Purchasing a cardiac CT scanner: What the radiologist needs to know

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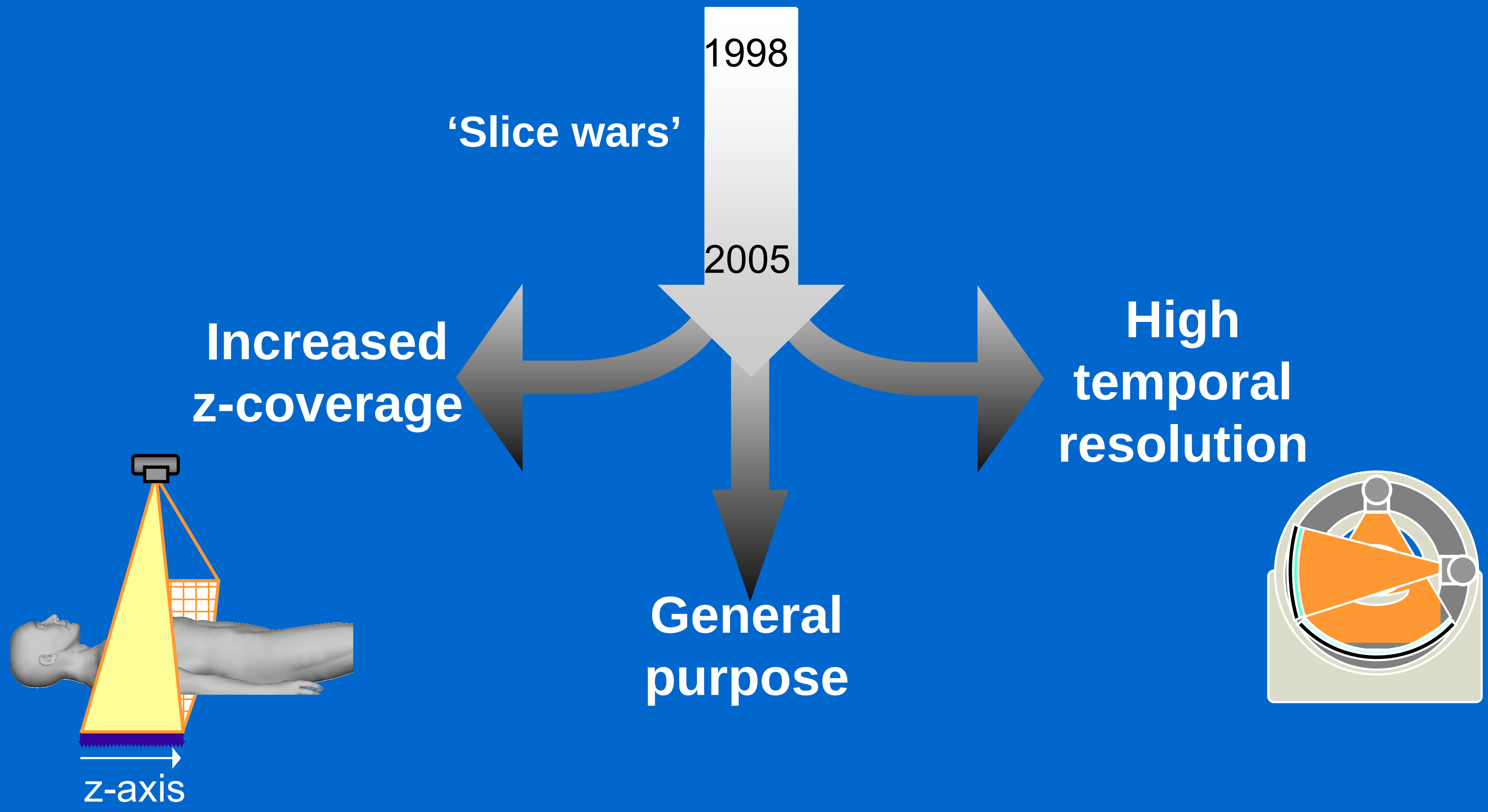
CT scanner development



Which scanner?

Top-of-the range CT scanners

Philips Brilliance iCT

Toshiba Aquilion ONE

Improved performance with 'difficult' patients?

Siemens Definition Flash

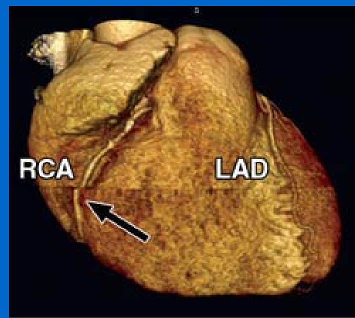
GE Discovery CT750 HD

What do you need on a cardiac scanner?

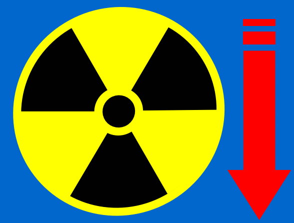
- High temporal resolution to ‘freeze’ cardiac motion

- Good 3-D spatial resolution to image narrow, tortuous arteries

- Fast volume coverage to minimise breathing and misregistration artefacts

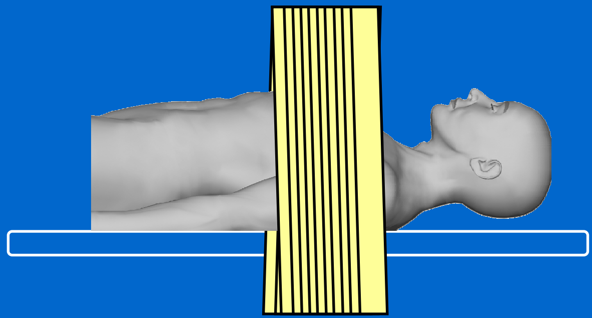


- High dose efficiency for low dose scans

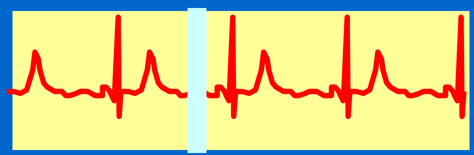


Conventional CCTA scan modes

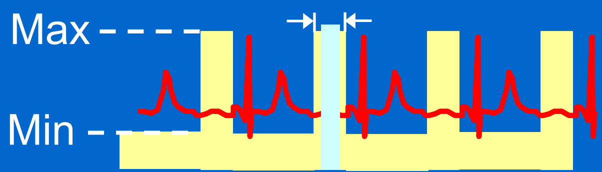
- Helical



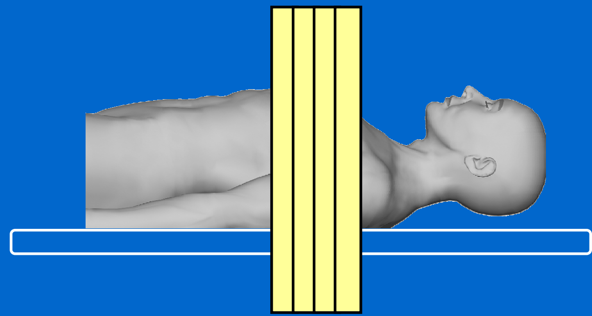
  - constant mA



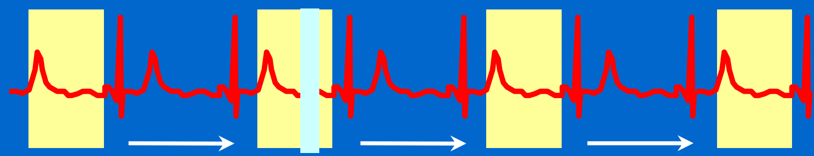
  - mA modulated



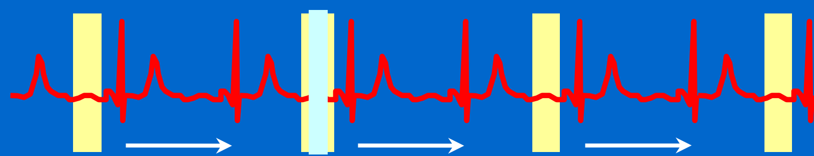
- Axial (Step and Shoot)



  - with 'padding'



  - single phase



Irradiation

Reconstruction

Cardiac CT: technical requirements (CCTA)

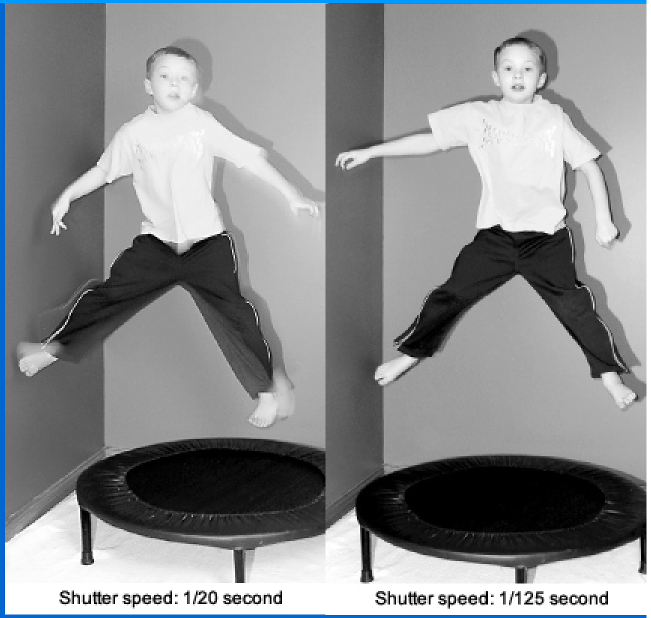
- Temporal resolution
- Spatial resolution
- Volume coverage
- Dose
- Other considerations

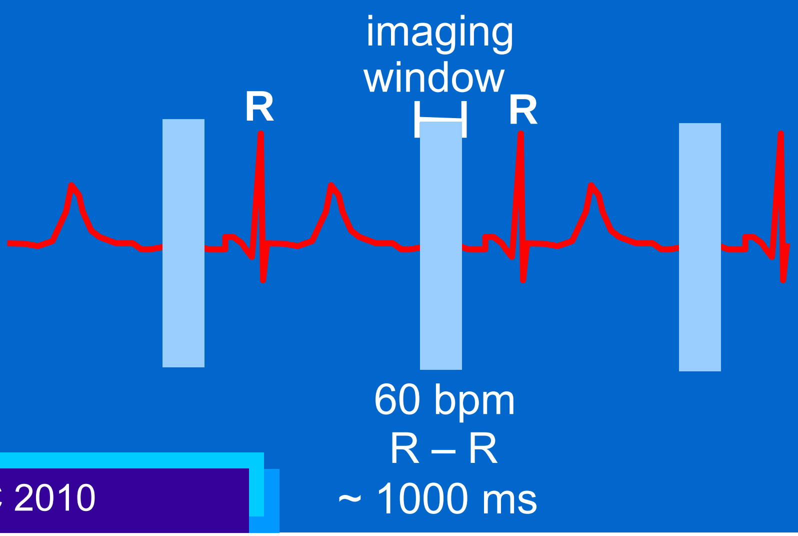
Cardiac CT: technical requirements (CCTA)

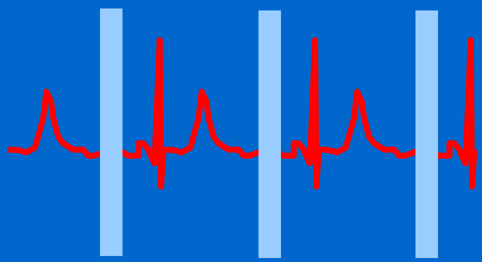
- Temporal resolution
- Spatial resolution
- Volume coverage
- Dose
- Other considerations

Temporal resolution

- To 'freeze' cardiac motion need short *'imaging window'*
  - time within one cardiac cycle over which data is acquired for image reconstruction
- Ideally imaging window < 15% R-R
  - at 60 bpm ~150 ms
  - higher heart rates – shorter times needed

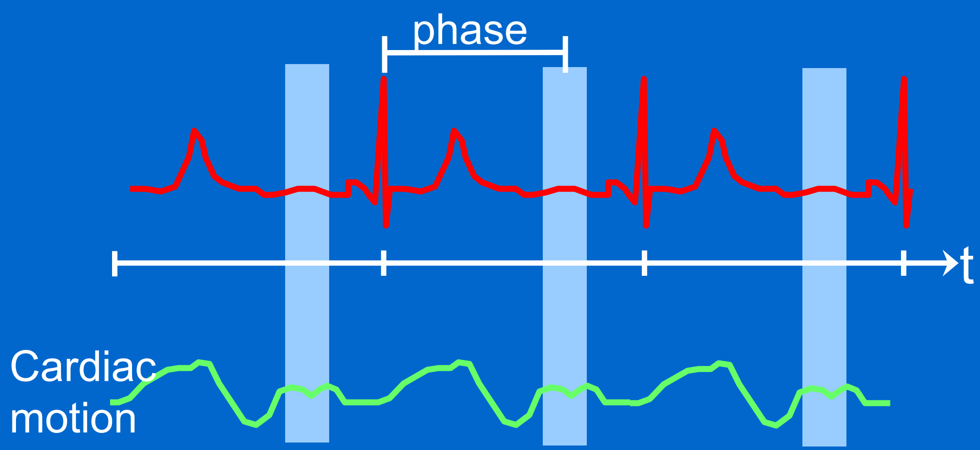


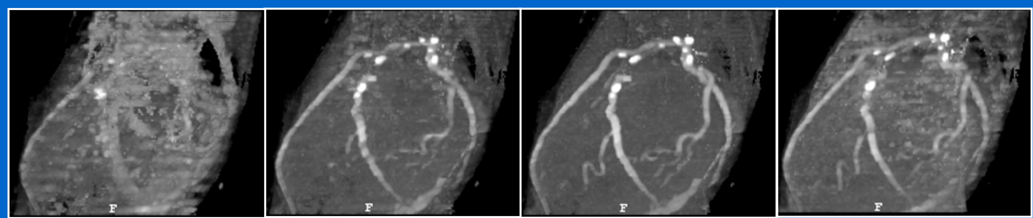




Temporal resolution

- Reconstruct images in most stationary phase of cardiac cycle
  - best phase dependant on heart rate



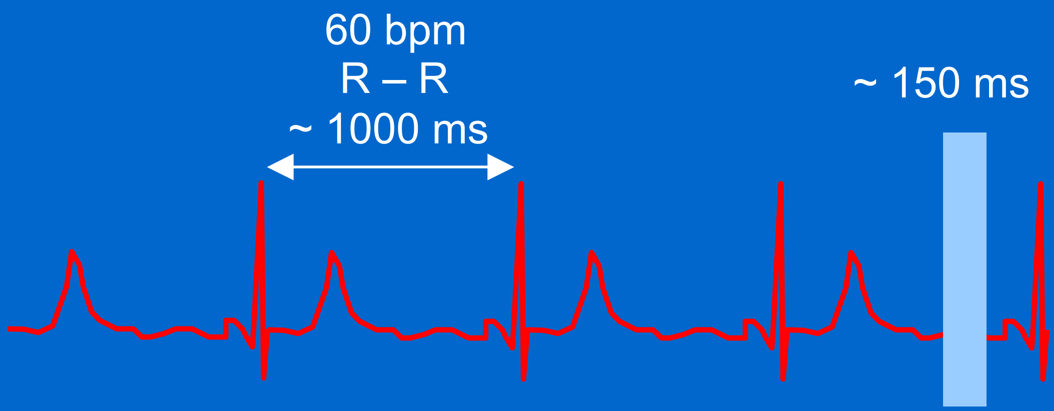


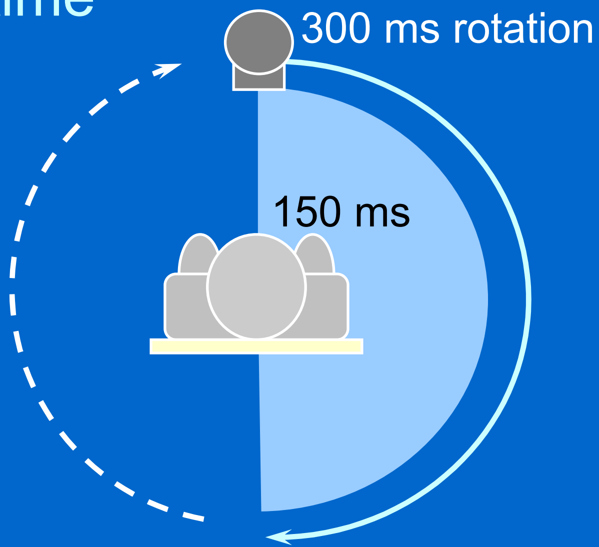
Optimal recon phase

How to improve temporal resolution

- Fast rotation times
  - currently 270 – 350 ms
  - 360° reconstruction not suitable

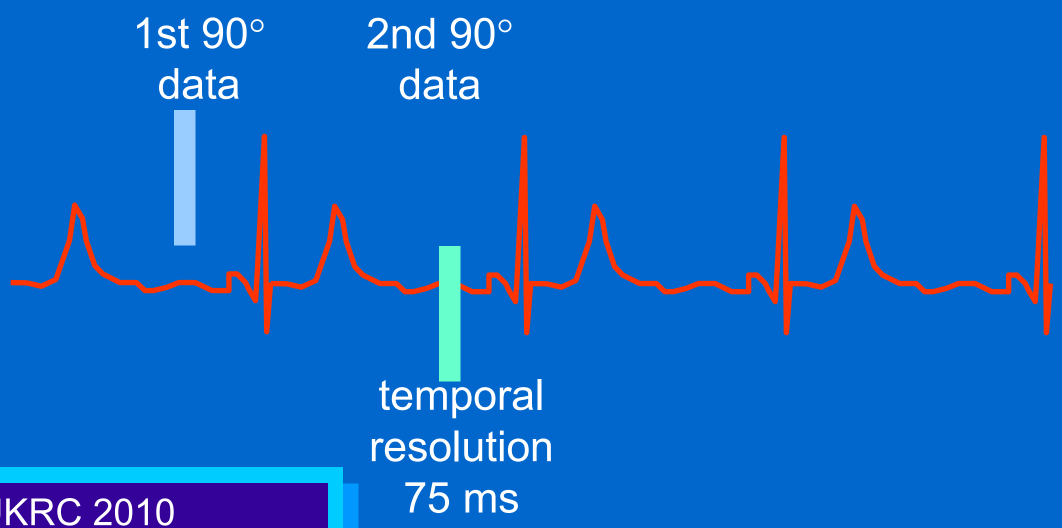
- Half-scan reconstruction method
  - temporal resolution (TR) ≅ ½ rotation time

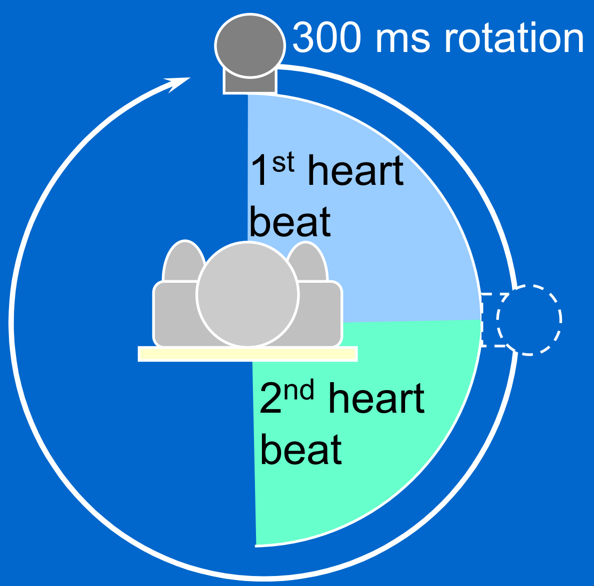




How to improve temporal resolution

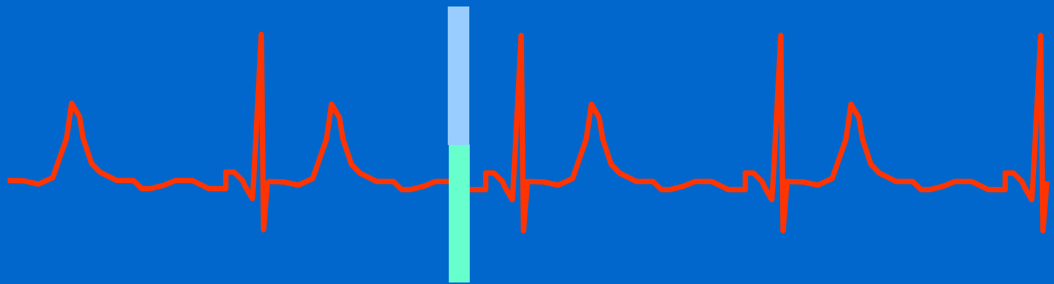
- Multi-segment reconstruction
  - uses multiple heart beats for image reconstruction
  - 2 segments: max TR ~ ¼ rotation time
  - 3 segments: max TR ~ ⅙ rotation time ….etc
- Temporal resolution achieved dependent on heart rate
  - can be optimised by adjusting rotation time

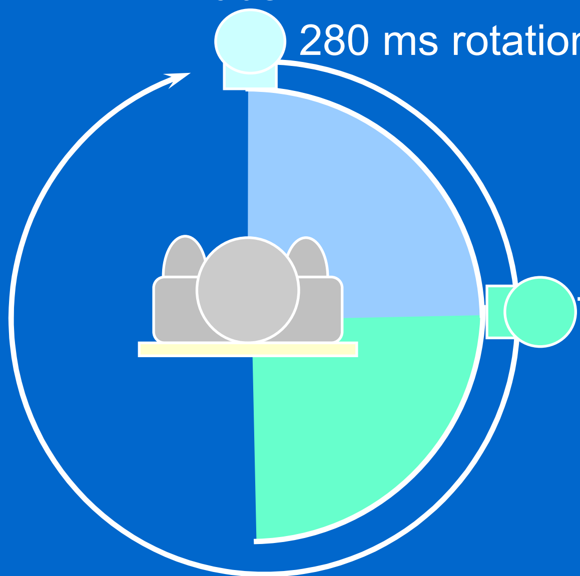




How to improve temporal resolution

- Dual-source technology
  - two 90° segments acquired simultaneously in single heart beat
  - Temporal resolution ≅ ¼ rotation time
  - heart rate independent
  - high temporal resolution allows more flexibility in reconstruction phase





Temporal resolution

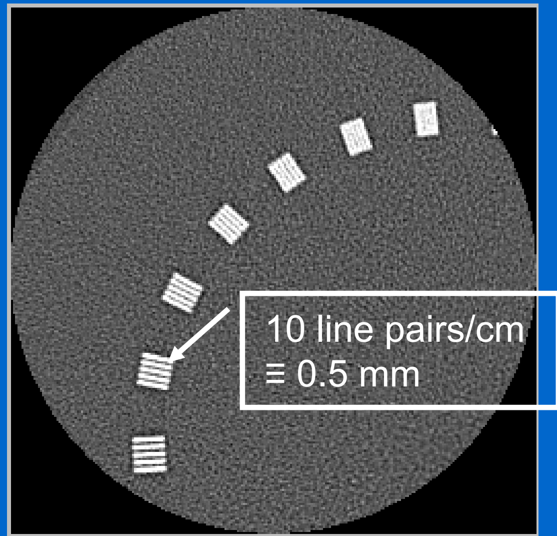
Scanner model	Tubes (#)	Rotation (ms)	Temporal resolution (ms)	
			Axial	Helical
GE Discovery CT750 HD	1	350	175	44 - 175
Philips Brilliance iCT	1	270	135	34 - 135
Siemens Definition Flash	2	285	75	38 - 75
Toshiba Aquilion ONE	1	350	35 - 175	35 - 175

Cardiac CT: technical requirements

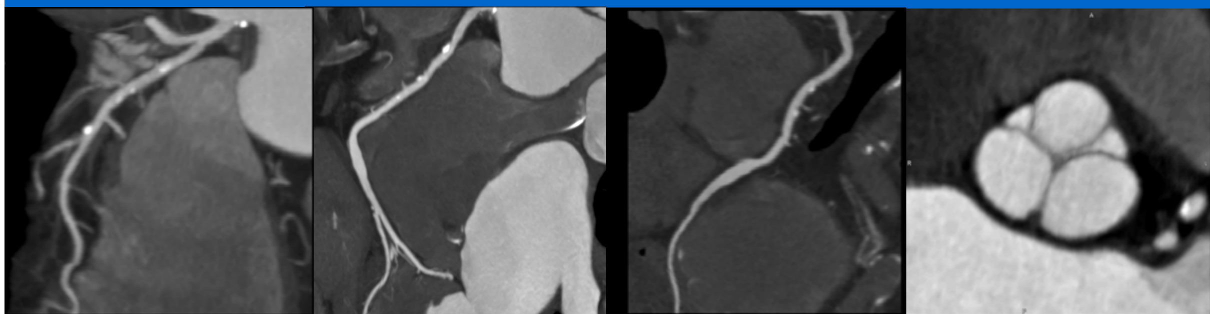
- Temporal resolution
- Spatial resolution
- Volume coverage
- Dose
- Other considerations

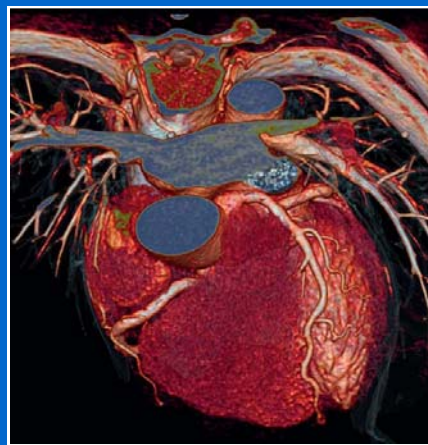
Spatial resolution

- Ability to discern small, high contrast structures



- Isotropic spatial resolution required
  - equal resolution in all planes

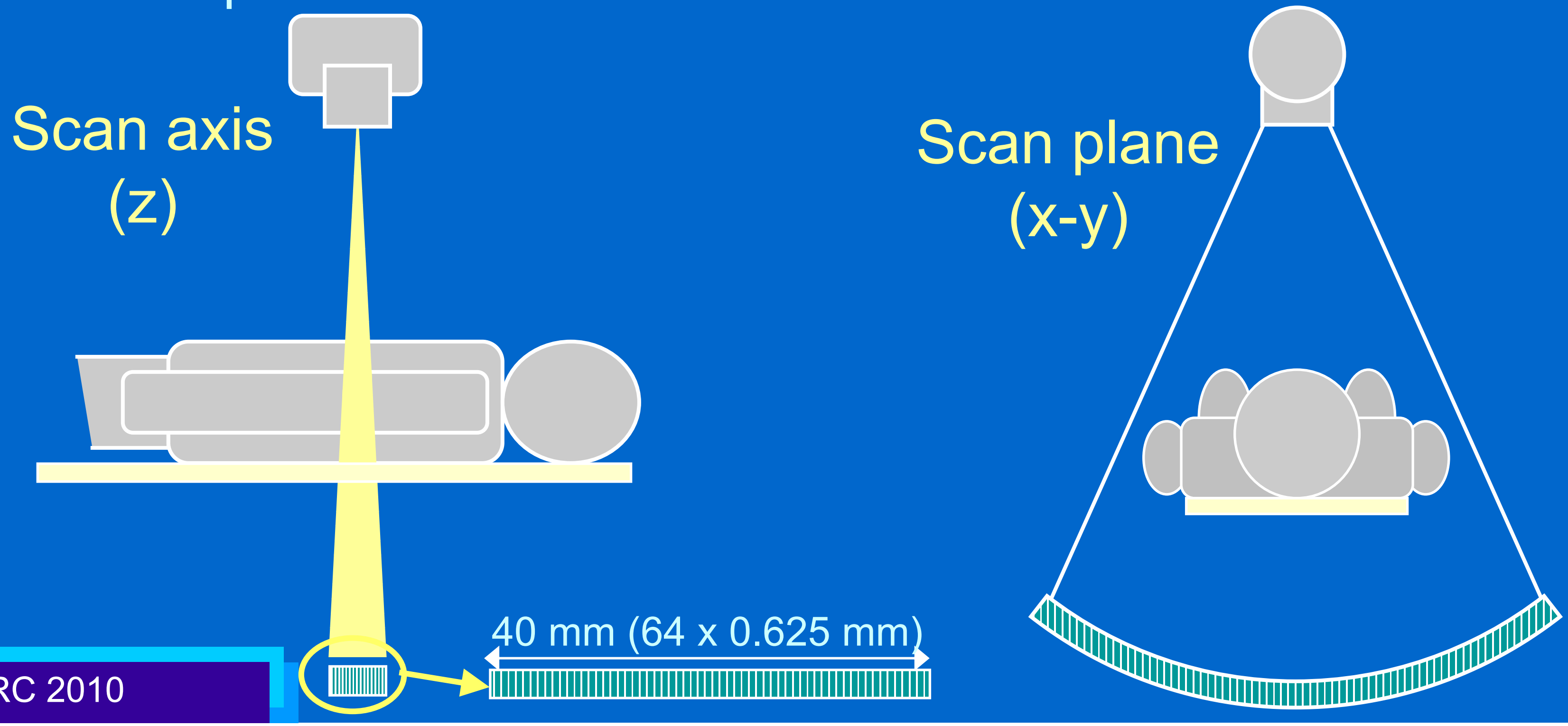




Voxel size: x=y=z

Spatial resolution

- Spatial resolution dependent on
  - focal spot and detector size
  - sampling density
- Also dependent on
  - reconstruction parameters e.g. reconstruction filter
  - temporal resolution



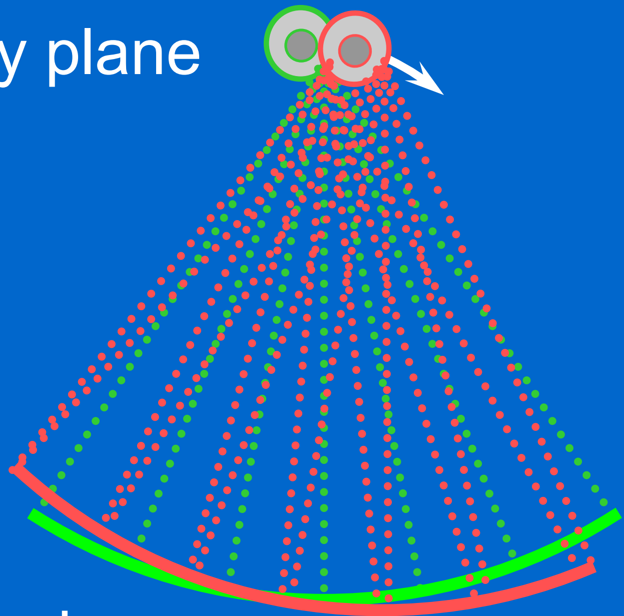
How to improve spatial resolution

- Flying (dynamic) focal spot (FFS)
  - improves sampling density
  - reduces artefacts

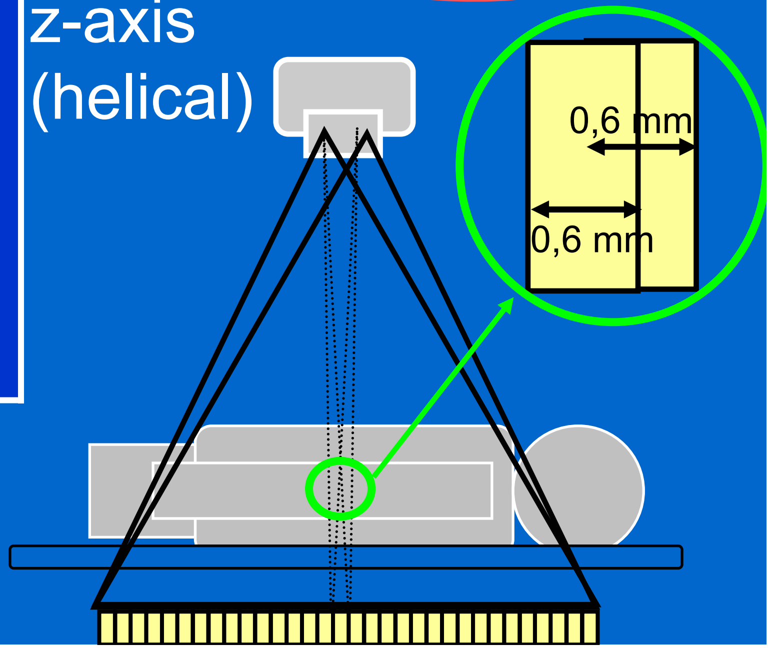
Manufacturer*	FFS availability	
	x-y plane	z-axis
GE	Yes	No
Philips	Yes	Yes
Siemens	Yes	Yes
Toshiba	No	No

* Not available on all scanner models

x-y plane



z-axis (helical)



How to improve spatial resolution

- Double slice reconstruction – volume axial mode

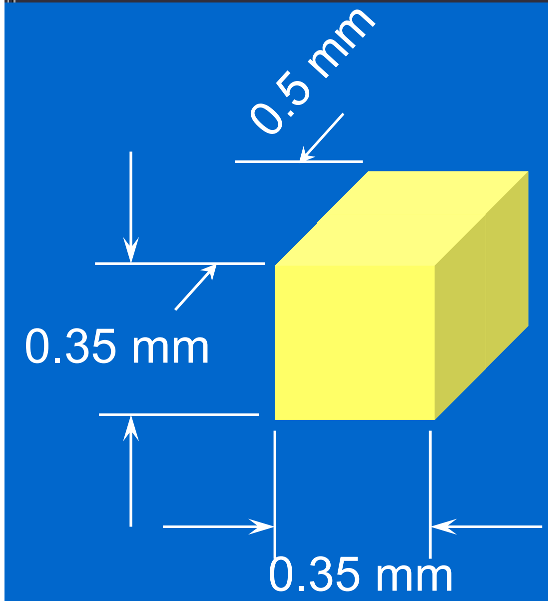
ConeXact reconstruction
Standard Mode

Volume | MultiView

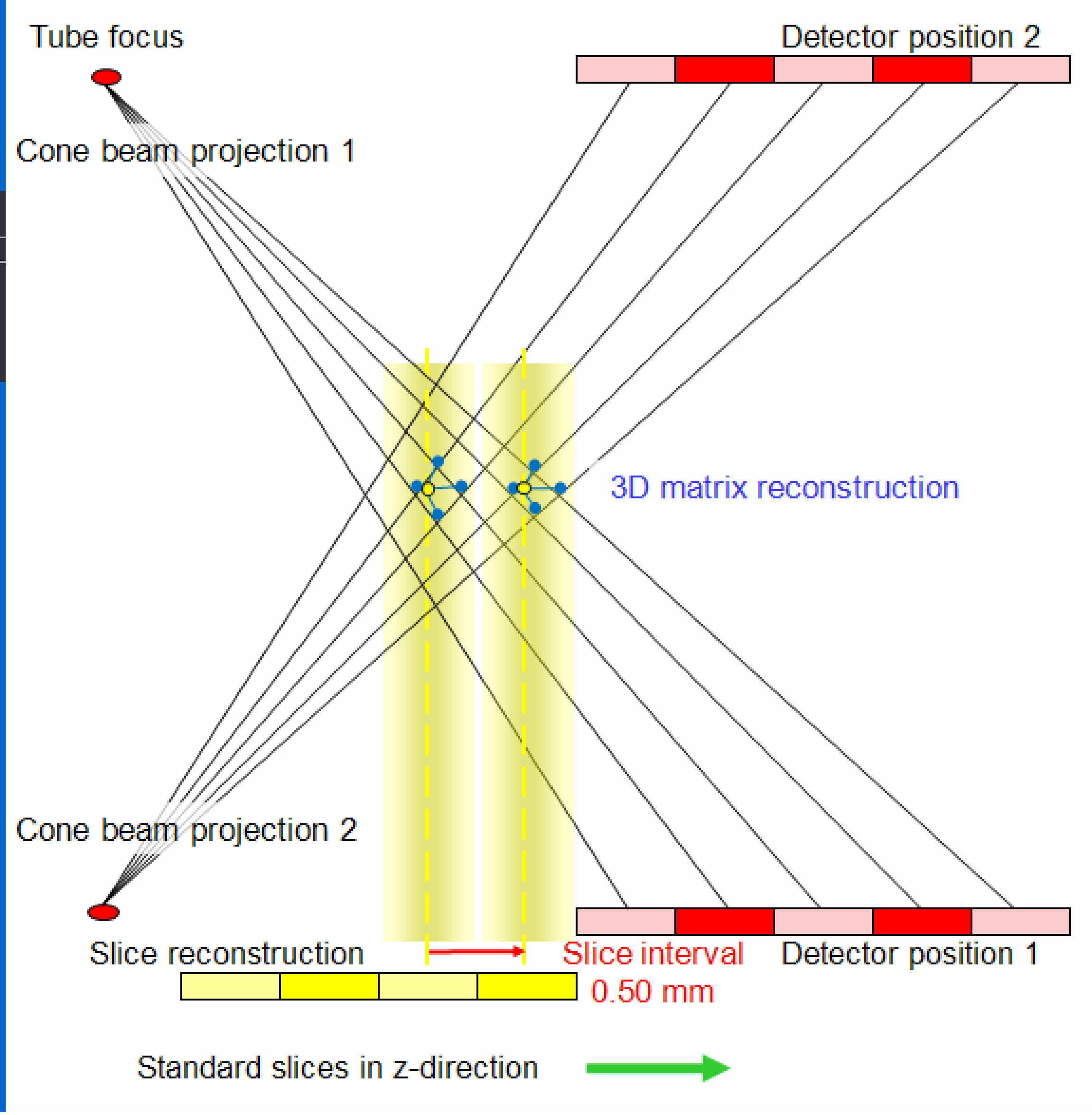
Volume Parameters

Scan Slice Thickness 0.5 mm

Slice Thickness 0.5 mm Interval 0.50 mm



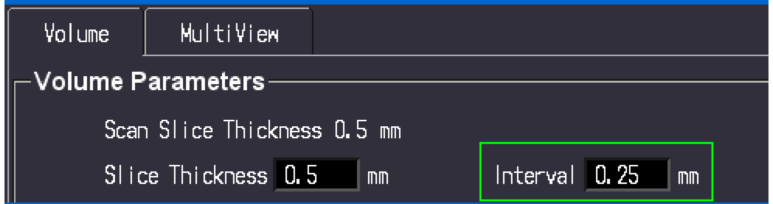
Courtesy J. Blobel, Toshiba

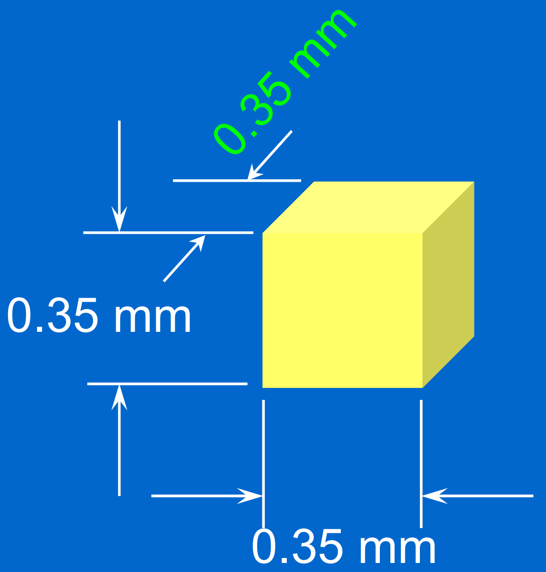


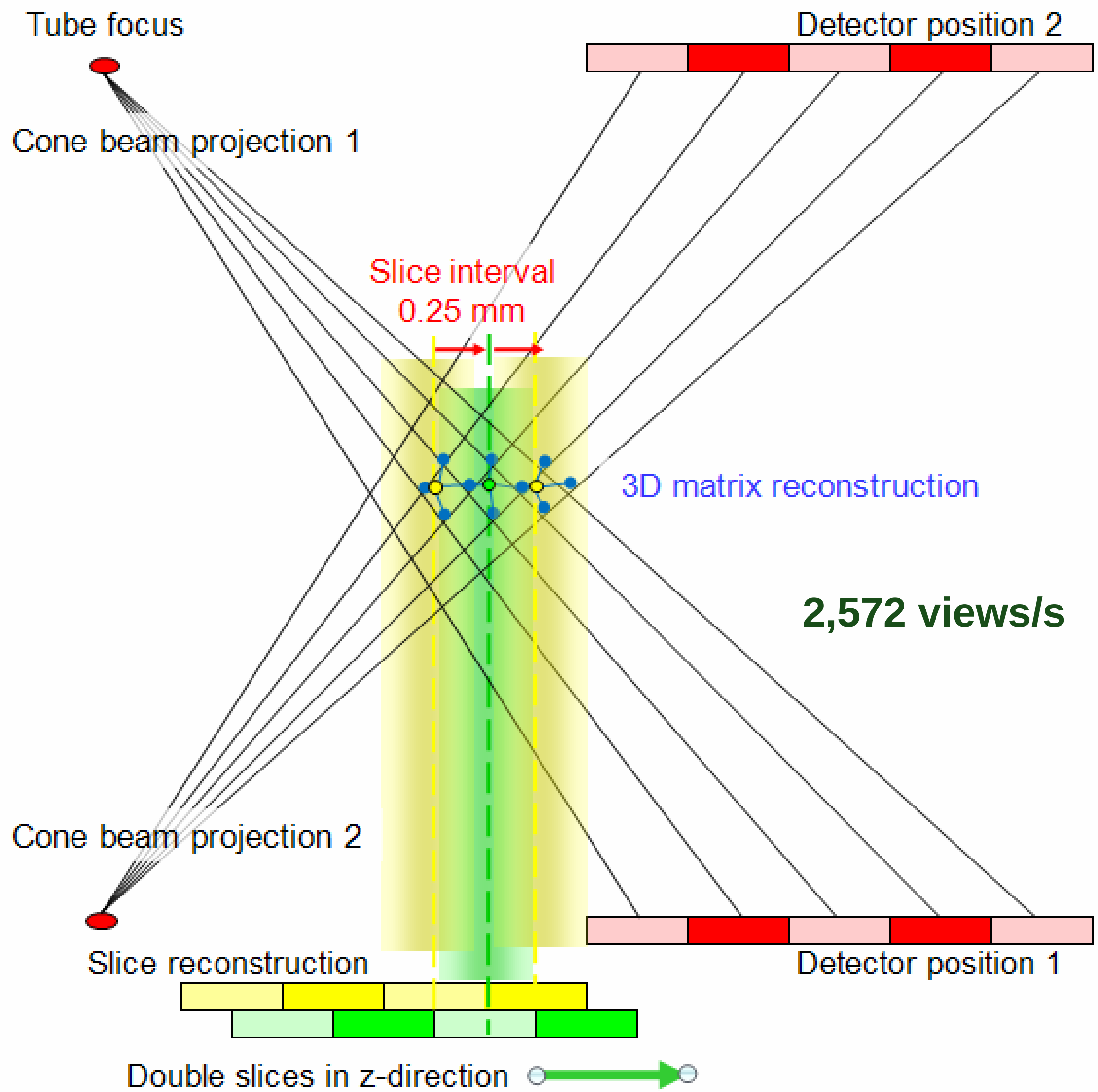
How to improve spatial resolution

- Double slice reconstruction – volume axial mode

ConeXact reconstruction
Double Slice Mode







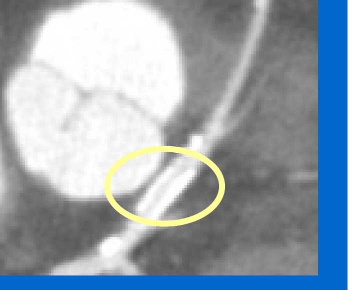
Courtesy J. Blobel, Toshiba

Spatial resolution

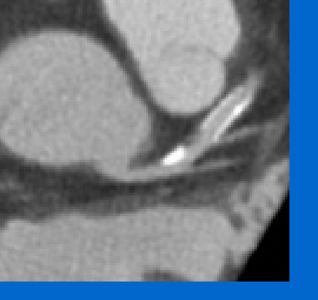
- Limiting spatial resolution:
  - up to 15 - 25 lp/cm (0.3 - 0.2 mm) in scan plane
  - up to ~13 lp/cm (0.4 mm) in z-axis

- Sharpest reconstruction filters result in high noise

- Generally for standard cardiac scans
  - x-y plane resolution ~ 8 lp/cm (0.6 mm)
  - z-axis resolution ~ 13 lp/cm (0.4 mm)



- For reduced 'blooming' e.g. stents, calcium
  - sharper filters may be used ~ 10 lp/cm (0.5 mm)



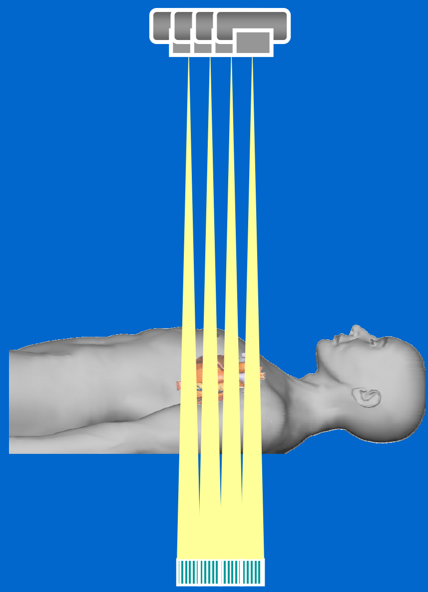
Images from Lin, EC et al; http://emedicine.medscape.com/article/1603072-overview

Cardiac CT: technical requirements

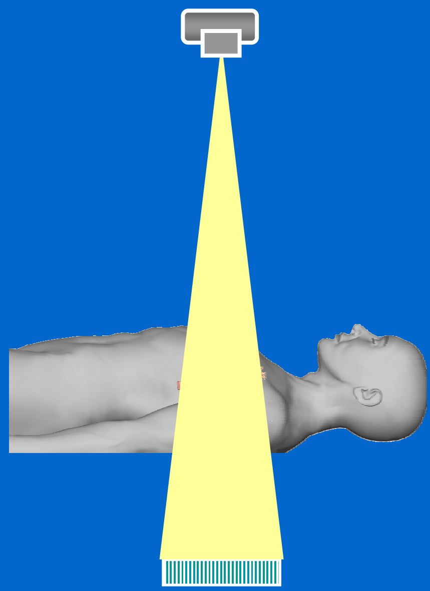
- Temporal resolution
- Spatial resolution
- Volume coverage
- Dose
- Other considerations

Volume coverage

- Aim to cover heart within a breath-hold and with a minimum number of heart beats

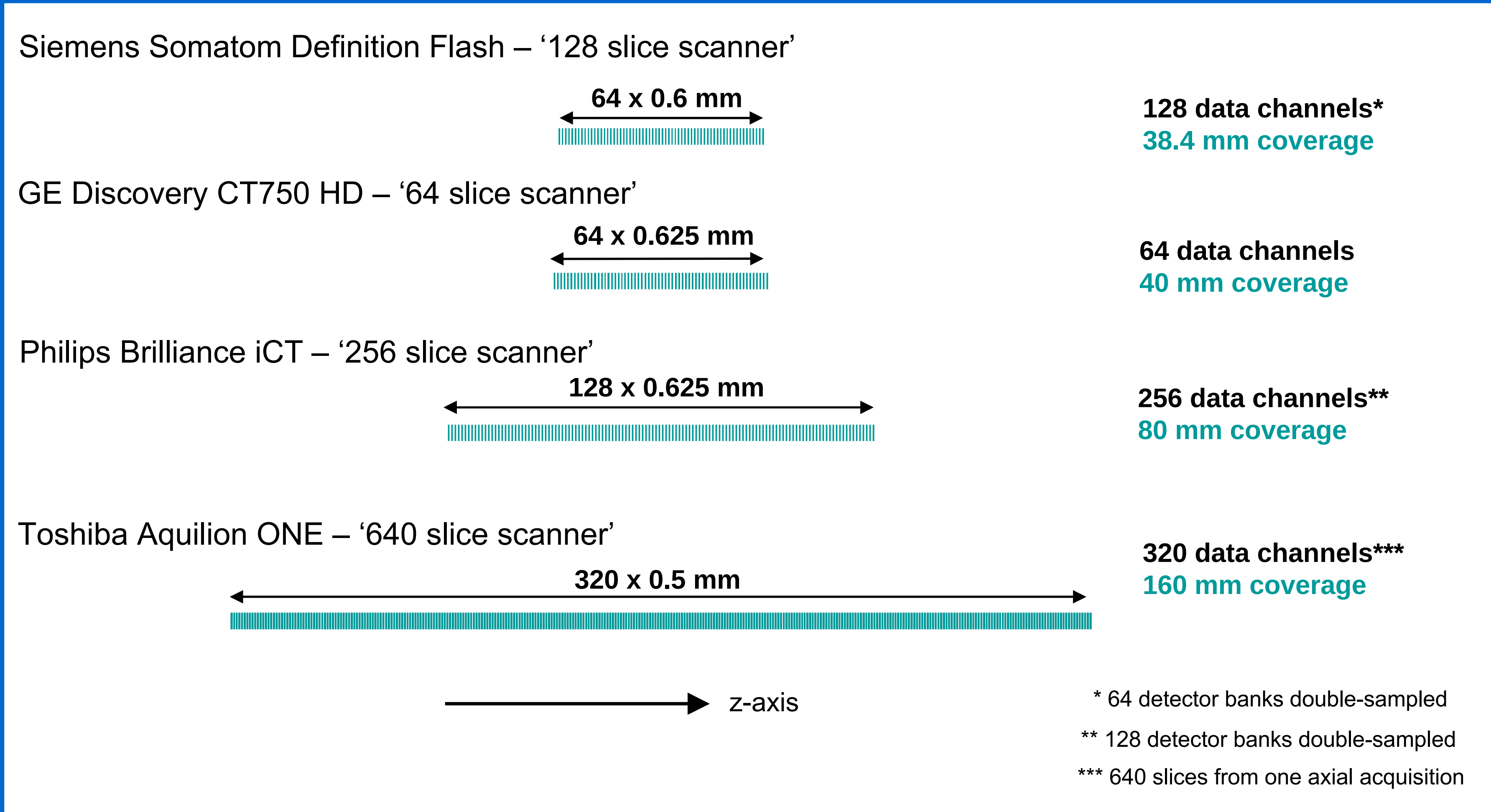


- Ideally, single heart beat
  - less chance of arrhythmia & breathing artefacts



Volume coverage

- z-axis detector configuration of top-of-the-range CT scanners



Volume coverage

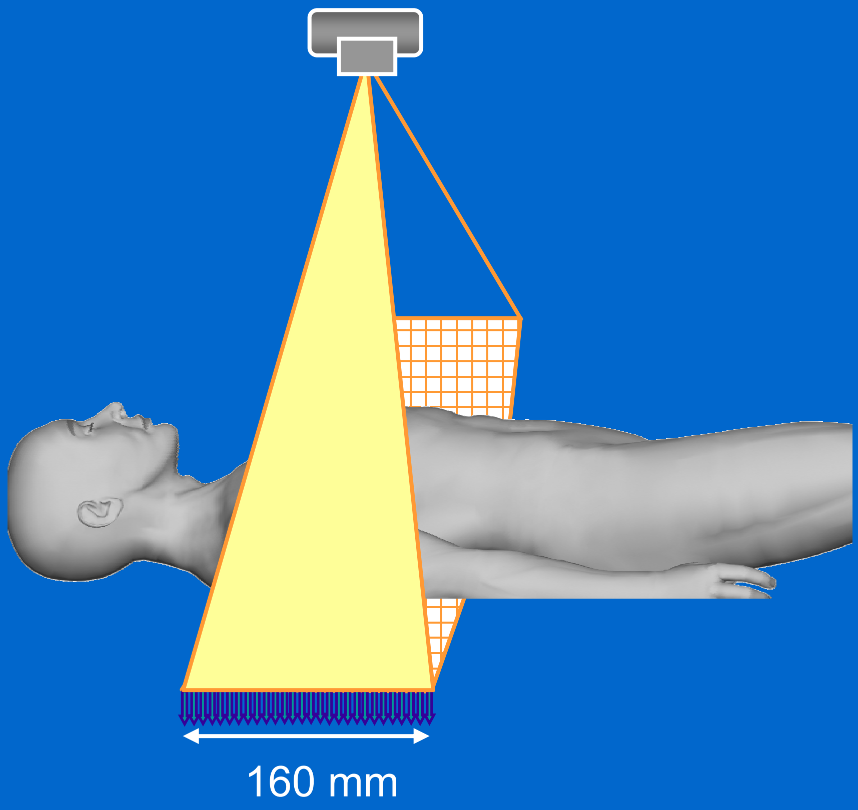
- Consider detector length NOT 'no. of slices'
- Number of heart beats required to cover volume depends on
  - detector length
  - scan mode

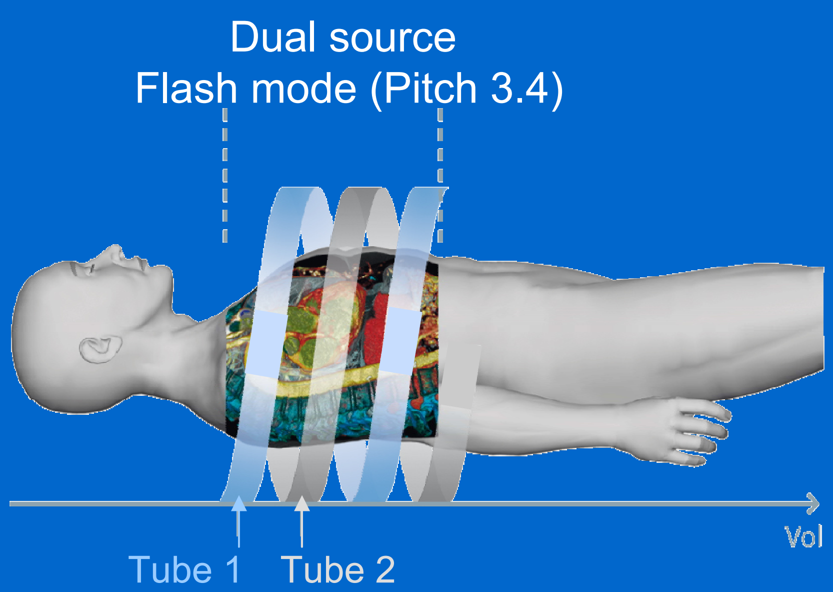
No. of heart beats required: 140 mm length, single segment

	Detector length (mm)		
Scan mode	40	80	160
Axial (step and shoot)	7	3	1
Helical – low pitch	4	2	-
Helical – high pitch	1	-	-

Volume coverage – ‘single beat’

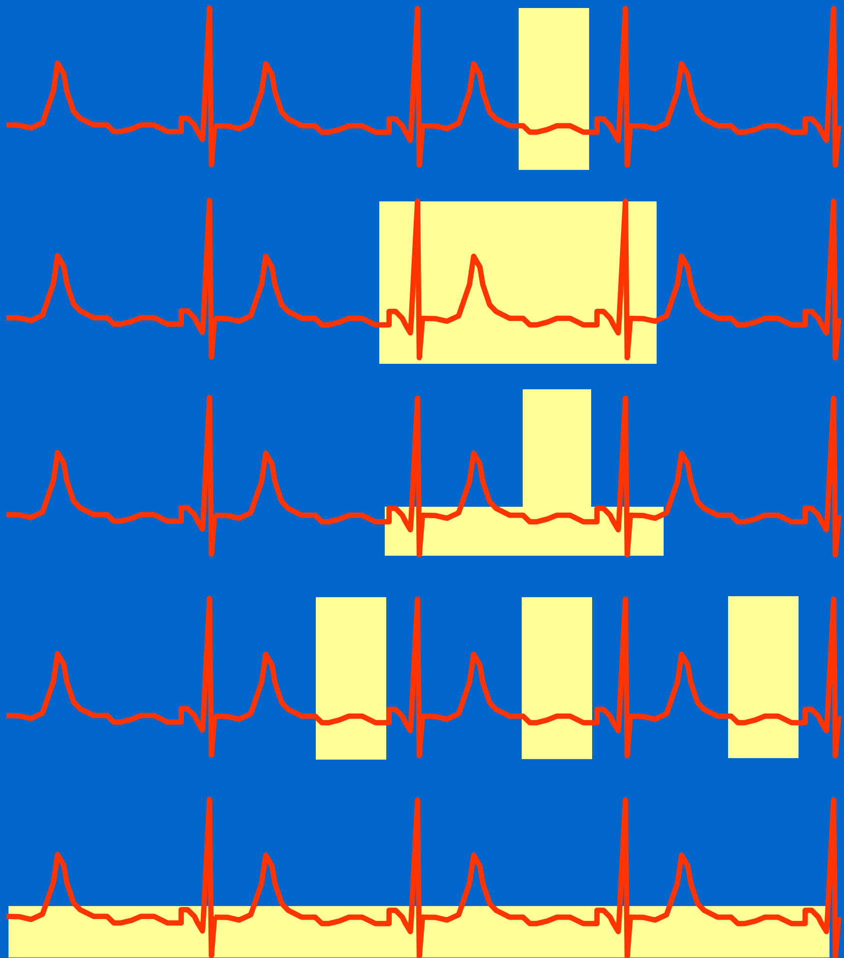
- Single heart beat coverage can be achieved in two ways:
  - full organ coverage
  - high helical pitch





Volume coverage – 'single beat'

- Full organ coverage
  - cardiac scanning: triggered axial mode, no table movement

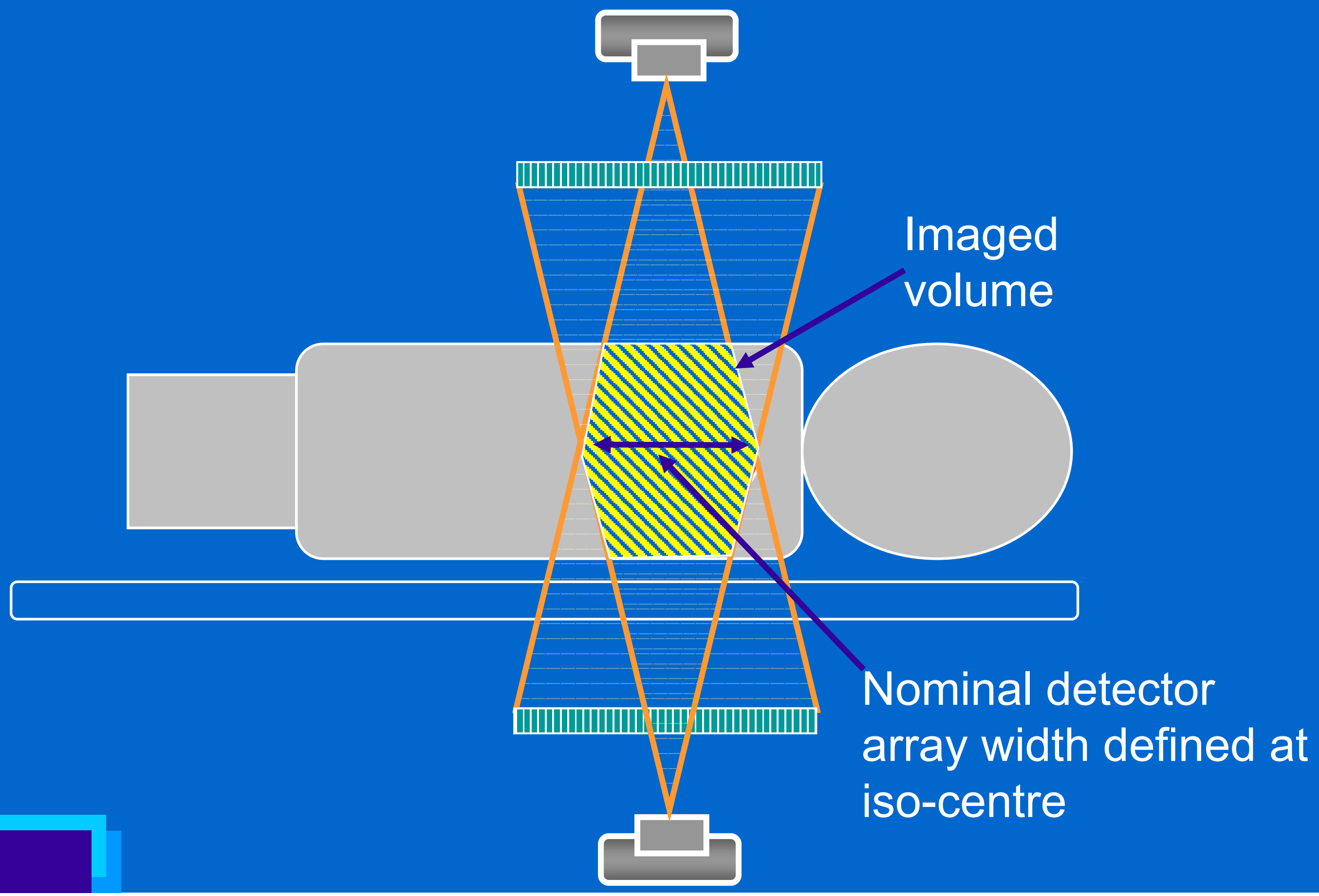


- Single beat, single rotation
  - standard CCTA
- Single beat, multiple rotations
  - increased flexibility
- Single beat, modulated
  - CCTA + functional
- Multi-beat, pulsed
  - CCTA, multi-segment
- Multi-beat, continuous
  - perfusion

Irradiation

Volume coverage

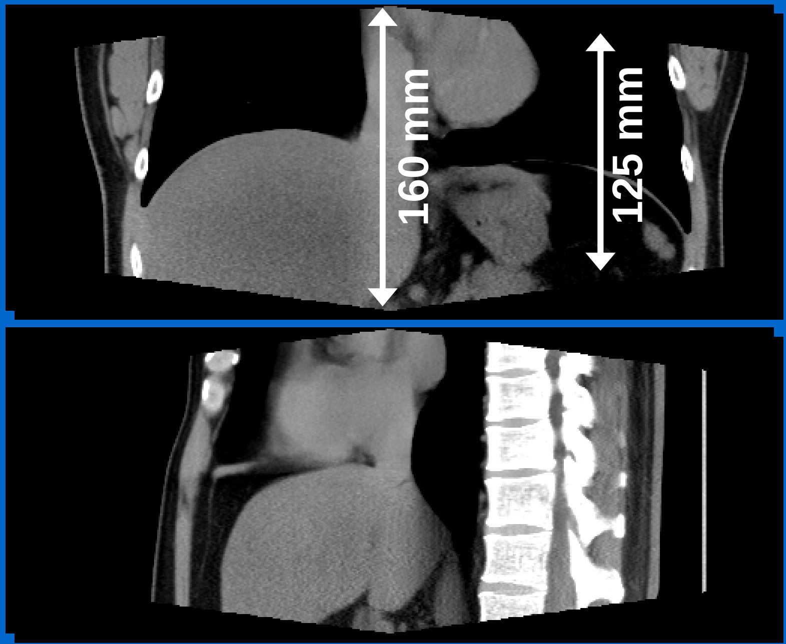
- Wide detector coverage
  - cone beam artefact: 3D reconstruction method
  - scatter: software corrections
  - roof-top effect: software corrections available on some systems



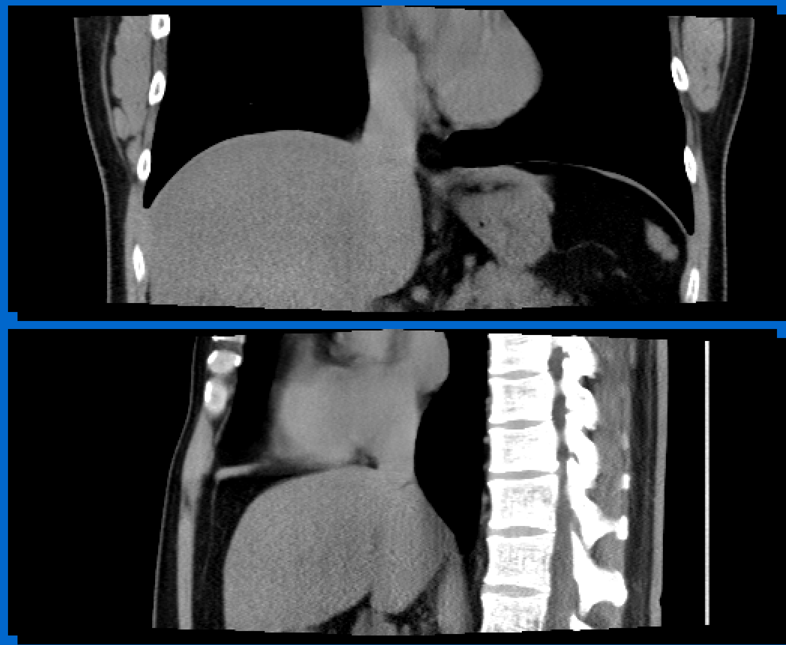
Volume coverage

- Reduced roof-top effect – Toshiba Aquilion ONE

Version 4.51

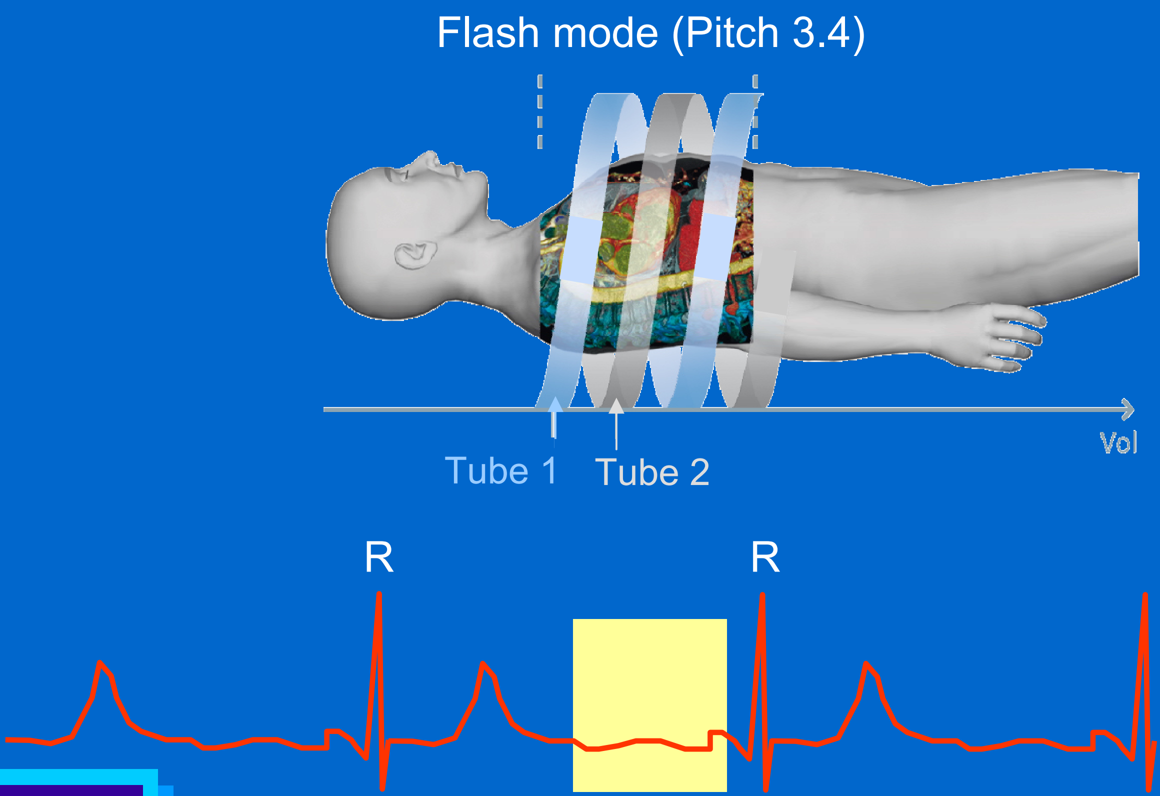


Version 4.61



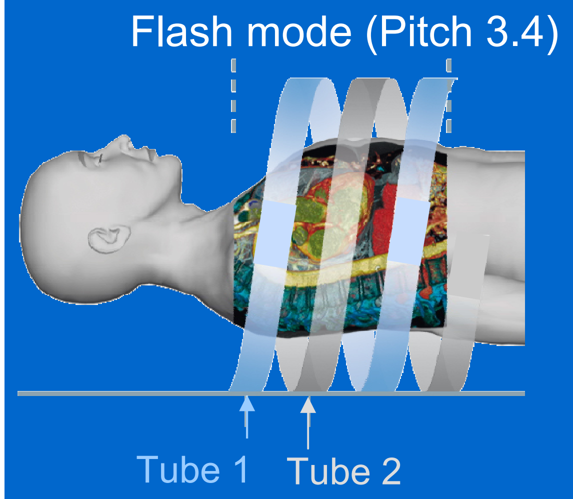
Volume coverage – 'single beat'

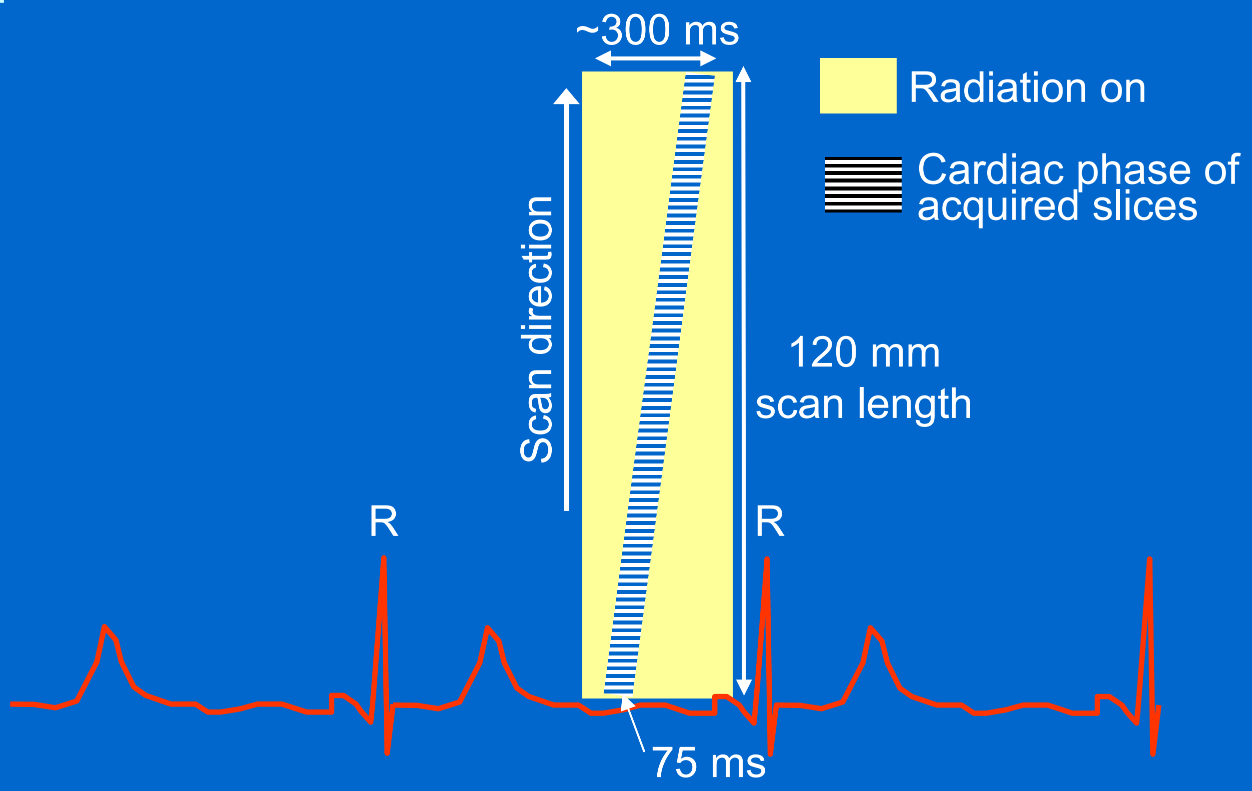
- High pitch helical (Siemens 'Flash' mode)
  - prospectively triggered helical mode
  - couch speed ~ 135 mm per rotation
  - cardiac volume acquired within single heartbeat



Volume coverage

- High pitch helical
  - limited to lower heart rates (<65 bpm)
  - images acquired at range of R-R phases (but high temp res)
  - scatter from two tubes: reference detector corrections
  - helical artefacts?





Cardiac CT: technical requirements

- Temporal resolution
- Spatial resolution
- Volume coverage
- Image noise
- Dose
- Other considerations

Dose in cardiac CT

- Dose primarily dependent on:
  - scan mode
  - scan protocol
  - dose reduction features

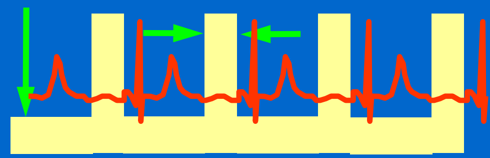
- Choice of scan mode and protocol dependent on patient
  - heart rate
  - heart rate variability
  - patient size

Dose in cardiac CT

- Scan mode

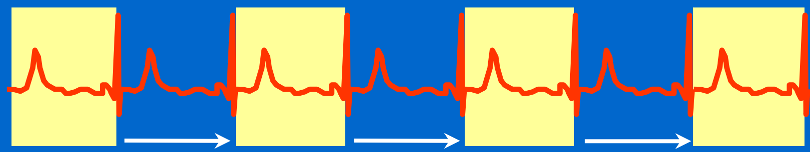
Helical

constant mA

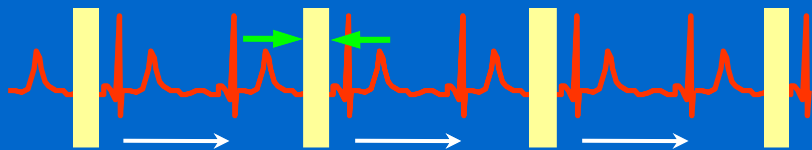


modulated mA

Axial



full cycle



narrow window

Dose in Cardiac CT

Variation of dose with scan mode: Siemens Definition Flash**

Helical – low pitch scan – no ECG modulation : 10 mSv

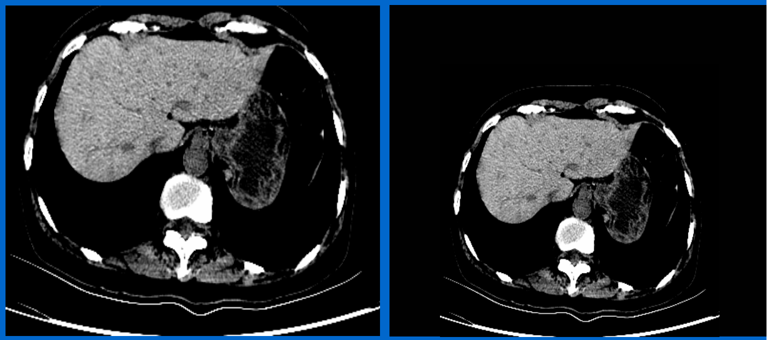
Scan mode	Effective dose (mSv)					
Maximum mA window	Narrow (Single phase)			Wide (40% phase range)		
Dose outside max mA window	0	4%*	25%	0	4%*	25%
Axial (step and shoot)	1.2			4.8		
Helical – low pitch		1.7	3.4		5.6	6.4
Helical – high pitch (Flash mode)	0.8					

* Siemens MinDose

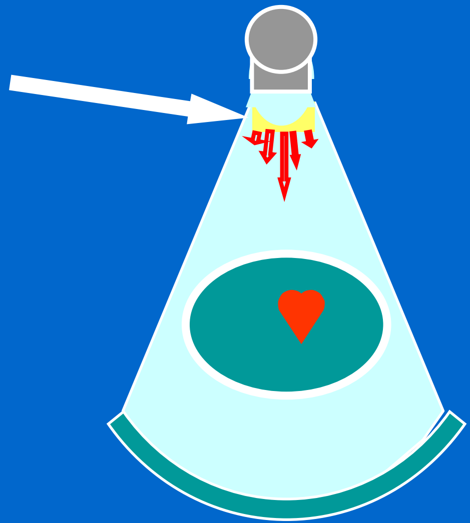
***Doses obtained using Siemens' Cardiac Dose Calculator (Accuracy ±10%)*
Assuming: 60 bpm, BMI 25; 0.014 mSv/DLP
Scan parameters: 100 kV, 160 mAs/rot/tube, 140 mm scan length
Scanner software version VA 34

Dose in cardiac CT

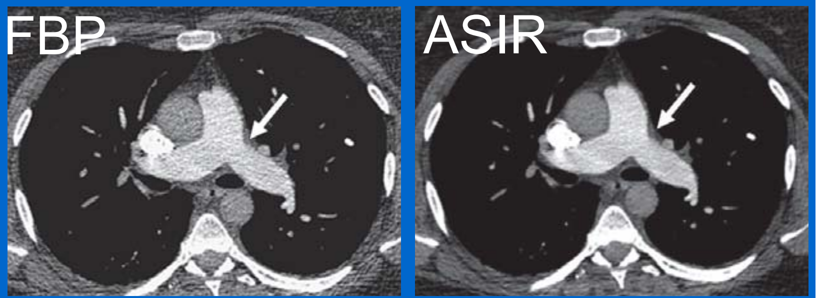
- Selection of appropriate mA and kV
  - automatic selection of mA may be available



- Use of small FOV bow-tie filter
  - reduces peripheral dose



- Use of iterative reconstruction
  - less noise at same dose
  - ~ 50% dose reduction for same image quality claimed



From Silva et al AJR Jan 2010

Dose in cardiac CT

- All manufacturers offer iterative reconstruction

Manufacturer	Iterative reconstruction
GE	Adaptive Statistical Image Reconstruction (ASIR)
Philips	iDOSE
Siemens	Iterative Reconstruction in Image Space (IRIS)
Toshiba	Adaptive Iterative Dose Reduction (AIDR)

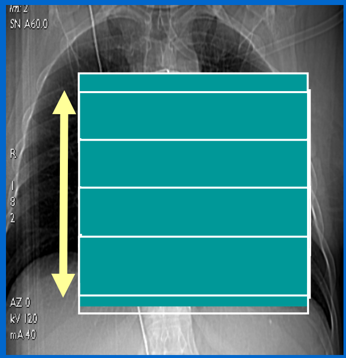
- Second generation iterative reconstruction methods currently in development

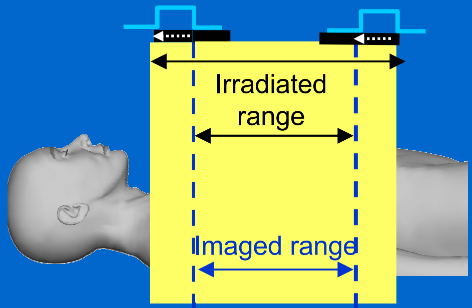
  e.g. GE: Model-based Iterative Reconstruction (Veo)

  Siemens: Sinogram Affirmative Iterative Reconstruction (SAFIRE)

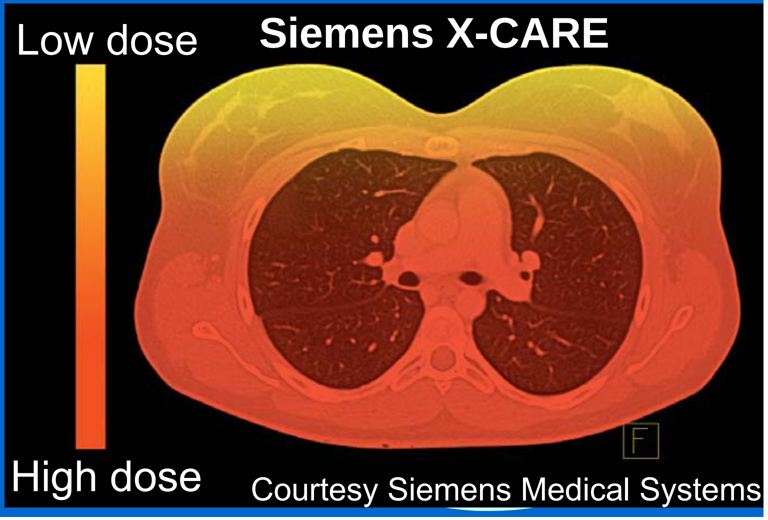
Dose in cardiac CT

- Optimisation of scan length: Dose increase ~10% per cm[1]
  - ‘adaptive collimation’ for wide beam axial scans
  - ‘dynamic collimation’ to reduce over-ranging in helical scans





- Partial irradiation to reduce surface organ dose
  - breast dose reduction up to 40%[2]



[1] With a base scan length of 10 cm

[2] Kalender W. et al. Reduction of dose to the female breast in thoracic CT; European Society of Radiology 2008; 18: 1674-1682

Cardiac CT: technical requirements

- Temporal resolution
- Spatial resolution
- Volume coverage
- Image noise
- Dose
- Other considerations

Other considerations

- User-friendliness
  - automated scan parameter optimisation
  - applications software / post-processing

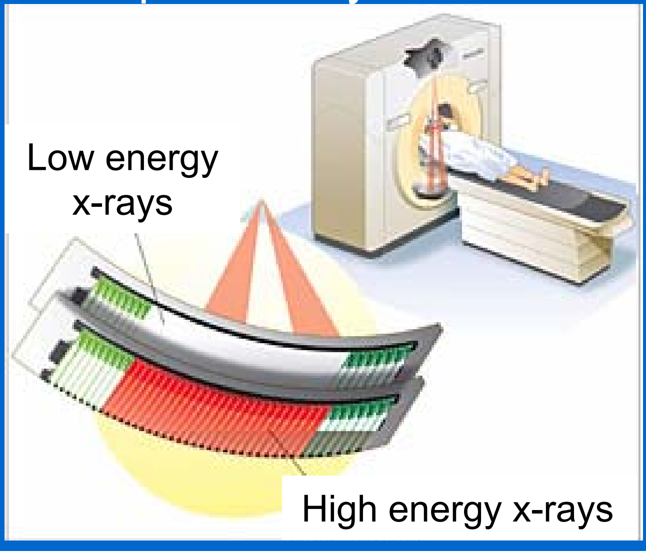
- Additional features
  - dual energy for *e.g.* myocardial perfusion, direct bone removal, virtual non-contrast, plaque differentiation….

Other considerations

- Dual energy approaches

Manufacturer	Dual energy method
Siemens	Dual source technology
GE	Rapid kV switching with ‘flying-focal spot’
Philips	Dual-layer detector

Philips dual-layer detector



Conclusions

- Cardiac CT scans benefit particularly from a high temporal and spatial resolution as well as fast volume coverage
- Cardiac doses depend largely on scan mode – choice of mode is mainly patient determined
- Optimal parameters and dose saving features should be used
- Manufacturers have moved in different directions in scanner development
- The 'best' scanner is dependent on local needs
  - dedicated cardiac, dedicated A&E, general purpose scanner…
- …and also £££££

Market review

Market review: *Advanced CT scanners for coronary angiography*

CEP10043, March 2010

www.dh.gov.uk/cep

www.impactscan.org