Technical Aspects of MSCT and ECG Gating

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Imaging Performance Assessment of CT Scanners

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ImPACT

Technical Aspects of MSCT and ECG Gating

- MSCT scanning
  - Principles
  - Current technology
- Particular challenges of imaging the heart
- ECG gating techniques
- Practical approaches to optimisation
- Dose
- The future

Cardiac CT

- Godfrey Hounsfield, inventor of clinical CT, 1972
  - 1979 Nobel prize
  - died Aug 12th 2004

- James Ambrose – Neuroradiologist AMH
  - Standing ovation at RSNA 1972, died March 12th 2006

Godfrey Hounsfield – Nobel Speech 1979

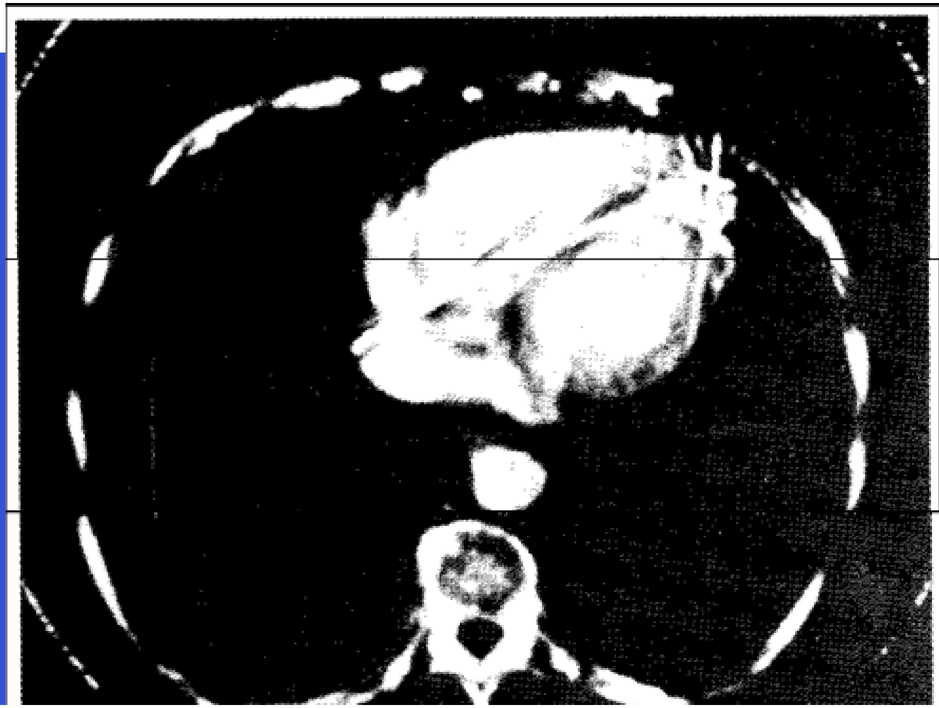
WHAT IMPROVEMENTS SHOULD WE EXPECT TO SEE IN THE FUTURE?

Various attempts have been made to achieve useful pictures of the heart. The time available for taking a picture of the heart is obviously longer than one heart beat.

Some experiments were conducted some time ago using conventional CT machines but in which the traverse of the detectors was synchronised to the heart beat via an electro-cargiograph, passing over the heart in diastole (when the heart movement is at a minimum).

Godfrey Hounsfield – Nobel Speech 1979

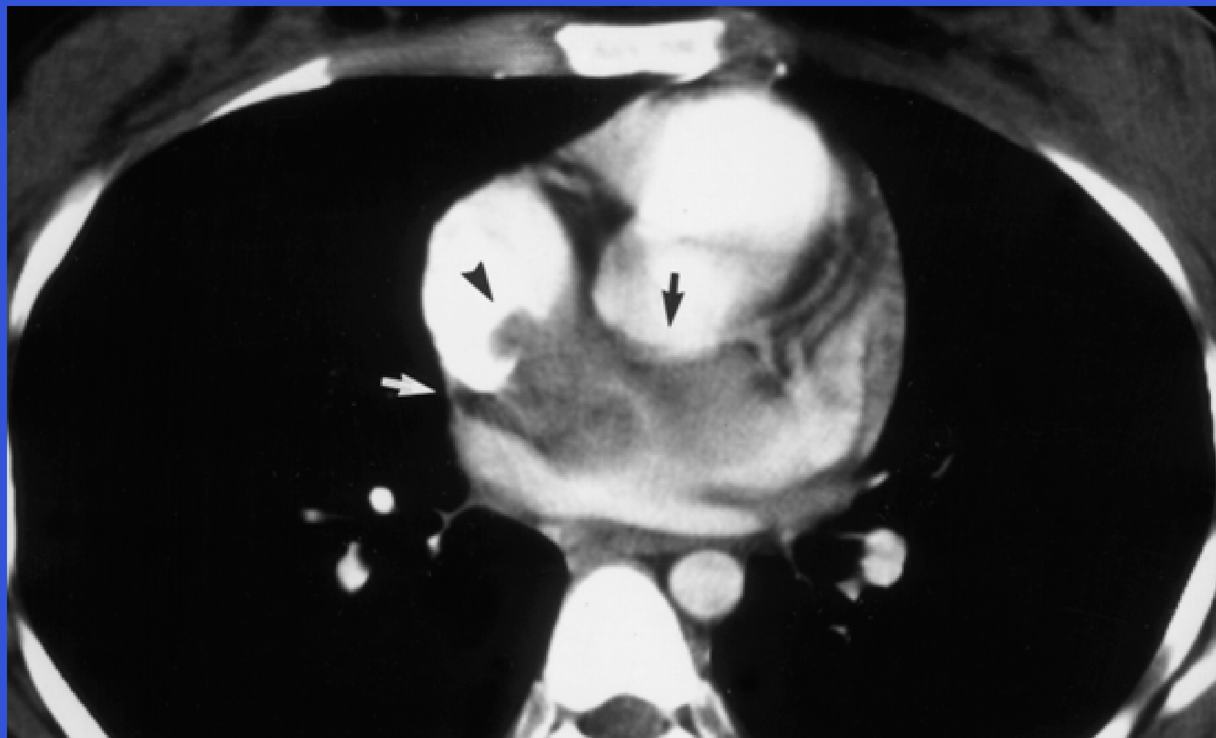
Fig. 14 shows a picture from the experiment. The heart chambers can be discerned by a little intravenous injected contrast media.



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

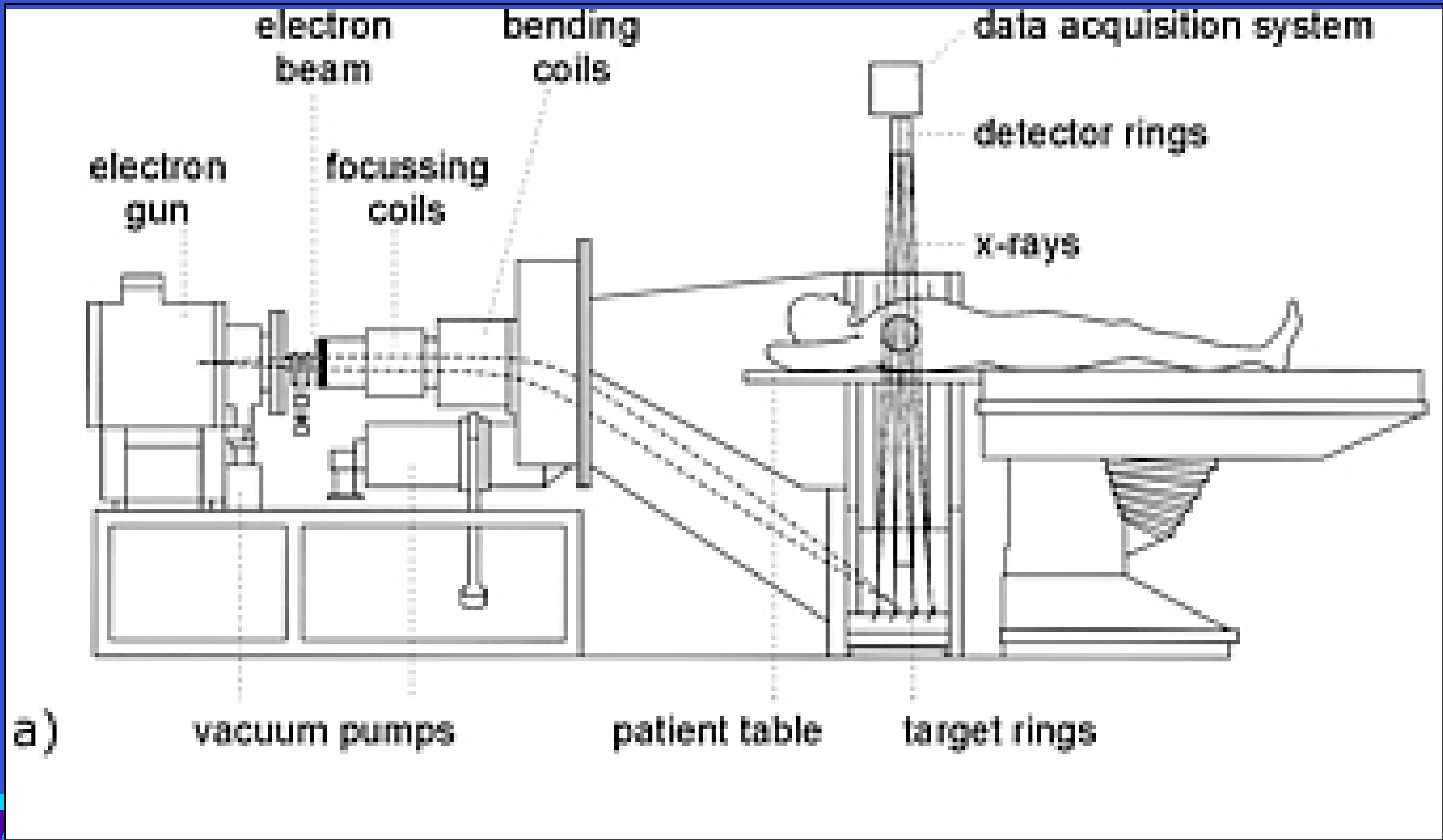
Cardiac CT: before multislice

- Single slice limited to gross morphology – tumour depiction, large vessels
- EBCT – Electron Beam CT scanner used extensively for calcium scoring



Electron Beam CT

- Temporal resolution 50 ms
- Slice thickness 3 mm
- Use primarily for calcium scoring

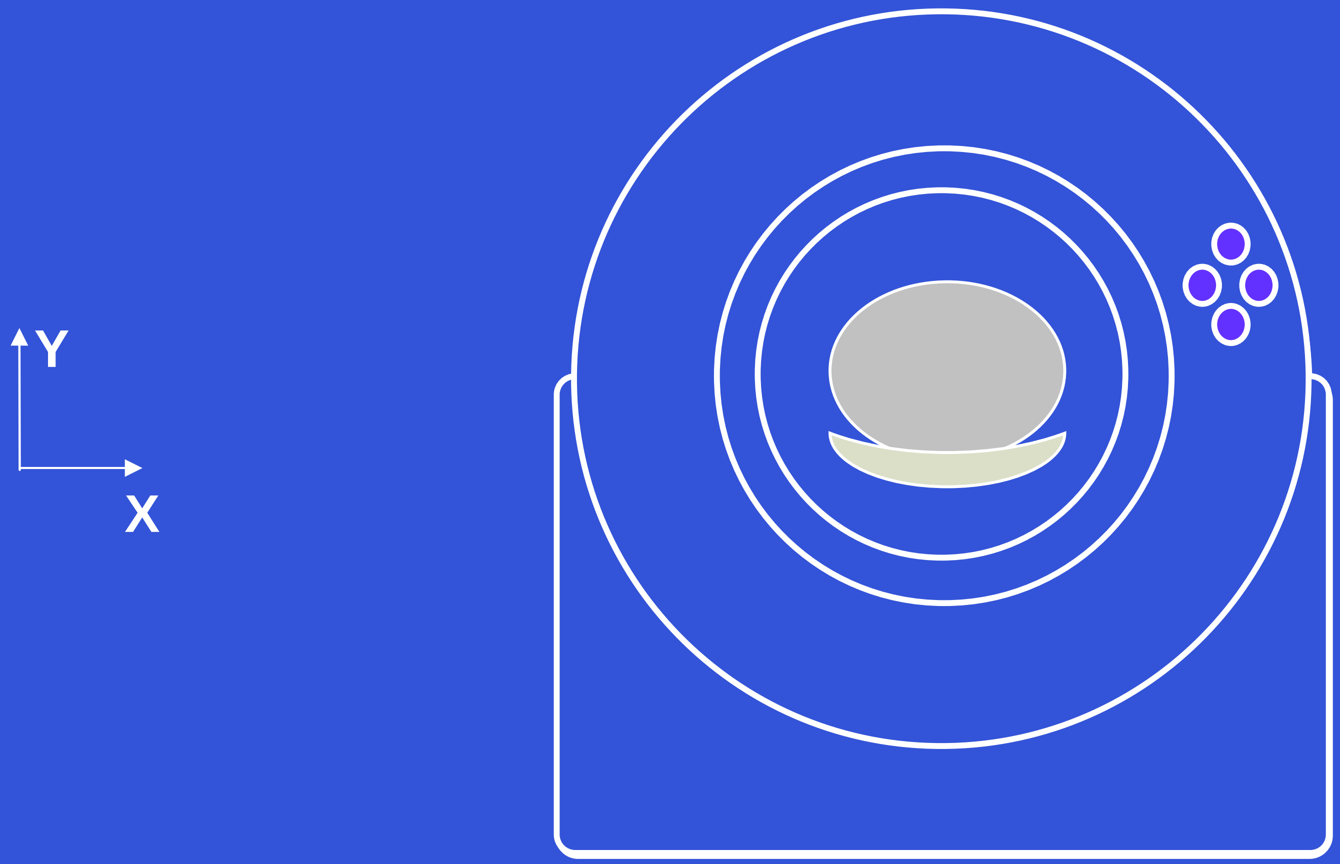


Development of Cardiac CT

- Number of advances in last 8-10 years
- Increase in scan speeds (0.5, 0.4, 0.33 sec / rot)
- Multi-slice technology
  - Up to 64 thin slices in one shot enabling multi-sector reconstruction and/or heart to be covered in shorter time
- Software
  - Developments in ECG gating techniques
  - Specialised methods of image reconstruction for cardiac

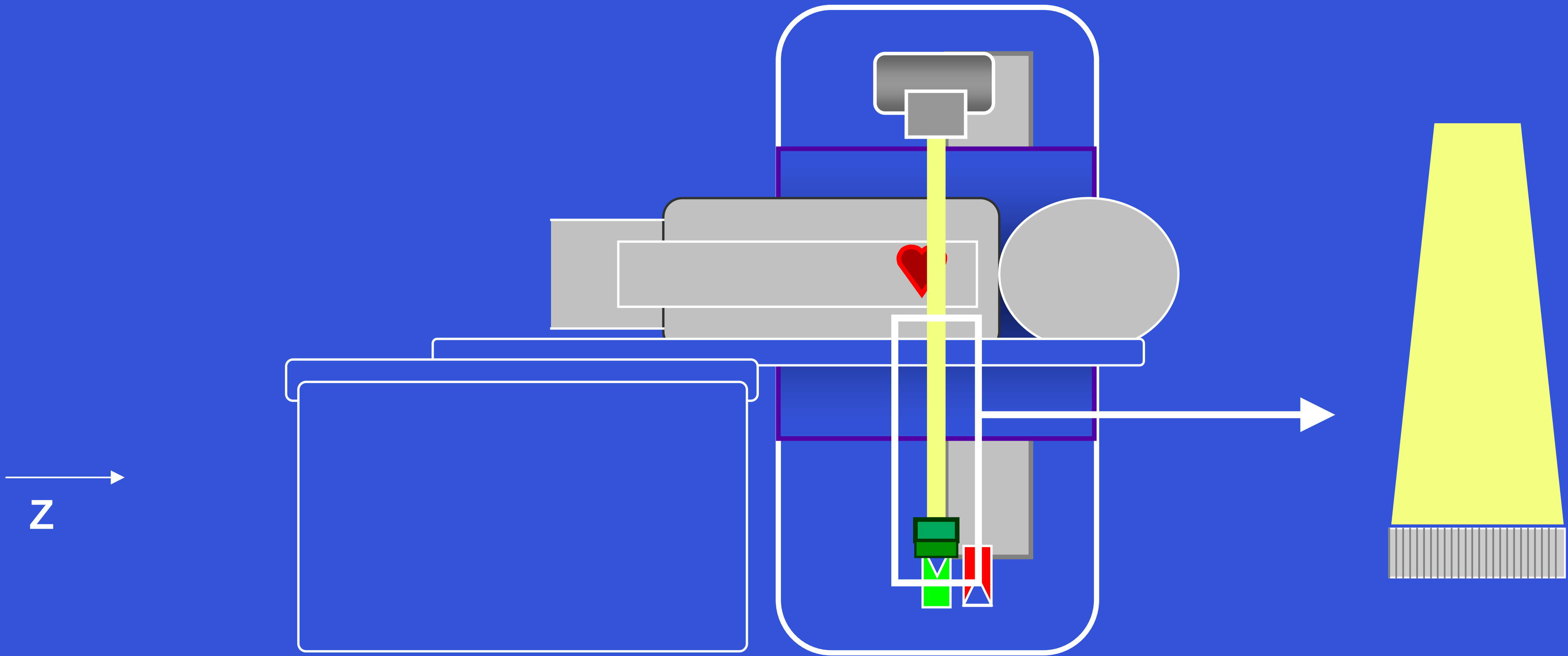
Multi-slice CT Scanners

- Tube and detectors rotate continuously around the patient
  - Slip rings transfer power and data to and from the gantry
  - Current rotation times down to 0.33, 0.4 sec



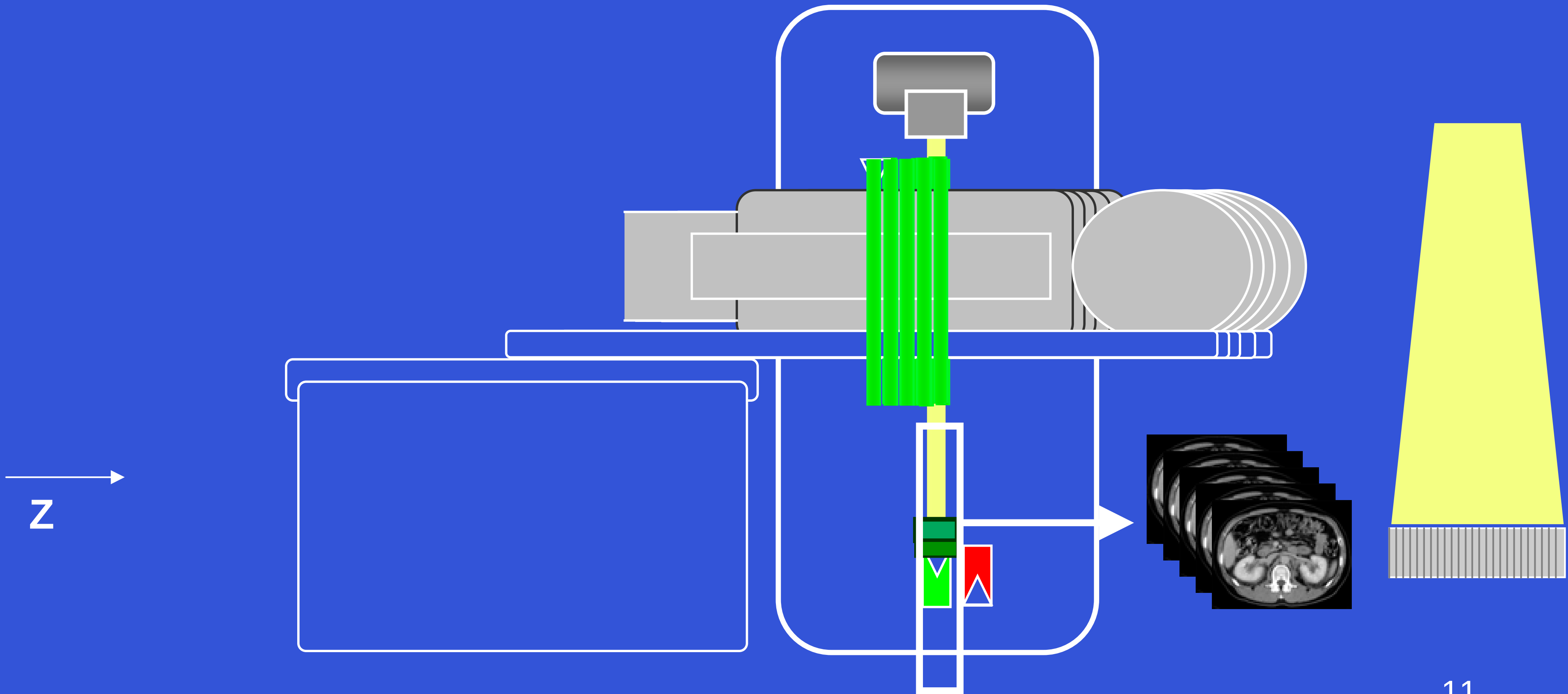
Multi-slice CT Scanners

- Beam widths (20 – 40 mm)
- 4, 16, 64 slice (+others) data acquisition



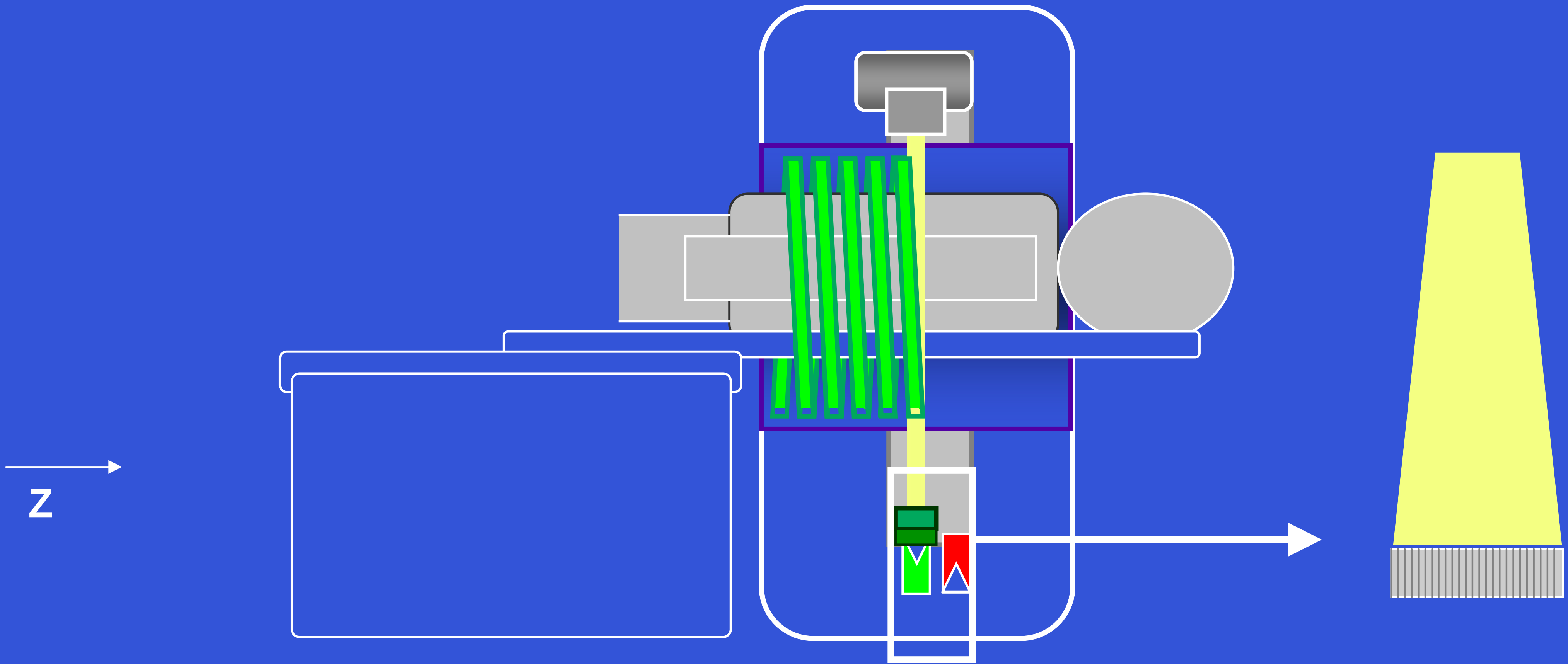
Multi-slice CT Scanners

- Axial acquisition
  - In multi-slice limited number of slices due to diverging beam (not reccomended above ~ 10 slices)



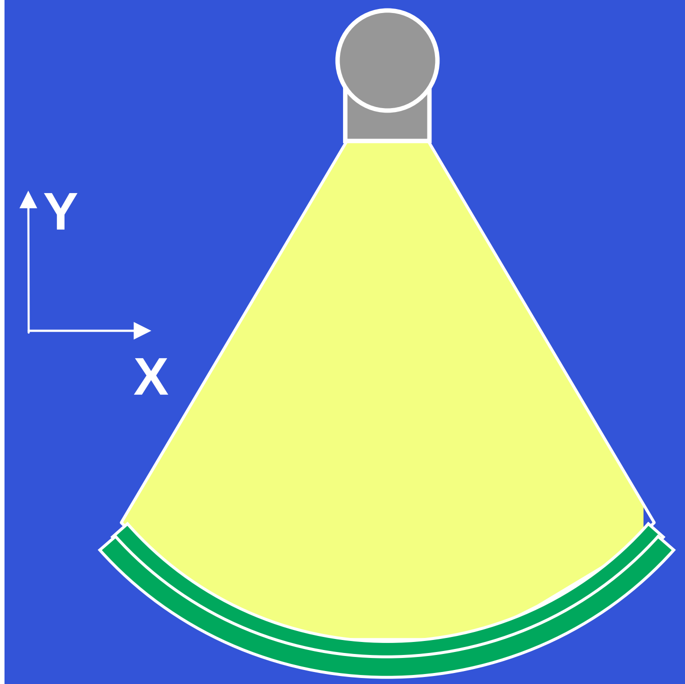
Multi-slice CT Scanners

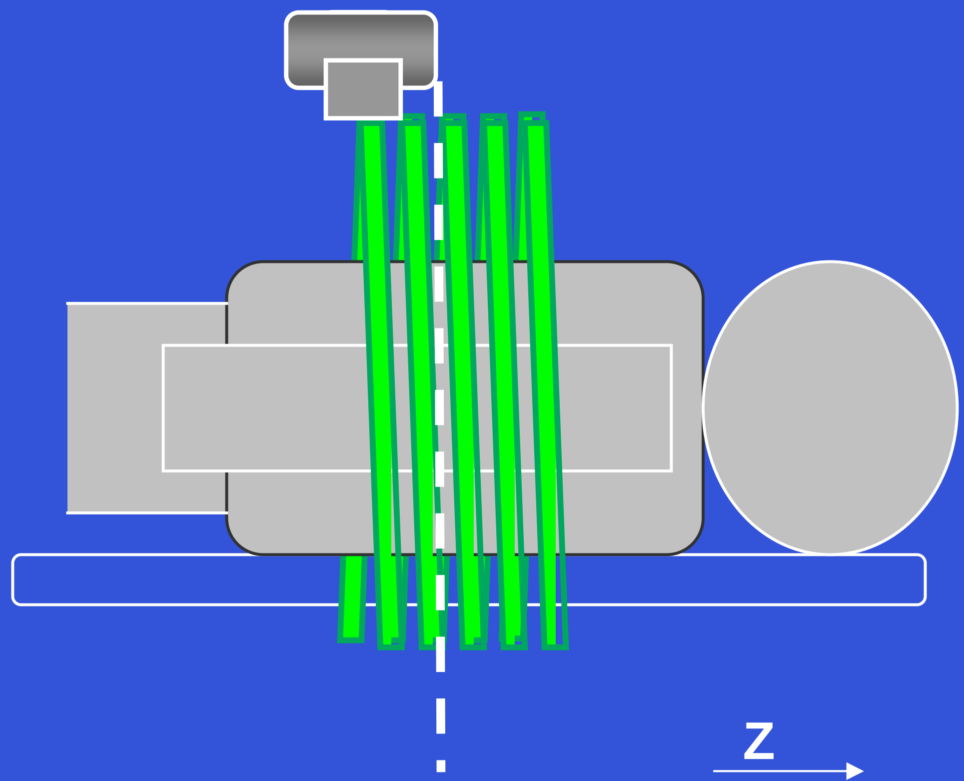
- Helical Acquisition
- Acquiring up to 64 slices of data simultaneously
  - 64 x 0.625 mm, 64 x 0.6 mm, 64 x 0.5 mm

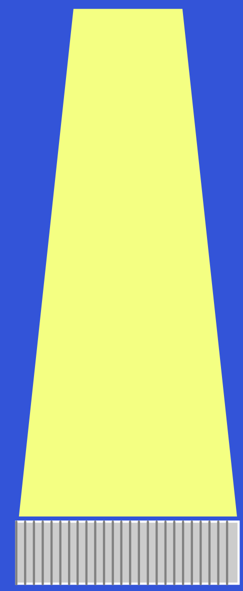


Multi-slice CT Scanners

- Attenuation data taken at different angles through the patient
- Images are reconstructed from the helical data set by interpolating projection data to the required reconstructed image position

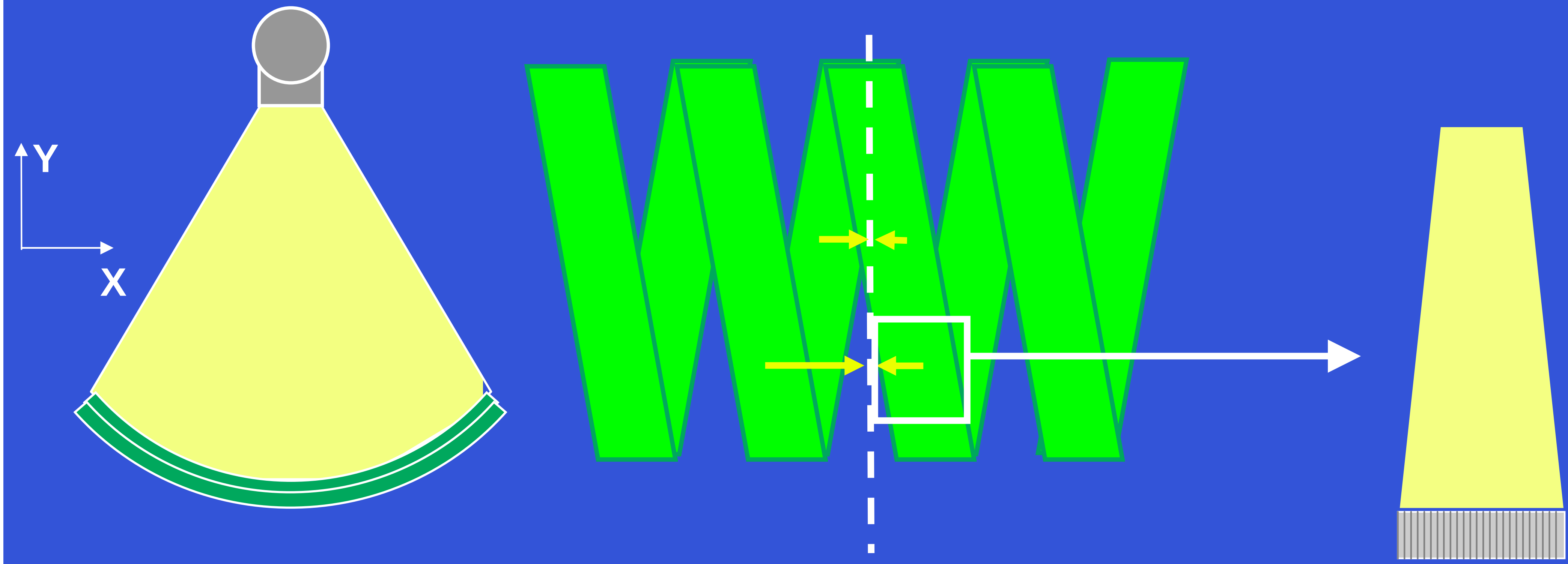






Multi-slice CT Scanners

- Attenuation data taken at different angles through the patient
- In helical acquisition, projection data is interpolated to the required reconstructed image position

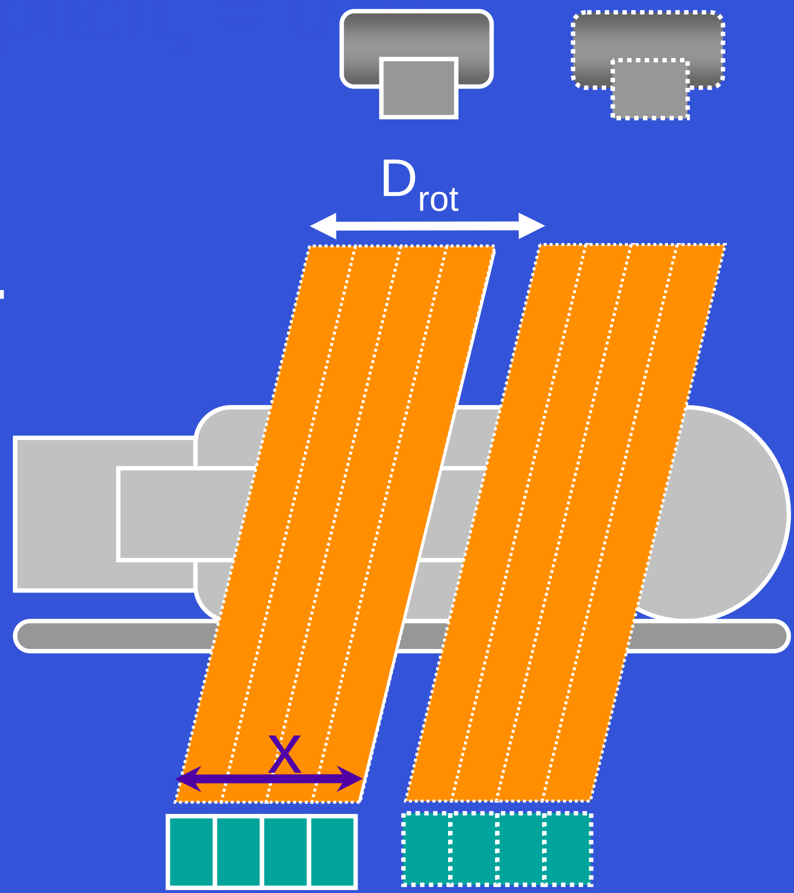


Multi-sector reconstruction and pitch

- Normal helical scanning performed at pitch ~ 1

$$\text{Pitch}_x = \frac{\text{table travel in one rotation}}{\text{beam width}}$$

$$\text{Pitch}_x = 1.25$$



$$\text{Pitch}_x = \frac{D_{rot}}{X}$$

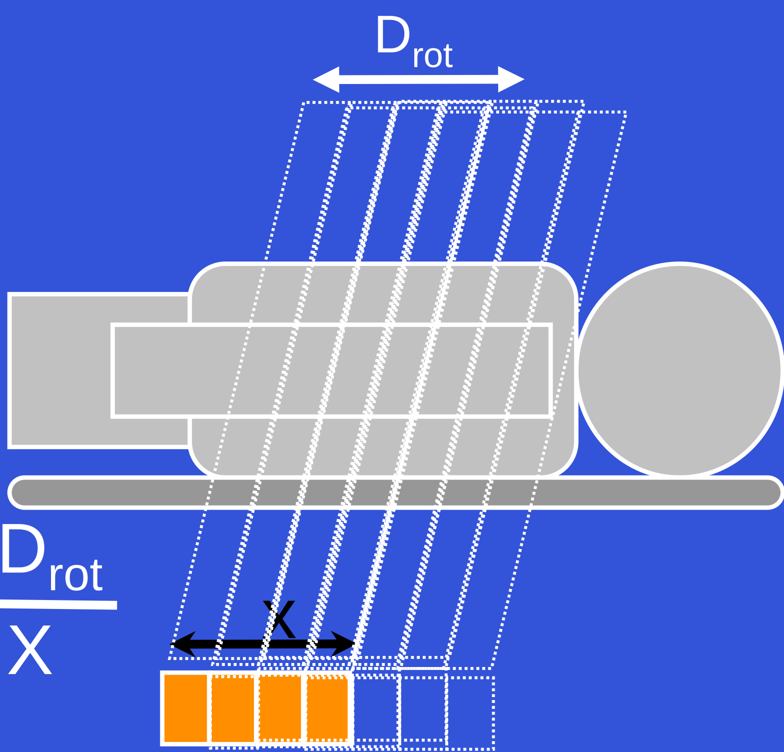
Multi-sector reconstruction and pitch

- Cardiac scanning generally performed at very low pitches ($pitch_x = 0.2$)

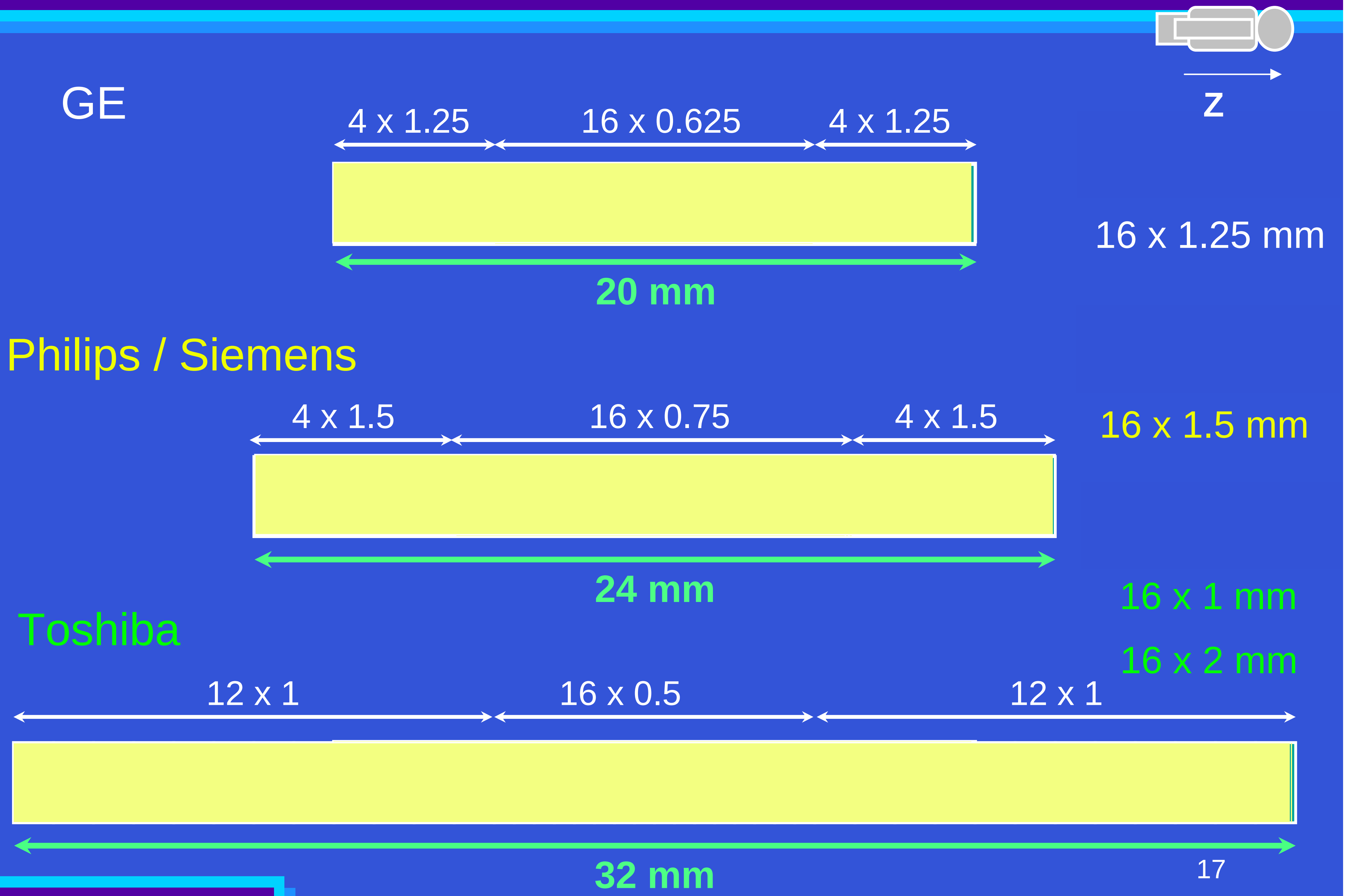
$$Pitch_x = \frac{\text{table travel in one rotation}}{\text{beam width}}$$

$$Pitch_x = 0.25$$

$$Pitch_x = \frac{D_{rot}}{X}$$

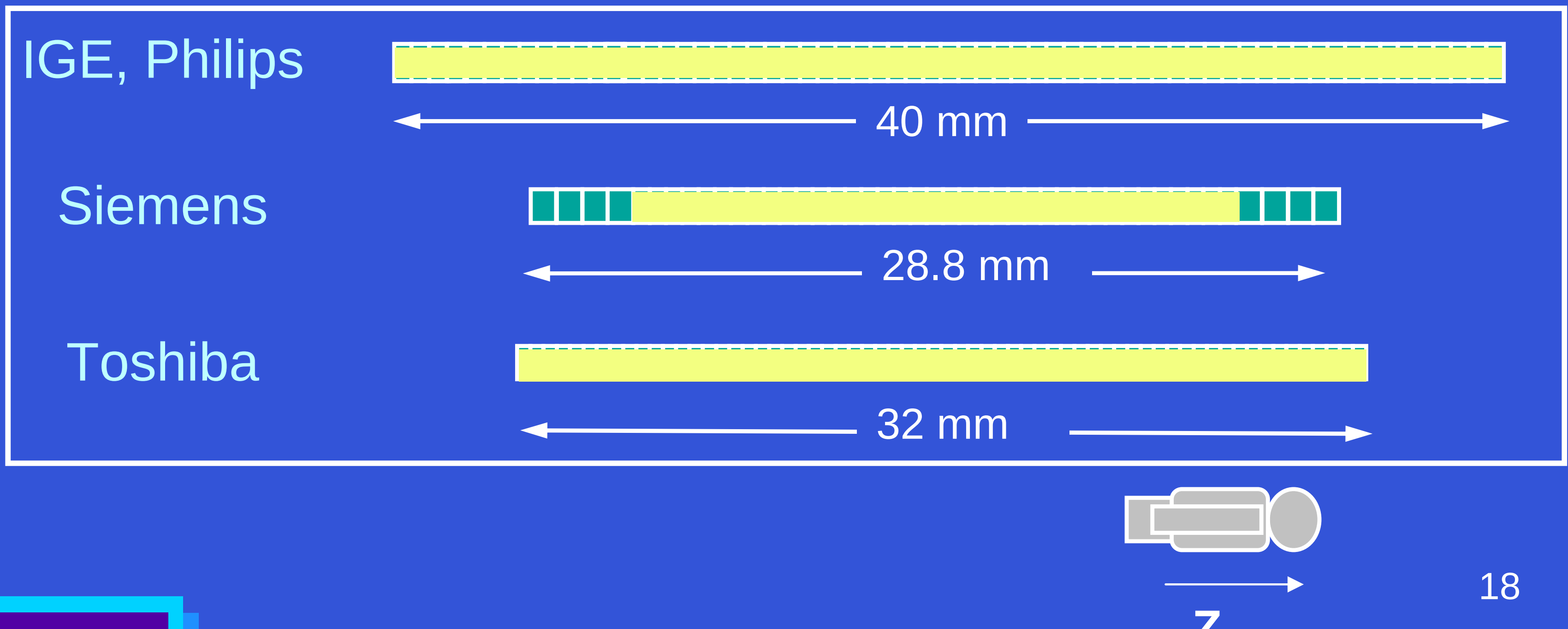


Detectors -16 Slice Scanners



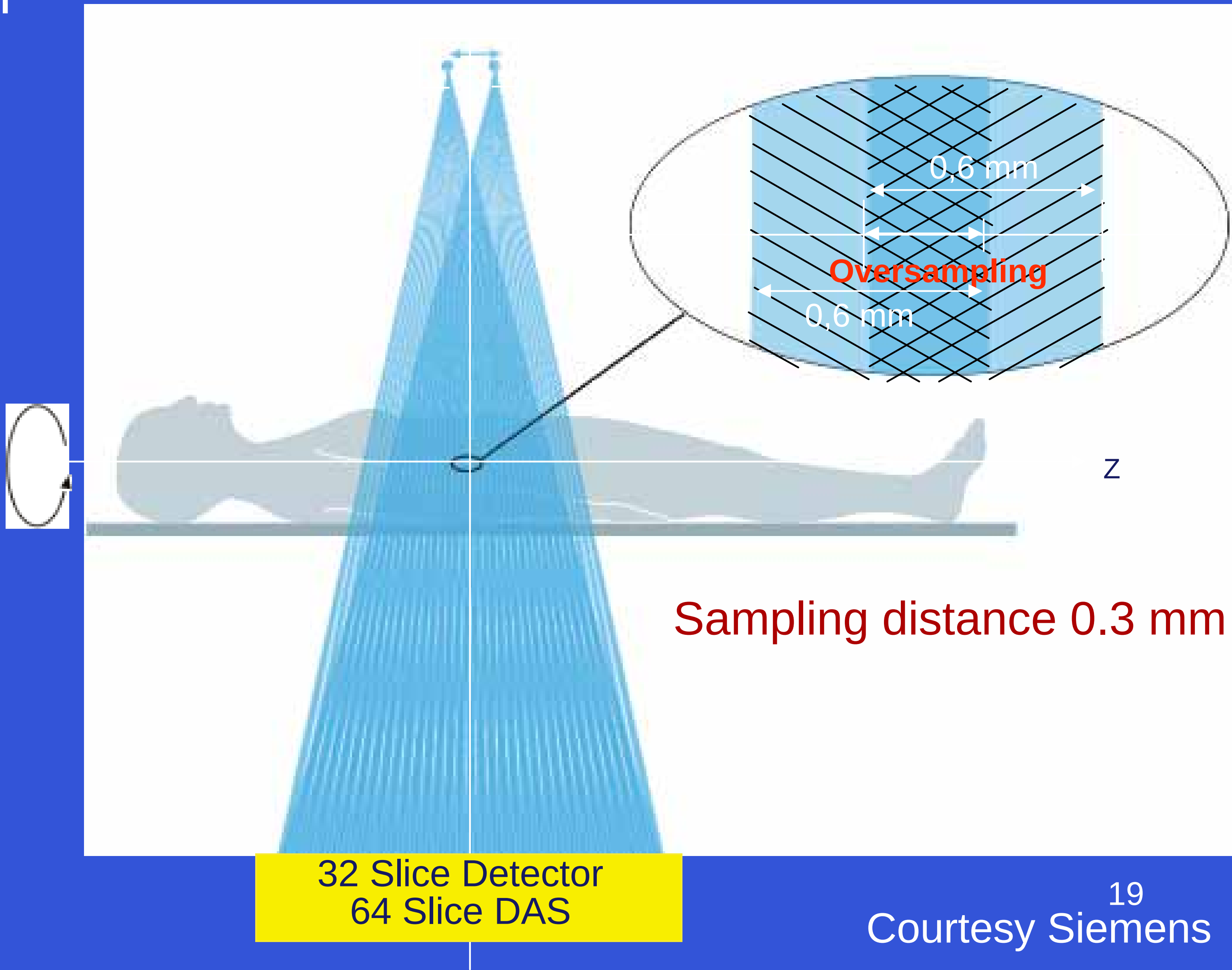
Detectors – 64 Slice Scanners

- GE LightSpeed 32, 64, Philips Brilliance 40, 64
  - 64 x 0.625mm, length = 40 mm
- Siemens Sensation 64
  - 32 x 0.6 (double sampled in z-axis to give 64) and 8 x 1.2, length = 28.8 mm, length for 0.6 mm elements = 19.2
- Toshiba Aquilion 32, 64
  - 64 x 0.5mm, length = 32 mm



Siemens

- 64-Slice CT: double z-Sampling: Overlap doubles information



Courtesy Siemens

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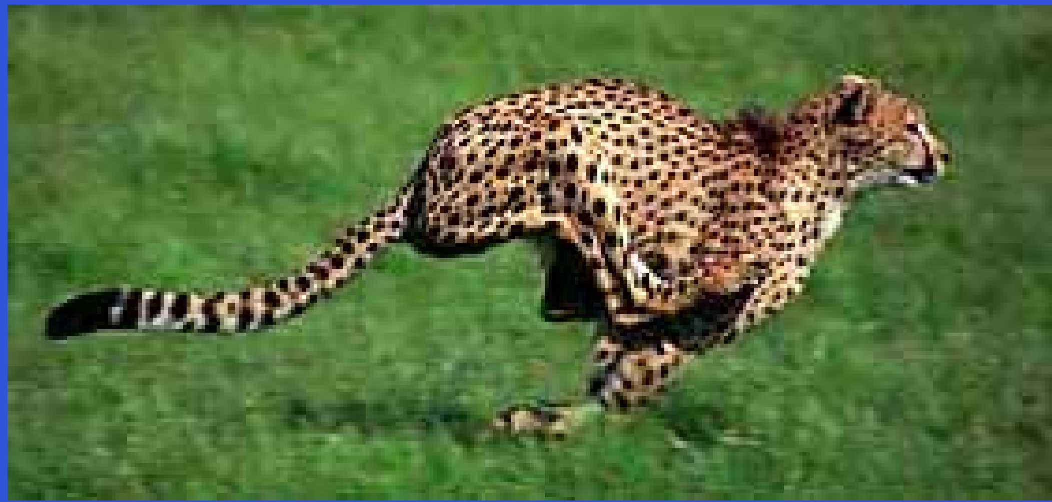
Imaging the heart

- 'Shutter speed'
- Coverage
  - Mis-registration



What are the challenges ?

- Moving object (60 -120 beat/min ie 1 -2 beat /sec)
  - Scanners ~ 1 – 2 rotation /sec
  - Vessels move at different times/rates

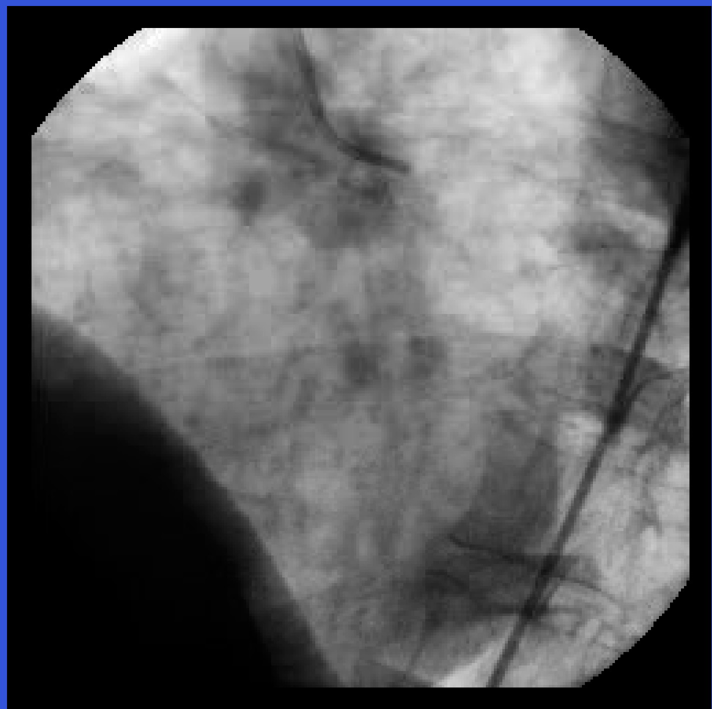
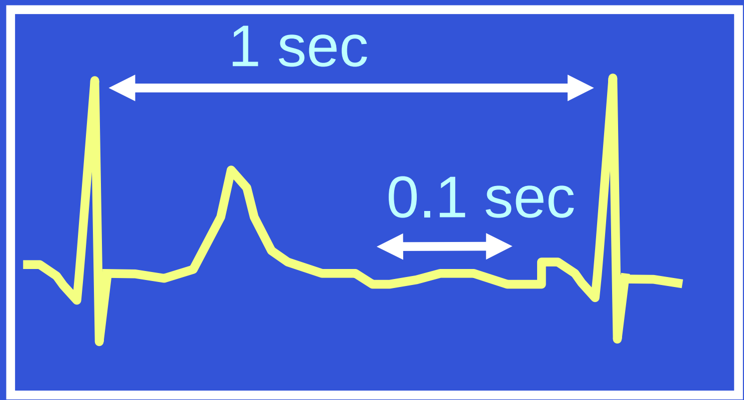


Image window

- Need a snap shot of ~100 ms, at heart rates ~ 60 bpm
  - For less than 1 mm movement, in 3-D, of a coronary artery at diastole
  - More strict criteria
    - reconstruction at more than one phase
    - small distal parts of CA
    - quantifying coronary stenoses
    - assessment of plaque

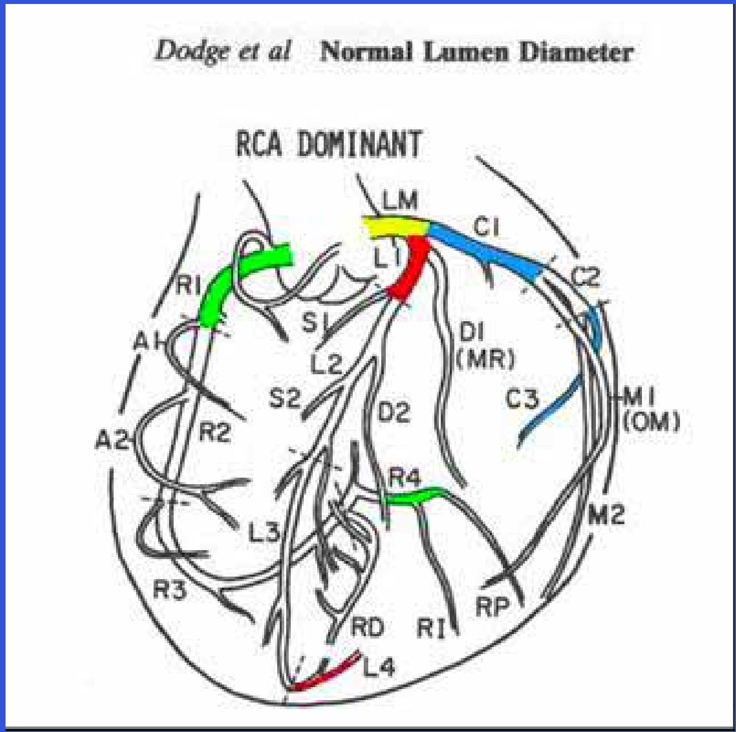


^ Roos et al BIR Jan 2006

What are the challenges ?

- Tortuous vessels, narrowing to < 1 mm
  - Good isotropic spatial resolution

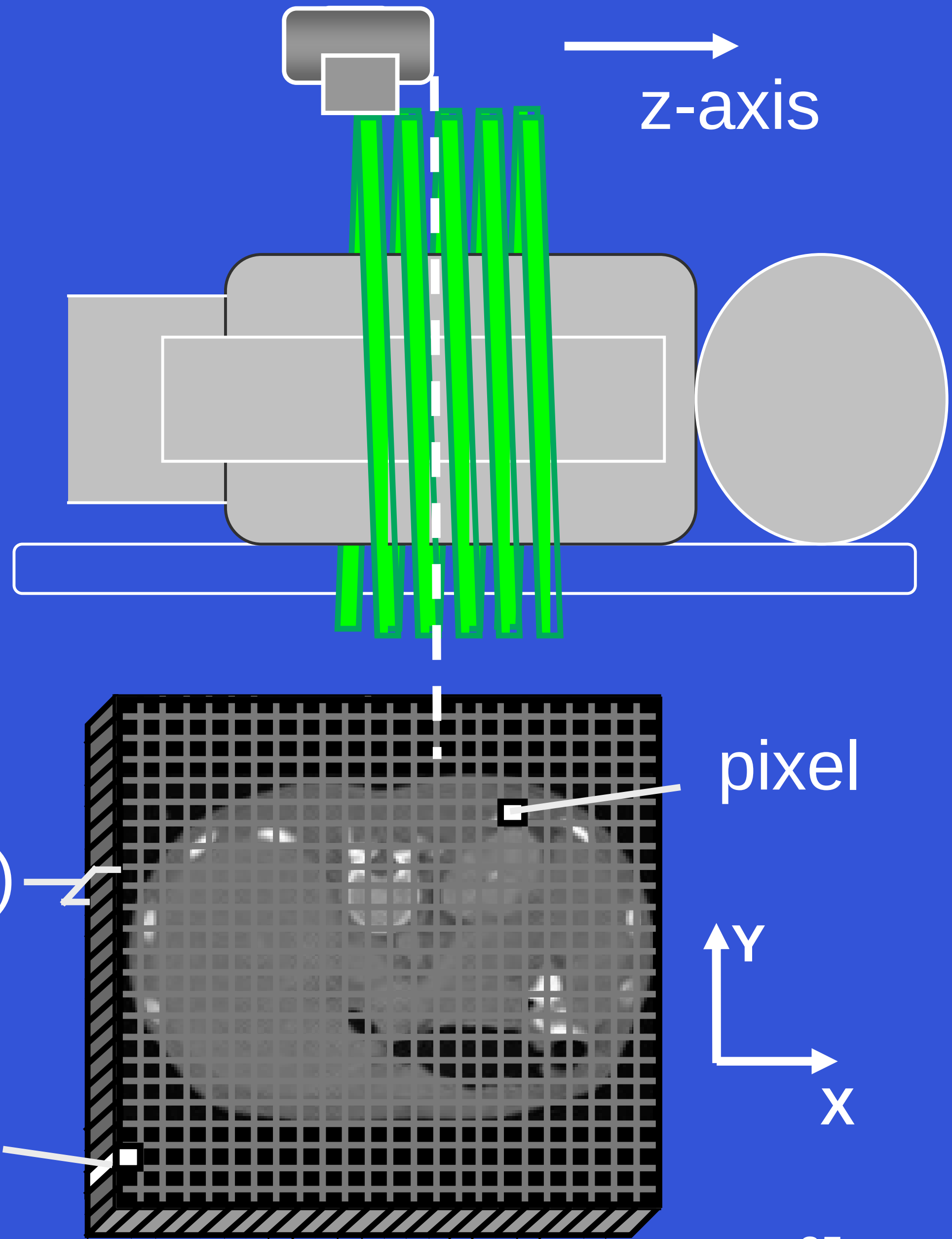
	Proximal segment mm	Distal segment mm
LM	4.3	-
LAD	3.5	0.8
LCX	3.2	1.3
RCA	3.7	1.8

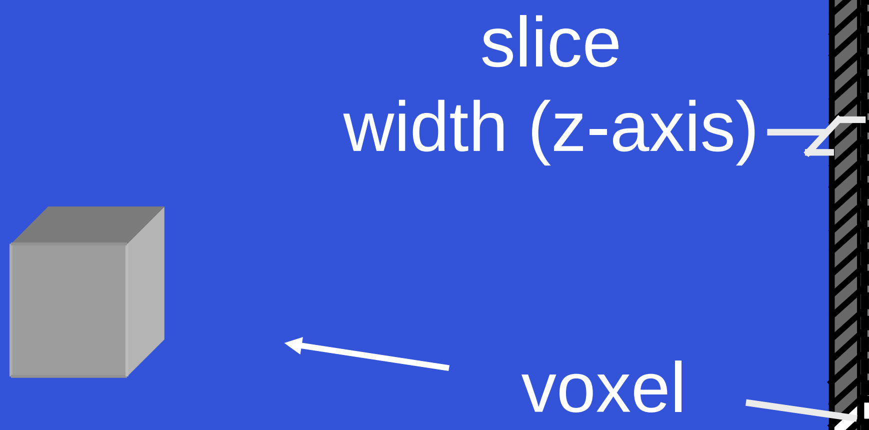


Lumen diameter of normal coronary artery segments J.T. Dodge et al., Circulation, 1992, 86:232-246

Spatial Resolution

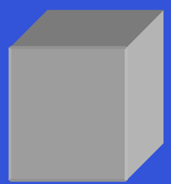
- 3-D resolution of image
  - In-plane
  - Z-axis (slice thickness)
- Isotropic resolution
  - Voxel equal sided





Spatial Resolution

- In-plane (X-Y) determined by detector size, sampling, convolution kernel (+ many other factors)
- Z-axis determined by detector size and sampling
- Actual perceived resolution depends on heart motion



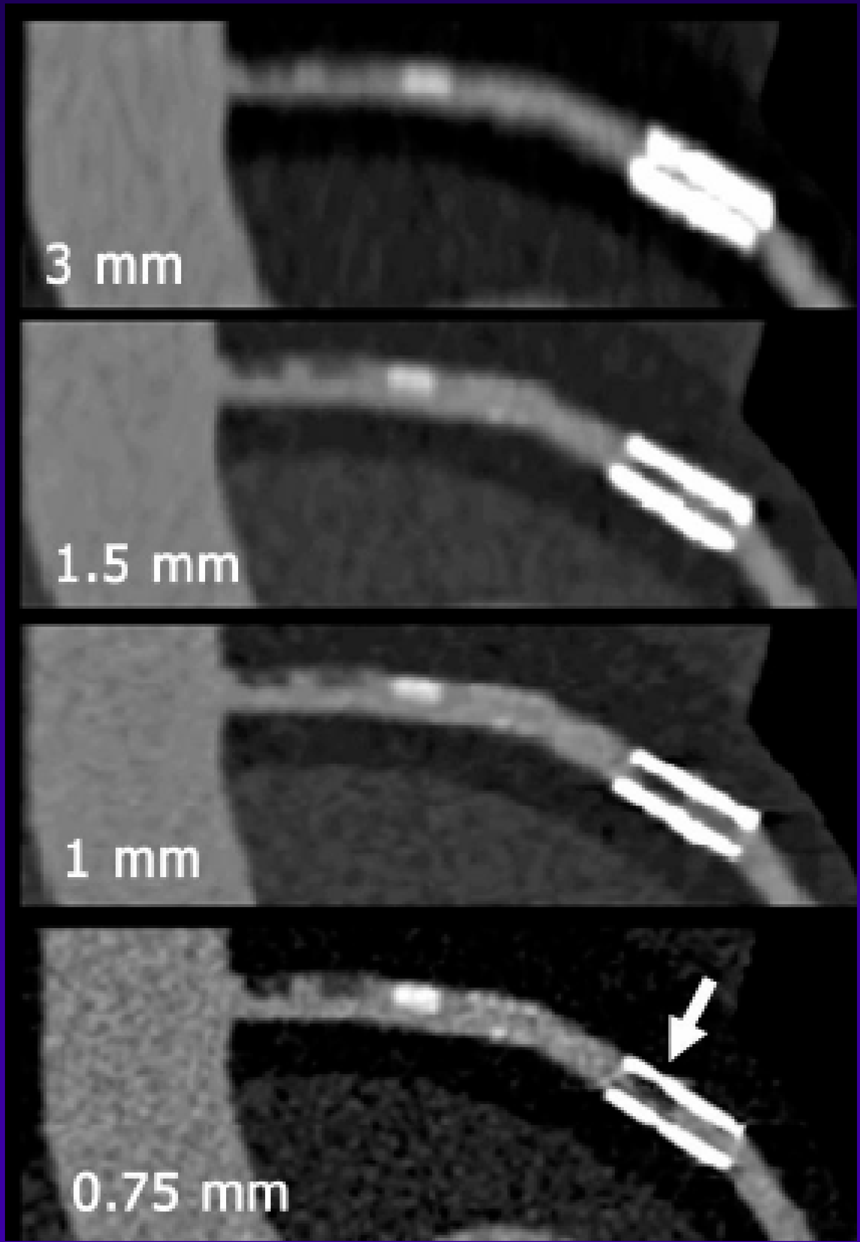
In plane

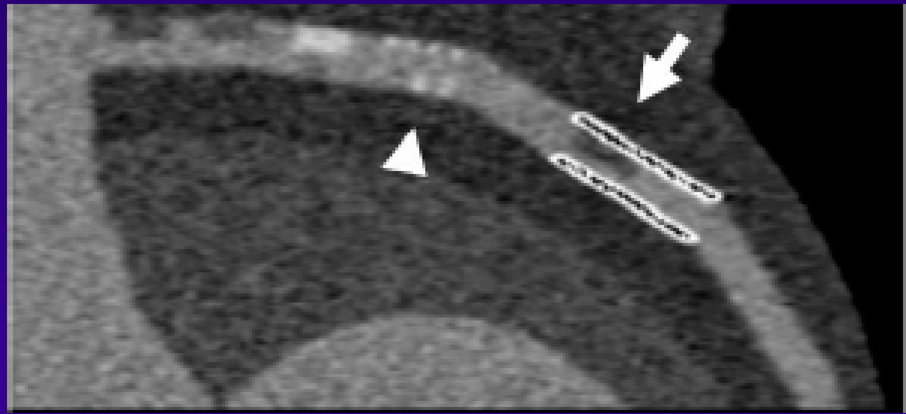
Standard resolution	~ 0.6 mm
High resolution	~ 0.4 mm

Z-Axis

Down to ~ 0.4 mm

Spatial Resolution

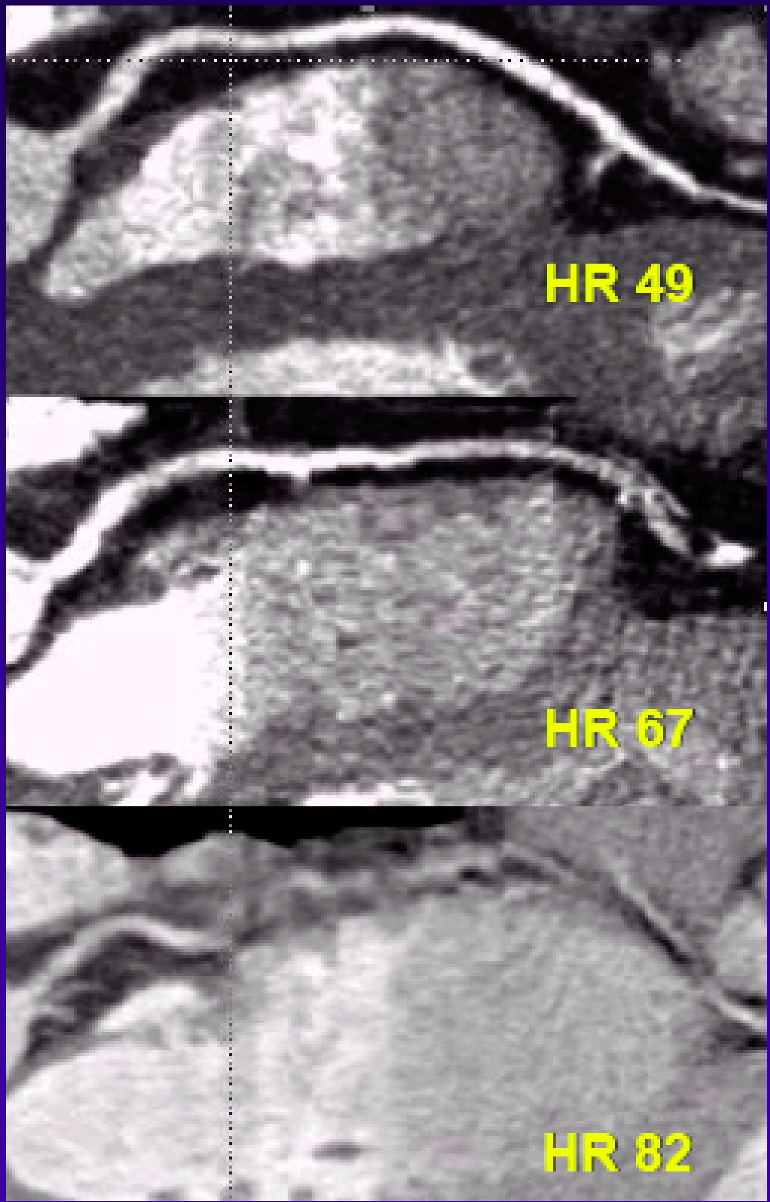




Flat Panel Technology

Flohr, Herz '03

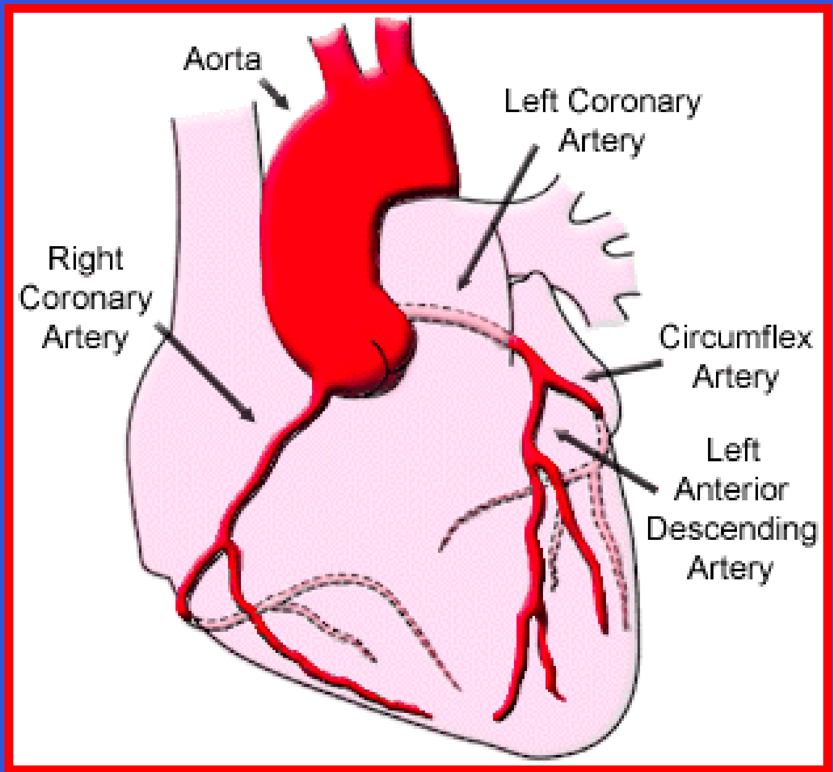
Spatial Resolution

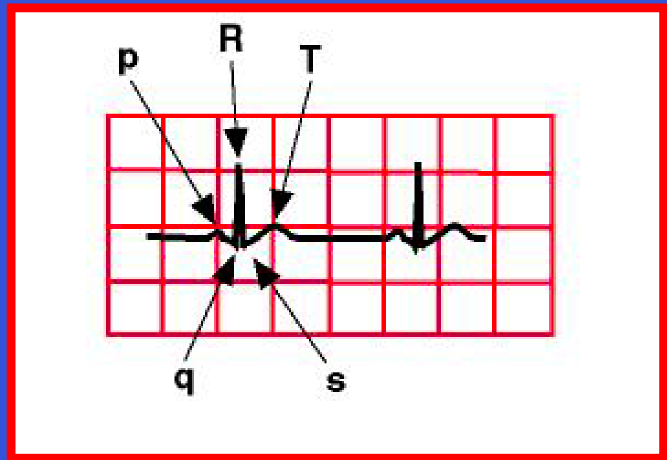


Nieman, Heart '02

Flohr, Herz '03

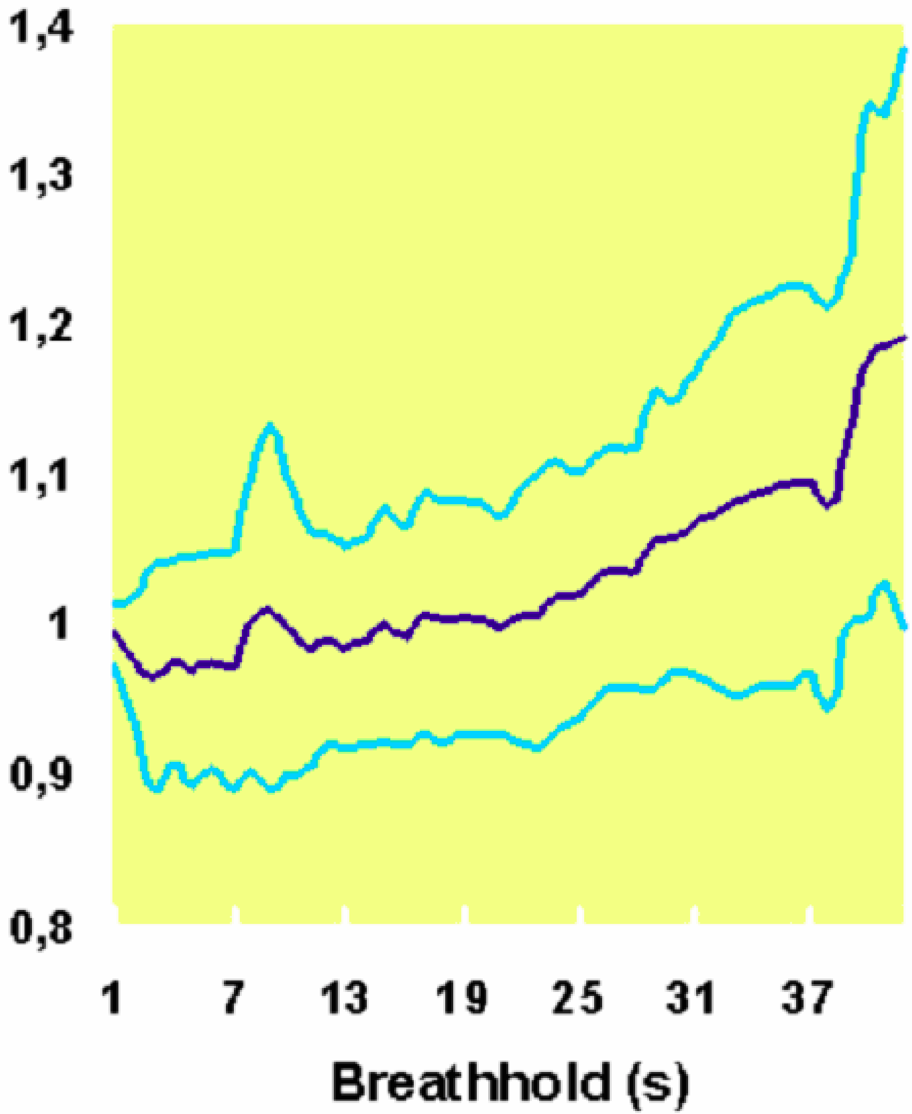
What are the challenges ?

- ~ 12 cm in length
  - To image heart in one breath-hold
- ~ Varying and irregular heart rates
  - Few beats
- 



Heart Rate and Breath-hold

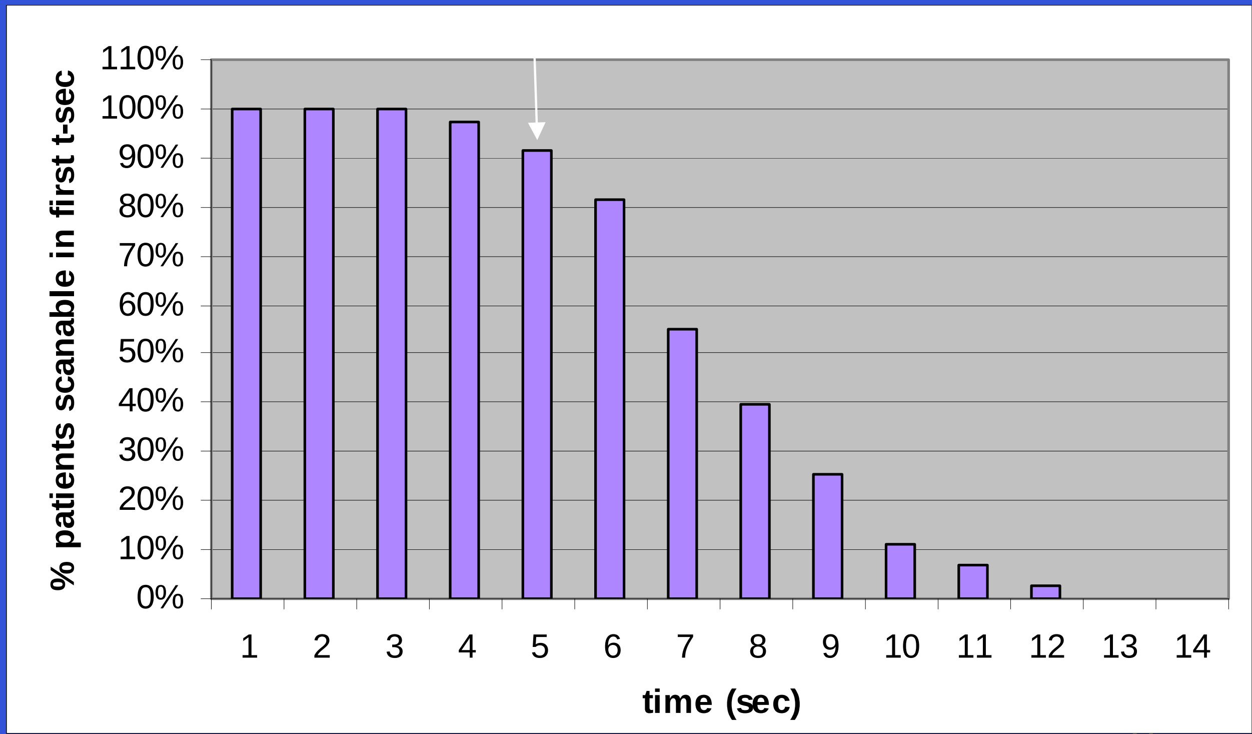
HR (t) / HR (t_0)



Nieman, Heart '02

Stability with Time

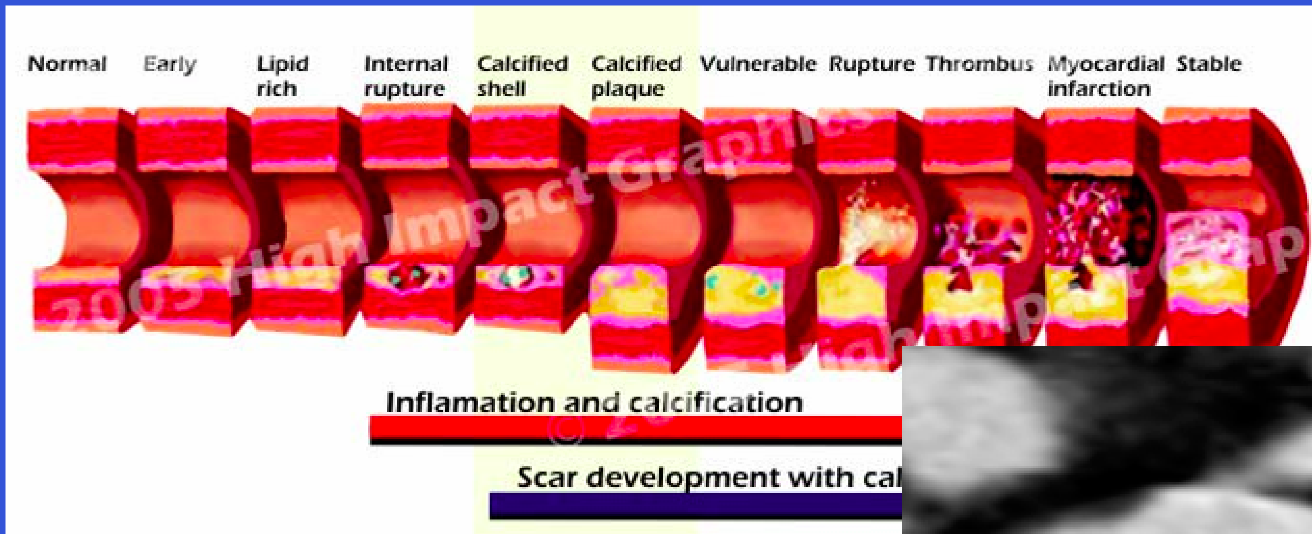
- 100 Cardiac patients
  - evaluated on LightSpeed 16 and Pro 16 scanners
  - Average scan time 20 sec, heart rates ranged from 40 to 110 bpm
- % of Case with Stable Heart Rate
  - 4 beat 97%
  - 5 beat 92%
  - 8 beat 39%
  - 10 beat 10%



Courtesy GE

What are the challenges ?

- Good low contrast resolution (plaque)
  - require noise levels equivalent to current CT imaging

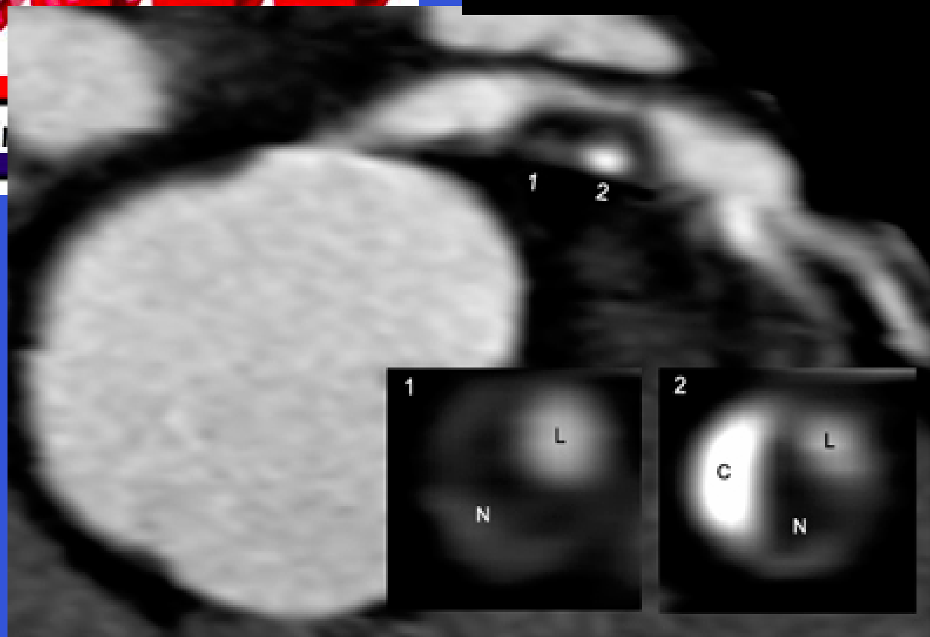


L – Vessel Lumen

N – Non-calcified plaque

C – Calcified plaque

Lumen:	250 HU
Lipid:	30 HU
Fibrous:	80 HU
Calcified:	500 HU

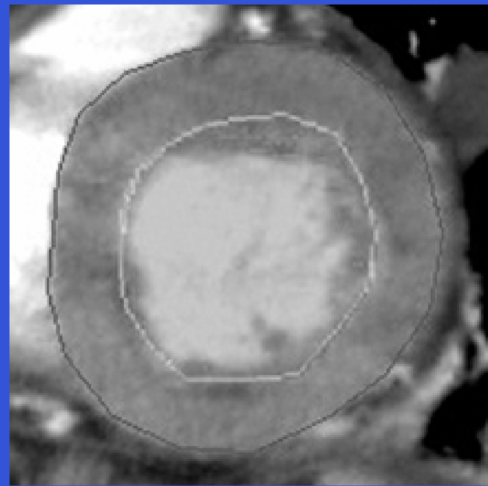


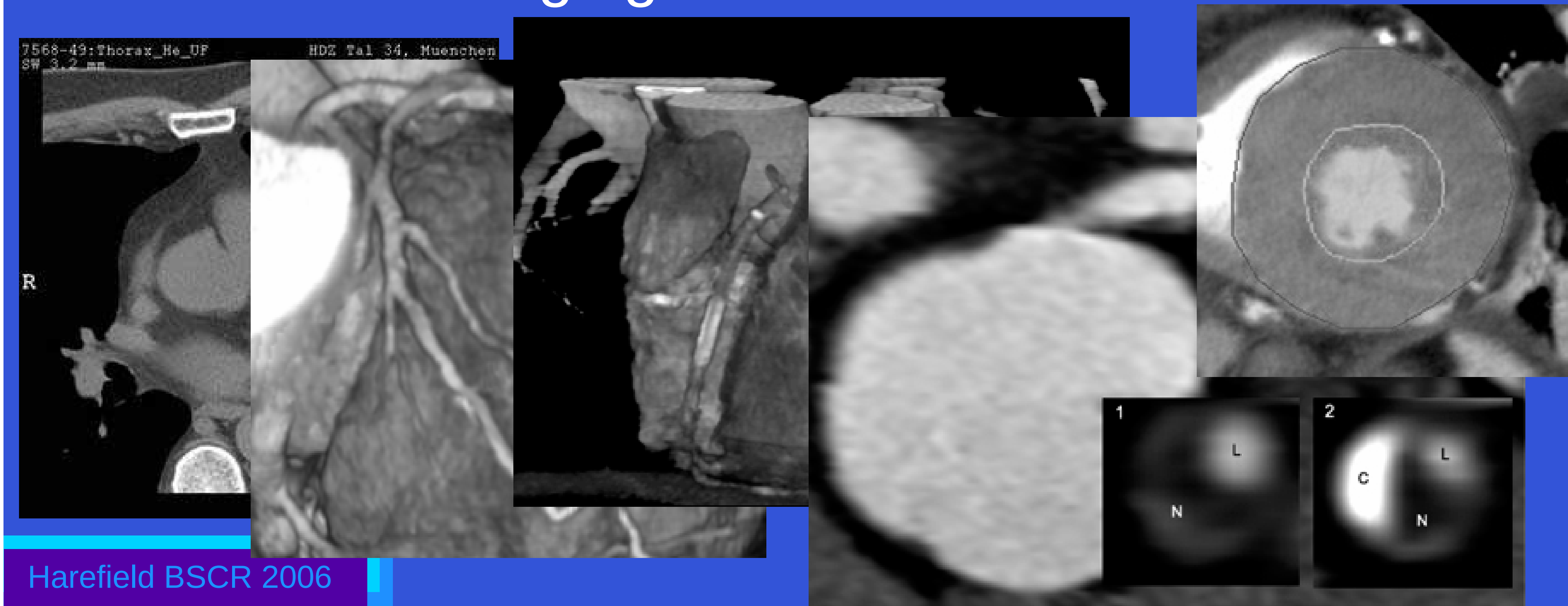
What are the challenges ?

- Requirements for imaging the heart
  - Image for <100ms
  - Isotropic resolution < ~ 1 mm
  - Low contrast differentiation
  - One breath hold and few beats

Applications of cardiac CT

- Calcium scoring
- Coronary angiography
- Follow-up of interventional work
- Coronary plaque imaging
- Functional imaging





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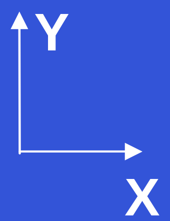
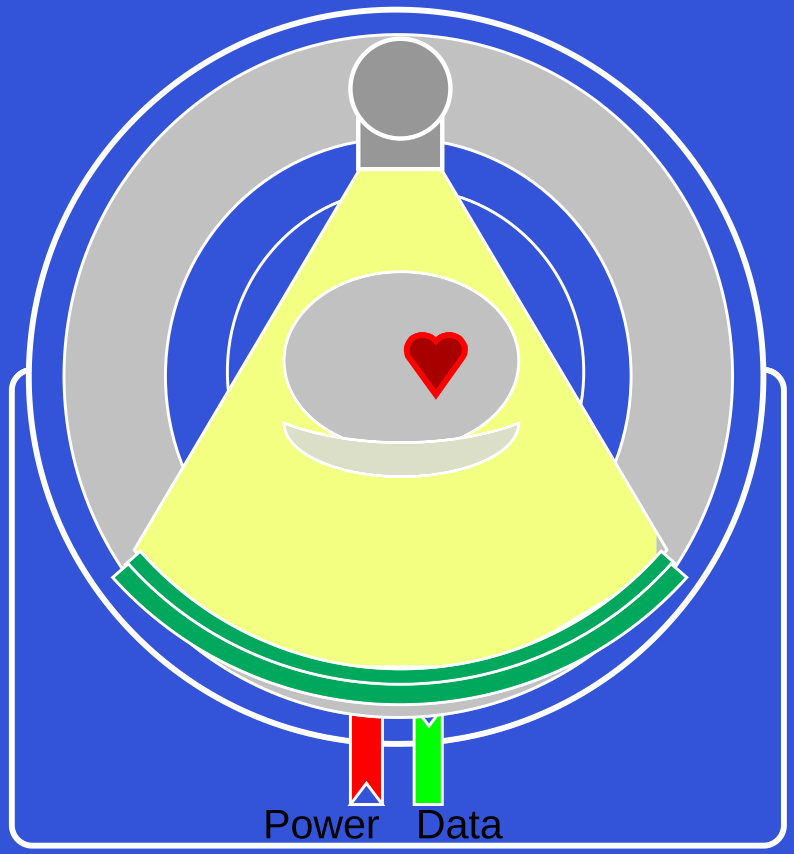
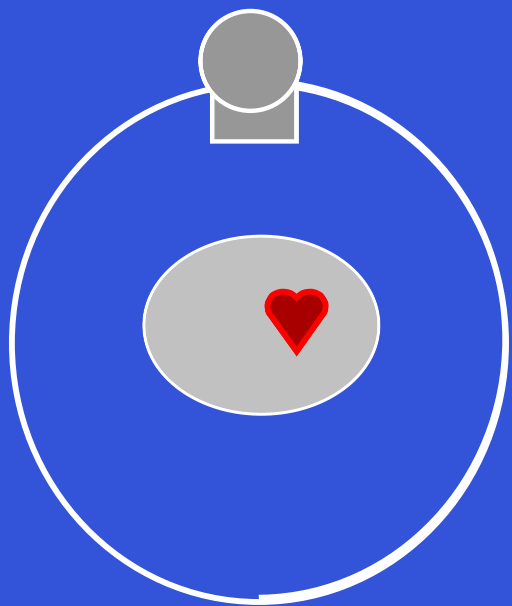
CT imaging requirements

- To reconstruct images
  - 180° of scan data is required (180 ° + fan angle)
- Effective image acquisition time is ~ 0.5 x rotation time
  - ~ 250 ms (for .5s)





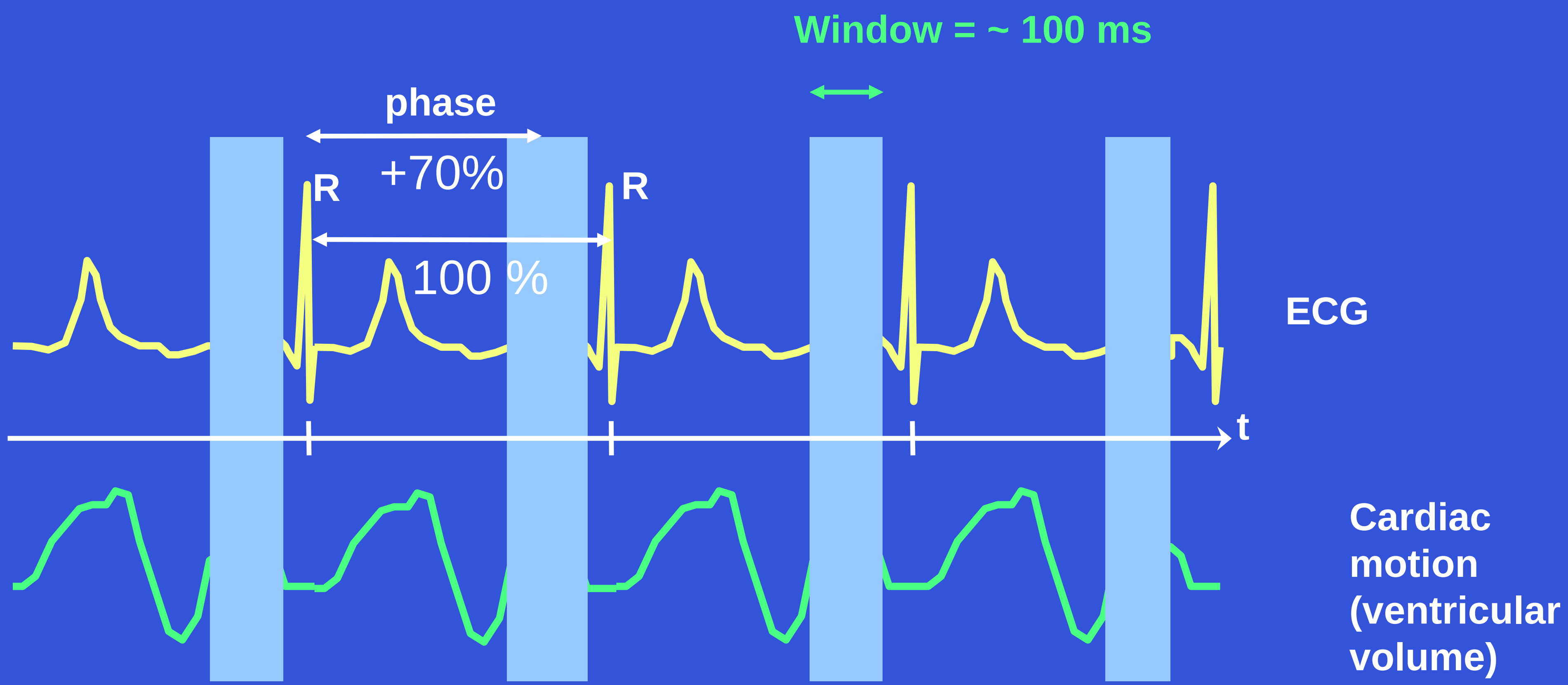


CT Imaging Requirements

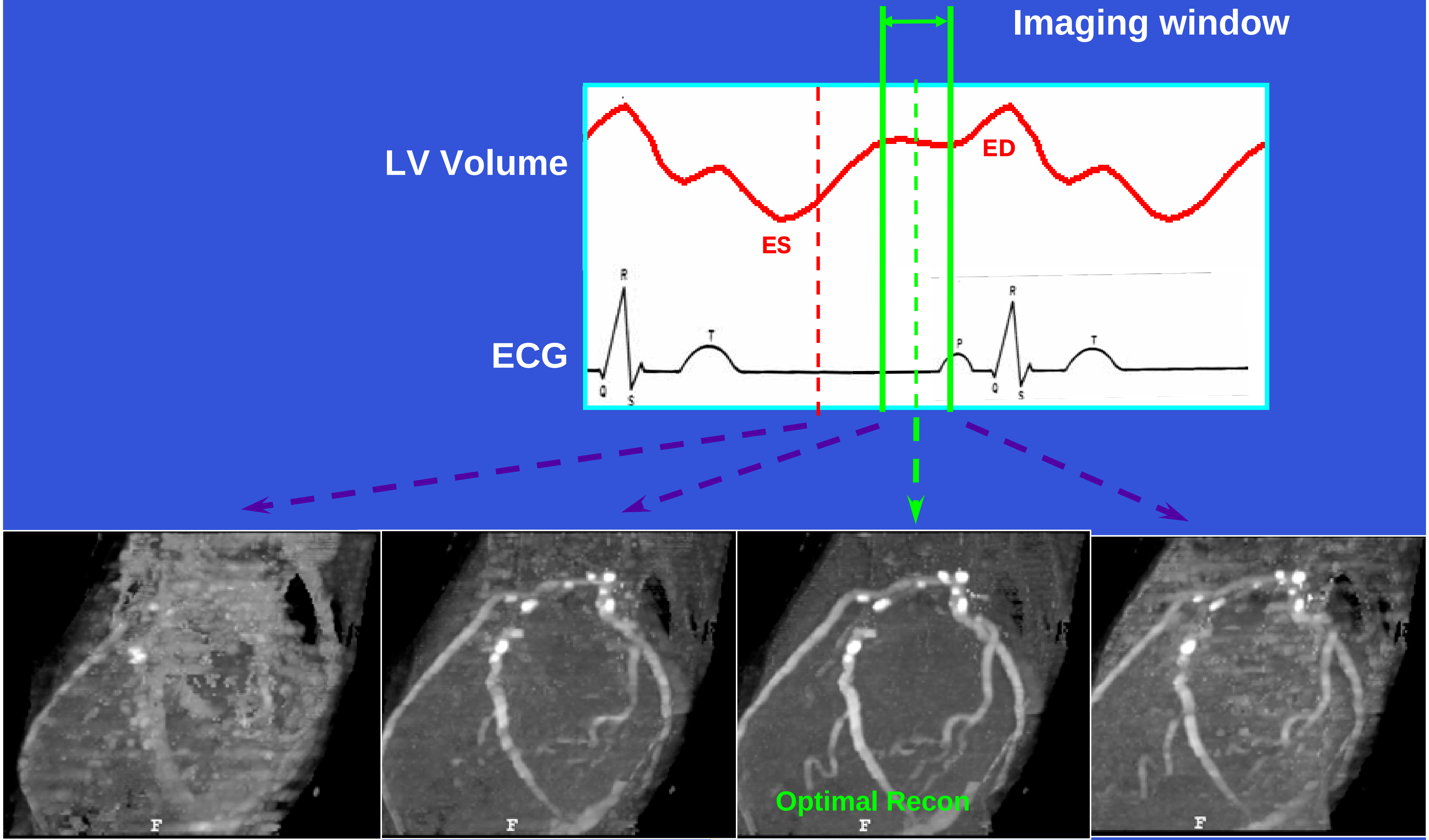
- ECG
  - ECG is monitored before and throughout scan
- Contrast
  - Uniform distribution of contrast media throughout study
- Beta – blockers
  - Sometimes required to lower heart rate

Principles of Data Acquisition

- Imaging window during period of least cardiac motion
  - ~ 100 ms at 60 bpm ie ~ 10% of cardiac cycle
- Position defined in terms of percentage of phase relative to R-R interval (+/- %)

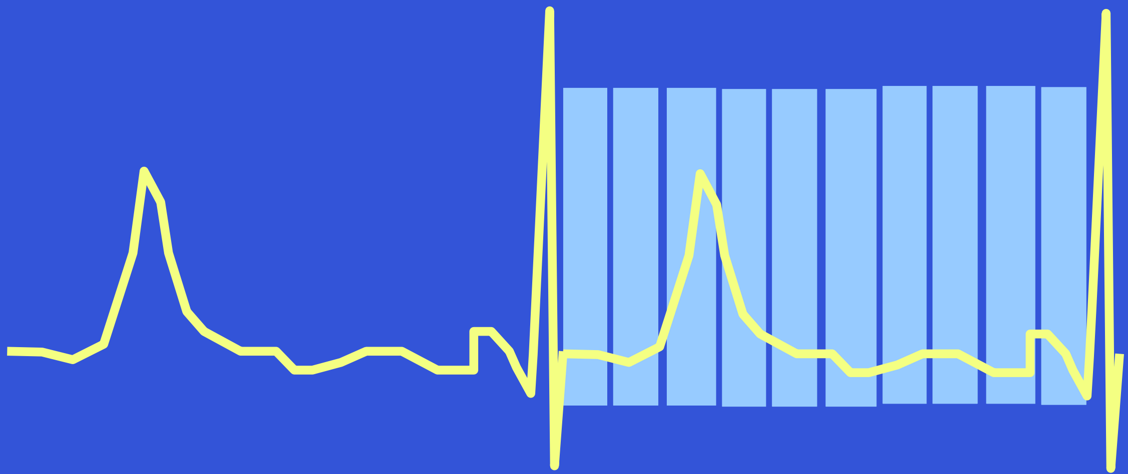


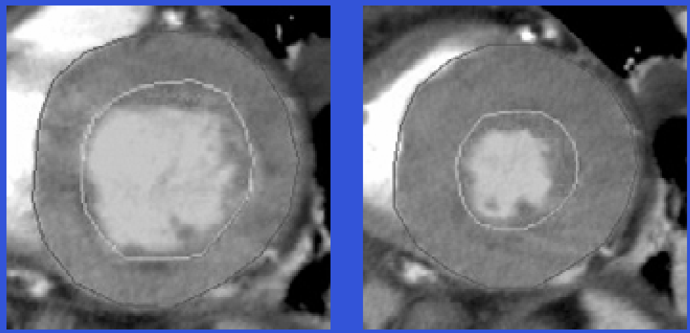
Choosing the best phase for reconstruction



Phase of reconstruction

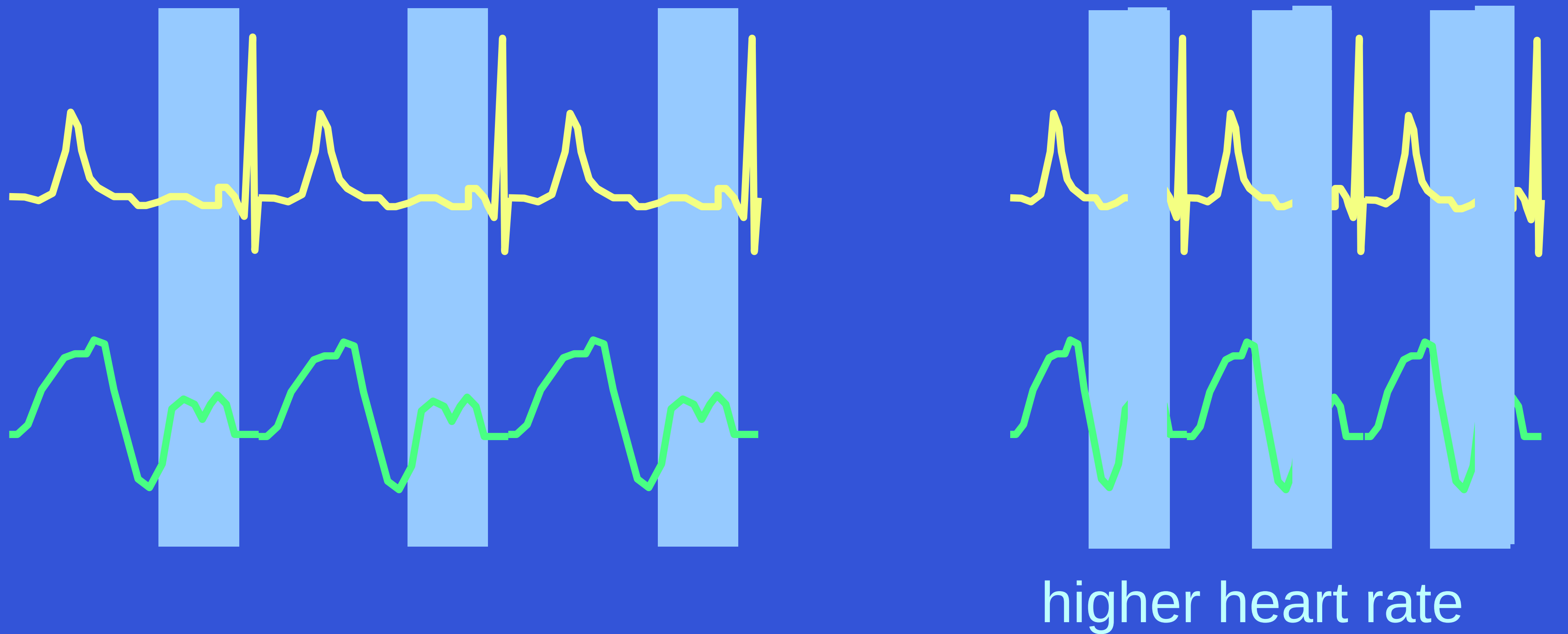
- Actual phase depends on particular area of interest
  - ~70% of the R-R interval for LCA
  - sometimes 40% for the RCA
- Many phases can be reconstructed
  - eg can be reconstructed at 5, or 10% intervals for functional imaging





Principles of Data Acquisition

- Image window may be too wide for higher heart rates

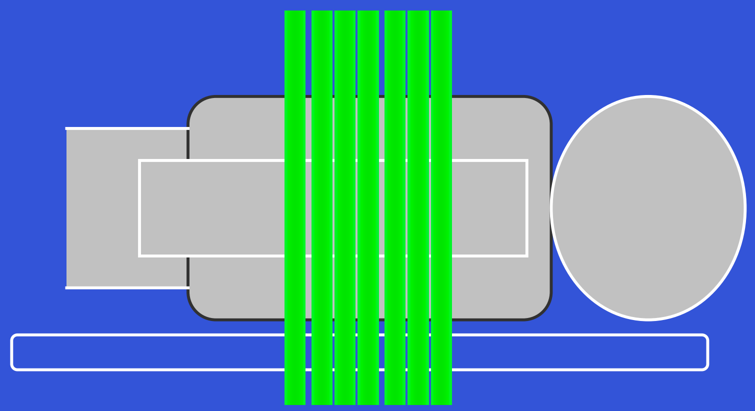


- At higher heart rate 100 ms window covers region of greater movement $\Rightarrow$ Need smaller temporal window

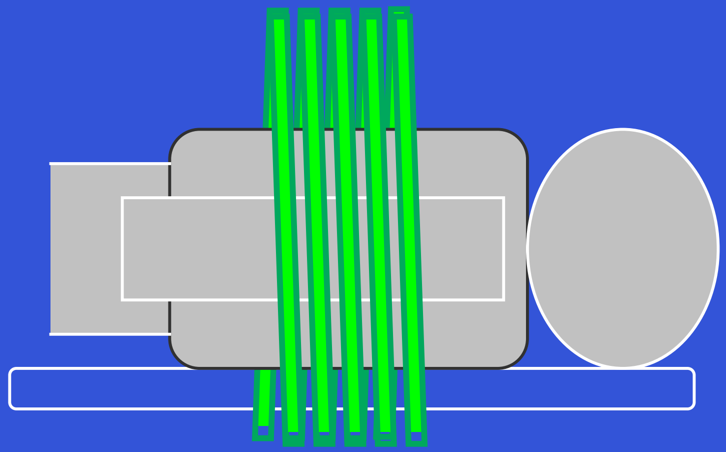
Image acquisition

- Cardiac CT data are acquired in two main modes

Sequential, 'stop and shoot'
Prospective ECG gating
(ECG triggering)



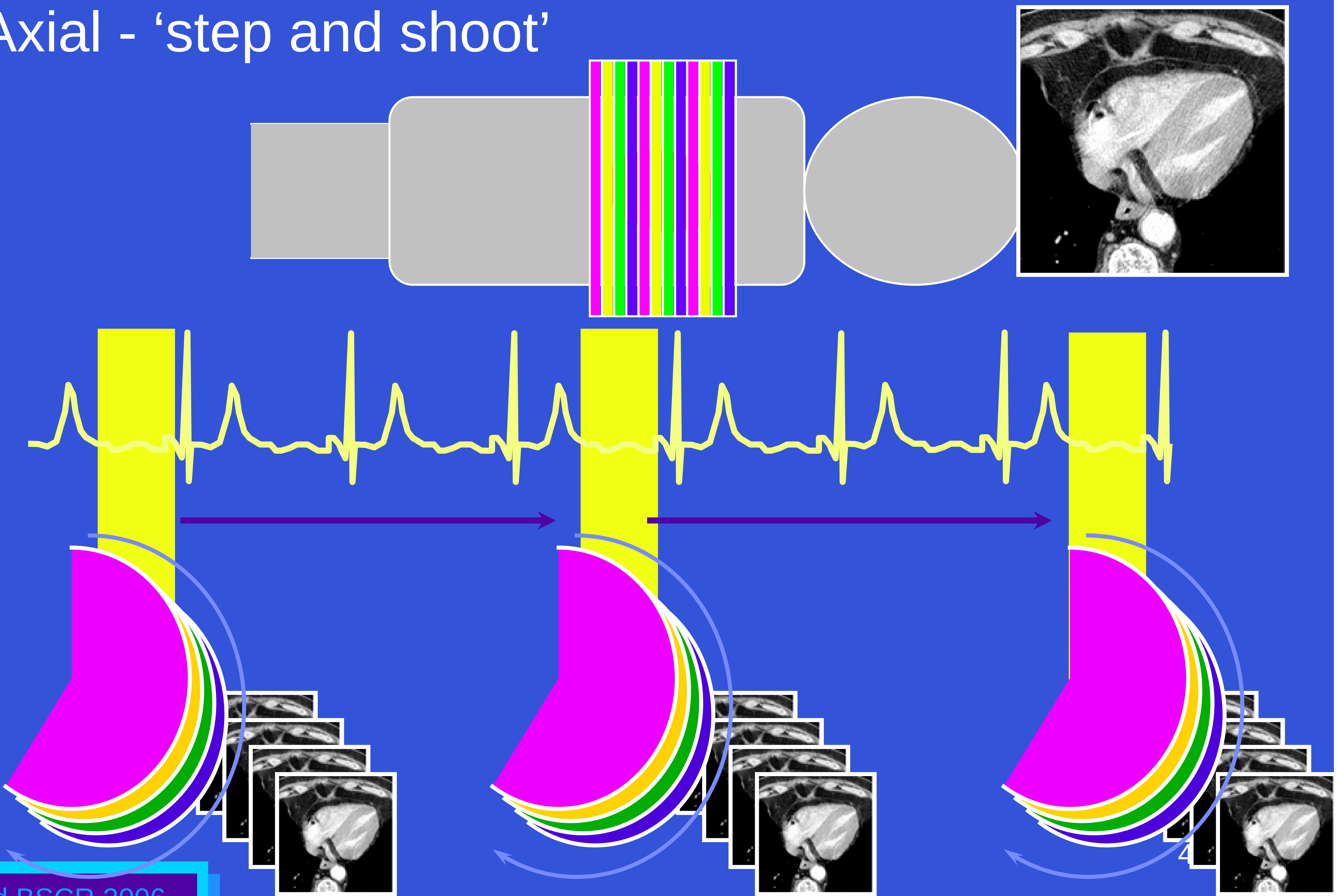
Helical
Retrospective ECG gating



Z

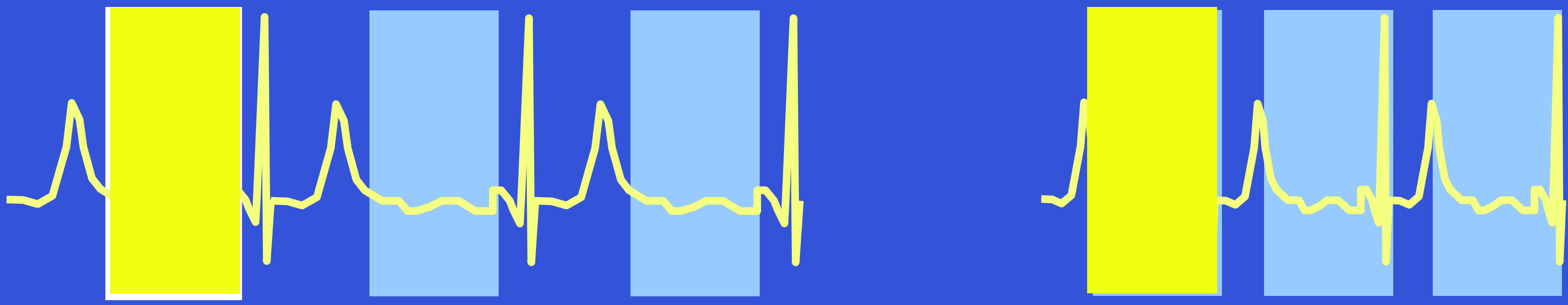
Prospectively gated cardiac CT

- Axial - ‘step and shoot’



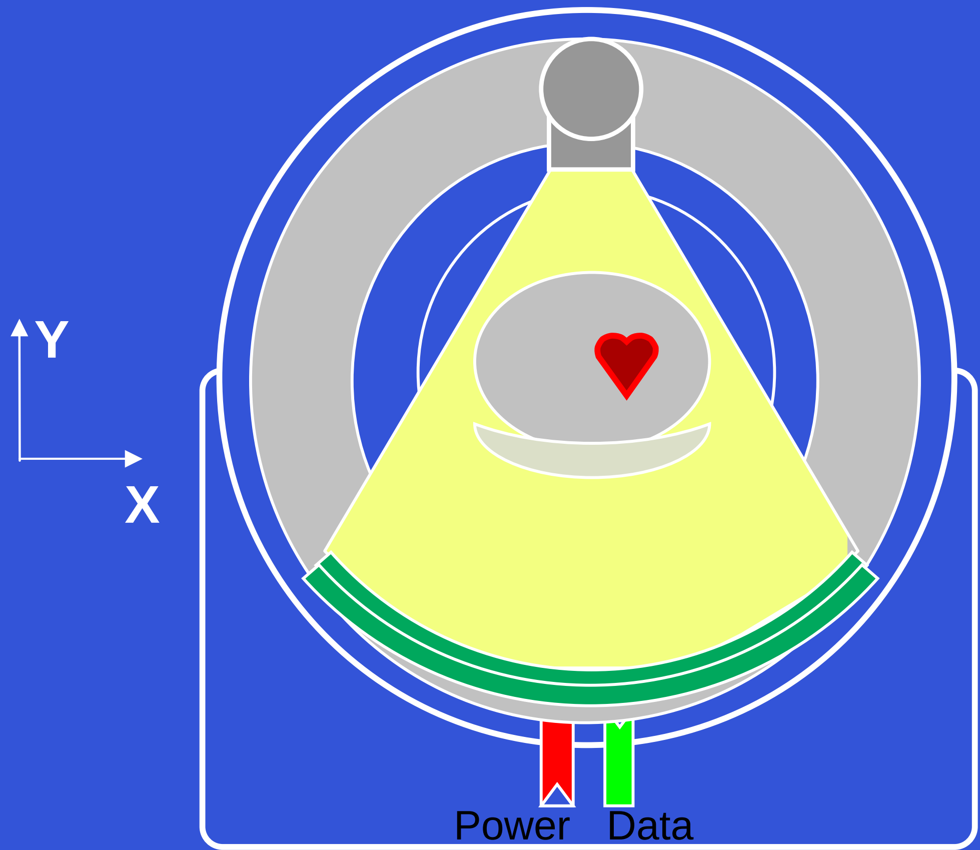
Prospective gating – ECG Triggering

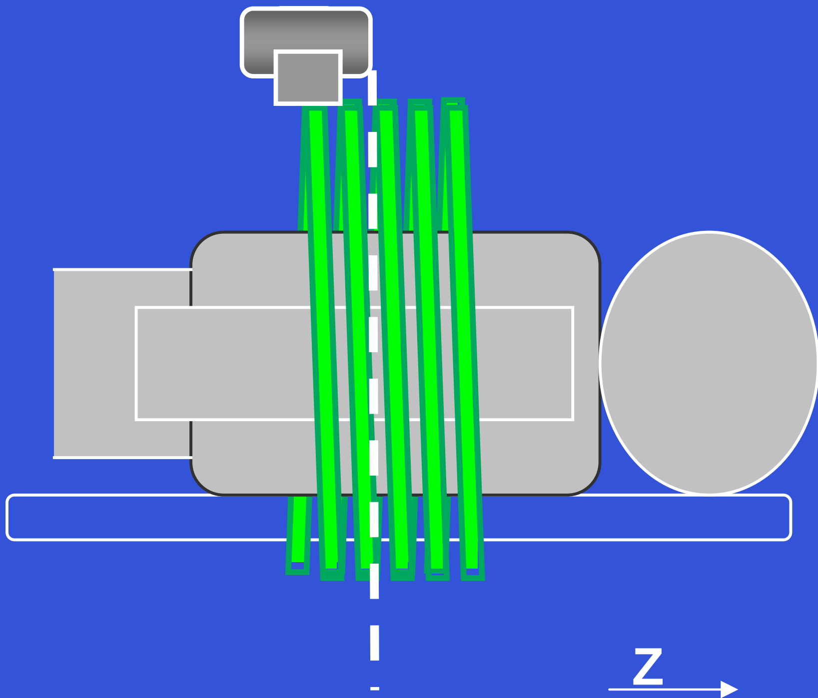
- X-rays on only for data collection
- Coverage limited by breath hold considerations on 4 slice scanners
- Tends to be used for calcification scoring
  - Can't acquire 64 thin slice, slice widths of ~ 3mm
- Increasing heart rate leads to poorer images
  - More heart motion included in 180 degree window



Retrospective gating of image data

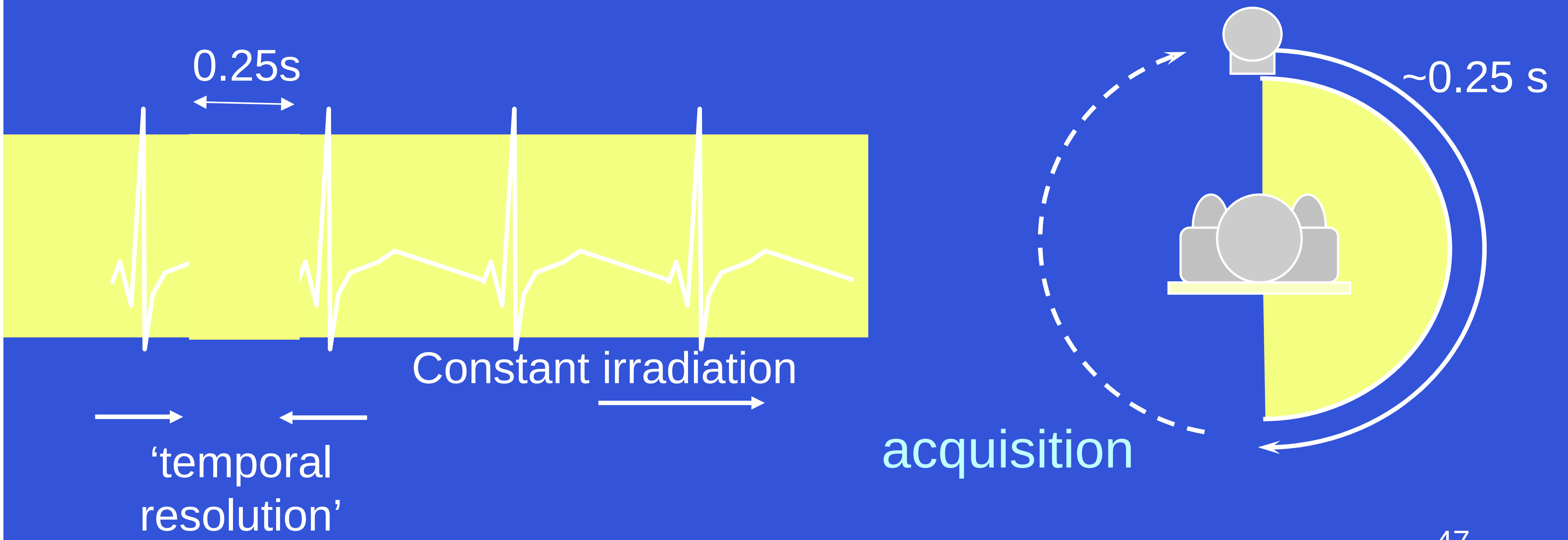
- Continuous irradiation and data collection in helical acquisition
- Single or multi-sector reconstruction





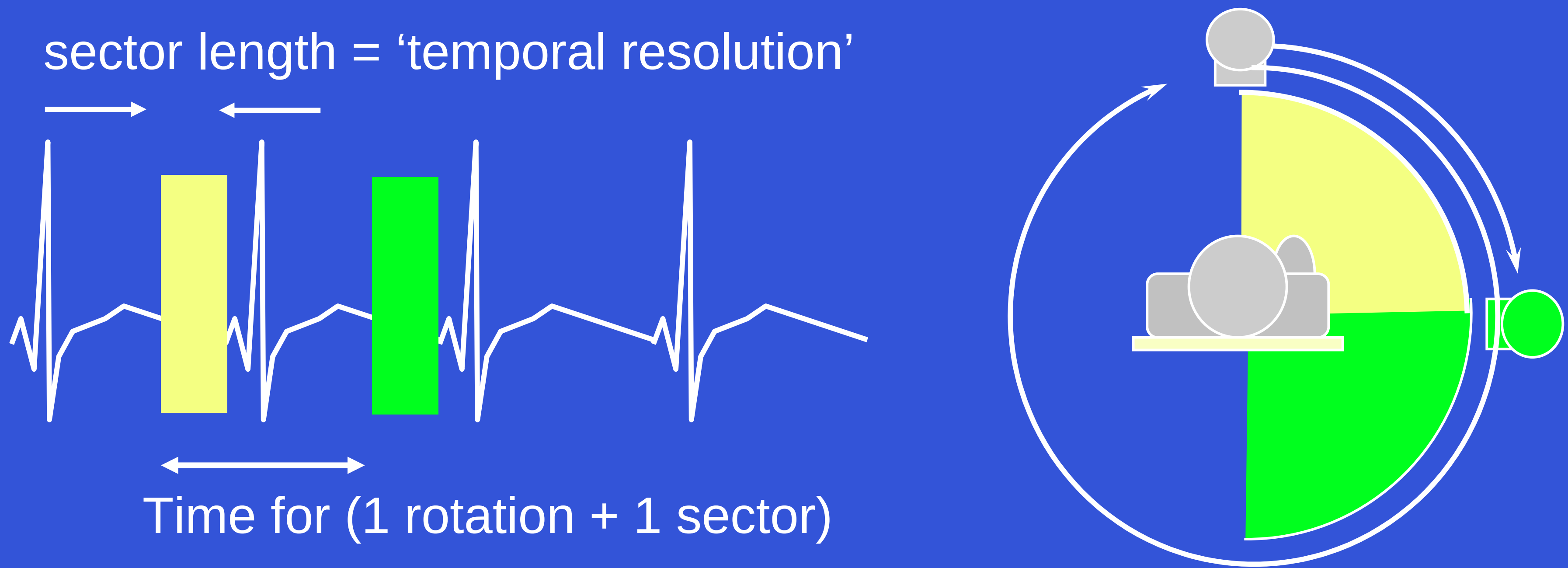
Multi-sector reconstruction

- Single sector
  - 180° sector of data
  - Sector time window = ½ rotation time
    - eg 0.5 sec rotation (500 ms), sector = 0.25 s (250 ms)
  - Data from one heart beat



Multi-sector reconstruction

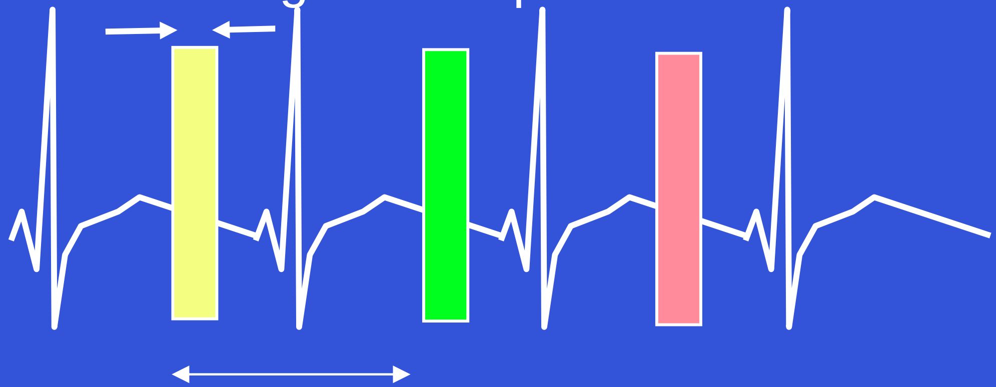
- Two sector
  - Two sectors each of 90 °
  - Sector time = ¼ rotation, eg = 125 ms (with 0.5 s rot)
  - Data from 1 ¼ rotations, two heart beats



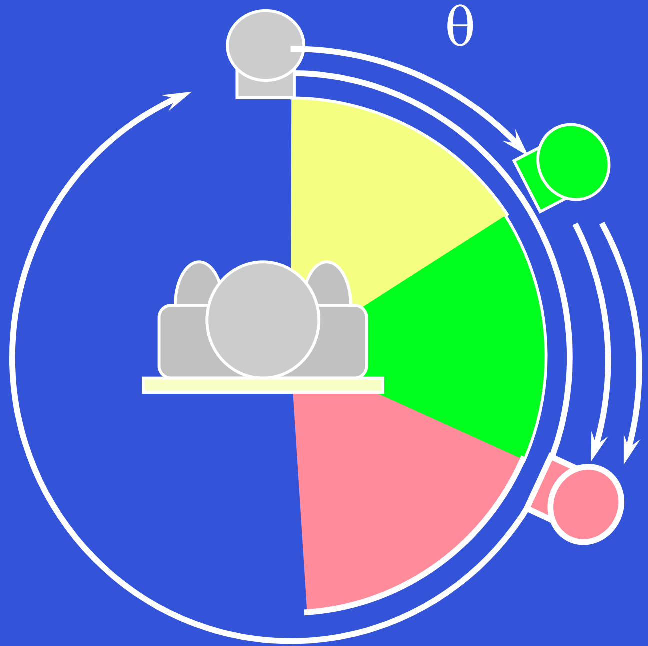
Multi-sector reconstruction

- 3-sector

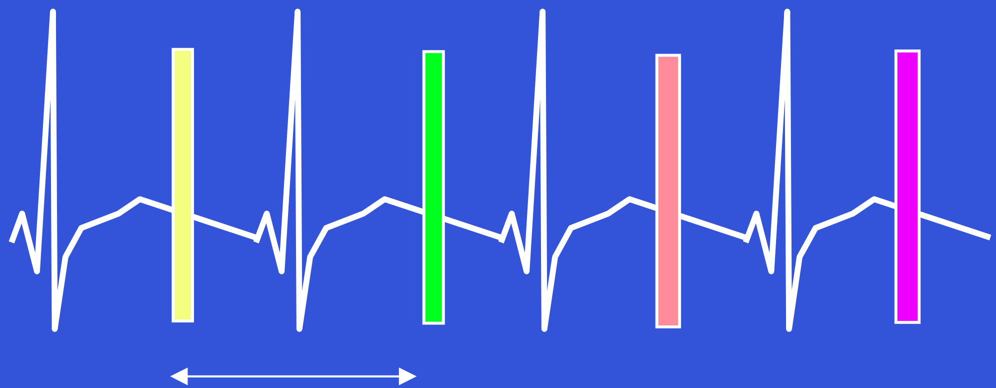
sector length = ‘temporal resolution’



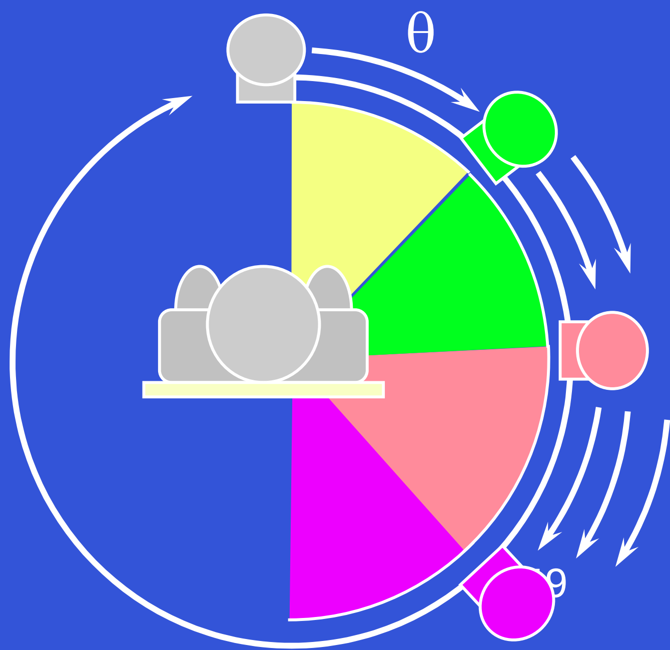
360° plus sector θ



- 4-sector



360° plus sector θ



Multi-sector reconstruction

- Temporal resolution
  - No. of sectors
  - Heart rate
  - Rotation time
- Pitch
  - No. of sectors
- Time to cover heart

heart rate

pitch

speed of coverage of heart

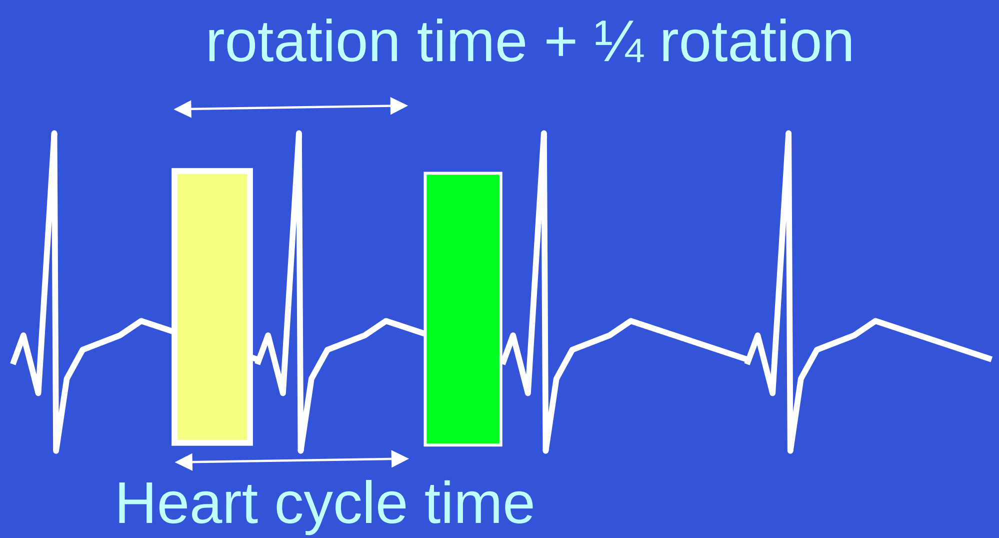
number of sectors

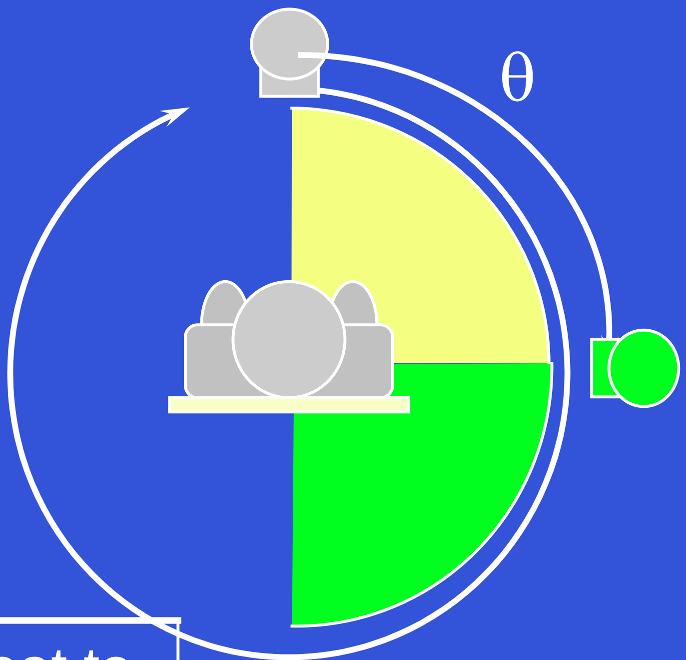
temporal resolution

registration

Temporal resolution

- Two sector - optimum timing (rotation and heart rate)

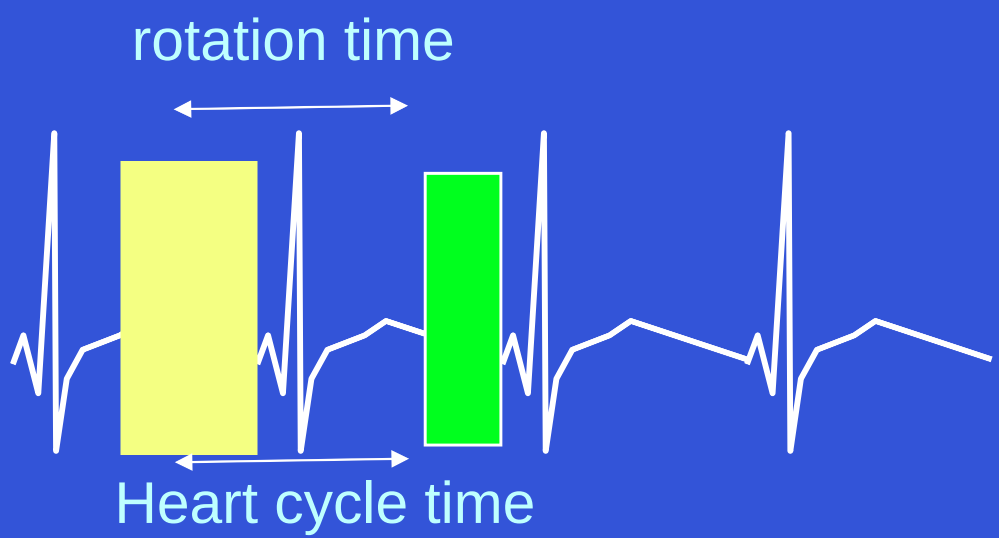


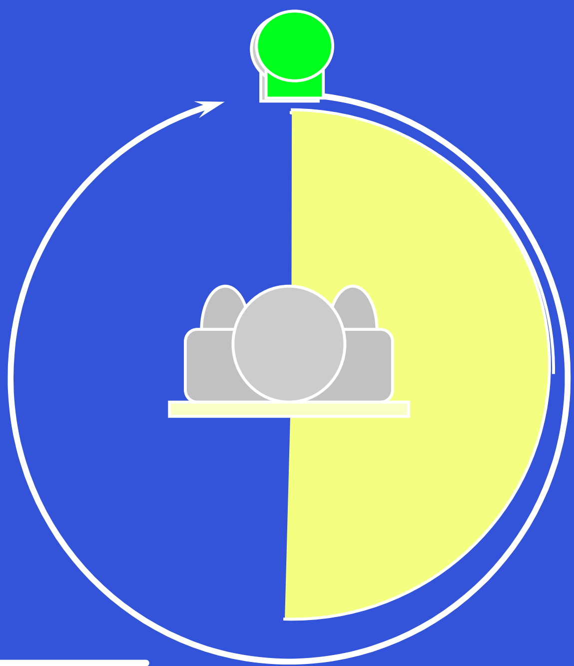


Rotation time (ms)	Sector time (ms)	No rotations	Heart rate (bpm)	Beat to beat time
500	125	1+1/4	96	0.625 s
420	105	2 + 1/4	63	0.96 s

Temporal resolution

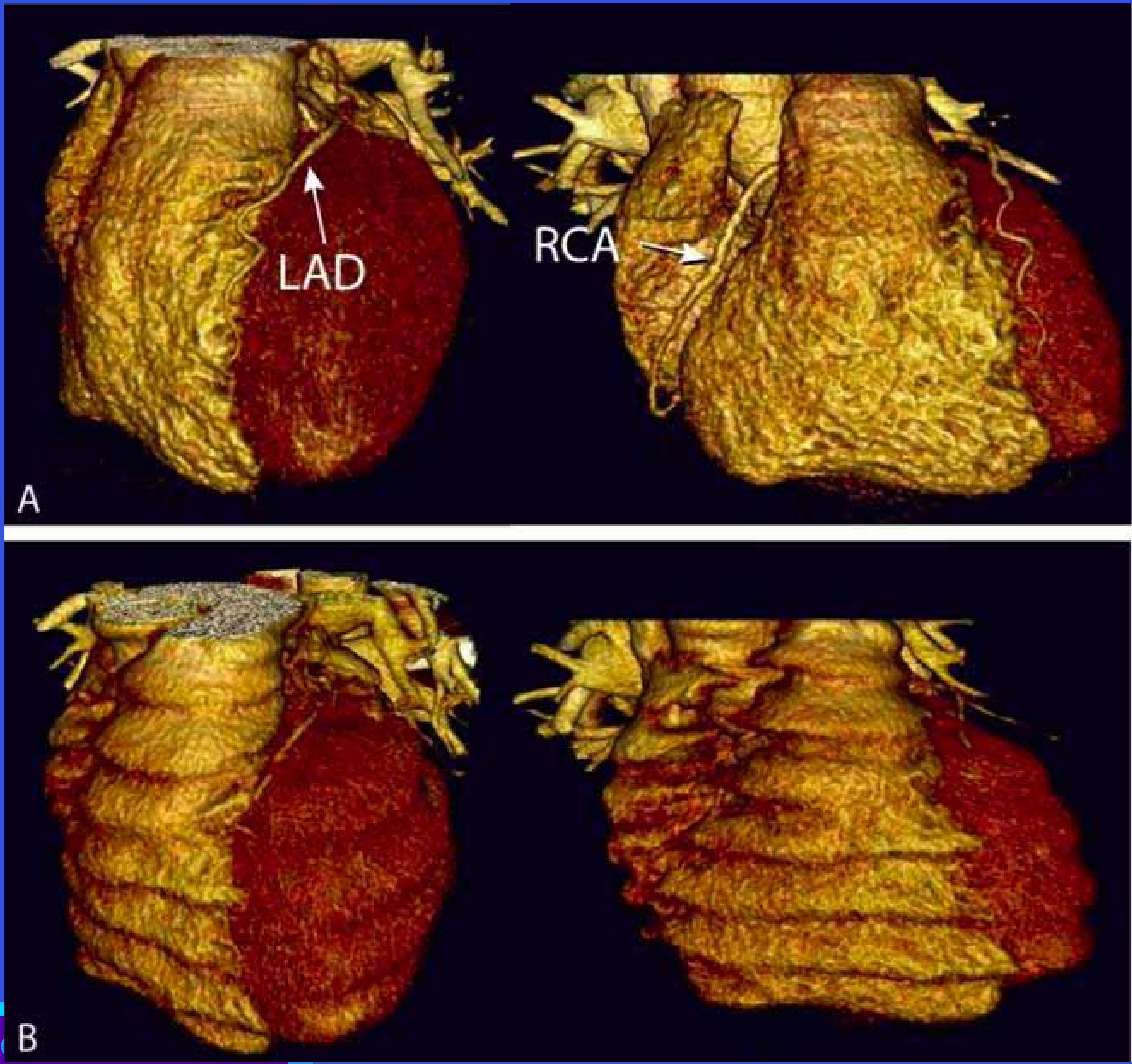
- Two sector – synchronisation





Rotation time (s)	Heart rate (bpm)	Heart rate (bps)	Each beat
0.5	120	2	0.5 s

Coronary arteries

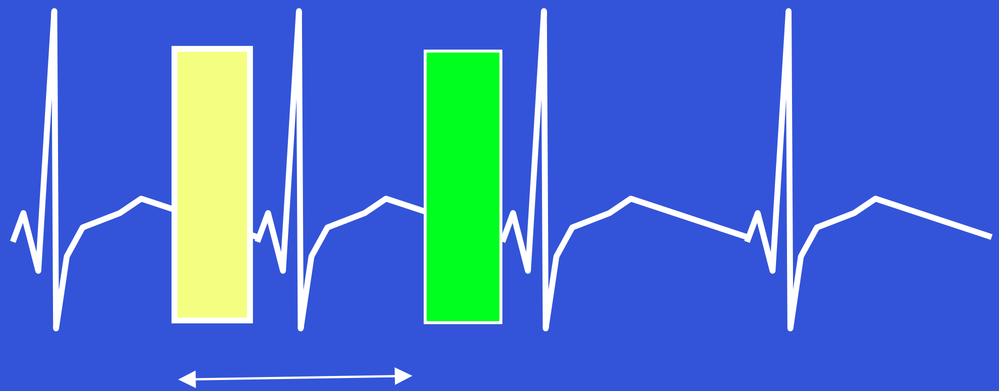


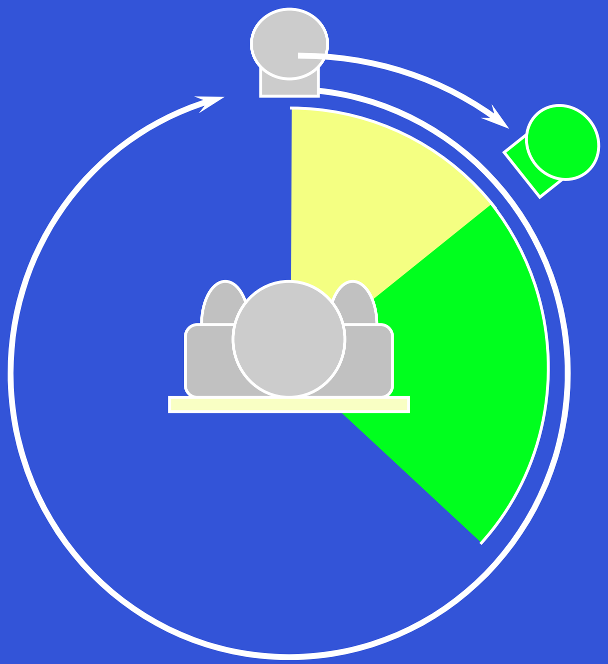
ECG-HR optimum timing

Synchronized

Temporal resolution

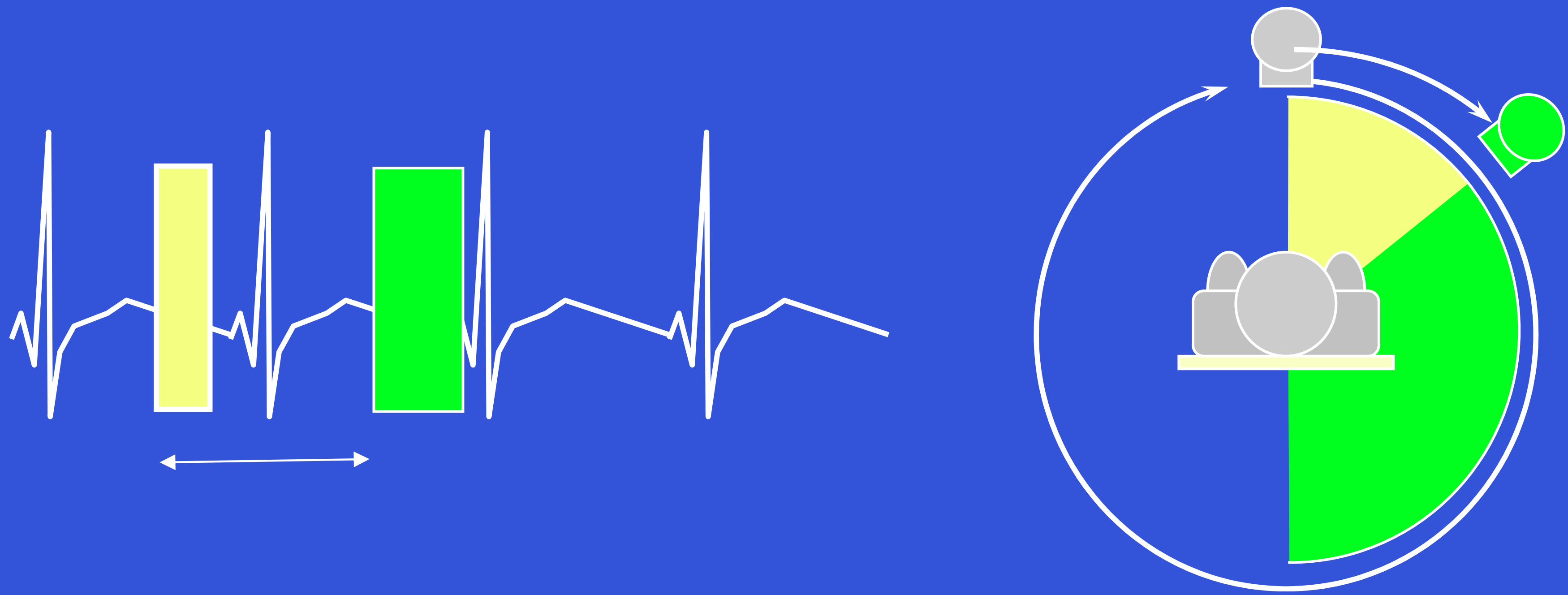
- Two sector – midway





Temporal resolution

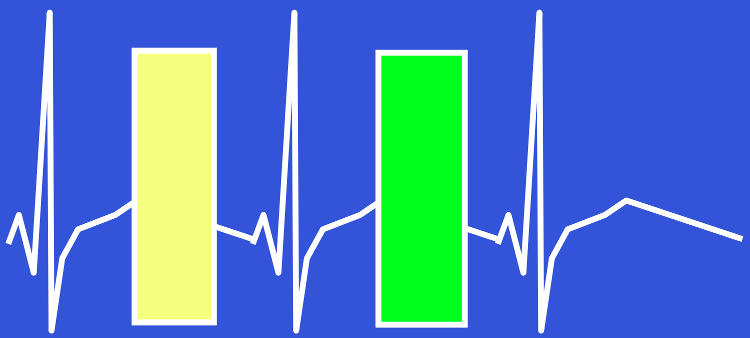
- Two sector – midway

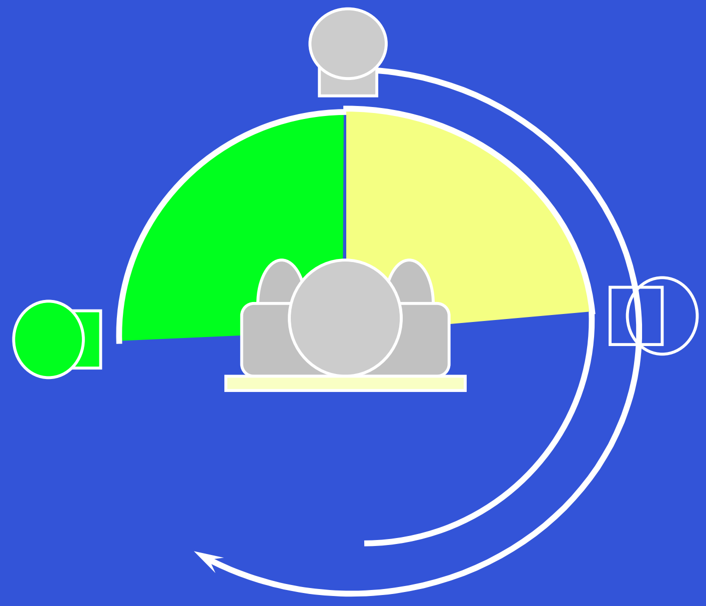


- Unequal sectors can be used
- Temporal resolution determined by largest sector

Temporal resolution

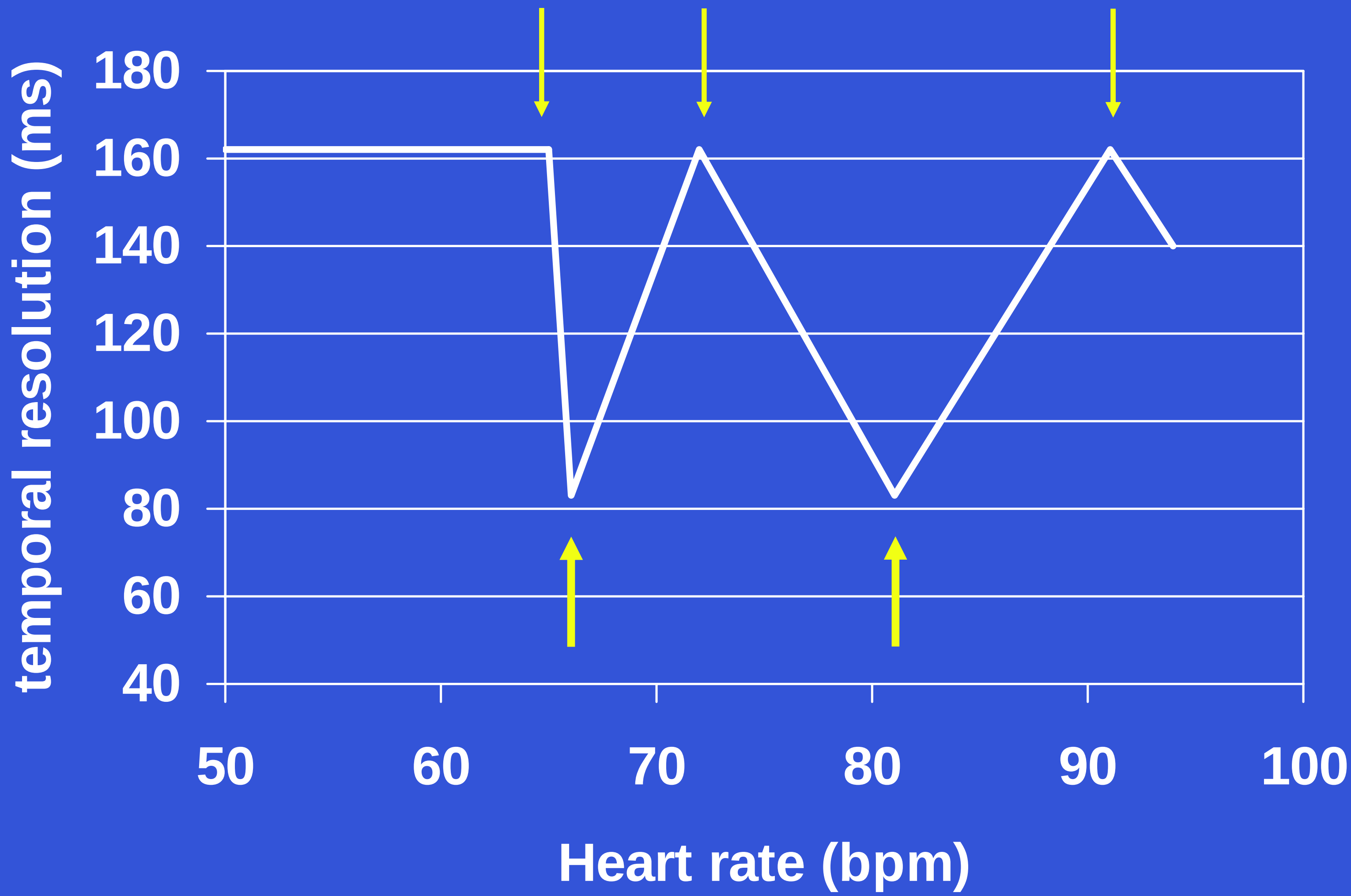
- Can use 180° opposite projections
  - More options of data for next sector
  - Perfect matching at (1/2 rotation + 1/4)
- 2-sector





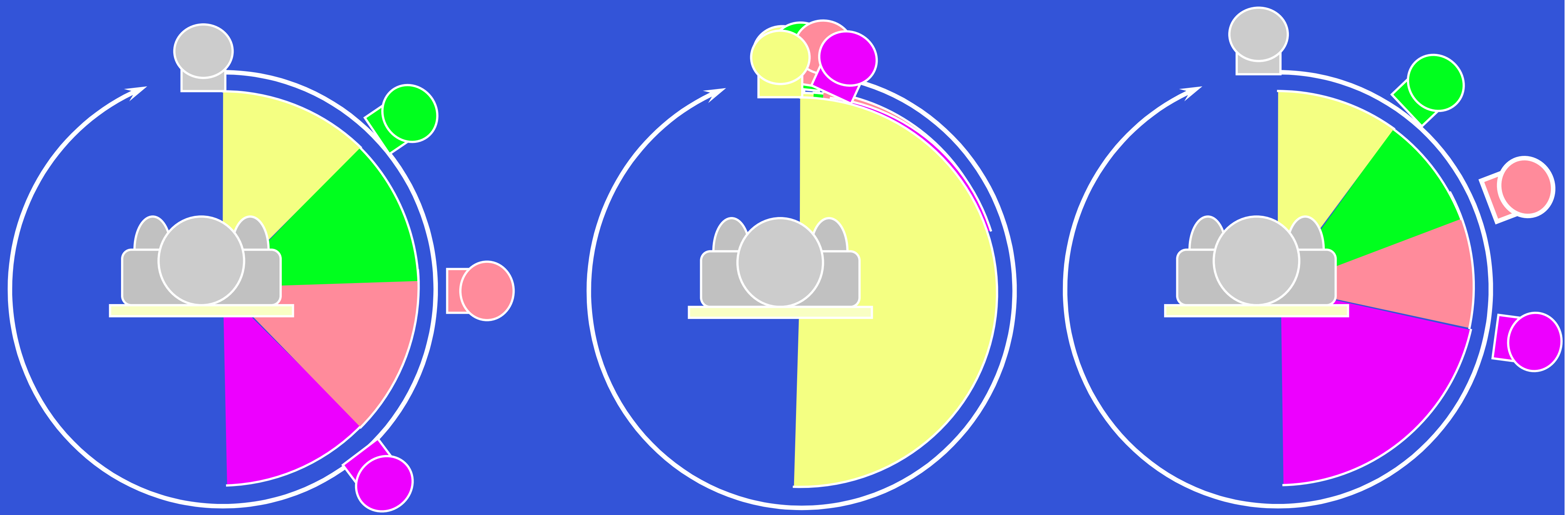
Temporal resolution graph – 2 sector

- Maximum two sector reconstruction, 0.33s rotation



Temporal resolution

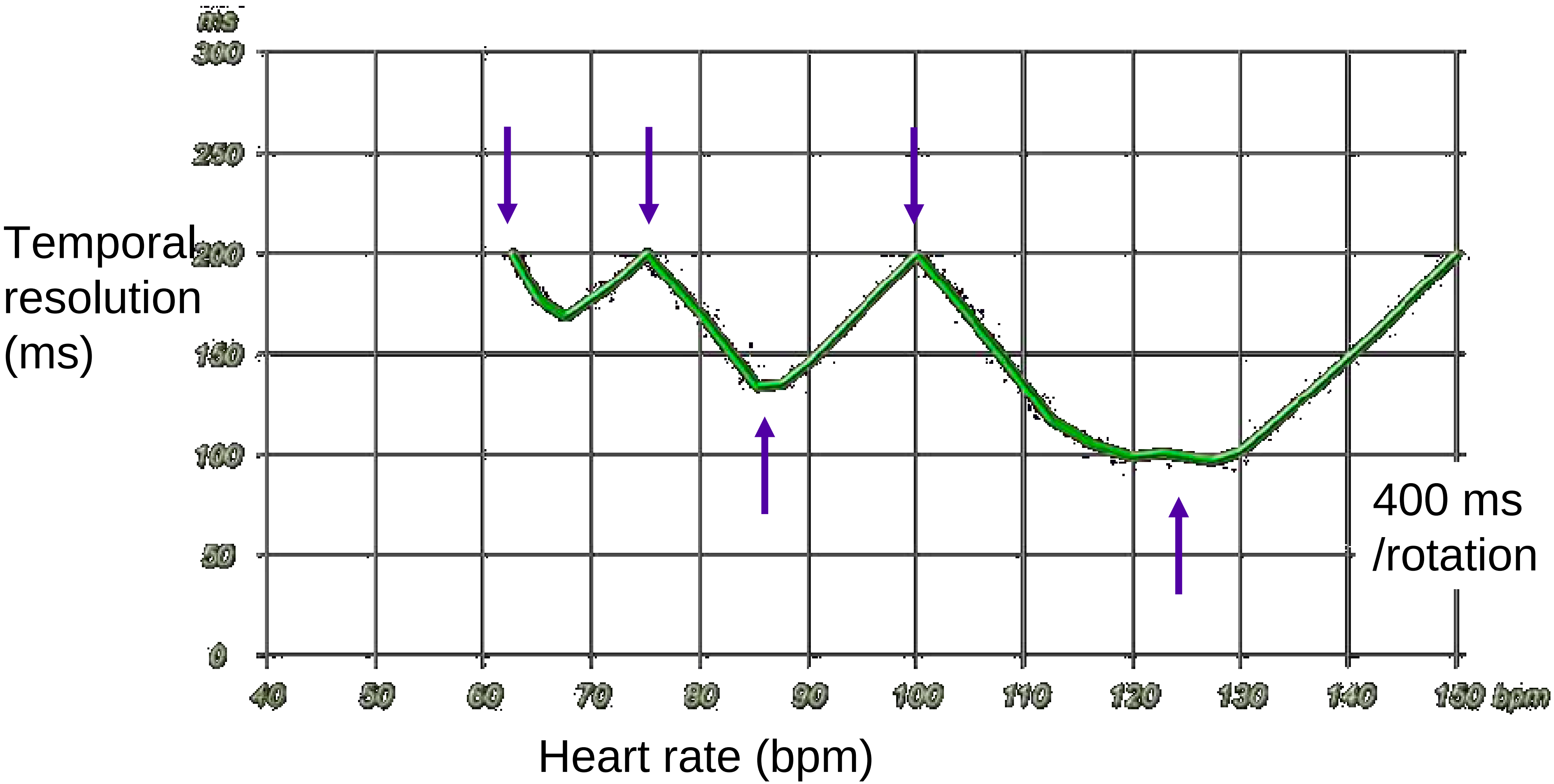
- Same principles apply for many sectors
  - eg 0.5 sec rotation, each sector = ~ 68 ms with perfect matching



Sector length ‘temporal resolution’ = (500/2)/4 = 68 ms

Temporal resolution graph – multi-sector

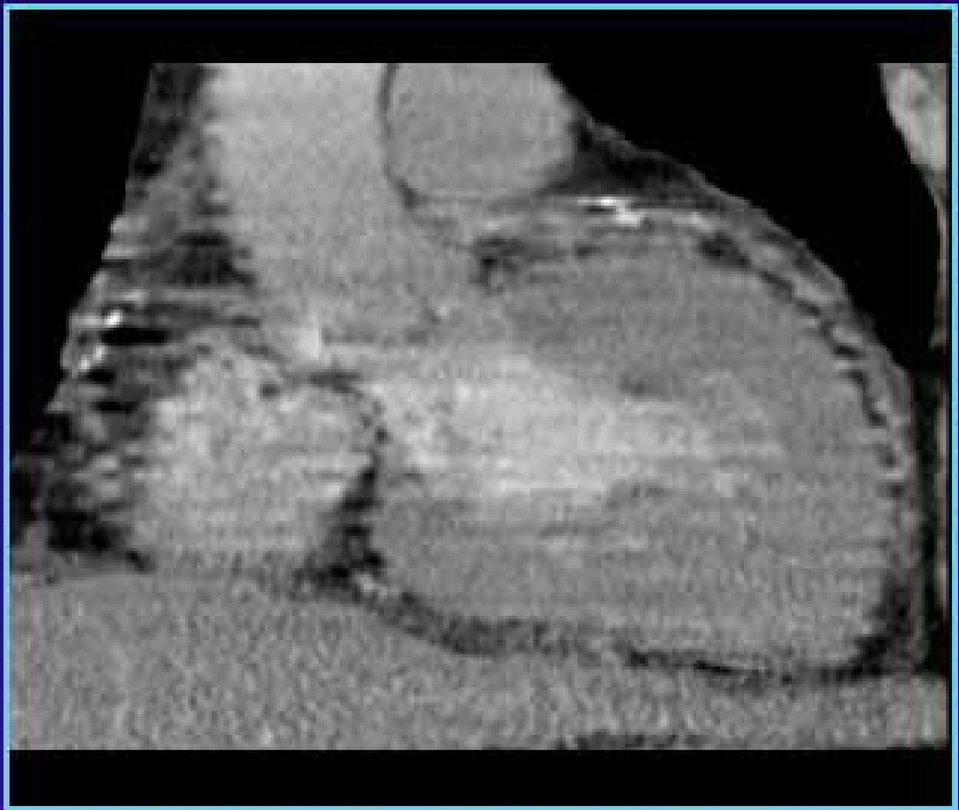
- Peaks at single sector, troughs at increasing number of multi-sectors



Courtesy Toshiba

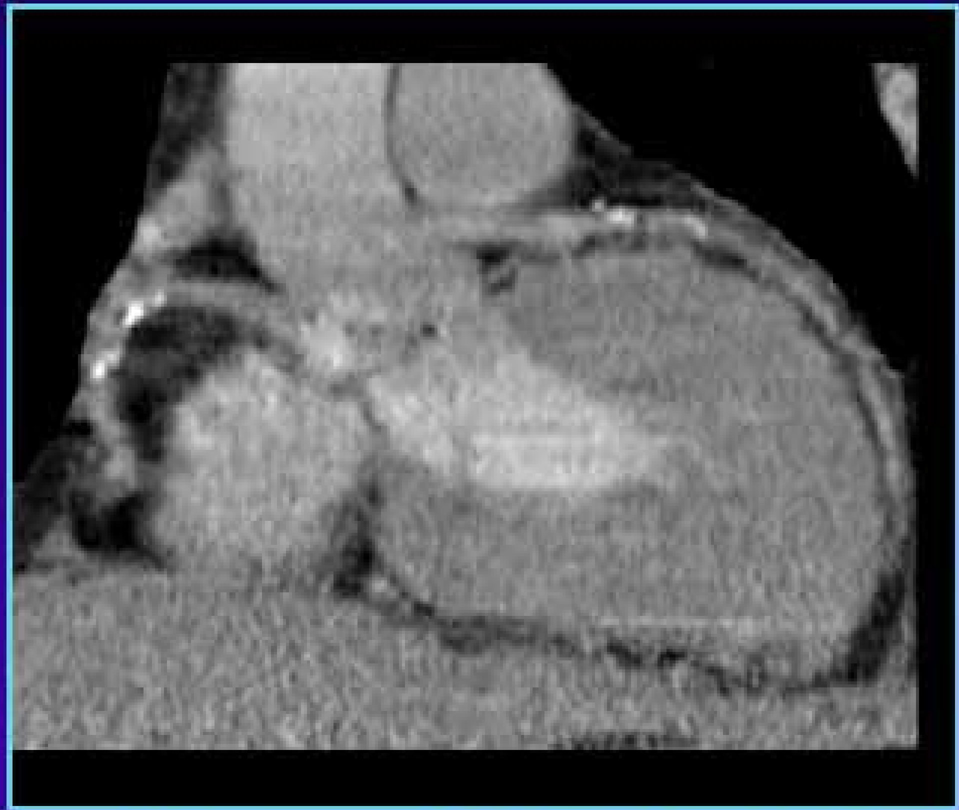
Temporal resolution

Single-segment vs Bi-segment (high HR)



Single Segment Reconstruction

250ms

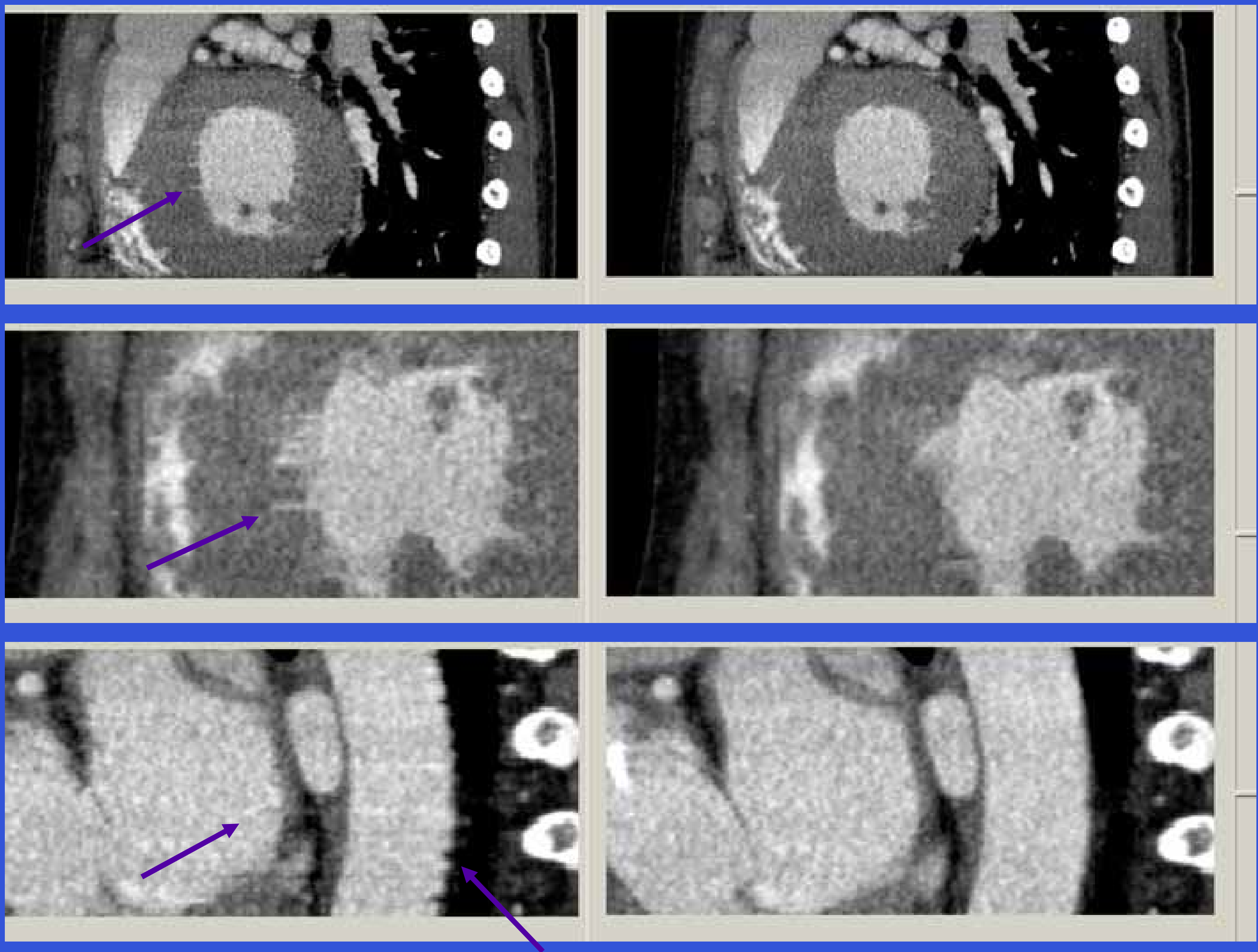


Bi-segment Reconstruction

125msec

Temporal resolution

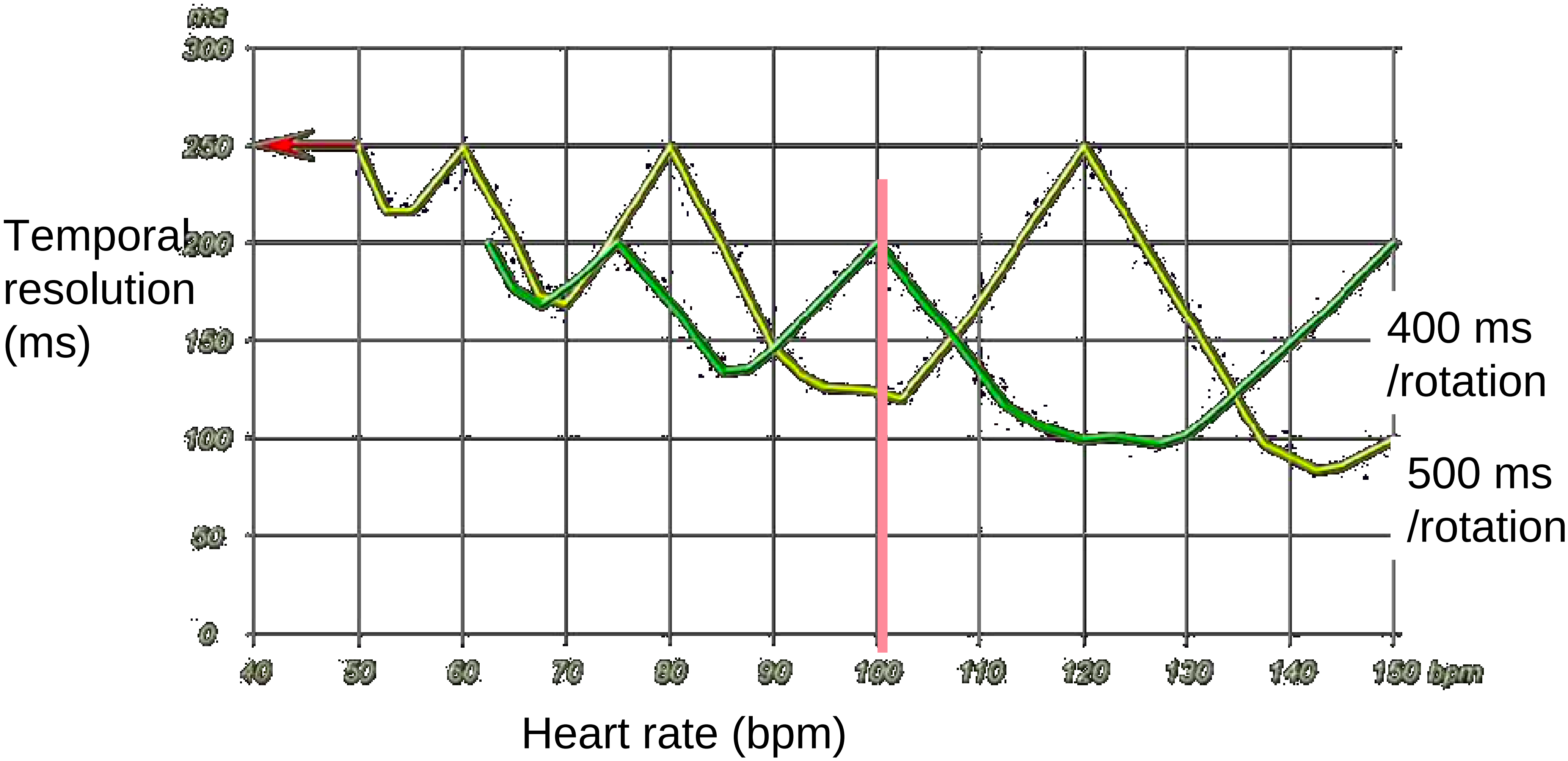
2 Sector ***3 Sector***



Courtesy Philips

Temporal Resolution and Rotation Time

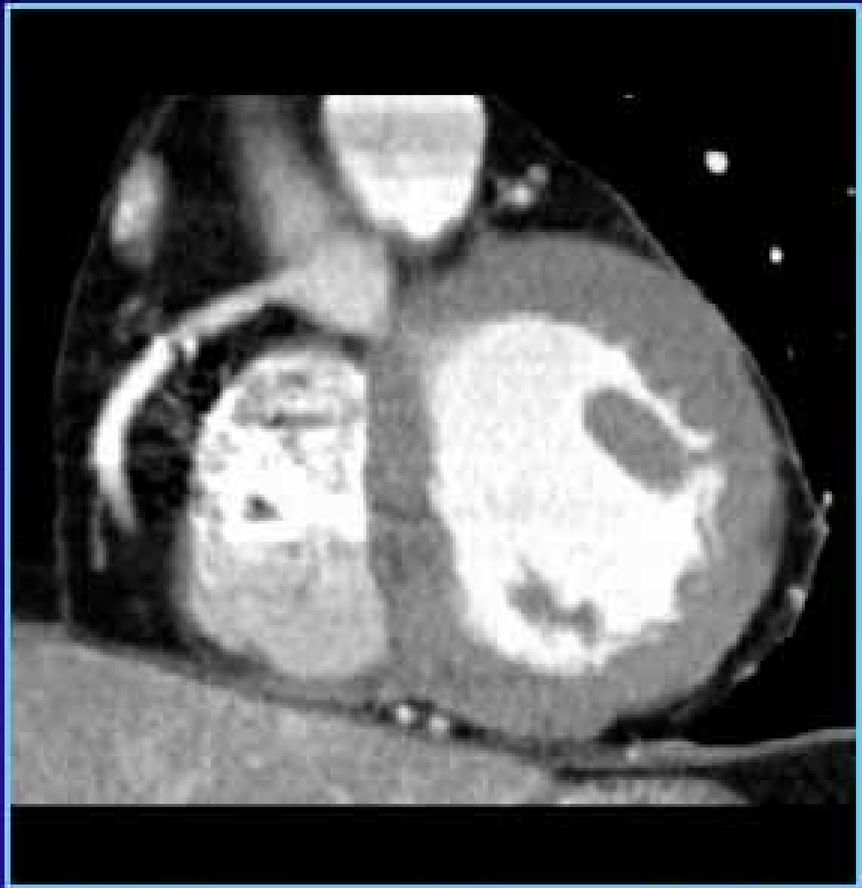
- Optimum temporal resolution depends on asynchrony of heart rate and rotation time



Courtesy Toshiba

Temporal resolution

Single segment vs Bi-segment (low HR)



Single Segment Reconstruction

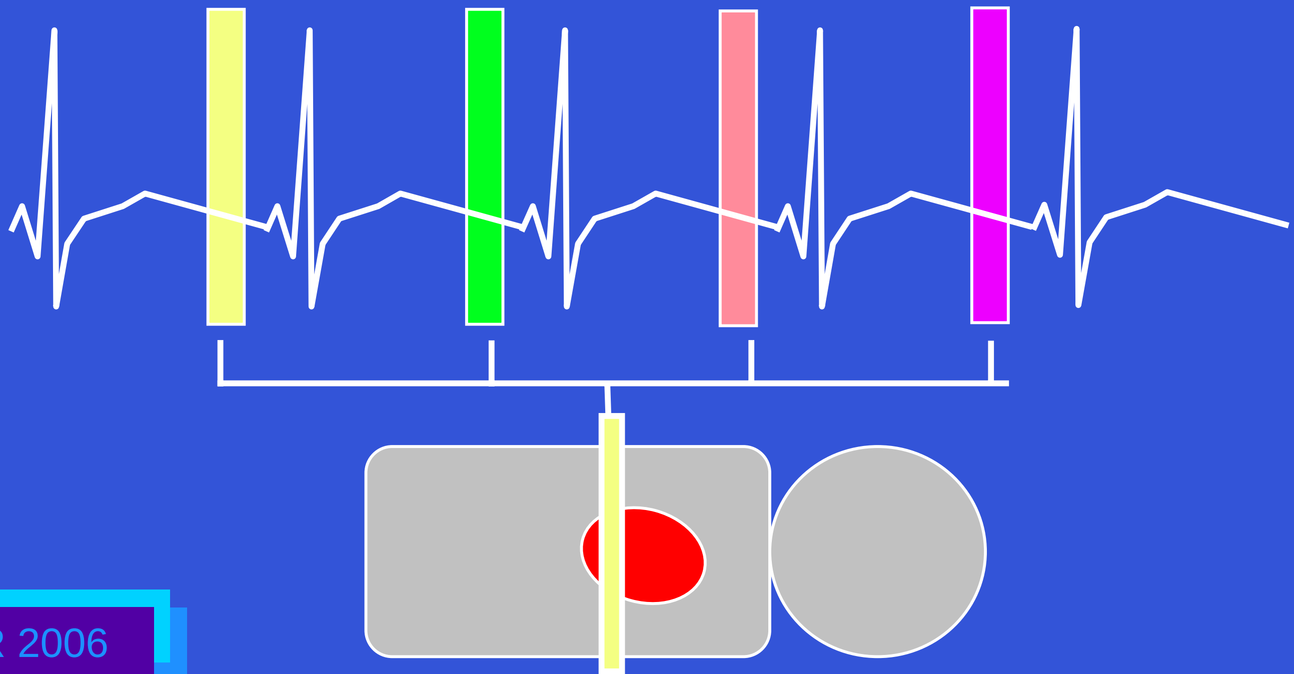
250ms

Bisegment Reconstruction

125ms

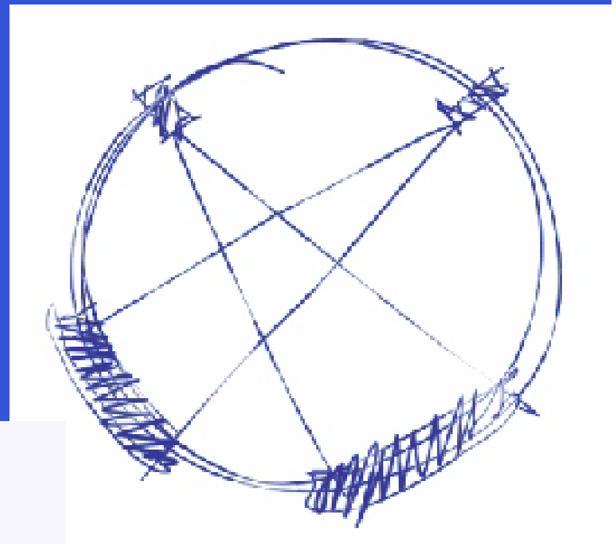
Temporal Resolution

- ‘Temporal resolution’ = sector length
  - Fastest rotation time gives shorter sector lengths
  - Multi-sector gives shorter lengths - avoid synchronisation
- More sectors require more beats
- Require steady heart beat for good registration



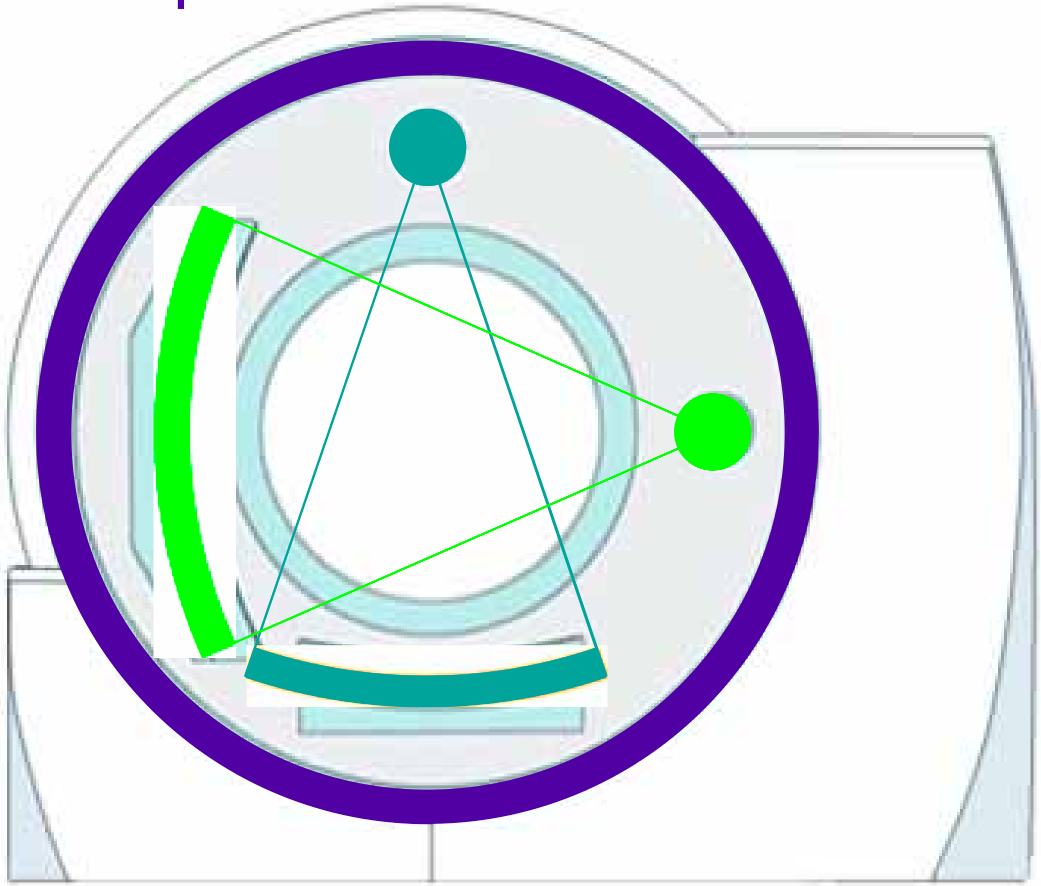
Temporal resolution

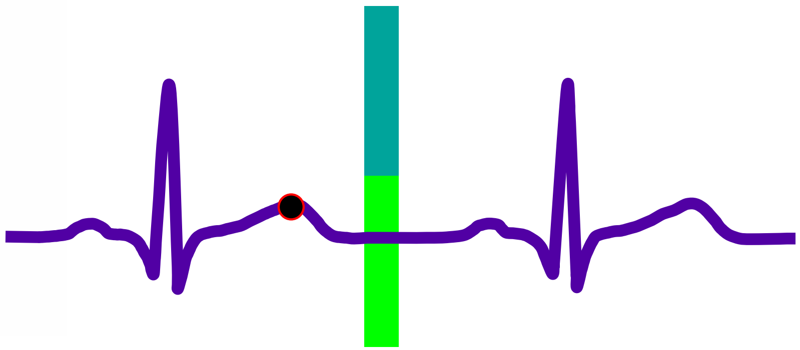
- Dual tube imaging
  - Siemens Definition launched RSNA '05
- Two tubes at 90°
  - 2 x 1/4 sectors simultaneously in 83 ms



Siemens Dual Source CT

Temporal resolution of 83 ms





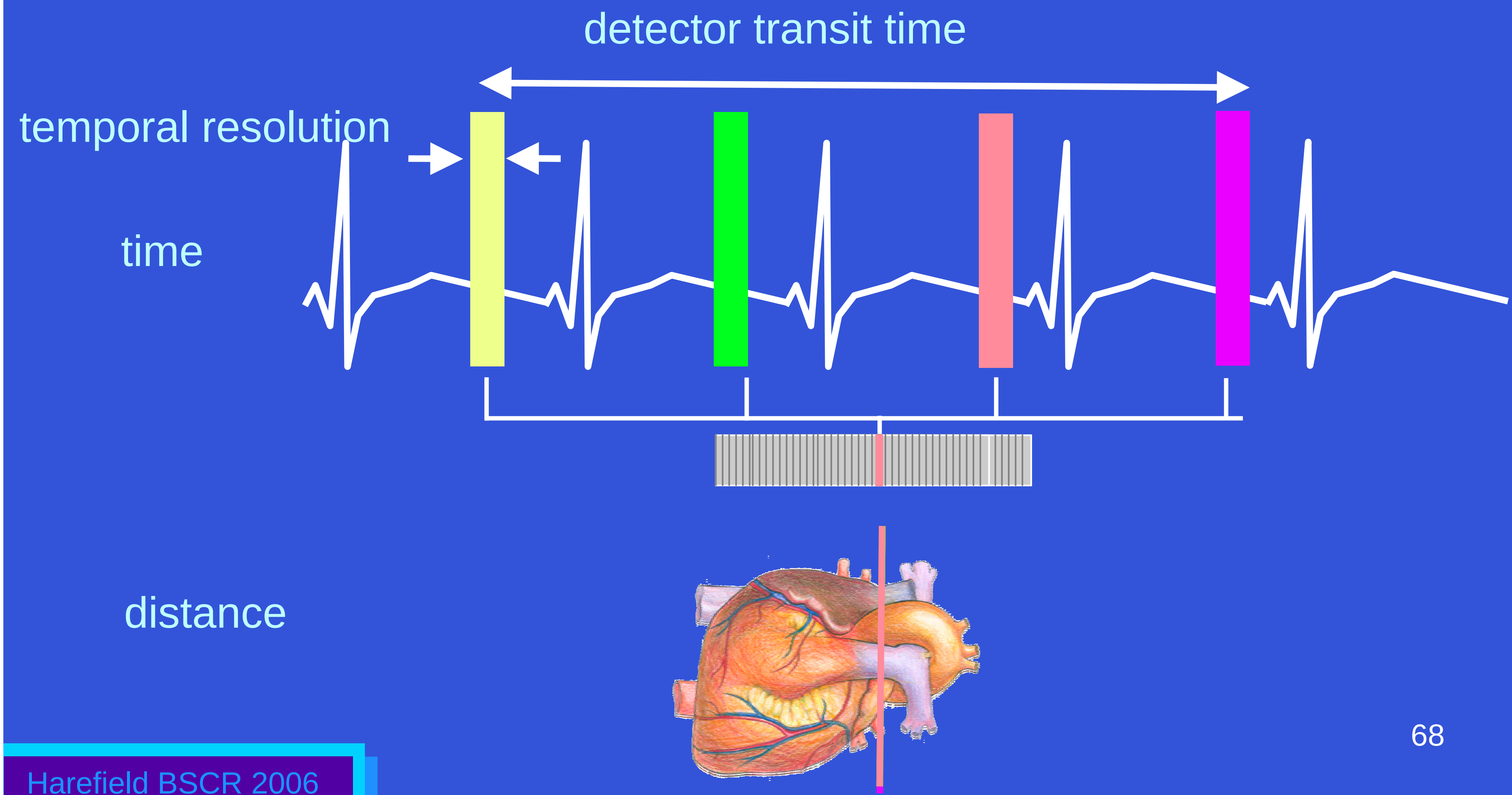
Temporal Resolution =

$$\frac{\text{Rotation Time}}{4} = \mathbf{83\ ms}$$

Courtesy Siemens

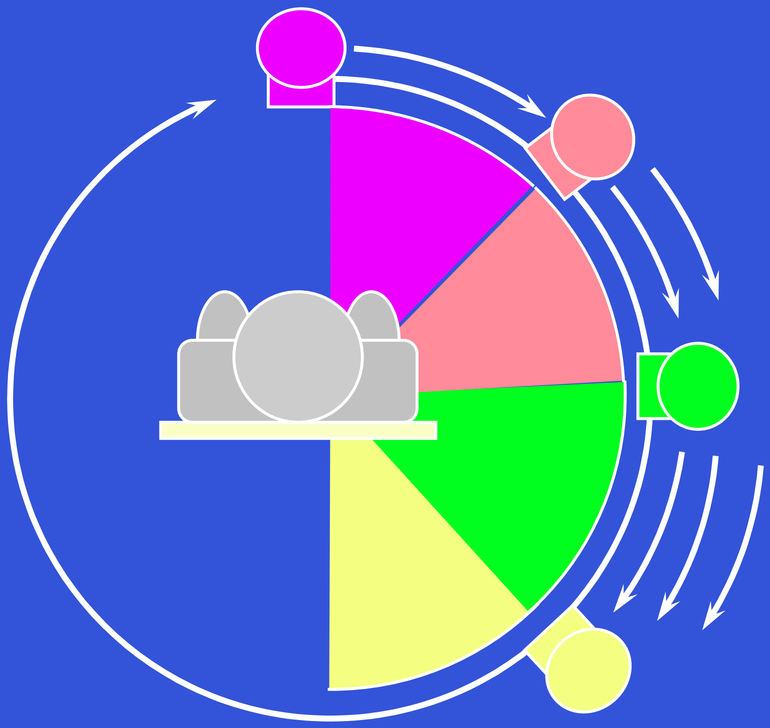
Multi-sector reconstruction - pitch

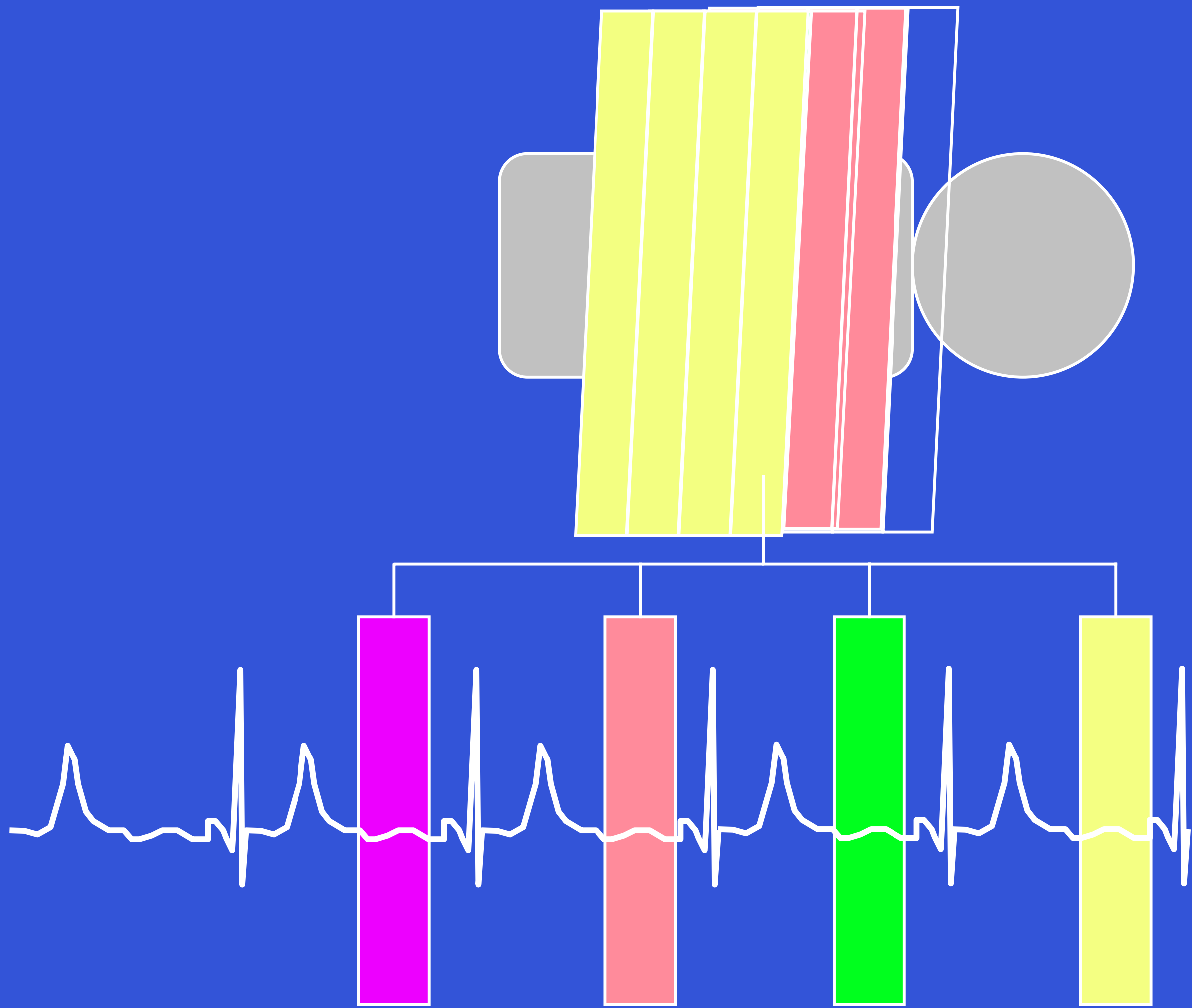
- To reconstruct from a number of sectors, the detectors need to image the given slice of heart for the equivalent number of heart beats



Multi-sector reconstruction - pitch

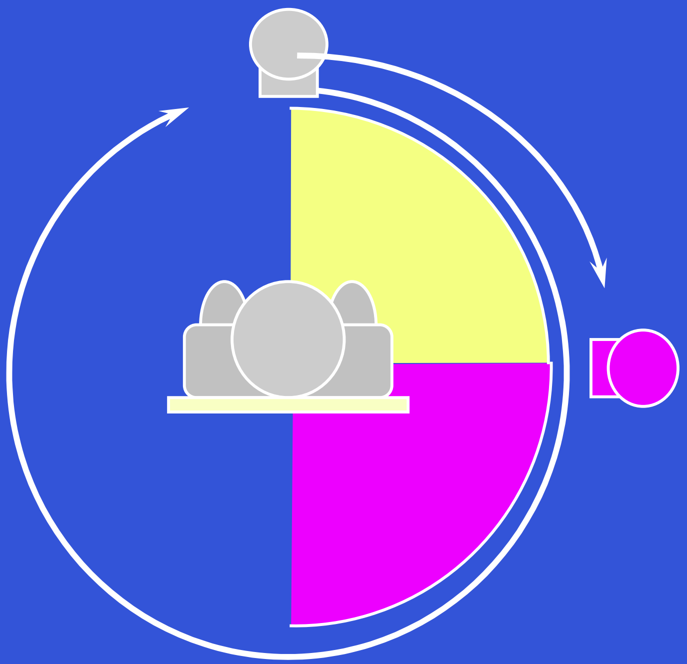
- Different detector banks contribute to each sector
  - Overlapping pitch



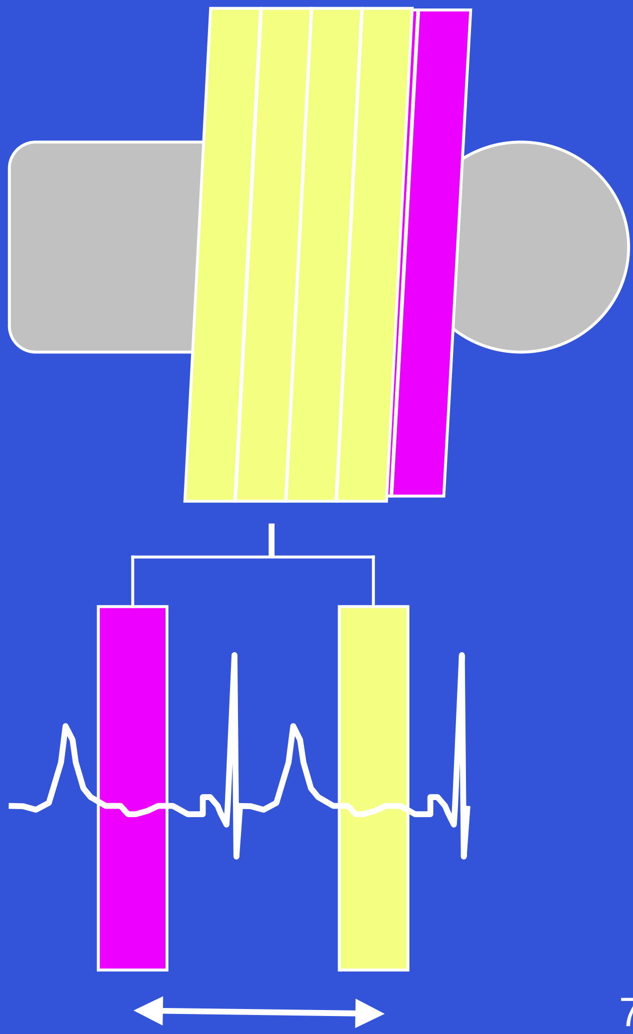


Multi-sector reconstruction - pitch

- eg 2 segments

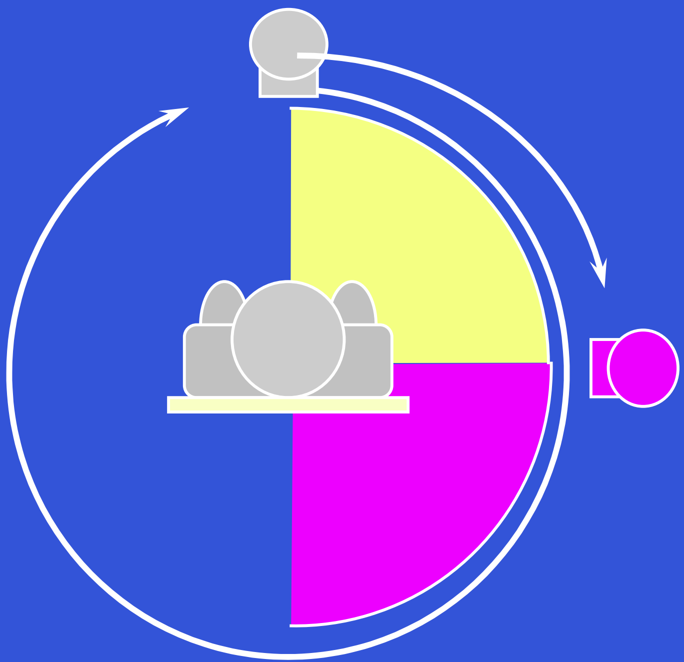


low pitch

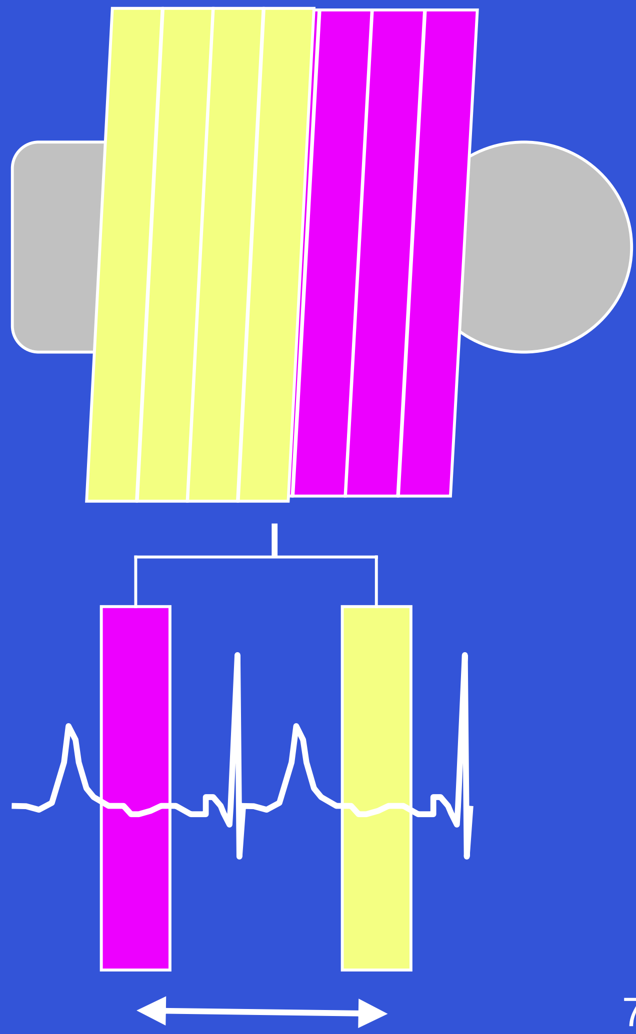


Multi-sector reconstruction - pitch

- eg 2 segments



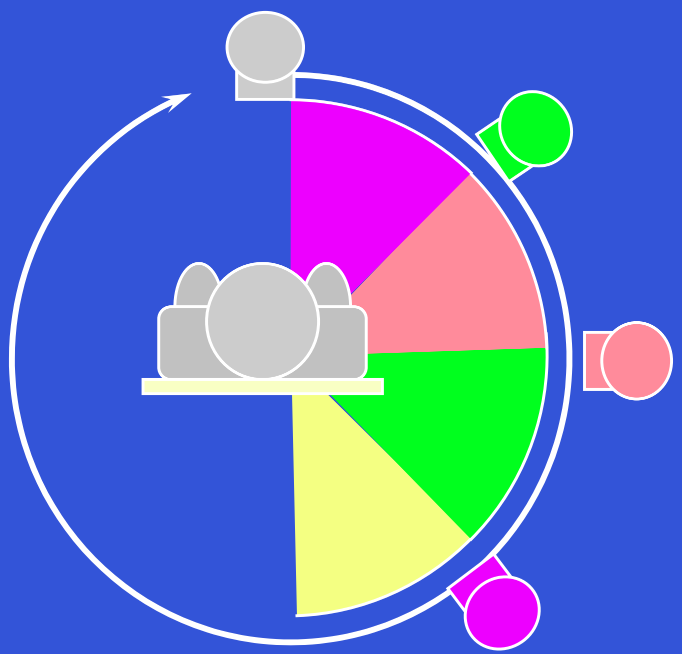
high pitch

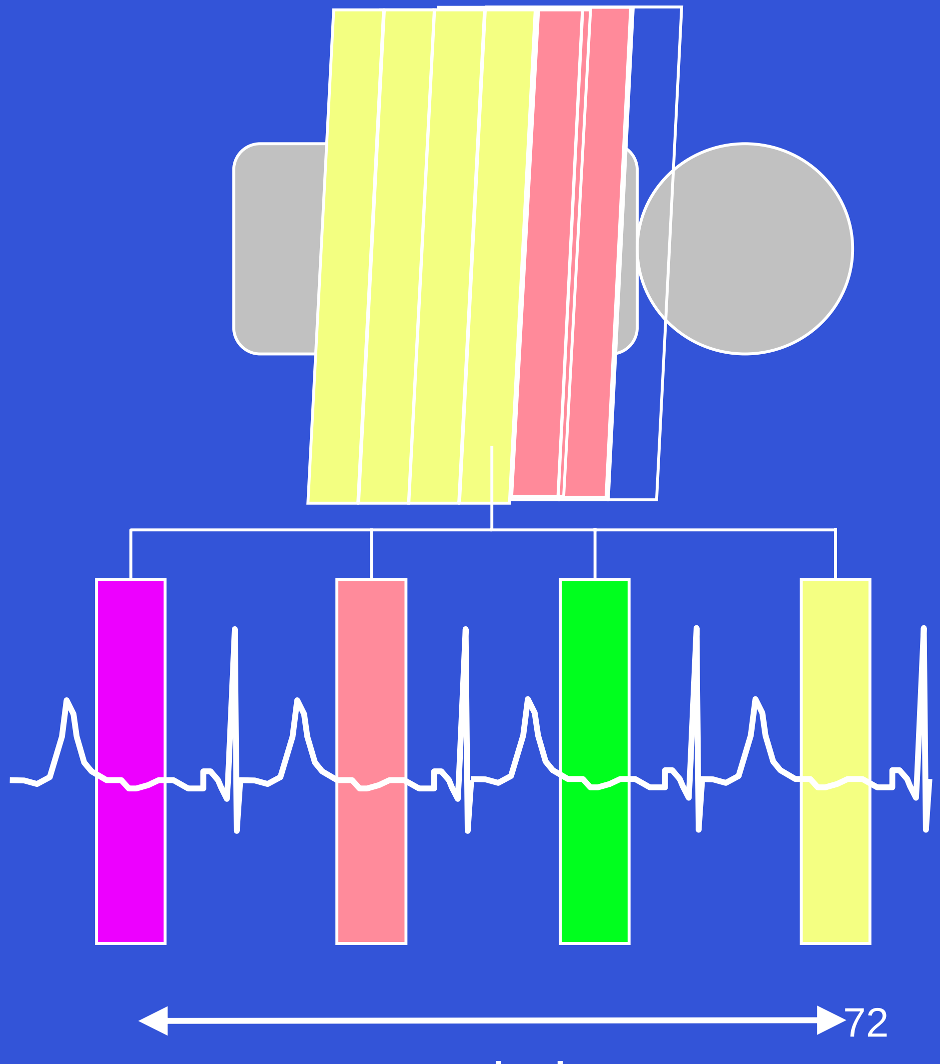


  – But if pitch too high there will be gaps in the reconstruction data

Multi-sector reconstruction - pitch

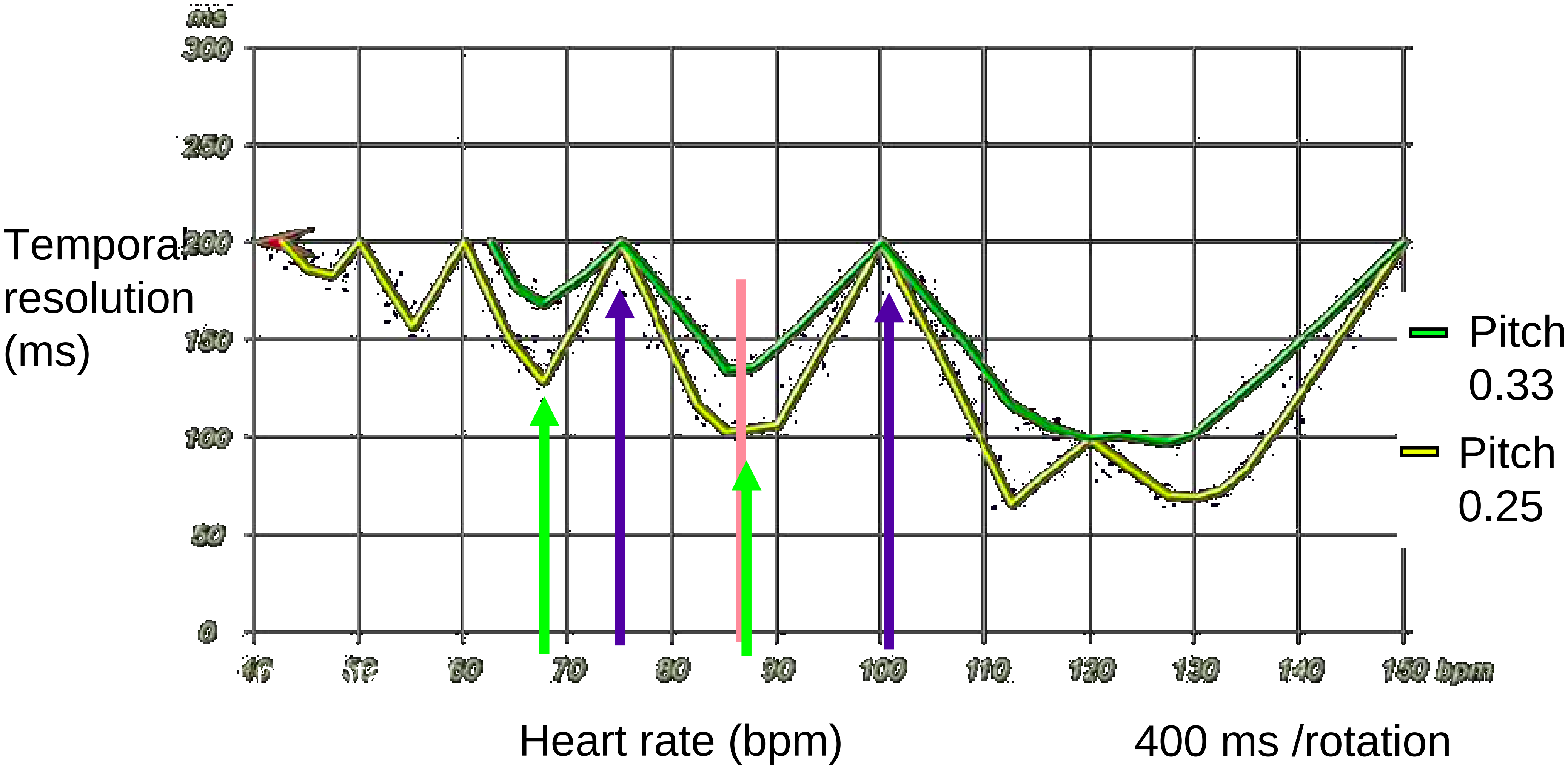
- Four segments – lower pitch (slower table speed)





Temporal Resolution and Pitch

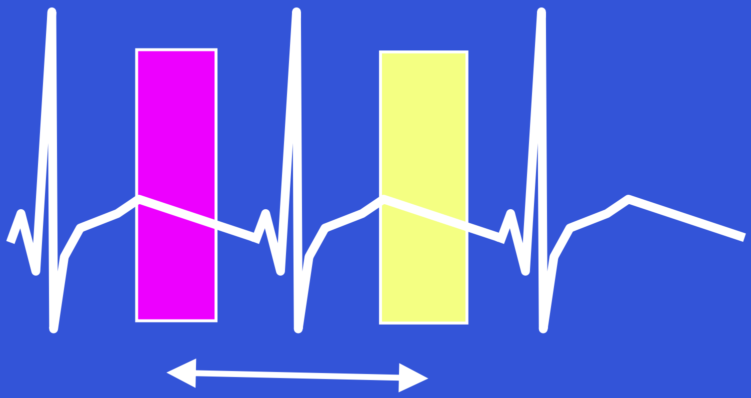
- Pitch does not affect optimum matching of rotation time and heart rate

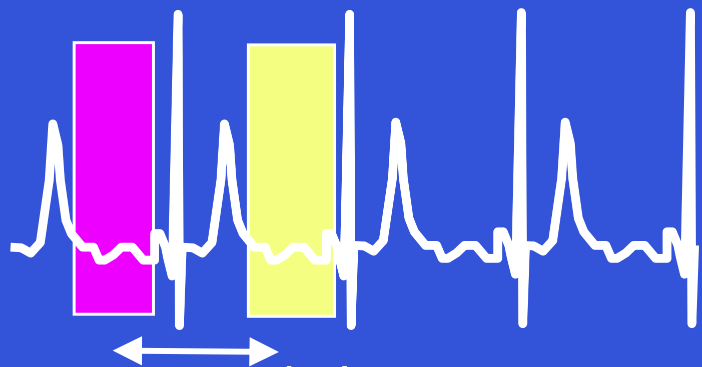


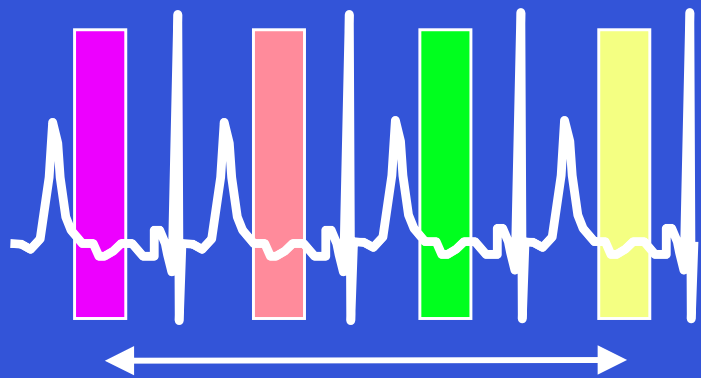
Courtesy Toshiba, see also Manzke et al, Med. Phys. 30 (12) December 2003

Heart rate

- Increased heart rate
  - Same number of sectors
    - Avoid synchronisation - change rotation time?
    - Pitch can increase ⇒ lower dose, faster coverage of heart
  - More sectors may be used
    - Pitch must decrease

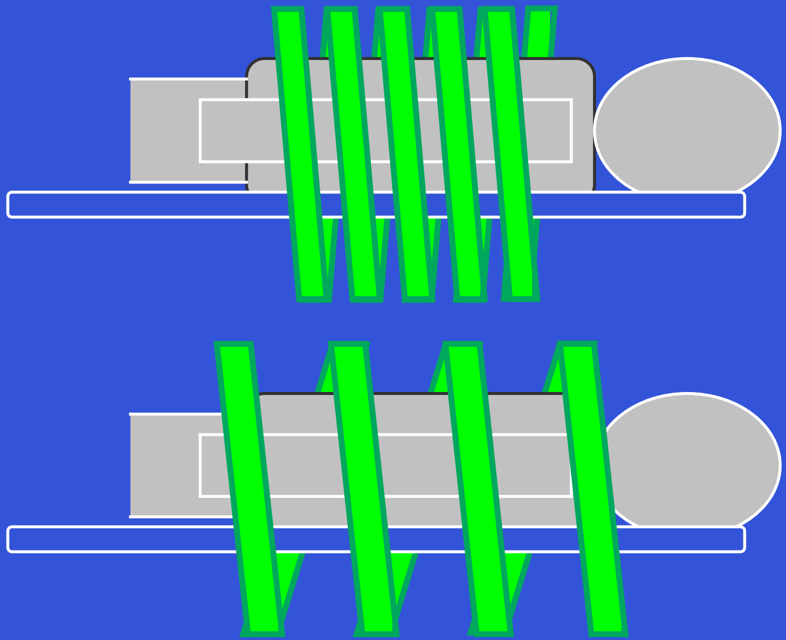


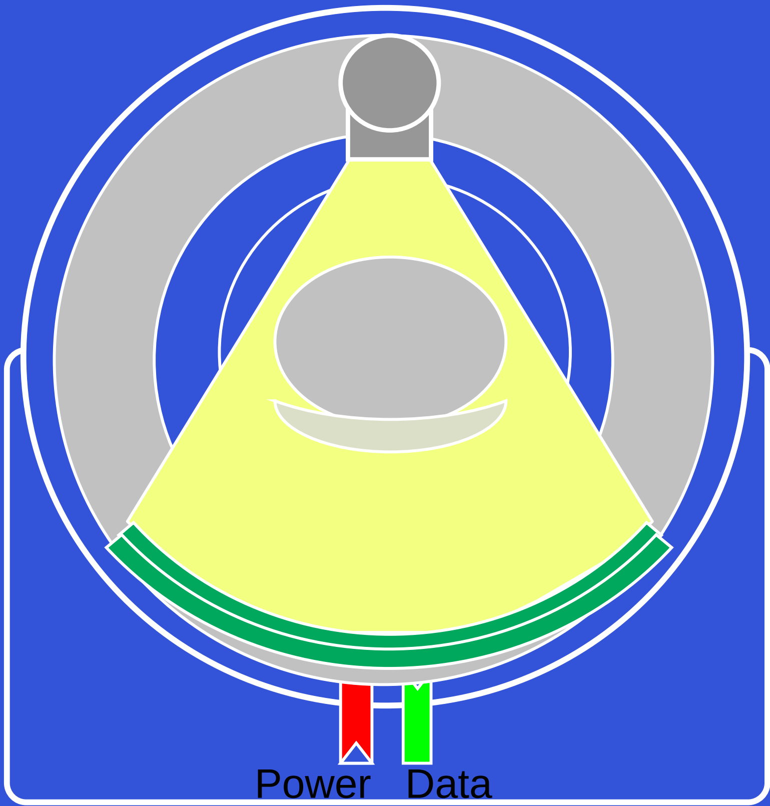




Time to cover heart

- Depends on
  - pitch, rotation time, detector acquisition length

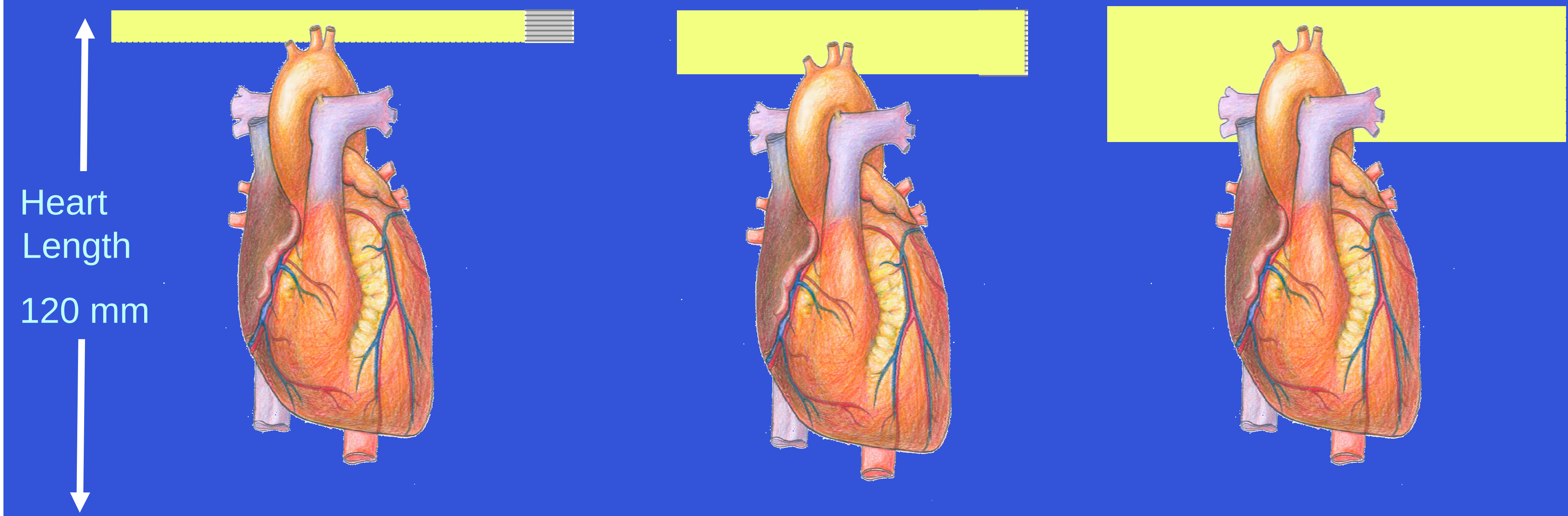




Time to cover heart

- Depends on
  - detector acquisition length

4 slice (10 mm) | 16 x slice (20 mm) | 64 slice (40 mm)



64 sec | 32 sec | 16 sec

Assumes 0.5 sec, 0.375 pitch

Time to cover heart

- Depends on
  - pitch, rotation time, detector acquisition length

64 slice scanners	IGE	Philips	Siemens (1 tube)	Siemens (2 tube)	Toshiba
Acquisition width	0.625	0.625	0.6	0.6	0.5
Min rotation times (s)	0.35	0.42	0.33	0.33	0.4
Detector length (mm)	40	40	19.2	19.2	32
Time to cover 120 mm ^ (s)	5.3	6.3	10.3	5.1	7.5

^assume pitch 0.2

Multi-sector reconstruction

- Temporal resolution
  - No. of sectors
  - Heart rate
  - Rotation time
- Pitch
  - No. of sectors
- Time to cover heart

heart rate

pitch

speed of coverage of heart

number of sectors

temporal resolution

registration

Technical Aspects of MSCT and ECG Gating

- MSCT scanning
  - Principles
  - Current technology
- Particular challenges of imaging the heart
- ECG Gating techniques
- Practical approaches to optimisation
- Dose
- The future

Practical approaches to optimisation

- Monitor pre-scan heart rate
  - To determine best combination of pitch, rotation time, number of sectors
- Finding the best phase
  - Motion maps
- Responding to change in heart rate
  - ECG editing

Pre-scan resting heart rate

Heart rate during breath hold is monitored

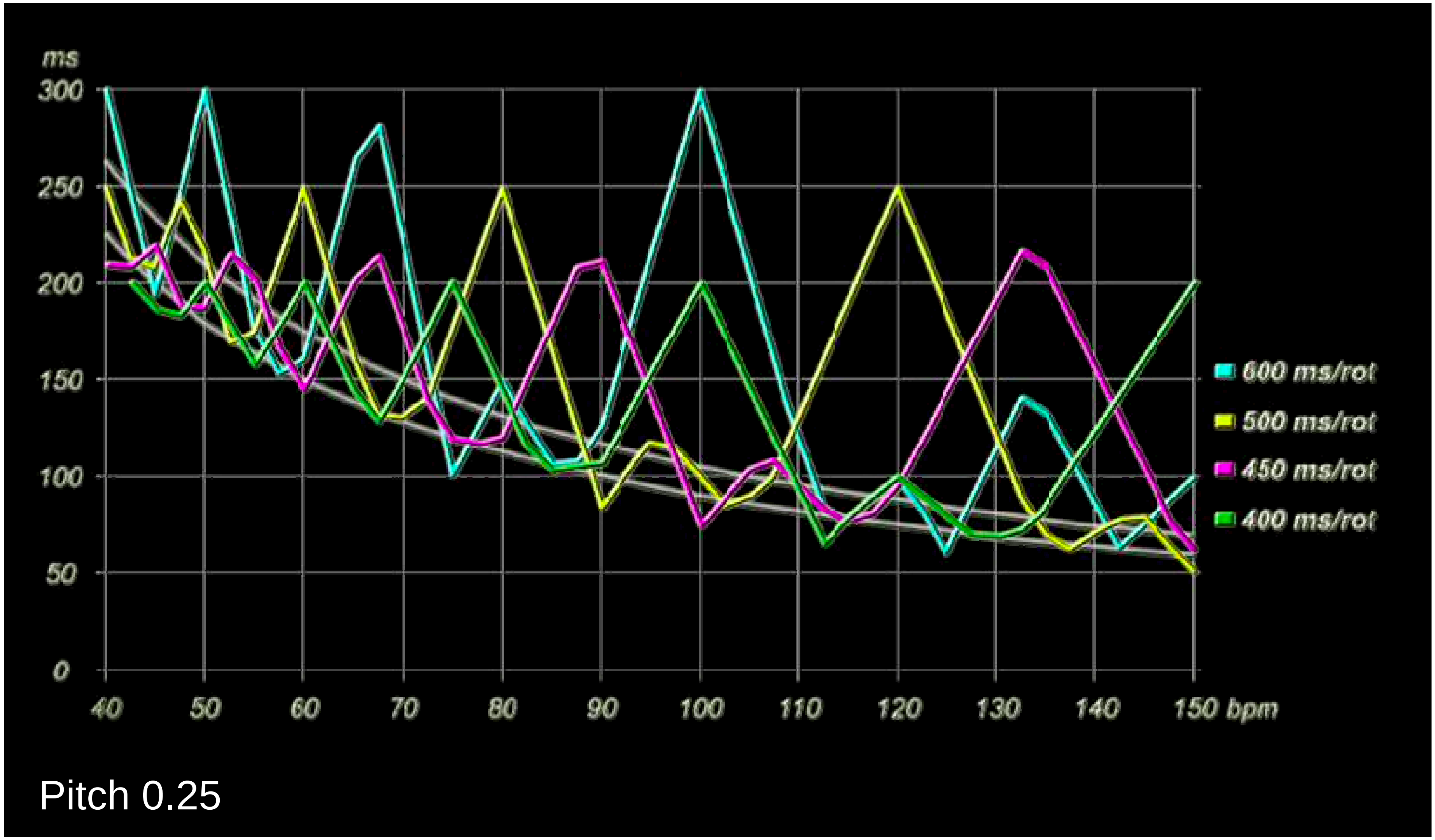
Courtesy Toshiba

Pre-scan resting heart beat

- Optimum combination of parameters – rotation time, pitch, no of sectors
- Selection - automatic using complex algorithms, semi-automatic, or guided by protocols

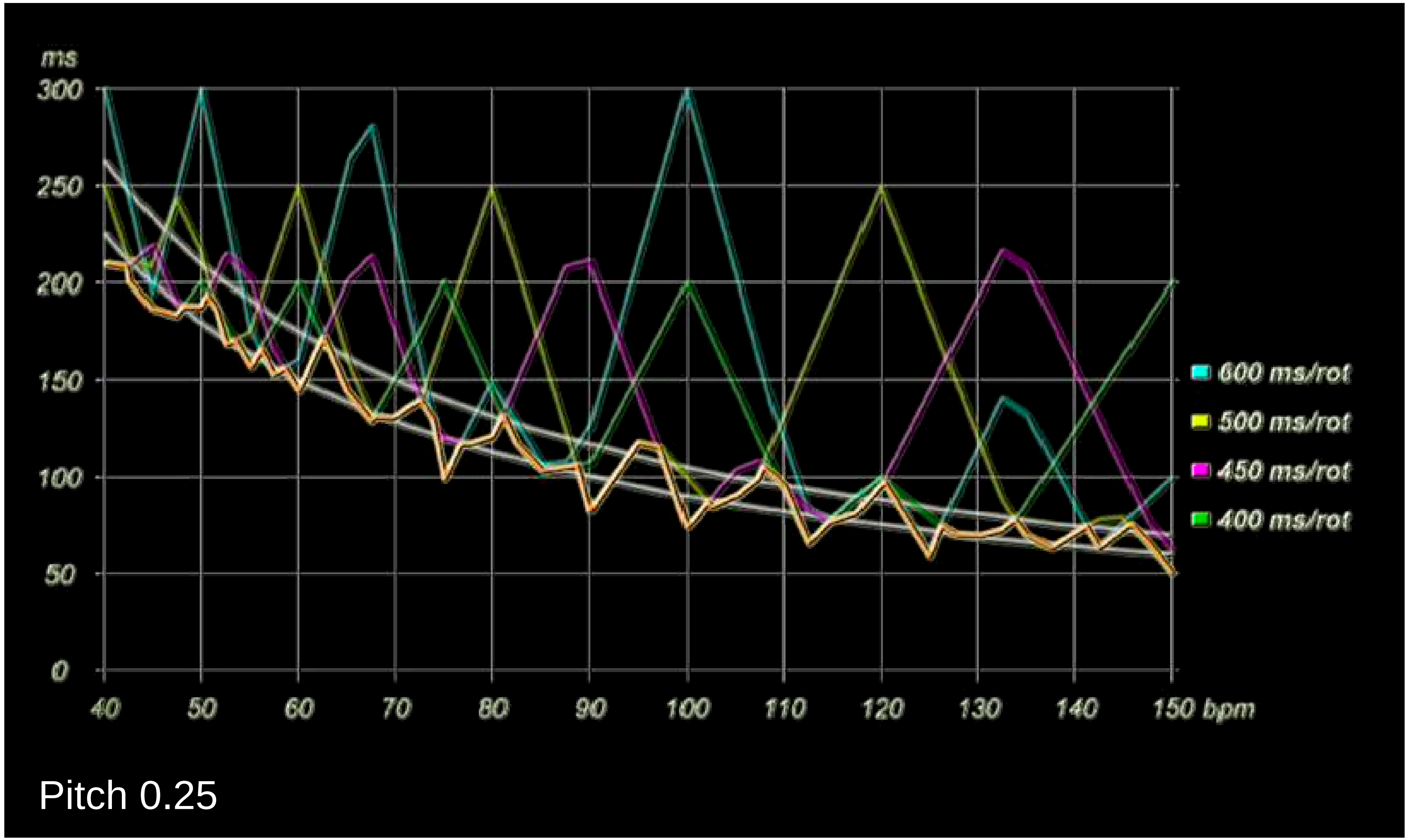
	IGE	Philips	Siemens (1 tube)	Siemens (2 tube)	Toshiba
Minimum scan time	0.35	0.42	0.33	0.33	0.42
No of sectors	1, 2, 4	Up to ?5	1 or 2	1 or 2	Up to 5

Automatic selection of rot. time, pitch & sectors



Courtesy Toshiba

Automatic selection of rot. time, pitch & sectors



Courtesy Toshiba

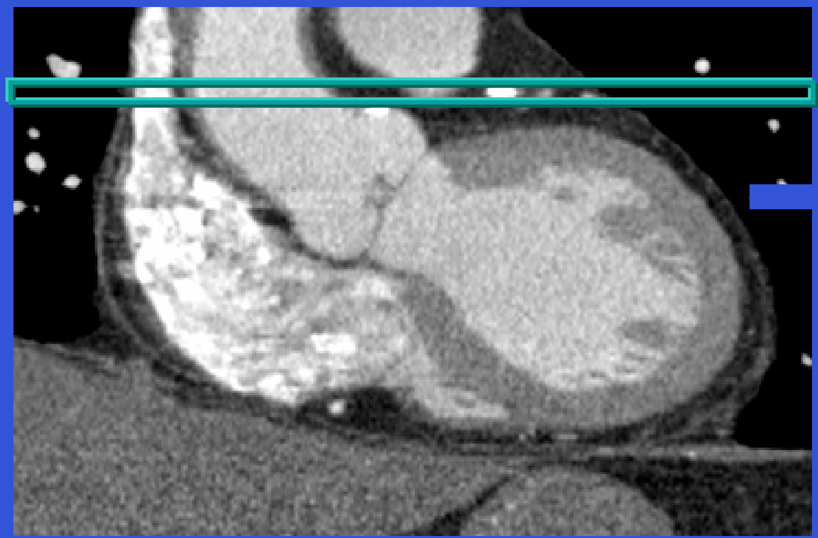
Phase of reconstruction

- Actual phase depends on particular area of interest
  - ~70% of the R-R interval for LCA
  - sometimes 40% for the RCA
- Exact matching of phase to heart motion

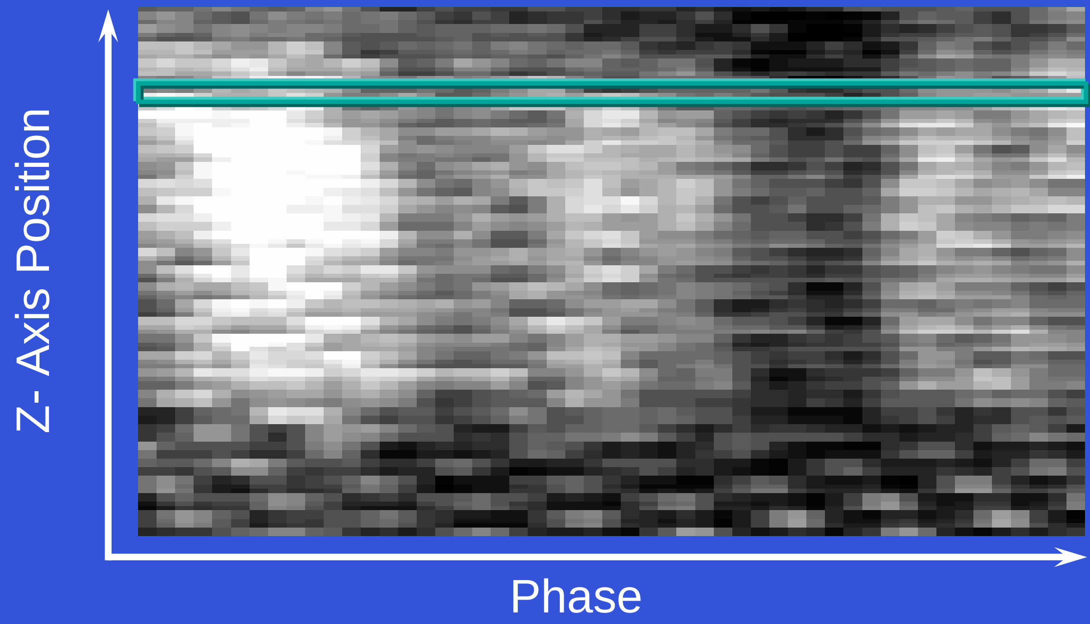
Finding the optimum phase

- Motion Maps

For reference only



Raw data motion map

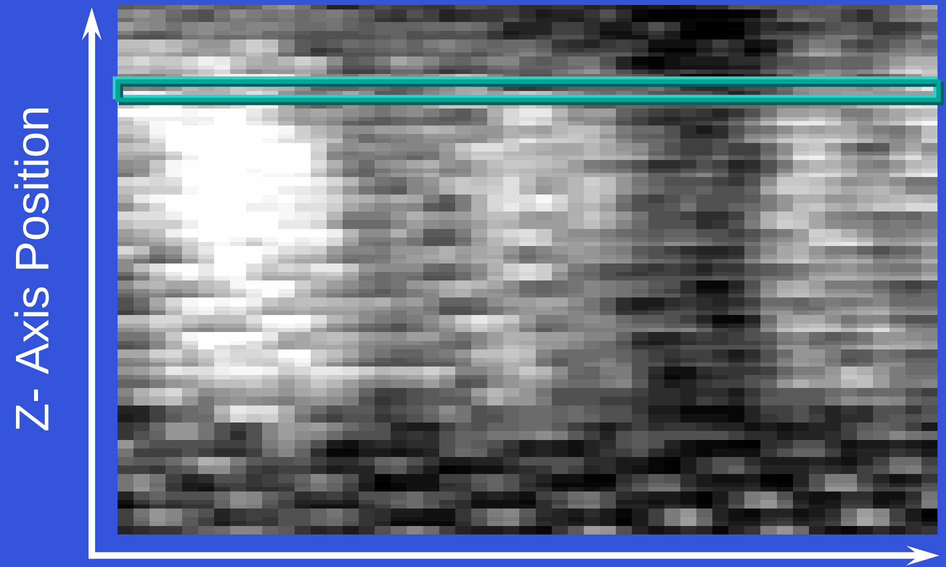


Using a raw data motion map movement in the cardiac cycle is determined

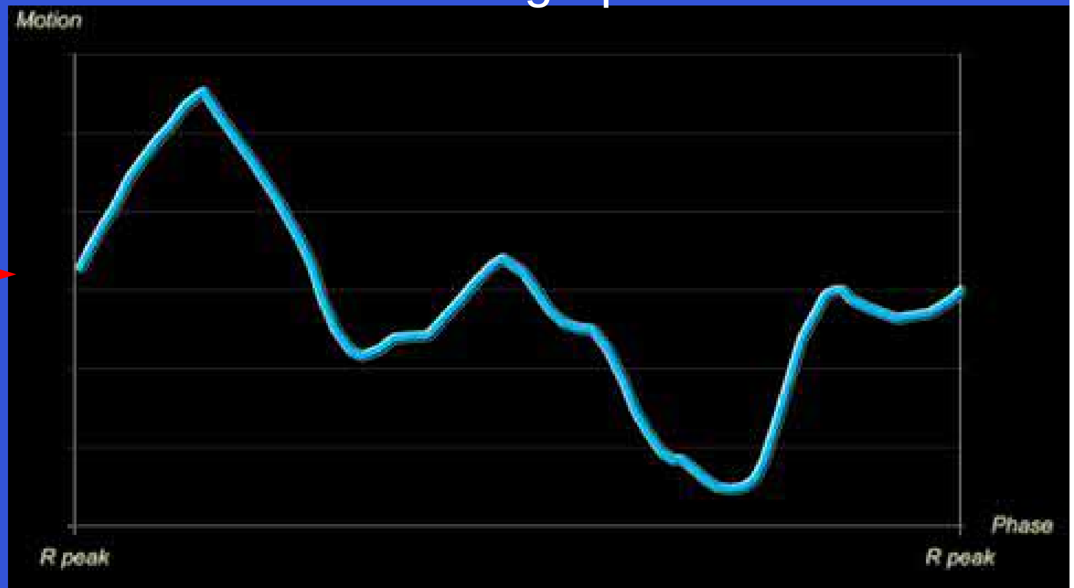
Finding the optimum phase

- Motion Maps

Raw data motion map



Motion graph

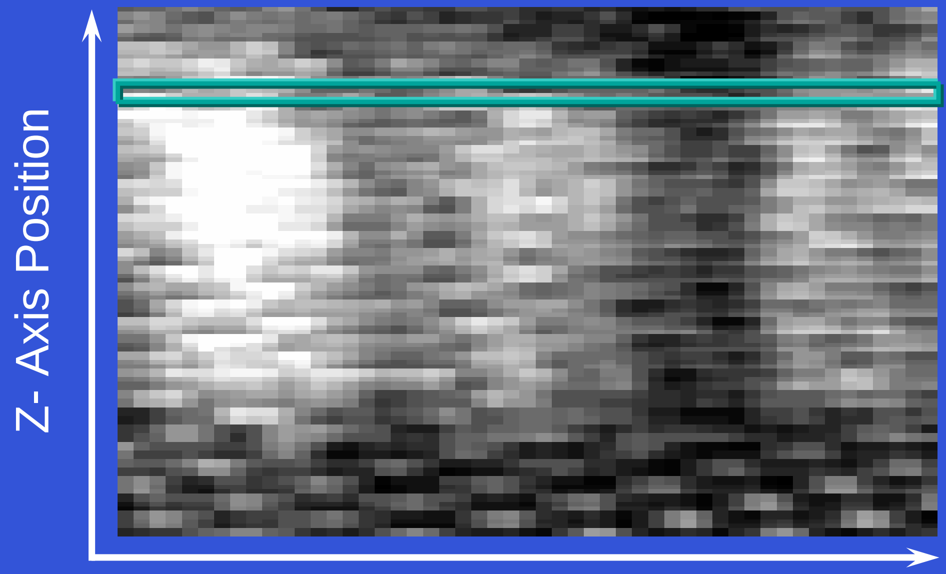


The raw data motion map is converted into a motion graph

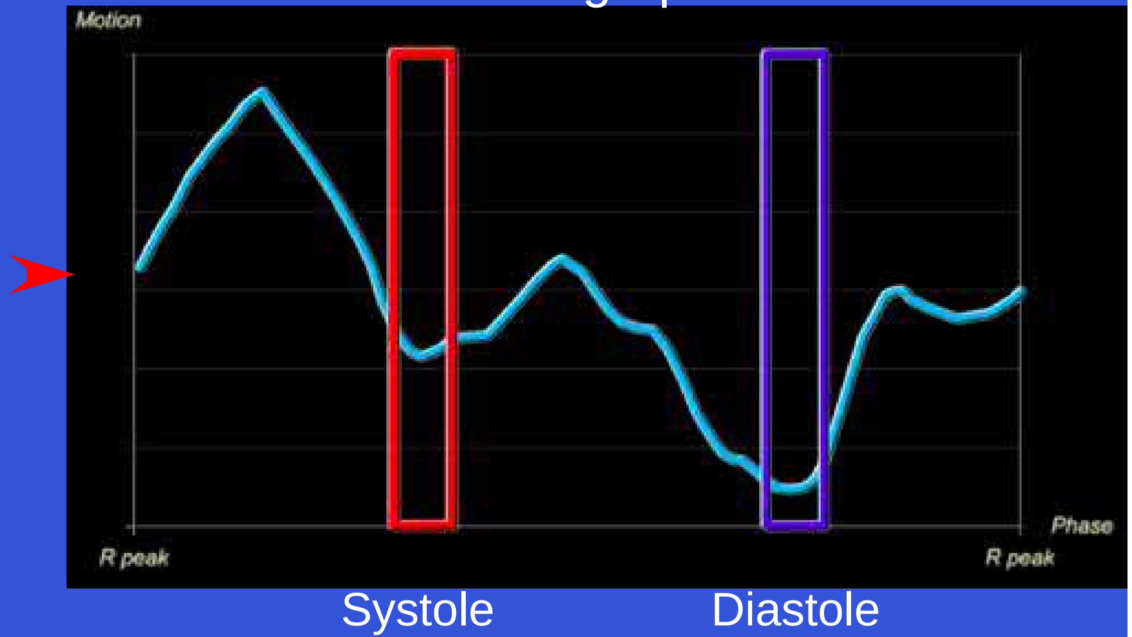
Finding the optimum phase

- eg optimum phase may be 72% not 70%

Raw data motion map



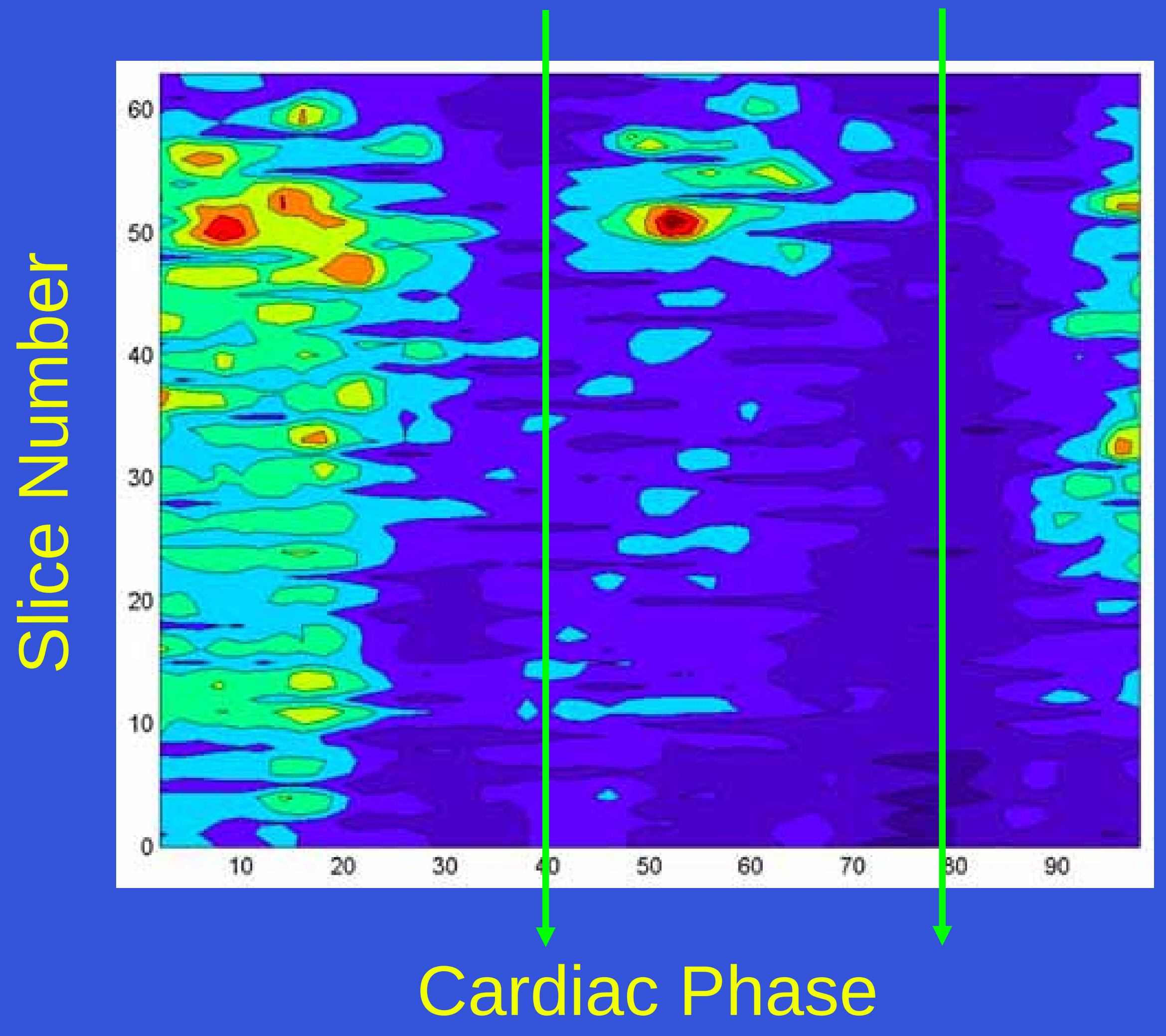
Motion graph



The troughs indicate the least motion phases used for reconstruction

Finding the optimum phase

Example: Min:56, Max:67, Avg 60



Courtesy: Philips, R. Manzke, M. Grass, Philips Research Labs, Hamburg, Germany

Responding to change in heart rate

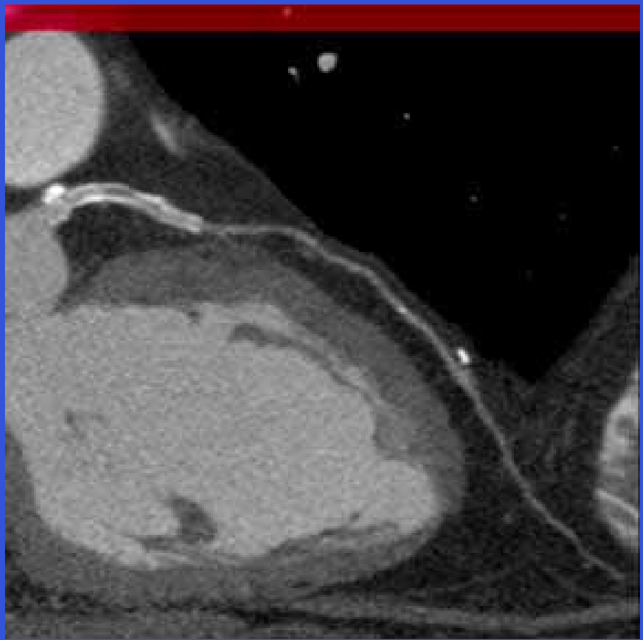
- Retrospective ECG Editing of reconstruction data

Courtesy Siemens

ECG Editing

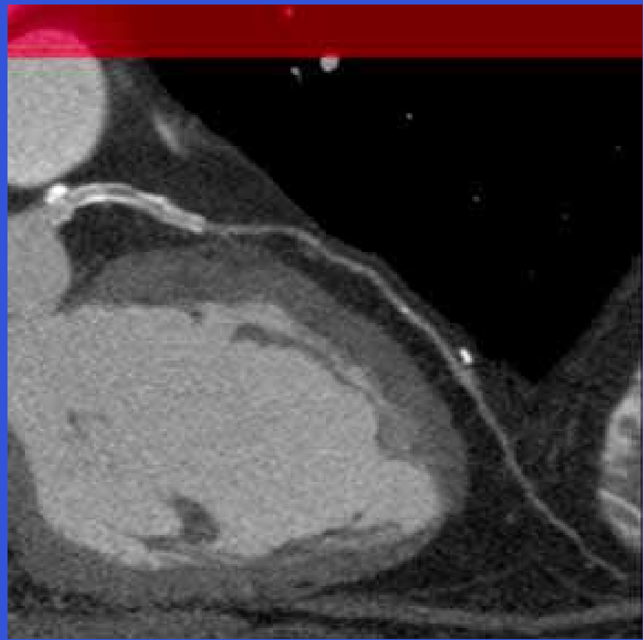
- Important in 64 slice scanners where fewer beats are used to cover heart

16 slice scanner



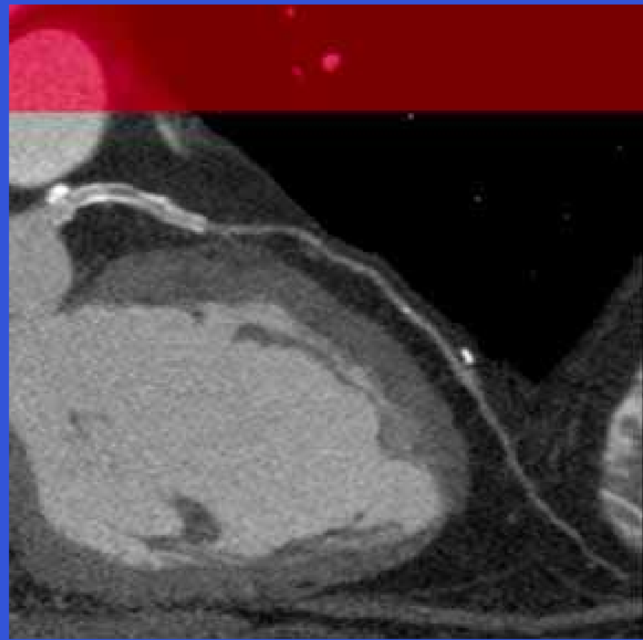
24 beat scan

32 slice scanner



12 beat scan

64 slice scanner



6 beat scan

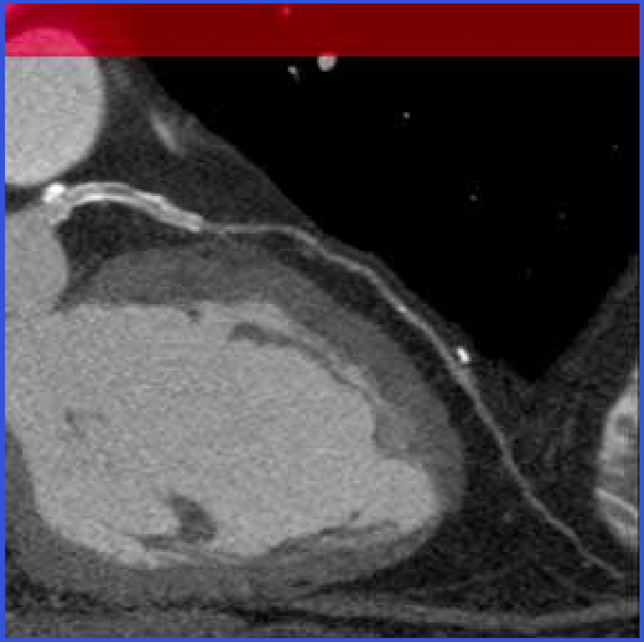
1 beats recorded incorrectly

Courtesy Toshiba

ECG Editing

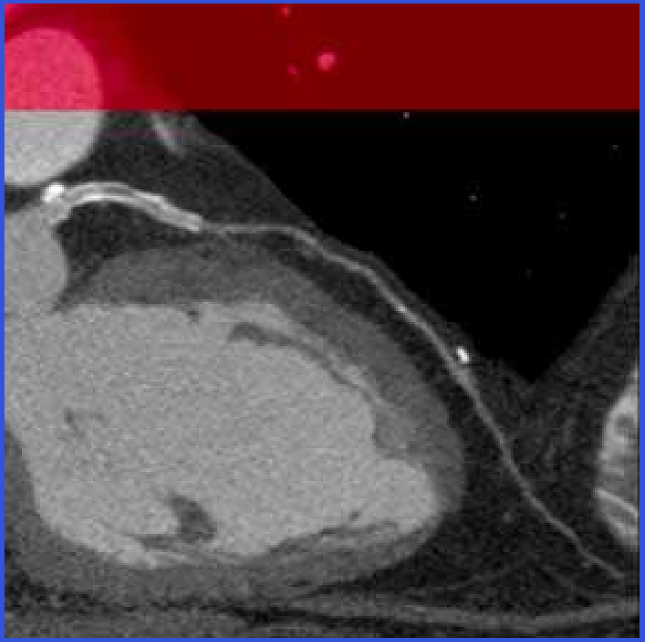
- Important in 64 slice scanners where fewer beats are used to cover heart

16 slice scanner



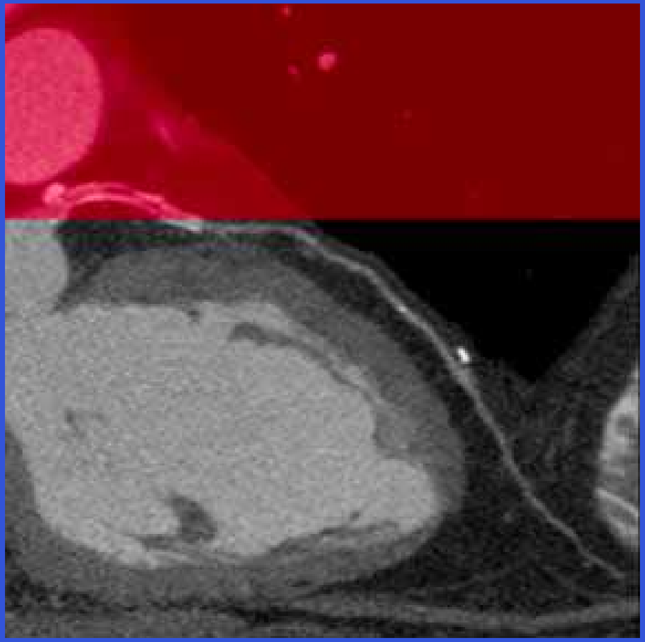
24 beat scan

32 slice scanner



12 beat scan

64 slice scanner



6 beat scan

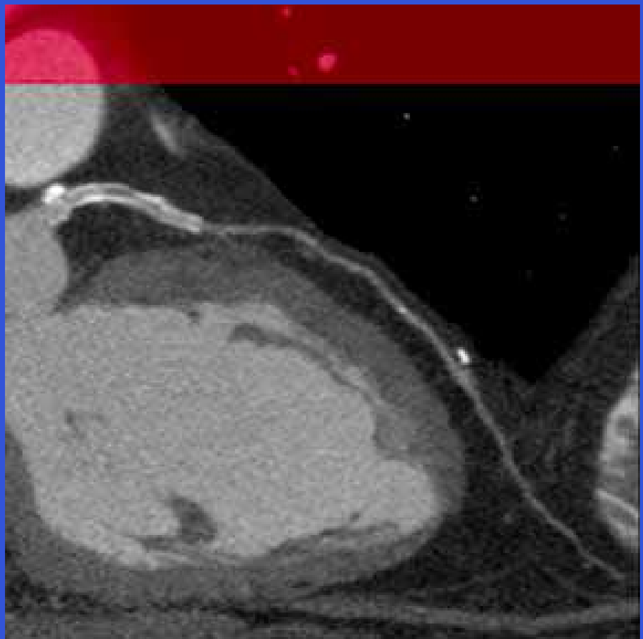
2 beats recorded incorrectly

Courtesy Toshiba

ECG Editing

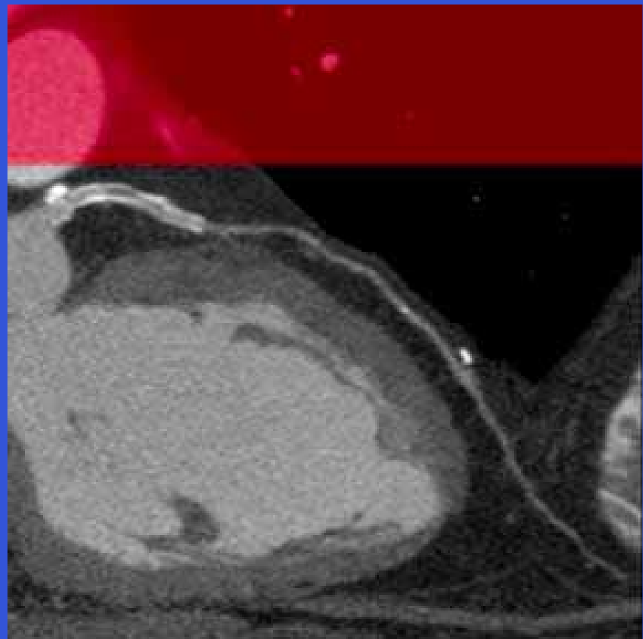
- Important in 64 slice scanners where fewer beats are used to cover heart

16 slice scanner



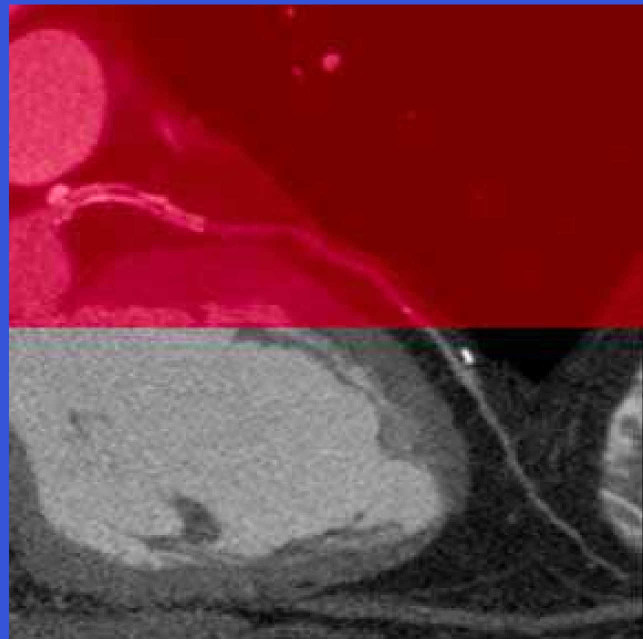
24 beat scan

32 slice scanner



12 beat scan

64 slice scanner



6 beat scan

3 beats recorded incorrectly

Courtesy Toshiba

Example - ECG Editing

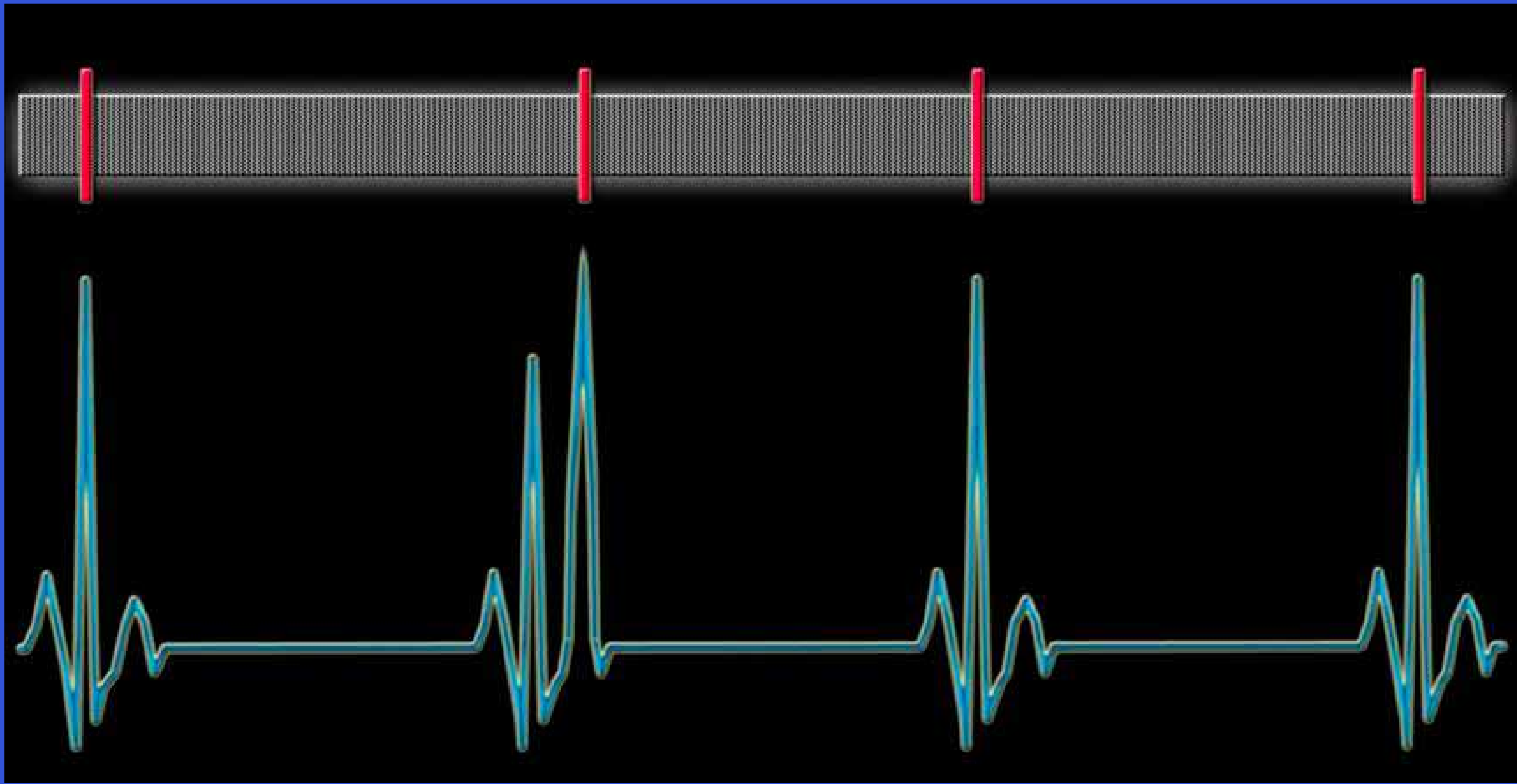
Enhanced T-peak

During registration T-peak exceeds R-peak

Courtesy Toshiba

Example - ECG Editing

Enhanced T-peak

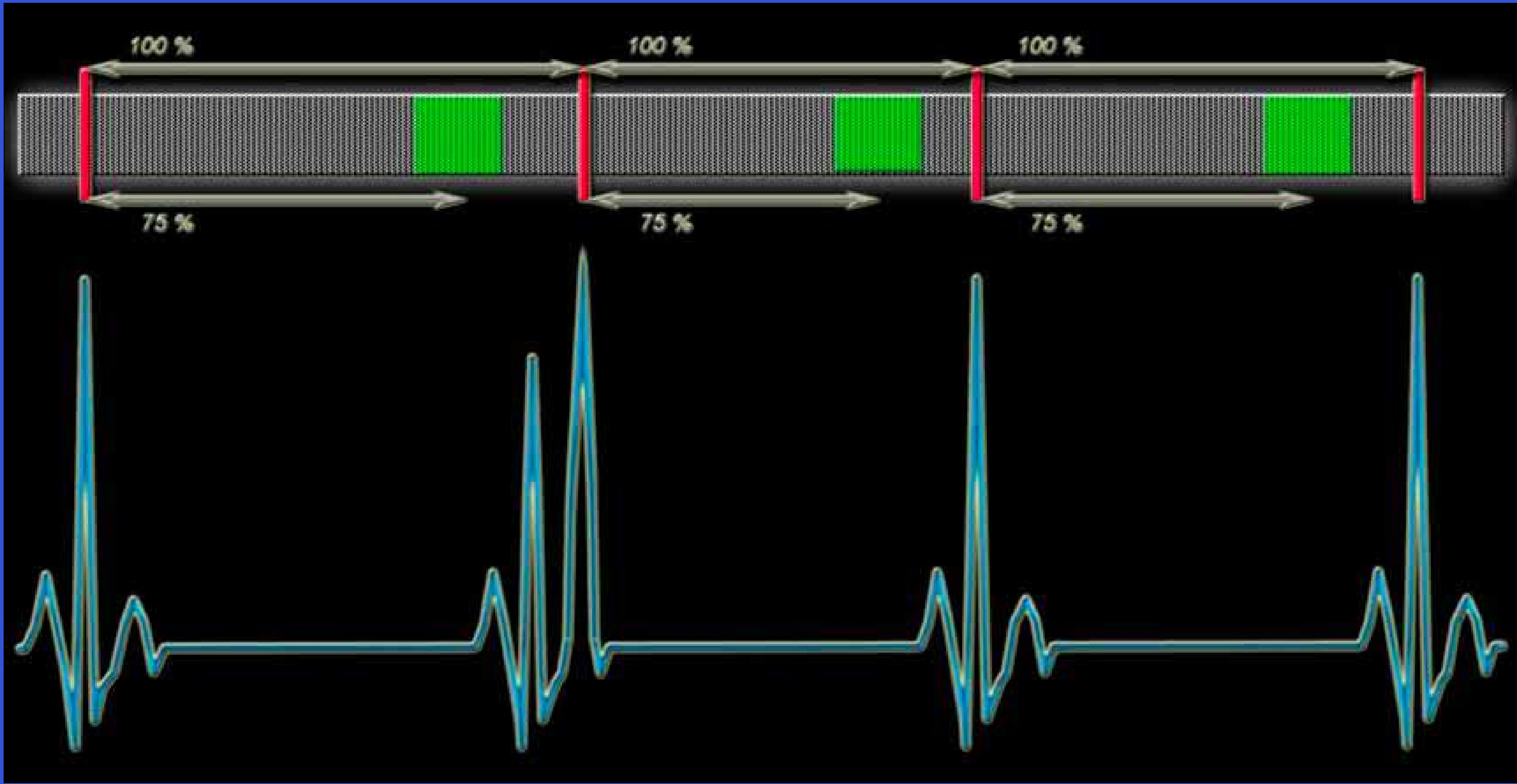


R-peaks are incorrectly recognized and time markers are incorrectly set

Courtesy Toshiba

Example - ECG Editing

Enhanced T-peak

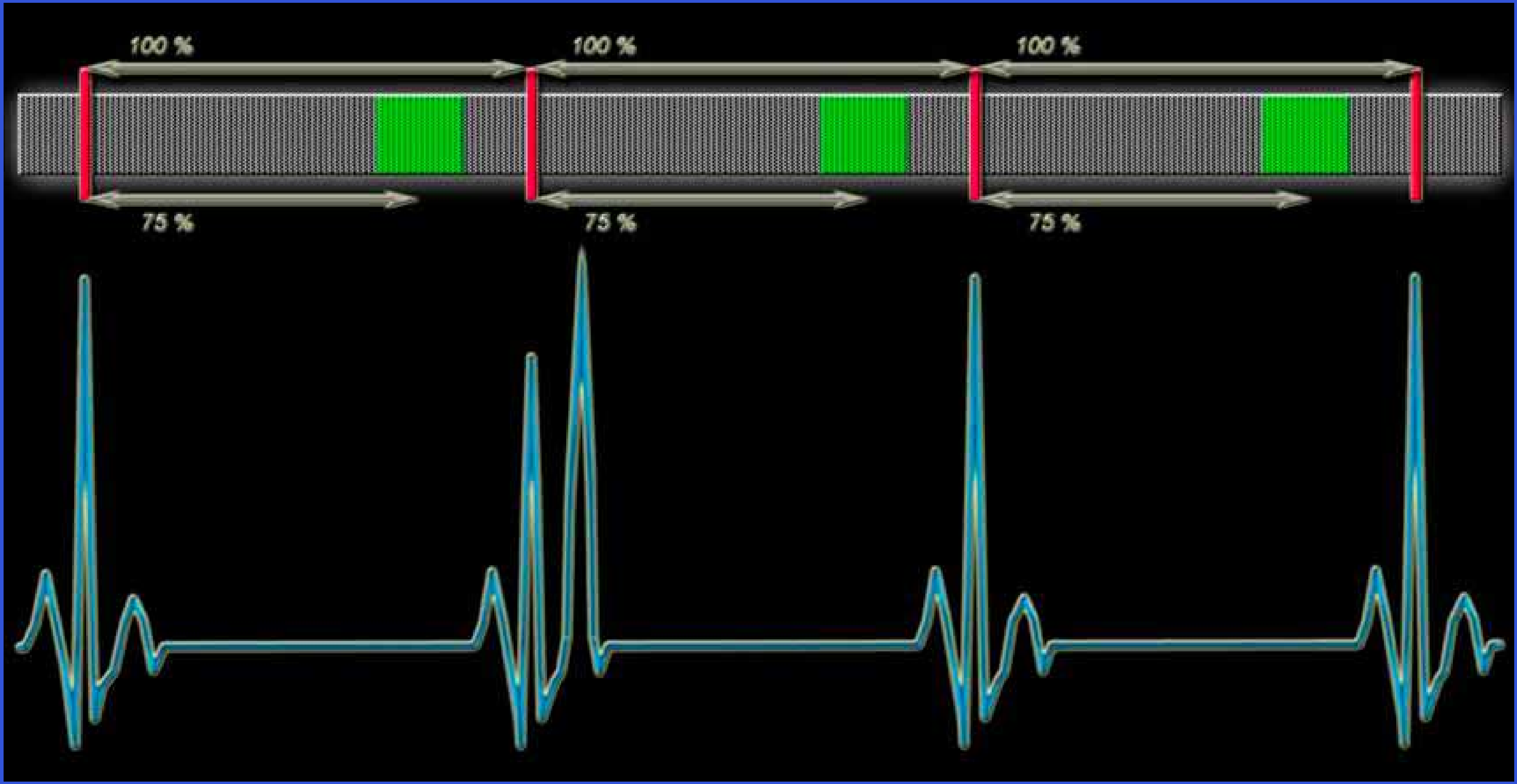


Raw data from wrong phase is used prior and after the T-peak

Courtesy Toshiba

Example - ECG Editing

Enhanced T-peak



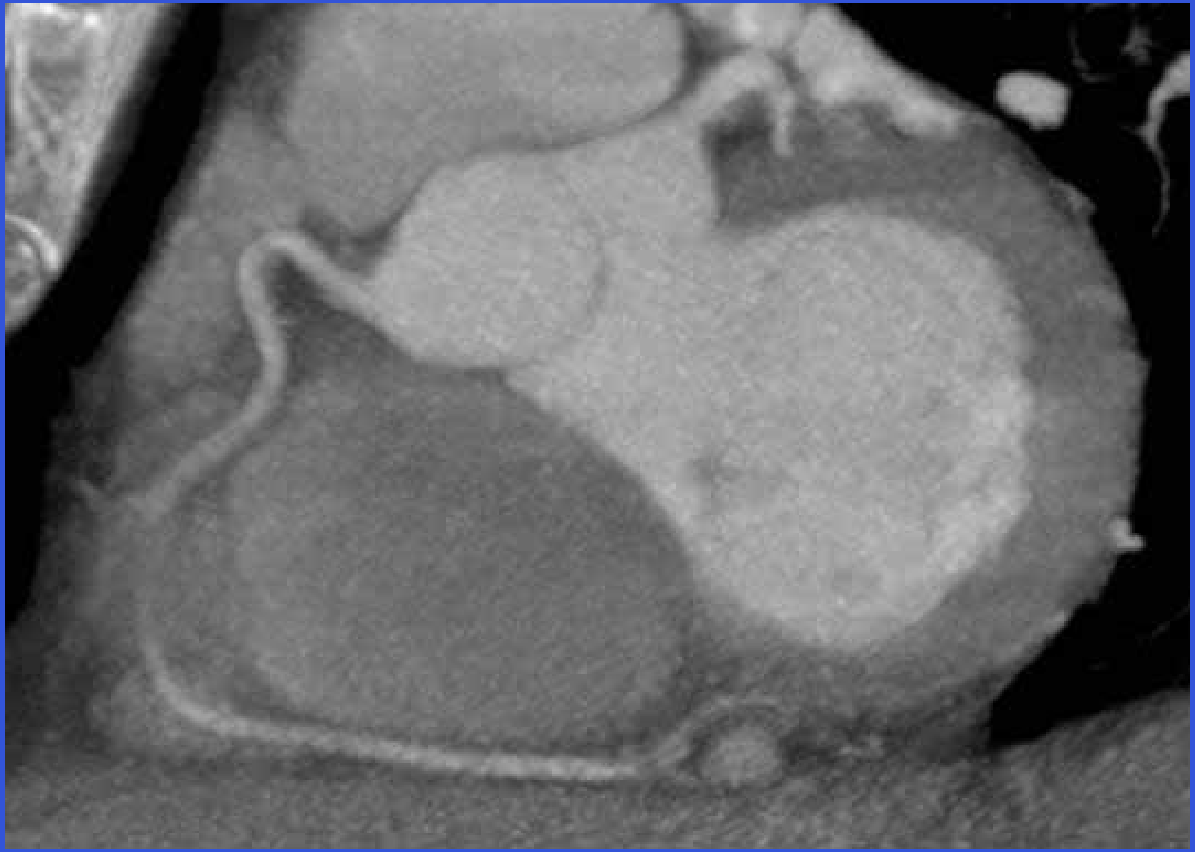
Correct phase, specific raw data is used for reconstruction

Courtesy Toshiba

Example - ECG Editing

Sub optimal ECG

64 slice, one T instead of R-peak



Courtesy Toshiba

Example - ECG Editing

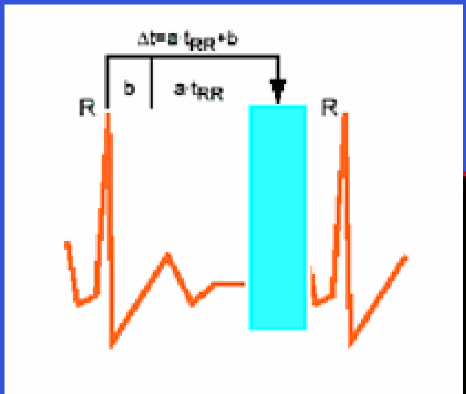
ECG Editor

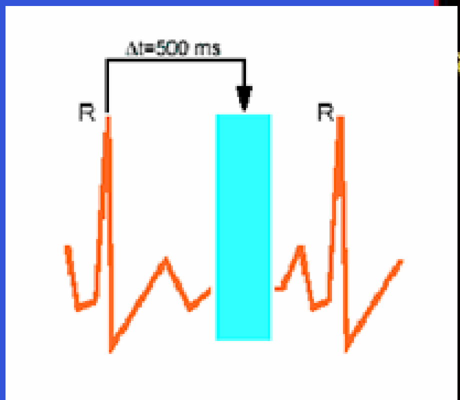
64 slice, move T-peak to R-peak

Courtesy Toshiba

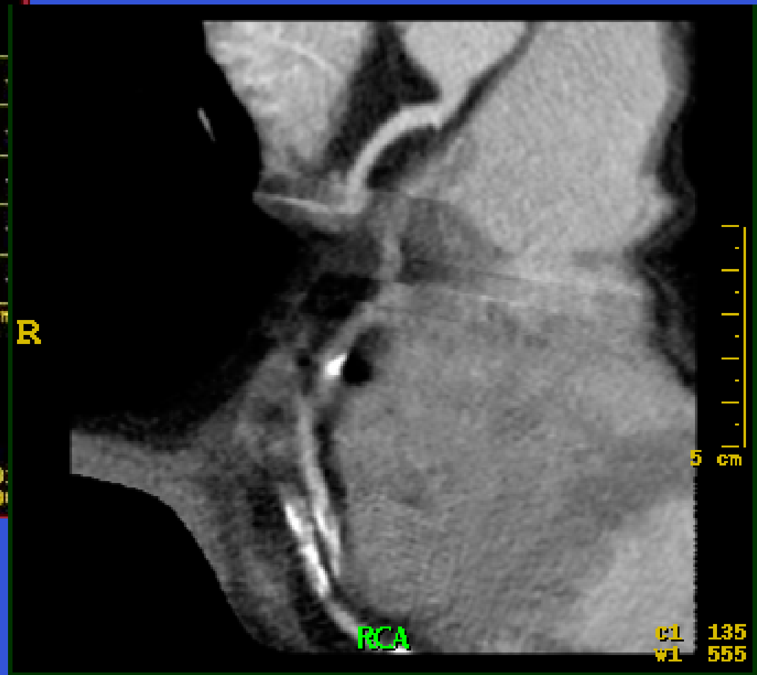
ECG tracking to deal with irregular beat

Track the R-to R in real time





Variable Beat-to-Beat



Fixed Offset

Courtesy: Philips (Dr. Martin Hoffmann, Uni-Ulm, Germany)

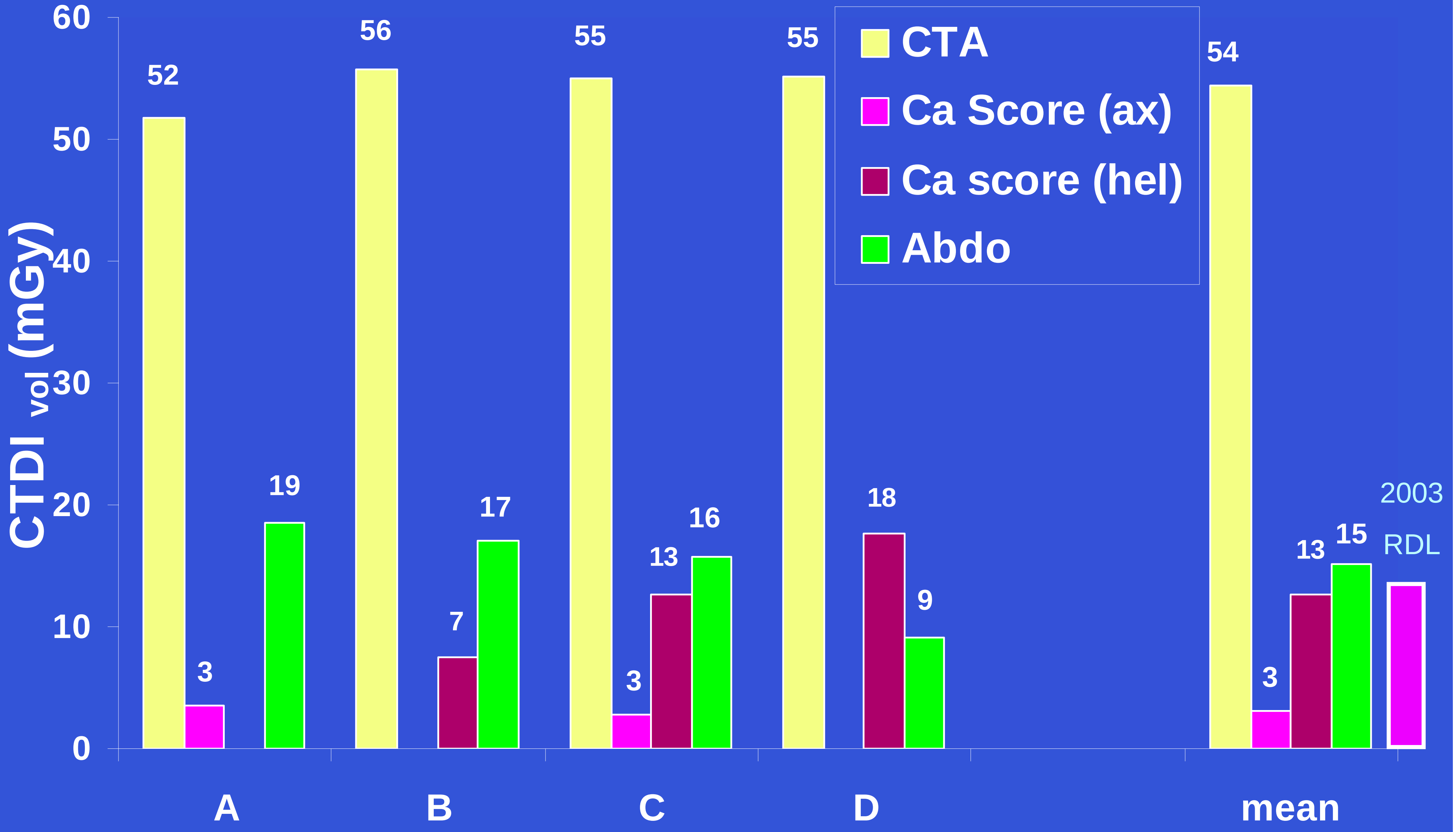
Technical Aspects of MSCT and ECG Gating

- MSCT scanning
  - Principles
  - Current technology
- Particular challenges of imaging the heart
- ECG Gating techniques
- Practical approaches to optimisation
- Dose
- The future

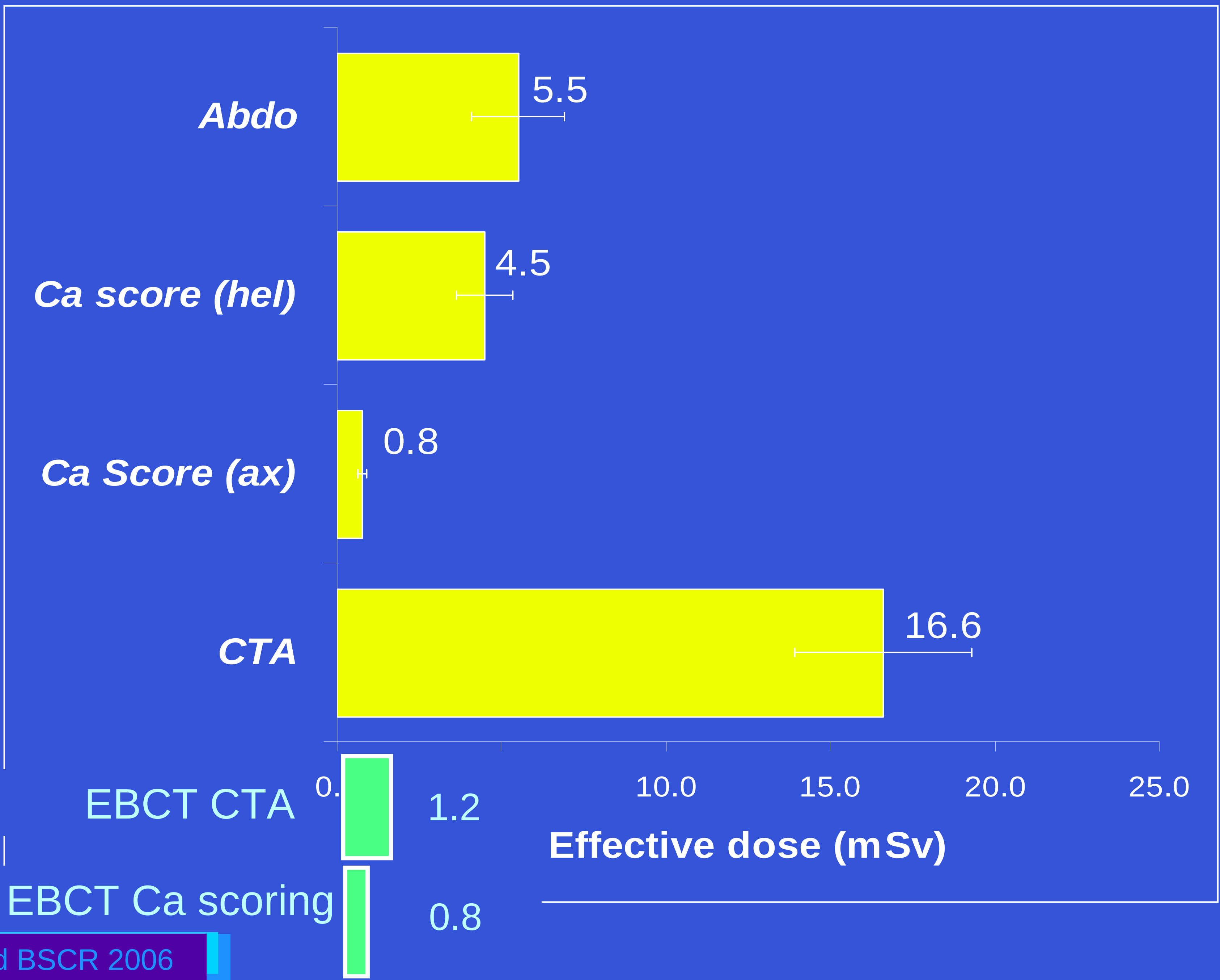
Dosimetry

- Overlapping pitch
  - High dose
  - Where possible increase pitch to reduce dose
- Might expect dose to increase
  - only reconstruct part of the data set for any one image
  - 10% of data $\Rightarrow$ ~ 3 x dose to achieve similar iq
- Typical dose values
  - Comparison with other examinations and modalities
- Dose saving techniques
  - ECG dose modulation
  - Special beam shaping filters

Organ Doses for Cardiac Scanning



Effective Doses



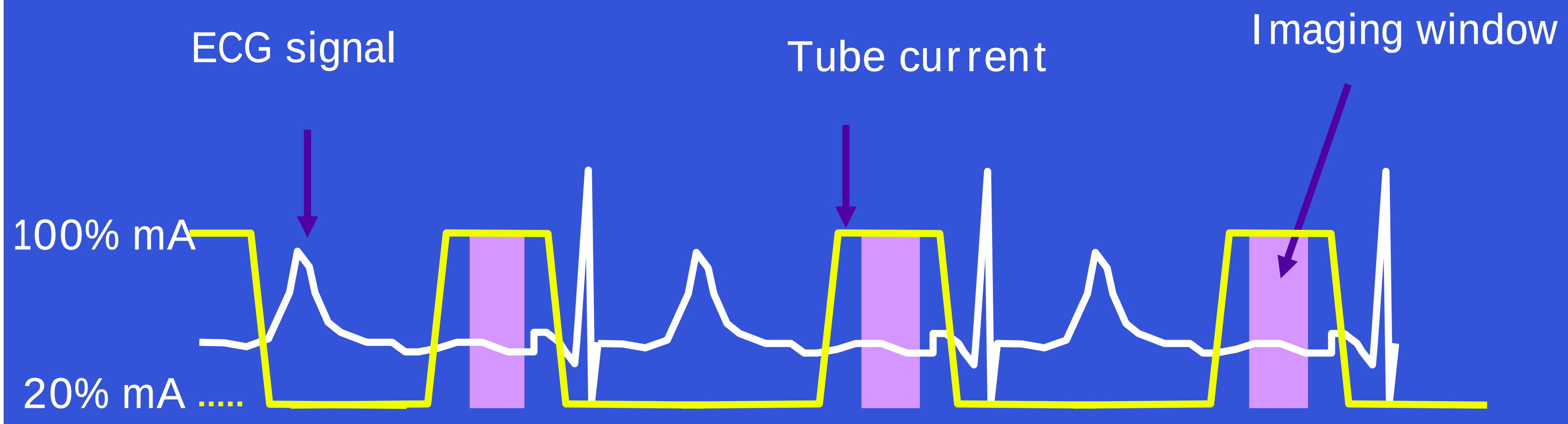
Dosimetry

- Cardiac CT radiation doses are relatively high.
- Ball park figures (dependent on technique etc)

mSv	
~ 10 – 15	CT angiography
~ 5	planar coronary angiography
~ 5	PET ^{82}Rb
~ 2	PET $^{13}NH_3$
~ 10	SPECT

ECG Tube Current Modulation

- ECG current modulation is used
  - mA reduced outside of required reconstruction phase down to ~ 20%
  - Net dose savings ~ 50%
- Can be automatically suspended if ECG changes



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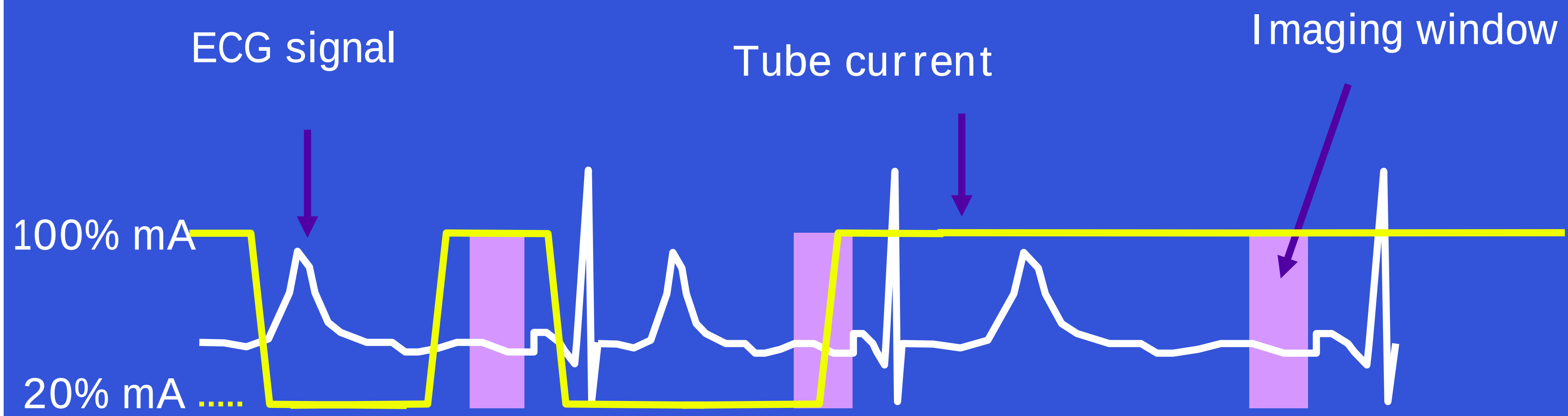
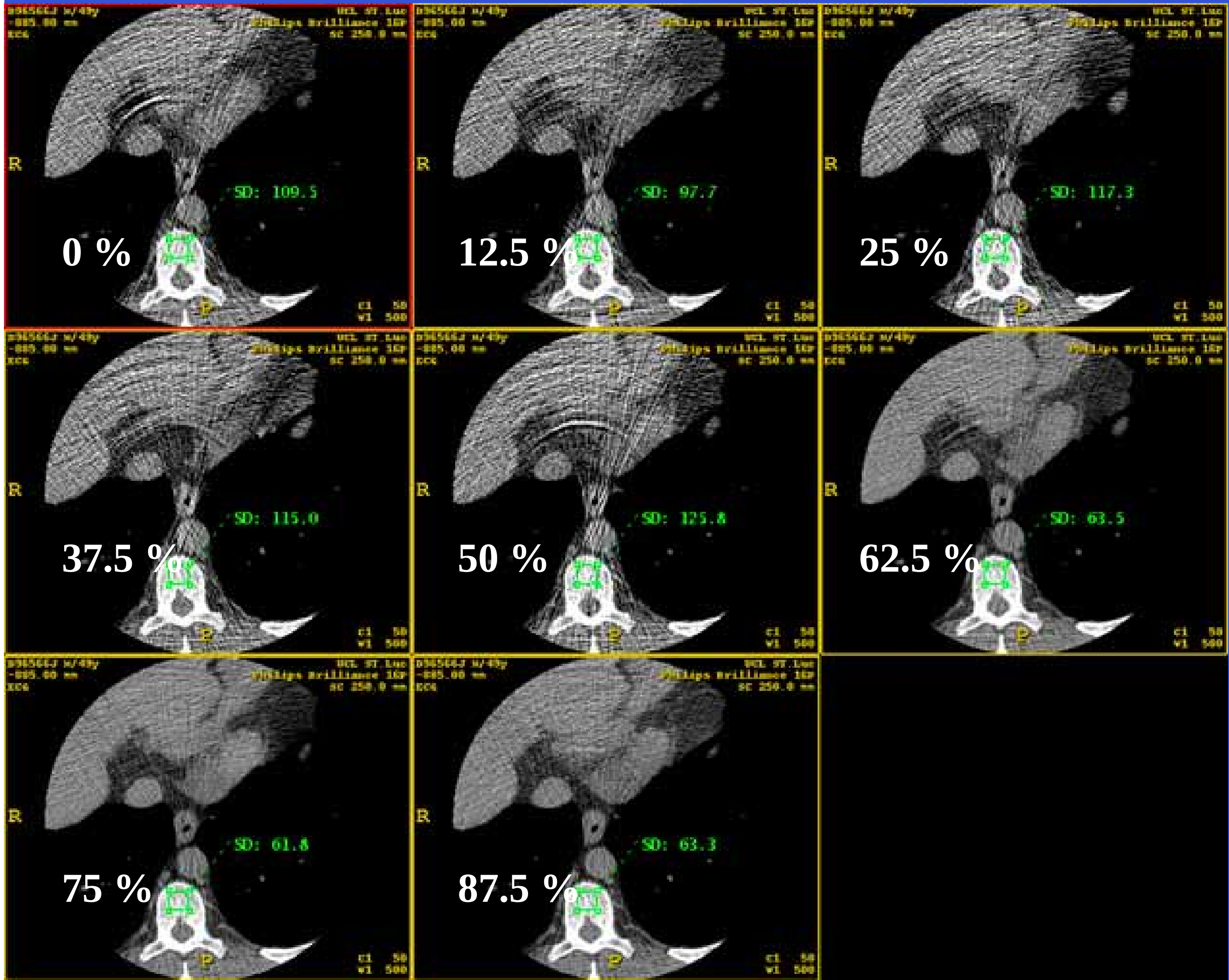
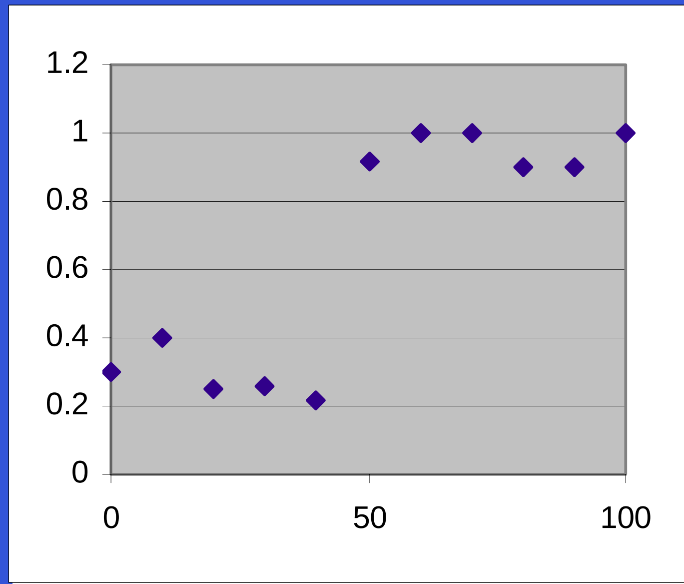


ECG Tube Current Modulation

- Image noise affected in phases of lower mA



Calculated relative mAs from noise values

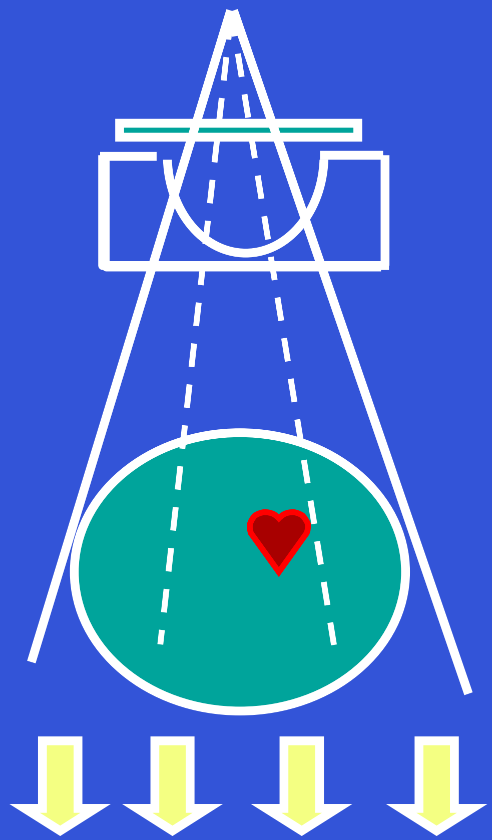


Noise α $1/\sqrt{mAs}$

Estimated dose Saving ~ 45%

Beam Shaping Filters

- Beam shaping filters more appropriate for small fov reconstruction within a larger fov



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What are the challenges ?

- Requirements for imaging the heart
  - Image for <100ms - multi-sector, or two tube
  - Isotropic resolution < ~ 1 mm ✓
  - Low contrast differentiation ✓ at the expense of high dose
  - One breath hold and few beats ✓

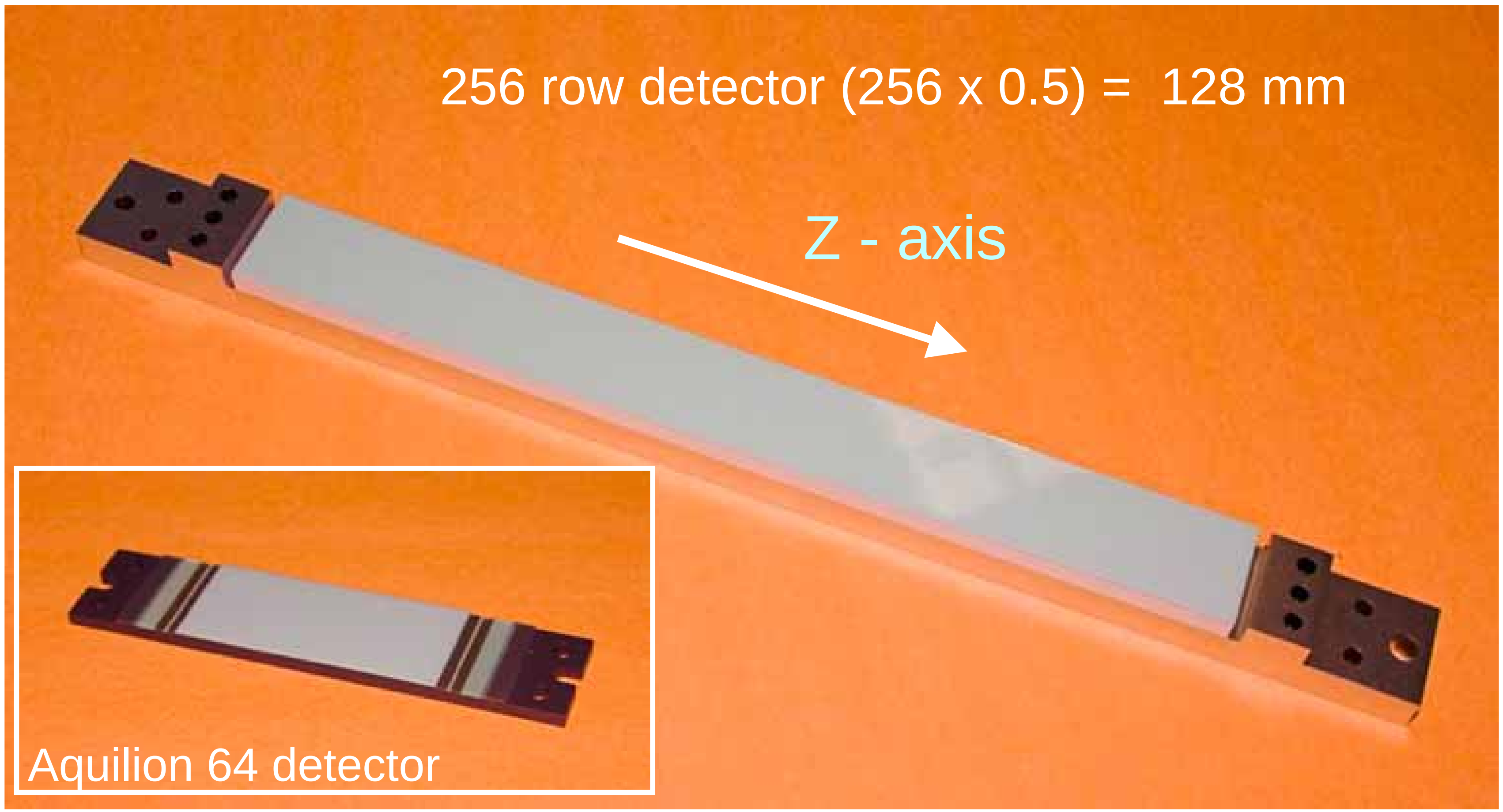
Future of cardiac CT

- Extending current developments:
  - Faster gantry rotation
    - <0.2s/rot, need mechanical forces >75G
  - Bigger tubes and generators
  - Advanced reconstruction methods
  - EBCT?
- Larger detector arrays
- Flat panel detectors
- Dual energy imaging

Faster gantry rotation ?

Larger detector arrays

- 128/256 row scanners in next couple of years
  - Allow whole organ coverage in single rotation



Detector mock-ups courtesy of Toshiba

Large matrix detector array

- 256 x 0.5 mm = 128 mm coverage

Courtesy of Toshiba

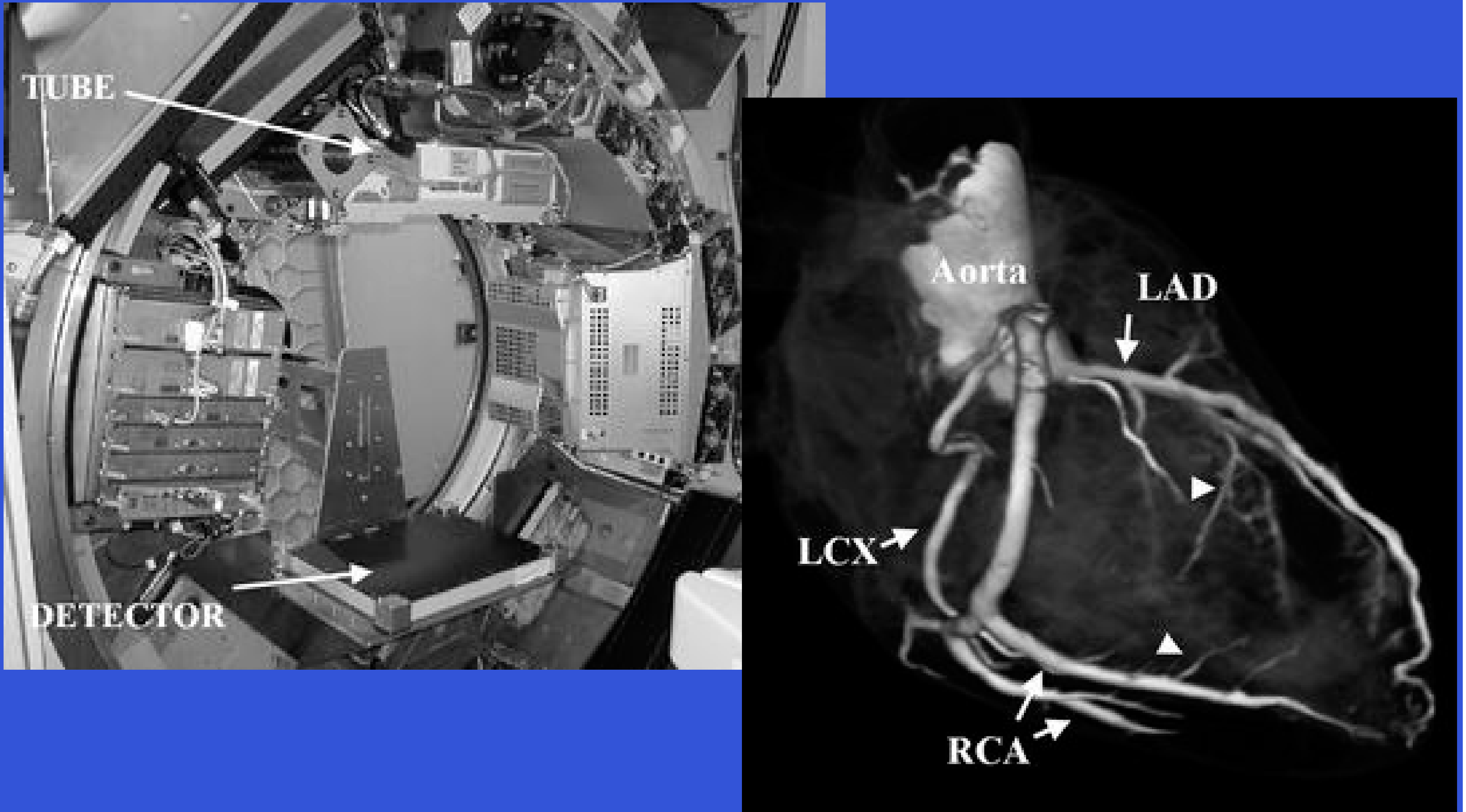
Large matrix detector array

Total Organ Scanning

Philips MDCT (WIP)

Courtesy of Philips

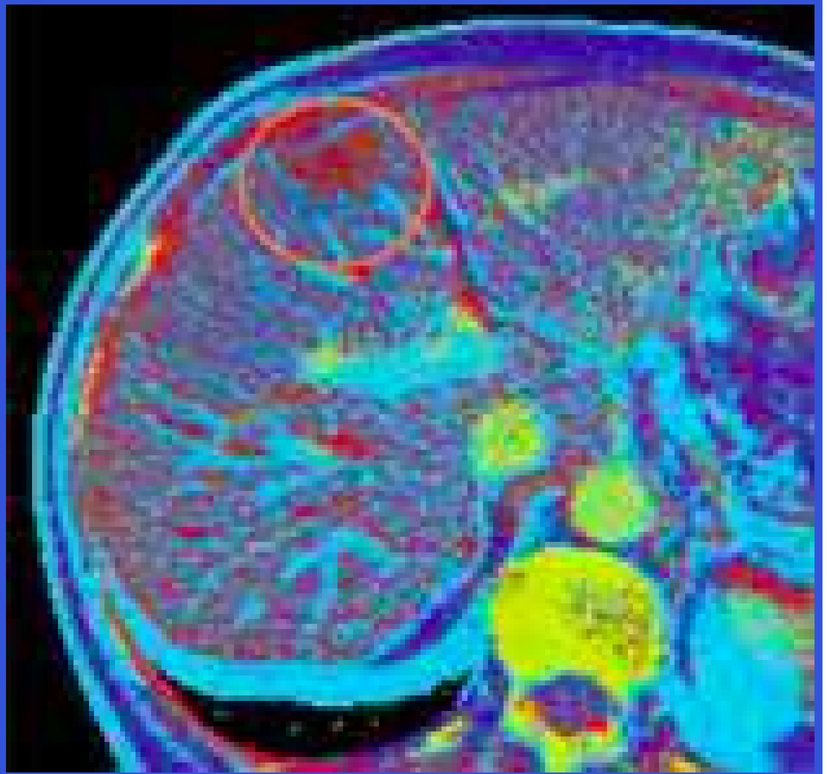
Flat panel detectors



From Nikolaou
Harefield BSCR 2006

Dual energy imaging

- Performed with two tubes (Siemens)
  - Each tube operates at different voltage
- Detector discrimination (Philips, GE)
  - Dual layer detector, sensitive to different energies
- Contrast resolution can be improved
  - Plaque discrimination?



Courtesy Siemens

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  - Derek Tarrant, Mike Hayden – Philips
  - Susie Guthrie - Siemens
  - Henk DeVries - Toshiba

Technical Aspects of MSCT and ECG Gating

S. Edyvean

Imaging Performance Assessment of CT Scanners

St. Georges Hospital

www.impactscan.org

ImPACT