3A PhD seminar

02.12.2024

A Monte Carlo simulation for Prompt Gamma Time Imaging in protontherapy

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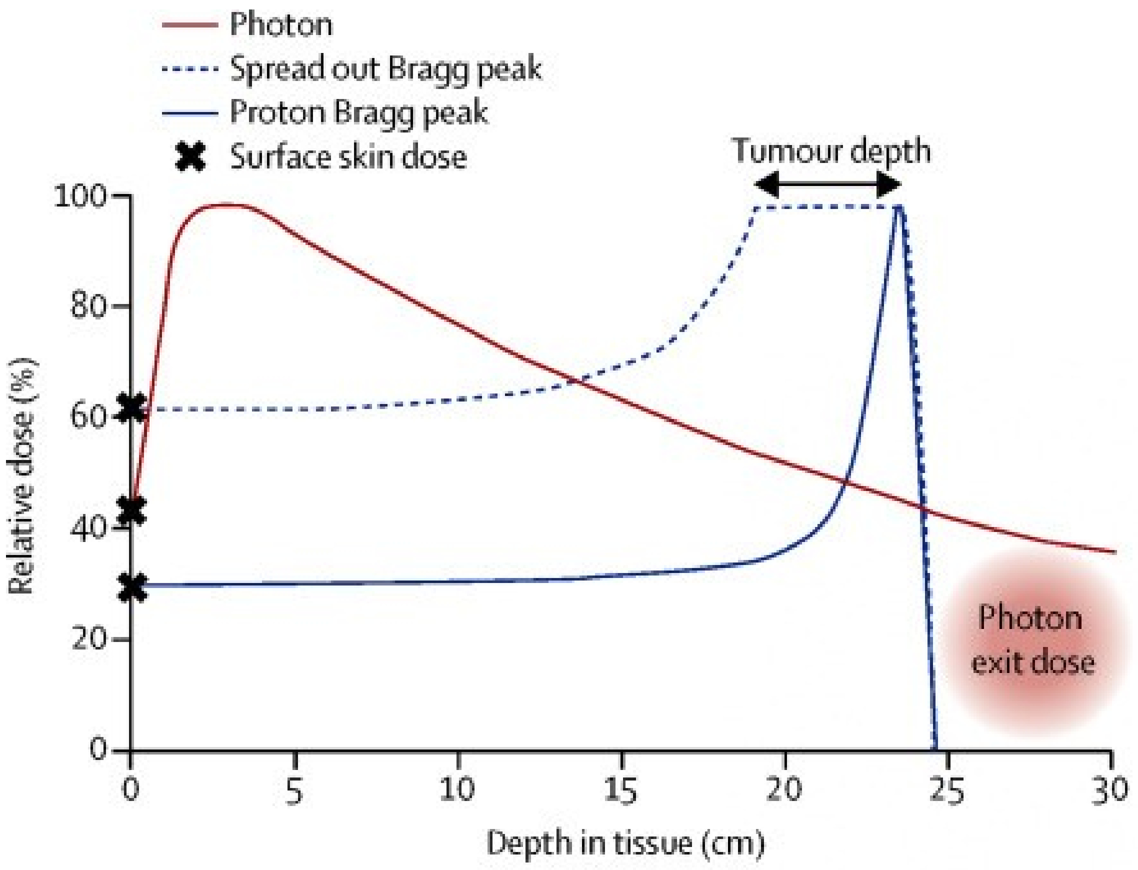
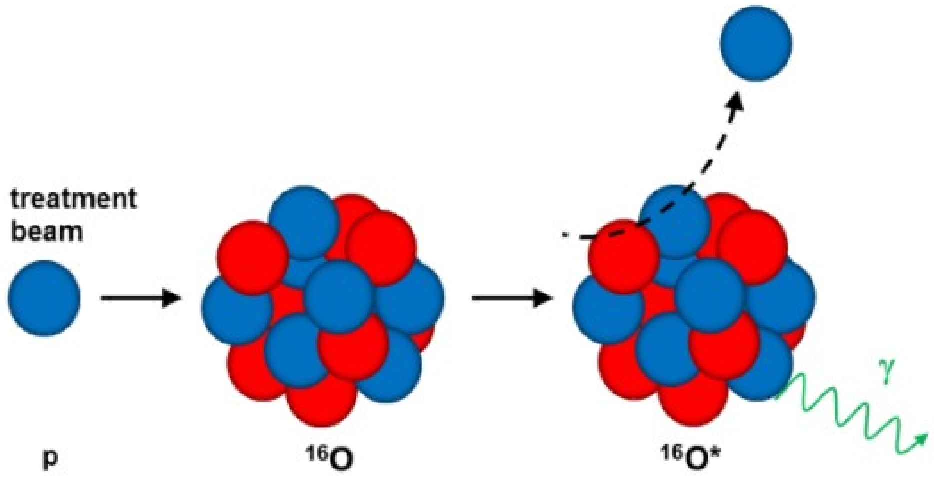
Context: protontherapy



Radiotherapy dose profile comparison

Ballistic precision (Bragg peak)



Prompt Gamma emssion (PG)

Energy range : 0 < E < 15 MeV

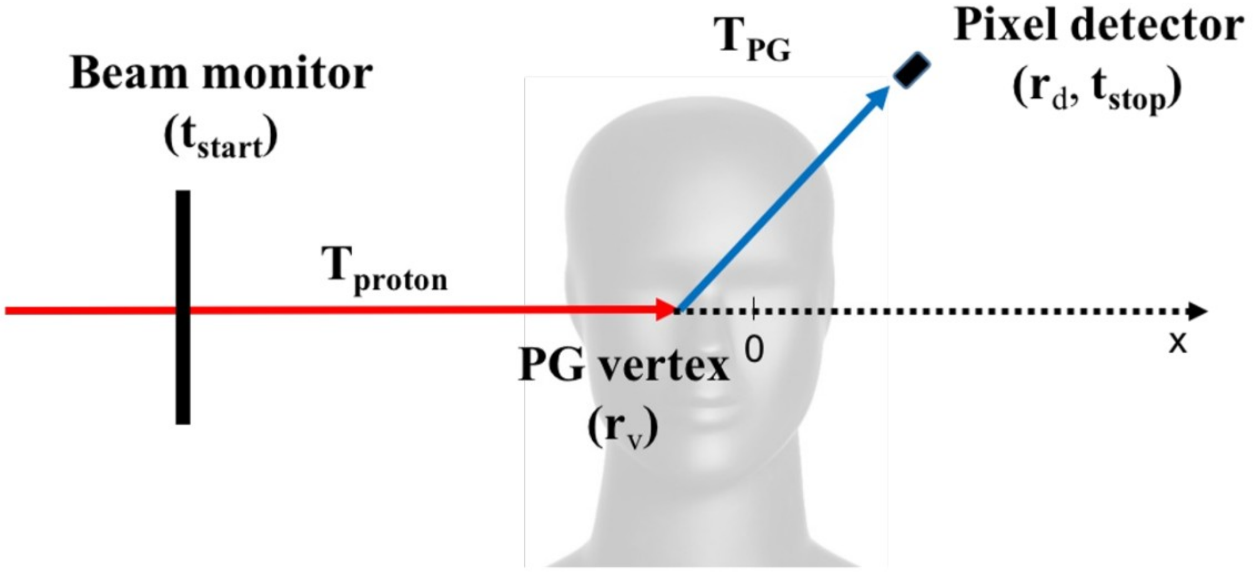
Prompt emission: < 1 ps

Emission correlated to the proton beam dose deposition

Low statistic

PGTI (Prompt Gamma Time Imaging)

Objective:
Reconstruct the emission vertices of the PGs to monitor in **real-time** protontherapy treatments using the proton and PGs **Time-Of-Flights** (TOFs).



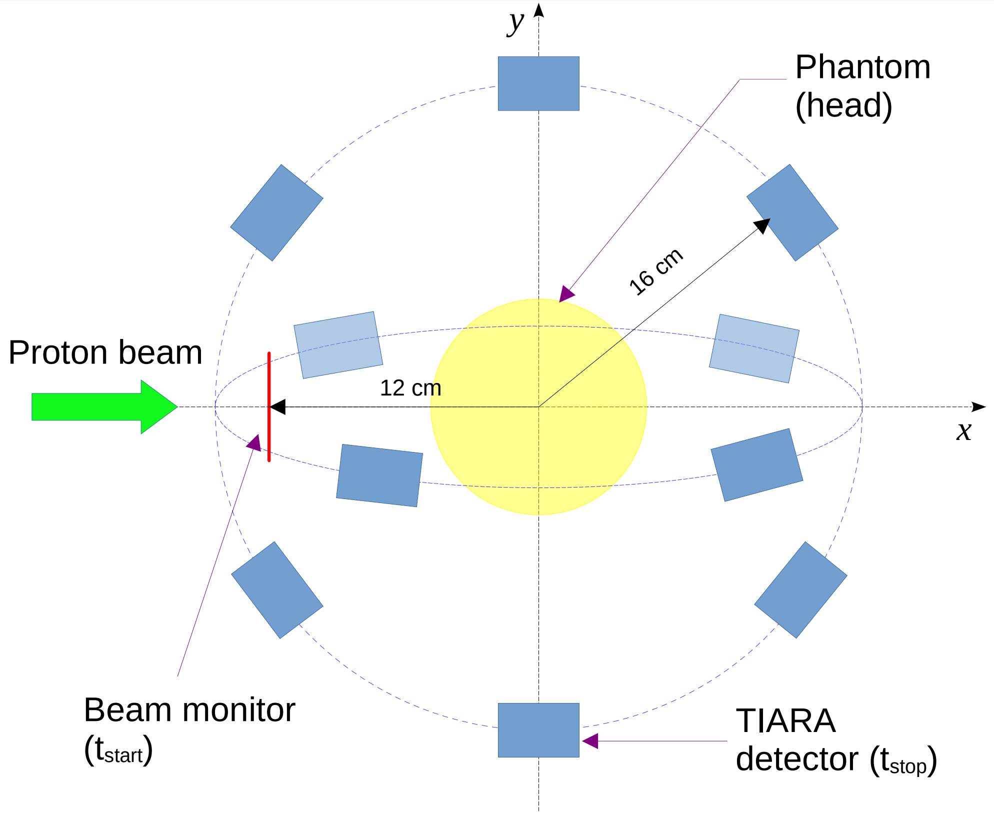
$$TOF = T_{proton}(\vec{r}_v, \vec{v}) + \frac{1}{c}\left\|\vec{r}_d - \vec{r}_v\right\|$$

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

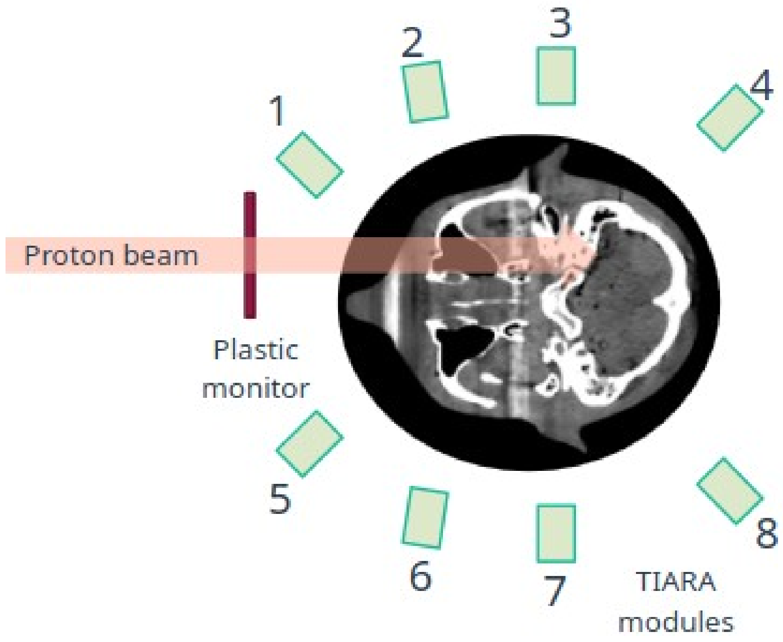
Geant4 simulation
Version 10.4 patch 3
Physics List: QGSP_BIC_HP_EMY

Beam test simulation

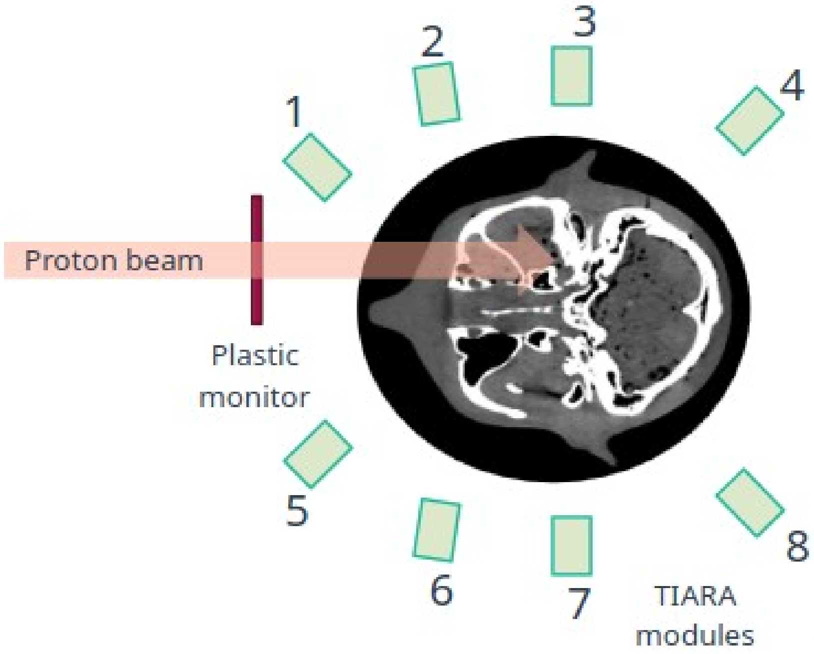
Setup reproduction from a beam test made at CAL in March 2024 (**data measured by A. ANDRE from LPSC**)
- 8 **PbF_2 detectors** placed around the RANDO phantom
- **Plastic** beam monitor
- RANDO phantom

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

Empty sinuses

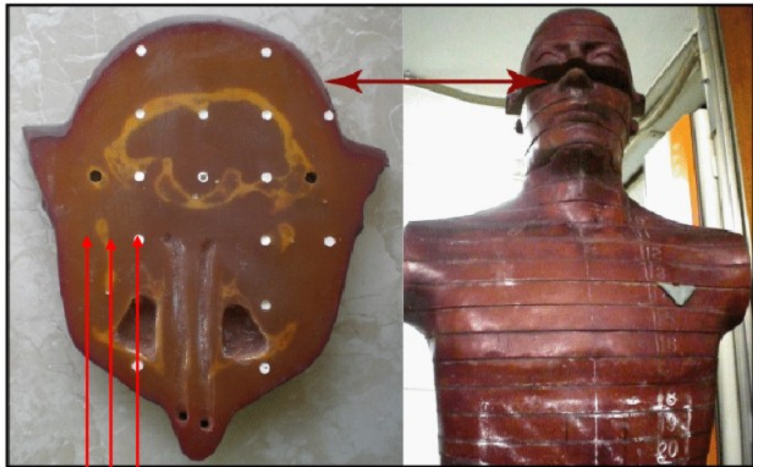


Filled sinus



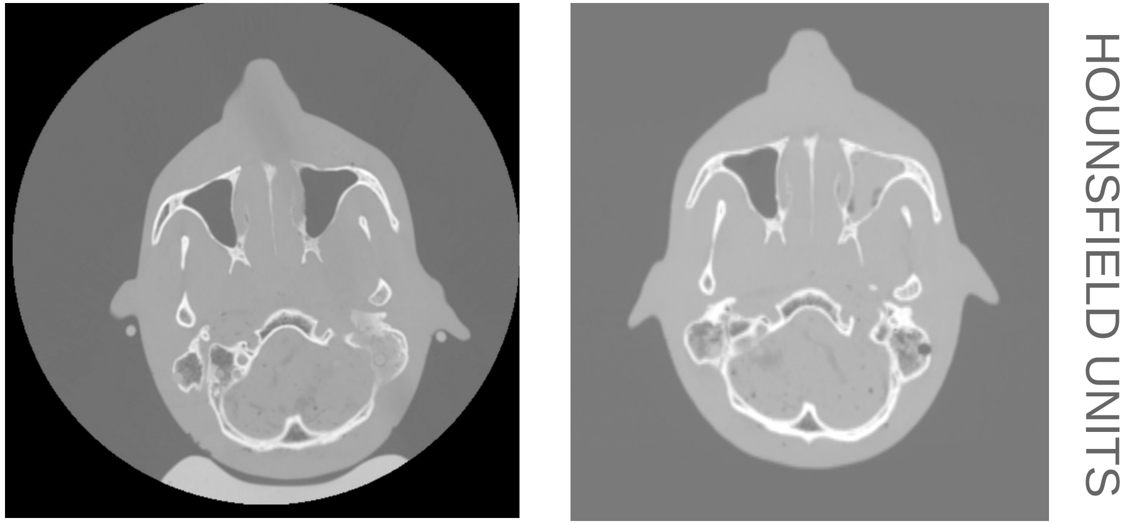
RANDO phantom calibration

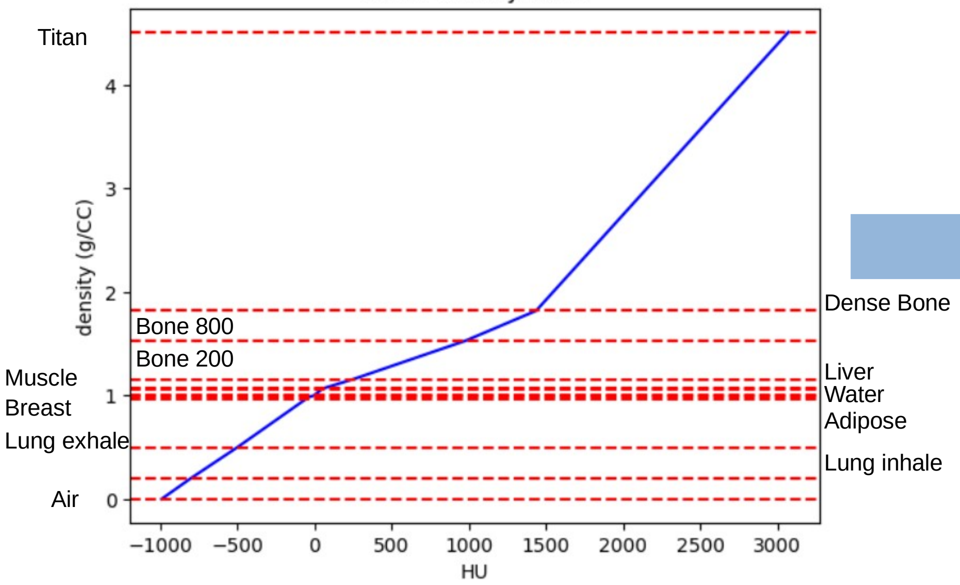
DICOM data

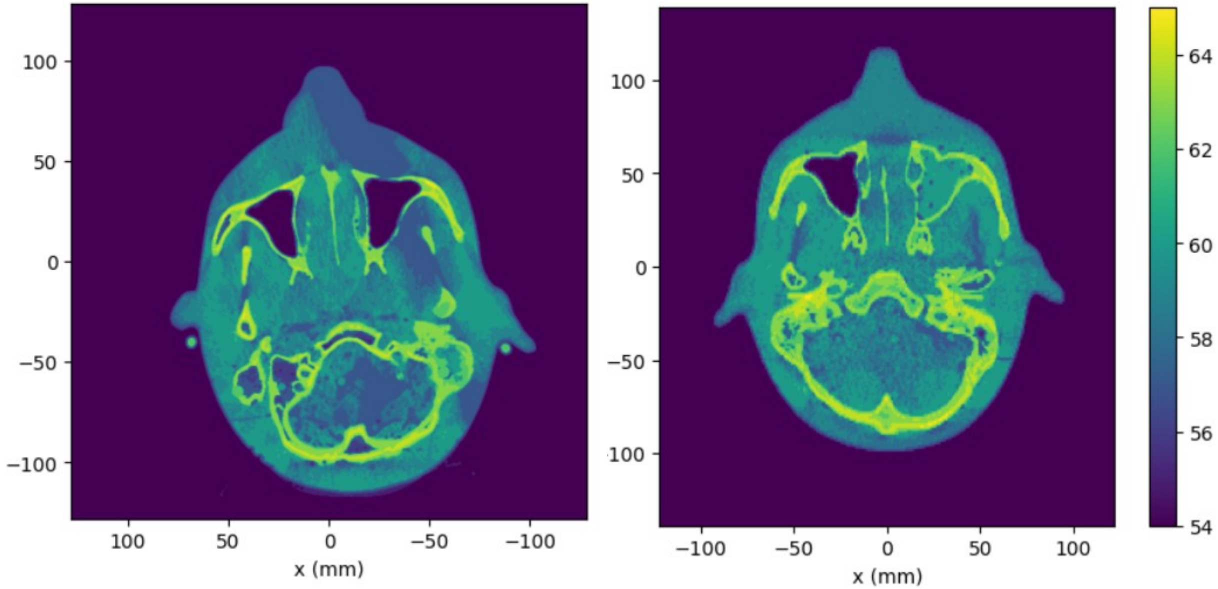


RANDO phantom used for beam test

CT SCAN







Materials identification

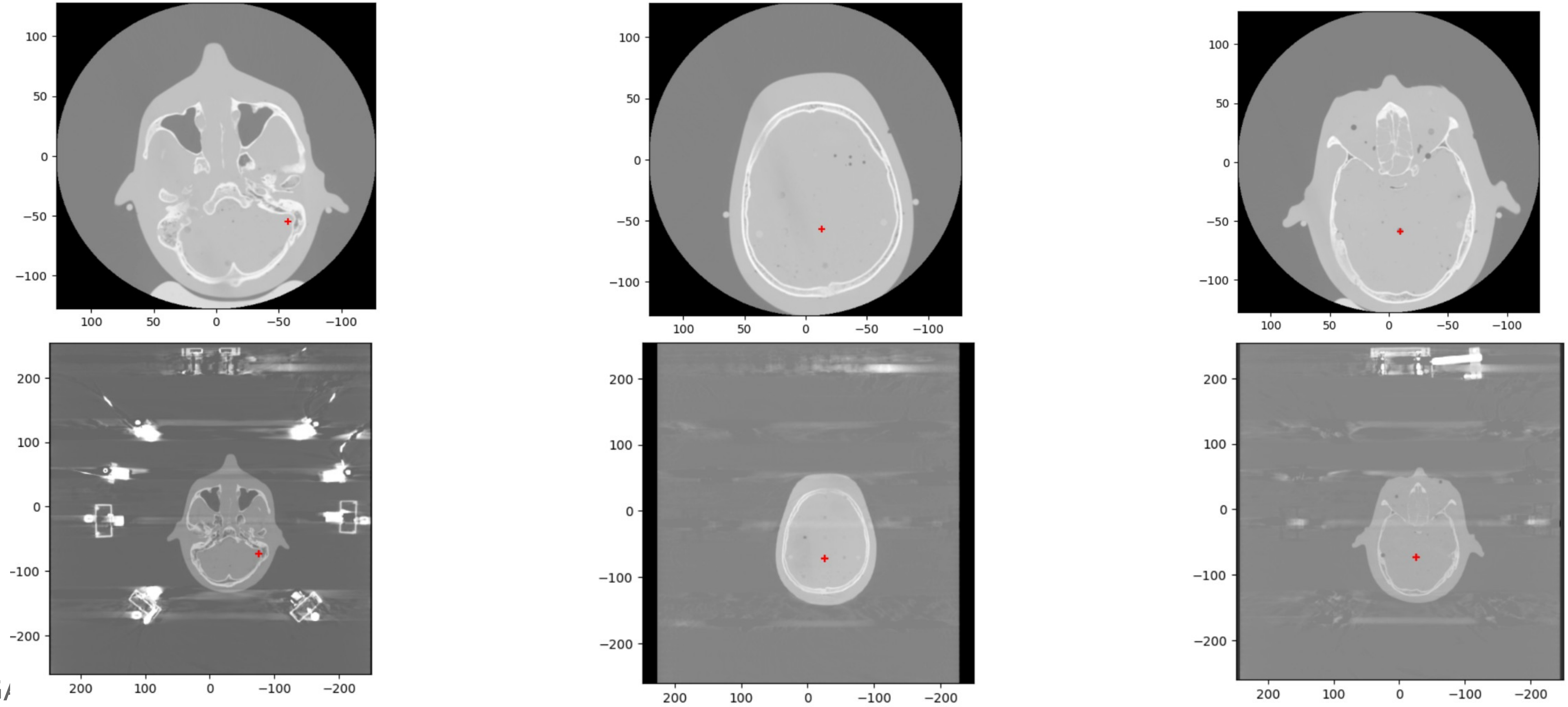
Phantom placement

PGTI
PROMPT GAMMA TIME IMAGING

Placement of the detectors in regards to the phantom

Method:

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



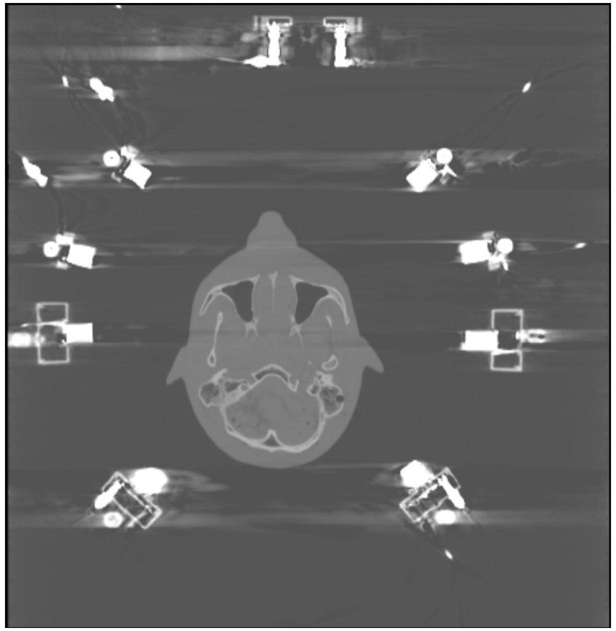
Phantom placement

PGTI PROMPT GAMMA TIME IMAGING

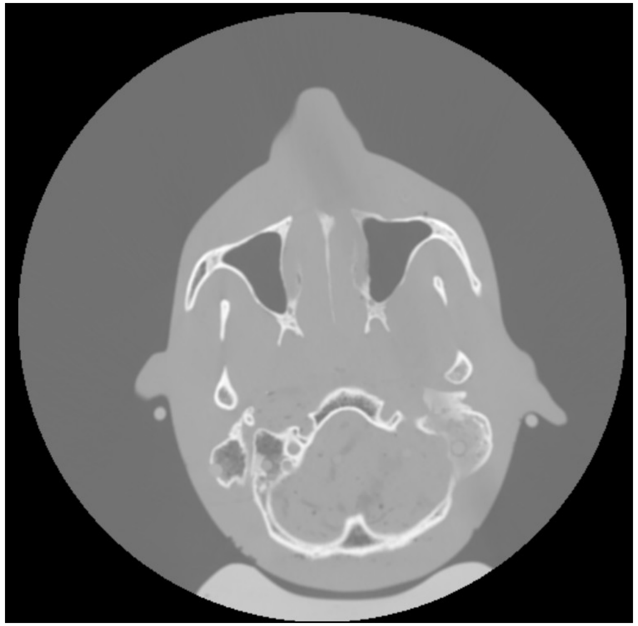
Placement of the detectors in regards to the phantom

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)

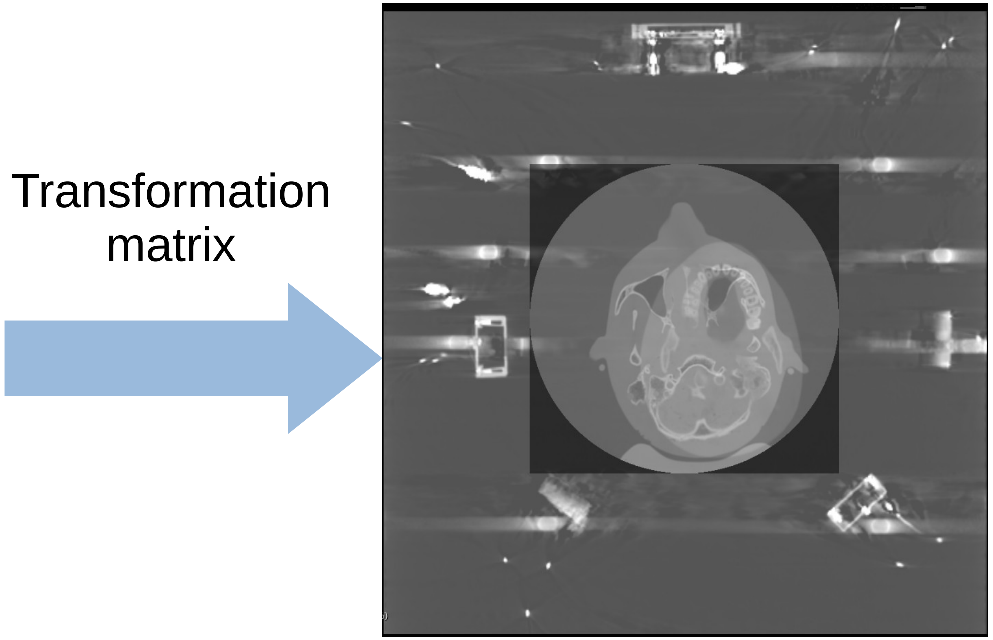


Scan of the phantom in the set-up



Scan of the phantom RANDO

Transformation matrix



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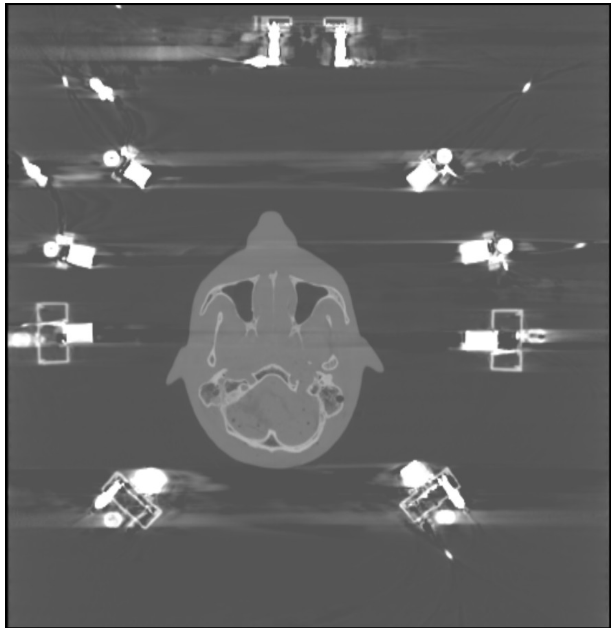

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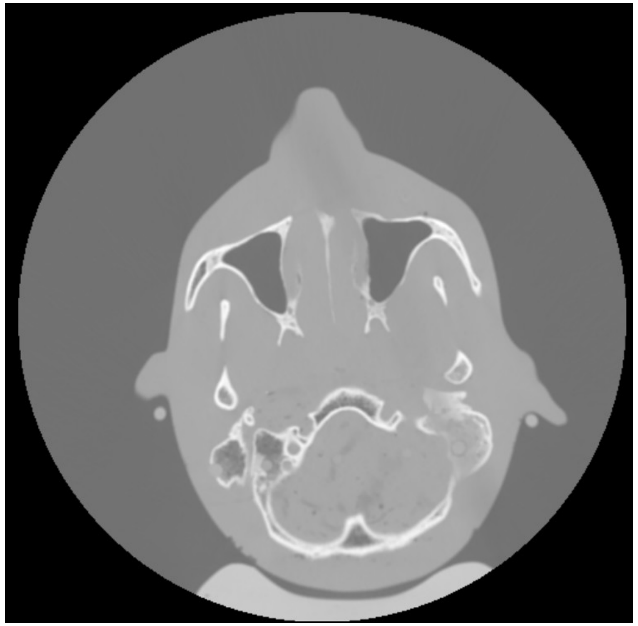

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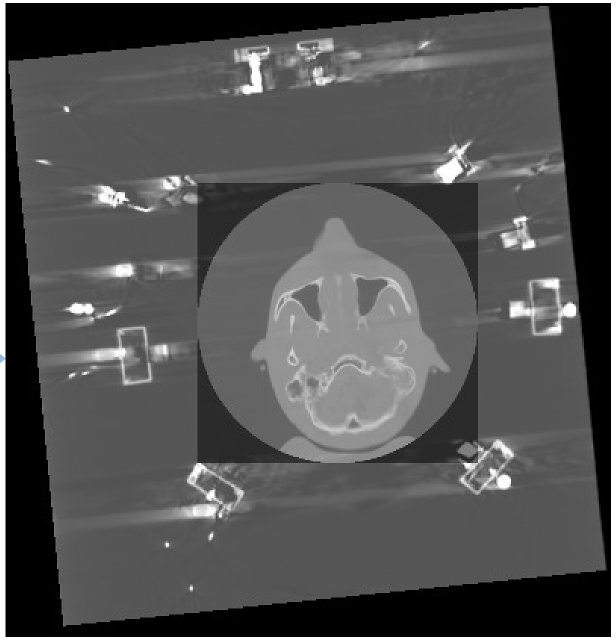


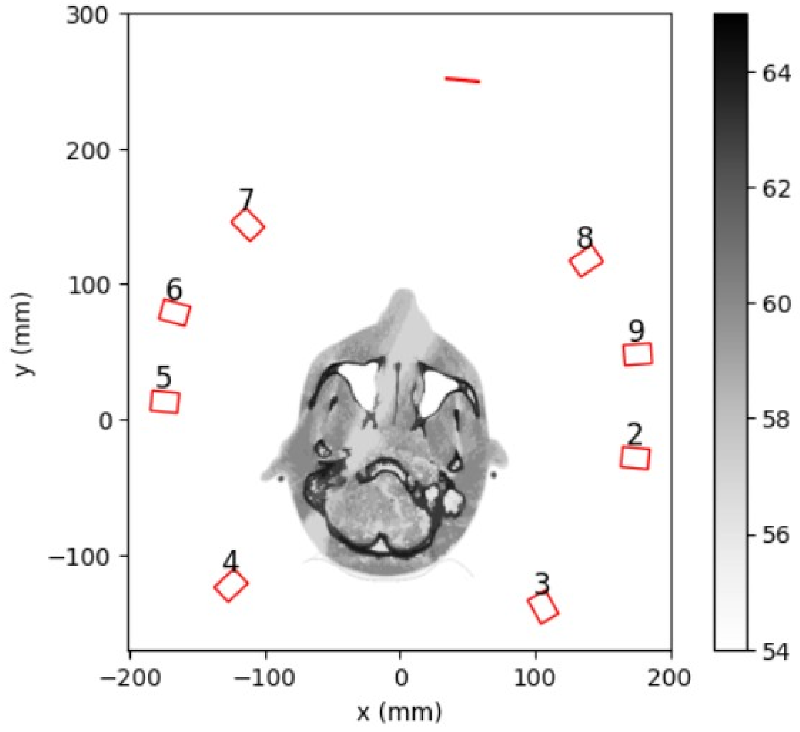
Phantom placement

Placement of the detectors in regards to the phantom

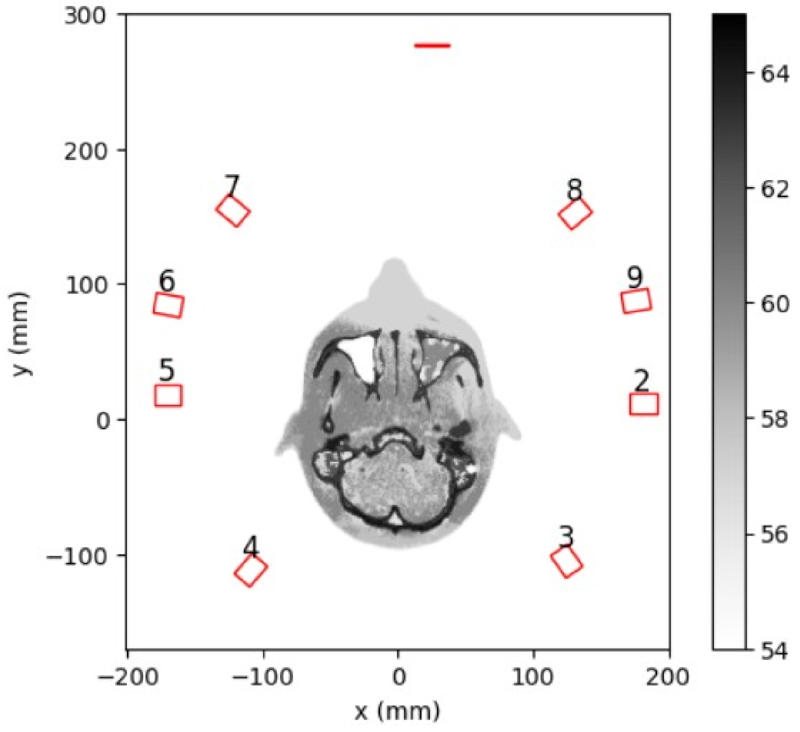
Method:

- Specific **points selection** in both image we want to match
- Use of **minimisation function** to find the accurate rotation and translations for both images to match

Empty sinuses



Full sinus

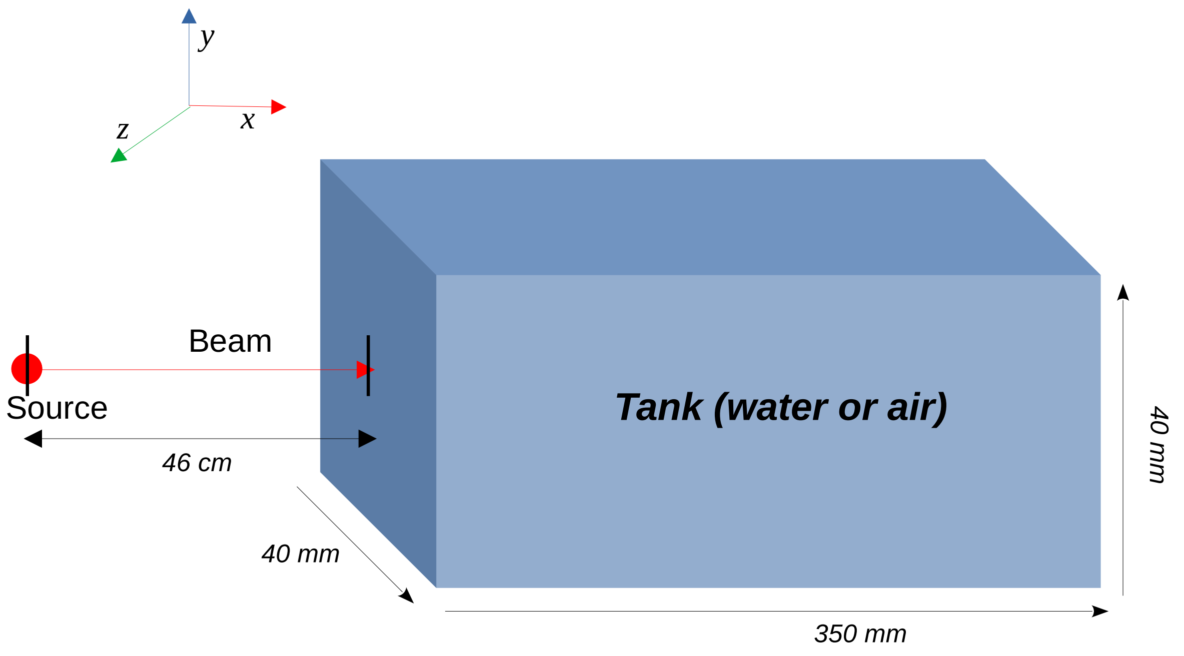


Proton beam calibration

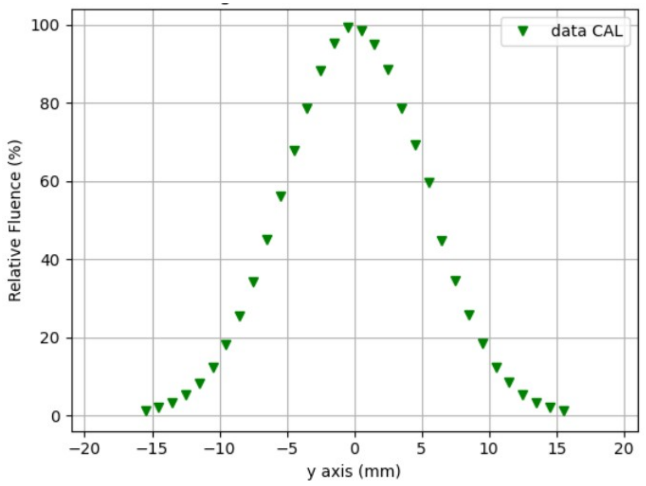
New Geant4 application to replicate the characteristics of the beam used at CAL (**Centre Antoine Lacassagne**).

Target: Tank filled with water or air

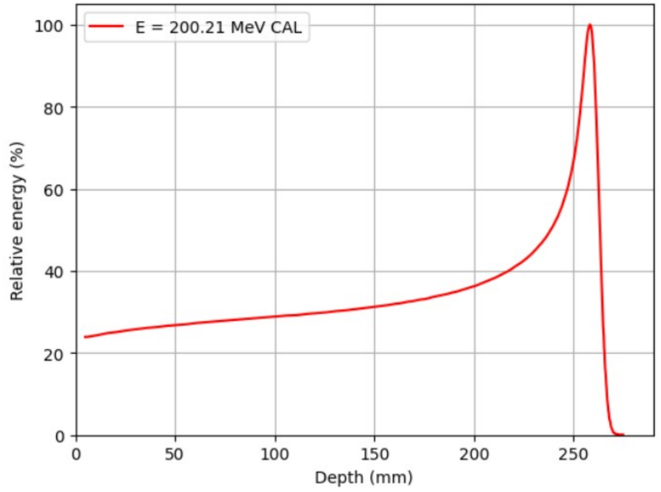
Modification of the characteristics of the beam so that it matches the one at CAL



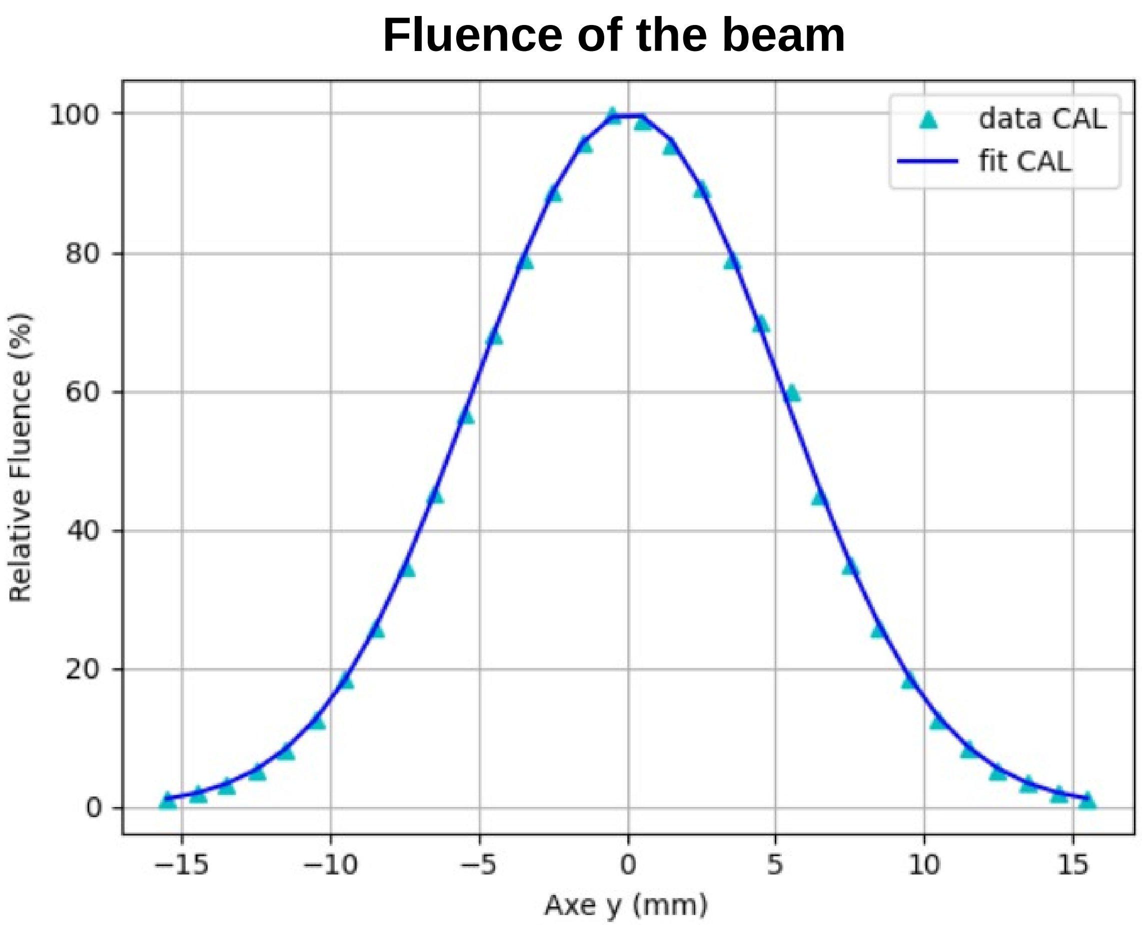
Fluence



Energy deposition profile



Proton beam calibration



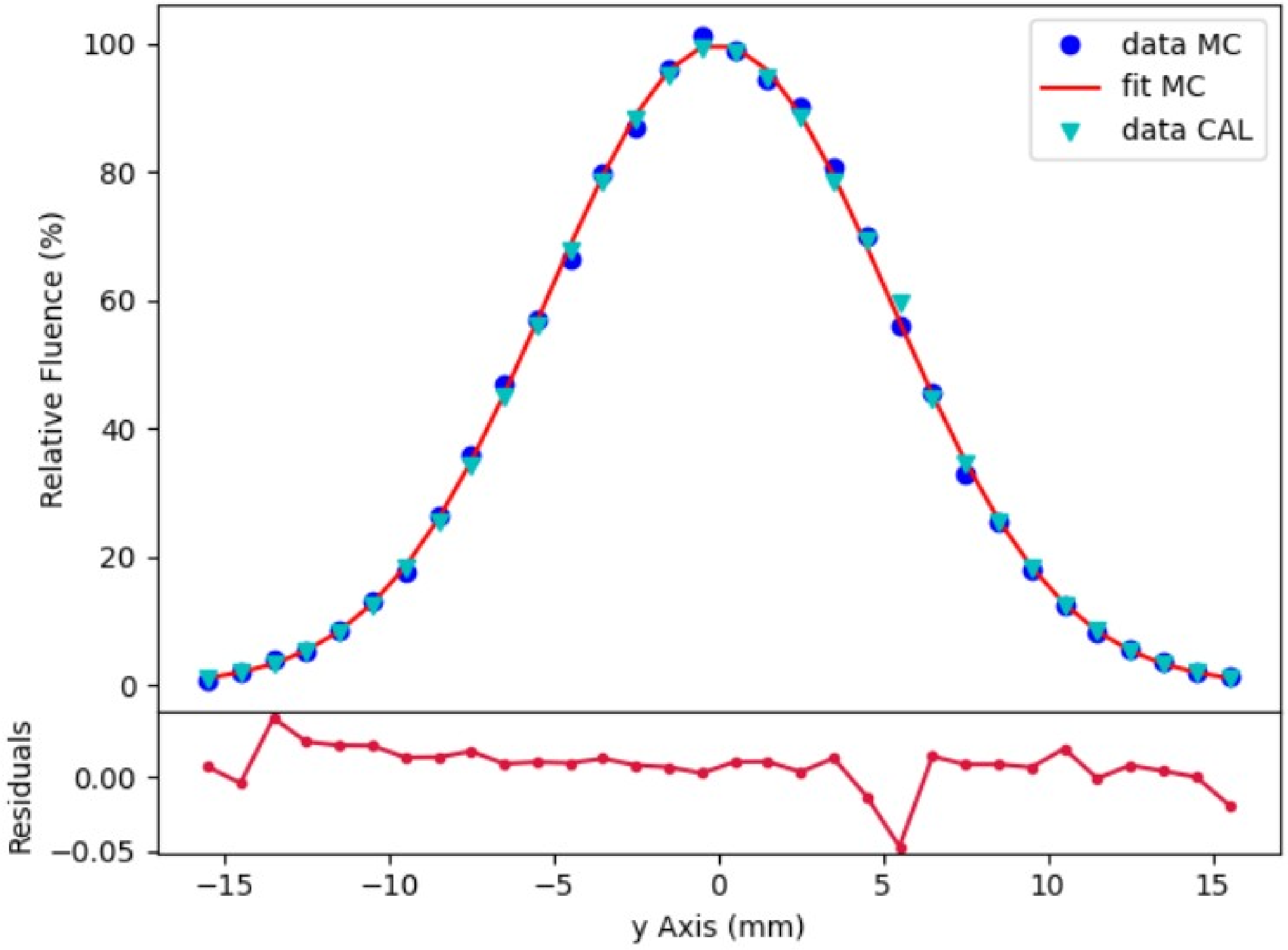
σ_{CAL} = 5.17 ± 0.01 mm

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

Fluence of the beam and residuals



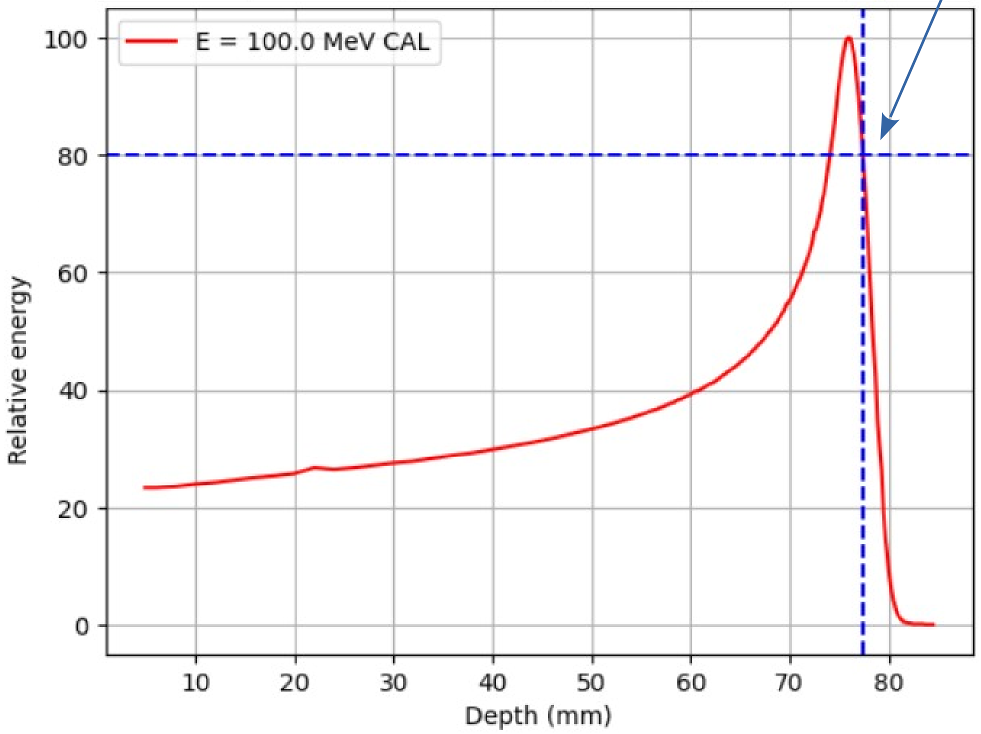
σ_{MC} = 5.17 ± 0.02 mm ; μ_{MC} = 0.00 ± 0.02 mm

Proton beam calibration

PGTI
PROMPT GAMMA TIME IMAGING

R80

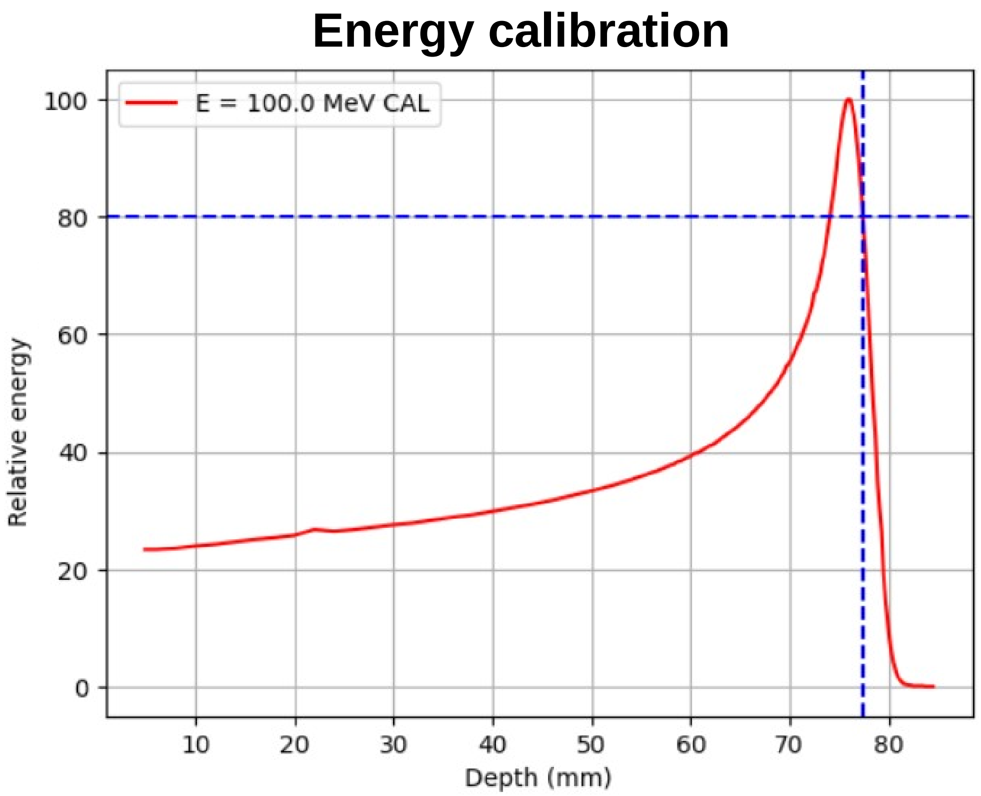
Energy calibration



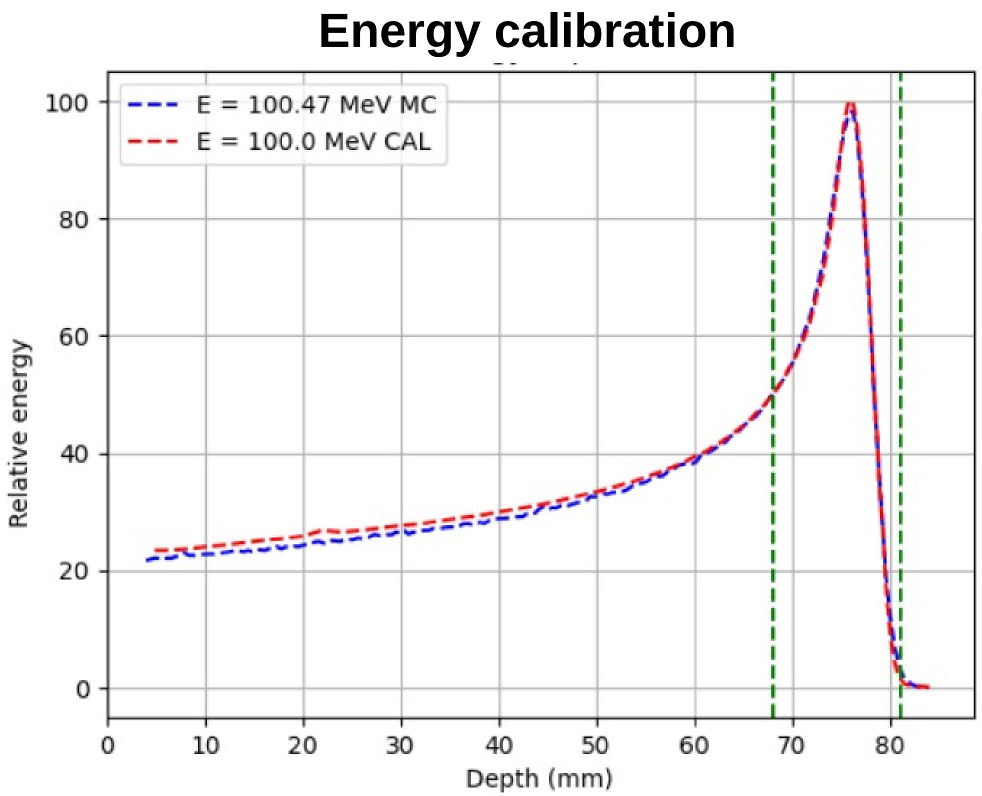
Adapted **curve_fit** function on the simulated data to determine the **energy E** et the value of **sigma σ_E** for the simulation to match the data from CAL

Proton beam calibration

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



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



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)

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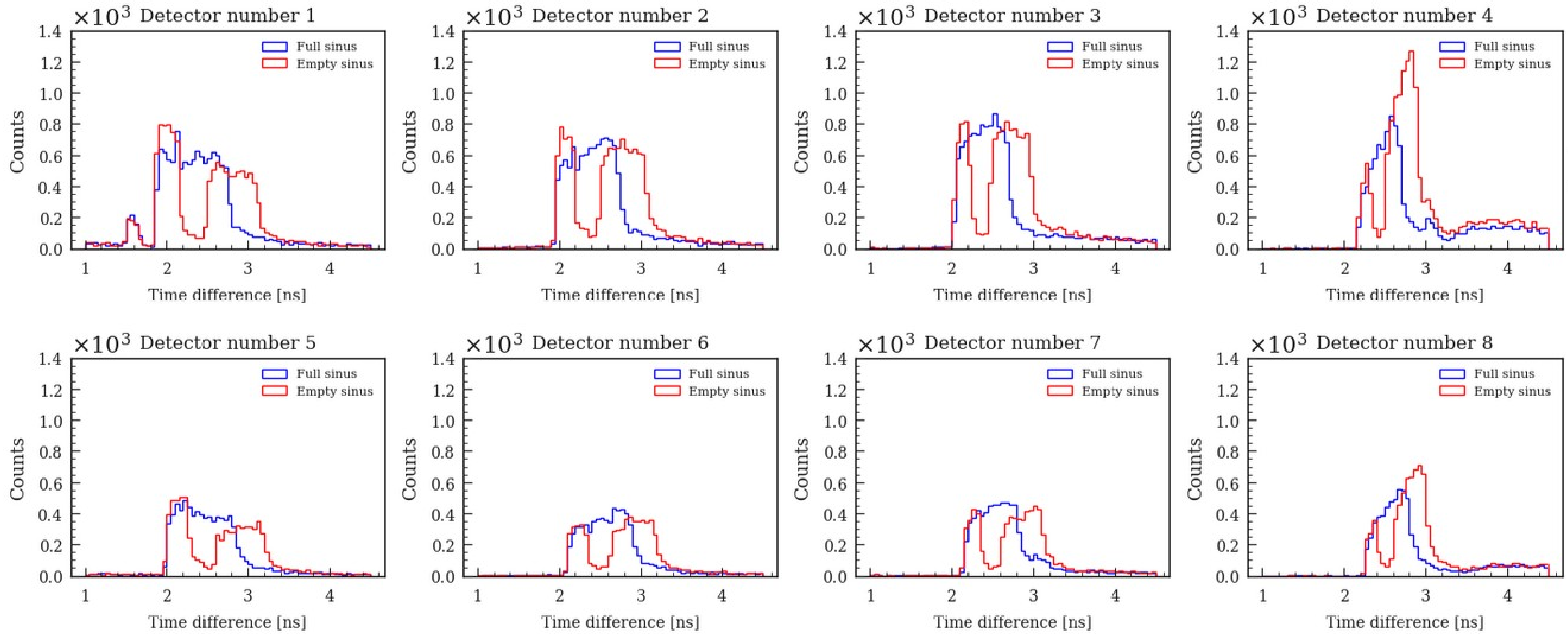
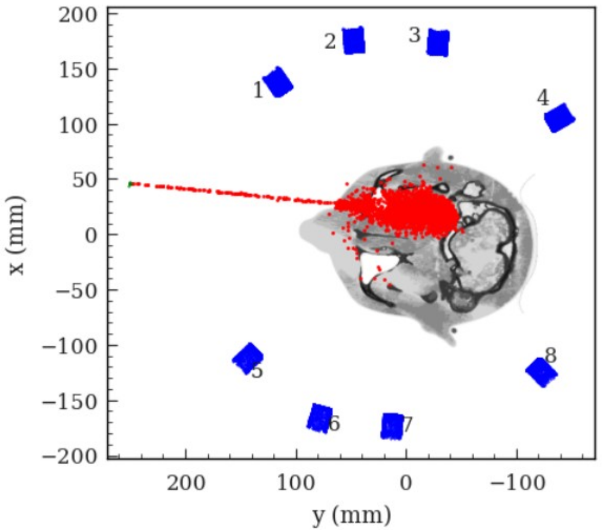
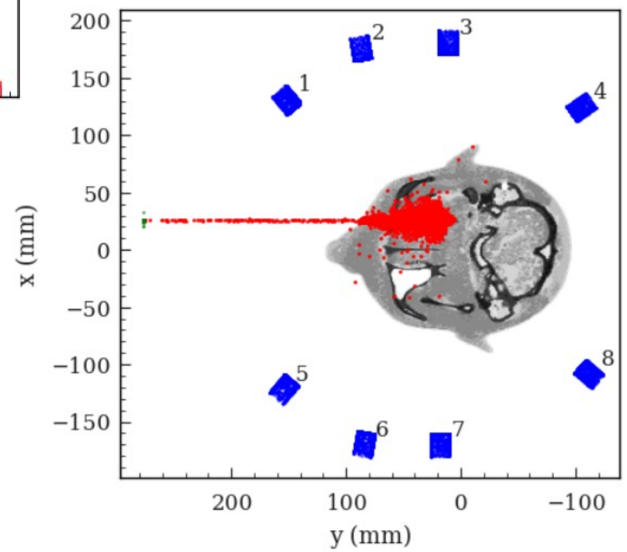
PROMPT GAMMA TIME IMAGING







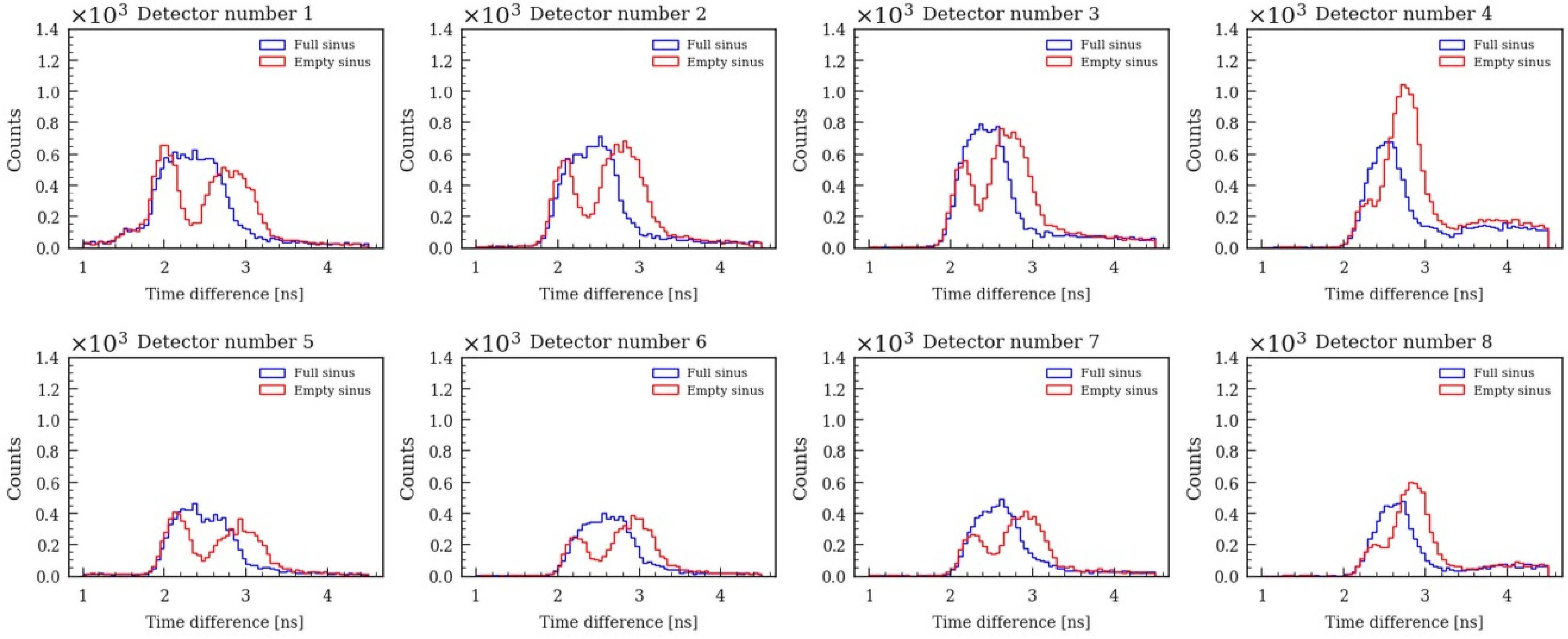
- 🔴 : vertices positions
- 🟢 : interaction with the beam monitor
- 🔵 : Interaction with the TIARA detector

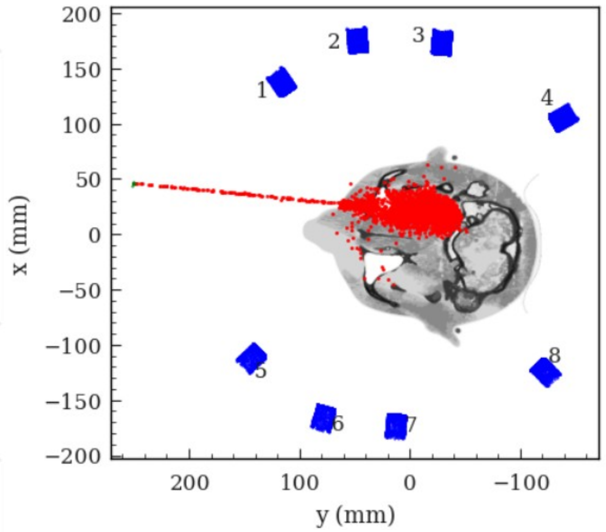
Stat: 100.10^6 protons

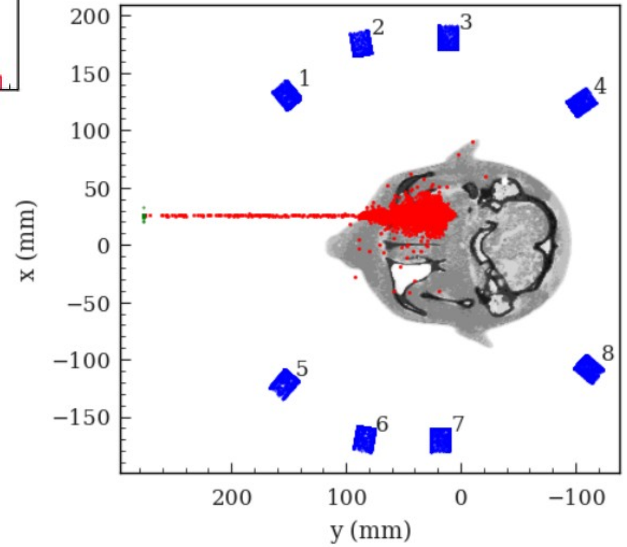
Particles	%
Gamma	62
Neutrons	27
Protons	3

Time-Of-Flight (time resolution: 100 ps)

PGTI
PROMPT GAMMA TIME IMAGING







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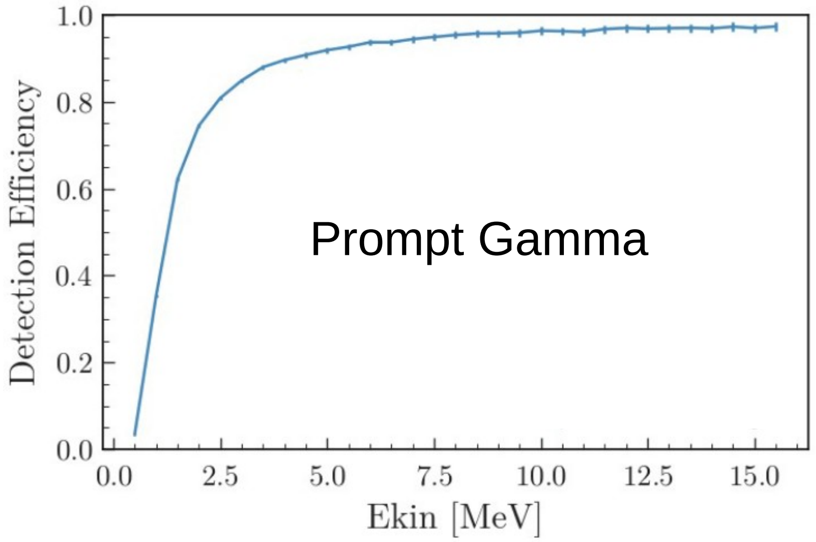
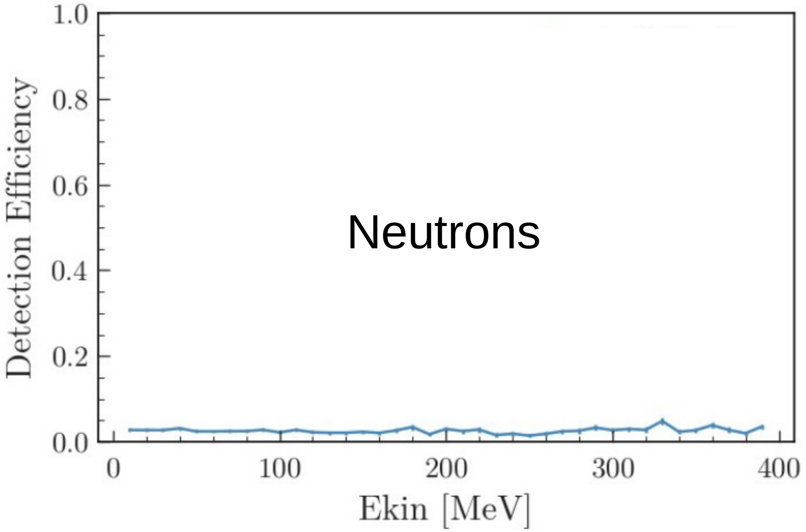
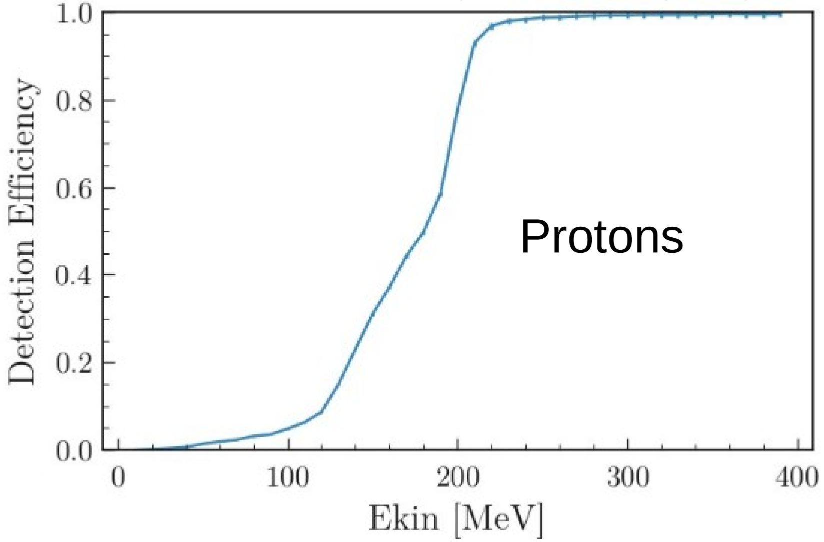
Detection efficiency





Courtesy of A. ANDRE (LPSC)



Detection efficiency obtained for **PG**, **neutrons** and **protons** from precise simulation of the TIARA modules

Particles	%
Gamma	62
Neutrons	27
Protons	3

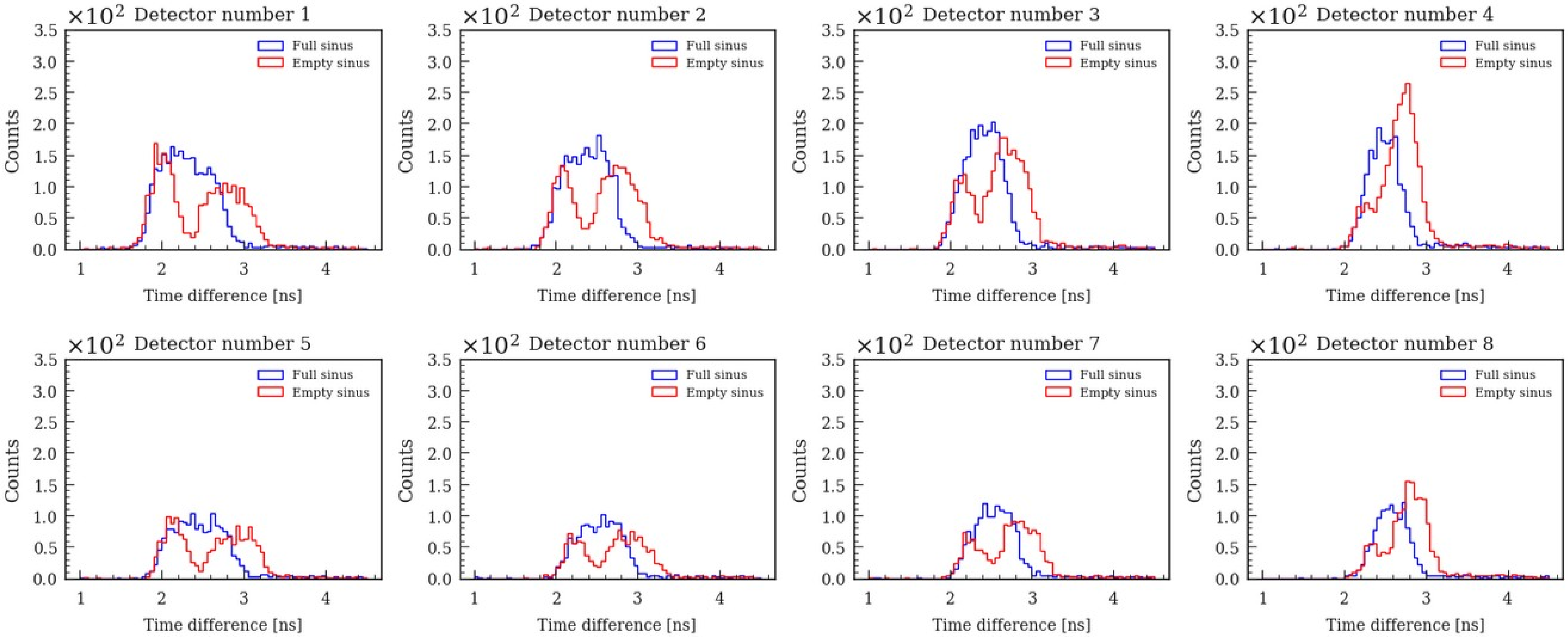
Stat : **100.000** detected particles

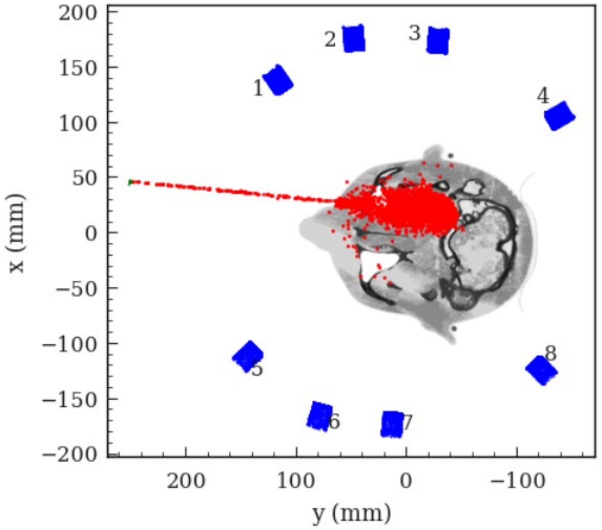
→

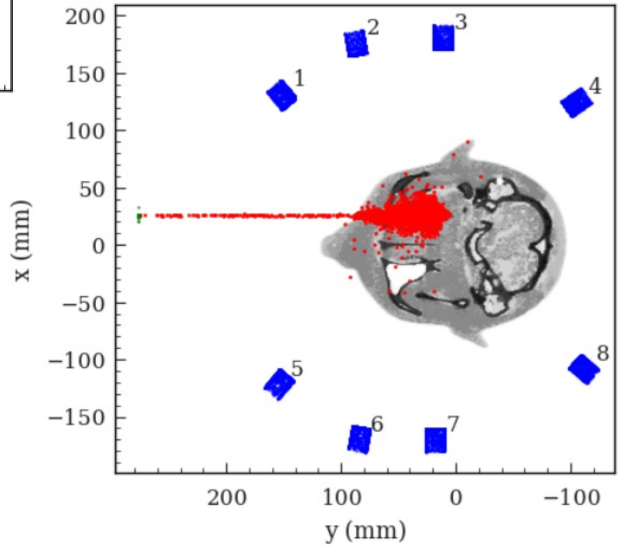
Particles	%
Gamma	**99.7**
Neutrons	**0**
Protons	**0.3**

Stat : **15.000** detected particles

Time-Of-Flight (detection efficiency)







- 🔴 : vertices positions
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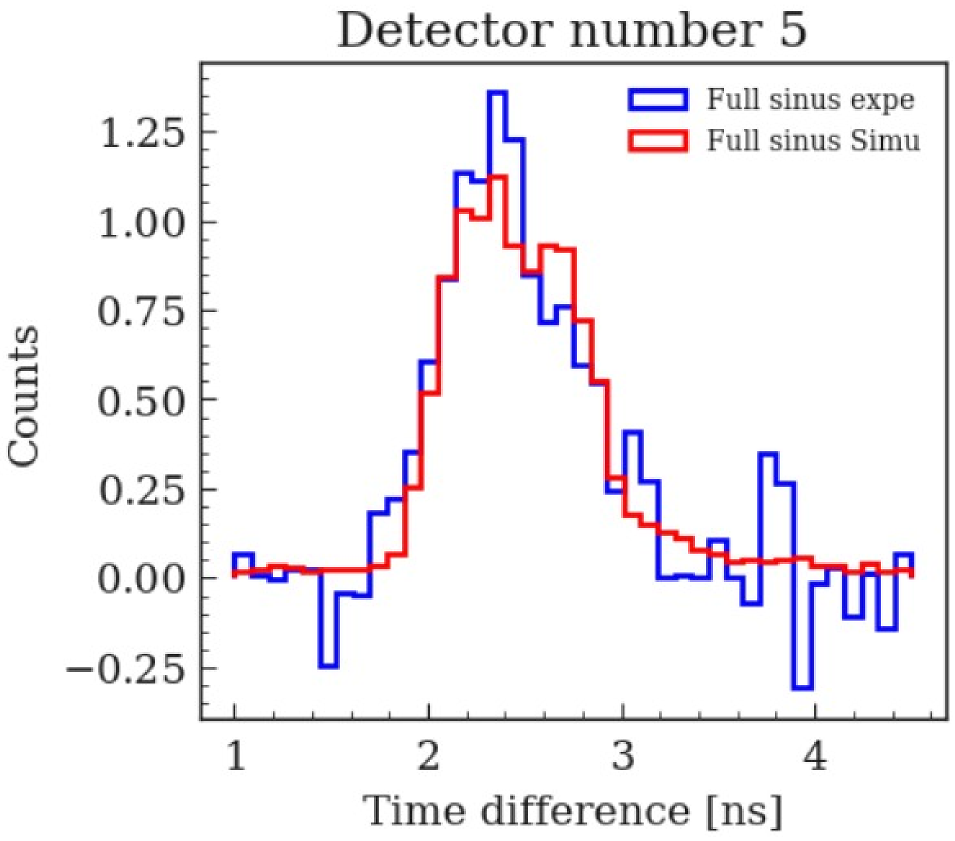
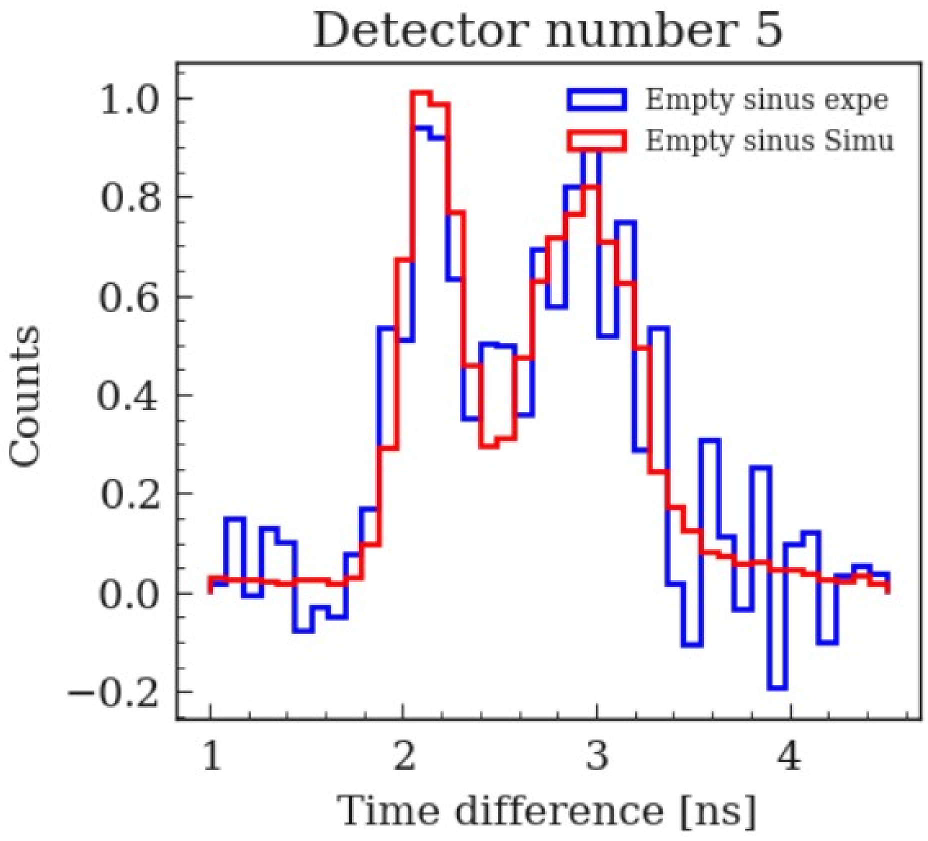
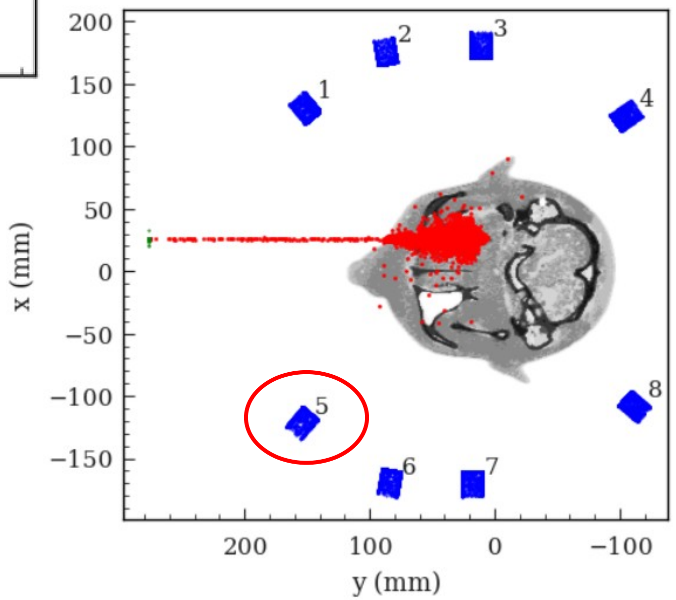
Stat: 100.10^6 protons

Particles	%
Gamma	99.7
Neutrons	0
Protons	0.3

Comparison with experimental results







Conclusion

- **Successful implementation of the Phantom RANDO and the proton beam for a range of energies**
- **Implementation of the detectors caracteristics (time resolution and detection efficiency depending on the particles)**
- **Encouraging results for the Time-of-flight comparison (analysis in progress)**

Thank you for your attention!