Status of simulation and reconstruction studies in Lyon

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on behalf of IPNL and CREATIS
Proton CT R&D, Nice 25.04.2013

Contents

- Proton CT studies in Lyon (PROTOM project)
- Motivation – proton imaging for proton treatment planning
- Spatial resolution – reconstruction algorithm
- Electron density studies
- Future plans / Feedback

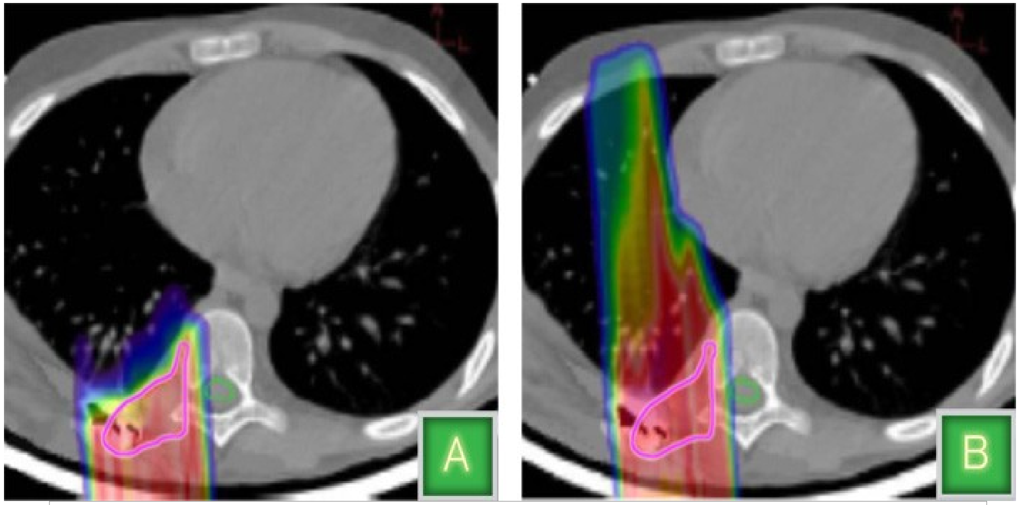
- Main motivation: to investigate the principal limitations/benefits of the utilization of proton imaging for treatment planning (TP) in proton therapy

- Current total range uncertainty/margins in TP up to 3%

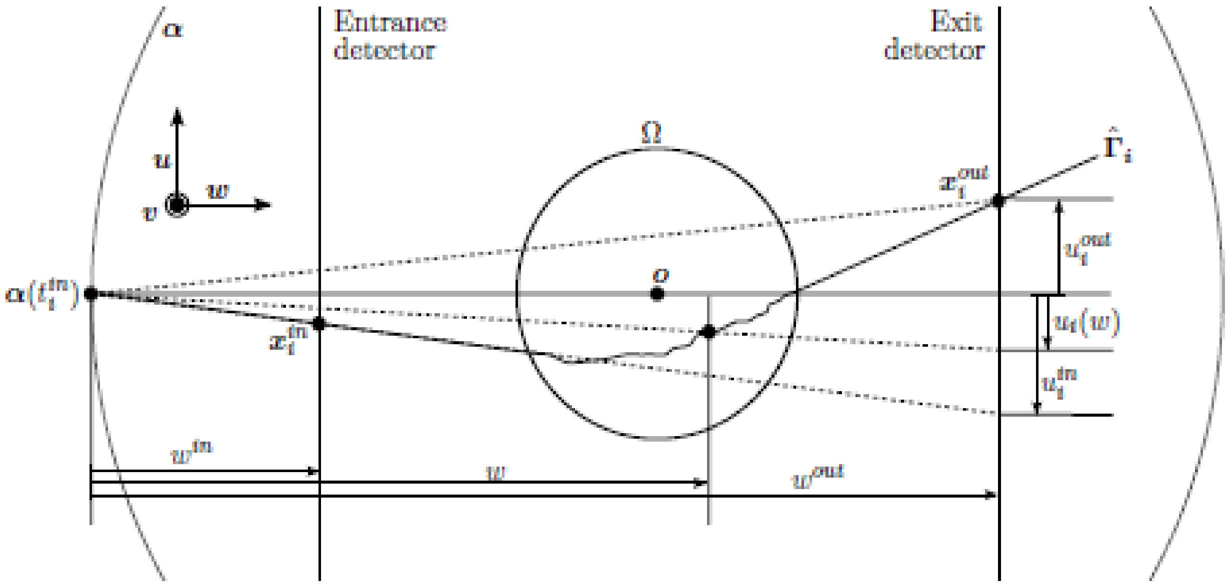
- Start with Monte Carlo studies (GATE) and perfect detectors

- We want to know if and how much one can gain in terms of electron density resolution and imaging dose, when using protons for imaging

- In the framework of PROTOM project (1yr duration - 2012)



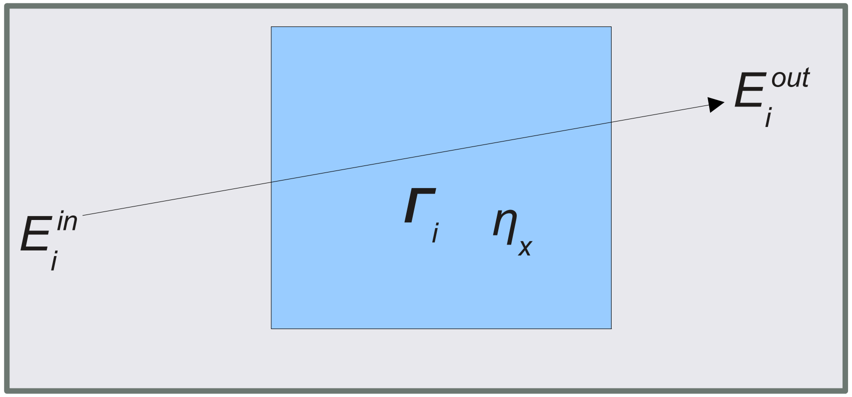
Schulte, Dept. of Radiation Medicine, Loma Linda University Medical Center



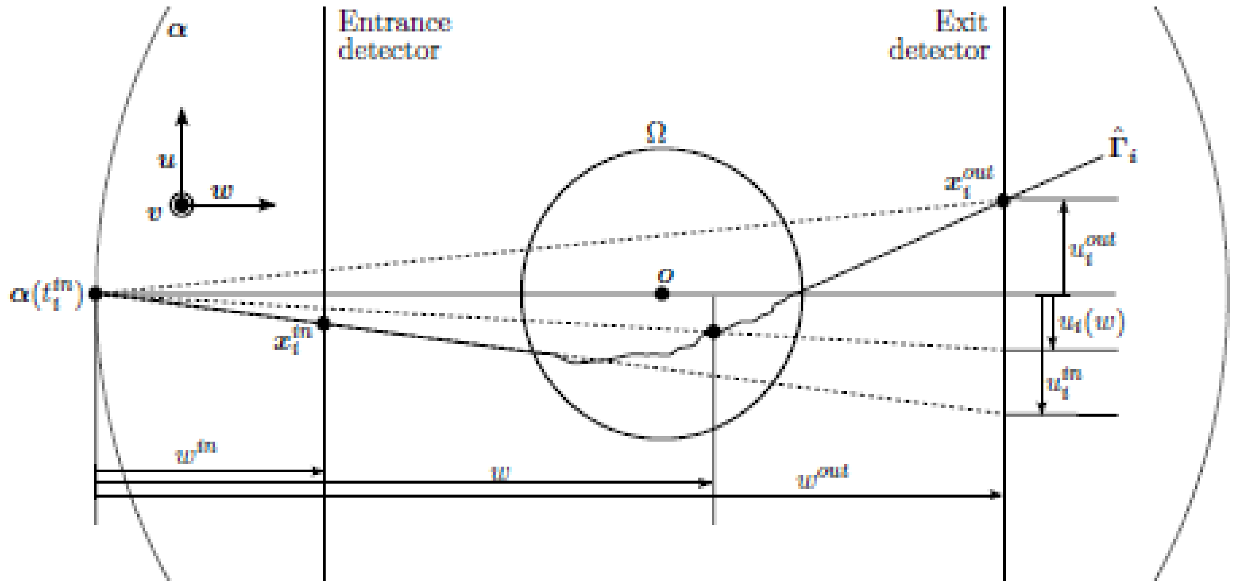
α
Entrance detector
Exit detector
u
w
v
Ω
$\hat{\Gamma}_i$
x_i^{out}
u_i^{out}
o
$\alpha(t_i^{in})$
$u_i(w)$
x_i^{in}
u_i^{in}
w^{in}
w
w^{out}

$$-\frac{\mathrm{d}E}{\mathrm{d}x}(\boldsymbol{x}) = \eta(\boldsymbol{x}) S(I(\boldsymbol{x}), E(\boldsymbol{x}))$$

$$\int_{\boldsymbol{\Gamma}_i} \eta(\boldsymbol{x})\,\mathrm{d}l = \int_{E_i^{out}}^{E_i^{in}} \frac{\mathrm{d}E}{S(I_{water}, E)}$$

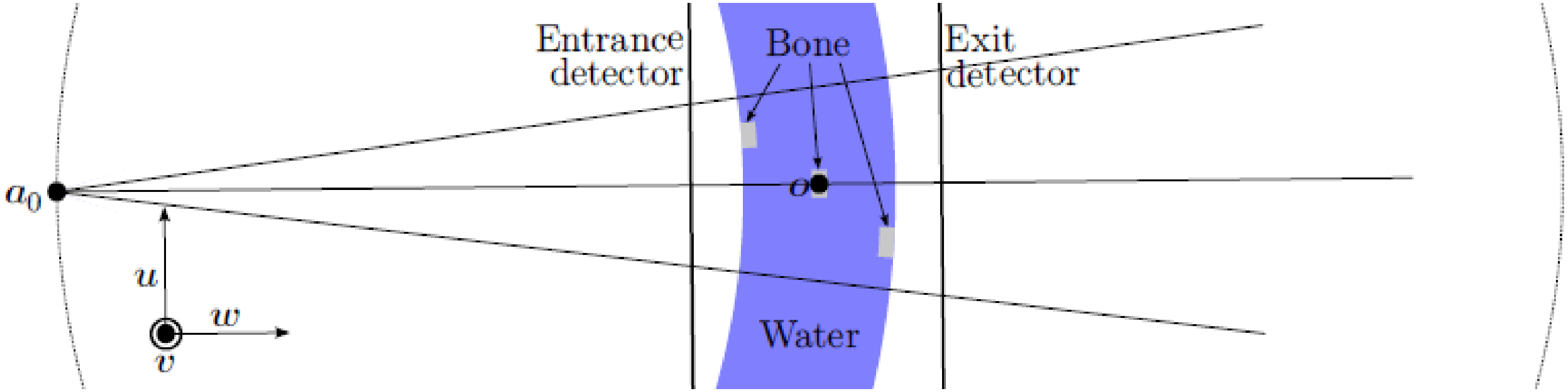


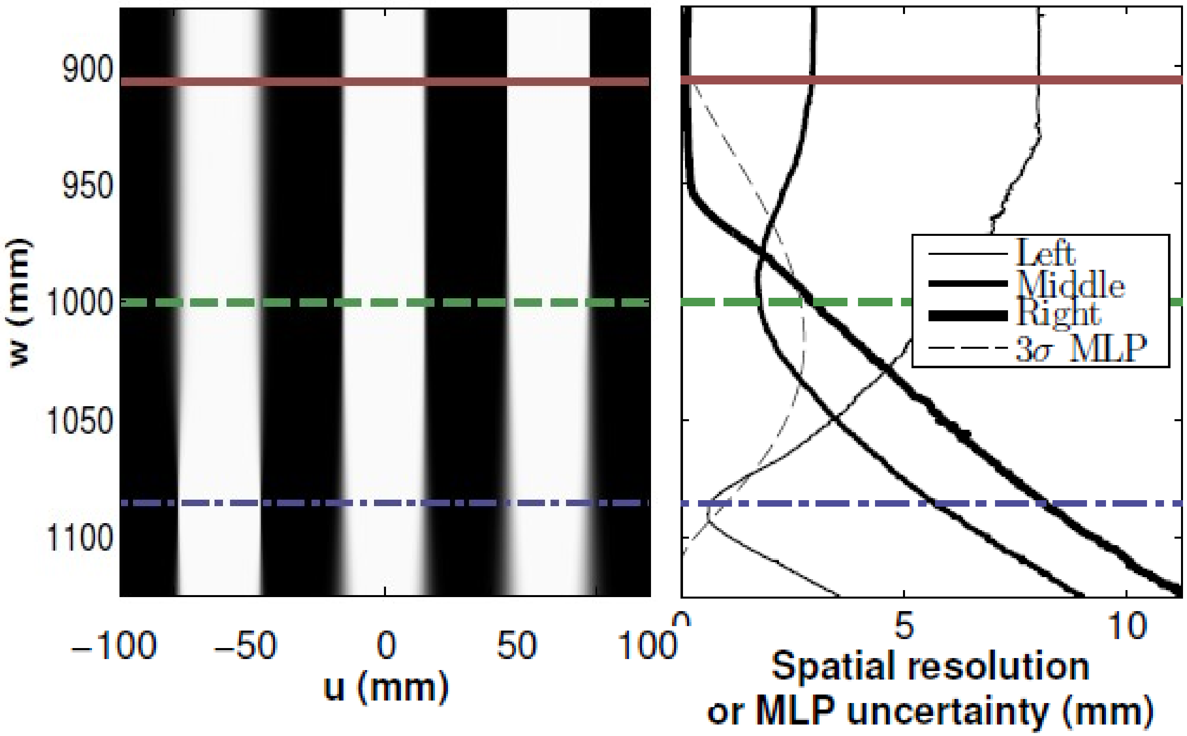
- Unlike X-ray reconstruction, proton imaging reconstruction is not a statistical/counting method
- Proton energy loss is determined both by the electron density of the material and by the mean excitation energy
- In the reconstruction we can't wave both as unknowns, so we fix the mean excitation energy



- Analytical Filtered Backprojection algorithms assume straight proton trajectories

- Proton are scattered during their passage through the patient





Filtered backprojection proton CT reconstruction along most likely paths

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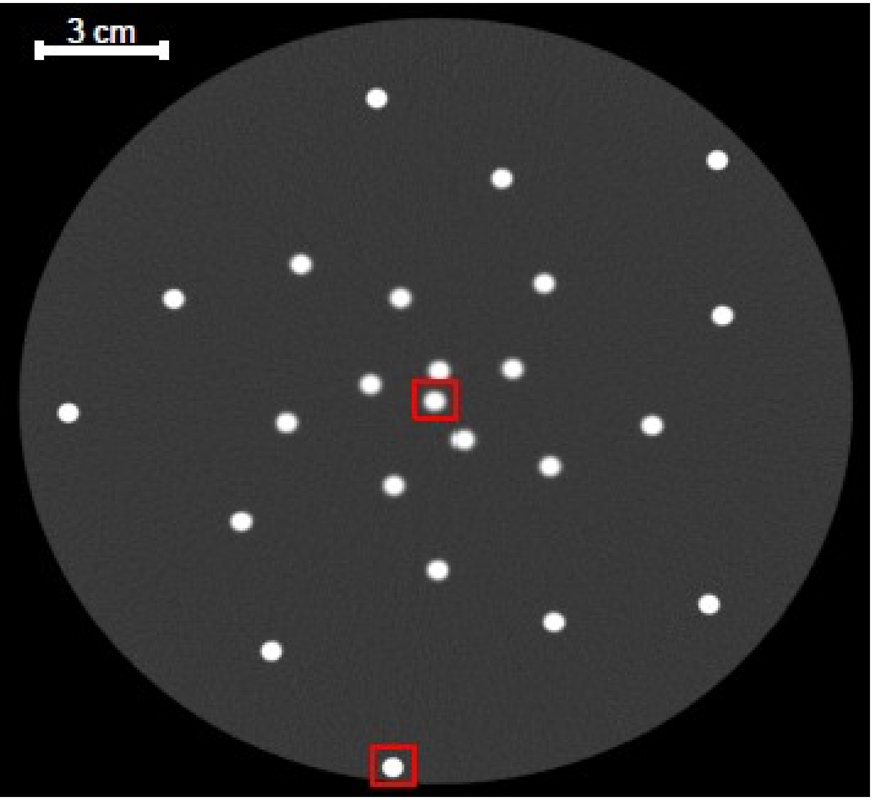
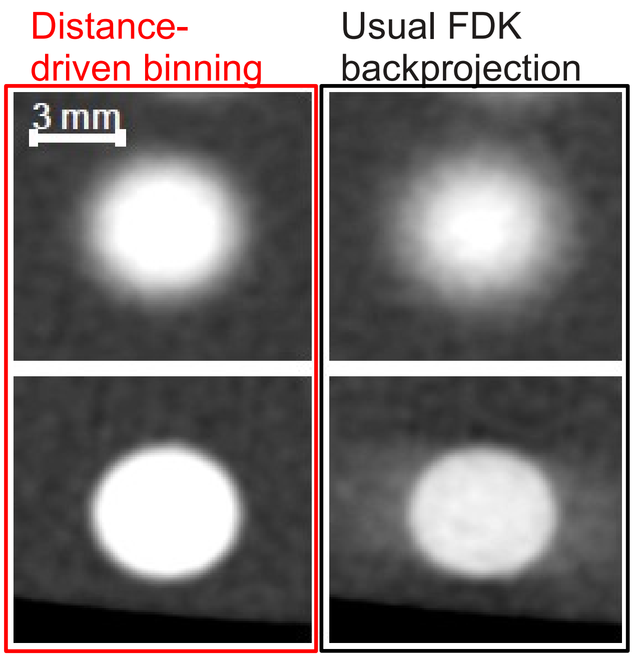
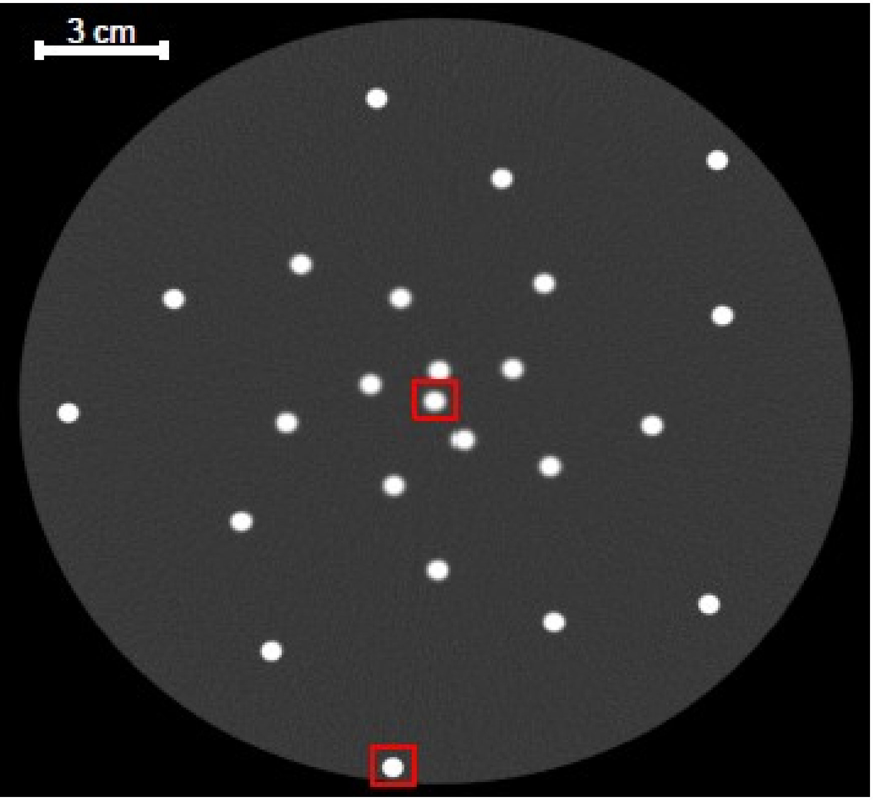
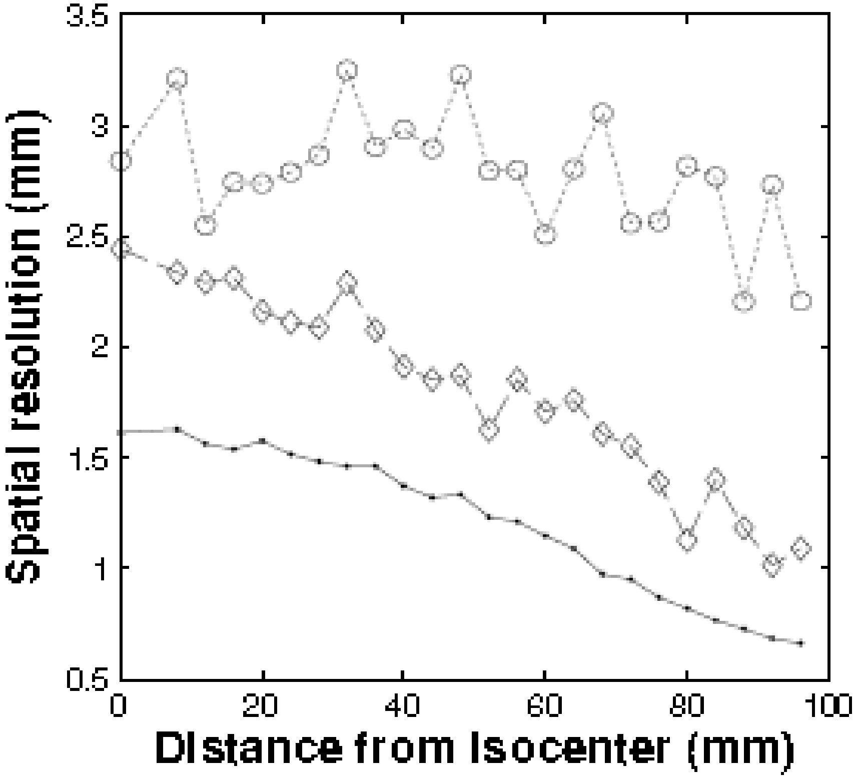
(Dated: September 27, 2012)





- Simulations of an ideal scanner
- 200 MeV protons, 15°x2° cone beam angle
- 720 projections, 900 protons mm^{-2} projection^{-1}, 0.5x1x0.5mm^3 voxels
- Tested spatial resolution using a water phantom with aluminium inserts





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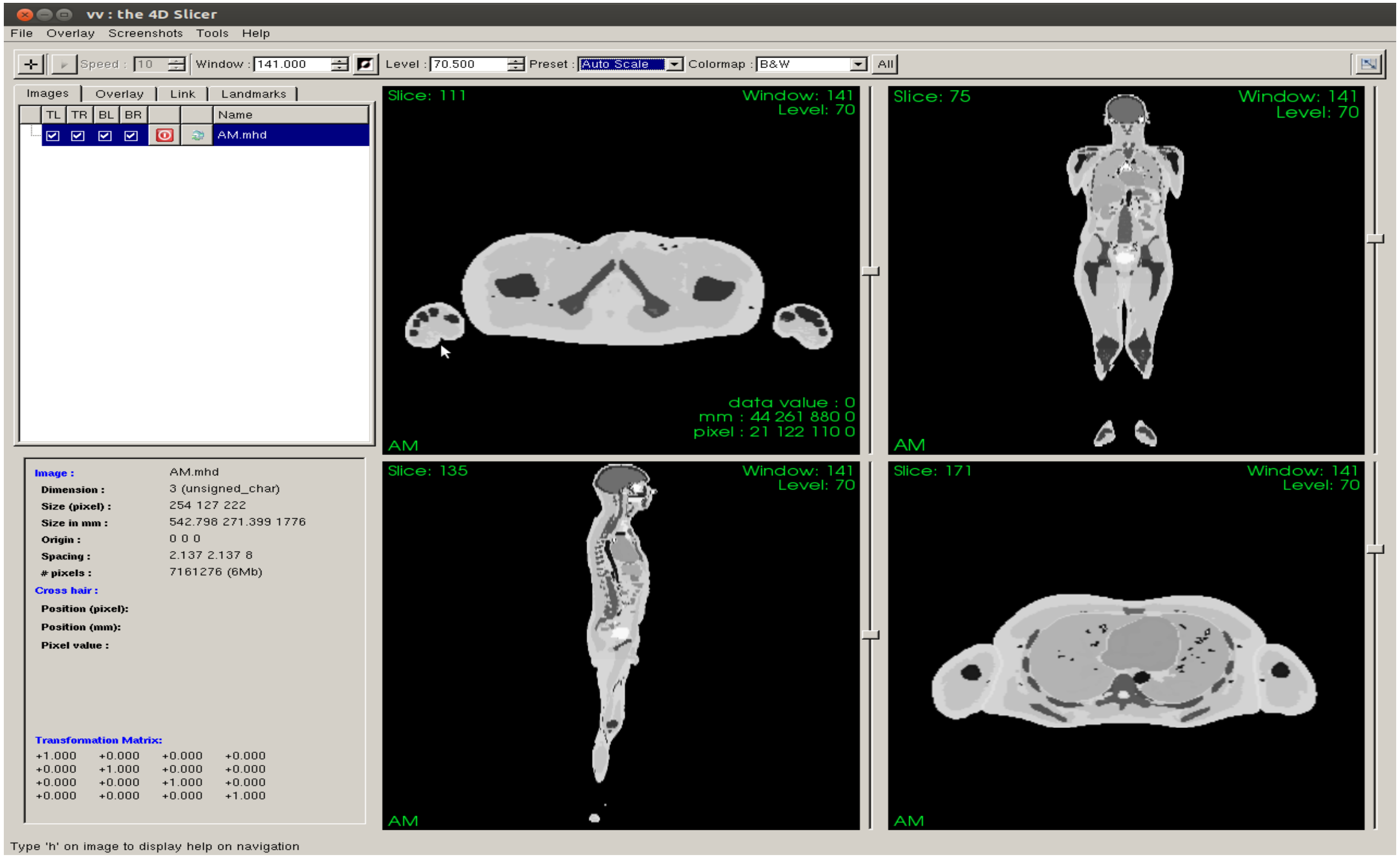
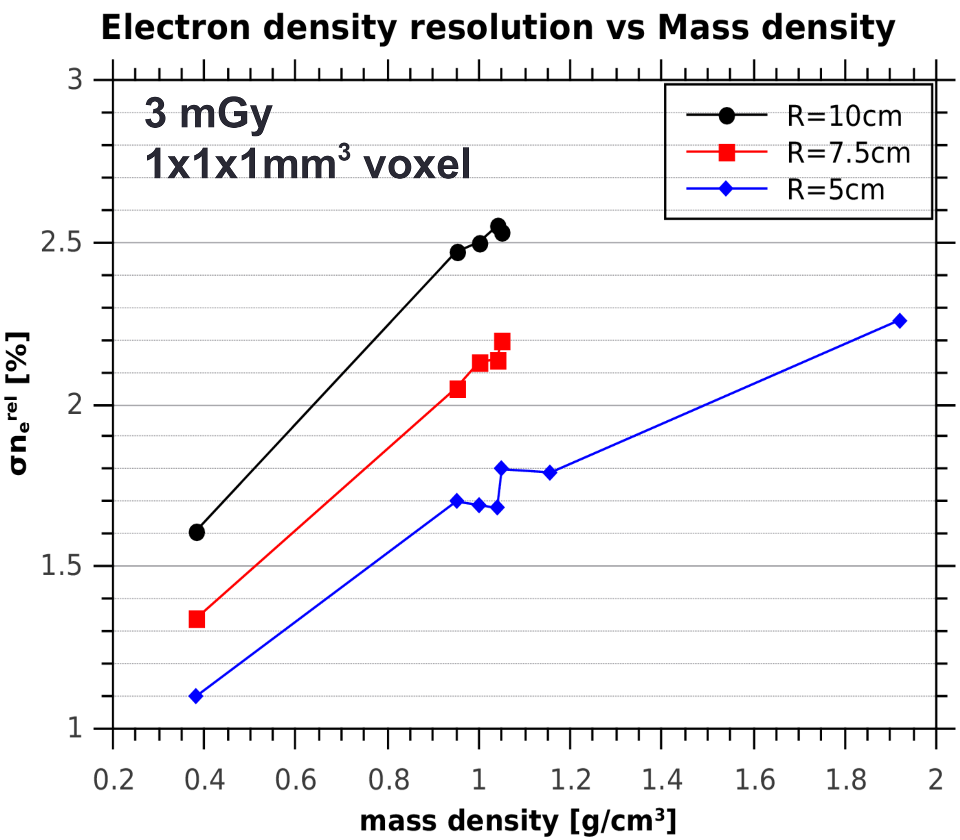
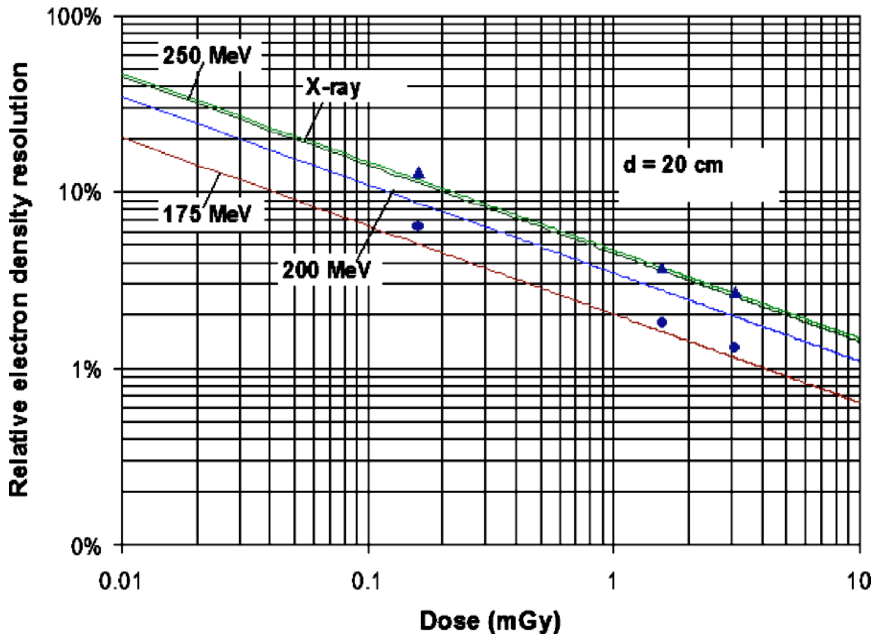


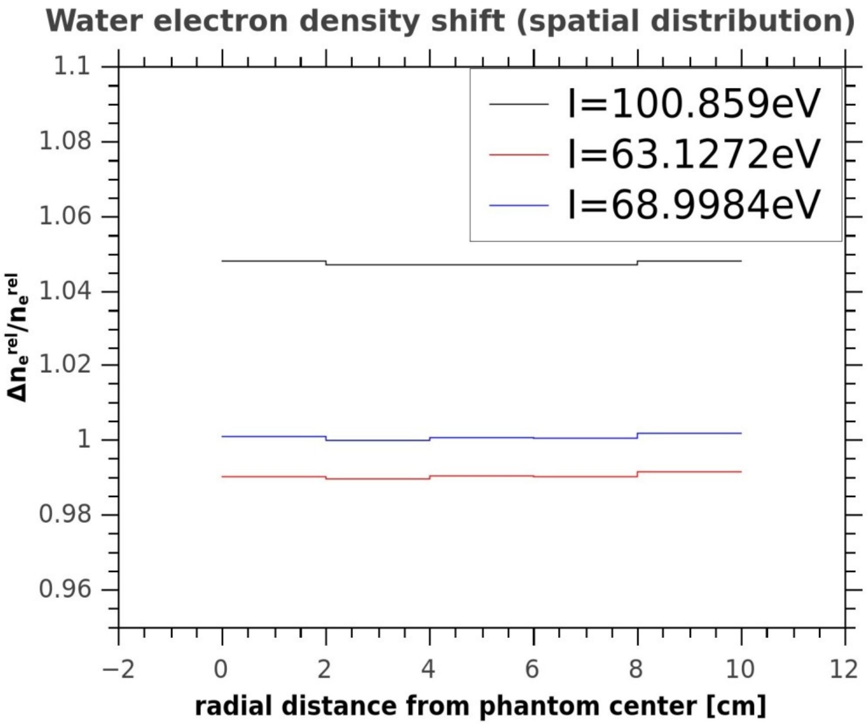
- Simulations of an ideal scanner for electron density studies
- Homogeneous and inhomogeneous targets of “realistic” materials
- 250 MeV protons, 1x1x1mm^3 voxels, 360 projections with a total of 90M protons, 3mGy



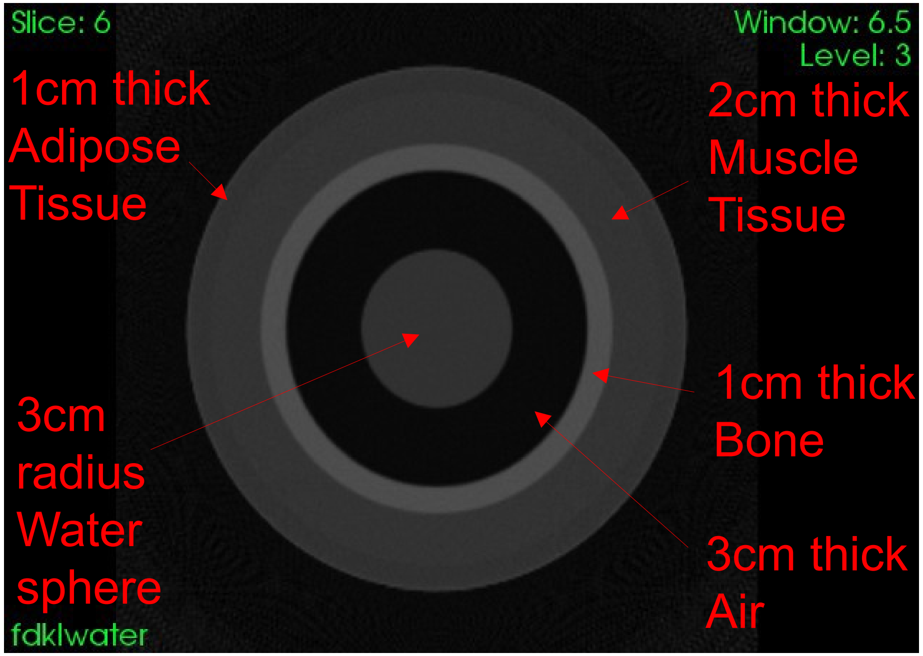
- Calculated electron density resolution for different materials and different phantom sizes (homogeneous cylinders)
- Compatible with studies performed so far (Loma Linda)
- Required 1% resolution can be achieved with about 20mGy

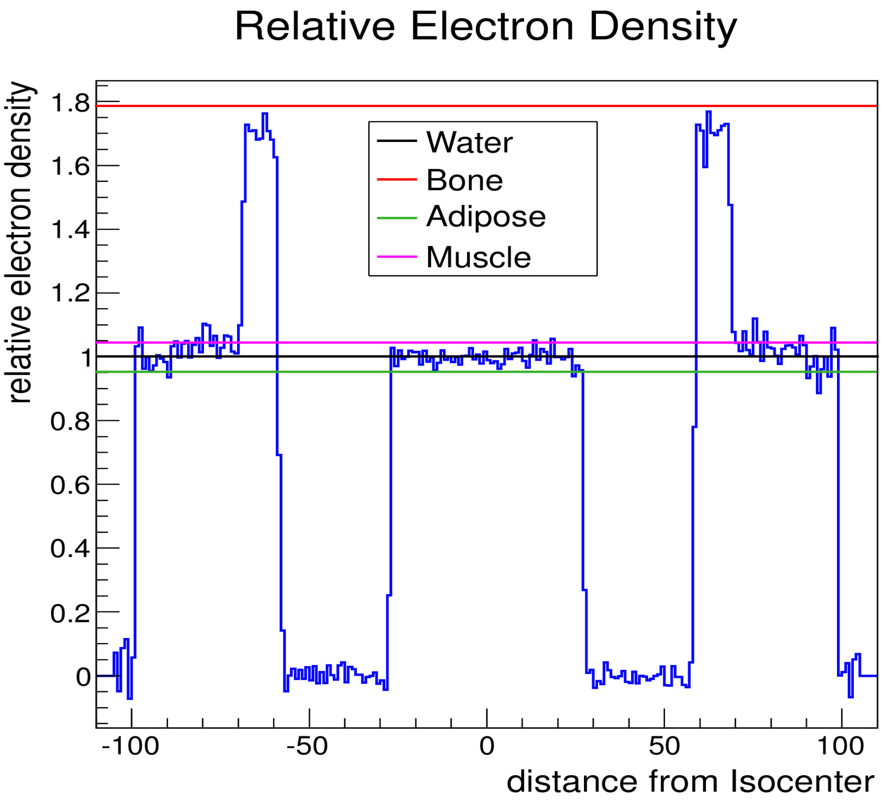


Radius	Adipose Tissue [% / eV]	Water [% / eV]	Bone [% / eV]
10 cm	0.1519	0.1508	-
7.5 cm	0.1513	0.1500	-
5 cm	0.1511	0.1484	0.1431
2.5 cm	0.1542	0.1479	0.1426



- Tissue dependence is small and for all tissues tested the bias was about 0.15%/eV
- Volume dependence is very small
- Location dependence is negligible


Slice: 6
Window: 6.5
Level: 3
1cm thick Adipose Tissue
2cm thick Muscle Tissue
3cm radius Water sphere
1cm thick Bone
3cm thick Air
fdklwater


Relative Electron Density
relative electron density
distance from Isocenter
Water
Bone
Adipose
Muscle
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-100
-50
0
50
100

- Investigating the influence of proton imaging in treatment planning:
- So far:
  - New analytical reconstruction algorithm taking into account proton MLP
  - Basic electron density resolution studies (performance, systematic uncertainties
  - First detector performance impact

- Starting:
  - Proton range uncertainties due to electron density uncertainties
  - Comparison with X-ray CT in terms of proton range/electron density
  - Thorough detector requirements study
  - Depending on the previous: demonstrator/prototype development

- Additional manpower to work on proton CT:
  - 1 PhD student (3yr)
  - 1 Post-Doc (2yr)

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- Feedback needed in:
  - Is there (already) any quantification of proton range uncertainty that can be achieved using pCT?
  - Have been detailed pCT – X-ray CT performed?
  - Hardware projects run already, do we know the principal performance and the detector requirements?
  - What are the main hotspots concerning analytical reconstruction algorithms?
  - Are iterative algorithms fast enough?

- People related to the PROTOM project in Lyon:

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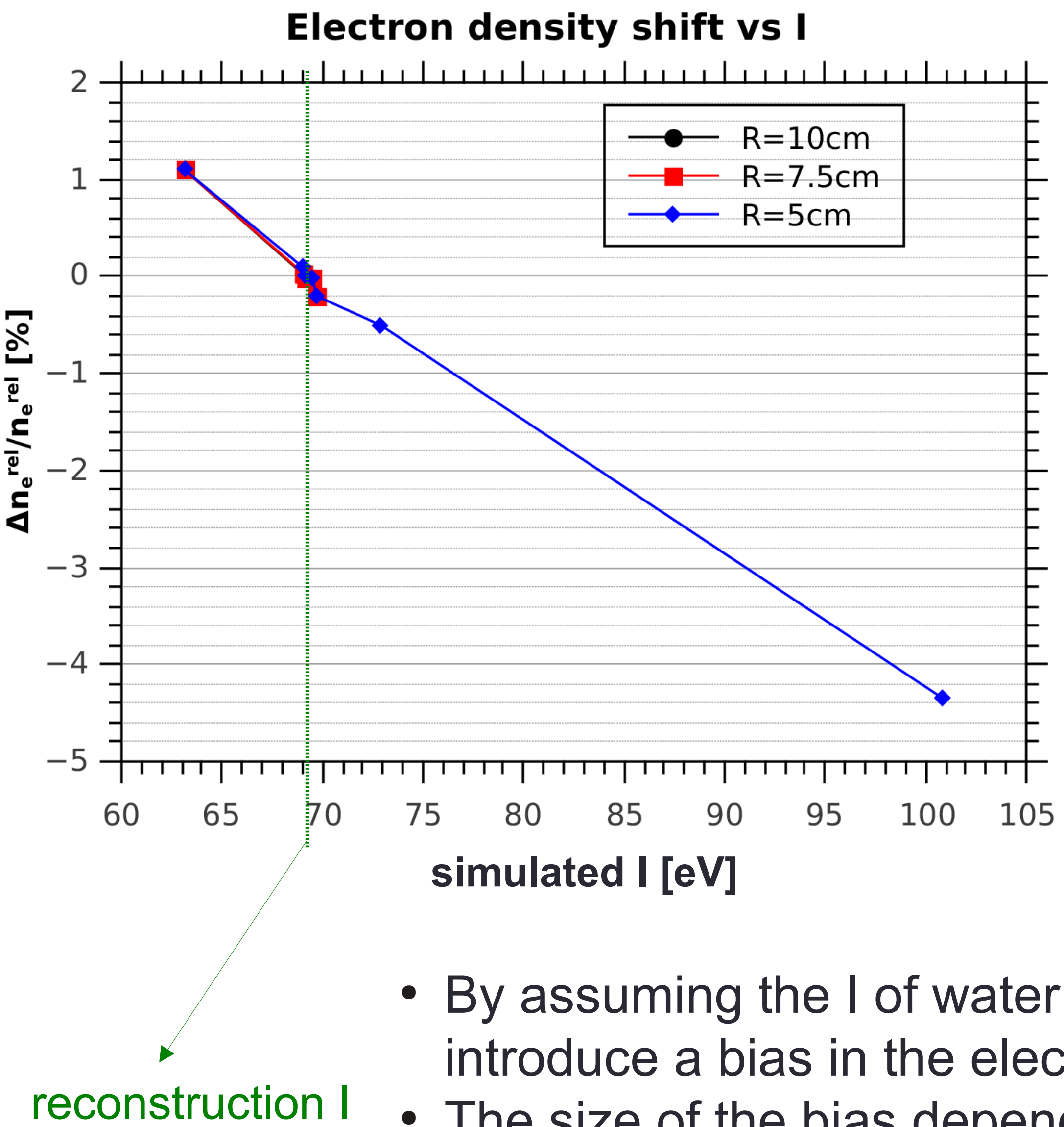
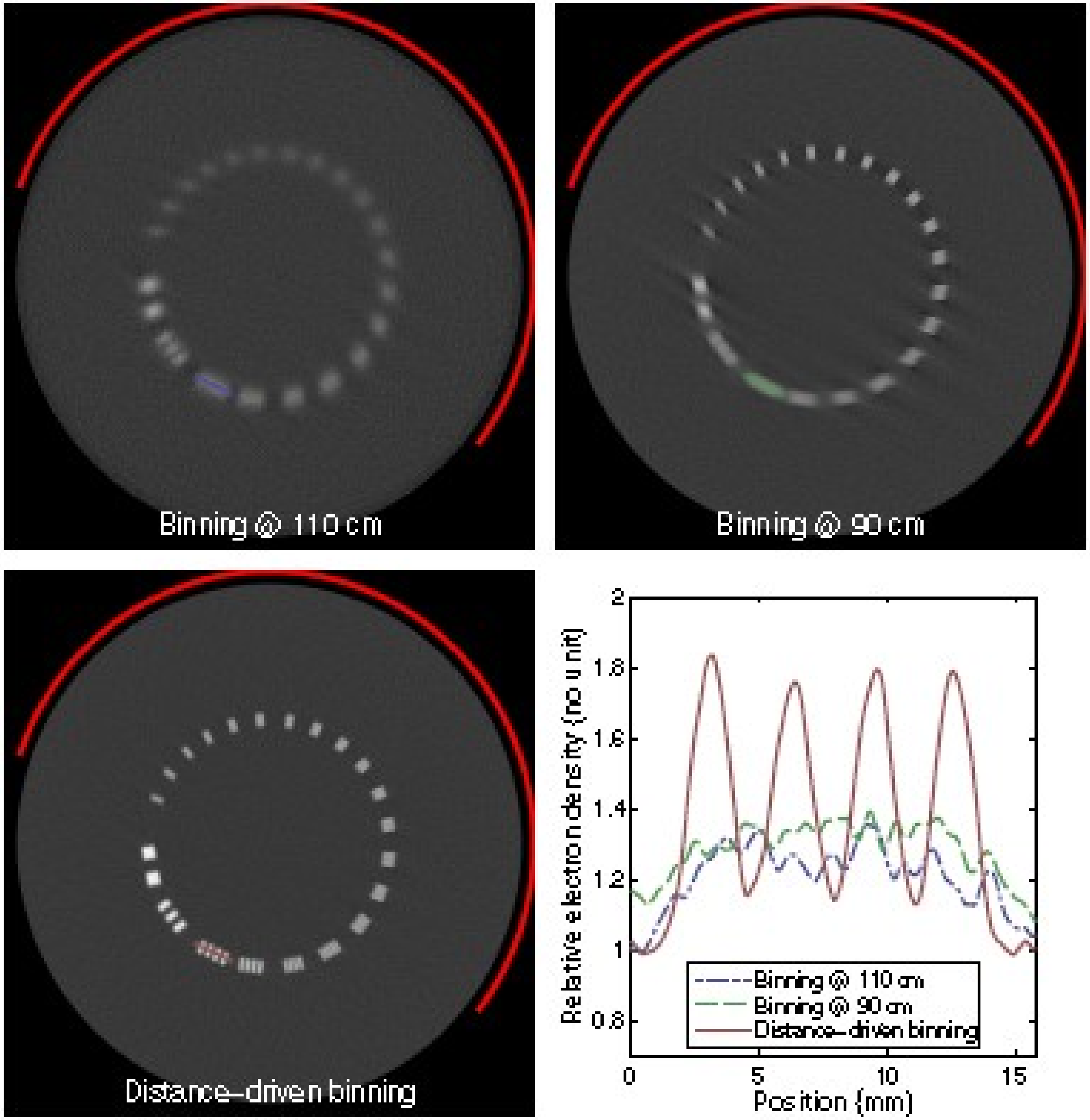
Backup Slides



- By assuming the I of water during reconstruction we introduce a bias in the electron density
- The size of the bias depends on the difference between the I of the tissue and the one used in reconstruction


Binning @ 110 cm
Binning @ 90 cm
Distance–driven binning
Relative electron density (no unit)
Position (mm)
Binning @ 110 cm
Binning @ 90 cm
Distance–driven binning

- Beyond ideal detectors, there is an ongoing study of the basic detector requirements
- As an example, the exit energy measurement resolution has a deep impact on electron density resolution