



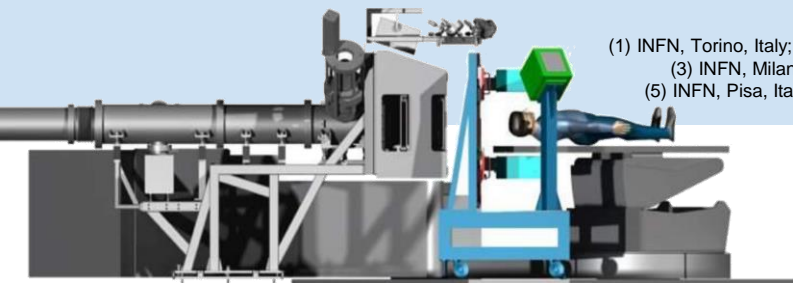
Monte Carlo simulation tool for online treatment monitoring in hadrontherapy with in-beam PET

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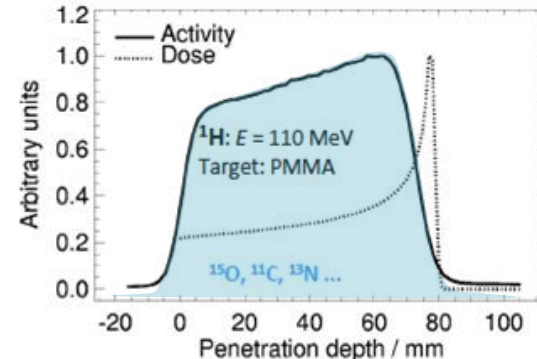
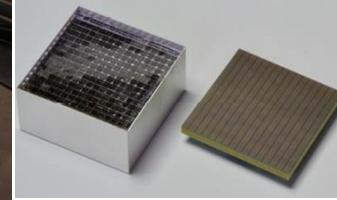
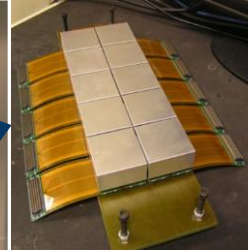
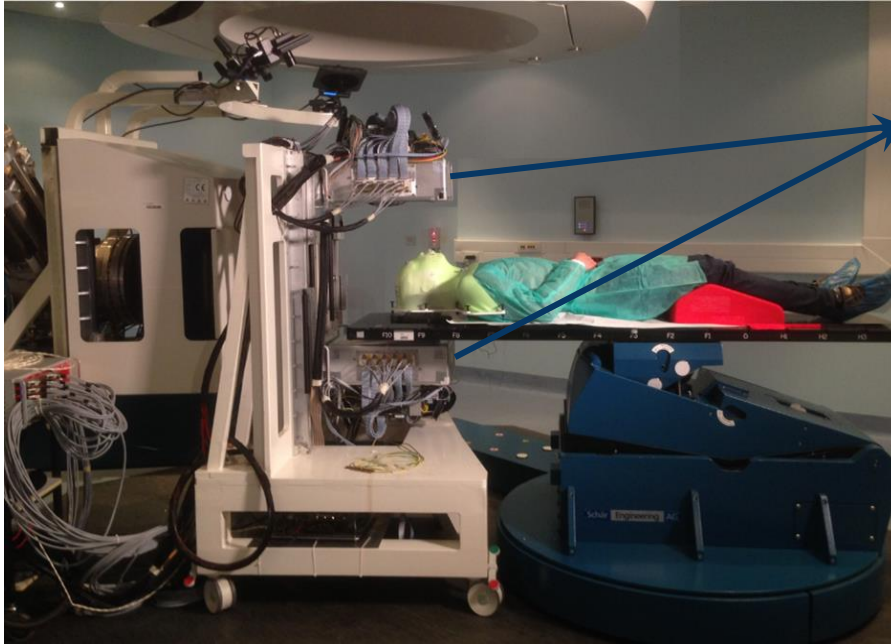
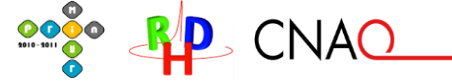
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Inside

The INSIDE In-beam PET Scanner

Pennazio F., et al., Acta Physica Polonica A 127.5 (2015); Marafini M., et al., Acta Physica Polonica, A. 127.5 (2015); Fiorina E., et al., Nucl. Instr. and Meth. in Phys. Research A 824 (2016); Piliero M.A., et al., Phys. Med. and Biology (2016); Bisogni M.G., et al., J. Med. Imaging (2017).



J Pawelke et al., Proceedings IBIBA 2007, Heidelberg

Main contributions:
 ^{11}C ($T_{1/2} \approx 20.3 \text{ min}$)
 ^{10}C ($T_{1/2} \approx 19.3 \text{ s}$)
 ^{15}O ($T_{1/2} \approx 2.0 \text{ min}$)
 ^{13}N ($T_{1/2} \approx 10.0 \text{ min}$)
 Other contributions:
 ^{14}O ($T_{1/2} \approx 70.59 \text{ s}$)
 ^{15}O ($T_{1/2} \approx 0.008 \text{ s}$)
 ^{12}N ($T_{1/2} \approx 0.01 \text{ s}$)

INnovative **S**olutions
 for **In**-beam
DosimEtry
 in Hadrontherapy

Why in-beam?

- negligible washout
- no image registration
- little/no slowing down of the clinical workflow
- **response during treatment**

Online Treatment Monitoring

Clinics

Planning:

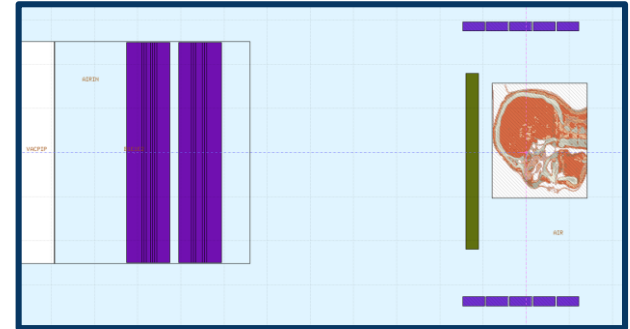
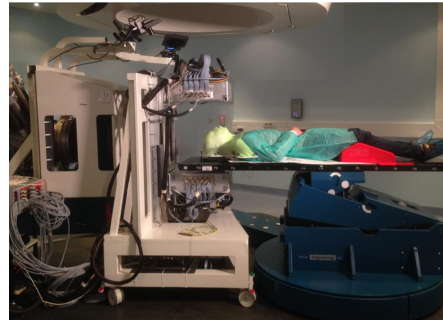
CT
Treatment plan
RT struct
RT dose

In-beam PET
measurements

In-beam PET
MC simulation tool

Treatment:

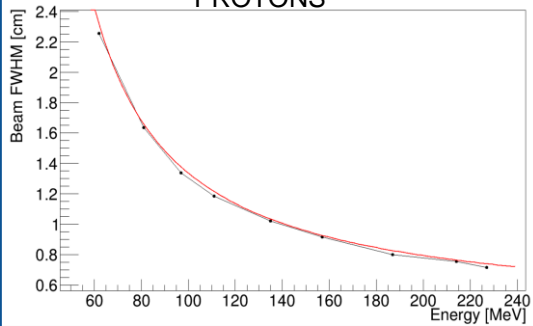
Fraction #1
Fraction #2
...
Fraction #n



Re-planning?

CNAO BEAM LINE

PROTONS

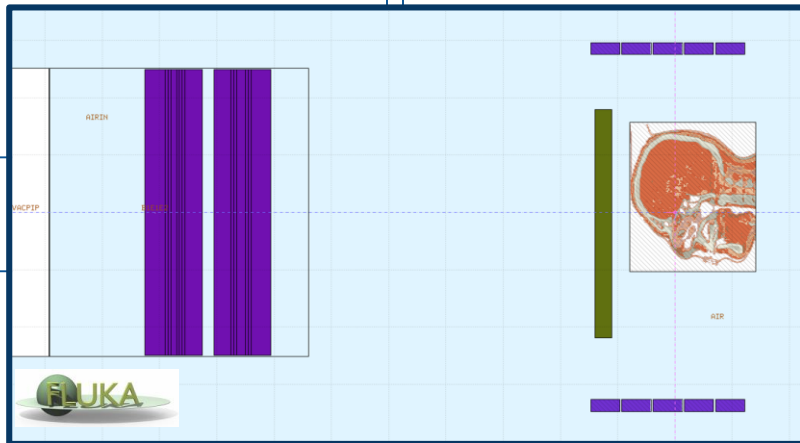
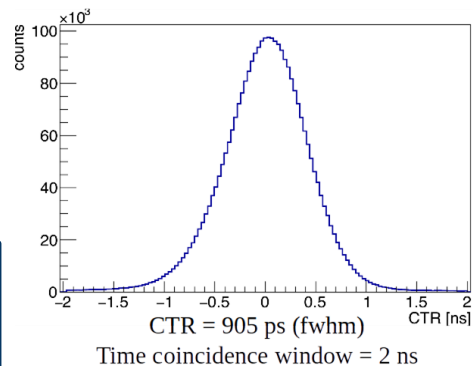


Model from Mirandola et al. Medical Physics 2015

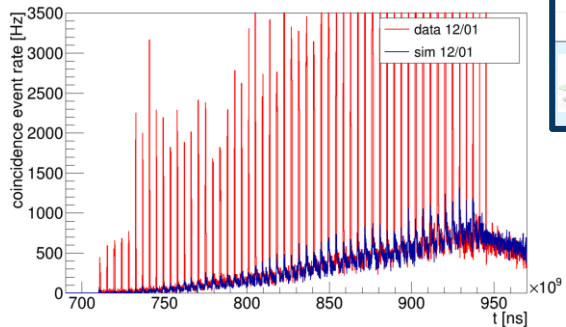
- geometry
- materials
- beam size

INSIDE IN-BEAM PET SCANNER

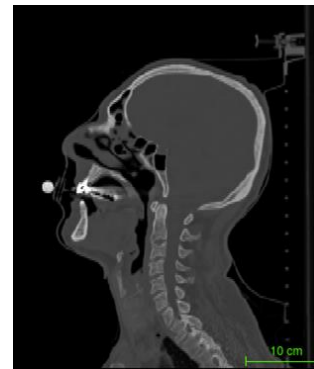
- geometry
- materials
- energy resolution
- time resolution



- particle (p,C)
- spot position
- energy
- time structure



- geometry
- materials
- additional inserts

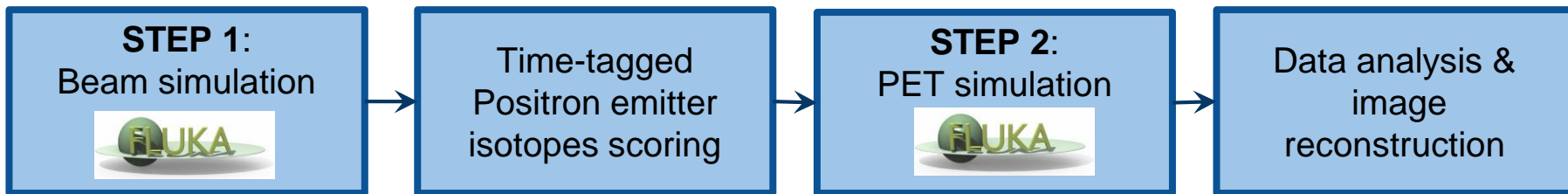


TREATMENT

PATIENT

The INSIDE In-beam PET Simulation Tool

Isotopes production gives a poor signal → all the statistics must be simulated.



The temporal structure of the beam delivery is simulated.

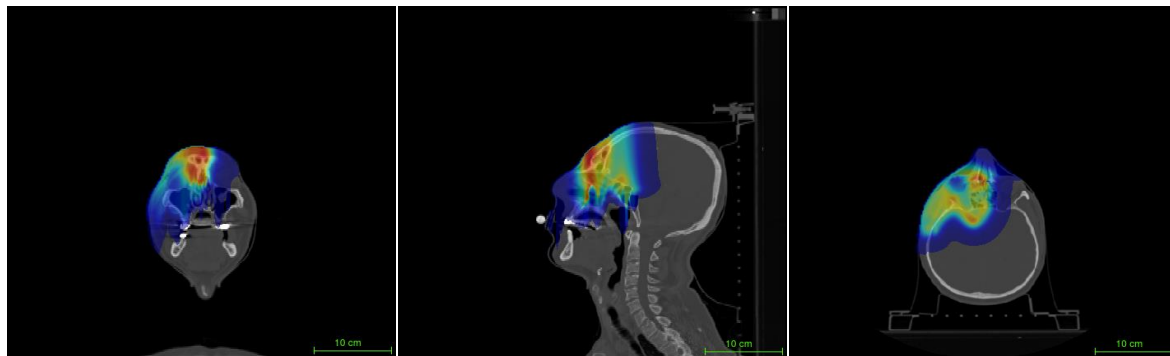
Isotope decays are simulated.

The 4D reconstructed image depends on the acquisition time.

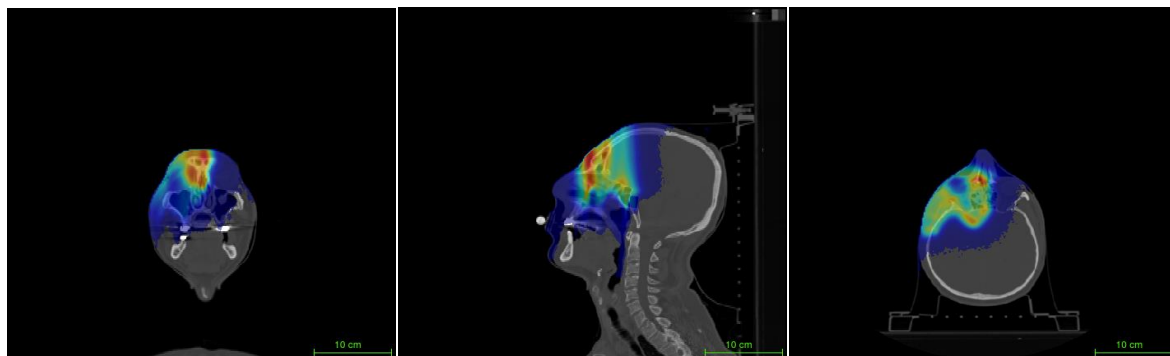
Patient #0

Carcinoma of the lacrimal gland
 $3.7 \cdot 10^{10}$ protons
[66.3, 144.4] MeV/u
(28-29)/30 fractions, 2.2 GyE
Vertex field

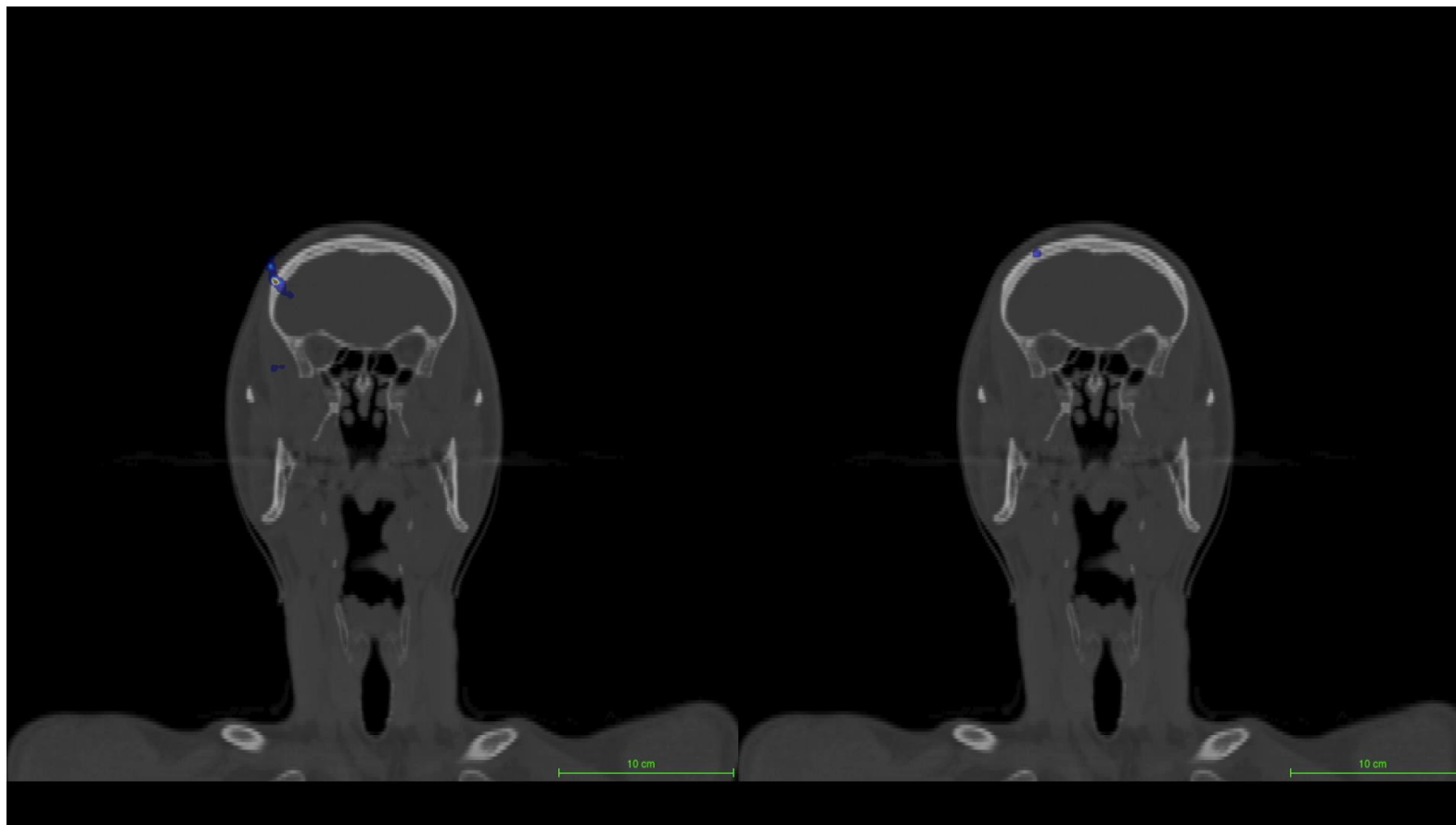
Planned dose from RT dose



Simulated dose



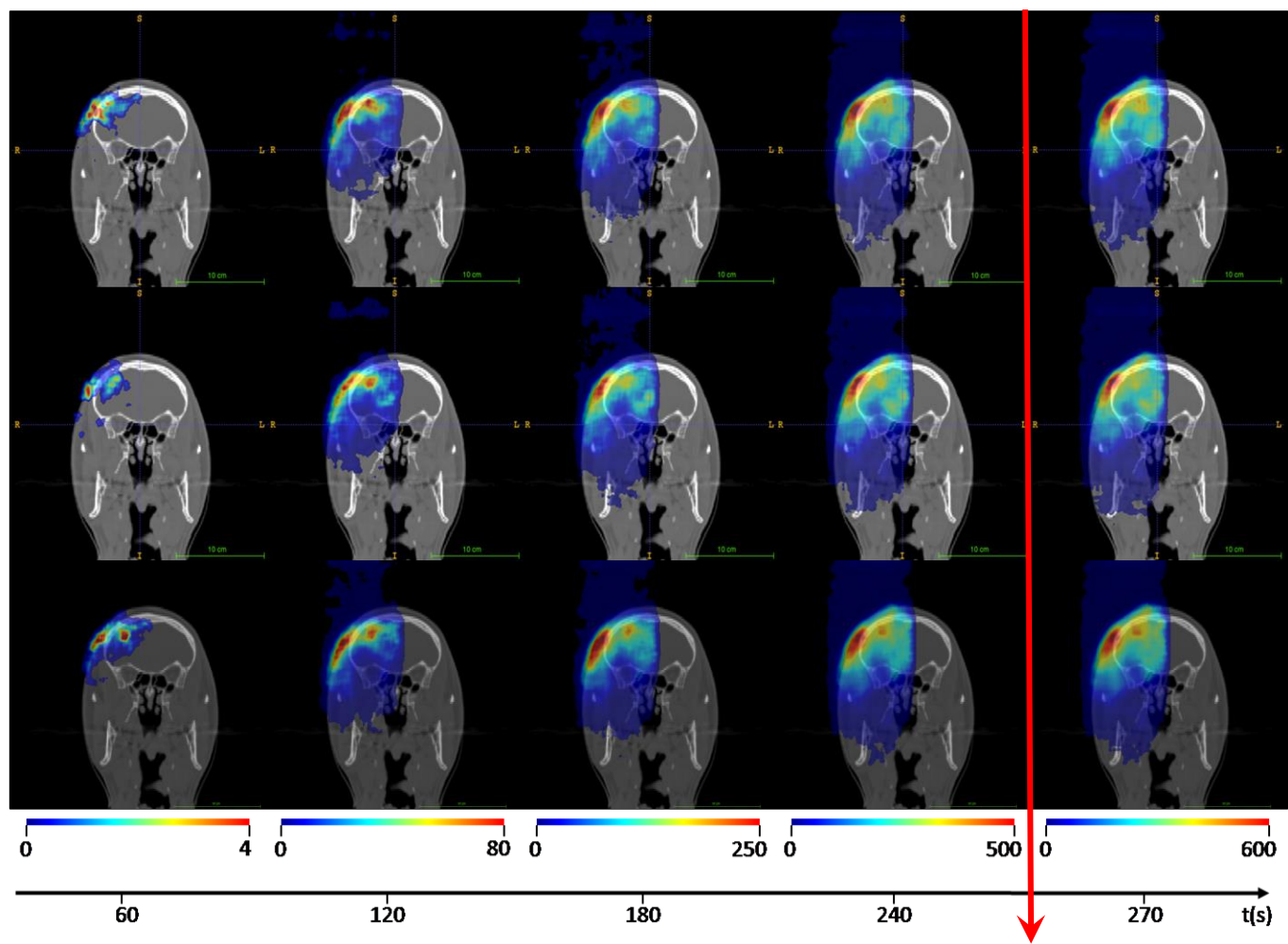
Time-resolved Image Series



Data 12/01

Data 12/02

Simulation 12/01



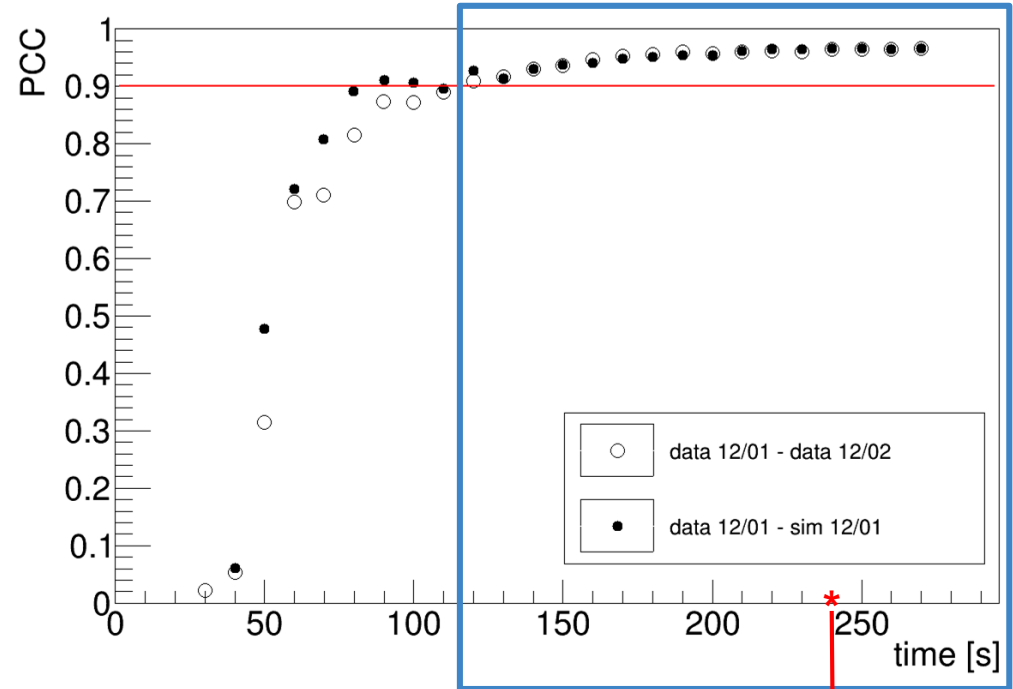
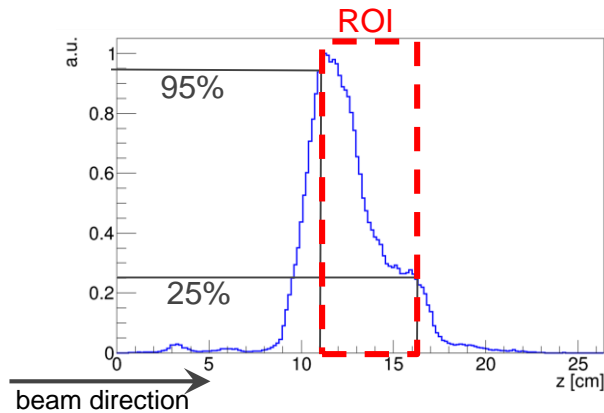
End of treatment

Pearson's Correlation Coefficient

Evaluation of the overall agreement in time.

$$\text{PCC} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}}$$

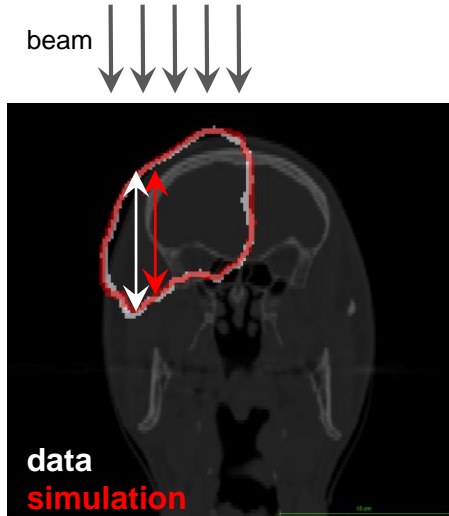
x, y: intensity values of the two images
x̄, ȳ: average intensity values



End of treatment

Beam's Eye View Analysis

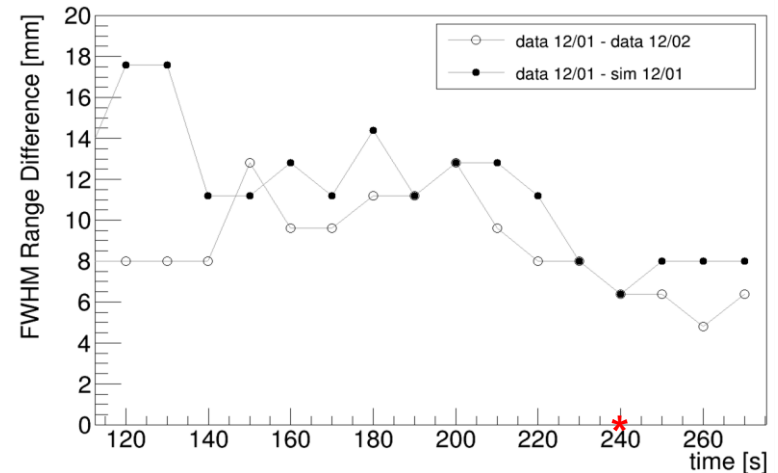
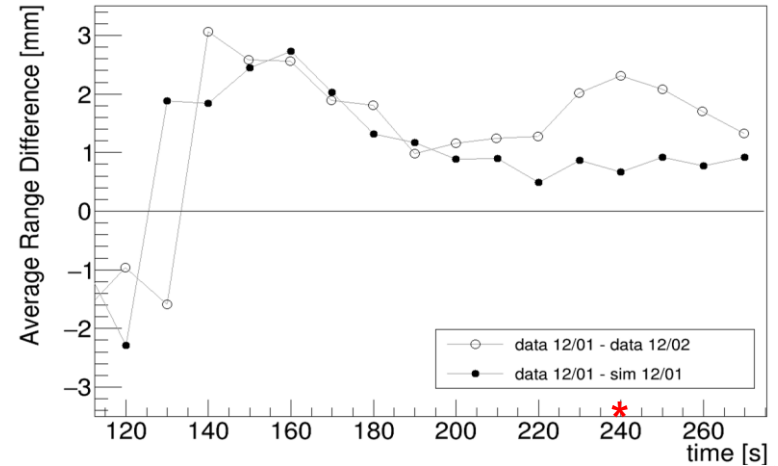
Evaluation of the activity range differences
in the direction of the beam.



3D surface at 10% of the
activity maximum

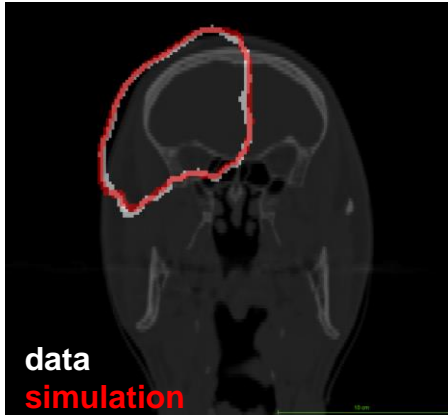
Study of the average and
FWHM values of the range
difference distribution in
time.

Very sensitive to mobile support positioning.



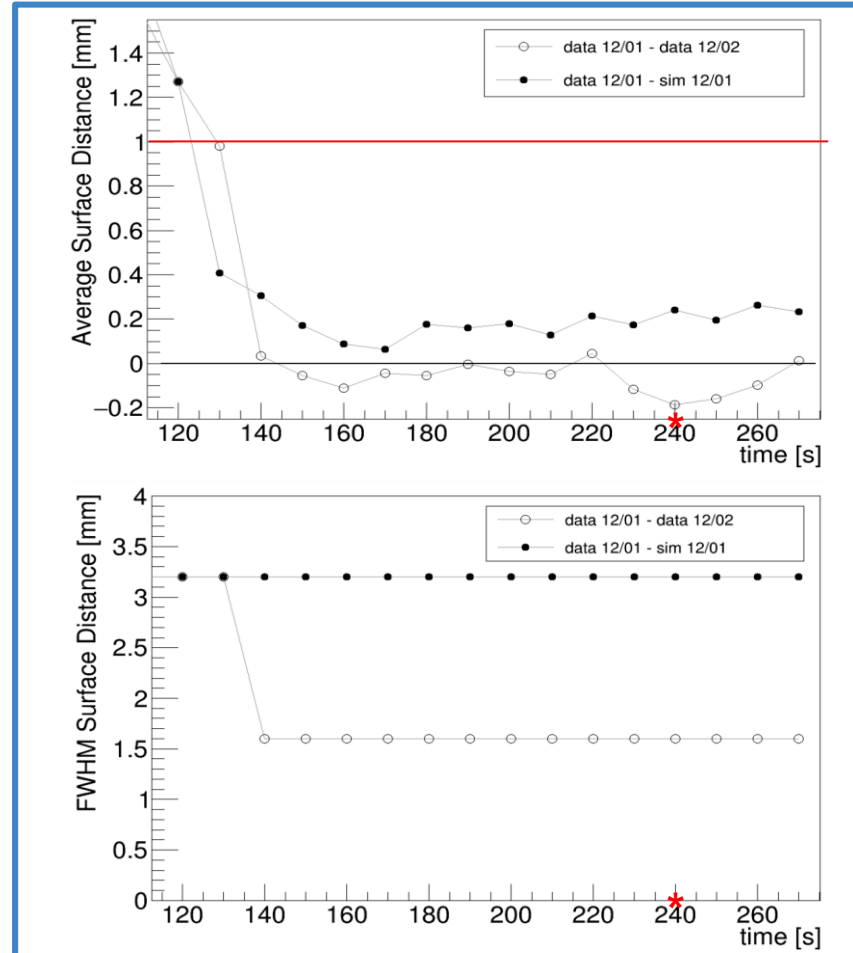
Overall View Analysis

Evaluation of the activity range differences without a preferential direction.



3D surface at 10% of the activity maximum

Study of the average and FWHM values of the surface distance distribution in time.



2018

New mobile support
compatible with most patients.

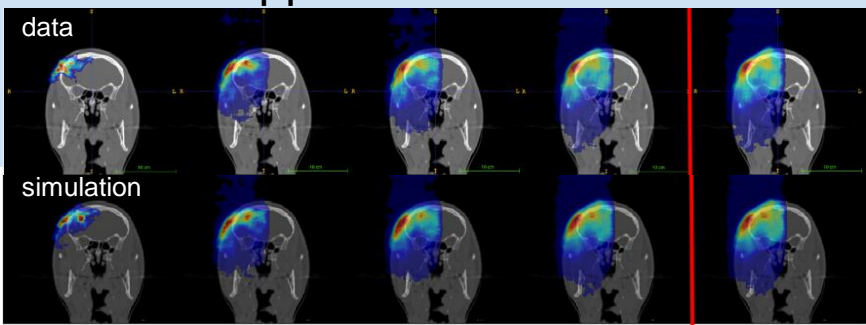
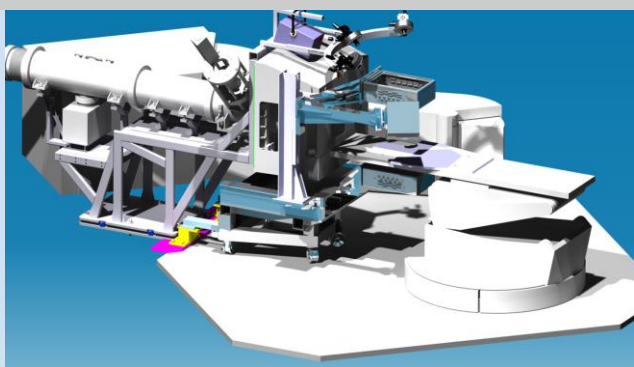
Integration with the Dose Profiler

Longitudinal clinical trial:

- both proton and carbon ion treatments
- selected pathologies (e.g. early cancer response, common morphological changes, OAR critical position)

The INSIDE in-beam PET simulation tool:

- validation of data acquisition
- study of the working limits to be applied in clinics.



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