

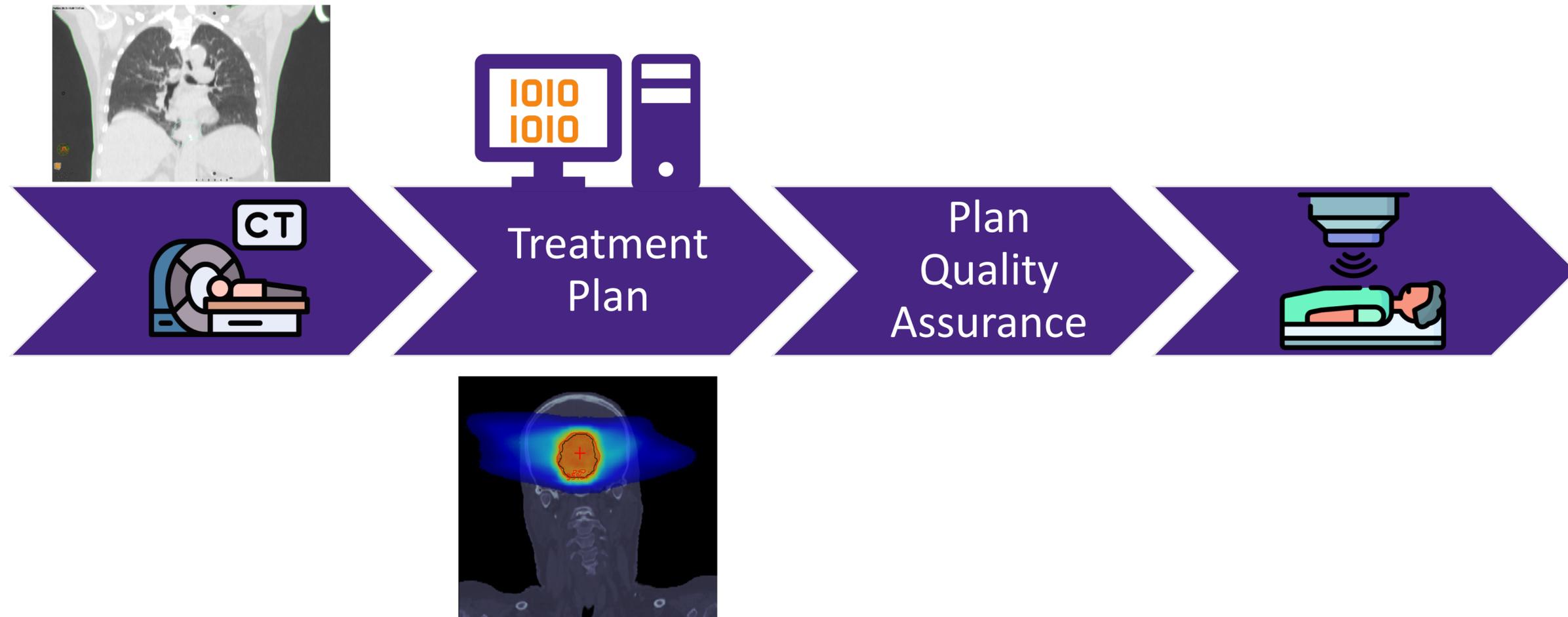


Fast Monte Carlo as a support tool for proton therapy

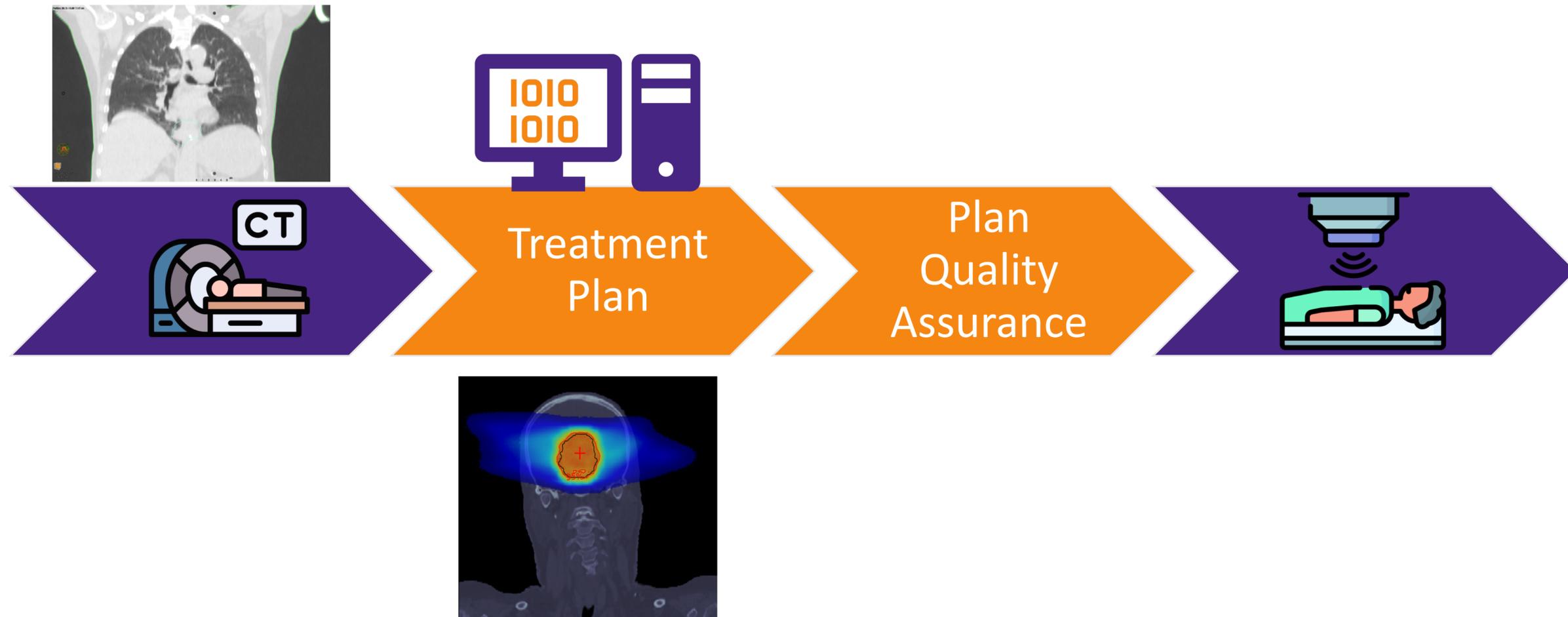
Giorgio Cartechini, Maastric clinic, Maastricht, The Netherlands
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GATE 10 Hackathon 2026 – Delft, 3-5 February 2026

Introduction:



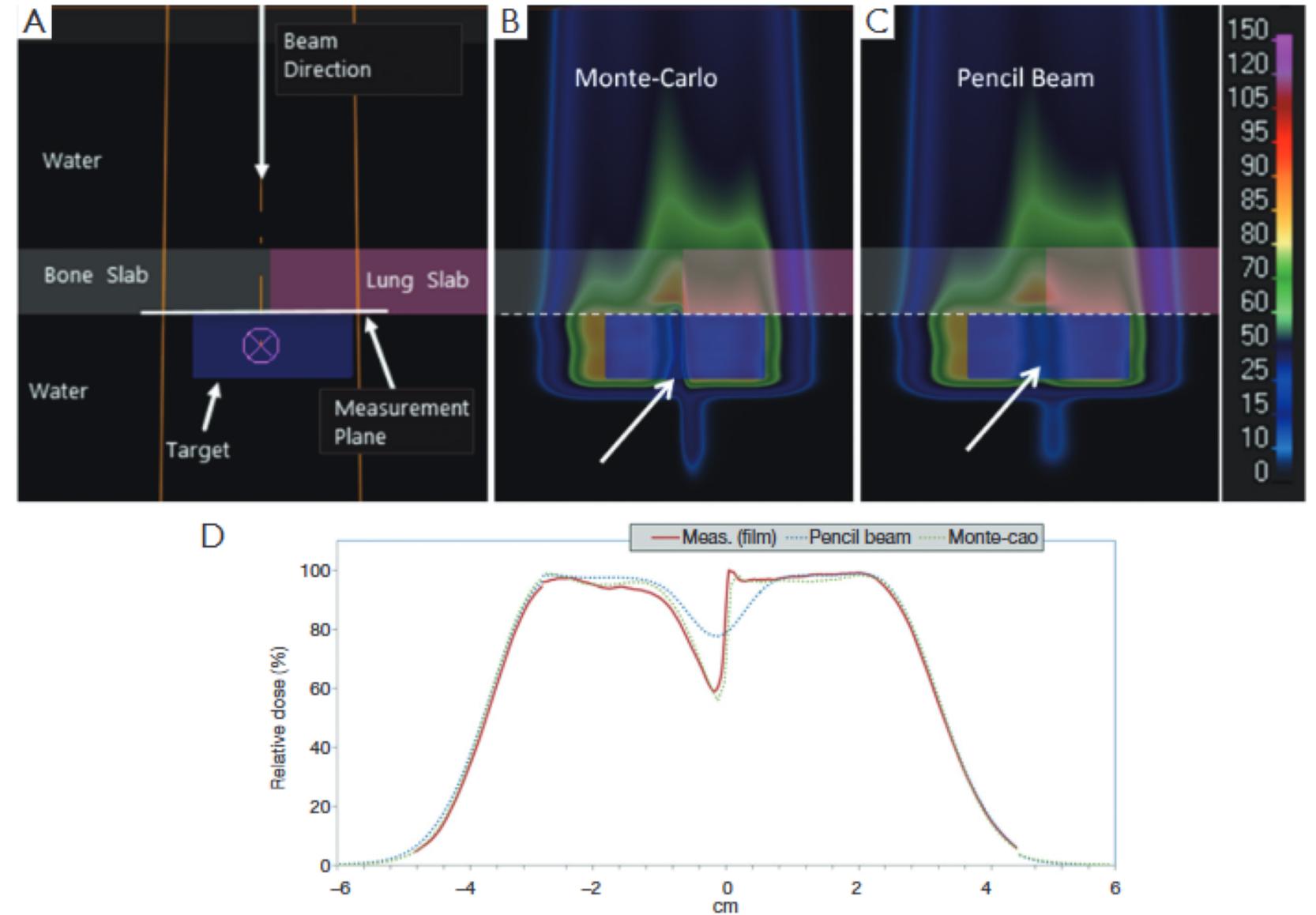
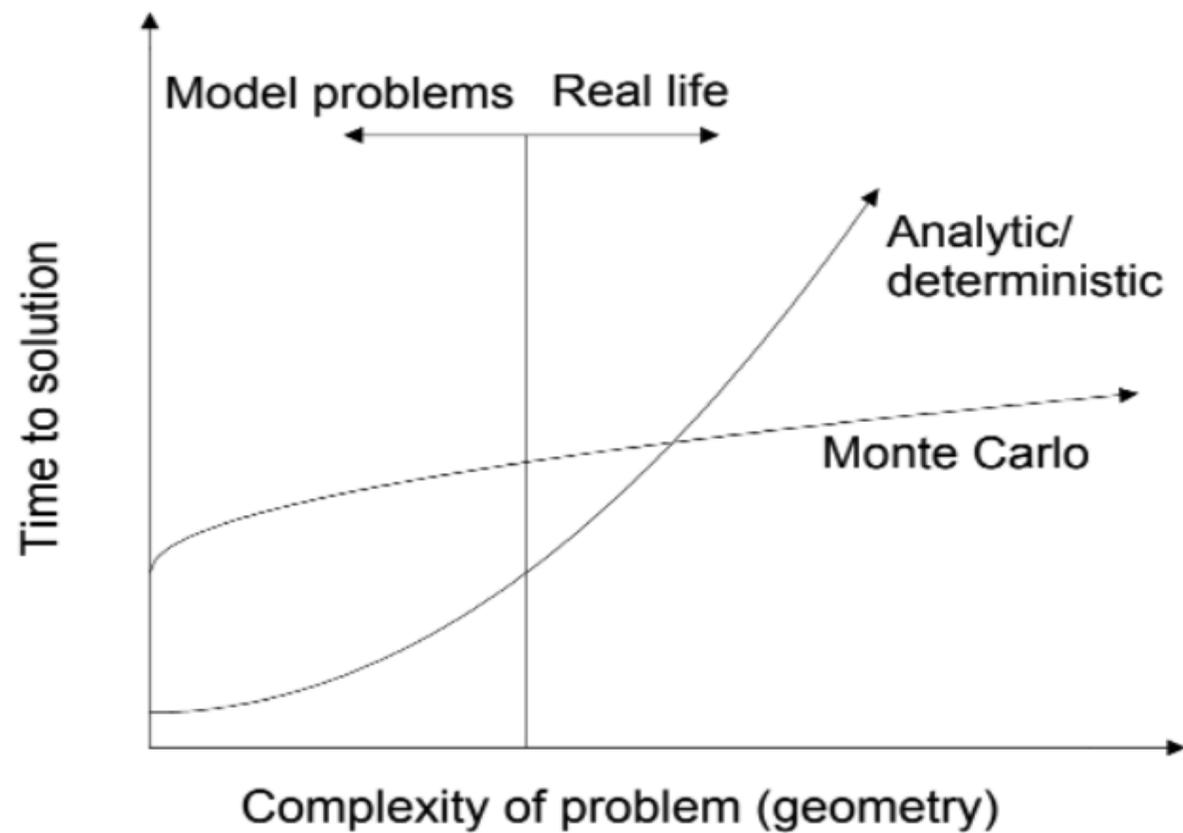
Introduction:



- The Monte Carlo algorithm is the standard for dose calculation in the radiotherapy fields
- Dose calculation engines must be accurate, precise, and fast

Monte Carlo as gold standard for particle therapy

Monte Carlo vs deterministic/analytic methods

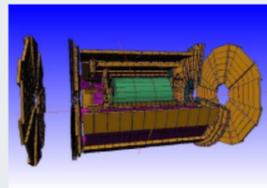


Saini, Jatinder, et al. *Translational lung cancer research* 7.2 (2018): 171.

General Purpose Monte Carlo: e.g. Geant4

Applications

High Energy Physics



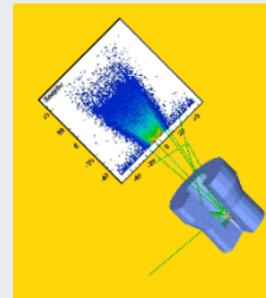
>>more high energy physics

Space and Radiation



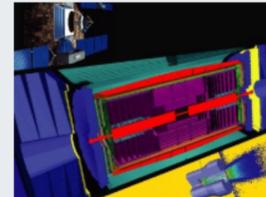
>>more space and radiation

Medical



>>more medical

Technology Transfer



>>more technology transfer

<https://geant4.web.cern.ch/>



https://www.reddit.com/r/funny/comments/fezb60/new_man_shampoo/

Commercial Monte Carlo dose engines for particle therapy

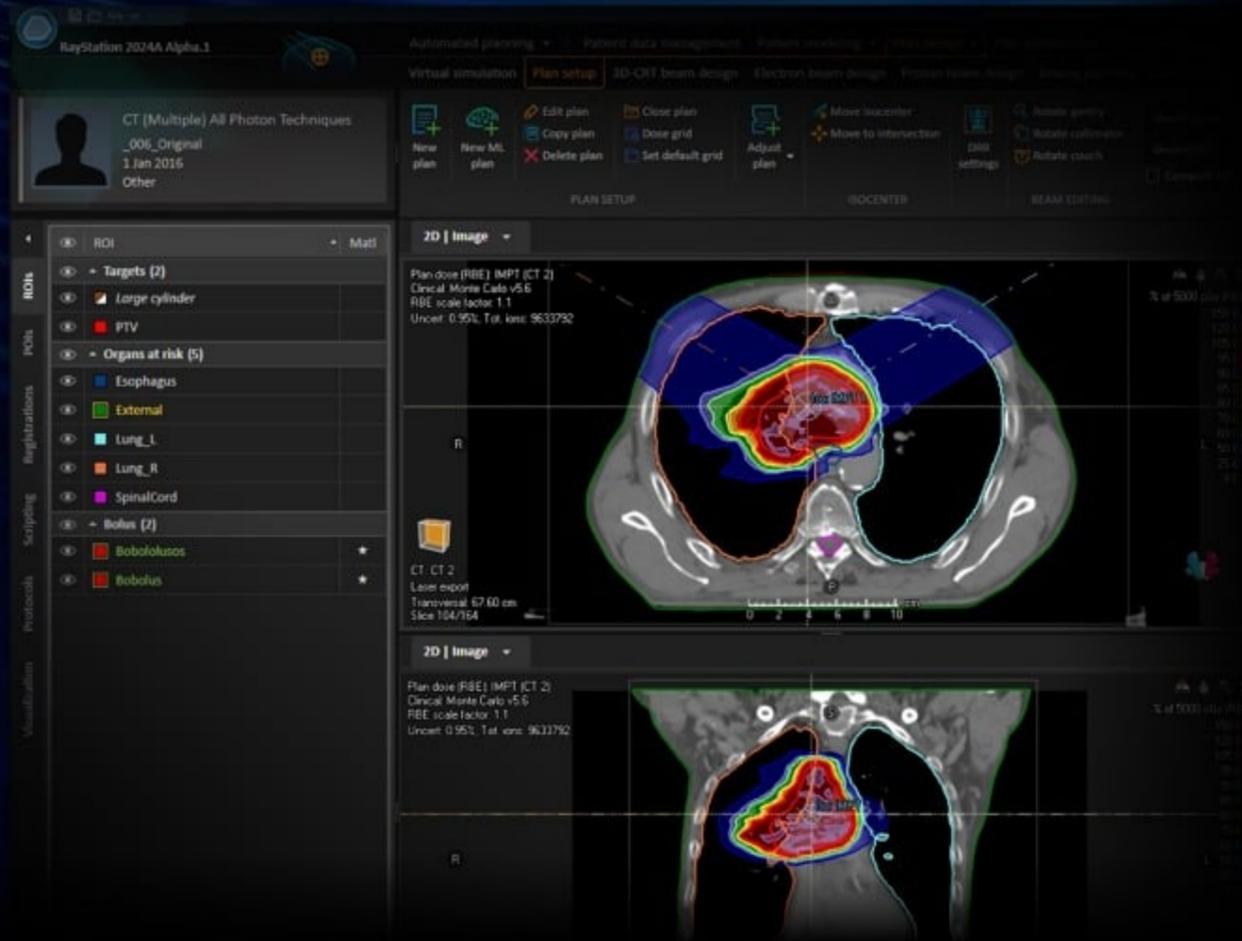
REVOLUTIONIZING COMPUTATION SPEED
We're talking seconds, not minutes

2-BEAM IMPT LUNG
1.2 MILLION VOXELS
64 ITERATIONS

9s OPTIMIZATION

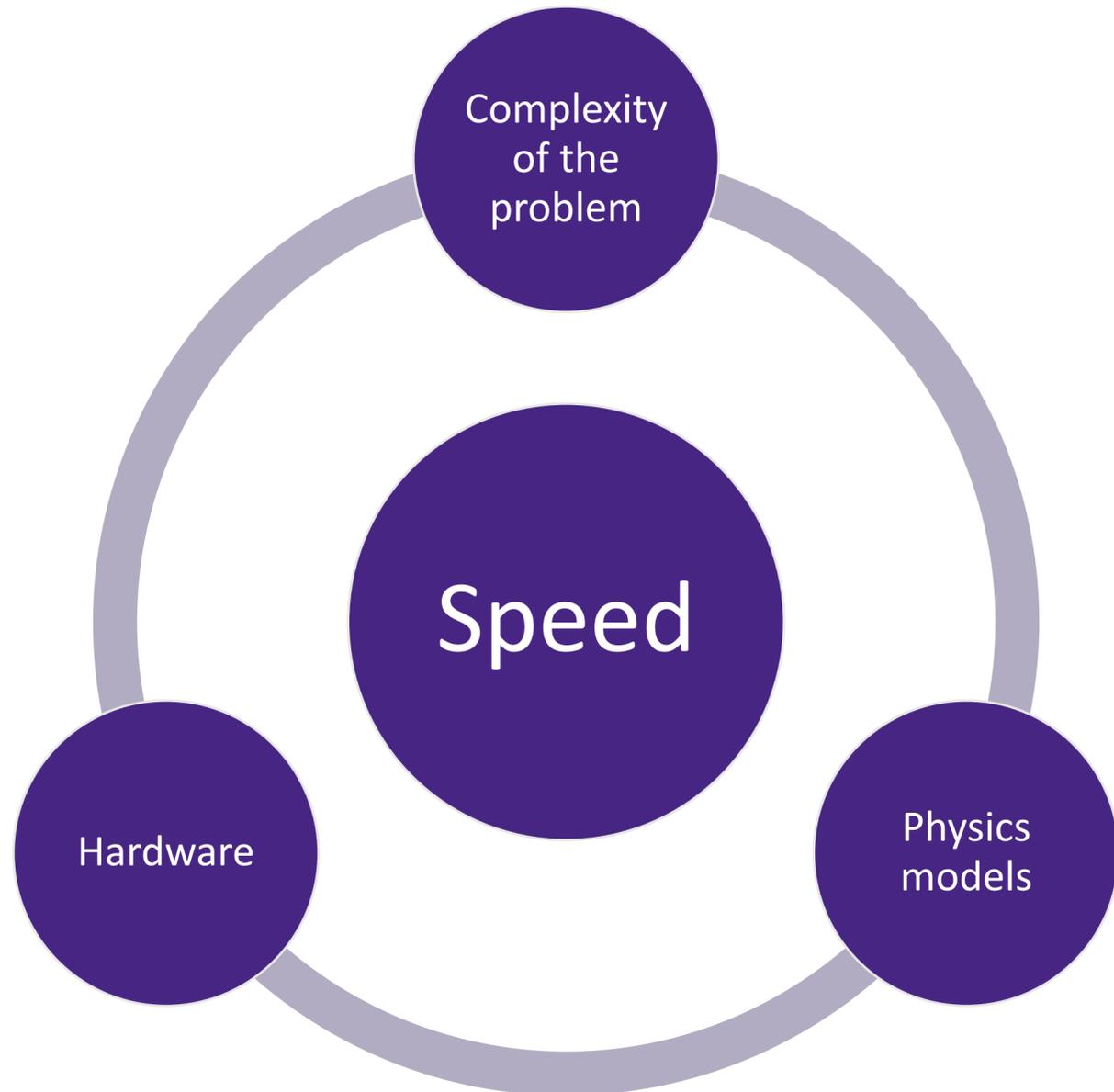
1s MC FINAL DOSE
1% UNCERTAINTY

RayStation GPU



<https://www.raysearchlabs.com/fast-and-accurate-dose-computations/>

Fast Monte Carlo dose engines for particle therapy



- GPU-based
- Electron, Carbon, proton and photons
- Next release: neutrons



- CPU-based
- protons and alphas
- **No** electrons, neutrons, or gammas are tracked

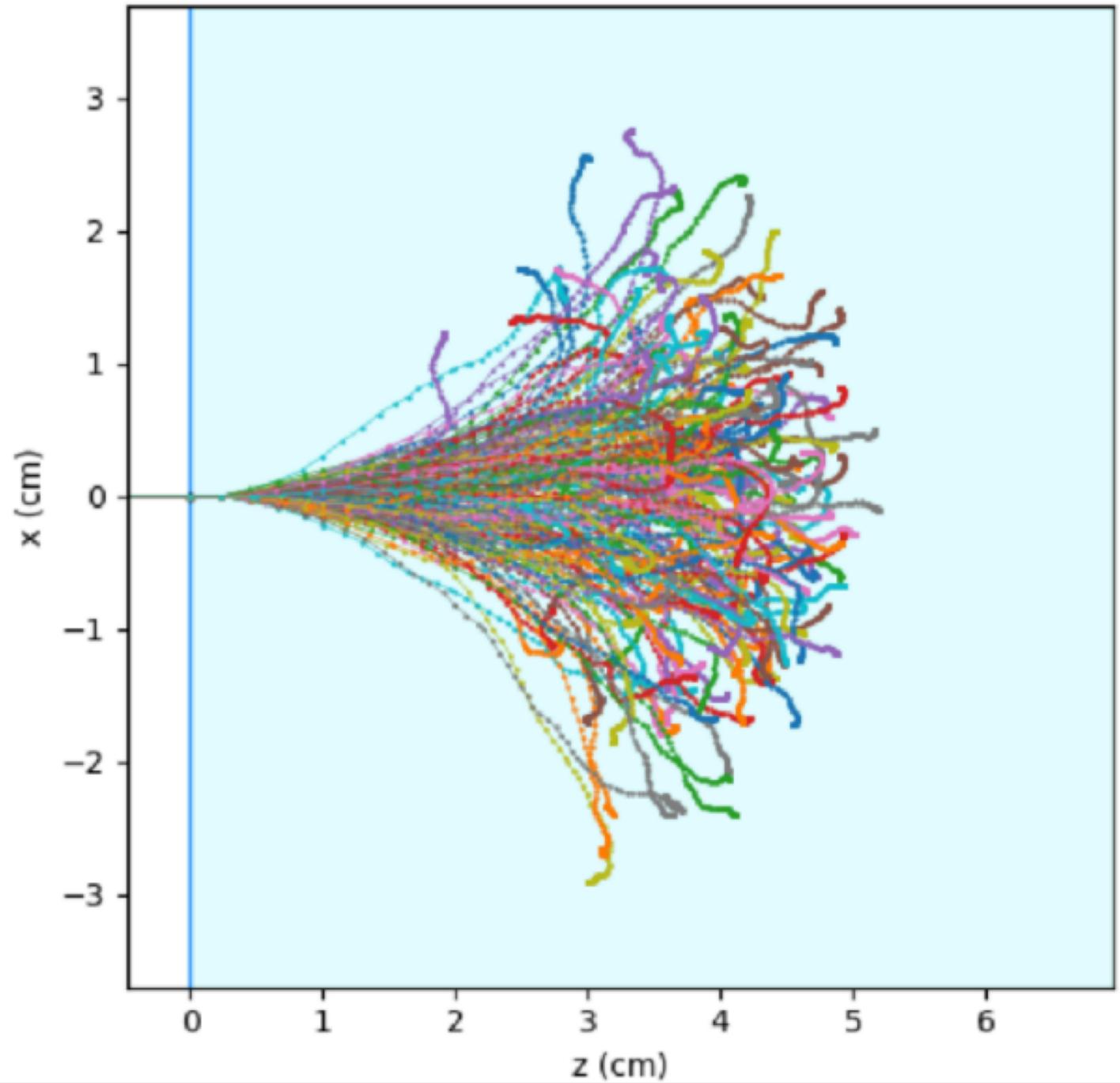
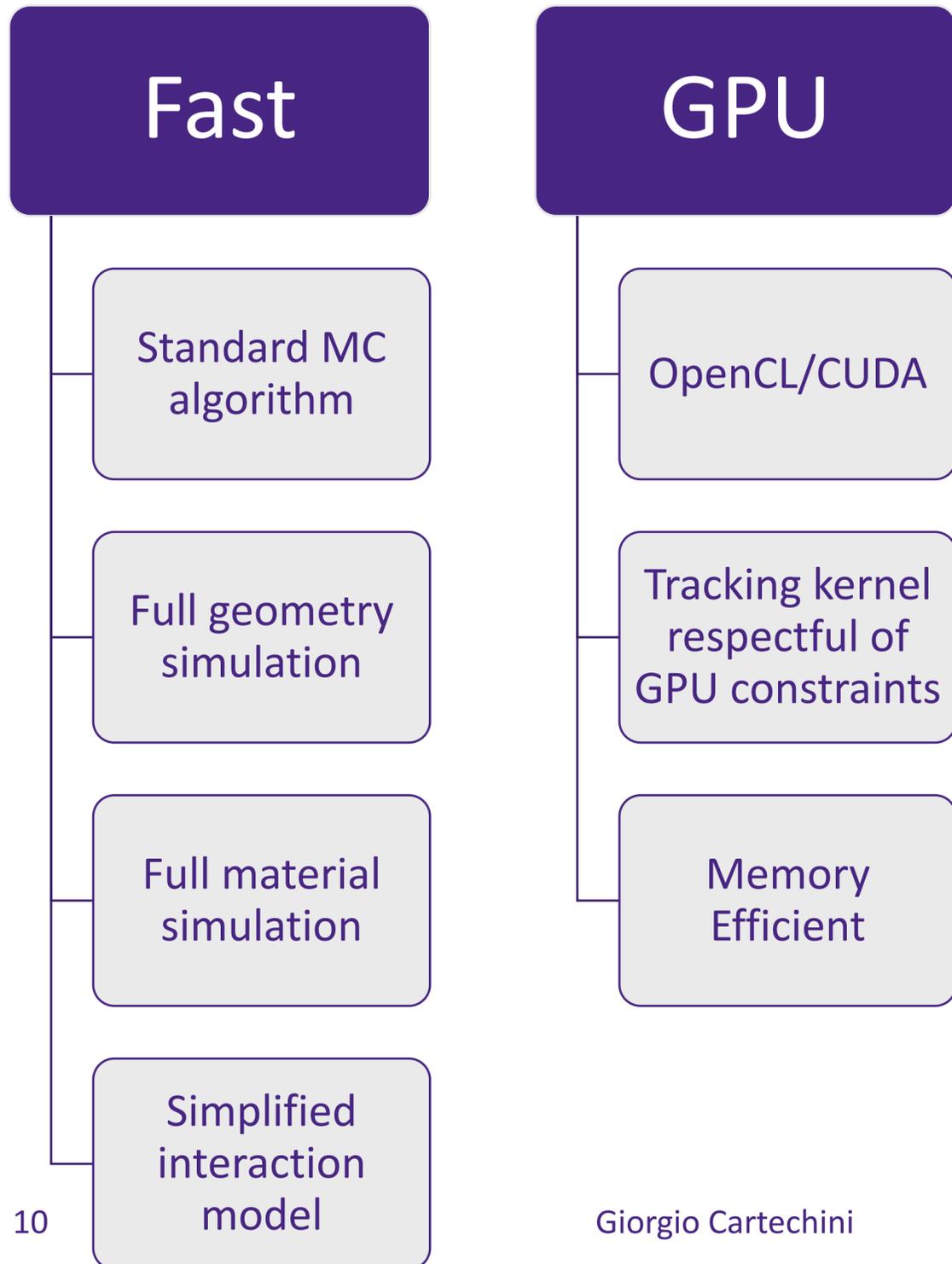
Fred

collaboration

www.fred-mc.org



FRED: Fast MC on GPU

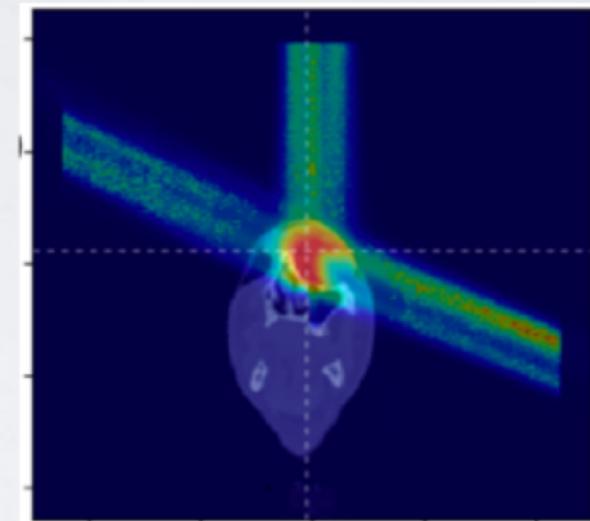


Tracking performance

Benchmark = dose calculation for 150 MeV protons in liquid water phantom with 2 mm voxel resolution.



	Hardware	primary/s	Patient plan recalculation*
FLUKA/GEANT4	single CPU core	$0,75 \times 10^3$	16 days
FRED	single CPU core	15×10^3	19 hours
FRED	single GPU card	1×10^7	2.3 min
FRED	cluster of 144 GPU cards	3×10^8	3 s



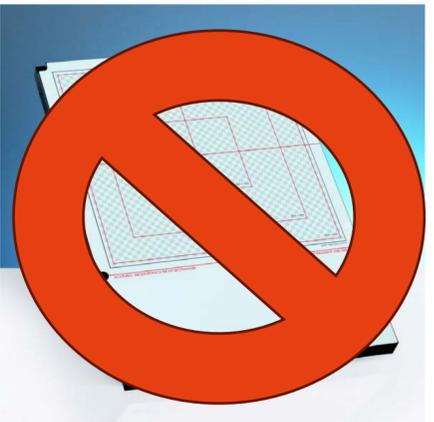
* Patient case: 3-fields Head-Neck plan at 1% of total protons = 700 mln primaries

FRED Applications @ Maastrro

Patient-specific QA (PSQA)



Before 2023



Planned dose Vs delivered dose

Started 2020
After 2023, only FRED



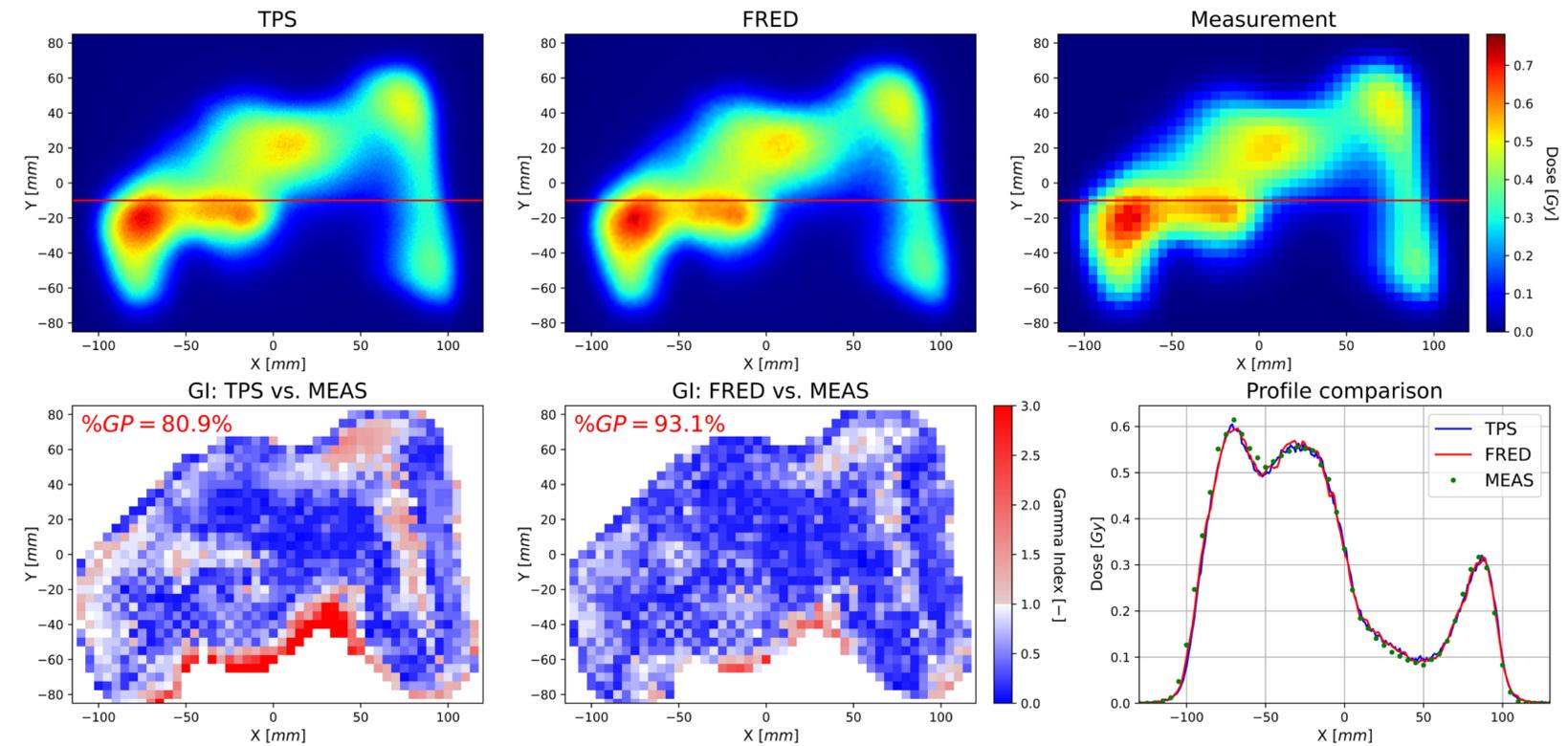
MC-based PSQA: five years of experience

FRED Recalculation takes a few minutes on 1 GPU

Only 2 plans failed and revealed planning issues

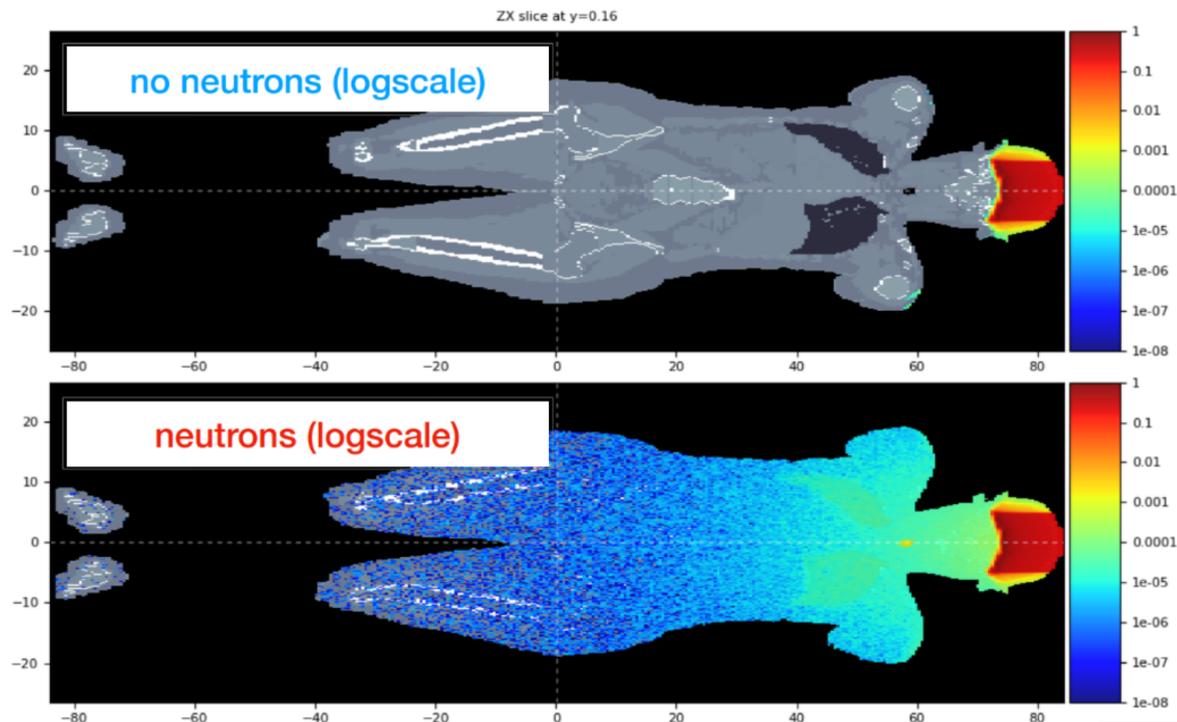
July 2020 - September 2024: **4783** plans of which **3137** machine logfile-based PSQA, with a final passing rate of 99.5%

2392 hours machine time (300 working days) spared, less routine QA work (assuming 30 min per PSQA measurement)



Out-of-Field dose for pregnant patients

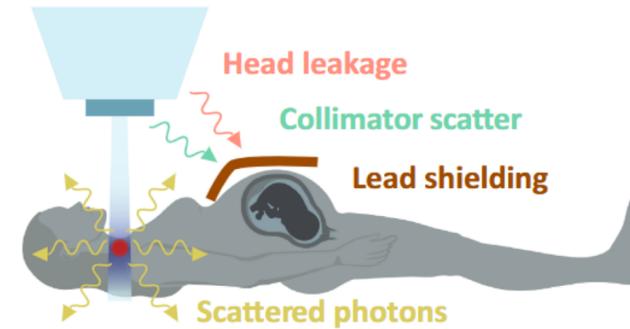
- The use of radiation therapy for pregnant patients is often excluded due to the dose absorbed by the fetus.
- Commercial TPS and Fast MC codes do not compute the dose out-of-field.
- In standard MC codes, the dose out-of-field requires higher statistics and longer computational time.



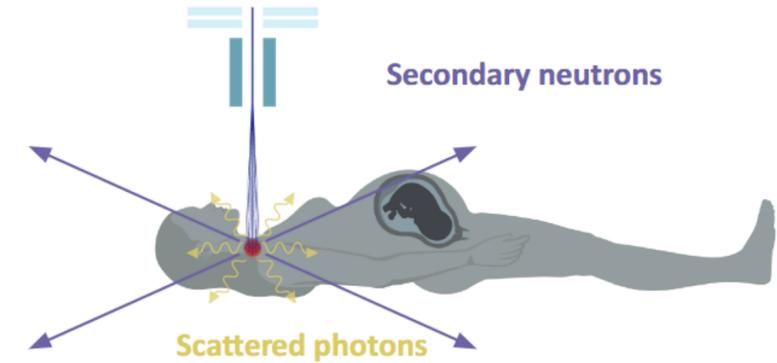
Giorgio Cartechini



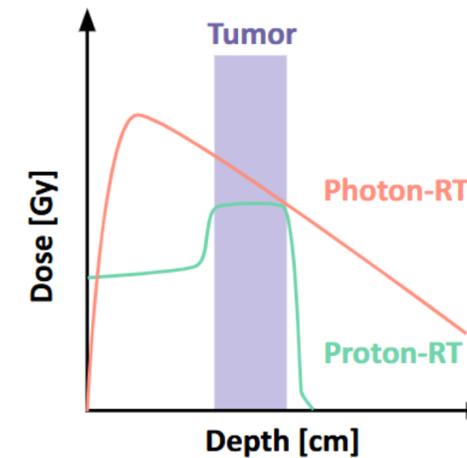
(A) **Photon-RT**



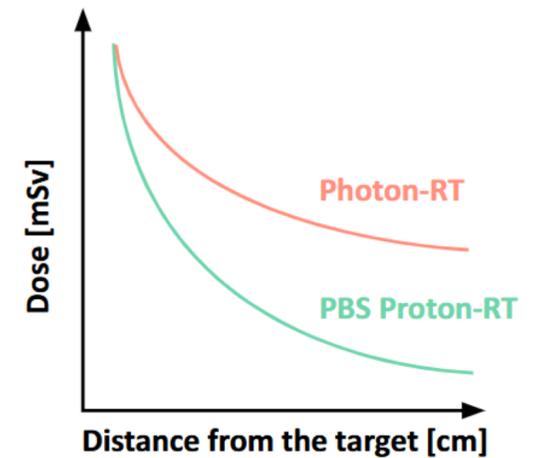
(B) **PBS Proton-RT**



(C) **In-field dose distribution**

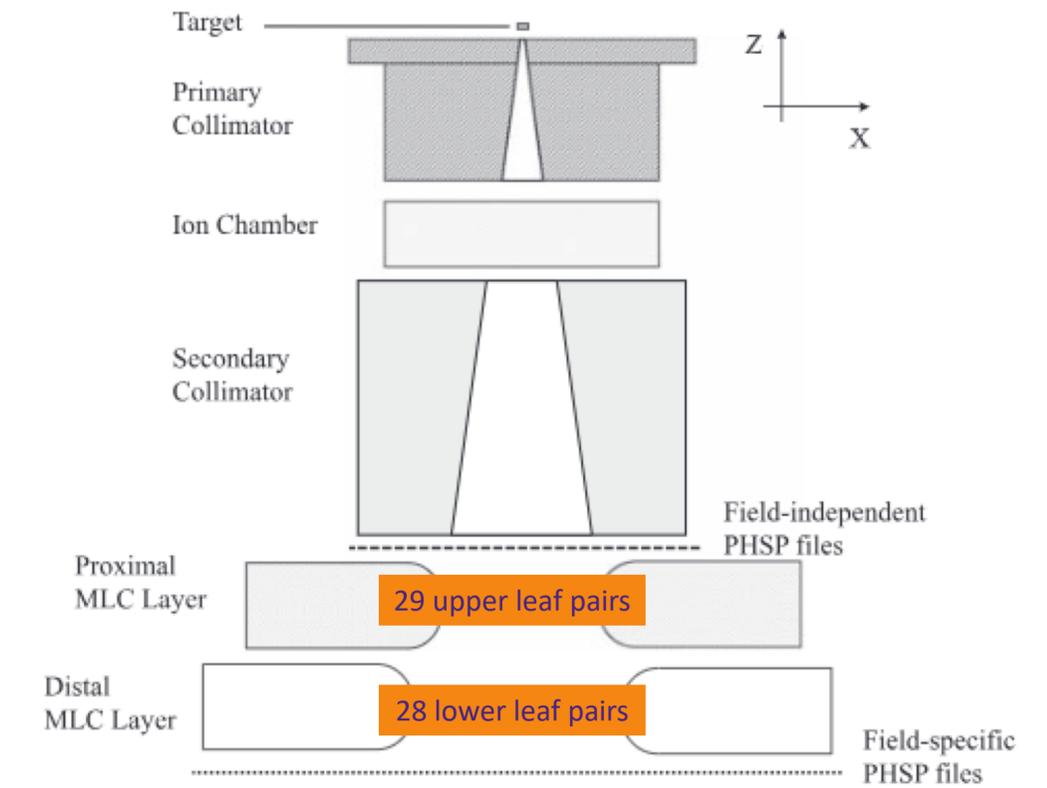
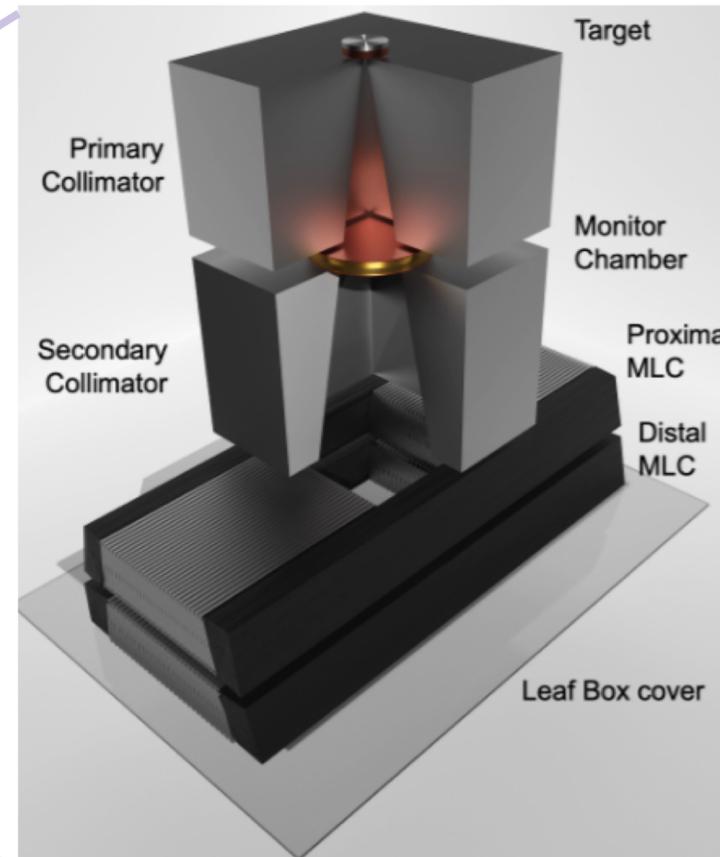
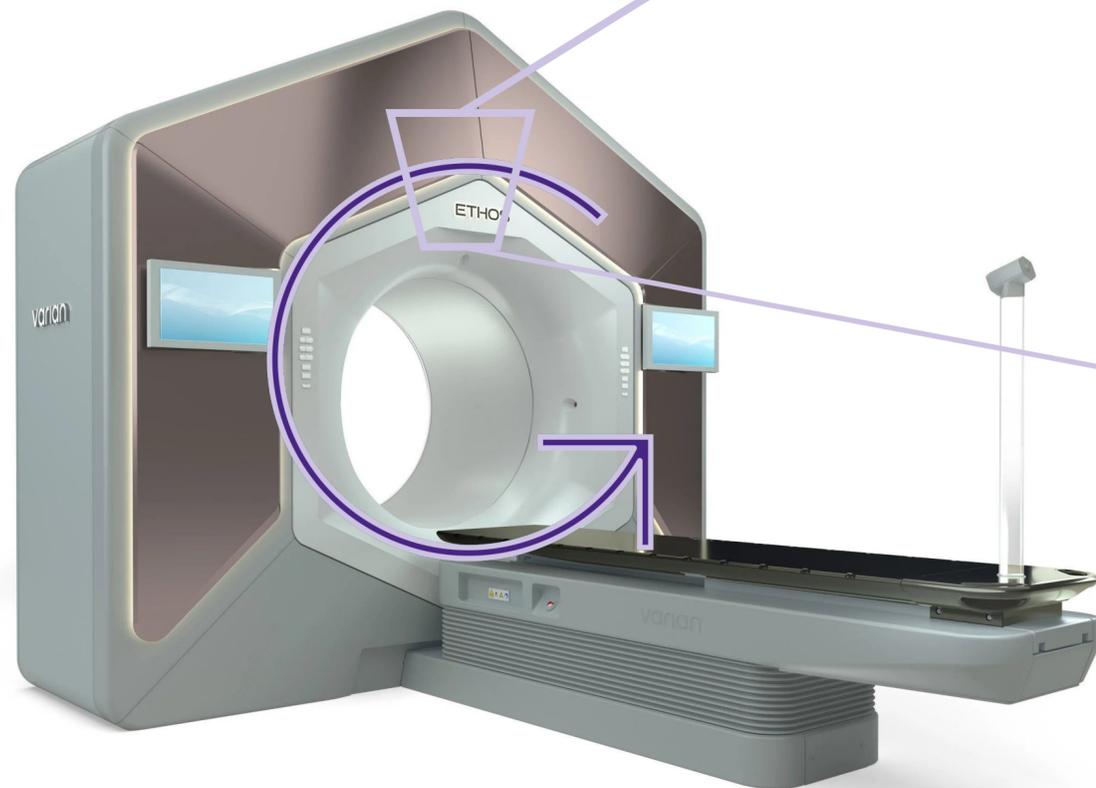


(D) **Out-of-field dose distribution**



Blommaert, J., et al. (2024). *Acta Obstetrica et Gynecologica Scandinavica*, 103(4), 767-774.

Photon machine beam commissioning: Ethos/Halcyon



L Laakkonen et al. Phys. Med. Biol. 68 (2023) 044002



Take home message

- General-purpose Monte Carlo (MC) codes are essential tools for research and development, providing simulations with high accuracy and great detail.
- However, their computational demands make them too slow for routine clinical use, where accurate results are needed within minutes.
- Fast MC codes, such as FRED and MCsquare, are specifically optimized for targeted clinical tasks like dose recalculation, balancing speed and accuracy.
- Despite this, general-purpose MC codes remain indispensable as reference benchmarks for developing, validating, and commissioning fast MC engines.

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Thank you!

Maastrro
In the best of hands



Fred