The scanning table: an IPHC tool for full characterization of AGATA detectors

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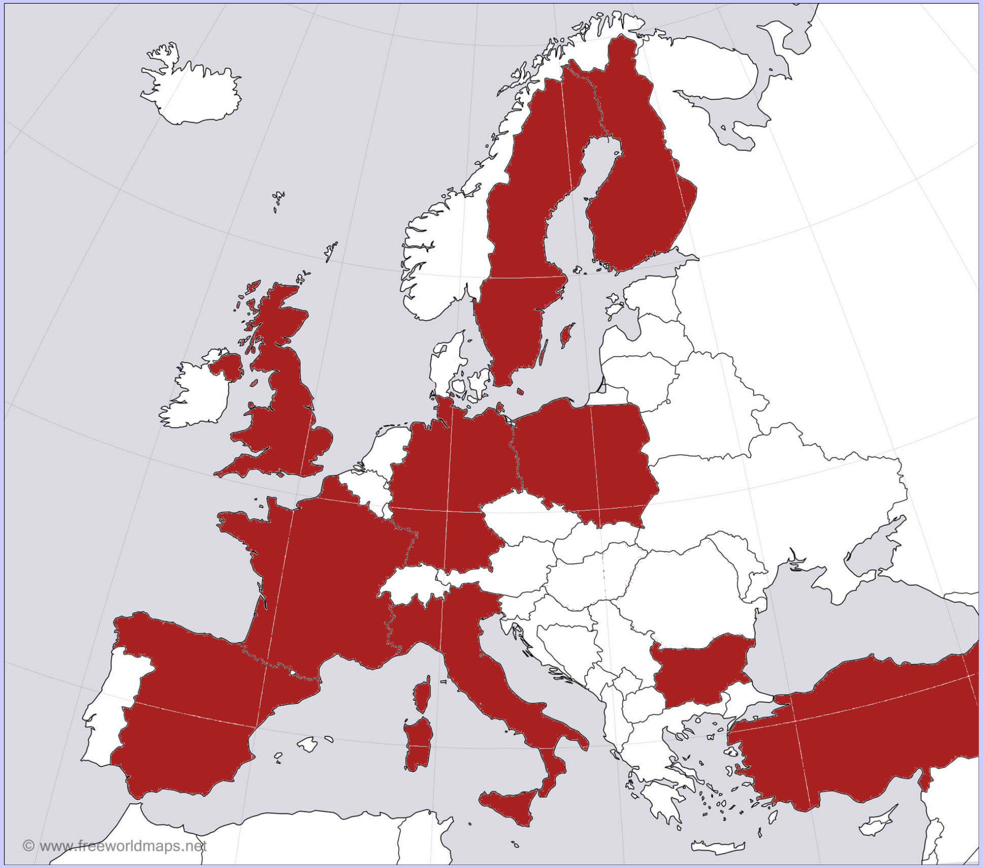
AGATA collaboration

The *Advanced Gamma Tracking Array* [AGATA] is an array of *High Purity Germanium* [HPGe] segmented gamma-ray detectors designed and built in the framework of a collaboration which involves 10 European countries and more than 40 research institutes.

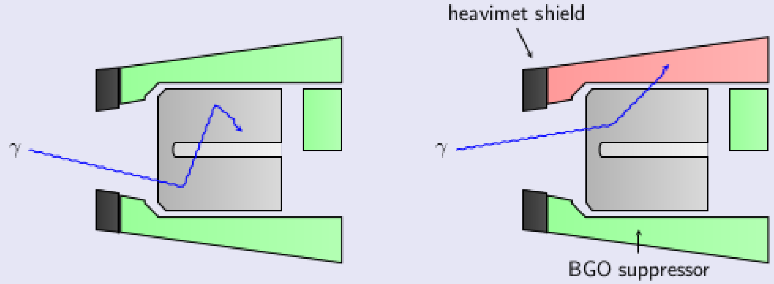


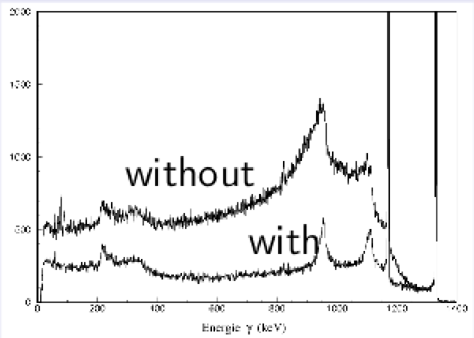
- Bulgaria
- Finland
- France
- Germany
- Italy
- Poland
- Spain
- Sweden
- Turkey
- UK

The aim of the collaboration is to build a new generation array which will grant better performances (efficiency/Energy resolution) compared to already existing arrays, to be used in experiments to study the structure of atomic nuclei as a function of angular momentum, isospin, and temperature at the limits of their stability. In particular the collaboration is interested in the study of the structure of the *exotic nuclei* which properties can help the community defining some terms of the nuclear force.

Gamma ray detection: old vs. new approach

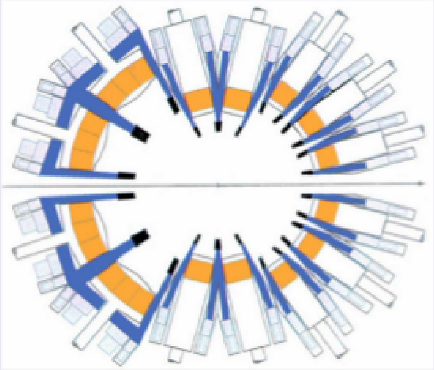
Resolving power: escape suppression arrays





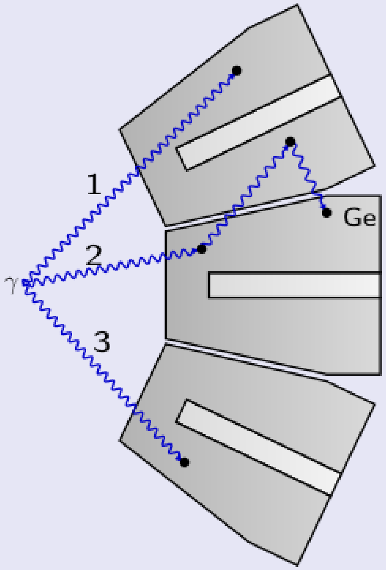
escape suppression

EUROBALL:

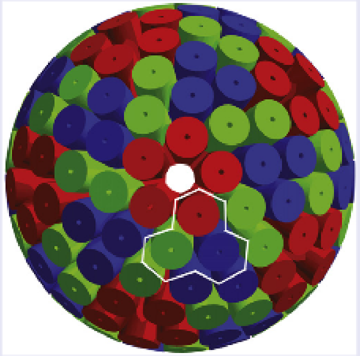


- 239 crystals
- $\epsilon_{1\,MeV} \sim 10\%$
- $\Omega_{total} \sim 95\%$
- $\Omega_{Ge} \sim 40\%$

Next step: γ-ray tracking



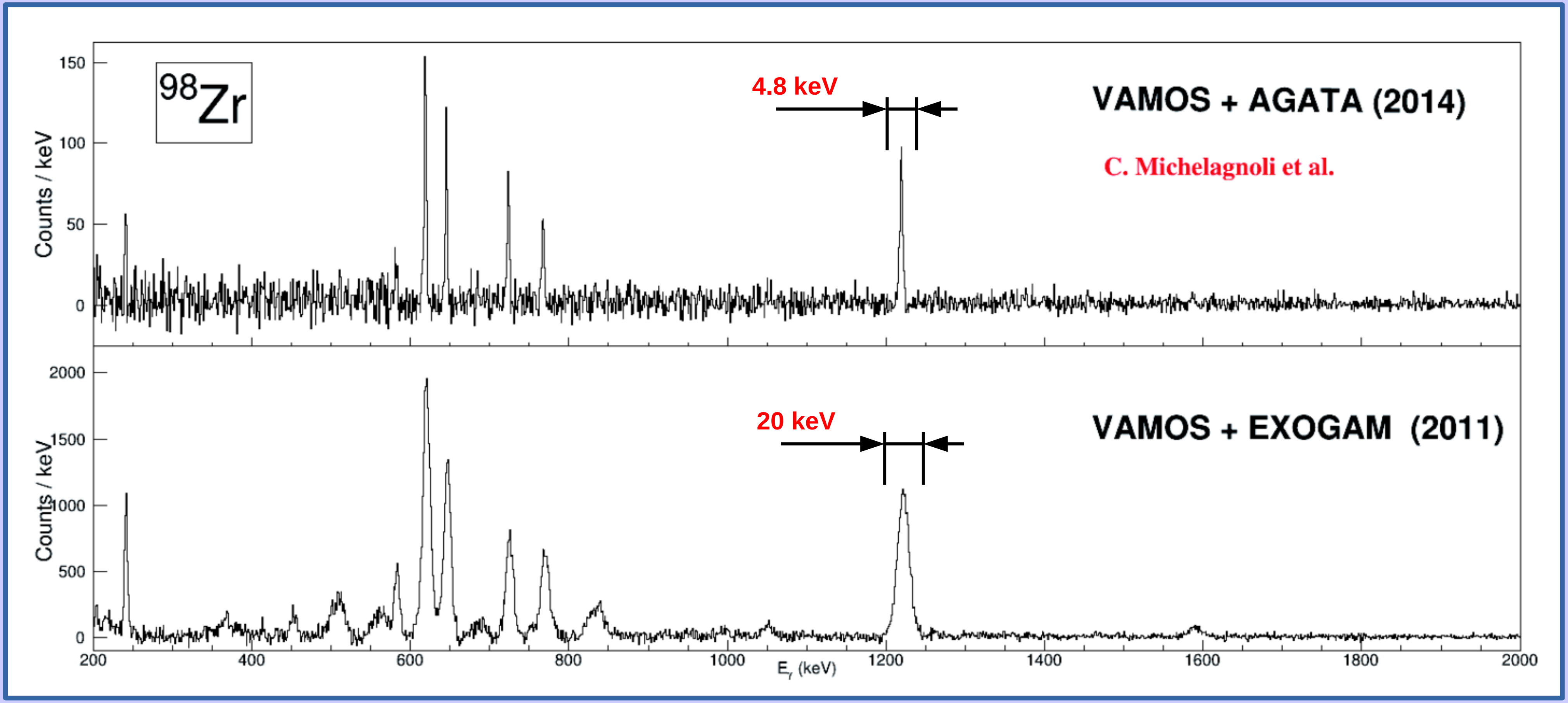
AGATA(NIMA 668 (2012) 26):



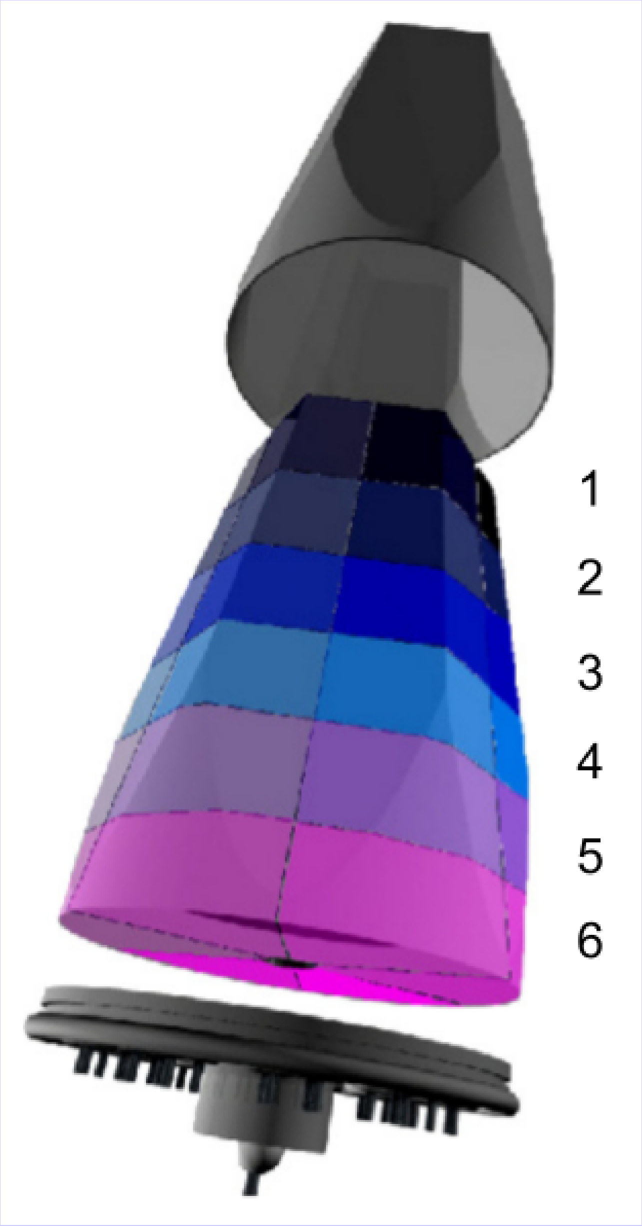
- 180 crystals
- $\epsilon_{1\,MeV} \sim 43\%$
- $\Omega_{Ge} \sim 82\%$

A performance example

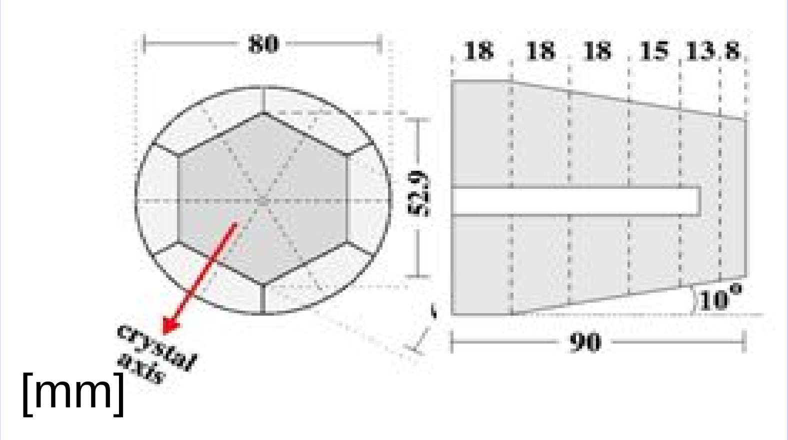
The feature of been able to track down gamma interaction position, increases the detection efficiency and energy resolution compared to the other arrays...

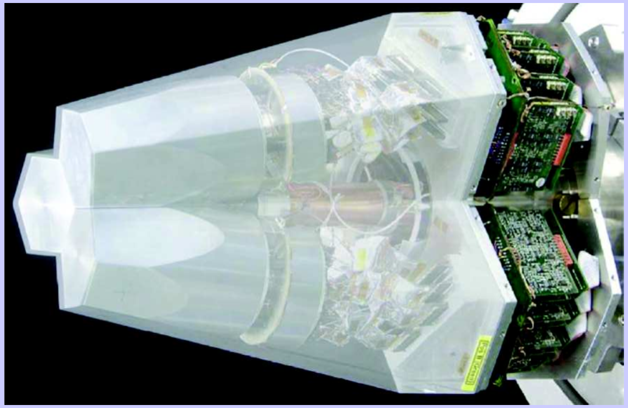


AGATA detector unit



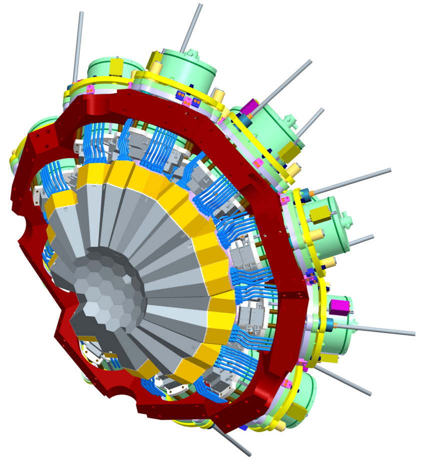
The unit of the AGATA array is a coaxial-like High Purity Germanium detector with 36-fold segmentation: **each segment can be considered an independent detector**

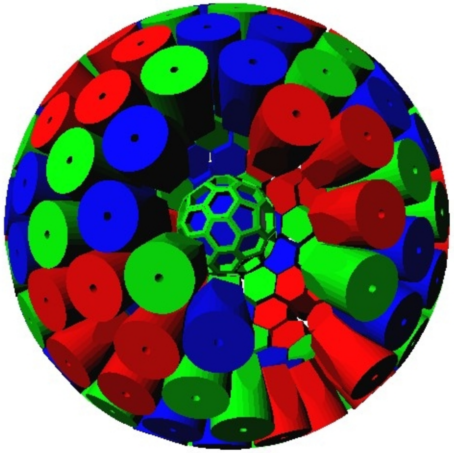


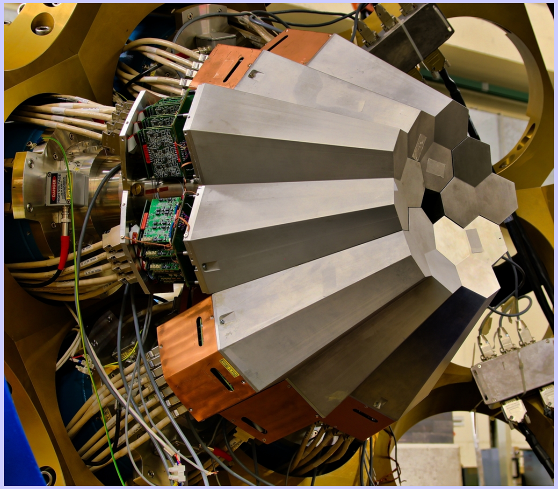


The AGATA array

- The final array will feature 180 detectors that will **cover a solid angle of ~80% of 4π.**
- 35 detectors are already in operation in GANIL laboratories in Caen (Normandy).

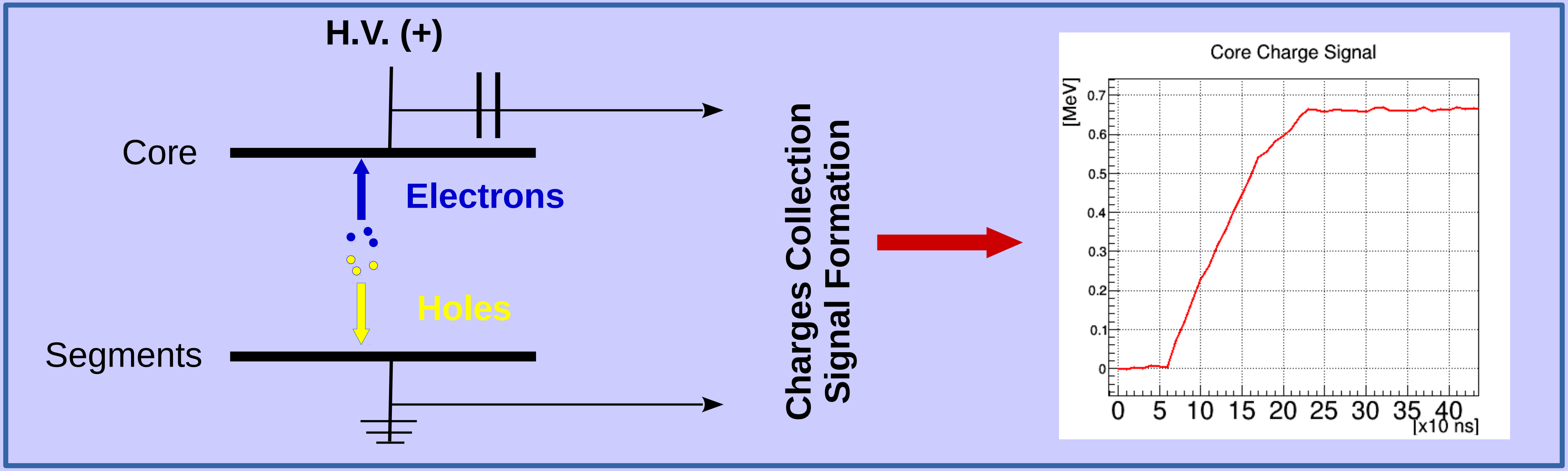






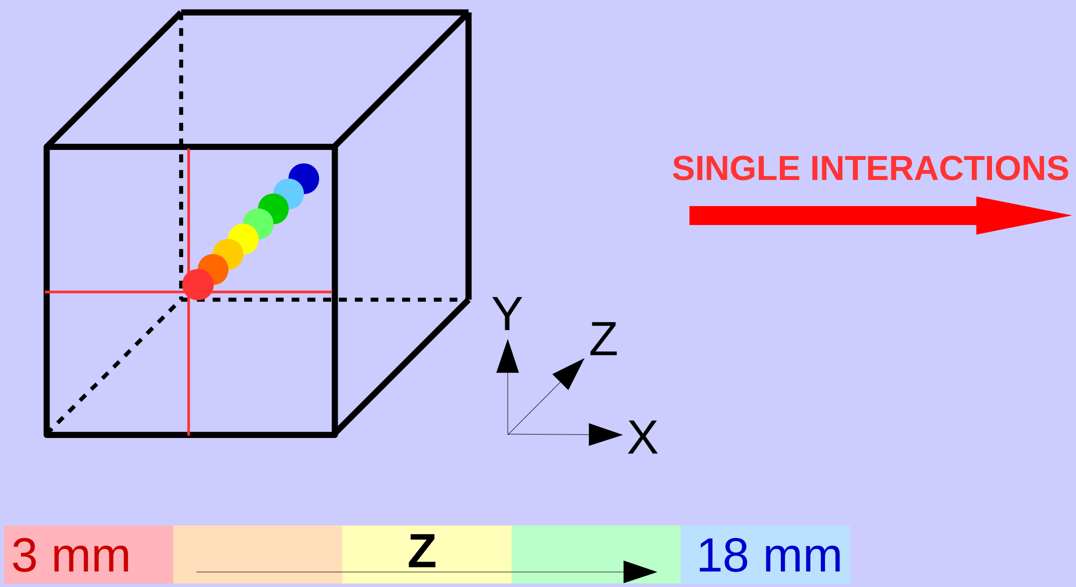
Gamma rays detection

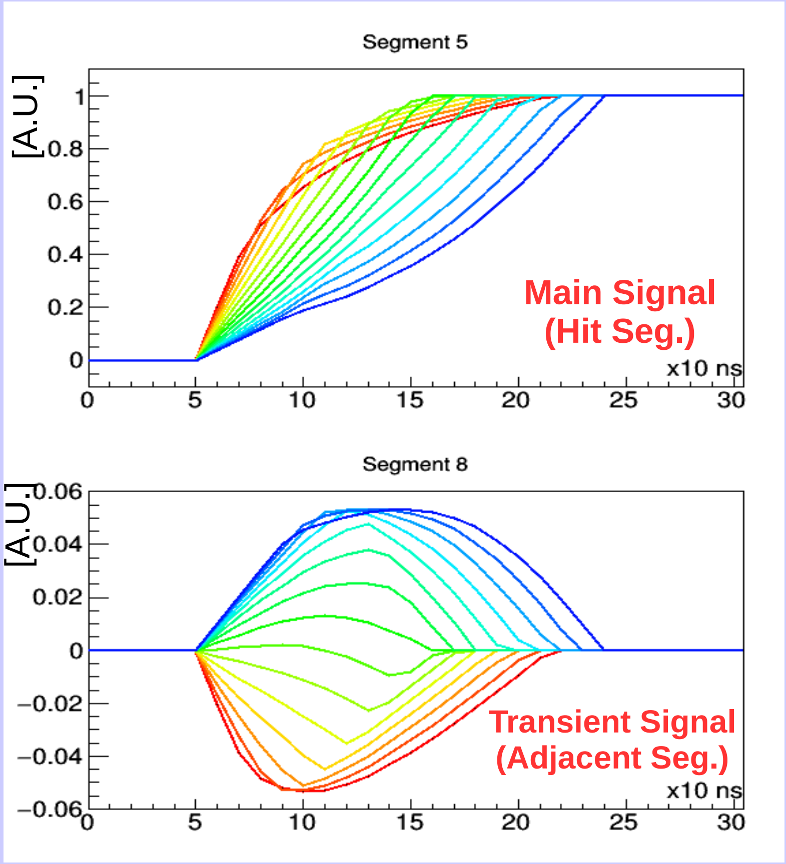
At the energy of interest (for this work), gamma rays can interact with the matter mainly with two different mechanisms: **photoelectric absorption**, **Compton scattering**.



How to track?

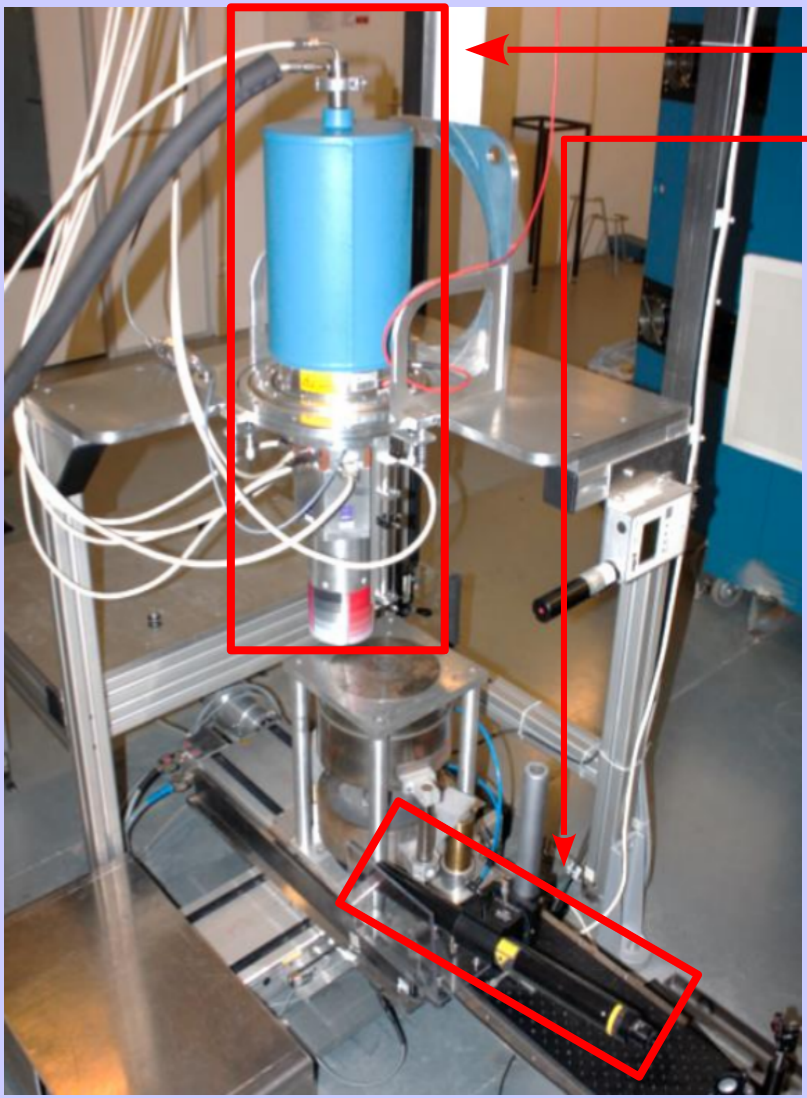
The shape of the signal depends on the interaction point (radius for coaxial detector) of the gamma ray. Using pulse shape comparison algorithms is then possible to track down the interaction points for gamma ray.





Databases of pulse shapes are needed!

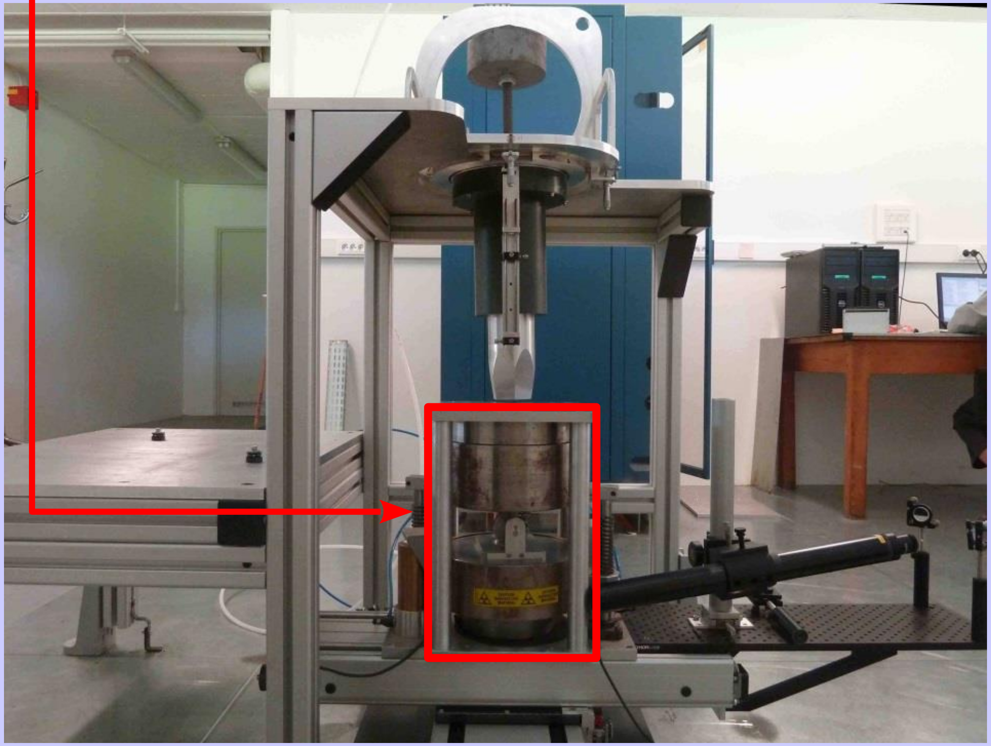
The IPHC scanning table [1]



The detector can be put on table in **vertical** or **horizontal** configuration

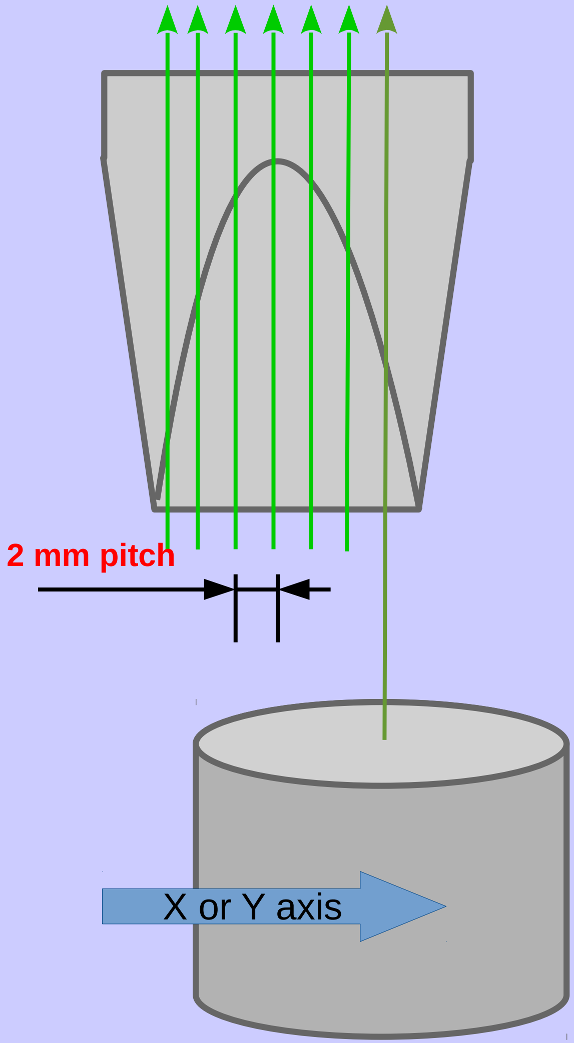
A **laser system** is used to align the detector

A cylindrical **collimator** collimates a strong gamma source into a **pencil-like beam**. It is moved in a plane by two perpendicular servo motors.

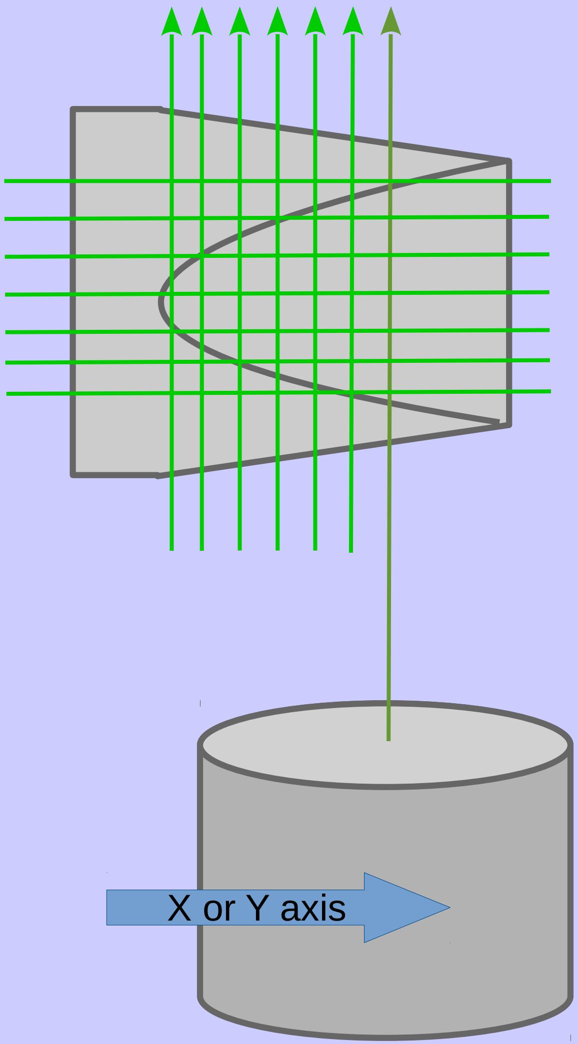


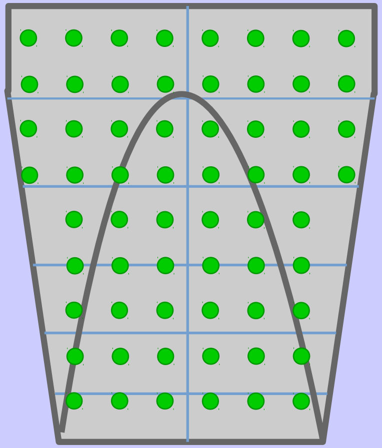
The IPHC scanning table [2]

VERTICAL CONF.



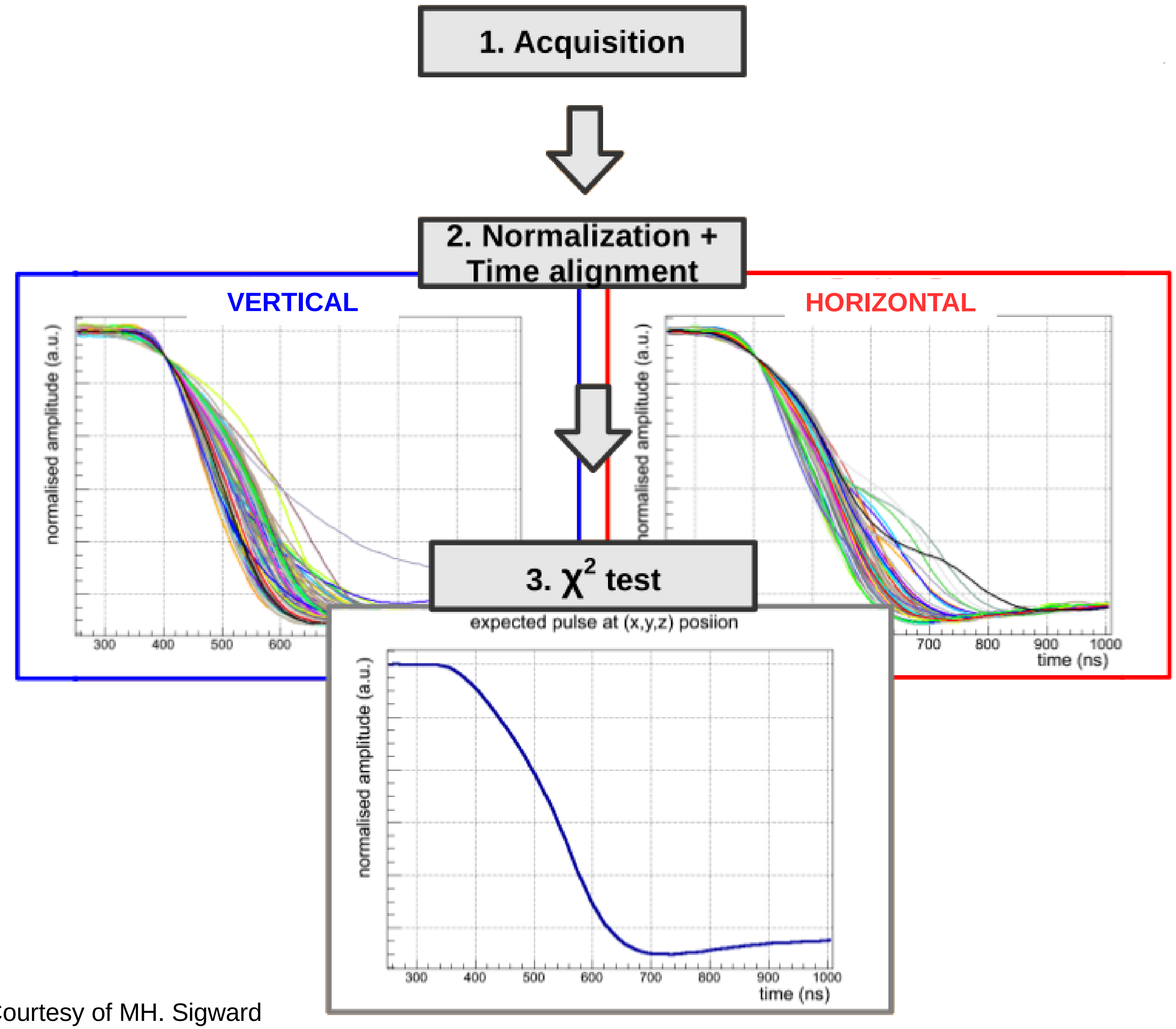
HORIZONTAL CONF.





Using pulse shape comparison algorithms it is possible to extract the pulse shape at every grid intersection.

The IPHC scanning table [3]

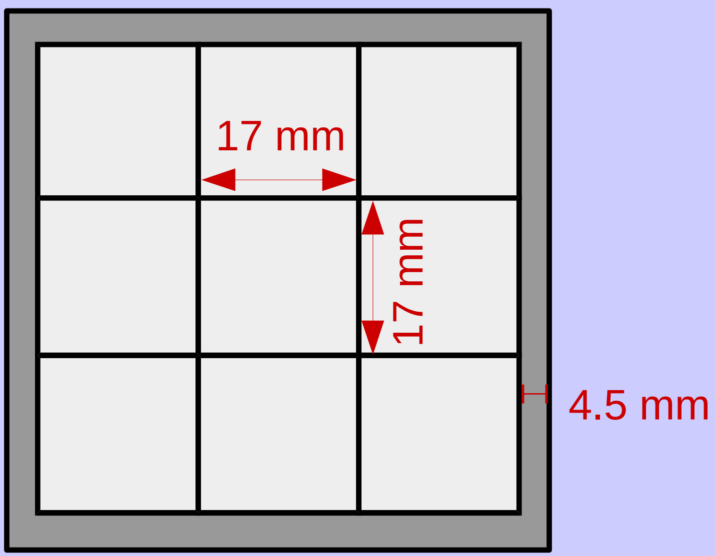


Courtesy of MH. Sigward

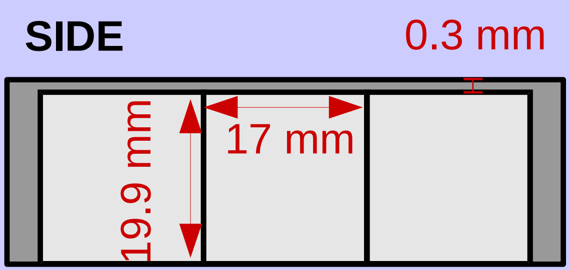
Simulations on a planar detector

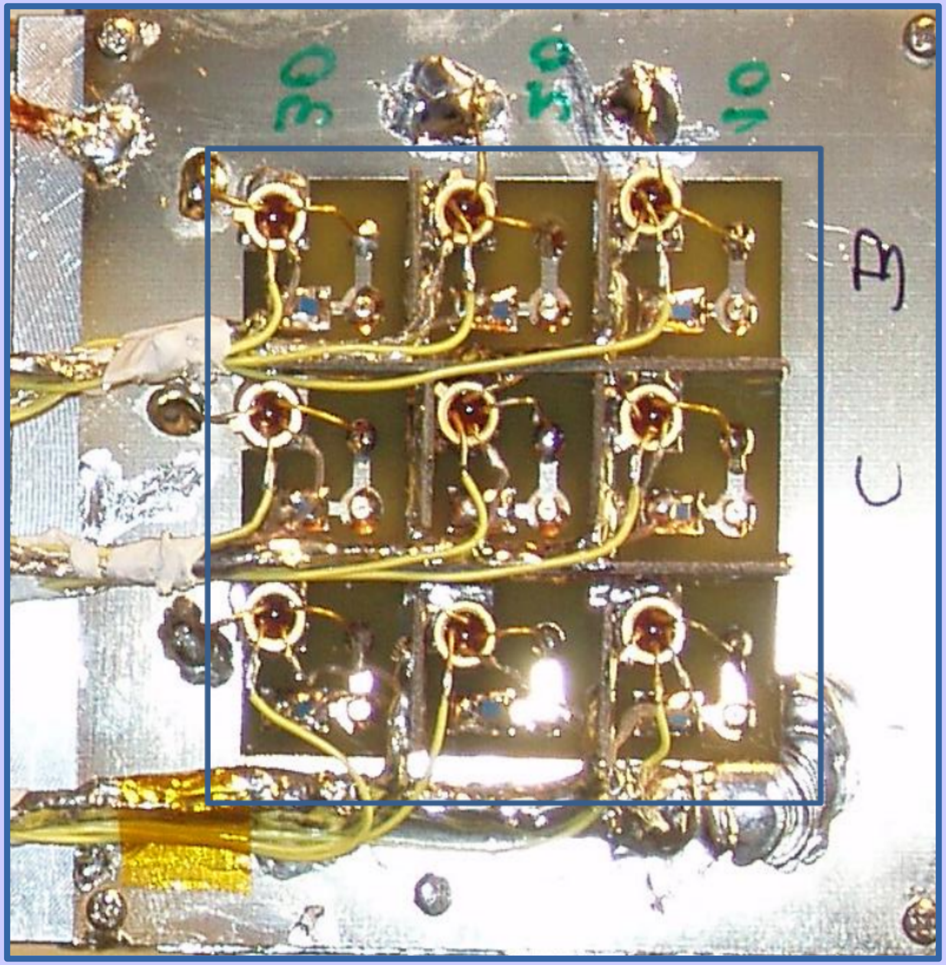
As first approach, simulations of a planar detector with 3x3 segmentation (simpler geometry) were performed

FRONT



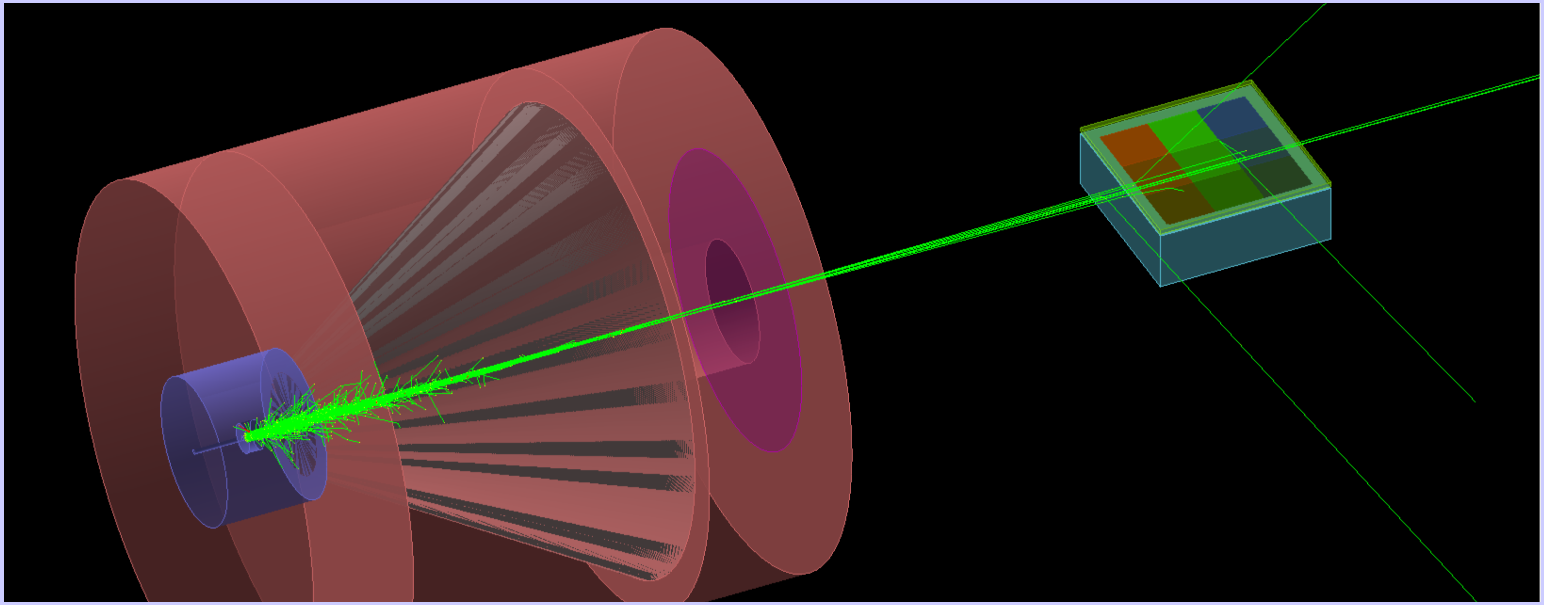
SIDE



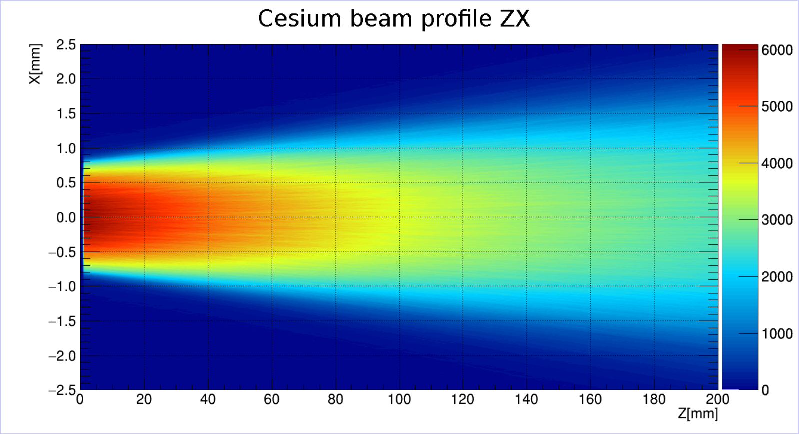


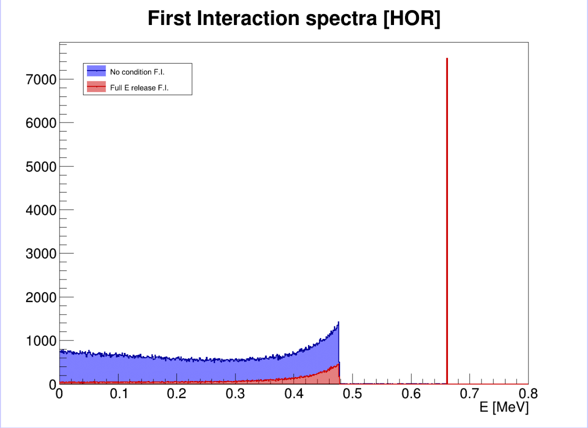
Simulation tools [1]

Geant4 → Simulates interaction of radiation with matter



Preliminary analysis on the beam and on the behavior of gamma rays inside the detector was performed

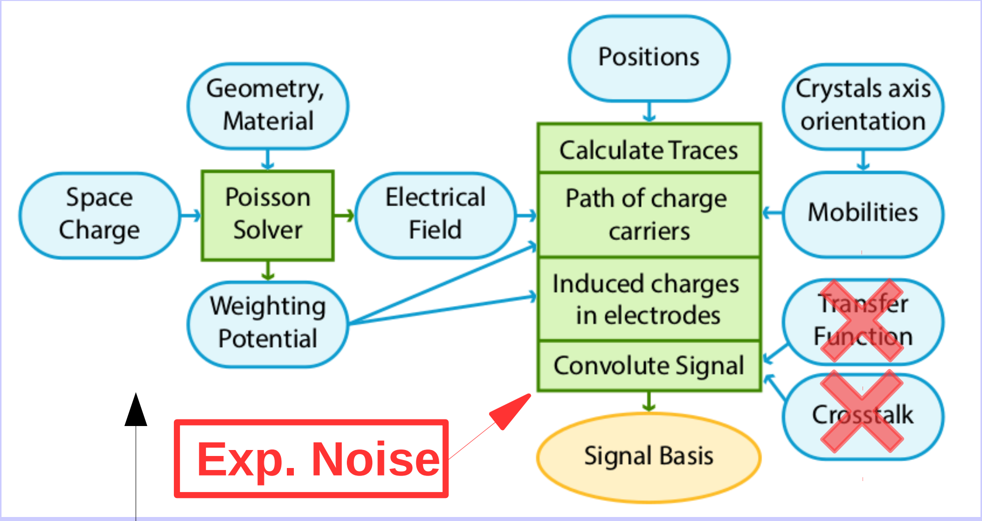




Simulation tools [2]

SIMION + ADL → Pulse shape calculation

- The Agata Detector Library [ADL] is a C based library, developed in Koln, that can be used to calculate the shapes of the pulses for a specific detector geometry.



B. Bruyneel et al.
DOI: 10.1140/epja/i2016-16070-9

- The SIMION software was used to calculate the weighting potentials and the electrical field for the 3x3 detector geometry. **A grid of 1x1x1 mm** was used to define the geometry and refine the potentials and fields.
- The **electron and holes mobility** parameters used are the one described in B.Brunyeel article

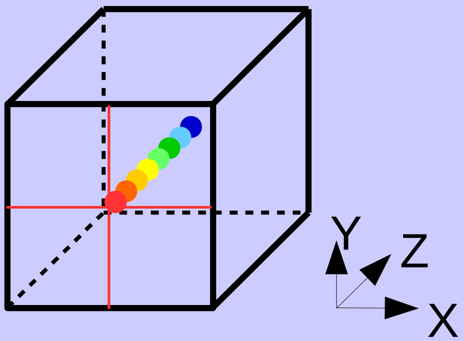
Electron mobility parameters			
Mobility along ⟨100⟩		Inter valley scattering rate	
E_0 [V/cm]	507.7	E_0 [V/cm]	1200
β	0.804	ν_0	0.459
μ_0 [cm^2/V s]	37165	ν_1	0.0294
μ_n [cm^2/V s]	145	ν_2	0.000054
Hole mobility parameters			
Mobility along ⟨100⟩		Mobility along ⟨111⟩	
E_0 [V/cm]	181.9	E_0 [V/cm]	143.9
β	0.735	β	0.749
μ [cm^2/V s]	62934	μ [cm^2/V s]	62383

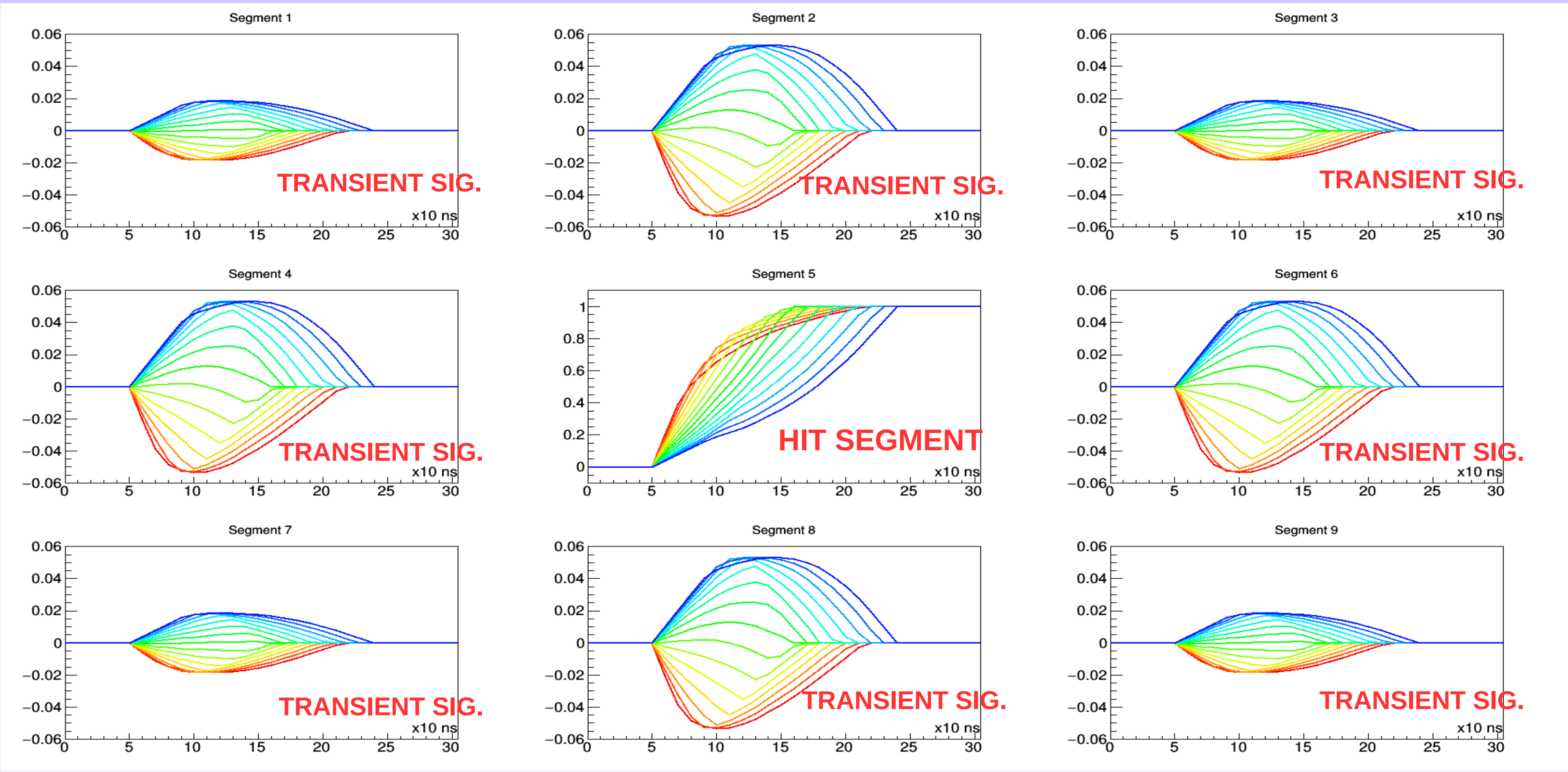
- Final pulses were convoluted with **experimental noise** sampled directly from the detector.

Simulation tools [3]

SIMION + ADL → Pulse shape calculation

[X = 25 mm   Y = 25 mm]





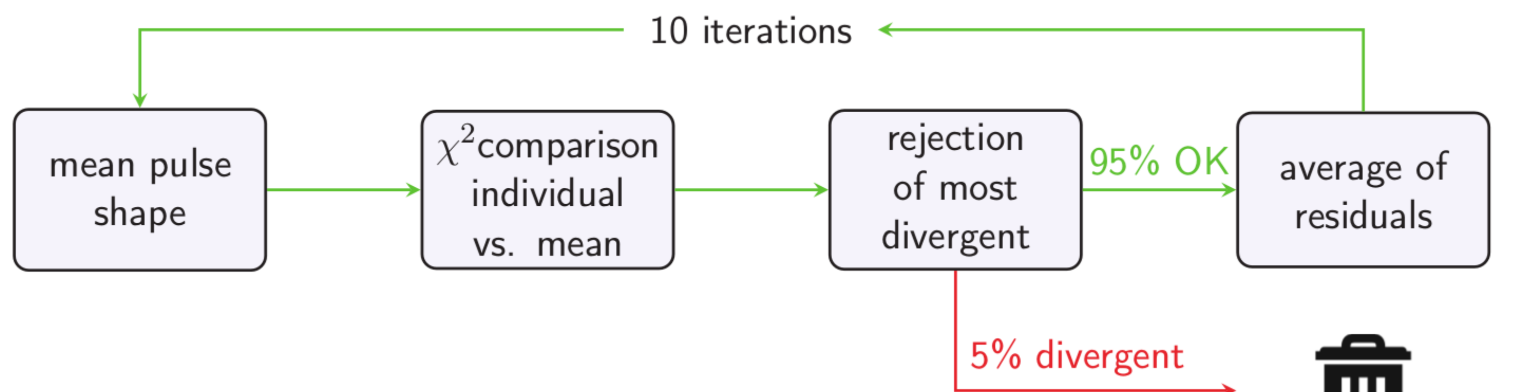
χ^2 Analysis [1]

$$\chi^2 = \frac{1}{N} \cdot \sum_{ch=0}^{9} \sum_{i=0}^{100} \left(\frac{H_{i,ch} - V_{i,ch}}{\sigma_{ch}} \right)^2$$

H_{ch} = Horizontal conf. data set
V_{ch} = Vertical conf. data set
N = total number of samples
σ_{ch} = noise amplitude of one channel

The χ^2 selection threshold is adaptive and at the end of the procedure the best 200 tests are selected (i.e.: 400 signals).

Refining procedure (~230 pulses remaining)



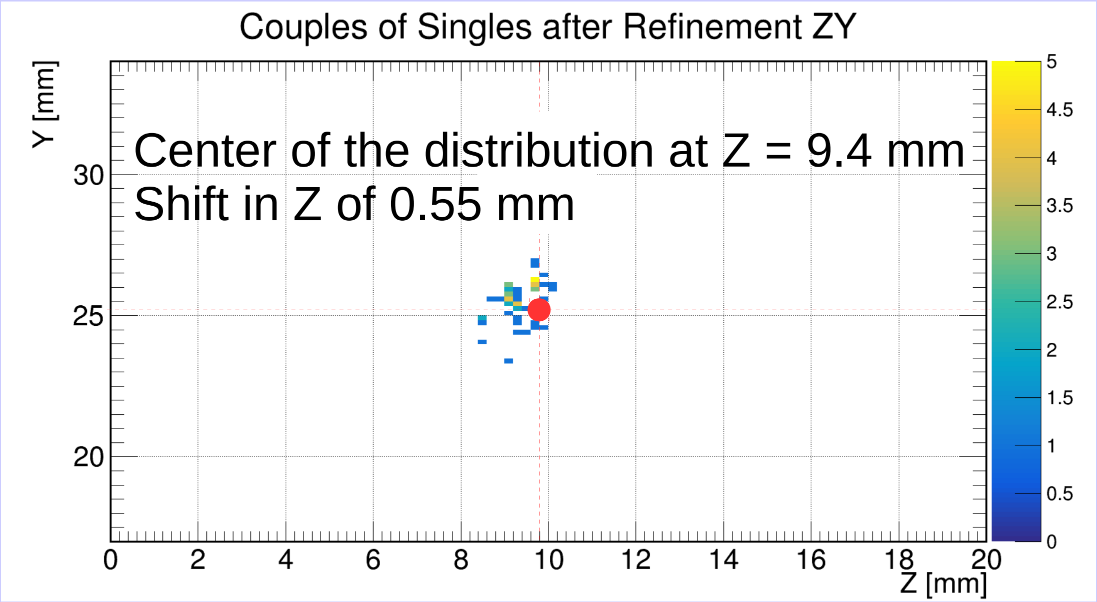
Picture taken from M. Ginsz PhD thesis

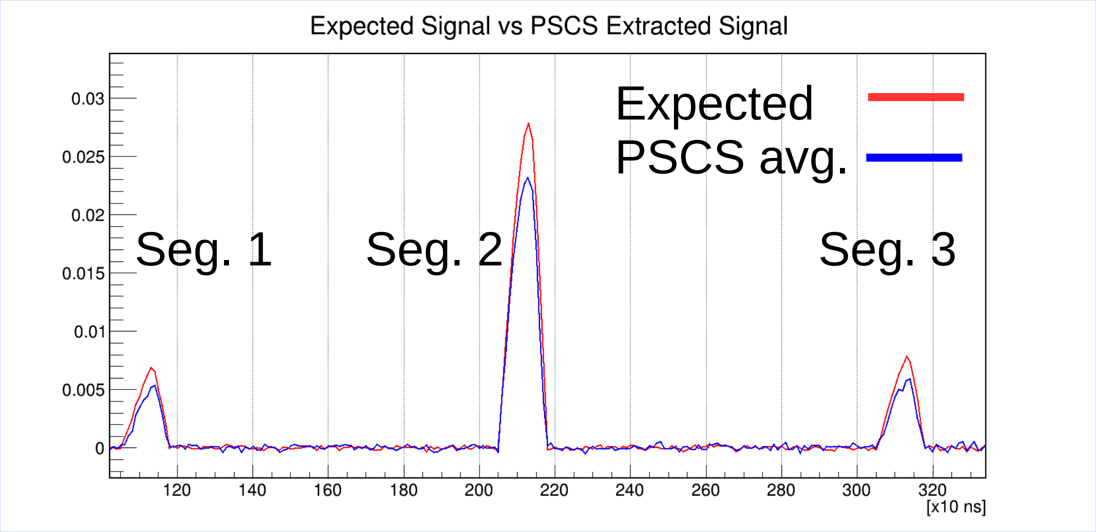
χ^2 Analysis [2]

- Number of **single interaction events** chosen as first parameters of quality
- Considering only the events that are totally absorbed in segment 5
- Various conditions applied for the selection

Crossing point at [25.5, 25.5, 9.95] mm	No Noise	With Noise
All	59%	49%
No Core – No Hit Seg.	50%	37%
Adjacent only	50%	37%

Some results [1]

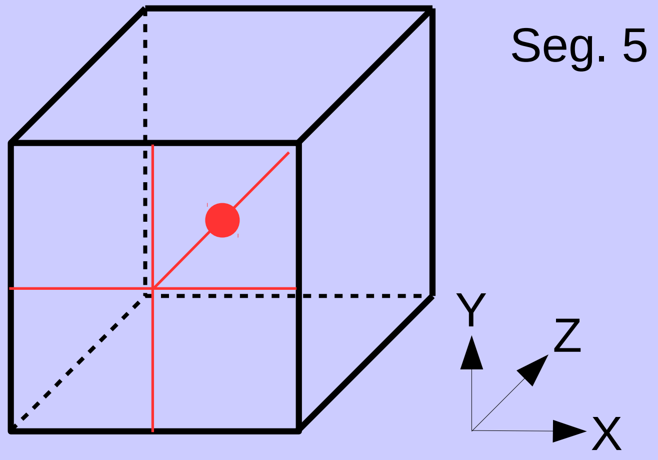




Position distribution of couples of singles is well centered in X and Y

Singles	49%

Crossing point at [25.5, 25.5, **9.95**] mm



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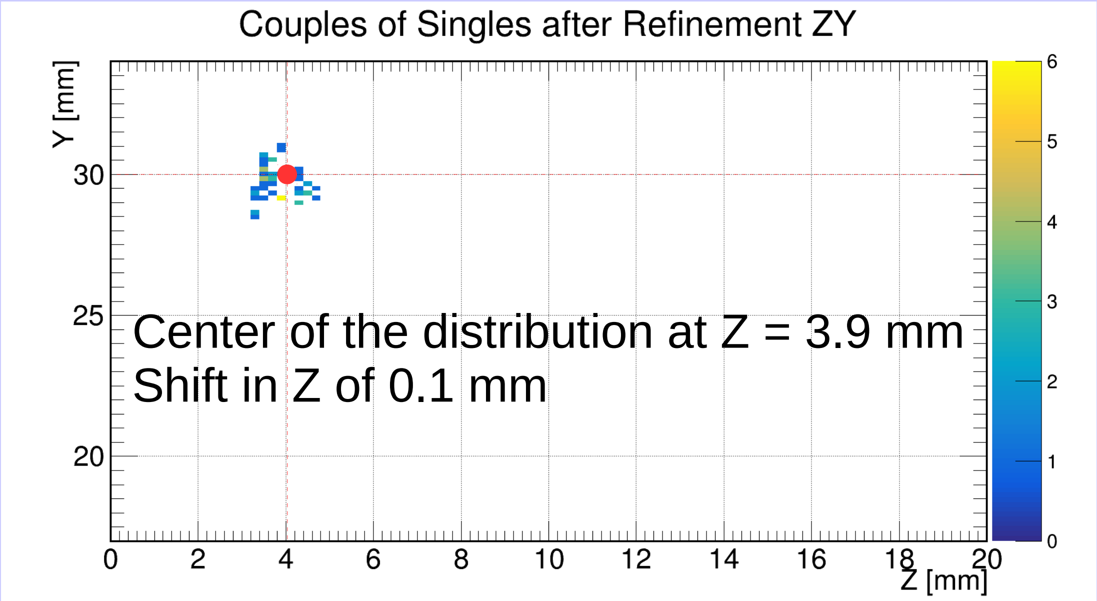
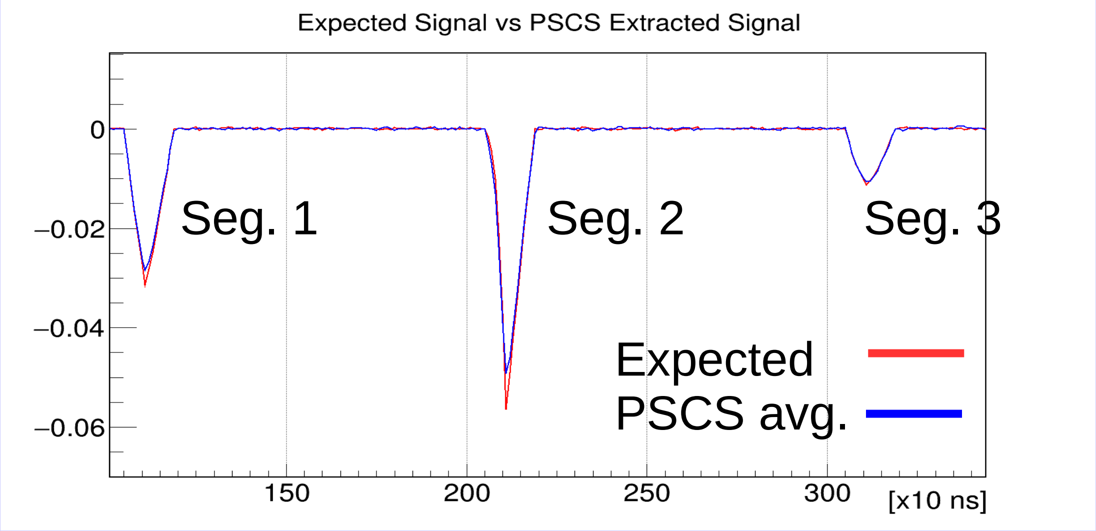
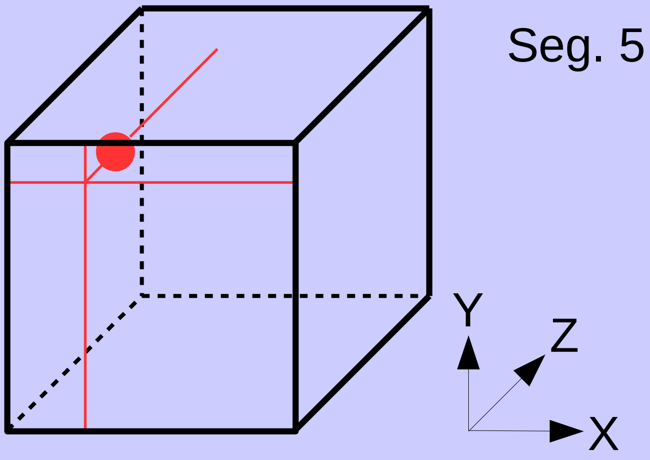




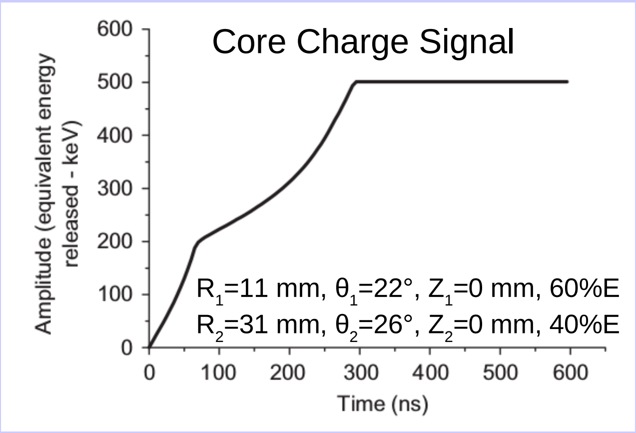
Position distribution of couples of singles is well centered in X and Y

Singles	45%

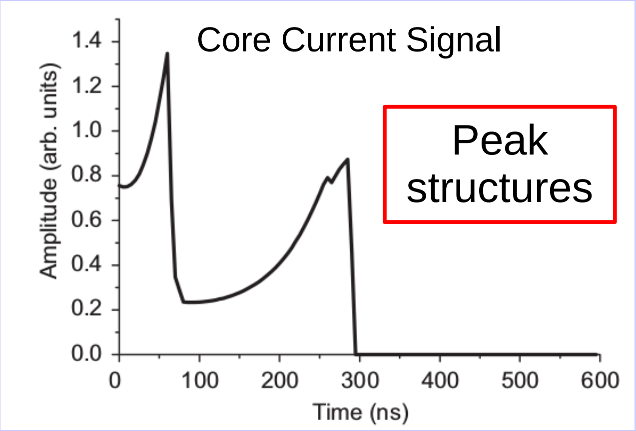
Crossing point at
[21.0, 30.0, **4.0**] mm



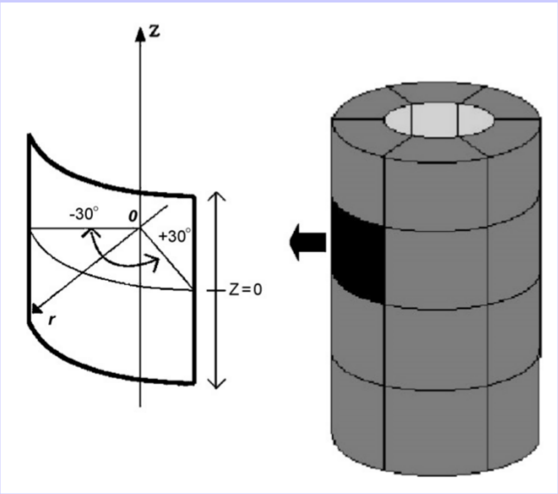
Crespi's second PSCS technique



FIRST ORDER DERIVATIVE

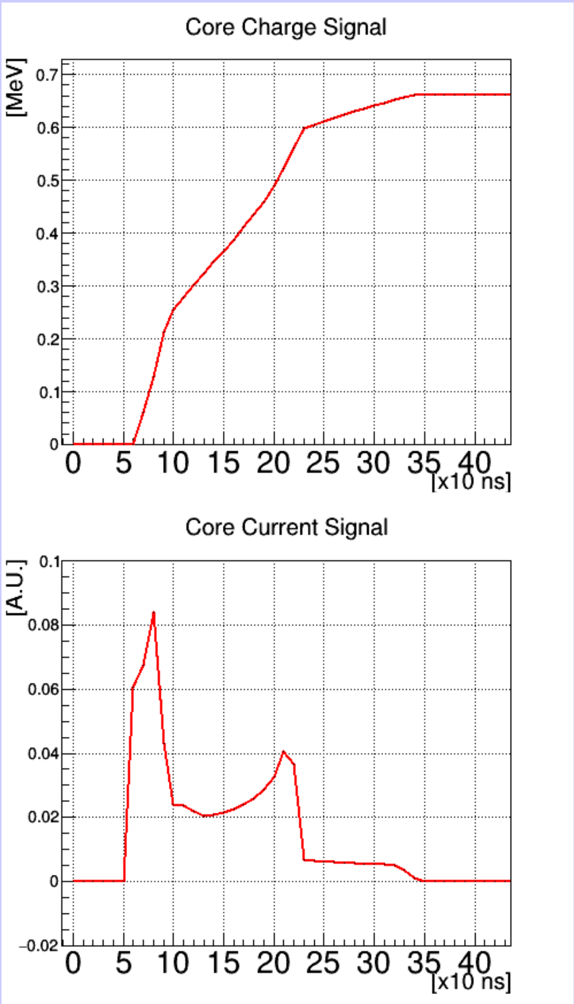


Crespi et. al.'s "A pulse shape analysis algorithm for HPGe detector" [10.106/j.nima.2006.10.003].



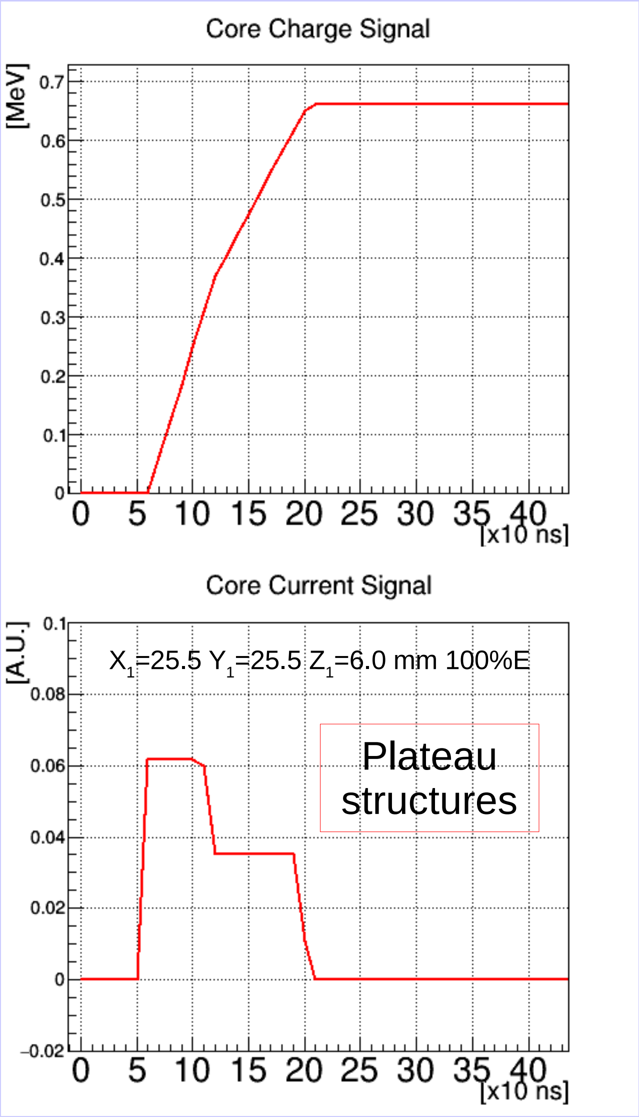
MARS detector (coaxial)

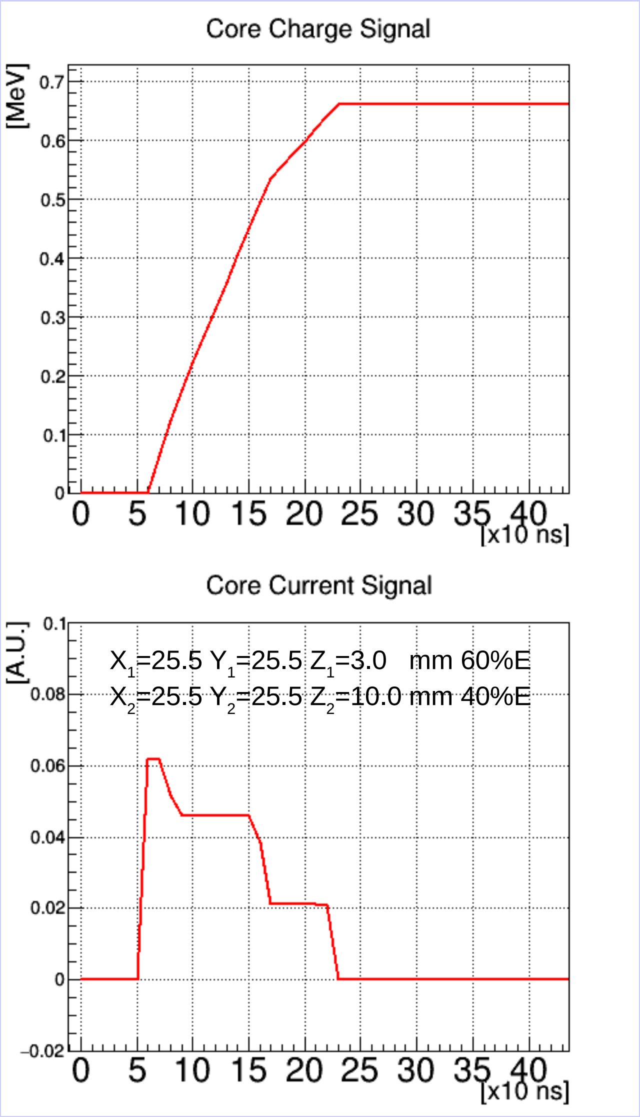
- By deriving the charge signal it is possible to obtain the correspondent current signal.
- The number of peak structures is proportional to the number of interactions of the gamma-ray.
- The positions of the peaks depend on the interaction radii(COAXIAL)/depth(PLANAR).

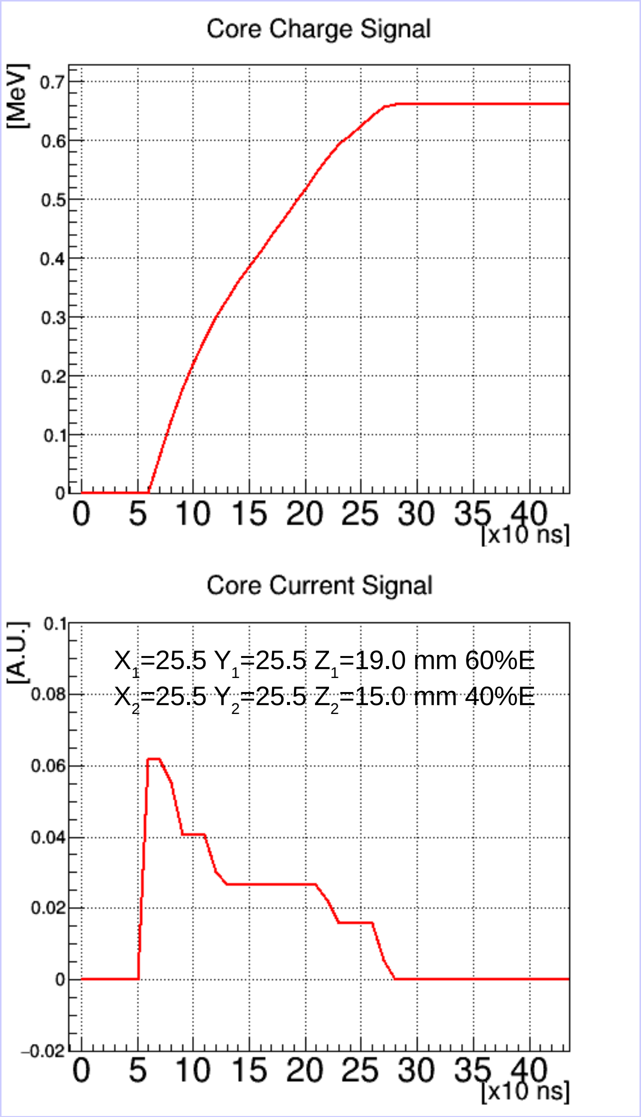


G4 + ADL simulation

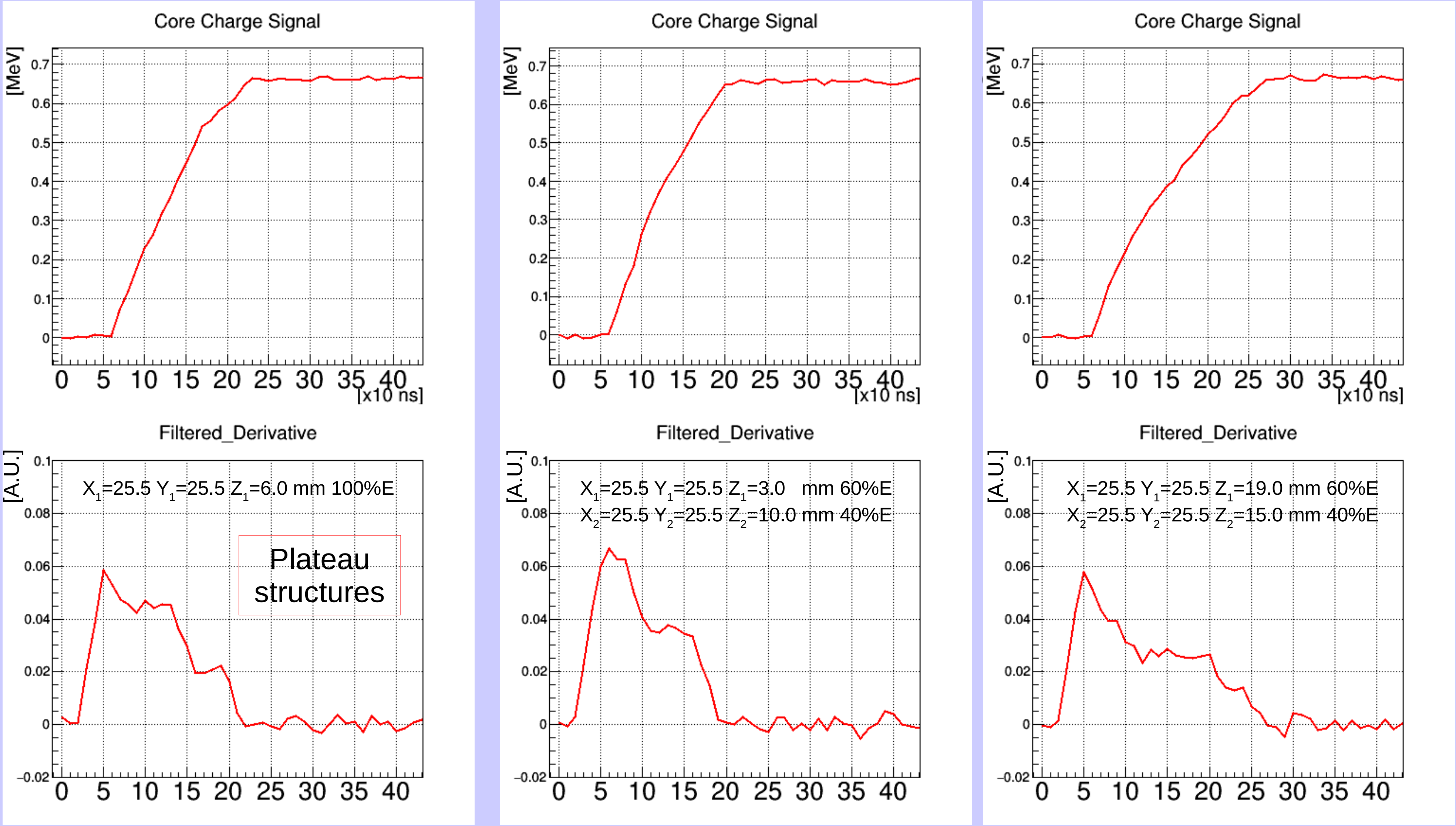
3x3 detector config: No Noise



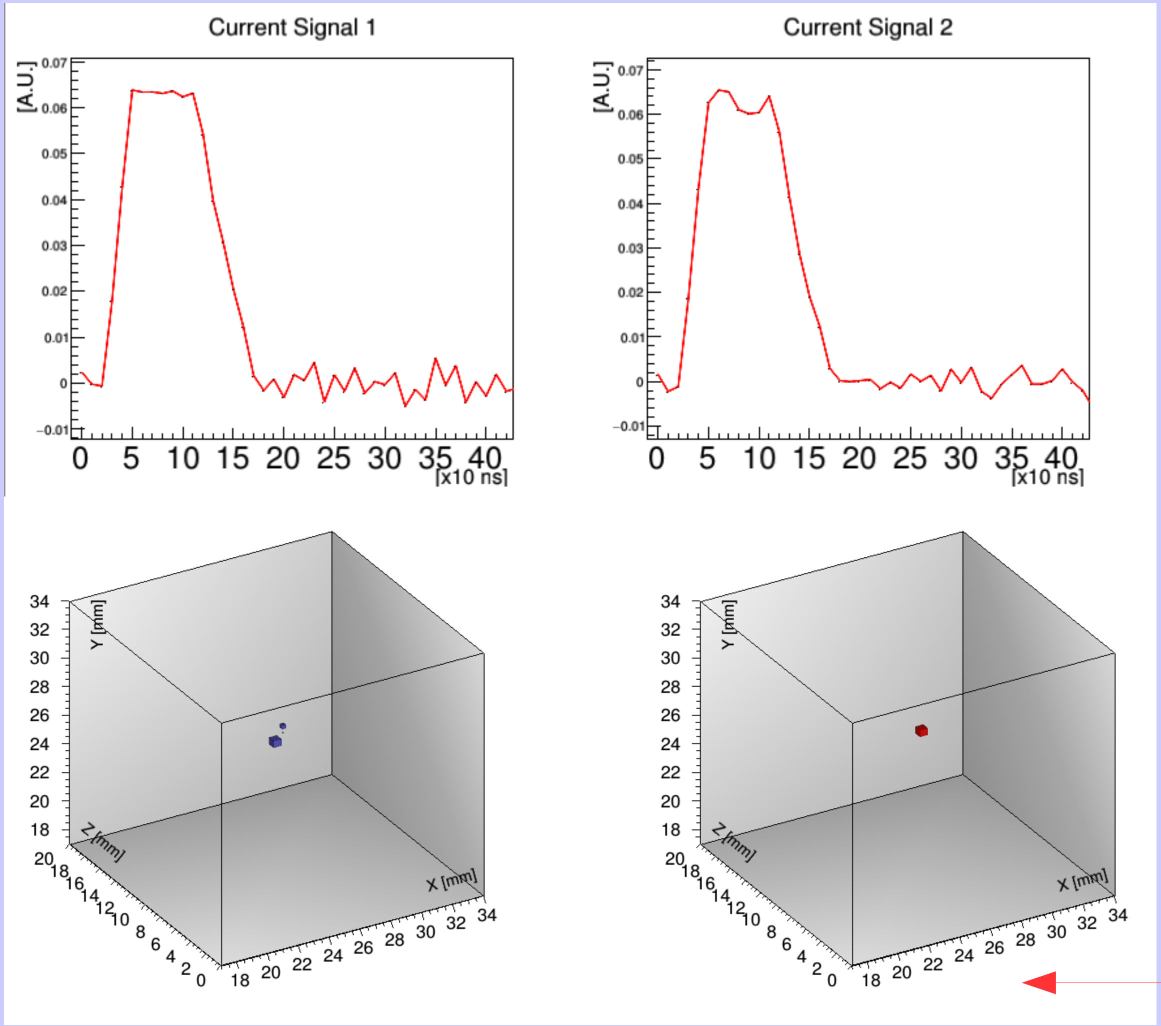




3x3 detector config: Noise



Selected pulses [1]

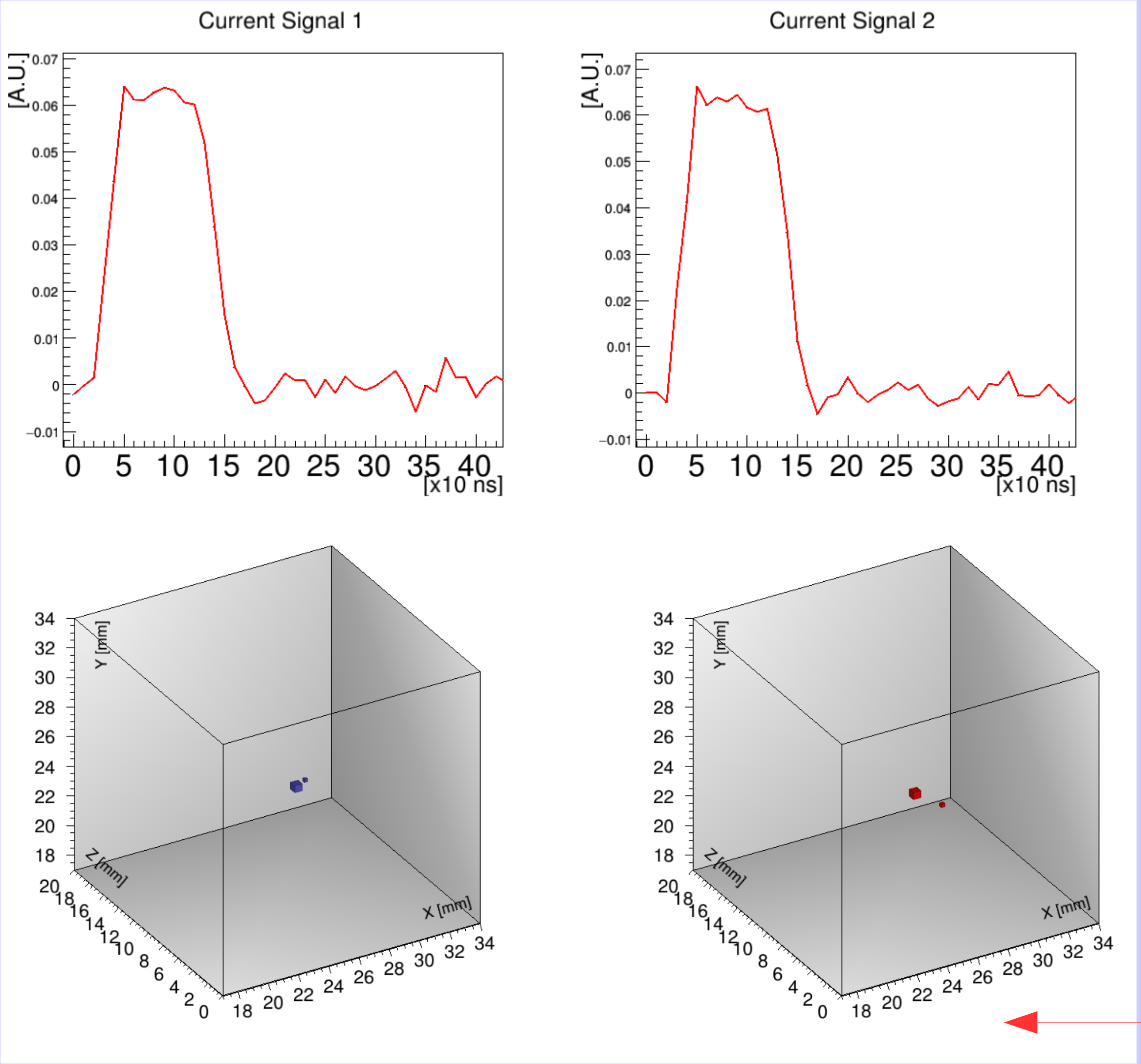


By looking at the selected couples of pulses, no clear difference can be noticed between multiple interaction and single interaction pulses.

Therefore it is not possible to disentangle multiple interaction, for the selected couples, for a 3x3 configuration detector, with the proposed algorithm.

[Cube size is proportional to the energy released at that position by the Gamma-ray]

Selected pulses [2]



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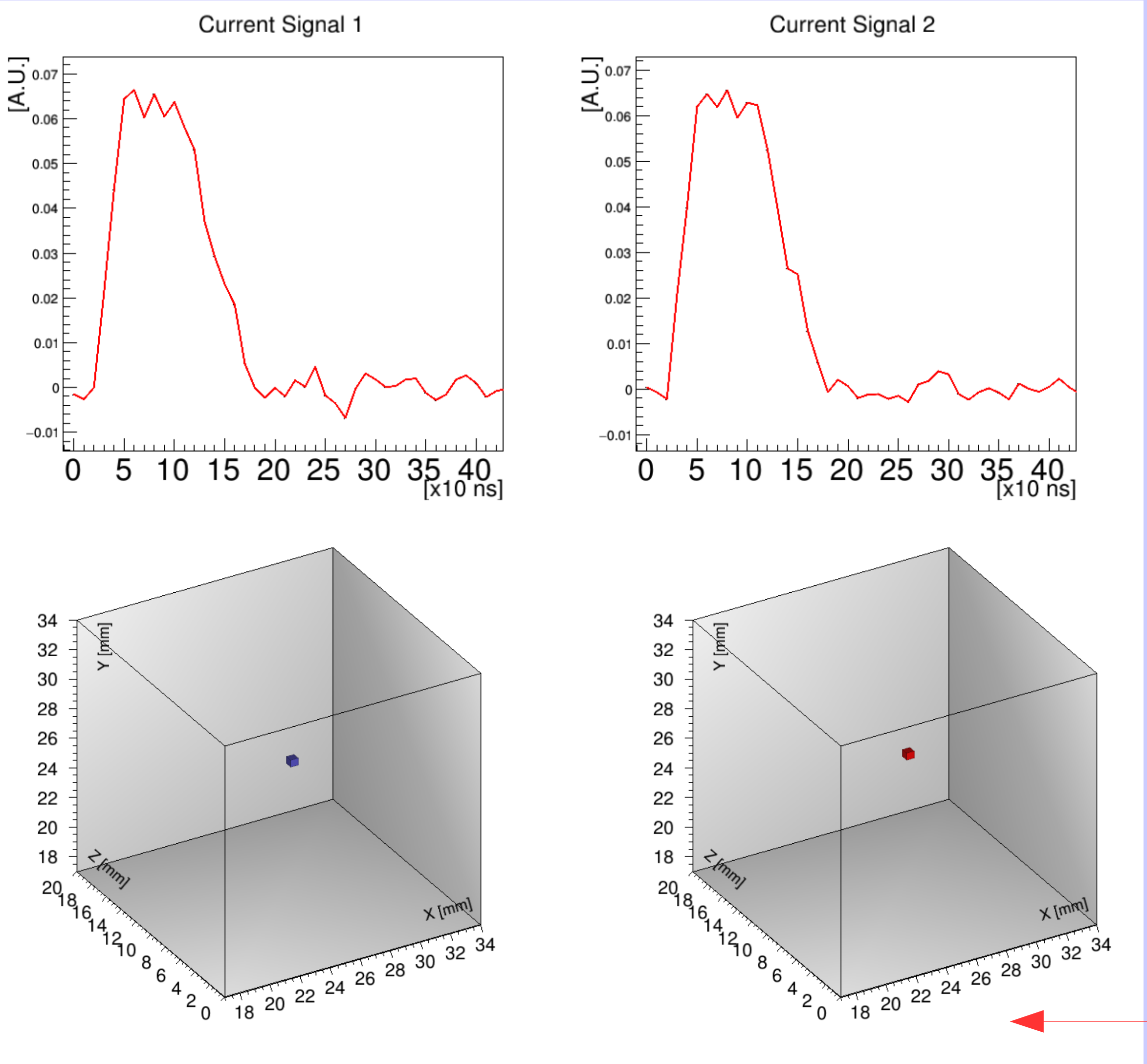
Selected pulses [3]



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Therefore it is not possible to disentangle multiple interaction, for the selected couples, for a 3x3 configuration detector, with the proposed algorithm.

[Cube size is proportional to the energy released at that position by the Gamma-ray]

Conclusions

- Simulations show a reasonable reliability of the system.
- Improvements must be done on the selection algorithm side in order to compensate the position shift due to the lack of sensitivity in certain points of the detectors.
- Impossible to disentangle multiple interaction for a 3x3 configuration detector.

WHAT’S NEXT?

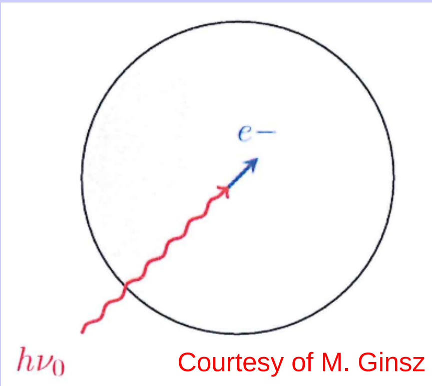
- Implement response function in the simulation.
- Compare the simulation with real data (planar geometry).
- Simulations of an AGATA detector and comparison with real data.

EXTRAS

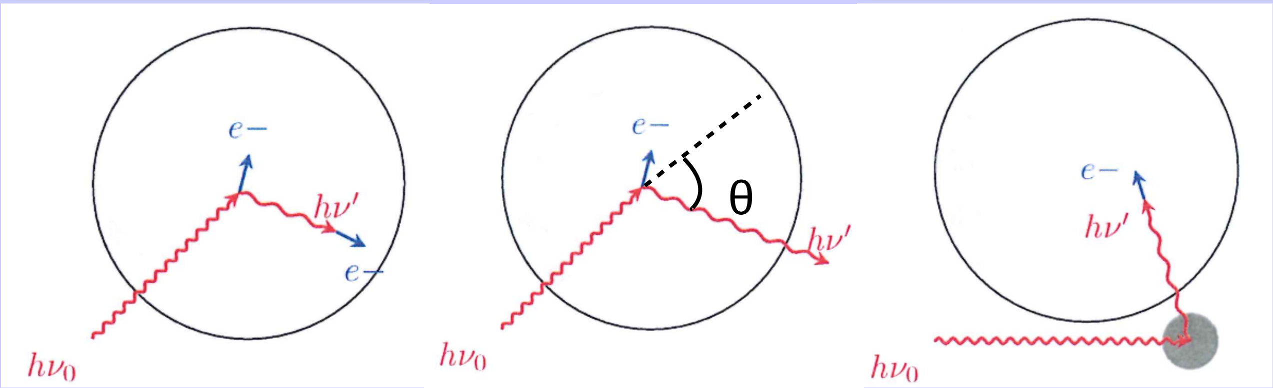
Gamma rays detection

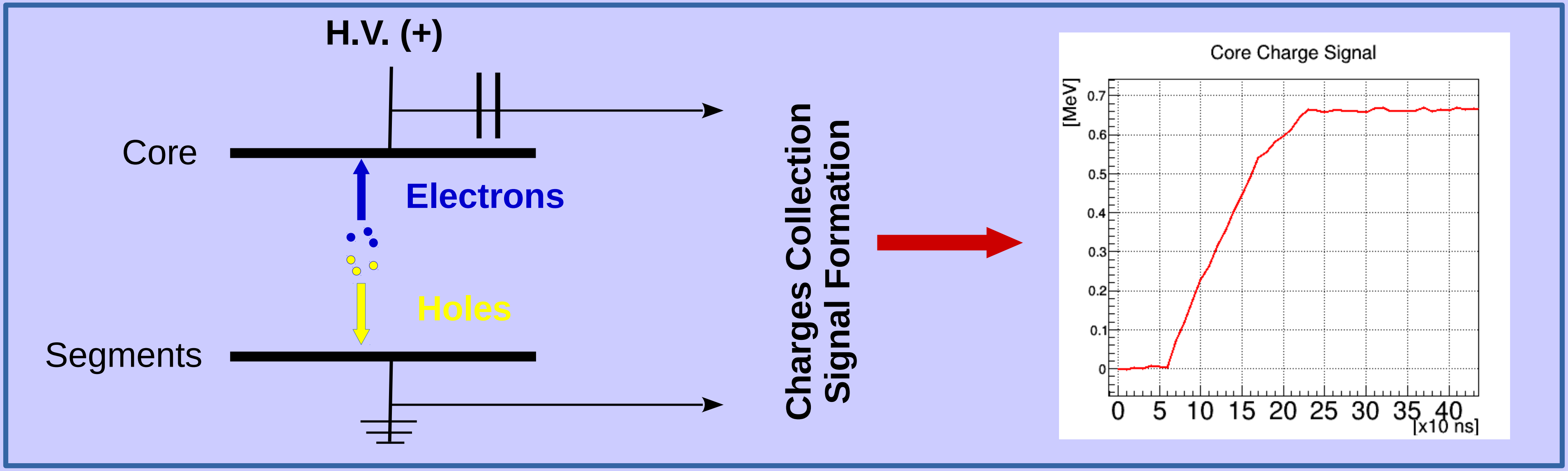
At the energy of interest (for this work), gamma rays can interact with the matter mainly with two different mechanisms:

Photoelectric absorption

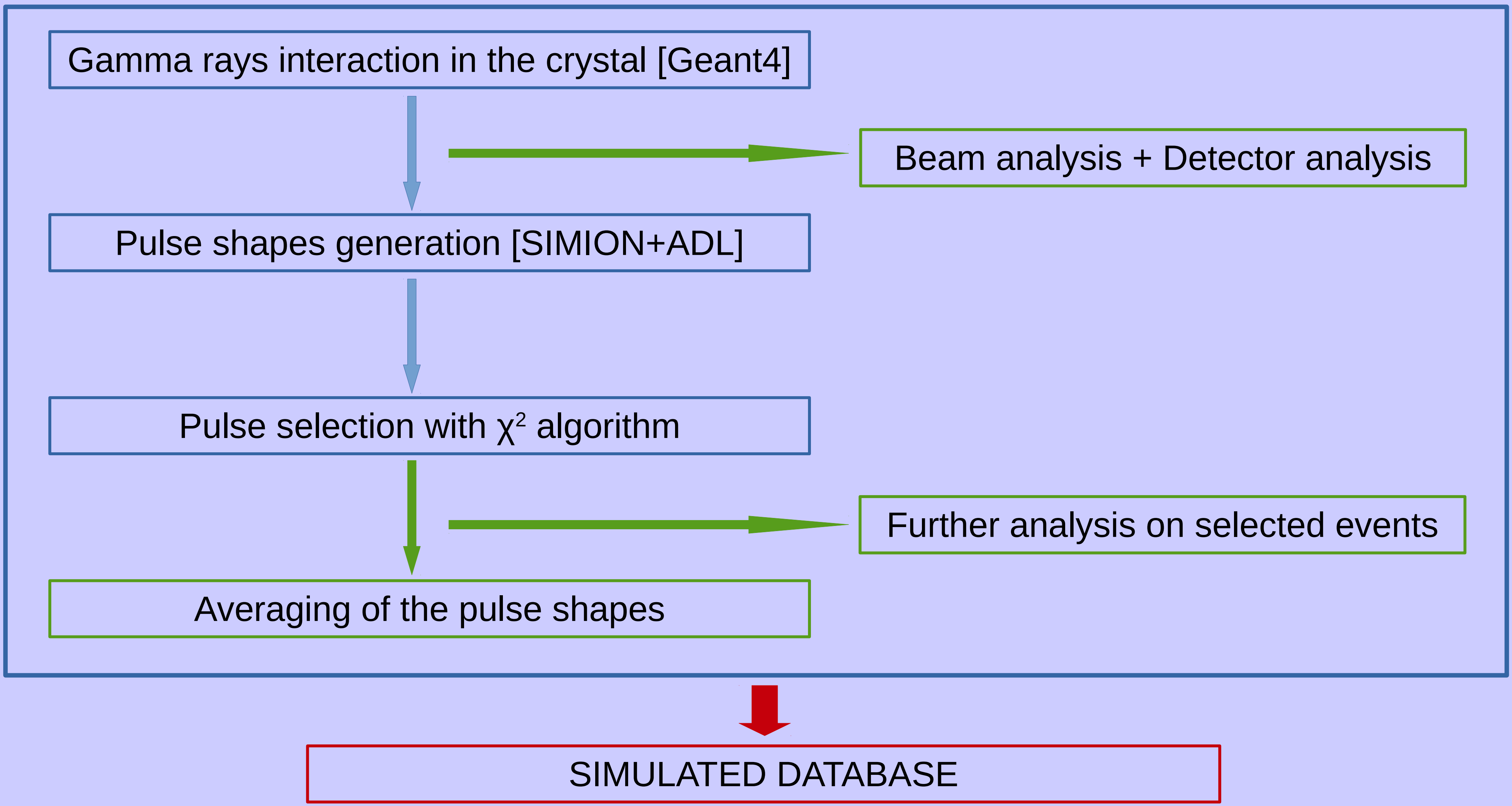


Compton scattering

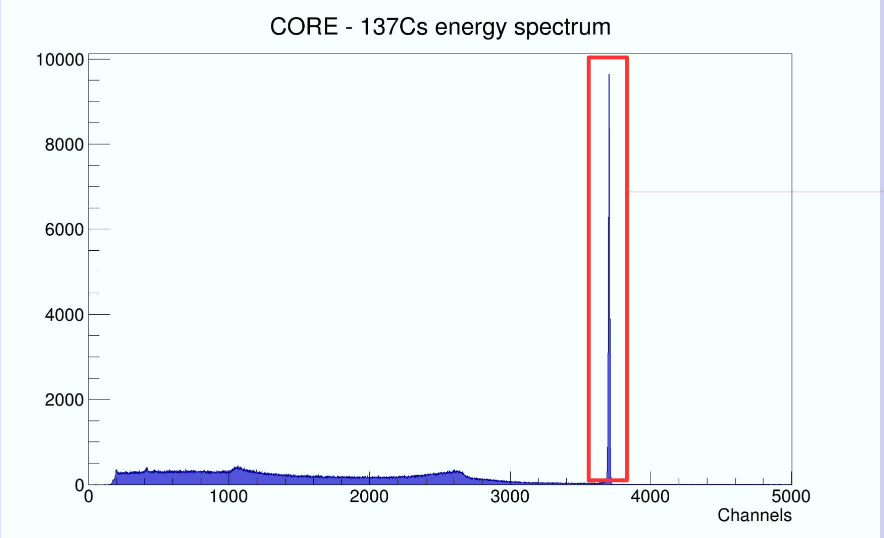


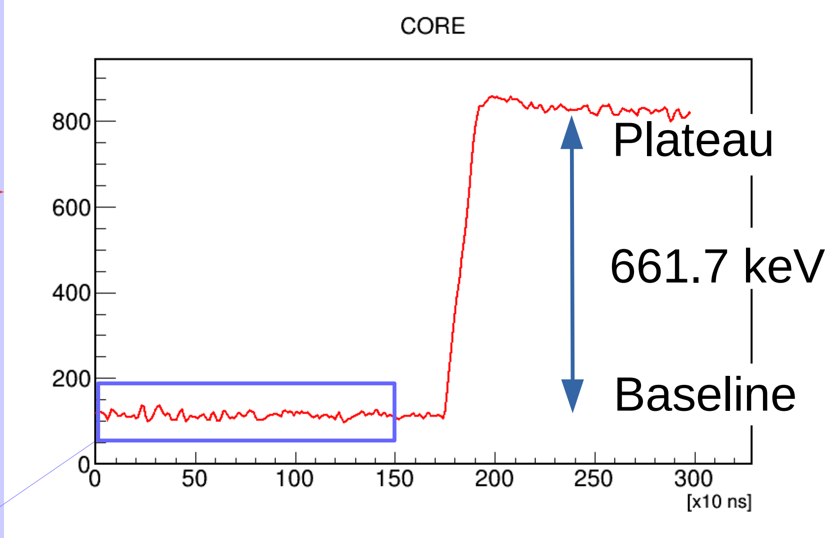


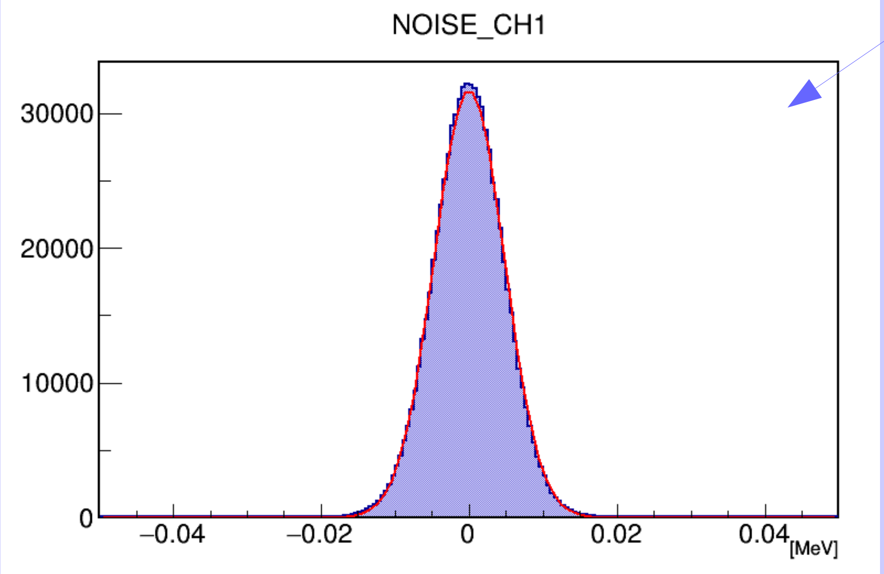
Analysis process recap



Experimental noise extraction







Experimental noise amplitude per channel

σ_{Core}= 4.7 keV

σ_{Seg1}= 1.8 keV σ_{Seg4}= 1.8 keV σ_{Seg7}= 2.2 keV

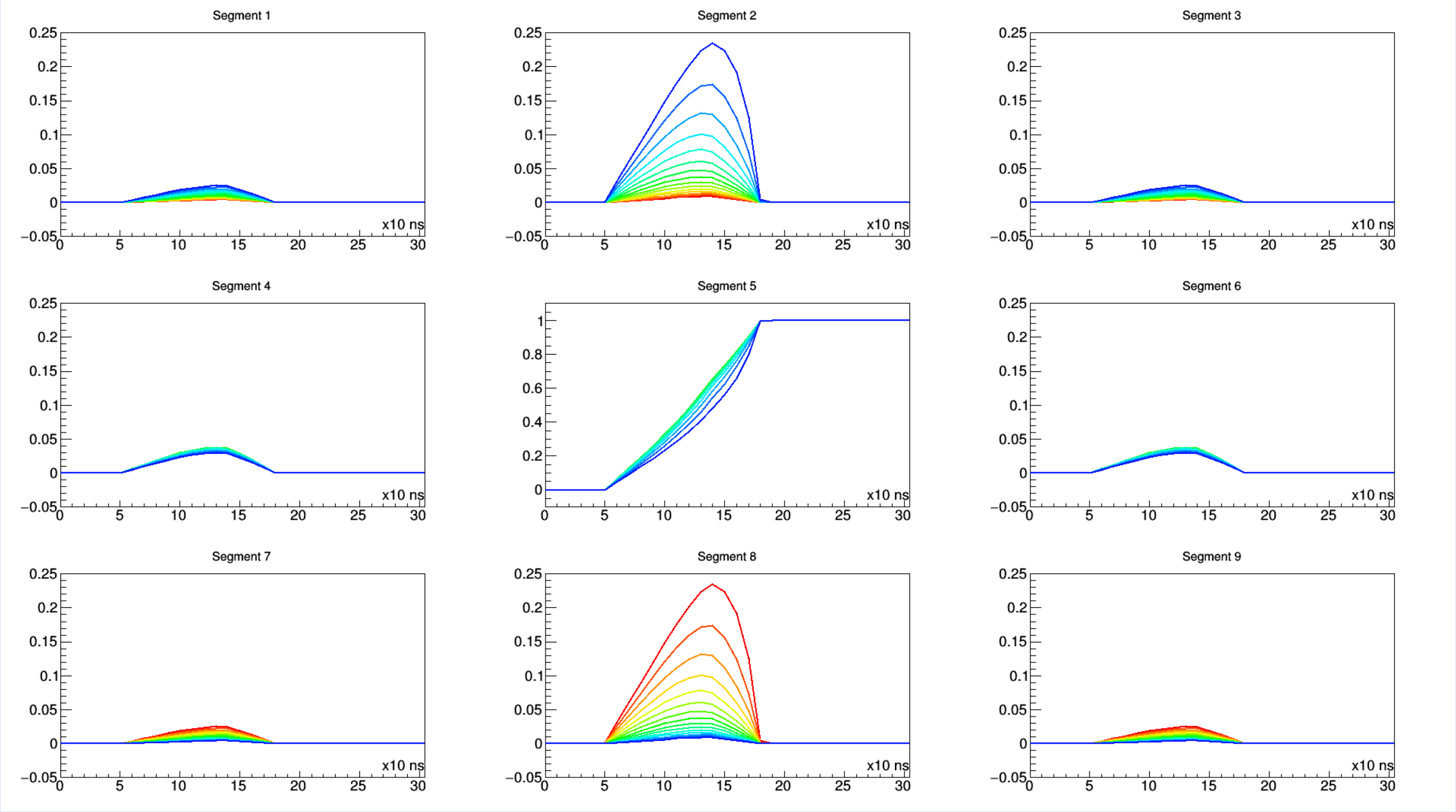
σ_{Seg2}= 1.9 keV σ_{Seg5}= 2.6 keV σ_{Seg8}= 1.8 keV

σ_{Seg3}= 2.2 keV σ_{Seg6}= 2.3 keV σ_{Seg9}= 2.2 keV

Simulated pulses along Y axis (no noise)

17 mm Y 34 mm

[X = 2.5cm Z = 1.2 cm]



Selection algorithm

$$\chi^2 = \frac{1}{N} \cdot \sum_{ch=0}^{9} \sum_{i=0}^{100} \left(\frac{H_{ch} - V_{ch}}{\sigma_{ch}} \right)^2$$

H_{ch} = Horizontal conf. data set
V_{ch} = Vertical conf. data set
N = total number of samples
σ_{ch} = noise amplitude of one channel

The χ^2 selection threshold is adaptive and at the end of the procedure the best 200 tests are selected (i.e.: 400 signals).