Proton CT
Short report on the proton imaging workshop

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CREATIS

Proton imaging workshop

Lyon, June 14 and 15, 2018
Organized by Nils Krah
http://protonimaging.sciencesconf.org/

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PRIMES UNIVERSITE DE LYON

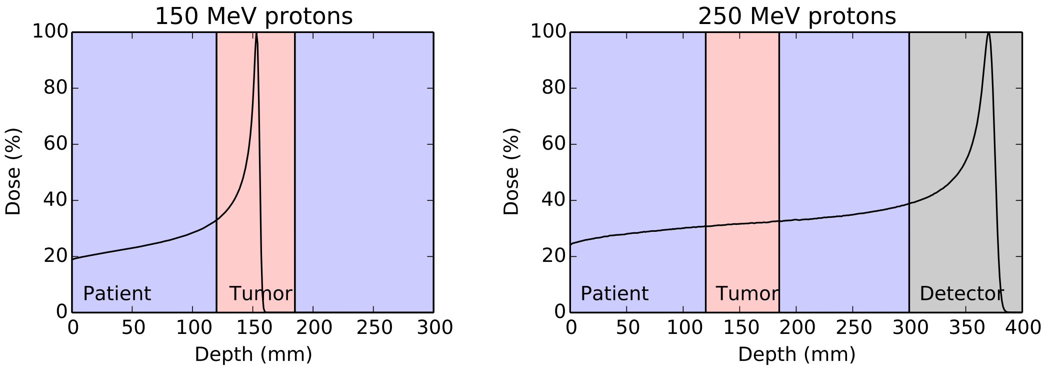
Introduction

- Proton CT is not new[1]
- Little interest in the 80s compared to photon CT
  - Expensive source
  - Lack of spatial resolution due to multiple Coulomb scattering
- Renewed interest with the development of proton therapy
  - Reduce uncertainty on proton range[2]
  - Lower imaging dose
  - Reduction of metal artifacts

[1] A.M. Cormack. "Representation of a Function by Its Line Integrals, with Some Radiological Applications". In: *Journal of Applied Physics* 34.9 (1963), pp. 2722–2727.

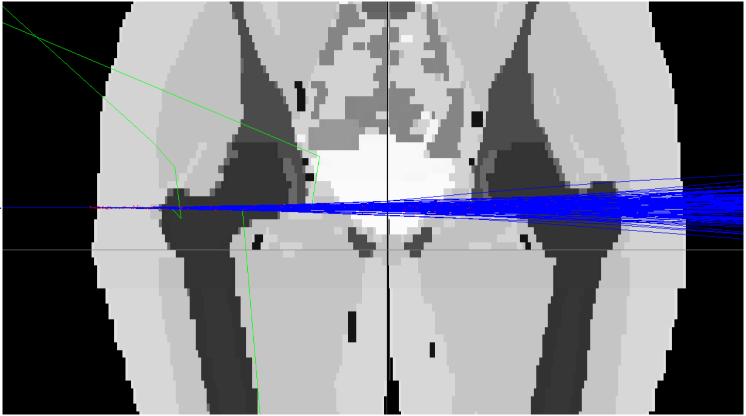
[2] H. Paganetti. "Range uncertainties in proton therapy and the role of Monte Carlo simulations". In: *Phys Med Biol* 57.11 (2012), R99–117.

Proton imaging



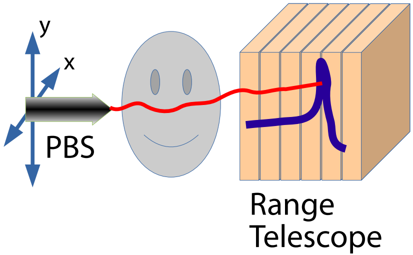
Multiple Coulomb scattering

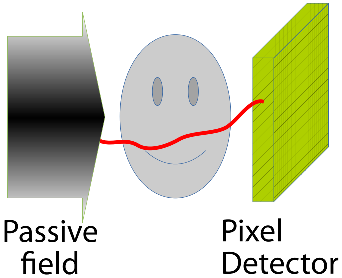
$p^+ \rightarrow$



$\Rightarrow$ Poor spatial resolution

Integrated mode setups

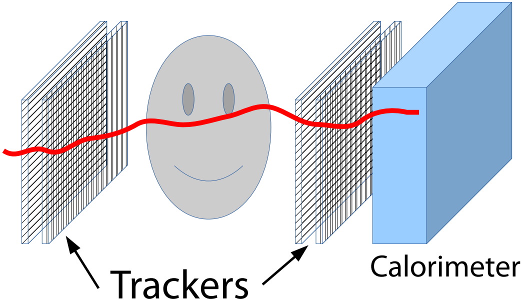




- Ilaria Rinaldi (Lyon / Maastricht): acq. in Orsay, PBS+range telescope
- Christian Finck (Strasbourg): simulations for PBS acquisitions

- Hsiao-Ming Lu (Boston): custom made modulator wheel and a commercial flat panel)

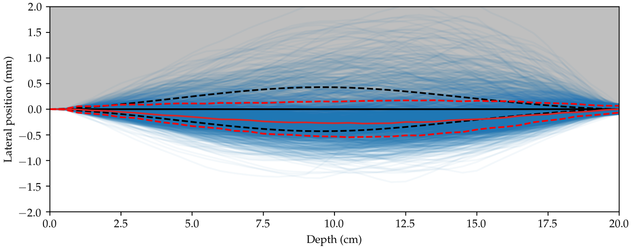
Single tracking scanners



- pCT collaboration (Reinhard Schulte): silicon strip trackers, 5-stage calorimeter
- PRaVDA (Nigel Allinson): silicon strip trackers
- Bergen project (Helge Pettersen): CMOS telescope, no up-stream trackers

Most likely path estimation from single tracking data

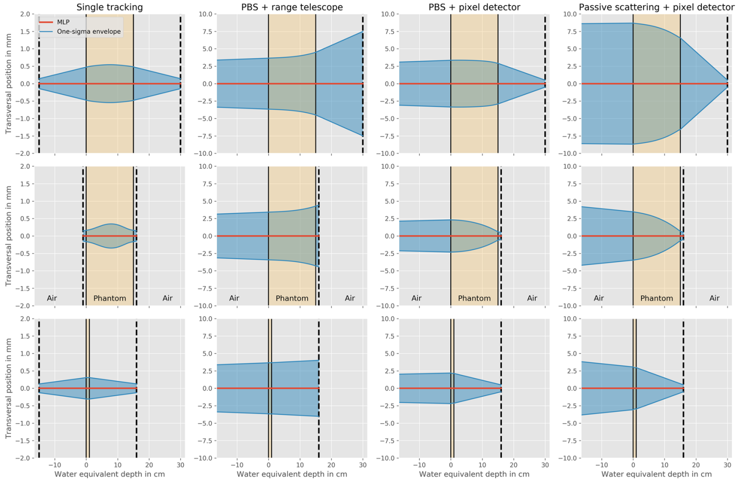
- One can estimate the path of each proton from tracked positions and angles, assuming an homogeneous object[3]
- Small difference in an object with longitudinal[4] and transverse heterogeneities (Feriel Khellaf, Lyon)



[3] D.C. Williams. "The most likely path of an energetic charged particle through a uniform medium". In: *Phys Med Biol* 49.13 (2004), pp. 2899–2911.

[4] C.-A. Collins-Fekete et al. "Extension of the Fermi-Eyges most-likely path in heterogeneous medium with prior knowledge information". In: *Physics in medicine and biology* 62 (24 2017), pp. 9207–9219.

Nils Krah, Lyon: framework for comparing set-ups[5]



[5]N. Krah et al. "A comprehensive theoretical comparison of proton imaging set-ups in terms of spatial resolution". In: *Physics in medicine and biology* (2018).

Proton CT reconstruction using most likely paths

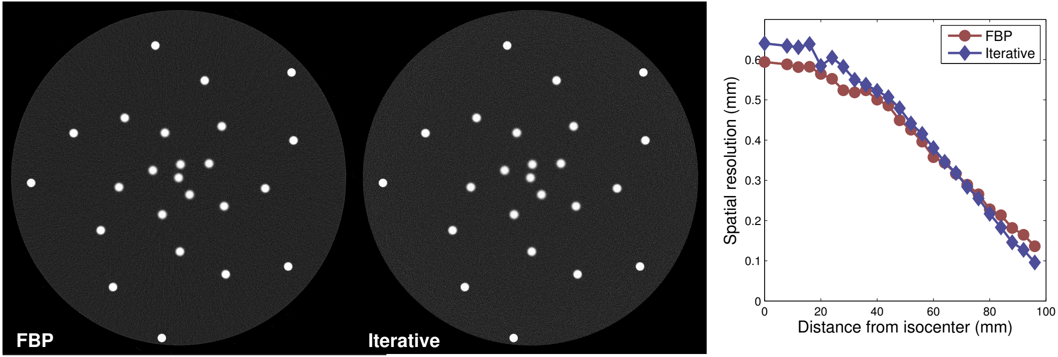
- Yair Censor (Haifa): iterative reconstruction can naturally account for curved paths (and other effects)[6]

- Simon Rit (Lyon): filtered backprojection reconstruction (FBP) algorithms using backprojection first strategies with small approximations[7]

[6] S.N. Penfold et al. "Total variation superiorization schemes in proton computed tomography image reconstruction". In: *Medical Physics* 37.11 (2010), pp. 5887–5895.

[7] S. Rit et al. "Filtered backprojection proton CT reconstruction along most likely paths". In: *Med Phys* 40.3, 031103 (2013), p. 031103.

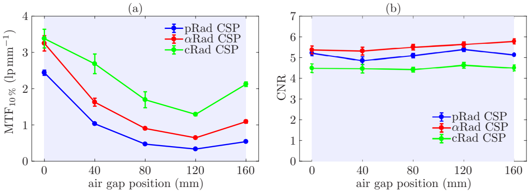
Proton CT reconstruction using most likely paths



[8] S. Rit and D.C. Hansen. "Comparison of Filtered Backprojection and Iterative Reconstruction for Proton CT Using Most Likely Paths". In: *IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)*. Seattle, USA, 2014.

[9] D.C. Hansen, T. Sangild Sorensen, and S. Rit. "Fast reconstruction of low dose proton CT by sinogram interpolation". In: *Phys Med Biol* 61.15 (2016), pp. 5868–5882.

- Tim Gehrke and Carlo Amato (Heidelberg): silicon pixel detector system for helium radiography, potential for spatial resolution improvements (reprinted from[10])



- Sebastian Meyer (Munich): quantitative investigation of helium and carbon CT, including clinical applications[11]

[10] T. Gehrke et al. “Theoretical and experimental comparison of proton and helium-beam radiography using silicon pixel detectors”. In: *Physics in medicine and biology* 63 (3 2018), p. 035037.

[11] S. Meyer et al. “Comparative Monte Carlo study on the performance of integration- and list-mode detector configurations for carbon ion computed tomography”. In: *Physics in medicine and biology* 62 (3 2017), pp. 1096–1112.

Particle filtering / “Cuts”

Selecting only particles that have not encountered nuclear interactions:

- Charles-Antoine Collins-Fekete (London): a most likely generating process filter in particle imaging,
- Lennart Volz (Heidelberg): importance of data filtering in helium CT.

Alternative approaches for proton CT

- Guillaume Landry (Munich): fluence field modulated proton CT to (further) reduce the imaging dose[12].
- Catherine Therese Quiñones (Lyon): scattering proton CT to reconstruct the scattering power[13].
- Jean Michel Létang (Lyon): combination with dual-energy CT to reconstruct the map of the mean excitation energy[14].

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[12] G. Dedes et al. "Application of fluence field modulation to proton computed tomography for proton therapy imaging". In: *Physics in medicine and biology* 62 (15 2017), pp. 6026–6043.

[13] C.T. Quiñones. "Proton computed tomography". PhD thesis. Institut National des Sciences Appliquées (INSA) de Lyon, 2016.

[14] G. Vilches-Freixas et al. "Deriving the mean excitation energy map from dual-energy and proton computed tomography". In: *Physics and Imaging in Radiation Oncology* 6 (2018), pp. 20–24.

Discussion on clinical workflows

- With current systems, ion radiography can be used in combination with a pre-treatment x-ray CT for verification of the treatment planning.
- Use of ion CT for treatment planning or image guidance probably requires further improvements of single tracking set-ups, e.g., faster acquisitions, larger field-of-view and more compact scanners.

Conclusions

- Several teams have demonstrated experimental feasibility of ion CT (protons and other ions), in integrated and single tracking modes
- Large improvement in spatial resolution with single tracking
- Further improvement with other ions than proton
- Importance of data filtering prior to reconstruction
- Several efficient FBP and iterative reconstructions with single tracking
- Network of groups working on ion imaging, see `http://ionimaging.org`

Acknowledgments

Open postdoc position!

`http://ionimaging.org`

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FONDATION RECHERCHE MÉDICALE