Utilizing machine learning for the Data Analysis of AGATA's PSA database.

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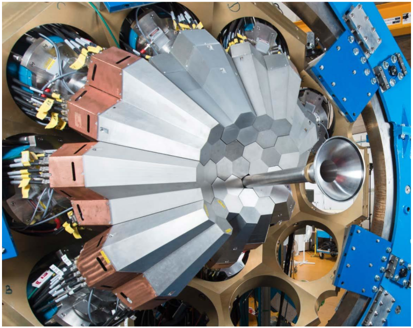
EuCAIFCon24

AGATA

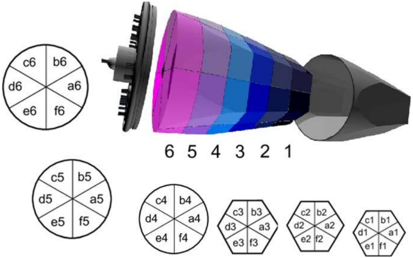
AGATA array

- Consists of 50 HPGe detectors (180 are planned to complete 4π sphere).
    - State of the art energy resolution 2keV at 1.33MeV.
- Capable of tracking gamma rays.



AGATA crystals

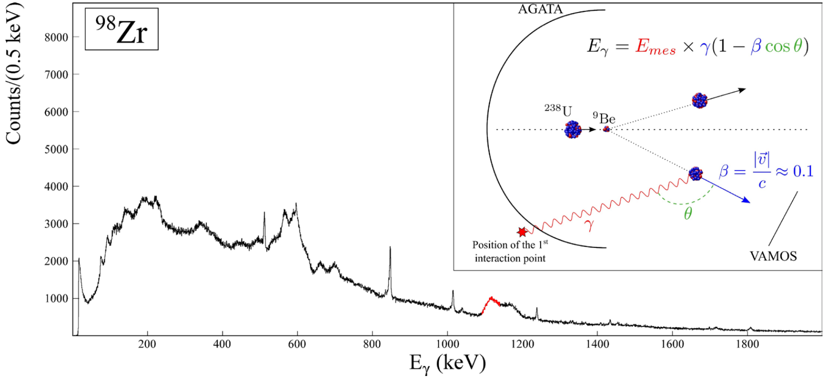
- Higher efficiency due to the electric segmentation.
    - No physical segmentation of the crystal (reduced dead layers between the segments).
- 36 signals for each of the segments and 1 signal for the full volume of the crystal (core signal).



In-beam Gamma-ray spectroscopy

Uncorrected spectrum

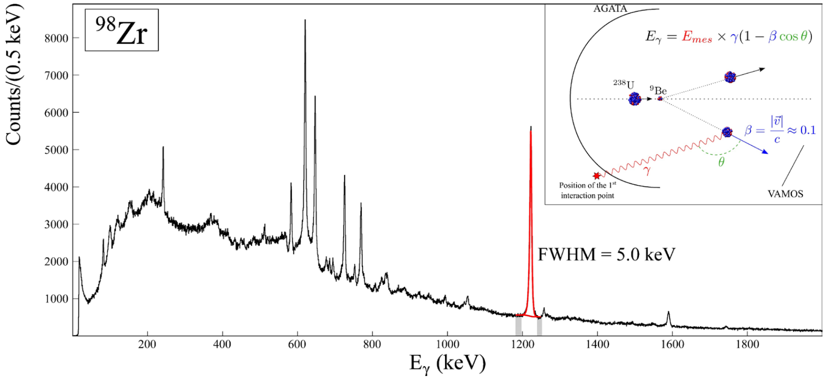
- In in-beam experiments product nuclei can move at speeds close to the speed of light where the Doppler effect becomes significant.
- The peaks coming from the moving nuclei are broadened due to Doppler effect.
- The sharp peaks seen in the spectrum come from the background of the experimental room.



In-beam Gamma-ray spectroscopy

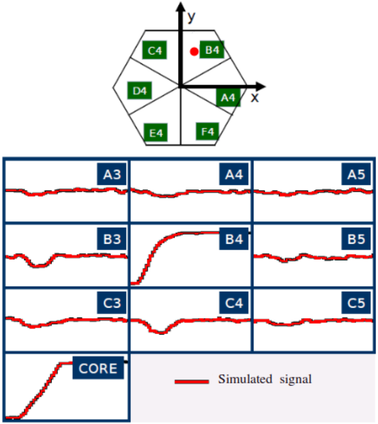
Doppler-corrected spectrum

- Doppler correction requires the position of the first interaction of the gamma rays.
- The FWHM after the Doppler correction at 1223 keV is 5 keV.



Pulse Shape Analysis (PSA)

- Simulated databases of signals are built for each crystal.
    - Each database has a 2 mm 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.



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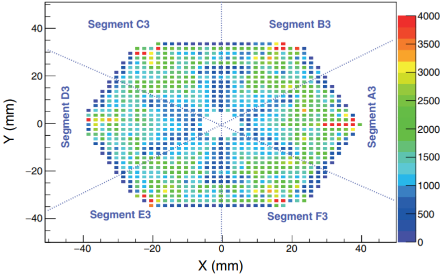

Korichi, A., Lauritsen, Eur. Phys. J. A 55, 121 (2019)

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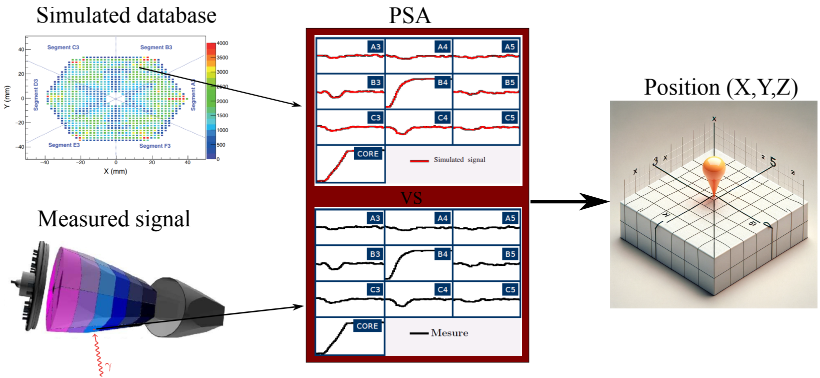
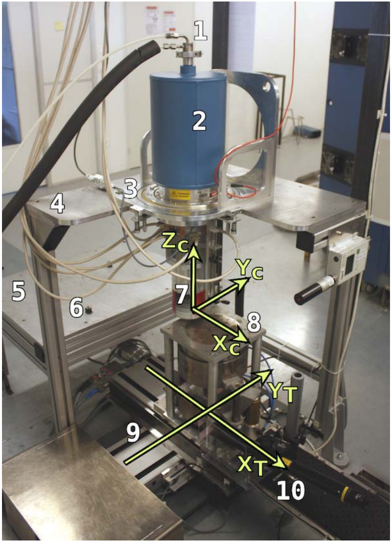


Experimental database: Strasbourg scanning table

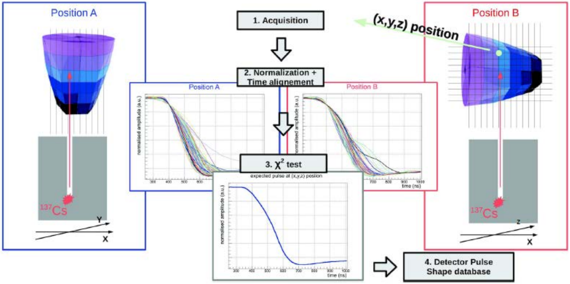
- The PSA can be improved by:
  - Improving the simulations.
  - replacing the simulated database with experimental one.
- Experimental databases were produced at LPHC Strasbourg.
  - To produce the databases the crystal had to be scanned.
  - Scanning the crystal means that we measure signals at every voxel of the crystal.
  - Laser positioning system was used to accurately position the crystal and the collimator.
  - A prototype crystal was scanned.



Picture from Michaël Ginsz, PhD thesis, Université de Strasbourg (2015)

Scanning process and Pulse Shape Comparison Scan (PSCS)

- 1 vertical (X,Y) and 1 horizontal(X,Z) scan.
- To get a 3D databases, a χ^2 analysis of both datasets is done.
- This method has been validated[1,2] but it is time consuming (5 days for the PSCS analysis.)



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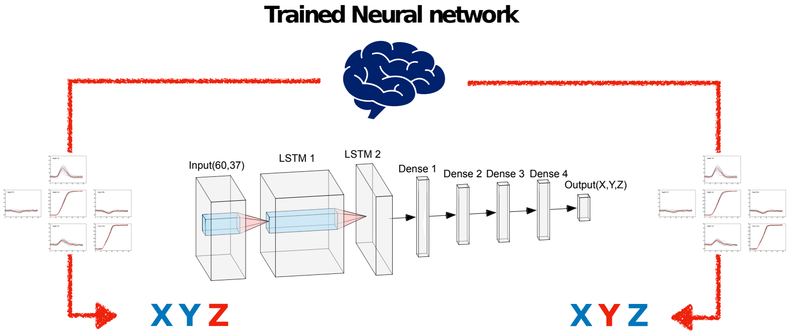
[1] B. De Canditiis and G. Duchêne, Eur. Phys. J. A 56 (2020)
[2] B. De Canditiis et al., Eur. Phys. J. A 57 (2021)

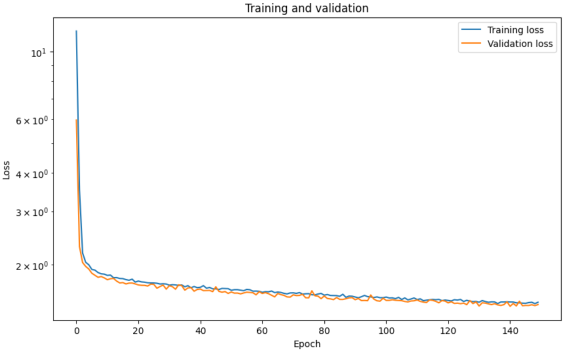
Neural networks

- 2 Long short-term memory (LSTM) layers were used.
  - LSTMs can process sequences of data like the signals and are very robust against time misalignment [X. Fabian et al. NIM-A 986 (2021): 164750.].
- The loss function was calculated only for the two known axes, this allows the network to learn patterns of each dataset without affecting the other.



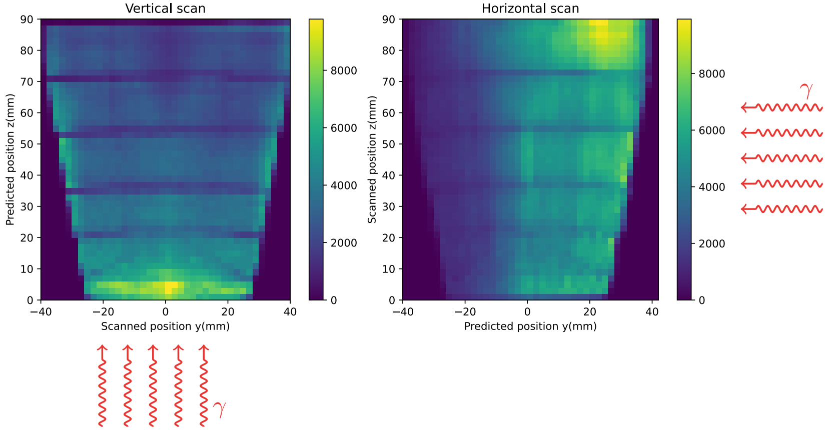
Neural networks

- A Gaussian noise layer was added to the input to reduce the overfitting.
- The number of epochs was optimised to avoid overfitting to be 150 epochs.



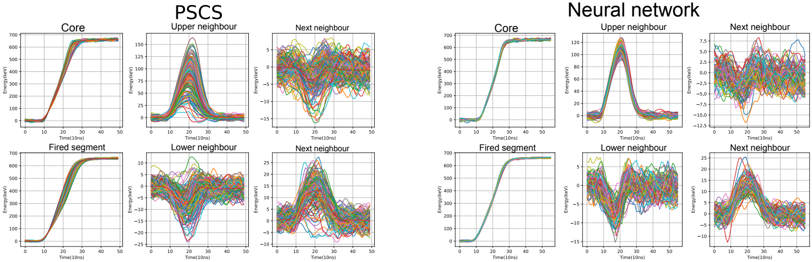
Predictions distribution

- The distribution of the predicted positions conforms with the attenuation of the gamma rays.



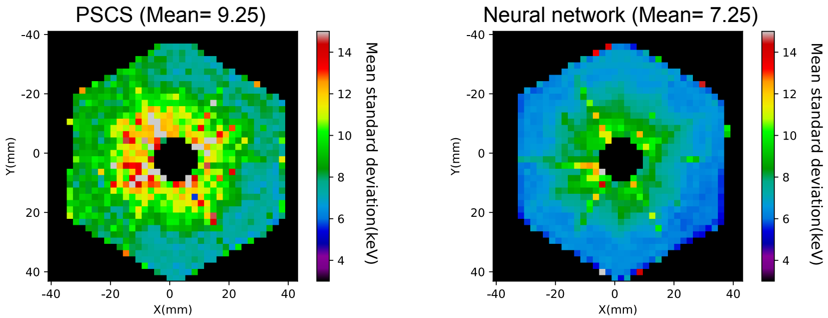
Model consistency

- The signals predicted at the same position should have the same shape.
- Below is a comparison between signals predicted at the same position using the PSCS method and the neural network.
- Both sets of signals show the same general shape, but the neural network shows more consistent signals.



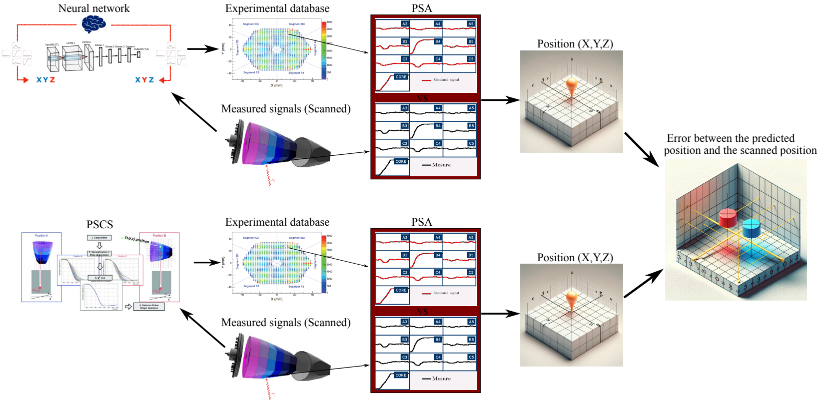
Model consistency

- The mean standard deviation of the signals predicted at the same position is used to evaluate the model consistency.
- It was calculated for the entire volume of the crystal.
- The neural network shows better homogeneity than the PSCS.



PSA database using the neural network

- The PSA databases were built by taking the mean signal per voxel in the crystal.
- Then the PSA was used to predict the position of the signals using the databases of the neural network (NN) and the PSCS.
- The predicted positions are compared with the scanned positions.



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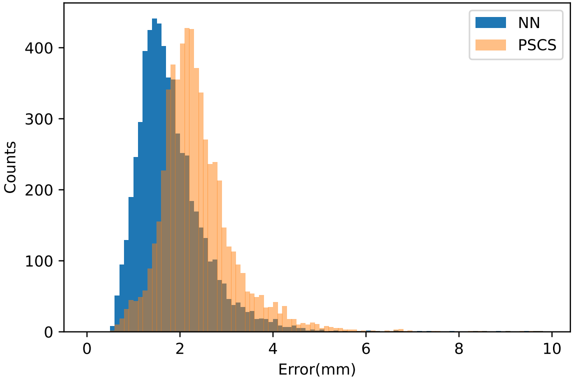

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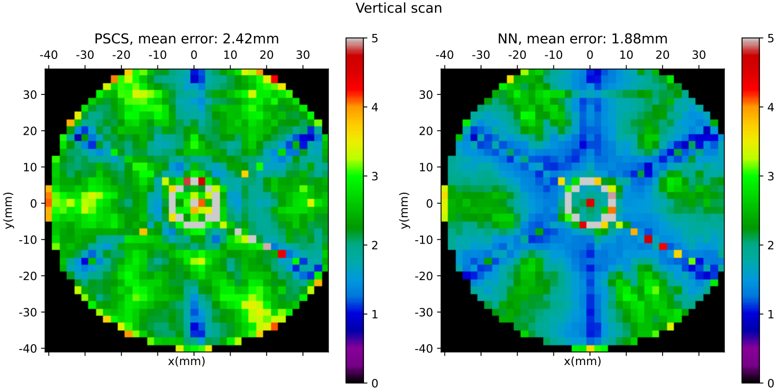
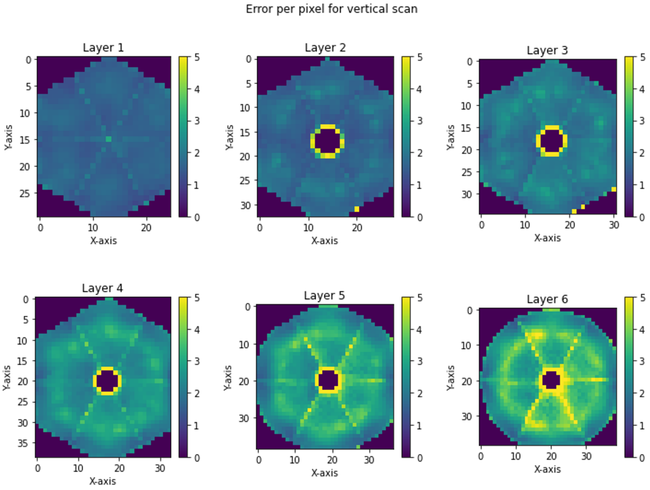


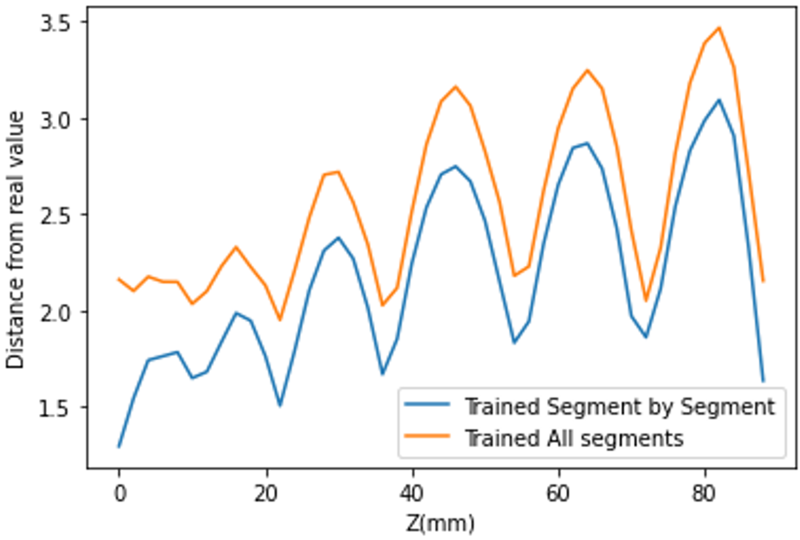
Summary and Conclusions

- Neural network was trained to process the Strasbourg scanning tables.
- Experimental bases were produced using the neural network and the PSCS, and then they were used for the PSA.
- The neural network 12 hours for training and 2 hour to process the two scans compared to 5 days for the PSCS.
- The neural network showed better consistency than the PSCS method.
- The neural network has 25% less error than the PSCS.

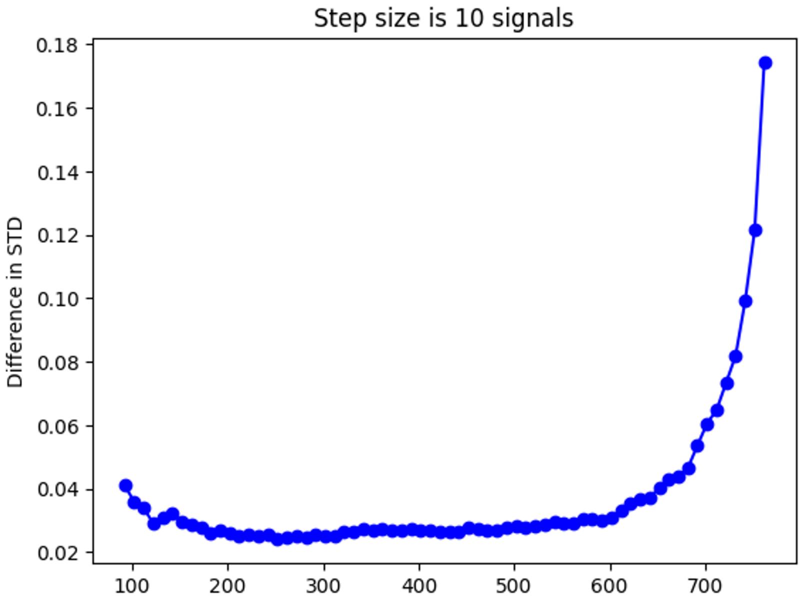
Backup: Error from the neural network



Backup: Train segment by segment



Backup: Remove noisy signals



Backup: Different architect