VNiVERSiDAD DSALAMANCA | Laboratorio Datación Radiaciones Ionizantes

CHARACTERIZATION OF B003 AGATA DETECTOR IN THE SALSA SETUP

Gala González Briz

XVII CPAN DAYS

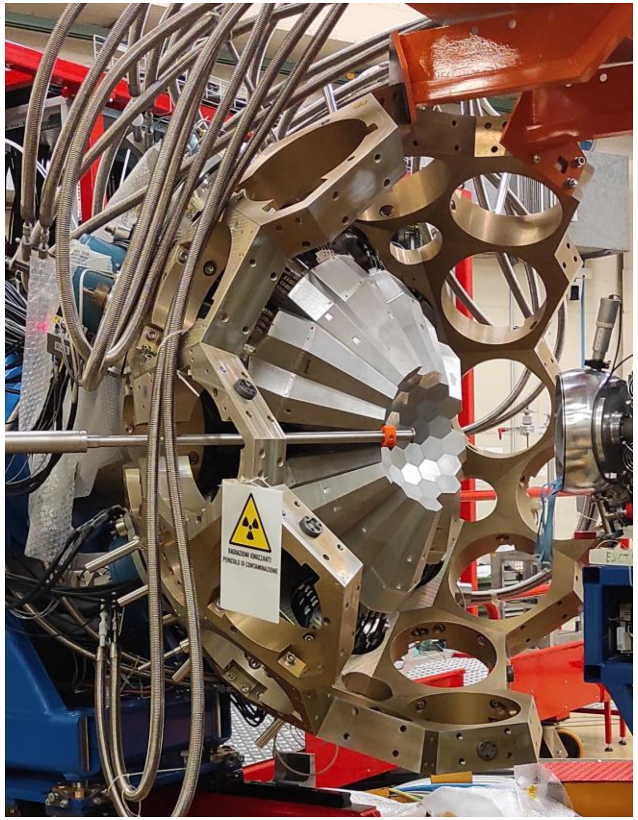
20th November 2025

TABLE OF CONTENTS

INTRODUCTION

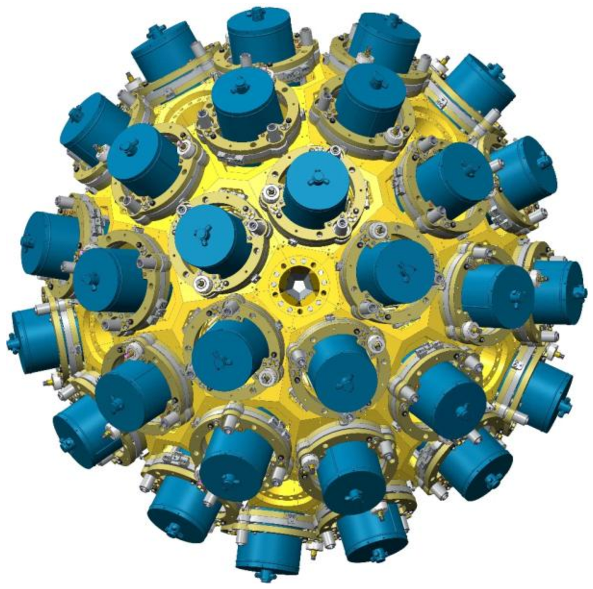
AGATA SPECTROMETER

- AGATA is a **4π γ-ray spectrometer**.
- It is used in **nuclear structure experiments in both radioactive and stable beam facilities**.
- It will be composed of 180 detectors, organized in triple cluster structures.
- In the collaboration, more than 40 research groups from 13 European countries are involved.



AGATA SPECTROMETER

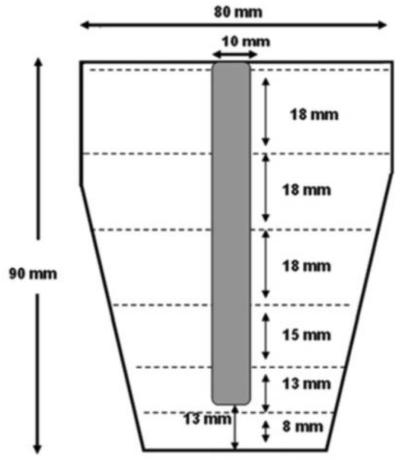
- AGATA is a 4π γ-ray spectrometer.
- It is used in nuclear structure experiments in both radioactive and stable beam facilities.
- It will be composed of **180 detectors**, organized in triple cluster structures.
- In the collaboration, more than 40 research groups from 13 European countries are involved.

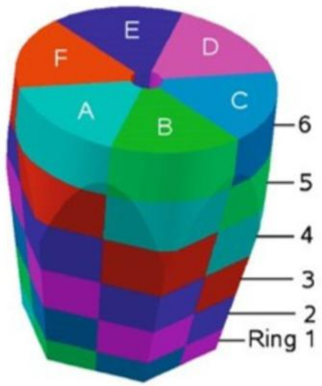


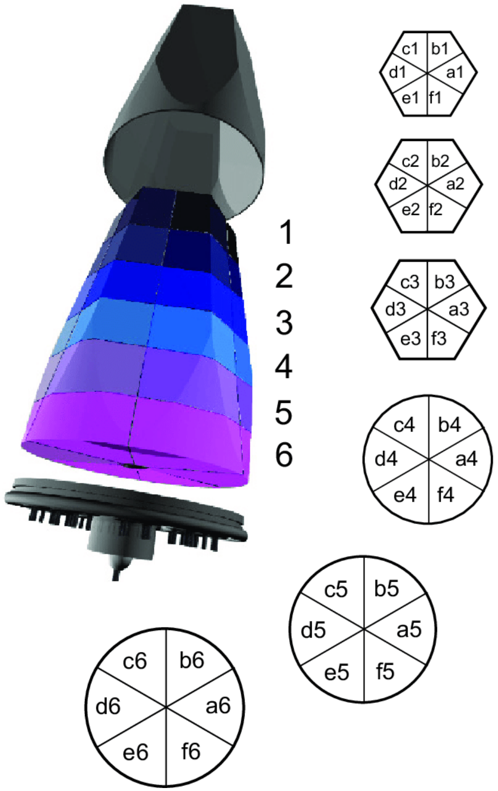
AGATA DETECTORS

- The detectors contain **n-type coaxial HPGe crystals**:
  - 2-3 kg Ge, V ≅ 380 cm^3
  - Asymmetric tapered hexagonal geometry.
  - The internal contact (core) is n-type
  - The external contact is p-type and it is **electrically segmented**

Volume subdivided in **36 segments + central core**

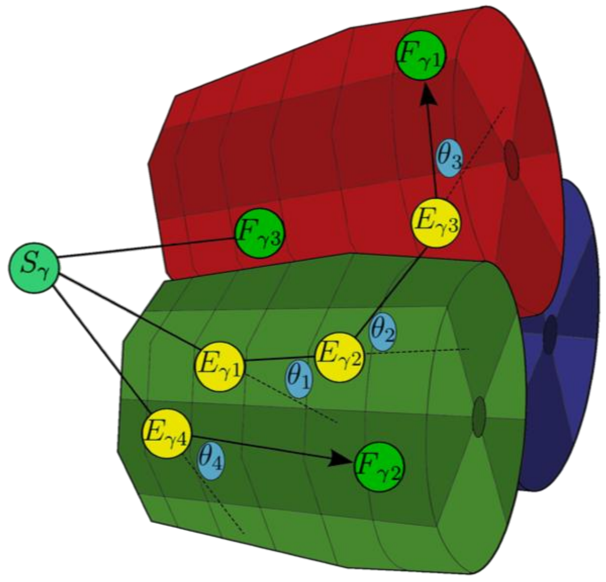




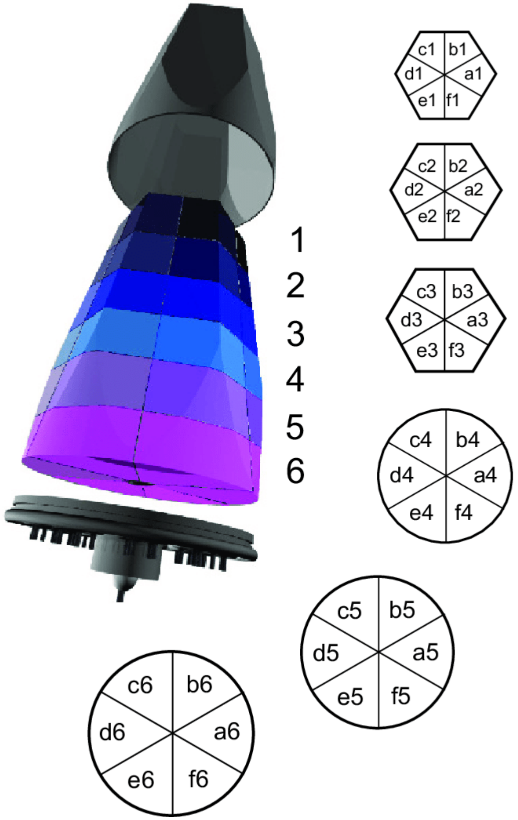


TRACKING: γ-RAY RECONSTRUCTION

- AGATA is based on **tracking to reconstruct the γ–ray**:
  - First interaction position to perform **better Doppler correction**
    → Improved **resolution**
  - Selection of full absorption events: **reduction of background**
    → Increased **sensitivity**
  - Anticompton detectors are not required as active shielding, thus it is possible to install a larger volume of active Ge, leading to a **greater solid angle coverage**
    → Improved **efficiency**



TRACKING: γ-RAY RECONSTRUCTION

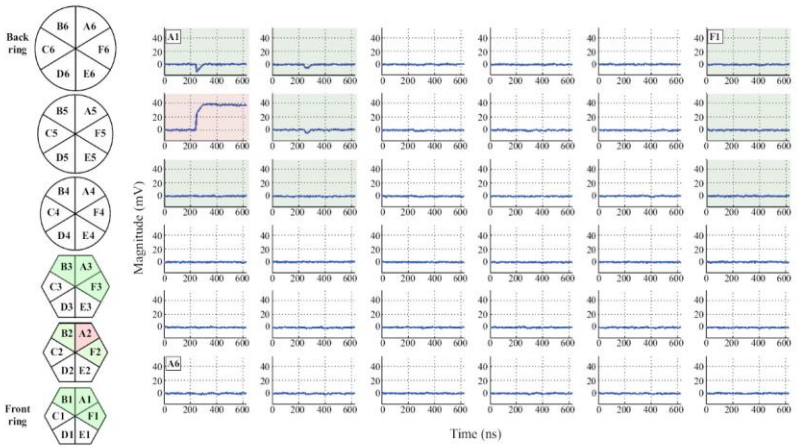


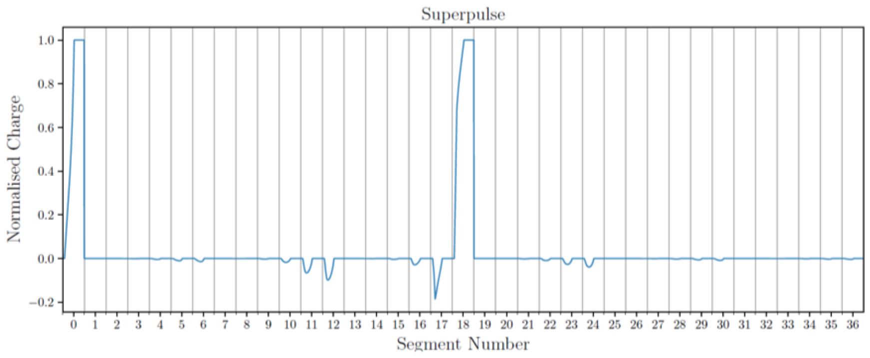
- To **perform tracking**, we need:
  - **Position sensitive HPGe detectors**:

    Electrical segmentation technology

    37 signals per detector (36 segments + central core)

TRACKING: γ-RAY RECONSTRUCTION





- To **perform tracking**, we need:
  - Position sensitive HPGe detectors:

    Electrical segmentation technology

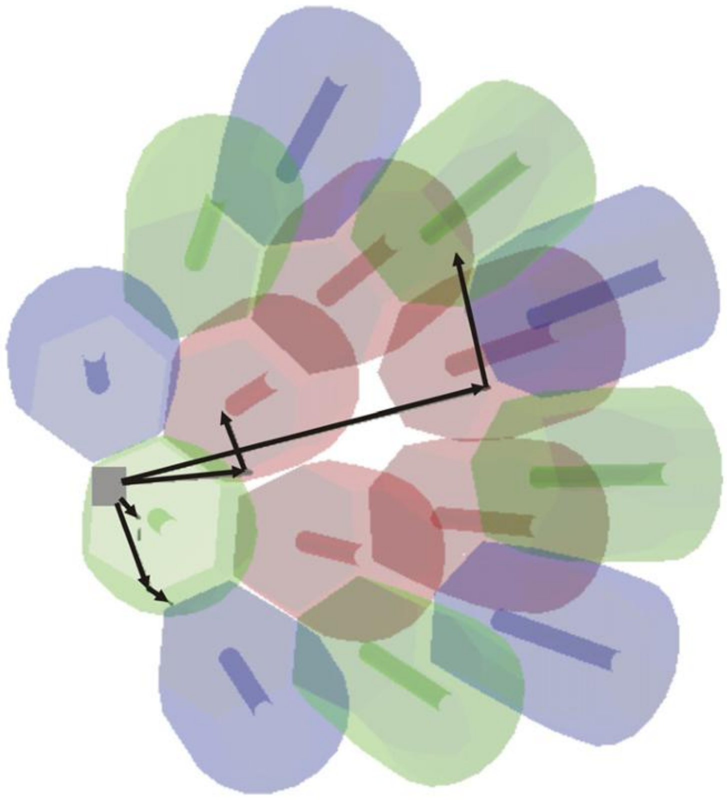
    37 signals per detector (36 segments + central core)
  - **PSA (Pulse Shape Analysis)** algorithms:

    Each set of pulse shapes provides information about the interaction positions and the energy deposited by the radiation

Electrical response of the detector → **PSA** → Determination of the interaction positions and energy

Simulated DB as reference is currently in use

TRACKING: γ-RAY RECONSTRUCTION



- To **perform tracking**, we need:
  - Position sensitive HPGe detectors:
    Electrical segmentation technology
    37 signals per detector (36 segments + central core)
  - PSA (Pulse Shape Analysis) algorithms:
    Each set of pulse shapes provides information about the interaction positions and the energy deposited by the radiation

    Electrical response of the detector → PSA → Determination of the interaction positions and energy

    Simulated DB as reference is currently in use
  - **Tracking algorithms**:
    The most probable trajectory is evaluated through tracking algorithms that are based on the Compton Scattering equation.

TRACKING: γ-RAY RECONSTRUCTION

- To **perform tracking**, we need:
  - **Position sensitive HPGe detectors**:
    Electrical segmentation technology
    37 signals per detector (36 segments + central core)
  - **PSA (Pulse Shape Analysis) algorithms**:
    Each set of pulse shapes provides information about the interaction positions and the energy deposited by the radiation

    Electrical response of the detector → PSA → Determination of the interaction positions and energy

    Simulated DB as reference is currently in use

Need for experimental characterization of detectors

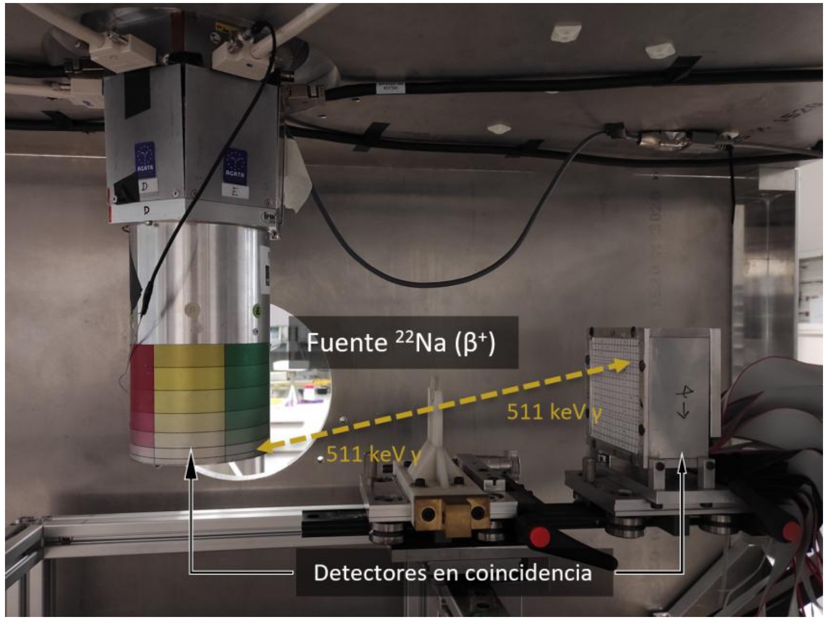
  - **Tracking algorithms**:
    The most probable trajectory is evaluated through tracking algorithms that are based on the Compton Scattering equation.

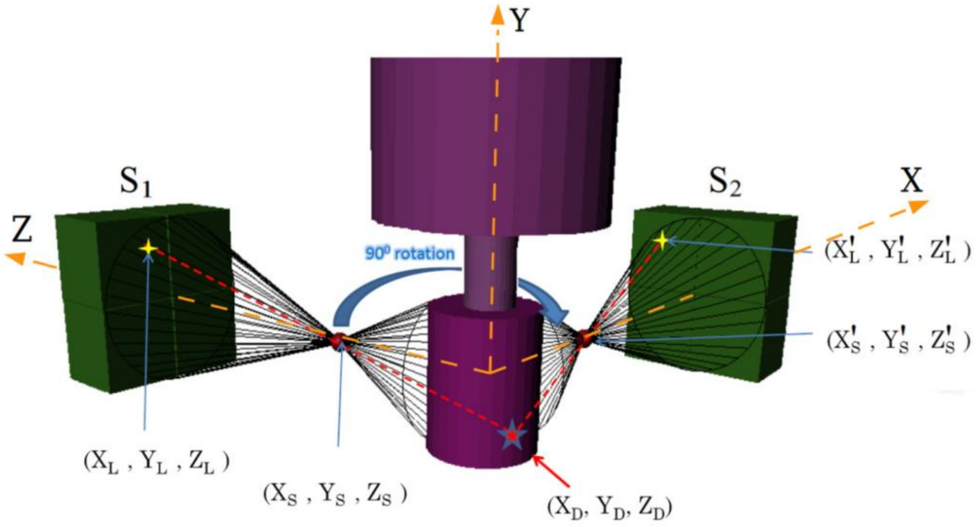
METHODOLOGY

SALSA: SAlamanca Lyso-based Scanning Array

- Objective: To **characterize a detector** by constructing an experimental database that **relates the radiation interaction position** within the crystal to its **electrical response (set of pulse shapes)**

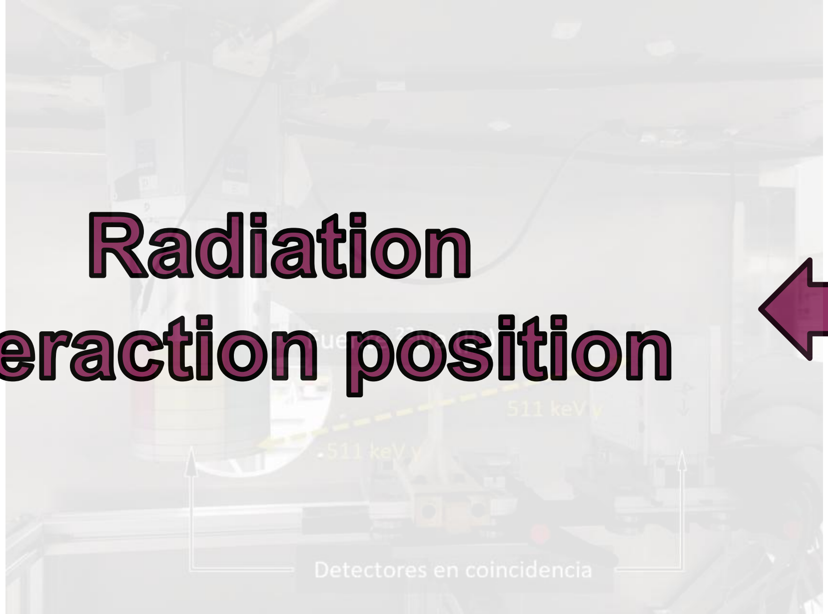
  - ^{22}Na: positron source → after annihilation, two 511 keV **photons are emitted at 180º → active collimation**
  - **Measurement in coincidence**, between the detector to scan (AGATA), and a γ-ray camera.



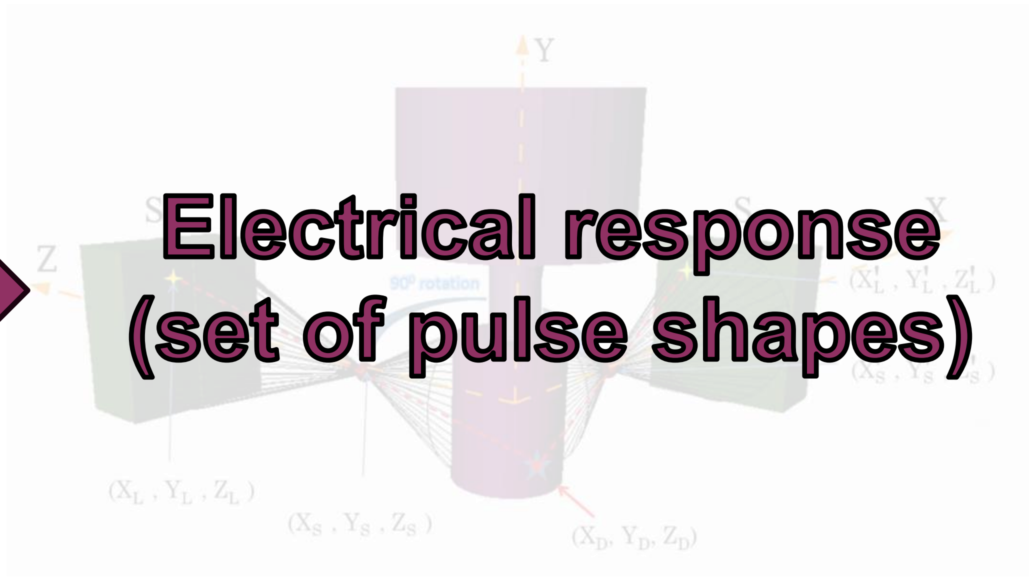


SALSA: SAlamanca Lyso-based Scanning Array

- Objective: To **characterize a detector** by constructing an experimental database that **relates the radiation interaction position** within the crystal to its **electrical response (set of pulse shapes)**
    - ^{22}Na: positron source → after annihilation, two 511 keV **photons are emitted at 180º** → **active collimation**
    - **Measurement in coincidence**, between the detector to scan (AGATA), and a γ-ray camera.



Radiation interaction position ⟷ **Electrical response (set of pulse shapes)**



EXPERIMENTAL SETUP

SALSA: SAlamanca Lyso-based Scanning Array

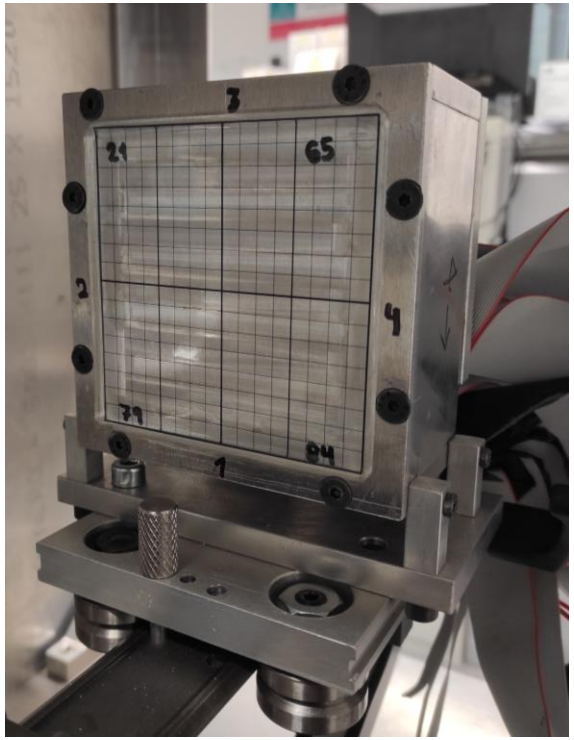
SALSA electronics

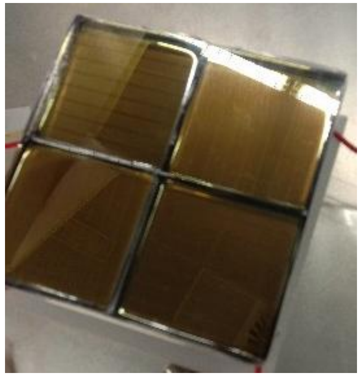
- We have **two detectors** with **its corresponding electronics** + the **coincidence electronic** setup

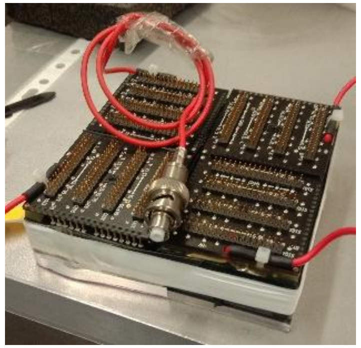
SALSA electronics

- We have **two detectors** with **its corresponding electronics** + the **coincidence electronic** setup

➢ ***γ*-camera electronics**







4 PSD (Position sensitive detectors)

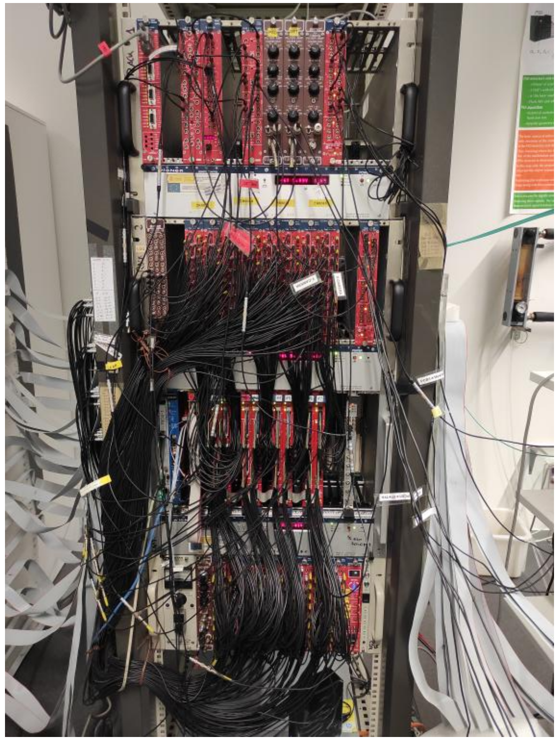
Scintillators:

LYSO crystals: 4 x (52x52x5 mm^3)

Pixelated photomultipliers:

4 x 64 = 256 pixels

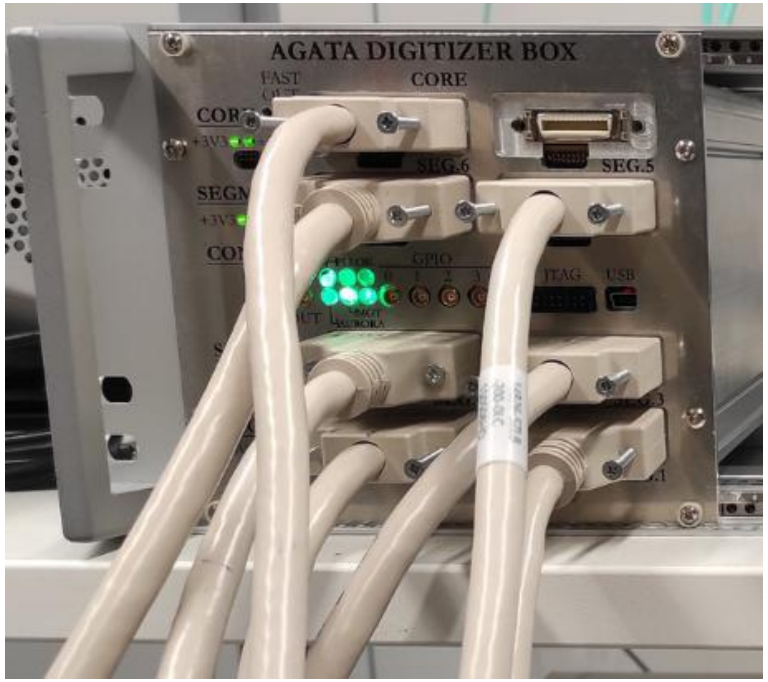
256 channels !!!

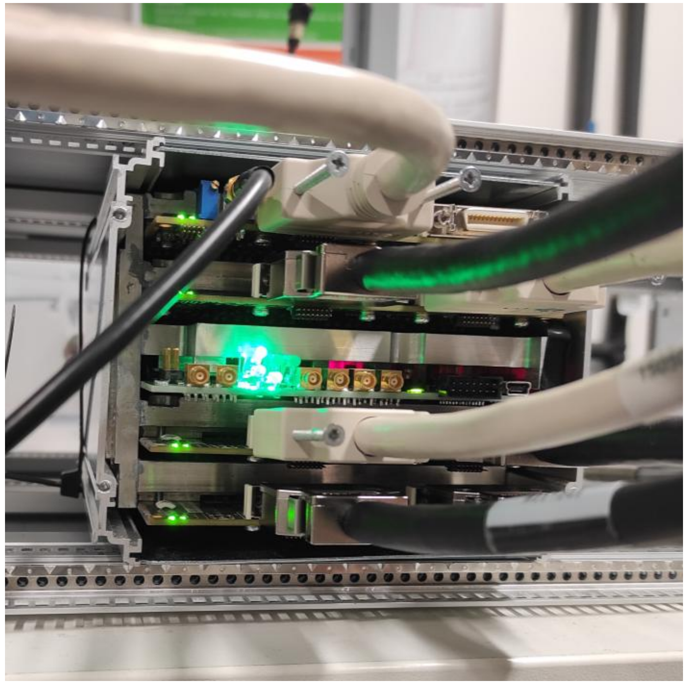


SALSA electronics

- We have **two detectors** with **its corresponding electronics** + the **coincidence electronic** setup

➢ **AGATA electronics**





Same electronics as in AGATA spectrometer, the one used in experiments

Digitizer for 38 channels:

36 segments

+ core

+ additional core signal for coincidences

ACHIEVEMENTS

Stages of the process

1. **Setting up the experimental system**
   - Acquistion electronics: AGATA (Digiopt), γ-camera (MBS) and coincidence
   - AGATA detector preparation:
     - Vacuuming the detector and cooling it down with LN_2
     - Initial test to check operation (e.g. FWHM measurements)
2. **Acquisition software update**: to launch both systems from the same platform
3. **Measurement** from two different configurations
4. **Analysis of results**
   - Matching: correlation of AGATA - γ-camera events
   - PSC: Analysis of AGATA signals
   - Calculation of straight lines and intersection
5. **Building the database** (Electrical pulse shapes – interaction positions)

Stages of the process

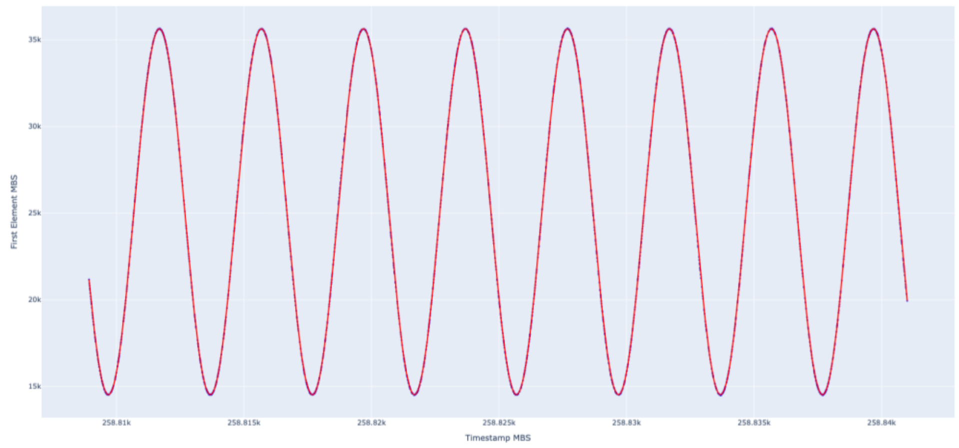
1. **Setting up the experimental system**
    - Acquistion electronics: AGATA (Digiopt), γ-camera (MBS) and coincidence
    - AGATA detector preparation:
        - Vacuuming the detector and cooling it down with LN_2
        - Initial test to check operation (e.g. FWHM measurements)
2. **Acquisition software update**: to launch both systems from the same platform
3. **Measurement** from two different configurations
4. **Analysis of results**
    - Matching: correlation of AGATA - γ-camera events
    - PSC: Analysis of AGATA signals
    - Calculation of straight lines and intersection
5. **Building the database** (Electrical pulse shapes – interaction positions)

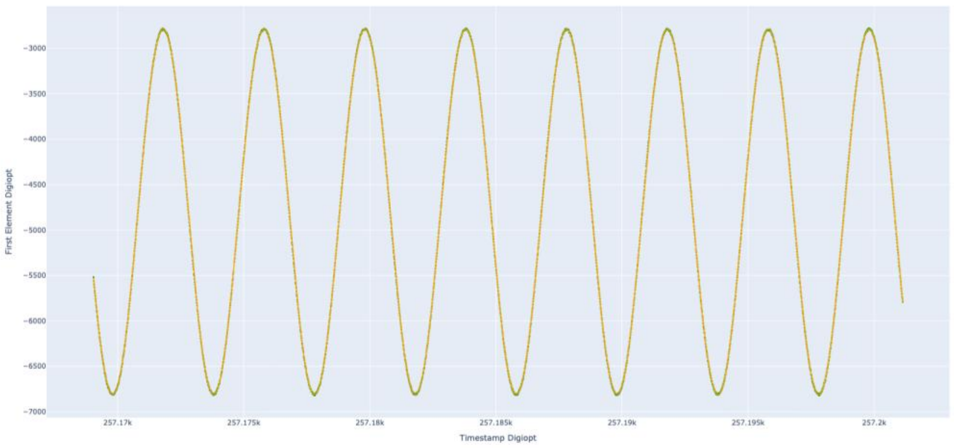
Matching

- **AGATA events must be linked with their corresponding MBS events in coincidence**:
  - AGATA digitizer process every event which triggers the detector
  - MBS (γ-camera) only records events in coincidence
- Find the relation between the two systems → we introduce a **logical signal (pulse) to mark the event**

Matching

- Trouble: **One clock runs ahead/behind another** → time shift does not work
- We need to find a method to solve the problem → introduce a **sine wave signal at the beginning** of each run to align in time the two systems

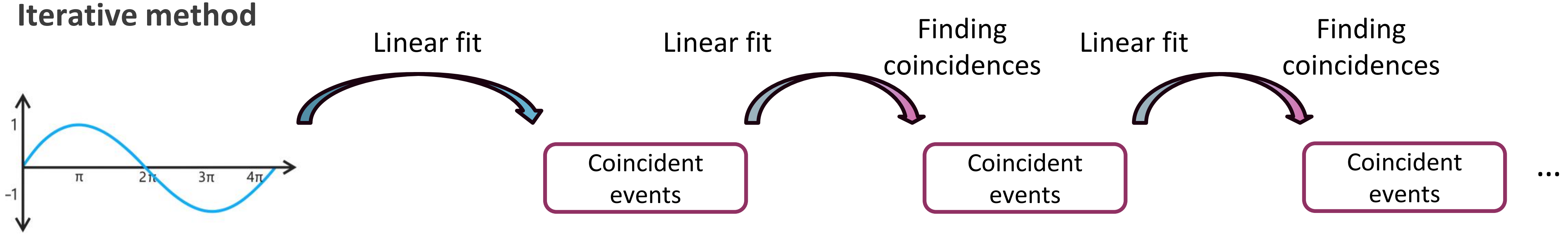




Matching

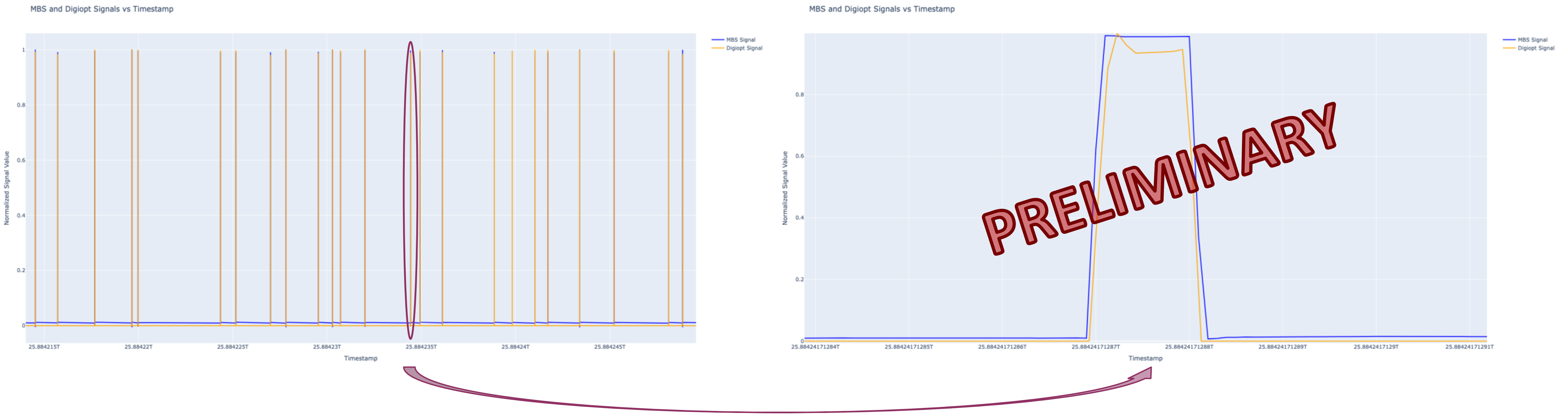
- Trouble: One clock runs ahead/behind another → time shift does not work
- We need to find a method to solve the problem → introduce a sine wave signal at the beginning of each run to align in time the two systems

- It seems to be a **linear correlation, but it isn't really**: The linear fitting works well at first, but the alignment worsens over time
- **Iterative method**



Matching

- The **iterative method provides very good performance**:
  - We achieve time <u>differences between AGATA and MBS < 40ns</u> (Sampling rate 1/10ns → one signal: 1ms)



PSC – Analysis of AGATA electric pulse shapes

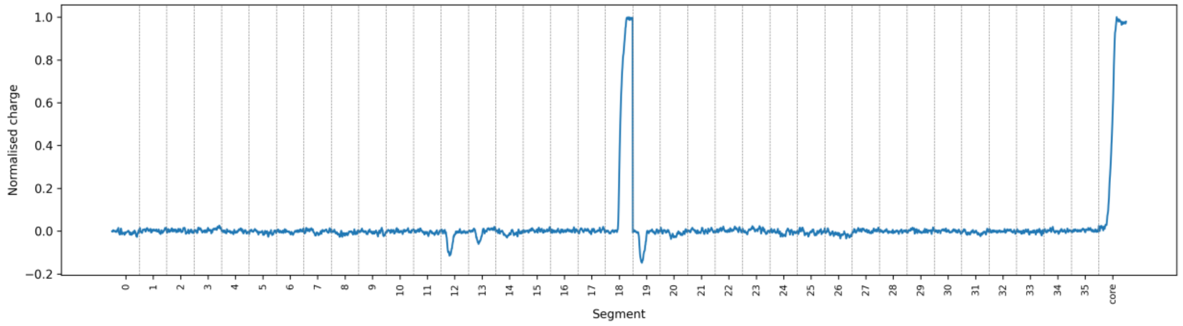
- Main goal: **Classify the events according to the shape of their set of pulses**
  - The relevant signals to consider are the core pulse shape and the triggered and its neighbour segment ones.
- Steps:
  - General data filtering
  - Signal treatment
  - Filtering according to the derivative of the net signal (triggered segment)
  - 1^{st} classification (core and net pulse shape)
  - Filtering according to the derivative of the net signal average
  - 2^{nd} classification (transient signals, the neighbour segments' ones)

PSC – Analysis of AGATA electric pulse shapes

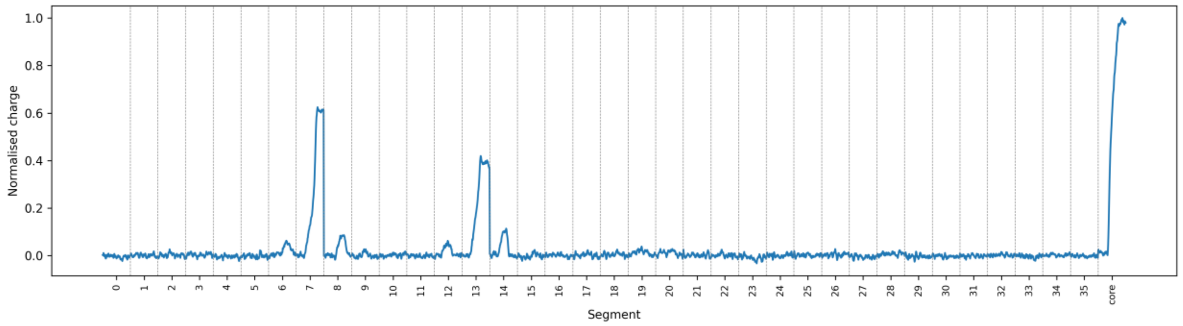
- Main goal: **Classify the events according to the shape of their set of pulses**
  - The relevant signals to consider are the core pulse shape and the triggered and its neighbour segment ones.
- Steps:
  - General data filtering ✓
  - Signal treatment ✓
  - Filtering according to the derivative of the net signal (triggered segment) ✓
  - 1^{st} classification (core and net pulse shape) ✓
  - Filtering according to the derivative of the net signal average ✓
  - 2^{nd} classification (transient signals, the neighbour segments' ones) ★

General data filtering

- **Some events cannot be considered for the comparison;** we select those verifying:
  - **Fold 1 events**: there is only one segment triggered



Fold 1



Fold 2

General data filtering

- **Some events cannot be considered for the comparison;** we select those verifying:
  - Fold 1 events: there is only one segment triggered
  - **Energy difference** between triggered segment and core **lower than 3 keV**

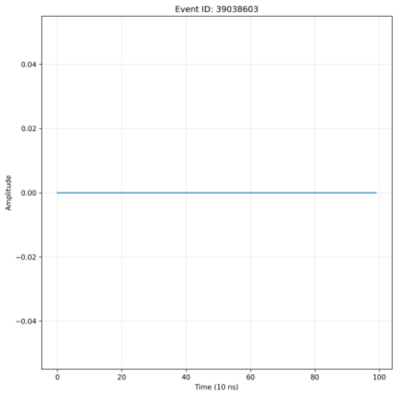
Baseline offset

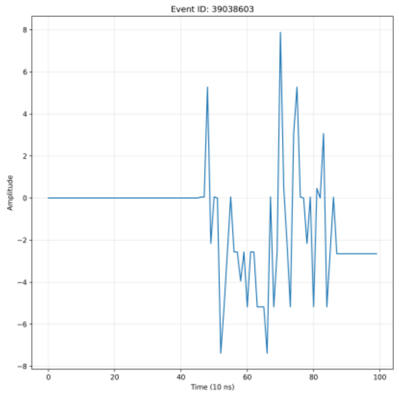
\+

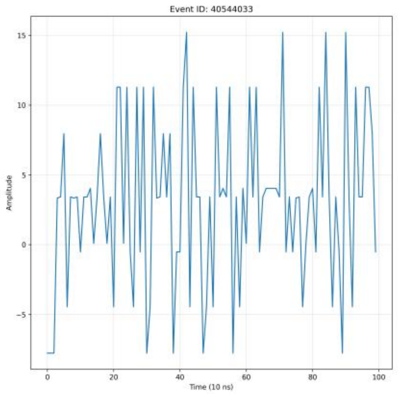
Gain calibration

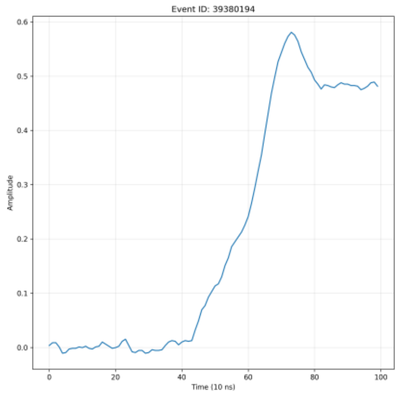
General data filtering

- **Some events cannot be considered for the comparison;** we select those verifying:
  - Fold 1 events: there is only one segment triggered
  - Energy difference between triggered segment and core lower than 3 keV
  - **Net signal and neighbour segments working properly**
    - In some cases, we observe electric pulse shapes having an unexpected behaviour



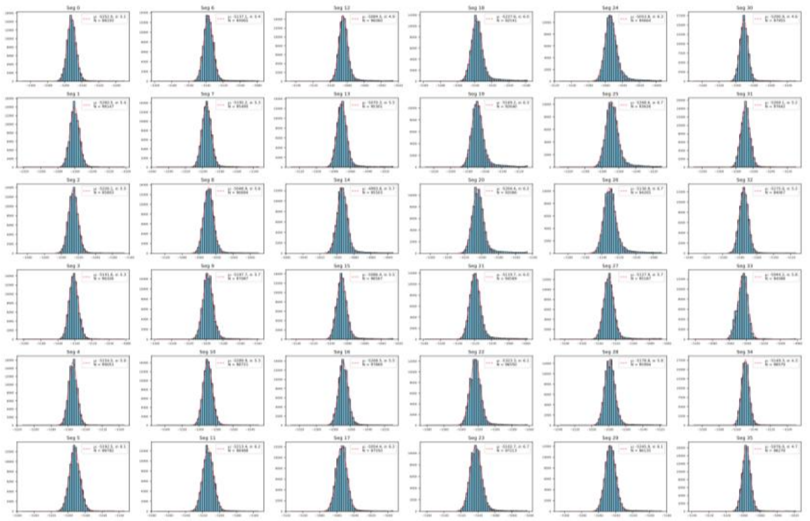






Signal processing

- It is required to prepare the signals before performing PSC:
   1. Apply an **offset to set the baseline to zero**



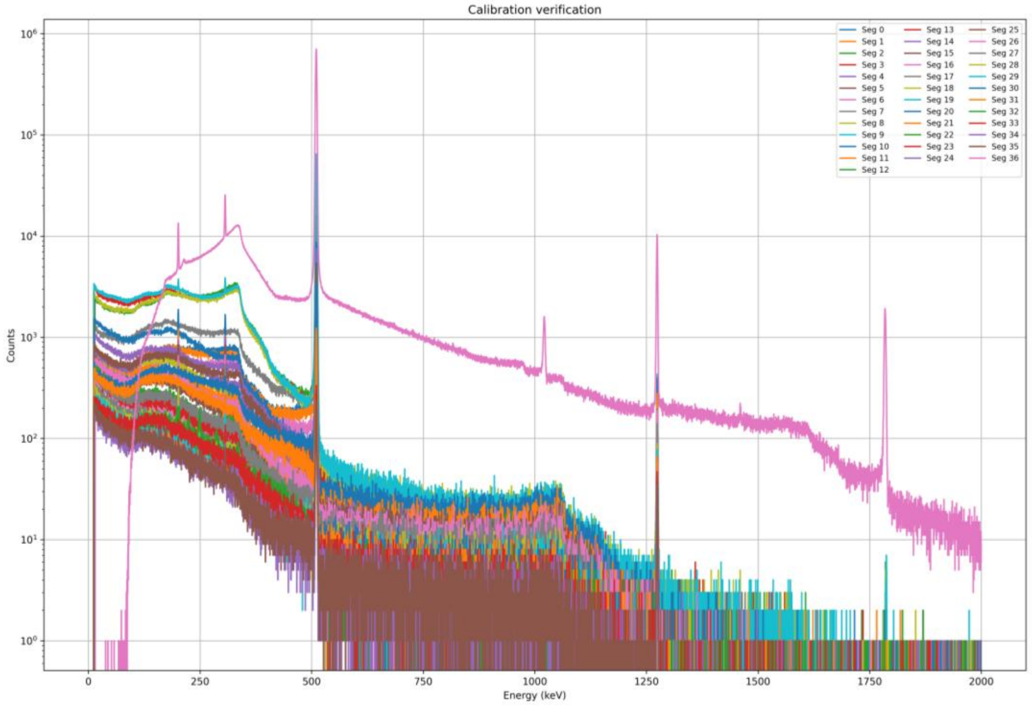
The baseline must be determined for each event

Signal processing

- It is required to prepare the signals before performing PSC:

  1. Apply an offset to set the baseline to zero
  2. **Align the gain of each channel**

     (prior calibration is necessary)



Signal processing

- It is required to prepare the signals before performing PSC:

  1. Apply an offset to set the baseline to zero
  2. Align the gain of each channel

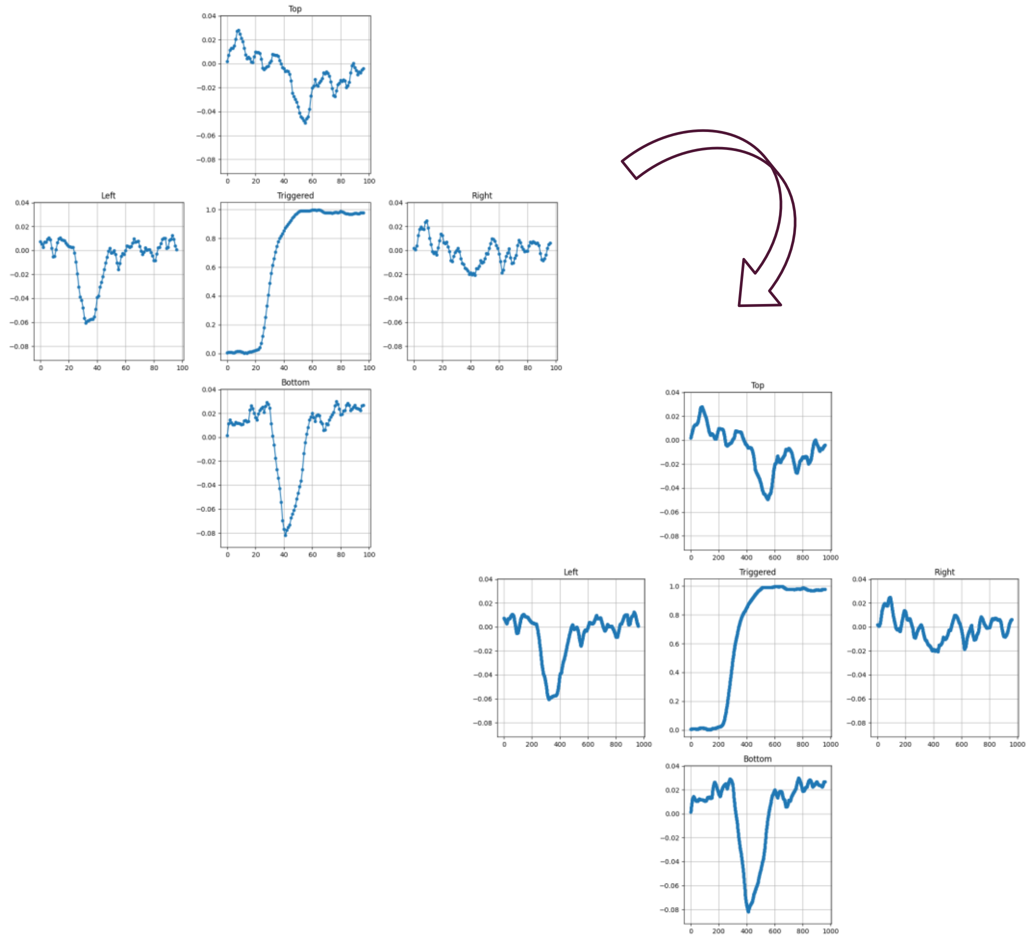
     (prior calibration is necessary)
  3. **Normalize** the pulse shapes

Signal processing

- It is required to prepare the signals before performing PSC:
  1. Apply an offset to set the baseline to zero
  2. Align the gain of each channel

     (prior calibration is necessary)
  3. Normalize the pulse shapes
  4. **Virtually increase the sampling rate**

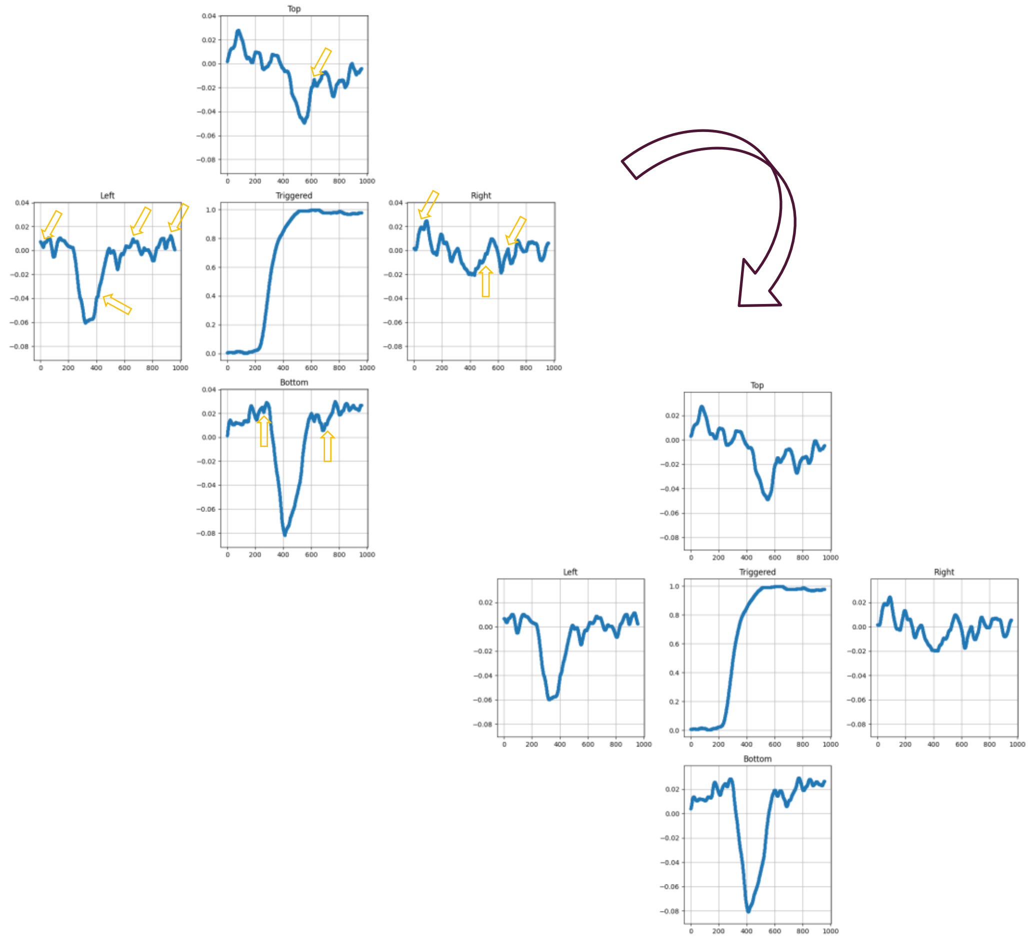
     (from 100 MHz to 1GHz)



Signal processing

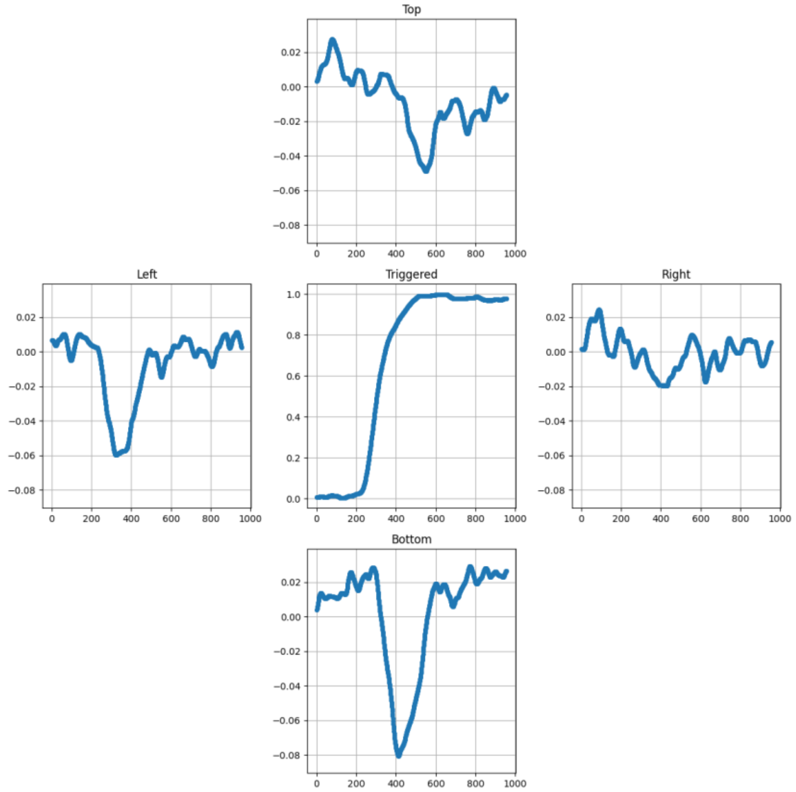
- It is required to prepare the signals before performing PSC:

  1. Apply an offset to set the baseline to zero
  2. Align the gain of each channel (prior calibration is necessary)
  3. Normalize the pulse shapes
  4. Virtually increase the sampling rate (from 100 MHz to 1GHz)
  5. Apply an **11-point moving average**



Signal processing

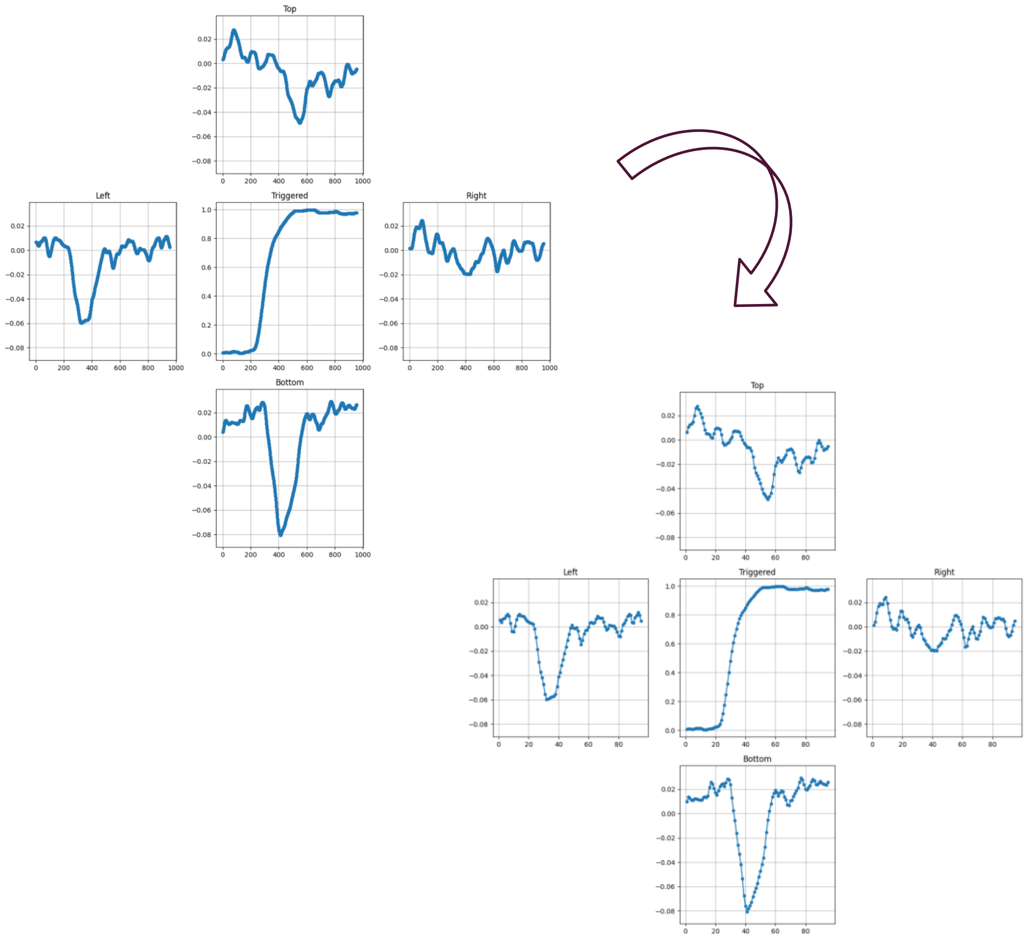
- It is required to prepare the signals before performing PSC:
  1. Apply an offset to set the baseline to zero
  2. Align the gain of each channel (prior calibration is necessary)
  3. Normalize the pulse shapes
  4. Virtually increase the sampling rate (from 100 MHz to 1GHz)
  5. Apply an 11-point moving average
  6. **Time alignment**: Net signal + transient ones (neighbours). Net signal T10 → shift to 25%



Signal processing

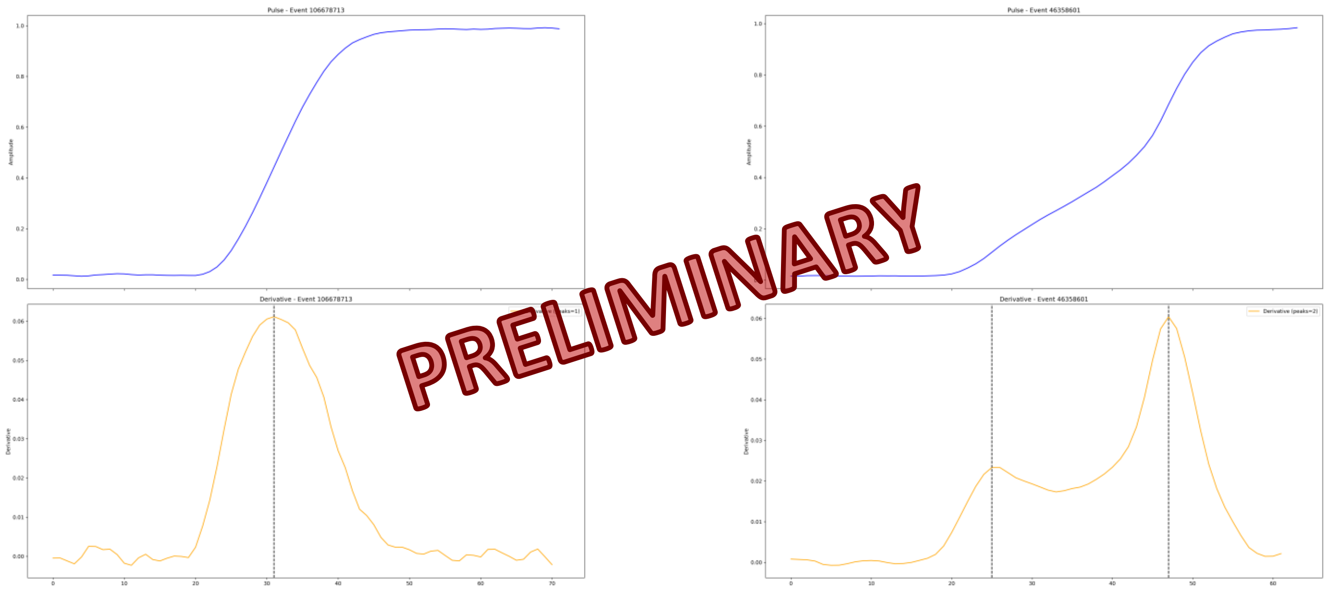
- It is required to prepare the signals before performing PSC:

1. Apply an offset to set the baseline to zero
2. Align the gain of each channel
   (prior calibration is necessary)
3. Normalize the pulse shapes
4. Virtually increase the sampling rate
   (from 100 MHz to 1GHz)
5. Apply an 11-point moving average
6. Time alignment: Net signal + transient ones (neighbours).
   Net signal T10 → shift to 25%
7. **Decrease the sampling rate** (from 1GHz to 100MHz)



Filtering: according to the net pulse shape derivative

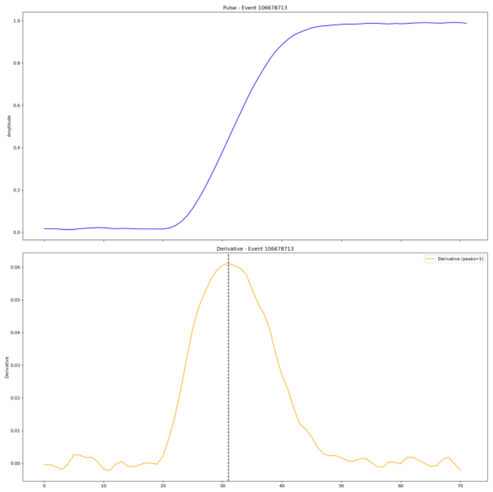
- The **number of peaks in the net signal derivative** equals the **number of interactions** experienced by the photon in the triggered segment [1]

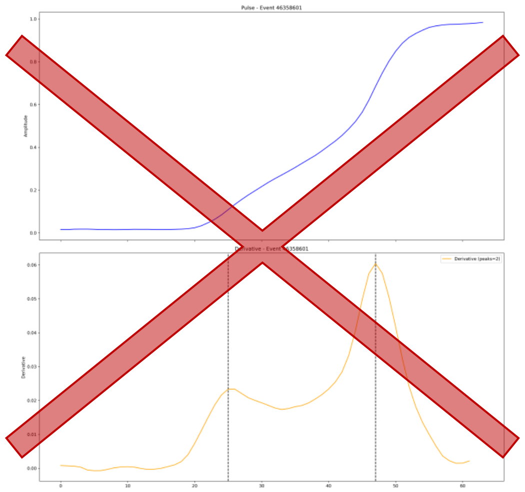


[1] Crespi, F. C. L., et al. (2007). *A pulse shape analysis algorithm for HPGe detectors*. NIM-A, 570(3), 459–466; doi: 10.1016/j.nima.2006.10.003

Filtering: according to the net pulse shape derivative

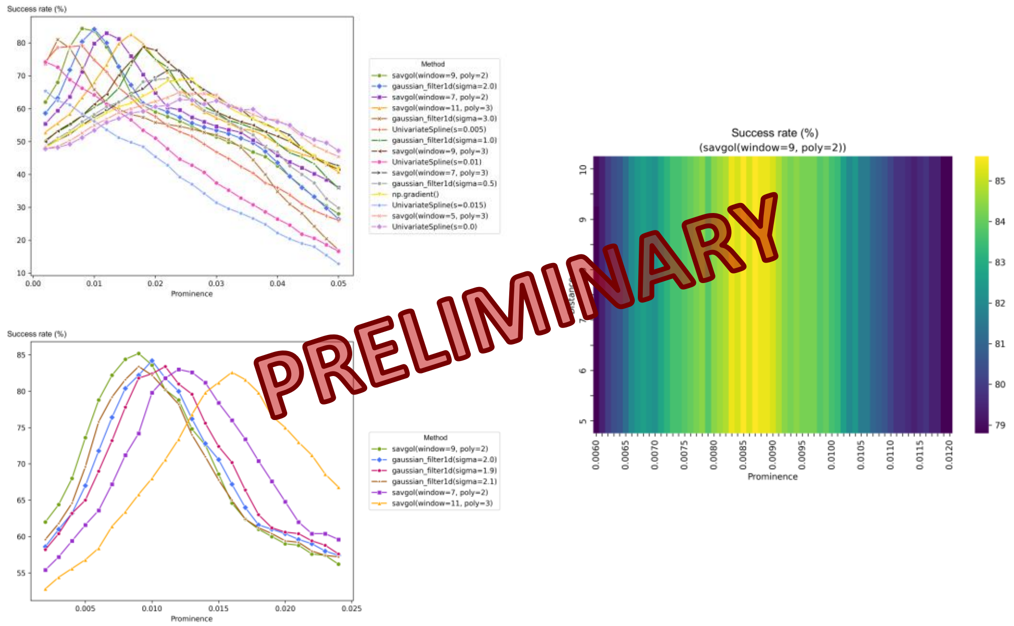
- The number of peaks in the net signal derivative equals the number of interactions experienced by the photon in the triggered segment
  - We are **interested in the events which correspond to a single interaction**; thus, we reject the cases where the derivative has more than one peak





Filtering: according to the net pulse shape derivative

- The number of peaks in the net signal derivative equals the number of interactions experienced by the photon in the triggered segment
  - We are interested in the events which correspond to a single interaction; thus, we reject the cases where the derivative has more than one peak
  - We study the **best technique to perform the filter**:
    - <u>Derivative calculation method</u>
    - Optimization of parameters: <u>find_peaks</u> function



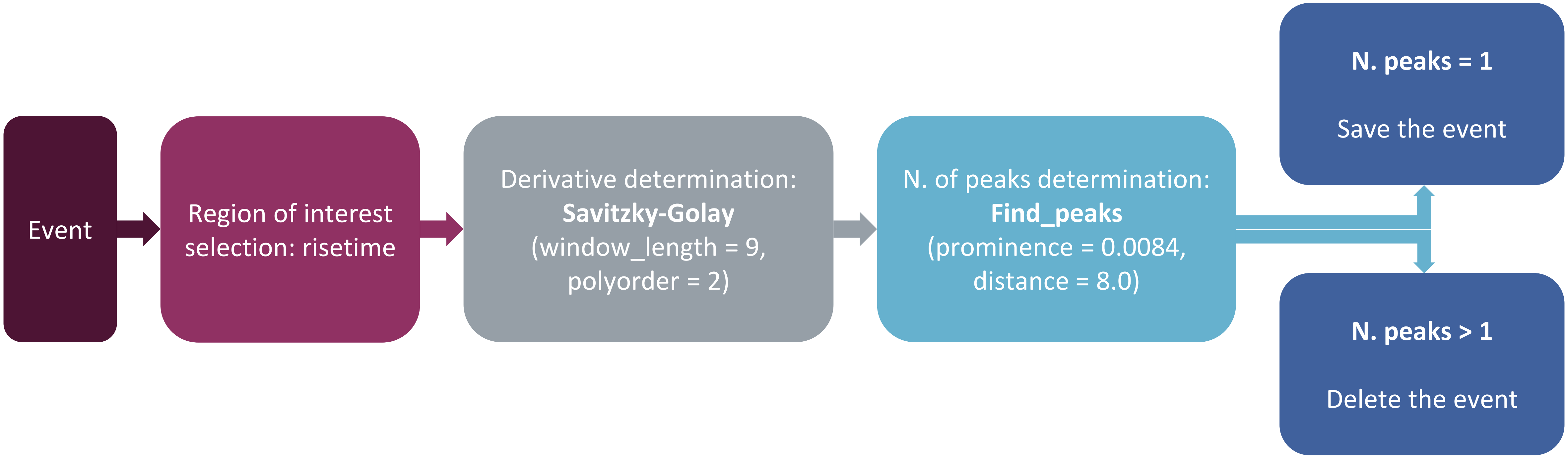
Filtering: according to the net pulse shape derivative

- The number of peaks in the net signal derivative equals the number of interactions experienced by the photon in the triggered segment
  - We are interested in the events which correspond to a single interaction; thus, we reject the cases where the derivative has more than one peak
  - We study the **best technique to perform the filter**:
    - Derivative calculation method
    - Optimization of parameters: find_peaks function

Best derivative method:
Savitzky-Golay
- Window_length = 9
- Polyorder = 2

Optimal parameters for find_peaks:
- Prominence = 0.0084
- Distance = 8.0

Filtering: according to the net pulse shape derivative



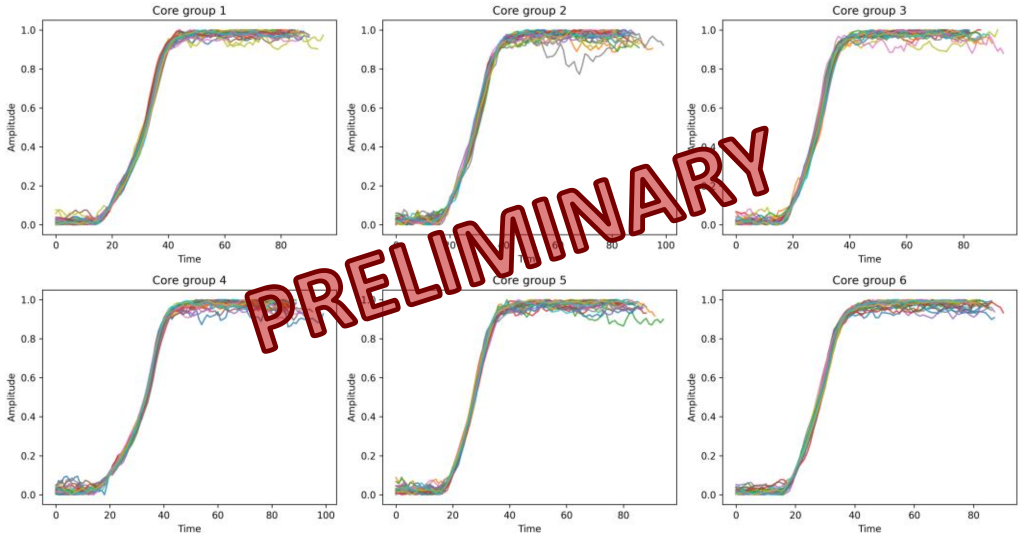
PSC (Pulse Shape Comparison)

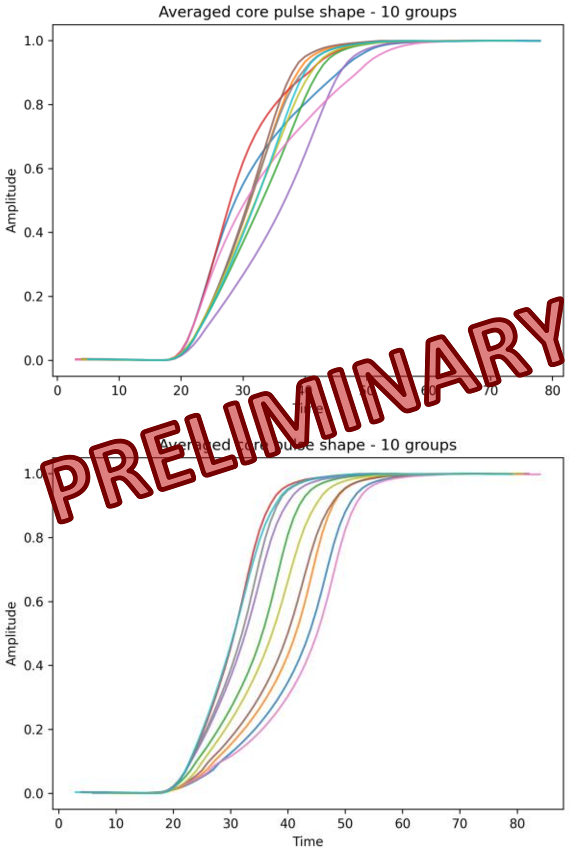
- We classify the events in groups according to:

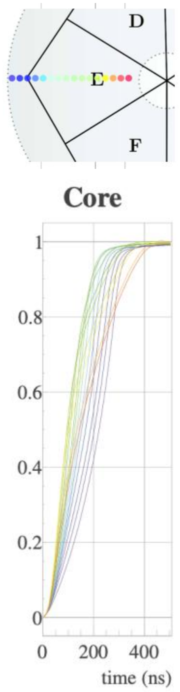
  1. The **triggered segment** (36 groups)

PSC (Pulse Shape Comparison)

- We <u>classify the events in groups</u> according to:
  1. The triggered segment (36 groups)
  2. **Core signal** (pulse shape) → **Wilcoxon signed-rank-based test** [2]





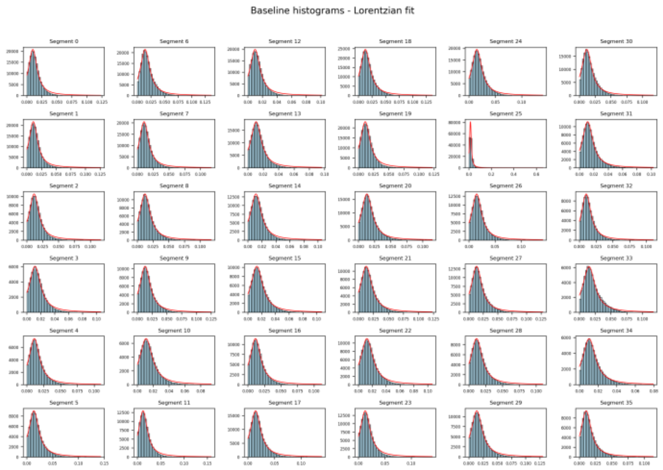


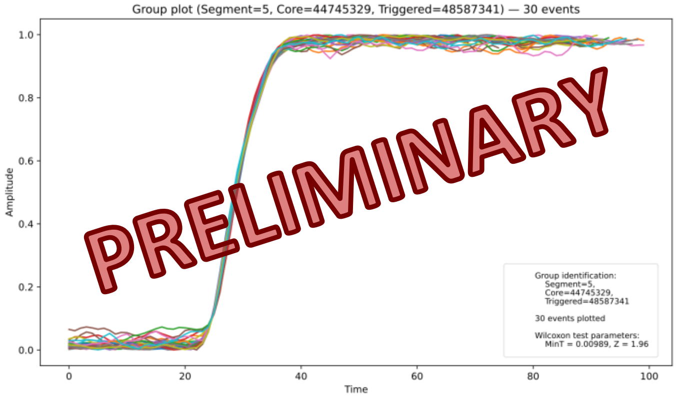
M. Ginsz thesis (2015)

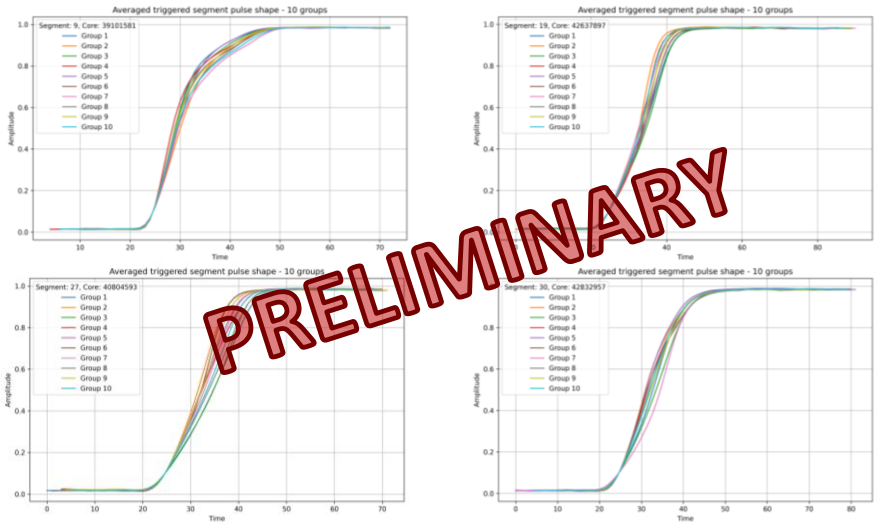
[2] Martín, S., et al. (2016). *Wilcoxon signed-rank-based technique for the pulse-shape analysis of HPGe detectors*. NIM-A, 823, 32–40, Elsevier B.V; doi: 10.1016/j.nima.2016.03.094

PSC (Pulse Shape Comparison)

- We classify the events in groups according to:
  1. The triggered segment (36 groups)
  2. Core signal (pulse shape) → Wilcoxon signed-rank-based test
  3. **Net signal** (pulse shape) → W. test (Optimized parameters by studying the baseline behaviour)





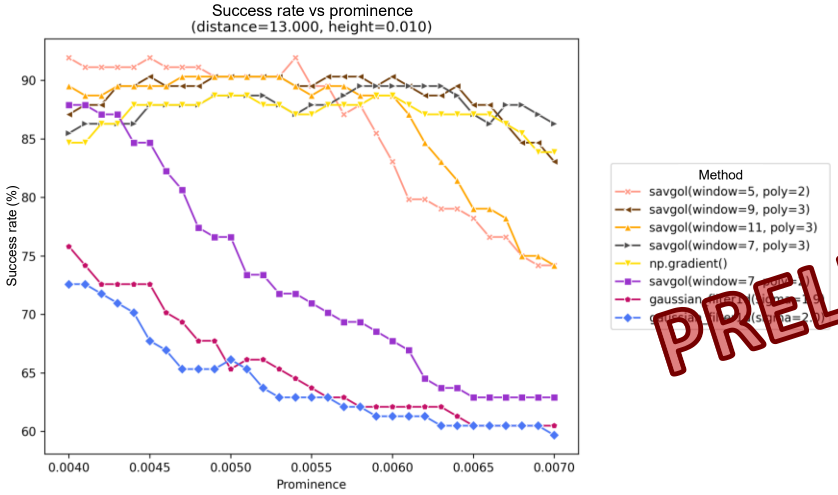


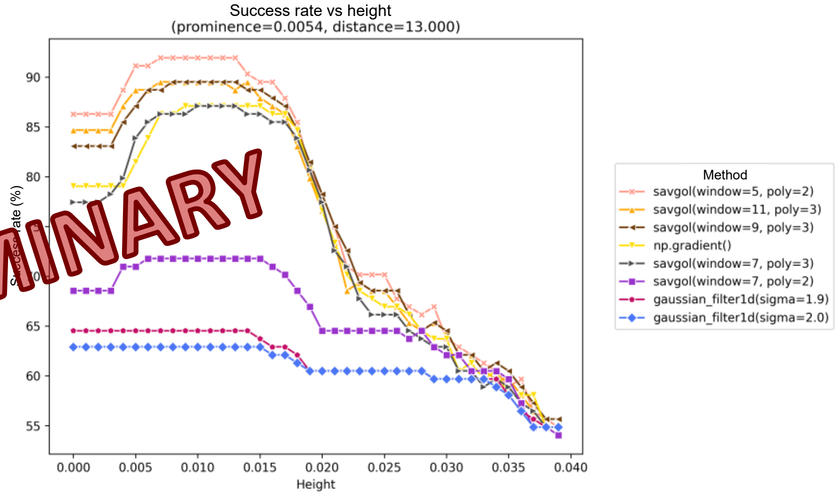
Filtering: according to the net pulse shape average derivative

- We **average the net signals** for each group → <u>noise is significantly reduced</u>

Filtering: according to the net pulse shape average derivative

- We average the net signals for each group → noise is significantly reduced
- We perform a similar study to determine the **best derivative method and the optimal parameter values**:





Filtering: according to the net pulse shape average derivative

- We average the net signals for each group → noise is significantly reduced
- We perform a similar study to determine the **best derivative method and the optimal parameter values**:

Best derivative method:

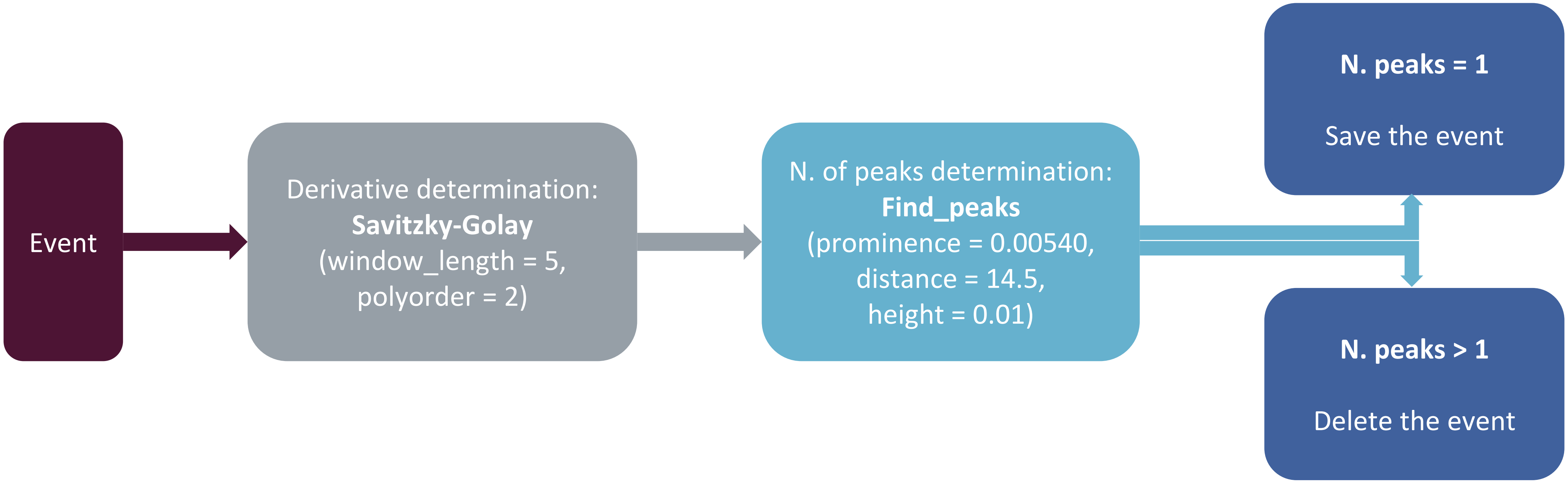
Savitzky-Golay

- Window_length = 5
- Polyorder = 2

Optimal parameters for find_peaks:

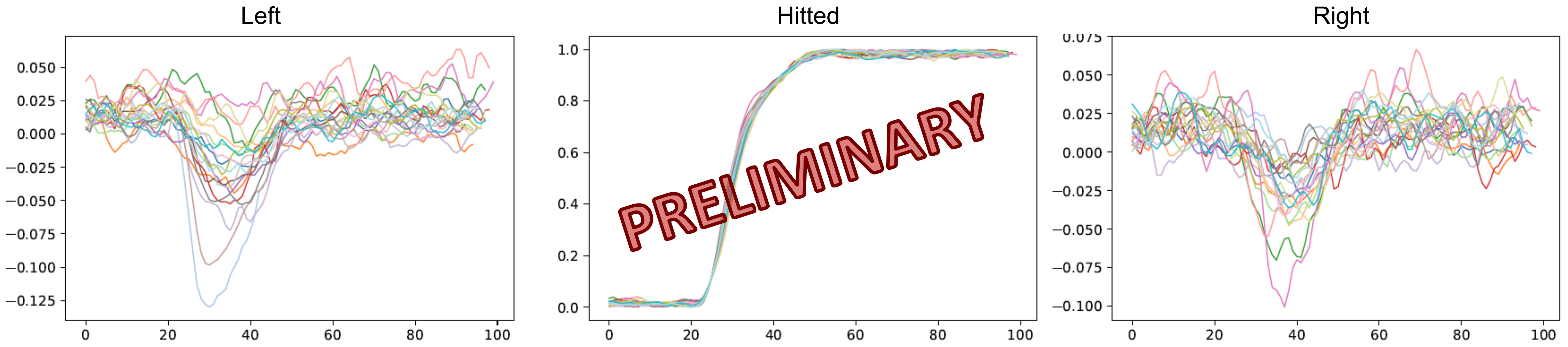
- Prominence = 0.00540
- Distance = 14.5
- Height = 0.01

Filtering: according to the net pulse shape average derivative



PSC (transient signals) – Current work

- Currently, we are working in the analysis of transient signals, those generated in the neighbour segments.



CONCLUSIONS

Conclusions

- AGATA is a 4π γ-ray spectrometer used for nuclear structure research. It is composed of HPGe detectors which require an experimental characterization
- We are developing a characterization method, SALSA, based on the active collimation of the radioactive beam.
- For the B003 AGATA detector, we have already completed the experimental setup, the data acquisition and we are now working on the software for the analysis.
- The results obtained for PSC (core and net signals) show a good agreement with the literature
- Next step to be finished is the comparison of transient signals

Future work

- To finish the B003 characterization:
  - Calculate the equations of the straight lines and determine the intersection points in the AGATA detector
  - Build the experimental database (electric pulse shapes – interaction positions)
- To validate the method:
  - Compare the results with those obtained at IPHC (Strasbourg)
- For future characterizations:
  - Improve the acquisition software

XVII CPAN DAYS
Centro Nacional de Física de Partículas, Astropartículas y Nuclear.
19-21 Noviembre 2025
Valencia

MINISTERIO
DE CIENCIA, INNOVACIÓN
Y UNIVERSIDADES

AGENCIA
ESTATAL DE
INVESTIGACIÓN

VNiVERSiDAD
D SALAMANCA

Laboratorio Datación
Radiaciones Ionizantes

AGATA
ADVANCED GAMMA
TRACKING ARRAY

THANK YOU FOR YOUR ATTENTION