Machine Learning applied to signals identification

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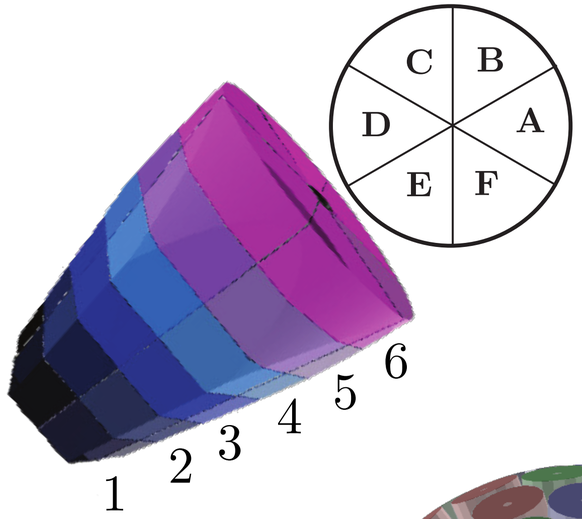
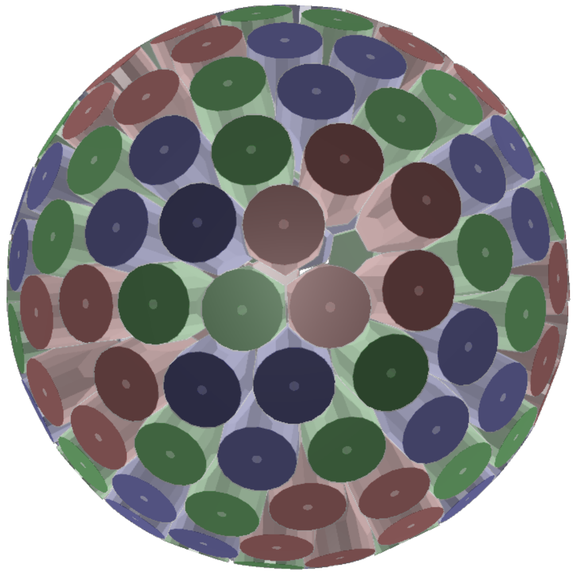
Rencontre Machine Learning, IP2I, 23/06/22

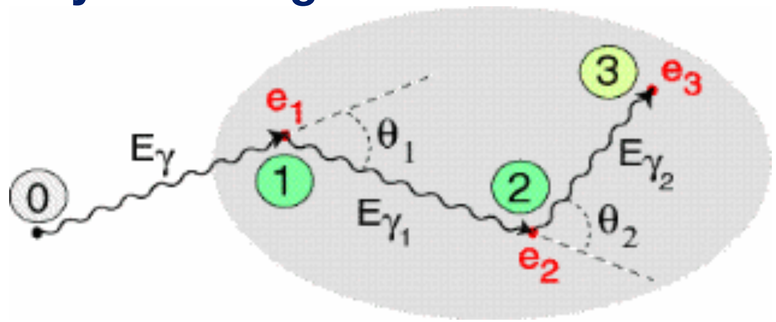
Introduction: The AGATA spectrometer

- State of the art for γ-ray detection
- 180 High purity Germanium crystals for a 4π detection
  - each detector is segmented in 36
- Two main algorithms:
  - PSA: Determination of the position of each interaction point
  - Tracking: Reconstruction of the γ-rays path

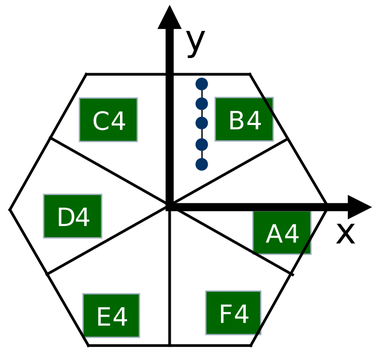




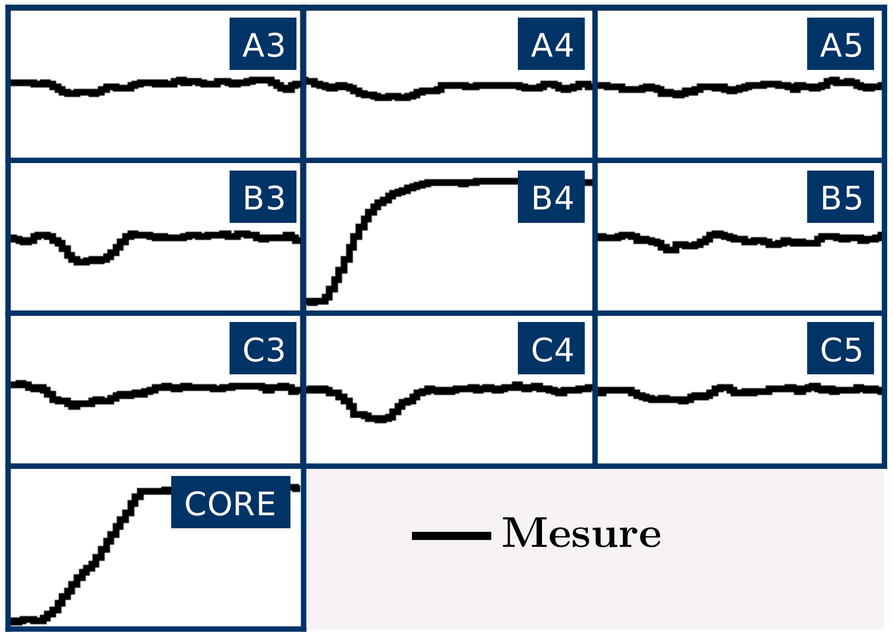
γ-rays tracking



Introduction: The PSA algorithm



- One interaction in the detectors create 36 segment signals
- The comparison of this signal to a signal basis allows to determine the position of the interaction



791 keV déposés dans le segment B4

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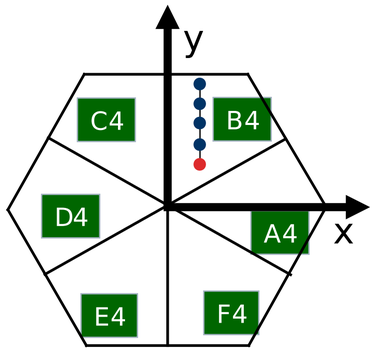

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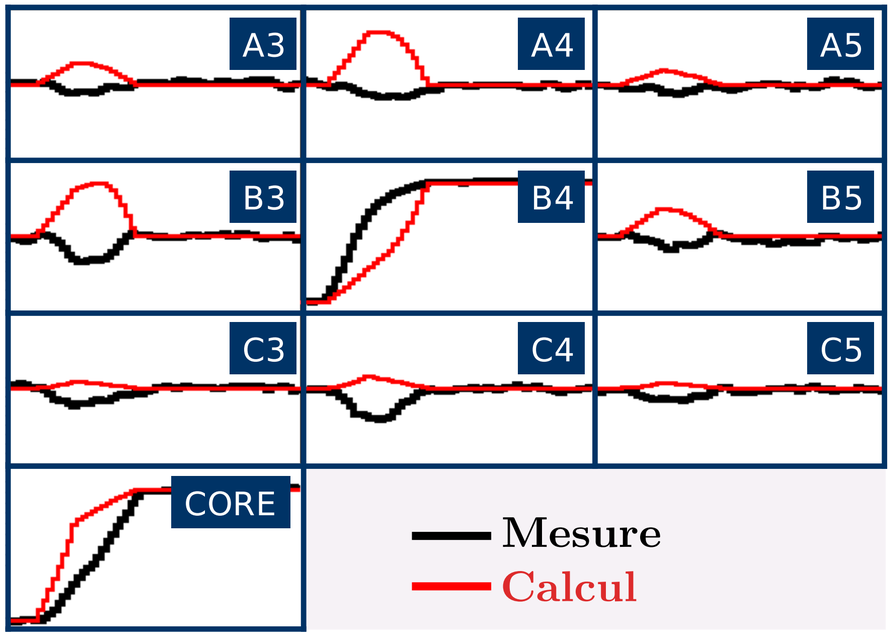

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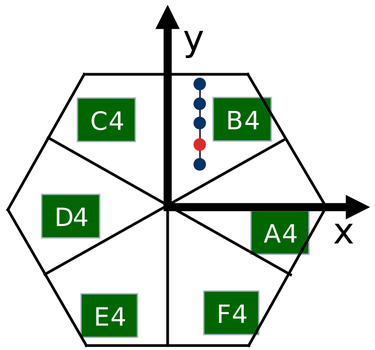

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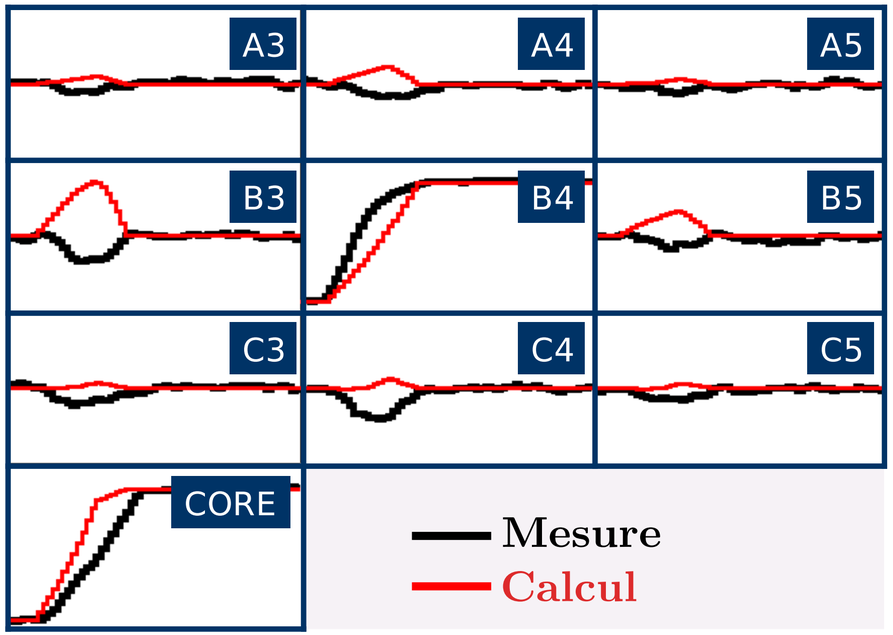

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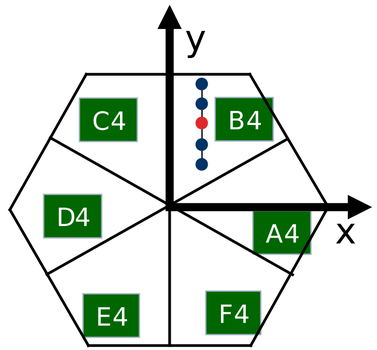

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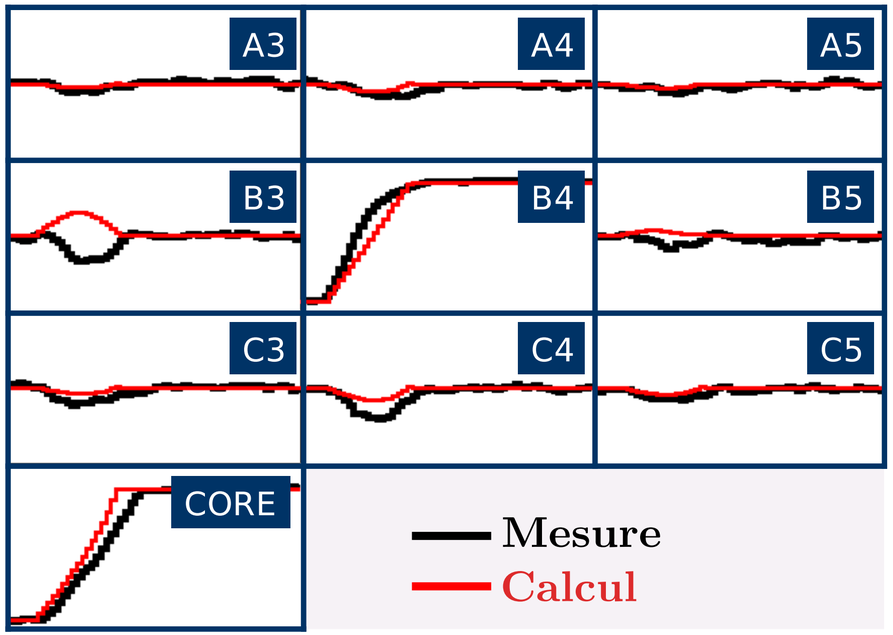

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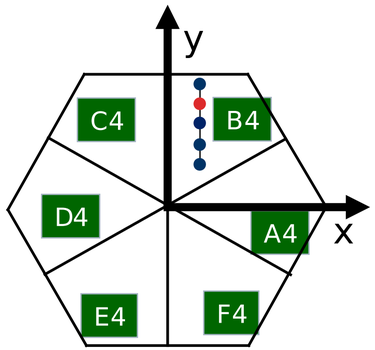

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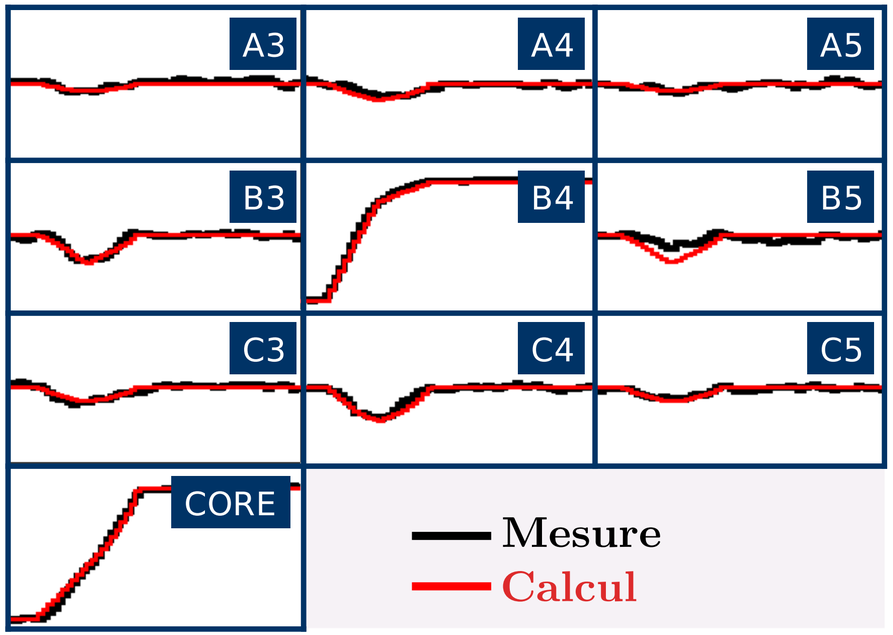

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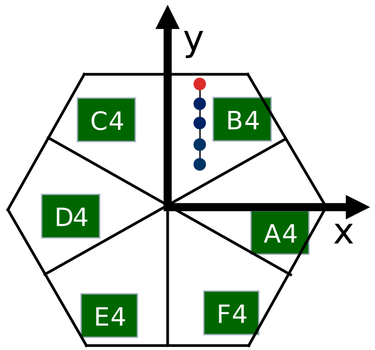

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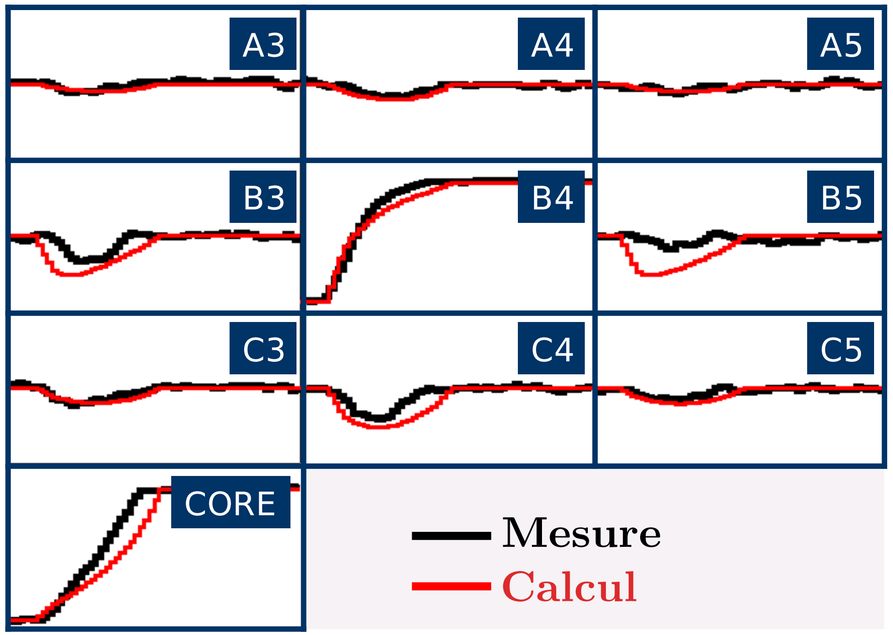

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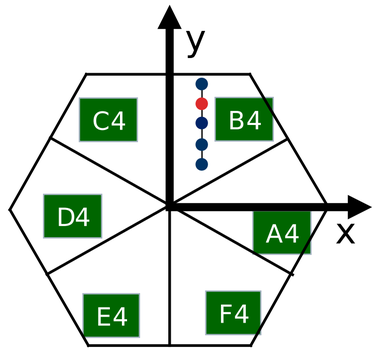
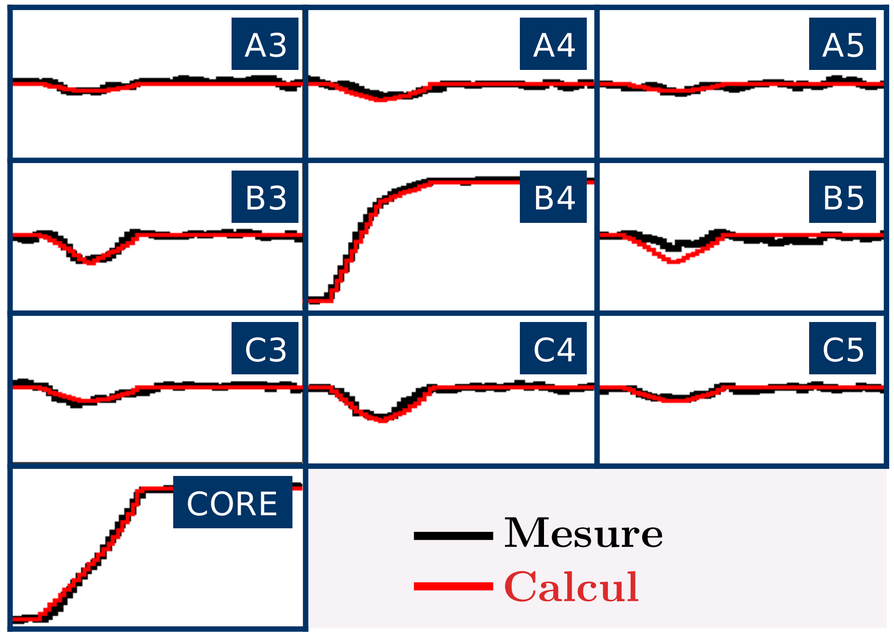
Introduction: The PSA algorithm

- One interaction in the detectors create 36 segment signals
- The comparison of this signal to a signal basis allows to determine the position of the interaction
- The simulated signals are never perfect:
  - We need a 3D experimental basis to benchmark the simulations





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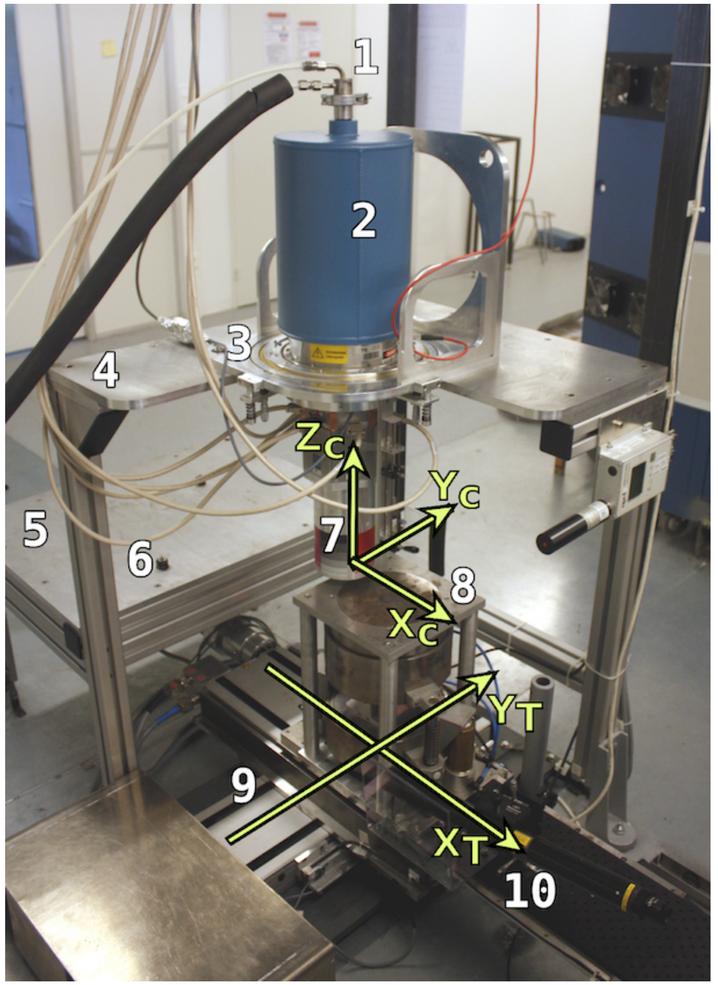
Introduction: The Strasbourg scanning table

The Strasbourg scanning table

- A motorized collimator with a 10μm precision,
- a system allowing the placement of the detector in vertical and horizontal positions,
- a laser alignment system,
- a digital acquisition system.



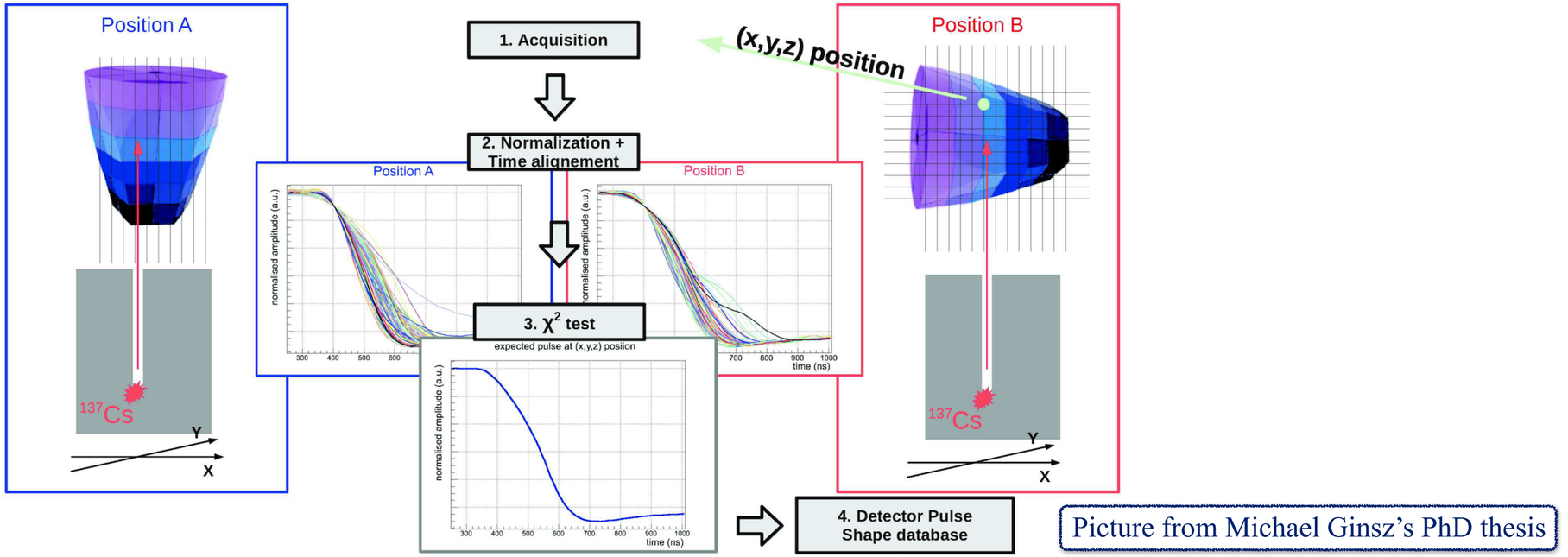
Picture from Bartolomeo De Canditiis's PhD thesis

Introduction: The Pulse Shape Comparison Scanning (PSCS) method

The Strasbourg scanning table

- 1 horizontal scan + 1 vertical scan,
- the 3D basis is obtained by a combined χ^2 analysis of both data-sets.
- Validated and published method, but 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

Introduction: Our work

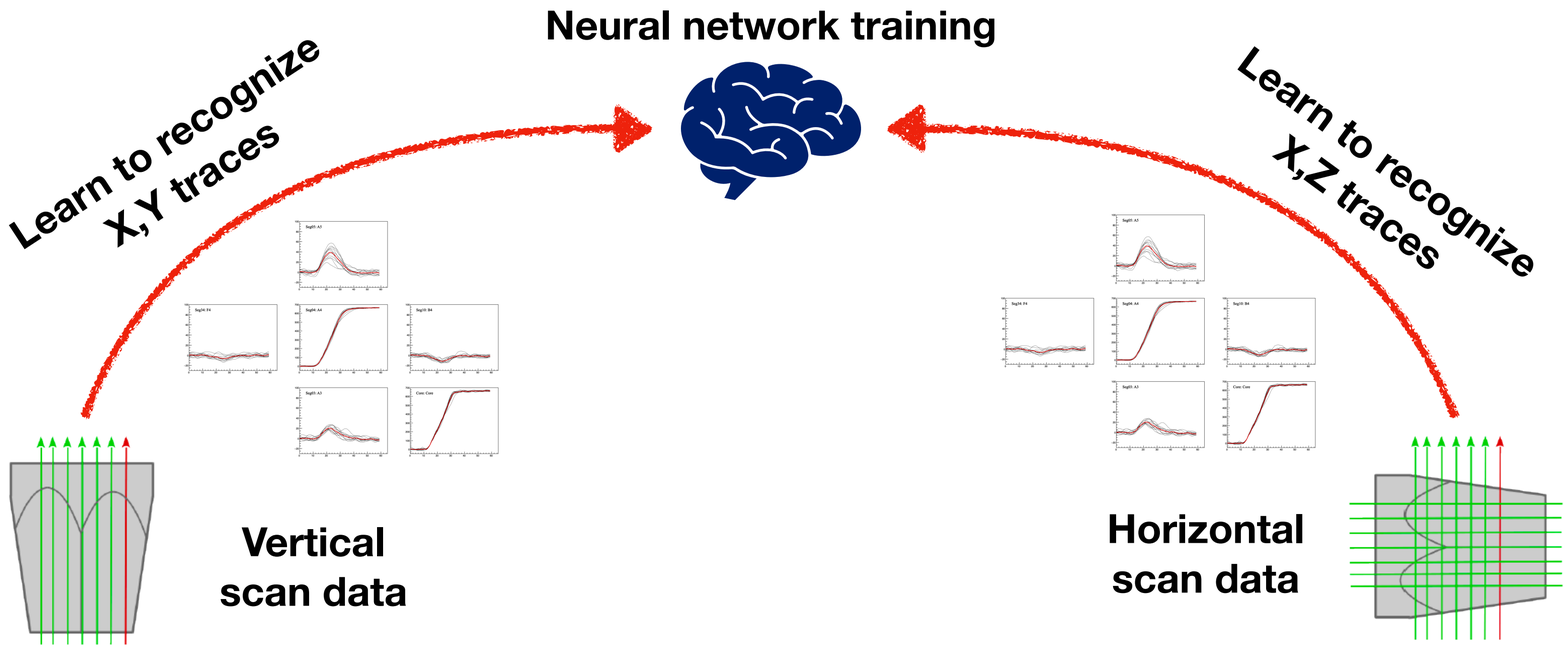
Machine learning @ IP2I

- After some trials on a Machine learning based PSA algorithm, we arrived to the conclusion that we need to work on 3D scanned data for a better understanding of our results.
- As a first trial with scanned data and machine learning, we were wondering if machine learning could be used to reconstruct the 3D basis from the two scanned data-sets, as the PSCS method is doing it.

Neural network analysis

Concept principle

- The network will be trained to recognize:
  - X and Y positions of traces from the vertical scan data-set,
  - X and Z positions of traces from the horizontal scan data-set,
- Once trained, the network should be able to give X,Y,Z for any trace.



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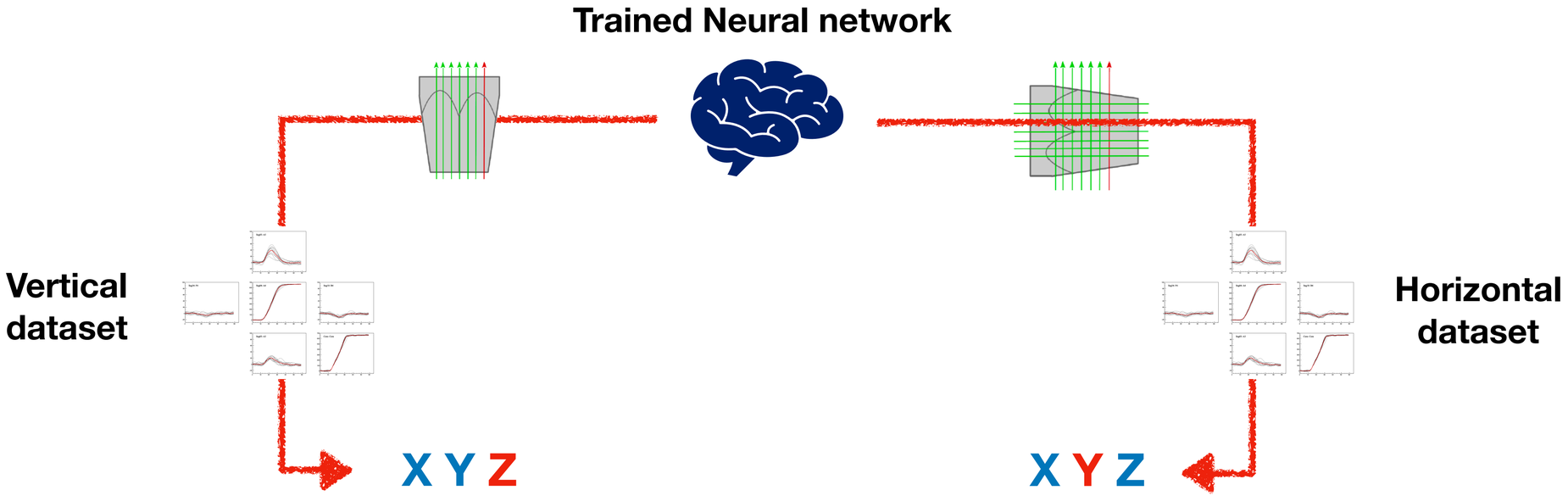


Neural network analysis

Network configuration

- 2 Long Short Term Memory layers:
  - efficient for signals analysis, and poorly affected by potential time mis-alignments
- 5 densely connected layers

Layer (type)	Output Shape	Param #
input (InputLayer)	[(None, 2280)]	0
reshape_3 (Reshape)	(None, 38, 60)	0
permute_3 (Permute)	(None, 60, 38)	0
lstm_6 (LSTM)	(None, 60, 500)	1078000
lstm_7 (LSTM)	(None, 500)	2002000
dense_15 (Dense)	(None, 200)	100200
dense_16 (Dense)	(None, 100)	20100
dense_17 (Dense)	(None, 100)	10100
dense_18 (Dense)	(None, 100)	10100
dense_19 (Dense)	(None, 3)	303

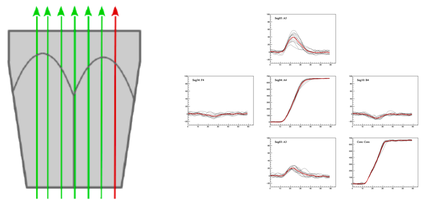
Total params: 3,220,803

Neural network analysis

Network training

- Selection of an "homogeneous" training data-set to limit geometrical effects:
  - ~10 traces/voxel ➙ 500k traces per scan position.
- Mean Square Error loss function, only calculated on the two known coordinates:
  - the network will iteratively improve its prediction either on X,Y or X,Z without affecting the prediction on the unknown axis.

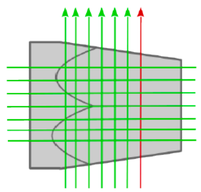
Scan: X_s, Y_s

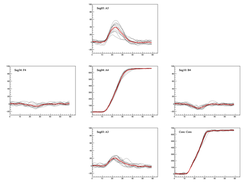


Prediction:
X_p, Y_p, Z_p

Loss function:
MSE(X_p, Y_p, 0)

Scan: X_s, Z_s





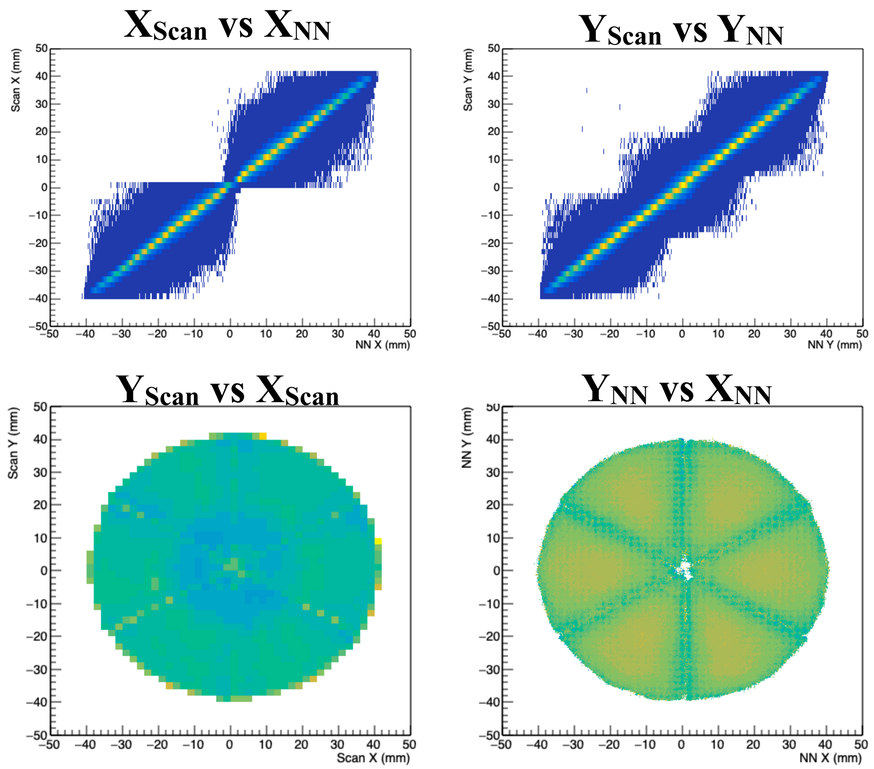
Prediction:
X_p, Y_p, Z_p

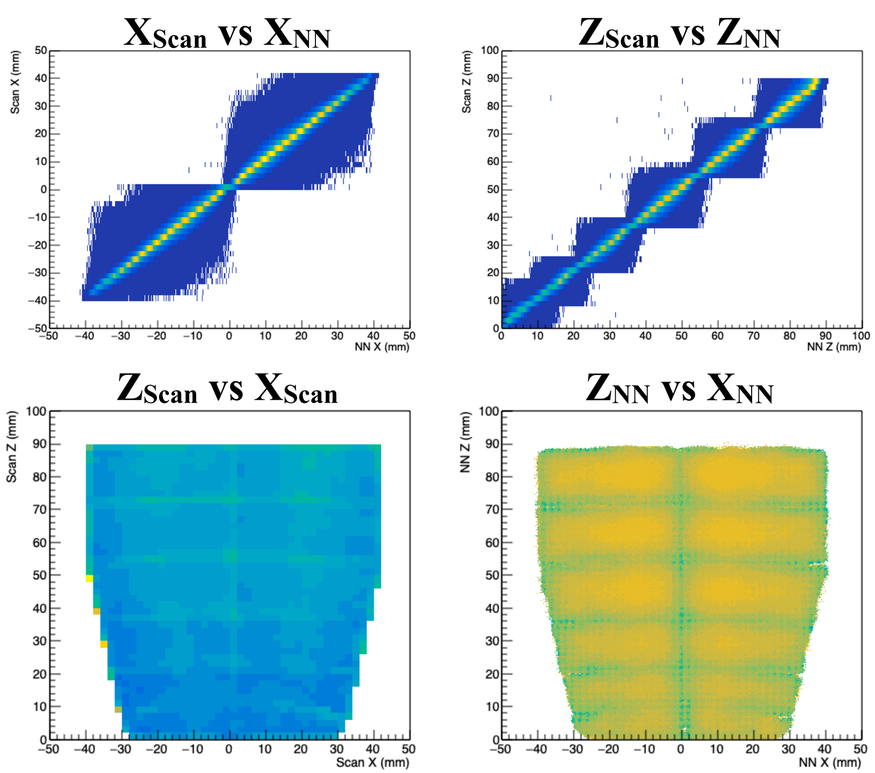
Loss function:
MSE(X_p, 0, Z_p)

Neural network analysis

Network processing

- Once trained, the full scanned data are analyzed by the network
  - Check that the two known axis are correctly reproduced



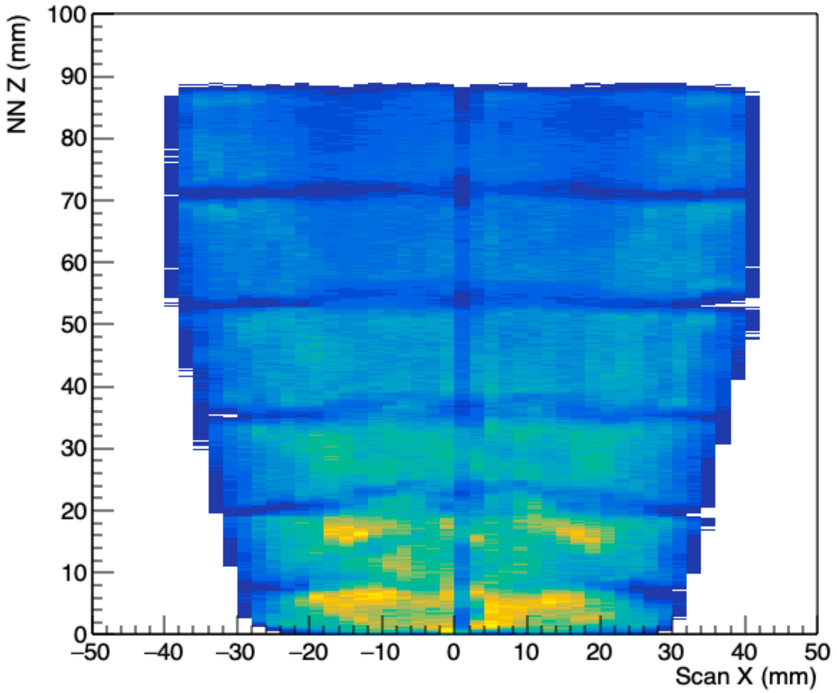


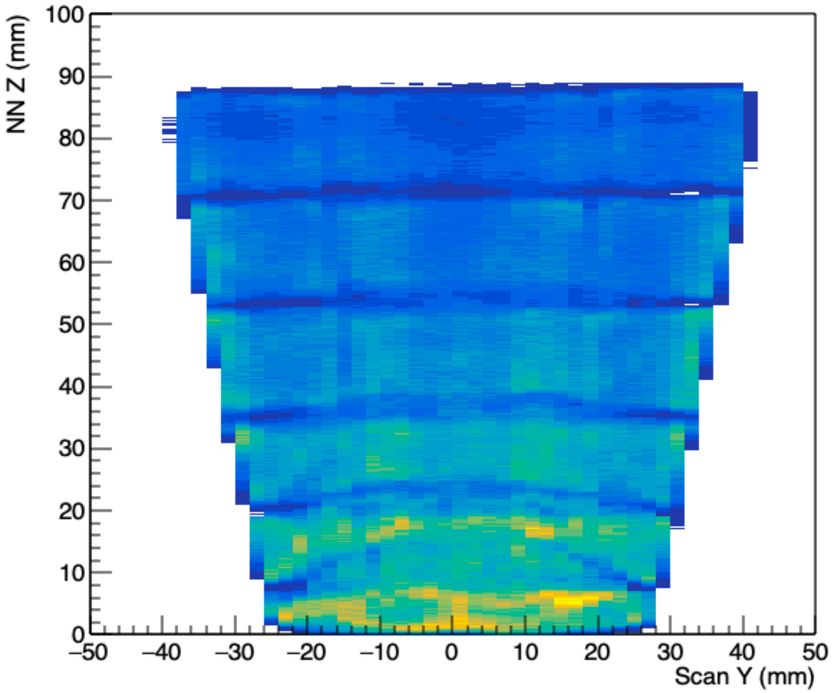
Results: Missing axis reproduction

NN predictions filtering

- Only keeping predictions for which the error on the two known axis is lower than 1mm.
- Removing the cases where the predicted segment is not the good one

Z predictions on the vertical (XY) scanned data





Results: Missing axis reproduction

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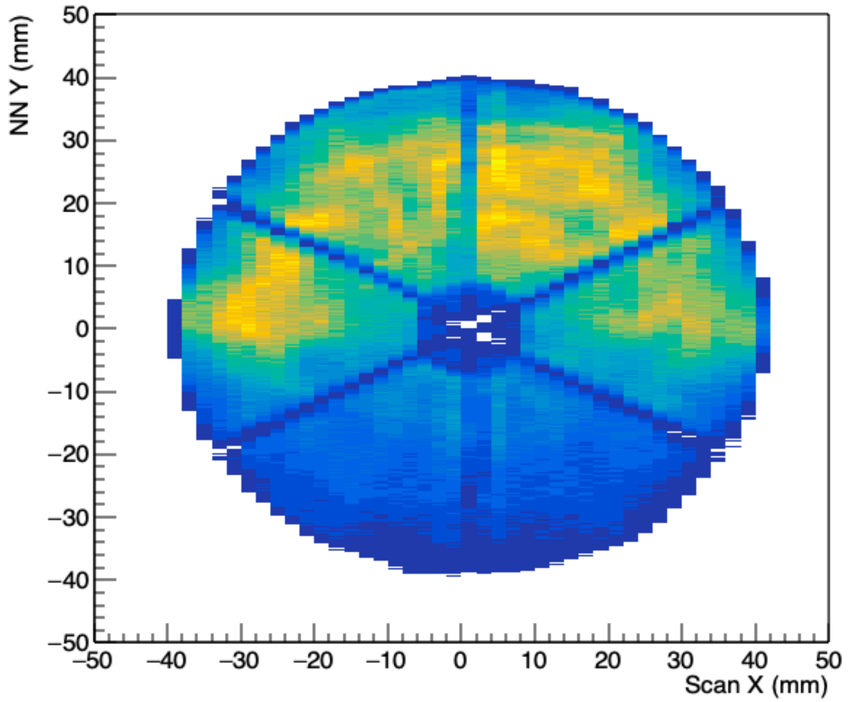
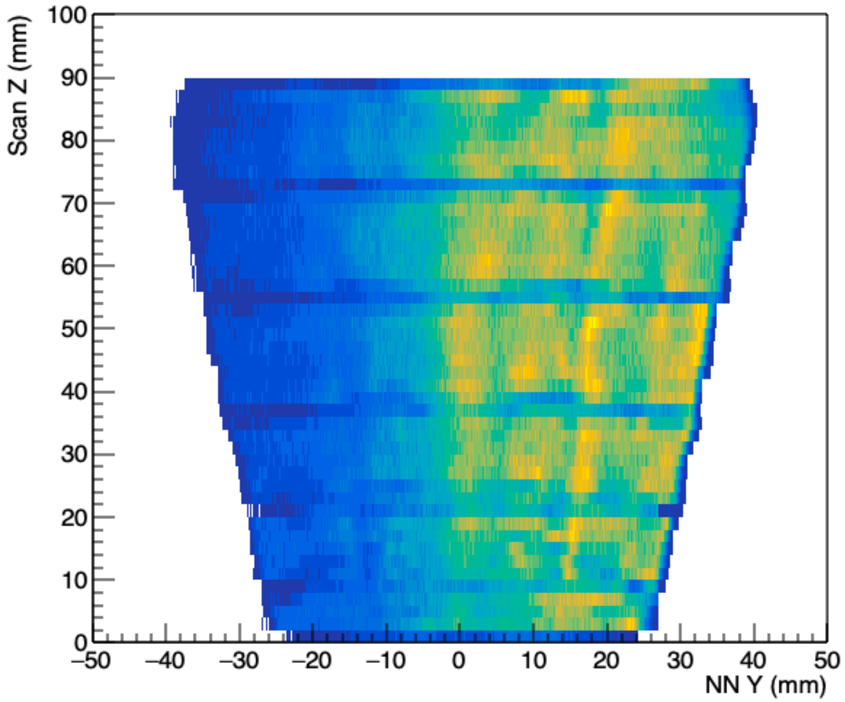
Y predictions on the horizontal (XZ) scanned data

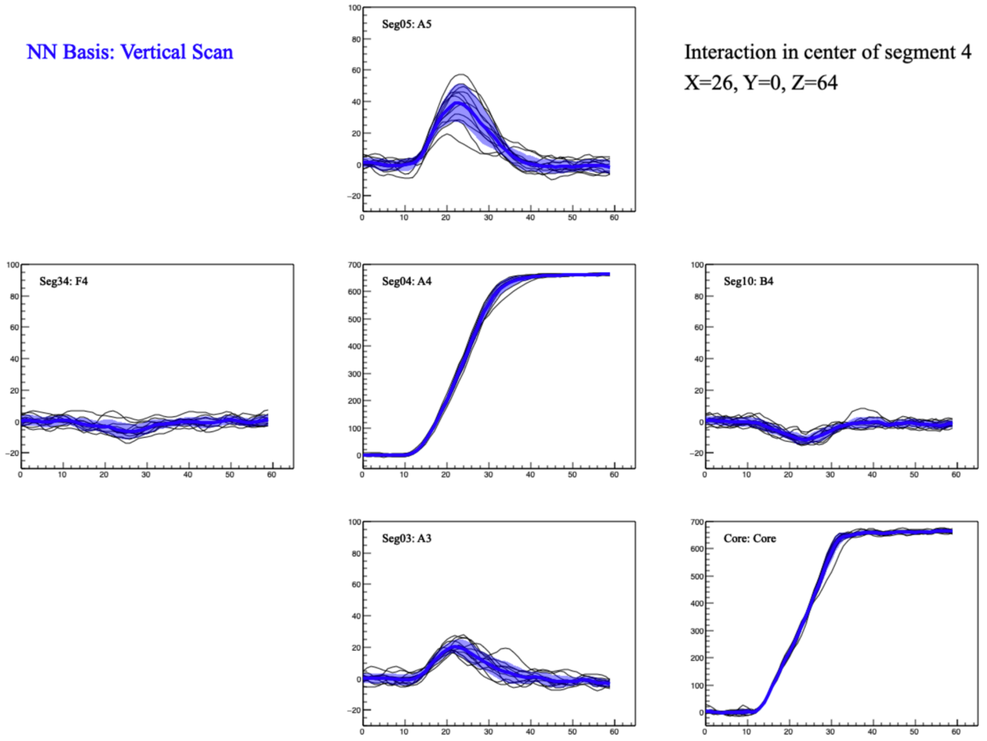




Results: 3D signal basis reconstruction

Some results

- Although this is still preliminary, the 3D signal basis seems to be well reproduced.
- Large gain in time processing:
  - **1 day** for data conversion, **30min** for training, **1h** for building the basis.



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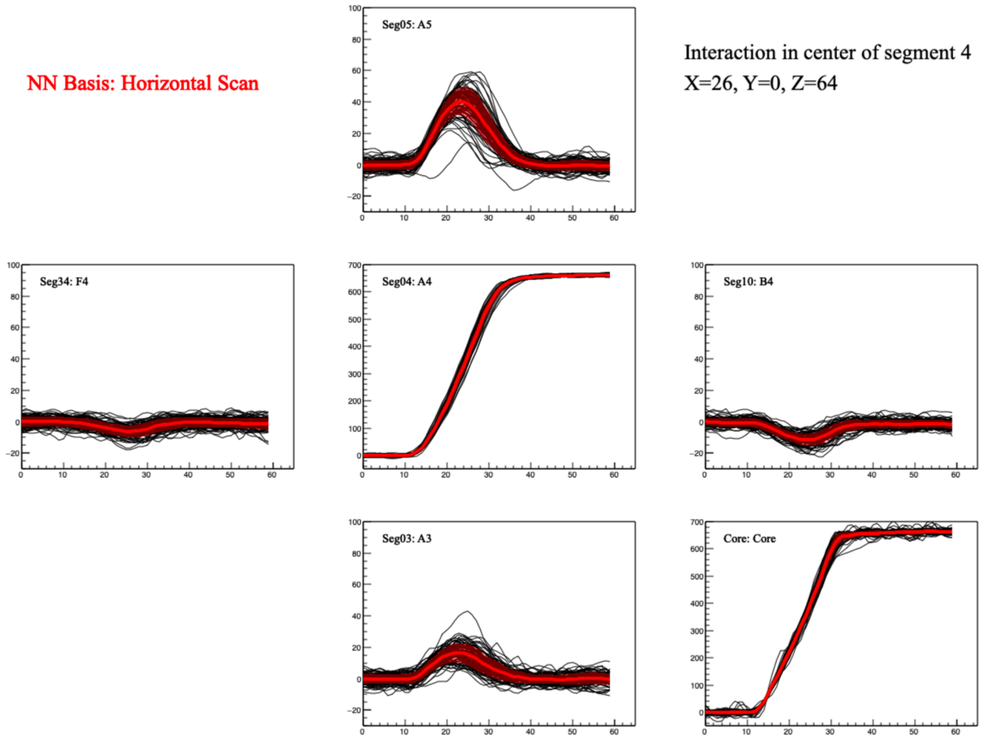
NN Basis: Horizontal Scan



Interaction in center of segment 4
X=26, Y=0, Z=64

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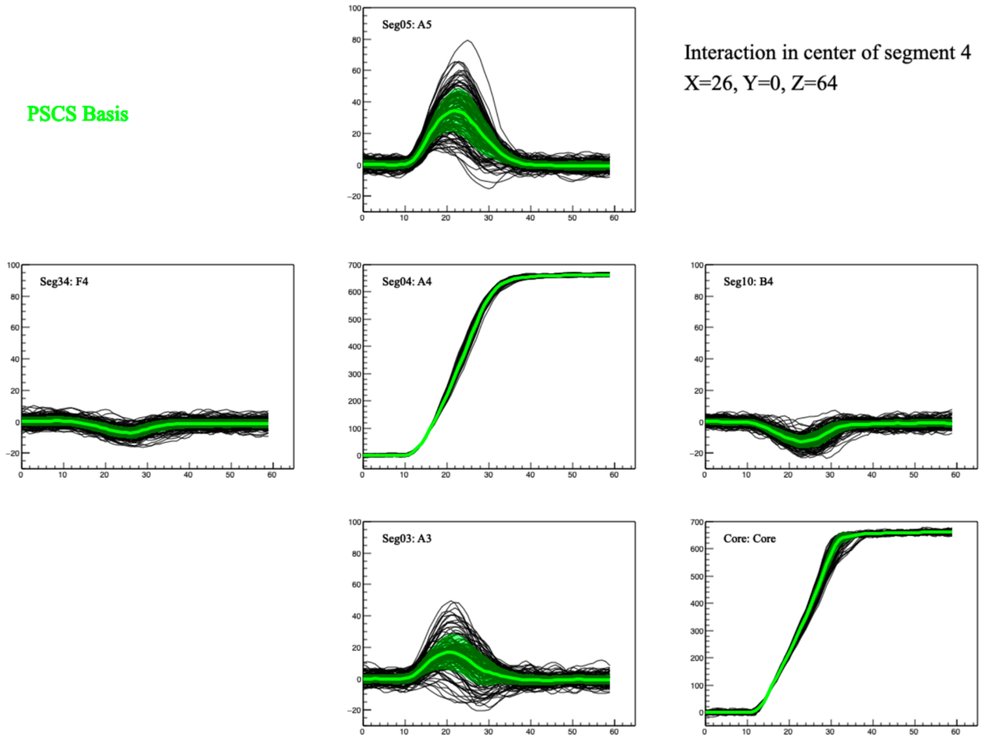

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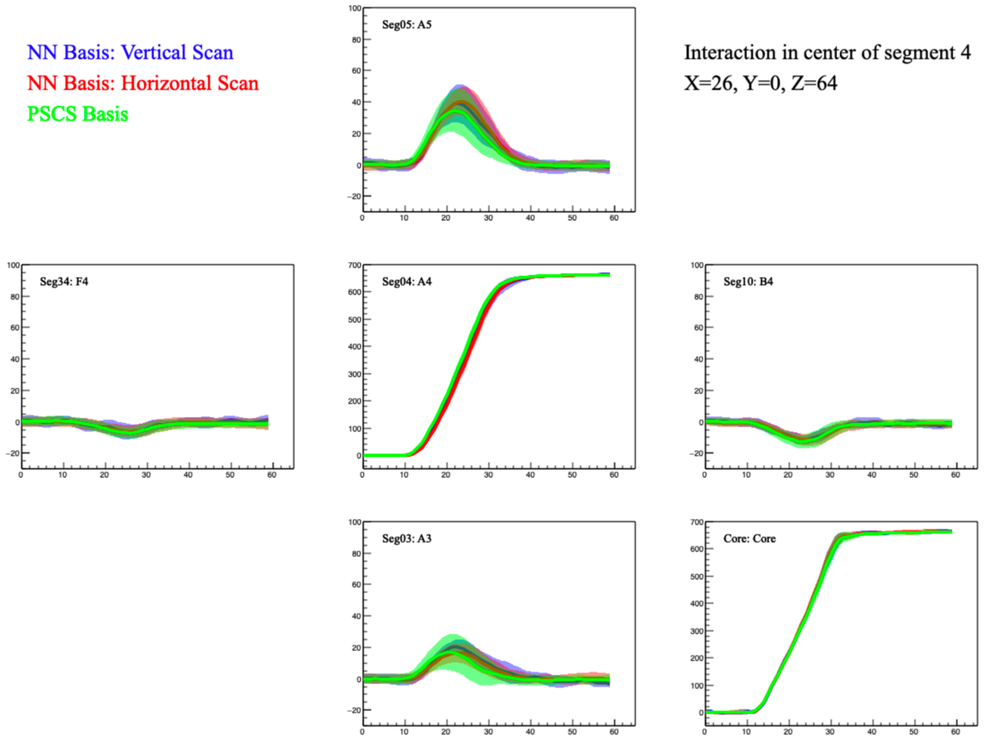

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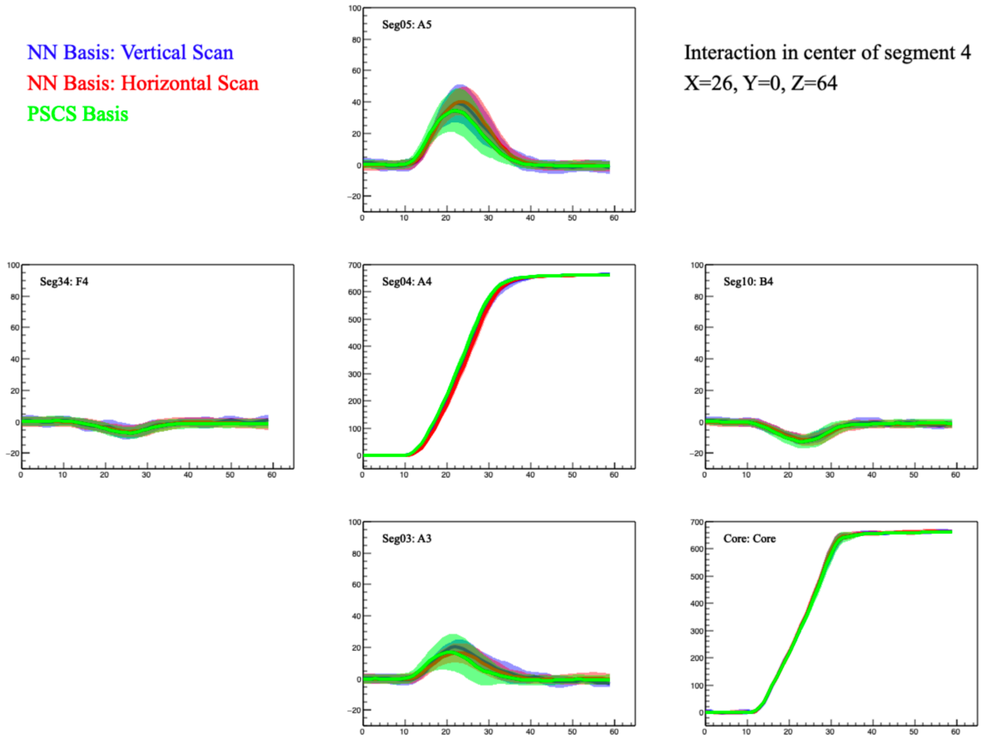

Thank you for your attention