MCMA 2017 - Napoli

Fred

a new GPU-based fast-MC code and its applications in proton beam therapy

A. Schiavi

Fast paRticle thErapy Dose evaluator

Collaboration

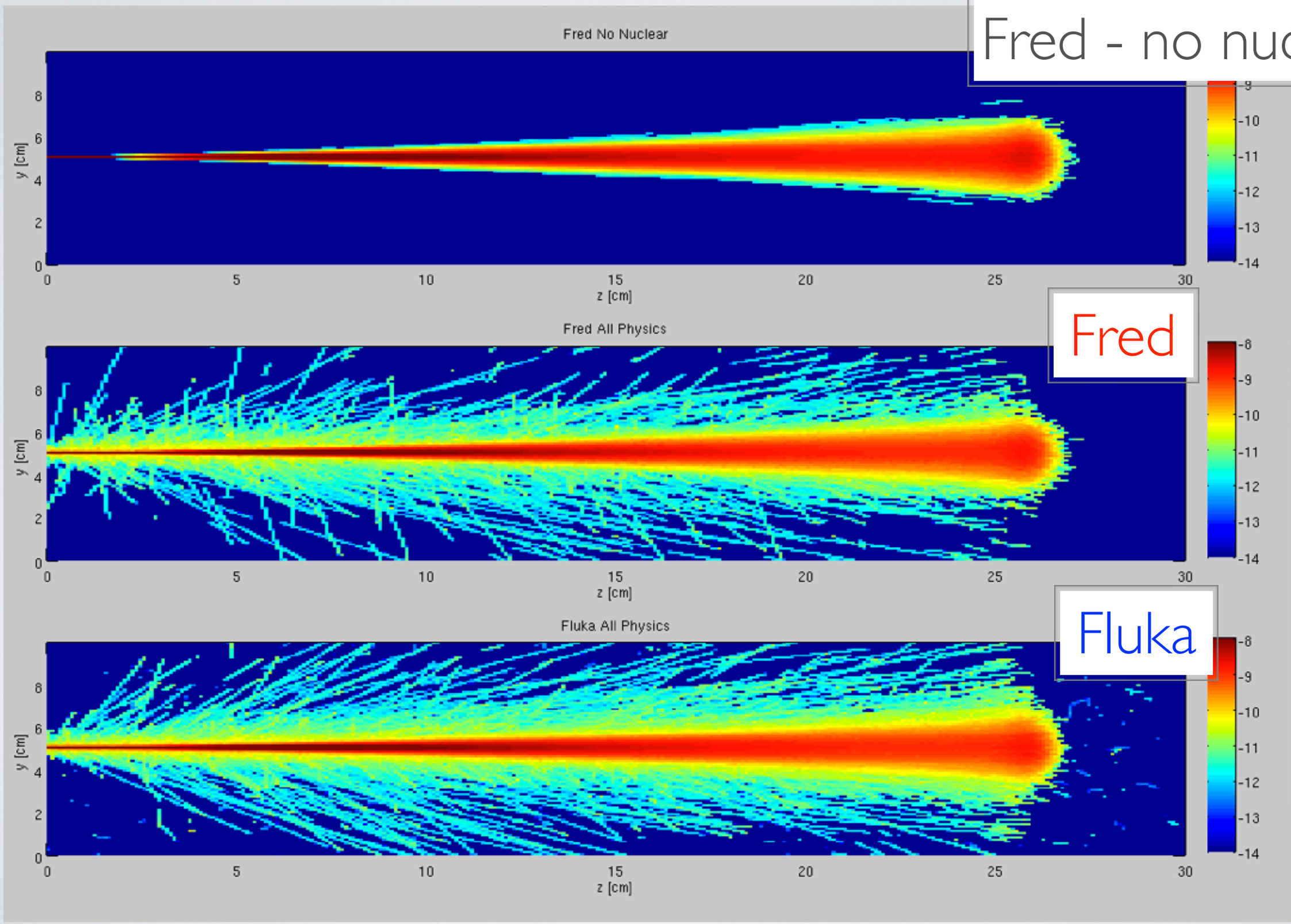
- A. Schiavi, V. Patera, M. Senzacqua, Univ. La Sapienza Roma /INFN (Italy)
- - G. Battistoni, S. Pioli - INFN (Italy)
- - I. Rinaldi, N. Krah - CNRS/IN2P3 and Lyon I University (France)
- A. Rucinski, J. Gajewski - PAN, Krakow (Poland)

FRED fast-MC platform

- MC for protons in voxel geometry
- Tabulated total stopping power in water (PSTAR-NIST), energy straggling (Gaussian and Landau-Vavilov regimes)
- MCS models: single-,double-,triple-gaussian, 2 gauss+Rutherford
- Nuclear interactions: elastic and inelastic; fragmentation; local deposition of heavy ions; tracking of secondary protons and deuterons
- HU to density conversion (Schneider) and stoppow calibration
- MC-TPS: dose optimization using DDO (Lomax)
- RBE models = fixed 1.1, LETd-based (Wedenberg, Carabe, Wilkens, Chen), table-based (LEM1, MKMPIDE)

Dose map of a pencil beam

200 MeV protons in liquid water

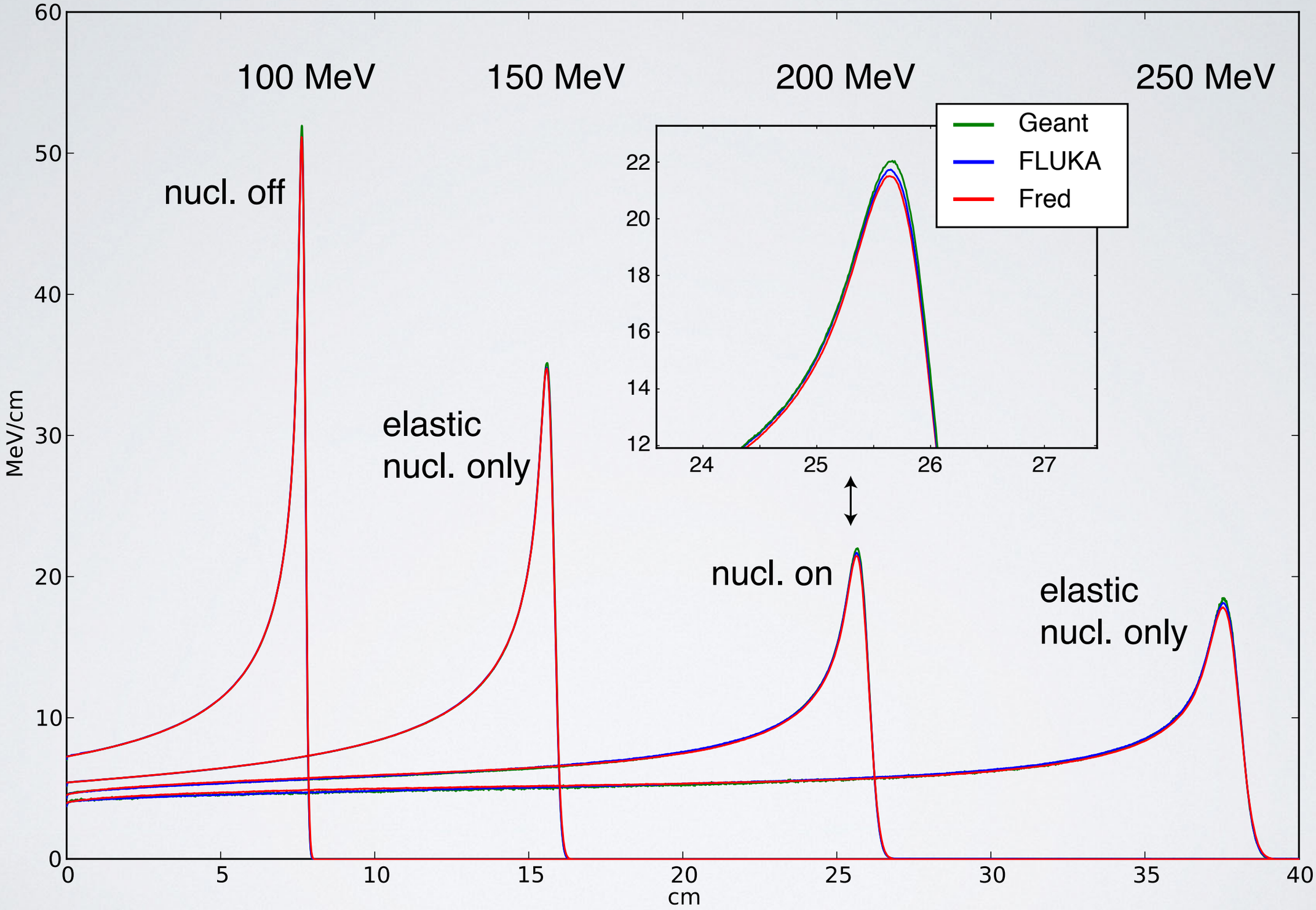


Fred - no nucl

Fred

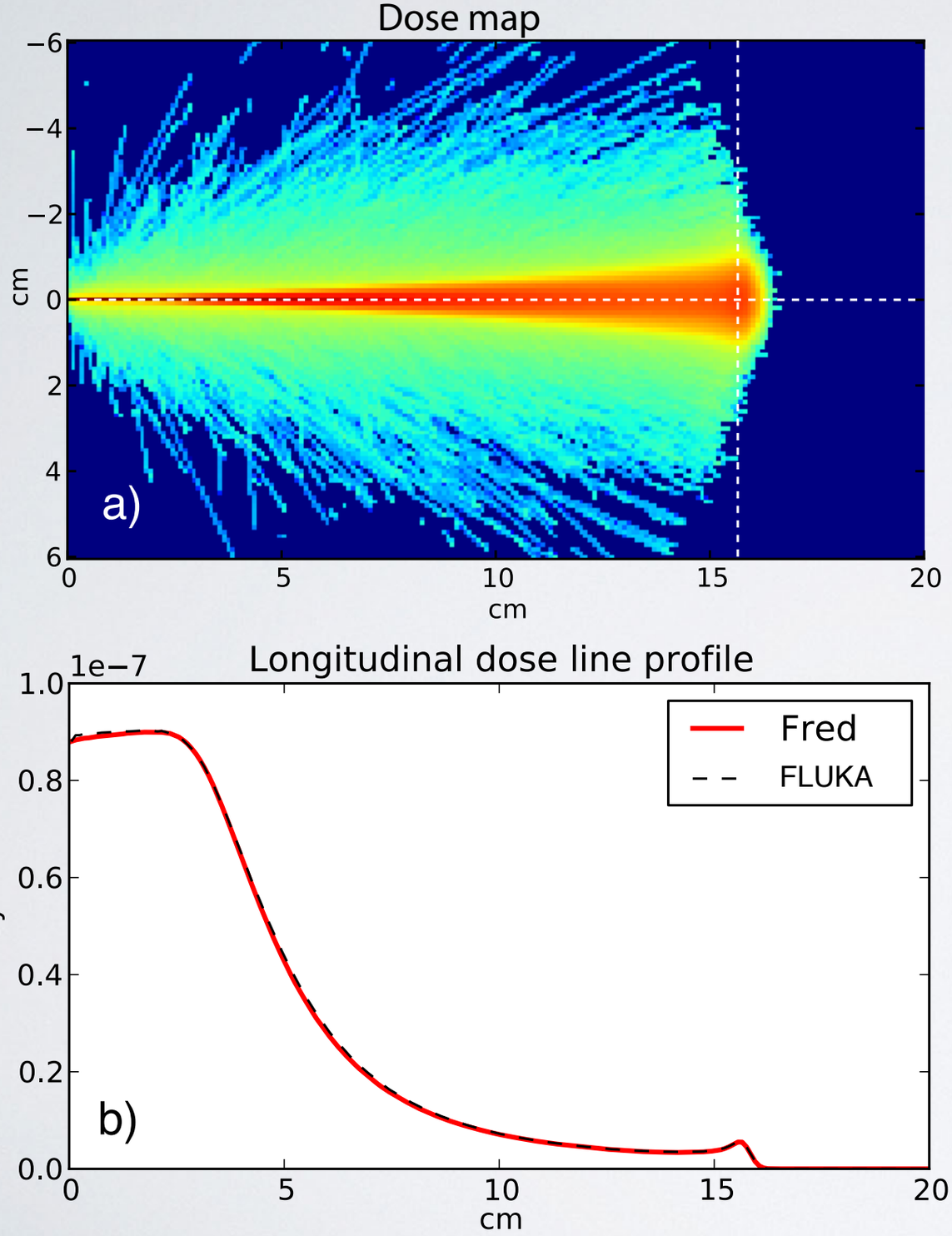
Fluka

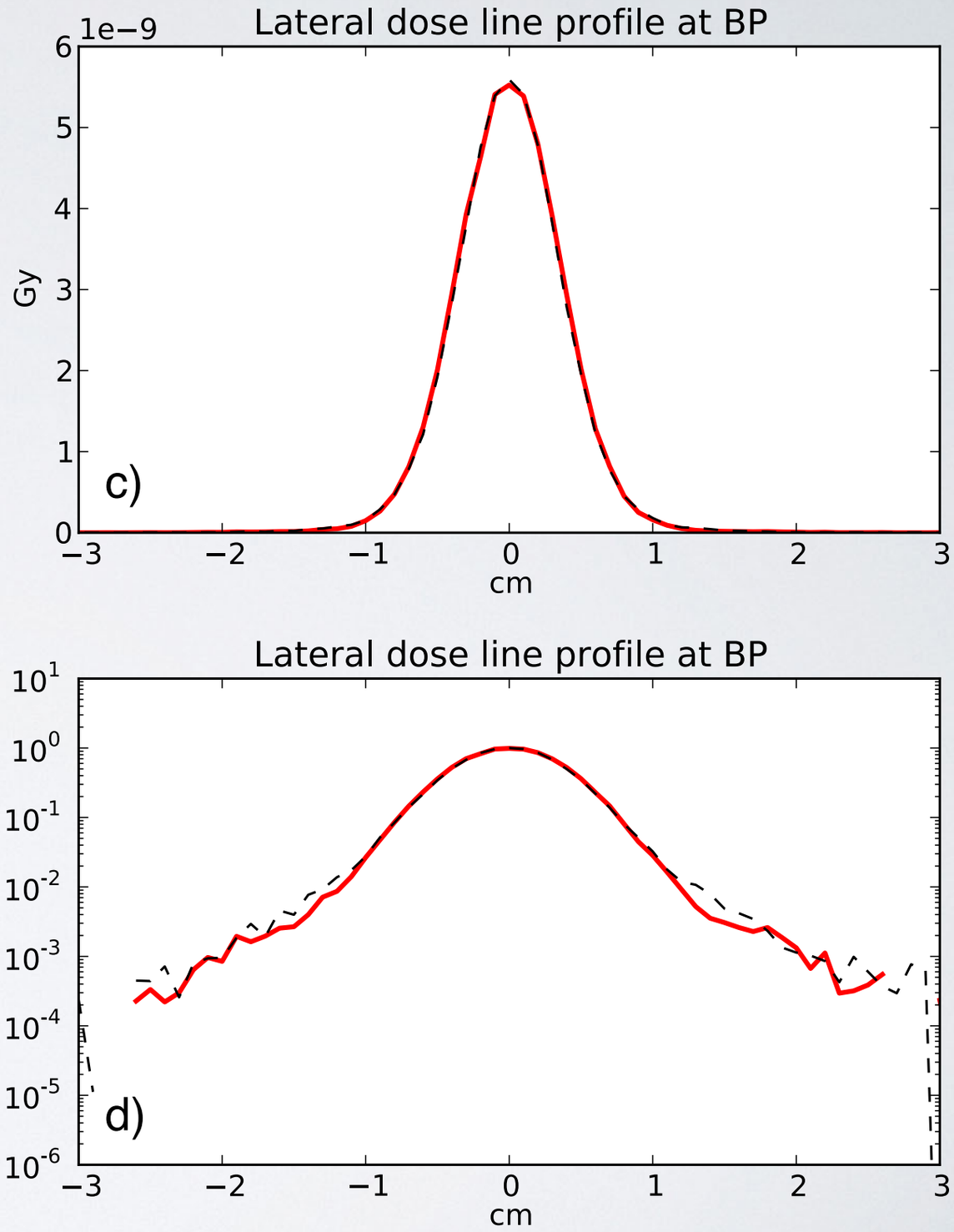
Water model: energy deposition

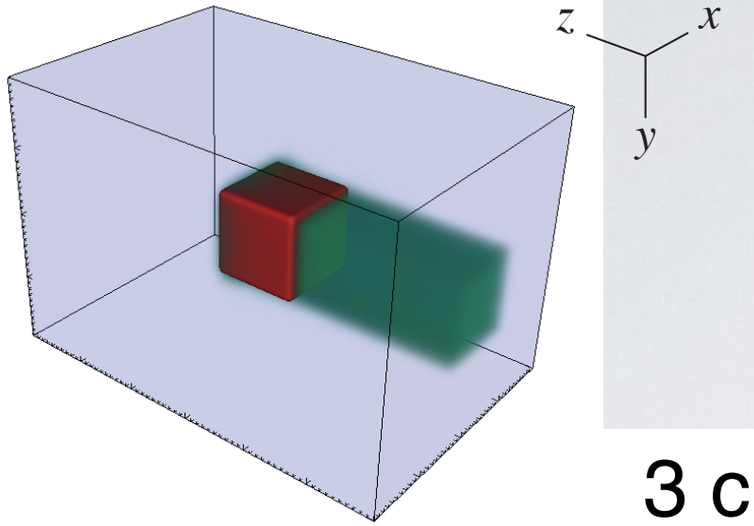


A. Schiavi et al, *PMB* **62** (2017) 7482–7504

Longitudinal profile and lateral tails



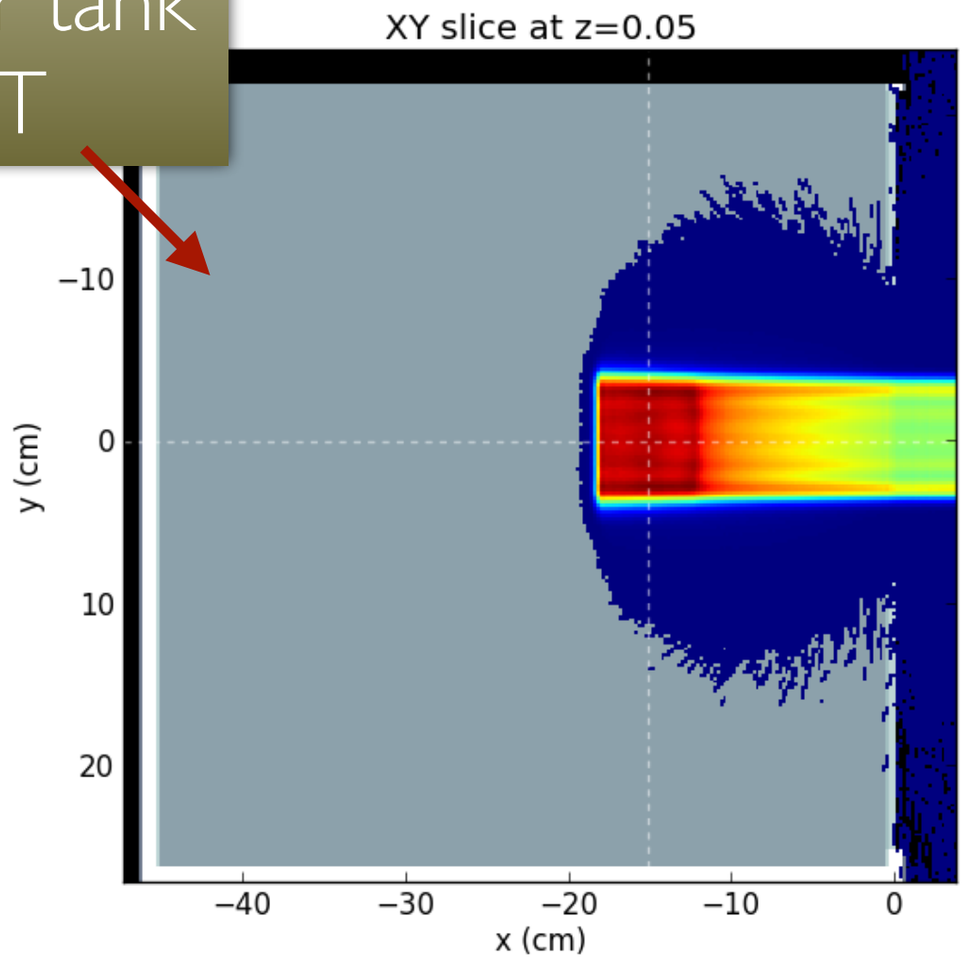




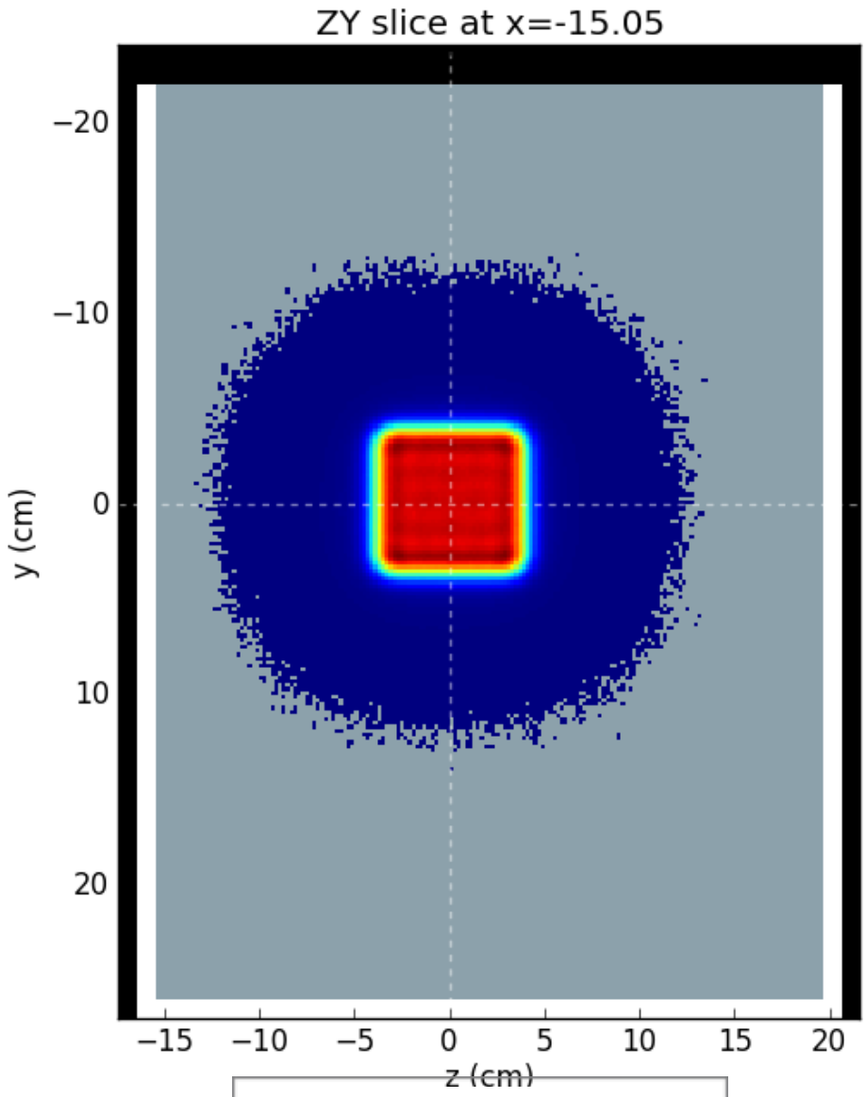
QA SOBP

3 cm cube at 15 cm depth

Water tank CT

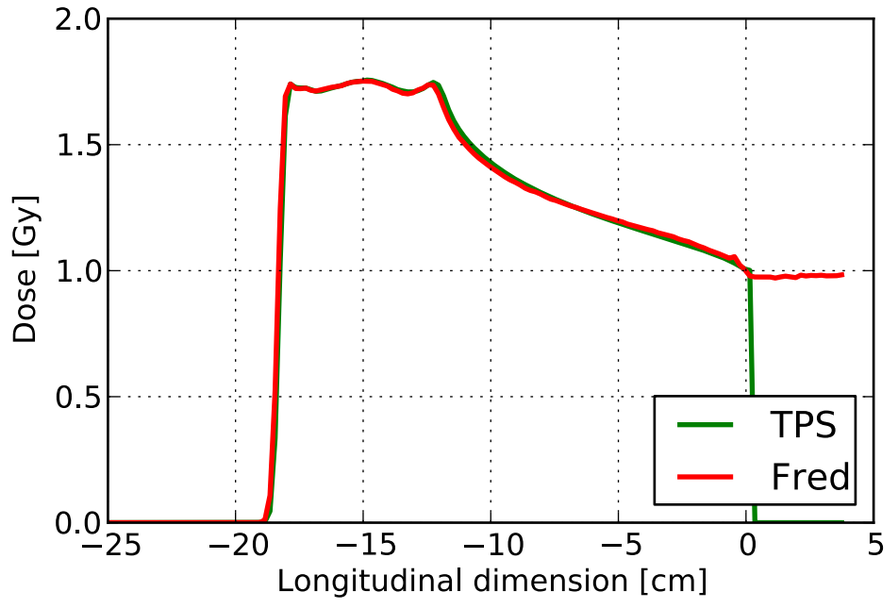


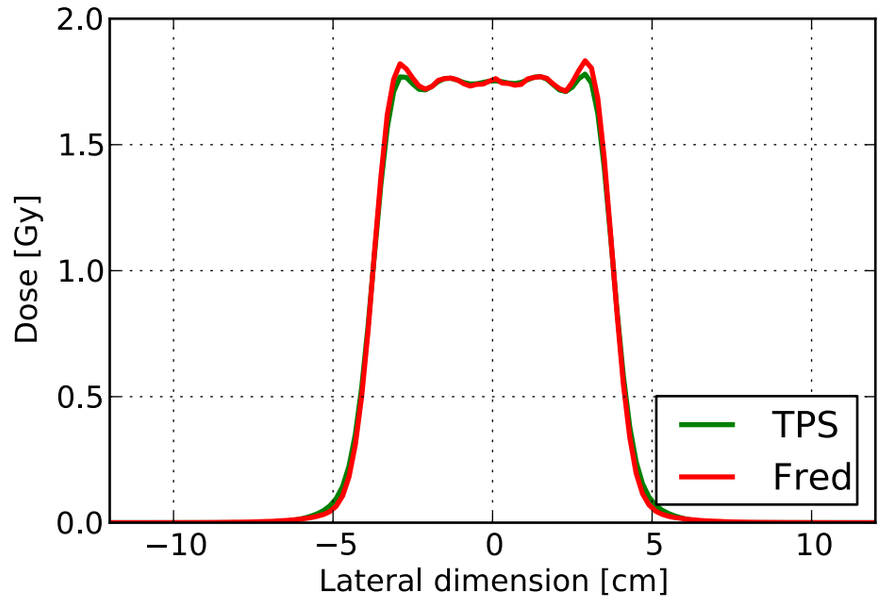
side-on

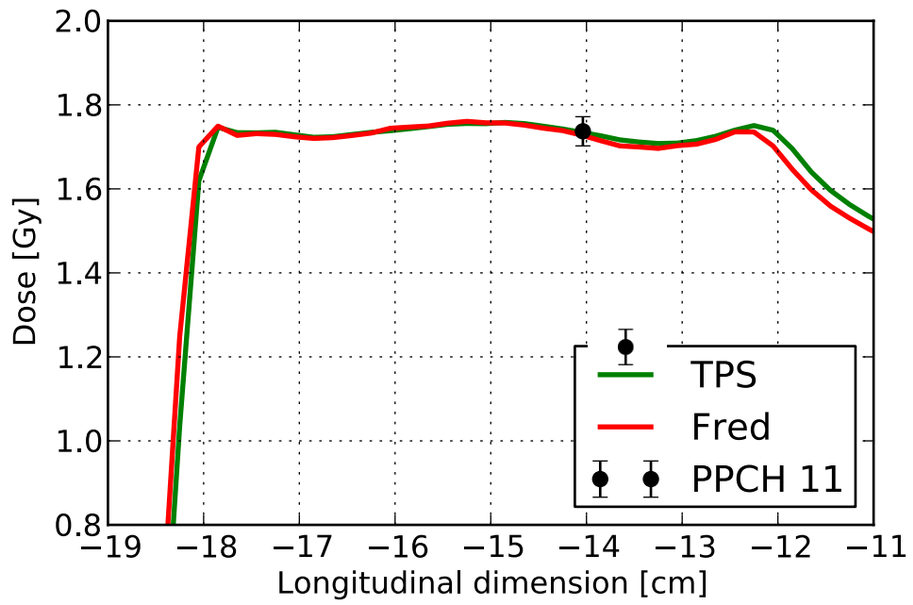


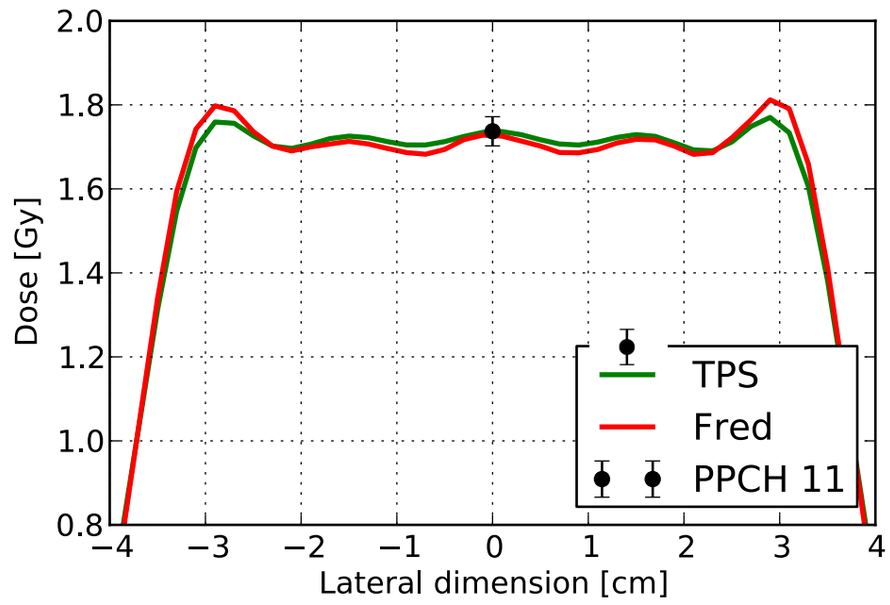
head-on

QA SOBP: dose profiles and measurements

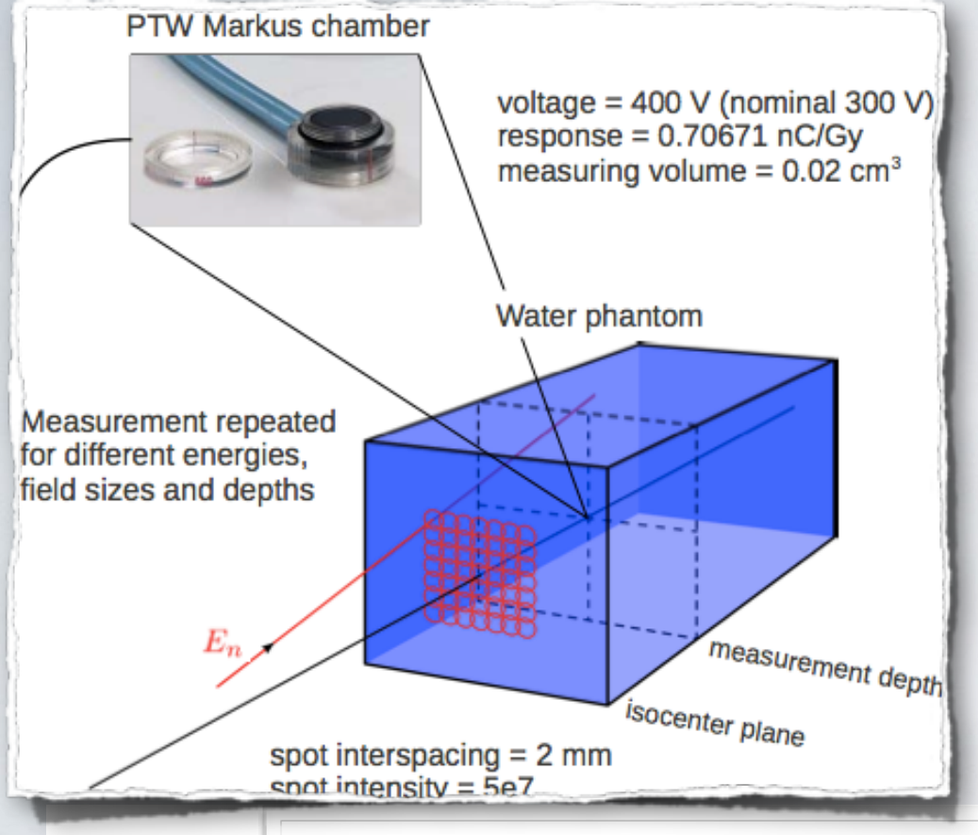




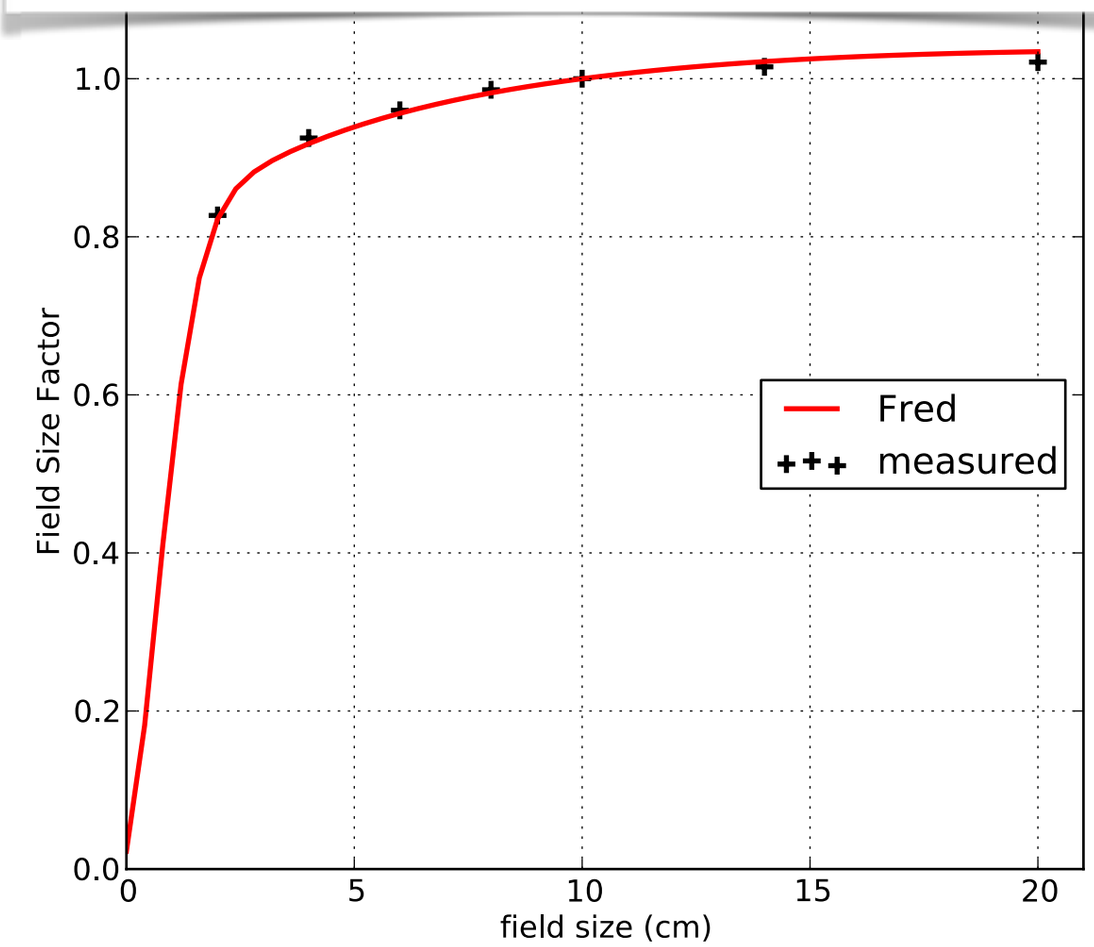


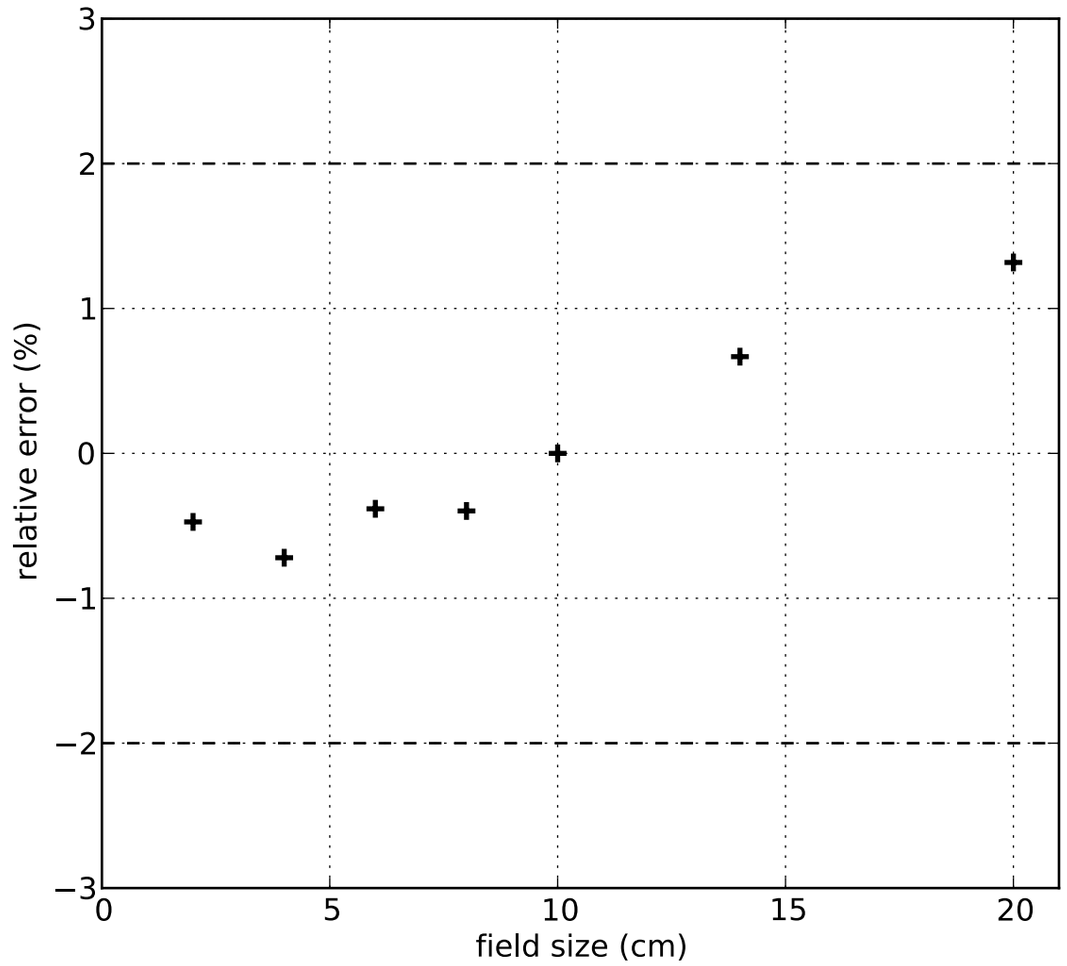


Field size factor



E = 226.61 MeV/u at 20 cm depth





Hardware for rapid MC recalculation

- standard codes
- expensive (€€€€€)
- maintenance (staff)

- low budget (€€€€)
- redundancy
- in-house maintenance

Parallel execution model in Fred

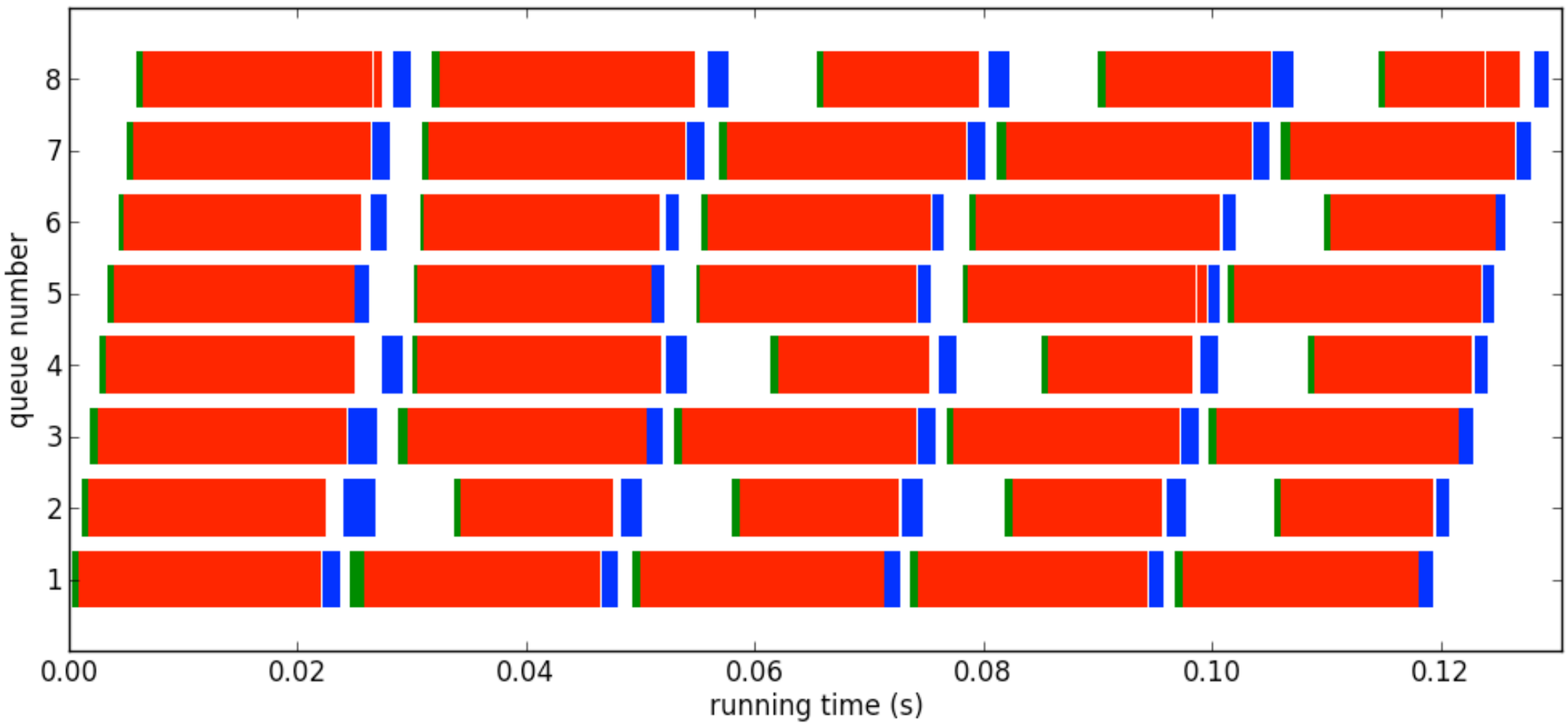
Extranode
MPI

Intranode
POSIX
Multi-threads

Fred
front-end

Intranode
Multi-GPU
OpenCl

Queues and timeline



Execution timeline for 8 queues
on 4 GPUs using OpenCL.
Host-to-device transfers (green), kernel execution (red),
and device-to-host (blue) transfers

Hardware and Performance

CPU

CPU [a]	Threads	primary/s	$\mu s/primary$
full-MC *	1	0.75 k	1330
FRED	1	15 k	68
FRED	16	50 k	20
FRED	32	80 k	12.5

* FLUKA or Geant4

benchmark: 150 MeV protons in a water phantom
on a 1 mm^3 dose scoring grid

TABLE 1. Computing times for different hardware architectures.
[a] motherboard with two Intel® Xeon E5-2687 8-Core CPU at 3,1GHz
[1] LAPTOP: Apple® MacBook Pro with one AMD® Radeon R9 M370X.
[2] DESKTOP: Apple® Mac Pro with two AMD® FirePro D300.
[3] WORKSTATION: Linux box with four NVIDIA® GTX 980.

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GPU

GPU	Cards	primary/s	$\mu s/primary$
AMD Radeon R9 M370X [1]	1	500 k	2
AMD FirePro D300 [2]	2	2000 k	0.5
NVIDIA GTX 1080	1	11200 k	0.09
NVIDIA GTX 980 [3]	1	5350 k	0.2
NVIDIA GTX 980	2	10200 k	0.1
NVIDIA GTX 980	3	15600 k	0.6
NVIDIA GTX 980	4	19900 k	0.05

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Applications to proton therapy

- Patient-specific QA protocol at CNAO

- Patient-specific HU-RSP calibration

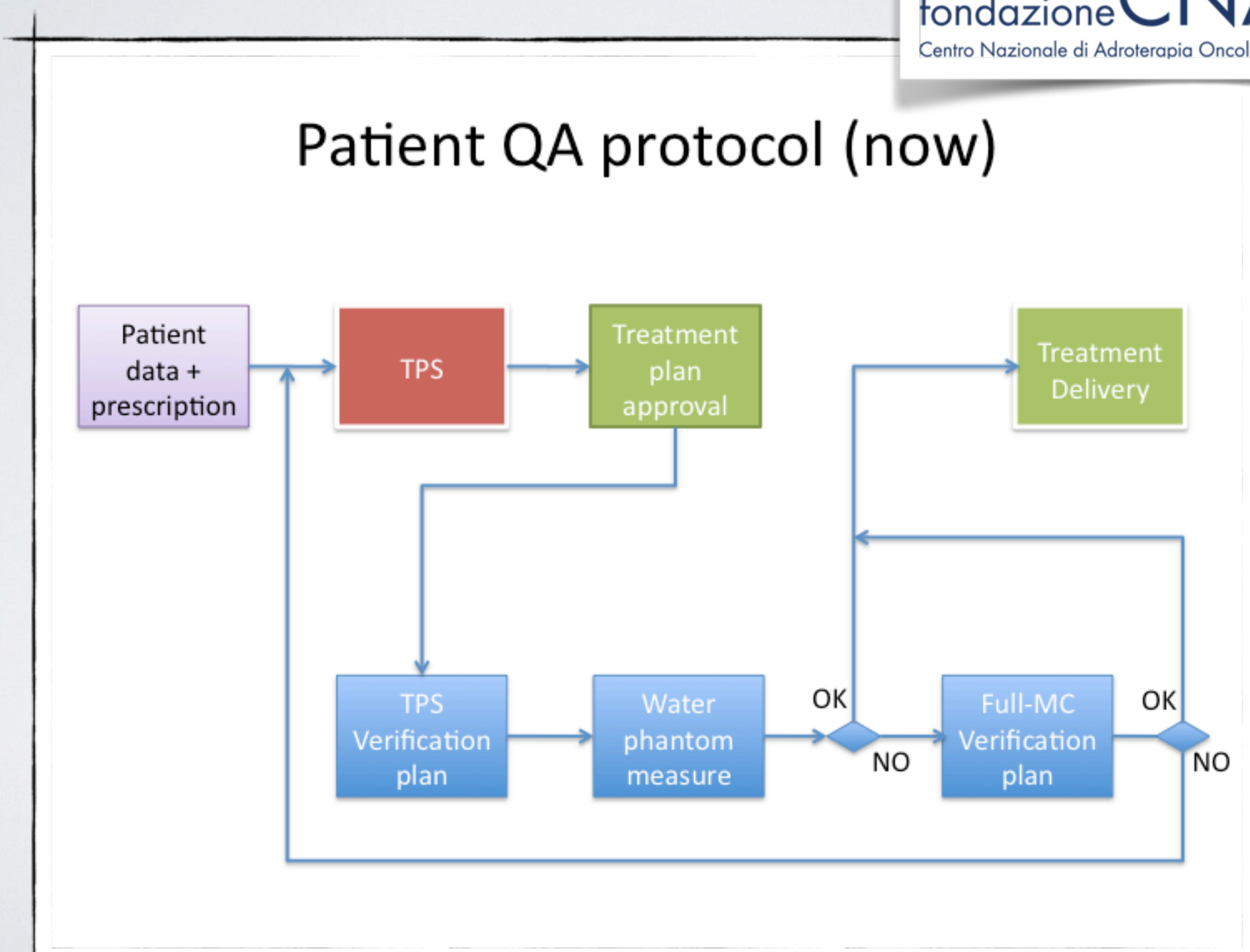
- Commissioning of CCB proton center in Krakow

- Dose monitoring using secondary protons

see S. Muraro talk this afternoon (ID 67)

Fast-MC recalculation of patient verification plans at CNAO

fondazione CNAO
Centro Nazionale di Adroterapia Oncologica



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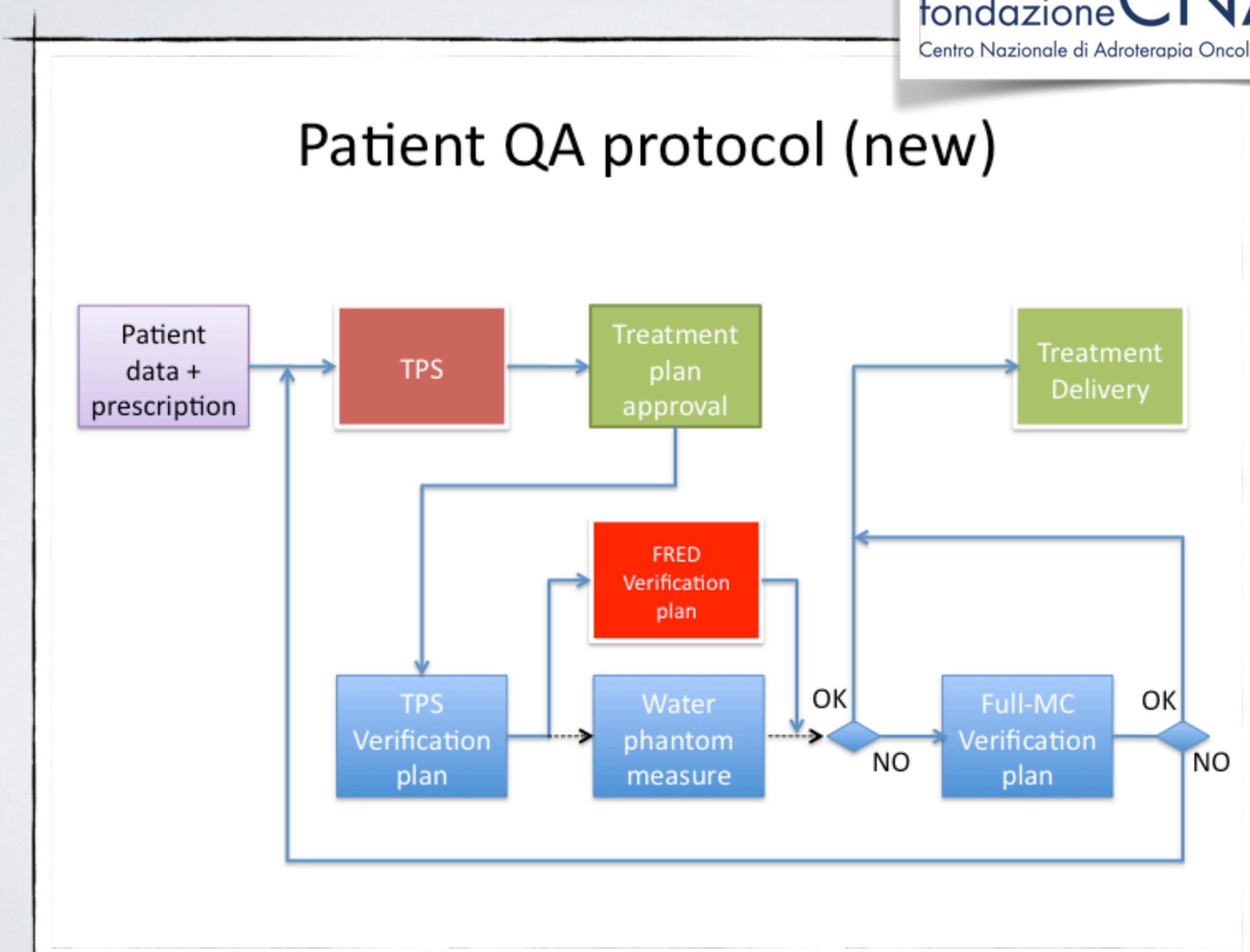
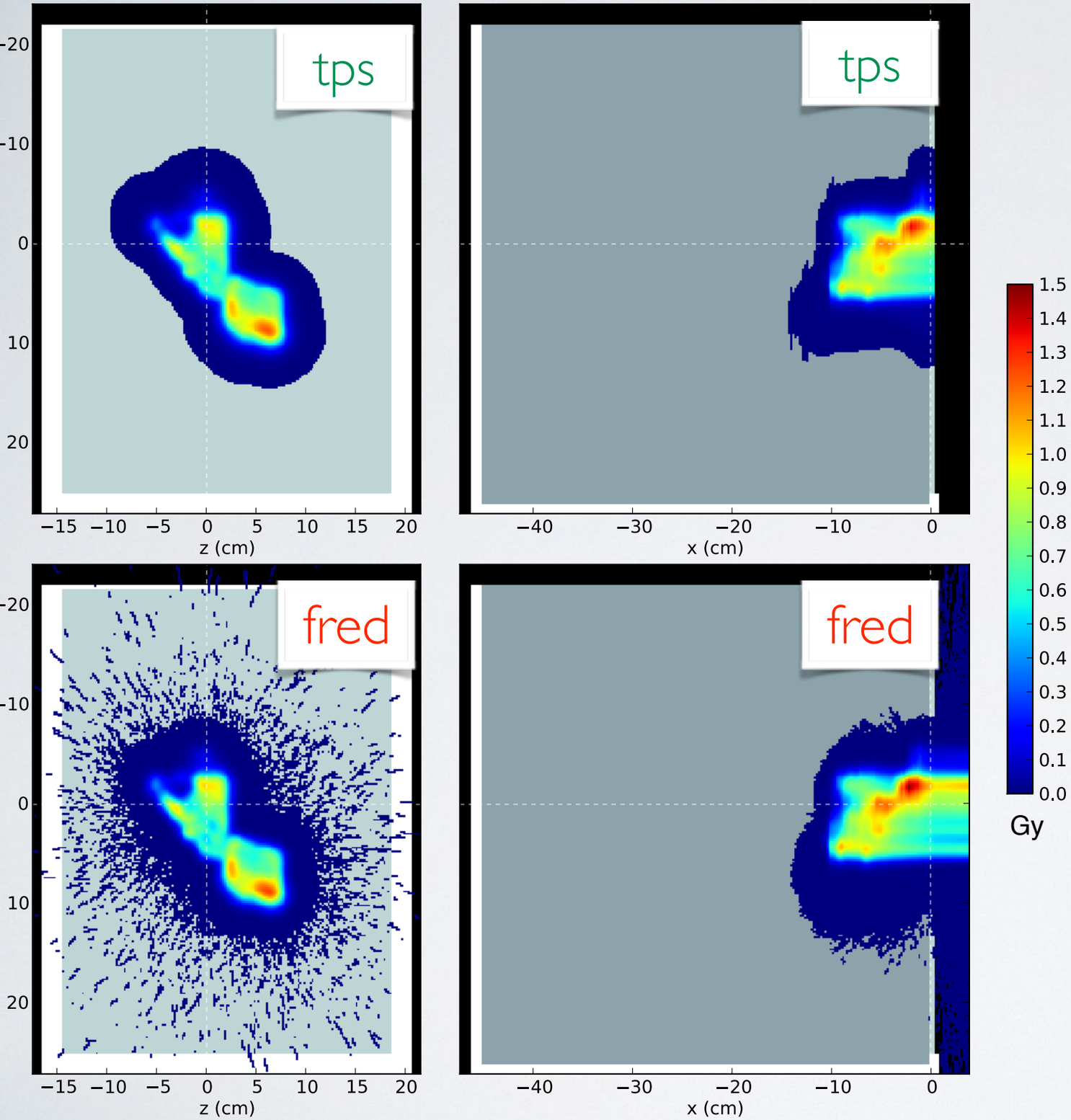
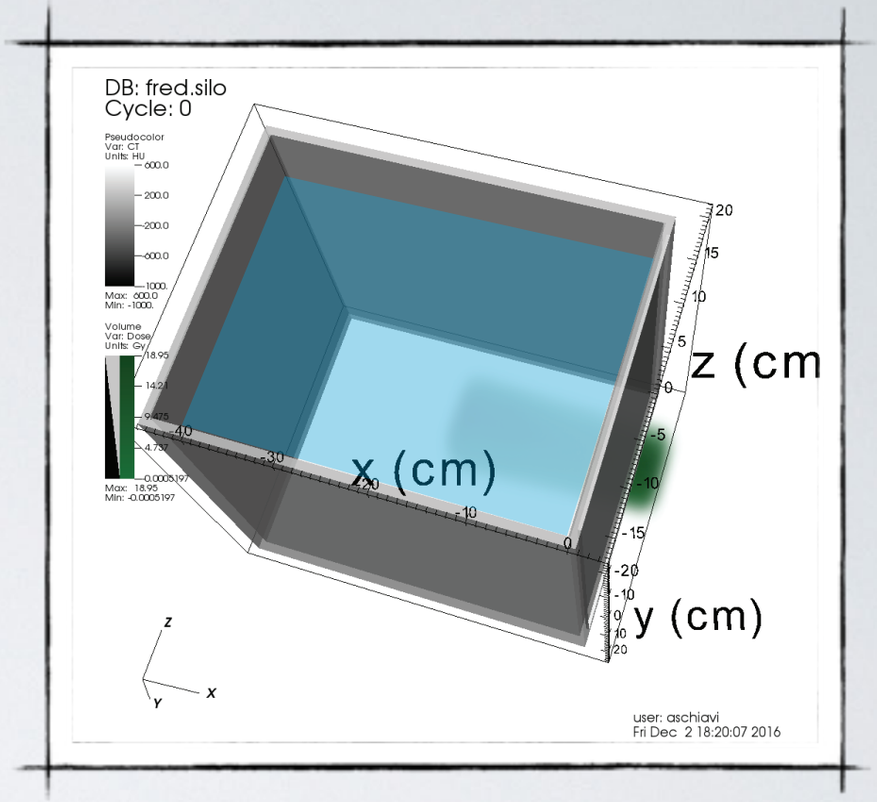


Patient verification plan





γ-index pass rates

99.6% @ 2mm/2%

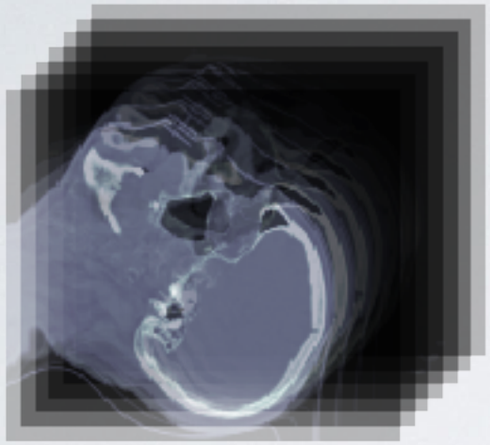
96.7% @ 1mm/1%

head-on

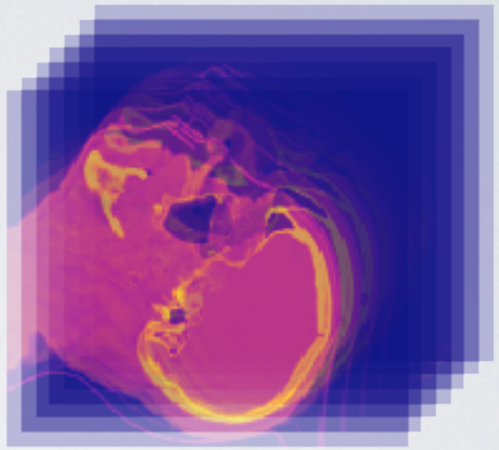
side-on

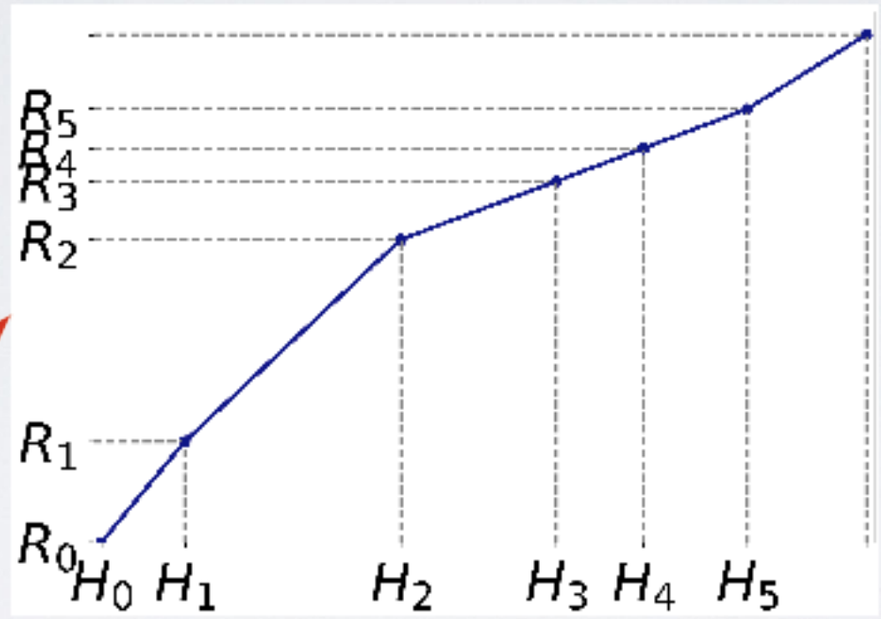
Patient-specific and treatment-specific HU-RSP calibration

HU



RSP

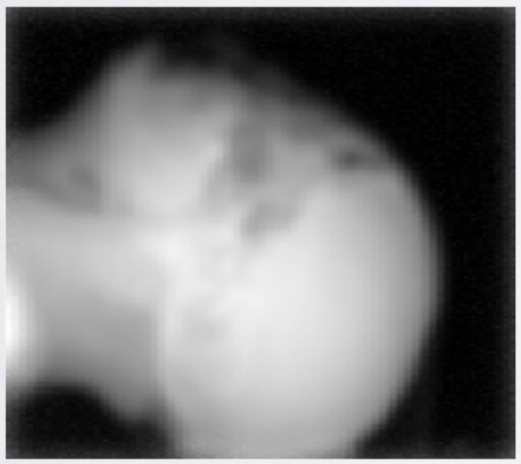




projection

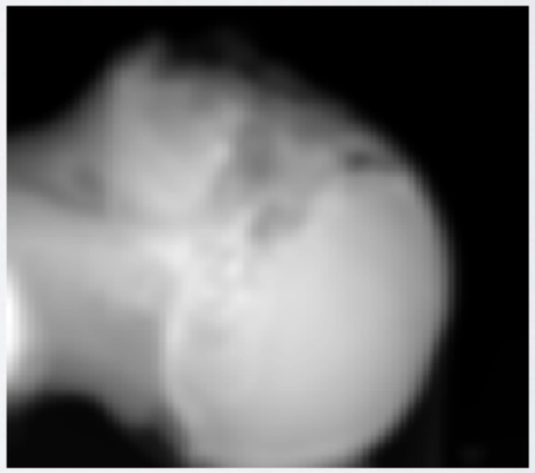
Optimize R_1, R_2, R_3 ...

Fred



Proton radiography (pR)

$$\min \|\mathrm{pR} - \mathrm{DRR}\|^2$$

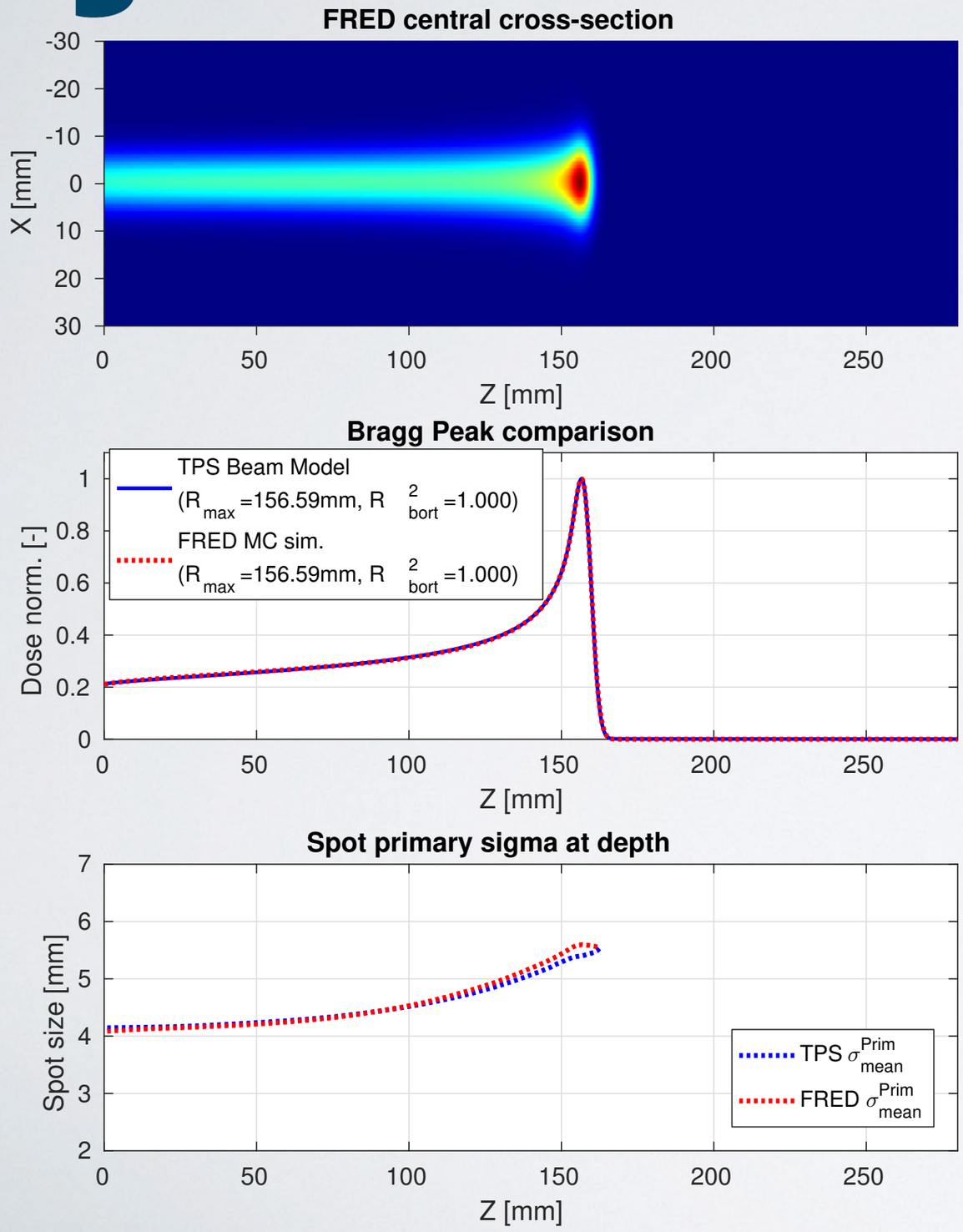


Digitally Reconstructed Radiography (DRR)

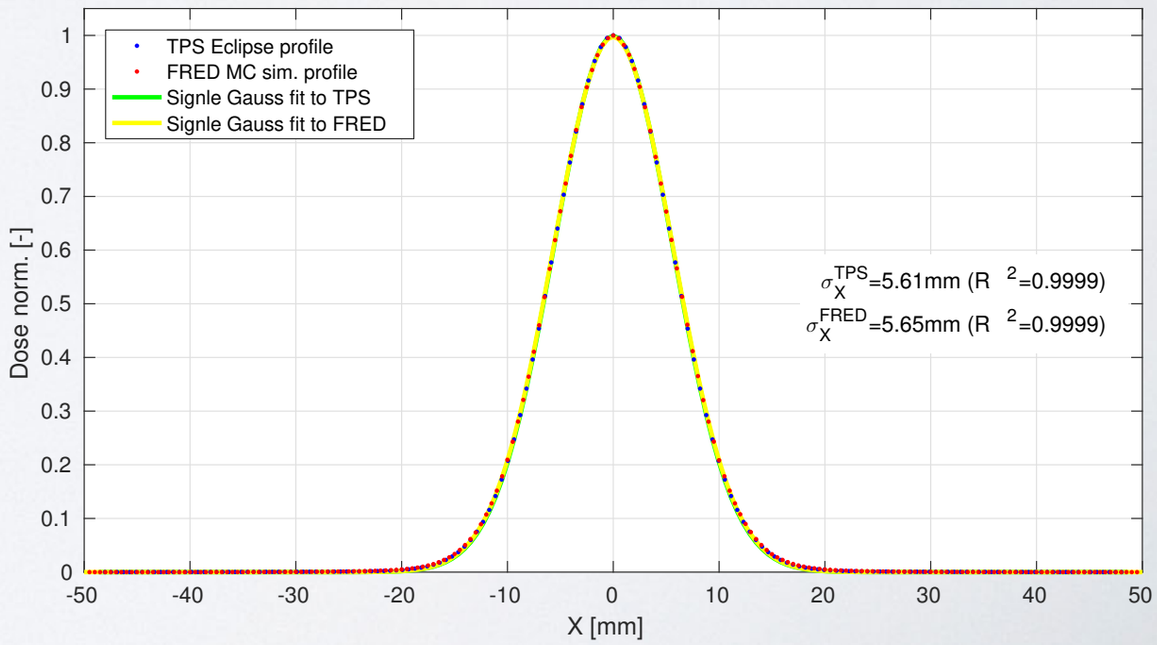
[1] Schneider et al. 2005, Medical Physics (PSI)

[2] Doolan et al. 2015, Physics in Medicine and Biology (MGH)

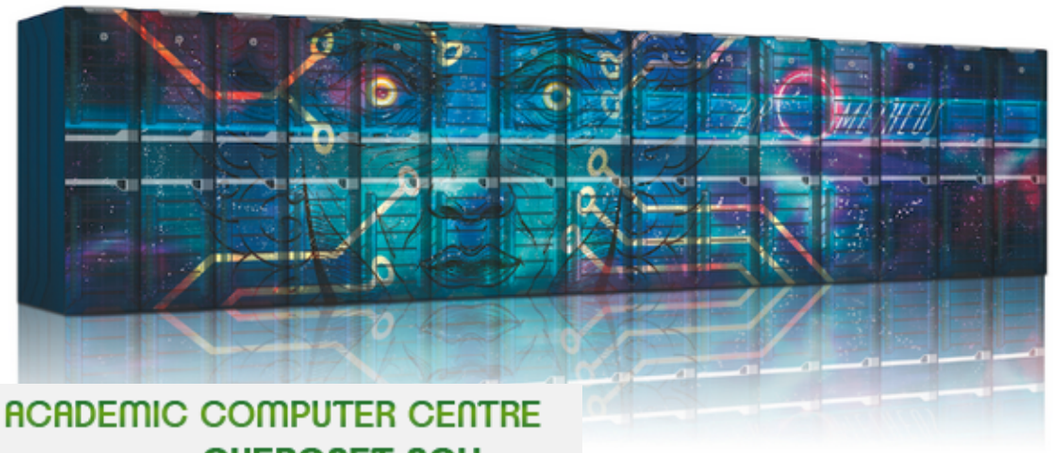
Fred commissioning @ CCB Krakow Proton Beam Therapy Centre



Fred code is currently being commissioned at CCB as a **quality assurance tool**.
Preliminary results show good agreement of single beam dose distributions calculated with Eclipse and Fred, indicating an accurate implementation of CCB beam model in the Fred MC-TPS code. Dose distributions for a complete plan can be obtained in about one minute using Fred on GPU.
Robustness studies of treatment plan strategy can be conducted on the HPC cluster Prometheus.

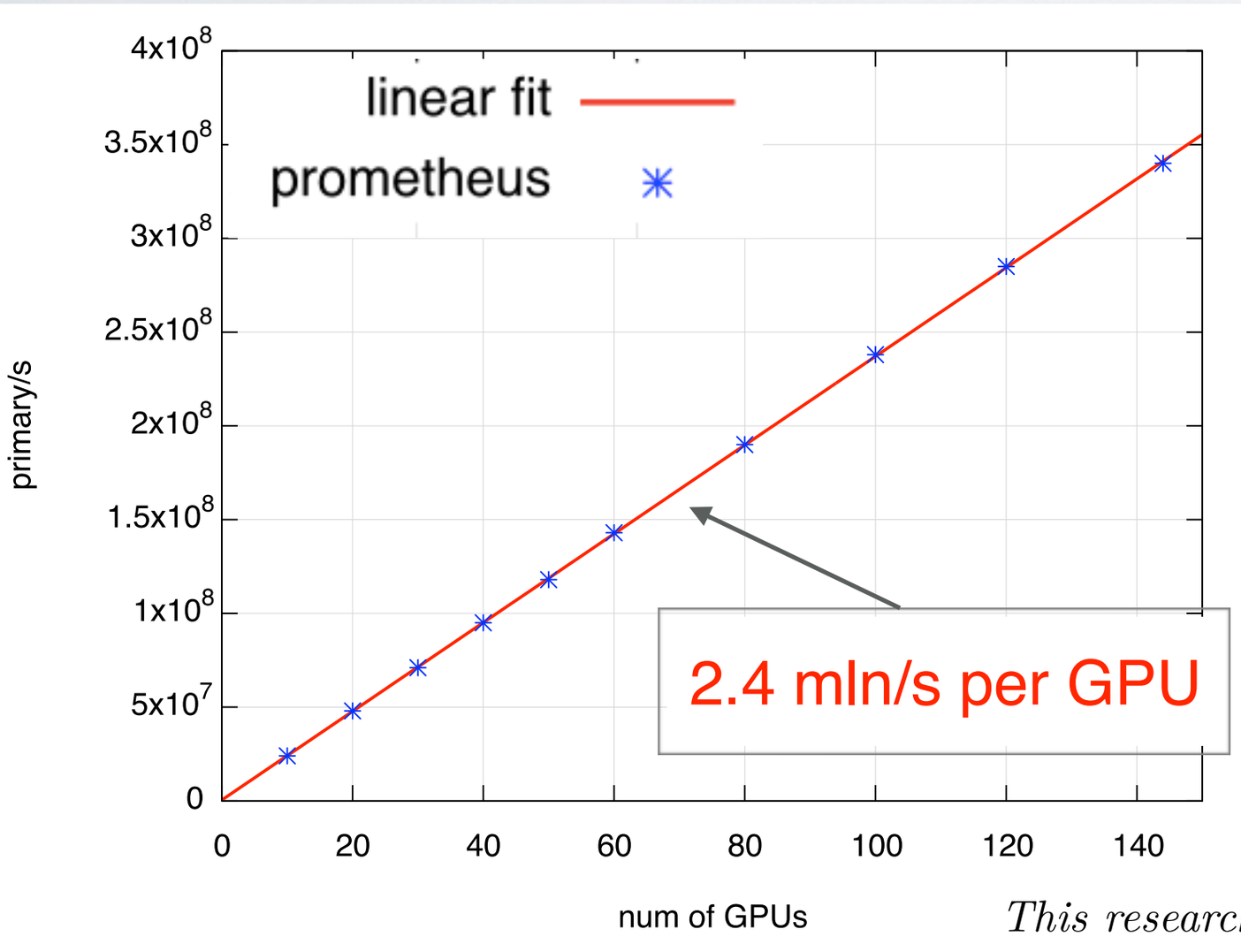


Top performance on Prometheus



ACADEMIC COMPUTER CENTRE
CYFRONET AGH

- 72 Nodes with 24 CPUs and 2 Tesla K40d GPUs
- Up to **144** GPUs in parallel + 1728 CPUs



perfect linear scaling

up to **0.3 billion** primary/s

This research was supported in part by PL-Grid Infrastructure.

Future developments and perspectives

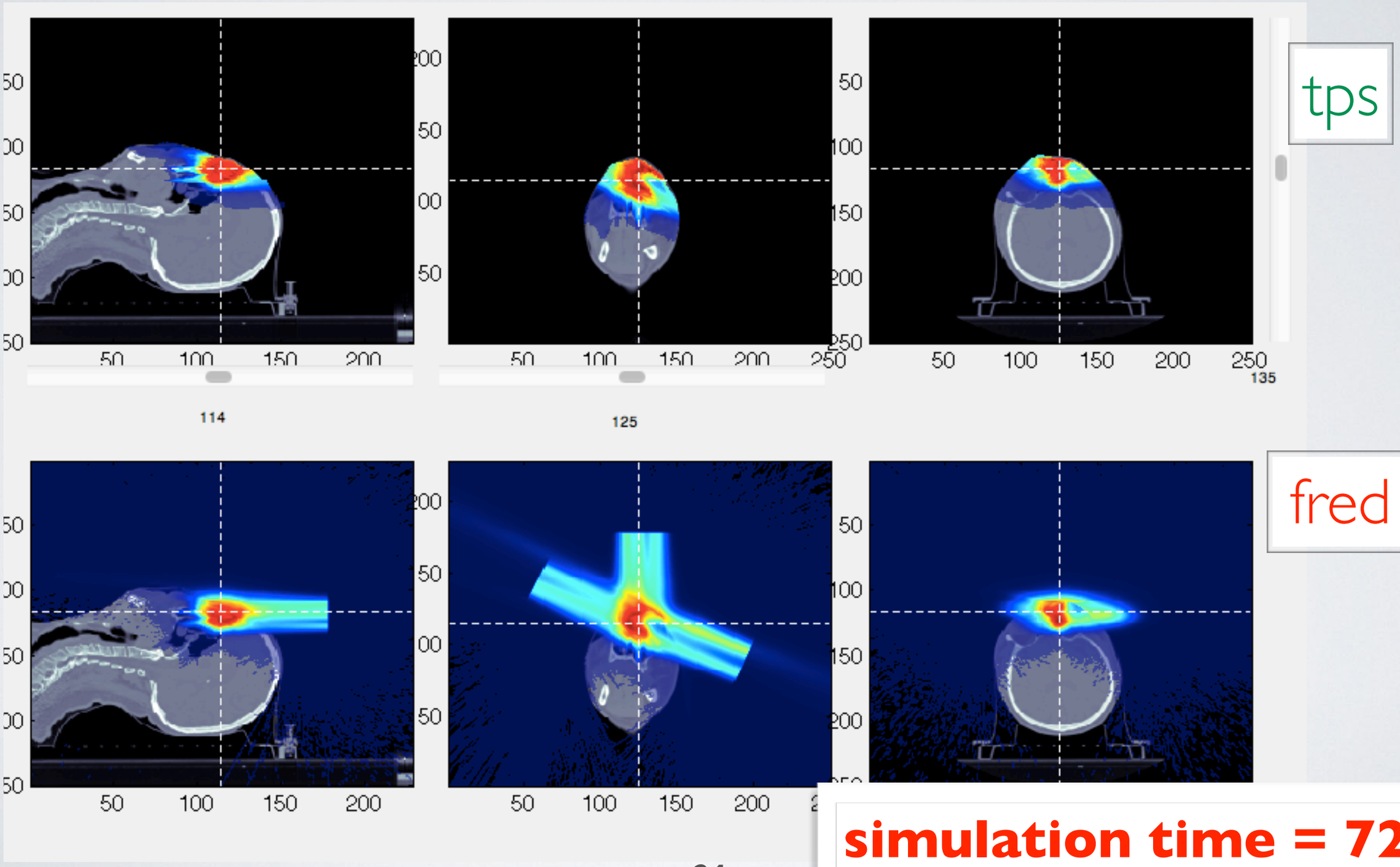
- clinical validation of fast-recalculation tool
- applications to clinical routine
- extensions to include other ions (Carbon, Helium) and secondary particles (alphas, delta-rays and neutrons)
- dose monitoring using charged secondary particles

Patient recalculation plan

recalculation at 1% = 700 million primary protons

gamma-index 97% @ 2mm/2%

gamma-index 92% @ 1mm/1%



Water-cooled 4 GPU workstation

Hardware:
4x GPU NVIDIA GTX 1080
1x CPU Intel i7-5930K @
3,50 GHz with 12 cores

20 mln primary/s

4x NVIDIA Titan-Xp
40 mln primary/s
budget: 10 kEuro

compare with new
NVIDIA DGX-1
(8x Tesla P100)
expected performance:
80 mln primary/s

budget: 125 kEuro

Case study: 3D raytracing for legacy F77 hydrocode

From 1 to 2 Mray/s (equivalent to 800 MPI processes)

Raytracing step well below hydrodynamic step