

Scanning materials of different densities

Lisa Falco



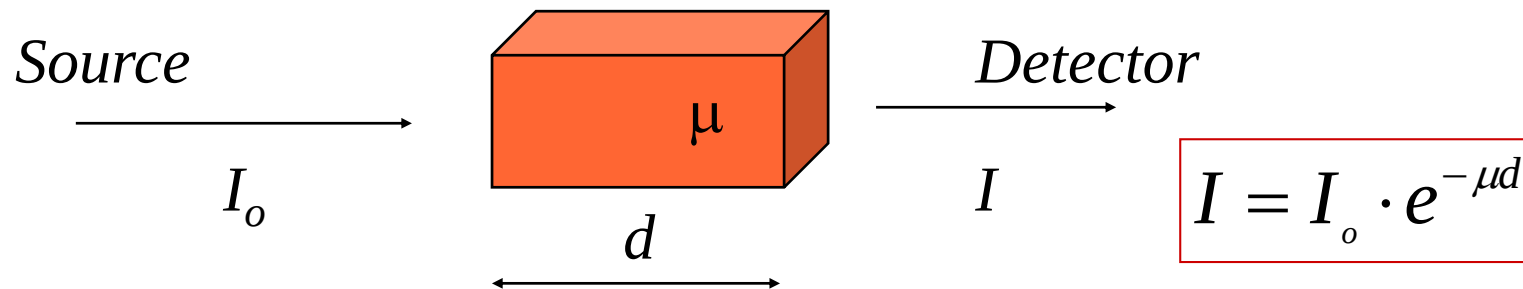
Motivation

- Tips for scanning different materials
 - ✓ High density materials
 - ✓ Low density materials
- Adjusting scan parameters
 - ✓ Energy
 - ✓ Filter
 - ✓ Integration time



X-ray attenuation

- Gradual loss of intensity of the X-rays through a medium

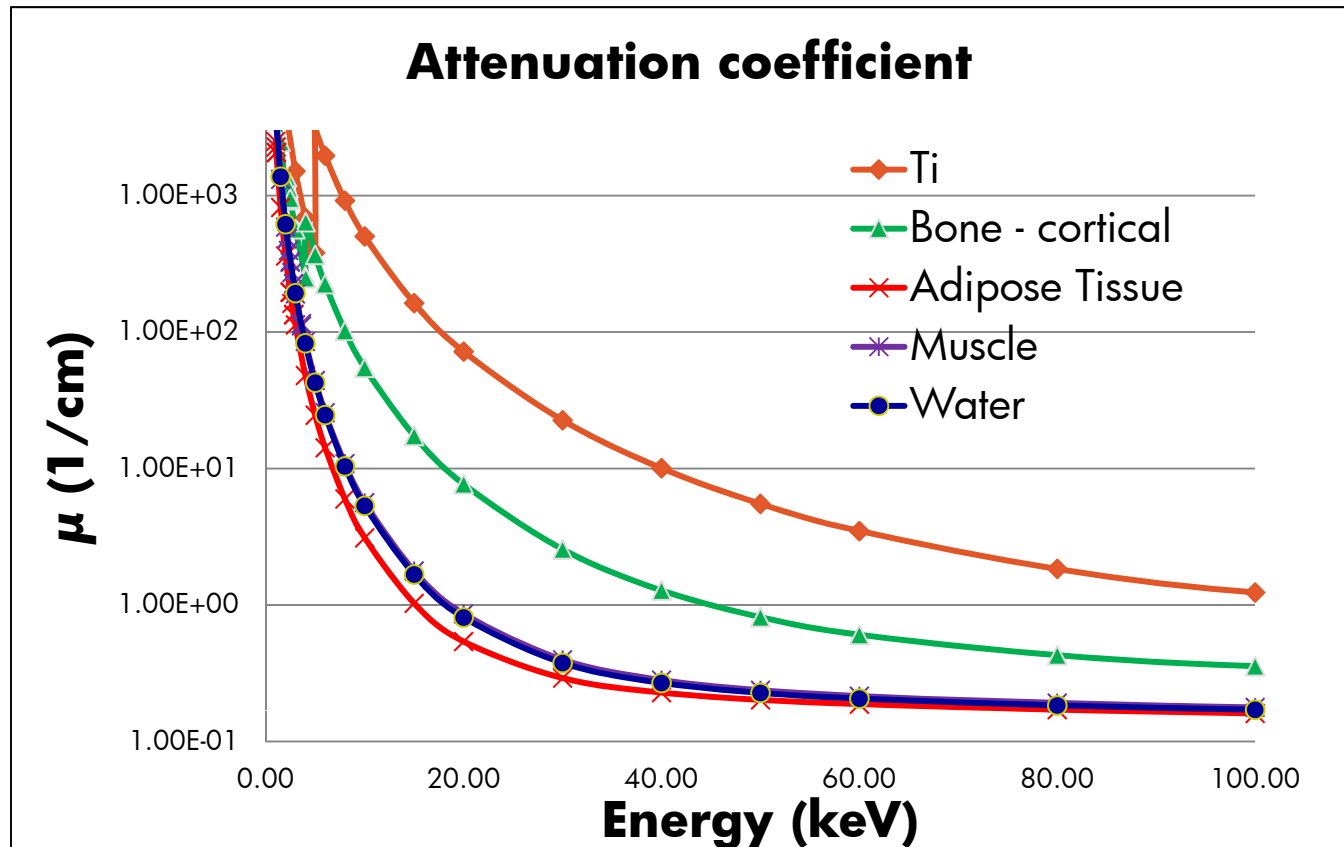


- Depends on:
 - ✓ Attenuation coefficient: μ
 - ✓ Distance through the object: d



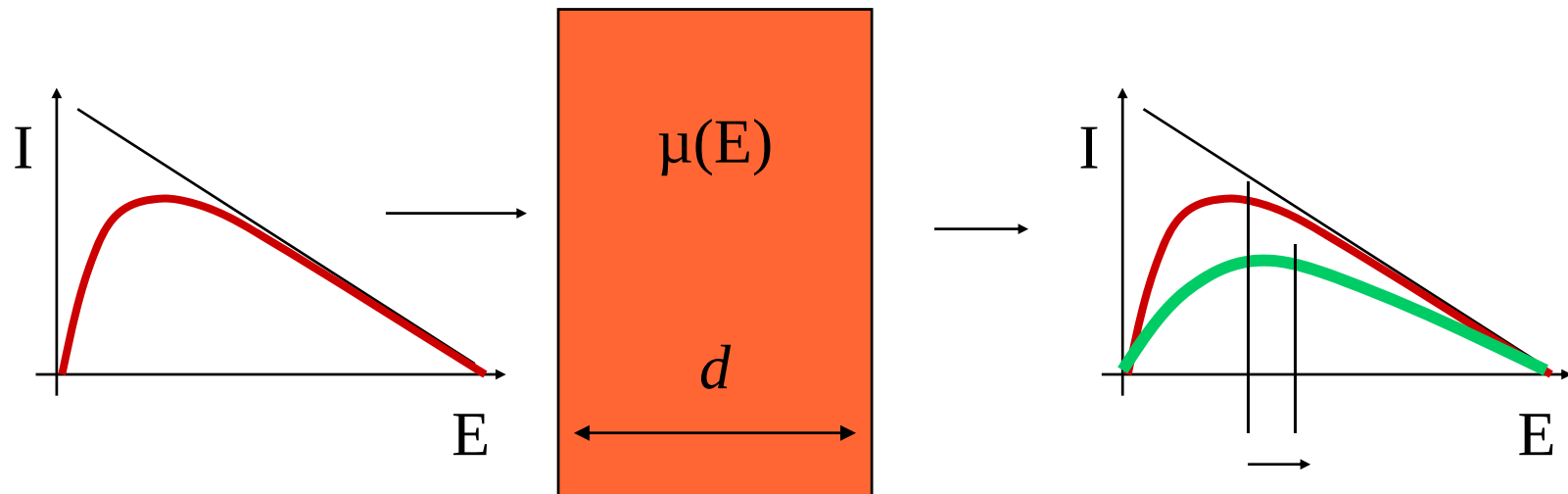
Attenuation coefficient μ [1/cm]

- Attenuation coefficient changes with **material**.
- Attenuation coefficient changes with **energy**.



X-ray attenuation

- Low energy X-rays are attenuated more than high energy X-rays
- Depending on object thickness/density, spectrum changes
- ➡ beam hardening artifacts



Filters

- Filters (0.1 mm Al, 0.5mm Al, 0.1mm Cu)
 - ✓ Reduce beam hardening artifacts (+)
 - ✓ Reduce the signal (–)

- Beam hardening – when is it a problem?
 - ✓ Can influence the segmentation
 - ✓ When measuring densities
 - ✓ Especially, when scanning high absorption materials



Energy settings

- Low energy
 - ✓ Higher attenuation
 - ✓ Lower x-ray beam intensity
 - ✓ Larger difference in attenuation
- }

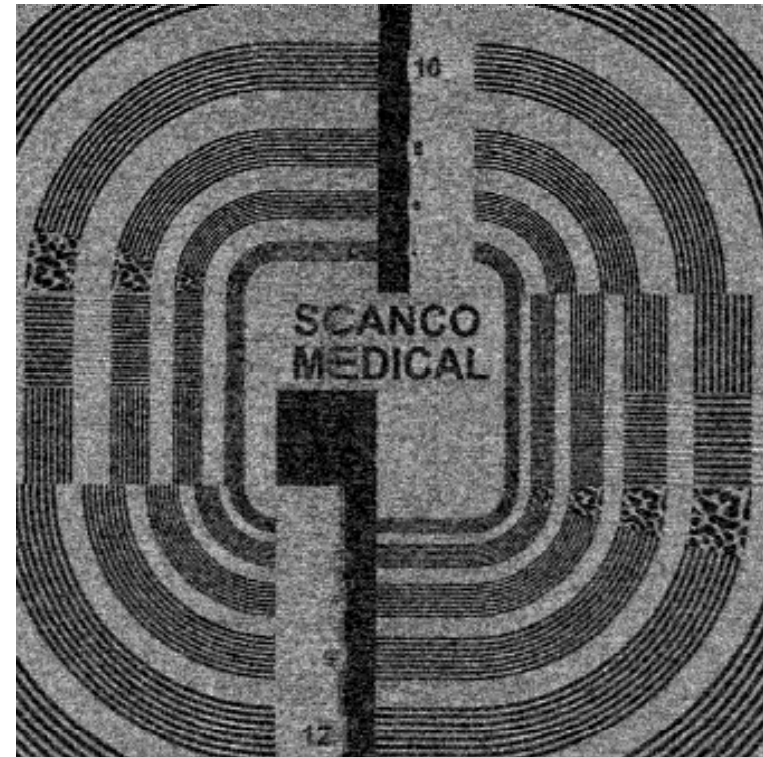
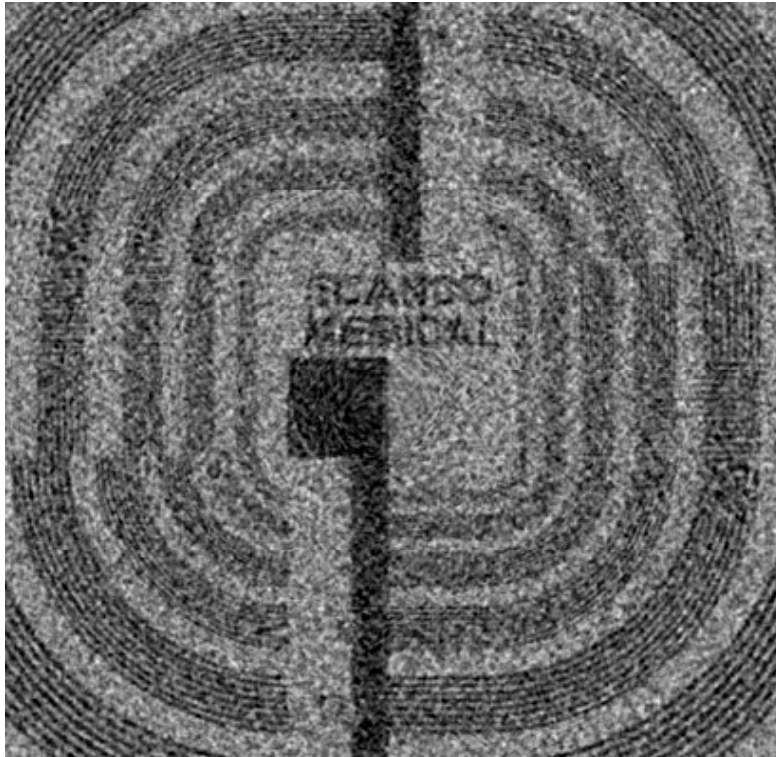
 less signal → more noise

- High energy
 - ✓ Lower attenuation
 - ✓ Higher x-ray beam intensity
 - ✓ Smaller difference in attenuation
- }

 more signal → less noise



Signal-to-noise ratio (SNR)



Same resolution, different SNR
Important to have enough signal



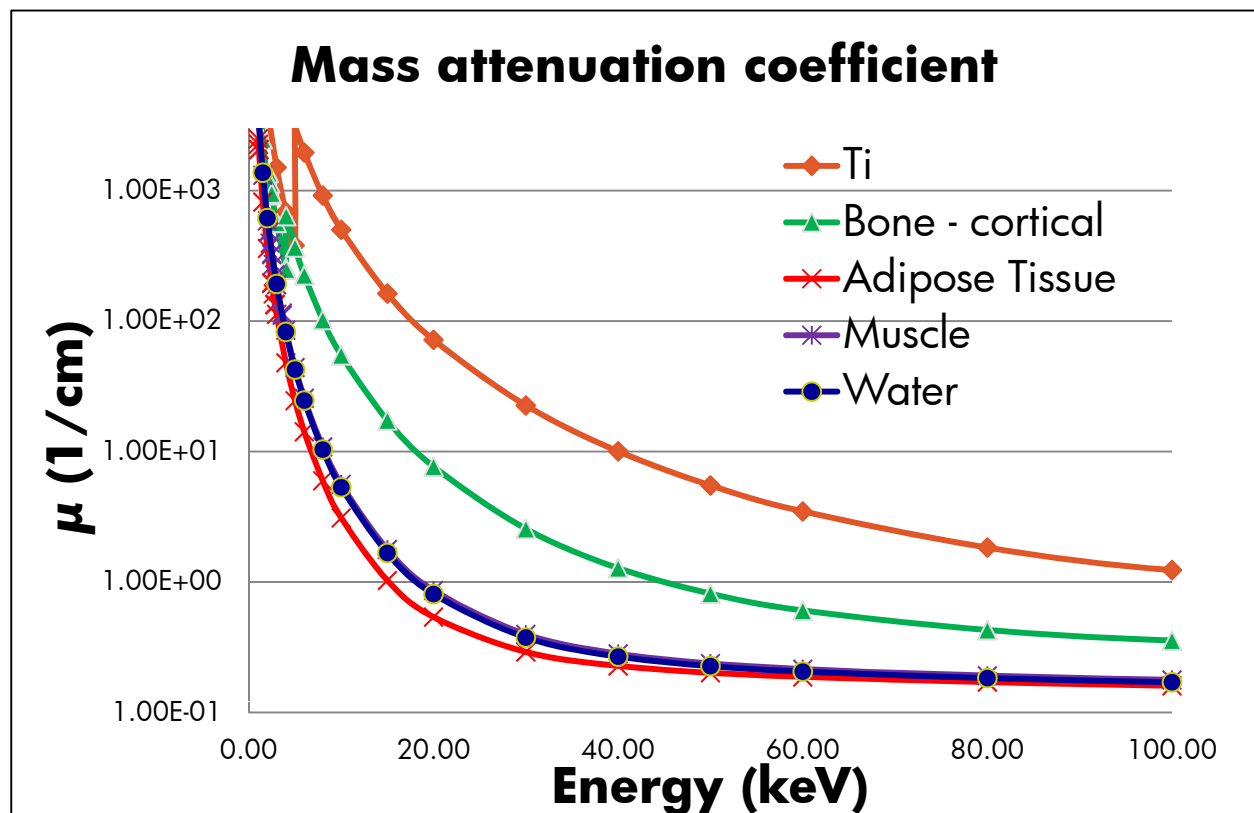
Improving the SNR

- Increase the signal by using:
 - ✓ Higher energy
 - ✓ More intensity
 - Beware of reduced spatial resolution
 - ✓ Longer integration time
 - Use also image averaging
 - More projections
 - ✓ Binning
 - Reduced nominal & spatial resolution



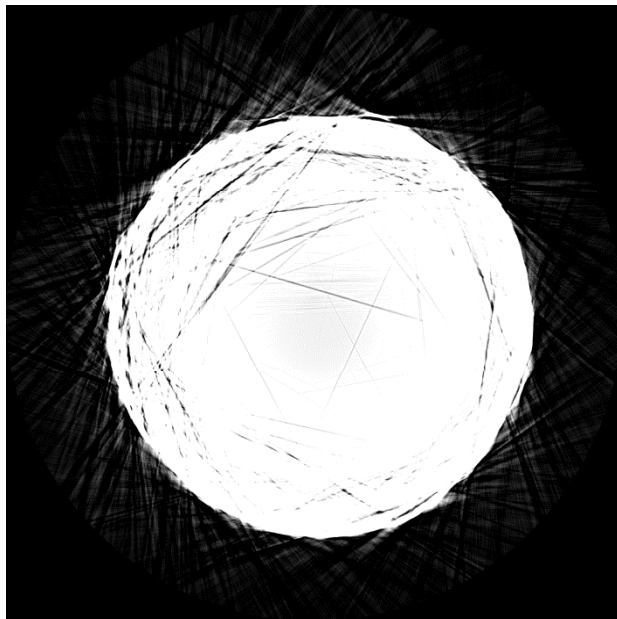
Scanning high density materials

- Attenuation generally decreases with higher energy
- For high density materials: scan at high energy

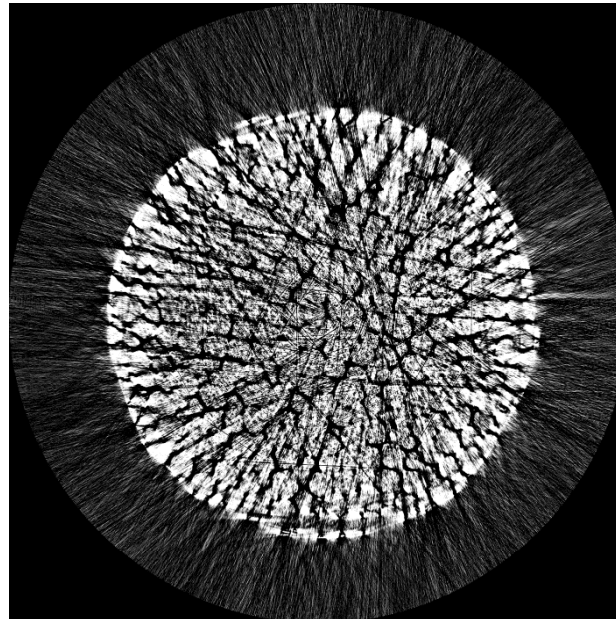


Scanning high density materials

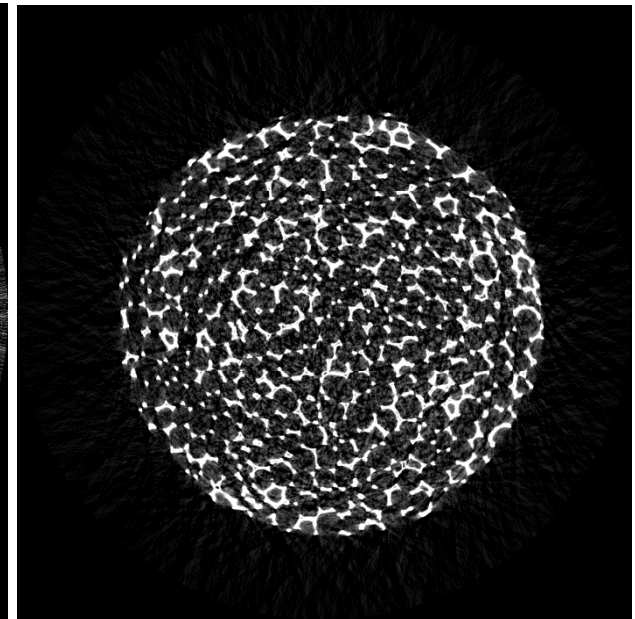
- Coated Ti foam, 14 mm FOV



45 kVp



70 kVp

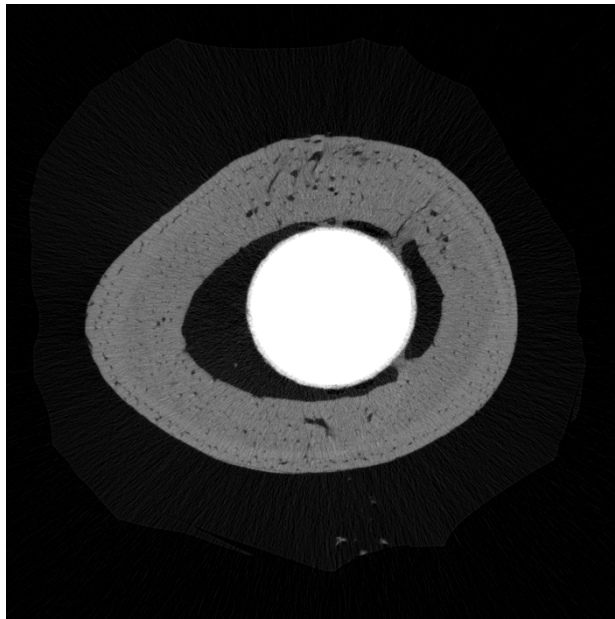


90 kVp

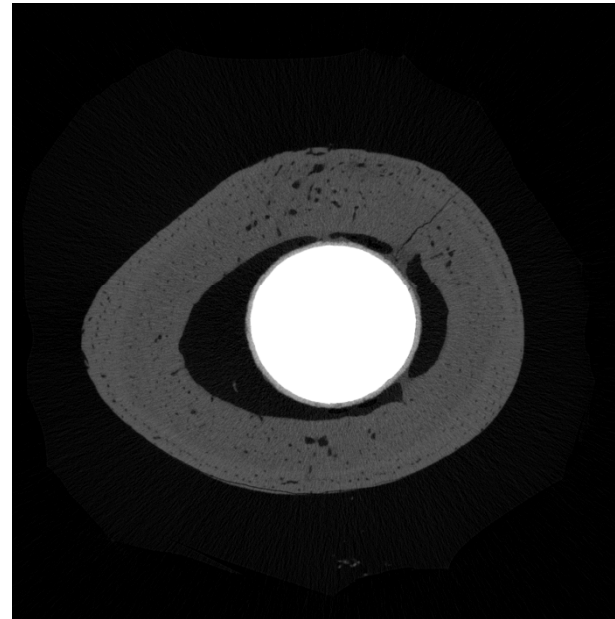


High density materials - Energy

- Ti implant in bone, 9 mm FOV
 - ✓ SNR better with 90 kVp
 - ✓ More detail around implant visible at 90 kVp



70 kVp

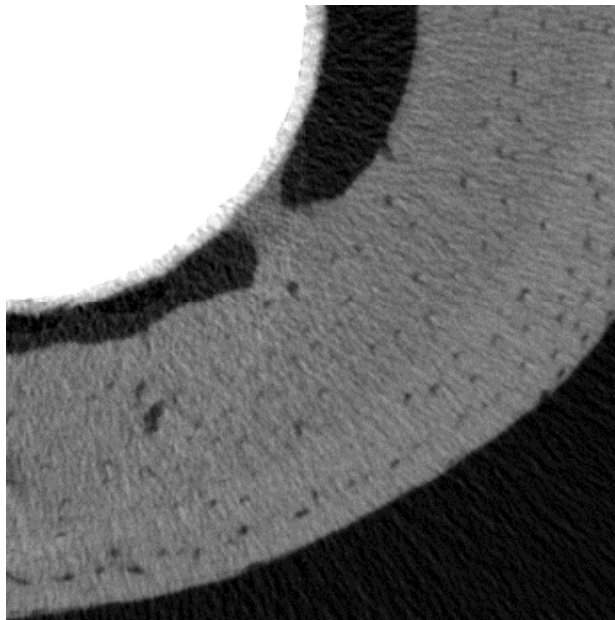


90 kVp

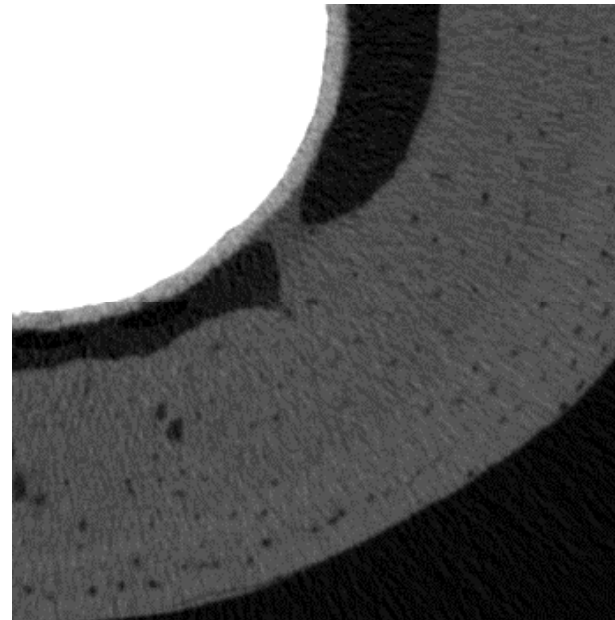


High density materials - Energy

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70 kVp

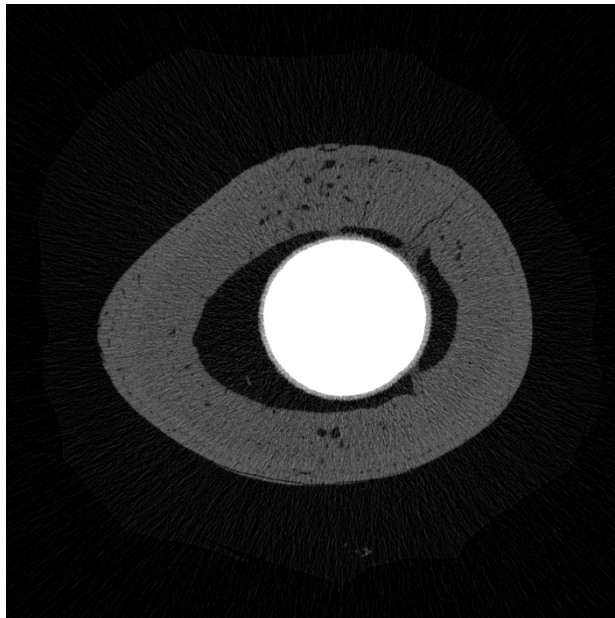


90 kVp

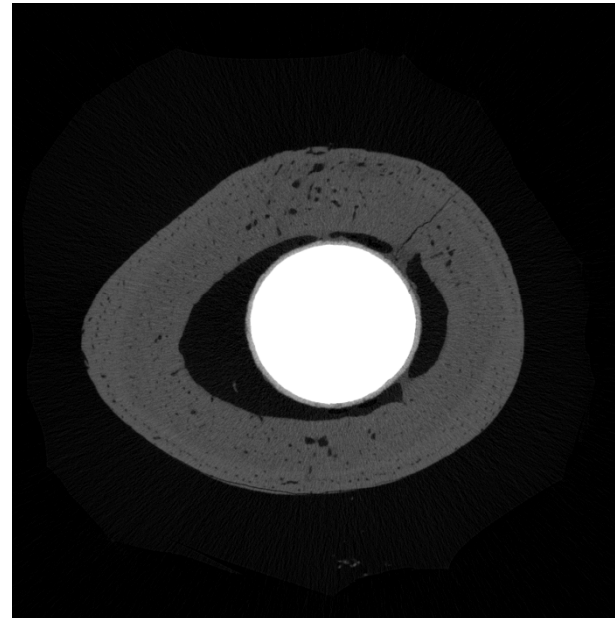


High density materials – Integration time

- Ti implant in bone, 9 mm FOV
 - ✓ Short integration times possible
 - ✓ SNR improves with longer scan times



Integration time: 0.3 ms
Total scan time: 14 min

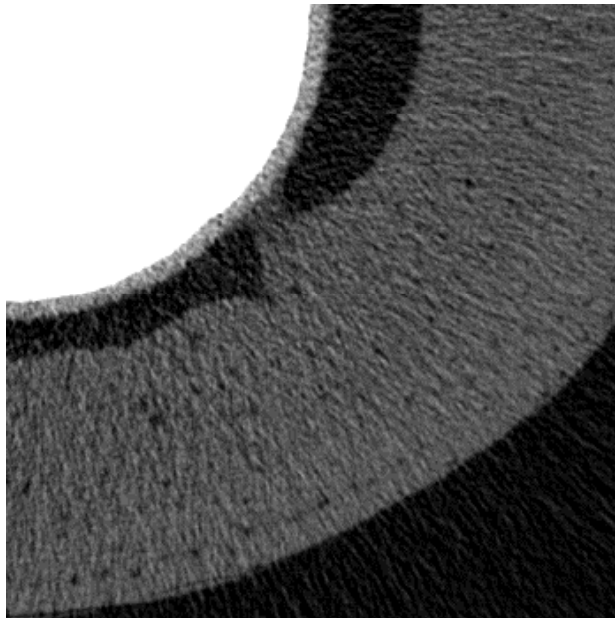


Integration time: 2.2 s
Total scan time: 86 min

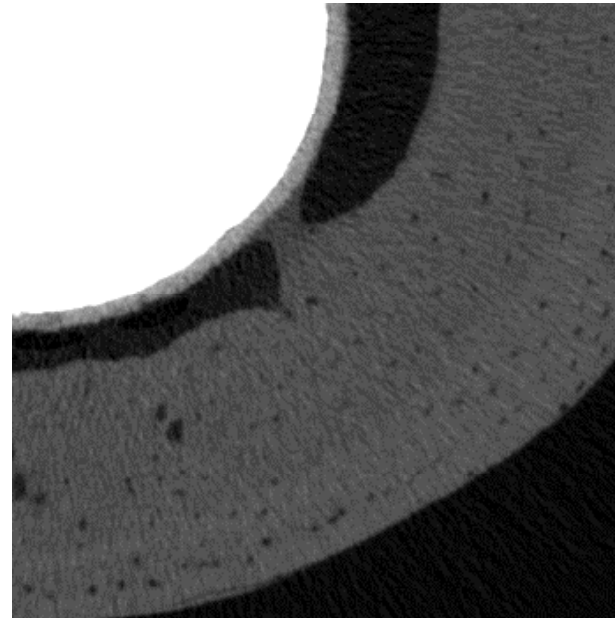


High density materials - Integration time

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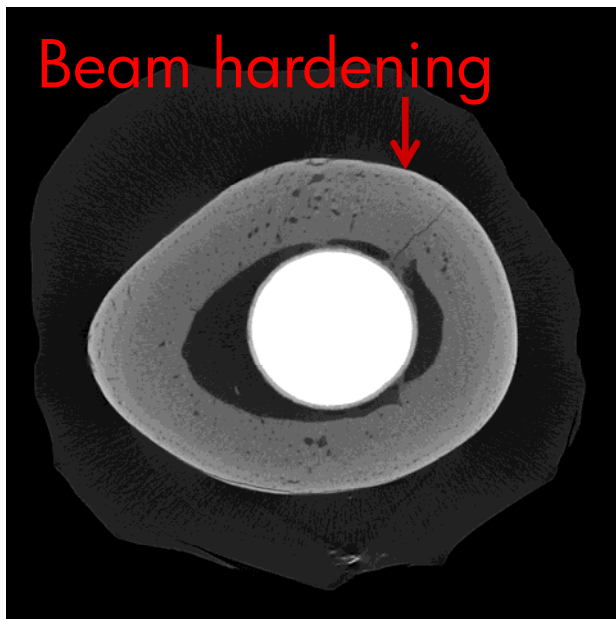


Integration time: 2 s
Total scan time: 86 min

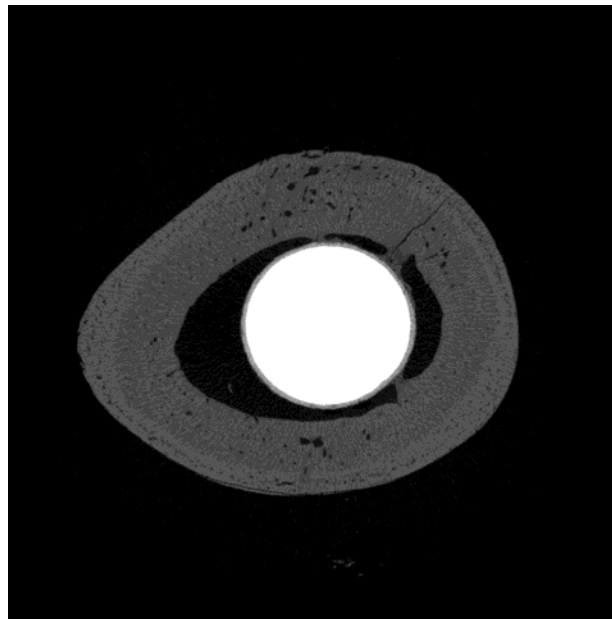


High density materials - Filters

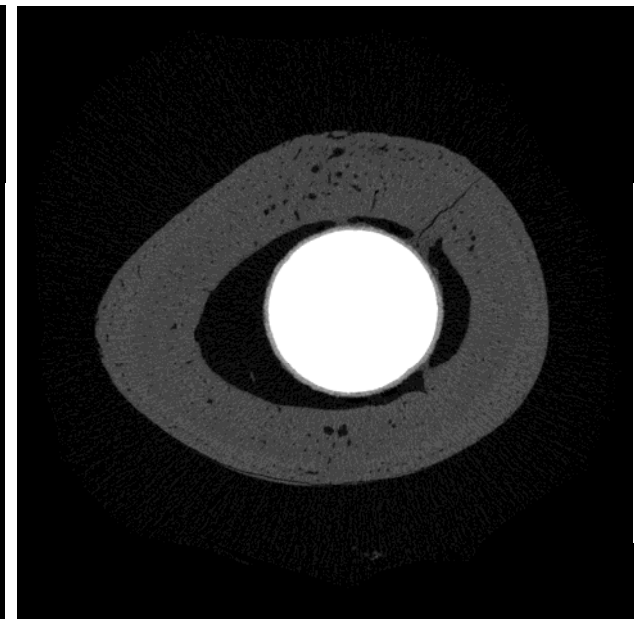
- Effects on beam hardening



No filter



0.5 mm Al

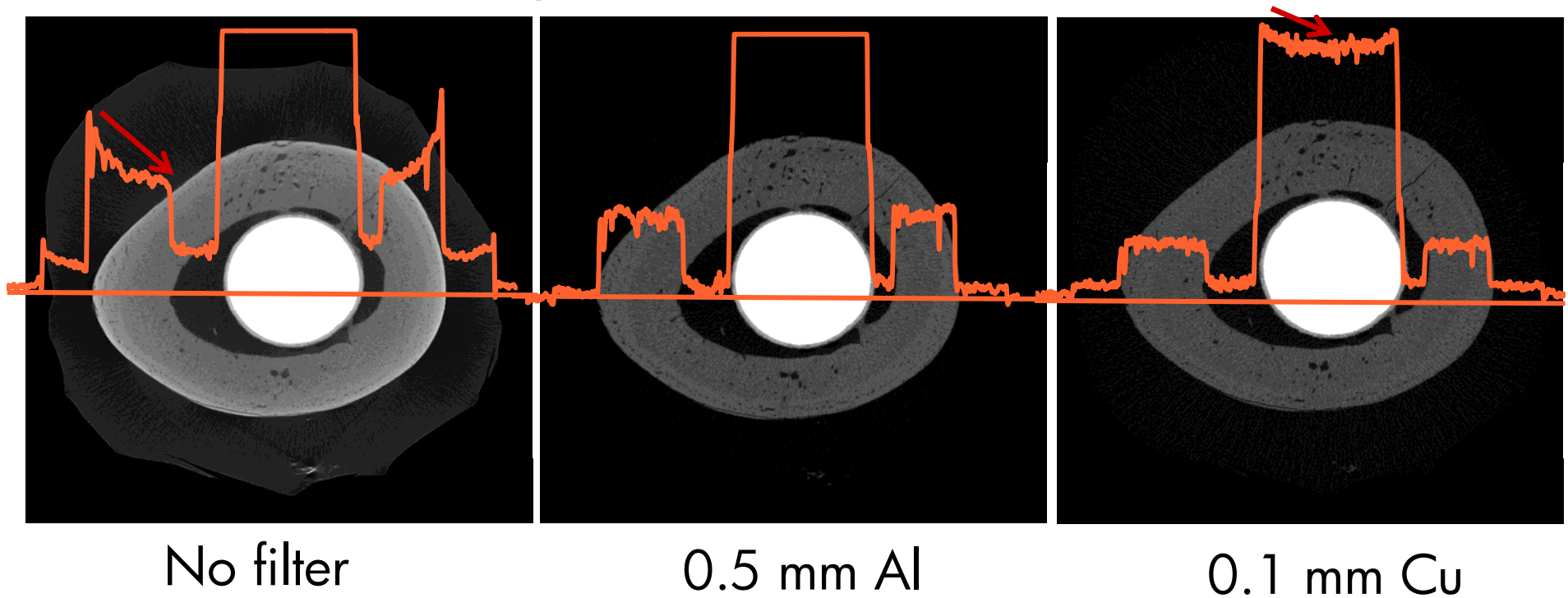


0.1 mm Cu



High density materials - Filters

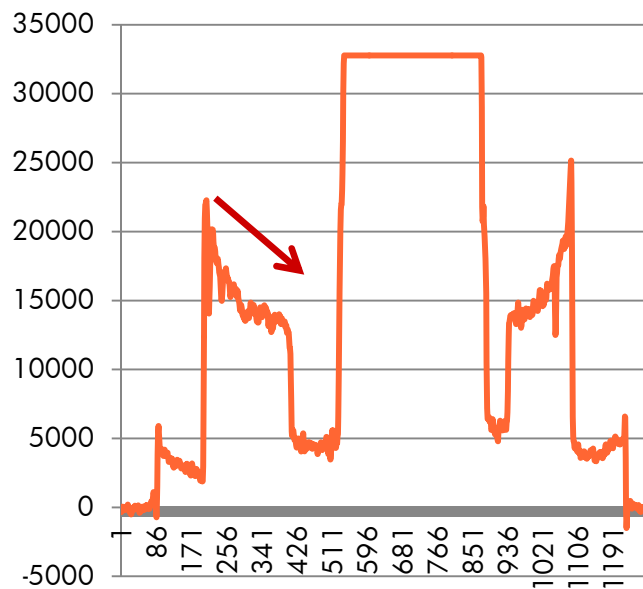
- Effects on beam hardening
Beam hardening



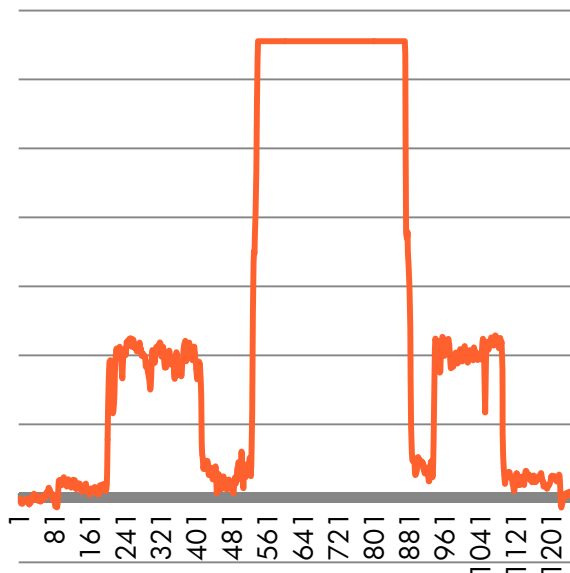
High density materials - Filters

- Effects on beam hardening

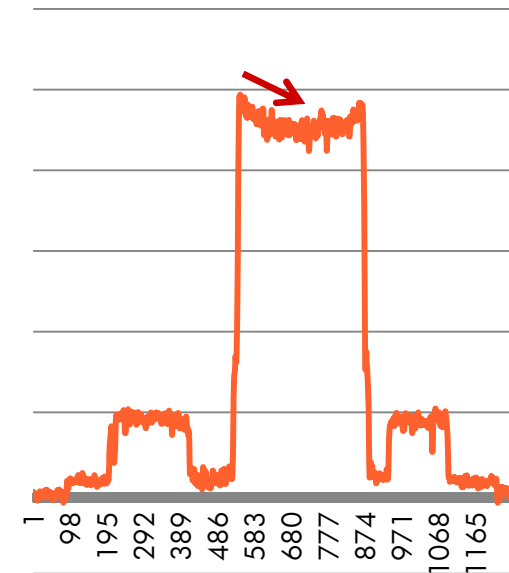
Beam hardening



No filter



0.5 mm Al

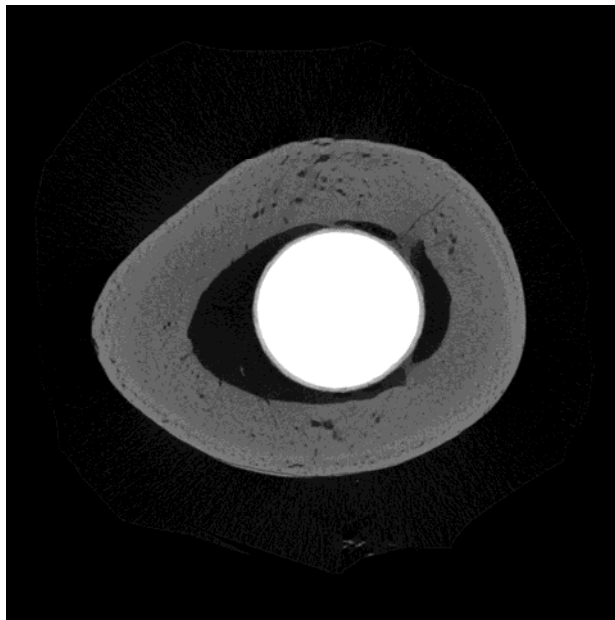


0.1 mm Cu

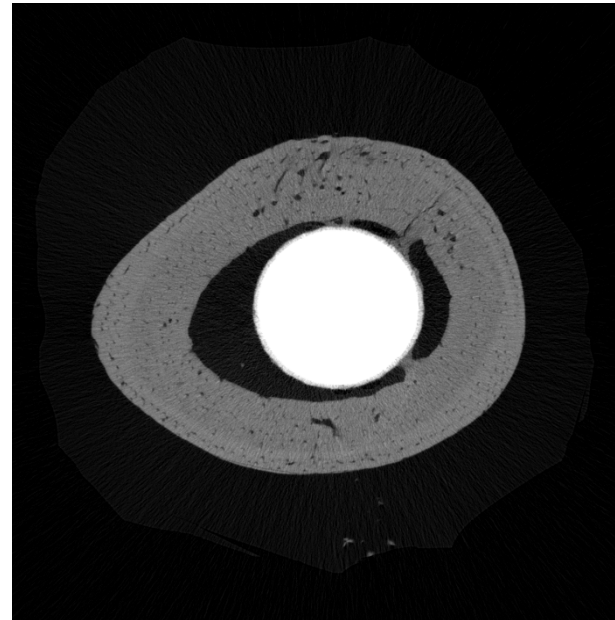


Beam hardening correction

- Ti implant in bone, 9 mm FOV
 - ✓ Use the right beam hardening correction file



PMMA

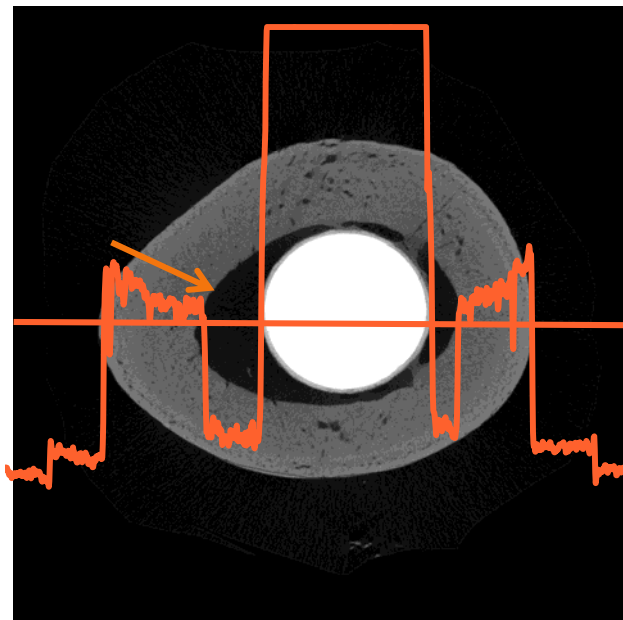


1200 mg HA

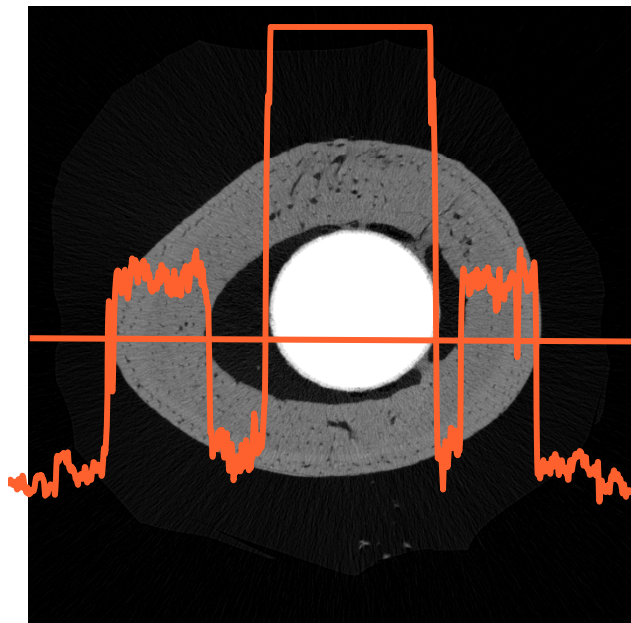


Beam hardening correction

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PMMA

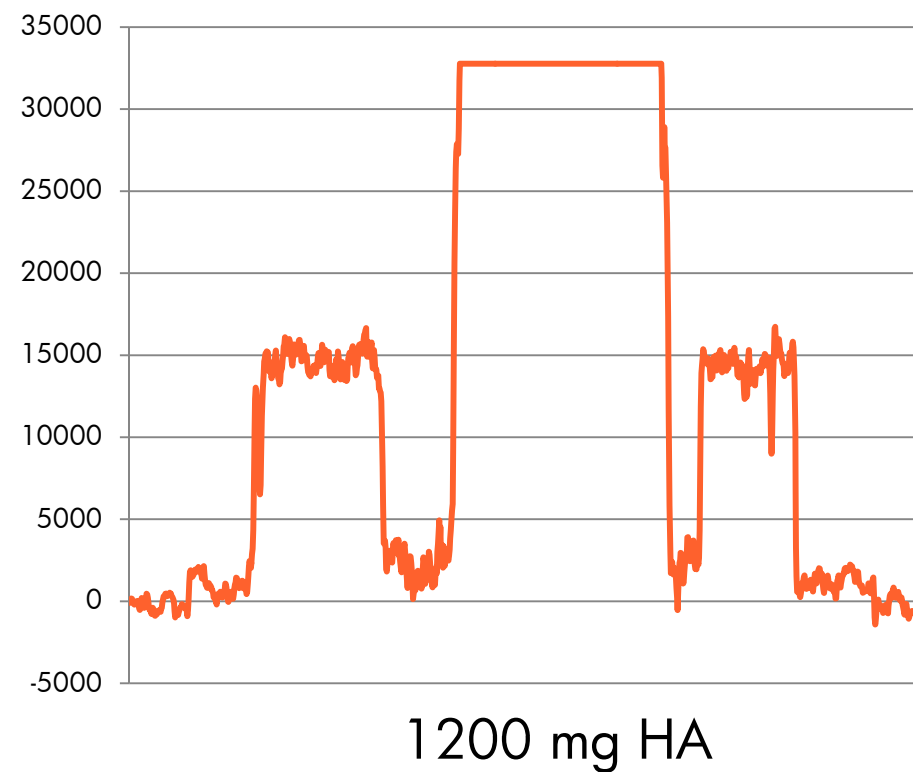
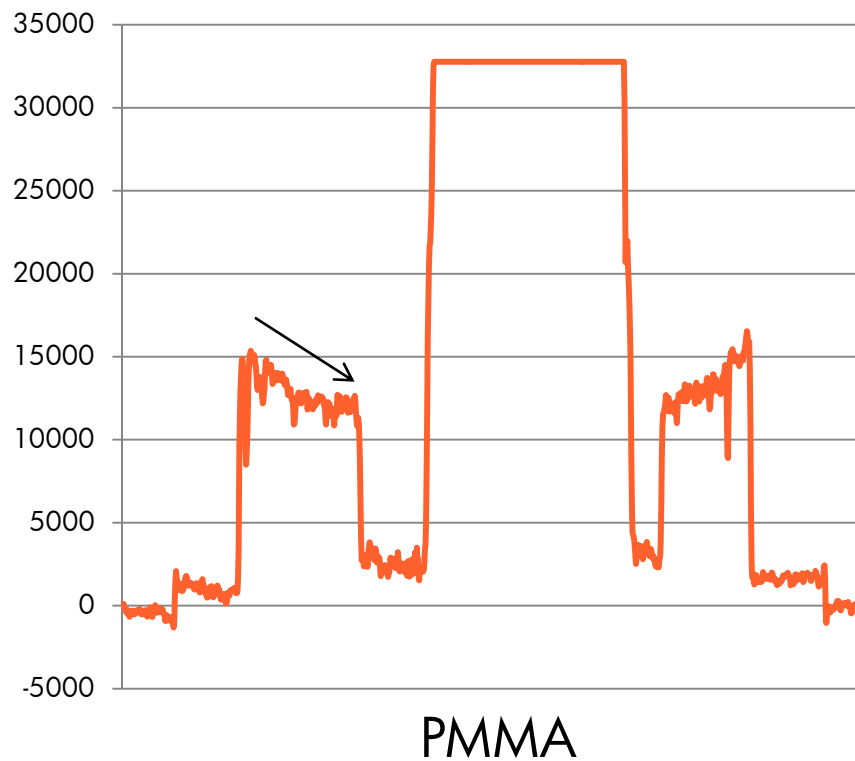


1200 mg HA



Beam hardening correction

- Ti implant in bone, 9 mm FOV
 - ✓ Use the right beam hardening correction file



Tips for scanning high density

- Scan at high energy: 70 kV or 90 kV
- Reduce beam hardening
 - ✓ Use filters
 - ✓ Use the right correction file
- If necessary improve the SNR by:
 - ✓ Increasing the integration time
 - ✓ Using high intensity (but beware of spatial resolution)
 - ✓ More projections



High density materials

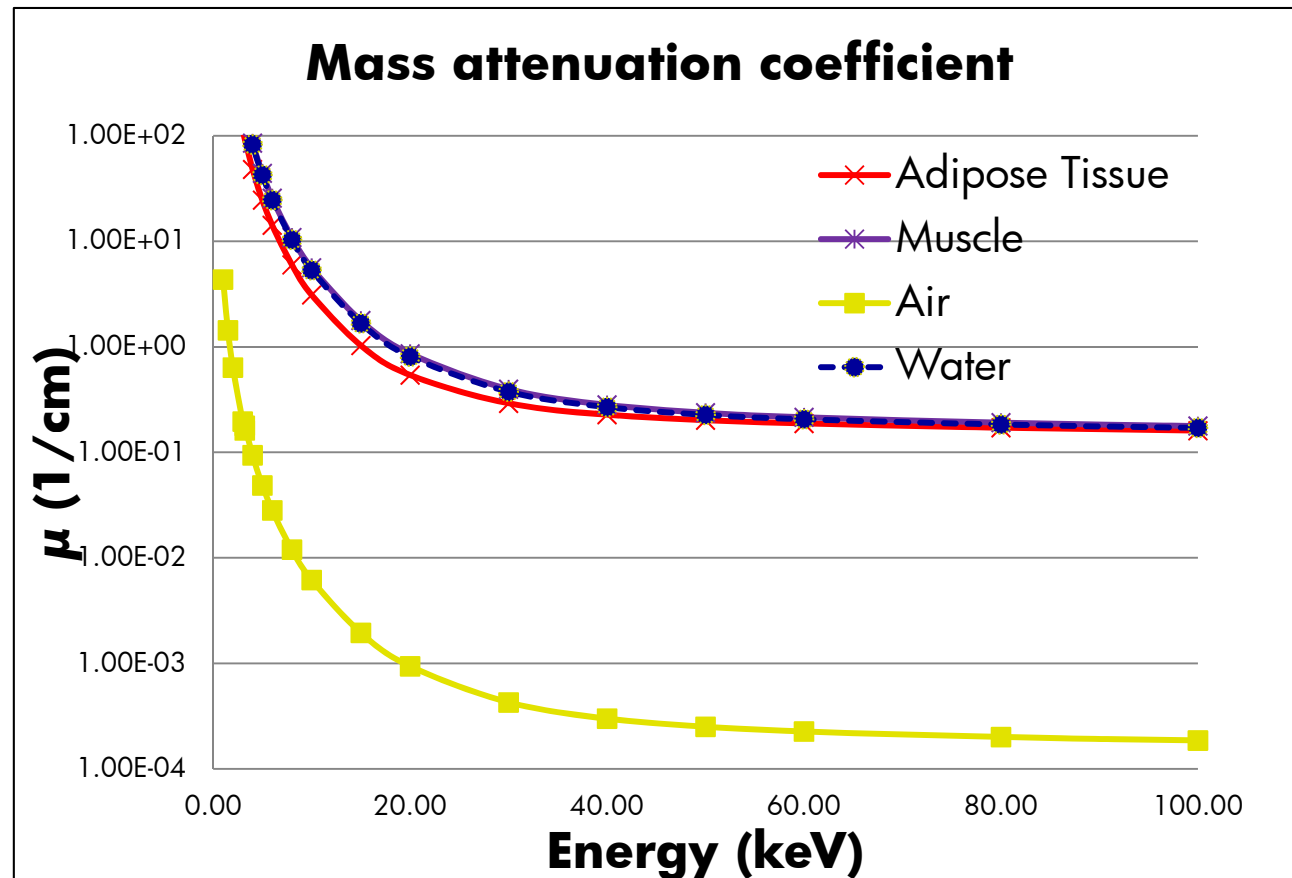
- Rule of thumb
 - ✓ Everything less absorbing than Titanium can normally be imaged if object not too large
 - ✓ Titanium screws up to ~4 mm in diameter, shape dependent
 - ✓ Smaller particles of Fe, Cu, Zn create artifacts but do not have to destroy the image, can be possible in alloys.
 - ✓ Denser materials are in most cases not possible to scan

Periodic Table of the Elements

1 IA 11A 1 H Hydrogen 1.008	2 IIA 2A 4 Be Beryllium 9.012																	18 VIIIA 8A 2 He Helium 4.003															
3 Li Lithium 6.941	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180																											
11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948																										
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80																
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29																
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 Lanthanides and Actinides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon 222.018																
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Lanthanides and Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [265]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [271]	111 Rg Roentgenium [272]	112 Cn Copernicium [285]	113 Nh Nihonium [284]	114 Fl Flerovium [289]	115 Uup Ununpentium [288]	116 Lv Livermorium [293]	117 Uus Ununseptium [294]	118 Uuo Ununoctium [294]																

Low absorbing materials

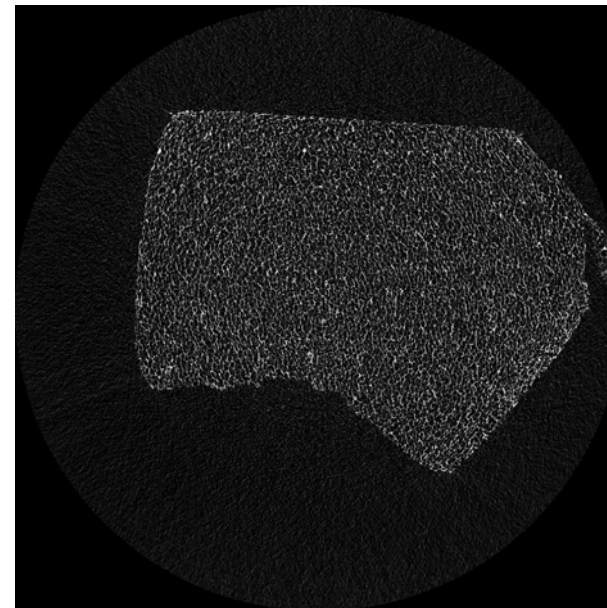
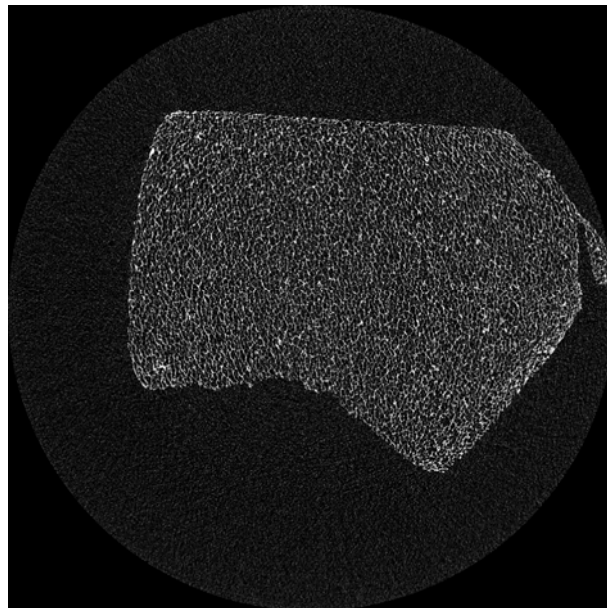
- Against air most materials can be distinguished



Low absorbing materials in air

- Possible to measure at both high and low energies

6W, 1000 projections/180°, no filter, integration time: 100 ms



Energy:

45 kV

90 kV

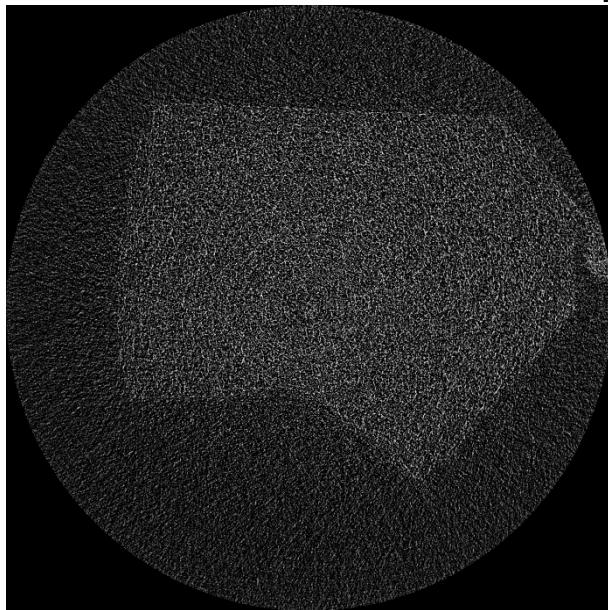


Styrofoam

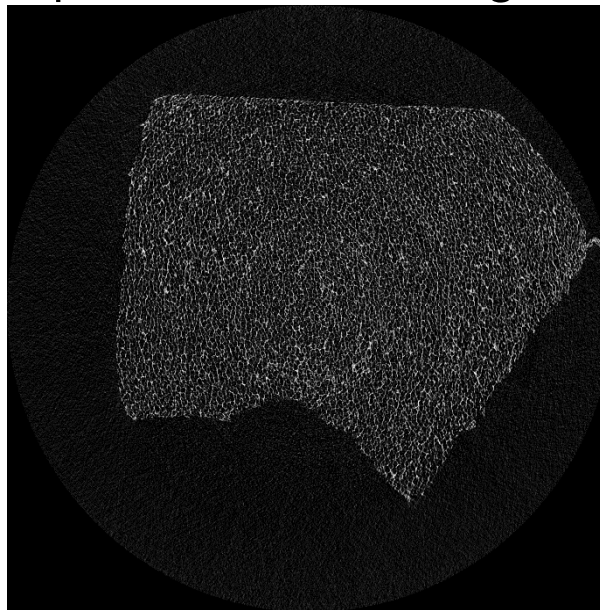
Low absorbing materials

- Important to have enough signal to detect small changes

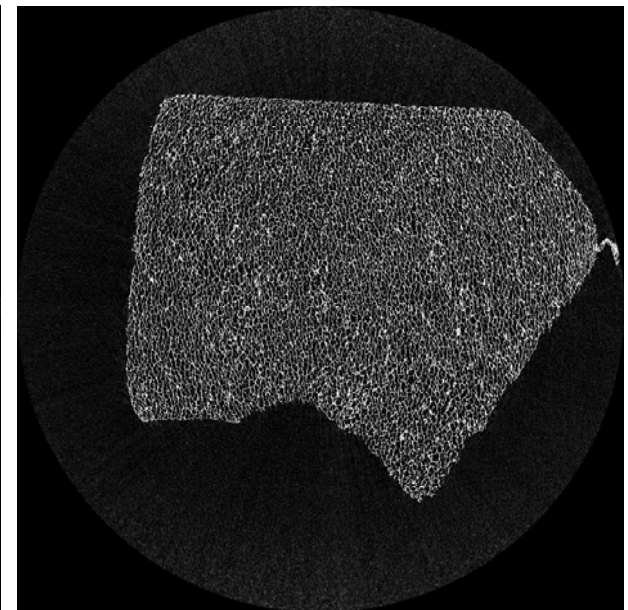
90 kV, 6W, 1000 projections/180°, Integration time: 3s



0.1 mm Cu



0.5 mm Al



No filter

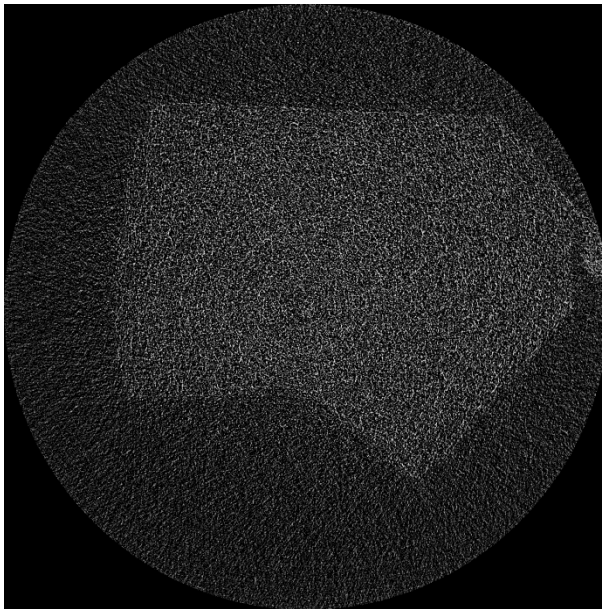


→ Filters reduce the SNR

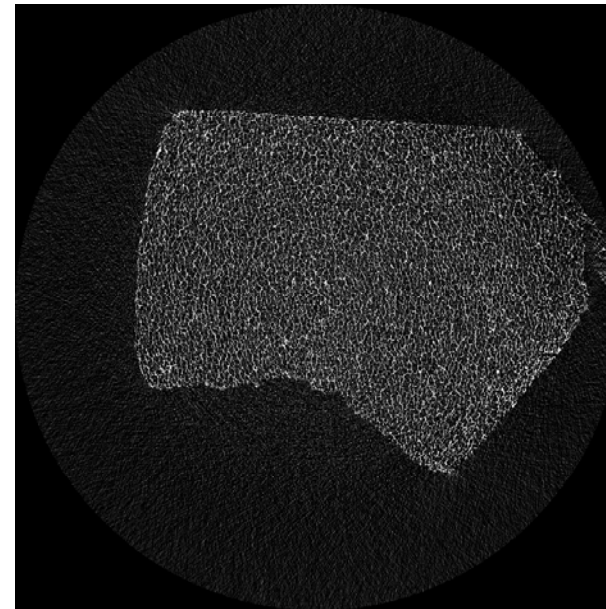
Low absorbing materials

- Important to have enough signal to detect small changes

90 kV, 6W, 1000 projections/180°, Filter: 0.1 mm Cu



Integration time: 3 s



15 s



➔ Longer integration time increase the signal

Tips for scanning low absorbing materials

- Use air as contrast
- Most energies possible
- Important to have enough SNR to detect small changes
 - ✓ Use thin filter – beam hardening is generally not a problem
 - ✓ Long integration time
 - Image averaging
 - Projections
 - ✓ Use high tube current (but beware of spatial resolution)



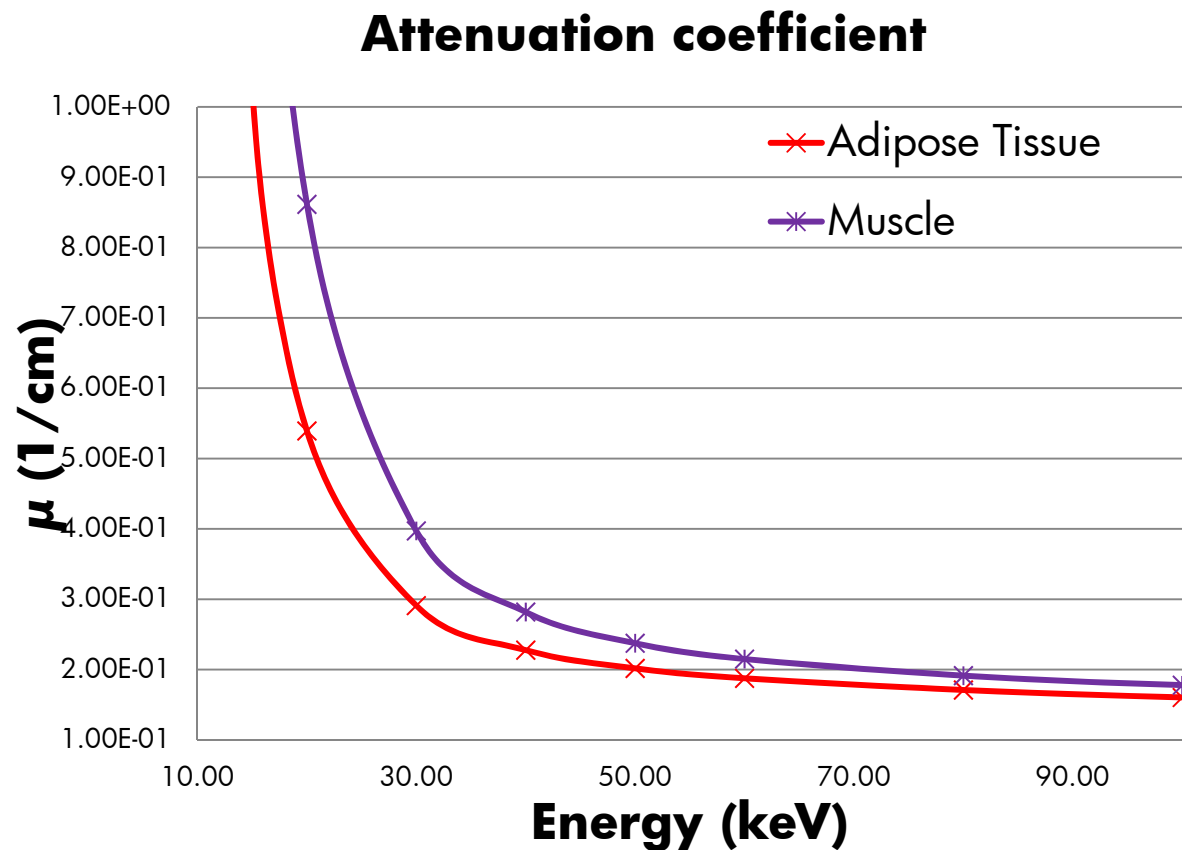
Low absorbing materials

- Hydrogels
 - ✓ Hydrogels in water – impossible
 - ✓ Dried hydrogels in air – possible
 - ✓ Stained hydrogels – possible
- Collagen fibres etc
 - ✓ Mostly possible against air



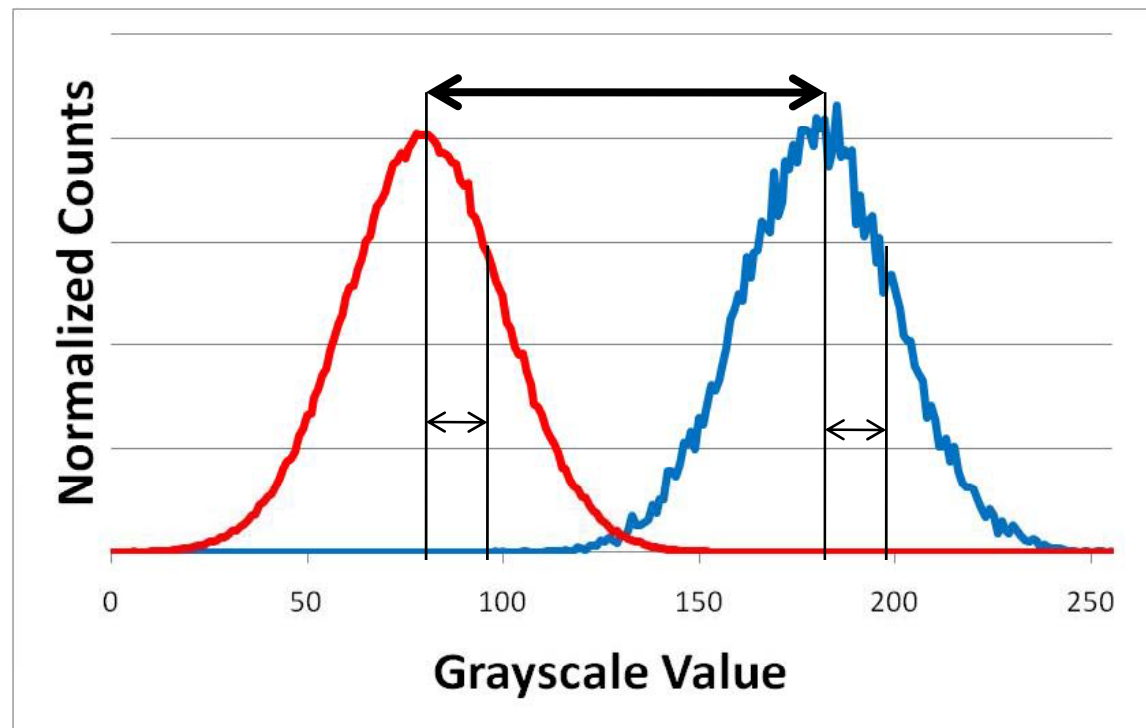
Low contrast materials

- The difference in attenuation for adipose and soft tissue is larger at lower energies.



Separability - Definition

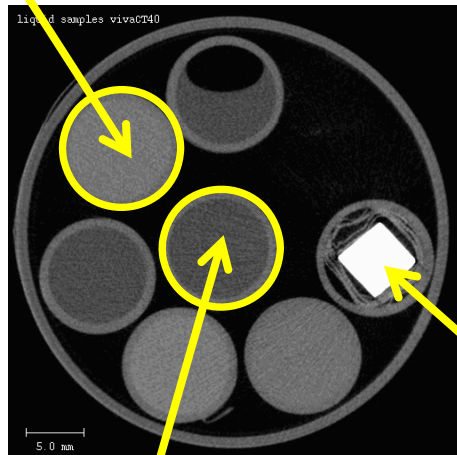
- Separability: $S = \frac{|\mu_2 - \mu_1|}{\sigma_1 + \sigma_2}$



Measurement - Sample

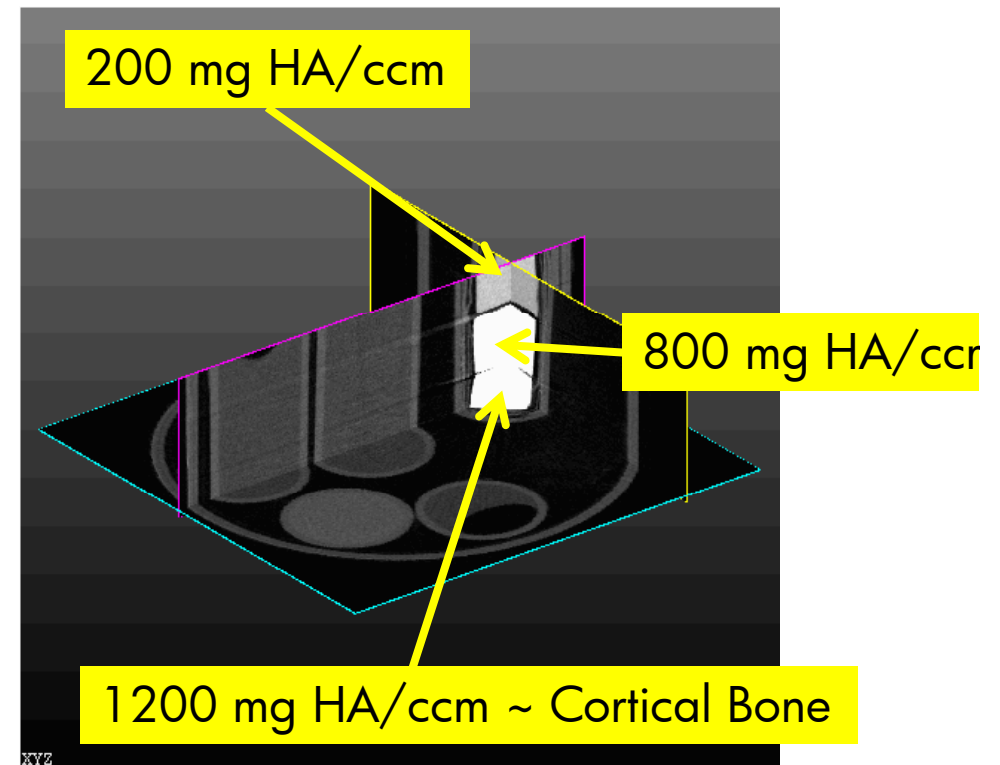
- ✓ Cube (5x5x5 mm³) with given mg HA/ccm density
- ✓ Liquid samples

Saline (0.9%)



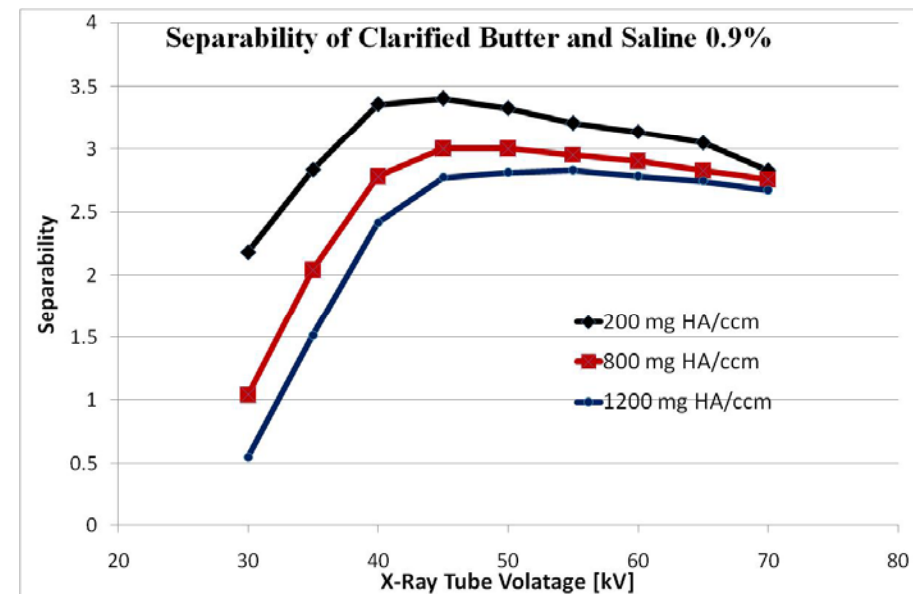
Clarified butter

Cube



Separability and Dose

- vivaCT 40
- @8 Watt (40 – 70 kV)
- Same integration time



- Increasing tube voltage:
 - ✓ increases dose
 - ✓ decreases separability



Tips for scanning low contrast

- Use 45 kV tube setting for adipose and soft tissue separability
- Use low resolution
 - ✓ Averaging reduces noise
 - ✓ Double the pixel size results in an increased separability by a factor $\sqrt{8}$
- Use high intensity (!Dose)
- Use a lot of projections (!Dose)
- Use long integration time (!Dose)
- More info in:
<http://www.scanco.ch>
Technical notes: Adipose vs Soft tissue



Conclusion

- High density materials
 - ✓ Scan at high energy
 - ✓ Use filter to avoid beam hardening
- Low absorbing materials
 - ✓ Measure the sample against air (if possible)
 - ✓ Make sure you have enough signal
- Low contrast
 - ✓ Better separability at lower energy
 - ✓ Adipose tissue – muscles: scan at 45 kV
- General
 - ✓ Control your SNR with enough integration time

