Characterizing the performance of a proton tomography system for x-ray CT cross-calibration

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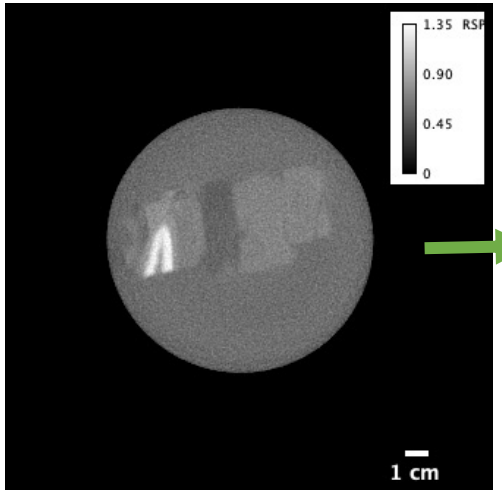
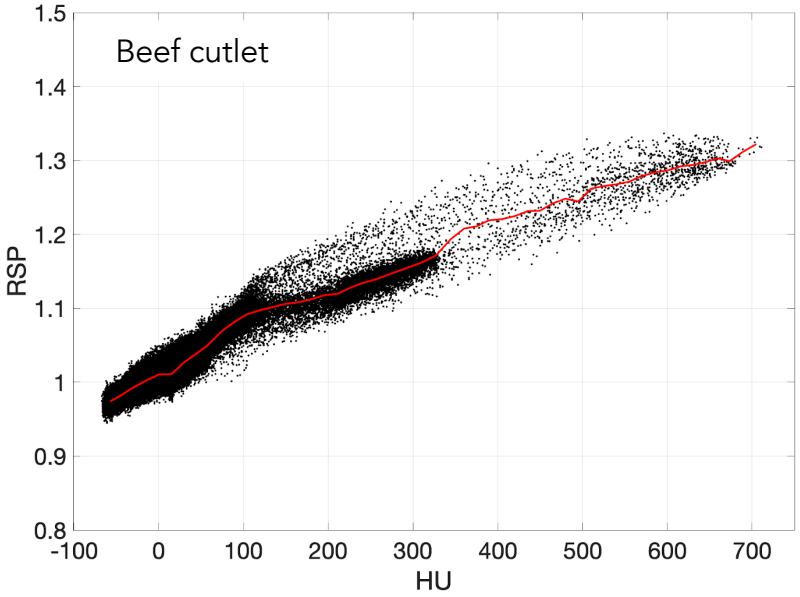
Cross-calibration approach



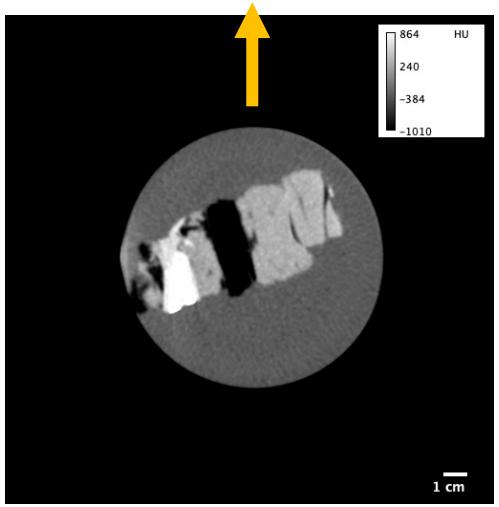
pCT

Voxel: 0.6x0.6x2.75 mm^3
$\sim 6 \times 10^8$ events



Preliminary cross-calibration curve through piecewise linear interpolation of the HU-RSP scatter plot

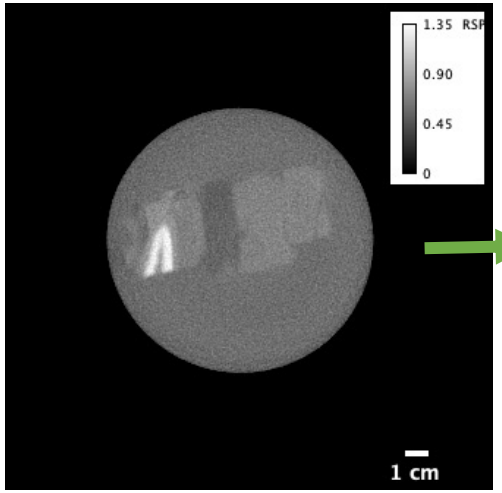
First curve in P. Farace et al., Med. Phys. (2020)



xCT

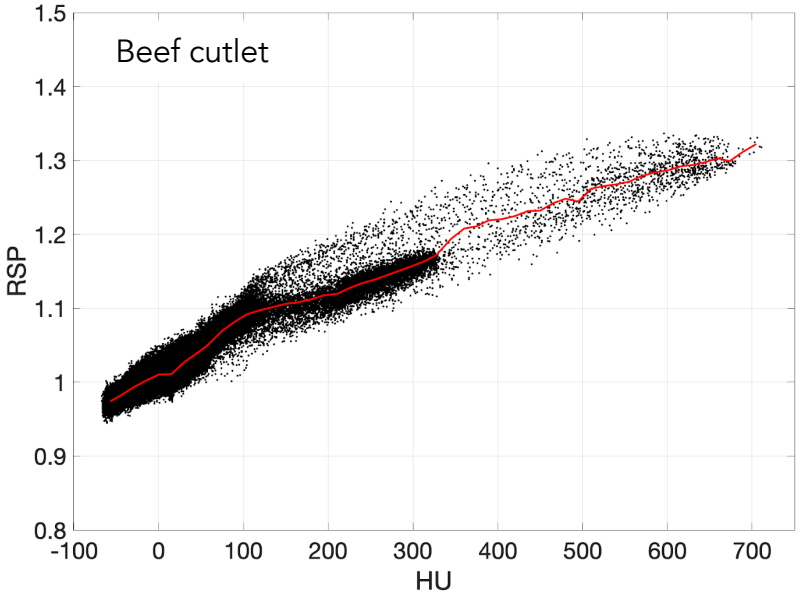
Brilliance CT scanner (Philips)

Cross-calibration approach



pCT

Voxel: 0.6x0.6x2.75 mm^3
~6×10^8 events



Preliminary cross-calibration curve
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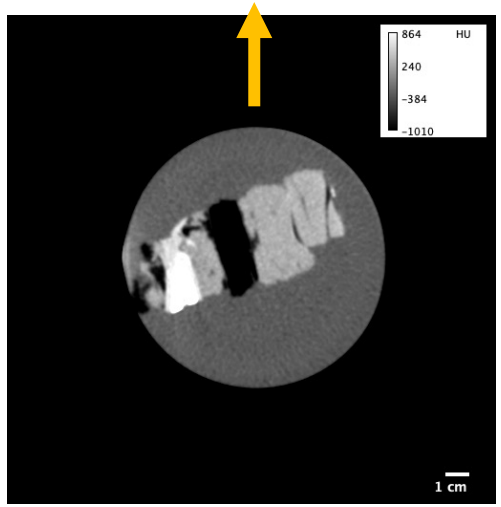


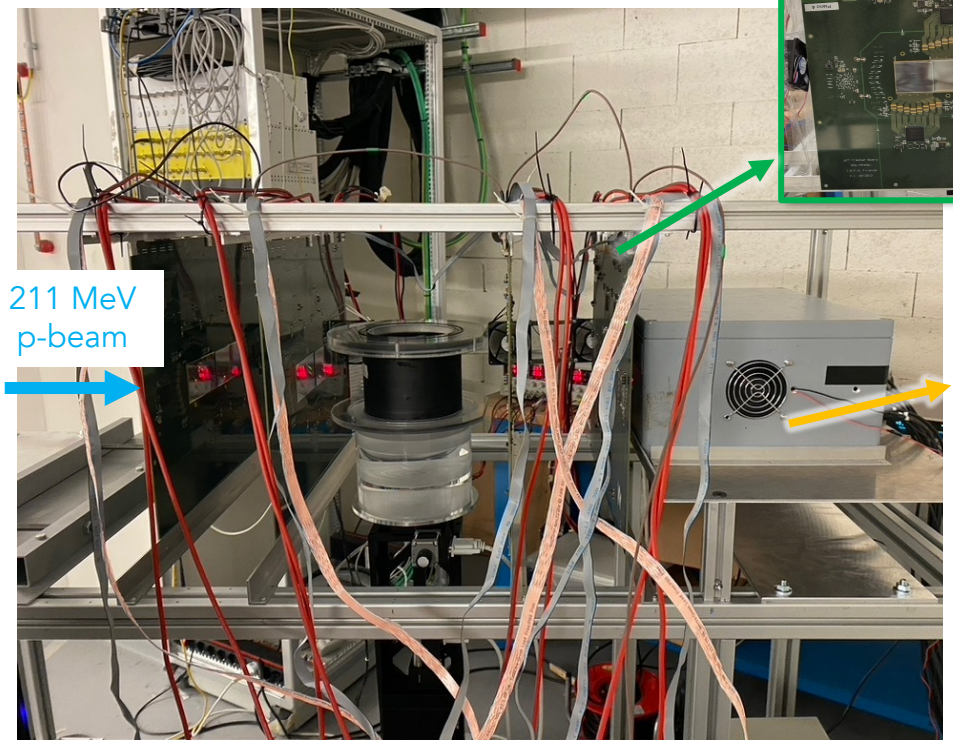
xCT

Brilliance CT scanner (Philips)

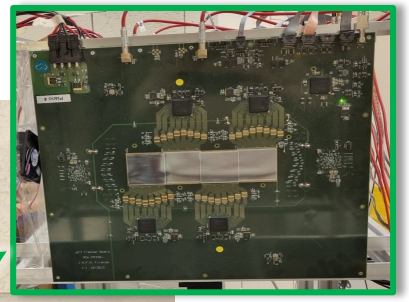
Image registration
Voxel size
Noise
Spatial resolution
Partial volume effects

INFN pCT apparatus

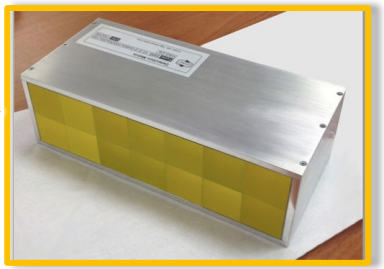
Cf. C. Civinini et al. Phys. Med. (2020)



Silicon tracker



YAG:Ce Calorimeter



FOV: 200x200 mm2
Voxel (0.39,0.39,1.50) mm3

Reconstruction algorithm:
Filtered back-projection algorithm* developed by Simon Rit group at CREATIS Research Lab, Lyon

xCT system, Trento PT centre

Brilliance CT Big Bore, Philips

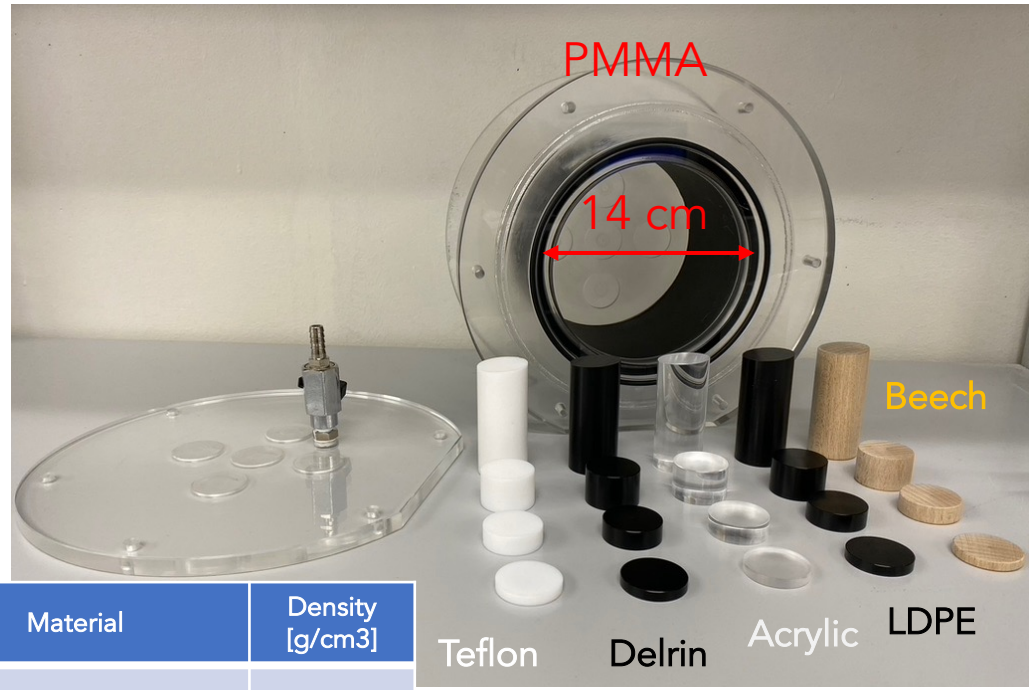
120 **kV**, 450/413 **mAs/mA**
FOV: 200x200 mm2
Voxel (0.39,0.39,1.50) mm3

Reconstruction algorithm:
Filtered back-projection algorithm, with standard kernel EB, according to the Standard Adult Head Protocol

* Rit S. et al., "Filtered backprojection proton CT reconstruction along most likely paths", Med Phys (2013)

Performance tests

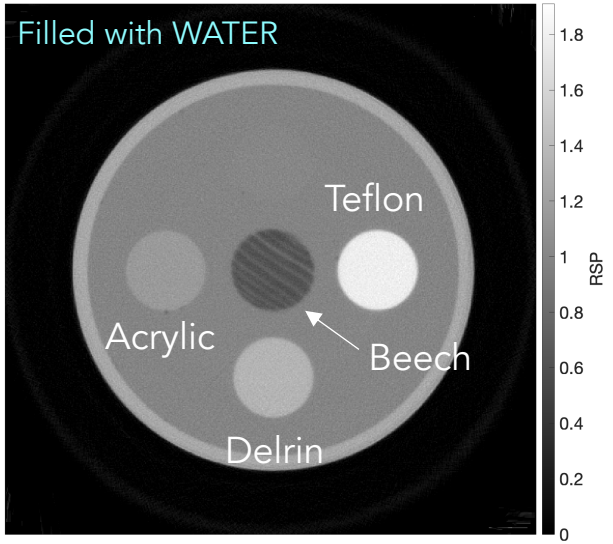
Custom-built phantom made of 5 different cylindrical inserts of 3 cm diameter, and that can be filled with air or water

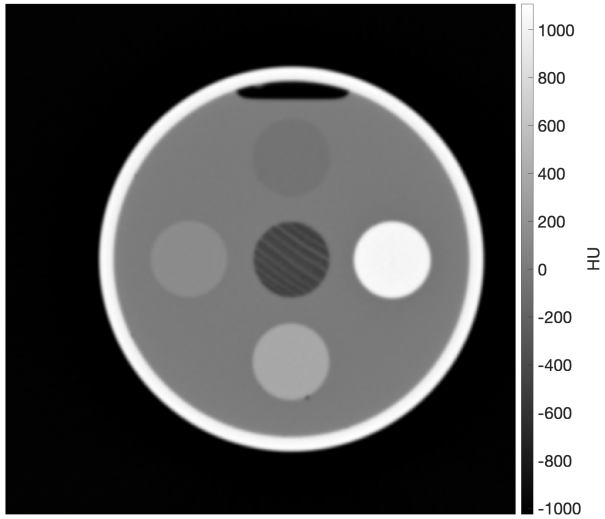


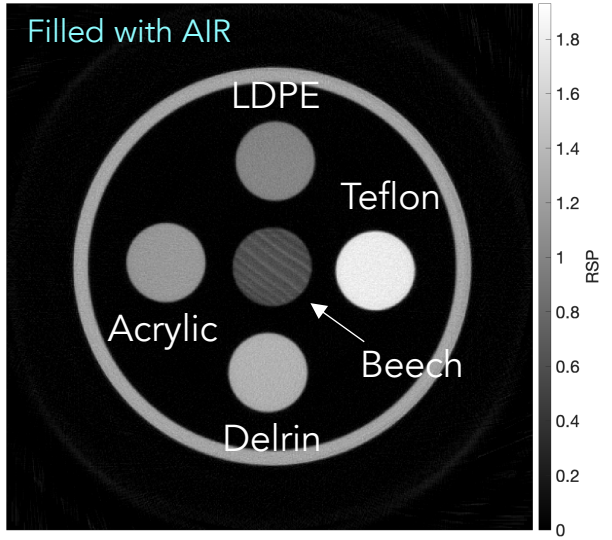
Material	Density [g/cm3]
Teflon	2.18
Delrin	1.41
Acrylic	1.20
Low-Density PolyEthylene	0.99

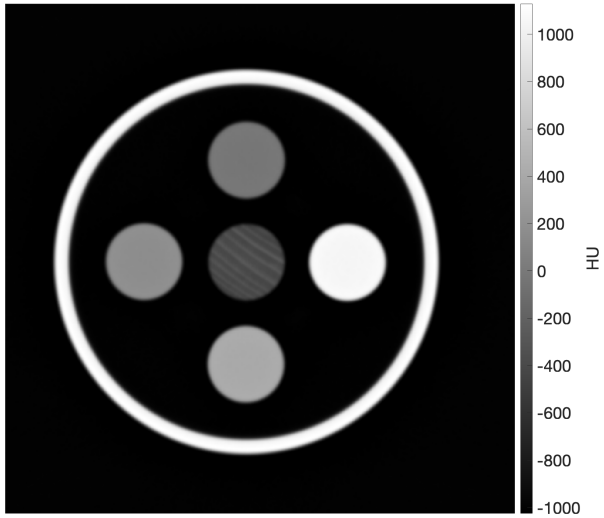
pCT

xCT





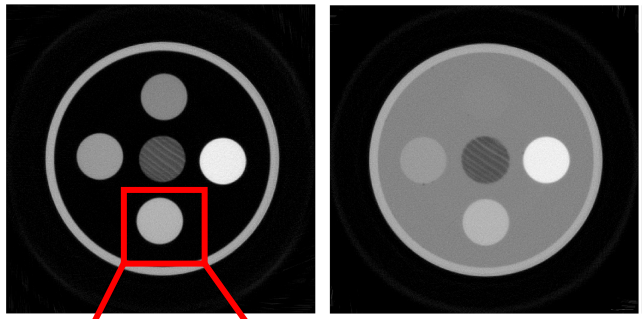




$\sim 6 \times 10^8$ events

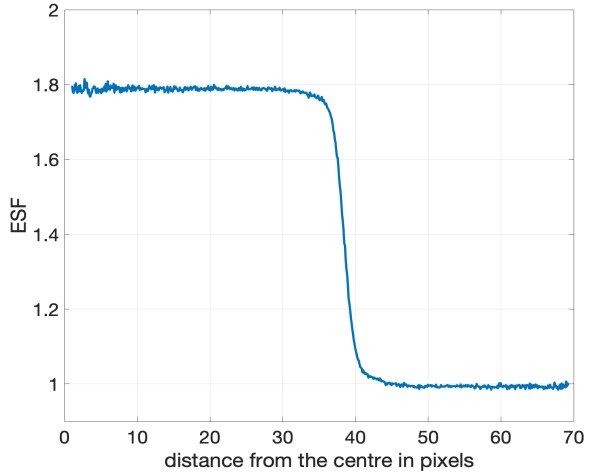
Spatial resolution

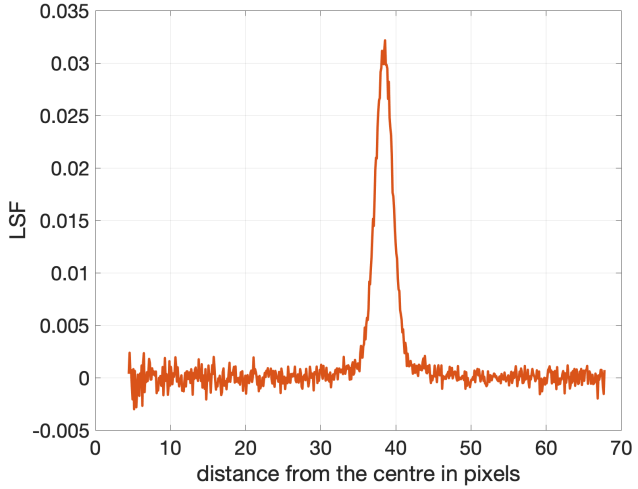
The modulation transfer function (**MTF**) is a basic measure of the performance of an imaging system describing the signal transfer characteristics of the system as a function of the spatial frequency

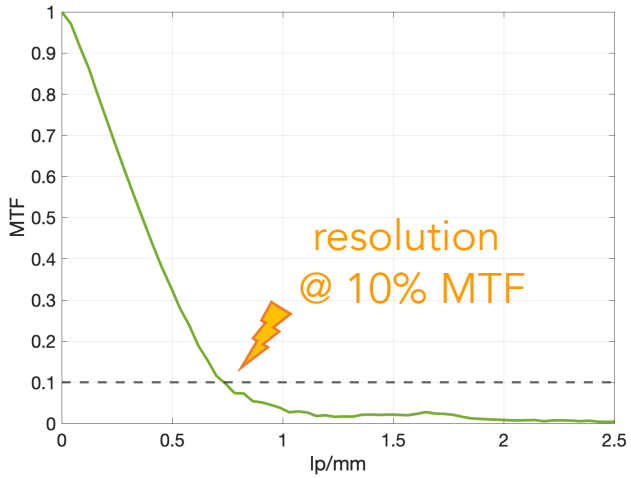


d/dx

FFT







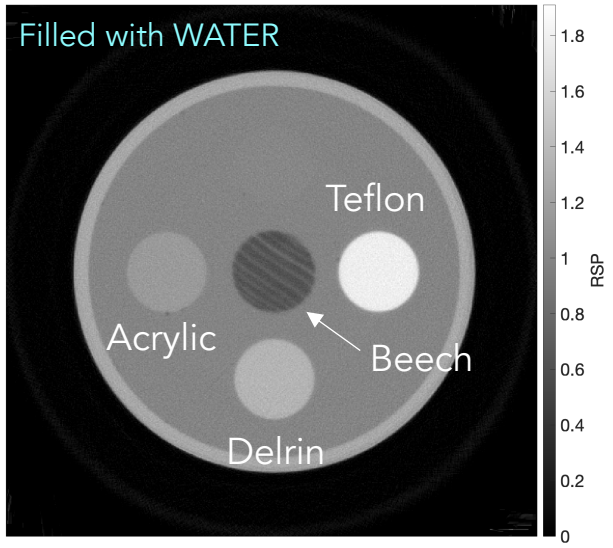
ESF spatial binning is over-sampled and re-binned into 1/10 of the pixel size*

Pre-sampled modulation transfer function

* cf. Buhr et al., Med. Phys. (2003)

Spatial resolution

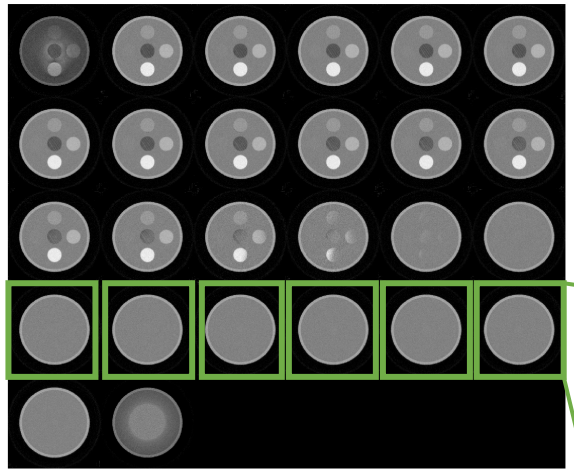
pCT



Material	Density [g/cm3]	pCT		xCT	
		Resolution in water [lp/mm]	Resolution in air [lp/mm]	Resolution in water [lp/mm]	Resolution in air [lp/mm]
Teflon	2.18	0.76 (0.03)	0.90 (0.01)	0.598 (0.005)	0.55 (0.01)
Delrin	1.41	0.72 (0.05)	0.91 (0.02)	0.599 (0.008)	0.54 (0.01)
Acrylic	1.20	0.74 (0.02)	0.95 (0.03)	0.57 (0.01)	0.56 (0.02)
LDPE	0.99	-	0.92 (0.03)	0.58 (0.02)	0.55 (0.02)

Non-linear imaging system

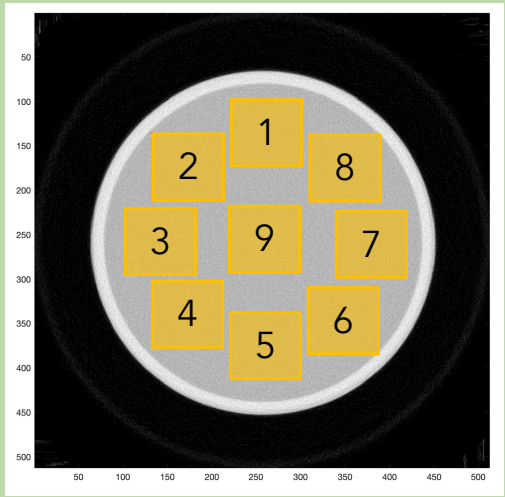
Noise power spectrum



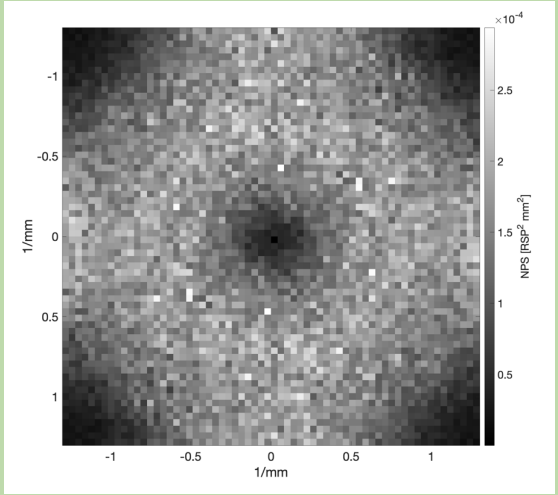
Uniform water slices

The standard deviation of noise provides no information about noise spatial characteristics (i.e., appearance) and thus has only a gross predictive value for object detectability.
The NPS characterizes both the magnitude and spatial frequency distribution of image noise.

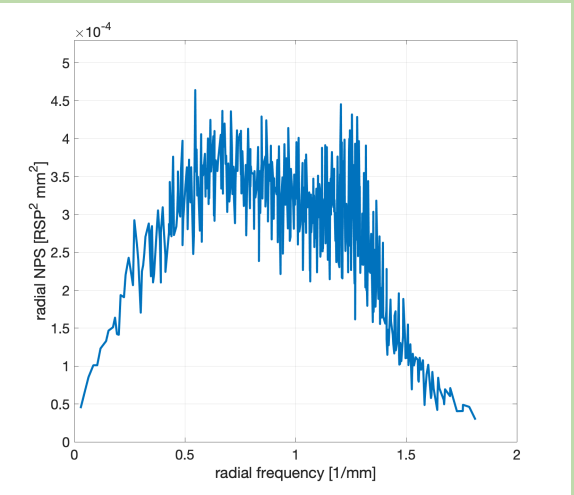
For each slice



2D NPS calculated*
for 9 (2.73cm-)squared ROIs



Mean 2D-NPS

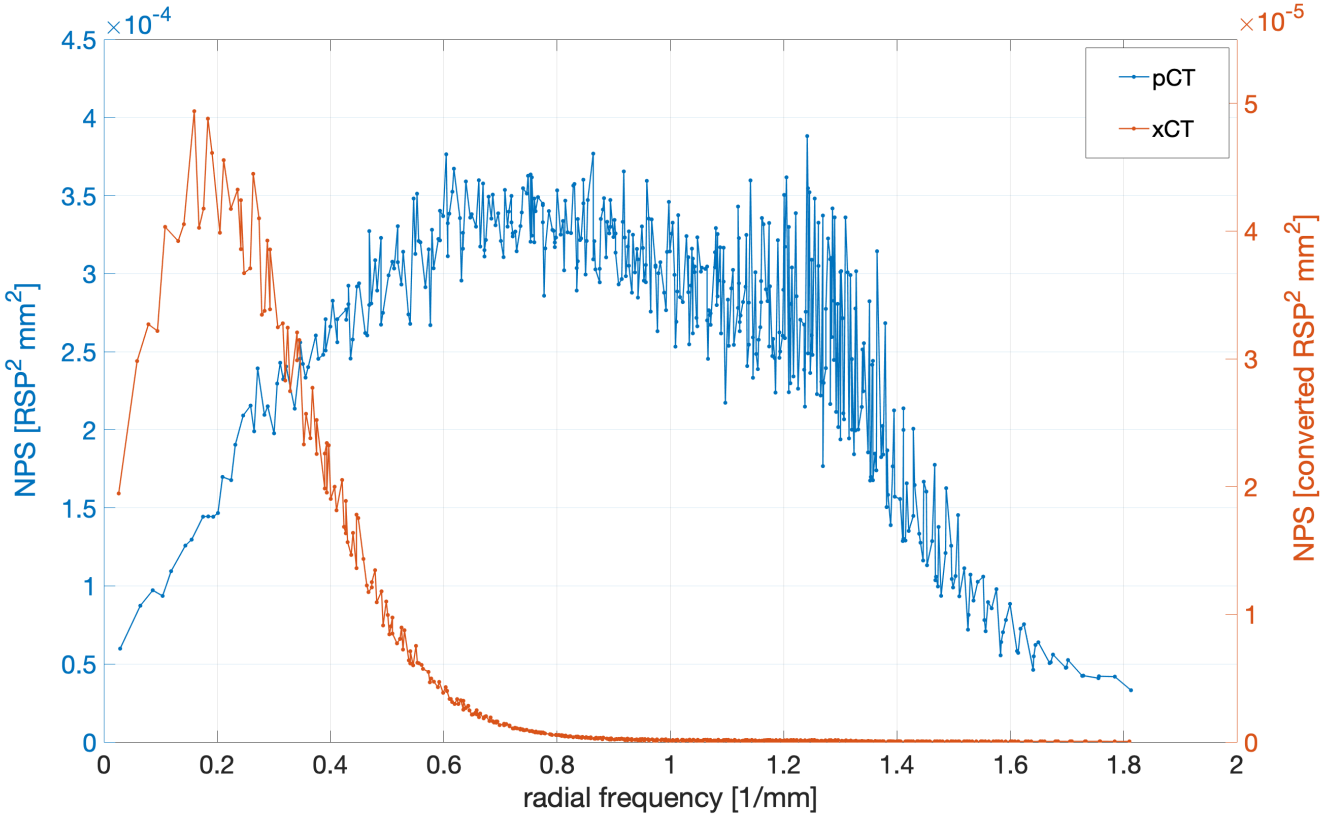


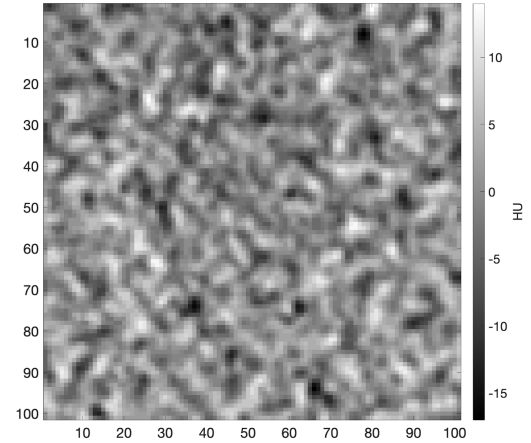
Radial 1D-NPS

*as in K.L. Boedeker et al., PMB (2007)

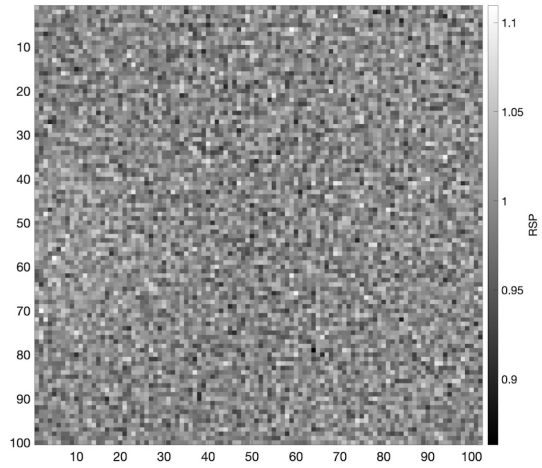
Noise power spectrum

➞ The **shape** of the NPS reflects the texture of the noise in terms of spatial correlation of voxel values





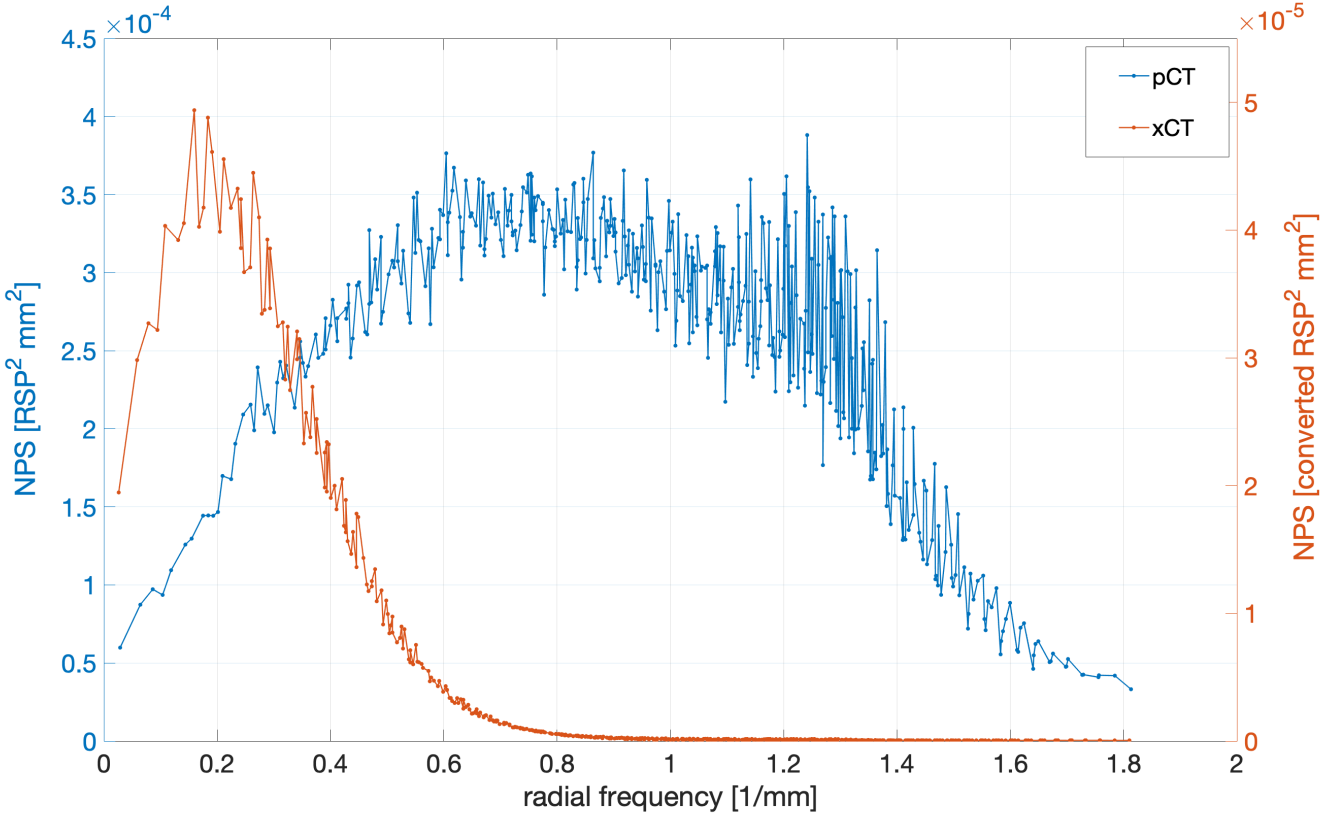
4x4cm²-ROI of xCT slice

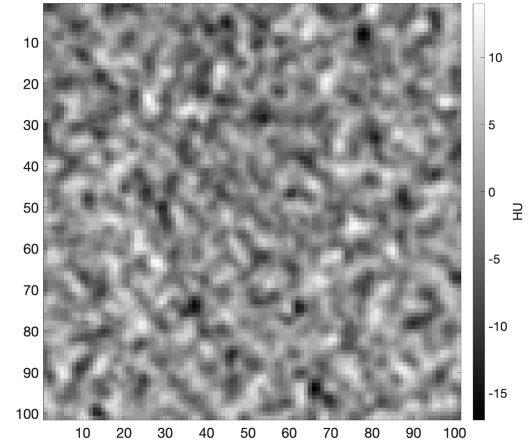


4x4cm²-ROI of pCT slice

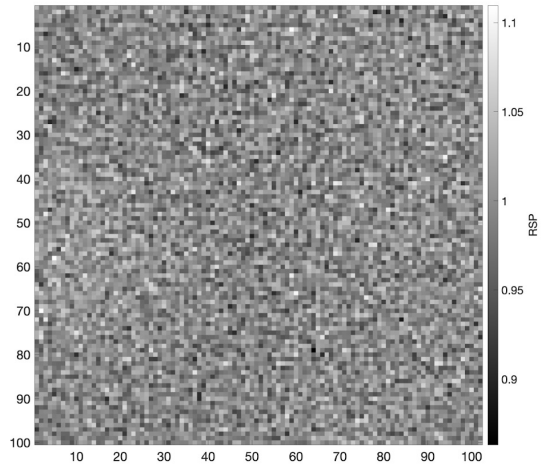
Noise power spectrum

- The **shape** of the NPS reflects the texture of the noise in terms of spatial correlation of voxel values
- The **area** under the NPS curve reflects the magnitude of the noise:
  area xCT = 0.0022 converted RSP² mm
  area pCT = 0.1189 RSP² mm



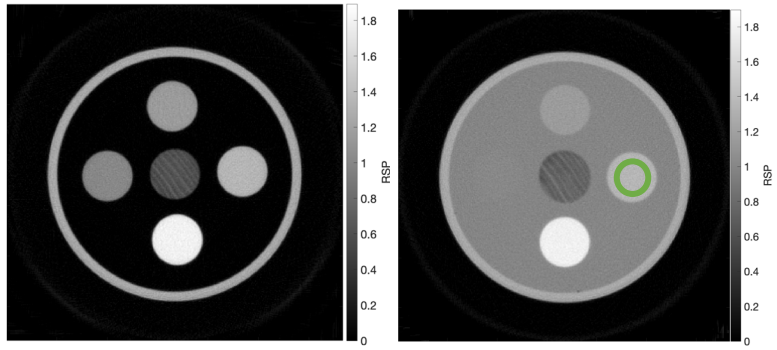


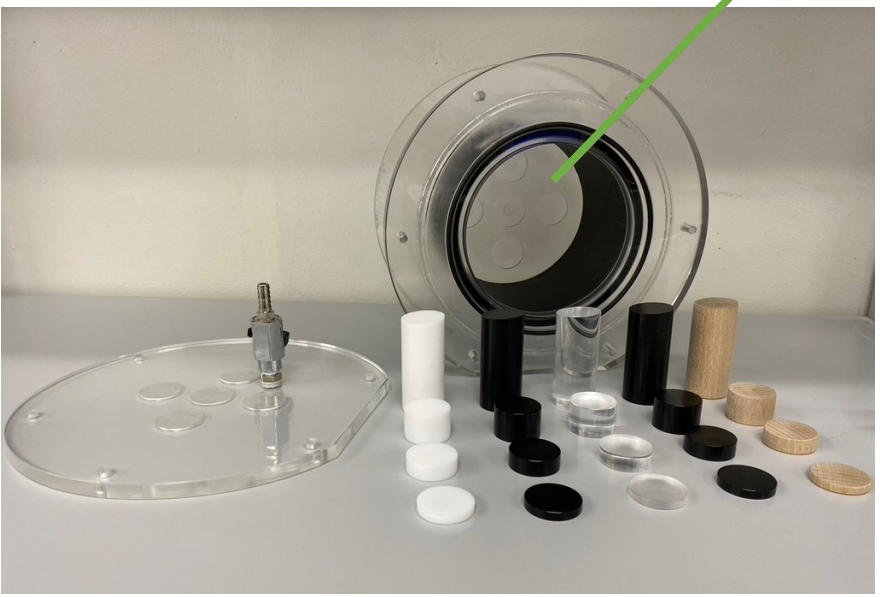
4x4cm²-ROI of xCT slice



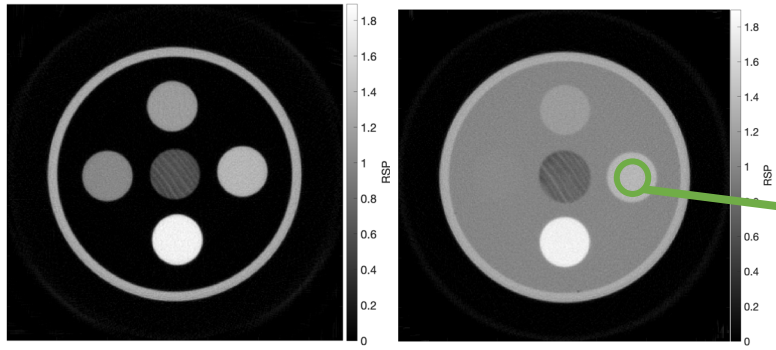
4x4cm²-ROI of pCT slice

Accuracy

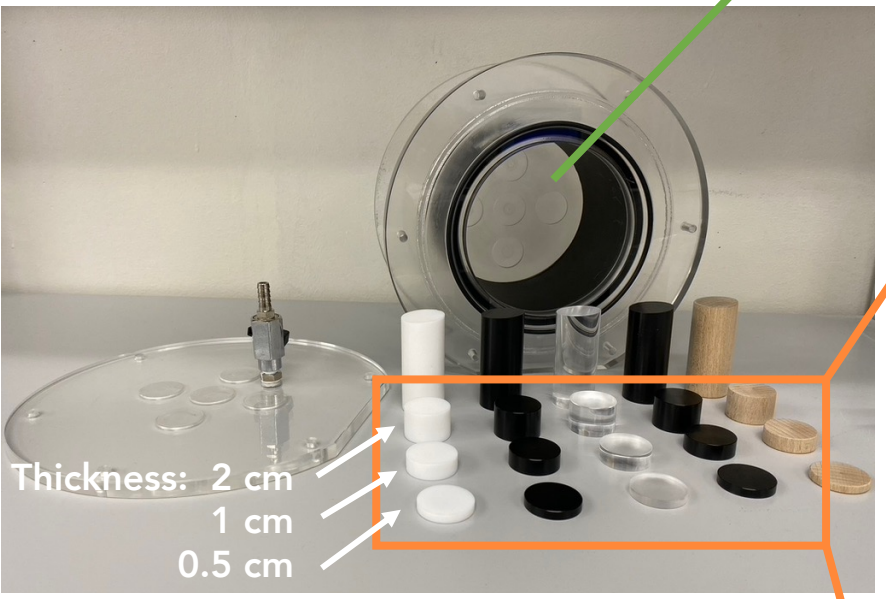




Accuracy



$$RSP_{acc} = \frac{RSP_{mean} - RSP_{ref}}{RSP_{ref}} \cdot 100\%$$

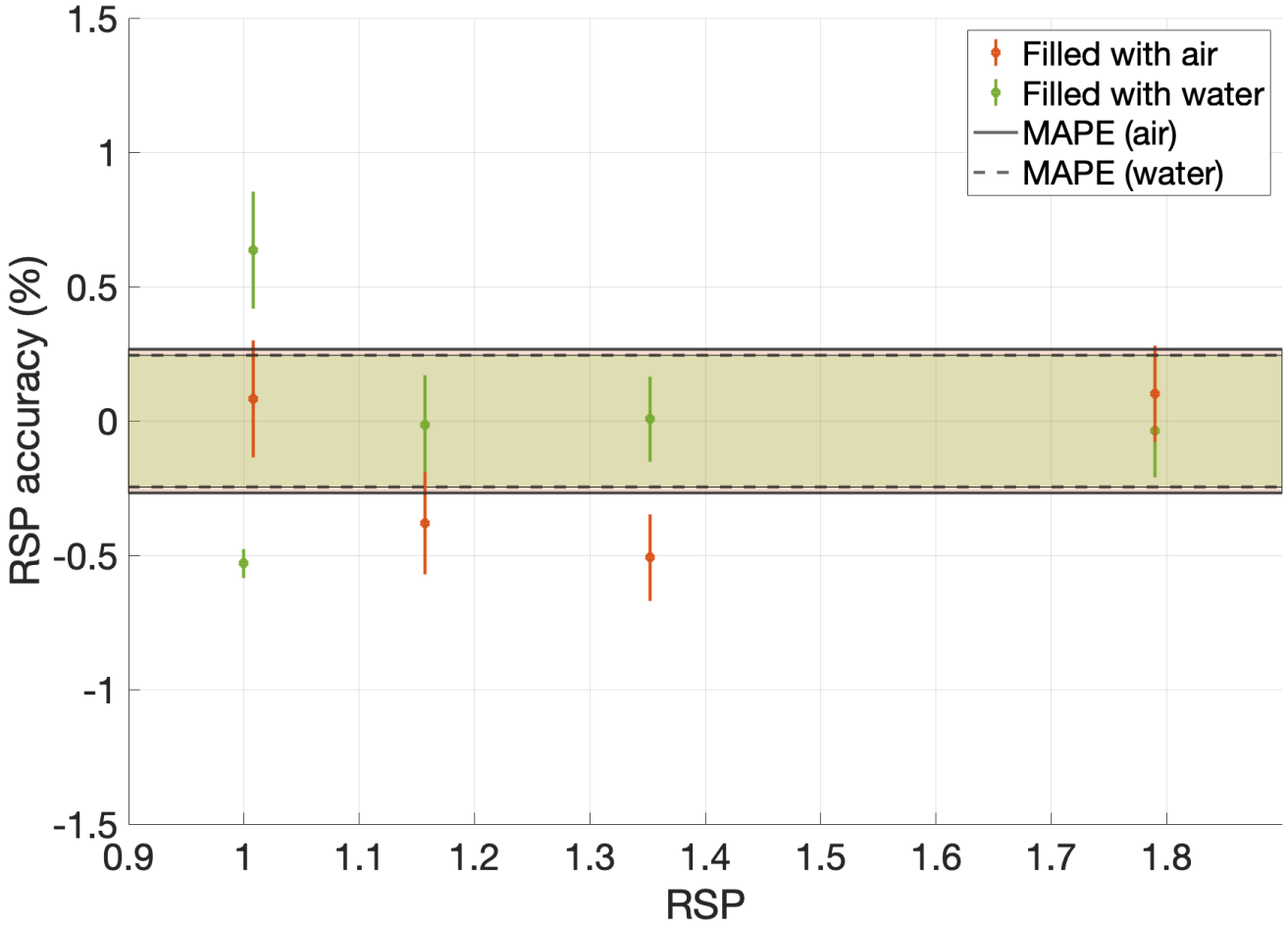


Multi-Layer Ionization Chamber
(Giraffe, IBA)

Material	RSP (MLIC*)
Teflon	1.79 (0.01)
Delrin	1.352 (0.007)
Acrylic	1.157 (0.005)
LDPE	1.008 (0.006)

*measured as in F. Fellin et al., Physica Medica (2017)

Accuracy



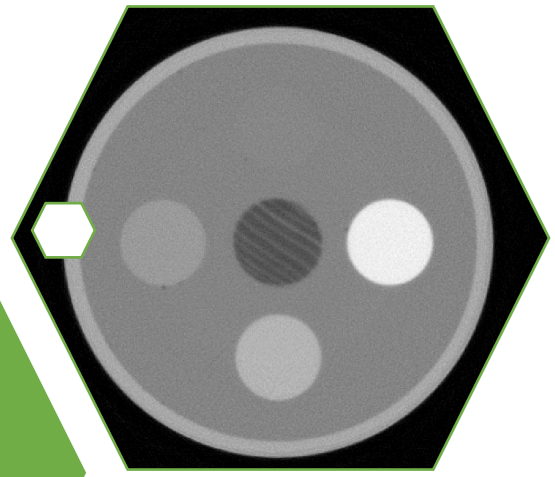
$$RSP_{acc} = \frac{RSP_{mean} - RSP_{ref}}{RSP_{ref}} \cdot 100\%$$

$$MAPE = \frac{\sum_{i=1}^{n} |RSP_{acc,i}|}{n}$$

with n the total number of inserts

→ MAPE (water) = 0.25 +- 0.07
MAPE (air) = 0.27 +- 0.09

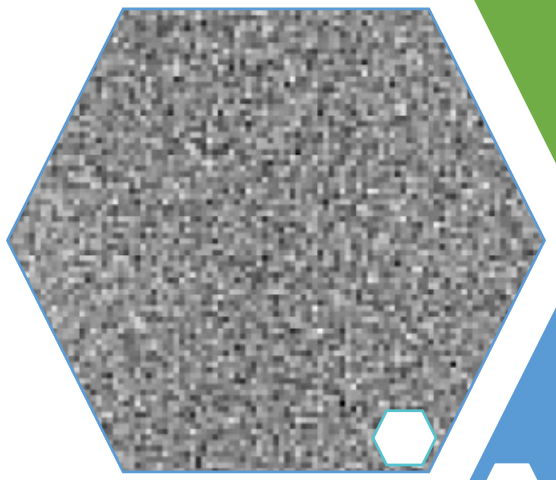
Conclusions



Spatial resolution

pCT @10% MTF

- in air ~0.91 lp/mm
- in water ~0.74 lp/mm



Accuracy

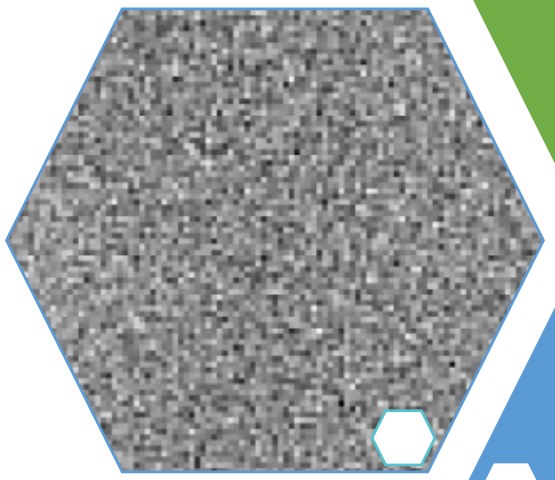
pCT MAPE

- in air ~ 0.27%
- in water ~ 0.25 %

Noise power spectrum

Finer grain noise than xCT noise

Conclusions



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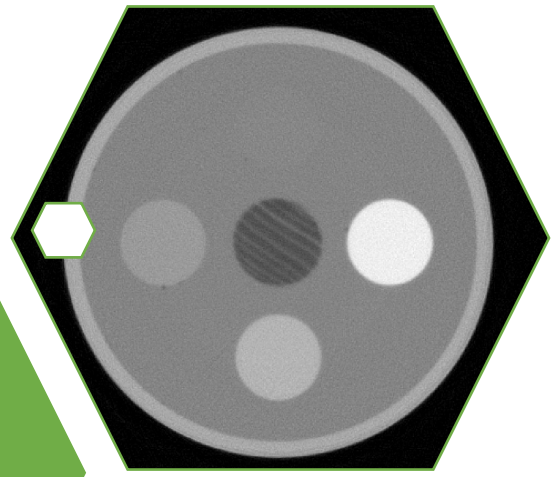


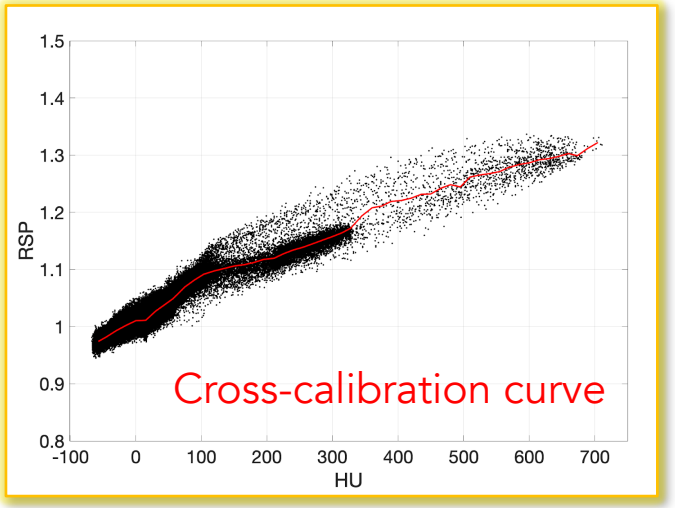
Noise power spectrum

Finer grain noise than xCT noise

Accuracy

pCT MAPE

- in air ~ 0.27%
- in water ~ 0.25 %



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