AI activities @ IP2I Lyon: PSA performances of A005

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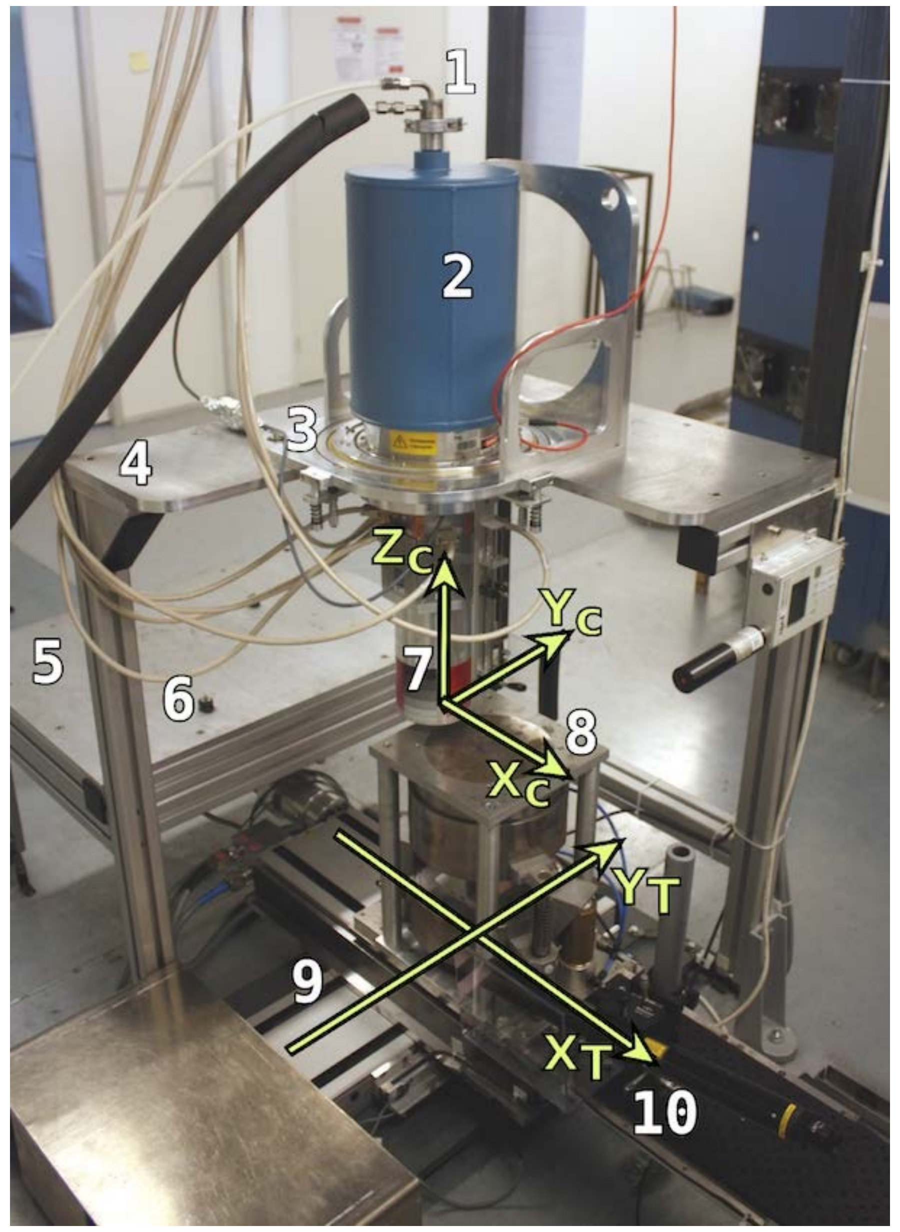
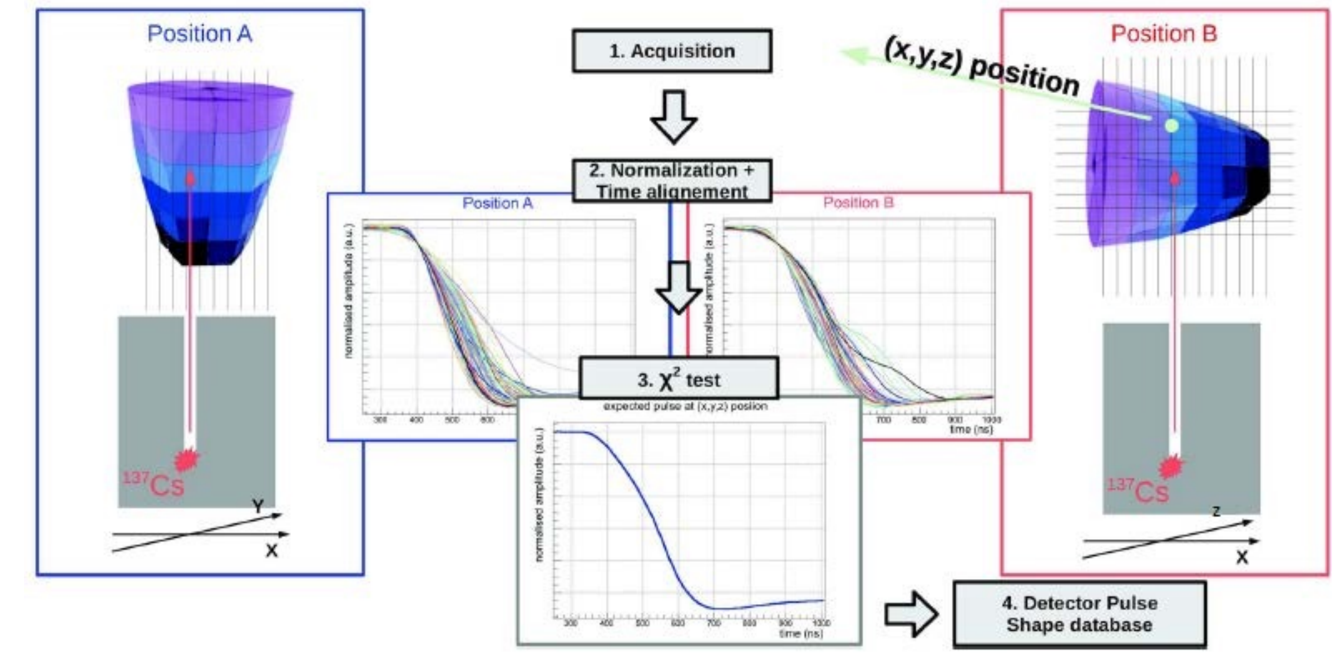
Institut de Physique des deux infinis de Lyon **(IP2I)**

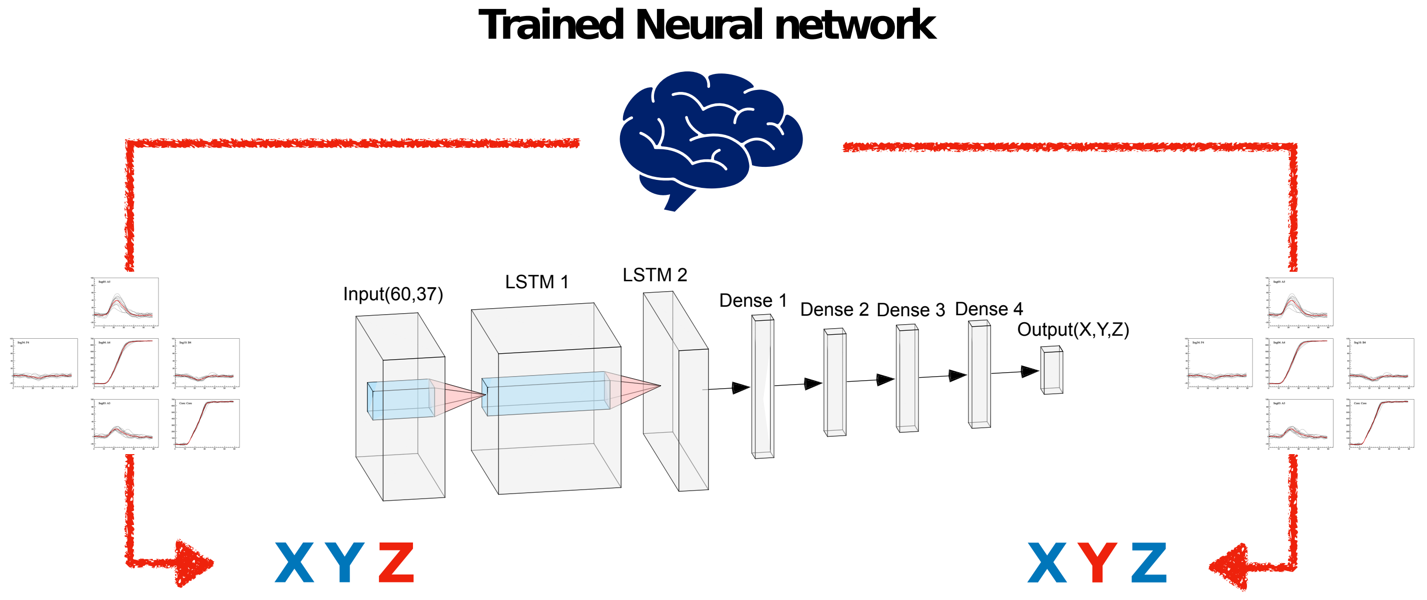
AGATA Week 2025, GSI

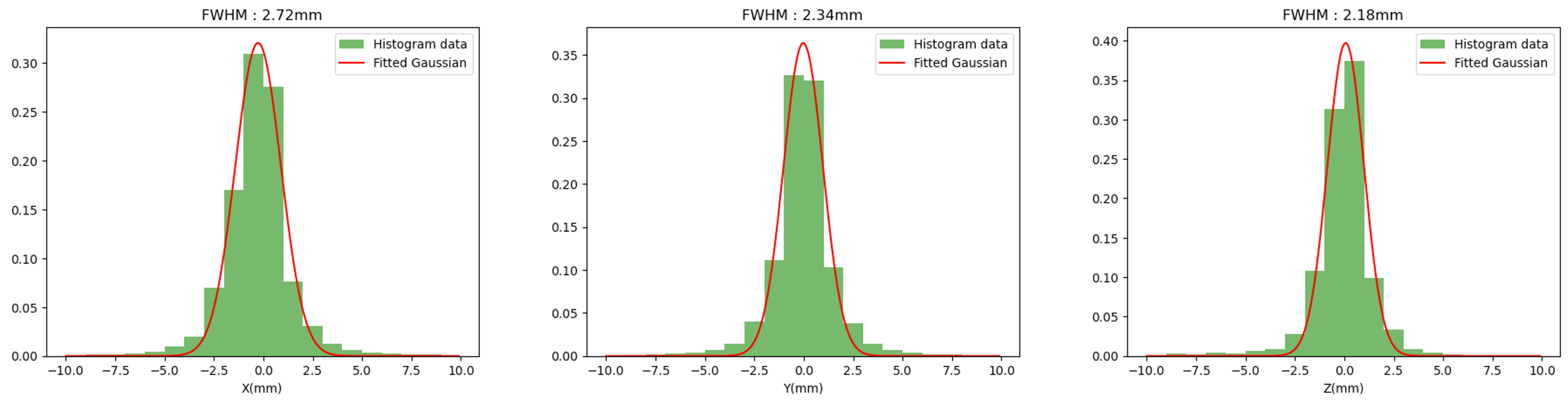
Conclusions and perspectives (of the 2024 AGATA Week)

- A005 has been scanned at IPHC Strasbourg:
  - ➥ Horizontal scan processed twice due to technical issues
- A machine learning analysis method has been developed
  - ➥ Experimental signal basis of A005 available for PSA
  - ➥ PSA performances on scanned data outperform:
    - ➢ PSCS basis
    - ➢ Simulated bases (ADL & AGATAGeFEM)
- Estimated 3D resolutions (FWHM) of PSA on scanned data
  - ➥ Experimental basis: **4.0 mm**
  - ➥ AGATAGeFEM **8.6 mm**
  - ➥ ADL **10.5 mm**
- To be done: push the PSA evaluation on in-beam data !
  - ➥ dataset with ^{98}Zr fission data (E680-GANIL)



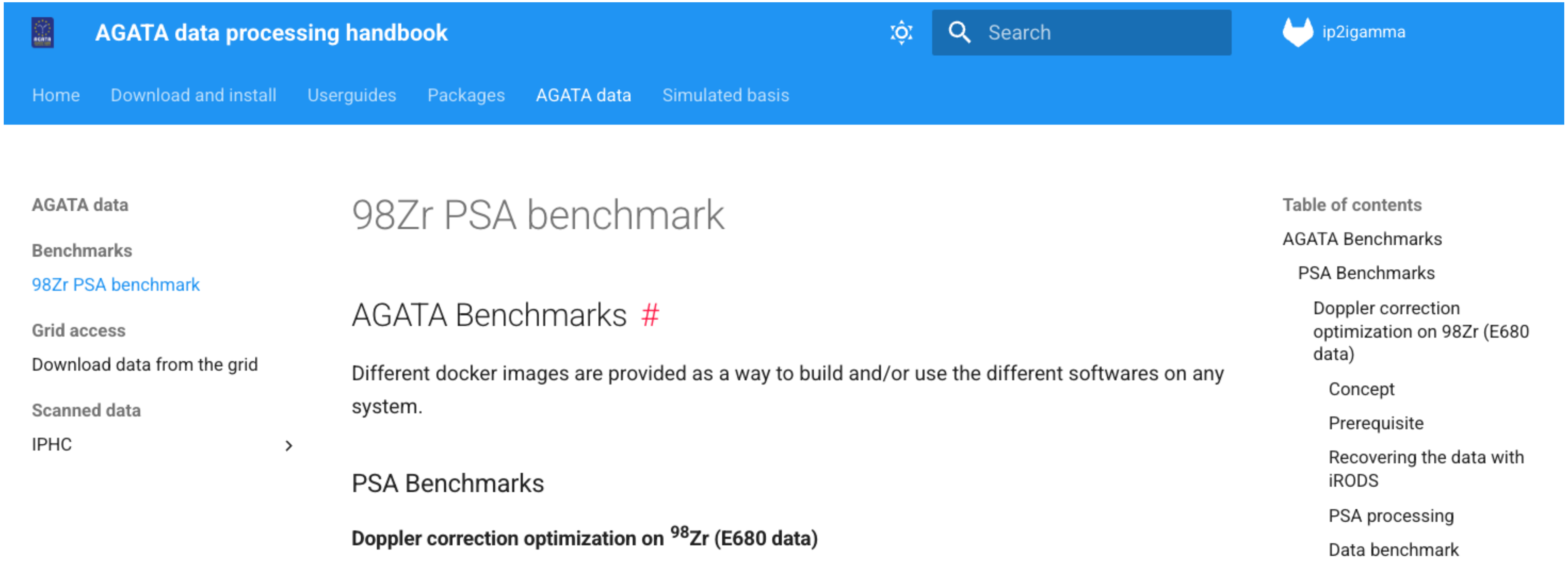






Application to in-beam data: ^{98}Zr spectrum from fission data (E680)

- Reminder:
  - ➥ Dataset from the E680 GANIL fission experiment
  - ➥ dataset and manual available on the AGATA handbook website: https://agata.pages.in2p3.fr/handbook



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

- **Reminder:**
  - ➥ Dataset from the the E680 GANIL fission experiment
  - ➥ dataset and manual available on the AGATA handbook website: https://agata.pages.in2p3.fr/handbook

Hopefully, A005 was used during the E680 experiment at position 03A !

```
#################################################################################################
###################  3  Database of AGATA germanium detectors  ################################
#################################################################################################

# These values should be checked carefully against the detector configuration used to take the data
GeDataBaseGANIL={
'00A': ['00', '$PSABASE/LibTrap_A001.dat'], '00B': ['01', '$PSABASE/LibTrap_B004.dat'], '00C': ['02', '$PSABASE/LibTrap_C010.dat'],
'02A': ['06', '$PSABASE/LibTrap_A009.dat'], '02B': ['07', '$PSABASE/LibTrap_B005.dat'], '02C': ['08', '$PSABASE/LibTrap_C008.dat'],
'03A': ['09', '$PSABASE/LibTrap_A005.dat'], '03B': ['10', '$PSABASE/LibTrap_B002.dat'], '03C': ['11', '$PSABASE/LibTrap_C009.dat'],
'04A': ['12', '$PSABASE/LibTrap_A008.dat'], '04B': ['13', '$PSABASE/LibTrap_B001.dat'], '04C': ['14', '$PSABASE/LibTrap_C003.dat'],
'10A': ['30', '$PSABASE/LibTrap_A003.dat'], '10B': ['31', '$PSABASE/LibTrap_B003.dat'], '10C': ['32', '$PSABASE/LibTrap_C005.dat'],
'11A': ['33', '$PSABASE/LibTrap_A006.dat'], '11B': ['34', '$PSABASE/LibTrap_B013.dat'], '11C': ['35', '$PSABASE/LibTrap_C006.dat'],
'12A': ['36', '$PSABASE/LibTrap_A002.dat'], '12B': ['37', '$PSABASE/LibTrap_B010.dat'], '12C': ['38', '$PSABASE/LibTrap_C001.dat'],
'13A': ['39', '$PSABASE/LibTrap_A007.dat'], '13B': ['40', '$PSABASE/LibTrap_B007.dat'], '13C': ['41', '$PSABASE/LibTrap_C007.dat'],
}
GeDataBase = GeDataBaseGANIL
```

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

➤ Reminder:
- ➥ Dataset from the the E680 GANIL fission experiment
- ➥ dataset and manual available on the AGATA handbook website: https://agata.pages.in2p3.fr/handbook

Hopefully, A005 was used during the E680 experiment at position 03A !

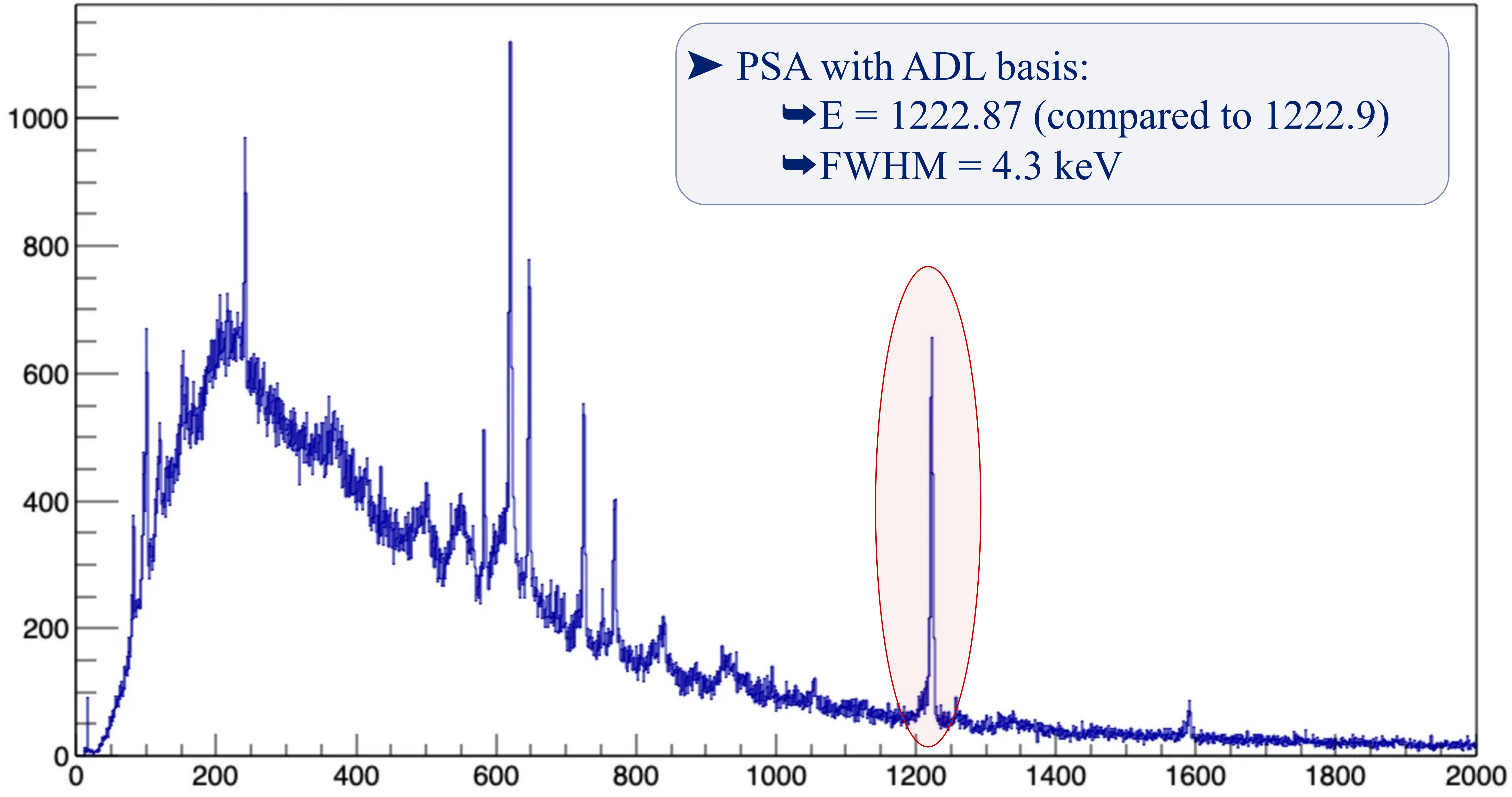
```
###############################################################################################
###################  3  Database of AGATA germanium detectors  ################################
###############################################################################################

# These values should be checked carefully against the detector configuration used to take the data
GeDataBaseGANIL={
'00A': ['00', '$PSABASE/LibTrap_A001.dat'], '00B': ['01', '$PSABASE/LibTrap_B004.dat'], '00C': ['02', '$PSABASE/LibTrap_C010.dat'],
'02A': ['06', '$PSABASE/LibTrap_A009.dat'], '02B': ['07', '$PSABASE/LibTrap_B005.dat'], '02C': ['08', '$PSABASE/LibTrap_C008.dat'],
'03A': ['09', '$PSABASE/LibTrap_A005.dat'], '03B': ['10', '$PSABASE/LibTrap_B002.dat'], '03C': ['11', '$PSABASE/LibTrap_C009.dat'],
'04A': ['12', '$PSABASE/LibTrap_A008.dat'], '04B': ['13', '$PSABASE/LibTrap_B001.dat'], '04C': ['14', '$PSABASE/LibTrap_C003.dat'],
'10A': ['30', '$PSABASE/LibTrap_A003.dat'], '10B': ['31', '$PSABASE/LibTrap_B003.dat'], '10C': ['32', '$PSABASE/LibTrap_C005.dat'],
'11A': ['33', '$PSABASE/LibTrap_A006.dat'], '11B': ['34', '$PSABASE/LibTrap_B013.dat'], '11C': ['35', '$PSABASE/LibTrap_C006.dat'],
'12A': ['36', '$PSABASE/LibTrap_A002.dat'], '12B': ['37', '$PSABASE/LibTrap_B010.dat'], '12C': ['38', '$PSABASE/LibTrap_C001.dat'],
'13A': ['39', '$PSABASE/LibTrap_A007.dat'], '13B': ['40', '$PSABASE/LibTrap_B007.dat'], '13C': ['41', '$PSABASE/LibTrap_C007.dat'],
}
GeDataBase = GeDataBaseGANIL
```

But it was having a broken segment… we can deal with it but not ideal case

```
PreprocessingFilter=(
"ActualClass          PreprocessingFilterPSA",  # name of the used daugther class
"SaveDataDir          $SAVEDIR/$CRYSTAL",       # normally Out/1R...
"EnergyGain           4",                       # channels/keV of the calibrated energy spectra
"XtalkFile            xinv_1325-1340.cal",      # cross talk correction coefficients for the energies
"WriteTraces          100" ,                    # number of traces written
{
'03A' : ("DeadSegment    12 0.9318 0.03083"),
}
)
```

Application to in-beam data: ^{98}Zr spectrum from fission data

- Reminder:
  - ➥ Dataset from the the E680 GANIL fission experiment
  - ➥ dataset and manual available on the AGATA handbook website: https://agata.pages.in2p3.fr/handbook
  - ➥ PSA characterization using the $2^+ \rightarrow 0^+$ transition at 1222.9 keV: v/c ~10%, ideal for Doppler correction evaluation.



Application to in-beam data: ^{98}Zr spectrum from fission data

- 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 Exp basis:
  - ➥E = **1222.75** (compared to 1222.9)
  - ➥FWHM = **4.03** keV

Application to in-beam data: ^{98}Zr spectrum from fission data

- PSA with ADL basis:
  - ➥E = **1222.87** (compared to 1222.9)
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  - ➥FWHM = **4.05** keV

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

To perform the neutron damage correction, a mapping of the electric-dependent sensitivity for electrons and holes is required.

This mapping needs to be included in the experimental basis.

How ? From simulations (ADL or AGATAGeFEM)

ADL format parsing from the SignalBasis class of AGAPRO

```
segPts[ii][jj].ePath = ptf[1];  // distance travelled by the electrons (
segPts[ii][jj].eS_CC = ptf[2];  // sensitivity for electrons
segPts[ii][jj].eE_CC = ptf[3];  // E-dependent sensitivity for electrons
segPts[ii][jj].hPath = ptf[5];  // distance travelled by the holes
segPts[ii][jj].hS_CC = ptf[6];  // sensitivity for holes
segPts[ii][jj].hE_CC = ptf[7];  // E-dependent sensitivity for holes
```

Application to in-beam data: ^{98}Zr spectrum from fission data

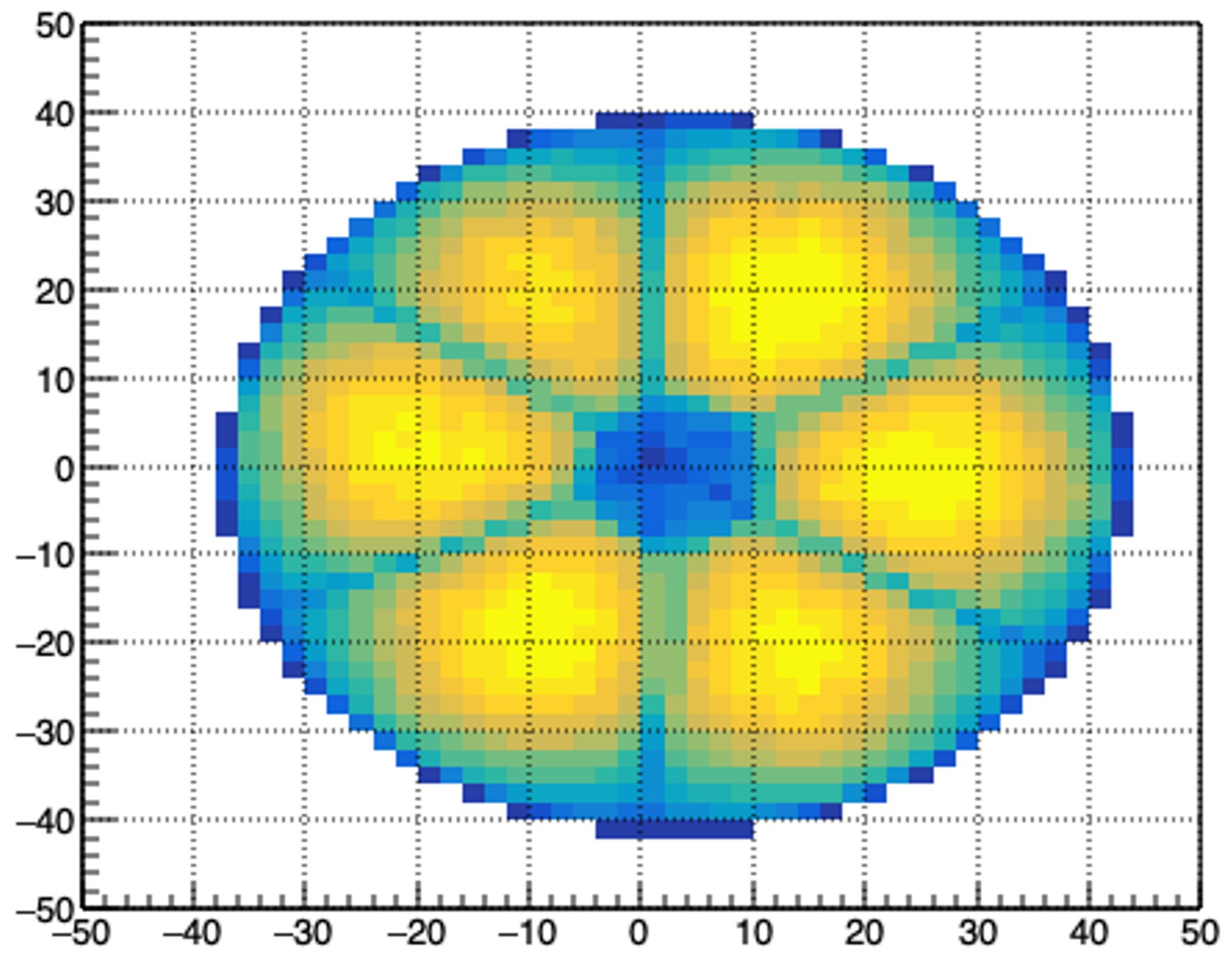
- PSA with ADL basis:
  - ➥E = **1222.87** (compared to 1222.9)
  - ➥FWHM = **4.3** keV

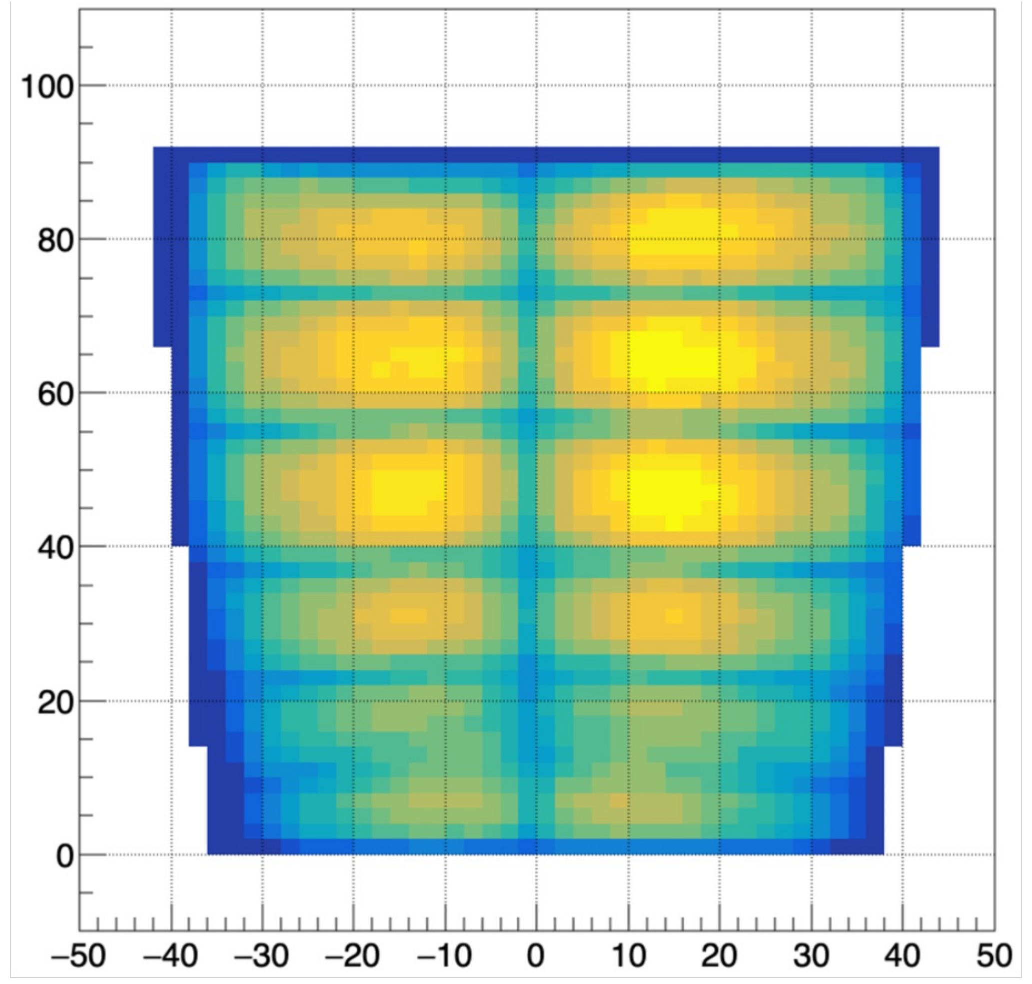
- PSA with AGATAGeFEM basis:
  - ➥E = **1222.82** (compared to 1222.9)
  - ➥FWHM = **4.05** keV

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

A005 scanning issues….

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





It appeared that the scanning issues on the first horizontal scan is not affecting the machine learning algorithm to build the experimental basis !

➥ We thus have in the end two experimental signal bases, from two different horizontal scans Exp_{old} and Exp_{new}

Application to in-beam data: ^{98}Zr spectrum from fission data

- 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

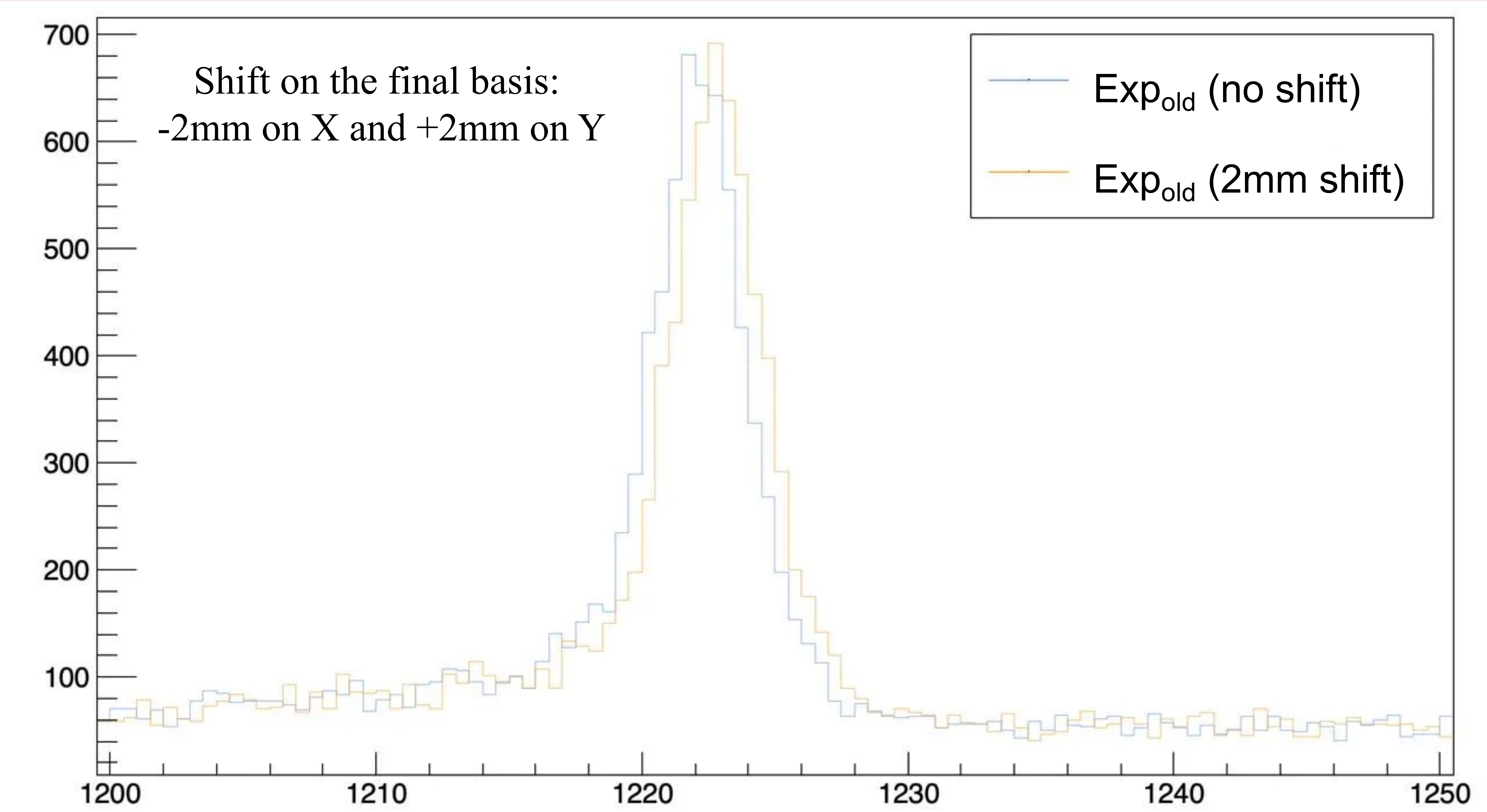
- PSA with Exp_{new} basis, copying neutron trapping parameters from ADL basis
  - ➥E = **1222.75** (compared to 1222.9)
  - ➥FWHM = **3.89** keV
- PSA with Exp_{new} basis, copying neutron trapping parameters from AGATAGeFEM basis
  - ➥E = **1222.73** (compared to 1222.9)
  - ➥FWHM = **3.92** keV

- PSA with Exp_{old} basis (old horizontal scan), copying neutron trapping 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: ^{98}Zr spectrum from fission data

- PSA with ADI
  - ➥E = 1222
  - ➥FWHM =
- PSA with AG
  - ➥E = 1222
  - ➥FWHM =
- PSA with Exp
  - ➥E = 1222
  - ➥FWHM =
- PSA with Exp
  - ➥E = 1222
  - ➥FWHM =
- PSA with Exp … basis
  - ➥E = 1222
  - ➥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: ^{98}Zr spectrum from fission data

- 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 Exp_{new} basis, copying neutron trapping parameters from AGATAGeFEM basis
  - ➥E = **1222.73** (compared to 1222.9) ⇒ E = **1222.91**
  - ➥FWHM = **3.92** keV ⇒ FWHM = **3.94** keV

- PSA with Exp_{old} basis (old horizontal scan), copying neutron trapping parameters from AGATAGeFEM basis
  - ➥E = **1222.27** (compared to 1222.9) ⇒ E = **1222.90**
  - ➥FWHM = **3.82** keV ⇒ FWHM = **3.94** keV

After optimization of bases positions, both scanned give equivalent resolution !

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

Adaptive Grid Search

- PSA with Exp_{new} basis, Adaptive Grid search
  - ➥E = **1222.9** (compared to 1222.9)
  - ➥FWHM = **3.94** keV

- PSA with Exp_{old} basis, Adaptive Grid search
  - ➥E = **1222.9** (compared to 1222.9)
  - ➥FWHM = **3.94** keV

Full Grid Search

- PSA with Exp_{new} basis, Full Grid search
  - ➥E = **1222.9** (compared to 1222.9)
  - ➥FWHM = **3.88** keV

- PSA with Exp_{old} basis, Full Grid search
  - ➥E = **1222.9** (compared to 1222.9)
  - ➥FWHM = **3.78** keV

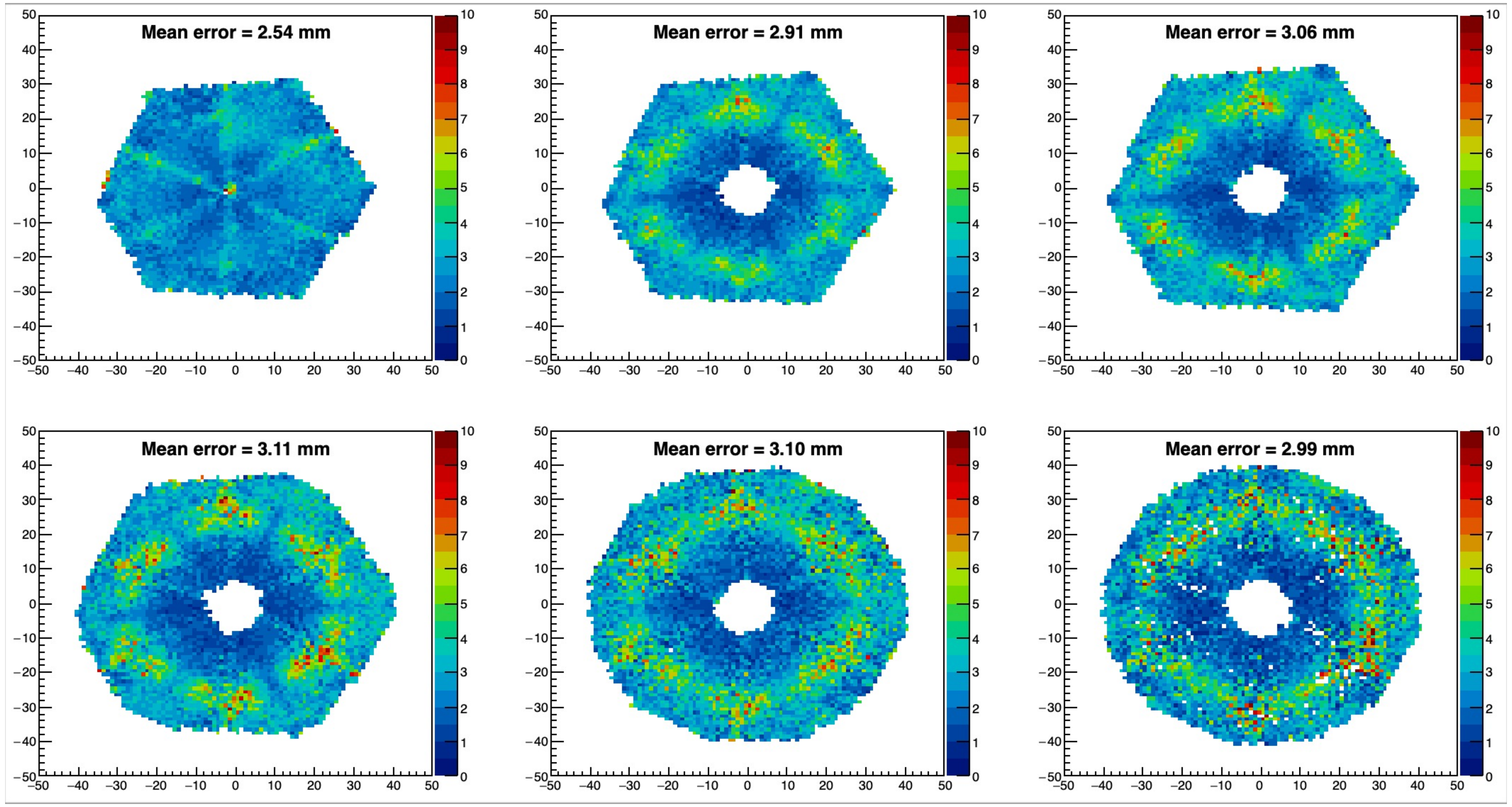
The full grid search slightly improves the resolution for PSA using the experimental basis.

➥ no clear effect observed for PSA using ADL

Application to in-beam data: PSA sensitivity

$\mathrm{Exp}_{\mathrm{old}}$ vs $\mathrm{Exp}_{\mathrm{new}}$

Arc distance error: $R \cdot |\theta_{\mathrm{new}} - \theta_{\mathrm{old}}|$



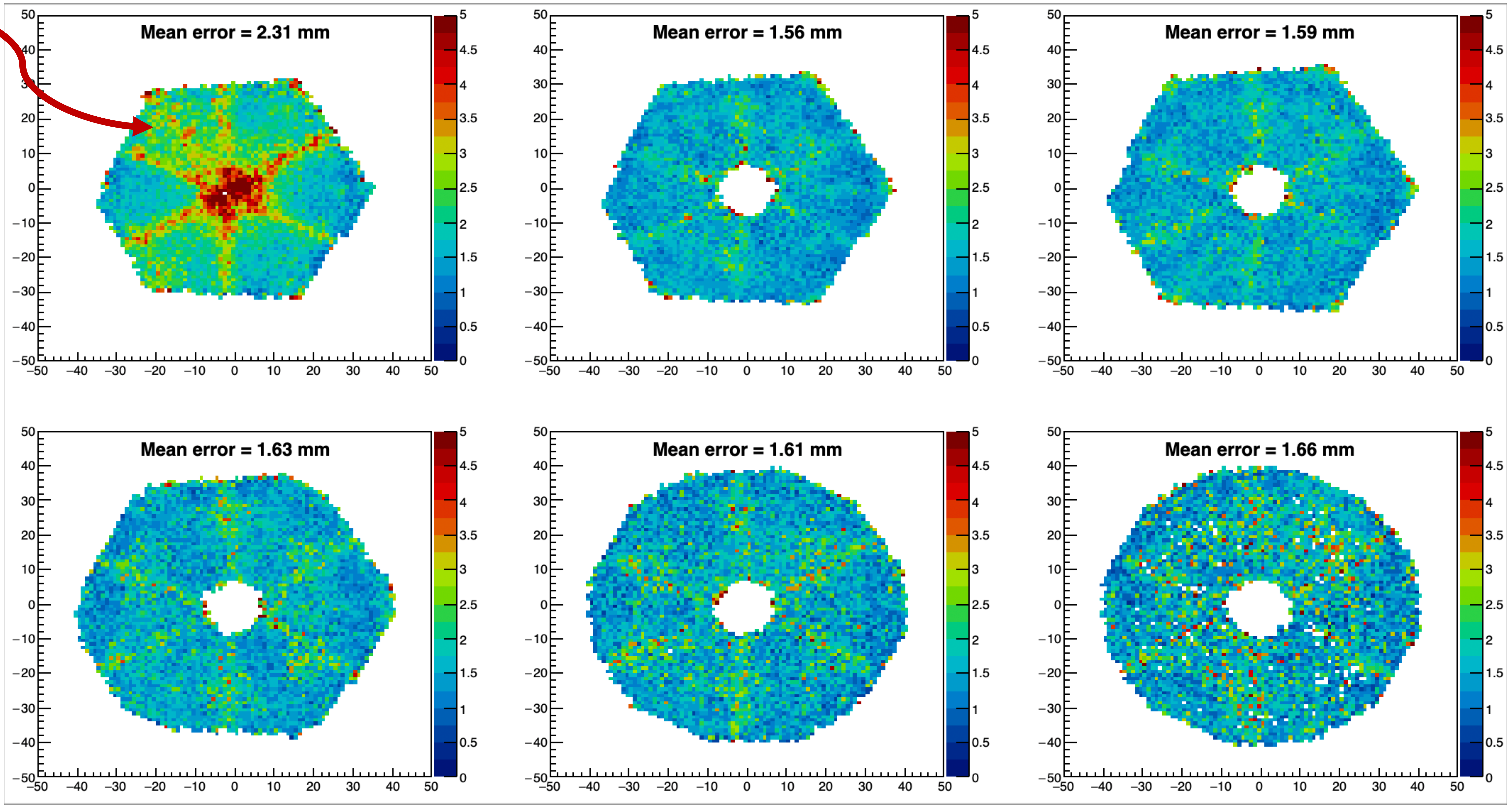
error as a function of the old scan position

Application to in-beam data: PSA sensitivity

Exp_{old} vs Exp_{new}

Error on R: $|R_{new} - R_{old}|$

Segment 12 broken



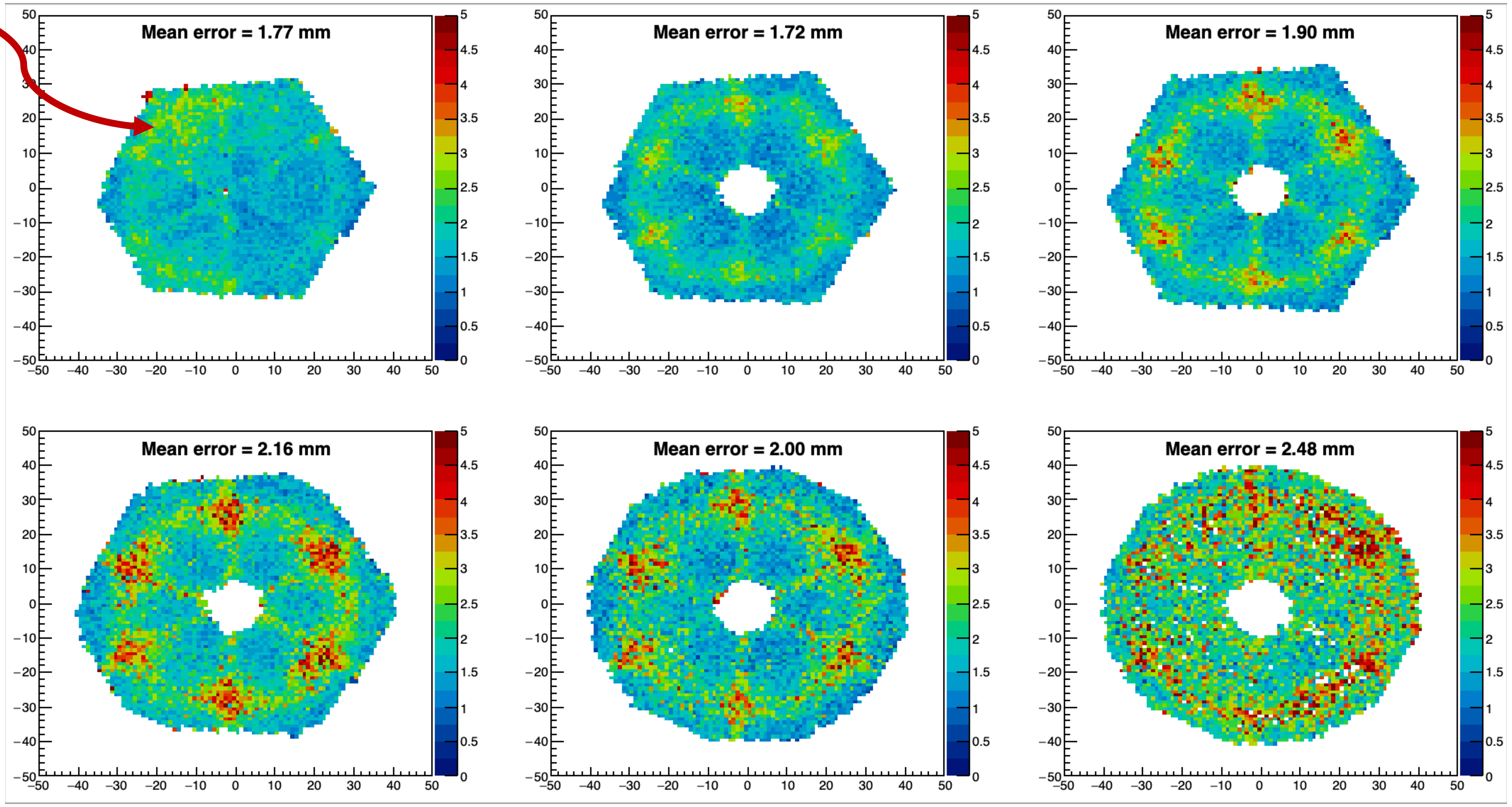
error as a function of the old scan position

Application to in-beam data: PSA sensitivity

Exp_{old} vs Exp_{new}

Error on Z: $|Z_{new} - Z_{old}|$

Segment 12 broken

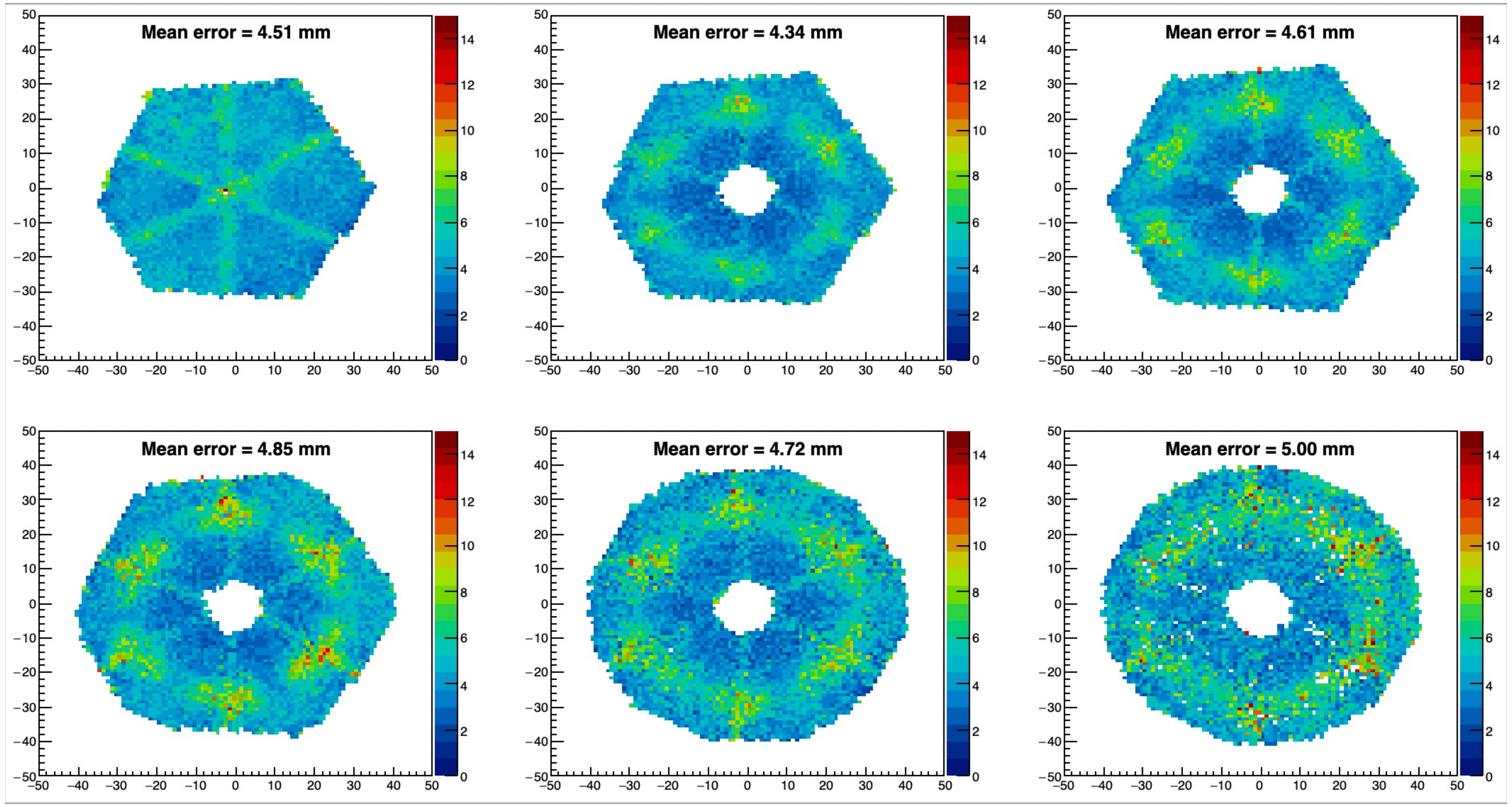


error as a function of the old scan position

Application to in-beam data: PSA sensitivity

Exp_{old} vs Exp_{new}

Error on 3D distance

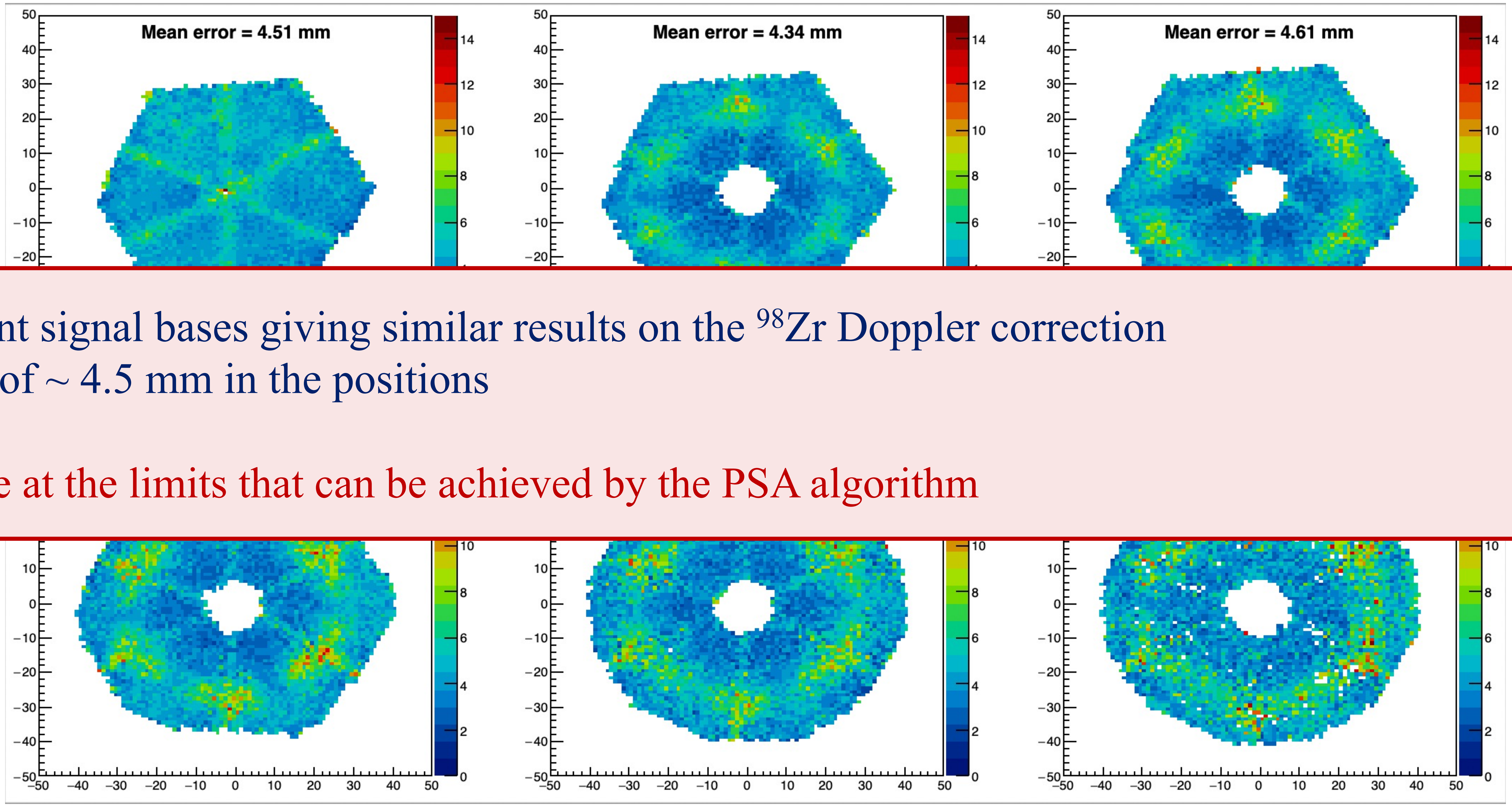


error as a function of the old scan position

Application to in-beam data: PSA sensitivity

Exp_{old} vs Exp_{new}

Error on 3D distance



- ➤ Two different signal bases giving similar results on the ^{98}Zr Doppler correction
- ➤ Mean error of ~ 4.5 mm in the positions

➥ We are at the limits that can be achieved by the PSA algorithm

error as a function of the old scan position

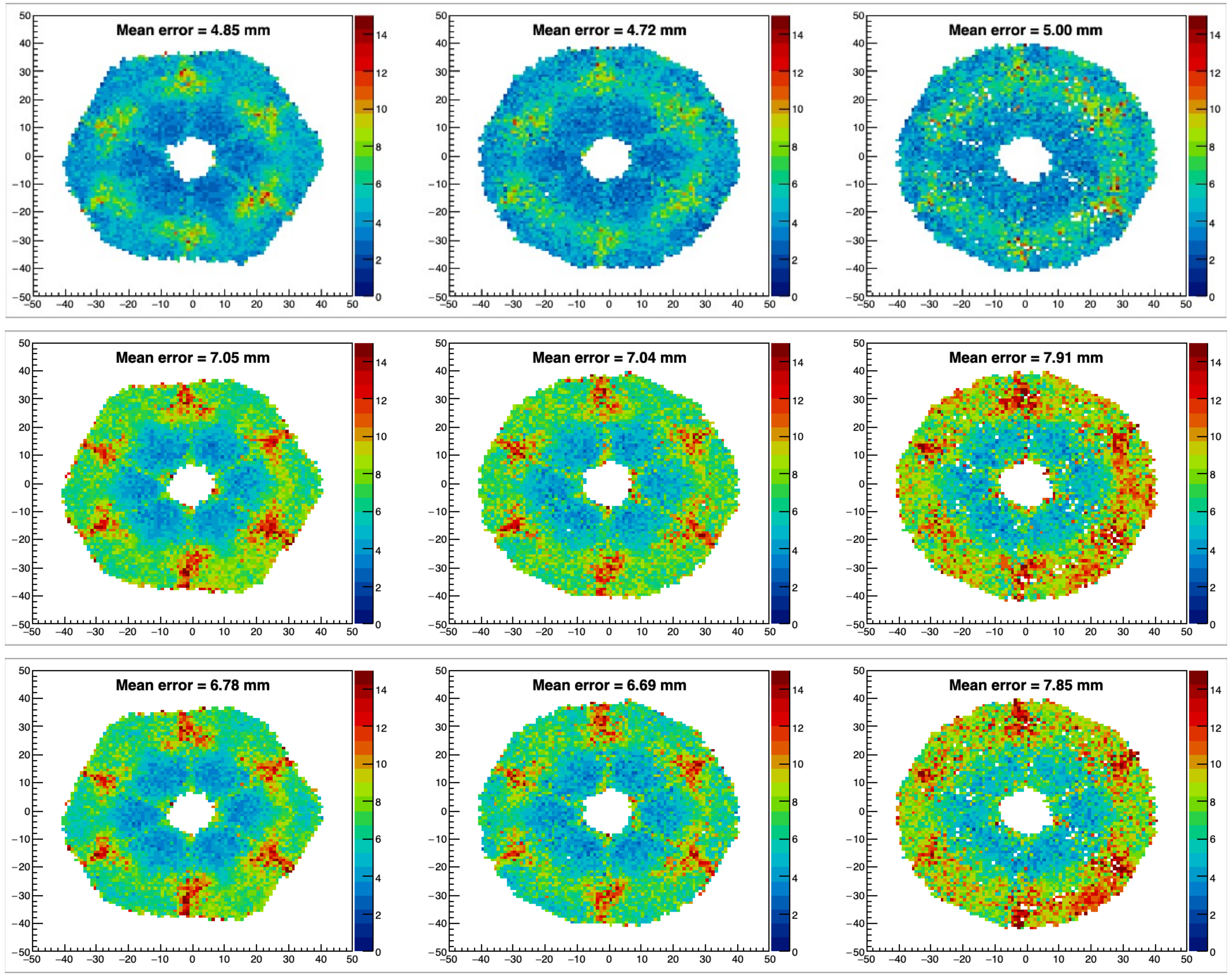
Application to in-beam data: PSA sensitivity

Comparison with simulated bases

Exp_{new} vs Exp_{old}

Exp_{new} vs ADL

Exp_{new} vs AGATAGeFEM (CC radius: 5.5mm)



Error on 3D distance as a function of the position given by the Exp_{new} basis

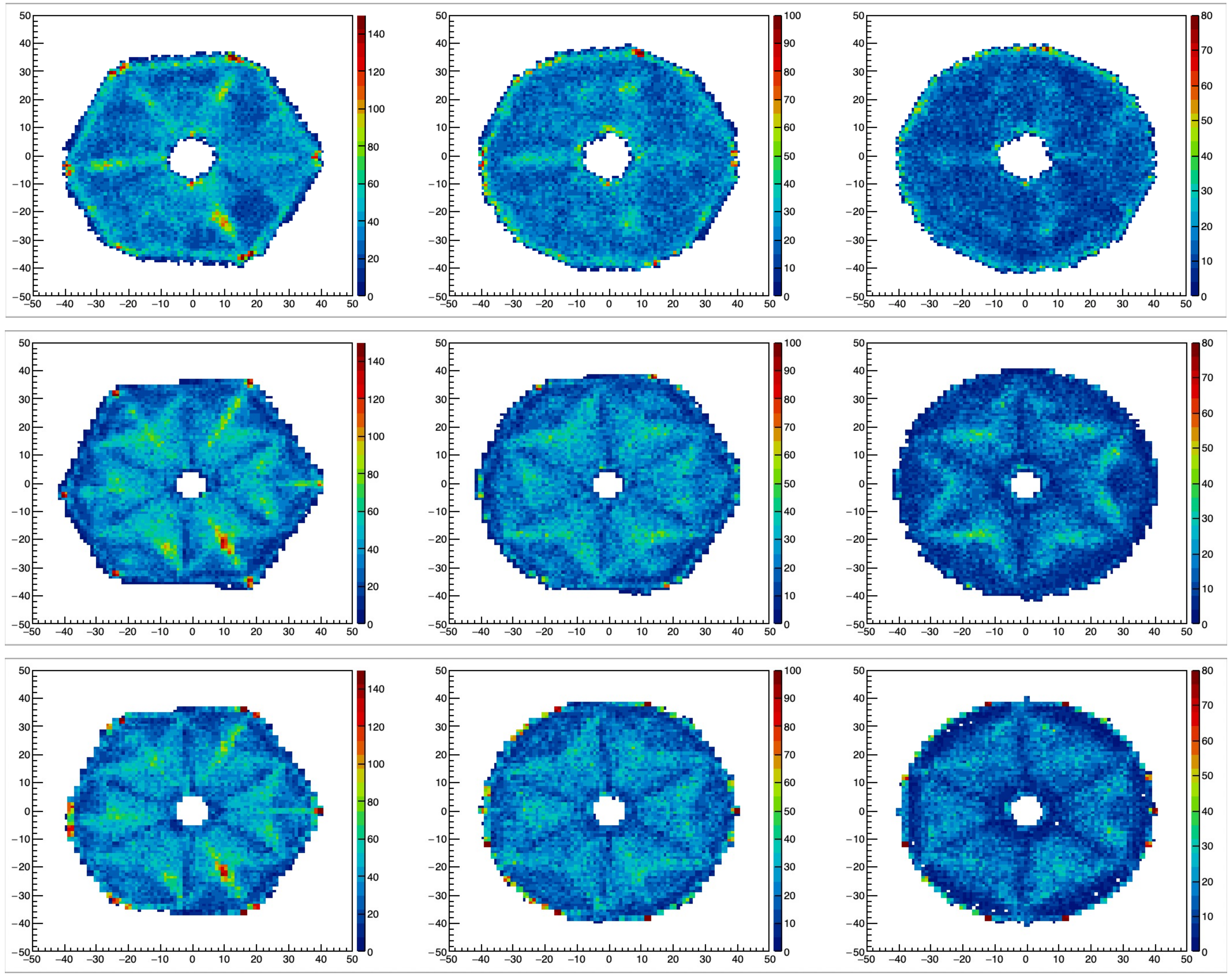
Application to in-beam data: PSA sensitivity

Comparison with simulated bases: hit patterns

Exp_{new}

ADL

AGATAGeFEM
(CC radius: 5.5mm)

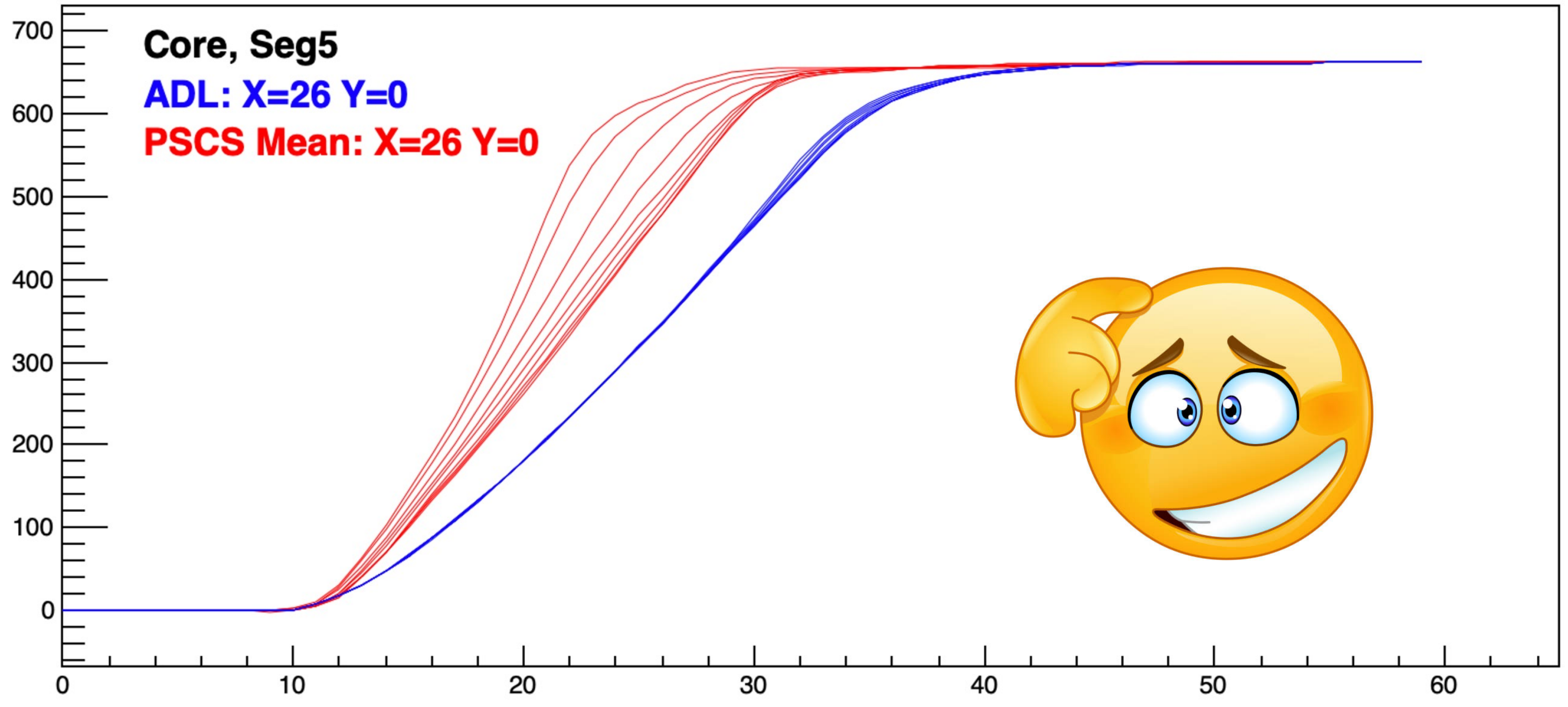


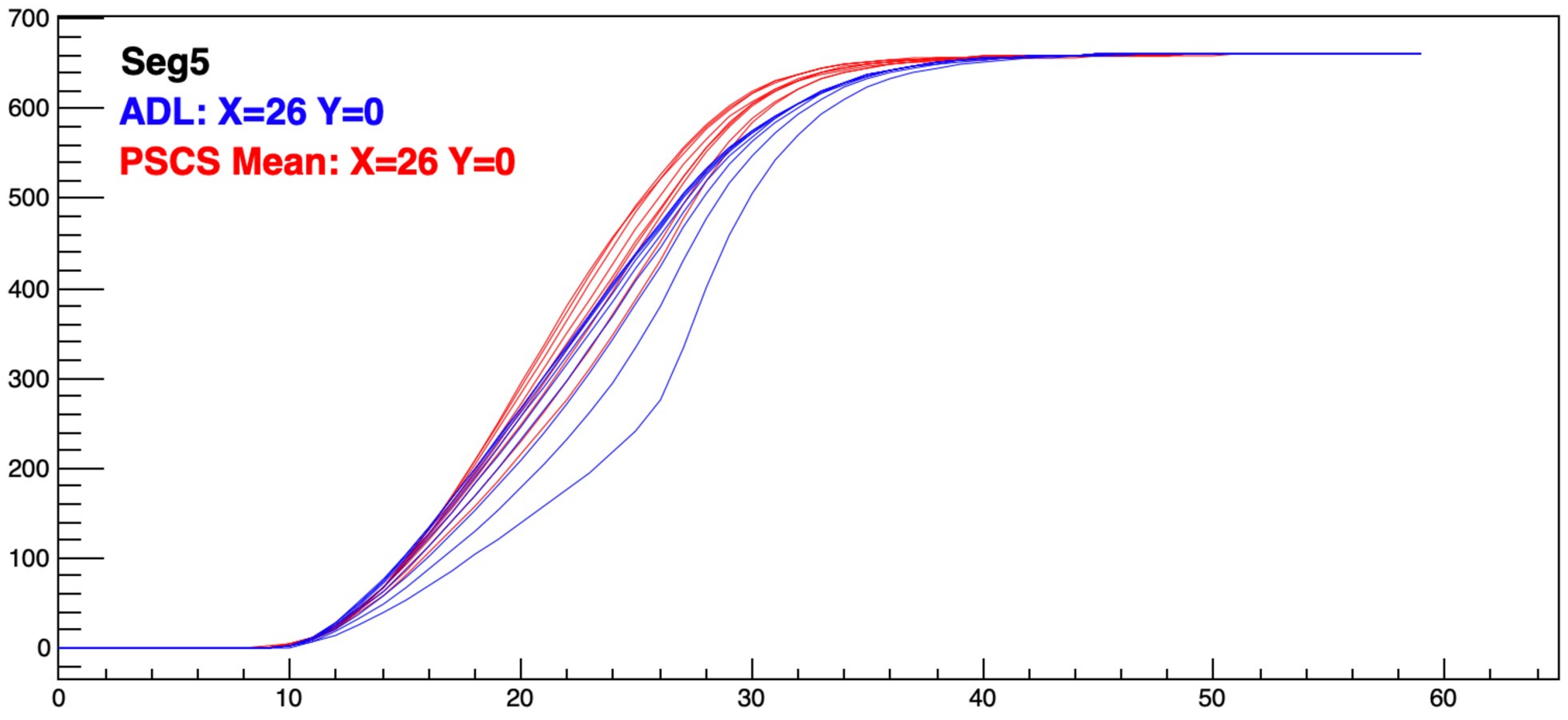
Exp:
small clustering on segments centers,
distribution fairly uniform.

Simulations:
broader clustering,
petal-like anisotropy.

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

- The core signal is too fast compared to simulations (first observed on S001 and confirmed on A005)

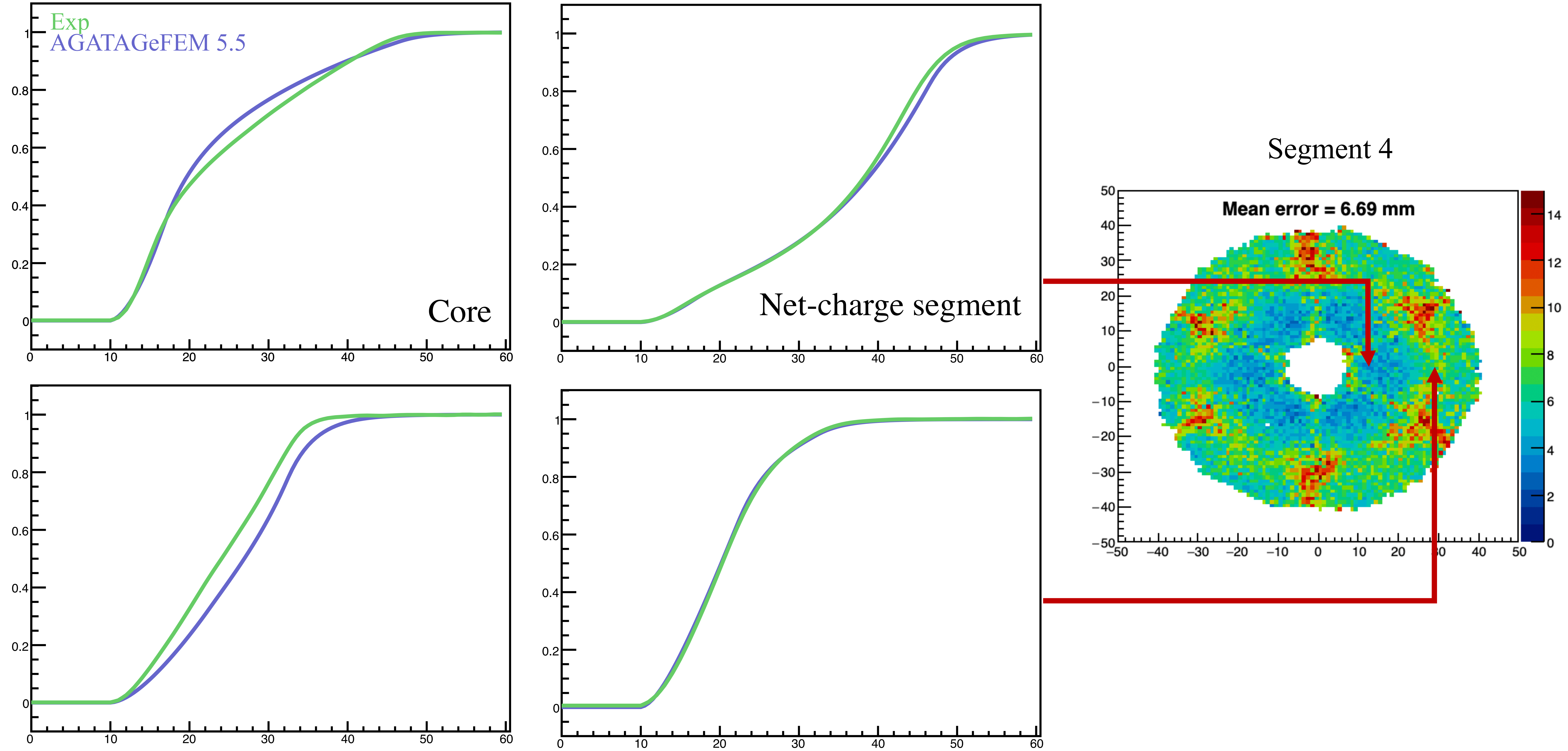




	Standard PSA	PSA excluding the core in the Chi2 estimation
➤ ADL:	➥FWHM = **4.32** keV	➥FWHM = **4.17** keV
➤ Exp:	➥FWHM = **3.78** keV	➥FWHM = **3.87** keV

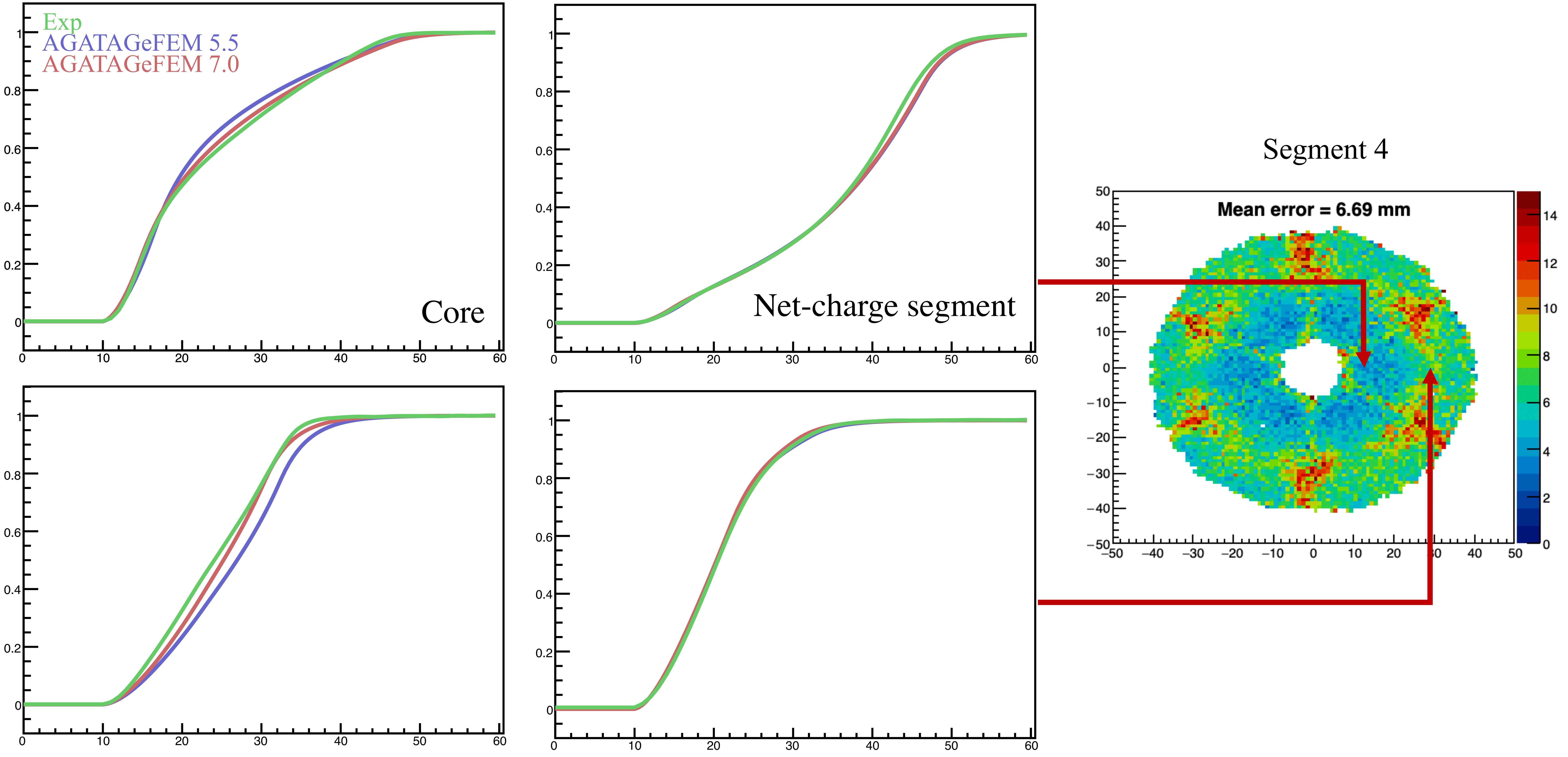
Up to now, we were thinking that this effect was a detector/electronic issue,
but it seems to be actually a simulation issue.

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



➤ For large radii, the simulated core signal are too slow, while net-charge segment in correct (same effect on ADL)

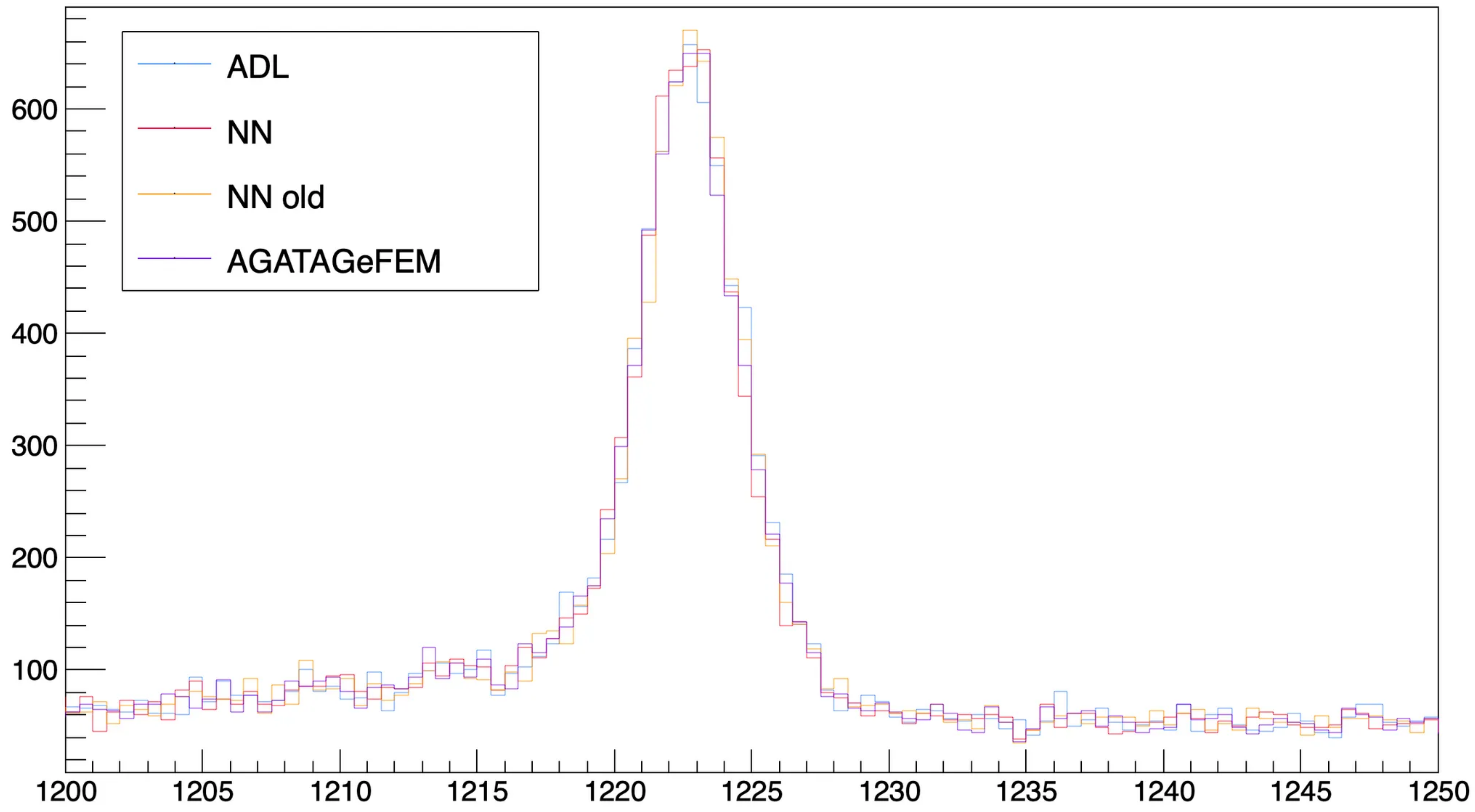
Application to in-beam data: Core signal issue in simulations



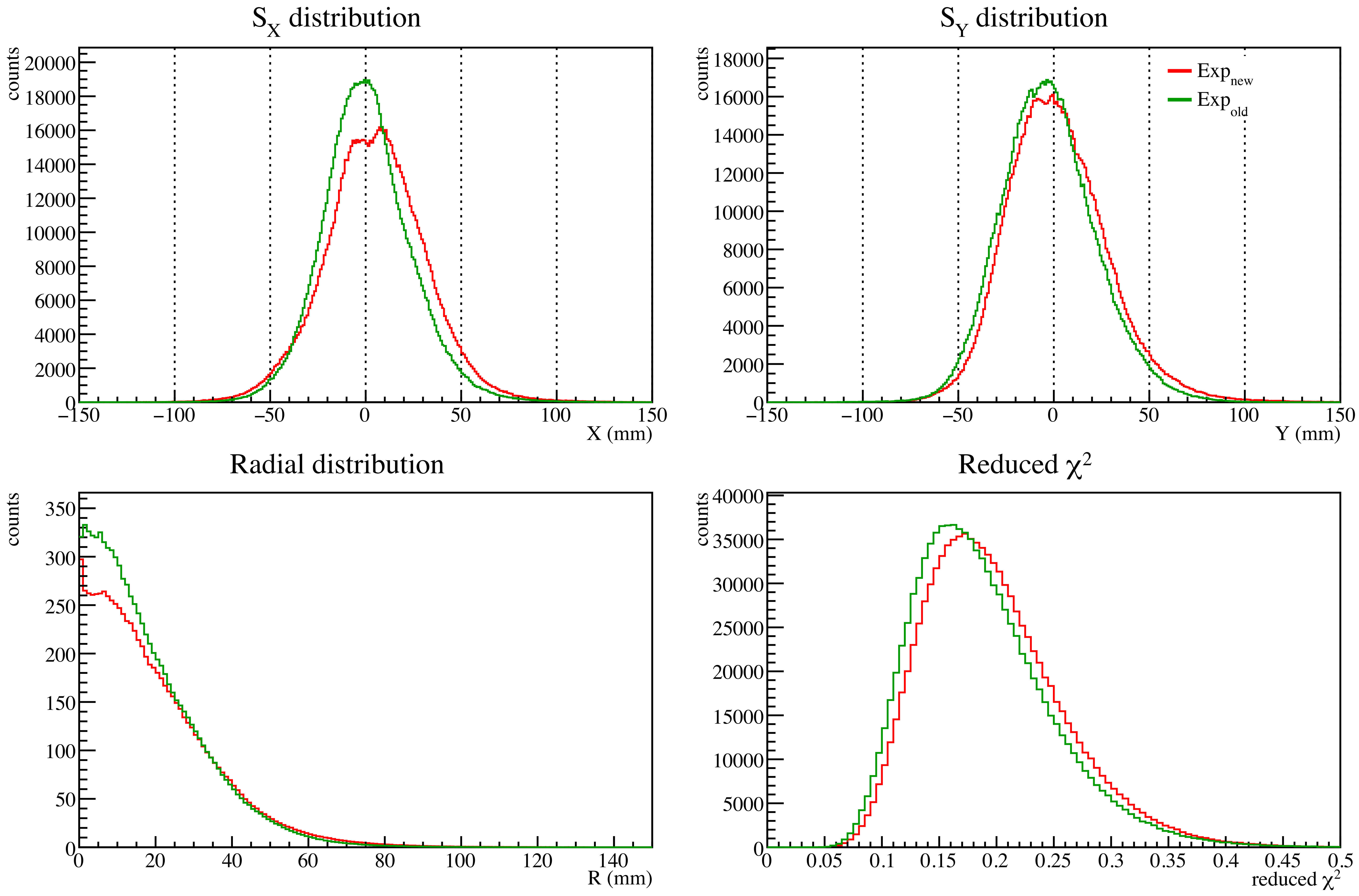
- ➤ For large radii, the simulated core signal are too slow, while net-charge segment in correct (same effect on ADL)
- ➤ Experimental signals are better reproduced using a larger CC radius

Preliminary results: characterization using in-beam imaging

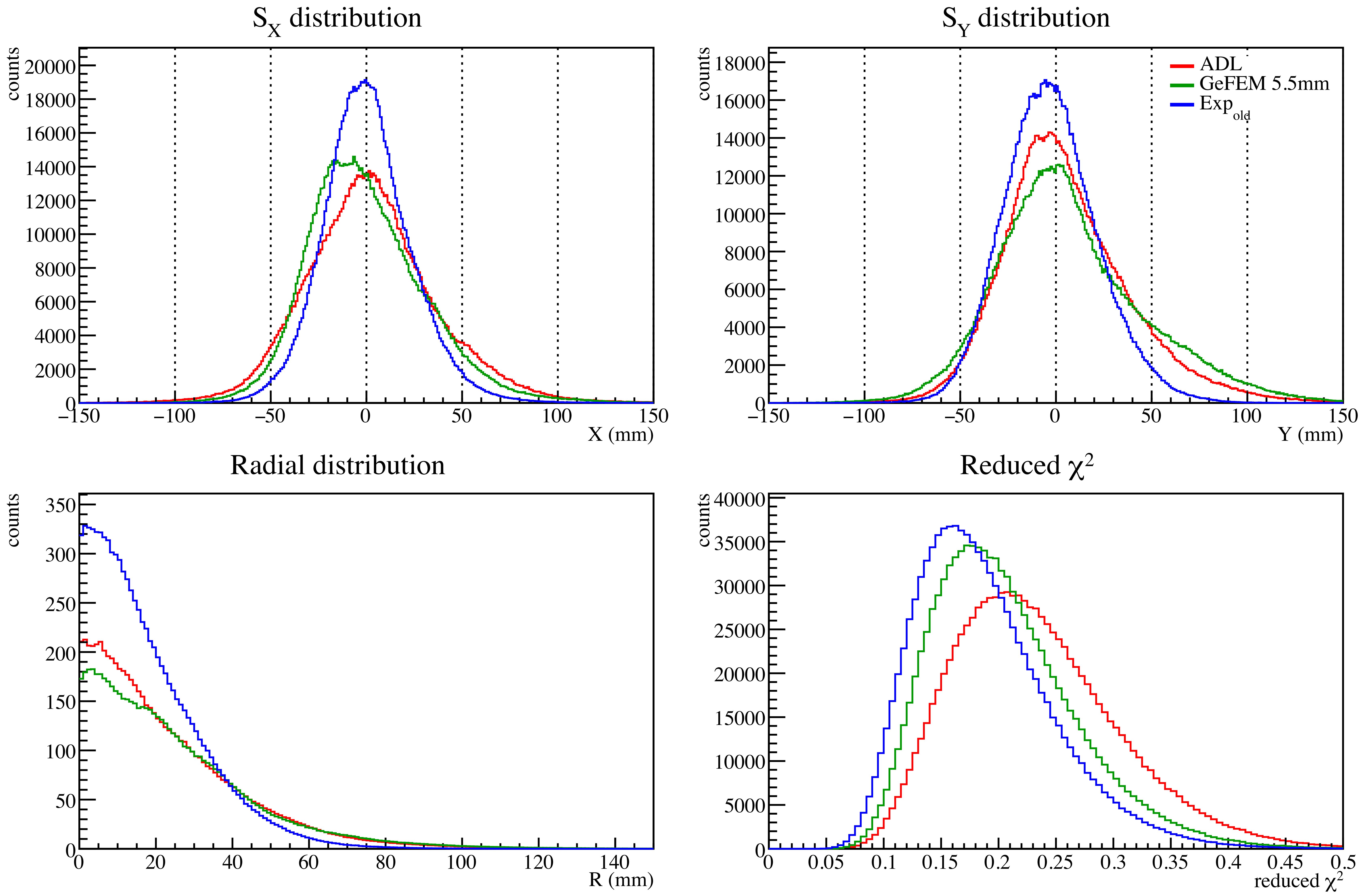
- ➤ Looking at the 1223 keV peak resolution works, but the sensitivity is small
  - ➥ we are mixing the AGATA position resolution with the VAMOS trajectory reconstruction
- ➤ Test of a new characterisation method based on in-beam source imaging



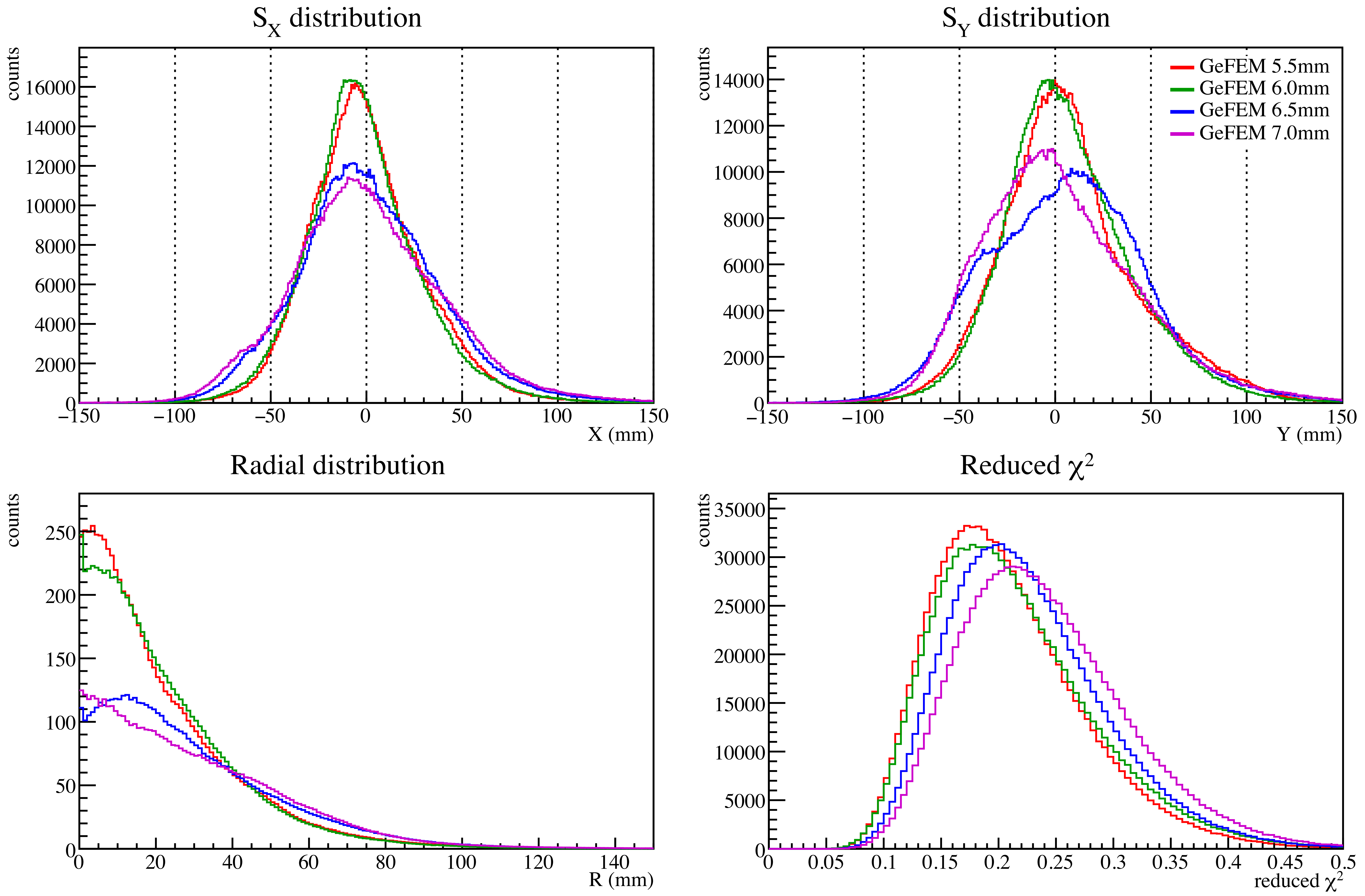
Preliminary results: characterization using in-beam imaging



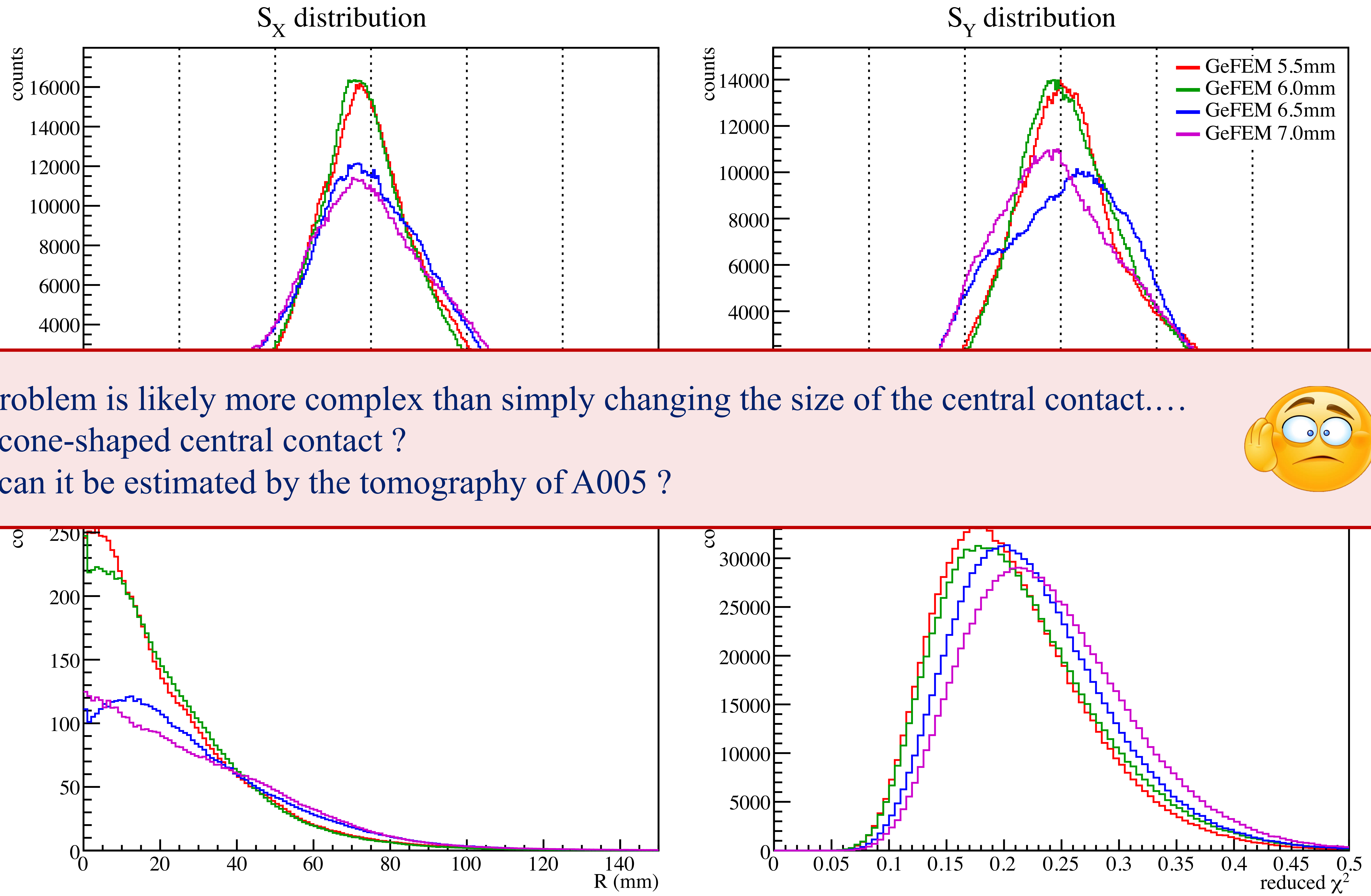
Preliminary results: characterization using in-beam imaging



Preliminary results: characterization using in-beam imaging



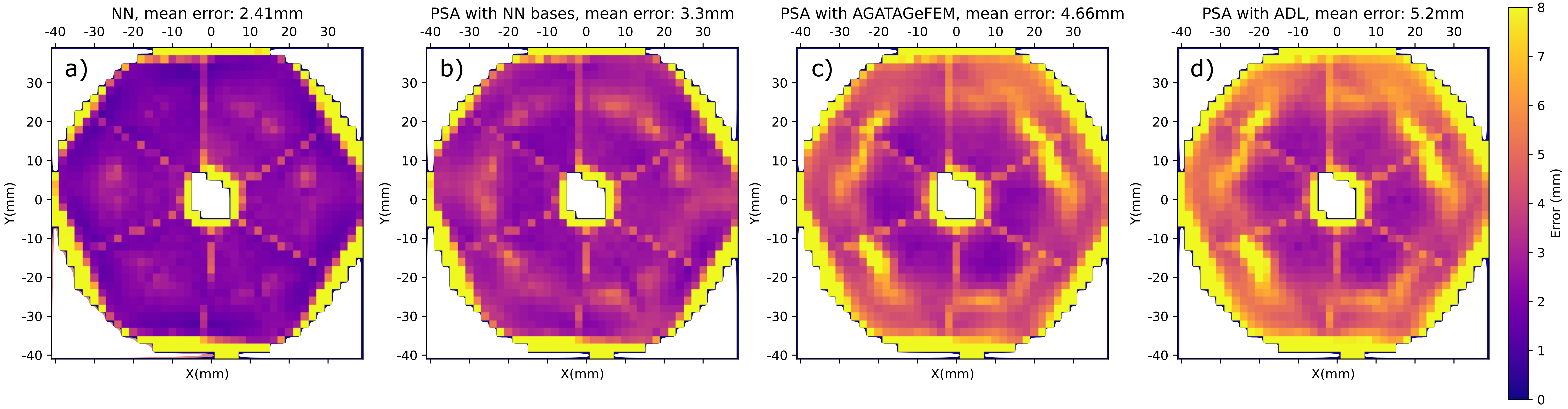
Preliminary results: characterization using in-beam imaging



- ➤ The problem is likely more complex than simply changing the size of the central contact….
  - ➡ cone-shaped central contact ?
  - ➡ can it be estimated by the tomography of A005 ?

What about a machine learning PSA algorithm ?

➤ The machine learning algorithm used to generate the experimental basis is a PSA algorithm, limited to fold 1 events.
➥ PhD thesis work of Mojahed Abushawish



Machine-learning PSA outperforms the standard PSA using the Exp basis !

➥ To be only seen as a proof of concept:

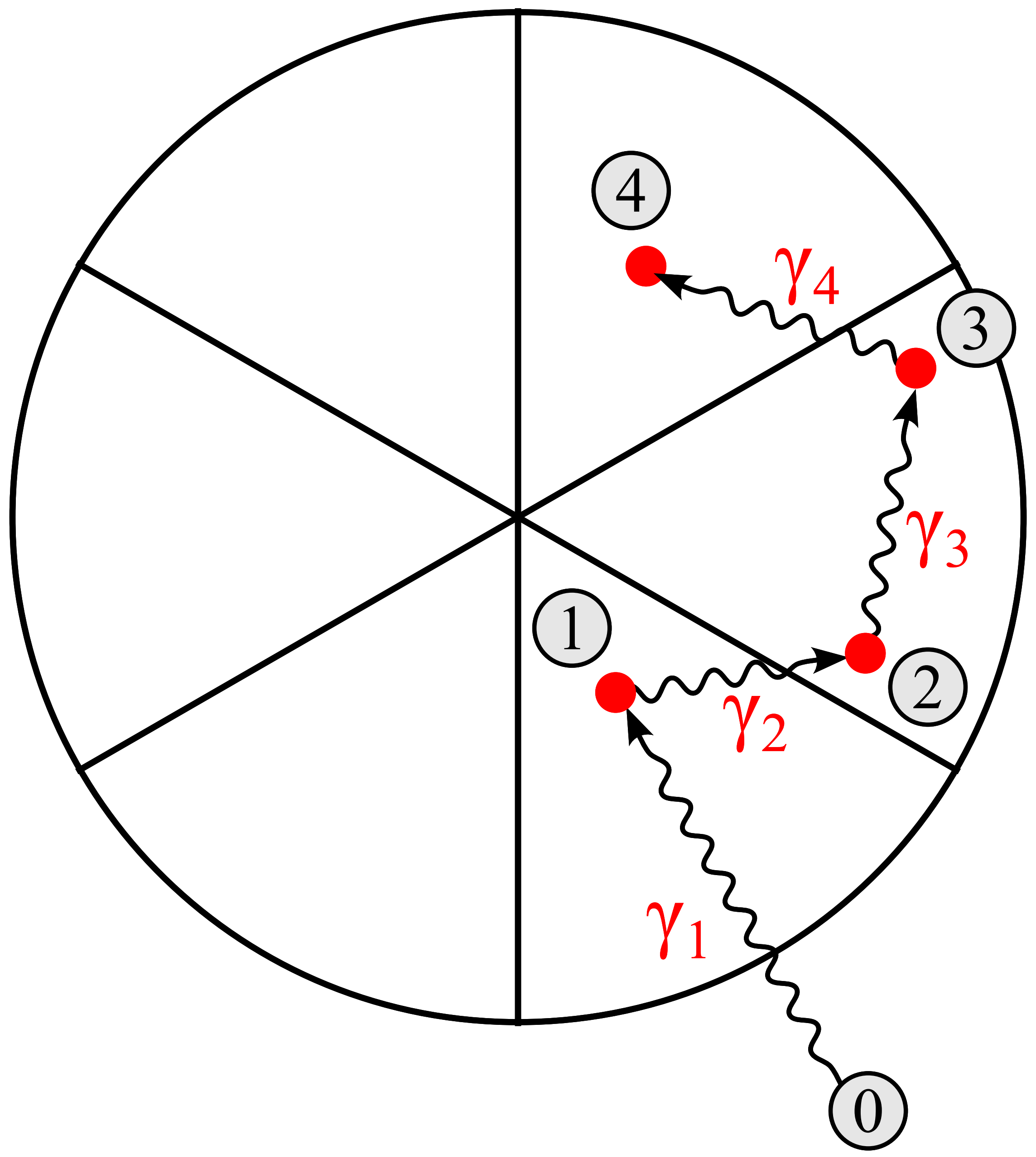
- only trained on A005 data (no generalized)
- limited to segment multiplicity one
- not compatible with the current online processing (require GPUs)

What about a machine learning to treat two interactions per segments ?

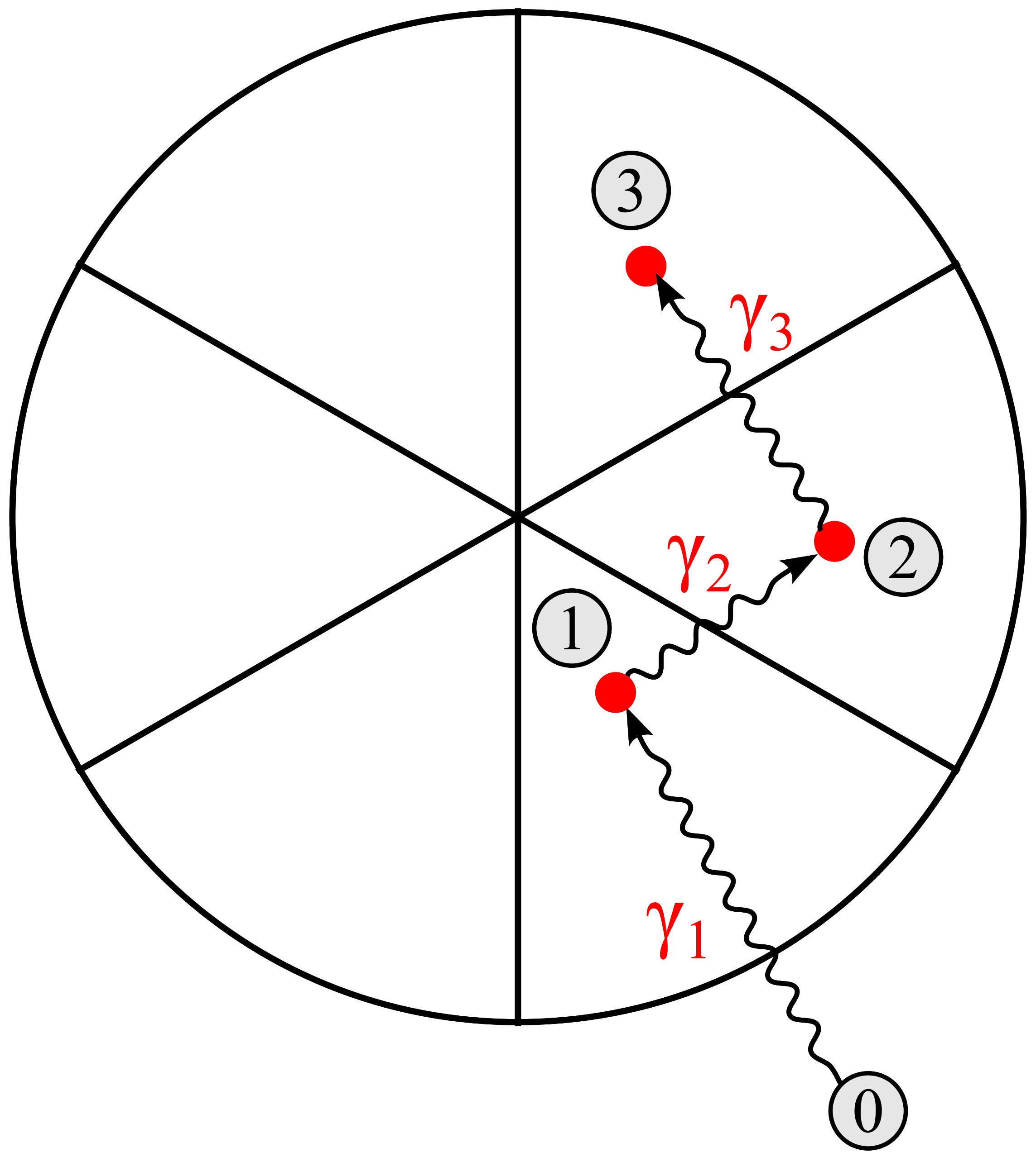
➤ **The multi hit problem:**

- ➥ a significant fraction of γ-rays undergo **multiple interactions within the same segment**
- ➥ **grid search cannot handle multi-hit** events due to the **combinatorial explosion** of possibilities
- ➥ the **current PSA treats these events as a single interaction**:
  - ➥ **Degraded position resolution**

γ-ray interactions



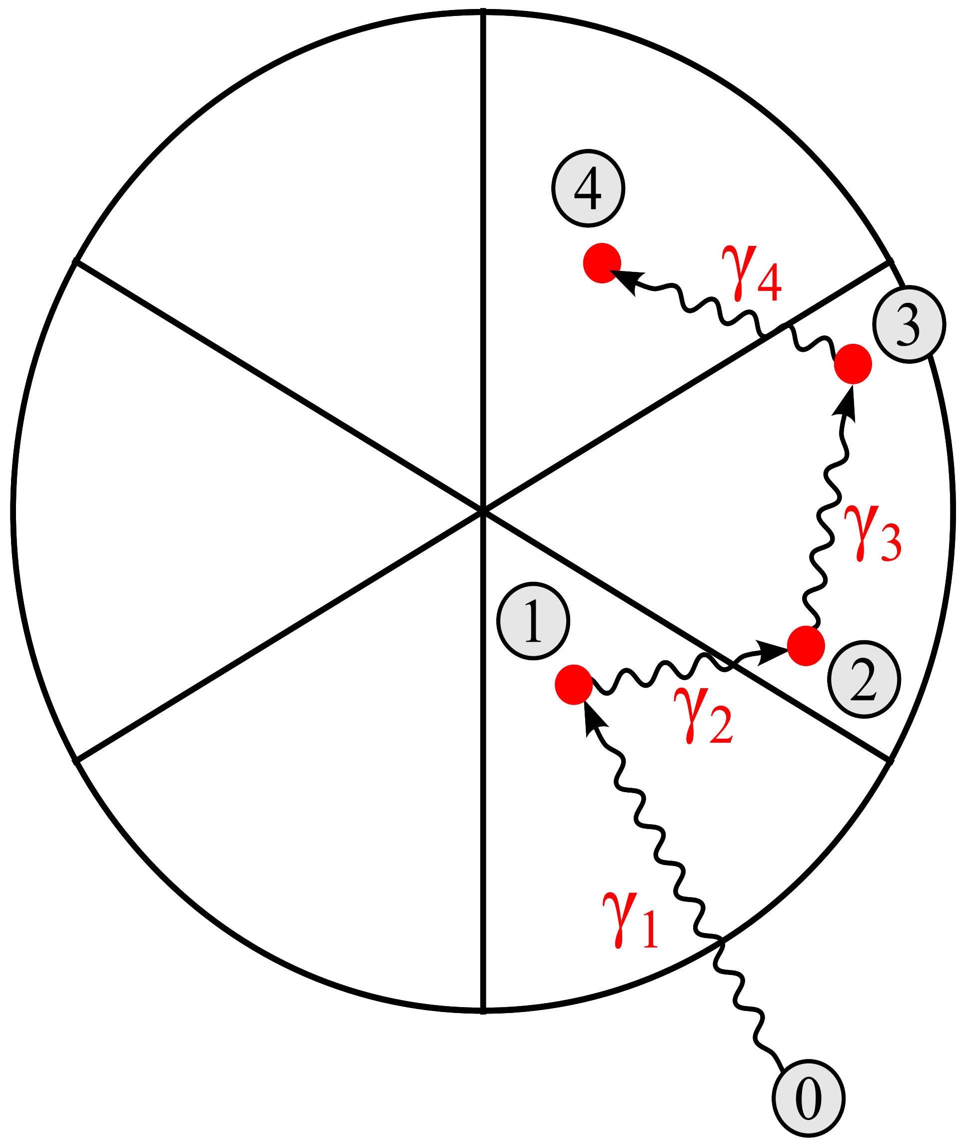
Curent PSA output



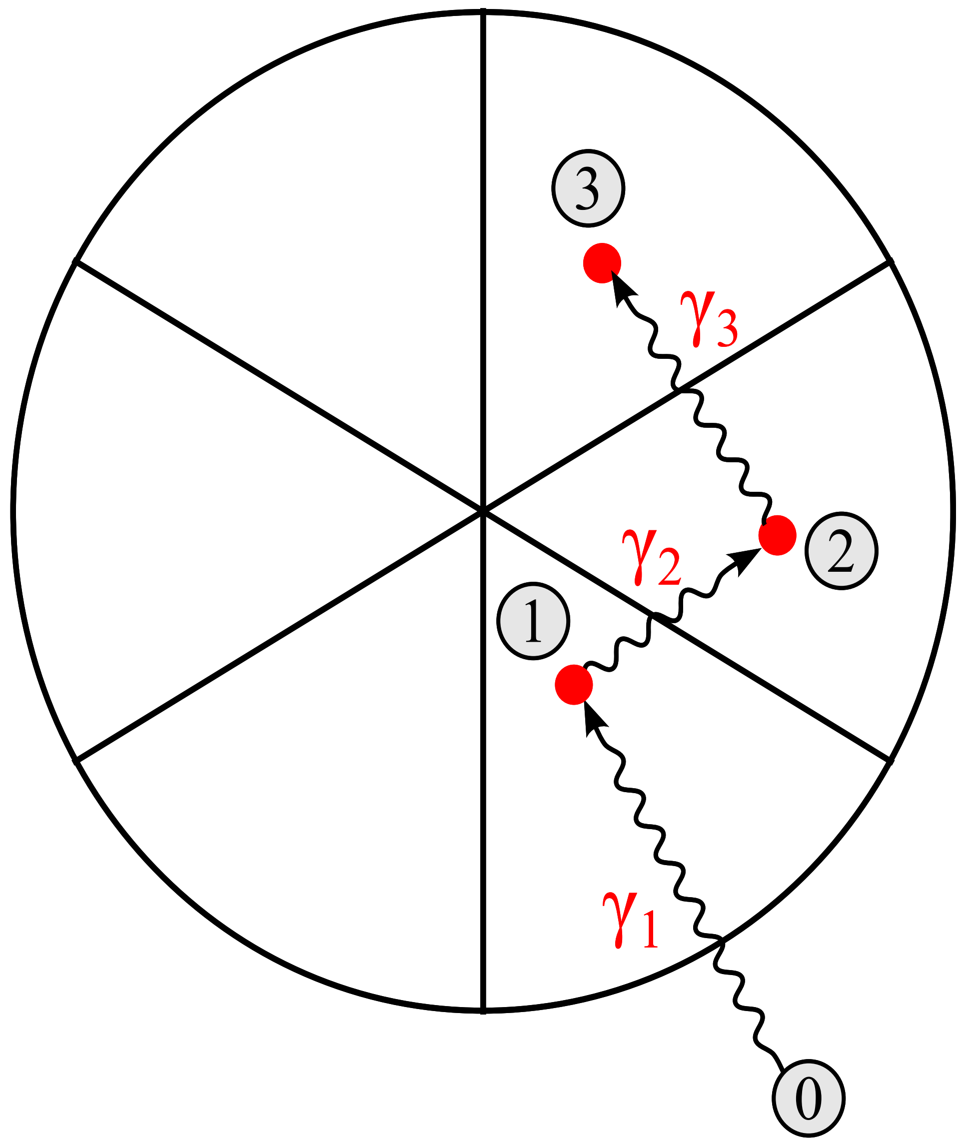
What about a machine learning to treat two interactions per segments ?

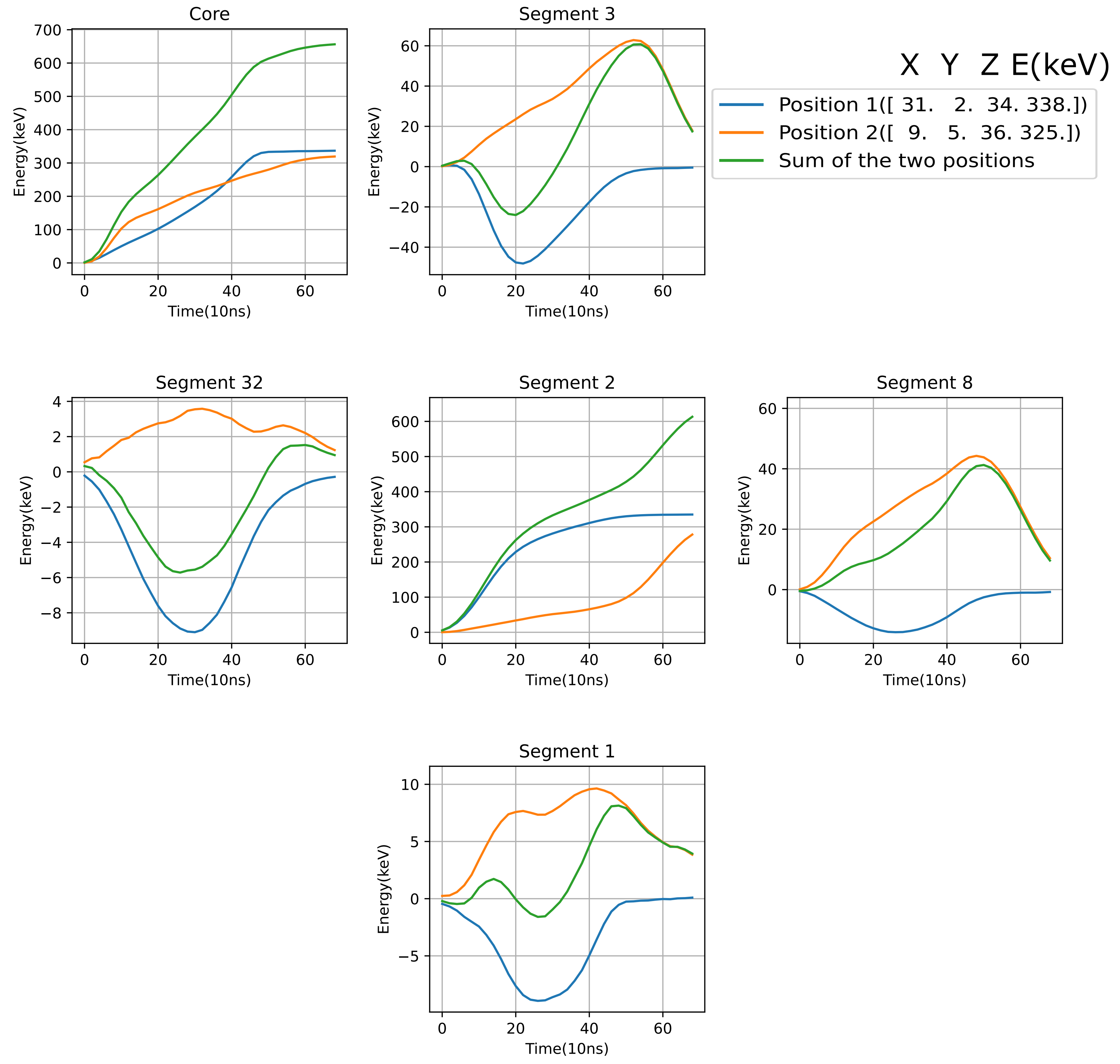
- **New ML-based approach to address the problem:**
  - ➥ A **synthetic dataset** was generated to **mimic two-interactions-per-segment events**
    - **Two signals**, from the scanned **labelled data**, from the **same segment**, are **summed** to create an **artificial two-hit event**
    - Each combined signal is associated with **two positions and energies** (X_1,Y_1,Z_1,E_1 and X_2,Y_2,Z_2,E_2)

γ-ray interactions



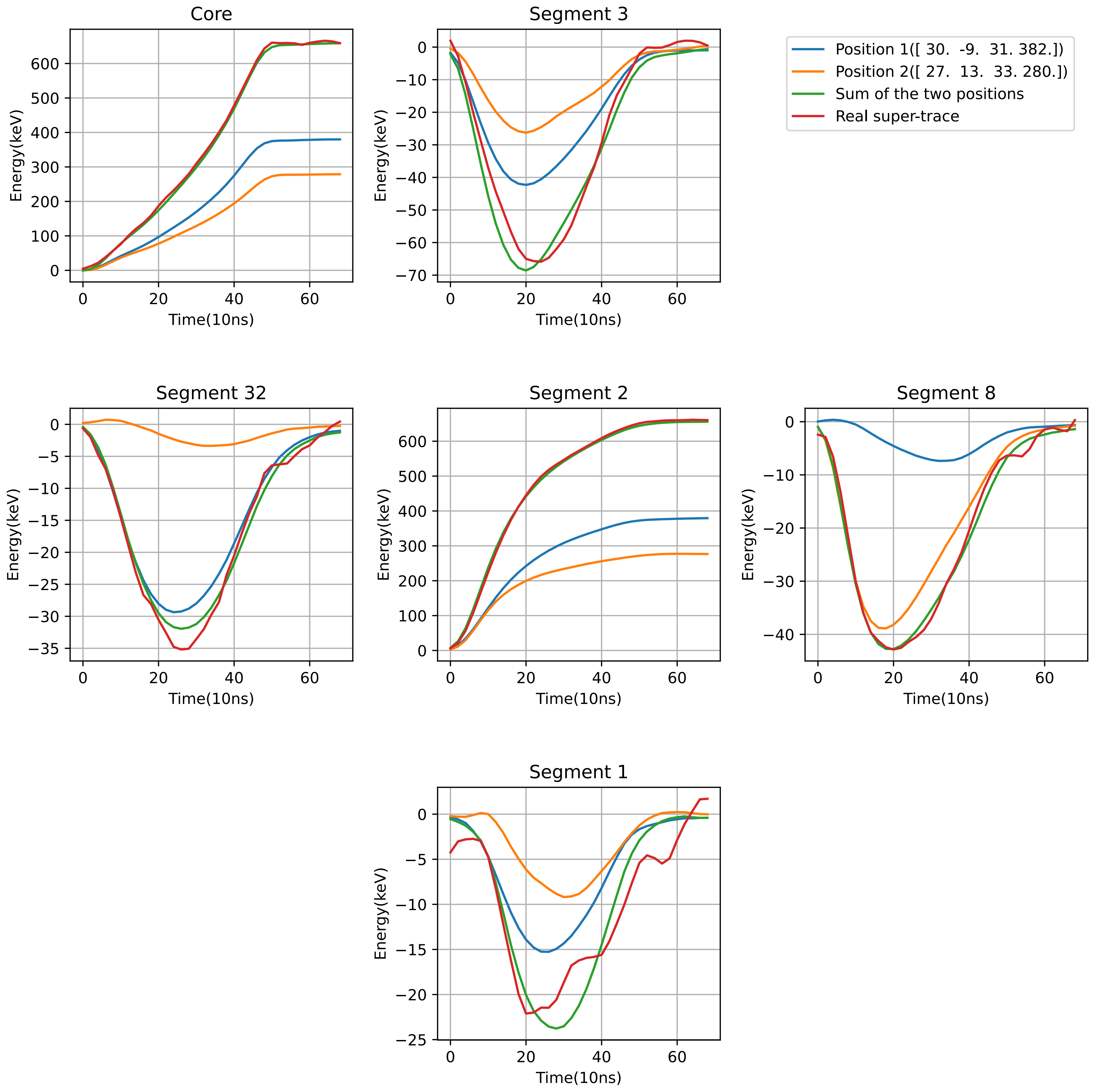
Curent PSA output

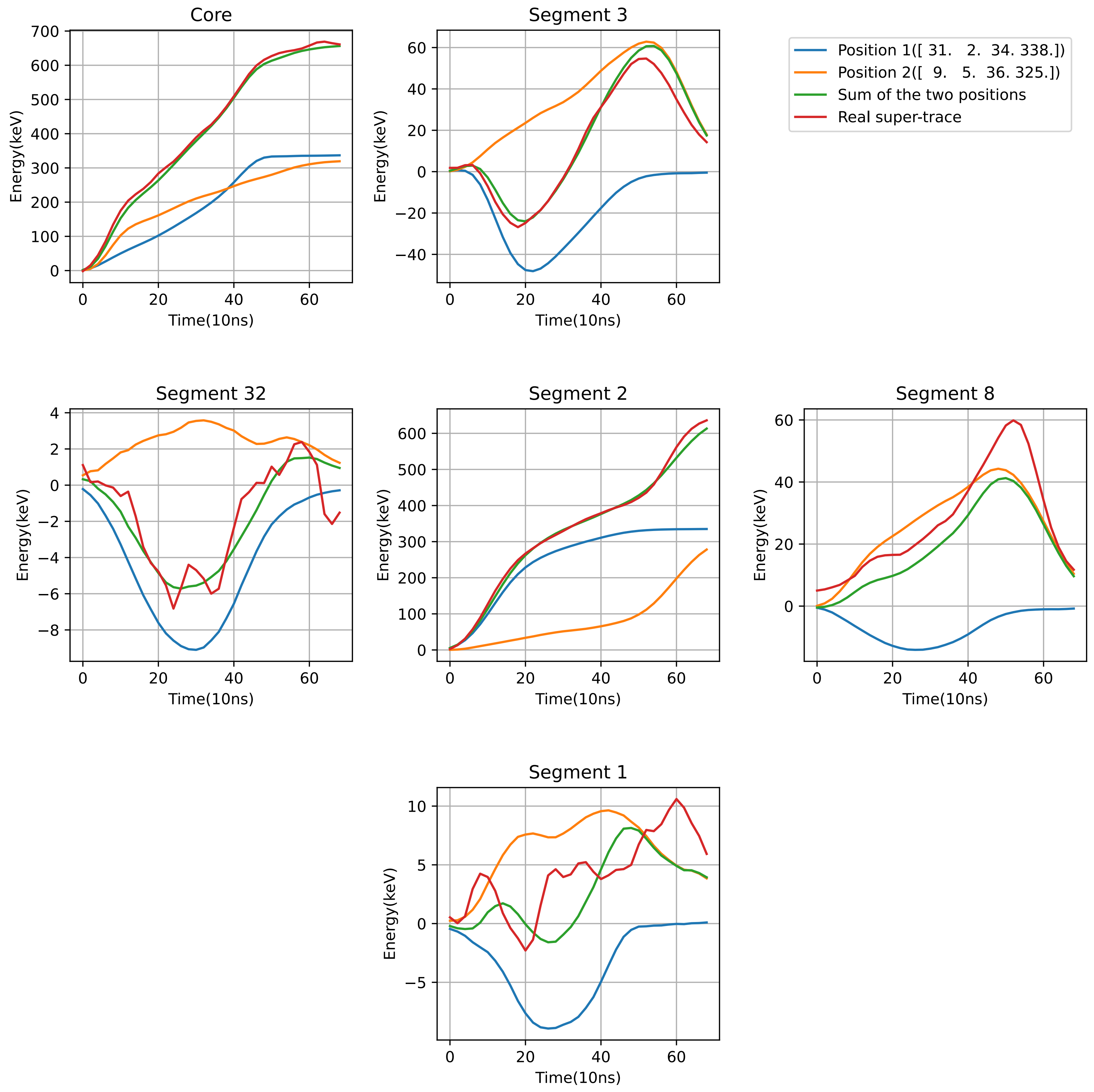




What about a machine learning to treat two interactions per segments ?

- A neural network was trained to **predict** the **position** and **deposited energy** of **each interaction**
- The model was then **applied to real data (never seen in the training)**
  - ➡ Two simulated signals were generated using the predicted positions from the two-hit NN
  - ➡ The **sum of the two simulated signals** closely **matches the actual two-hit signal**

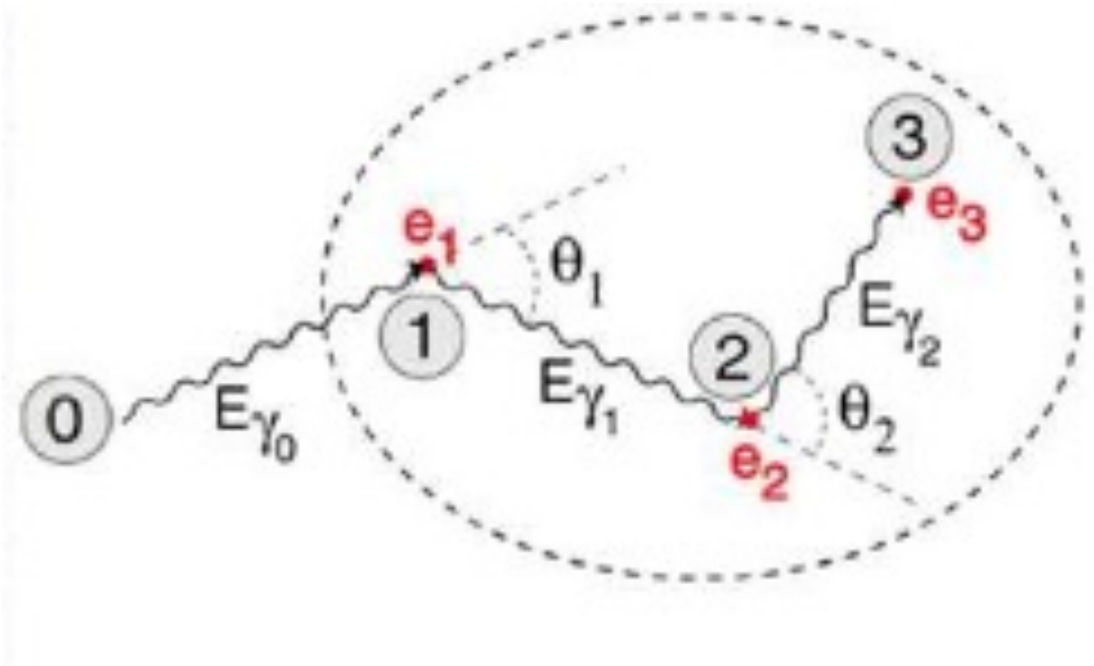


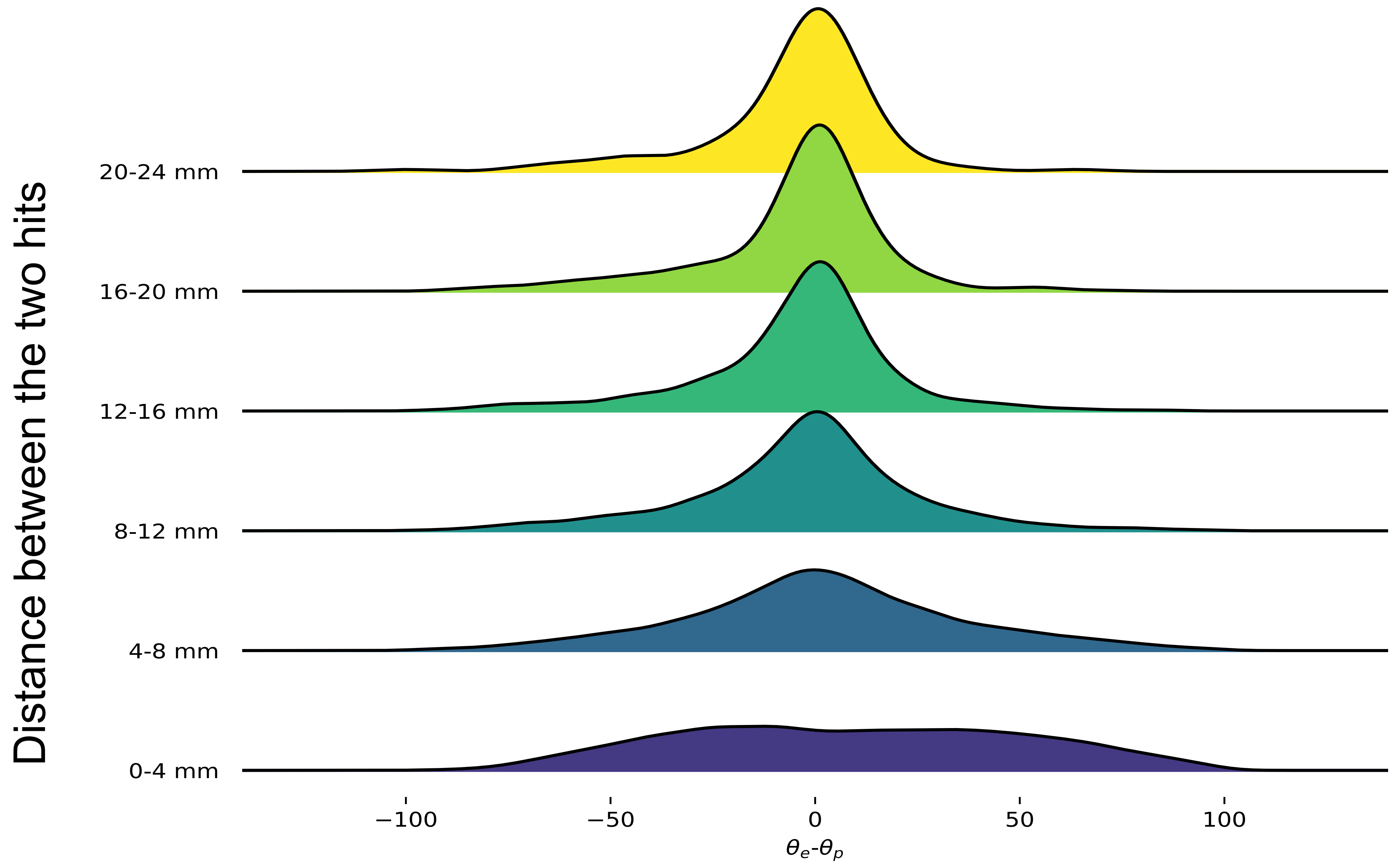


What about a machine learning to treat two interactions per segments ?

- **Experimental validation of the results**
  - ➥ The angle between interactions can be calculated:
    - using the **Compton scattering formula**, and
    - using the **reconstructed interaction positions**
- **A clear correlation is observed:**
  - ➥ **distance** between two hits **> 5 mm** → **two real interactions**
  - ➥ **distance** between two hits **< 5 mm** → much likely a **single hit**

$$\cos\theta = 1 + m_e c^2 \left(\frac{1}{E_\gamma - E_1} - \frac{1}{E_\gamma} \right)$$





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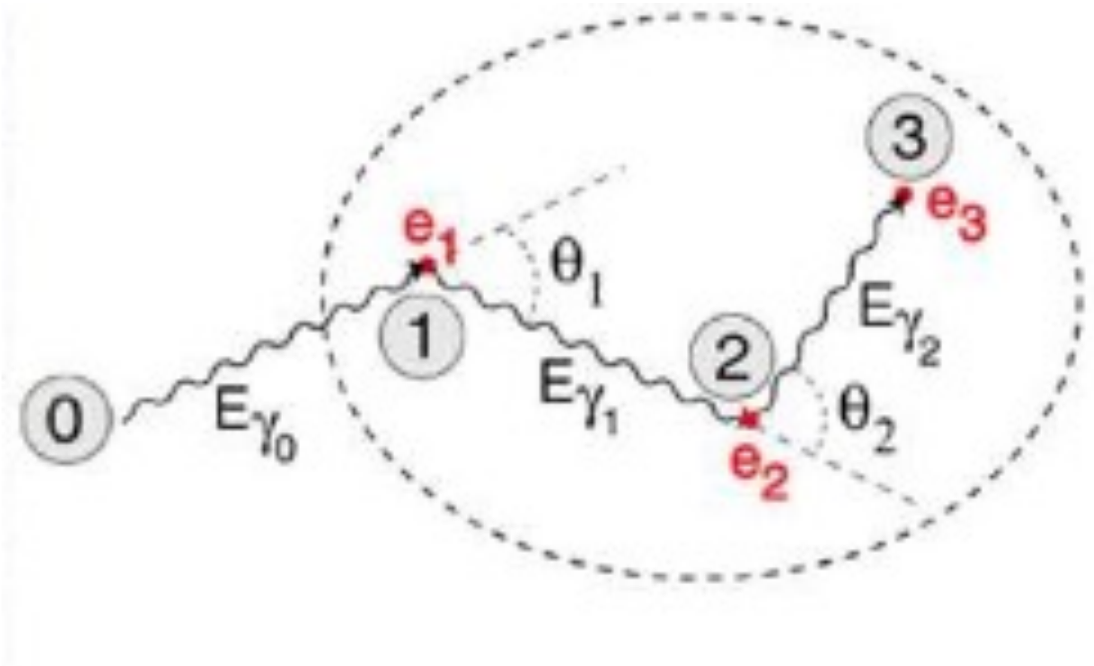

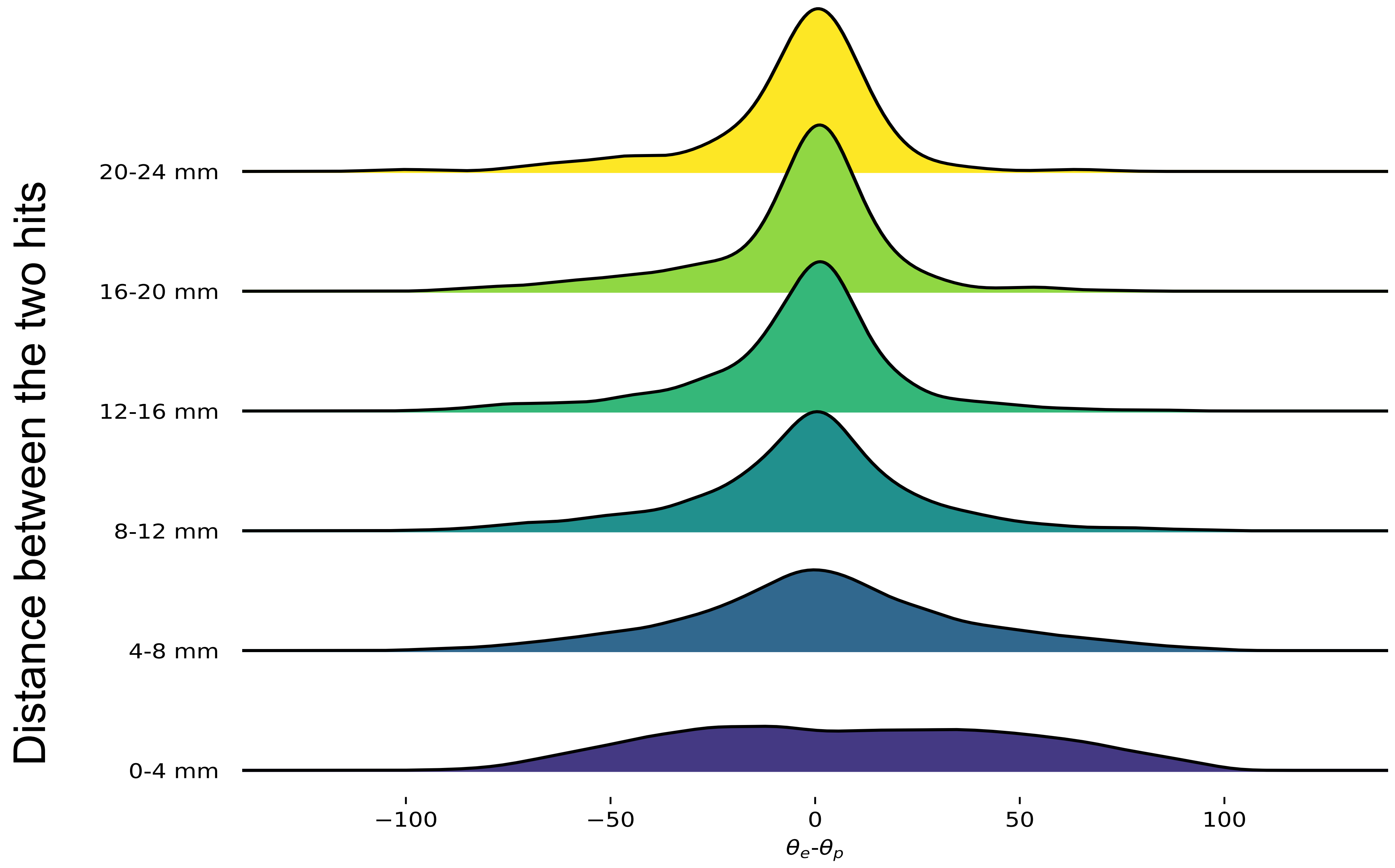

A similar approach to treat multiple hits per crystal has been also successfully tested !

Conclusions and perspectives

Conclusions

- **Standard PSA characterization:**
  - ➥ The experimental basis shows excellent results on in beam data from the 2015 GANIL campaign !
  - ➥ This work pointed out an issue on the core signal rise time in the simulated databases
  - ➥ Developments are ongoing on AGATAGeFEM to try to understand this effect
- **Machine learning PSA developments:**
  - ➥ The ML-based algorithm used to generate the experimental basis outperforms the standard PSA
  - ➥ The labelled data obtained from the scan allows for training a two-interaction per segment PSA

Perspectives

- **Standard PSA characterization:**
  - ➥ Investigate how the A005 experimental basis performs on other A-type crystals
  - ➥ Push forward the current work with B and C-types crystals (B003 soon available, and was used in the GANIL data)
- **New forces in the IP2I group:**
  - ➥ Arrival of Luca Zago in November for a two years post-doc.

Merci !