Electron density resolution determination and systematic uncertainties in proton computed tomography (pCT)

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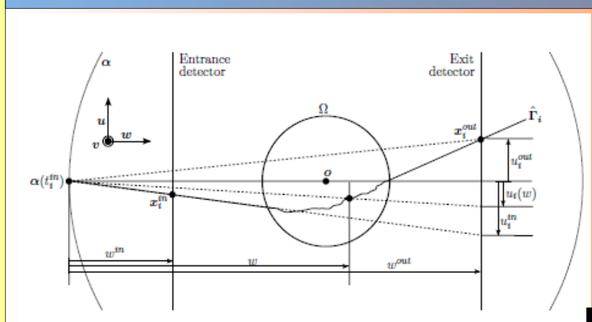
Proton therapy – Proton CT

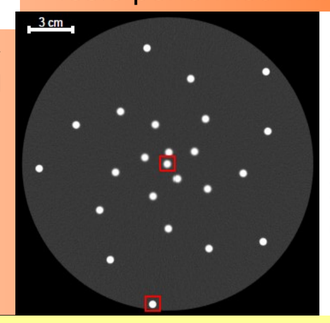
- Proton therapy:
  - Reduced total energy deposed in the patient with respect to conventional radiotherapy
  - Finite range of the proton beam
  - Total range uncertainty margin 2.5%+1mm to 3.5%+3mm [1]
- Proton CT:
  - Could reduce range uncertainty margin when compared to x-ray CT based treatment planning
  - Could reduce imaging dose to the patient

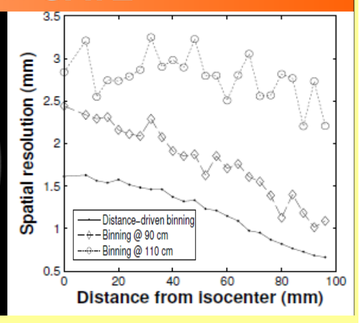
Reconstruction algorithm



- In-house developed distance-driven binning filtered backprojection (FDK) algorithm along most likely paths [2]
- Reconstruction algorithm implemented using RTK [3]
- All spatial resolution and electron density tests performed with **GATE** [4]

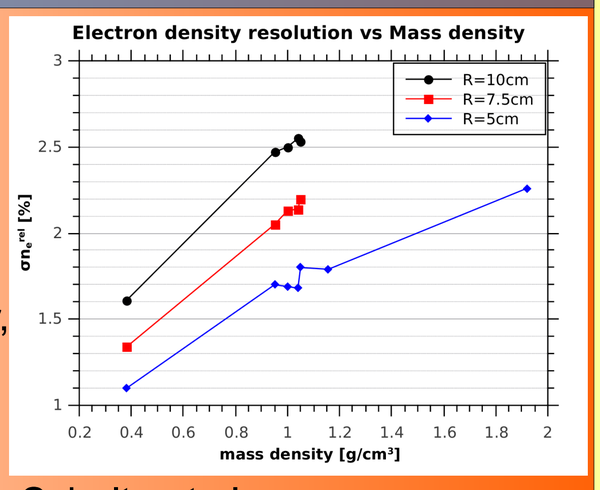
- Testing achieved spatial resolution using a water phantom with aluminium inserts (Ø5 mm) – Ideal scanner
- Comparing distance-driven binning with standard FDK algorithms (straight path) binned at 110 cm (after the target) and at 90 cm (before the target)
- Spatial resolution quantified with the 10%-90% distance of the edge profile of each insert



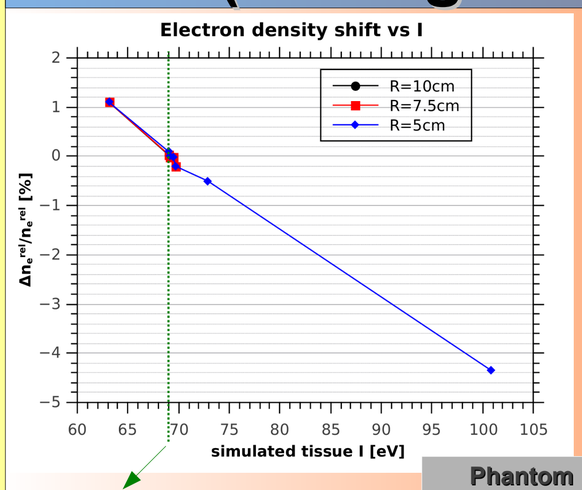


Electron density resolution

- For an ideal scanner and a 250 MeV proton fan beam :
  - In a 10 cm radius water phantom 2.5% electron density resolution at the center, using 3 mGy
  - Result compatible with the analytical formula presented by Schulte et al [5], predicting 1% resolution at about 20 mGy



Electron density bias (homogeneous phantom)

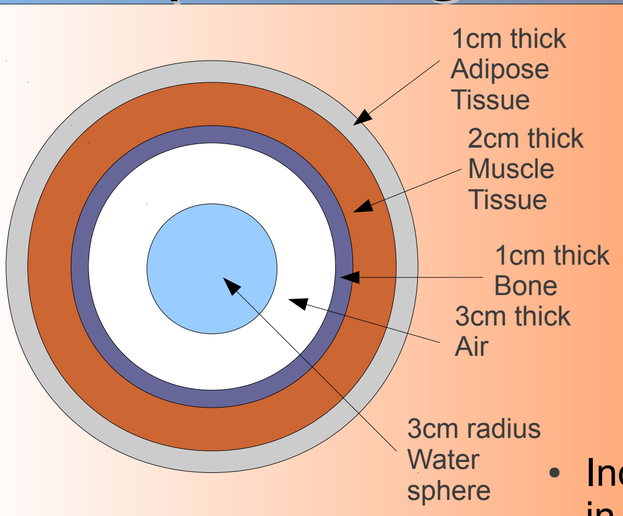


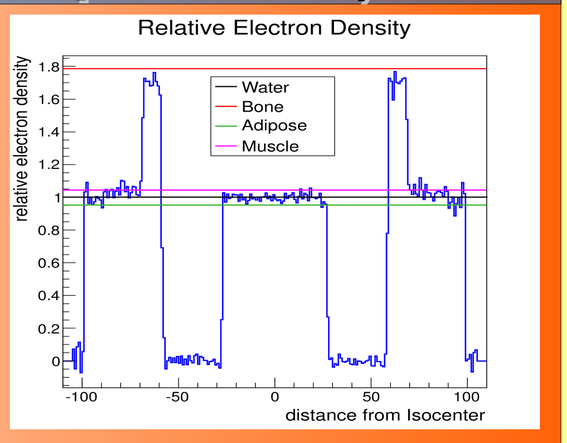
- Using a space-independent I (mean excitation energy) in the reconstruction biases the value of the reconstructed electron density

Phantom Radius	Adipose Tissue [%/eV]	Water [%/eV]	Bone [%/eV]
10cm	0.1519	0.1508	-
7.5cm	0.1513	0.1500	-
5cm	0.1511	0.1484	0.1431
2.5cm	0.1542	0.1479	0.1426

Electron density shift per eV of difference between reconstruction I and tissue simulated I, for different materials and volumes.

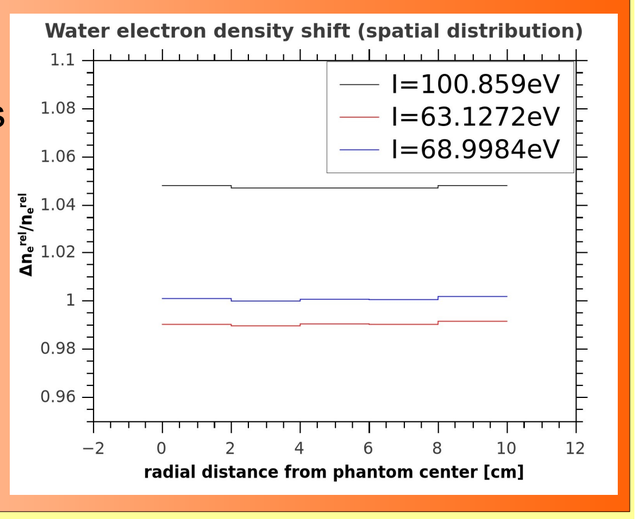
Electron density bias (inhomogeneous phantom)





- Indicative of the impact of the I used in reconstruction. Only the electron density of water remains unbiased.

- The shift in the reconstructed electron density depends only on the difference between the I of the tissue and the one assumed during reconstruction
- Electron density shift due to I is independent of the position in the phantom (<0.1% relative variation in different positions)
- Can be either corrected a posteriori or using a calibration phantom.



[1] H. Paganetti, Phys. Med. Biol. **57** (2012) R99-R117

[2] S. Rit, Med. Phys. (2012) in press

[3] www.openrtk.org

[4] www.opengatecollaboration.org

[5] R.W. Schulte, Med. Phys. **32** (2005) 1035-1046

Ongoing studies

- Identification of basic detector requirements (energy resolution, spatial resolution)
- Performing a virtual treatment planning using pCT, in order to quantify uncertainties in the proton range