

PAUL SCHERRER INSTITUT



Carla Winterhalter :: Post Doc :: Paul Scherrer Institut

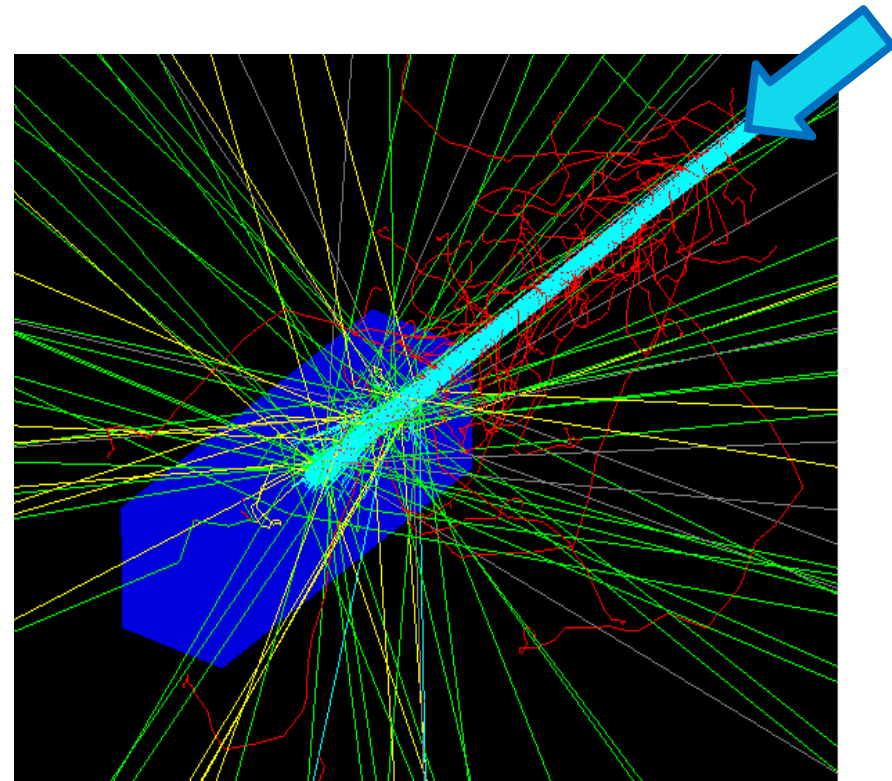
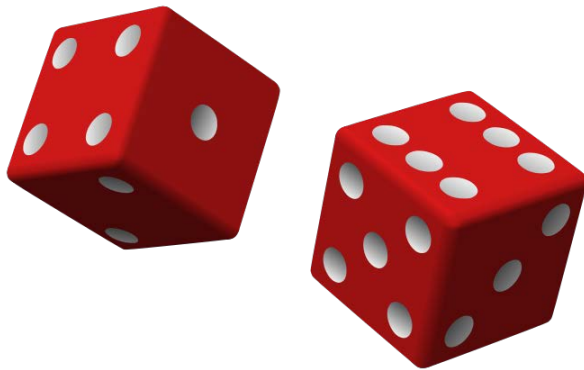
Francesca Albertini, Alisha Duetschler, Julian Ehwald, Jan Gajewski, Jan Hrbacek, Shubhangi Makkar, Keegan McNamara, Gabriel Meier, Antoni Rucinski, Sairos Safai, Angelo Schiavi, Michele Togno, Ye Zhang, Damien C. Weber and Antony Lomax.

Monte Carlo simulations for clinical and research applications in proton therapy at PSI

The 7th Annual Loma Linda Workshop, August 2-4, 2021

Simulate protons passing through material:

- Physics models
- Probabilities for interactions
- Random numbers are sampled



Proton = cyan
Electron = red
Gamma = green
Neutron = yellow

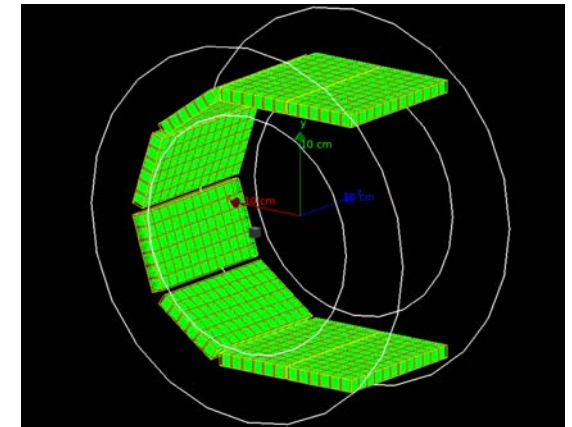
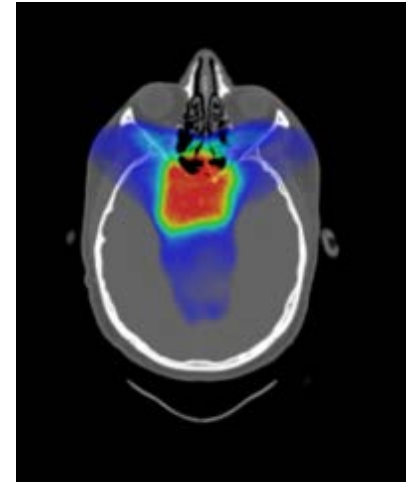
Applications of Monte Carlo techniques in proton therapy

- «Gold standard» for **proton dose calculations**
 - Quality assurance
 - Linear energy transfer, biological effective dose
- **Hardware & detector development**
 - Beam line and Gantry developments
 - Dosimetry equipment (Faraday cup, ionization chambers)
 - In-vivo dosimetry: PET and prompt gamma imaging
 - Proton imaging
- **Shielding** applications
- Interactions of the proton beam on the level of **DNA**

Monte Carlo techniques at the Centre for Proton Therapy at PSI

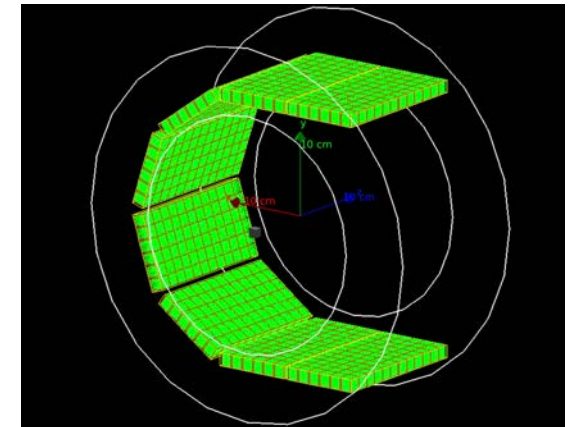
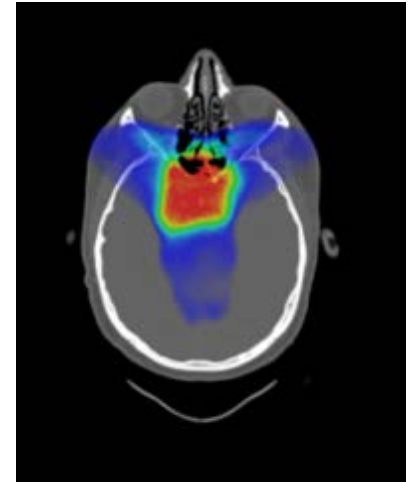
- **«Gold standard» for proton dose calculations**
 - Patient specific quality assurance
 - Daily adaptive proton therapy
 - Dose calculation with a magnetic field

- **Hardware & detector development**
 - PETITION project: Design & development of a novel PET detector



Monte Carlo techniques at the Centre for Proton Therapy at PSI

- **«Gold standard» for proton dose calculations**
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Disclaimer: This is only a **selected set of projects**, not ALL Monte Carlo work done at PSI (or even at CPT).

Monte Carlo for patient specific quality assurance in proton therapy

Patient specific quality assurance

Carla Winterhalter, Jan Gajewski & Antoni Rucinski (Institute of Nuclear Physics PAN, Krakow, Poland), Angelo Schiavi (University of Rome, INFN, Italy), Gabriel Meier, Jan Hrbacek

Motivation - Patient Specific QA:

1) Verify the TPS dose calculation

2) Verify the plan data transformation

3) Verify that plan can be delivered

Measure each field

in a water phantom.

(Lomax et al, 2004, Med Phys, 31

Trnkova et al 2016, Med Phys, 43)

Patient specific quality assurance

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**Reduce measurements
using MC calculations**



Carla Winterhalter, Jan Gajewski & Antoni Rucinski (Institute of Nuclear Physics PAN, Krakow, Poland), Angelo Schiavi (University of Rome, INFN, Italy), Gabriel Meier, Jan Hrbacek

FRED:

- Fast, GPU based Monte Carlo system (Schiavi et al, PMB 2017).
- Average calculation time, in the patient CT: 2.5 minutes (Gajewski et al. Frontiers in Physics 2020)



5th Annual Loma Linda Workshop (2019)

Antoni Rucinski: An Overview of FRED: A GPU-based Monte Carlo Tool for Proton Therapy

6th Annual Loma Linda Workshop (2020)

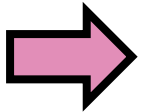
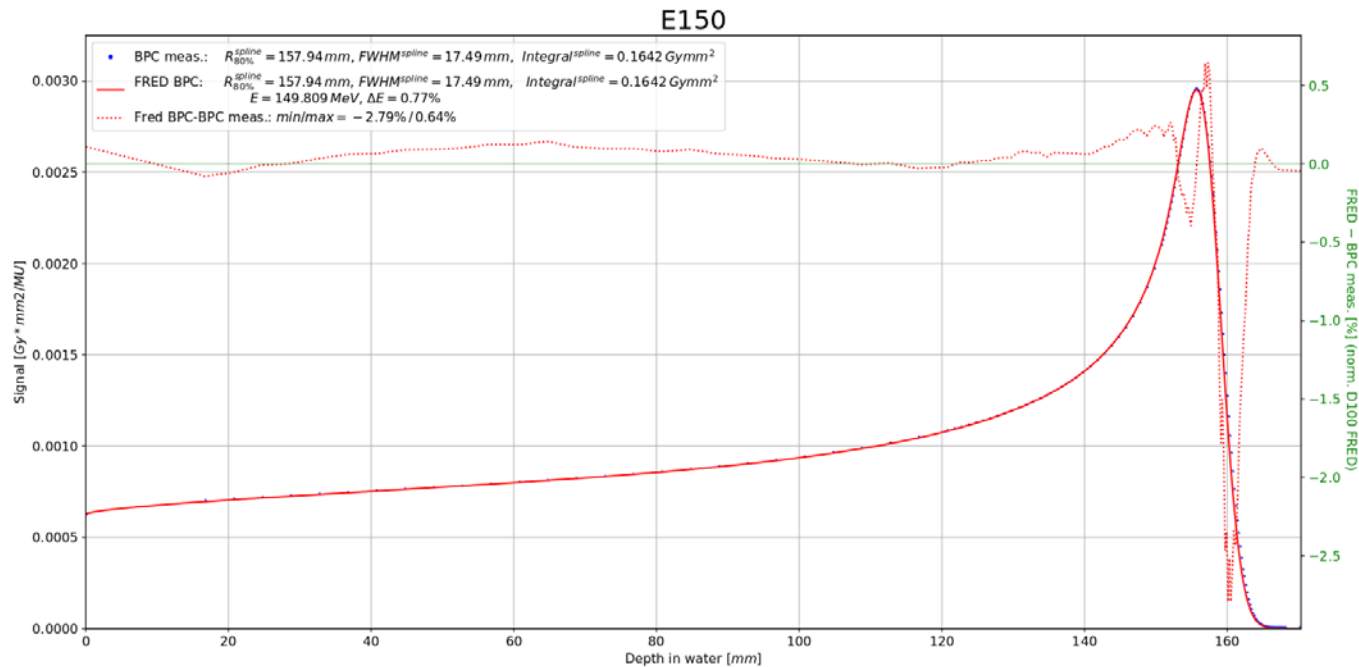
Jan Gajewski: Commissioning of GPU-accelerated Monte Carlo code Fred for clinical applications in proton therapy



Carla Winterhalter, Jan Gajewski & Antoni Rucinski (Institute of Nuclear Physics PAN, Krakow, Poland), Angelo Schiavi (University of Rome, INFN, Italy), Gabriel Meier, Jan Hrbacek

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Water tank

Proton beam



Carla Winterhalter, Jan Gajewski & Antoni Rucinski (Institute of Nuclear Physics PAN, Krakow, Poland), Angelo Schiavi (University of Rome, INFN, Italy), Gabriel Meier, Jan Hrbacek

FRED:

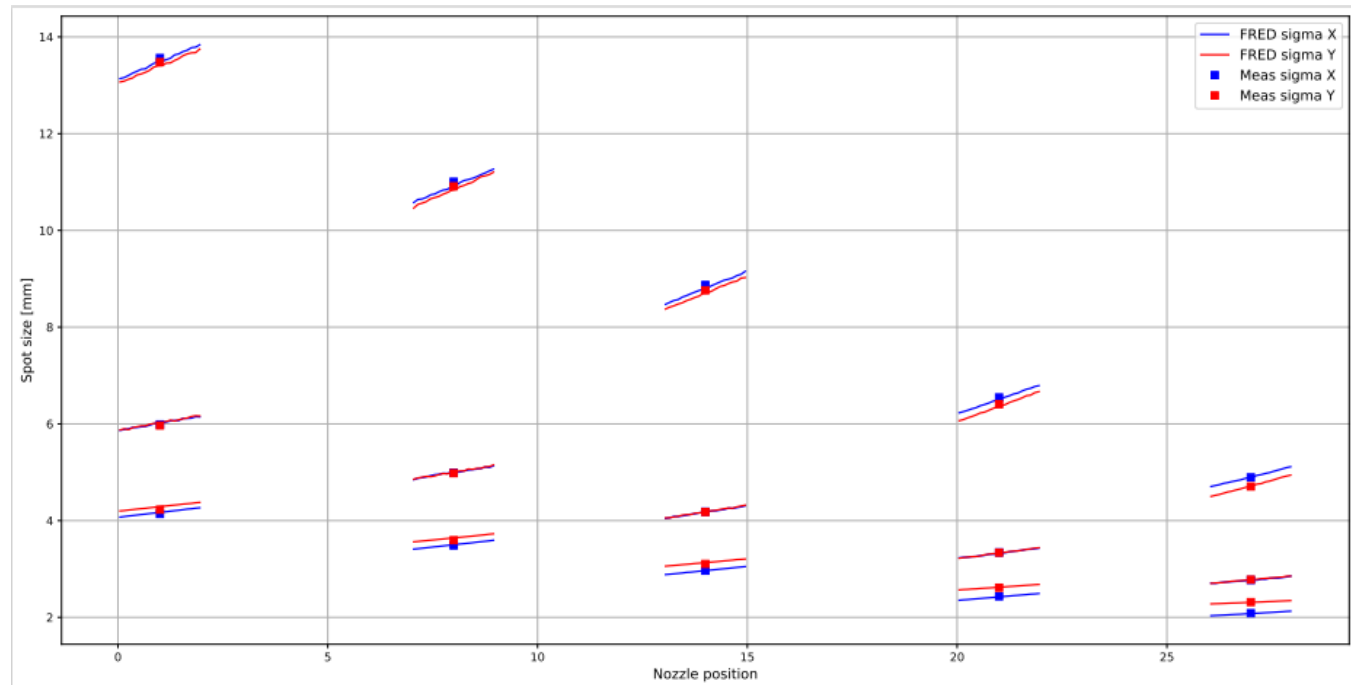
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With & without scattering material



Proton beam

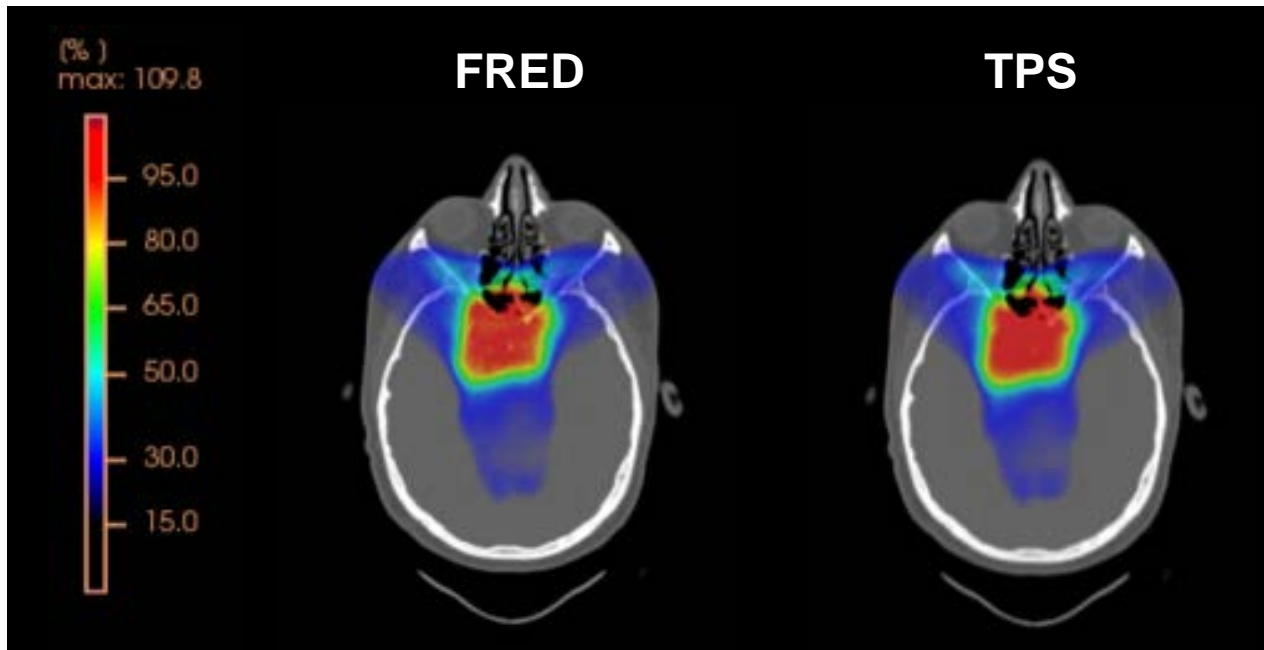




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FRED:

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- Currently setting up FRED for the PSI treatment planning system.
- First results look very promising

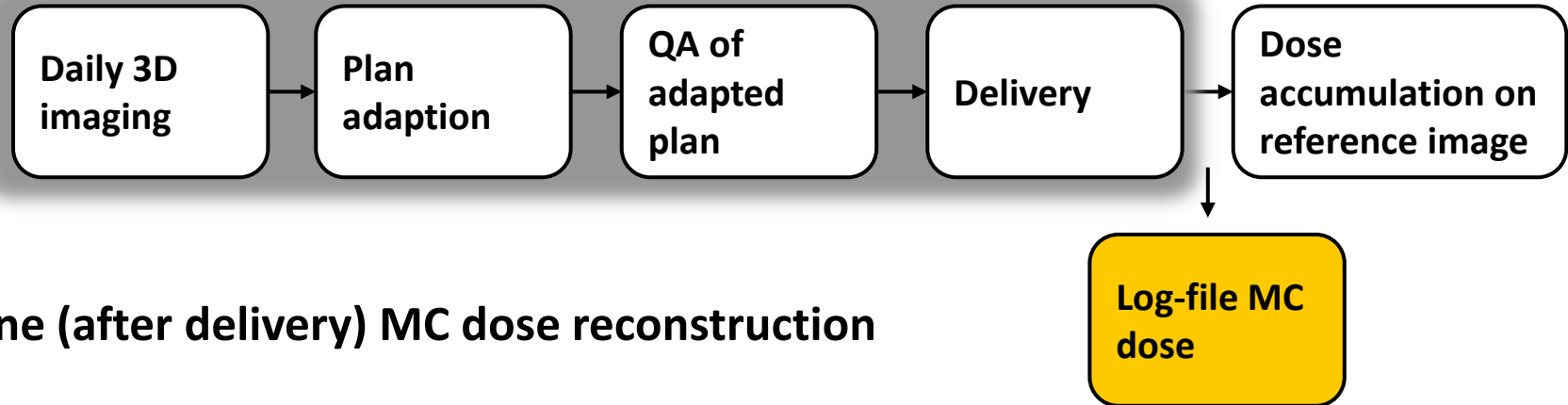
Monte Carlo for daily adaptive proton therapy

Daily adaptive proton therapy

Michael Matter, Lena Nenoff & Francesca Albertini (SNF, Project 320030_165961)

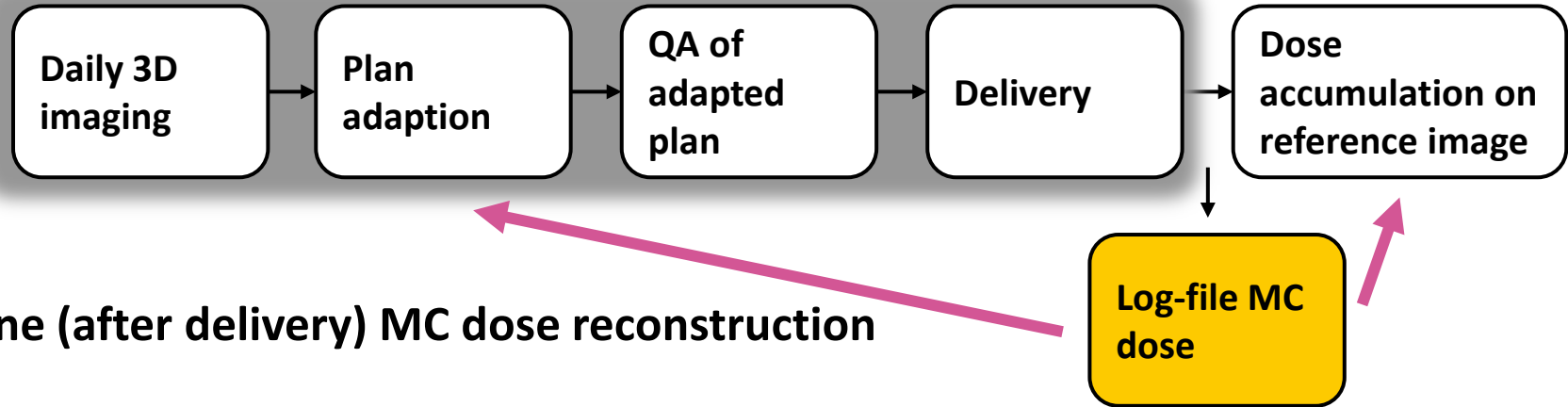


Michael Matter, Lena Nenoff & Francesca Albertini (SNF, Project 320030_165961)



Use offline (after delivery) MC dose reconstruction

Michael Matter, Lena Nenoff & Francesca Albertini (SNF, Project 320030_165961)

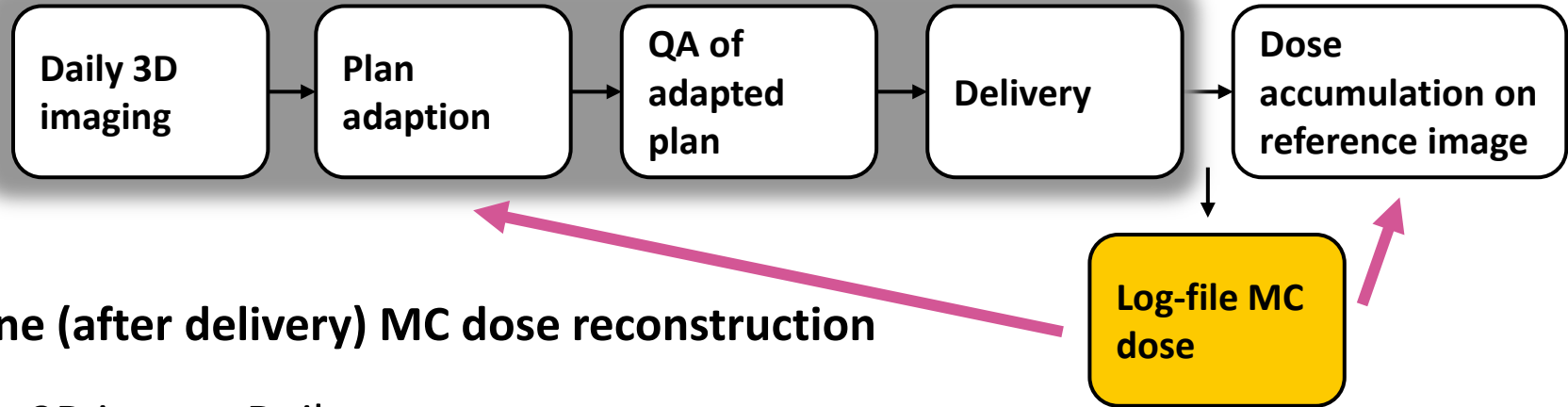


Use offline (after delivery) MC dose reconstruction

Potential applications:

- Dose accumulation on the reference image
- Feedback look for plan adaptation (“Update on yesterday’s dose”).

Michael Matter, Lena Nenoff & Francesca Albertini (SNF, Project 320030_165961)



Use offline (after delivery) MC dose reconstruction

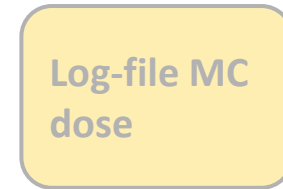
- Daily 3D image: Daily anatomy
- Log-file: Daily delivery information
- Monte Carlo: «Ground truth dose calculation»

«Best possible representation of the delivered dose»

Potential applications:

- Dose accumulation on the reference image
- Feedback look for plan adaptation (“Update on yesterday’s dose”).

Michael Matter, Lena Nenoff & Francesca Albertini (SNF, Project 320030_165961)



To be continued!
RAPTOR project
 Horizon 2020 Marie Skłodowska-Curie Actions,
 Grant No. 955956.

«Best possible representation of the delivered dose»

Potential applications:

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- Log-file: Daily delivery in
- Monte Carlo: «Ground t

Winterhalter et al. (2019), Phys Med Biol 64.3.
 Matter et al. (2020) Phys Med Biol. 65.19
 Nenoff et al, under review.

Monte Carlo for dose calculation with a magnetic field

Alisha Duetschler & Ye Zhang

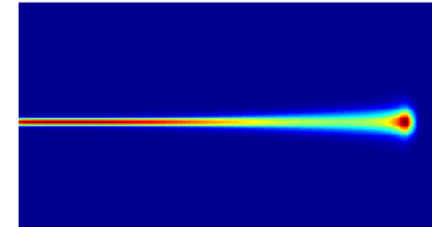


krebsliga

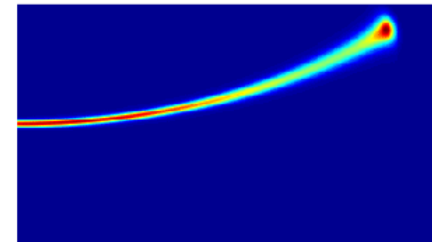
KFS-4517-08-2018

- MC calculations of protons in water in magnetic field
- Use results to parametrize beam for analytical dose calculation considering impact of the magnetic field

B = 0 T



B = 3.0 T



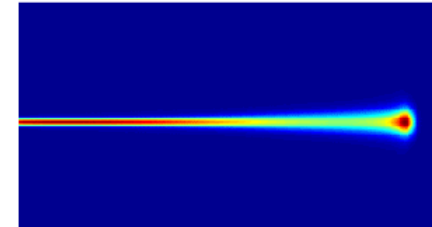
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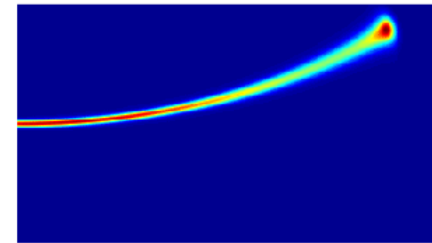
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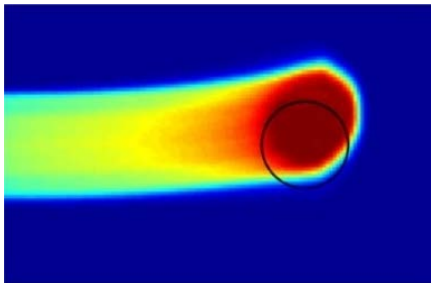
B = 0 T



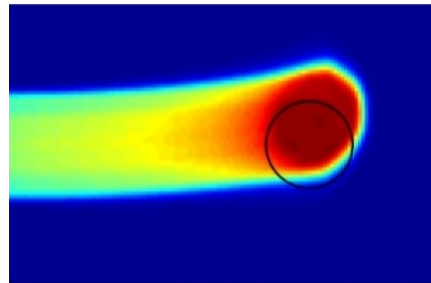
B = 3.0 T



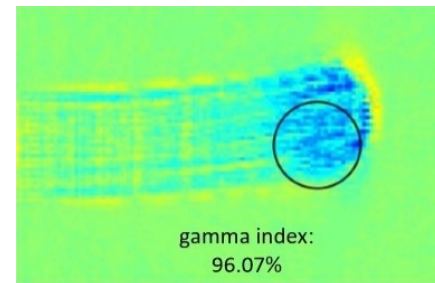
Monte Carlo with magnetic field (1.5T)



Analytical with magnetic field (1.5T)



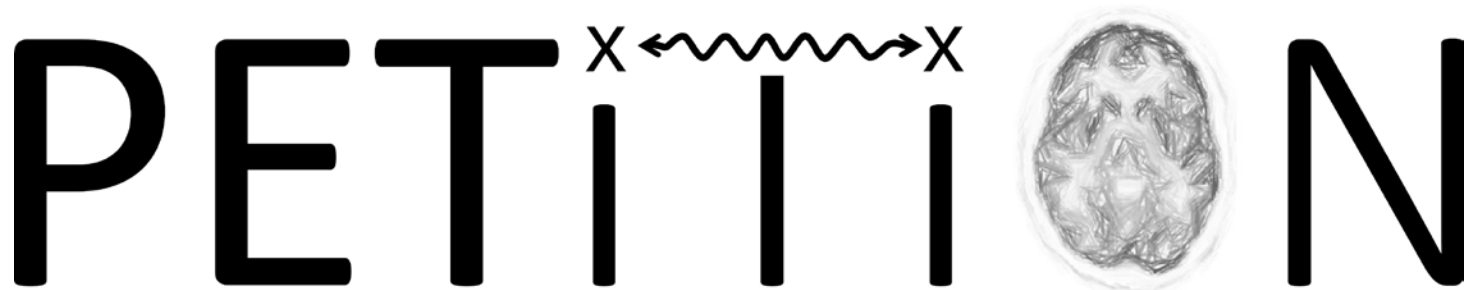
Analytical Minus Monte Carlo



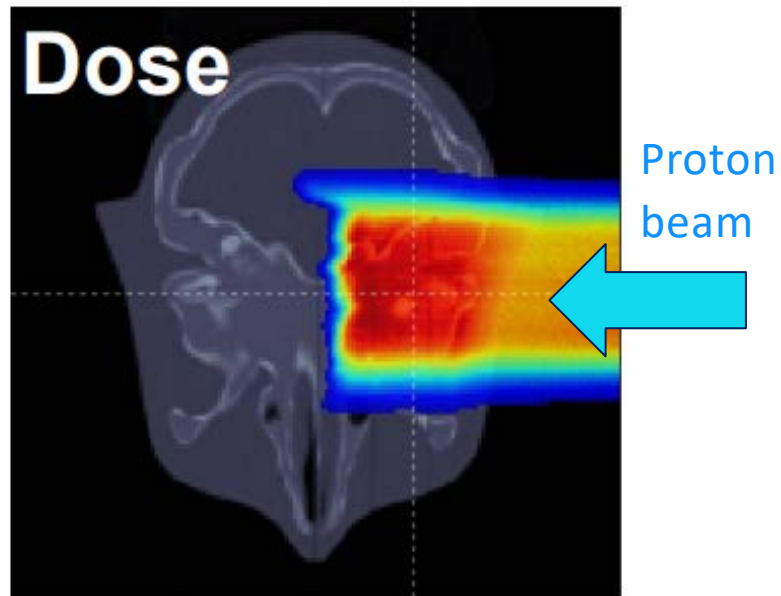
PETITION project:

Design & development of a novel PET
detector

PETITION

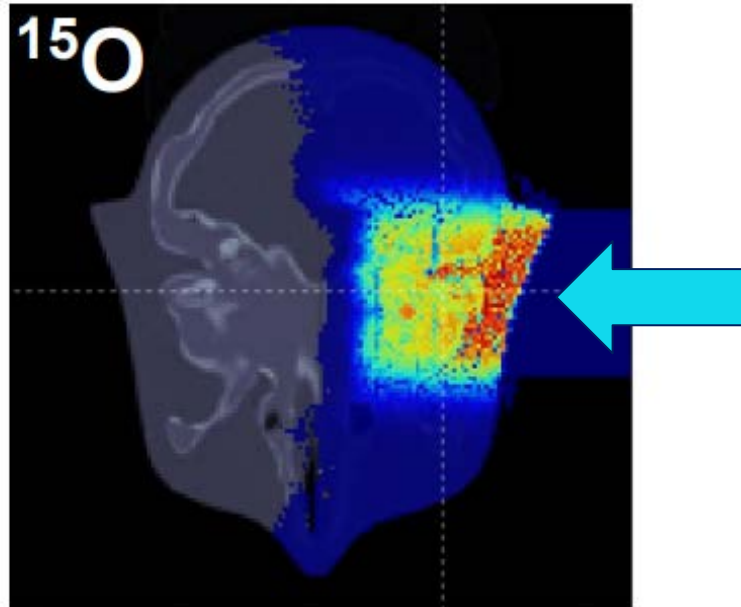
The word 'PETITION' is written in large, bold, black capital letters. The 'i' and 'i' in 'PETiTiON' are lowercase. Above the two 'i's, there is a diagram showing two 'X' marks connected by a wavy line with arrows pointing towards each other, representing a PET coincidence event. To the right of the 'iTi' part, there is a grayscale axial PET scan of a human brain, showing internal structures.

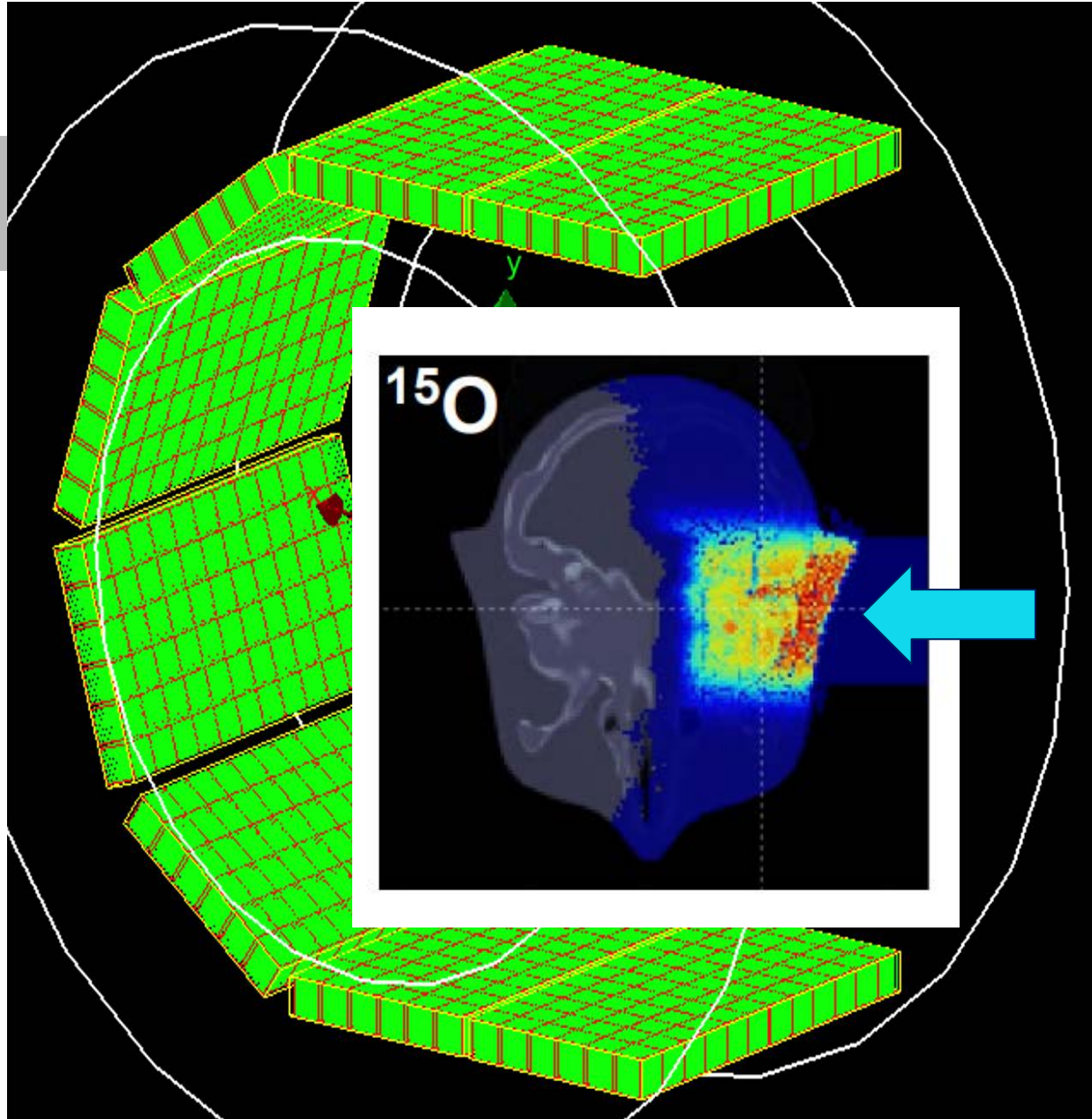
Monte Carlo for PET imaging



Monte Carlo for PET imaging

- Proton beam produces β^+ emitting isotopes

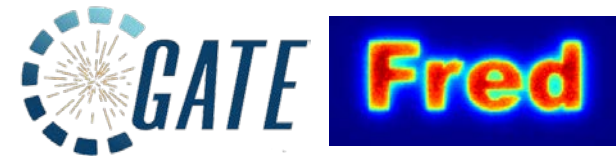




Monte Carlo for PET imaging

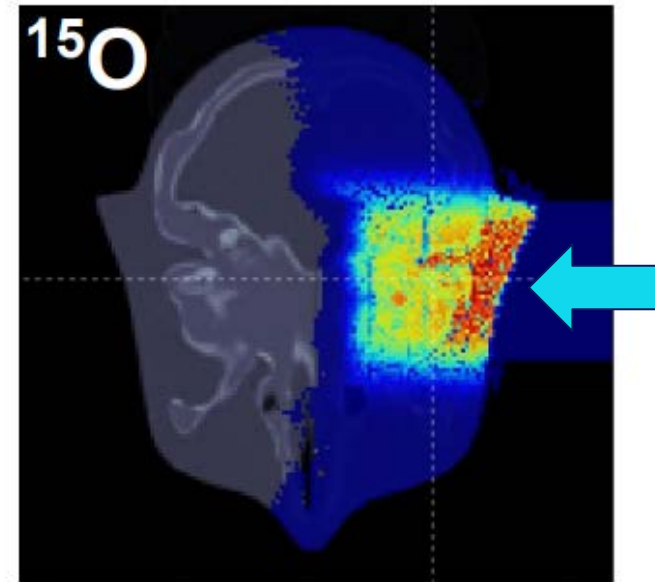
- Proton beam produces β^+ emitting isotopes
- Measure annihilation photons with a **dedicated detector** (developed at ETH Zurich).

Simulation of β^+ emitting isotopes



Keegan McNamara & Carla Winterhalter
Swiss National Science Foundation
Grant No. CRSII5189969

- Implementation of PET isotope scoring in FRED (on the GPU)
- Currently under validation (against GATE/Geant4)
- Full field activation calculations (scoring 7 isotopes) within a few minutes

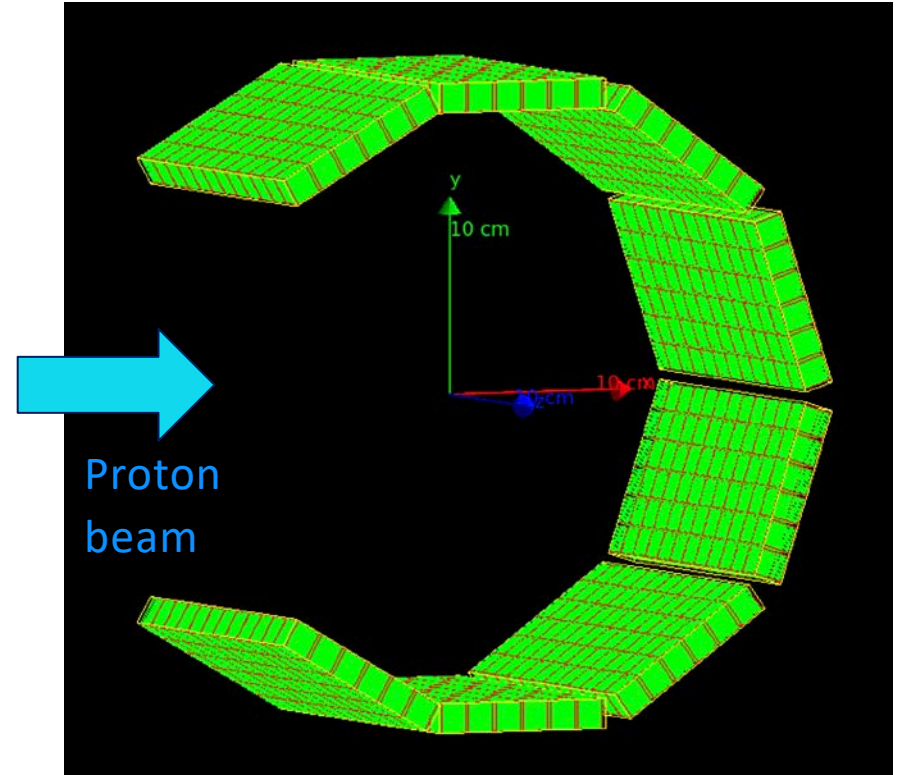
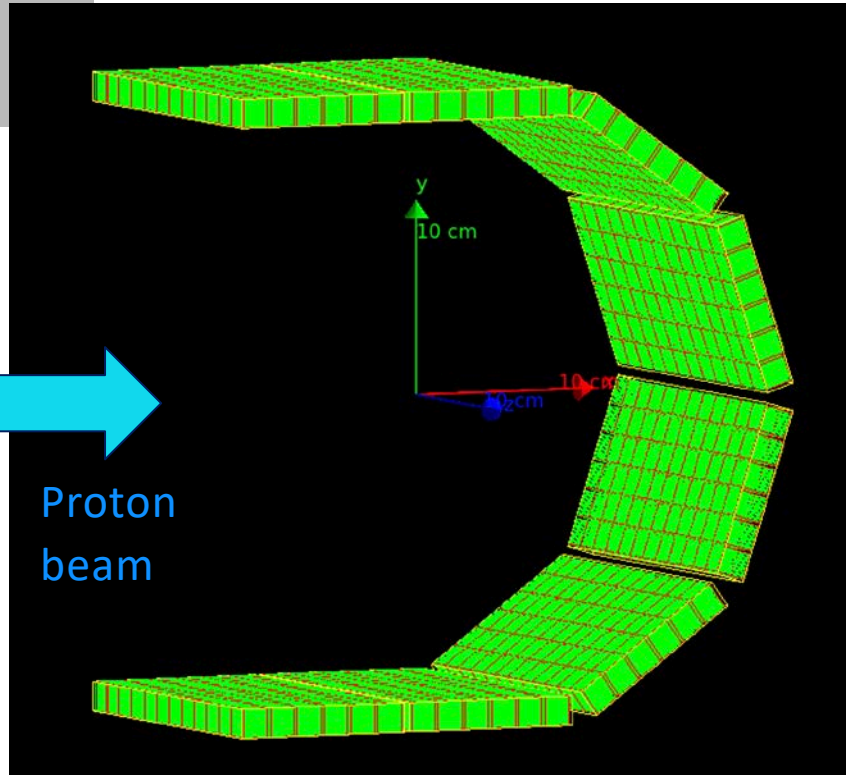


GPU accelerated Monte Carlo activation calculations for range verification

Presentation just after this one!

Shubhangi Makkar & Carla Winterhalter

Swiss National Science Foundation, Grant No. CRSII5189969



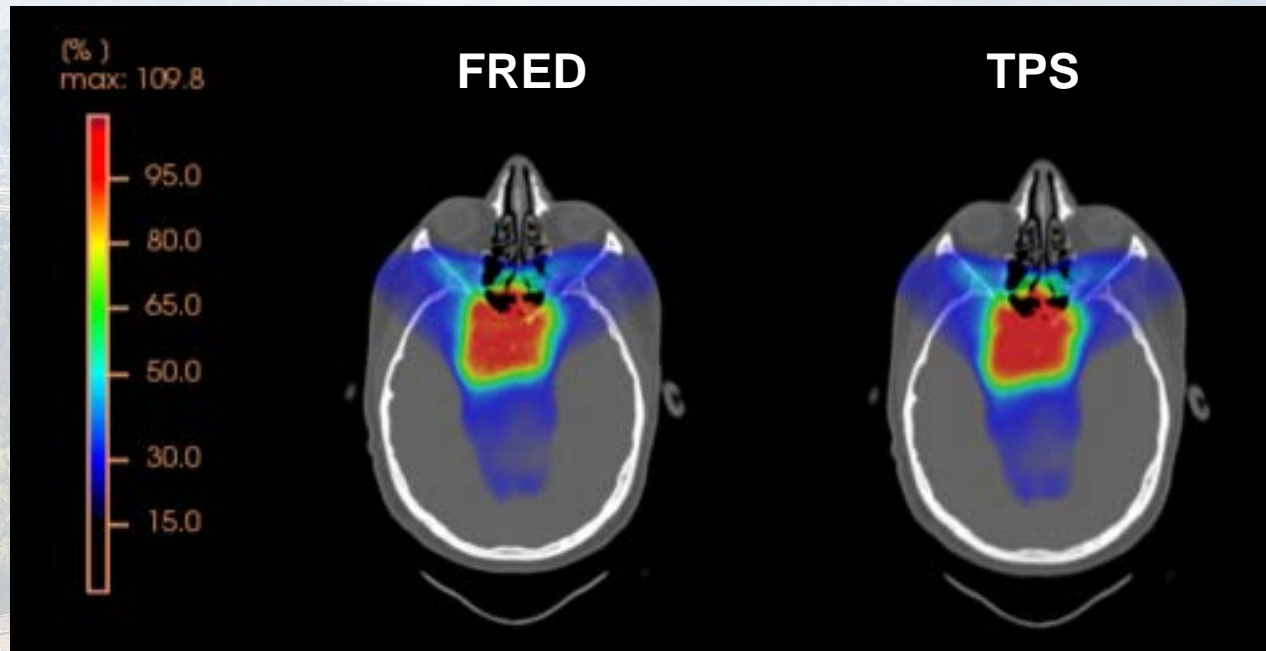
- Table top system, needs an opening for the proton beam
- Different design concepts are currently under evaluation (using GATE/Geant4 simulations)

Monte Carlo applications at PSI:



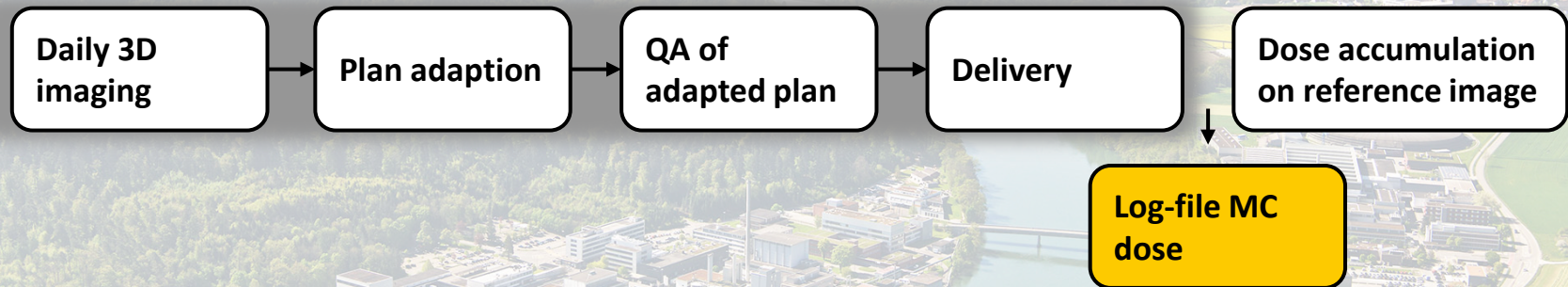
Monte Carlo applications at PSI:

- Fast MC calculations for **patient specific quality assurance**



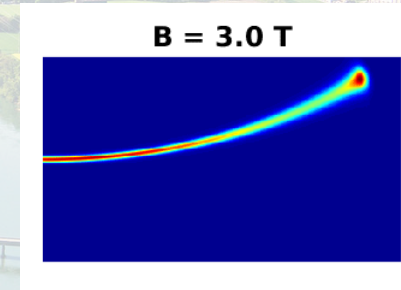
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- **Daily adaptive proton therapy:**
Offline, log-file MC calculations for dose accumulation.



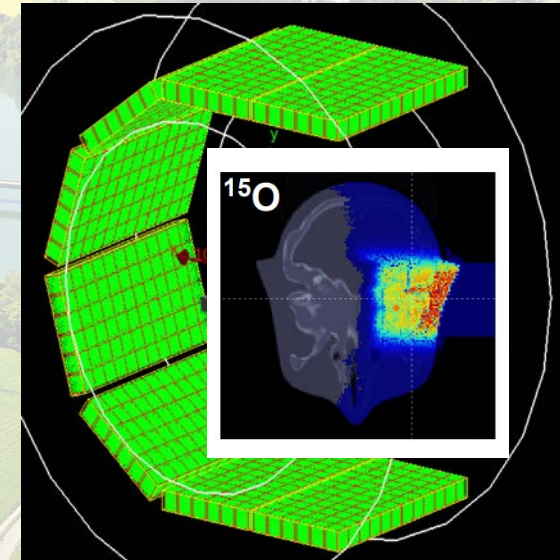
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- **β^+ emitting isotopes** and **PET detectors**



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