AG GdR Mi2b

09.10.2024

Monte Carlo simulation for Prompt Gamma Time Imaging in protontherapy

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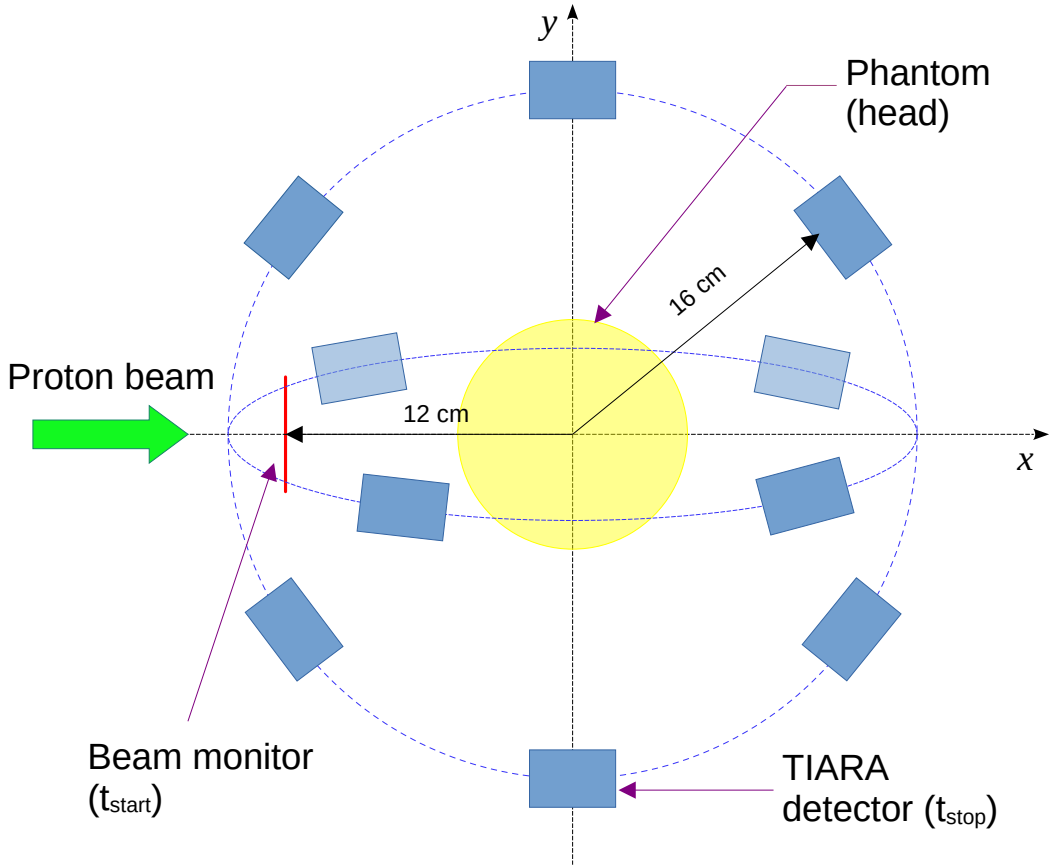
Simulation

Objective: make a simulation of the setup that gives results comparable to the real life experiments

Setup:

- **Proton beam:**
  - energy ranging from 100 MeV to 226 MeV
  - Gaussian dispersion
- **RANDO phantom:** placed in the middle of the simulation facing the beam
- **Beam monitor:** plastic or diamond, placed on the path of the proton beam before the phantom
- **30 PbF_2 Cerenkov radiator** placed all around the phantom



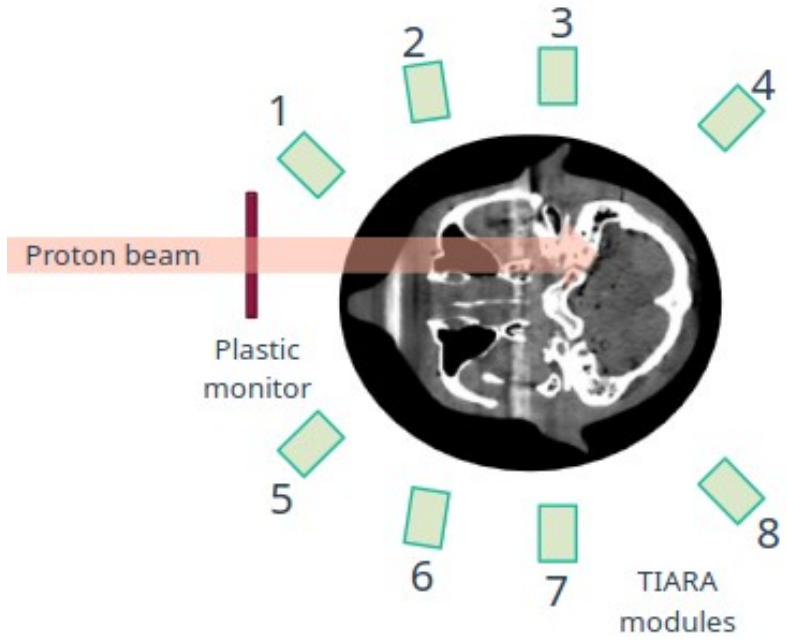
Geometry of the TIARA simulation

Beam test simulation

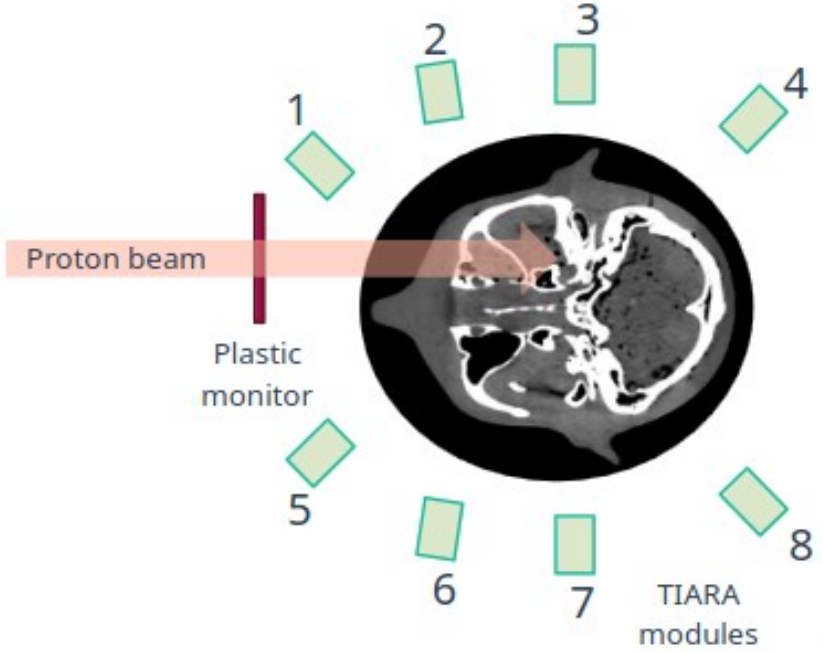
Setup reproduction from a beam test made at CAL in March 2024 (**data measured and presented by A. ANDRE**)
- 8 **PbF_2 detectors** placed around the RANDO phantom
- **Plastic** beam monitor
- RANDO phantom

2 models :
- 1st experiment with both **sinuses empty** (air)
- 2nd experiment with one sinus **filled with gel**

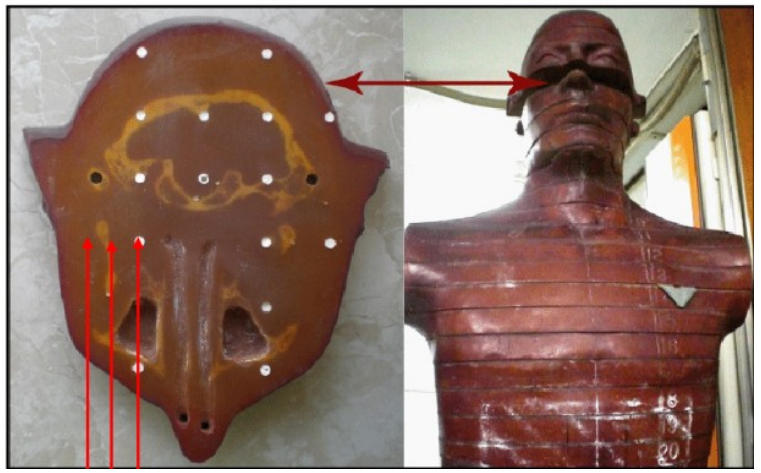
Empty sinuses



Filled sinus

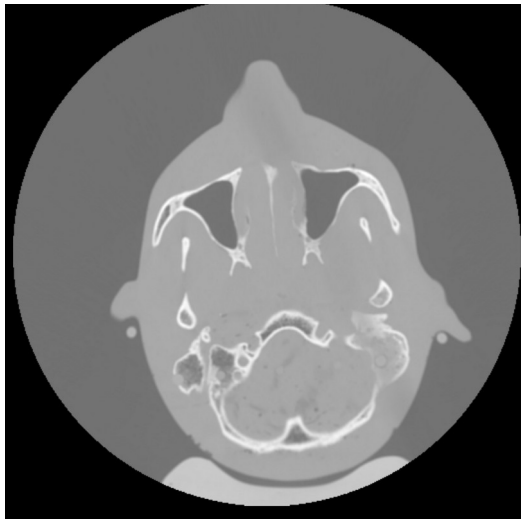


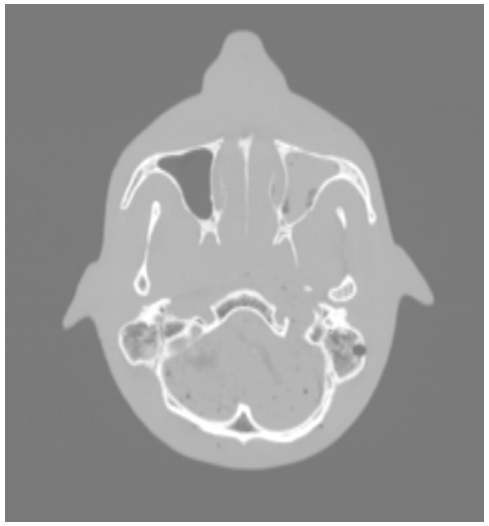
RANDO phantom calibration



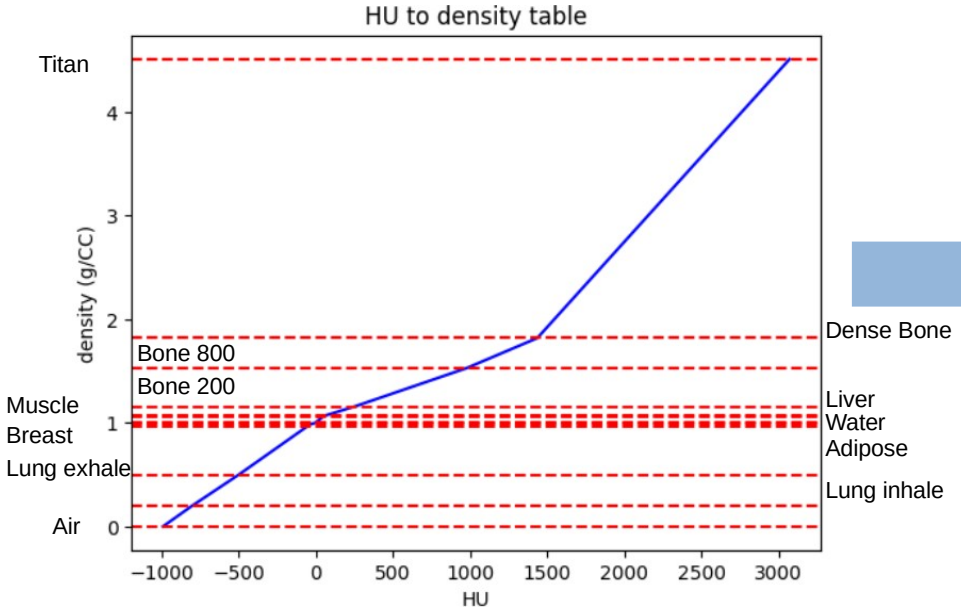
RANDO phantom used for beam test

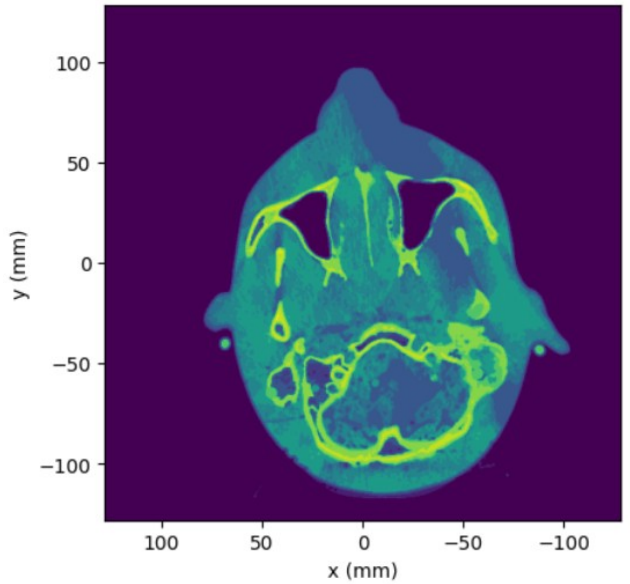
CT SCAN

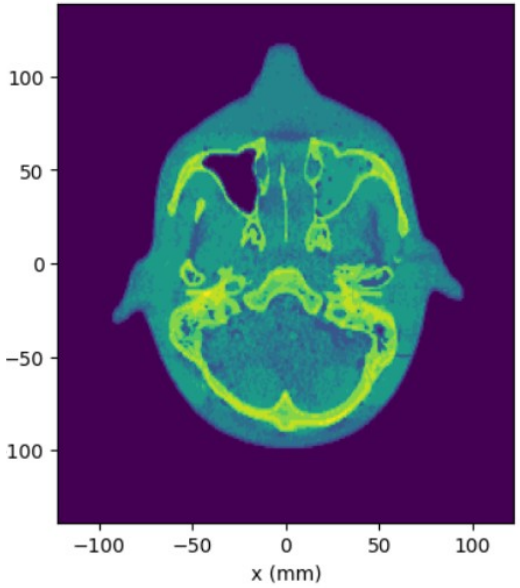




HOUNSFIELD UNITS





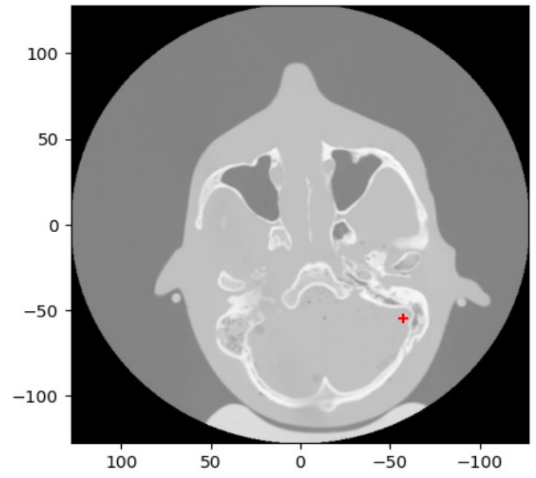


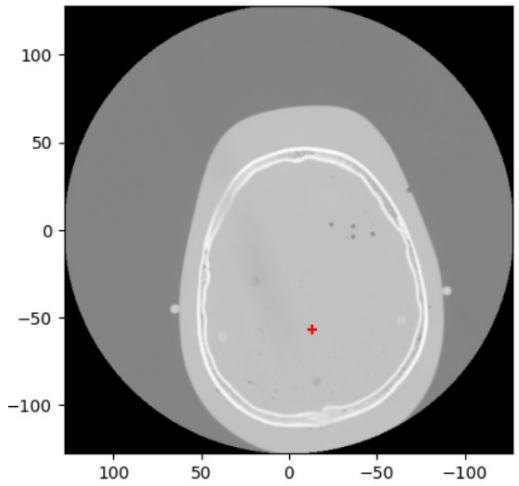
Phantom placement

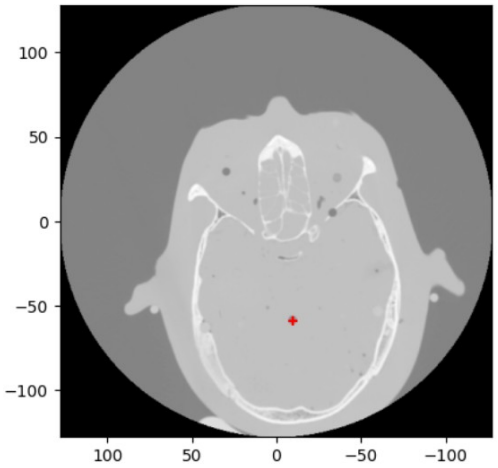
Placement of the detectors in regards to the phantom

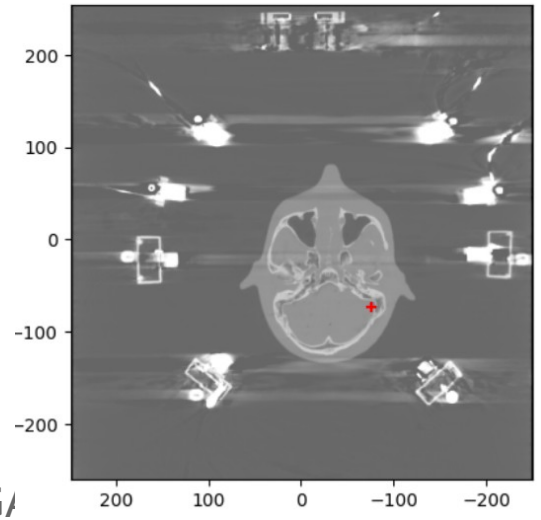
Method:

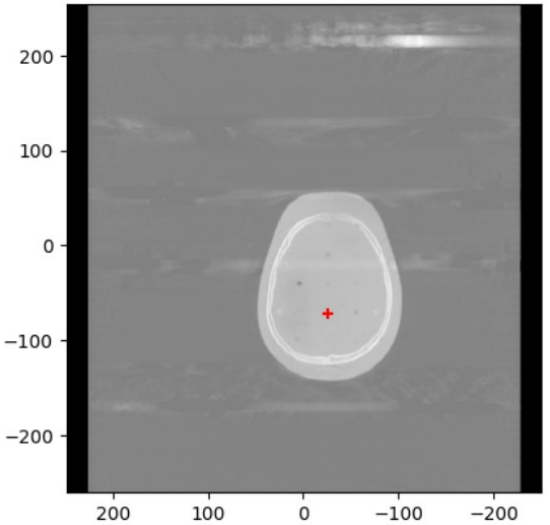
- Specific **points selection** in both image we want to match

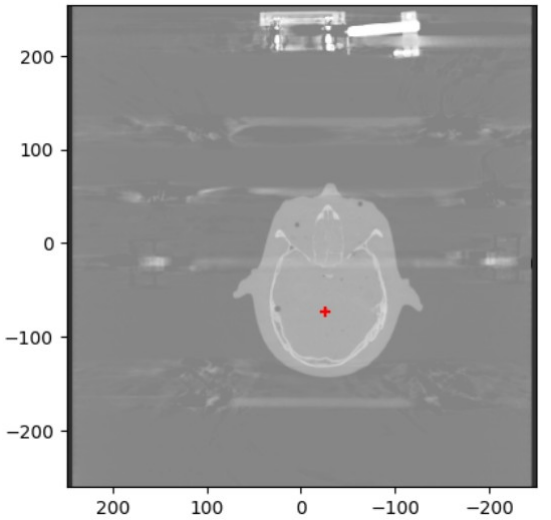










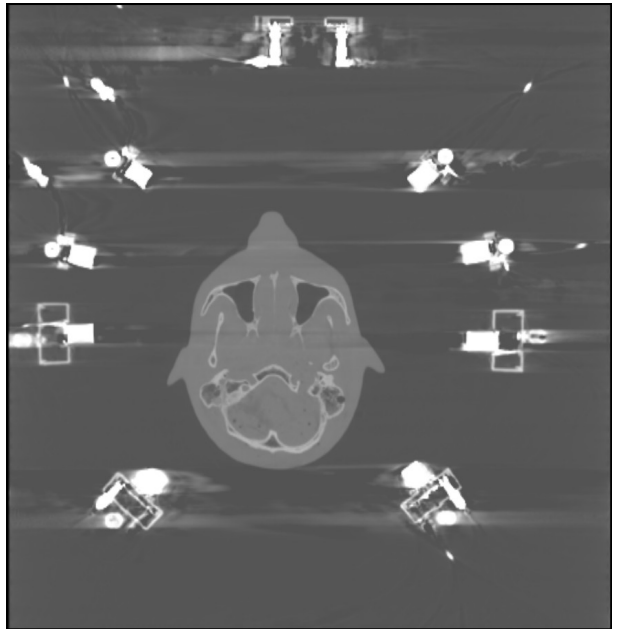


Phantom placement

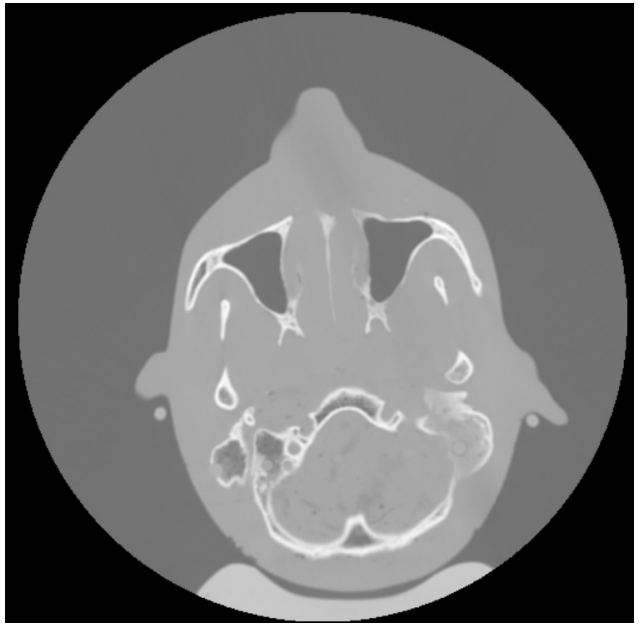
Placement of the detectors in regards to the phantom

Method:

- Specific **points selection** in both image we want to match
- Use of **minimisation function** to find the accurate rotations and translation for both images to match (rigid transformation)

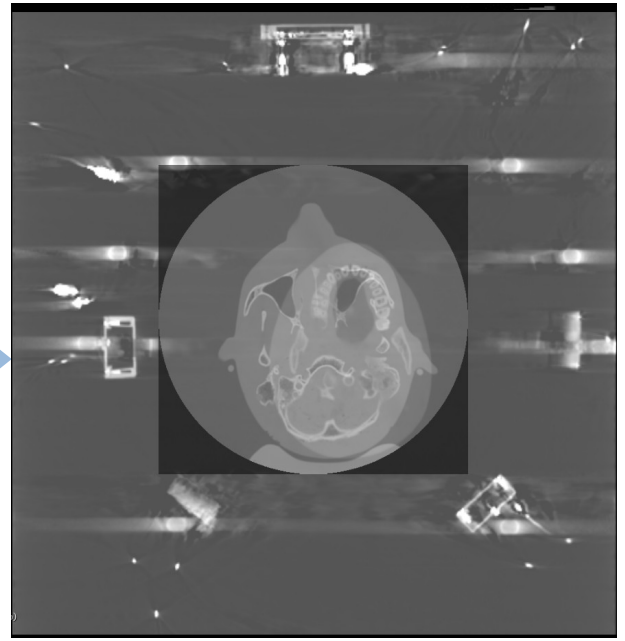


Scan of the phantom in the set-up



Scan of the phantom RANDO

Transformation matrix

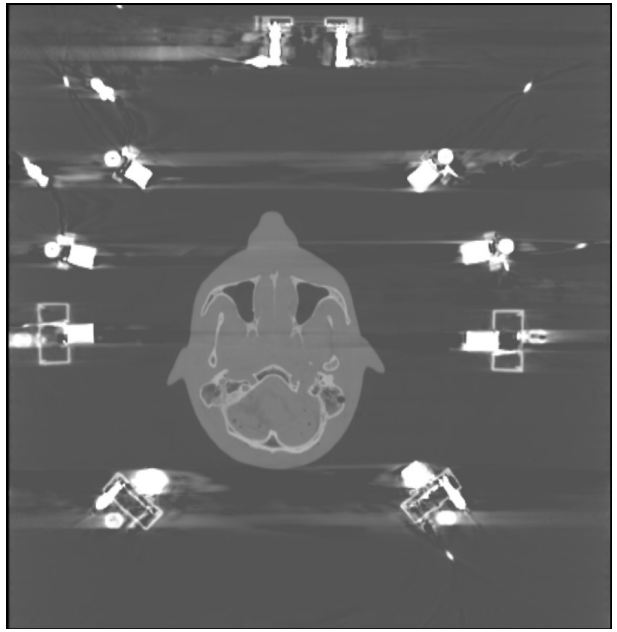


Phantom placement

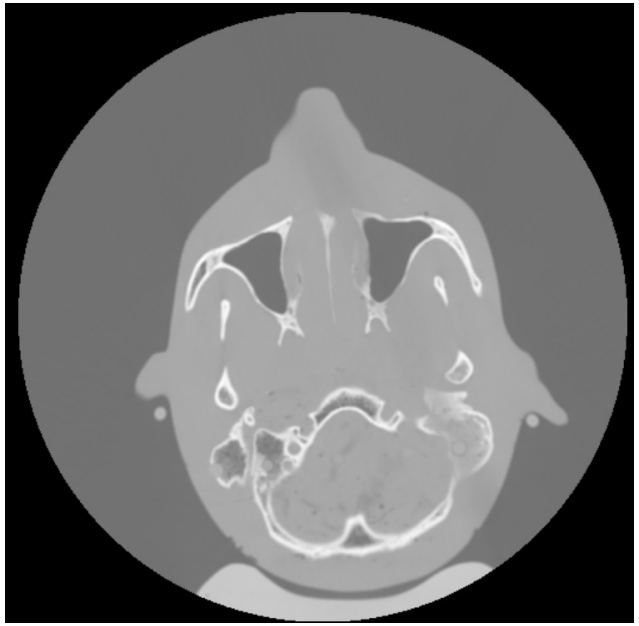
Placement of the detectors in regards to the phantom

Method:

- Specific **points selection** in both image we want to match
- Use of **minimisation function** to find the accurate rotations and translation for both images to match (rigid transformation)

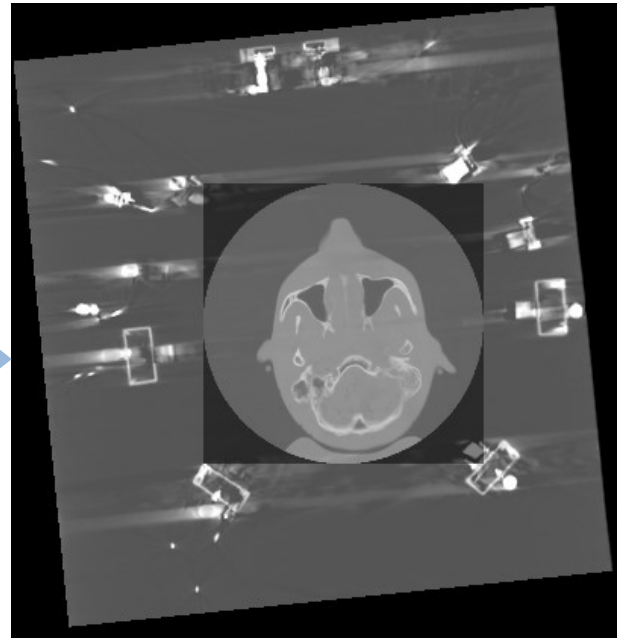


Scan of the phantom in the set-up



Scan of the phantom RANDO

Transformation matrix



Phantom placement

Placement of the detectors in regards to the phantom

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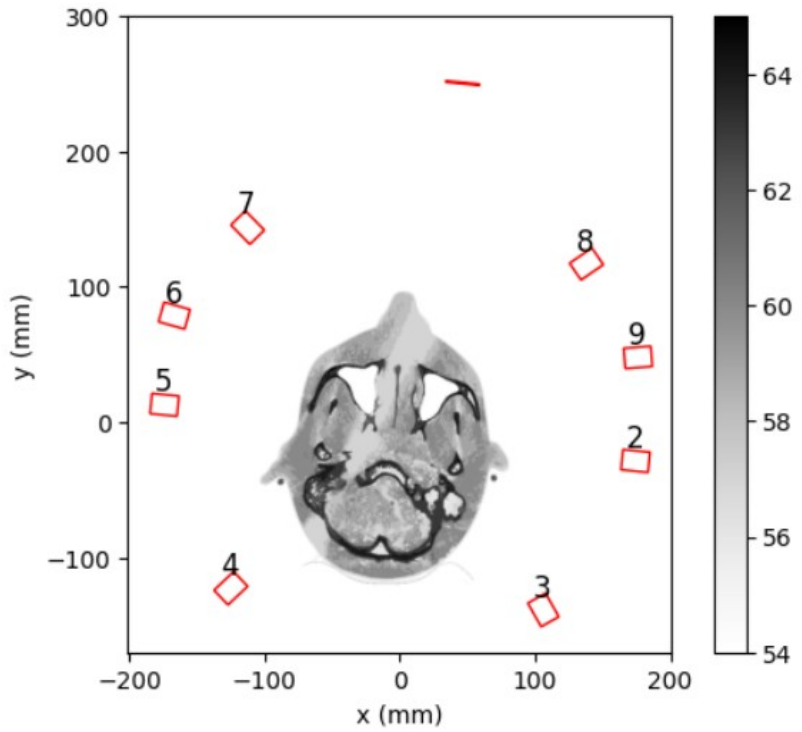
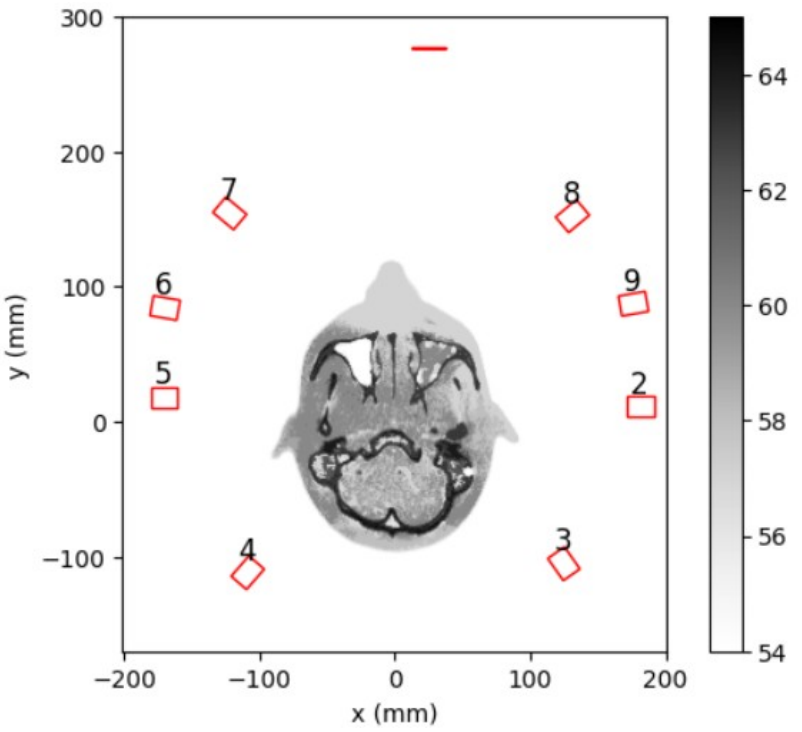
Empty sinuses



Full sinus

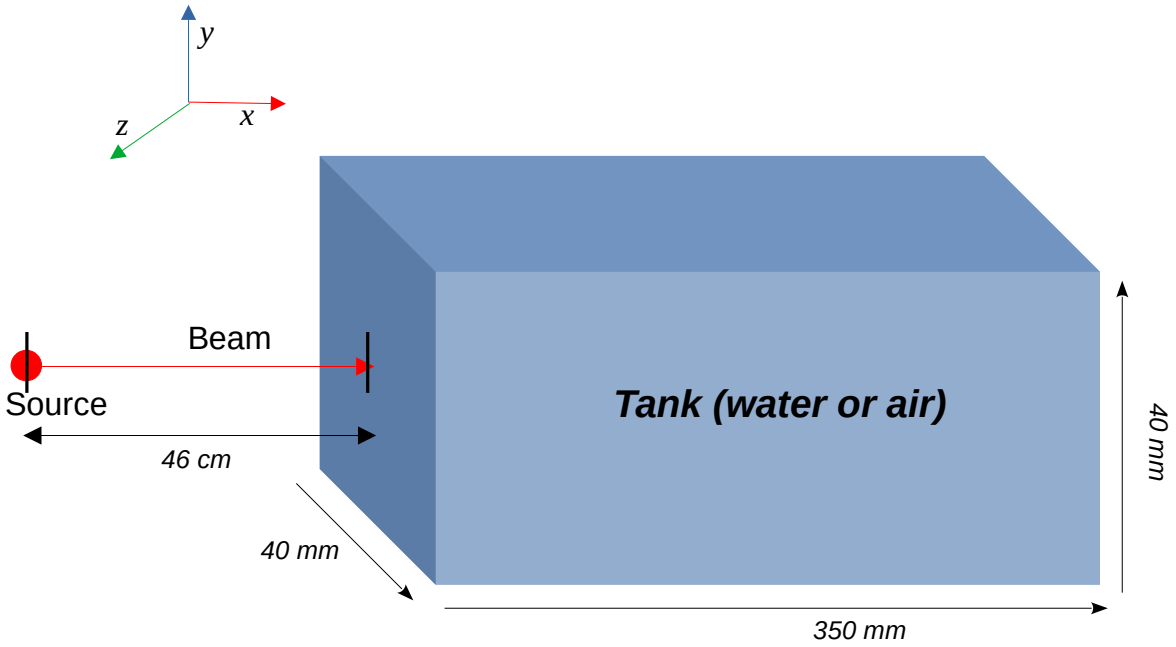


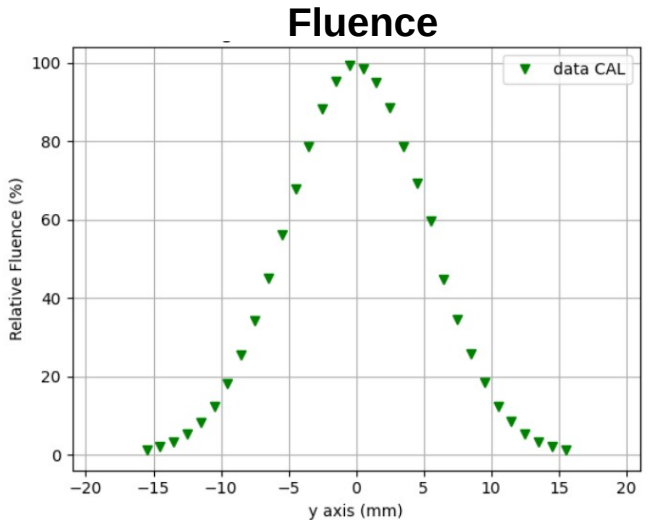
Proton beam calibration

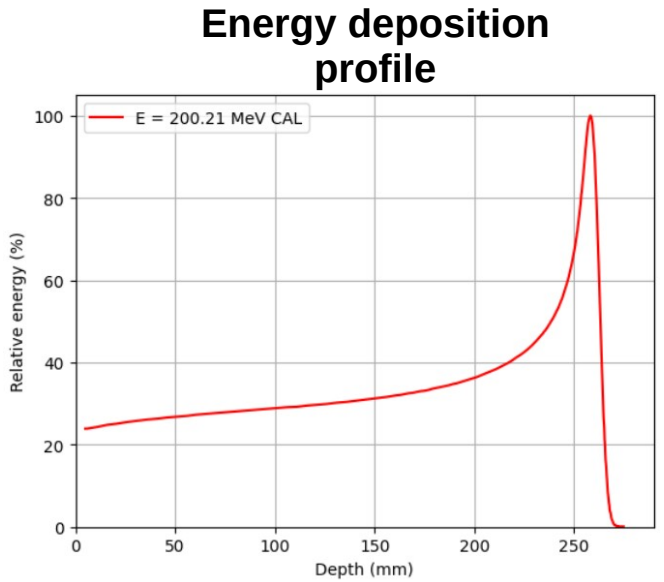
New Geant4 application to replicate the characteristics of the beam used at CAL (**Centre Antoine Lacassagne**).

Target: Tank filled with water or air

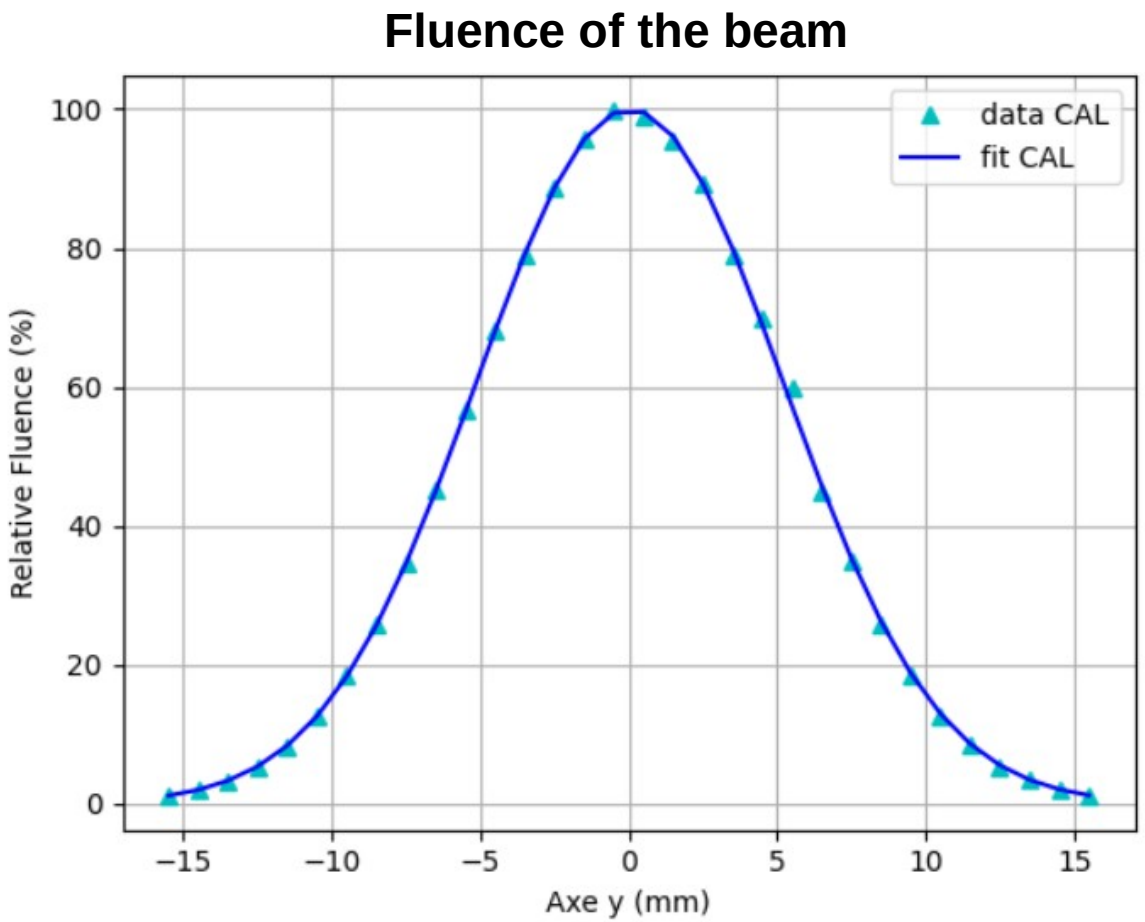
Modification of the characteristics of the beam so that it matches the one at CAL







Proton beam calibration



σ_{CAL} = 5.17 ± 0.01 mm

μ_{CAL} = 0.03 ± 0.01 mm

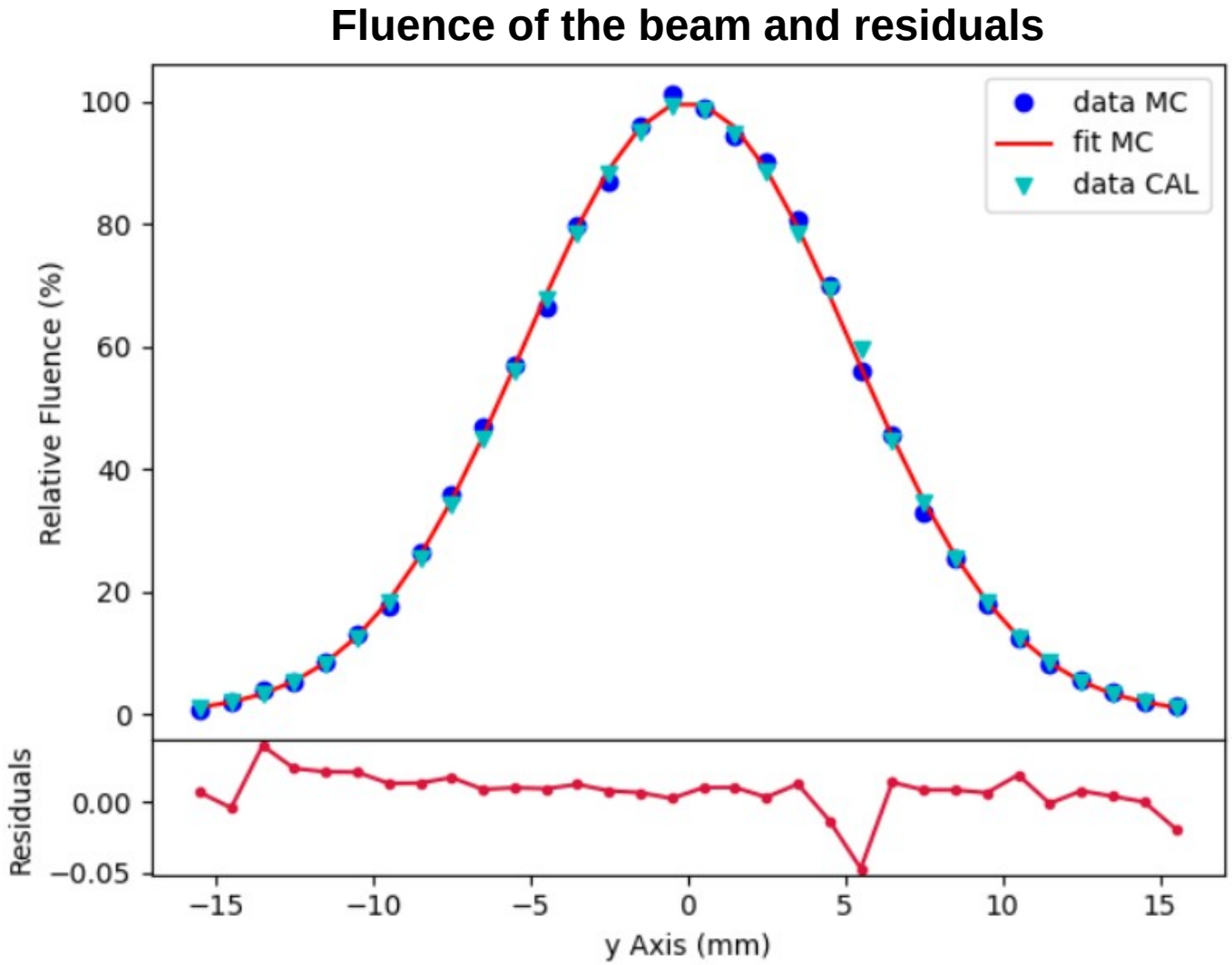
Geant4 parameters:

`/gps/pos/sigma_r` → Value of the standard deviation of the fluence

Data collection:

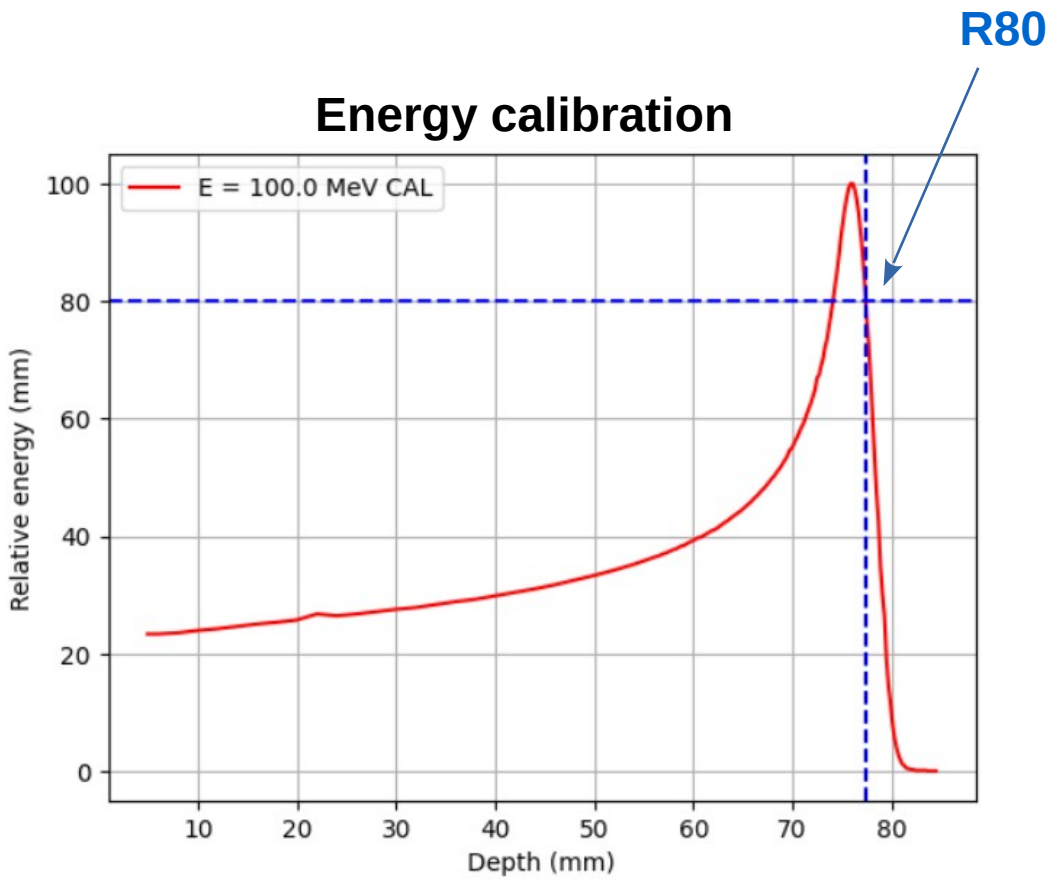
`/Score/quantity/flatSurfaceCurrent`

Proton beam calibration



σ_{MC} = 5.17 ± 0.02 mm ; μ_{MC} = 0.00 ± 0.02 mm

Proton beam calibration

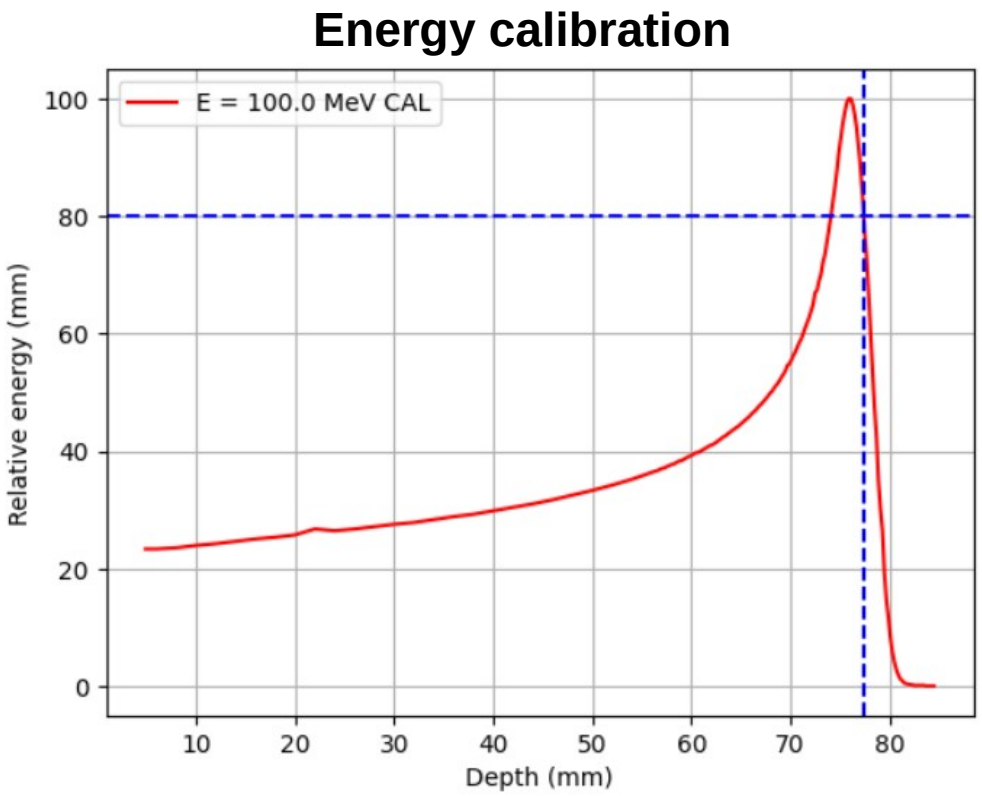


Adapted **curve_fit** function on the simulated data to determine the **energy E** et the value of **sigma σ_E** for the simulation to match the data from CAL

Proton beam calibration

$R80_{CAL}$ = 77.41 mm
$R80_{MC}$ = 77.38 mm

PGTI
PROMPT GAMMA TIME IMAGING



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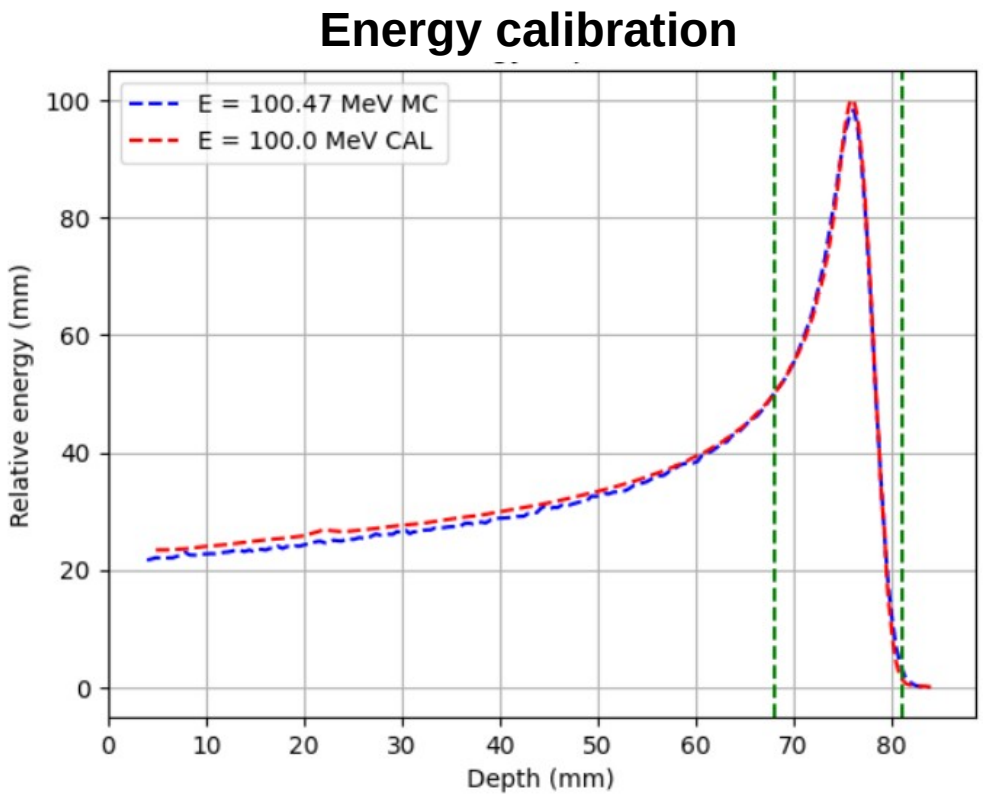


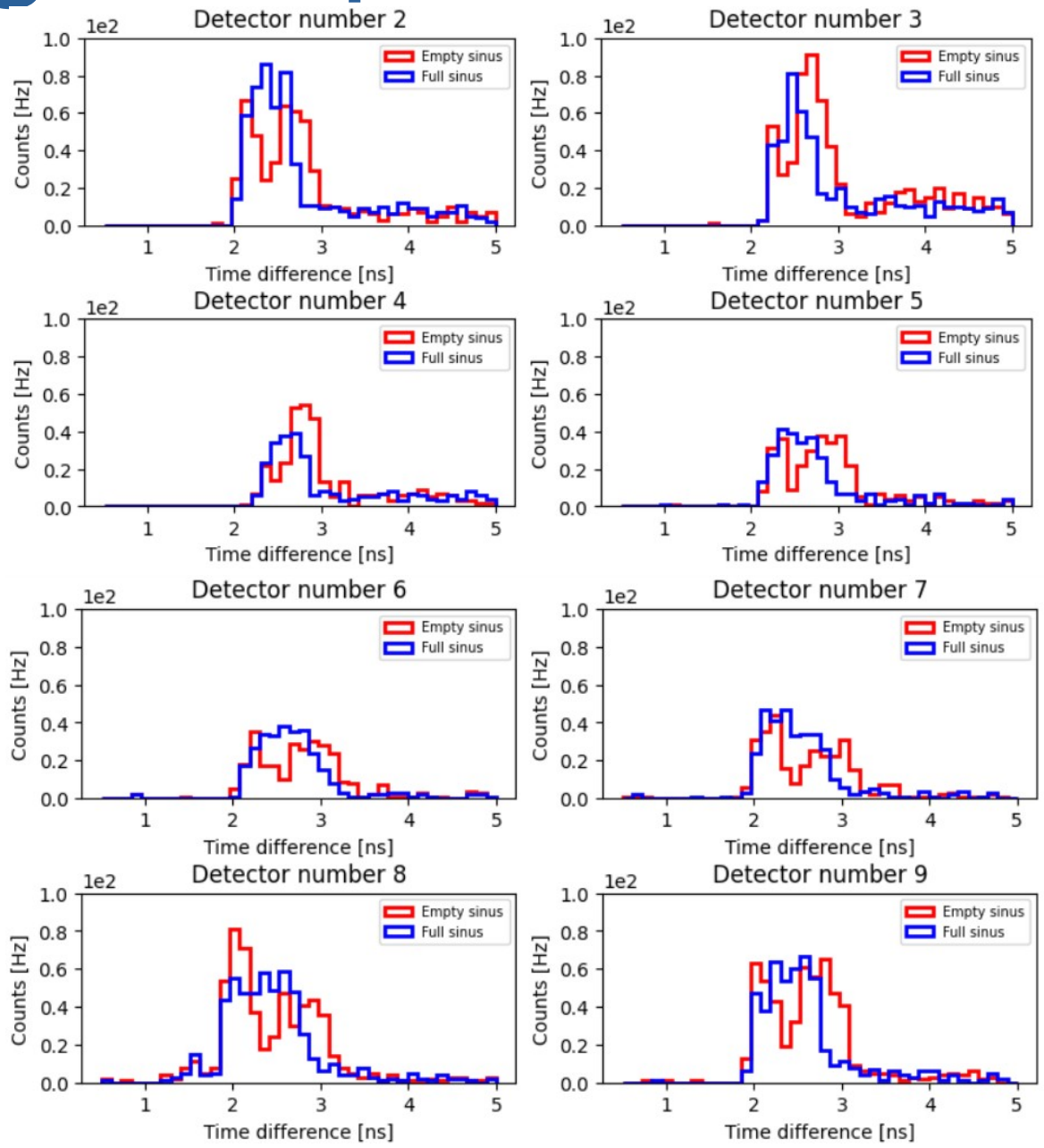
Principle: the code runs the simulation and gets the **energy depostion curve**. It then runs **curve_fit** and for each loop it takes the output deposited energy and compares it to the calibration data and runs the simulation again with new propositions for **E** and **σ_E**. For each loop, E, σ_E and the residual are saved in a file. We keep the data with the **smallest residual**.

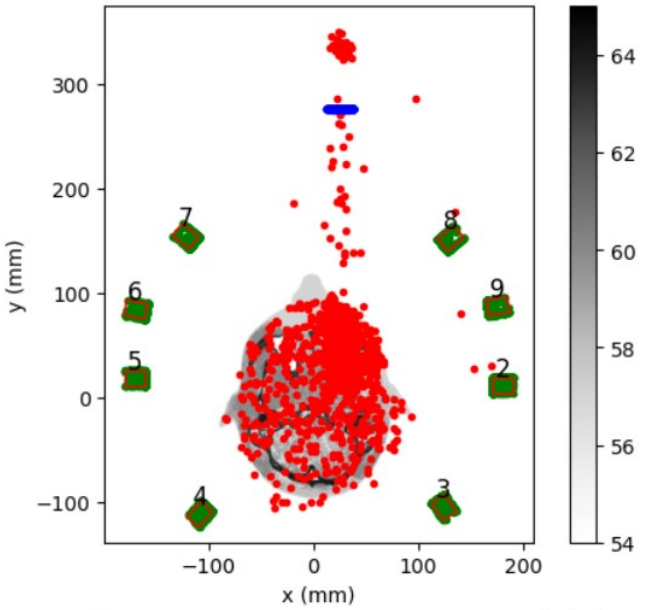
Time-Of-Flight (no particle selection)

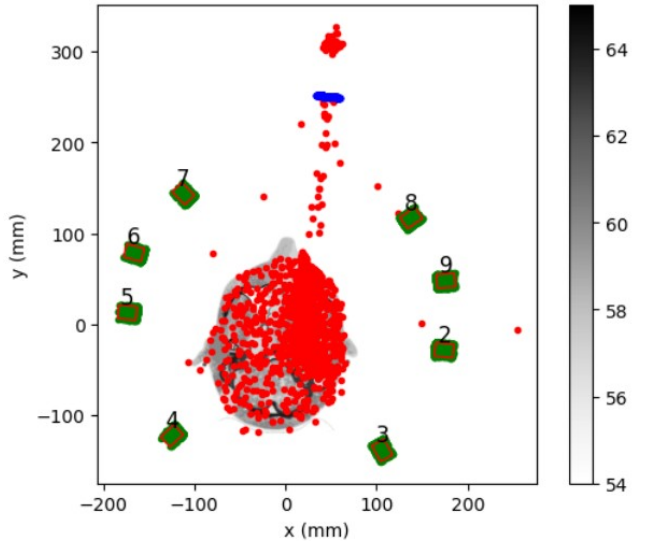
Particles	%
Gamma	65
Neutrons	29
Protons	3
Electrons	1.8
Positrons	0.3
Alpha/ Deuteron	0.06

- **Red**: vertices positions
- **Blue**: interaction with the beam monitor
- **Green**: Interaction with the TIARA detector

Stat: 4,000,000 protons







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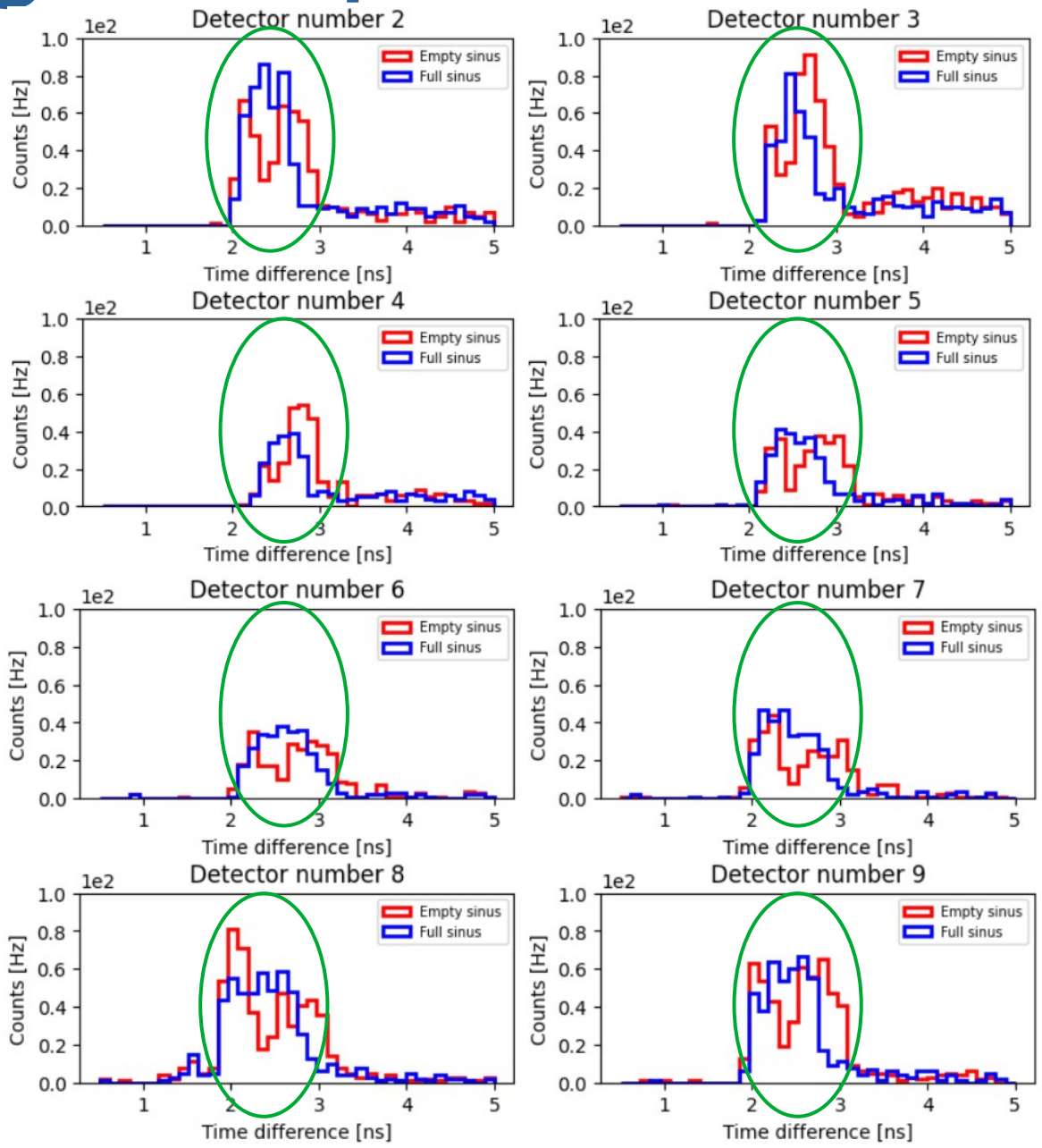
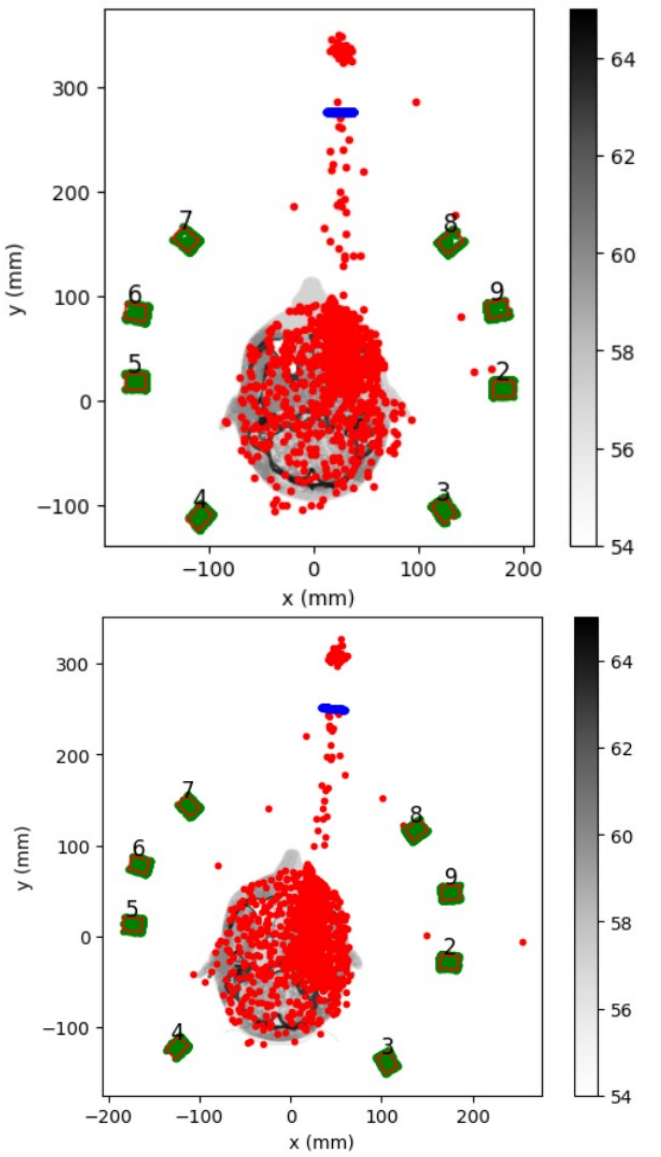
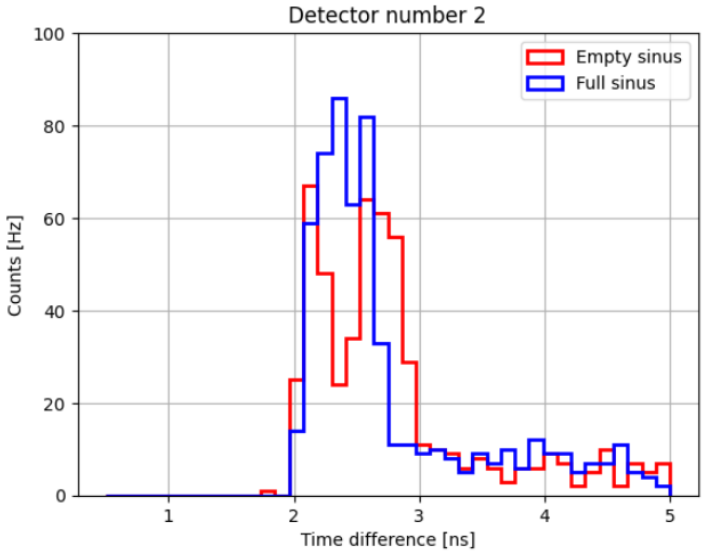
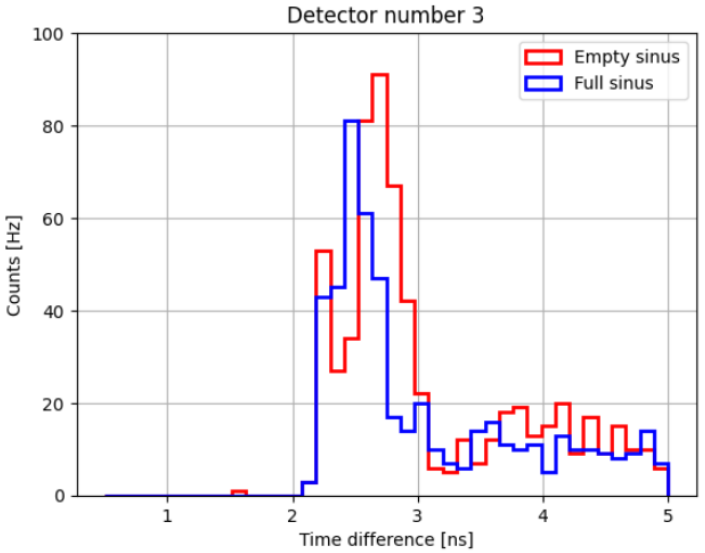
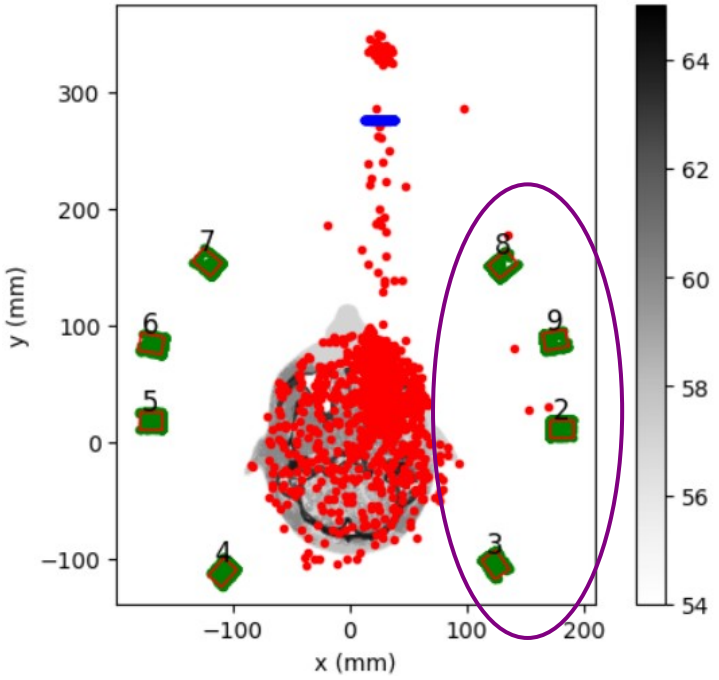


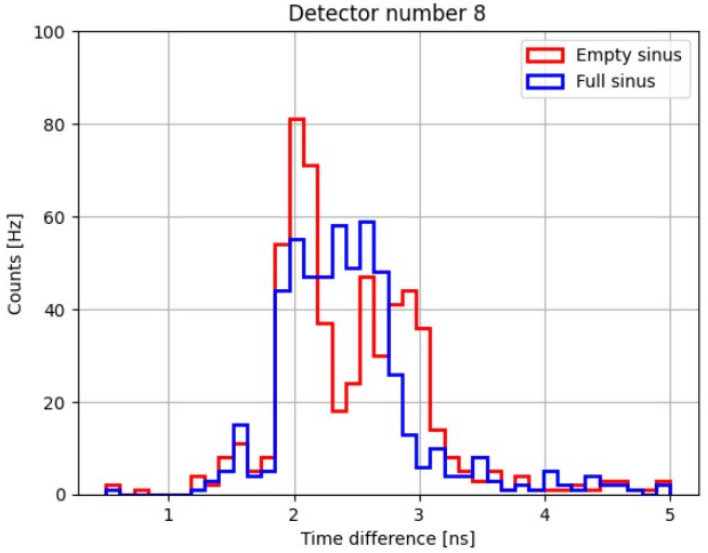


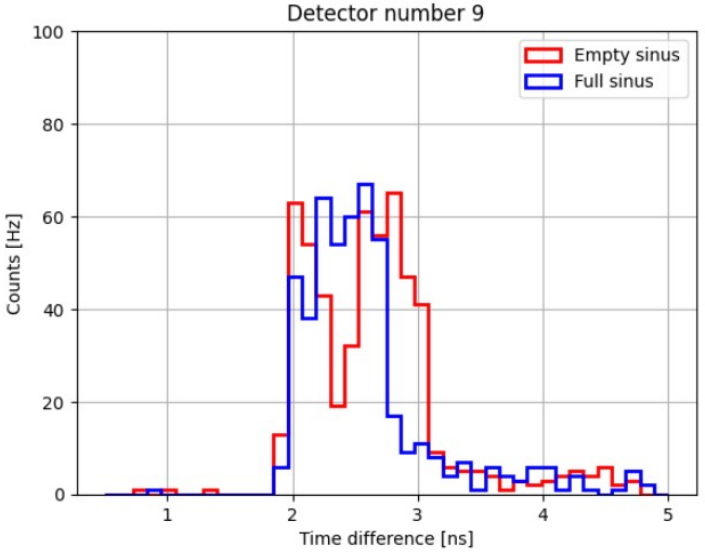
TOF

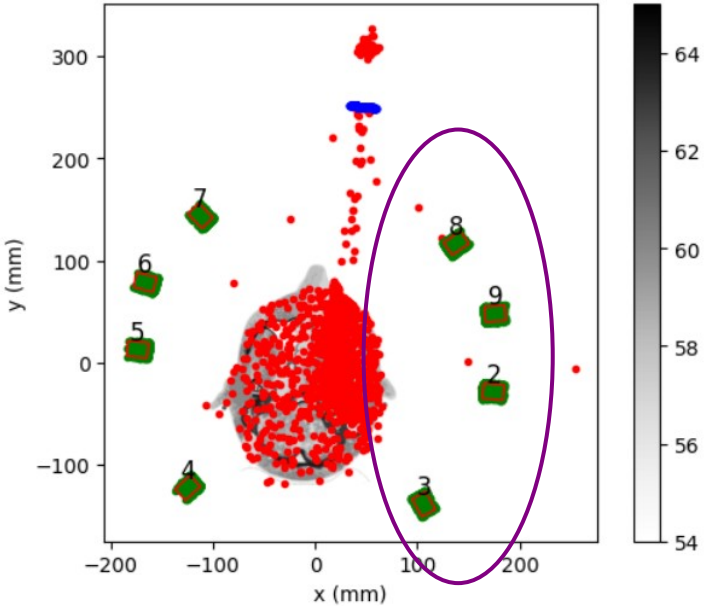

Detector number 2
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]


Detector number 3
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]

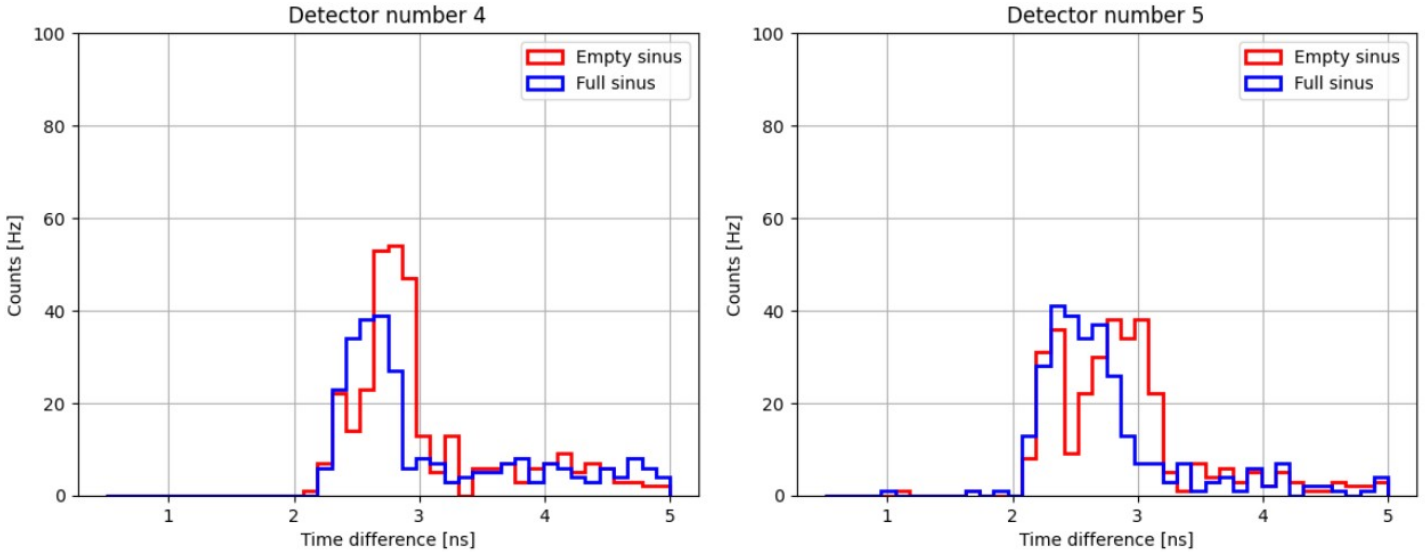

y (mm)
x (mm)


Detector number 8
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]

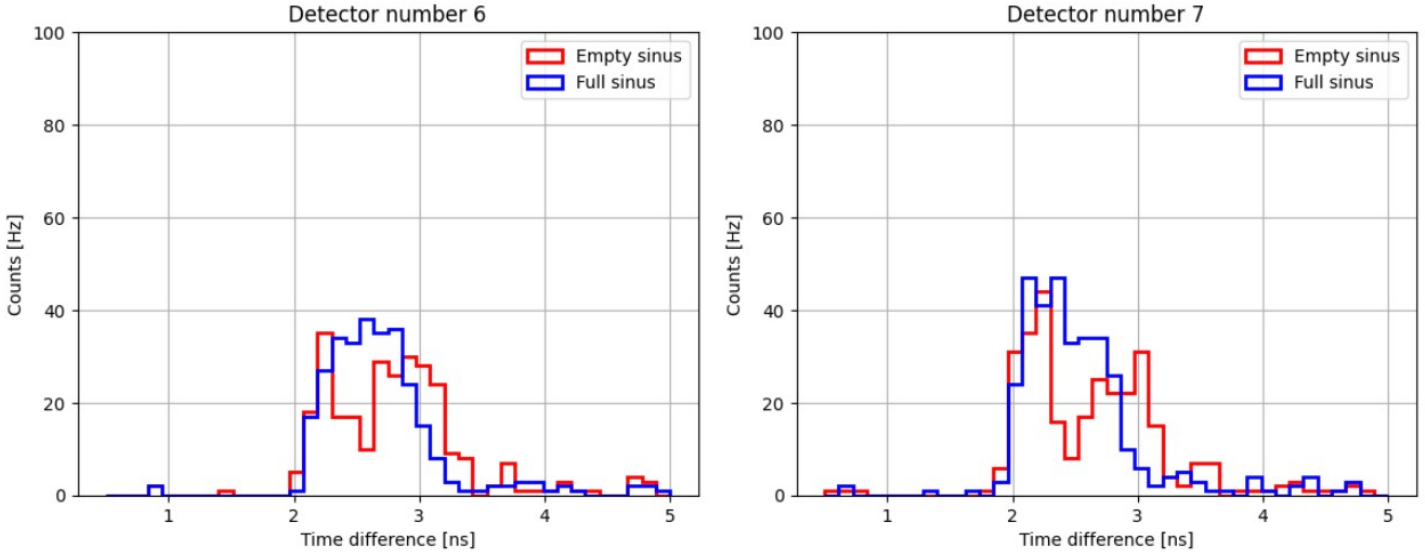

Detector number 9
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]


y (mm)
x (mm)

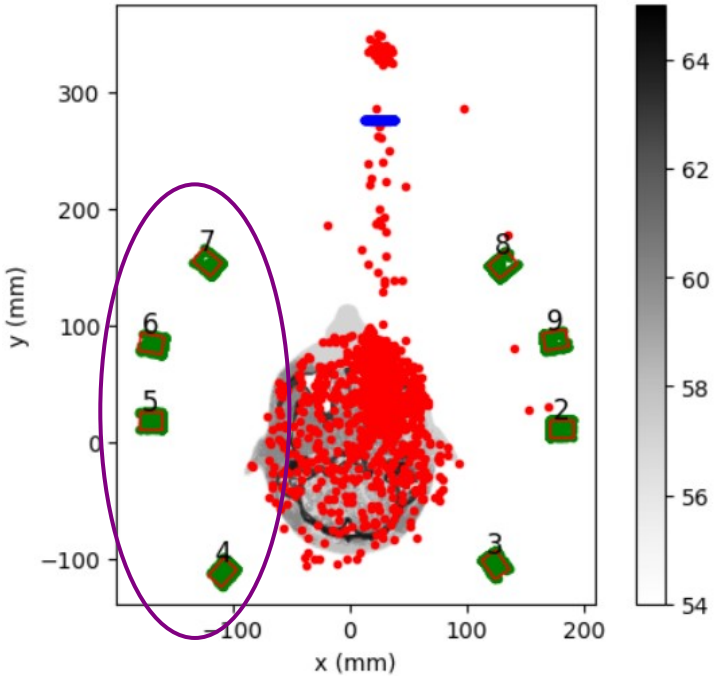
TOF

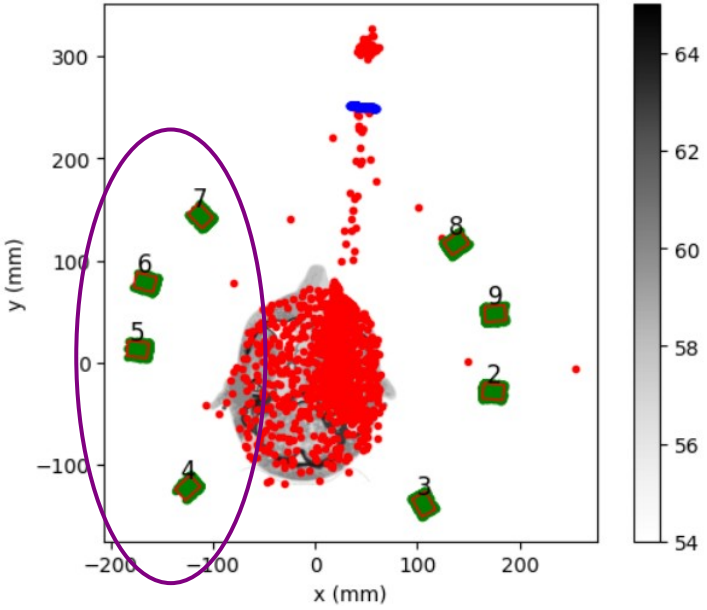

Detector number 4
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]

Detector number 5
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]

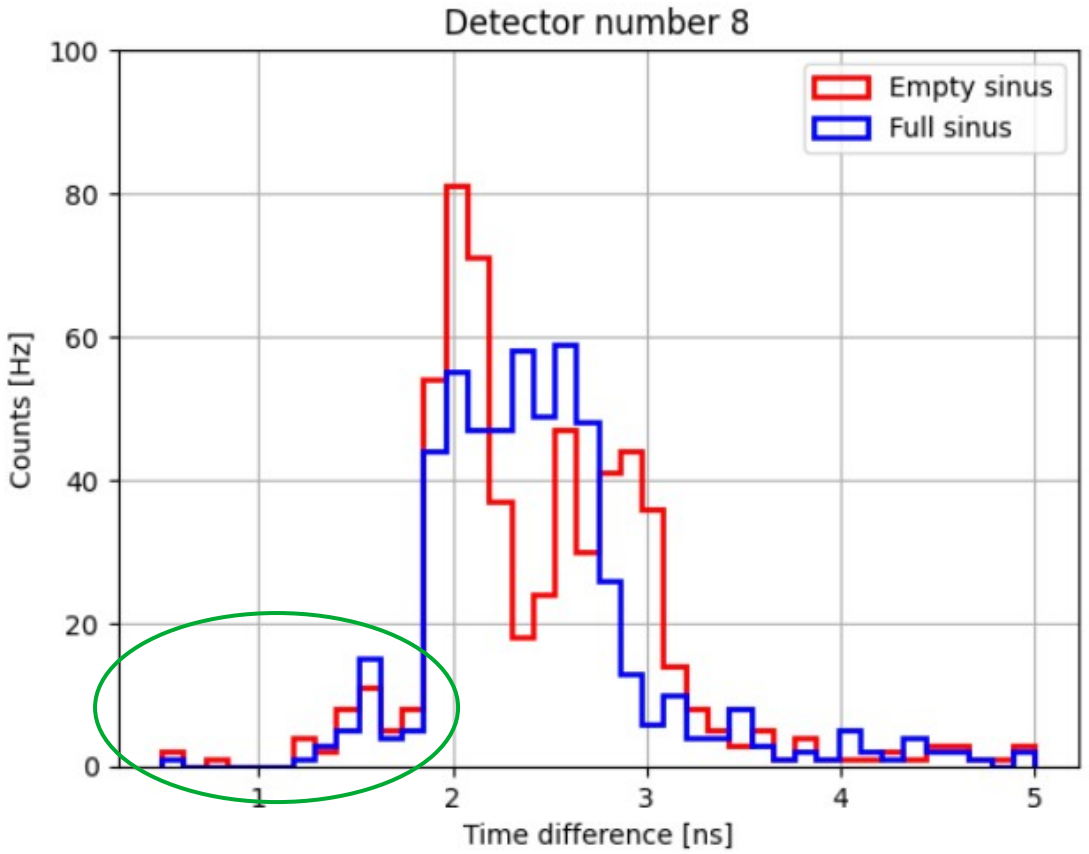

Detector number 6
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]

Detector number 7
Empty sinus
Full sinus
Counts [Hz]
Time difference [ns]

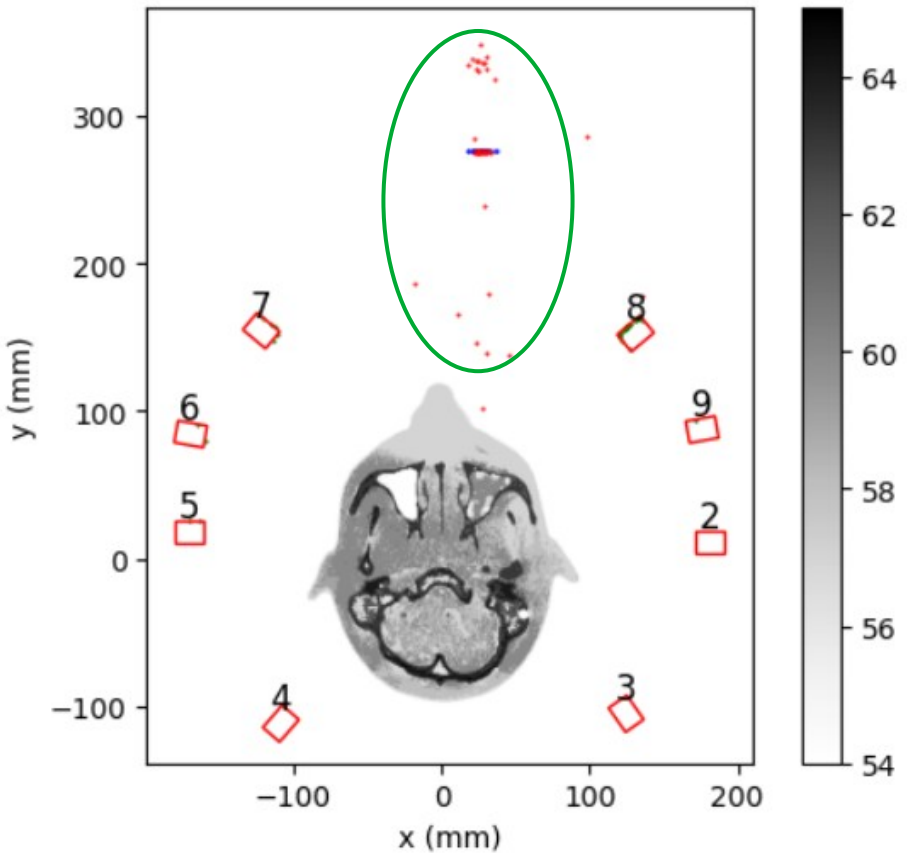

y (mm)
x (mm)


y (mm)
x (mm)

TOF

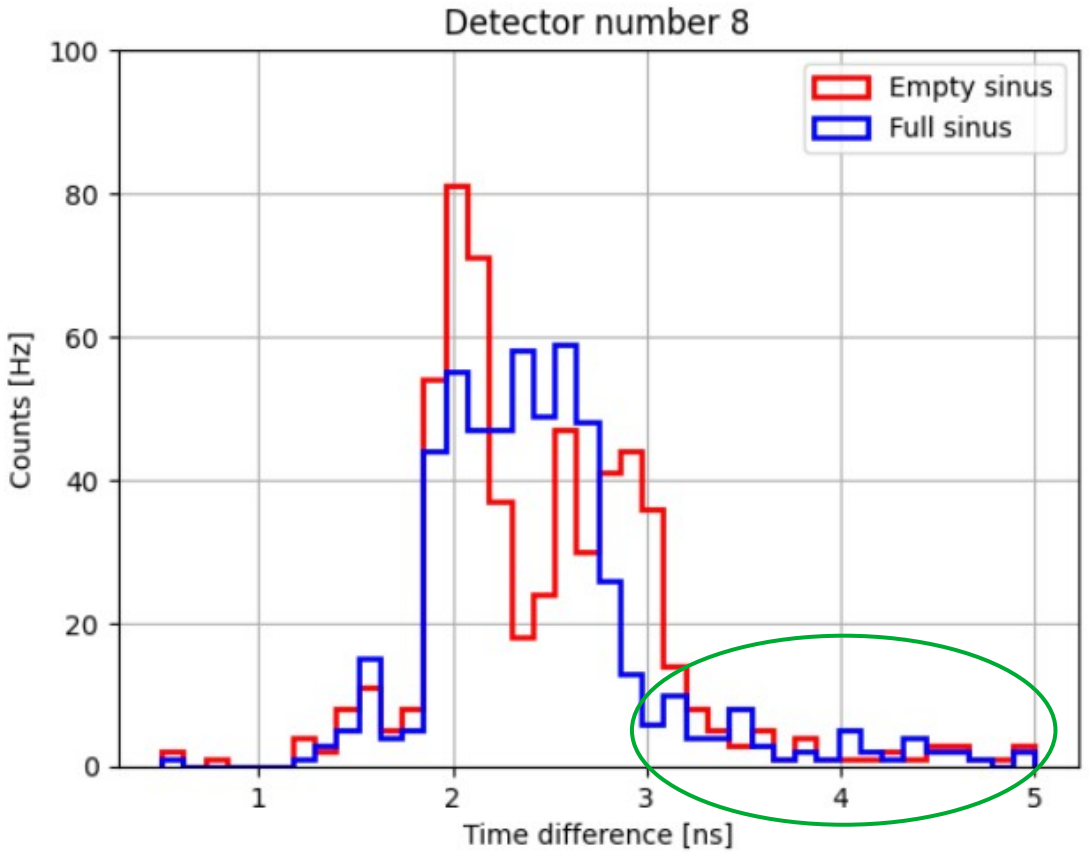


Particles coming from proton interactions in the beam monitor or before reaching the phantom

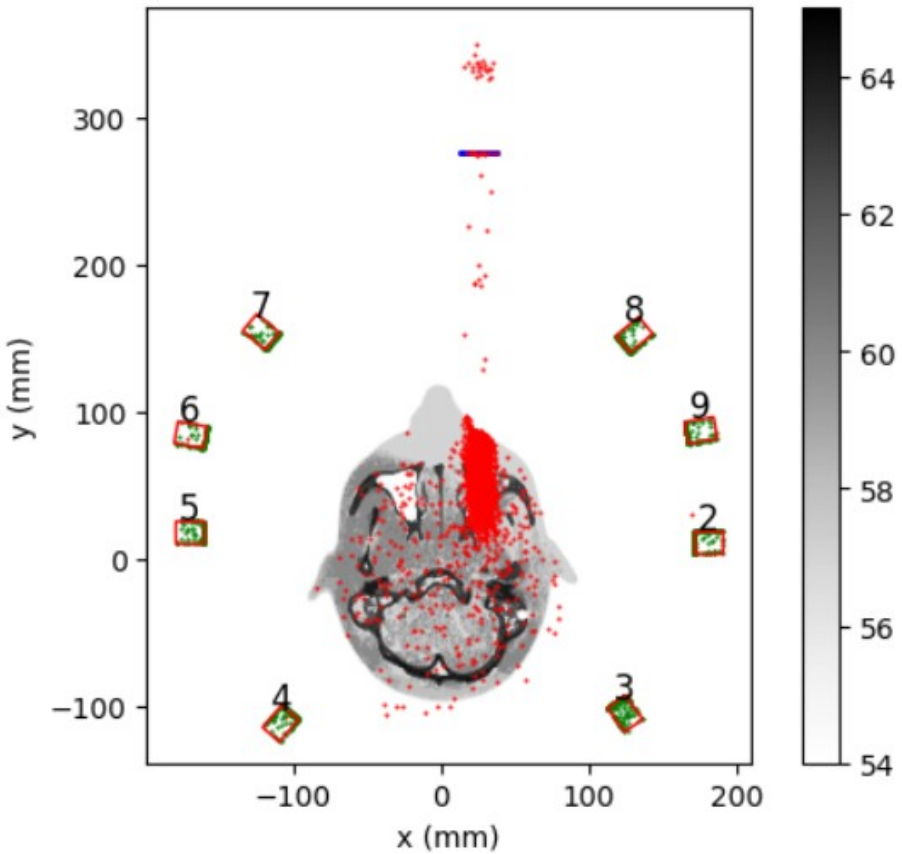


Red: vertices positions
Blue: interaction with the beam monitor
Green: Interaction with the TIARA detector

TOF

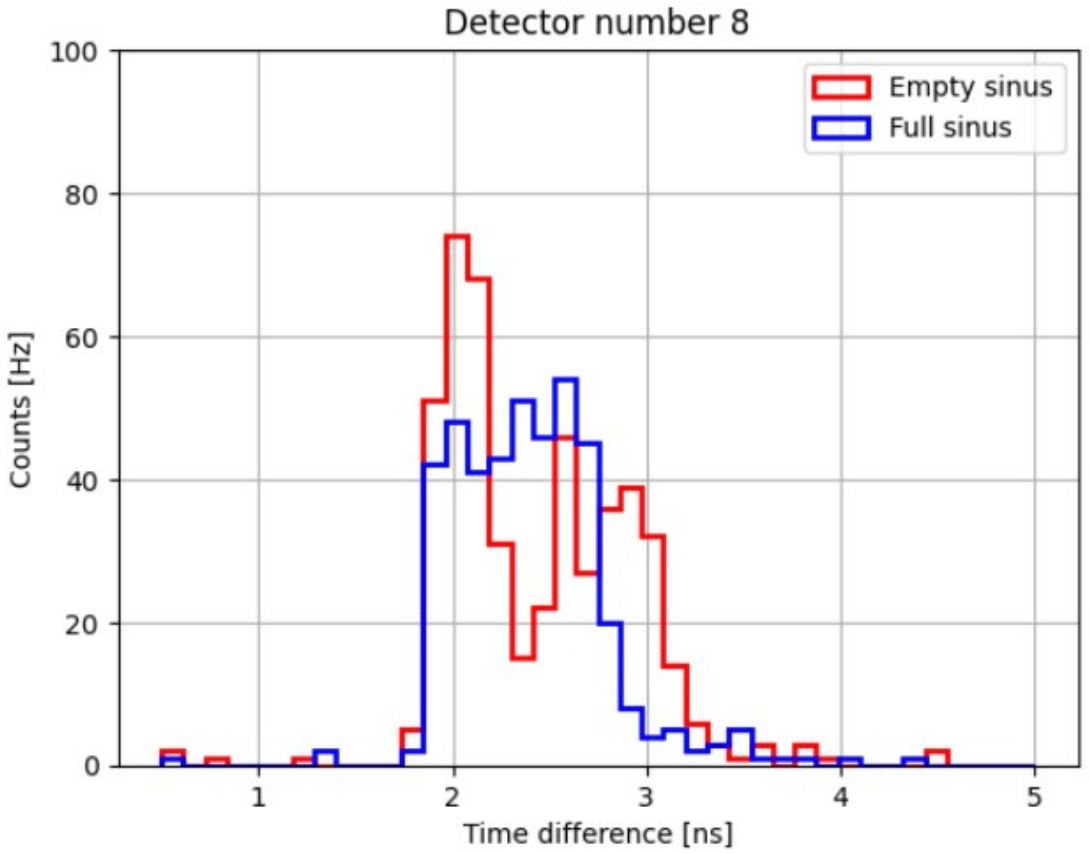


Mostly **neutrons** reaching the modules (~80 % against 20 % PGs)

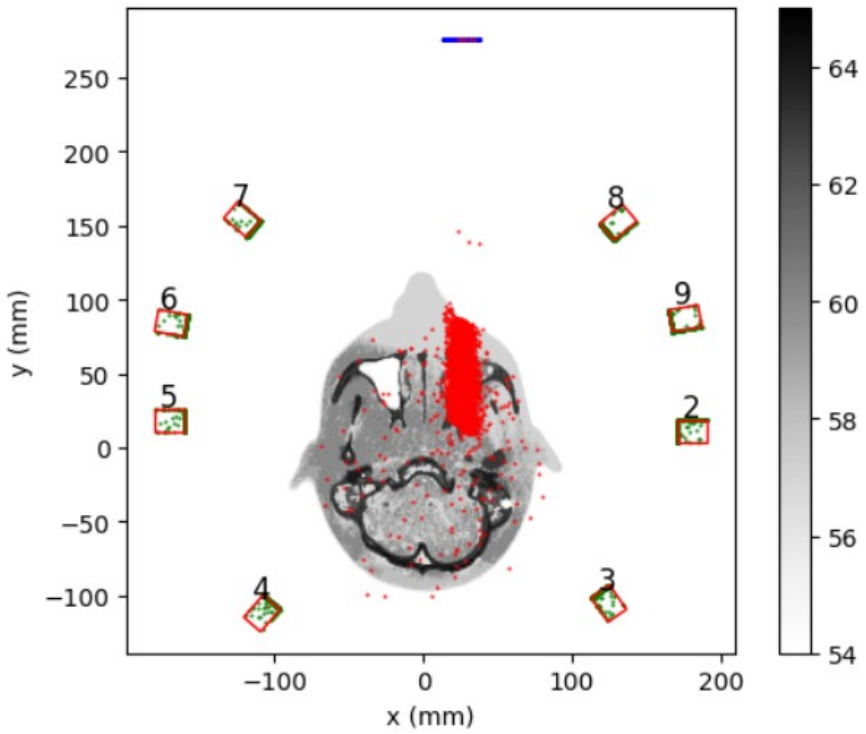


Red: vertices positions
Blue: interaction with the beam monitor
Green: Interaction with the TIARA detector

TOF

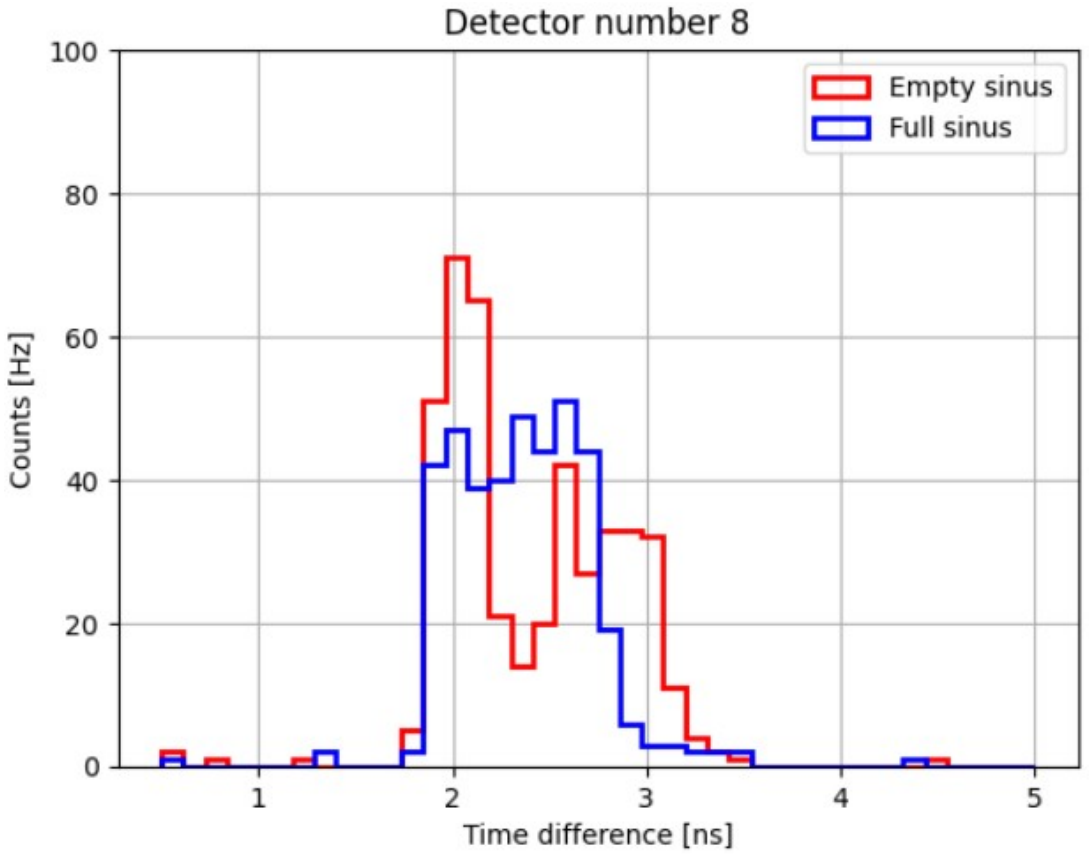


Selection on the PGs (~2,700 reached the tiara modules in this simulation)

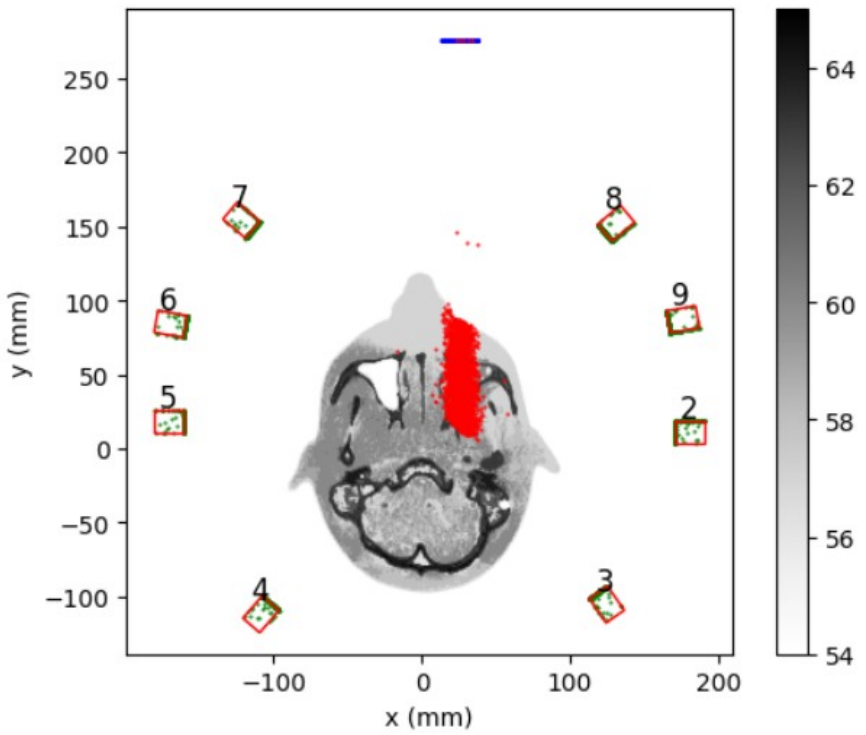


Red: vertices positions
Blue: interaction with the beam monitor
Green: Interaction with the TIARA detector

TOF



Selection on the PGs that come from primary protons (~2,500 reached the tiara modules in this simulation)



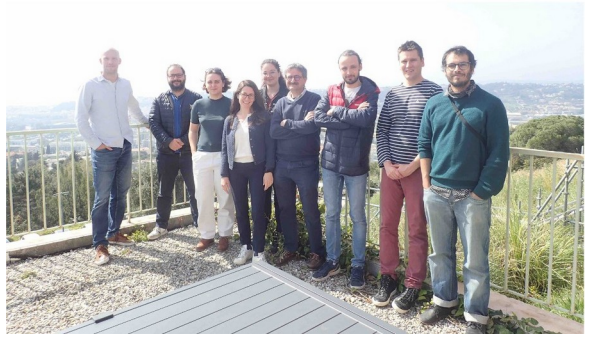
Red: vertices positions
Blue: interaction with the beam monitor
Green: Interaction with the TIARA detector

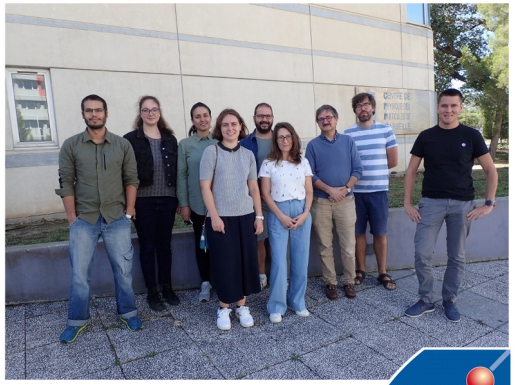
Conclusion

- **Successful implementation of the Phantom RANDO and the proton beam for a range of energies**
- **Encouraging results for the Time-of-flight (need for more statistics)**
- **Implementation of the detection efficiency in the detectors (work in progress)**

Thanks for your attention!

The **TIARA Collaboration**





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