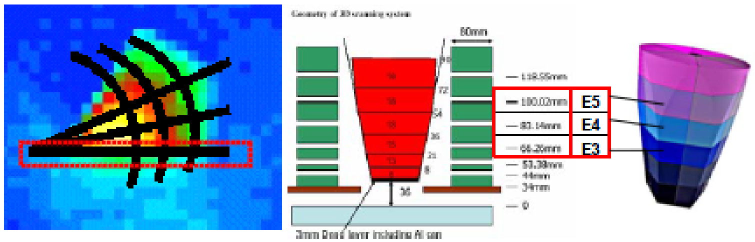


Figure 3.24a: *In panel a) an AGATA crystal segment section is reported ,the direction along which the scanned points lie is indicated by a black line surrounded by a red dotted line. In panel b) is reported a schematic representation of the Liverpool scanning system [91,94], the segments on which the following figure 3.24b refers are high lined.*

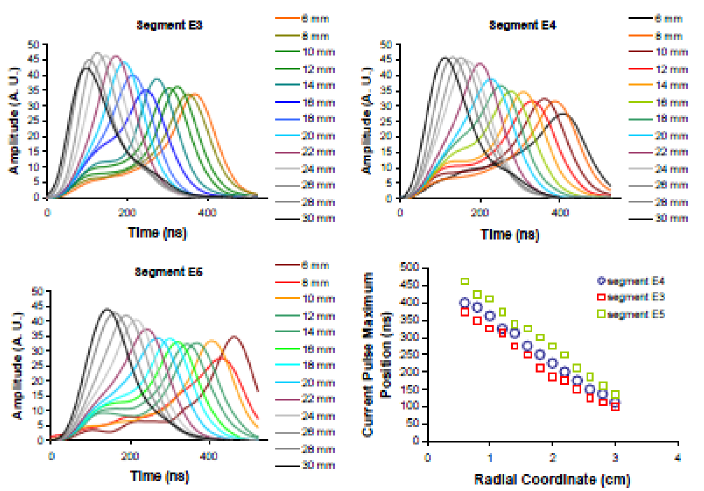
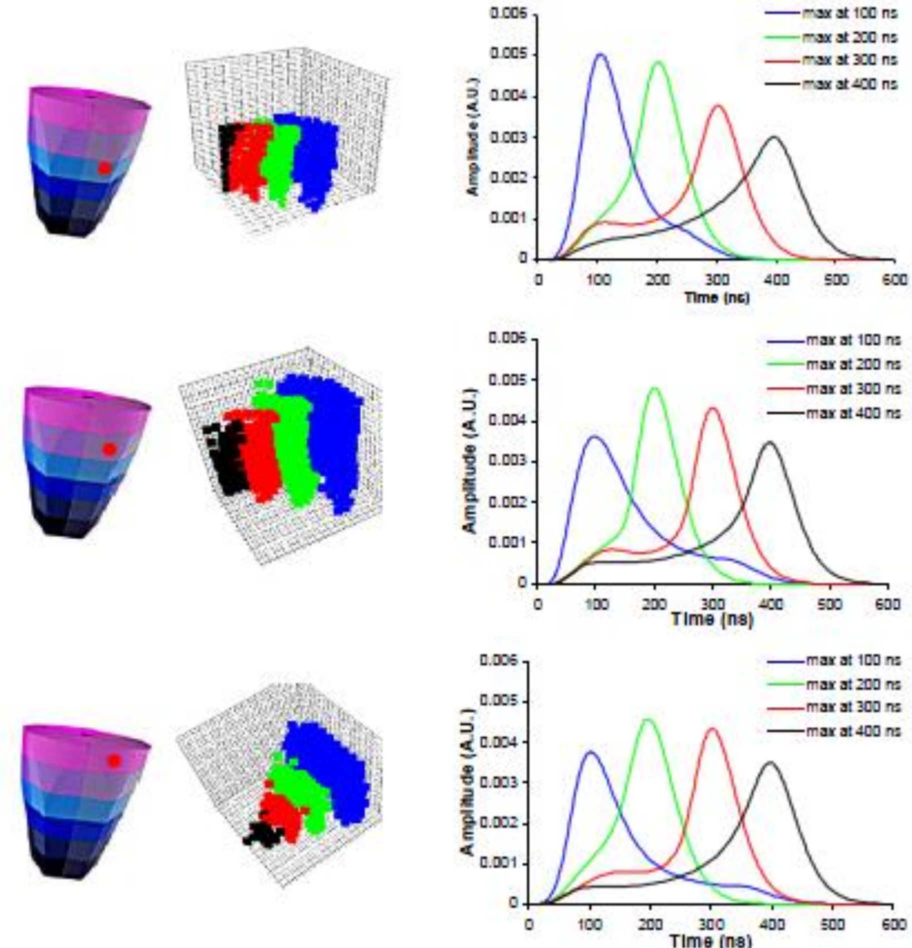


Figure 3.24b: *Current pulse shapes resulting after the superimposition of experimentally measured signals, for segments E3, E4 and E5, are respectively reported in the upper left, upper right and bottom left panels. In each figure the*



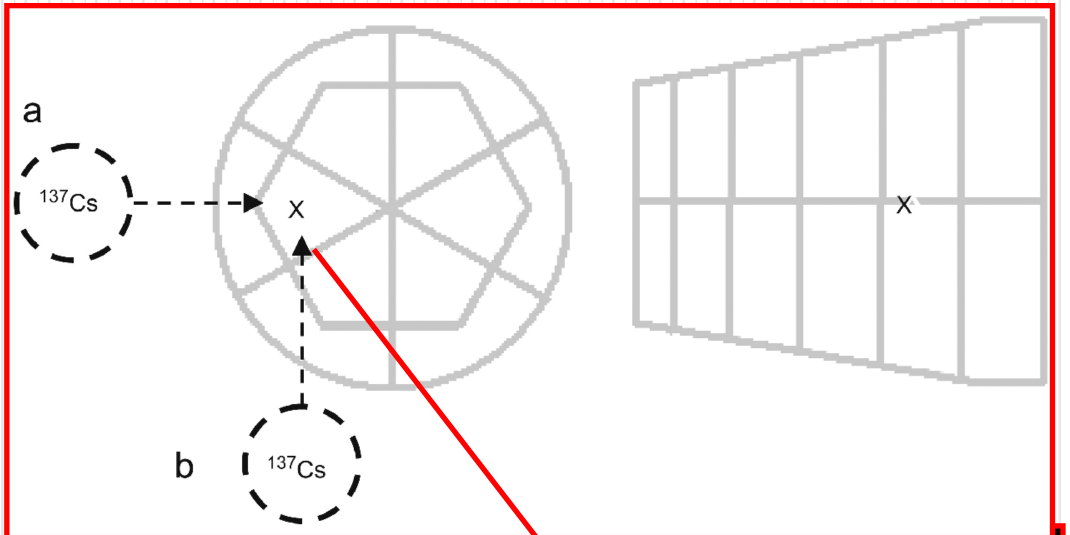
MGS basis*

*P.Medina,etal.,ASimpleMethodfortheCharacterizationofHPGeDetectors , IMTC 2004,Como,Italy,website: /http://mgs2005.in2p3.fr/Mgs.phpS.

- 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

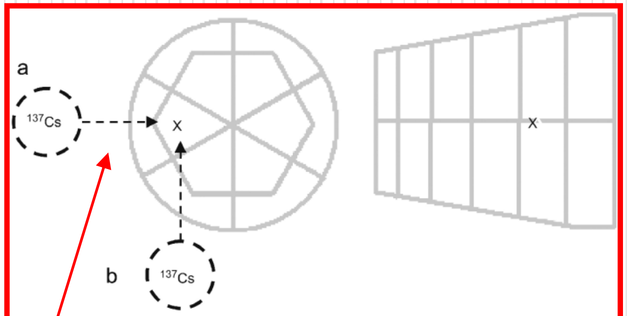
Energy release concentrated in a (known a priori) position inside the detector volume



The pairs of signals that have the SAME SHAPE (i.e. that minimize the χ^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) 440

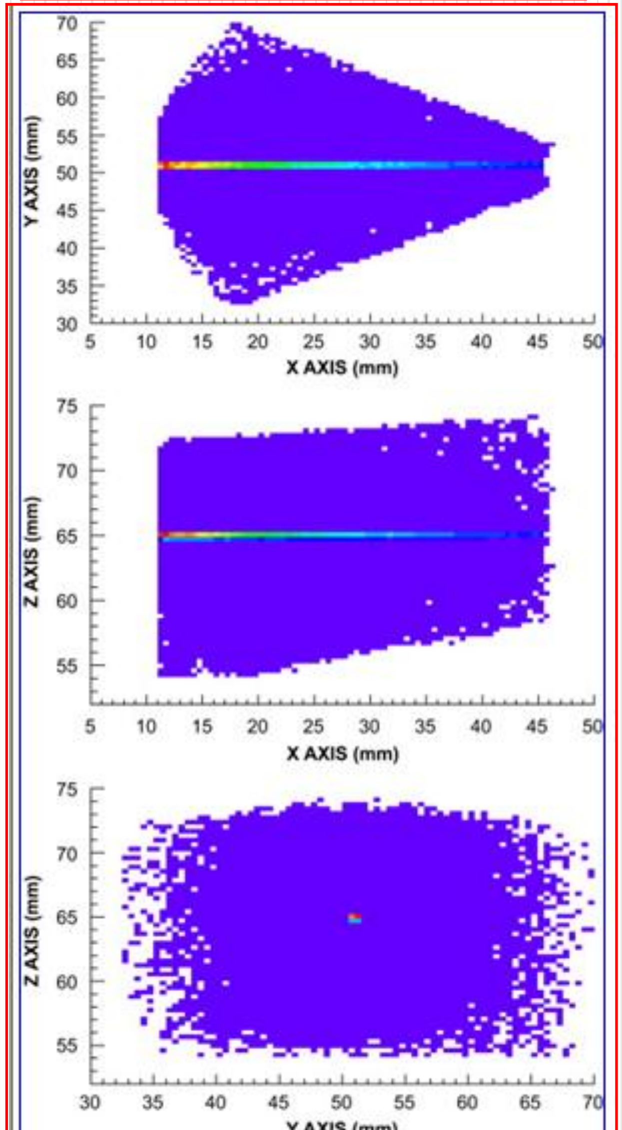
VALIDATION TEST WITH SIMULATED EVENTS



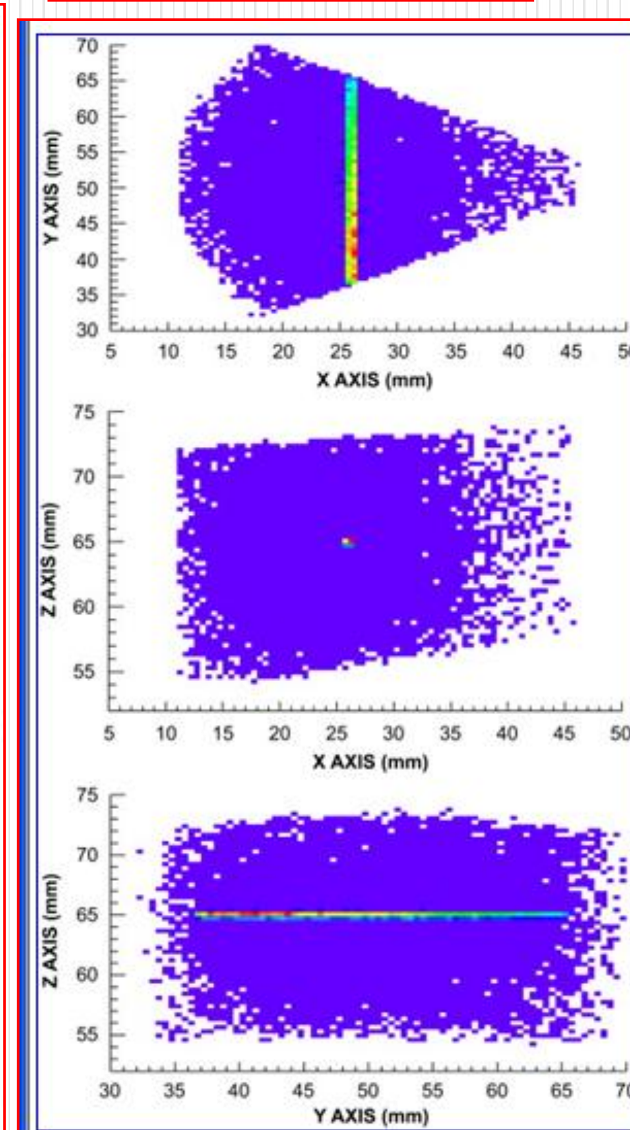
Simulation**:
A 662.7 keV γ-ray pencil beam hits a segment of the AGATA detector, in two perpendicular directions [a)] [b)]

**Simulation performed using a Geant4 based code :"Conceptual design and M onte Carlo simulations of the AGATA array", E. Farnea et al. NIMA 621 (2010) 331-343 (E. Farnea, D. Bazzacco, LNL-INFN(REP)—202 (2004) 158 website: http://agata.pd.infn.it.)

energy release – case (a)



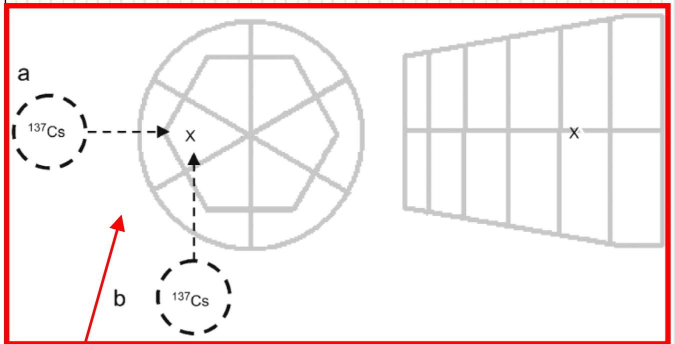
energy release – case (b)

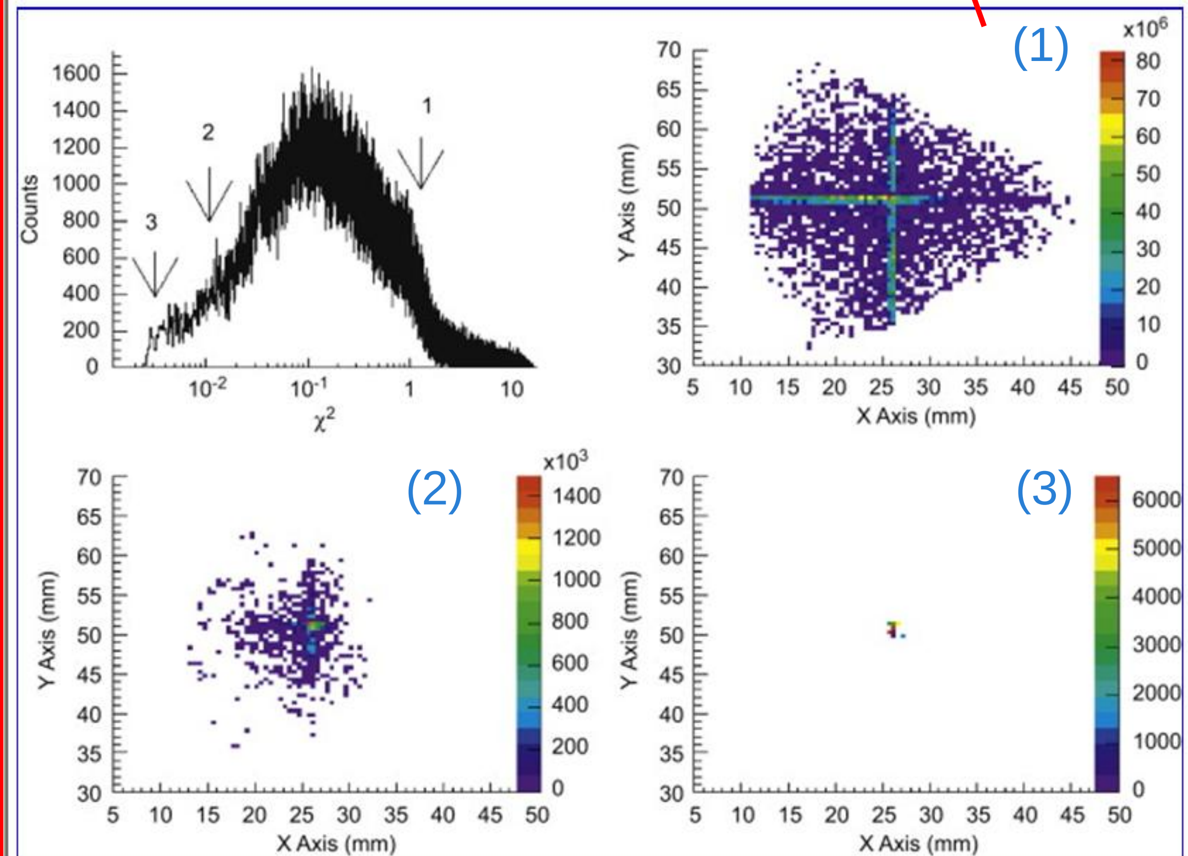


VALIDATION TEST WITH SIMULATED EVENTS

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 χ^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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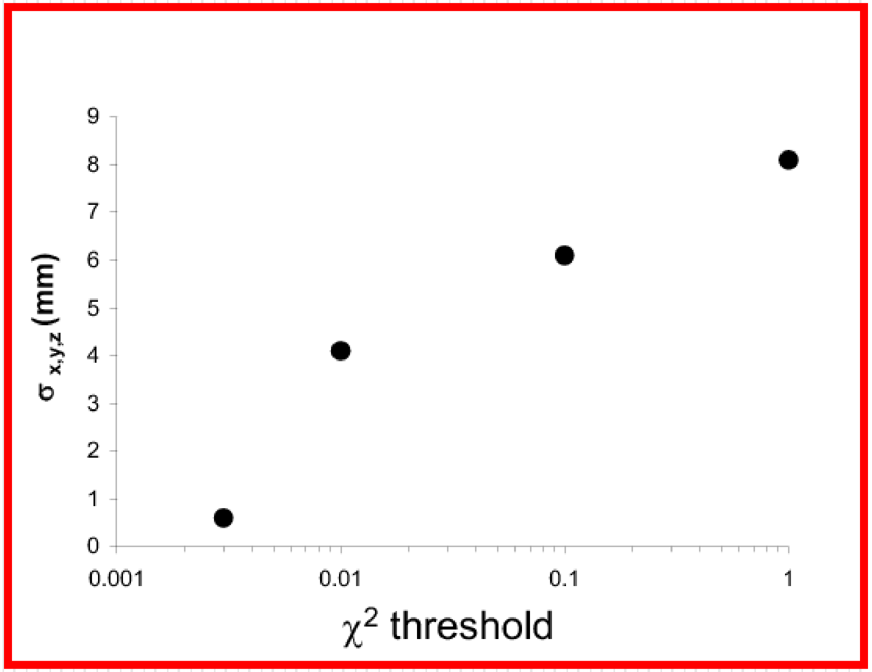
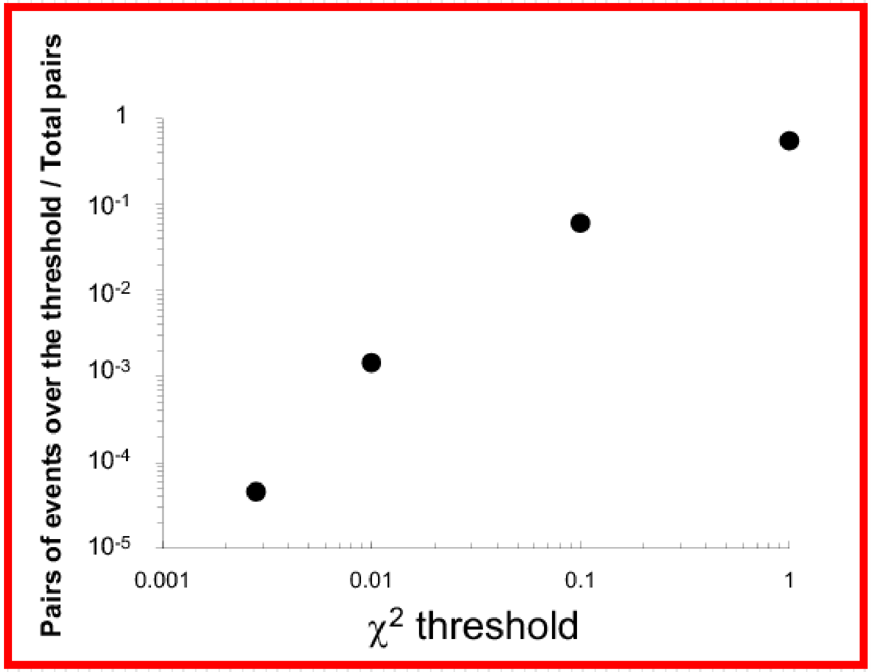
**Simulation performed using a Geant4 based code :"Conceptual design and M onte Carlo simulations of the AGATA array", E. Farnea et al. NIMA 621 (2010) 331-343
(E. Farnea, D. Bazzacco, LNL-INFN(REP)—202 (2004) 158 website: http://agata.pd.infn.it.)

- 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

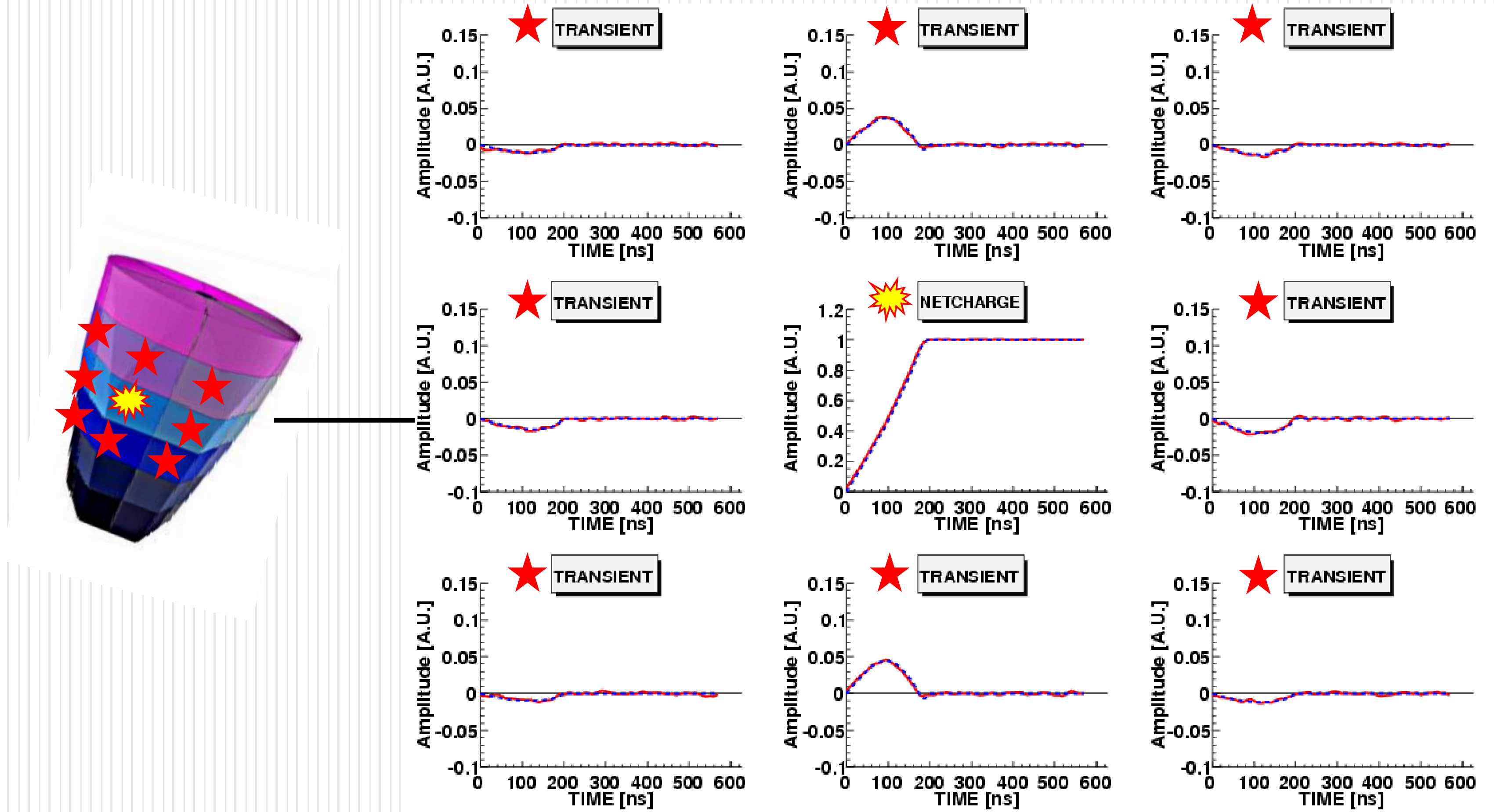
- Considering the signals acquisition rate the estimated time for a full volume scan of a large volume segmented HPGe detector (~240 cm^3) is of <u>less than a week</u>.





VALIDATION TEST WITH SIMULATED EVENTS

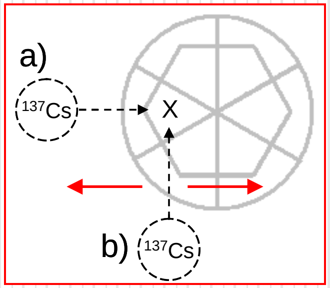
- The signal shape associated to the coordinates of the collimation lines crossing point (DOTTED BLUE LINE) is compared with the signal shapes obtained with the scanning procedure (SOLID RED LINE)
- The detector position response is extracted by averaging the signal shape associated to all the event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



VALIDATION TEST WITH SIMULATED EVENTS

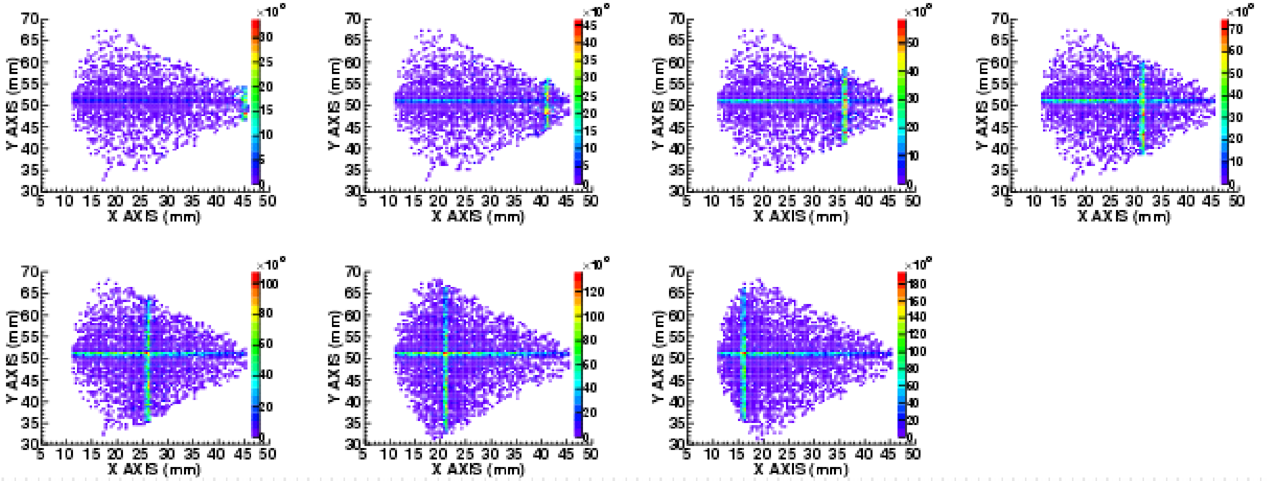
Same technique applied to different positions: the chosen points lie along the radial direction, having a relative distance of 5mm.

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



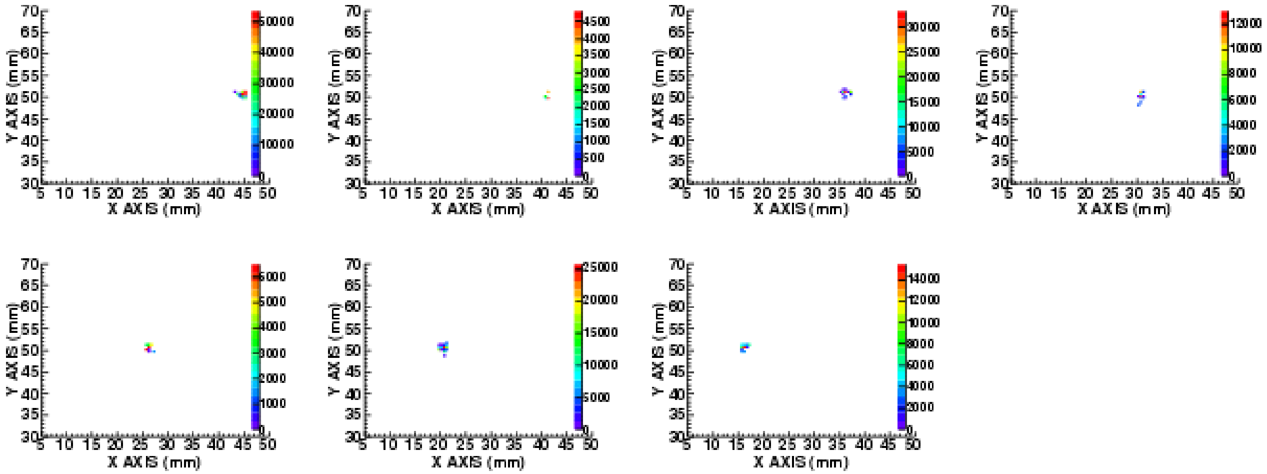
Total Energy Release

a)

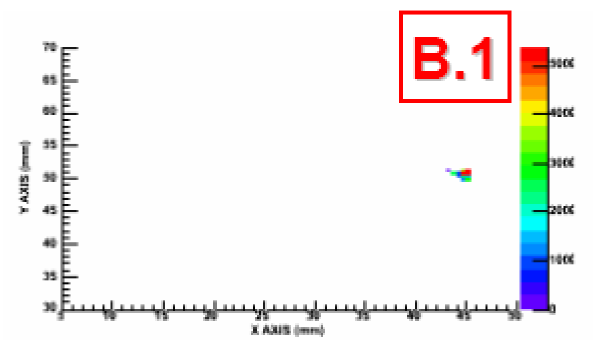


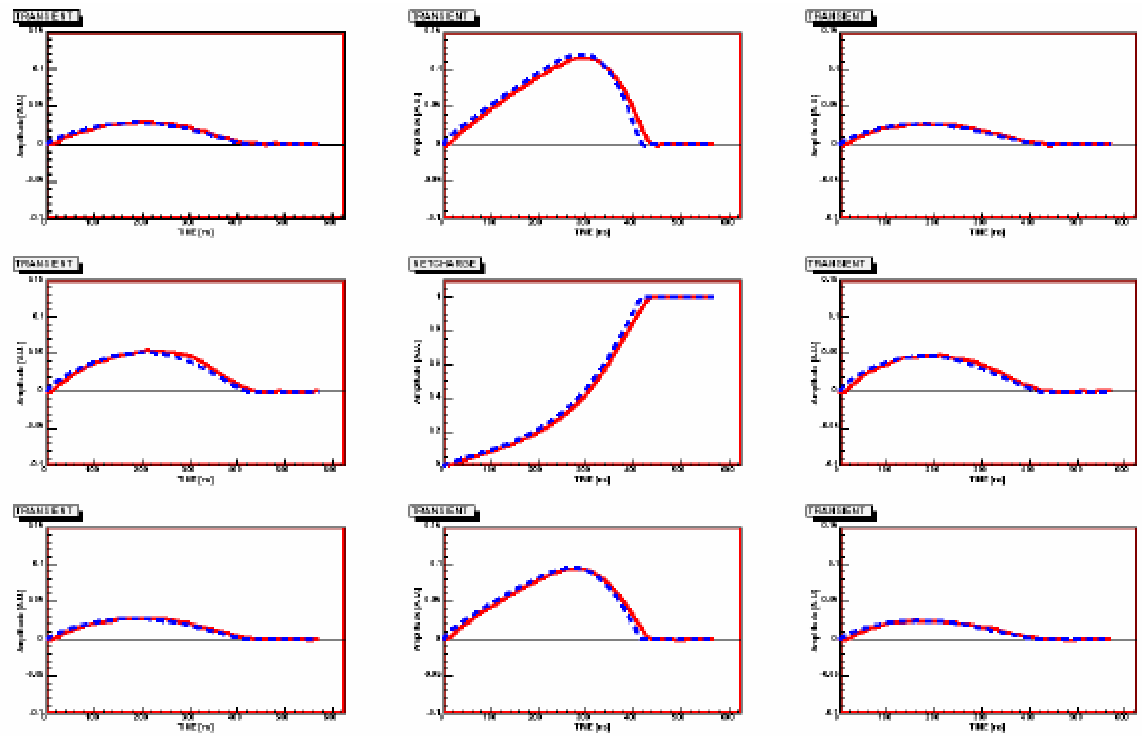
Energy Release Gated on χ^2

b)

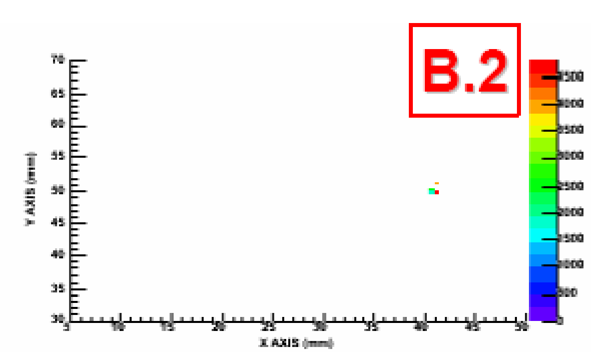


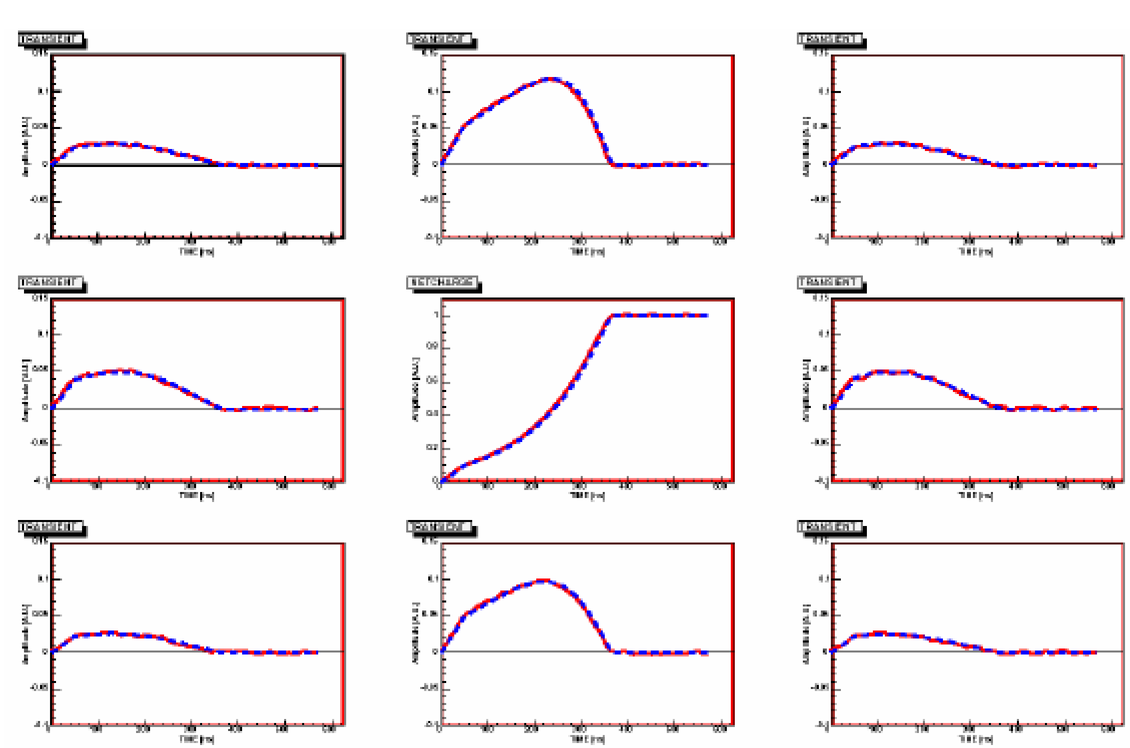
VALIDATION TEST WITH SIMULATED EVENTS



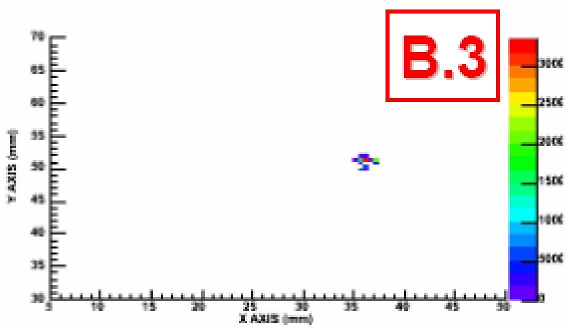


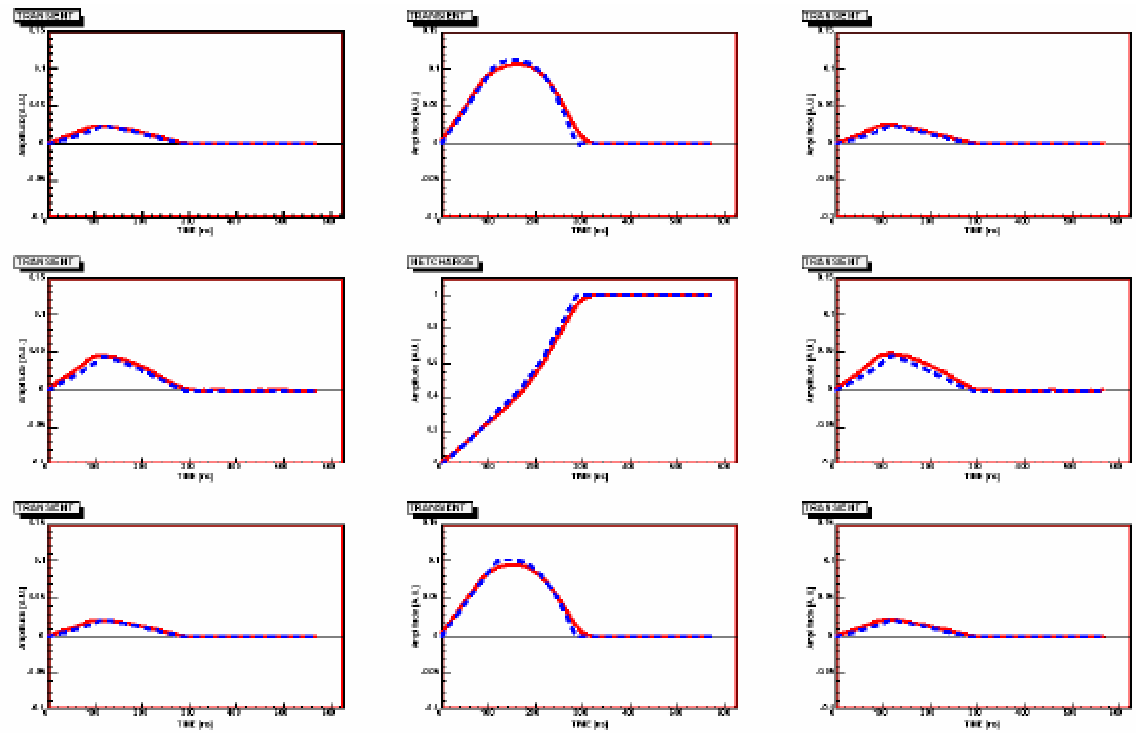
VALIDATION TEST WITH SIMULATED EVENTS





VALIDATION TEST WITH SIMULATED EVENTS





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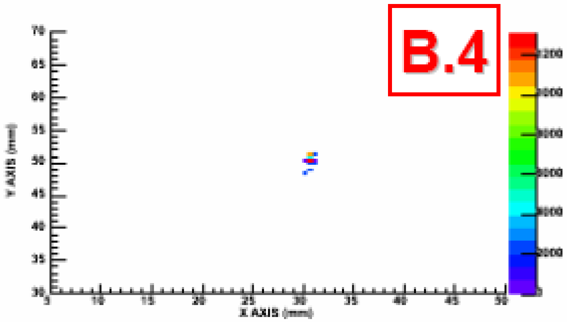
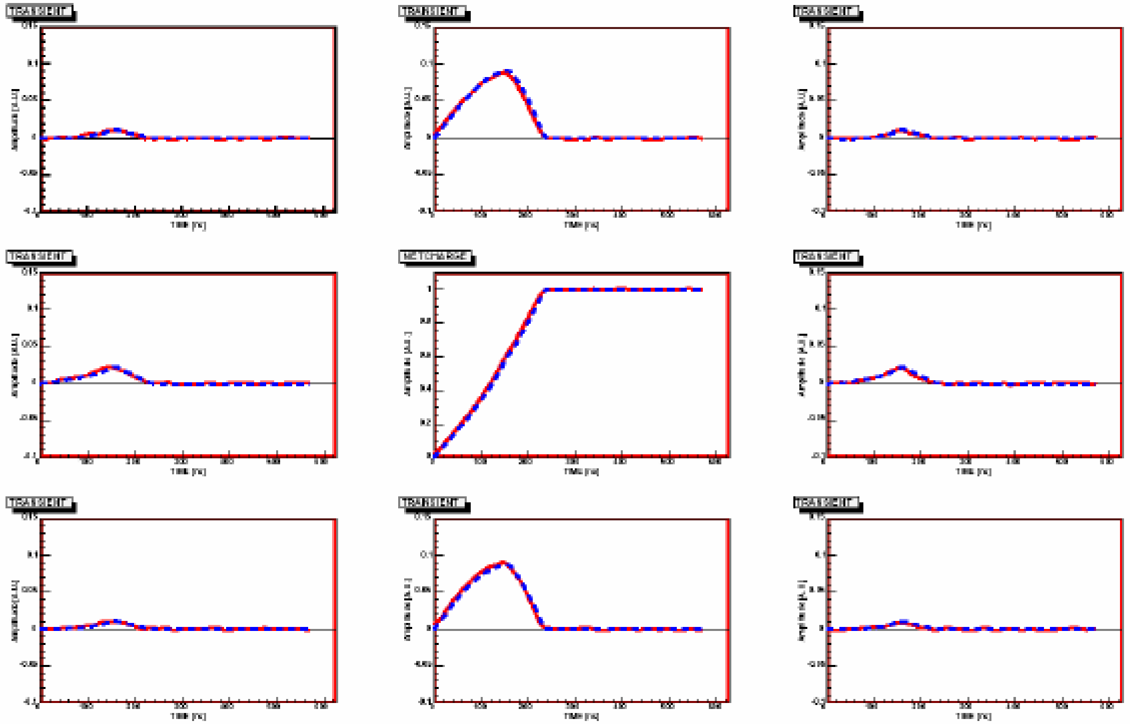
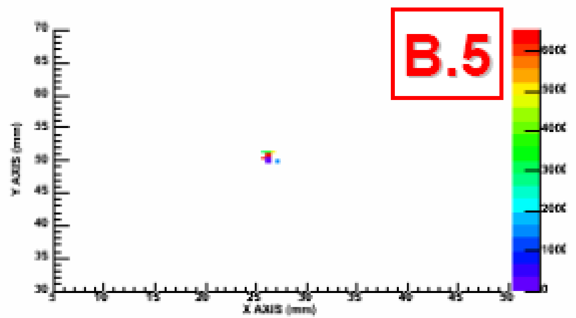
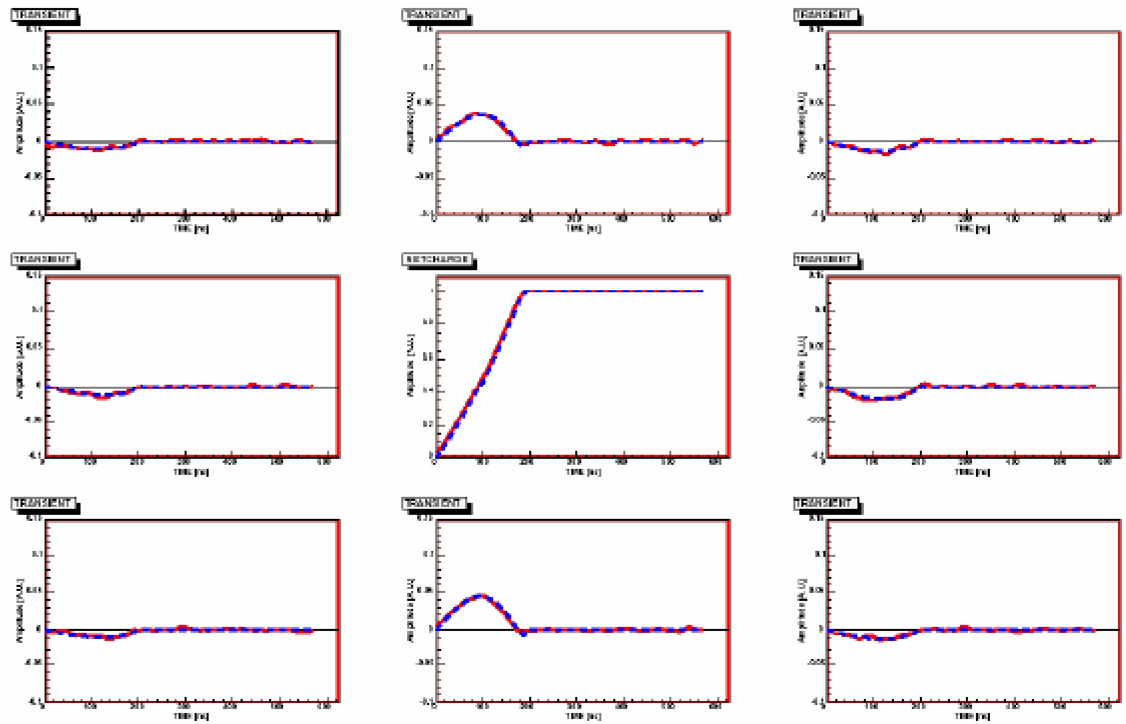




VALIDATION TEST WITH SIMULATED EVENTS





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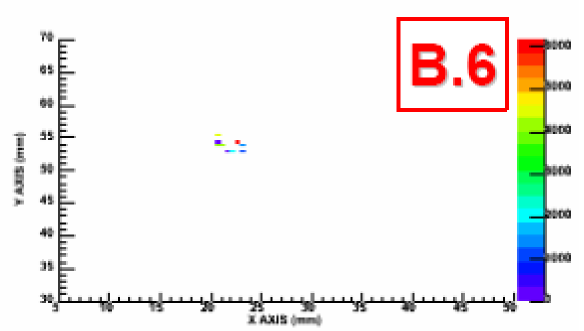
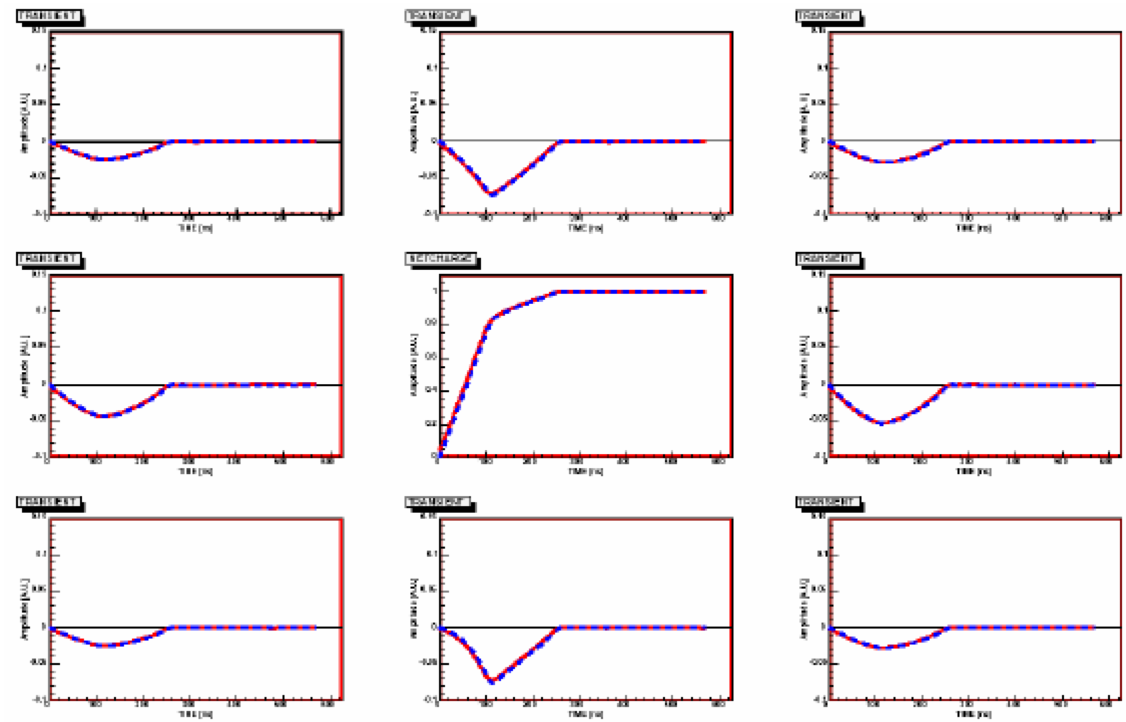
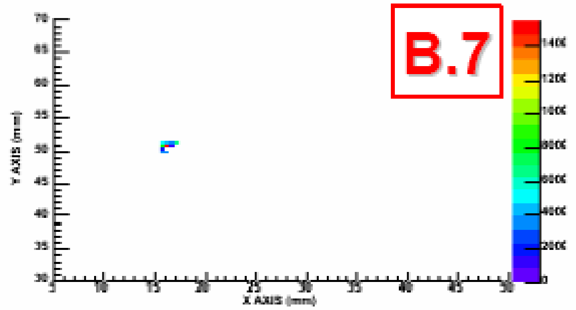
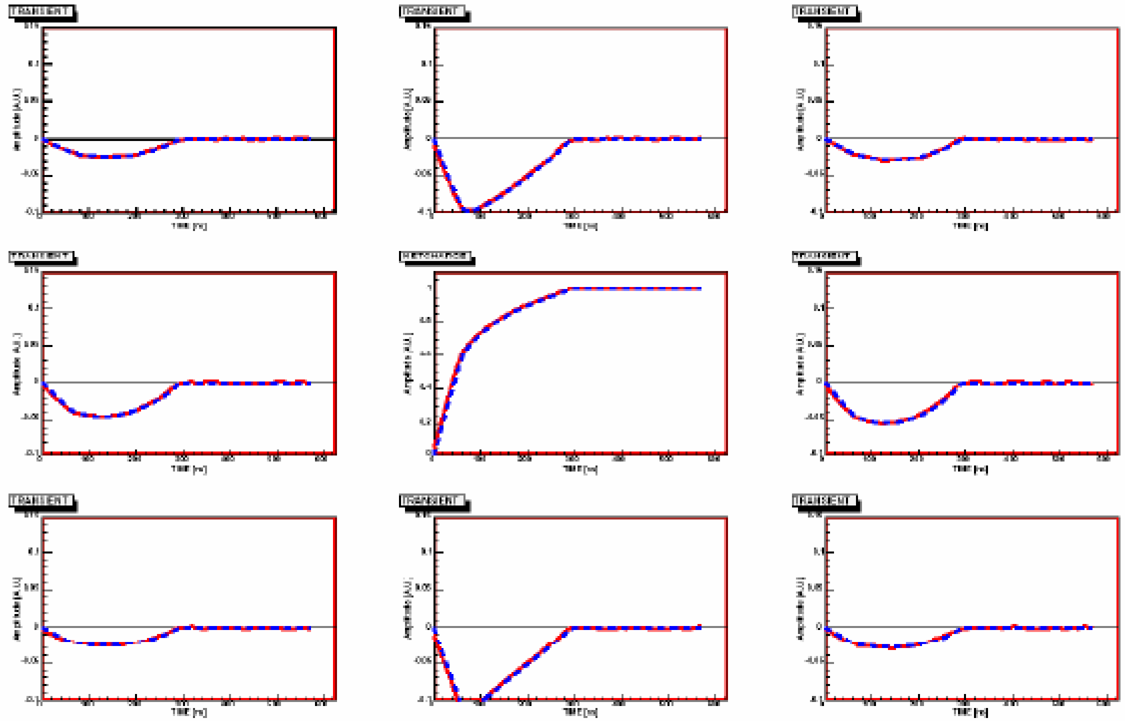


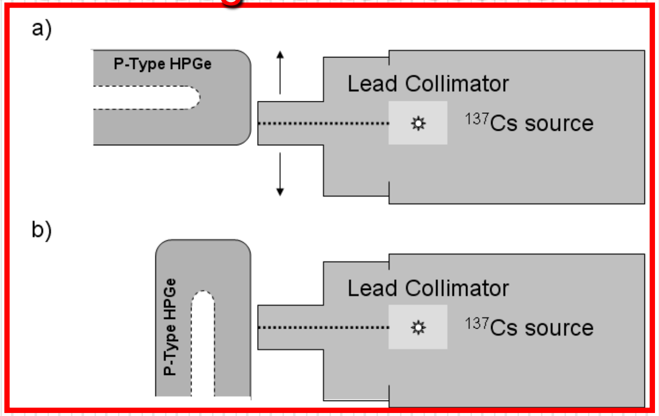


VALIDATION TEST WITH SIMULATED EVENTS





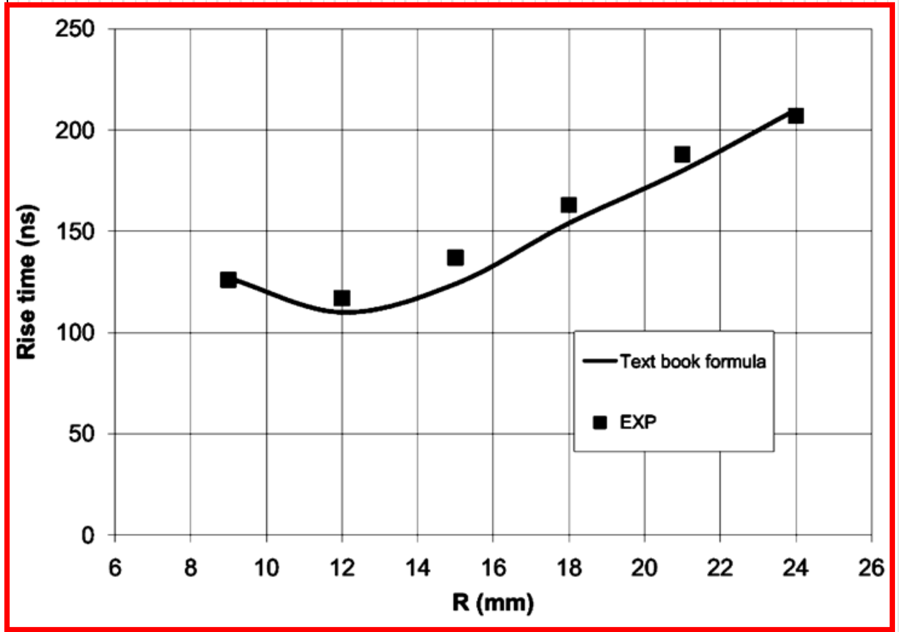
Application of the PSCS technique for the measurement of the position response of a non-segmented coaxial HPGe detector, along the radial direction*

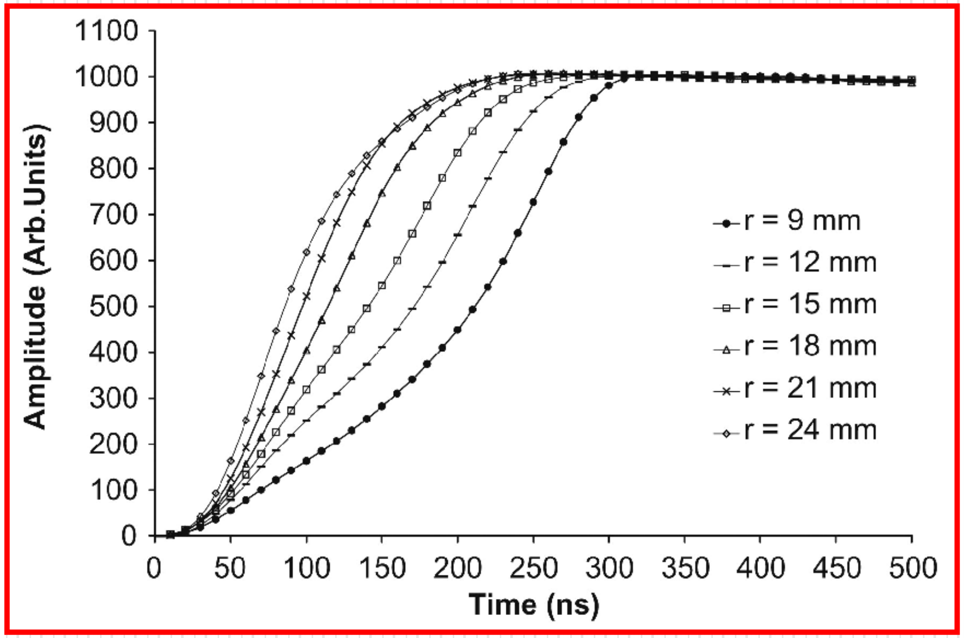


- P-Type HPGe
- 438 MBq ^{137}Cs collimated source
- collimation line at a distance of 9,12,15,18,21,24 mm from the detector centre
- signal shapes digitised at 100 M Sample/s at the output of the preamplifier
- 60 s per measure

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

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





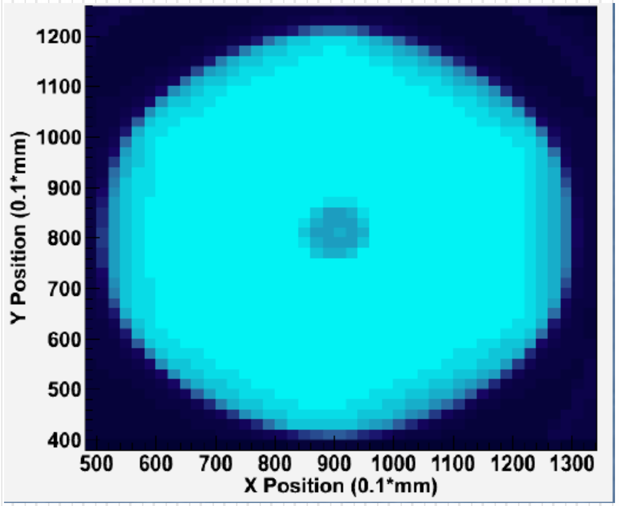
C001 data taken in Liverpool:

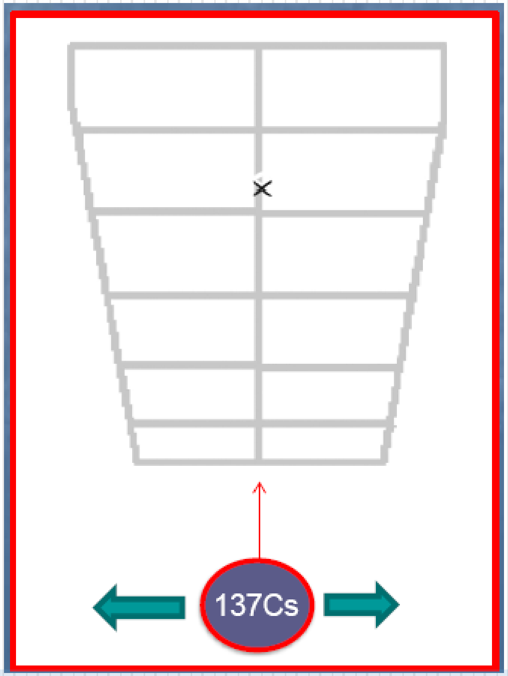
1) Front Face Singles ScanC001 data taken in Liverpool:

-Traces of 128 samples digitized at 100 MHz

-The trigger was generated through a CFD on the core with a threshold of ~300 keV

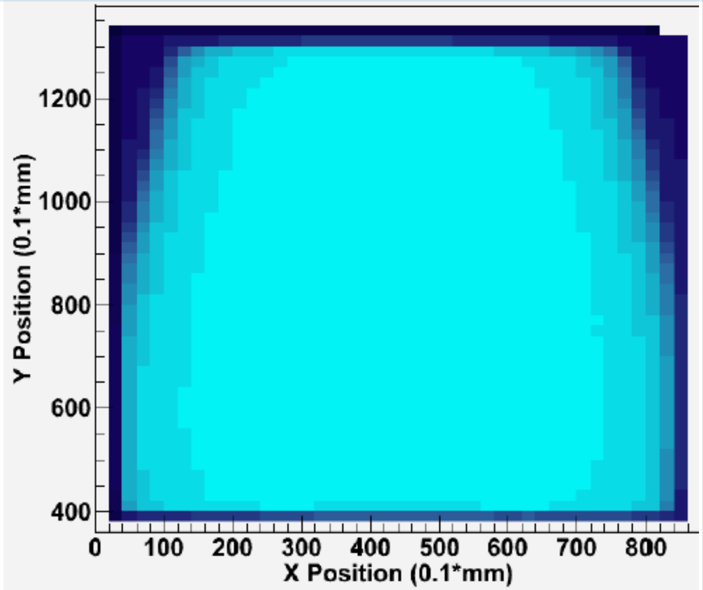
-137Cs source collimated to 1mm swept Across Front face of the detector Step Lenght = 1 mmStep Duration = 60 s
X-start 48 mm, X-range 86 mm
Y-start 39 mm, Y-range 86 mm



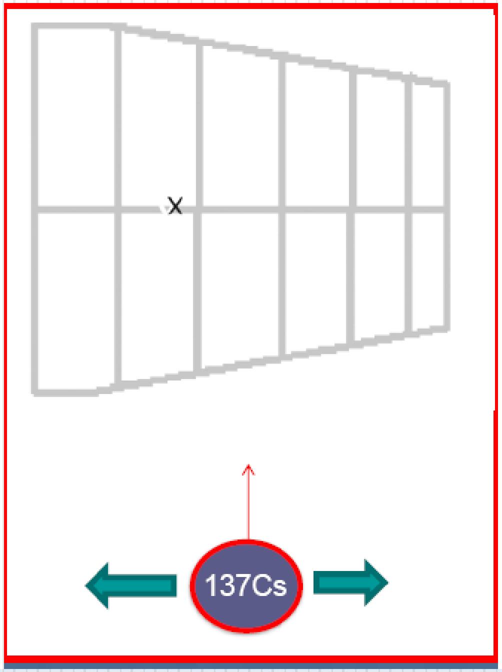


2) Side Singles Scan Data
C001 data taken in Liverpool :

-137Cs source collimated to 1mm swept
Across Side face of the detector
Step Lenght = 1 mm
Step Duration = 30 s
X-start 3 mm, X-range 82 mm
Y-start 38 mm, Y-range 95 mm



3) Higher Statistics Side Singles Scan Data
137Cs source collimated to 1mm swept across
Side face of the detector
(Step Dur. = 150s)(performed only for 2
detector rings)

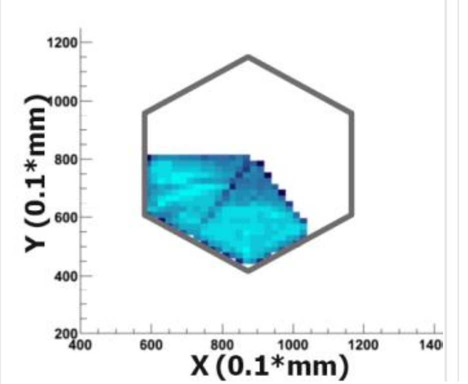


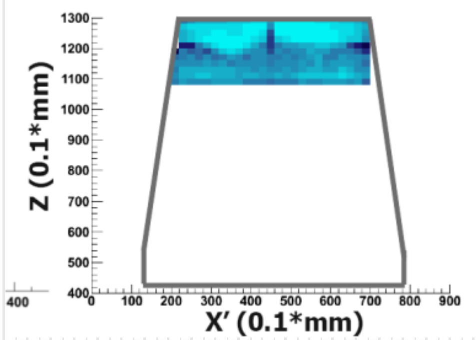
4) Planar Singles Scan Data (not yet used)
137Cs source collimated to 1.5 mm thick
plane

PSCS has been used to extract the position response of 4 detector segments: A1,A2,F1,F2

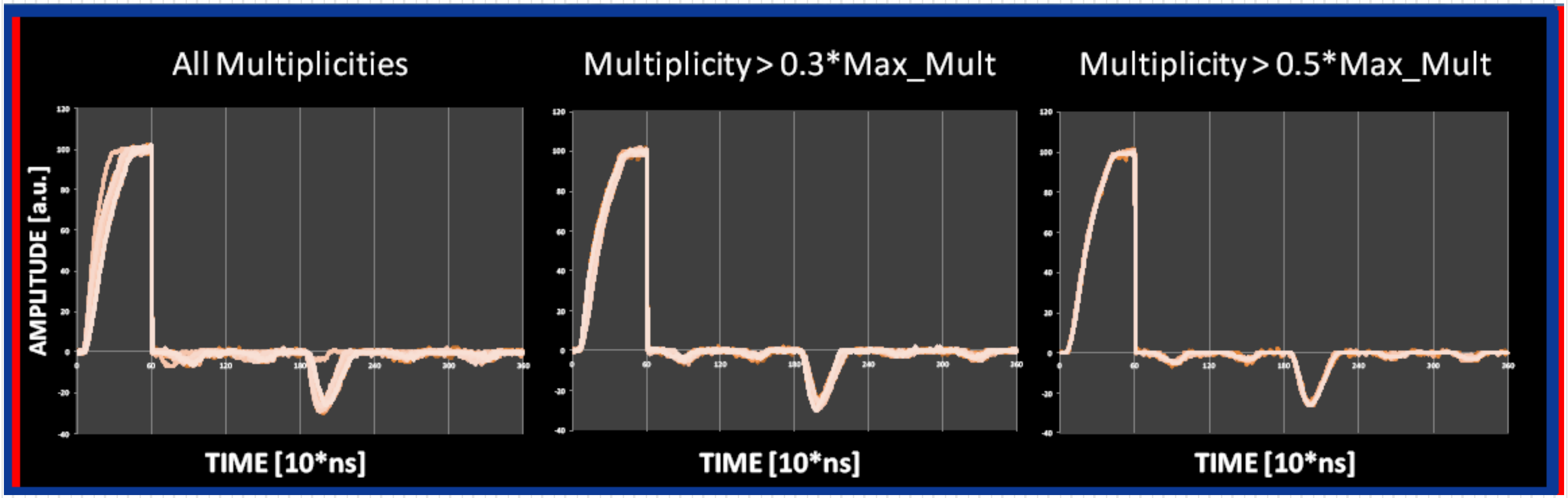
- " Brute Force" comparison not possible (CPU time)

- **Signal Parameterization (used also for RS_3D)**

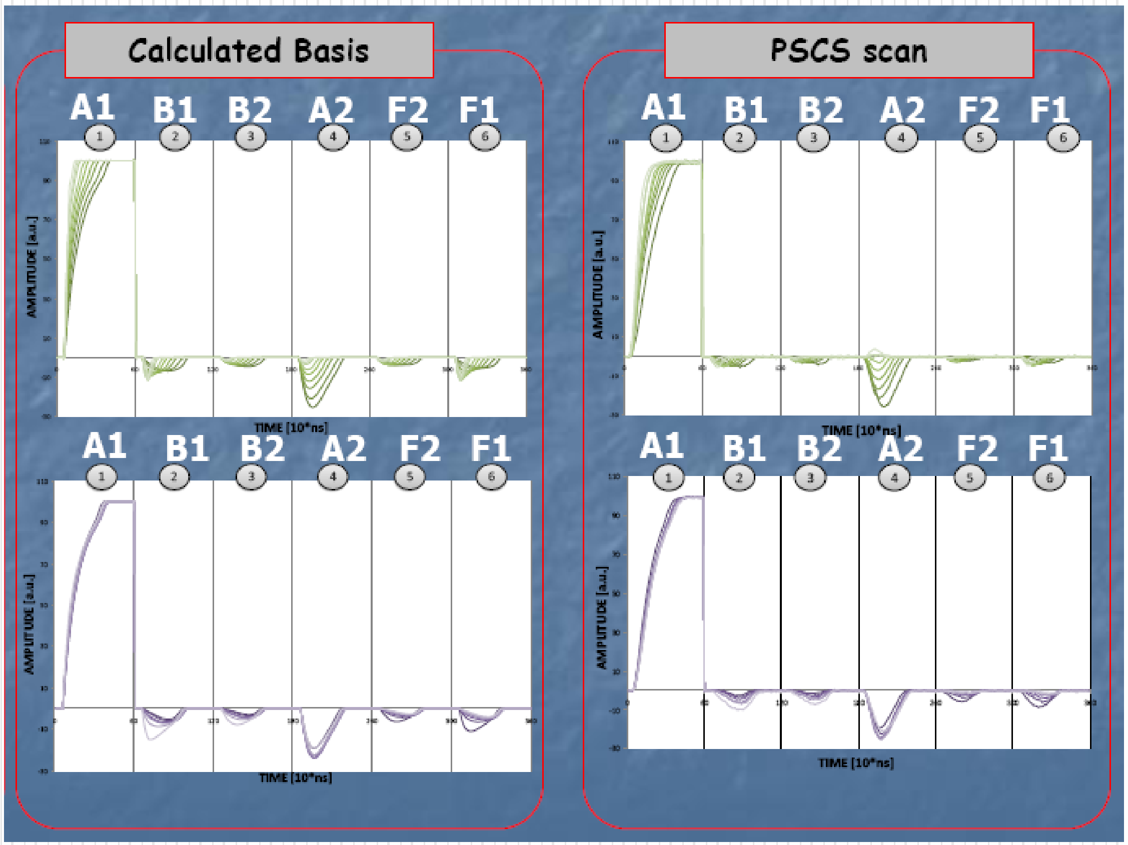


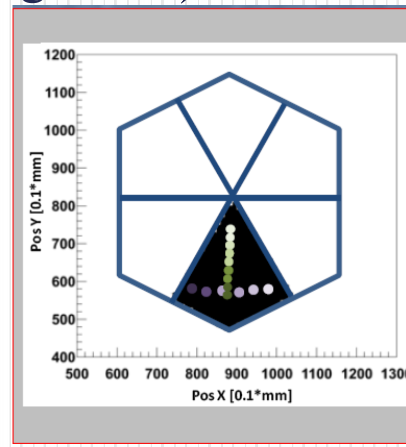


Selecting Shapes with an higher Multiplicity value allows to obtain an improved result

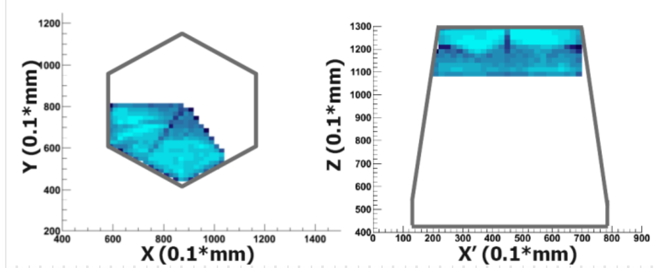


- **Calculated Basis*: currently implemented and used in AGATA experiments (C001 Asymmmetric Detector, used for experimental data acquisition in Liverpool University**)**
- **Experimental Basis: extracted using PSCS scan***(4 segments)**





Pos X [0.1*mm]	Pos Y [0.1*mm]	Pos X [0.1*mm]	Pos Y [0.1*mm]
882	493	806	513
883	523	839	504
883	554	873	500
884	585	906	500
885	616	940	504
886	646	973	513
887	677		
888	708		
889	739		



*Bart Bruyneelet al., NIMA599 (2009), p. 196
***A. Boston et al., Nucl. Instr. and Meth. B261 (2007), p. 1098
***F.C.L. Crespiet al., NIMA 593 (2008), p.440

Signals Shapes that reproduce the same trend have been extracted with the Standard Coincidence Scan

This variant of the PSCS method requires **<u>no collimators</u>**, thus reducing further the time duration of the measurements. Specifically, **<u>Geant4 simulations of an AGATA triple cluster with a ^{60}Co</u>** source placed in different positions have been performed. The spatial distributions of single interaction events, obtained by imposing a gate on the Compton edge of the 1172 keV gamma line, is calculated.

The technique relies on the fact that **<u>the combination of the number of counts in each detector voxel is in principle unique, provided that a sufficient number of measurements with a source illuminating the detector from different directions (3 at least) is available</u>**. In this way the calculated number of counts per voxel can be compared with the number of events with a specific line-shape acquired in the 3 measurements. It will be therefore possible to associate each line-shape with a position, thus measuring the detector position response.