Scan & Reco

Tips & Tricks for Getting it Right

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Volume Graphics
User Group Meeting 2017

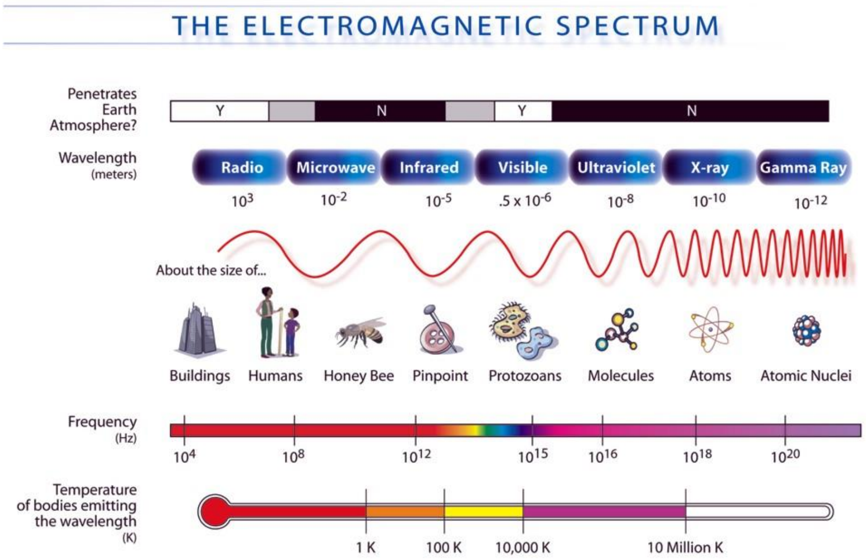
Overview

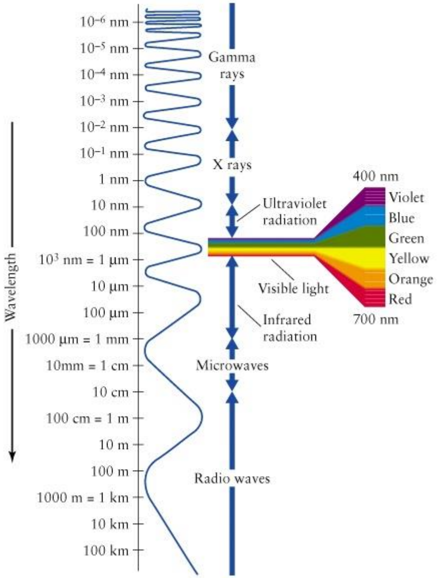
- X-Ray Basics
- Different Kind of Resolutions
- Consequences / Rules
- 3D-CT
- Artifacts
- Reconstruction
- Resulting Guideline for 3D-CT Scans

X-Ray Basics

X-Rays

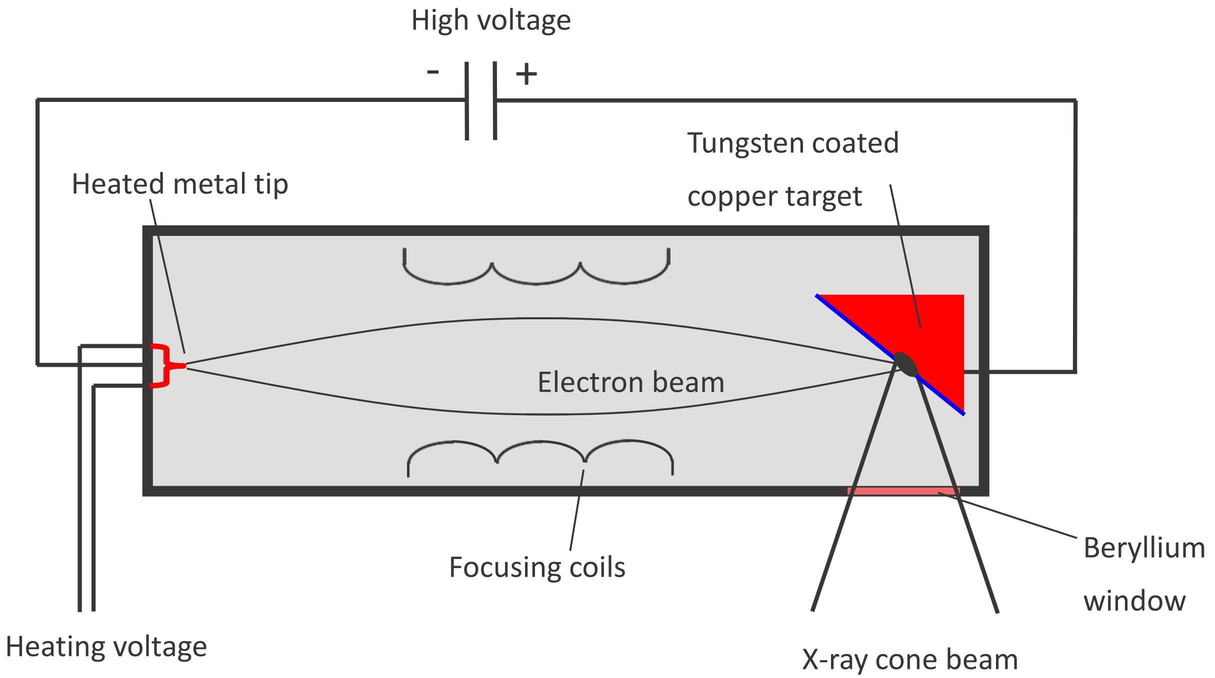
- X-rays are electromagnetic waves
- The energy of the X-rays determines their wavelength
- The shorter the wavelength, the deeper is the penetration into matter



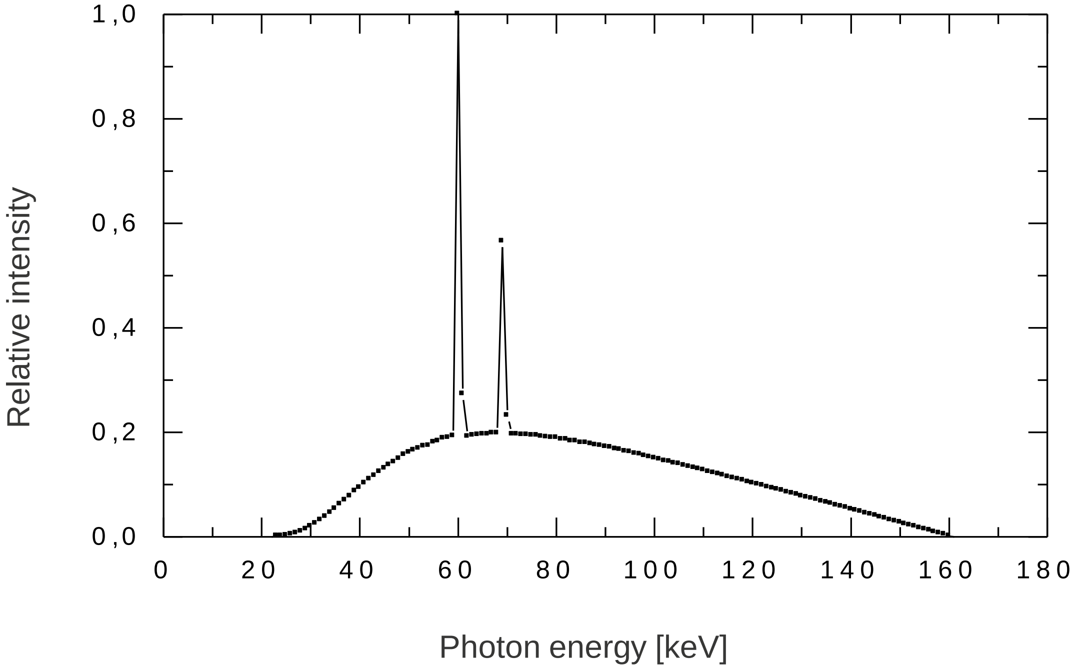


Generation of X-Rays

In an evacuated enclosure, electrons are released from a heated tip (filament), accelerated and focused on a metal target (anode).

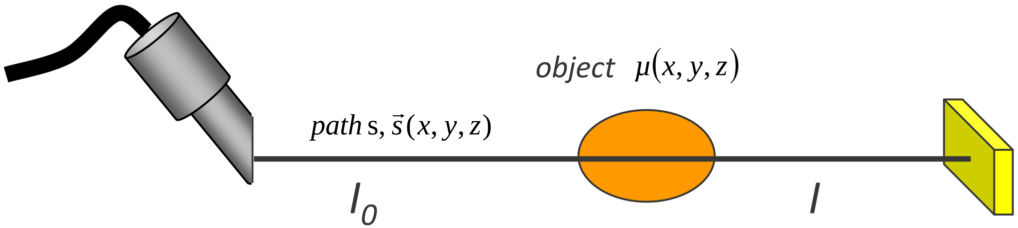


Polychromatic X-Ray Spectrum



Polychromatic spectrum with characteristic lines (W)

Attenuation of X-Rays by an Object



Attenuation of X-rays (Lambert-Beer Law):

$$I = I_0 \cdot e^{-\int_s \mu(\vec{s}) \cdot ds}$$

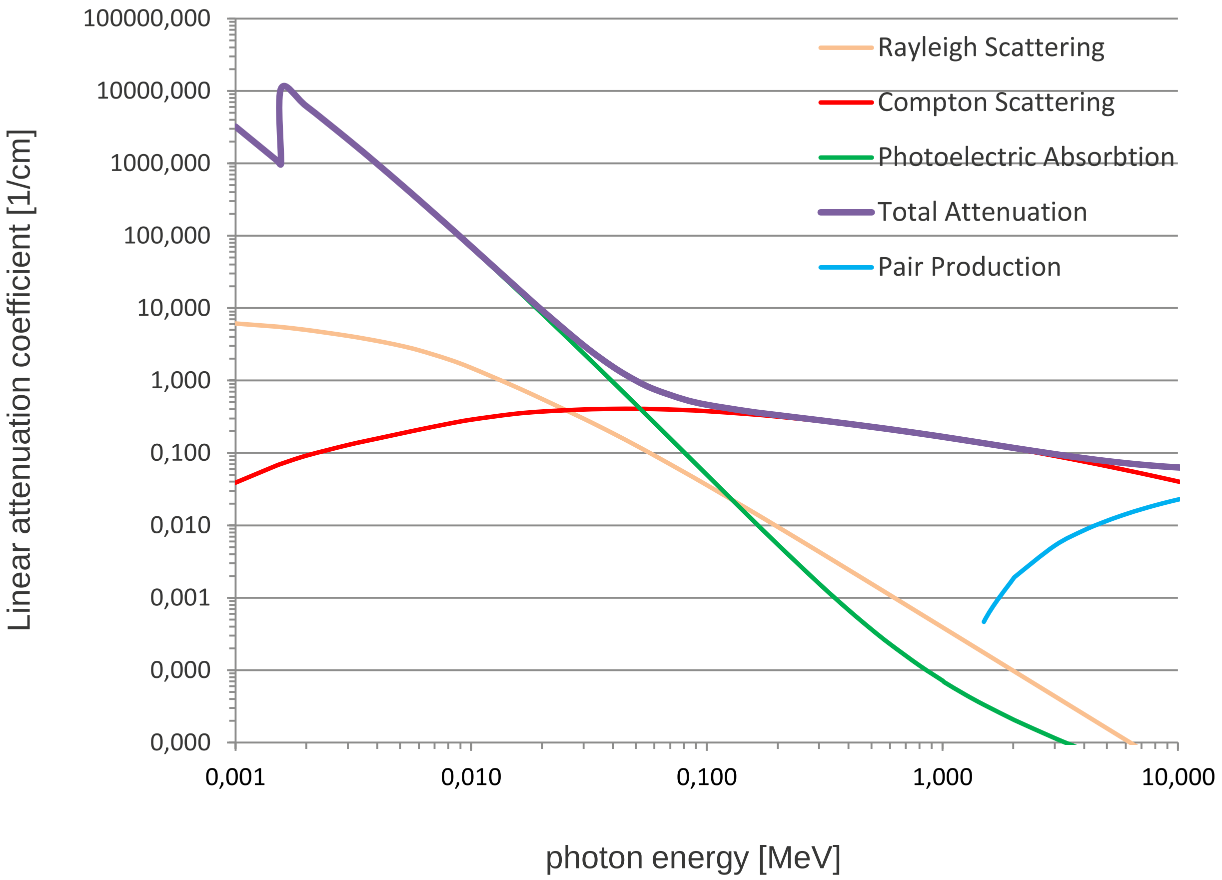
μ: linear attenuation coefficient

In reality: μ = μ(E)

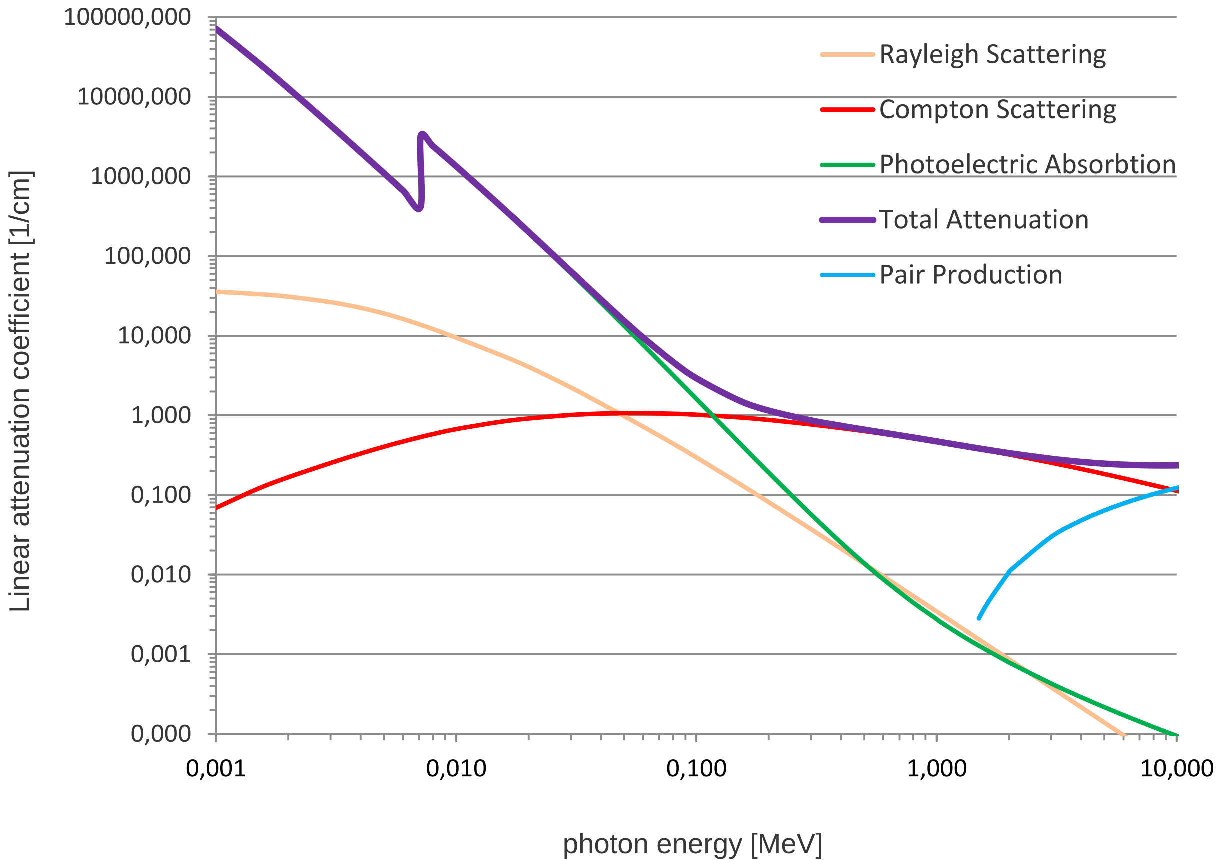
⇨ image artifacts arise
⇨ misinterpretations possible

$$I = I_0 \cdot e^{-\int_E \int_s \mu(\vec{s}, E) \cdot ds \cdot dE}$$

Attenuation in Aluminum

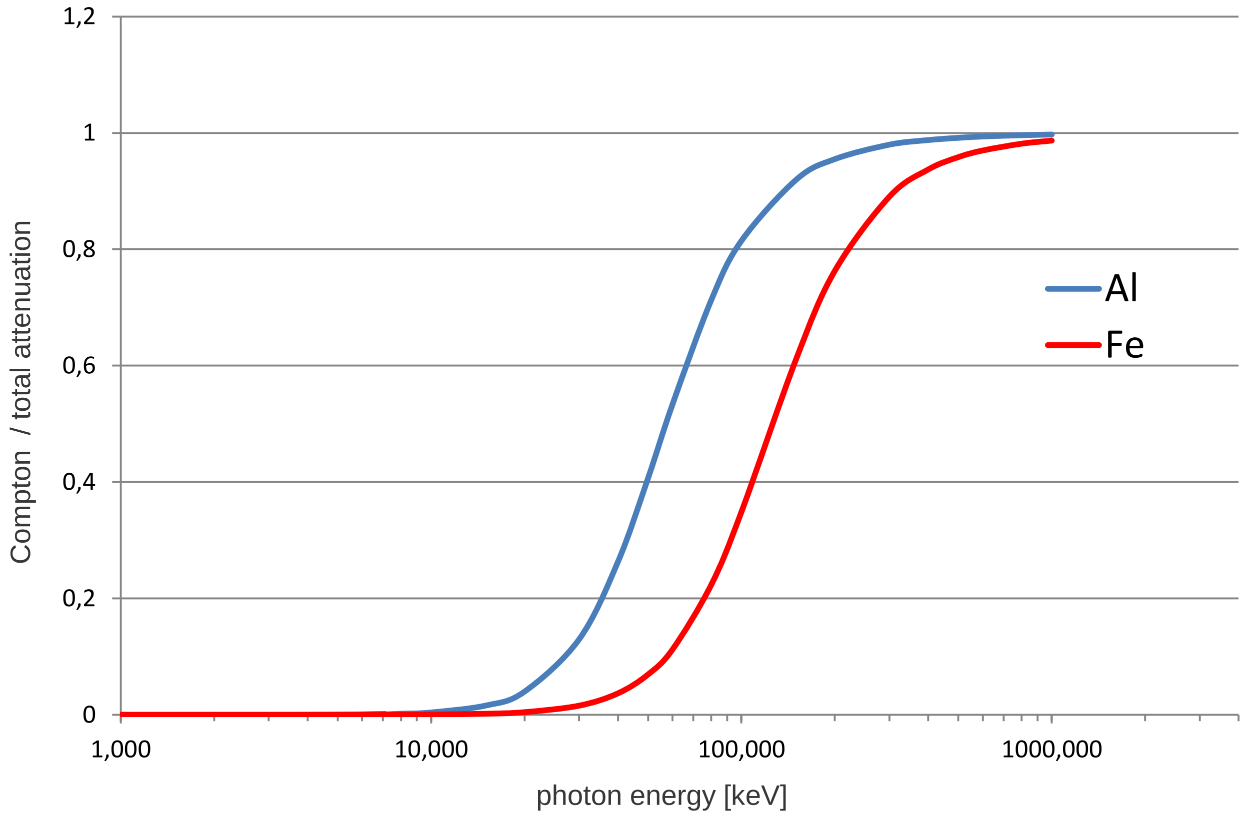


Attenuation in Iron

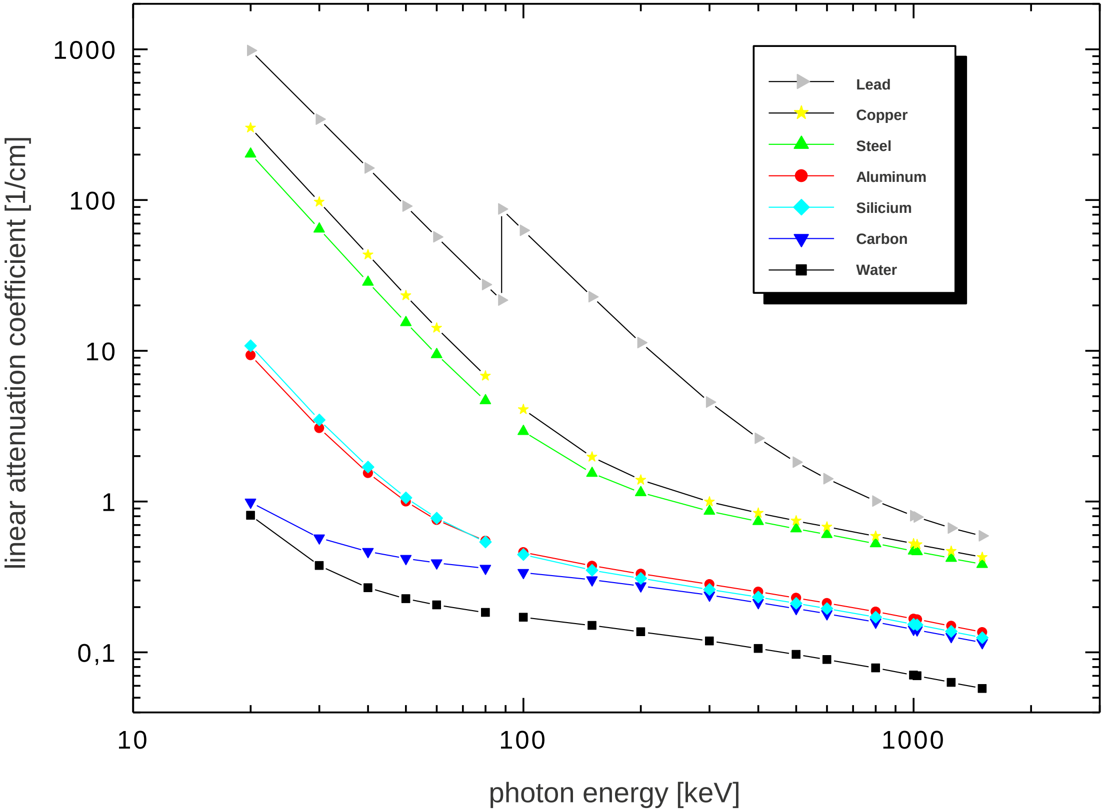


Amount of Attenuation caused by Compton Effect

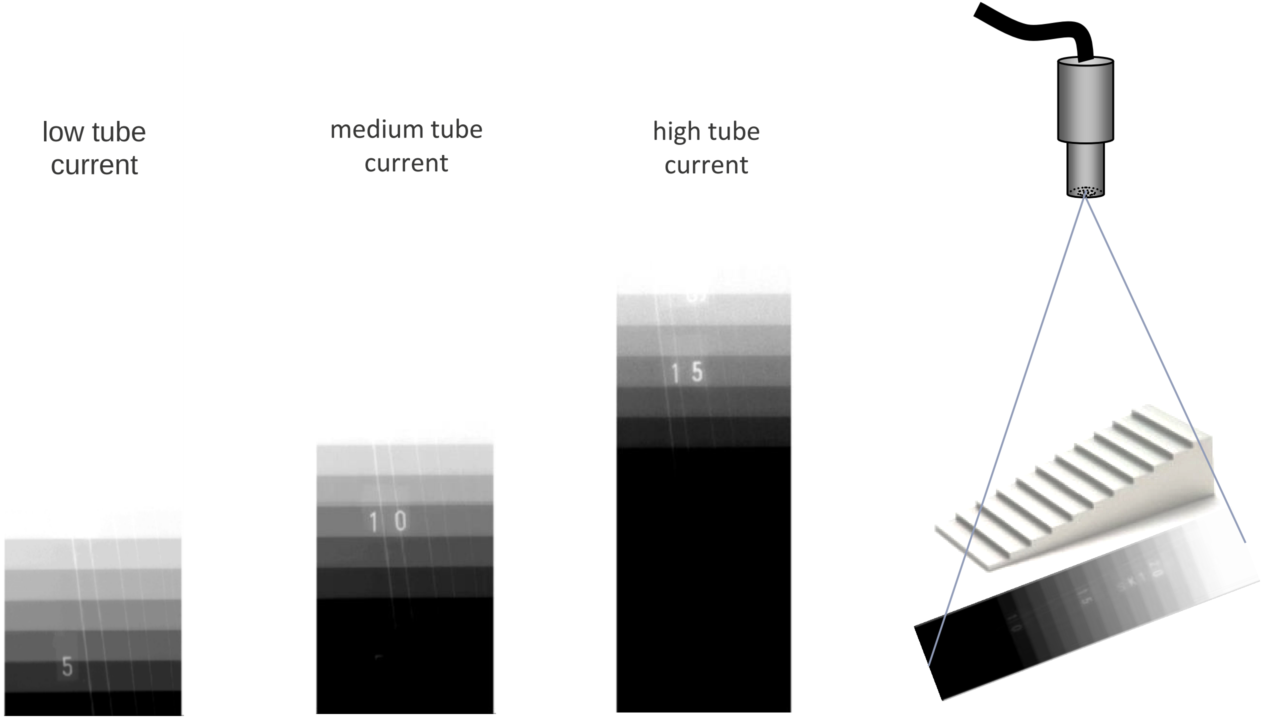
Be aware, that the stronger the Compton effect is, the more scattering occurs.



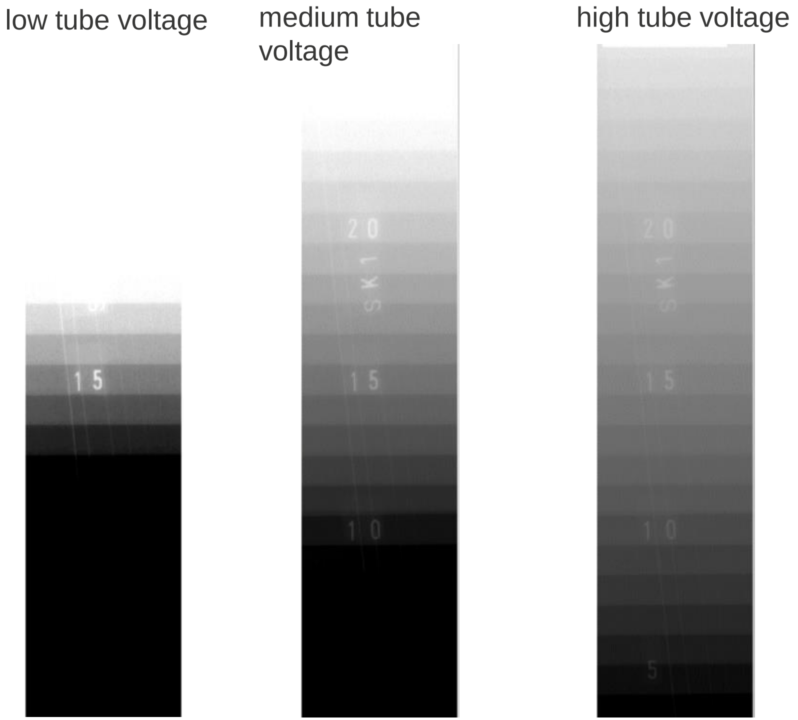
X-Ray Attenuation in different Materials

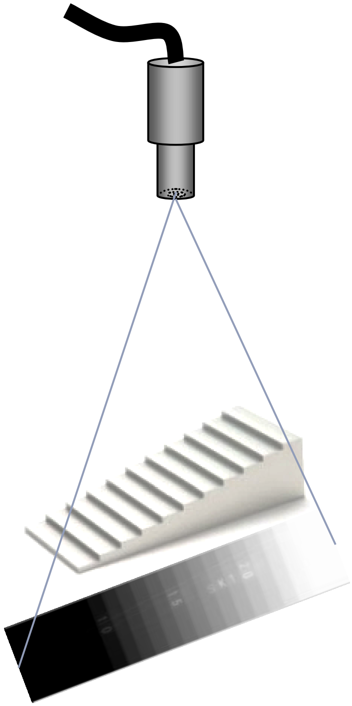


Influence of the Tube Current for the Illustration of a Step Wedge (X-Ray Film)



Influence of the Tube Voltage for the Illustration of a Step Wedge (X-Ray Film)



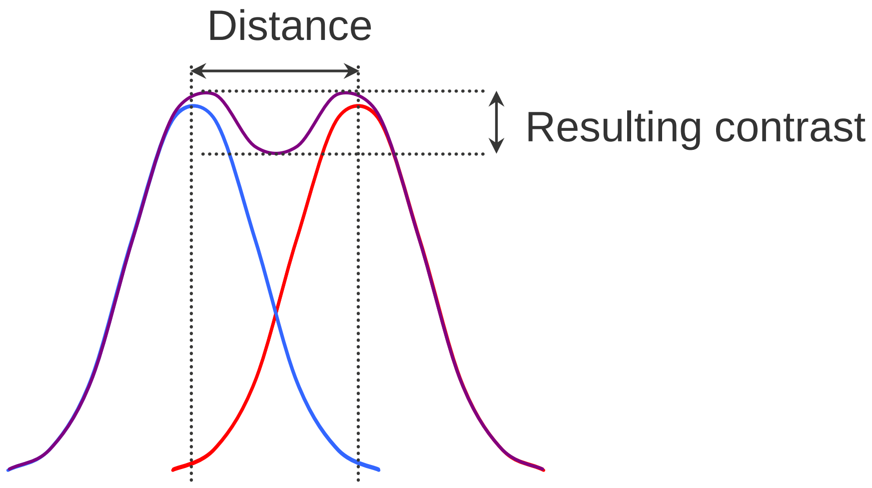


⇨ Common CT situations require much higher voltages than 2D X-ray investigations in order to get contrast for all occurring thicknesses

Resolutions

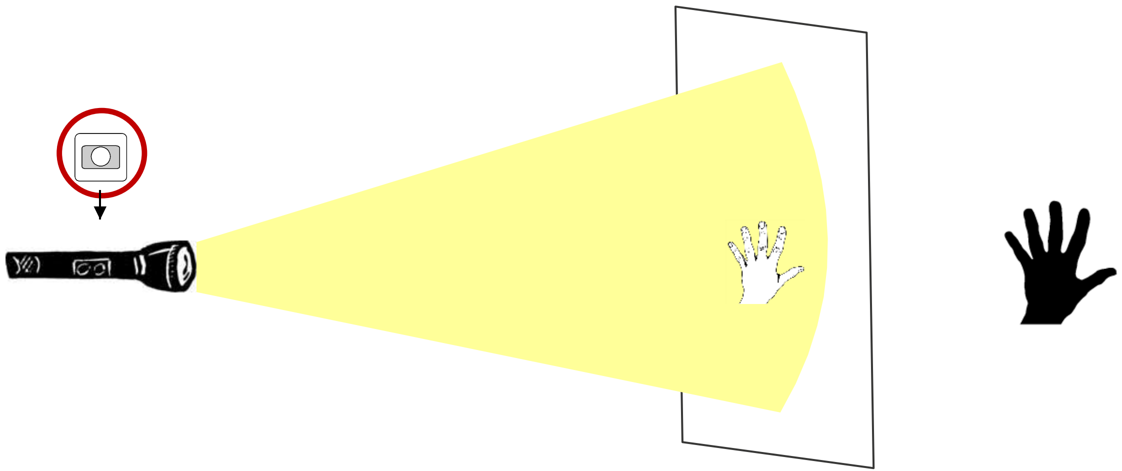
Definition of Spatial Resolution

Spatial resolution is defined as the capability of an image forming system to separately determine signals from neighboring, high-contrast features (points).



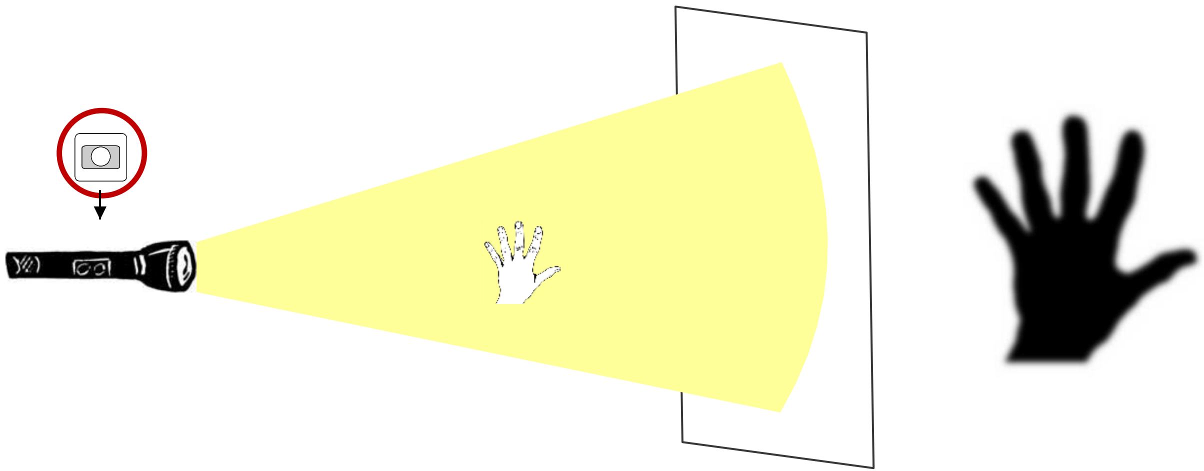
Signals are spread and do overlap

Influence of Focal Spot Size on Spatial Resolution



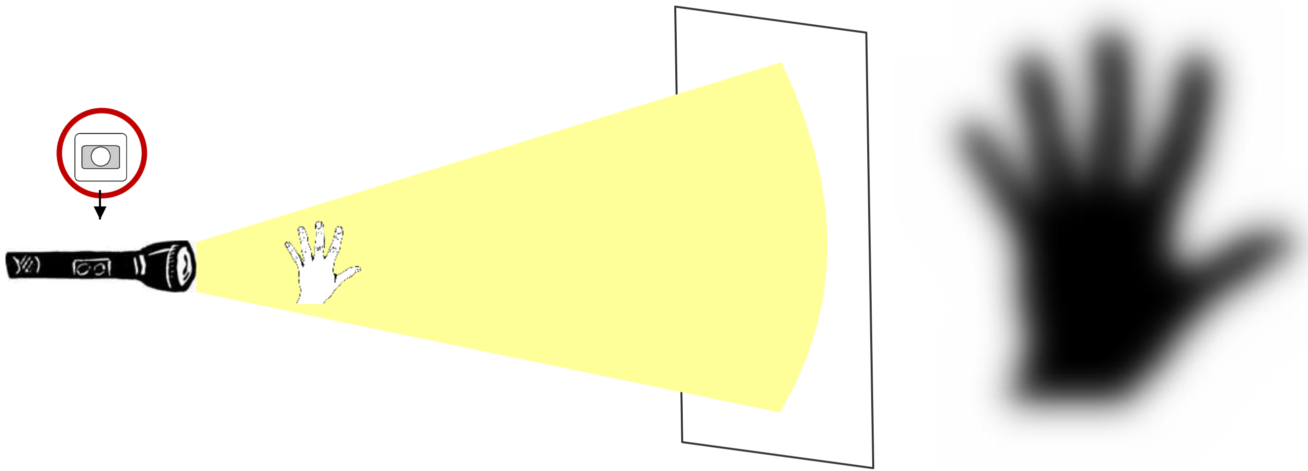
Large focal spot ; small magnification

Influence of Focal Spot Size on Spatial Resolution



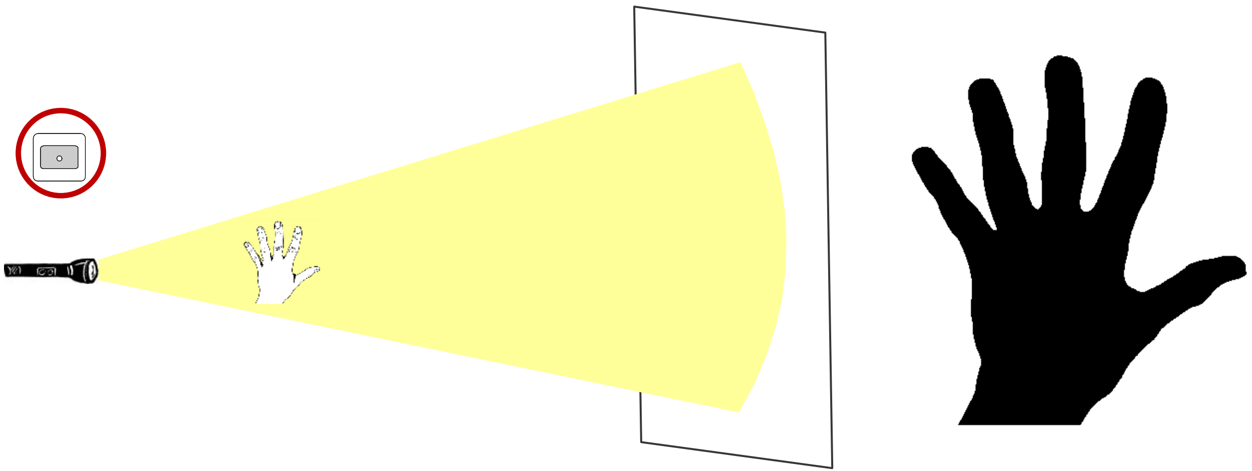
Large focal spot ; medium magnification

Influence of Focal Spot Size on Spatial Resolution



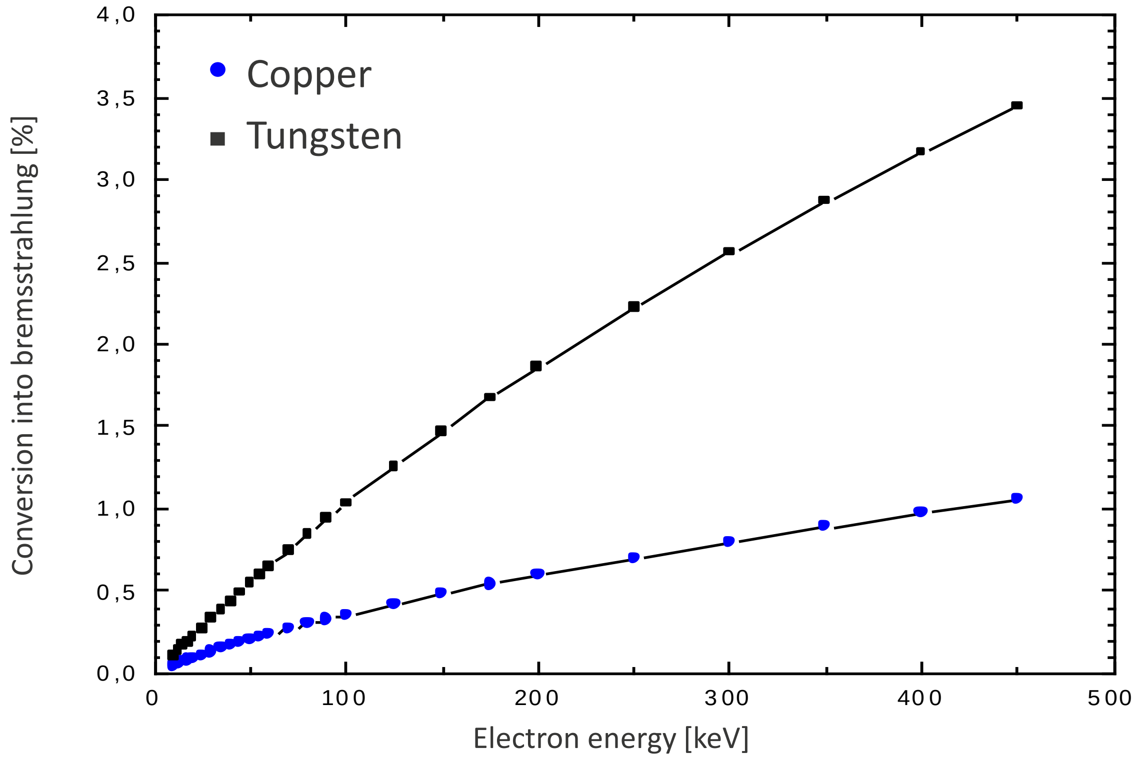
Large focal spot ; high magnification

Influence of Focal Spot Size on Spatial Resolution



Small focal spot ; high magnification

Conversion Rates



Source:
National Institute of
Standards and Technology

Focal Spot Sizes

Inside an X-ray tube electrons strike onto the target and their kinetic energy will be converted into:

- Heat (~ 98 - 99 %)
- X-ray (~ 1 - 2 %)

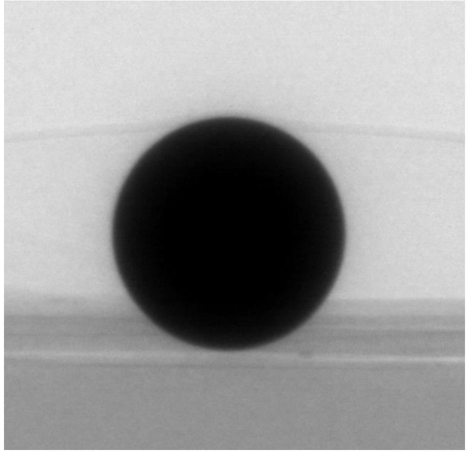
- The Target has to withstand a thermal energy of more than 100 GW/m^2

⇨ **Heating limits minimal focal spot size**

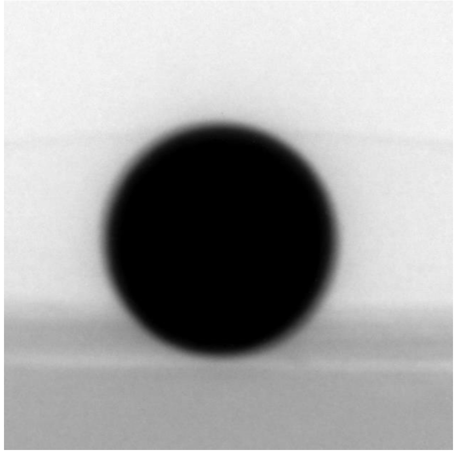
(besides other physical effects, see next pages)

⇨ **X-ray inspection has to deal with very limited number of photons “the X-ray world is dark!!!”**

Example: Influence of Focal Spot Size on Spatial Resolution



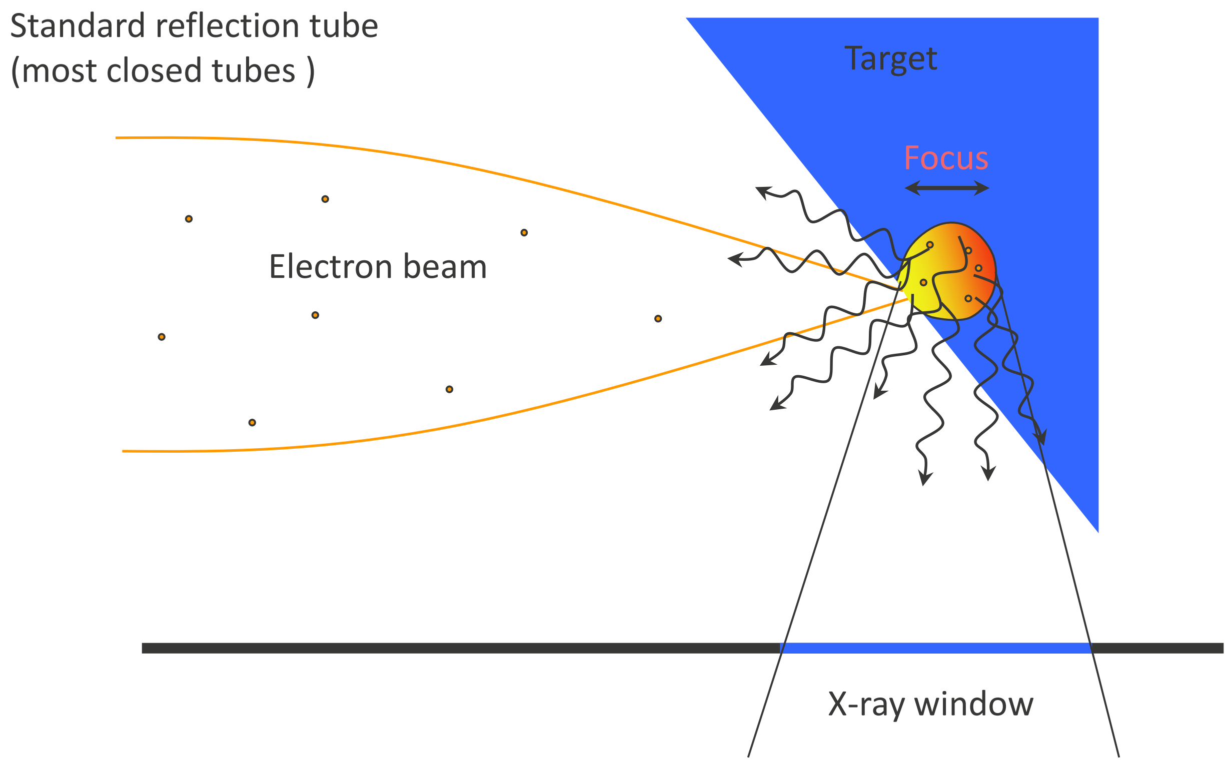
4 Watt



10 Watt

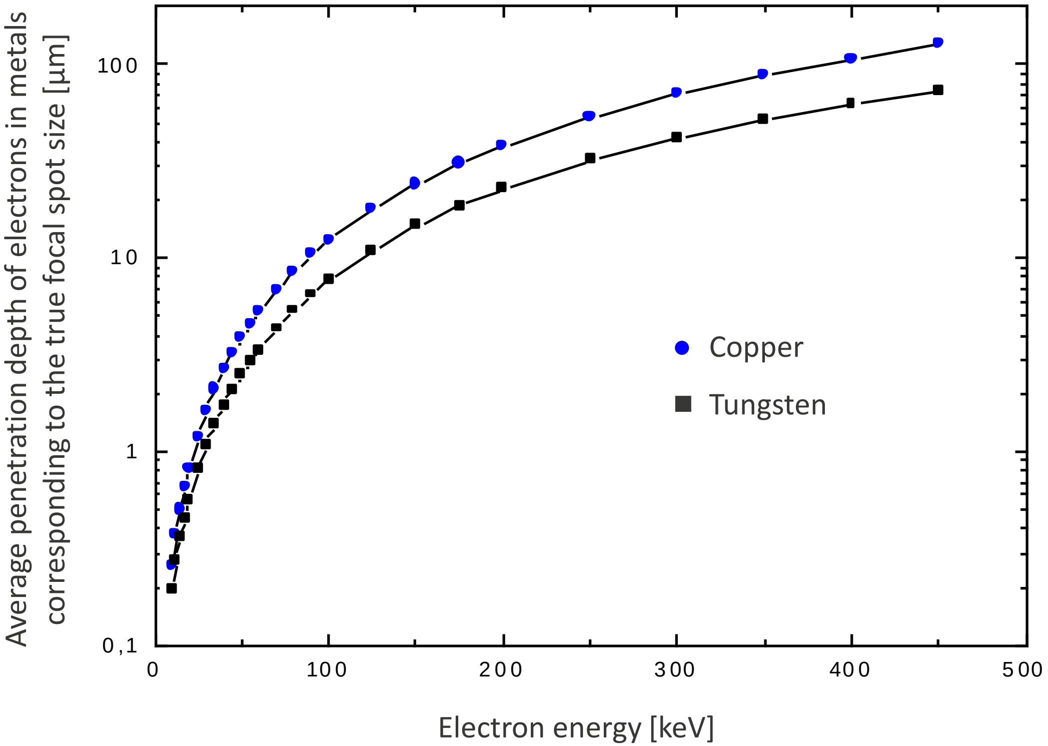
tip of a ball-pen (0.8mm)

Focal Spot Sizes



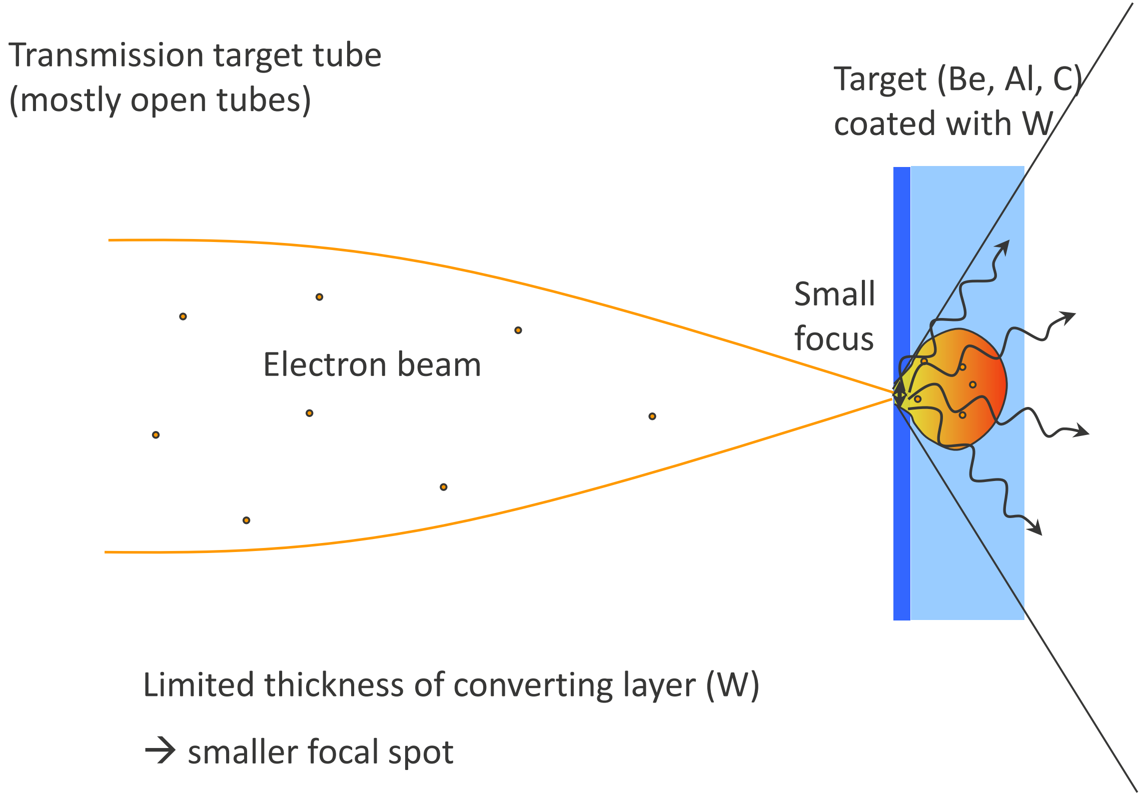
Even for small power (slight heating) the penetration depth of the electrons into the target and not the focusing itself limits the effective spot size.

Focal Spot Sizes



Source:
National Institute of
Standards and Technology

Focal Spot Sizes

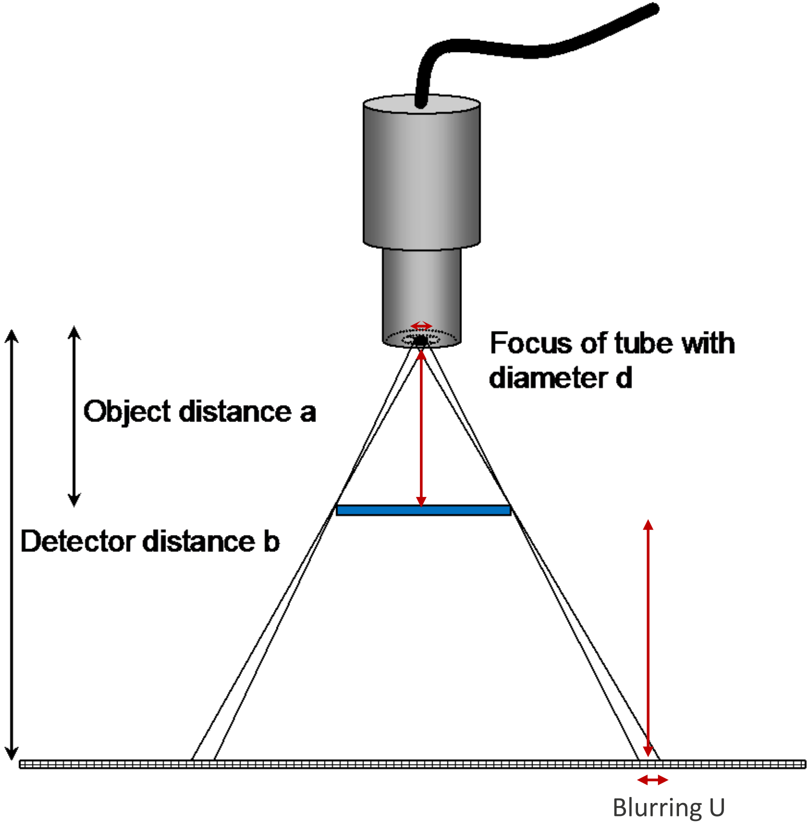


Limited thickness of converting layer (W)

→ smaller focal spot

→ **but: additional reduction of conversion efficiency !!!**

Spatial Resolution using Magnification Technique



Blurring by focus (penumbra):

Detector layer: $U = d \cdot \frac{b-a}{a} = d \cdot (M-1)$

Object layer: $U' = d \cdot \frac{(M-1)}{M} \approx d$

Blurring caused by detector elements:

Detector layer: $U_D = 2d_{Det}$

Object layer: $U'_D = \frac{2d_{Det}}{M}$

$\Rightarrow$ ***With high magnification, the focal spot restricts the spatial resolution***

$\Rightarrow$ ***With small magnification, the detector restricts the spatial resolution***

Effects on Spatial Resolution

Resulting minimal blurring of an edge or a point:

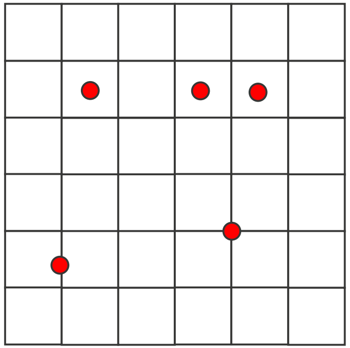
$$U_{total} = \sqrt{(U_{FS})^2 + (U_{Det})^2 + (U_{xxx})^2}$$

Blurring caused by focal spot: $U_{FS} = d \cdot \frac{(M-1)}{M}$ with focal spot size d

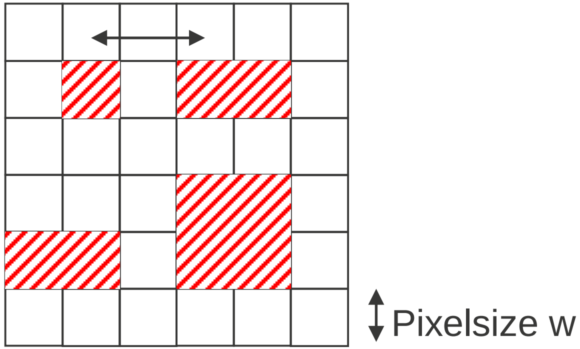
Blurring caused by detector: $U_{Det} = \frac{2 \cdot d_{\det}}{M}$ with size of detector pitch d_{det}

U_{xxx}: Blurring caused by other influences, such as mechanics, geometry, temperature drift of components, artefacts, etc.

Pixel Size and Image Resolution



Projection of details
onto the detector



Resulting X-ray image

⇒ The effectively achievable spatial resolution is at least two times the size of the image pixel w!
But even for direct magnification technique it will never be better than the size of the focal spot of the X-ray tube!

⇒ Smaller details with sufficient contrast can be seen because of the variation of the absorption, but their size cannot be measured. (feature recognition)

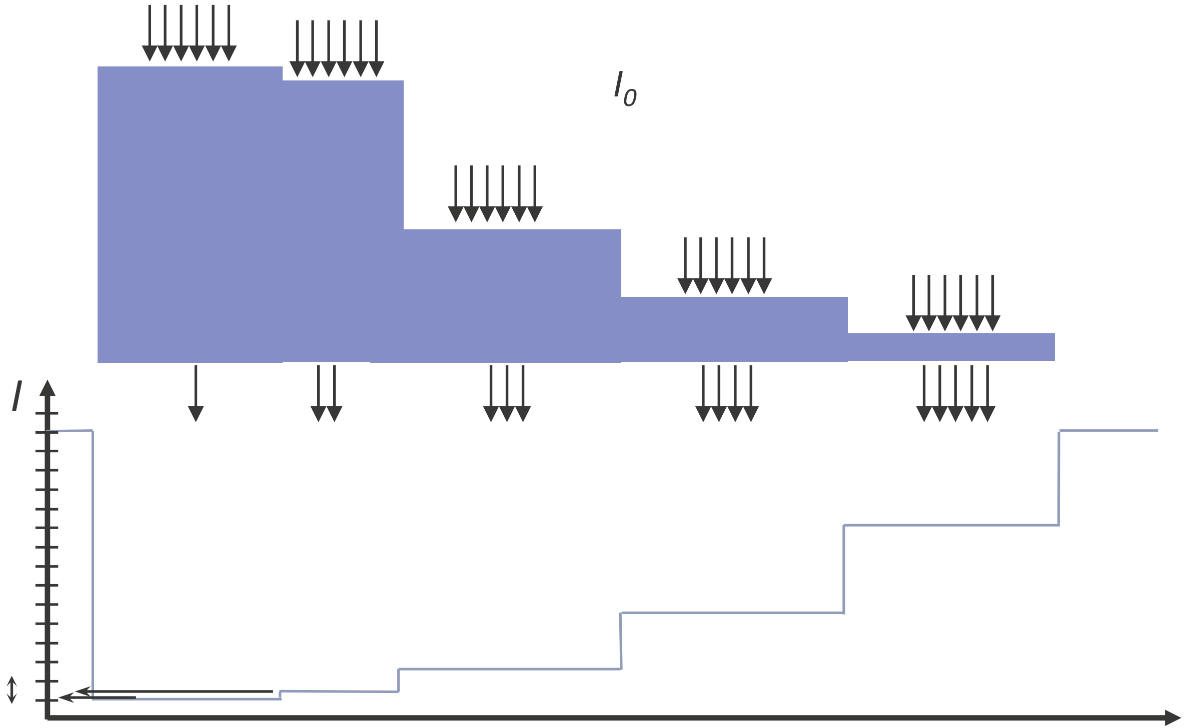
Rules to achieve a good Spatial Resolution

- In case of insufficient resolution of the detector, the spatial resolution of the system must be achieved by choosing a capable magnification.

- In case of using a high magnification, the limiting factor for the spatial resolution is the spot size of the X-ray tube.

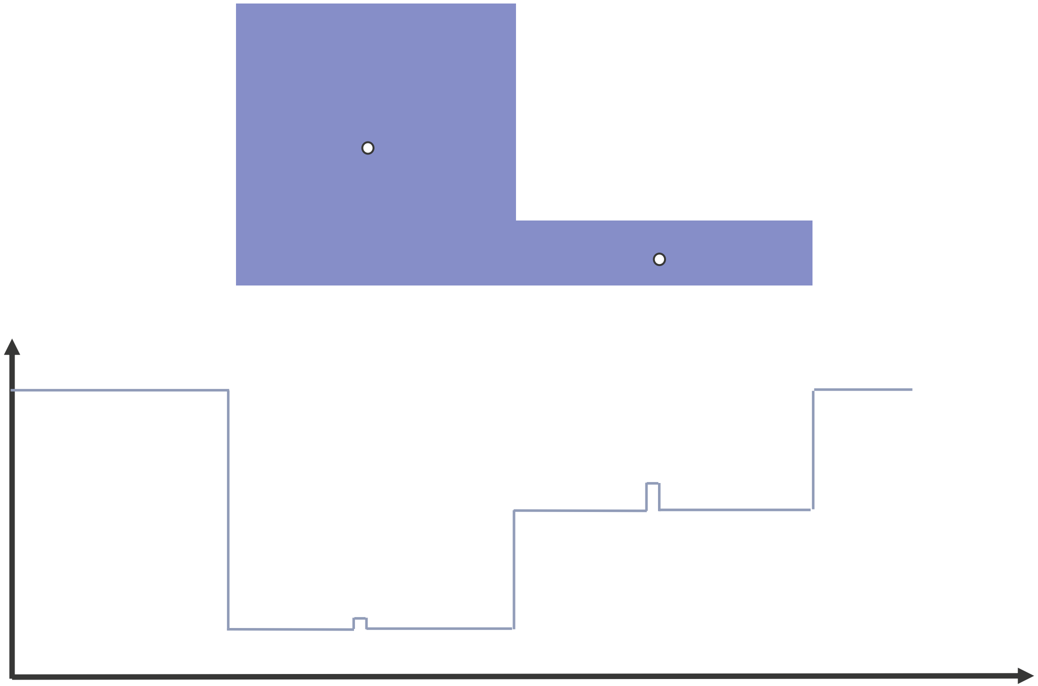
- Spot size and magnification should be well adapted:
  the pixel size of the image should be around half the spot size.
  Smaller image pixel sizes do not deliver more information but only blow up the data sets; bigger sizes lead to a waste of possible information!

Contrast Resolution



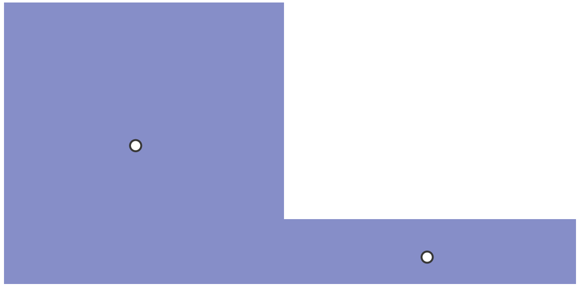
Contrast resolution depends on detector dynamics
(digital resolution, AD conversion, noise of electronics)

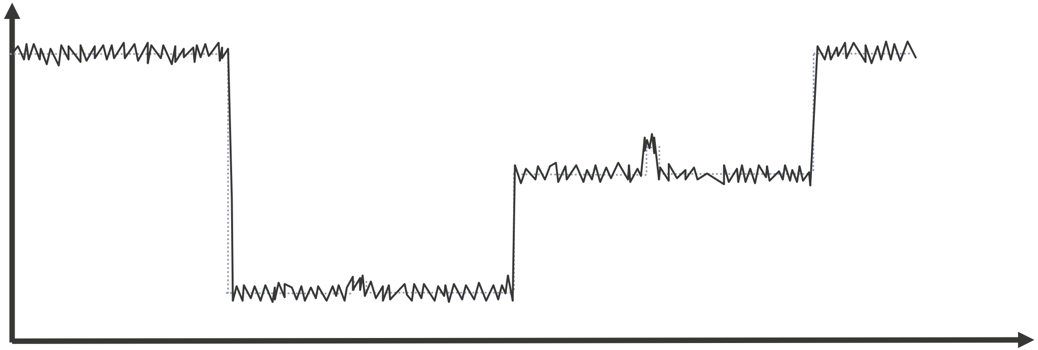
Contrast Resolution



Contrast depends on thickness of material and defect

Contrast Resolution





Contrast resolution depends on noise level

Contrast Resolution

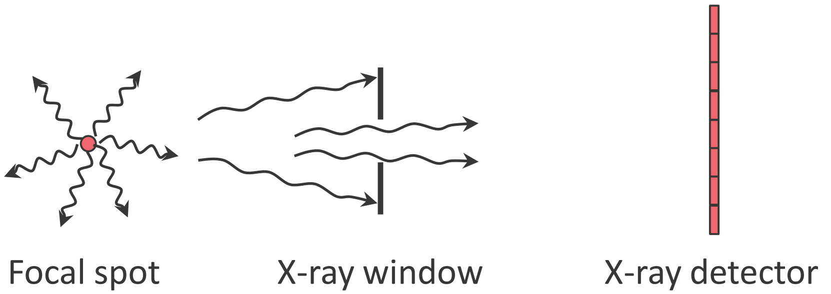
Sources of noise:

- Detector noise
- Compton scattering
- X-ray tube:

  Poisson statistics of photons: SNR $\propto \sqrt{N}$
  (especially important for low power)

  Remember that X-ray world is dark!!!

Available X-Ray Power



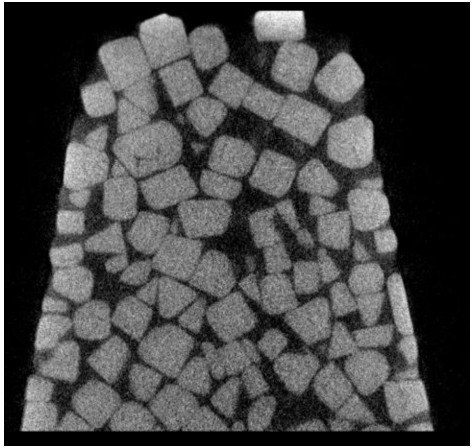
- 10 Watt tube power (measured at the spot) means 0.1 Watt X-ray power
- These 0.1 Watt are distributed in a sphere around the focal spot
- <u>Example:</u> modern 100 µm pitch detector in 1m distance

  Power per detector pixel P: $P = [(0.1\text{ mm})^2 / (4\pi * 1\text{ m}^2)] * 0.1\text{ W}$

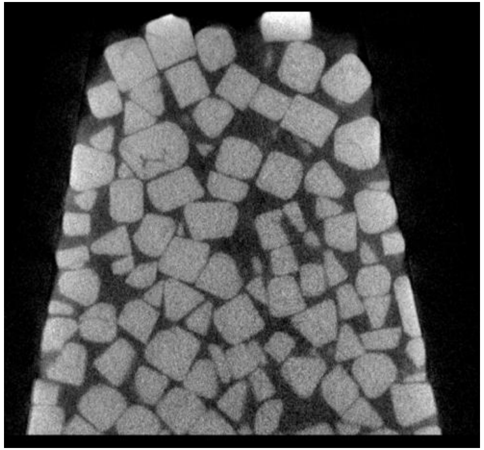
  $P = 0.796$ nano Watt per detector pixel
- 16 bit detector: ~ 0.1 pico Watt per bit (unweakened intensity)
- What we neglected: self-absorption inside the tube, tube window, limited conversion rate of the scintillator, …

Example: Effect of Scanning Time

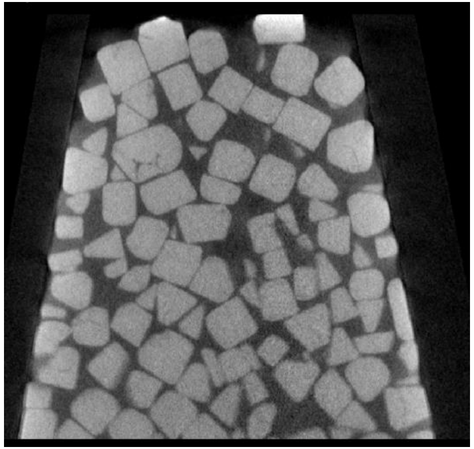
Grains of salt, 3 µm voxel size



13 min

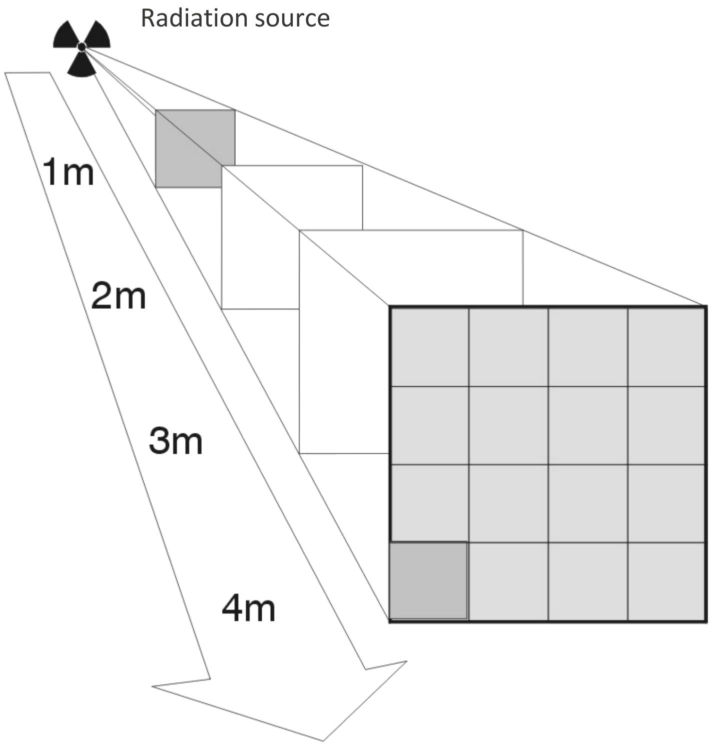


25 min



60 min

Remember the Distance-Square-Law



2 x distance

=

¼ of the intensity

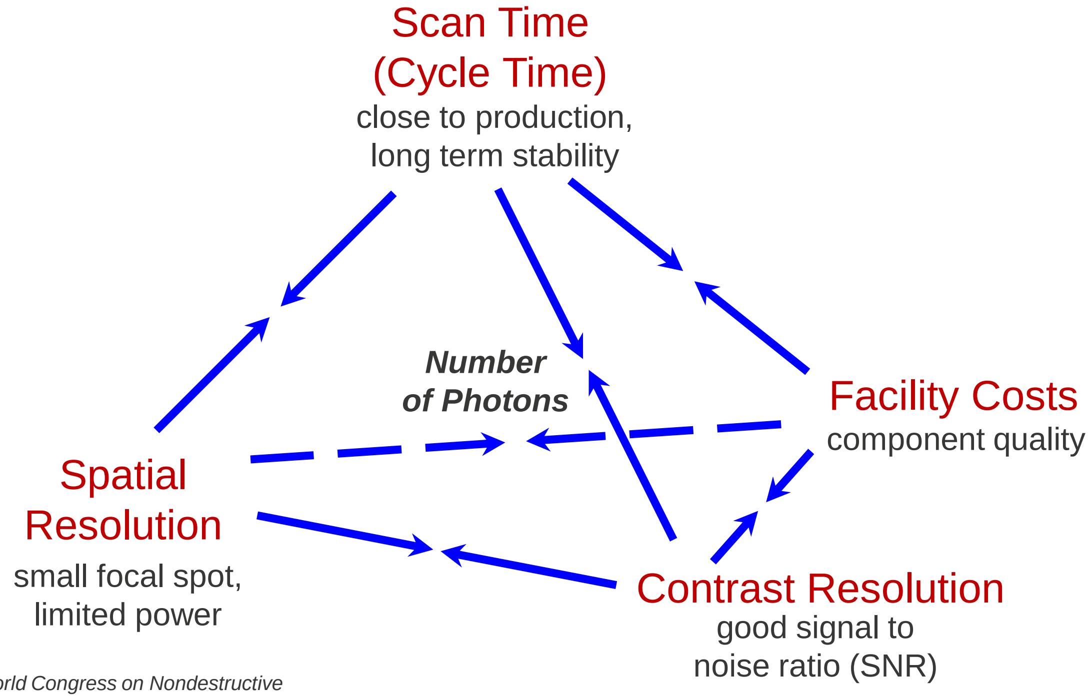
Magnification

versus

Contrast !!!

Physical Boundary Conditions

X-Ray Testing Pyramid*

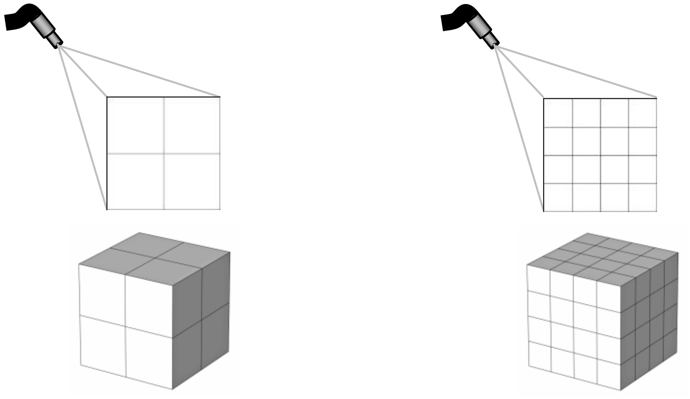


** Gondrom et al., World Congress on Nondestructive Testing, Montreal, 2004*

Effects of Detector on Contrast Resolution

Resolution in a projection

Resolution in volume



Doubling the resolution by simply using a smaller detector pitch (same detector type and same geometry) results in ¼ photons per detector pixel and ⅛ photons per 3D voxel.

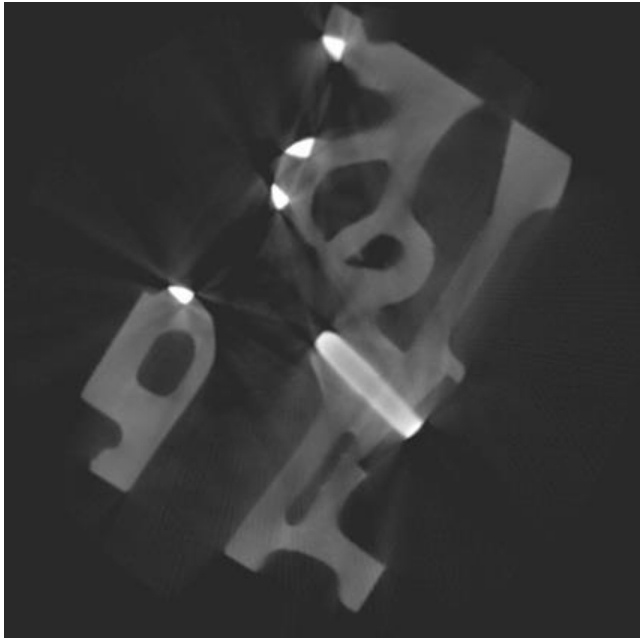
To get the same contrast quality in 3D, which is in fact the signal to noise ratio (SNR) determined by the detected photons, the measurement time has to be 8 times longer – even in theory!

In reality, 8 times longer is not enough because of a thinner scintillator and a reduced fill-factor of the detector photo-diodes! Doubling the detector resolution on the same area may result in 20 times less detected photons (half scintillator thickness + smaller fill-factor).

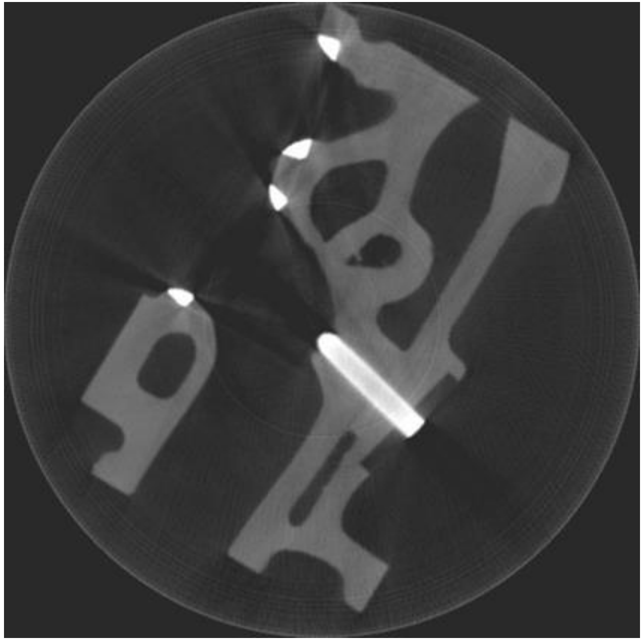
⇨ Think of using a more sensitive detector type instead !!!

Example:
Effect of Compton Scattering on Contrast Resolution of a CT

Not only the object but as well the walls of the X-ray system cause scattering ⇨ collimation is recommendable.



Strong scattering



Reduced scattering (Collimation)

Source:
Gondrom, Purschke, Siegle
CT at BOSCH Schwieberdingen, 1998

Consequences / Rules

Consequences

> Be aware that achieving a good contrast initially is by far more important than a good spatial resolution !!!

> One has to be able to detect details at all, before trying to determine their size !!!

> Contrast resolution can be limited due to short cycle times (specially relevant for production environment)

→ high power of the X-ray tube is mandatory

→ high power leads to bigger focal spot size and thus limits the spatial resolution

> Reduce scattering effects as much as possible by collimation!

Consequences

> Do not choose a detector with too many pixels!

> Instead of binning detector pixels, start with a proper detector type and do not use more than the number of pixels really needed!

  > Higher resolution detectors have smaller bulk factors

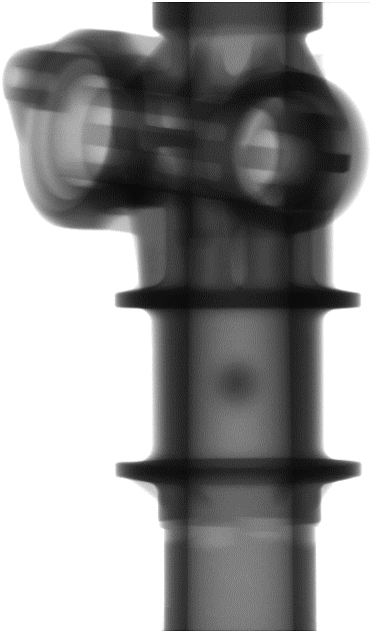
  > Higher resolution detectors have thinner scintillators

  > Higher resolution detectors often have higher electronic noise level due to smaller electrical capacities

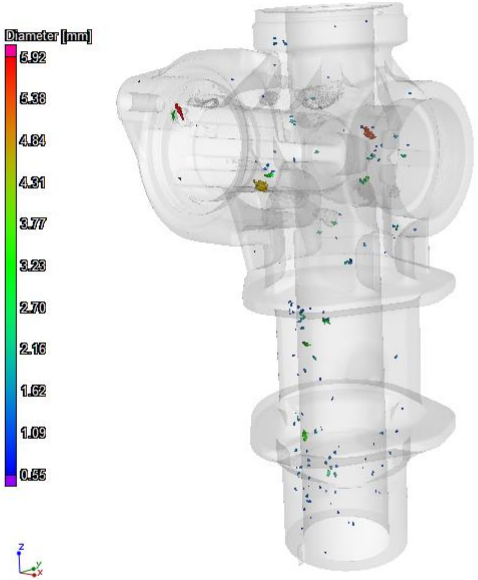
→ All this leads to higher noise level in the data.

3D-CT

Motivation

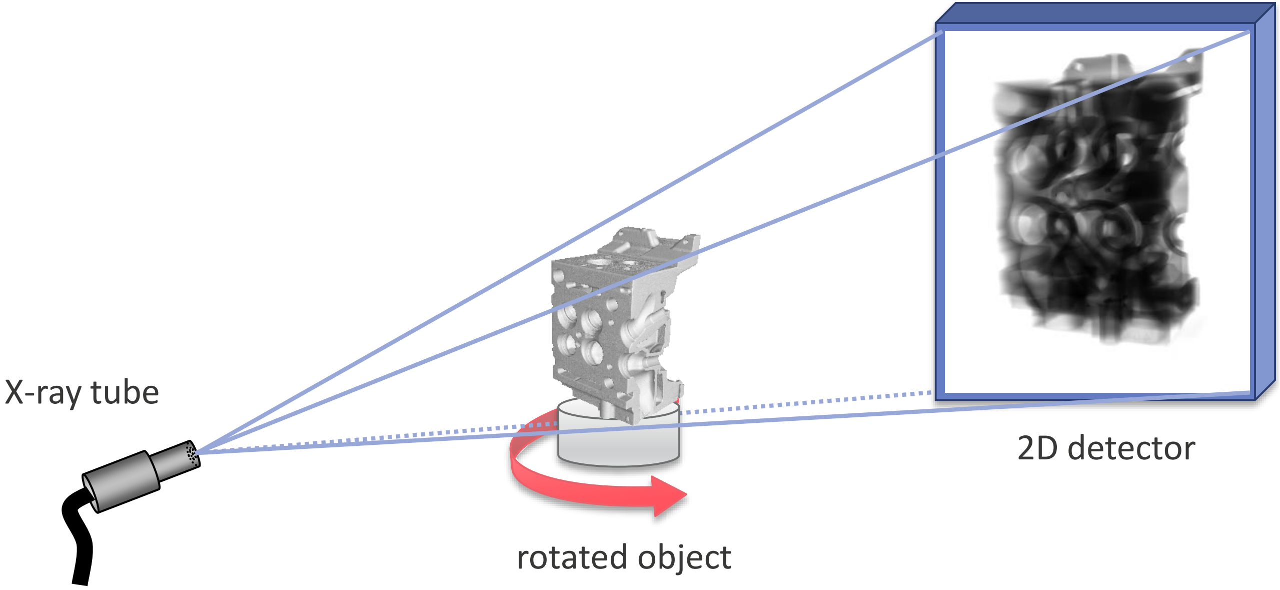


2D X-ray: shadow image without depth resolution

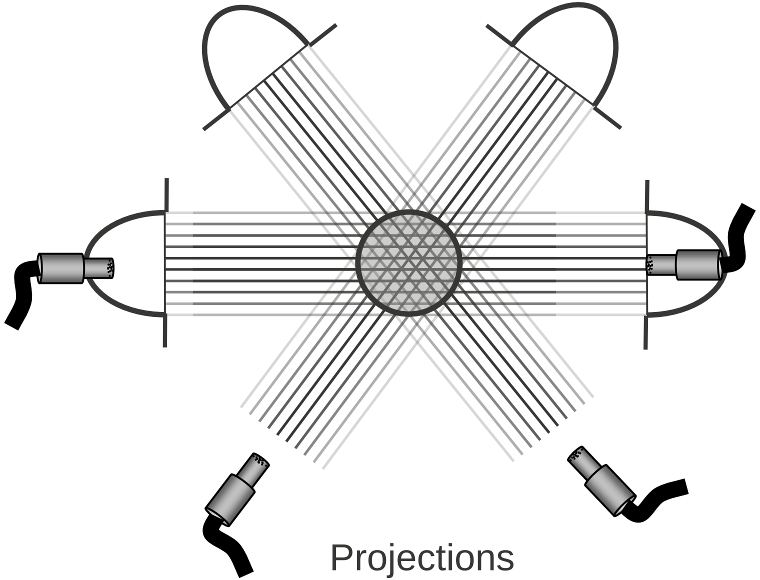


3D-CT with full volumetric information

Principle of 3D-CT

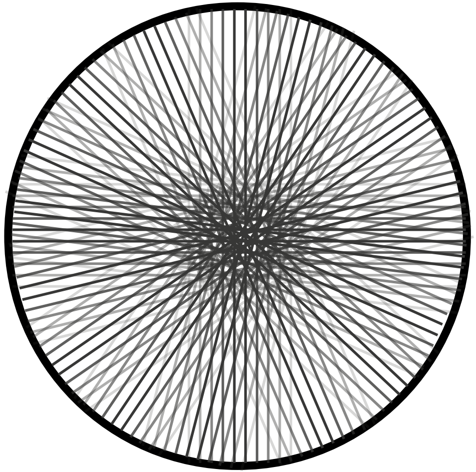


Principle of Unfiltered Backprojection



Projections

$$I, I_0 \Rightarrow P = \ln\left(\frac{I_0}{I}\right)$$

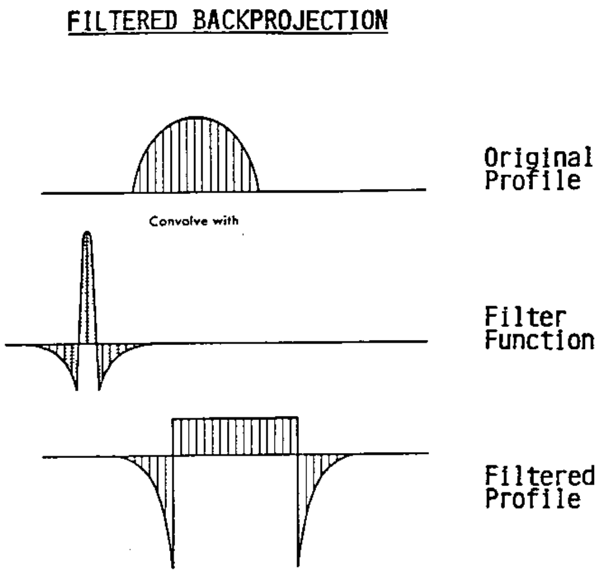


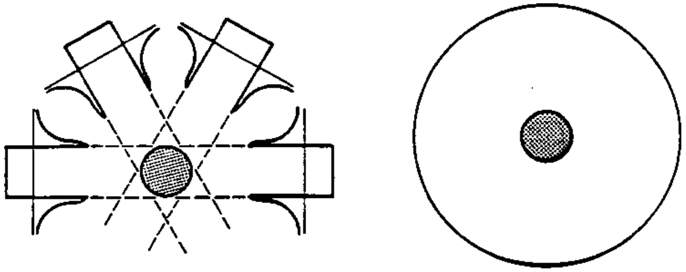
CT image (tomogram)

$$P = \ln\left(\frac{I_0}{I}\right) = \mu \cdot d$$

Extremely blurred images with low contrast resolution !

Principle of Filtered Backprojection (FBP)

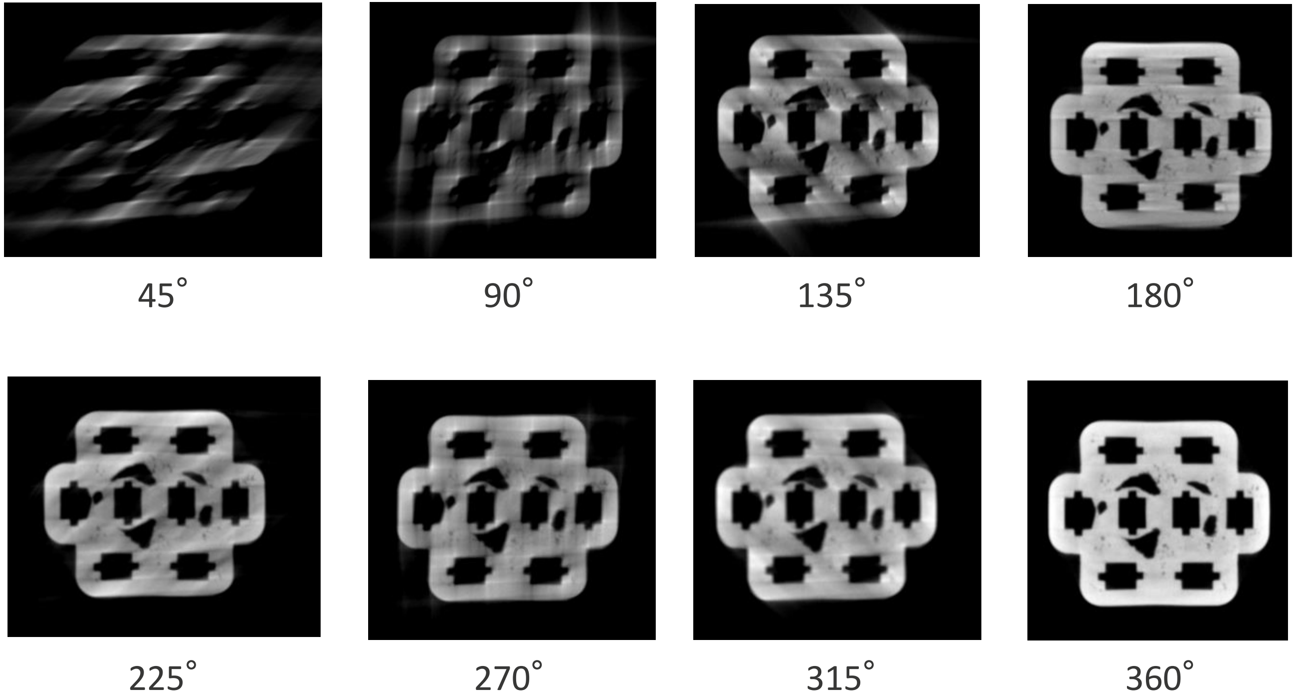




Filtered projections and image

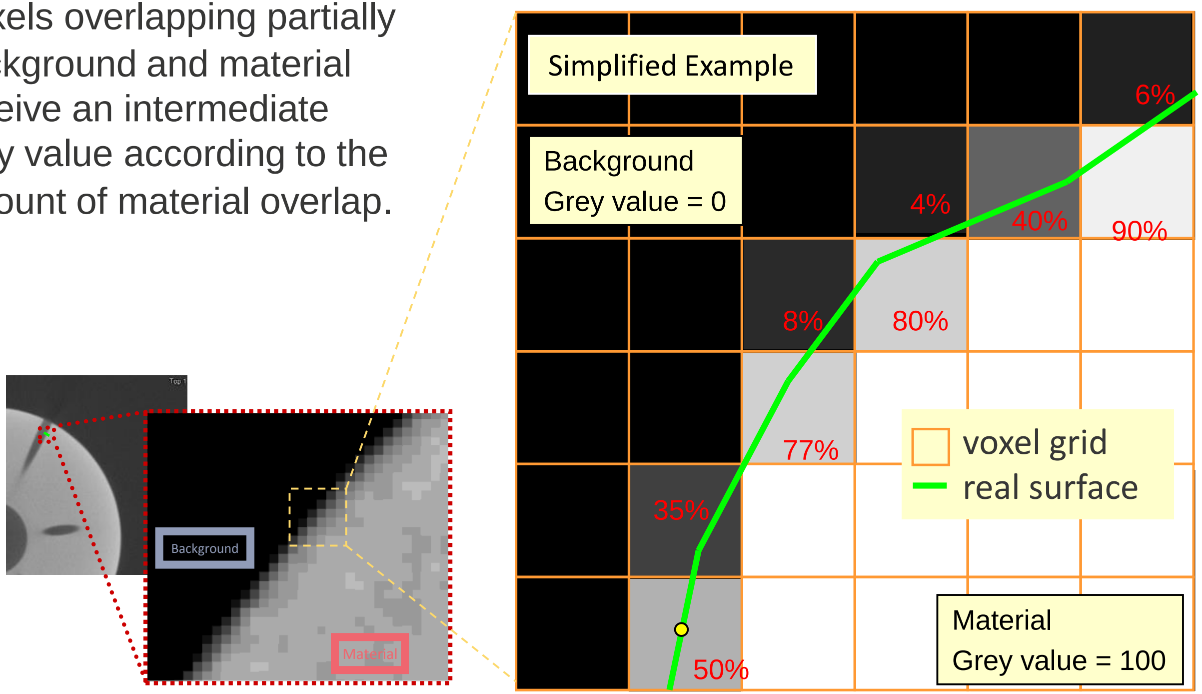
Sharp images with very good contrast resolution.

Formation of a Tomogram using FBP



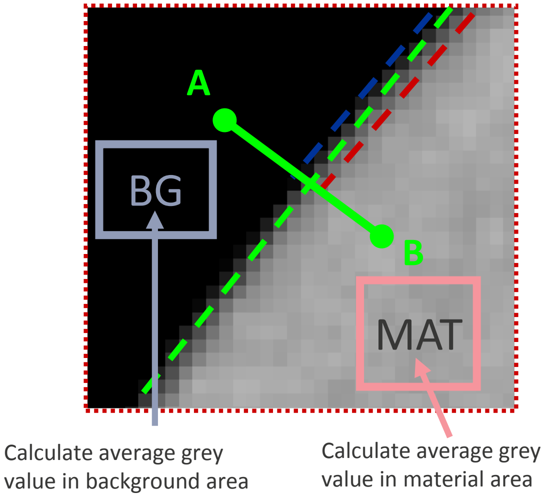
Surface Determination

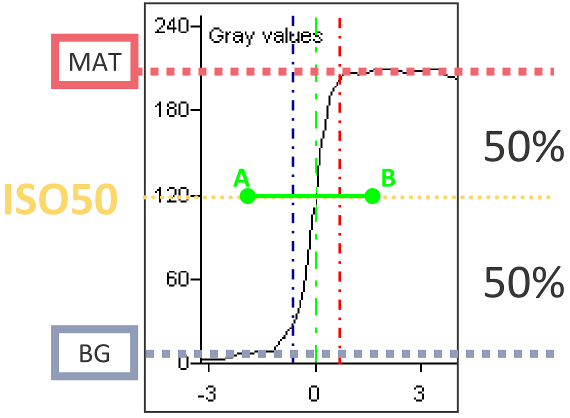
Voxels overlapping partially background and material receive an intermediate grey value according to the amount of material overlap.



Surface Determination

- In theory: The object's exact surface is described by a simple **grey value threshold → ISO50 threshold.**
  - ISO50=(average material grey value + average background grey value)/2



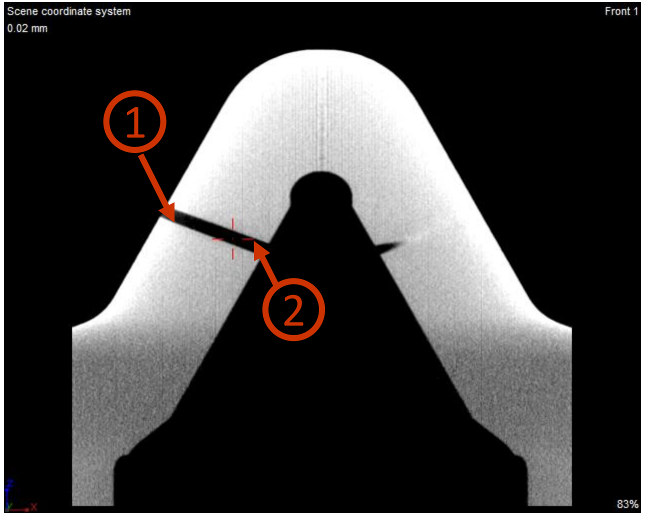


Grey value profile along line A-B

CT Artifacts

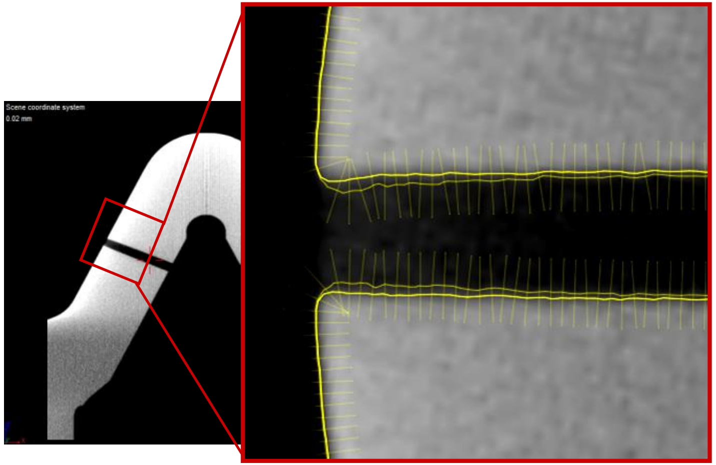
- A ISO50 threshold applied globally will typically cause geometry errors on “real data” since the local surface threshold at position 1 differs from the one at position 2, e.g. due to beam hardening artifacts.

- Fuel nozzle example: locally measured ISO50 threshold at:
  1 = 38900
  2 = 32700



Precise Surface Determination

- A proper surface determination uses a local adaptive edge detection algorithm to minimize measurement uncertainty.
- All geometry related tools take full advantage of this feature to reduce **measurement uncertainty**.

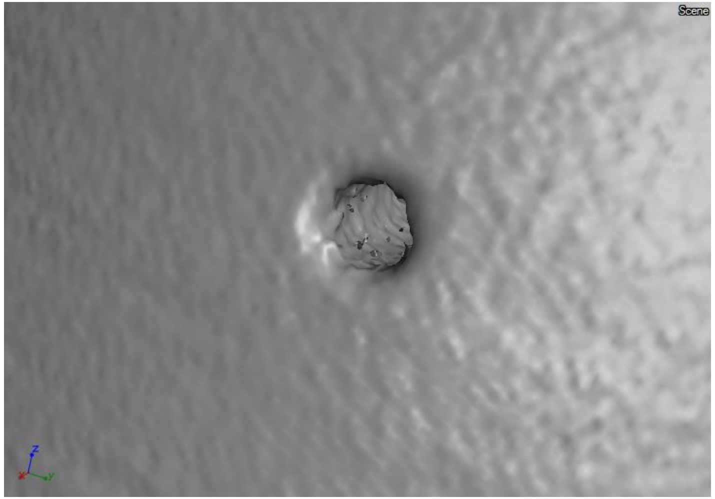


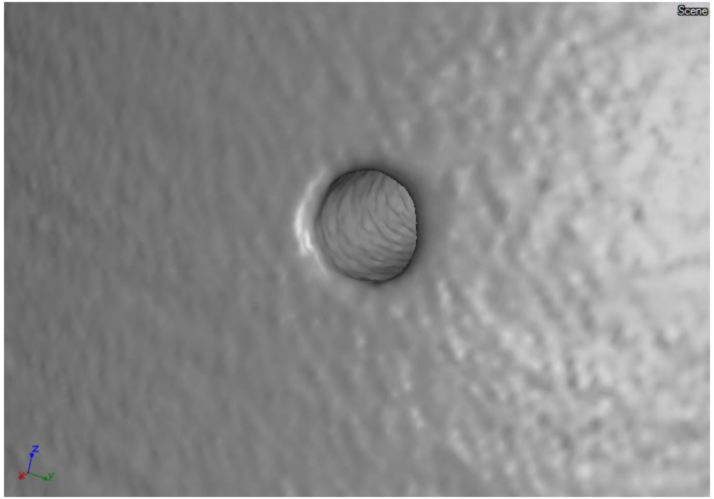
Thin yellow line = ISO50 surface

Thick yellow line = adaptive surface.

Precise Surface Determination

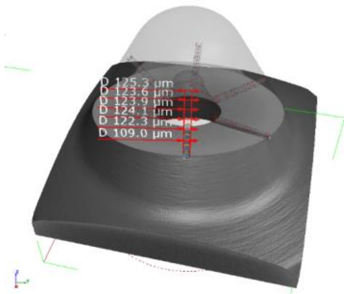
Injector borehole without (left) and with (right) local adaptive surface determination.

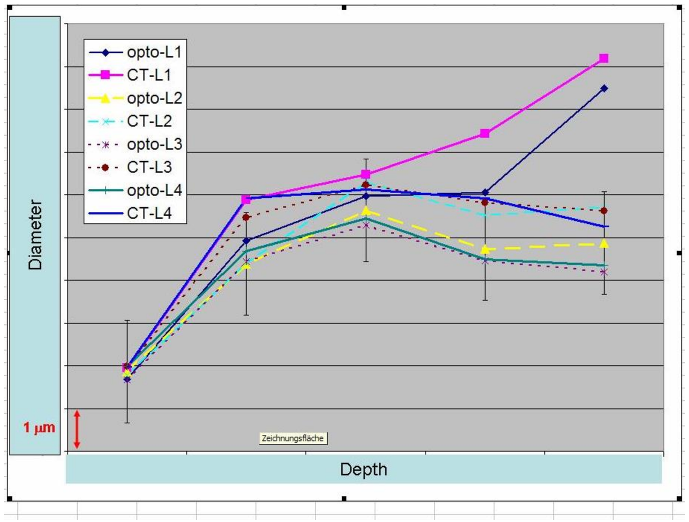




Example

- Measure 6 fuel injector nozzle boreholes diameters in 5 positions.
  - Scan/Voxel resolution 8 μm
  - CT measurement with local adaptive surface compared to standard opto-tactile measurement < 1μm





The graph shows the comparison of 4 classical **opto-tactile** drill hole diameter measurements with **CT** based measurements.

Achievable Measurement Uncertainty in 3D-CT

- Spatial resolution is still determined by the detector resolution, the magnification and the focal spot as shown in the previous chapters.
- But remember that spatial resolution is defined as the min. distance needed in order to separate two neighboring features (points).
- If one wants to measure in the sense of metrology, the interesting distances are normally by far bigger than the spatial resolution.
- The surface of an object can be determined with excellent sub-voxel accuracy in high quality CT data sets.

→ Measurements based on these surfaces are not limited by the spatial resolution (as long as the scaling or with other words the distances of the surfaces are big compared to spatial resolution)

→ Rule of thumb: very good CT data (low noise level und no artefacts) allow metrology with a measurement uncertainty of up to $^{1}/_{10}$ of the voxel size (of course not point to point).

Artifacts

Artifacts

- **beam hardening (loss of soft radiation)**

  - polychromatic source

  - energy dependency of linear attenuation coefficient μ(E)

- **detector**

  - non-linearity

  - defect Pixel

- **scattered radiation**

  - geometrical configuration

  - energy

- **insufficient discrete sampling**

  - aliasing

  - edge artifacts

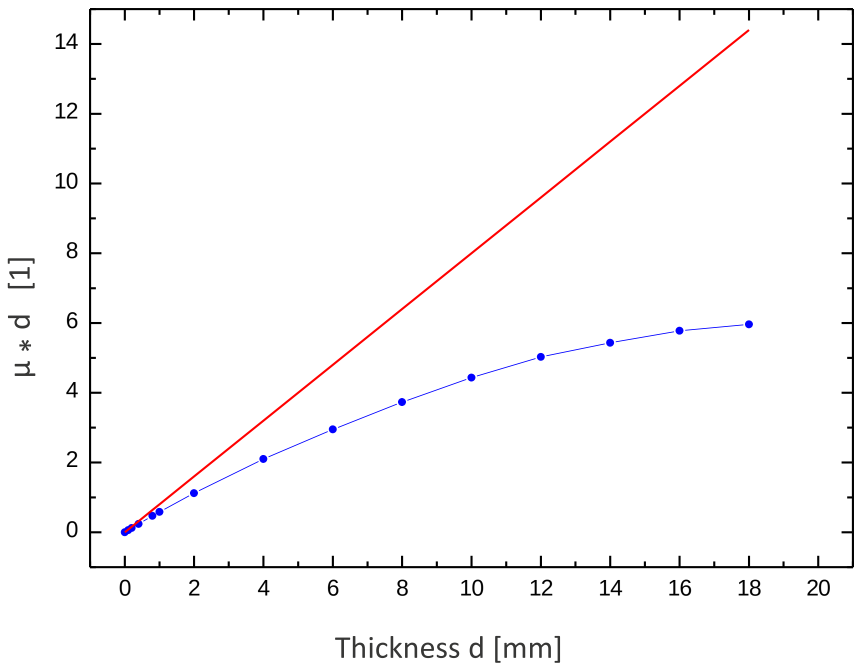
  - partial volume effect

- **wrong mathematical description (3D Feldkamp, incomplete data)**

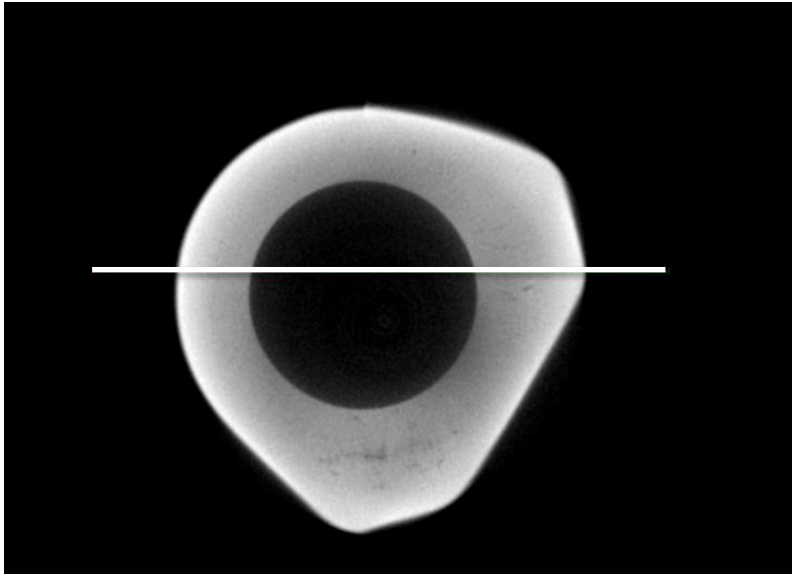
Characteristic Line of an X-Ray System

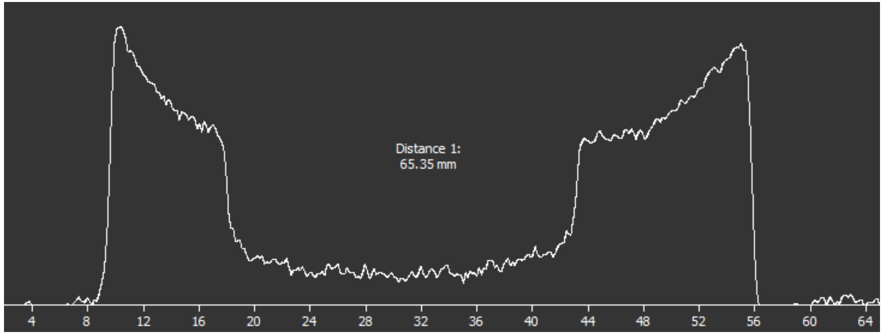
Influences from

- X-ray source
- Detector
- Energy dependence of attenuation coefficient µ
- Scattering

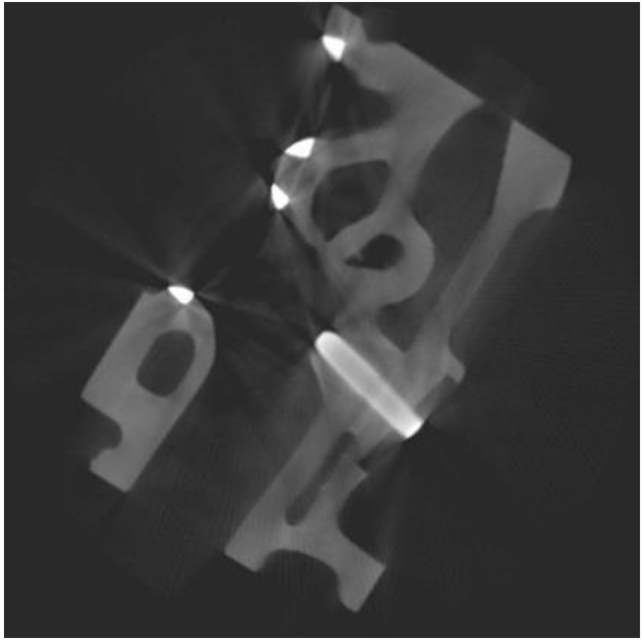


Beam Hardening

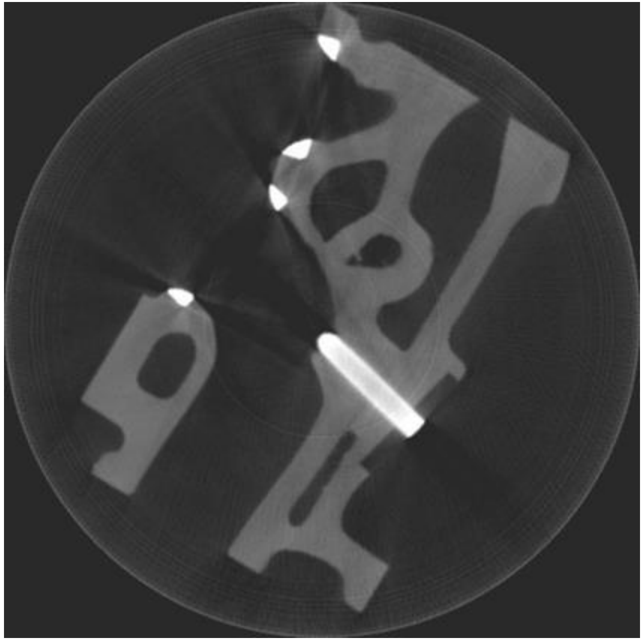




Compton Scattering



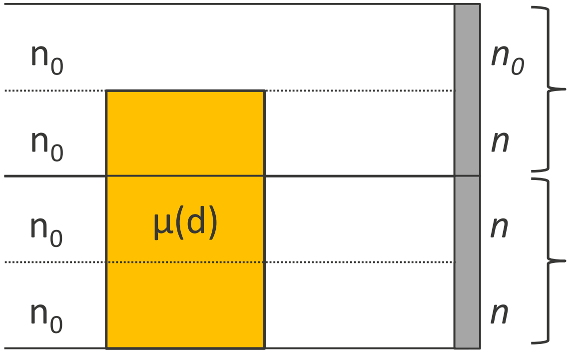
Strong scattering



Reduced scattering (Collimation)

Source:
Gondrom, Purschke, Siegle
CT at BOSCH Schwieberdingen,
1998

Partial Volume Effect



Detector 1:

$n_{total} = n_0 + n = n_0 + n_0\, e^{-\mu d}$

Detector 2:

$n_{total} = 2\, n = 2\, n_0\, e^{-\mu d}$

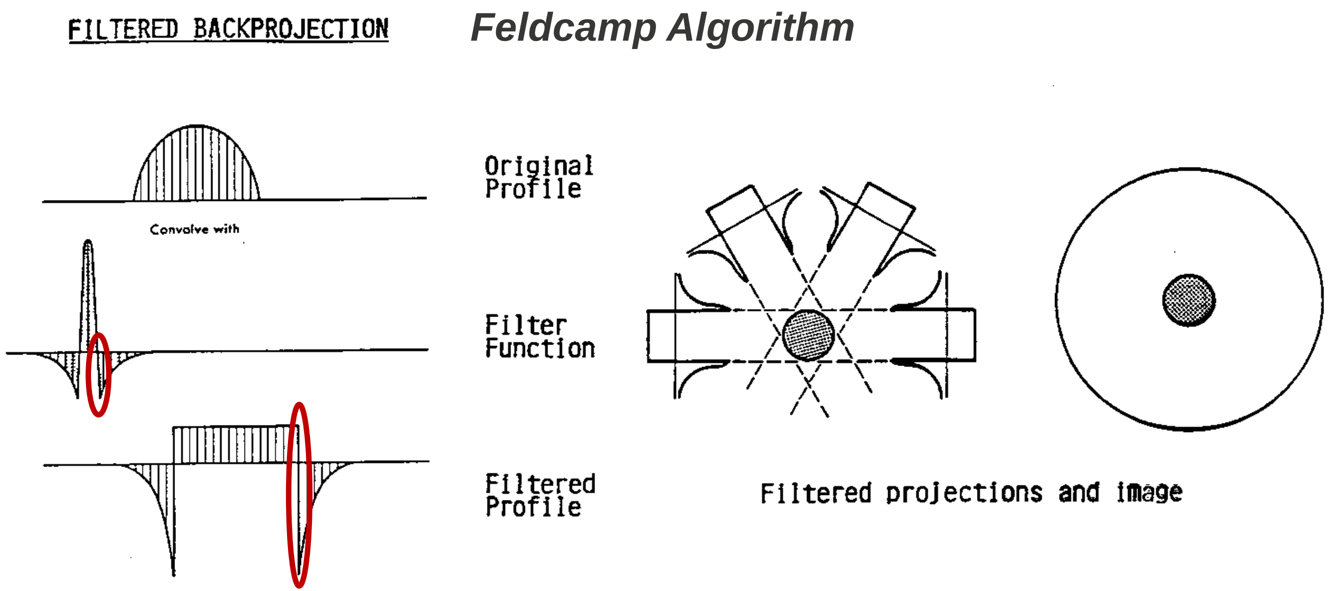
$$P(D1) = \ln\left(\frac{2n_0}{n_0 + n_0 e^{-\mu d}}\right) = \ln\left(\frac{2}{1 + e^{-\mu d}}\right) \qquad P(D2) = \ln\left(\frac{2n_0}{2n_0 e^{-\mu d}}\right) = \ln\left(\frac{1}{e^{-\mu d}}\right)$$

But reconstruction algorithm expects P(D1) = ½ P(D2)

Algorithms based on filtered back-projection calculate $\ln\{avg(I/I_0)\}$, but the real attenuation is $avg\{\ln(I/I_0)\}$ → underestimation of attenuation!

⇨ **Artifacts arise!**

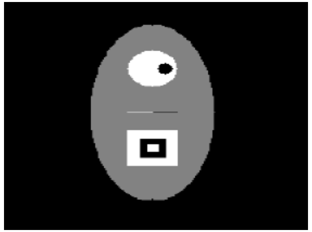
Filtered Backprojection

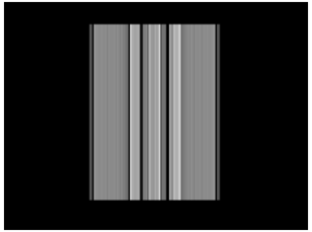


Numerical filtering (non-continuously) combined with partial volume effect
→ Problems at discontinuities in the projection (density changes, edges,…)
Discontinuities occur due to discrete and limited sampling, resulting in black and white sprites in the reconstruction!

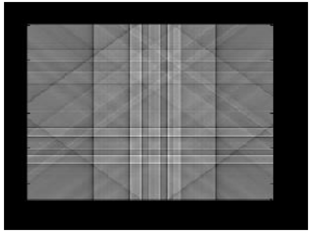
Filtered Backprojection

Formation of a tomogram:

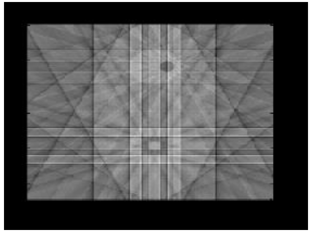




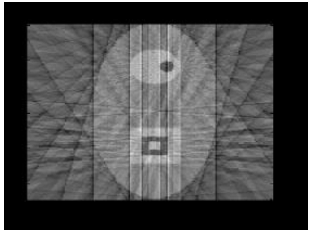
1 projection



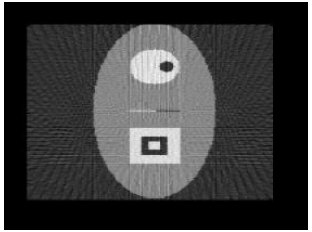
4 projections



8 projections



30 projections

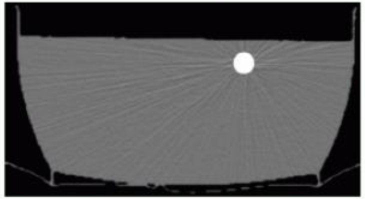


60 projections

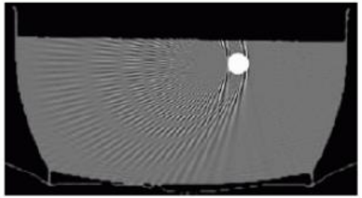
The more projections are used, the less artifacts (black and white stripes) due to discontinuities (edges) occur.

Typical Image Artifacts

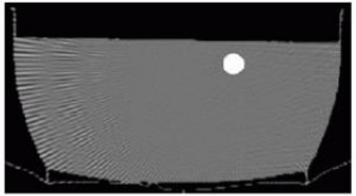
Simulated phantom



Effect of noise

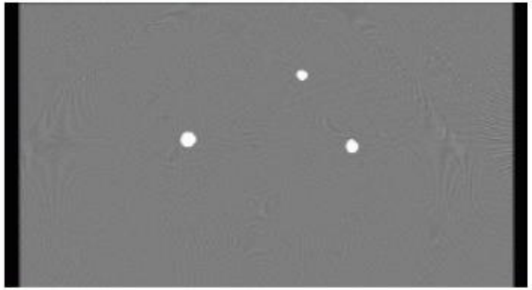


Edge effect (‘circle like’ aliasing on sharp edges due to too limited number of projections)

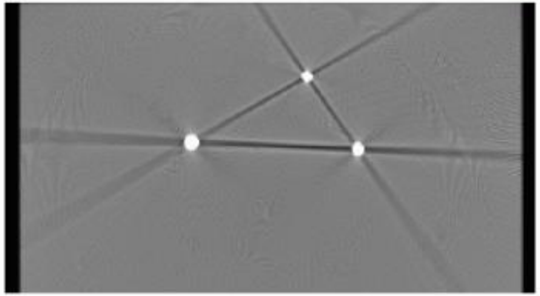


Aliasing effect for bigger but still insufficient number of projections

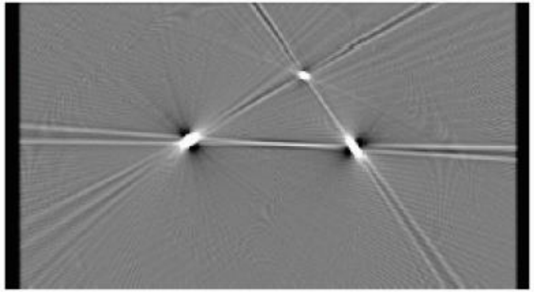
Typical Image Artifacts



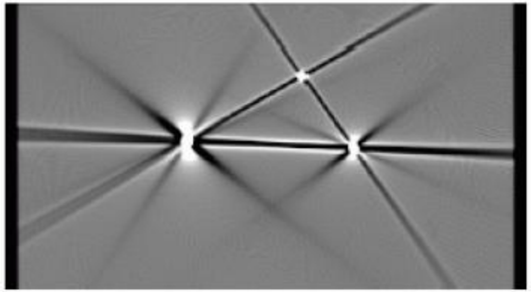
Simulated phantom



+ beam hardening



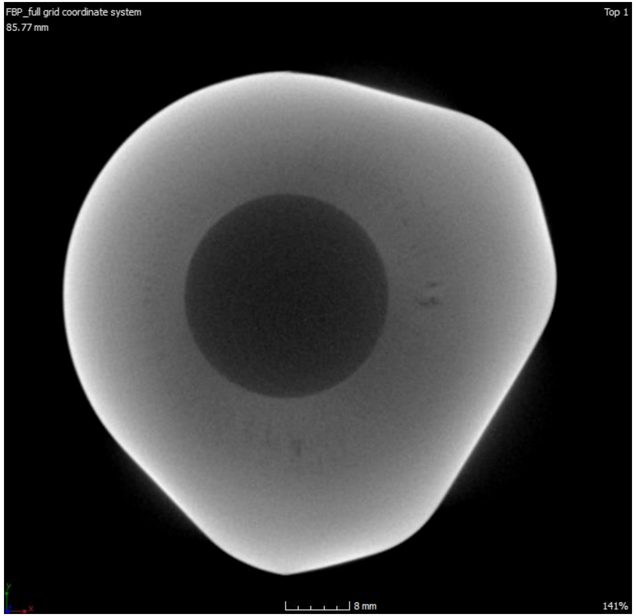
+ scattering



+ partial volume effects

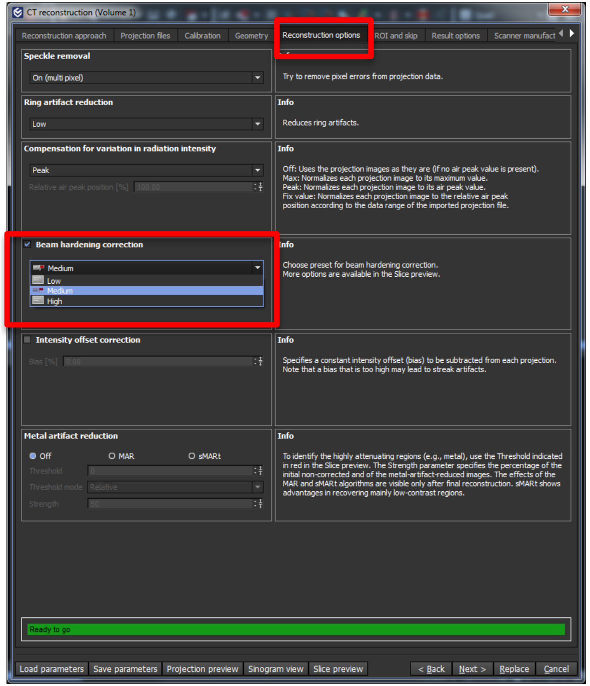
Reconstruction

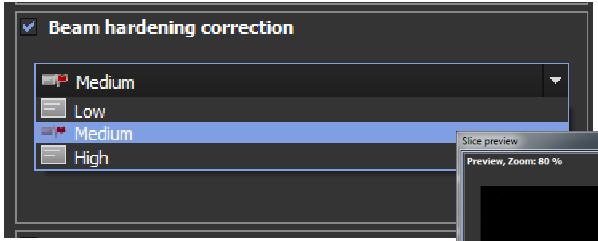
Beam Hardening Correction

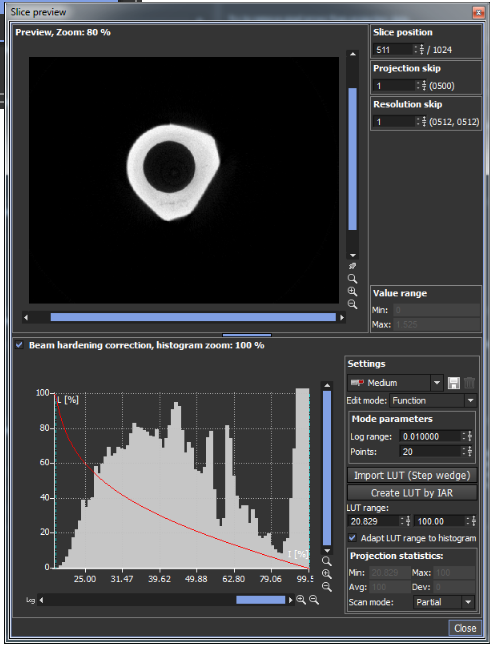


Correction by linearization of the characteristic line.

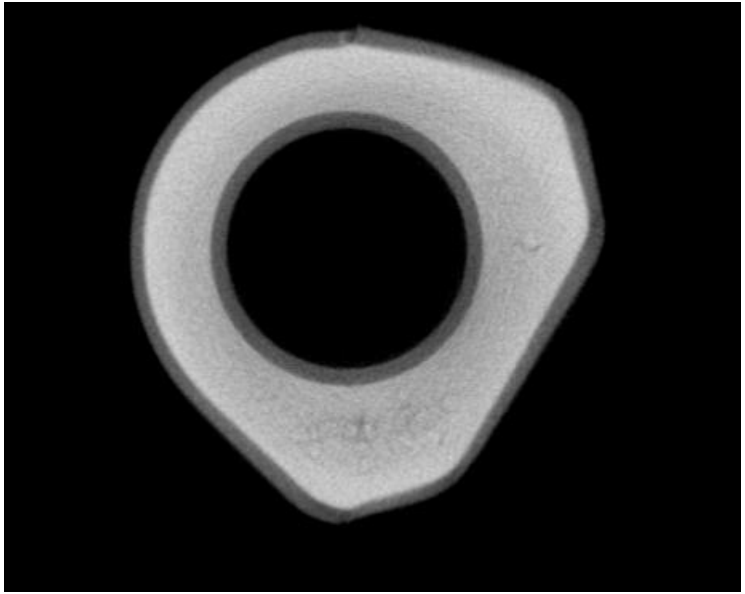
Beam Hardening Correction

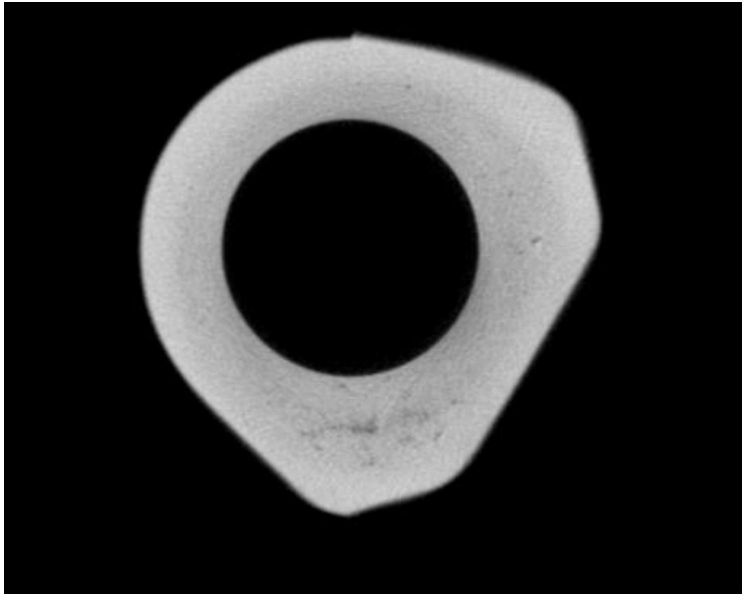




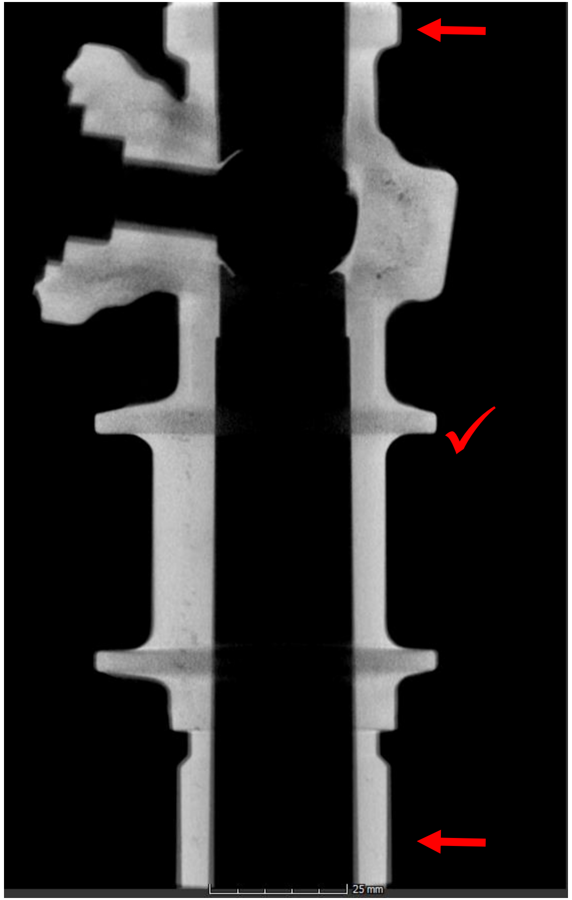


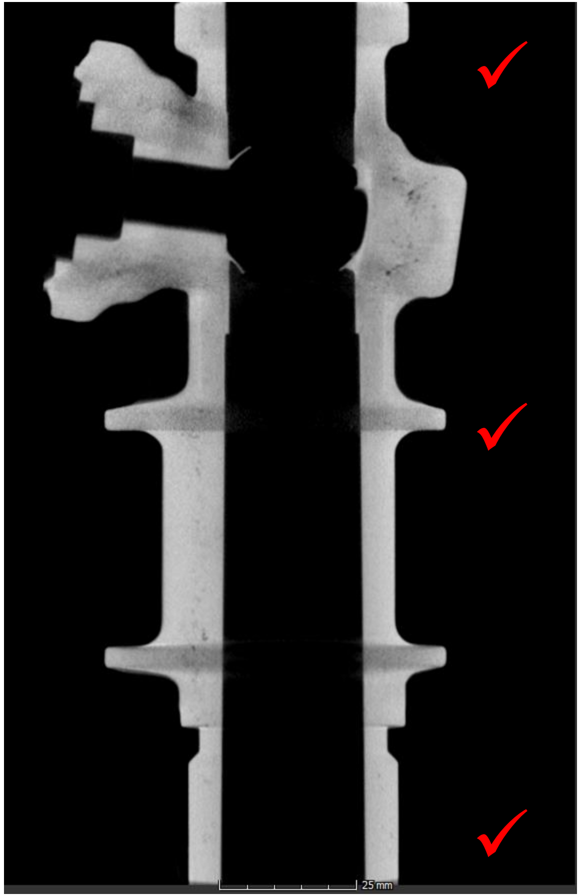
Detector or Object Shift Correction



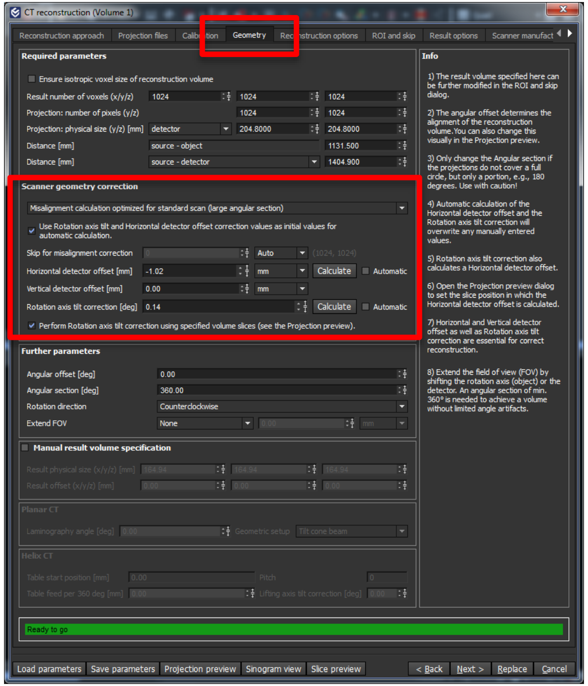


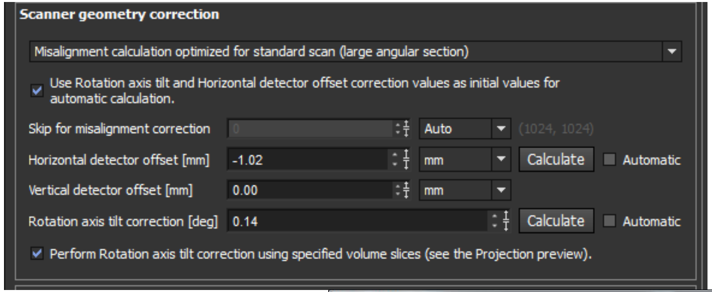
Axis Tilt Correction



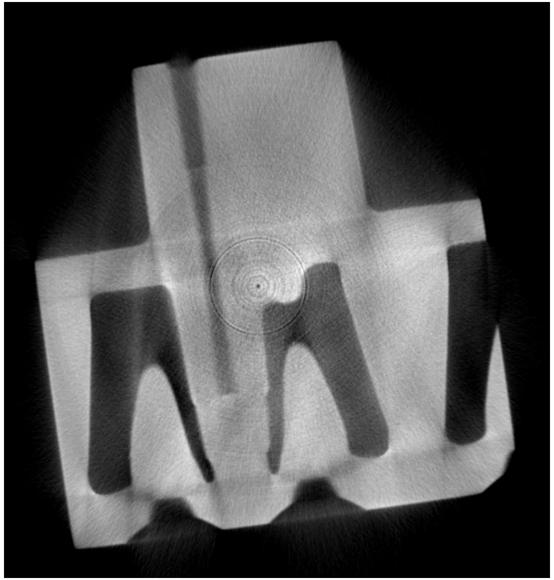


Scanner Geometry Correction

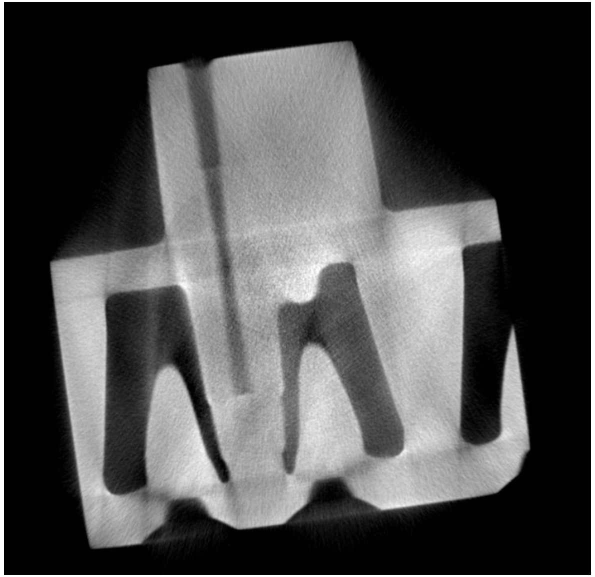




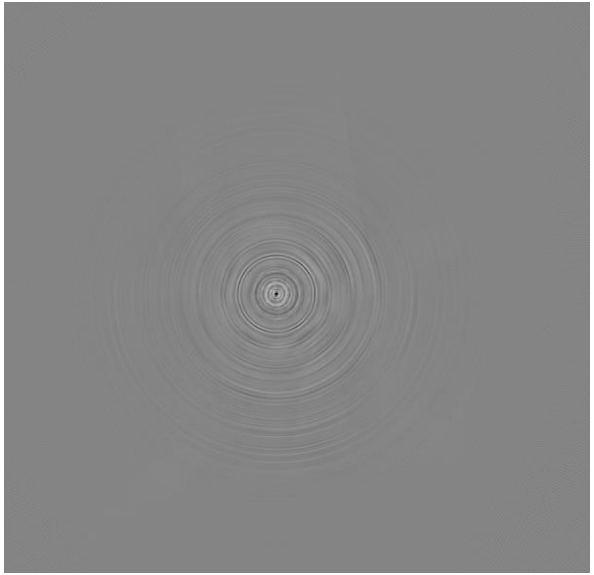
Ring Artefact Correction (RAC)



without

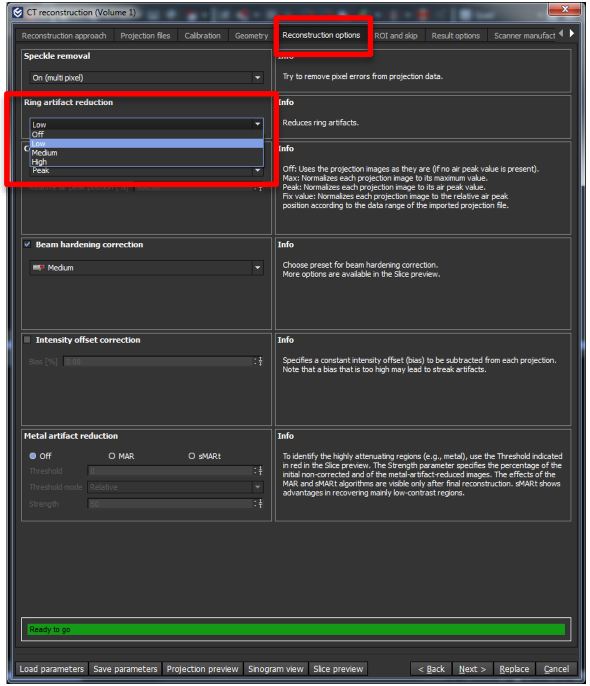


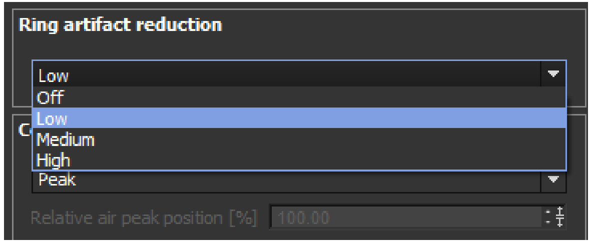
with



difference

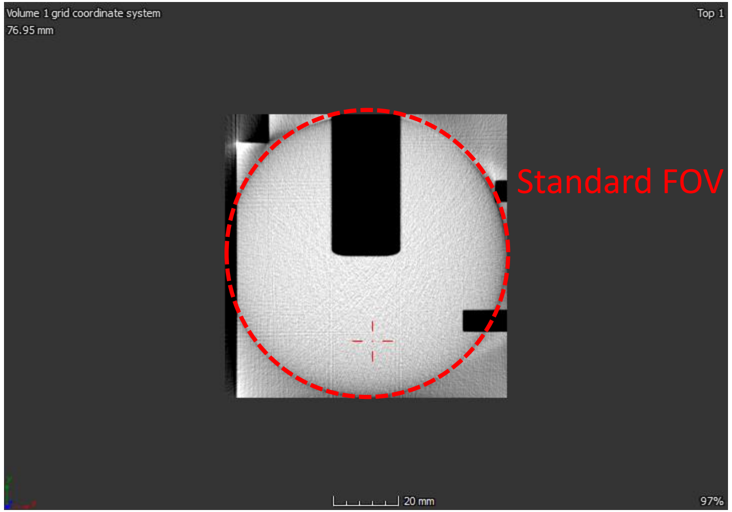
Ring Artefact Correction (RAC)

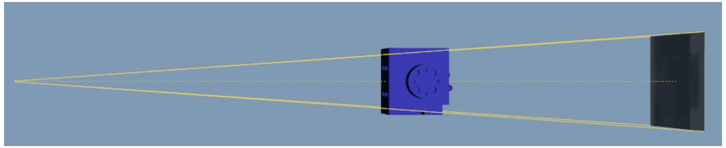




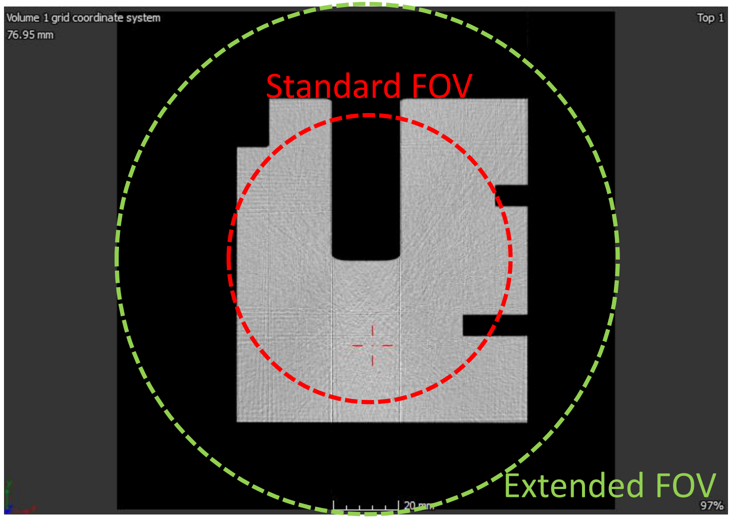
FOV Enlargement

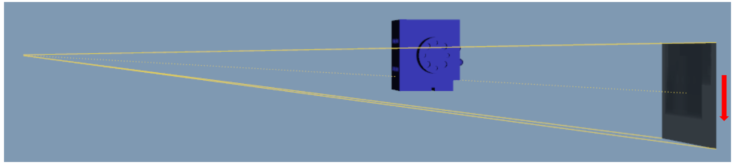
Without FOV enlargement

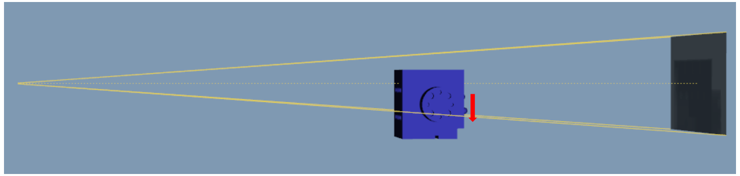




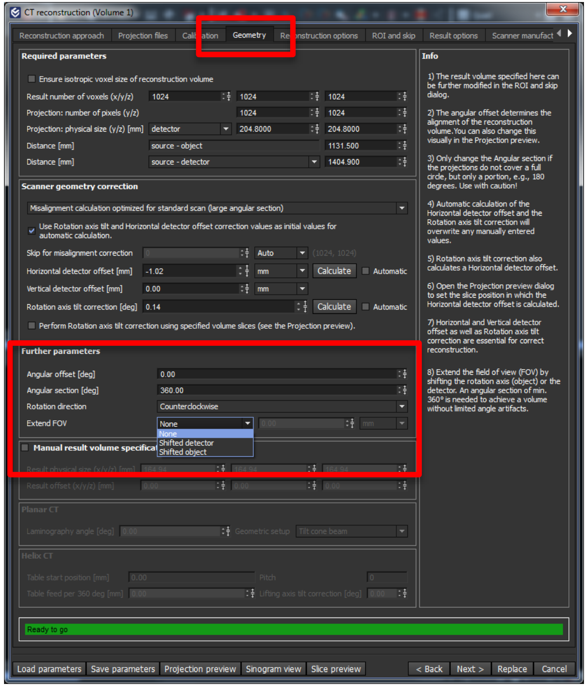
With FOV enlargement

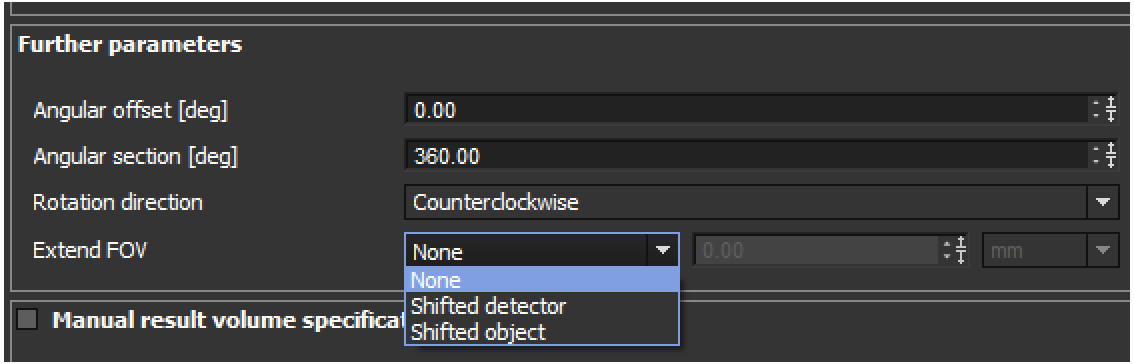






FOV Enlargement

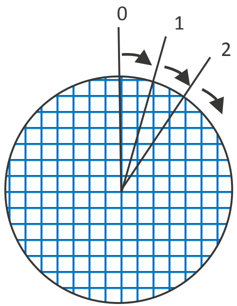




On the fly CT

Most fast or inline CT scans are performed “on the fly”, which means that images (projections) are taken during the rotation without stopping the sample.

→ in-motion blurring occurs, as diverse voxels are smeared in one projection, specially outside the center

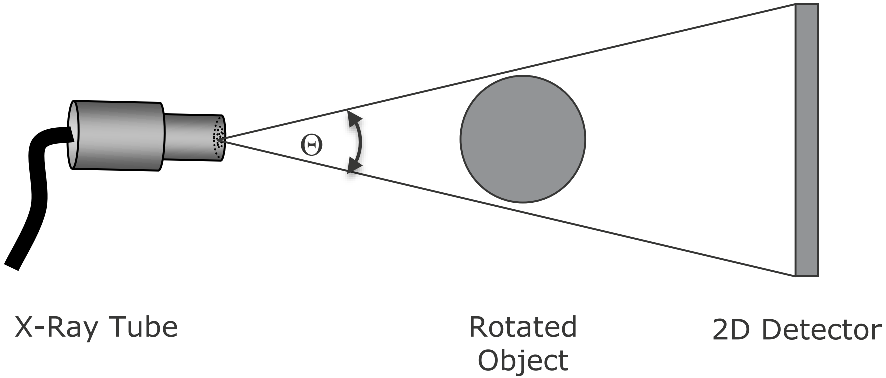


Remark:
in a ‘normal’ stop-and-go scan a small detail like a point or an edge is maximally blurred over 2 voxels

On the fly CT

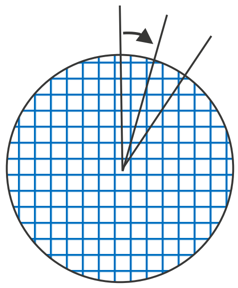
What can be done to reduce this blurring?

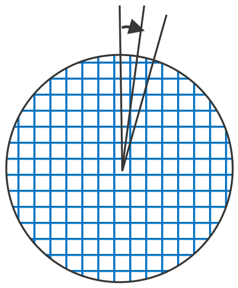
- Use as many projections as possible
- There is no urgent need to perform a 360° scan
- Already a limited angle CT scan delivers complete and correct data if the scan area is 180° + Θ
  (Θ is the angle seen by the detector)



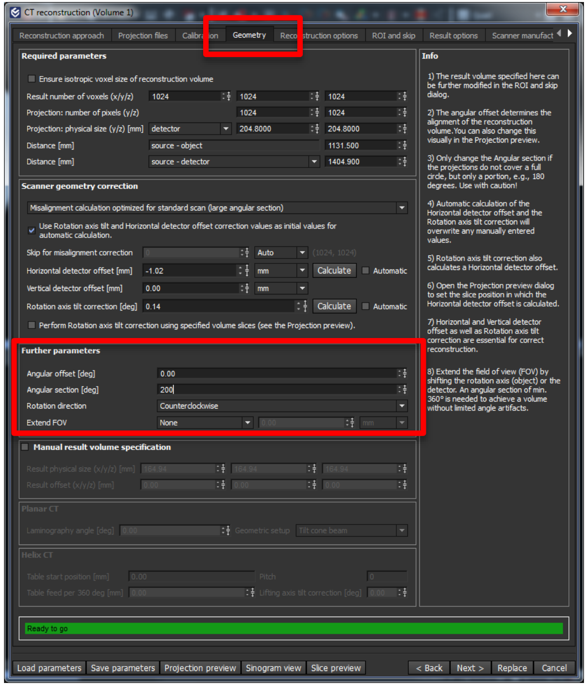
On the fly CT

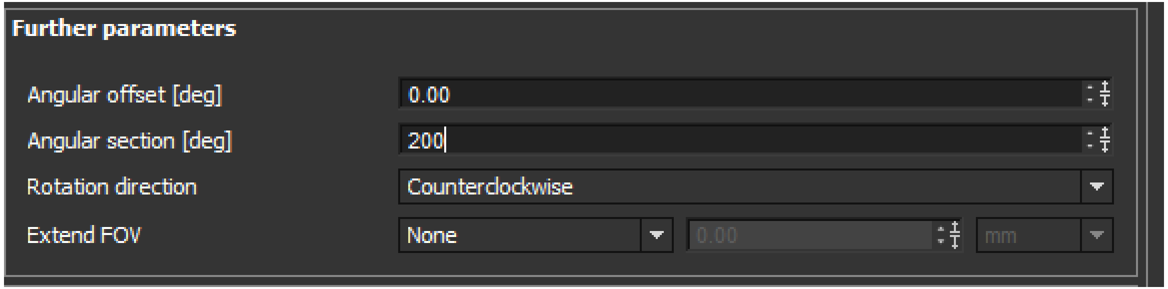
Doing a 180° + Θ scan instead of a 360° scan reduces the blurring as no longer the whole circumference has to be covered by the projections





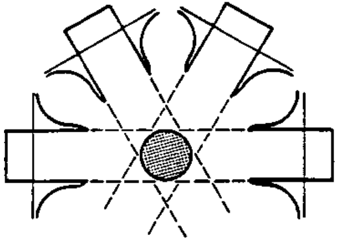
On the fly CT


CT reconstruction (Volume 1)
Reconstruction approach
Projection files
Calibration
Geometry
Reconstruction options
ROI and skip
Result options
Scanner manufact
Required parameters
Ensure isotropic voxel size of reconstruction volume
Result number of voxels (x/y/z) 1024 1024 1024
Projection: number of pixels (y/z) 1024 1024
Projection: physical size (y/z) [mm] detector 204.8000 204.8000
Distance [mm] source - object 1131.500
Distance [mm] source - detector 1404.900
Scanner geometry correction
Misalignment calculation optimized for standard scan (large angular section)
Use Rotation axis tilt and Horizontal detector offset correction values as initial values for automatic calculation.
Skip for misalignment correction Auto
Horizontal detector offset [mm] -1.02 mm Calculate Automatic
Vertical detector offset [mm] 0.00 mm
Rotation axis tilt correction [deg] 0.14 Calculate Automatic
Perform Rotation axis tilt correction using specified volume slices (see the Projection preview).
Further parameters
Angular offset [deg] 0.00
Angular section [deg] 200
Rotation direction Counterclockwise
Extend FOV None
Manual result volume specification
Planar CT
Helix CT
Info
1) The result volume specified here can be further modified in the ROI and skip dialog.
2) The angular offset determines the alignment of the reconstruction volume. You can also change this visually in the Projection preview.
3) Only change the Angular section if the projections do not cover a full circle, but only a portion, e.g., 180 degrees. Use with caution!
4) Automatic calculation of the Horizontal detector offset and the Rotation axis tilt correction will overwrite any manually entered values.
5) Rotation axis tilt correction also calculates a Horizontal detector offset.
6) Open the Projection preview dialog to set the slice position in which the Horizontal detector offset is calculated.
7) Horizontal and Vertical detector offset as well as Rotation axis tilt correction are essential for correct reconstruction.
8) Extend the field of view (FOV) by shifting the rotation axis (object) or the detector. An angular section of min. 360° is needed to achieve a volume without limited angle artifacts.
Ready to go
Load parameters
Save parameters
Projection preview
Sinogram view
Slice preview
< Back
Next >
Replace
Cancel


Further parameters
Angular offset [deg]
0.00
Angular section [deg]
200
Rotation direction
Counterclockwise
Extend FOV
None
0.00
mm

3D Reconstruction Methods

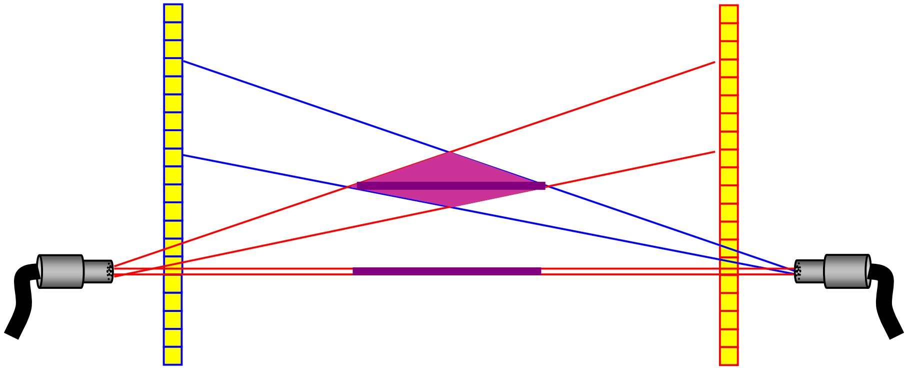
2D Feldkamp:



top view

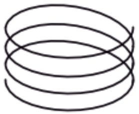
3D Feldkamp:

- no more 2D but a 3D blurring → FDK wrong outside central plane
- Results is only acceptable for small angles (FDK only approximation)

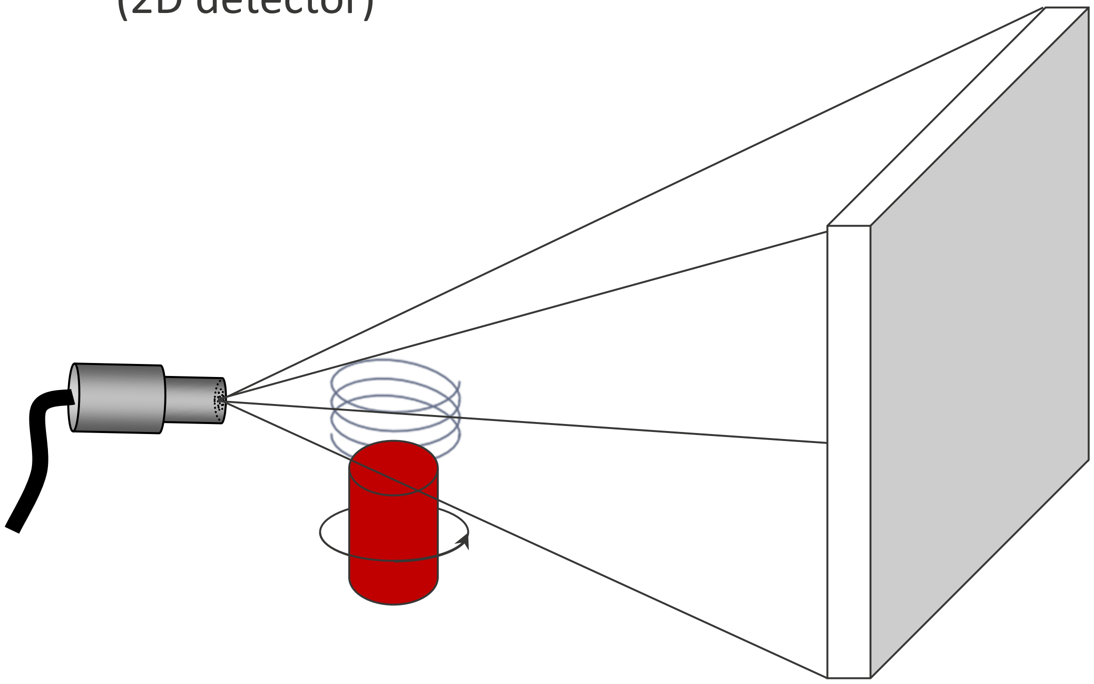


side view

Helical CT

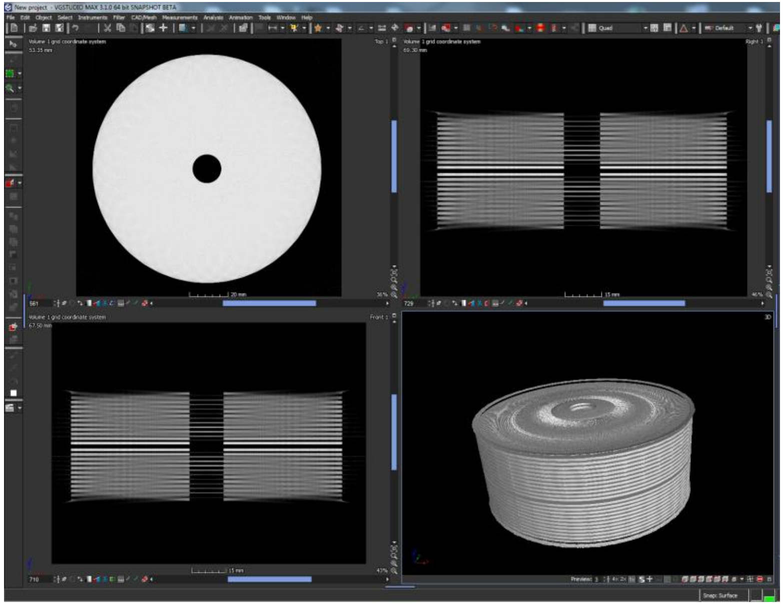


Cone beam helix scan
(2D detector)

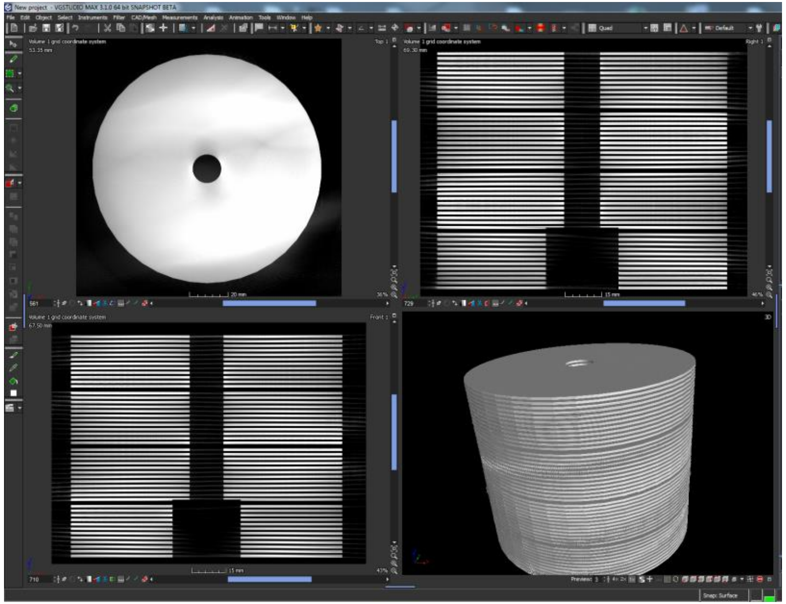


Helical CT

CD-ROM stack

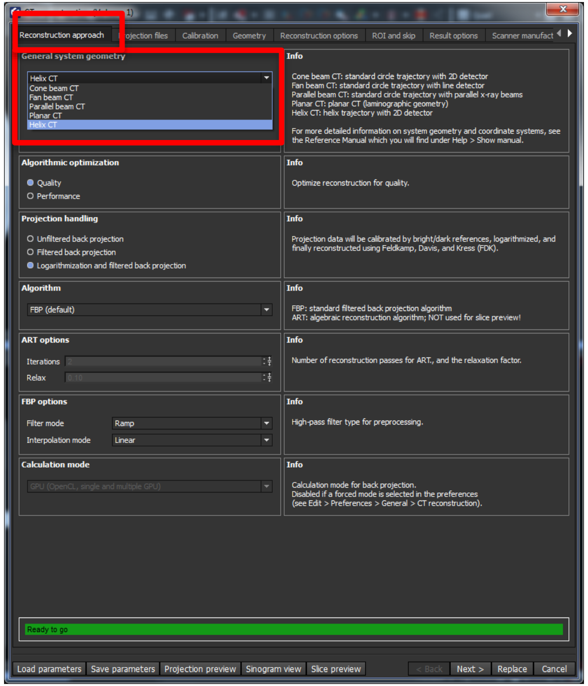


FDK artifacts

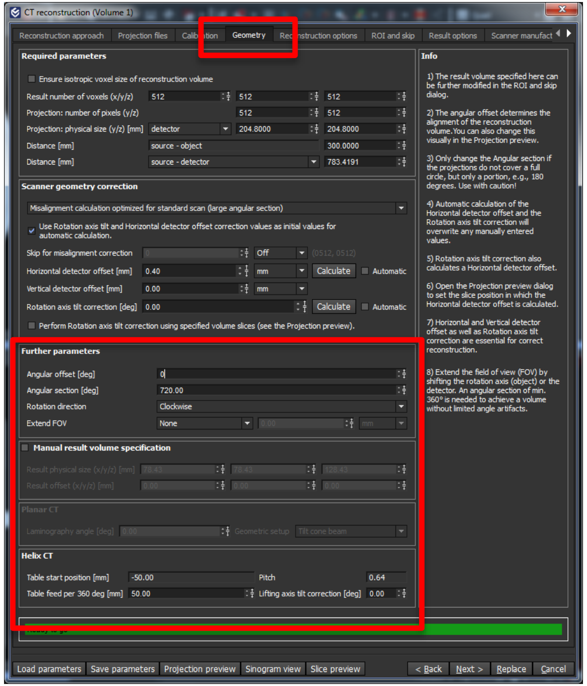


Helical reconstruction

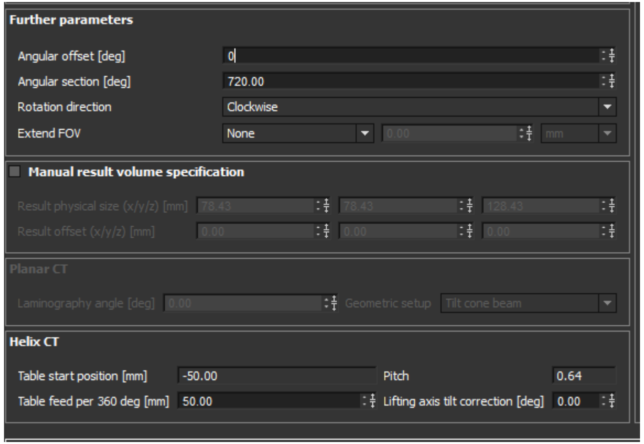
Helical CT



Reconstruction approach
Projection files
Calibration
Geometry
Reconstruction options
ROI and skip
Result options
Scanner manufact
General system geometry
Helix CT
Cone beam CT
Fan beam CT
Parallel beam CT
Planar CT
Helix CT
Info
Cone beam CT: standard circle trajectory with 2D detector
Fan beam CT: standard circle trajectory with line detector
Parallel beam CT: standard circle trajectory with parallel x-ray beams
Planar CT: planar CT (laminographic geometry)
Helix CT: helix trajectory with 2D detector
For more detailed information on system geometry and coordinate systems, see the Reference Manual which you will find under Help > Show manual.
Algorithmic optimization
Quality
Performance
Optimize reconstruction for quality.
Projection handling
Unfiltered back projection
Filtered back projection
Logarithmization and filtered back projection
Projection data will be calibrated by bright/dark references, logarithmized, and finally reconstructed using Feldkamp, Davis, and Kress (FDK).
Algorithm
FBP (default)
FBP: standard filtered back projection algorithm
ART: algebraic reconstruction algorithm; NOT used for slice preview!
ART options
Iterations
Relax
Number of reconstruction passes for ART, and the relaxation factor.
FBP options
Filter mode
Ramp
Interpolation mode
Linear
High-pass filter type for preprocessing.
Calculation mode
GPU (OpenCL, single and multiple GPU)
Calculation mode for back projection.
Disabled if a forced mode is selected in the preferences
(see Edit > Preferences > General > CT reconstruction).
Ready to go
Load parameters
Save parameters
Projection preview
Sinogram view
Slice preview
< Back
Next >
Replace
Cancel

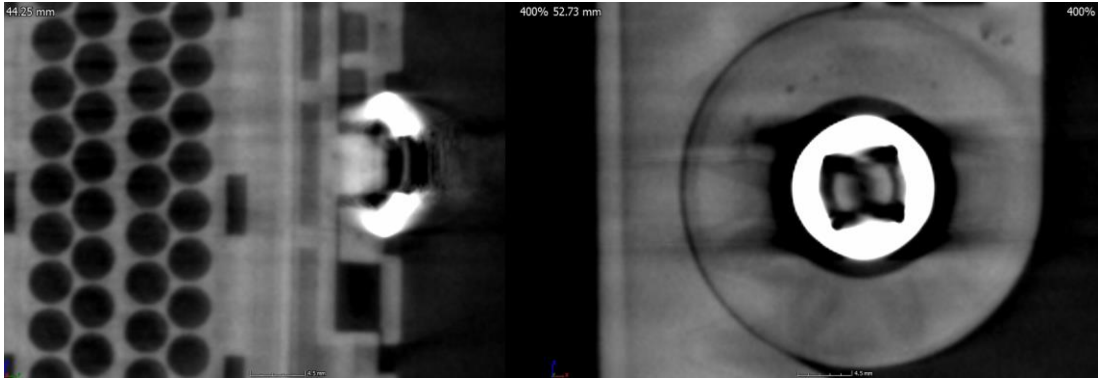


CT reconstruction (Volume 1)
Reconstruction approach
Projection files
Calibration
Geometry
Reconstruction options
ROI and skip
Result options
Scanner manufact
Required parameters
Ensure isotropic voxel size of reconstruction volume
Result number of voxels (x/y/z) 512 512 512
Projection: number of pixels (y/z) 512 512
Projection: physical size (y/z) [mm] detector 204.8000 204.8000
Distance [mm] source - object 300.0000
Distance [mm] source - detector 783.4191
Scanner geometry correction
Misalignment calculation optimized for standard scan (large angular section)
Use Rotation axis tilt and Horizontal detector offset correction values as initial values for automatic calculation.
Skip for misalignment correction Off
Horizontal detector offset [mm] 0.40 mm Calculate Automatic
Vertical detector offset [mm] 0.00 mm
Rotation axis tilt correction [deg] 0.00 Calculate Automatic
Perform Rotation axis tilt correction using specified volume slices (see the Projection preview).
Further parameters
Angular offset [deg] 0
Angular section [deg] 720.00
Rotation direction Clockwise
Extend FOV None
Manual result volume specification
Result physical size (x/y/z) [mm]
Result offset (x/y/z) [mm]
Planar CT
Laminography angle [deg]
Geometric setup
Tilt cone beam
Helix CT
Table start position [mm] -50.00
Pitch 0.64
Table feed per 360 deg [mm] 50.00
Lifting axis tilt correction [deg] 0.00
Info
1) The result volume specified here can be further modified in the ROI and skip dialog.
2) The angular offset determines the alignment of the reconstruction volume. You can also change this visually in the Projection preview.
3) Only change the Angular section if the projections do not cover a full circle, but only a portion, e.g., 180 degrees. Use with caution!
4) Automatic calculation of the Horizontal detector offset and the Rotation axis tilt correction will overwrite any manually entered values.
5) Rotation axis tilt correction also calculates a Horizontal detector offset.
6) Open the Projection preview dialog to set the slice position in which the Horizontal detector offset is calculated.
7) Horizontal and Vertical detector offset as well as Rotation axis tilt correction are essential for correct reconstruction.
8) Extend the field of view (FOV) by shifting the rotation axis (object) or the detector. An angular section of min. 360° is needed to achieve a volume without limited angle artifacts.
Load parameters
Save parameters
Projection preview
Sinogram view
Slice preview
< Back
Next >
Replace
Cancel

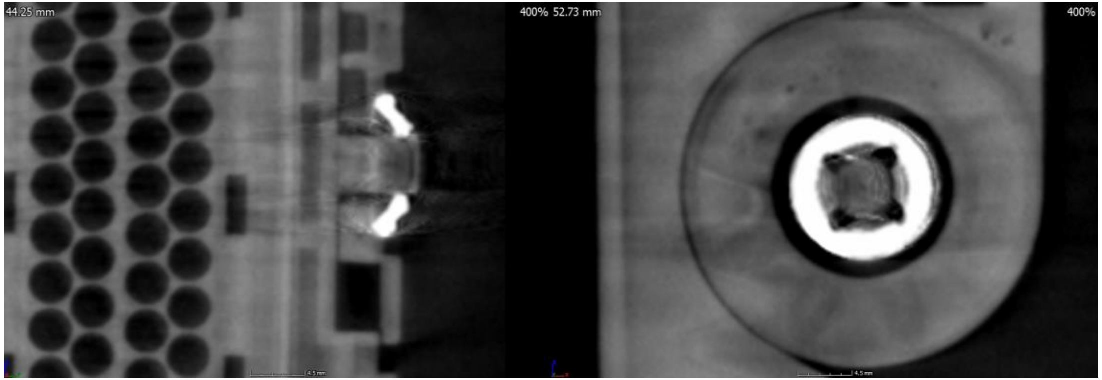


Further parameters
Angular offset [deg] 0
Angular section [deg] 720.00
Rotation direction Clockwise
Extend FOV None 0.00 mm
Manual result volume specification
Result physical size (x/y/z) [mm] 78.43 78.43 128.43
Result offset (x/y/z) [mm] 0.00 0.00 0.00
Planar CT
Laminography angle [deg] 0.00
Geometric setup Tilt cone beam
Helix CT
Table start position [mm] -50.00
Pitch 0.64
Table feed per 360 deg [mm] 50.00
Lifting axis tilt correction [deg] 0.00

Metal Artefact Reduction (MAR)



without



with

Resulting Guideline for 3D-CT Scans

Rules for a Satisfying CT Scan

First Step:

Adjust the geometrical resolution you need to have by choosing the corresponding magnification (voxel size).

Ensure that the object is not projected beyond the detector. Try to using FOV enlargement if the object is too big.
Rotate the sample and check if it is fully imaged onto the detector during the rotation.

Remark:
Region of interest (ROI) measurements with higher resolution are possible, but they in general will cause a degradation in image quality.

Rules for a Satisfying CT Scan

Second Step:

Reduce the scattering effect by collimating the X-ray beam in such a way, that only the detector is illuminated.

Be aware that this can have a huge effect!
It is e.g. not exceptional for a 450 kV setup, to have the situation that more than 30% of the detected intensity is caused by scattering from the walls and the object holders.

Rules for a Satisfying CT Scan

Third Step:

Choose a proper X-ray energy by adapting the tube voltage.

As a rule of thumb the penetrating intensity behind the object should be in the range of 10 -20% of the non-attenuated X-ray intensity (I_0).
The ideal value would be 14% (calculated for monochromatic radiation).
The code of practice published by VDA and DGZfP request a value of at least 10% !

In case of strong absorbing objects use a pre-filter (e.g. Cu) just in front of the tube in order to achieve this rule of thumb.
This will as well reduce beam-hardening artifacts.

Rules for a Satisfying CT Scan

Fourth Step:

Adapt the tube current and the detector integration time in order to achieve an I_0 in the X-ray image that is as ~ 90% of the detector dynamics. (~ 60000 for a 16 bit detector, 15000 for a 14 bit detector,…)

Ensure that the detector is not overexposed at all !!!

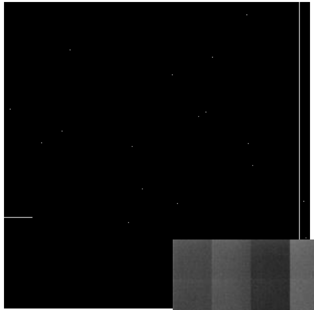
Be aware that integration time and tube current are more or less linear with detected intensity.
Higher integration time leads to longer measurements. Higher tube power leads to a bigger focal spot of the tube, which limits the achievable best resolution.

As a rule enhance the tube current until the focal spot size (see tube manual) is in the order of the chosen resolution. Then adapt the integration time so that I_0 is as high as possible!

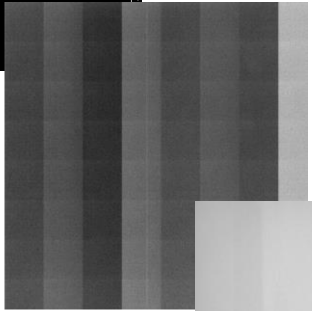
Rules for a Satisfying CT Scan

Fifth Step:

Perform a ***proper*** bad-pixel-, dark- and bright-image correction. To do so, average **a lot** of images for the resulting dark and the bright image.

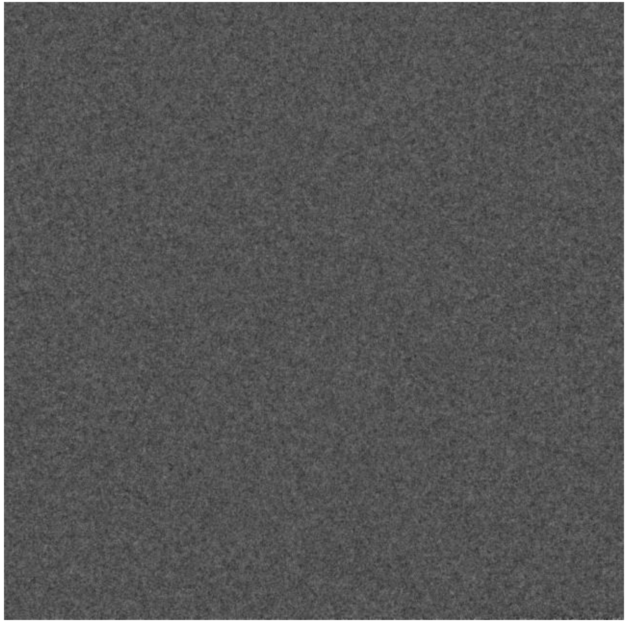


Bad pixel



Dark image

Gain image

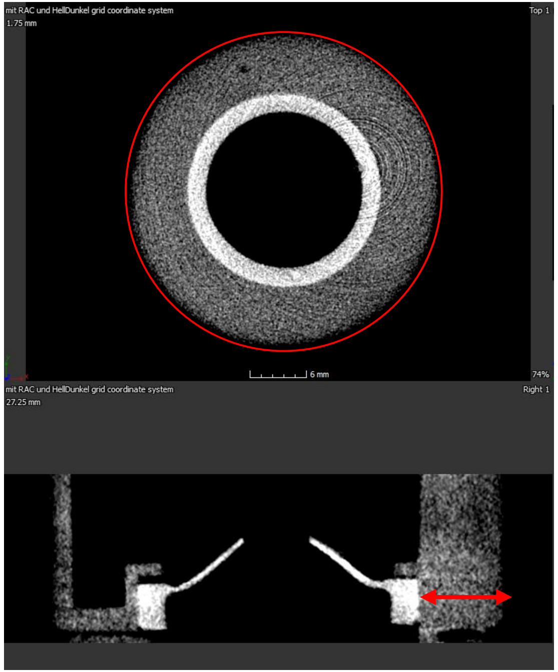


Corrected image

Rules for a Satisfying CT Scan

Example: effect of applying a bad pixel correction

Rules for a Satisfying CT Scan



without DBC

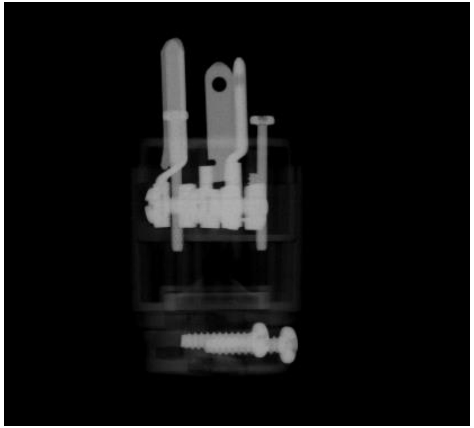
with DBC

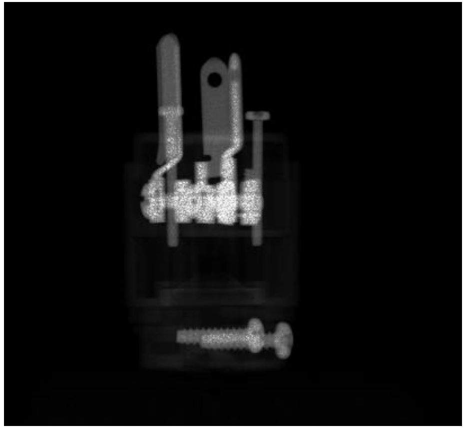
Only dark- and bright correction of projections delivers correct shape of the object
(of course the effect is the bigger the worse the data quality is).

Rules for a Satisfying CT Scan

Cross check if the intensity behind the object is still in the range of 10 - 20% of the non-attenuated X-ray intensity (I_0) as it may be that the uncorrected detector had a high dark current.

If not repeat from the third step iteratively !!!
Normalization will fail if the object is not penetrated:





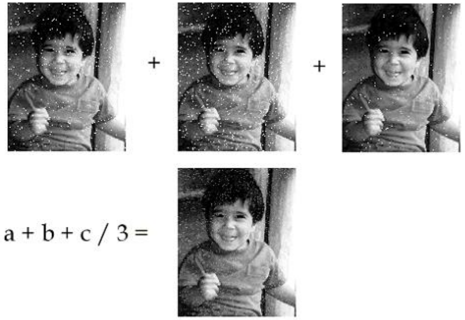
Rules for a Satisfying CT Scan

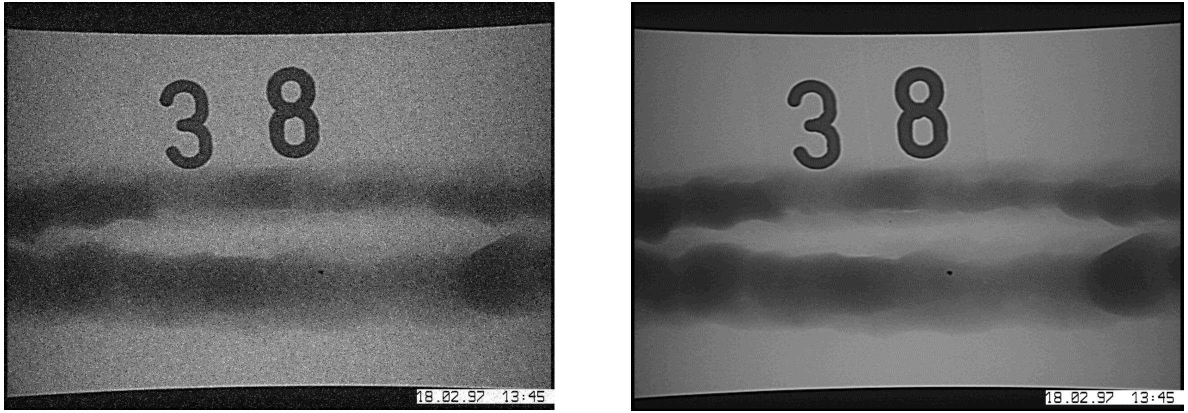
Sixth Step:

If measurement time is uncritical, several images can be averaged per projection to reduce noise and enhance contrast resolution.

Alternatively (if possible preferable) enhance the number of projections! This will reduce edge artefacts and aliasing effects on top.

Rules for a Satisfying CT Scan





Rules for a Satisfying CT Scan

Rule: The more projections are taken, the better the results will be.

But: Scanning time must not be too long as the CT system maybe is not stable for a long-term measurement (temperature drifts, tube and detector stability,…)

Rule: **Consider physics first !**
Means that it is always better to consider the physical effects that cause artefacts and reduce them, instead of trying to perform software corrections. Those corrections may help, but for sure the better the scan is, the better the results are and the easier such corrections can be applied.

Thank you