Simulation of PSCS techniques on a planar segmented HPGe gamma-rays detector

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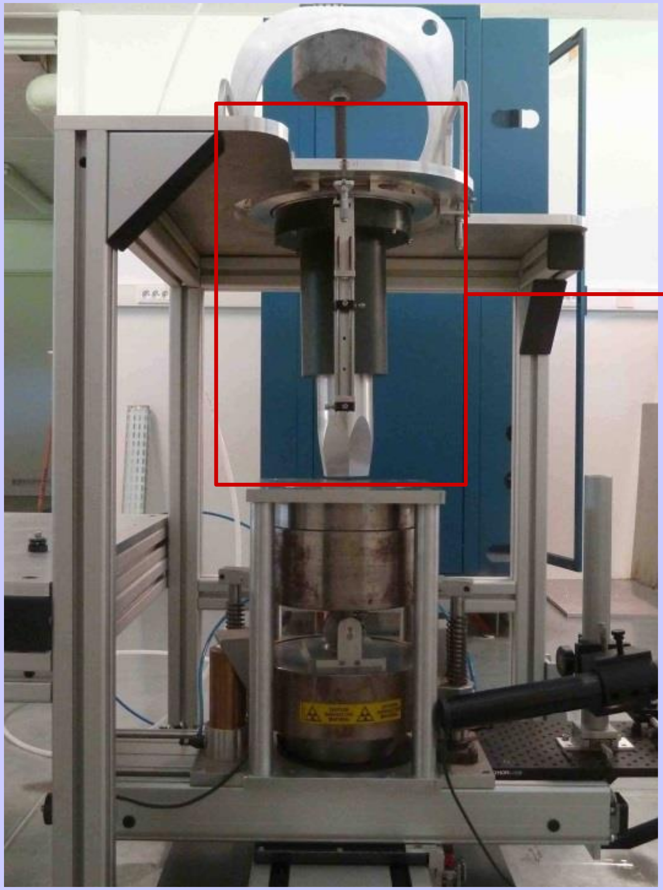
Aim and summary

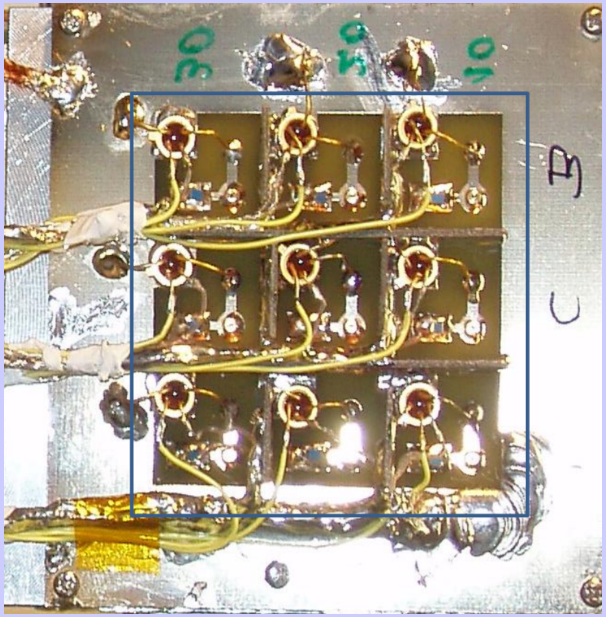
This study aims to quantify the accuracy of the scanning system used at the IPHC in Strasbourg

- Geometry of GEANT4 simulated system
- Pulse-shape generation with ADL + SIMION
- Pulse Shape Comparison Scanning (PSCS) technique results

The system

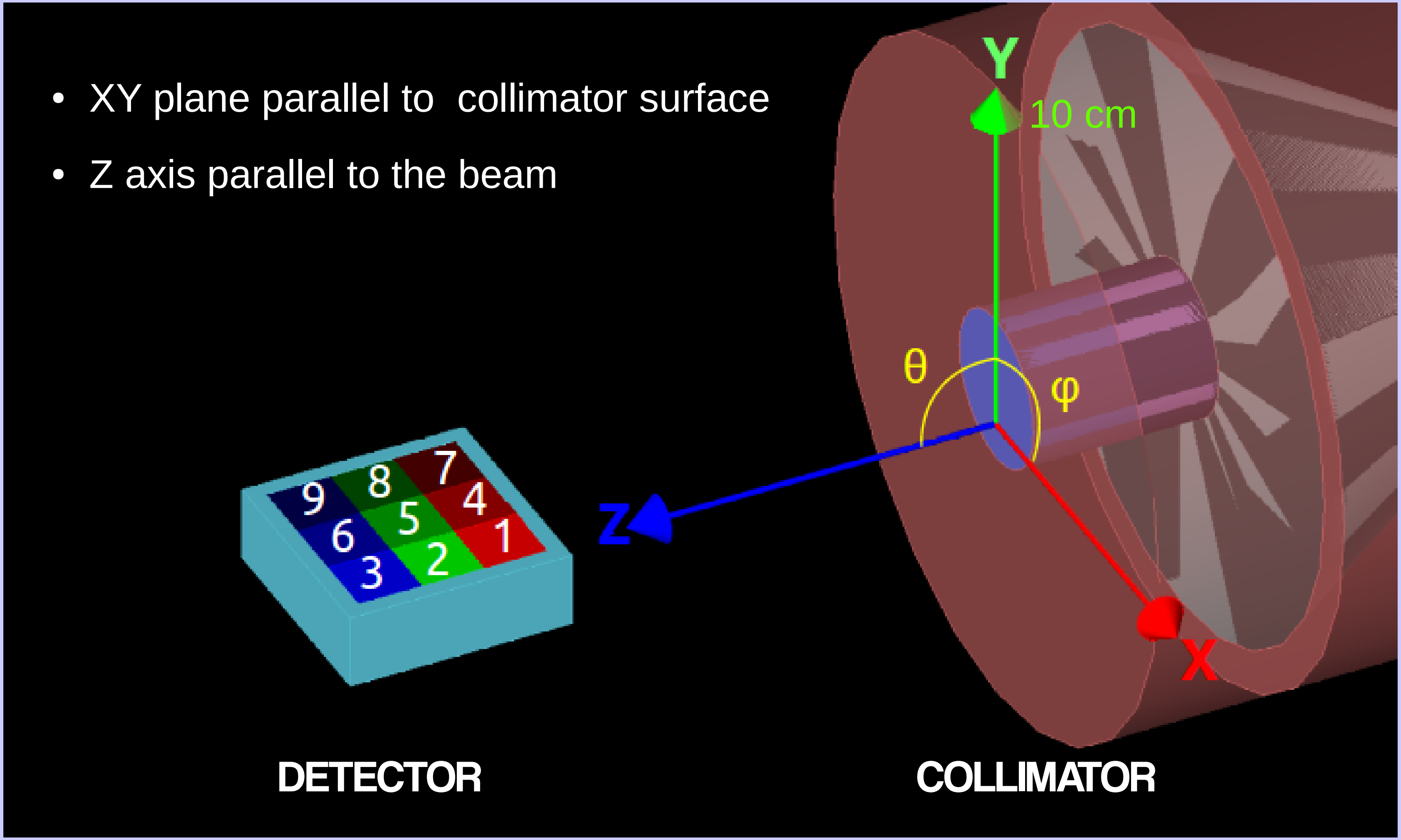
- Scanning table: the system allow horizontal and vertical scanning with a gamma-ray beam. With the PSCS it’s possible to reconstruct a database of pulse shapes at each grid point of the scan.





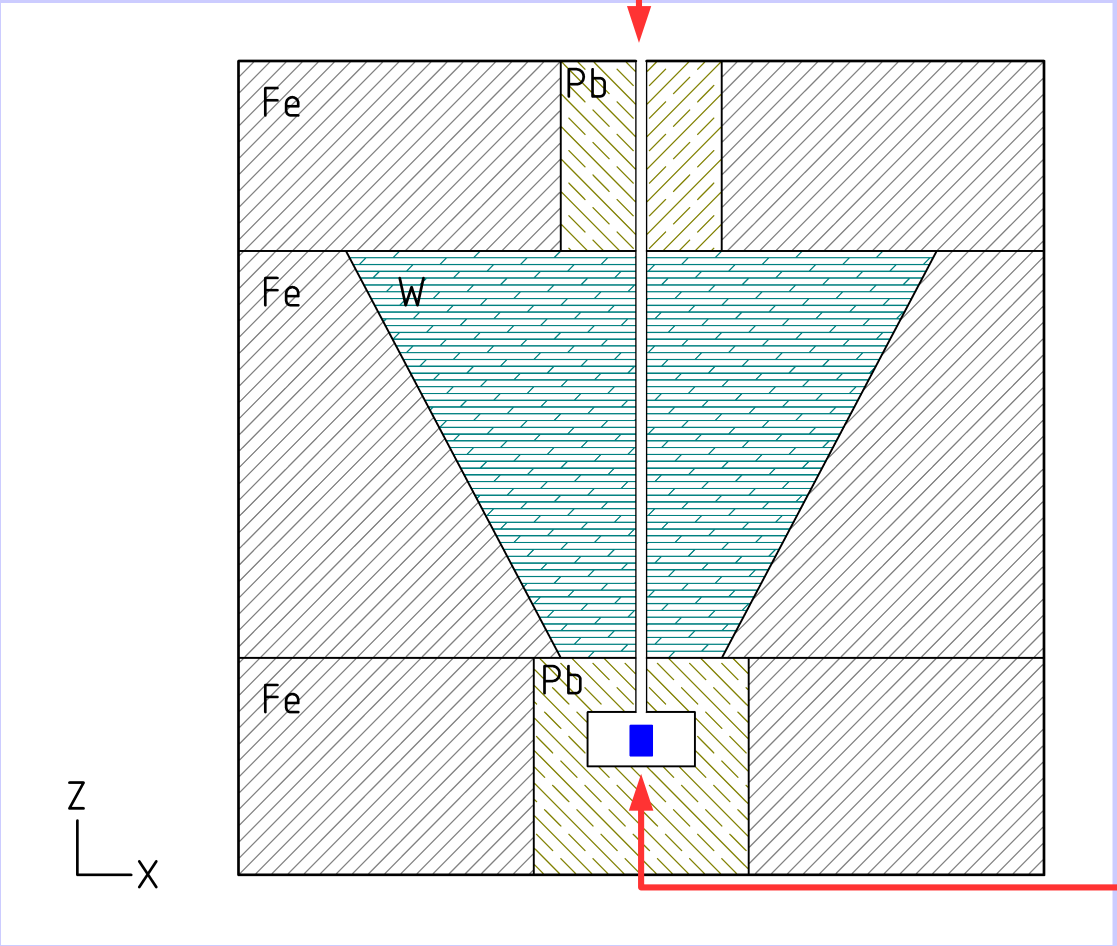
- Detector: HPGe planar gamma ray detector with 3x3 segmentation.

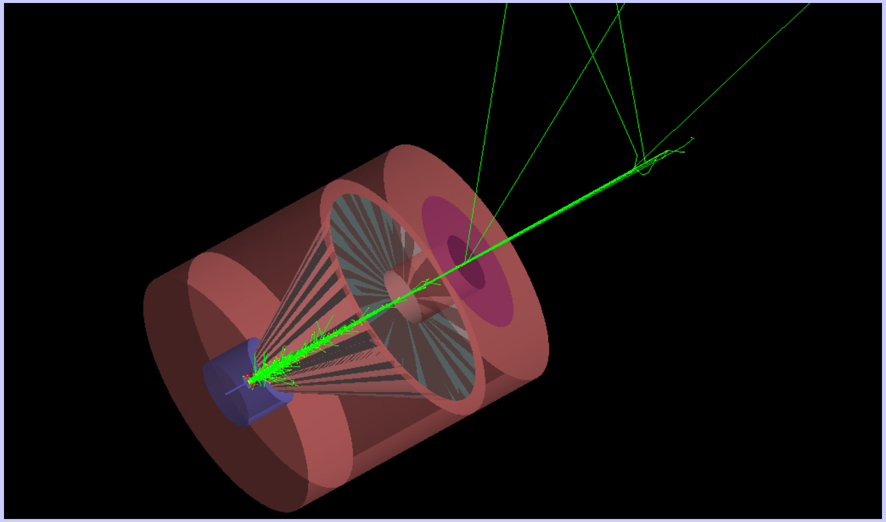
Simulation frame



Collimator model geometry

Diaphragm diameter 1.6 mm



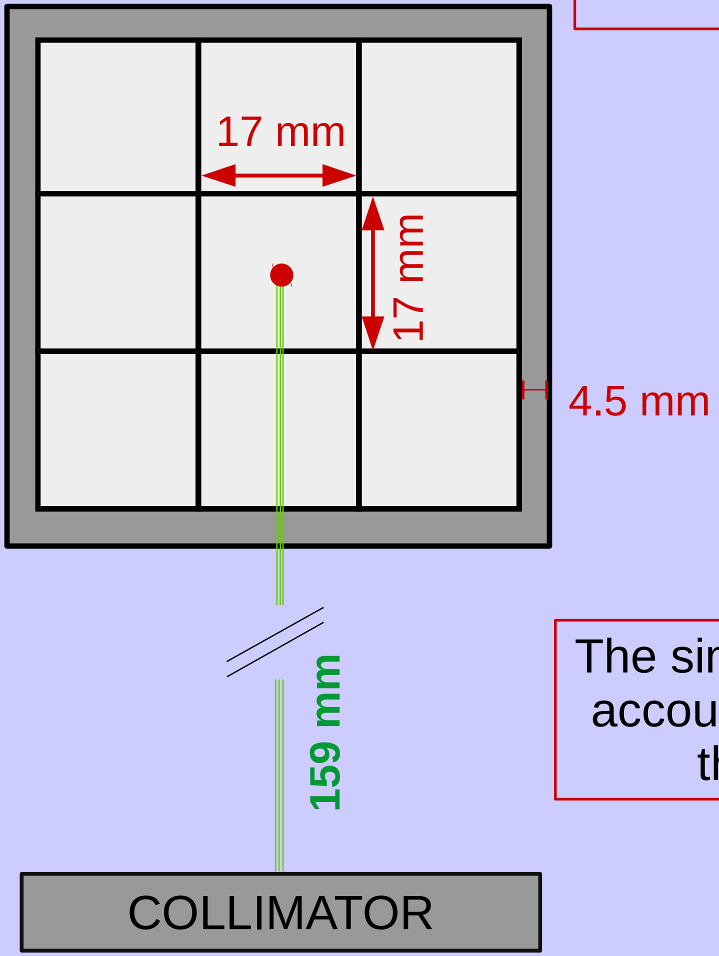


^{241}Am ^{137}Cs sources used

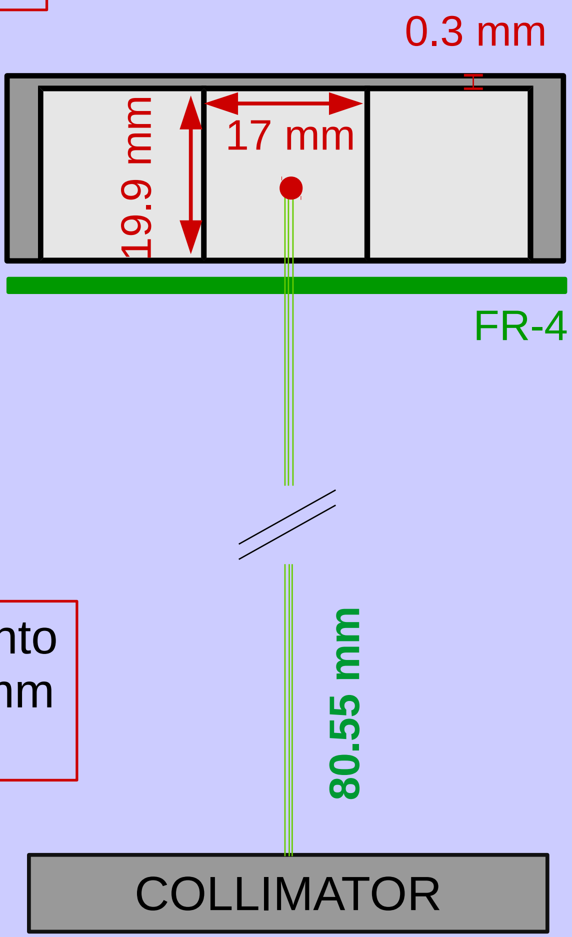
Detector model geometry

- Red dot: center of "Segment 5"

VERTICAL

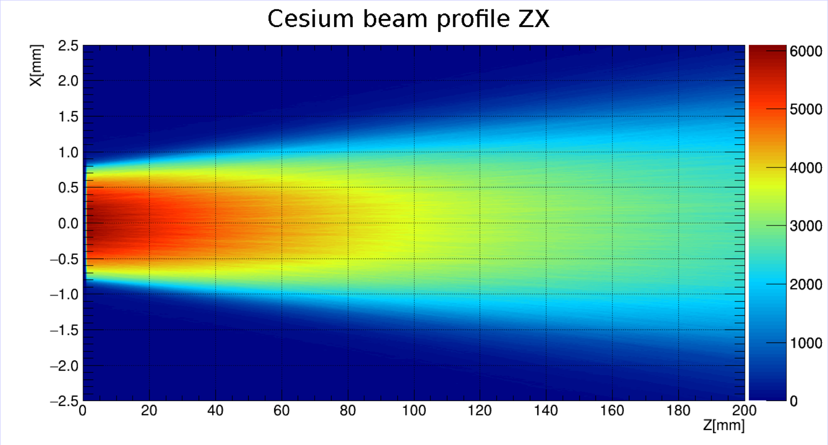


HORIZONTAL

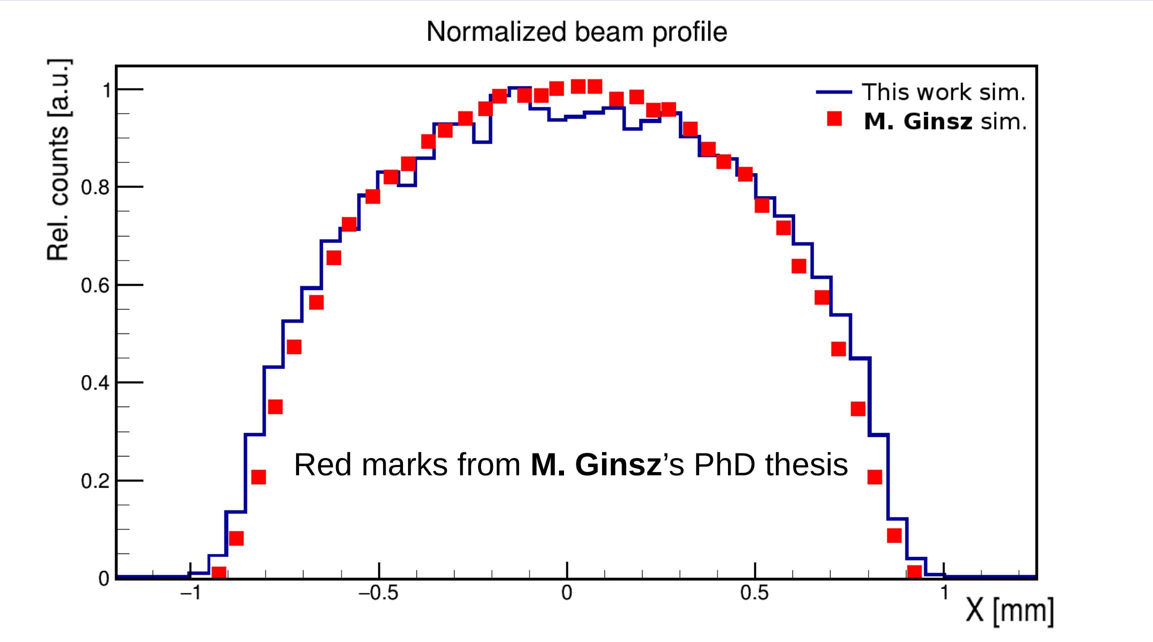


The simulation takes into account also the ~1 mm thick end-cap

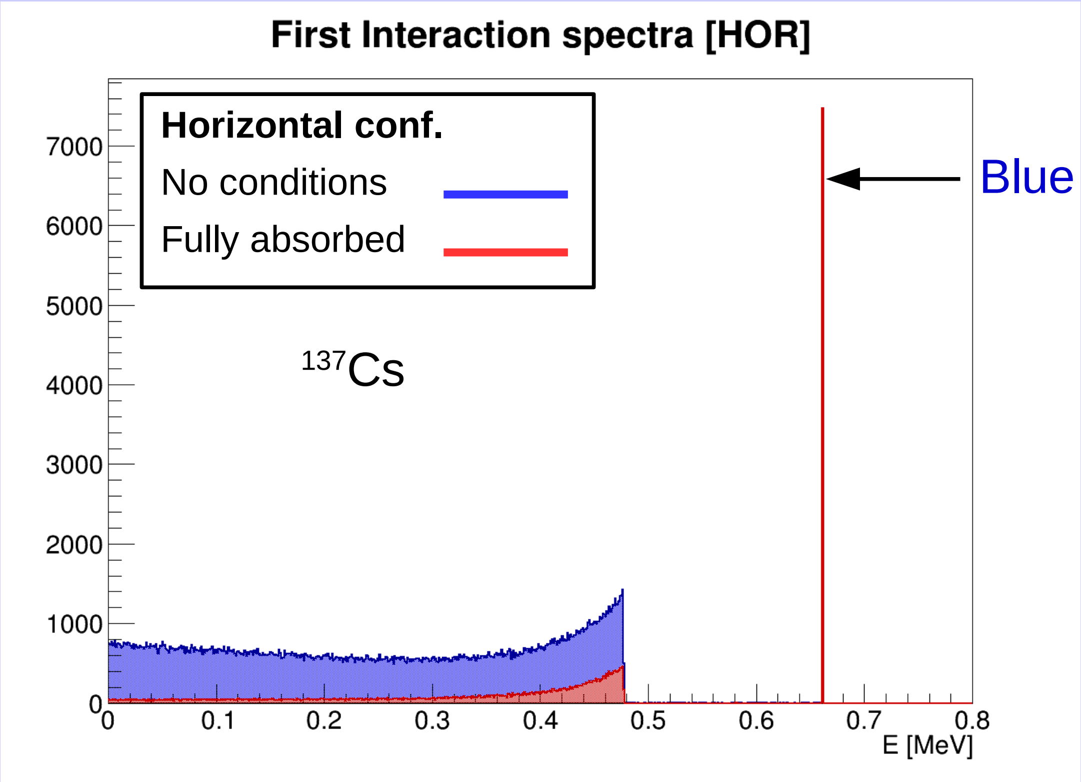
Beam Analysis



- Beam profile is reconstructed knowing the positions and the momentum of the exiting gamma-rays.
- The beam profile is comparable with the one obtained by M. Ginsz in a previous simulation.
- Beam spot has ~2mm diameter inside the detector.



Detector analysis



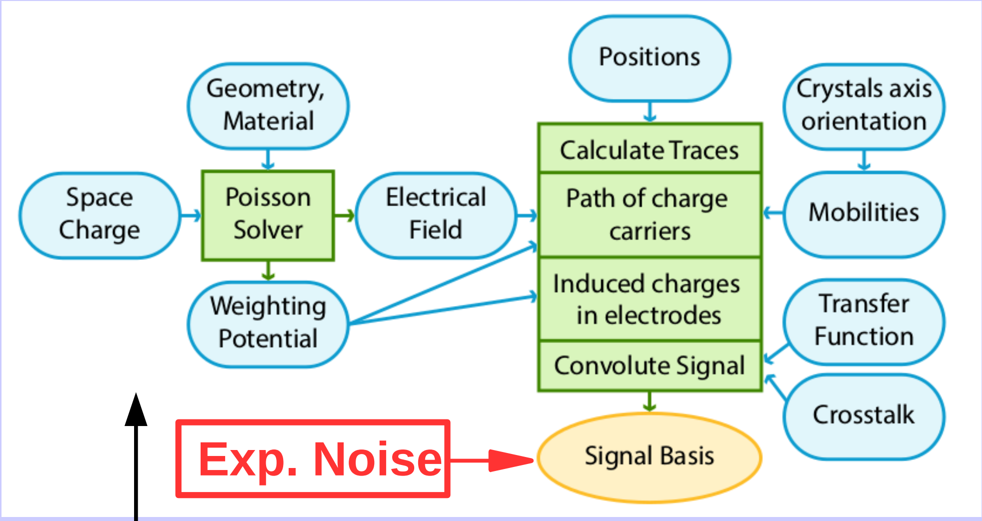
Blue and Red peaks overlap

- By analyzing the spectra of first interaction of gamma-rays that enter segment 5 [blue] it can be seen that part of the gamma rays undergo a single-interaction photoelectric absorption. This percentage increases if only events that are fully absorbed in the shot segment are considered [red].

	$\gamma_{emitted}$	$\gamma_{detected}$	$\gamma_{full\,abs}$	γ_{signle}	$\frac{\gamma_{single}}{\gamma_{detected}}$	$\frac{\gamma_{signle}}{\gamma_{full\,abs}}$
Hor	685467	327179	48285	7478	2.28±0.03%	15.4±0.2%
Ver	1153784	293848	32605	4964	1.68±0.02%	15.2±0.2%

ADL simulation

- 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.

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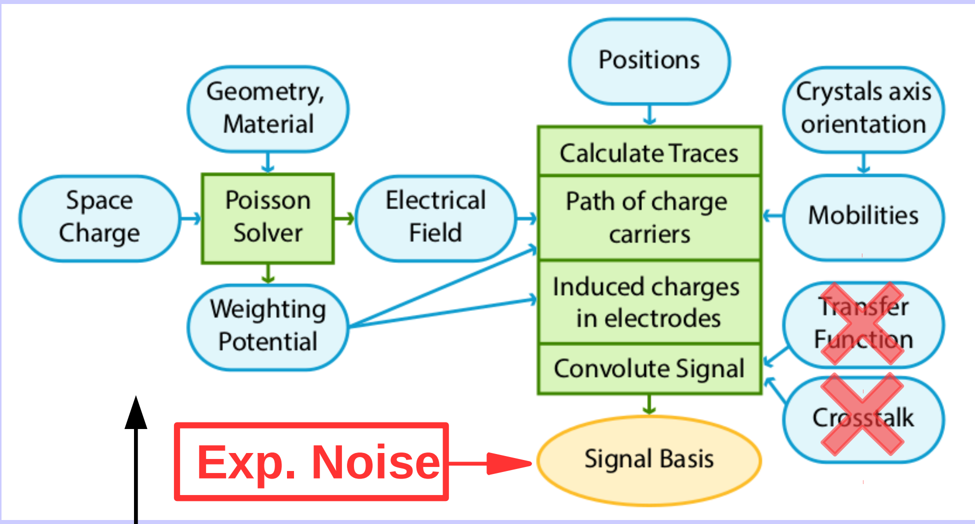

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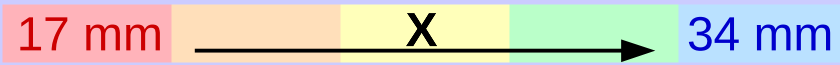
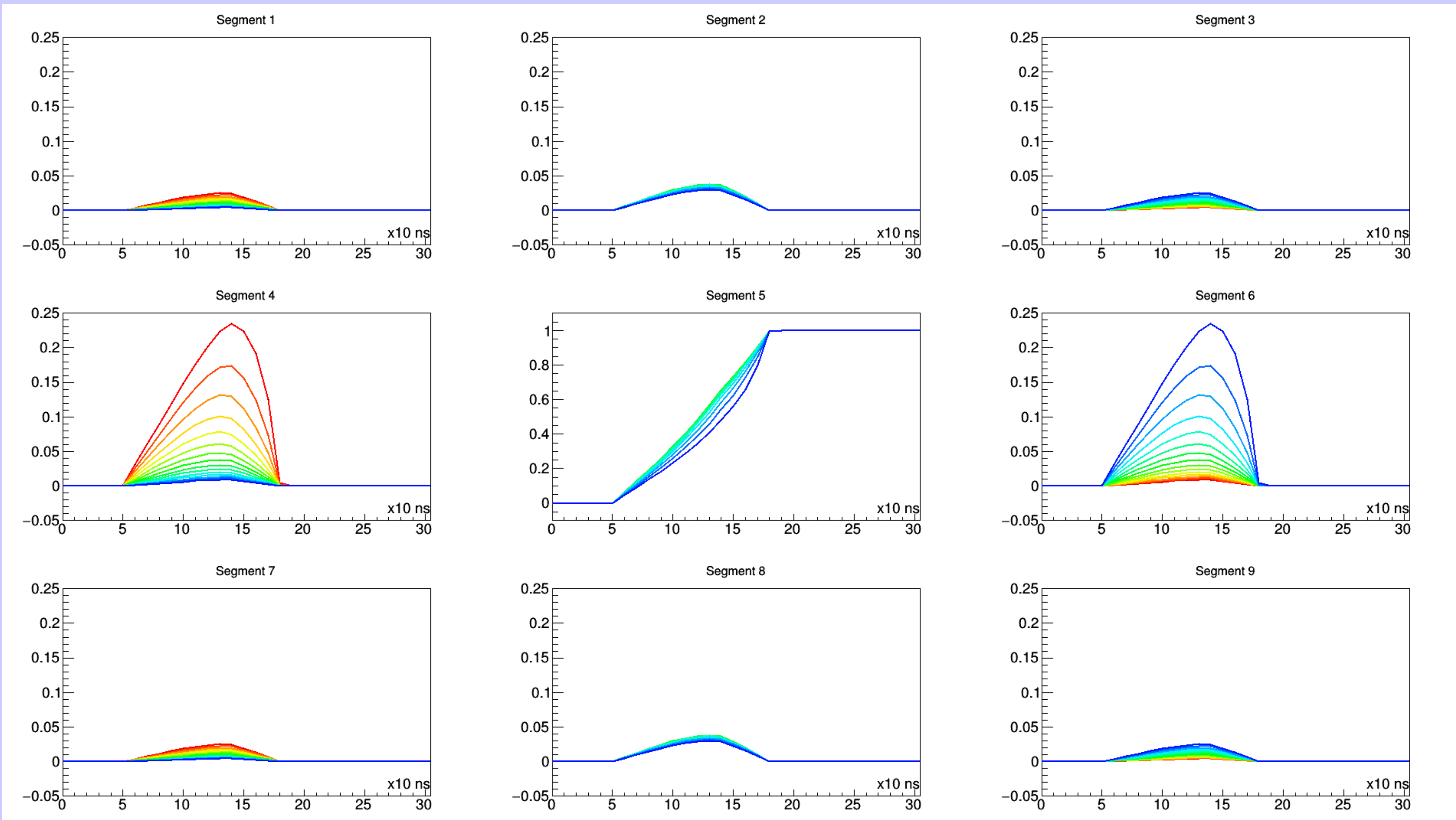
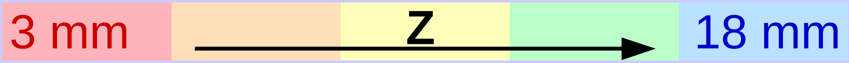
Simulated pulses along X axis (no noise)



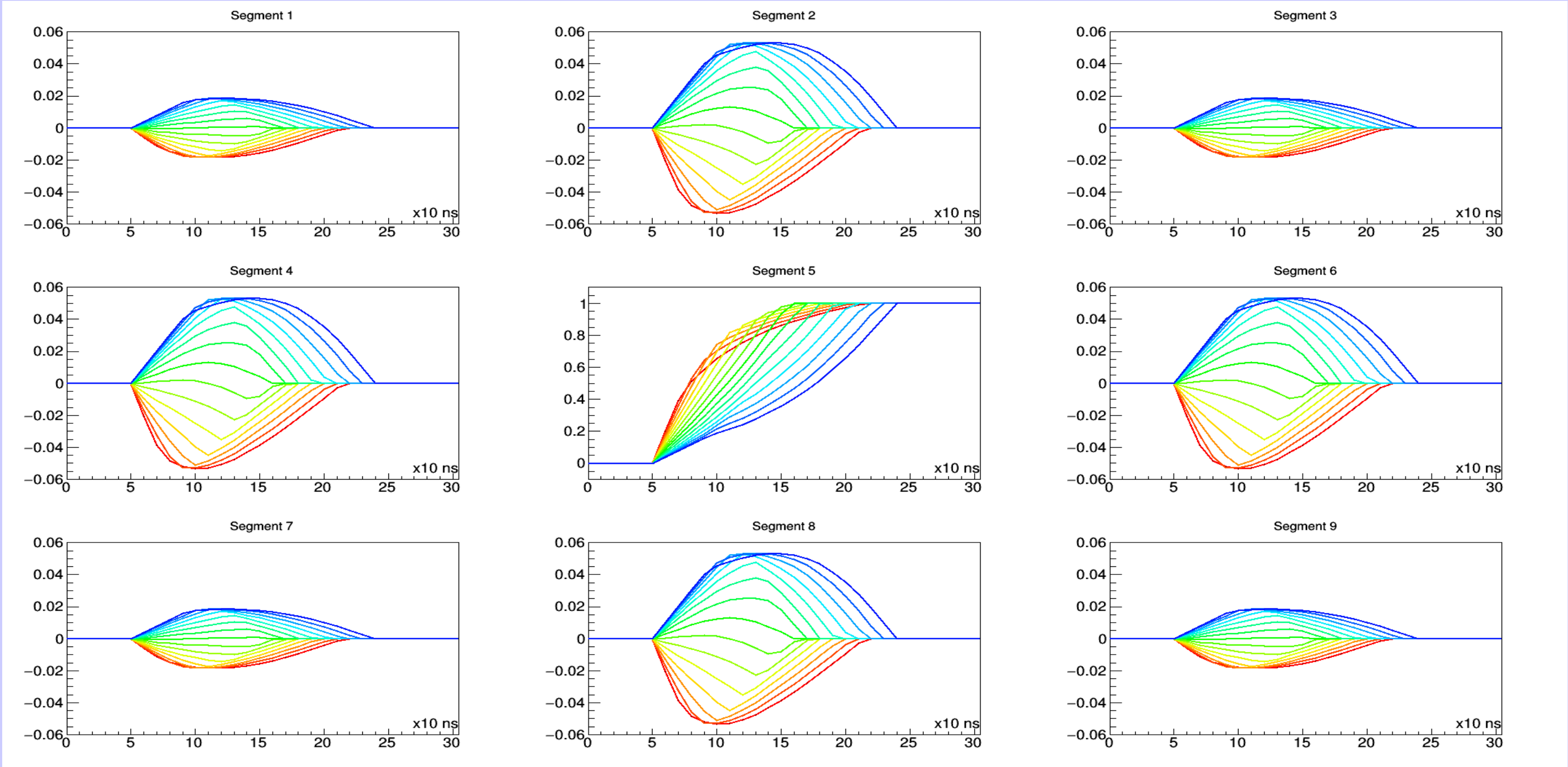
[Y = 25 mm   Z = 12 mm]



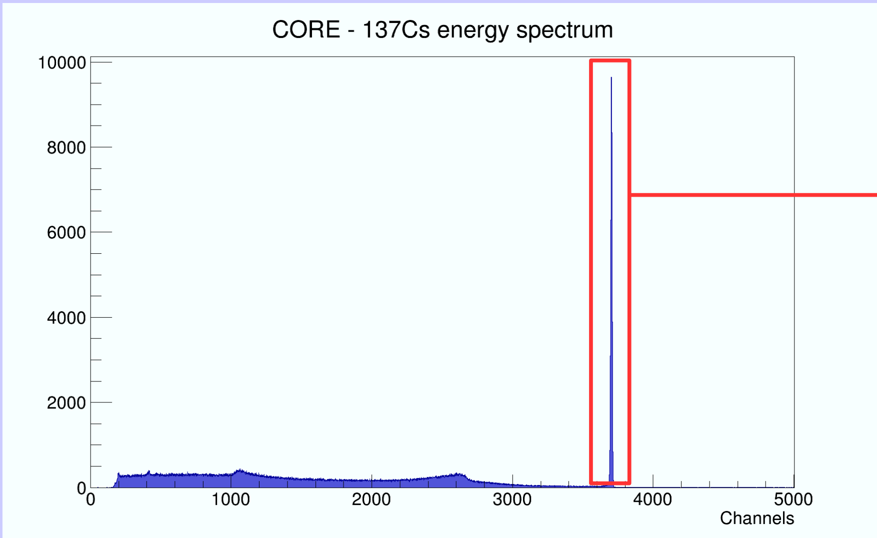
Simulated pulses along Z axis (no noise)

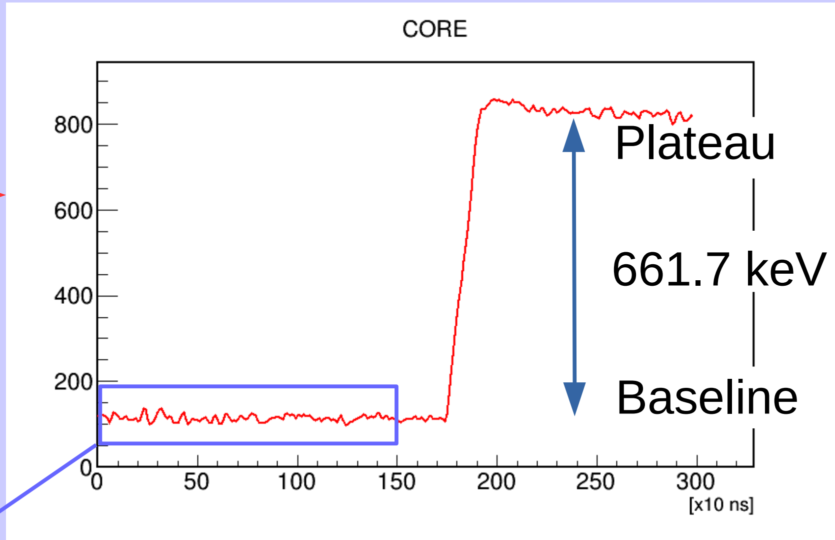


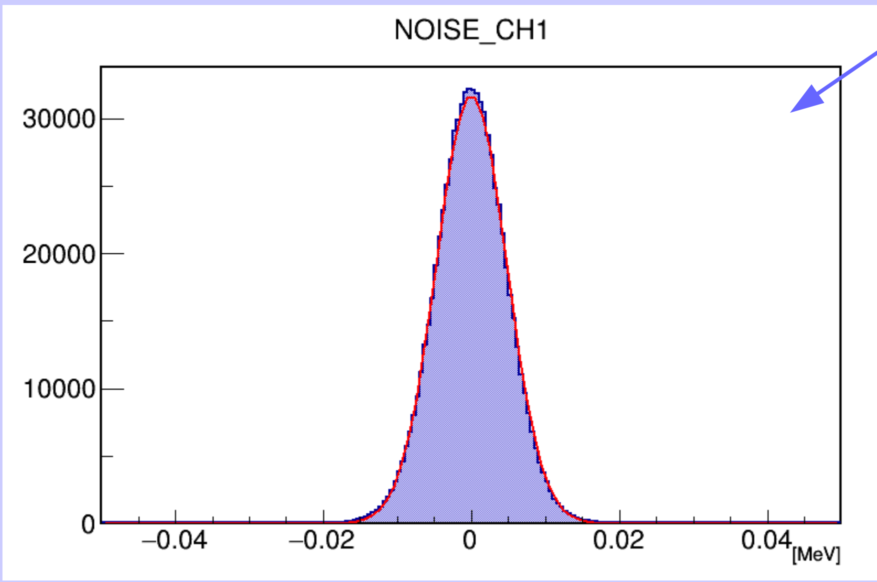
[X = 25 mm   Y = 25 mm]



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

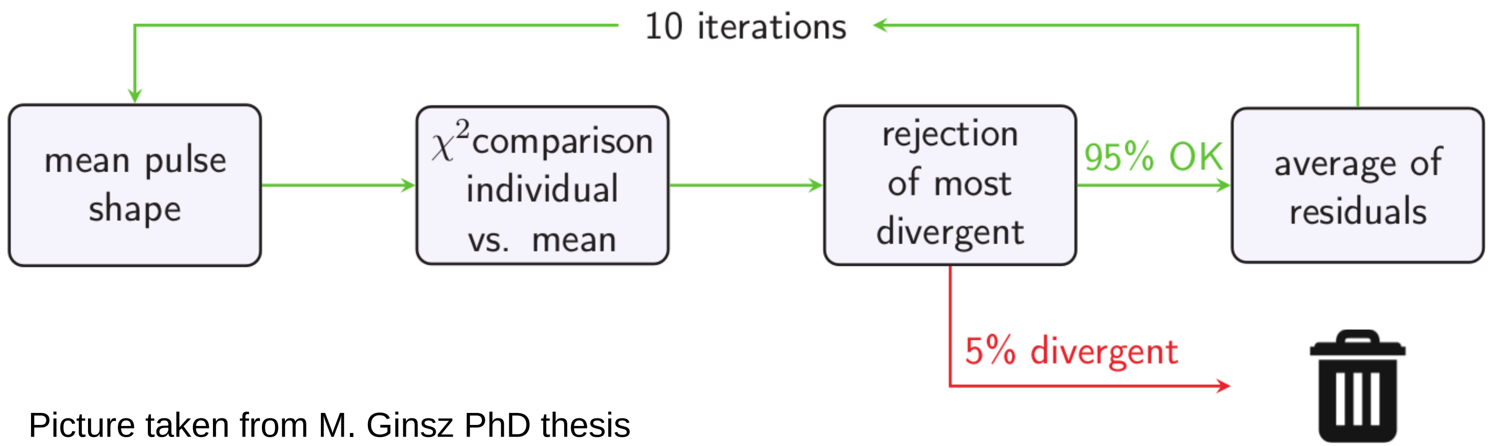
χ^2 Analysis [1]

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

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).

Refining procedure



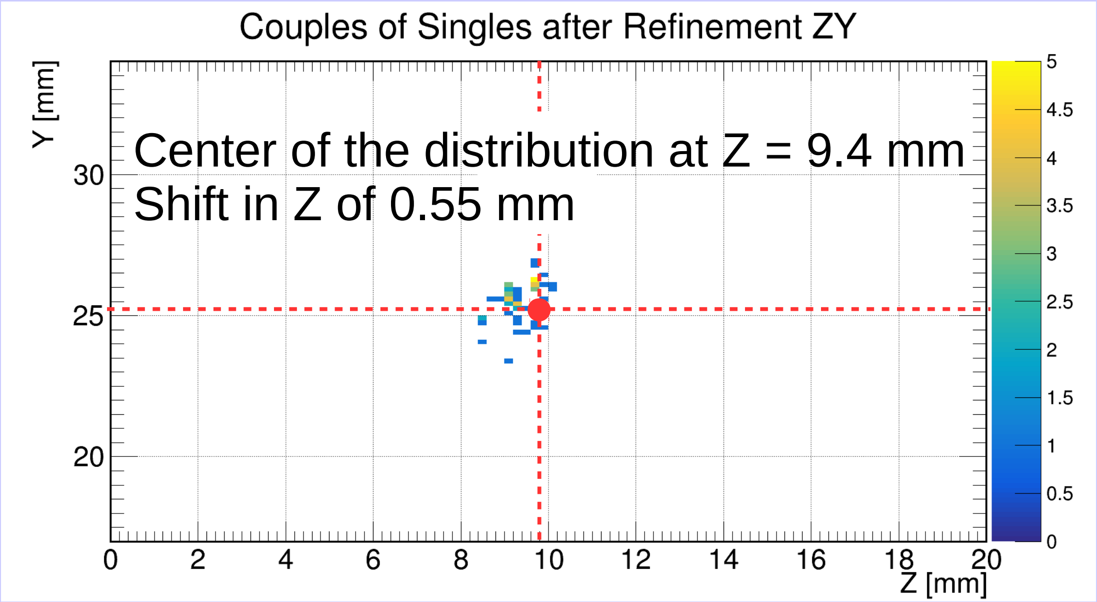
Picture taken from M. Ginsz PhD thesis

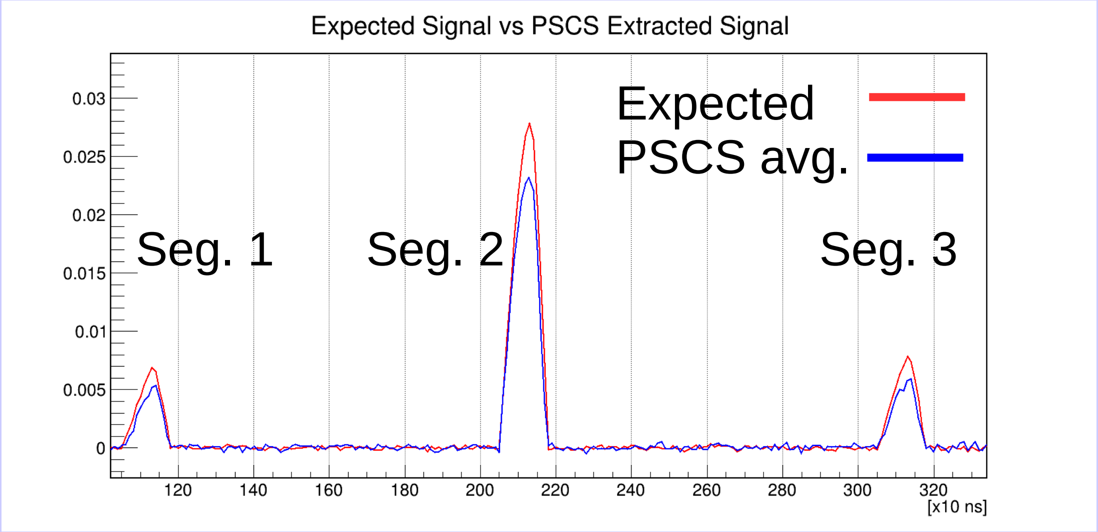
χ^2 Analysis [2]

- Number of **couples of singles** and overall **singles** 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	Singles	59%	49%
	Couples of singles	43%	25%
No Core – No Hit Seg.	Singles	50%	37%
	Couples of singles	29%	15%
Adjacent only	Singles	50%	37%
	Couples of singles	29%	14%

χ^2 Analysis [3]

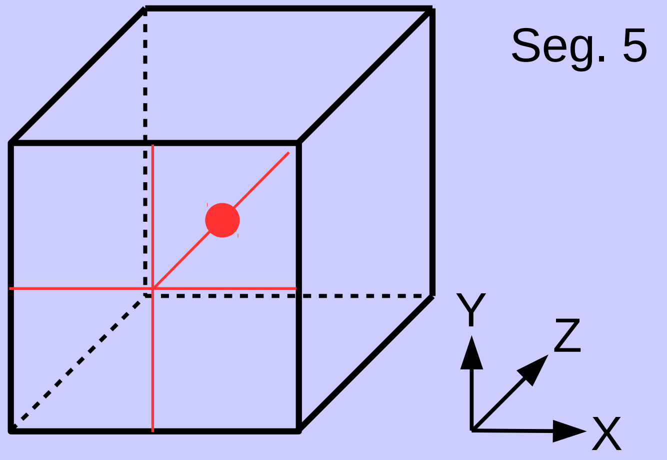




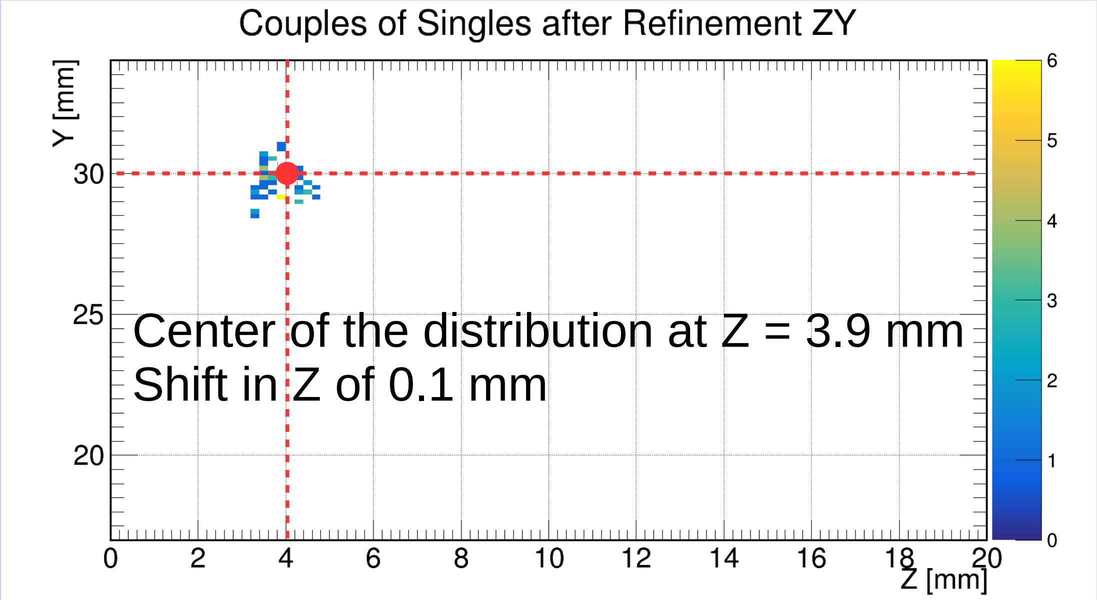
Position distribution of couples of singles is well centered in X and Y

Singles	49%
Couples of singles	25%

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

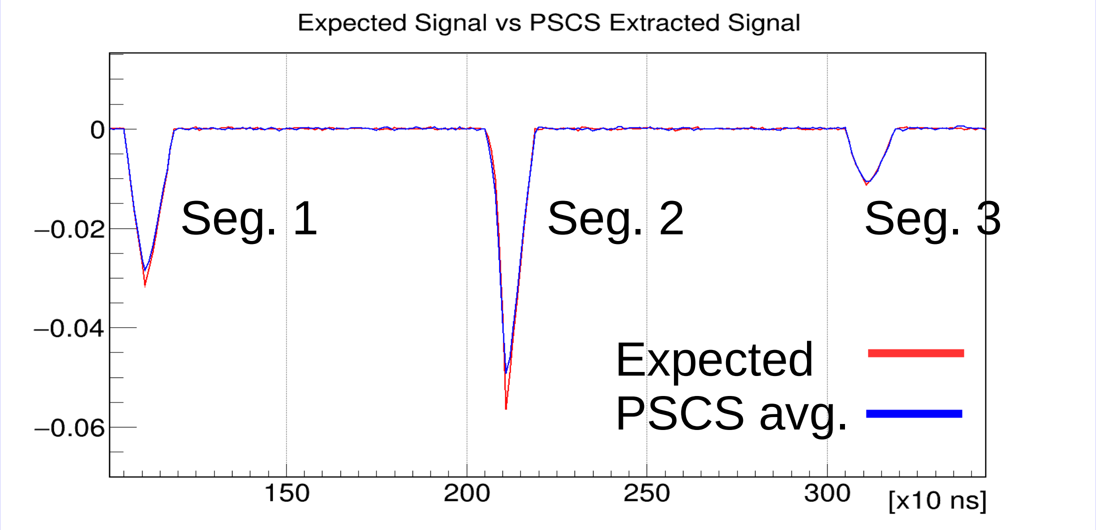


χ^2 Analysis [4]

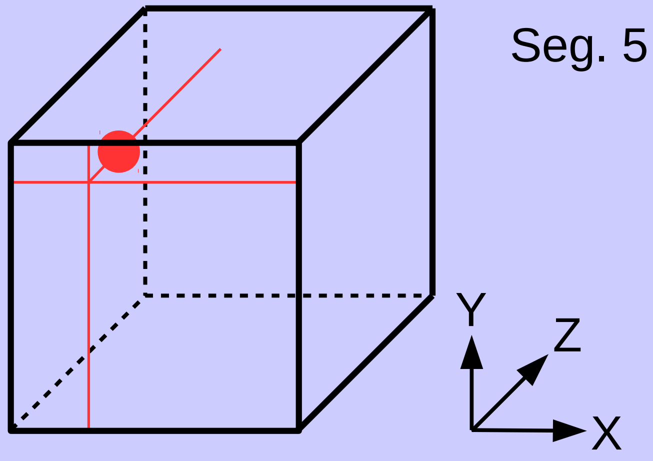


Position distribution of couples of singles is well centered in X and Y

Singles	45%
Couples of singles	25%



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



Conclusions

- Simulations show a reasonable reliability of the system.
- Improvements must be done on the selection algorithms side in order to compensate the position shift due to the lack of sensibility in certain points of the detectors.

WHAT’S NEXT?

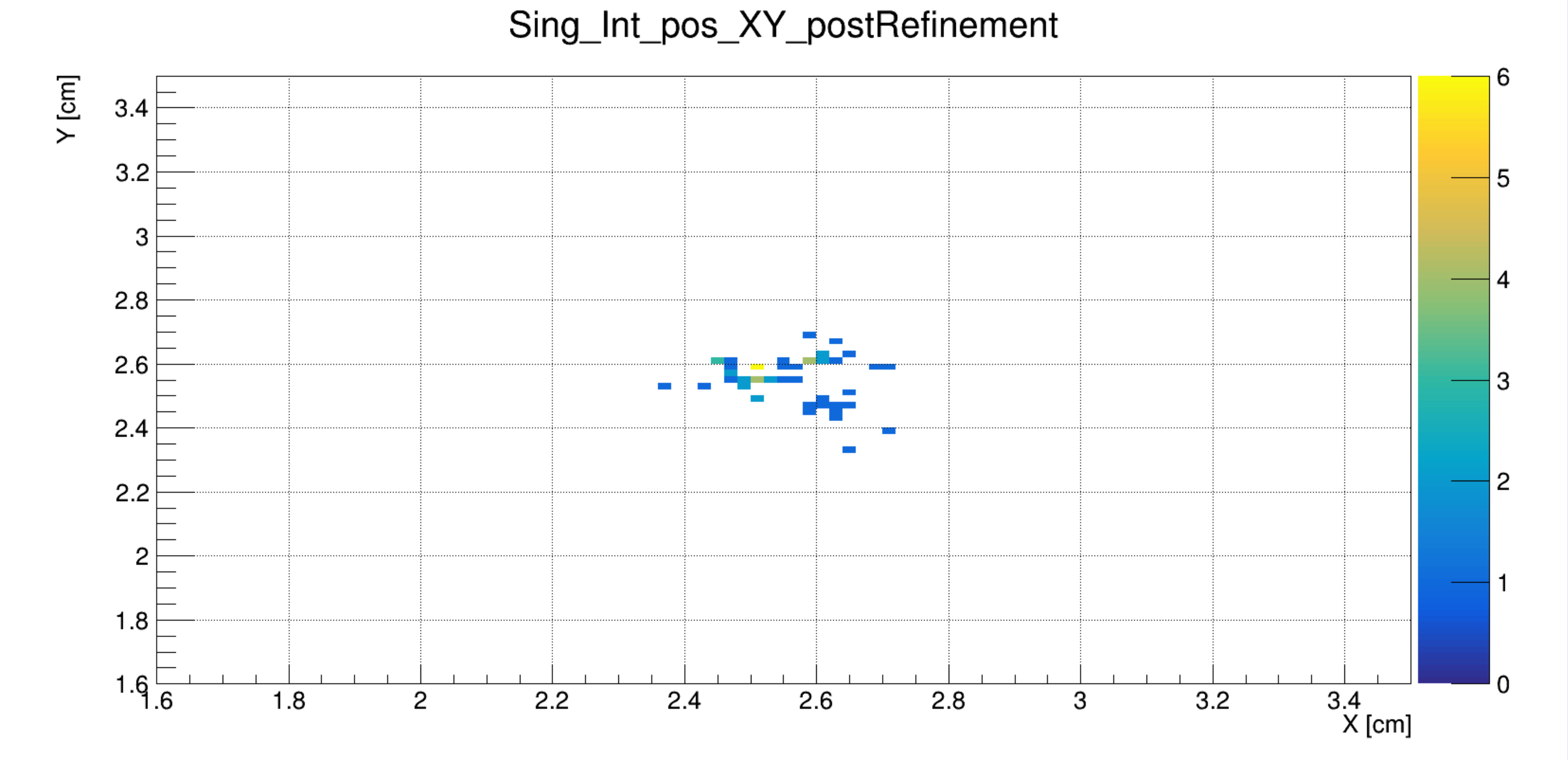
- Implement response function in the simulation
- Improve singles selection with the algorithm described in Crespi et. al.’s paper “A pulse shape analysis algorithm for HPGe detector” [10.106/j.nima.2006.10.003]. Single interaction events can be selected by looking at the current pulse from net charge collecting segment.
- Compare the simulation with real data
- Simulations of an AGATA detector

EXTRAS

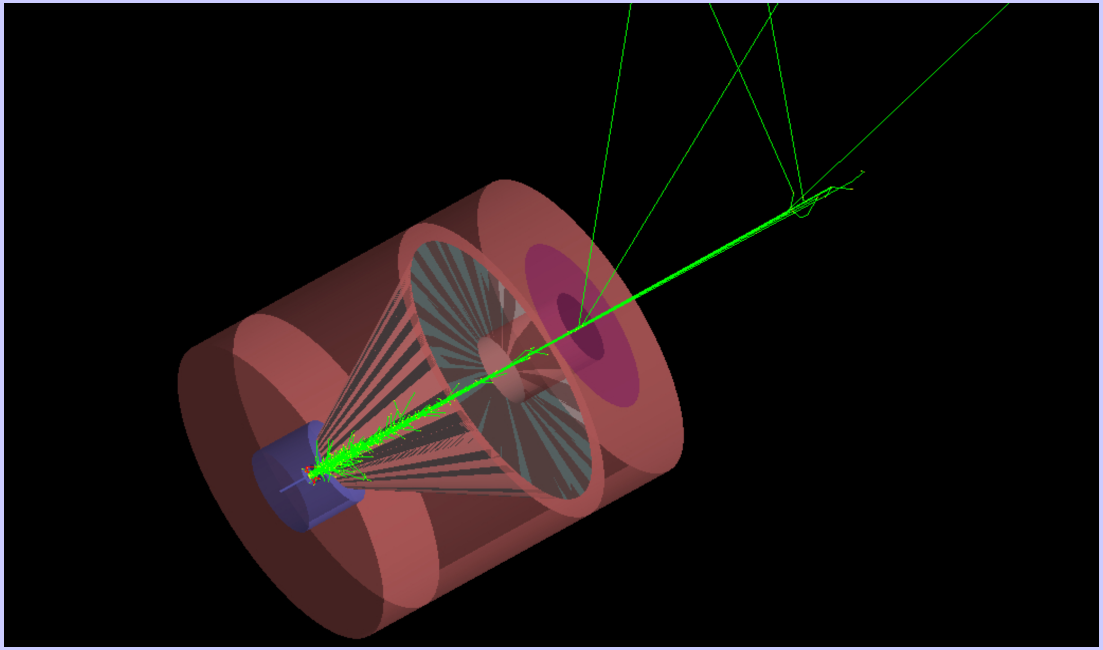
χ^2 Analysis: Border point

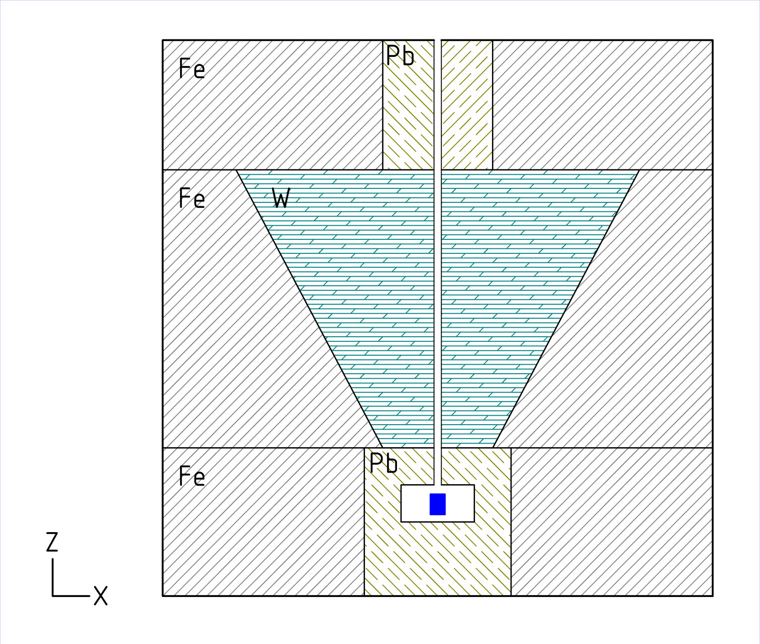
Crossing point at [21.0, 30.0, 4.0] mm		No Noise	With Noise
All	Singles	61%	45%
	Couples of singles	36%	25%
No Core – No Hit Seg.	Singles	59%	45%
	Couples of singles	36%	22%
Adjacent only	Singles	59%	45%
	Couples of singles	38%	22%

Middle XY single couples distribution



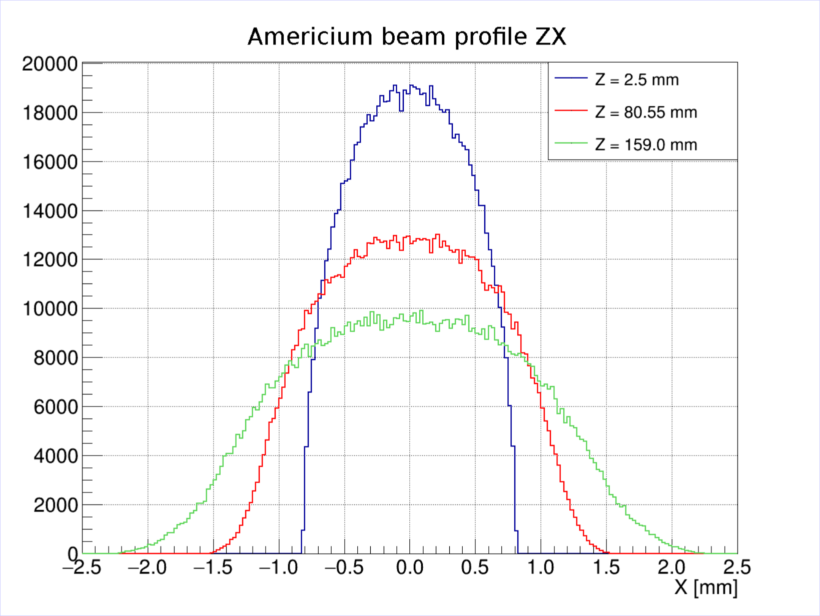
Collimator model geometry

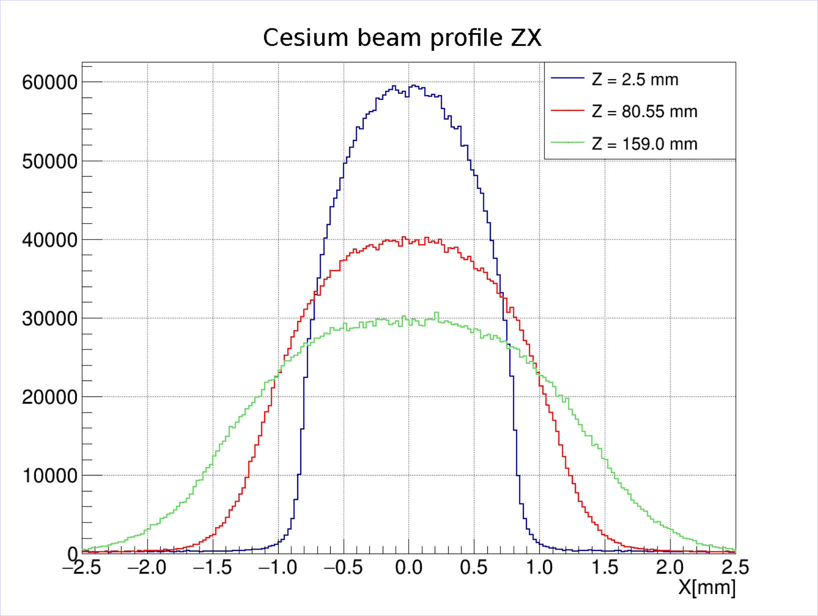




- The collimator is a metallic cylinder 189 mm high with an external diameter of 220 mm. The diaphragm has a 1.6 mm diameter.
- Materials: Iron, Lead, Tungsten (gamma-absorbers).
- Two extended sources where simulated:
  - Spherical ^{241}Am (Ø=1 mm, E = 59.5 keV).
  - Cylindrical ^{137}Cs source (3×3 mm, E = 661.7 keV).
- Gamma-rays are generated uniformly in θ and φ.

Beam Analysis



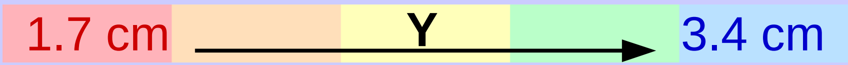


Z	RMS (Am)	RMS (Cs)
2.50 mm	0.41 mm	0.47 mm
80.55 mm [Hor]	0.61 mm	0.69 mm
159.0 mm [Ver]	0.84 mm	0.93 mm

As 95% of events are expected to be within two RMS errors, this parameter gives a good indication of the beam width at a certain depth.

The beam width for Cs source is slightly bigger. That’s because higher energy gamma-rays have higher probability to cross the edges of the diaphragm of the collimator.

Simulated pulses along Y axis (no noise)



[X = 2.5cm   Z = 1.2 cm]