partrec

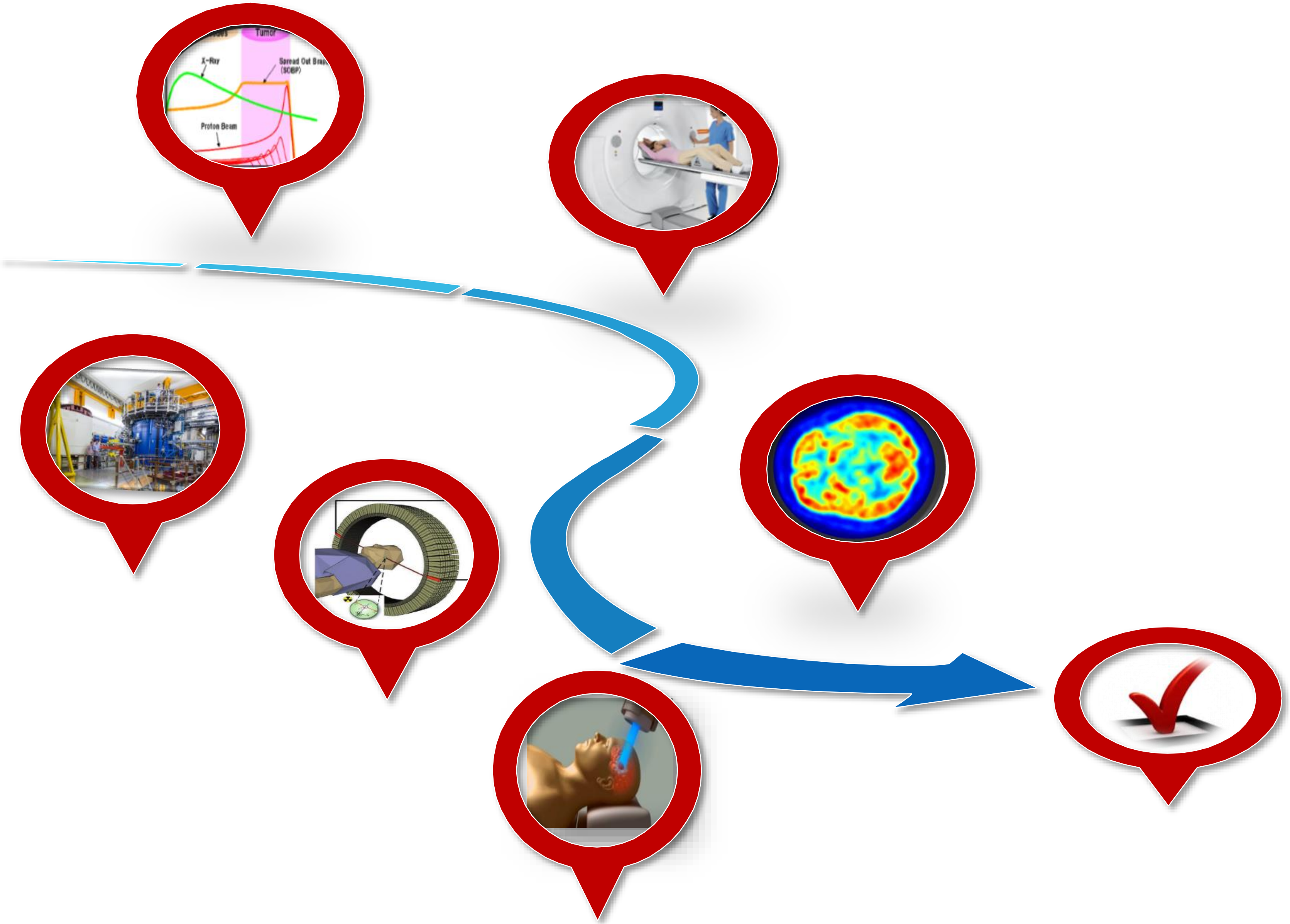
Translating N-12 imaging to the clinic using Monte Carlo simulations

Zahra Ahmadi Ganjeh, Brian Zapien Campos, Peter Dendooven

Particle Therapy Research Center (PARTREC) and Department of Radiation Oncology, University Medical Center Groningen (UMCG), University of Groningen, Netherlands

IV Geant4 International User Conference at the physics-medicine-biology frontier

October 2022



Outline

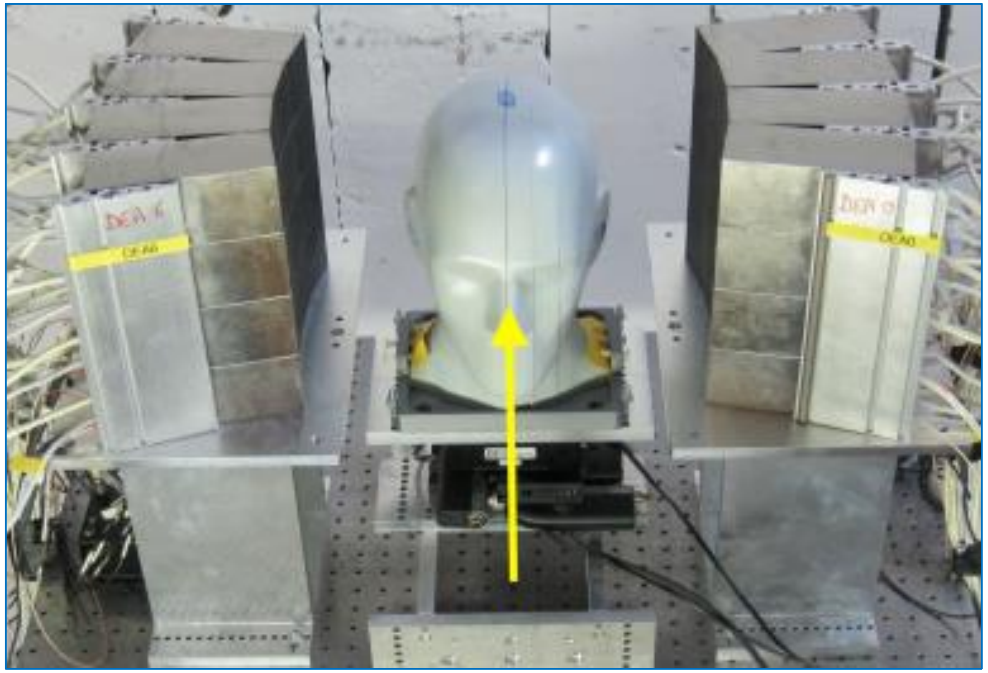
- Motivation
- Proton therapy
- PET in proton therapy
- Methods
- Experimental setup and Monte Carlo Simulation

Motivation

RIVER: Real – time in vivo verification of proton therapy

Aim: major step towards translating nitrogen-12 imaging to the clinic

- ➢ What is the precision of nitrogen-12 imaging for in-vivo verification in clinical head-and-neck cancer proton therapy?
- ➢ What reduction in the probability of complications can be achieved, given the demonstrated precision of nitrogen-12 imaging?



- Dendooven et al, 2019, Corrigendum: Short-lived positron emitters in beam – on imaging during proton therapy, Phys Med Biol, 64.
- Buitenhuis et al., 2017, Beam-on imaging of short-lived positron emitters during proton therapy, Phys Med Biol, 62(12).
- Dendooven et al, 2015, Short-lived positron emitters in beam – on PET imaging during proton therapy, Phys Med Biol, 60(23).
- Ozoemelam et al, 2020, Feasibility of quasi-prompt PET-based range verification in proton therapy, Phys Med Biol, 65(24).
- Ozoemelam et al, 2020, Real-Time PET Imaging for Range Verification of Helium Radiotherapy, Front. Phys, 8.
- Ozoemelam et al, 2019, The production of positron emitters with millisecond half-life during helium beam radiotherapy, Phys Med Biol, 64(23).

Proton Therapy @ Groningen

Two particle accelerators-Groningen

Proton therapy center

- ✓ **The first Dutch proton therapy center in the Netherlands.**
- ✓ **Started operations in early 2018.**

AGOR cyclotron

- ➢ **Beginning of 1996.**
- ➢ **The central facility of PARTREC.**
- ➢ **Spot scanning and scattered beam.**
- ➢ **Large capacity for experiments.**
- ➢ **Protons up to 190 MeV.**
- ➢ **Lighter ions (helium- neon) up to 90 MeV/u.**

https://umcgresearch.org/nl/w/partrec

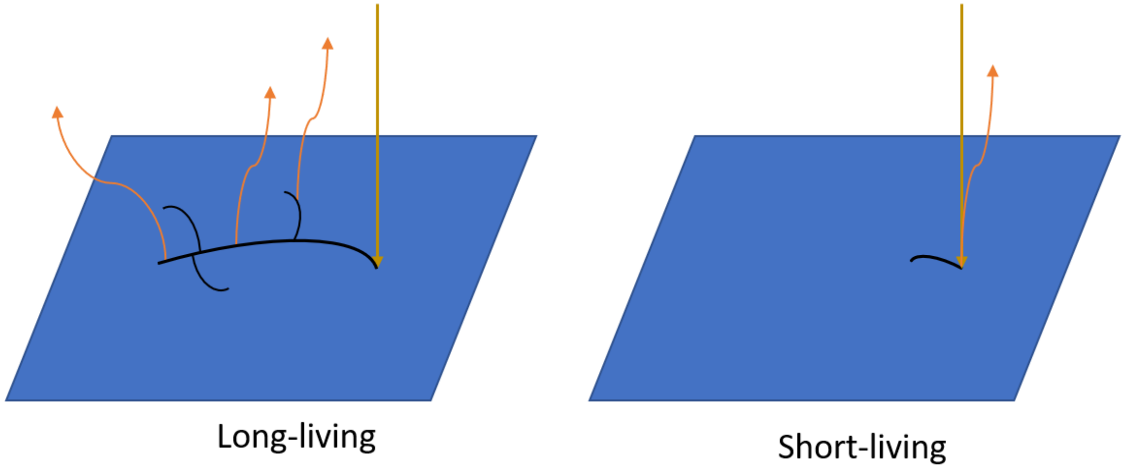
PET imaging in proton therapy

- Proton therapy is very sensitive to uncertainties introduced during treatment planning and dose delivery.
- PET imaging of proton-induced positron emitter distributions is the practical approach for in vivo, in situ verification of proton therapy
- The long-living isotopes can build up in the irradiated area, but will also spread around. This will create blurring for PET imaging.
- The radioactive intensity of an isotope is inversely proportional to its half-life. Therefore, the long-living isotopes have insufficient intensities to provide the required counting statistics which is needed for real-time feedback.

What is the idea?

Very short-living isotopes

- An in-vivo PET verification using very short-living isotopes is being developed.
- A very short-living isotope will decay at the immediate location of the Bragg peak.
- At PARTREC, research is conducted into developing in-vivo verification based on very short-living isotopes.
- At PARTREC, N-12 is being considered as a very short-living isotope (11ms) to be used in in-vivo verification.

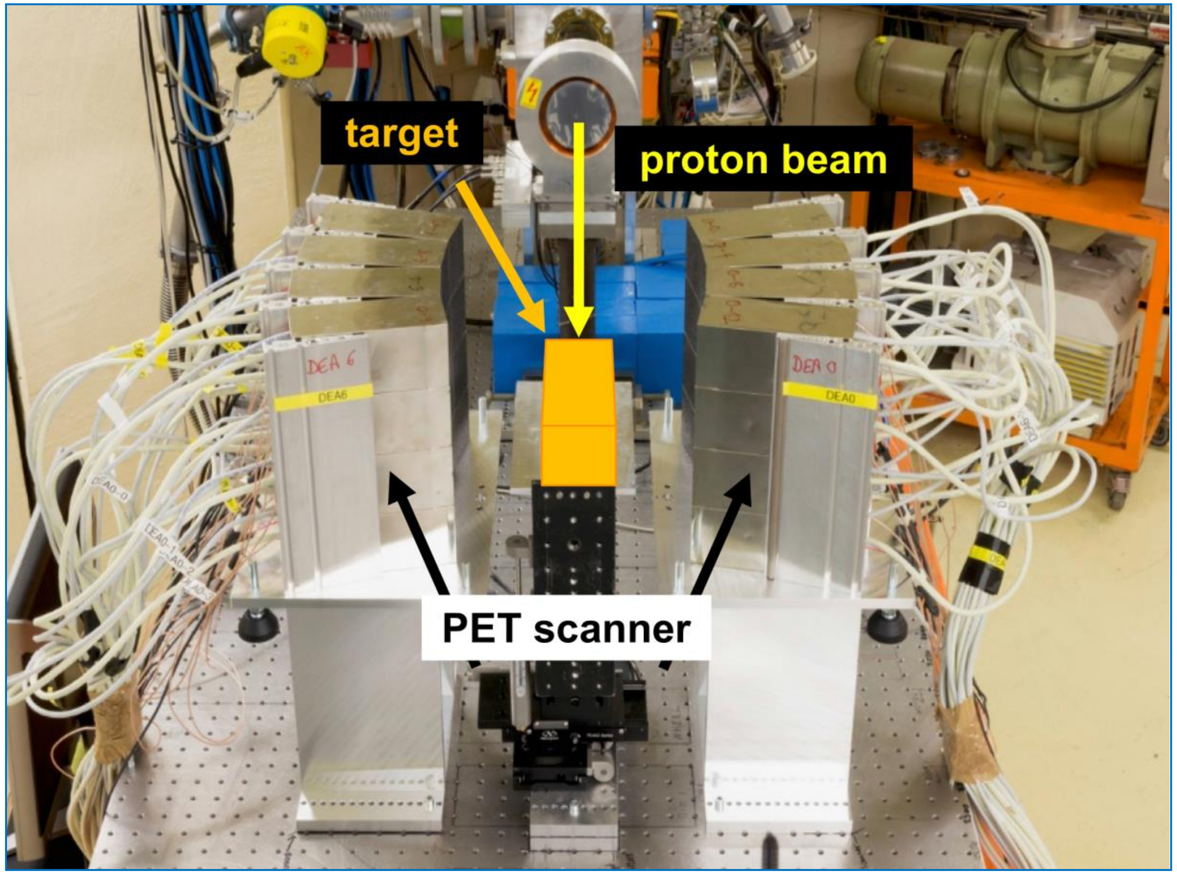


Experimental setup

- The experimental setup for imaging beam–induced positron activity at the AGOR cyclotron facility.

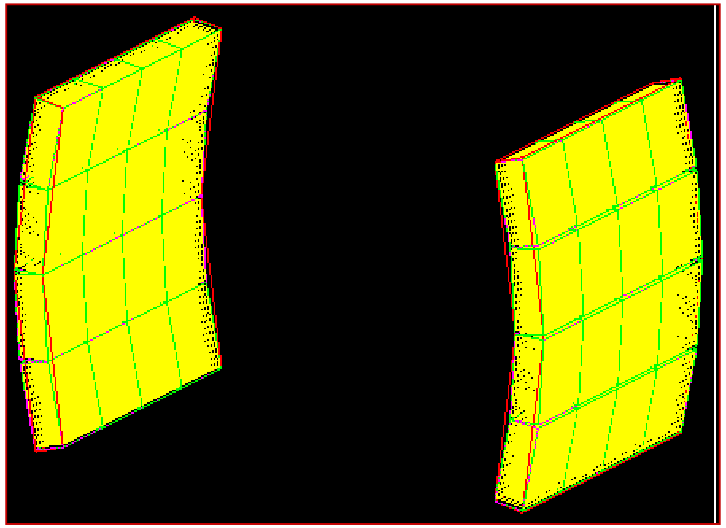
- PET scanner, available in–house, is 1/6 th of a Siemens Biograph mCT scanner

- The beam bombards the target installed in –between two modules of a Simens mCT PET scanner.

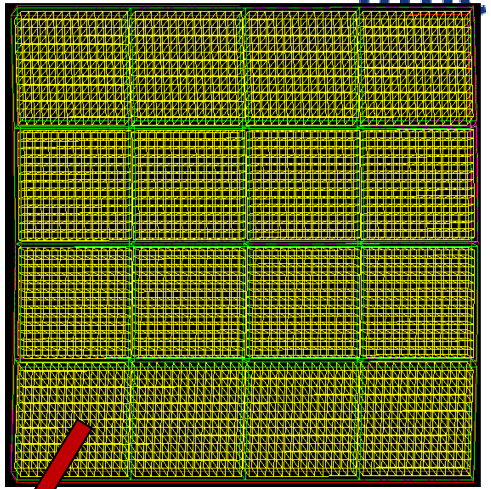


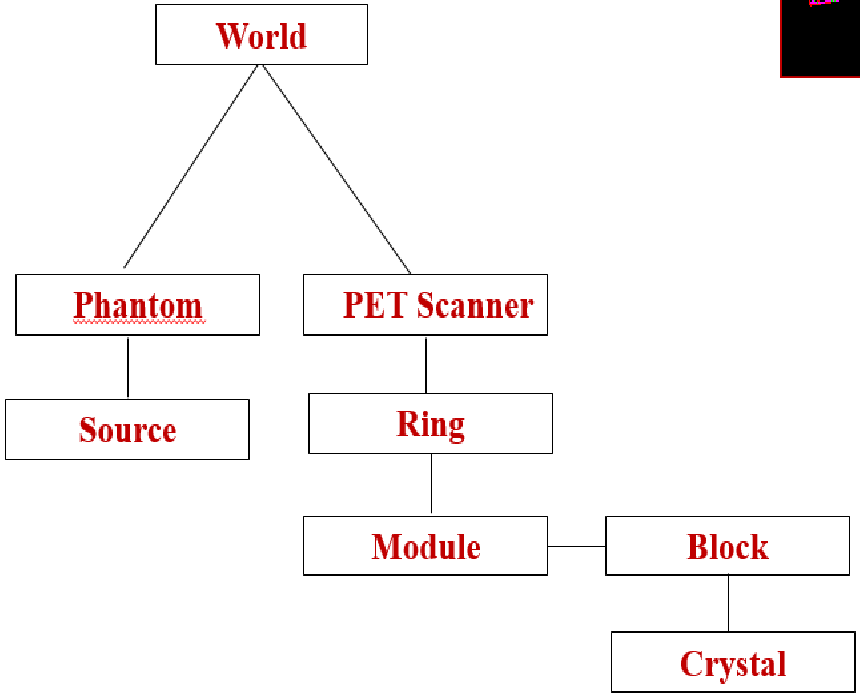
Geometry Construction

Geant4
Application
for
Tomographic
Emission

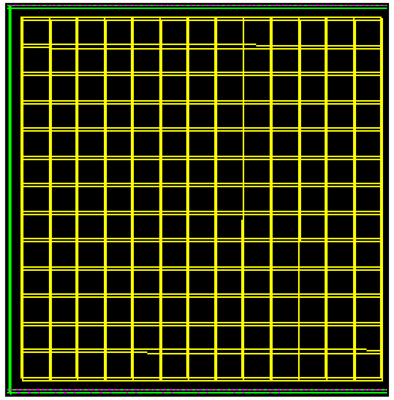


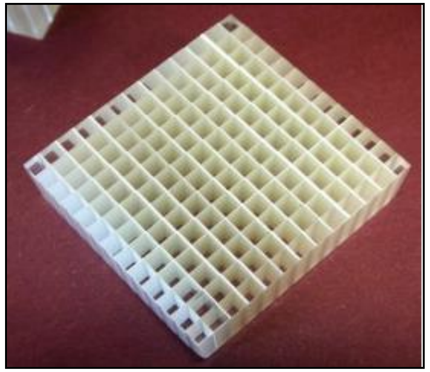
52×52 array of LSO scintillator



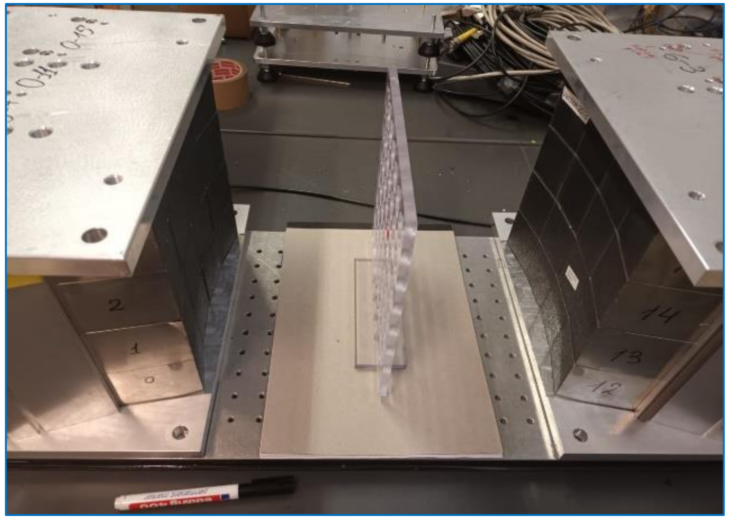


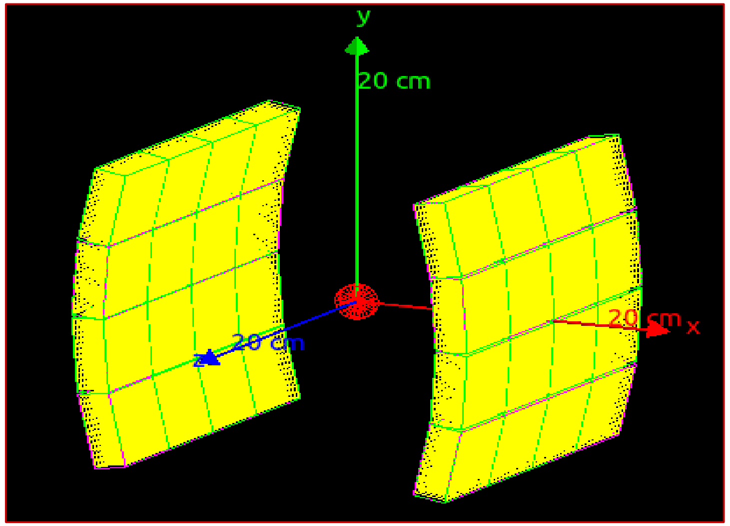
13×13 array of LSO scintillator,
4 mm
4mm
20 mm



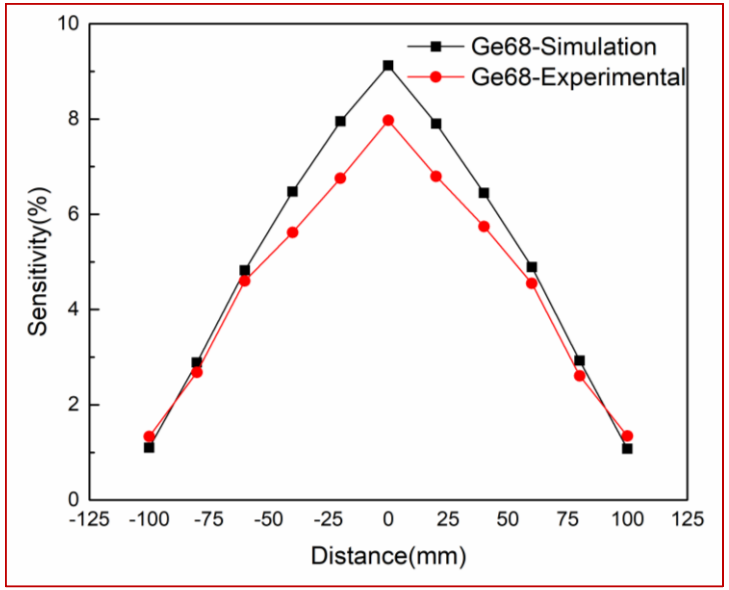


PET sensitivity-Validation





Distance from center-to-center: **21cm,** Ge68 - source



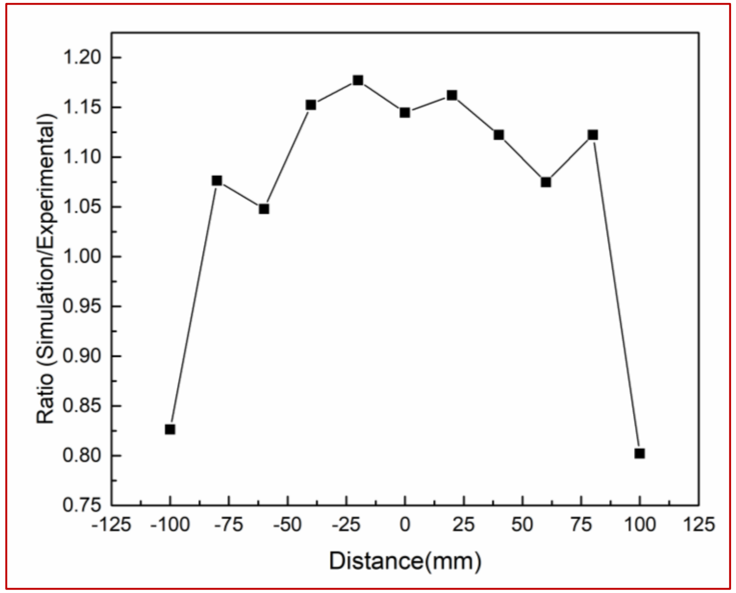
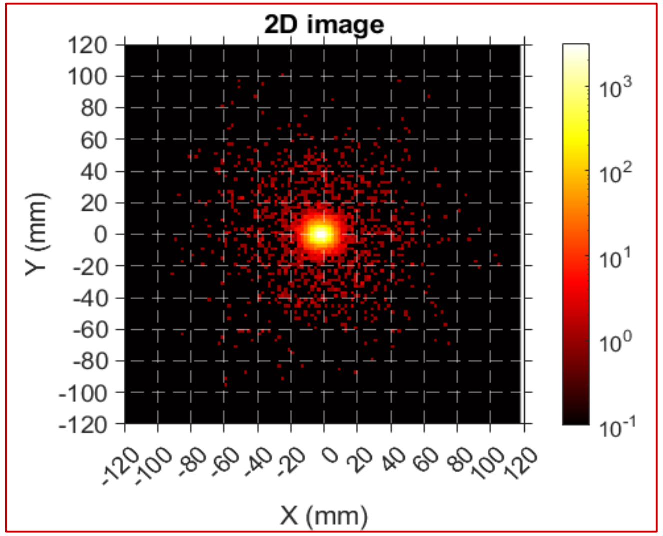
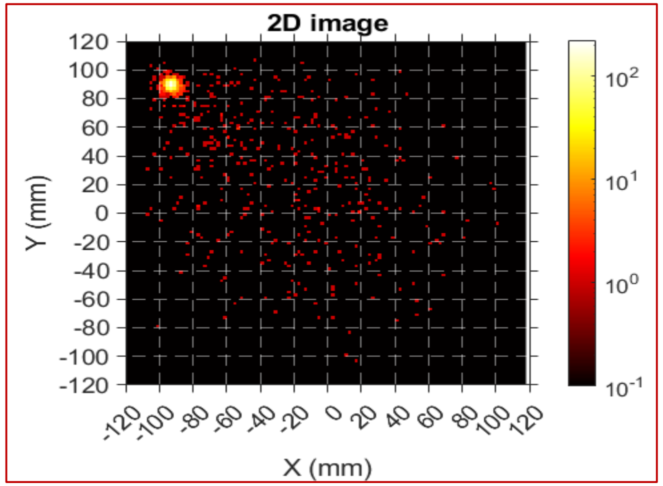


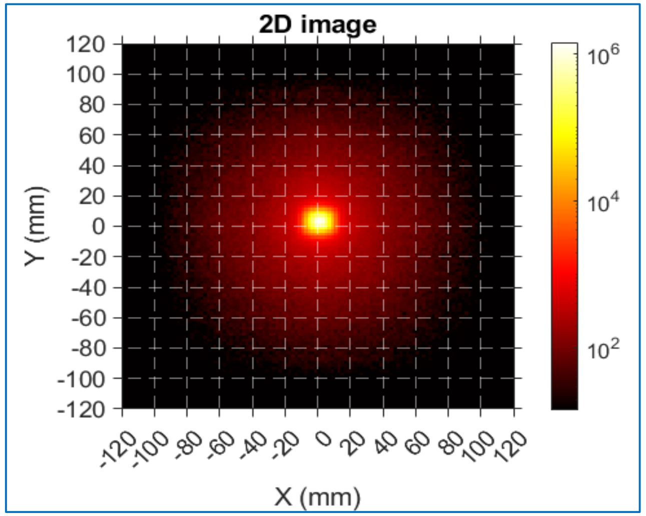
Image reconstruction

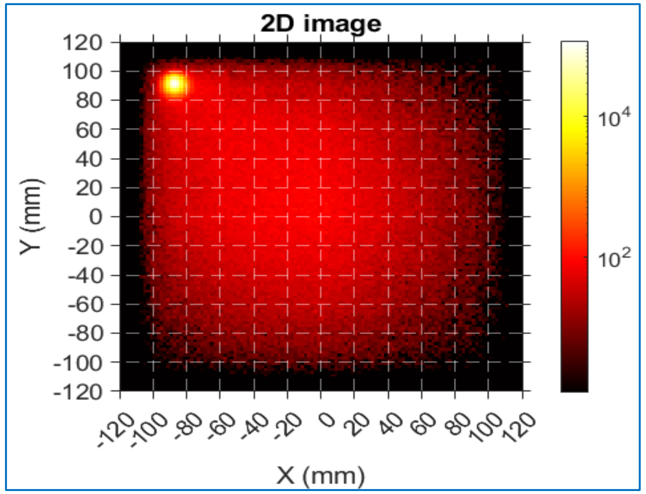
Simulation:





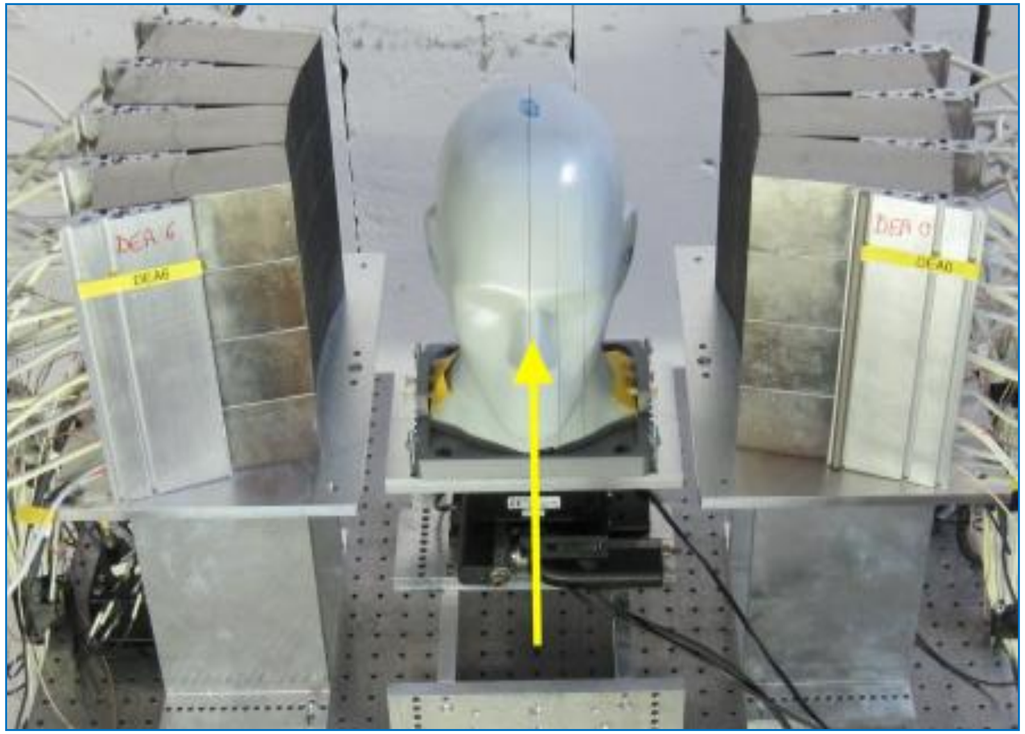
Experimental:



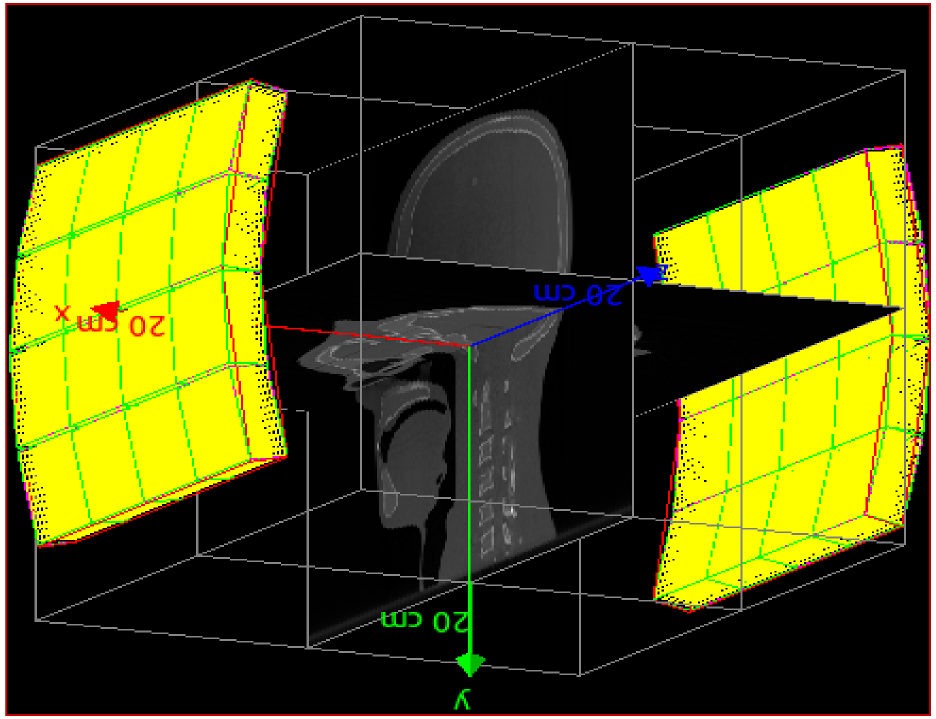


2D images: cross sections of LoRs with plane parallel to the scanner panels that contains the source in the middle.

Geometry Construction

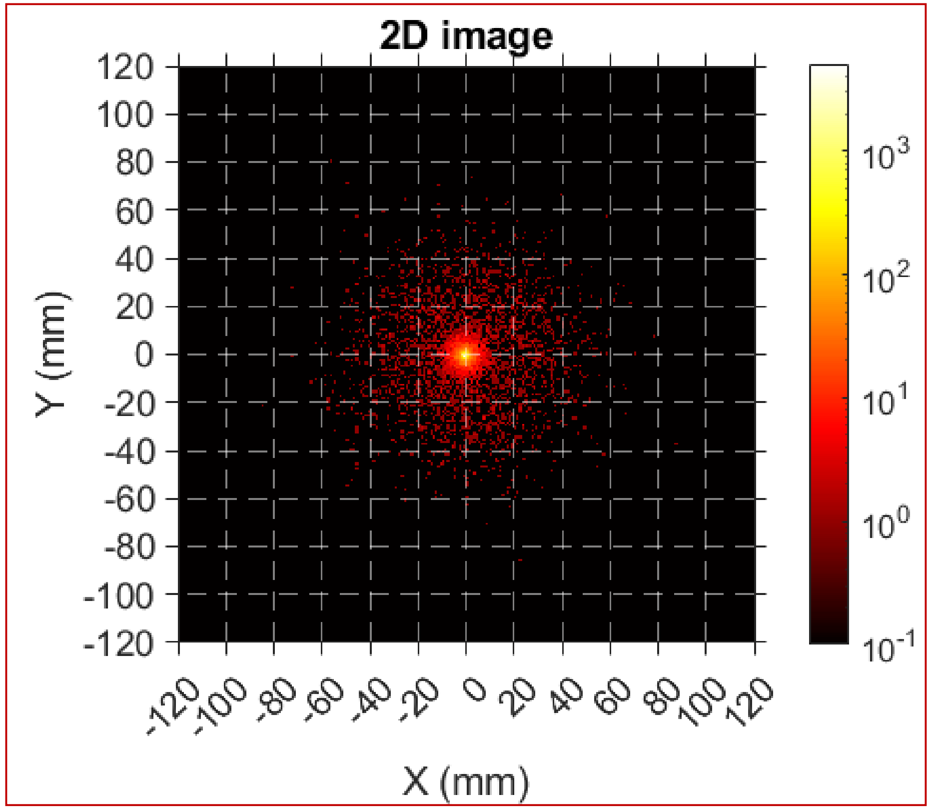


Experimental setup

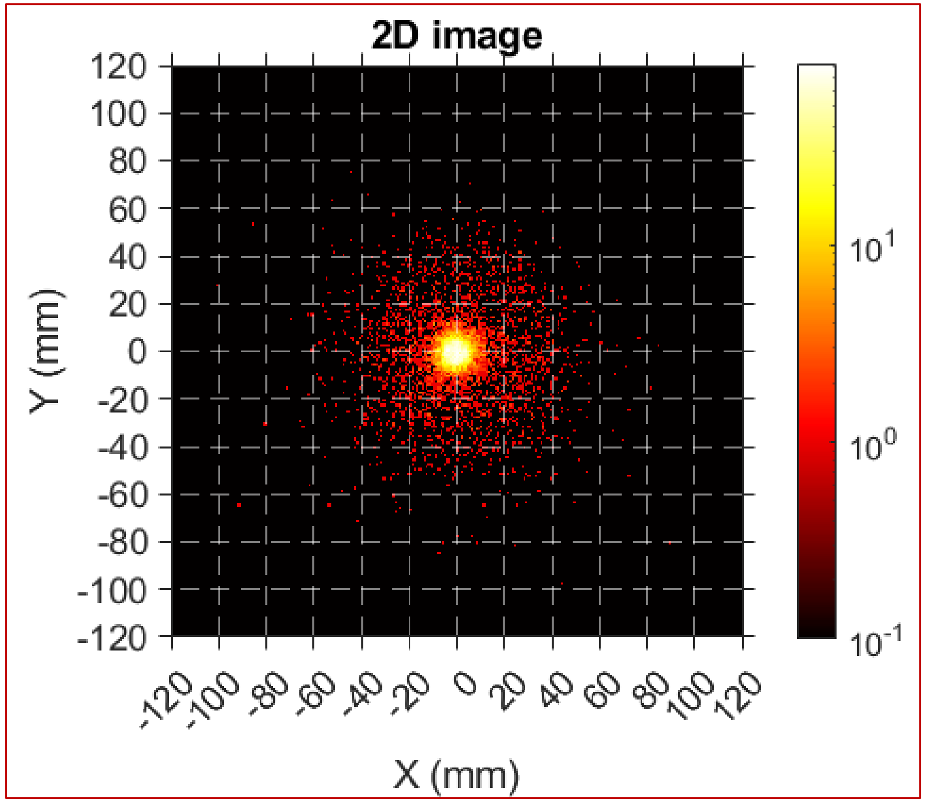


Simulation setup

Gamma point source and N12 - positron source (with head phantom)

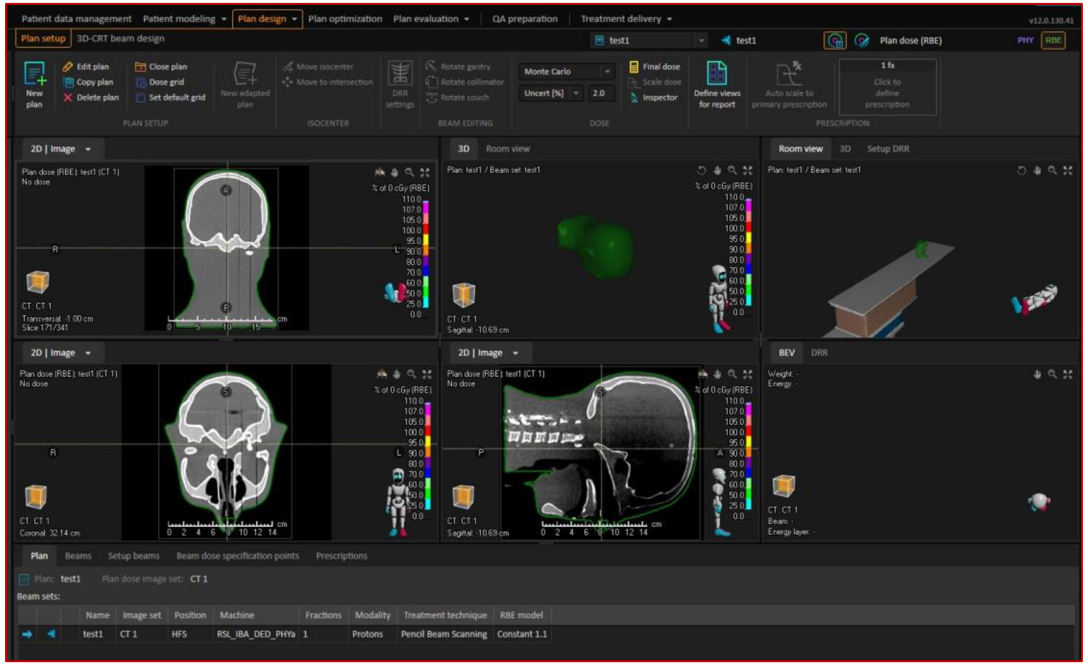


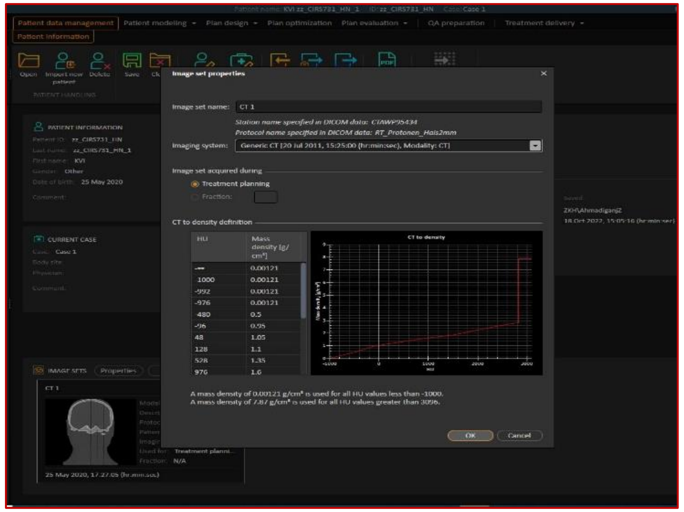
Gamma source

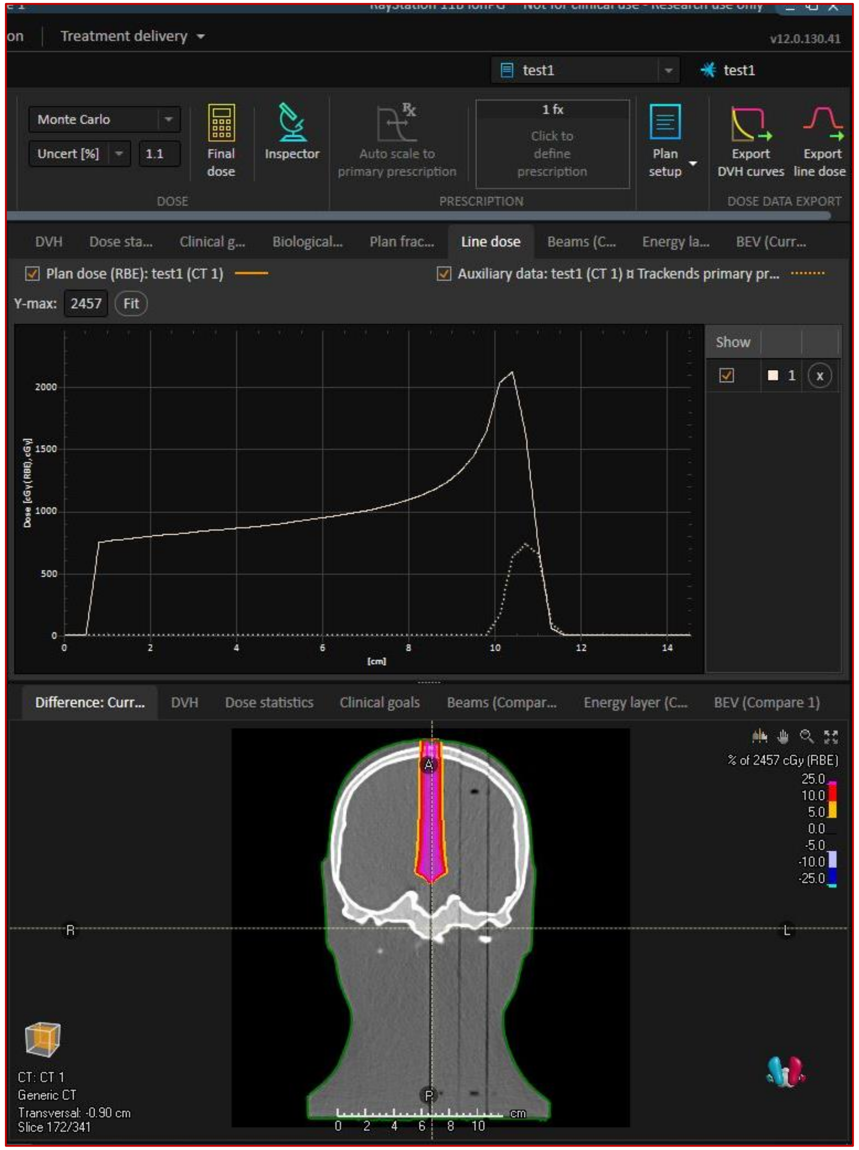


Positron source

RayStation

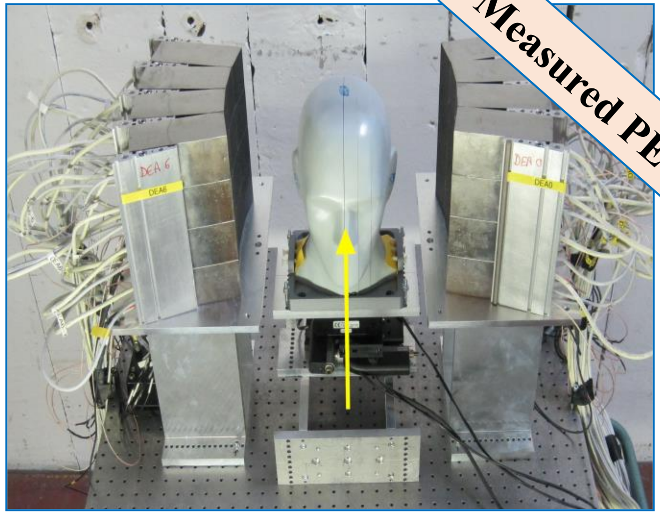

Patient data management
Patient modeling
Plan design
Plan optimization
Plan evaluation
QA preparation
Treatment delivery
Plan setup
3D-CRT beam design
Plan
Beams
Setup beams
Beam dose specification points
Prescriptions
Name
Image set
Position
Machine
Fractions
Modality
Treatment technique
RBE model
test1
CT 1
HFS
RSL_IBA_DED_PHYa
1
Protons
Pencil Beam Scanning
Constant 1.1



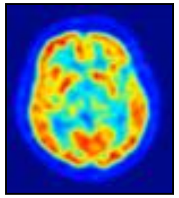

Treatment delivery
v12.0.130.41
test1
Monte Carlo
Uncert [%]
1.1
Final dose
Inspector
Auto scale to primary prescription
1 fx
Click to define prescription
Plan setup
Export DVH curves
Export line dose
DOSE
PRESCRIPTION
DOSE DATA EXPORT
DVH
Line dose
Plan dose (RBE): test1 (CT 1)
Y-max:
2457
Fit
Show
[cm]
Difference: Curr...
Dose statistics
Clinical goals
% of 2457 cGy (RBE)
CT: CT 1
Generic CT
Transversal: -0.90 cm
Slice 172/341

Ongoing works

Measured PET



Reconstruction 2D PET image

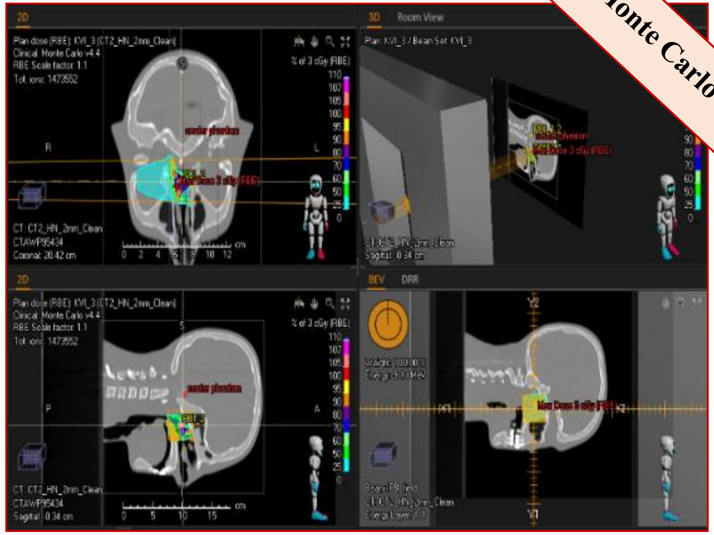


Measured PET

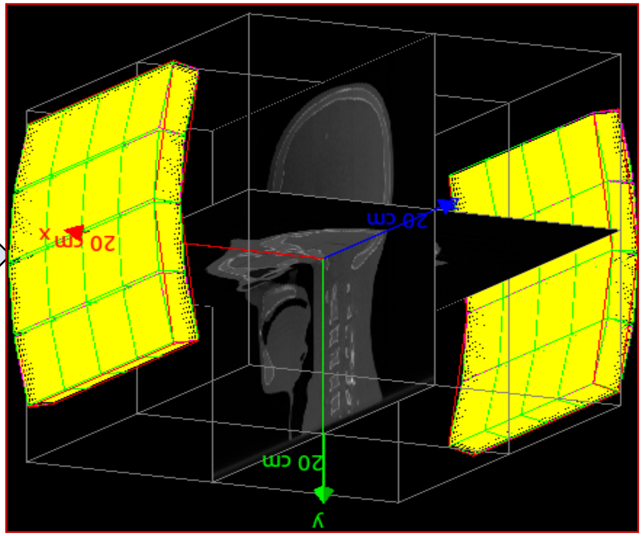
Comparison

Head phantom in the RayStation treatment planning system.

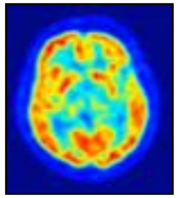
Monte Carlo Simulation



Gate simulation



Matlab image reconstruction



Simulated PET

Conclusion

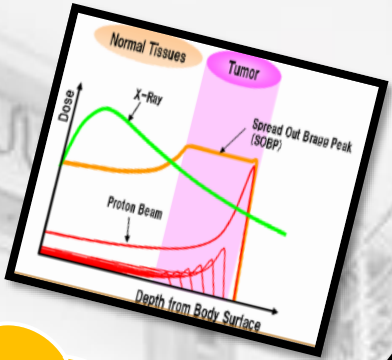
- ✓ **The RIVER project will make a major step towards translating N-12 real–time in – vivo verification for proton therapy to the clinic.**

- ✓ **The accuracy will have been determined under simulation and clinically realistic situation.**

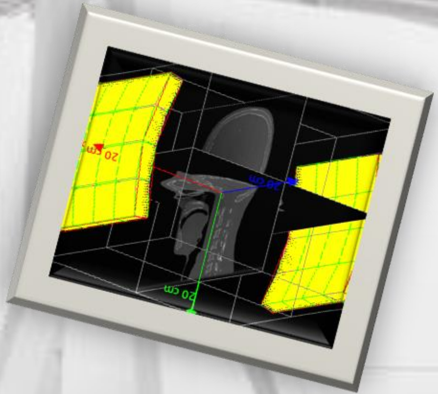
- ✓ **This method will allow optimal radiotherapy treatment plan design and increase the number of patients benefiting from proton therapy.**

- ✓ **It will reduce the complications and thus improve the quality of life of patients that already now receive proton therapy.**

Thank you for your attention



RIVER project



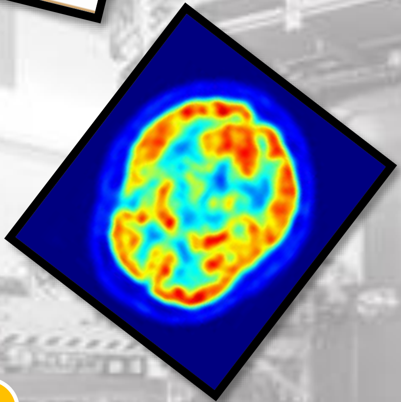


Foto: Peter Tahl