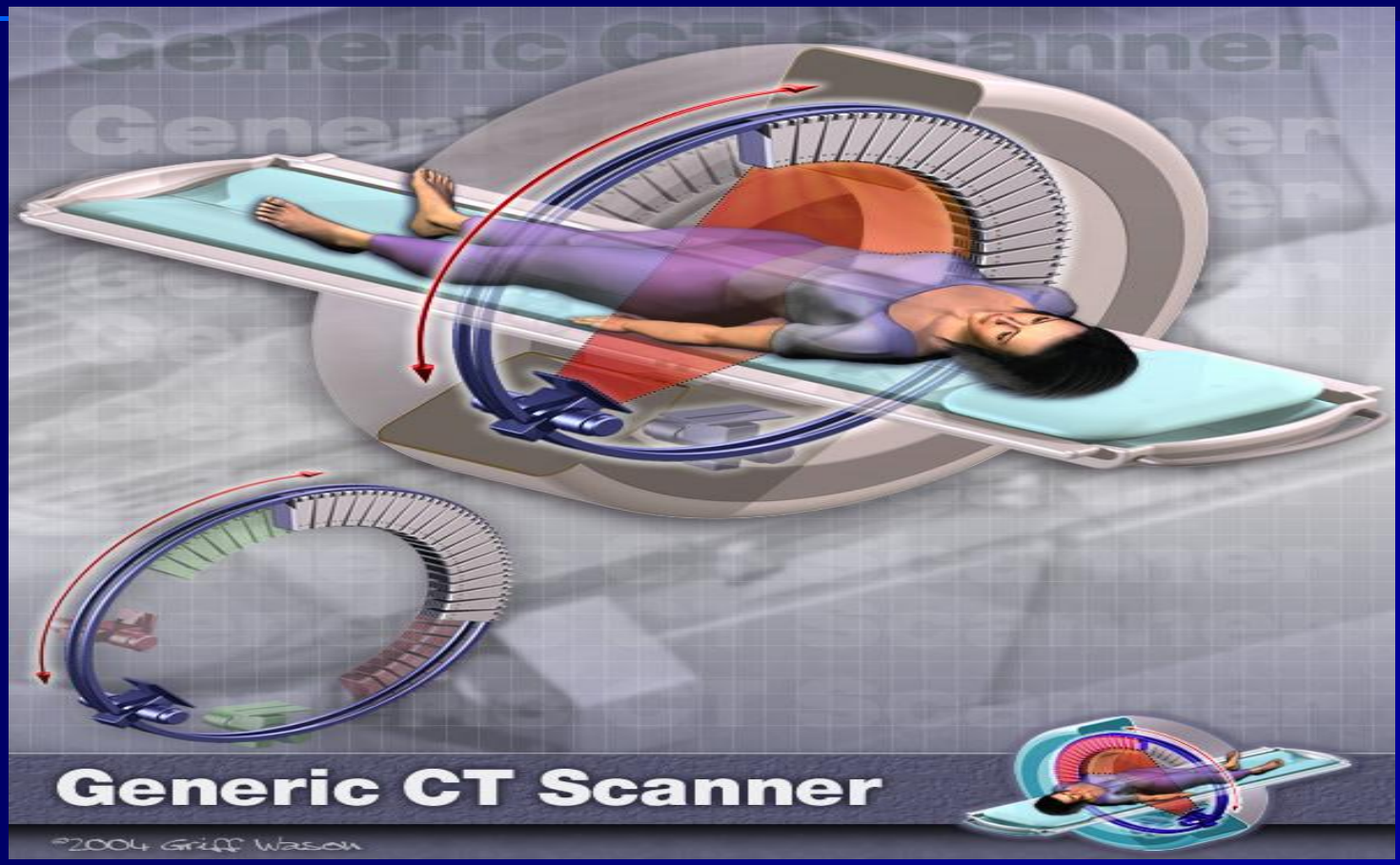
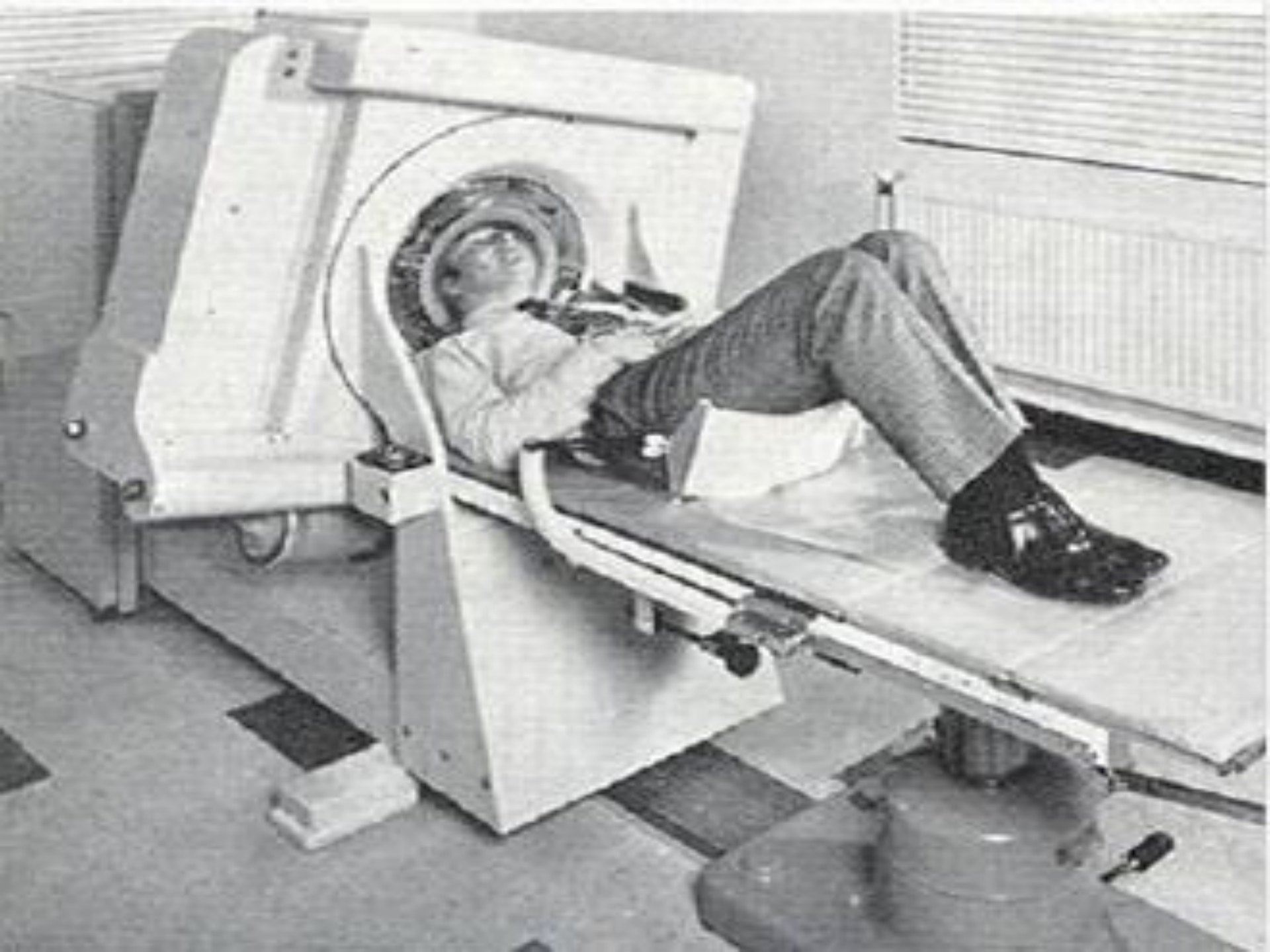

بسم الله الرحمن الرحيم

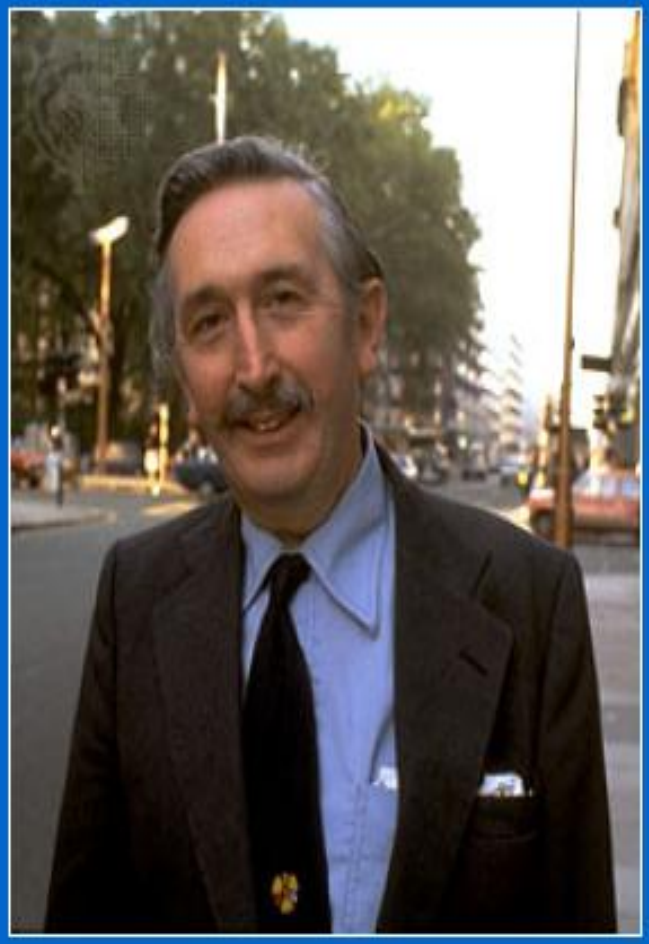
PHYSICAL PRINCIPLES OF COMPUTED TOMOGRAPHY

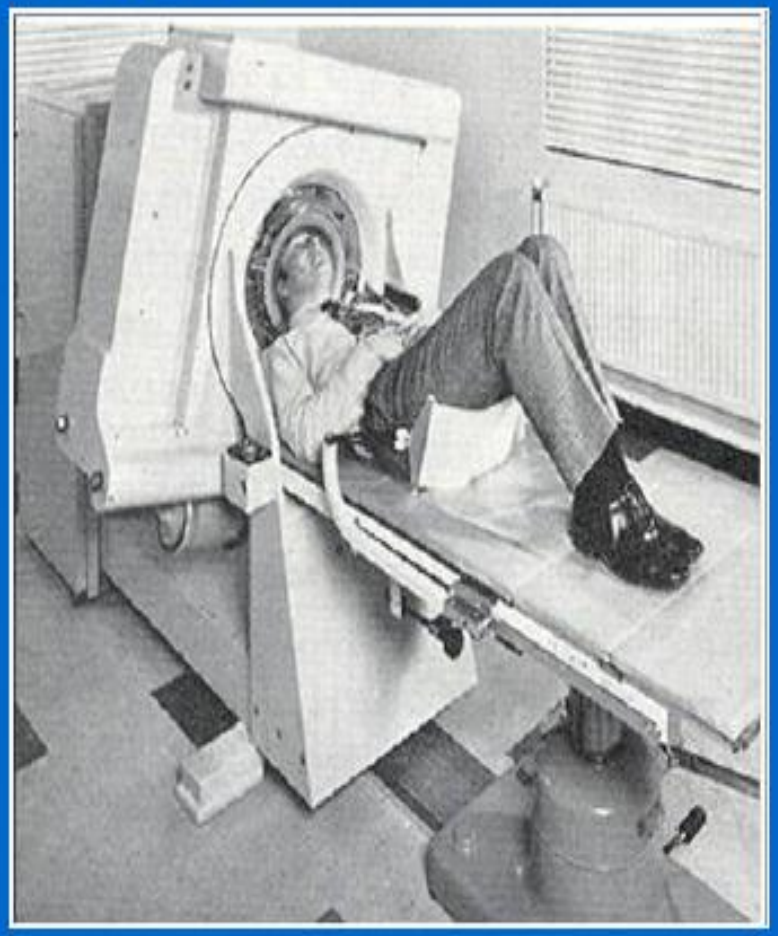


Presentation: **Mohamad Akbarnejad**
Radiobiology and radiation protection MSc



- Godfrey Hounsfield, inventor of clinical CT, 1971
  - 1979 Nobel prize
  - 1st Oct 1971 – 1st patient scanned

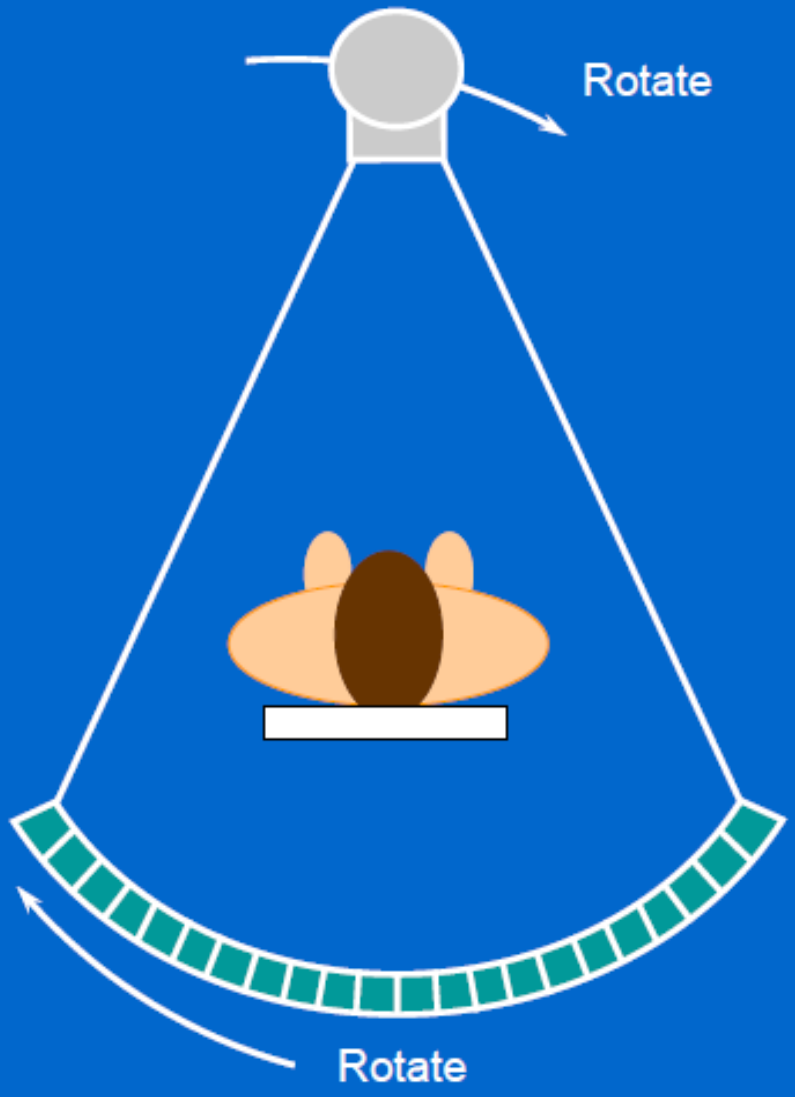




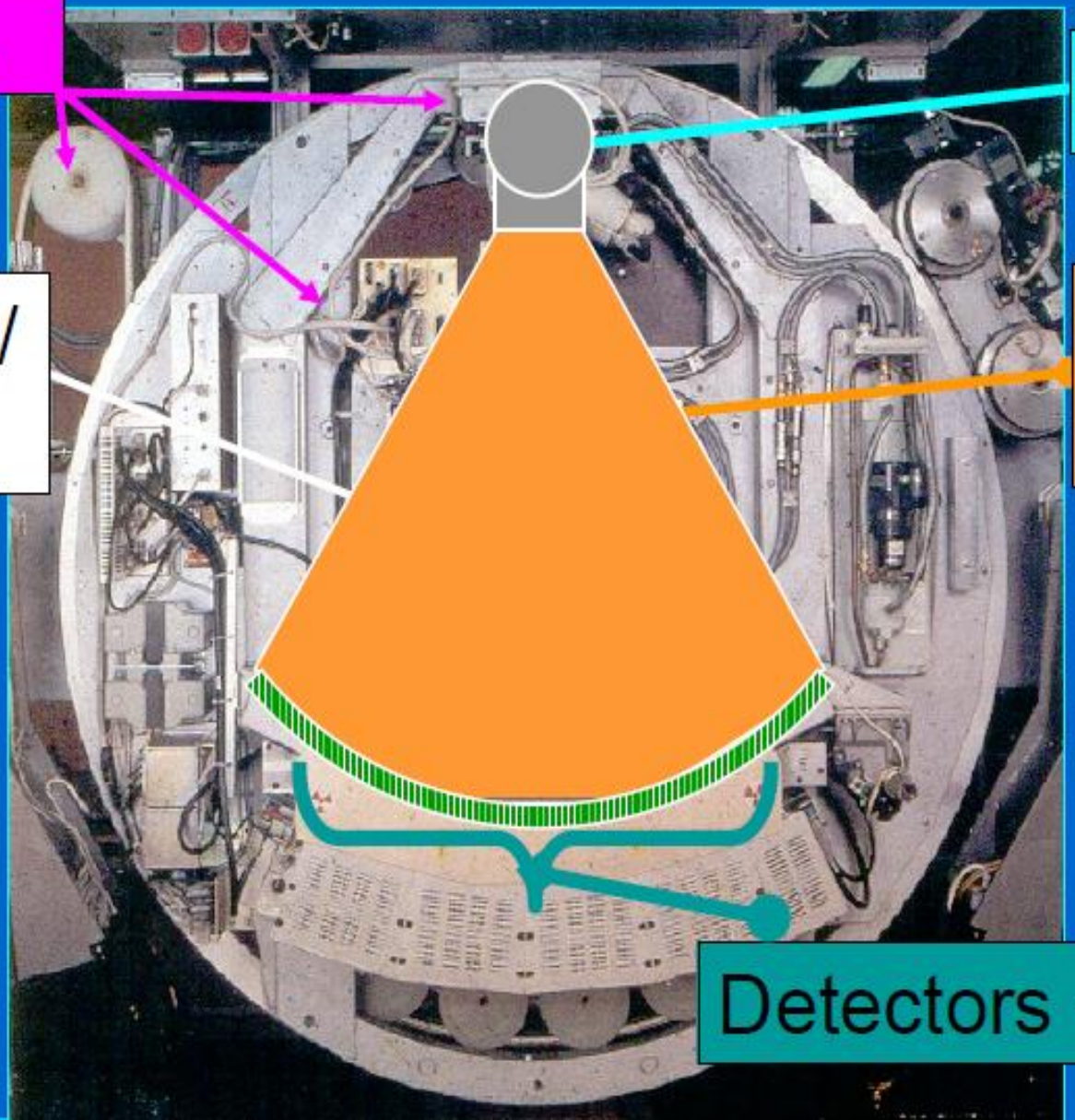
“Third generation” CT scanners

- 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



The scanner

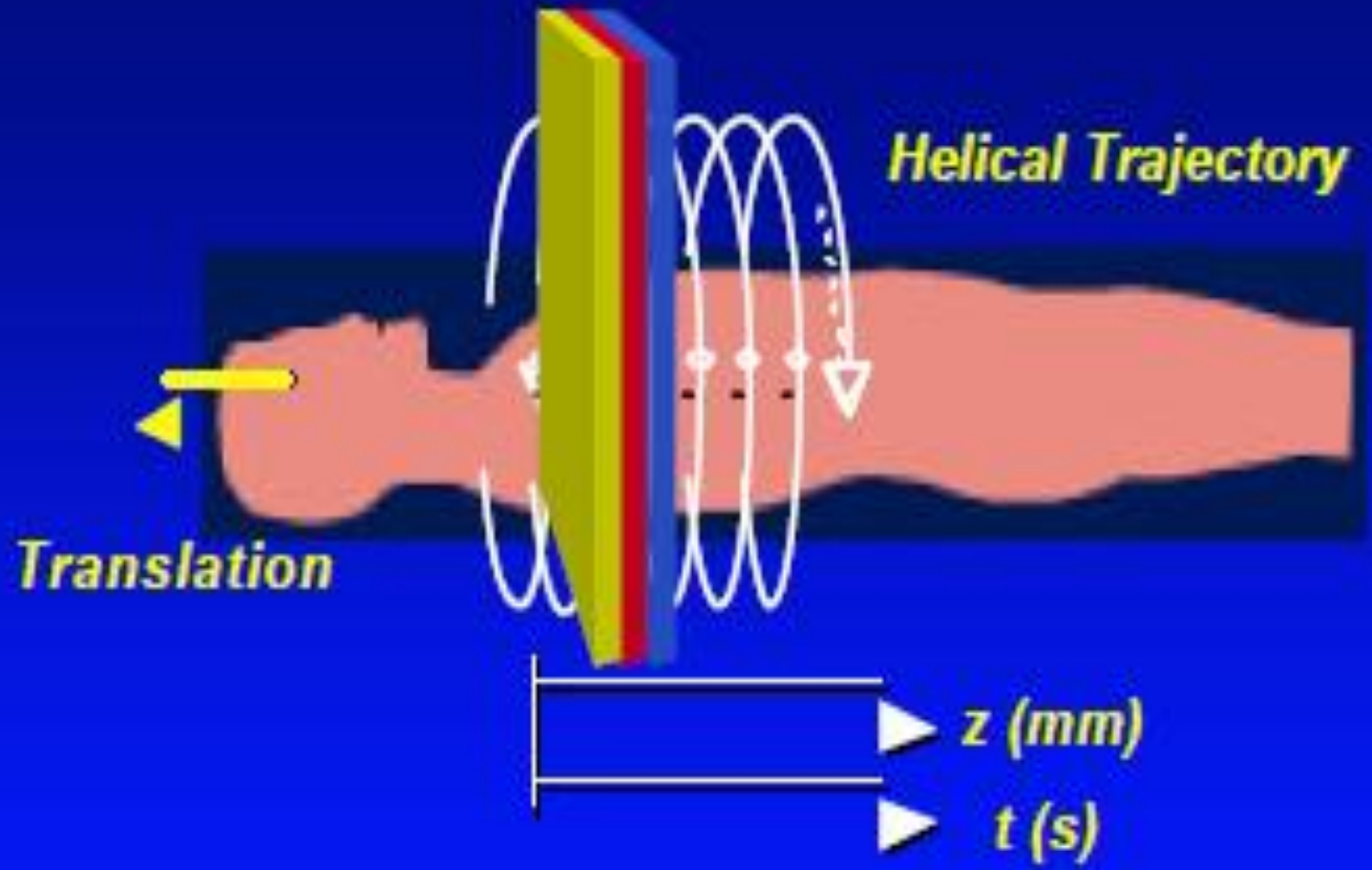


Helical/Spiral:

Helical CT

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

Helical Single-Section Mode



Interpolation using samples from single row detector ring

Capabilities of Single Row Detector CT (SDCT)

- Large tissue volumes scanned in short times
- Inter-scan delay eliminated
- Decrease scan time

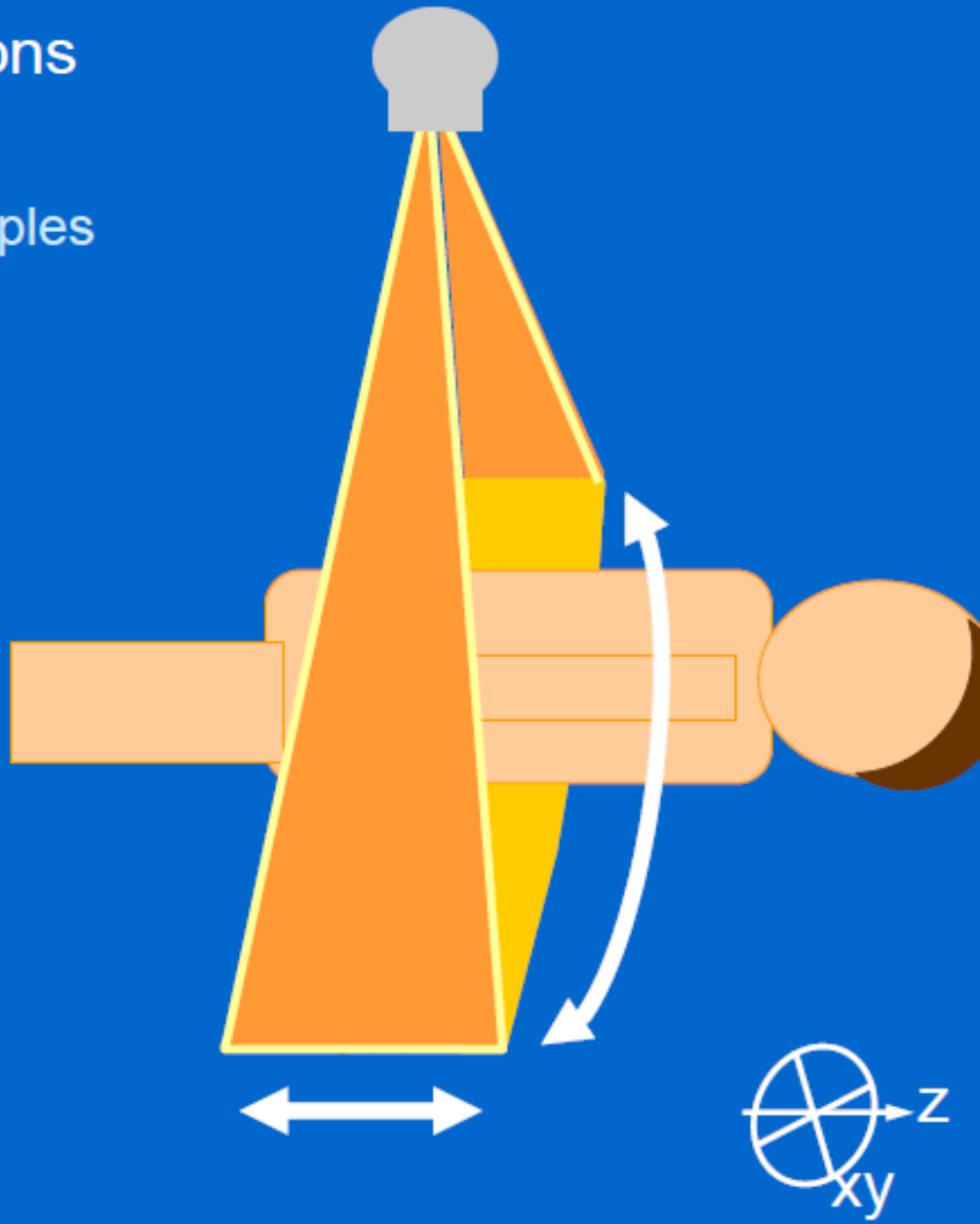
Limitations of SDCT

- Large volume scan in short duration is limited
- Near isotropic resolution only over small volume
- Poor utilization of X-ray tube

- Multiple row detector CT (MDCT) offers substantial improvement in volume coverage, scan speed with efficient use of x -ray tube

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

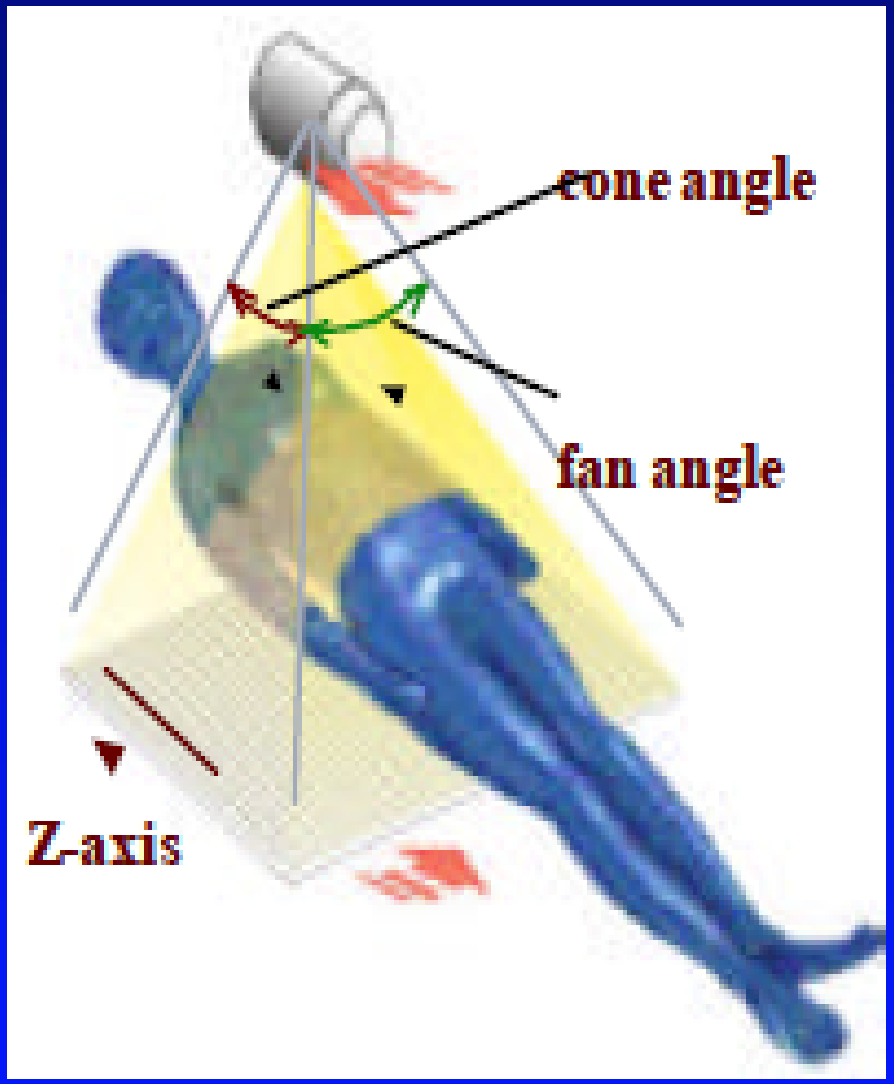


Multi-slice CT - coverage

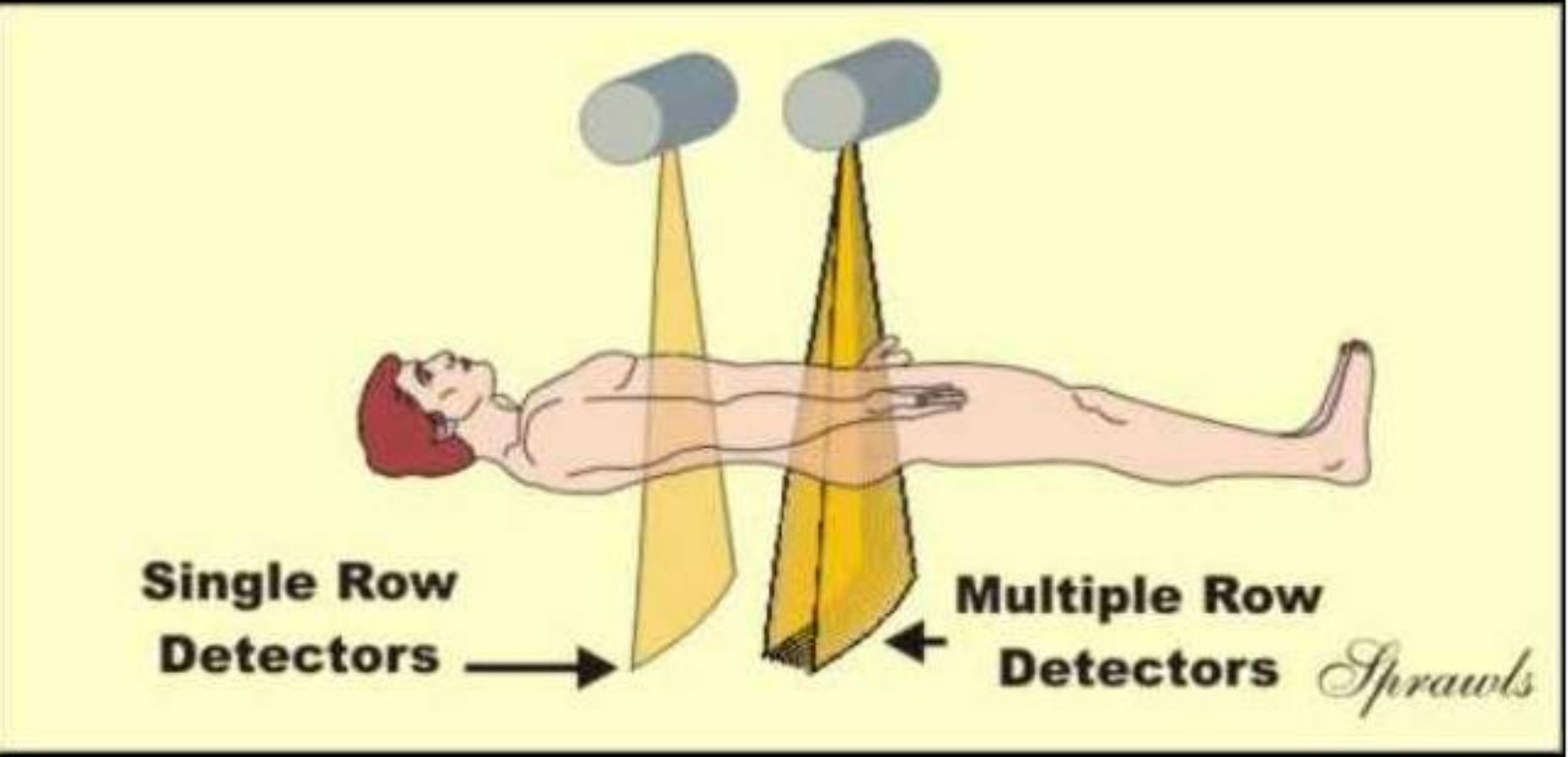
10 20 40 80 160 mm

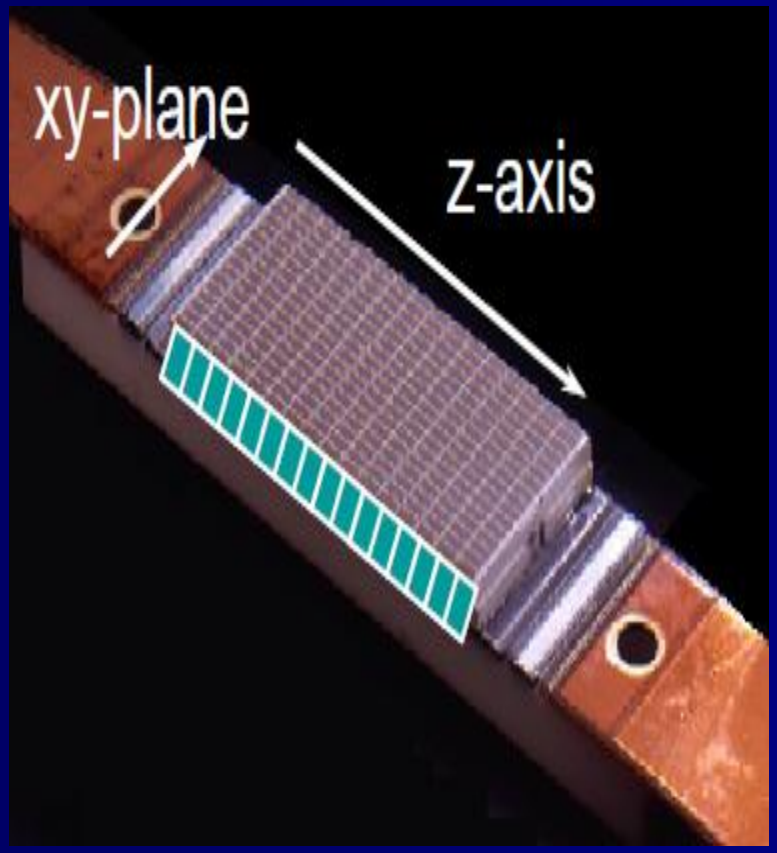
z-axis

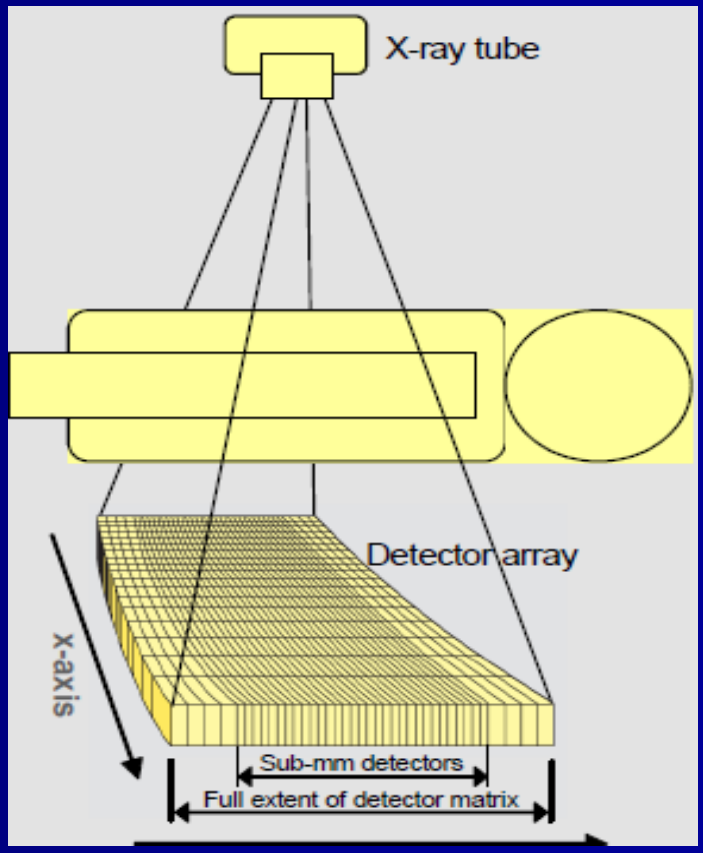
Cone Beam Geometry



- In MDCT, widening beam aperture in z-direction increases cone angle, that results in significant cone beam artifacts

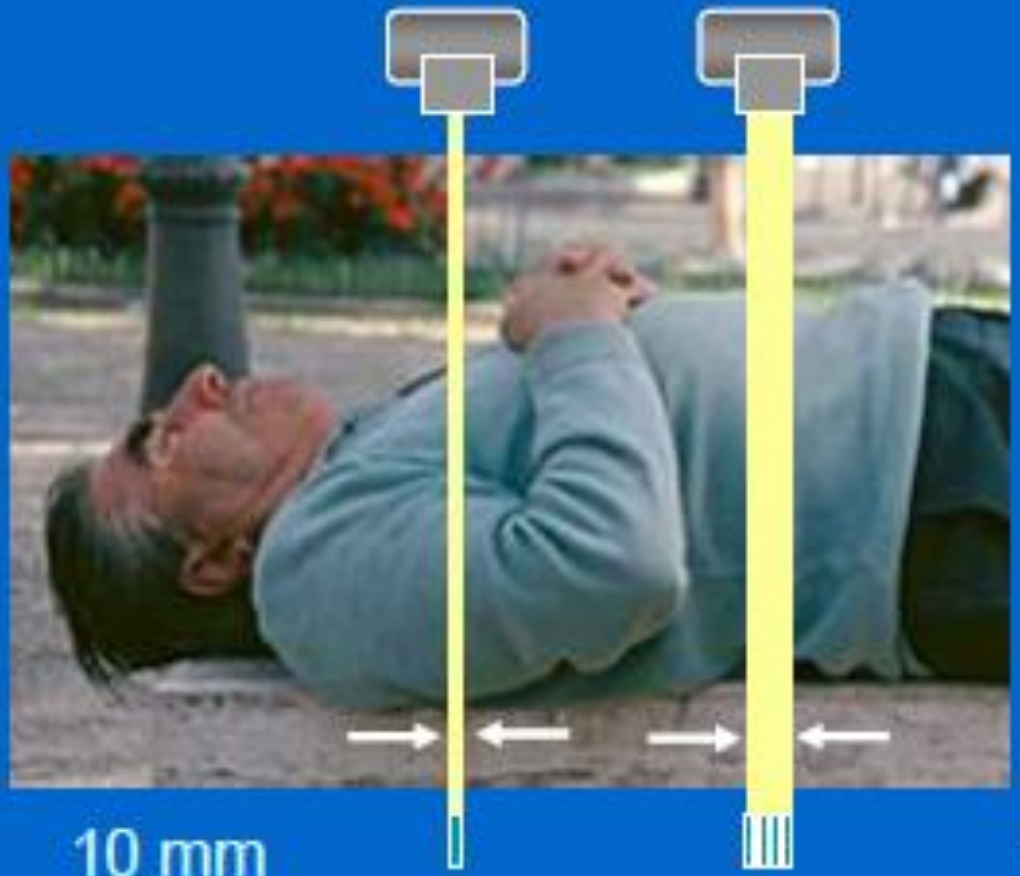

Single Row
Detectors
Multiple Row
Detectors
Sprawls


xy-plane
z-axis


X-ray tube
Detector array
x-axis
Sub-mm detectors
Full extent of detector matrix

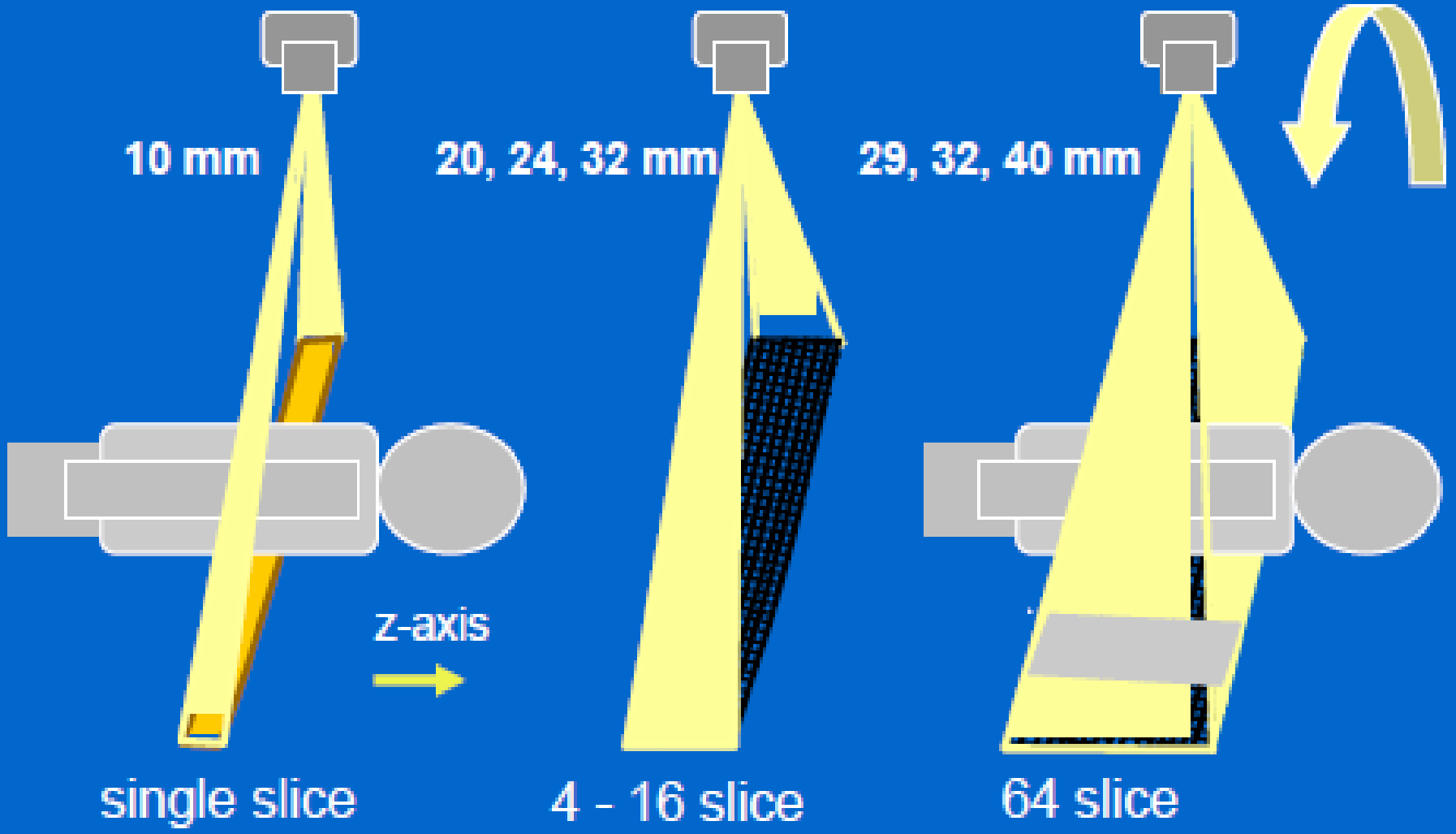
Multi-Slice CT

- Wider beam widths



Multi-Slice CT

- Wider beam widths



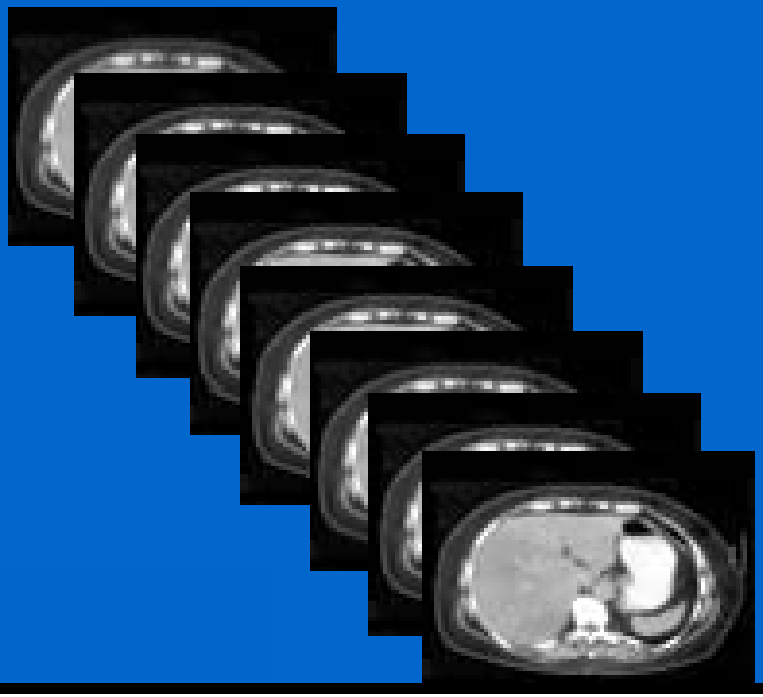
Issues in Multi-Slice CT

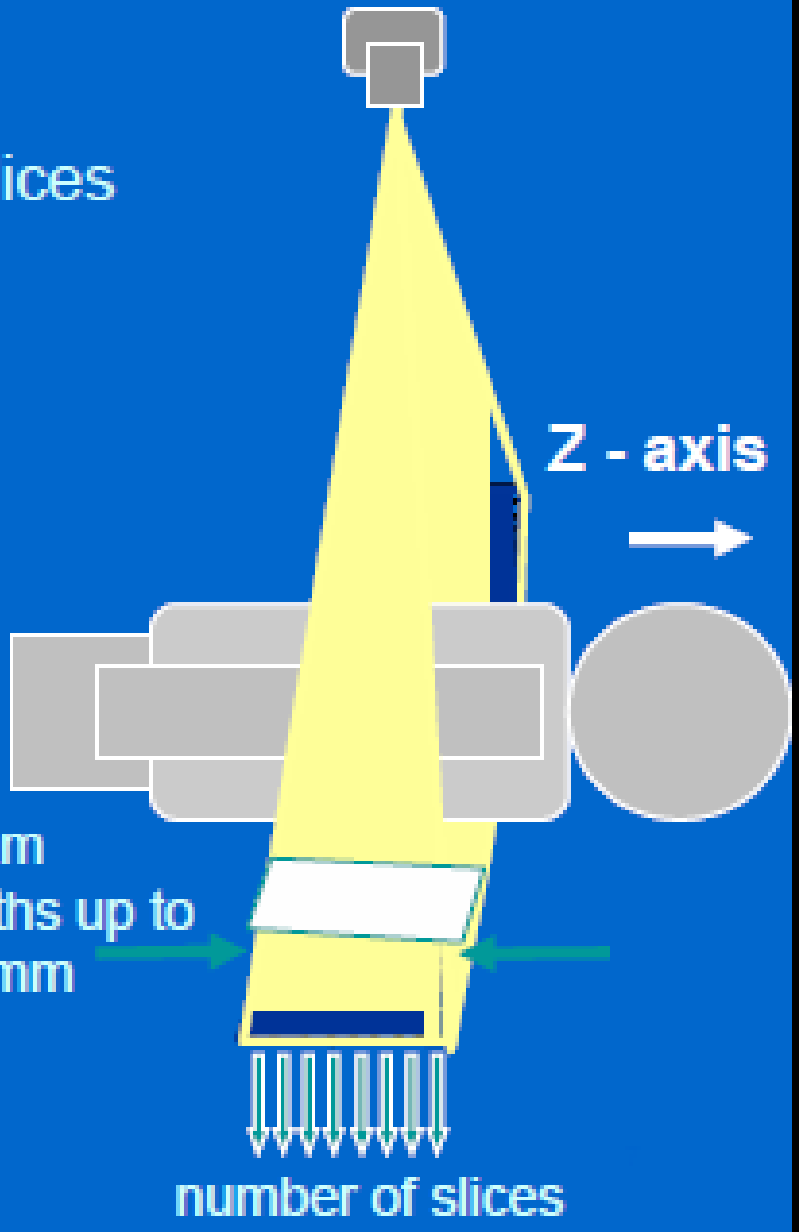
- Thin slice data acquisition
  - 4,16, 32, 40, 64 simultaneous slices
    - Eg

      4 x 0.5 or 5 mm

      16 x 0.625 or 1.25 mm,

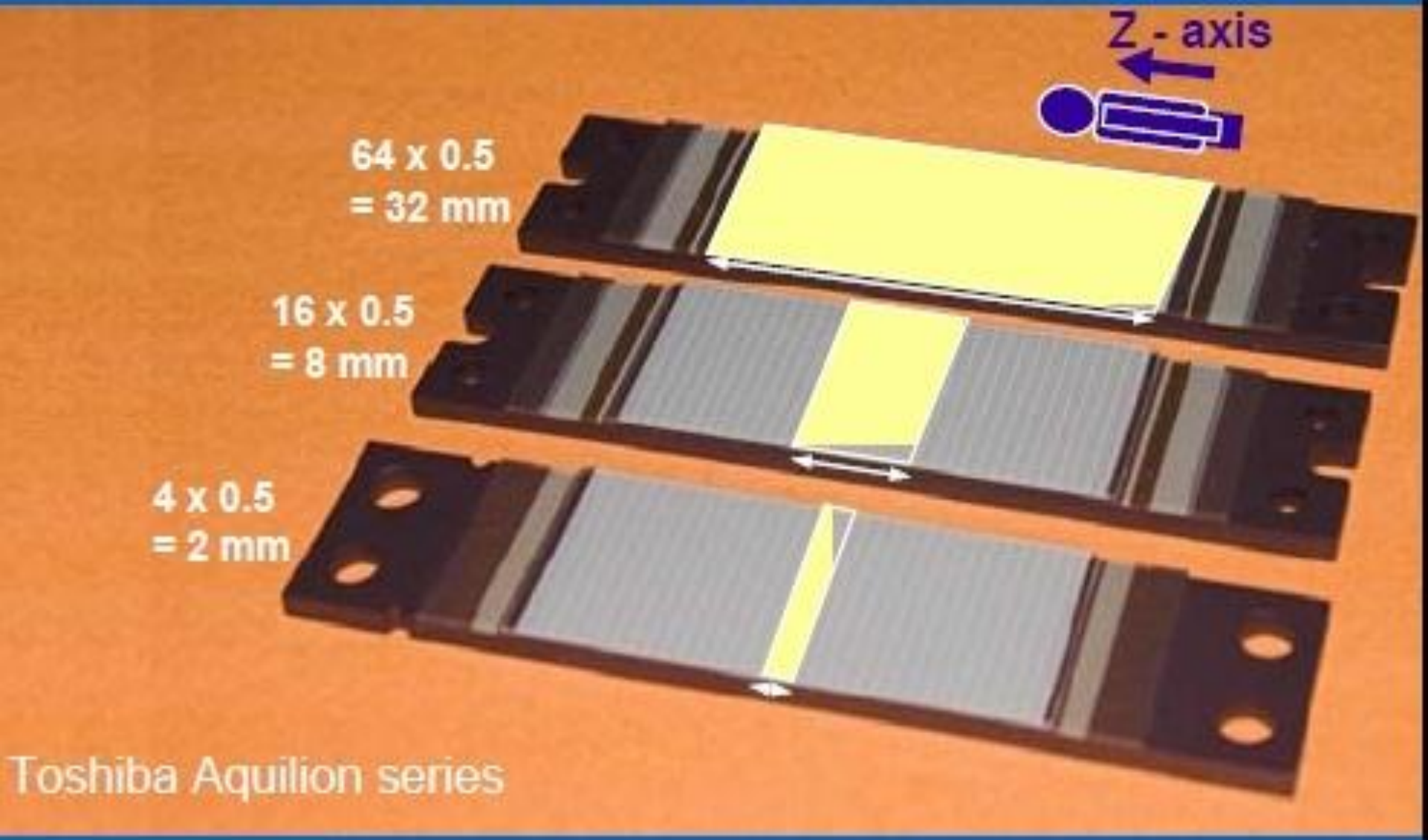
      64 x 0.5 or 0.625 mm





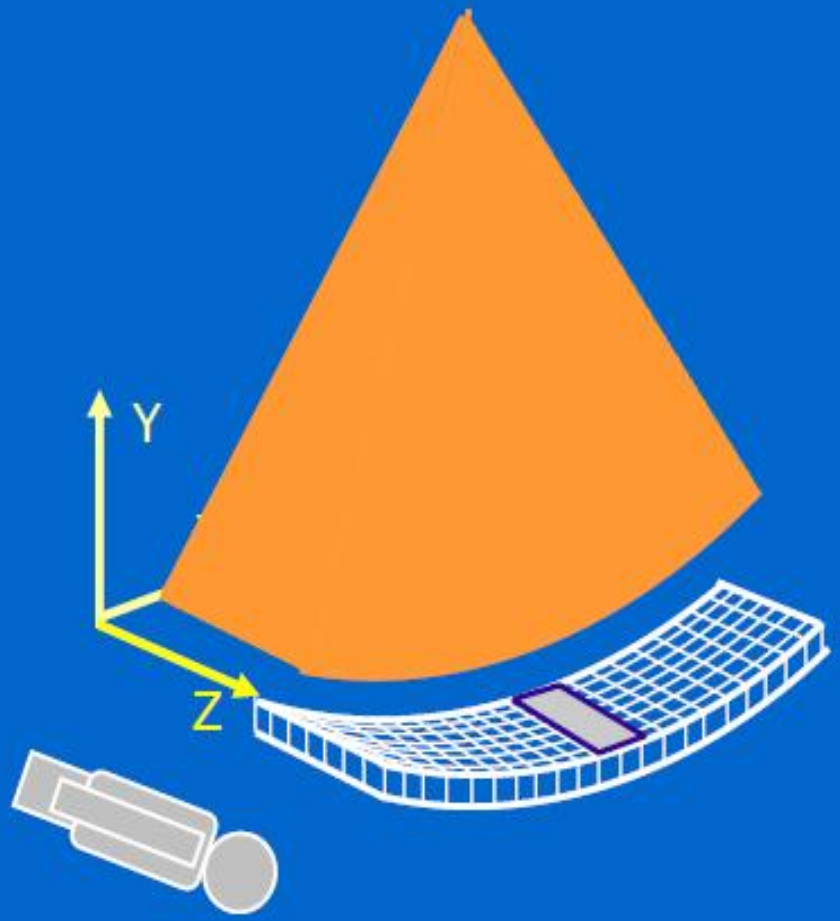
Multi-Slice CT

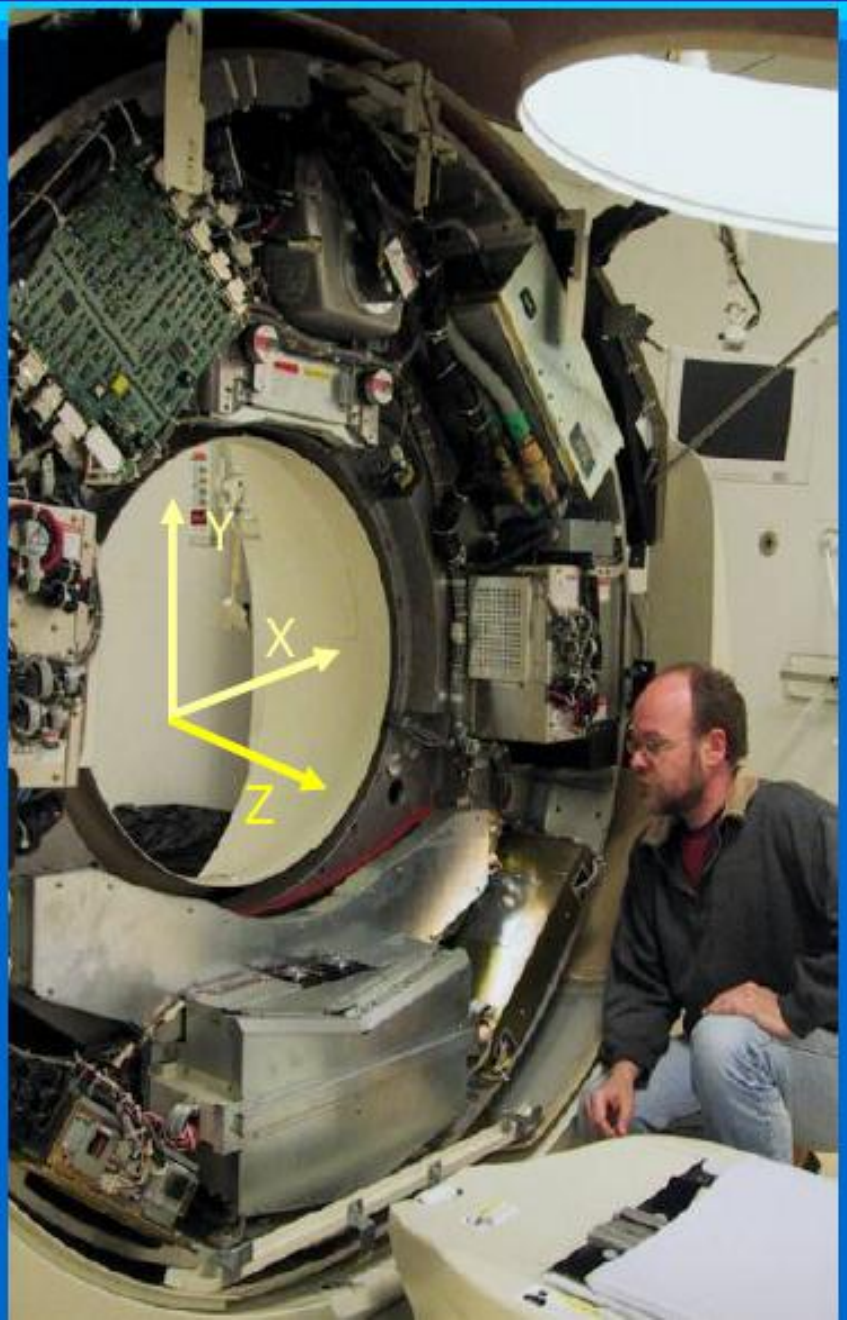
- Thinner slices and more of them



Toshiba Aquilion series

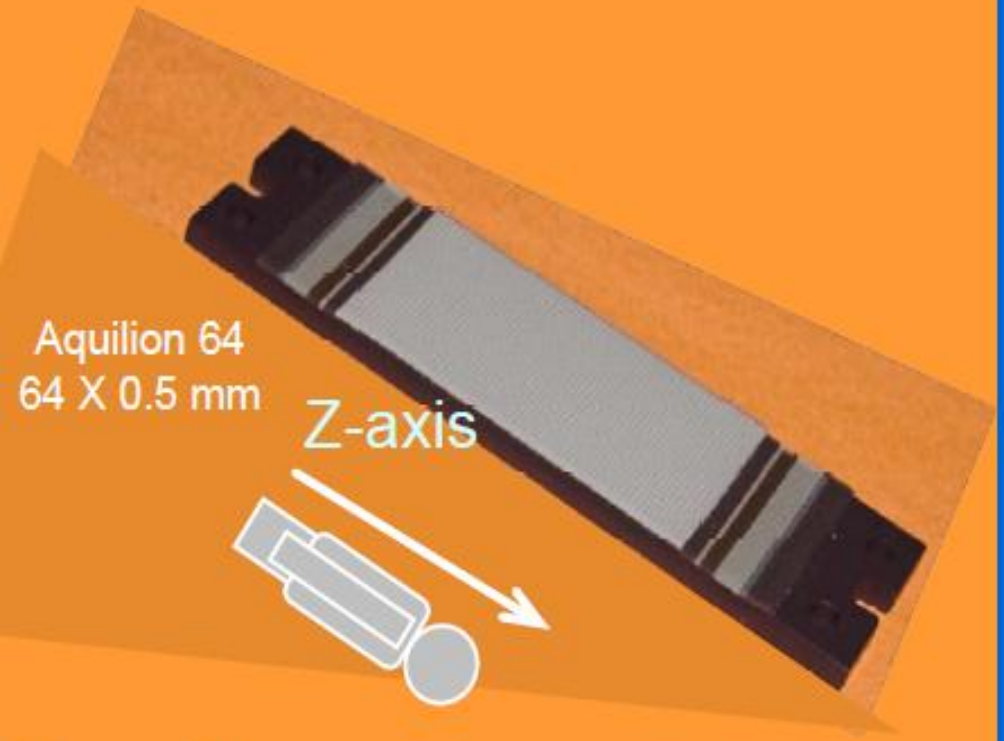
The scanner





Typical detector length ~ 40 mm

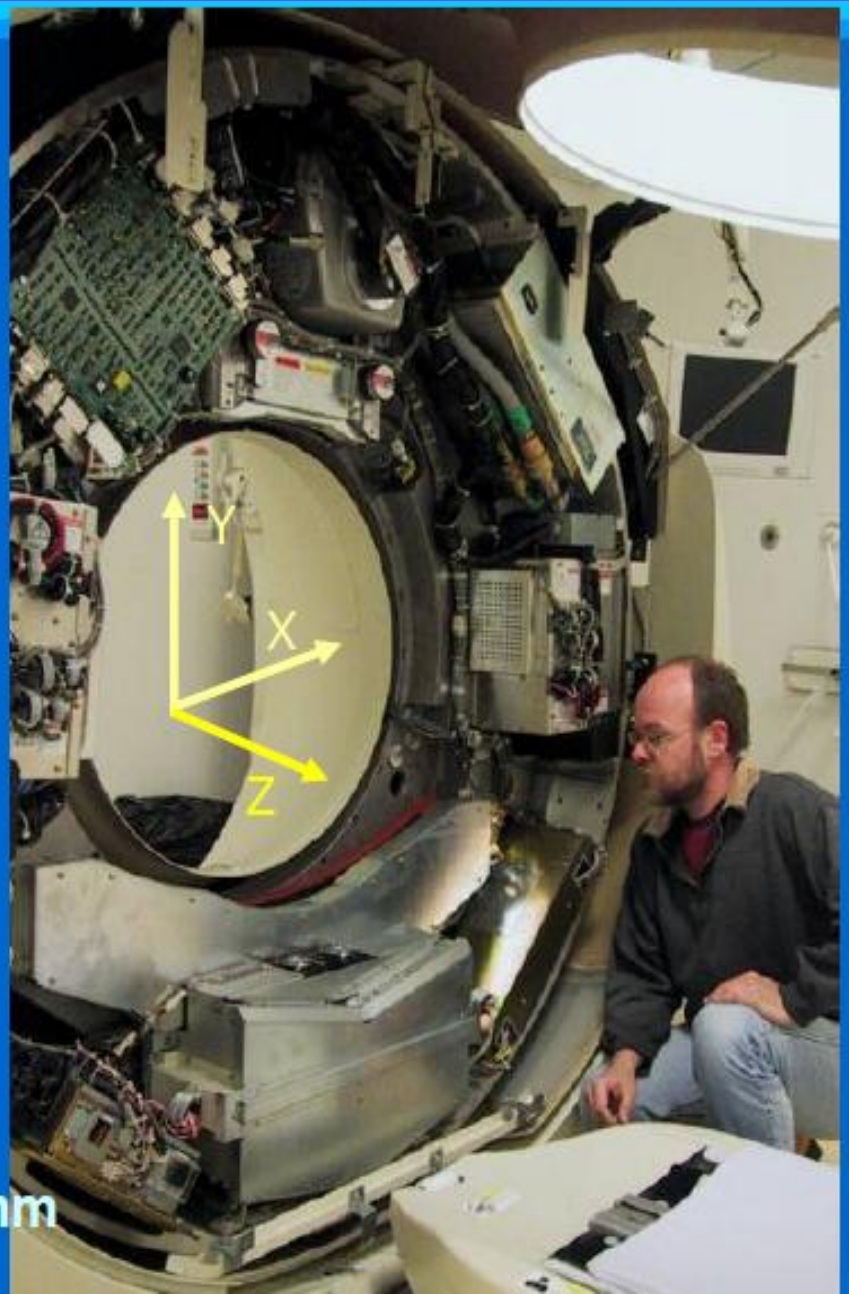
The scanner



Depending on scanner:

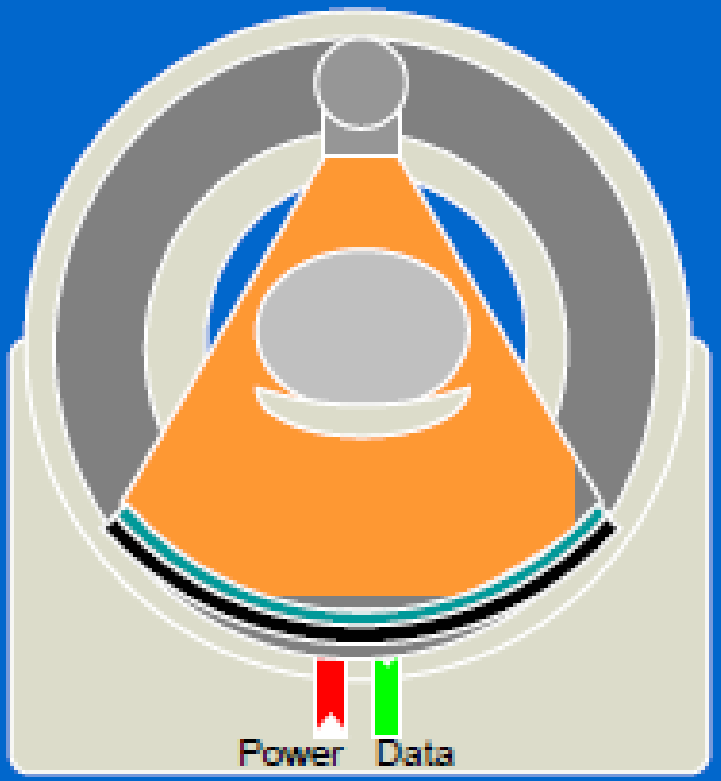
4, 16, 64, 128, 320 rows (slices of data)

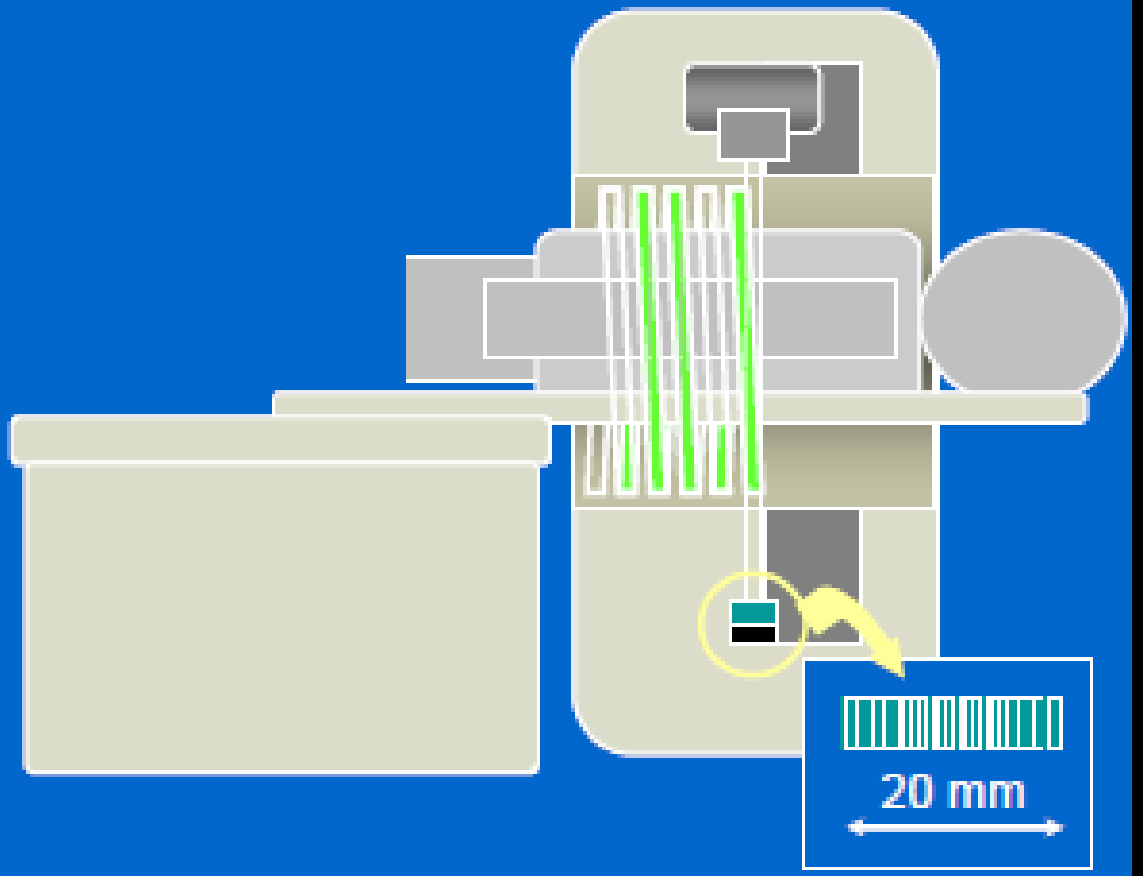
min size of detector element ~ 0.5, 0.6 mm



Multi-Slice CT

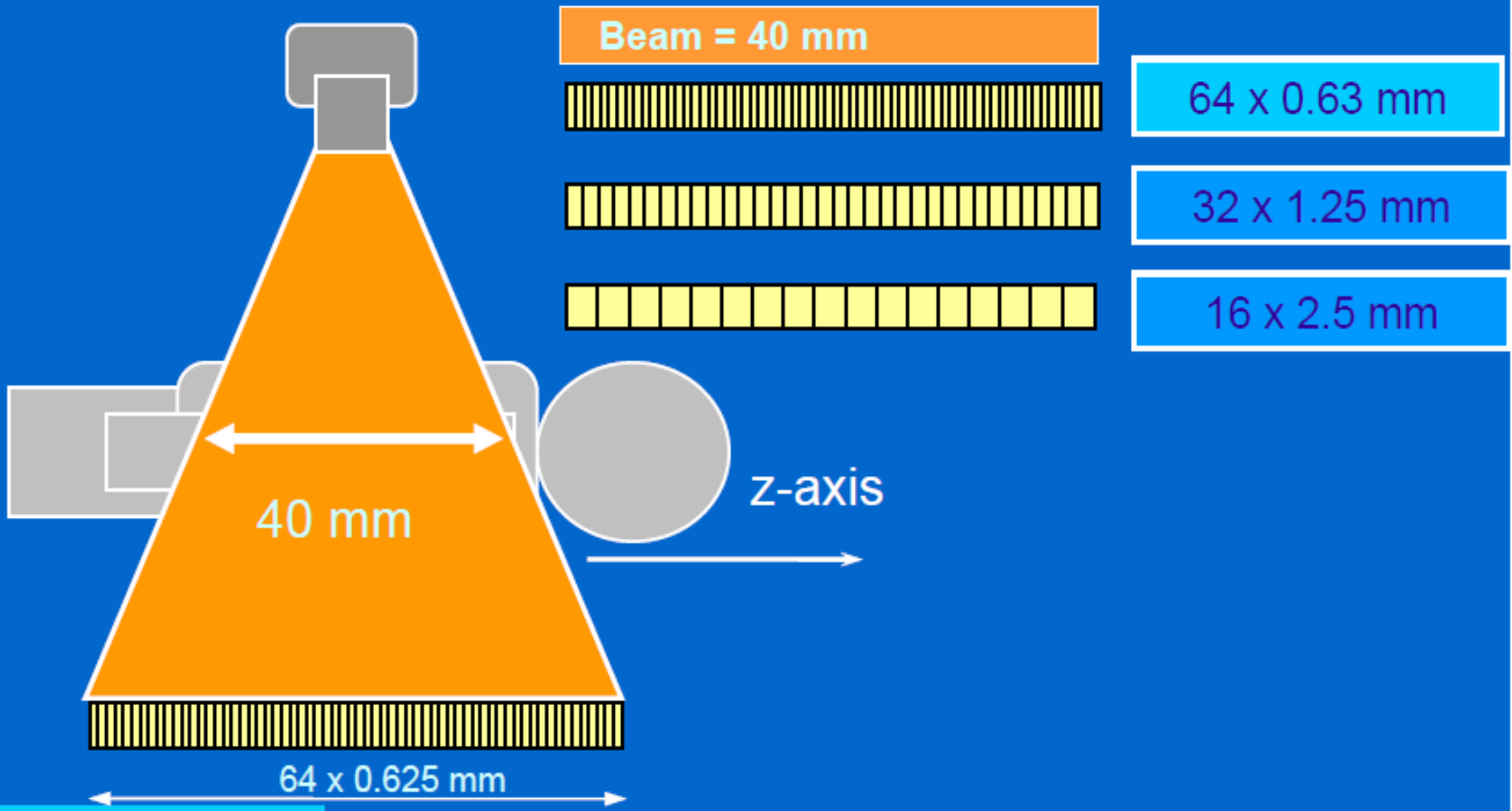
- Rotating tube and detectors – same as single slice
- Many axial images
- Helical scanning – many data sets





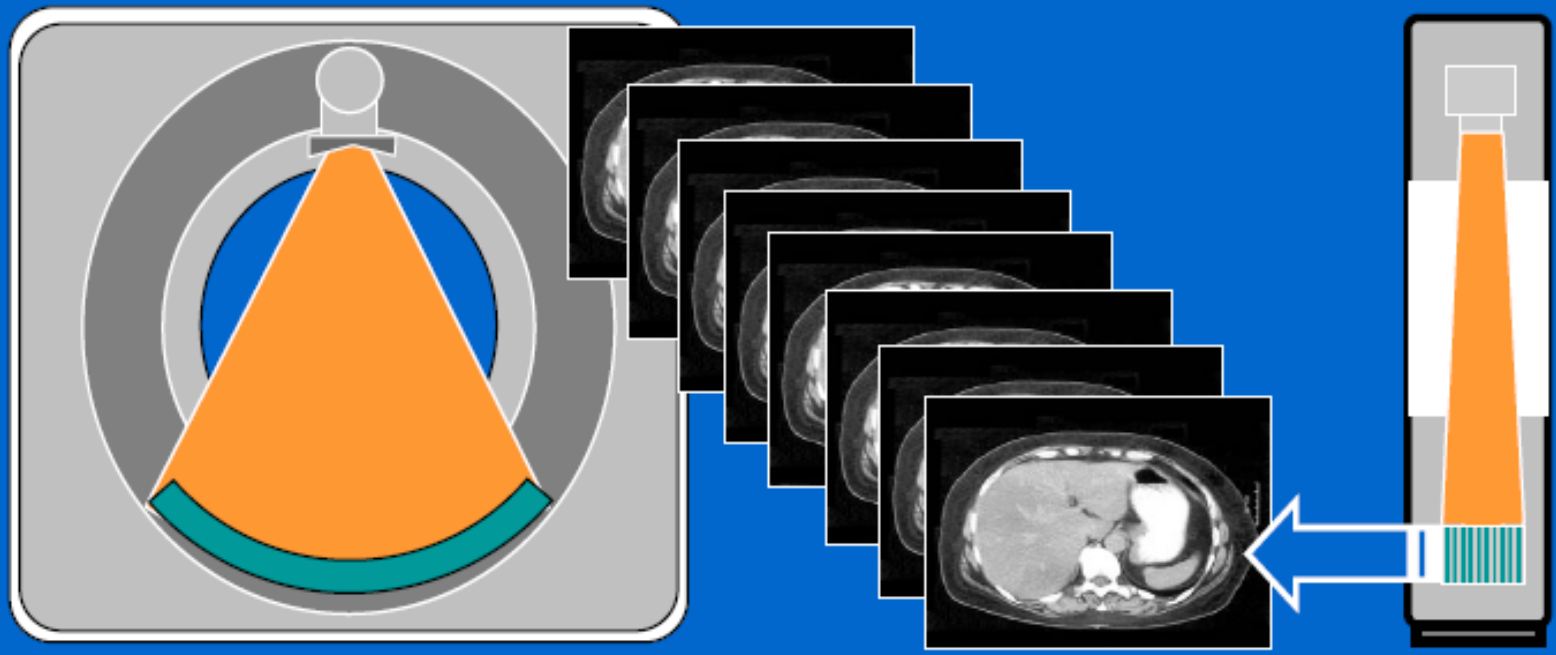
Beam width, detectors and slices

- GE LightSpeed 64
  - 64 x 0.625 mm detectors



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

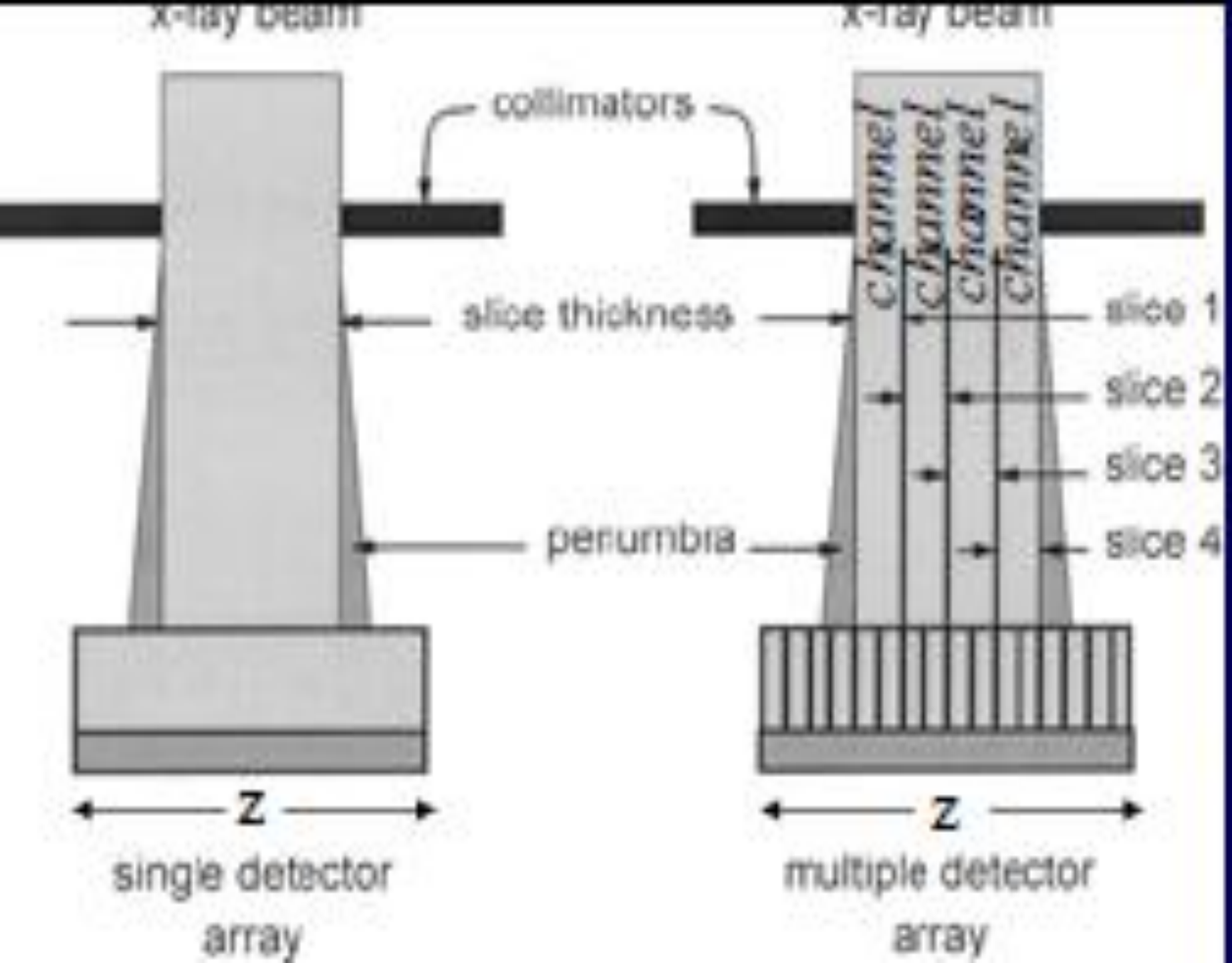


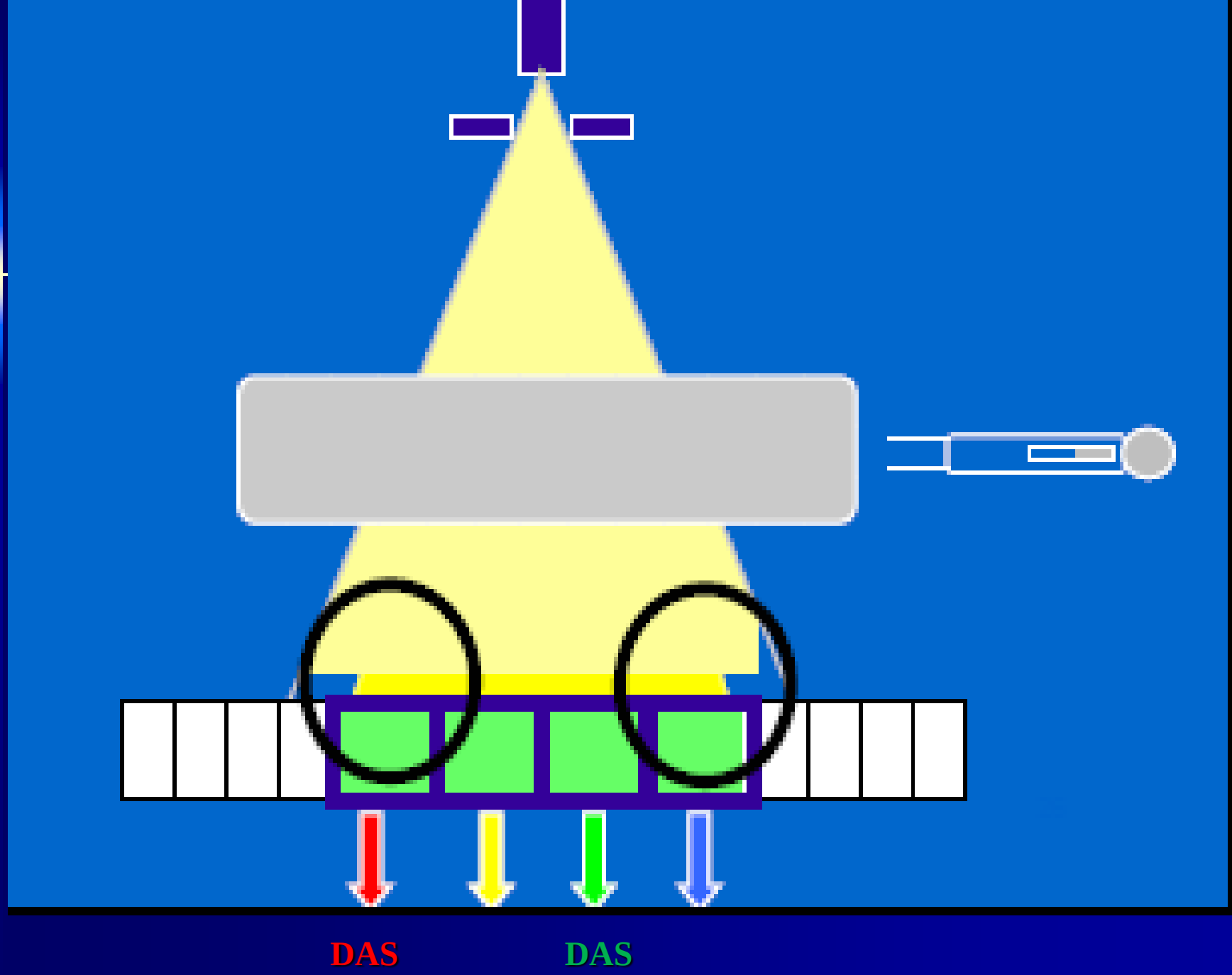
xy-plane
images

z-axis
patient axis
scan direction

DAS :

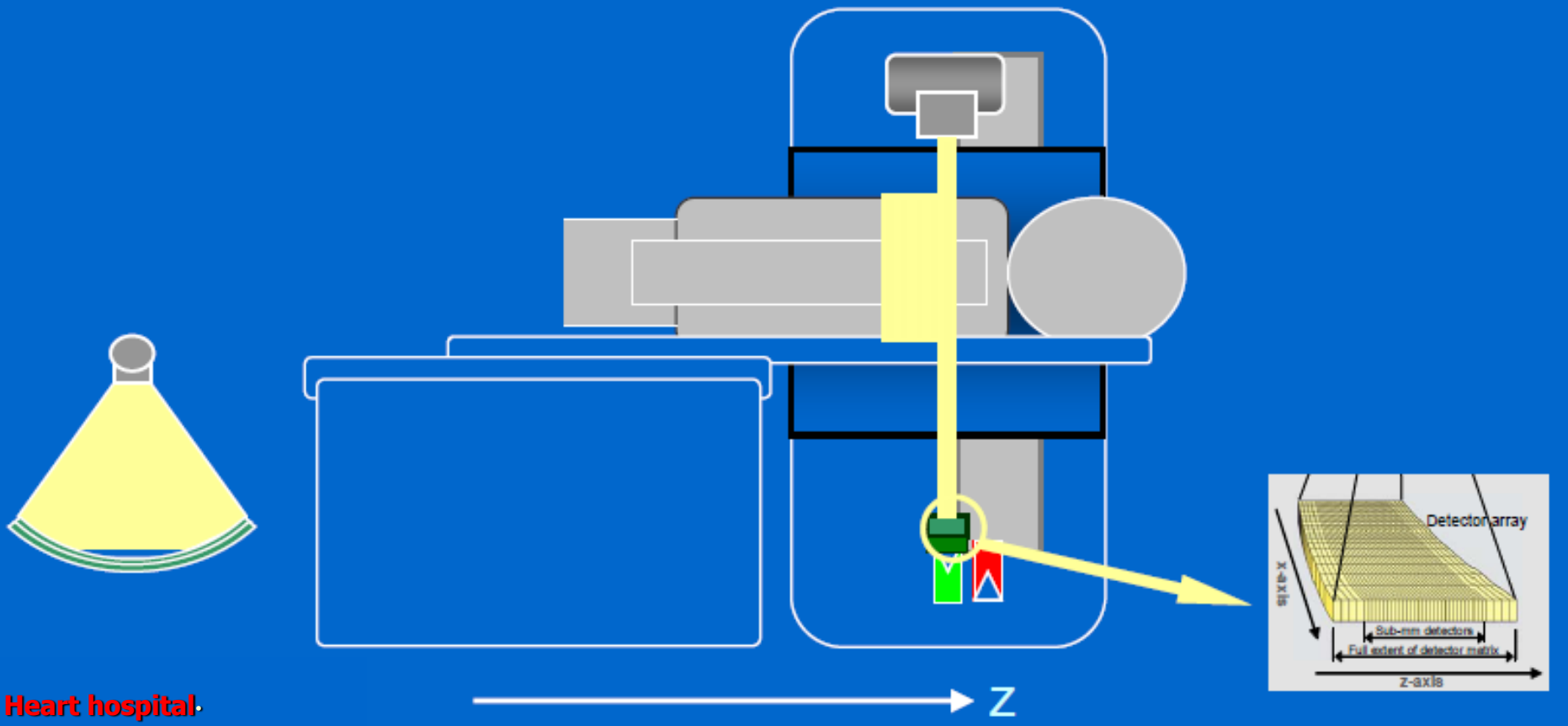
Data acquisition system


x-ray beam
collimators
slice thickness
penumbra
Z
single detector array
x-ray beam
channel
channel
channel
channel
slice 1
slice 2
slice 3
slice 4
Z
multiple detector array


DAS
DAS

Axial scanning – ‘step and shoot’

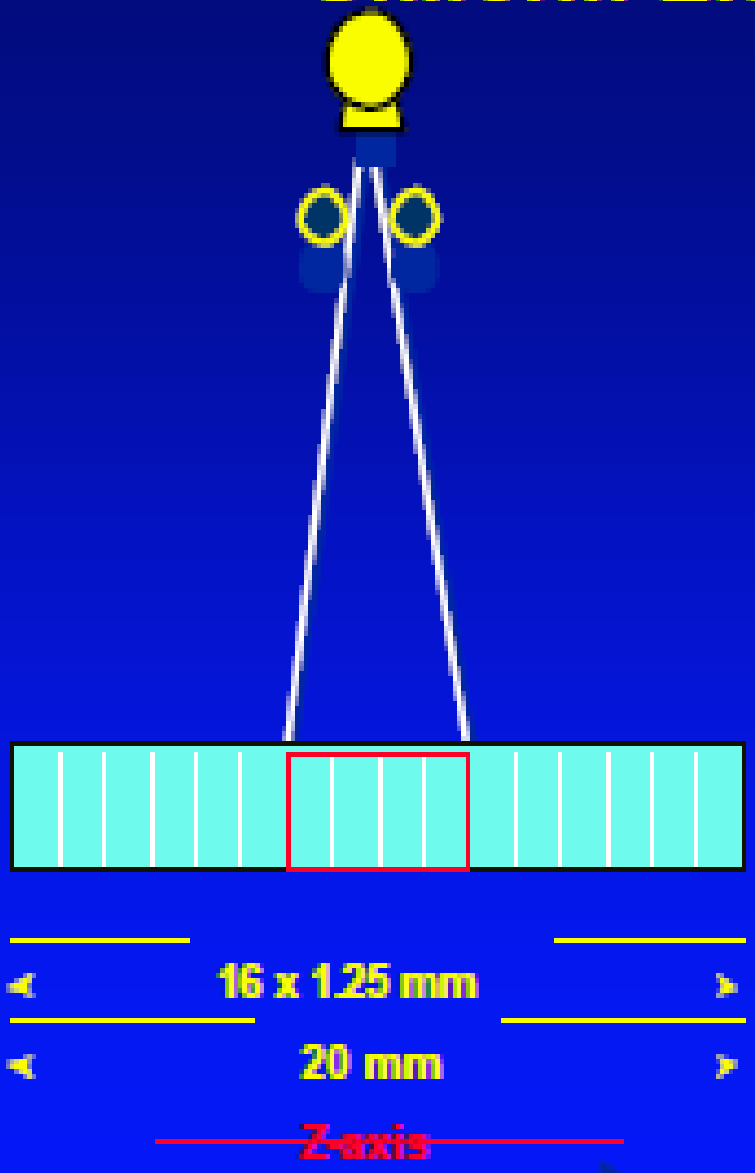
– Also known as sequential scanning



Detector array:

- Uniform
- Non – uniform
- Hybrid

Uniform Element Arrays

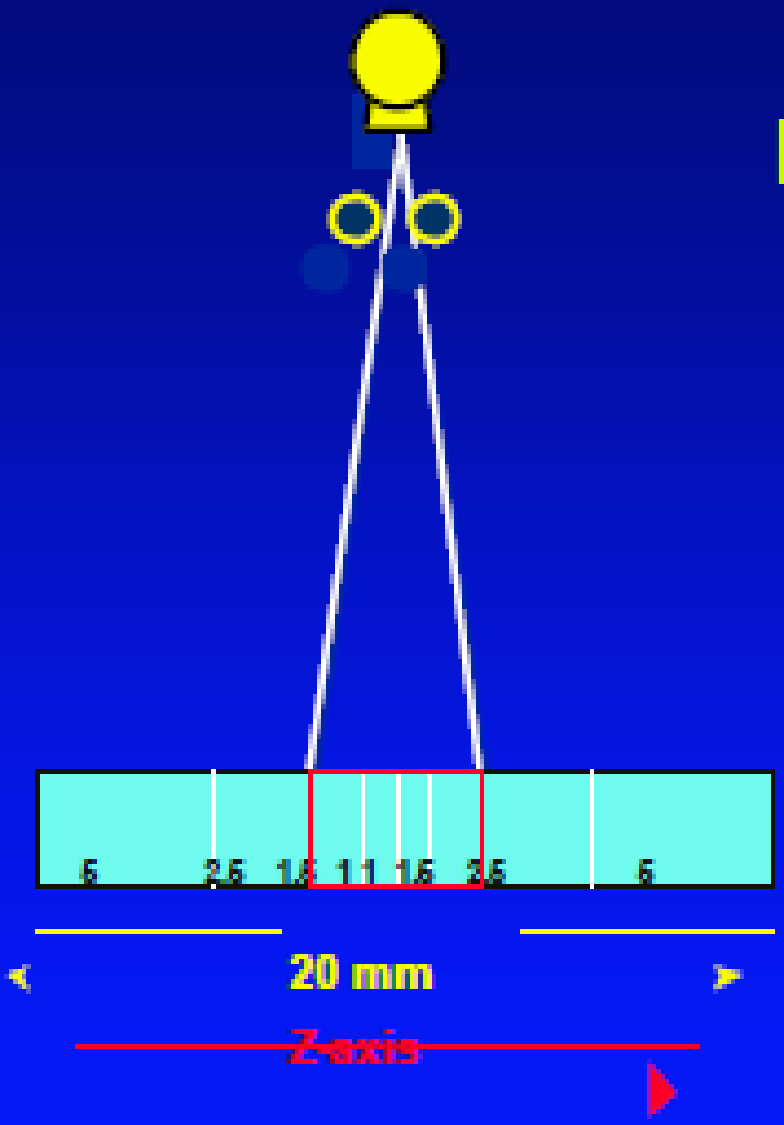


Possible section widths

2 x 0.63 mm
4 x 1.25 mm
4 x 2.5 mm
4 x 3.75 mm
4 x 5 mm
2 x 7.5 mm
2 x 10 mm

Lightspeed, GE Medical Systems

Non-Uniform Element Arrays

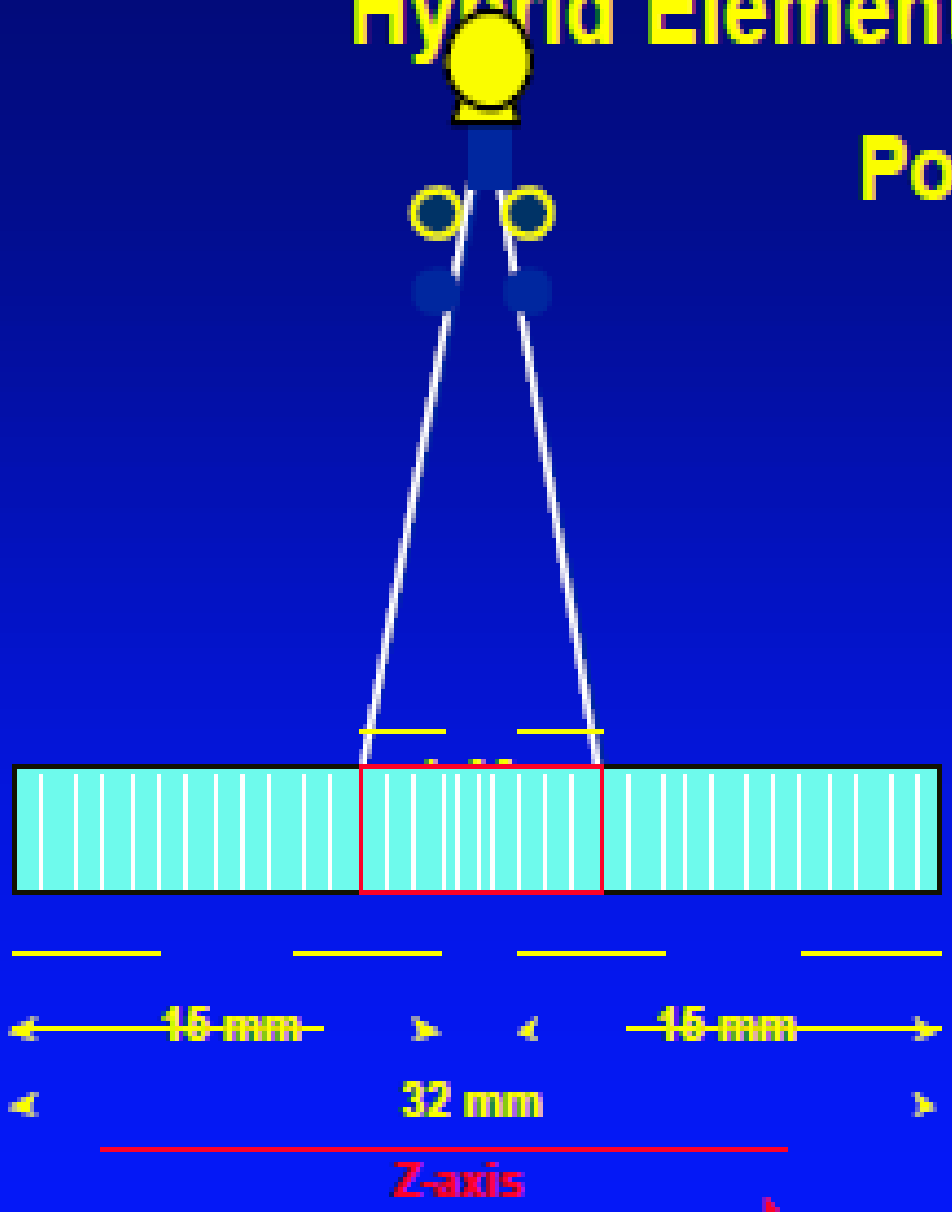


Possible section widths

- 2 x 0.5 mm
- 4 x 1 mm
- 4 x 2.5 mm
- 4 x 5 mm
- 2 x 8 mm
- 2 X 10 mm

Volume Zoom, Siemens Medical Systems

Hybrid Element Arrays

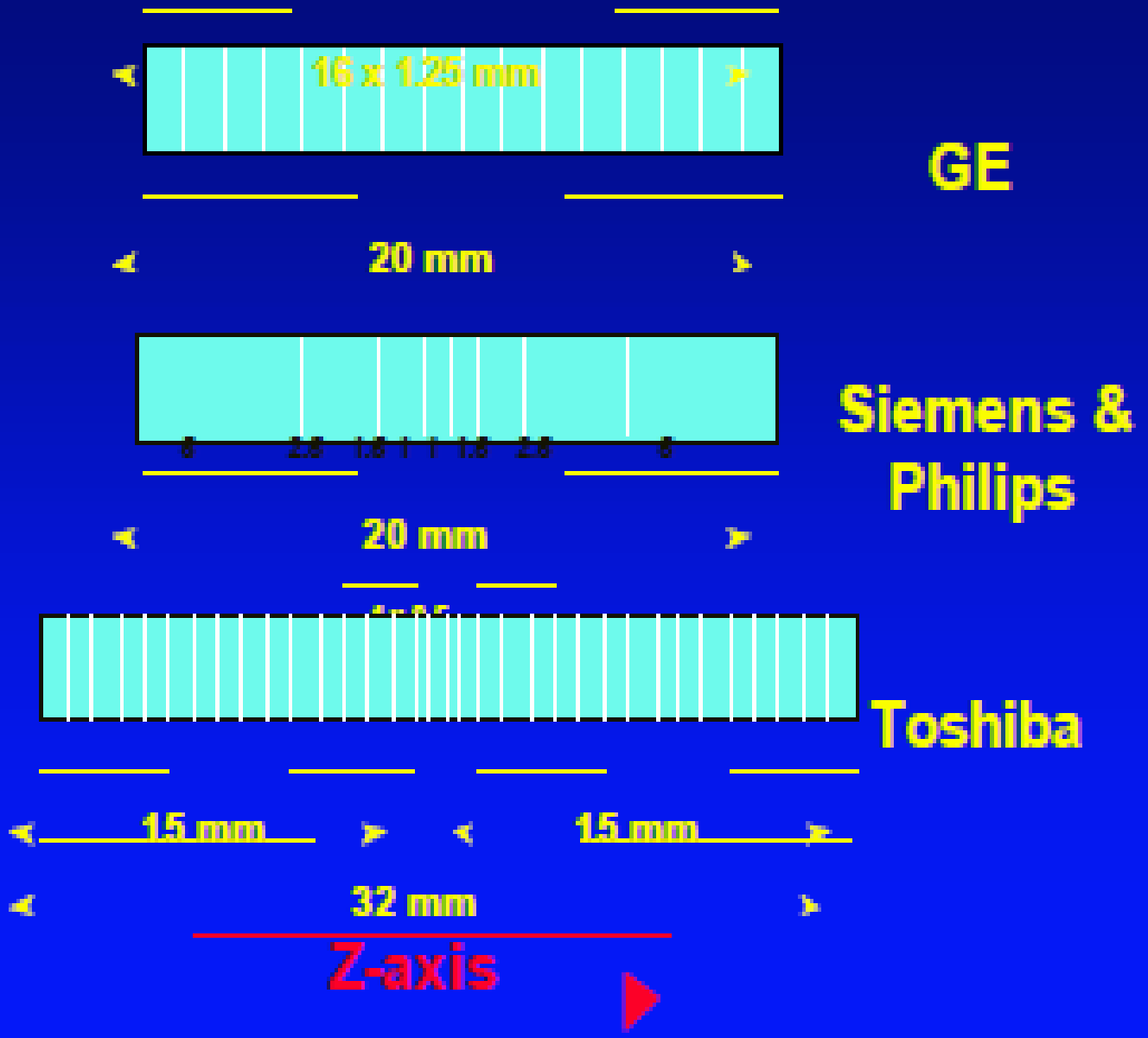


Possible section widths

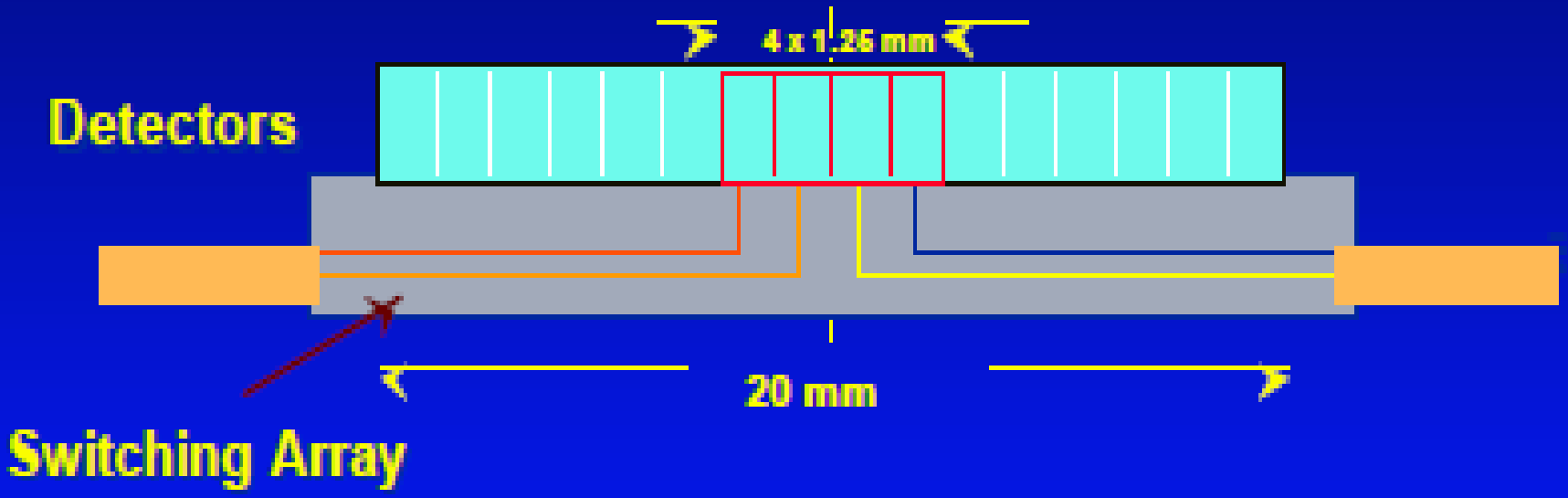
4 x 0.5 mm
4 x 1 mm
4 x 2 mm
4 x 3 mm
4 x 5 mm
4 x 8 mm
2 x 10 mm

Acquilion, Toshiba Medical Systems

MDCT: Detector Element Arrays

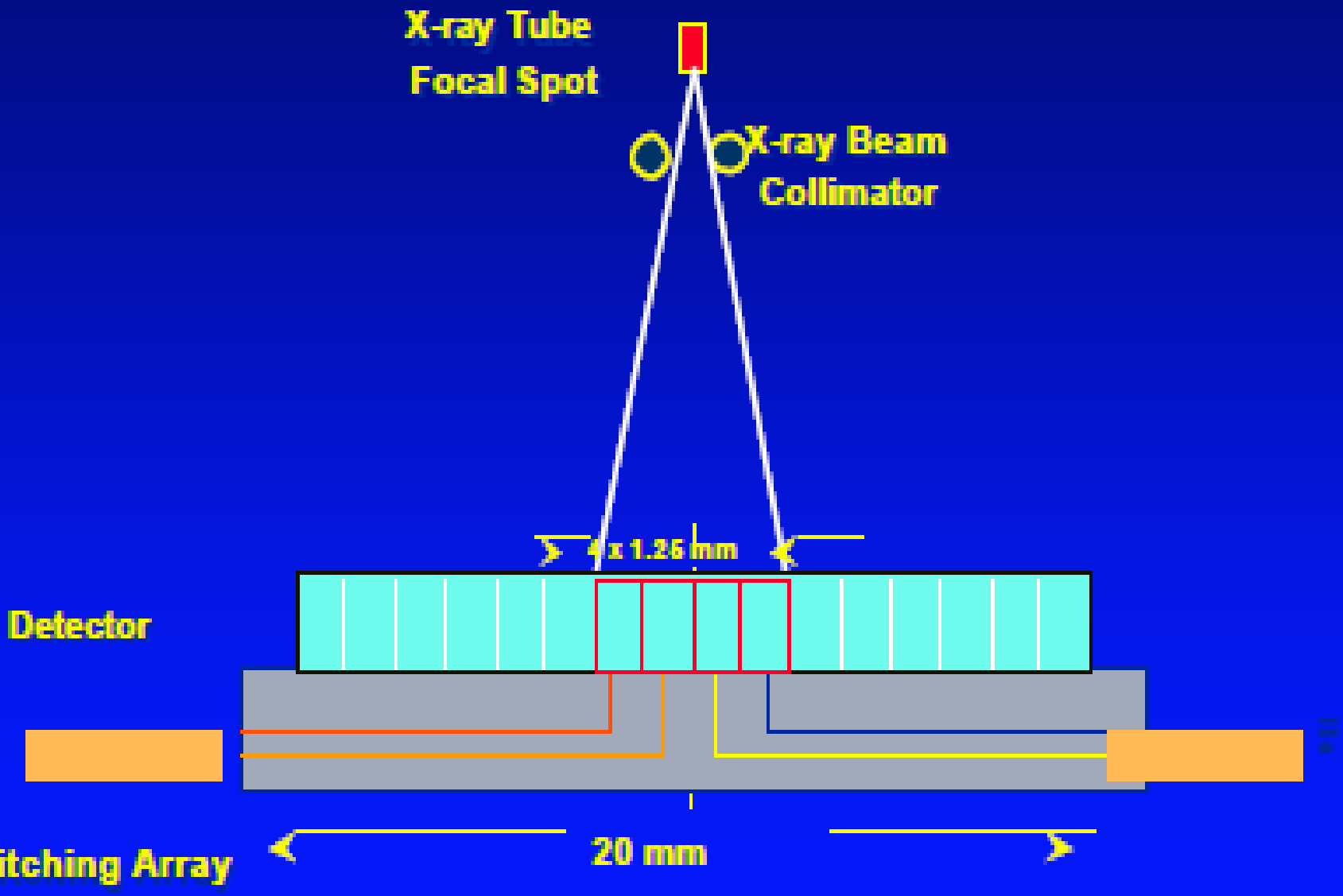


How are detector elements used in MDCT?

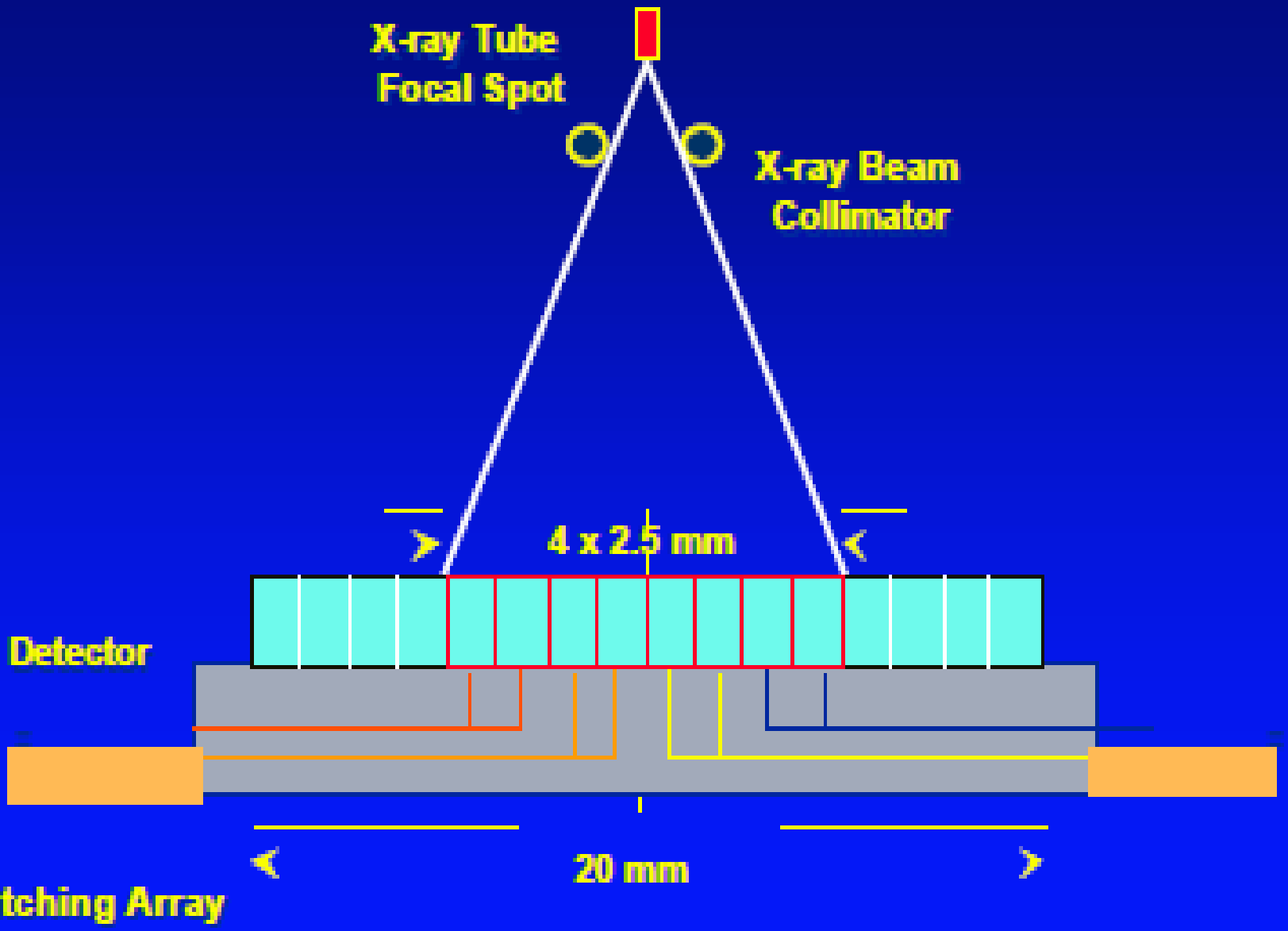


4-section scanners collect four simultaneous channels of data

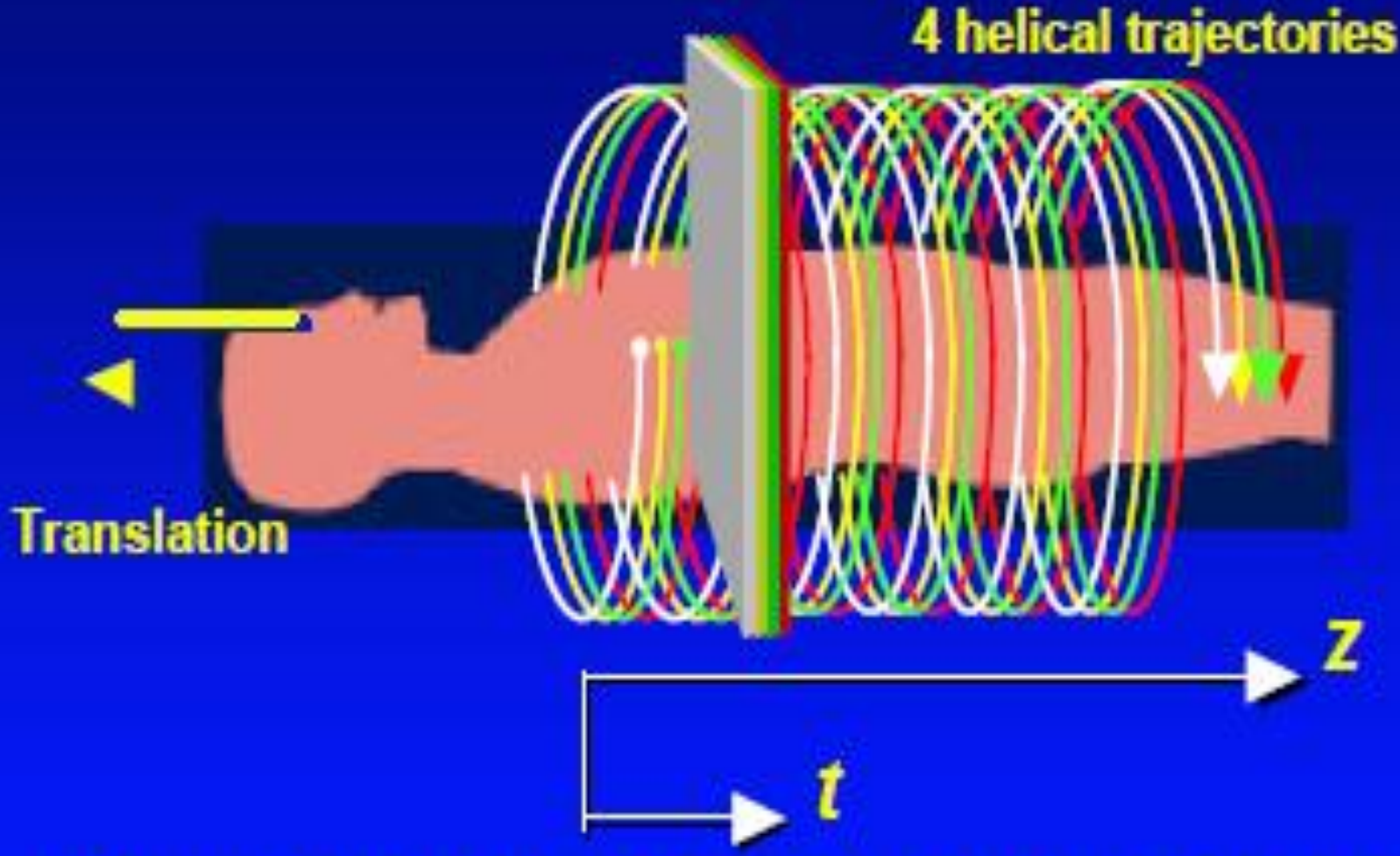
Detector Configuration: For 4 x 1.25 mm



Detector Configuration: For 4 x 2.5 mm

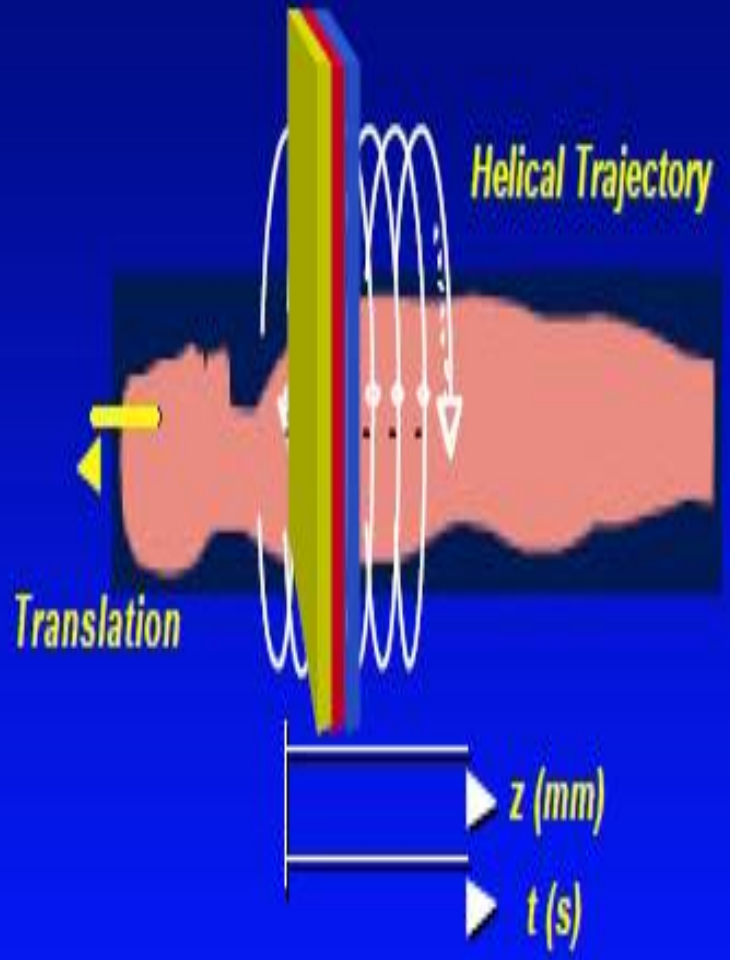


Helical Multiple Section Mode



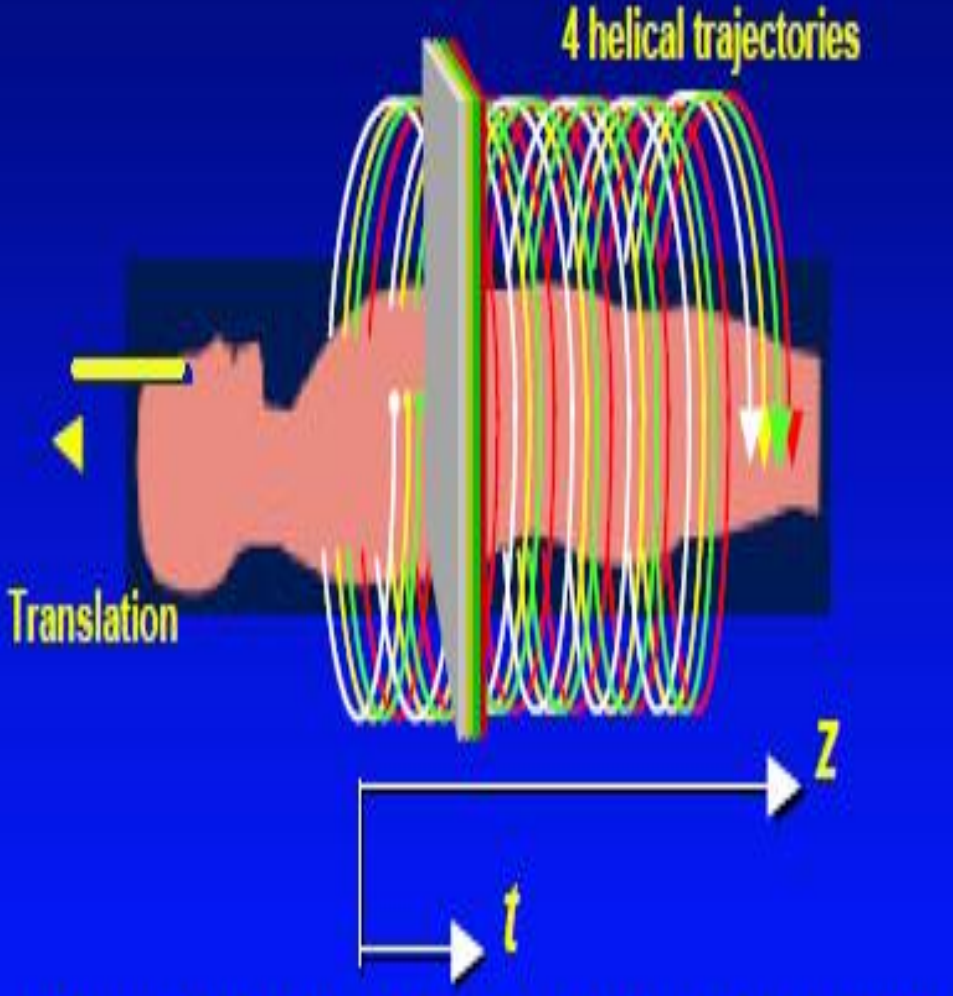
Interpolation using samples of ALL detector rings

Helical Single-Section Mode



Interpolation using samples from single row detector ring

Helical Multiple Section Mode



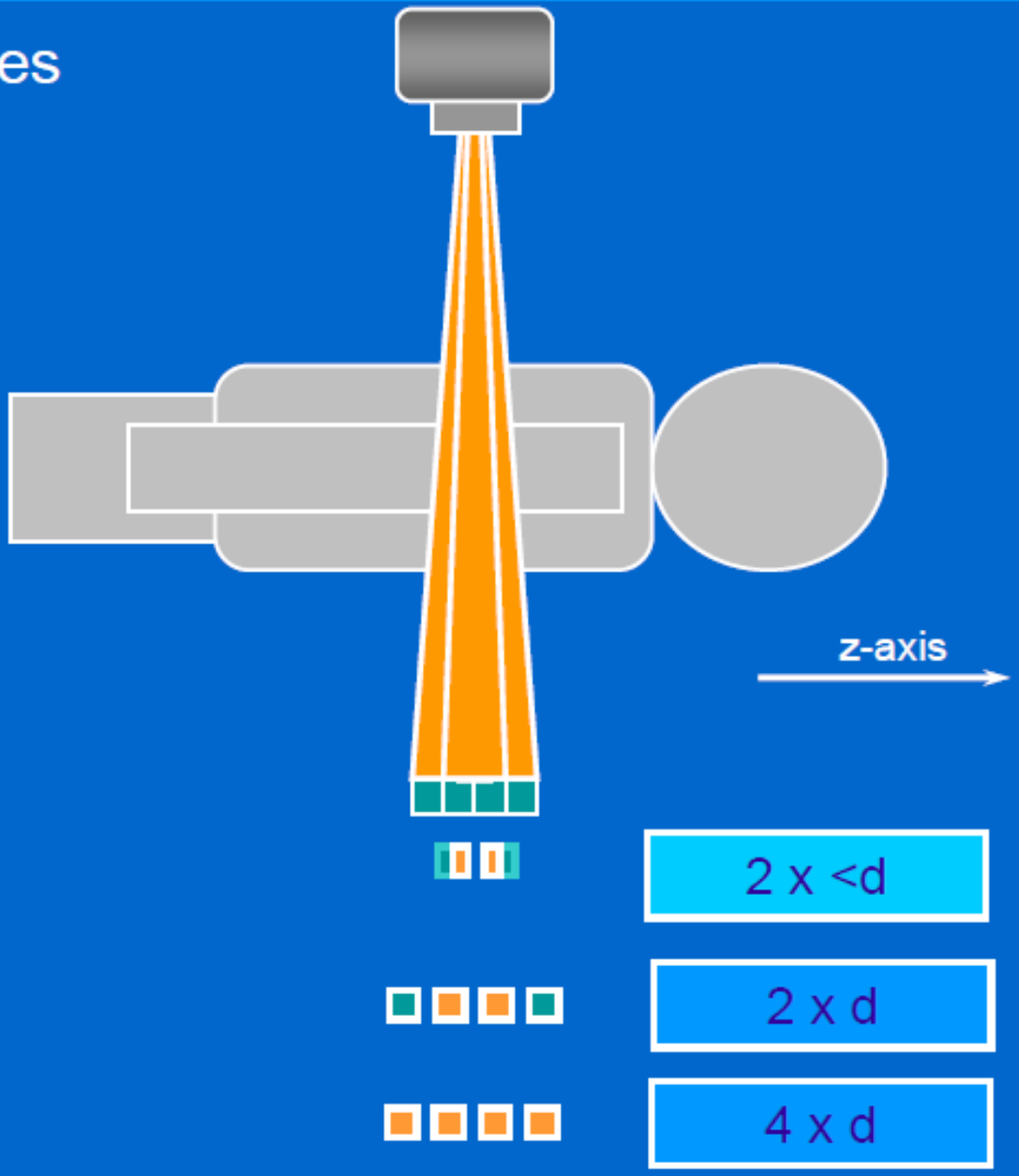
Interpolation using samples of ALL detector rings

The Detector's Evolution…

Slices & detectors

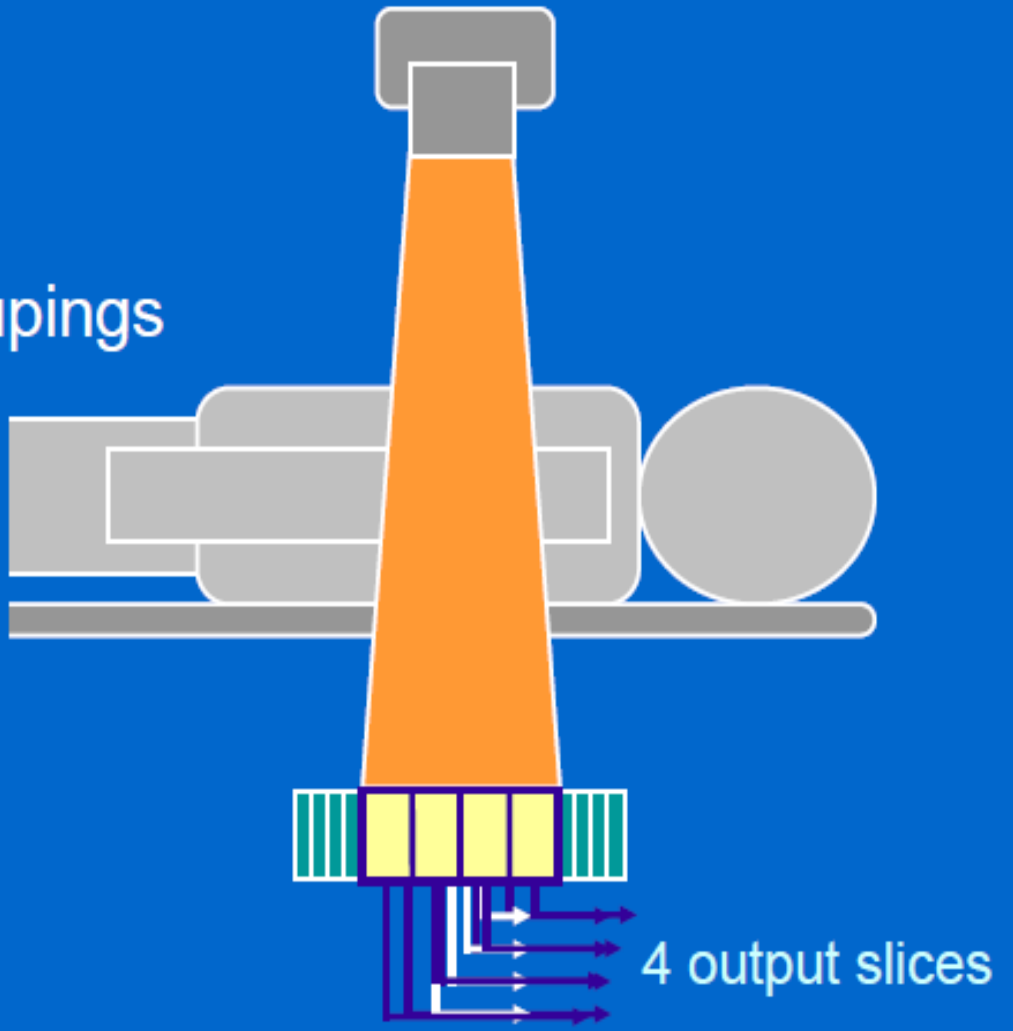
- Just 4 detectors reduces options for scanning

- Narrow coverage
  - eg. 5 mm
    for d=1.25 mm



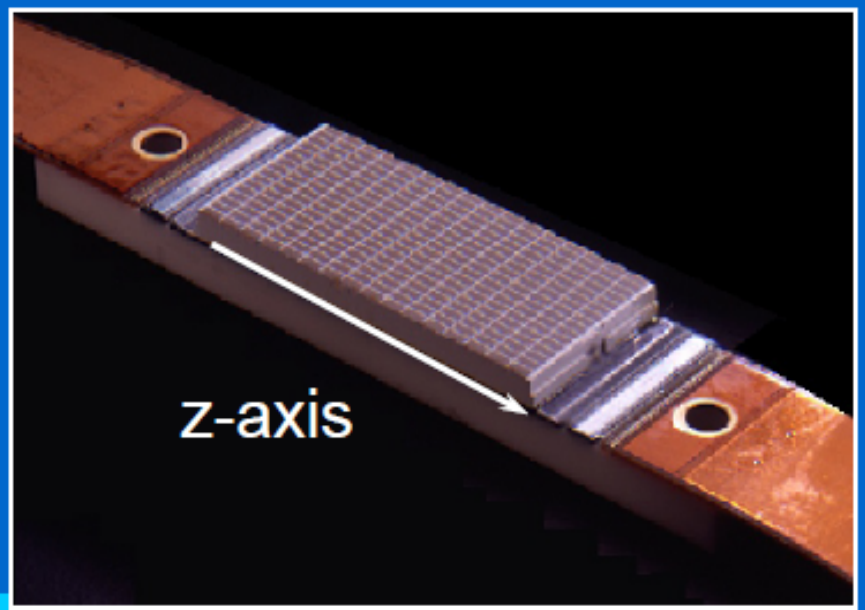
Slice width selection: 4 slice

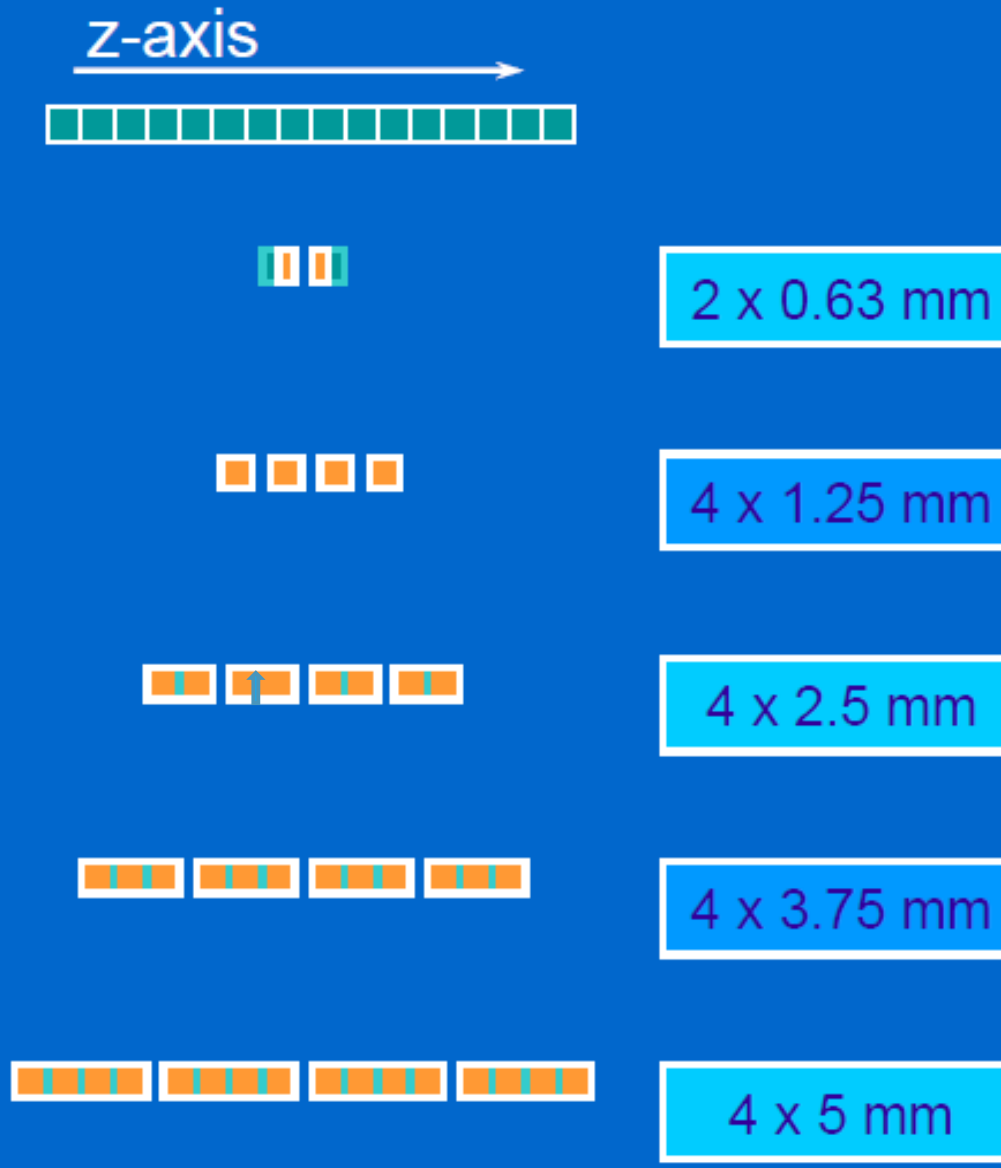
- For more flexibility
  AND
  greater coverage
  need more detectors
- Can collect data from groupings of detectors
  - individual detectors
    - 4 x d
  - pairs
    - 4 x 2d
  - triples
    - 4 x 3d



Slice options: real example

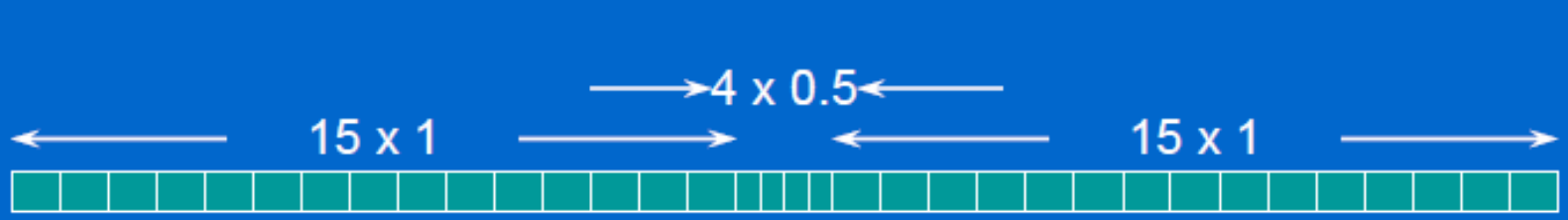
- GE LightSpeed
  - 4 slices
  - 16 detectors
- Detector output combined to define data acquisition width
- Coverage up to 20 mm





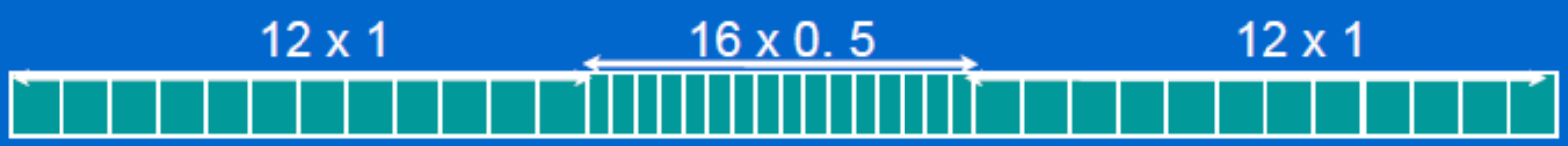
Adaptive arrays

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



Aquilion 4
34 detectors

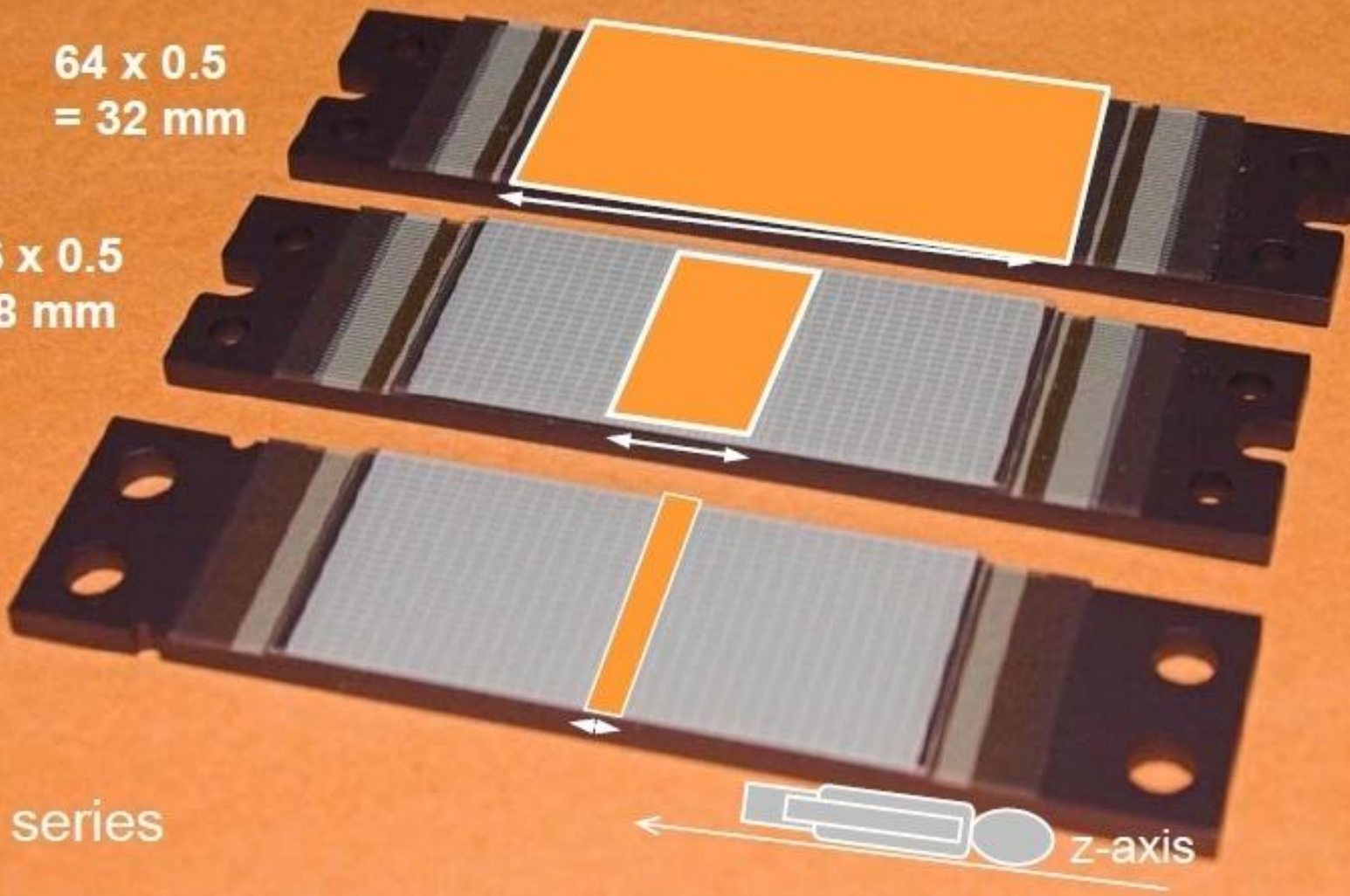
4 x 0.5
4 x 1
4 x 2
4 x 3
4 x 5
4 x 8



Aquilion 16
40 detectors

16 x 0.5
16 x 1
16 x 2

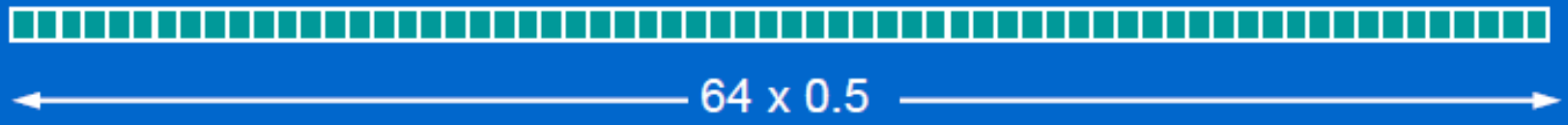
More “thinnest-slice” coverage



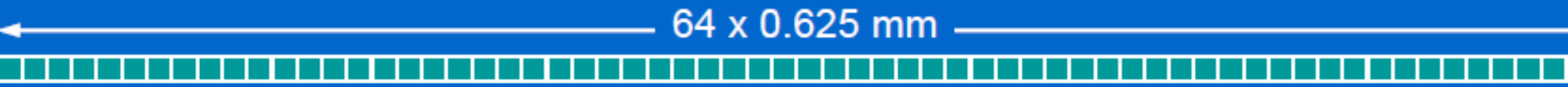
Aquilion series

Detector mock-ups courtesy of Toshiba

64 slice scanners

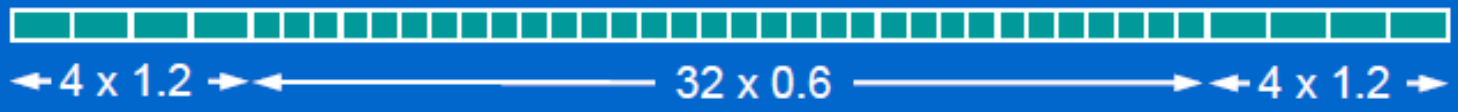


Toshiba Aquilion 64



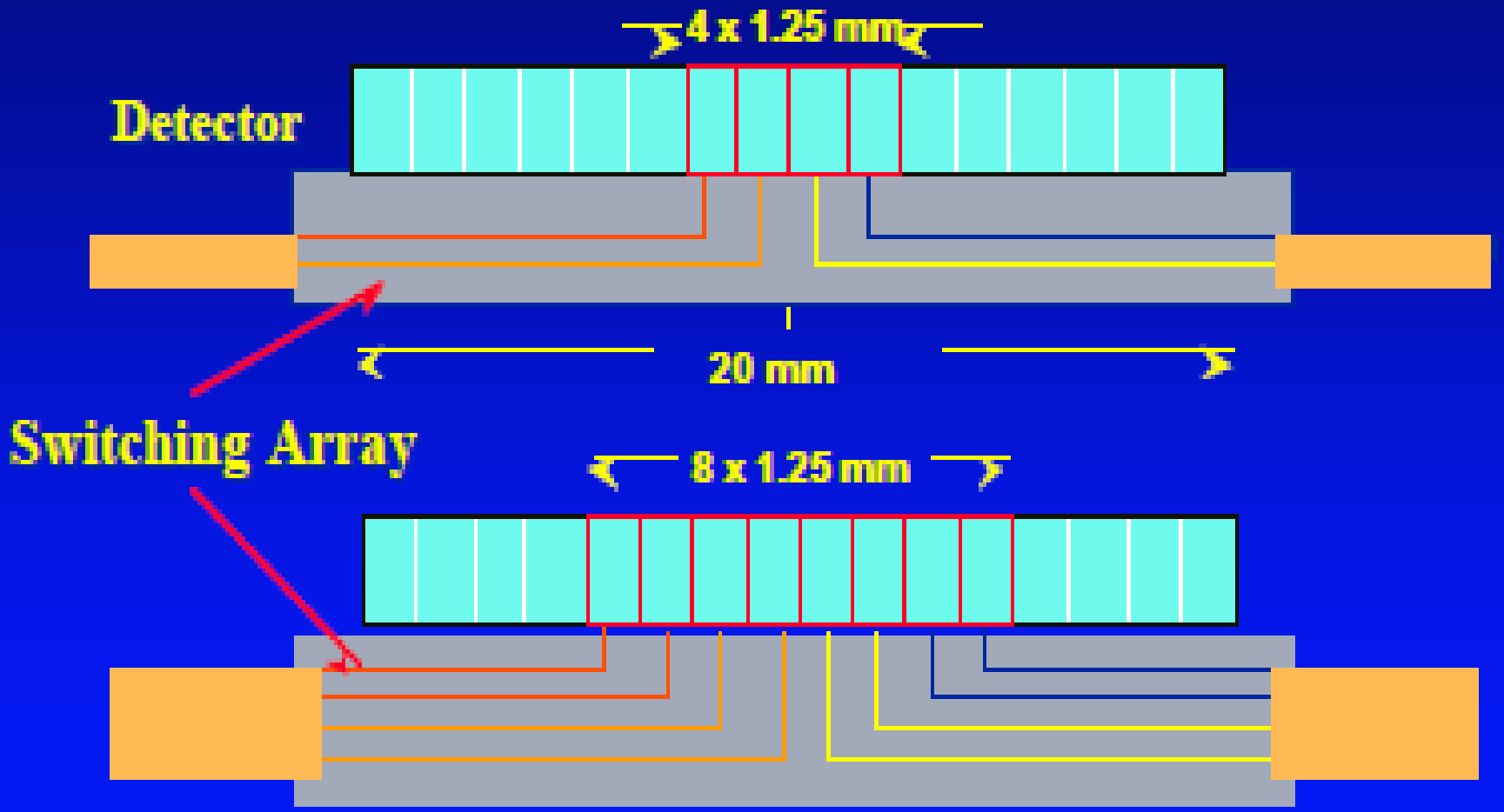
GE LightSpeed VCT

Philips Brilliance CT64

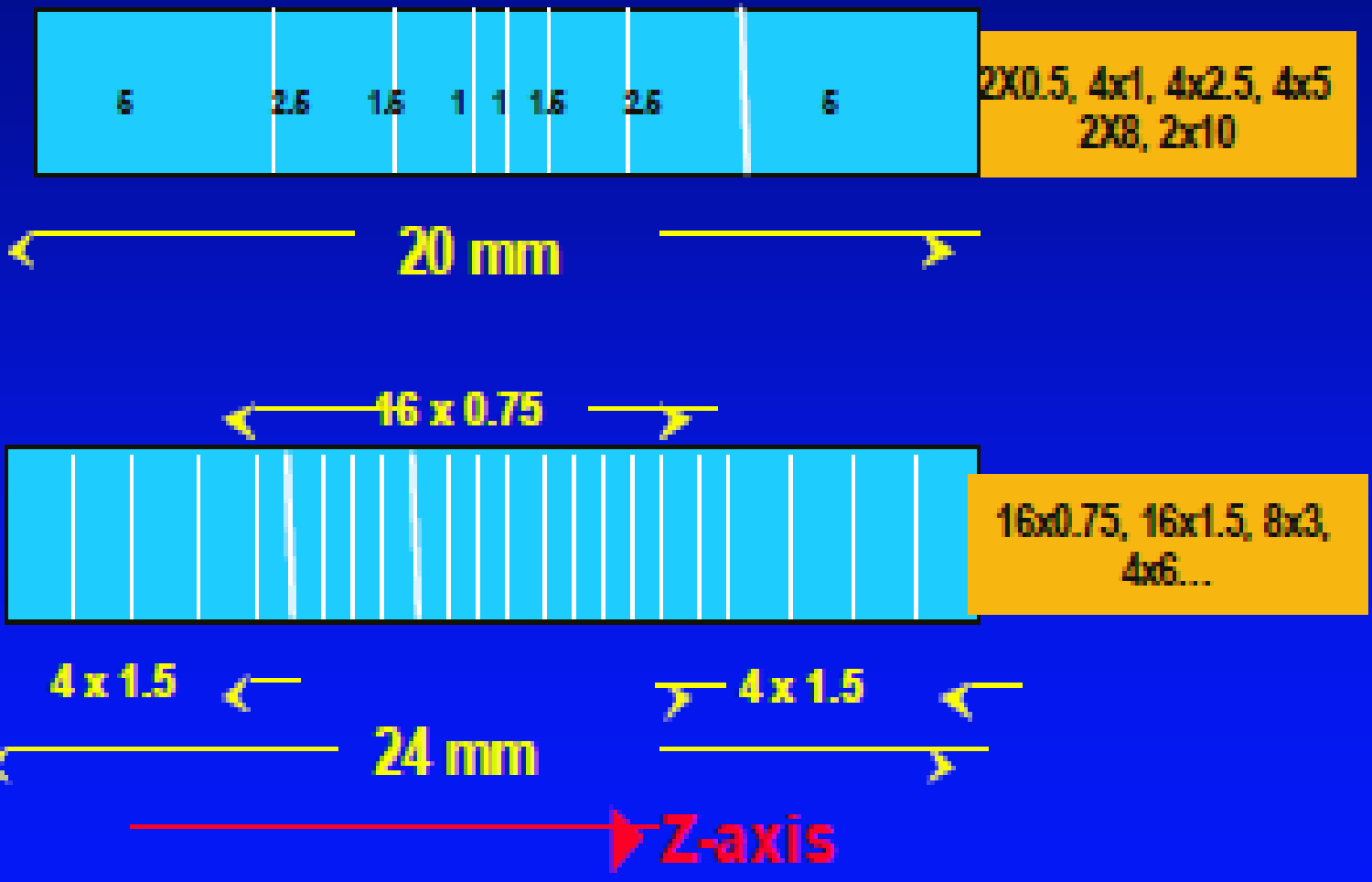


Siemens Sensation 64

DAS channels: Four versus Eight

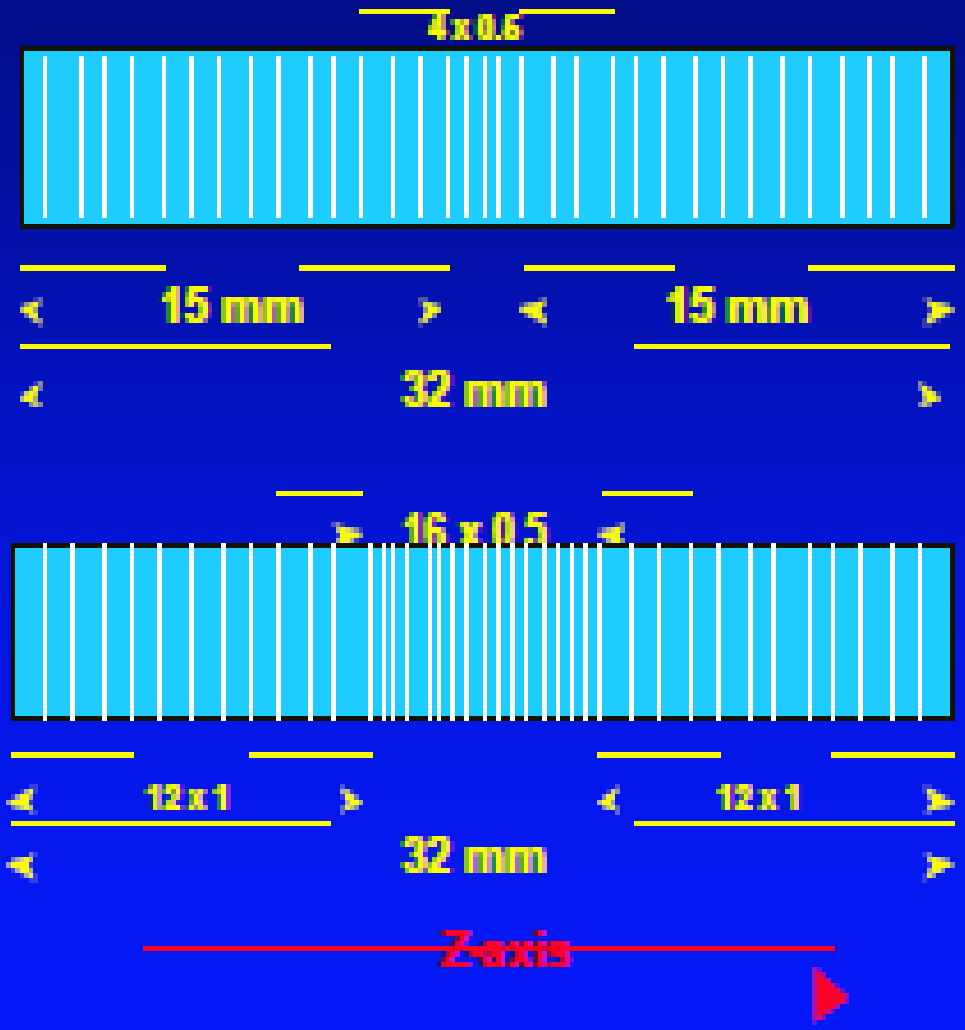


Detector Evolution: 4 vs 16 sections per rotation



Siemens & Philips Medical Systems

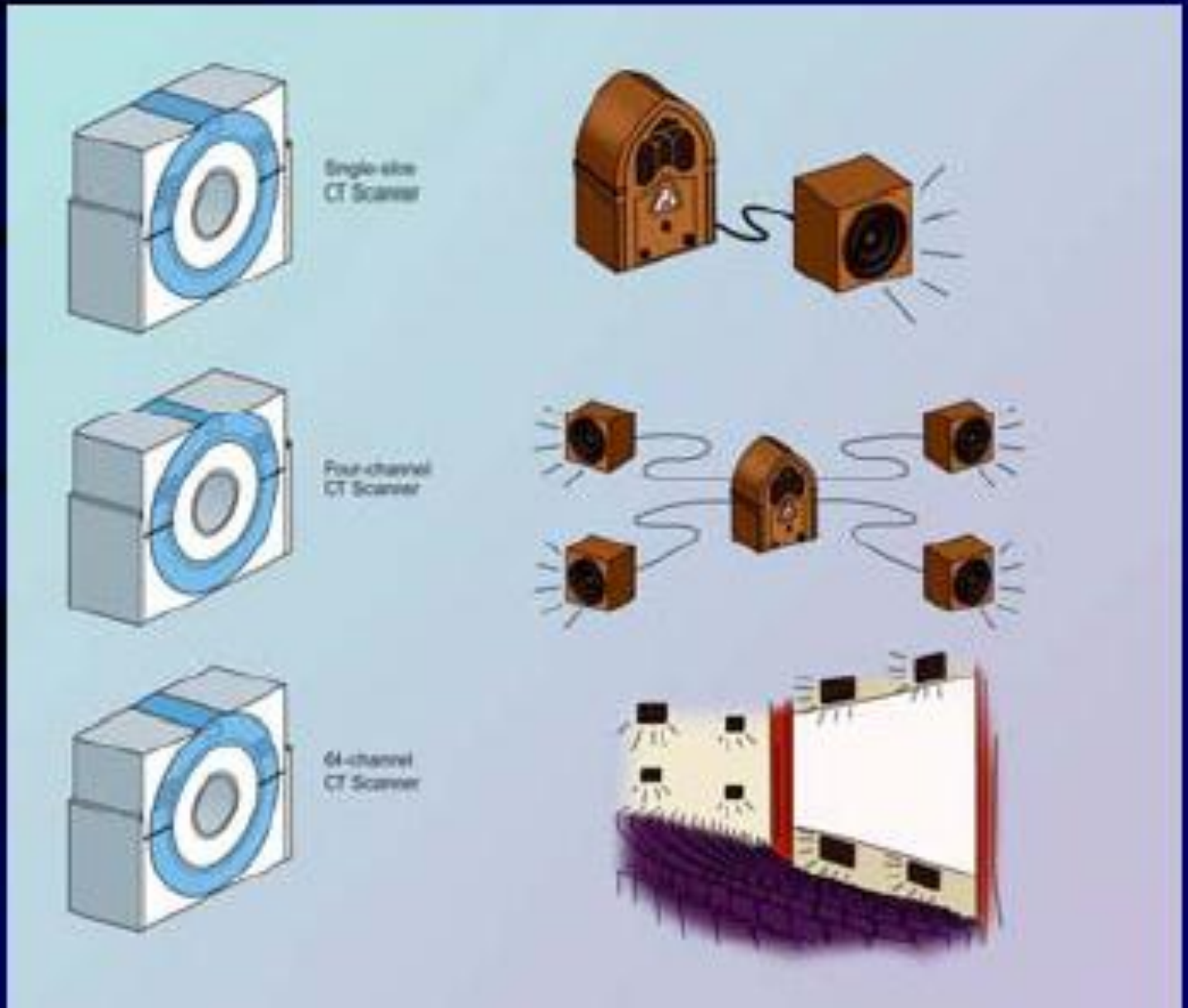
Detector Evolution: 4 vs. 16 sections per rotation



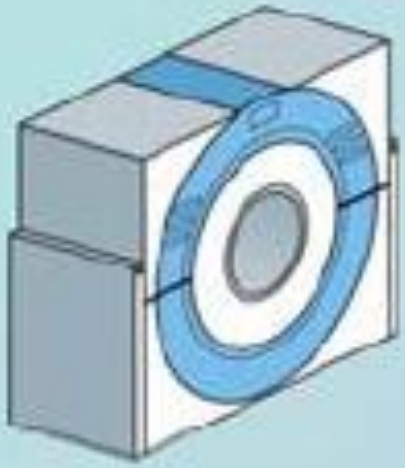
4x0.5, 4X1, 4x2, 4x3
up to 4x8

16x0.5, 16X1, 16x2,
up to 8x4

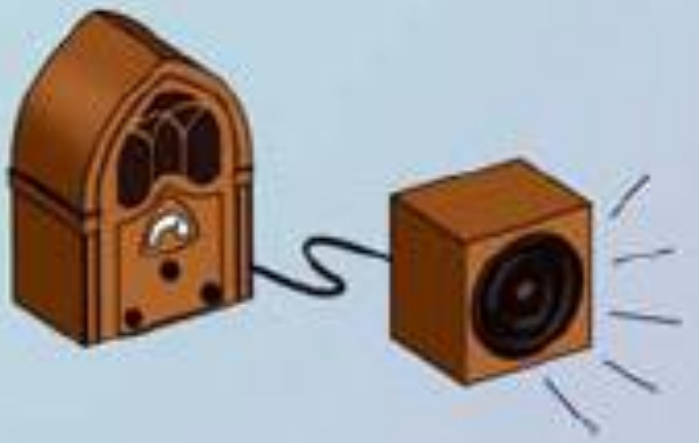
Channels (or data channels)

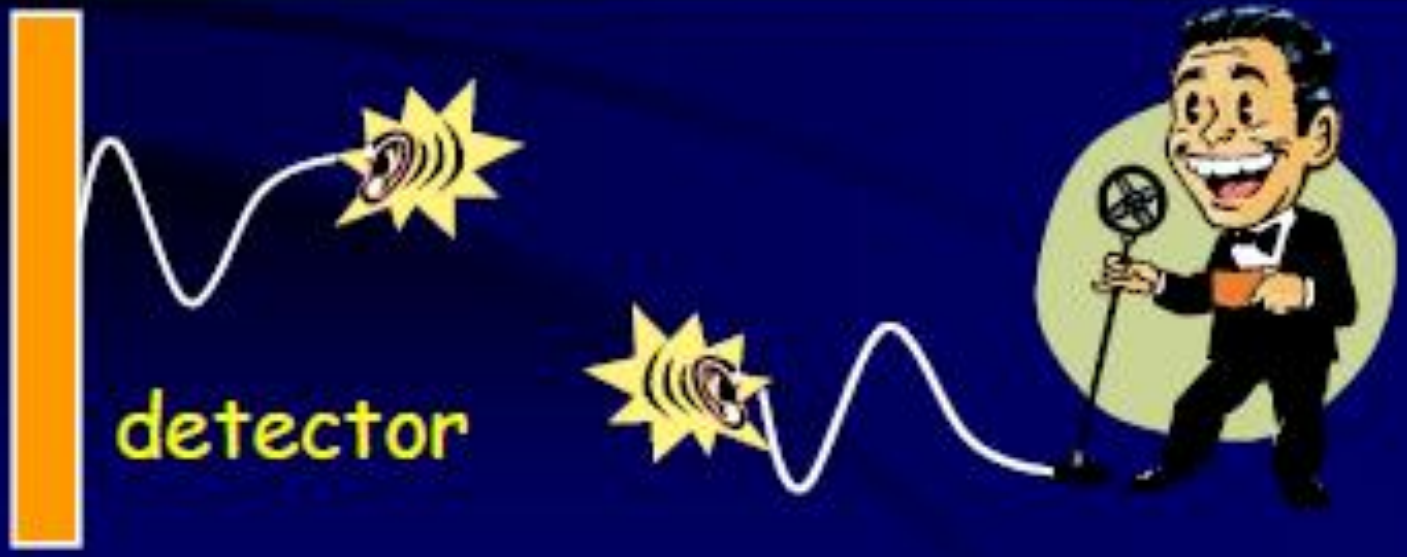


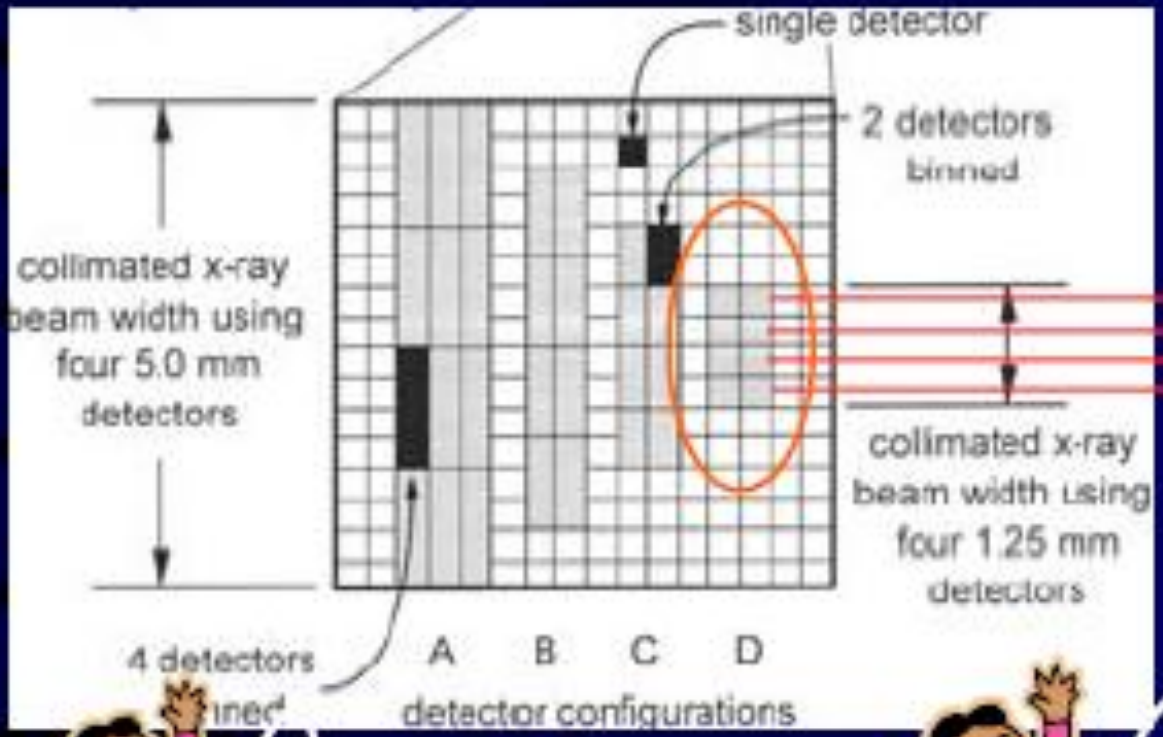
Detector Configuration

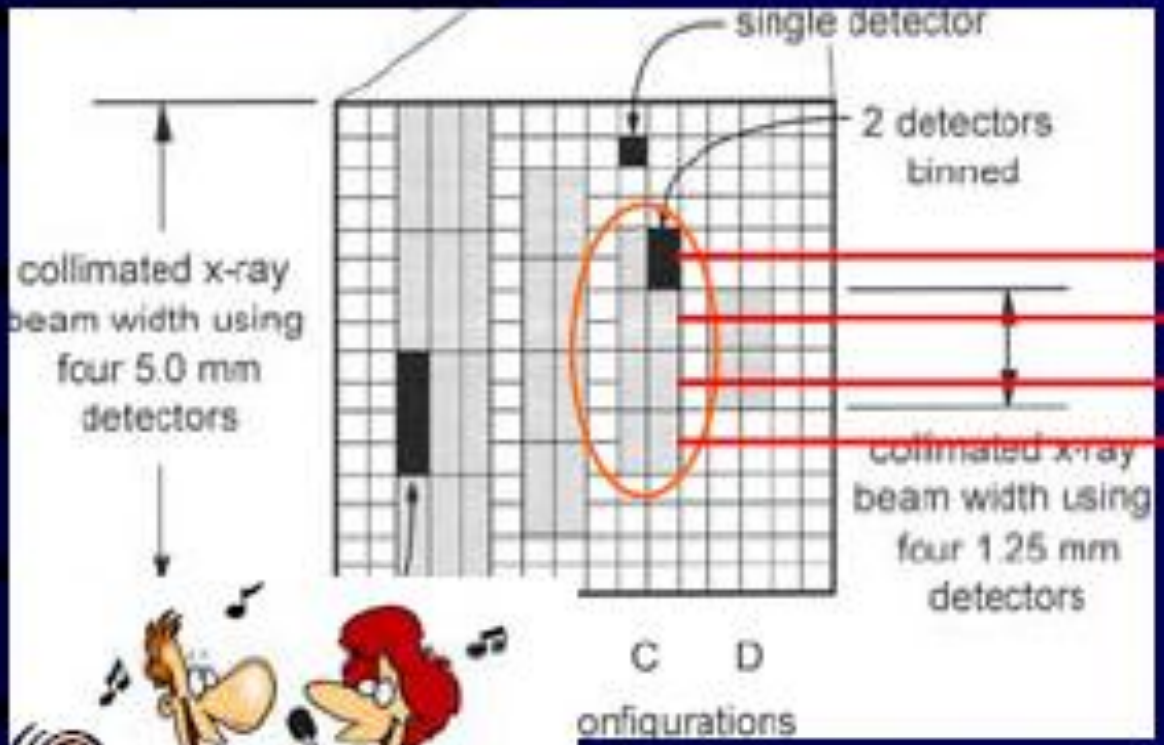


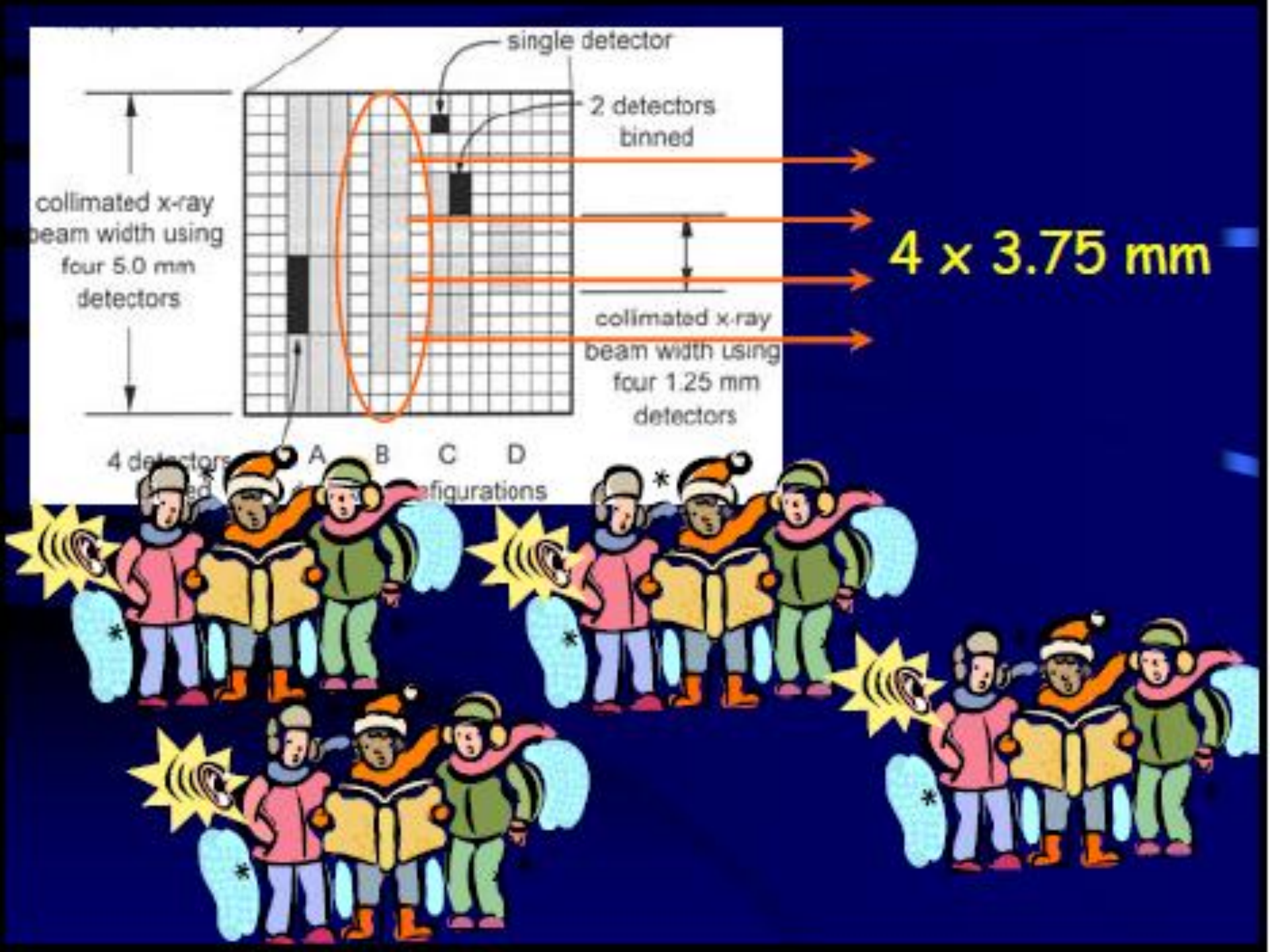
Single-slice
CT Scanner

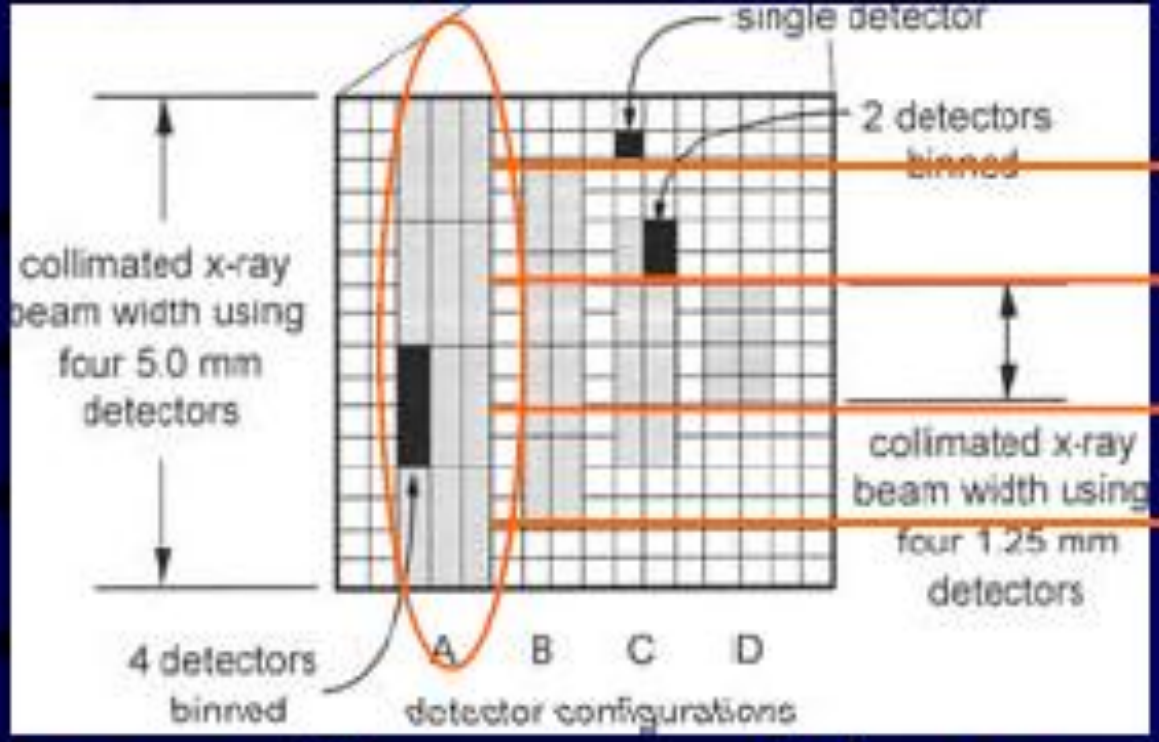





single detector
2 detectors
binned
collimated x-ray
beam width using
four 5.0 mm
detectors
4 x 1.25 mm
collimated x-ray
beam width using
four 1.25 mm
detectors
4 detectors
A
B
C
D
detector configurations

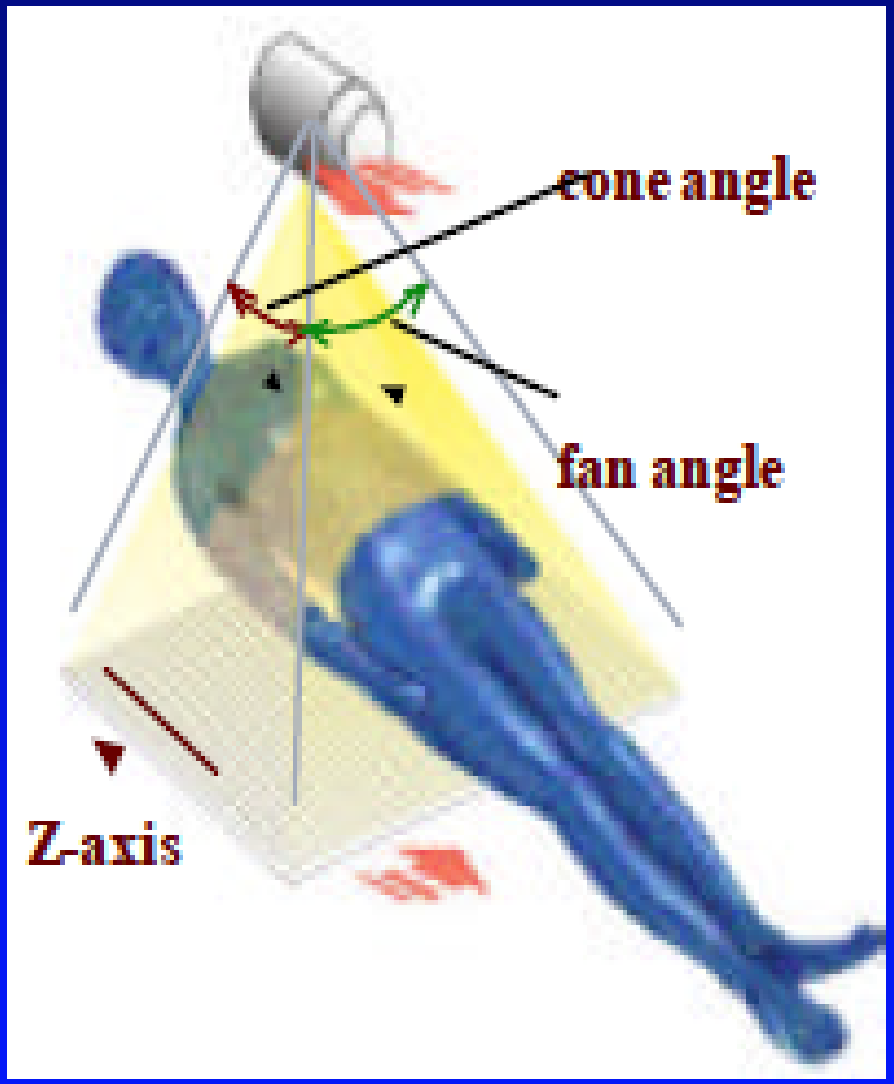

single detector
2 detectors
binned
collimated x-ray
beam width using
four 5.0 mm
detectors
4 x 2.5 mm
collimated x-ray
beam width using
four 1.25 mm
detectors
C
D
onfigurations


single detector
2 detectors binned
collimated x-ray beam width using four 5.0 mm detectors
4 x 3.75 mm
collimated x-ray beam width using four 1.25 mm detectors
A
B
C
D

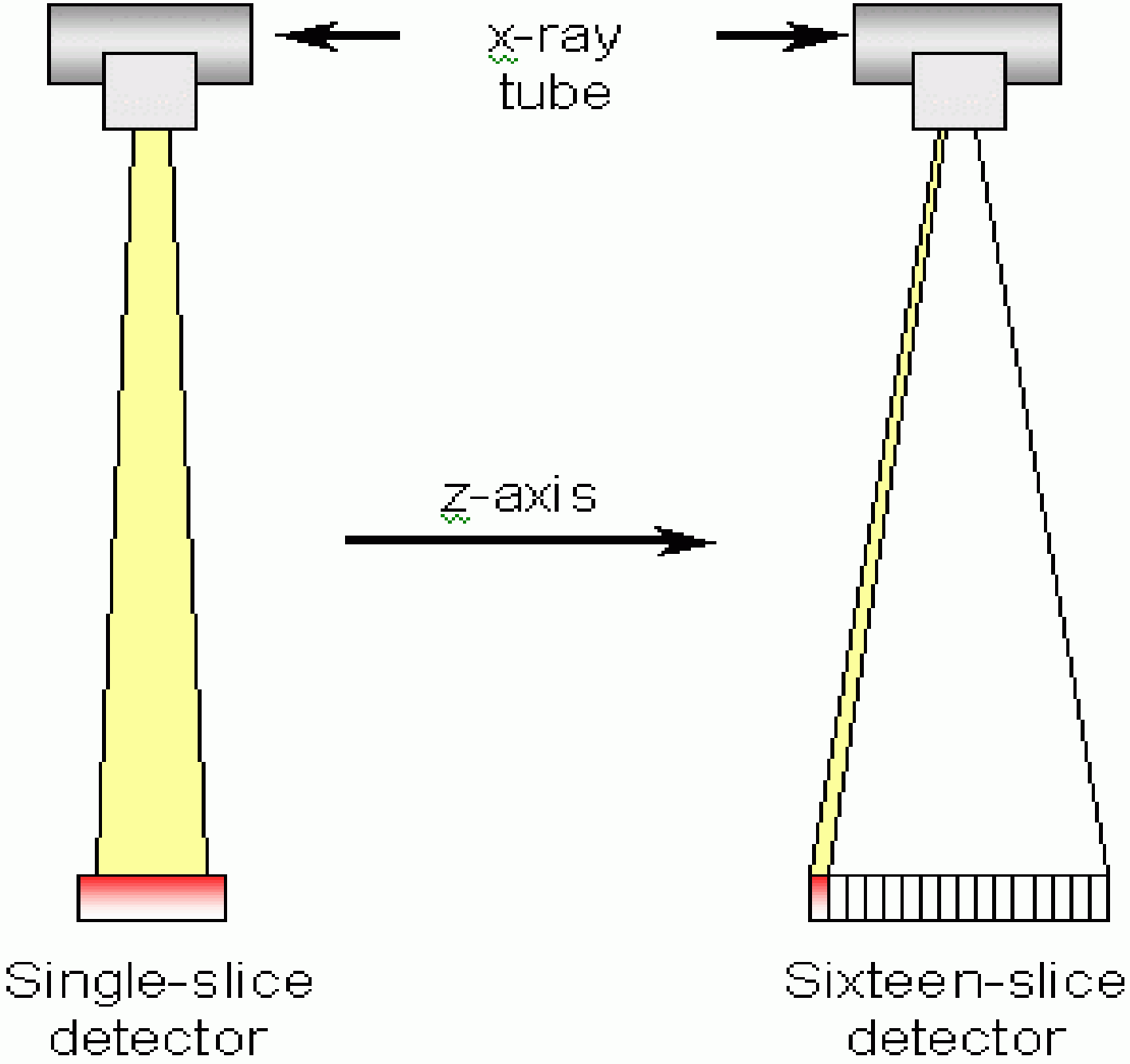

single detector
2 detectors binned
collimated x-ray beam width using four 5.0 mm detectors
4 x 5 mm
collimated x-ray beam width using four 1.25 mm detectors
4 detectors binned
A
B
C
D
detector configurations

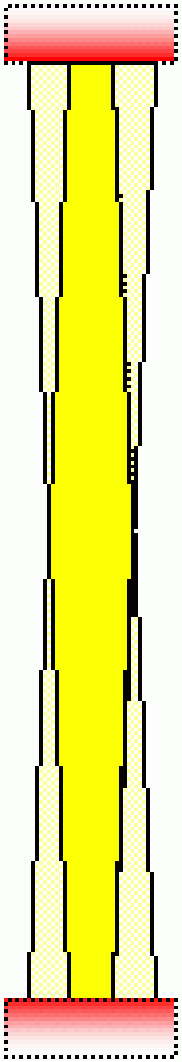
MDCT Episode II: Attack of the Cones

Cone Beam Geometry

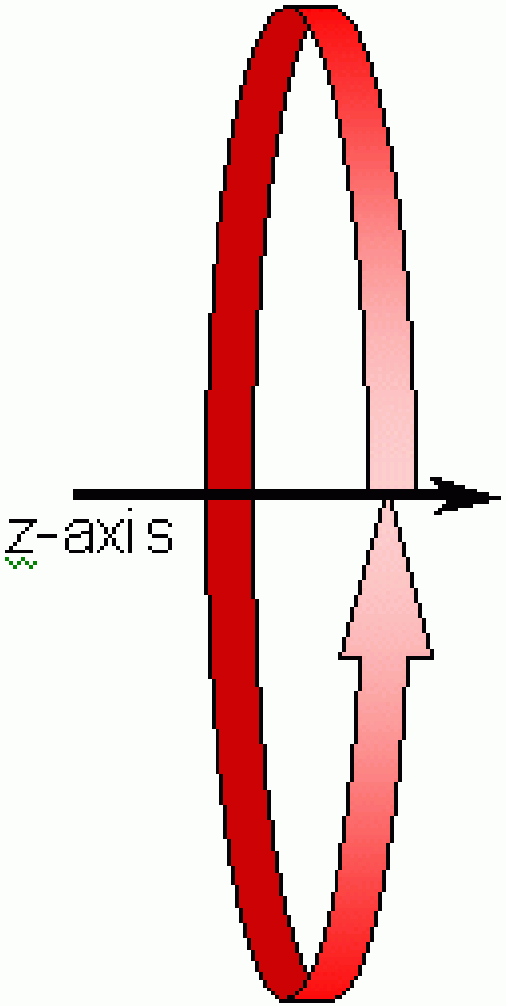


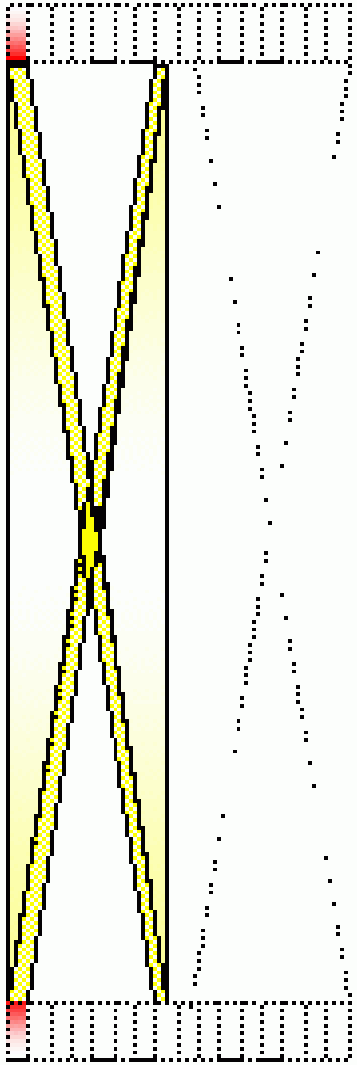
- In MDCT, widening beam aperture in z-direction increases cone angle, that results in significant cone beam artifacts


x-ray
tube
z-axis
Single-slice
detector
Sixteen-slice
detector

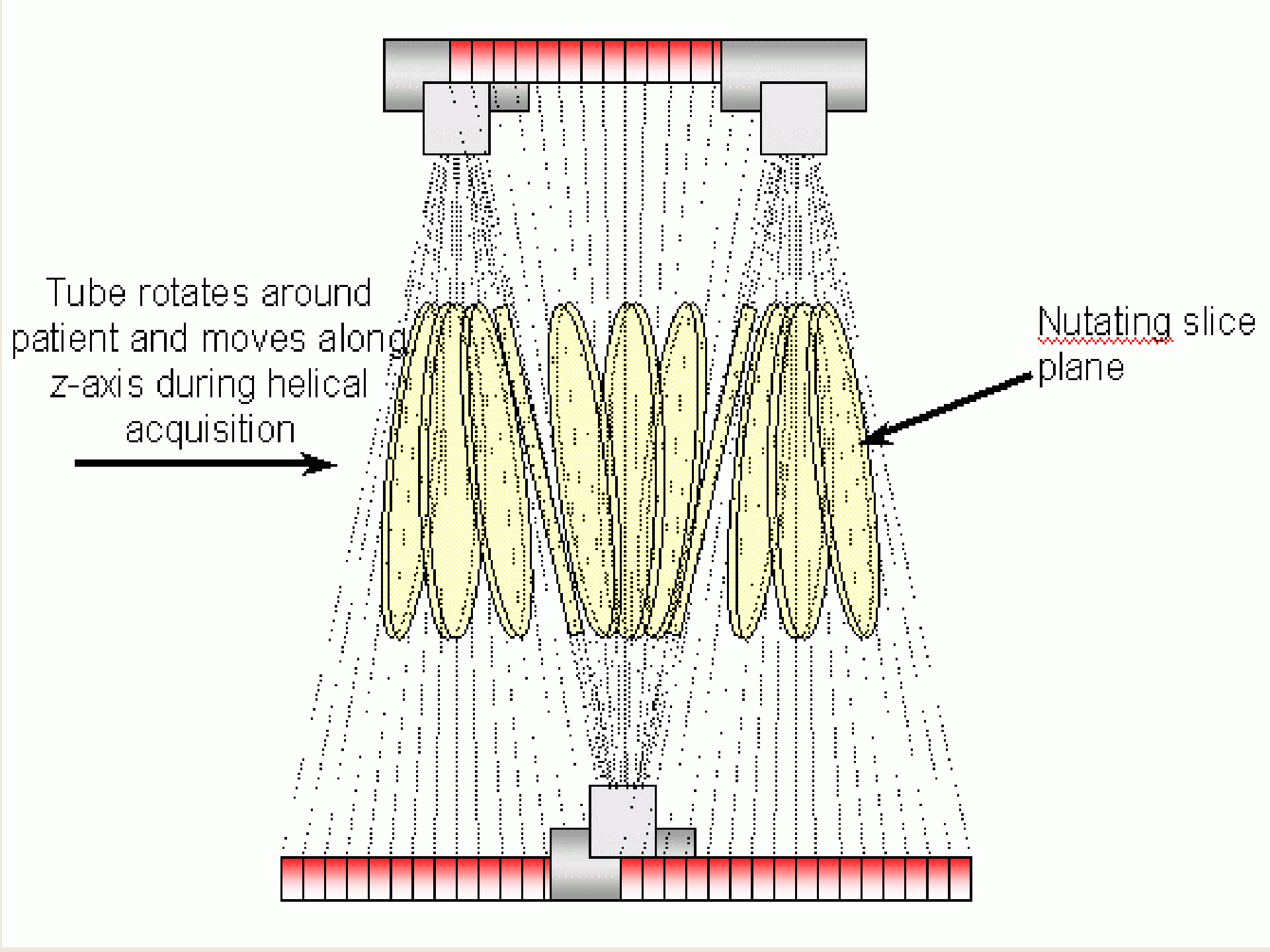


Single-slice detector

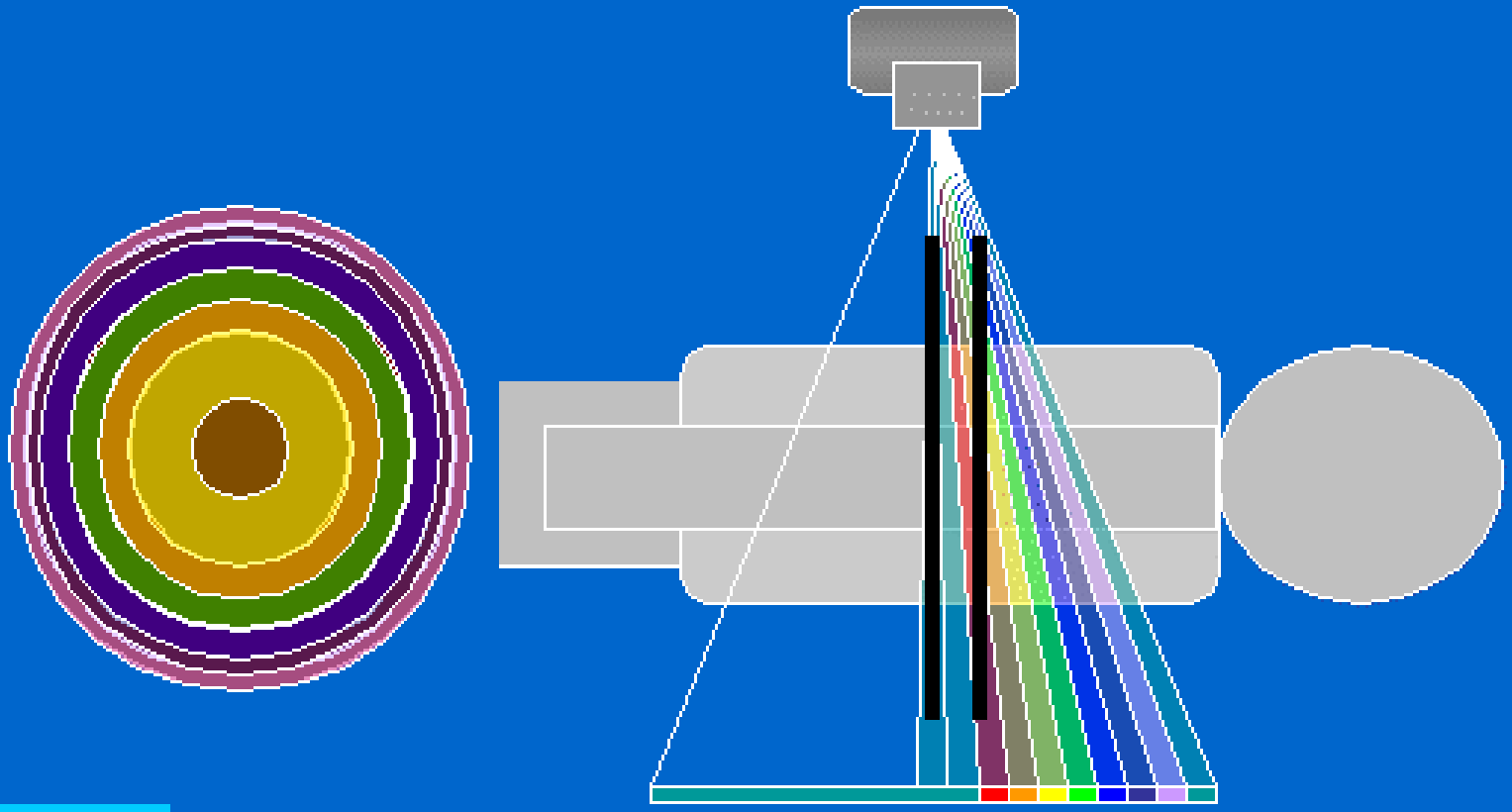




Outer element of sixteen-slice detector

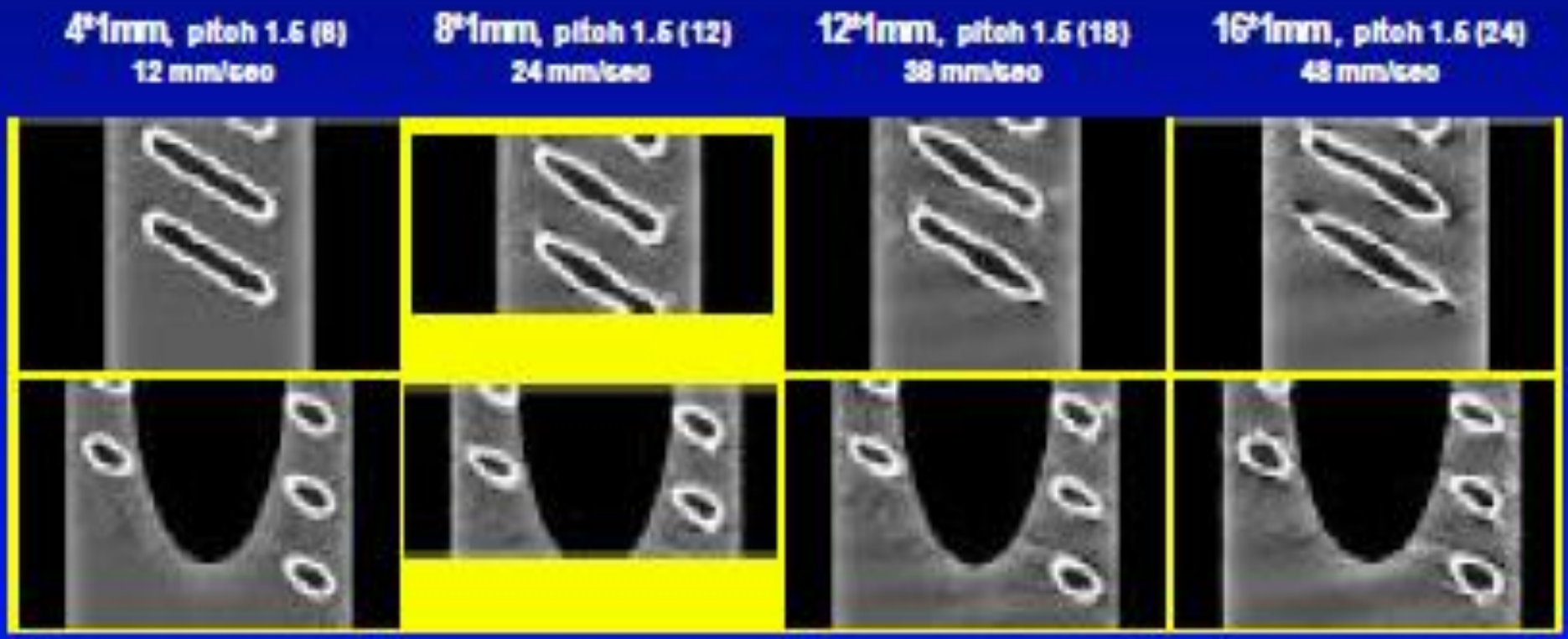

Tube rotates around patient and moves along z-axis during helical acquisition
Nutating slice plane

Distortion



Key Problem: Cone Angle

- What happens, if the cone angle of the rays is neglected ?



- Image results for > 4 sections are clinically unacceptable !

Courtesy Siemens Medical Systems

MSCT Faster Scanning

Detector	Beam Thick. (mm)	# rotations	Total scan time (sec)
1 x 1.25	1.25	160	128
4 x 1.25	5	40	32
8 x 1.25	10	20	16
16 x 1.25	20	10	8
64 x .625	40	5	4

1.25mm images and 20cm scan length at 0.8sec rotation and 1.0 pitch

The 3 Fs of CT

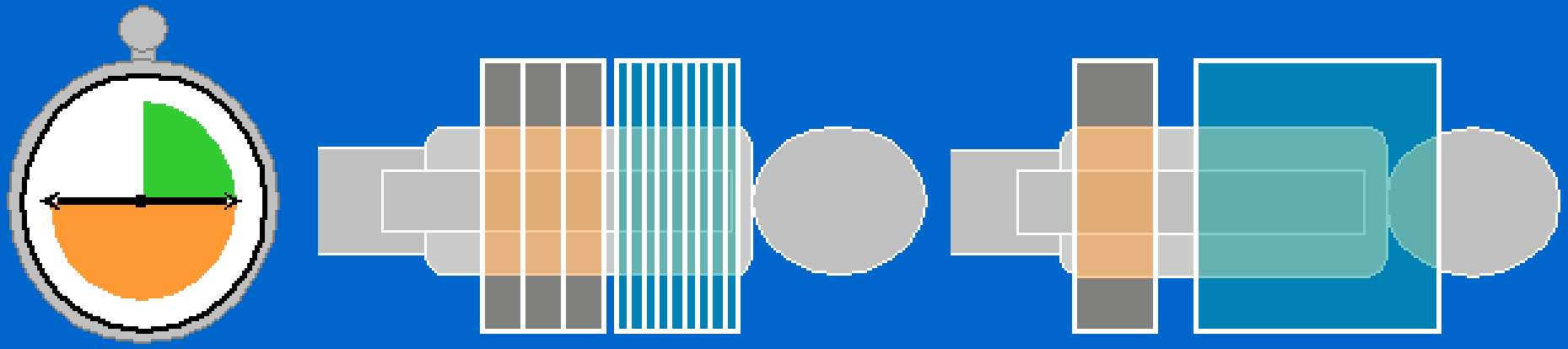
- **F**aster

- **F**urther

- **F**iner

Benefits of multi-slice

- Faster
  - Same scan in shorter time
- Thinner
  - Thinner slices give excellent z-axis resolution
- Further
  - Wider collimations allow large scan volumes



? 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

Question:


Thank you for your attention!