Particle Therapy Treatment Plans on GPU

A. Schiavi
Università di Roma “La Sapienza”
and INFN

Collaboration

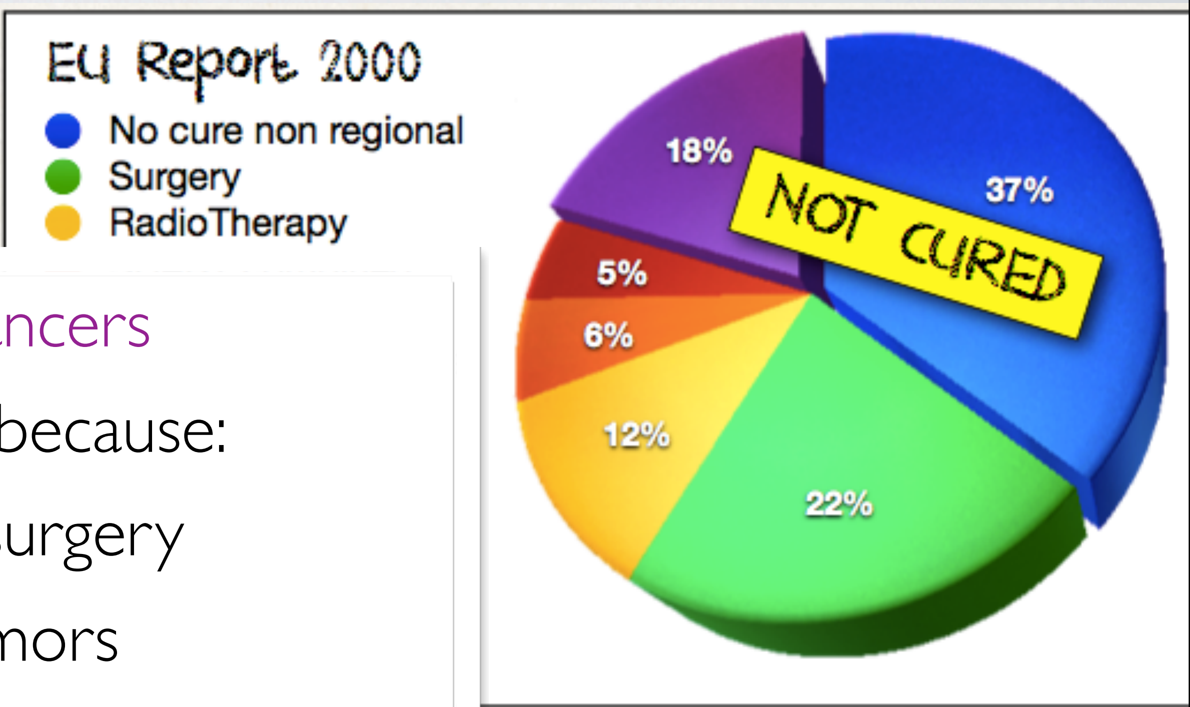
- G. Battistoni - INFN-MI
- V. Patera - Univ. La Sapienza Roma / INFN
- S. Pioli - INFN-LNF / Univ. La Sapienza Roma
- A. Schiavi - Univ. La Sapienza Roma /INFN
- M. Senzacqua - Univ. La Sapienza Roma

Outline

- ~~particle therapy with active beam scanning~~
- fast-MC code structure and implemented physical models
- dose deposition accuracy vs full-MC code
- Fred as a recalculation tool for commercial TPS plans
- parallel execution modes, hardware and performance

European cancer treatment survey

More than 45% of cases are cured (surgery or std RT)



18% are localized cancers

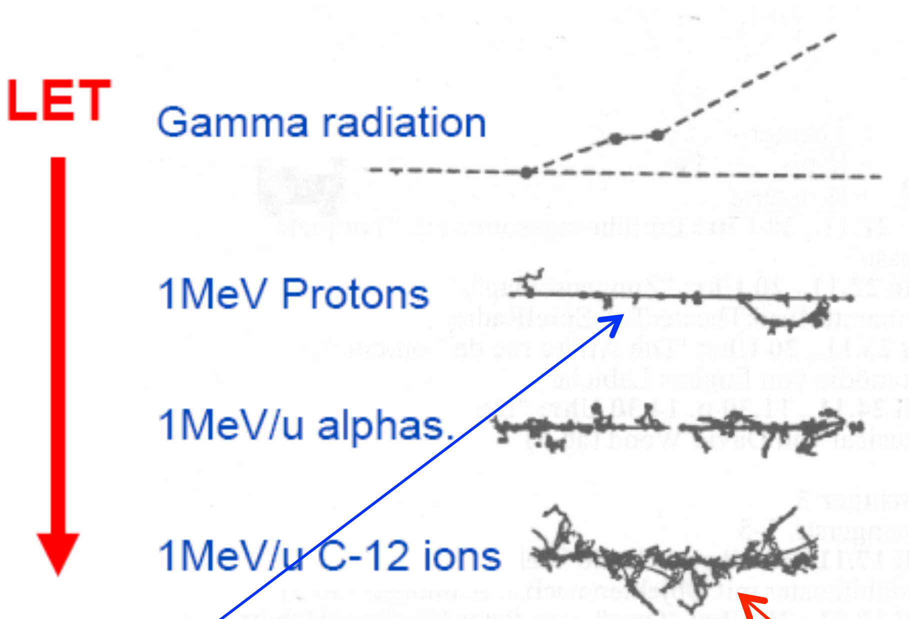
which are not treated because:

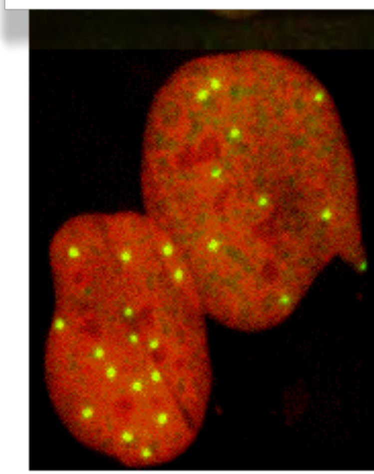
- anatomy prevents surgery
- radioresistant tumors
- too close to critical organs

Particle therapy may be used in these cases and might also become the preferred approach for other cancers

How to “kill” cancer cells

Ionisation tracks





High LET

Local deposition of high doses

lz et al. Rad. Res. 2001 Immunoflourescence image
pair protein p21;

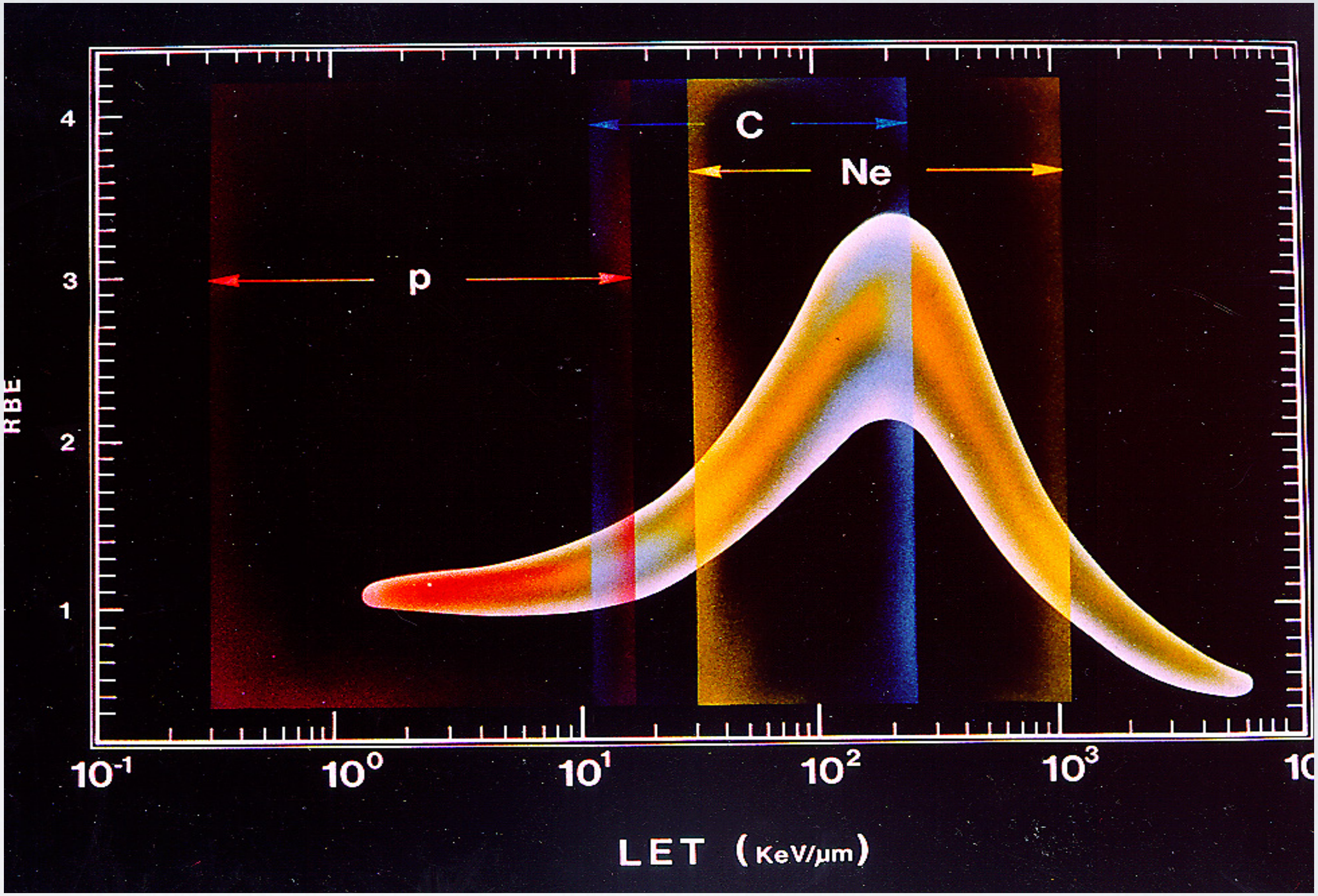
charged particles have high damaging power on the DNA scale-length

p at the Bragg peak
when R_{res} ~ 0.2 mm
E ~ 4 MeV
LET ~ 10 keV/μm
<d> ~ 4 nm

^{12}C at the Bragg peak
when R_{res} ~ 1 mm
E ~ 200/12 MeV
LET ~ 140 keV/μm
<d> ~ 0.3 nm

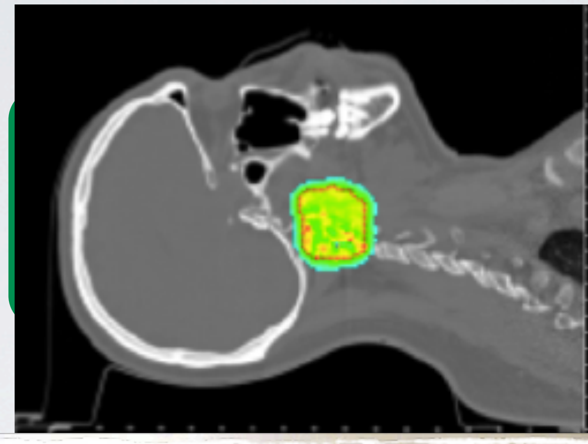
RadioBiological Effectiveness

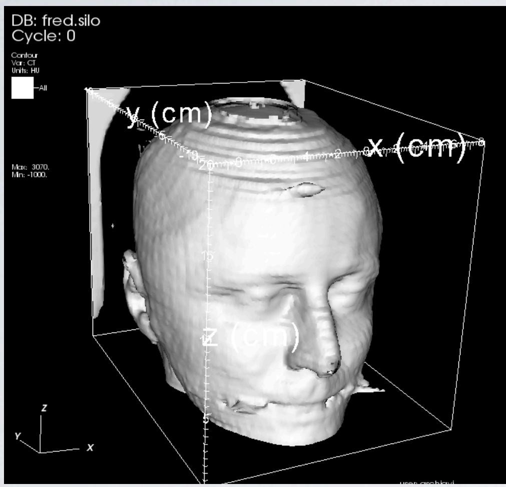
$$R.B.E. = \left(\frac{D_{RX}}{D_r} \right)_{SF=SF_0}$$

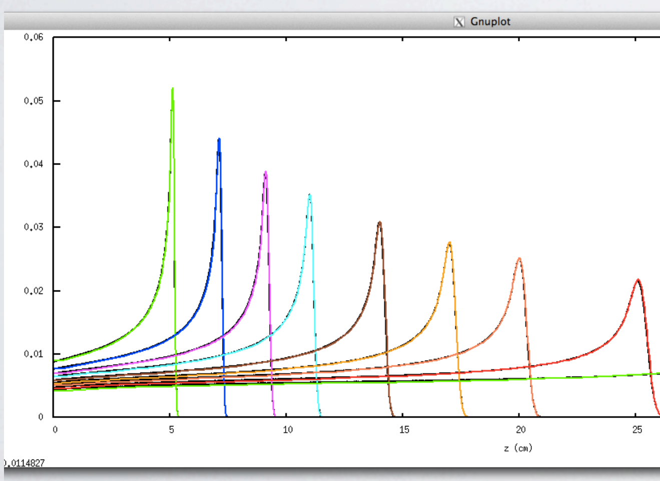


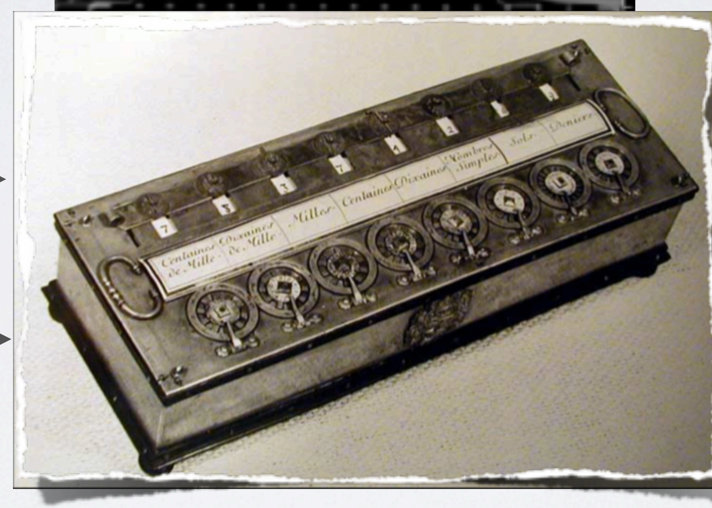
also to consider that PT has higher effectiveness in poorly oxygenated tissues (typically neoplasms)

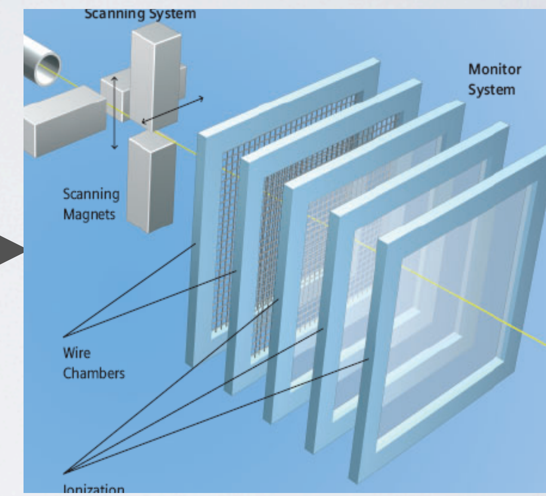
Treatment Planning System



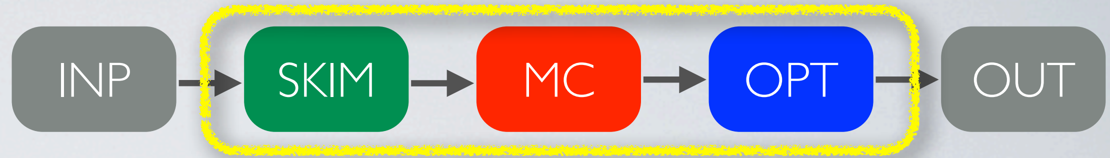








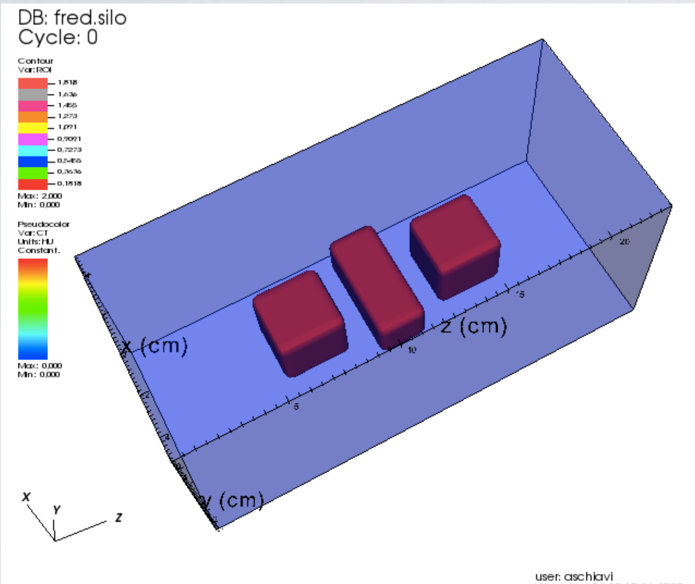
Fred

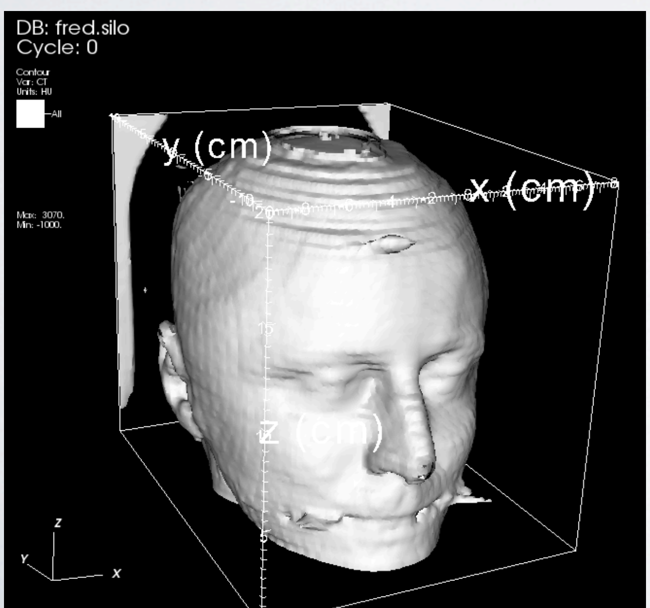


- fast-MC code for protons in voxel geometry
- Tabulated total stopping power in water (PSTAR)
- MCS models: single-,double-,triple-gaussian, 2 gauss+Rutherford
- Nuclear interactions: elastic and inelastic; fragmentation; local deposition of heavy ions; tracking of secondary protons and deuterons
- HU to density conversion (Schneider) and stoppow calibration
- dose optimization using DDO (Lomax)
- RBE = 1.1 for protons

INP → SKIM → MC → OPT → OUT

INPUT





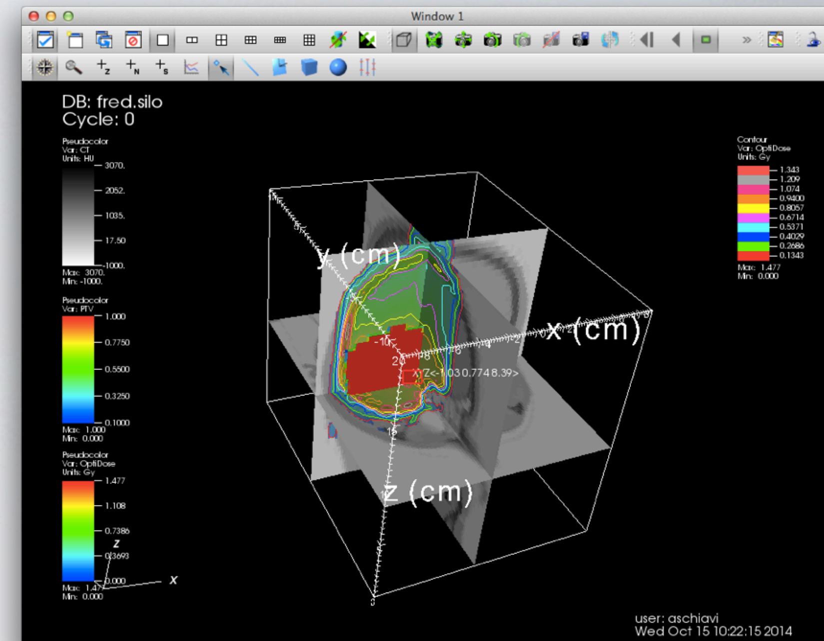
- text input file (flexible format)
- geometry and ROIs definition
- accelerator file (CNAO settings)
- voxel resampling; optimization param

- DICOM import
- RTSTRUCT (PTV,OAR,etc.)
- RTPLAN (raster file)

INP → SKIM → MC → OPT → OUT

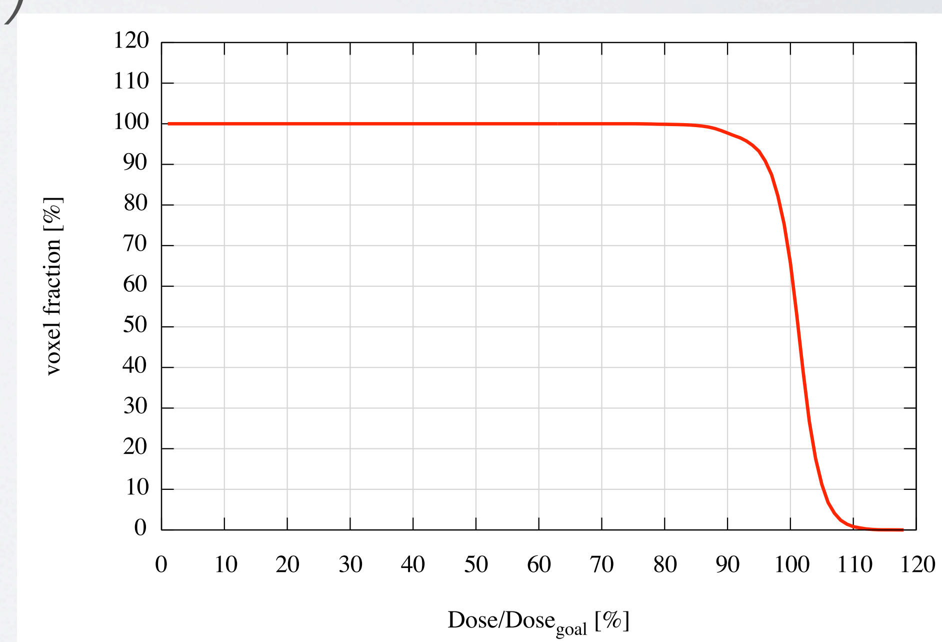
OUTPUT

3D maps using SILO library (VisIT/Paraview)



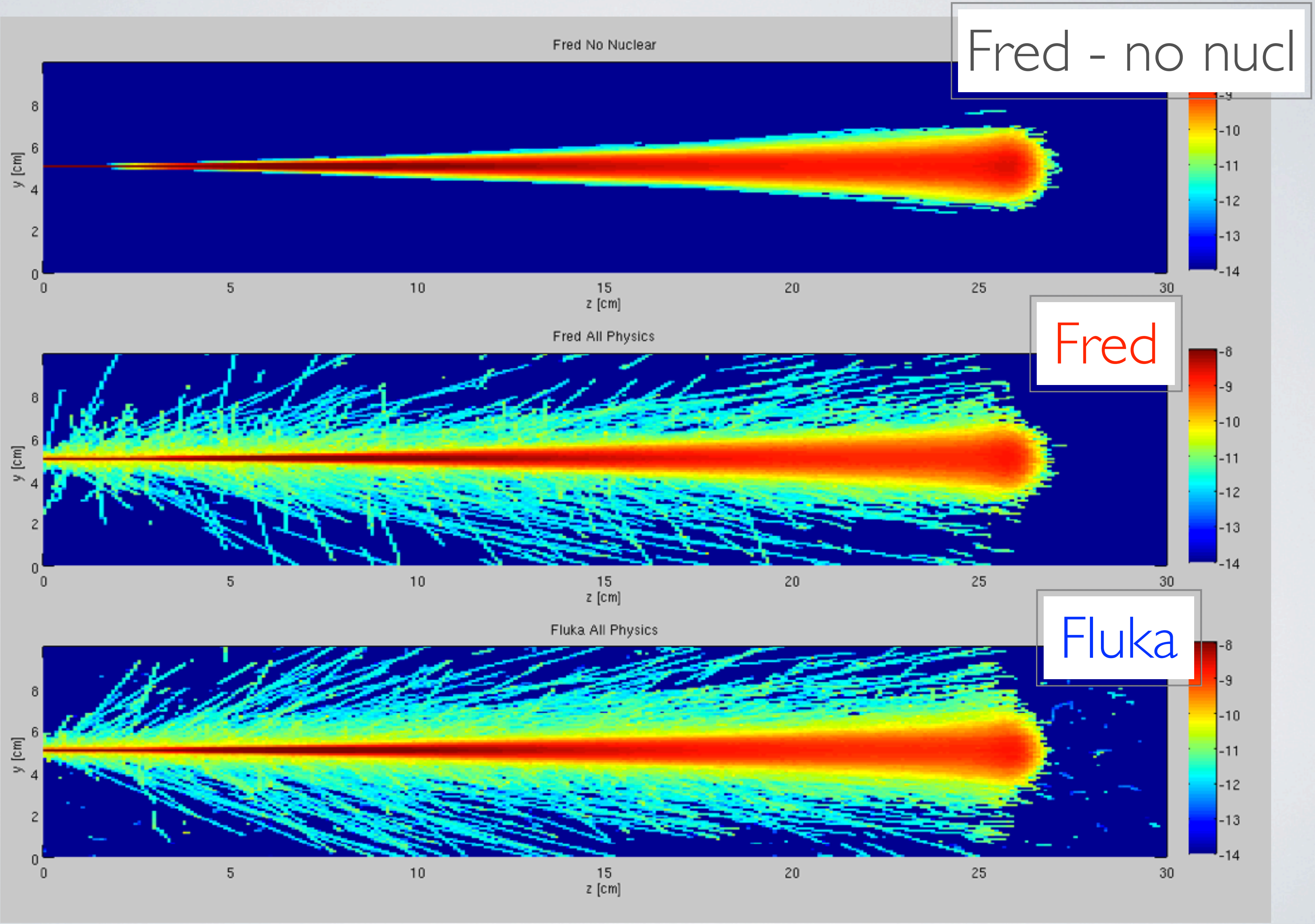
binary output for post-processing (MatLab, Python)

ROI { dose statistics, DVH }

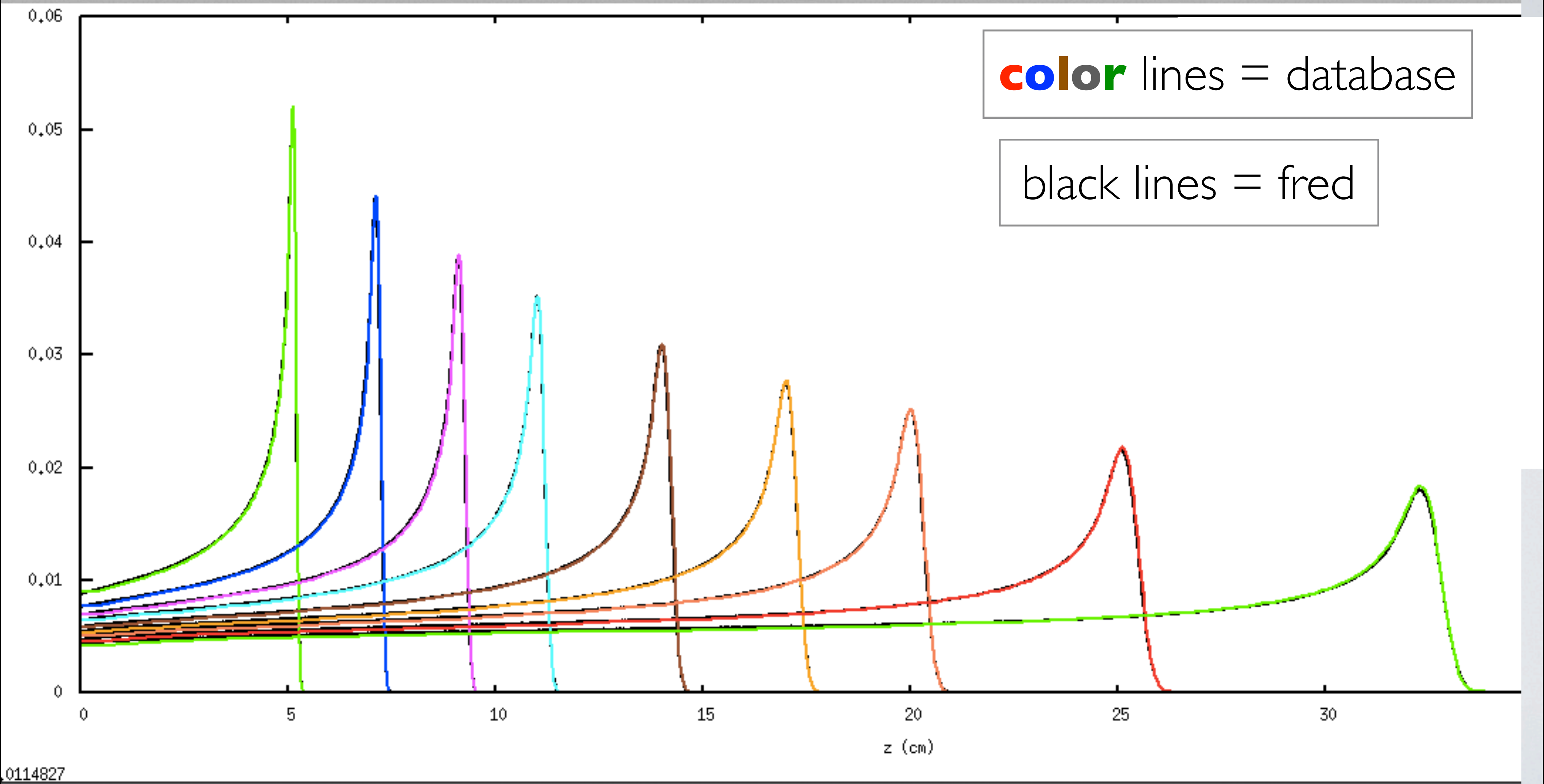


Single pencil beam - dose map

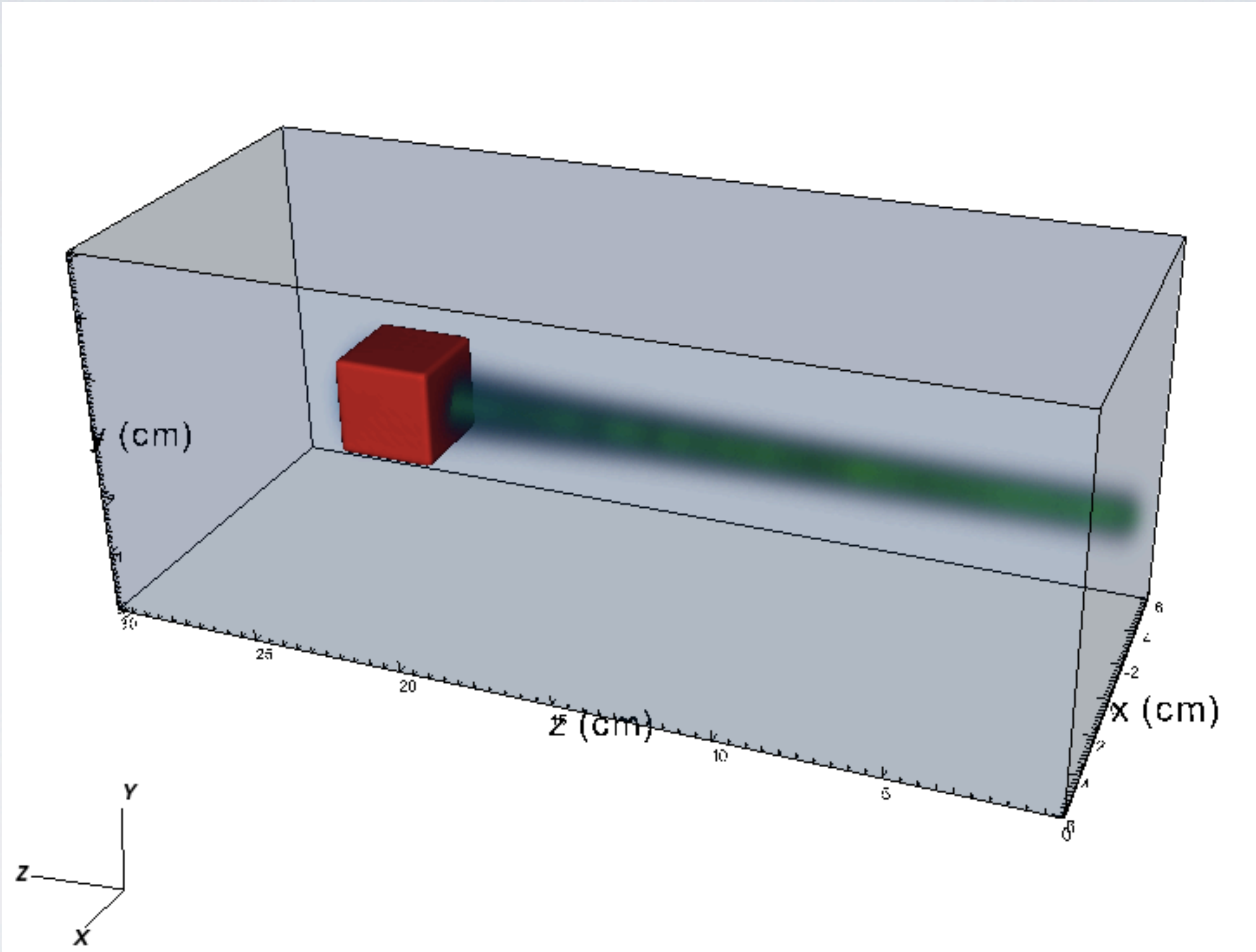
200 MeV protons
in liquid water



Bragg curves in water

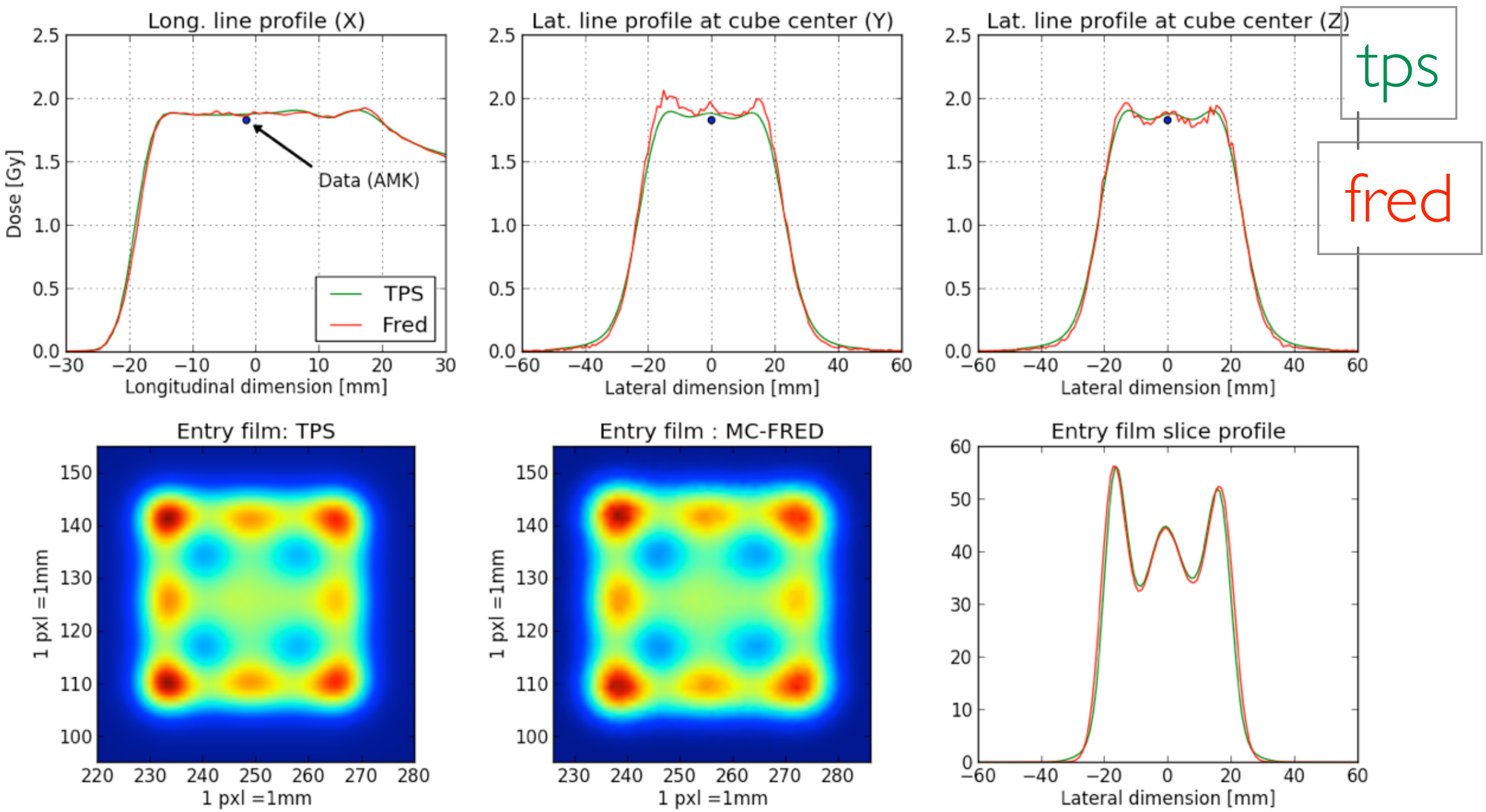


SOBP 3 cm cube at 20 cm depth



SOBP 3 cm cube at 20 cm depth

20.000 primary protons per PB



FastMCREC

In-room imaging for patient positioning (CBCT)

- patient positioning
- geometry match
- delivery uncertainties

we need also **dosimetric** verification of TP on the day of treatment

OPTIONS

FULL-MC recalculation using standard codes	~ 70 h/core
Commercial TPS using analytical pencil beam algorithm	~ 1 h/core

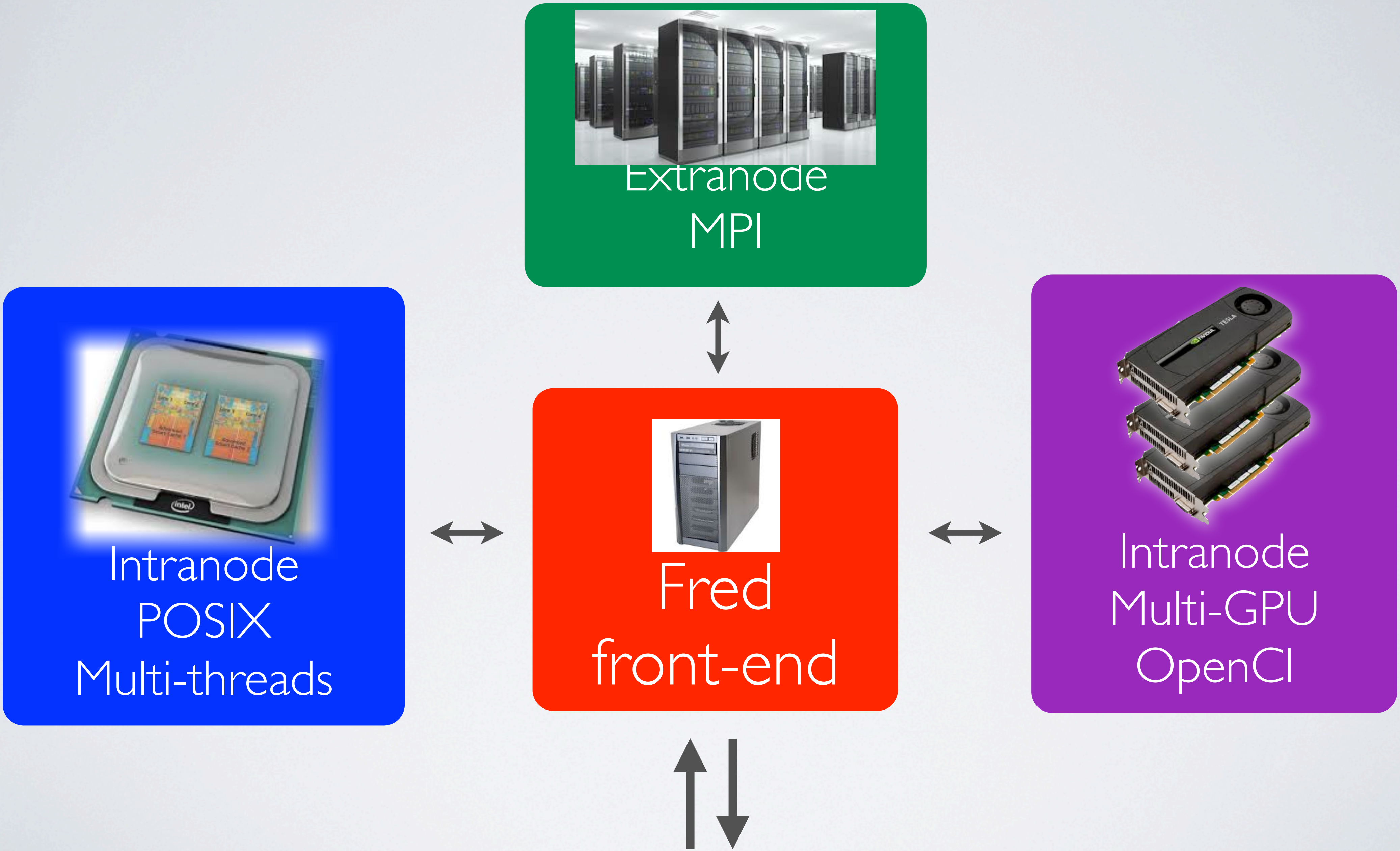
we need an answer while the patient is on the bench, i.e. **within a minute**

MC fast-recalc hardware

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

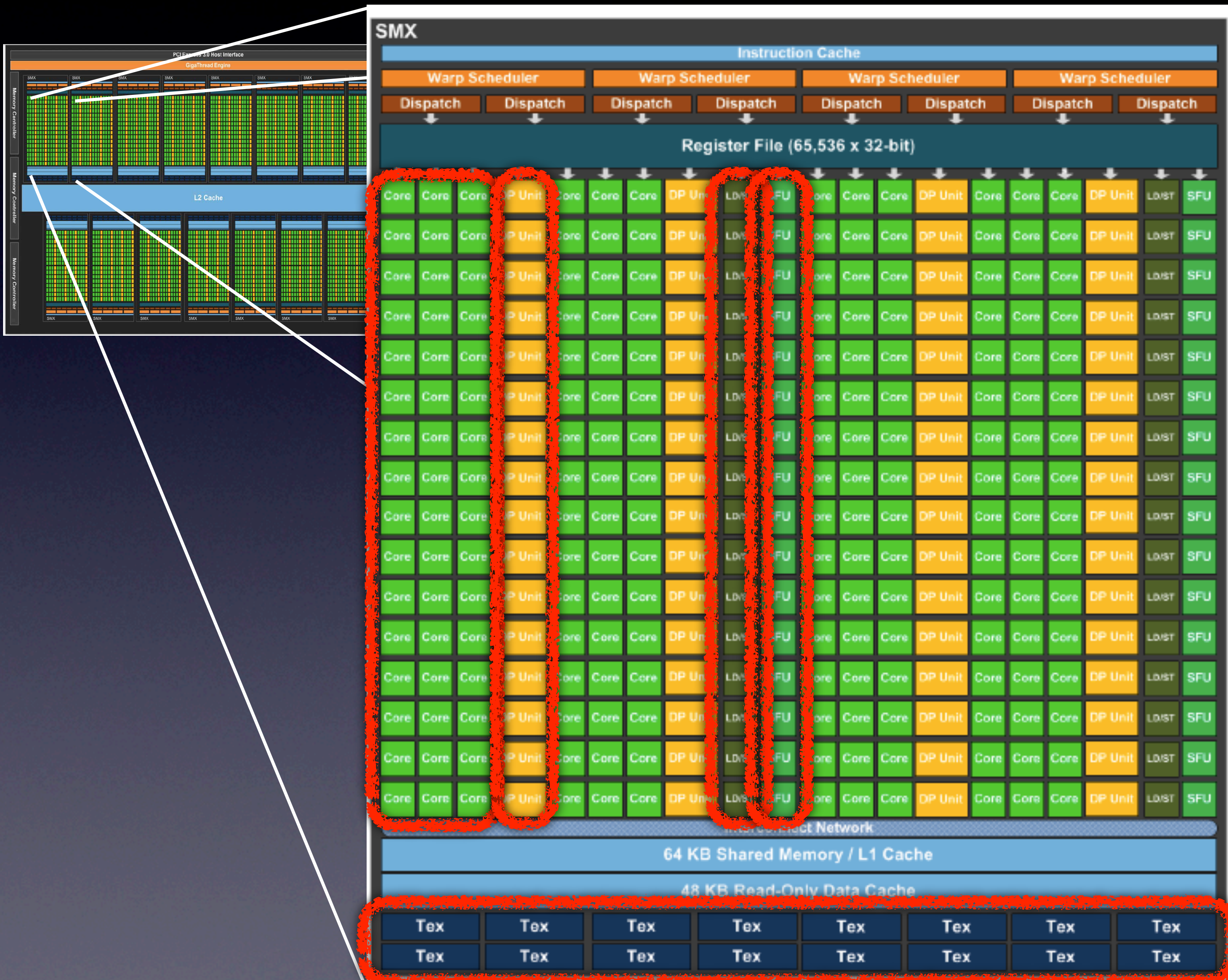
- low budget (€€€€)
- redundancy
- in-house maintenance

Parallel execution model in Fred



Anatomy of a GPU

Kepler architecture



192 CUDA cores
SP unit and IA unit

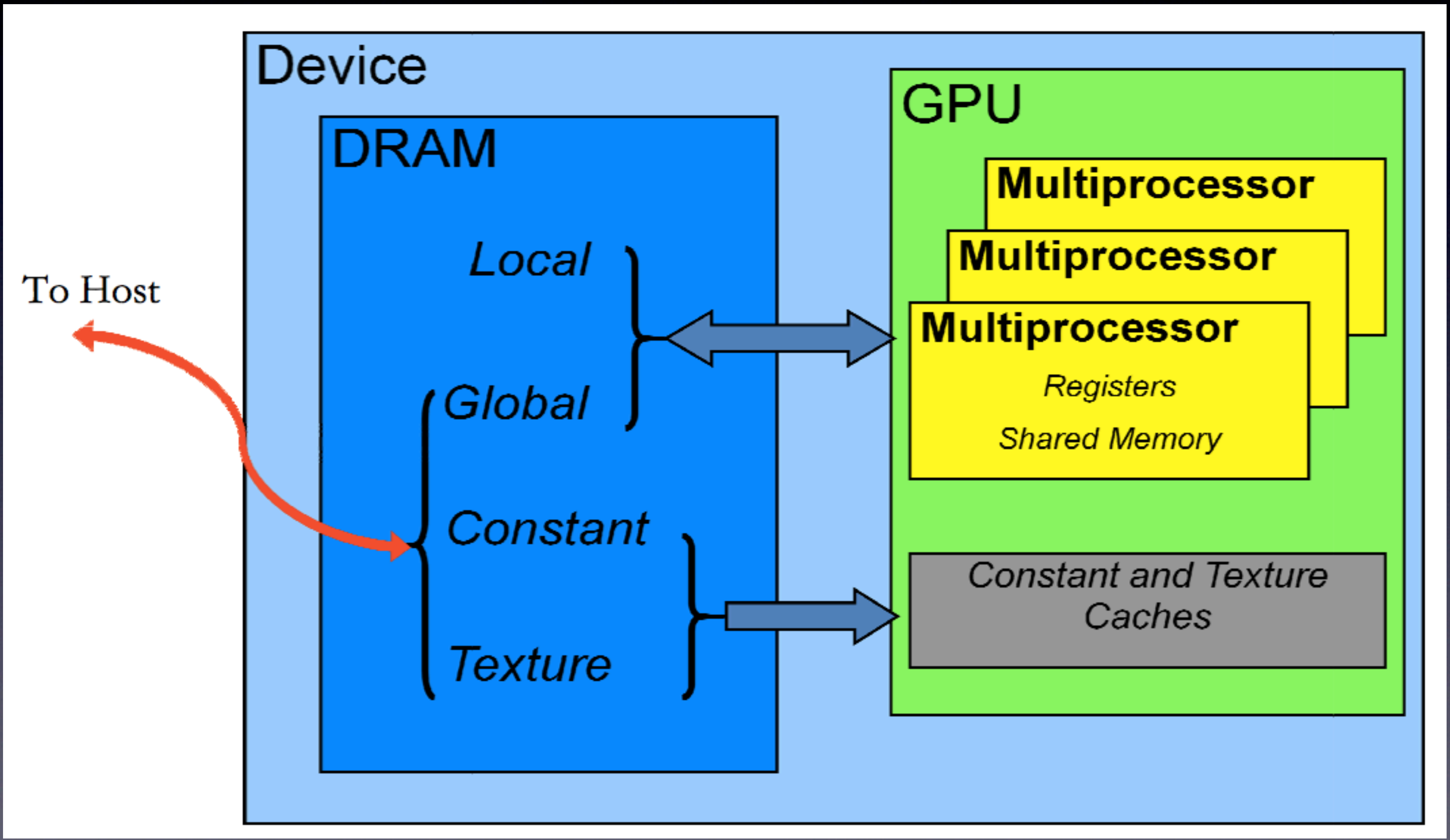
64 Double
Precision units

32 Load/Store
units

32 Special
function units

16 Texture
units

Memory paths



Performance on CPU and GPU

2x Intel Xeon 8-Core
E5-2687W 3,1GHz

		THREADS	primary/s	μs/primary
CPU	FLUKA	1	0.75K	1340
CPU	FRED	1	15K	68
CPU	FRED	16	48K	21
CPU	FRED	32	80K	12.5
GPU	FRED	1 GPU*	800K	1.35
GPU	FRED	2 GPU**	3500K	0.3

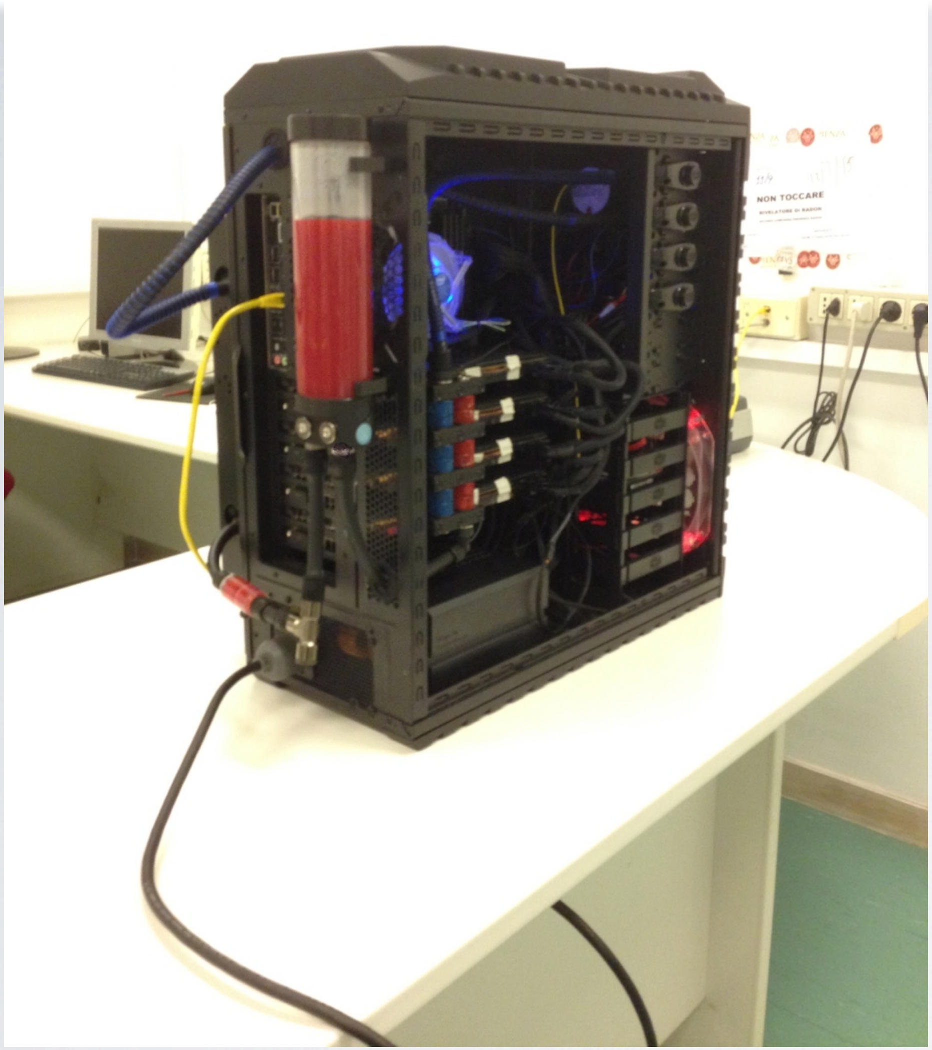
BENCHMARK SETUP

- 150 MeV protons
- FWHM = 1cm
- liquid water phantom (20x20x20 cm)
- voxel resolution = 2x2x2mm (TPS-like)
- FRED: complete physics model
- FLUKA: HADROnTHErapy defaults

* LAPTOP: MacBookPro (AMD Radeon R9 M370X)

** DESKTOP: Mac Pro (AMD FirePro D300)

Water-cooled 4 GPU workstation



Hardware concept and realization: S.Pioli

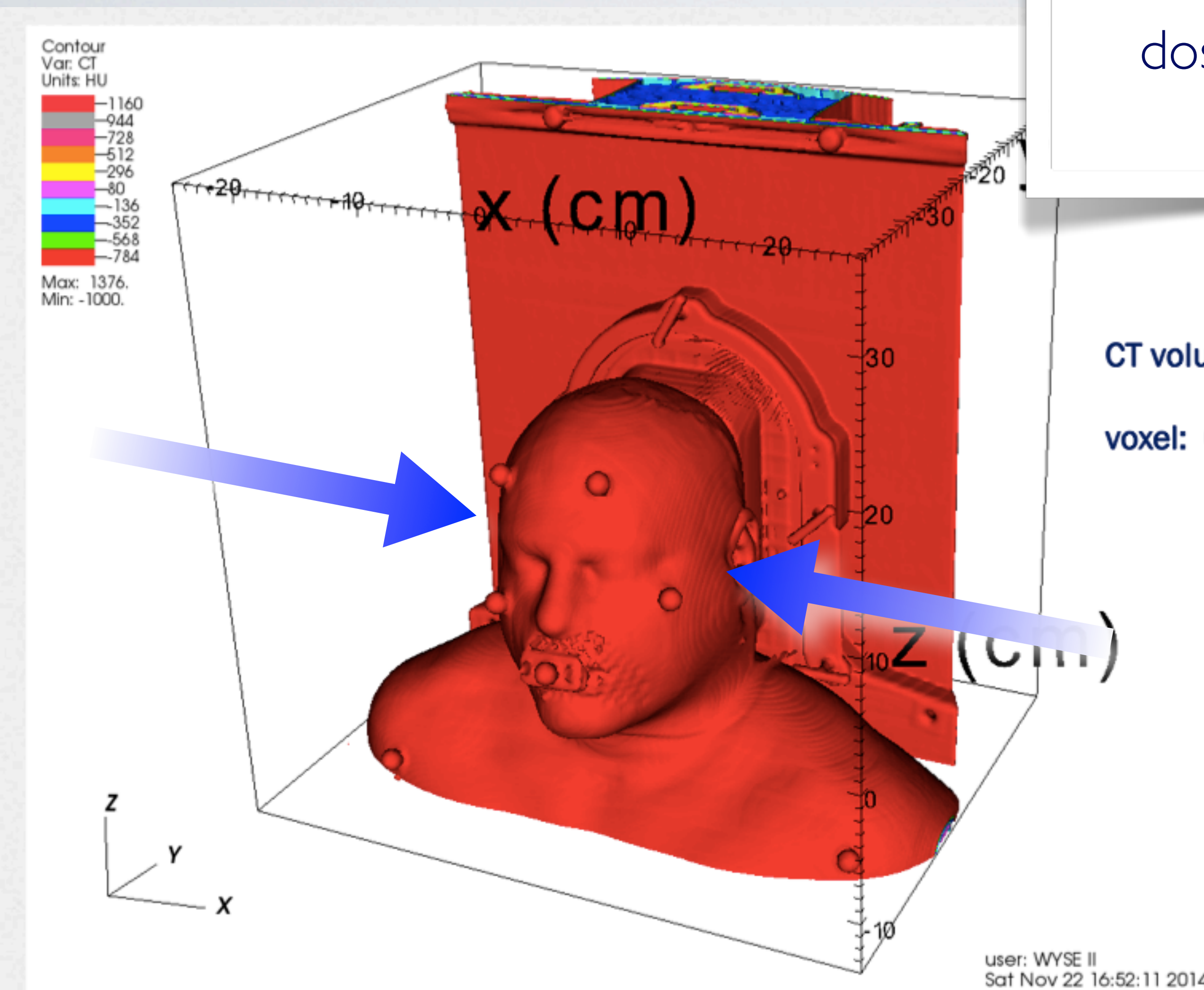
Hardware:
4x GPU NVIDIA GTX 980
1x CPU Intel i7-5930K
@ 3,50 GHz with 12-core

Clinical case: glioblastoma

6400 pencil beams, 5000 primary each

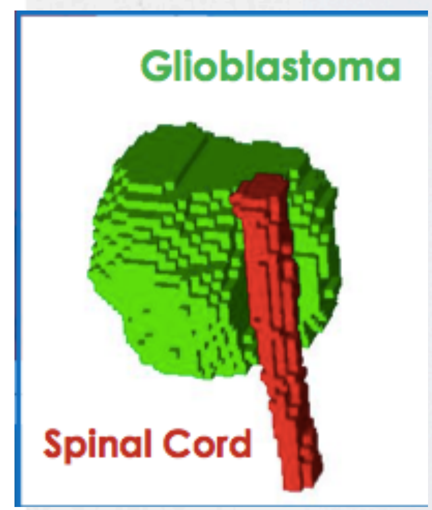
dose scoring volume resolution:

2 x 2 x 2 mm

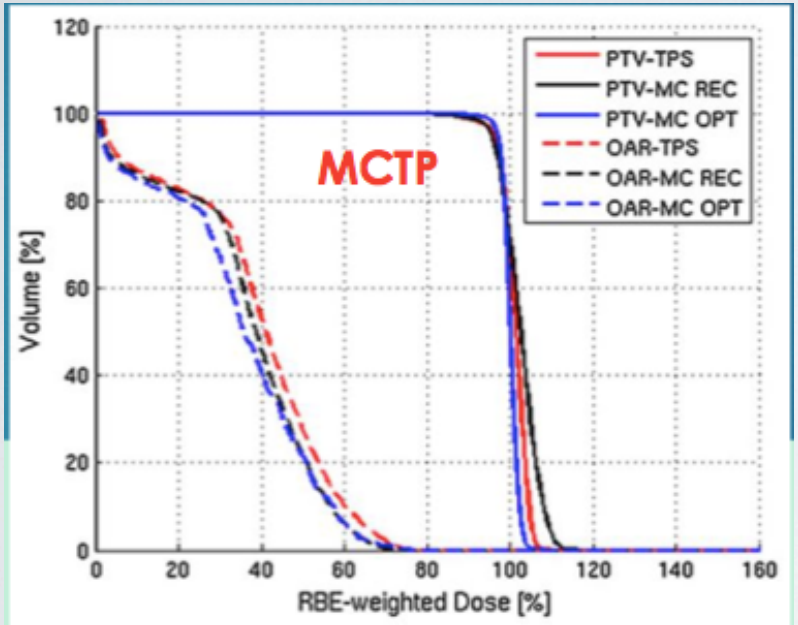


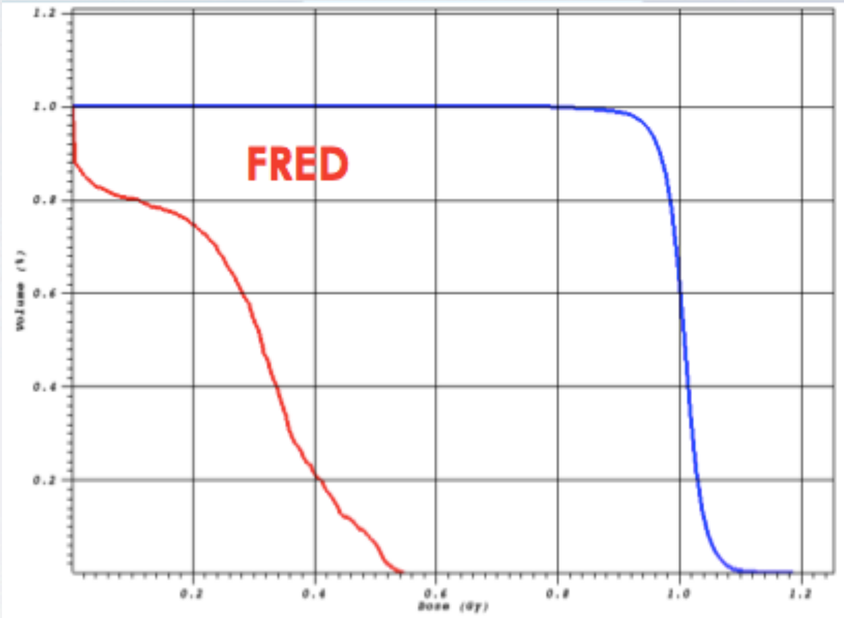
CT volume: 0,42 m³

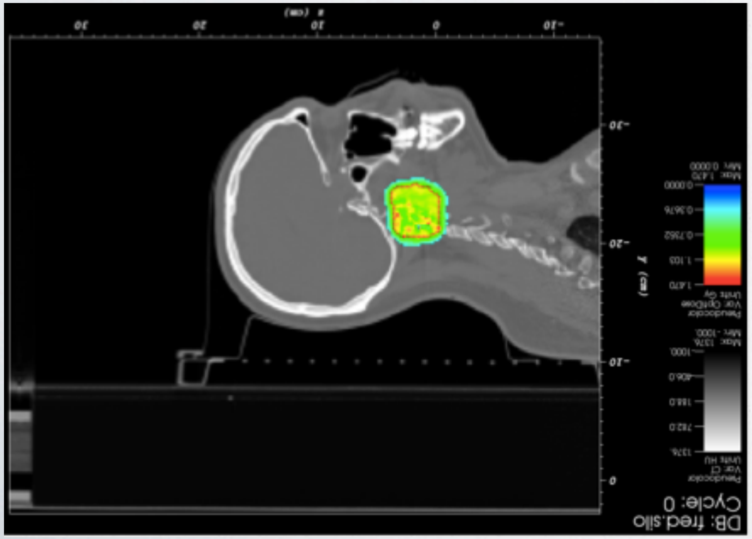
voxel: 0,2 x 0,2 x 0,2 cm³



Clinical case example: glioblastoma







complete recalculation of TP performed in less than 30 s on a 4 GPU water-cooled workstation developed at URLS

Speed-up

Std full-MC code (Fluka) : 72h on single CPU
=> **10 ms/primary**

GPU fast-MC code (Fred): 20 s on a single GPU
=> **0.5 μs/primary**

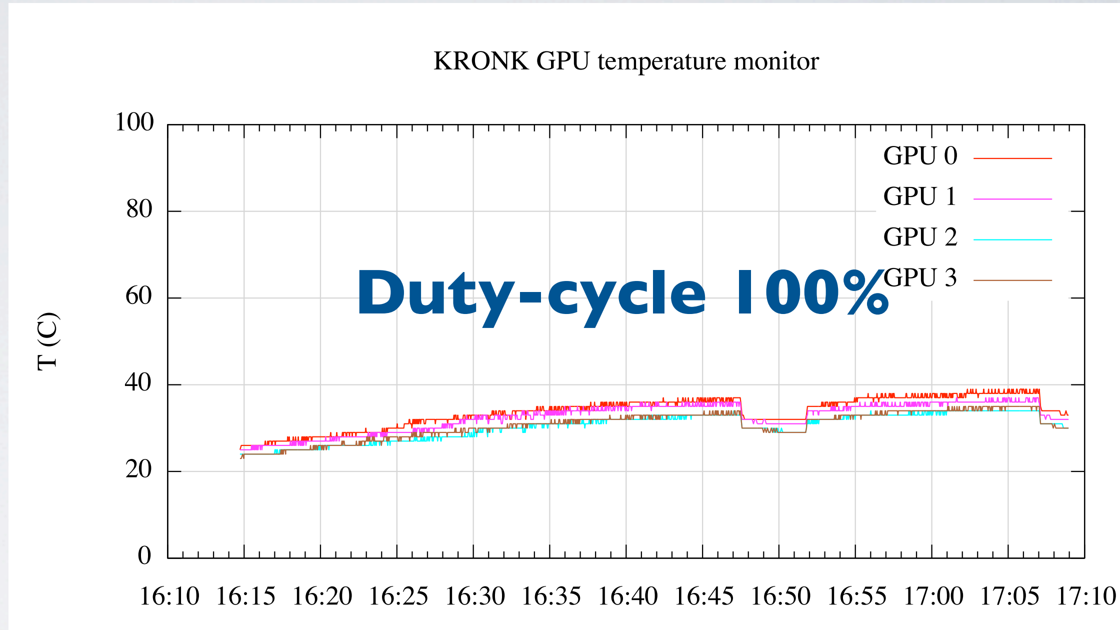
Speed-up is a very personal, qualitative and usually ill-defined procedure to measure computational performance

... nevertheless, we can get an accurate answer 20.000 x faster than before: ENCOURAGING!

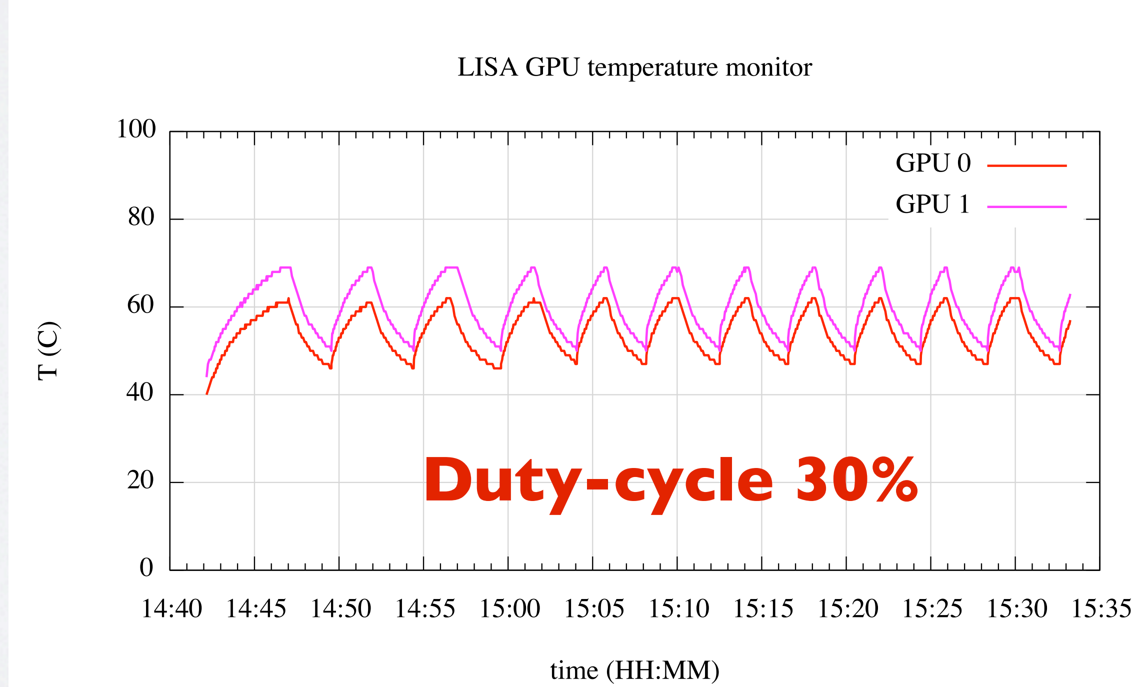
Heat and Duty-cycle

6 core + 4 GPU
water cooling

Sustained calculation test: temperature of all GPU cards must stay below 70°C



Water-cooling



Air-cooling

FUTURE DEVELOPMENTS AND PERSPECTIVES

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