

# Image reconstruction in proton computed tomography

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**IMAGE RECONSTRUCTION WITH PROTON  
COMPUTED TOMOGRAPHY**

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**INTRODUCTION**

- Proton therapy has outstanding results in cancer therapy due to the protons' nature: they have a very localized dose deposit
- Before every radiotherapy, there is a need for imaging – this is carried out by X-ray CT most of the time – it gives information about the absorption of photons – a conversion is needed to be made from Hounsfield units to proton Relative Stopping Power (RSP) – this results in some errors
- Use the same particle for imaging we use for the treatment – proton CT

**THE BERGEN PCT COLLABORATION**

The ALPIDE chip

- Aims to build a proton CT based on the high energy particle detectors used in the CERN ALICE Collaboration (technology transfer)
- The detector system is based on the ALPIDE chip (Monolithic Active Pixel Sensor)
- Steps of the imaging:  
Irradiate patient (~100 MeV protons) – detector senses the signals – process signals – reconstruct the image

The Bergen proton CT

**THE RICHARDSON-LUCY ALGORITHM**

- Statistical iterative algorithm
- Models the problem as a linear equation system

$$A \cdot X = Y$$

Matrix containing the interaction coefficients between protons and pixels/voxels

Vector containing the known Water Equivalent Path Lengths of the protons

Vector containing the estimated proton RSP values

**GOALS AND DEVELOPMENTS**

- Hadron therapy is one of the most effective treatments for cancer: less damage in healthy tissues, more dosage in the tumour
- Imaging is a crucial part – but photon CT (used currently in the clinical practice) has its limitations – let's use proton CT – but protons do Coulomb scattering – calculating RSP at voxel level and handling proton trajectories are crucial tasks
- Goals: testing, improving and optimizing a framework which uses the Richardson-Lucy algorithm for imaging

The workflow of the process

- Generating data with Monte Carlo simulations (Geant4 & GATE) – very time consuming – parallelization
- Comparing 3 different setups: ideal, silicon pixel and silicon strip detector
- Most Likely Path calculation of the protons – using cubic spline approximation
- Grouping data in batches – check MSE between iterations – if < threshold – process data in the next batch

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**SPATIAL RESOLUTION**

- Using Derenzo phantom (epoxy cylinder with different sized aluminium rods)
- Evaluating spatial resolution with Modulation Transfer Function: average individual rods – get their point spread function – get MTF with 2D Fourier transformation
- Average MTF<sub>50%</sub> for the different setups:

- 1.43 lp/cm (ideal)
- 1.17 lp/cm (pixel)
- 0.94 lp/cm (strip)

**RSP RECONSTRUCTION**

- Using CTP404 phantom (epoxy cylinder with 8 rods of different materials)
- Comparing the reconstructed RSP values of the 3 setups to the ground truth values
- The biggest relative difference between the ground truth and the reconstructed values was ~4%

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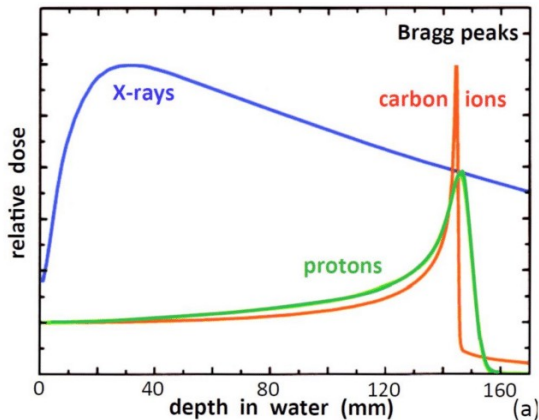
**SUMMARY**

- We have developed a framework that uses the Richardson-Lucy algorithm for imaging with protons – has never been used for this purpose before
- Reached a significant improvement in the runtime (days – minutes)
- There is still room for improvement in the spatial and the RSP reconstruction, however promising results have been achieved

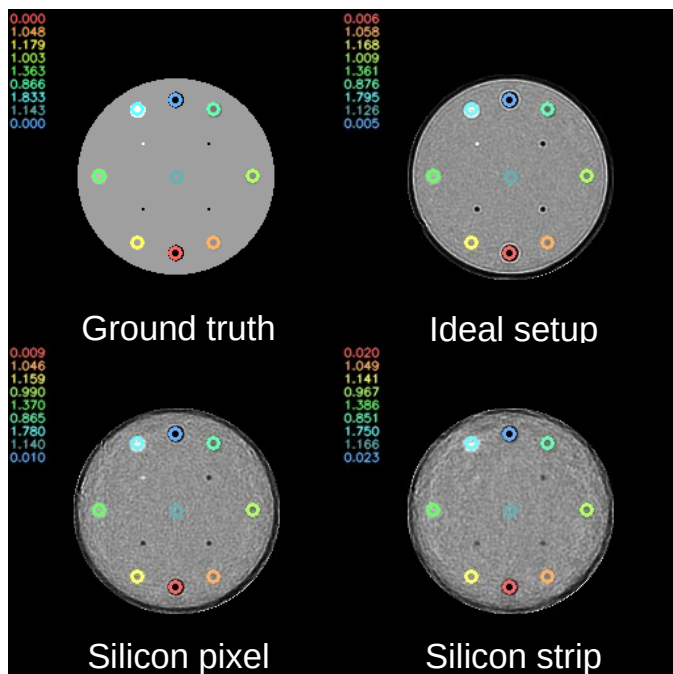
**REFERENCES**

[1] G. Burdakov, A. Lőrincz, D. János, G. Papp, G. G. Burdakov, Proton Computed Tomography Based on Richardson-Lucy Algorithm  
[2] A. Papp et al., A high-precision digital processing pipeline for proton CT  
[3] G. Burdakov et al., High-precision digital processing pipeline for proton CT  
[4] G. Burdakov et al., High-precision digital processing pipeline for proton CT  
[5] G. Burdakov et al., High-precision digital processing pipeline for proton CT  
[6] G. Burdakov et al., High-precision digital processing pipeline for proton CT  
[7] G. Burdakov et al., High-precision digital processing pipeline for proton CT  
[8] G. Burdakov et al., High-precision digital processing pipeline for proton CT  
[9] G. Burdakov et al., High-precision digital processing pipeline for proton CT  
[10] G. Burdakov et al., High-precision digital processing pipeline for proton CT

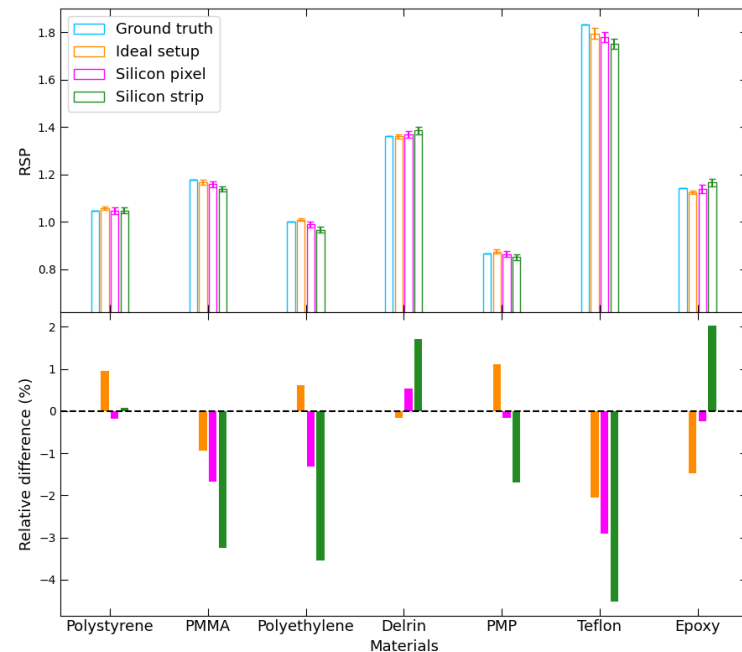
# Richardson-Lucy algorithm for imaging



- Protons & heavy ions: Coulomb scattering → Bragg peak → localized dose deposit



- Hadron therapy: outstanding cancer treatment – but there are challenges with the imaging



- First time using Richardson-Lucy algorithm for medical imaging
- Optimizing the framework: speed & accuracy
- Testing the algorithm on 2 phantoms: spatial resolution & RSP reconstruction
- Promising results (using  $\sim 10^6$  protons), comparable with other used algorithms