Computational Challenges in Image Reconstruction for Proton Computed Tomography

CERN School of Computing on IT Services

Ferney-Voltaire, France

04-08 11 2024

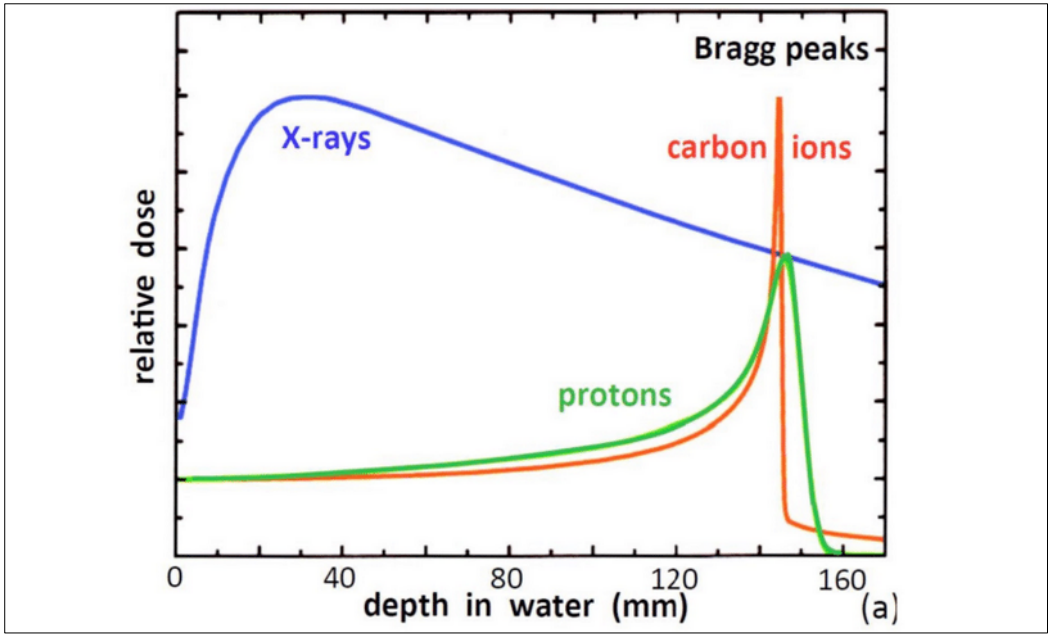
GÁBOR BÍRÓ

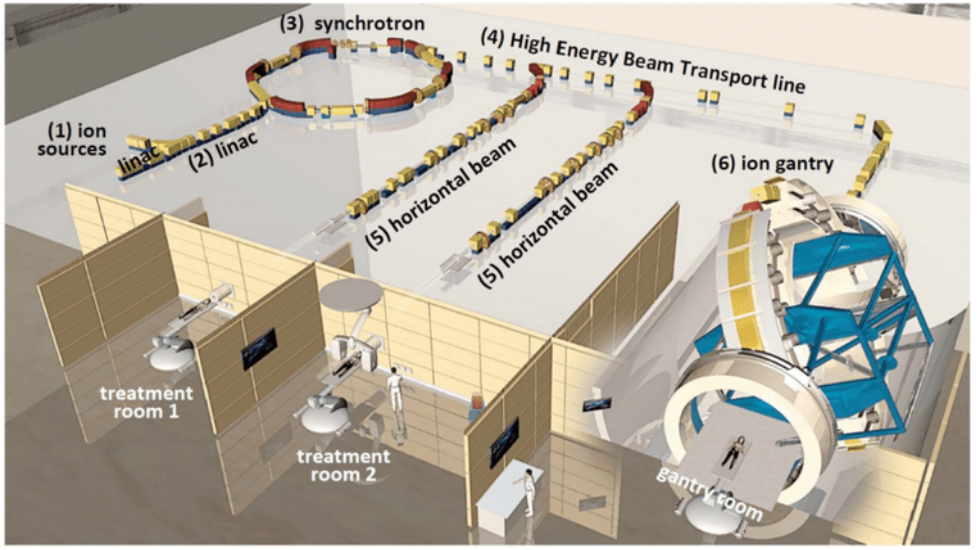
biro.gabor@wigner.hun-ren.hu

Zsófia Jólesz
Bence Dudás
Gergely Gábor Barnaföldi
Gábor Papp

Hadron therapy

- Cancer treatment: surgery, chemotherapy, radiotherapy, immunotherapy
- Key advantage of ions: Bragg peak
- Effective eradication of all tumor cells ↔ avoid injury to healthy tissue





Layout figure of HIT Centre (Heidelberg)

- Challenge(s): Stopping power of tissue in front of the tumor has to be known
- Current practice: Hounsfield units (X-ray attenuation in tissue) → energy loss of protons
  - **The conversion is not accurate! (uncertainty: ~7%)**

Proton Computed Tomography

Irradiation of the phantom with high energy (~100 MeV) protons

↓

Detector signals

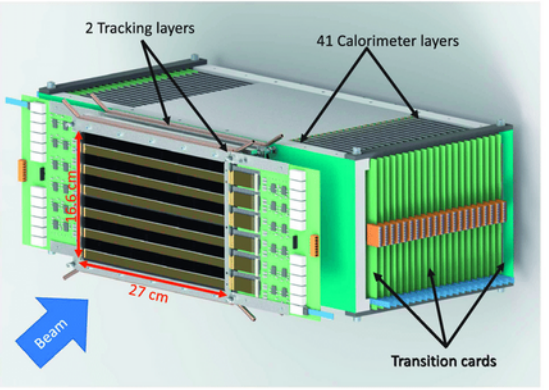
↓

Track (proton energy and direction) reconstruction

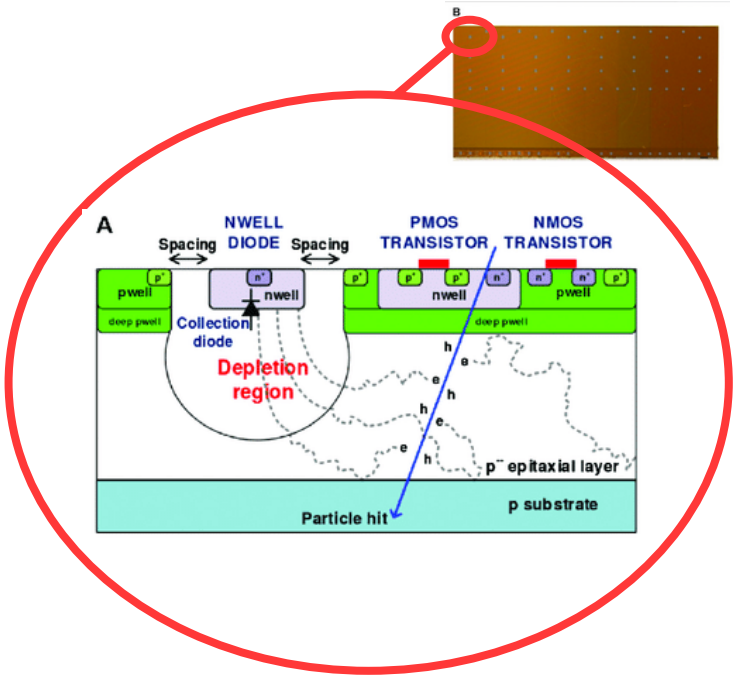
↓

Reconstruction of the RSP map (image) of the patient

- Bergen pCT Collaboration
- The detector system is based on the ALPIDE chip (**ALICE ITS**), using planes of Monolithic Active Pixel Sensors (MAPS)
- Digital tracking calorimeter with 41+2 sensor+absorber layer
- 1024 × 512 pixel (29μm^2) per layer, resulting in ~5μm track position resolution
  - ~10^2 tracks per readout frame
- **The challenge**: processing ~10^7 primaries per projection (2D) within **minutes**



Front. Phys. 8 (2020), 460



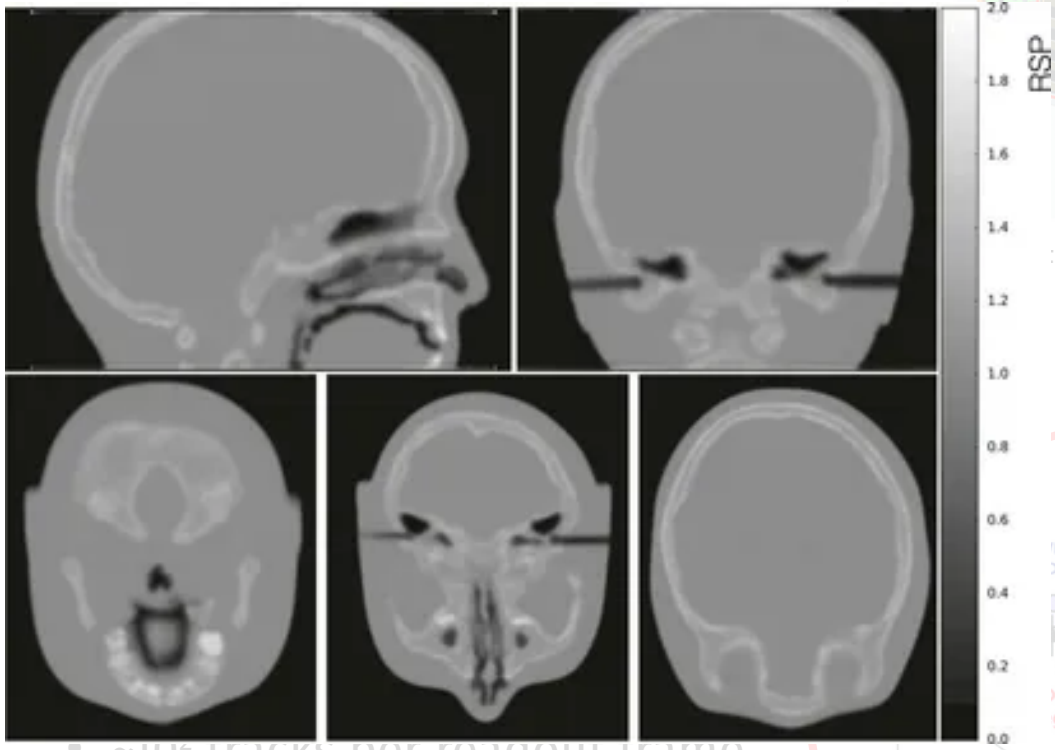
Proton Computed Tomography

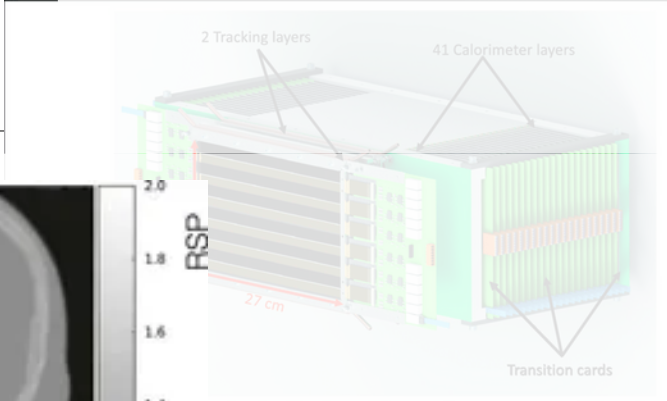
Irradiation of the phantom with high energy (~100 MeV) protons

Detector signals

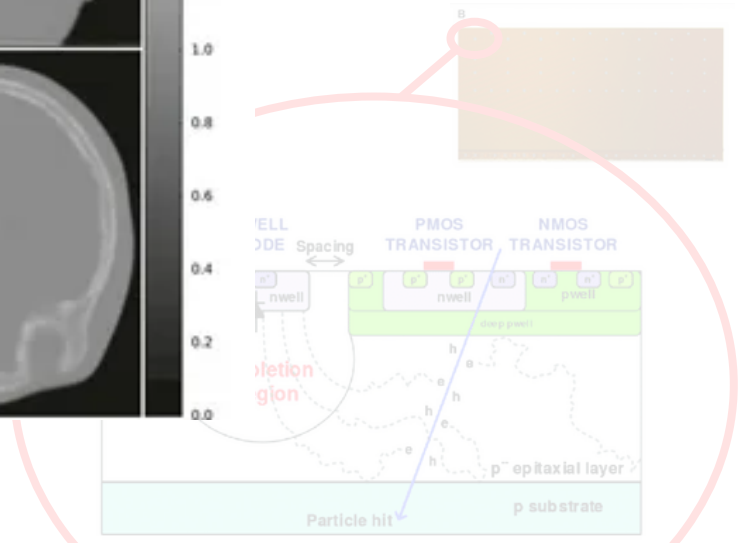
Track (proton energy and direction) reconstruction

Reconstruction of the RSP map (image) of the patient



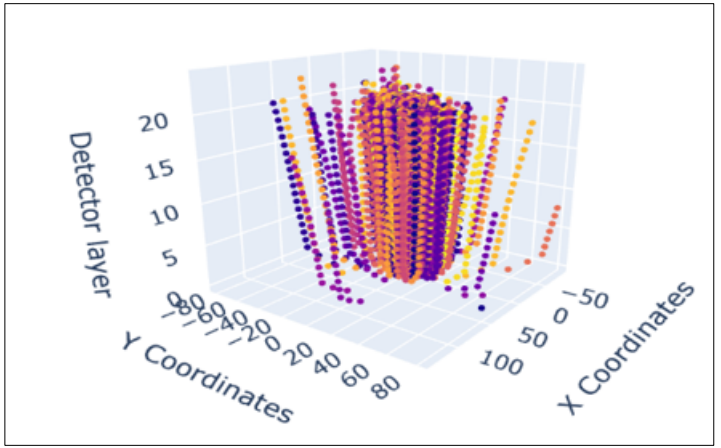


ront. Phys. 8 (2020), 460



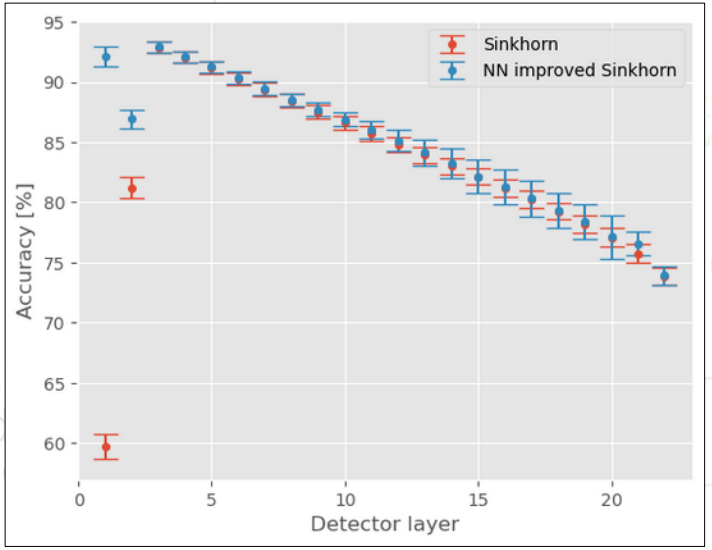
- ~10² tracks per readout frame
- **The challenge**: processing ~10⁷ primaries per projection (2D) within **minutes**

Workflow



Proton kinematics at the first detector layer

Matching of the hits from the neighboring layers (using MC data)



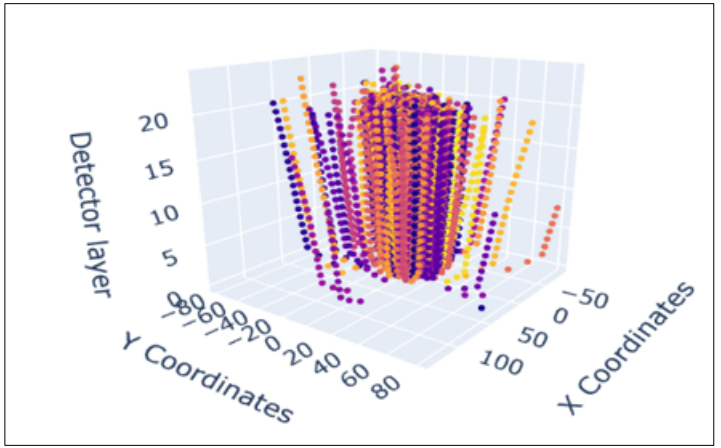
Determination of the Most Likely Path (on a 512^3 grid)
(nuclear interactions; inelastic collisions; multiple Coulomb scattering)

Image reconstruction
(Richardson-Lucy alg.)

$$x_i^{k+1} = x_i^k \frac{1}{\sum_j A_{i,j}} \sum_j \frac{y_j}{\sum A_{l,j} x^k} A_{i,j}$$

Evaluation

Workflow



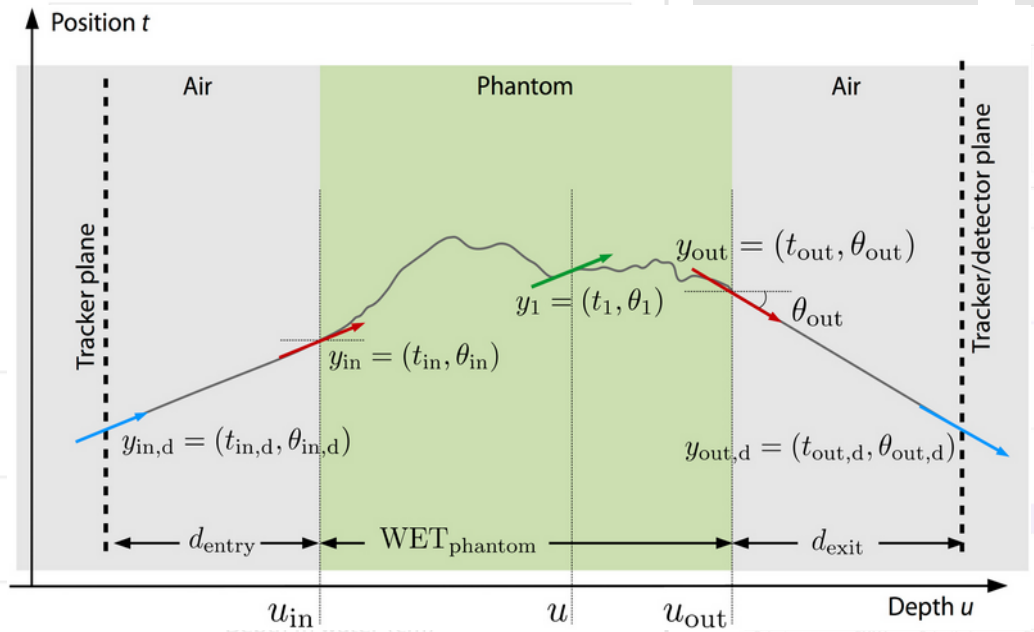
Proton kinematics at the first detector layer

Determination of the Most Likely Path (on a ~512^3 grid)
(nuclear interactions; inelastic collisions; multiple Coulomb scattering)

Image reconstruction
(Richardson-Lucy alg.)

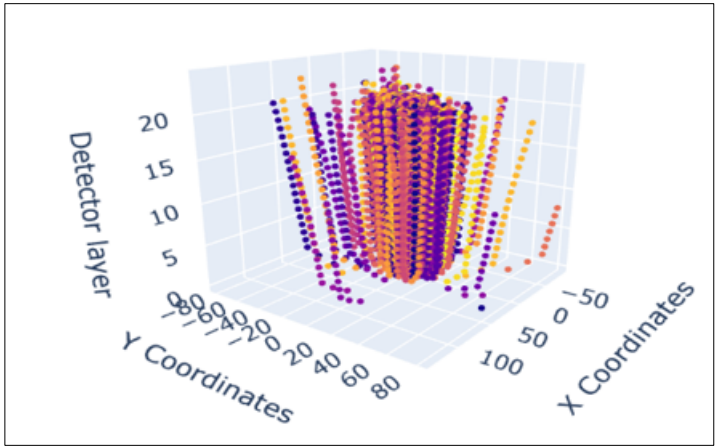
$$x_i^{k+1} = x_i^k \frac{1}{\sum_j A_{i,j}} \sum_j \frac{y_j}{\sum A_{l,j} x^k} A_{i,j}$$

Evaluation



Phys. Med. Biol. 63 (2018) 135013

Workflow

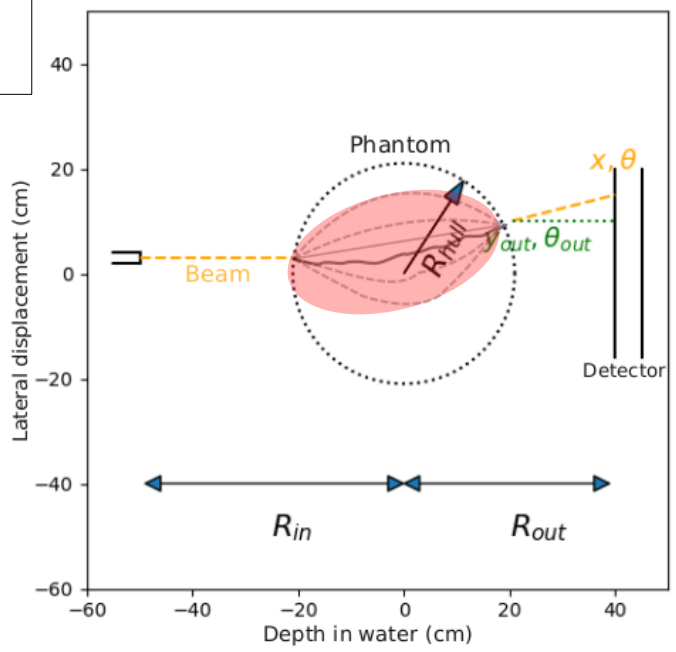


Proton kinematics at the first detector layer

Determination of the Most Likely Path (on a ~512^3 grid)
(nuclear interactions; inelastic collisions; multiple Coulomb scattering)

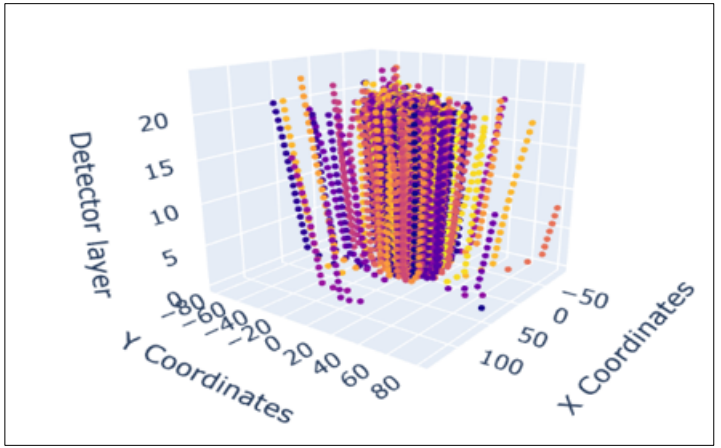
Image reconstruction
(Richardson-Lucy alg.)

$$x_i^{k+1} = x_i^k \frac{1}{\sum_j A_{i,j}} \sum_j \frac{y_j}{\sum A_{l,j} x^k} A_{i,j}$$



Evaluation

Workflow

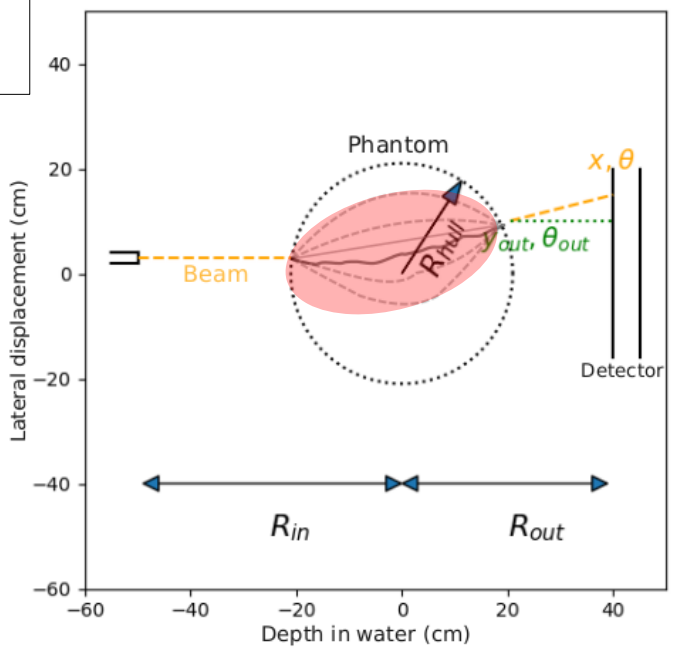


Proton kinematics at the first detector layer

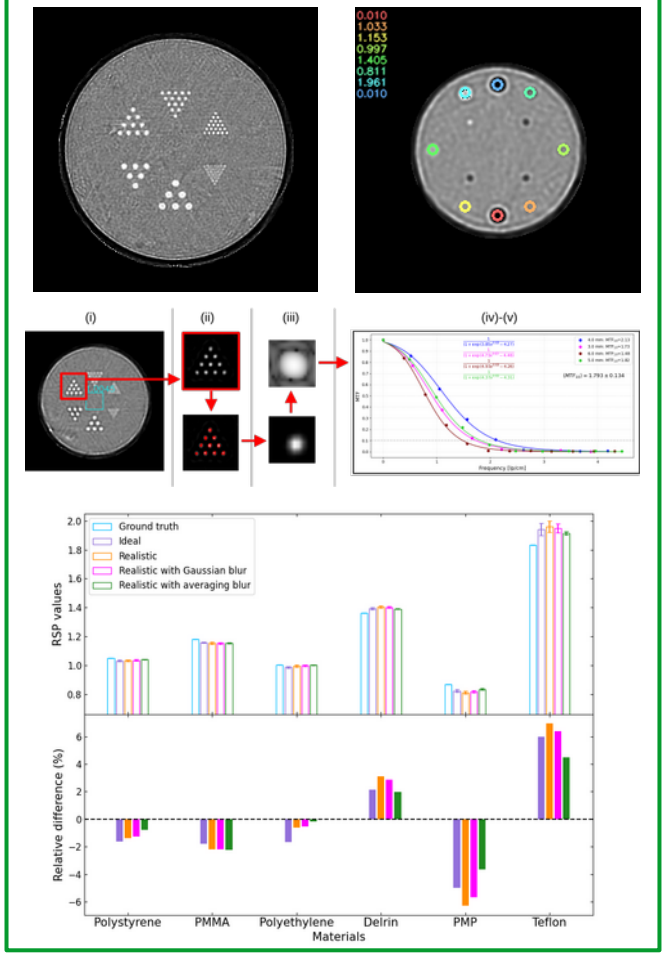
Determination of the Most Likely Path (on a ~512^3 grid)
(nuclear interactions; inelastic collisions; multiple Coulomb scattering)

Image reconstruction
(Richardson-Lucy alg.)

$$x_i^{k+1} = x_i^k \frac{1}{\sum_j A_{i,j}} \sum_j \frac{y_j}{\sum A_{l,j} x^k} A_{i,j}$$



Evaluation



Summary

Hadron therapy is an effective cancer treatment mode

Proton computed tomography is aimed for precise dose planning

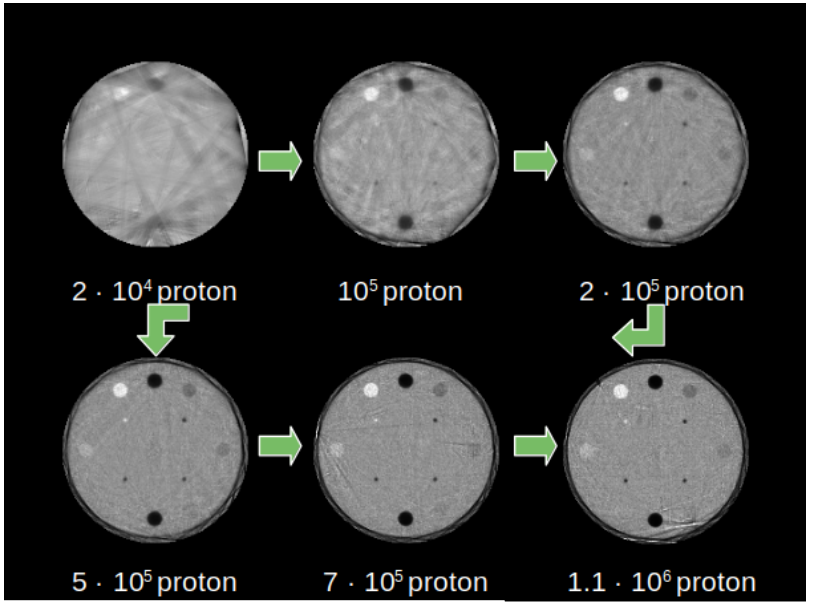
Bergen pCT Collaboration: detector design based on ALPIDE chips (ALICE)

Track reconstruction with deep neural networks

Iterative, GPU-accelerated image reconstruction

Preliminary results:

- 1% RSP accuracy
- 1.4 lp/cm
- ~10 minutes



arXiv:2212.00126
arXiv:2411.<...>

Thank you for your attention!

Grants: OTKA K135515, 2021-4.1.2-NEMZ_KI-2024-00031 and 2021-4.1.2-NEMZ_KI-2024-00033, the Wigner Scientific Computing Laboratory, and RRF-2.3.1-21-2022-00004 within the framework of the Artificial Intelligence National Laboratory.