

Image reconstruction in proton computed tomography

Zimányi Winter Workshop
on Heavy Ion Physics
Budapest
2-6/12/24

ZSÓFIA JÓLESZ
jolesz.zsofia@wigner.hun-ren.hu

Gábor Bíró
Gábor Papp

ArXiv:2212.00126



EÖTVÖS LORÁND
UNIVERSITY | BUDAPEST






IMAGE RECONSTRUCTION WITH PROTON
COMPUTED TOMOGRAPHY

Zsófia Jólesz¹, Gábor Bíró¹, Gábor Papp¹, Gegegy Gábor Barnaföld²

¹HUN-REN Wigner Research Centre for Physics, 29-33 Konkoly-Thege Miklós út, 1121 Budapest
²Eötvös Loránd University, Rázmány Péter Sétány 1/A, H-1117 Budapest

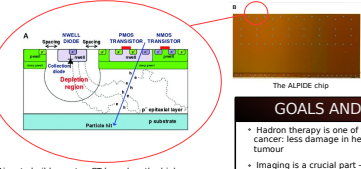
**24TH ZIMÁNYI
SCHOOL**
BUDAPEST, HUNGARY

DECEMBER 2-6, 2024.

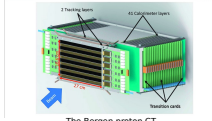
INTRODUCTION

- 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



- 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

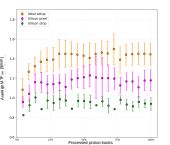
- Statistical iterative algorithm
- Models the problem as a linear equation system

$$\mathbf{A} \cdot \mathbf{x} = \mathbf{y}$$

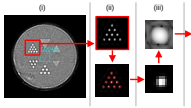
Matrix containing the interaction coefficients between protons and pixels/voxels Vector containing the known Proton Path Lengths of the protons

Vector containing the estimated proton RSP values

SPATIAL RESOLUTION



- Using Derrero phantom (epoxy cylinder with different sized aluminum rods)
- Evaluating spatial resolution with Modulation Transfer Function: average individual rods → get their point spread function → get MTF with 2D Fourier transformation
- Average MTF_{50%} for the different setups:
 - 1.43 lp/cm (ideal)
 - 1.17 lp/cm (pixel)
 - 0.94 lp/cm (strip)

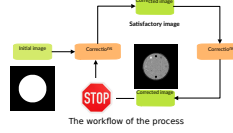


ACKNOWLEDGEMENTS

- 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 RSP reconstruction, however promising results have been achieved

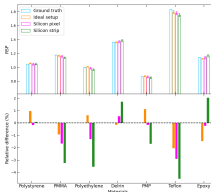
RESULTS

THE WORKFLOW OF THE PROCESS



The workflow of the process

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%

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 RSP reconstruction, however promising results have been achieved

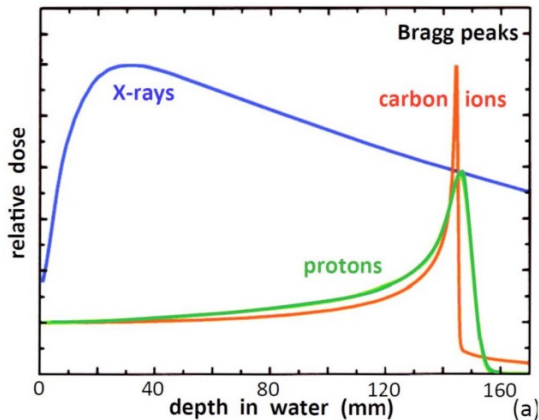
REFERENCES

[1] Bíró, G., Szűcs, Z., Jólesz, Z., Papp, G., Barnaföld, G. (2023) Image reconstruction with protons. *Journal of Applied Computational Physics*, 15(1), 1-10.

[2] Kohn, M. et al. (2019) *Medical Imaging 2019: Physics of Medical Imaging*. SPIE, 11111-11117.



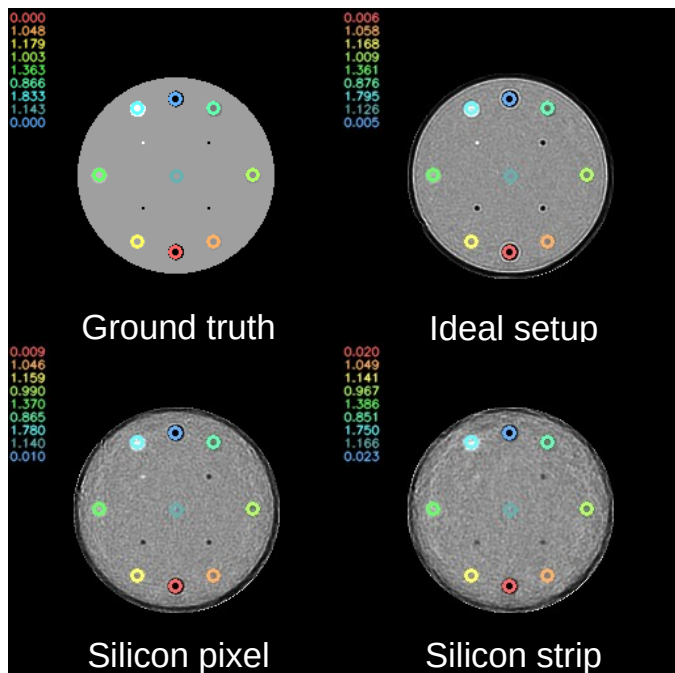
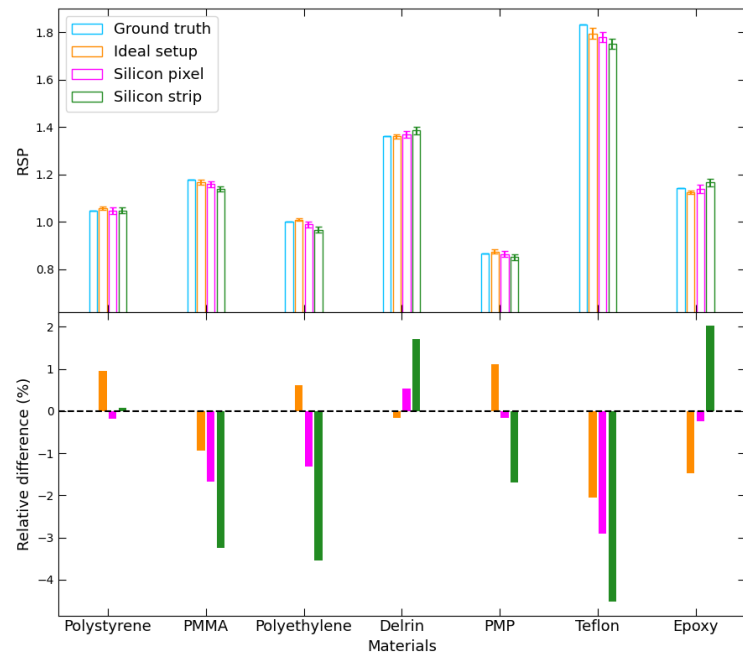
Richardson-Lucy algorithm for imaging



- 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