Development of self-calibration techniques for γ-ray energy-tracking arrays

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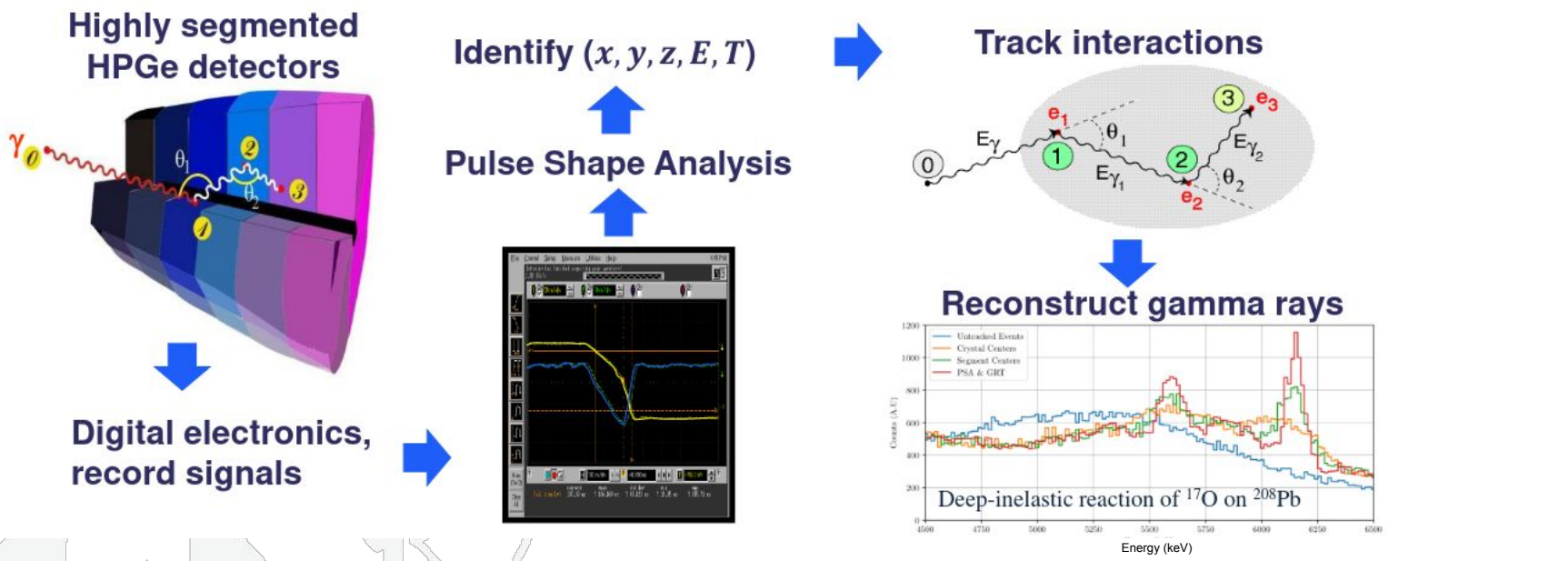
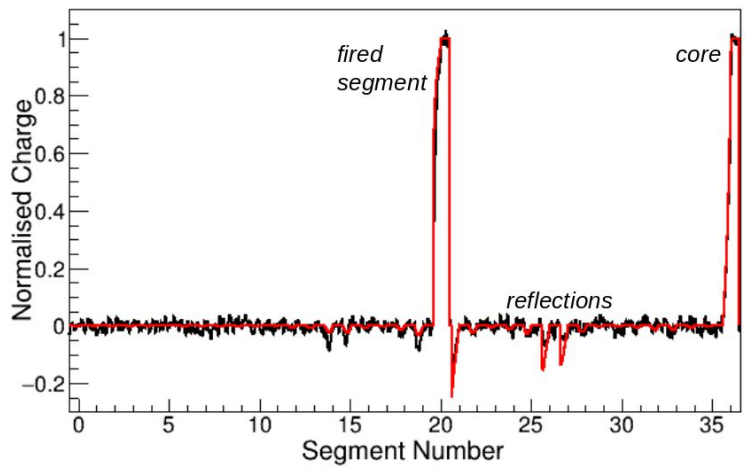
Gamma-ray tracking array



PSA:



- Gamma-ray tracking array: highly segmented HPGe (36 segments)
- Pulse Shape Analysis (PSA) => interaction position
- PSA performed by comparing with **signal basis** for every detector

Current challenges

signal basis generation

Experimental (scanning)

- long acquisition times
- different conditions between scanning and experiment, e.g. noise, radiation damage
- mechanical alignment

Analytical (calculated)

- intrinsic space-charge density
- the electron/hole mobility
- crystal temperature and
- crystal orientation
- passivated and contact thickness
- shape of charge cloud

Self-calibration concept

- Generate signal basis in experimental way

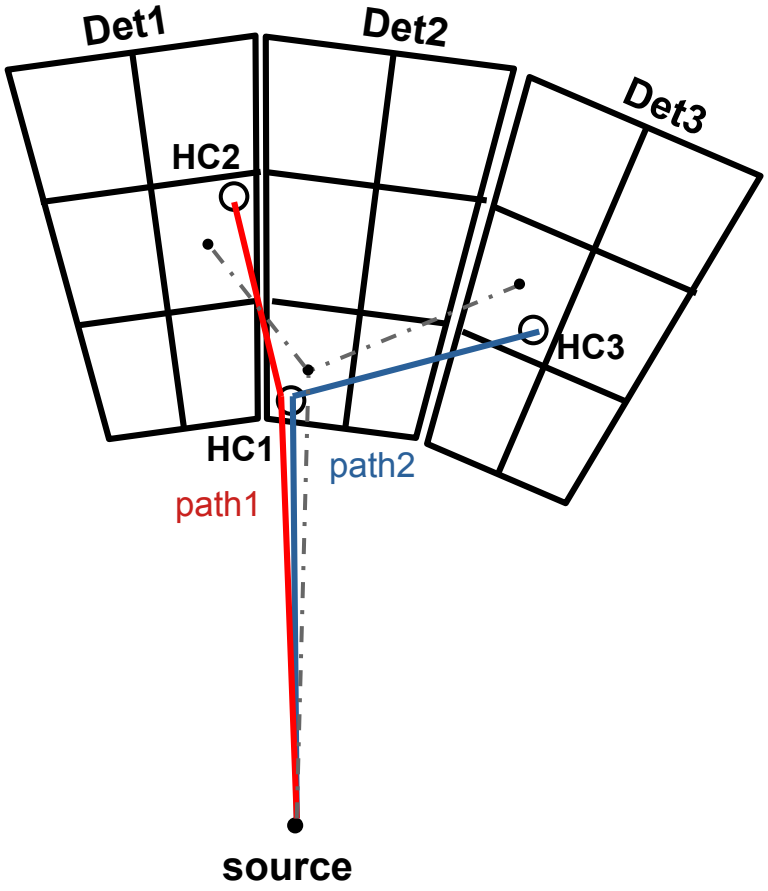
S. Heil, S. Paschalis, and M. Petri, Eur. Phys. J. A (2018) **54**: 172

Group interaction points from different gamma-rays into hit collections

Use Compton formula to order interaction points

Define tracks between interaction points that also link the hit collections with each other

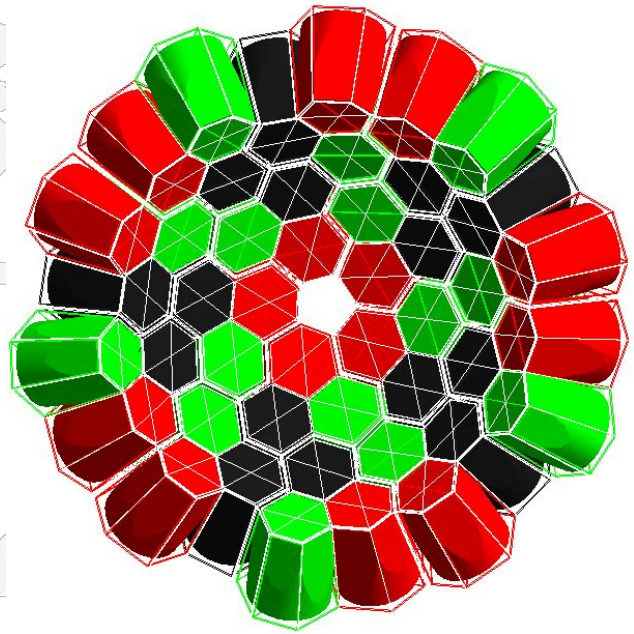
Optimise coordinates of hit collection using the tracks that link their constituent points and Compton formula



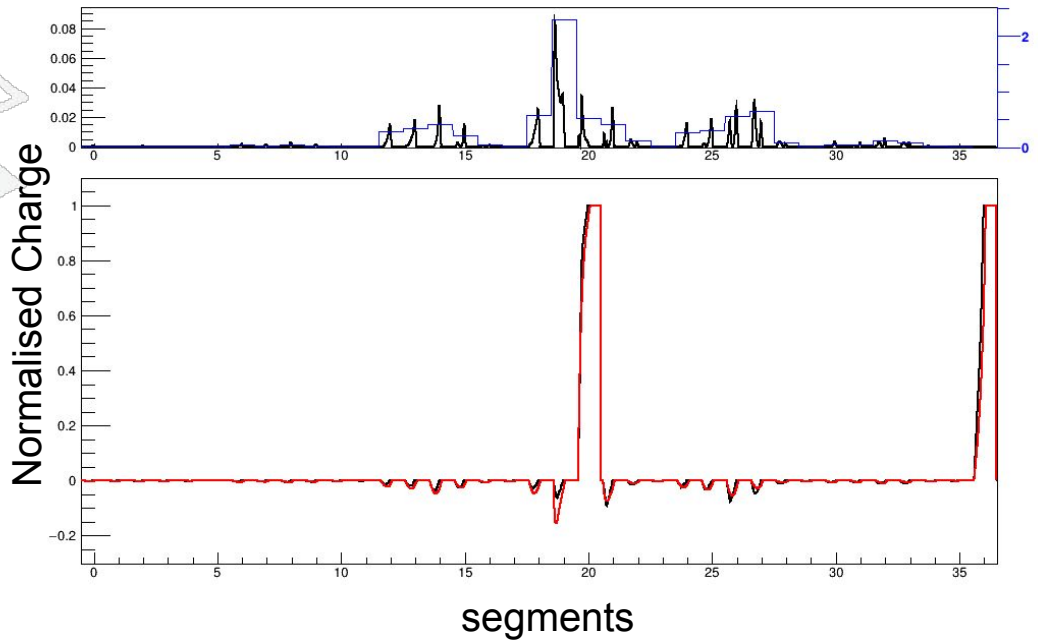
- Produce pulse shape basis for all detectors
- Strong gamma source illuminate the whole array
- Compton formula optimize scattering events

Simulation with Pulse Shape

Geant4 simulation:

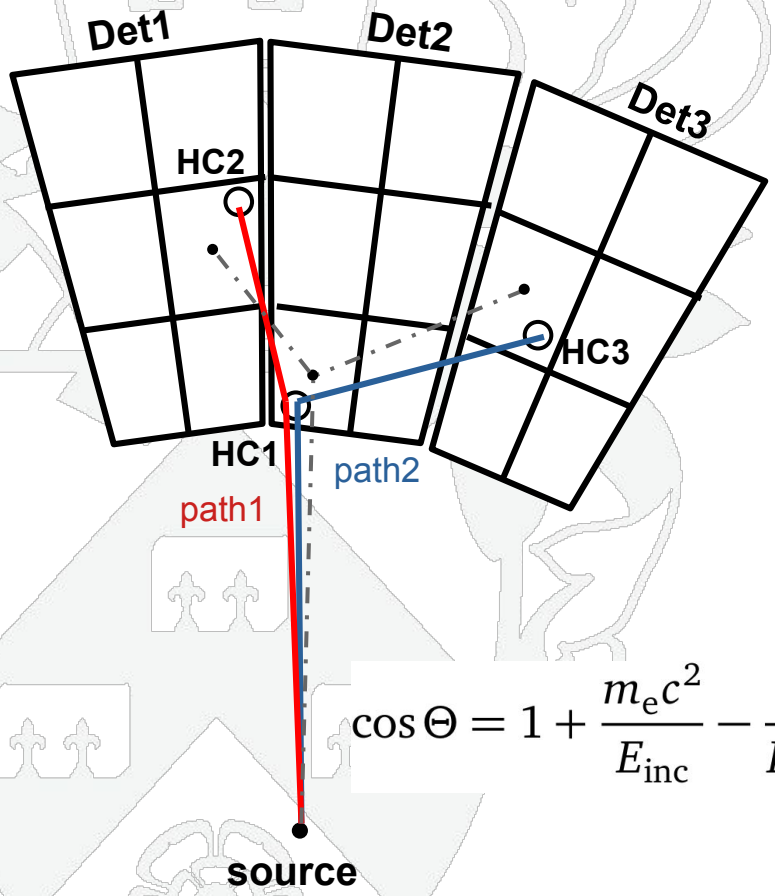


Group pulse shape:

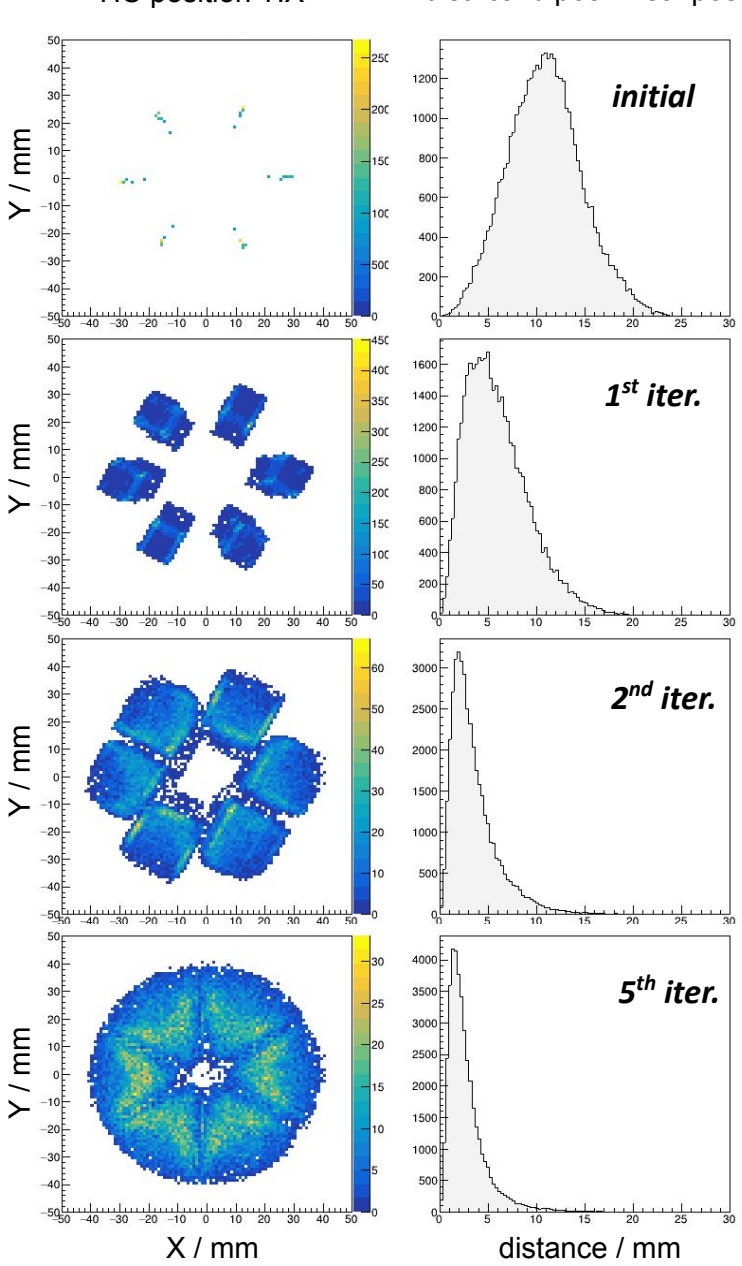


- Geant4 simulate AGATA-1Pi array, save Compton scattering events
- Pulse shape basis linear interpolation → simulation data
- Group pulse shape according to similarity

Simulation: Position optimization

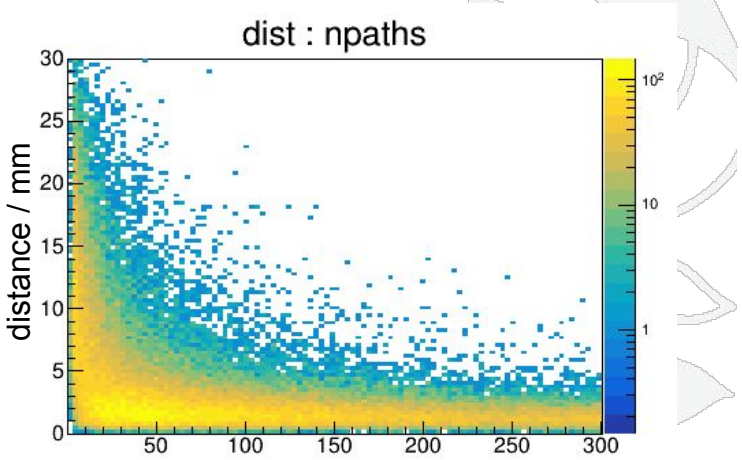


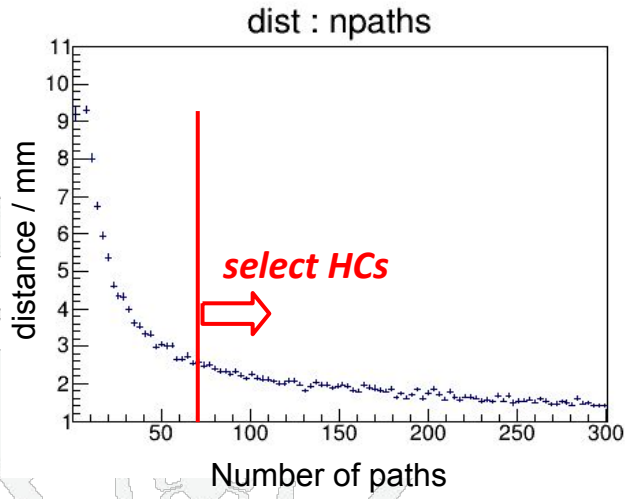
$$\cos\Theta = 1 + \frac{m_e c^2}{E_{inc}} - \frac{m_e c^2}{E_{inc} - E_{dep}}$$

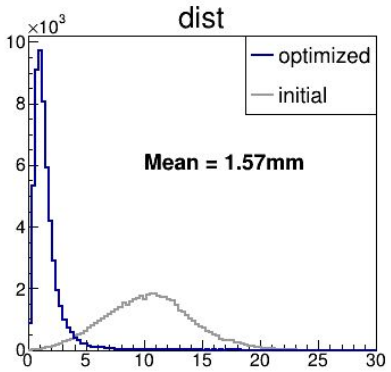


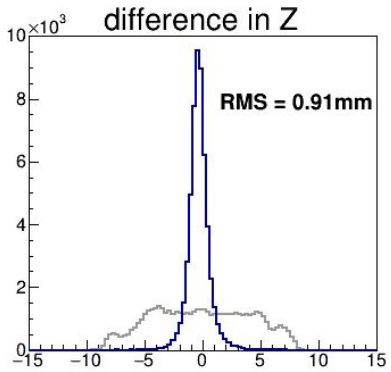
Simulate 2MeV gamma 2e10 events

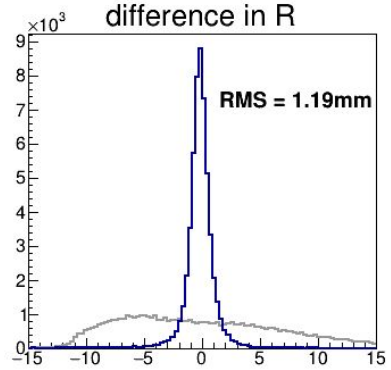
Simulation: Position fidelity

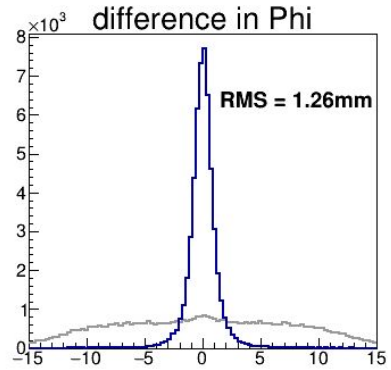












Simulate 2MeV gamma 2e10 events

- Select HC linked with large number of paths
- Converged HC position reach ~1mm (RMS) fidelity
- Slightly worse resolution in phi direction

Simulation: Position fidelity

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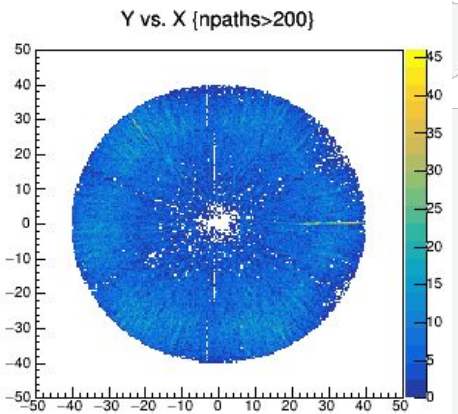
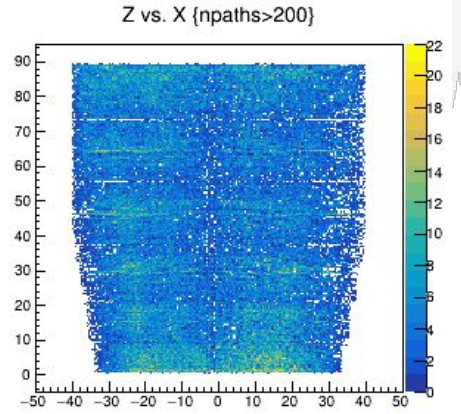
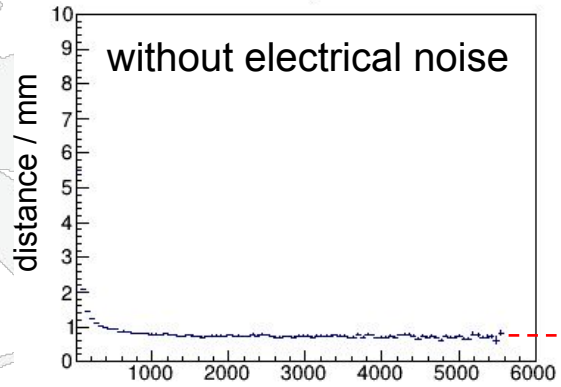
2MeV gamma 2e11 events

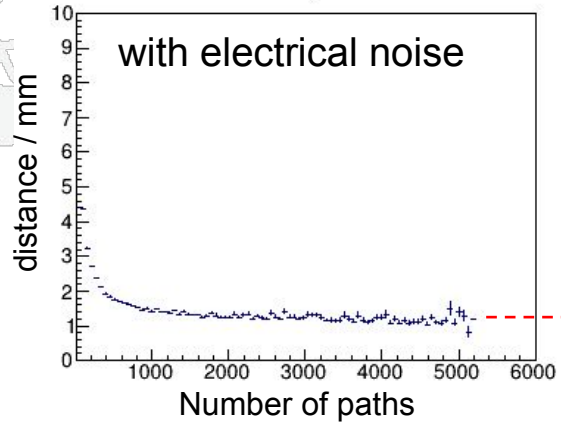
Distance between self-calib position and "real" position







Better than 1mm



1-2 mm

Self-calibration basis (simulation)

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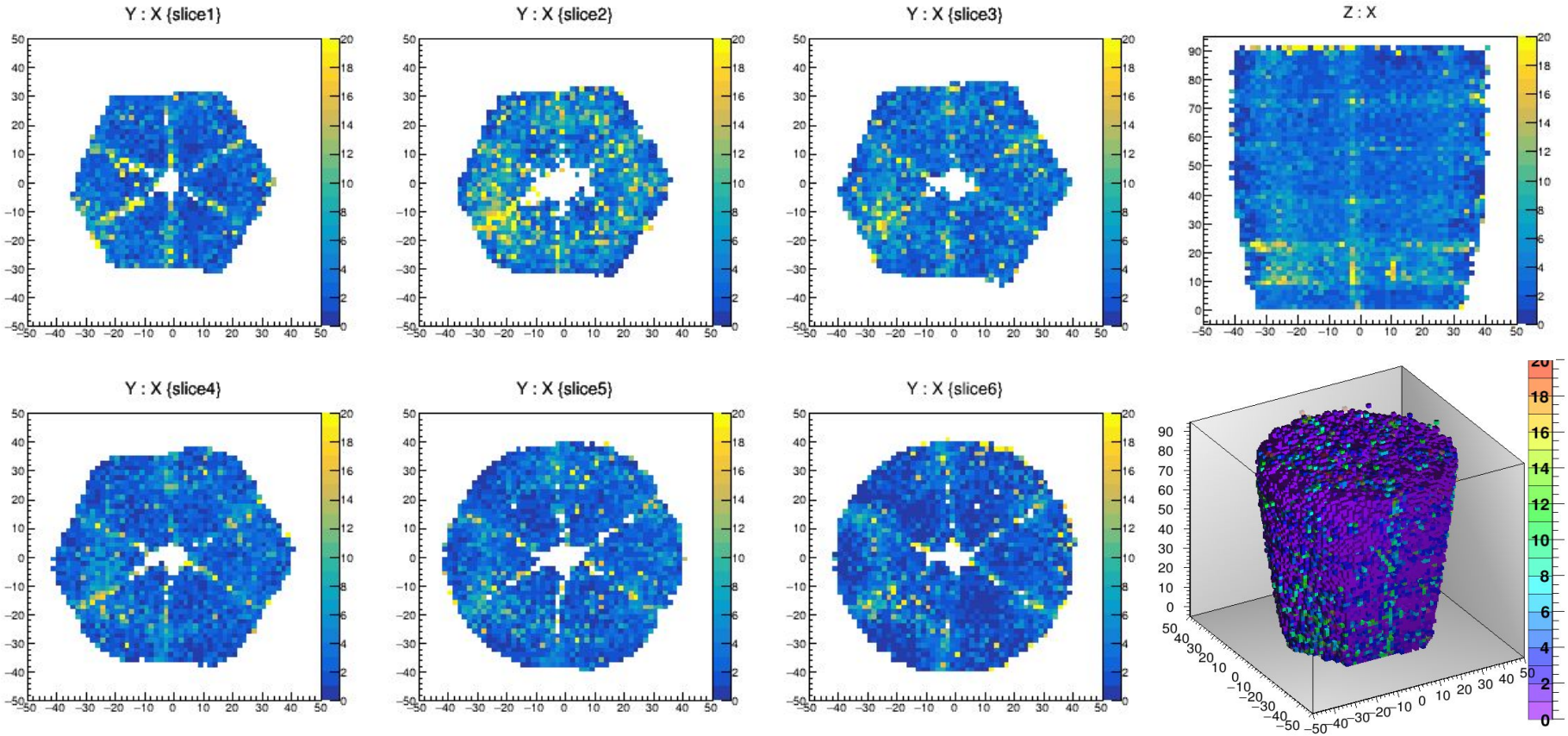
Chi2 difference: self-calib pulse vs. real pulse

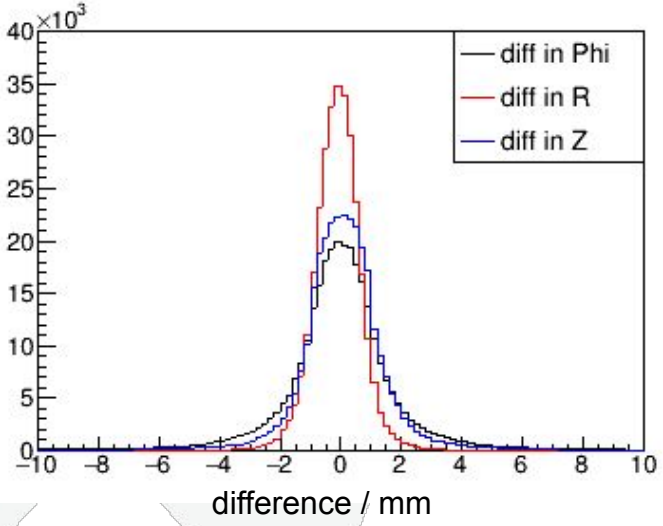


- Large Chi2 observed around segment boundary

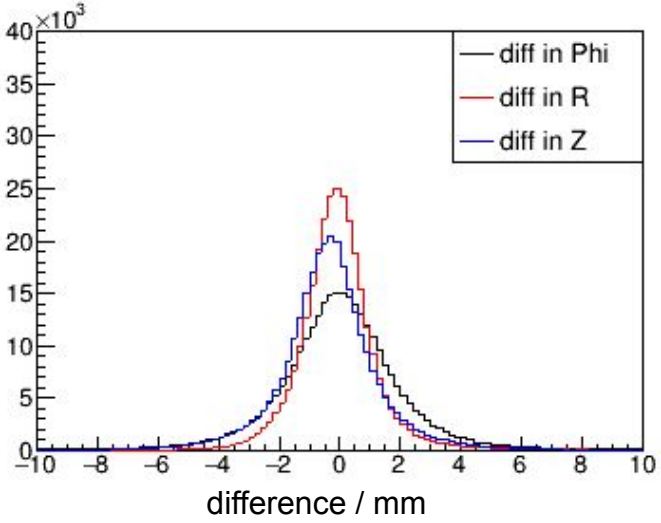
Simulate 2MeV gamma 2e10 events

PSA position resolution (simulation)

Using the calculated Basis on a 2mm grid

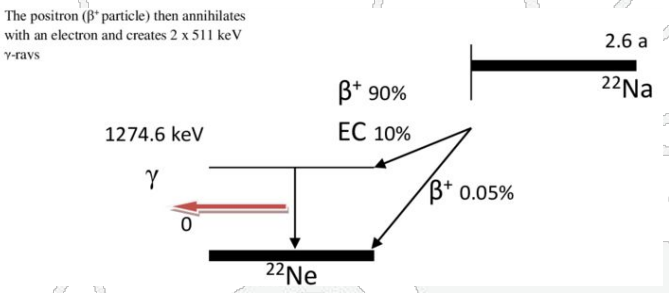


Using the self-calibrated basis

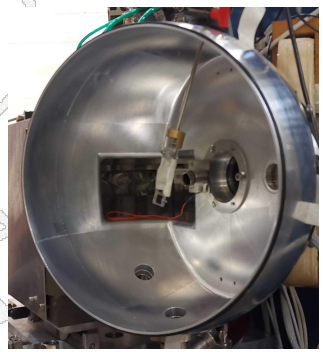


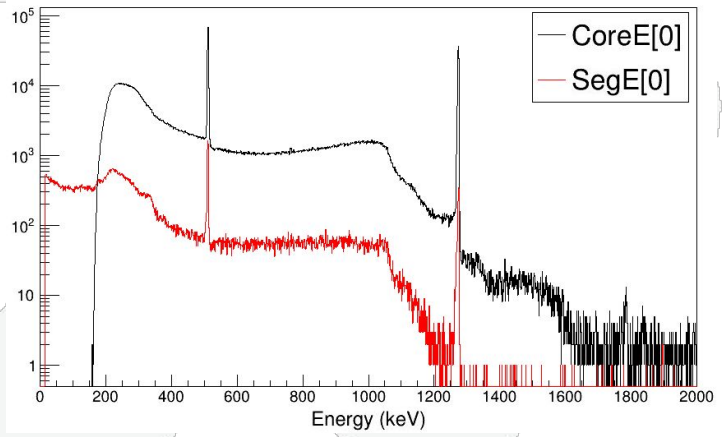
Experiment: source data

^{22}Na source, 130kBq

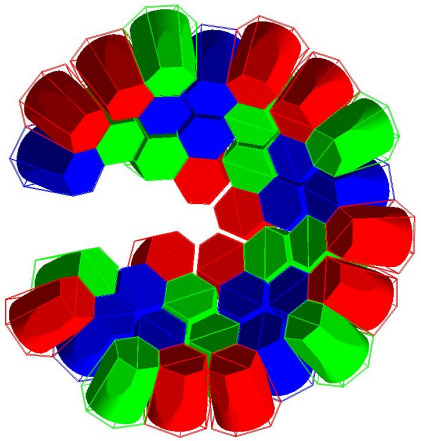


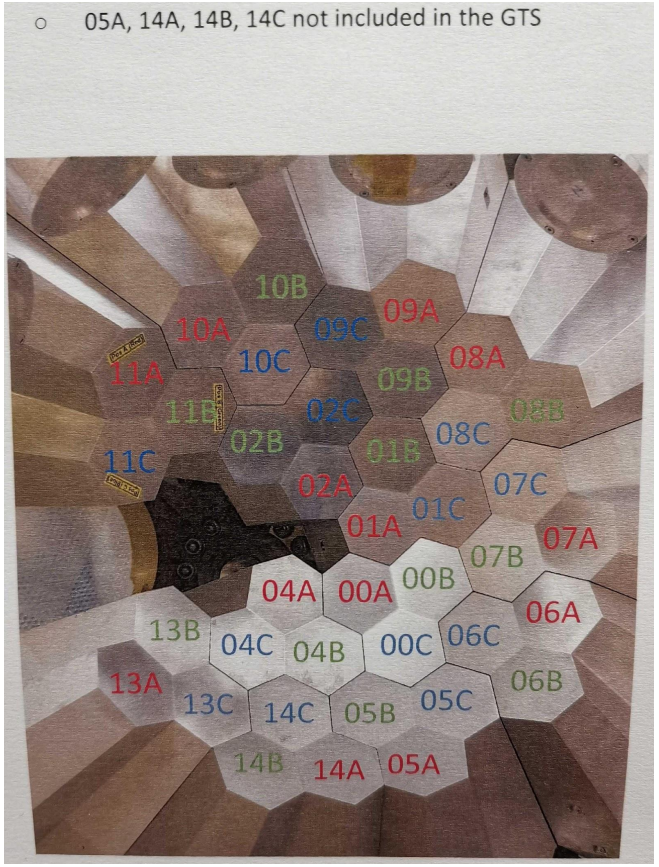
source at target position





13 ATC at LNL





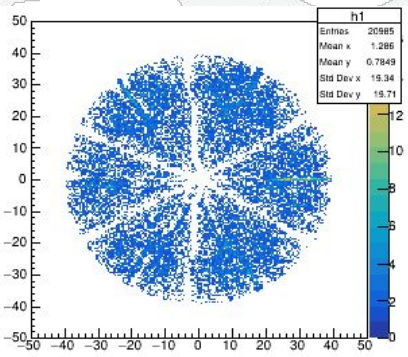
- ^{22}Na source at center of array
- Large signals, CoreE>200keV (small relative noise level)
- Compton scattering events (fold 2 trigger)

Self-calibration result

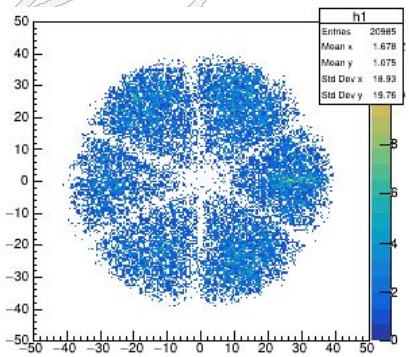
Simulation data (same size as source data)

source data

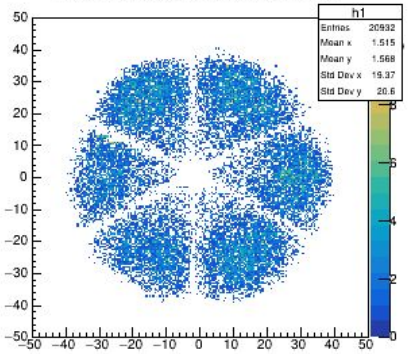
Real HitCollection Position



Calib HitCollection Position



Calib HitCollection Position



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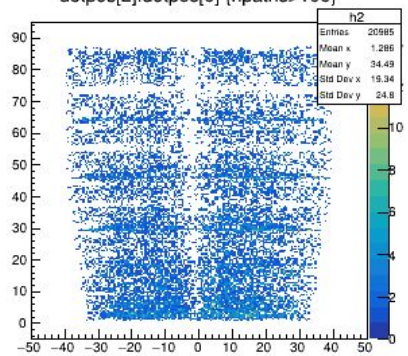

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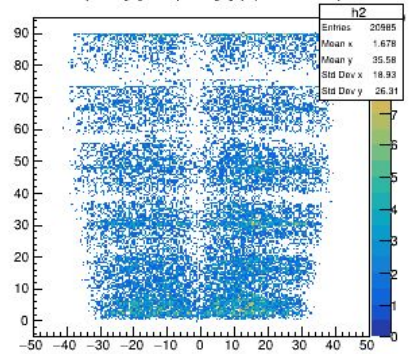

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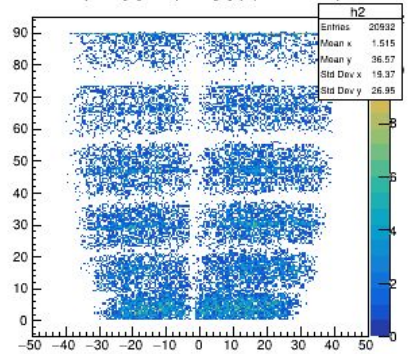
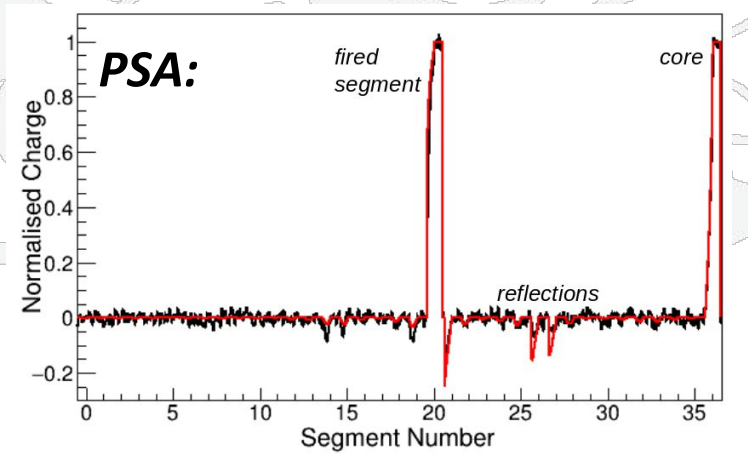
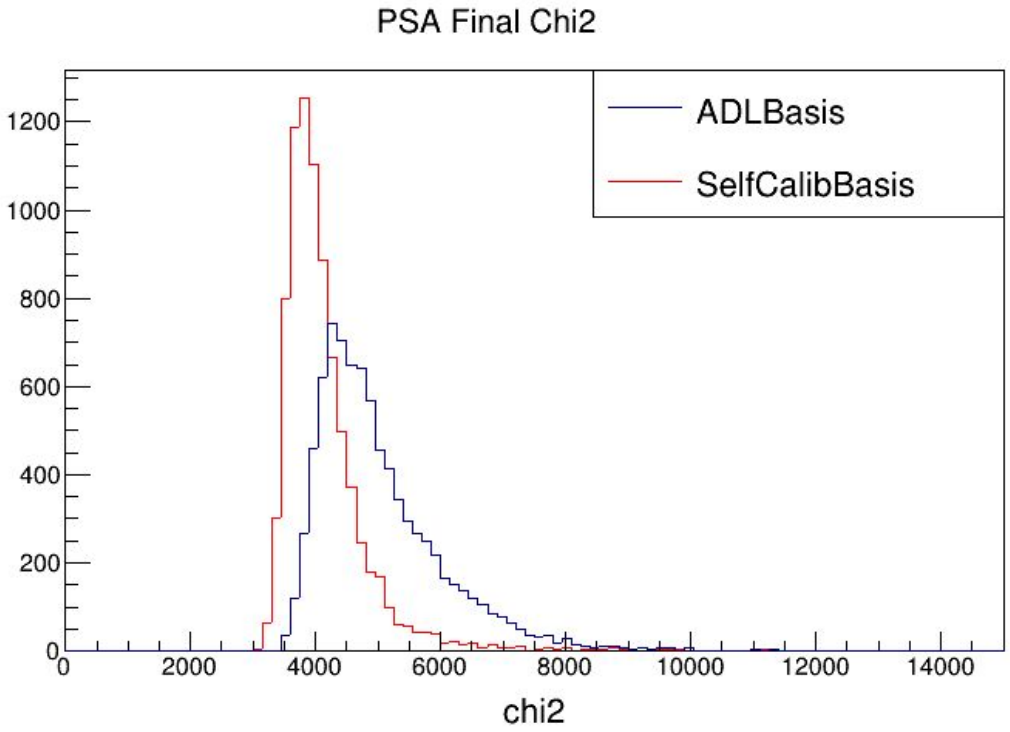


- Identify incoming gamma energy by OFTtracking (set sigma_thet = 3.2)
- consistent results between simulation and source calibration

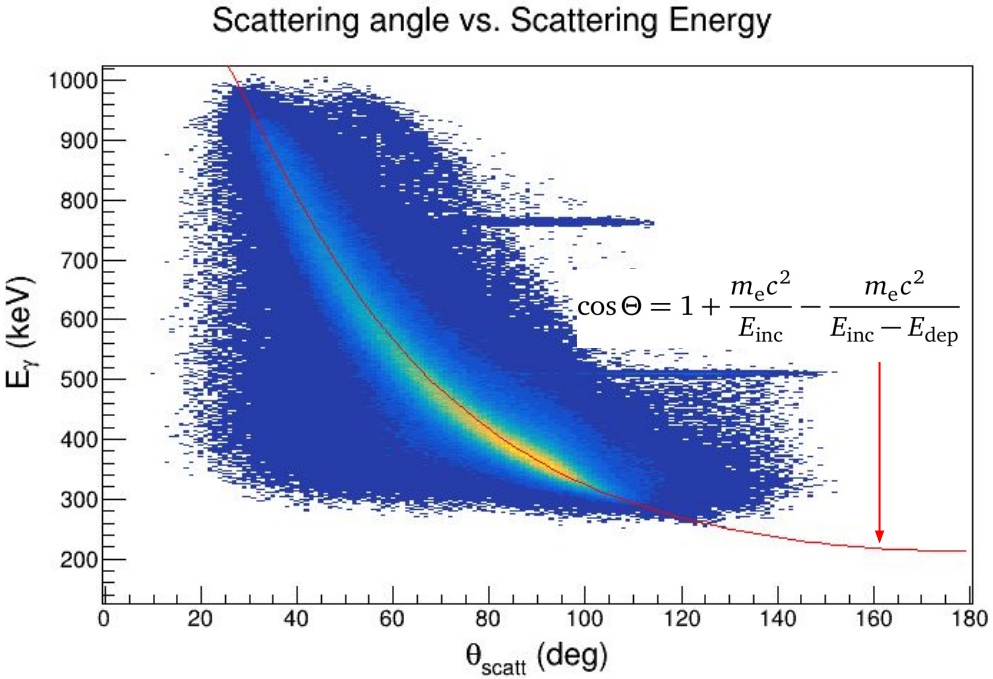
Pulse Shape Analysis (PSA)

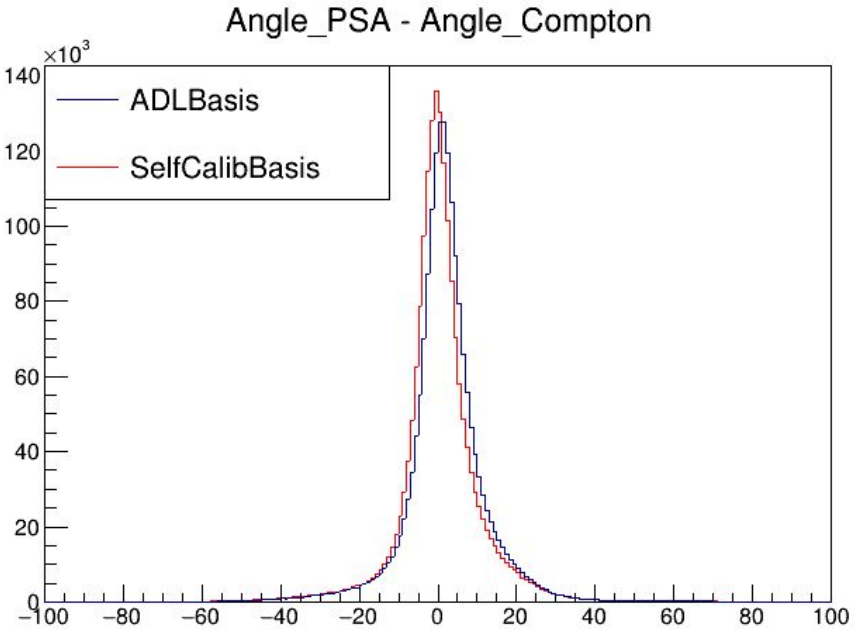


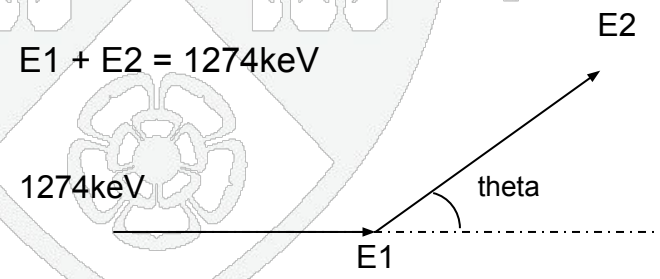


- ADL (AGATA Detector Library): theoretical calculated basis on 2 mm grid
- Chi2: the difference between experimental signal and the signal basis fitting
- The PSA final chi2 with self-calibration basis is smaller than that with ADL basis ⇒ self-calibration basis better describe experimental signal

Compton Scattering Angle







- Compton scattering of 1274keV gamma
- Interaction position from PSA with ADL basis and SelfCalib basis
- Comparing scattering angle from PSA and the Compton angle from energy deposit

Data size and Computing resources

Data size

- ^{22}Na source, 33 detectors, fold 2 trigger, Ecore>200keV ⇒ 18TB
- Ecore>300keV required in analysis ⇒ 25% data

Computing resources

- group pulse shape
  - separate process for each detector:
    17 GB memory, 15 cpus (40 hours)
- position optimization
  - all in one process:
    160 GB memory, 60 cpus (1 hour)

Summary

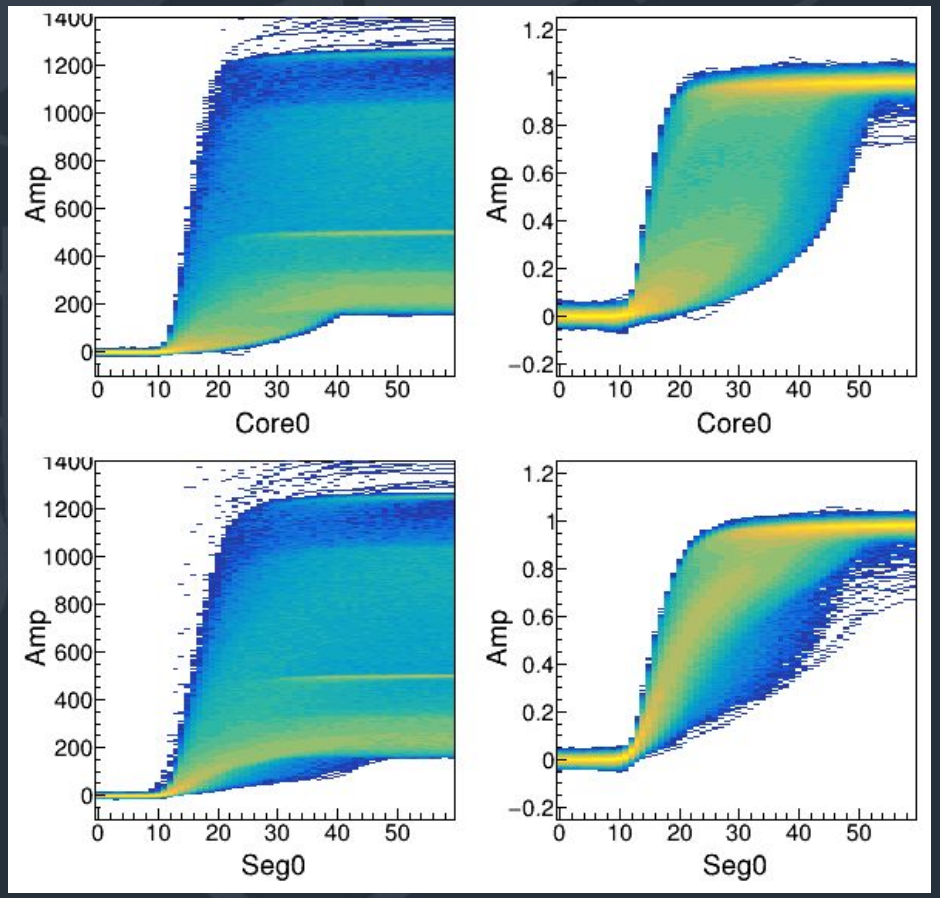
- Self-calibration is tested with AGATA simulation data with pulse shape yielding reasonable results
- Influences of statistics, noise levels are studied
- Experimental data is taken with ^{22}Na source at LNL, self-calibration with experimental data give results consistent with simulation data
- PSA with self-calibration basis and original basis are compared, yielding some improvements with self-calibration basis

Thank you for your attention

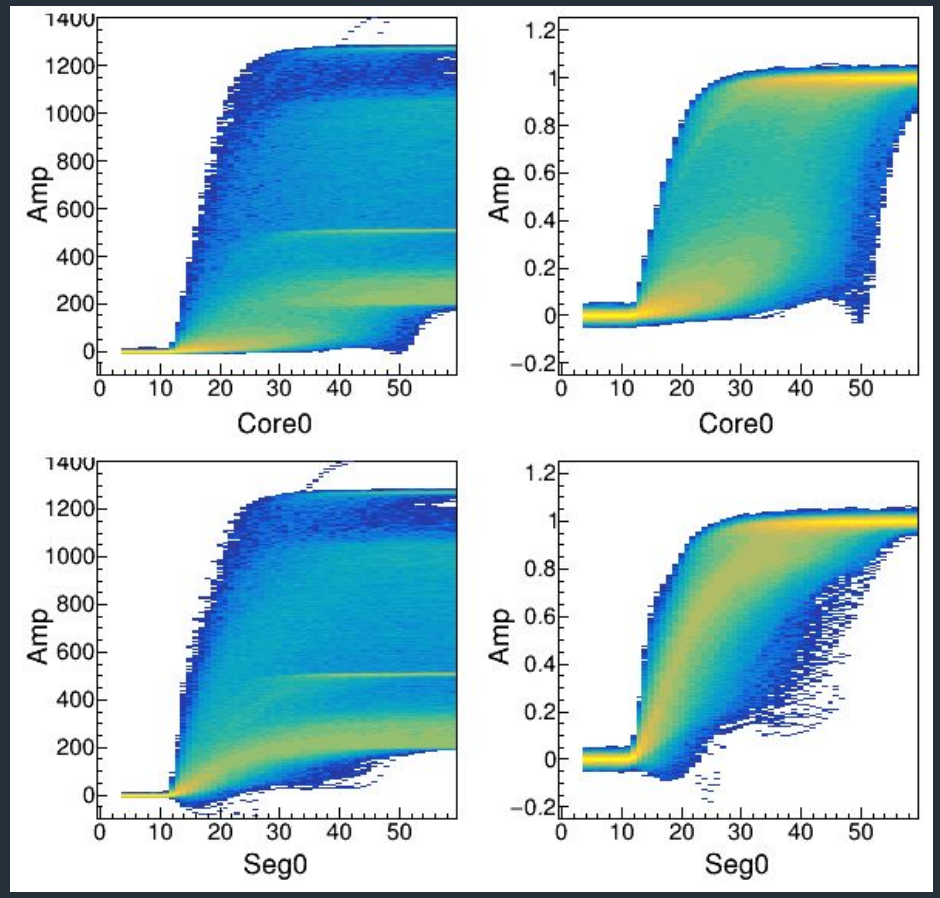
Backup

Pulse shape

Source calibration



Simulation with noise



Position converge (simulation)

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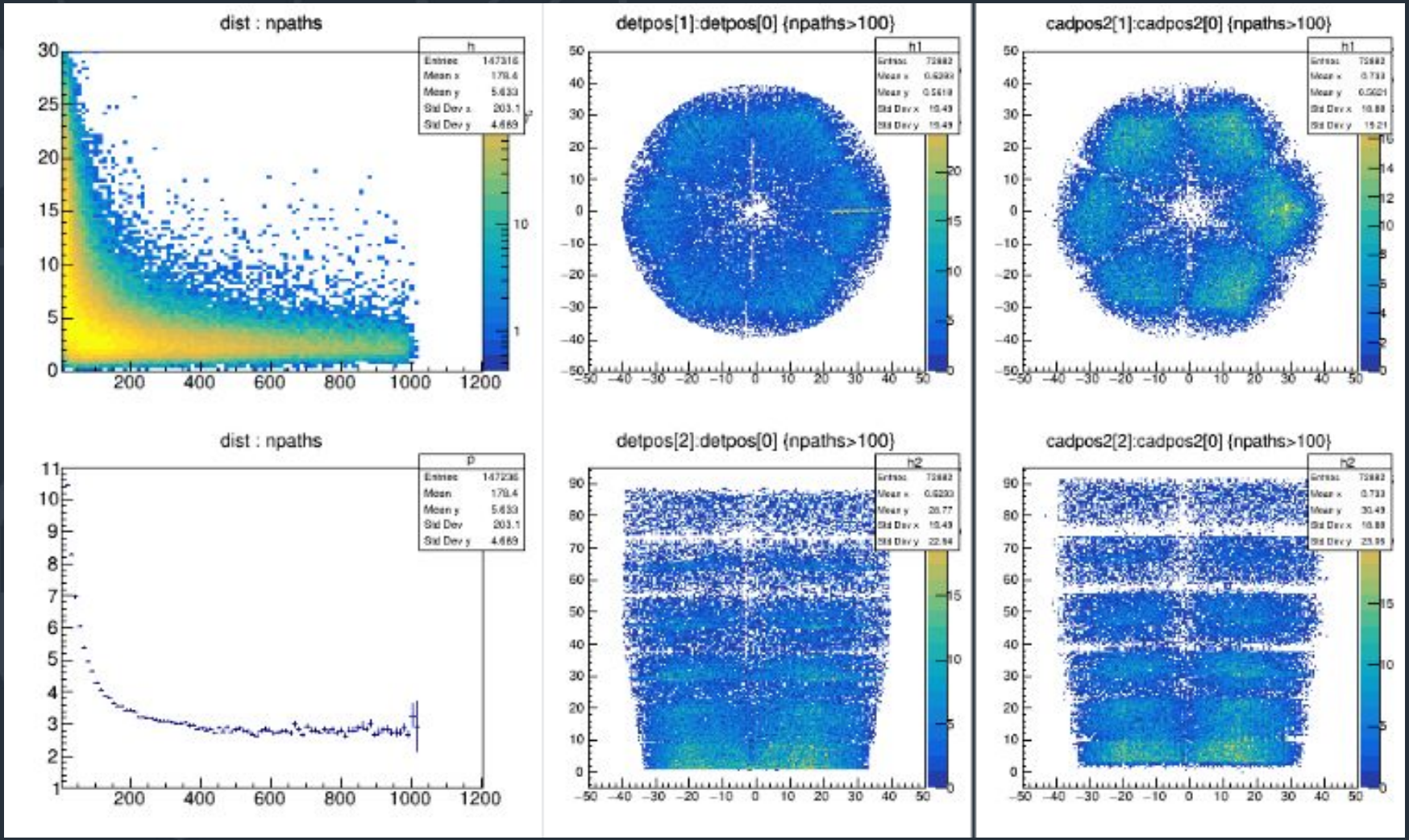
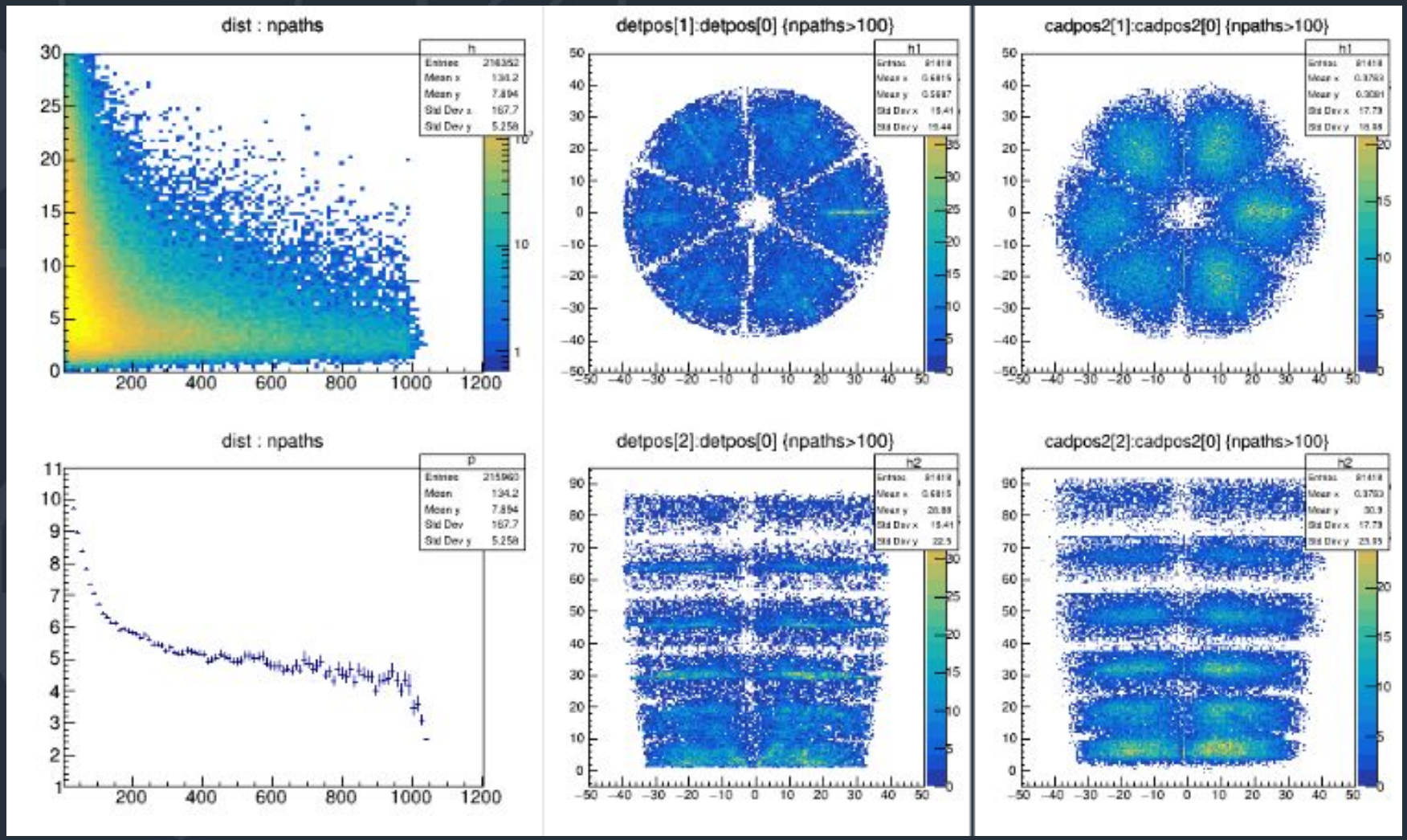
Ecore>200keV, without noise



Position converge (simulation)

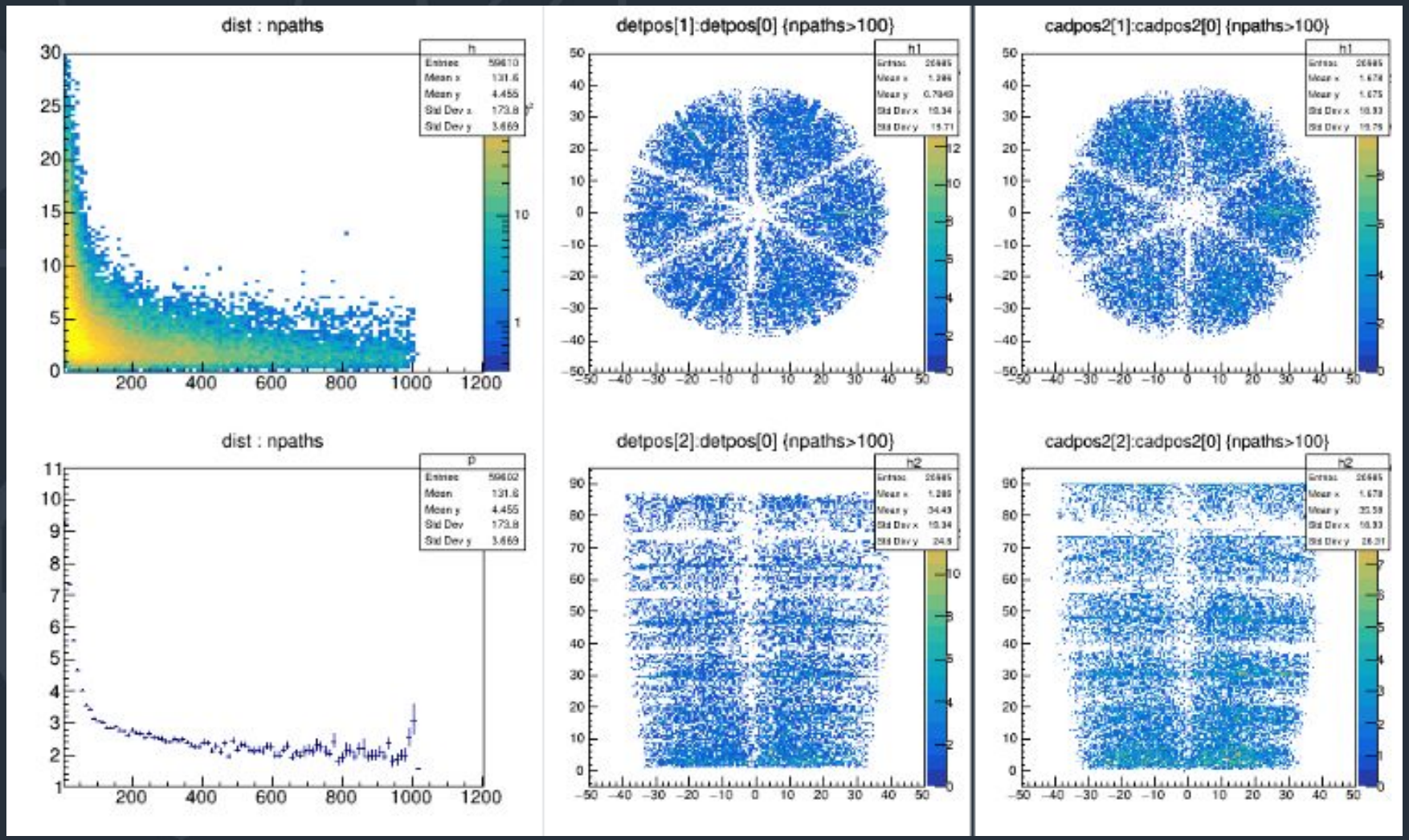
UNIVERSITY of York

Ecore>200keV, with noise

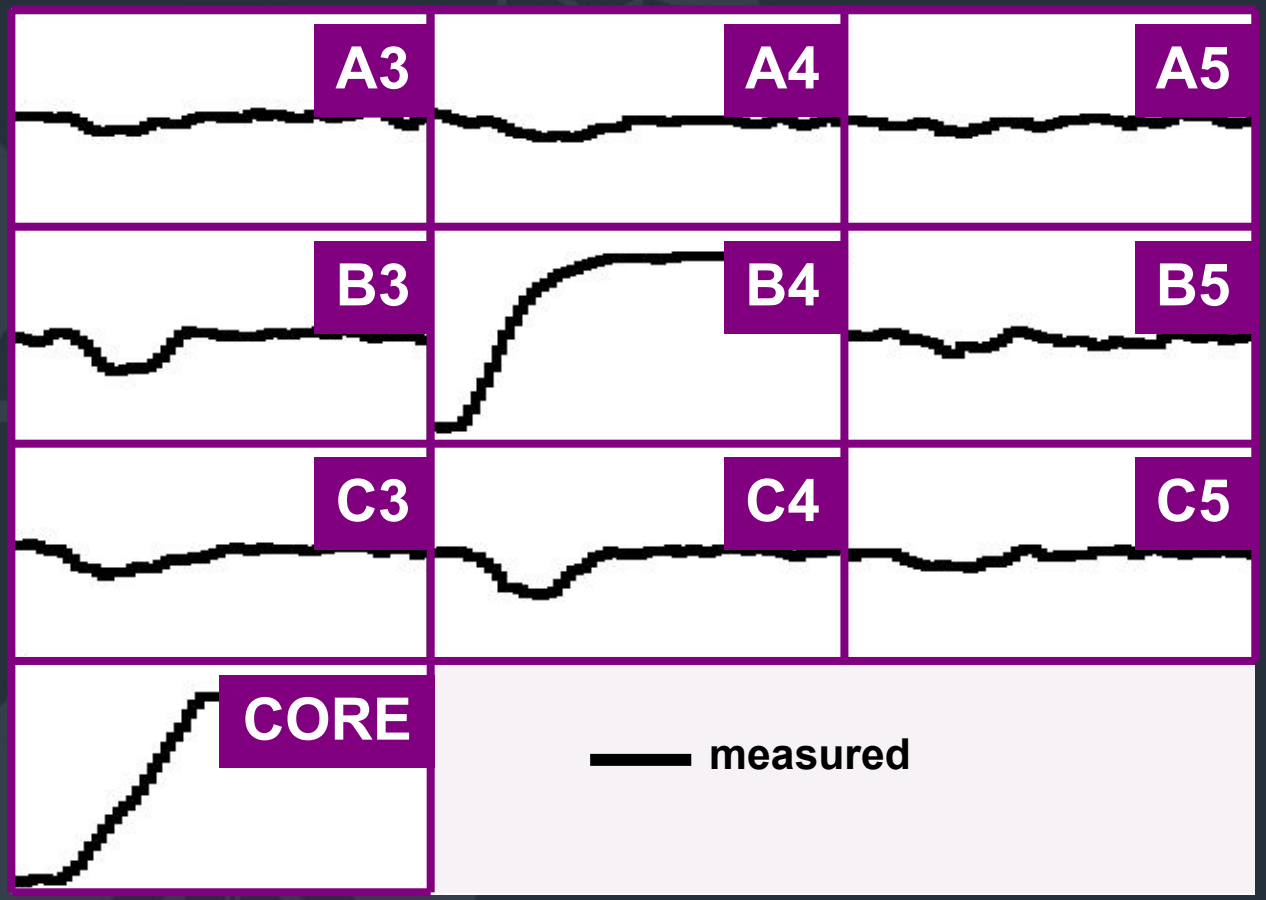


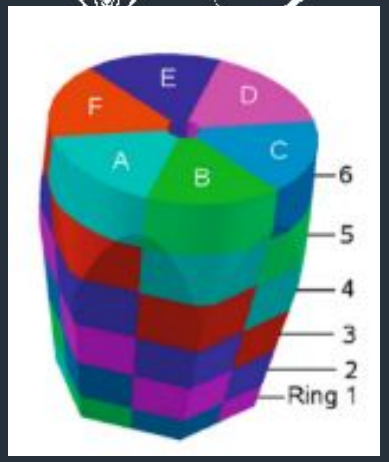
Position converge (simulation)

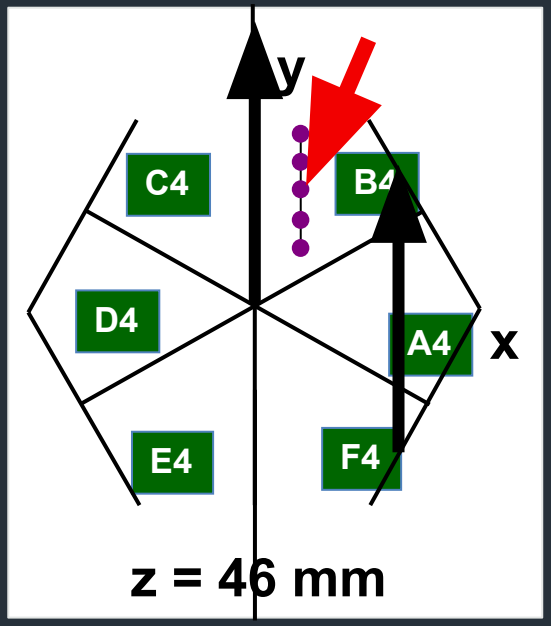
Ecore>300keV, with noise



Pulse Shape Analysis concept

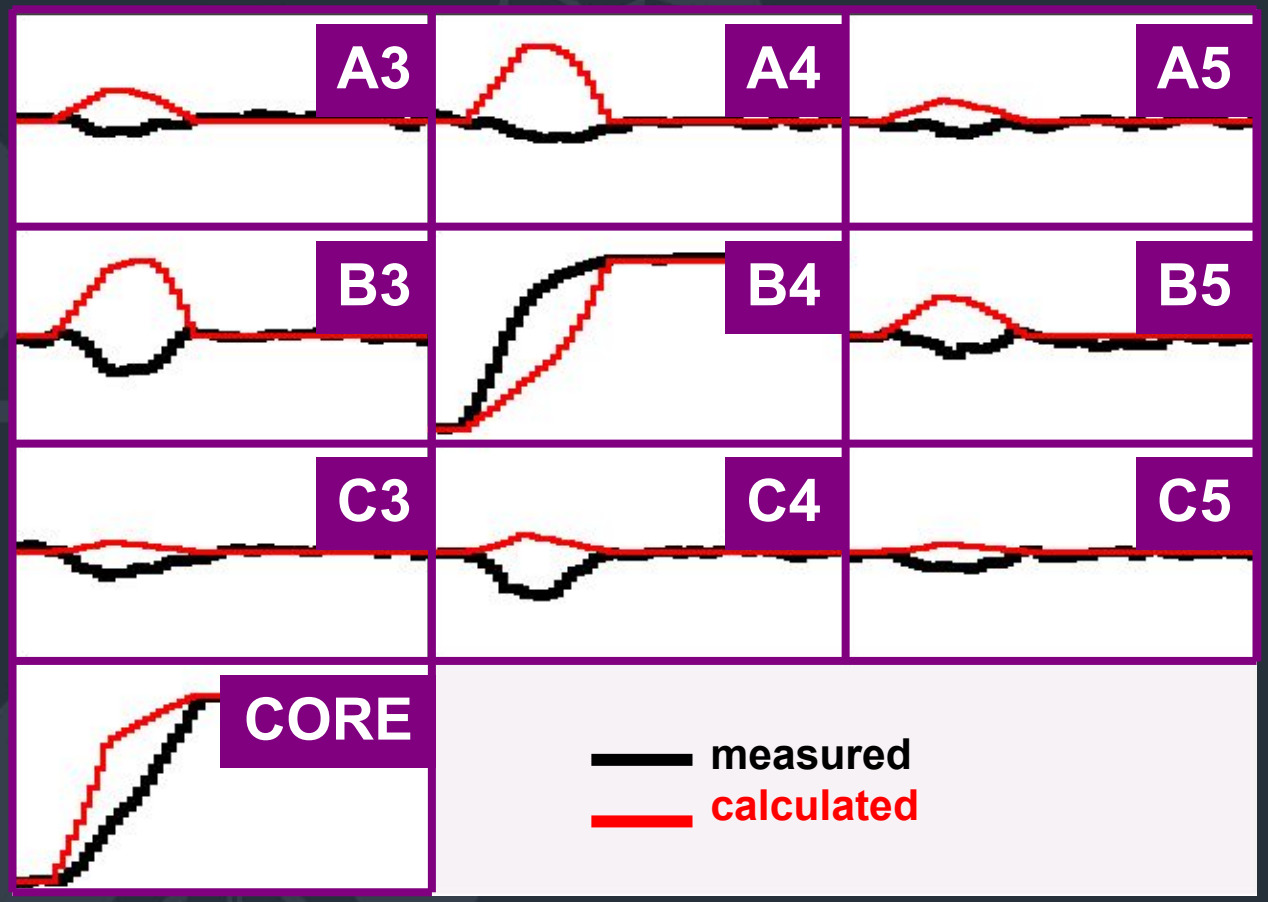




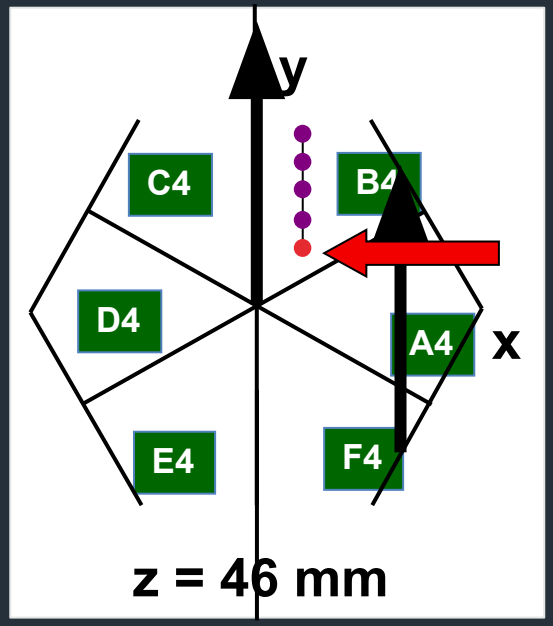


791 keV deposited in segment B4

Pulse Shape Analysis concept

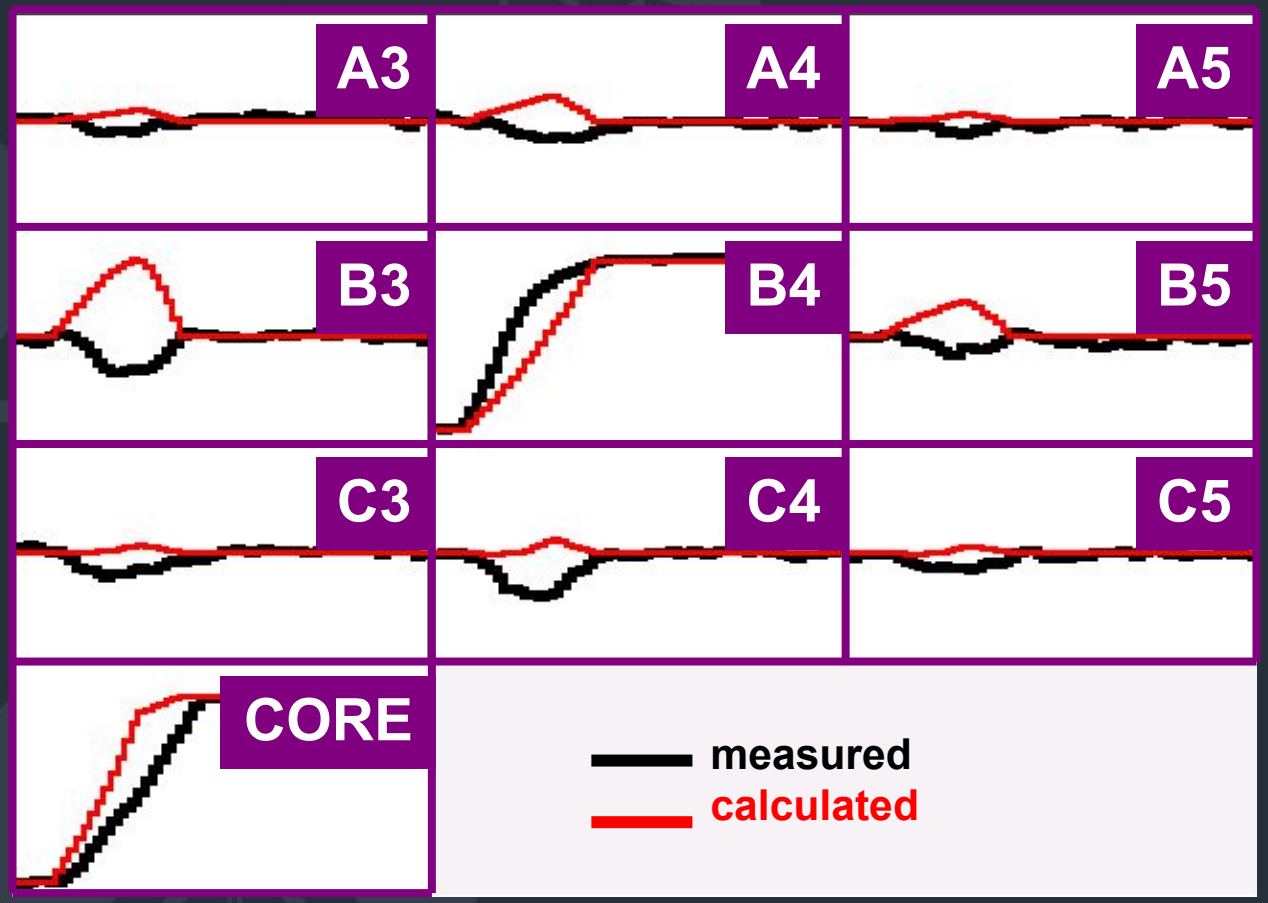


(10,10,46)



791 keV deposited in segment B4

Pulse Shape Analysis concept



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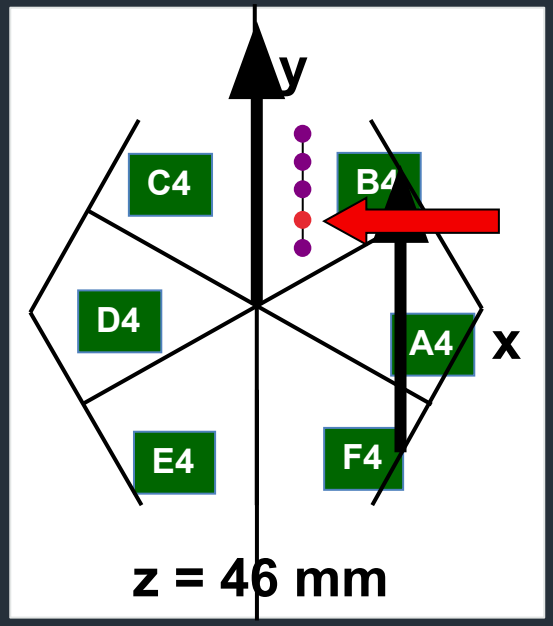
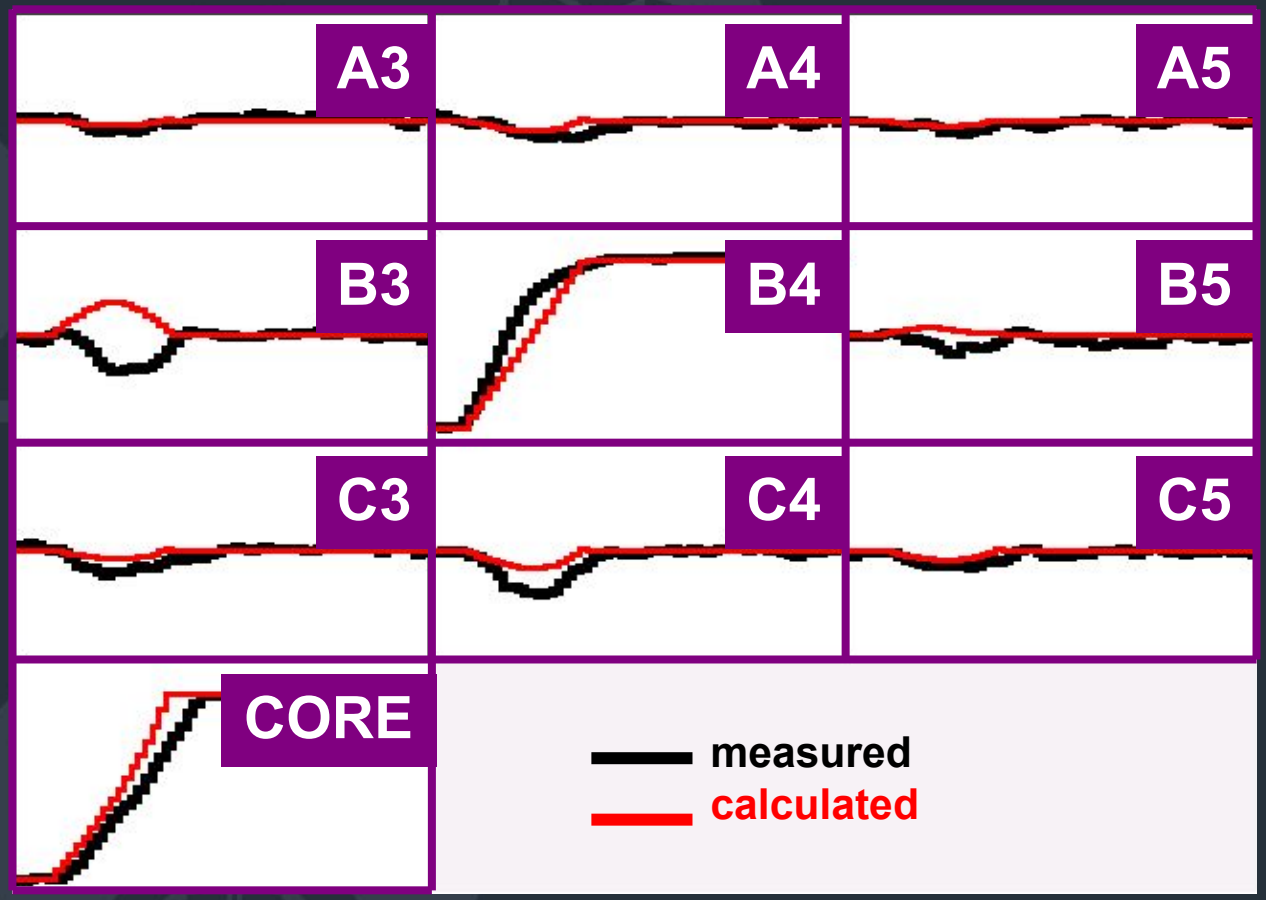


791 keV deposited in segment B4

Pulse Shape Analysis concept



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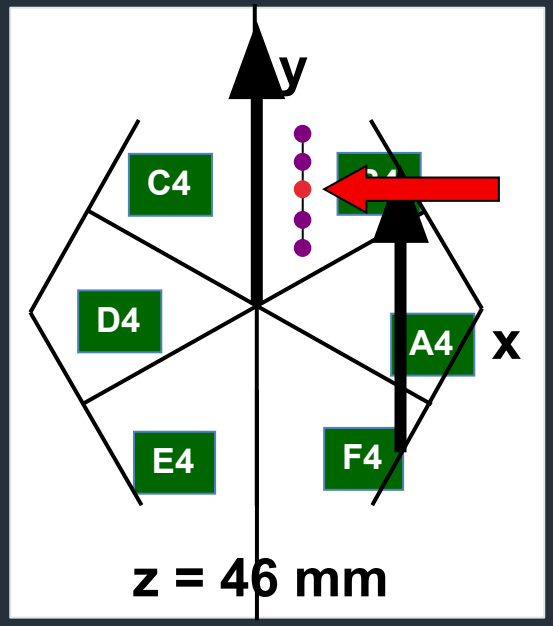
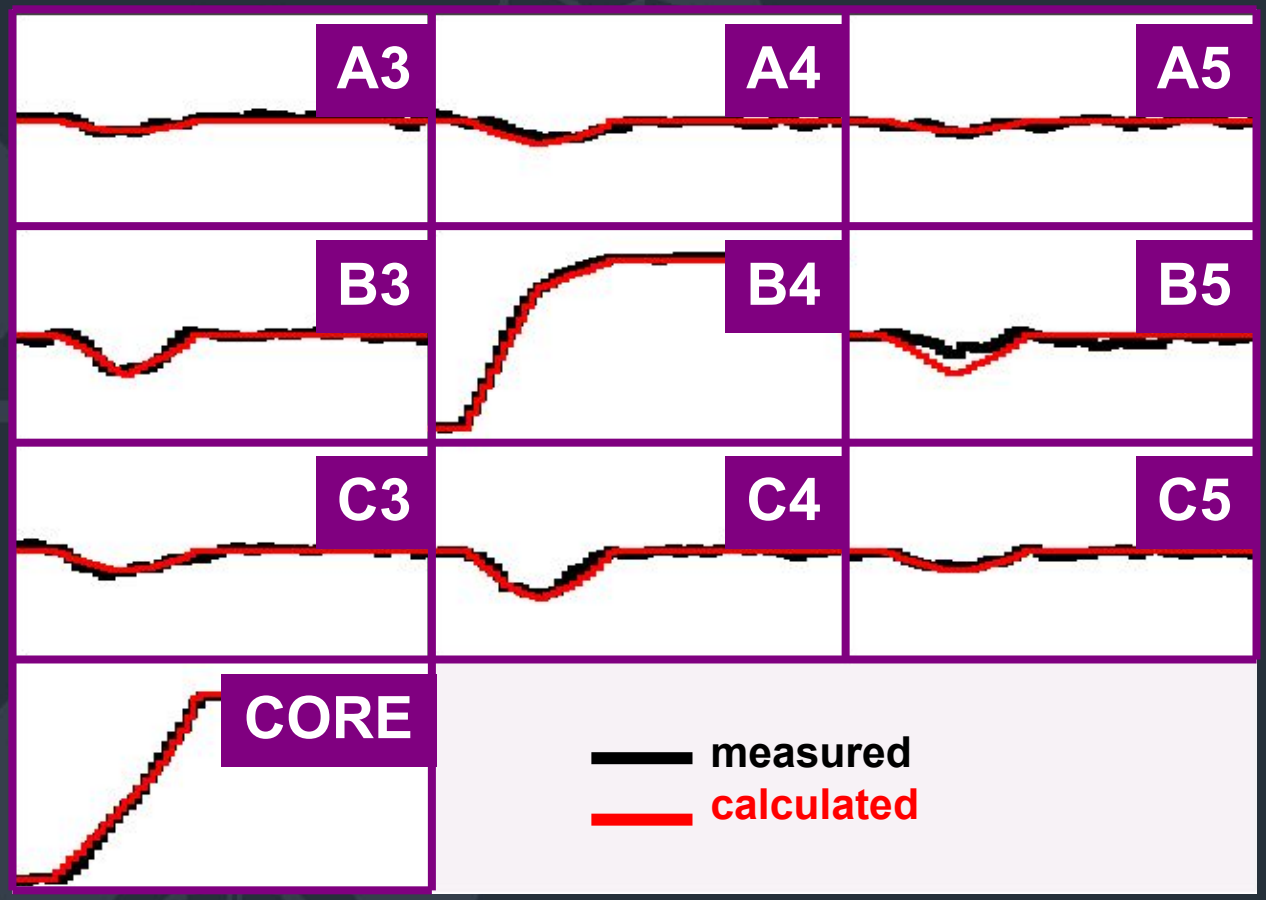


791 keV deposited in segment B4

Pulse Shape Analysis concept



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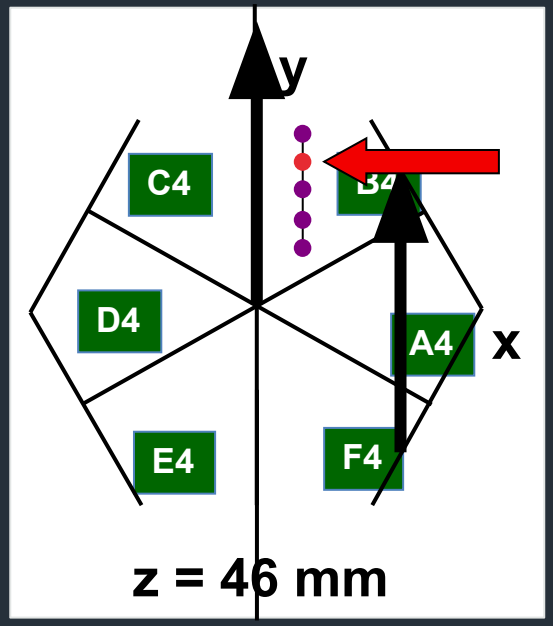
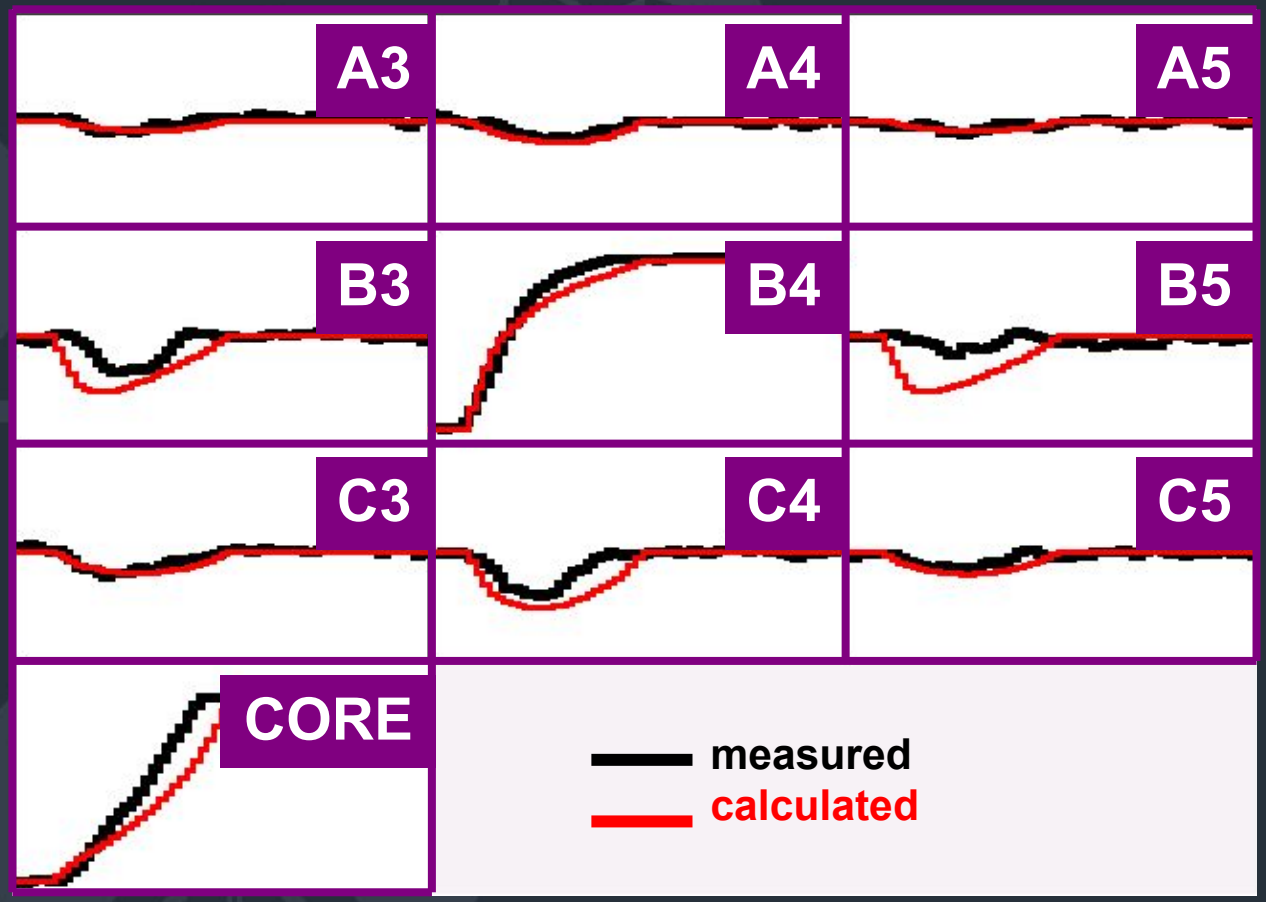
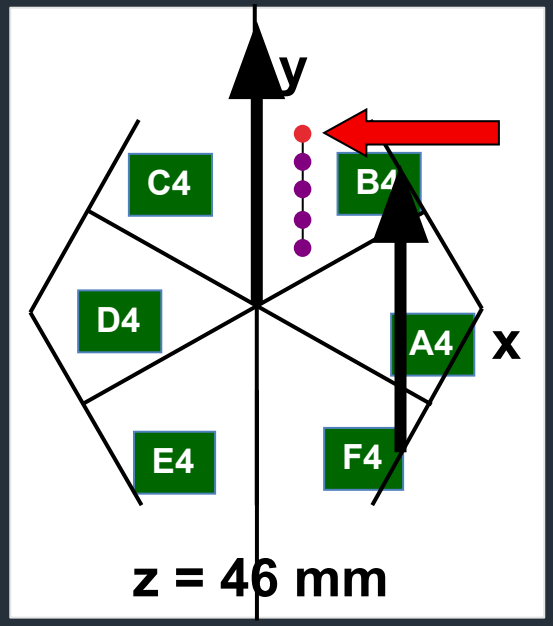


791 keV deposited in segment B4

Pulse Shape Analysis concept

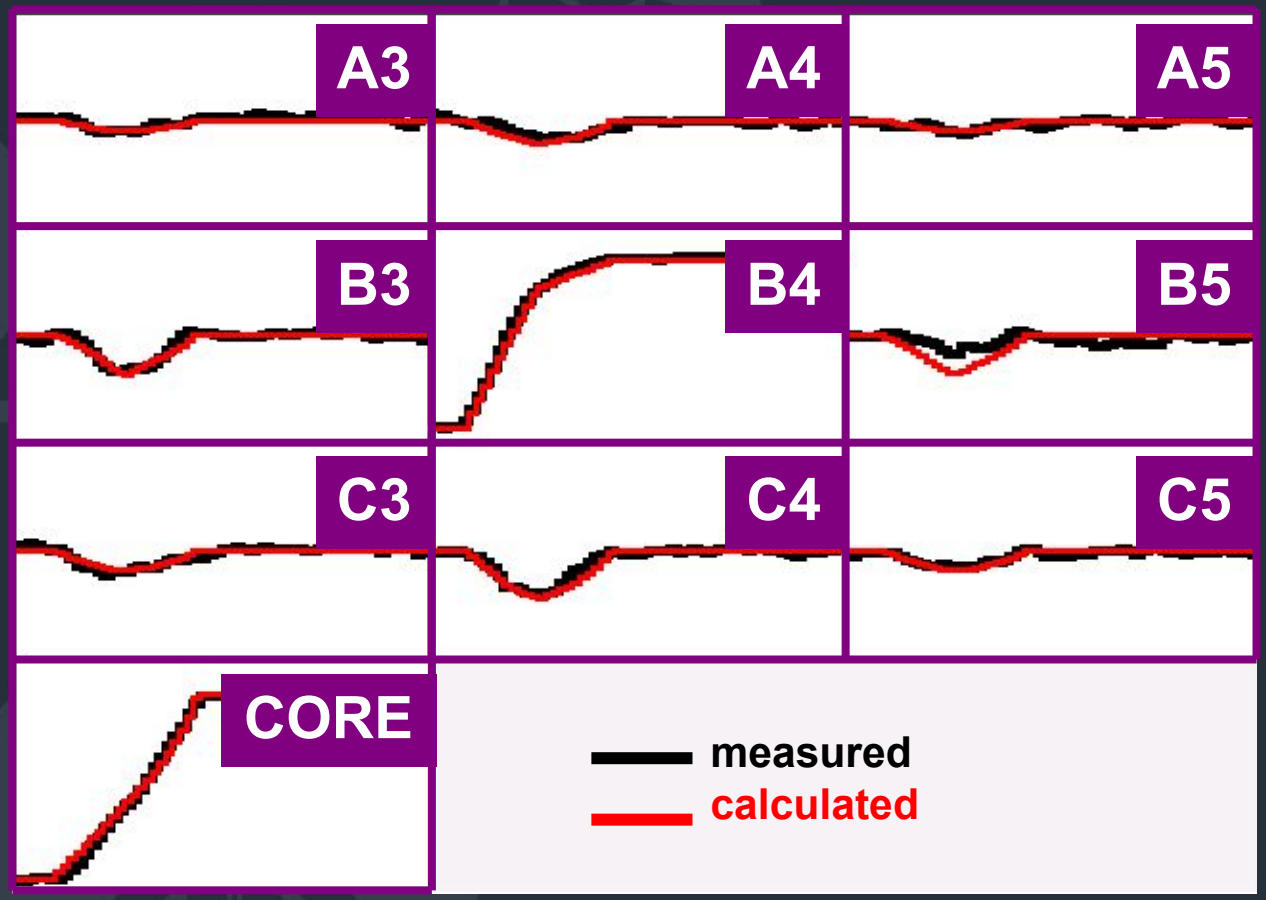


(10,30,46)



791 keV deposited in segment B4

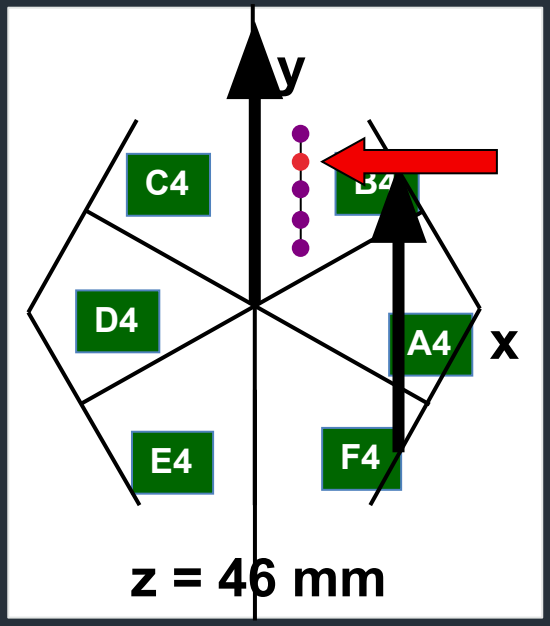
Pulse Shape Analysis concept



791 keV deposited in segment B4

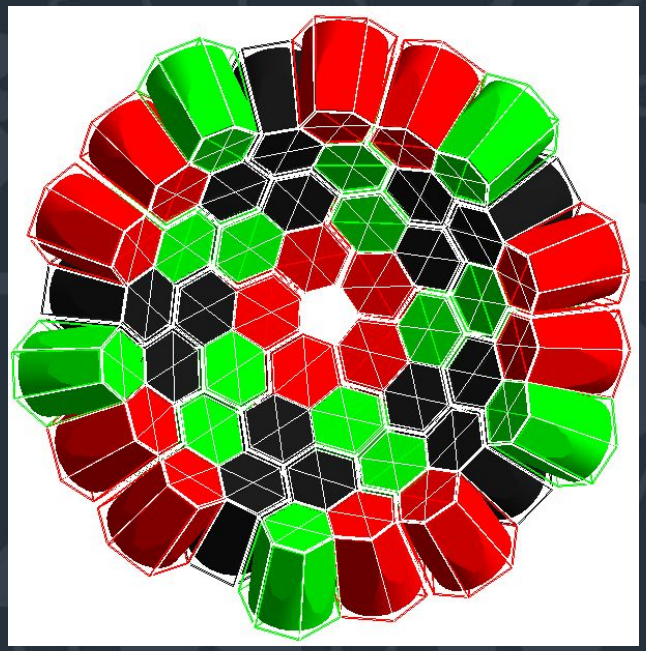
Result of *Grid Search* algorithm

(10,25,46)

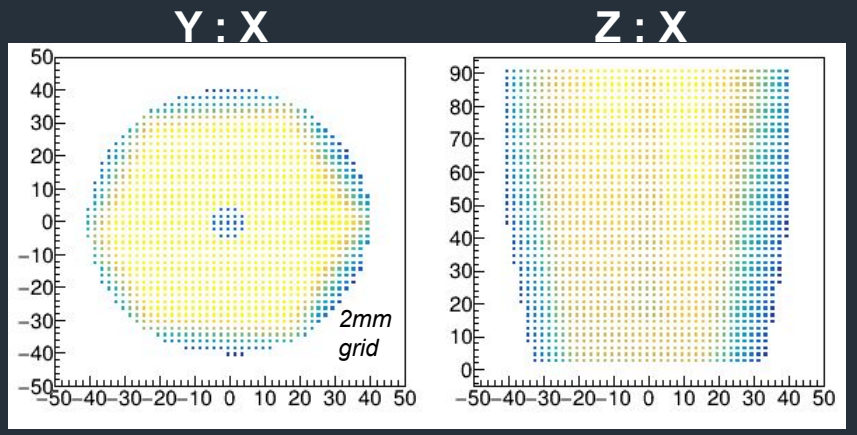


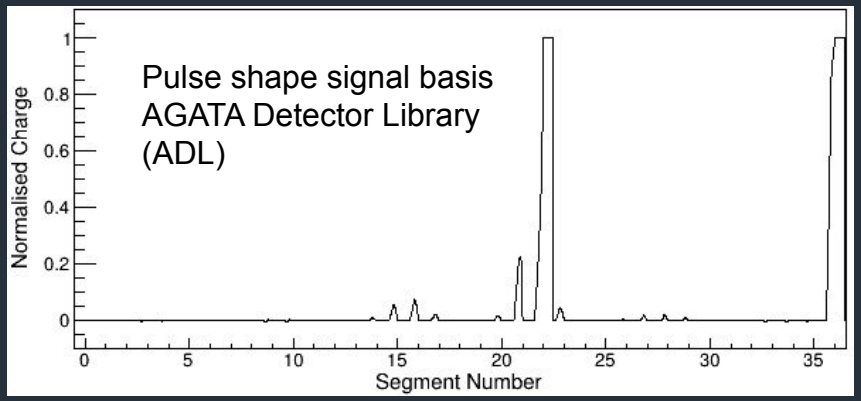
Simulation with Pulse Shape

Geant4:



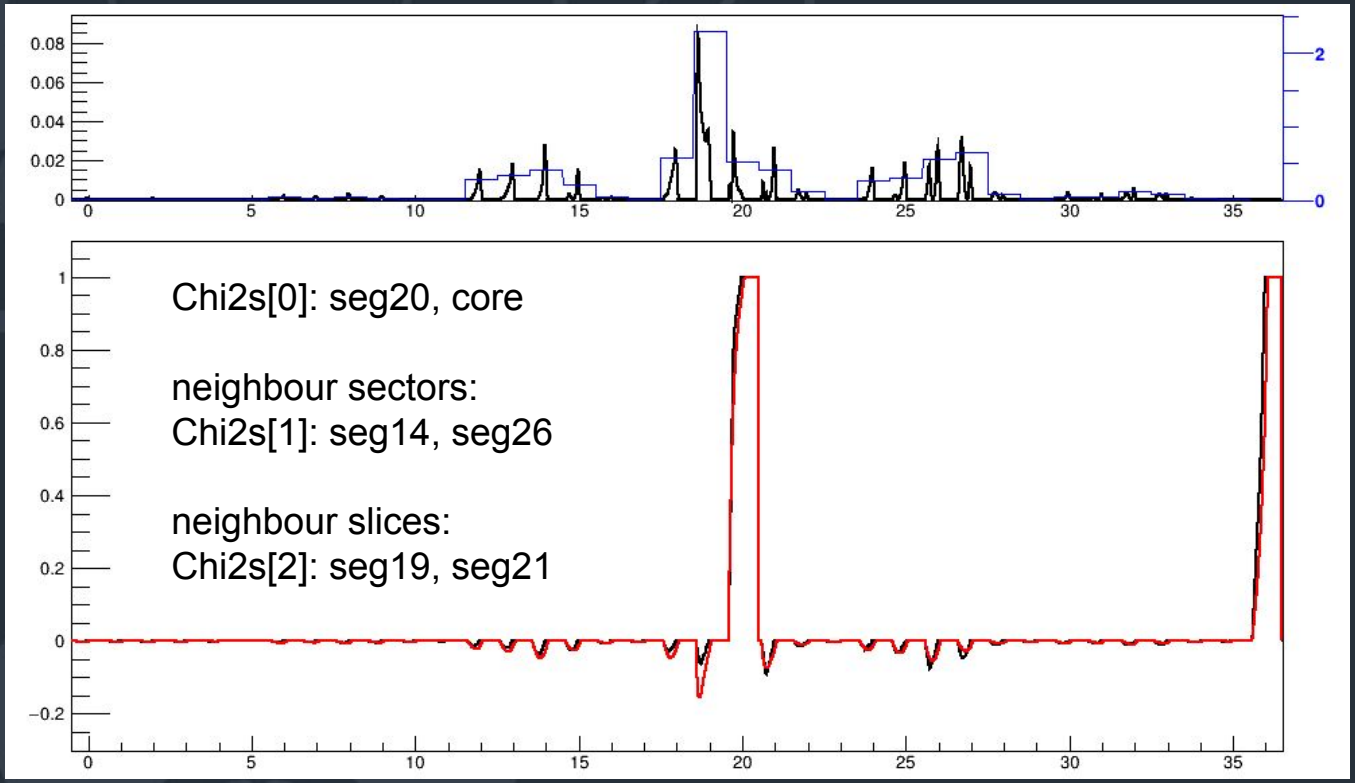
Signal Basis:





- AGATA-1Pi array: 45 detectors
- Geant4: Compton events information
- Linear interpolation ADL pulse shape basis

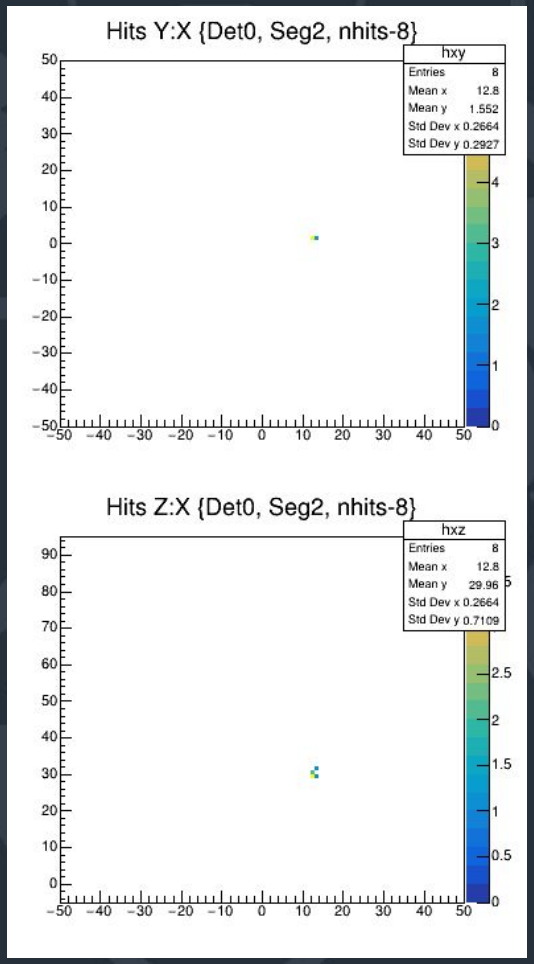
Group Pulse Shape

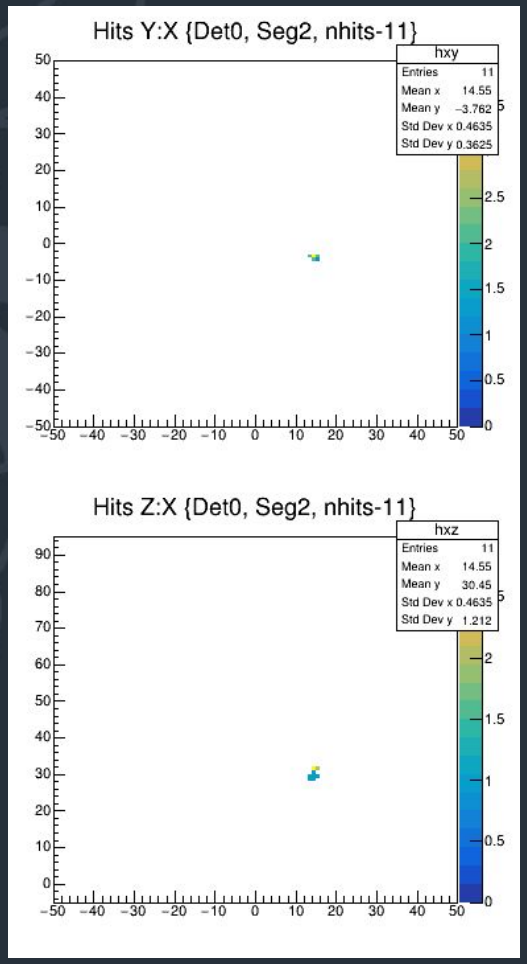


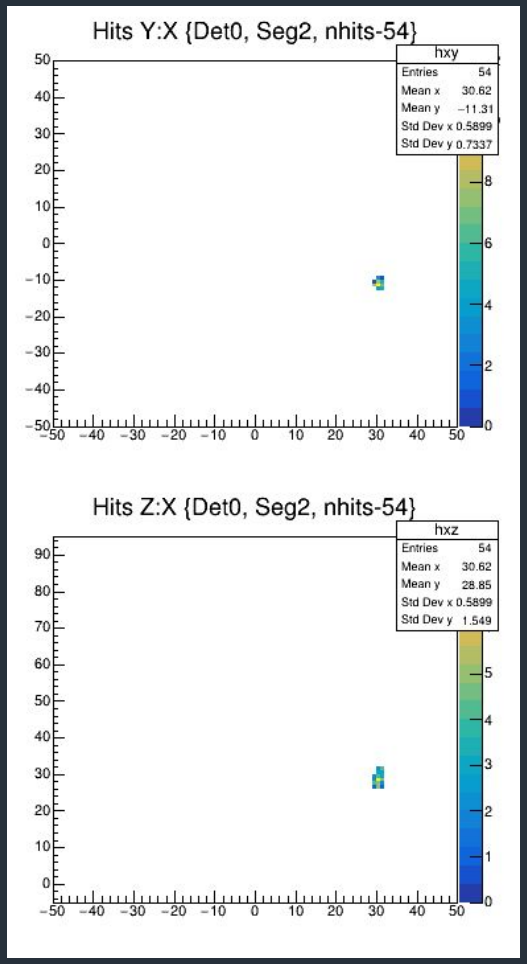

```
seg    = 20
nhits1 = 1 : 1571.00
nhits2 = 1 : 1590.26
nfired = 36
Eng1   = 1571
Eng2   = 1590.26
chi2   = 7.29173
dist   = 9.98804
rdifphi= 7.03852
diffr  = 5.51792
diffz  = 4.50787

PhiRZ1 = -165.32  29.76  31.31
PhiRZ2 = -177.72  35.28  26.80
difphi = 12.4017 degree
```

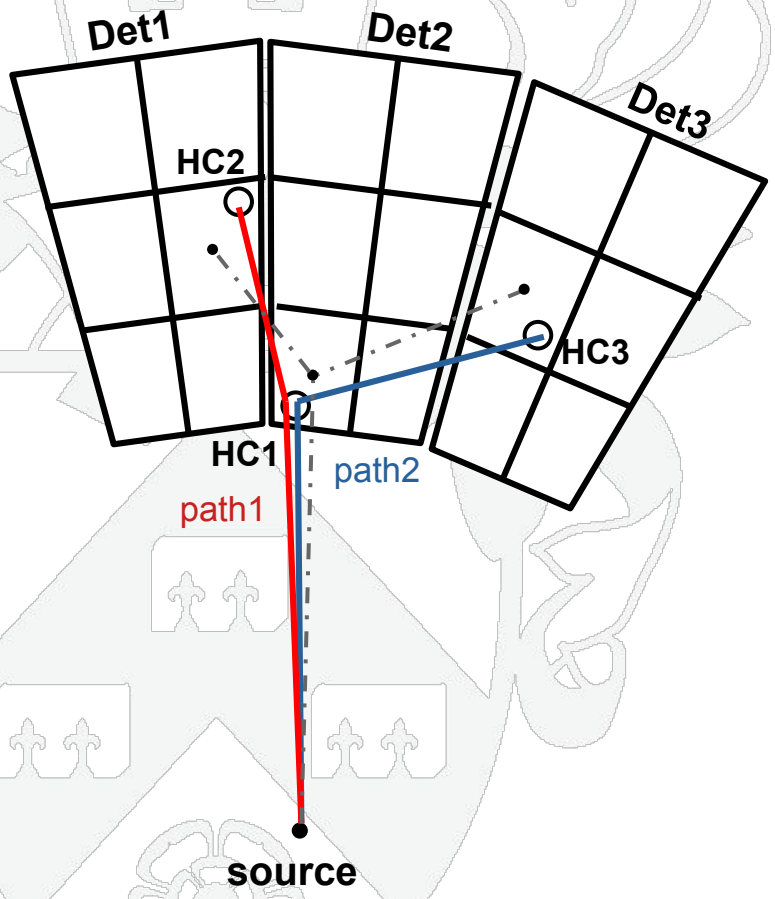
Group Pulse Shape







Position optimization

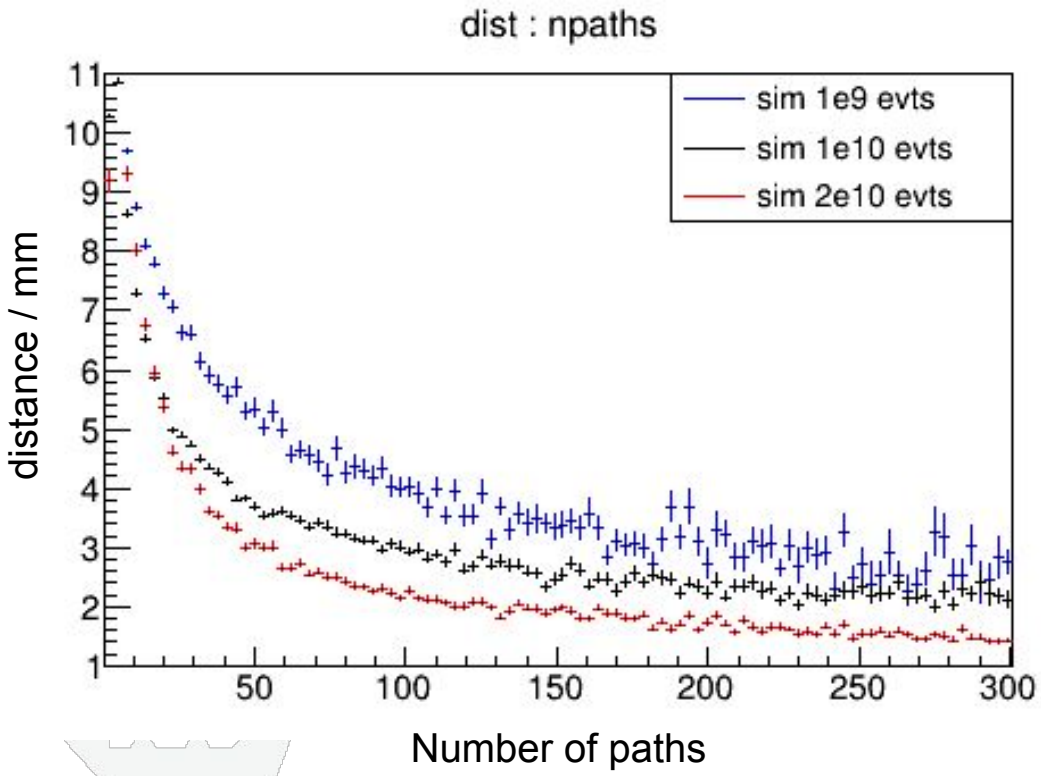


- Initial HC position: segment center
- Compton scattering angle:

$$\cos\Theta = 1 + \frac{m_e c^2}{E_{inc}} - \frac{m_e c^2}{E_{inc} - E_{dep}}$$

- Scattering angle from path Θ'
- Optimize HC position
  → reduce angle difference
- Loop HCs and iteration

Position resolution



- Simulation data size influence to position resolution

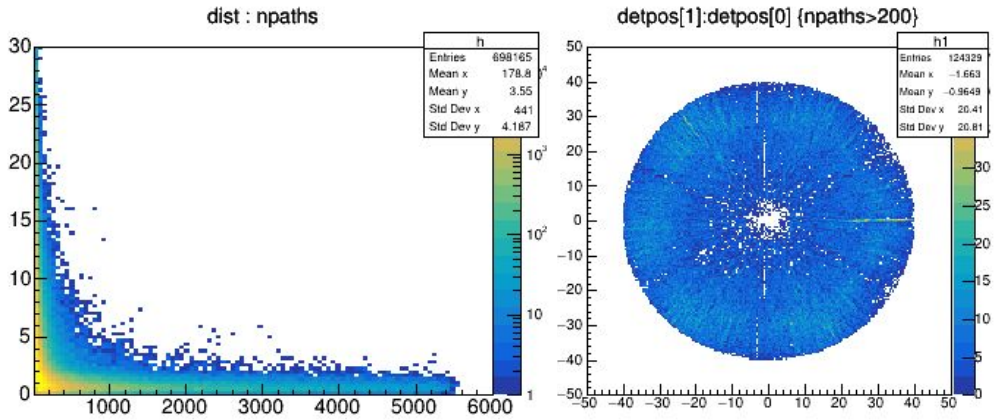
Simulation: Position resolution

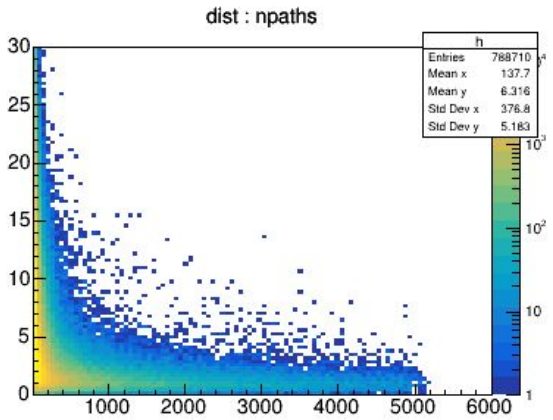
UNIVERSITY of York

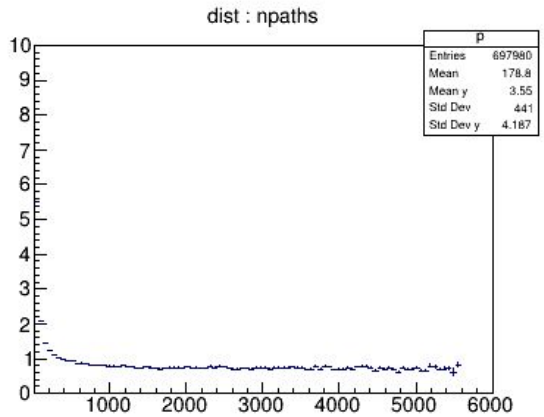
Simulate 2MeV gamma 1e11 events

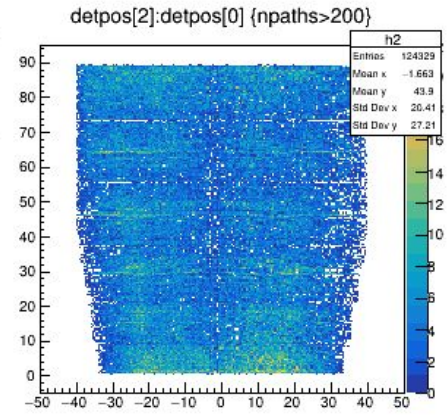
without noise

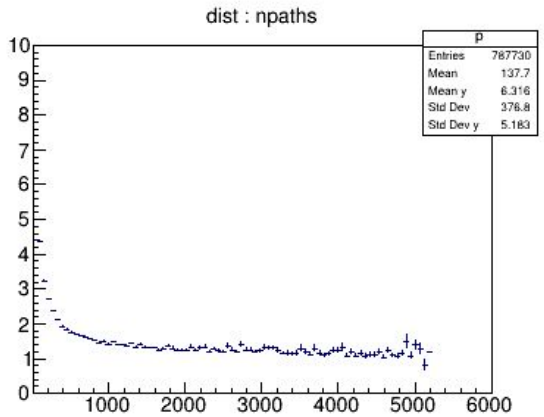
with noise









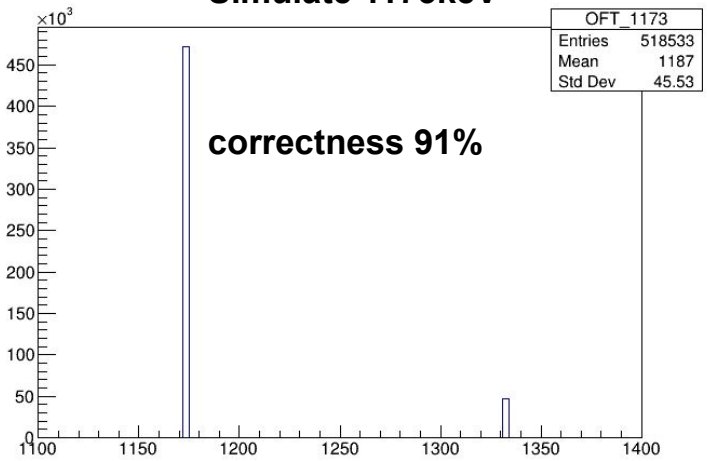


Gamma source

Identify incoming energy according to figure of merit from OFT

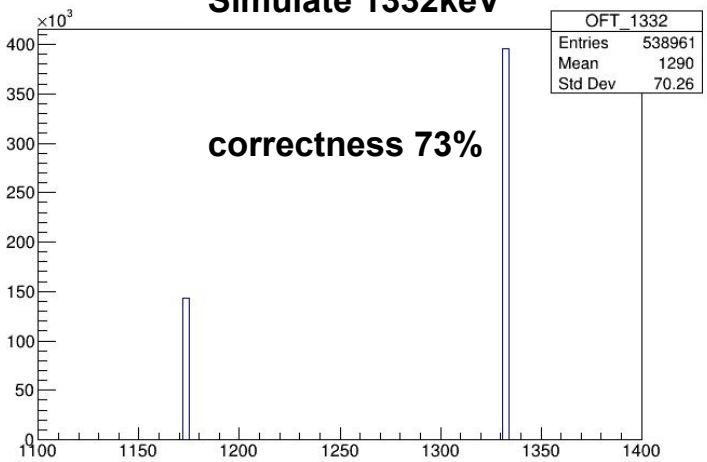
^{60}Co source

Simulate 1173keV



correctness 91%

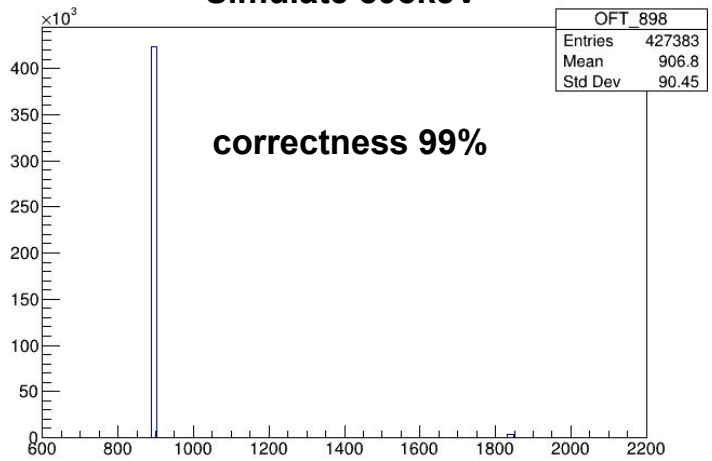
Simulate 1332keV



correctness 73%

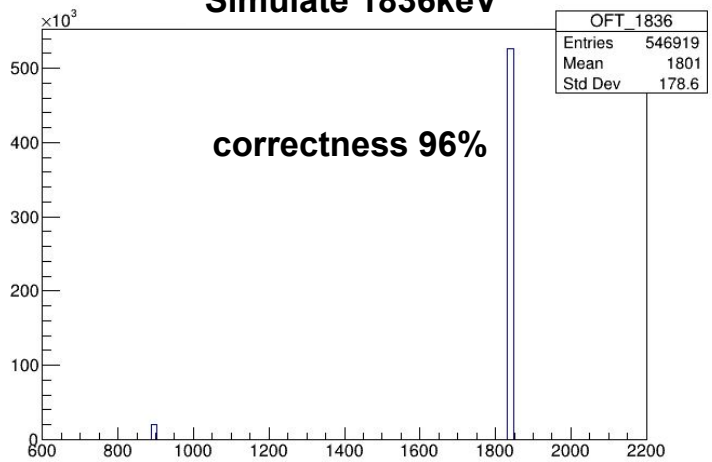
^{88}Y source

Simulate 898keV



correctness 99%

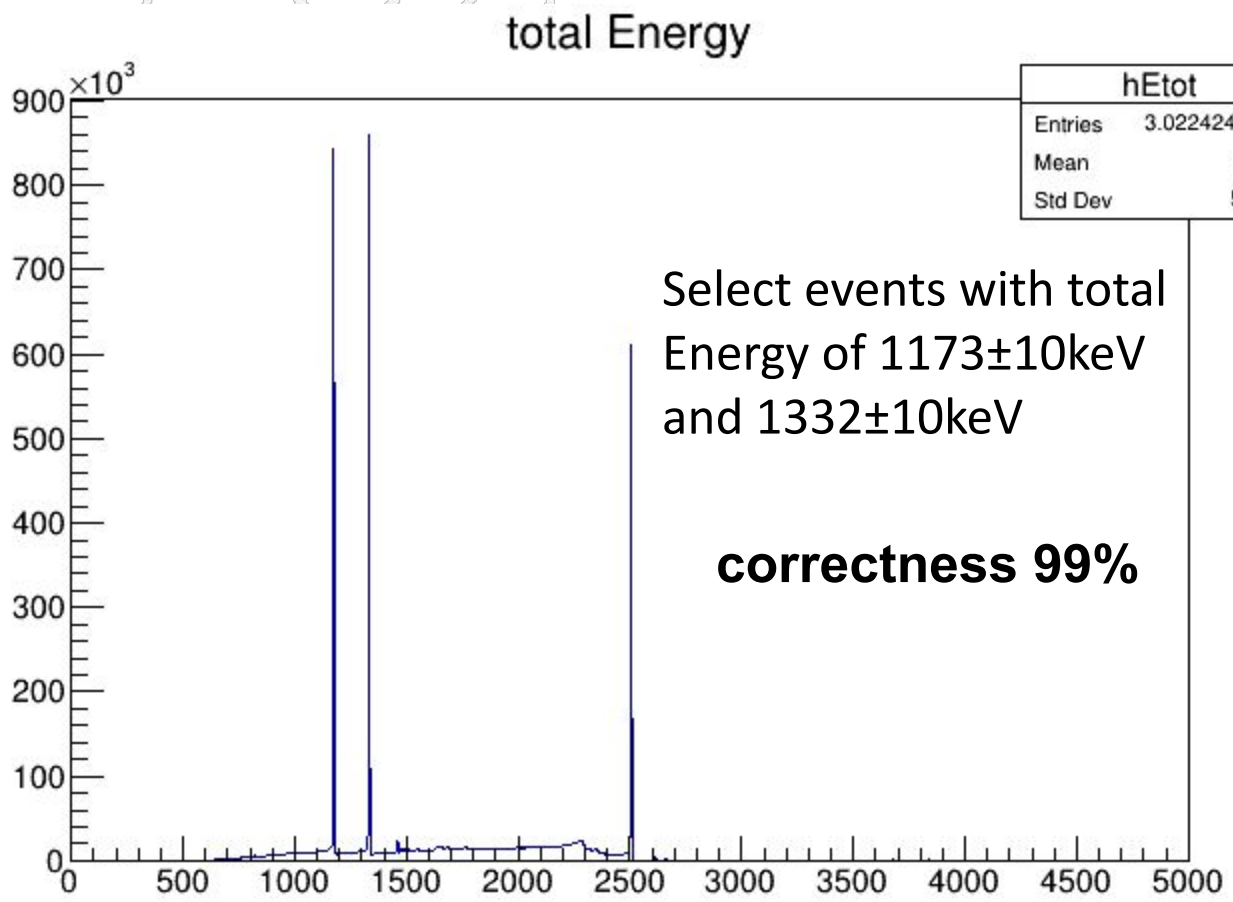
Simulate 1836keV



correctness 96%

^{60}Co source

Identify incoming energy according to total energy deposit in array



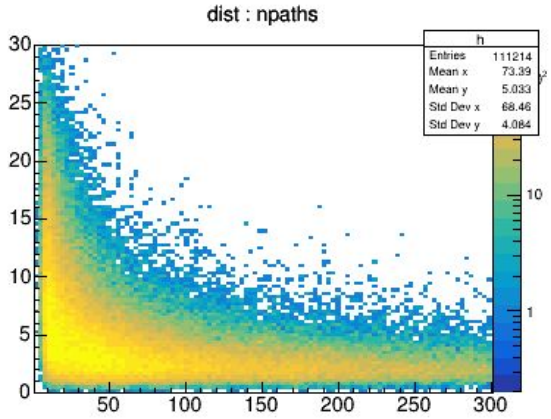
Select events with total Energy of 1173±10keV and 1332±10keV

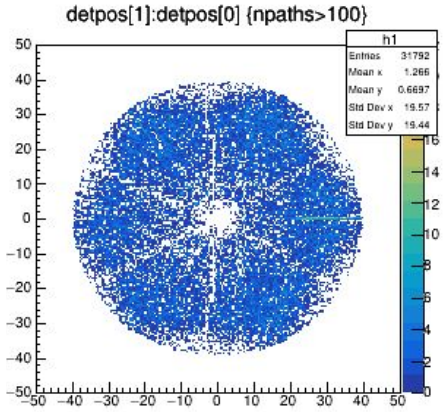
correctness 99%

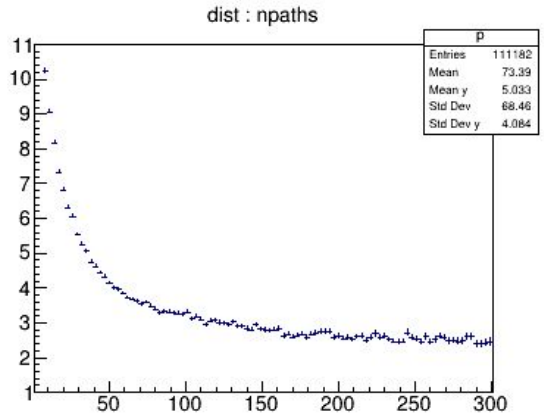
^{60}Co source

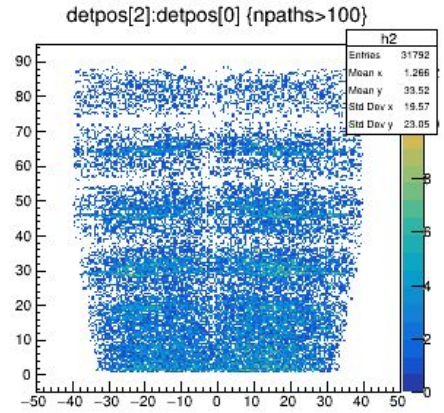
Simulate ^{60}Co source 2e10 evts (energy gate ±10keV, ~2e8 good evts)

accurate source position

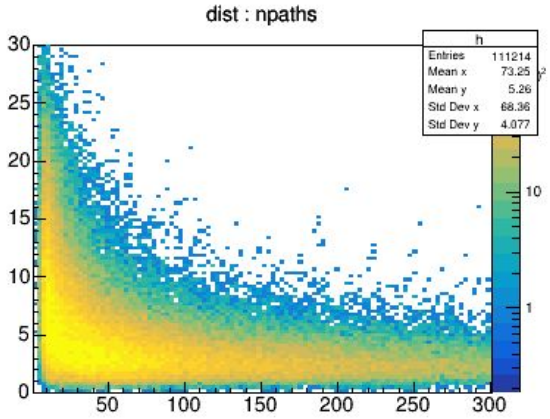


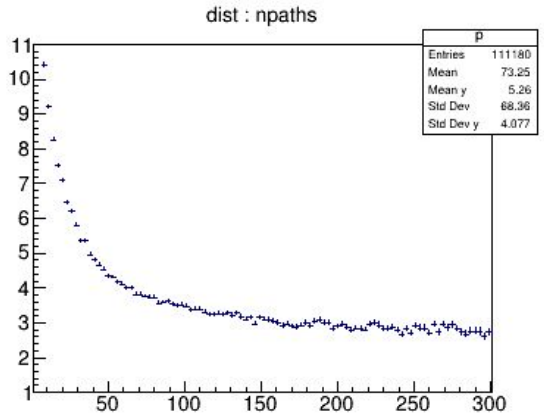




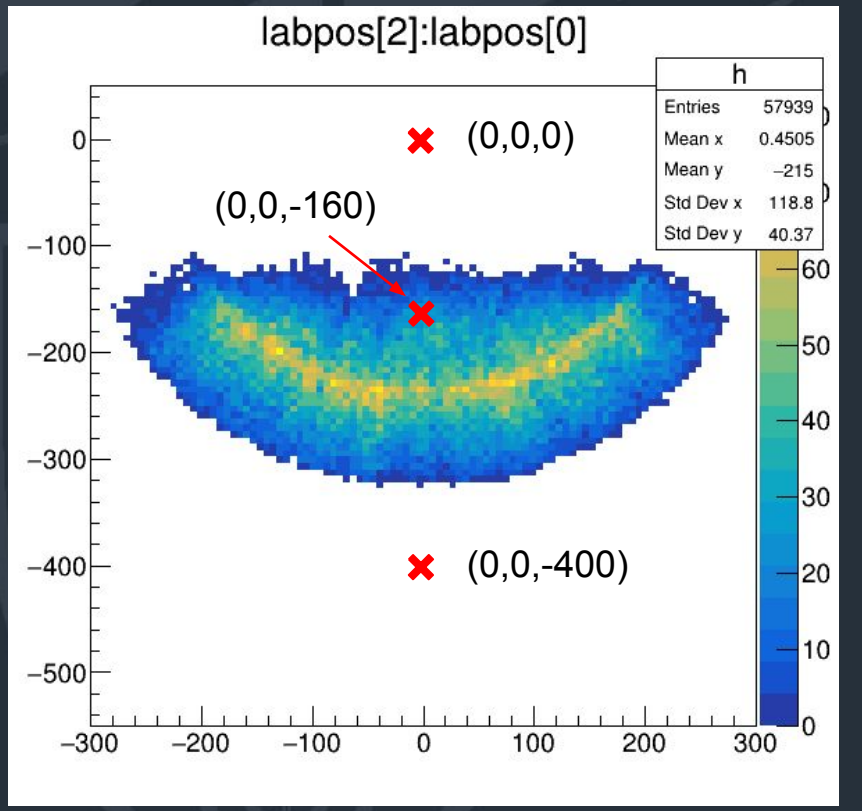


10mm mistake

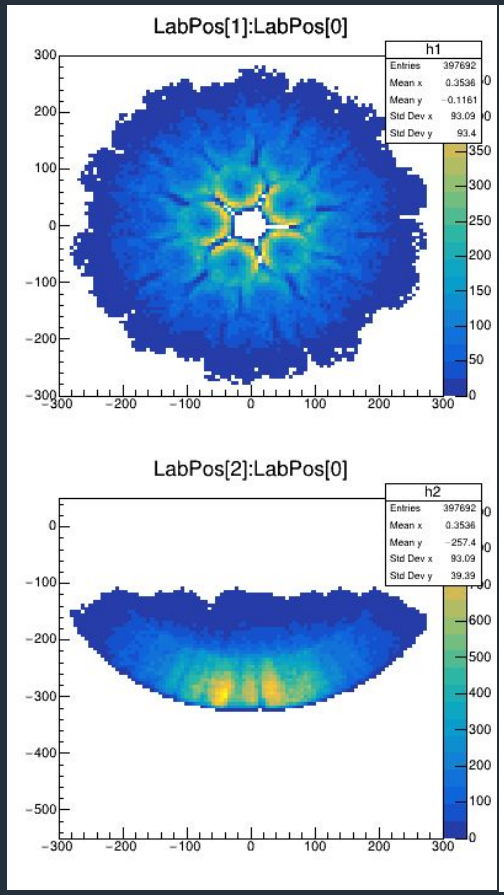




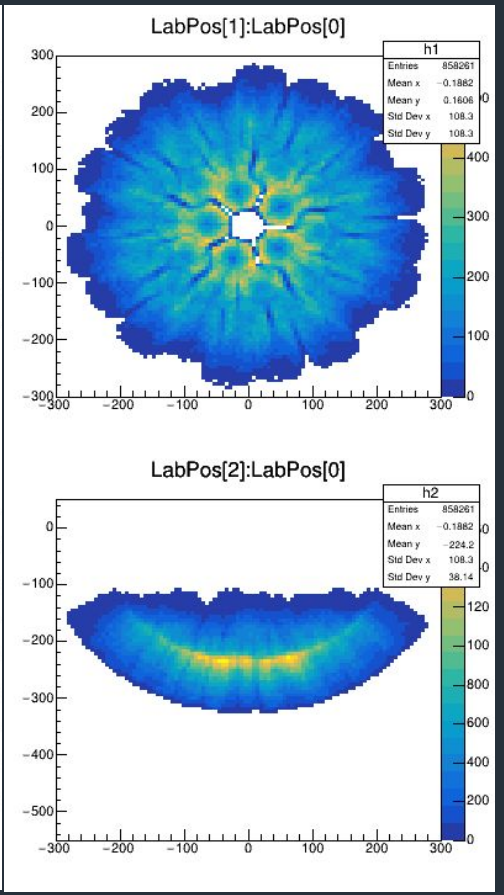
Source position



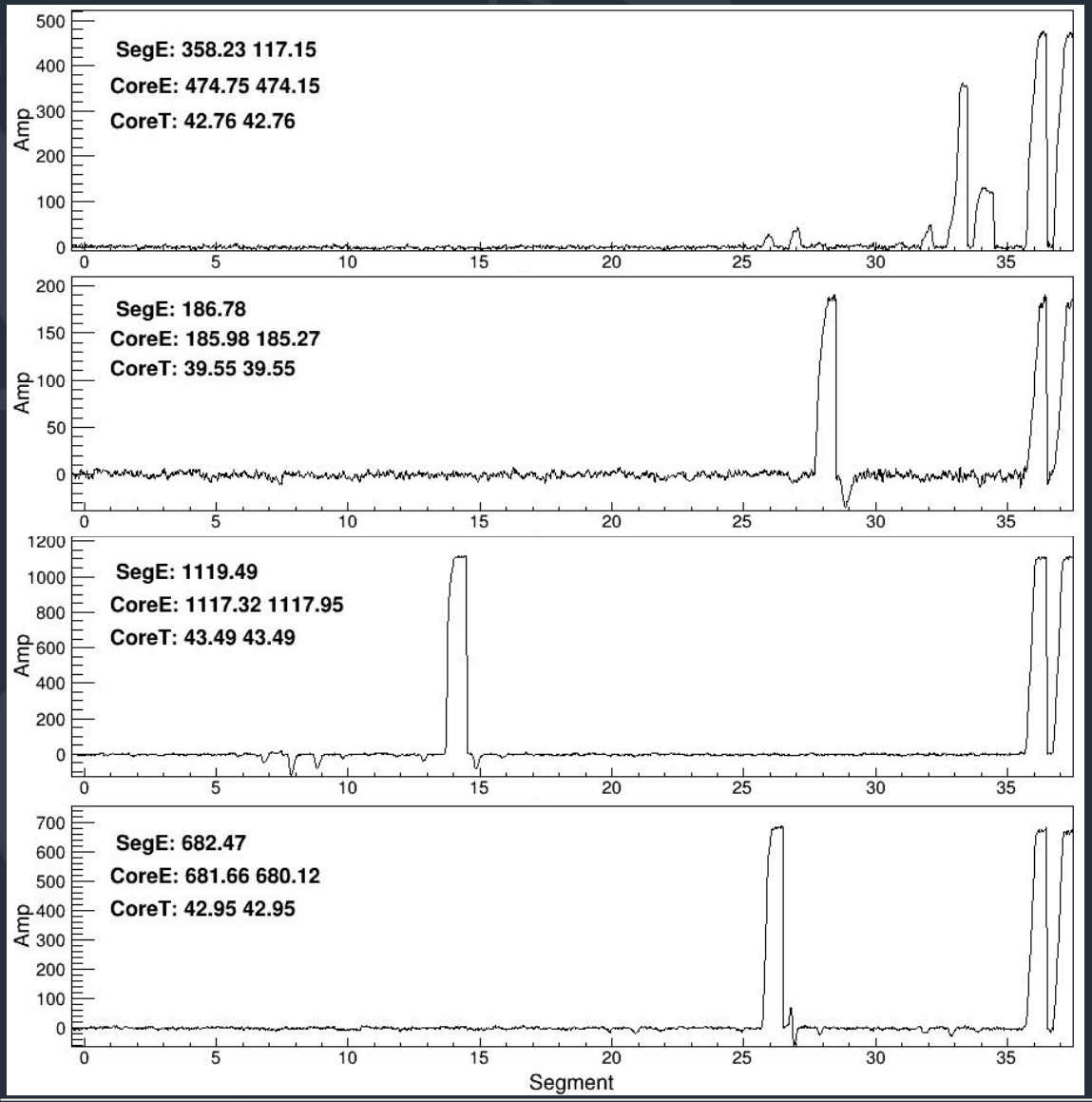
Source at (0,0,-400)



Source at (0,0,-160)



Calibration data



✗ multi segments hit

✗ small signal

✗ small Compton signal

○ accepted