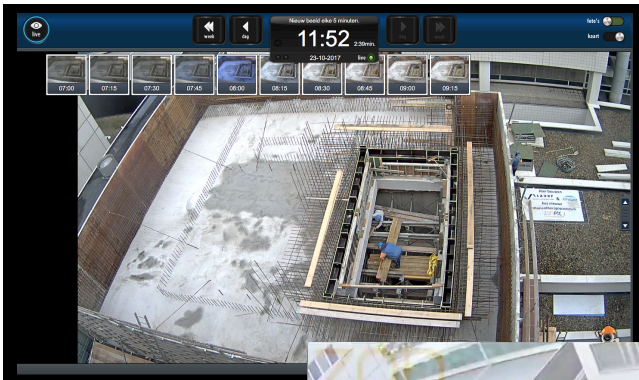
DUAL-ENERGY CT IN PROTON THERAPY

Isabel Almeida, MAASTRO Clinic

7th NCS Lustrum Symposium

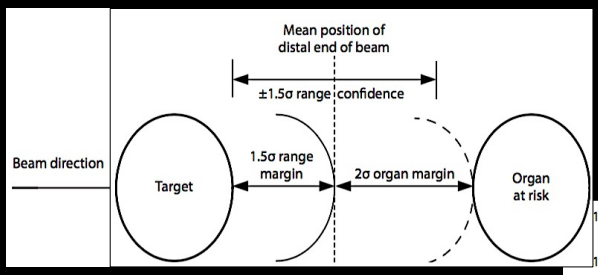
ZONPTC
Zuid-Oost Nederland Protonen Therapie Centrum



http://zonptc.bouwwebcam.nl

https://www.youtube.com/watch?v=3vVVf5Bqn7g

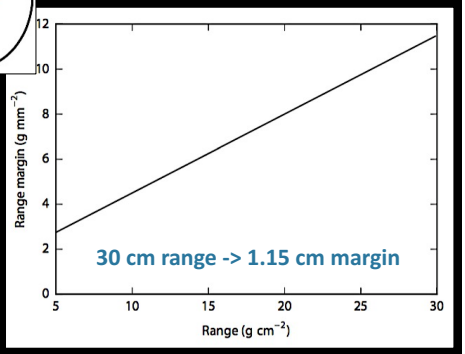
Range uncertainties and margins



*Figures from PhD Thesis of Verburg JM,
Reducing Range Uncertainty in Proton Therapy

- Margin recipes

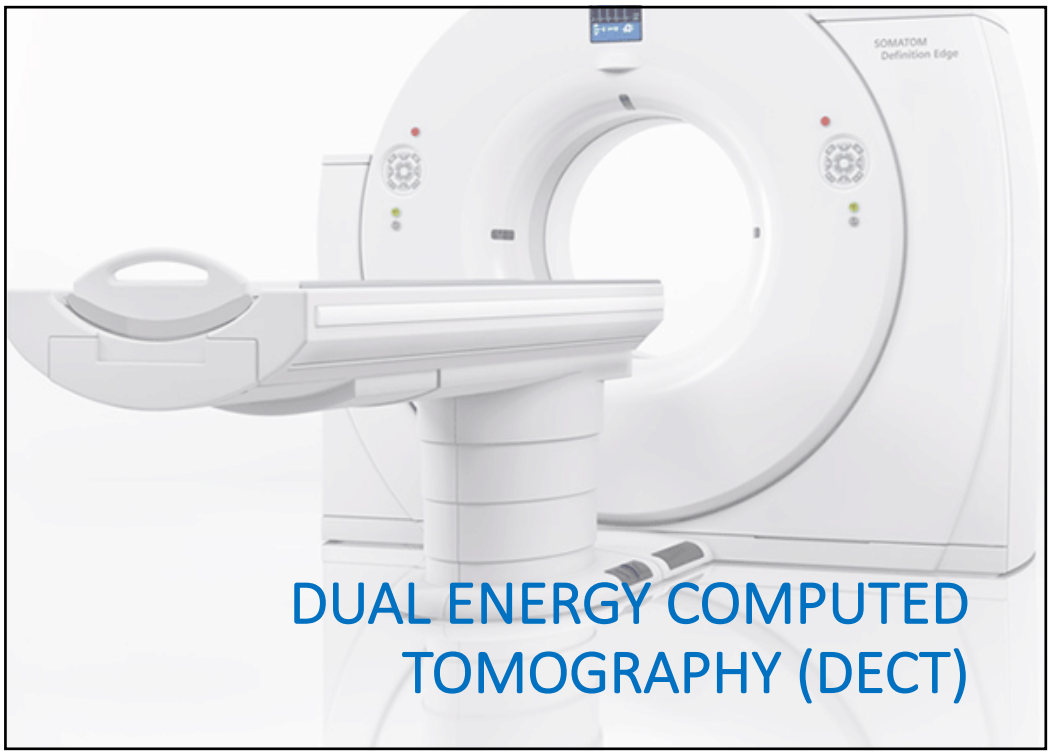
Example: 3.5%*R +1mm



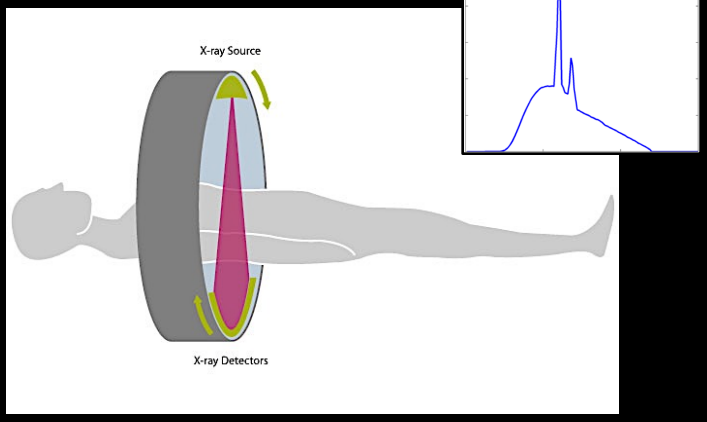
More on range uncertainties: Paganetti H. Phys Med Biol. 2012 Jun 7; 57(11): R99–R117

Contents

- Dual-energy CT (DECT)
- DECT in proton therapy (PT)
- Uncertainties in DECT for PT
- Final remarks



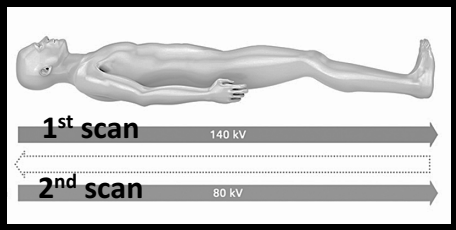
DUAL ENERGY COMPUTED TOMOGRAPHY (DECT)



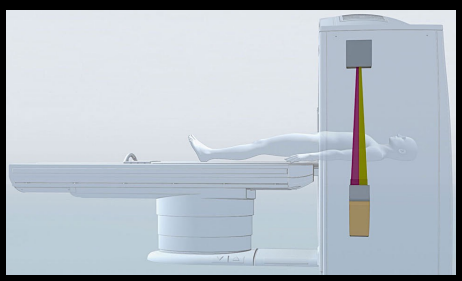
- SINGLE-SOURCE DECT
- DUAL-SOURCE DECT

Single-source DECT

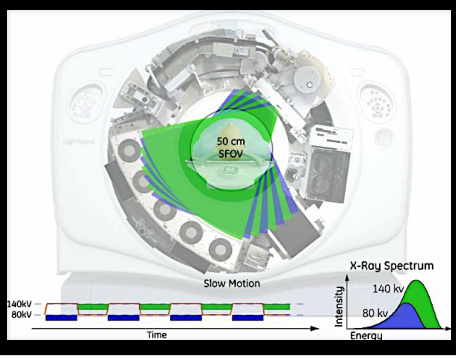
DUAL-SPIRAL



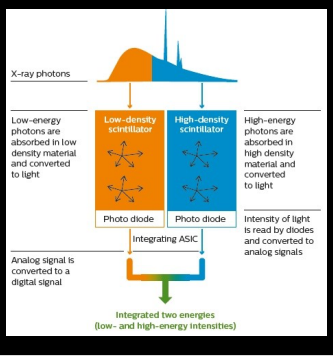
TWIN-BEAM



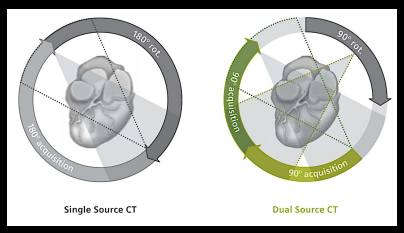
FAST-KV SWITCHING

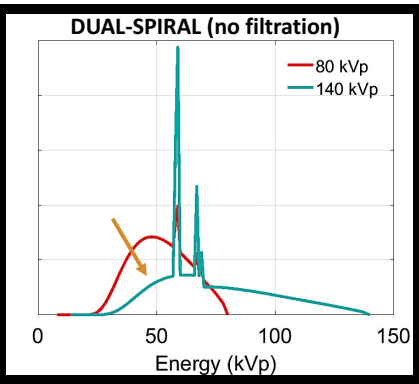


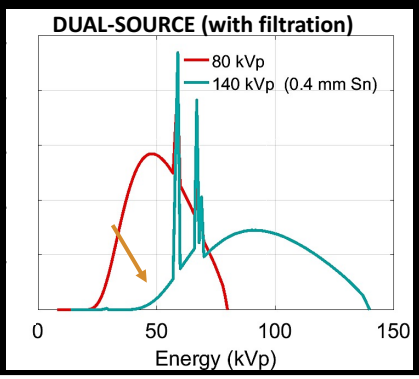
DUAL-LAYER DETECTOR



Dual-source DECT

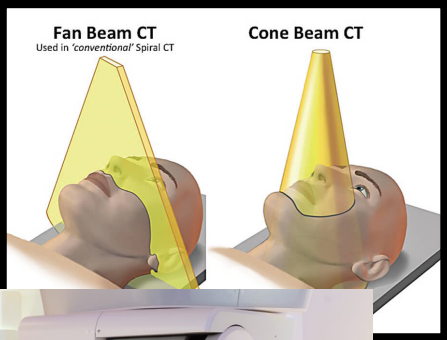




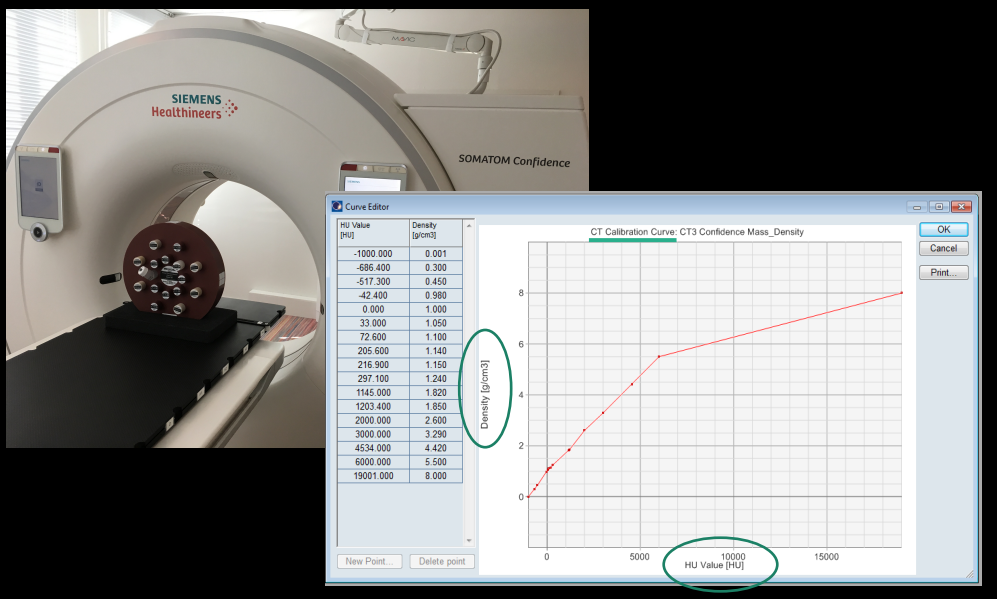


Cone-beam DECT

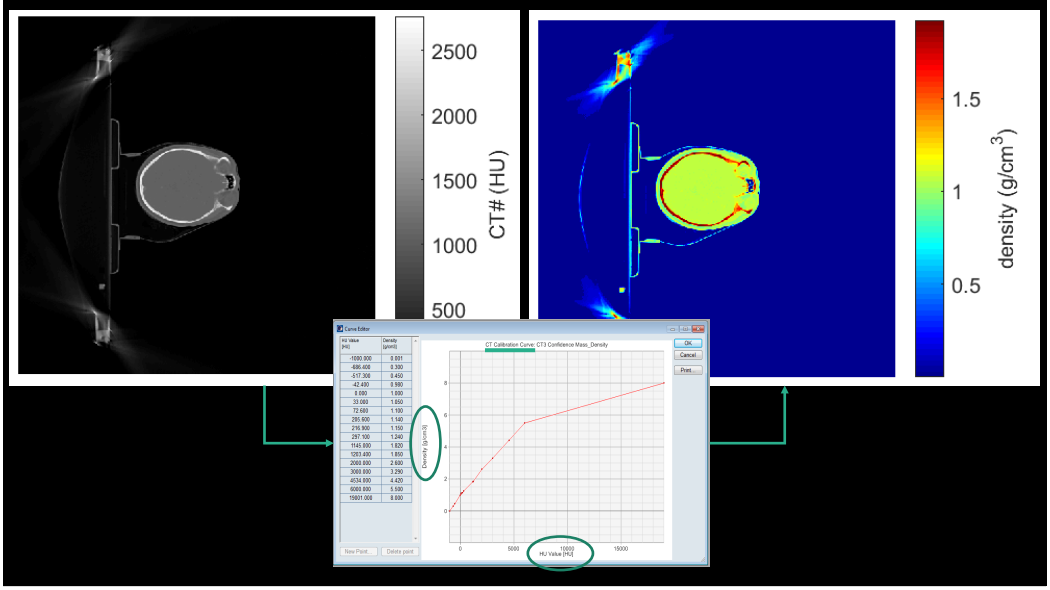
medPhoton

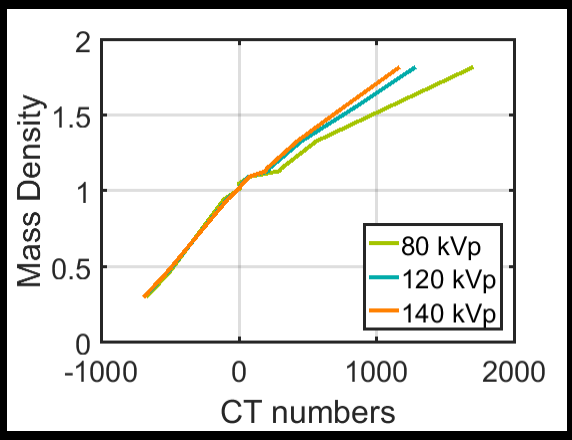


SECT calibration

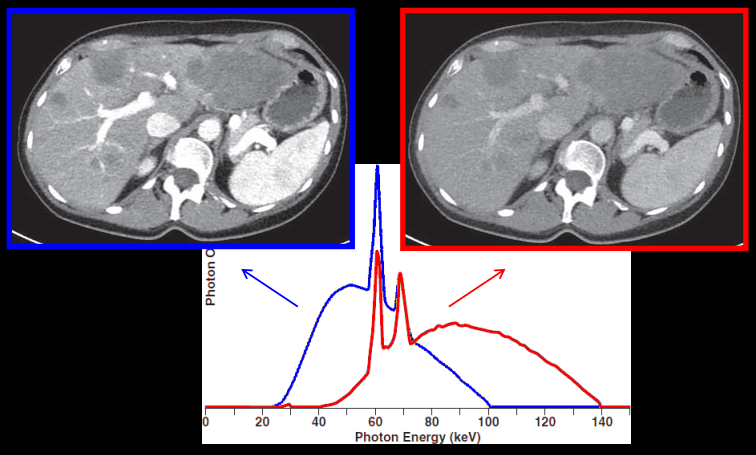


H&N patient scanned at 120 kVp





CT IMAGE DEPENDS ON THE X-RAY ENERGY



CT IMAGE DEPENDS ON THE X-RAY ENERGY

*Images from Johnson TRC, AJR 2012; 199:S3–S8

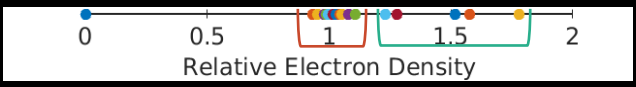
Soft tissue

	Density (g/cm^3)	Elemental Compositions		Effective Atomic Number
Breast	0.98	Hydrogen Oxygen Carbon N, Mg, Cl, Ca	8.97% 71.13% 16.45%	6.88
Brain	1.051	Hydrogen Oxygen Carbon N, Cl	9.97% 72.13% 16.34%	6.16
Liver	1.096	Hydrogen Oxygen Carbon N, Mg, Cl, Ca	8.4% 68.41% 18.5%	7.67

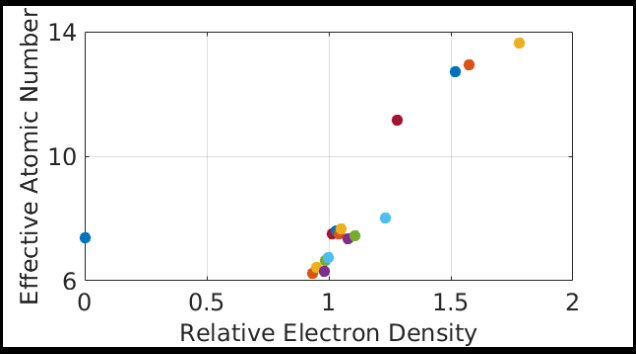
*Inserts GAMMEX RMI 467 phantom

16 ICRU H&N Tissues

1D-space

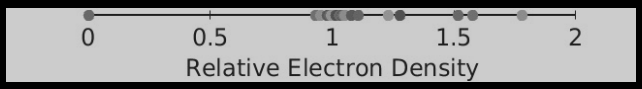


2D-space

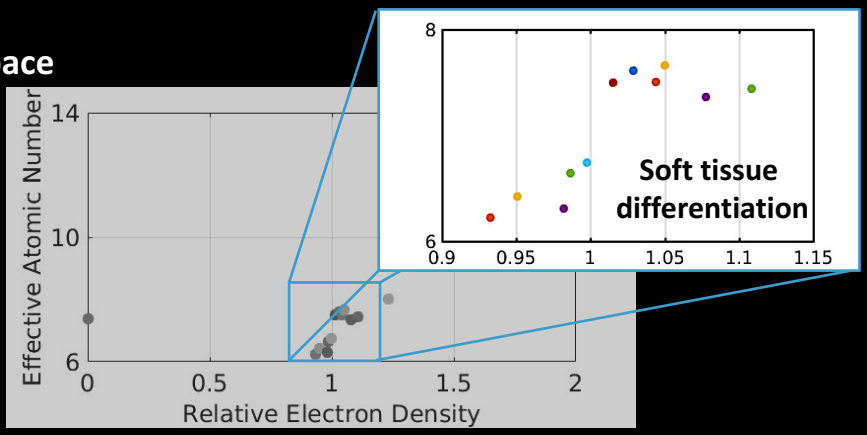


16 ICRU H&N Tissues

1D-space



2D-space



Stopping power ratios calculation

Mean excitation energy of the medium (eV)

BETHE FORMULA

$$\mathrm{SPR} = \frac{\varrho_{e,\mathrm{medium}}}{\varrho_{e,\mathrm{water}}} \cdot \frac{\ln\left(\frac{2m_e c^2\beta^2}{(I_{\mathrm{medium}}/\mathrm{eV})(1-\beta^2)}\right) - \beta^2}{\ln\left(\frac{2m_e c^2\beta^2}{(I_{\mathrm{water}}/\mathrm{eV})(1-\beta^2)}\right) - \beta^2}$$

Relative Electron Density

Mean excitation energy of water (eV)

Proton energy (MeV)

Stopping power ratios calculation

SECT

BETHE FORMULA

$$\mathrm{SPR} = \frac{\varrho_{e,\mathrm{medium}}}{\varrho_{e,\mathrm{water}}} \cdot \frac{\ln\left(\frac{2m_e c^2\beta^2}{(I_{\mathrm{medium}}/\mathrm{eV})(1-\beta^2)}\right) - \beta^2}{\ln\left(\frac{2m_e c^2\beta^2}{(I_{\mathrm{water}}/\mathrm{eV})(1-\beta^2)}\right) - \beta^2}$$

~~CT # to relative electron density~~

~~Bragg Rule~~

CT# to SPR curve

Stopping power ratios calculation

DECT

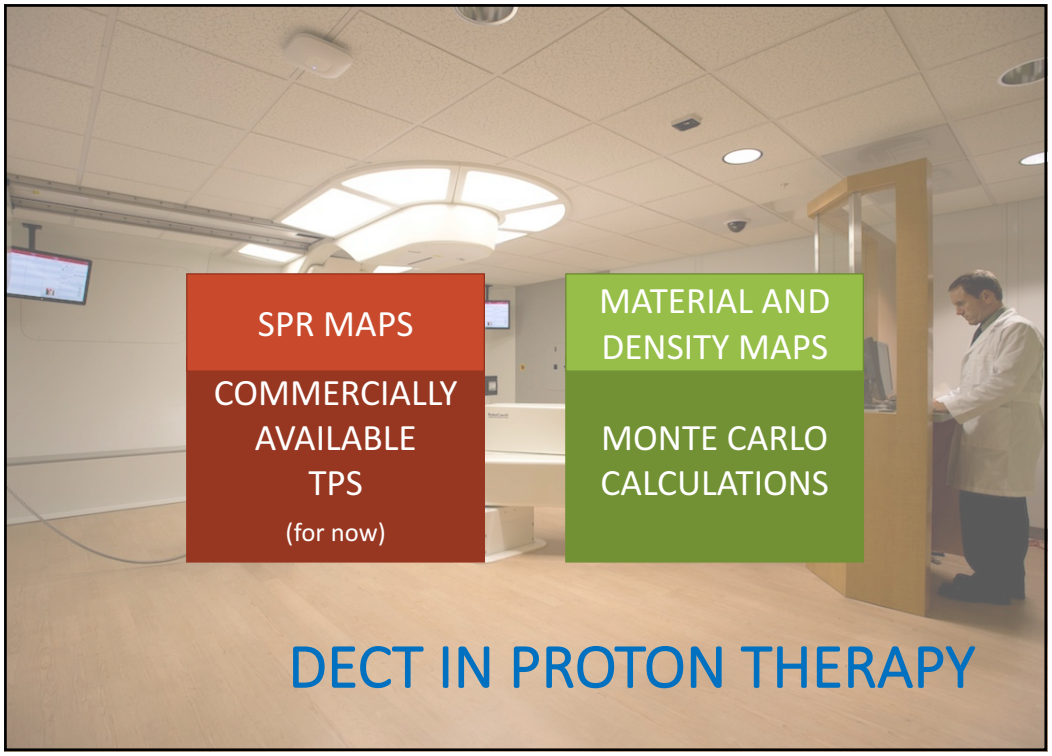
BETHE FORMULA

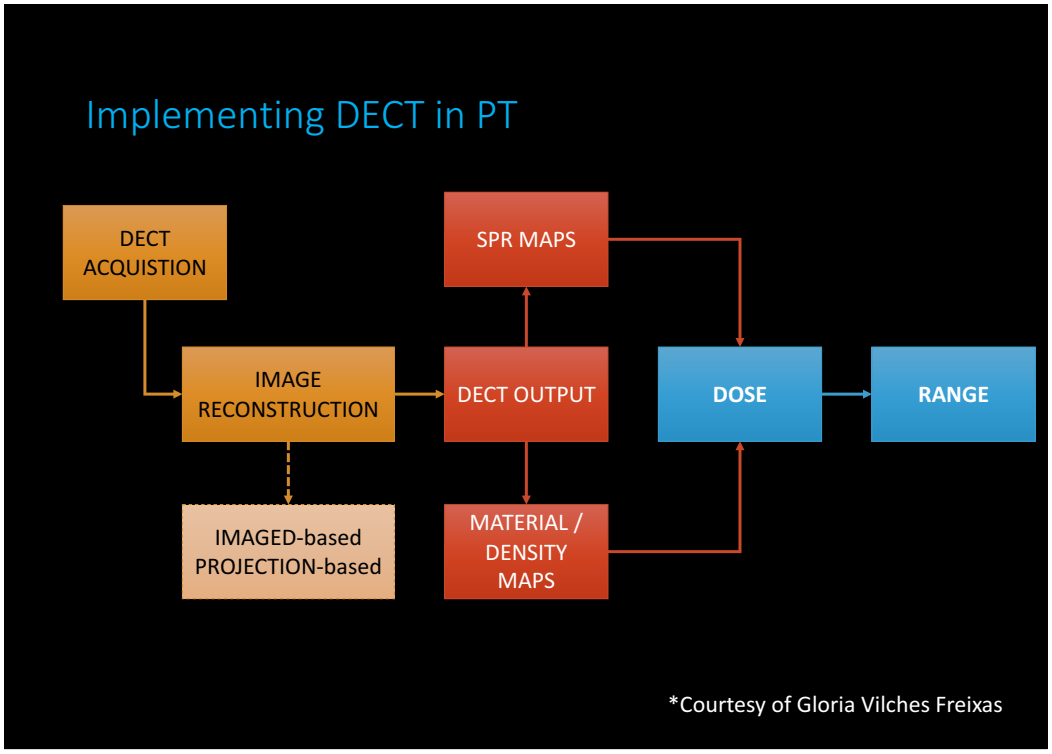
$$\mathrm{SPR} = \frac{\varrho_{e,\mathrm{medium}}}{\varrho_{e,\mathrm{water}}} \cdot \frac{\ln\left(\frac{2m_e c^2\beta^2}{(I_{\mathrm{medium}}/\mathrm{eV})(1-\beta^2)}\right) - \beta^2}{\ln\left(\frac{2m_e c^2\beta^2}{(I_{\mathrm{water}}/\mathrm{eV})(1-\beta^2)}\right) - \beta^2}$$

Yang, PMB 2010

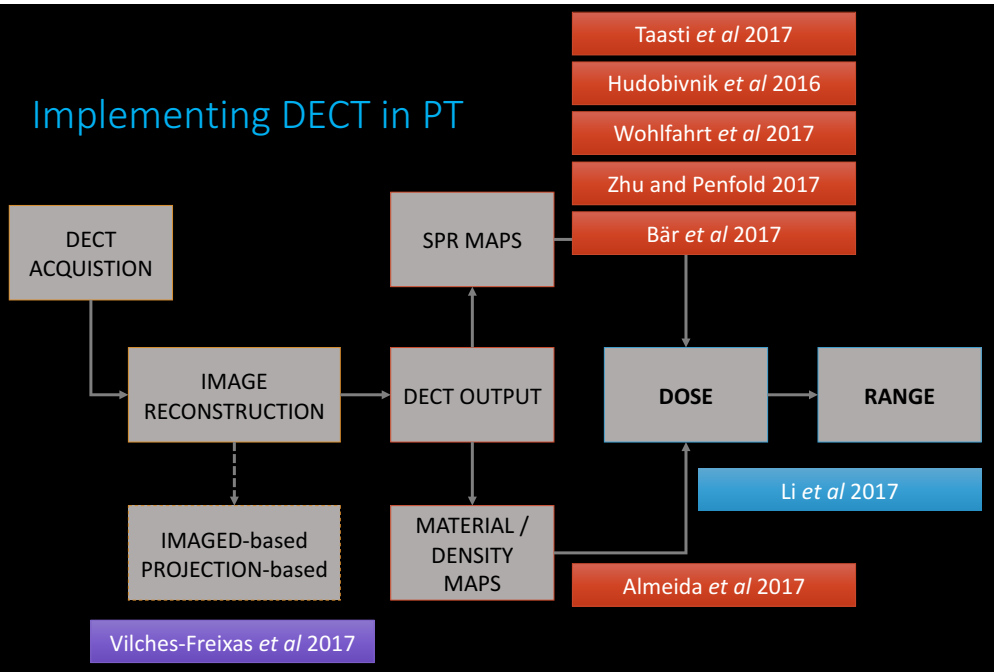
(Saito et al, MP 2012)

Effective Atomic Number
(Landry et al, PMB 2013)
(Saito et al. MP 2016)


SPR MAPS
COMMERCIALLY AVAILABLE TPS
(for now)
MATERIAL AND DENSITY MAPS
MONTE CARLO CALCULATIONS
DECT IN PROTON THERAPY


Implementing DECT in PT
DECT ACQUISTION
IMAGE RECONSTRUCTION
IMAGED-based PROJECTION-based
SPR MAPS
DECT OUTPUT
MATERIAL / DENSITY MAPS
DOSE
RANGE
*Courtesy of Gloria Vilches Freixas

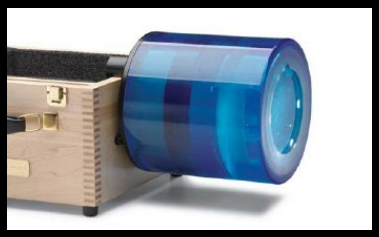
Implementing DECT in PT

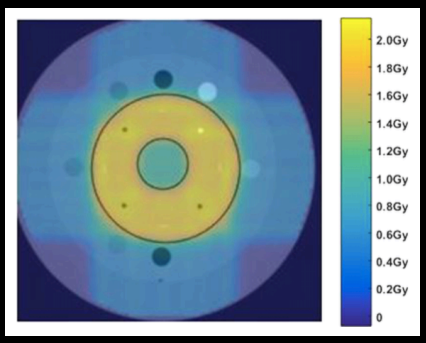


Dose differences DECT *vs* SECT

Zhu and Penfold, Med Phys 2016;43:2845

- Scans CIRS for calibration
- DECT and SECT images of Catphan
- Dose distribution in a ”donut” target

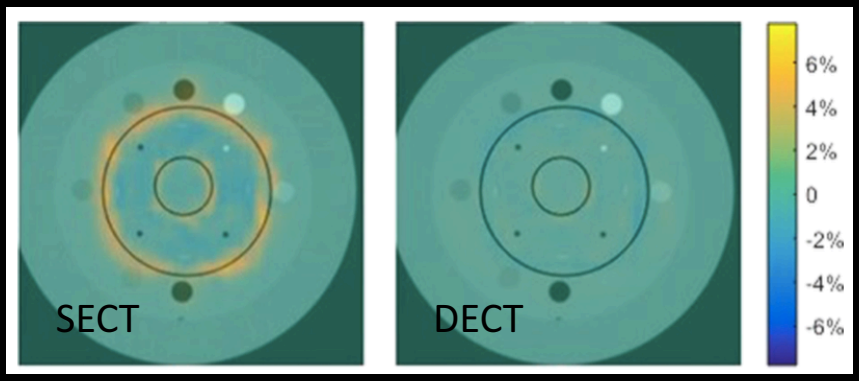




Dose differences DECT *vs* SECT

Zhu and Penfold, Med Phys 2016;43:2845

	SECT	DECT
Maximum dose difference	**7.8%**	**1.4%**
Root mean square error	**2.1%**	**0.4%**



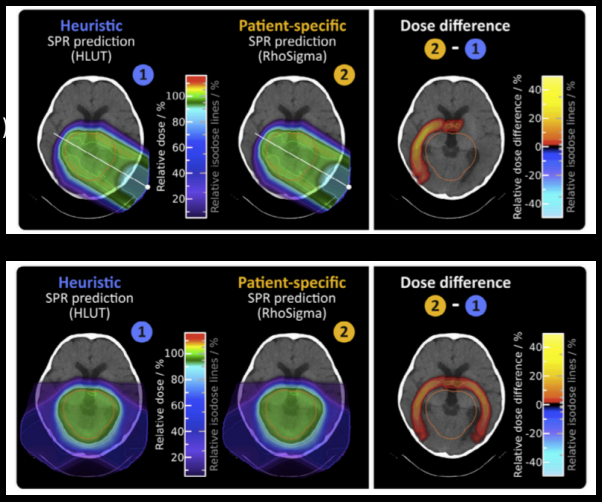
Range shifts between HU-SPR LUT and DECT patient specific SPR prediction

Wohlfart et al IJROBP 2017 (II)

Follows the work from:

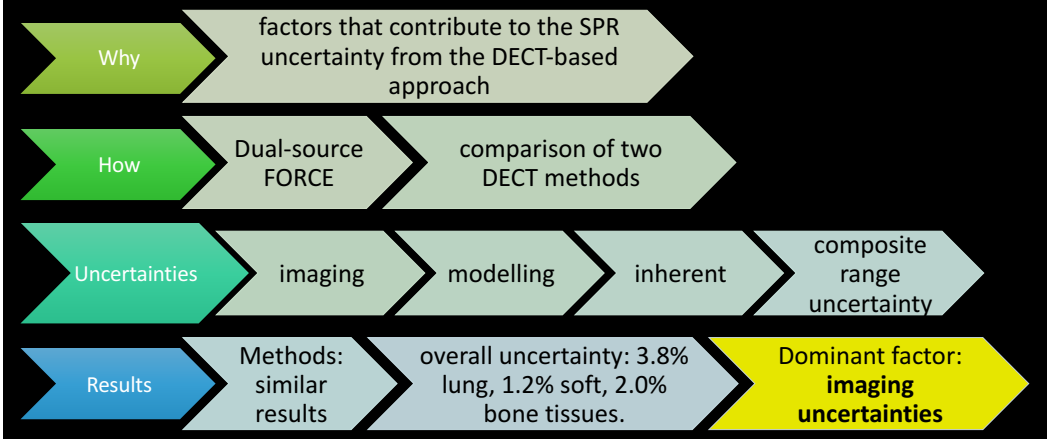
- Wohlfahrt et al IJROBP 2016
- Wohlfahrt et al IJROBP 2017 (I)

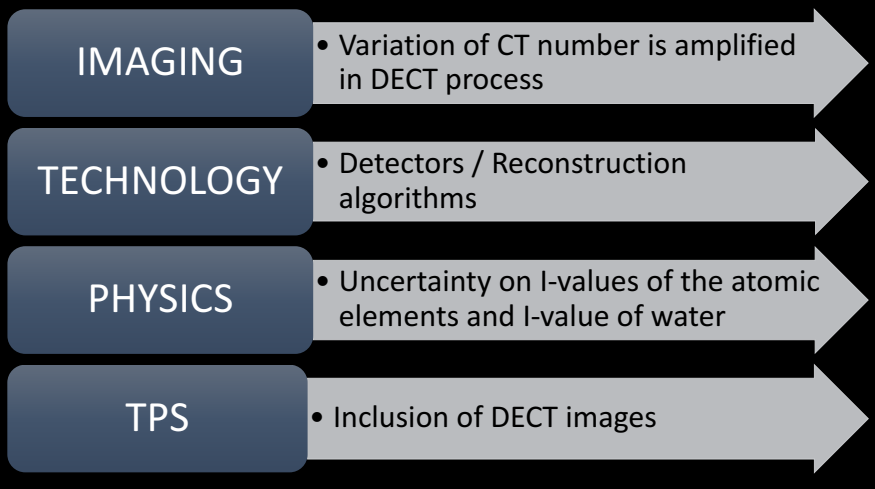
- Proof of concept with anthropomorphic phantom
- DECT proofed to be more accurate than SECT

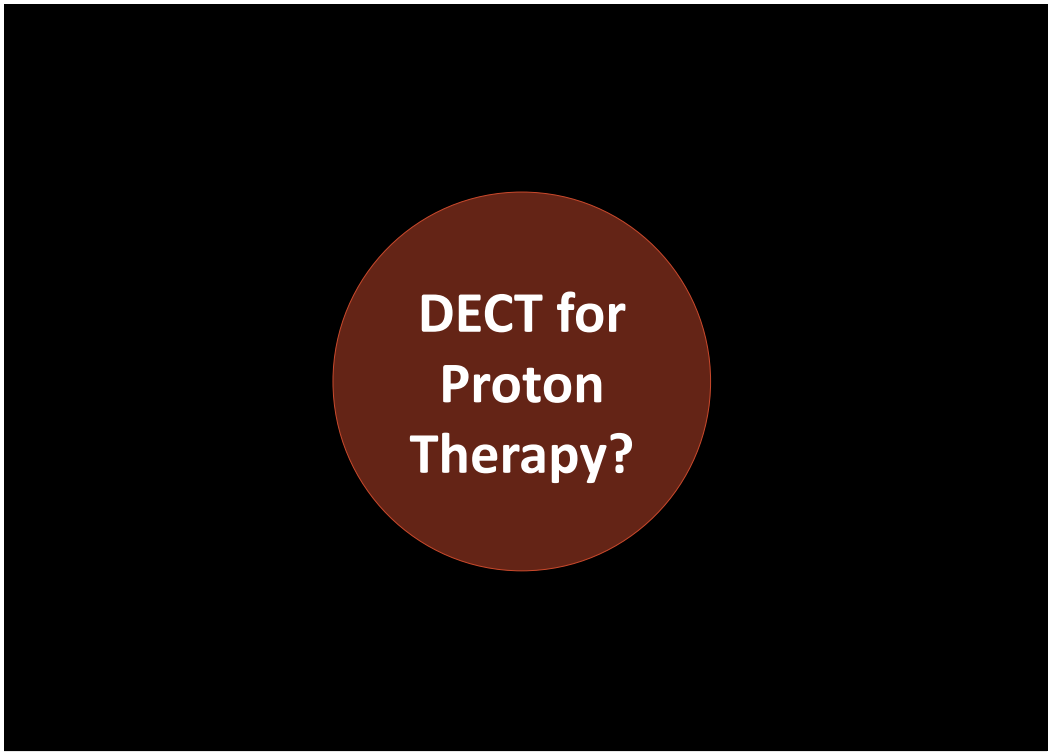


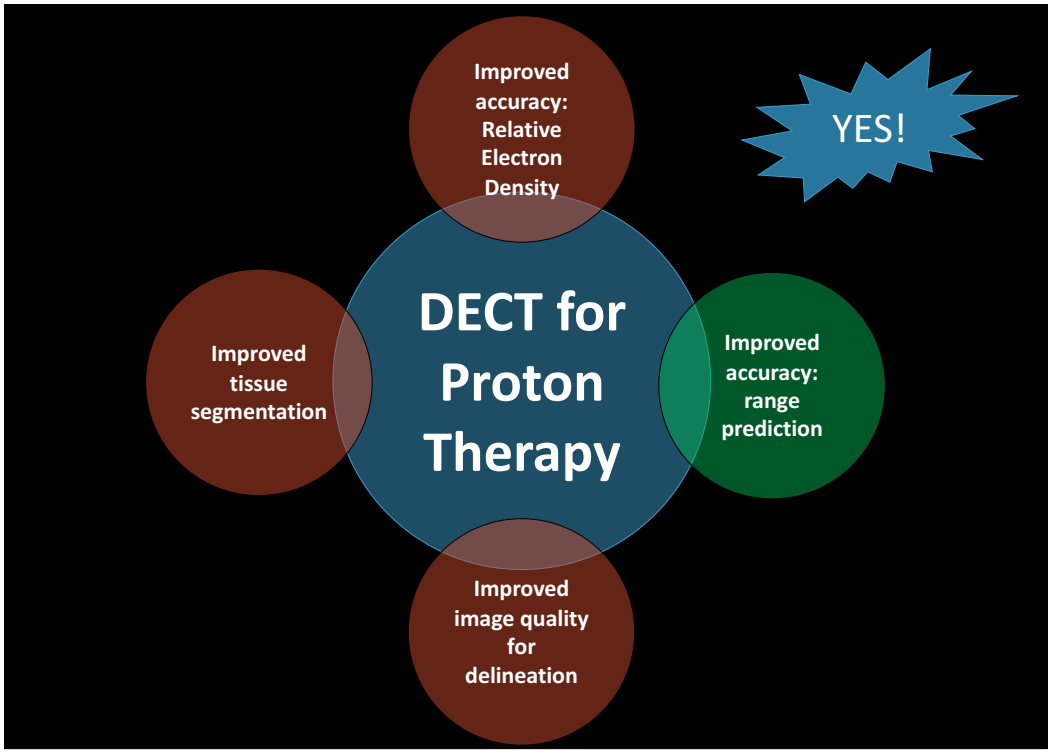
Uncertainties related to SPR estimation from DECT

Li et al. Phys Med Biol 2017;62:7056-7074






DECT for Proton Therapy?


Improved accuracy: Relative Electron Density
YES!
Improved tissue segmentation
DECT for Proton Therapy
Improved accuracy: range prediction
Improved image quality for delineation

MAASTRO - Physics Research Group

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Thank you!

More references

- Hudobivnik et al. Med. Phys. 2016 43(1)
- Taasti et al. Med. Phys. 2016 43(10)
- Bär et al. Med. Phys. 2017 Jun;44(6):2332-2344
- Möhler et al. Phys Med Biol. 2016 Jun 7;61(11):N268-75
- Wohlfahrt et al. Int J Radiat Oncol Biol Phys. 2017 1;97(2):427-434
- Vilches-Freixas et al. Med. Phys. 2017 44(9):4548-4558.
- ...