Physics & Technology of Multi-slice CT

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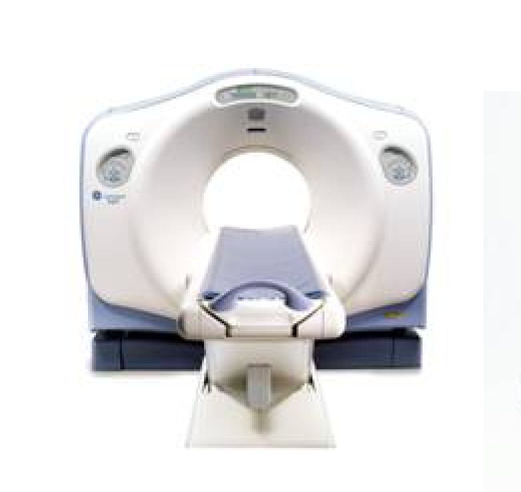
ImPACT

Aims

- Some key factors about MSCT
  - construction of scanners
  - reconstruction techniques
  - artefacts
  - other factors
- Concepts and ideas
  - keep it non-mathematical!

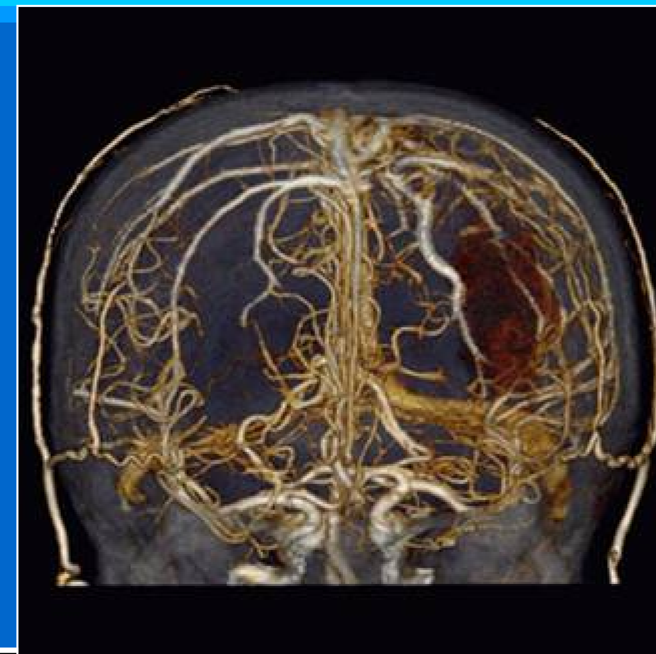
MSCT scanners

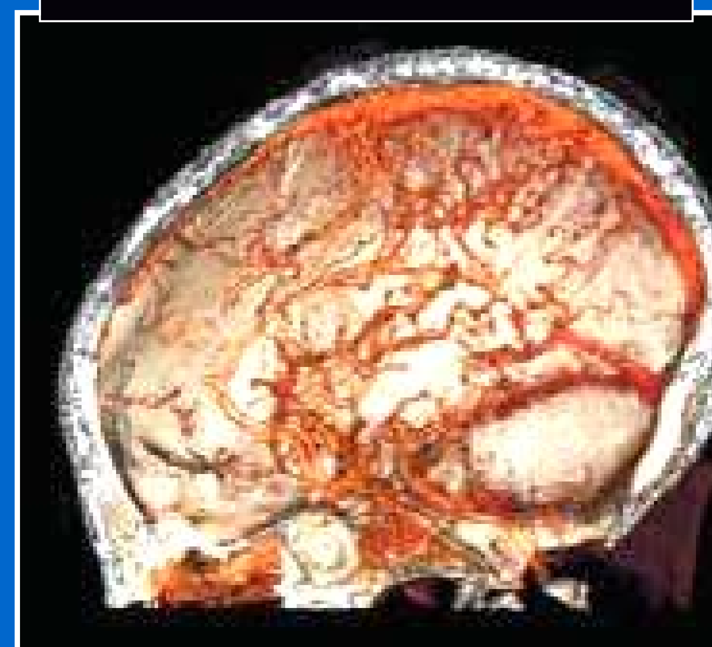
- 1991 Dual slice
- 1998 Four slice
- 2002 16 slice
- 2003 32 slice
- today
  - 64 sub-mm slices
  - 0.4 s rotation



Clinical scanners

- Image quality and capability increasing



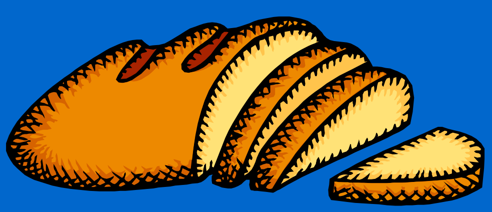


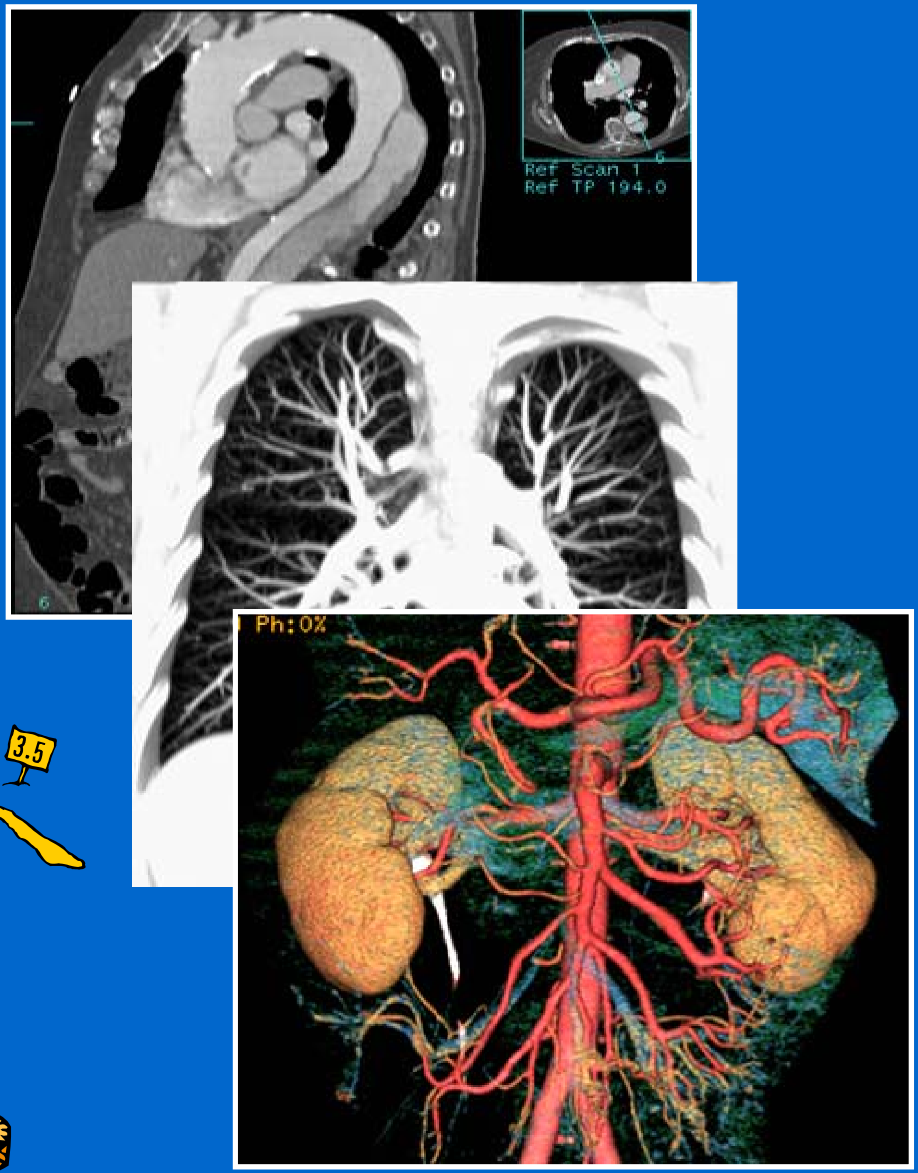
The 3 Fs of CT

- **F**aster

- **F**urther

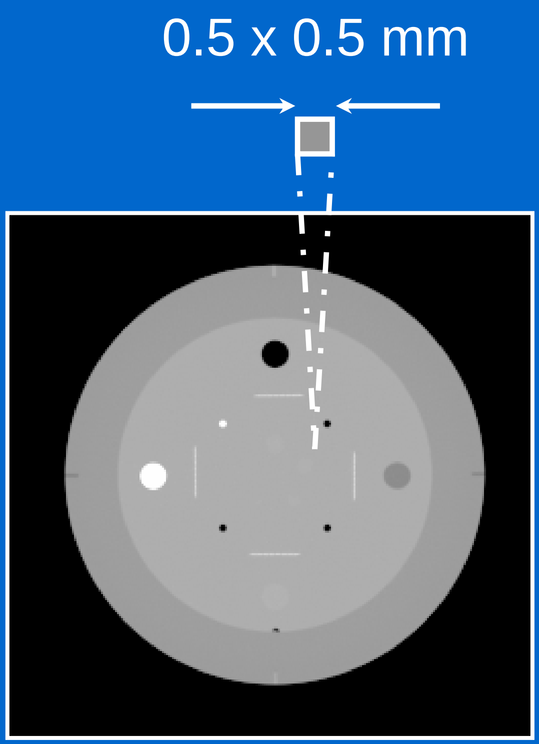
- **F**iner

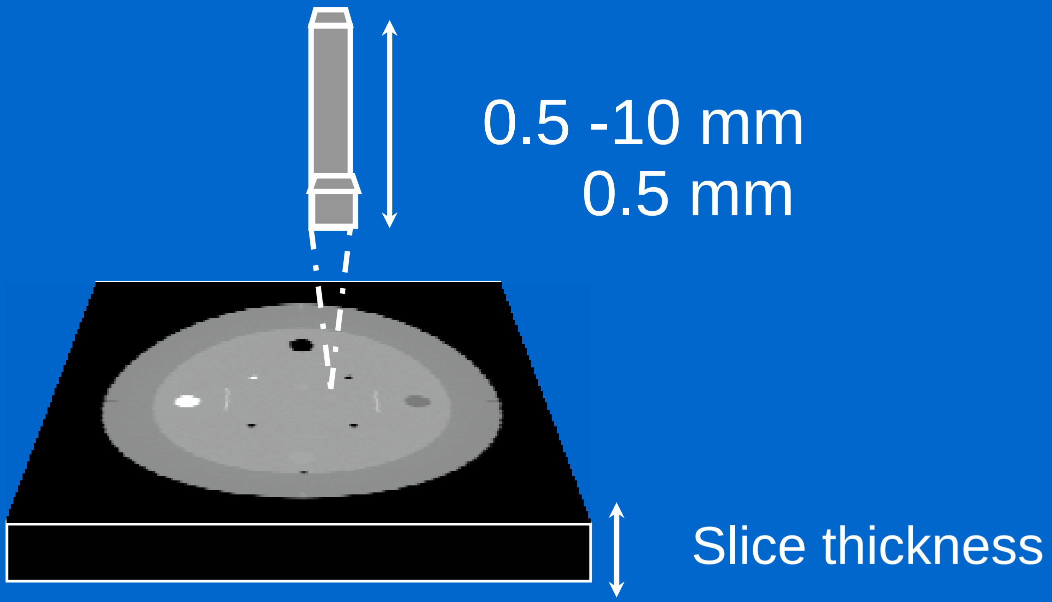




Isotropic imaging

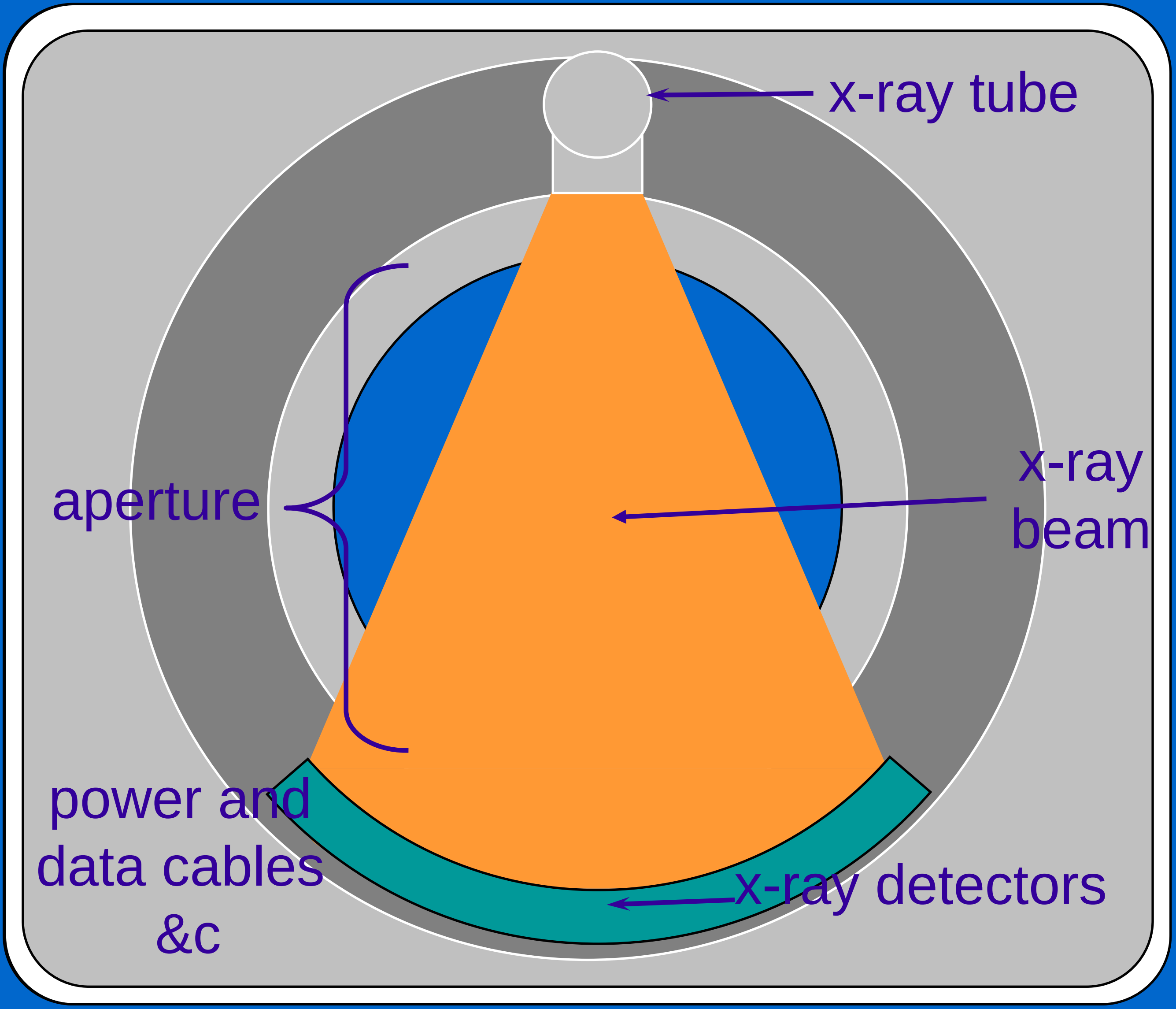
- 2D pixel in a CT image represents a 3D voxel
- Resolution is ideal when equal in all 3 dimensions
  - best results with slice thickness equal to (axial) pixel size
  - routine 0.5 - 1 mm slice thickness achieves this goal





Scanner design

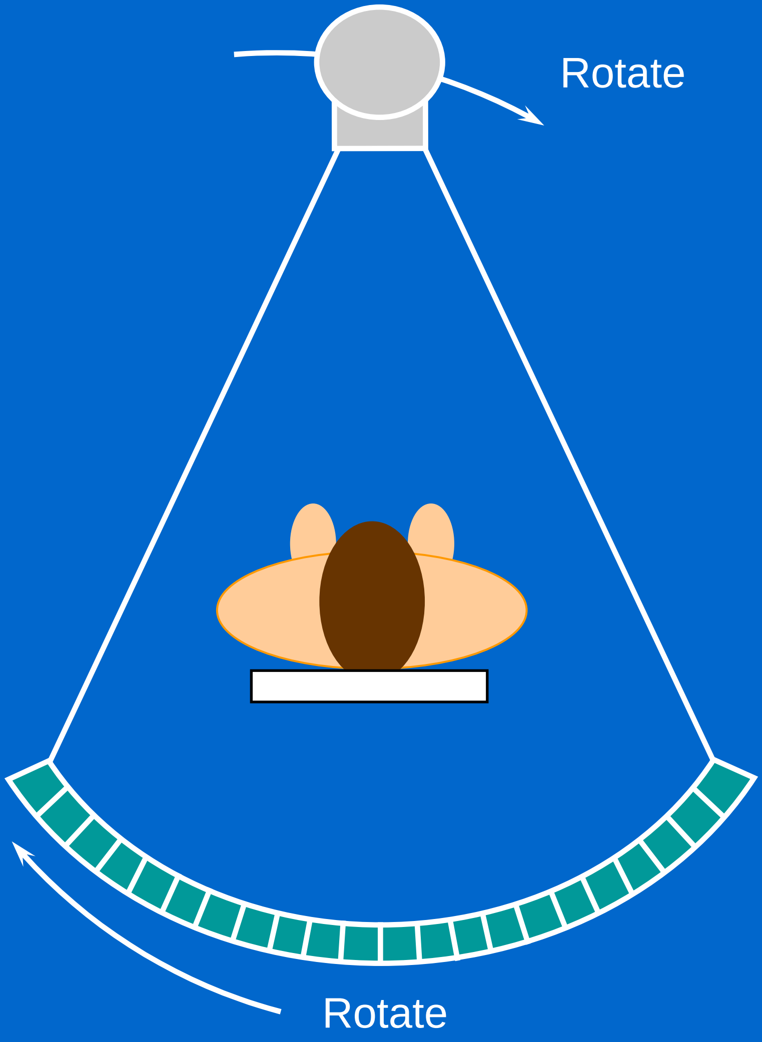
- What's under the covers ?



"Third generation" CT scanners

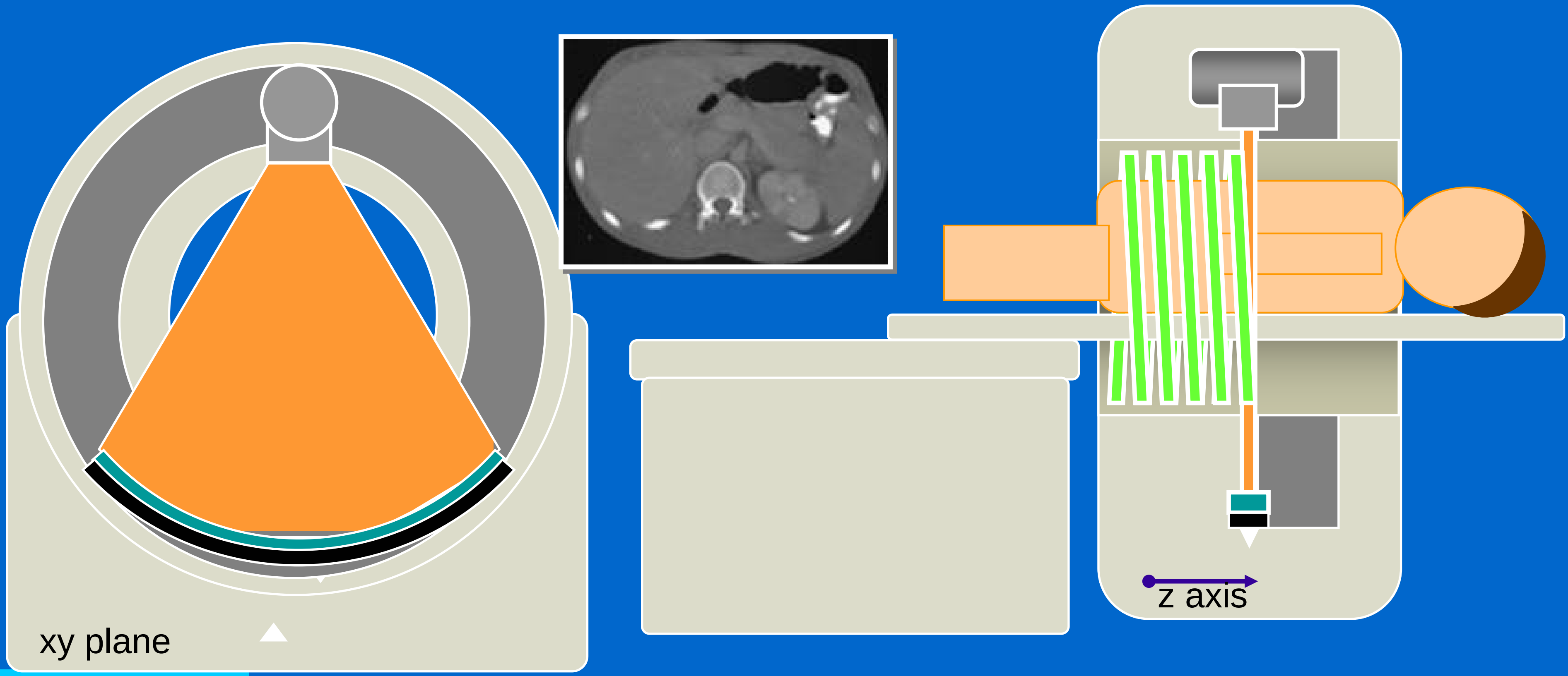
- Tube & detectors
  - rotate around patient gathering x-ray projections
- Projection data used to form slice images
  - filtered back projection

Rotate – Rotate
the modern scanner design



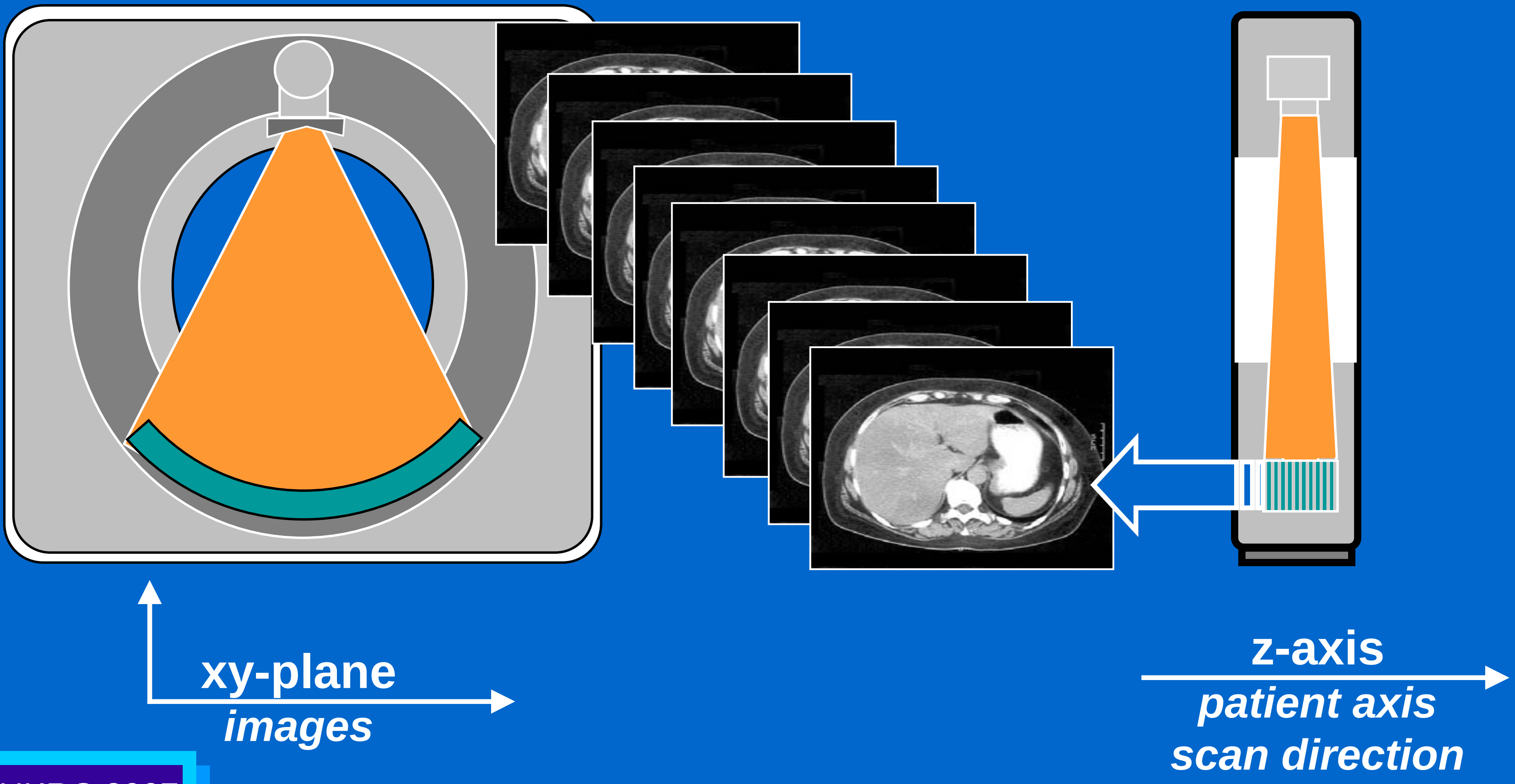
Helical CT

- Continuous gantry rotation + continuous table feed
- Scan data traces a helical path - or 'spiral' - around patient
  - data used to form axial images

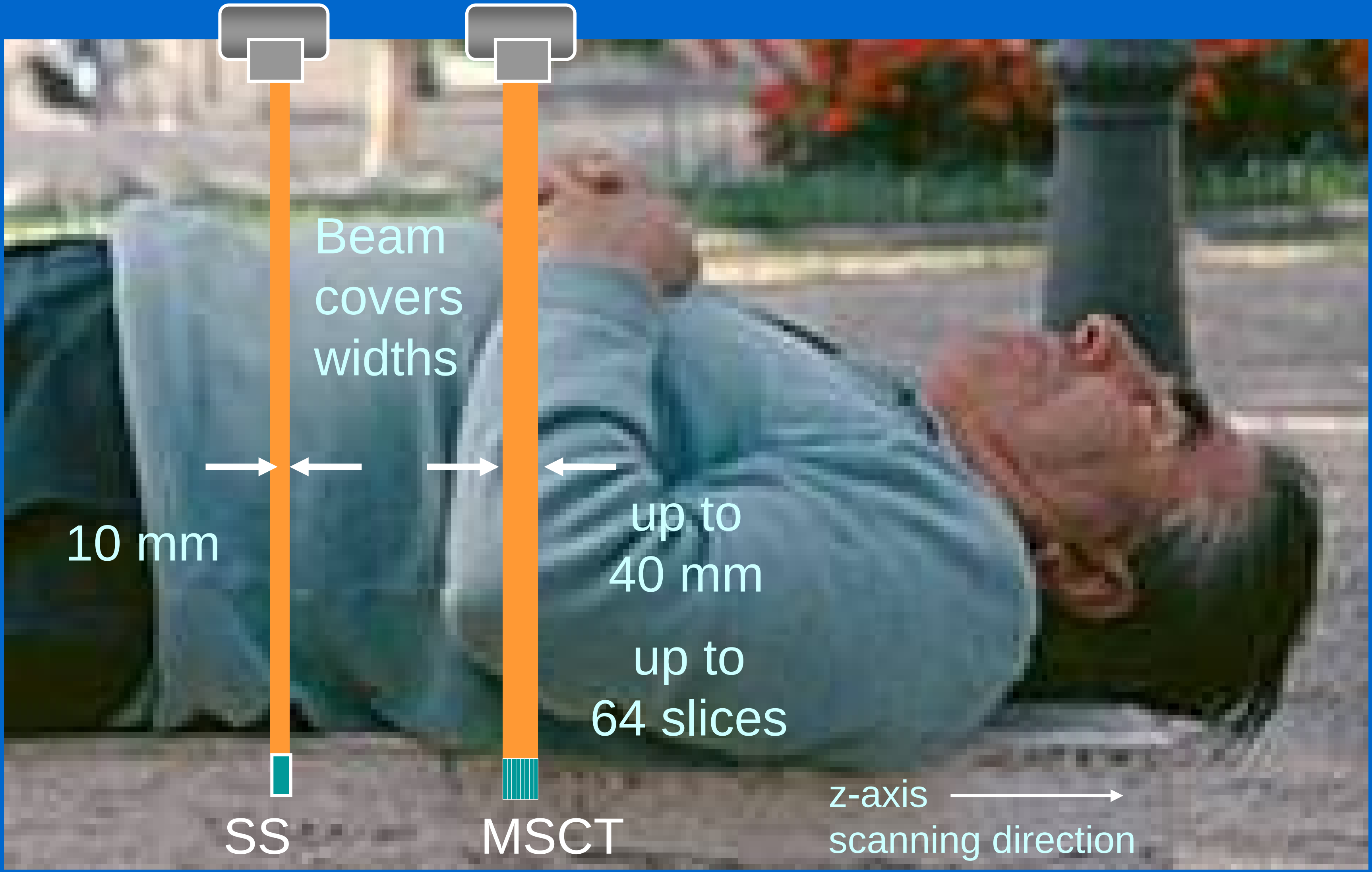


Multi-slice CT scanning

- Many features in common with single slice (SSCT)
  - multiple parallel detector banks along z-axis
  - enables a number of projections to be acquired simultaneously

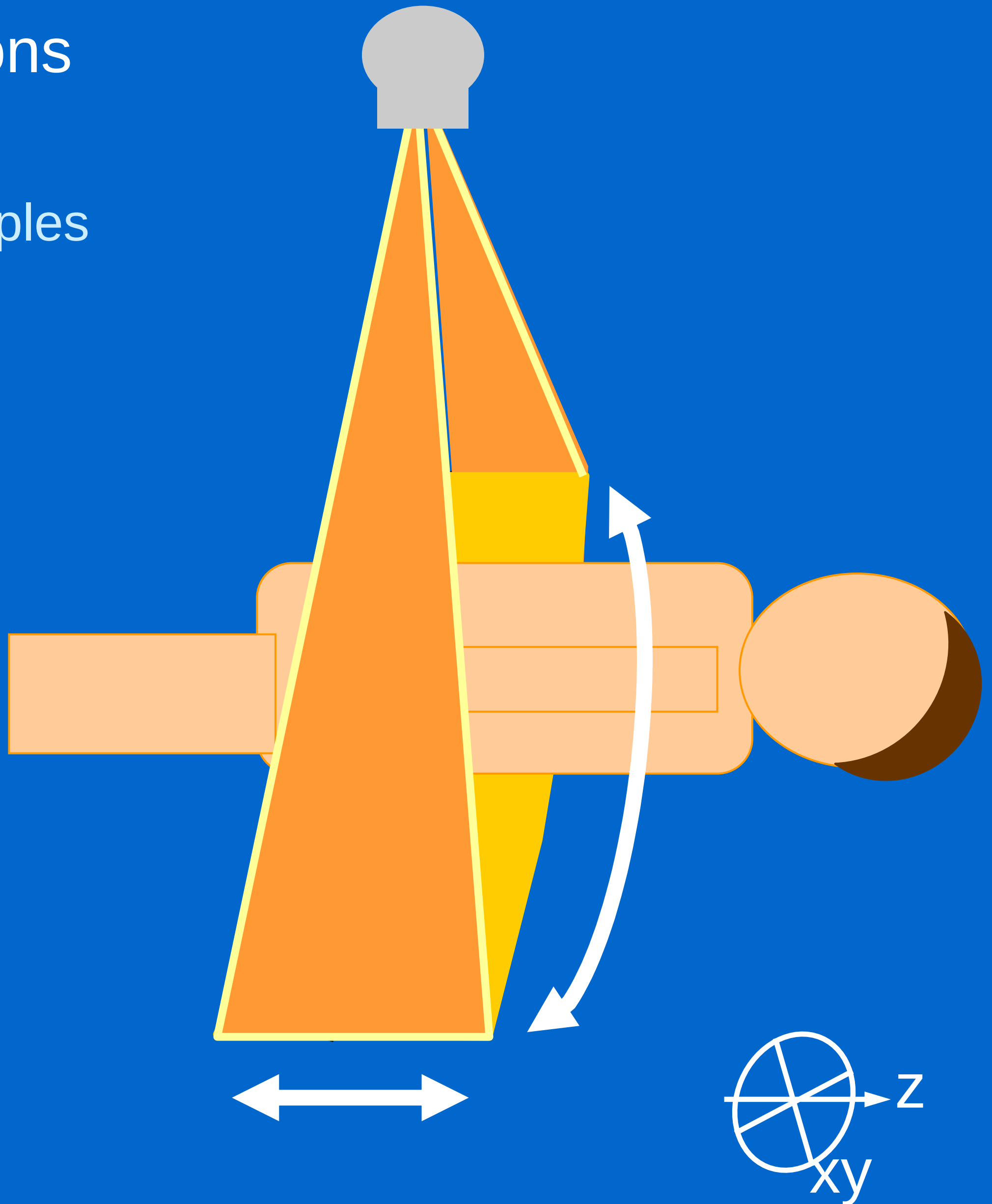


MSCT scanning: in scale



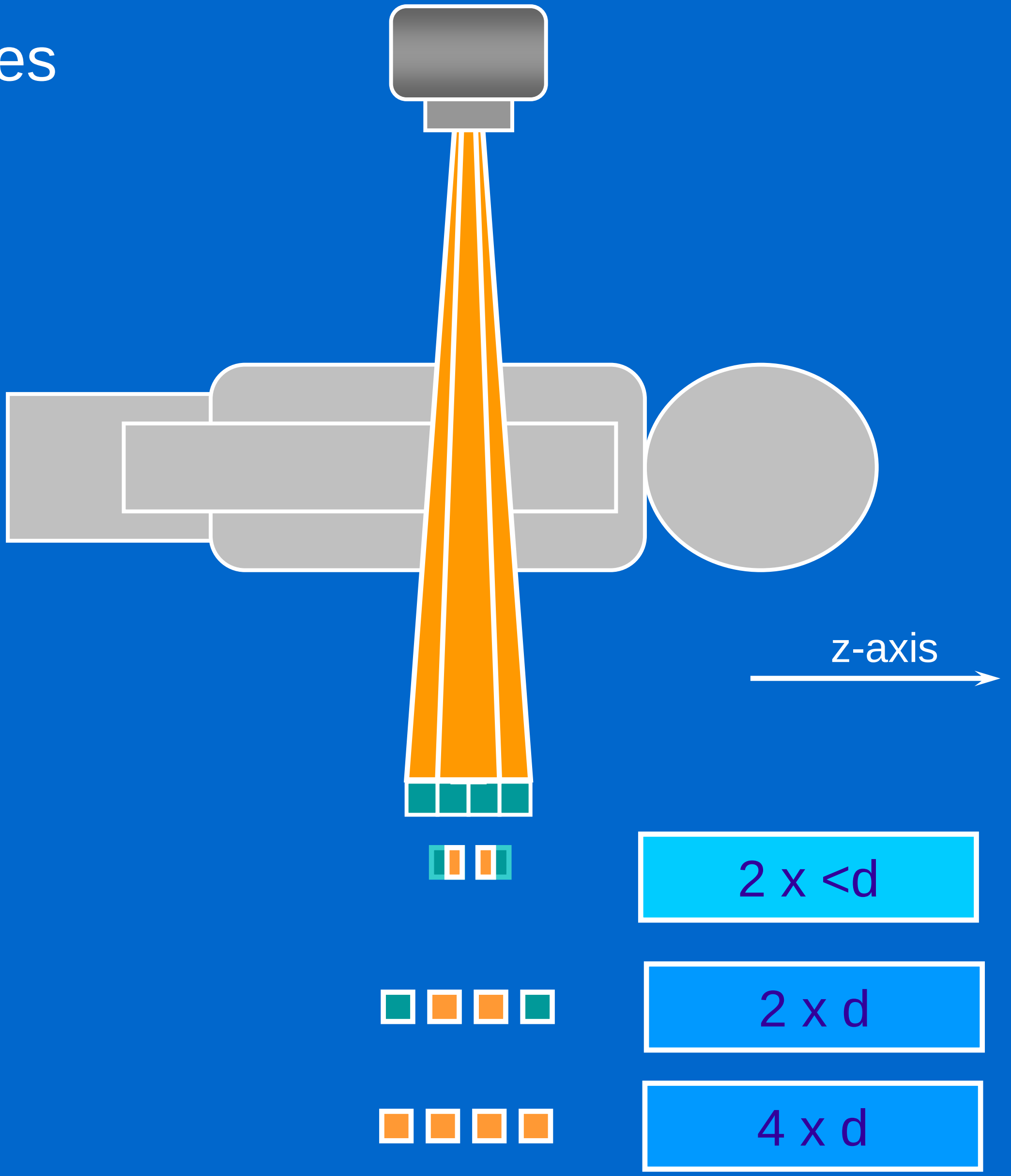
Detector banks

- Array extends in 2 directions
  - xy-plane
    - arc to collect many samples for each projection
  - z-axis
    - along the patient length
- SSCT
  - z-axis coverage: one element
- MSCT
  - many z-axis elements



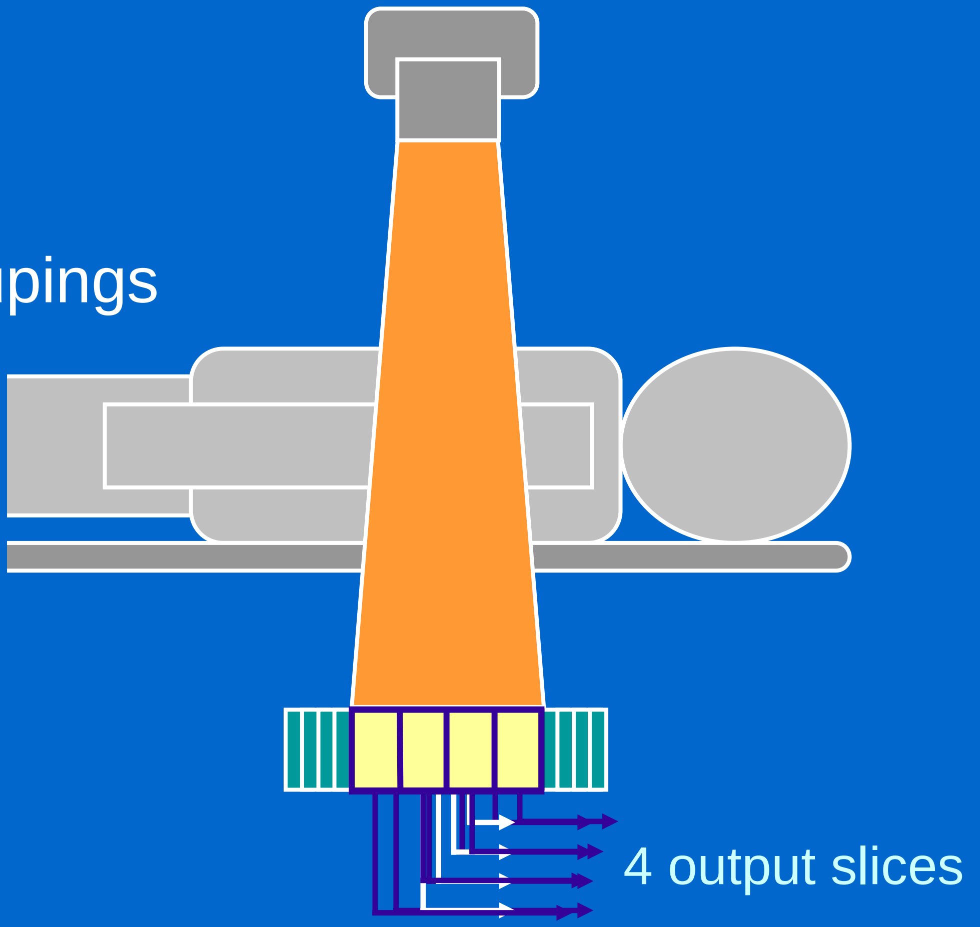
Slices & detectors

- Just 4 detectors reduces options for scanning
- Narrow coverage
  - eg. 5 mm for d=1.25 mm



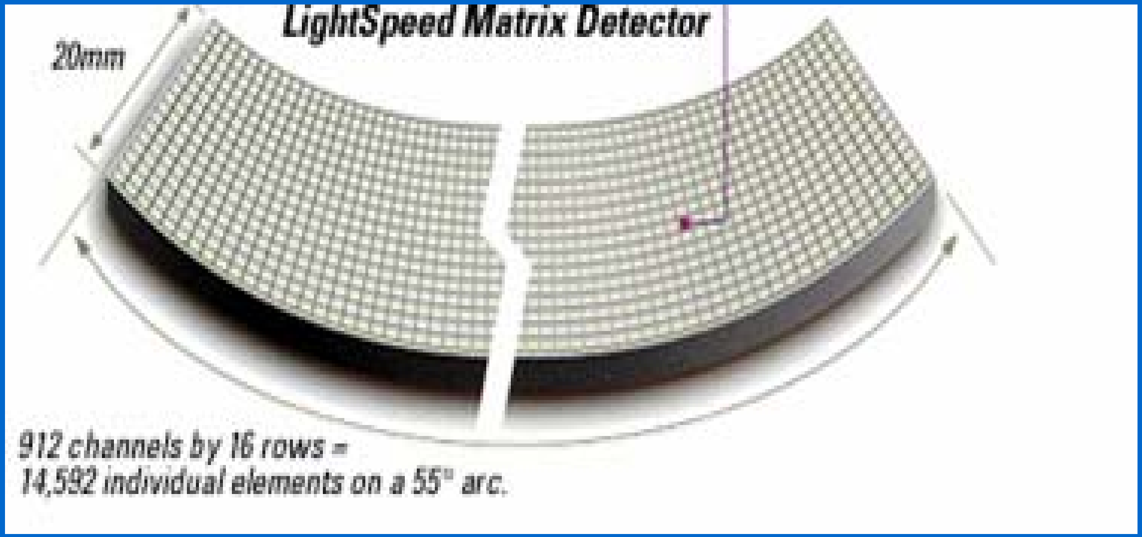
Slice width selection: 4 slice

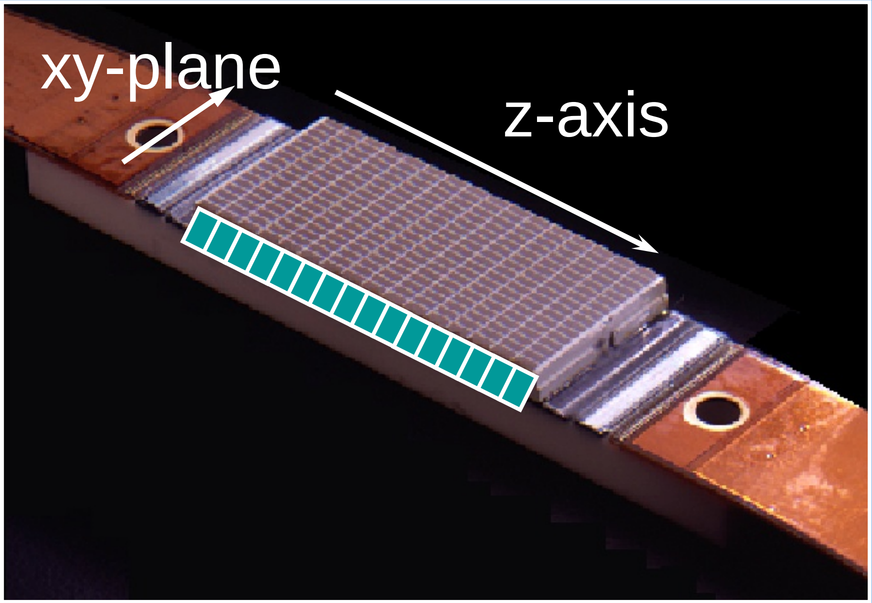
- For more flexibility
  AND
  greater coverage
  need more detectors
- Can collect data from groupings of detectors
  - individual detectors
    - 4 x d
  - pairs
    - 4 x 2d
  - triples
    - 4 x 3d



Slice options: real example

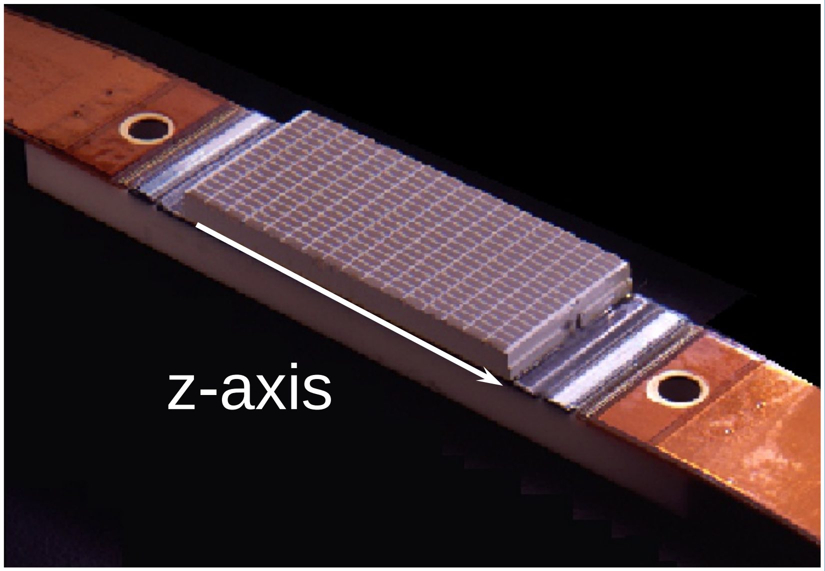
- GE LightSpeed
  - 4 slices
  - 16 detectors in z-axis

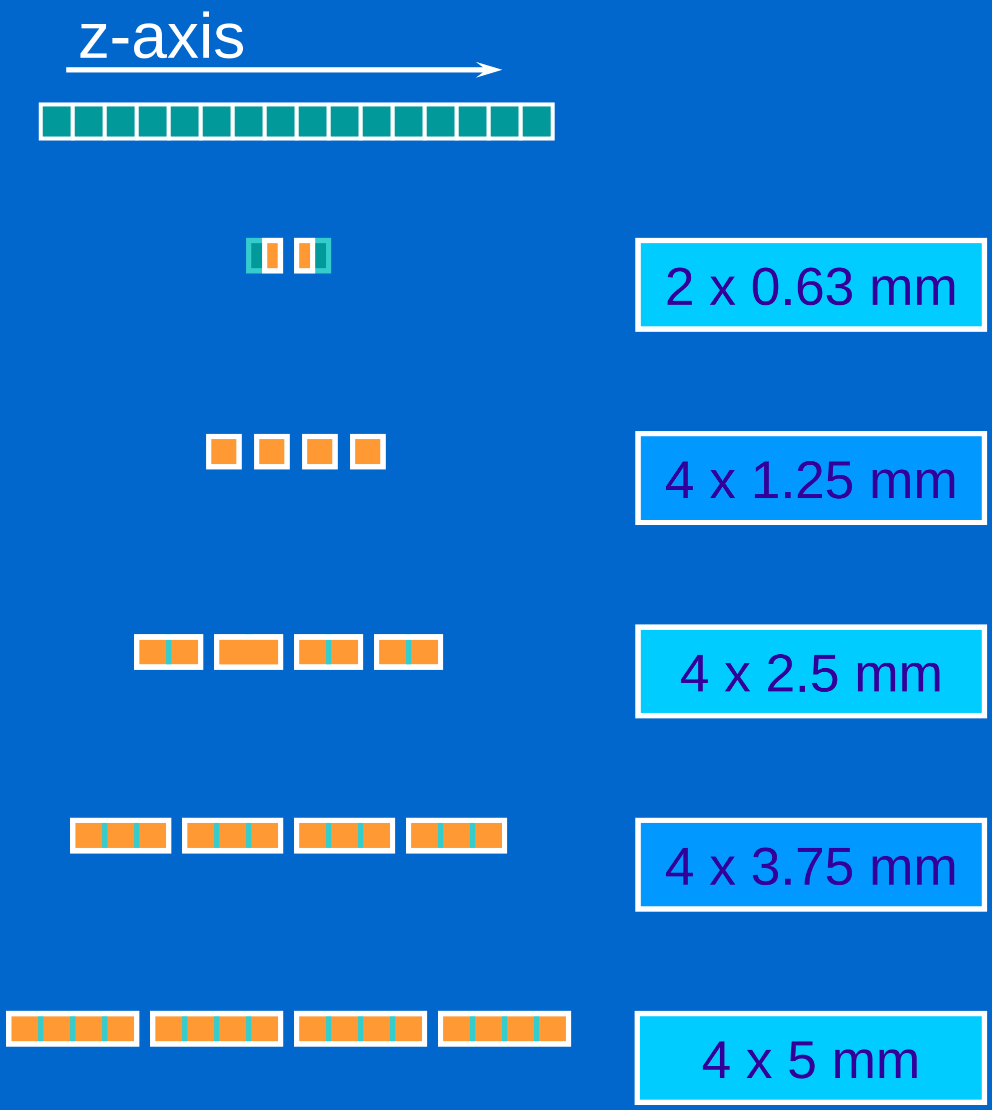




Slice options: real example

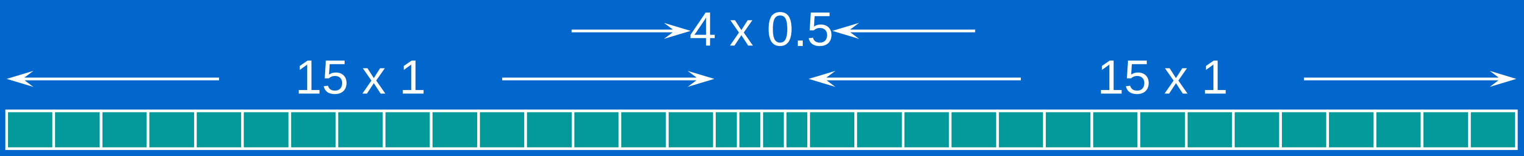
- GE LightSpeed
  - 4 slices
  - 16 detectors
- Detector output combined to define data acquisition width
- Coverage up to 20 mm





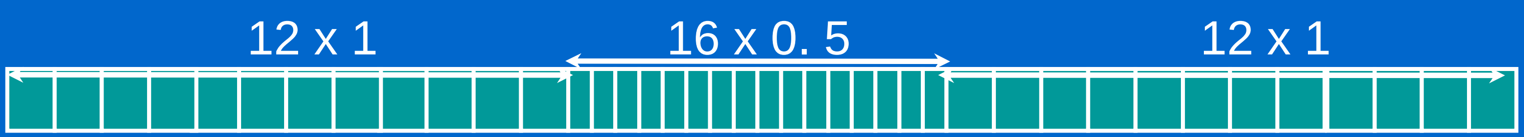
Adaptive arrays

- Detector elements not all same size
  - e.g. Toshiba Aquillion series



4 x 0.5
4 x 1
4 x 2
4 x 3
4 x 5
4 x 8

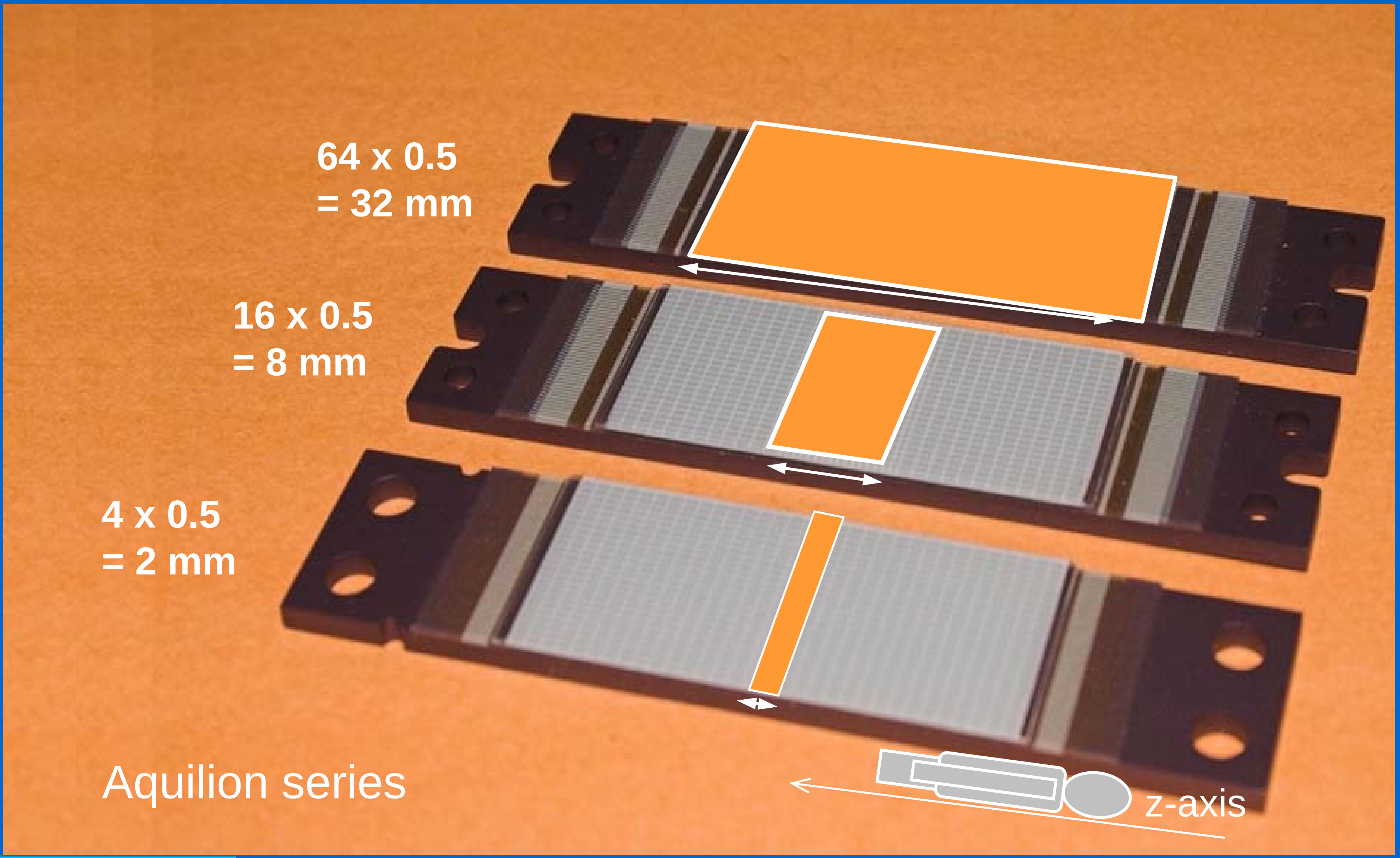
Aquilion 4
34 detectors



16 x 0.5
16 x 1
16 x 2

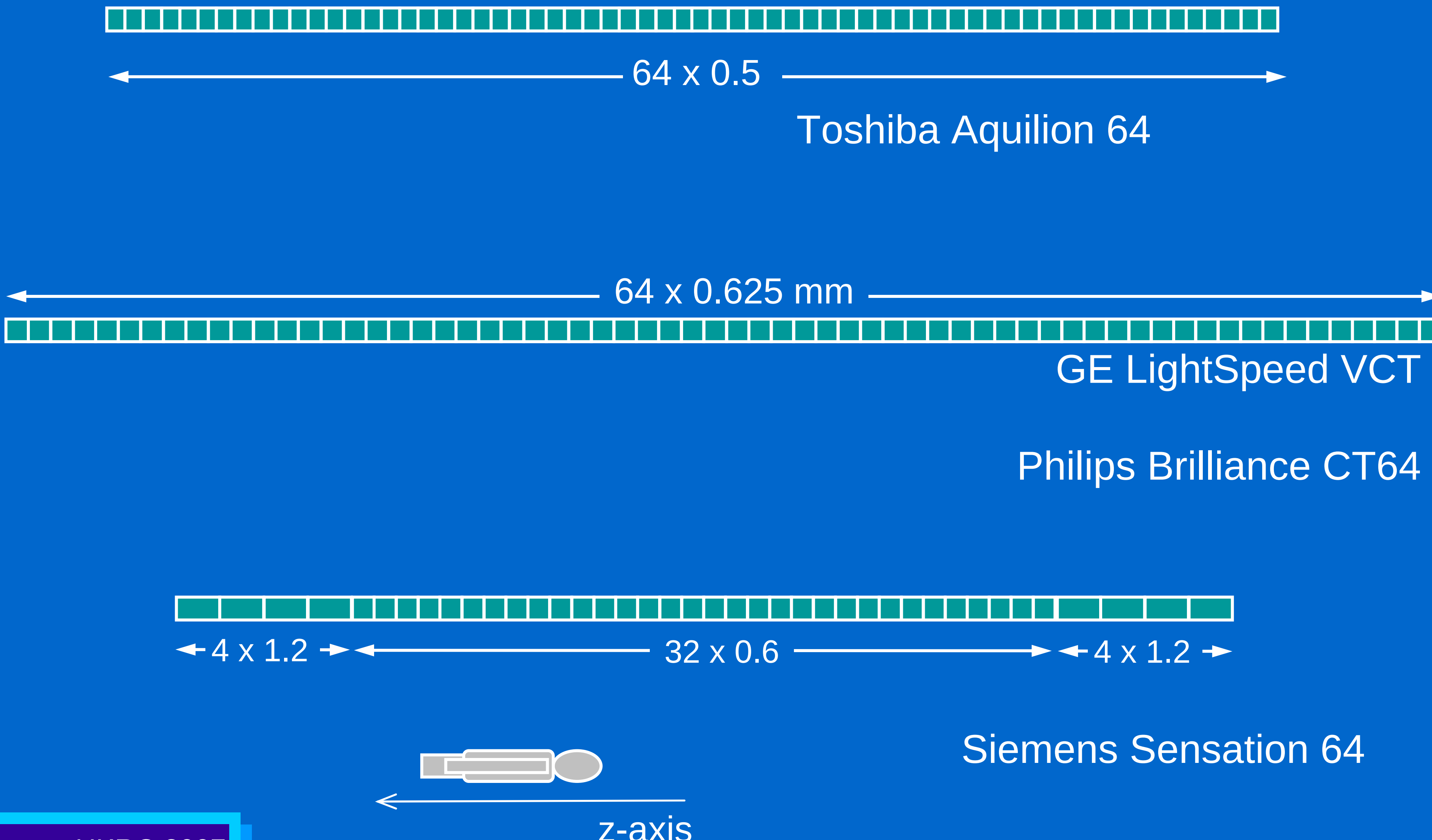
Aquilion 16
40 detectors

More "thinnest-slice" coverage



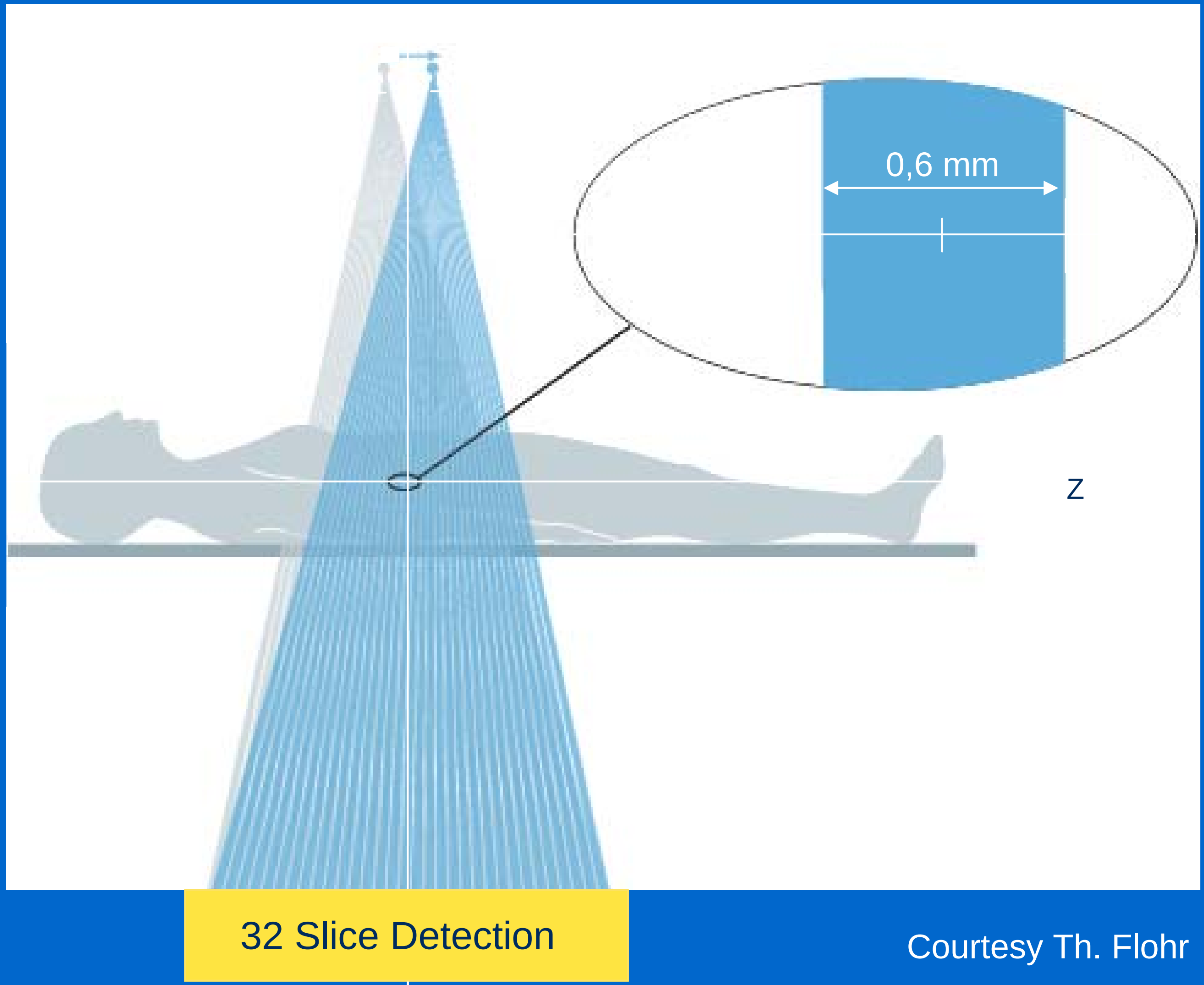
Detector mock-ups courtesy of Toshiba

64 slice scanners



64-Slice CT: double sampling

- z-flying focal spot
- 32 detectors -> 64 data channels



Courtesy Th. Flohr

? CT

- Multi-slice CT MSCT
- Multi-detector CT MDCT
- Multi-channel CT MCCT
- Multi-row CT (MRCT less common as abbreviation)

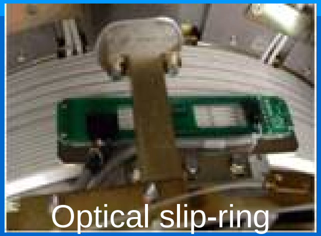
- All effectively the same thing

- Note: care when using “SSCT”
  – normally used for single slice
  – can sometimes refer to single source
    - check the context

Design considerations

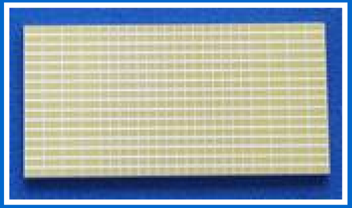
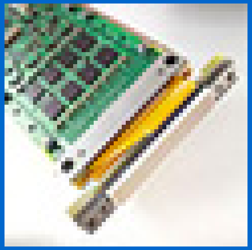
- Scan gantry
  - mechanical stresses
  - data & power feed





- Tubes
  - high currents
    - narrow slices; fast rotations
  - tube cooling
  - generator response


- Detectors
  - responsive
  - efficient
  - small

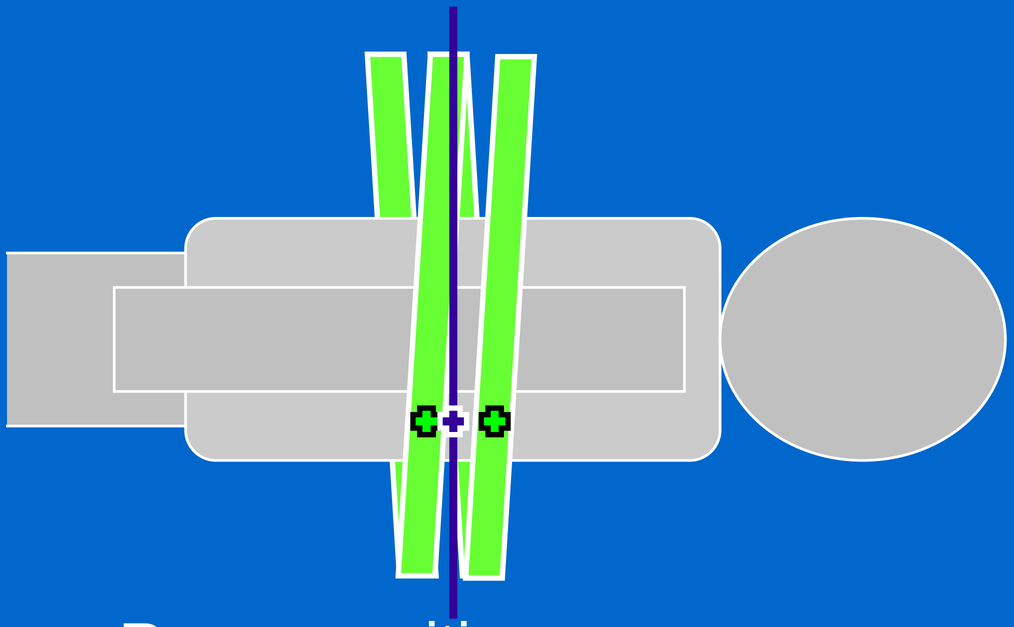
- Electronics / computers / reconstruction hardware

More challenges for MSCT

- Reconstruction
- Artefacts
- Dose efficiency
- Data management

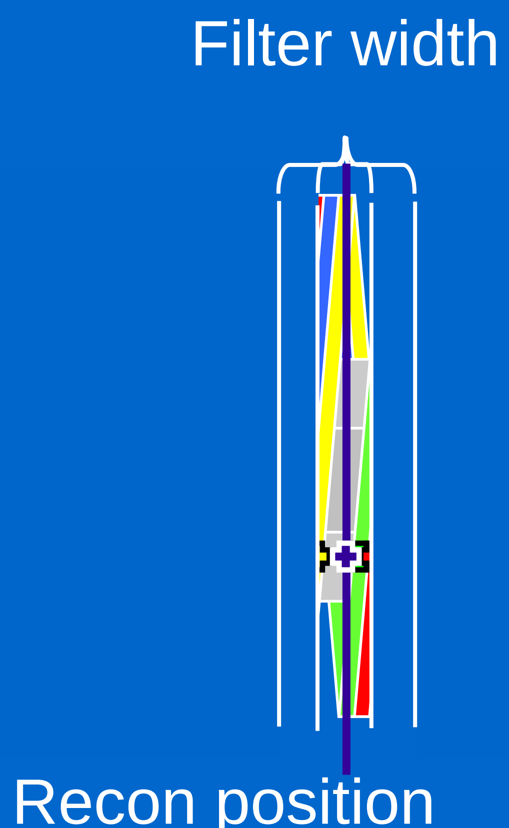
Using helical data

- Single slice: interpolate using 2 nearest data points



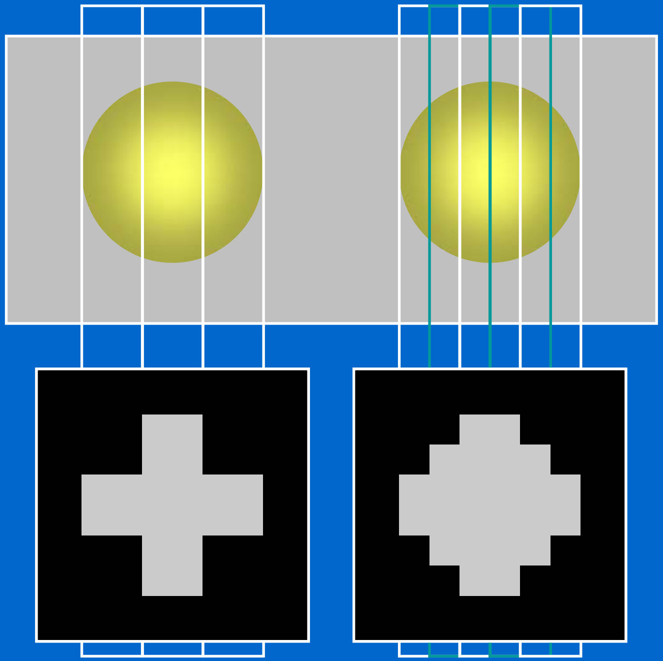
Using helical data

- Single slice: interpolate using 2 nearest data points
- Up to 8 slice MSCT: use all data within a variable ‘filter width’ for interpolation



Flexibility of reconstruction

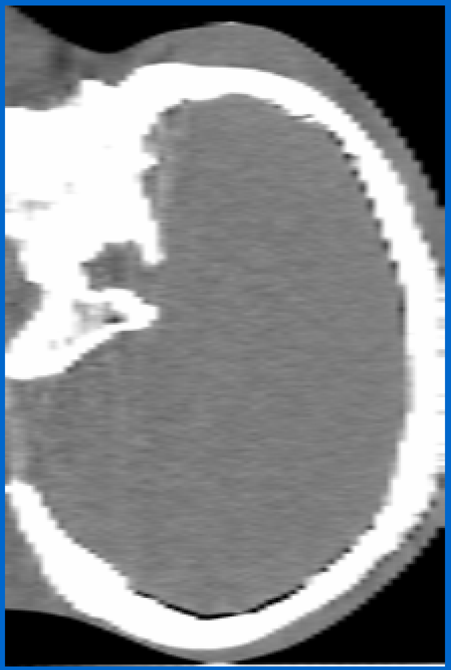
- 'Overlapping' reconstructions
  - better z-axis resolution
  - better 3D imaging



contiguous

Helical, overlapping

MPR of skull from 5mm slices

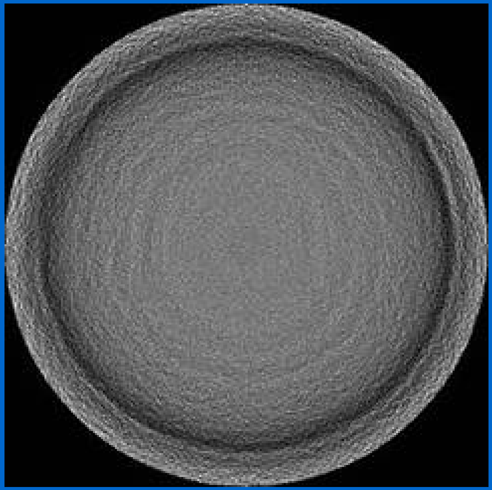


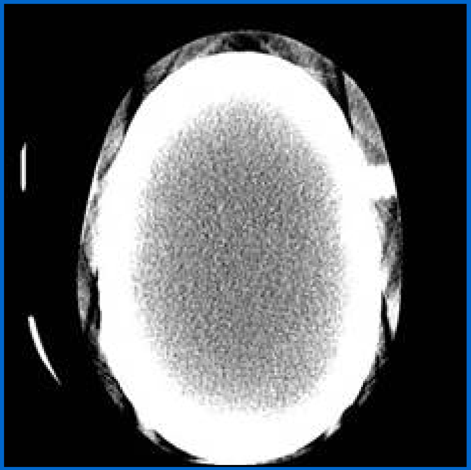
MPR of skull from 5mm slices recon every 2.5 mm

Artefacts

- All standard (SS) CT artefacts can still occur
  - ring artefact
  - beam hardening

- Specific issues for MSCT
  - cone beam
  - helical artefacts

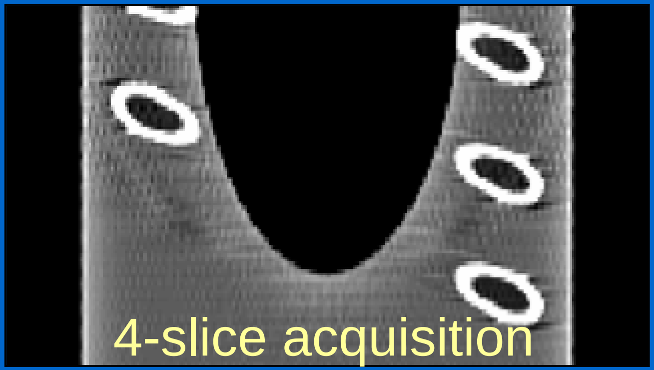




Cone beam artefacts

- Seen as streaks in image as number of slices increases
- Due to large cone angles and narrow slices

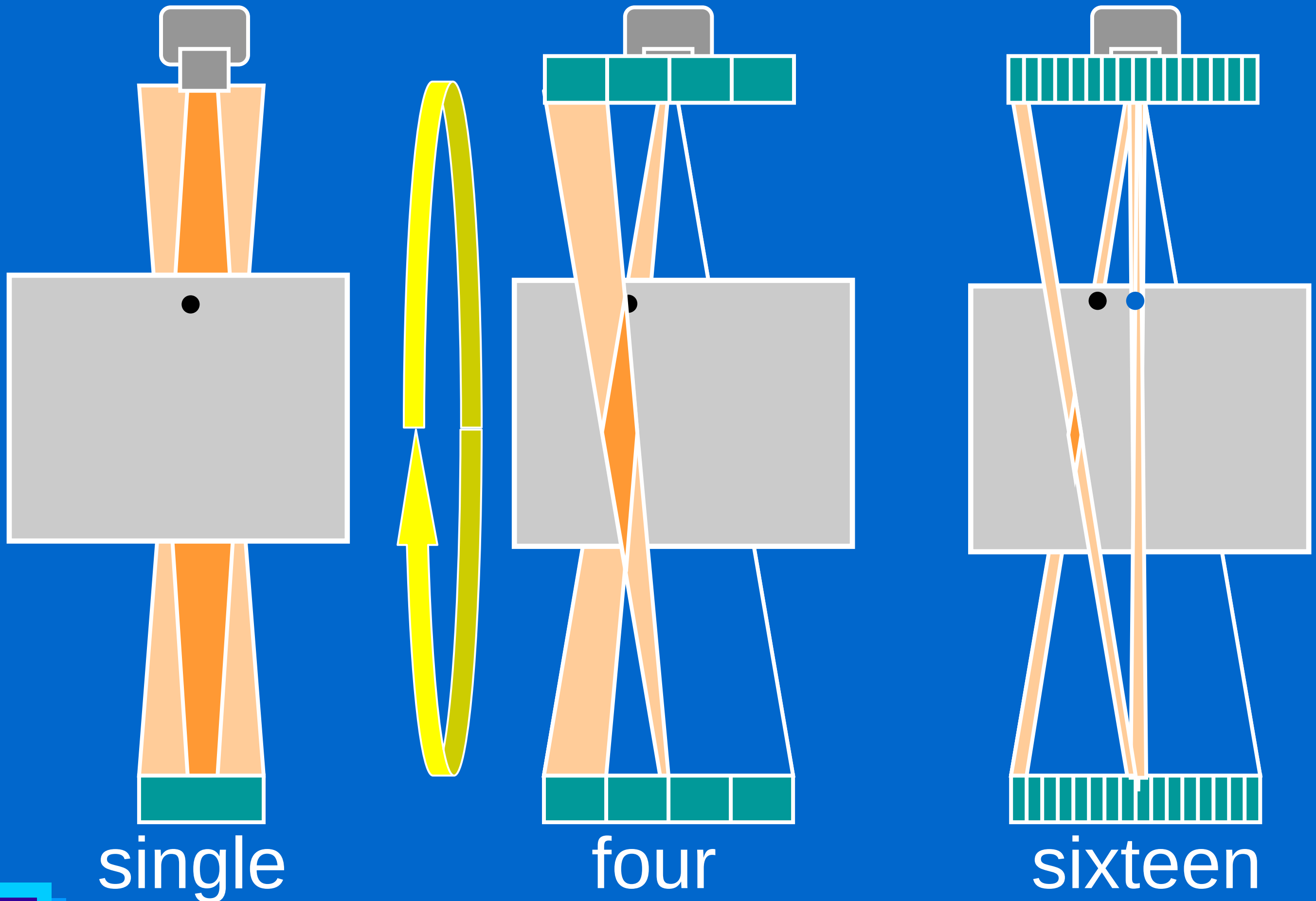
Thorax phantom



Courtesy: Siemens

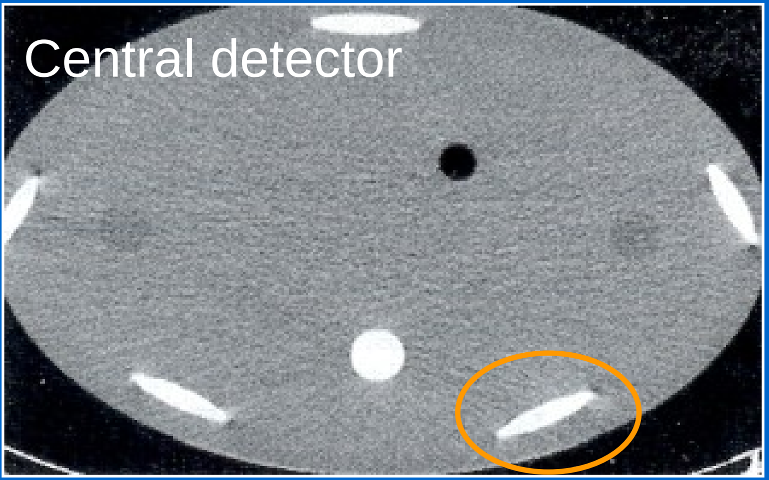
Cone beam

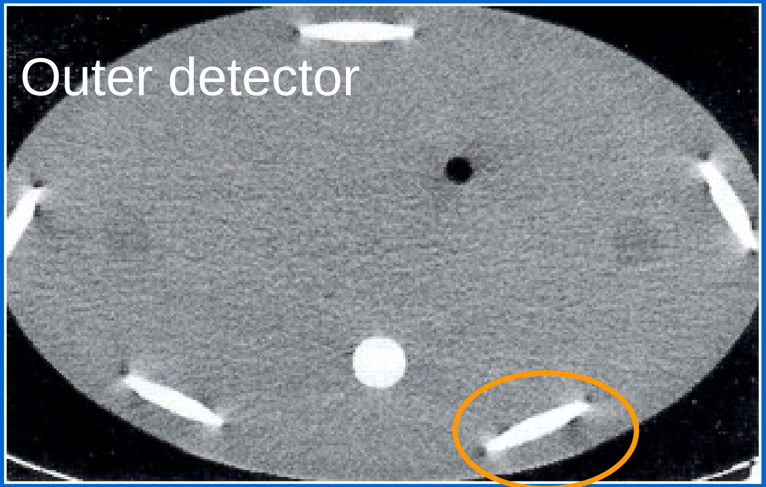
- As number of slices increases, beam is more diverging, outer slices are distorted
- Negligible up to 8 slices, significant for 16 slice scanners



Cone beam artefact

- Beyond 8 slices, special reconstructions needed to avoid cone beam artefacts
- Range of techniques are used
  - tilted (hyperplane, or non-orthogonal)
  - 3D (Feldkamp / FDK) reconstructions

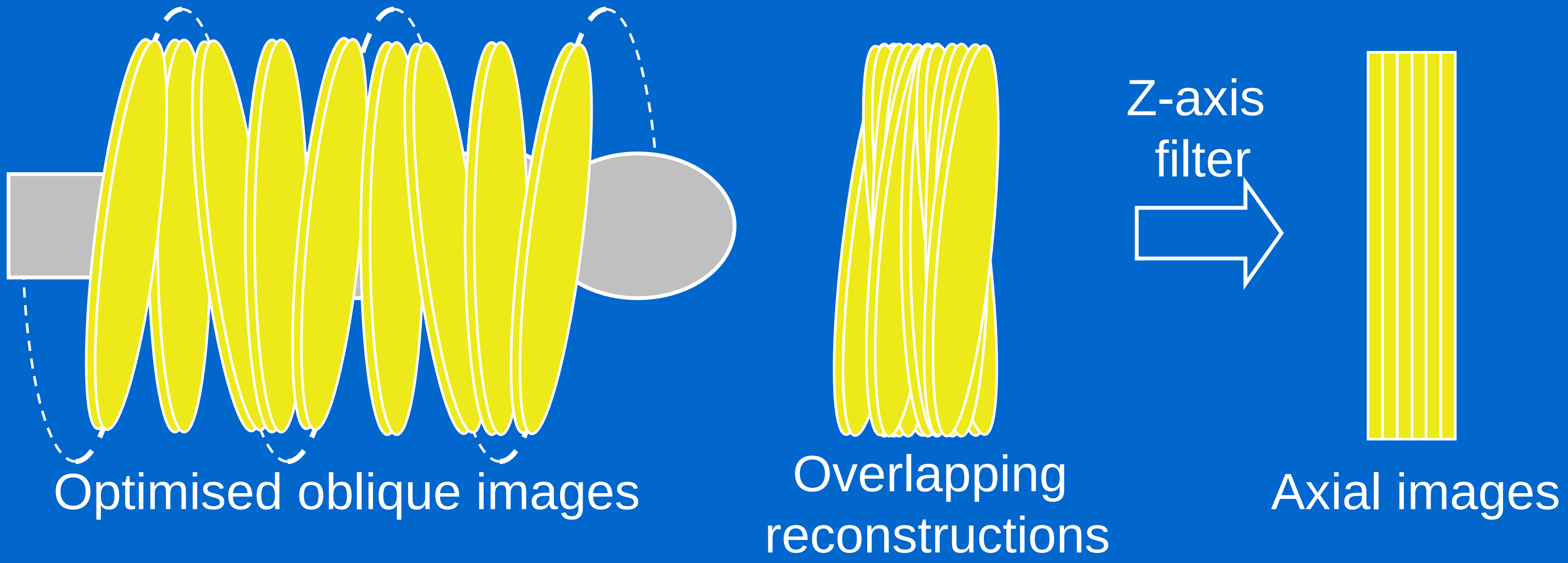




courtesy GE

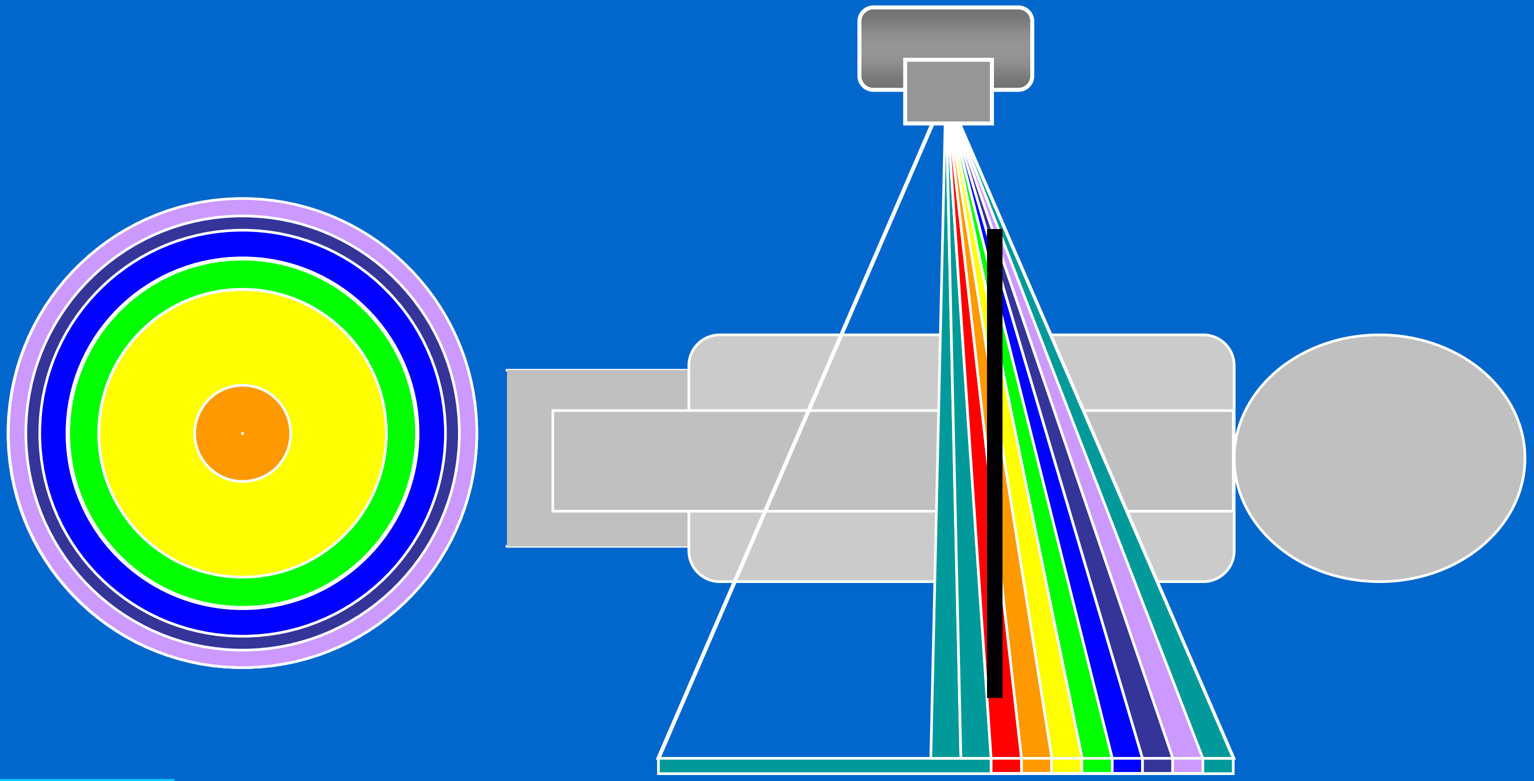
Tilted reconstruction

- ASSR techniques uses tilted reconstructions
  - images back projected along optimal oblique planes
  - reconstructed images then filtered to produce axial images



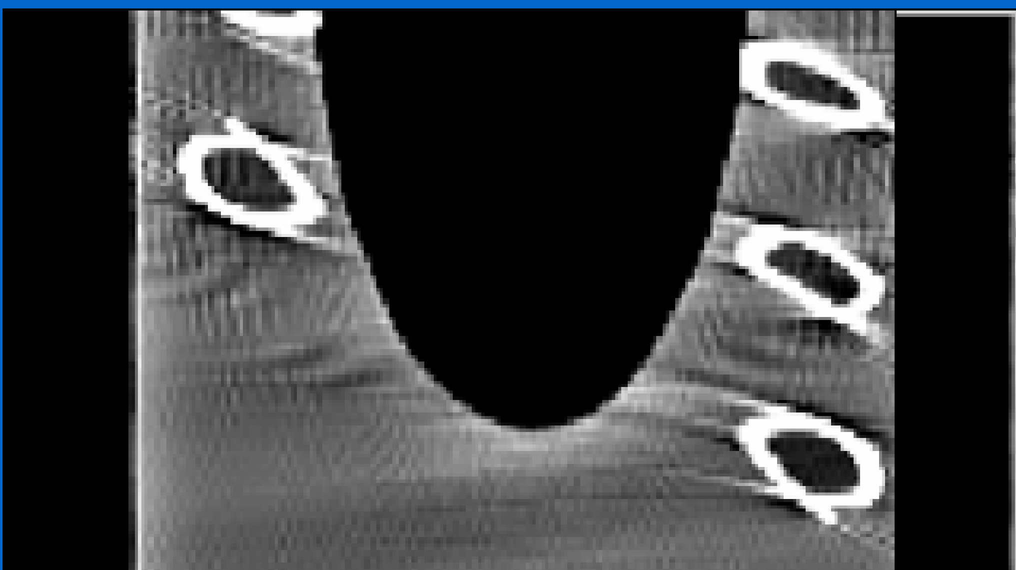
3D reconstruction

- Feldkamp based three dimensional reconstructions
  - extension of back projection to third dimension
  - requires more computing power

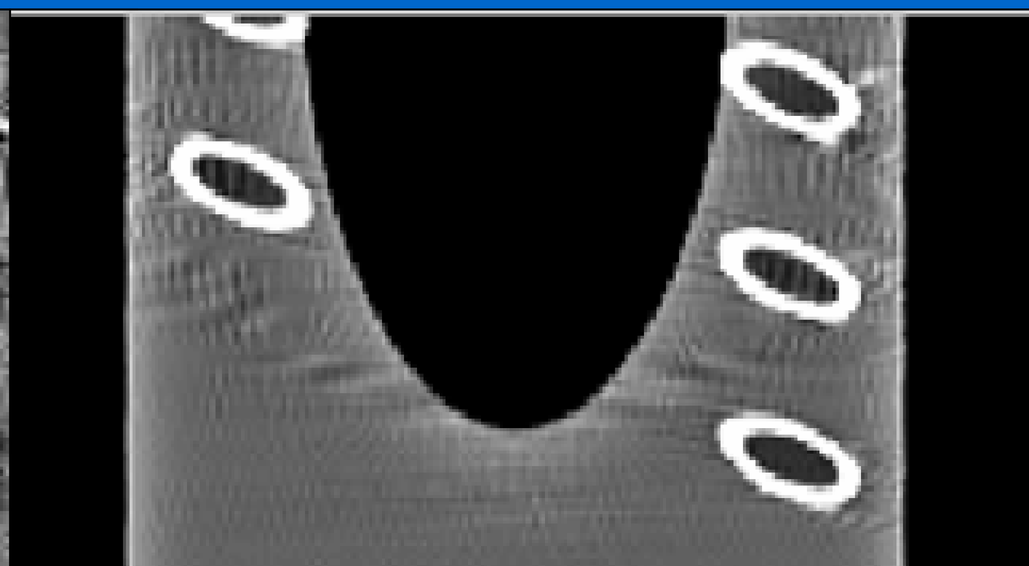


Effectiveness of cone beam algorithms

16-slice acquisition



standard reconstruction

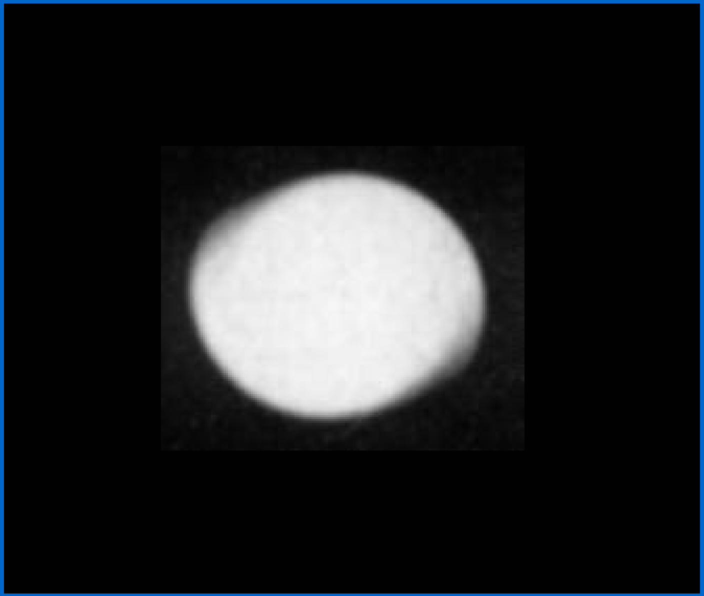


cone beam reconstruction

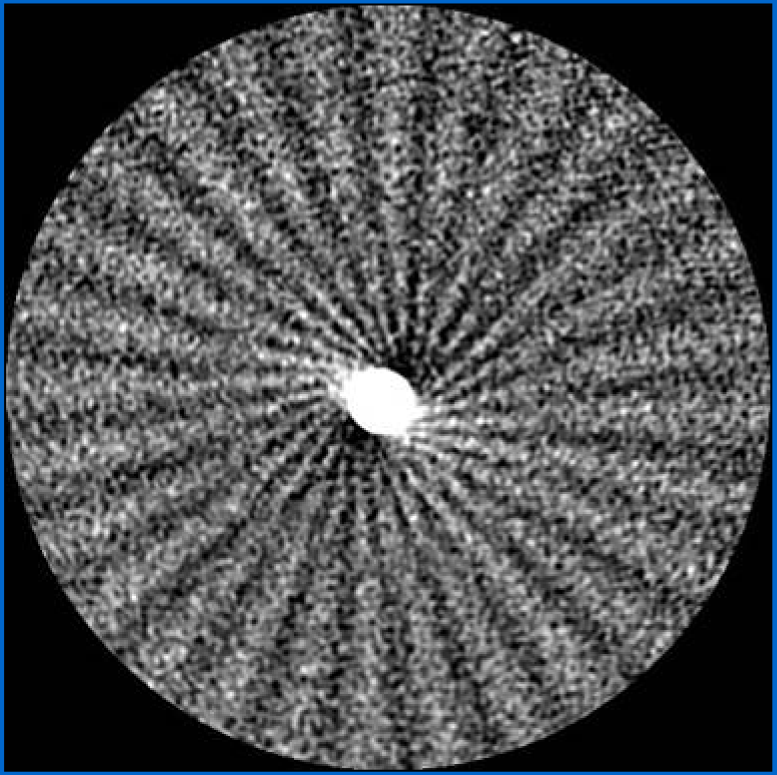
Courtesy: Siemens

Helical artefacts

- Arise from variation in sampling along the z-axis

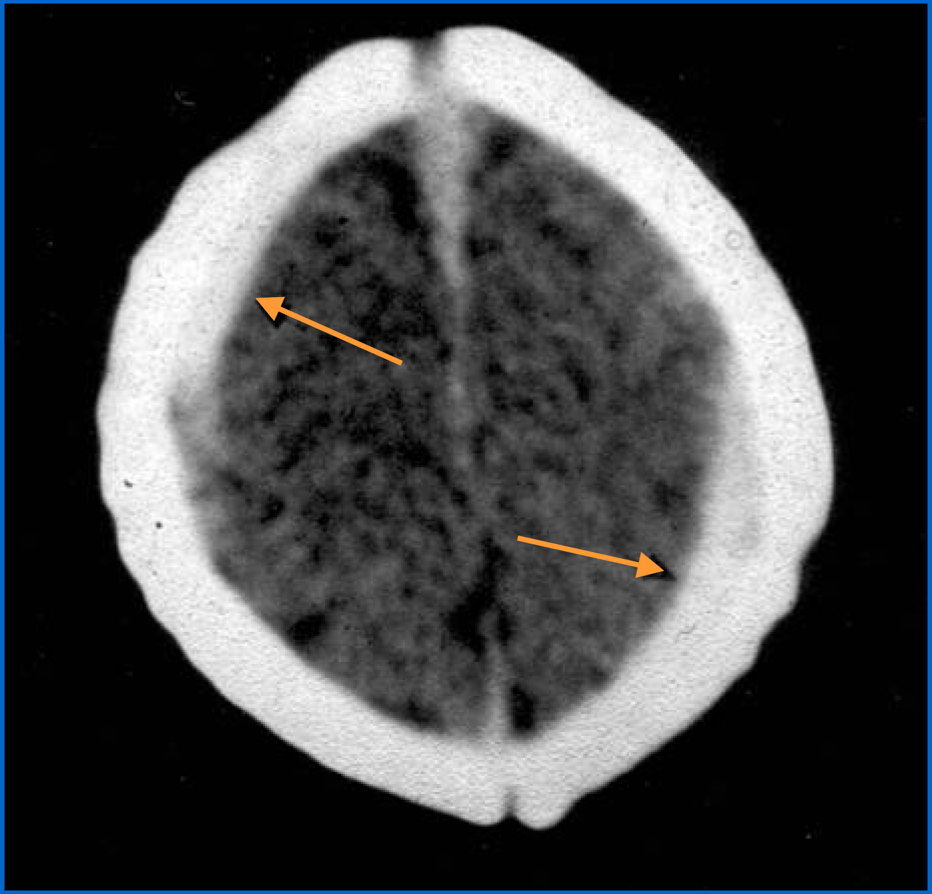


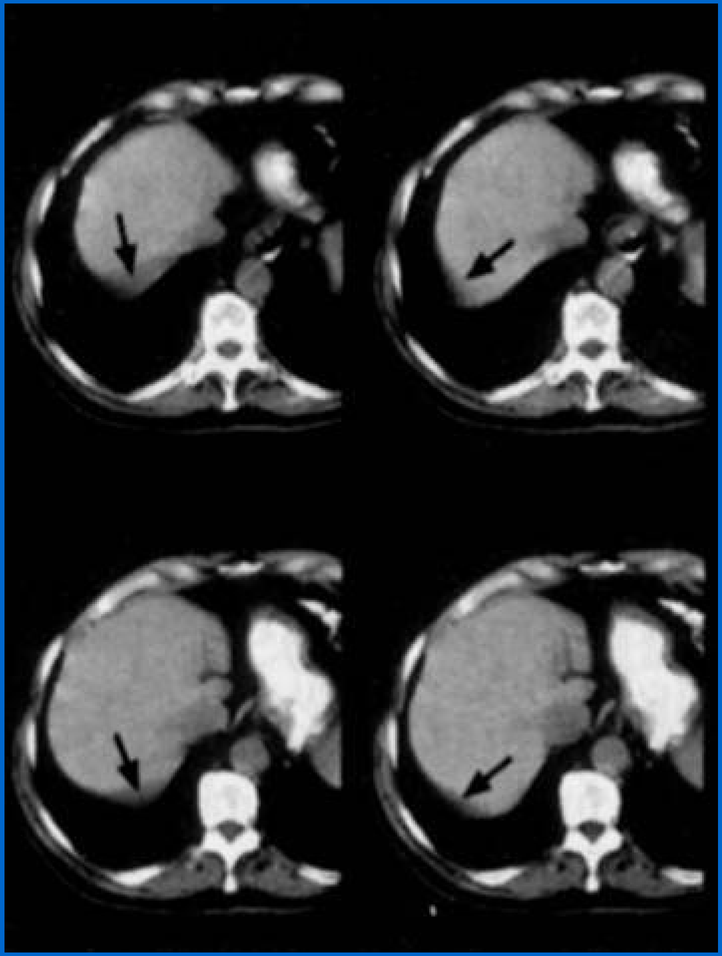
Conical phantom
single-slice helical



Spherical air pocket
8 x 2.5 mm slice helical

Helical artefacts - clinically



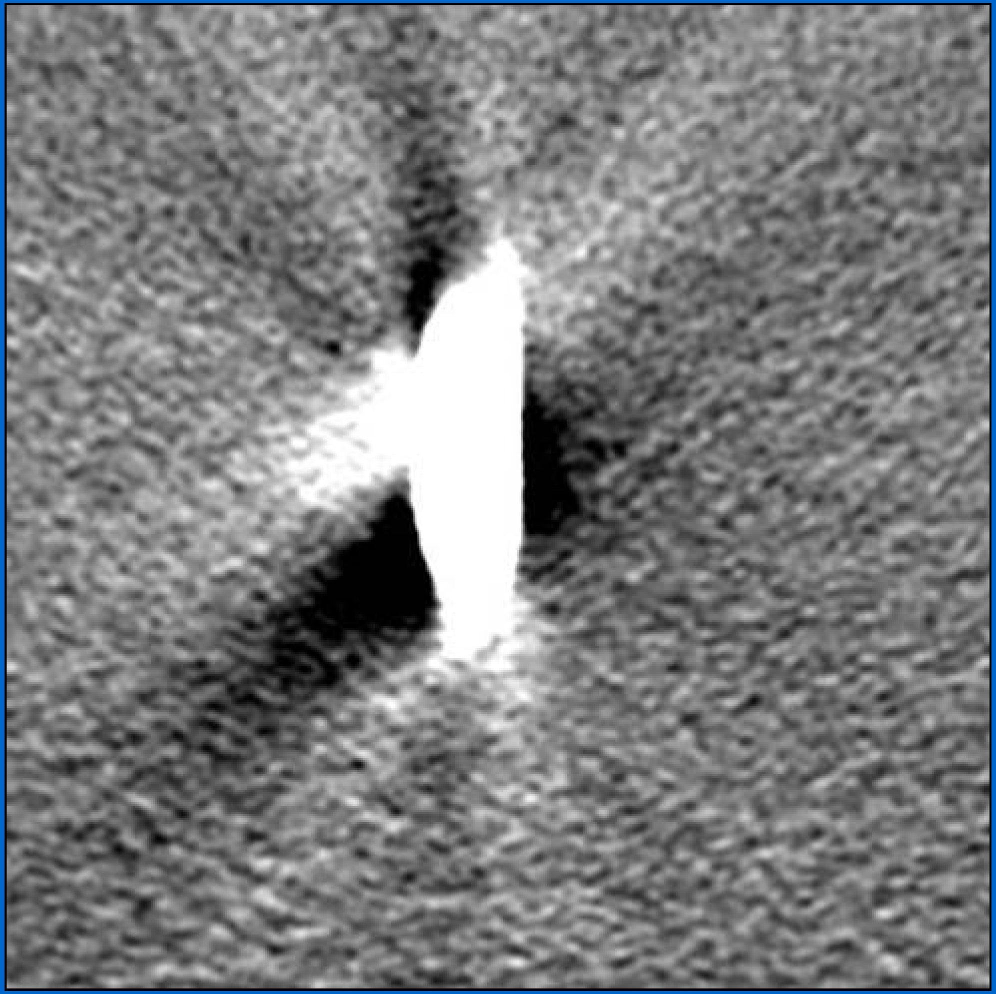


From “Artefacts in spiral-CT images and their relation to pitch and subject morphology”, Wilting, JE and Timmer, J. EJR 9(2) 1999

Windmill artefact in consecutive slices

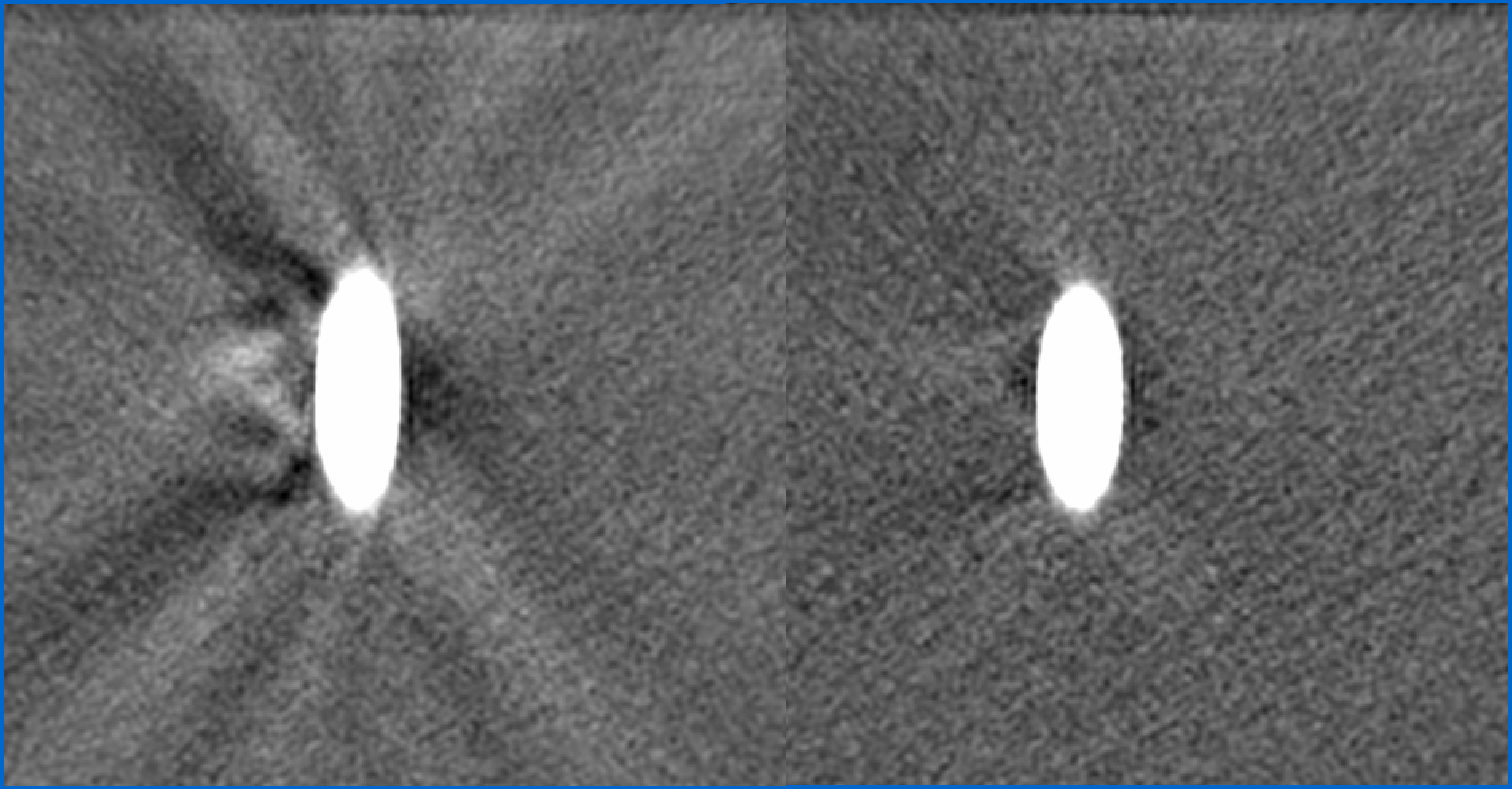
- Teflon rod at 60° to horizontal

Pitch$_x$ = 1.5
16 x 1.5 mm acquisition
5 mm recon.



Helical artefact

- Processing can compensate for helical scanning
- Reduces artefact

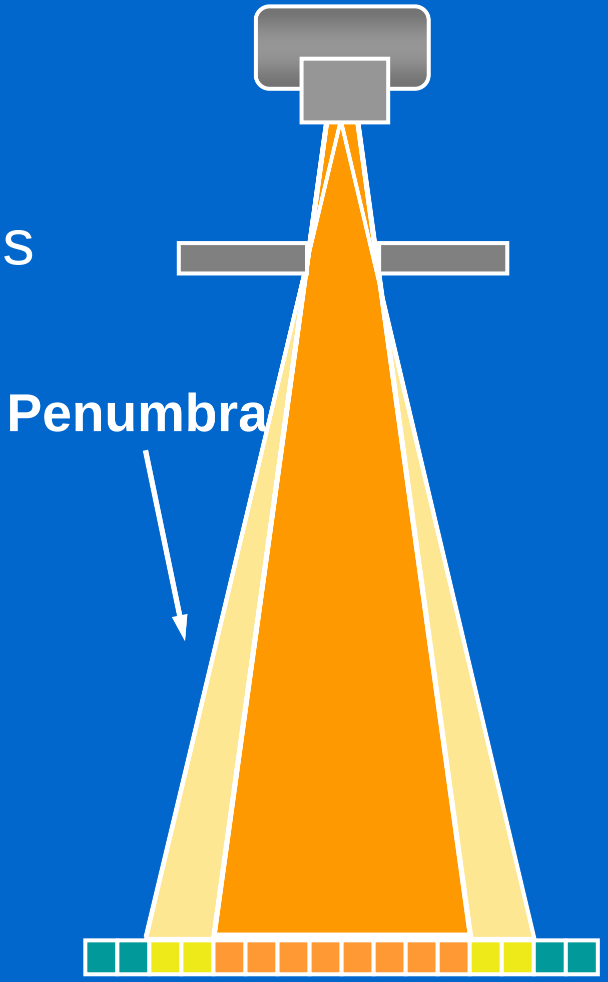


MSCT and dose

- CT is a high-dose exam
  - more CT studies being undertaken
  - even more exams with new MSCT apps
- Automatic exposure controls (AEC)
- Differences between single and multi-slice
  - over-beaming
  - over-ranging

Z-axis over-beaming

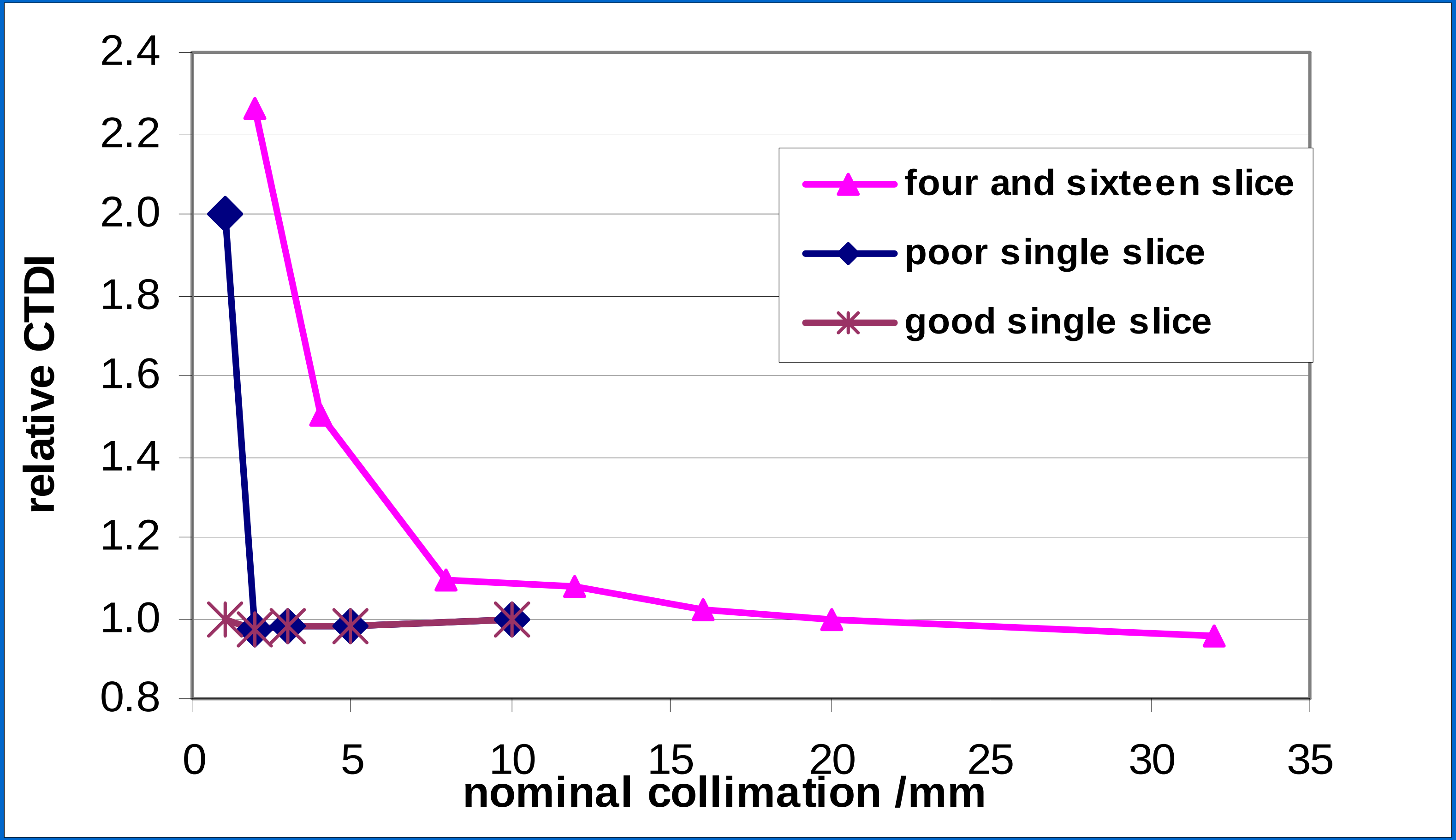
- Beams are wider than the nominal value
  - due to finite size of focal spot
- Irradiated beam width ~ 3mm wider
  - e.g. 4 x 2.5 mm slices, 12.5 mm beam
- Less significant as beam width increases
  - wider collimations routinely used



Nominal beam	Excess beam	Geometric Efficiency
10 mm	25%	72%
25 mm	10%	80%
40 mm	6%	95%

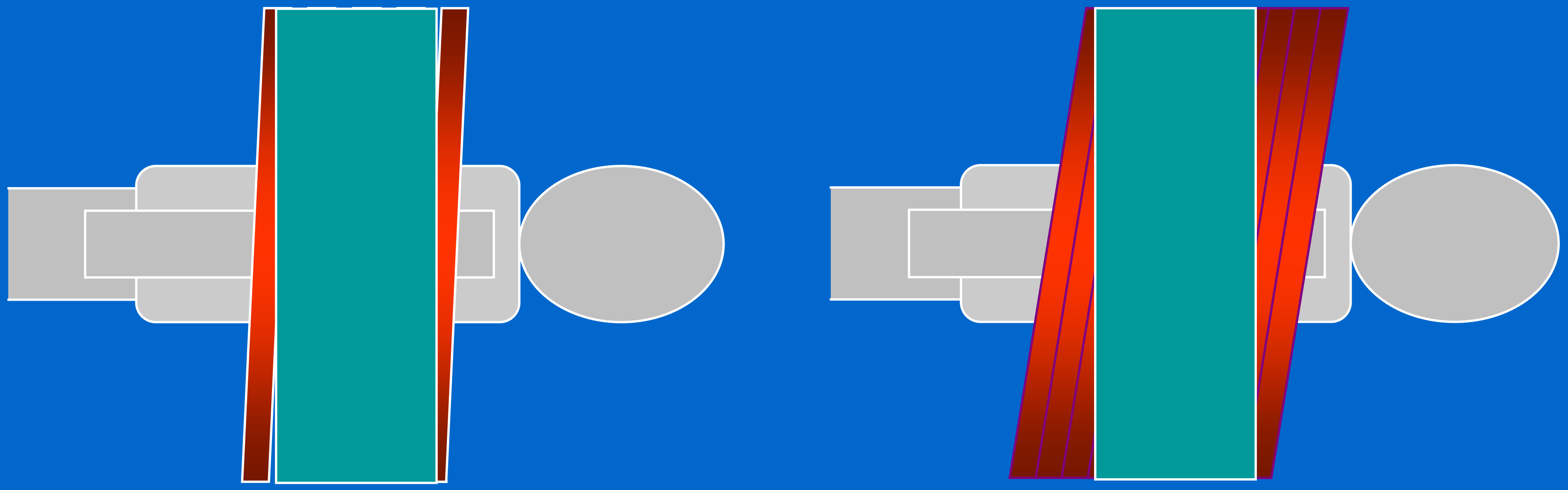
Wider beams – lower dose

- Efficiency increases with collimation (beam width)
- More coverage means thin slices at lower dose



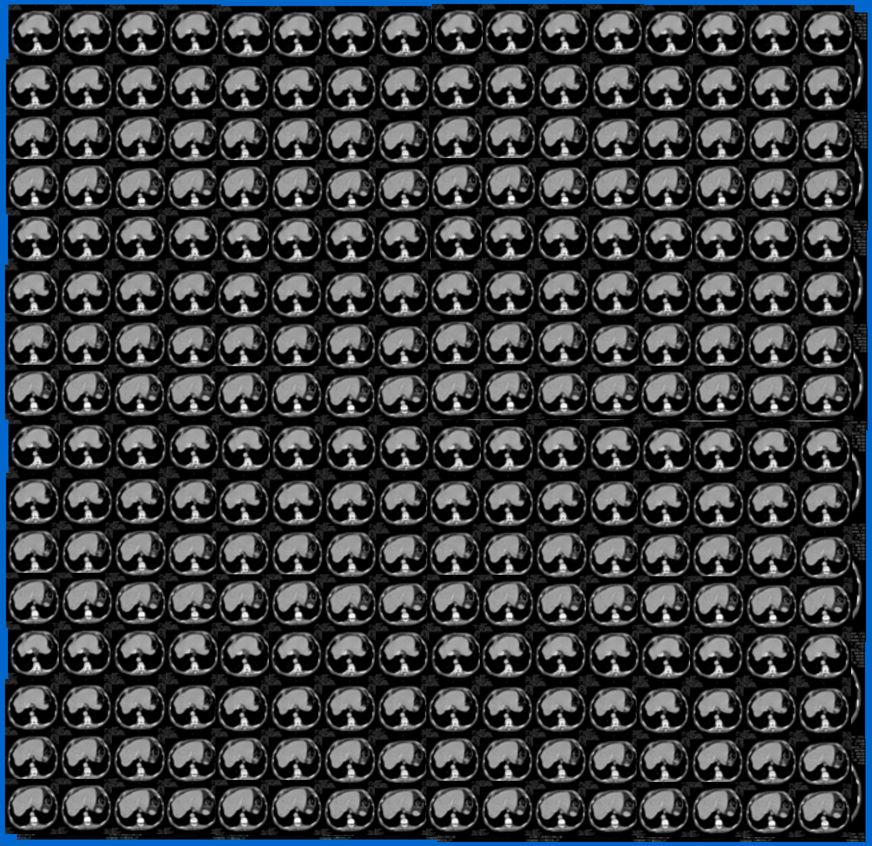
Overranging

- To image entire volume, data is needed at both ends of scan
  - requires more rotations to acquire
- This is more significant for multi-slice, wider beams, and for short scan ranges



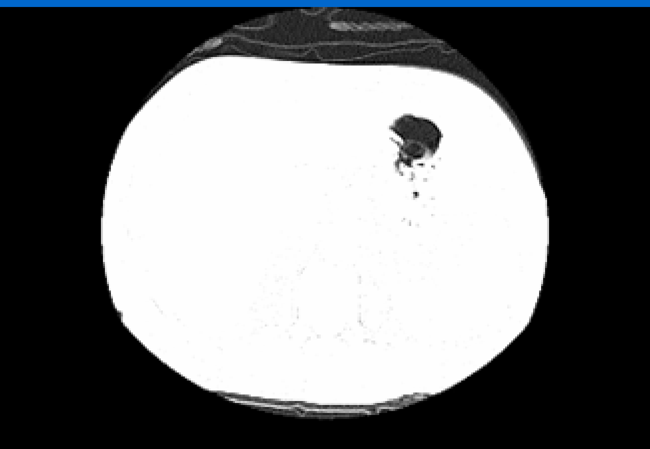
Data explosion!

- Scan data throughput from gantry to computer
  - Single slice, 1 second rotation : ~ 2 megabytes per second
  - 4 slice, 0.5 s rot : 16 MB/s
  - 16 slice, 0.5 s rot : 64 MB/s
  - 64 slice, 0.5 s rot : 256 MB/s
- Image production speed
  - 2005: ~ 64 MB/s
- Data processing burden
- Network traffic …
- Archive issues…
- Images per exam
- Image viewing capacity?



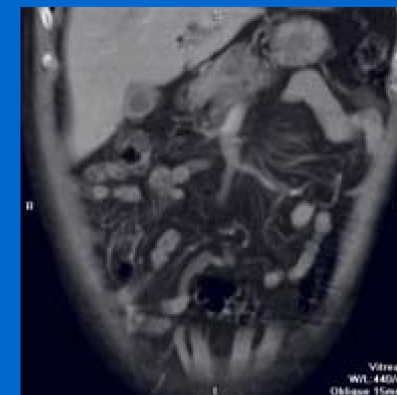
Reporting & navigation tools

- How am I supposed to look at 800 images?



'Stack' View

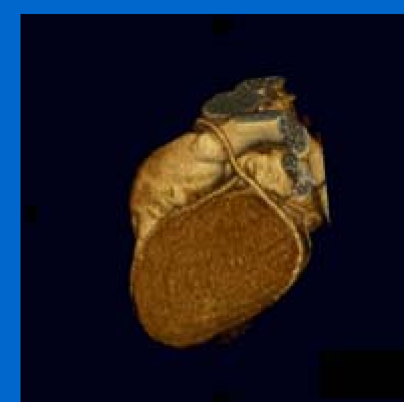
"Get in the volume"



Coronal Slab VR

Axial Slab MIP

MPR



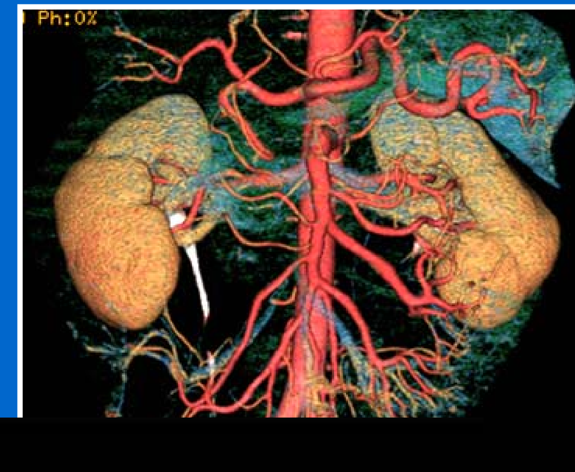
3D VR

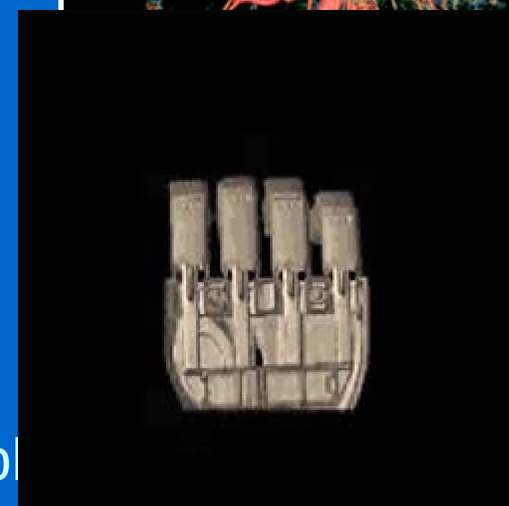
Courtesy Matthew Benbow, RBH

In summary

- Multislice CT scanning has progressed hugely since 1998
  - there are challenges that arise with MSCT – and have been met
    - eg ConeBeam reconstructions
- 16 and 64 slice changes CT from slice to volume scanning
  - image quality can now be routinely isotropic
  - 3D data sets readily available
  - data sets are there to be explored flexibl
- New applications still developing

  … and new scanners coming





Acknowledgements

- for scanner information & images
  - GE Healthcare
  - Philips Medical
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  - Toshiba
  - University of Erlangen
  - Matthew Benbow, RBCH

- Thanks also due to
  - Sue, Maria and Margaret at ImPACT
  - David Platten & Nick Keat

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