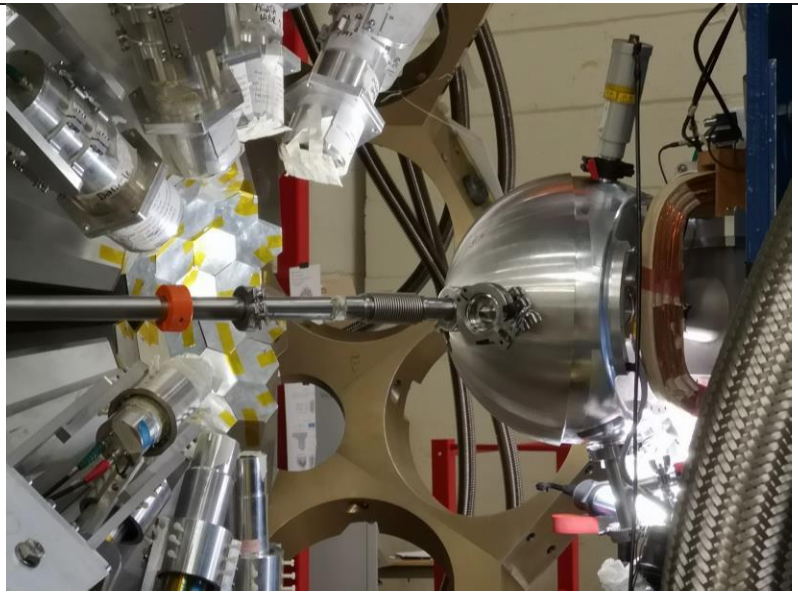
# Report on AGATA EXP_013 (22.85):

# Octupole collectivity in neutron-deficient plutonium isotopes



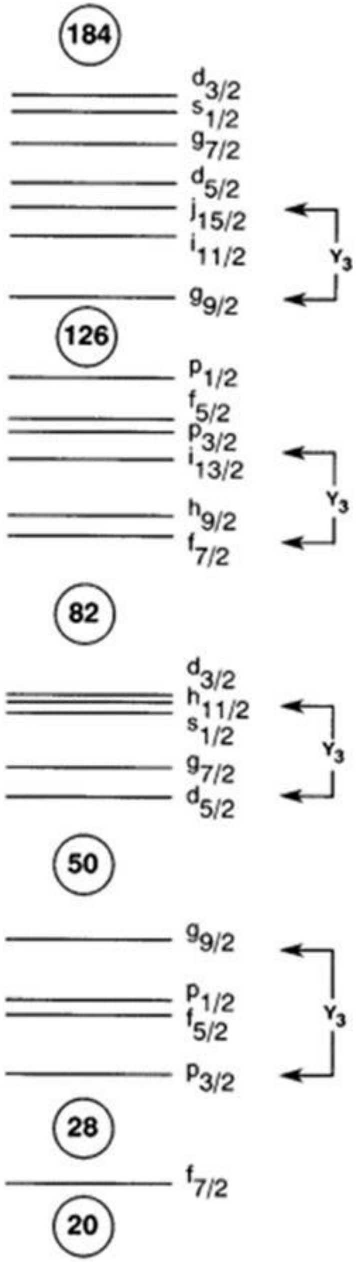
Hamid Ayatollahzadeh

24th AGATA Week, ACC Meeting

Università Degli Studi di Milano

09.09.24 – 13.09.24

# Octupole deformation



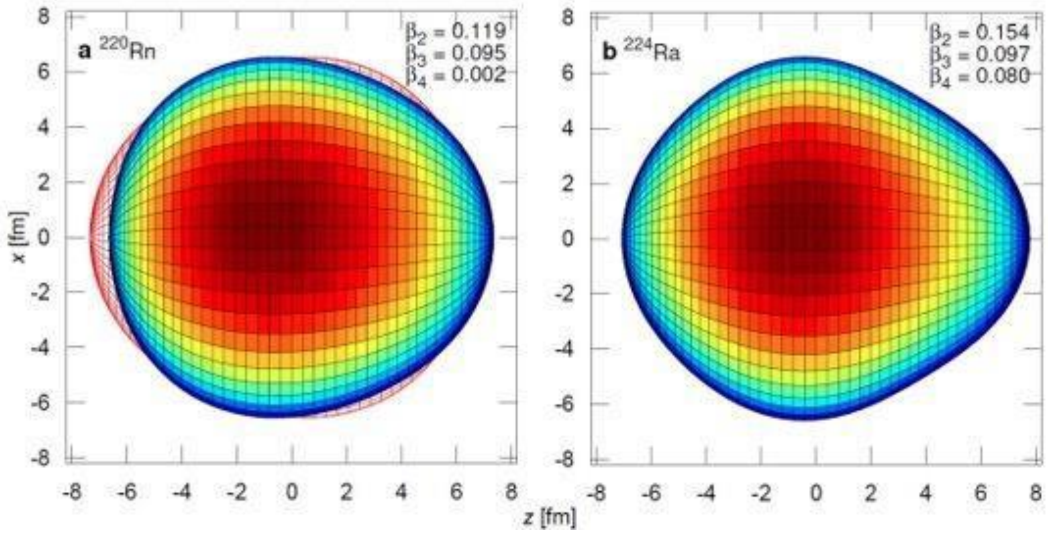

134 ($j_{15/2}$, $g_{9/2}$)

88 ($i_{13/2}$, $f_{7/2}$)

56 ($h_{11/2}$, $d_{5/2}$)

34 ($g_{9/2}$, $p_{3/2}$)

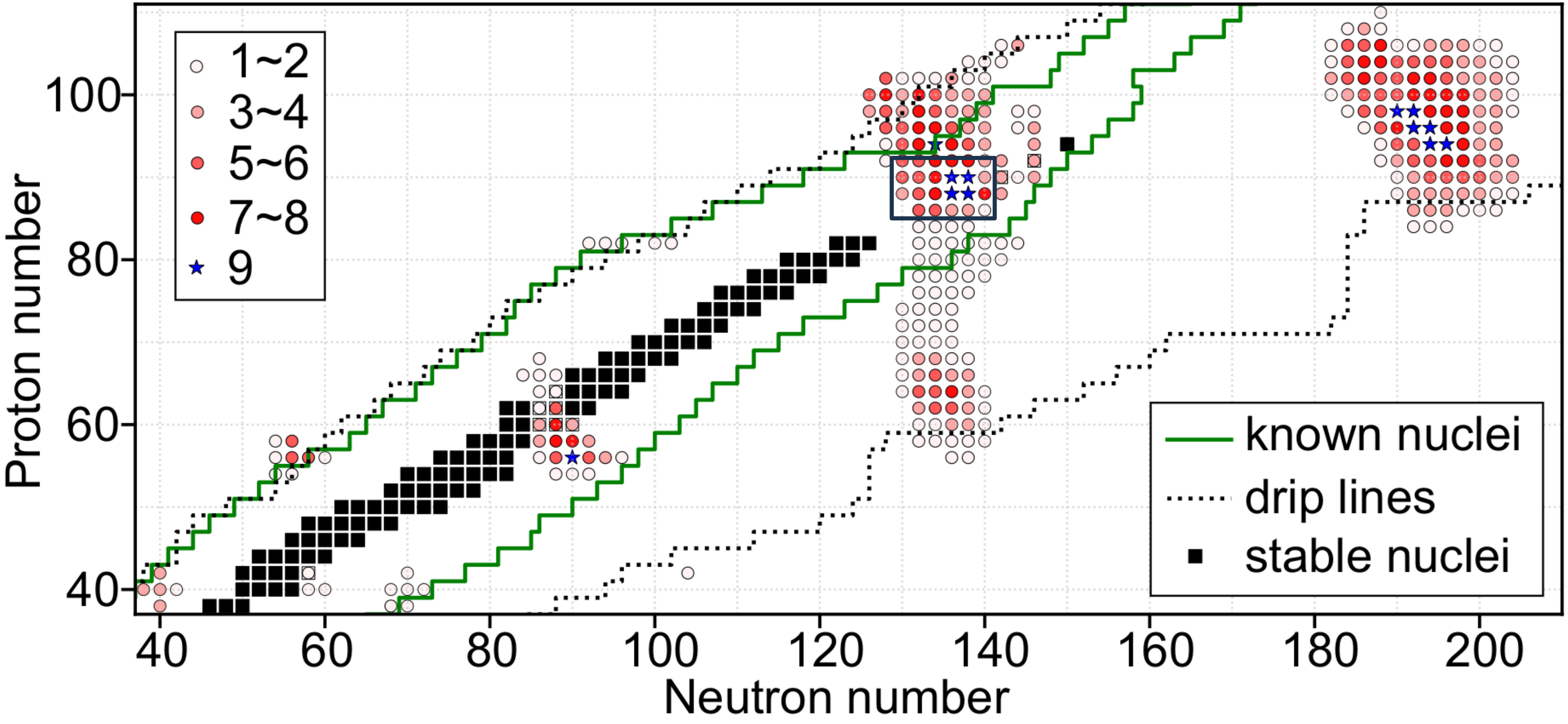
- $\Delta j = \Delta \ell = 3$
- Reflection-asymmetric nuclei
- Octupole magic numbers: 34, 56, 88, 134




L. Gaffney, P. Butler, M. Scheck, *et al.* *Nature* **497**, 199–204 (2013).

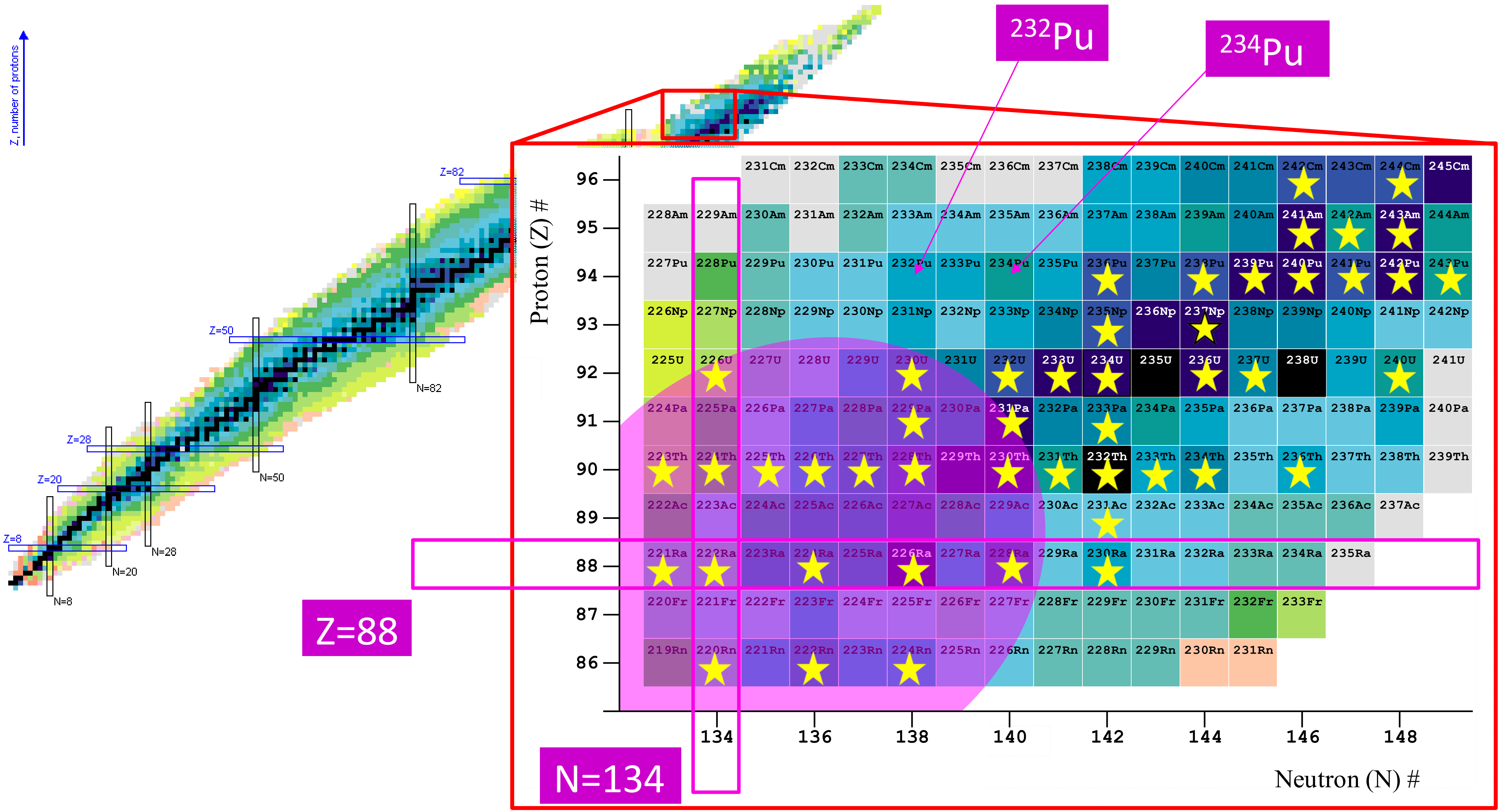
- N=Z=56 close to $^{112}$Ba
- Z=56 N=88 close to $^{146}$Ba
- Z=88 N=134 close to $^{224}$Ra

# Regional understanding




Y. Cao *et al.* theoretical predictions of non-zero $\beta_3$ parameter.
$^{232,234}$Pu have model multiplicities of 5-6, and 3-4, respectively.

# Regional understanding



# Experimental details

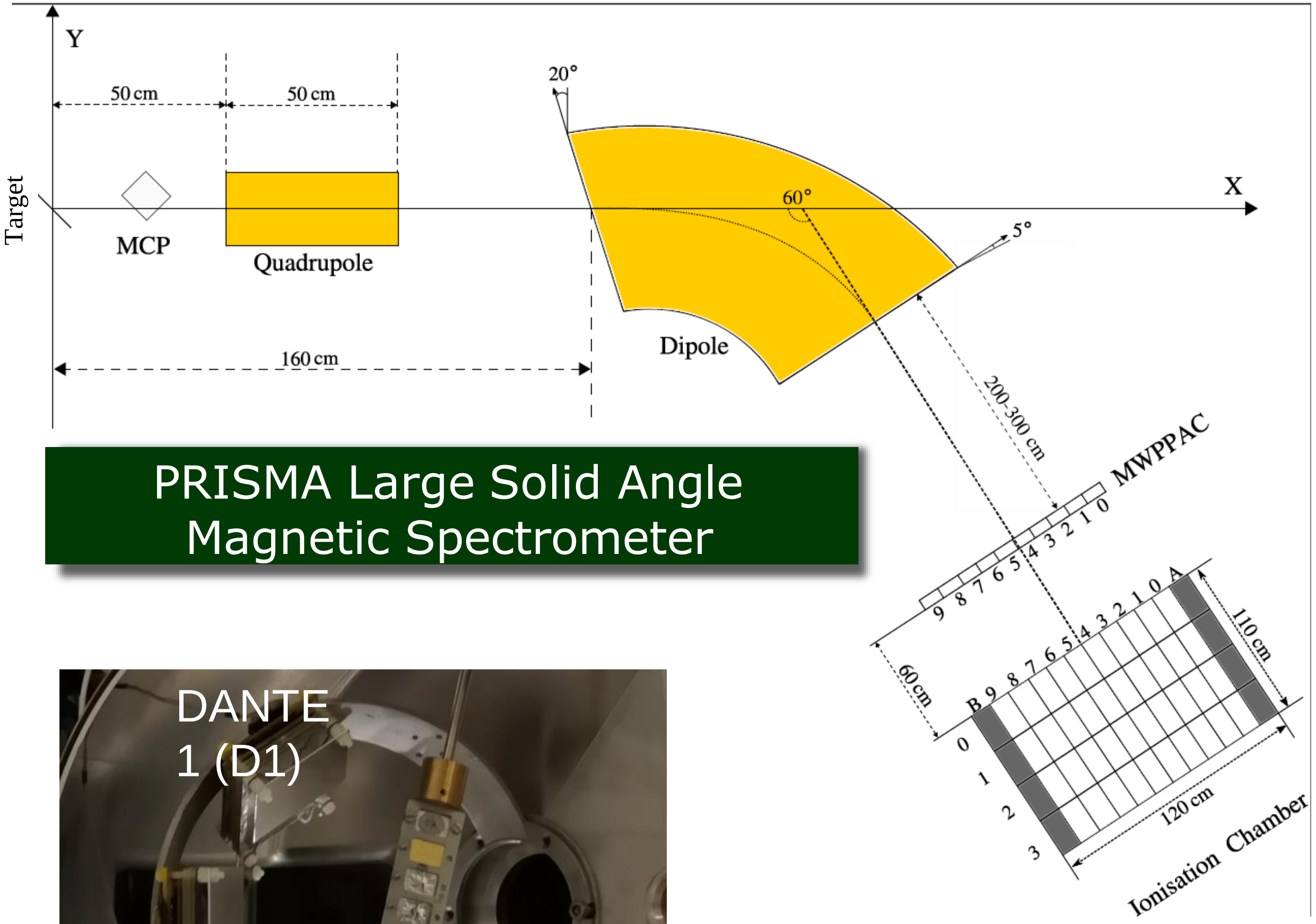
$$^{112}_{50}\mathrm{Sn} + \, ^{238}_{92}\mathrm{U}$$

808 MeV

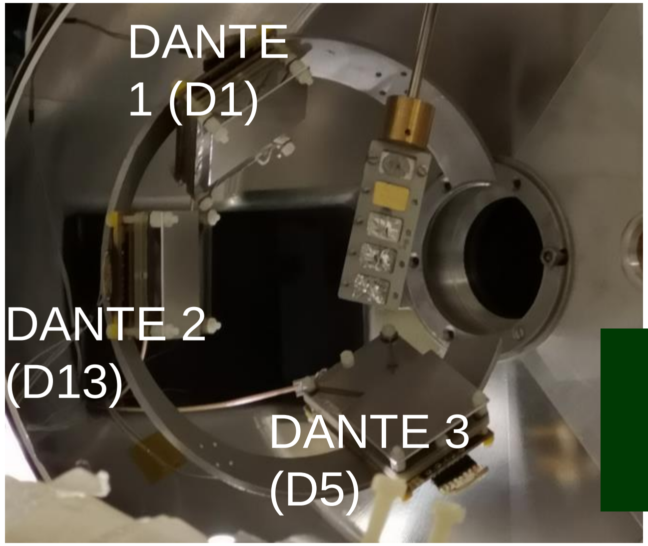
$$\rightarrow \, ^{116}_{48}\mathrm{Cd} + \, ^{234}_{94}\mathrm{Pu} \quad (\sigma \sim 0.7 \text{ mb})$$

$$\rightarrow \, ^{118}_{48}\mathrm{Cd} + \, ^{232}_{94}\mathrm{Pu} \quad (\sigma \sim 0.4 \text{ mb})$$

AGATA
(Advanced GAmma Tracking Array)



PRISMA Large Solid Angle Magnetic Spectrometer



DANTE array with 3 detectors not originally in merge

# Stages of Analysis

1. PRISMA analysis → *Z* identification, trajectory reconstruction, *q* selection, *A*/*q* calibration, and mass calibration.

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3. AGATA – PRISMA coincidences → Check mass assignments, ToF calibration, observe coincidence spectra.

4. DANTE analysis → Timestamp alignment, integrate DANTE events into replay, gate on DANTE-PRISMA events.

# Stages of Analysis - PRISMA

**MCP (x,y)**
- 2D – gate
- Calibration

**PPAC (ToF)**
- Thresholds
- *Calibration*

**PPAC (x,y)**
- Thresholds
- 2D – gates
- Calibration

**IC (energy)**
- Thresholds
- *Calibration*

**SIDE (veto)**
- Thresholds

↓

**Z – identification (ΔE – E)**

- ToF alignment coarse (ToF vs $X_{FP}$ gated on Z)
- ToF alignment fine-tuning (A/q vs $X_{FP}$ gated on Z)
- Set ToF offset

*Optical parameters optimization*

**TRAJECTORY RECONSTRUCTION**

↓

**Q – identification (E – Rβ)**

↓

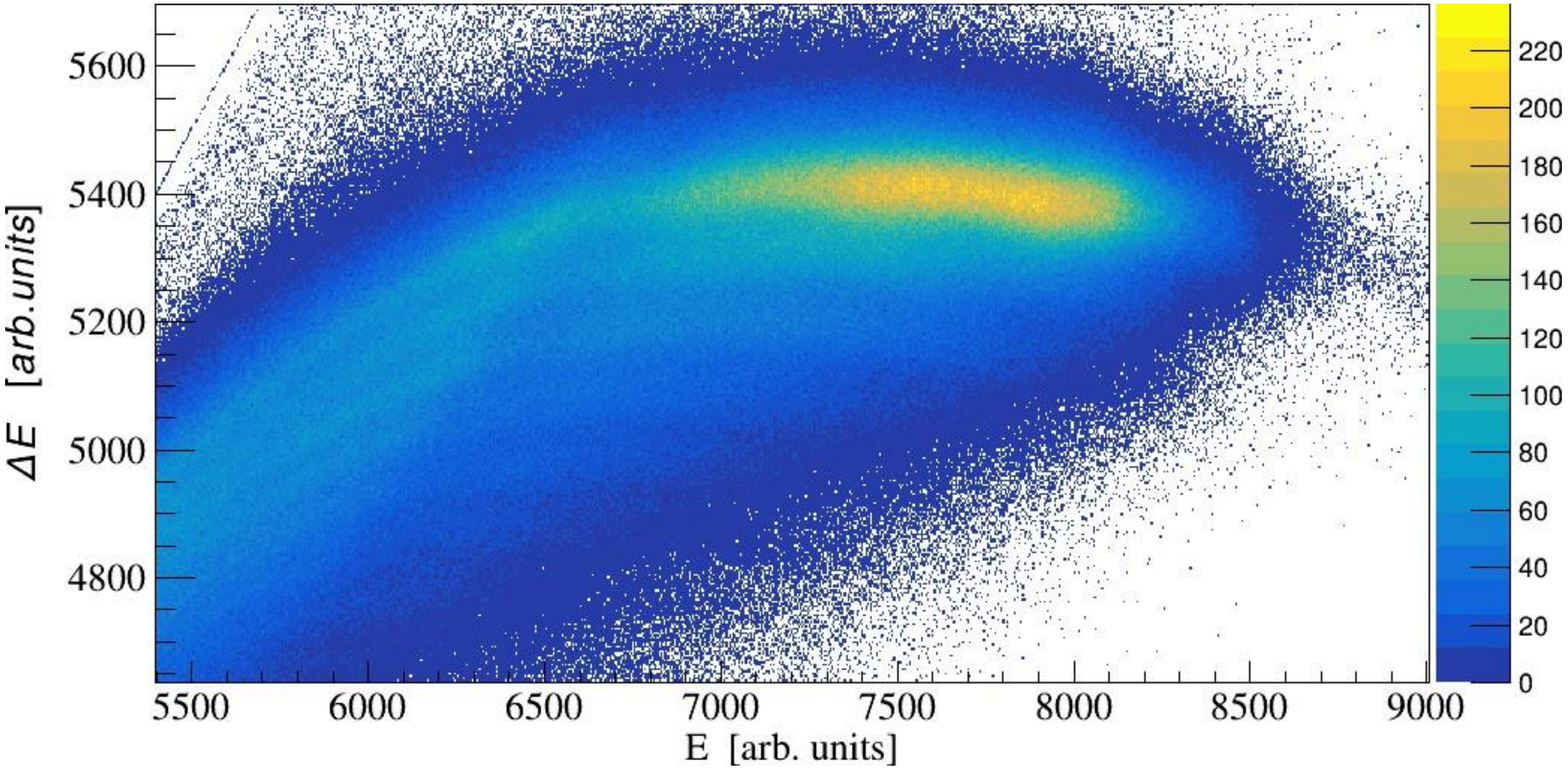
*A/q Aberration correction*

**Mass calibration**

Credit Elia Pilotto – AGATA analysis workshop 2023

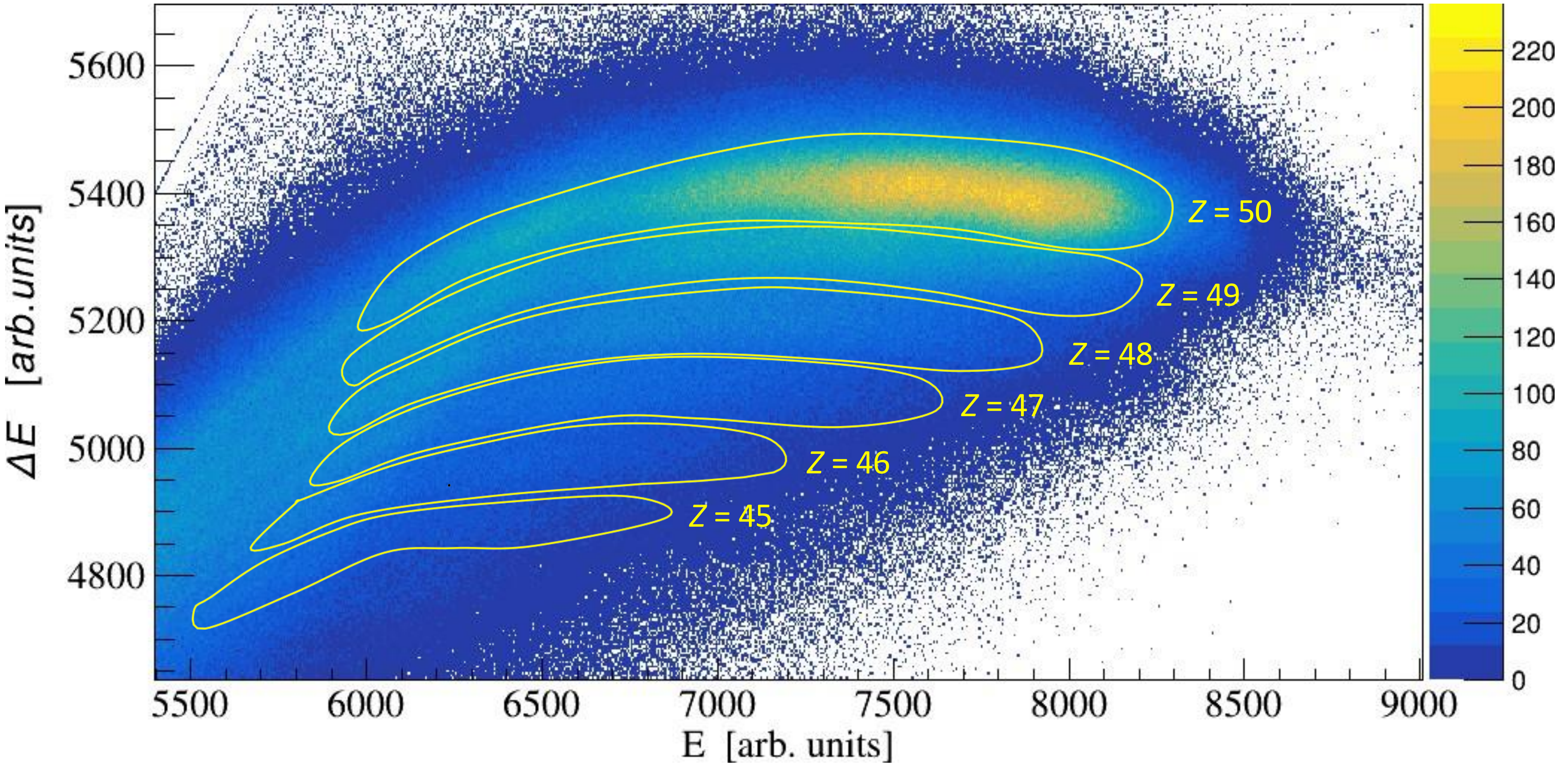
# PRISMA - *Z* identification

Data from one run ~ 6% of total collected



# PRISMA - *Z* identification

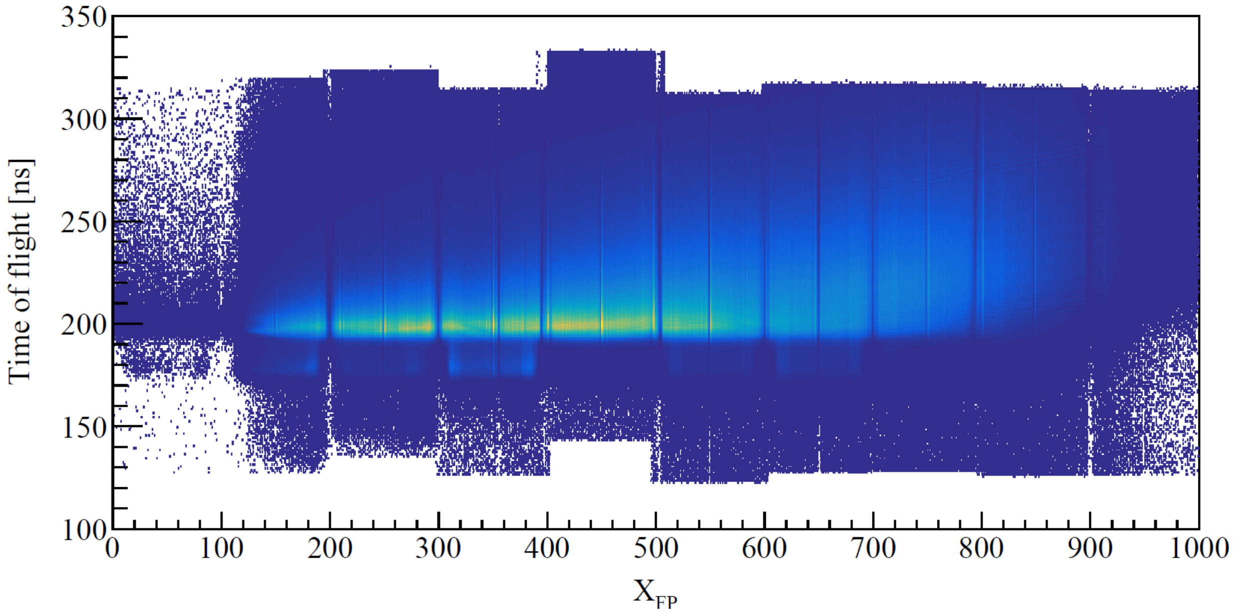
Data from one run ~ 6% of total collected

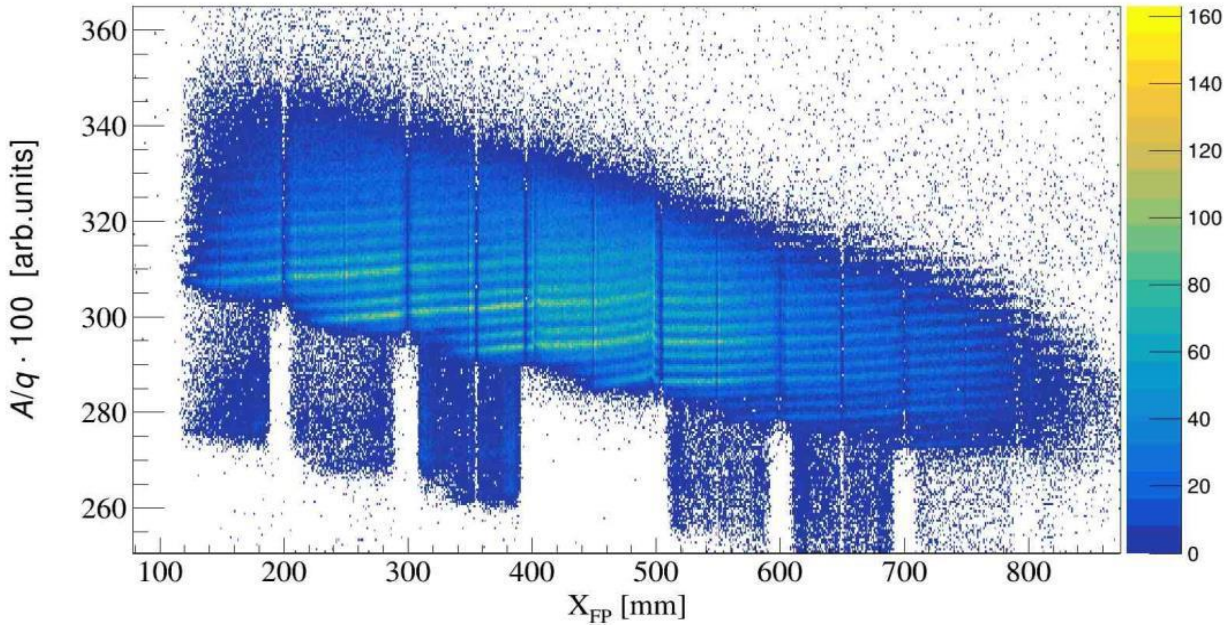


# PRISMA – ToF alignment and offset

MWPPAC segments aligned using X_FP

A/q vs. X_fp used for fine tuning of alignment



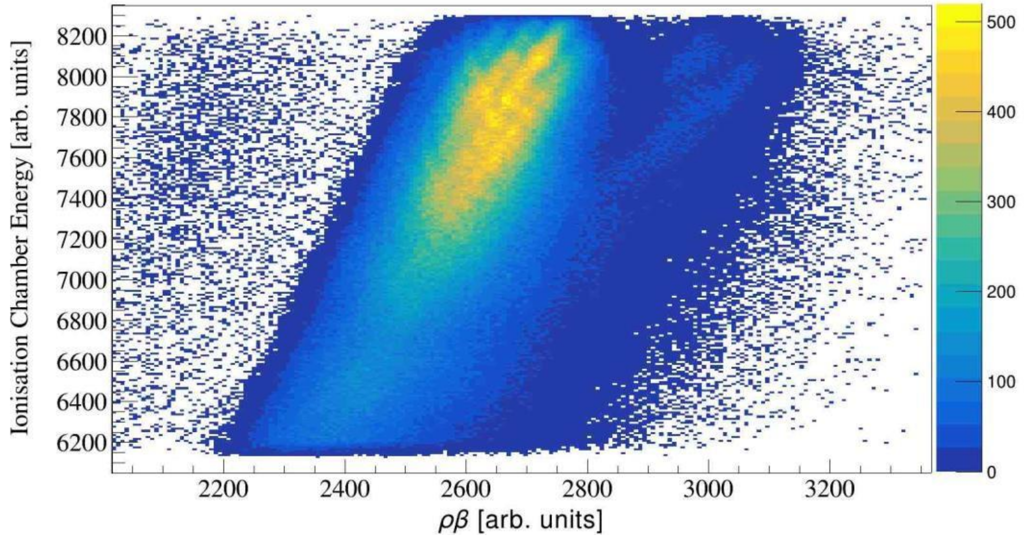

Estimation of Time-of-flight is determined using the length of PRISMA and ion velocity.

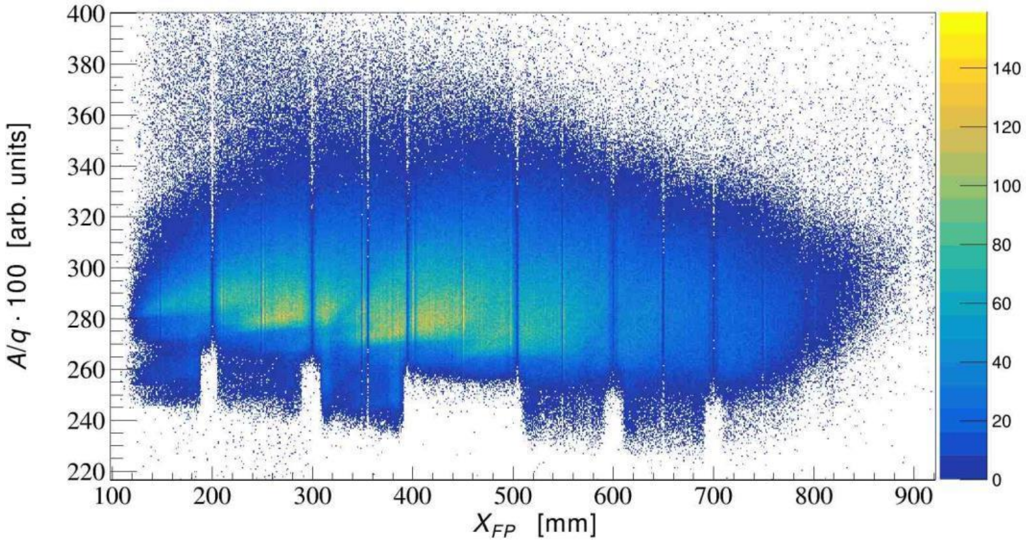
Estimated ToF value at this stage ≈ 200 ns -> used to fix the ToF offset parameter.

Estimated value tuned when looking at Doppler corrected gamma-rays.

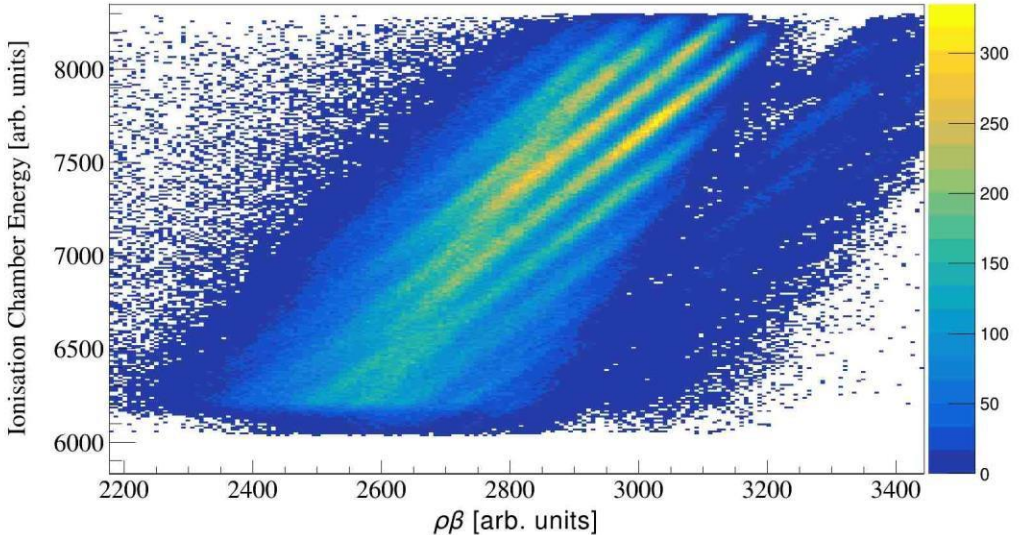
# PRISMA – Trajectory reconstruction

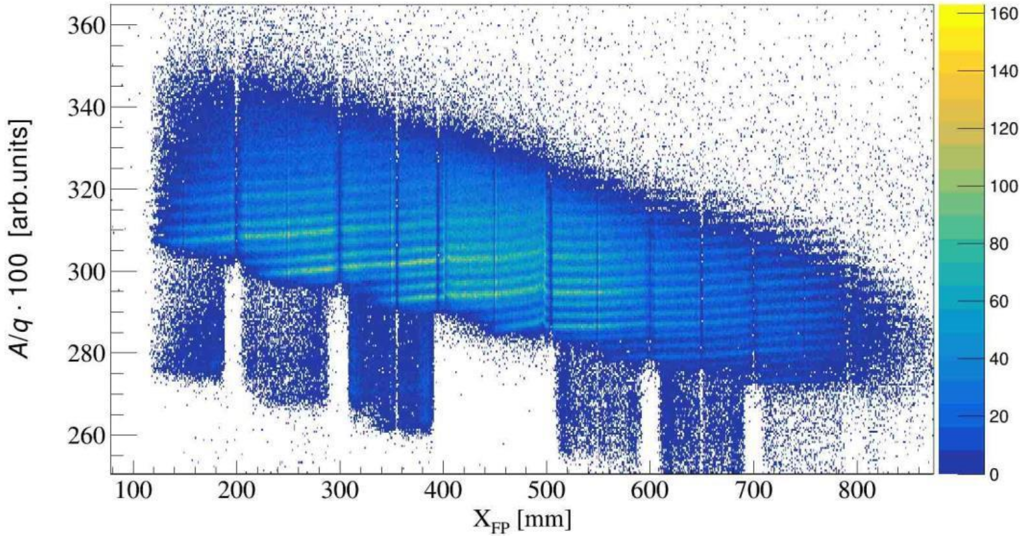
**Bad optical parameters**




**Good optical parameters**

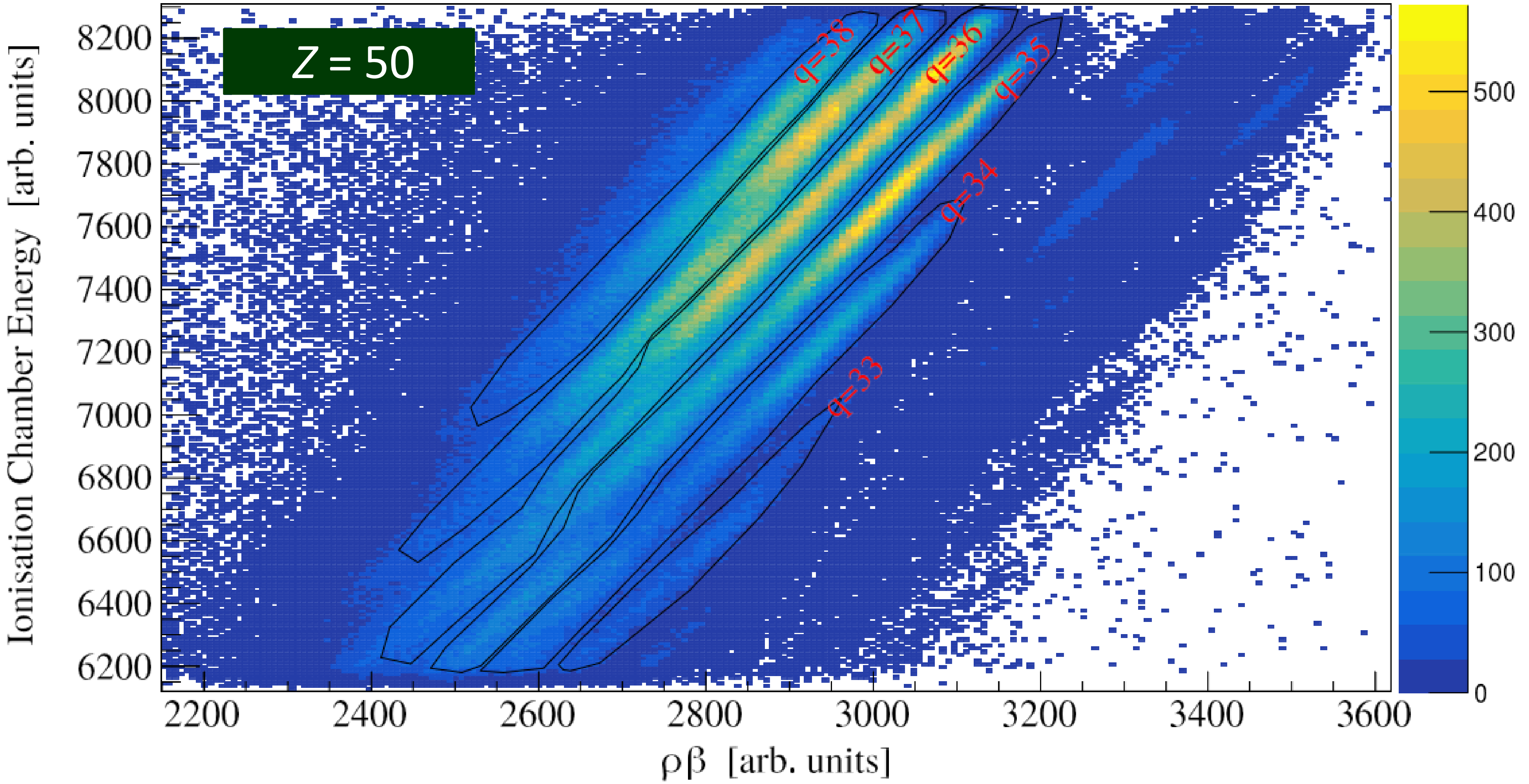


# PRISMA – charge state selection

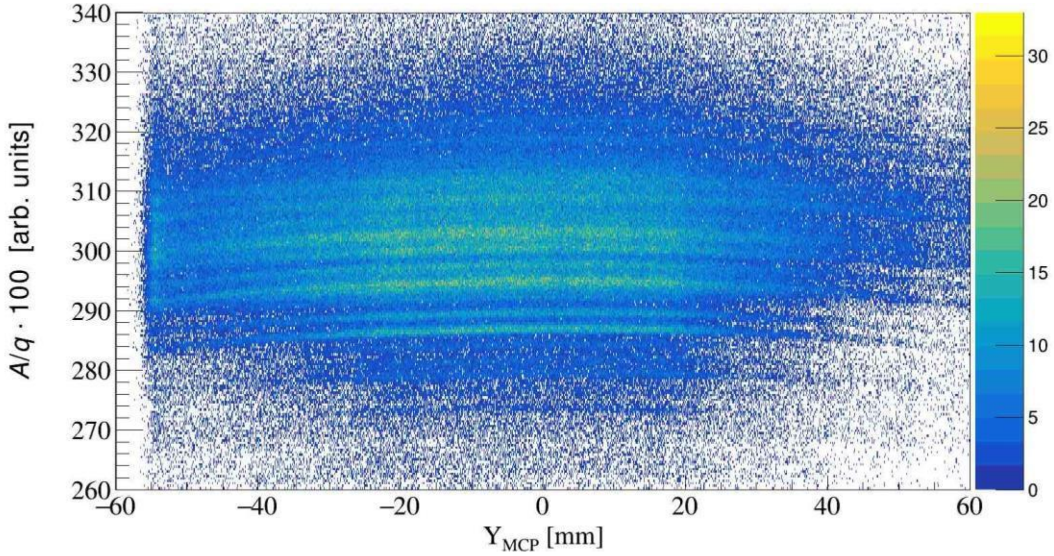
$$E_k \propto q \cdot \rho\beta$$

Charge state ($q$) gates applied to each $Z$ gated distribution

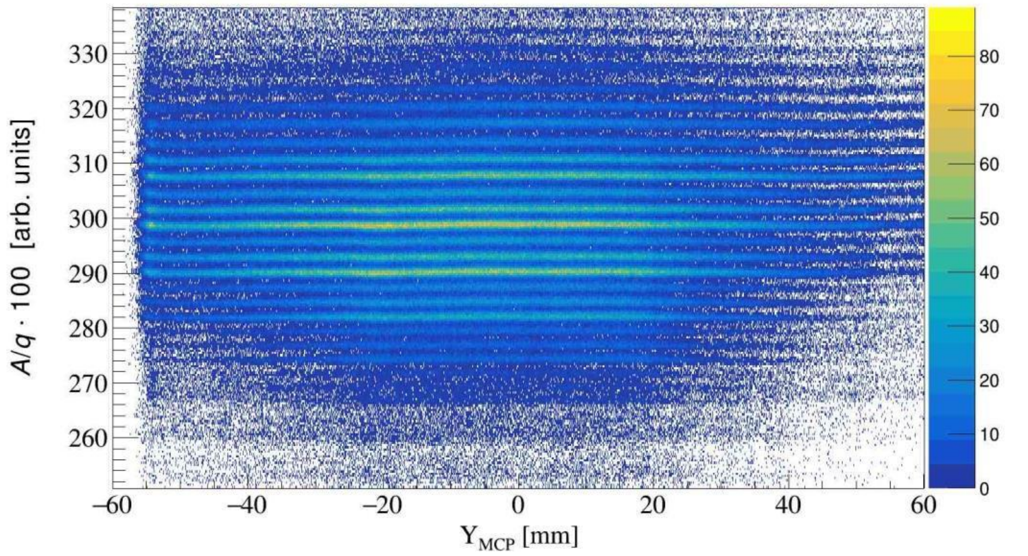


# PRISMA - A/q calibration

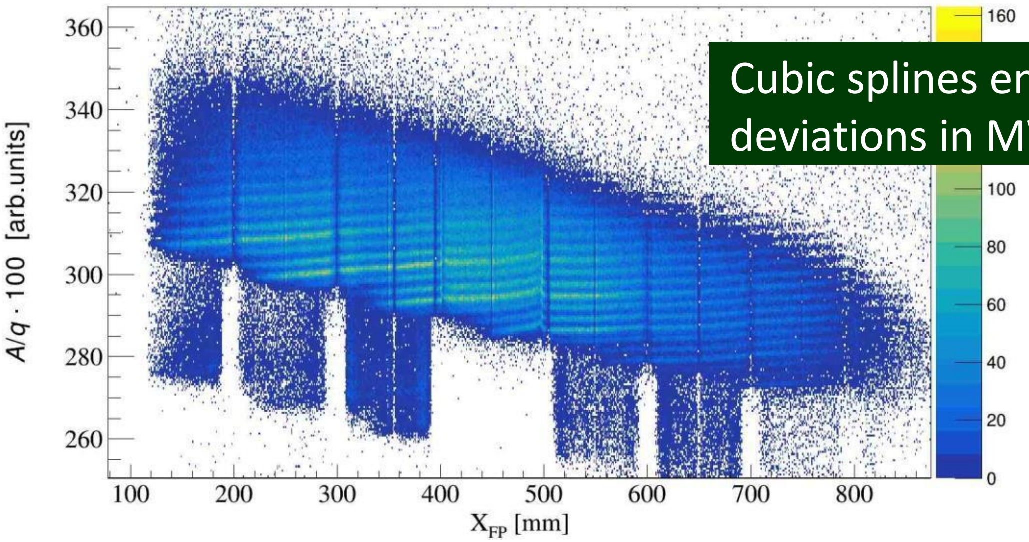
Before aberrational corrections

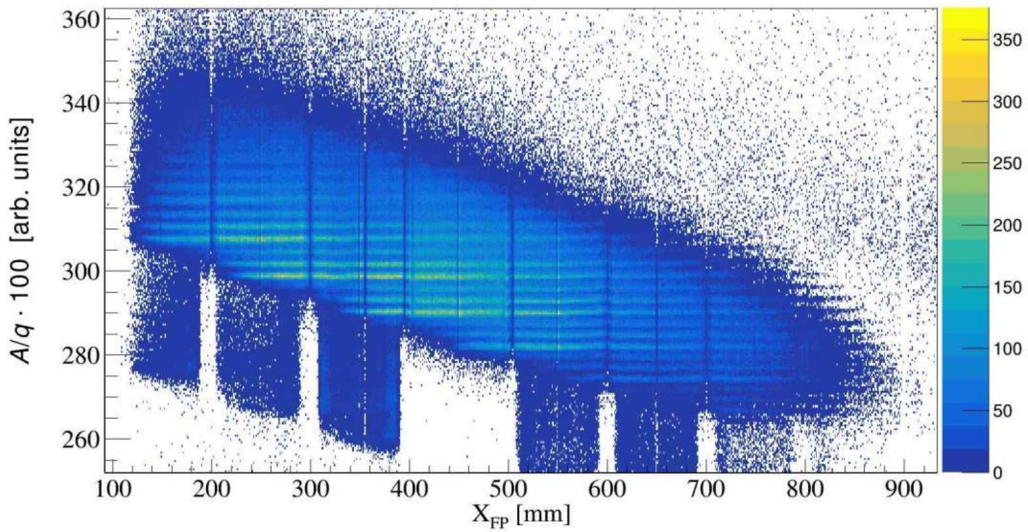



After aberrational corrections

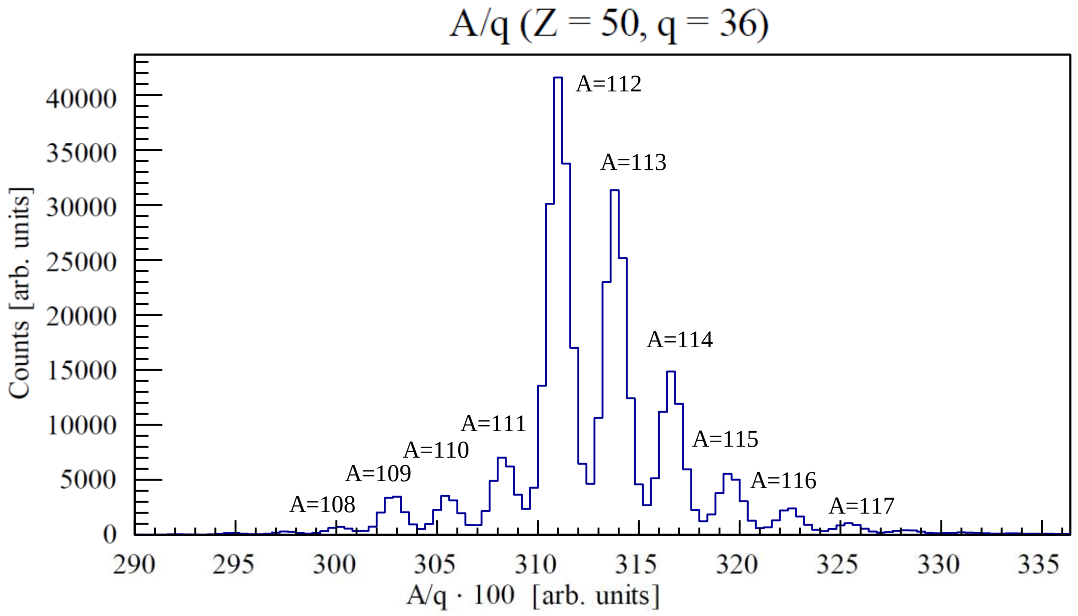



Cubic splines employed to map deviations in MWPPAC sections.



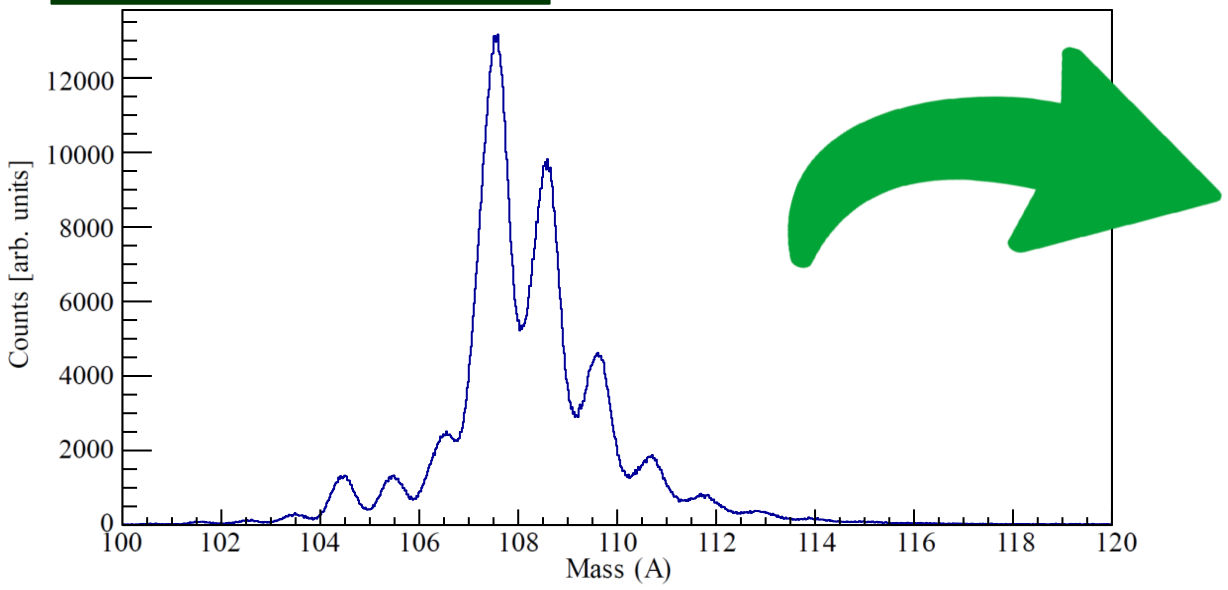



# PRISMA - Linear calibration

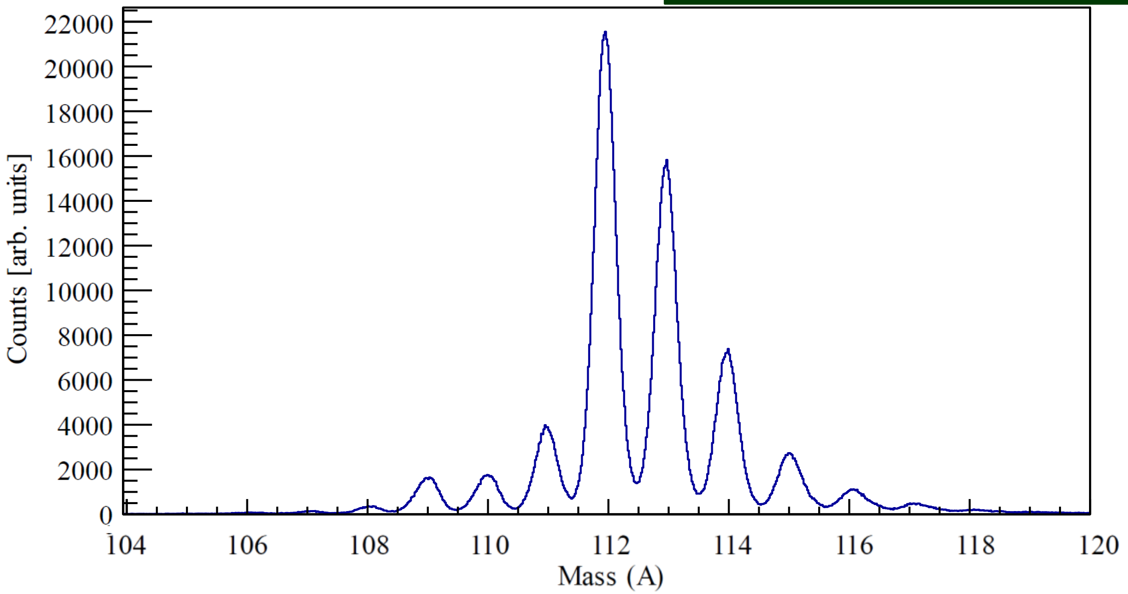



A/q linear calibration applied by measuring centroid of ZQ-gated 1D A/q distributions and comparing observed with expected A/q values.

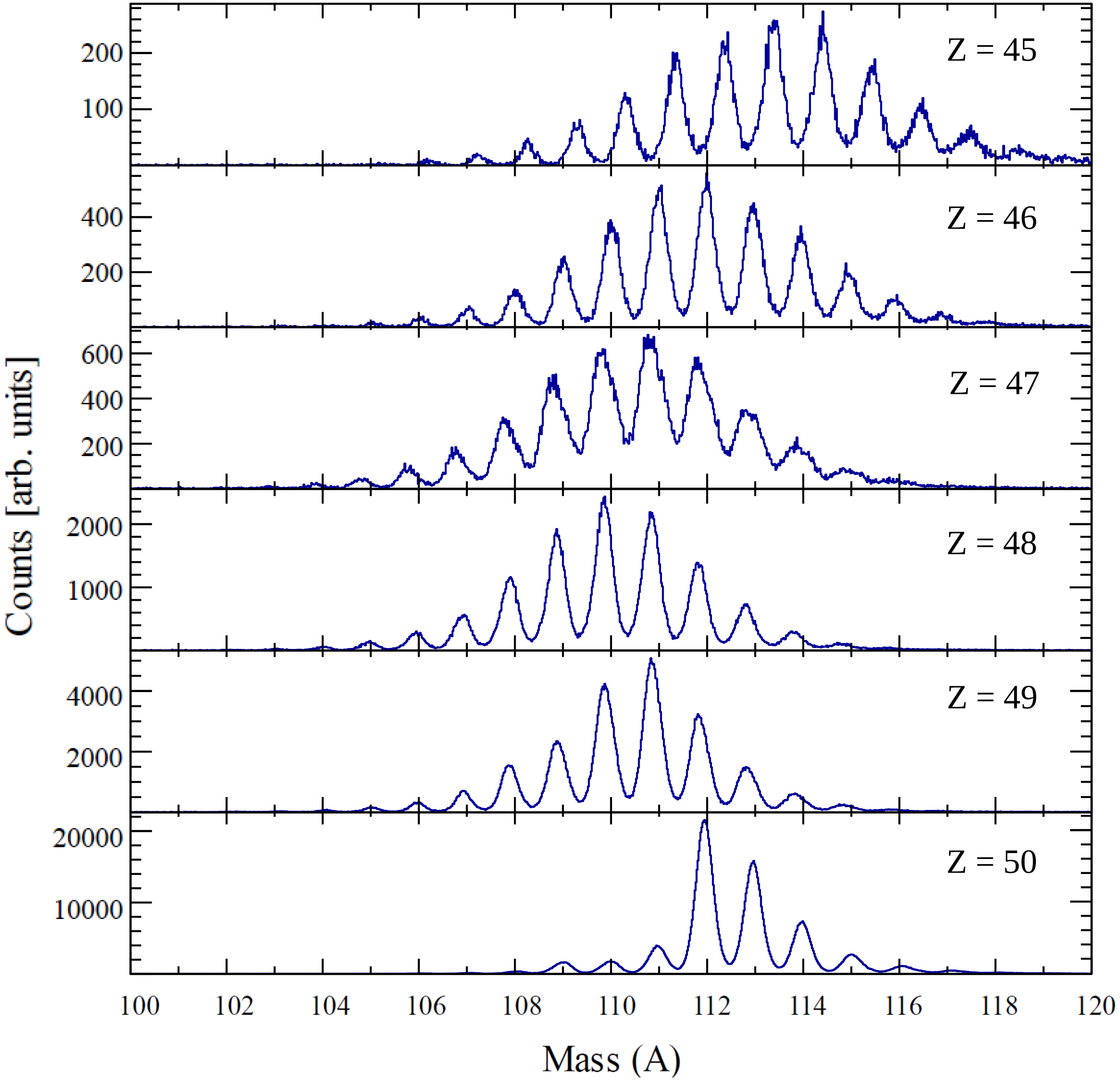
Mass (Z = 50) before linear calibration




Mass (Z = 50) after linear calibration



# PRISMA - Mass distributions



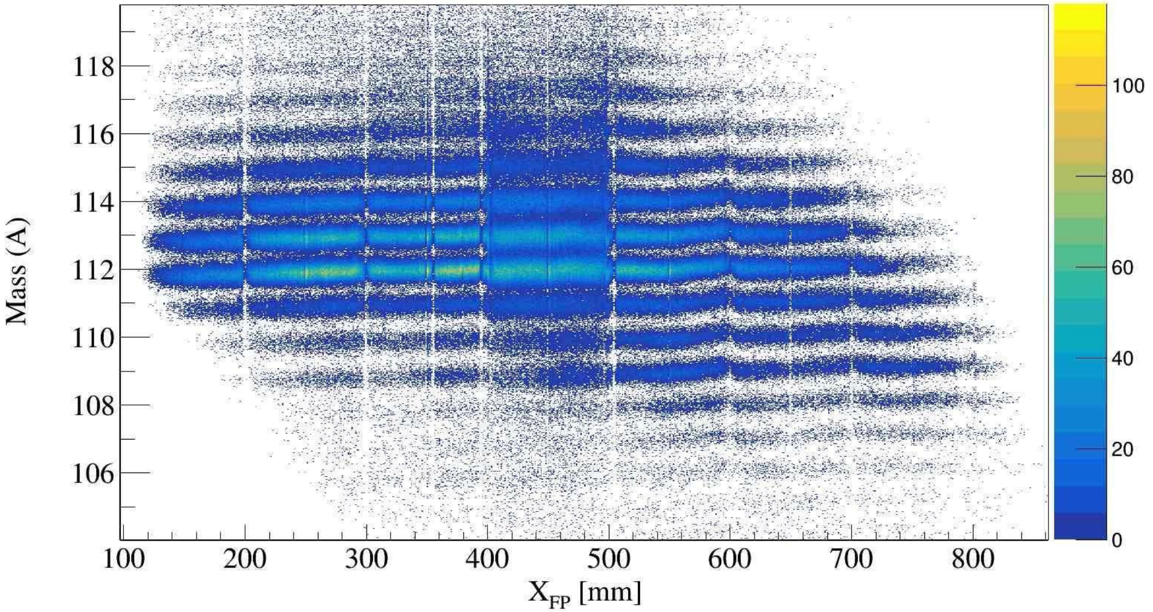

Mass resolutions

$$Z = 50 \rightarrow \frac{1}{248.6}$$

$$Z = 49 \rightarrow \frac{1}{230.8}$$

$$Z = 48 \rightarrow \frac{1}{228.7}$$

Mass assignments are gated on to look at coincidence gamma-ray spectra either using 2D gate or rounding to nearest integer.



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2. AGATA analysis → Neutron damage correction, final energy calibration, and global time alignments.

POST - PSA

3. AGATA – PRISMA coincidences → Check mass assignments, ToF calibration, observe coincidence spectra.

4. DANTE analysis → Timestamp alignment, integrate DANTE events into replay, gate on DANTE-PRISMA events.

# AGATA – Experiment Status

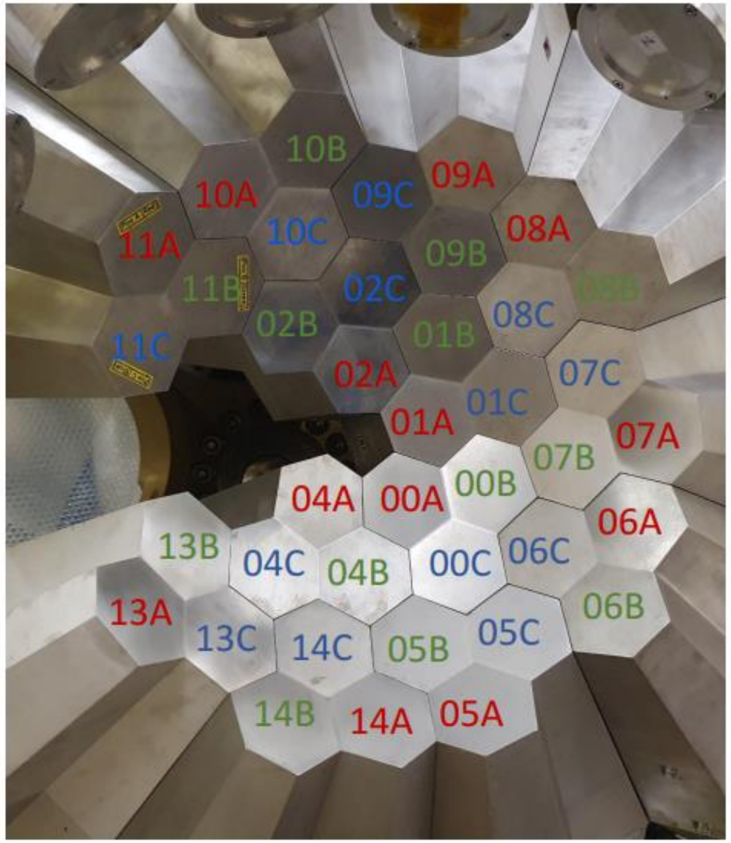
## AGATA status before EXP013 (10-03-2023)

- 02B, 05A, 14A, 14B, 14C not included in the GTS
- 00A anode rebooting often

**Status of the 34 operational AGATA detectors:**

- **Detectors with problematic segments:**
  - 01A: column C and D changing time diff with core (TT.spec) after GTS alignment (?)
  - 01B: **seg. A2 missing** (signal in scope, digi problem) **recovered as a lost seg. 1** (B3 change adcoffset if needed)
  - 04A: **seg. B3 gain drifting?** (digi problem?) **recovered as a broken seg. 8** (seg. B1 no peak in fold1) (signal in scope fine for both)
  - 05B: **seg. A3** bad resolution (signal in scope digi problem?) **recovered as a broken seg. 2**
  - seg. E1 gain drifting?
  - 08A: **seg. B3 missing** (signal in scope, digi problem) **recovered as a lost seg. 8**
  - 08B: seg. A1, A2, B1, B2, B3, B4 gain drifting (digi problem) not possible to recover
  - 11A: **seg. F1 missing** (signal in scope, digi problem) **recovered as a lost seg. 3** all segments with a huge extra peak (electronic noise filtered in the Prep level)
  - 13C: seg. D1 and D4 gain drifting?

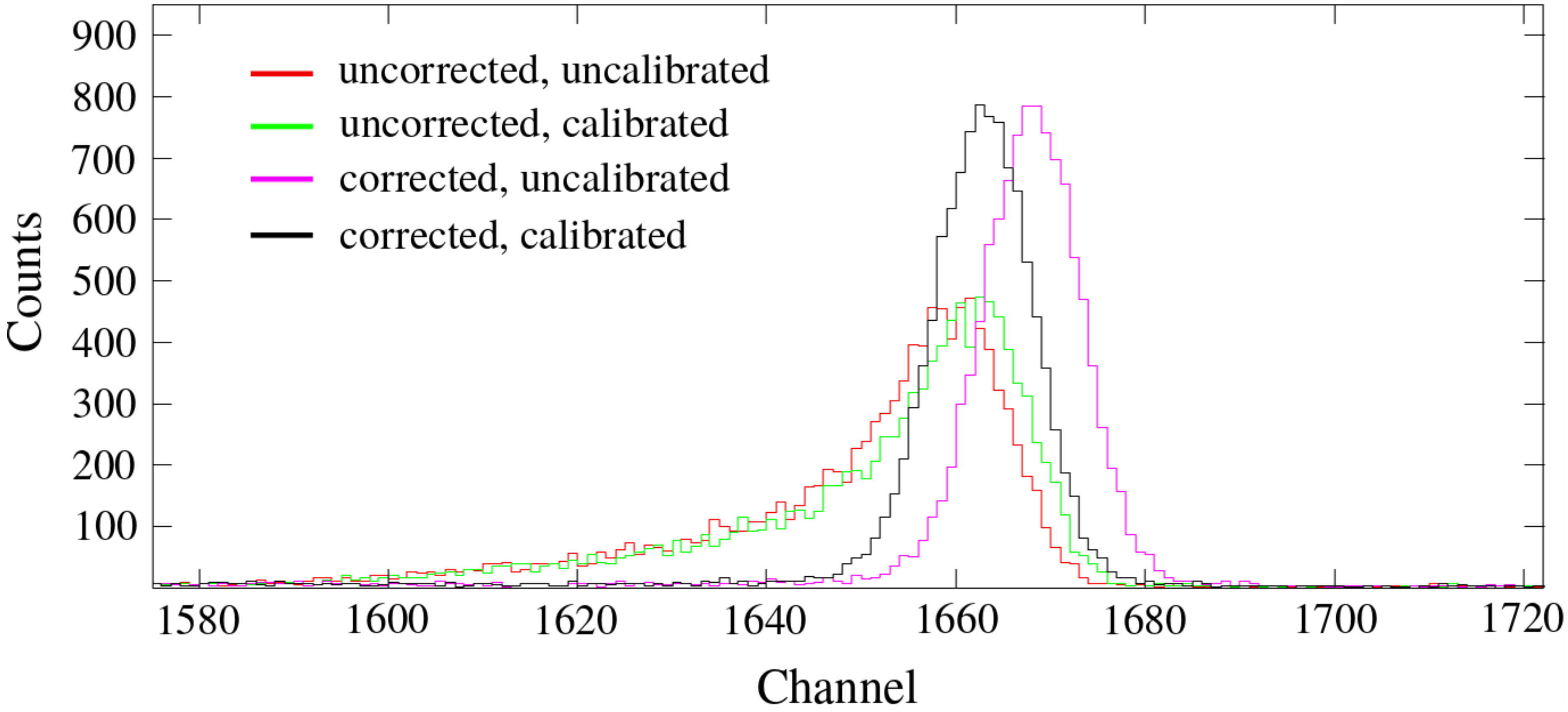
- **Detectors with problematic cores:**
  - 04C: core 37 missing (signal in scope, digi problem)
  - 06C: core with strange noise in the trace which makes cores energy with an extra peak around 105keV
  - 11A: core 37 missing (signal in scope, digi problem), cores energy with an extra peak around 100keV
  - 07C: core signal is noisy and recovers over the time, this change affects the gain of the core and of the segments
  - 05C: gain jumps of the core over time, affect the gain of the core and of the segments




- **Detectors with neutron damage:**
  - **All detectors corrected**

# AGATA – Neutron Damage Corrections

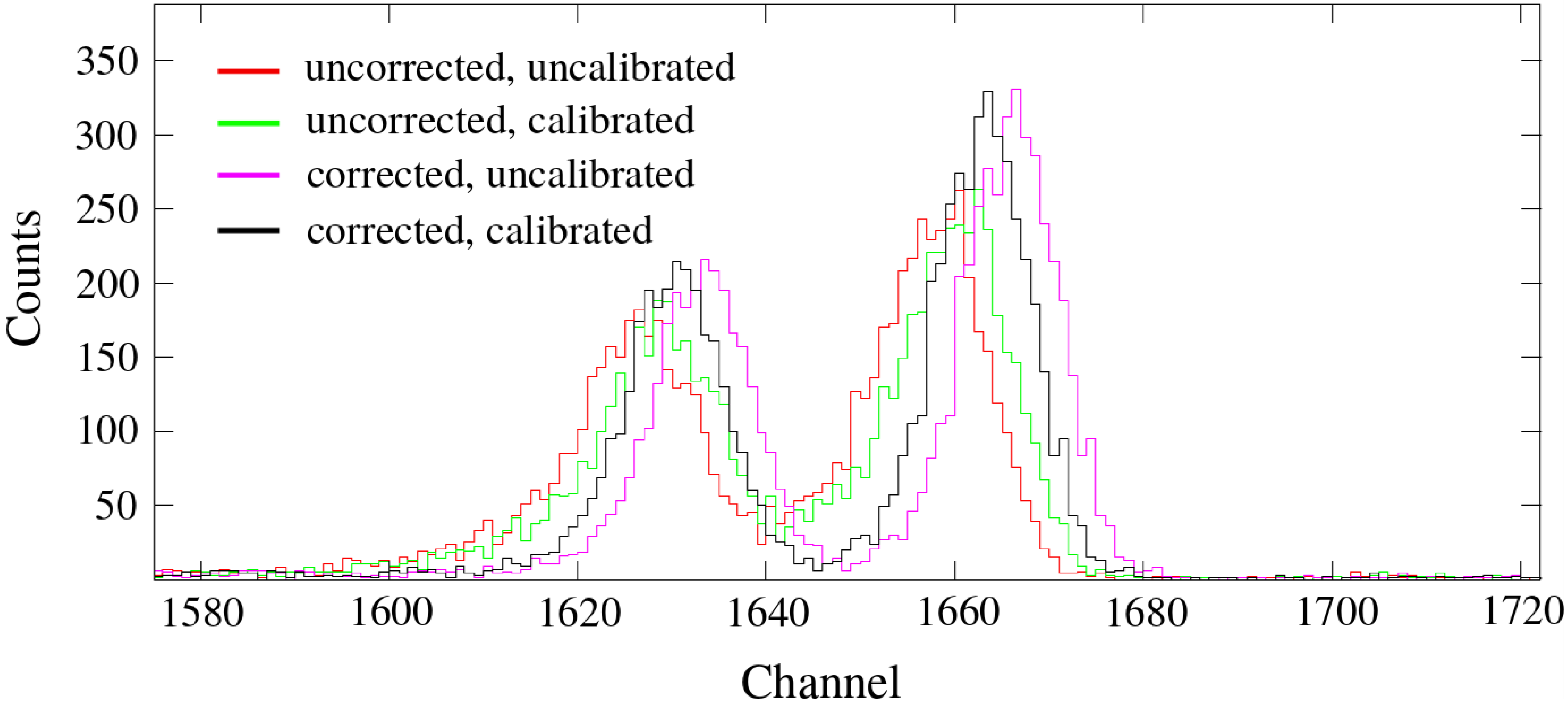
Crystal 09A, segment 15, 1332 keV peak from $^{60}Co$ source run after experiment using traces.




- Compared with core signals to determine whether to use ForceSegmentsToCore option.
- 1332 keV peak appears at channel 1665 due to offset and gain applied.
- FWHM improved significantly.

# Neutron Damage Corrections – Problematic Crystals

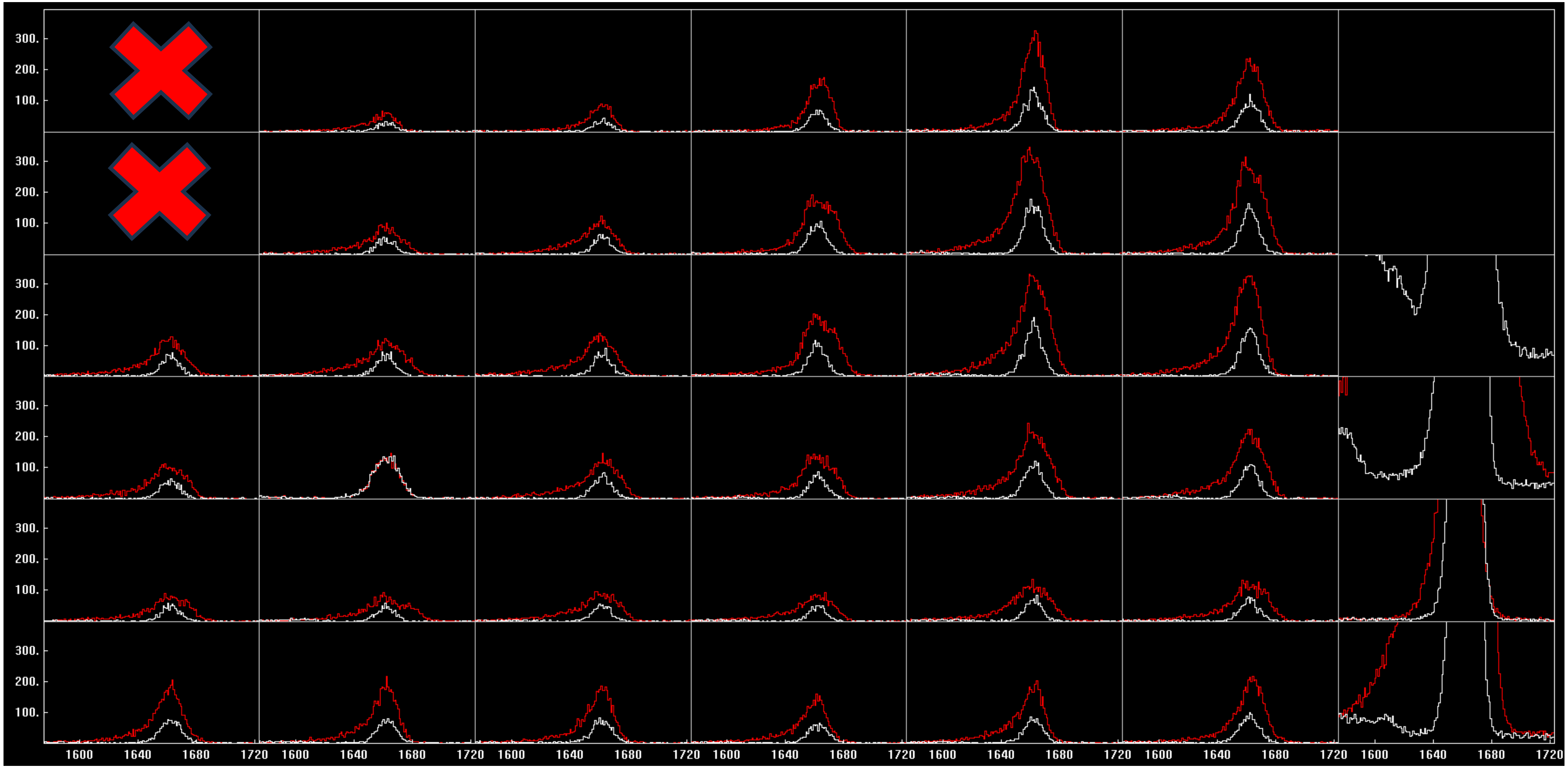
Crystal 07C, segment 29



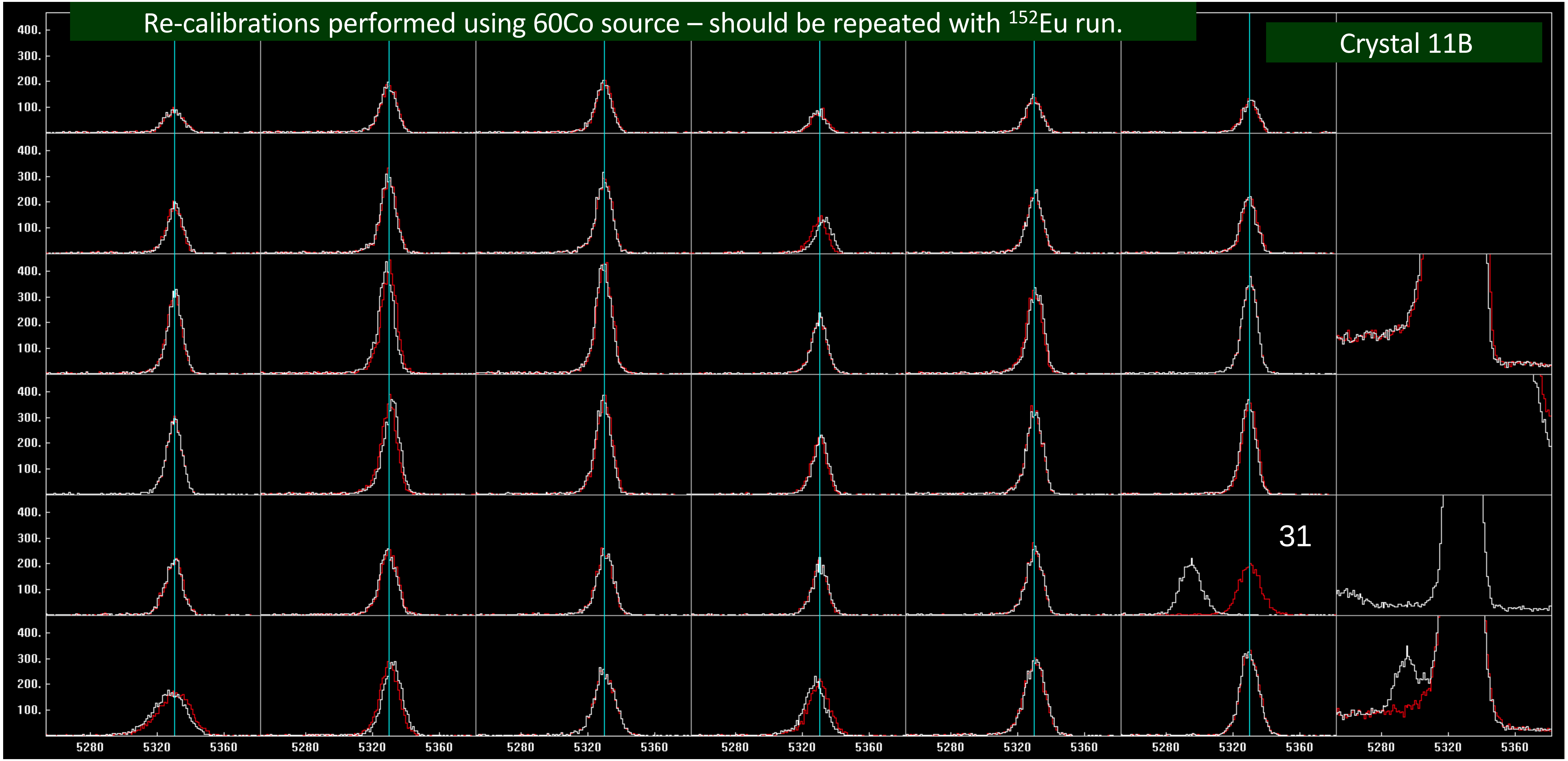

- Double hump peaks seen in all segment signals.
- Source of this is unknown
- Peaks from core signals used for recovery as they don't show same effect.

# Neutron Damage Corrections – Problematic Crystals

Crystal 08A, Missing segments 4 and 5 in segment (red) and core (white) signals, therefore removed from use.



# AGATA - Final Energy re-calibrations



# AGATA – Force Segments To Core

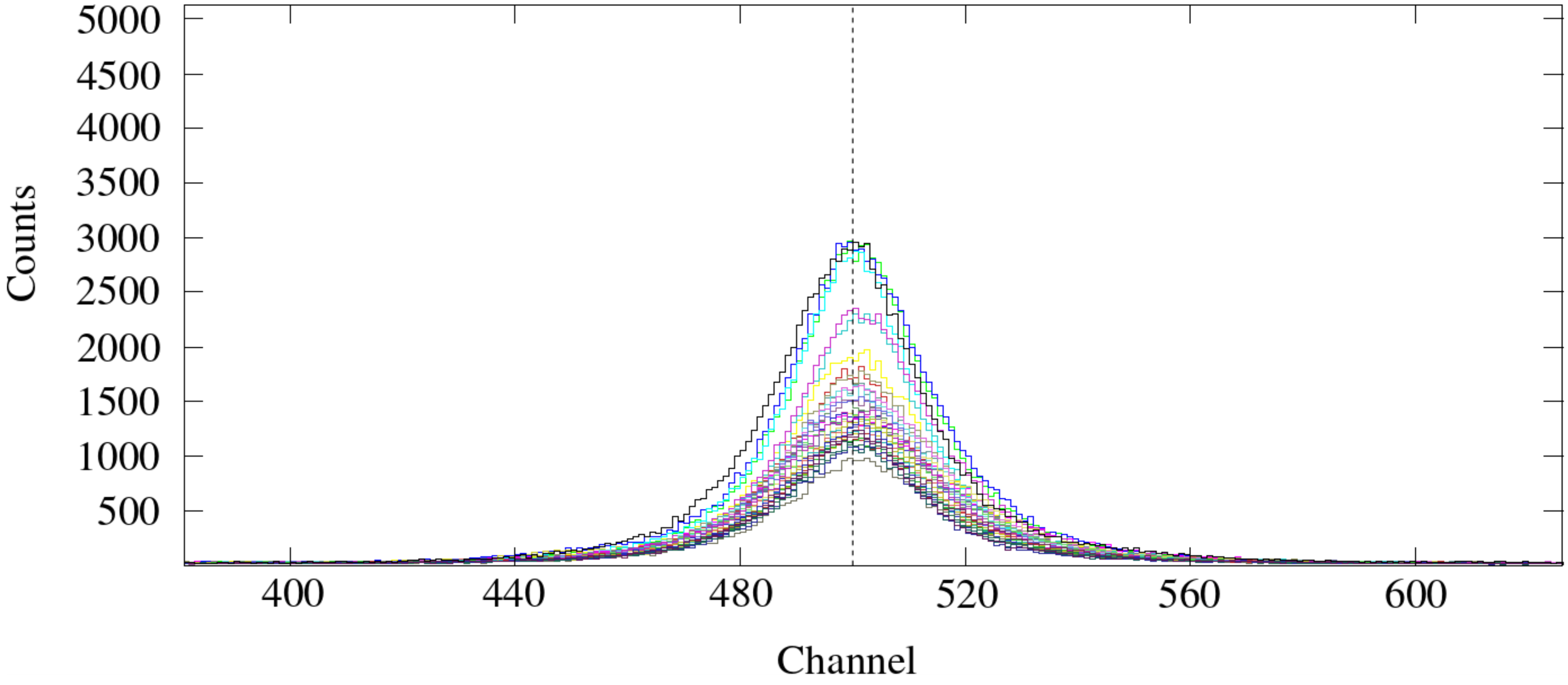
| Crystal | NDC parameters used in Trapping | ForceSegmentsToCore |
|---|---|---|
| 00A | Segments | No |
| 00B | Cores | Yes |
| 00C | Segments | No |
| 01A | Segments | No |
| 01B | Segments | No |
| 01C | Segments | No |
| 02A | Segments | No |
| 02C | Segments | No |
| 04A | Segments | No |
| 04B | Segments | No |
| 04C | Segments | No |
| 05B | Segments | No |
| 05C | Segments | No |
| 06A | Cores | Yes |
| 06B | Segments | No |
| 06C | Segments | No |
| 07A | Segments | No |
| 07B | Segments | No |
| 07C | Cores | Yes |
| 08A | Cores | Yes |
| 08B | Cores | Yes |
| 08C | Segments | No |
| 09A | Segments | No |
| 09B | Segments | No |
| 09C | Segments | No |
| 10A | Cores | Yes |
| 10B | Segments | No |
| 10C | Cores | Yes |
| 11A | Segments | No |
| 11B | Cores | Yes |
| 11C | Segments | No |
| 13A | Segments | No |
| 13B | Segments | No |
| 13C | Segments | No |

Crystals 00B, 06A, 07C, 08A, 08B, 08B, 10A, and 11B use the ForceSegmentsToCore option.

In these cases, the neutron damage correction was repeated using the trapping parameters from the core signals.

# AGATA - Global Time Alignments

Run 40 – segment 0 compared to all other segments




- All segment peaks should align at 500 after Global Time Alignment has been performed.
- Alignment is performed on the output of the tracking.
- Checked for every data run and only performed if necessary.

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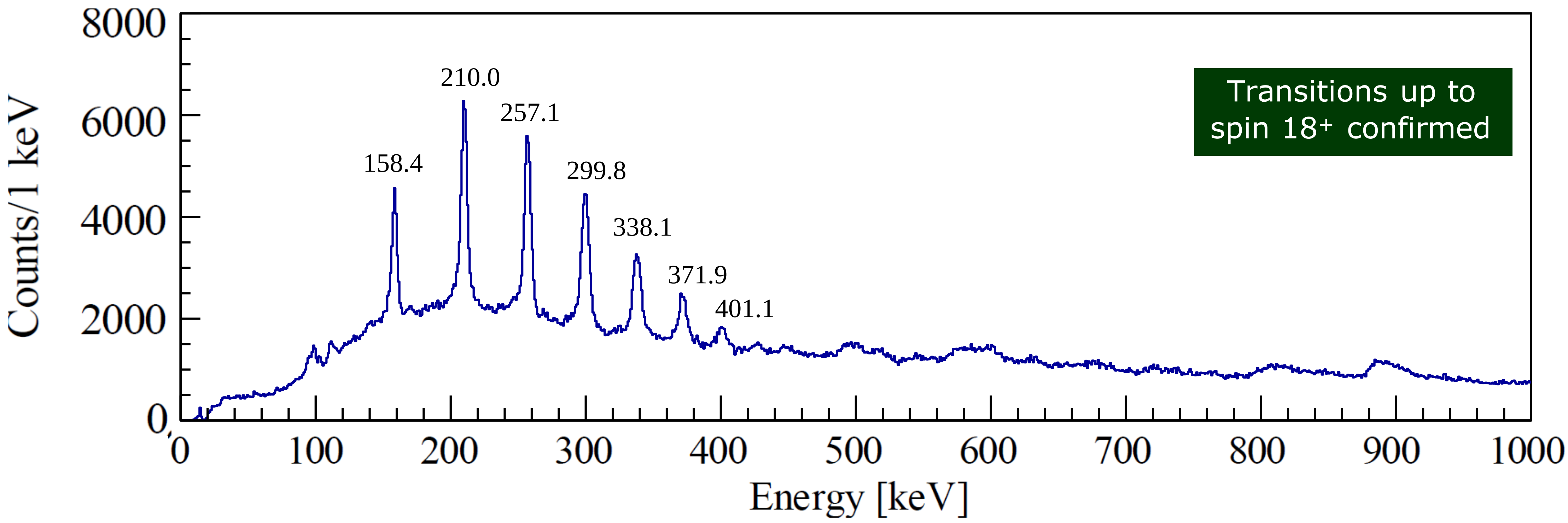
# AGATA-PRISMA Coincidences

$^{238}U$ Doppler-corrected tracked γ-ray spectra gated on binary partner Sn (Z = 50, A=112) using full dataset.



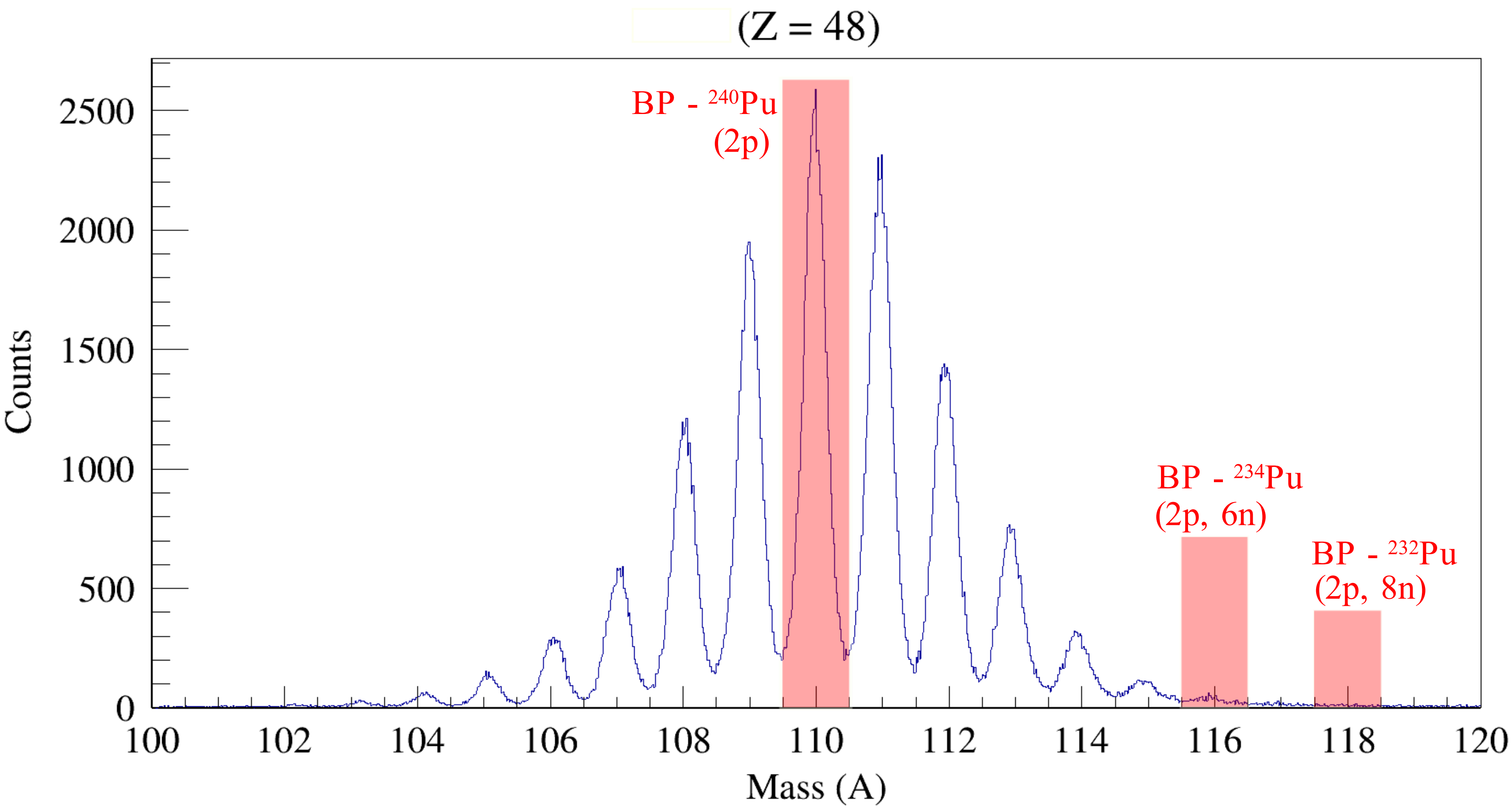

Transitions up to spin $18^{+}$ confirmed

AGATA data not yet updated in selector

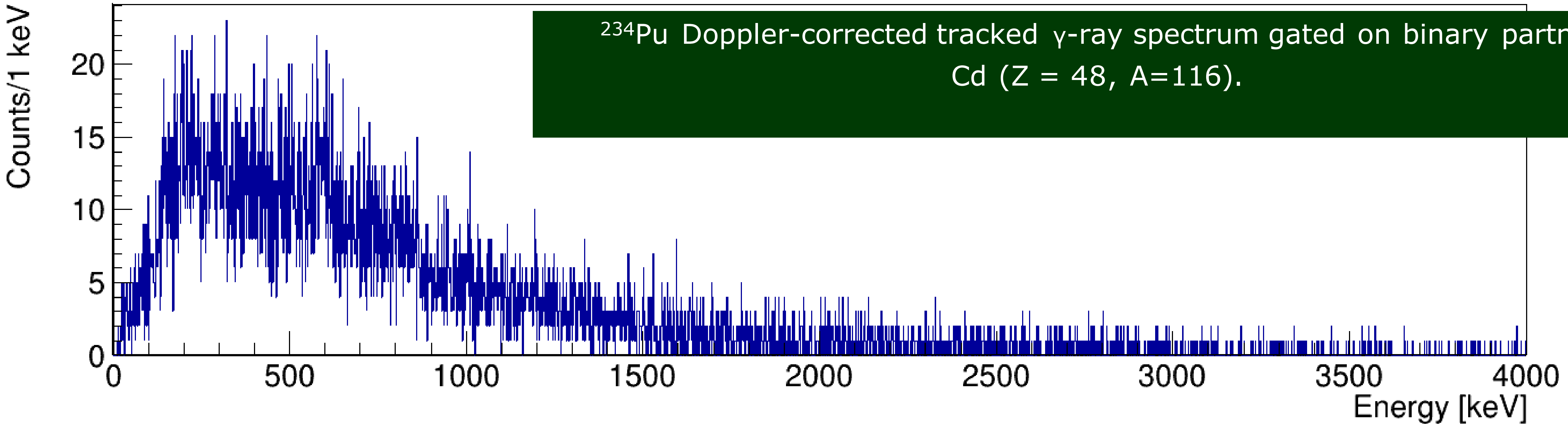
# AGATA-PRISMA Coincidences

Initial mass assignment predicted *A*=112 to be dominant channel.

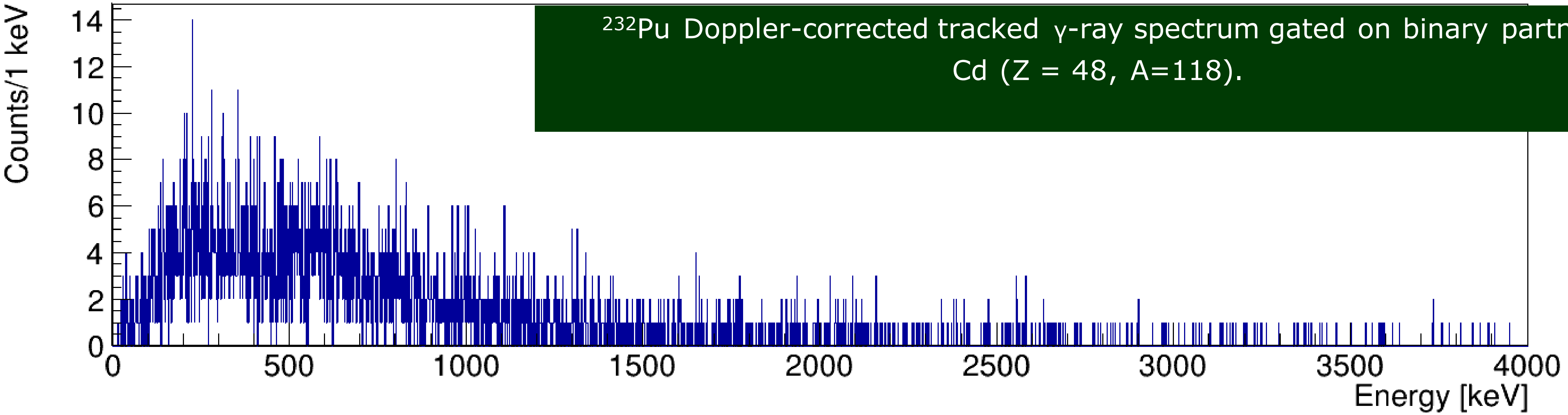
This was altered to *A*=110 after observing gamma-rays of known energy.



# AGATA-PRISMA Coincidences

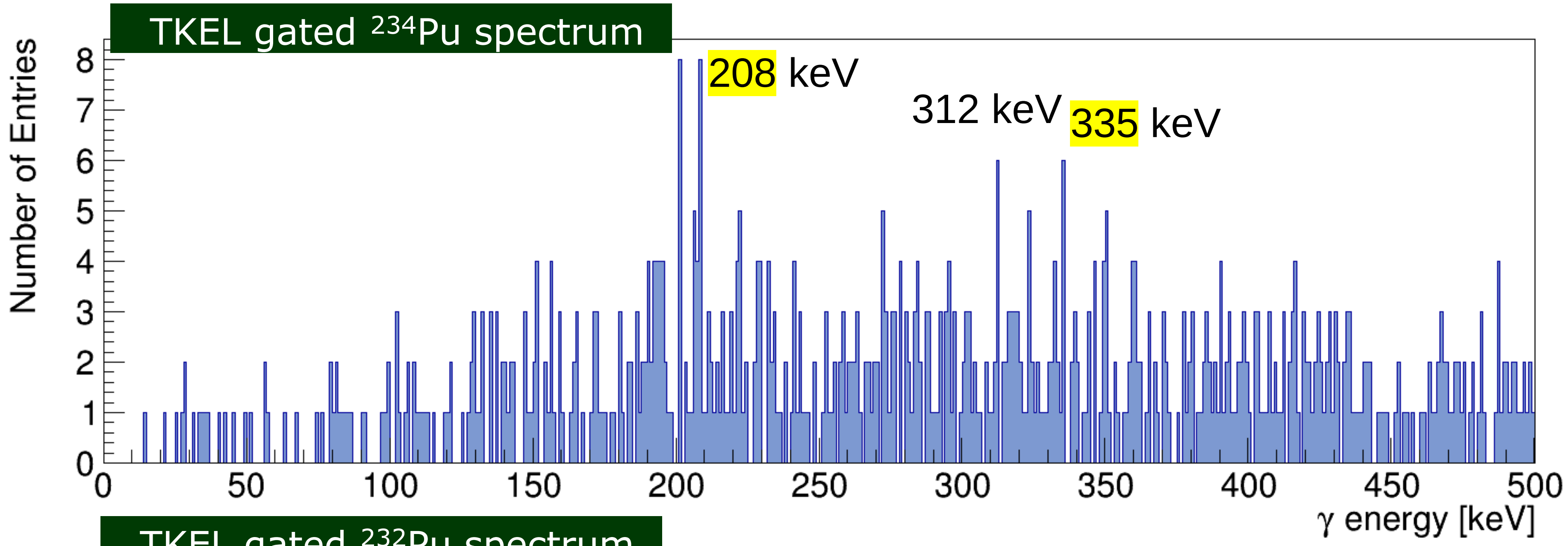


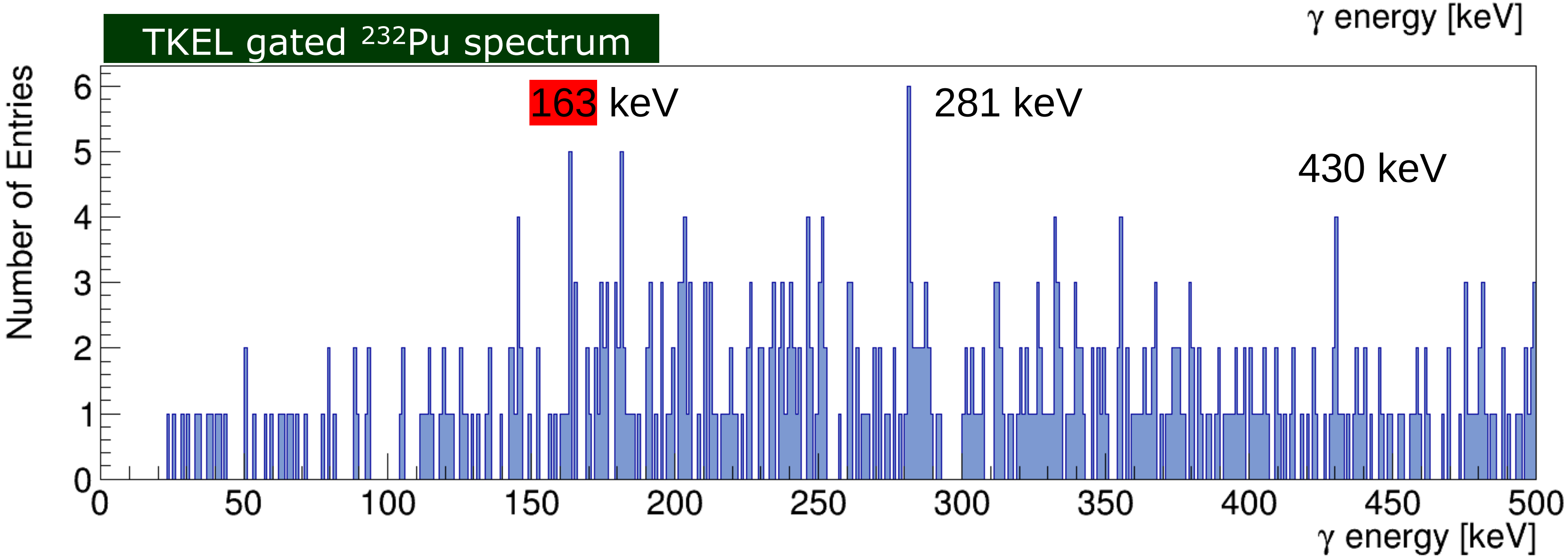

$^{234}Pu$ Doppler-corrected tracked γ-ray spectrum gated on binary partner Cd (Z = 48, A=116).




$^{232}Pu$ Doppler-corrected tracked γ-ray spectrum gated on binary partner Cd (Z = 48, A=118).

# AGATA-PRISMA Coincidences – TKEL gates




$^{236}_{94}Pu_{142}$

| Transition | Energy (keV) |
|---|---|
| $16^+ \rightarrow 14^+$ | 372 |
| $14^+ \rightarrow 12^+$ | 339 |
| $12^+ \rightarrow 10^+$ | 301 |
| $10^+ \rightarrow 8^+$ | 258 |
| $8^+ \rightarrow 6^+$ | 210 |
| $6^+ \rightarrow 4^+$ | 158 |
| $4^+ \rightarrow 2^+$ | 103 |
| $2^+ \rightarrow 0^+$ | 45 |

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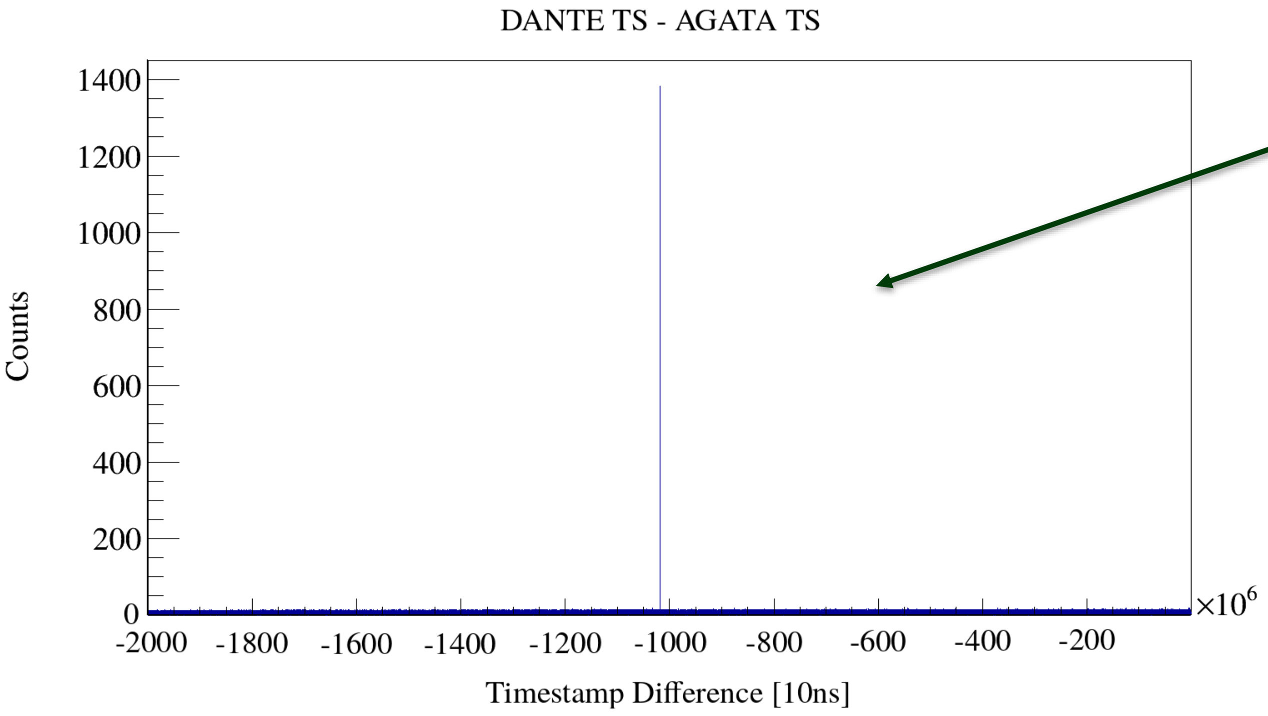
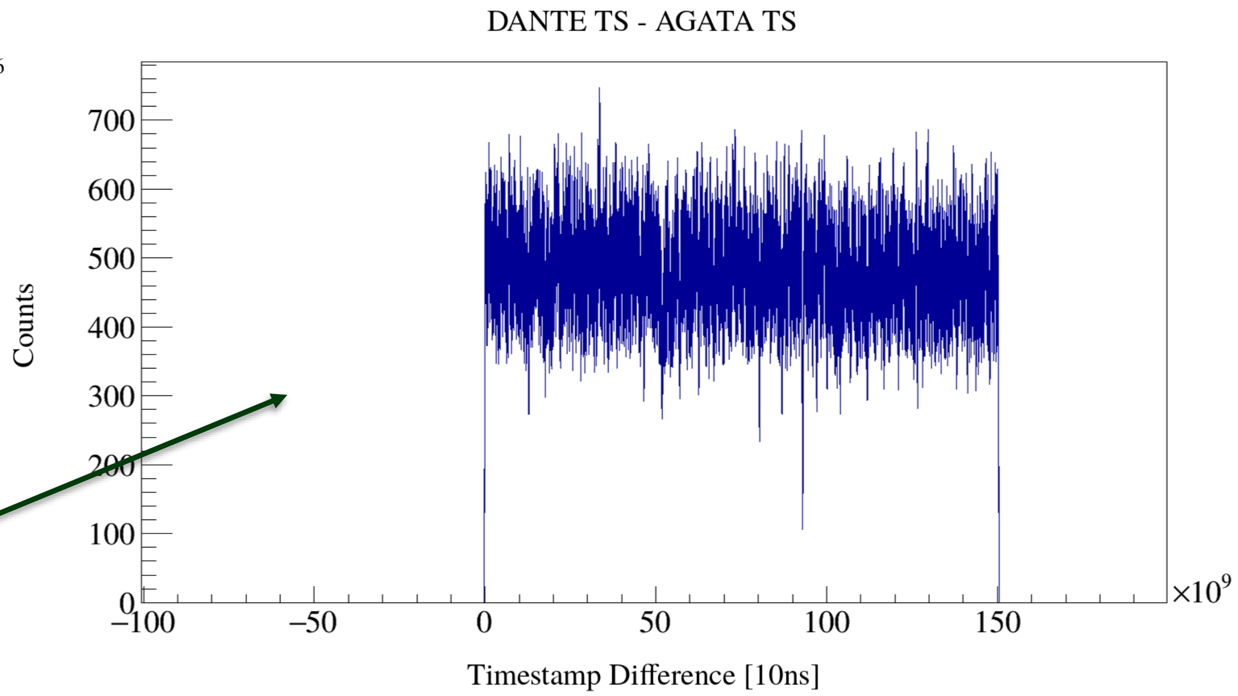
# DANTE Analysis




Timestamp peak for run_0020

Runs 16-26 show clear peaks from which DANTE can be aligned with AGATA.

~18% of total data can be aligned currently.




Runs 27-50 do not show any significant peak structure.

After run_0026 two DANTE digitizers were changed.

Timestamp peak for run_0033

# Summary

Things that need to be done:

- PRISMA analysis to be repeated using correct MCP mask calibration coordinates.
- DANTE time alignment; issue with later runs to be fixed and timestamps between AGATA and DANTE to be aligned.
- Observe AGATA-PRISMA-DANTE coincidences after applying DANTE to the replay. Gate on ToF and TKEL to improve resulting gamma-ray spectra by gating out target-like fission products.
- Hopefully observe transitions in $^{234}Pu$, from which a level scheme can be tentatively established.
- Look at AGATA-PRISMA coincidences to observe transitions in projectile-like reaction products.

# Collaborators

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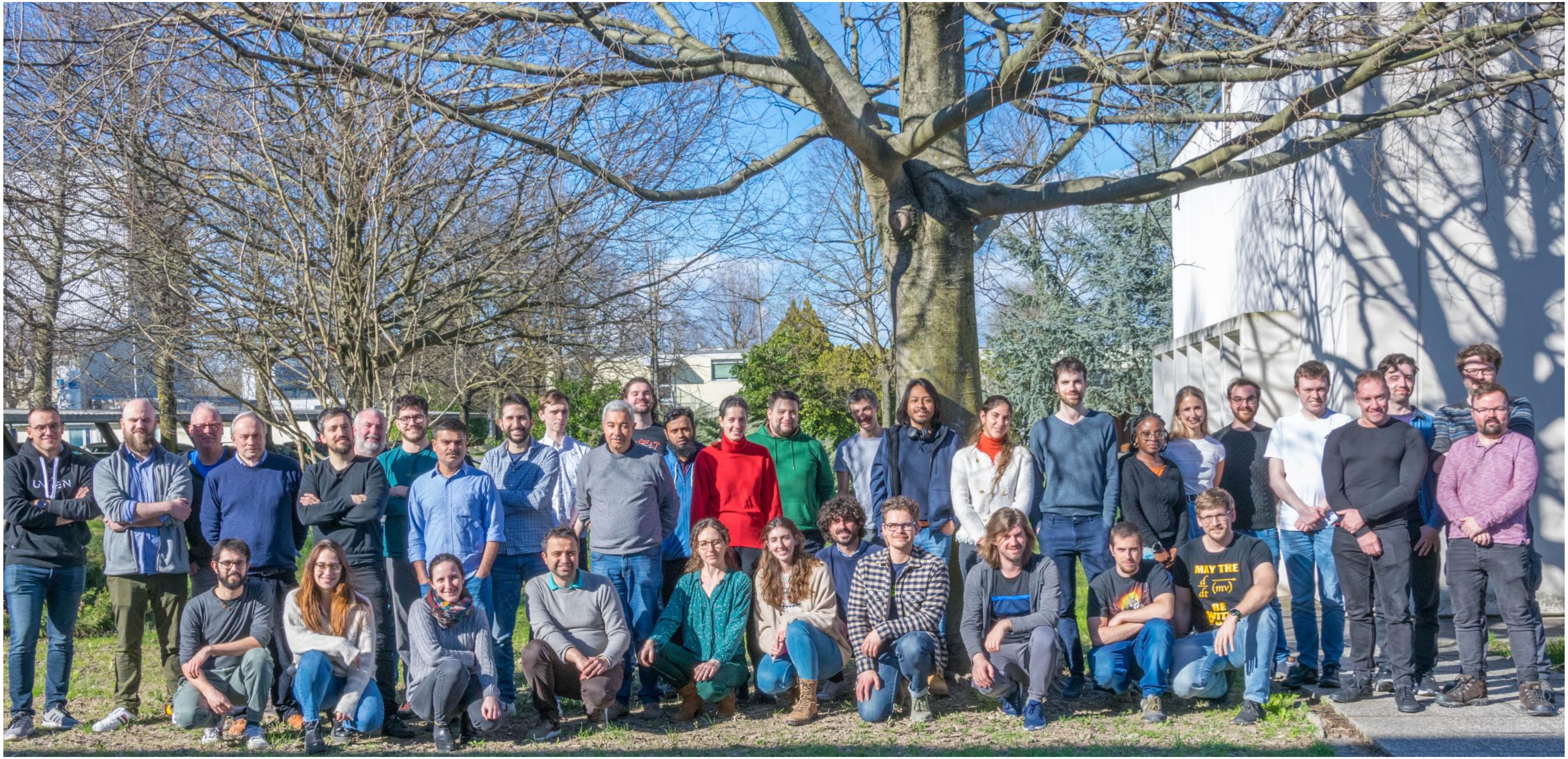
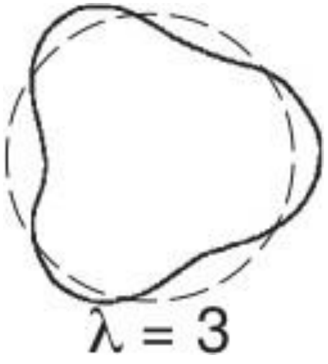
[13] Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

# Thankyou



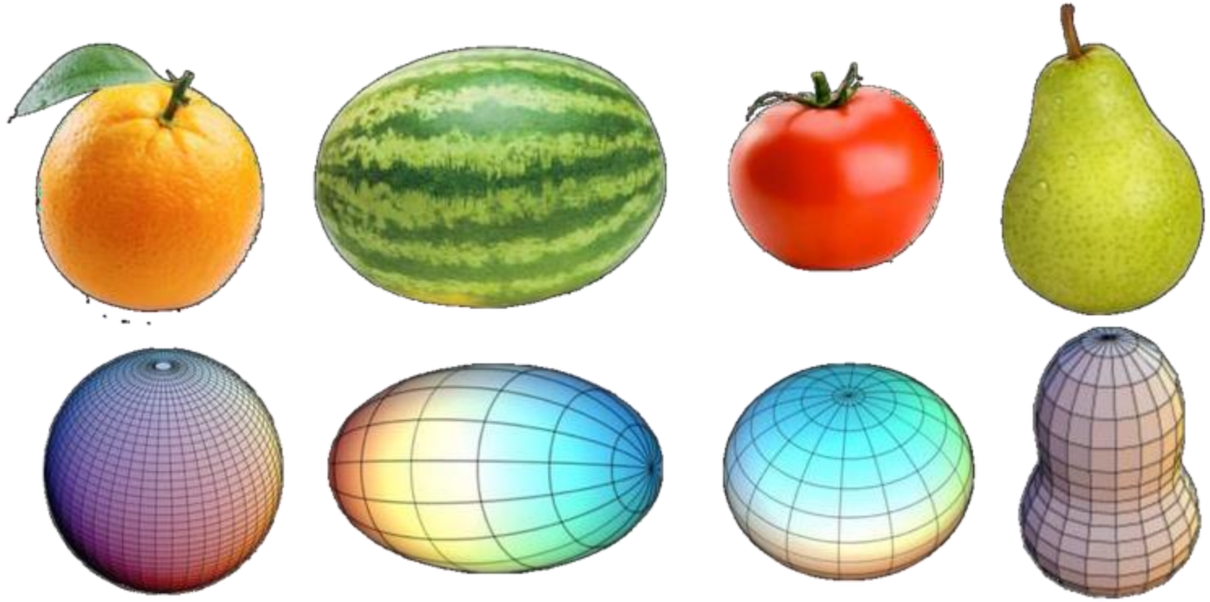
# Octupole deformation

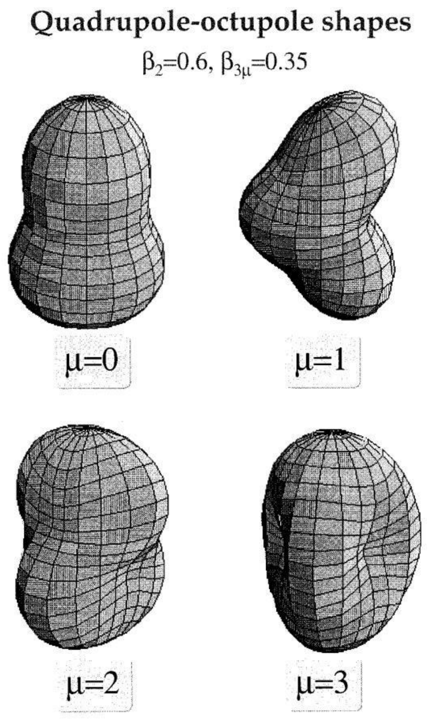
The nuclear shape is described by spherical harmonics multiplied by an expansion coefficient (deformation parameter).



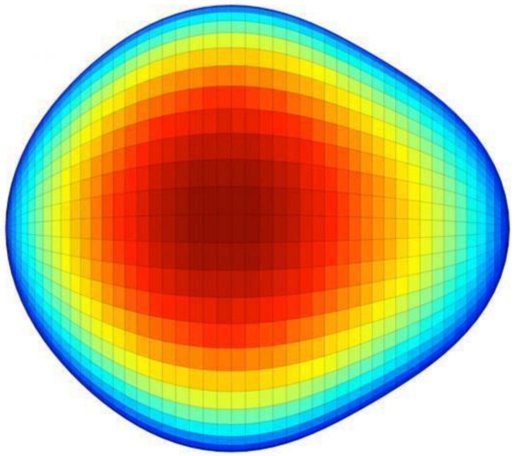

$$R(\theta,\phi) = R_0[1 + \sum_{\lambda,\mu} \alpha_{\lambda,\mu} Y_\lambda^\mu]$$

| Spherical | Prolate | Oblate | Pear-shaped |
|---|---|---|---|

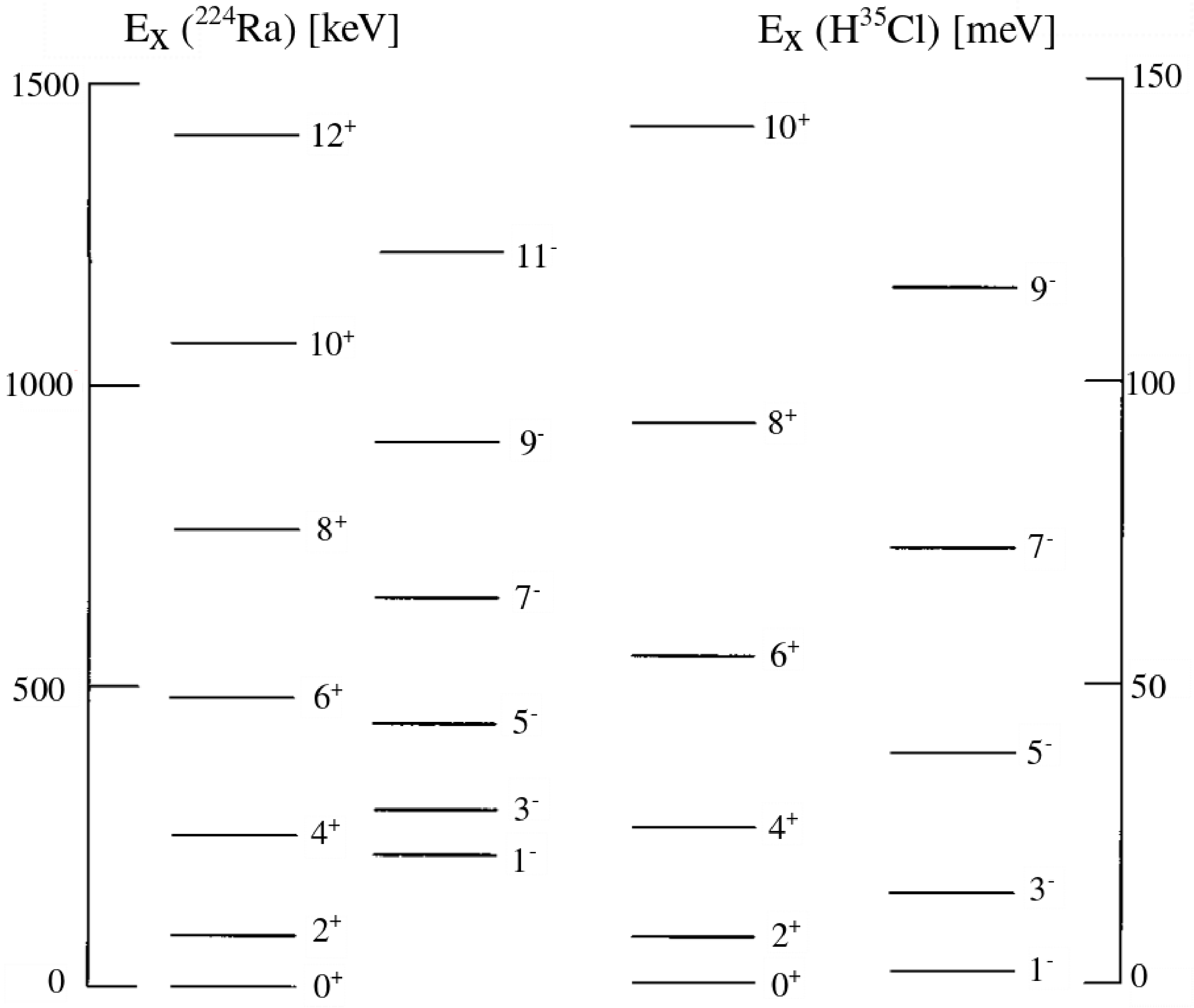


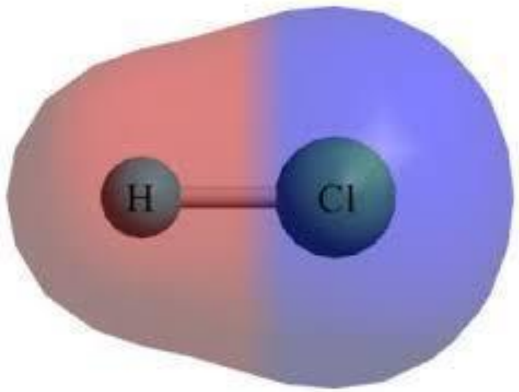


# Spectroscopic features of octupole deformation



$^{224}Ra$

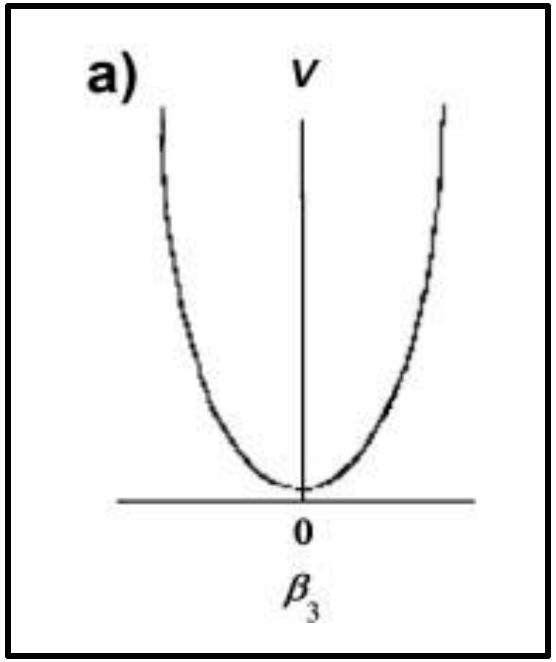


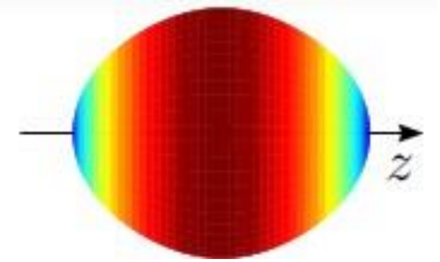

HCl

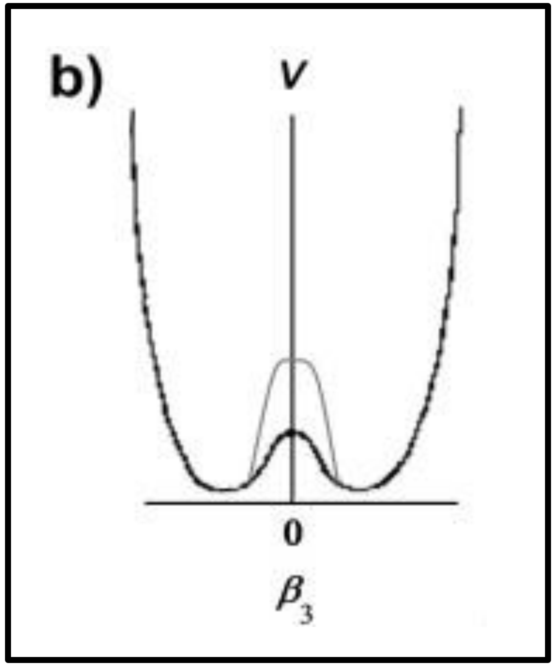
# Spectroscopic features of octupole deformation

Angular momentum increasing

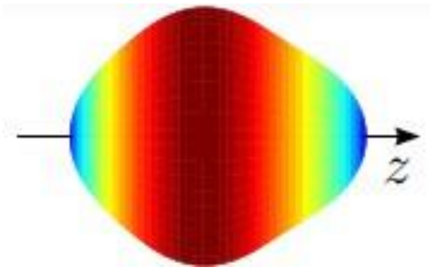


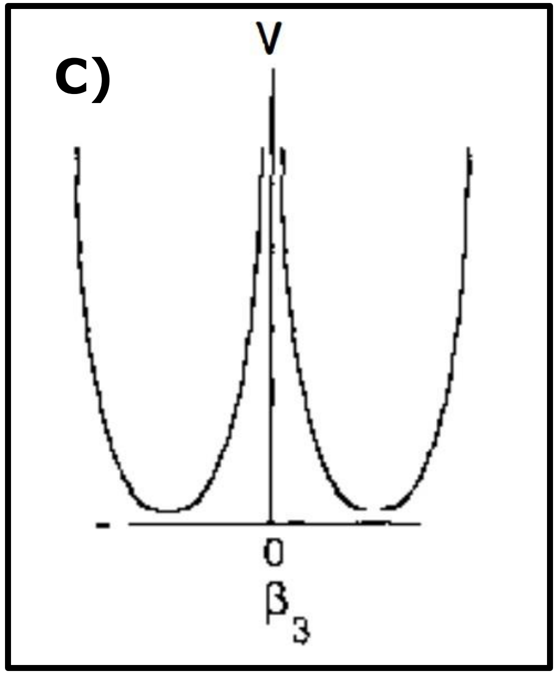

Octupole vibrational



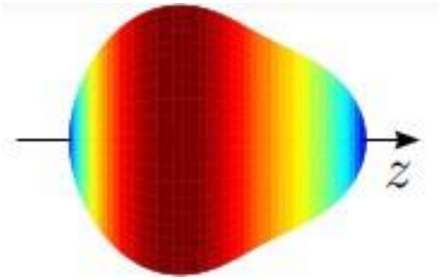




Octupole deformed (static)



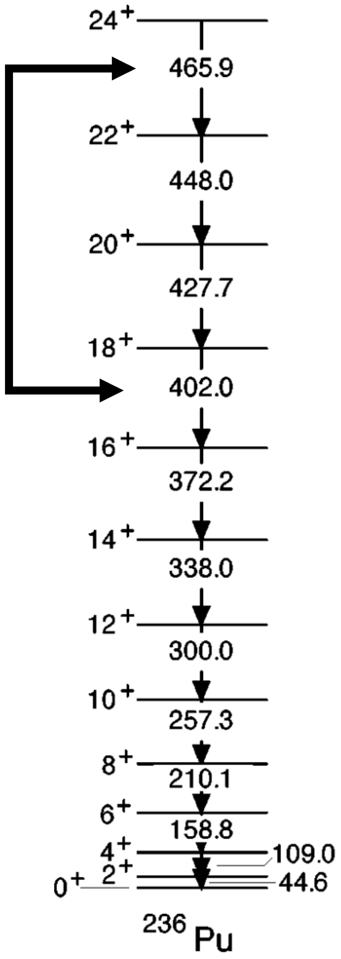

Octupole deformed (rigid)

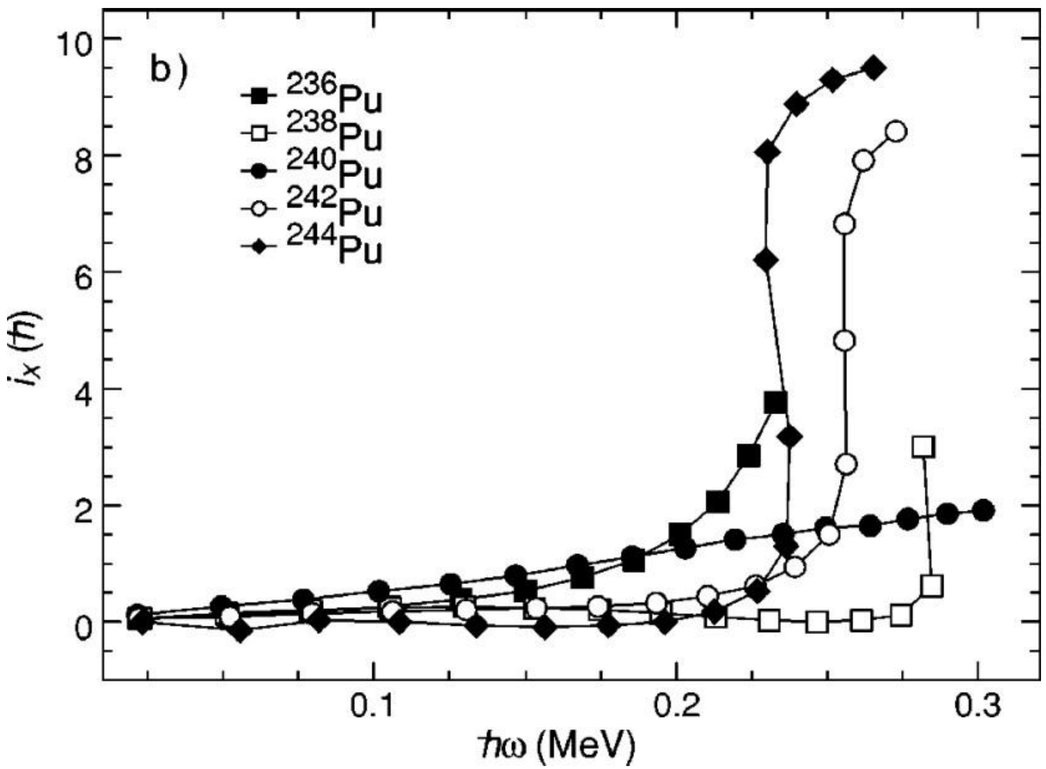


# Previous plutonium studies

- An experiment by K. Abu Saleem et al. studied the $^{236}Pu$ isotope [K. Abu Saleem et al., Phys. Rev. C 70, 024310 (2004)] using the $^{237}Np(^{209}Bi,^{210}Pb)$ transfer reaction.
- Additional four γ-ray transitions identified in $^{236}Pu$ adding to established level scheme.

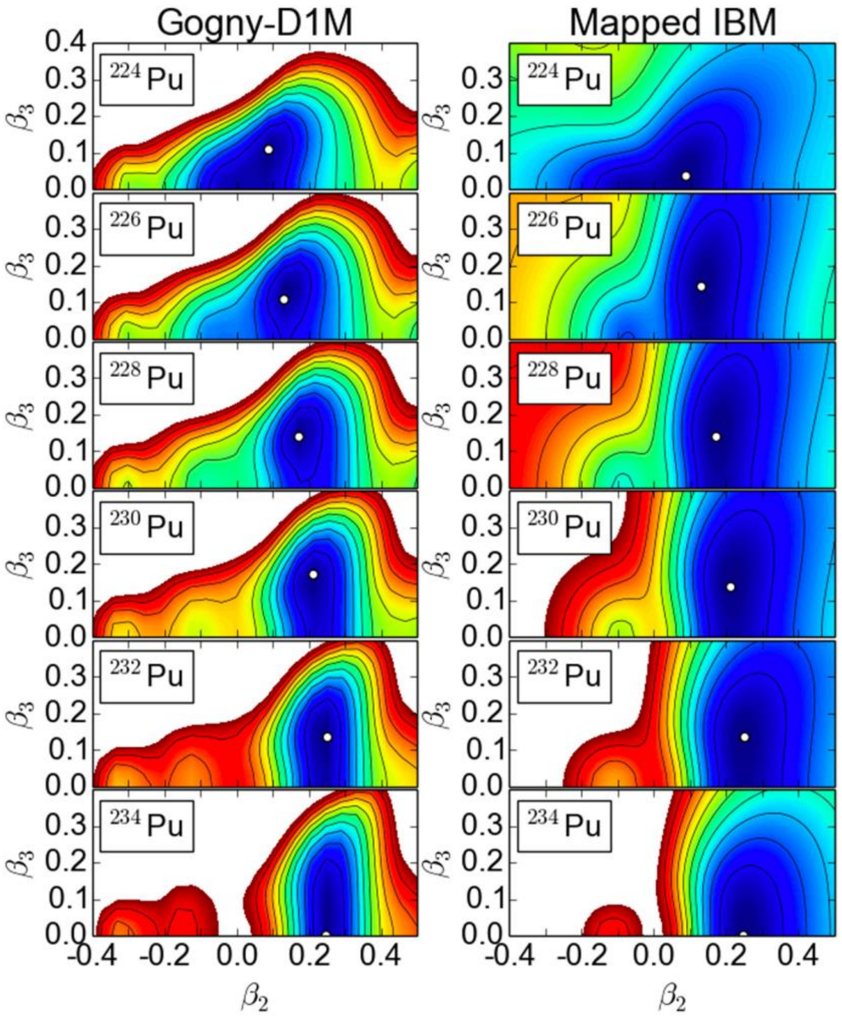
added γ rays



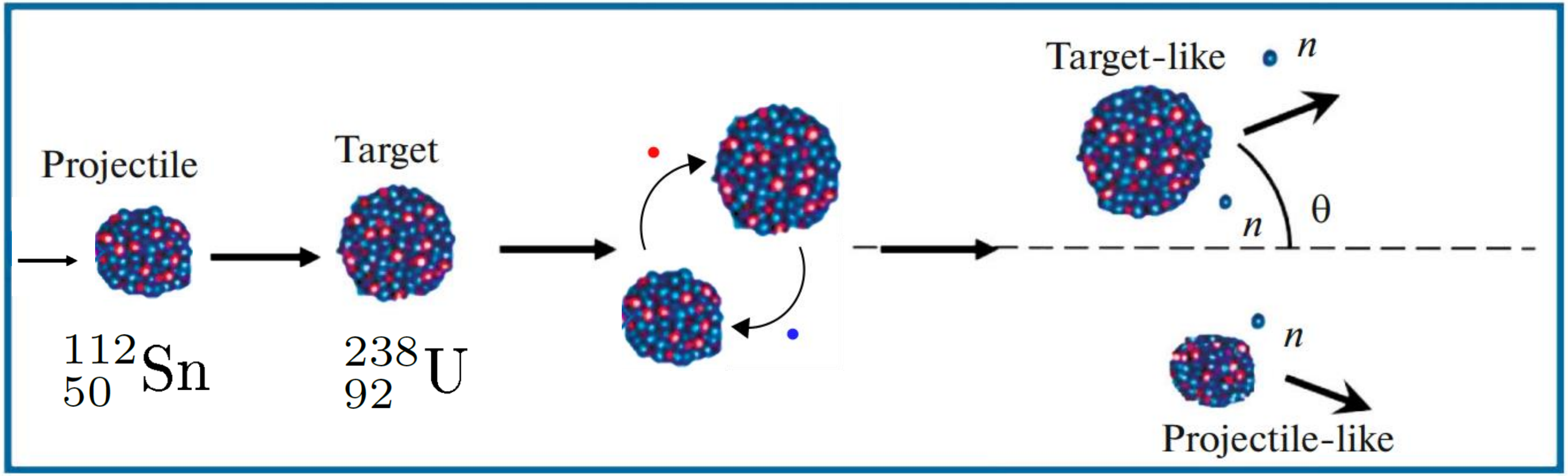

- Alignments show delayed backbending for plutonium isotopes with $^{236}Pu$ and $^{238}Pu$.
- Only $^{238\text{-}240}Pu$ show interleaving alternating parity states indicating stronger octupole effects.

# Theoretical predictions




- Potential-energy surface for $^{234}$Pu has $\beta_3 \simeq 0$ whereas $^{232}$Pu has $\beta_3 \simeq 0.22$.

# Multi-nucleon transfer reactions



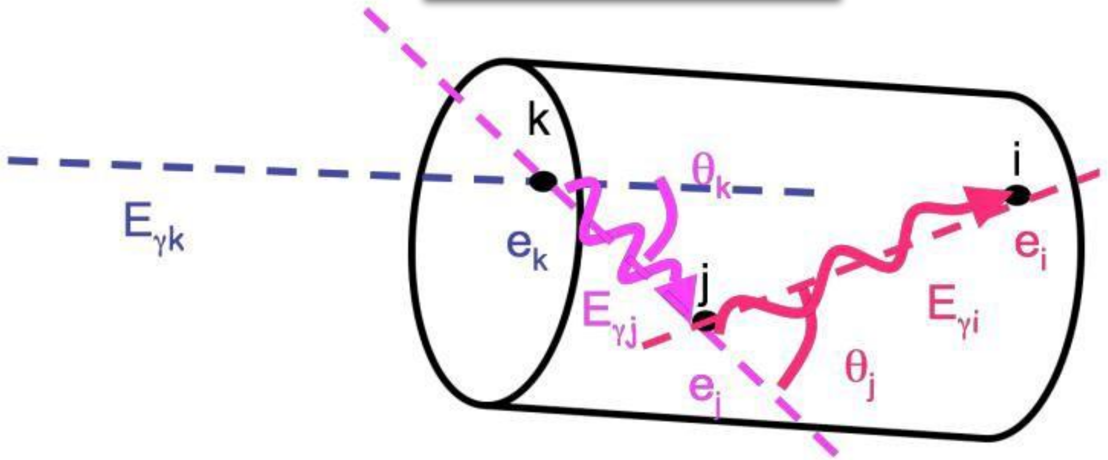

- Able to probe exotic nuclei past the current experimental limit when using fusion, fragmentation and other methods.
- Combination of MNT reactions with AGATA-PRISMA detector setup allows improved efficiency and selectivity.

# AGATA - Gamma-ray tracking

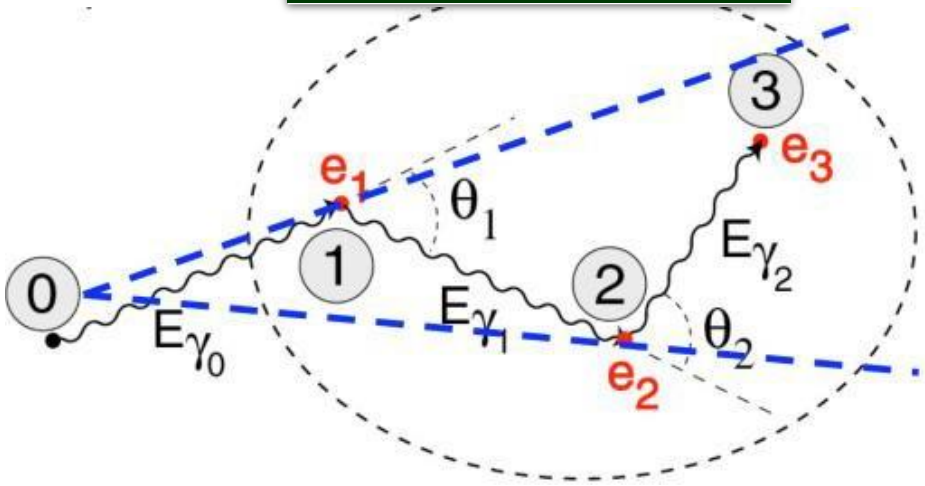
- Segmented germanium crystals allows reconstruction of gamma-ray energy.
- Two algorithms are employed to determine correct interaction sequence.
- Negates the requirement for Compton suppression and improves the overall detection efficiency of the apparatus.

| | Ph. Eff. | P/T |
|---|---|---|
| Forward-tracking | 61.6 (33.9) | 84.2 (57.7) |
| backtracking | 40.3 (25.3) | 67.0 (46.7) |

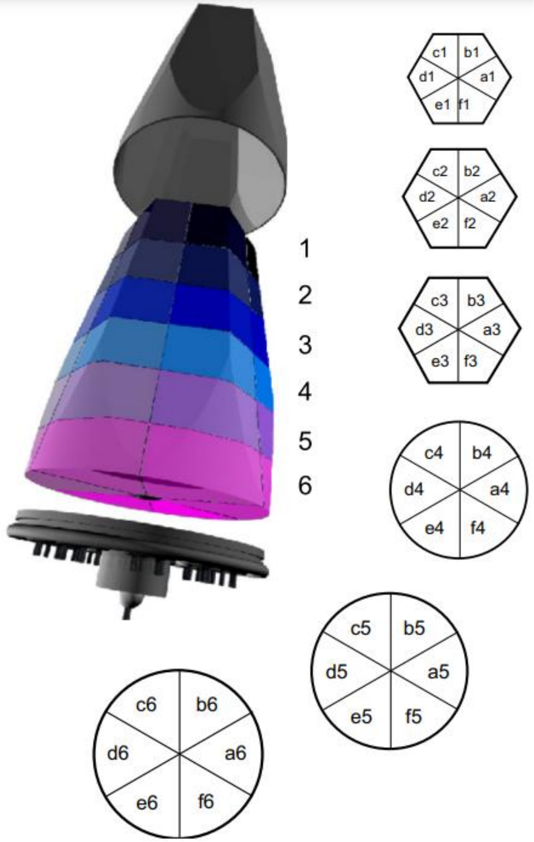
Backtracking




Forward Tracking

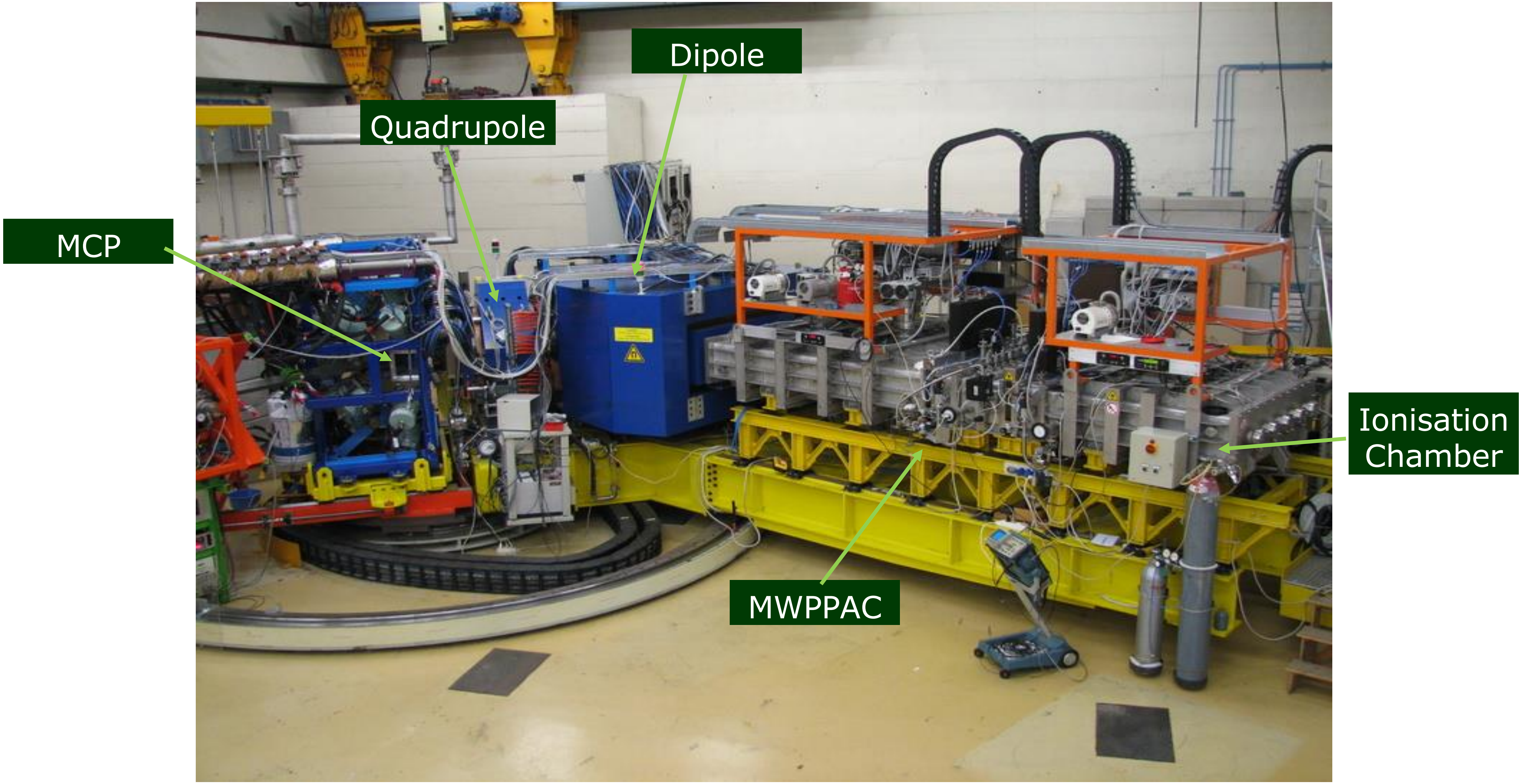


# AGATA- Advanced Gamma-ray Tracking Array



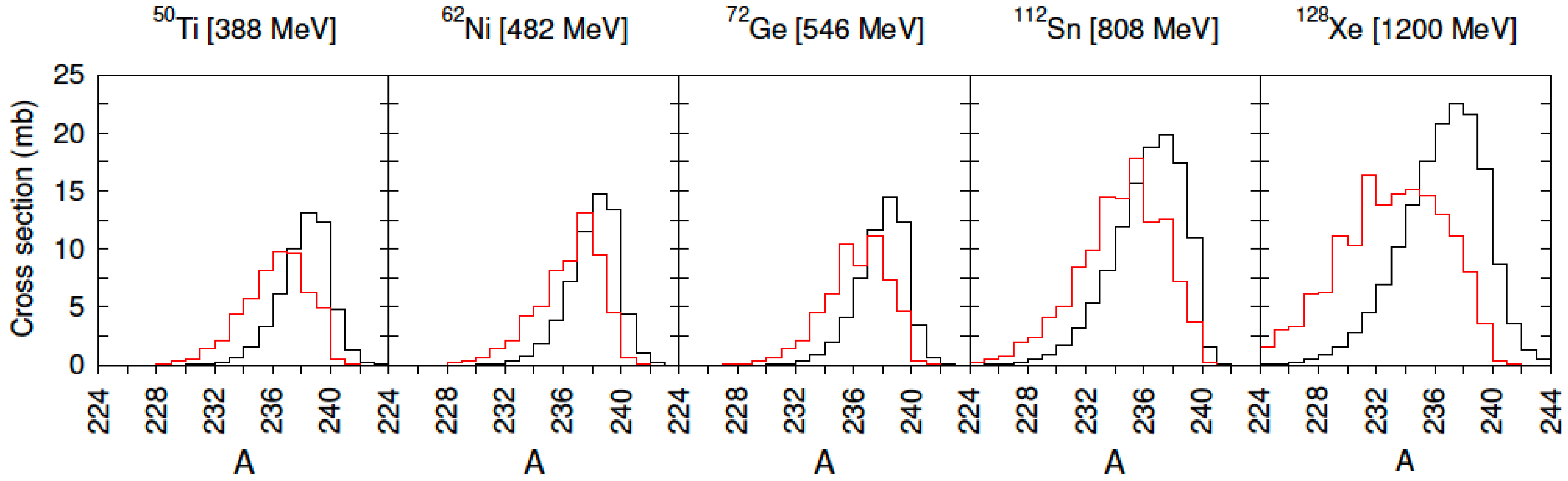

- New generation of gamma-ray spectrometers.
- Employs the novel technique of gamma-ray tracking to reconstruct events.
- 13 triple clusters.
- 36-fold segmentation.

# PRISMA Magnetic Spectrometer



# GRAZING Calculations

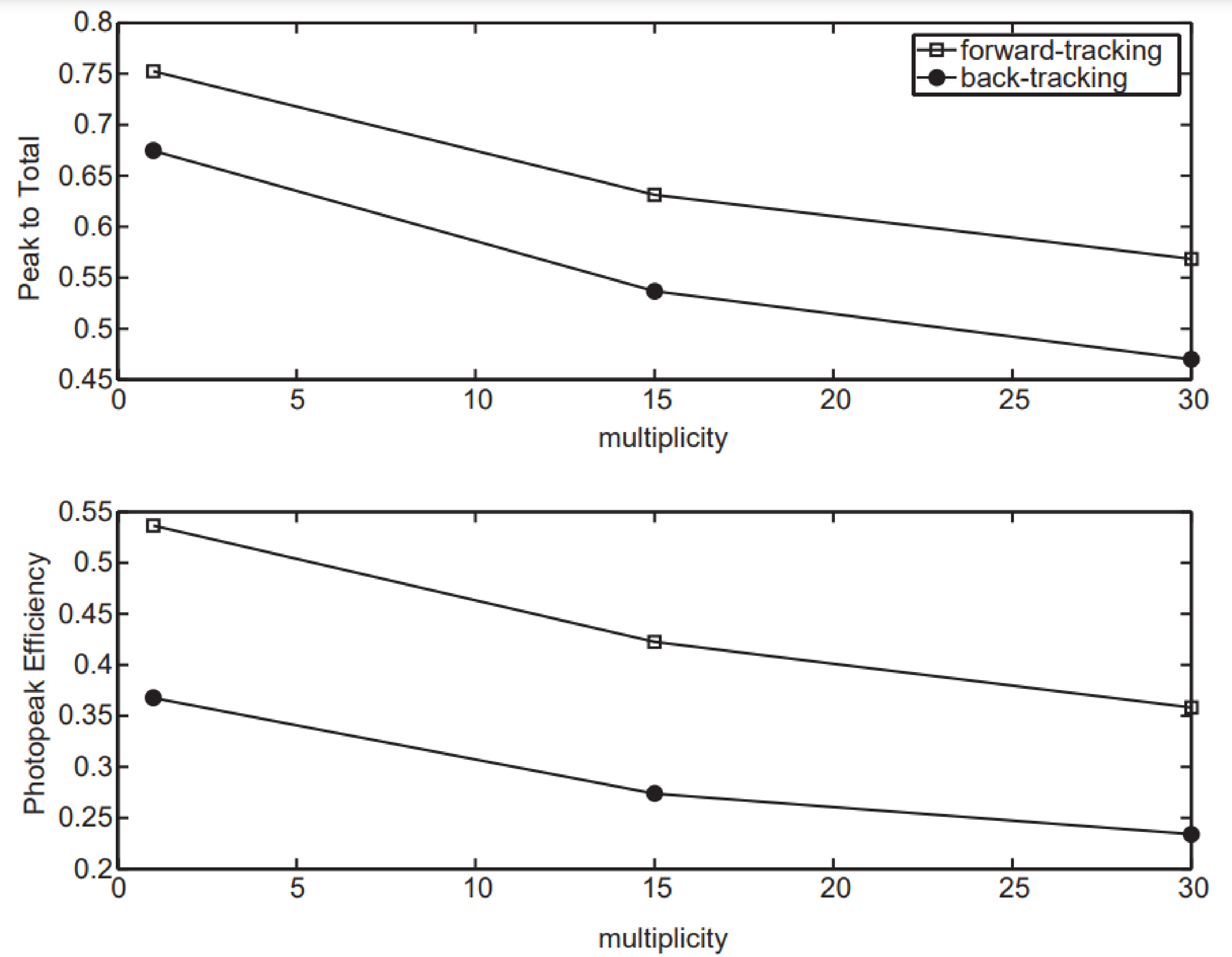
Multi-nucleon transfer reactions on $^{238}$U targets:
results of Grazing calculations



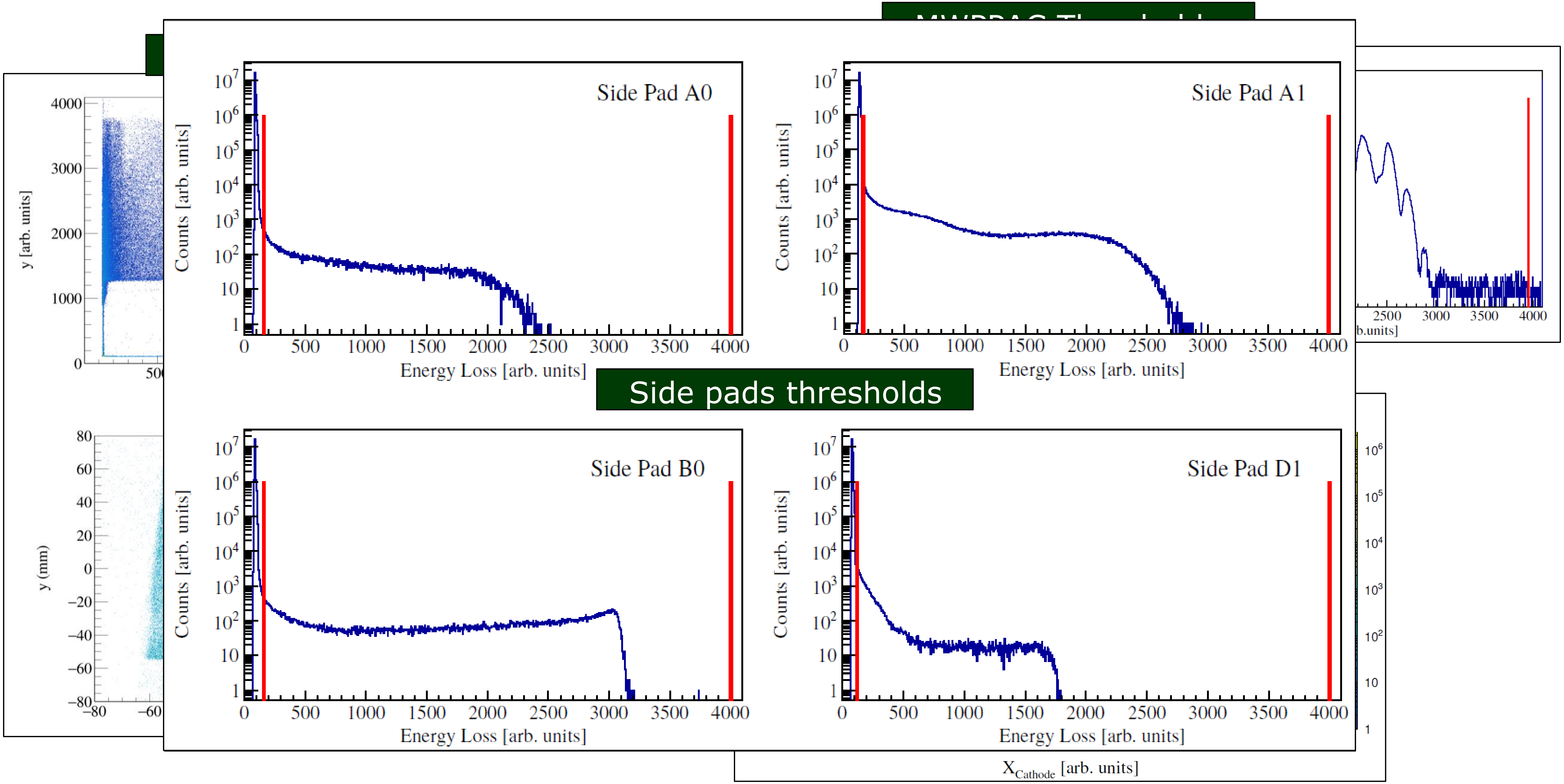

$\sigma(^{234}Pu)=4.4$ mb $\sigma(^{234}Pu)=4.3$ mb $\sigma(^{234}Pu)=4.5$ mb $\sigma(^{234}Pu)=14.0$ mb $\sigma(^{234}Pu)=14.0$ mb

$^{238}$U+$^{112}$Sn already suggested: Zhu et al. Chinese Physics C 41, 12 (2017)

# Forward tracking vs. backtracking



# PRISMA - Calibrations



# PRISMA - Mass calibration

$$mass = \left(\frac{A}{q}\right)_{cal} \cdot q_{eff}$$

Explain that once the calibrated A/q is obtained that an effective charge state has to be determined.

This allows fine tuning of the mass distribution.

Show example of the calculation and before and after the fine tuning to the centroids of the mass distributions.

# GRID Access

AGATA
ADVANCED GAMMA TRACKING ARRAY

IP2I Gamma softwares userguides
Last update: 2024-07-02

Search docs

Docs » AGATA data » Download data from the grid

## Data download from the grid

### Preparation

The Grid is a cooperation of many different clusters and research organizations, and as such, there is no centralized user management. Yet, there must be a way for the system to identify you and your work. This is why **Grid certificates** and **Virtual Organizations** (VOs) are introduced

Your digital identity starts with a private key. certificate, which is issued by a Certificate A and it says that the person who owns the pri Certificate Authority.

Now this is your identity. Big international co become part of Virtual Organizations. To give passport) and the VO provides authorization

The AGATA collaboration is sharing a docker image with the Grid UI installed. This docker image generation is done here

For the following, the docker application needs to be installed.

To install the AGATA Grid docker image:

```
docker pull gitlab-registry.in2p3.fr/ip2igamma/docker_images:agata_grid
```

### Start docker image

CERTIF_DIR: repository on you computer containing your produce the certificated in the `.pem` format, required by the grid UI. r image. - DATA_DIR: repository where the data will be dowloaded

ATA_DIR is `/path/to/data`, apply:

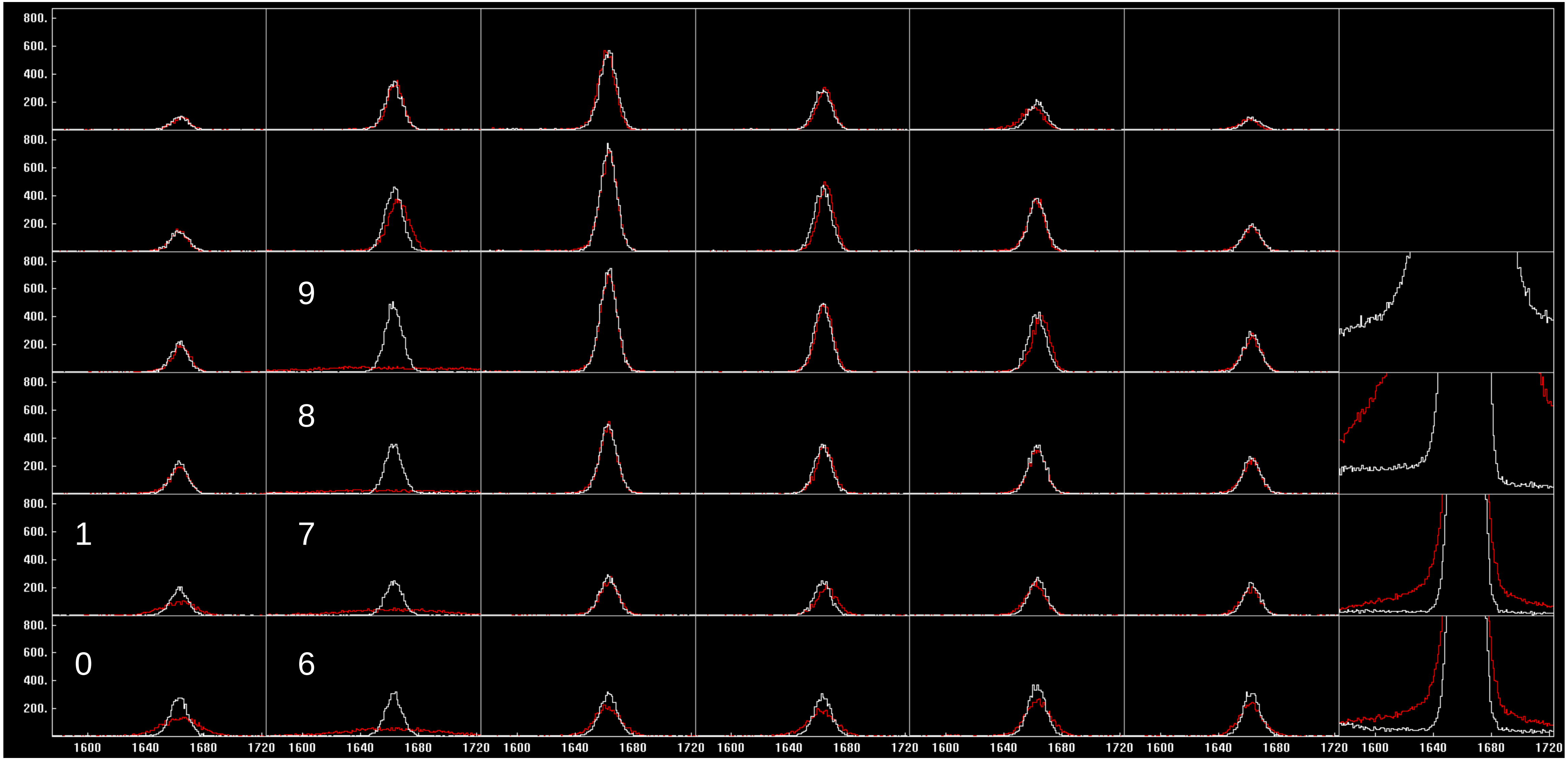
```
docker run -it --rm -v ${CERTIF_DIR}:/root -v ${DATA_DIR}:/data gitlab-registry.in2p3.fr/ip2igamma/docker_images:agata_grid
```

Explain process of getting onto GRID was lengthy and for a university that doesn't have a local representative that deals with the access this was a difficult process.

Credit Jeremie Dudouet for continued help and creation of docker image that resulted in quick access to trace files necessary for neutron damage and final energy calibration.

# Neutron Damage Corrections – Problematic Crystals

Crystal 08B, poor resolution in segments 0, 1, 6, 7, 8, and 9 - Recovered using core signals (white)



# AGATA-PRISMA Coincidences