CHARACTERIZATION OF B003 AGATA DETECTOR IN THE SALSA SETUP

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26th AGATA Week and ACC meeting (Warsaw)

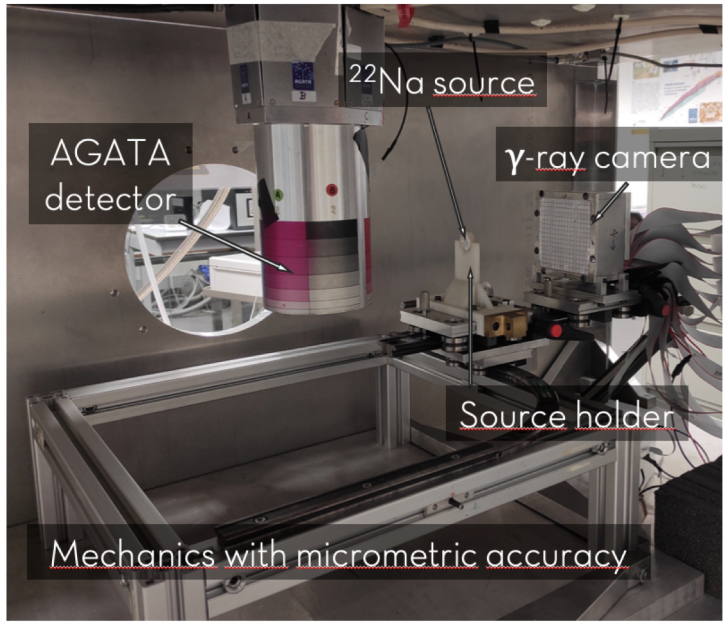
9th September 2026

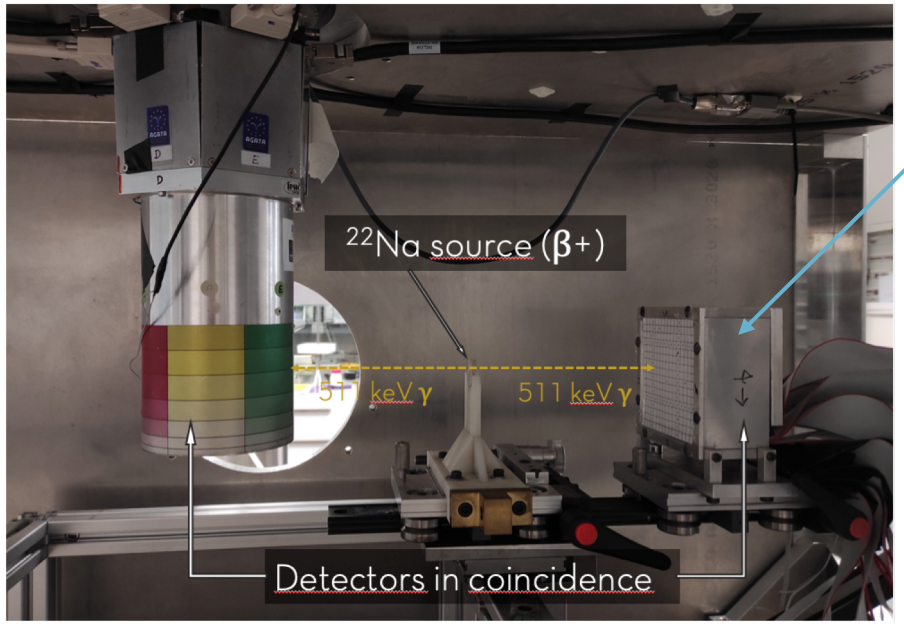
TABLE OF CONTENTS

1. **Introduction**
   - SALSA methodology
2. **Characterization steps**
   - Setting up the experimental system
   - Measurement from two different configurations
   - Dataprocessing method
     - Matching
     - Data preprocessing and filtering
     - PSC – Analysis of AGATA electric pulse shapes
     - Calculation of tracks(straight lines) and intersections
     - Building the database
   - Results
3. **Conclusions**

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**
  - **Active collimation:** ^{22}Na ($285\ kBq$) → two 511 keV photons are emitted at 180°
  - **Measurement in coincidence**, between the detector to scan (AGATA), and a γ-ray camera





γ-ray camera:
- 256 pixels (channels)
- sub-millimetre accuracy

AGATA digitizer:
- Digi-Opt12

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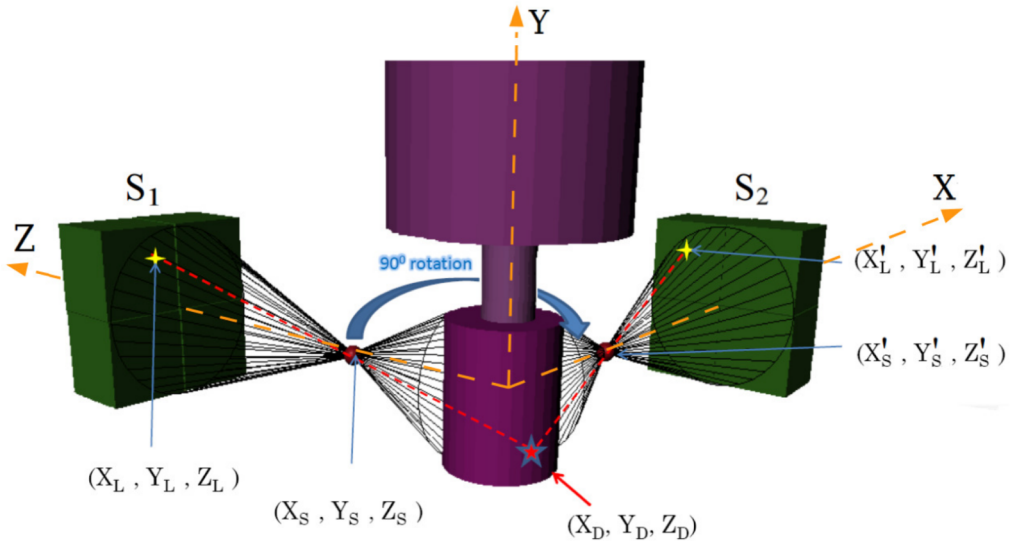
  - Possible **rotations** for each detector:
    - AGATA cryostat: Every 120°, 3 possible positions
    - γ-ray camera: 90° rotation, 2 possible positions

    → **6 possible configurations**

    Effective rotations: differences of 30° or 90°

  - **PSC**: To relate events measured from configurations 1 and 2

    → **Own PSC algorithm** developed in the Salamanca group



[1] N. Goel: http://dx.doi.org/10.1016/j.nima.2012.10.028
[2] A. Hernandez-Prieto: http://dx.doi.org/10.1016/j.nima.2016.03.103

Characterization steps

1. **Setting up the experimental system** (~ 1 year and 4 months)
   - Acquistion electronics: AGATA (Digi-Opt12), γ-ray camera (MBS) and coincidence
   - AGATA detector setting: Vacuuming, cooling down and initial test to check operation, with the help of M.H. Sigward (IPHC) (1-2 weeks)
   - Acquisition software update: to launch both systems from the same platform and enter data directly to a DB







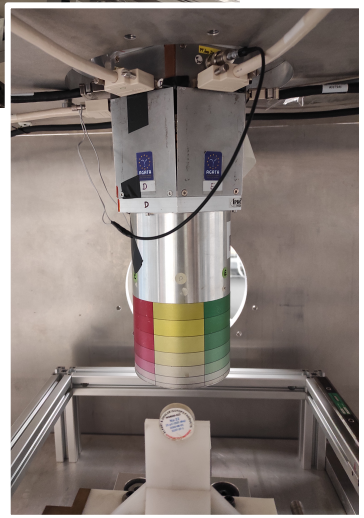
Characterization steps

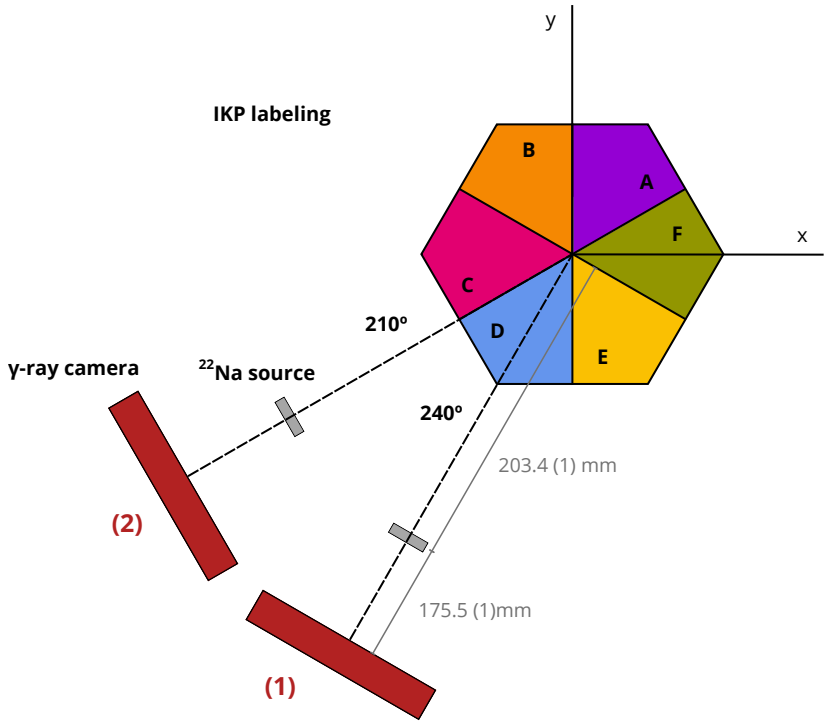
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2. **Measurement** from two different configurations (~ 4 months)

Characterization steps – Measurement

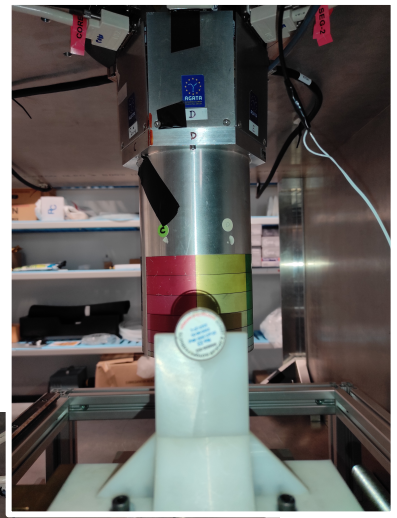
Configuration 1 (~ 3 months)

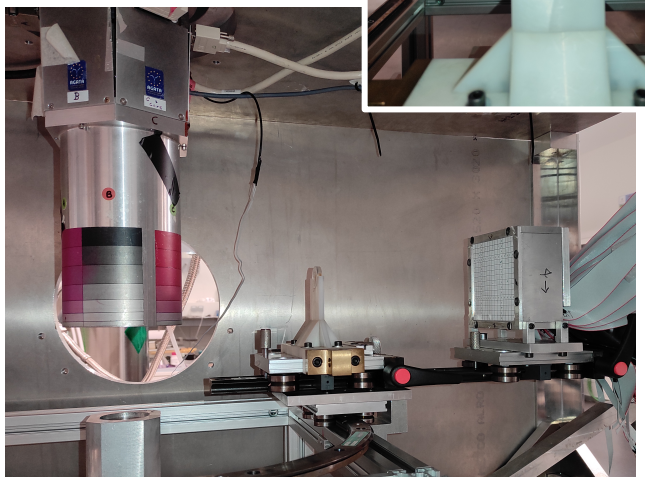






Configuration 2 (~ 1 month)





Characterization steps – Measurement

Configuration 1 (~ 3 months)

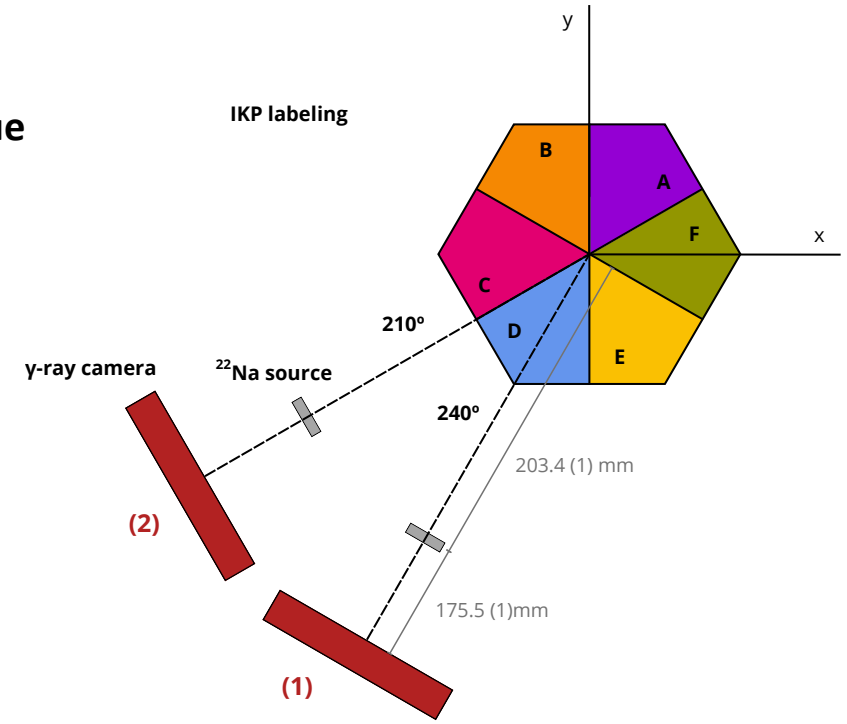
Test the whole system / fixing any issue

Effective time:

145h 41m 4s → ≃ 6 days

Online DB injection time:

406h 23m 58s → ≃ 17 days



Configuration 2 (~ 1 month)

Effective time:

158h 42m 58s → ≃ 6.5 days

Online DB injection time:

398h 10m 58s → ≃ 16.5 days

➡ ~ 70% of the acquisition time is spent on the online preprocessing of the data in coincidence and uploading it to the DB

Characterization steps

1. **Setting up the experimental system** **(~ 1 year and 4 months)**
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   - Matching: correlation of AGATA - γ-ray camera events
   - Data preparation: filtering + preprocessing
   - PSC (Pulse Shape Comparison): Analysis of AGATA signals
   - Calculation of straight lines representing the γ-ray directions and intersection

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Dataprocessing method - Matching

We need to **link AGATA events** with their **corresponding MBS (γ-ray camera)** ones in coincidence:

- AGATA digitizer process every event which triggers the detector
- MBS only records events in coincidence

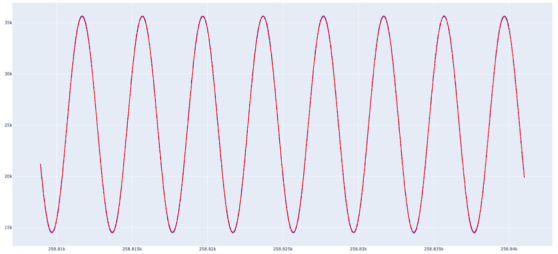
The **reliability** of the final results depends on the events being well correlated

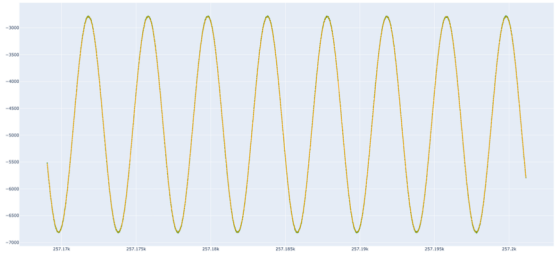
To find the relation between the two systems → we introduce a **logical signal to mark the event**

Dataprocessing method - Matching

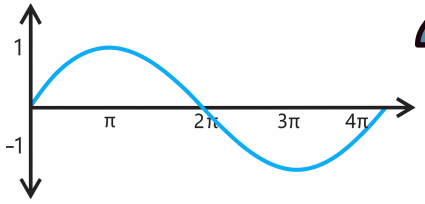
⇒ Trouble: **One clock runs ahead/behind another one** → time shift does not work properly

- To tackle the problem: we introduce a **sine wave signal at the beginning** of each run to align the two systems in time


Timestamp MBS


Timestamp Digiopt

- The correlation is **not** as **linear** as it seems: the linear fitting works well at the beginning, but the alignment worsens over time
- We design an **<u>iterative method</u>**



Linear fit → Coincident events

Linear fit → Finding coincidences → Coincident events

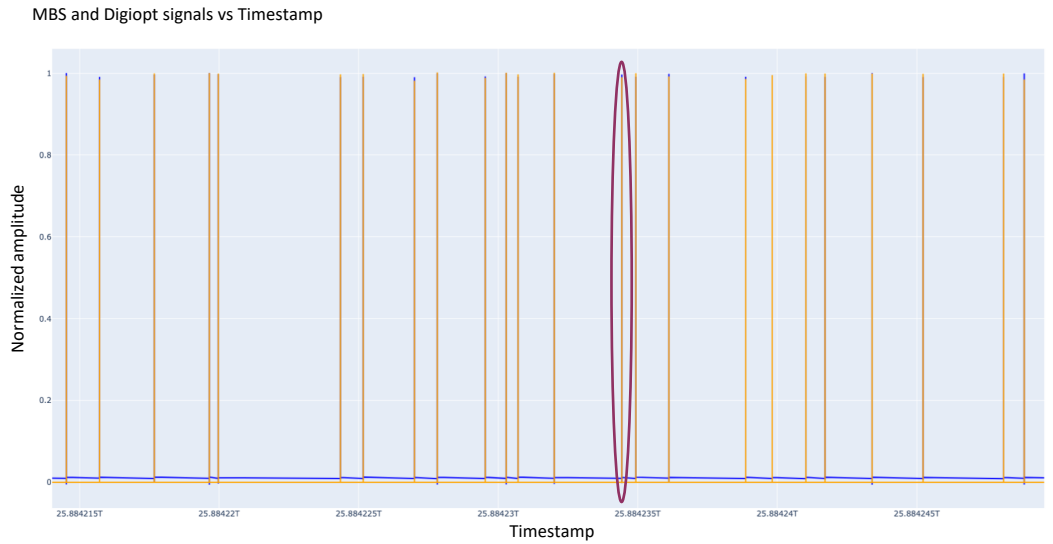
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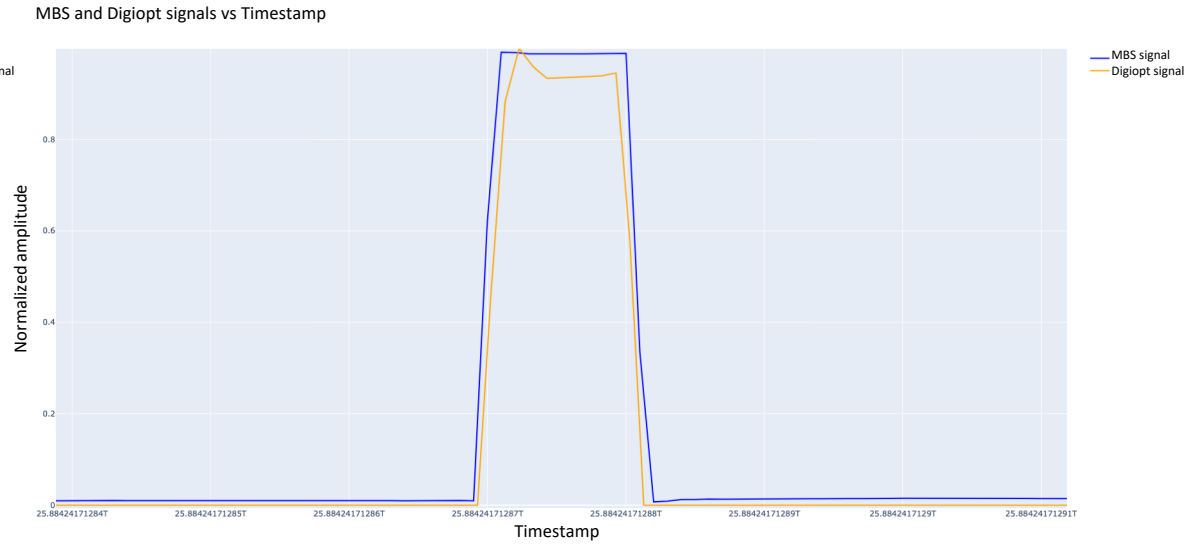
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Dataprocessing method - Matching

The **iterative method provides very good performance**: **Events are fully correlated**

- We achieve <u>time differences between AGATA and MBS data < 30 ns</u> (Sampling rate: 100 MHz ≡ 1/10 ns; one signal: 1ms)





Characterization steps

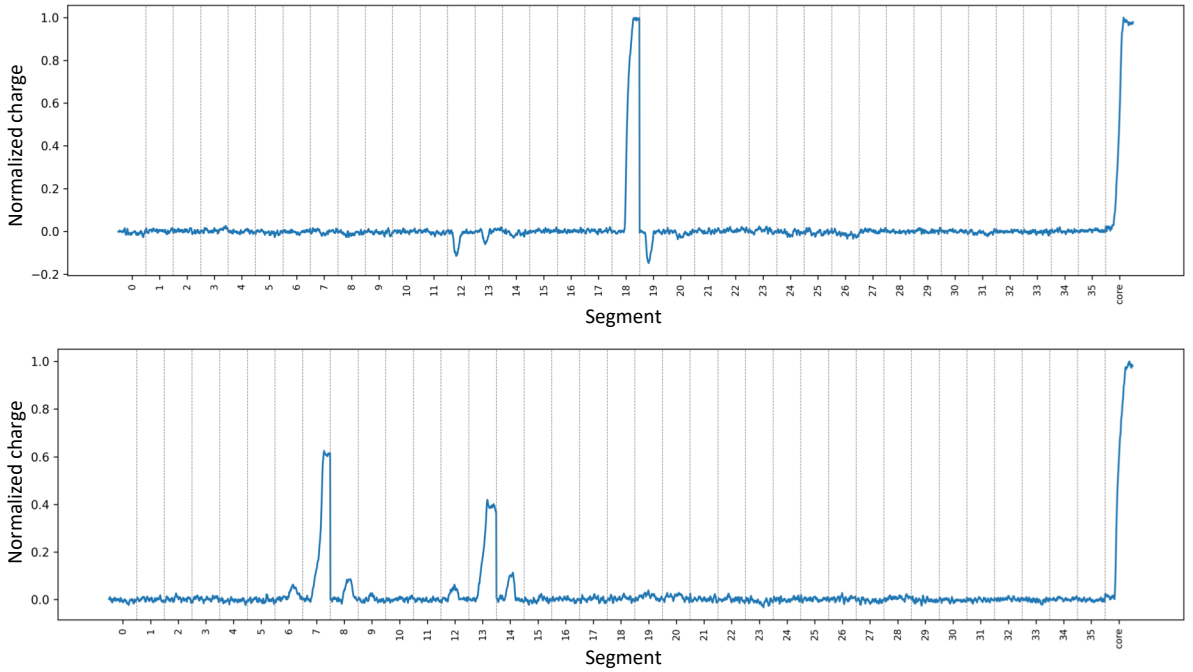
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Dataprocessing method – Preprocessing – Data filtering

For our purposes, we need to **filter the data** and consider only those events that satisfy:

- **<u>Condition 1</u>: Fold 1** AGATA events (there is only one segment triggered)

Condition	Description
1	Selection of fold 1 events
2	Energy window
3	Selection of single interaction events



Fold 1

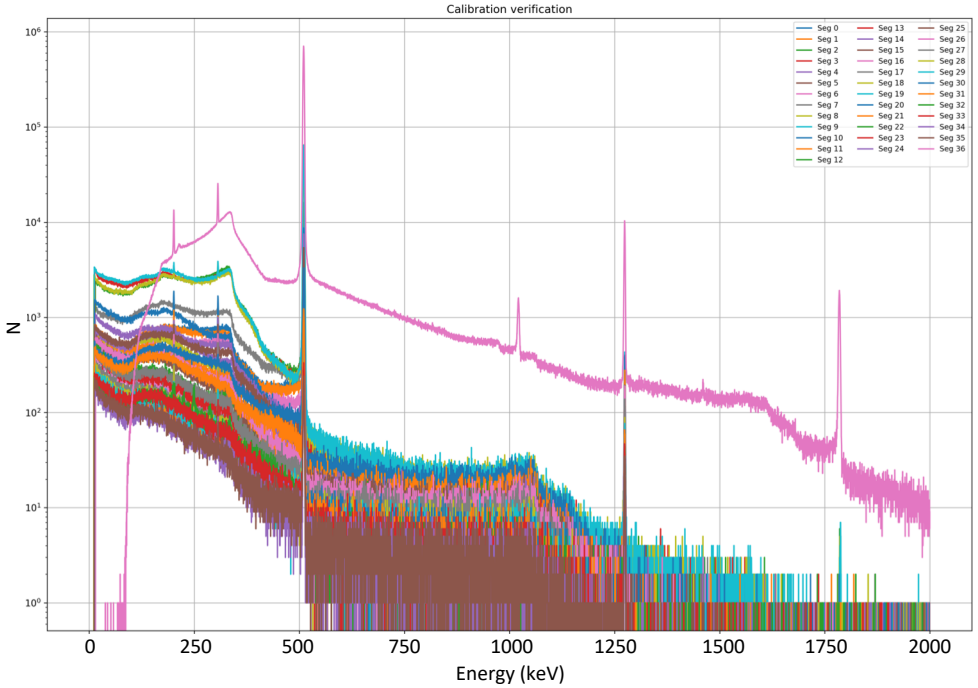
Fold 2

Dataprocessing method – Preprocessing – Data filtering

For our purposes, we need to **filter the data** and consider only those events that satisfy:

- **<u>Condition 2</u>**: Energy window in AGATA

Condition	Description
1	Selection of fold 1 events
2	Energy window
3	Selection of single interaction events



$$\left|E_{Triggered} - E_{core}\right| < 3\ keV \text{ and } E_{Triggered} = 511 \pm 3\ keV$$

Baseline offset

+

Gain calibration

Dataprocessing method – Preprocessing – Data filtering

For our purposes, we need to **filter the data** and consider only those events that satisfy:

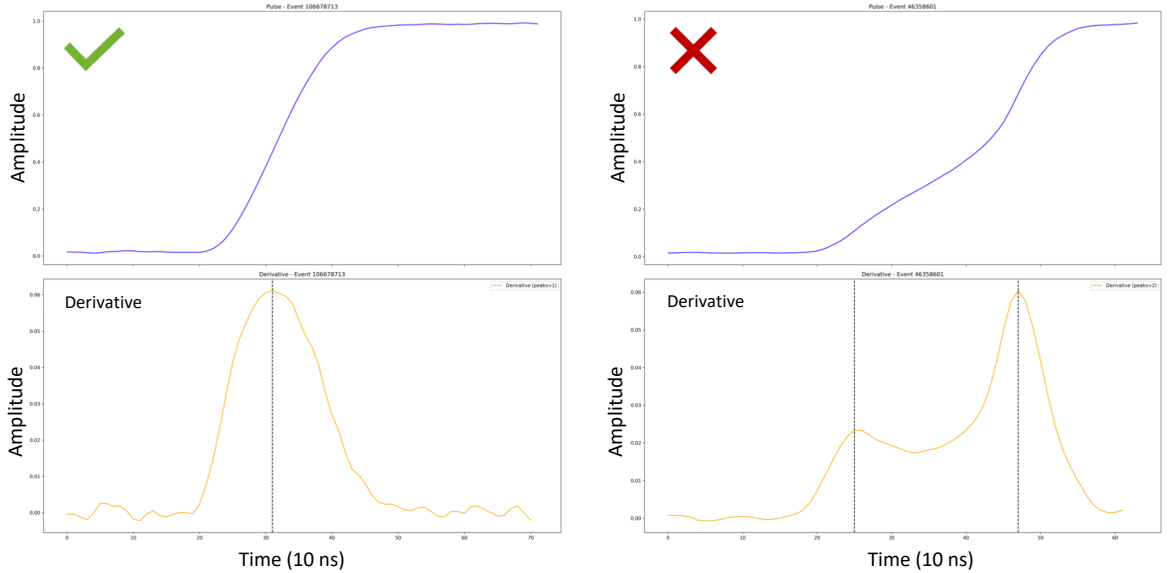
- **<u>Condition 3</u>: Single interaction events**: according to the net pulse shape derivative

Condition	Description
1	Selection of fold 1 events
2	Energy window
3	Selection of single interaction events

  - The **number of peaks in the net signal derivative** equals the **number of interactions** experienced by the photon in the triggered segment [3]

We are interested in the events which correspond to a single interaction

We reject the cases where the derivative has more than one peak



After optimization in Salamanca, best technique developed:

<u>Savitzky-Golay derivative method</u>:
- Window_length = 9
- Polyorder = 2

***<u>find_peaks</u>* <u>from Python</u>**:
- Prominence = 0.0084
- Distance = 8.0

[3] F.C.L. Crespi doi: 10.1016/j.nima.2006.10.003

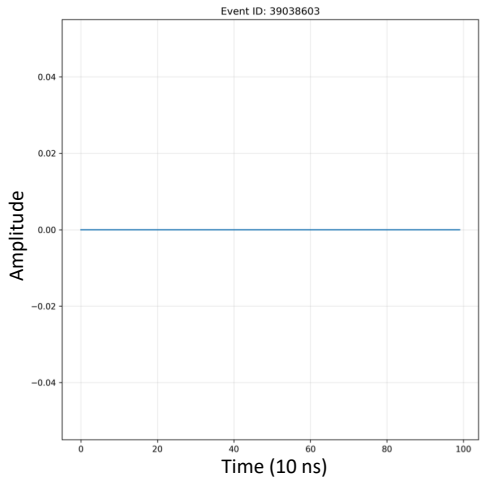
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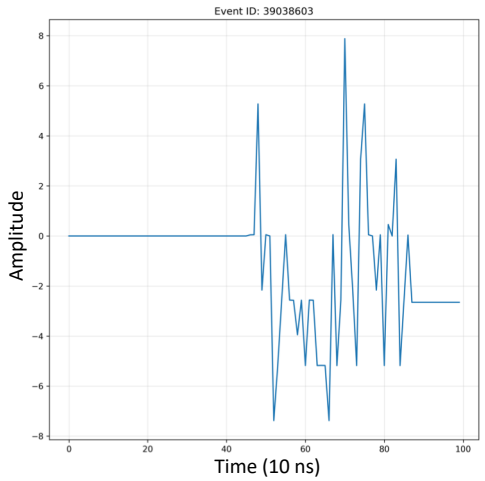
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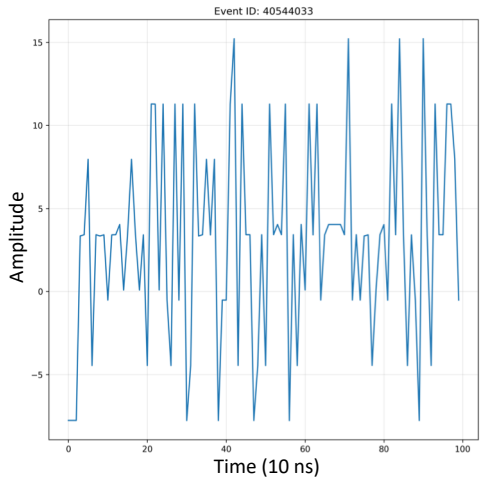
- **<u>Additional condition</u>:**

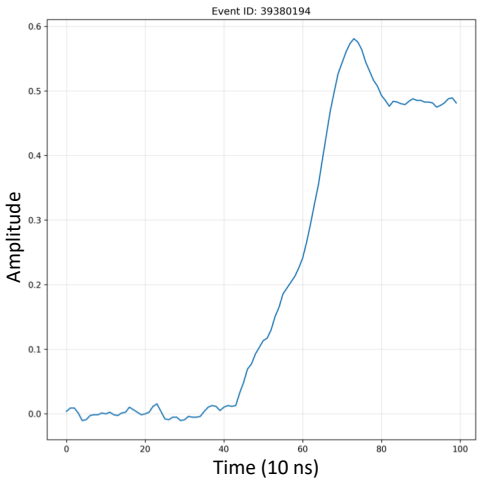
  To solve measurement issues: In some cases, **the triggered or the neighbouring segments were not working properly**

  - Reject events which contain pulse shapes exhibiting an unexpected behaviour (relevant signals: net one and those from adjacent segments)

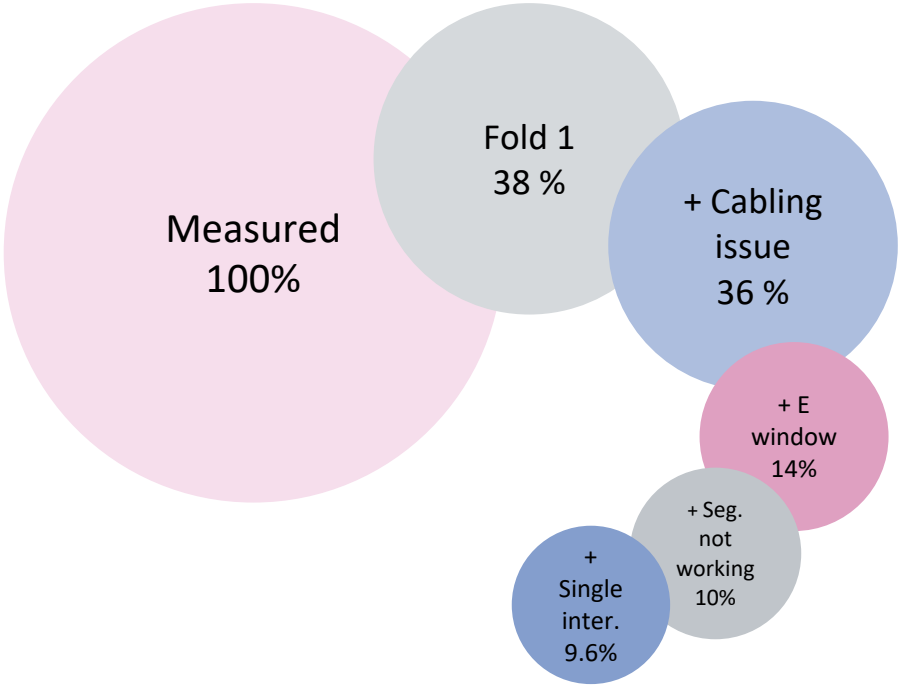








Dataprocessing method – Preprocessing – Data filtering



Only ~ 10% of events are useful for PSC

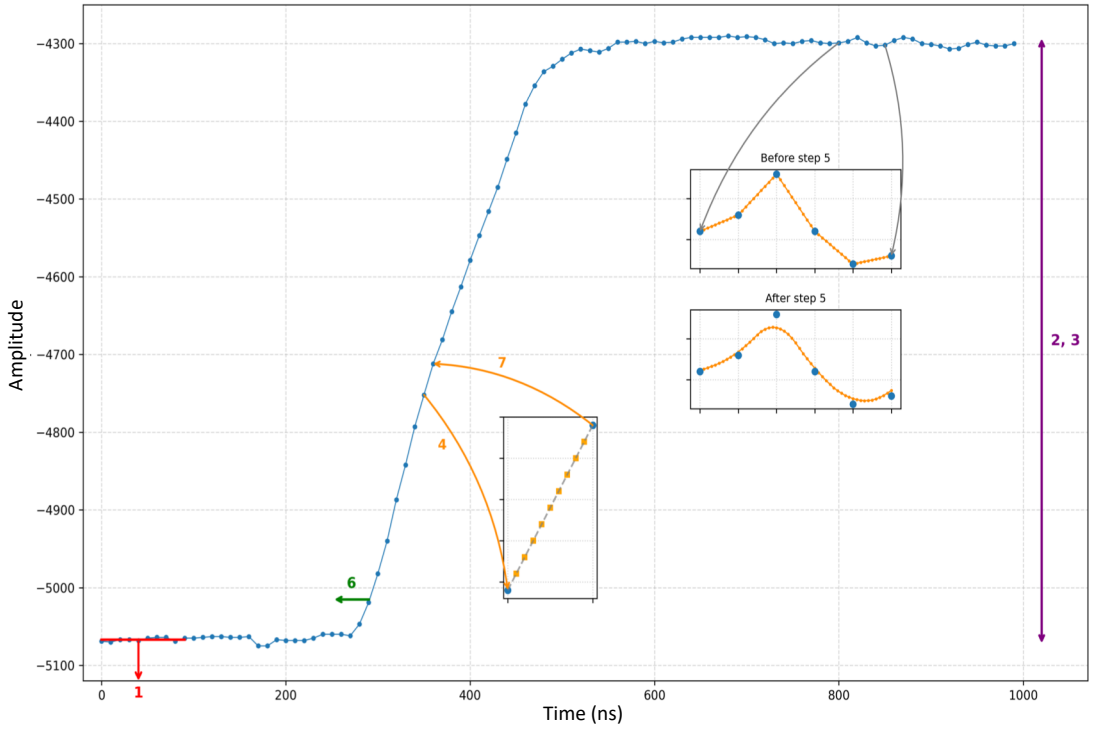
Filter type	$N_{rejected}$	$N_{accepted}$	$\%_{acc. / total\ cond.}$	$\%_{acc. / total\ meas.}$
Measured		79808591		100.0
Cond. 1 (Fold 1)	49498928	30309663	38.0	38.0
Add. condition (Cabling issue)	1598028	28711635	94.7	36.0
Cond. 2 (E window)	17848912	10862723	37.8	13.6
Add. condition (Seg. not working properly)	2919529	7943194	73.1	10.0
Cond. 3 (Single interaction)	320193	7623001	96.0	9.6

Dataprocessing method – Preprocessing

To prepare each signal before performing PSC → We carry out a method according to Strasbourg's procedure

STEPS:

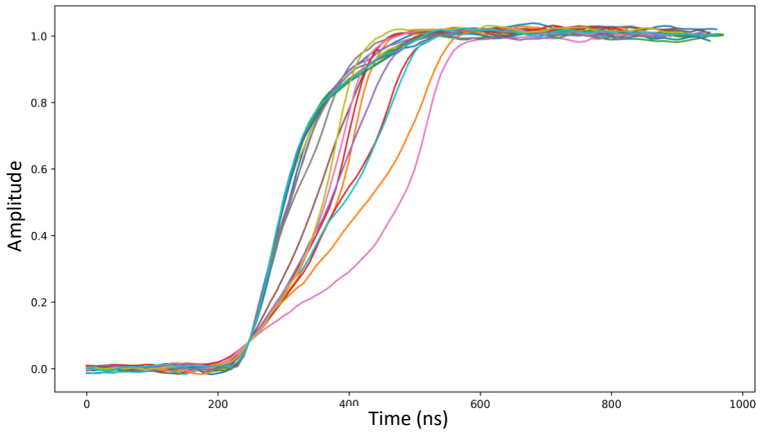
1. Apply an offset to set the baseline to zero
2. Align the gain of each segment (prior calibration is required)
3. Normalization of net and transient pulse shapes according to net signal
4. Interpolation between two digital points to virtually increase the sampling rate (from 100 MHz to 1GHz)
5. Apply an 11-point moving average
6. Time alignment
7. Decrease the sampling rate (from 1GHz to 100 MHz)



Dataprocessing method – Preprocessing – Time alignment

To perform the time alignment:

- Net signal: Time at 8% of amplitude is shifted to 250 ns



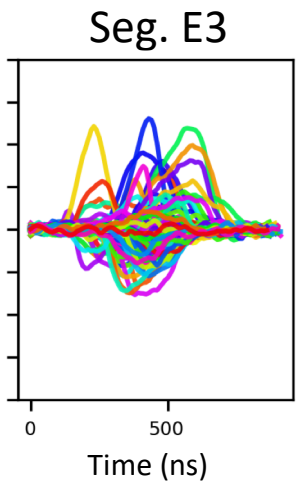
- Transient signals:

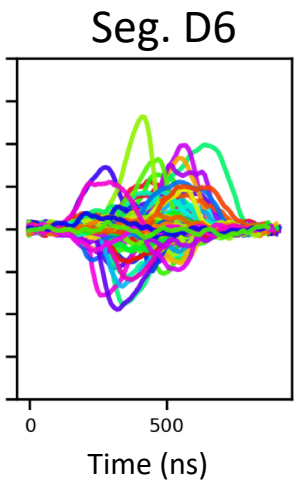
First method tested

Signals shift according to the net one

The same offset is applied to all pulses

It does not provide good results, it is not possible to carry out the subsequent PSC

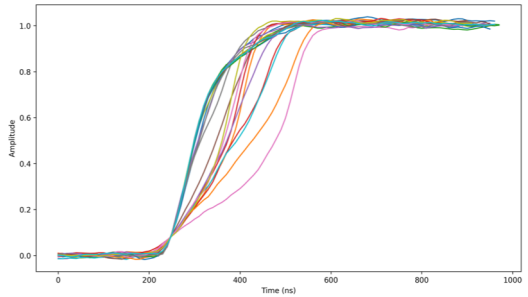




Dataprocessing method – Preprocessing – Time alignment

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- Net signal: Time at 8% of amplitude is shifted to 250 ns



- Transient signals:

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Signals shift according to the net one

The same offset is applied to all pulses

⇩

It does not provide good results, it is not possible to carry out the subsequent PSC

Second method proposed

Each transient signal is aligned independently, using a peak detection algorithm based on the first derivative of the pulse

⇩

Successful results achieved

Dataprocessing method – Transient signals time alignment

Transient signals are aligned independently, by means of a peak detection algorithm based on the first derivative of the pulse:

1. Calculate the **absolute value** of the pulse: $A = \{a_i,\ \ i = 1, n\}, \quad a_i = |p_i|$

2. For each sample i, **select m*[1] points on the left and m on the right:**
$$L_i = \{l_j,\ \ j = i - m, i - 1\}, \quad R_i = \{r_j,\ \ j = i + 1, i + m\}$$

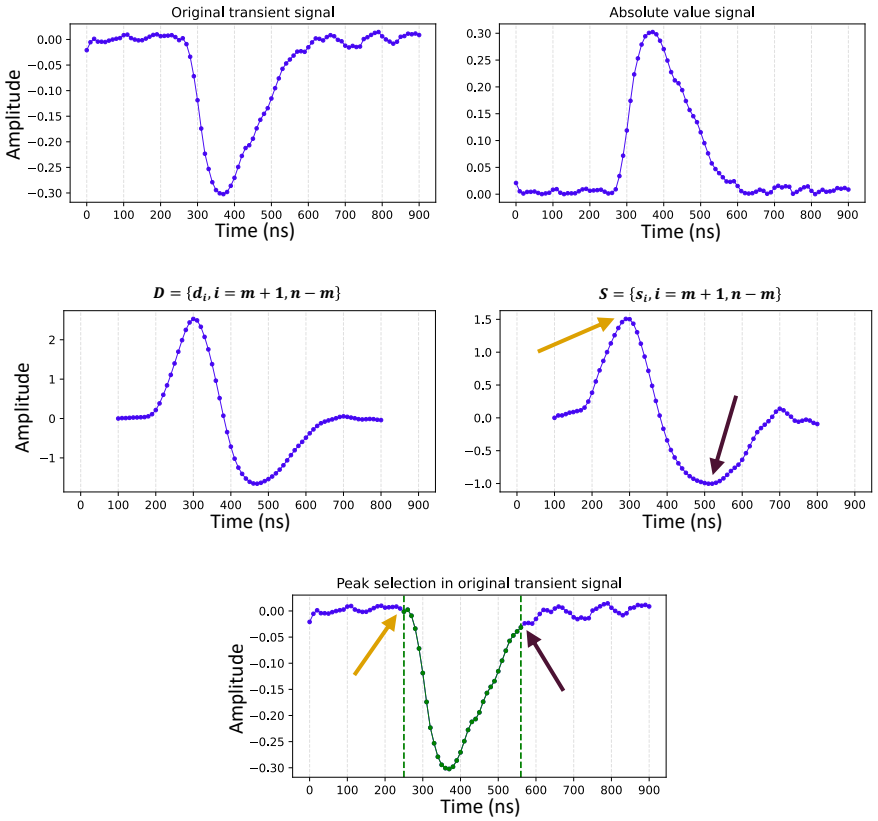
3. **Sum** the values of L_i **and** R_i: $L_{i,\,sum} = \sum_j L_i$, $\quad R_{i,\,sum} = \sum_j R_i$

4. Determine the **metrics**:
$$d_i = R_{i,\,sum} - L_{i,\,sum}$$
$$sd_i = R_{i,\,sum} + L_{i,\,sum}$$
$$s_i = d_i / \sqrt{sd_i}$$

5. Find the **minimum and maximum values of** $S = \{s_i,\ \ i = m + 1,\ n - m\}$:
They correspond to the **limits** of the possible "peak"*[2]

6. Check whether there is a "peak":
If $|S(i_{min})| \geq peth$*[1] **and** $|S(i_{max})| \geq peth \rightarrow$ **There is**

7. Apply shift: $i_c = (i_{min} + i_{max})/2$ $\quad i_c$ to 500 ns

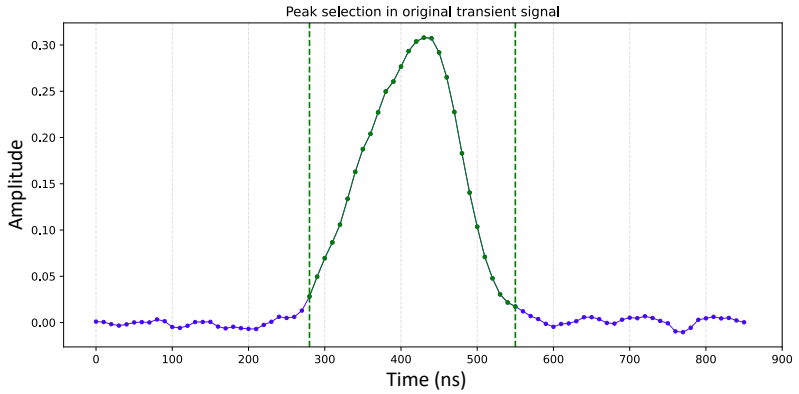


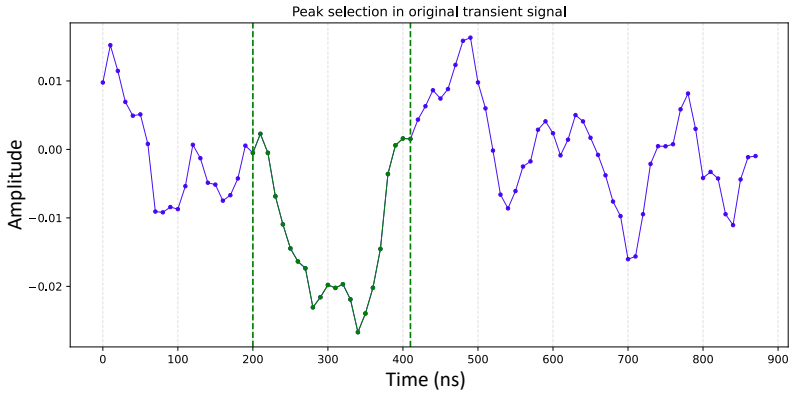
*[1] Optimized for sampling rate 1GHz: $m = 120$, $peth = 0.8$

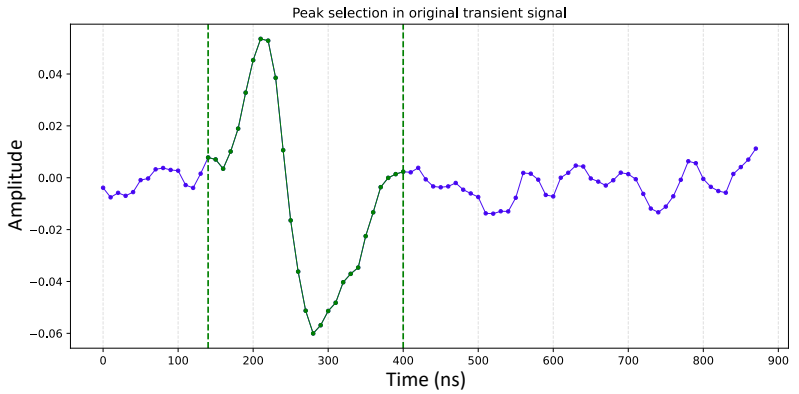
*[2] "peak" refers to a structure that is statistically different from noise

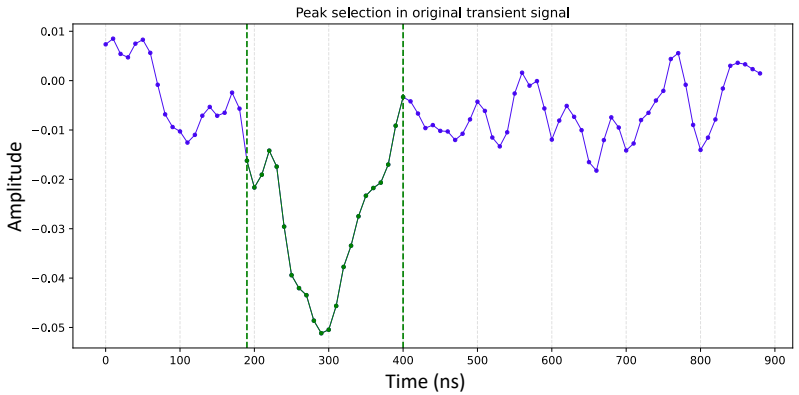
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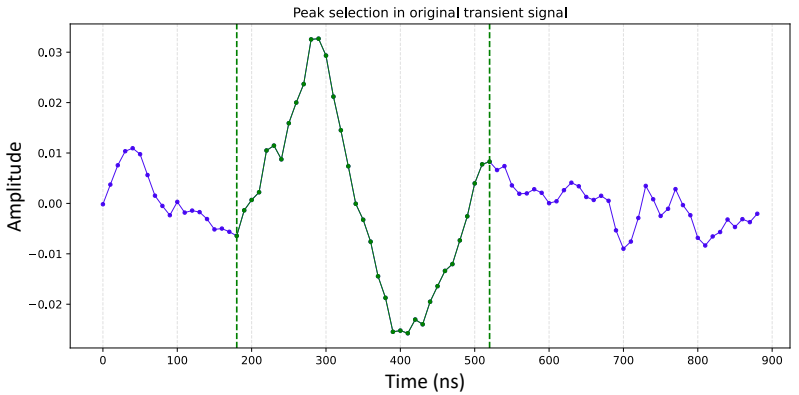
Transient signal selection (examples):

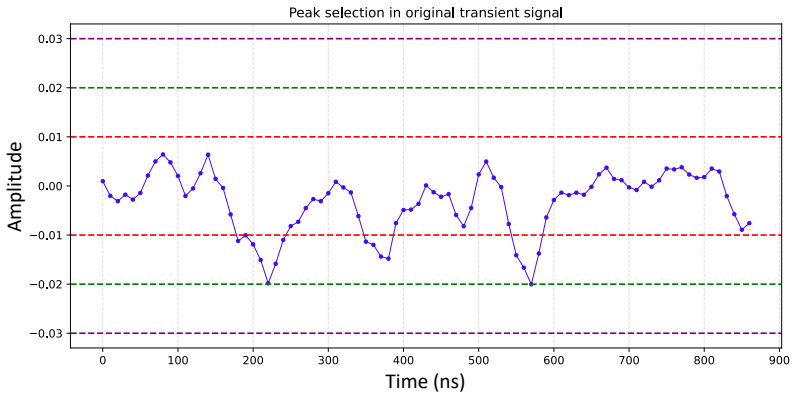






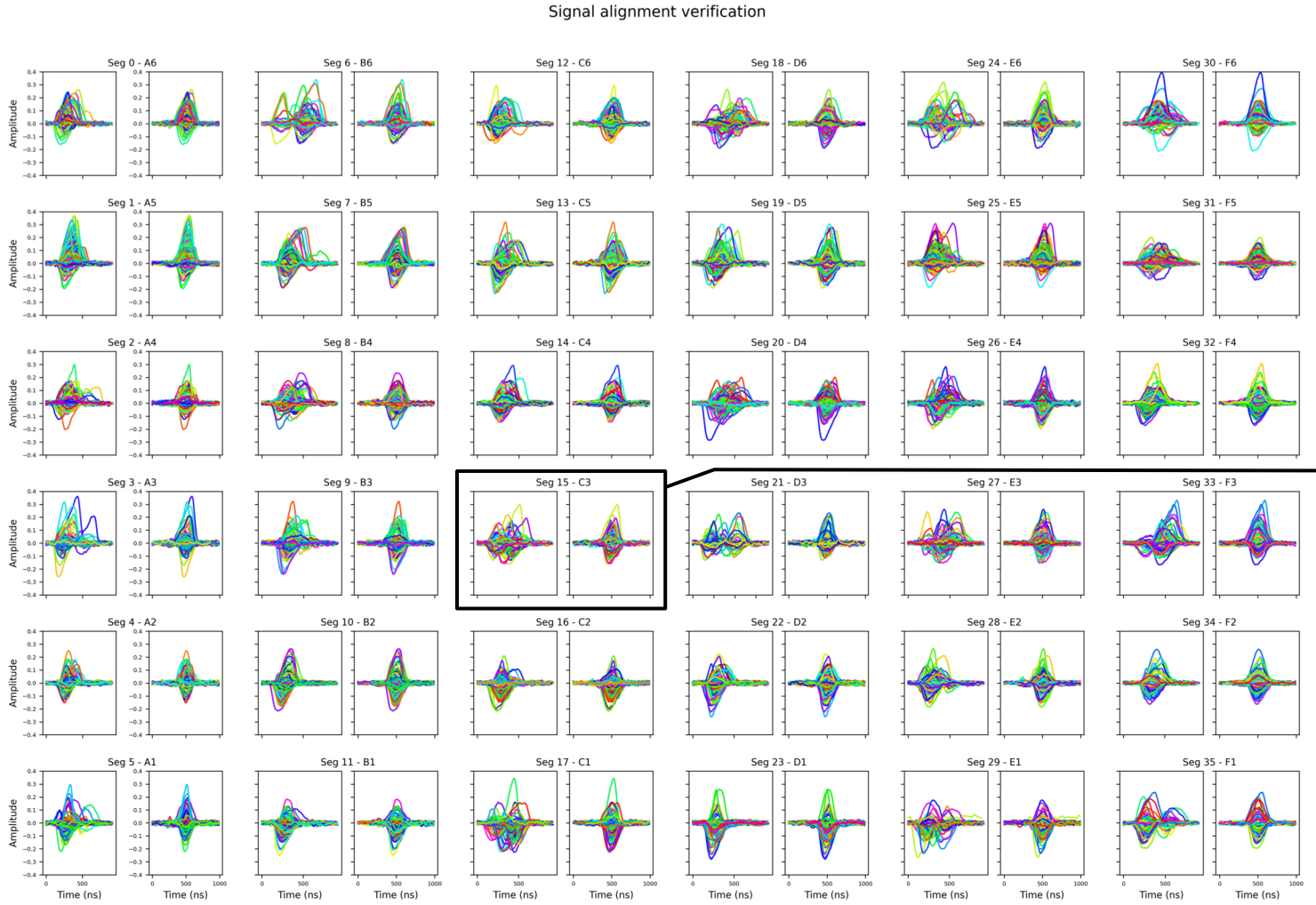


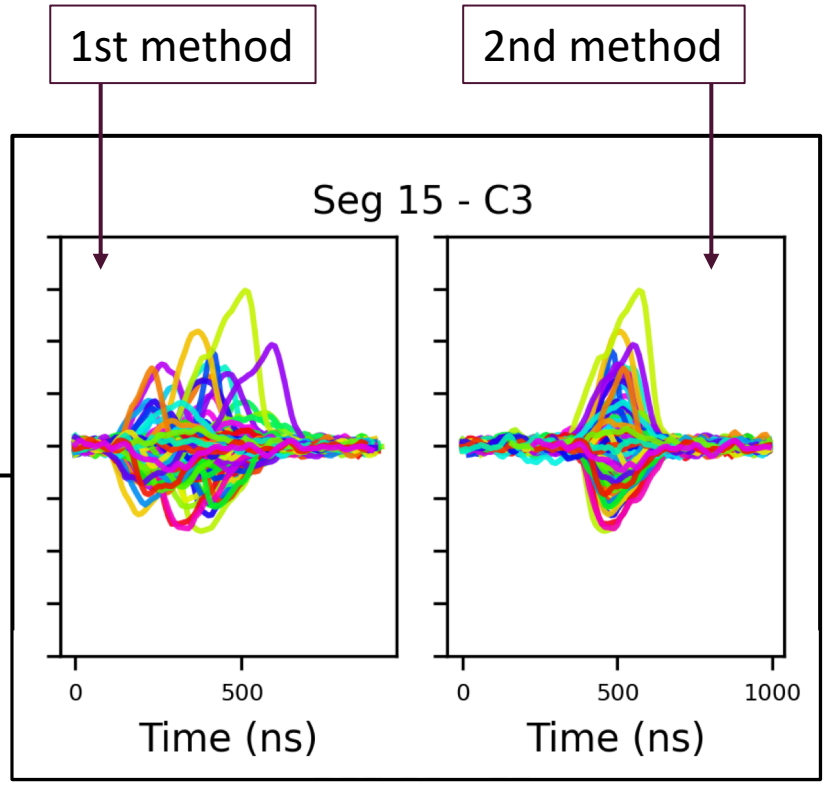




The algorithm determines there is no peak

Dataprocessing method – Preprocessing – Time alignment





Characterization steps

1. **Setting up the experimental system (~ 1 year and 4 months)**
   - Acquistion electronics: AGATA (Digi-Opt12), γ-ray camera (MBS) and coincidence
   - AGATA detector setting: Vacuuming, cooling down and initial test to check operation, with the help of M.H. Sigward (IPHC) (1-2 weeks)
   - Acquisition software update: to launch both systems from the same platform and enter data directly to a DB
2. **Measurement** from two different configurations (~ 4 months)
3. **Dataprocessing method (~ 10 months)**
   - Matching: correlation of AGATA - γ-ray camera events
   - Data preparation: filtering + preprocessing
   - PSC (Pulse Shape Comparison): Analysis of AGATA signals
   - Calculation of tracks(straight lines) representing the γ-ray directions and intersection

Dataprocessing method – Pulse Shape Comparison

Main goal: To classify the events in groups of statistically non differing pulse shapes

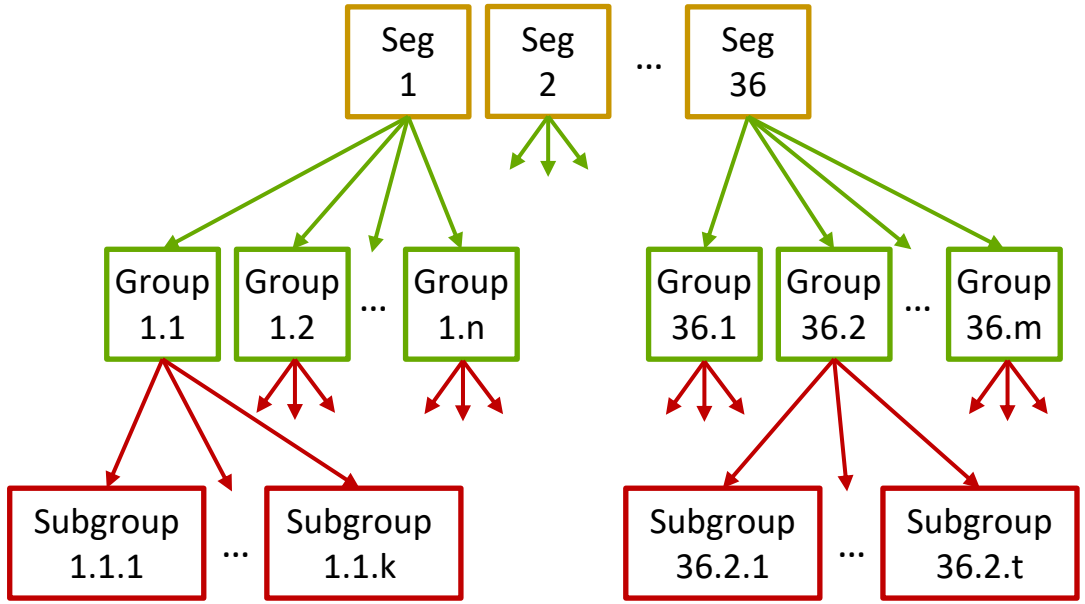
Step 1. Dividing the set of all events into **36 groups** according to the **triggered segment** (Step prior to comparison)

Step 2. Classification according to the **net signal** (pulse-shape)

→ The USAL PSC algorithm[4] is used to compare the pulse shapes of the net signals

Step 3. Classification according to the **transient signals**

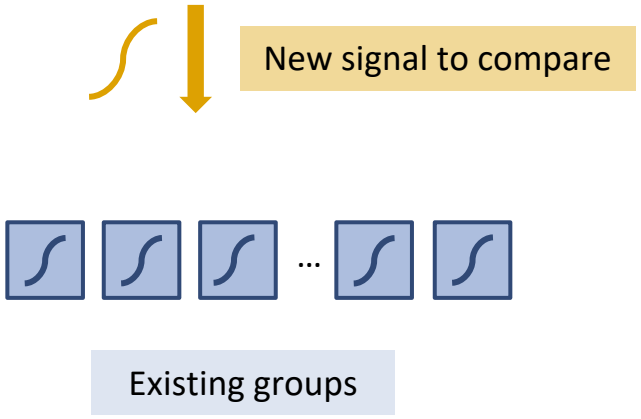
→ USAL PSC algorithm



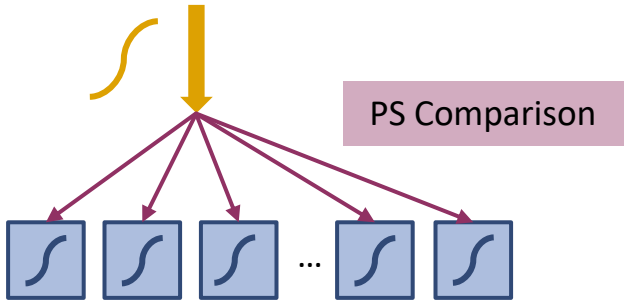
[4] Martín, S., et al. (2016). *Wilcoxon signed-rank-based technique for the pulse-shape analysis of HPGe detectors*. NIM-A, 823, 32–40, Elsevier B.V; doi: 10.1016/j.nima.2016.03.094

Dataprocessing method – Pulse Shape Comparison

1. A **new signal** is fed into the comparison algorithm

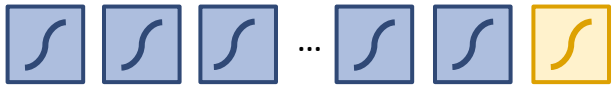


2. It is **compared with reference pulse shapes** from all the existing groups



3. **Is it statistically different** from the signals of all the existing groups?

Yes → It forms a **new group**



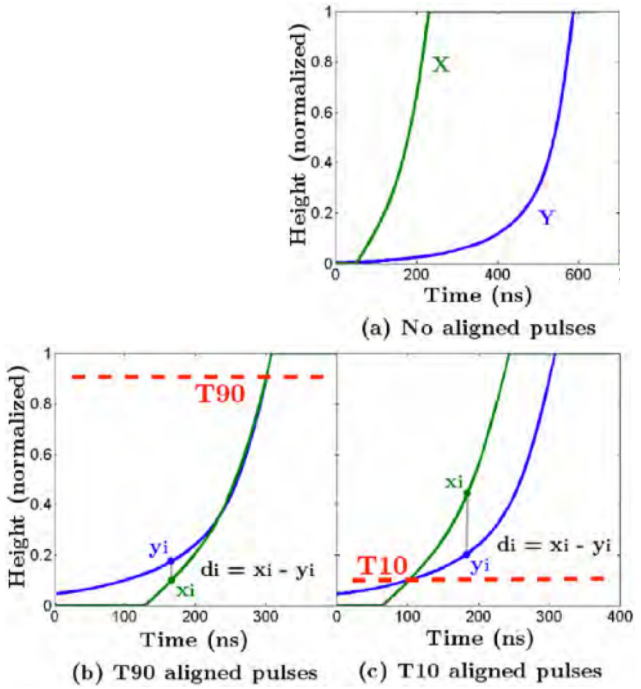
No → It is **added to the group** that is statistically **most similar**



Dataprocessing method – USAL PSC algorithm

We employ **our own pulse-shape comparison algorithm** that uses the **Wilcoxon signed-rank-based-test**:

Goal → To determine whether or not two pulse shapes differ statistically



1. Align signals in time, at **T10** (10% of total amplitude)

2. Determine the differences: $\boldsymbol{d_i = x_i - y_i}$, $D = \{d_i,\ i = 1, n\}$

If $\boldsymbol{d_i < MinT \rightarrow d_i = 0}$ (Experimental signals, to take noise into account)

3. **Sort differences** by their **absolute value**: assign a rank based on the absolute value of the difference

Rank 1 to the smallest and rank n to the largest

4. **Add up** the ranges of the positive differences ($\boldsymbol{R_+}$) and, separately, the ranges of the negative ones ($\boldsymbol{R_-}$)

5. **Compare $\boldsymbol{R_+}$ and $\boldsymbol{R_-}$ with $\boldsymbol{R(z)}$**

$$R(z) = \frac{n(n+1)}{4} - z\sqrt{\frac{n(n+1)(n+2)}{24}}$$ (z: Statistical significance)

If $\boldsymbol{R_+ > R(z)}$ and $\boldsymbol{R_- > R(z)}$ → Signals do not differ statistically

Any other case → Signals differ statistically

6. Perform the same procedure for the signals aligned to **T90**. **Only if in both cases**, T10 and T90, the **pulses do not differ statistically, they are considered as non differing**

Pulse Shape Comparison – Net signal

The USAL PSC algorithm requires two parameters:

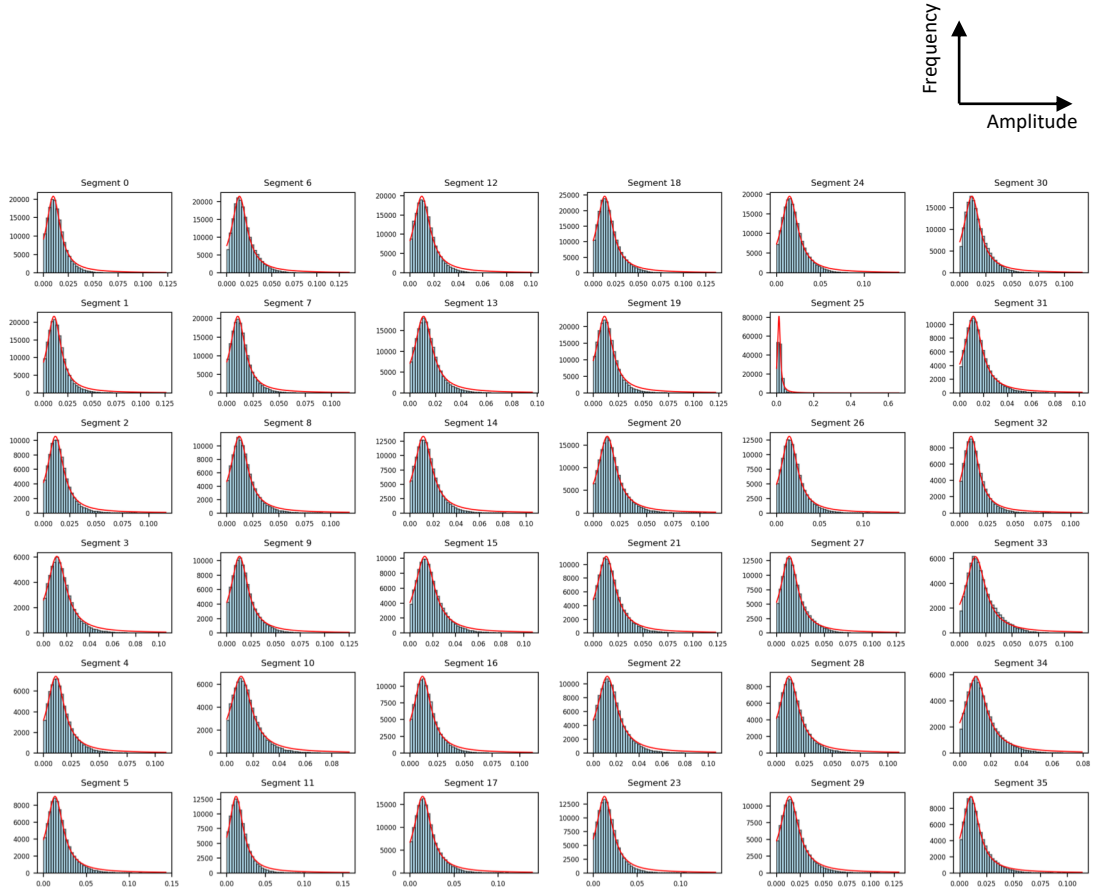
- $\boldsymbol{Z = 1.96}$: **Statistical significance** (1.96 corresponding to 2σ)
- $\boldsymbol{MinT}$: It depends on **fluctuations in the baseline noise**

The $MinT$ value is optimized through a baseline analysis:

the distributions are fitted to Lorentzian curves

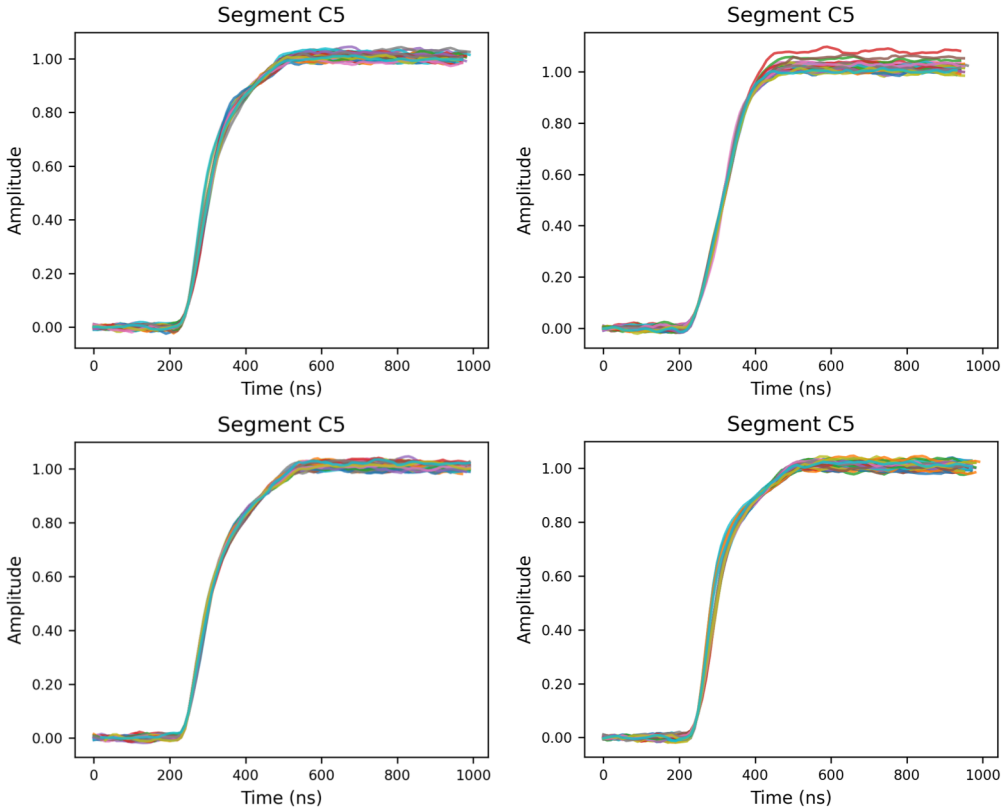
Baseline fit $\rightarrow \bar{\gamma} = 0.01$

Choice $\rightarrow \boldsymbol{MinT = 2\bar{\gamma} = 0.02}$

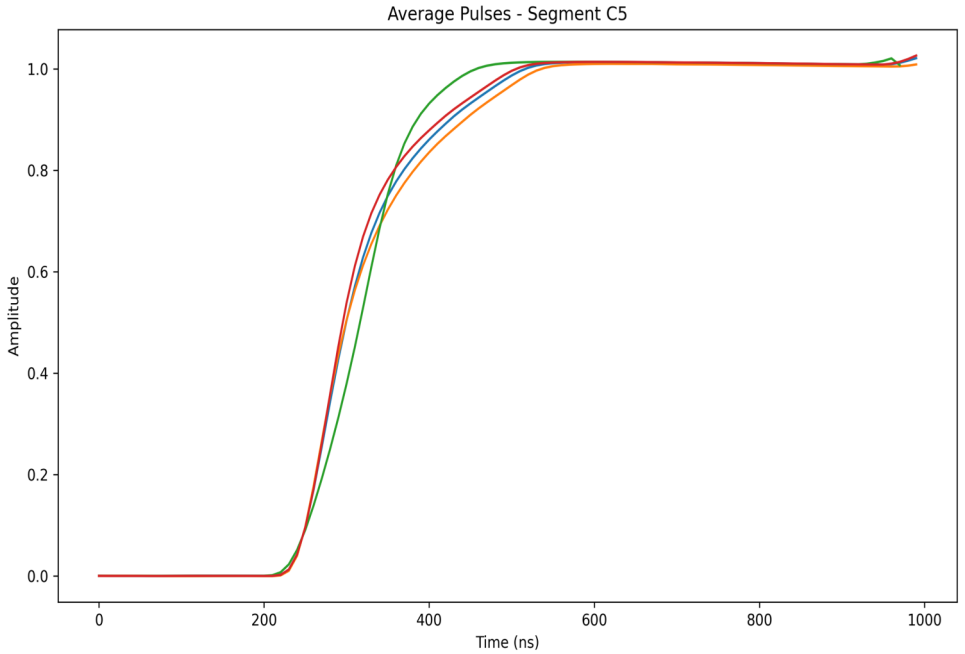


Pulse Shape Comparison – Net signal

Classification of events according to the pulse shape of the **net** signal (USAL PSC algorithm):



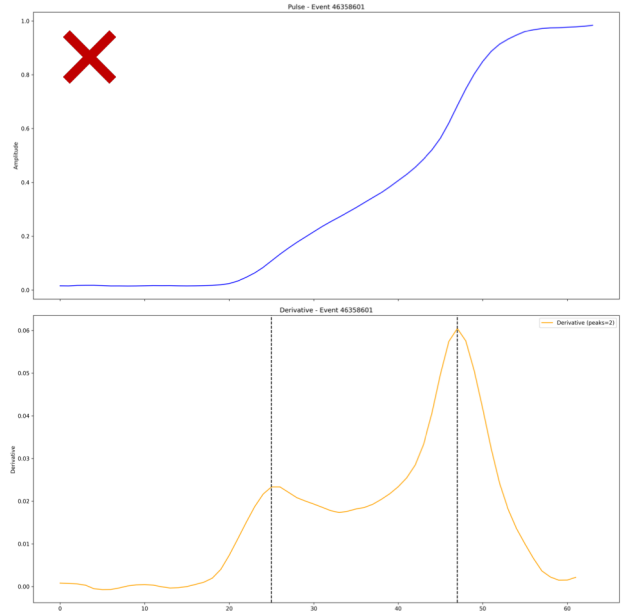
An averaged signal is obtained from each **group of statistically non differing pulse shapes**:



Pulse Shape Comparison – Data filtering

⇒ We realized that some signals corresponding to **multiple interaction events survive to the previous filtering process**, as statistical noise hides the presence of multiple peaks in the pulse-shape derivative

Therefore, we **filter again the data** according to the **derivative of the averaged net pulse shape**: (Similar to filtering condition 3)



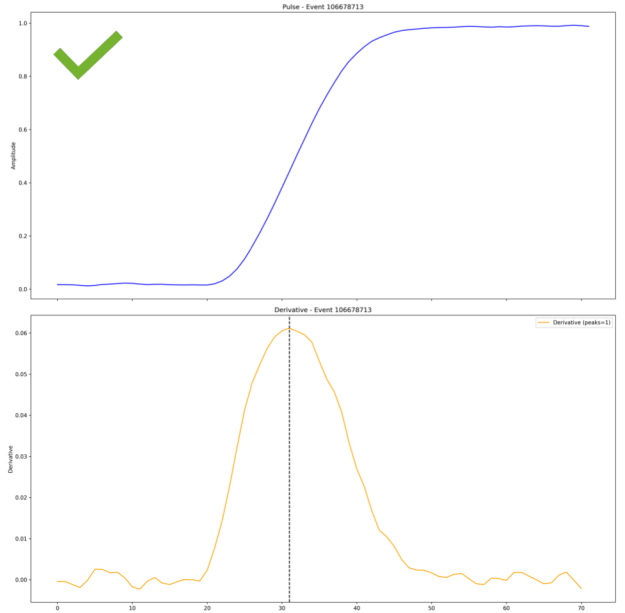
Optimized parameters for averaged signals

<u>Savitzky-Golay derivative method</u>:

- Window_length = 5
- Polyorder = 2

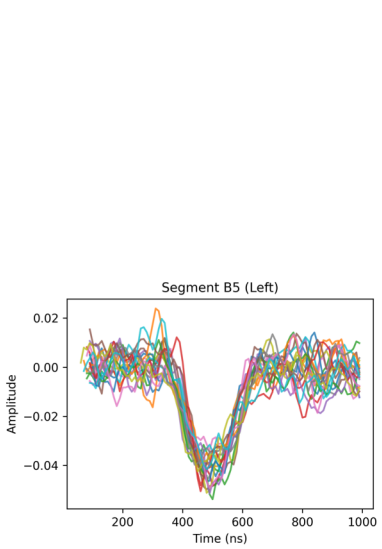
<u>For *find_peaks* from Python</u>:

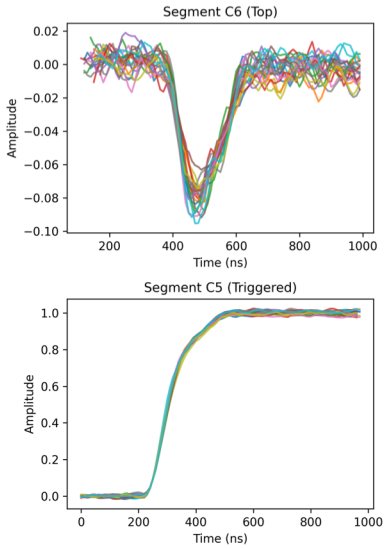
- Prominence = 0.00540
- Distance = 14.5
- Height = 0.01

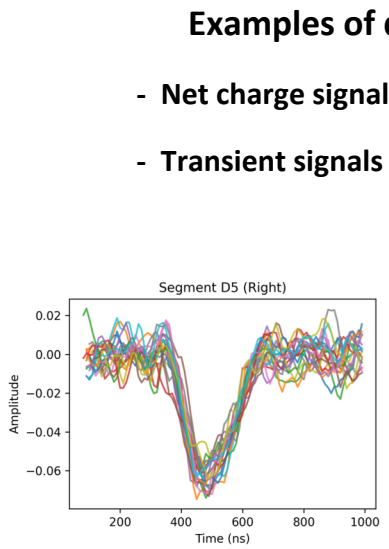


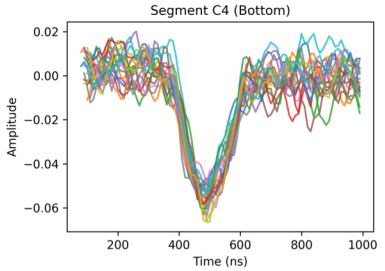
Pulse Shape Comparison – Transient signals

Classification of events <u>according to the pulse shape of the **transient** signals</u> (USAL PSC algorithm):



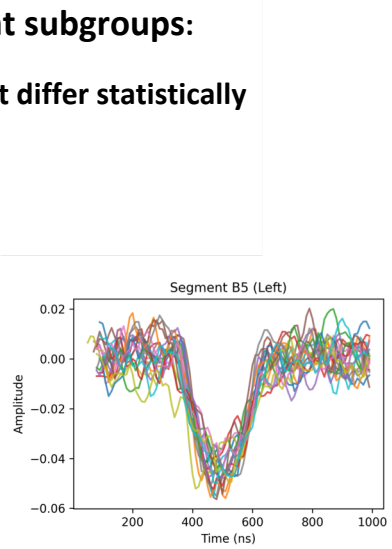


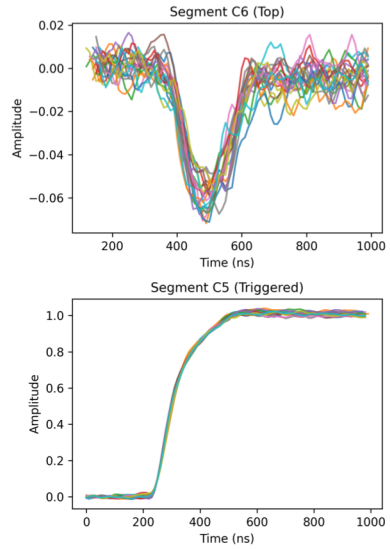


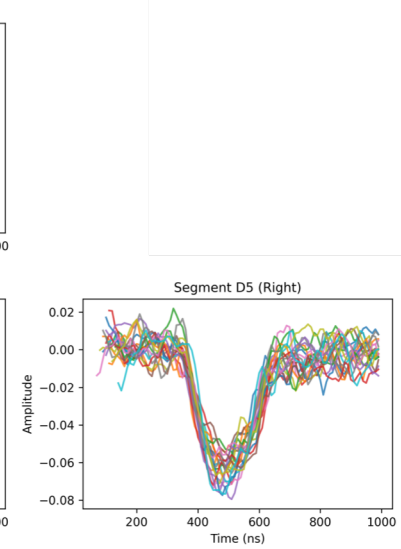


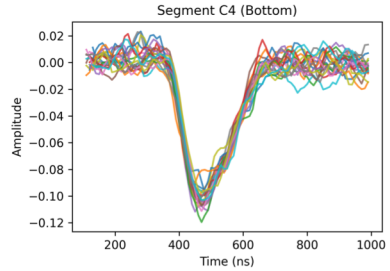
Examples of different subgroups:

- **Net charge signal does not differ statistically**
- **Transient signals do**



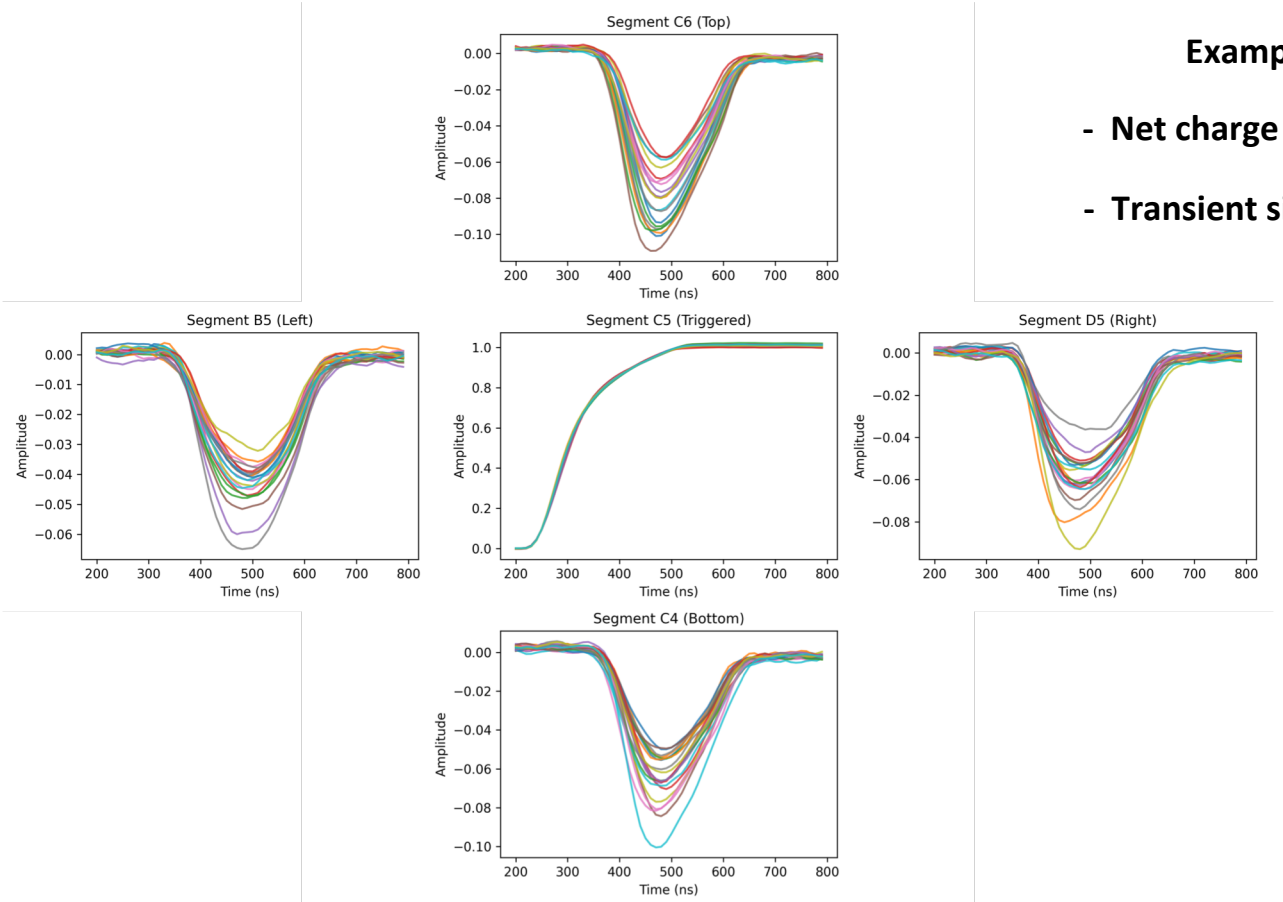






Pulse Shape Comparison – Transient signals

An <u>averaged signal</u> is obtained from each **group of statistically non differing pulse shapes**:



Examples of different subgroups:

- **Net charge signal does not differ statistically**
- **Transient signals do**

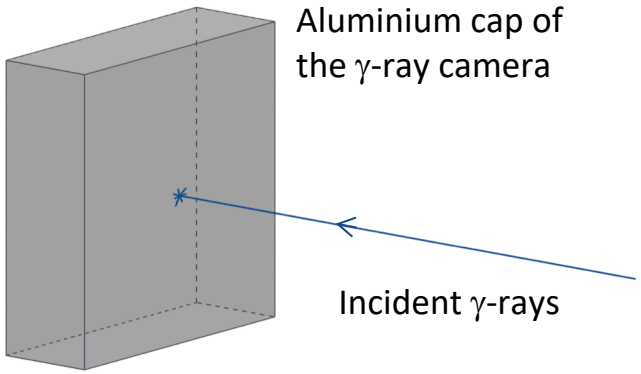
Characterization steps

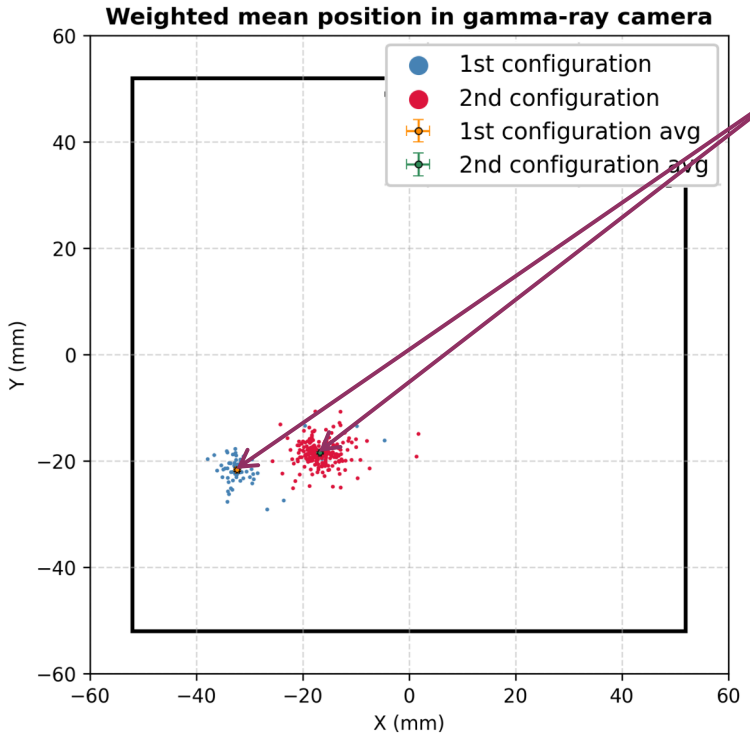
1. **Setting up the experimental system (~ 1 year and 4 months)**
   - Acquistion electronics: AGATA (Digi-Opt12), γ-ray camera (MBS) and coincidence
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   - Matching: correlation of AGATA - γ-ray camera events
   - Data preparation: filtering + preprocessing
   - PSC (Pulse Shape Comparison): Analysis of AGATA signals
   - Calculation of tracks(straight lines) representing the γ-ray directions and intersection

Reconstruction of lines and intersection

For each set of events with statistically non differing pulse shapes, we determine the **positions** at which the photons interact **in the γ-ray camera**:

For a given subgroup…





Calculate the central position Iterative algorithm developed:

Calculation of a weighted mean according to the **distance between each single point and the mean** determined in the previous iteration

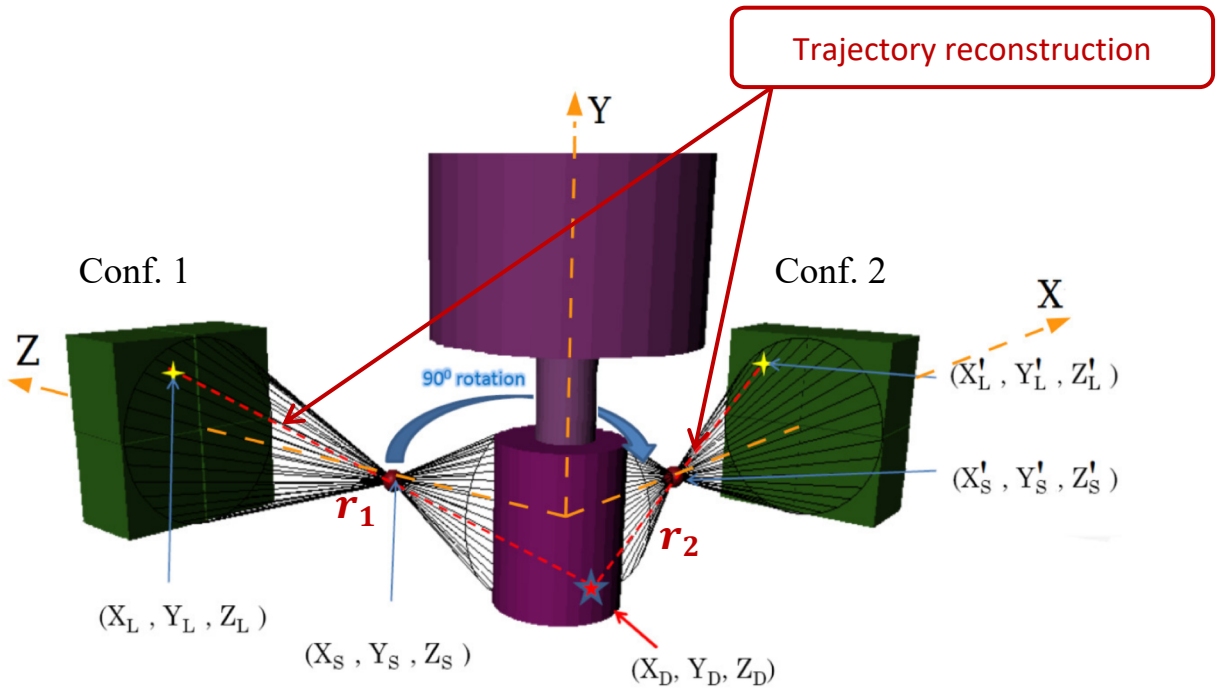
Weight: $\boldsymbol{w_i = \frac{1}{d}}$

Scattering in the aluminium cap:

We asume that the **centre of the distribution** corresponds to the **photons that are not scattered**

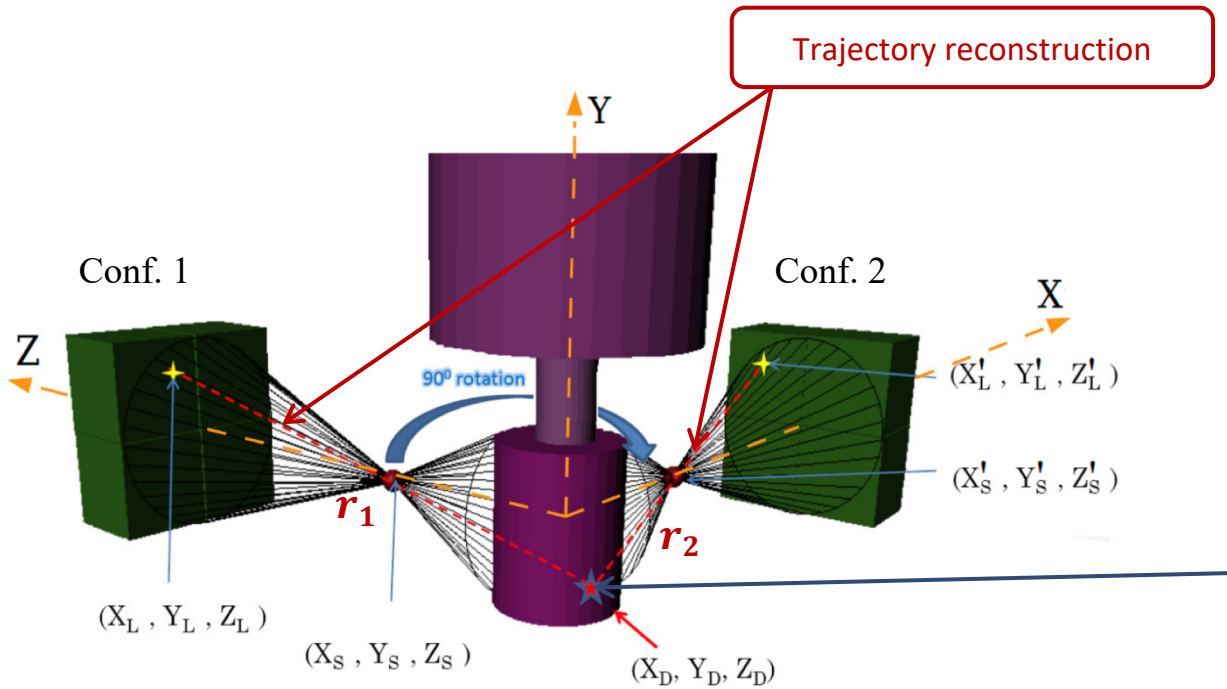
Reconstruction of lines and intersection

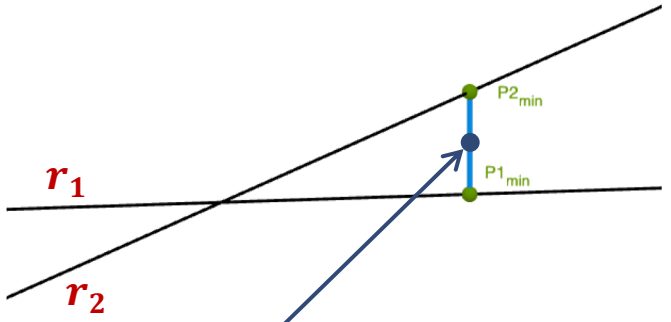
For each set of events with statistically non differing pulse shapes, we **reconstruct the tracks (straight lines)** that represent the **directions of the γ-rays**:



Reconstruction of lines and intersection

For each set of events with statistically non differing pulse shapes, we calculate the **interaction position** in the **AGATA** detector:





Intersection in the AGATA crystal:

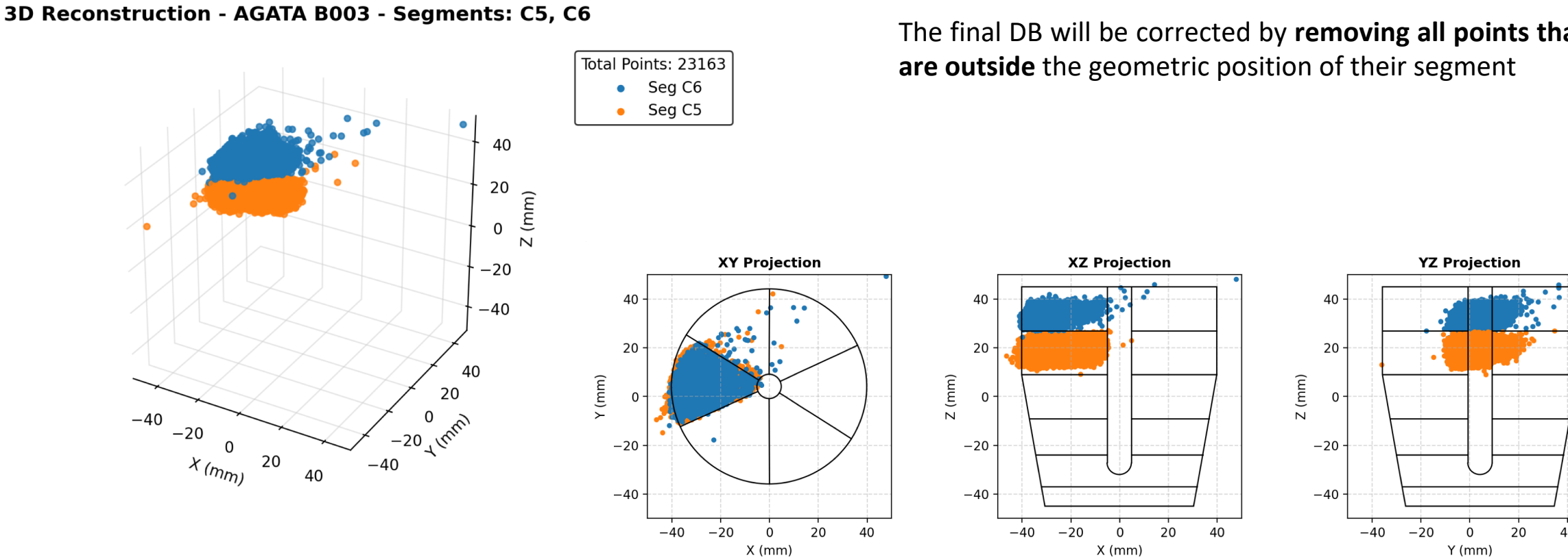
Determined by the **points on the lines where the distance between them is as short as posible**: maximum proximity. The intersection corresponds to the **midpoint** between these positions.

Characterization steps

1. **Setting up the experimental system** (~ 1 year and 4 months)
   - Acquistion electronics: AGATA (Digi-Opt12), γ-ray camera (MBS) and coincidence
   - AGATA detector setting: Vacuuming, cooling down and initial test to check operation, with the help of M.H. Sigward (IPHC) (1-2 weeks)
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   - Matching: correlation of AGATA - γ-ray camera events
   - Data preparation: filtering + preprocessing
   - PSC (Pulse Shape Comparison): Analysis of AGATA signals
   - Calculation of straight lines representing the γ-ray directions and intersection
4. **Building the database** (Electrical pulse shapes – interaction positions)

Building the database

After correction, we achieve the characterized volume:

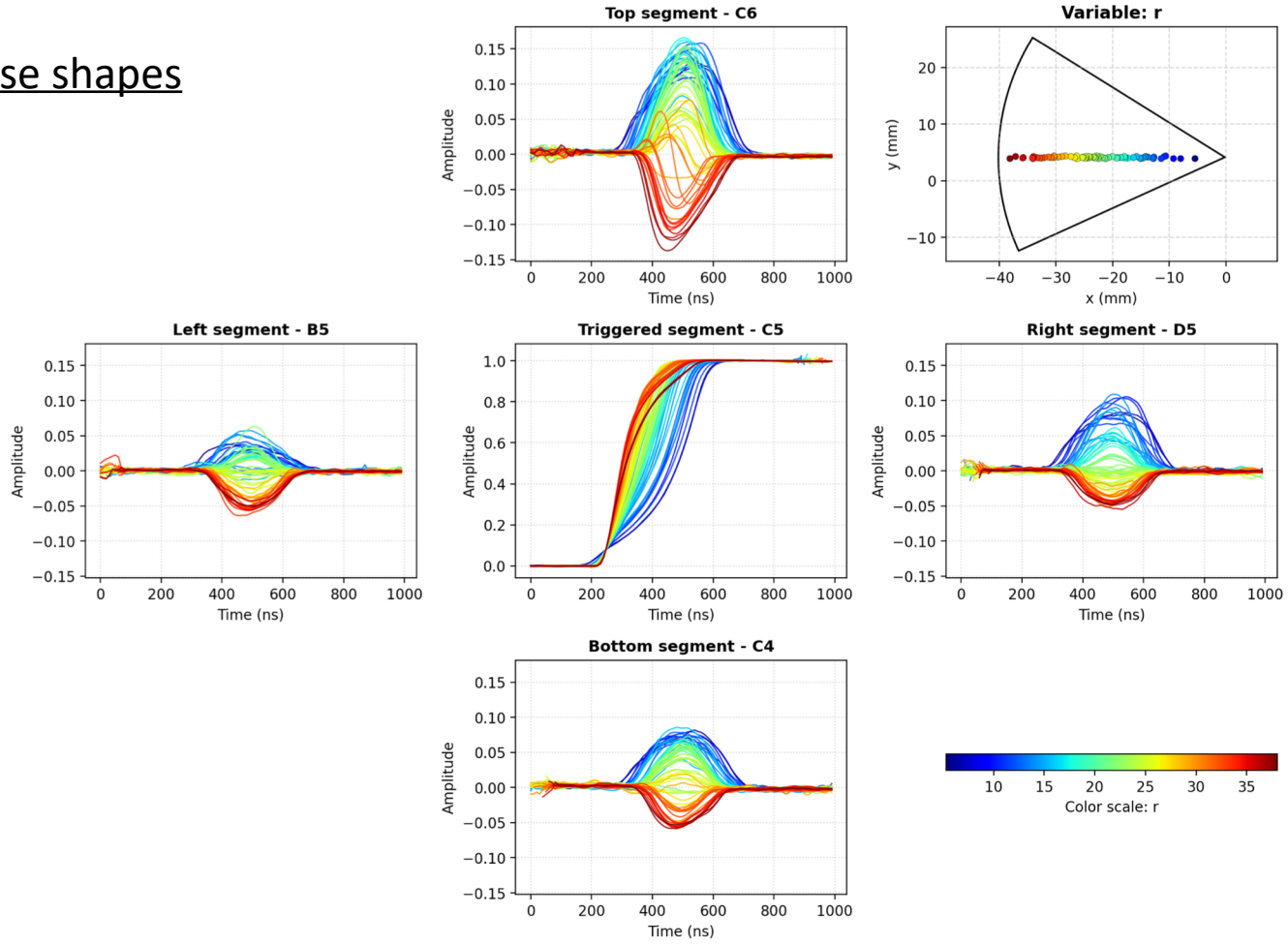


The final DB will be corrected by **removing all points that are outside** the geometric position of their segment

Results

DB: Radiation interaction position ↔ electrical pulse shapes

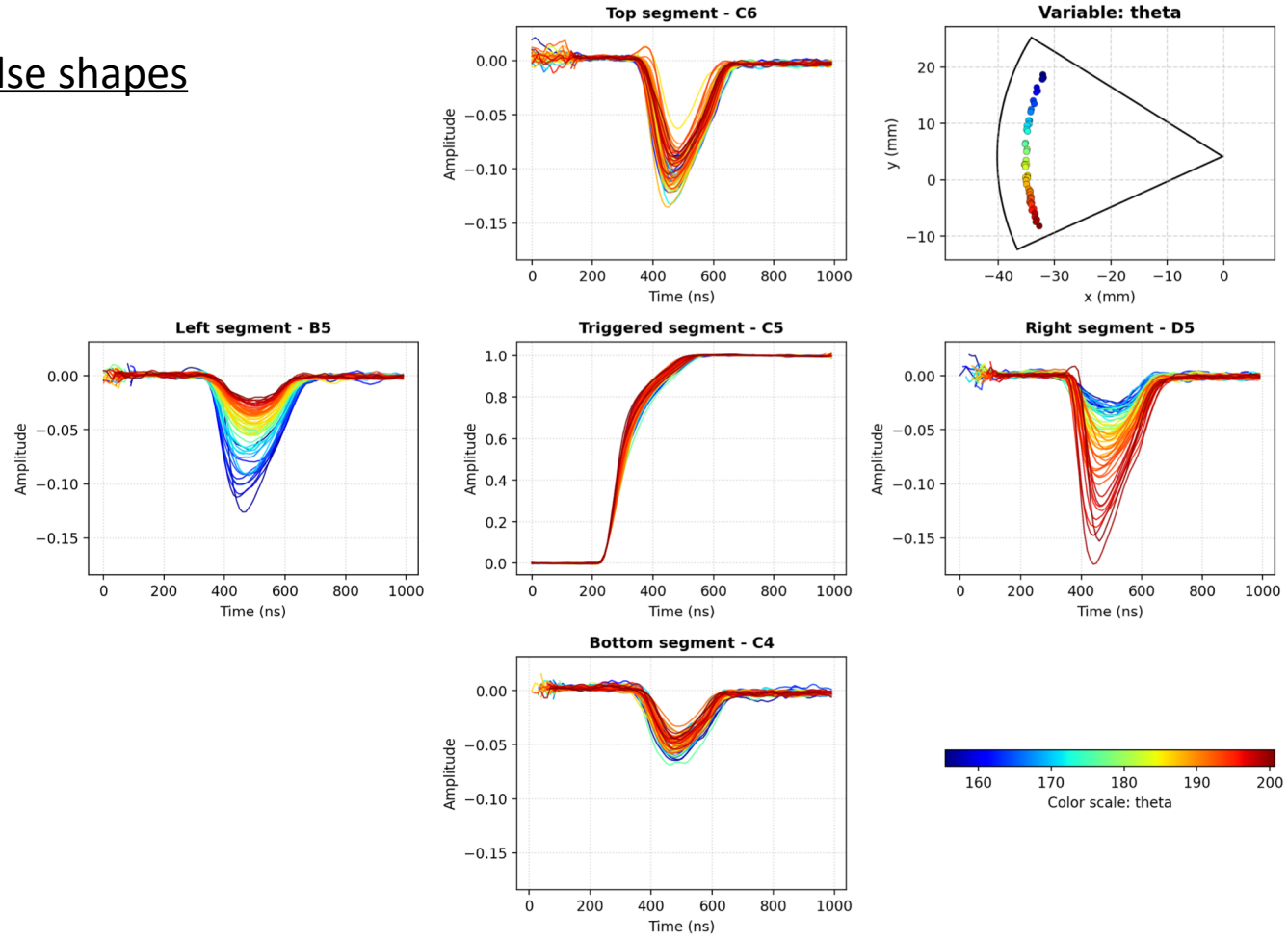
- **Radial: varying**
  - $y \in [3.90, 4.40]\ mm$
  - $z \in [20.50, 21.50]\ mm$
- Azimuthal: constant
- Height: constant



Results

DB: Radiation interaction position ↔ electrical pulse shapes

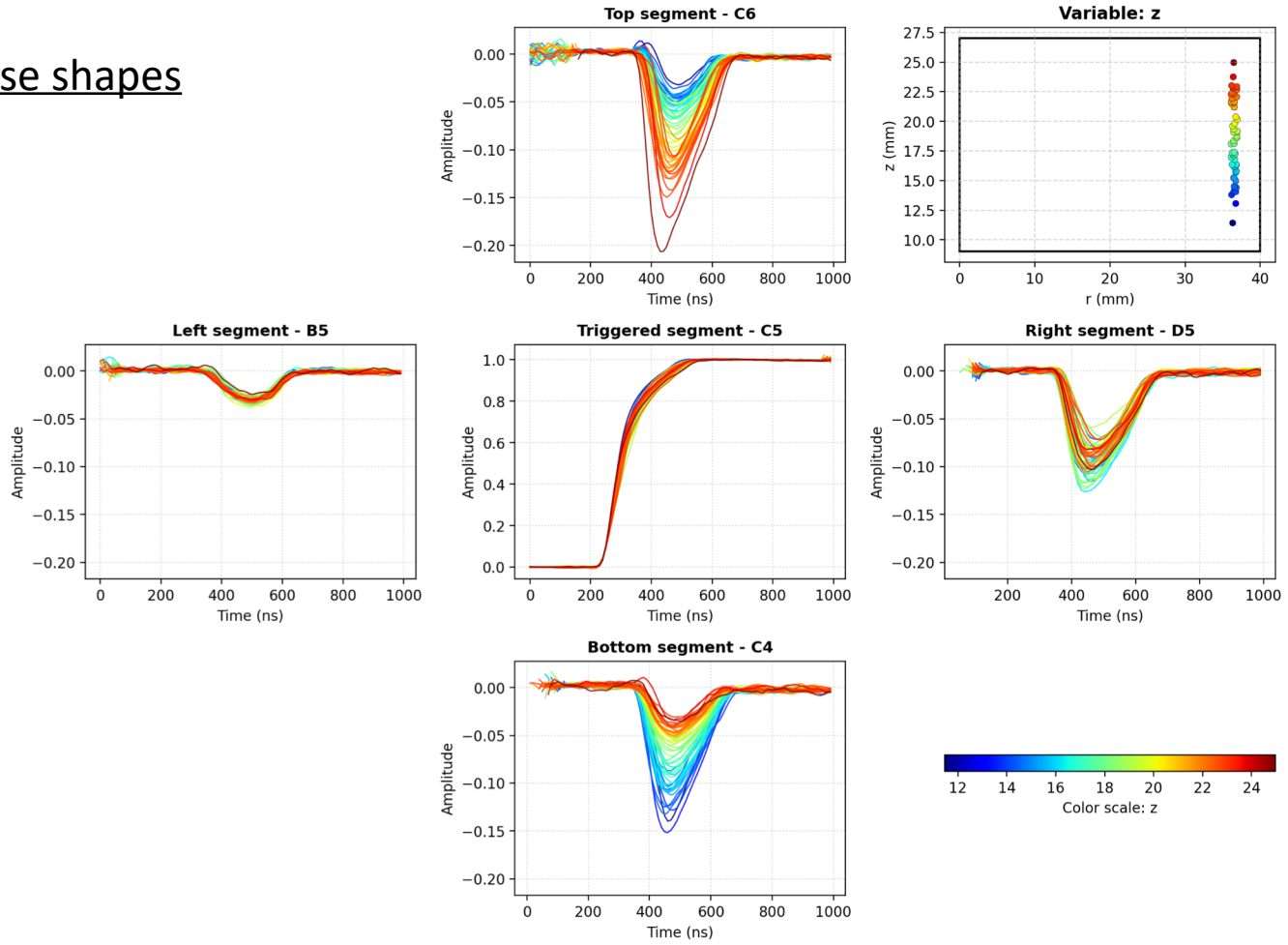
- Radial: constant
- **Azimuthal: varying**
  - $r \in [34.75, 35.25]\ mm$
  - $z \in [20.50, 21.50]\ mm$
- Height: constant



Results

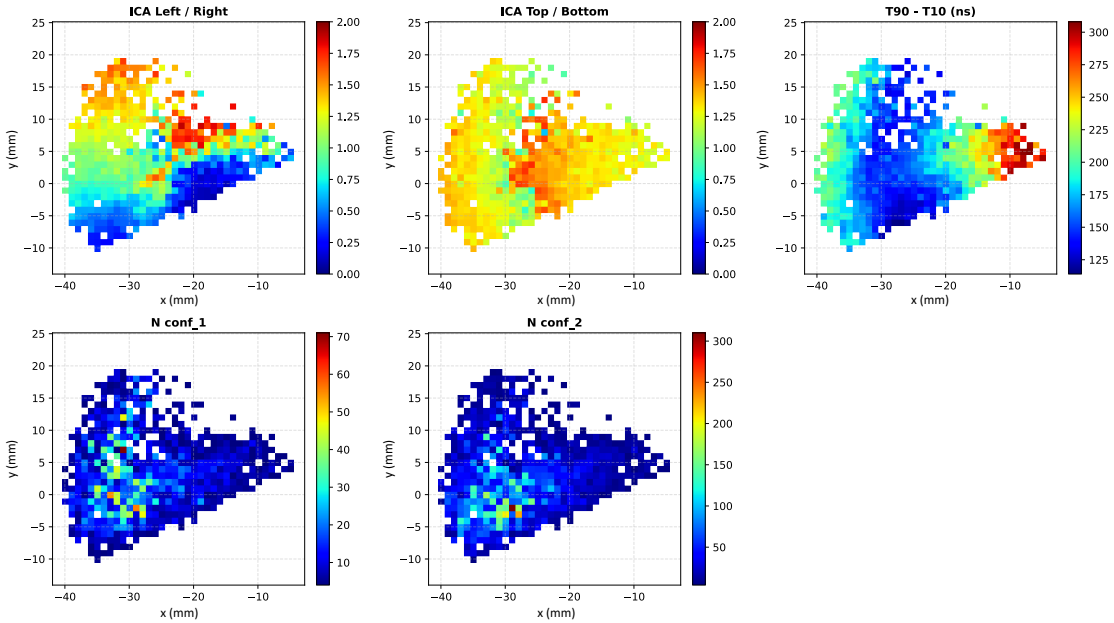
DB: Radiation interaction position ↔ electrical pulse shapes

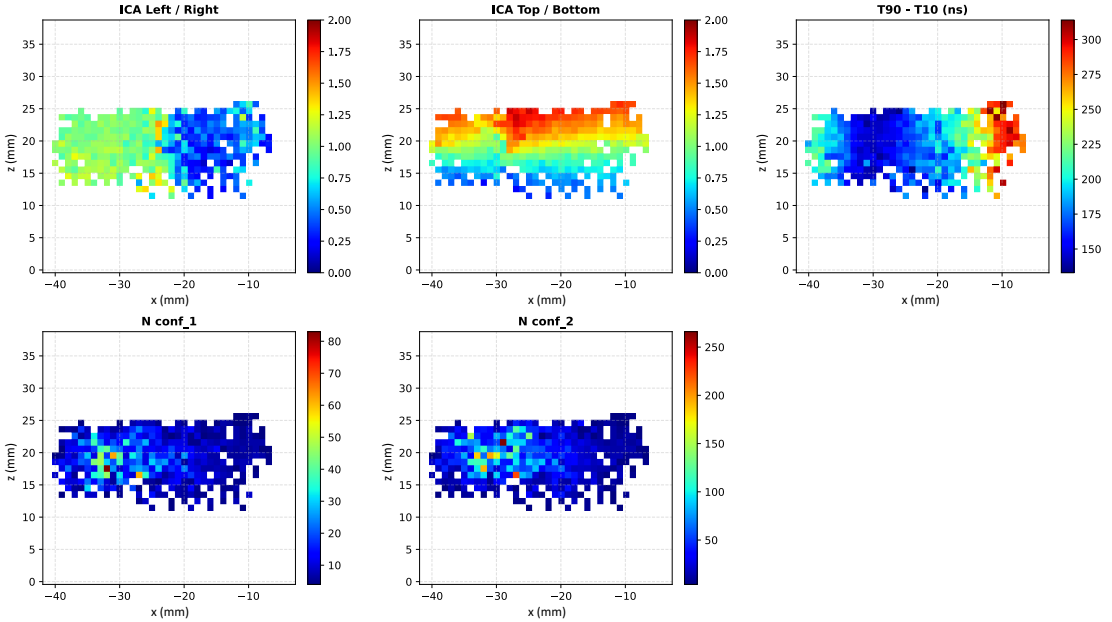
- Radial: constant
- Azimuthal: constant
- **Height: varying**
  - $x \in [-35.9, -35.1]\ mm$
  - $y \in [-5.4, -4.6]\ mm$



Results

$1\ x\ 1\ x\ 1\ mm^3$ grid



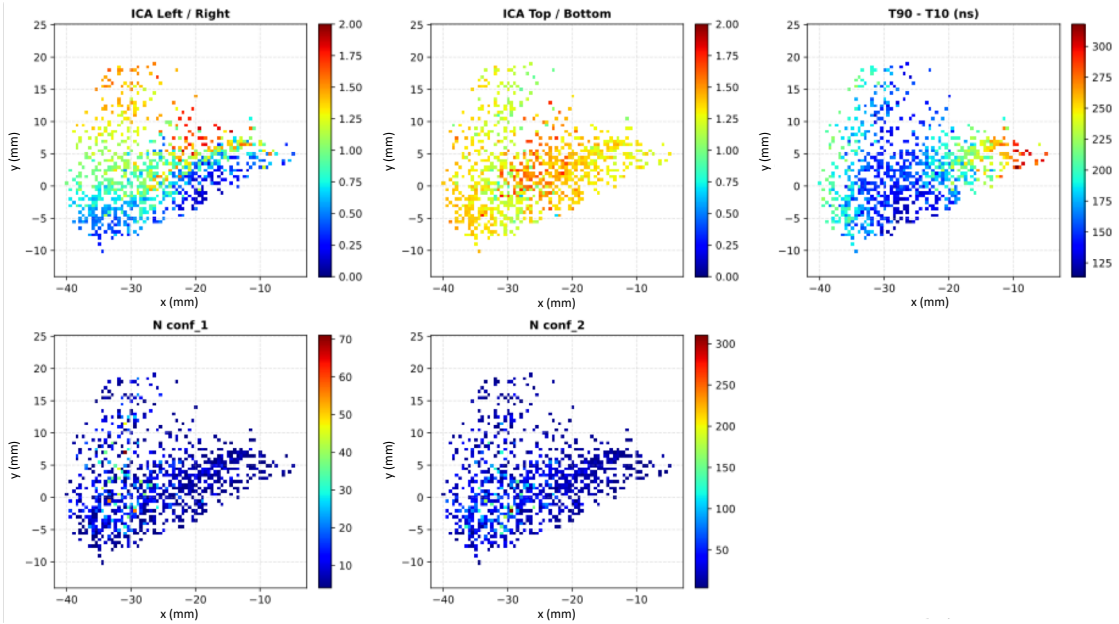


$z \in [20.50, 21.50]\ mm$

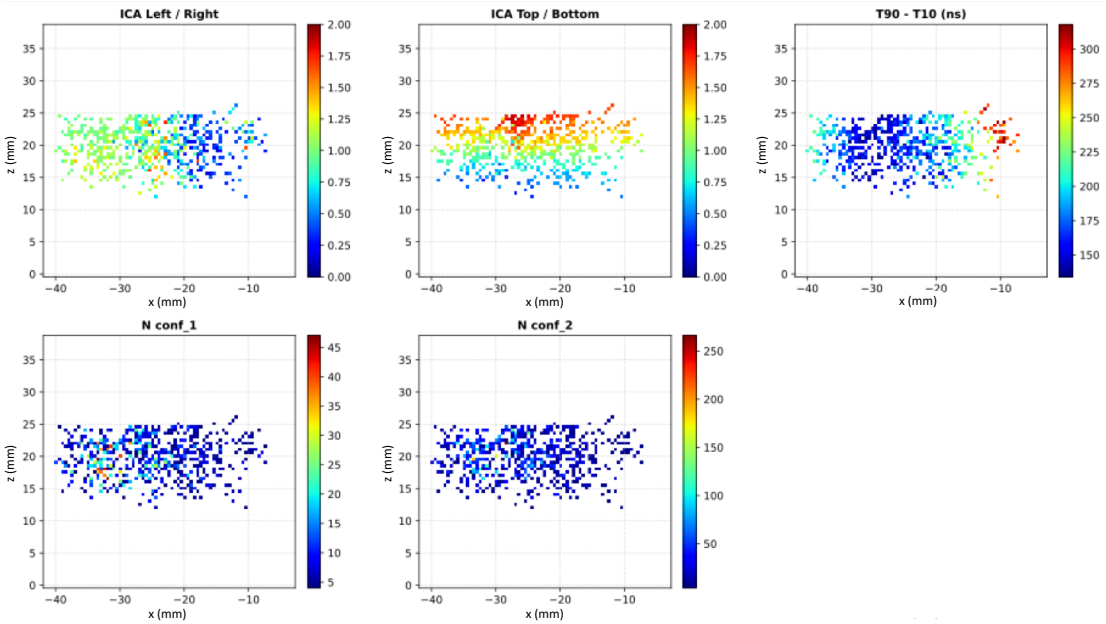
$y \in [2.50, 3.50]\ mm$

Results

$0.5\ x\ 0.5\ x\ 0.5\ mm^3$ grid



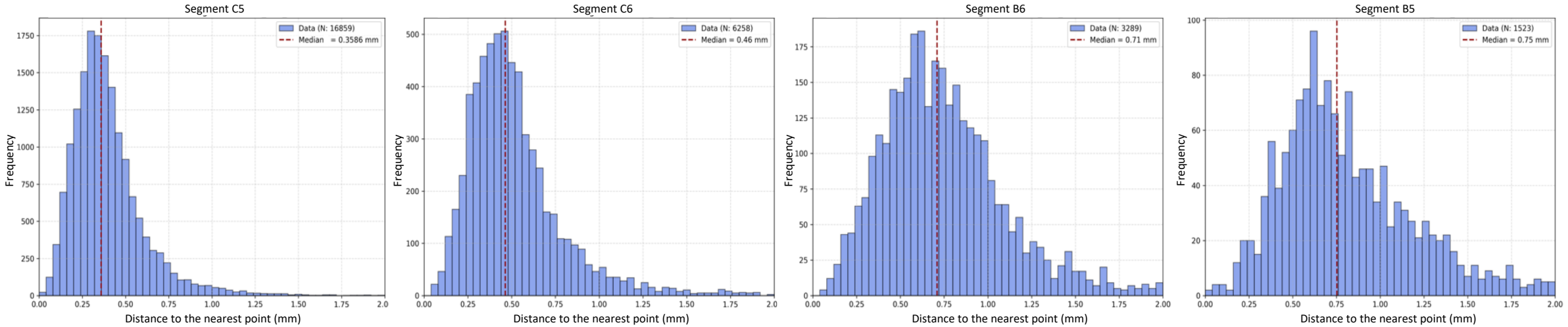
$z \in [20.75, 21.25]\ mm$



$y \in [2.75, 3.25]\ mm$

Results – AGATA position resolution provided by SALSA

Position resolution provided by SALSA as the **distance between each point and the nearest one**



For the segments which have been studied, the **medians of the minimum distance between characterized interaction points** in the AGATA crystal are **lower than 1mm** → **The SALSA method enables the detection of differences in AGATA signals corresponding to differences in interaction positions of less than 1 mm**

Conclusions

1. We have performed the **first partial characterization** of an AGATA detector (B003) using the **SALSA** method
    - The main limitation for scanning other segments was the measurement time, to have enough statistics

2. The results obtained show that the **position resolution of the AGATA crystal is less than 1 mm**
    - The **SALSA method** enables this position resolution to be achieved

Future work

1. Next step: We will carry out a **comparison with the B003 DB obtained at IPHC** (Strasbourg) to validate SALSA method

2. To **reduce the scanning time**, an improvement could be made in the **acquisition software** (technical priority):
   - Currently the data ingestion into the DB is very time-consuming
   - **Time estimation** for a full characterization of an AGATA detector using the SALSA method:

Status	Scanning time for each configuration	Time for full scanning (6 configurations)
Current setup	~ 1 month	~ 6 months
Improving online preprocessing (data ingestion into DB) – To ensure no delay	~ 1 week	~ 6 weeks

3. Improve the **energy resolution in the γ-ray camera** by replacing the LYSO crystal by **another scintillator**. This would diminish the point cloud in the ancillary detector



THANK YOU
FOR YOUR ATTENTION



MINISTERIO
DE CIENCIA, INNOVACIÓN
Y UNIVERSIDADES

AGENCIA
ESTATAL DE
INVESTIGACIÓN

VNiVERSiDAD
D SALAMANCA

LD
RI

SALSA (SAlamanca Lyso-based Scanning Array)

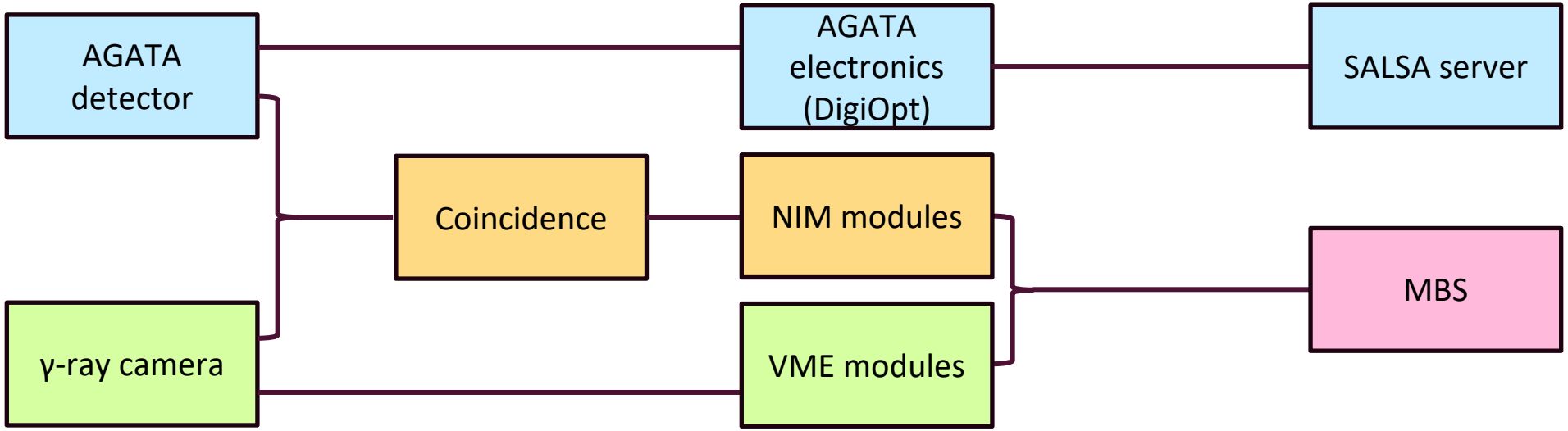






SALSA electronics

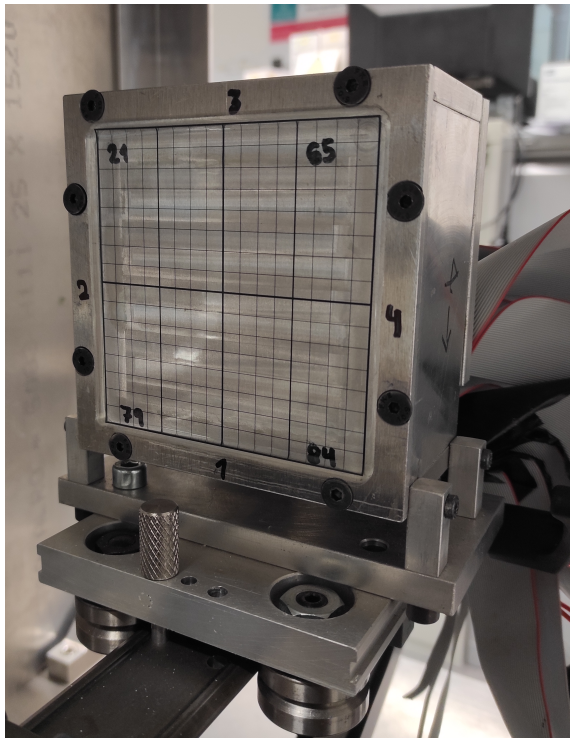
- We have **two detectors** with **its corresponding electronics** + the **coincidence electronic** setup

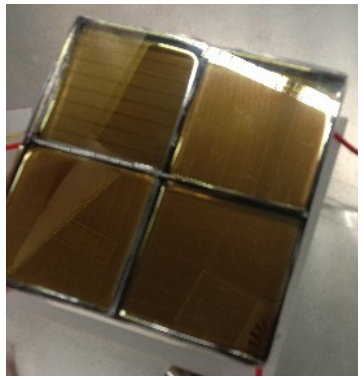


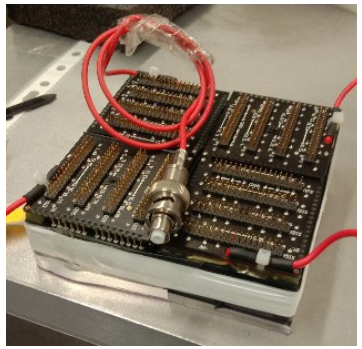
SALSA electronics

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

➢ **γ-ray camera electronics**







4 PSD (Position sensitive detectors)

Scintillators:

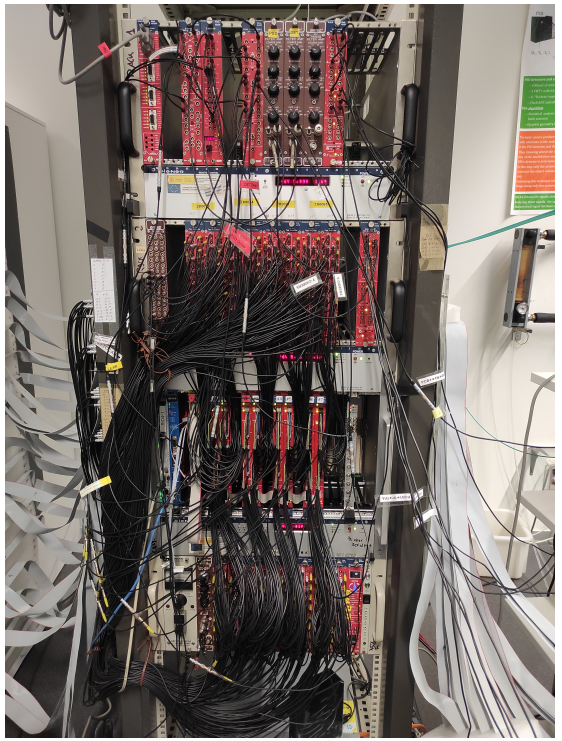
LYSO crystals: 4 x (52x52x5 mm^3)

Pixelated photomultipliers:

H10966A-100 Hamamatsu

4 x 64 = 256 pixels

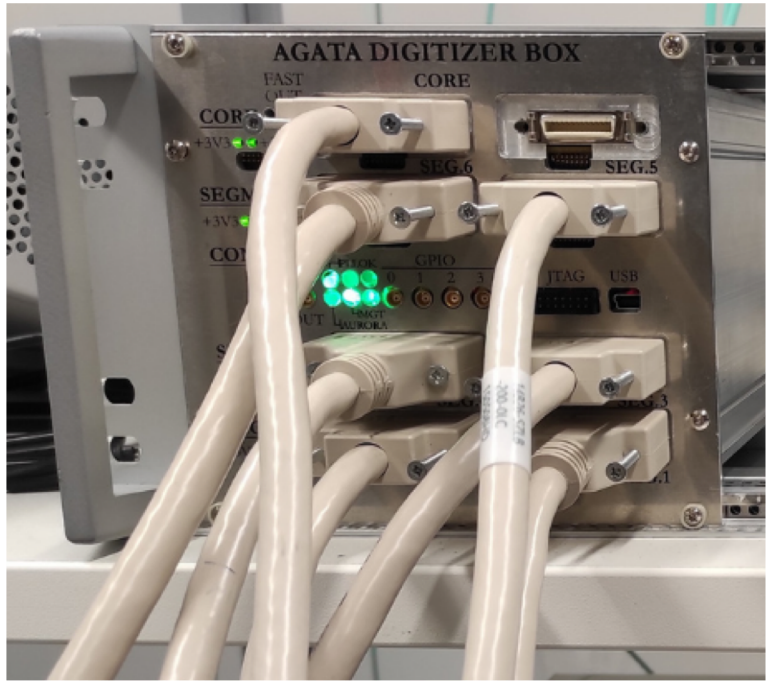
256 channels



SALSA electronics

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

➢ **AGATA electronics**





AGATA Digi-Opt12 (Same digitizer as AGATA)

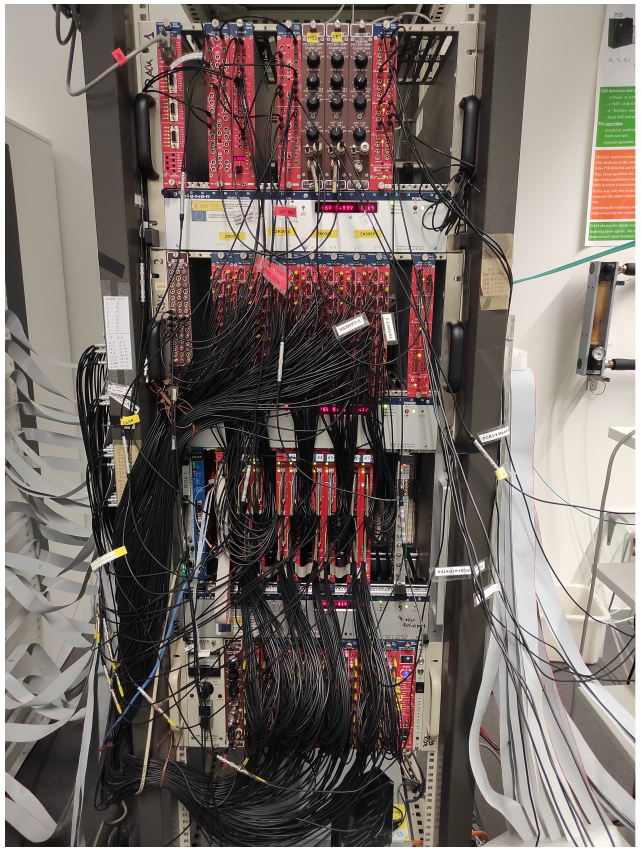
Digitizer for 38 channels:

36 segments

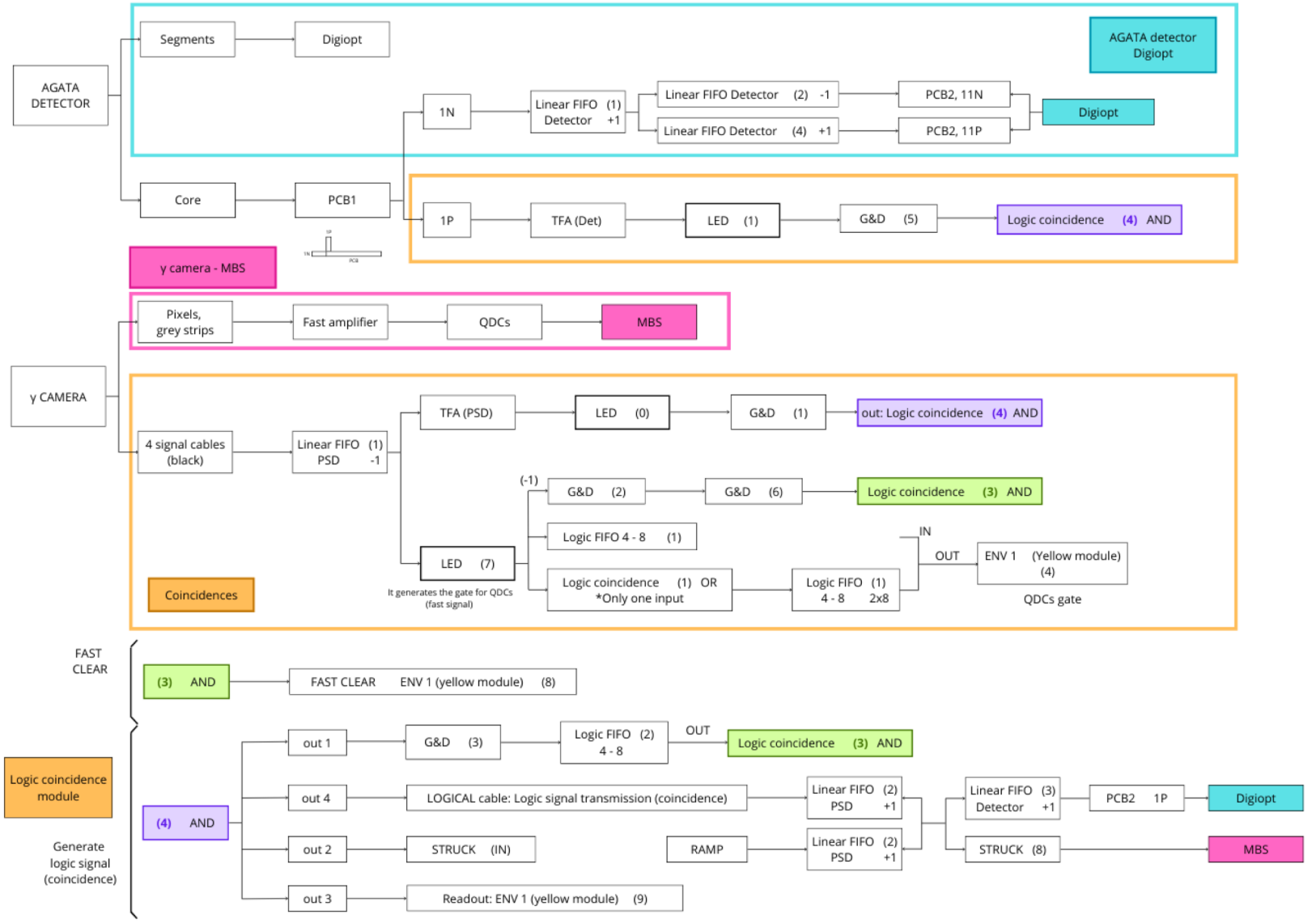
+ core

+ additional core signal for coincidences

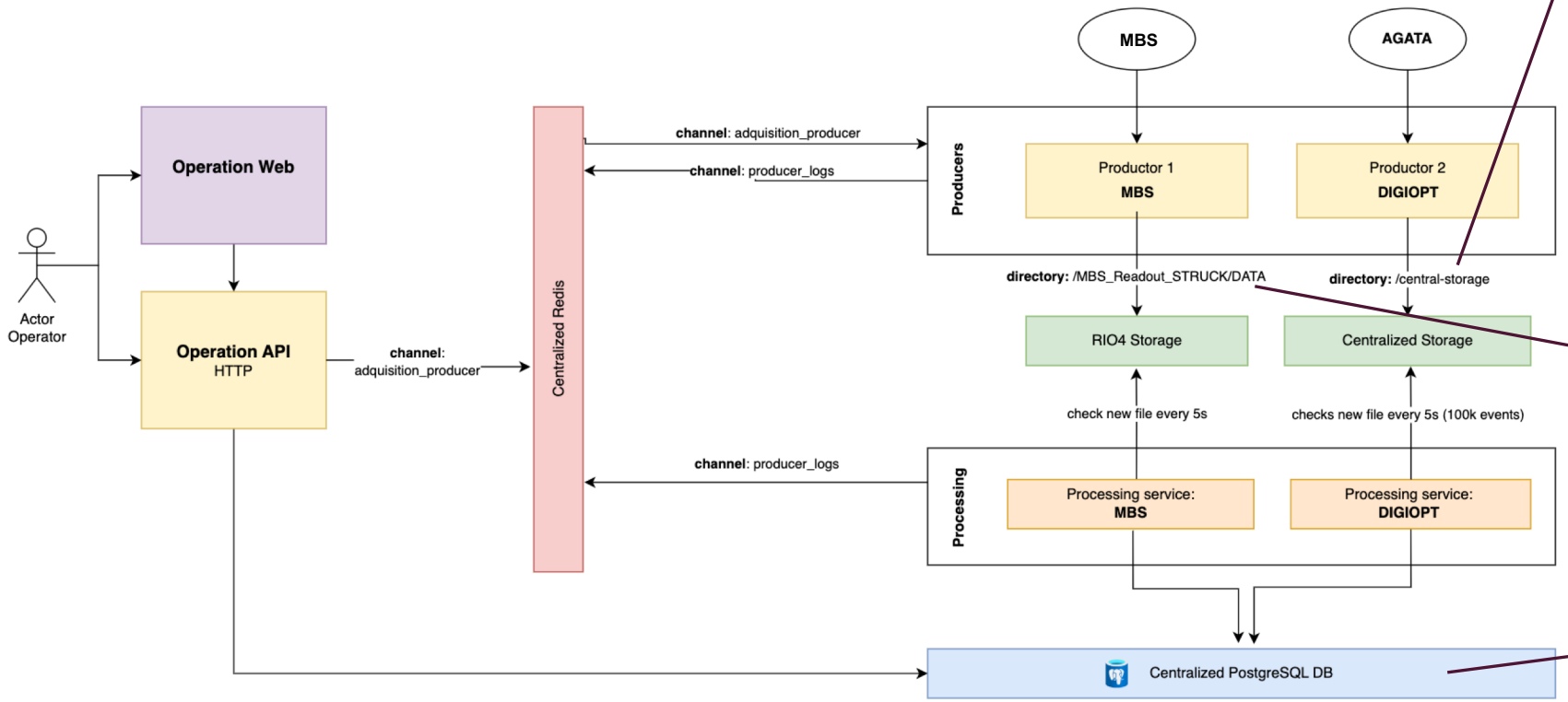
SALSA electronics



We do not have a universal clock



SALSA server infrastructure



SALSA server

HP ProLiant DL380p Gen8 (Chasis 8 LFF)
Processor: Intel Xeon
Local storage: 8x 500 GB SATA HDD @ 7.2RPM

XEN server

Intel(R) Xeon(R) Silver 4310 CPU @ 2.10GHz
CPU(s): 24
RAM: 128 GB DDR4 ECC @ 2666 MHz (4x 32 GB DIMMs)
Local storage: 446.6 GB Enterprise SSD (Dell PERC H3xx Controller)

Mass Storage: ~112.7 TB Dell PowerVault ME4

Compute server

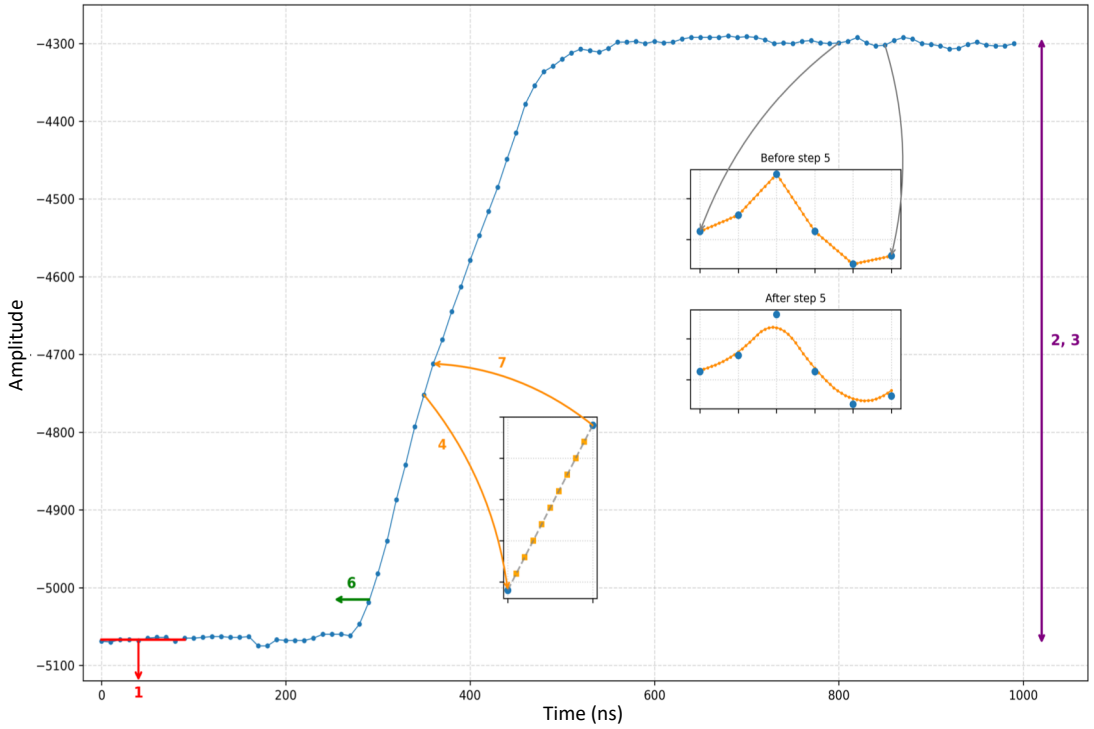
Intel(R) Xeon(R) Gold 6248R CPU @ 3.00GHz
CPU(s): 96
RAM: 256 GB DDR4 ECC @ 2933 MHz (8x 32 GB DIMMs)
Local storage (NVMe): 1 TB Samsung 980 PRO + 2 TB PNY CS3140 (NVMe PCIe SSDs)
Local storage (HDD): 4 TB Toshiba Enterprise HDD (MG08ADA4)

Dataprocessing method – Preprocessing

To prepare each signal before performing PSC → We carry out a method according to Strasbourg's procedure

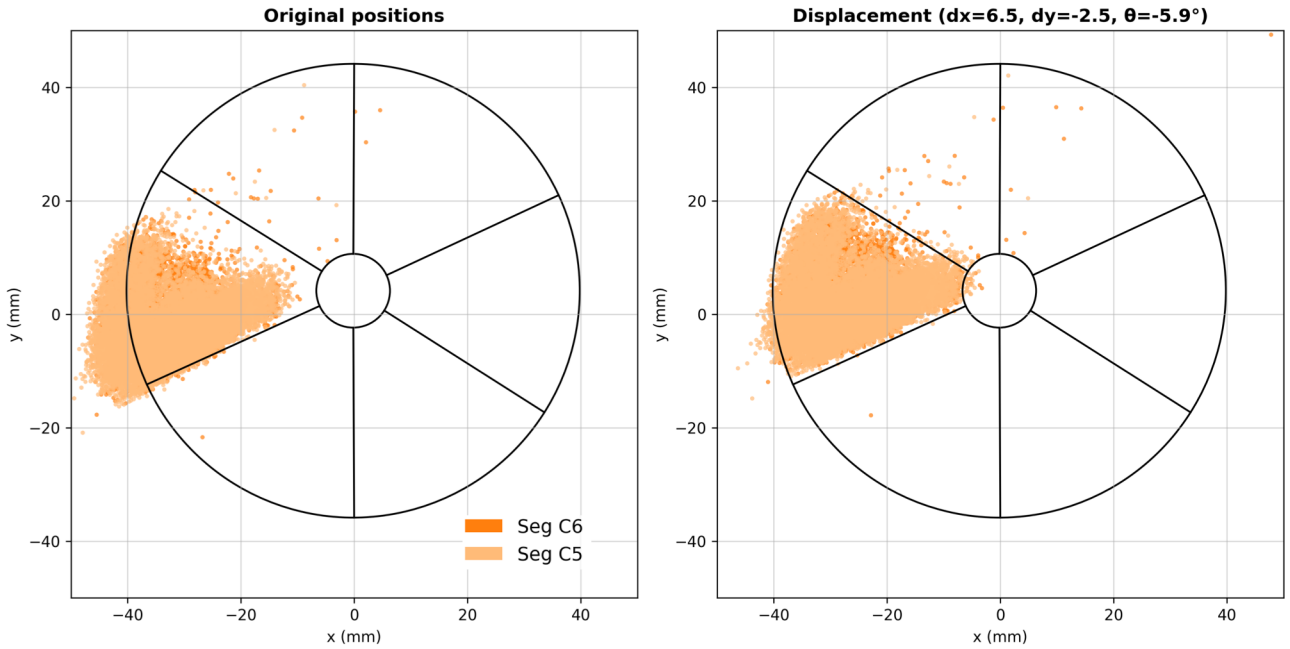
STEPS:

1. Apply an offset to set the baseline to zero
2. Align the gain of each segment (prior calibration is required)
3. Normalization of net and transient pulse shapes according to net signal
4. Interpolation between two digital points to virtually increase the sampling rate (from 100 MHz to 1GHz)
5. Apply an 11-point moving average
6. Time alignment
7. Decrease the sampling rate (from 1GHz to 100 MHz)



Reconstruction of lines and intersection

Displacement correction to the total volume of the crystal to centre and position it in agreement with the criteria of the characterization WG *



To centre the volume:

$dx = 6.5\ mm$

$dy = -2.5\ mm$

$dz = 1.0\ mm$

$d\theta = -5.9º$

To place it in accordance to WG:

$dx = -0.18\ mm$

$dy = 4.15\ mm$

* BC-EF segmentation line on the y-axis; vertex A on the x-axis (AGATA label)