Investigation of dual energy CT tissue characterization methods for particle beam dose calculation

Hugo Bouchard, PhD, MCCPM
Senior Research Scientist
Radiation dosimetry group
National Physical Laboratory

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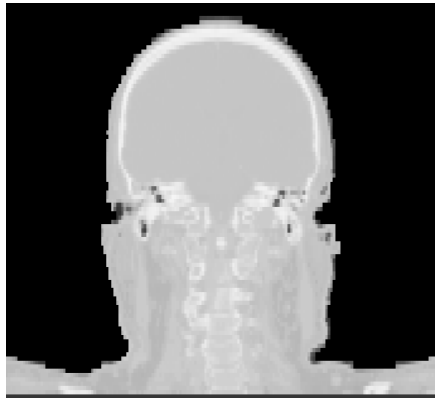
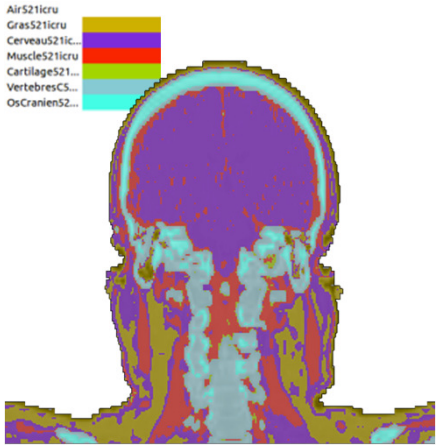
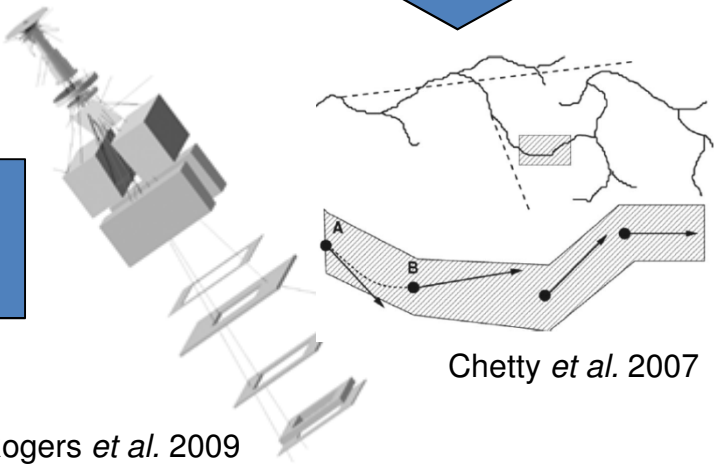
Radiotherapy treatment planning



Tissue characterization, contour and segmentation



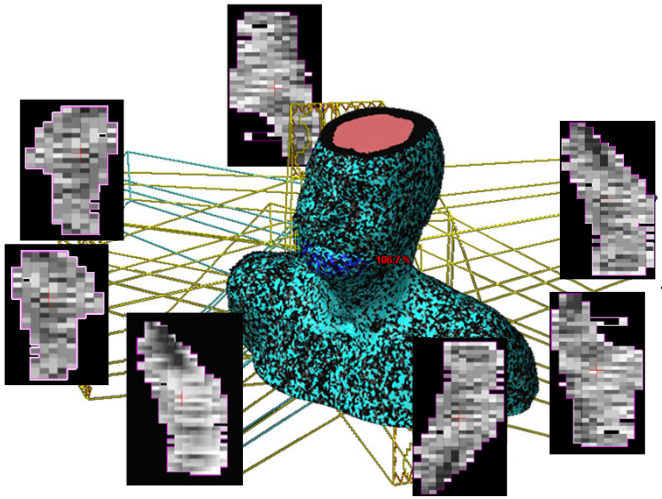
Physical modelling



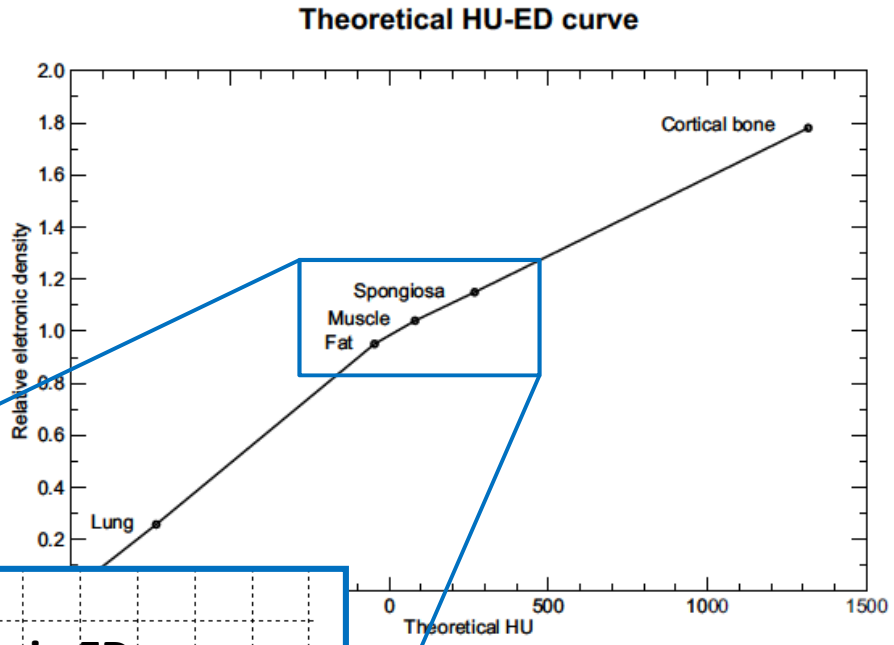
Chetty *et al.* 2007

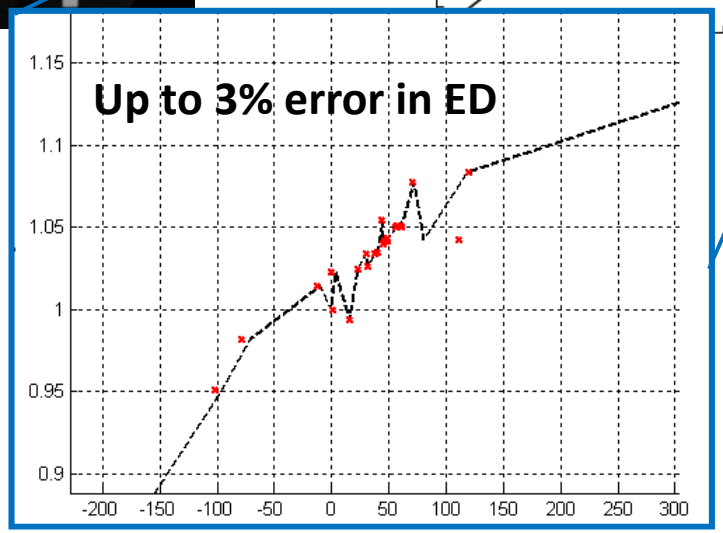
Rogers *et al.* 2009

Optimisation and planning

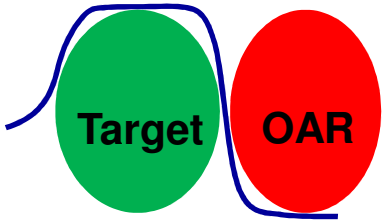


Conventional (SE)CT calibration for RT

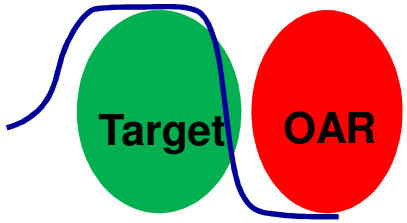




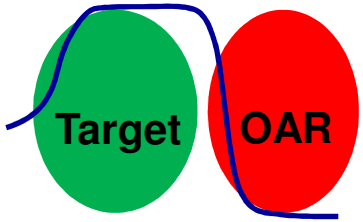
Dose calculation requires accurate data



Range = ok

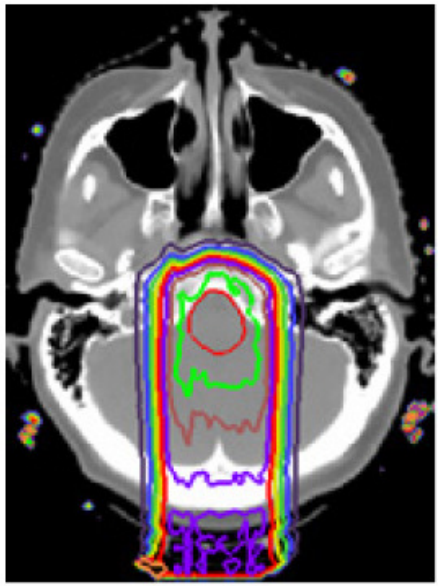


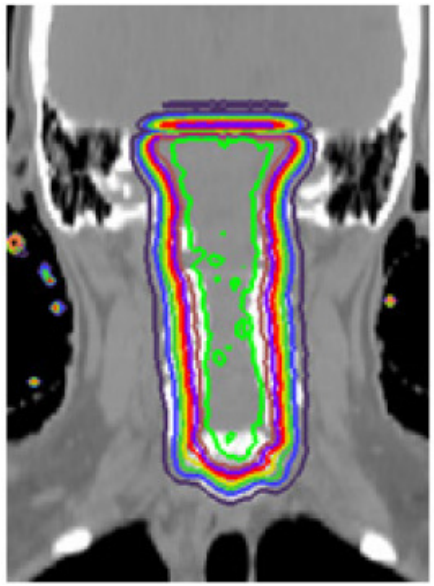
Range = overestimated



Range = underestimated

Proton therapy: OAR sparing is **critical** (e.g. skull base)

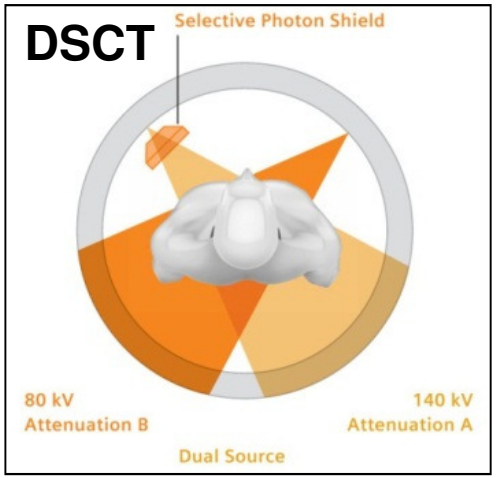


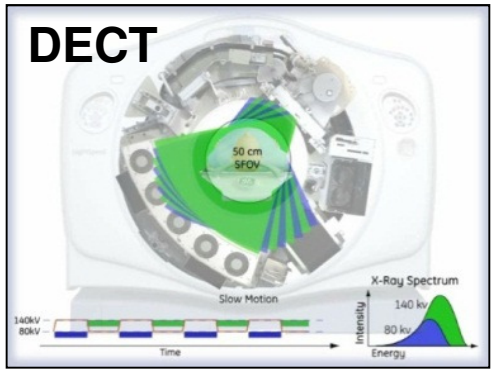


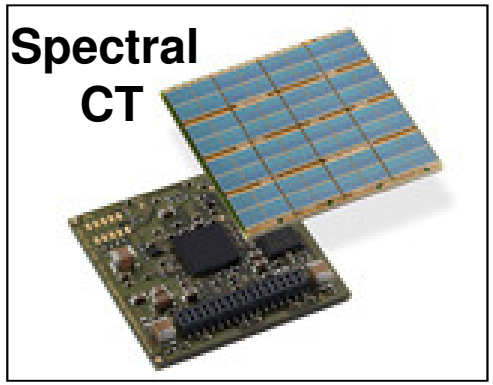
Paganetti *et al.* Phys. Med. Biol. 2008

Advanced parameter extraction with DECT

- Dual source CT: 2 perpendicular kV sources
  - Siemens SOMATOM Definition Flash
- Dual energy CT: rapid kV switching
  - GE Gemstone Spectral Imaging
- Spectral CT: single kV + energy discrimination
  - Philips IQon
- Applications for radiology (e.g., Alvarez & Macovski 1976)
- Techniques for RT are recent (e.g., Bazalova *et al.* 2008)
  - Spectrum-based
  - ~2% accuracy in ED







SECT stoichiometric calibration

- PMB 1996

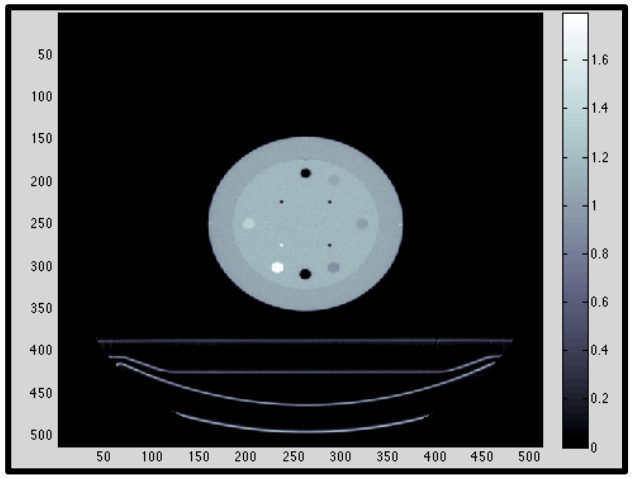
Phys. Med. Biol. **41** (1996) 111–124. Printed in the UK

The calibration of CT Hounsfield units for radiotherapy treatment planning

Uwe Schneider†§, Eros Pedroni‡ and Antony Lomax‡

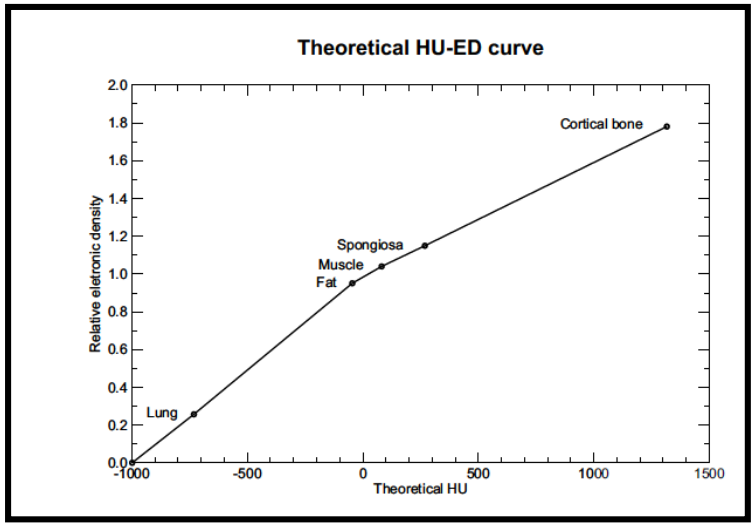
† Medical Physics Group, Section of Physics, University of Munich, Garching, Bavaria, Germany
‡ Department of Radiation Medicine, Paul Scherrer Institute, Villigen, Switzerland

Received 23 February 1995



Model
HU = $f(x_1,x_2,\ldots)$

ICRP/ICRU data



DECT stoichiometric calibration

- PMB 2014

TB, GG, US, PMB/482935, 7/02/2014

IOP Publishing | Institute of Physics and Engineering in Medicine — Physics in Medicine and Biology

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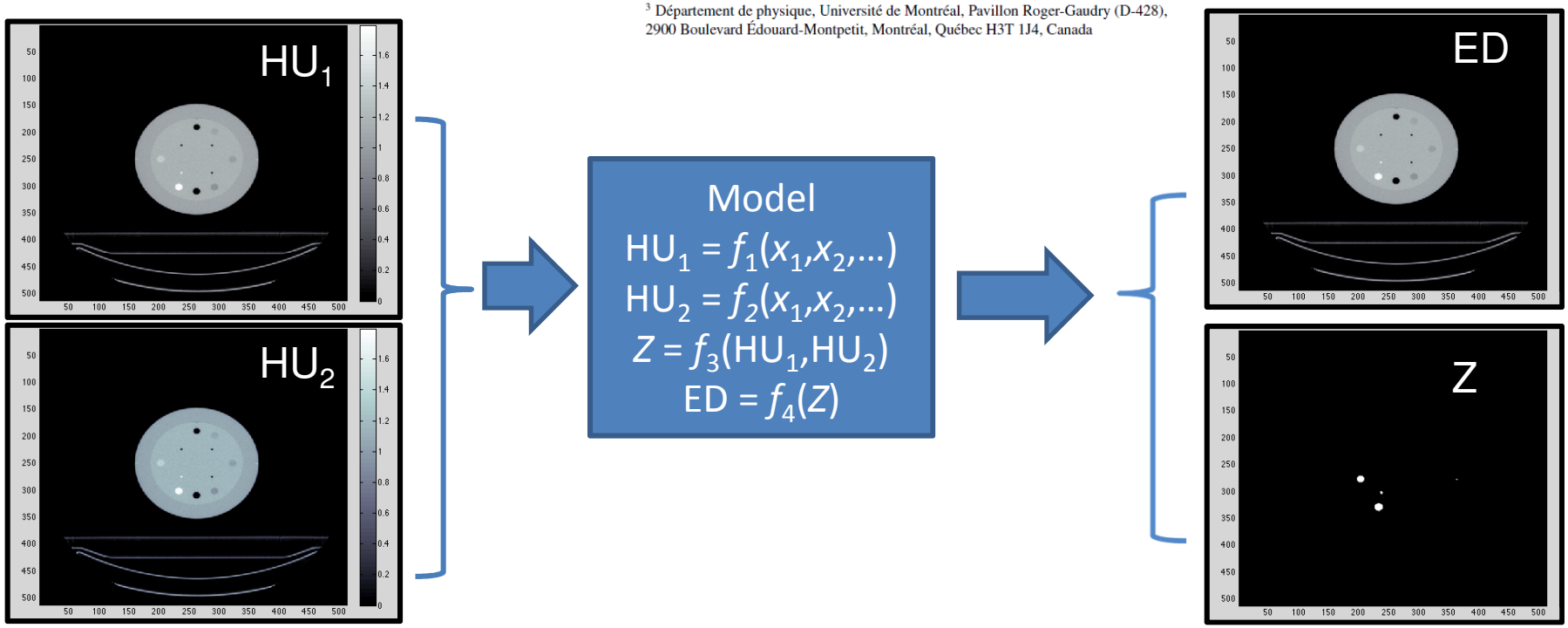
A stoichiometric calibration method for dual energy computed tomography

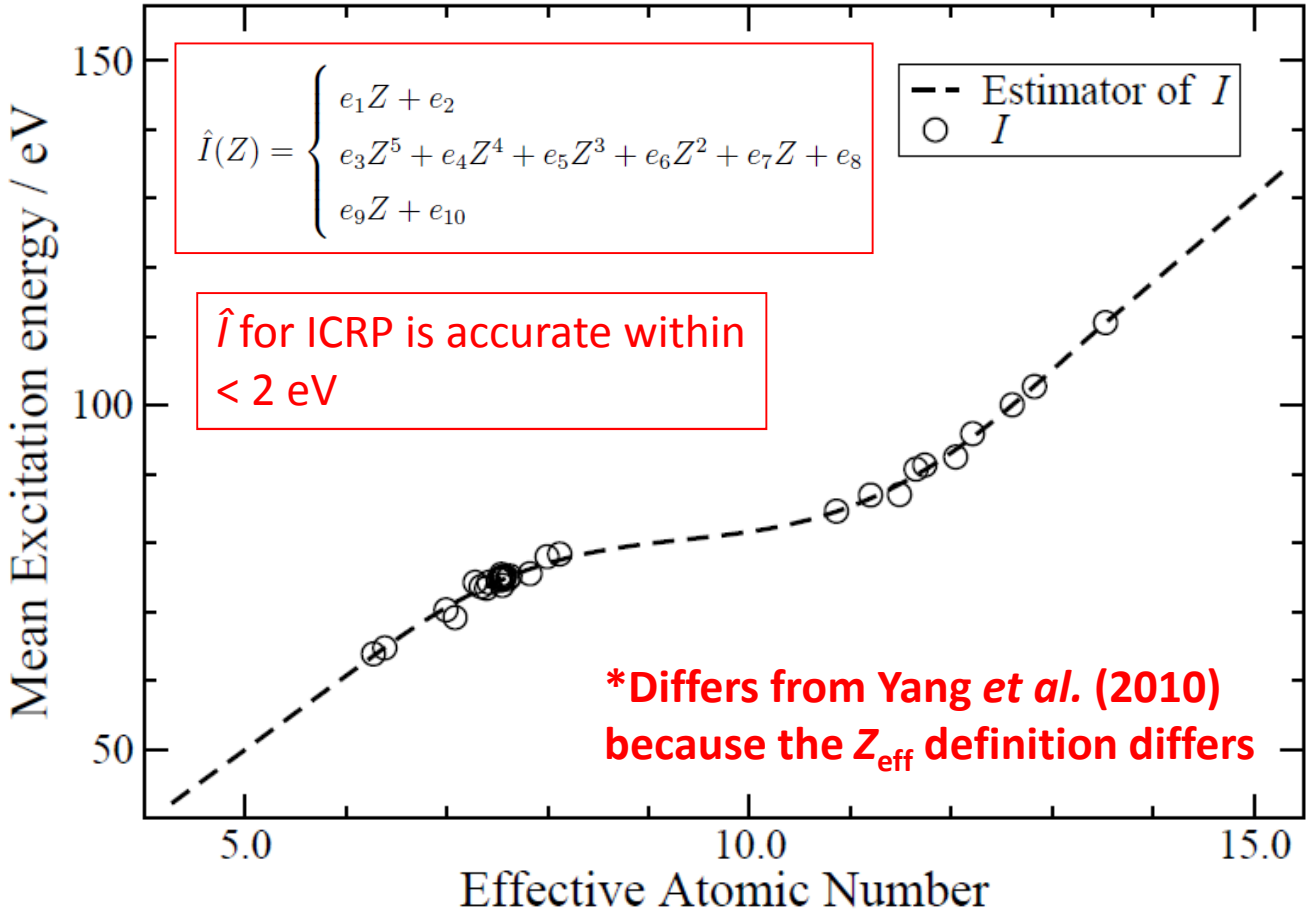
Alexandra E Bourque[1,2], Jean-François Carrier[2,3] and Hugo Bouchard[2,3]

[1] Medical Physics Unit, Montreal General Hospital (L5-113), McGill University, 1650 Cedar Avenue, Montreal, Quebec H3G 1A4, Canada
[2] Centre hospitalier de l'Université de Montréal (CHUM), 1560 Sherbrooke est, Montréal, Québec H2 L 4M1, Canada
[3] Département de physique, Université de Montréal, Pavillon Roger-Gaudry (D-428), 2900 Boulevard Édouard-Montpetit, Montréal, Québec H3T 1J4, Canada



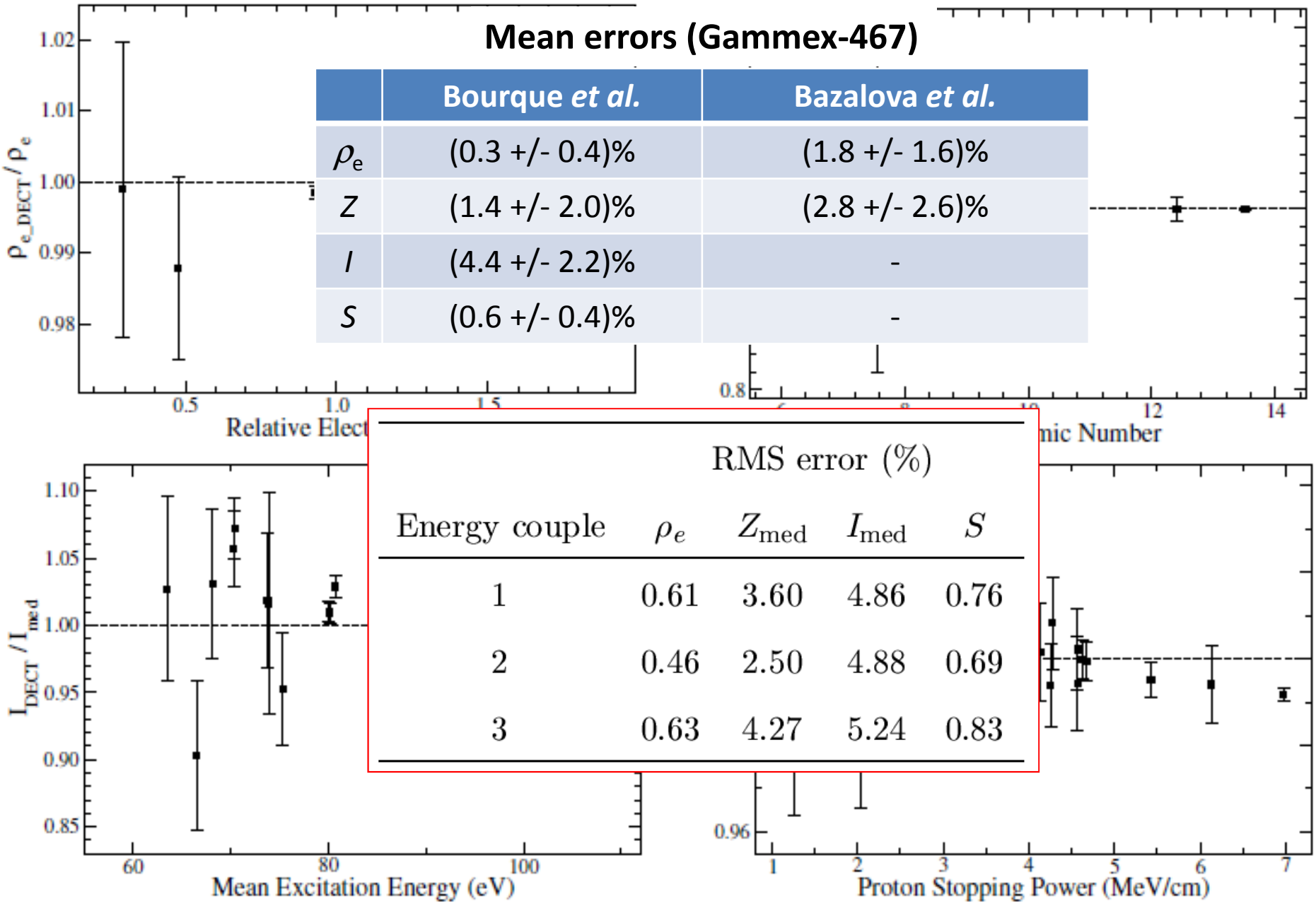
Stopping powers and *I*-value

$$S = \rho_e \frac{k_0}{\beta^2}\left[\ln\left(\frac{2m_e c^2\beta^2}{I_{\text{med}}(1-\beta^2)}\right) - \beta^2\right]$$



Mean errors (Gammex-467)

	Bourque *et al.*	Bazalova *et al.*
ρ_e	(0.3 +/- 0.4)%	(1.8 +/- 1.6)%
Z	(1.4 +/- 2.0)%	(2.8 +/- 2.6)%
I	(4.4 +/- 2.2)%	-
S	(0.6 +/- 0.4)%	-



RMS error (%)

Energy couple	ρ_e	Z_{med}	I_{med}	S
1	0.61	3.60	4.86	0.76
2	0.46	2.50	4.88	0.69
3	0.63	4.27	5.24	0.83

Ion beam range uncertainty

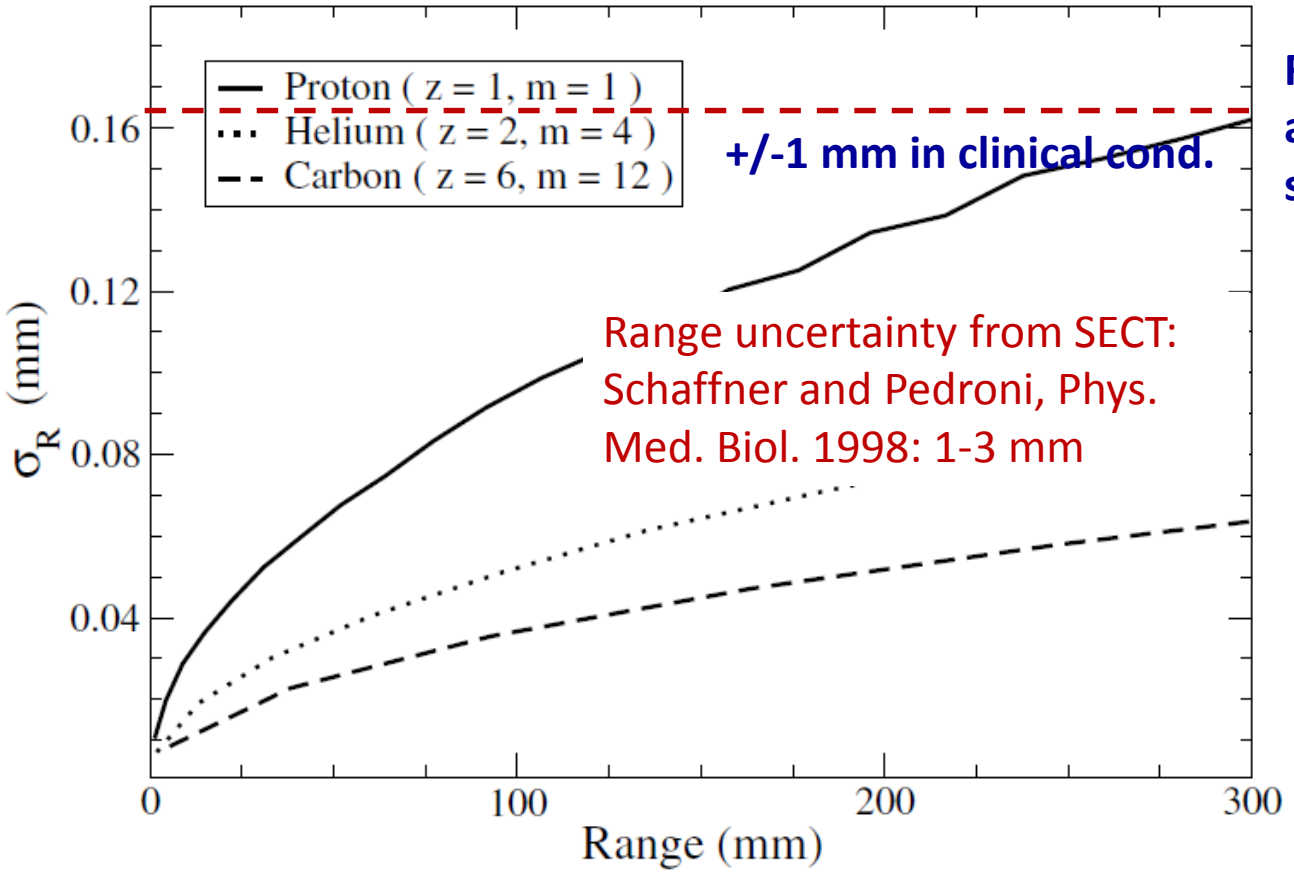
- Continuous slowing down approximation through *N* voxels

$$\Delta E \approx \sum_{i=1}^{N} \Delta x_i S_i,$$

$$\rightarrow \quad \hat{R} \approx \frac{E_0}{\left[\frac{1}{N}\sum_i S_i\right]}$$

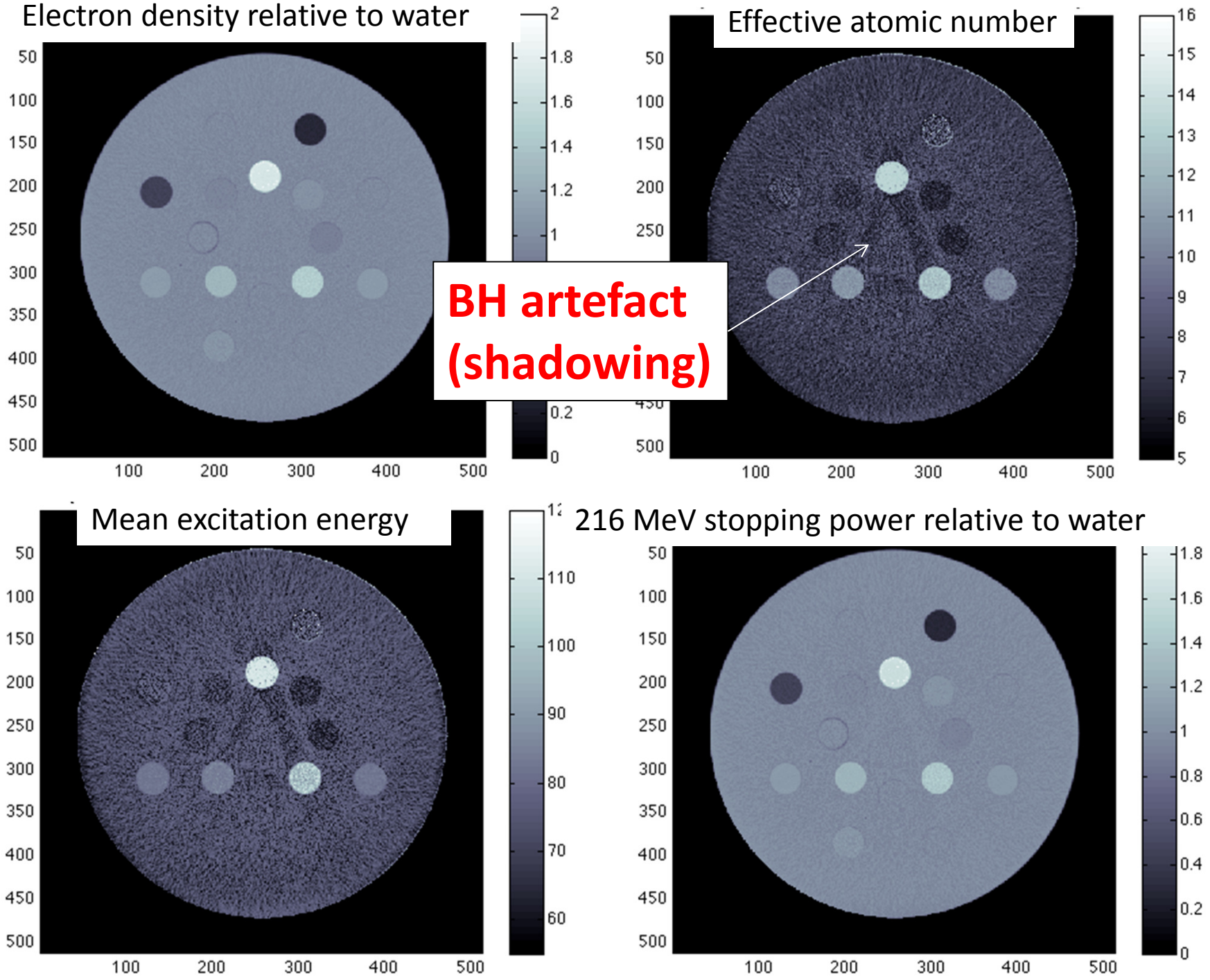
$$\rightarrow \quad \sigma_{\hat{R}} \approx \sqrt{\hat{R}\Delta x}\sqrt{\frac{\overline{\sigma_S^2}}{\overline{S}^2}},$$

Ion beam range uncertainty



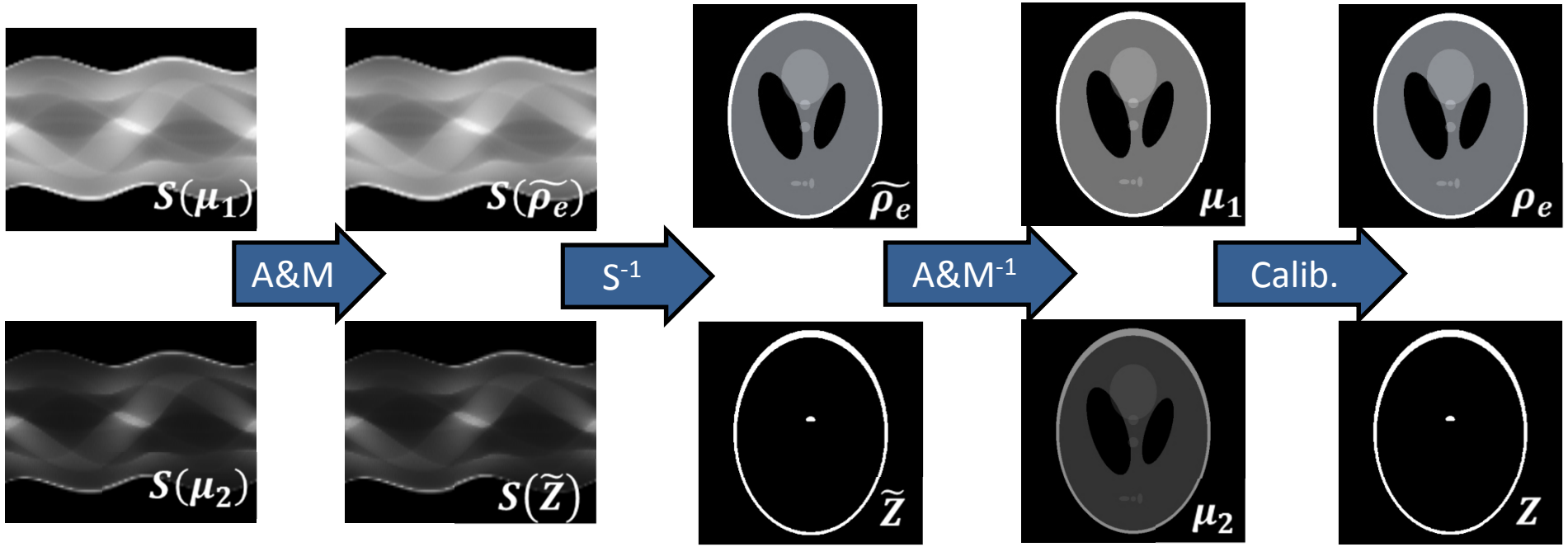
Factor of 6-8 between average values and single-voxel values

Figure 9. Ideal uncertainty on the range of protons, helium ions and carbon ions in water as a function of the range of the beam.


Electron density relative to water
Effective atomic number
BH artefact
(shadowing)
Mean excitation energy
216 MeV stopping power relative to water

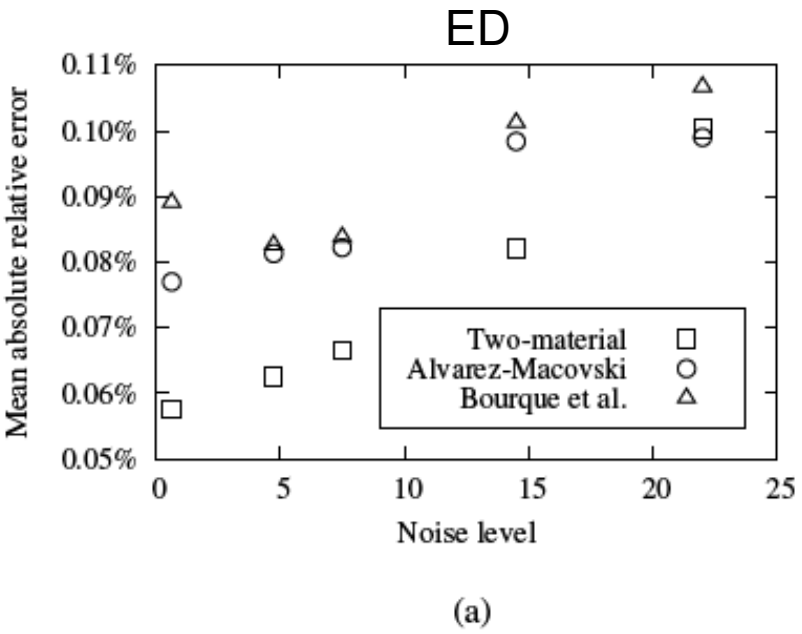
A theoretical comparison of tissue parameter extraction methods for dual energy computed tomography (under review)

Jean-Étienne Tremblay,[1] Stéphane Bedwani,[1,*] and Hugo Bouchard[2,†]

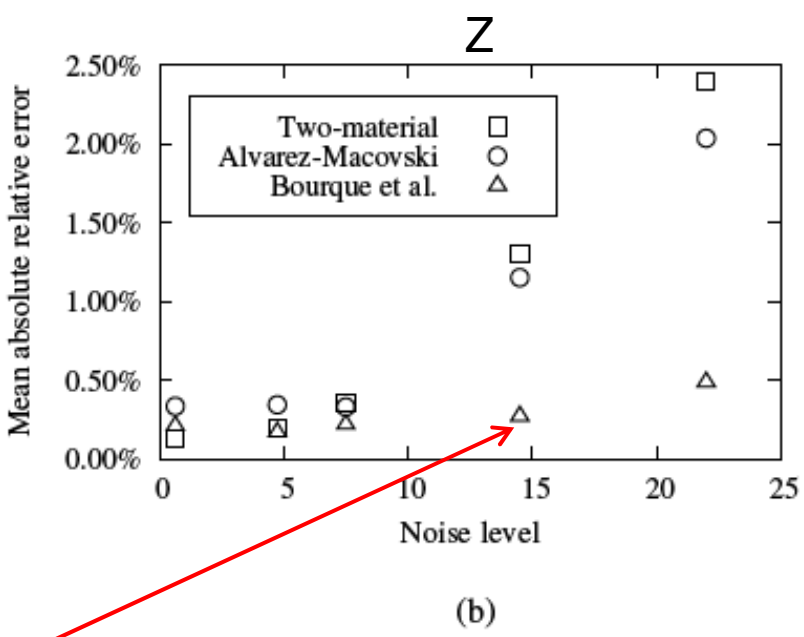


Sinogram-based **method (generic)**

Calibration-based **method**

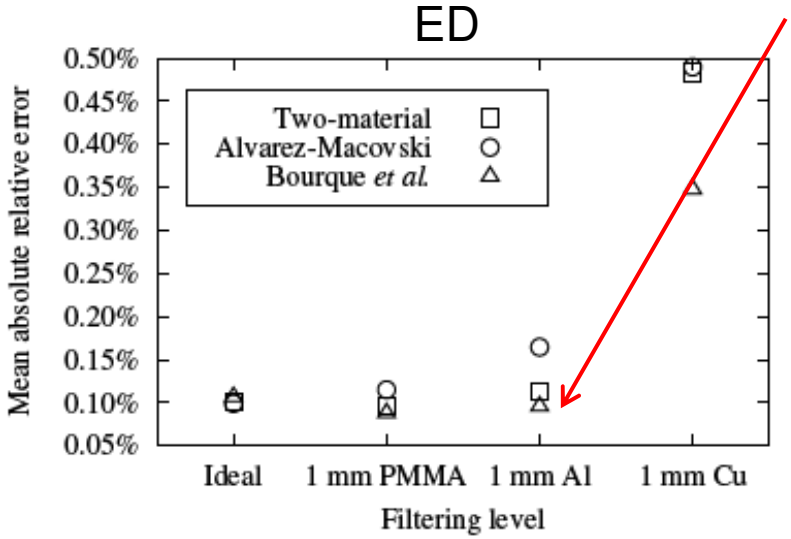


(a)

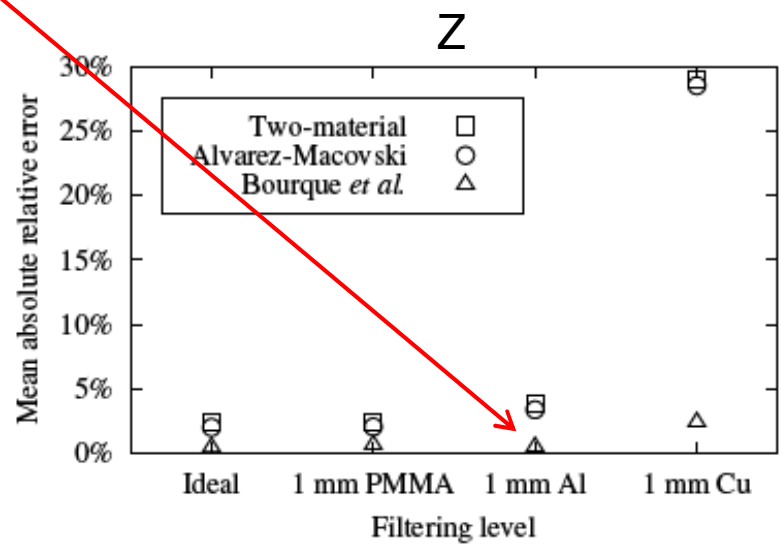


(b)

Calibration is more reliable

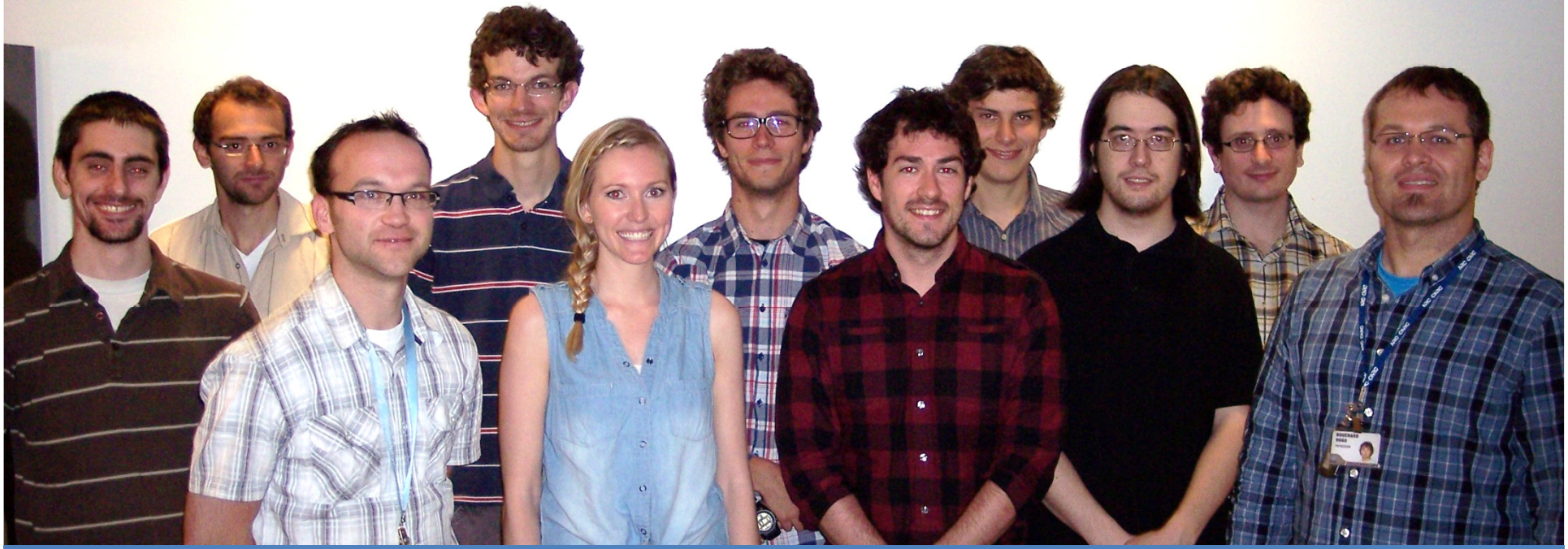


(c)



(d)

Acknowledgements



Colleagues

- Dr Jean-Francois Carrier – CHUM – U. Montreal
- Dr Stephane Bedwani – CHUM
- Real Besner – CHUM
- Dr David Roberge - CHUM
- Danis Blais – CHUM

Students

- Mikael Simard - Polytechnique
- Arthur Lalonde – Polytechnique
- Alexandra Bourque – McGill
- Jean-Etienne Tremblay – Polytechnique
- Anthony Di Salvio – U. Montreal
- A. Labine – U. Montreal