# Machine learning and imaging approaches to improve the AGATA position resolution

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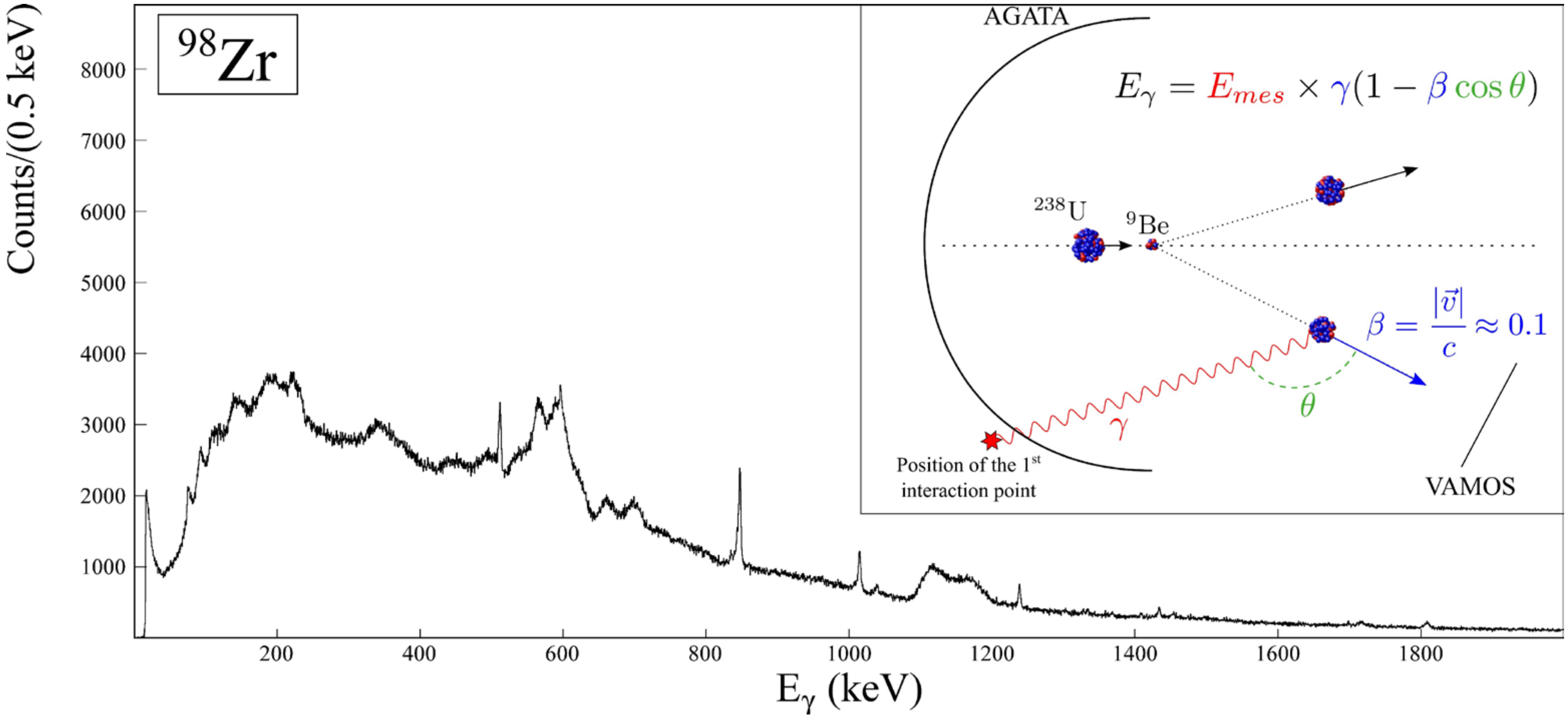
# In-beam Gamma-ray spectroscopy: Doppler correction



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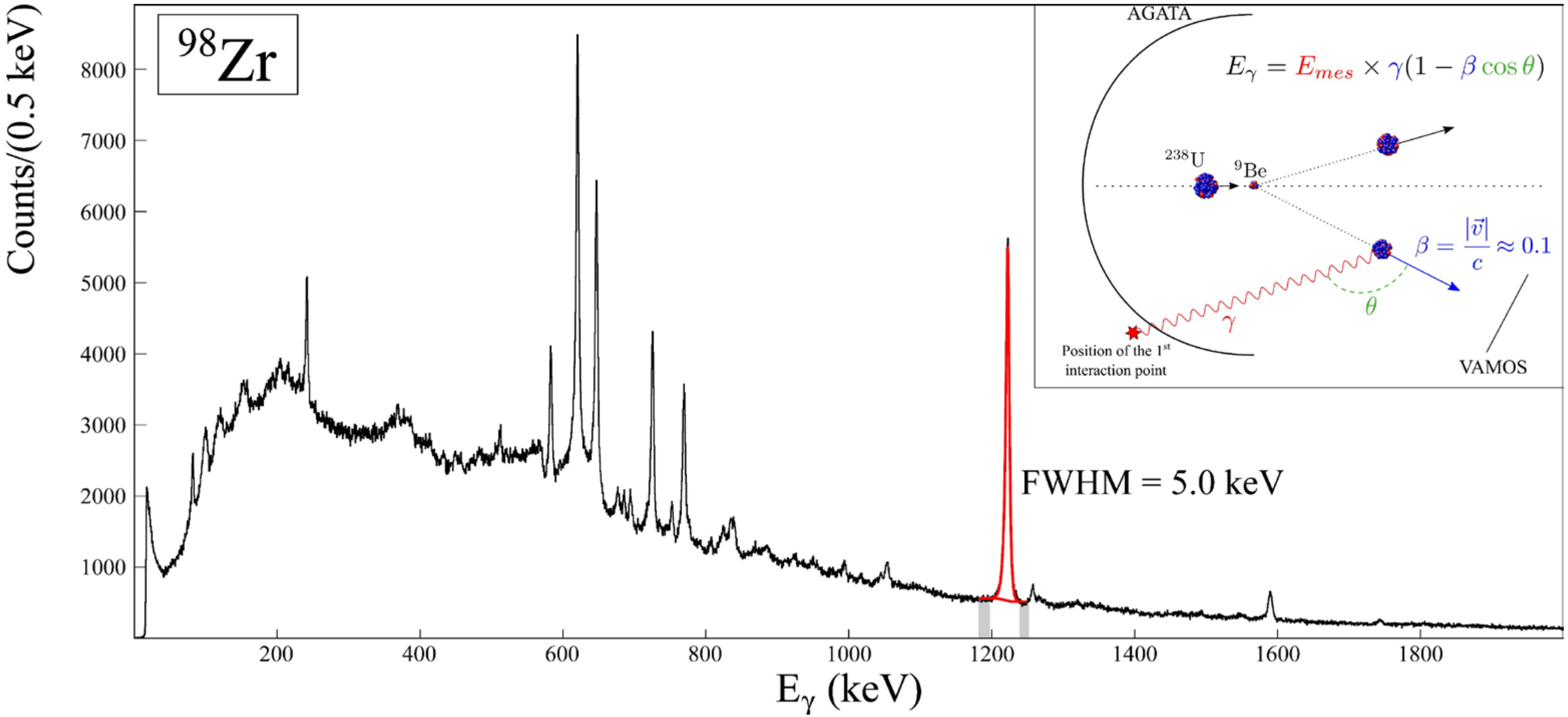
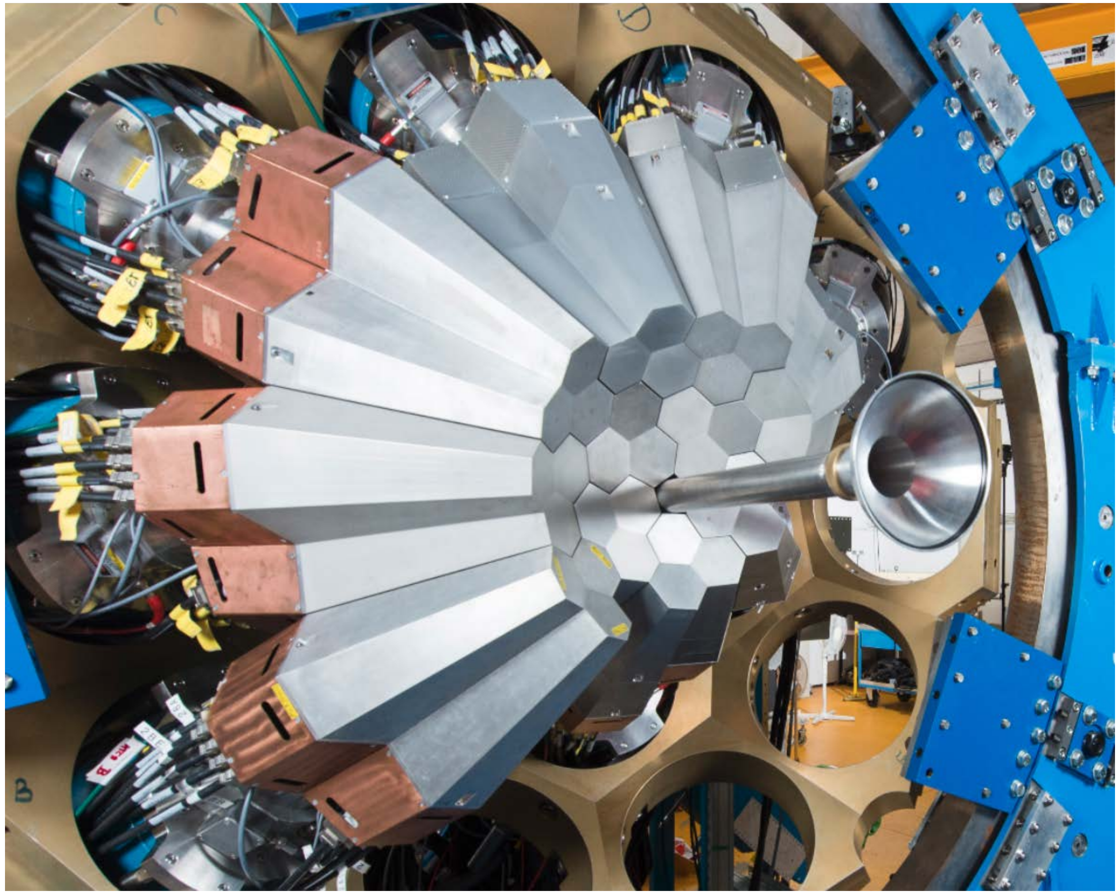


# AGATA: Advanced GAmma Tracking Array



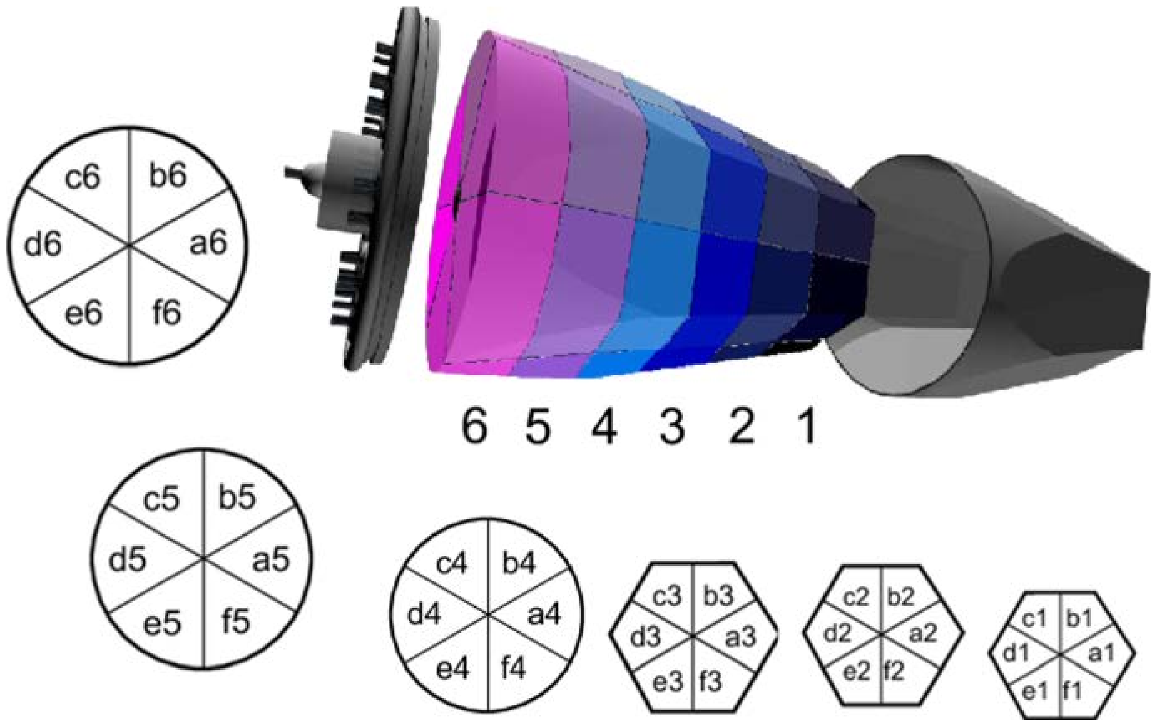
- Consists of 50 HPGe detectors(40 has been used in site and 180 are planned to complete $4\pi$ sphere).
  - ✓ High efficiency due to the continuous HPGe crystals.
  - ✓ State of the art energy resolution 2keV at 1.33MeV.

- Capable of tracking Gamma-rays.
  - ✓ Accurate Doppler correction.
  - ✓ Better photopeak to background ratio.



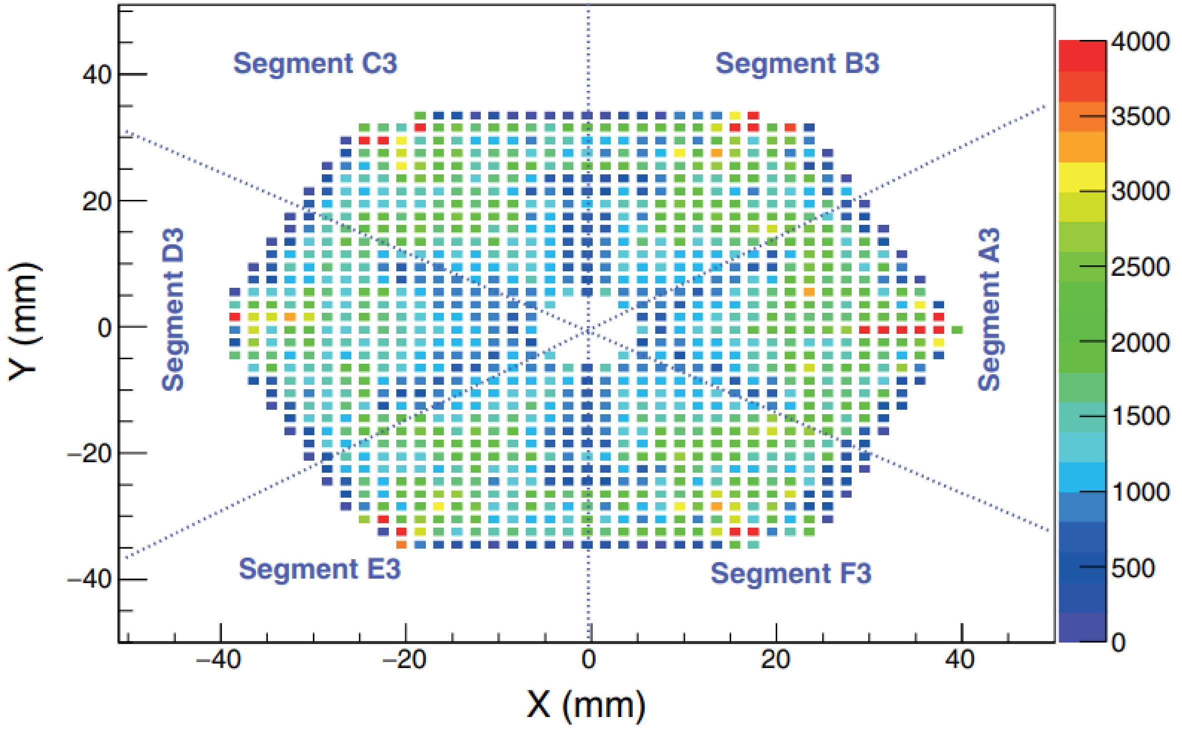
# AGATA: highly segmented HPGe

- Electronic segmentation.
  - ✓ No physical segmentation of the crystal(no dead layers between the segments).
  - ✓ Increases the detection efficiency.
- Allows for accurate measurement of the interaction point of the gamma ray.



# PSA: Pulse Shape Analysis algorithm

- Simulated databases of signals are built for each crystal.
  - ✓ Each database has a 2mm Cartesian grid of points.
  - ✓ 700-2000 Points per segment.
- An adaptive grid search is used to find the point with the closest simulated signal to the measured one.
  - ✓ A wide grid is first evaluated.
  - ✓ Then a full grid search is done to the voxel with the closest signal.




Korichi, A., Lauritsen, *Eur. Phys. J. A* **55**, 121 (2019)

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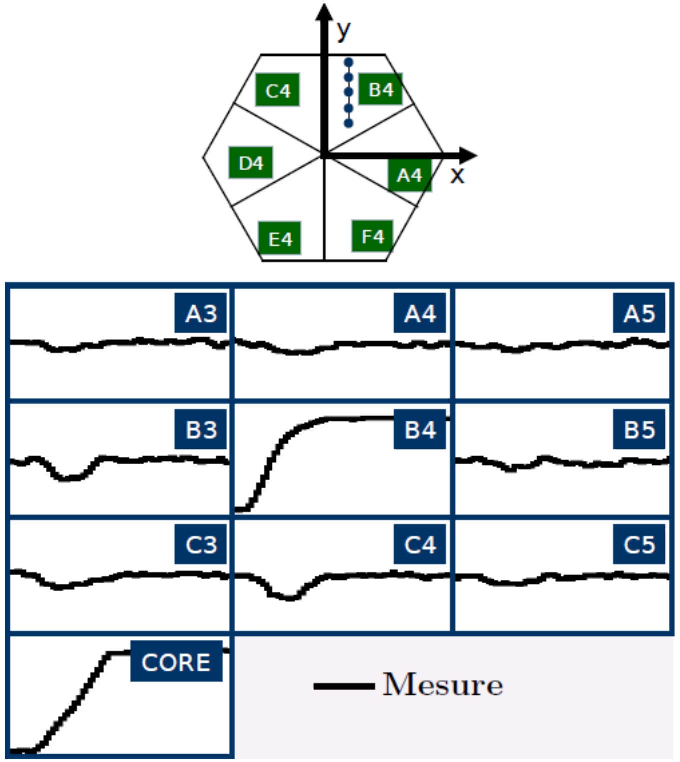

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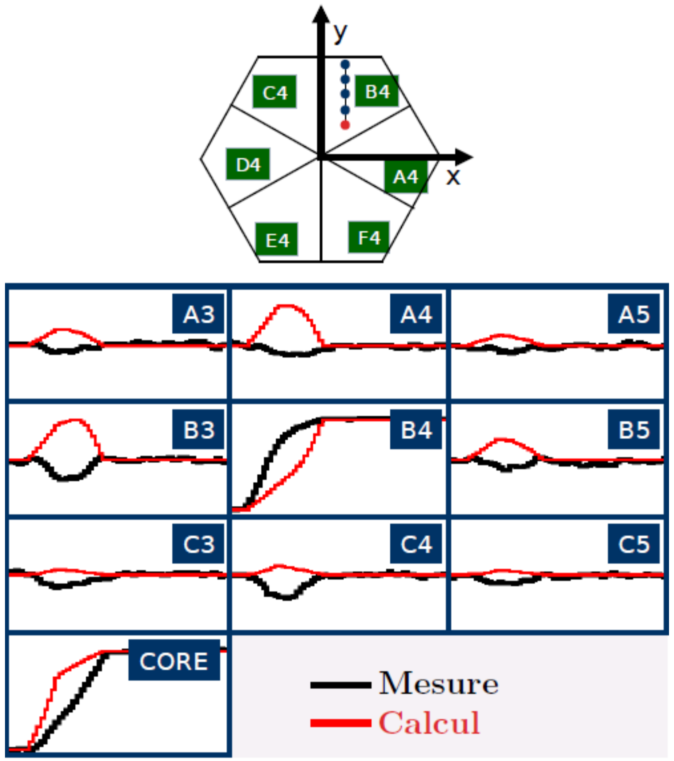

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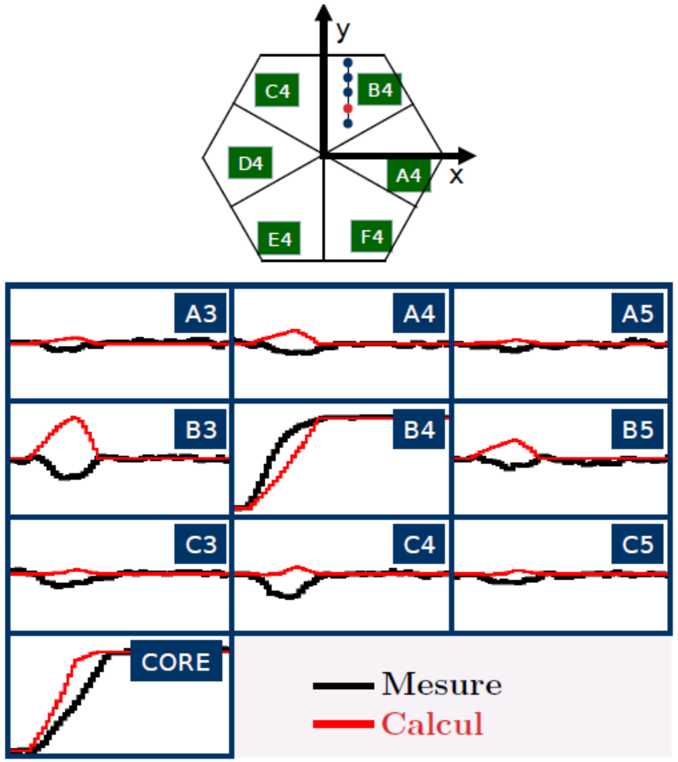

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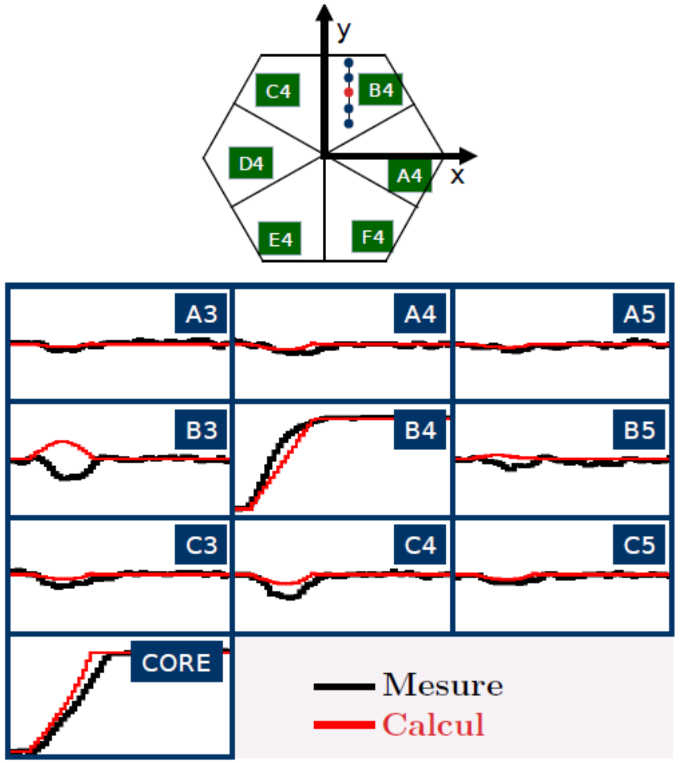

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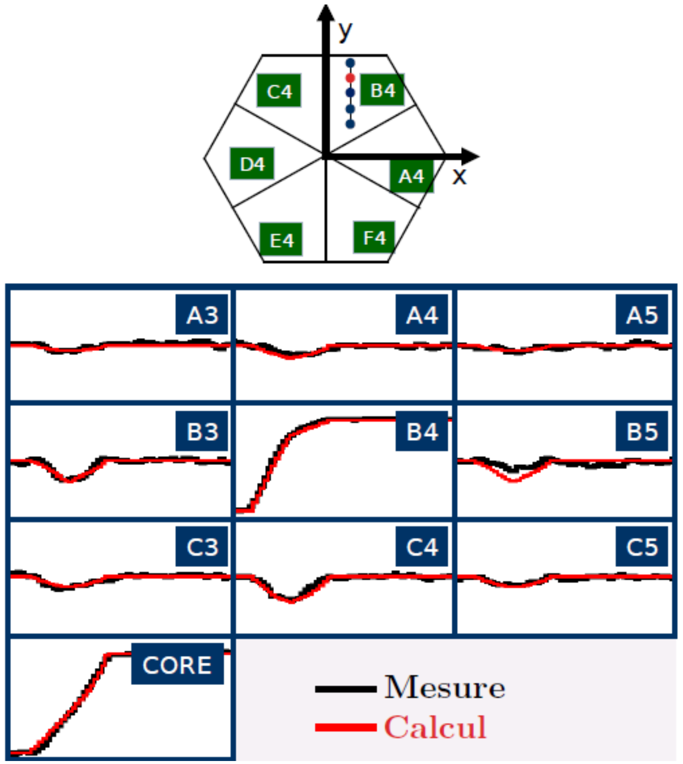

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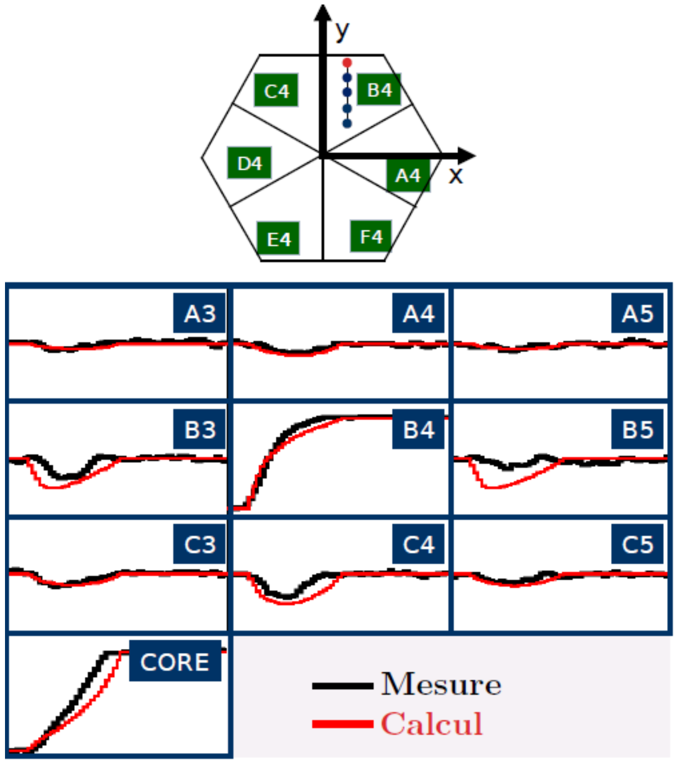

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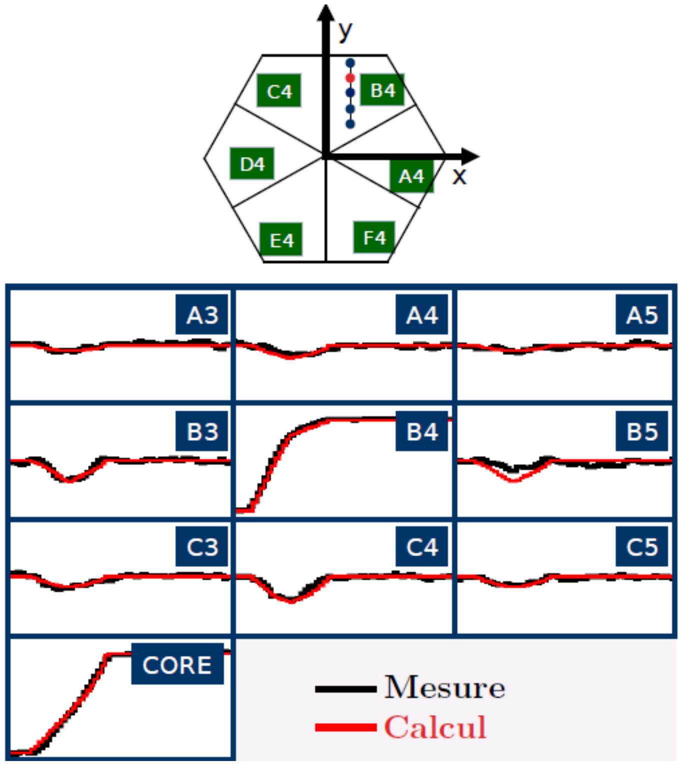
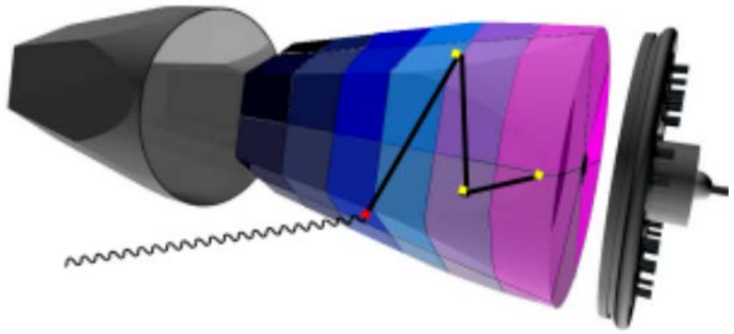
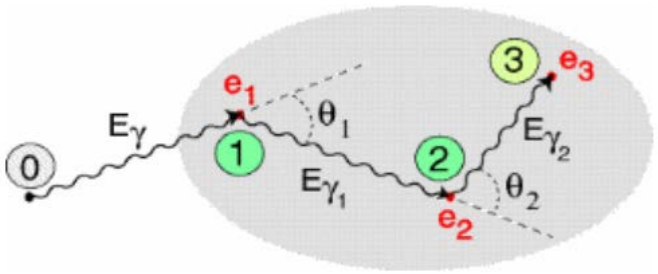


# The tracking of the gamma ray



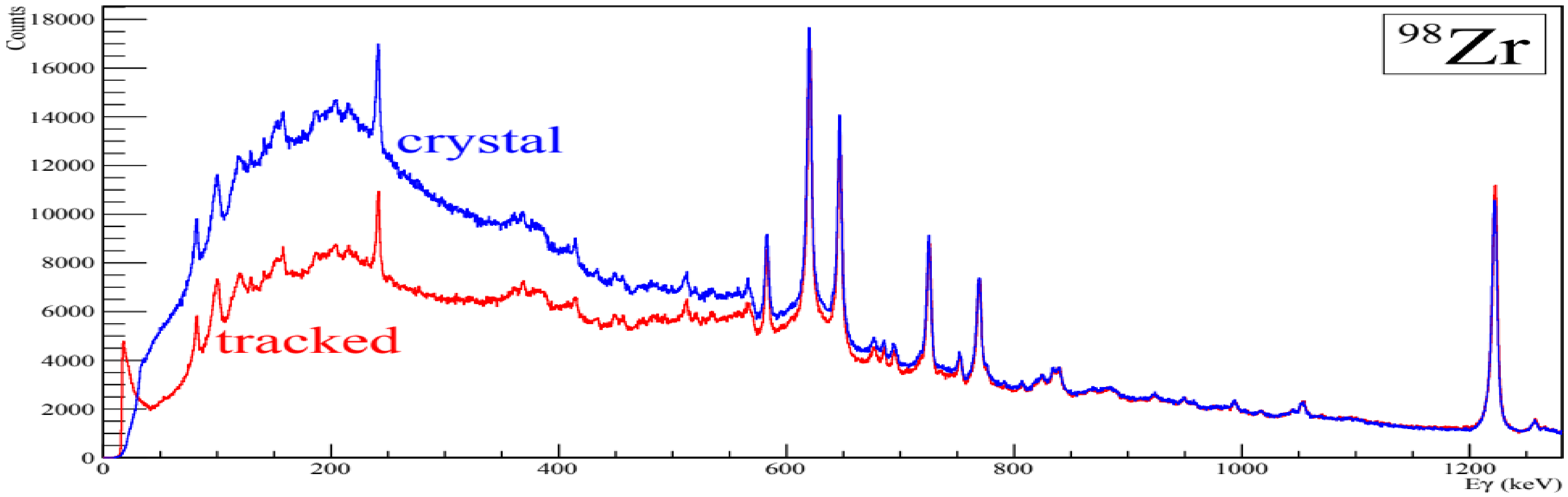
- Gamma-ray are tracked back to the source using Compton diffusion formula.
  - ✓ Allows for the determination of the first interaction point.
    - ✓ Accurate Doppler correction.
  - ✓ Improve the photopeak to background ratio.





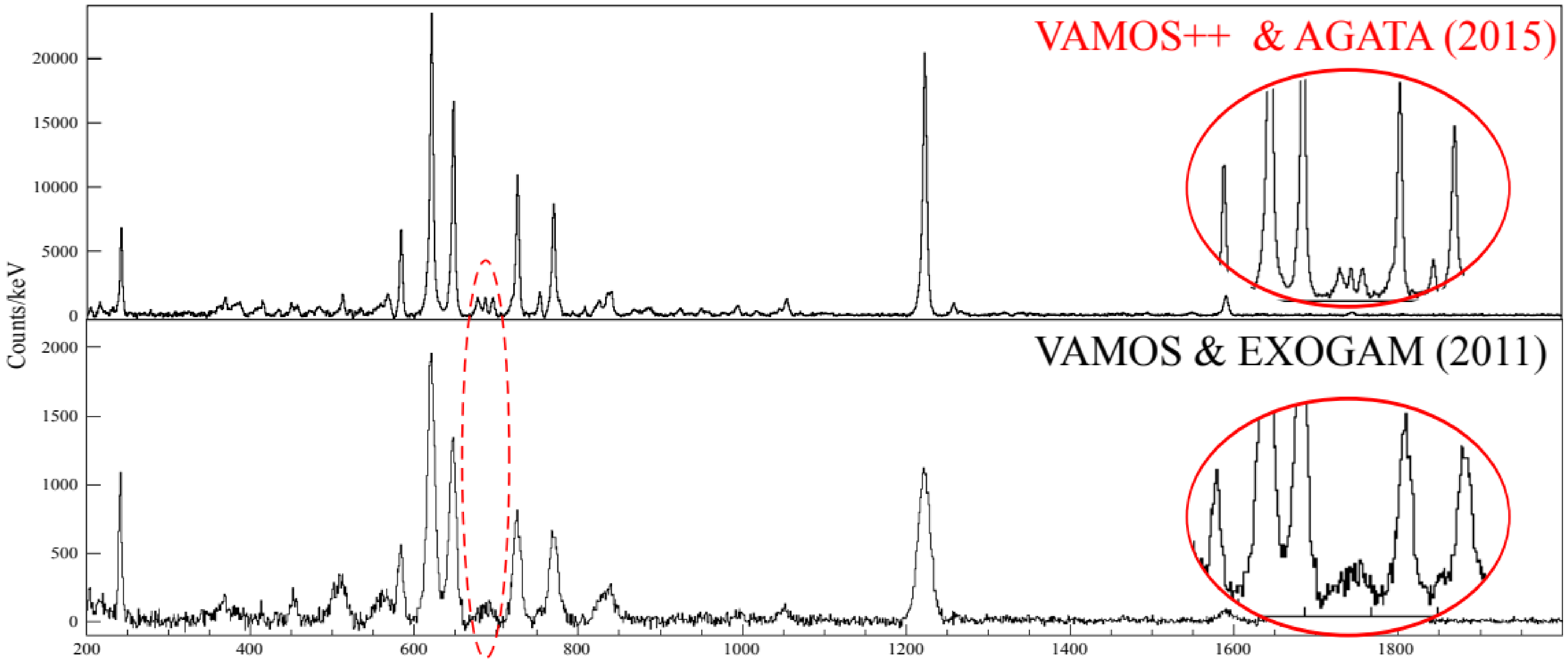
# AGATA capabilities

- The tracking method reduces the low energy background significantly.



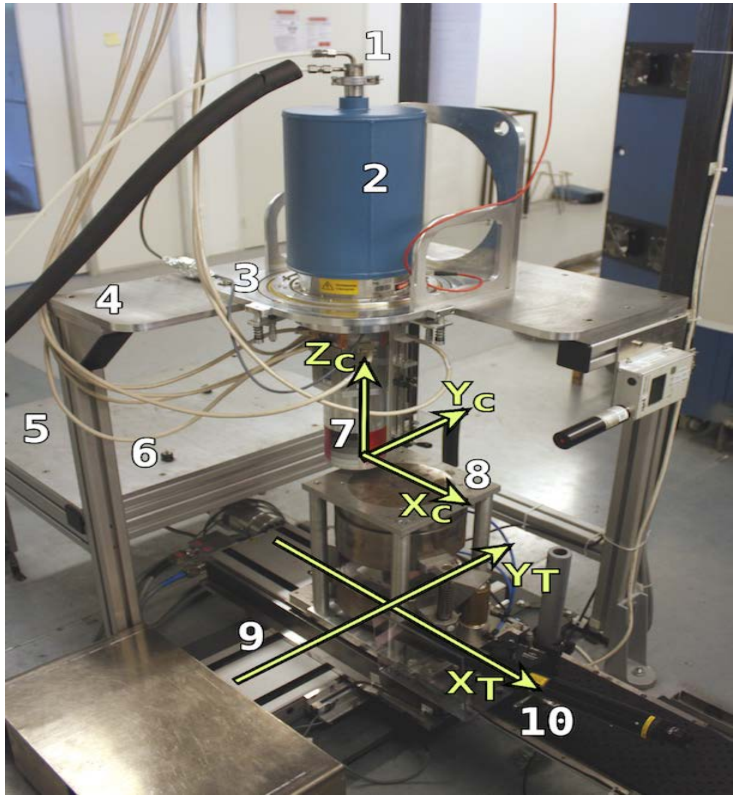
# Doppler correction with PSA + Tracking





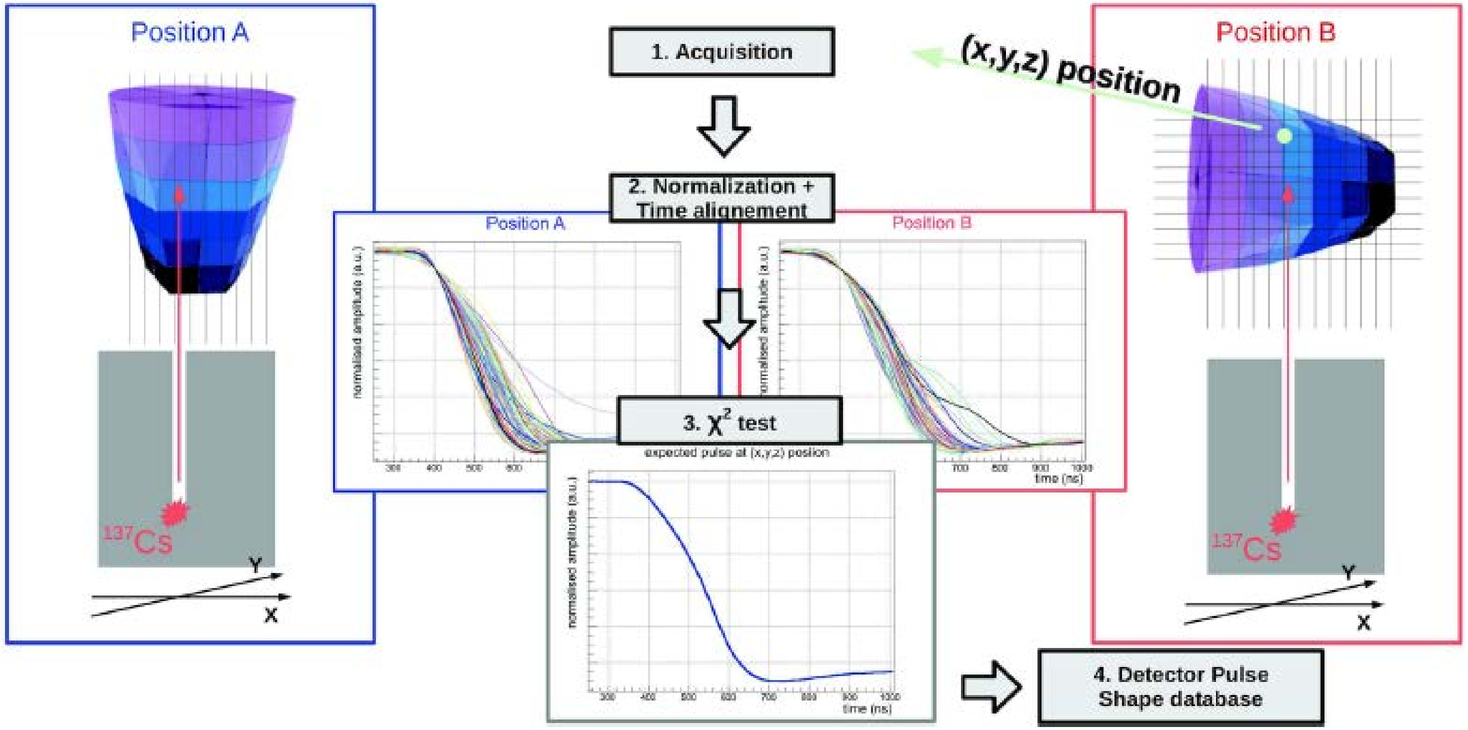
# Improving the PSA

- To improve the PSA we need to improve the databases.
  - ✓ By improving the simulations.
  - ✓ By replacing the simulations with experimental data.
  - ✓ In both cases we need experimental databases.
- Experimental databases were produced at Strasbourg.
  - ✓ To produce the databases the crystal had to be scanned.
  - ✓ Scanning the crystal means that we measure signals at every point of the crystal.
  - ✓ A prototype crystal was scanned
  - ✓ The source used is 137Cs.



# The scanning process

- 1 vertical (X,Y) and 1 horizontal(X,Z) scan.
- To get a 3D databases, a $\chi 2$ analysis of both datasets is done.
- This method has been validated and published but it's very time consuming (5 days for the PSCS analysis)

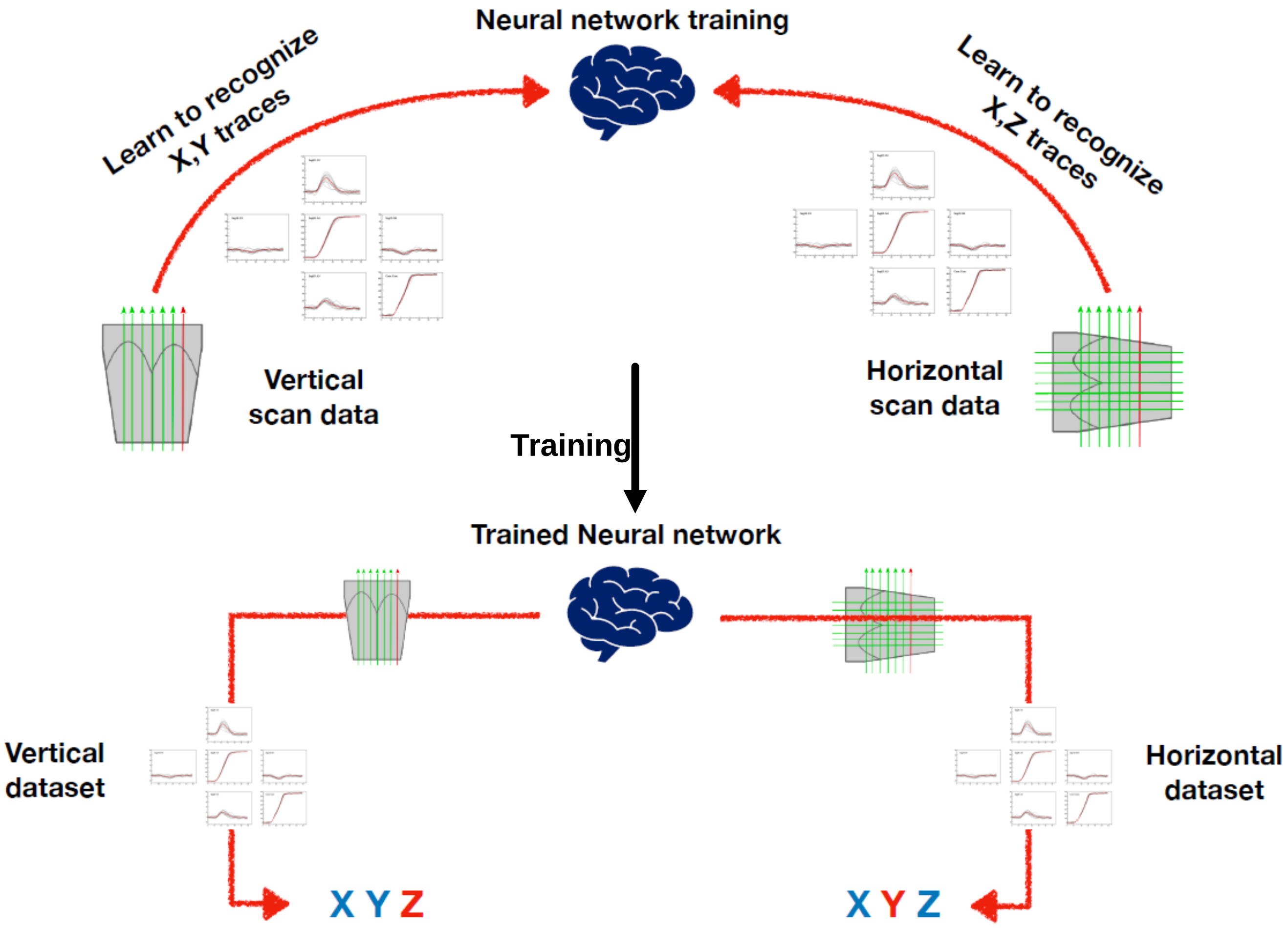



B. De Canditiis *et al.*, Eur. Phys. J. A 57 (2021), B. De Canditiis and G. Duchêne, Eur. Phys. J. A 56 (2020)

Picture from Michael Ginsz's PhD thesis

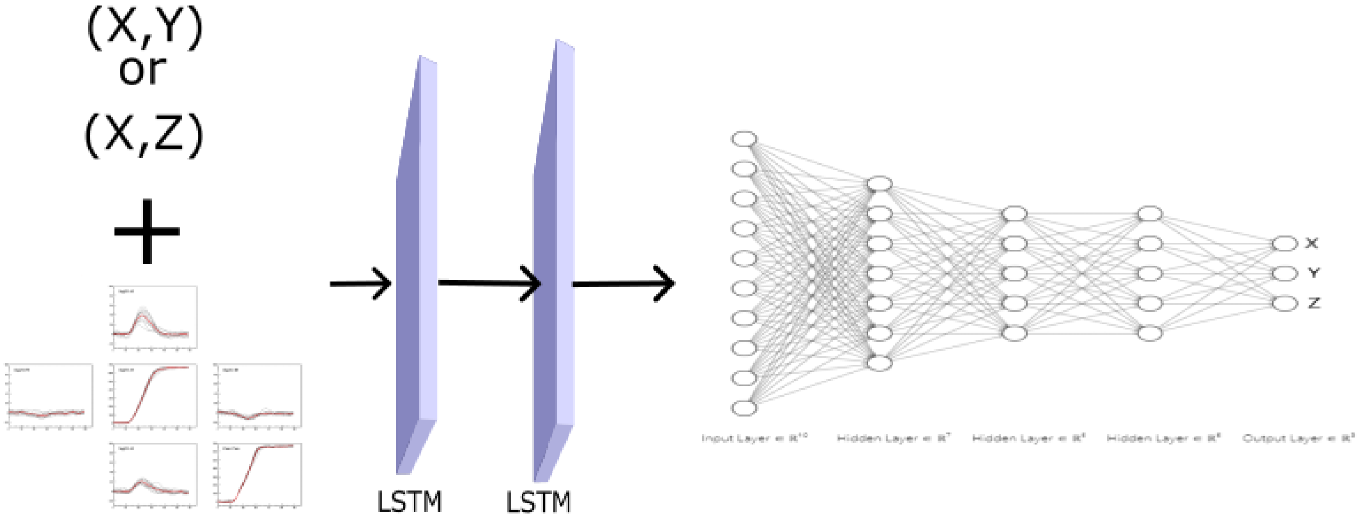
# Neural networks to produce the 3D databases





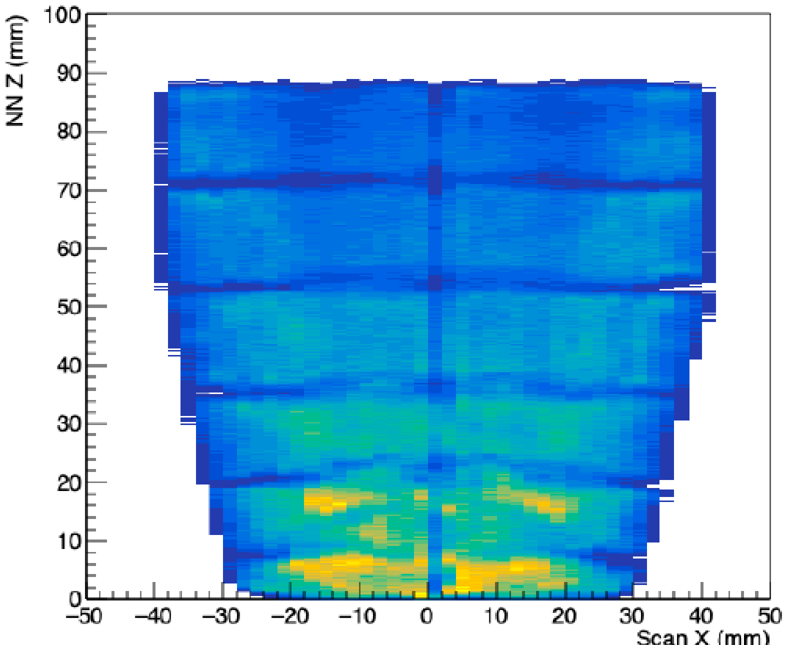
# Neural networks: LSTM

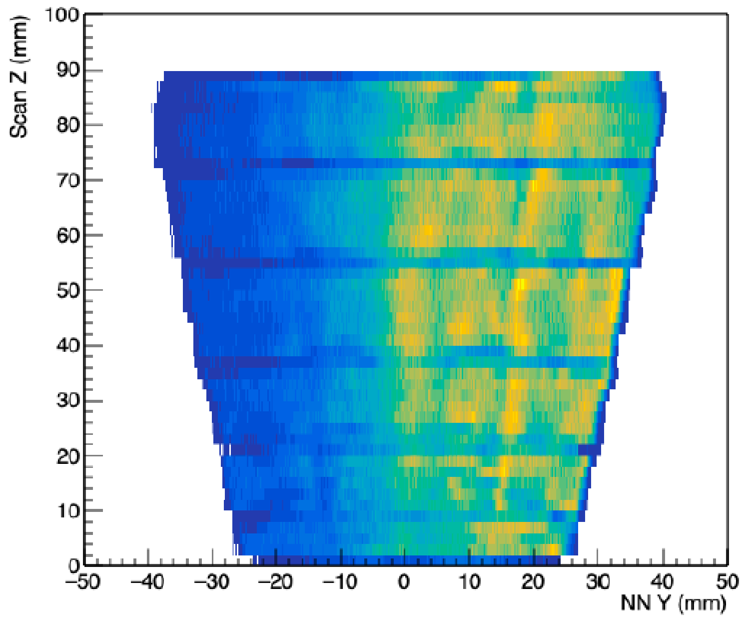
- 2 Long short-term memory (LSTM) layers were used.
  - ✓ LSTMs can process sequences of data like the signals.
  - ✓ Are very robust and are not affected by time misalignments.
- The loss function was calculated only for the two known axis, this allows the network to learn patterns of each dataset without affecting the other.



# Data preparation

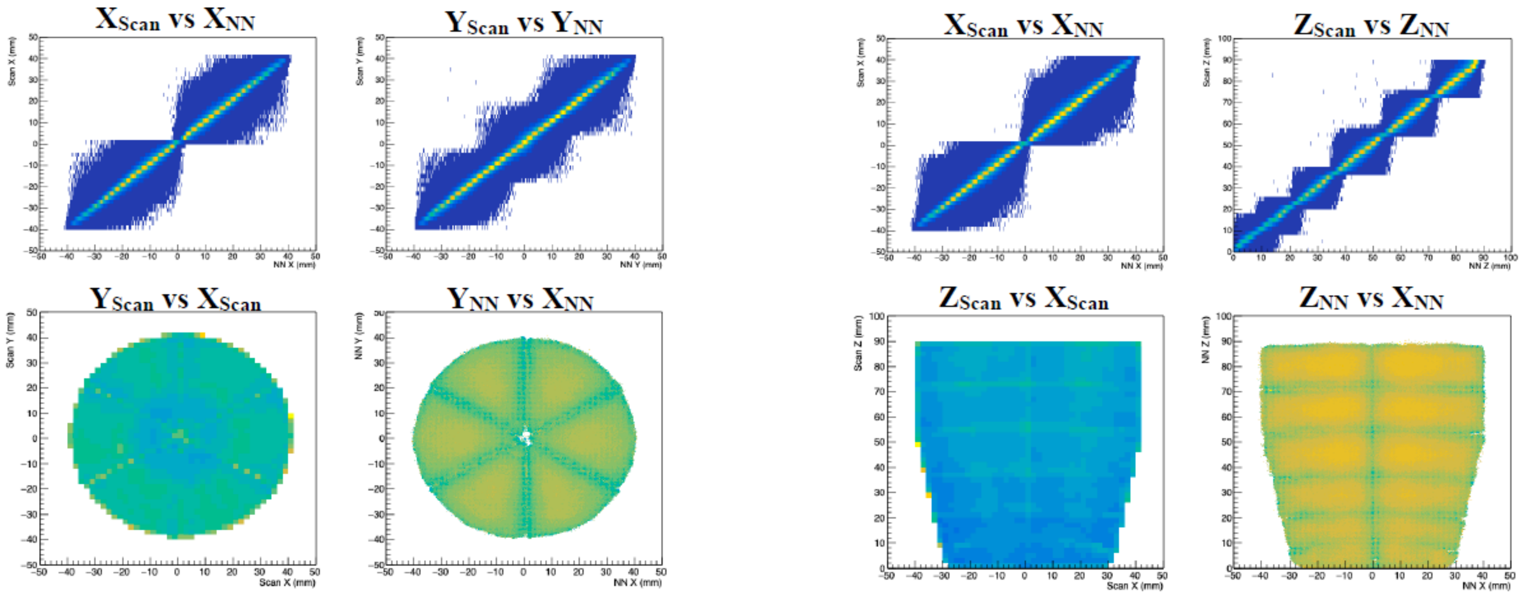
- The data must be homogenous to avoid bias from the neural network.
  - ✓ Only 10 signals/voxel are kept.
  - ✓ 500k signals per scan in total.
- Gate on the 662KeV photopeak and selection of segment multiplicity of 1.
  - ✓ To avoid Compton scattering signals and assure the signals at the right position.
- Remove dummy signals.



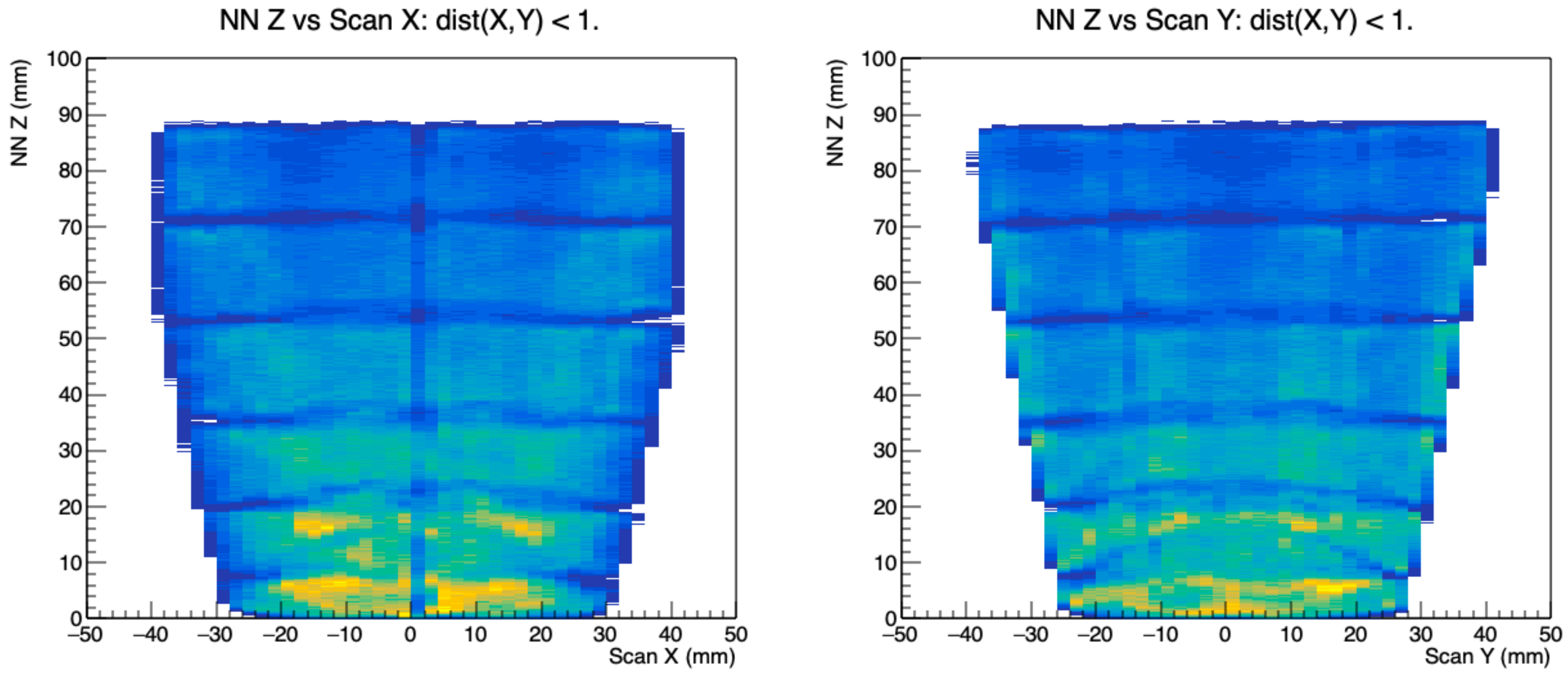
# Analysis of neural network results

- The two known axis are compared with the predictions of the network.
- The bad predictions can be due to bad signals.
- Only the predictions with error on the known axis of less than 1mm are kept.

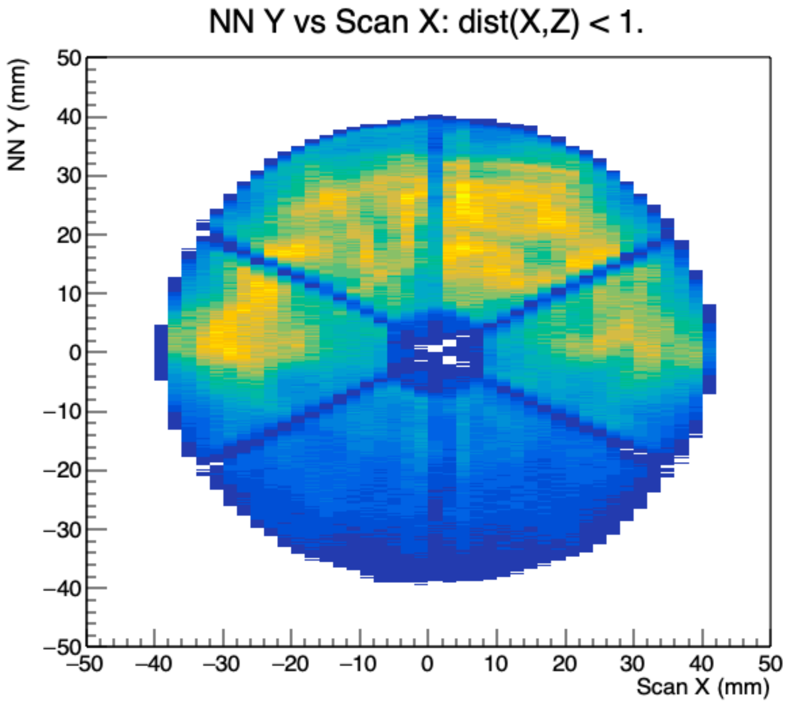


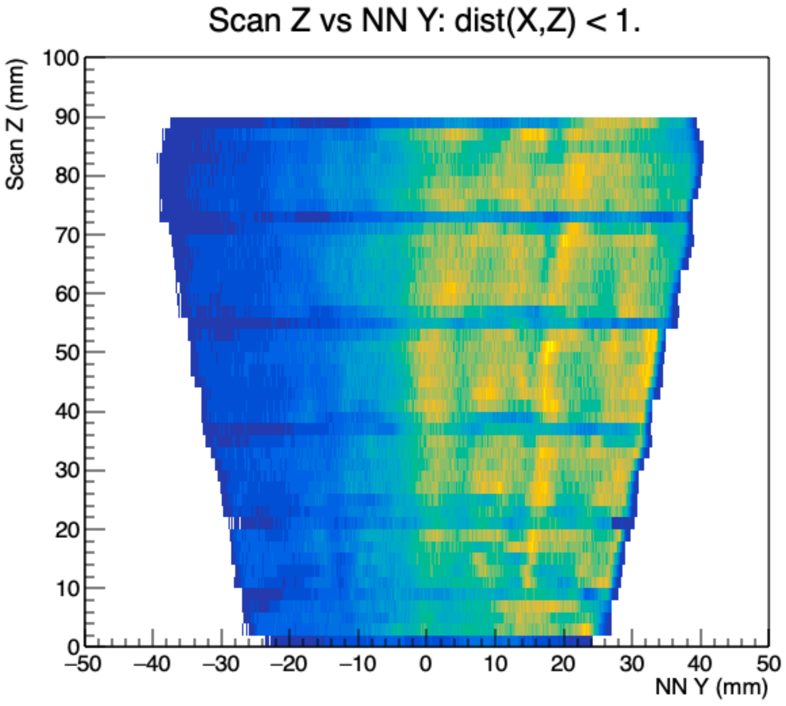
# Neural network results: Vertical scan distribution



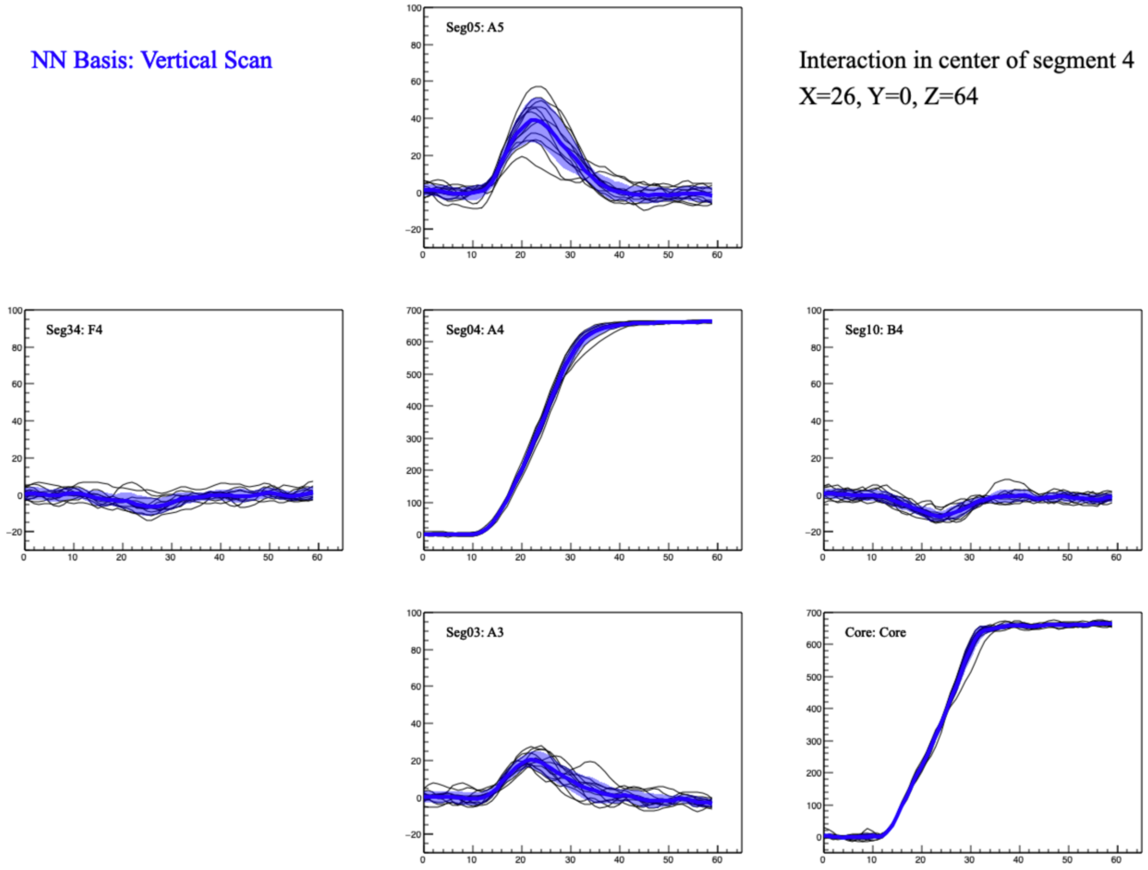


# Neural network results: Horizontal scan distribution

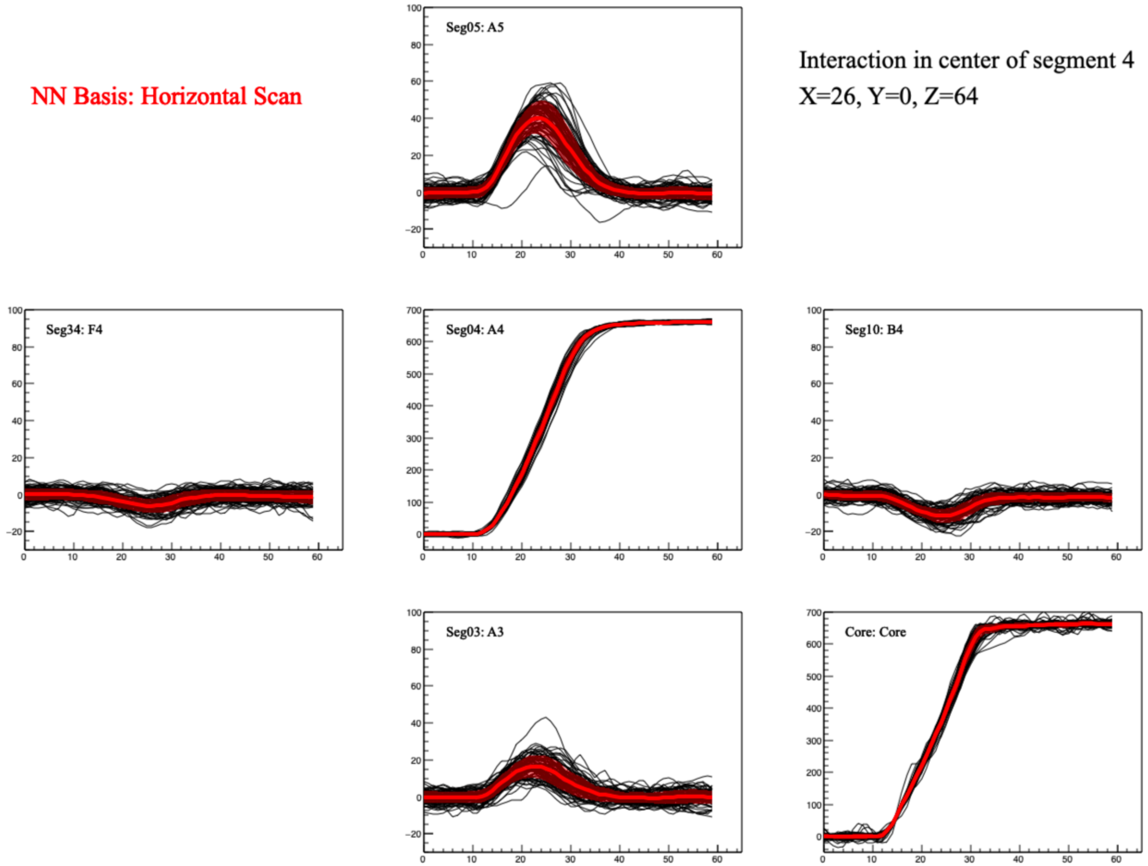


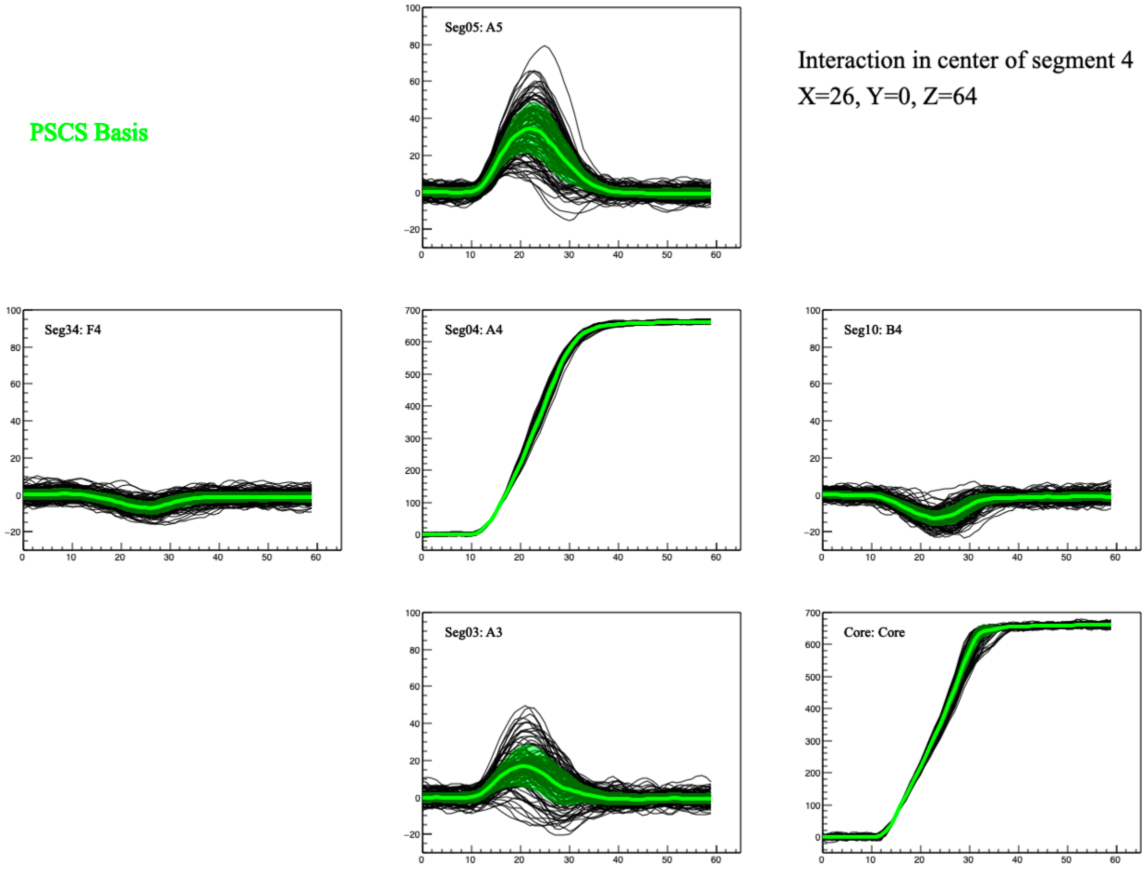
# Neural network results: Vertical Signals



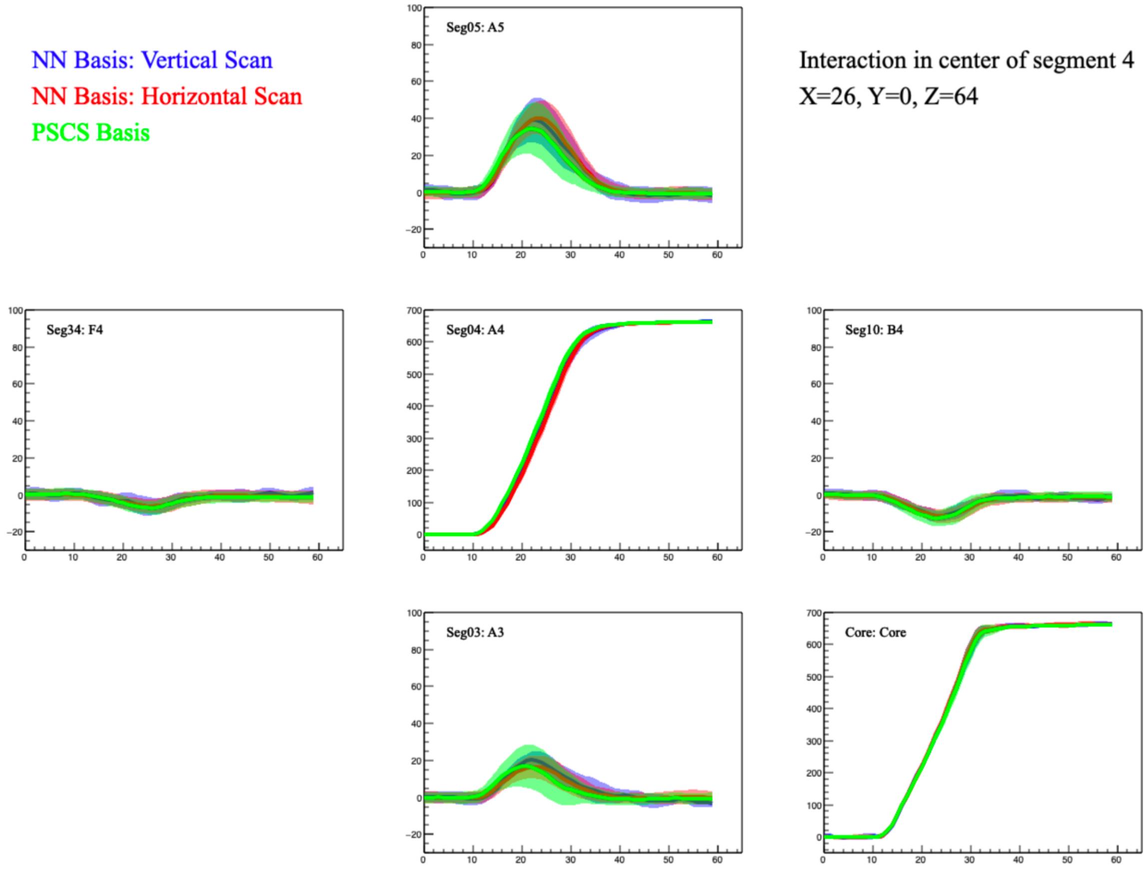
# Neural network results: Horizontal signals



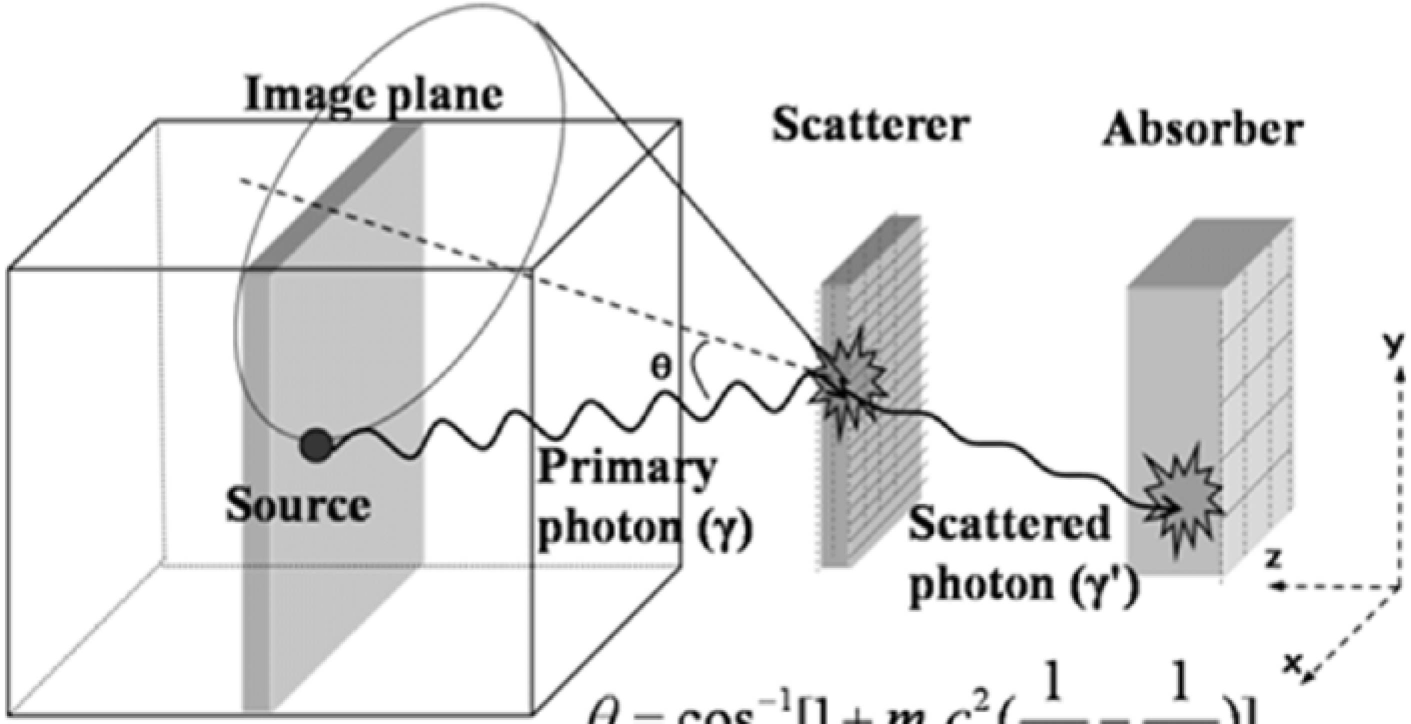
# PSCS method signals



# Neural network Vs PSCS



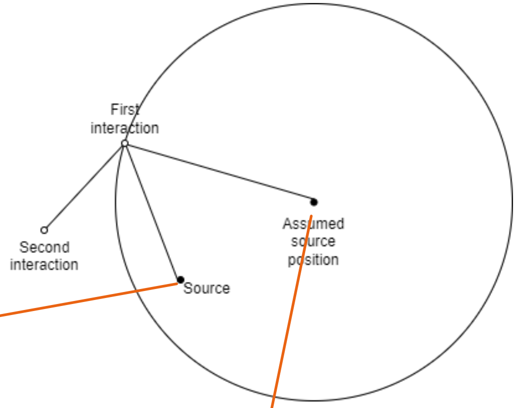
# Imaging using Compton scattering

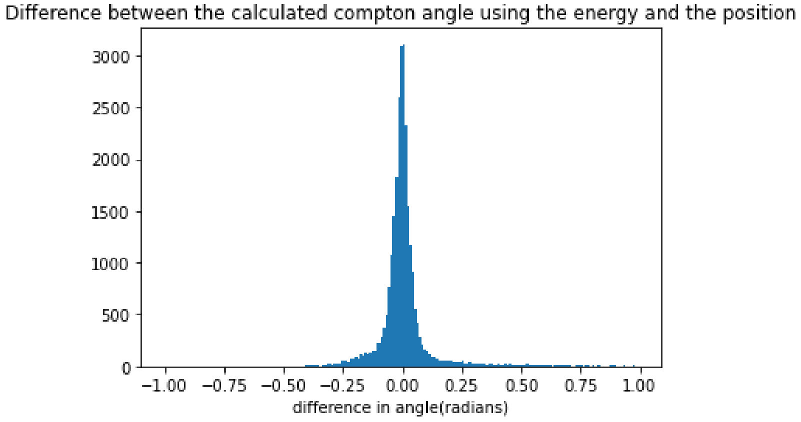


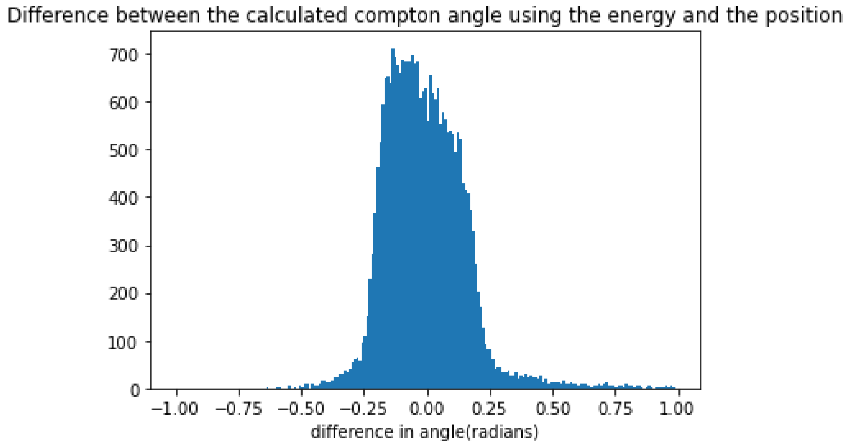

$$\theta = \cos^{-1}[1 + m_0c^2(\frac{1}{E_\gamma} - \frac{1}{E_\gamma^{'}})]$$

# Imaging using an optimizer

- The scattering angle can be calculated from the energy and from the position.
- Minimizing the difference between the two will give the source position



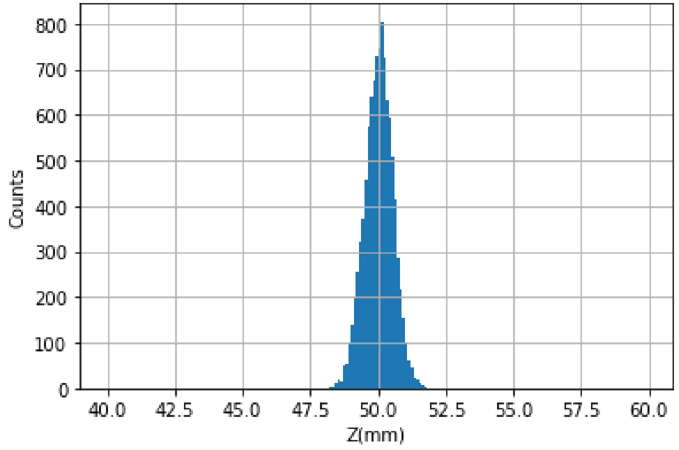



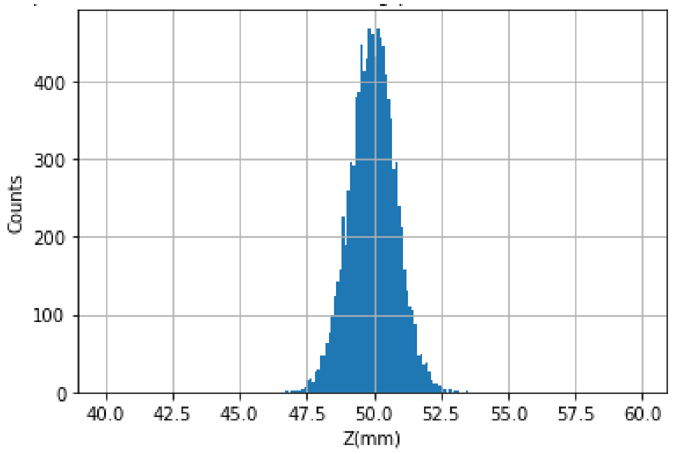
# Imaging using Compton scattering

Imaging of a source located at (0,0,50)mm in the sphere of AGATA

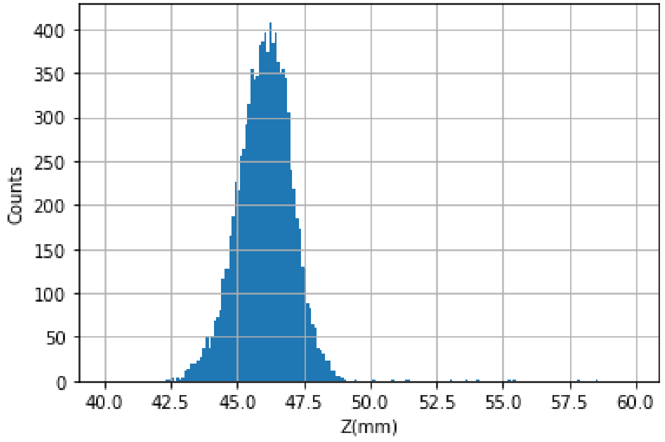
Experimental position error




Two times the experimental position error




Experimental position error with bad tracking



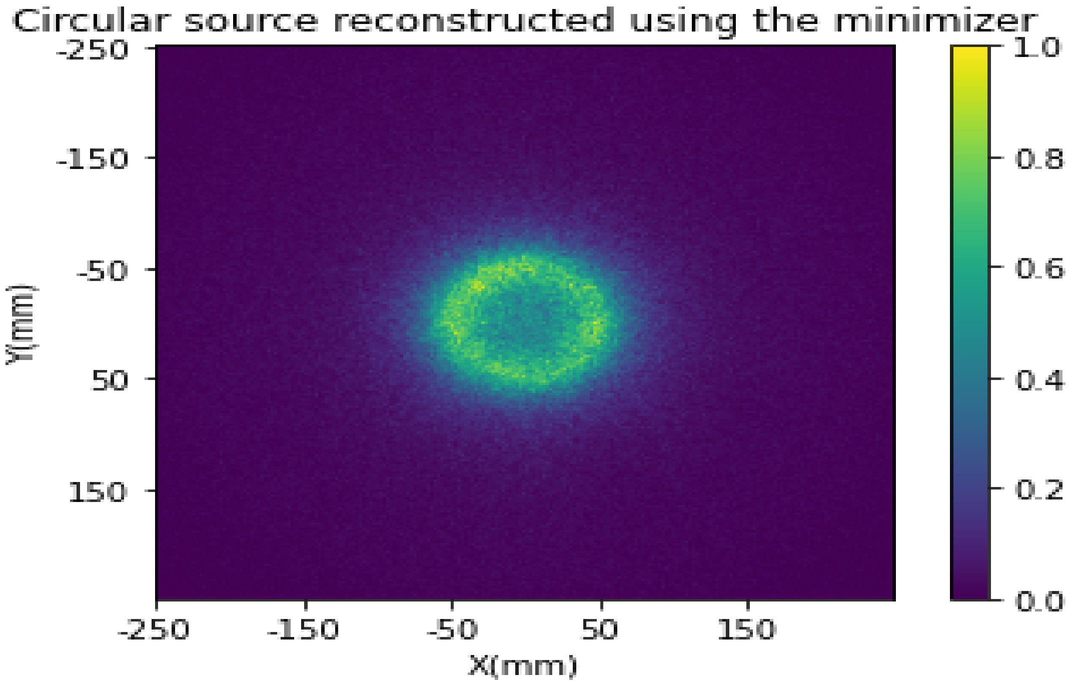

FWHM 1.3mm 2mm 2.4mm

# Conclusions and prospects.

- The neural network 30 minutes for training and 1 hour to process the two scans compared to 5 day.
- Since we can’t know what is the exact position of a signal, it’s complicated to determine which method is more accurate.
- We developed a fast imaging method using Compton scattering to characterize the PSA.
- The imaging method will be used to characterize the results of the neural network.
- This work can open the door for neural network PSA.

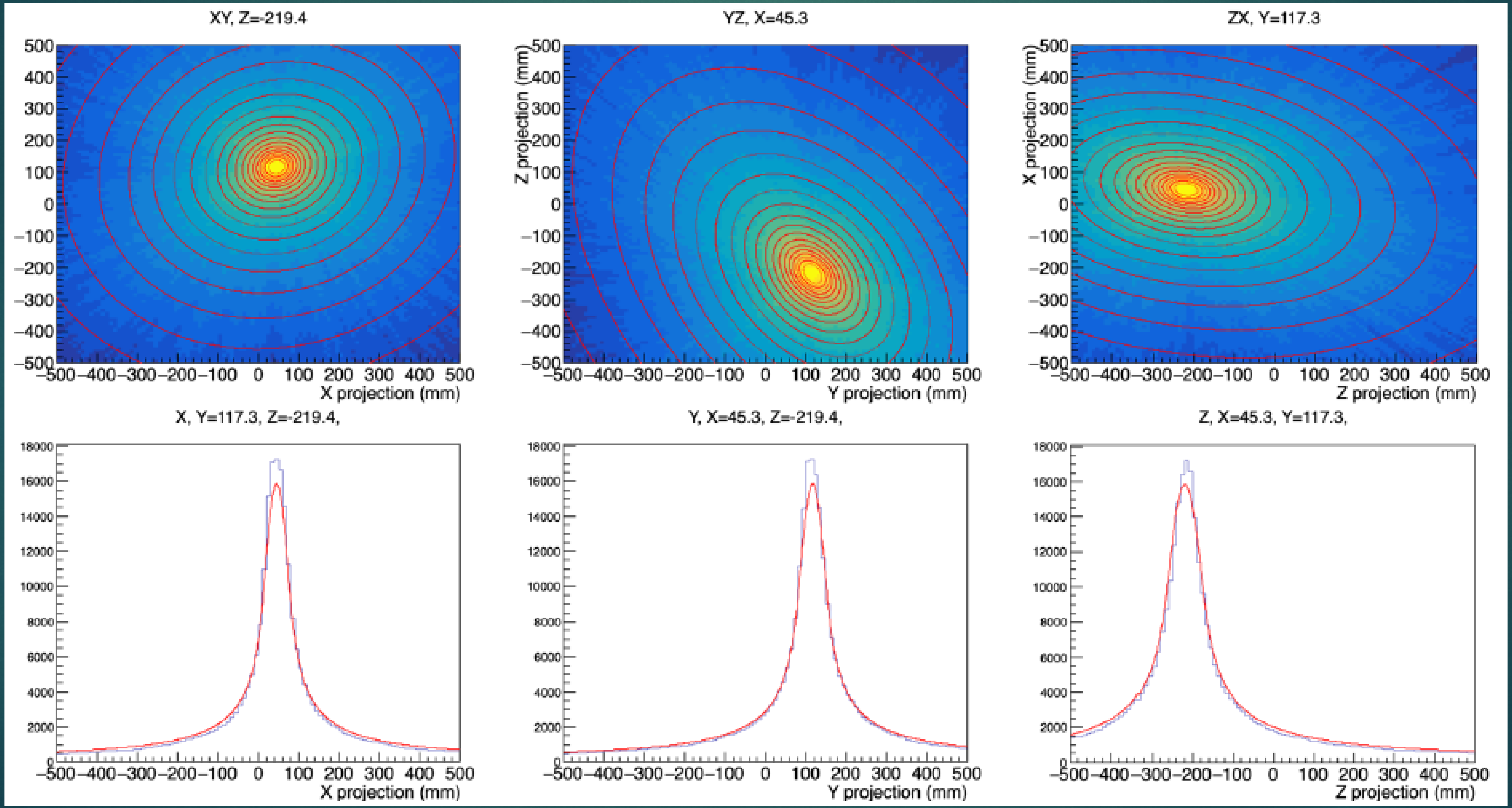
Thank you for your attention ☺

# Imaging using Compton scattering



# Imaging using 3D histograms

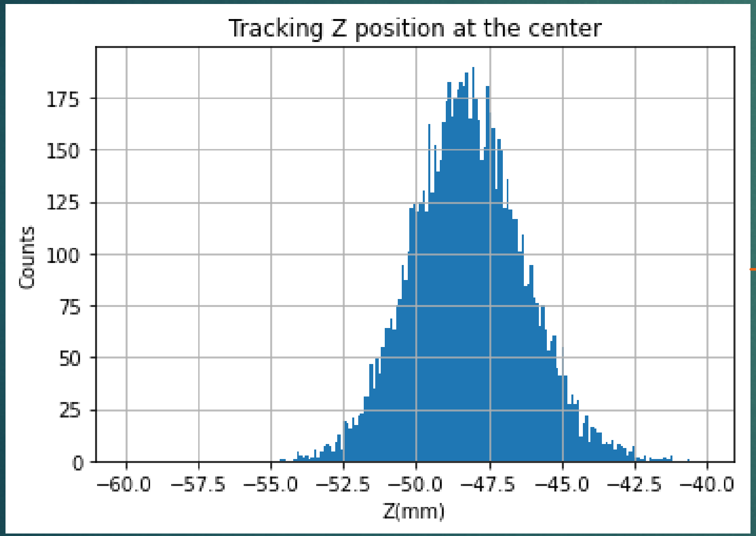




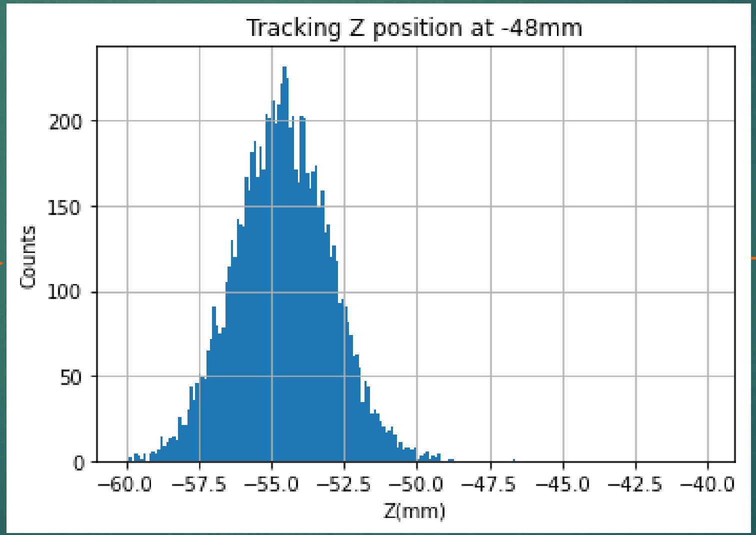
# Results of the minimizer with experimental data

- This source run was conducted during GANIL campaign in the autumn of 2021.
- The source used is Eu located at (0,0,-55)mm.

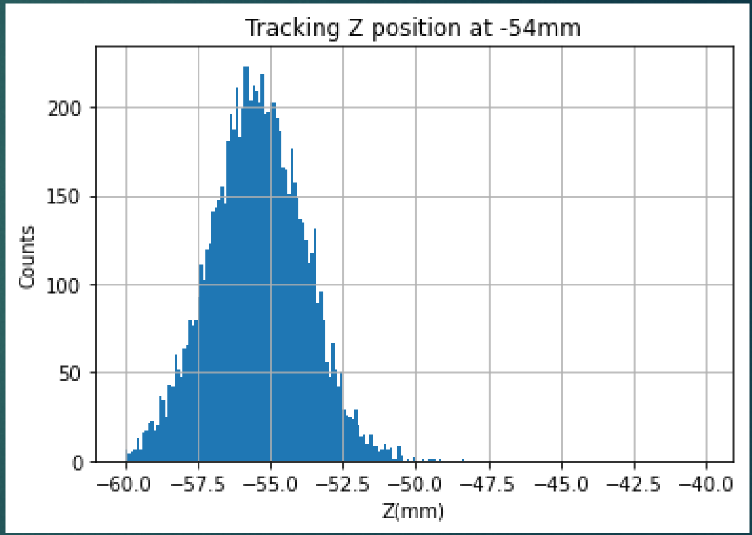
[ -3.63   0.55 -48.23]




[ -3.8   0.5 -54.58]



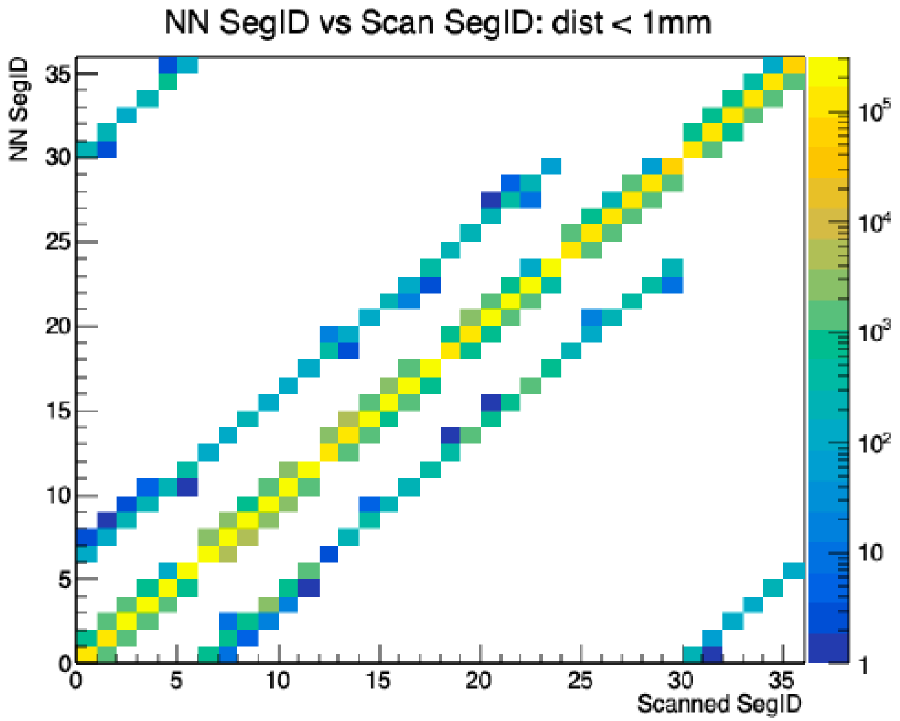

[ -3.71   0.52 -55.46]




FWHM: 4.5mm 3.83mm 3.78mm

# Analysis of neural network results

- Only 2% of the predicted segments were wrong.



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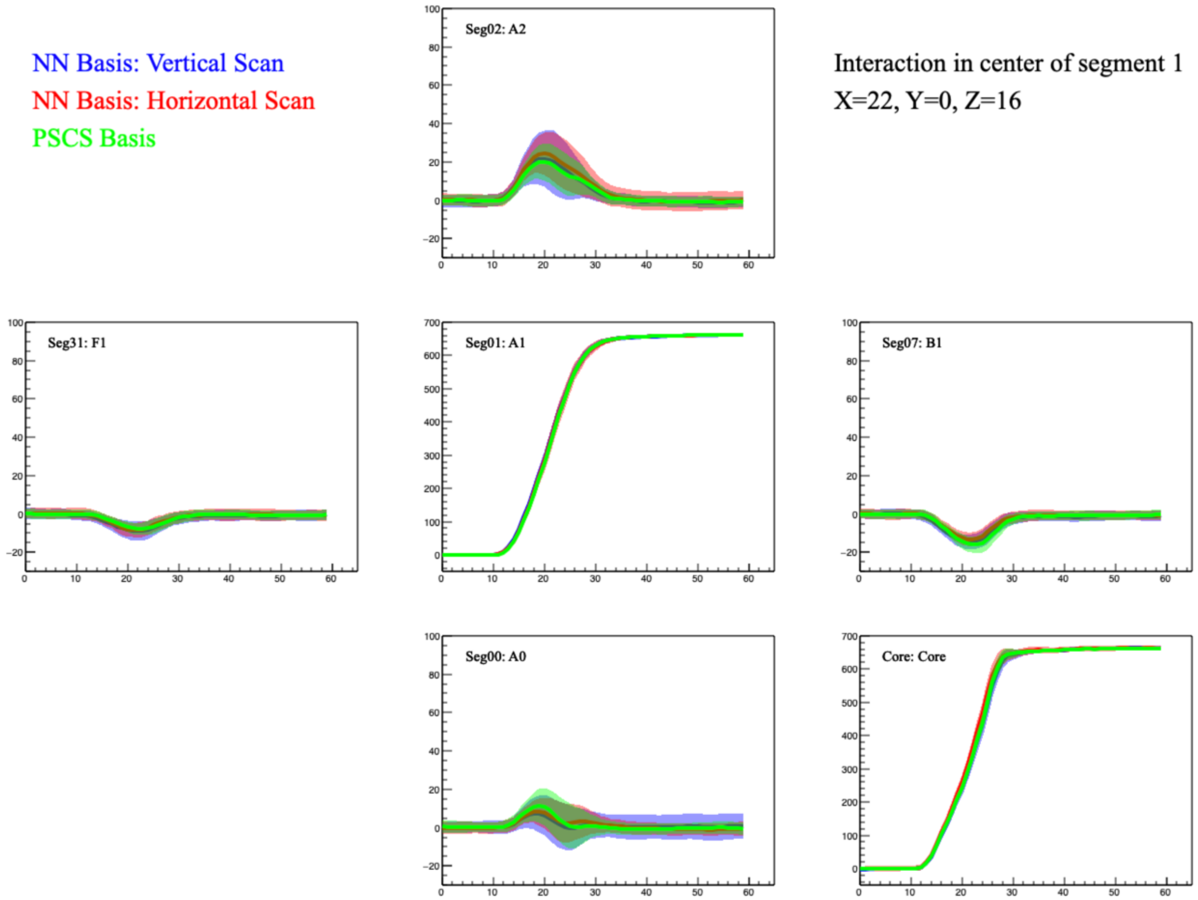

# The Strasbourg scanning tables

- A motorized collimator with a 10$\mu m$ precision.
- A system allowing the placement of the detector in vertical and horizontal positions.
- A laser alignment system.
- Detector scanned in this work: the symmetric S001 crystal, with a 137Cs source.