Technical Aspects of Cardiac CT

S. Edyvean

ImPACT (Imaging Performance Assessment of CT Scanners)

St. Georges Hospital, London

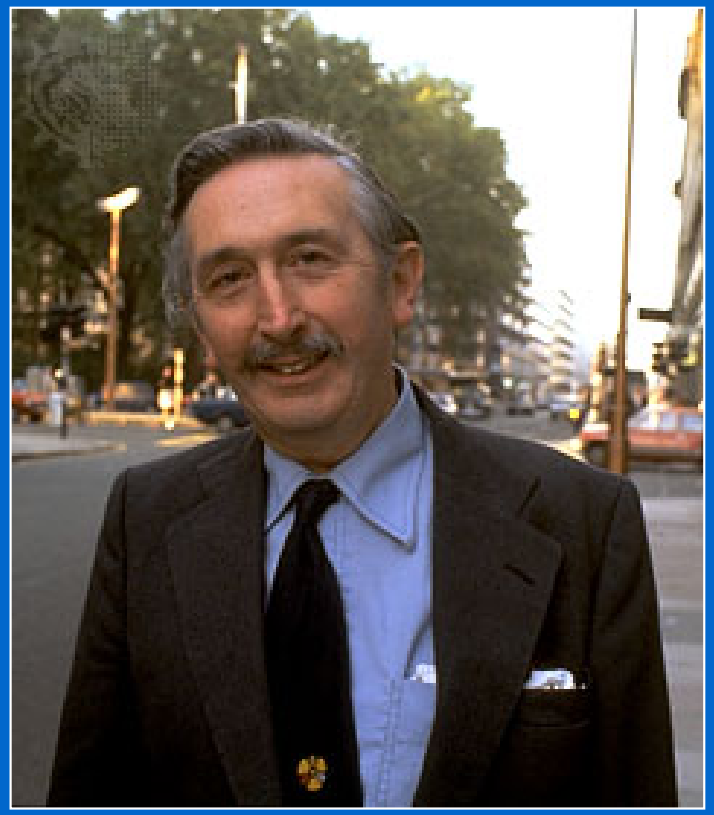
www.impactscan.org

Technical Aspects of Cardiac CT

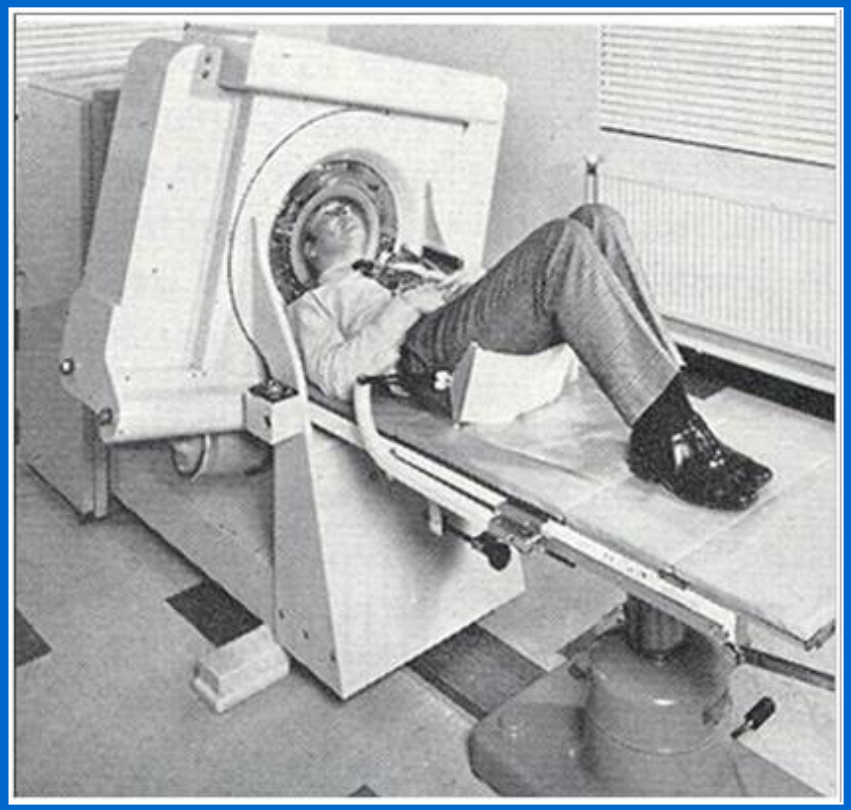
- Introduction
- Multi-slice CT (MSCT)
- Scanning the heart with MSCT
- Improving
  - Temporal resolution
  - Volume coverage
  - Spatial resolution

Cardiac CT

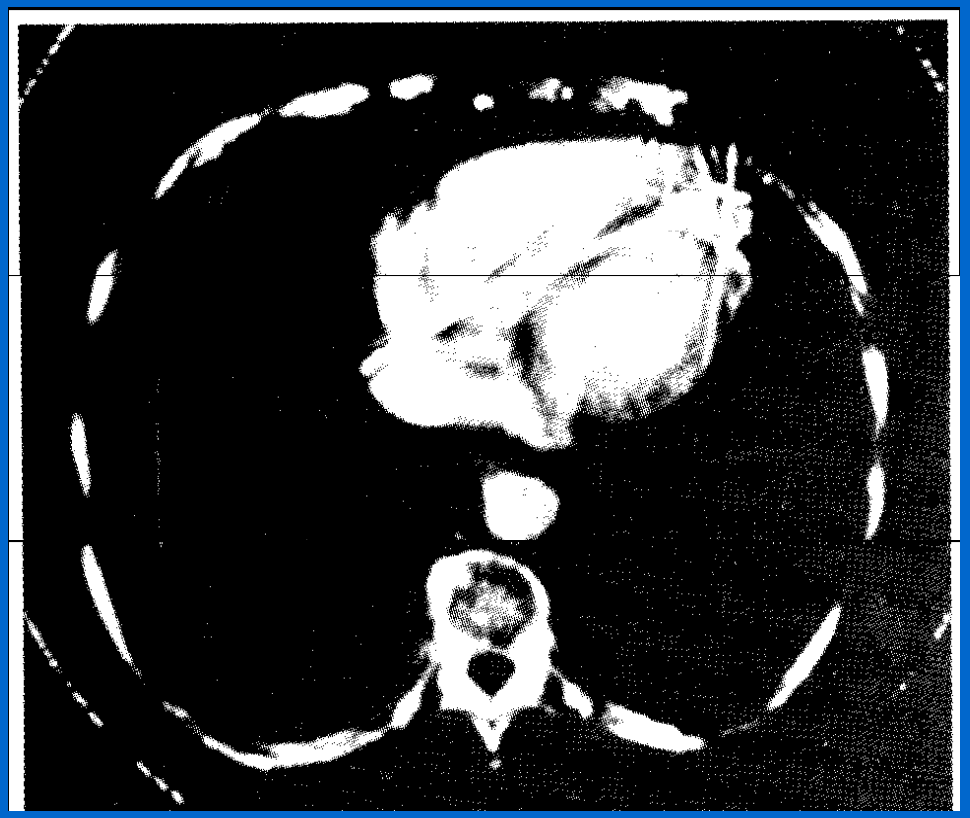
- Godfrey Hounsfield, inventor of clinical CT, 1971
  - 1979 Nobel prize
  - 1st Oct 1971 – 1st patient scanned



1919 – 2004



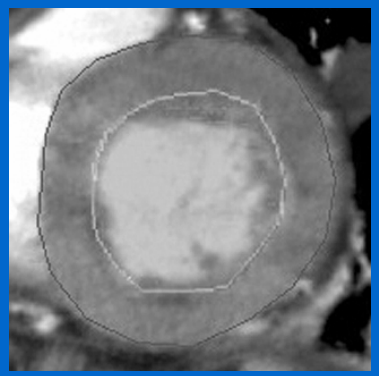
Godfrey Hounsfield – Nobel Speech 1979

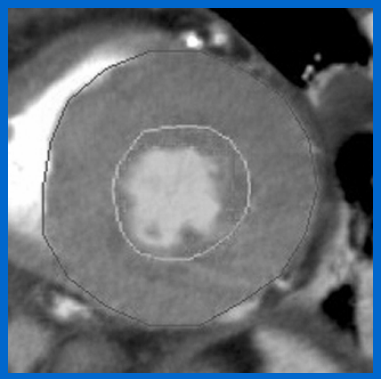


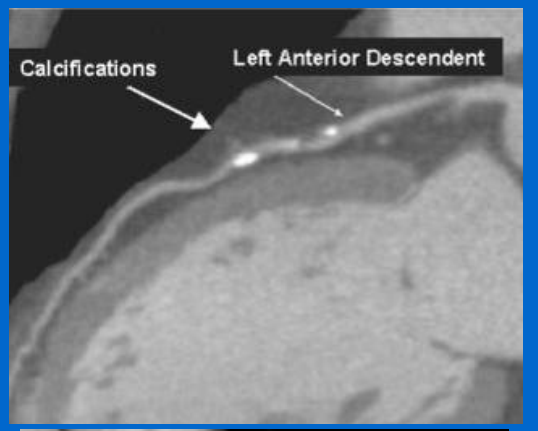
A further promising field may be the detection of the coronary arteries. It may be possible to detect these under special conditions of scanning.

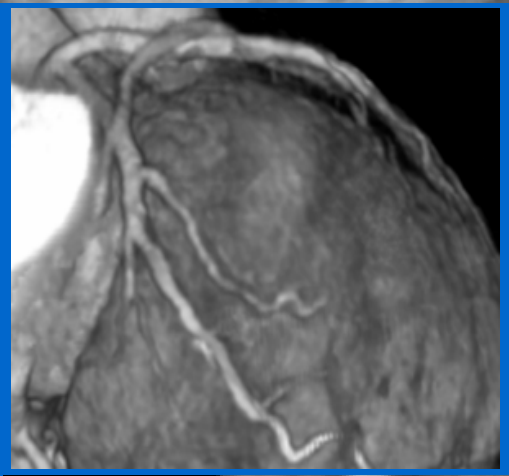
Applications of cardiac CT

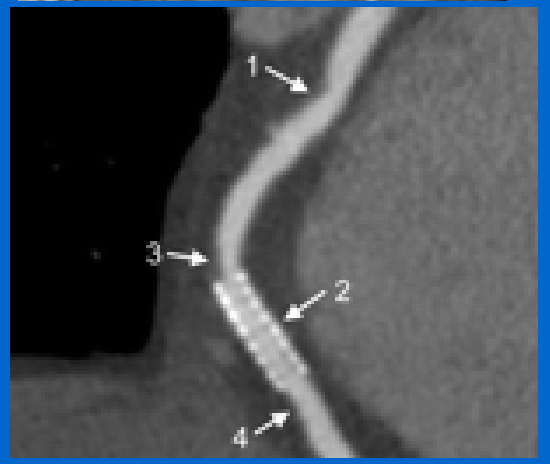
- Calcium scoring
  - calcified plaque
- Coronary CT angiography (CTA)
  - Coronary artery anatomy
  - Stenosis
  - Stent viability
  - Graft anatomy and patency
- Functional imaging





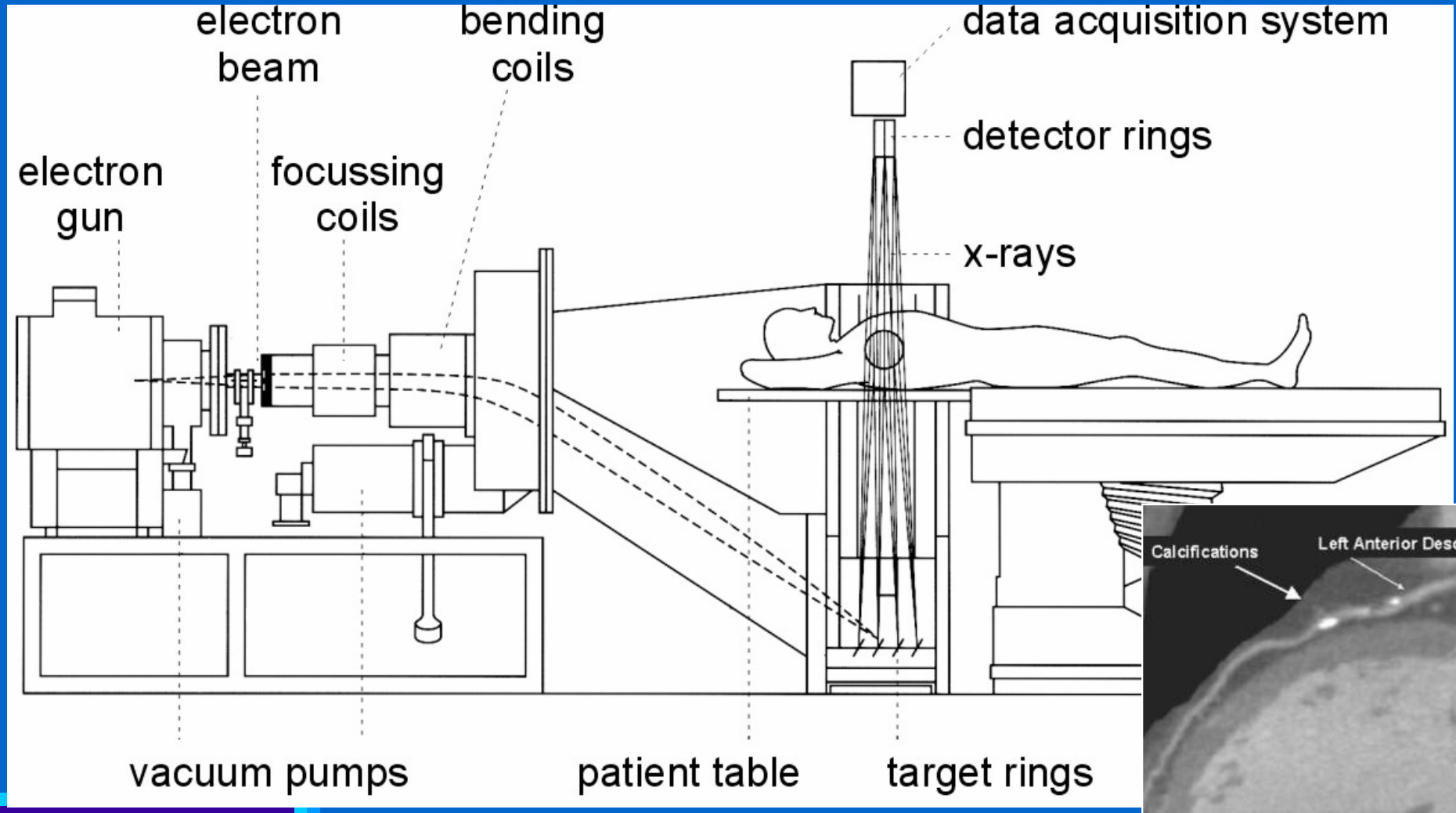






Cardiac CT

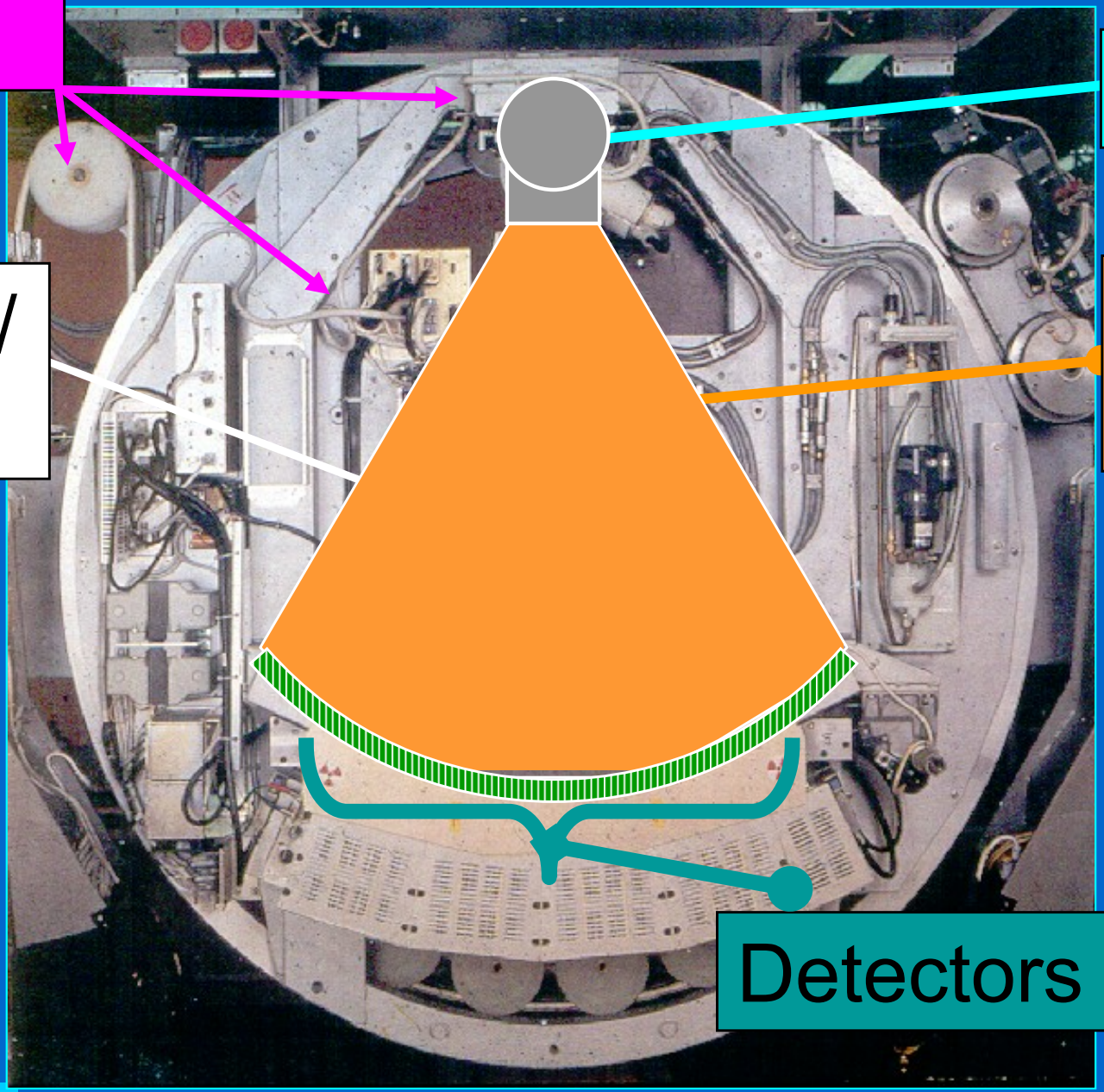
- 1990's: Electron beam CT (EBCT)
  - Calcium scoring (Agatston score)



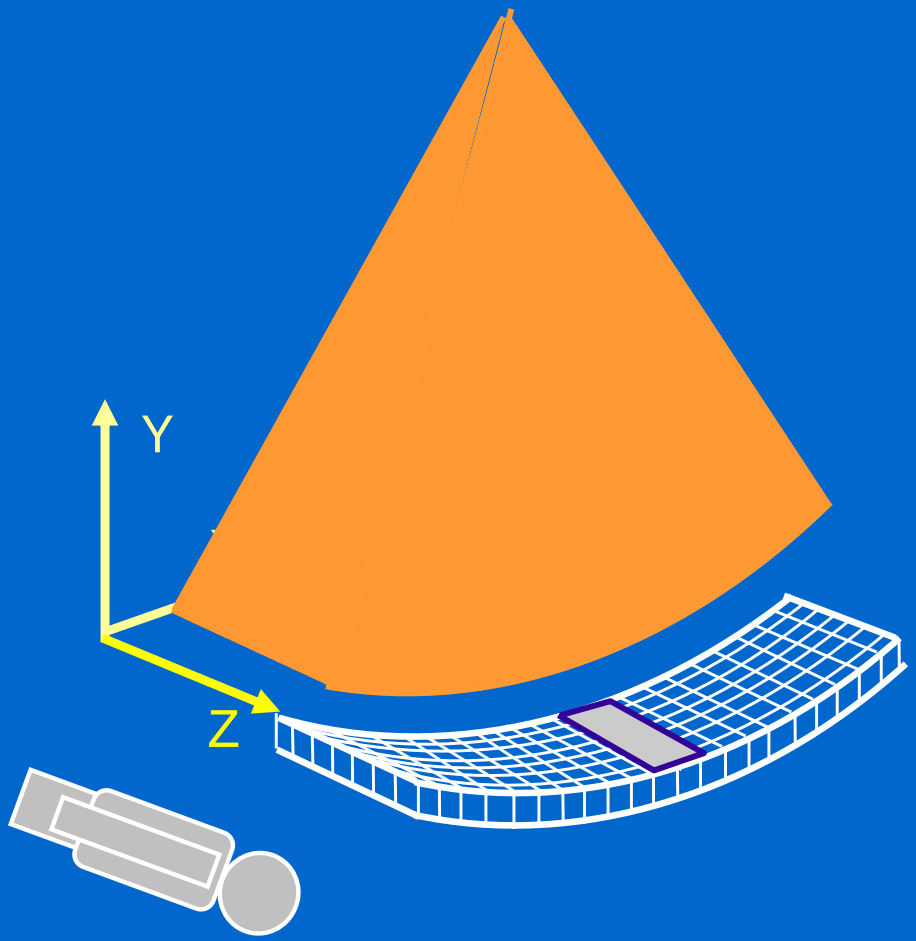
Modern multi-slice scanners

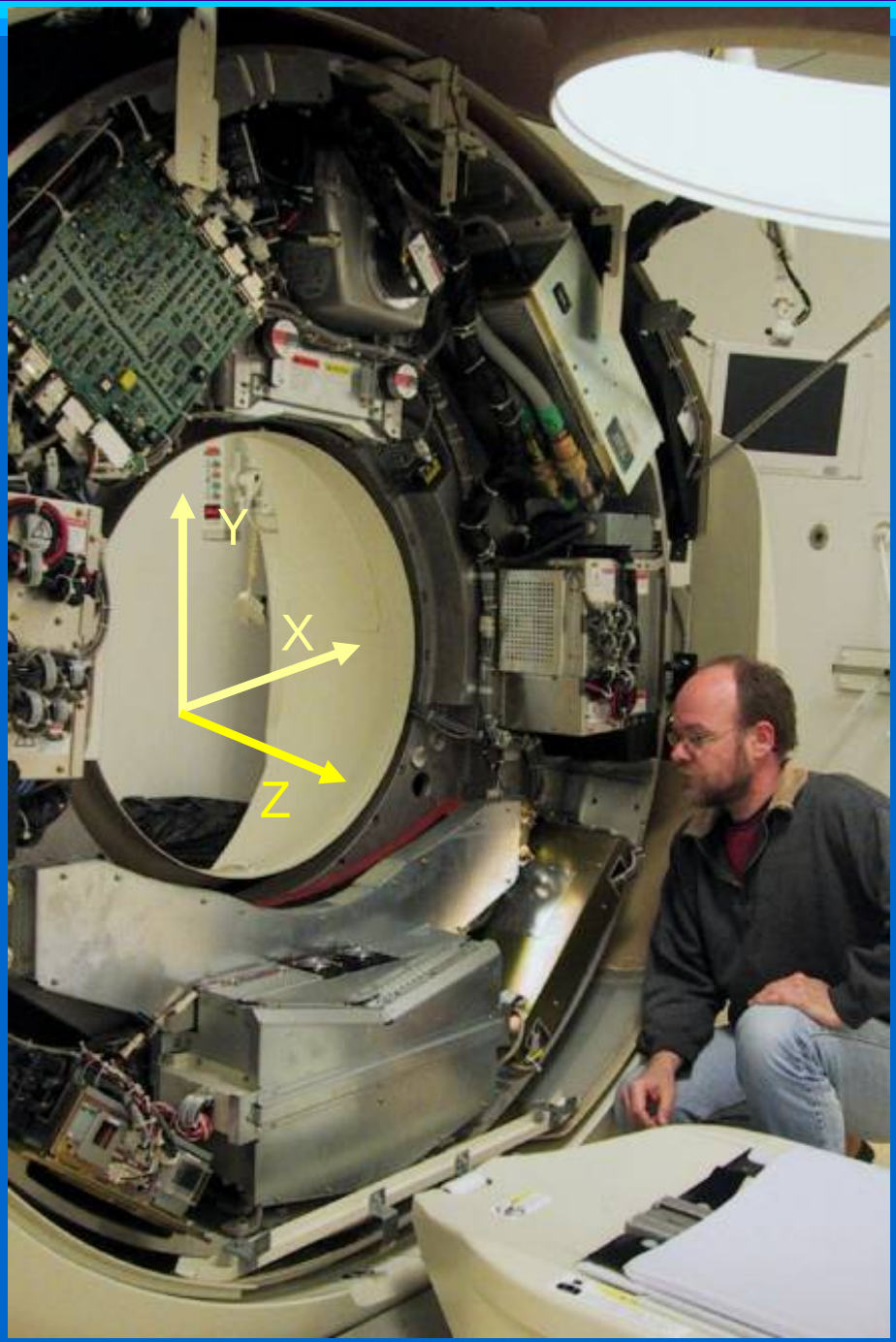
- 1998 (4 slice), 2001(16 slice), 2004 (64 slice), ...

The scanner



The scanner



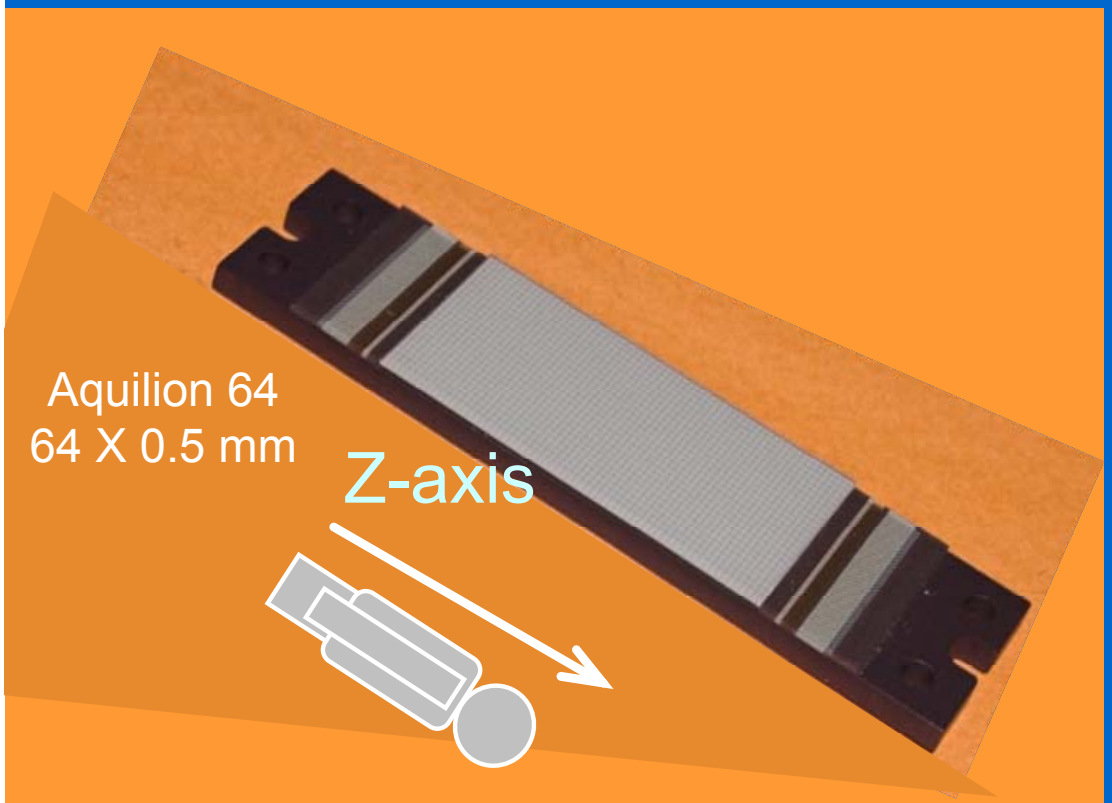


Picture courtesy of K. Gelijns, Leiden

Typical detector length ~ 40 mm

(20 - 160 mm)

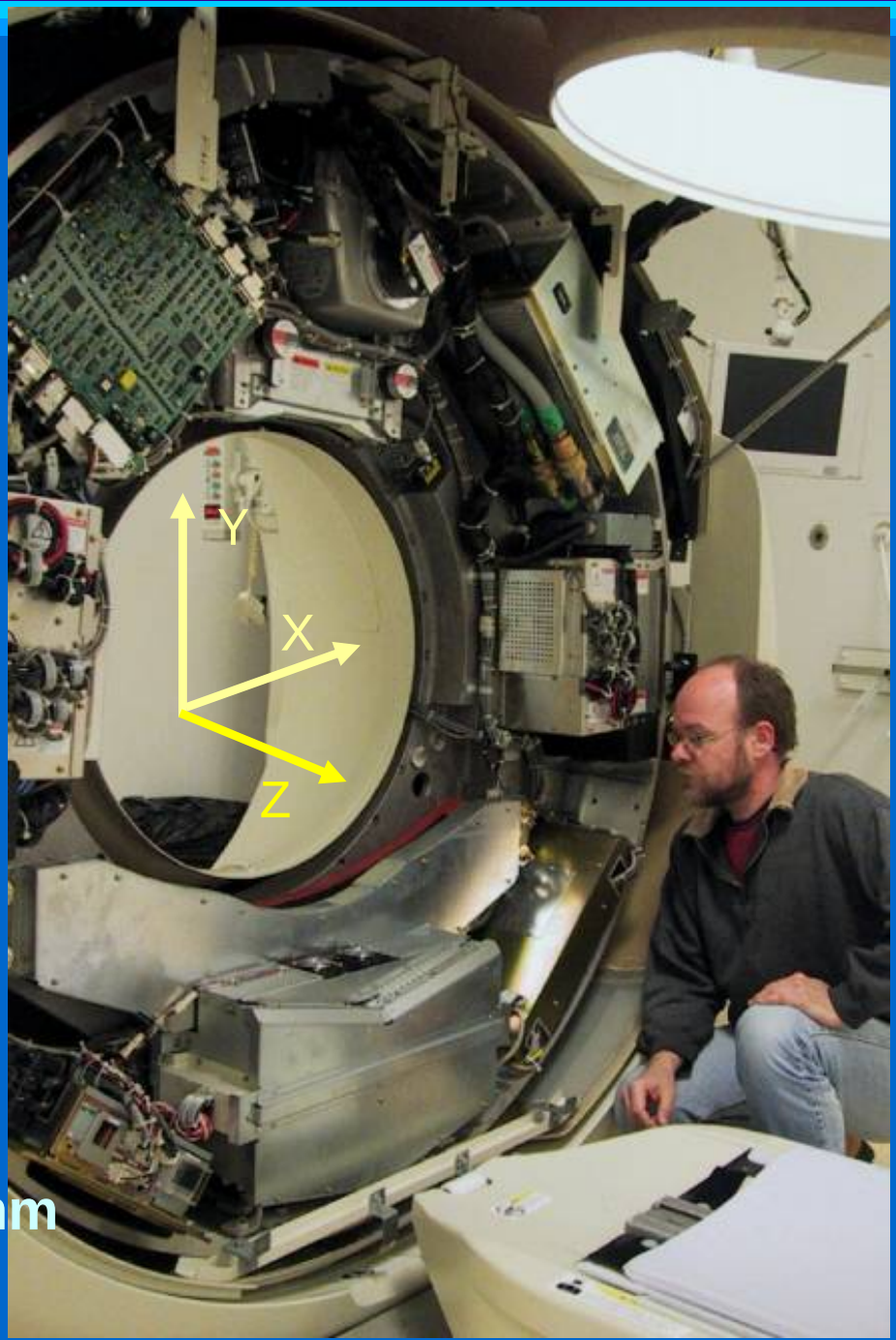
The scanner



Depending on scanner:

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

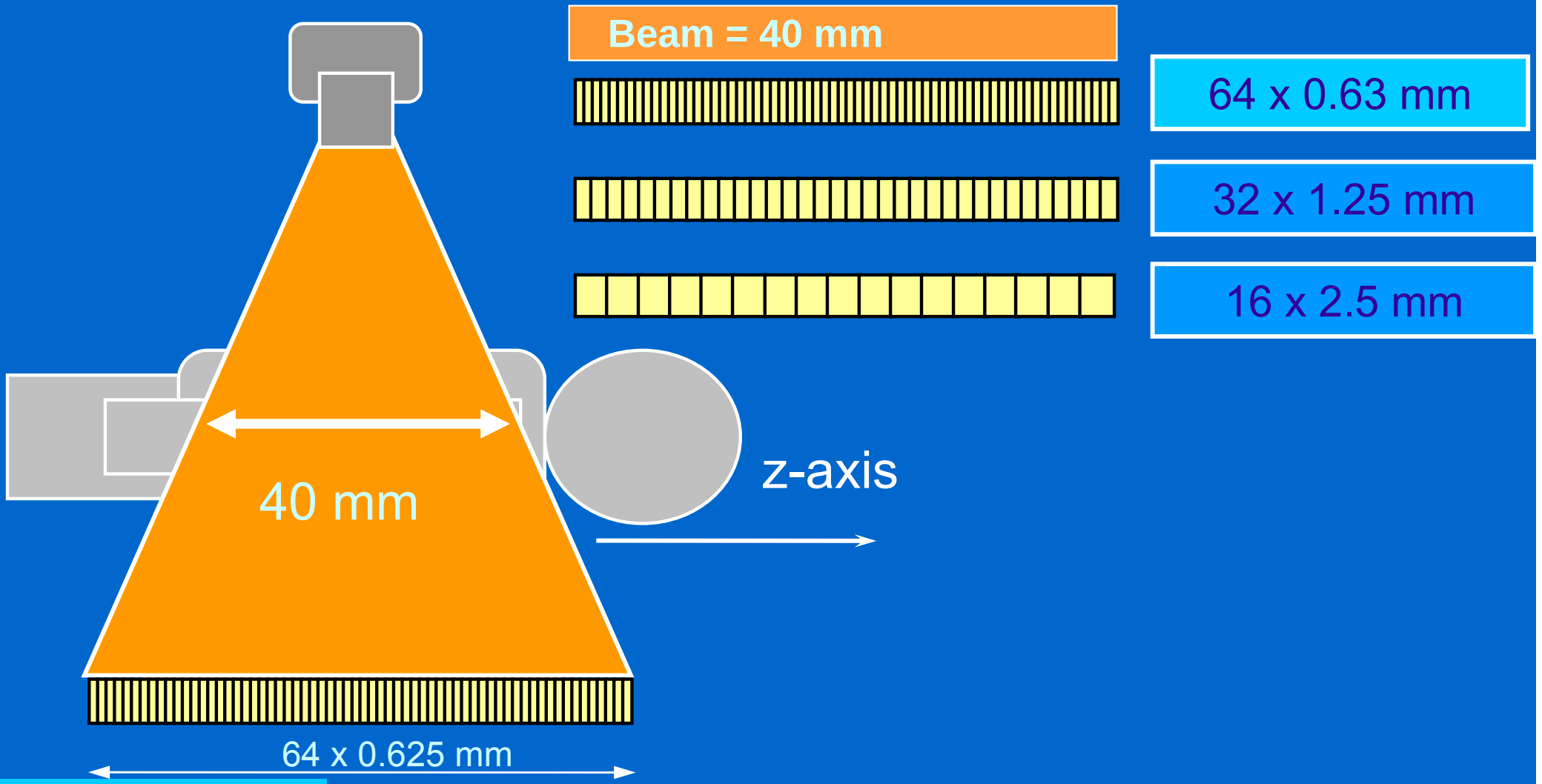
min size of detector element ~ 0.5, 0.6 mm



Picture courtesy of K. Gelijns, Leiden

Beam width, detectors and slices

- GE LightSpeed 64
  - 64 x 0.625 mm detectors



Multi-slice CT - coverage

10 20 40 80 160 mm

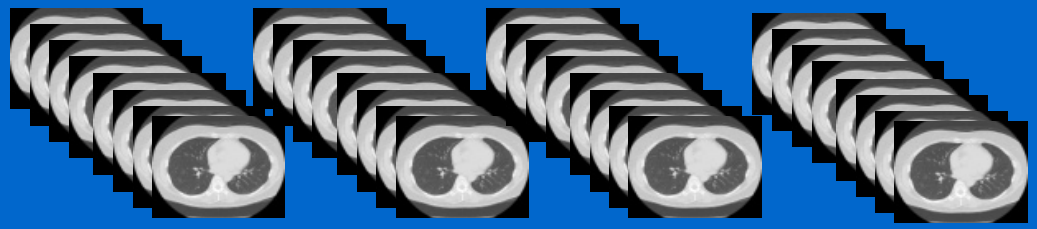
z-axis

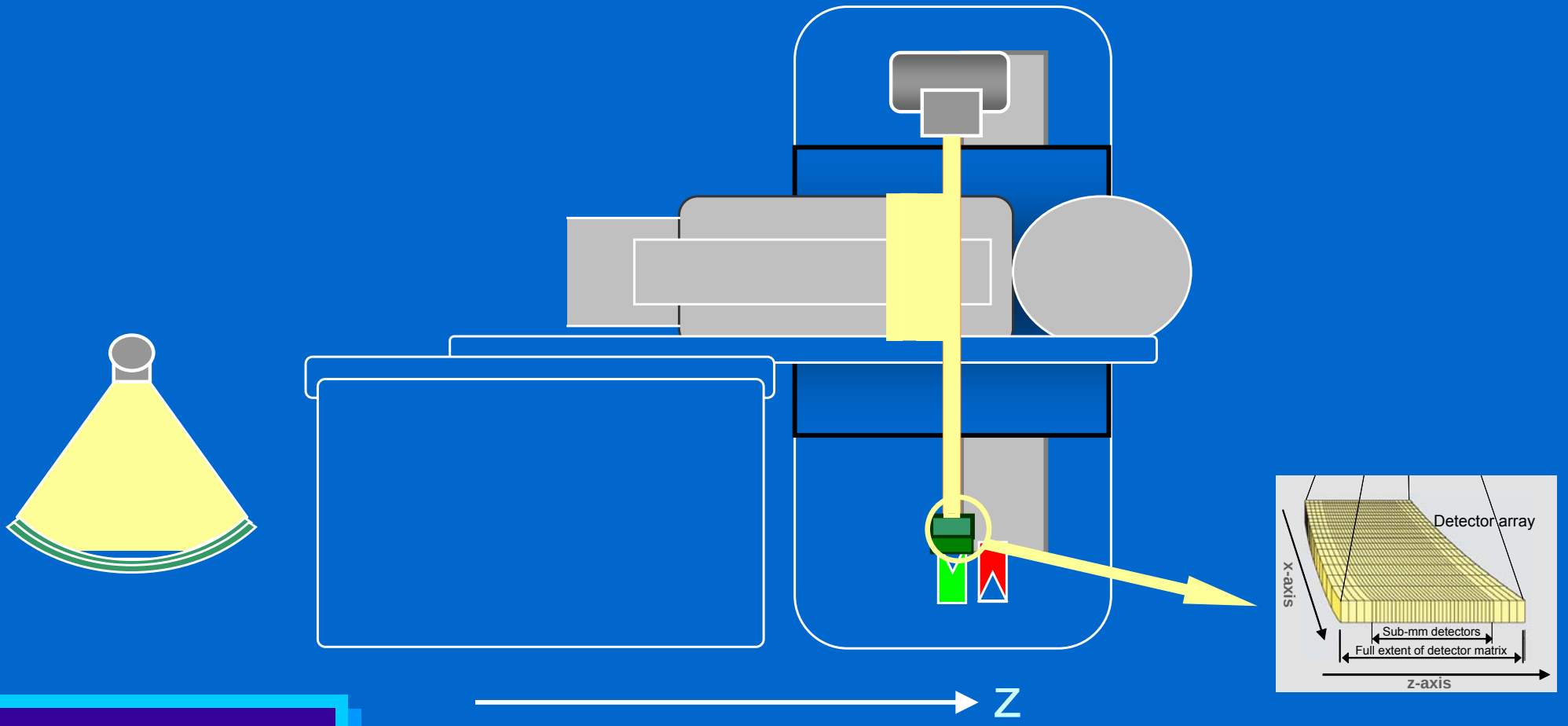
Scanner rotation speeds

Typical fastest rotation speeds < 0.5 sec/rot
(0.5, 0.4, 0.3, 0.27 sec/rot)

Axial scanning – ‘step and shoot’

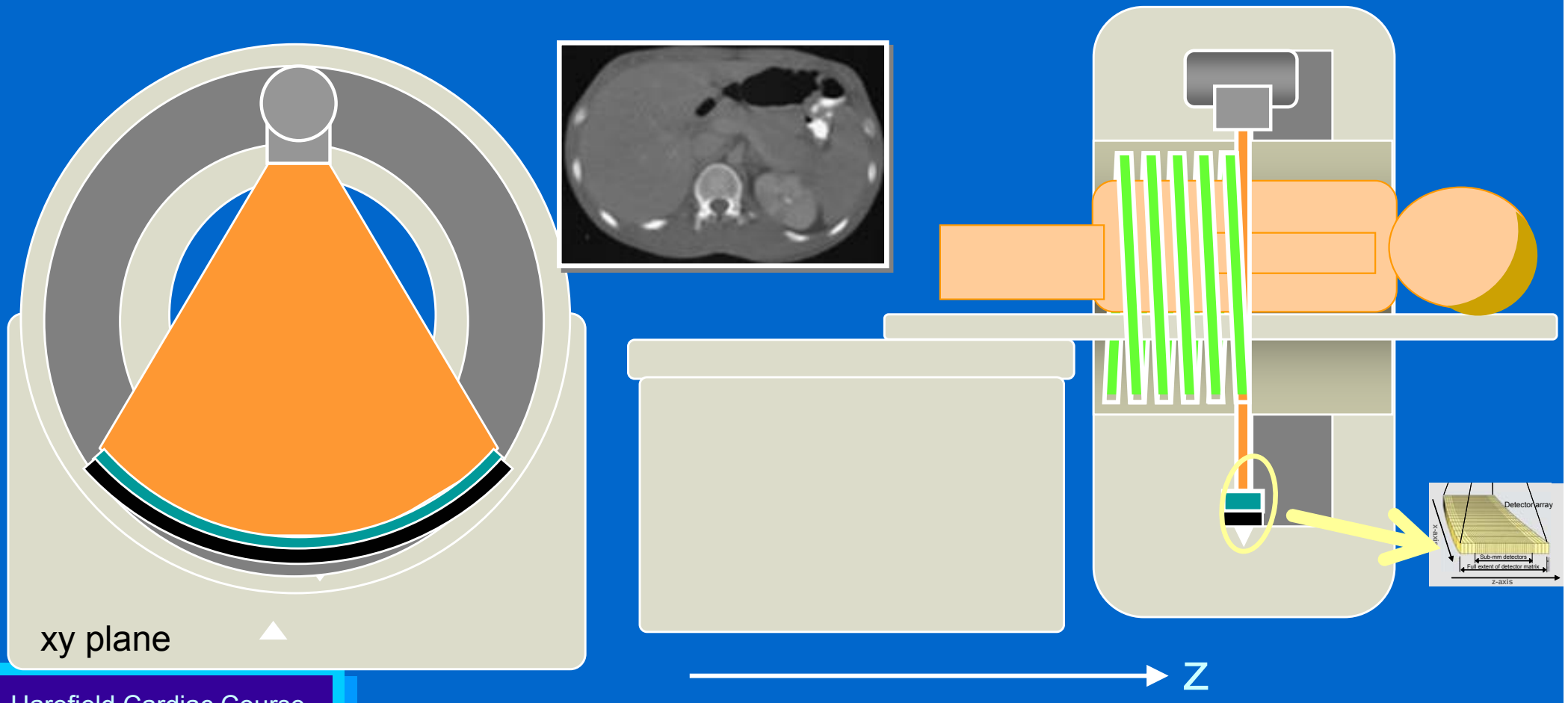
– Also known as sequential scanning





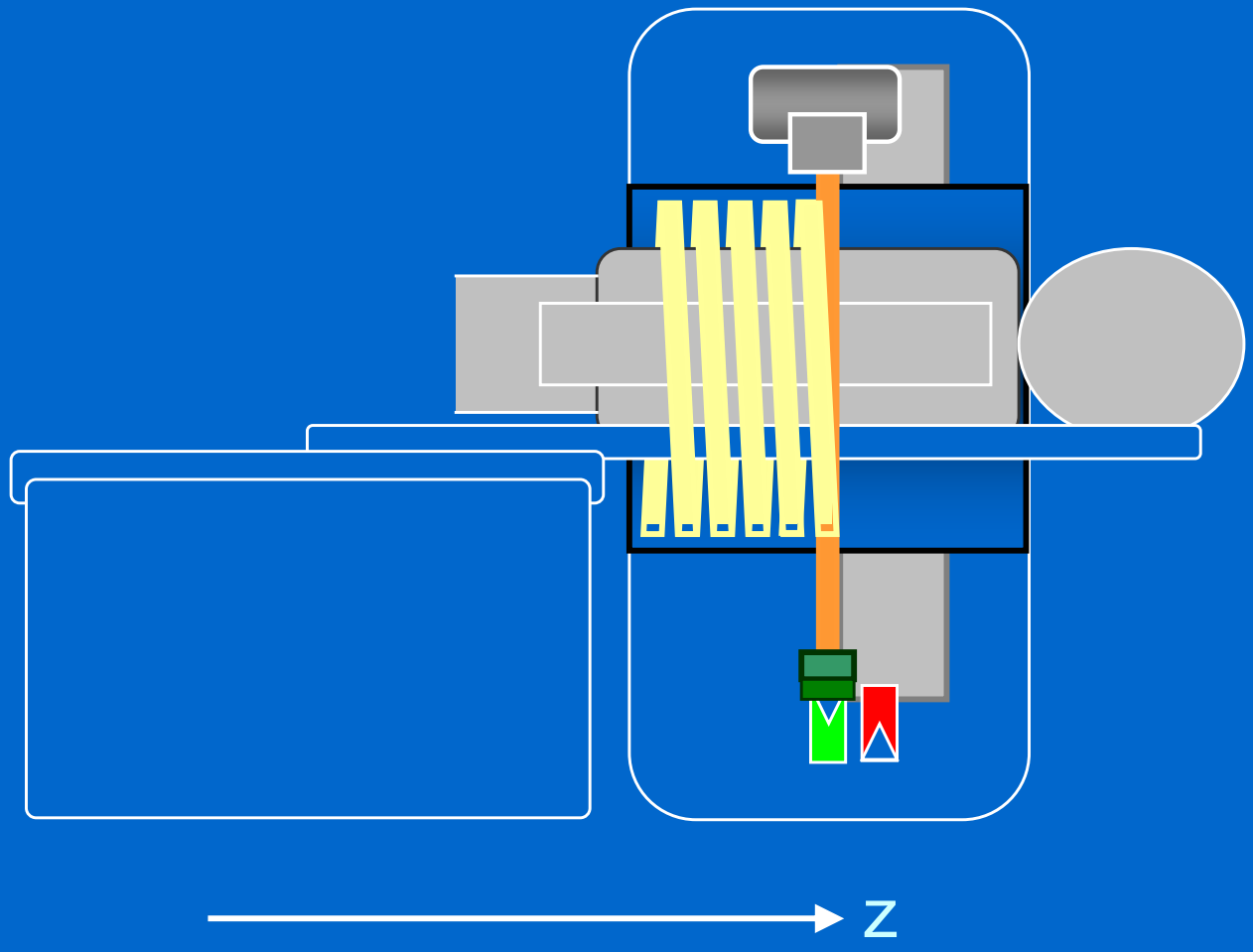
Helical (spiral) scanning

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



Helical (spiral) scanning - pitch

$$\text{Pitch} = \frac{\text{table travel / rotation}}{\text{X-ray beam width}}$$

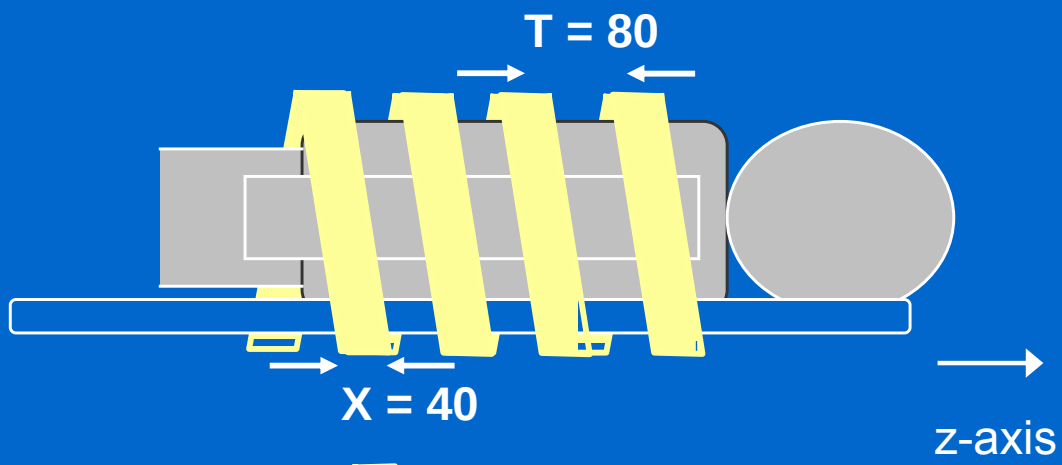


Helical (spiral) scanning - pitch

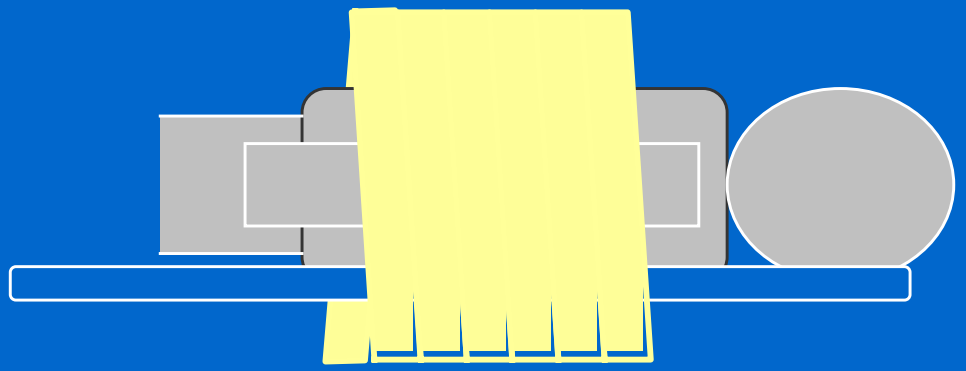
pitch 2

Table travel/rot = 80 mm

Beam width = 40 mm



pitch 1



pitch 0.5

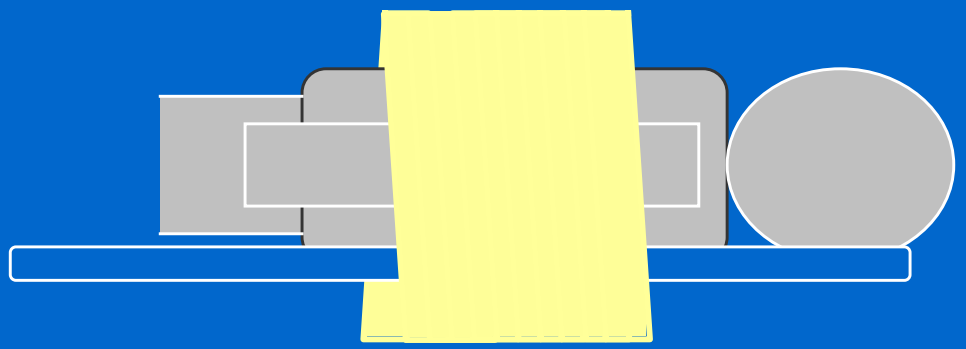
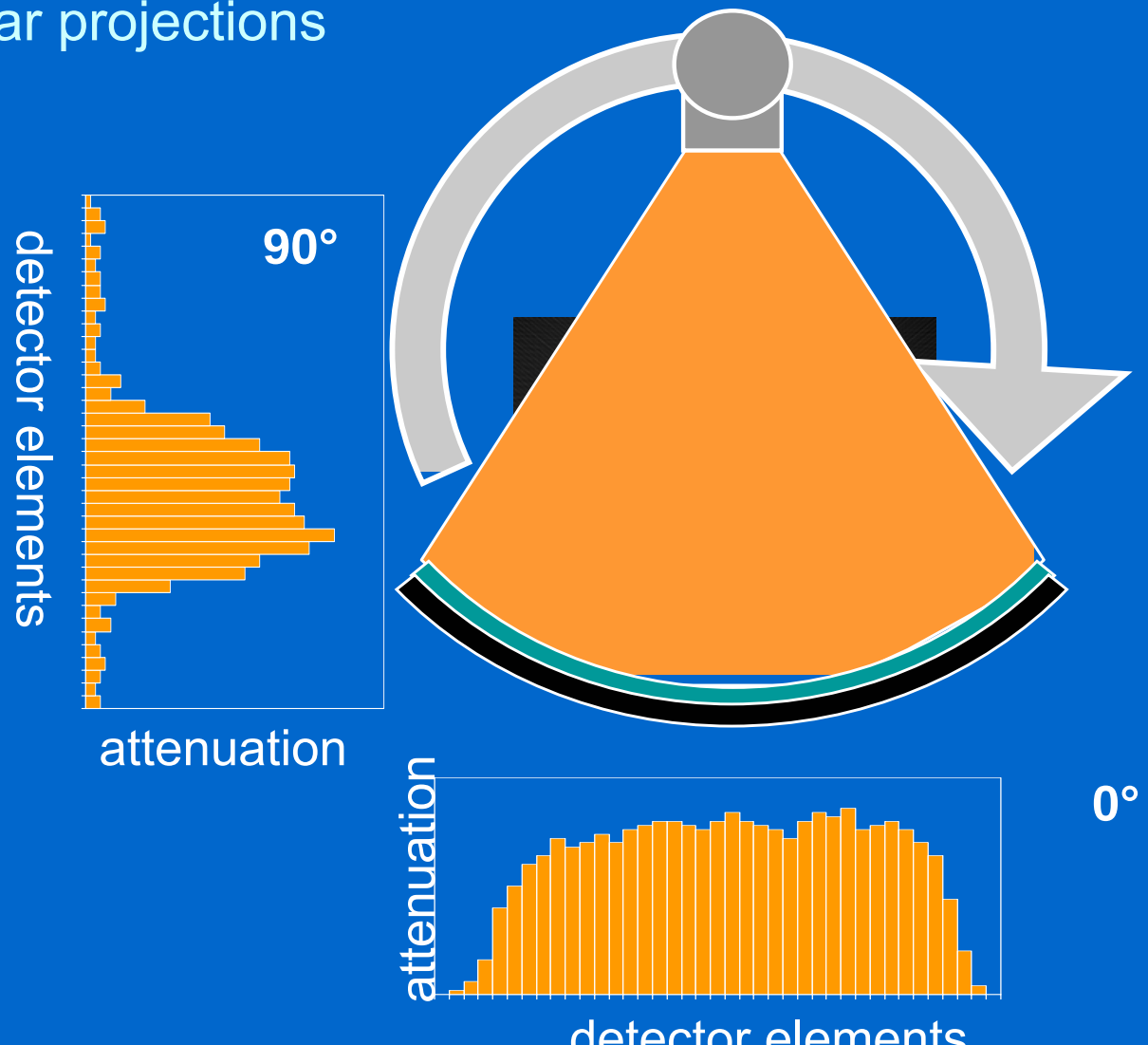
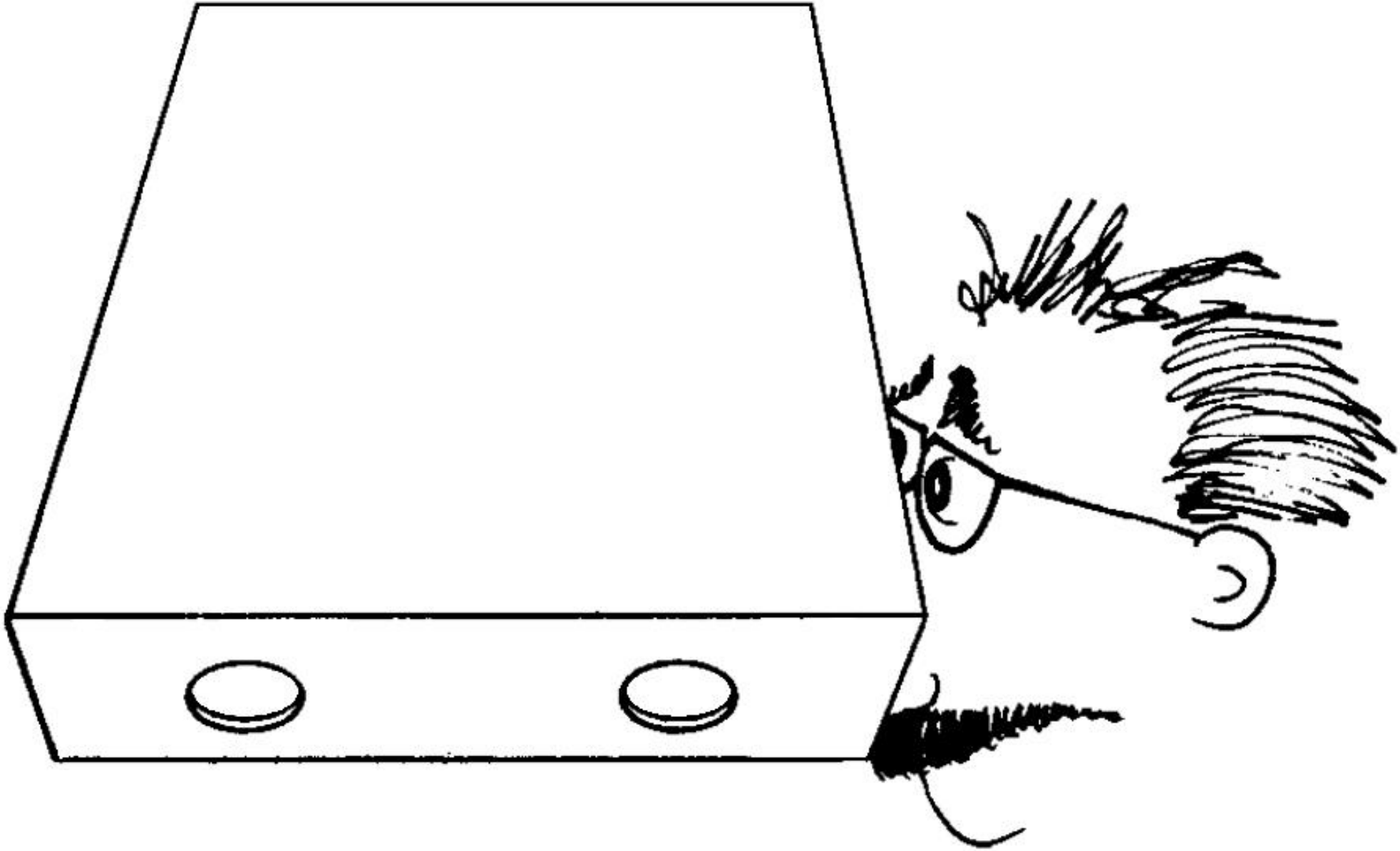


Image reconstruction

- Attenuation profiles through every angle
  - ~1000 detector elements
  - ~1000 angular projections





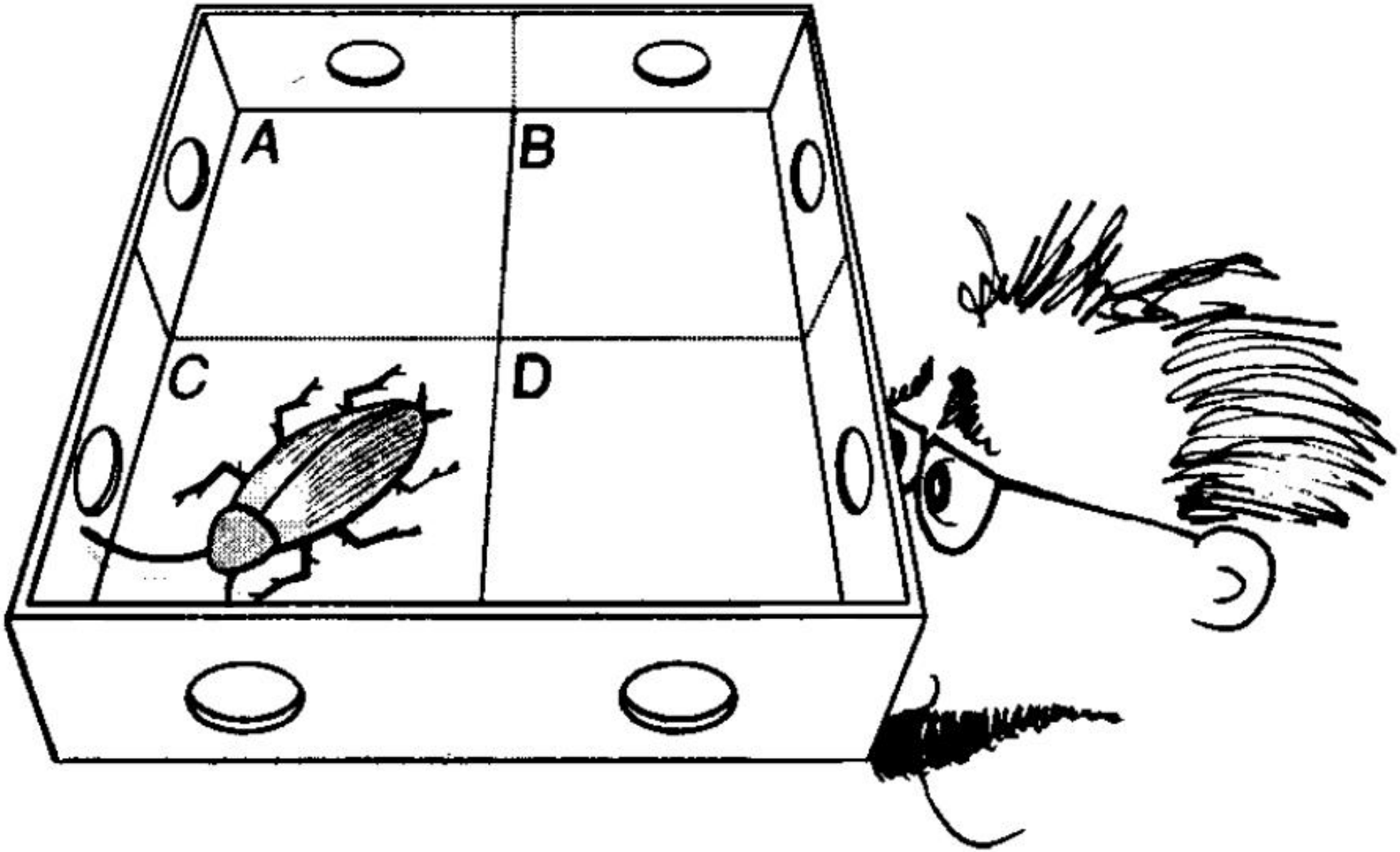
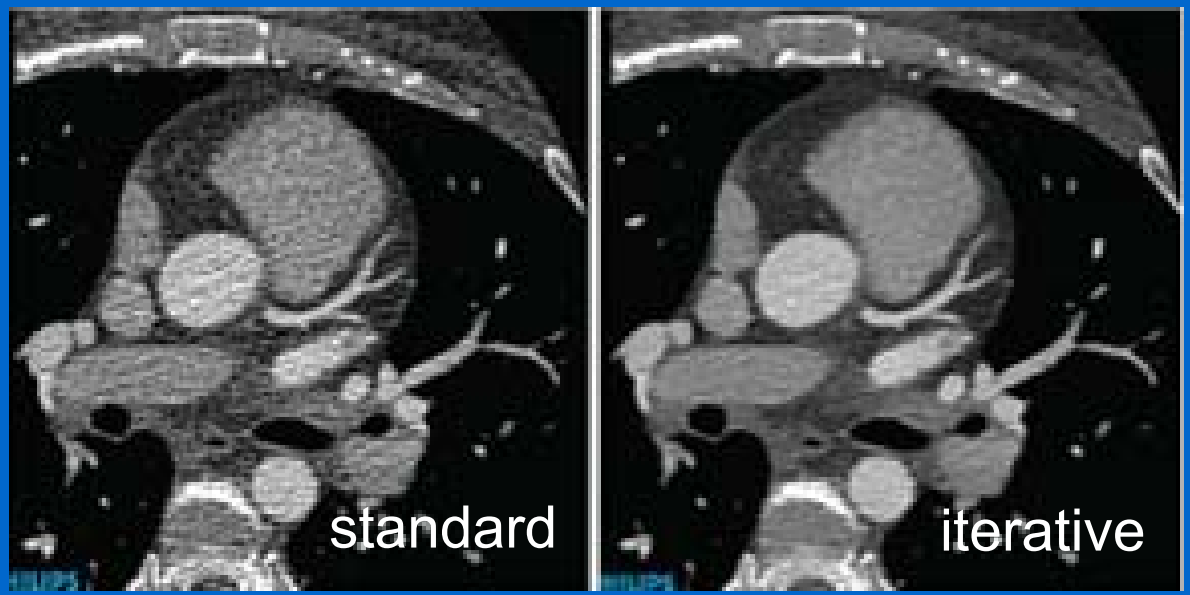

A
B
C
D

Image reconstruction

- Analytical techniques
  - 2-D Filtered back projection (slices up to ~ 12)
  - Techniques to overcome cone beam artefacts (slices > 12)
    - 3-D approximations (Tilted slice, Feldkamp)
  - Cone beam reconstruction
- Iterative reconstruction
  - ASIR, MBIR (VEO), IRIS, SAFFIR, AIDR, iDOSE ….



Courtesy Philips

CT Image

- Pixel value (CT number)
  - Represents average attenuation of the 3-D volume element

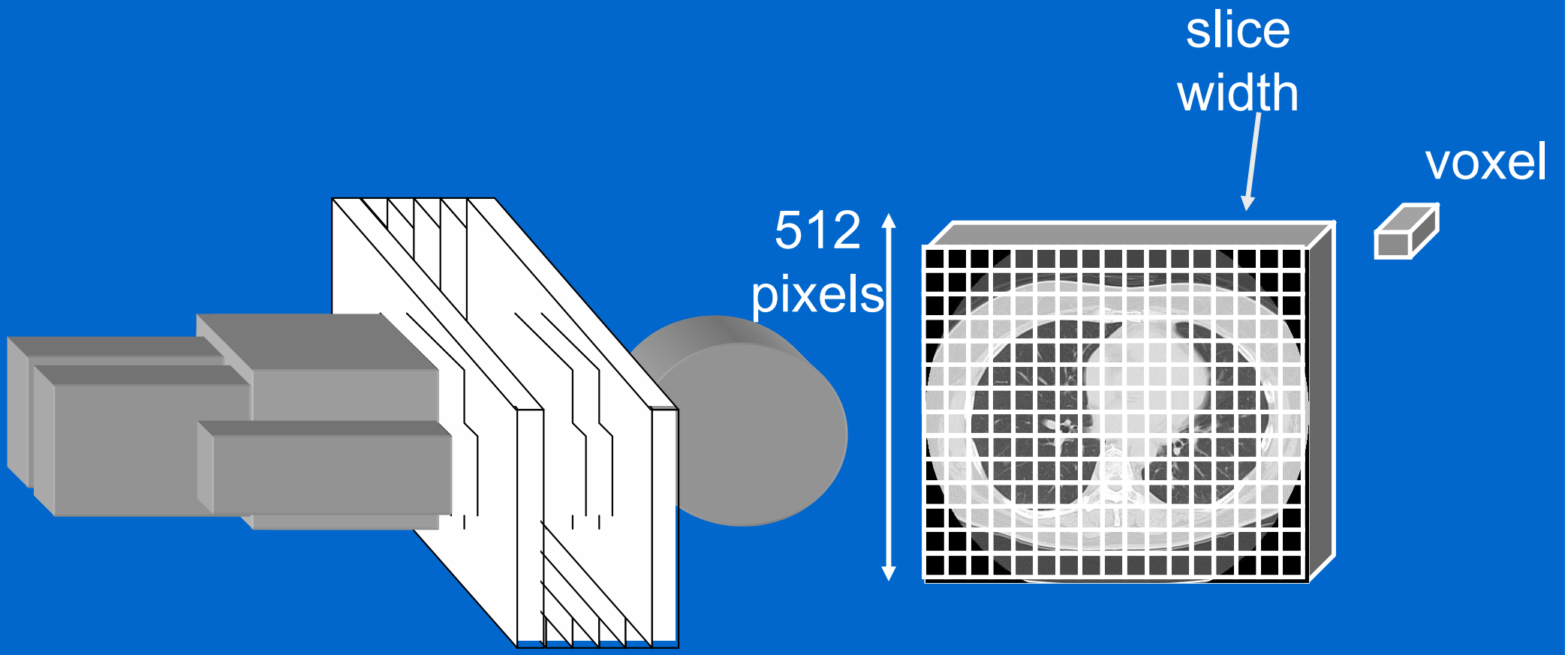
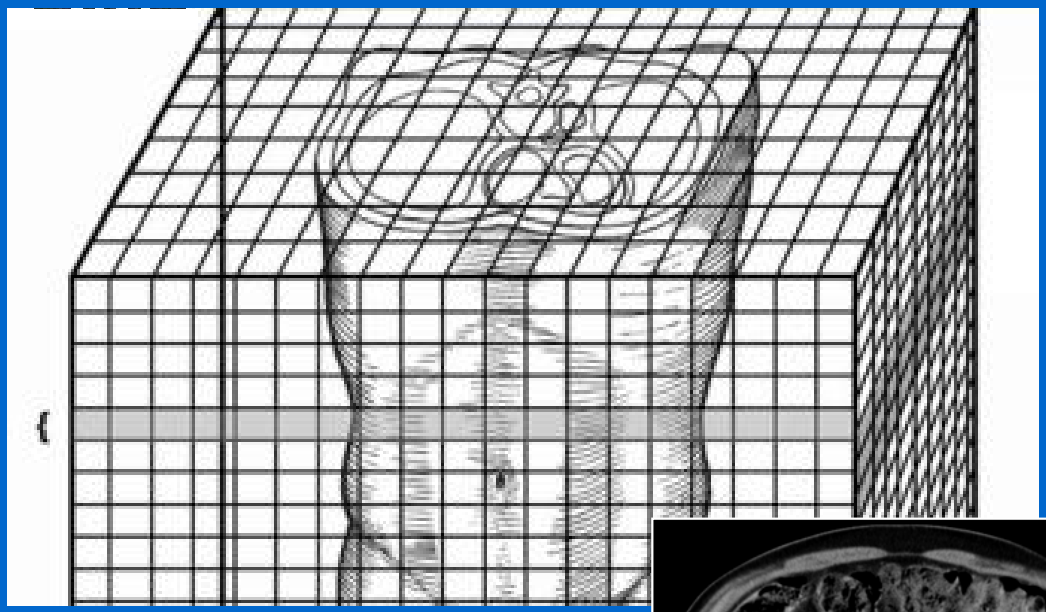
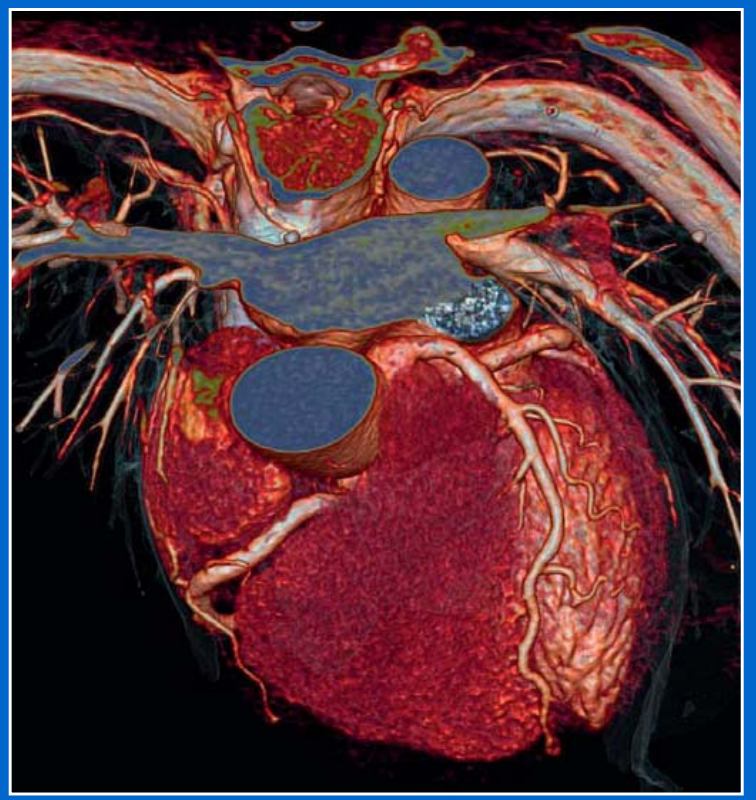


Image presentation

- Volume set of data
  - that can be reconstructed in any direction by a variety of techniques



axial



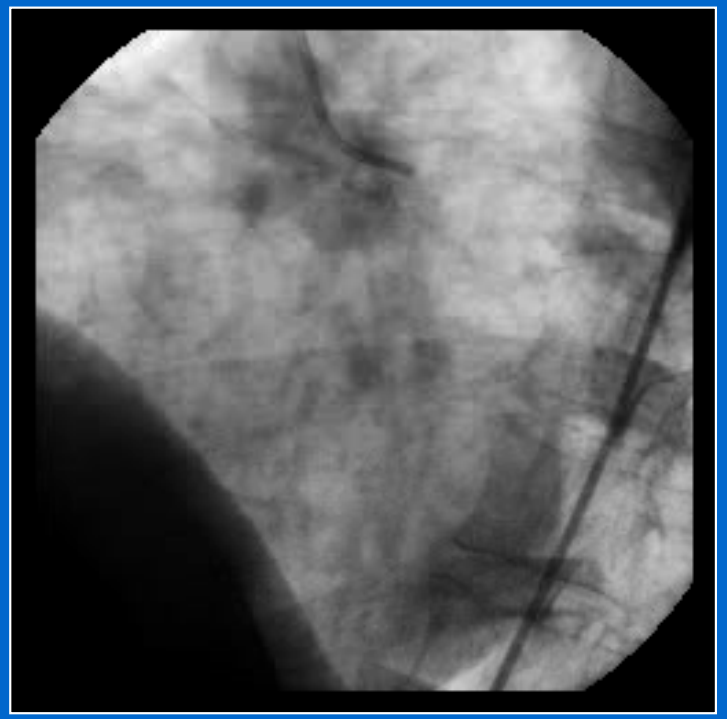
0.3 x 0.3 x 0.3 mm

Technical Aspects of Cardiac CT

- Introduction
- Multi-slice CT (MSCT)
- Scanning the heart with MSCT
- Improving
  - Temporal resolution
  - Volume coverage
  - Spatial resolution

The heart

- Heart rate
  - Average 60 bpm (1 beat per sec) (40 bpm – 120 bpm)
  - Vessels move at different speeds



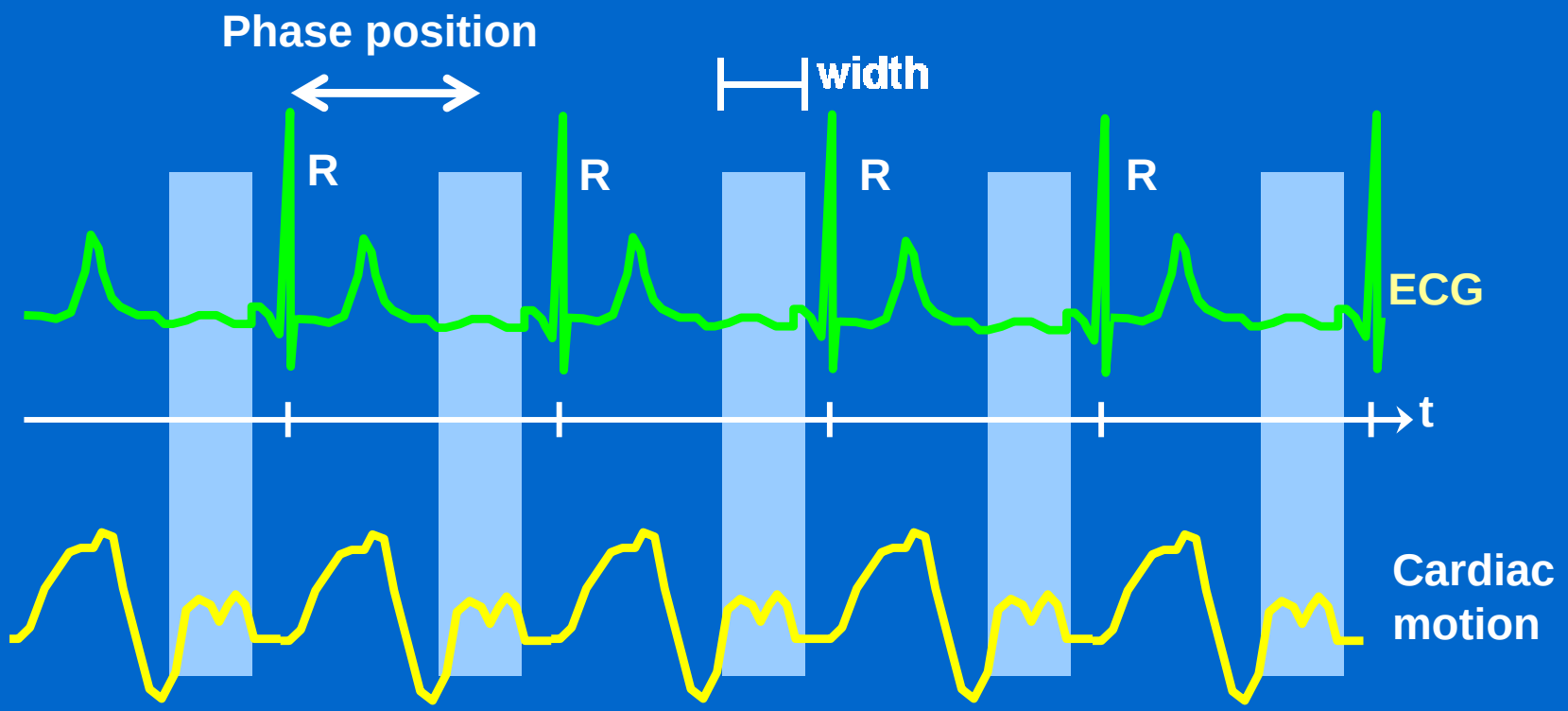
Conventional angiography

Cardiac CT - ECG signal

- Acquisition and reconstruction linked to ECG

Cardiac CT – ECG phases

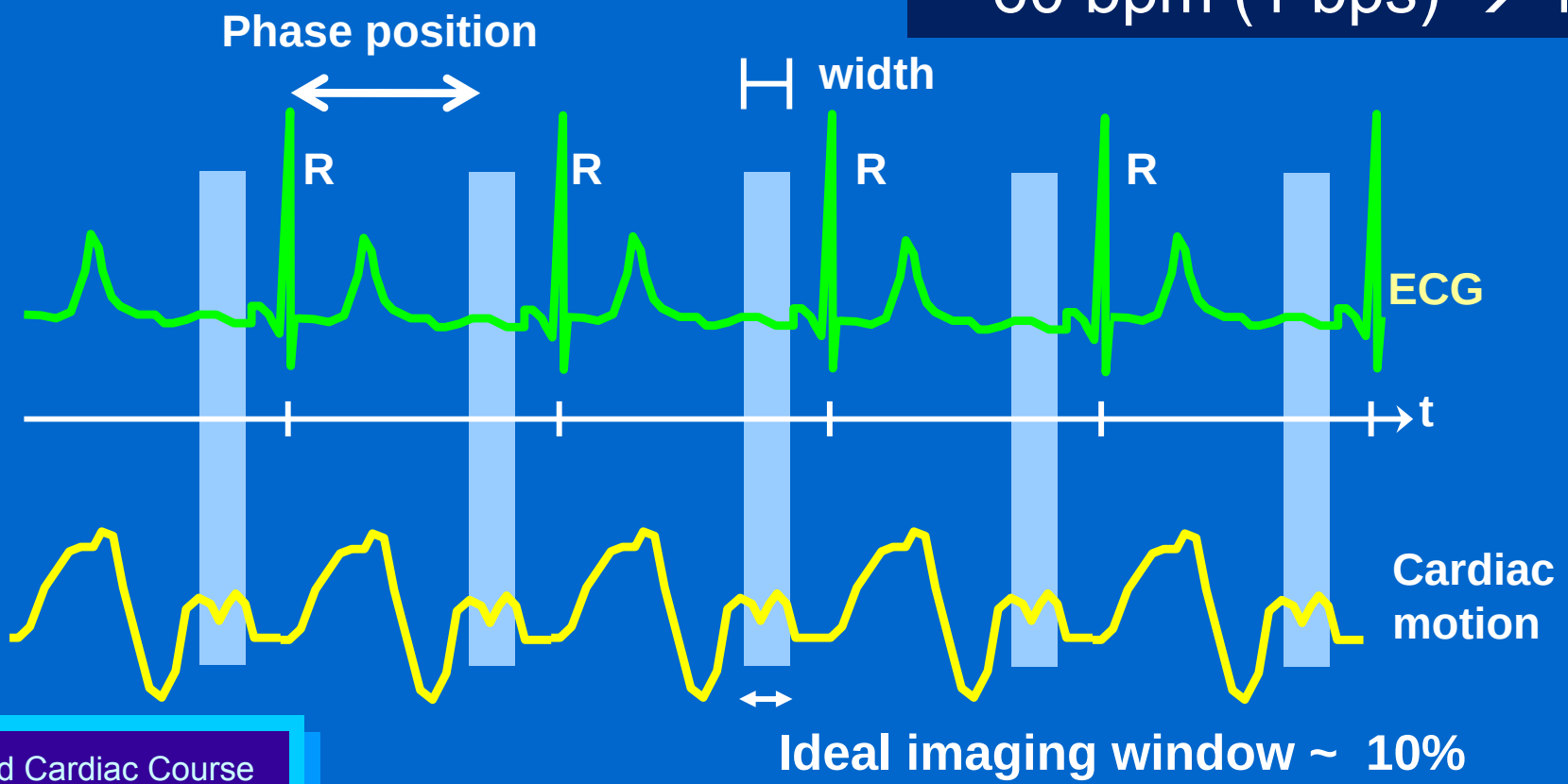
- To ‘freeze’ cardiac motion:
  - Image during phase of least cardiac motion
  - Phase given as percentage of R-R interval (eg 70%)
  - Ideal width at least 10% of R-R interval



Cardiac CT – ECG phases

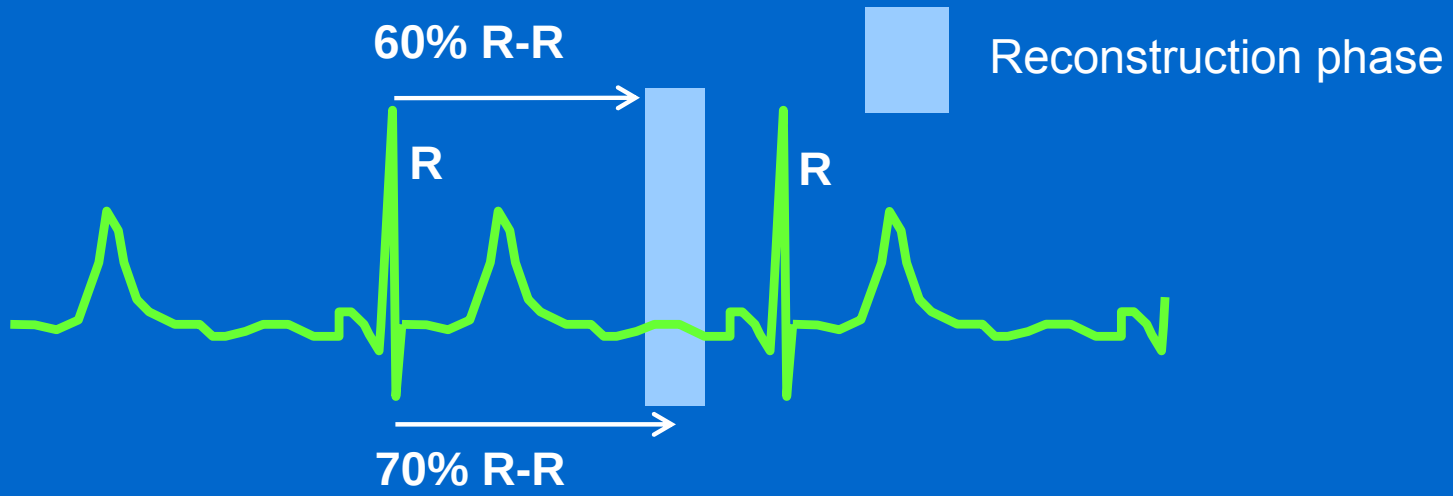
- To ‘freeze’ cardiac motion:
  - Image during phase of least cardiac motion
  - Phase given as percentage of R-R interval
  - Ideal width at least 10% of R-R interval:

60 bpm (1 bps) → 100 ms



Cardiac CT – ECG phases

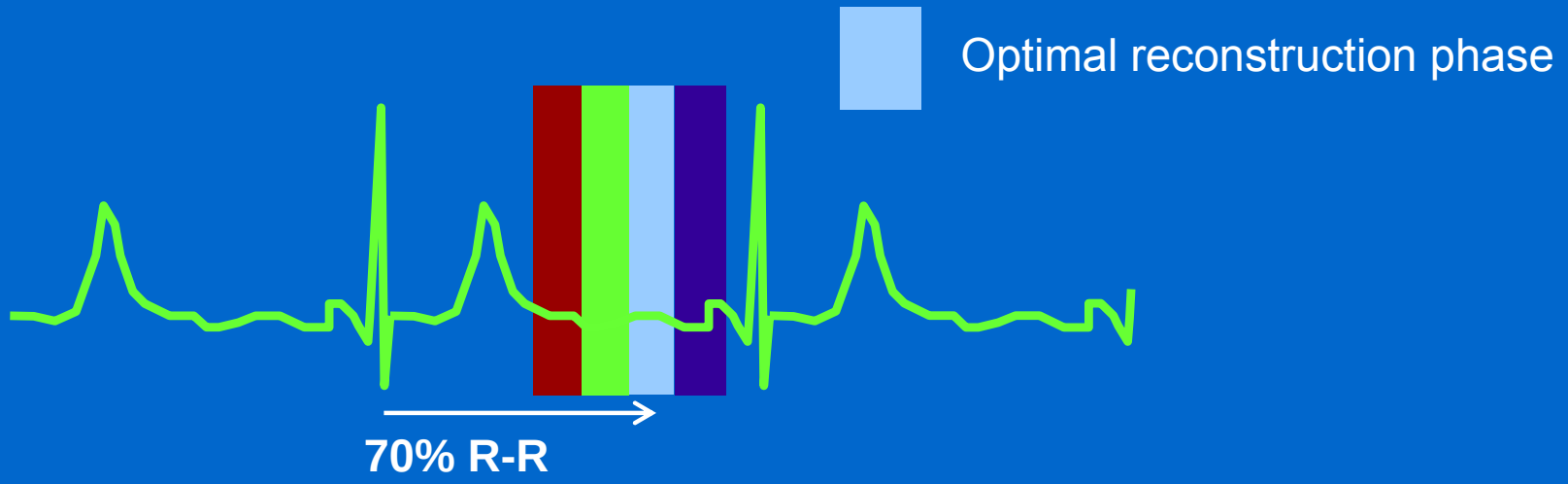
- 2 definitions of phase position

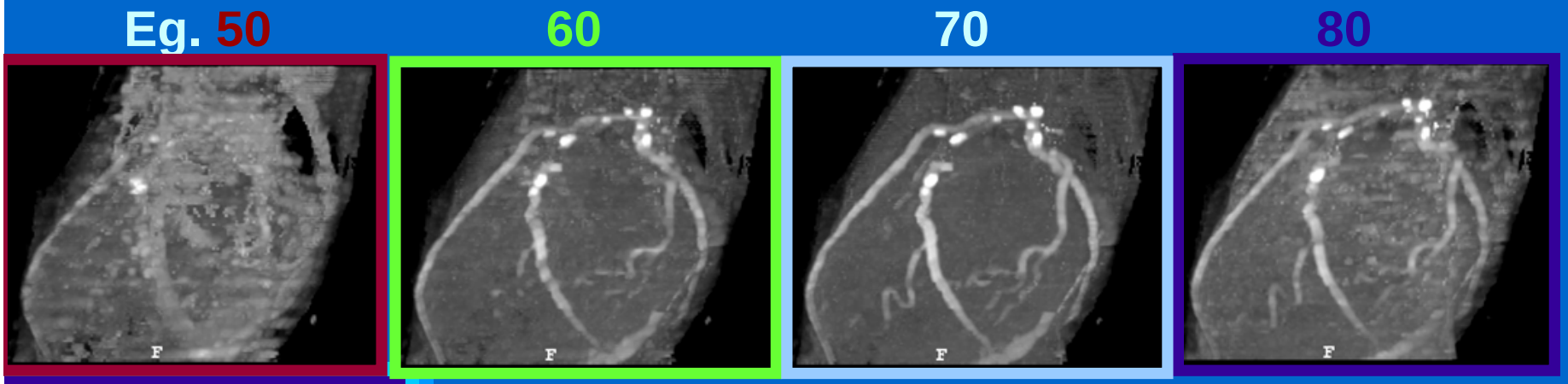


  - Beginning of phase window (eg 60%)
  - Middle of phase window (eg 70%)

Cardiac CT – ECG phases

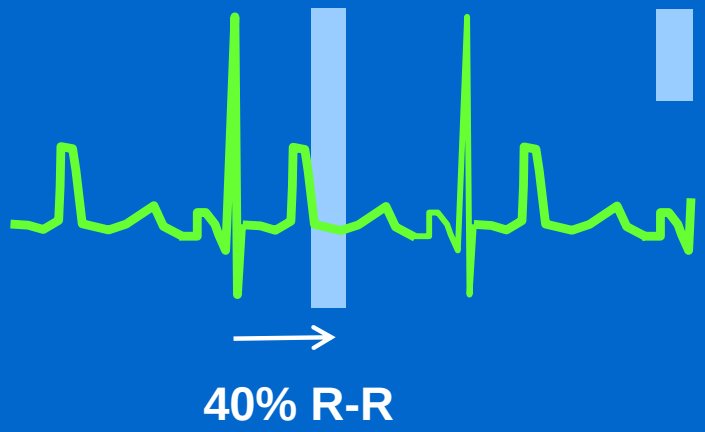
- Optimal phase for reconstruction for CTA
  - ~ 70 %





Cardiac CT – ECG phases

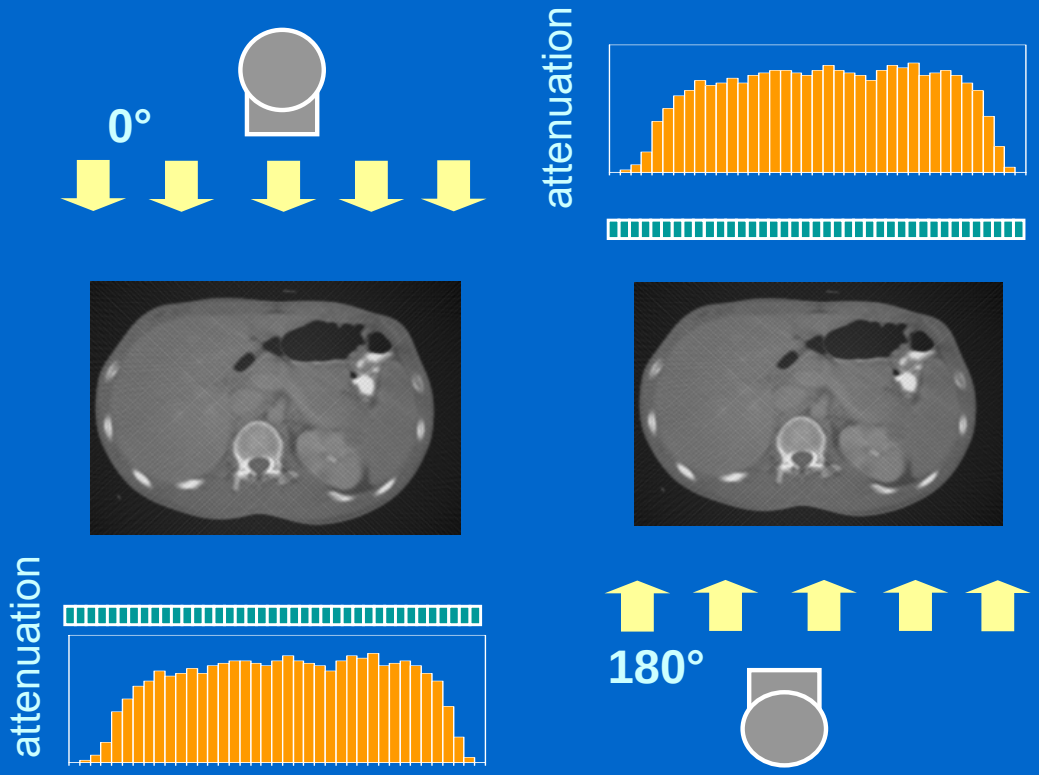
- For higher heart rates
  - ~ 30 – 40% phase position (also for RCA)
  - This region doesn't shorten as much as the 70% region

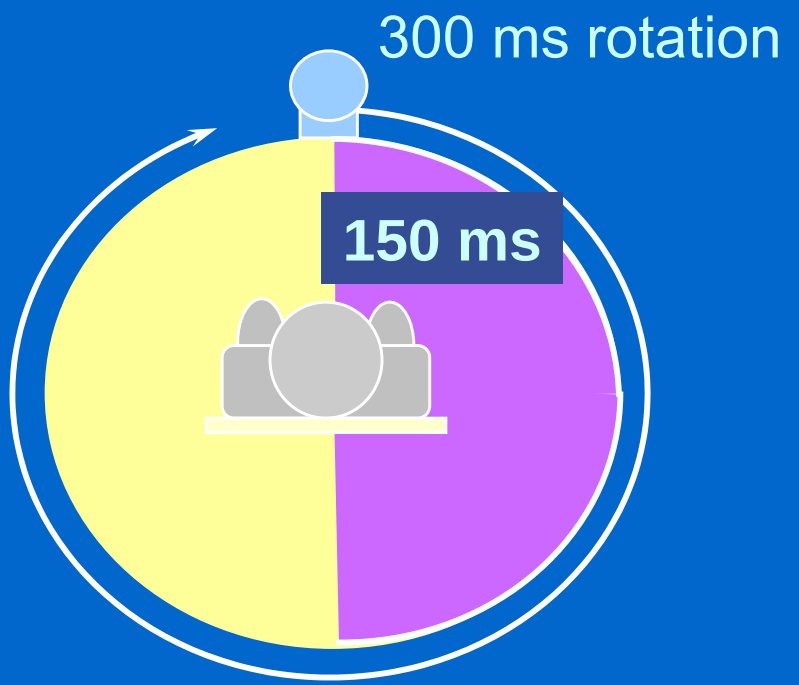


Some flexibility of reconstruction phase position required

Data acquisition – how much data do you need?

- Opposing projections provide the same information
  - To reconstruct images only 180° of scan data is required
- Image time = rotation / 2





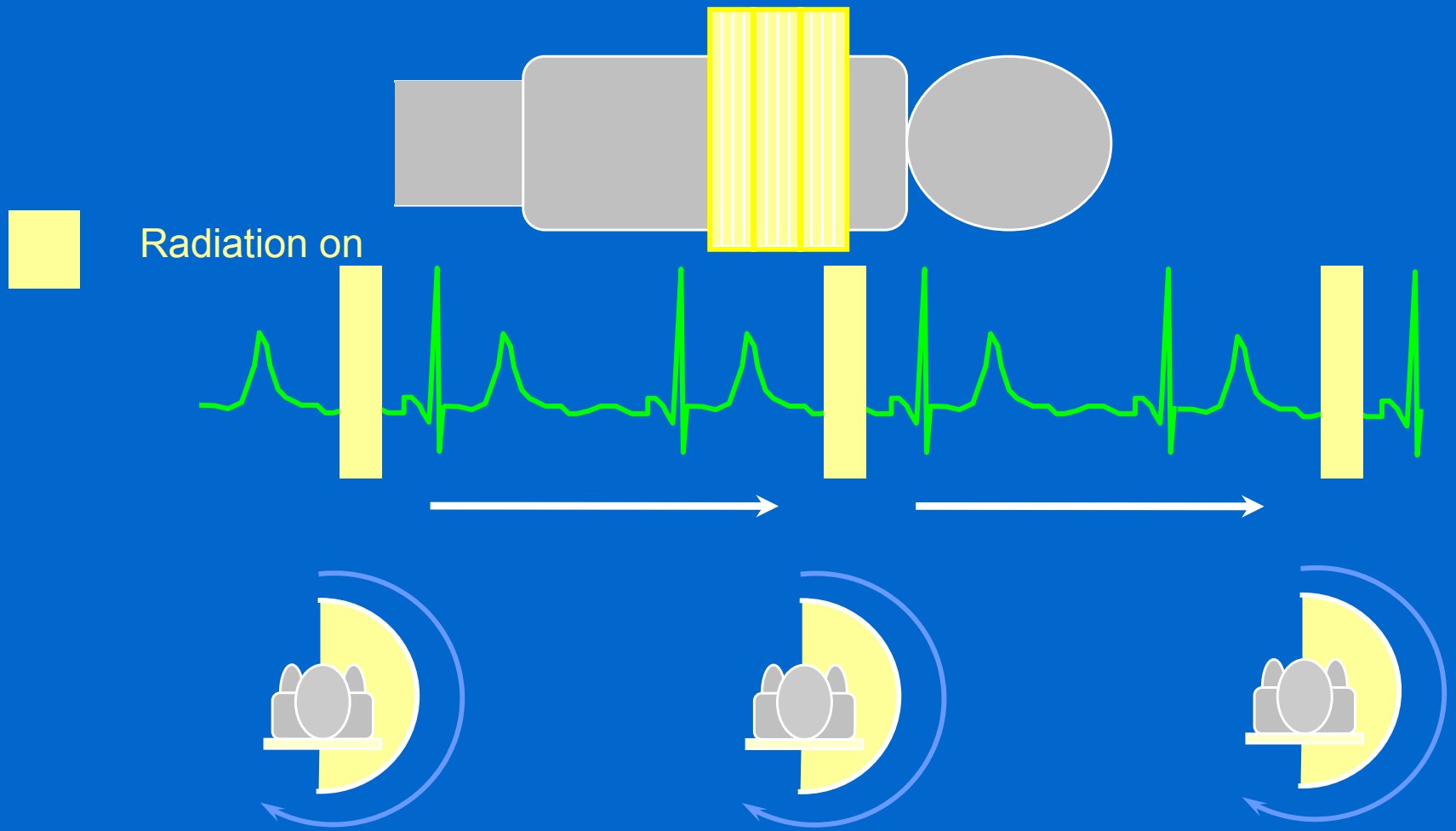
one z-axis position

Cardiac CT - scan modes

Scan	Cardiac
Axial	Prospective triggering
Helical	Retrospective gating

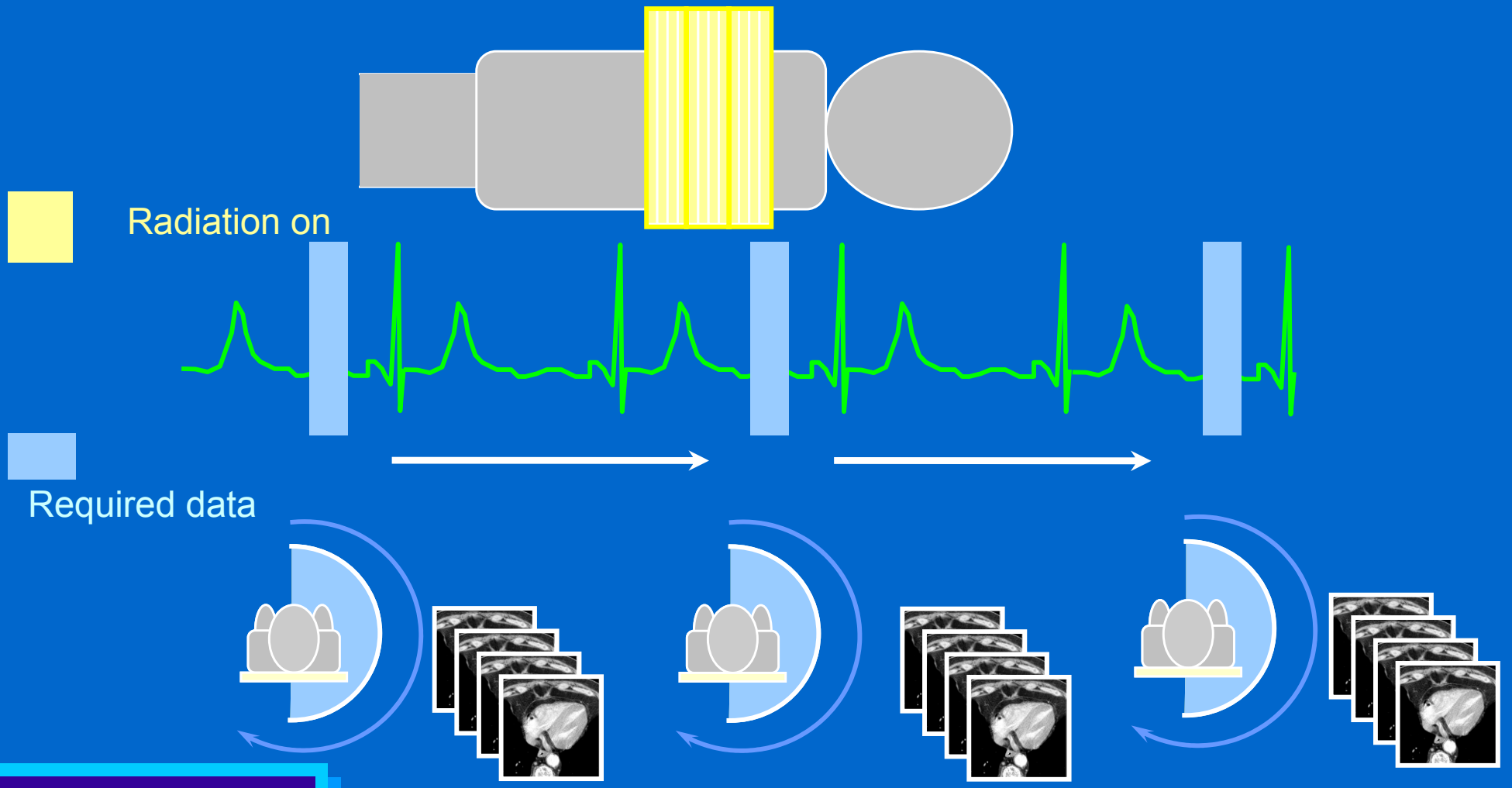
Cardiac CT- axial scanning

- R wave recognised - scan triggered



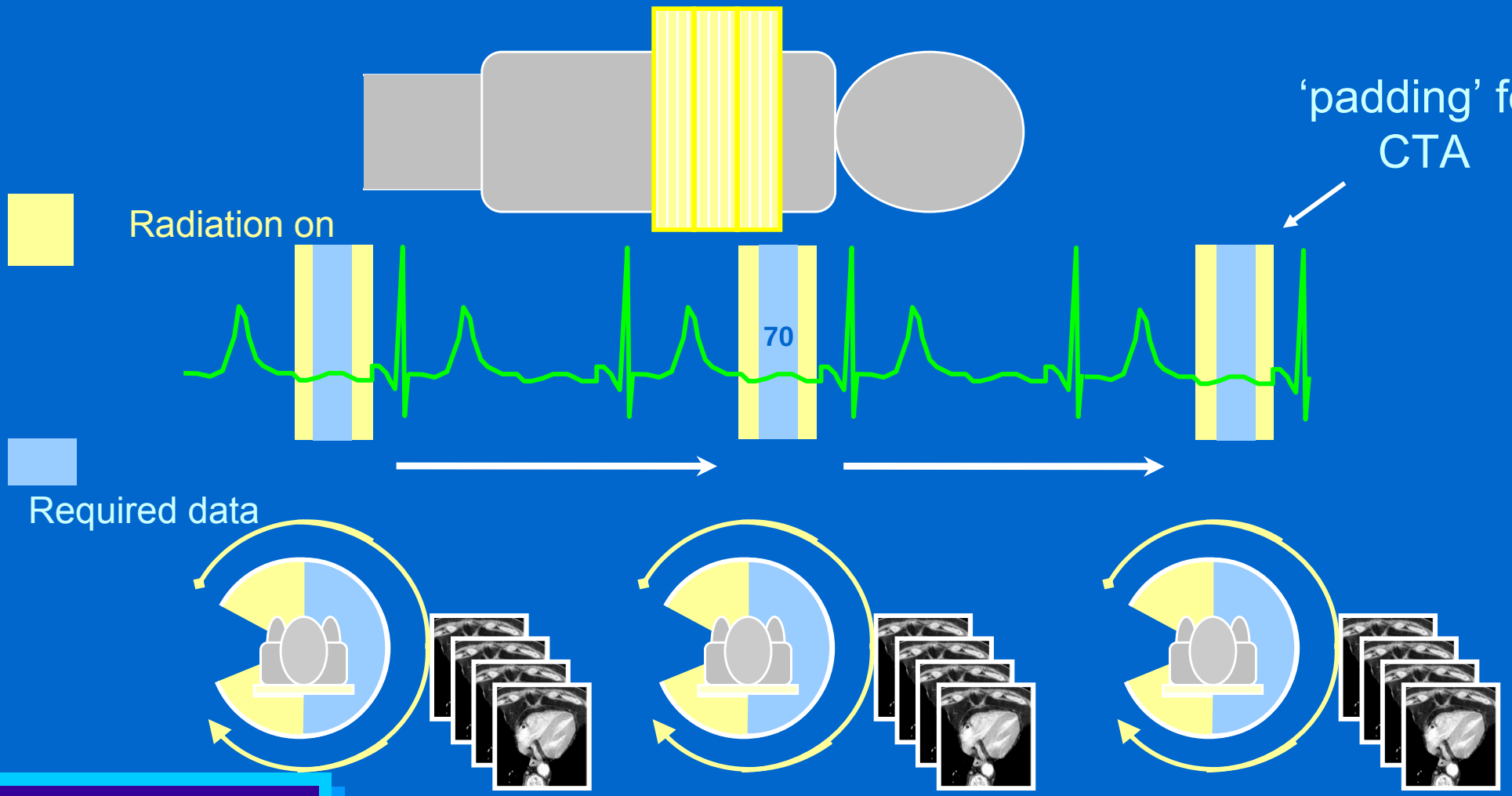
Cardiac CT- axial scanning

- Images reconstructed



Cardiac CT - axial scanning with padding

- Axial scanning with ‘padding’
- More flexibility with reconstructed phase position



Cardiac CT - axial scanning with padding

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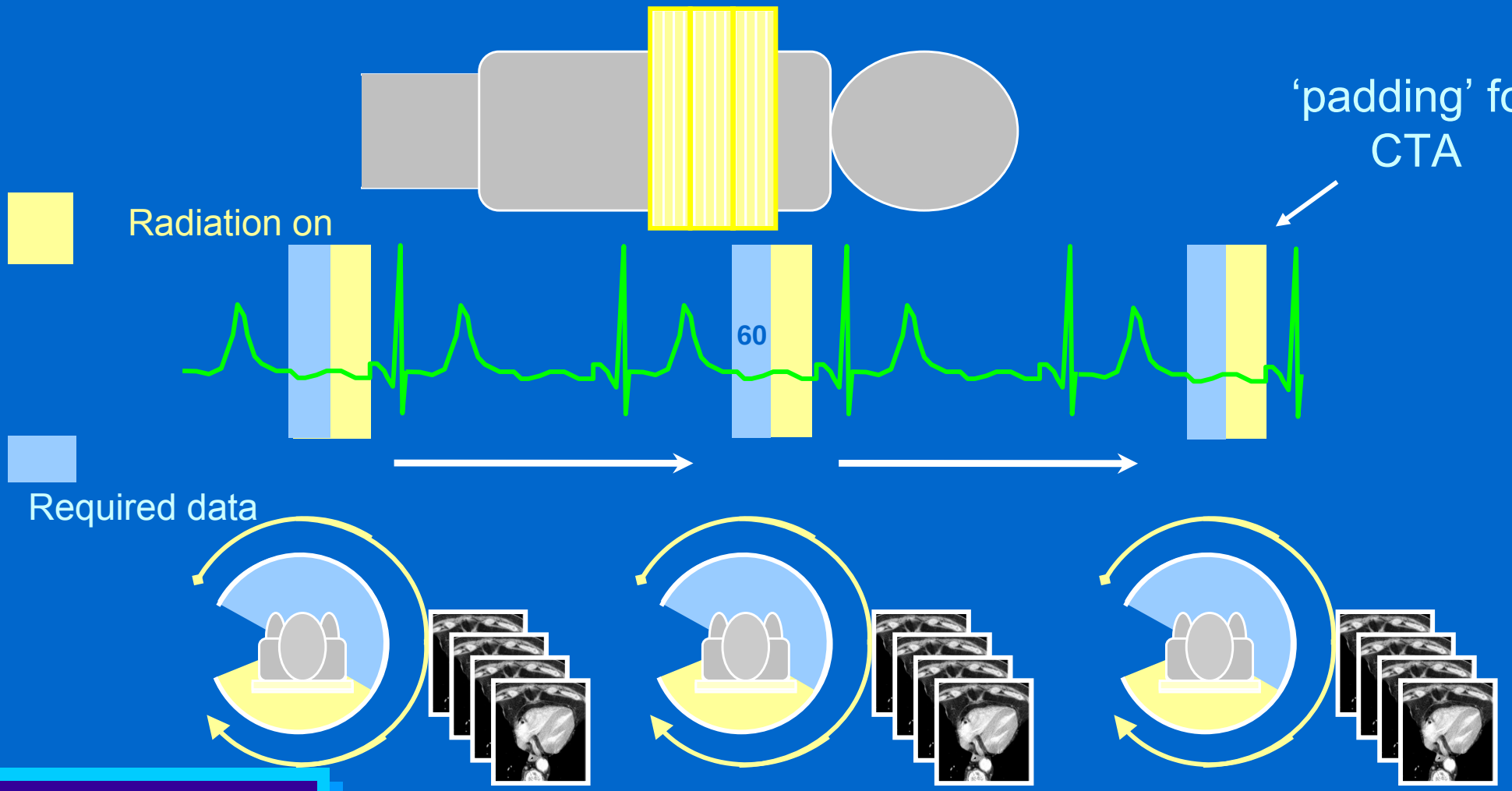
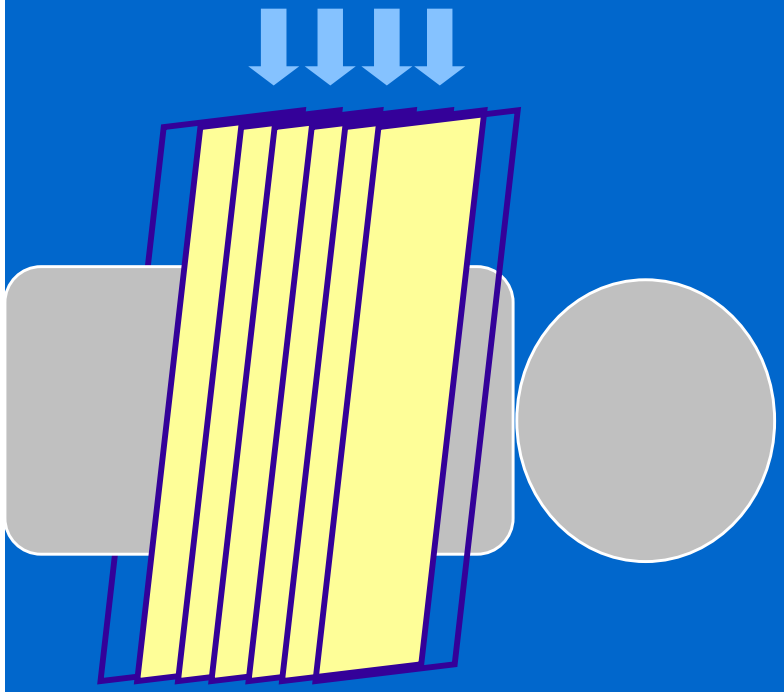
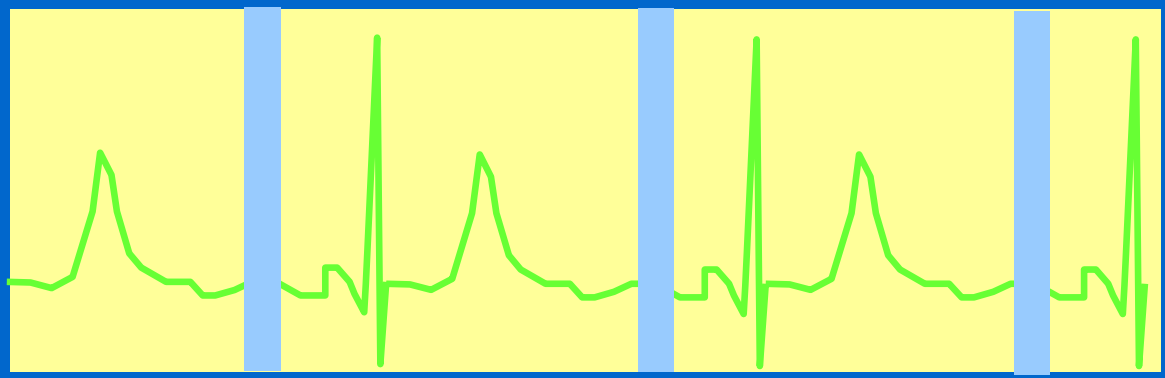


Cardiac CT – helical scanning

- Scan with overlapping pitch ~ 0.2
- Image reconstruction selected retrospectively

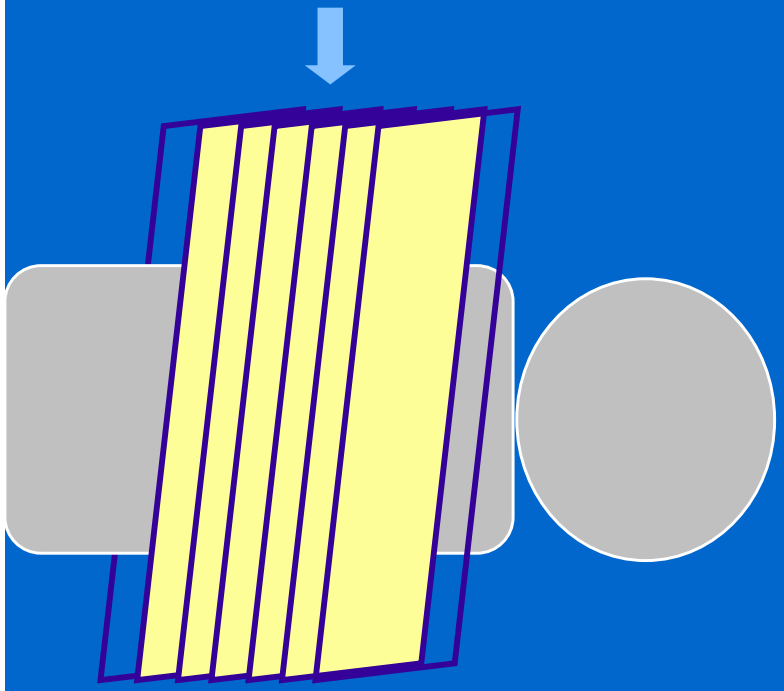


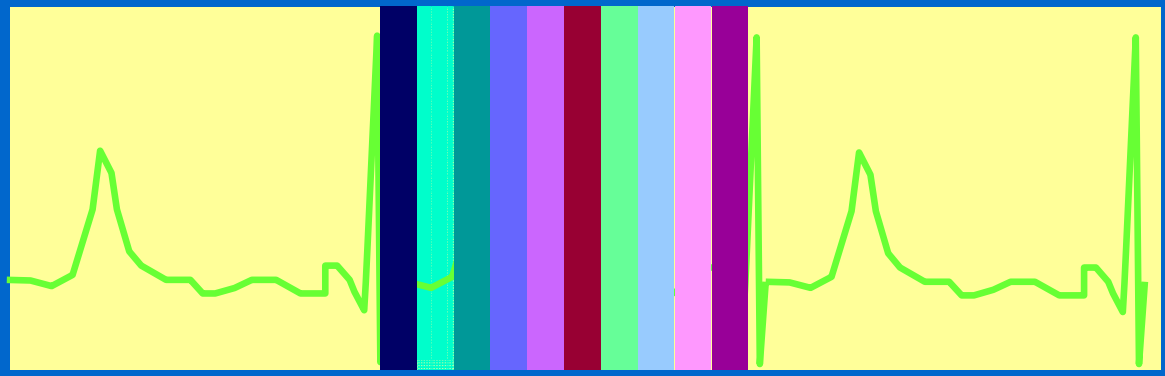


X-rays on

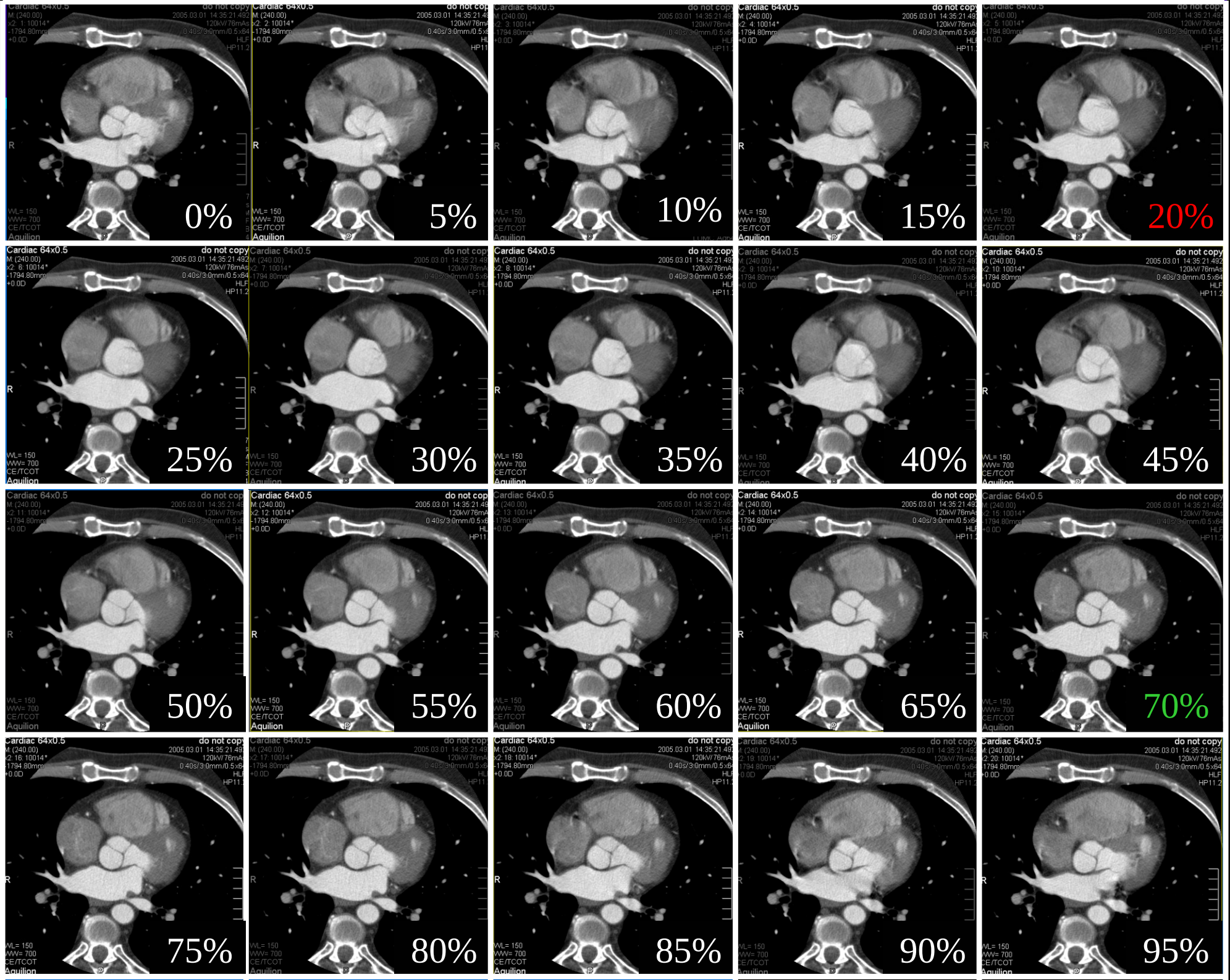
Cardiac CT – helical scanning

- Scan with overlapping pitch ~ 0.2
- Image reconstruction selected retrospectively
  - Choose best phase for cardiac CTA
  - Multiple phases for functional studies





X-rays on


0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%


0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%
85%
90%
95%

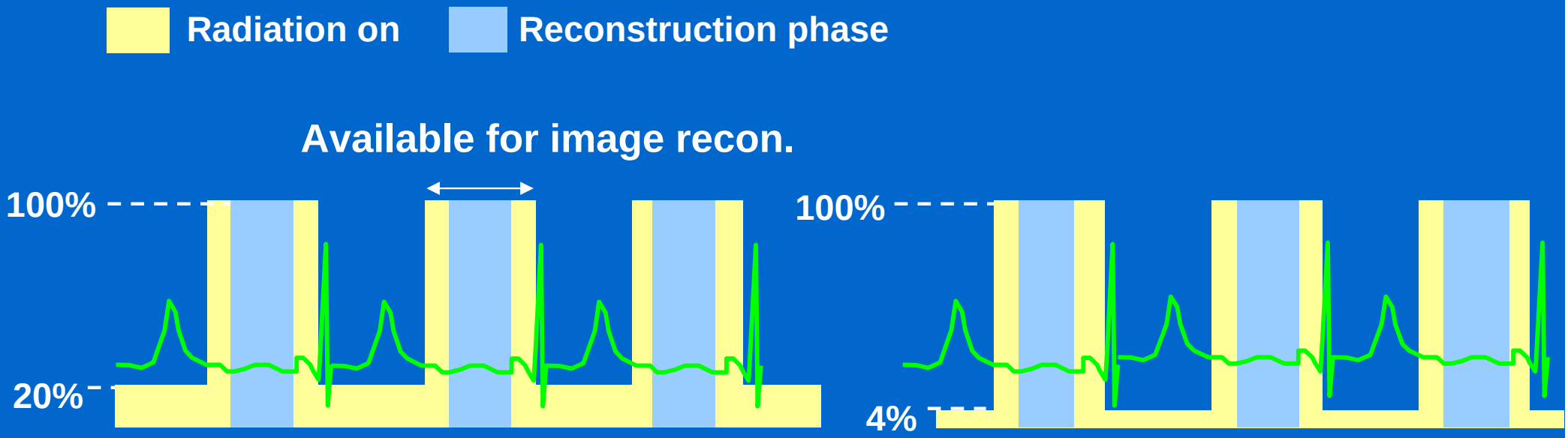
Functional Imaging

- Using all phases in cine loop

phase

Helical cardiac CT– ECG dose modulation

- Tube current (mA) decreased to a prescribed minimum value outside phase region of interest
  - eg 20%, 4% of maximum dose
- Full dose at required phase region, with a margin
- Other phases can still be used for functional study



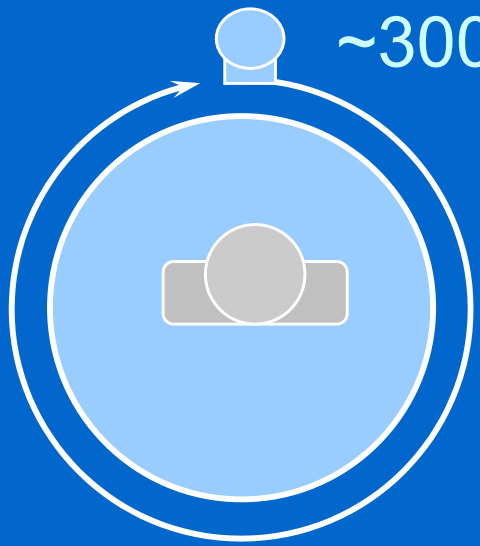
Helical pitch in cardiac scanning

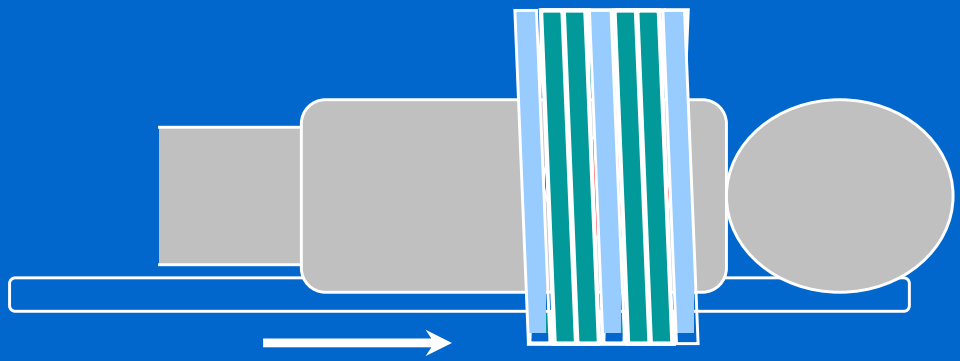
Helical cardiac CT - pitch

- Gantry rotates faster than heart rate. Eg. :
  - 0.3 sec scan = 3 rotations / second
  - Heart rate: @ 60 bpm = 1 beat per second

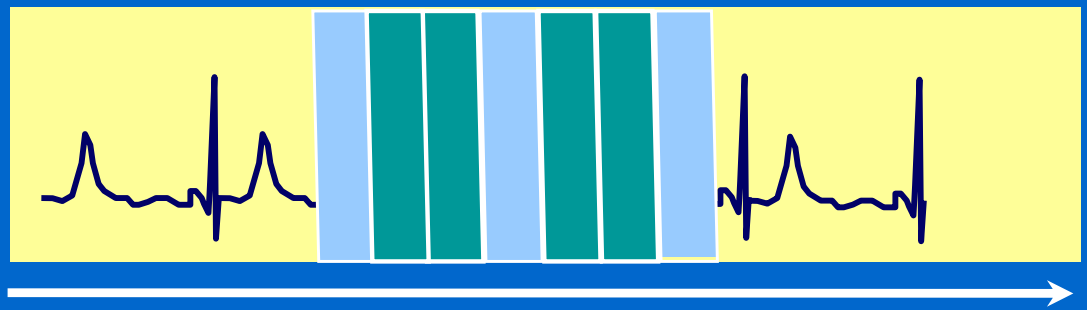
3 rotations per heart beat

- If Pitch =1, gaps in cardiac anatomy



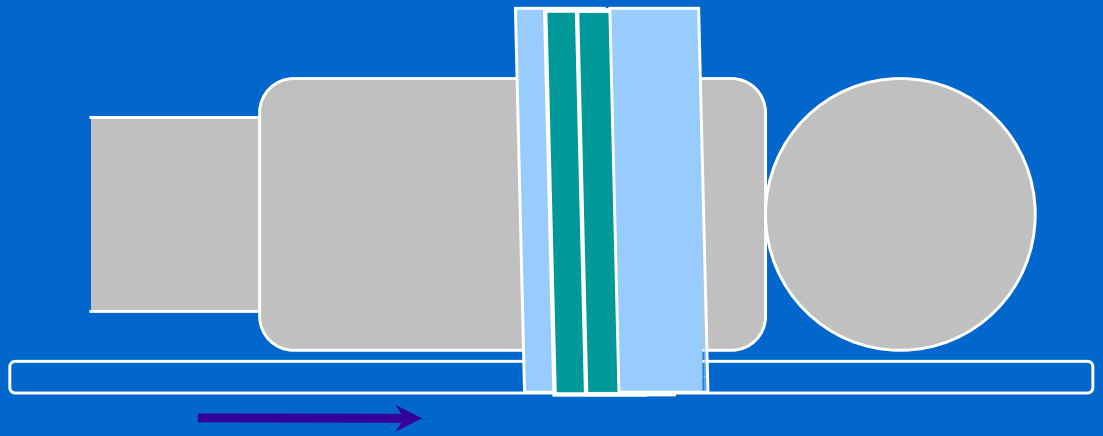


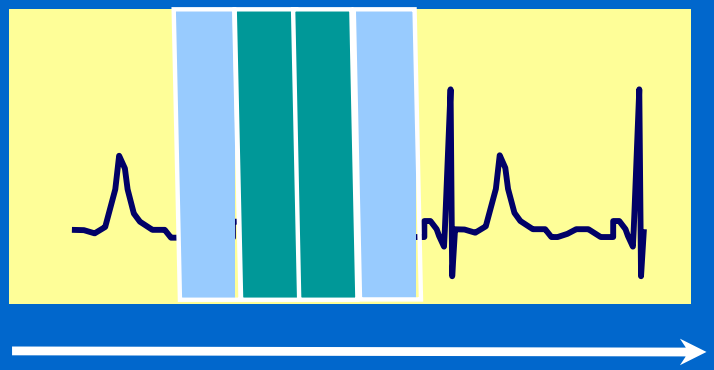
Scanner rotations



Helical cardiac CT - pitch

- Require an overlapping pitch
  - **~0.2 – 0.3 to eliminate gaps in coverage**

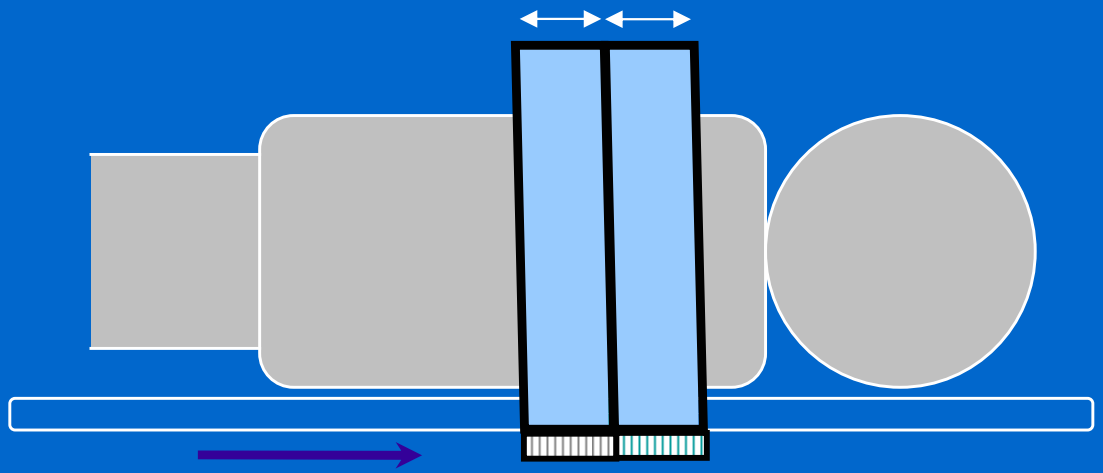




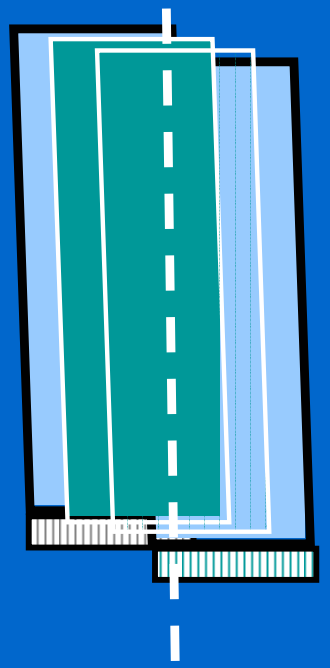
Helical cardiac CT - pitch

- Require an overlapping pitch
  - **~0.2 – 0.3 to eliminate gaps in coverage**

Example: pitch 0.33



Example: pitch 0.25



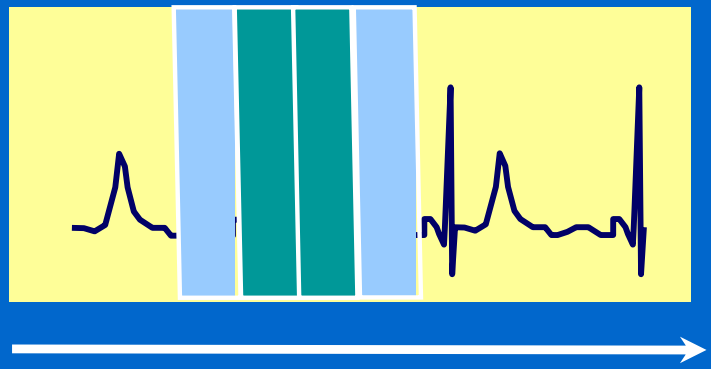


Image position

Cardiac CT – scan modes

Scanning mode	Cardiac gating	Features
Axial/Sequence	Prospective triggering	Padding
Helical	Retrospective gating	ECG modulation

Technical Aspects of Cardiac CT

- Introduction
- Multi-slice CT (MSCT)
- Scanning the heart with MSCT
- Improving
  - Temporal resolution
  - Speed of volume coverage
  - Spatial resolution

Heart rates and required imaging times

Heart rate (Beats per min.)	Heart rate (Beats per sec.)	Time for one beat (R-R) (sec.)	**Useful 'still' time ~ 10% of (R-R)**
40	0.7	1.5 sec	**150 ms**
60	1	1 sec	**100 ms**
120	2	0.5 sec	**50 ms**

Typical scanners: **shortest rotation times**	**Rotation times (sec)**	**Half rot. time (ms)**
	0.27	**135 ms**
	0.33	**165 ms**
	0.4	**200 ms**
	0.5	**250 ms**

Techniques to improve temporal resolution

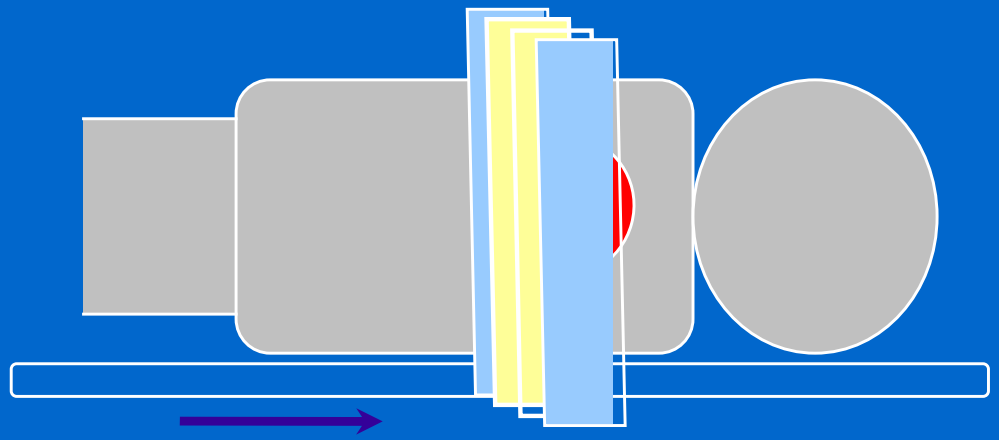
- Patient
  - Aim for a slow and regular heart rate (beta blockers)

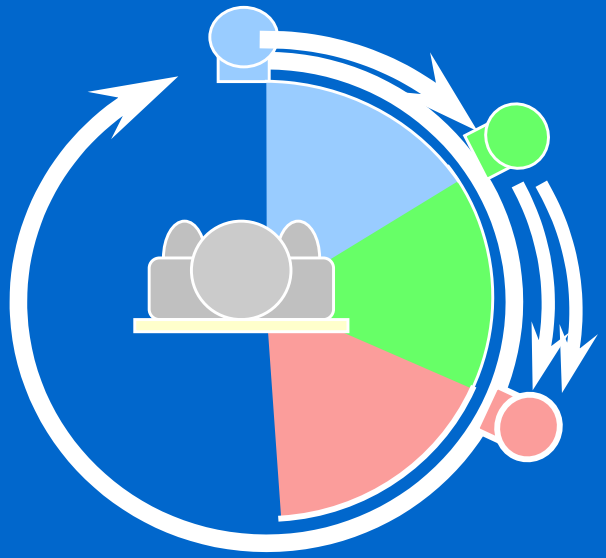
Techniques to improve temporal resolution

- Scanner - shorten imaging time ('shutter speed')
  - Shorter rotation times
  - Multi-sector reconstruction (all manufacturers)
  - Two tubes (Siemens)

Multi-sector reconstruction

- Used in helical^ scanning – sectors of data taken from different rotations

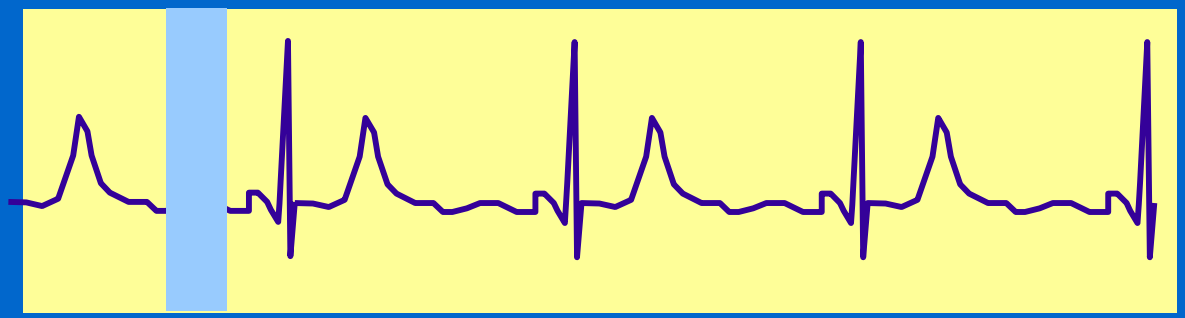




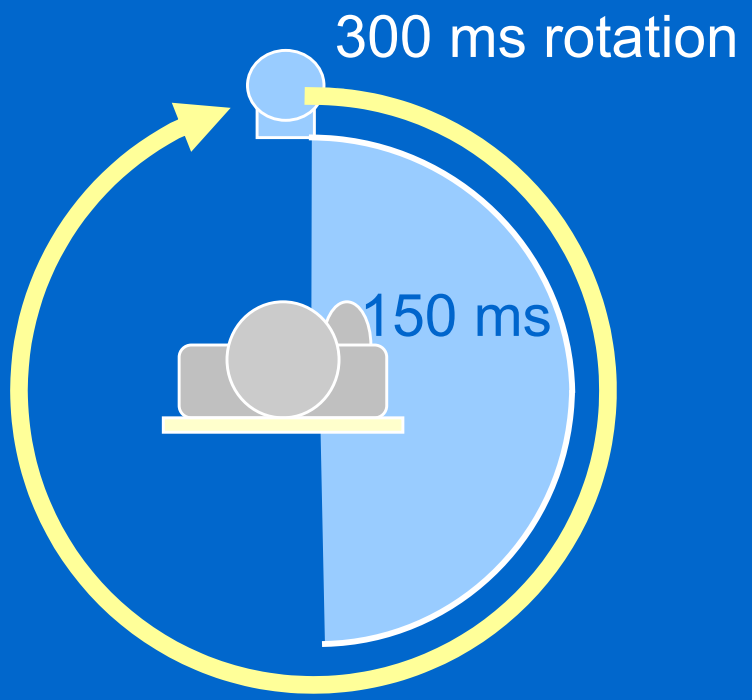
^ Except Toshiba Aquilion One where multi-sector axial scanning is possible

Multi-sector reconstruction

- Single sector
  - Single sector of 180 ° eg sector time = 150 ms
  - Each image uses data from one heart beat



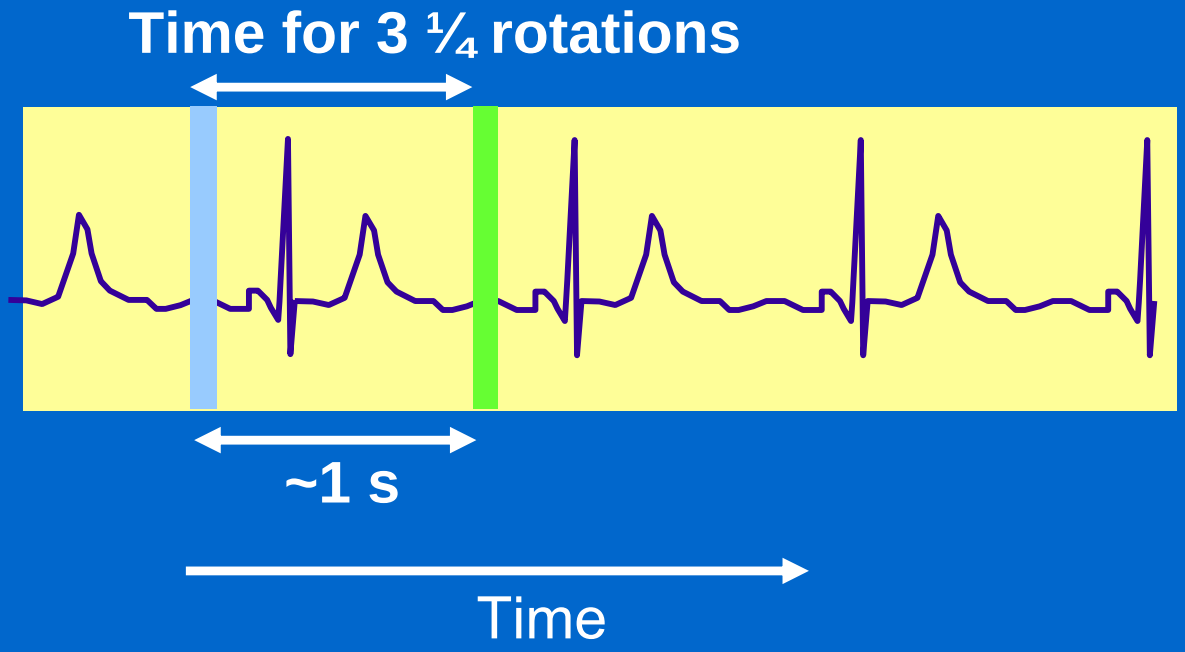
Time

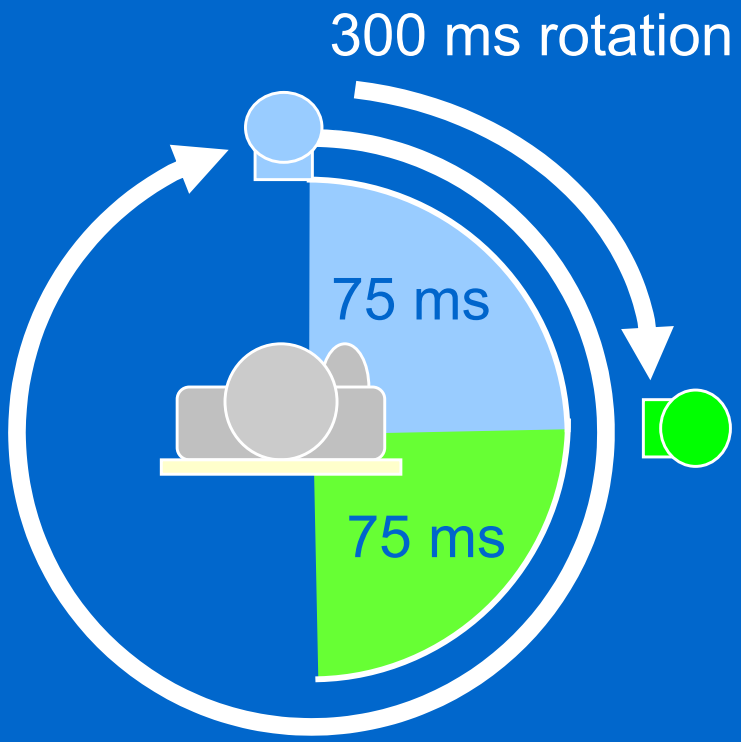


one z-axis position

Multi-sector reconstruction

- Two sector
  - Two sectors each of 90 ° eg. Sector time = 75 ms
  - Each z-axis image uses data from two heart beats

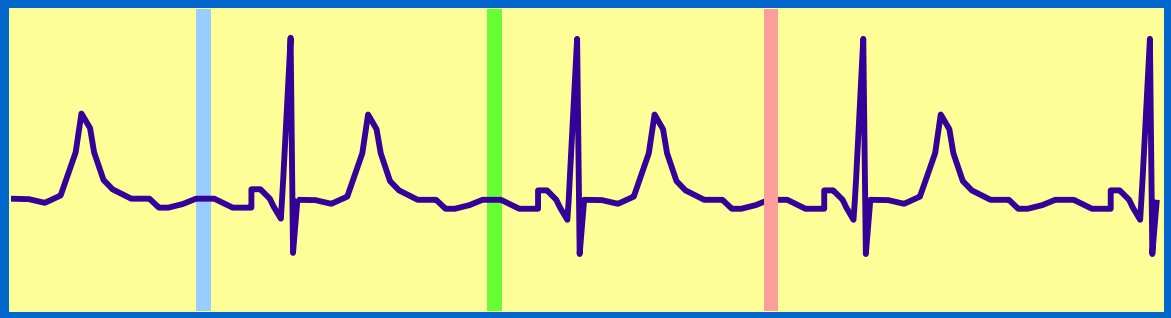


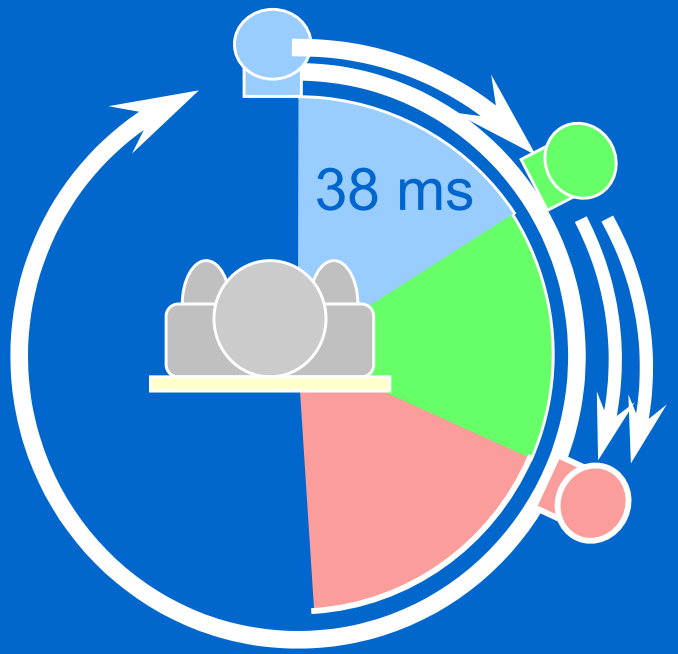


same z-axis position

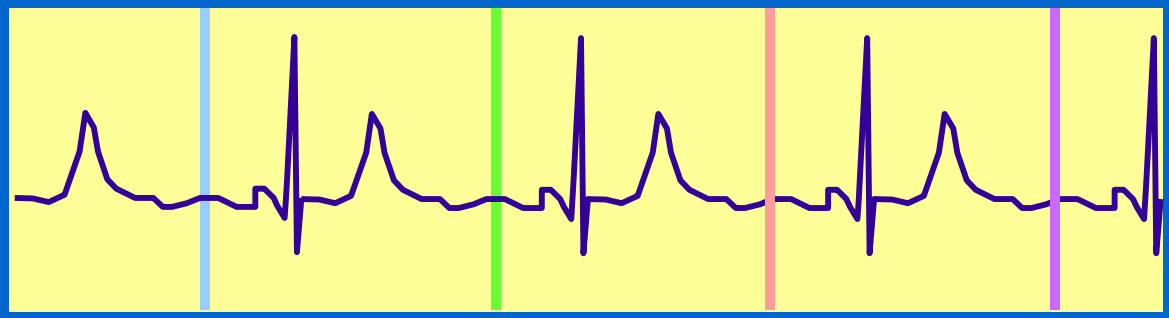
Multi-sector reconstruction

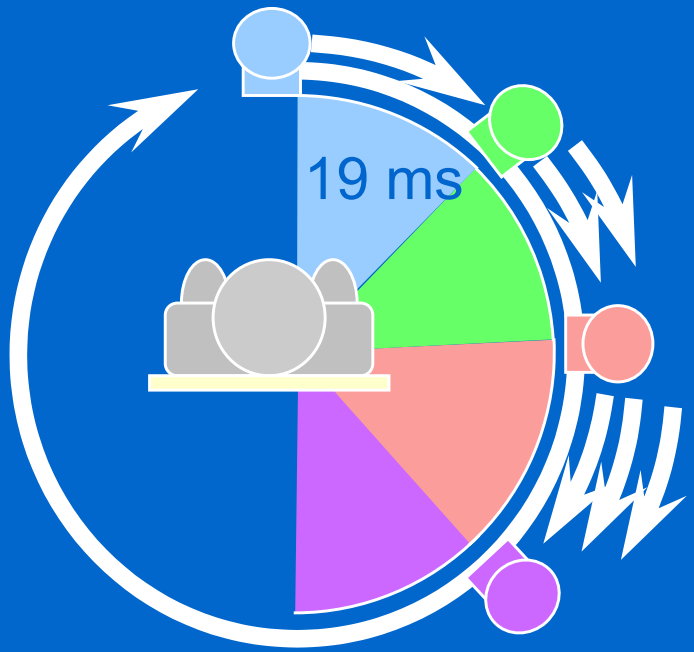
- 3-sector (~38 ms)





- 4-sector (~19 ms)

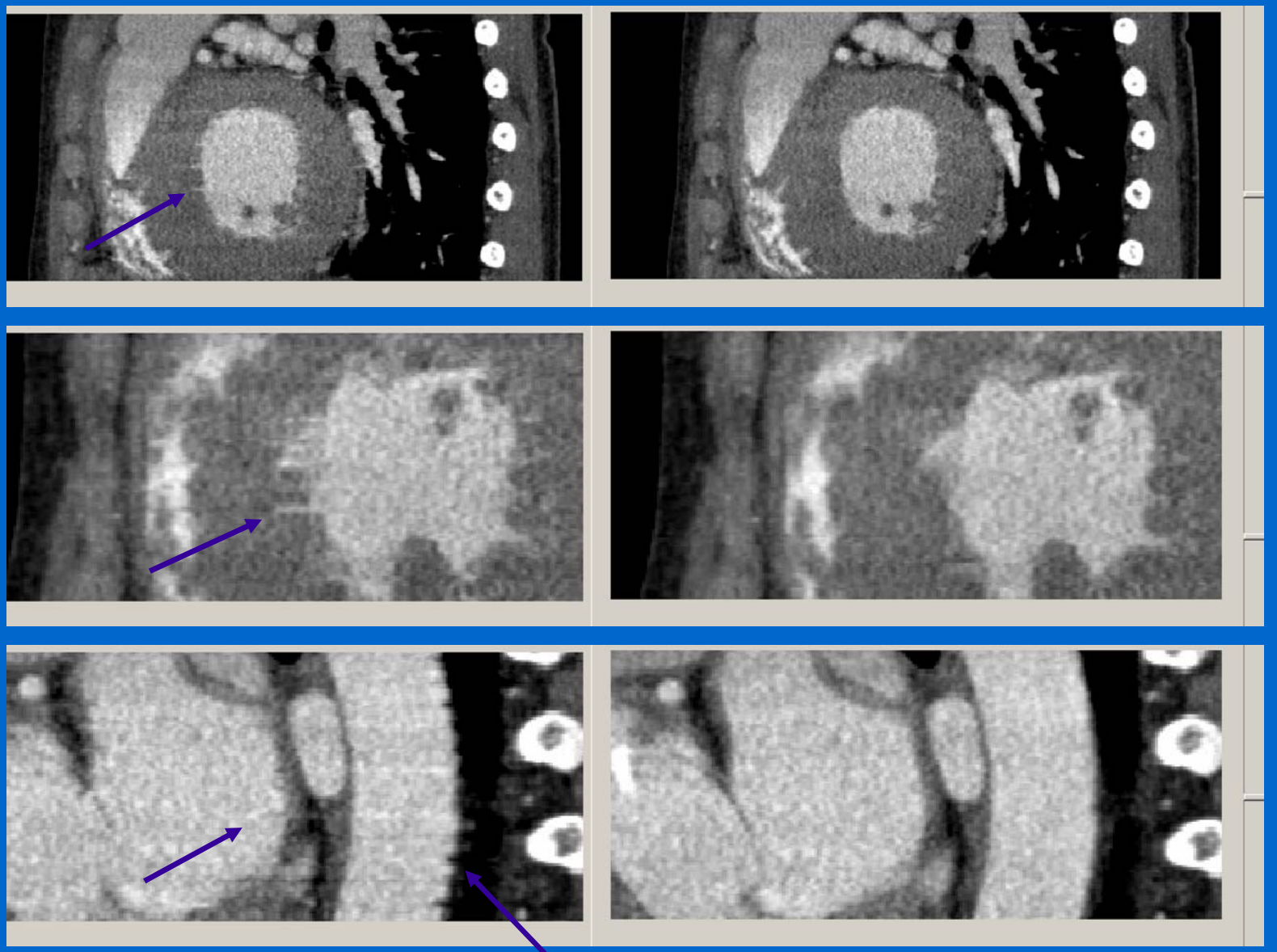




Multi-sector reconstruction

2 sectors

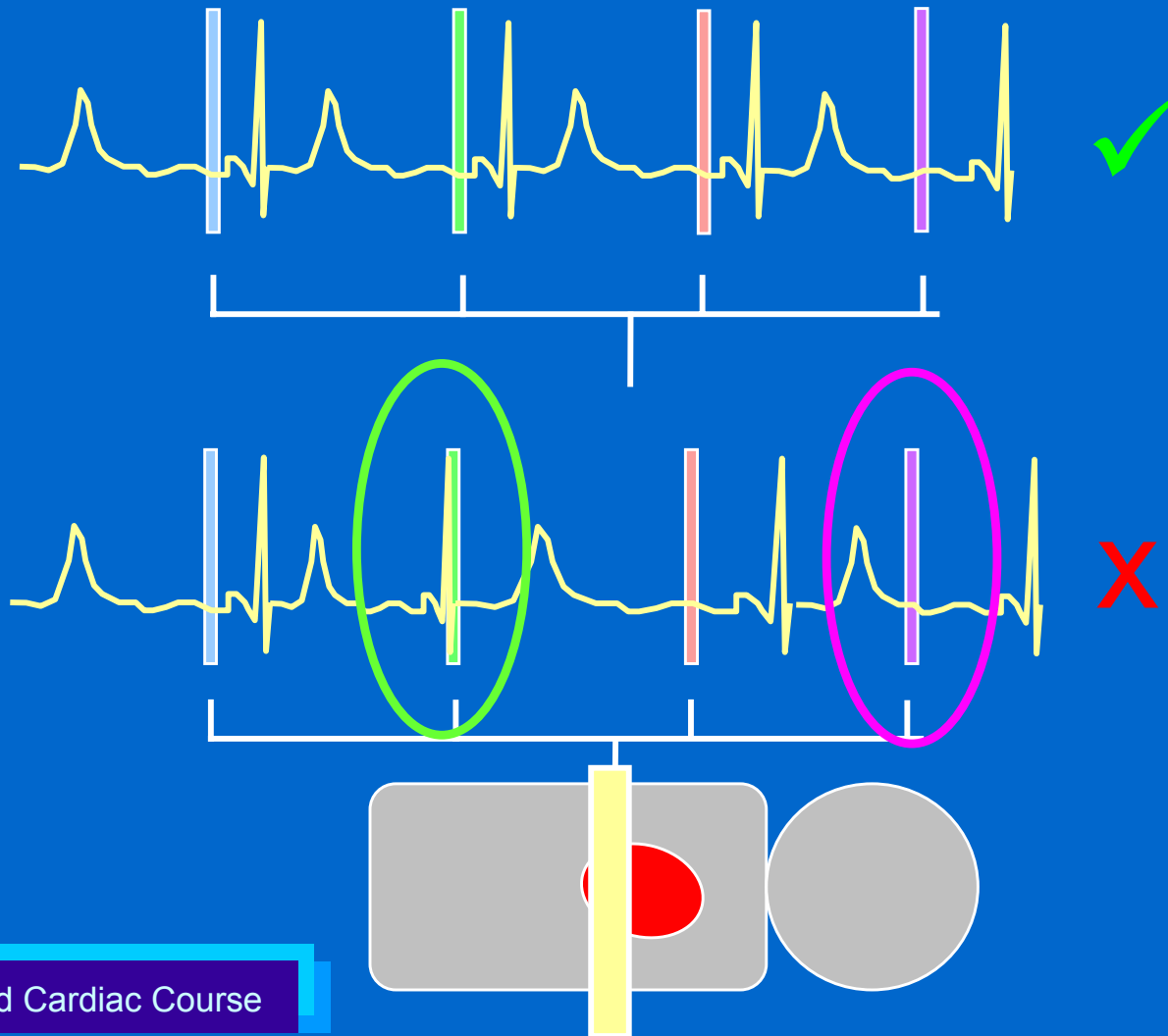
3 sectors

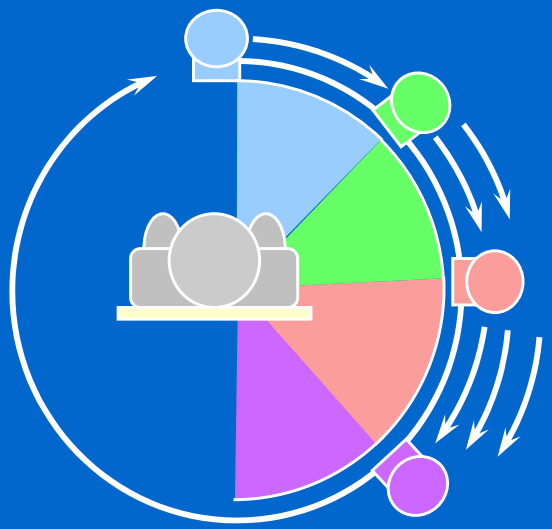


Courtesy Philips

Multi-sector reconstruction - issues

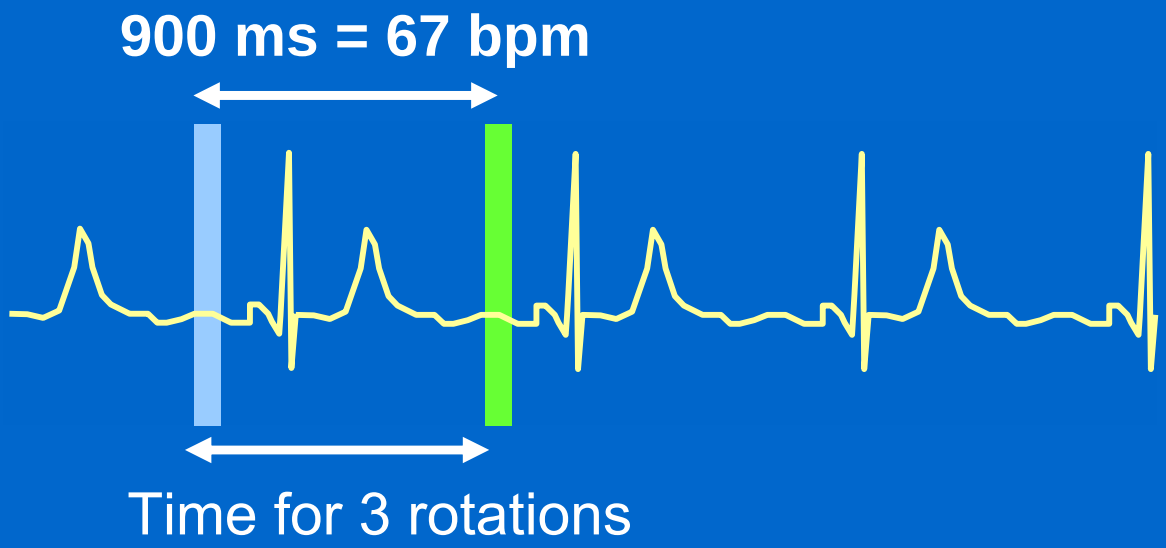
- In theory good for fast heart rates but…
  - Require steady heart rate for good registration of sectors

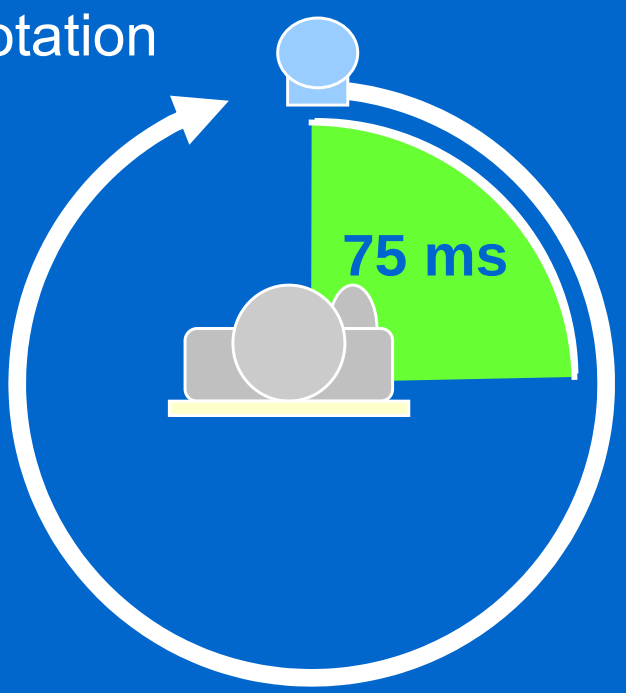




Multi-sector reconstruction - issues

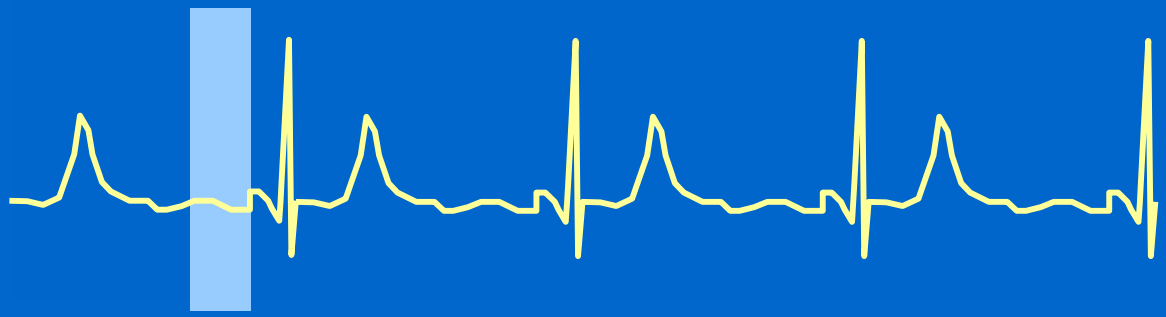
- Temporal resolution optimised only for specific heart rates
- Worst case when heart rate in synchrony with tube rotation

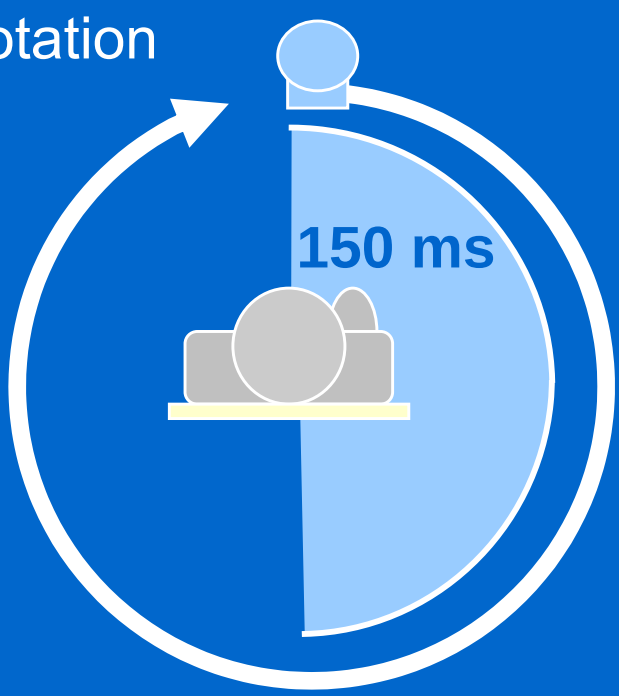




Multi-sector reconstruction - issues

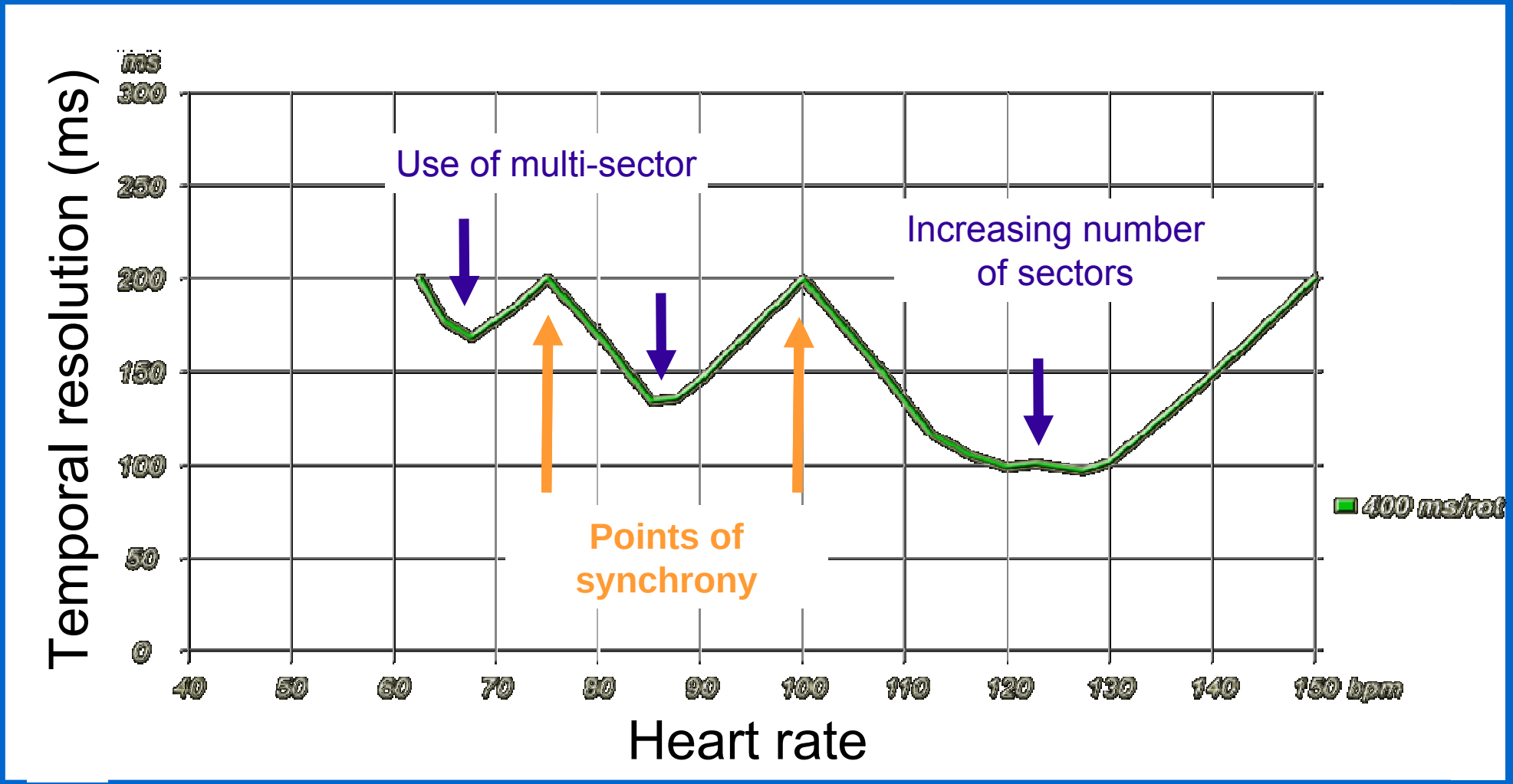
- Temporal resolution optimised only for specific heart rates
- Worst case when heart rate in synchrony with tube rotation
- In this instance reconstruction reverts to single sector





Multi-sector reconstruction - issues

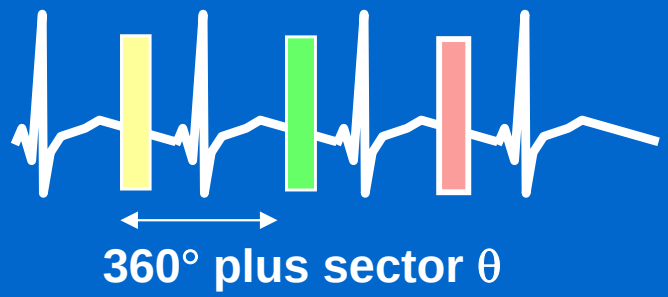
- Complex relationship between heart rate, rotation time, pitch and effect on temporal resolution

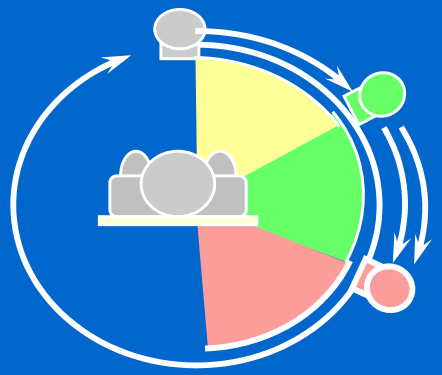


Multi-sector reconstruction

- Manufacturers
  - different number of sector options
  - Automatic selection to varying degrees

	IGE^	Philips	Siemens (1 tube)	Siemens (2 tube)	Toshiba
No of sectors	1, 2, 4	Up to 5	1 or 2	1 or 2	Up to 5

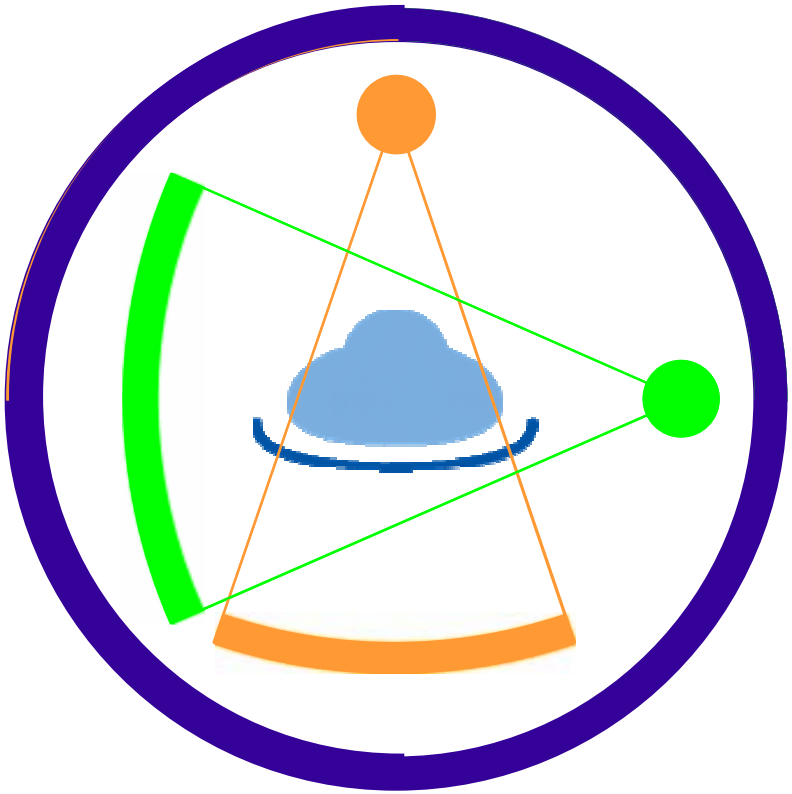


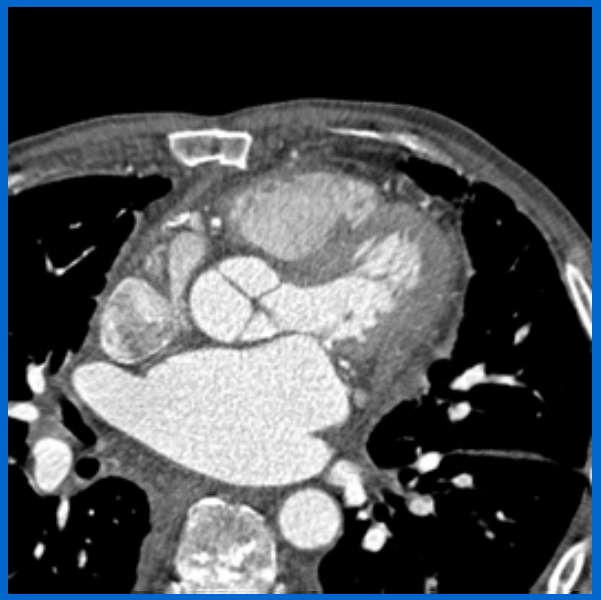


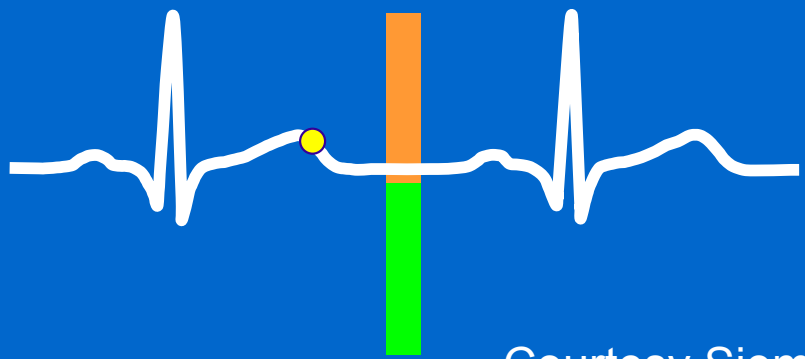
^snapshot, snapshot burst, snapshot burst plus

Two tubes - Siemens Dual Source

- Acquires 2 sectors of data simultaneously - in ¼ rotation
  - Definition Classic - 83 ms resolution (for 0.33 sec rotation)
  - Definition Flash – 75 ms (0.285 s rotation)



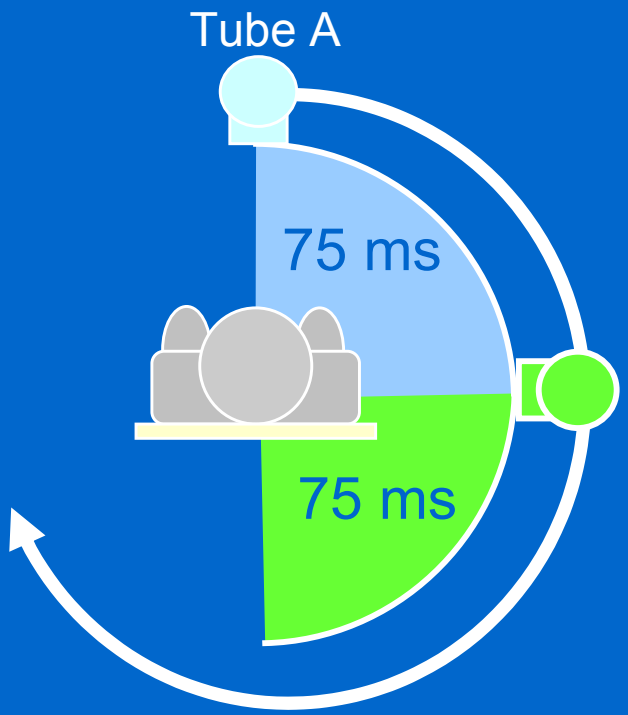


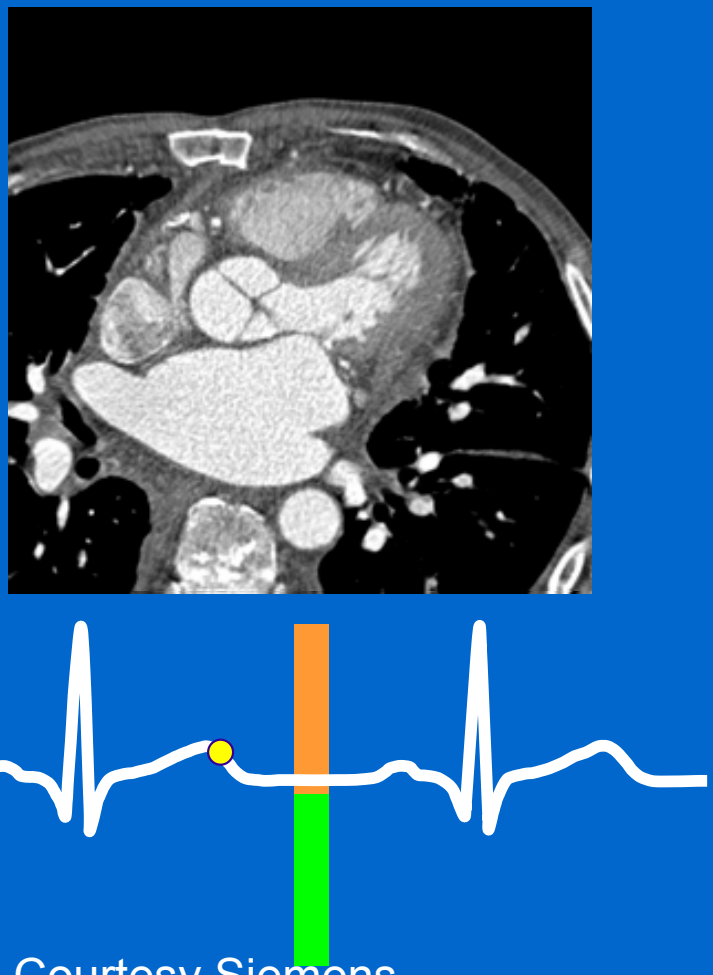


Courtesy Siemens

Two tubes - Siemens Dual Source

- Acquires 2 sectors of data simultaneously - in ¼ rotation
  - Definition Classic - 83 ms resolution (for 0.33 sec rotation)
  - Definition Flash – 75 ms (0.285 s rotation)
- From one heart beat – acquired 2 sectors simultaneously



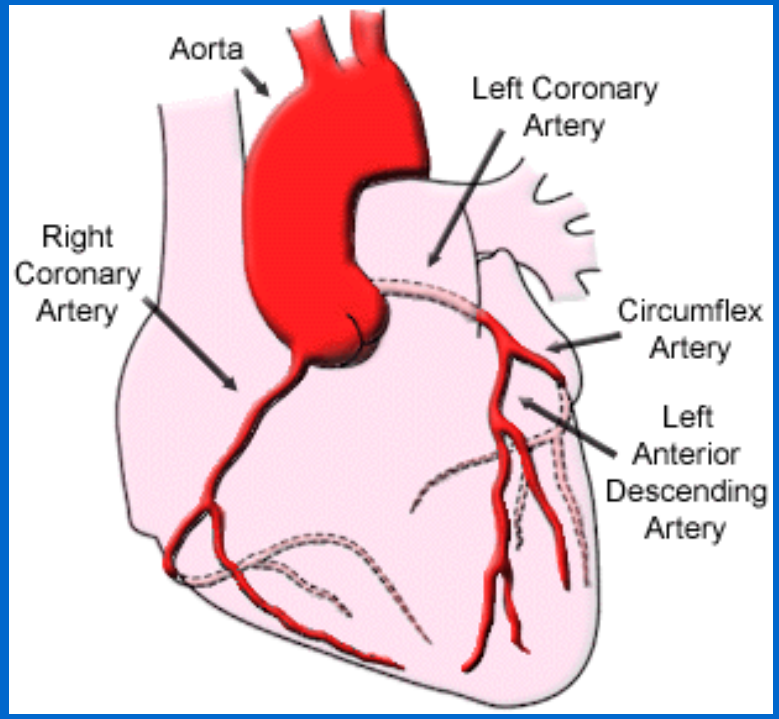


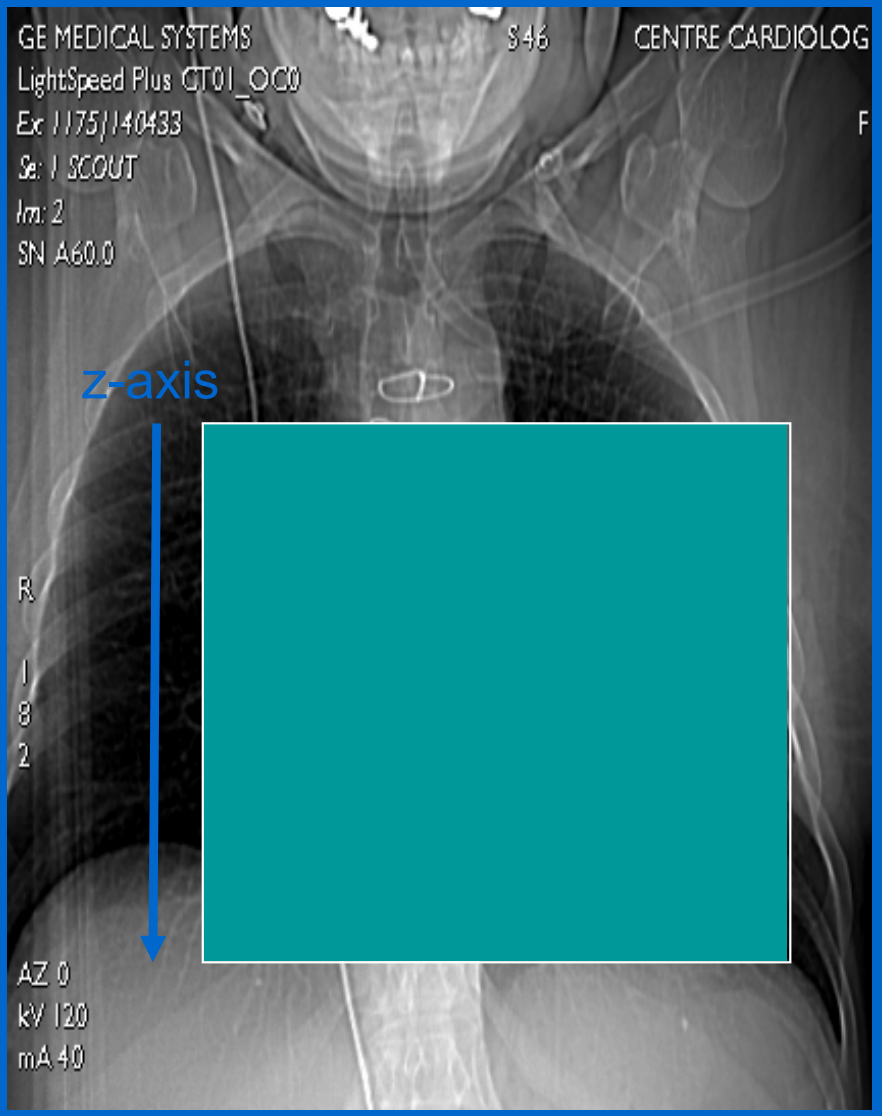
Courtesy Siemens

Challenges in imaging the heart - volume coverage

Volume coverage

- Scan length: ~ 120 – 140^ mm





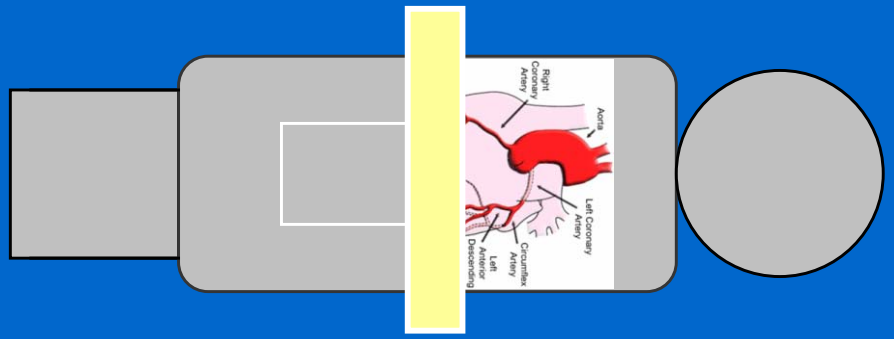
^Haulseiter, JAMA 2009 301(5), pp 500 - 507

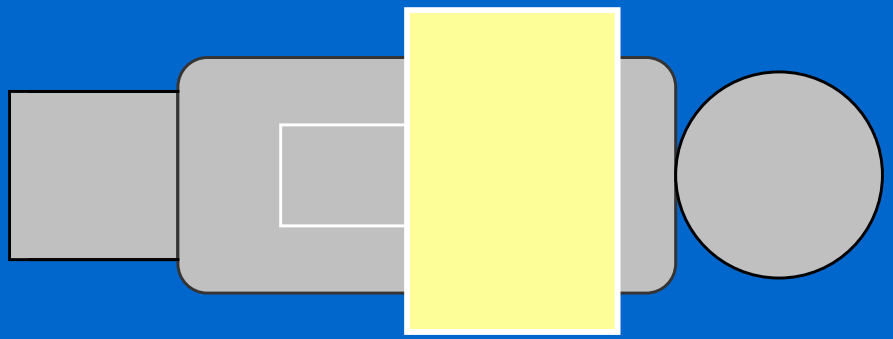
Volume coverage

- Scanner detector lengths^

‘Slices’	Typical lengths
4	< 20 mm
16	20 – 32 mm
’64’	~ 30 – 40 mm
> 64	40 – 160 mm

Improved detector coverage

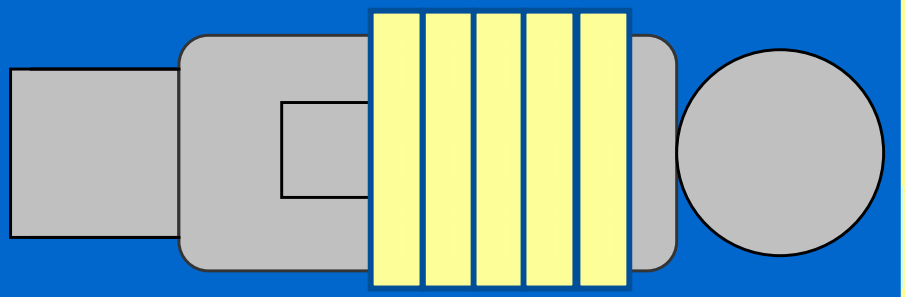


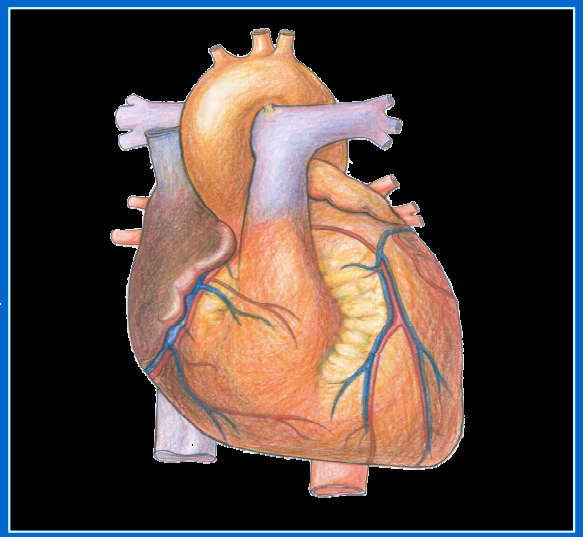


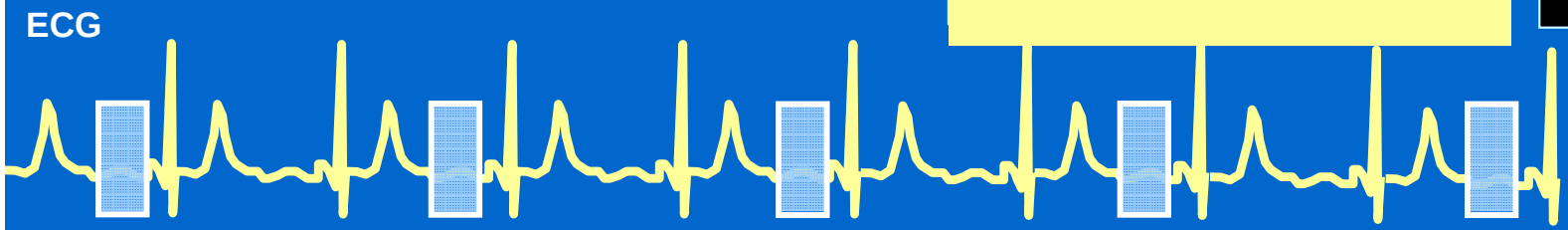
^ For thin slices sometimes shorter detector length used

Volume coverage

- Motion needs to be repeatable – regular heart rate
  - reduce potential for mis-registration

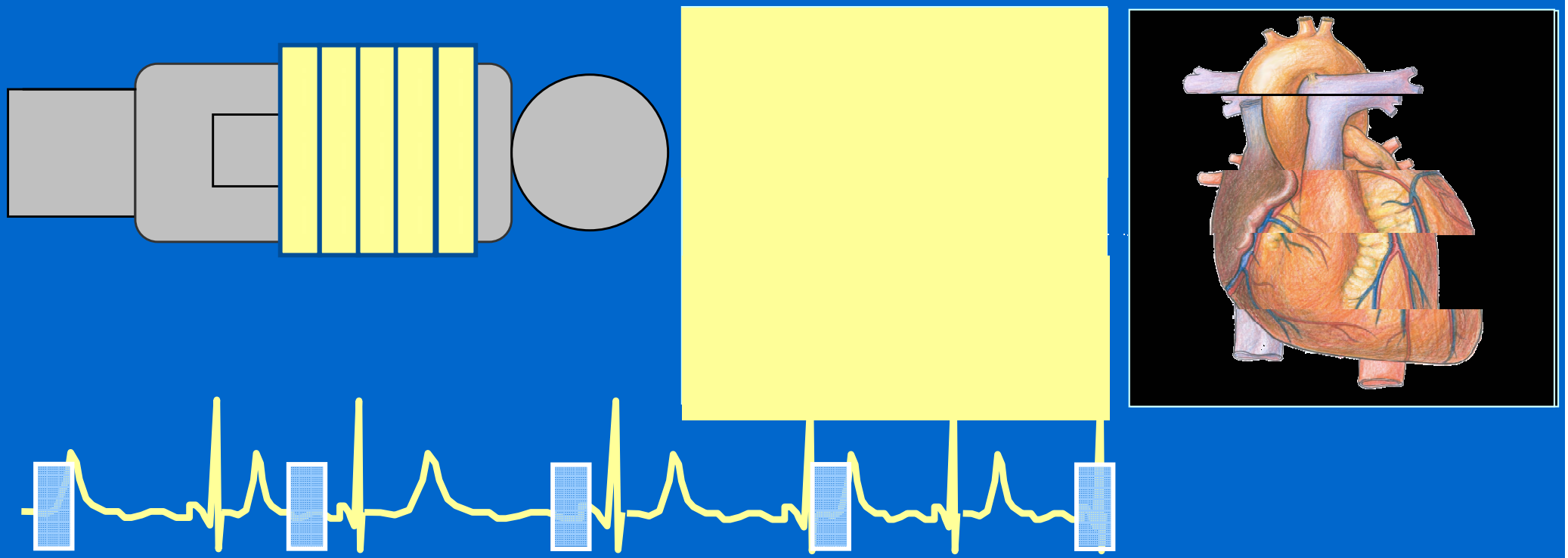




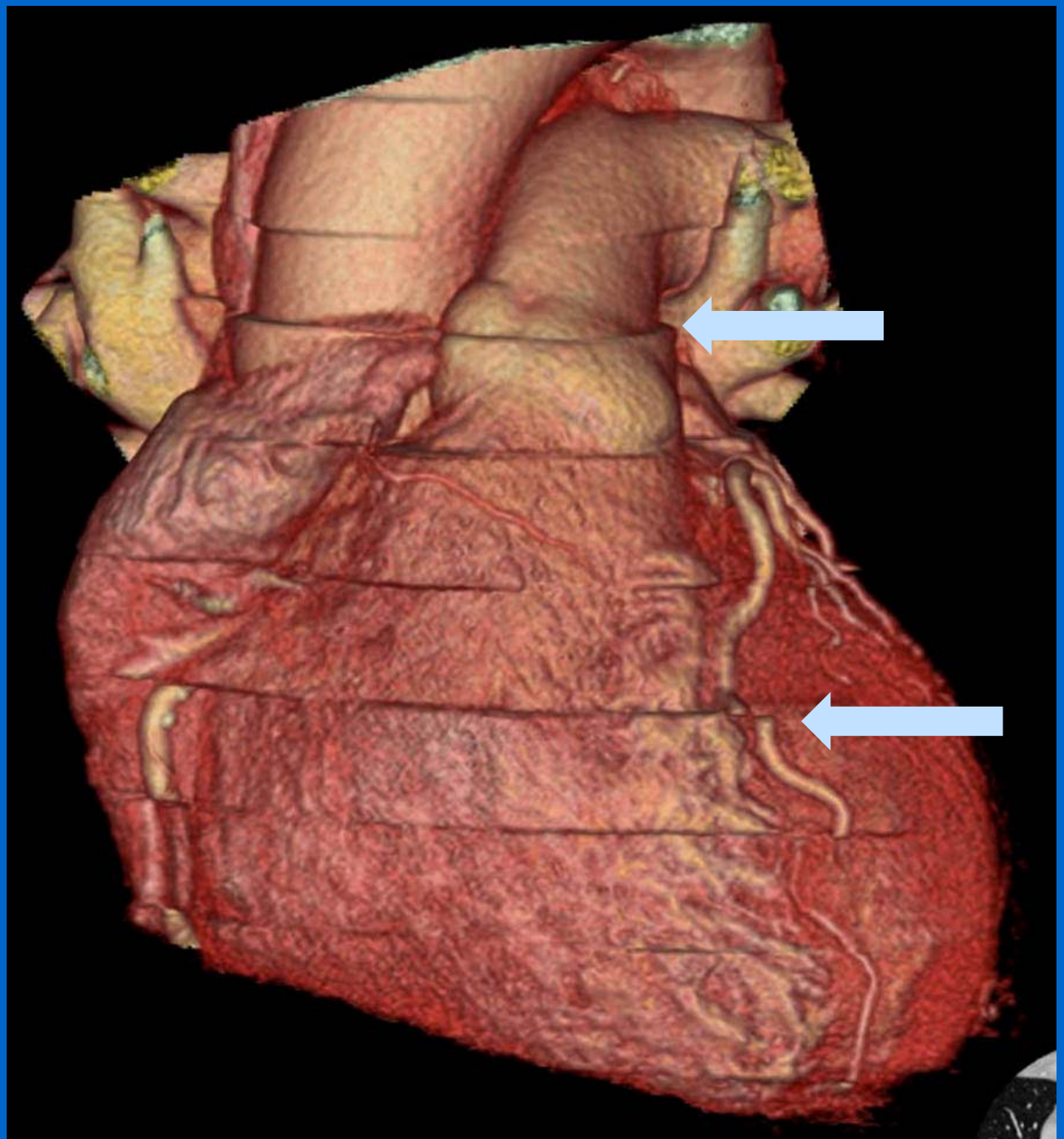


Volume coverage

- Motion needs to be repeatable – regular heart rate
  - reduce potential for mis-registration

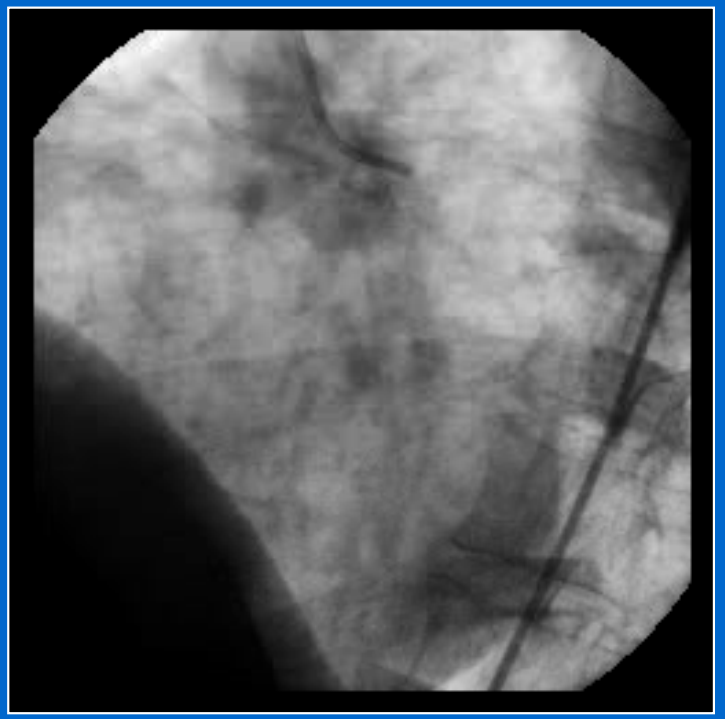


Challenges in imaging the heart - volume coverage



The heart

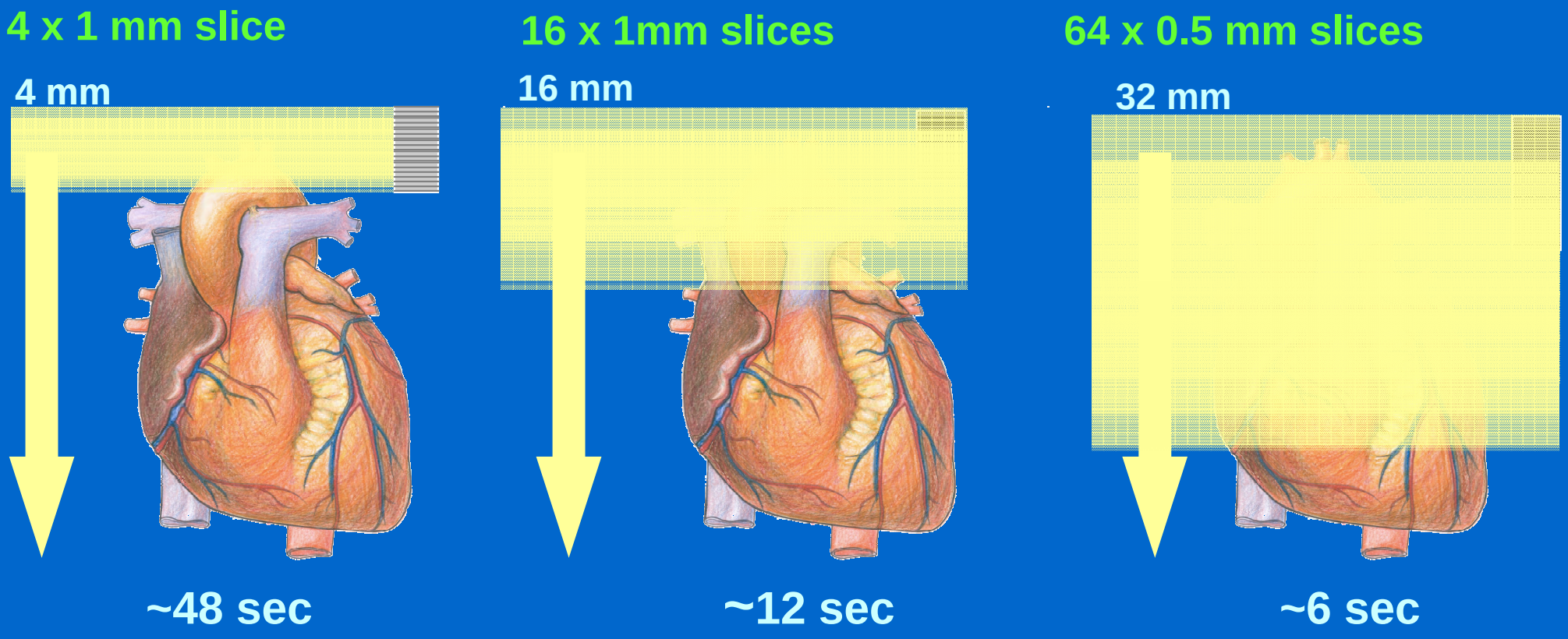
- Heart rate
  - Average 60 bpm (1 beat per sec) (40 bpm – 120 bpm)
  - Vessels move at different speeds
- Not necessarily regular
  - Rate increases with breath hold
  - Arrhythmia, ectopic beats



Conventional angiography

Volume coverage – helical scan

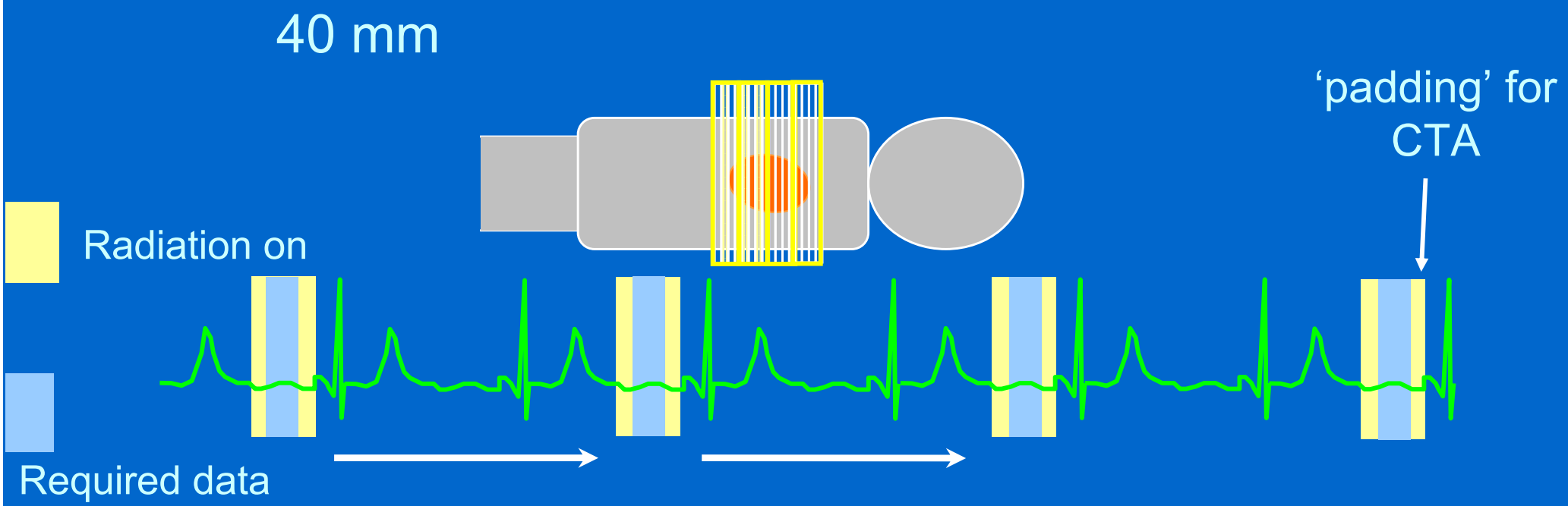
- Breath hold issues with 4 slice scanner
- Time to cover heart (number of beats) decreases with larger detector array



0.5 s rotation, 0.33 pitch

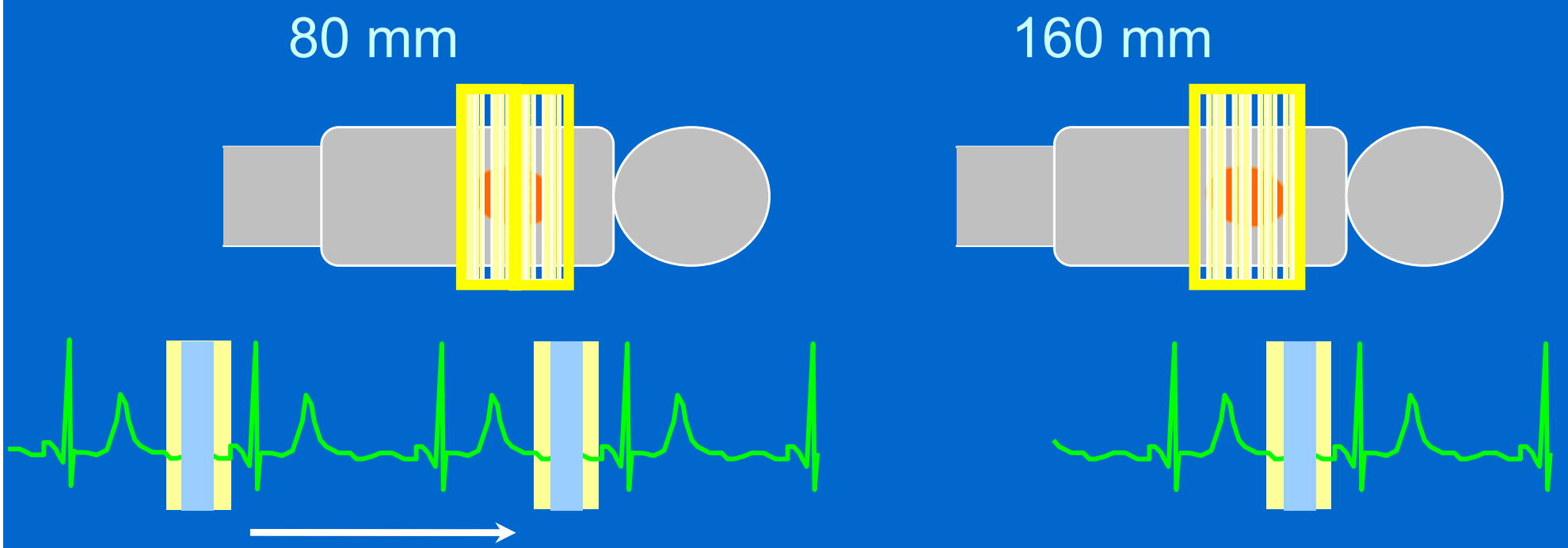
Volume coverage – axial scan

- Number of heart beats depends on detector coverage



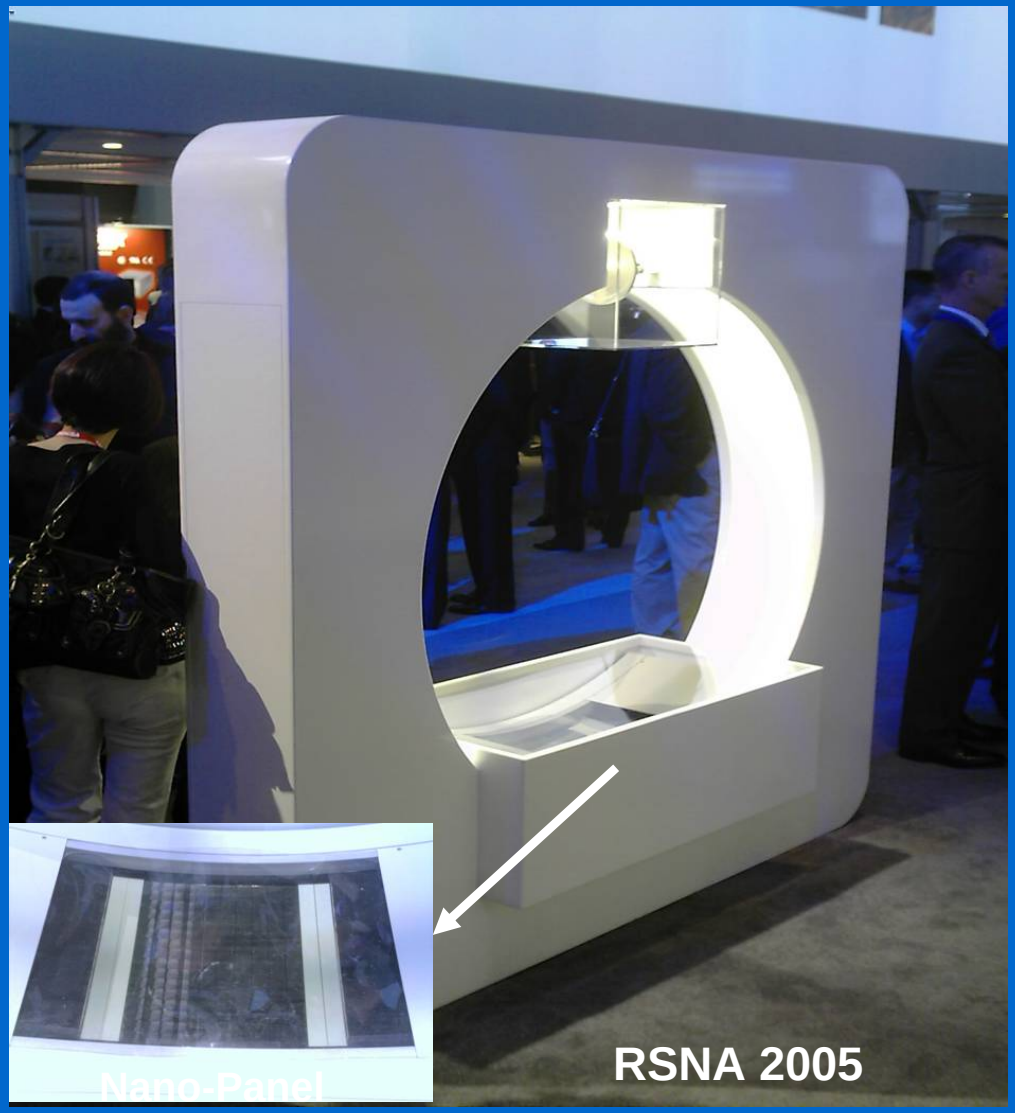
Volume coverage – axial scan

- Number of beats decreases with larger detector array



Philips Brilliance iCT

8 cm coverage

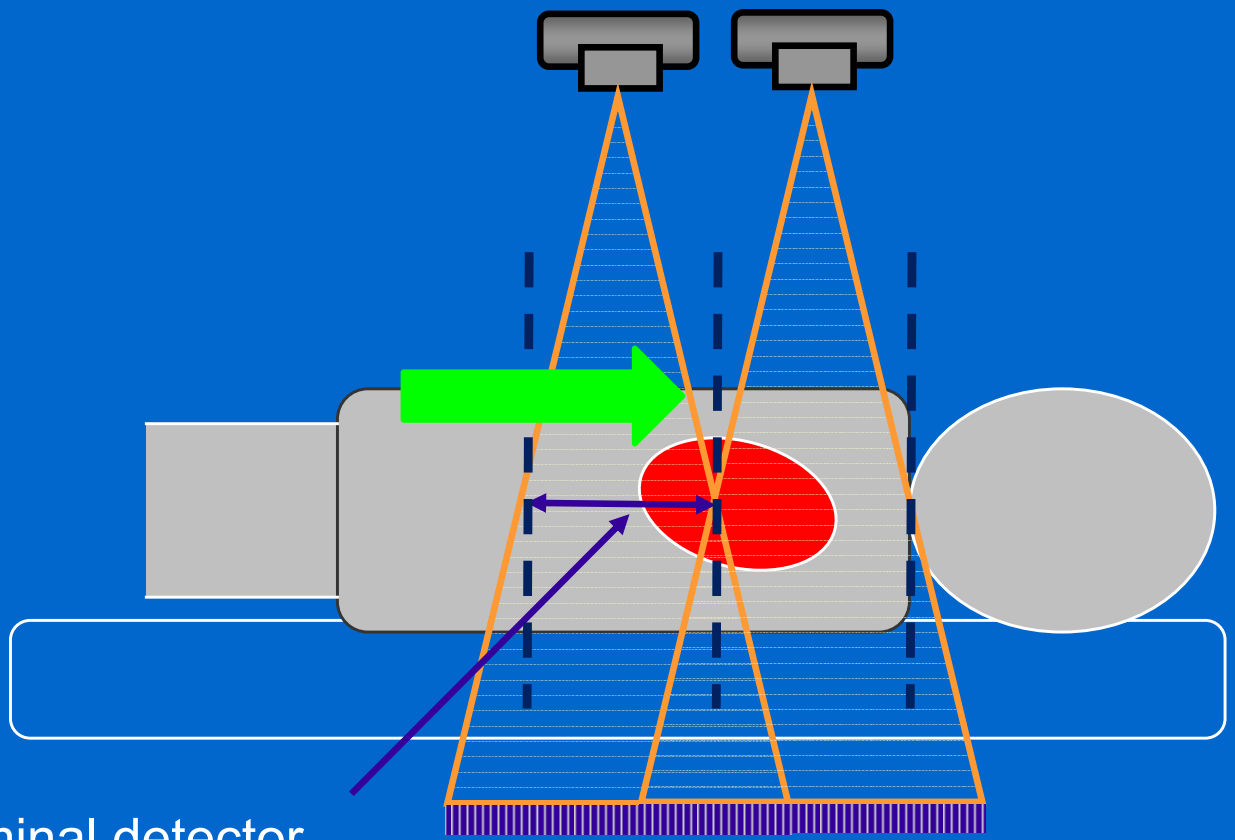


128 x 0.6 mm

Courtesy of Philips

Volume coverage – overlap

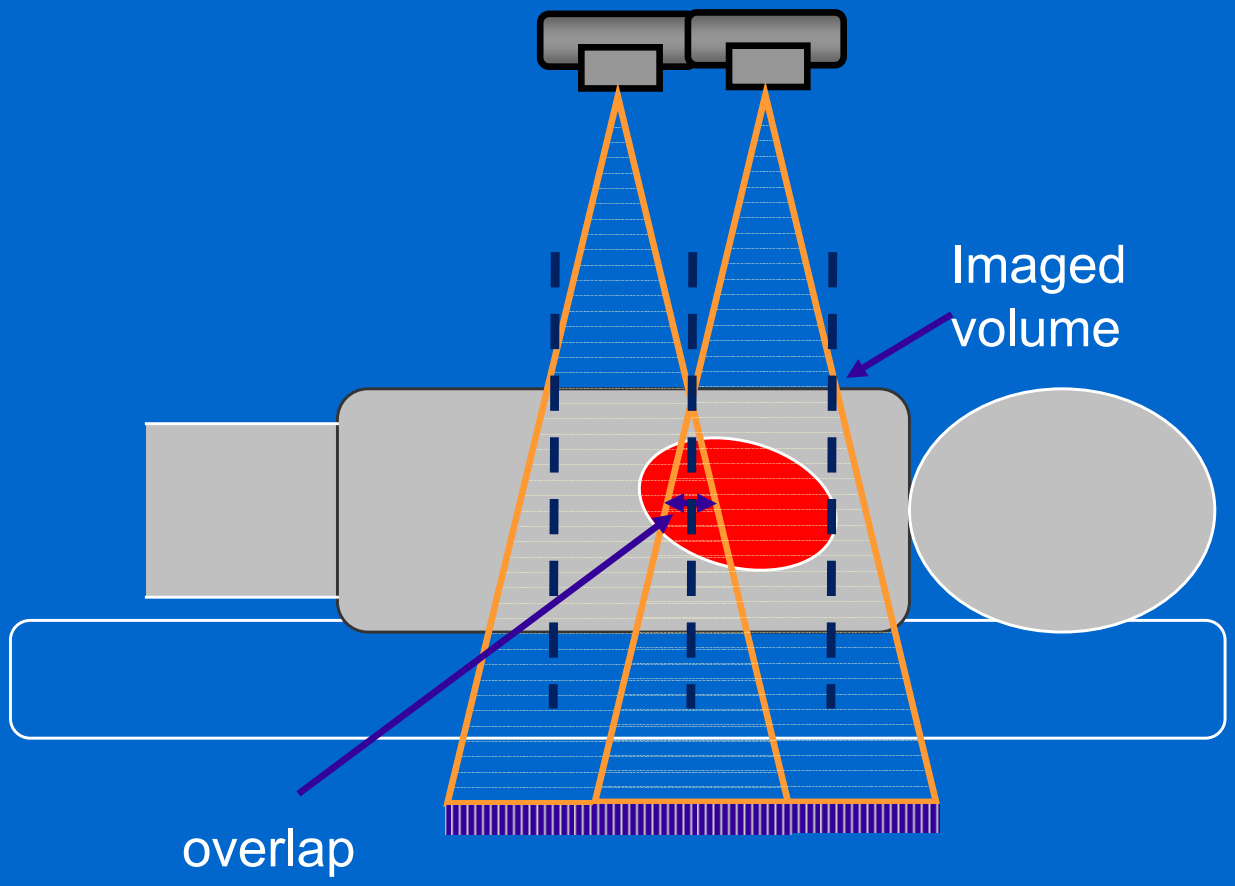
- Small overlap with larger (>40 mm) detector coverage



Nominal detector array width defined at iso-centre

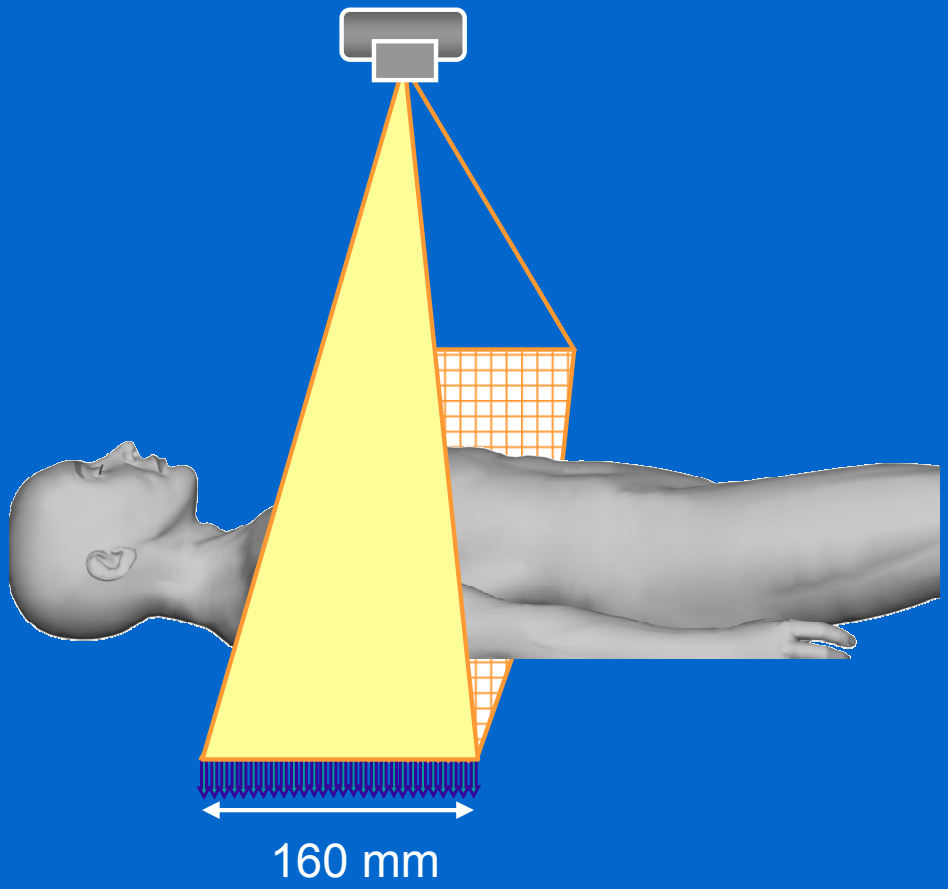
Volume coverage – overlap

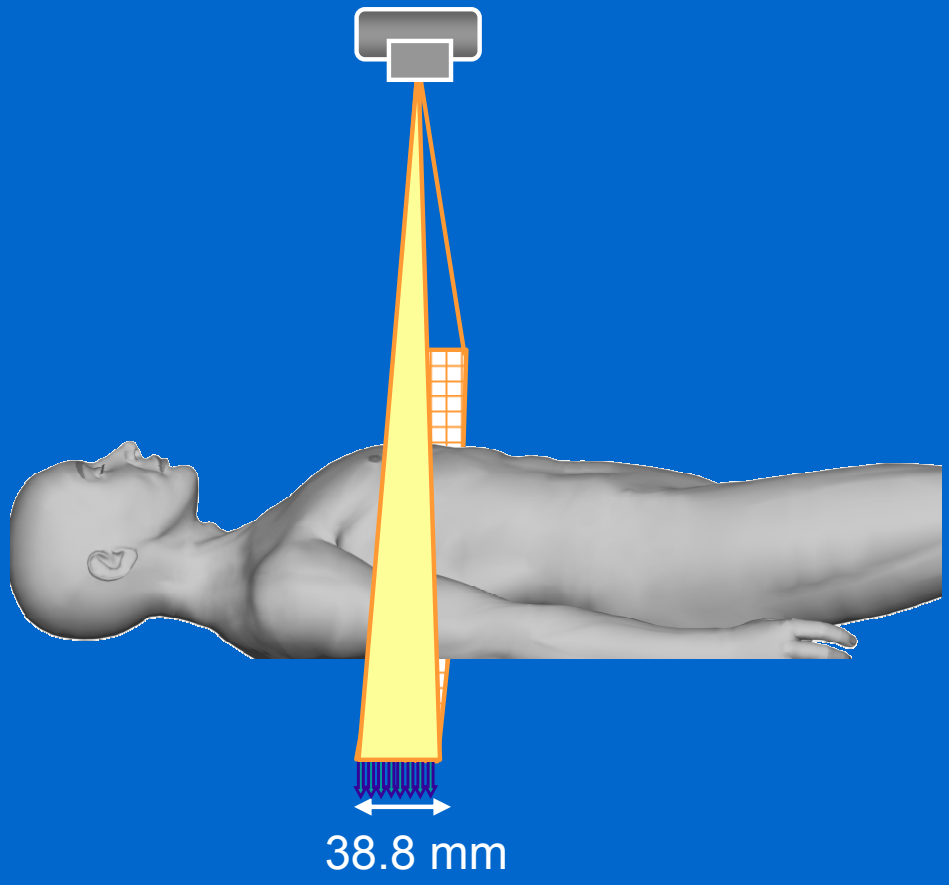
- Small overlap with larger (>40 mm) detector coverage



Volume coverage – single beat

- Single heart beat coverage achieved in two ways:
  - full organ coverage (axial)
    Toshiba Aquilion One
  - high helical pitch
    Siemens Flash





Volume coverage – single beat

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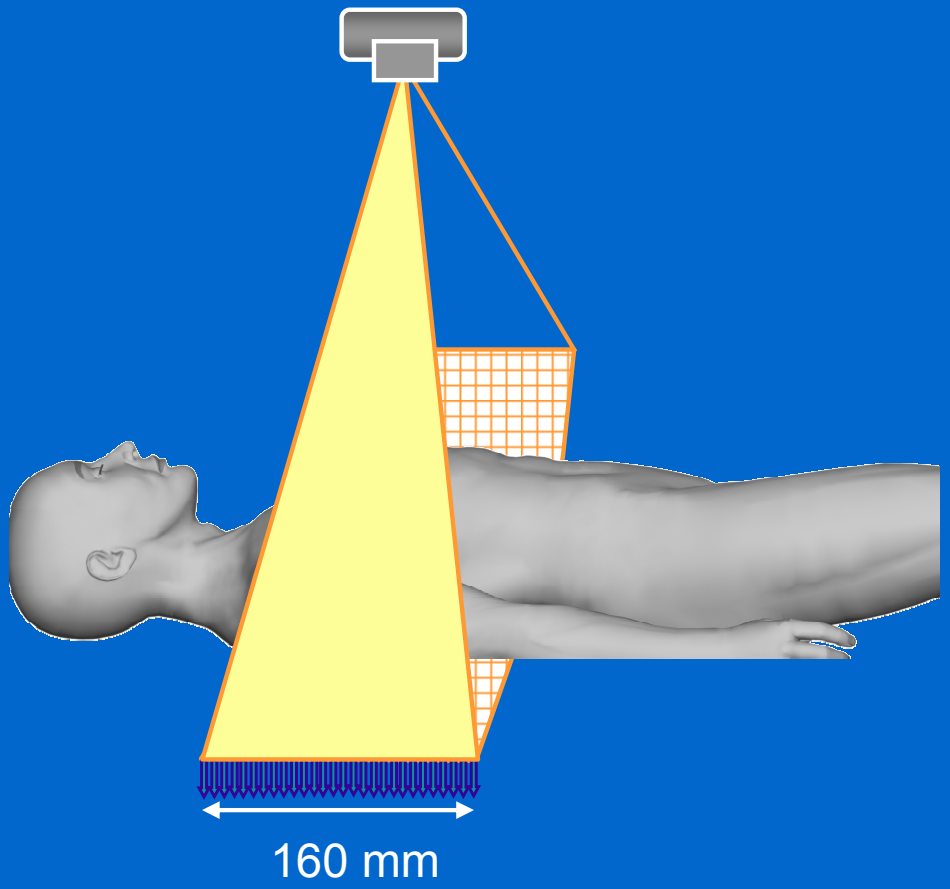
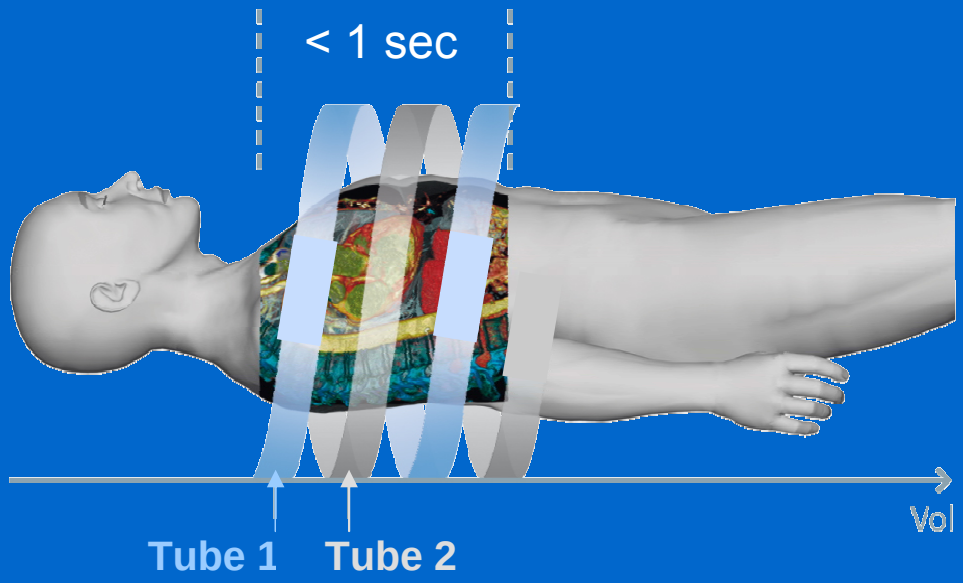
  - high helical pitch
    Siemens Flash

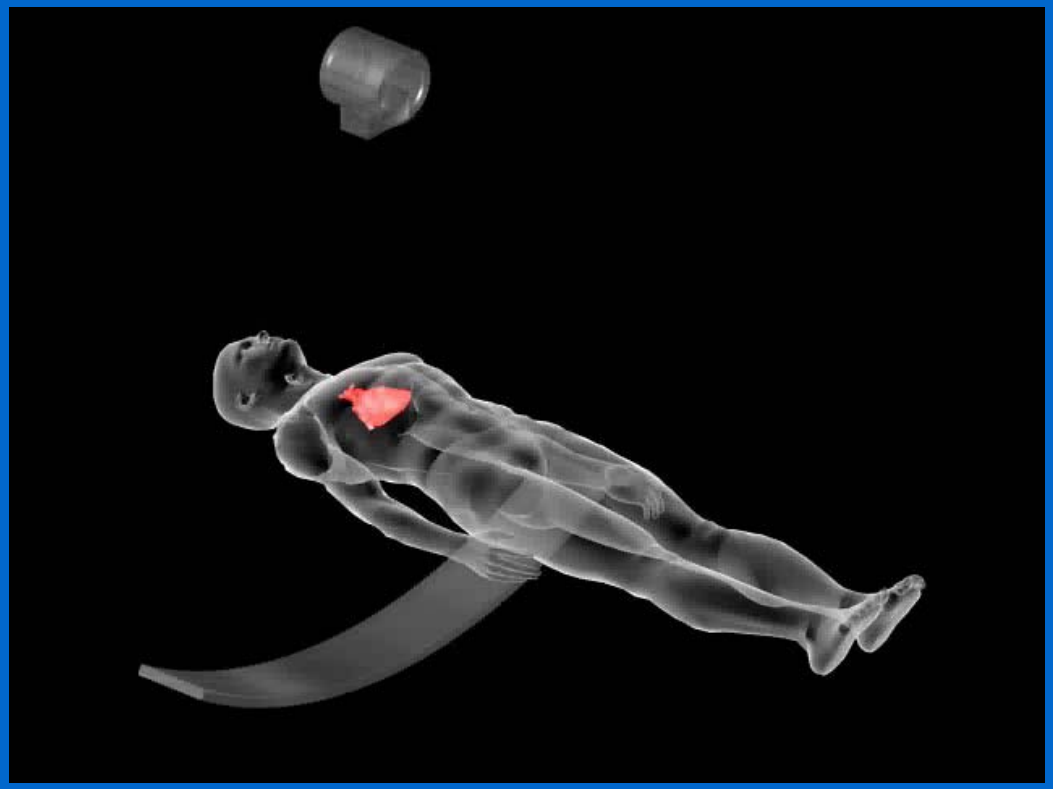


Dual source
Flash mode (Pitch 3.4)



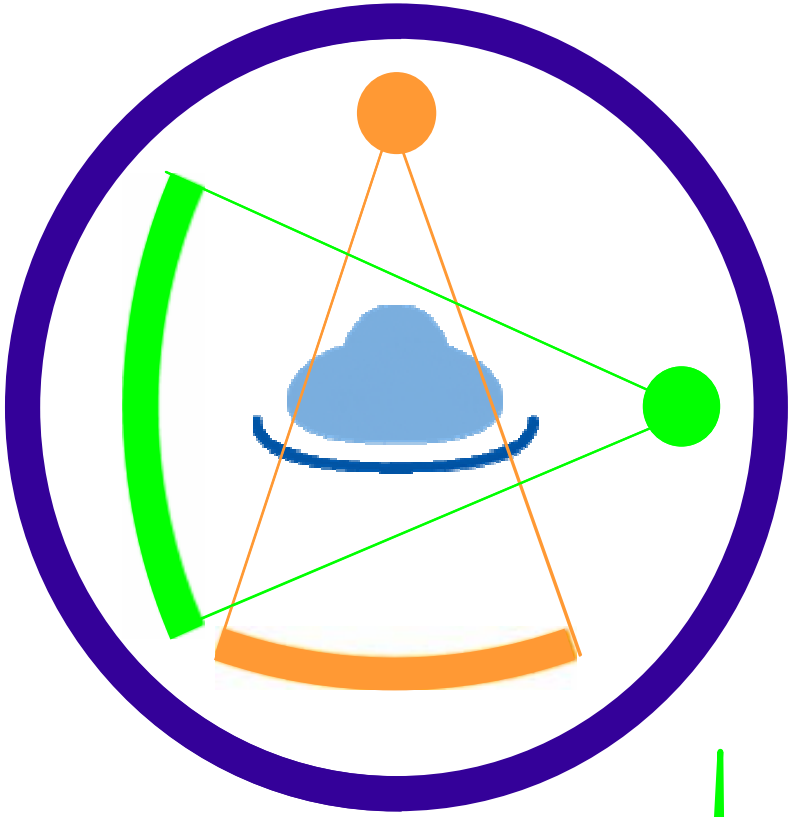
Volume coverage – single beat

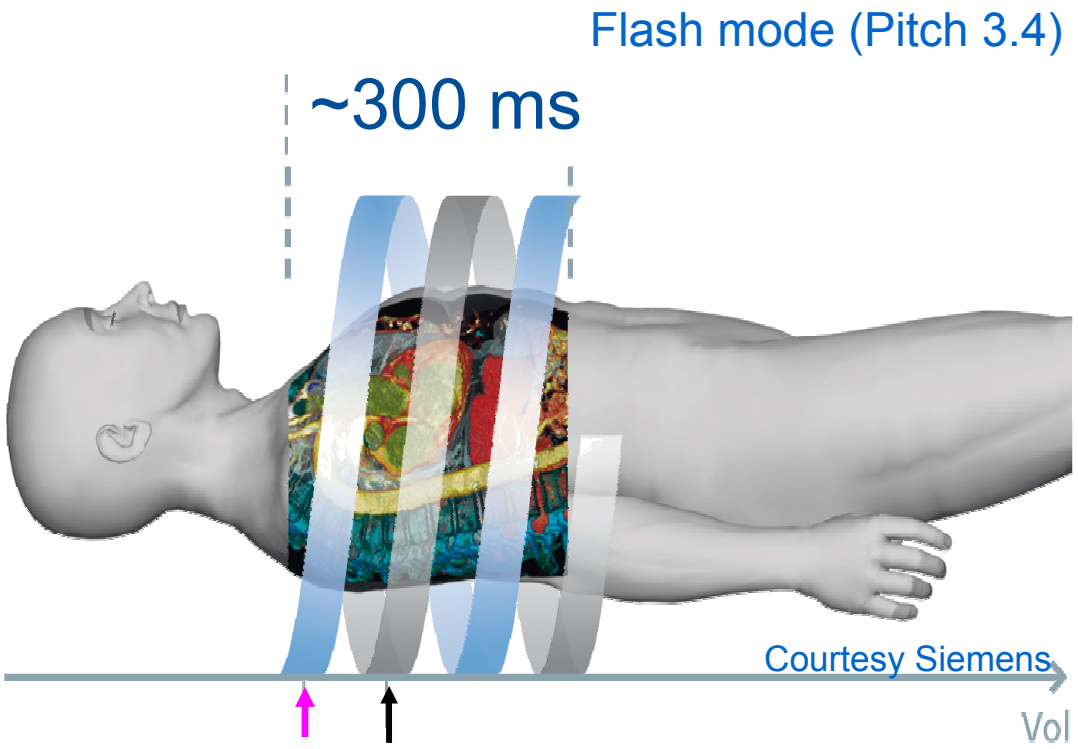
- Toshiba Aquilion One
  - 320 x 0.5 mm = 160 mm coverage (axial)
  - (Helical up to 80 mm, but not needed for cardiac)

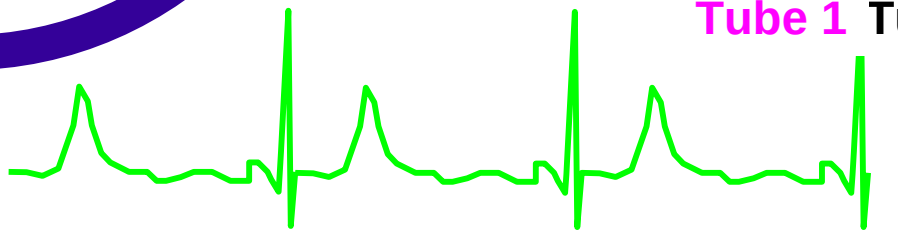


Volume coverage – single beat high pitch

- Siemens Definition Flash
  - 2 tubes, data treated separately, one heart beat
  - ‘Prospectively triggered’ helical

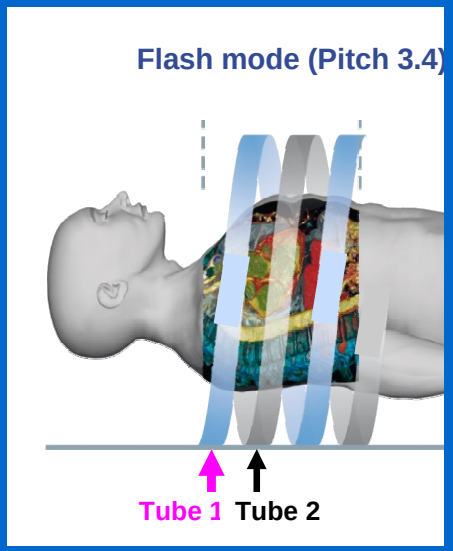


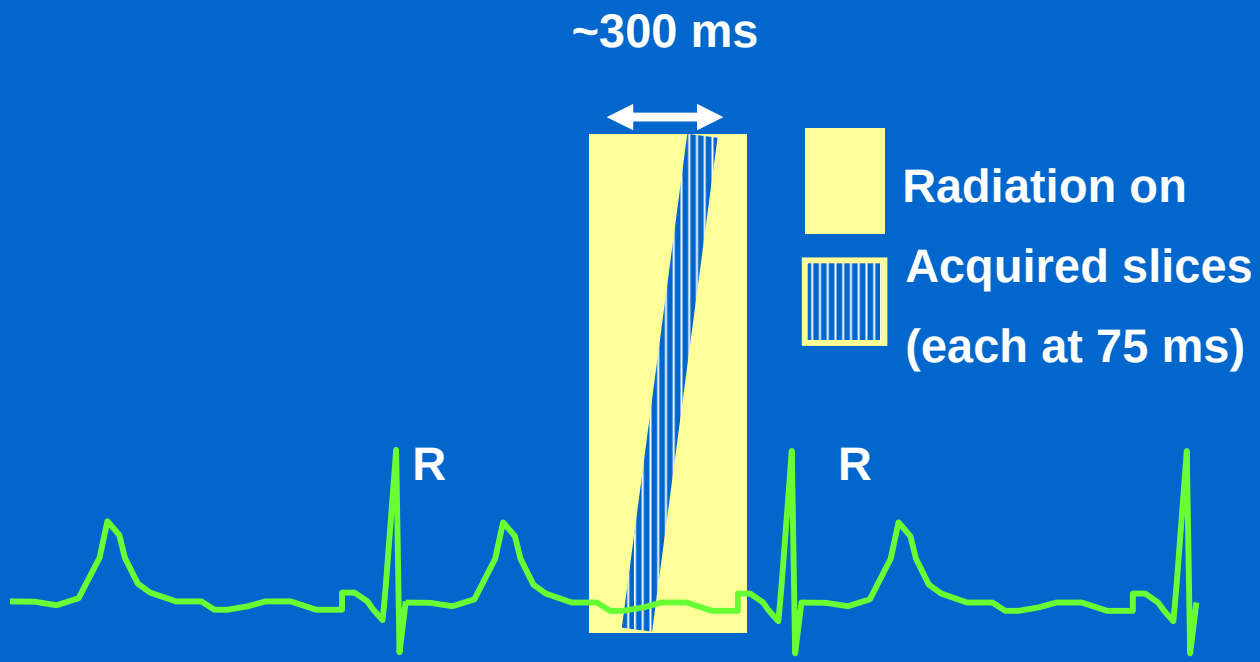




Volume coverage – single beat high pitch

- Siemens Definition Flash
  - high pitch helical (pitch 3.4), each image 75 ms
  - phase difference between first and last ~ 300 ms
  - only suitable for regular heart rates < 65 bpm





Cardiac CT

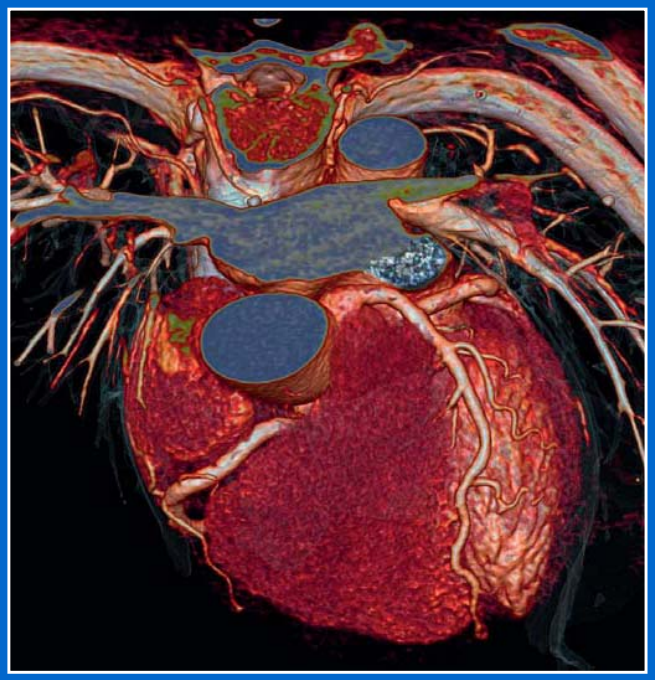
- Improved temporal resolution
  - Fast scan speeds, multi-sector reconstruction, dual tube
- Fast volume coverage
  - Larger detector arrays
  - High pitch scanning (‘Flash’)

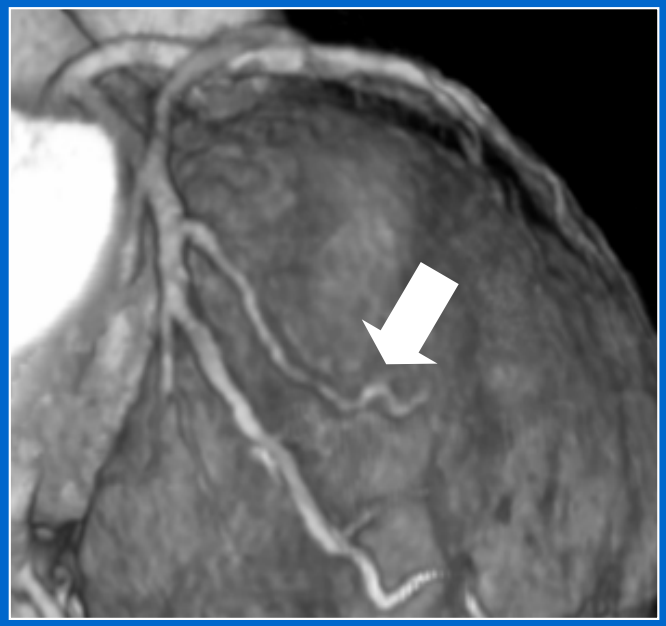
Technical Aspects of Cardiac CT

- Introduction
- Multi-slice CT (MSCT)
- Scanning the heart with MSCT
- Improving
  - Temporal resolution
  - Volume coverage
  - Spatial resolution

Image quality issues - spatial resolution

- Ideally isotropic spatial resolution < 1 mm
  - equal resolution in all planes





Voxel size: x= y = z

MSCT technology – spatial resolution

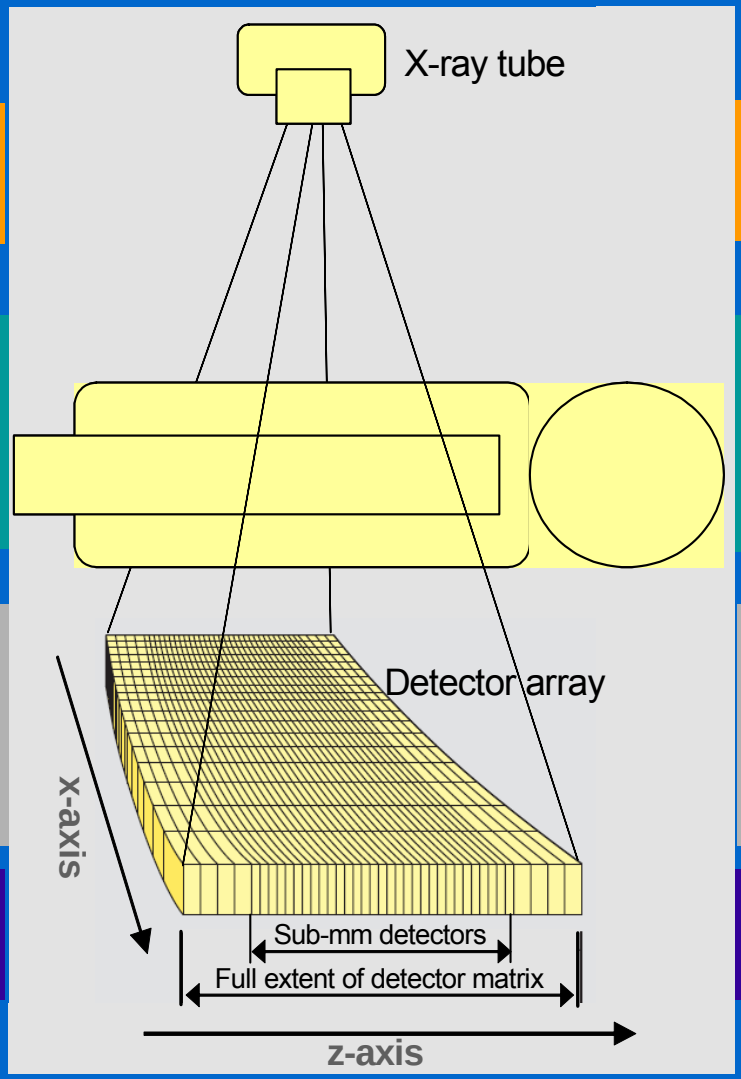
Scan plane

Focal spot size

Detector size
~ 0.5 mm

Number of samples

Recon algorithm



Z-axis

Focal spot size

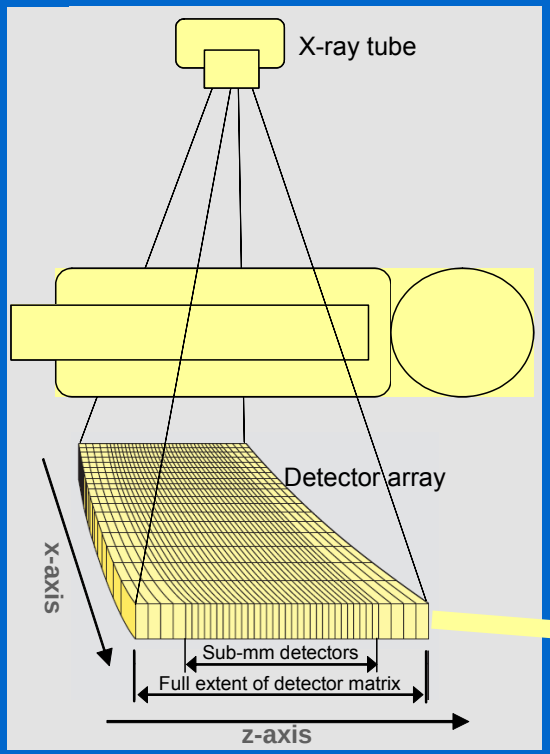
Detector size (slice)
~ 0.5 mm

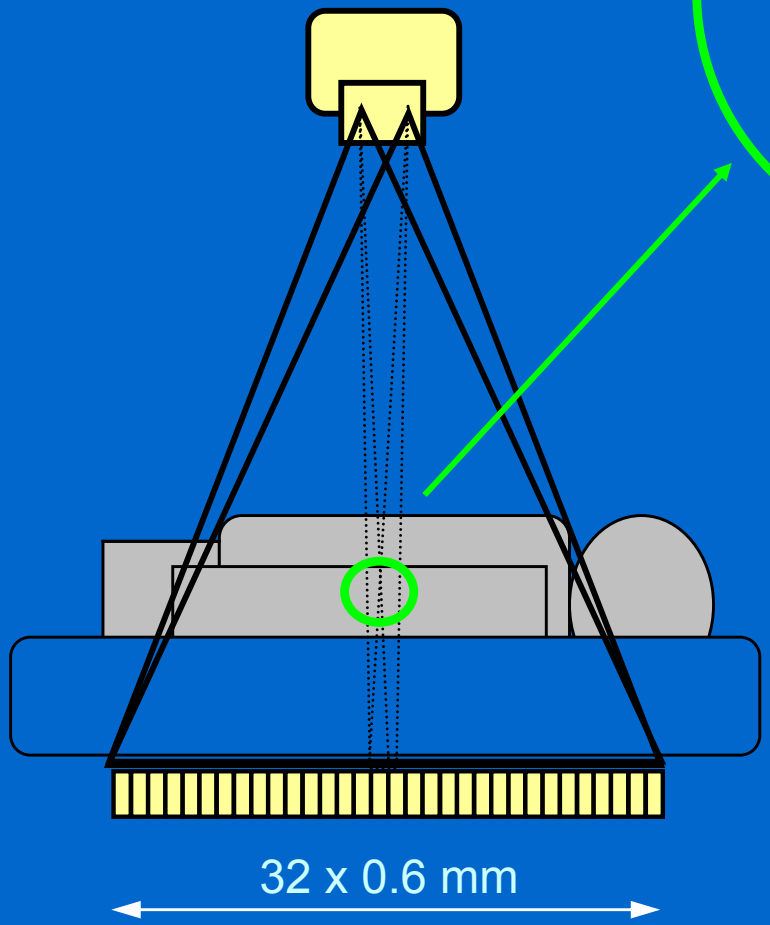
Dynamic focal spot –
doubles samples

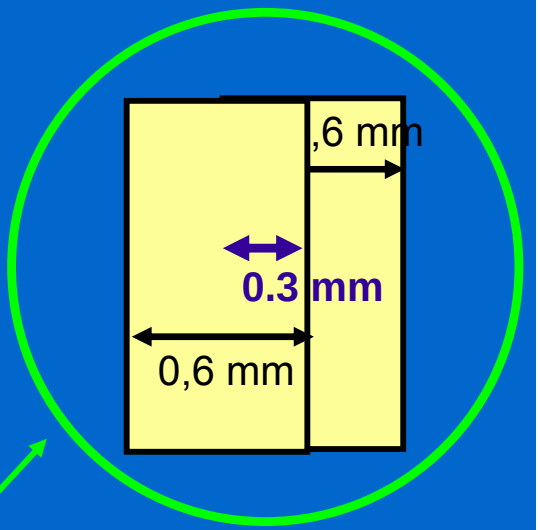
Recon techniques

Double sampling – Z-axis

- 32 detectors – 64 ‘slices’
  - Double sampling in z-axis
  - Improved resolution in 3-D reconstructions





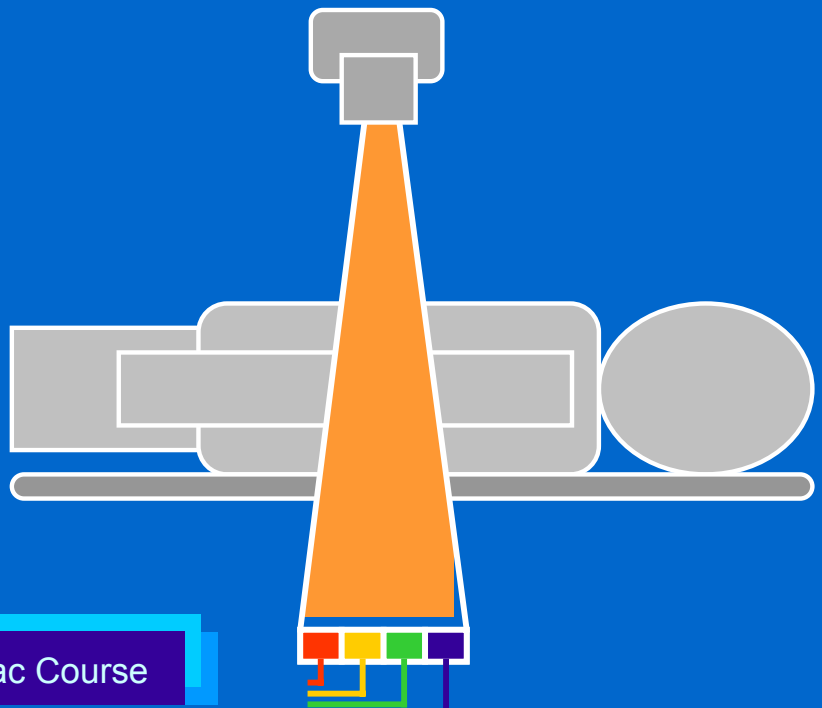


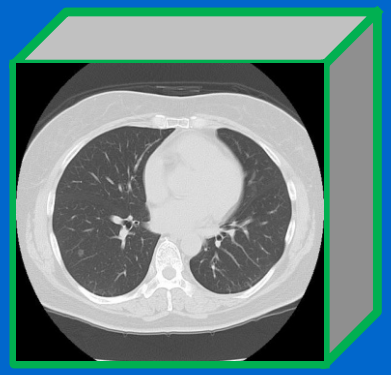
Sampling distance 0.3 mm

32 Slice Detector - 64 Slice DAS

Spatial resolution – Z-axis

- Minimum slice thickness - detector acquisition width
- Acquire thick – recon thick
  - eg 4 x 5mm will produce >= 5 mm slices
- Acquire thin – recon thick or thin
  - eg 8 x 2.5 mm will give 2.5 mm or 5 mm slices





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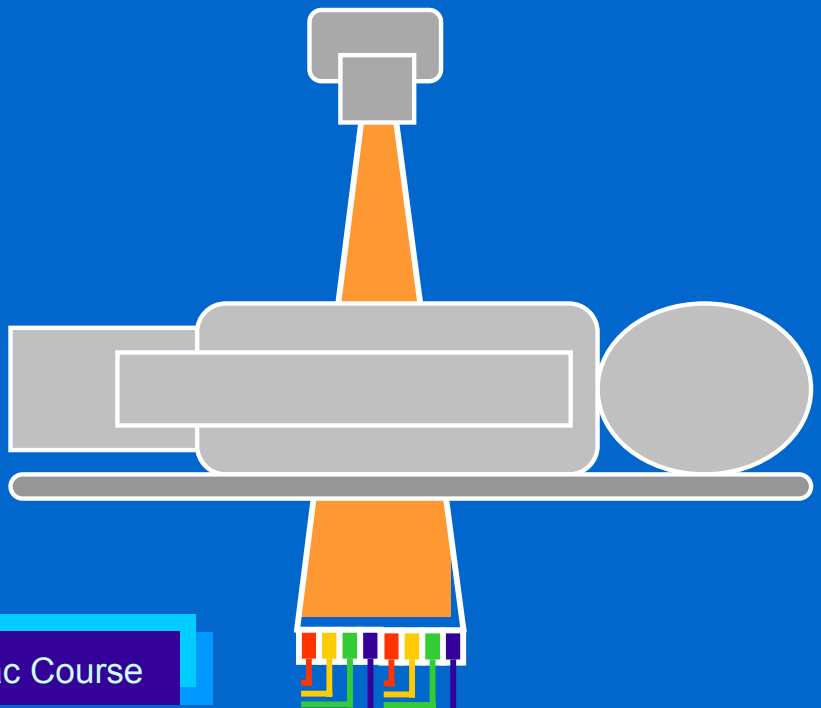
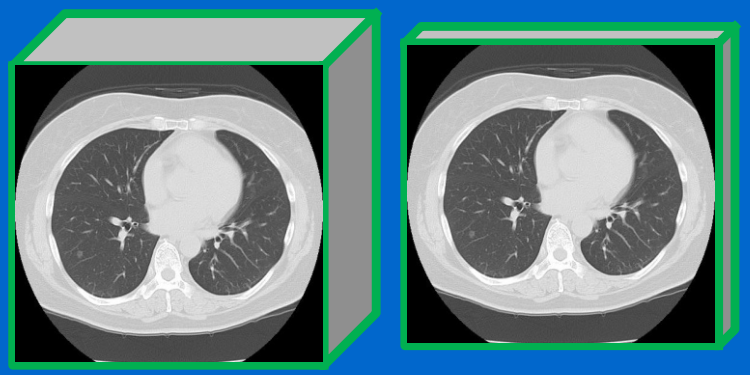
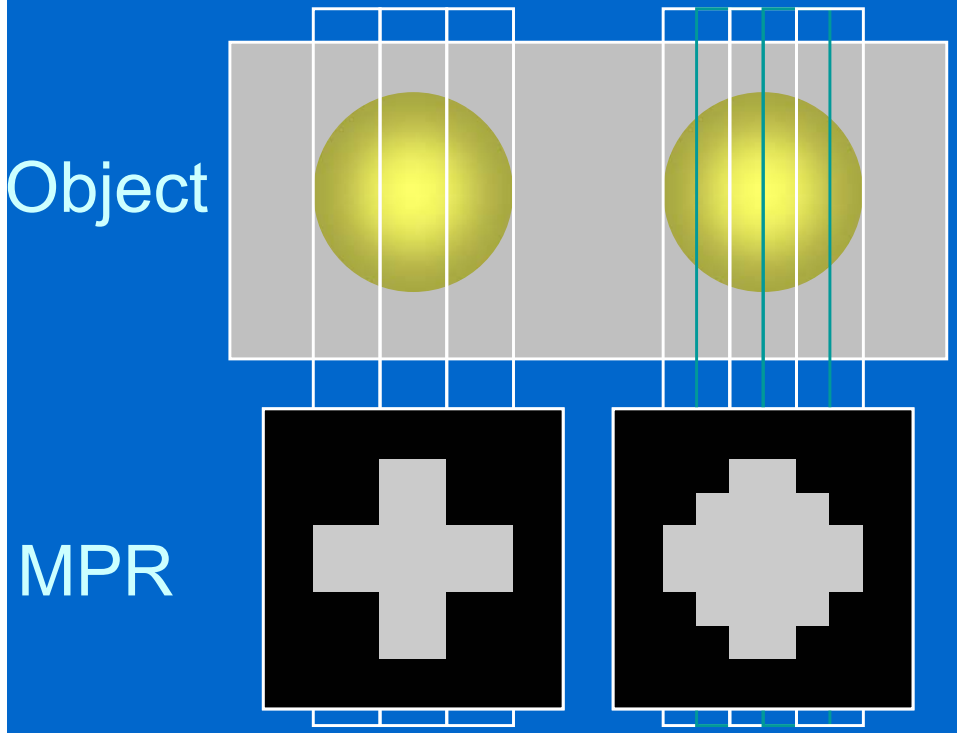




Applies in axial and helical

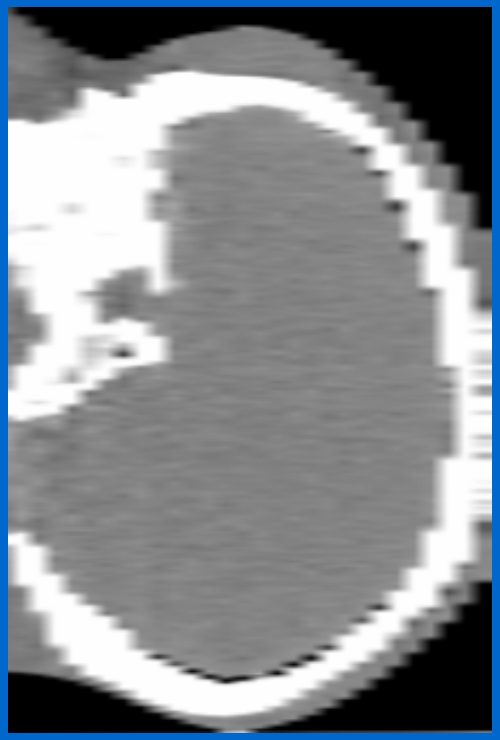
Spatial resolution – Z-axis

- Helical scanning - ‘Overlapping’ reconstructions
  - better z-axis resolution in 3-D reconstructions

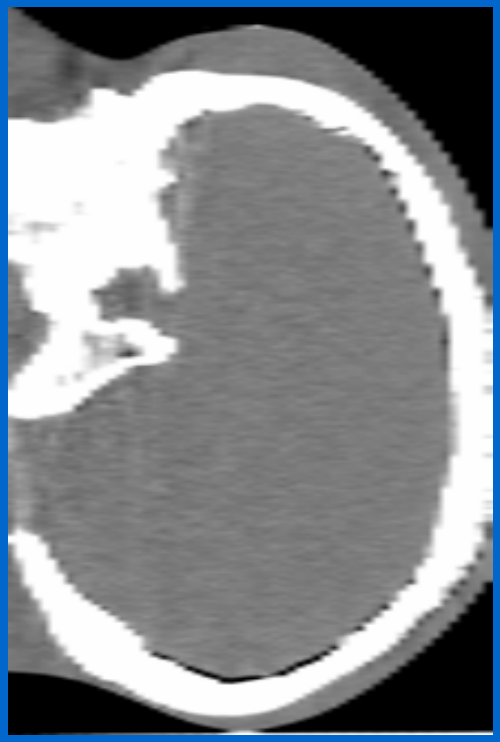


contiguous

Helical, overlapping



MPR of skull from 5mm slices

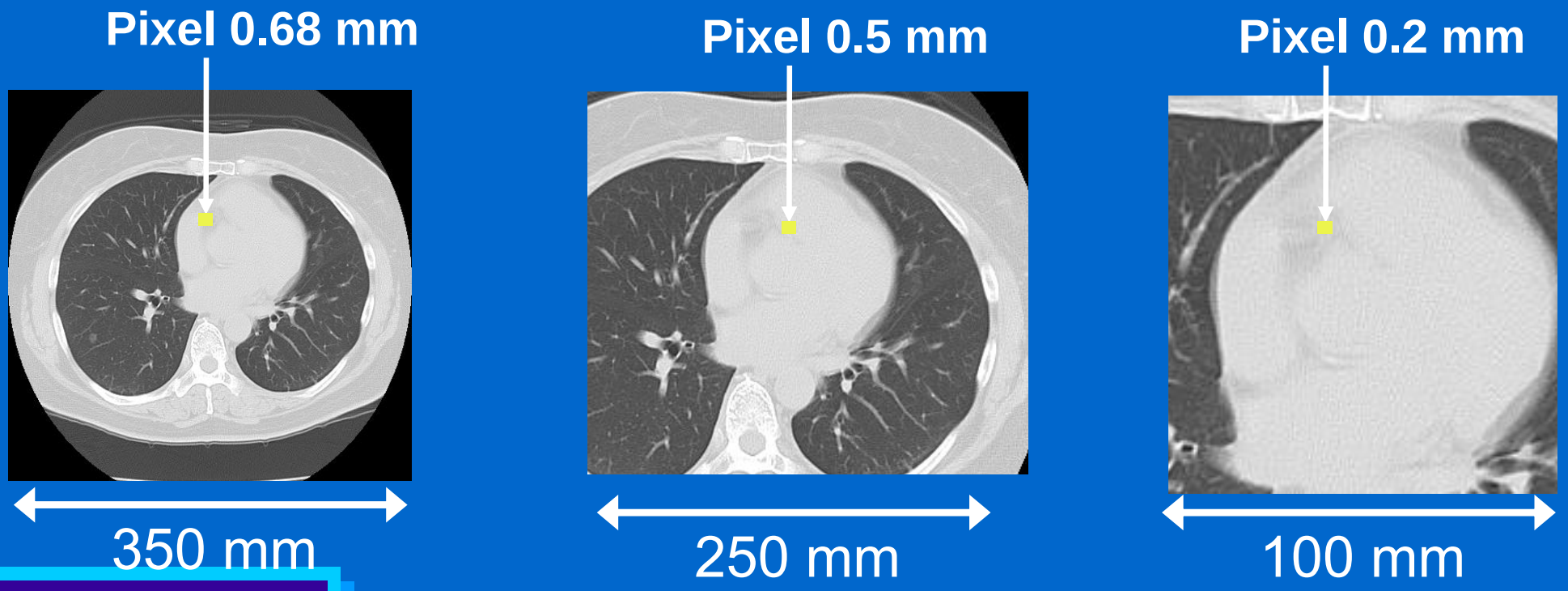


MPR of skull from 5mm slices recon every 2.5 mm

Spatial resolution – display

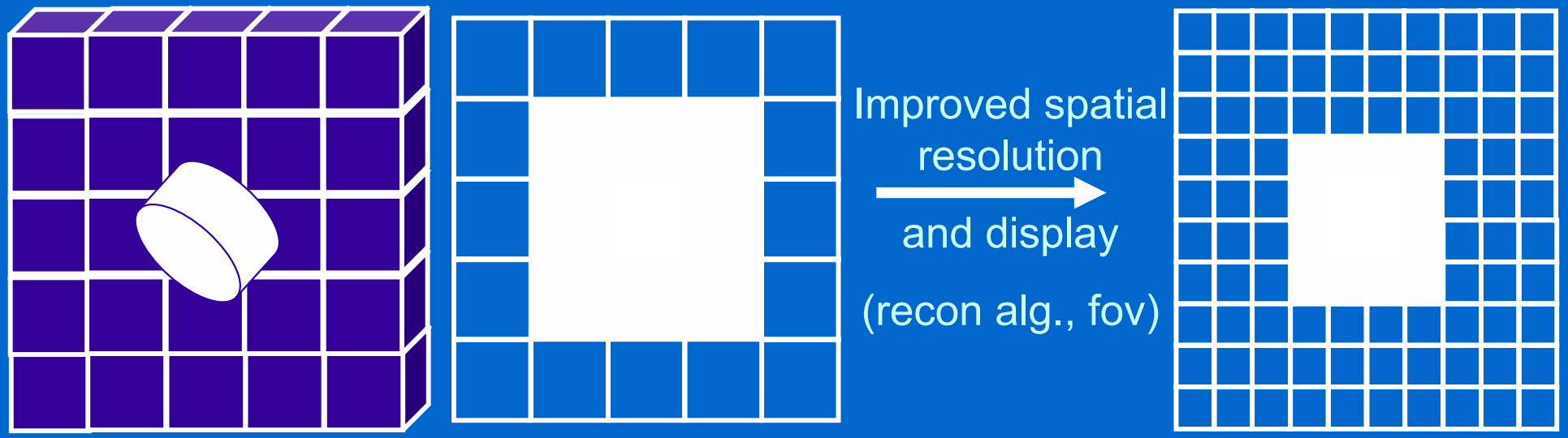
- Optimise pixel size (pixel size = fov / matrix)

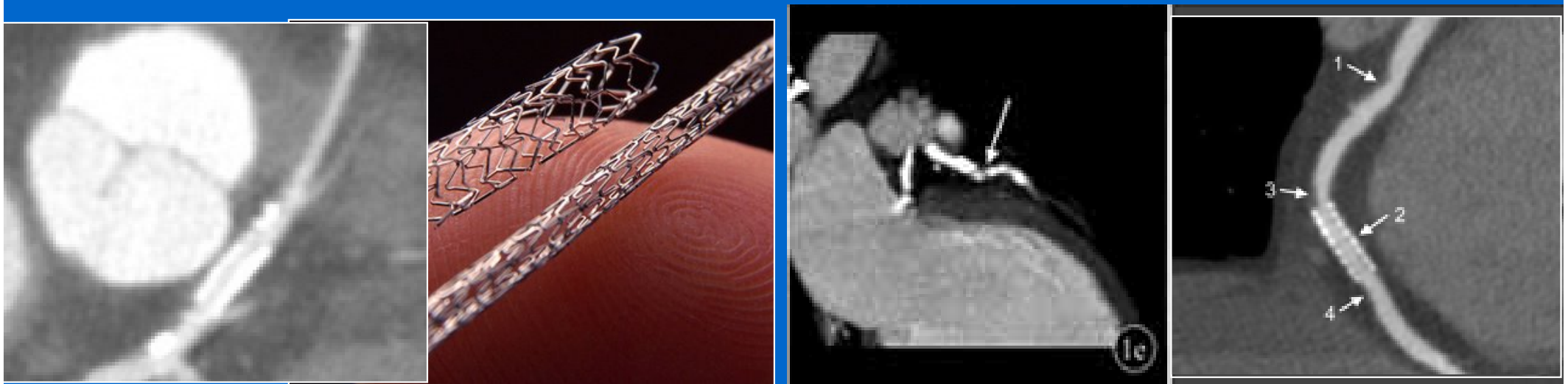
Fov (mm)		Pixel size (mm)
350	350 / 512 =	0.68
250	250 / 512 =	0.5
100		0.2



Blooming Artefact

- Blooming artefact – calcium/stent obscures vessel
- Improvement with better spatial resolution





Cardiac CT - scan modes

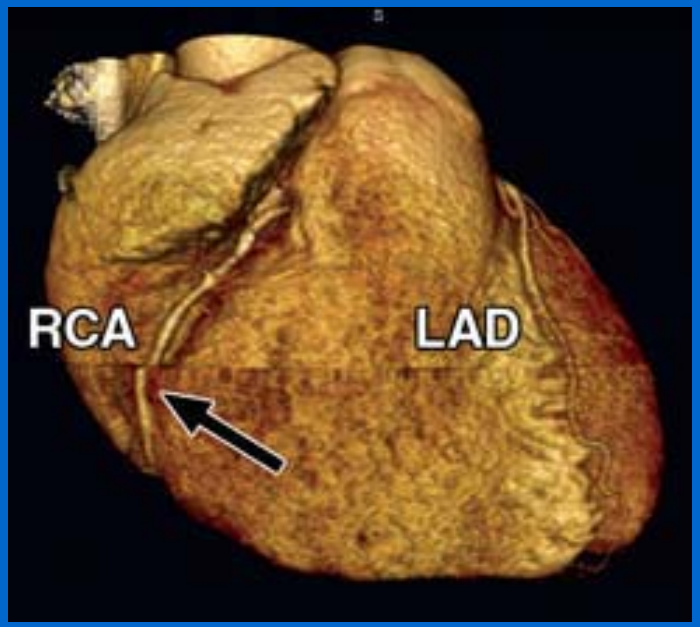
Scanning mode	Cardiac scanning mode	Features
Axial / Sequence	Prospective triggering (gating)	Padding
Helical	Retrospective gating	ECG modulation
Helical (Flash)	Prospective triggering	(High pitch)

Cardiac CT

- Improved temporal resolution
  - Fast scan speeds, multi-sector reconstruction, dual tube
- Fast volume coverage
  - Larger detector arrays
  - High pitch scanning (‘Flash’)
- Spatial resolution
  - Acquired image width
  - Fov
  - Overlapping recons
  - Improved bloomng artefacts

What do you need on a cardiac scanner?

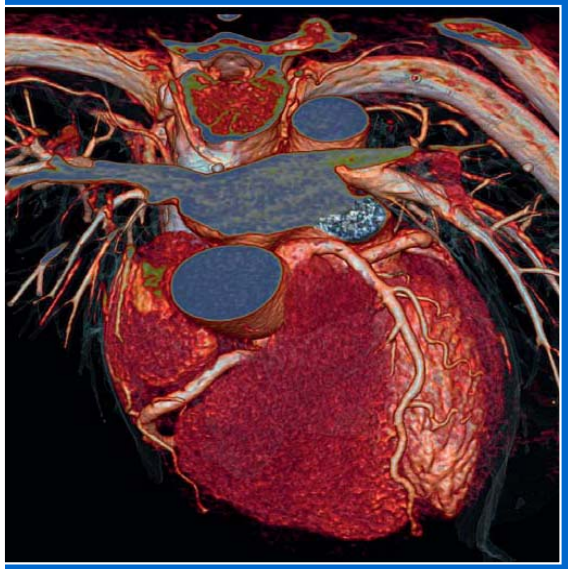
- Good temporal resolution
  - to ‘freeze’ cardiac motion
- Fast volume coverage
  - to minimise breathing and mis-registration artefacts
  - to minimise chance of ectopic beats

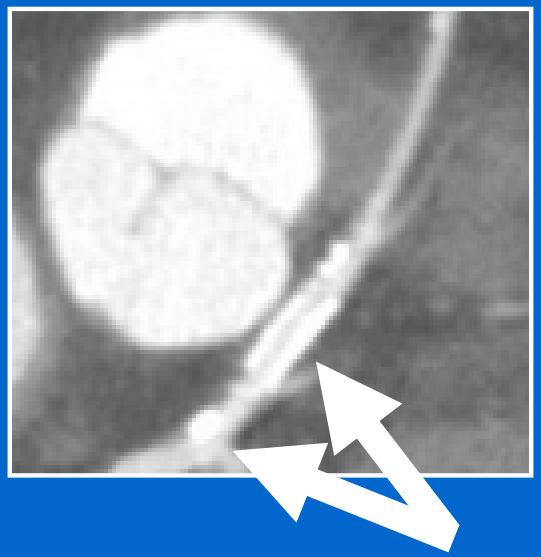


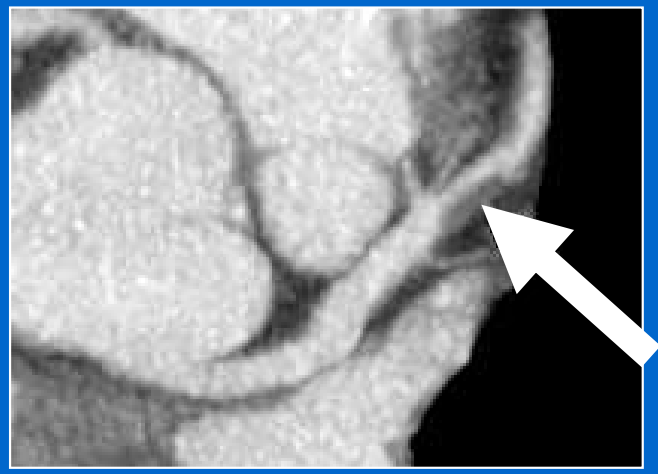

Shutter speed: 1/125 second

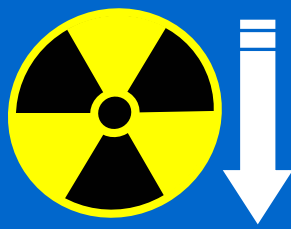
What do you need on a cardiac scanner?

- Good 3-D high contrast spatial resolution
  - to image narrow, tortuous arteries
- Reduced artefacts from calcium and stents
- High dose efficiency
  - for low dose scans with good image quality









Teaching material

- This talk and others
  - www.impactscan.org
- CTISUS.org

Report on Cardiac CT

Market review: Advanced CT scanners for coronary angiography

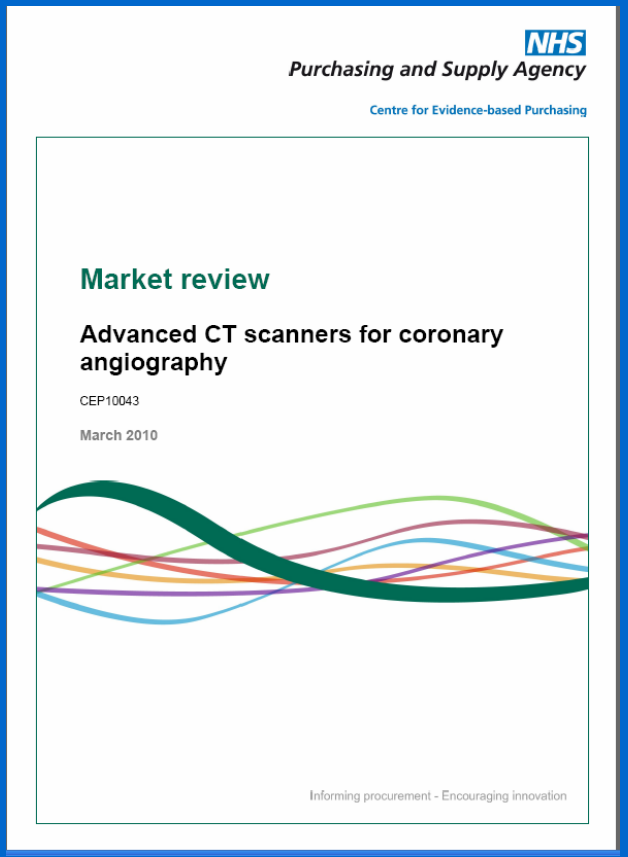
CEP10043, March 2010

http://www.impactscan.org/reports/CEP10043.htm

Advanced CT scanners for coronary angiography. CEP10043, Mar-10

This market review is intended to help prospective purchasers make informed choices and achieve best value from investment in high-end CT systems for Coronary CT Angiography applications. It should be read in conjunction with CEP's buyer's guide to multi-slice CT scanners (CEP08007) and the associated comparative specification reports (CEP08027, CEP08028).

Electronic access to a PDF version of this report is available from the CEP website.



Technical Aspects of Cardiac CT

S. Edyvean

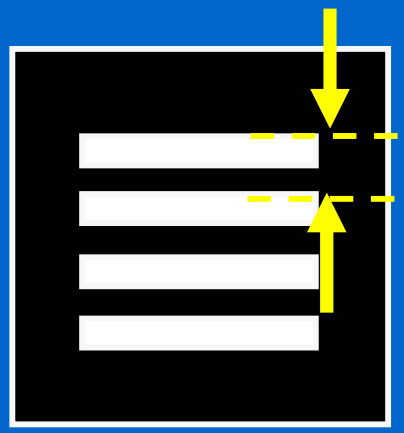
Imaging Performance Assessment of CT Scanners

St. Georges Hospital

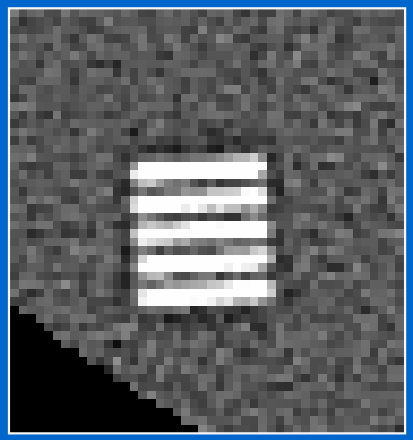
www.impactscan.org

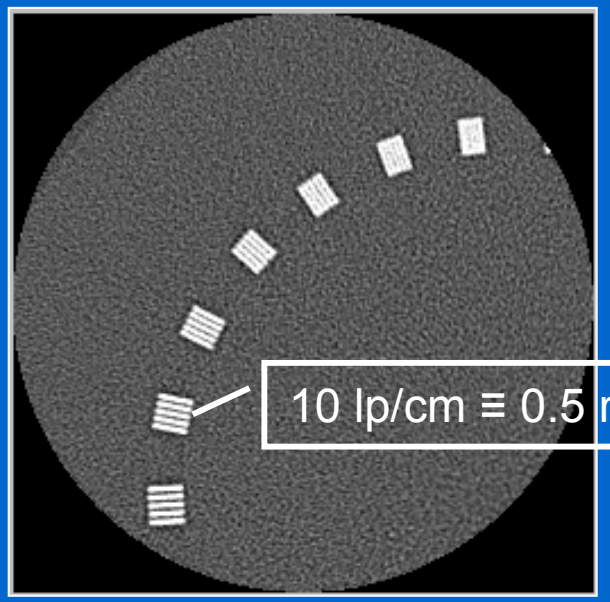
Cardiac scanner spatial resolution

- Scanner limiting spatial resolution:
  - Scan plane: up to 25 lp/cm (0.2 mm)
  - Z-axis: up to 15 lp/cm (0.33 mm)
- Sharpest filters not utilised in cardiac CTA
  - high noise



Line pair (object plus gap)

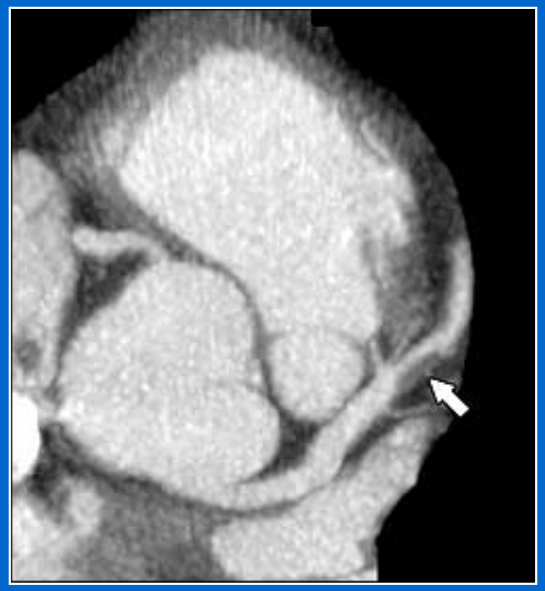


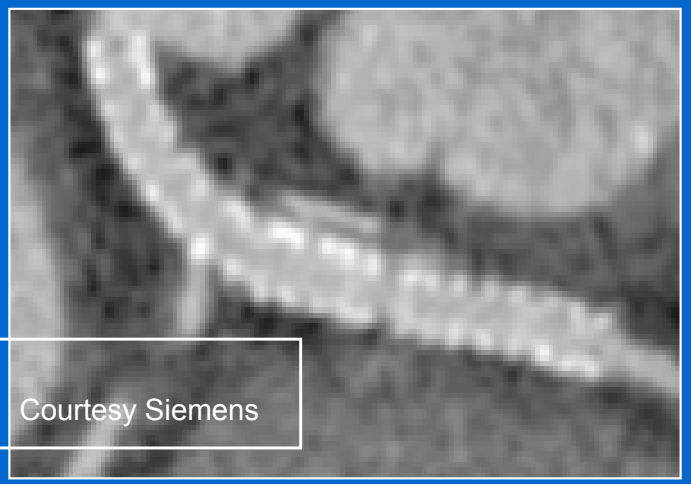


Images from Lin, EC et al; http://emedicine.medscape.com/article/1603072-overview

Cardiac scanner spatial resolution

- For standard cardiac scans
  - Scan plane: ~ 8 lp/cm (0.6 mm)
  - Z-axis: ~ 13 lp/cm (0.4 mm)
- For reduced ‘blooming’ e.g. stents, calcium
  - sharper filters may be used scan plane ~ 10 lp/cm (0.5 mm)





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