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7 CT

Acknowledgements: Sue Edyvean (HPA – UK) for many of her slides

Radiography

- Origin of the signal?
  - What are
    - The relevant parameters
    - The major problems

- What kind of information can be detected?
  - Typical pixel size?

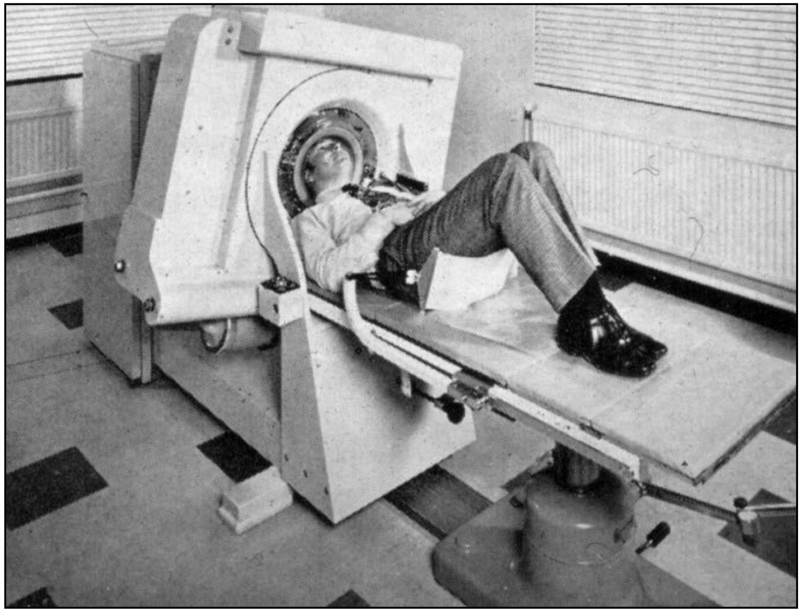
- What kind of risk?

Objectives

- Explain the principle of CT image acquisition
- Describe the challenges of image quality assessment when dealing with CT imaging
- Describe the principle of DECT

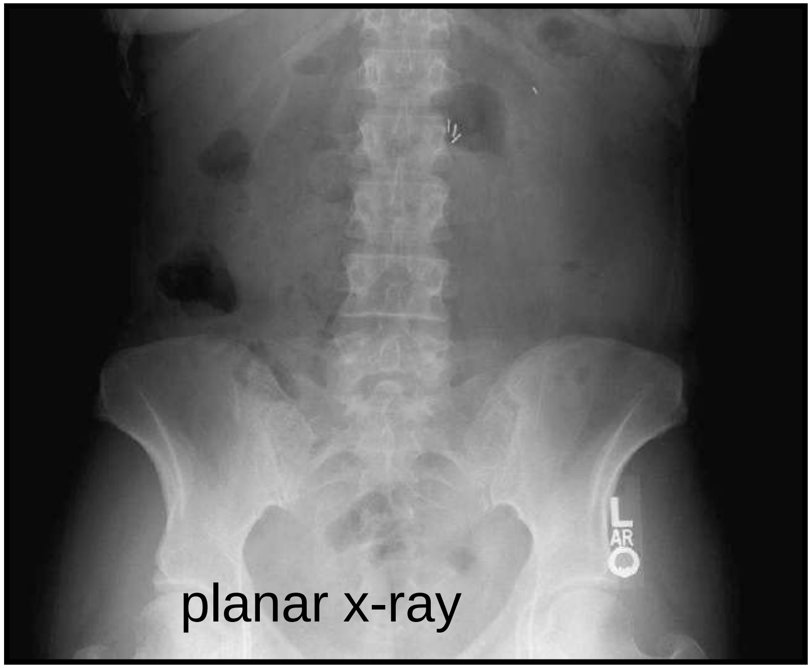
Development of the CT Scanner

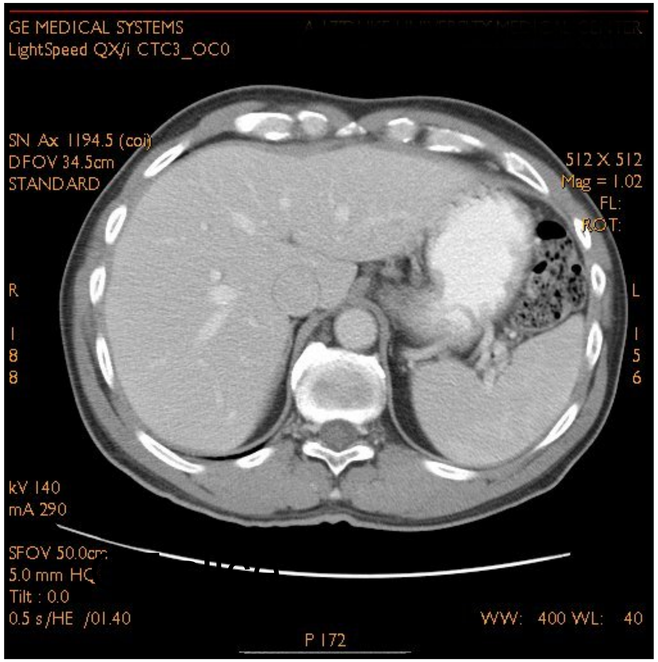
- 1st clinical CT scanner
  - developed at EMI Medical by Godfrey Hounsfield
  - prototype installed at Atkinson Morley's Hospital, Wimbledon, London
  - 1st clinical scan 1st October 1971



What is CT?

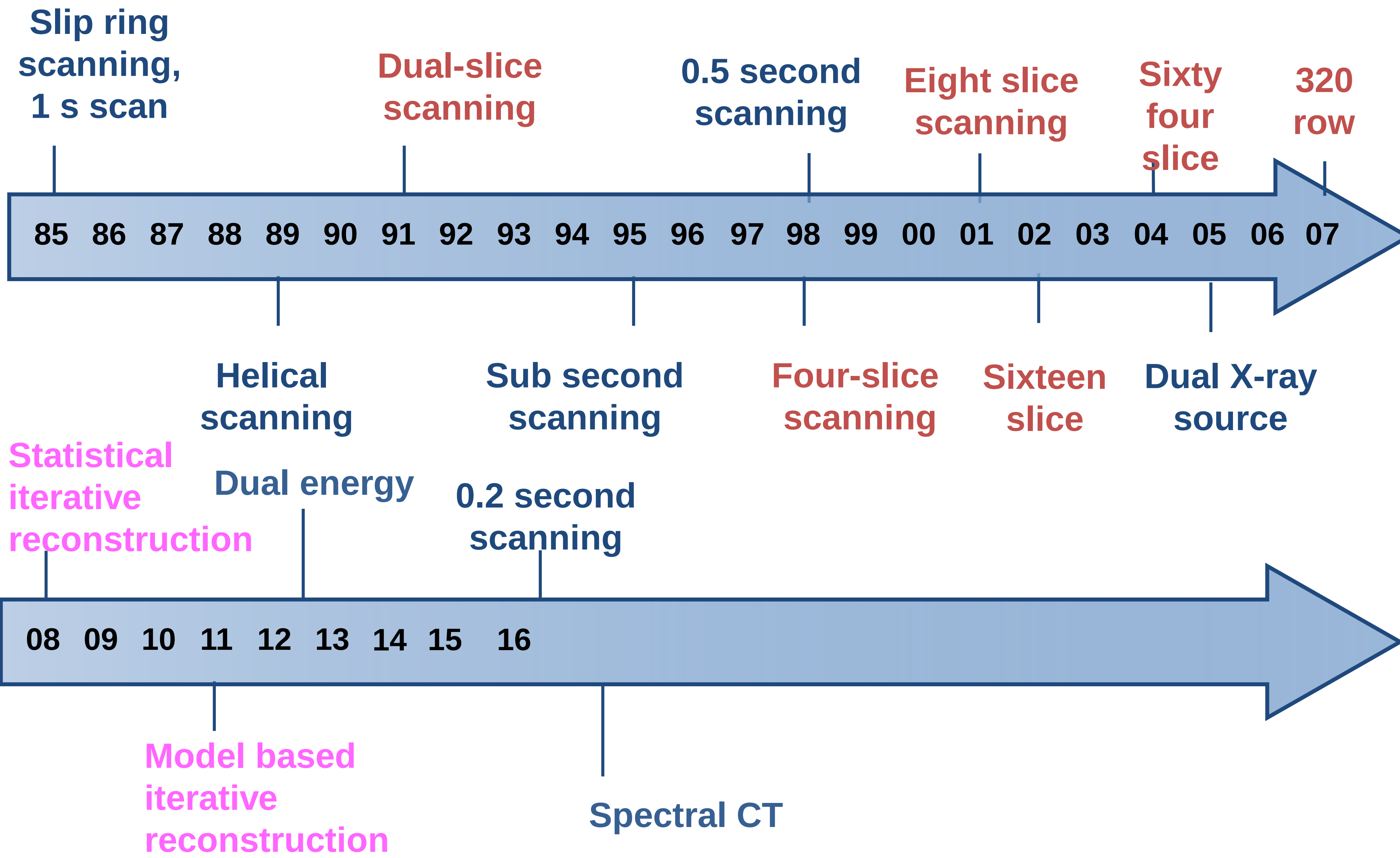
- Computed Tomography
  - Computed – determined by mathematical methods
  - Tomos – section, graphia – to write or draw
- An x-ray device capable of cross sectional imaging
  - creates images of ‘slices’ through the patient





What challenges?

Technological advances, 1985 - 2014

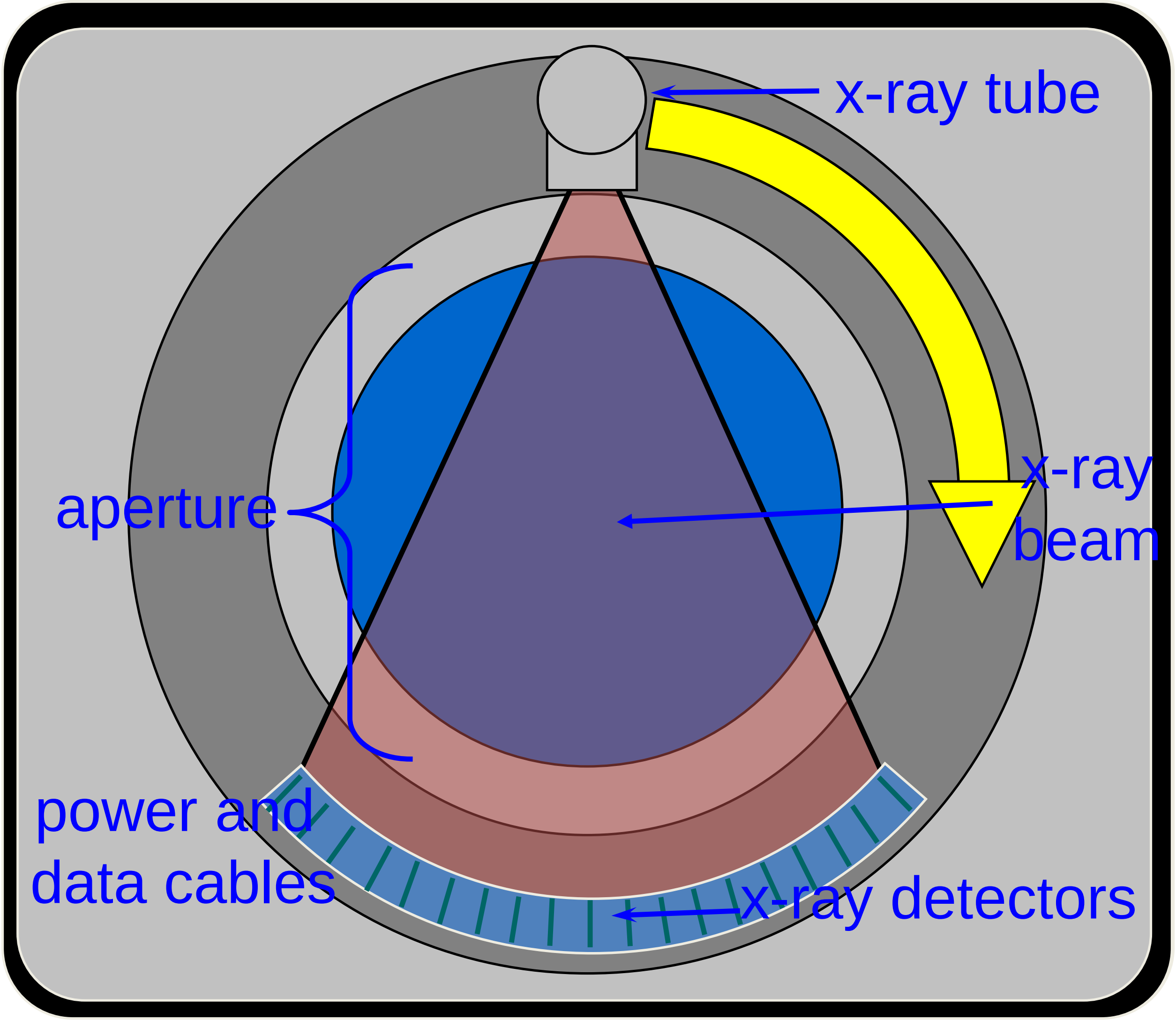


Modern multi-slice scanners

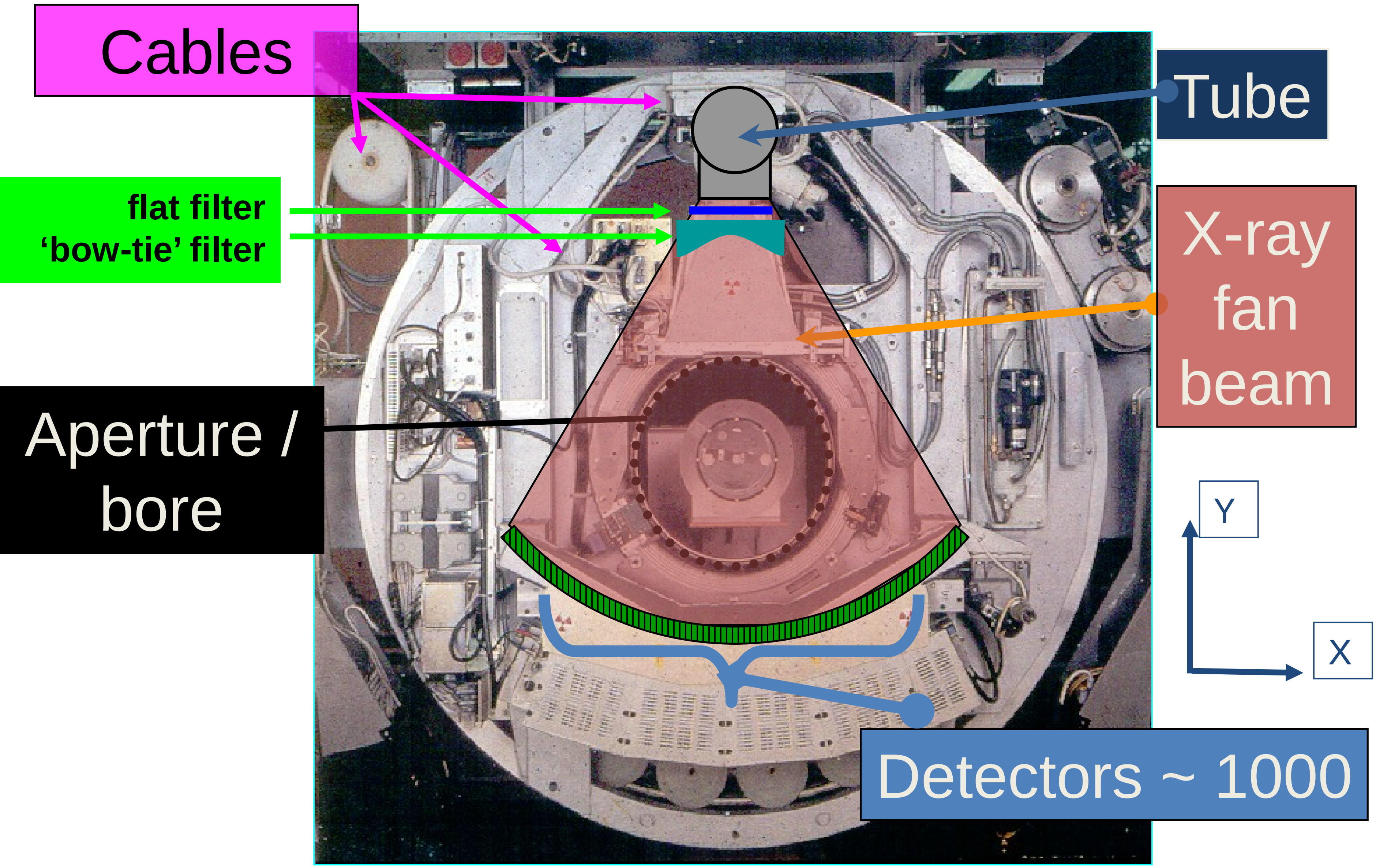
- 1998 (4 slice); 2004 (64 slice)
- 2007 (320 detector rows)
- 2012 Sub-mSv chest acquisitions

Construction of a CT scanner

- What's under the covers ?

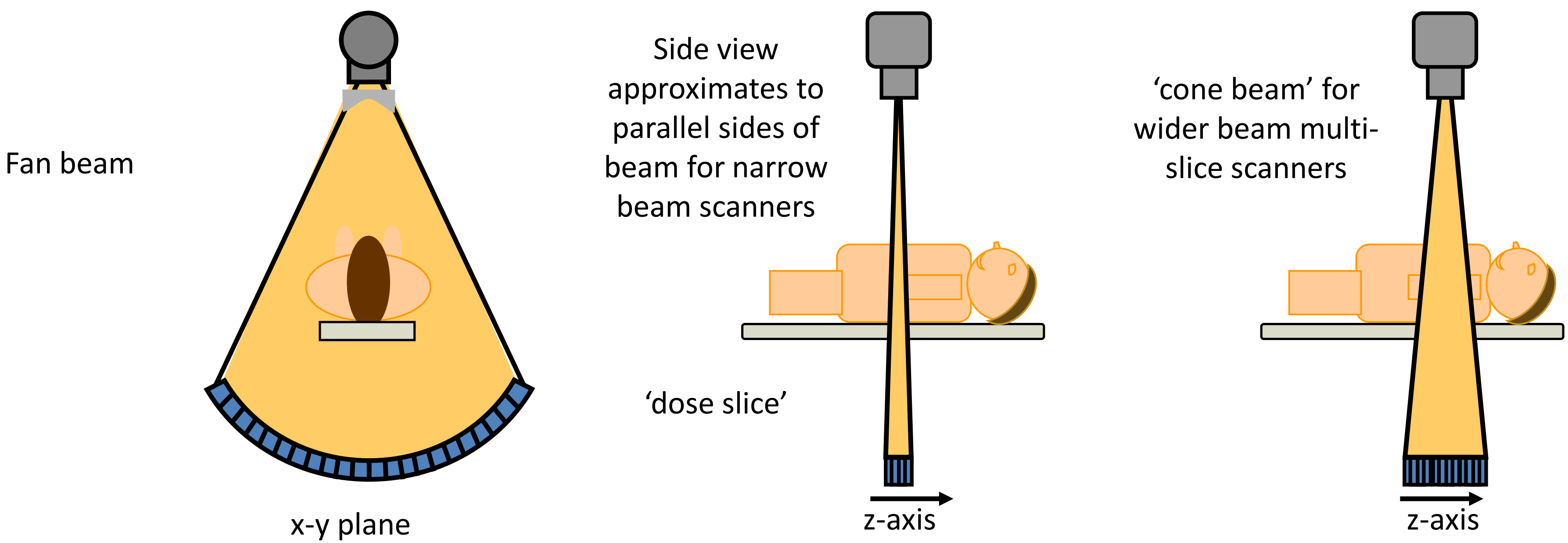


The CT scanner



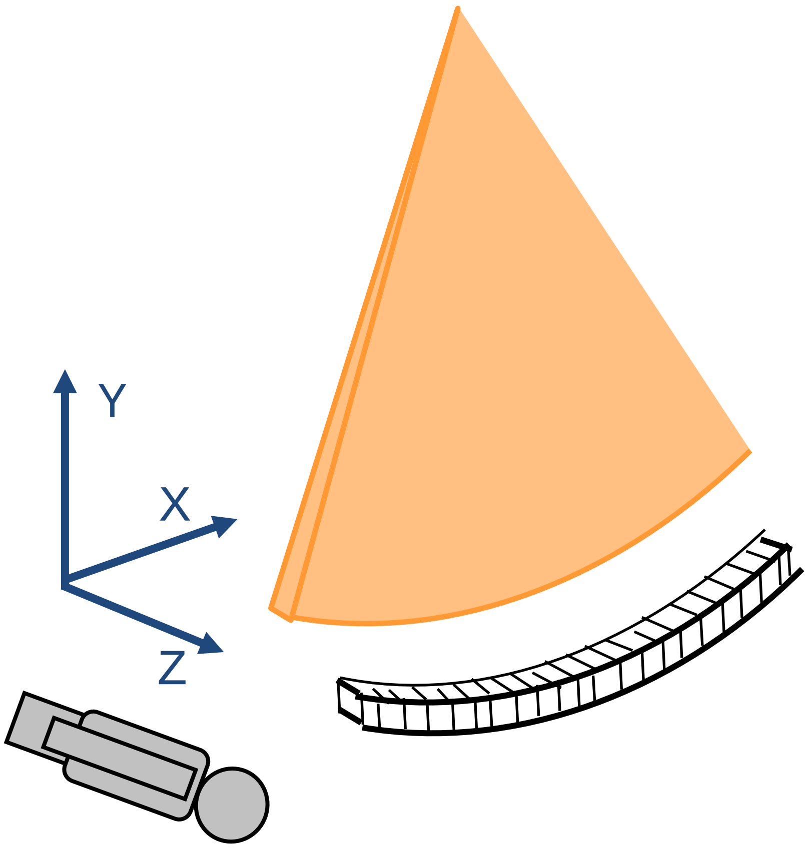
CT scanner

- The X-ray beam is often referred to as a fan beam where the beam width along the longitudinal axis is small
- For multi-slice scanners where the longitudinal beam width is no longer small the X-ray beam is often referred to as ‘cone beam’



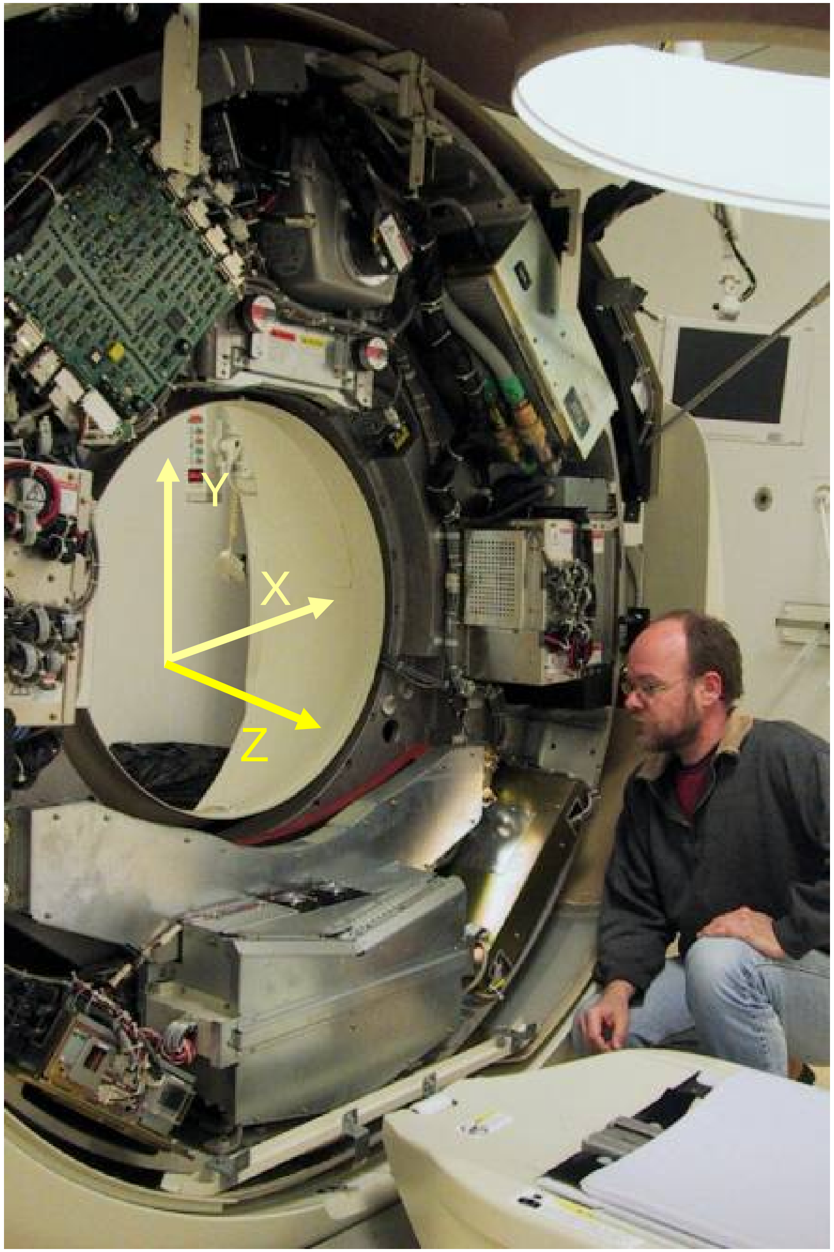
The CT scanner - demonstrating a fan beam

X - ray fan beam



1 - ~ 4 slice

10 to 20 mm beam

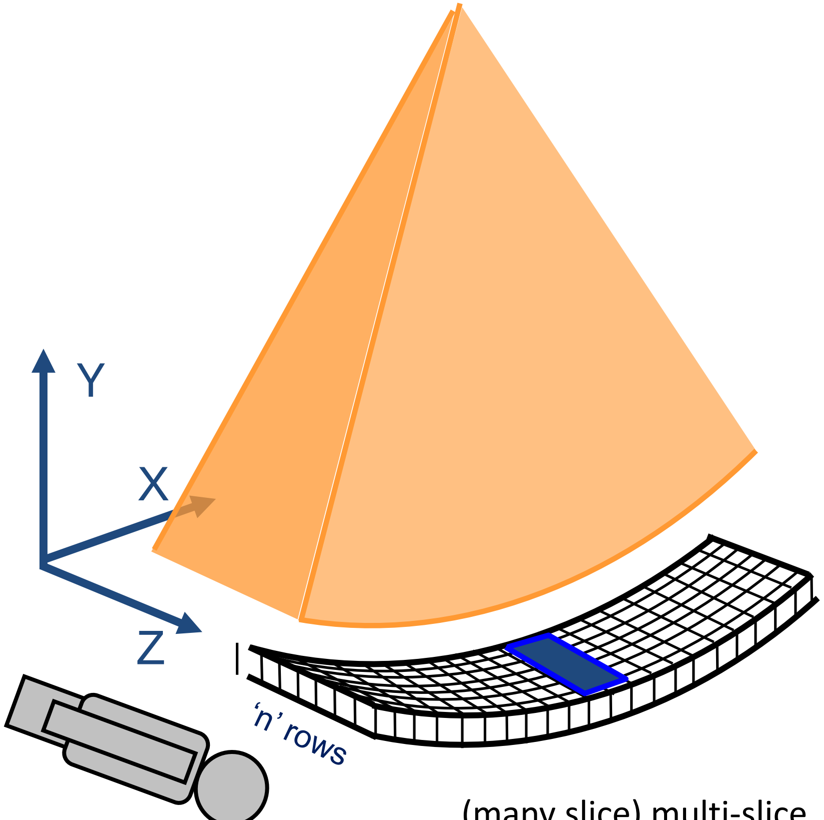


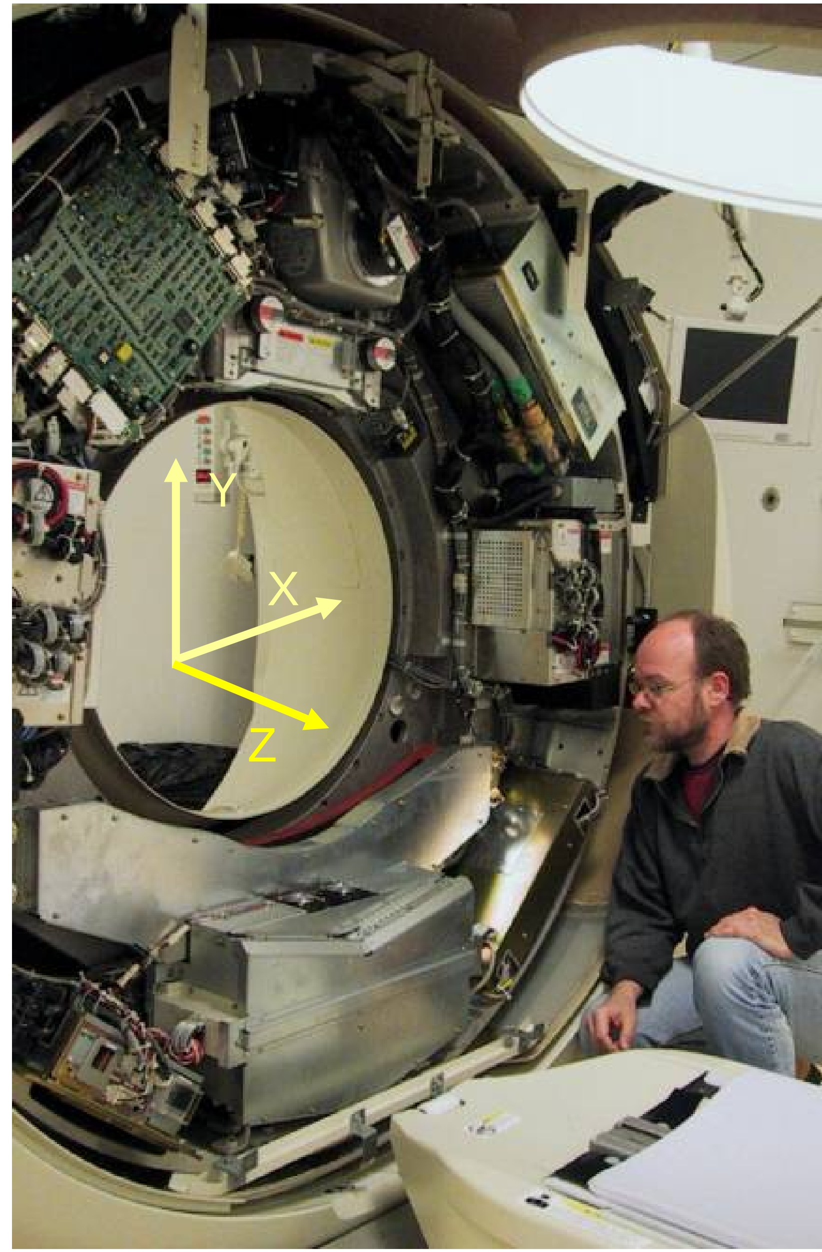
Picture courtesy of K. Gelijns, Leiden

The CT scanner – Multi-slice

X - ray fan beam → cone beam

Wider beam and more slices



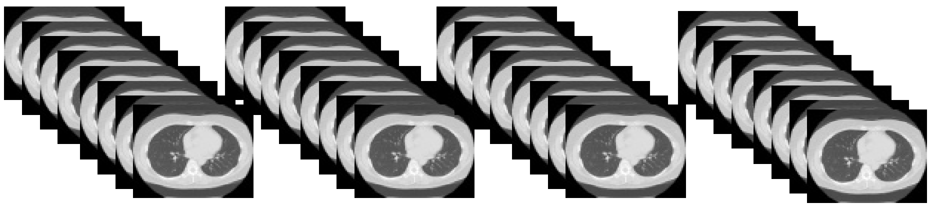


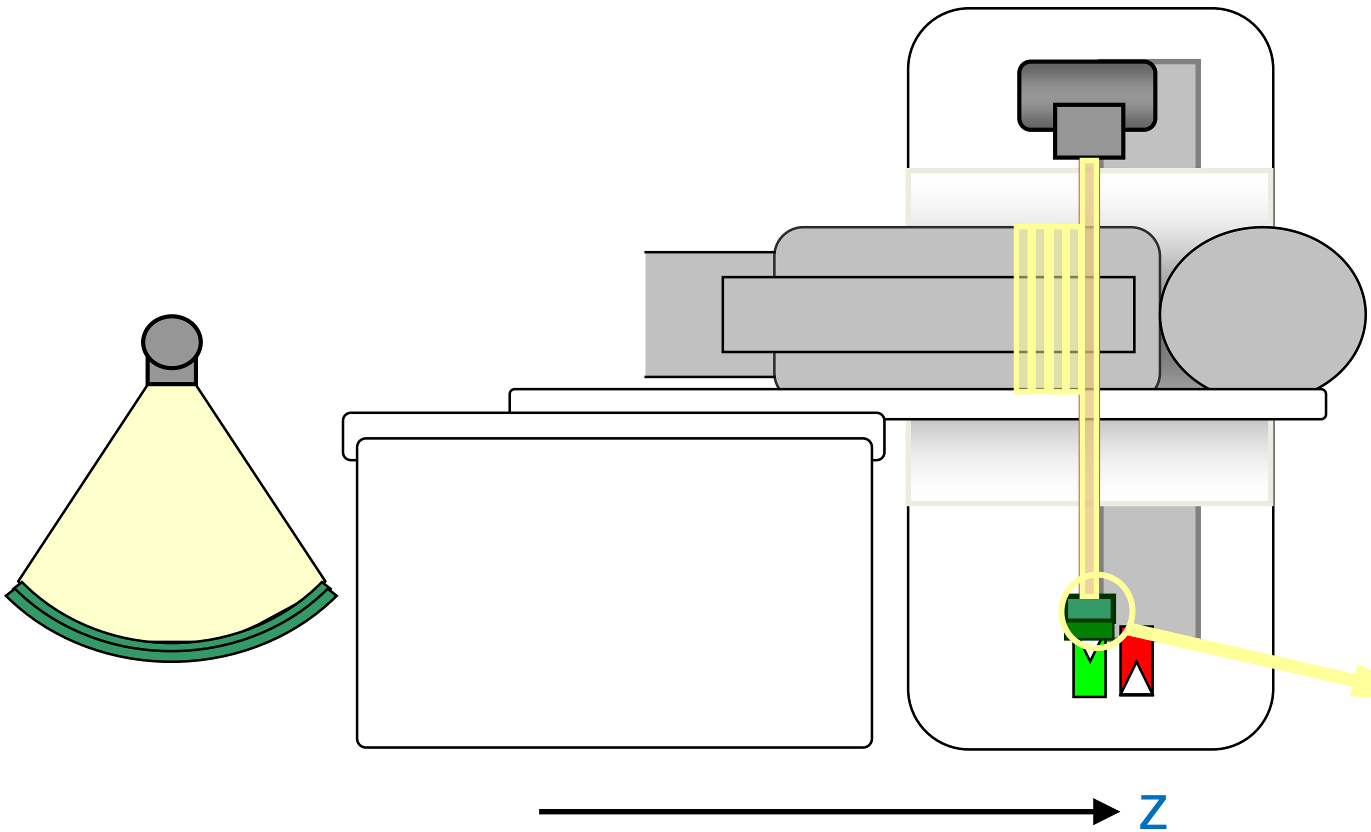
Z- axis length typically ~ 40 mm
(from 10 mm up to 160 mm)

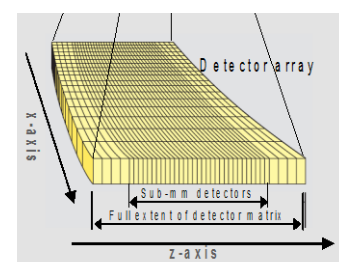
Picture courtesy of K. Gelijns, Leiden

Axial scanning – ‘step and shoot’

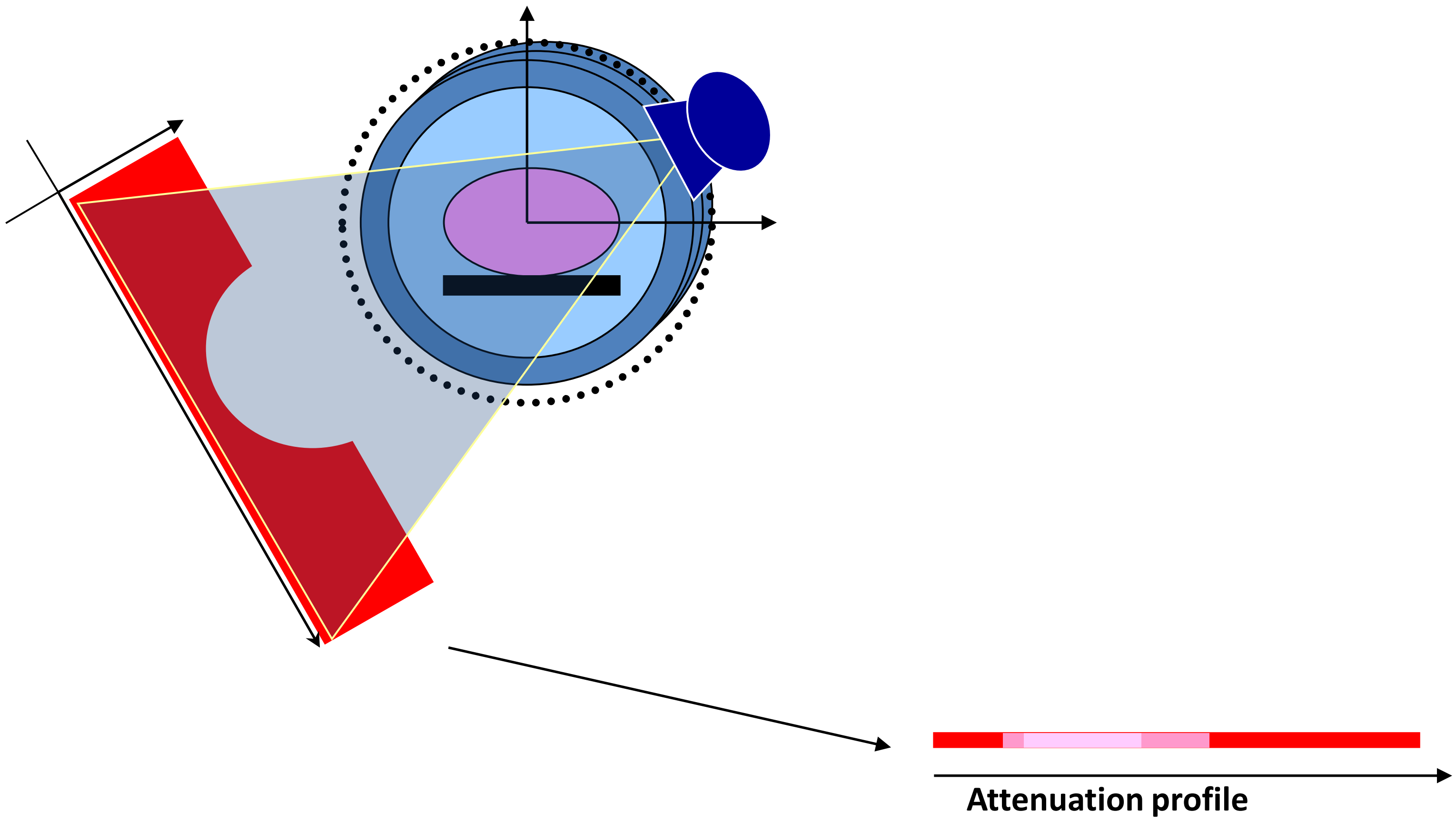
– Also known as sequential scanning







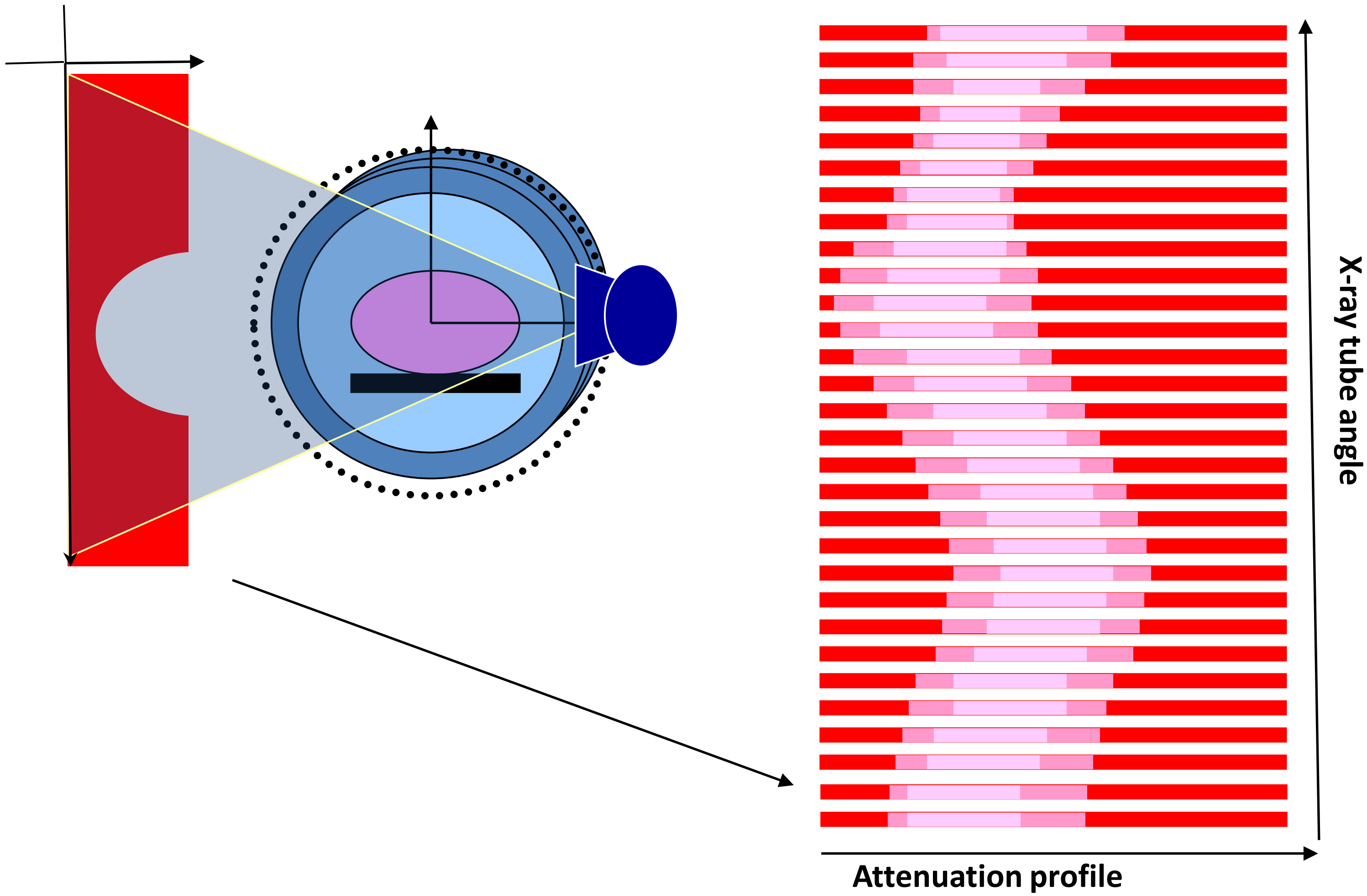
Acquisition of the data



Acquisition of the data

Profile as a function of X-ray tube rotation angle

Sinogram

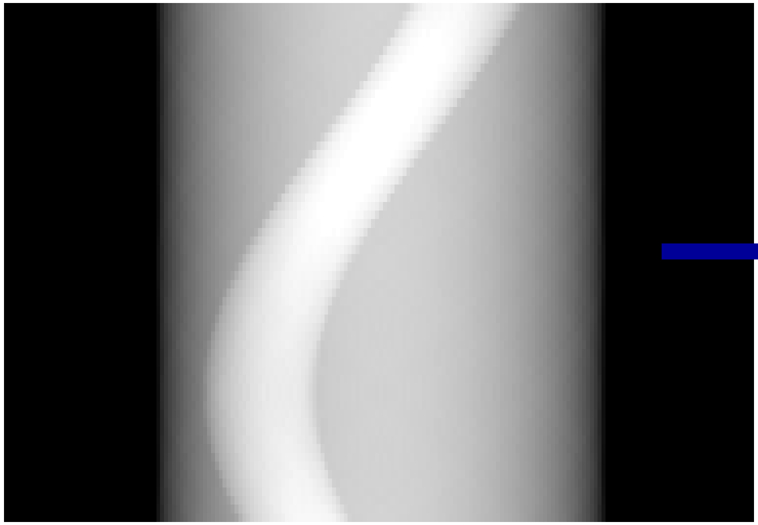


Simple back-projection

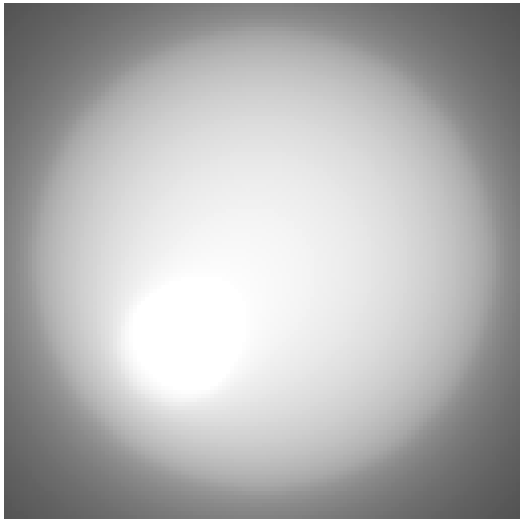
- Problem

We have the raw data : **sinogram**

We are interested in μ values of each voxel



Sinogram



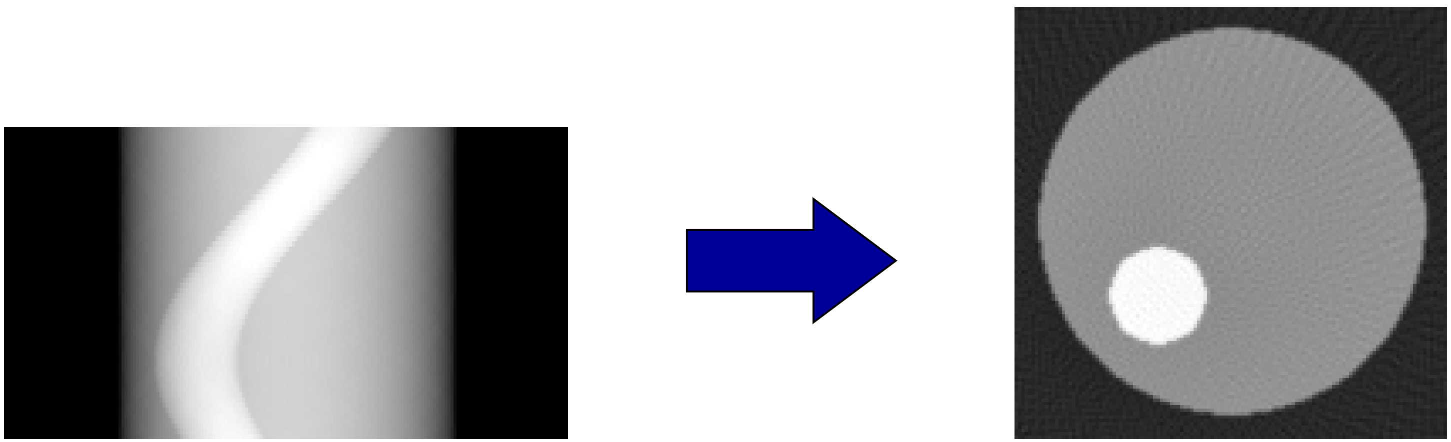
Image

Image reconstruction

- Problem

We have the raw data :
sinogram

We are interested in μ
values of each voxel

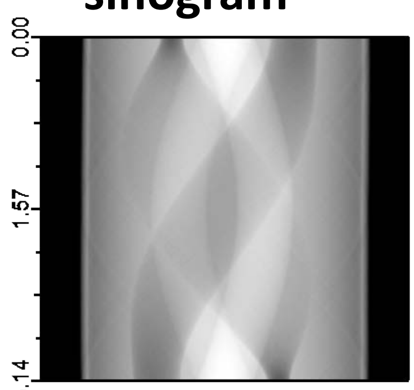


Analytical methods are not feasible
The standard way is to use the Filtered Back Projection (FBP) method
Iterative reconstructions are now standard options

FBP

original

sinogram

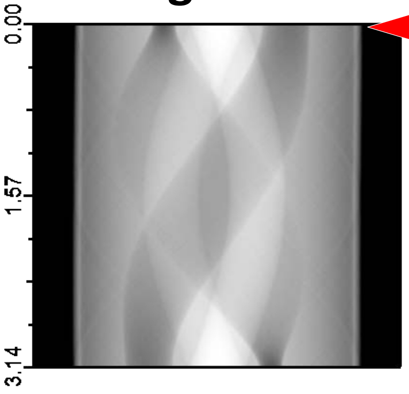


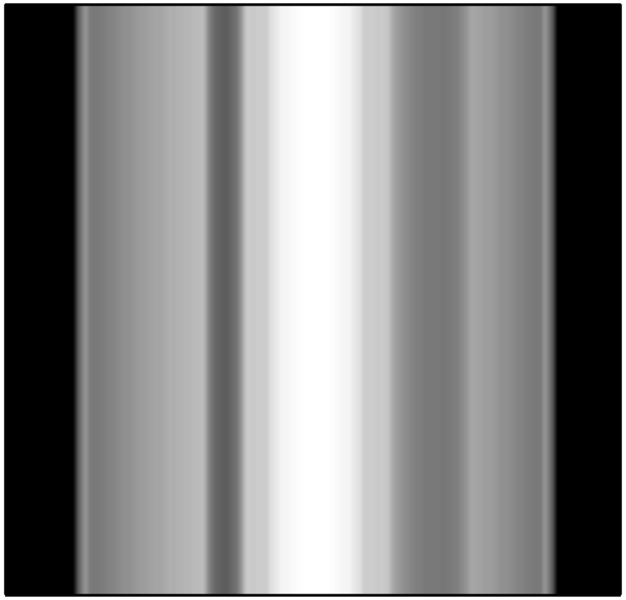
FBP

Each line is an attenuation profile at an given X-ray tube angle

original

sinogram



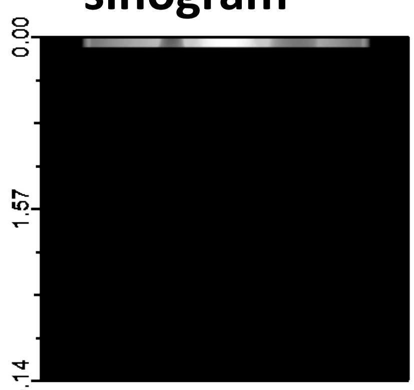


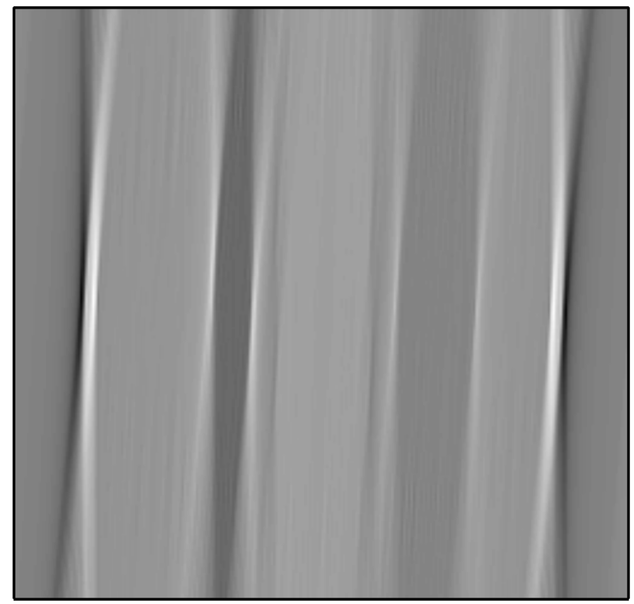
One attenuation profile is considered

FBP

original

sinogram



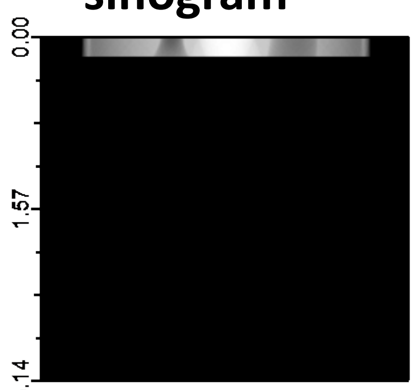


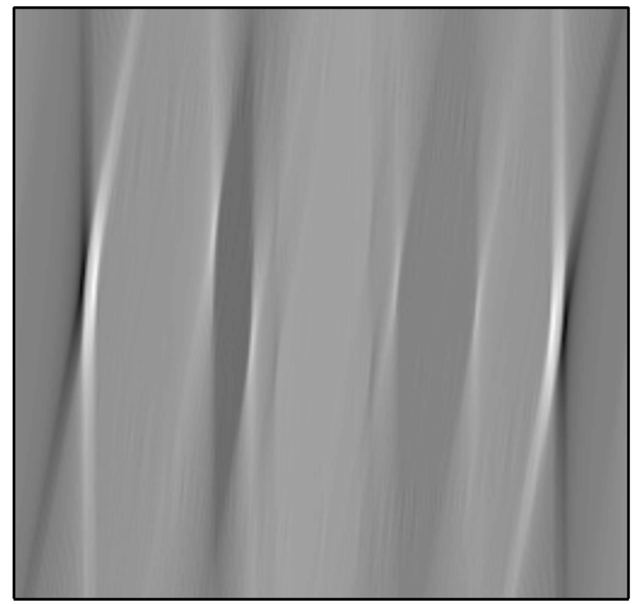
5° are considered

FBP

original

sinogram



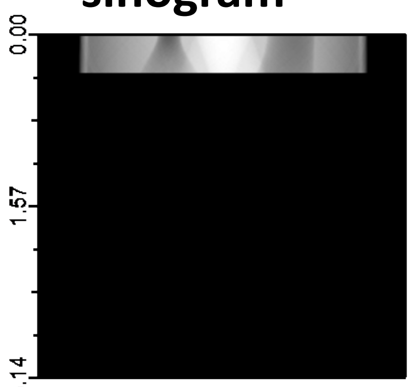


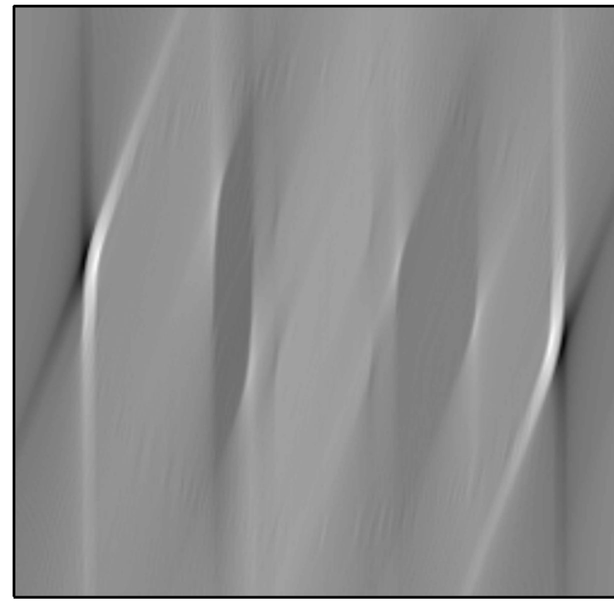
10° are considered

FBP

original

sinogram

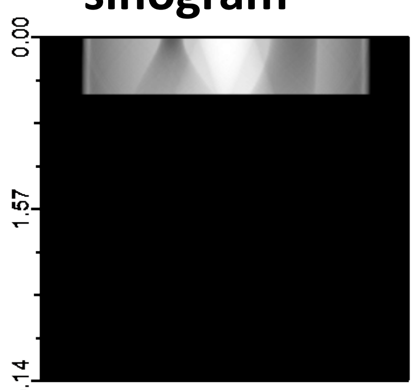


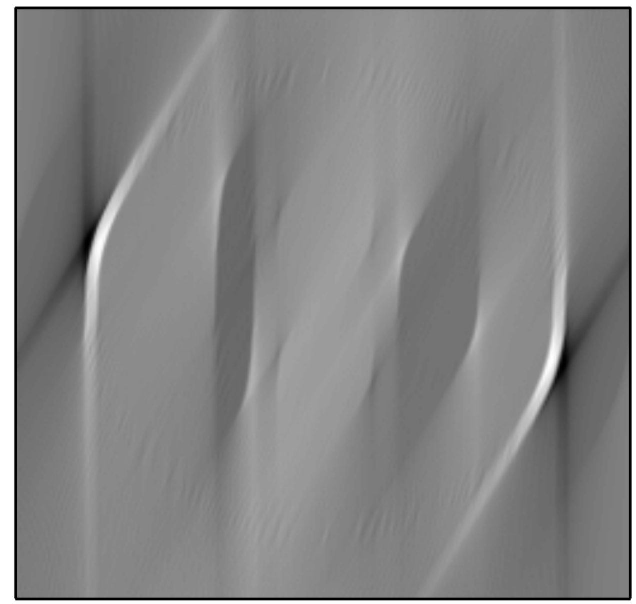


20° are considered

FBP


original

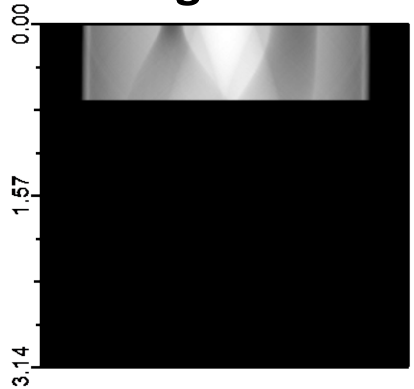
sinogram


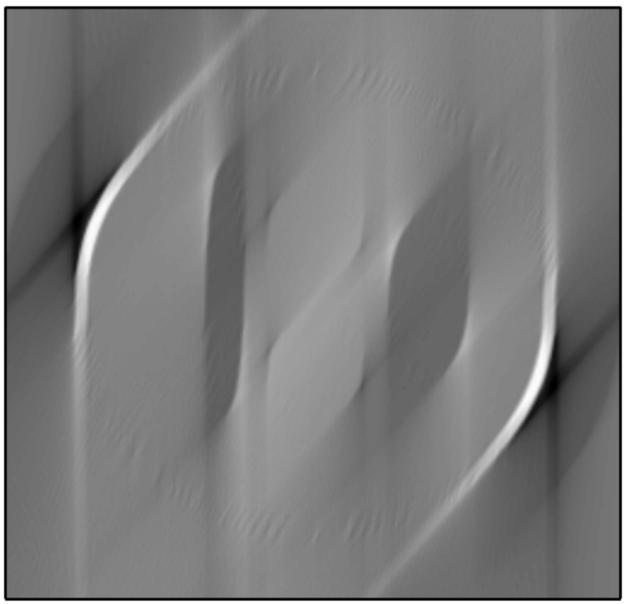

30° are considered

FBP

original

sinogram



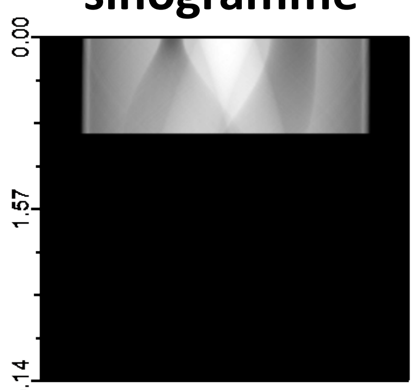


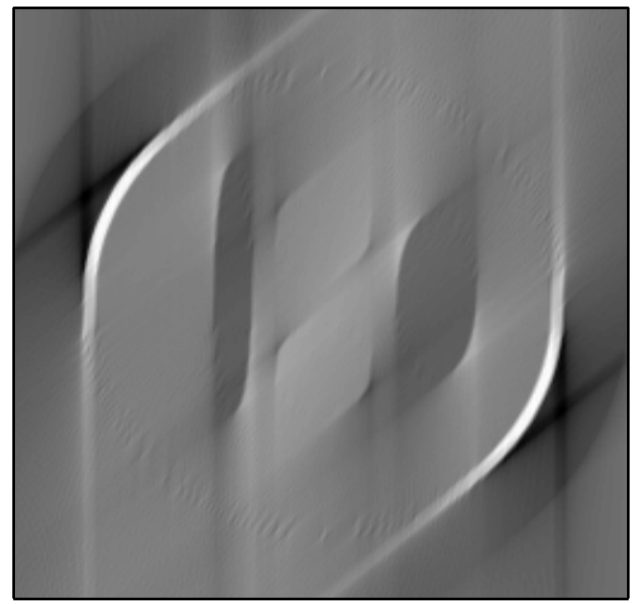
40° are considered

FBP

original

sinogramme



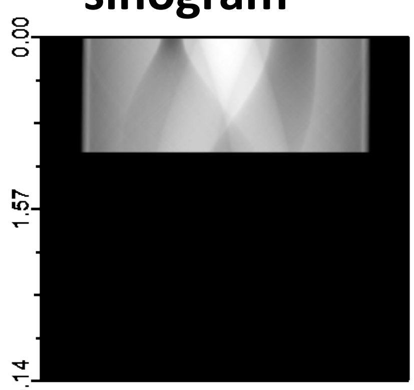


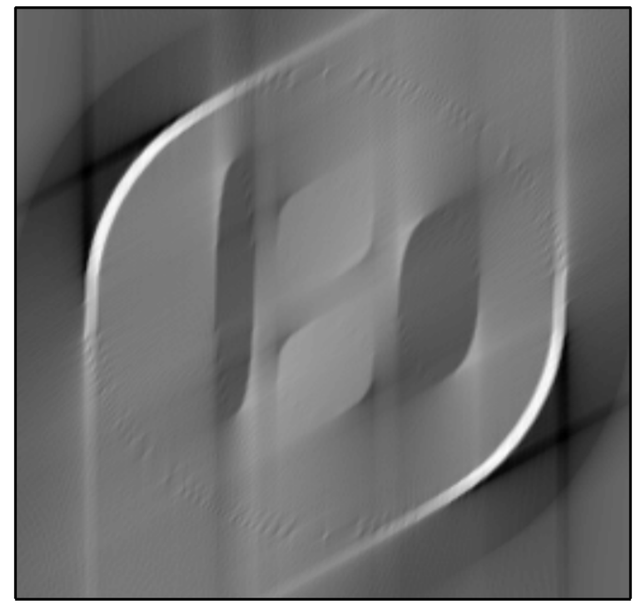
50° are considered

FBP

original

sinogram



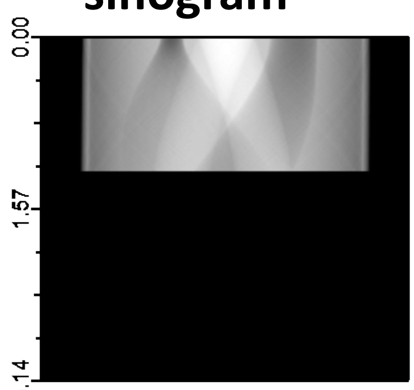


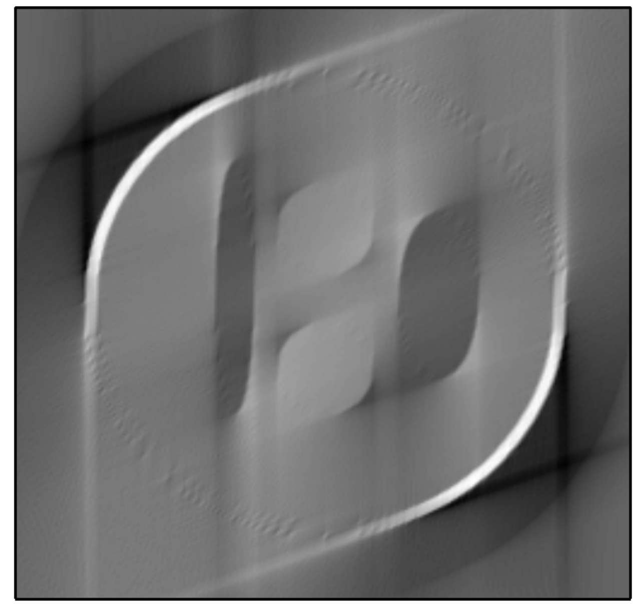
60° are considered

FBP

original

sinogram



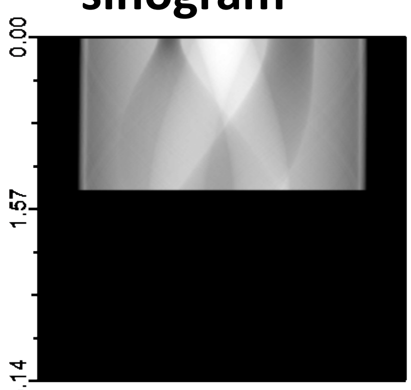


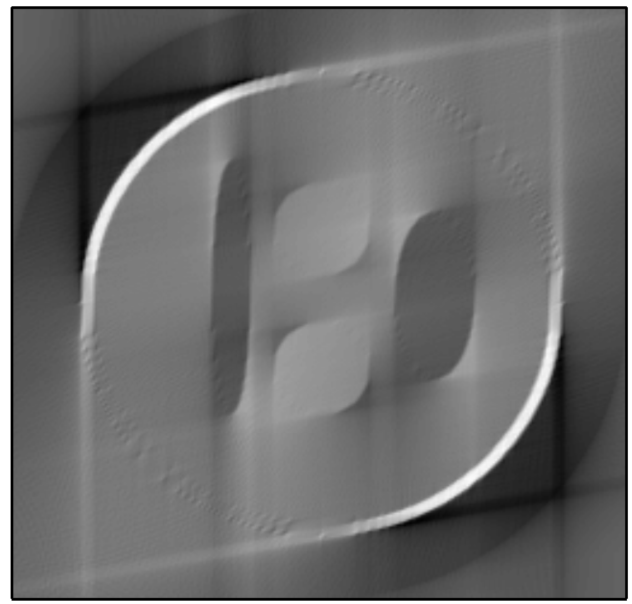
70° are considered

FBP

original

sinogram



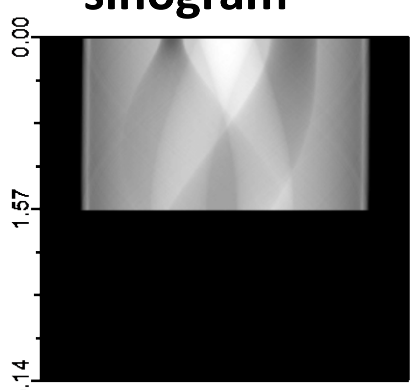


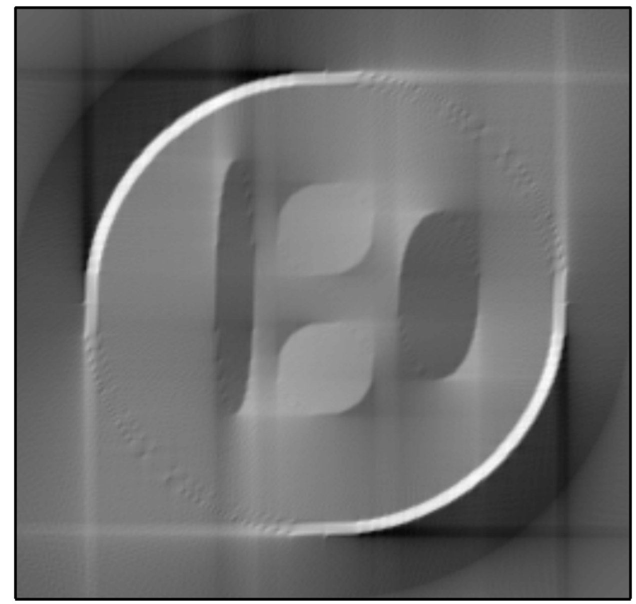
80° are considered

FBP

original

sinogram



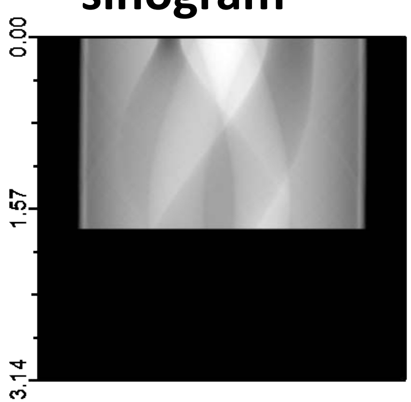


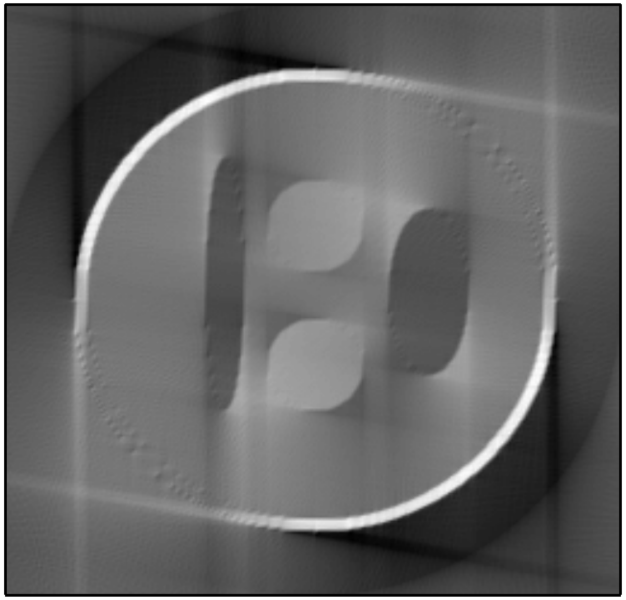
90° are considered

FBP

original

sinogram



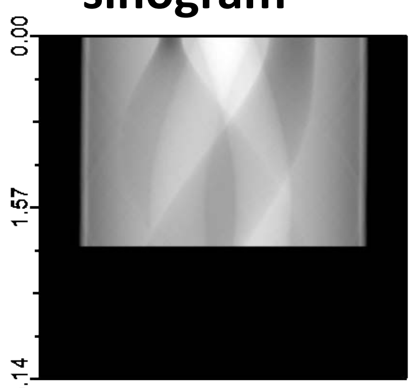


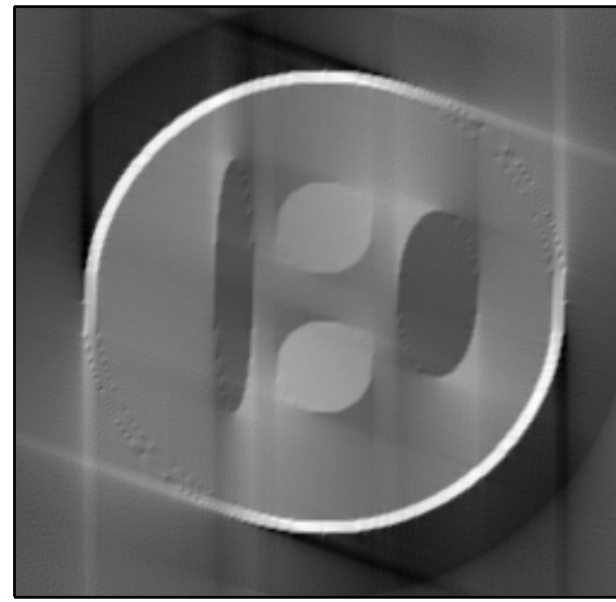
100° are considered

FBP

original

sinogram



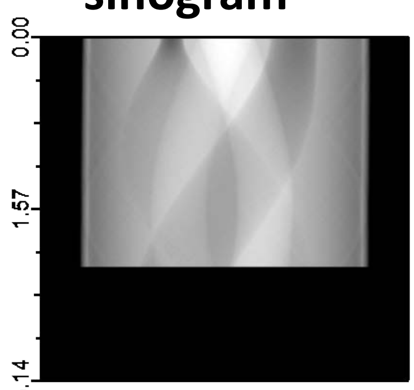


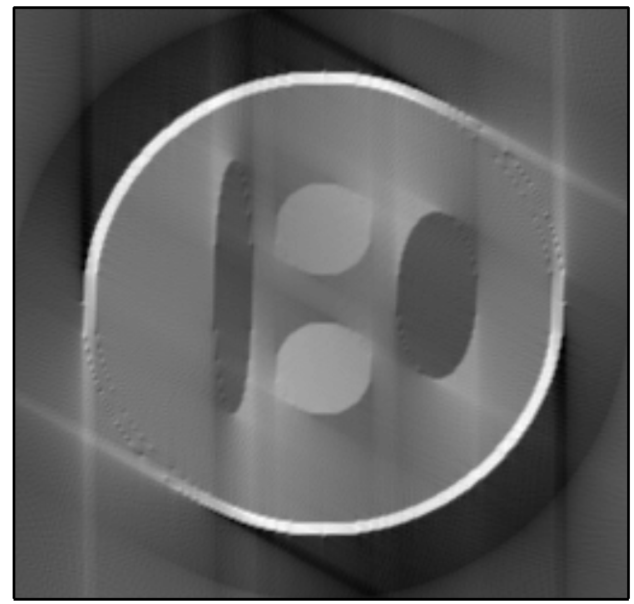
110° are considered

FBP

original

sinogram



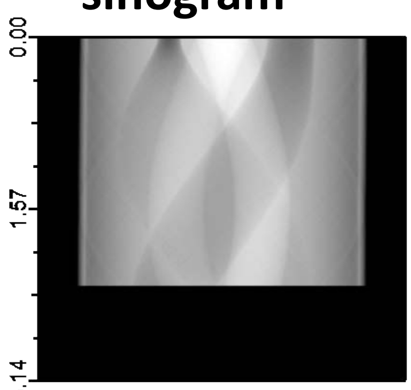


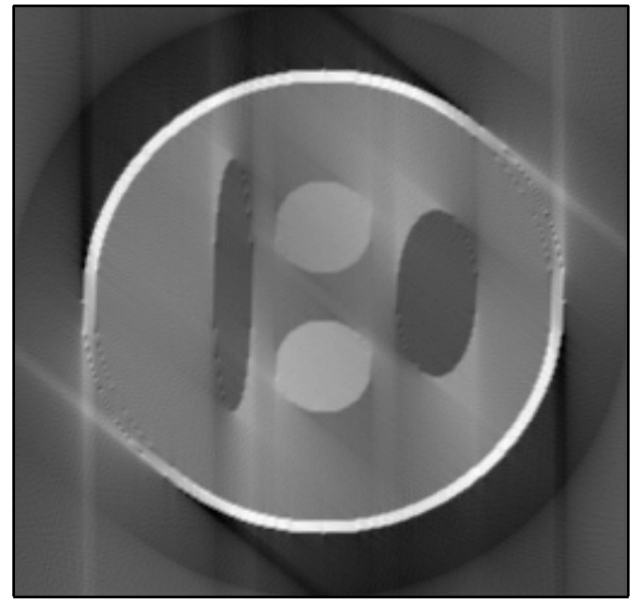
120° are considered

FBP

original

sinogram



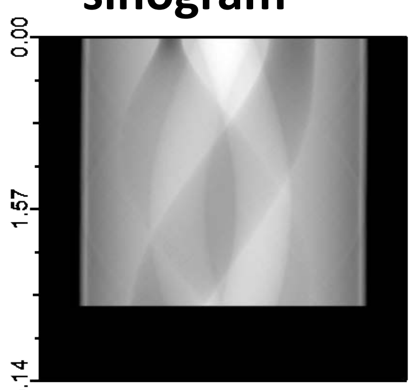


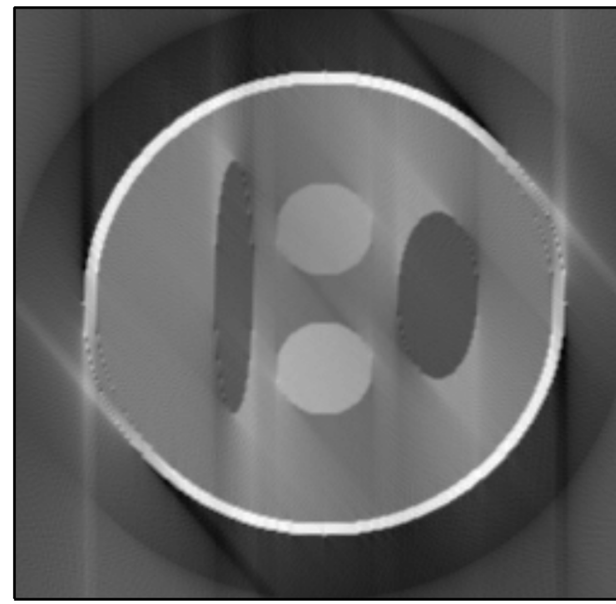
130° are considered

FBP

original

sinogram



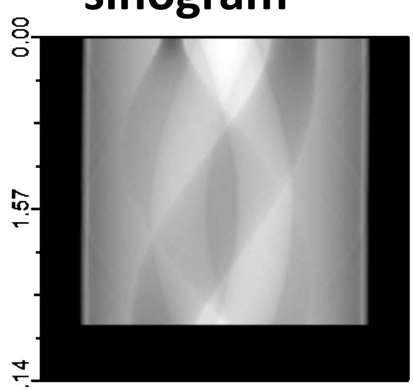


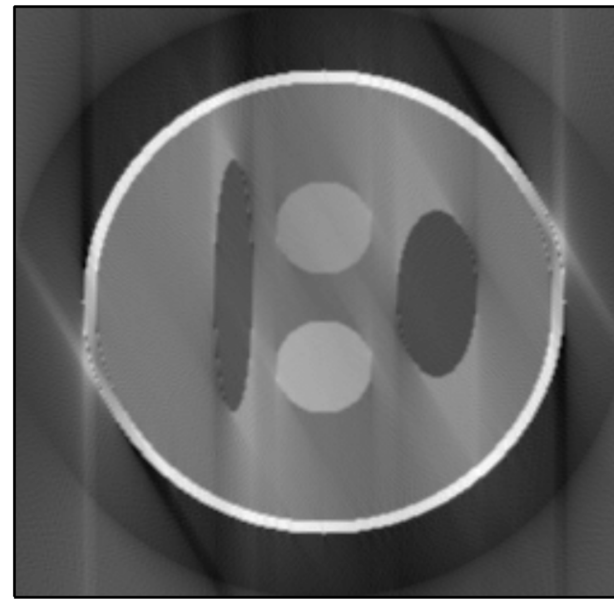
140° are considered

FBP

original

sinogram



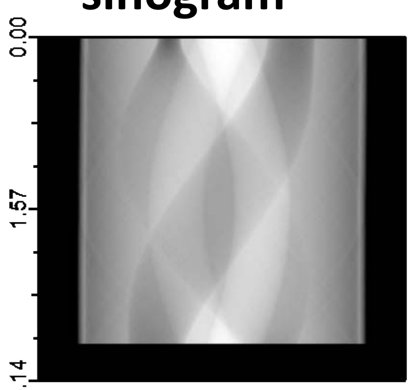


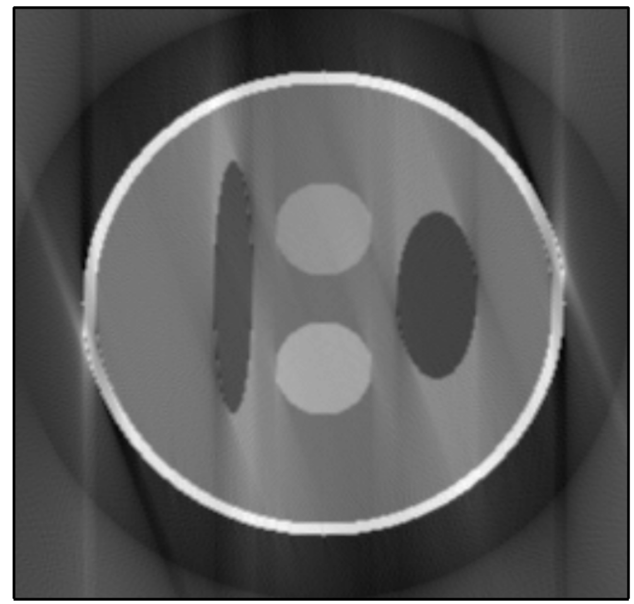
150° are considered

FBP

original

sinogram



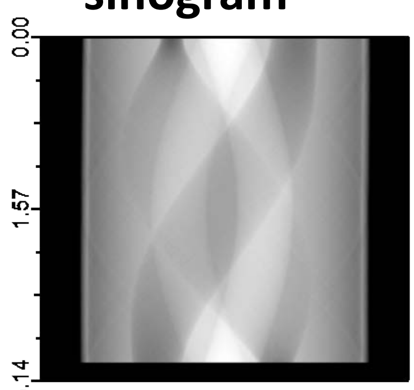


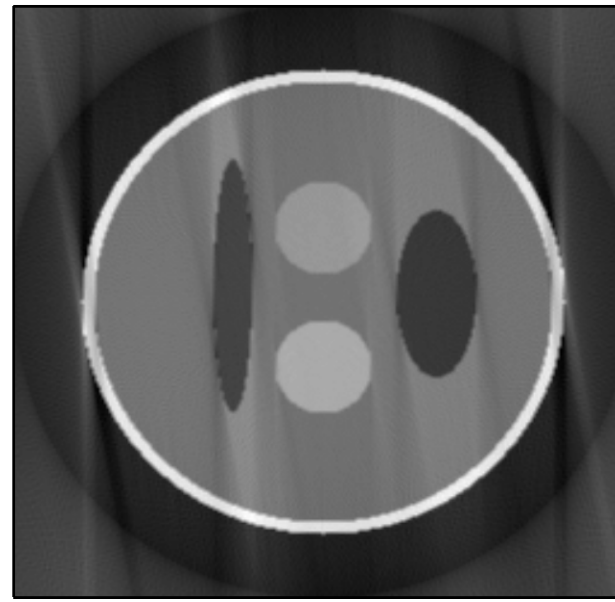
160° are considered

FBP

original

sinogram



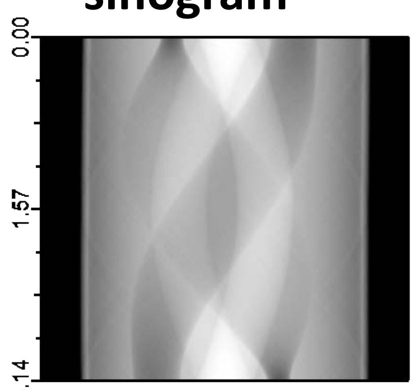


170° are considered

FBP

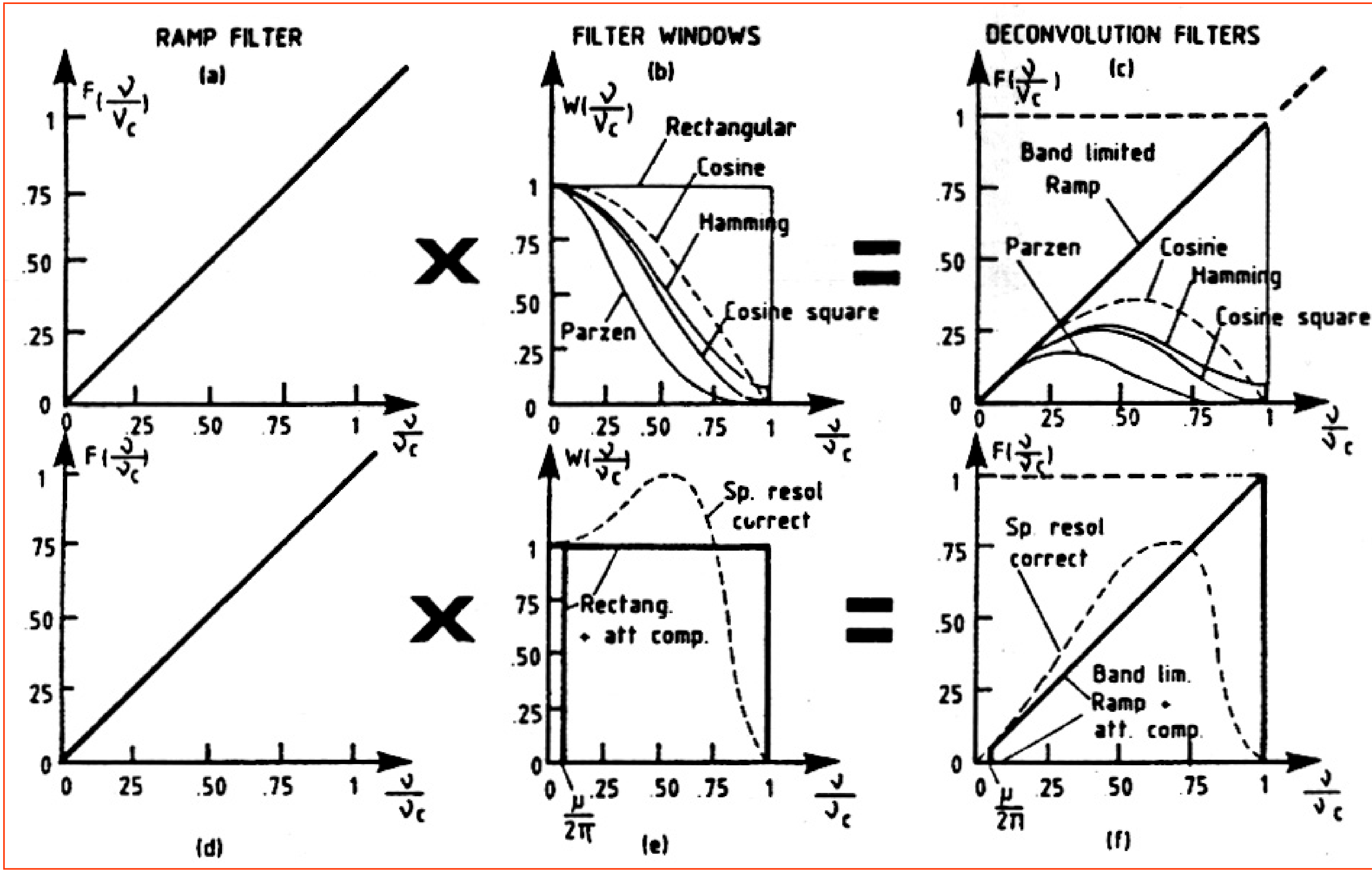

original

sinogram




180° are considered

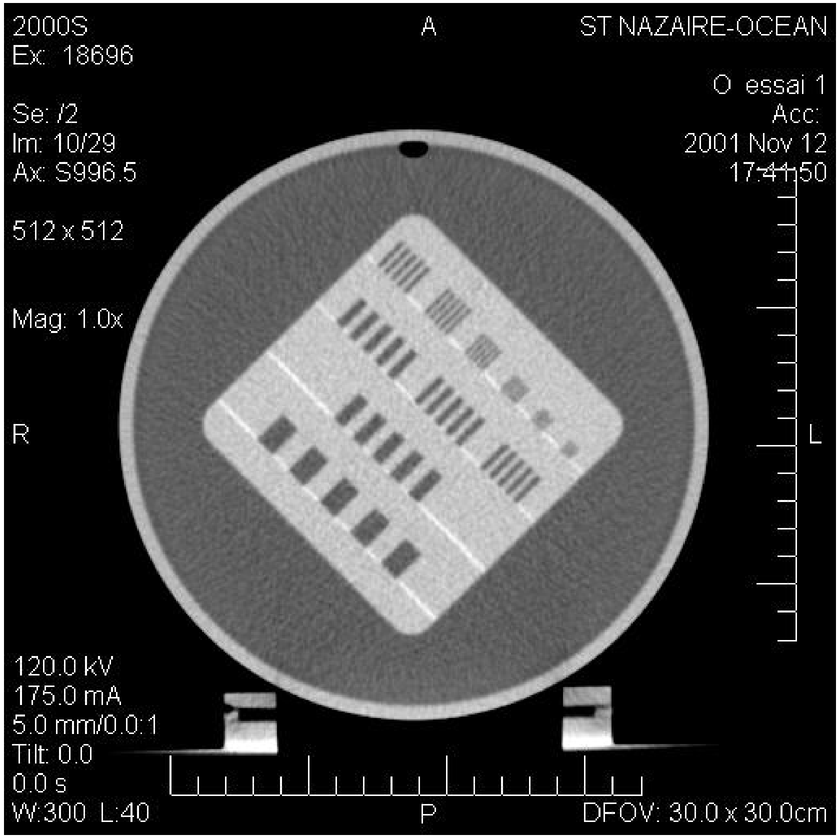
Reconstruction filter (kernel)



Effect of the reconstruction filter

- Influence on
  - Spatial resolution and image noise

Smooth



Bone

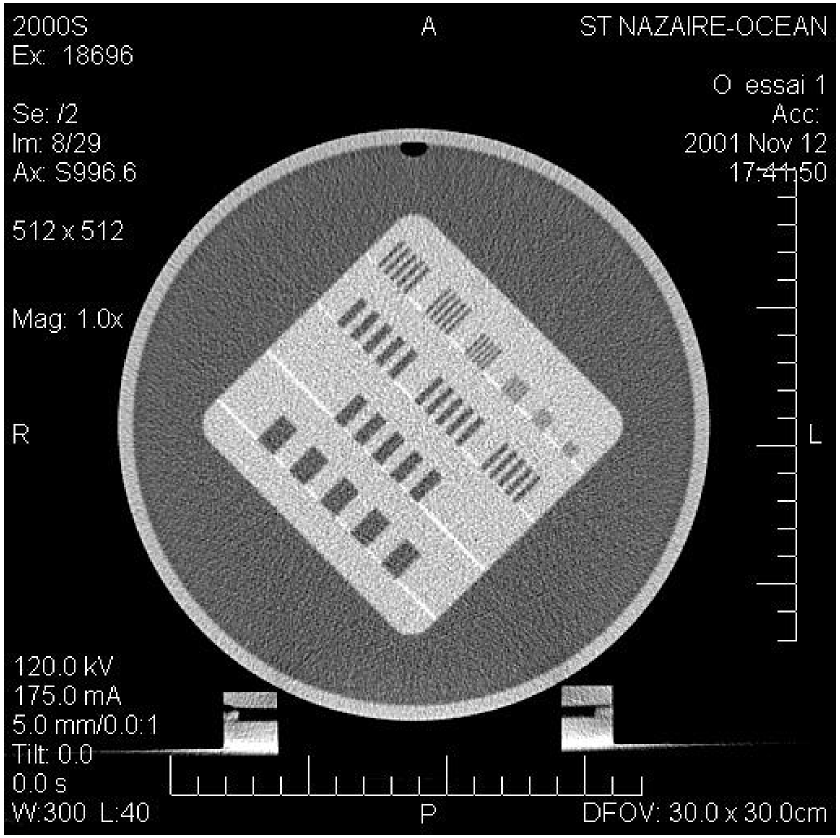


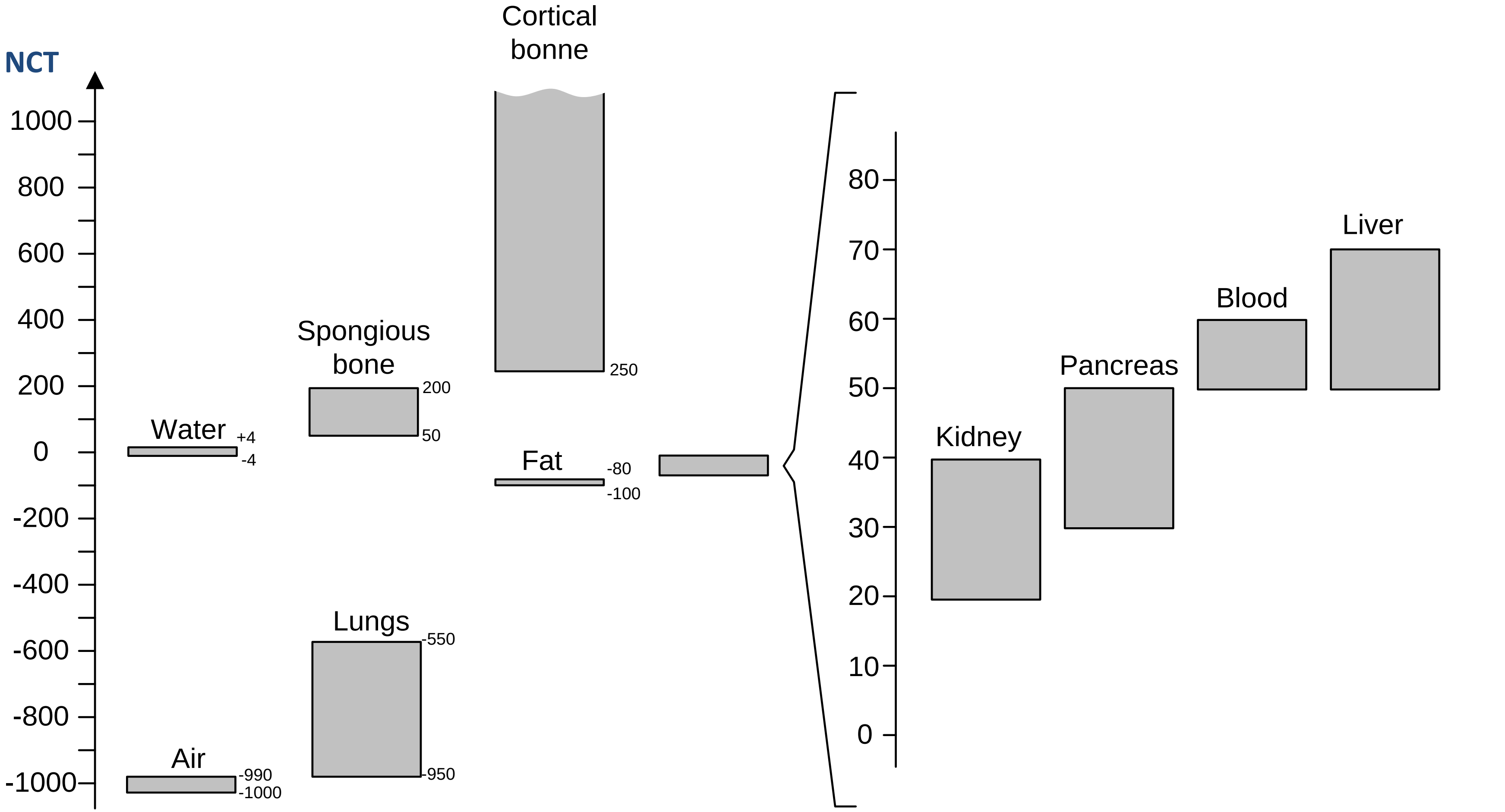
Image representation

- Hounsfield units
  - Linear attenuation coefficient relative to water

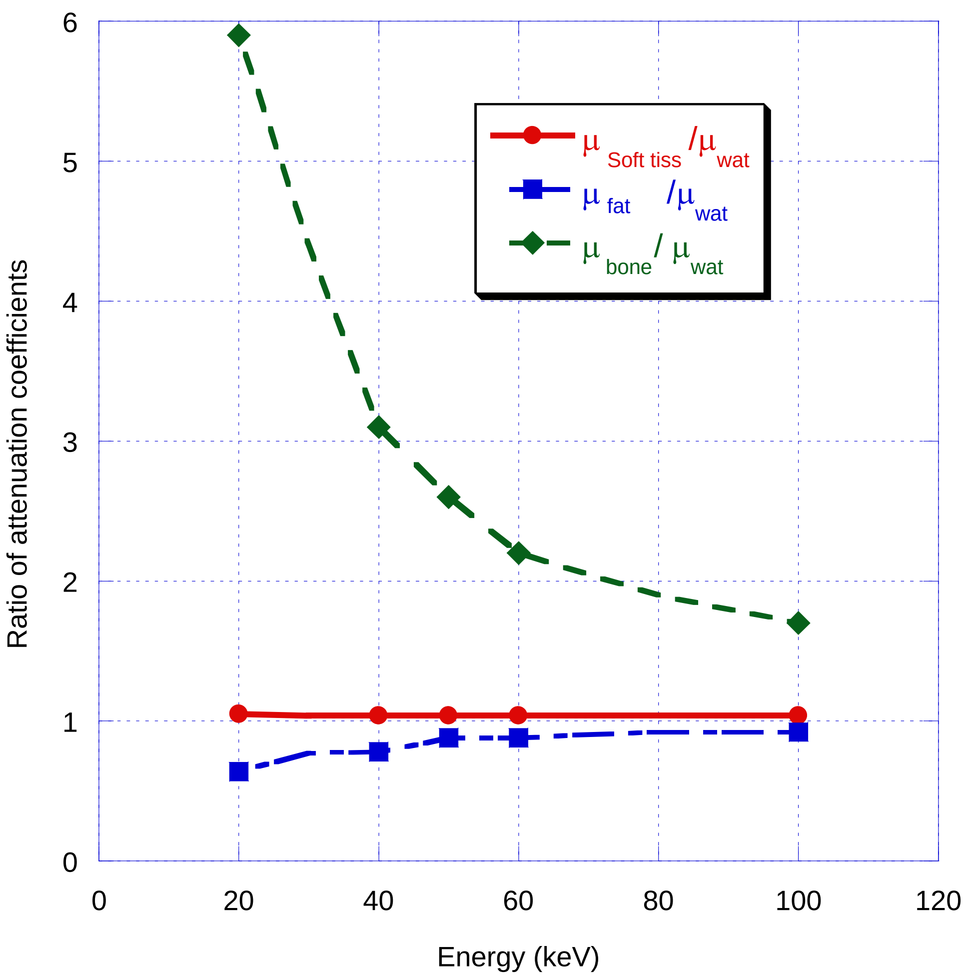
$$\mathrm{NCT}\left(\mathrm{tissue}\right) = 1000\,\frac{\mu_{\mathrm{tissue}} - \mu_{\mathrm{water}}}{\mu_{\mathrm{water}}} \qquad \left(\mathrm{unit:}\ ./.\right)$$

  - Typical values
    - NCT(water) = 0 (by definition)
    - NCT(air) = -1'000
    - NCT(bone) = 250 to 2'000

Image representation

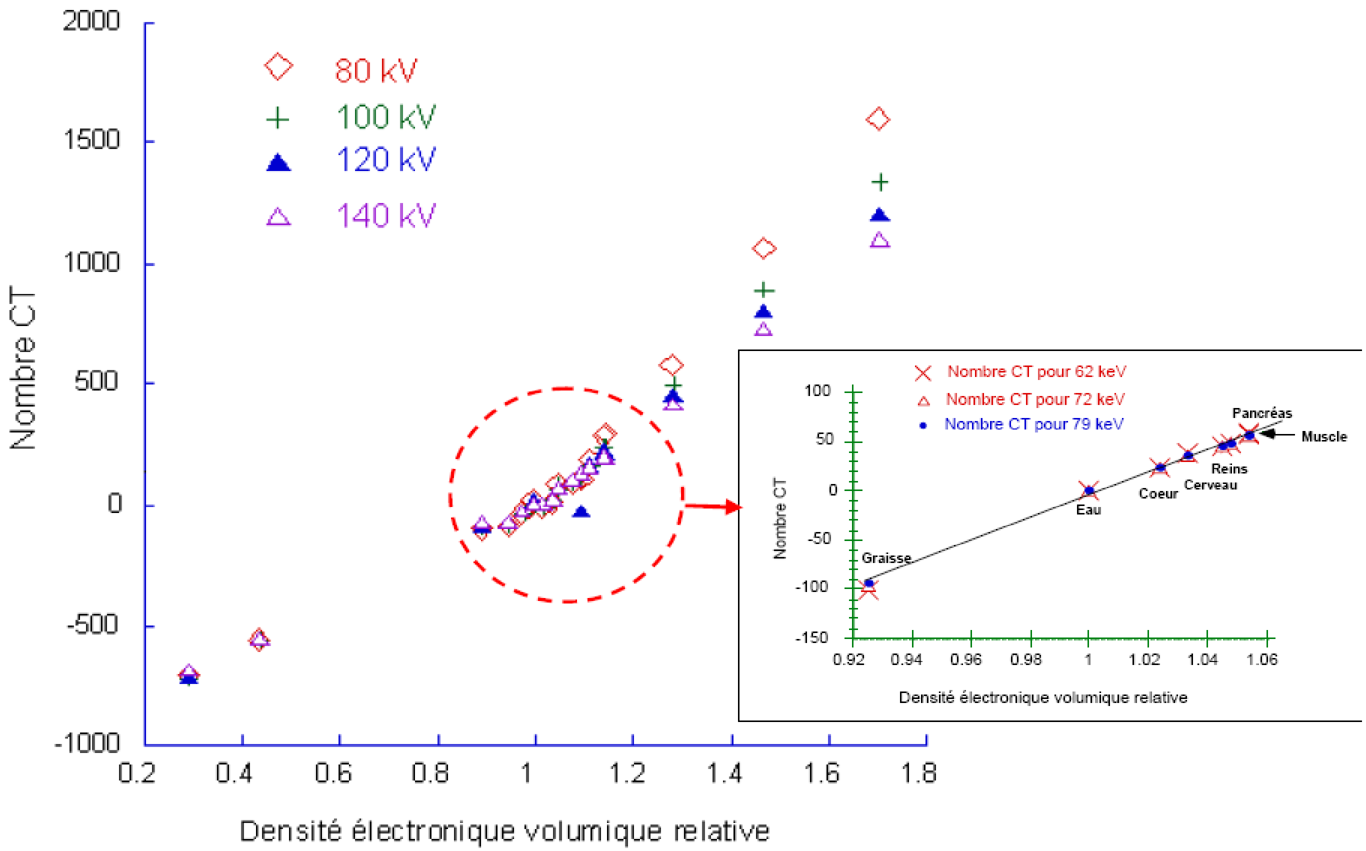


Influence of beam energy on CT



Density and CT

Tissu	Graisse	Sang	Cerveau	Coeur	Rein	Muscle	Pancréas
Densité électronique relative	0.925	1.054	1.033	1.024	1.045	1.054	1.048



Exercices

- The CT number of a muscle is 40 HU. Considering that at the effective energy used the linear attenuation coefficient of water is equal to : 0.19 cm^{-1}

- Calculate the linear attenuation coefficient of the muscle

- How would change the CT number of the muscle if we would reduce the X-ray beam energy by 20 % ?
  - Justify why

Image representation

- Windowing
- Eye dynamic range
  - env. 200 grey levels can be resolved
  - Impossible to resolve more than 4000 grey levels available
- Limitation of the range of grey level one analyses

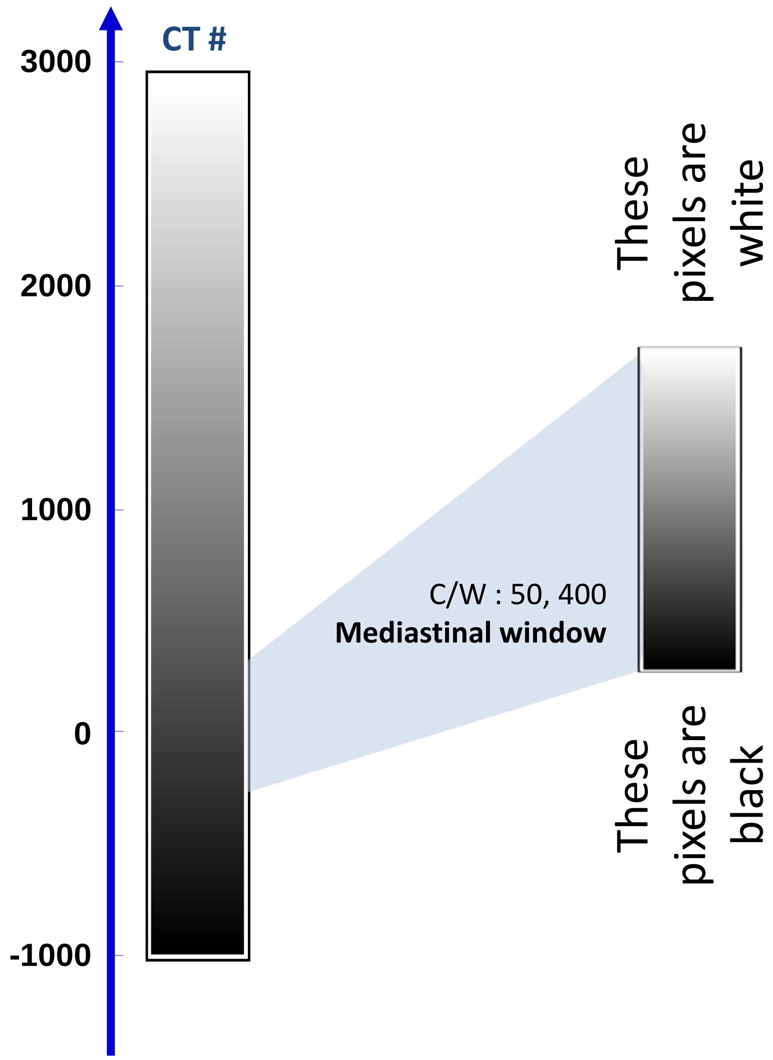
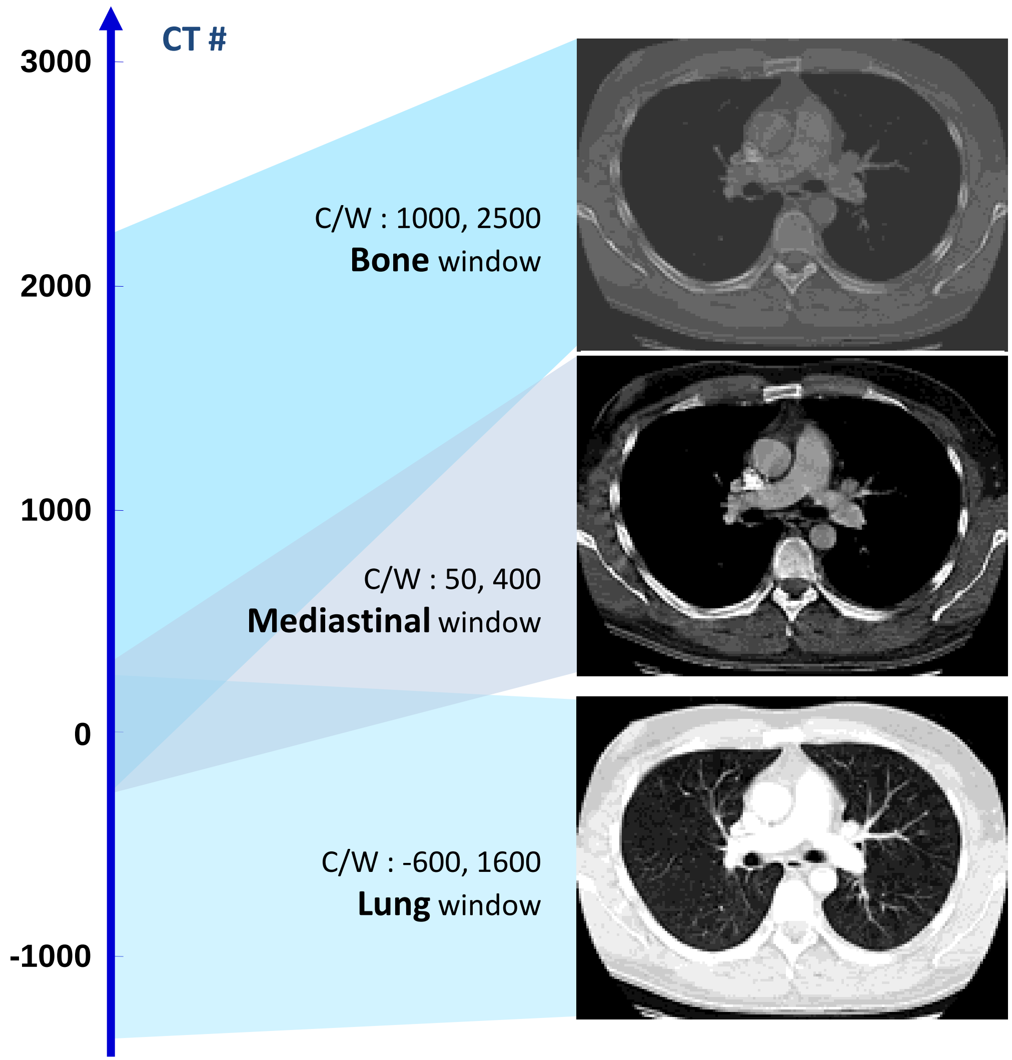


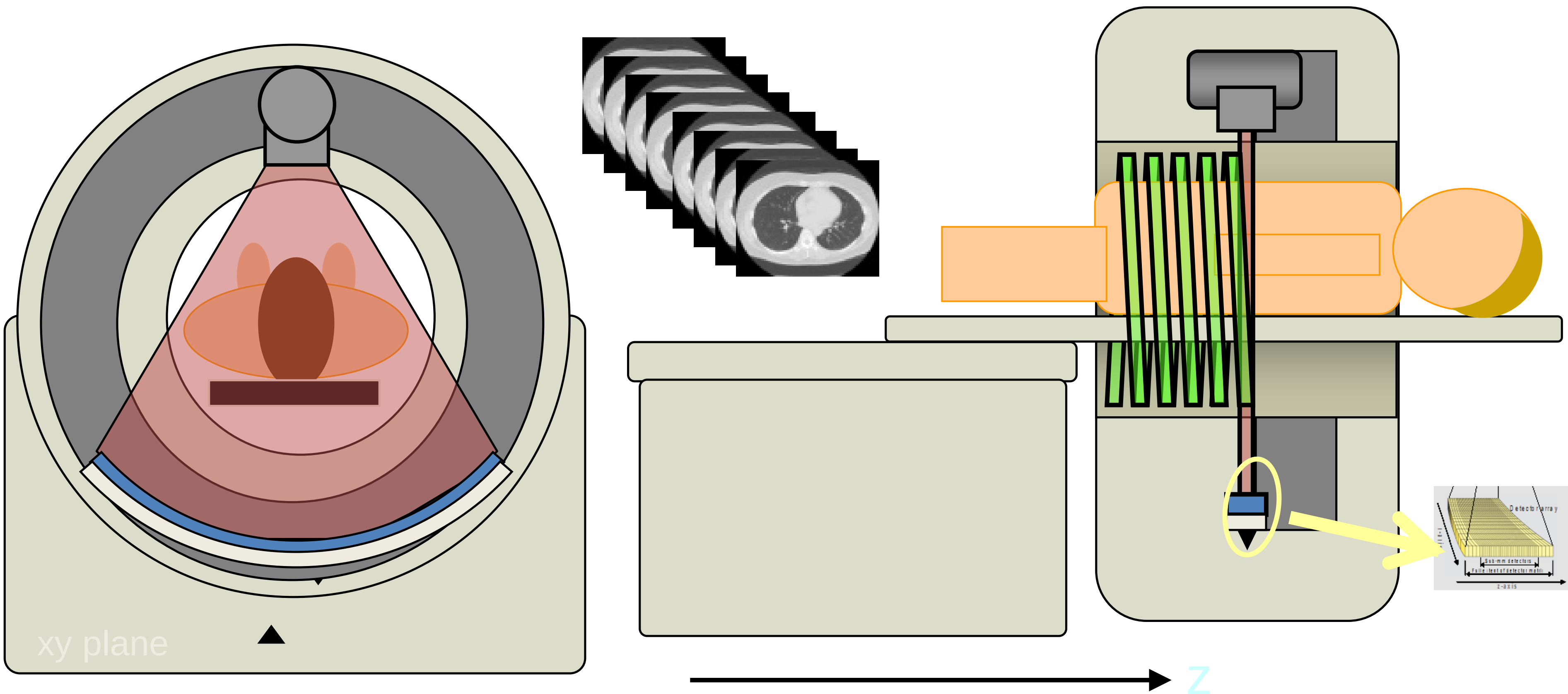
Image representation

- Windowing
- Eye dynamic range
  - env. 200 grey levels can be resolved
  - Impossible to resolve more than 4000 grey levels available
- Limitation of the range of grey level one analyses

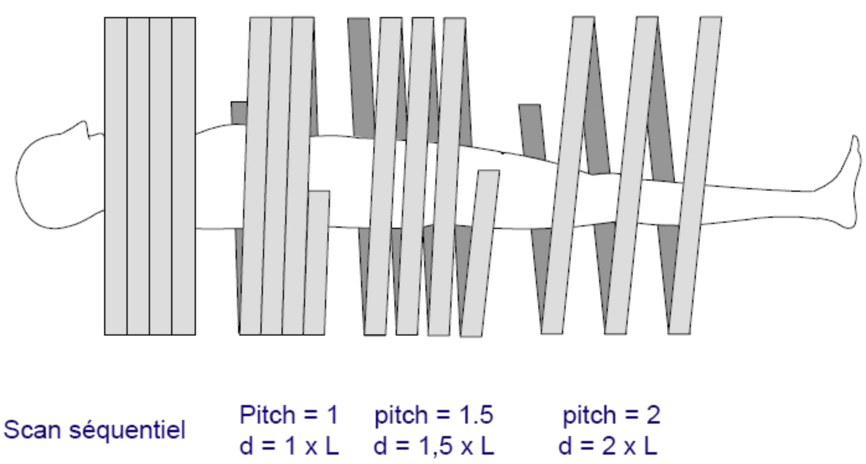


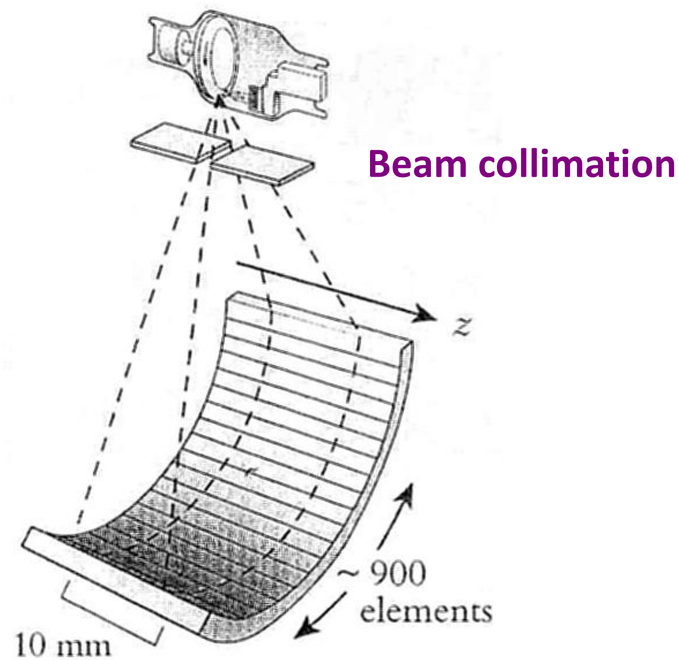
Helical (spiral) scanning

- Continuous gantry rotation + continuous table feed
- Scan data traces a helical path - or ‘spiral’ - around patient
  - – data used to form axial images (interpolation of attenuation profiles)



Pitch definition





$$\text{Pitch} = \frac{\text{Table advance per tube rotation}}{\text{X-ray beam nominal collimation}}$$

p = 1 : **exact coverage**

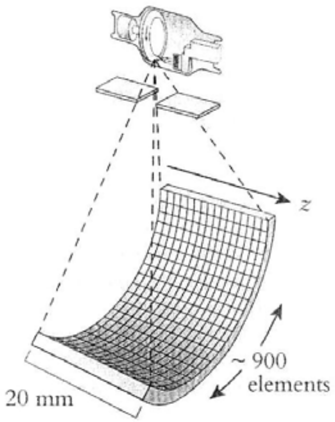
p < 1 : **over coverage**

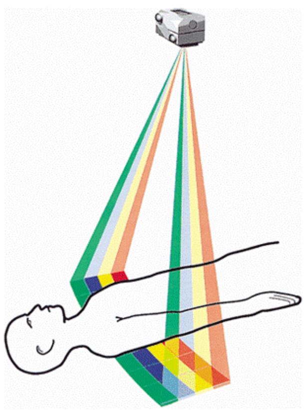
p > 1 : **partial coverage**

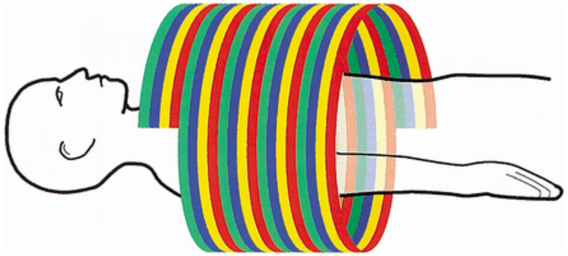
(loss of axial resolution, not that much of a problem with MDCT)

MDCT : Multi-detector row CT

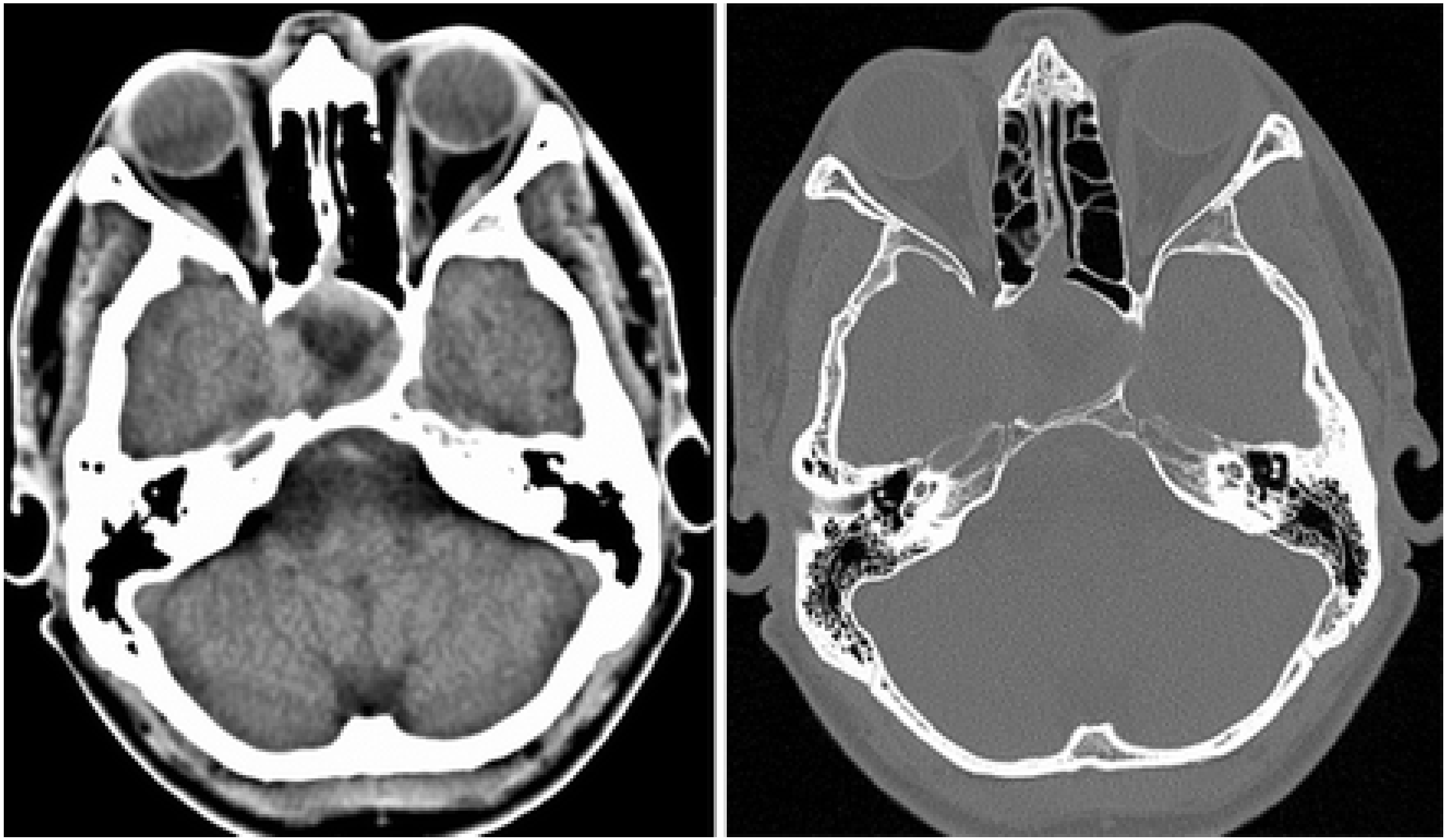
- Isotropic volume acquisition
  - Voxels of cubic shape (sub-millimeters)
  - Slice reformatting (MPR Multi-Plane Reformatting)
    - From transverse slice
      - Sagittal, coronal
  - Large volume acquisition in a single breath hold (< 15 s) with an excellent longitudinal resolution







Applications



Clinical performance of four-section CT in sequential scan mode. Follow-up images in a patient after surgical removal of pituitary tumor. Left: 4-mm-thick image with standard head kernel for soft-tissue evaluation. Right: 1-mm-thick image with bone kernel for bone evaluation. Both images were generated from the same scan data (four sections at 1-mm collimation).

Radiology June 2005 TG Flohr

Exercise

- The acquisition parameters for a chest acquisition are the following:
  - Detector configuration:64x0.625
  - Rotation time: 0.6 s
  - Pitch factor:1.4
  - Scan length: 35 cm

What is the acquisition time?

Parameters and image quality

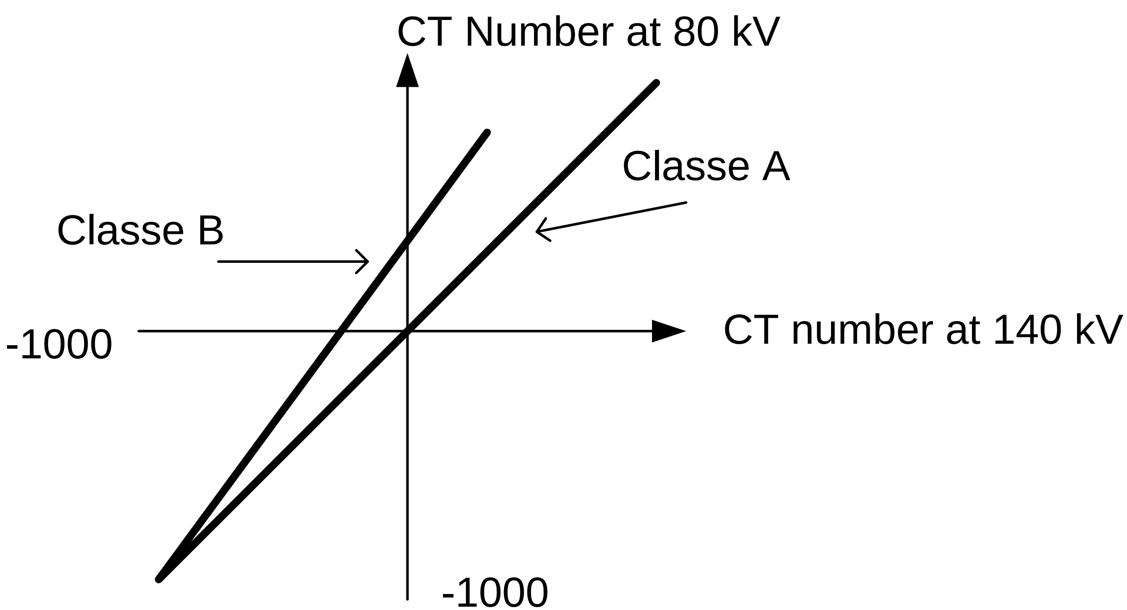
- In plane spatial resolution
  - Pixel size
    - Image 512x512 en general
      - Depends on the reconstructed field of view
  - Reconstruction filter
- Longitudinal spatial resolution
  - Reconstructed slice thickness
  - Detector configuration
    - 16x1.25 16x0.625 for example
  - Pitch value

Parameters and image quality

- How would you increase the contrast of tissues in CT ?
- How would you increase the in plane spatial resolution ?
  - What would be the impact
- How would you increase the longitudinal spatial resolution ?
  - What would be the impact

Exercices

- Two categories of material (classes A et B) are scanned at 80 kV and then at 140 kV. How would you analyze the following behavior ?

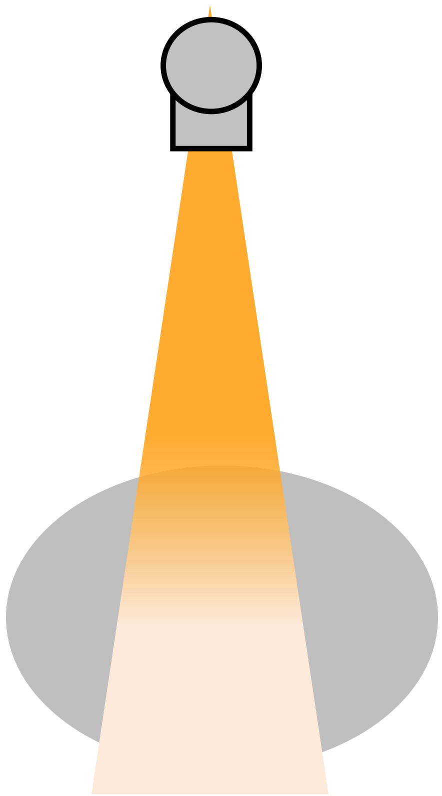


Exercices

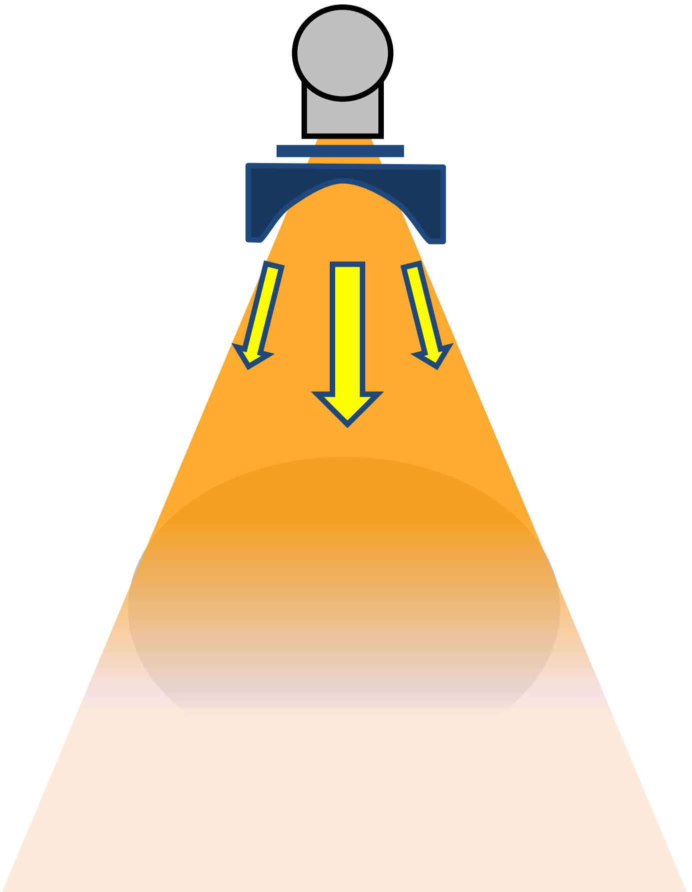
- What is roughly the pixel size of a radiograph ?
- What is roughly the pixel size of a CT image?
  - What is the higher frequency one can expect to get?
- Propose a solution to increase the data sampling in CT
- How would you reduce the acquisition time
  - For cardiac application for example

Dose distribution in Scan Plane

- In CT whole body irradiated



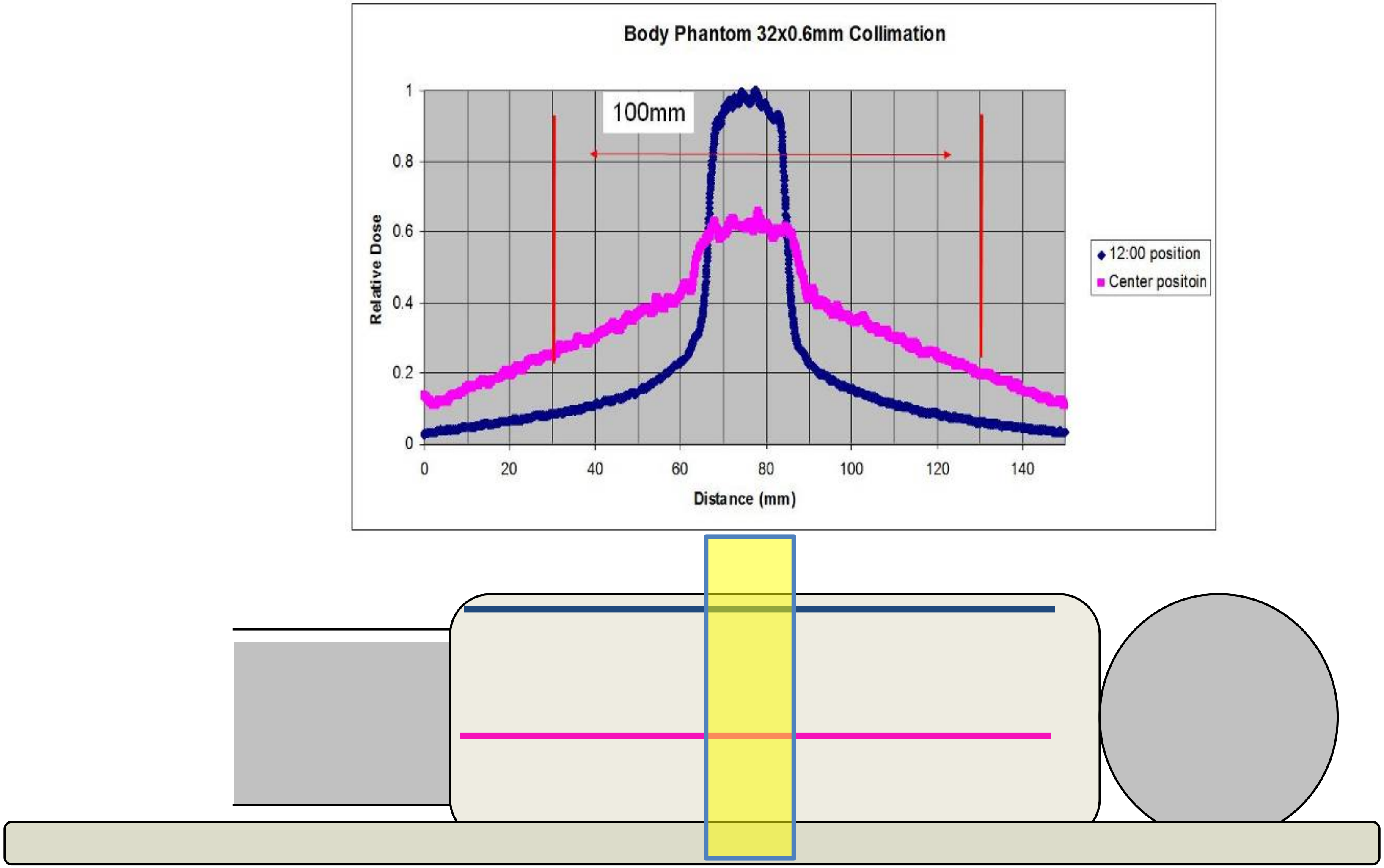
Projection radiography



X-ray CT

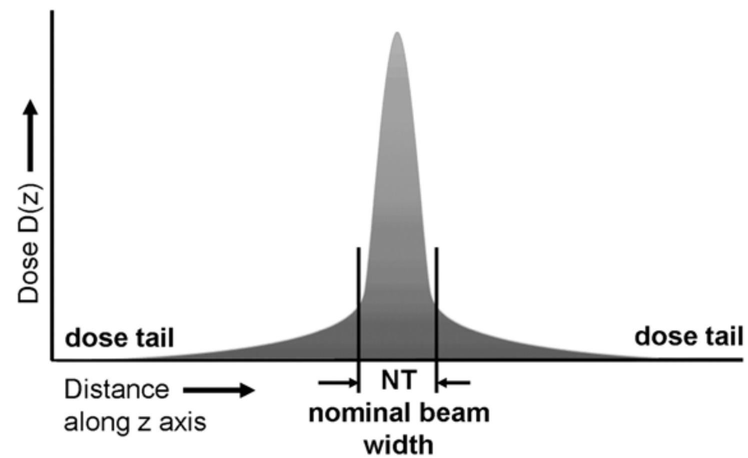
Dose distribution in CT

Dose profile from one slice



Dose indicators in CT: CTDI and DLP

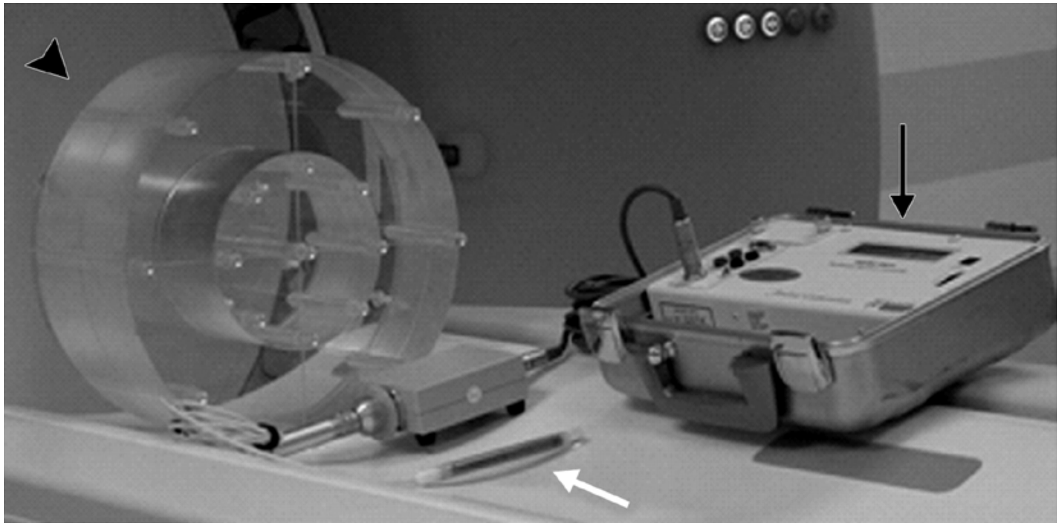
- Computed Tomography Dose Index
  - Introduced in the seventies by the FDA
    - Can be measured in air or in phantom
      - Normalized Computed Tomography Dose Index in air (${}_{n}CTDI_{air}$)
        - » Tube output in mGy per mAs at isocentre



The radiation dose profile along a line perpendicular to the plane of a single axial CT scan shows a peak where the primary beam slices through the CTDI phantom.
The tails of the dose profile are caused by scattered radiation. The integral of the area under the curve is normalized to the nominal beam width *NT* to determine the CTDI. A $CTDI_{100}$ value is obtained if integration limits of ±50 mm are used

Bauhs J A et al. Radiographics 2008;28:245-253

CTDI evaluation



Equipment typically used to measure $CTDI_{100}$ includes an integrating electrometer (black arrow), a 100-mm-long CTDI ionization chamber (white arrow), and a CTDI phantom made of polymethylmethacrylate (arrowhead).

All CTDI measurements made with a pencil ionization chamber are performed with a stationary patient table.

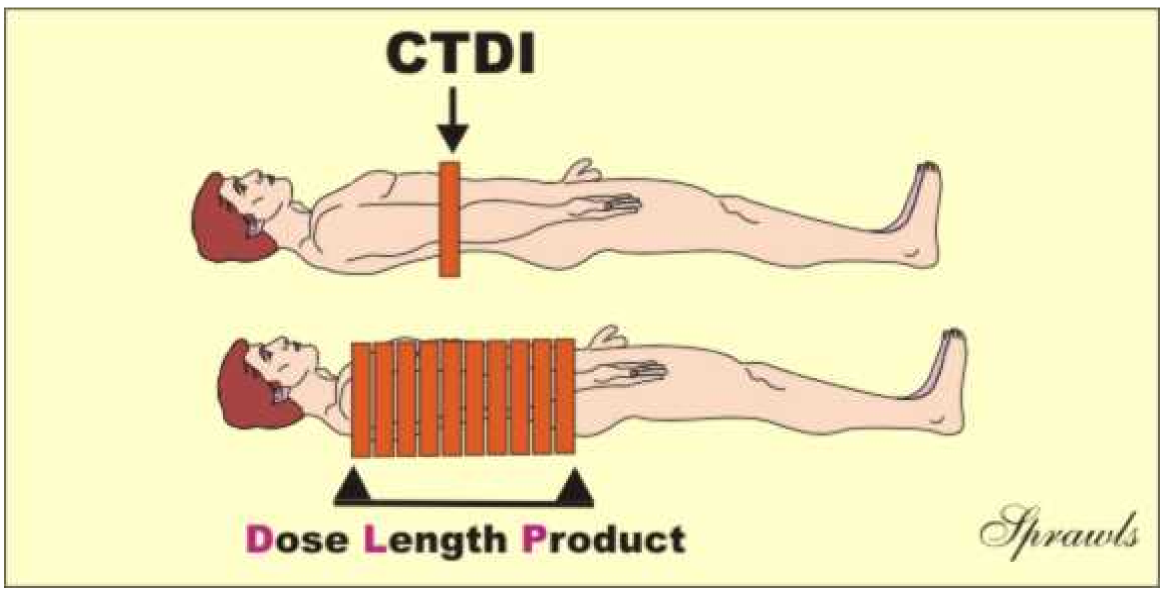
$${}_{n}CTDI_{w} = 1/3\ {}_{n}CTDI_{centre} + 2/3\ {}_{n}CTDI_{periphery}$$

$${}_{n}CTDI_{vol} = {}_{n}CTDI_{w} / \text{pitch}$$

Bauhs J A et al. Radiographics 2008;28:245-253

Dose length product (DLP)

- Dose descriptor used to indicate overall exposure for CT
- DLP = $CTDI_{vol}$ x scan length
- Relates to risk



How to calculate effective dose (2)

DLP conversion to effective dose (Adults)

Region of body	Normalized effective dose E_{dlp} ($mSv\ mGy^{-1}\ cm^{-1}$)
Head	0.0023
Neck	0.0054
Chest	**0.017**
Abdomen	0.015
Pelvis	0.019

Conclusion

- Present situation of CT
  - Sub-millimeter 3D imaging procedure
  - Cardiac → between 70 and 140 ms acquisition time
- 10% radiological examinations → 70 % exposure dose
- FBP → Iterative reconstruction
  - Non linear process → image quality assessment becomes challenging