Development of a self-calibration technique for gamma-ray tracking arrays

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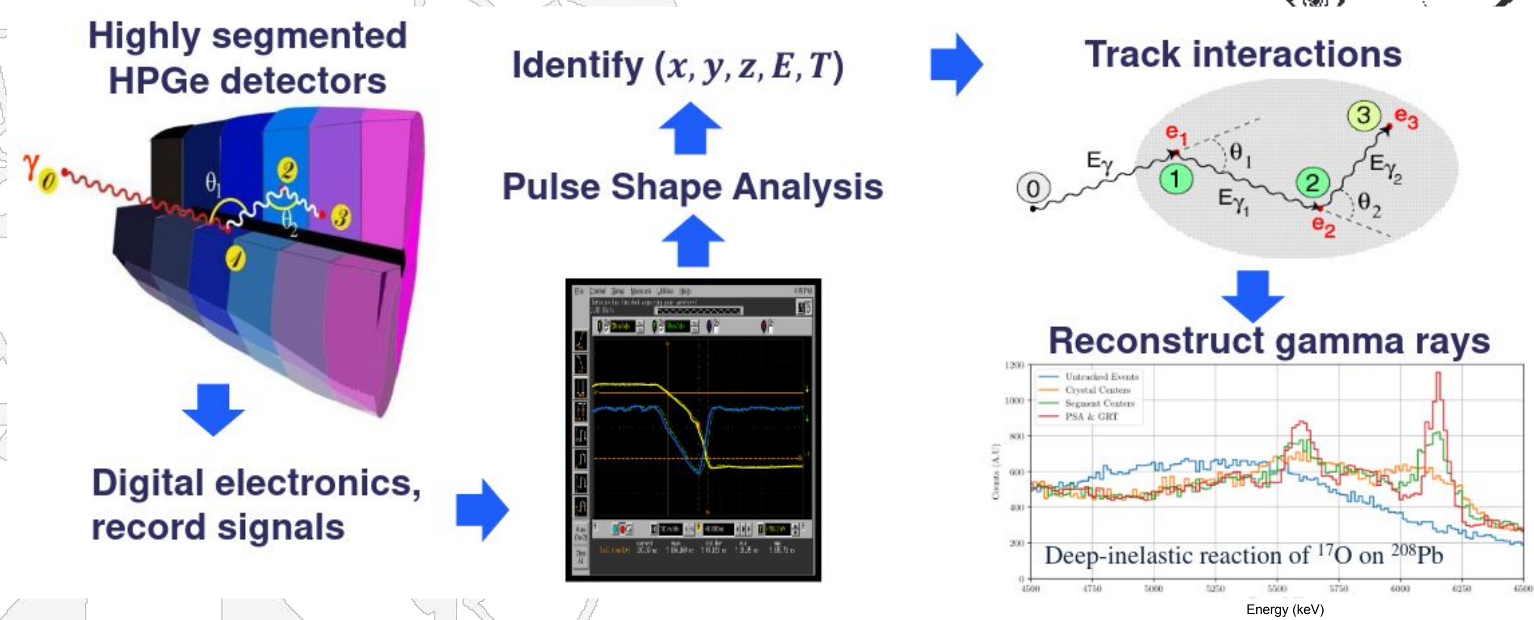
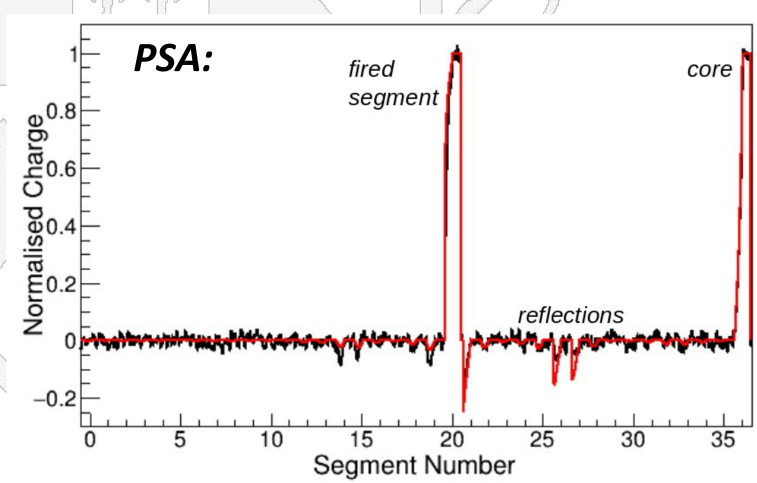
1. University of York, 2. STFC Daresbury Laboratory, 3. University of Liverpool

the 24th AGATA week, Milano

Gamma-ray tracking array





- 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

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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

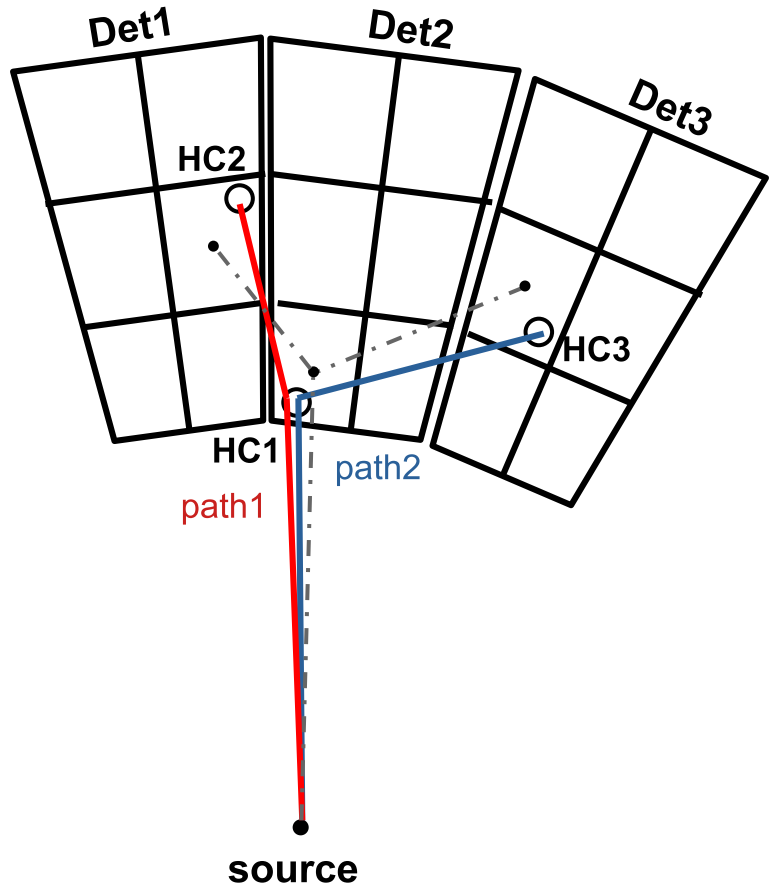
S. Heil, S. Paschalis, and M. Petri,
Eur. Phys. J. A (2018) **54**: 172

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

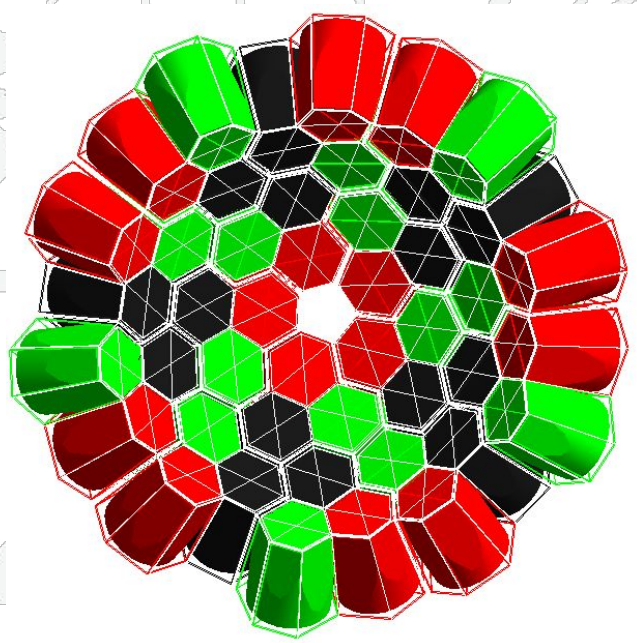
Optimise coordinates of hit collection using the tracks that link their constituent points and Compton formula



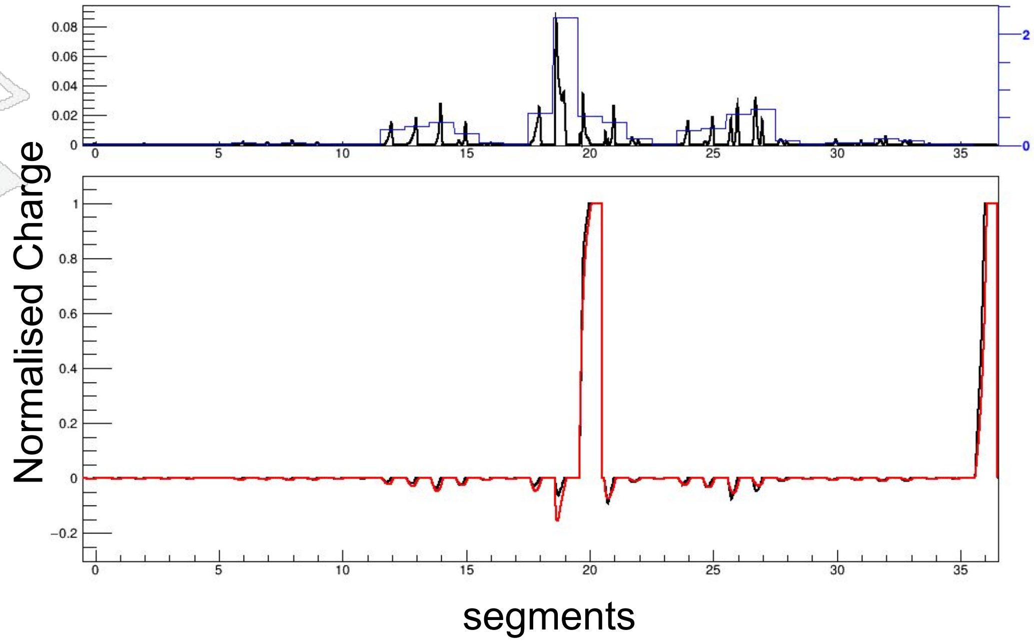
- Produce pulse shape basis for all detectors
- Strong gamma source illuminate the whole array
- Compton formula optimize scattering events

Simulation with Pulse Shape

Geant4 simulation:

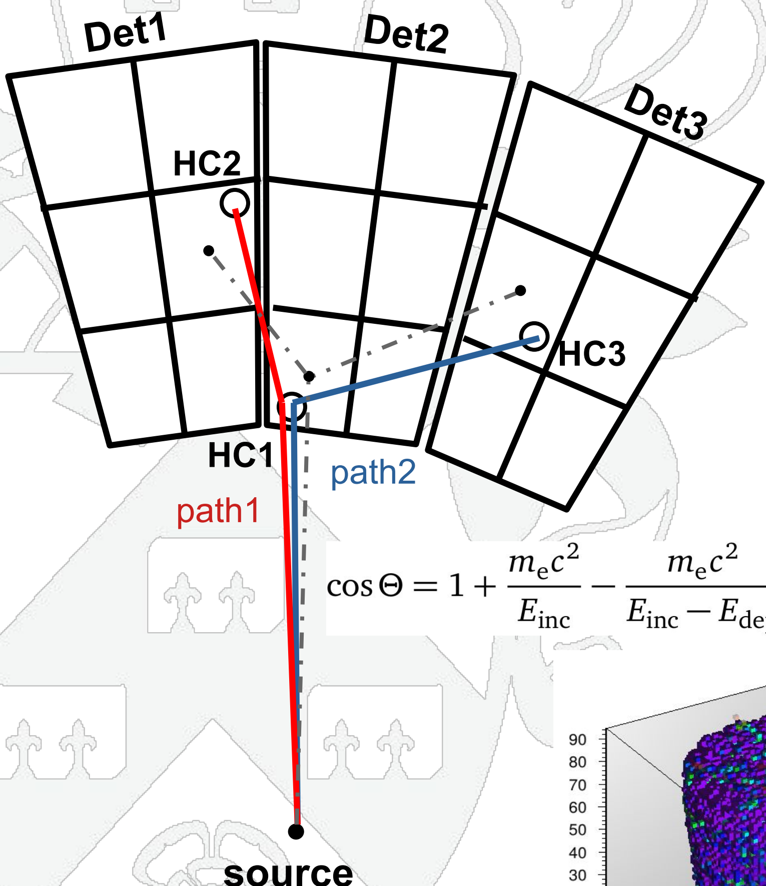


Group pulse shape:

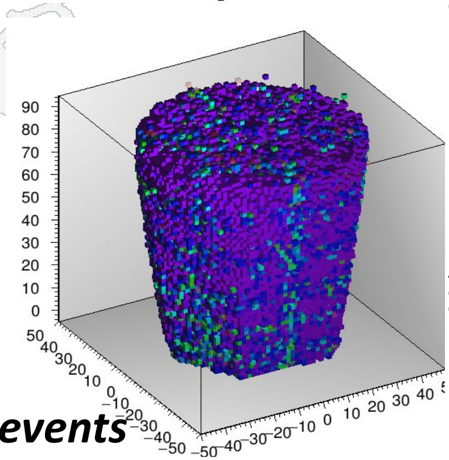


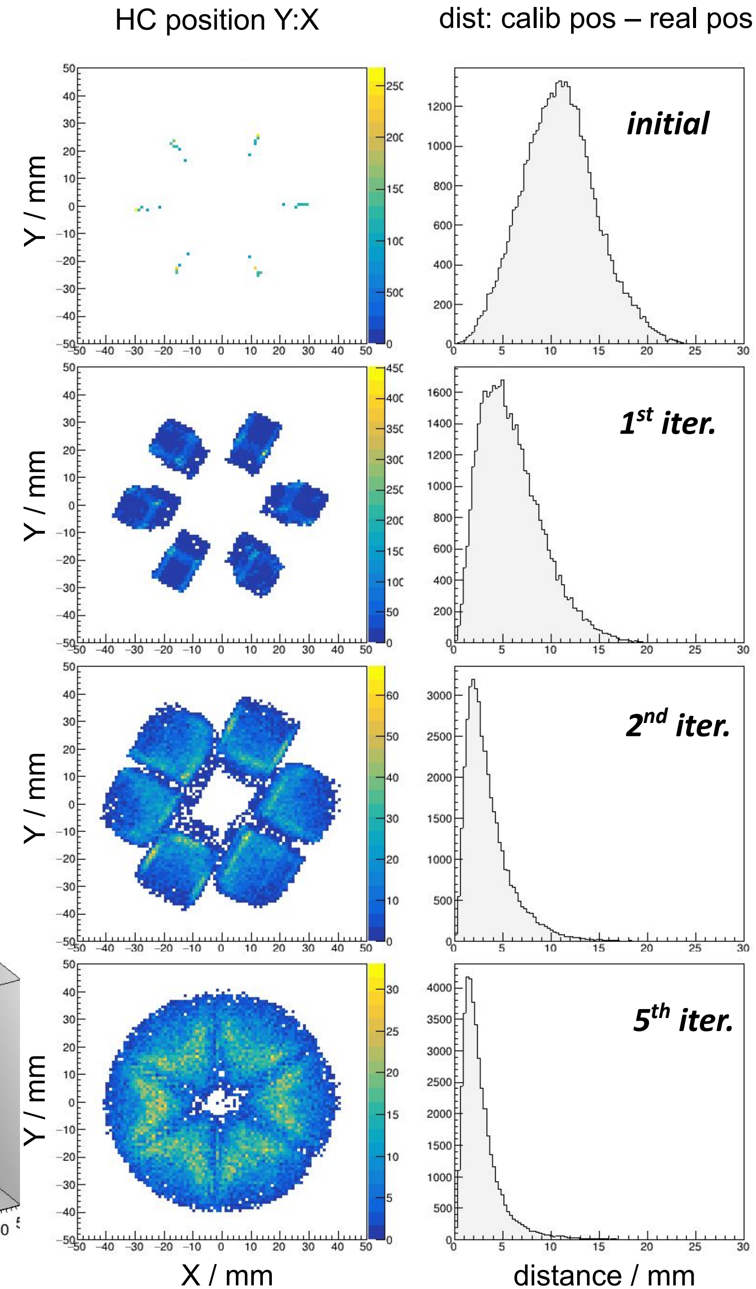
- Geant4 simulate AGATA-1Pi array, save Compton scattering events
- Pulse shape basis linear interpolation → simulation data
- Group pulse shape according to similarity

Simulation: Position optimization



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

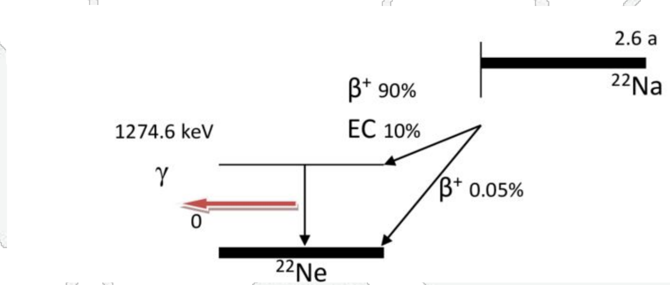




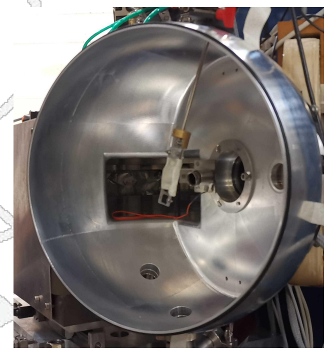
Simulate 2MeV gamma 2e10 events

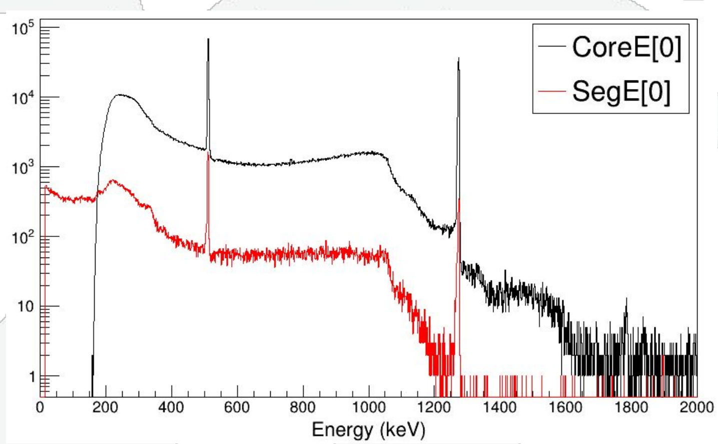
Experiment: source data

^{22}Na source, 130kBq

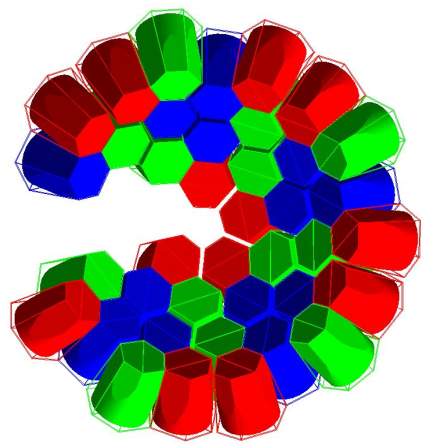


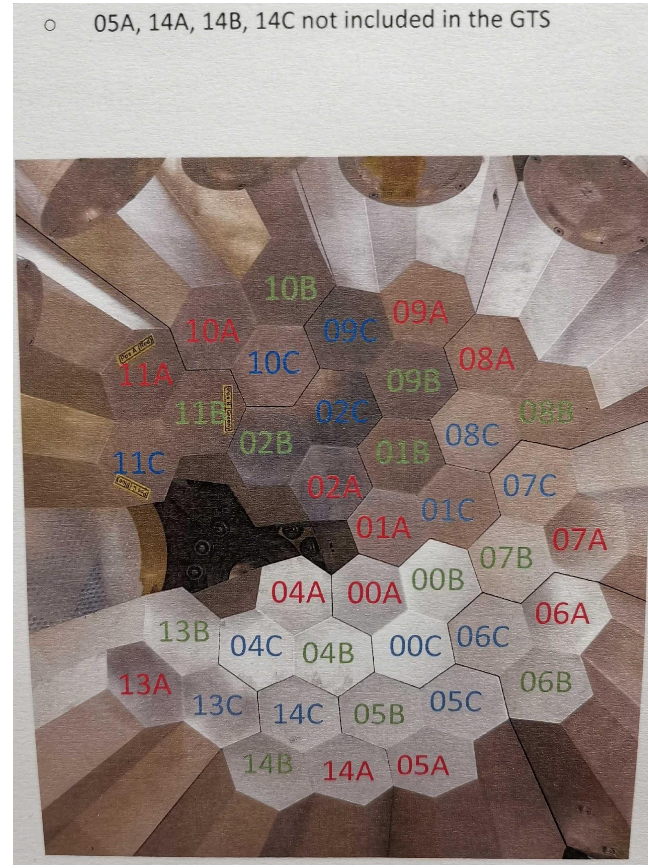
source at target position





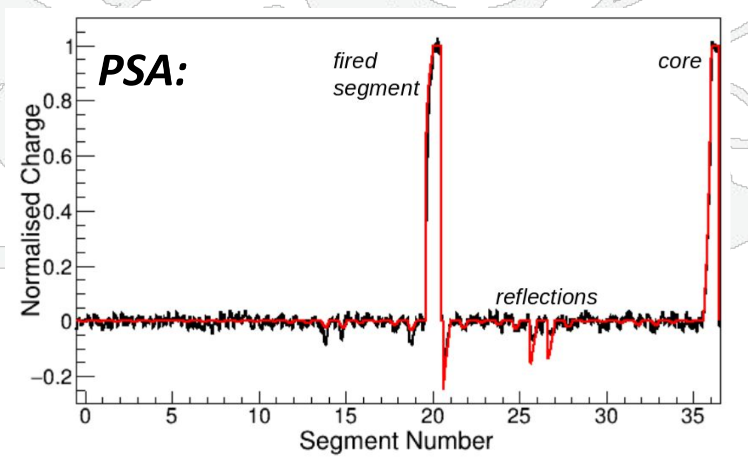
13 ATC at LNL

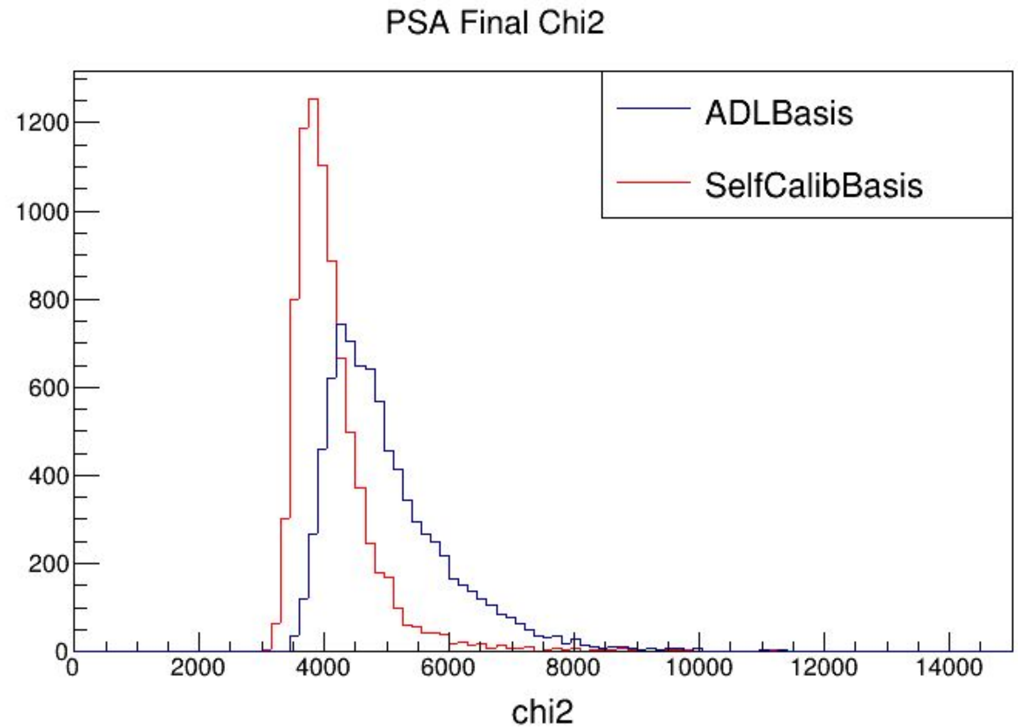




- ^{22}Na source at center of array
- Large signals, CoreE>200keV (CoreE>300keV data is used for self-calibration)
- Compton scattering events (fold 2 trigger)

Pulse Shape Analysis (PSA)

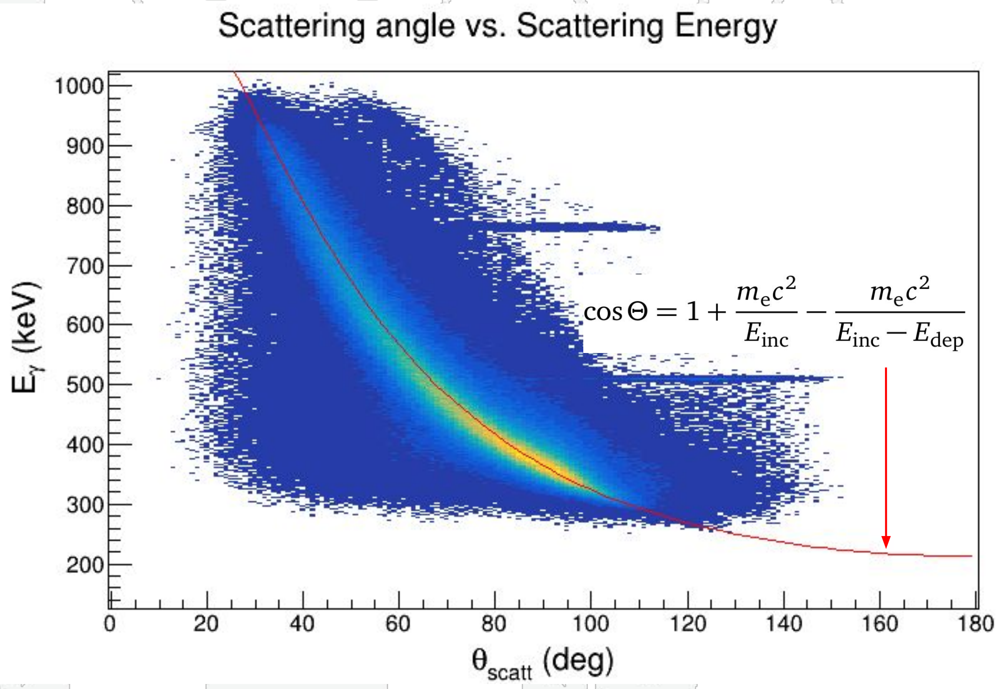


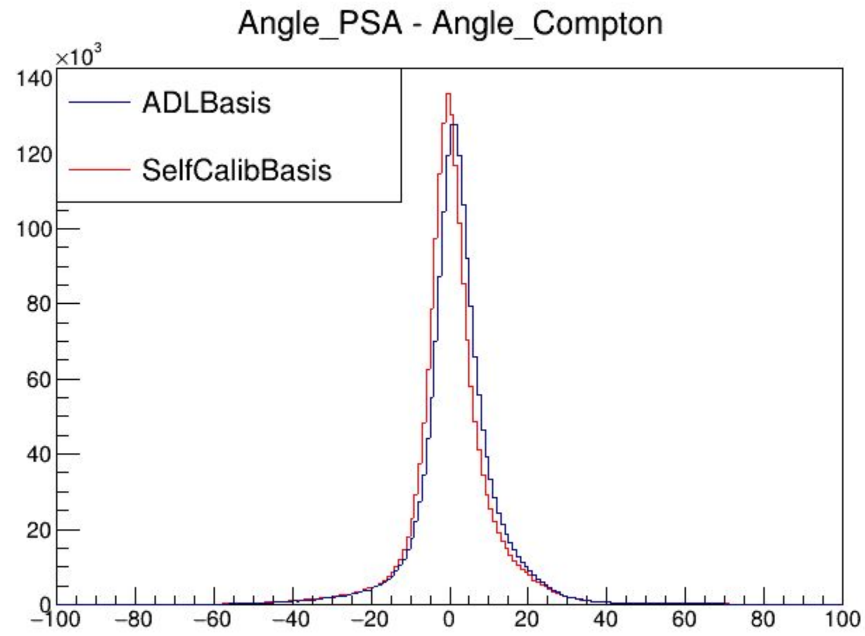


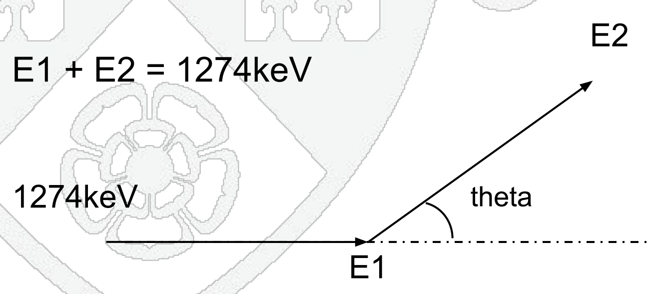
- ADL (AGATA Detector Library): theoretical calculated basis on 2 mm grid
- Chi2: the difference between experimental signal and the signal basis fitting
- The PSA final chi2 with self-calibration basis is smaller than that with ADL basis

  ⇒ self-calibration basis better describe experimental signal

Compton Scattering Angle

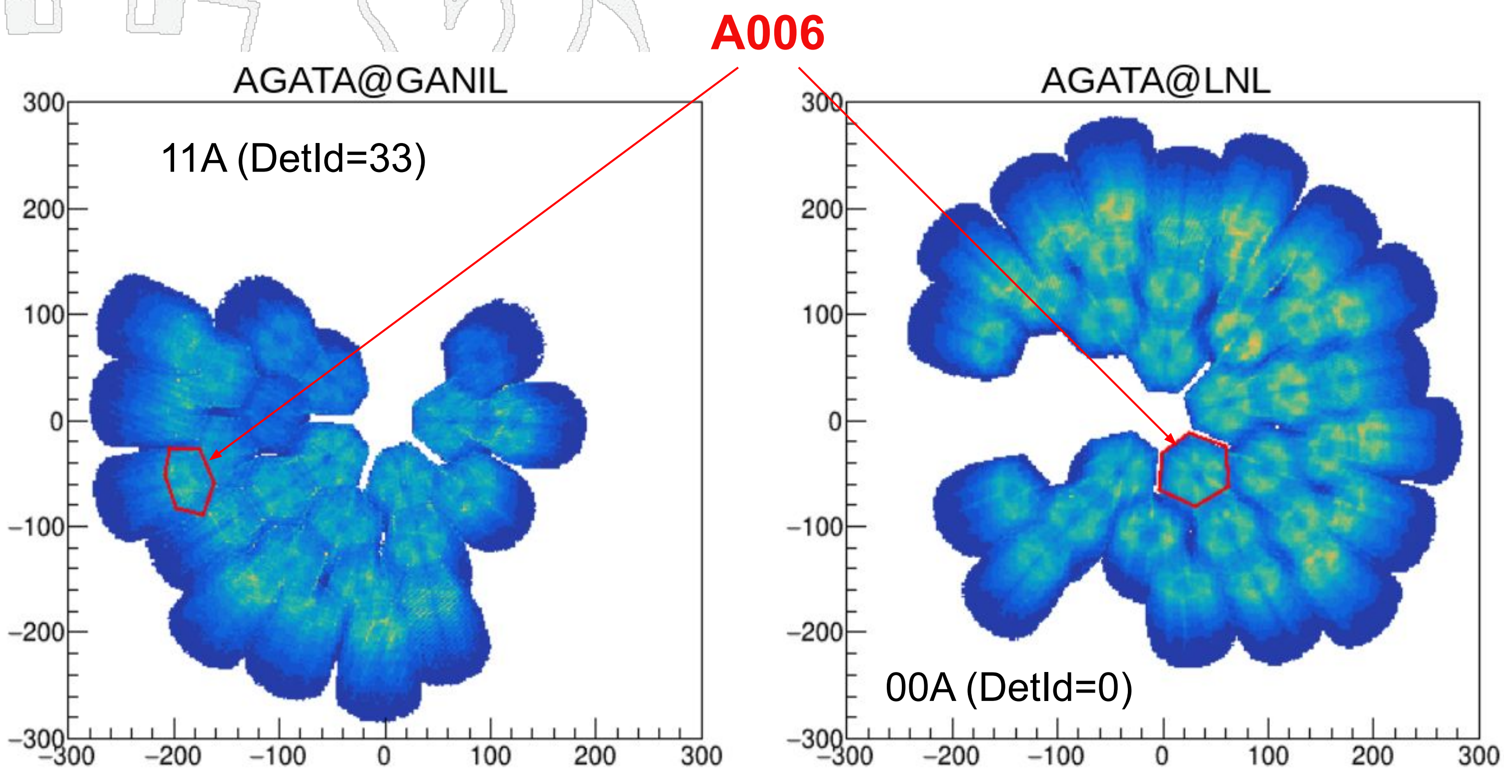






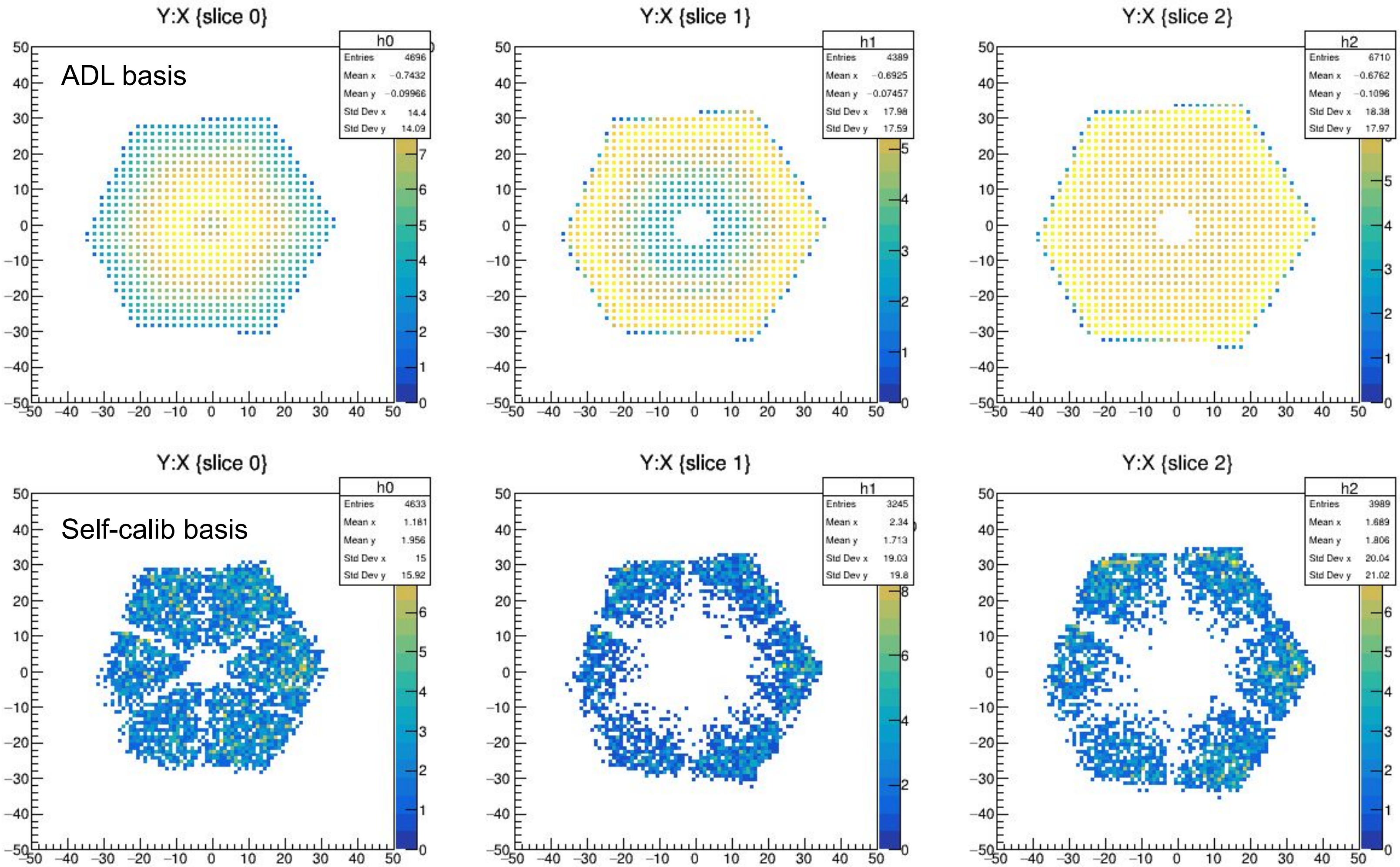
- Compton scattering of 1274keV gamma
- Interaction position from PSA with ADL basis and SelfCalib basis
- Comparing scattering angle from PSA and the Compton angle from energy deposit

GANIL benchmark data

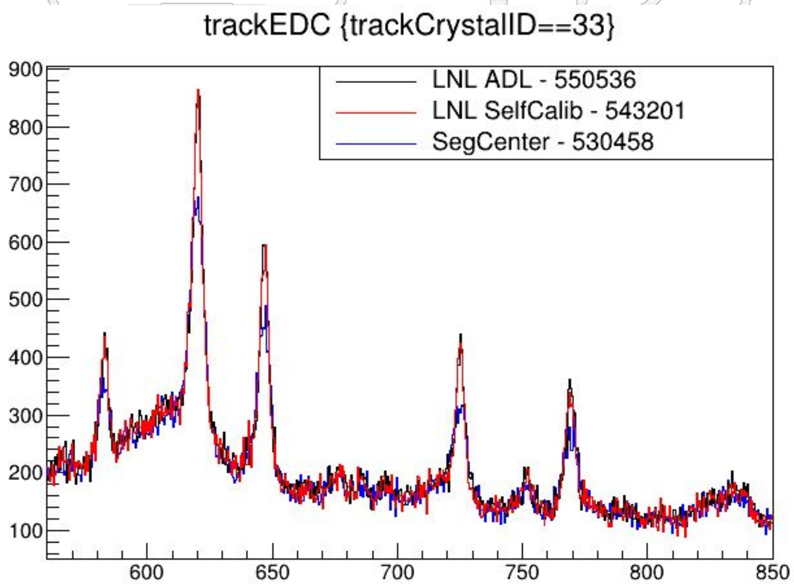


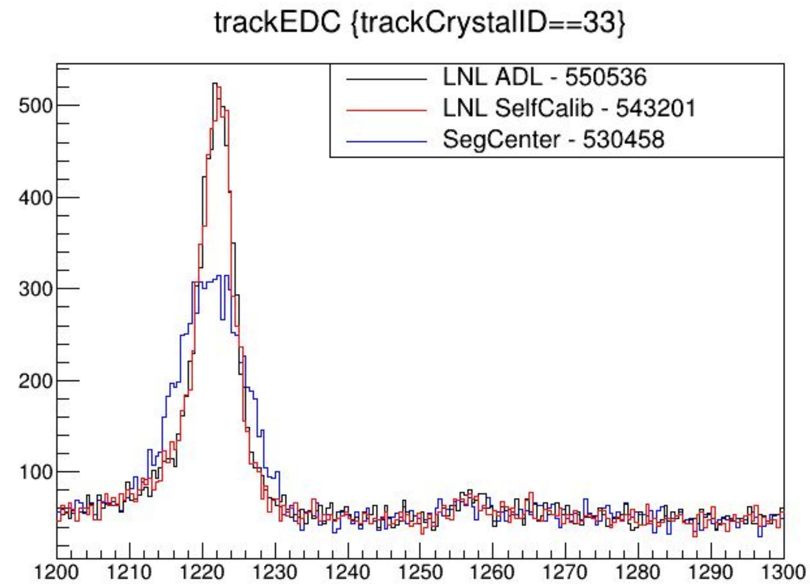
- E680 fission data of ^{98}Zr
- Crystal A006 commonly used in GANIL setup and LNL setup
- Electronics following the crystal can be different between two setups

A006 Signal basis



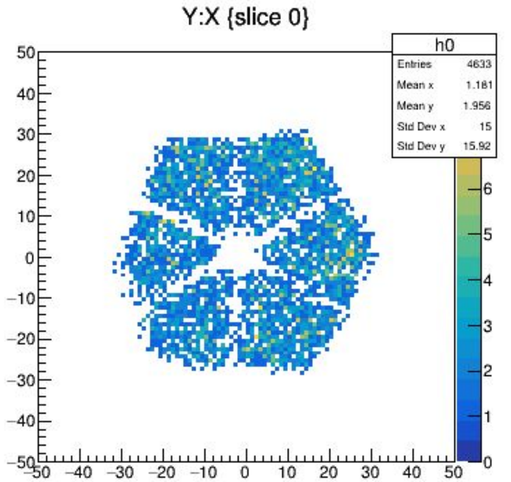
GANIL benchmark data

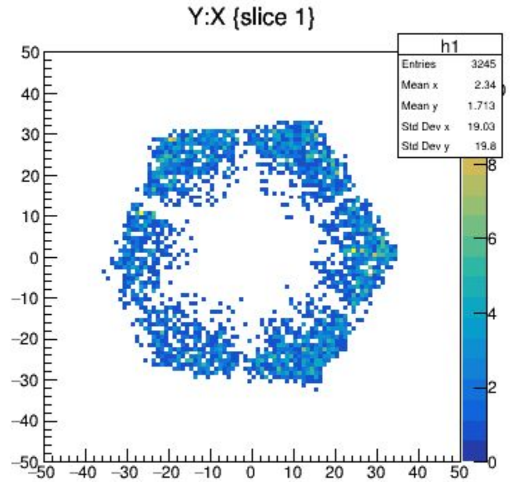


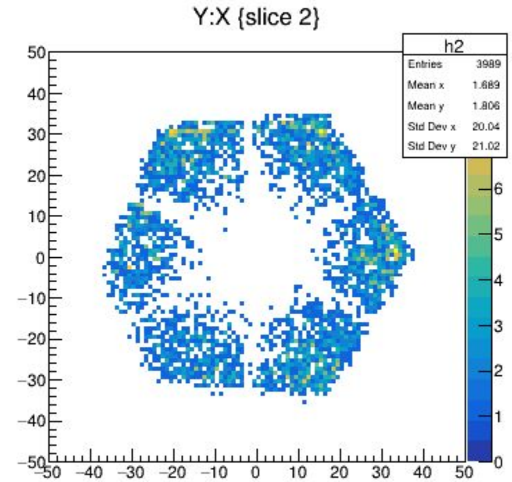


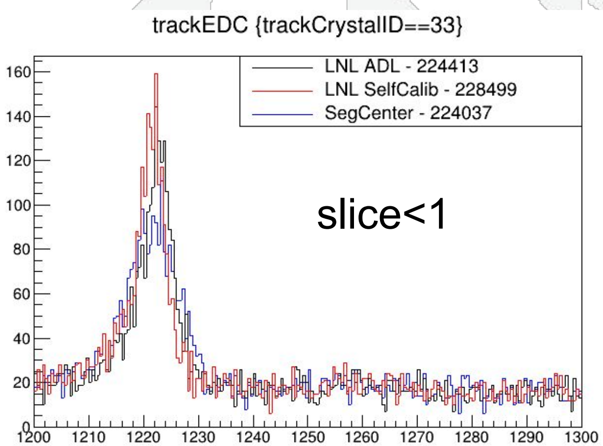
- A006 spectra with ADL basis, self-calib basis and segment center

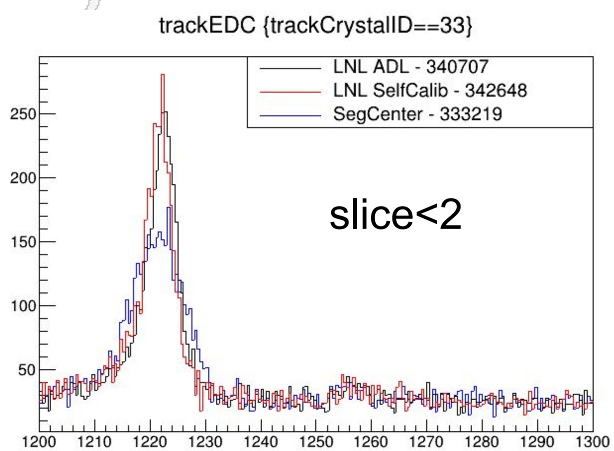
GANIL benchmark data

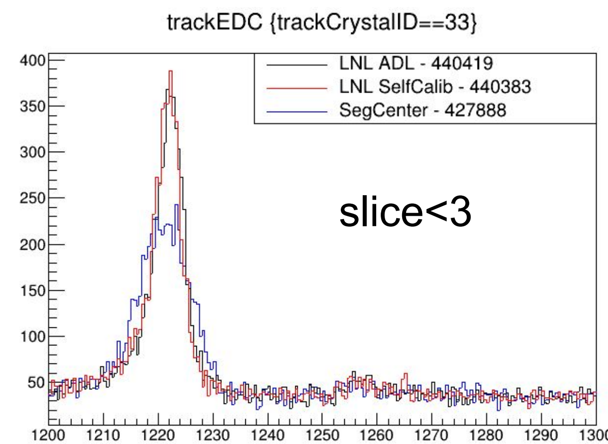






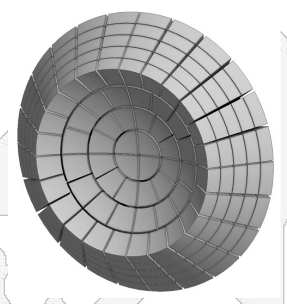


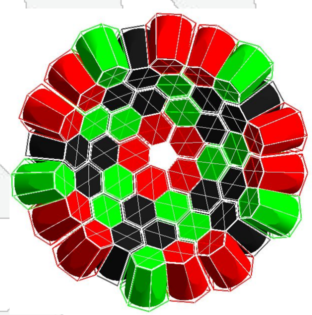


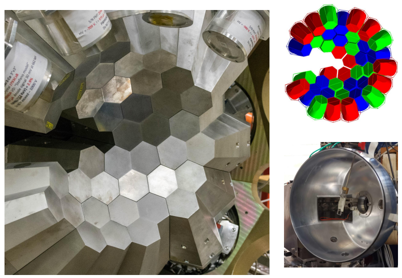


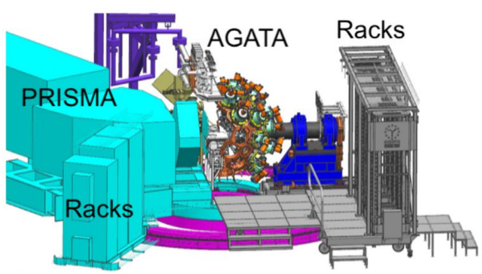
Next step

- Produce optimized bases for the whole array from high statistic source calibration data
- Validating the Self-Calibration bases with the clean spectra from a simple in-beam gamma-ray experiment







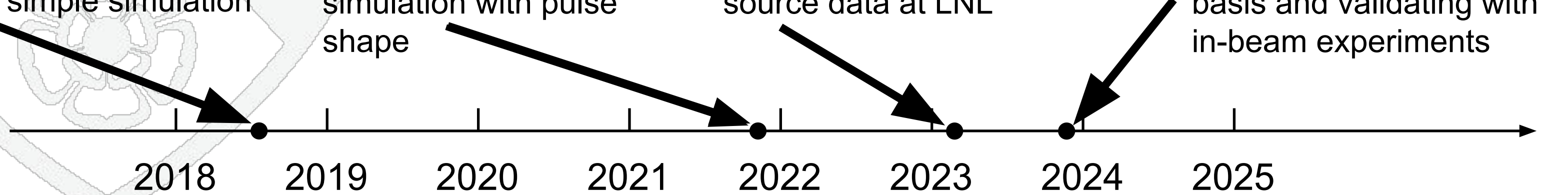


2018: proof of principle with a simple simulation

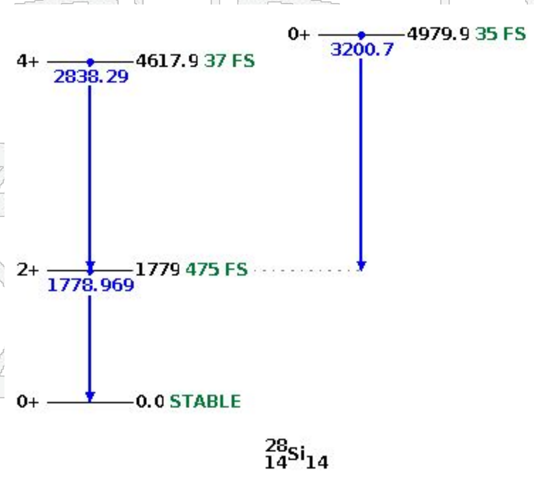
2022: test with AGATA simulation with pulse shape

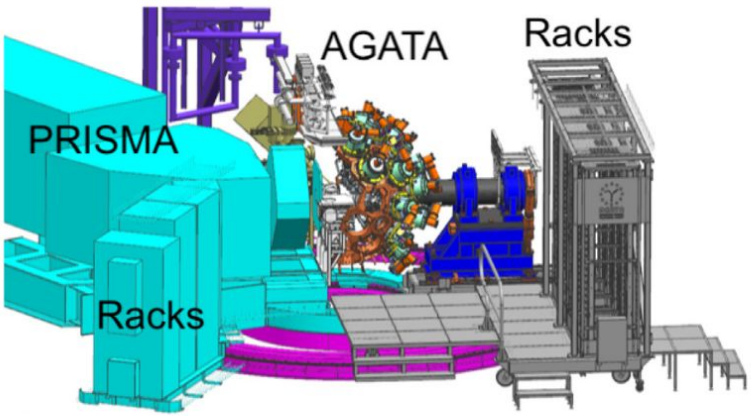
2023: test with real gamma source data at LNL

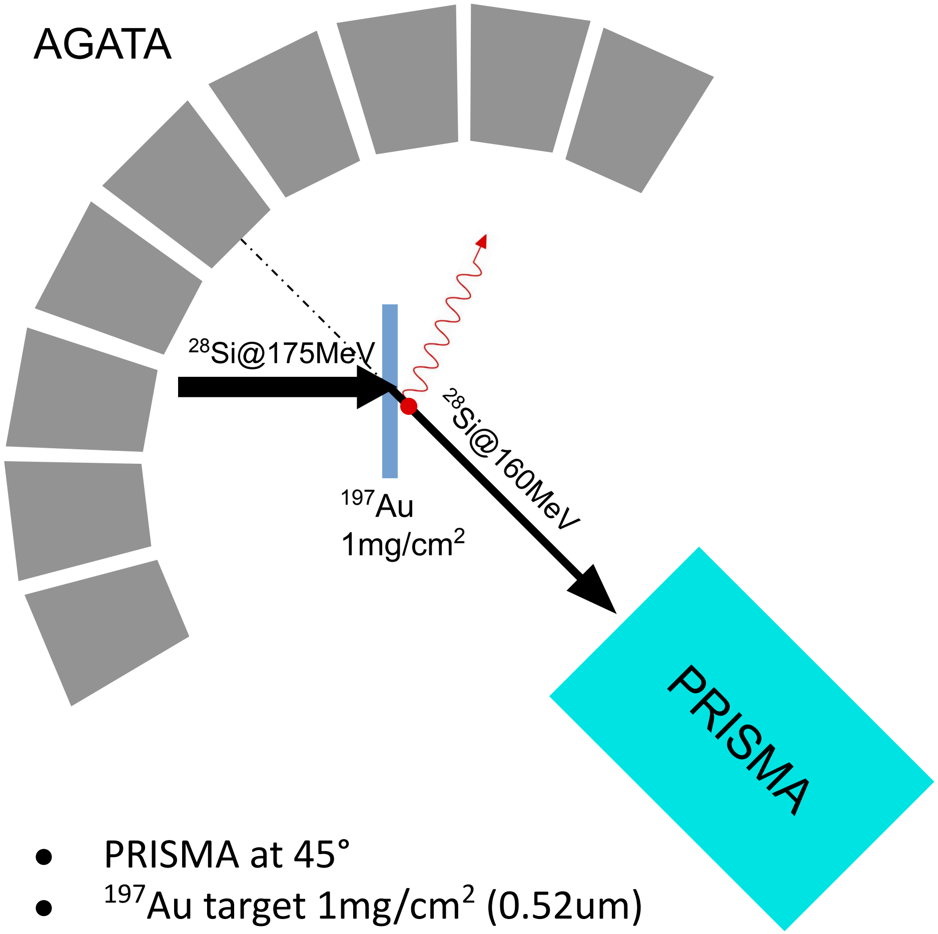
2024: produce optimized basis and validating with in-beam experiments



Experimental Approach

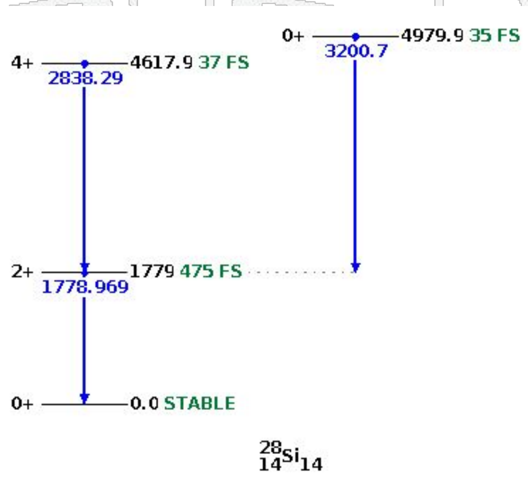


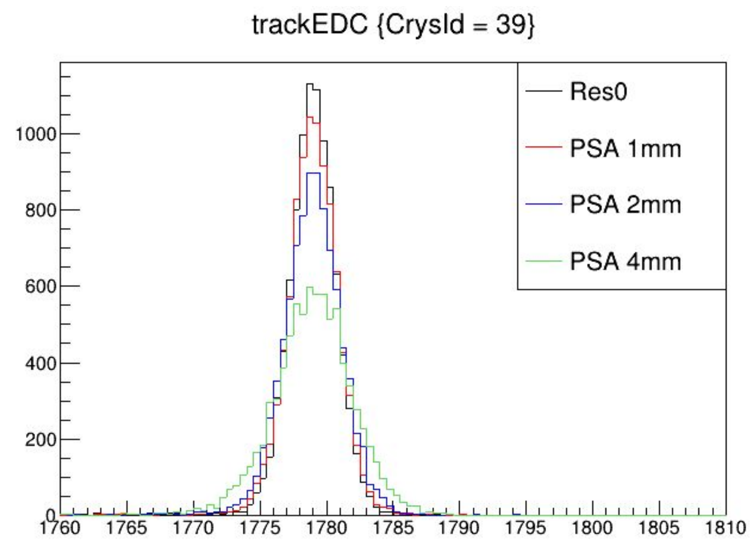


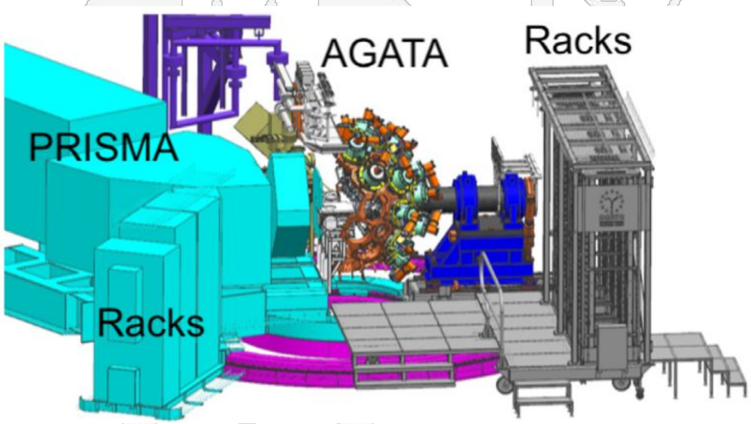


- PRISMA at 45°
- ^{197}Au target 1mg/cm^2 (0.52um)
- ^{28}Si scattered to 45°, 160MeV (β=0.11)
- ^{28}Si 2^+ $t_{1/2}$ = 0.475ps
- Scheduled in December 2024

Experimental Estimates



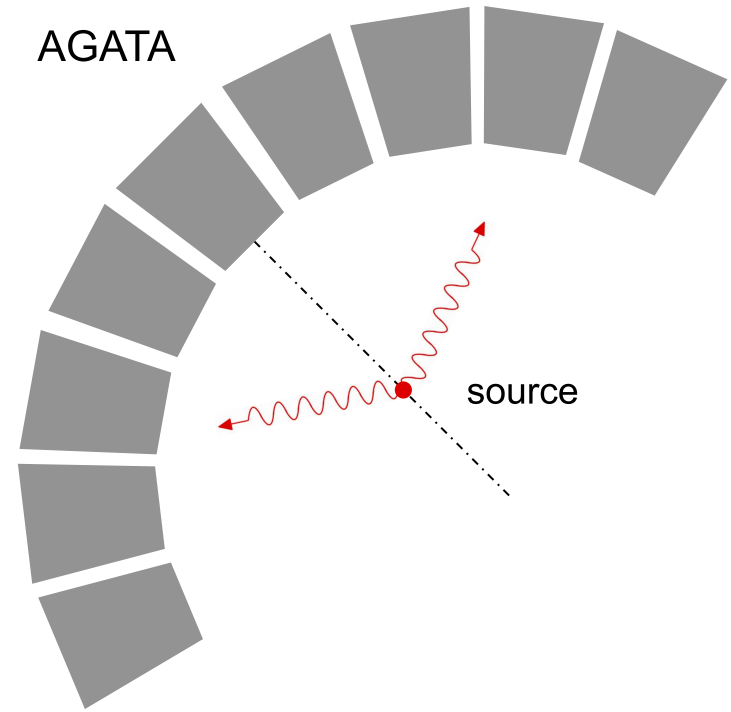




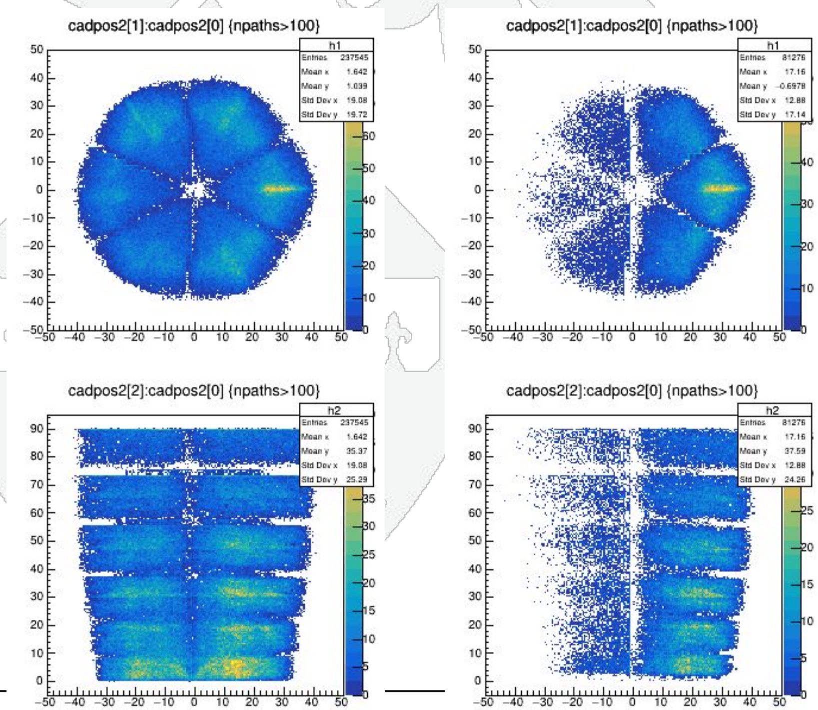
- Beam intensity: ^{28}Si 1-pnA
- Target thickness: ^{197}Au 1-mg/cm^2
- GOSIA estimated yield 400,000 gamma-particle coincidences per day
- PRISMA rate 3kHz
- PRISMA energy resolution 1/1000
- MCP entrance detector position resolution 1mm

Source calibration

- Strong ^{88}Y source, ~500kBq x2
- source at some positions (target position, close to some detectors, ...)
- Flod 2 trigger with core energy threshold 300keV or higher
- Save trace data, validation rates below 1kHz per crystal
- Data taking for 7 days



Det 00 Det 39



Selfcalib basis from simulation data, ^{88}Y source at target position, 1e11 decays

Summary

- Self-calibration technique is developed with AGATA simulation data with pulse shape
- 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, observing some improvements with self-calibration basis
- The self-calibration basis is applied to the GANIL benchmark data, yielding reasonable results
- Calibration data taking with strong ^{88}Y source and benchmark experiment were proposed and scheduled in December 2024

Collaboration

S. Chen[1], S. Paschalis[1], M. Bentley[1], M. Petri[1], M. Labiche[2], F. Holloway[3], L. Harkness-Brennan[3], A.J. Boston[3], J.J. Valiente Dobón[4], M. Rocchini[5], A. Goasduff[4,6,7], R.M. Pérez-Vidal[4], D. Kalaydjieva[8], K. Stoychev[8], N. Marchini[9], M. Zielińska[10], A.O. Macchiavelli[11], I.Y. Lee[12], J. Dudouet[13]

[1] University of York, York, UK. [2] STFC Daresbury Laboratory, Daresbury, UK. [3] University of Liverpool, Liverpool, UK. [4] INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy. [5] Università degli Studi and INFN Sezione di Firenze, Florence, Italy. [6] Dipartimento di Fisica dell'Università di Padova, Padova, Italy. [7] INFN, Sezione di Padova, Padova, Italy. [8] University of Guelph, Canada. [9] INFN Firenze, Italy. [10] Irfu, CEA, Université Paris-Saclay, France. [11] Oak Ridge National Laboratory, USA. [12] Lawrence Berkeley National Laboratory, USA. [13] Université de Lyon, CNRS/IN2P3, Villeurbanne Cedex, France

Thank you for your attention

Backup

TAC comments

- The PRISMA MWPPAC focal plane detector is known to have quite low efficiency for Z<20 ions. Please consider about 50-60% intrinsic efficiency for Z=14 ions.

➢ *If the statistics are lower than expect, we can combine data from several detectors.*

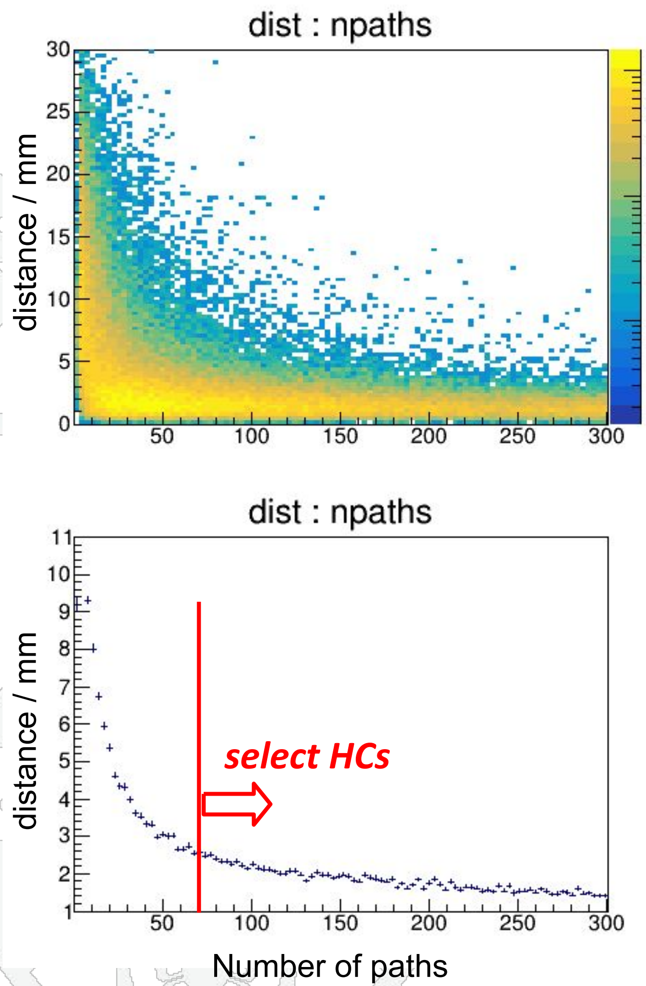
- Could the target (Au) excitation be a problem for you? You will have many gamma-ray transitions around 200-500 keV which may be problematic for your event selection. Have you considered the possibility to use instead Nb, Pt, Pb targets?

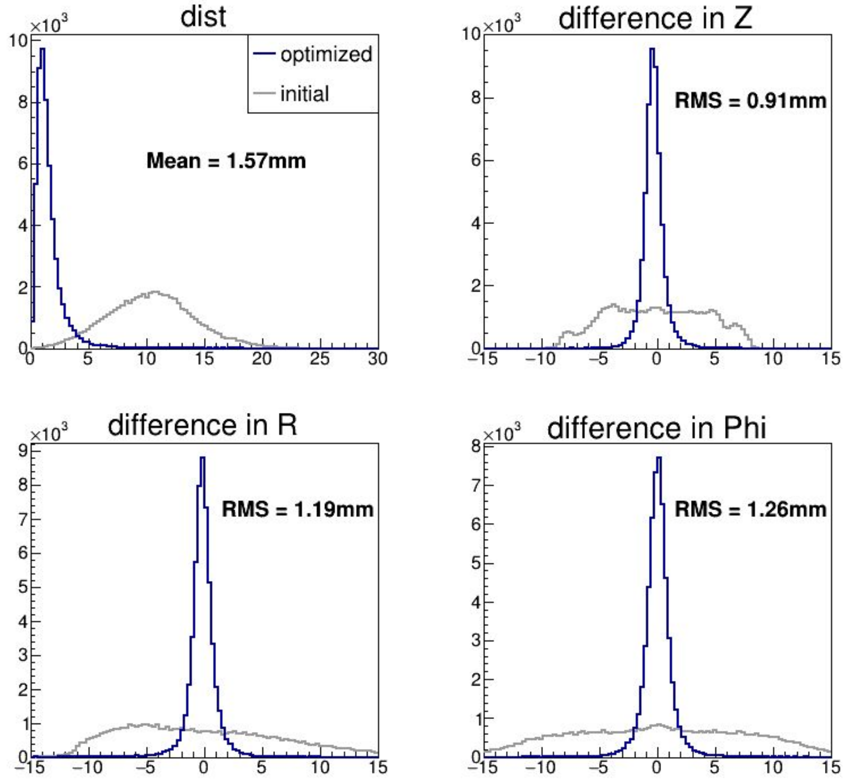
➢ *We don't think the Au excitation will make serious problem. If it does, we can use Pb target instead.*

- Beam: The required energy from Tandem is high: in this configuration (double stripper in the Tandem) the required beam current is at the very limit: it could be that the maximum current achievable is lower, around 1pnA.

➢ *We will use 1-mg/cm^2 Au target and 1pnA ^{28}Si beam.*

Simulation: Position fidelity



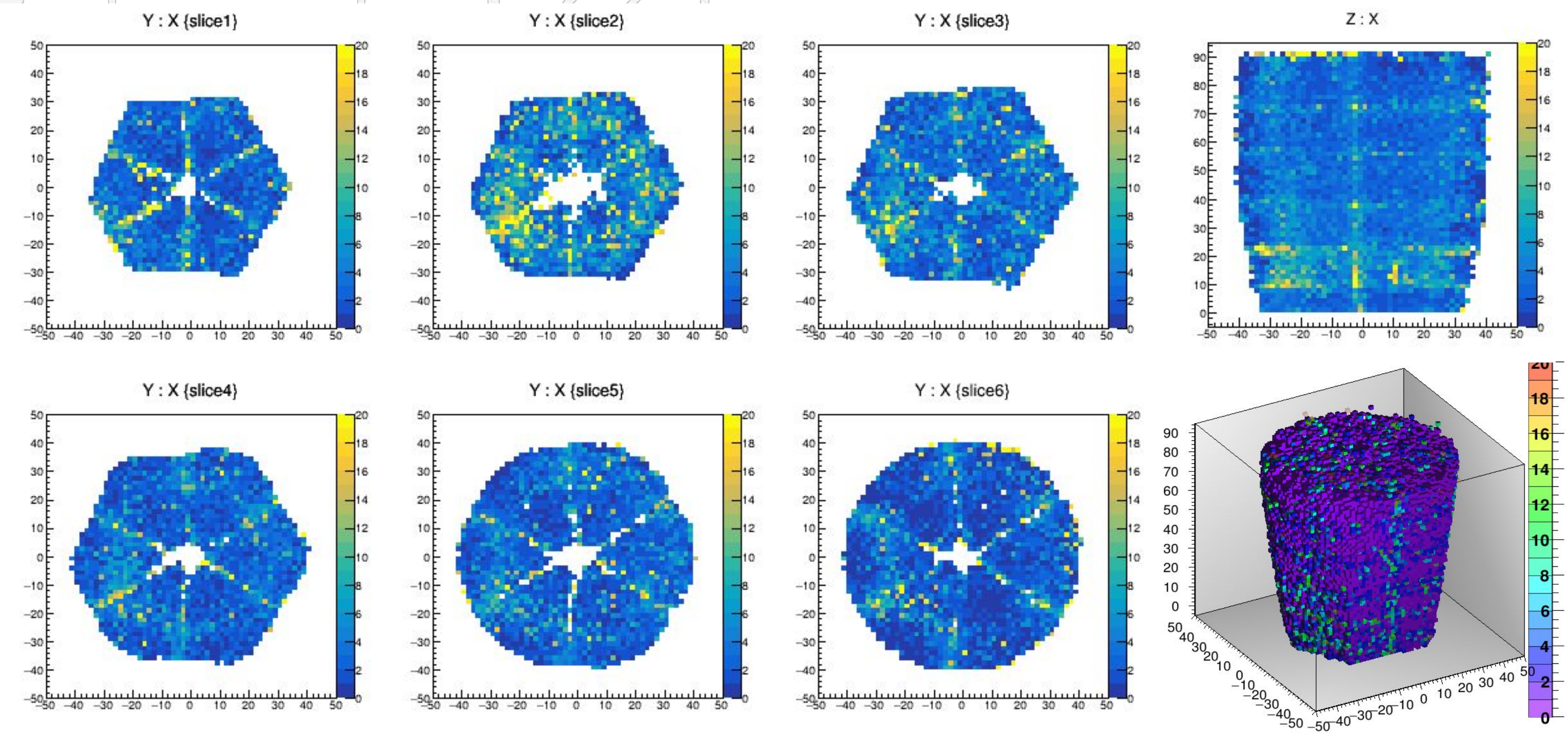


- Select HC linked with large number of paths
- Converged HC position reach ~1mm (RMS) fidelity
- Slightly worse resolution in phi direction

Simulate 2MeV gamma 2e10 events

Self-calibration basis (simulation)

Chi2 difference: self-calib pulse vs. real pulse

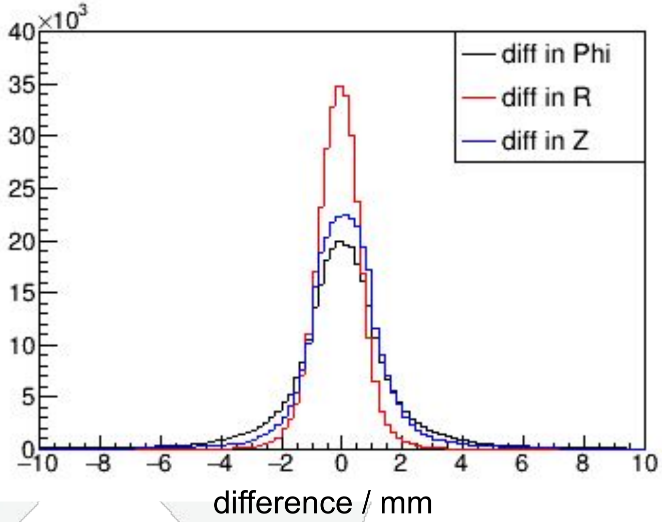


- Large Chi2 observed around segment boundary

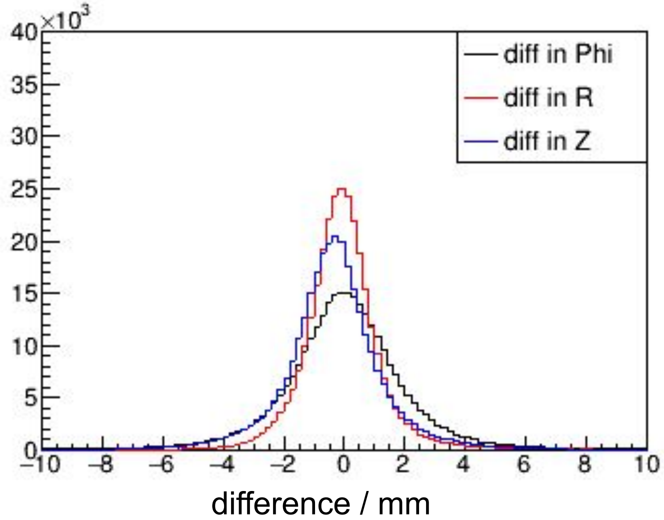
Simulate 2MeV gamma 2e10 events

PSA position resolution (simulation)

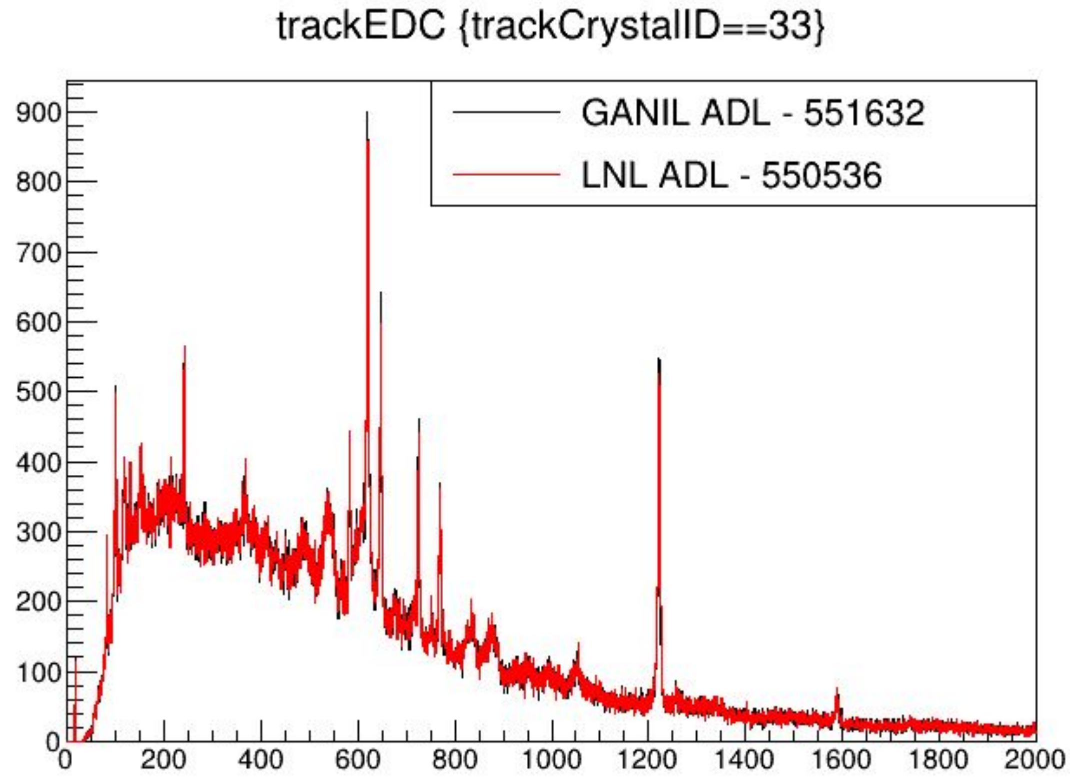
Using the calculated Basis on a 2mm grid



Using the self-calibrated basis

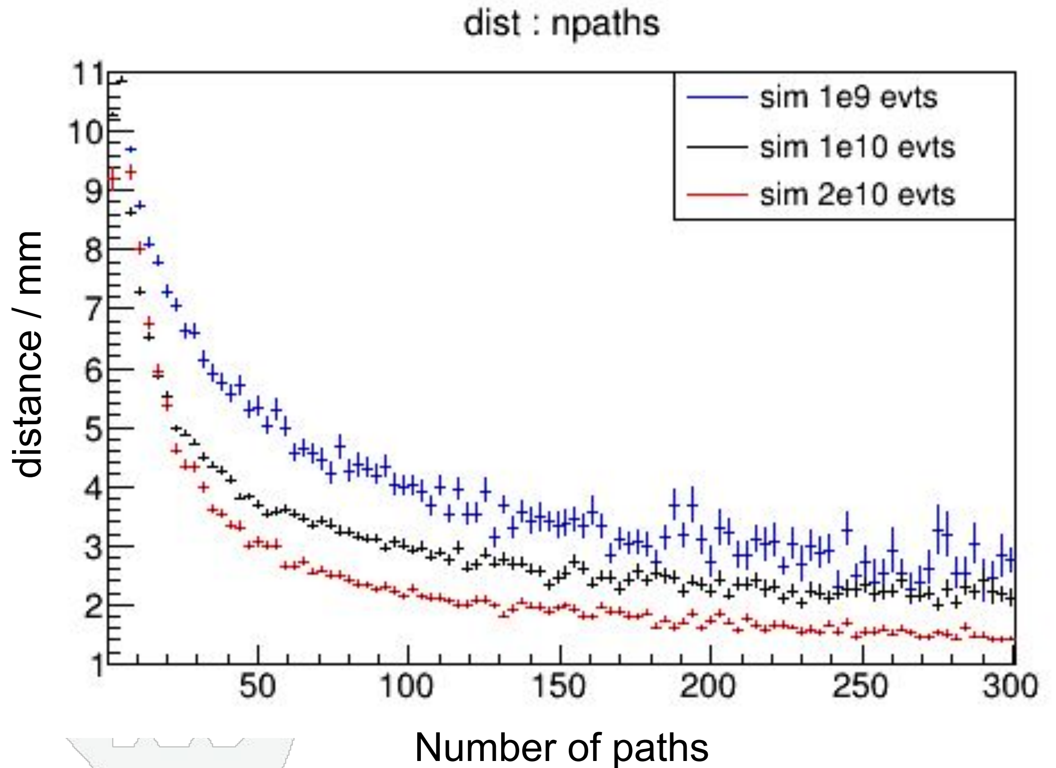


GANIL benchmark data



- A006 spectra with GANIL cross-talk parameters and LNL cross-talk parameters

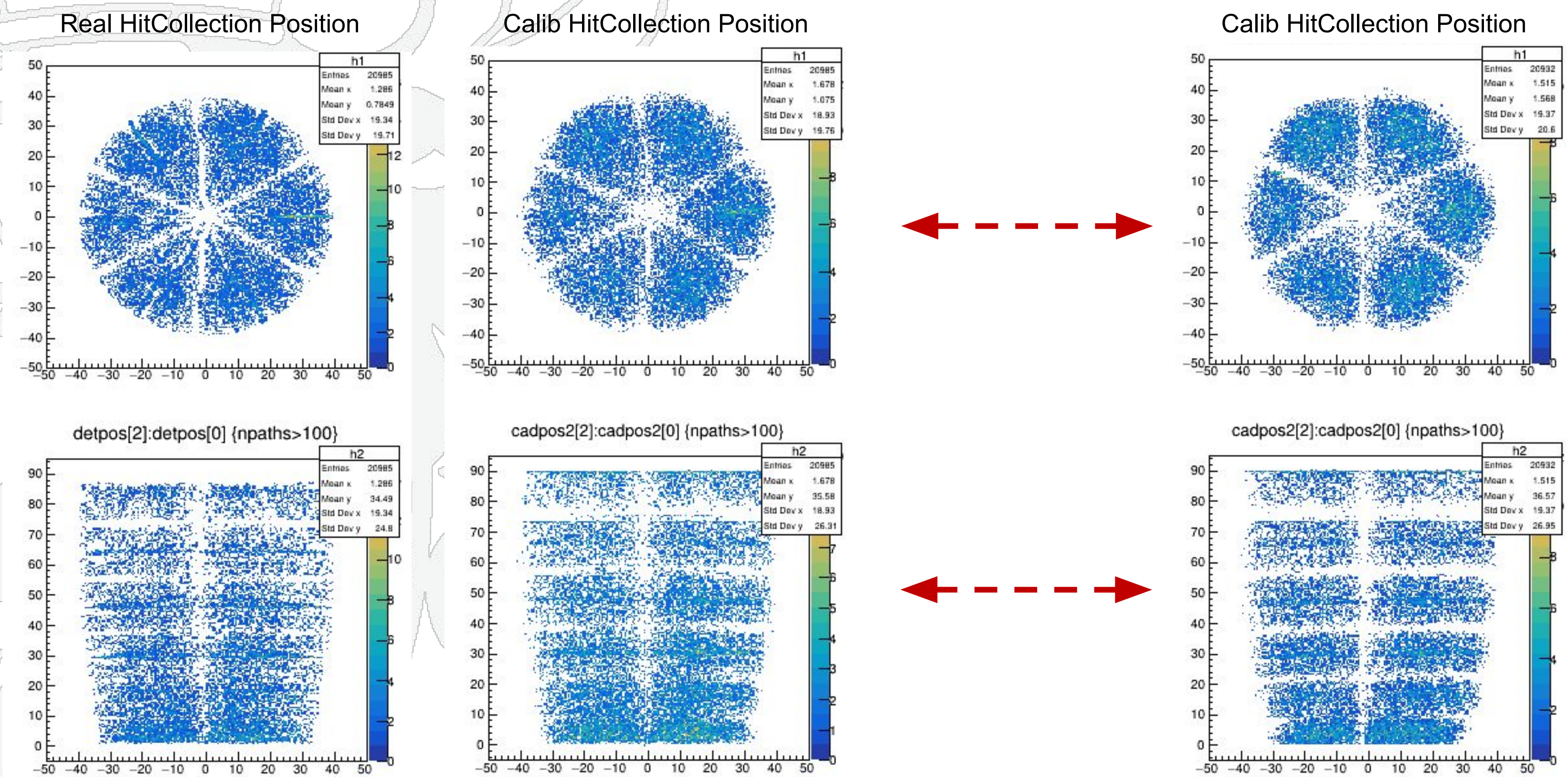
Position resolution



- Simulation data size influence to position resolution

Self-calibration result

Simulation data (same size as source data) | source data



- Identify incoming gamma energy by OFTtracking
- consistent results between simulation and source calibration

Simulation: Position fidelity

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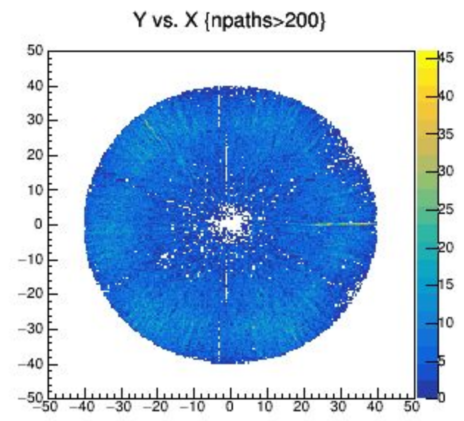
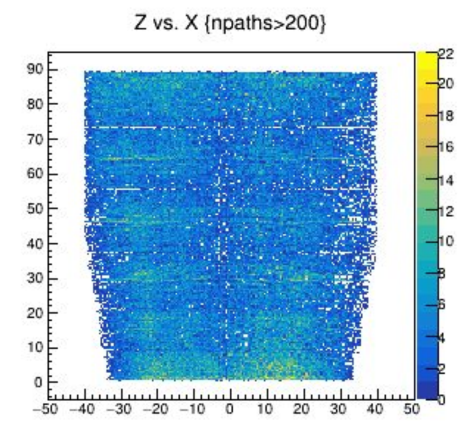
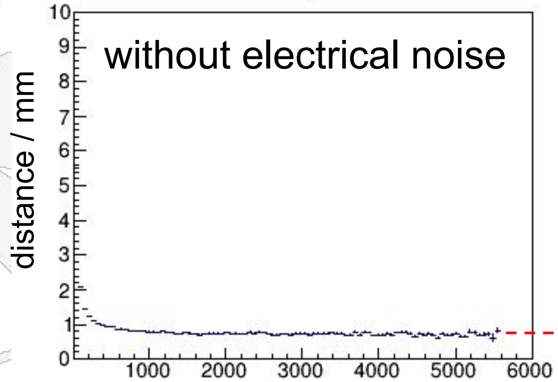
2MeV gamma 2e11 events

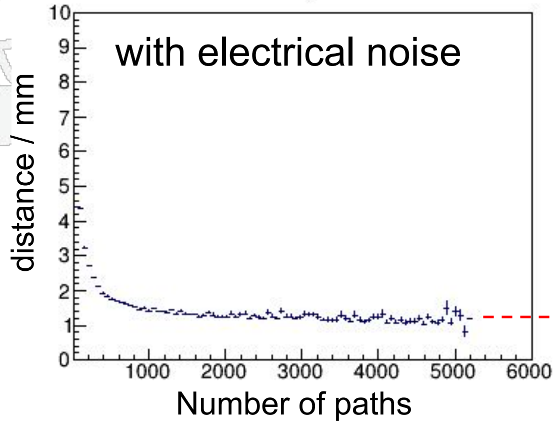
Distance between self-calib position and "real" position







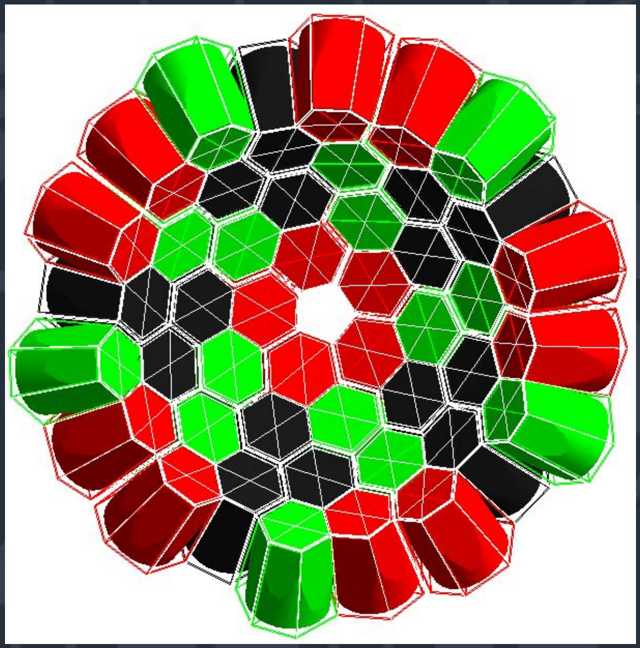
Better than 1mm



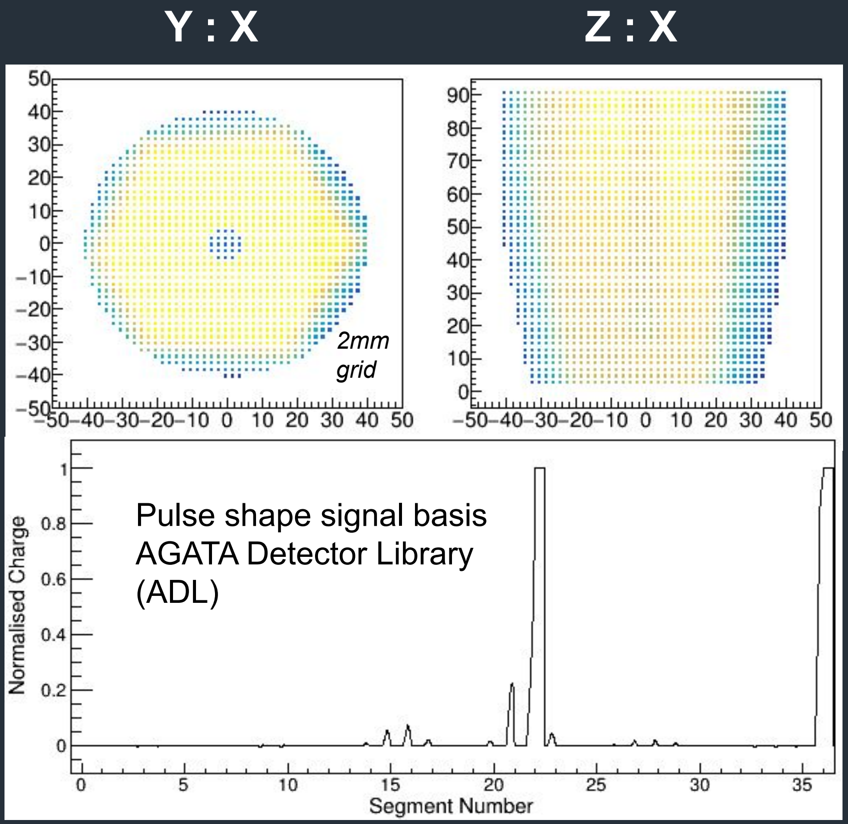
1-2 mm

Simulation with Pulse Shape

Geant4:

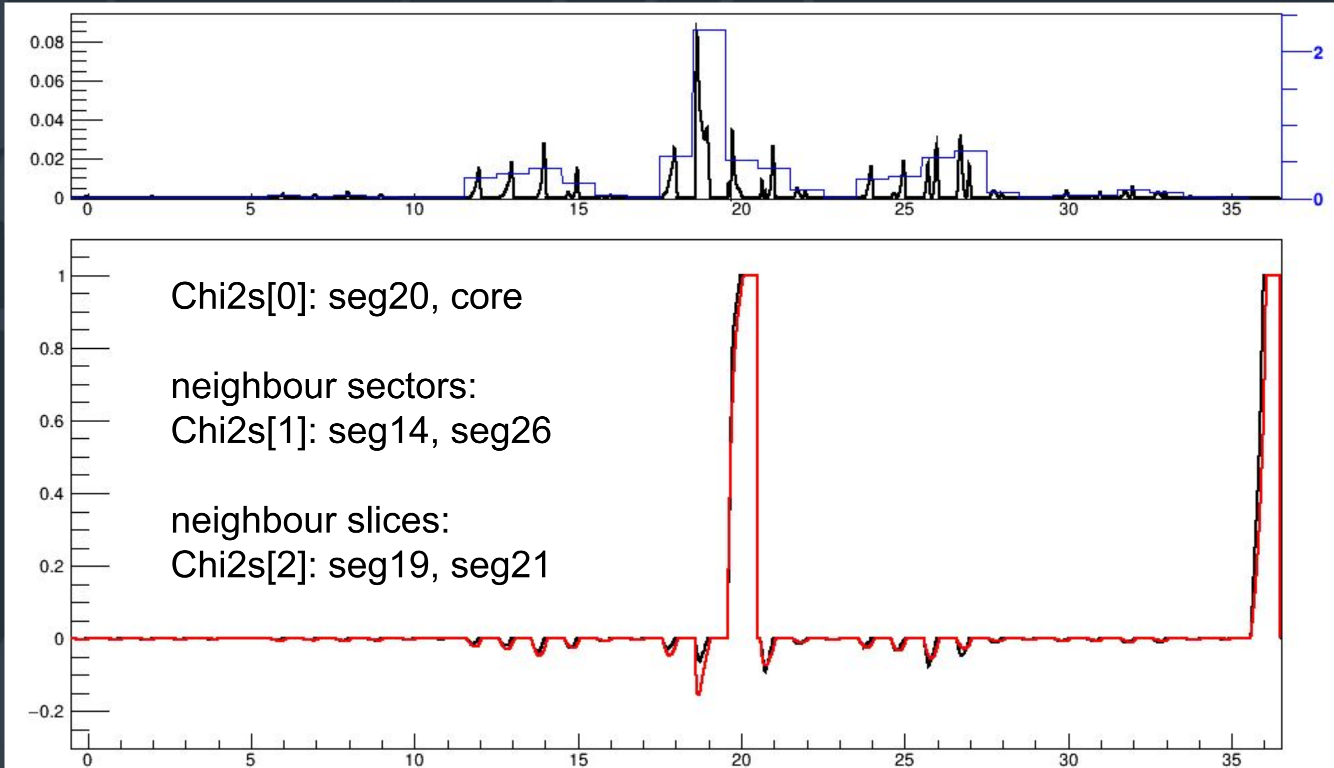


Signal Basis:



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

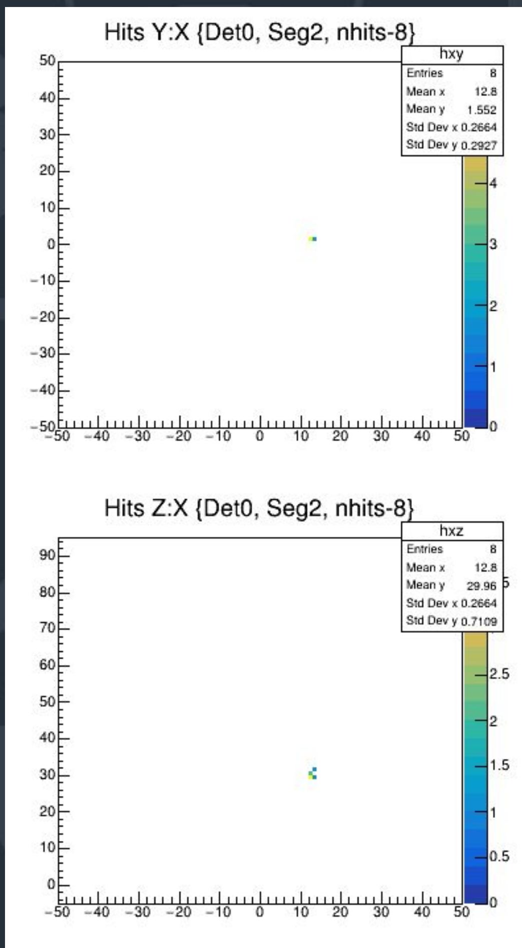
Group Pulse Shape

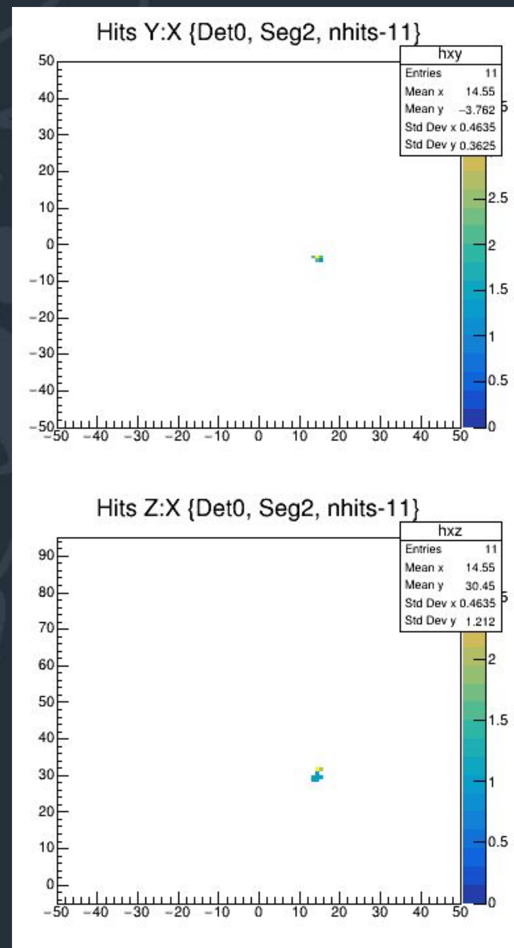


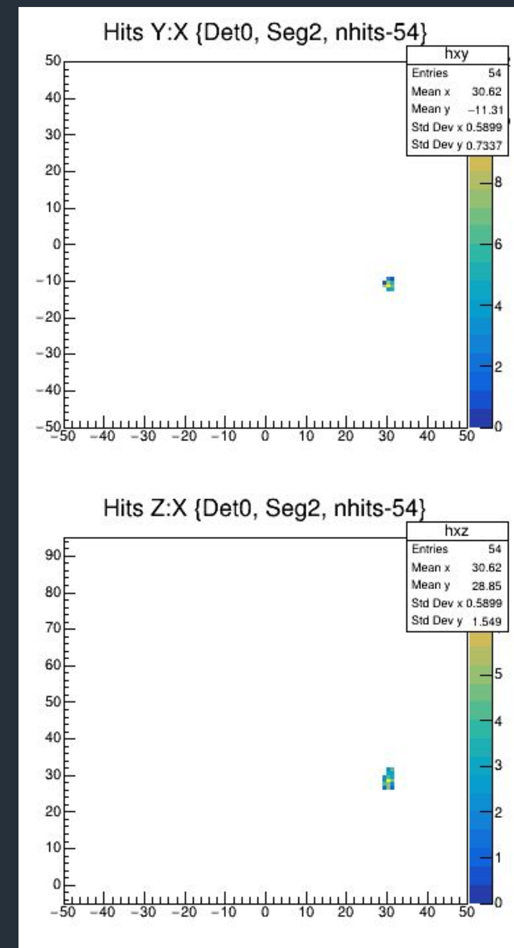

```
seg     = 20
nhits1 = 1 : 1571.00
nhits2 = 1 : 1590.26
nfired = 36
Eng1    = 1571
Eng2    = 1590.26
chi2    = 7.29173
dist    = 9.98804
rdifphi= 7.03852
diffr   = 5.51792
diffz   = 4.50787

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

Group Pulse Shape



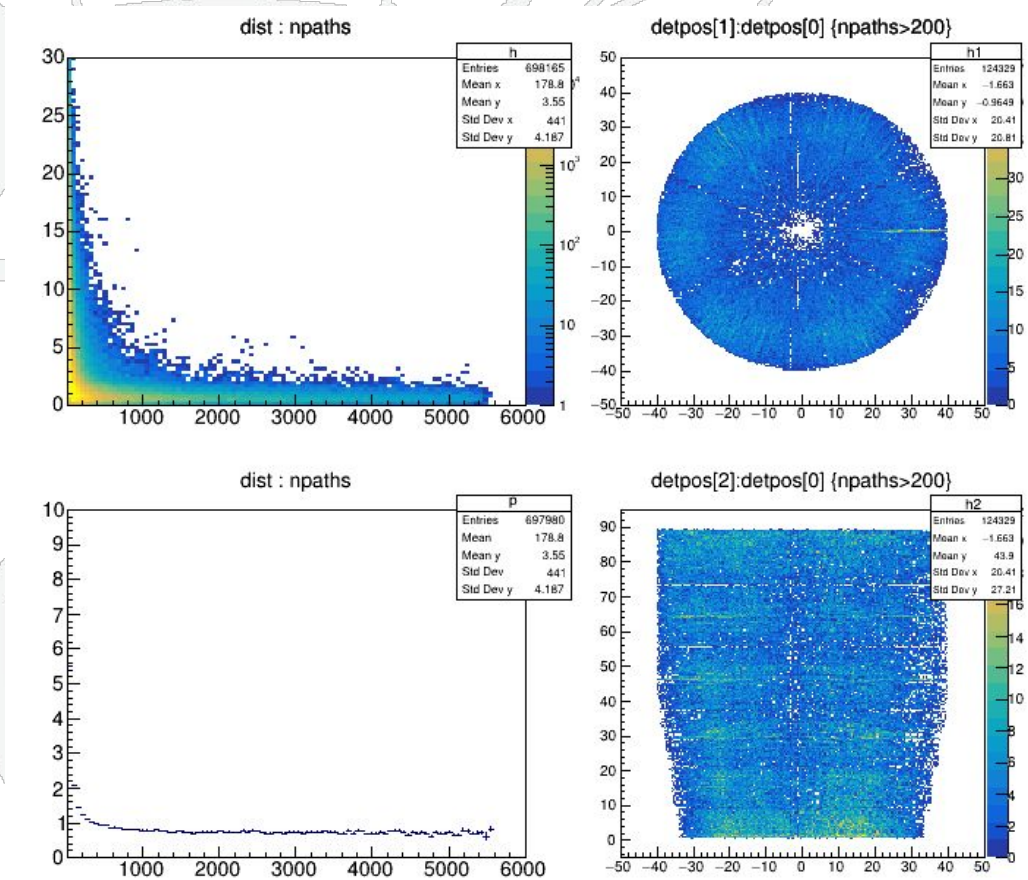




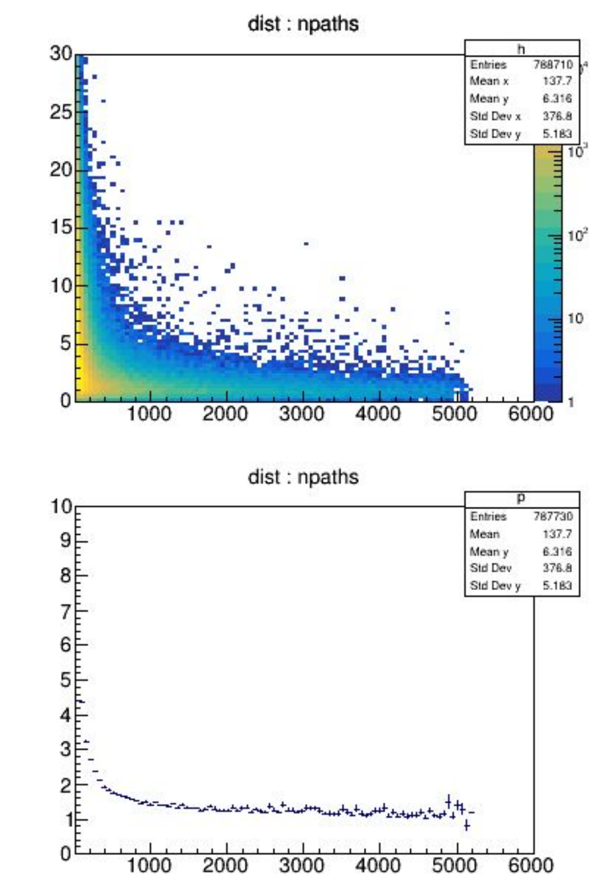
Simulation: Position resolution

Simulate 2MeV gamma 1e11 events

without noise



with noise

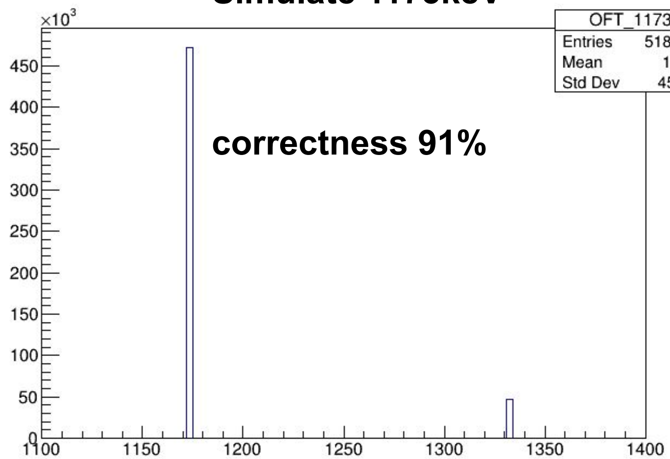


Gamma source

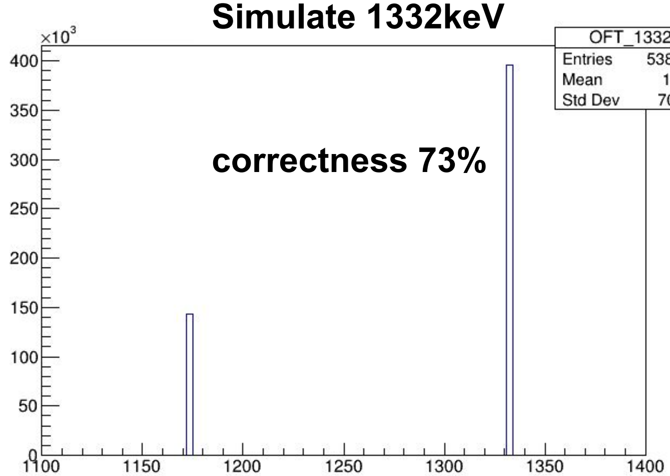
Identify incoming energy according to figure of merit from OFT

^{60}Co source

Simulate 1173keV

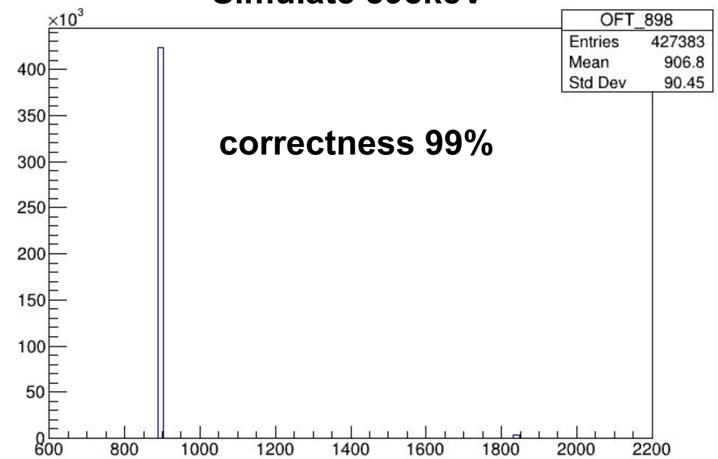


Simulate 1332keV

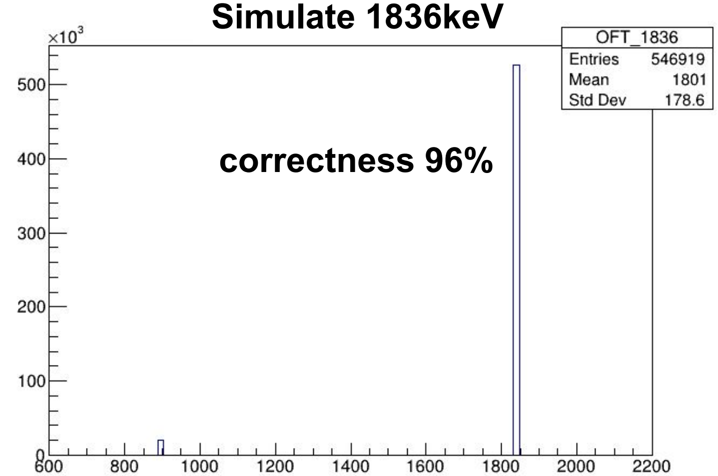


^{88}Y source

Simulate 898keV

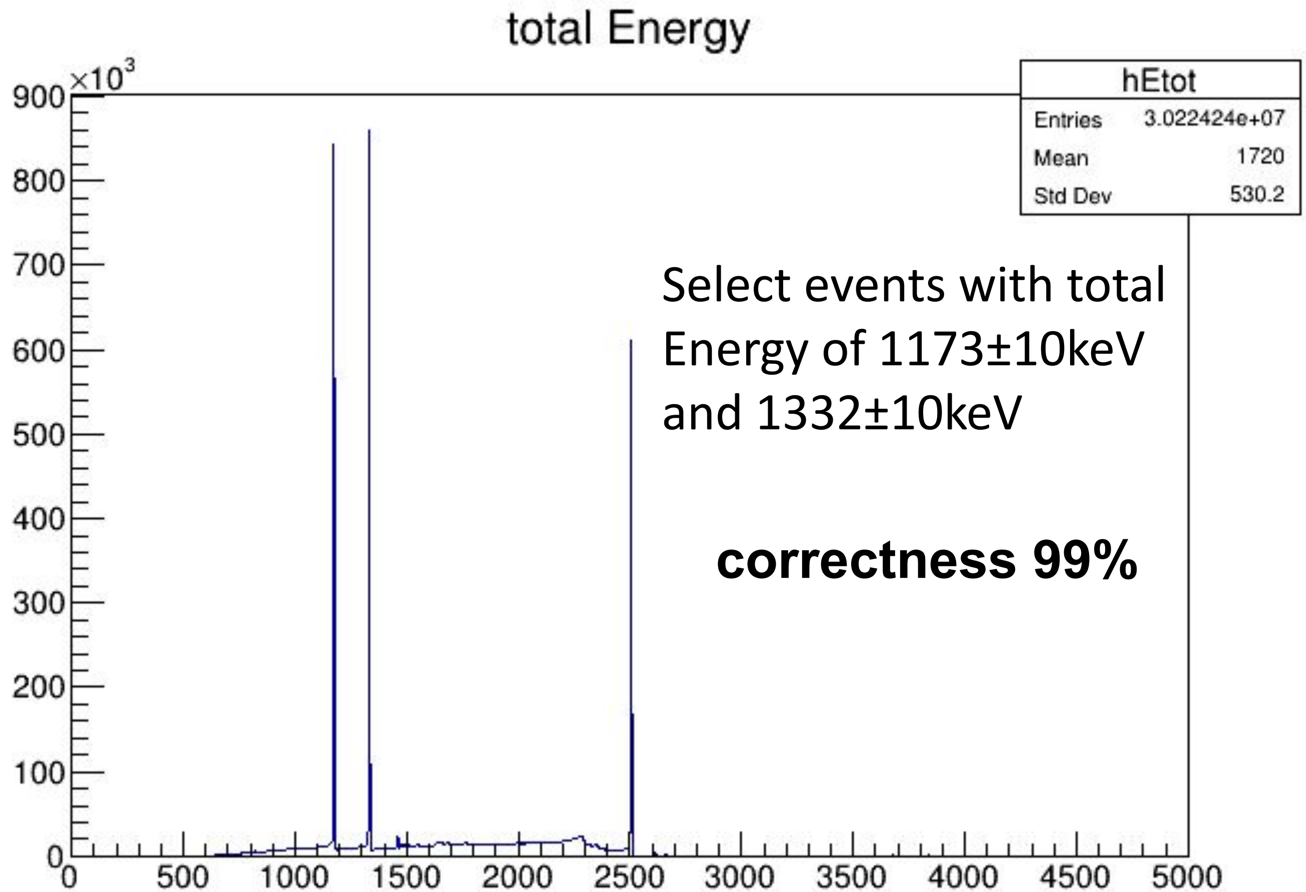


Simulate 1836keV



^{60}Co source

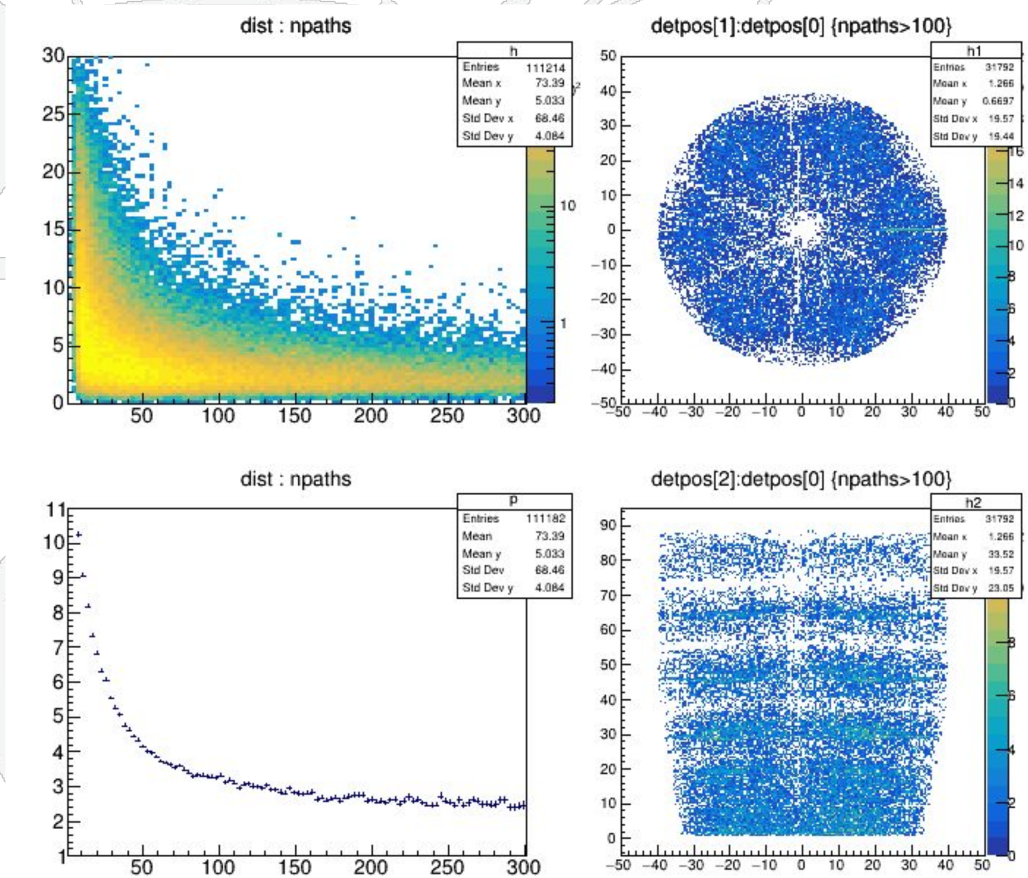
Identify incoming energy according to total energy deposit in array



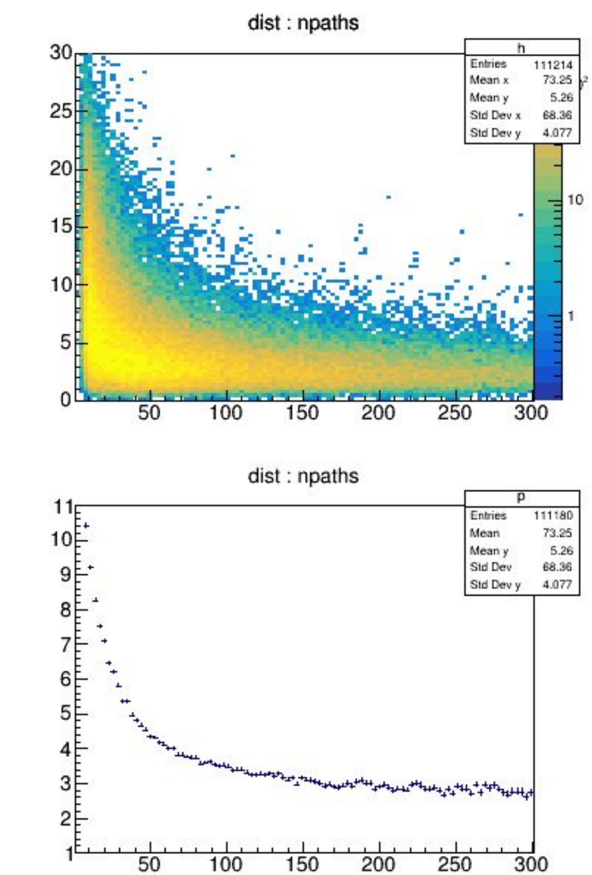
^{60}Co source

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

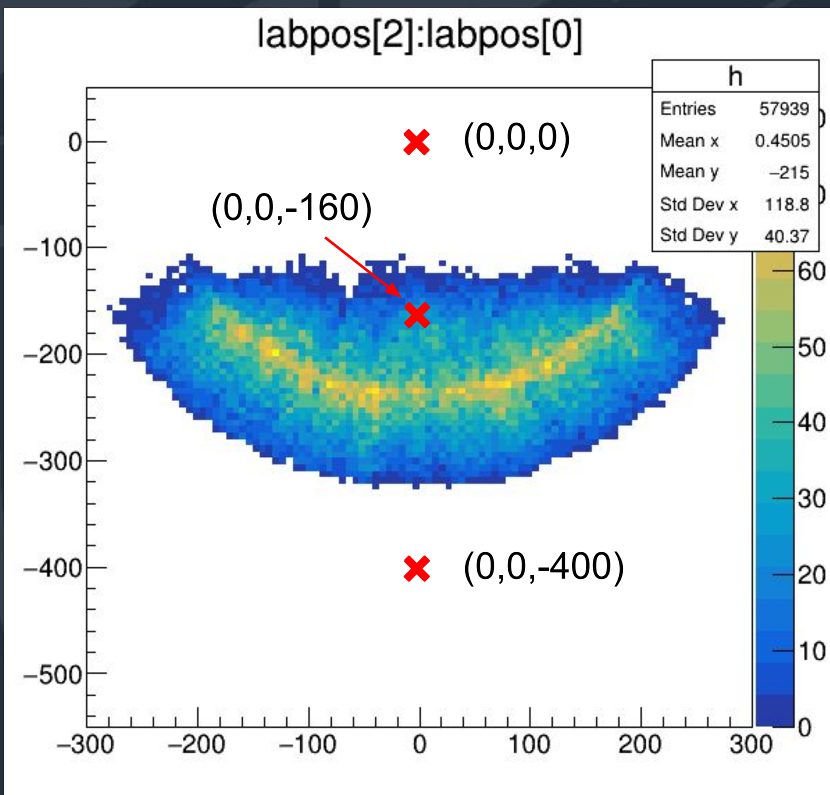
accurate source position



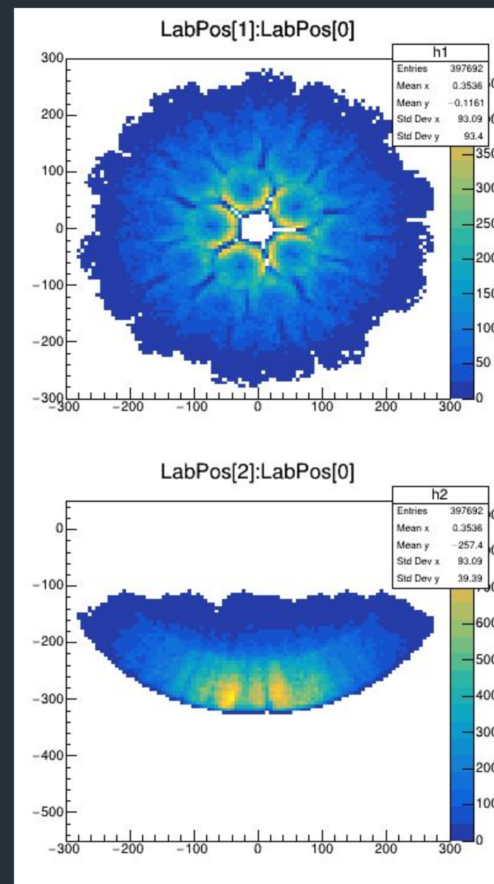
10mm mistake



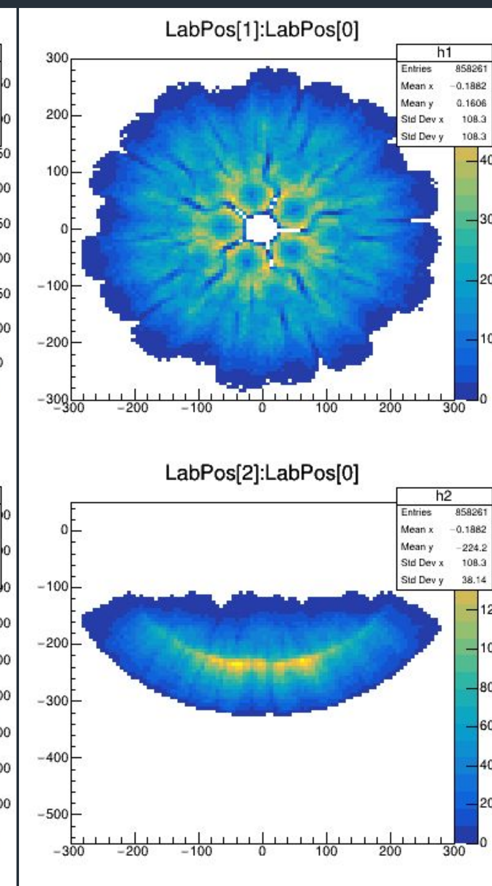
Source position



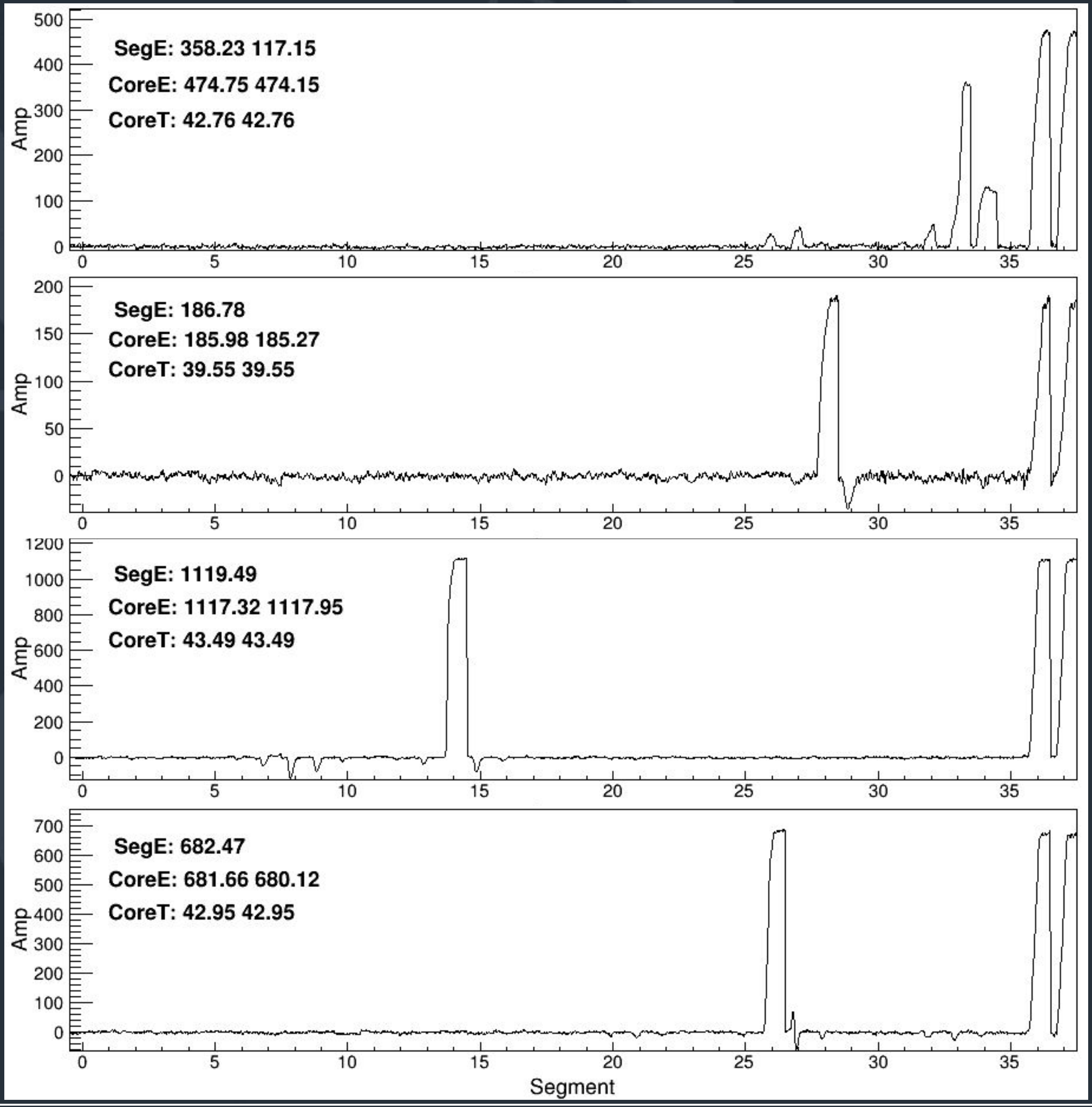
Source at (0,0,-400)



Source at (0,0,-160)



Calibration data



- ✗ multi segments hit
- ✗ small signal
- ✗ small Compton signal
- ○ accepted