PSA activities @ IP2I Lyon: Scanning data analyzed with machine learning techniques

Jérémie Dudouet

Institut de Physique des deux infinis de Lyon **(IP2I)**

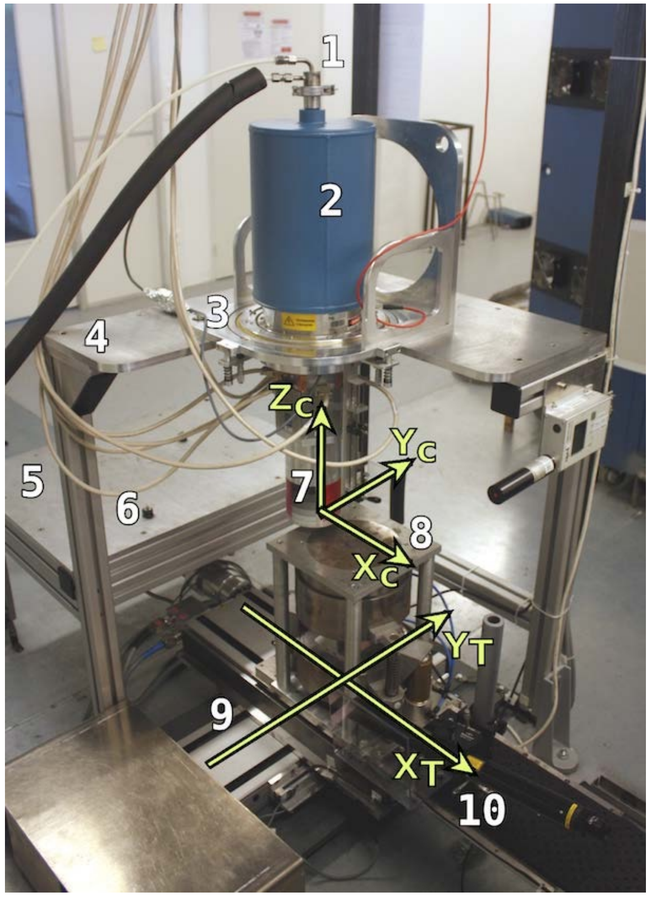
AGATA France 2025, Orsay

The Strasbourg scanning table

➤ Scanning capabilities:
- ➥ motorized collimator with a precision of 10 µm
- ➥ system allowing the placement of the detector in vertical and horizontal position
- ➥ laser alignment system
- ➥ digital electronic (TNT2)

➤ Scanning concept:
- ➥ not performing a real 3D scan (too long), but two 2D scans (vertical and horizontal)
- ➥ 3D basis obtained by Pulse Shape Comparison Scanning (PSCS) method

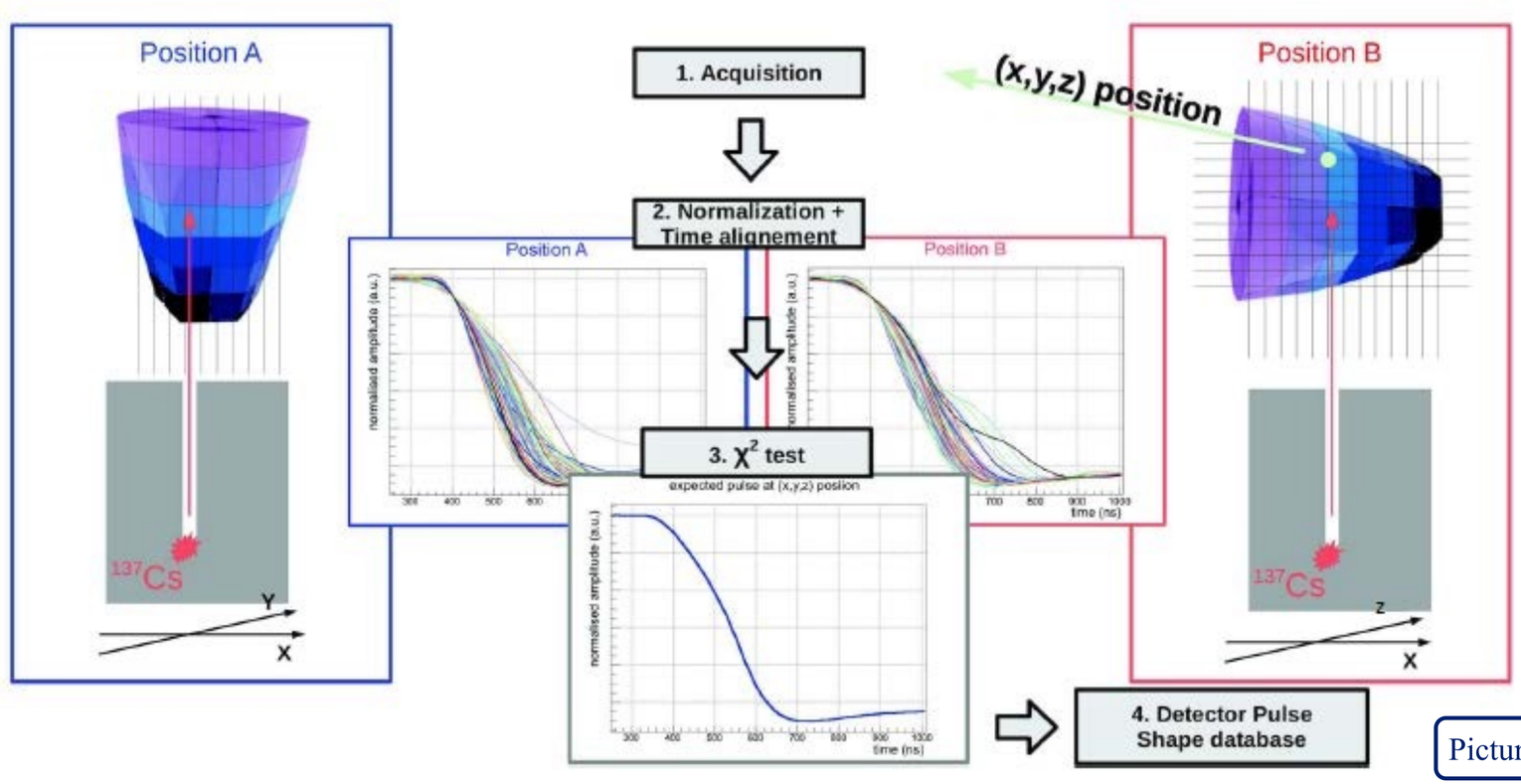
➤ Detector scanned:
- ➥ S001: a prototype symmetric detector
- ➥ A005: scan finalized this summer



The PSCS principle

- 1 horizontal scan + 1 vertical scan,
- the 3D basis is obtained by a combined analysis of both data-sets.
- Validated and published method, but time consuming (5 days for the PSCS analysis)

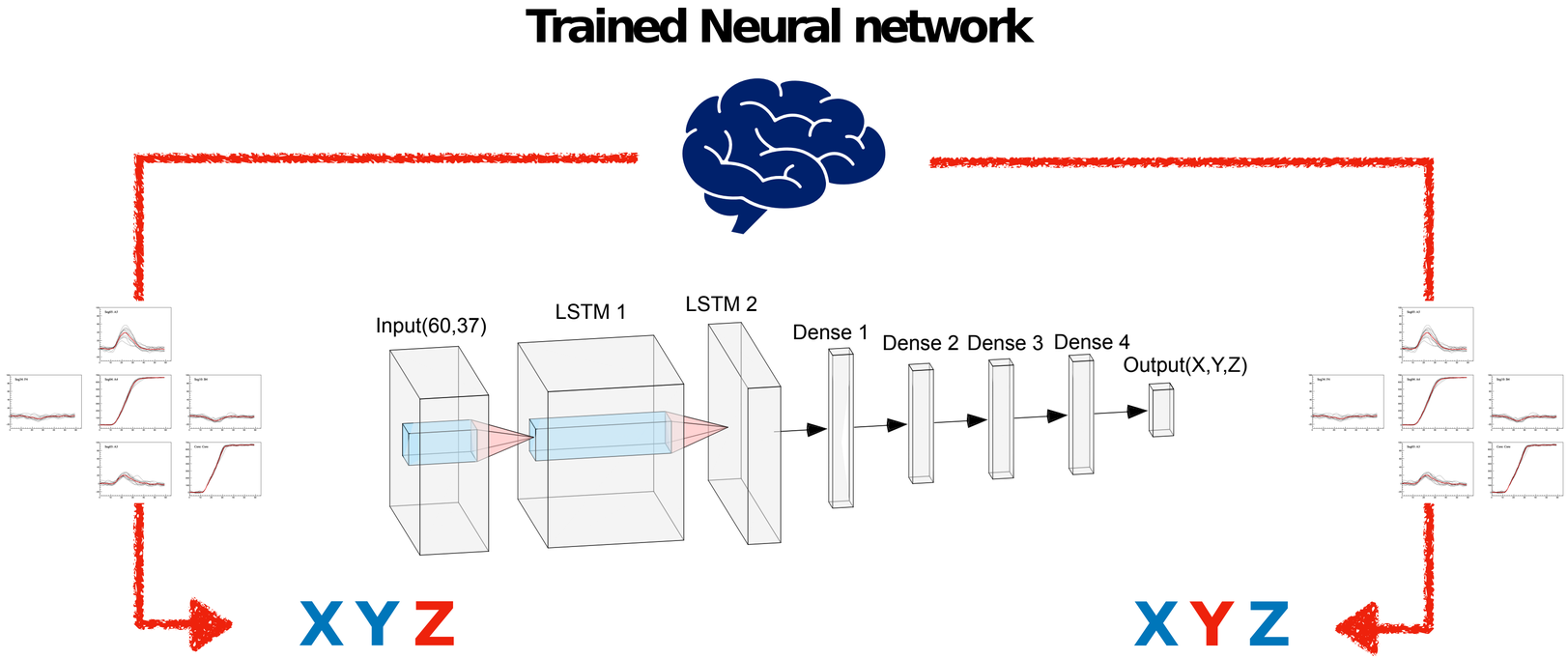
B. De Canditiis et al., Eur. Phys. J. A 57 (2021), B. De Canditiis and G. Duchêne, Eur. Phys. J. A 56 (2020)



Picture from Michael Ginsz's PhD thesis

New method proposed @ IP2I based on neural networks

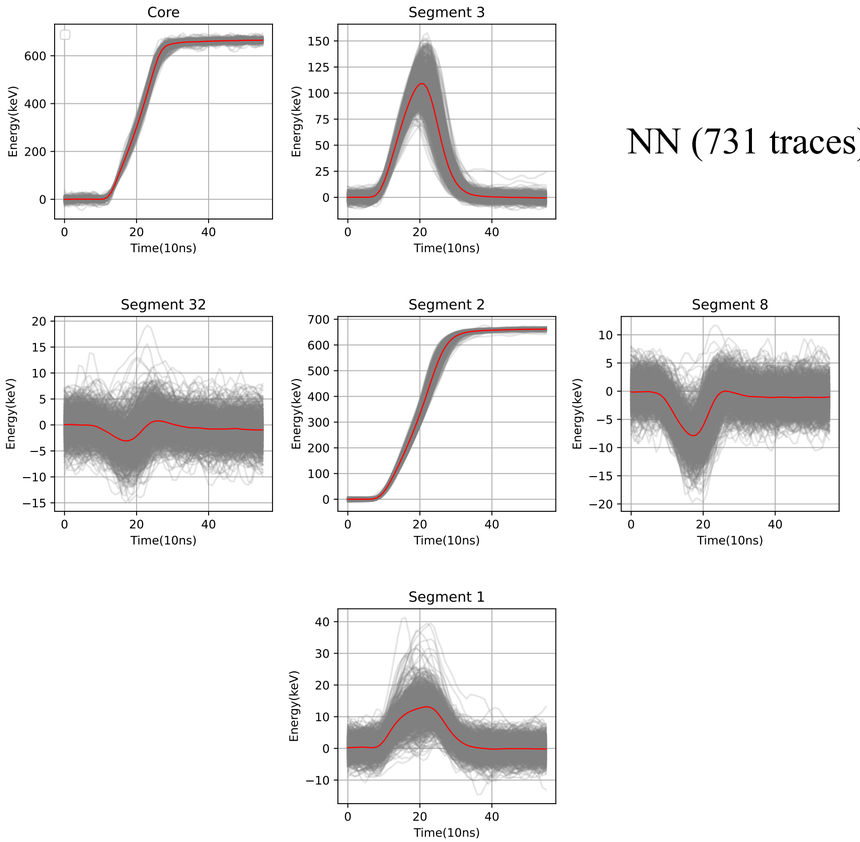
- 2 Long short-term memory (LSTM) layers were used as starting point.
  - ➥very robust against time misalignment
- 4 dense layers are added to obtain a 3D output (X,Y,Z)
- The loss function is calculated only for the two known axes
  - ➥ this allows the network to learn patterns of each dataset without affecting the other.



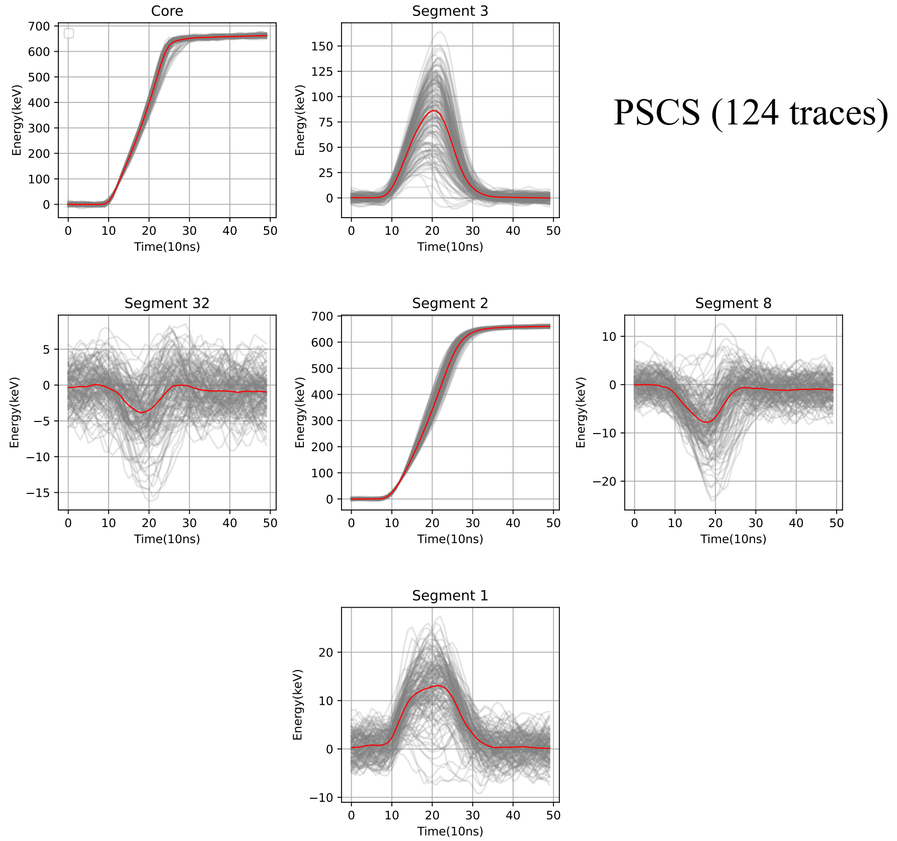
S001: Model consistency

➤ Average trace between Neural network and PSCS looks similar but more statistics and less fluctuations in NN

Traces predicted at position (22,0,34) in segment 2



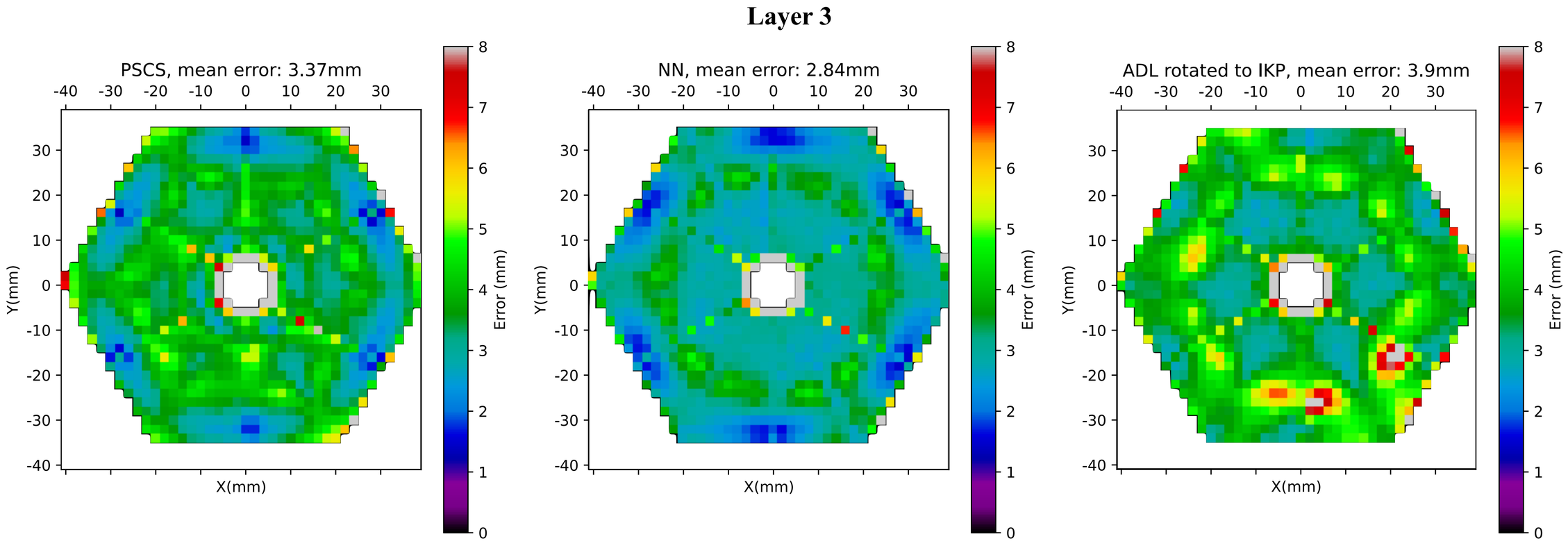
NN (731 traces)



PSCS (124 traces)

S001: PSA results

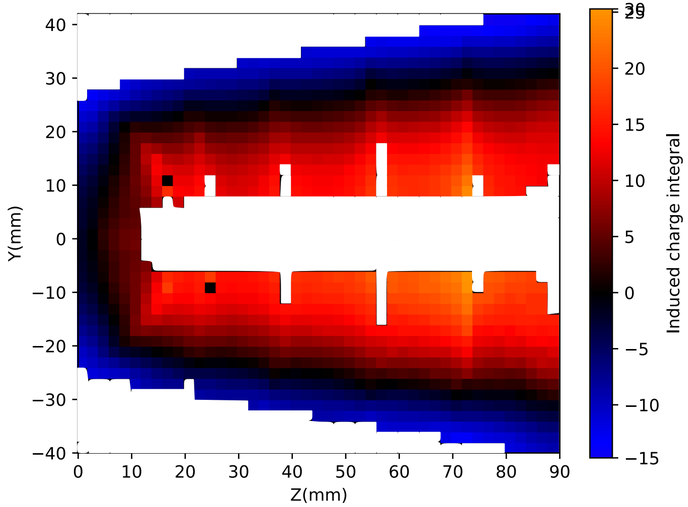
- PSA results:
  - Clear patterns appear at middle radius

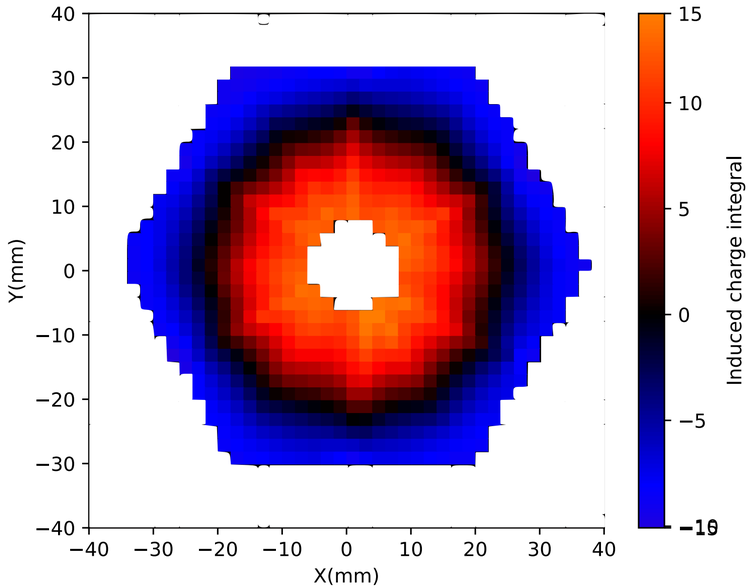


S001: PSA results

- PSA algorithm effect:
  - The clustering effects in the middle of the segment is enhanced by the algorithm:
  - The clustering regions corresponds to voxels where the transient signal area are almost null

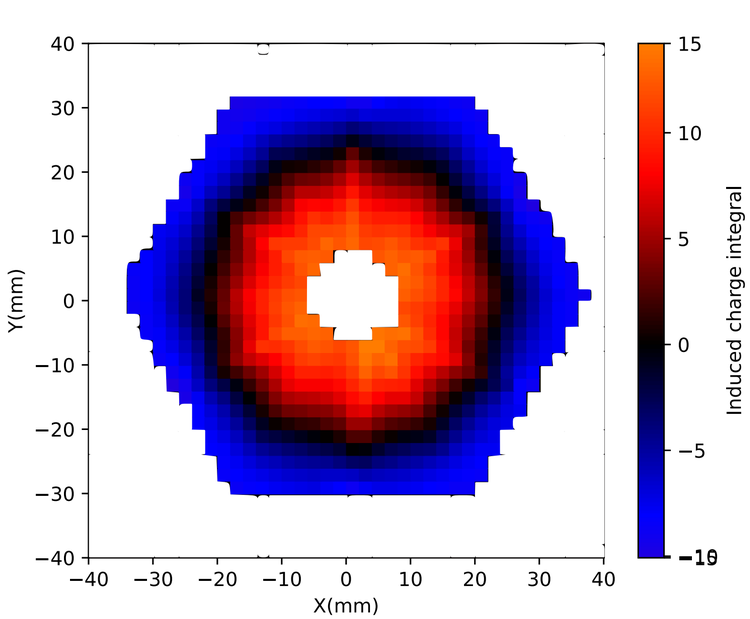
Integral of the transient signals in the first neighbouring segments

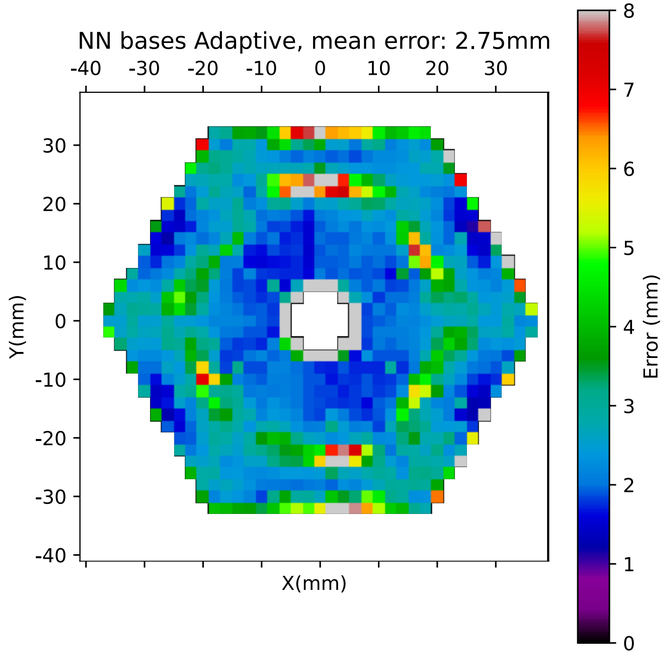




S001: PSA results

- PSA algorithm effect:
  - The clustering effects in the middle of the segment is enhanced by the algorithm:
  - The clustering regions corresponds to voxels where the transient signal area are almost null
  - In this regions, the PSA adaptive grid search is less efficient to find the good coarse grid voxel.

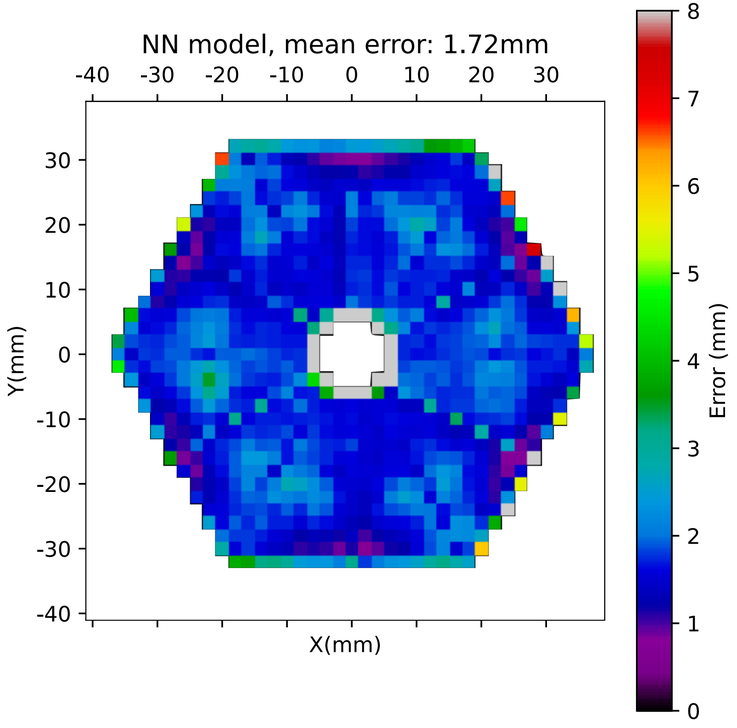


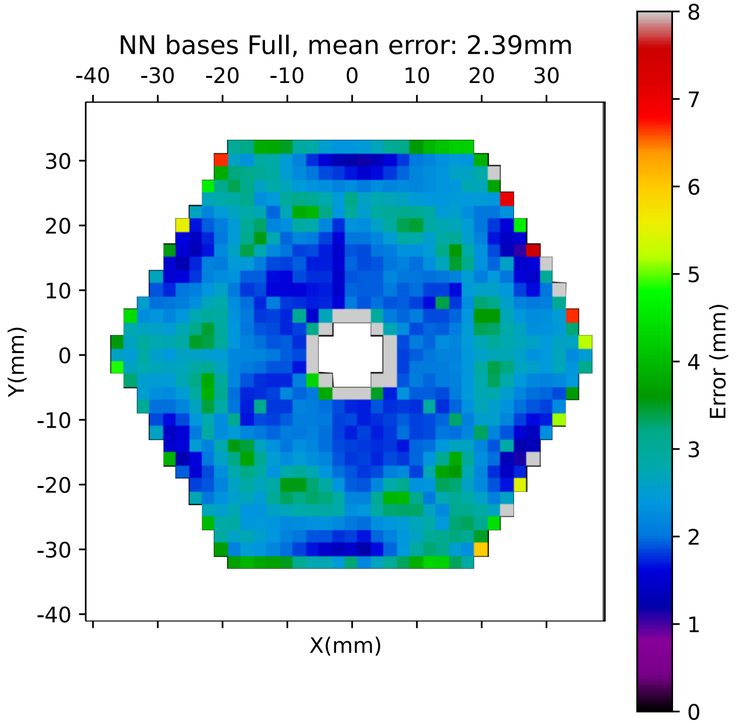


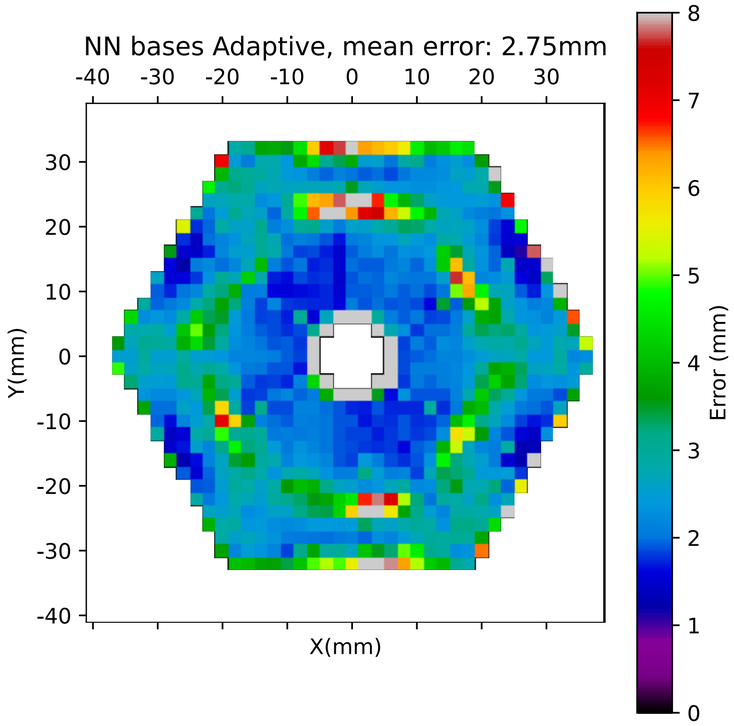
S001: PSA results

- PSA algorithm effect:
  - The clustering effects in the middle of the segment is enhanced by the algorithm:
    - NN model: present but very limited
    - PSA full grid search: clearer pattern
    - PSA adaptive grid search: stronger effect

Layer 2

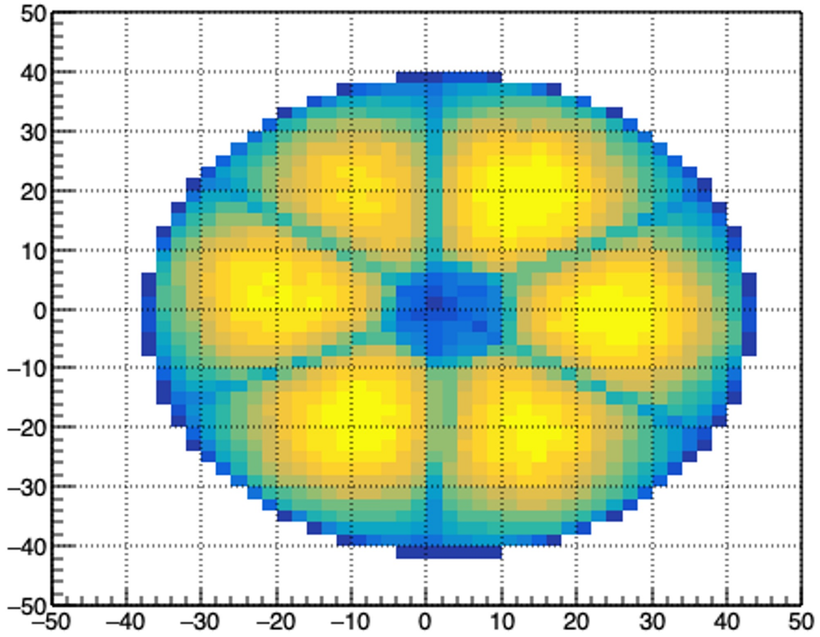


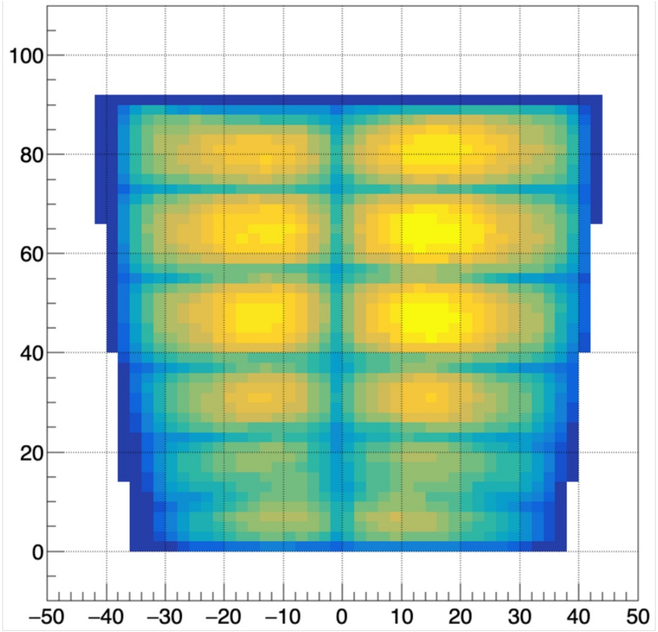




A005 scanning issues….

- Scanning of A005:
  - ➥ Vertical scan processed in August 2023 ➔ Full calibration processed
  - ➥ Horizontal scan processed in February 2024 ➔ Full recalibration that shown some scanning issues
  - ➥ New Horizontal scan processed in July 2024 ➔ Full recalibration

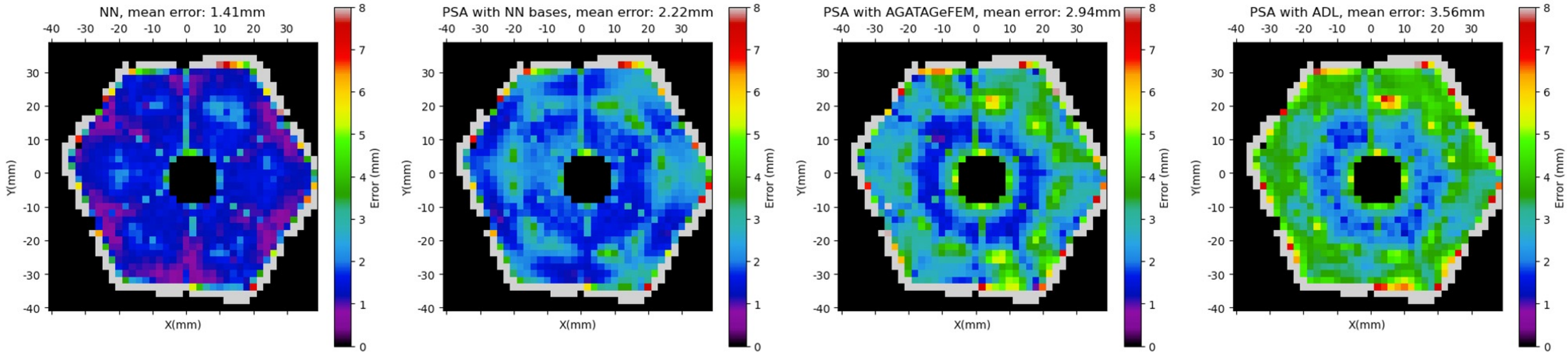




A005: Results

- Comparison of:
  - NN results
  - PSA with NN basis
  - PSA with AGATAGeFEM, rotated to IKP convention (thanks Joa)
  - PSA with ADL, using IKP to AGATA filter and PSA rotation filter

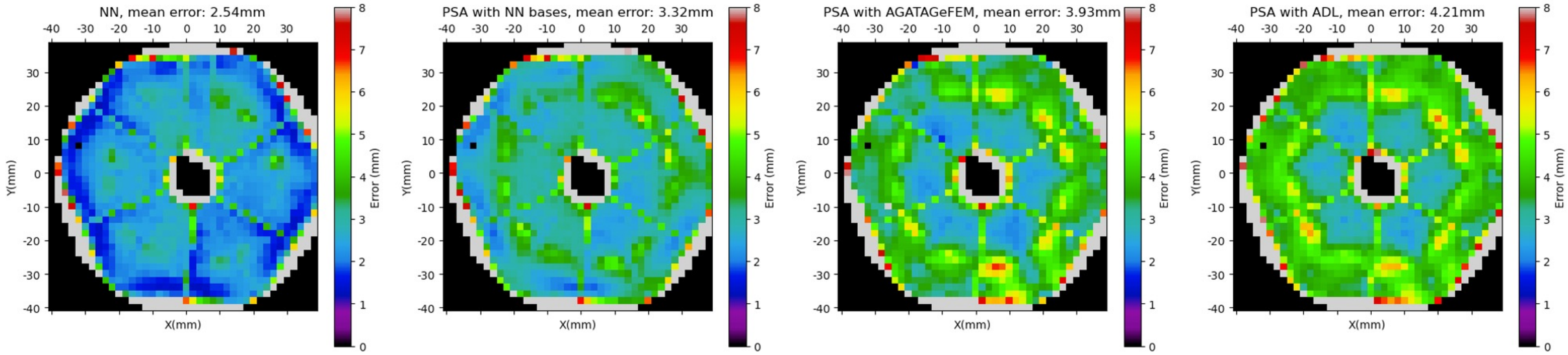
Layer 1



A005: Results

- Comparison of:
  - NN results
  - PSA with NN basis
  - PSA with AGATAGeFEM, rotated to IKP convention (thanks Joa)
  - PSA with ADL, using IKP to AGATA filter and PSA rotation filter

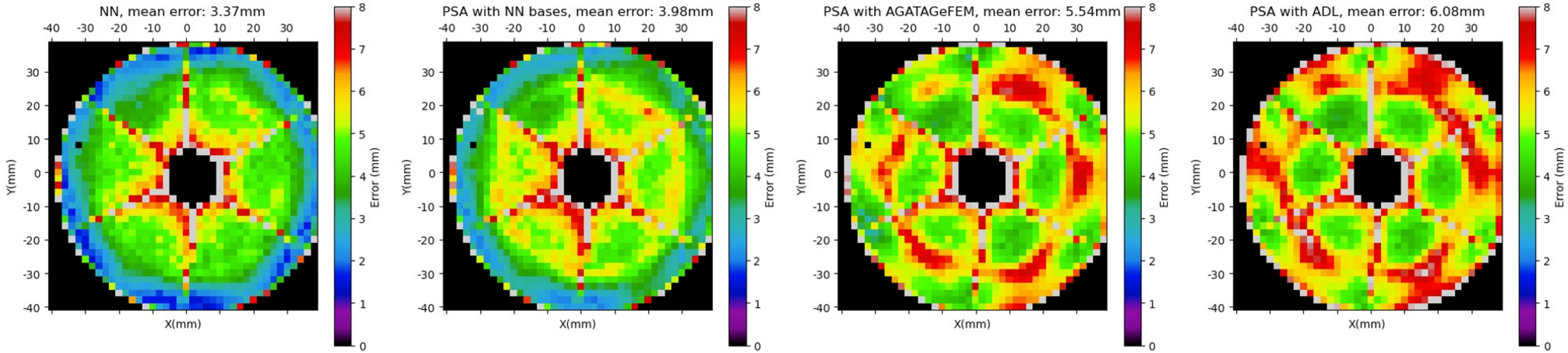
Layer 3



A005: Results

- Comparison of:
  - NN results
  - PSA with NN basis
  - PSA with AGATAGeFEM, rotated to IKP convention (thanks Joa)
  - PSA with ADL, using IKP to AGATA filter and PSA rotation filter

Layer 5



On average, the results comply with AGATA specifications,
but there is room for improvement in the regions where the hot spots are located.

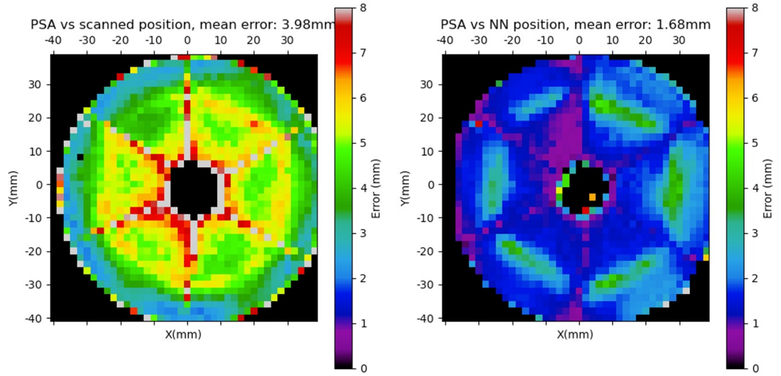
A005: Results

- Up to which level can we trust the scanned positions ?
  - ➥Given values are relative to the scan positions, but what about **random Compton** or **multiple hits in one segment ?**
- To test the robustness of the NN, we trained it with 50% of the data with bad random labels
  - ➥ after training, the network was still able to predict the good positions

A005: Results

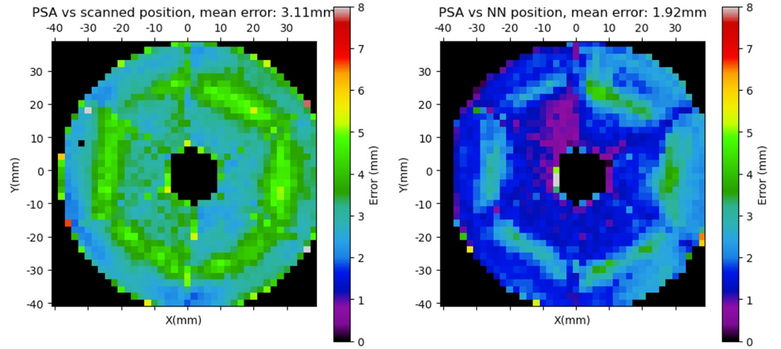
- Up to which level can we trust the scanned positions ?
  - ➥Given values are relative to the scan positions, but what about **random Compton** or **multiple hits in one segment ?**
- To test the robustness of the NN, we trained it with 50% of the data with bad random labels
  - ➥ after training, the network was still able to predict the good positions
- Selecting only photopeak events (limiting random Compton events), the results are much better in the last layer

All energies



Error on X and Y, for layer: 5

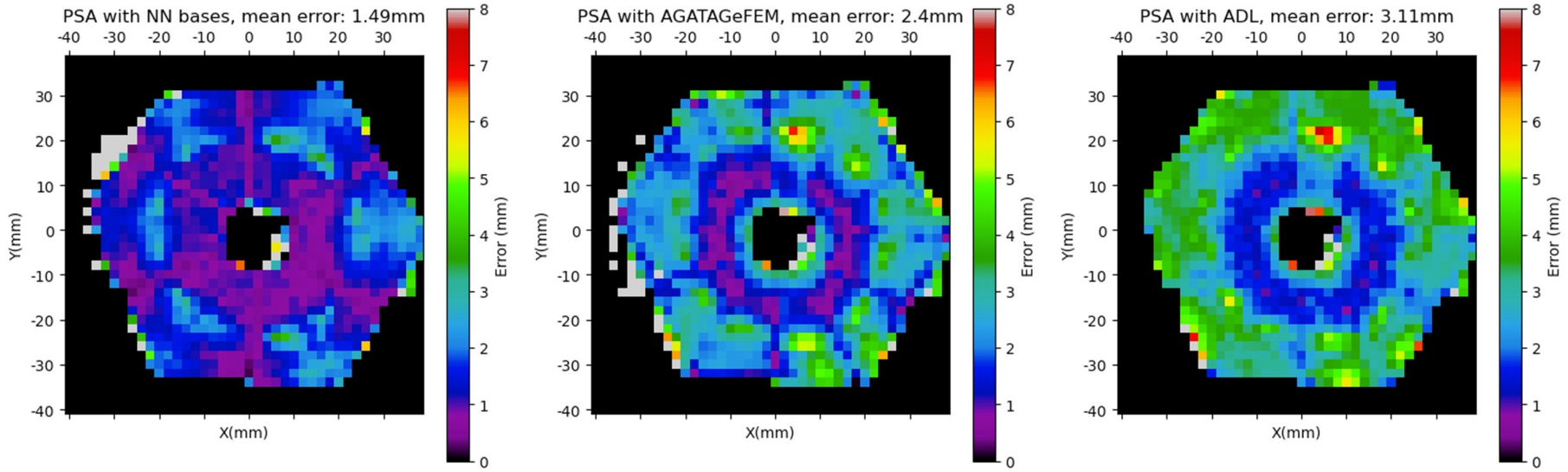
Photopeak only



A005: Results

- Comparison between PSA basis compared to NN predictions (assumed to be more precise than scanning):
  - NN experimental basis
  - AGATAGeFEM basis
  - ADL basis

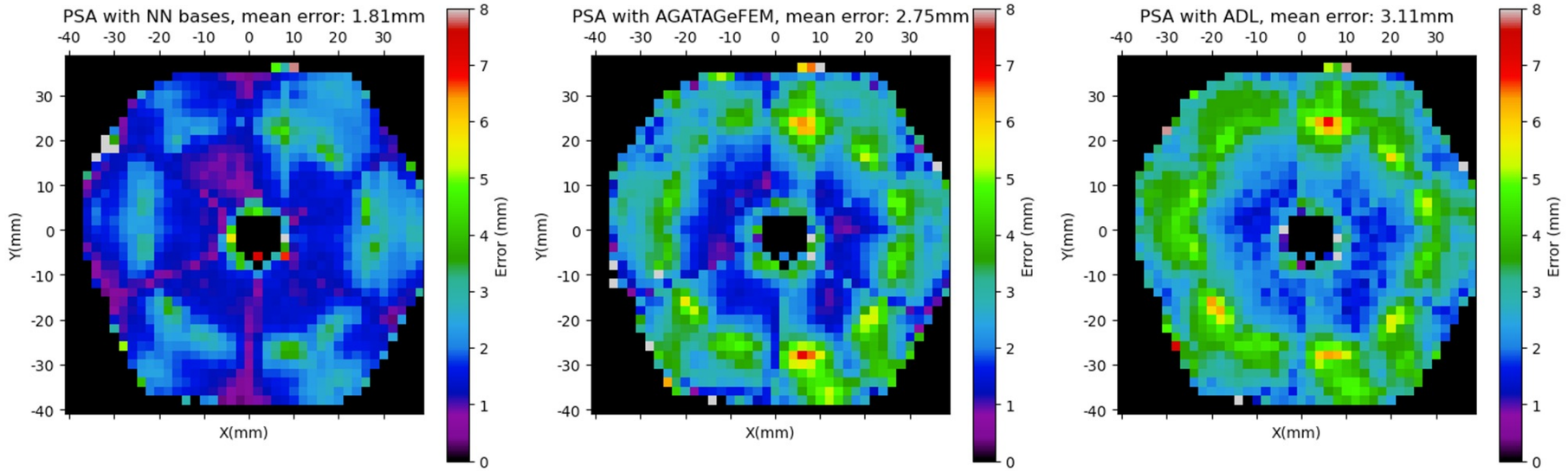
Layer 1



A005: Results

- Comparison between PSA basis compared to NN predictions (assumed to be more precise than scanning):
  - NN experimental basis
  - AGATAGeFEM basis
  - ADL basis

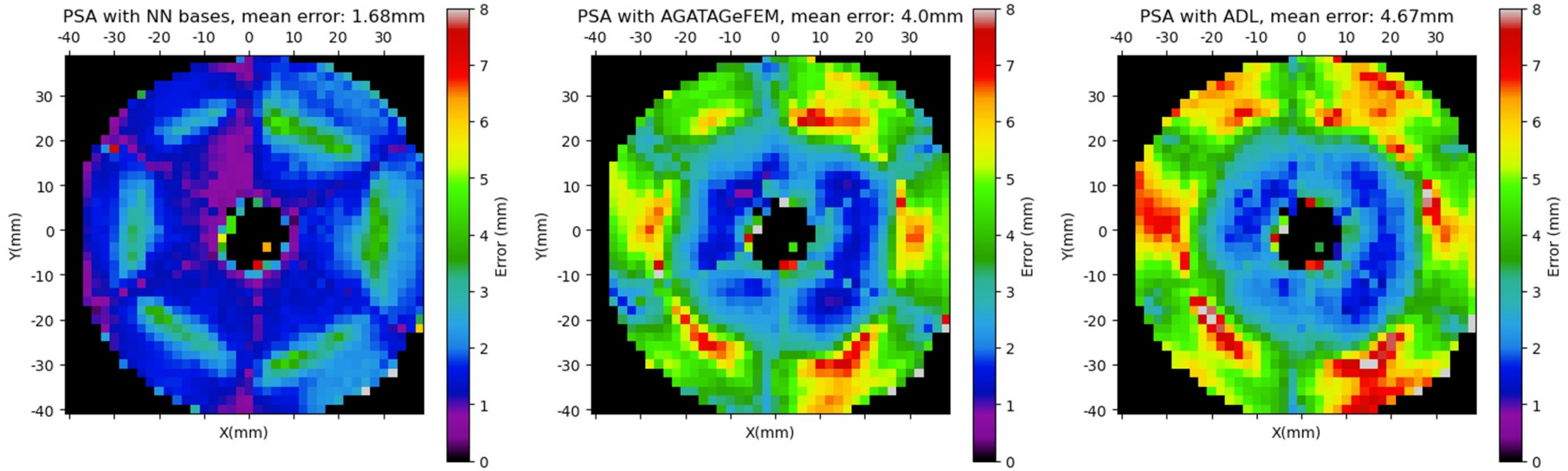
Layer 3



A005: Results

- Comparison between PSA basis compared to NN predictions (assumed to be more precise than scanning):
  - NN experimental basis
  - AGATAGeFEM basis
  - ADL basis

Layer 5

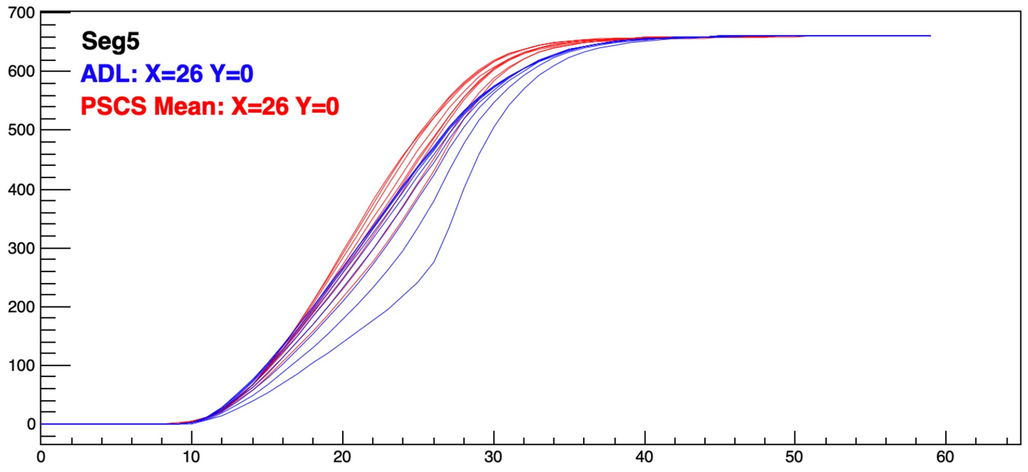


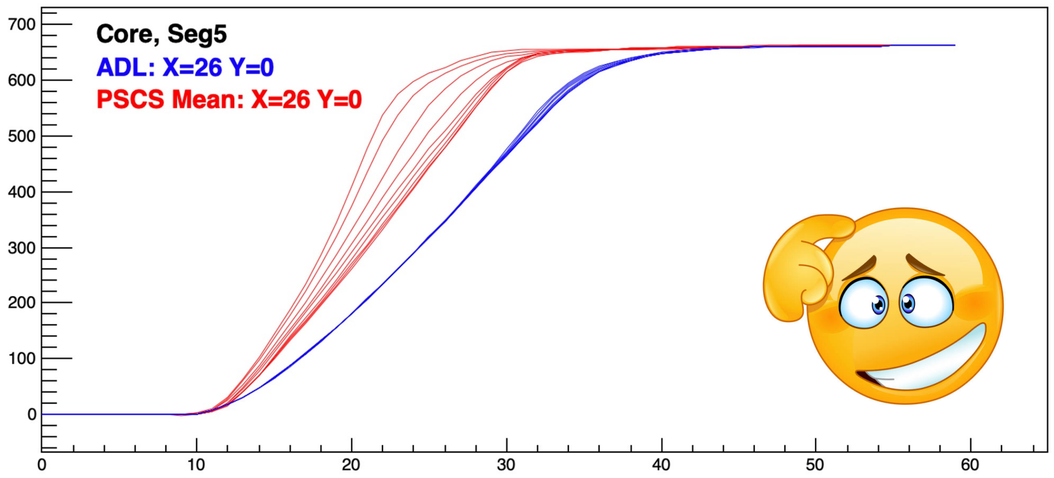
➔ **Effects inherent to the PSA algorithm**

➔ **Effects coming from the basis simulations (ADL ~ AGATAGeFEM)**

S001: PSA results

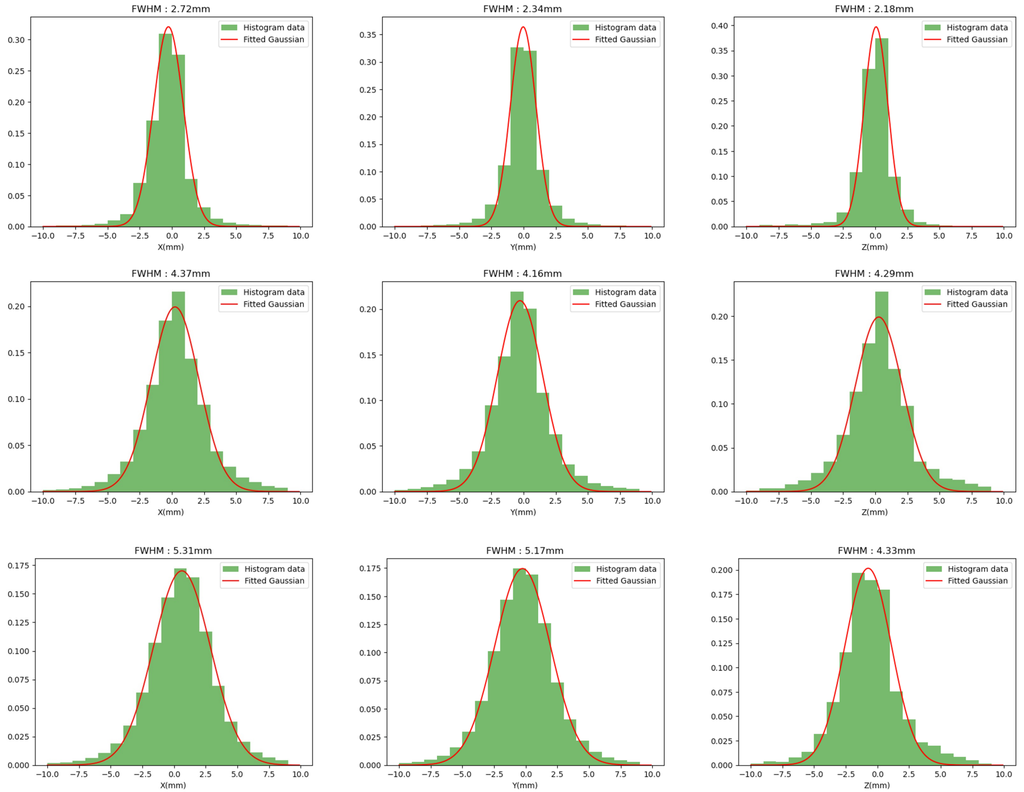
➤ The core signal is too fast compared to simulations and we don't know why…(real effect of electronic effect ?)





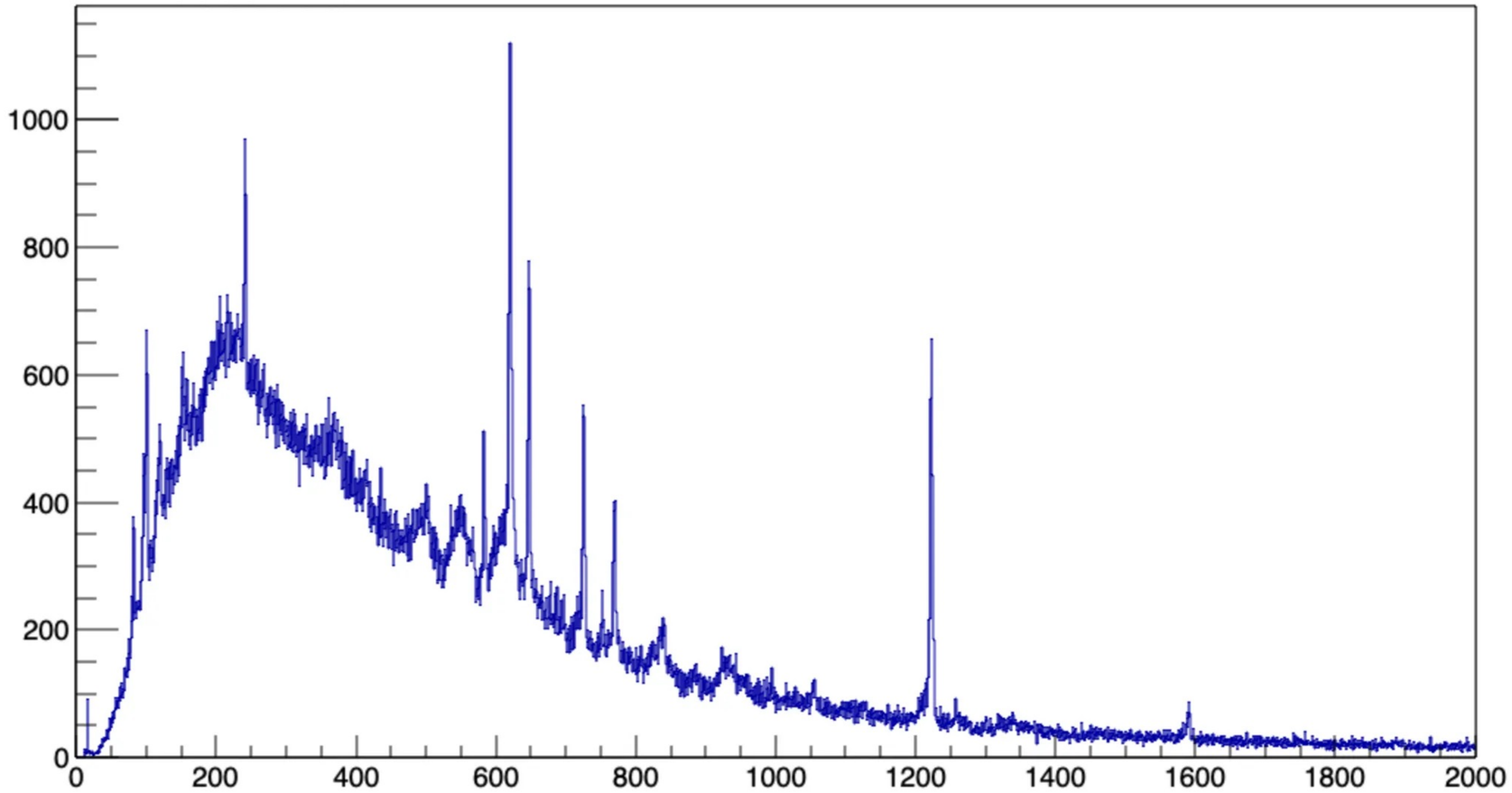
A005: Results

- Average PSA Position resolution (FWHM):
  - NN: **2.4 mm**
  - AGATAGeFEM **4.3 mm**
  - ADL **4.9 mm**



Application to in-beam data: 98Zr spectrum from fission data (E680)

- PSA with ADL basis:
  - E = 1222.87 (compared to 1222.9)
  - FWHM = 4.3 keV



Application to in-beam data: 98Zr spectrum from fission data (E680)

- PSA with ADL basis:
  - E = **1222.87** (compared to 1222.9)
  - FWHM = **4.3** keV
- PSA with AGATAGeFEM basis:
  - E = **1222.82** (compared to 1222.9)
  - FWHM = **4.05** keV
- PSA with NN basis:
  - E = **1222.75** (compared to 1222.9)
  - FWHM = **4.03** keV

Application to in-beam data: 98Zr spectrum from fission data (E680)

- PSA with ADL basis:
  - E = **1222.87** (compared to 1222.9)
  - FWHM = **4.3** keV

- PSA with AGATAGeFEM basis:
  - E = **1222.82** (compared to 1222.9)
  - FWHM = **4.05** keV

- PSA with NN basis:
  - E = **1222.75** (compared to 1222.9)
  - FWHM = **4.03** keV

We need to determine the neutron damage parameters !
How ? From simulations….

Application to in-beam data: 98Zr spectrum from fission data (E680)

- PSA with ADL basis:
  - E = **1222.87** (compared to 1222.9)
  - FWHM = **4.3** keV

- PSA with AGATAGeFEM basis:
  - E = **1222.82** (compared to 1222.9)
  - FWHM = **4.05** keV

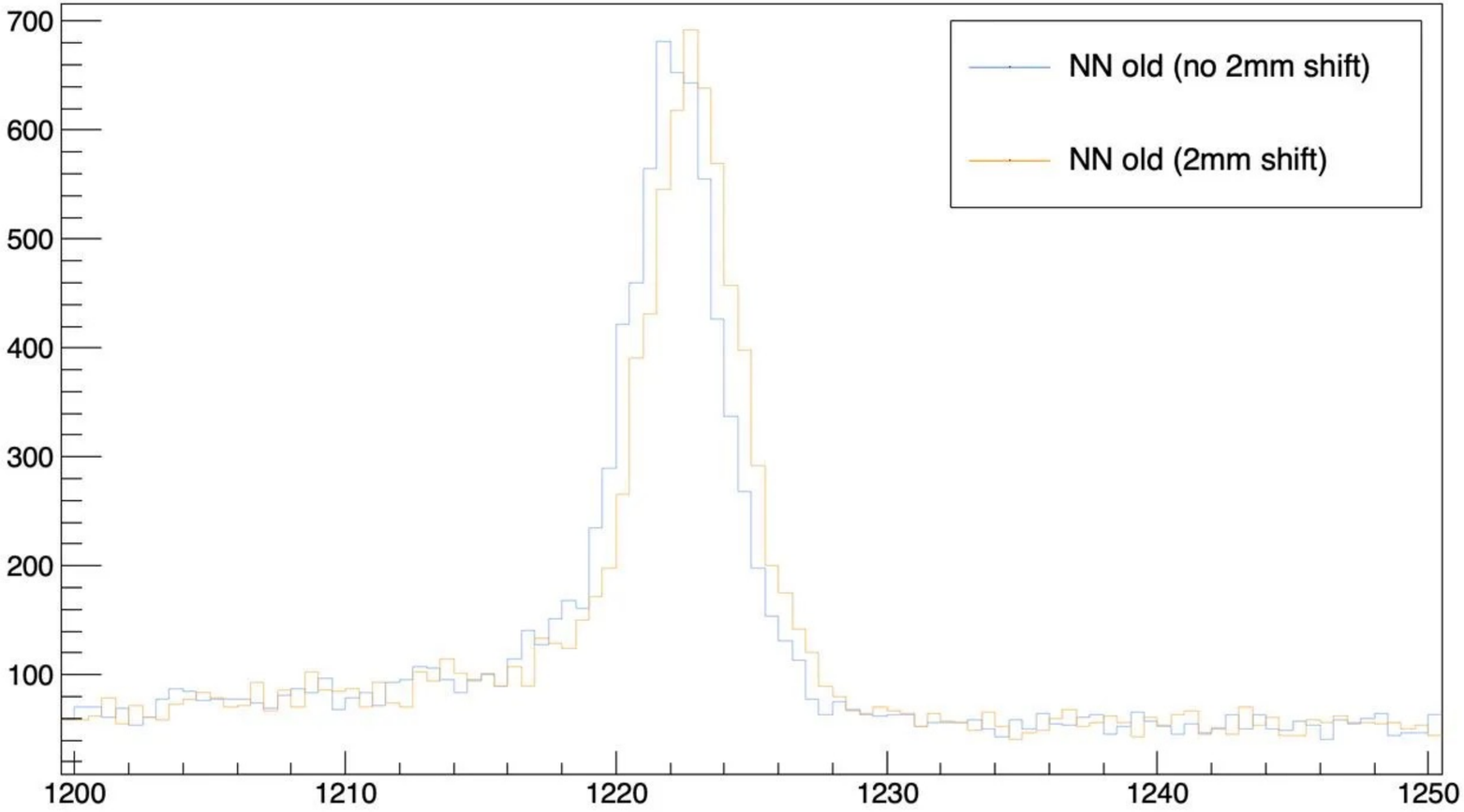
- PSA with NN basis, copying NN parameters from ADL basis
  - E = **1222.75** (compared to 1222.9)
  - FWHM = **3.89** keV
- PSA with NN basis, copying NN parameters from AGATAGeFEM basis
  - E = **1222.73** (compared to 1222.9)
  - FWHM = **3.92** keV

- PSA with NN basis of the old horizontal scan, copying NN parameters from AGATAGeFEM basis
  - E = **1222.27** (compared to 1222.9)
  - FWHM = **3.82** keV

Even if the FWHM seems better, the energy is bad: 1222.26 instead of 1222.9 !

Application to in-beam data: 98Zr spectrum from fission data (E680)

Shift on the final basis: -2mm on X and +2mm on Y



Application to in-beam data: 98Zr spectrum from fission data (E680)

- PSA with ADL basis:
  - E = **1222.87** (compared to 1222.9)
  - FWHM = **4.3** keV

- PSA with AGATAGeFEM basis:
  - E = **1222.82** (compared to 1222.9)
  - FWHM = **4.05** keV

- PSA with NN basis, copying NN parameters from ADL basis
  - E = **1222.75** (compared to 1222.9)
  - FWHM = **3.89** keV
- PSA with NN basis, copying NN parameters from AGATAGeFEM basis
  - E = **1222.73** (compared to 1222.9)
  - FWHM = **3.92** keV

- PSA with NN basis of the old horizontal scan, copying NN parameters from AGATAGeFEM basis
  - E = **1222.27** (compared to 1222.9) ⇒ E = **1222.90**
  - FWHM = **3.82** keV ⇒ FWHM = **3.94** keV

Application to in-beam data: 98Zr spectrum from fission data (E680)

Estimation of the basis position on the new scanned basis

```
"TranslateXY          0 0 0",
```

```
Mean       : 1222.73    (0.04391965)
FWHM (real): 3.918976   (0.08881136)
```

```
"TranslateXY          -1 0 0",
```

```
Mean       : 1222.92    (0.04341069)
FWHM (real): 3.939838   (0.08562413)
```

```
"TranslateXY          -2 0 0",
```

```
Mean       : 1223.094   (0.04344093)
FWHM (real): 3.950094   (0.08596217)
```

Application to in-beam data: 98Zr spectrum from fission data (E680)

- PSA with ADL basis:
  - E = **1222.87** (compared to 1222.9)
  - FWHM = **4.3** keV

- PSA with AGATAGeFEM basis:
  - E = **1222.82** (compared to 1222.9)
  - FWHM = **4.05** keV

- PSA with NN basis, copying NN parameters from ADL basis
  - E = **1222.75** (compared to 1222.9)
  - FWHM = **3.89** keV
- PSA with NN basis, copying NN parameters from AGATAGeFEM basis
  - E = **1222.73** (compared to 1222.9) ⇒ E = **1222.91**
  - FWHM = **3.92** keV ⇒ FWHM = **3.94** keV

- PSA with NN basis of the old horizontal scan, copying NN parameters from AGATAGeFEM basis
  - E = **1222.27** (compared to 1222.9) ⇒ E = **1222.90**
  - FWHM = **3.82** keV ⇒ FWHM = **3.94** keV

After optimization, both scanned basis gives equivalent resolution !
A shift of ~1mm is observed between the X values of vertical and new horizontal scan !

Application to in-beam data: Adaptive vs Full Grid Search

Adaptive Grid Search

- PSA with NN basis, new H scan, Adaptive Grid search
  - E = **1222.9** (compared to 1222.9)
  - FWHM = **3.94** keV
- PSA with NN basis, old H scan, Adaptive Grid search
  - E = **1222.9** (compared to 1222.9)
  - FWHM = **3.94** keV

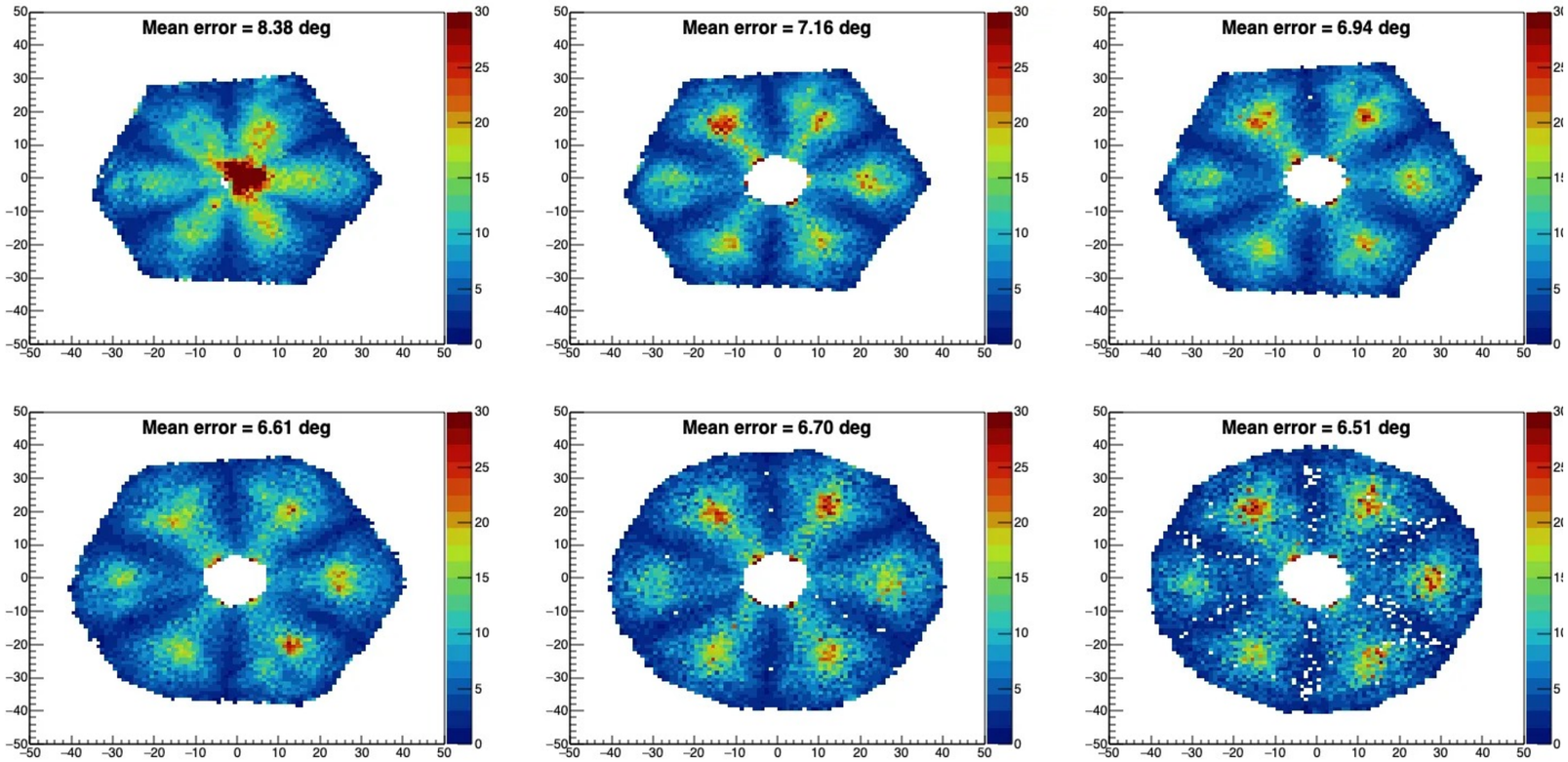
Full Grid Search

- PSA with NN basis, new H scan, Adaptive Grid search
  - E = **1222.9** (compared to 1222.9)
  - FWHM = **3.88** keV
- PSA with NN basis, old H scan, Adaptive Grid search
  - E = **1222.9** (compared to 1222.9)
  - FWHM = **3.78** keV

Application to in-beam data: PSA sensitivity

NN basis, old vs new horizontal scan

$$Error\ on\ \theta: abs(\theta_{new} - \theta_{old})$$

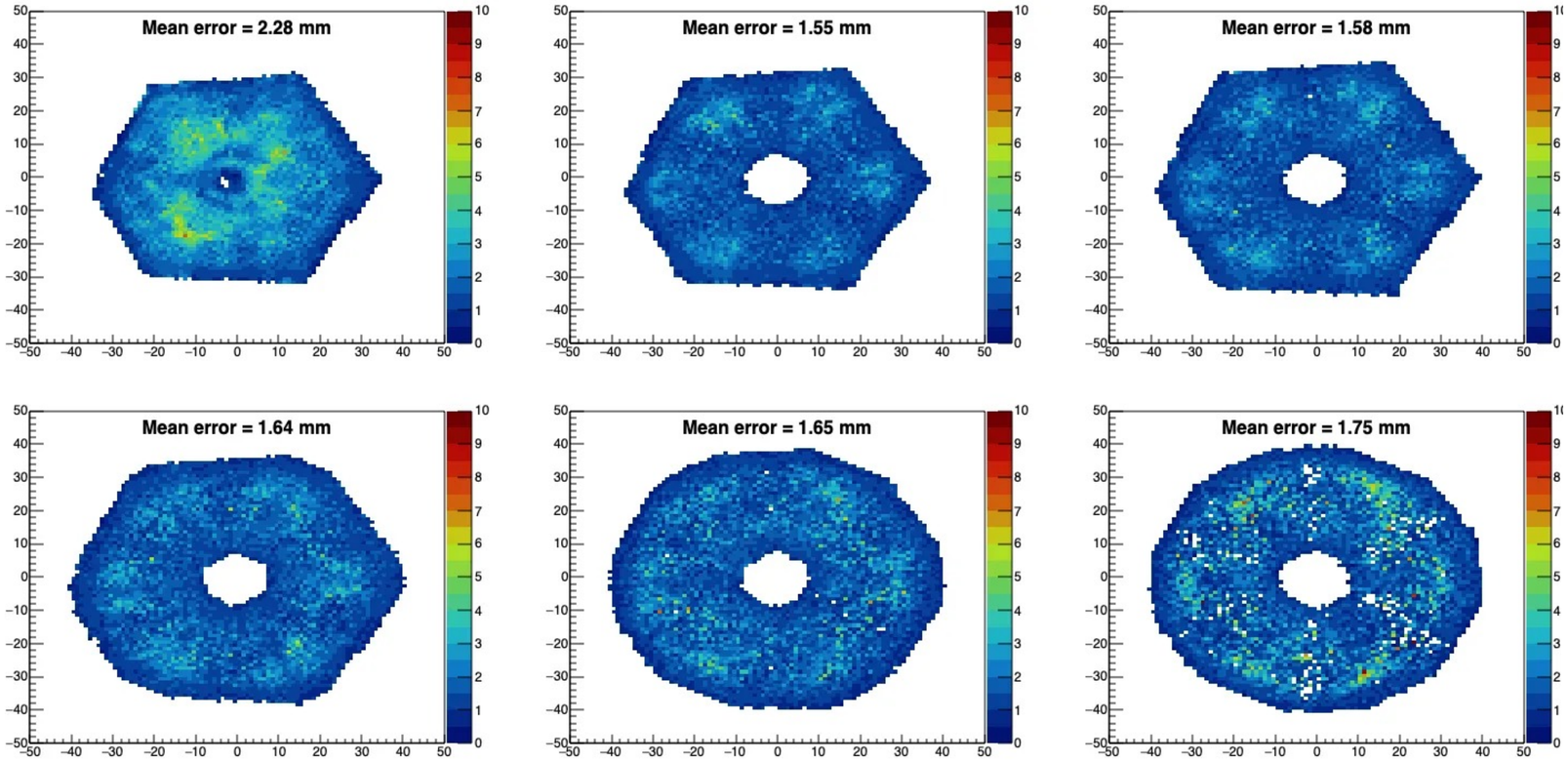


error as a function of the average position

Application to in-beam data: PSA sensitivity

NN basis, old vs new horizontal scan

$$Error\ on\ Radius: abs(R_{new} - R_{old})$$

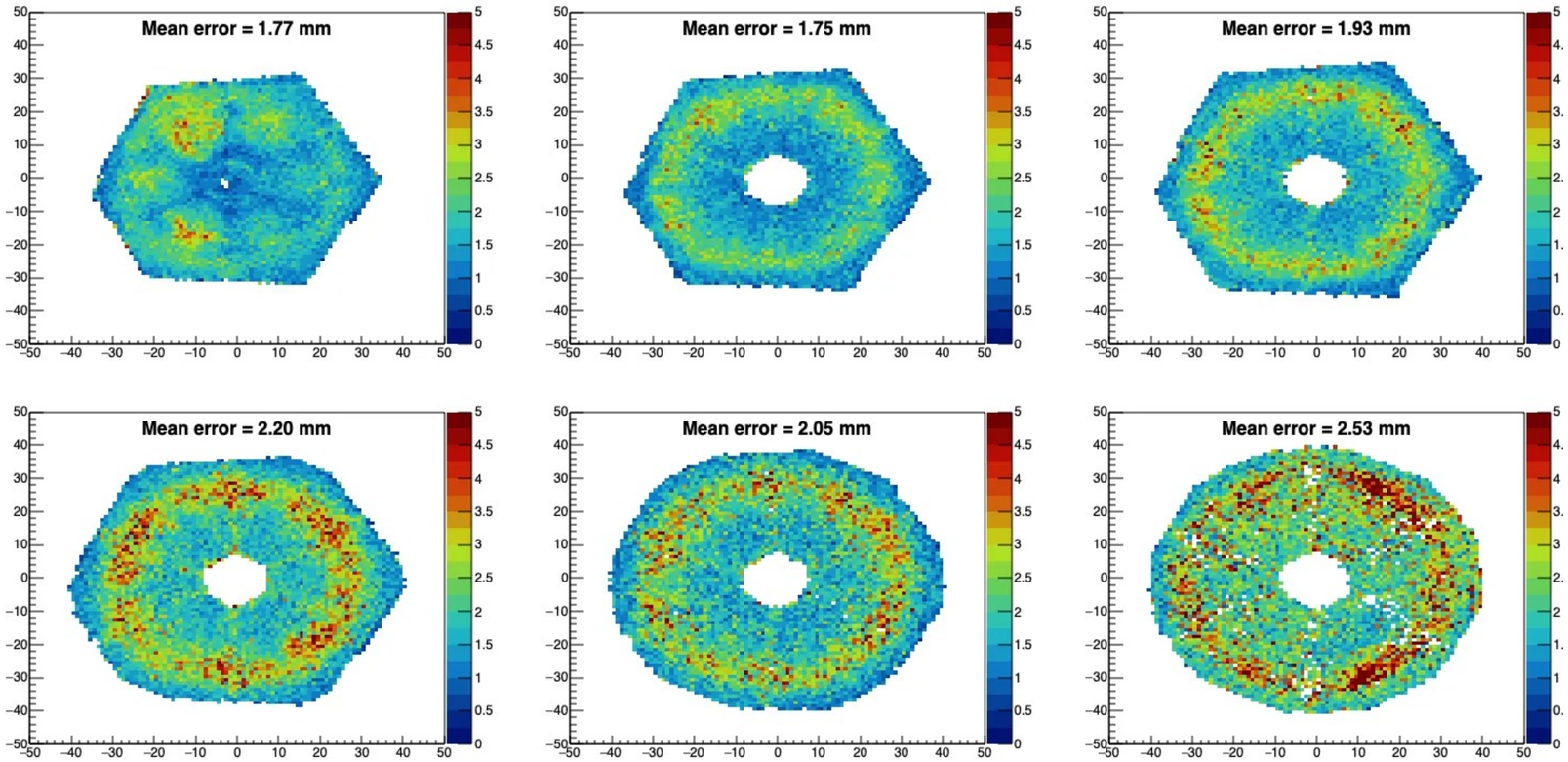


error as a function of the average position

Application to in-beam data: PSA sensitivity

NN basis, old vs new horizontal scan

$$Error\ on\ Z: abs(Z_{new} - Z_{old})$$

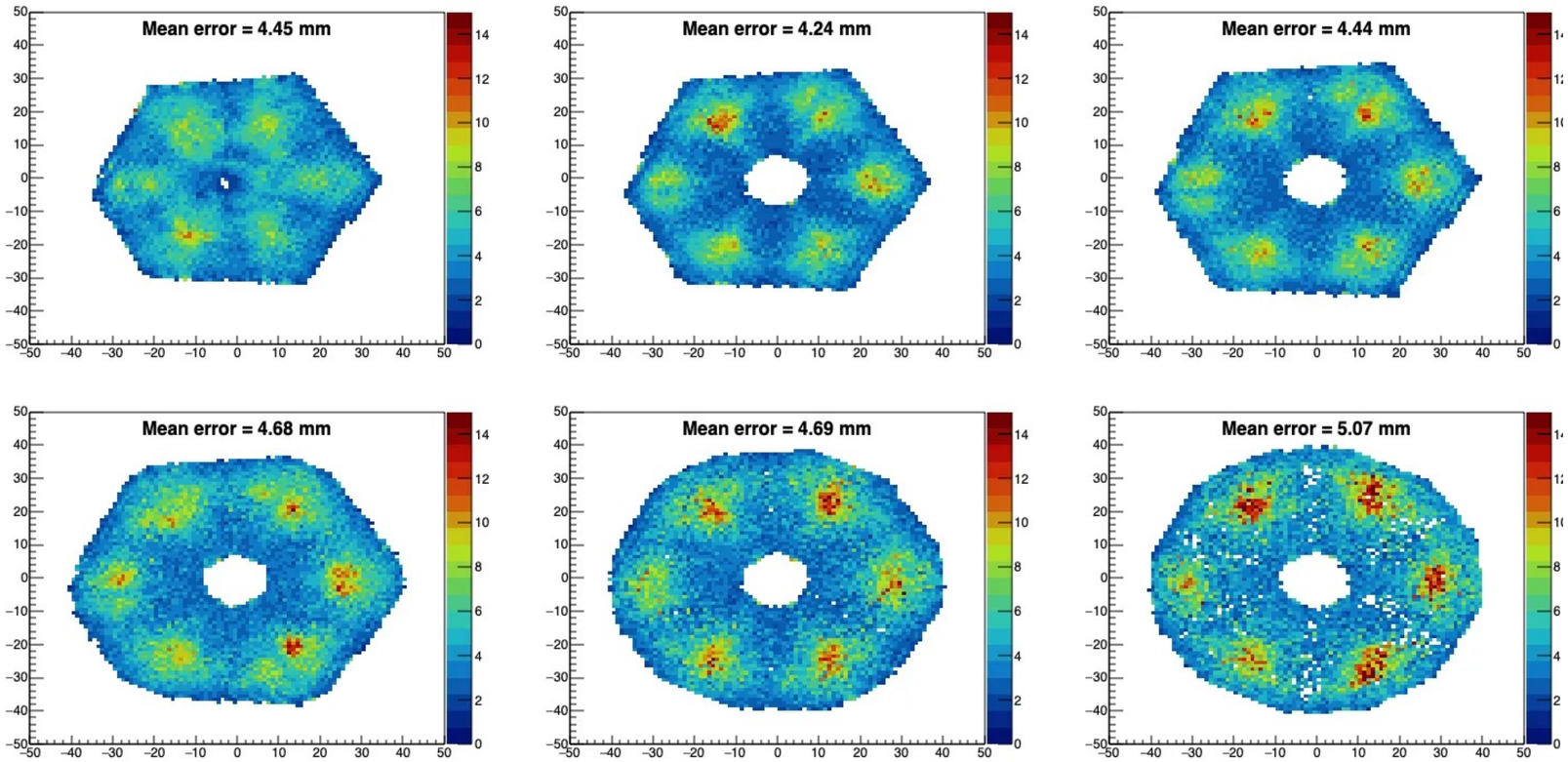


error as a function of the average position

Application to in-beam data: PSA sensitivity

NN basis, old vs new horizontal scan

Error on 3D distance



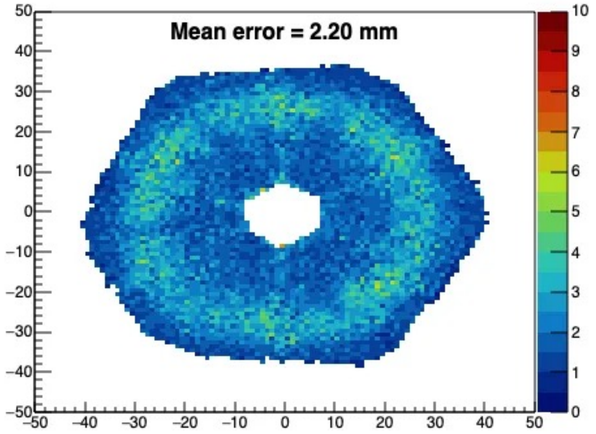
error as a function of the average position

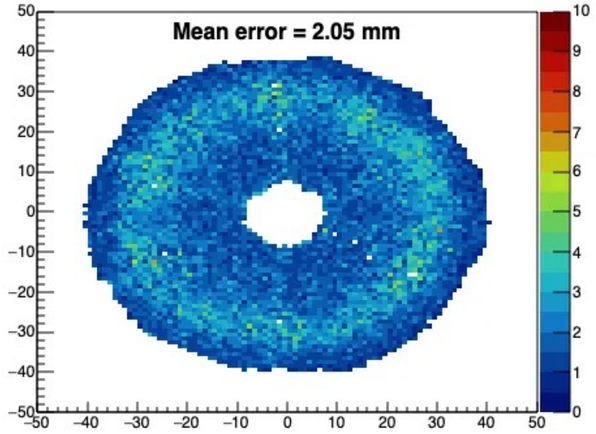
Application to in-beam data: PSA sensitivity

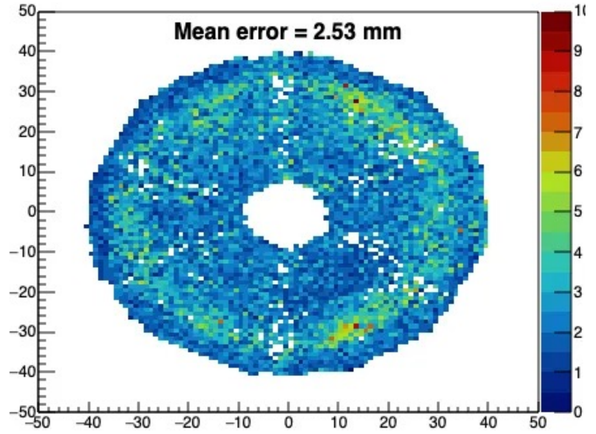
Comparison with ADL: Full Grid Search

Error on Z

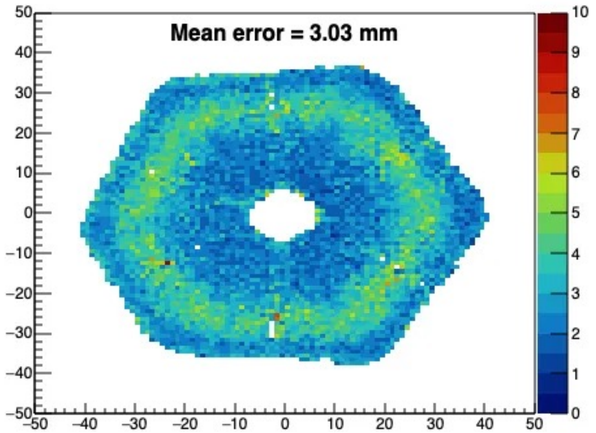
NN old vs NN new

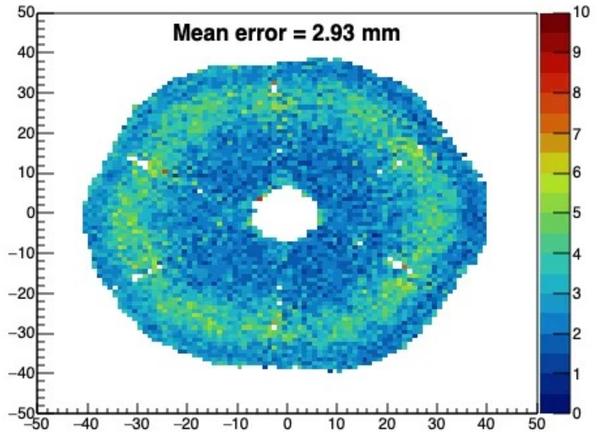


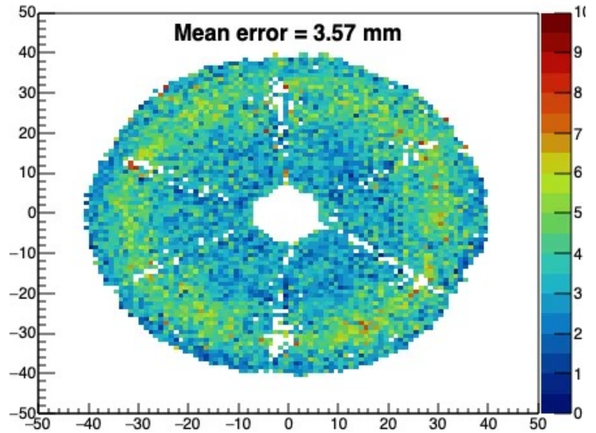




ADL vs NN new





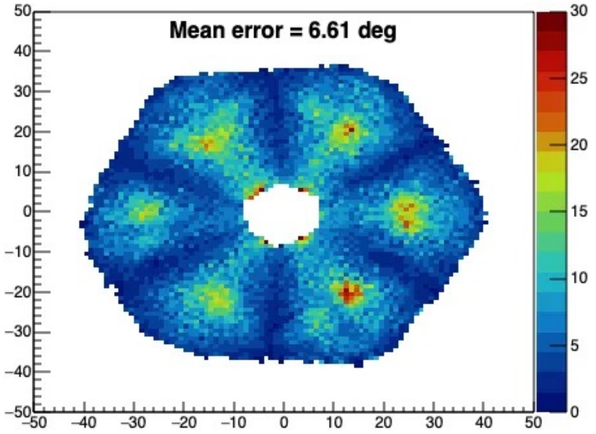


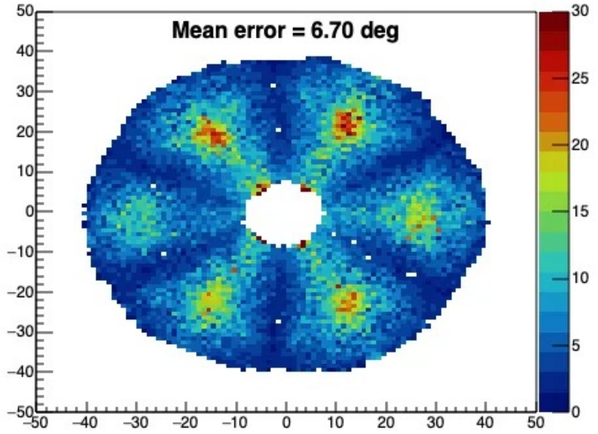
Application to in-beam data: PSA sensitivity

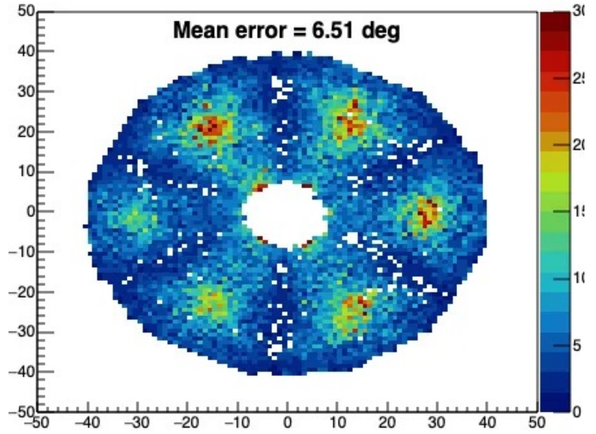
Comparison with ADL: Full Grid Search

$Error\ on\ \theta$

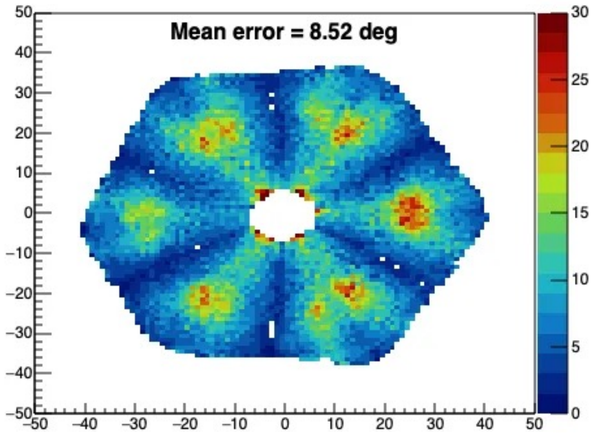
NN old vs NN new

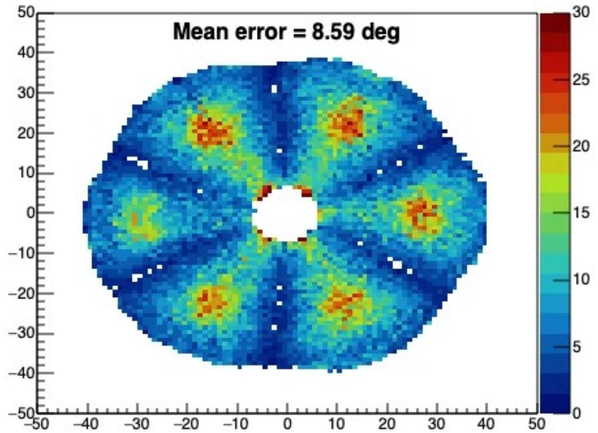


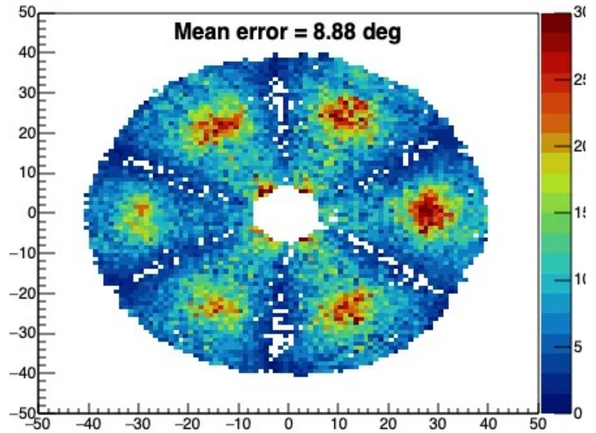




ADL vs NN new





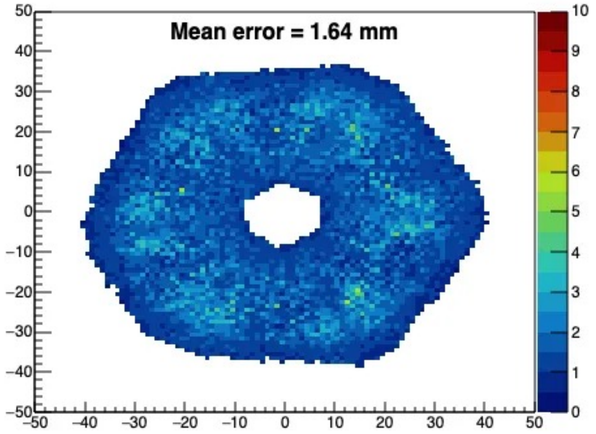


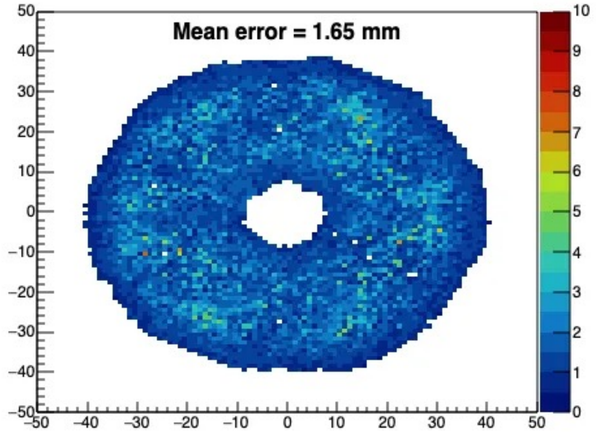
Application to in-beam data: PSA sensitivity

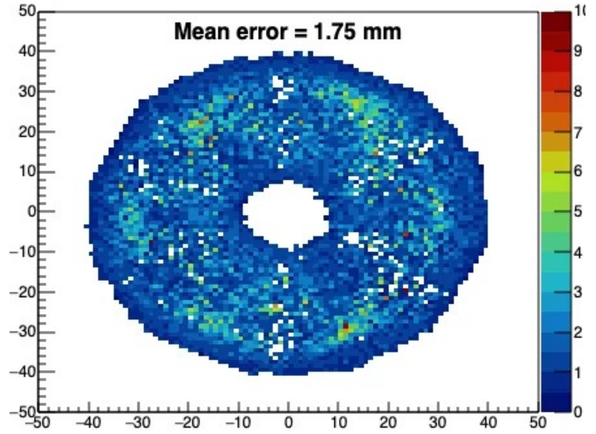
Comparison with ADL: Full Grid Search

Error on Radius

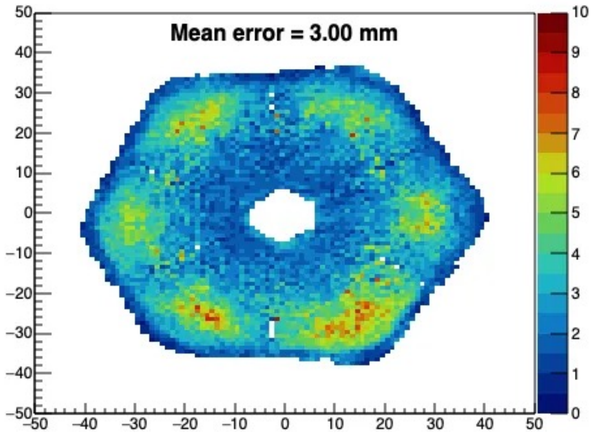
NN old vs NN new

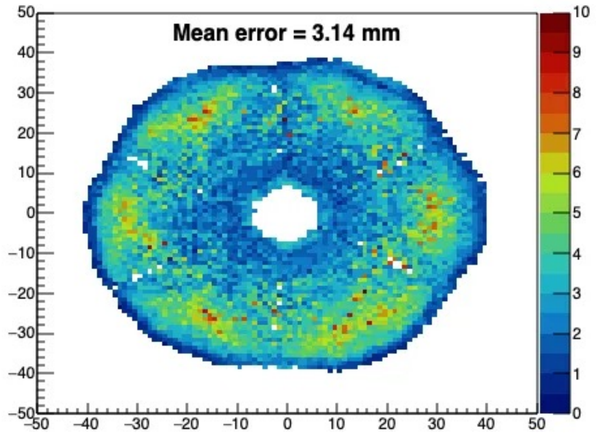


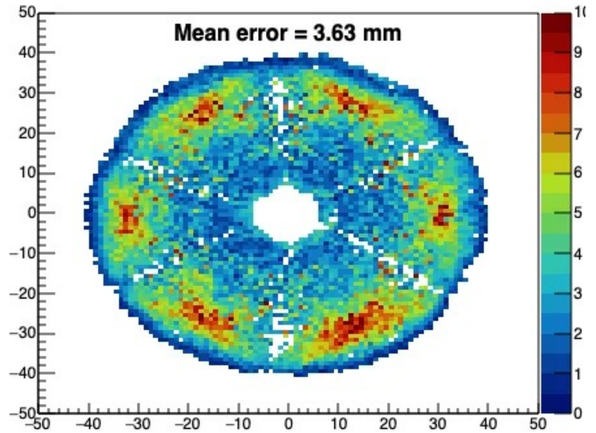




ADL vs NN new





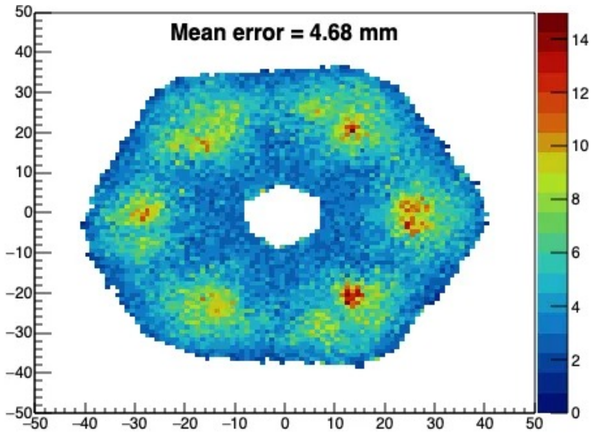


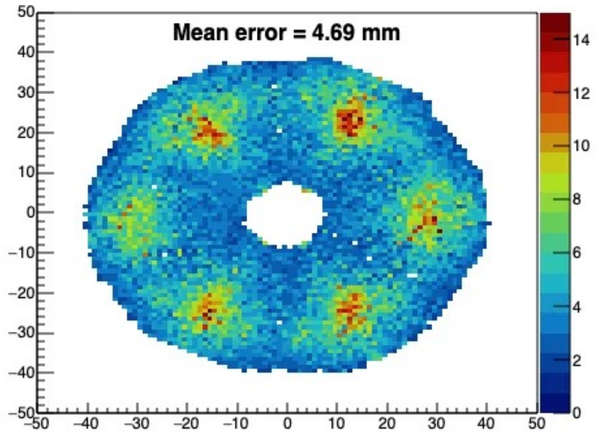
Application to in-beam data: PSA sensitivity

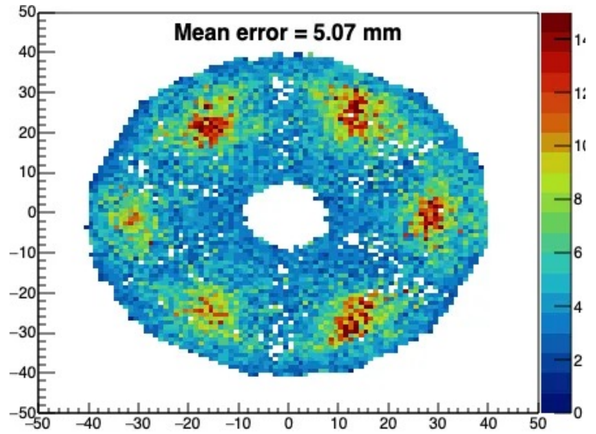
Comparison with ADL: Full Grid Search

Error on 3D distance

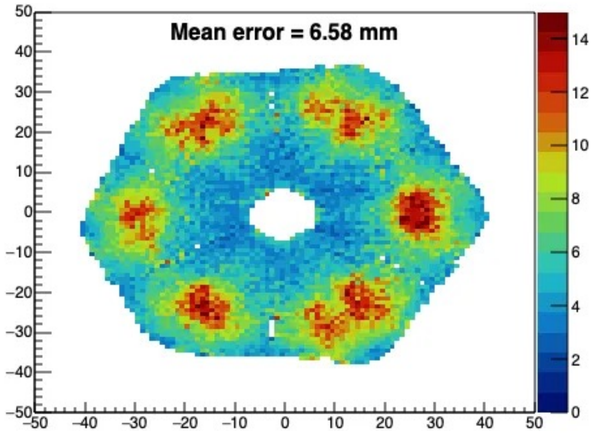
NN old vs NN new

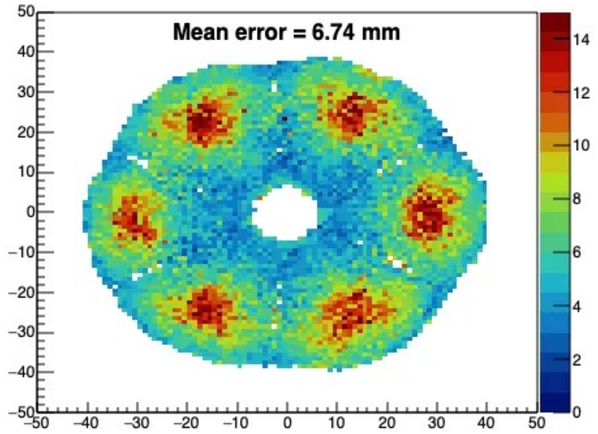


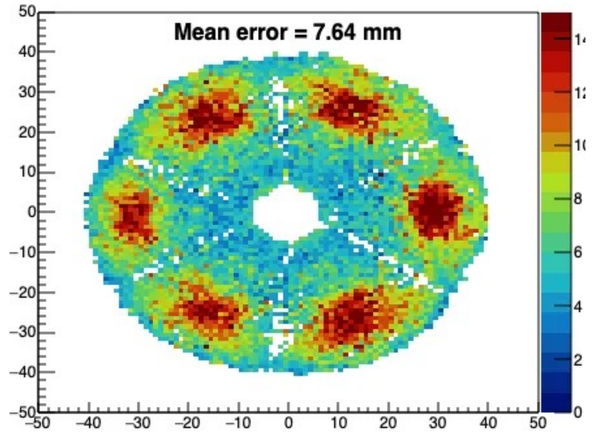




ADL vs NN new







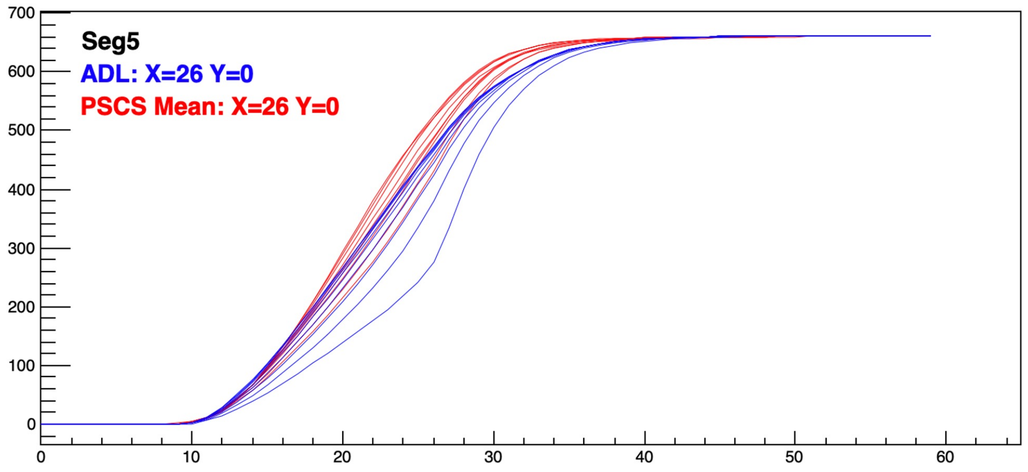
Application to in-beam data: PSA sensitivity

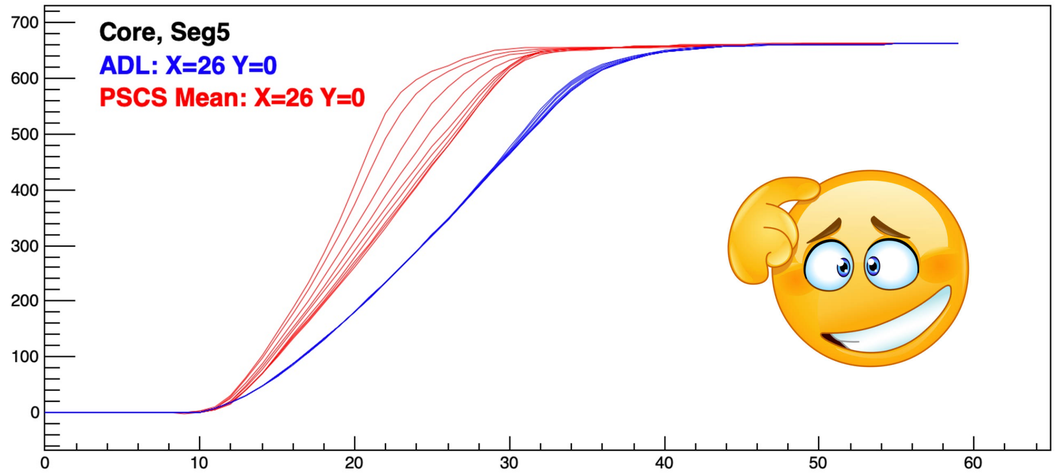
FWHM vs Z

	ADL	NN
➤ Layer 0:	**5.18** keV	**4.70** keV
➤ Layer 1:	**4.42** keV	**4.14** keV
➤ Layer 2:	**3.62** keV	**4.12** keV
➤ Layer 3:	**3.93** keV	**3.67** keV
➤ Layer 4:	**4.88** keV	**3.53** keV
➤ Layer 5:	**4.37** keV	**3.83** keV

Application to in-beam data: Core signal problem in simulations

➤ The core signal is too fast compared to simulations and we don't know why…(real effect of electronic effect ?)





	Standard PSA	PSA excluding core in the Chi2 estimation
➤ ADL:	➥FWHM = **4.32** keV	➥FWHM = **4.17** keV
➤ NN:	➥FWHM = **3.78** keV	➥FWHM = **3.87** keV

Up to now, we were thinking that this effect was a detector/electronic issue,
but it seems to be actually a simulation problem.

Application to in-beam data: New AGATAGeFEM version characterization

AGATAGeFEM evaluation vs contact central radius

	Energy	FWHM
➤ Previous version	**1222.82** keV	**4.08** keV
➤ New version, 5.5mm	**1222.78** keV	**3.90** keV
➤ New version, 6.0mm	**1222.81** keV	**3.96** keV
➤ New version, 6.5mm	**1222.76** keV	**4.03** keV
➤ New version, 7.0mm	**1222.75** keV	**3.90** keV

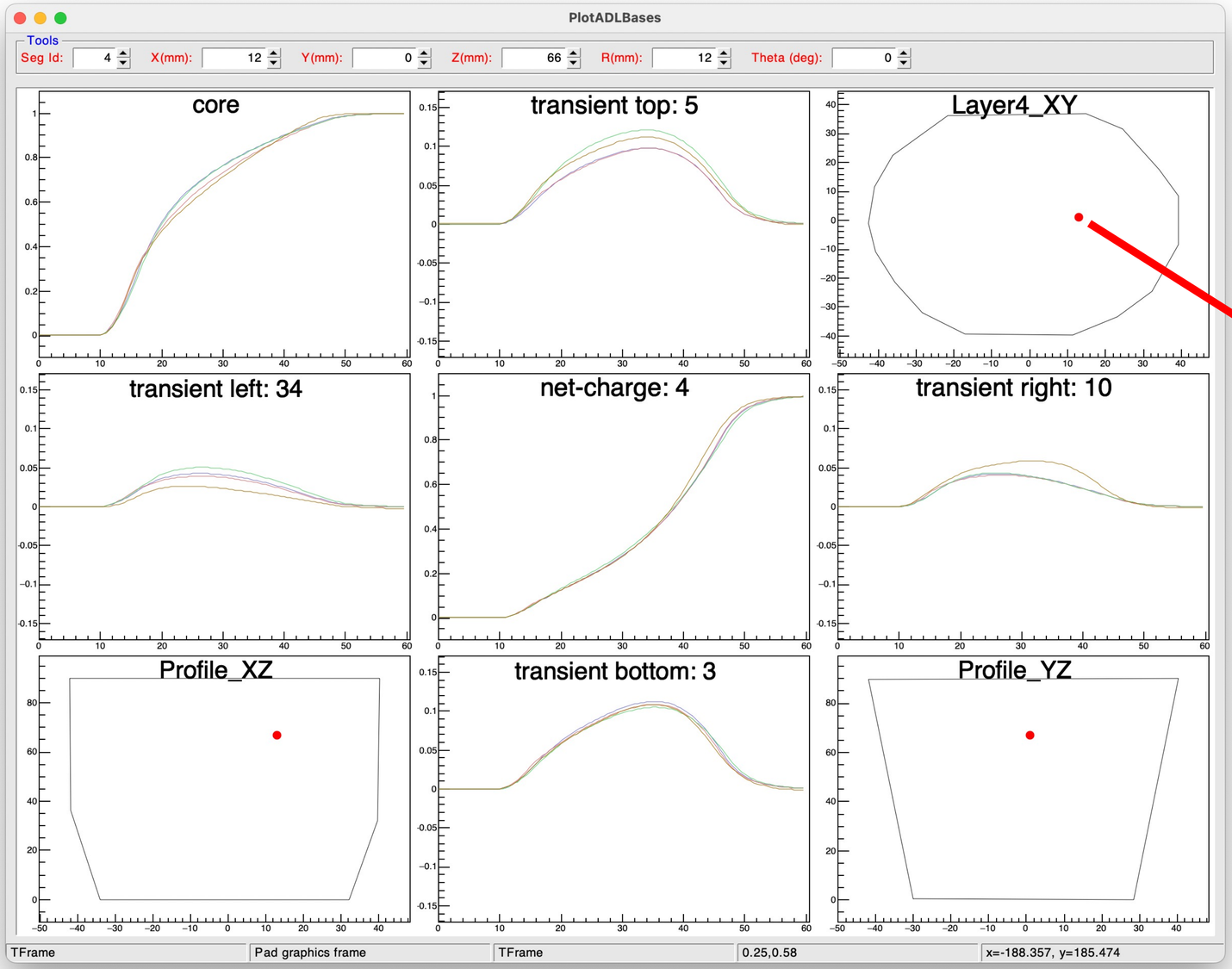
Application to in-beam data: New AGATAGeFEM version characterization

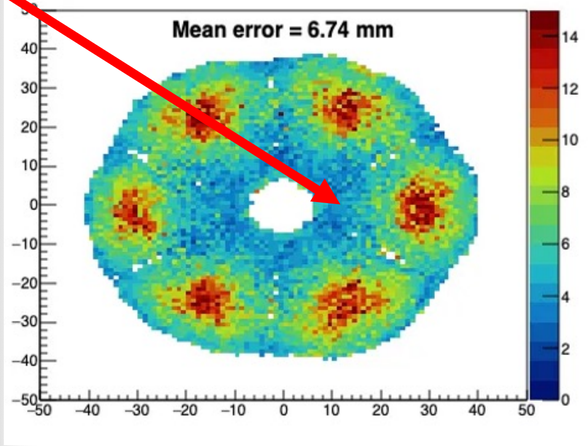
NN

ADL

AGATAGeFEM 5.5

AGATAGeFEM 7.0





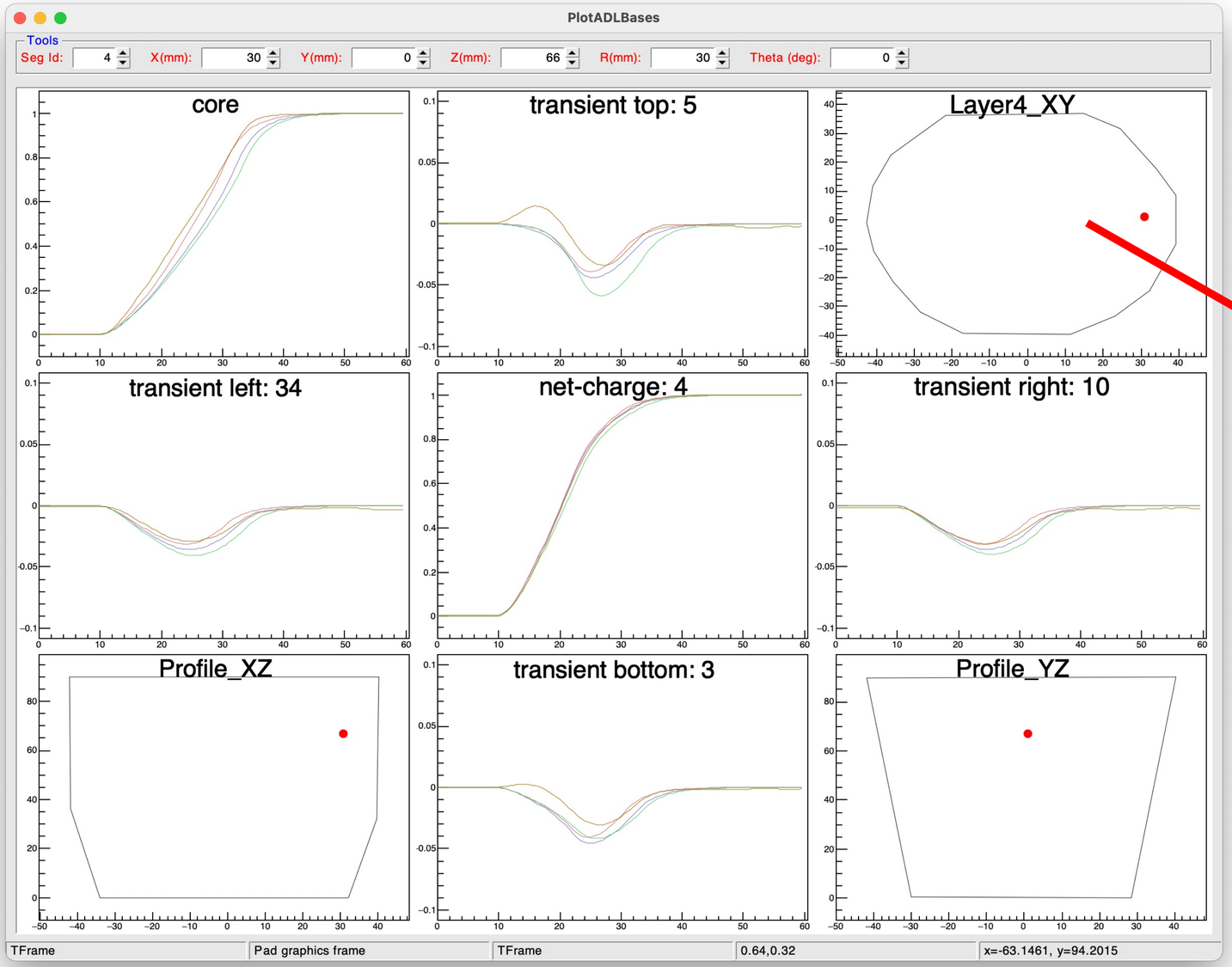
Application to in-beam data: New AGATAGeFEM version characterization

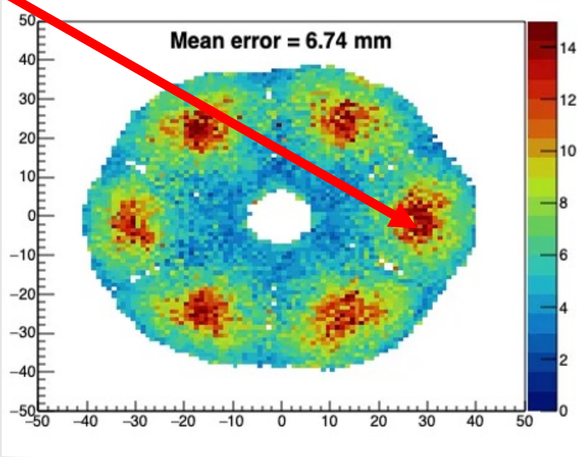
NN

ADL

AGATAGeFEM 5.5

AGATAGeFEM 7.0



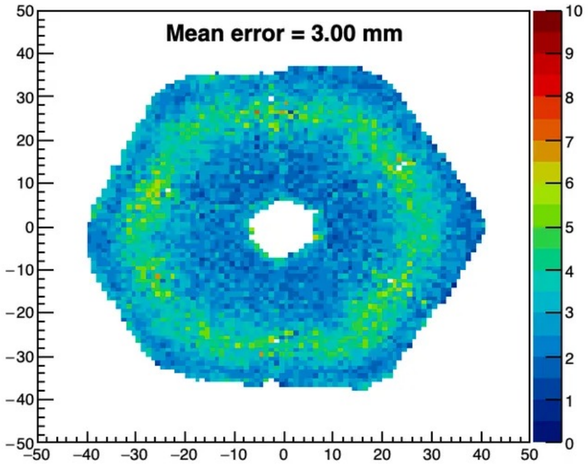


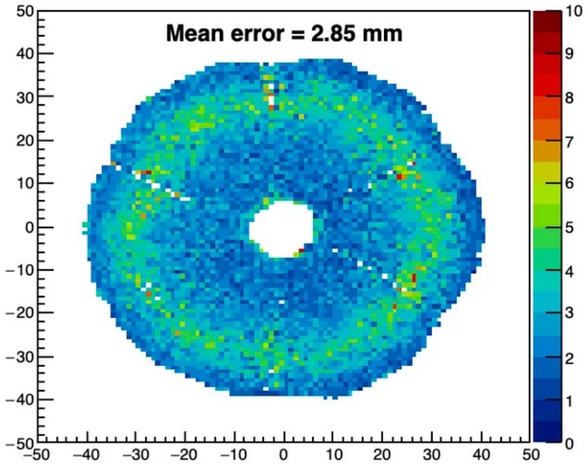
Application to in-beam data: New AGATAGeFEM version characterization

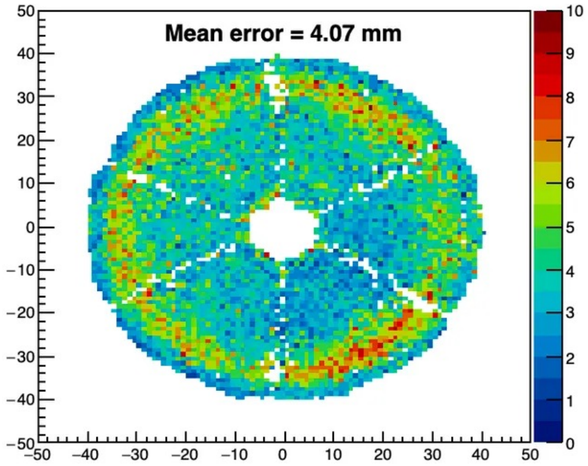
Comparison with NN: Full Grid Search

Error on Z

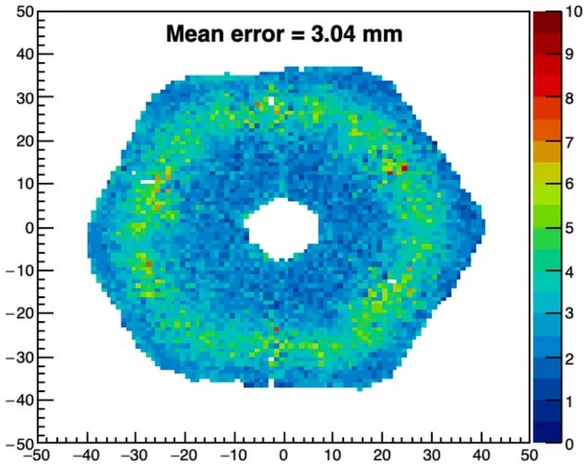
NN old vs AGATAGeFEM 5.5mm

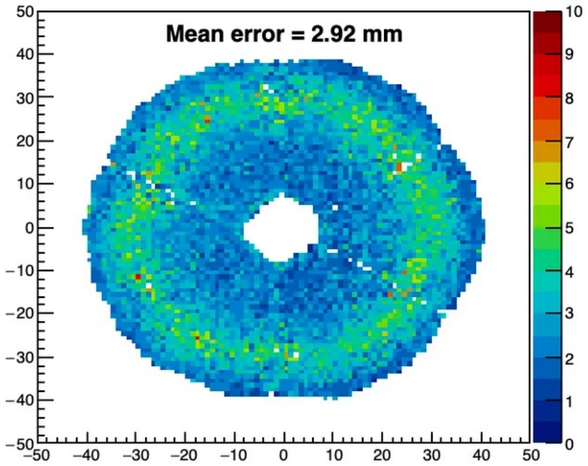


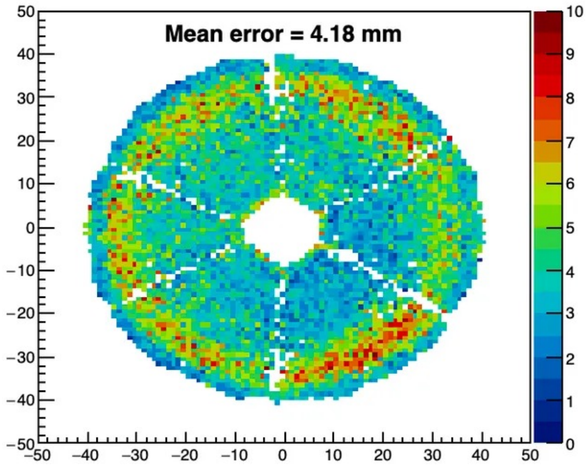




NN old vs AGATAGeFEM 7.0mm





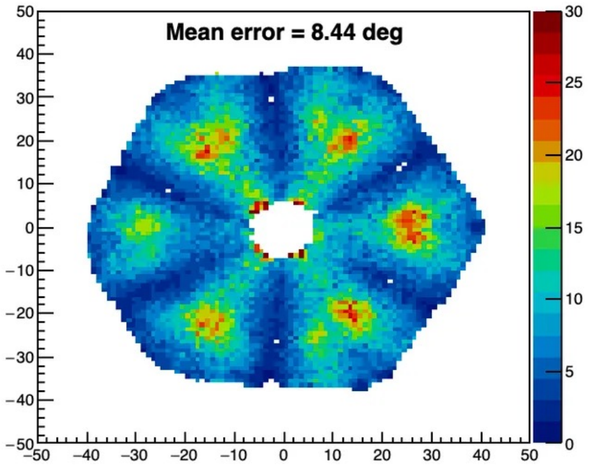


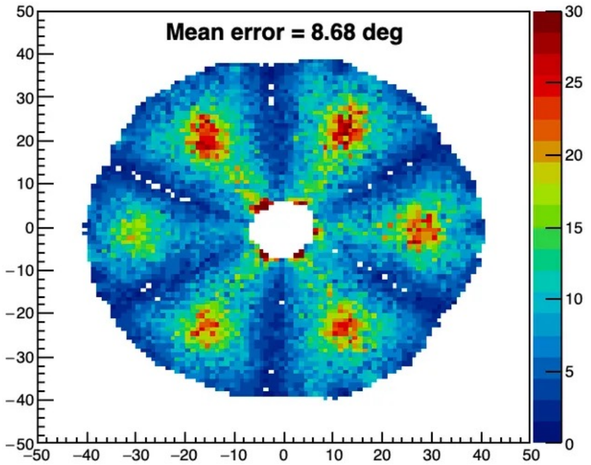
Application to in-beam data: New AGATAGeFEM version characterization

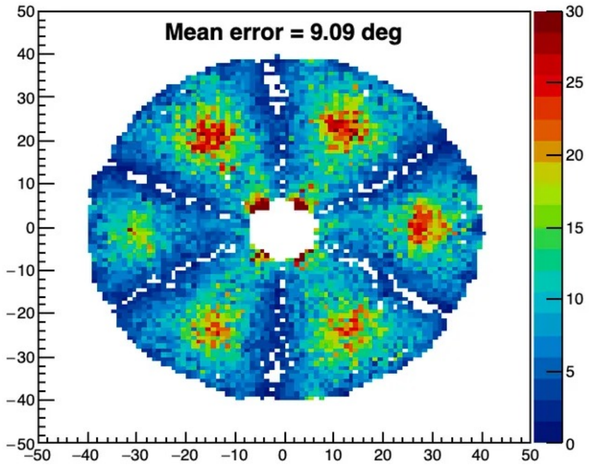
Comparison with NN: Full Grid Search

$Error\ on\ \theta$

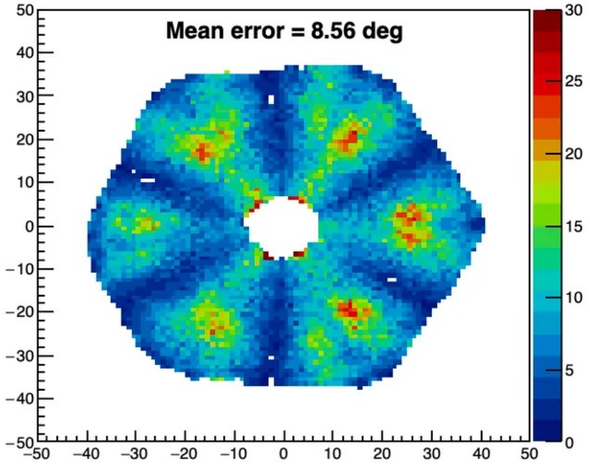
NN old vs AGATAGeFEM 5.5mm

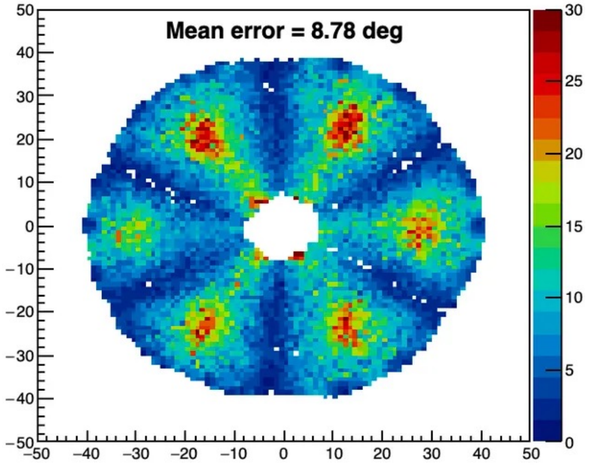


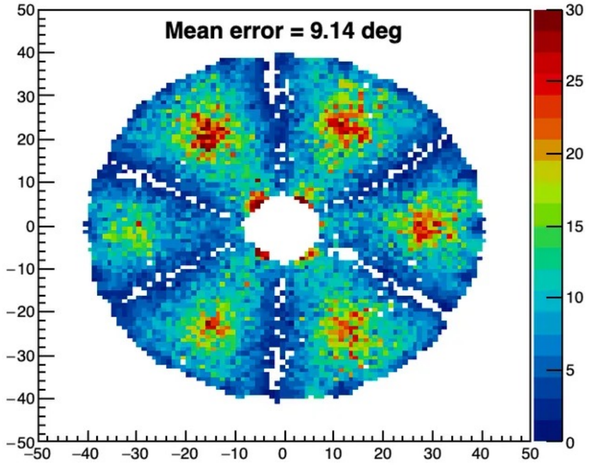




NN old vs AGATAGeFEM 7.0mm





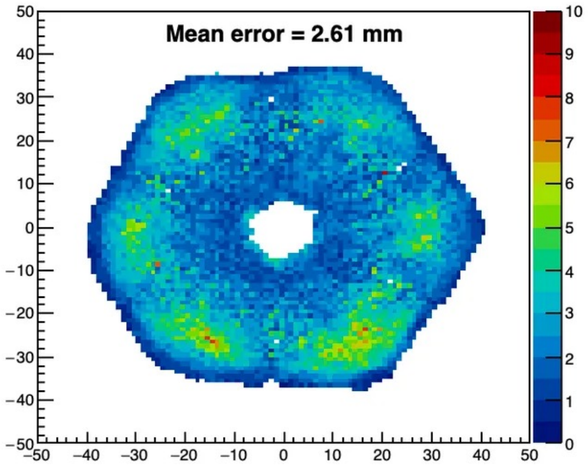


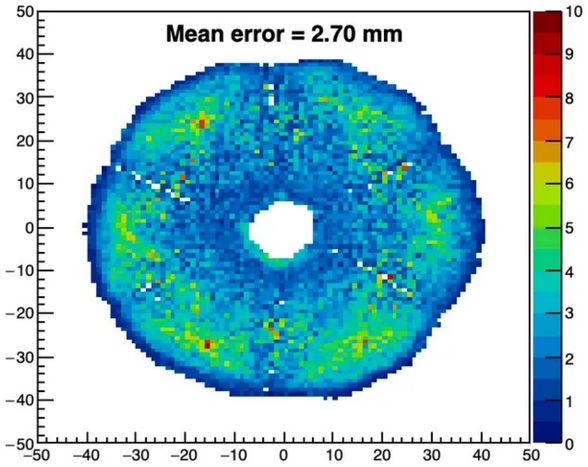
Application to in-beam data: New AGATAGeFEM version characterization

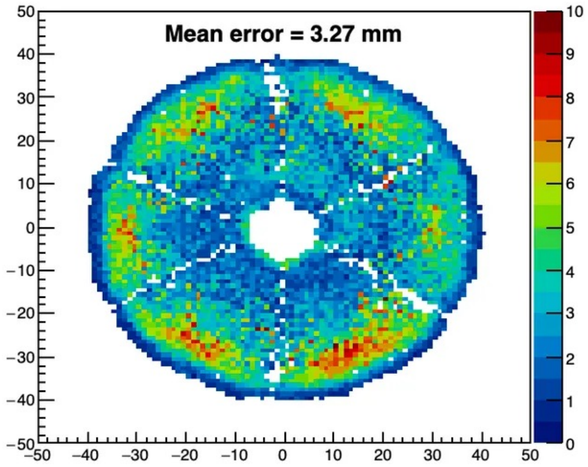
Comparison with NN: Full Grid Search

Error on Radius

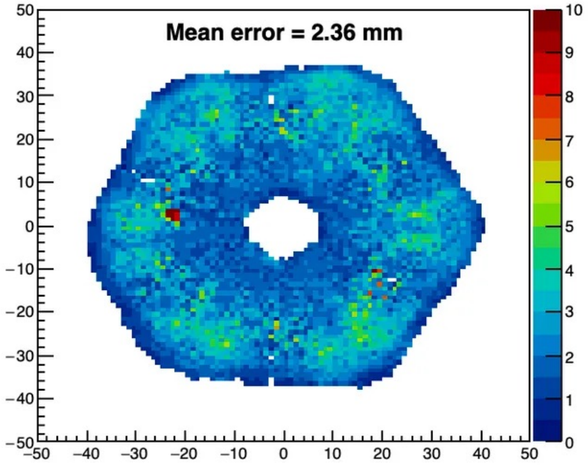
NN old vs AGATAGeFEM 5.5mm

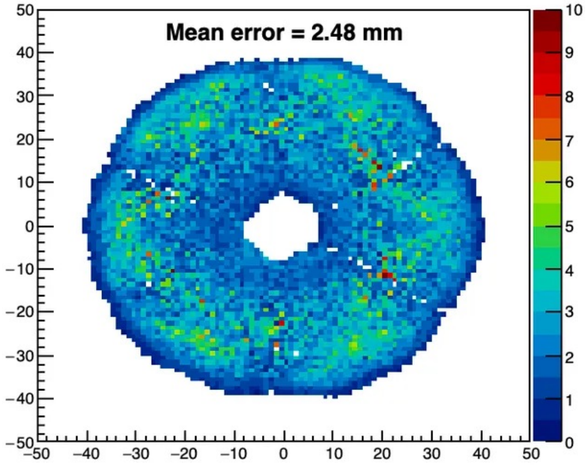


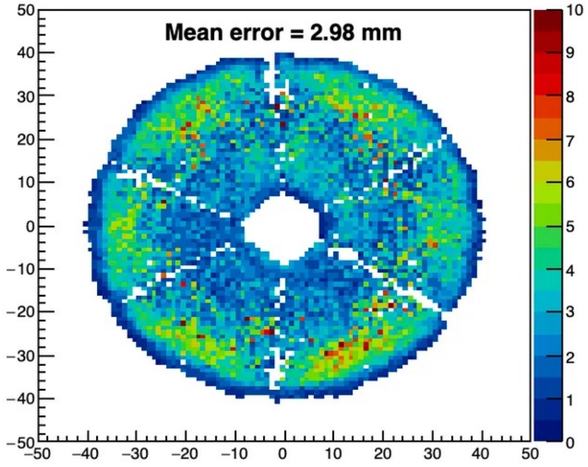




NN old vs AGATAGeFEM 7.0mm





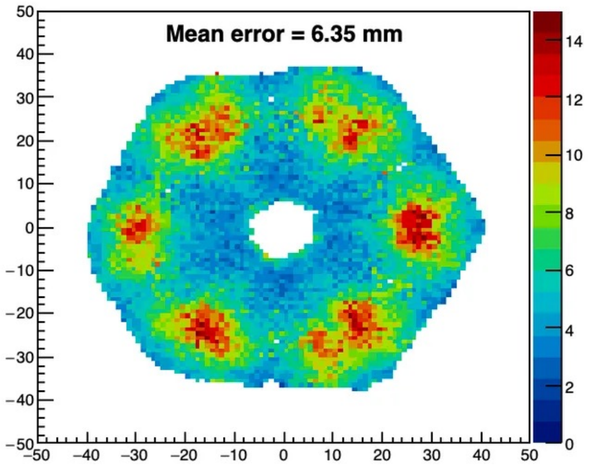


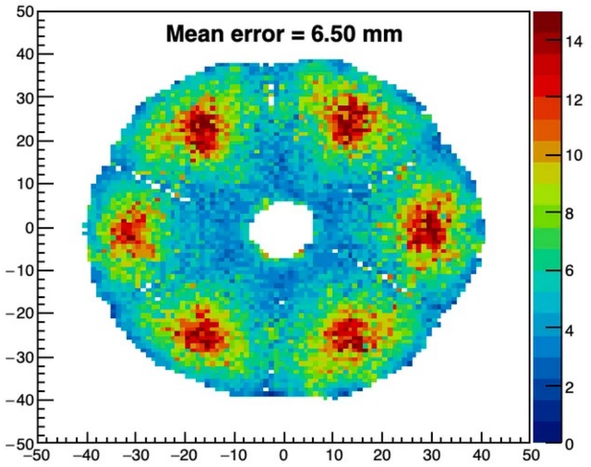
Application to in-beam data: New AGATAGeFEM version characterization

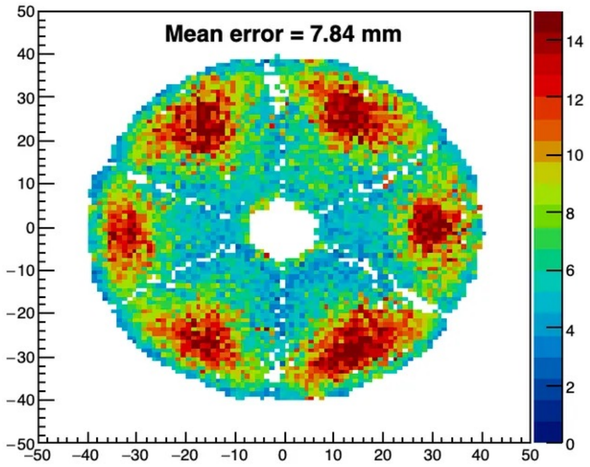
Comparison with NN: Full Grid Search

Error on 3D distance

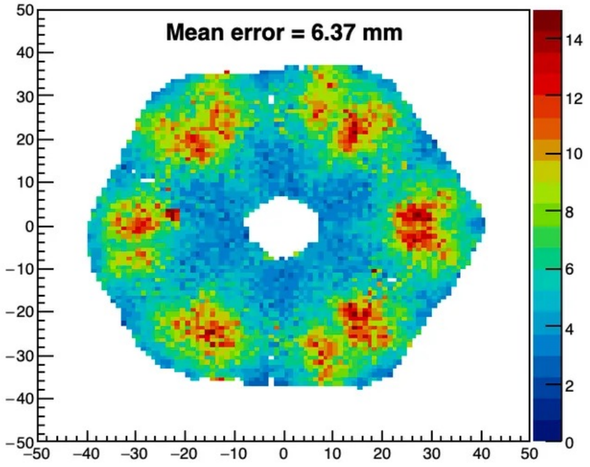
NN old vs AGATAGeFEM 5.5mm

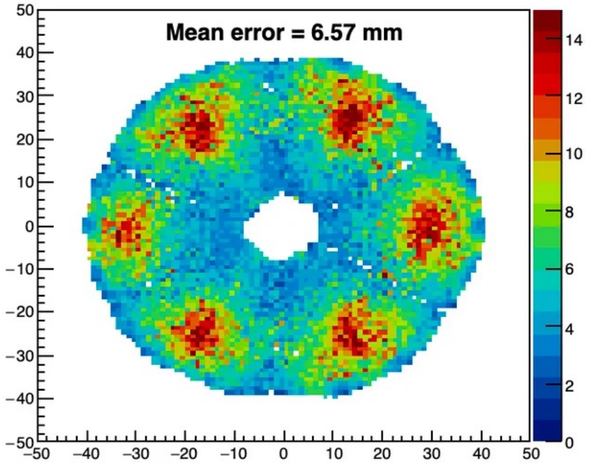


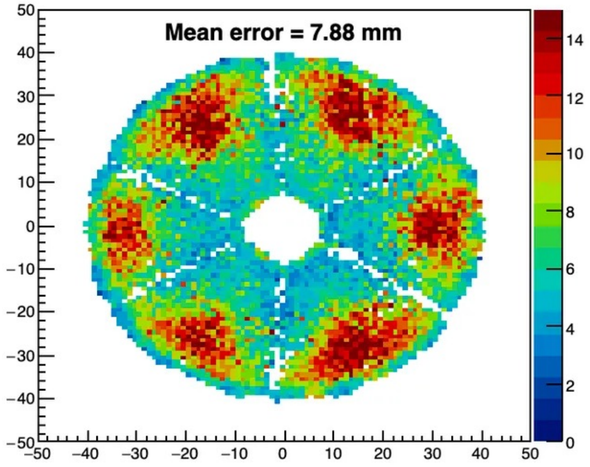




NN old vs AGATAGeFEM 7.0mm







Merci !