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History and Generations of Computed Tomography

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Definition of Generation

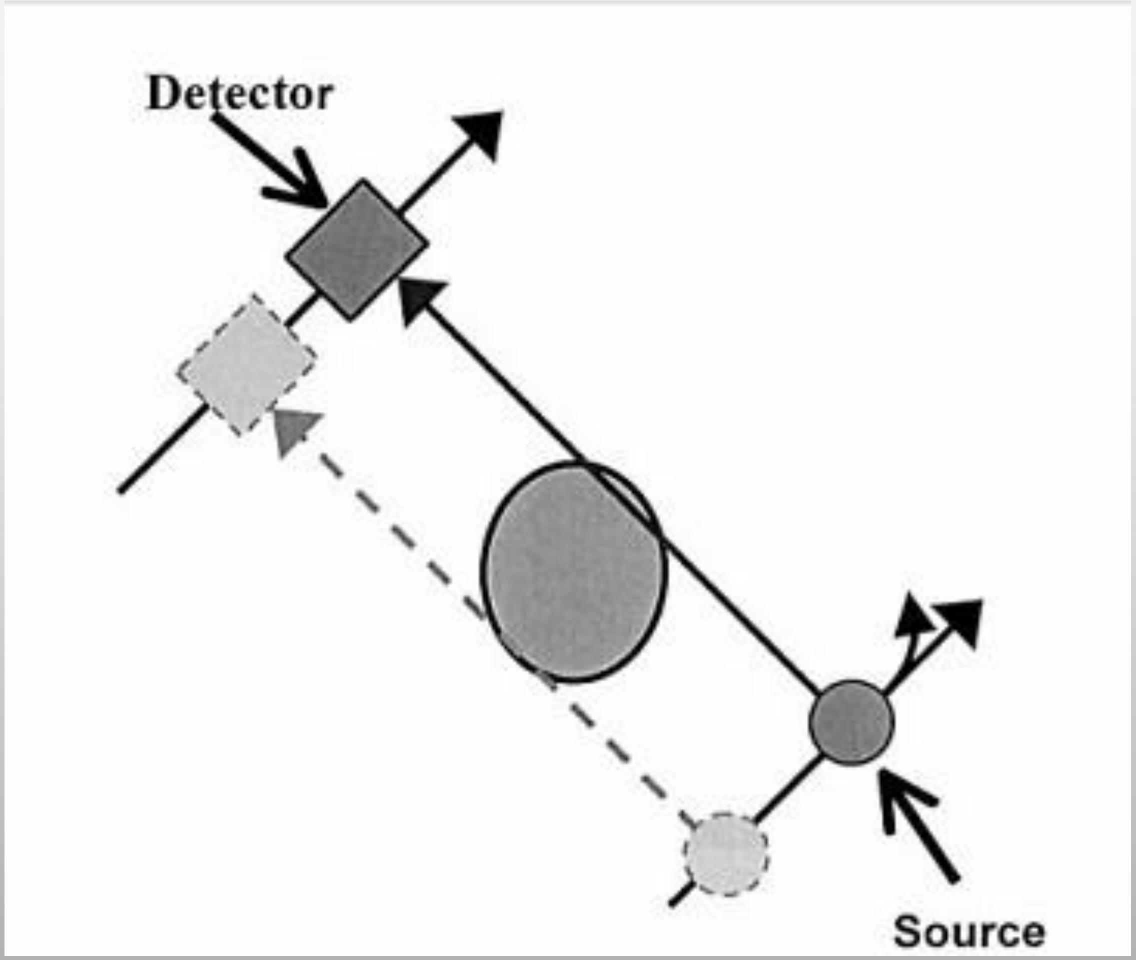
- Classification of computed tomography (CT) based upon: arrangement of components and mechanical motion required to collect data
- "Generation" the order in which CT scanner design has been introduced, and each has a number associated with it
- NOTE: higher generation number NOT a higher performance system

First Generation

Design: single X-ray source and single X-ray detector cell to collect all the data for a single slice

- Source and detector, rigidly coupled
- Beam: Pencil beam
  - translated across patient to obtain set of parallel projection measurements at one angle
- Source/detector rotate slightly and a subsequent set of measurements are obtained during a translation past patient
- Process is repeated once for each projection angle until 180 projections , across a 24 cm FOV
- Translation and rotation process, this geometry is referred to as a translate/rotate scanner

First Generation CT

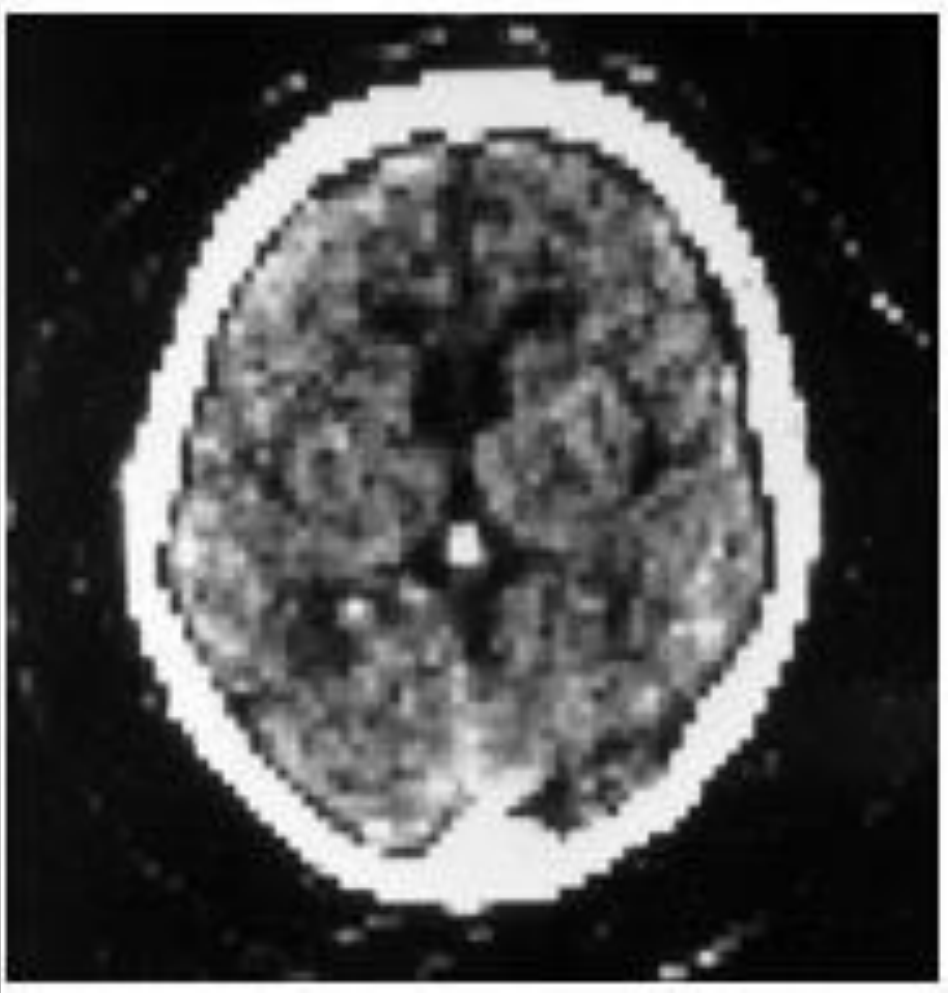


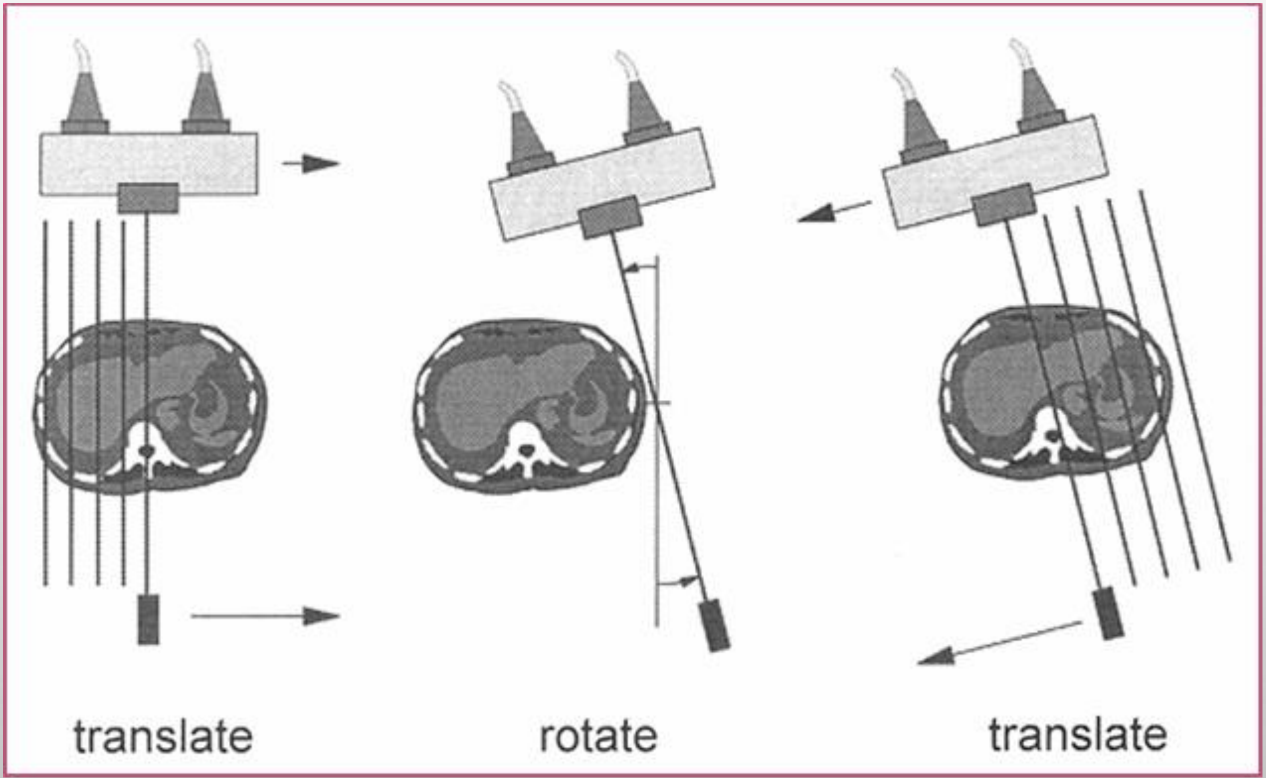
First CT

- EMI Mark I scanner (1973)
- Earliest versions:4.5 minutes for a single scan and thus were restricted to some regions (patient motion controlled)

- Later versions: procedures = series of scans
  - procedure time reduced some what by using two detectors so that two parallel sections were acquired in one scan
- Contrast resolution of internal structures was unprecedented, images had poor spatial
- Resolution very poor

1st CT Generation Image

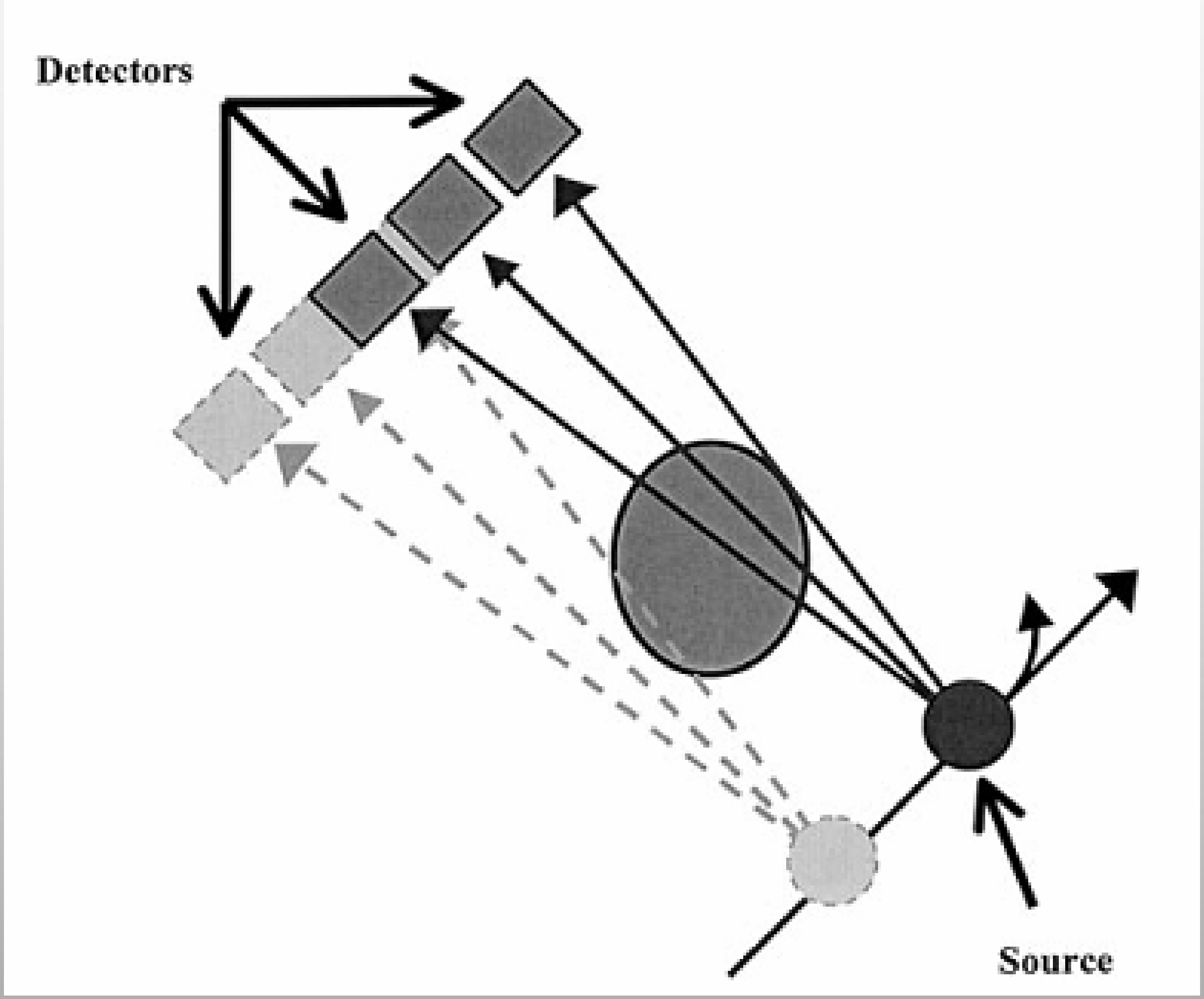



translate
rotate
translate

Second Generation

- Design: multiple detectors
  - B/C X-ray source emits radiation over a large angle, the efficiency of measuring projections was greatly improved
- Source and array of detectors are translated as in a first generation system
  - but since beam measured by each detector is at a slightly different angle with respect to object, each translation step generates multiple parallel ray projections
- Multiple projections obtained during each traversal past the patient
  - this scanner is significantly more efficient and faster than 1st one
- This generation :a translate/rotate scanner

Second Generation CT



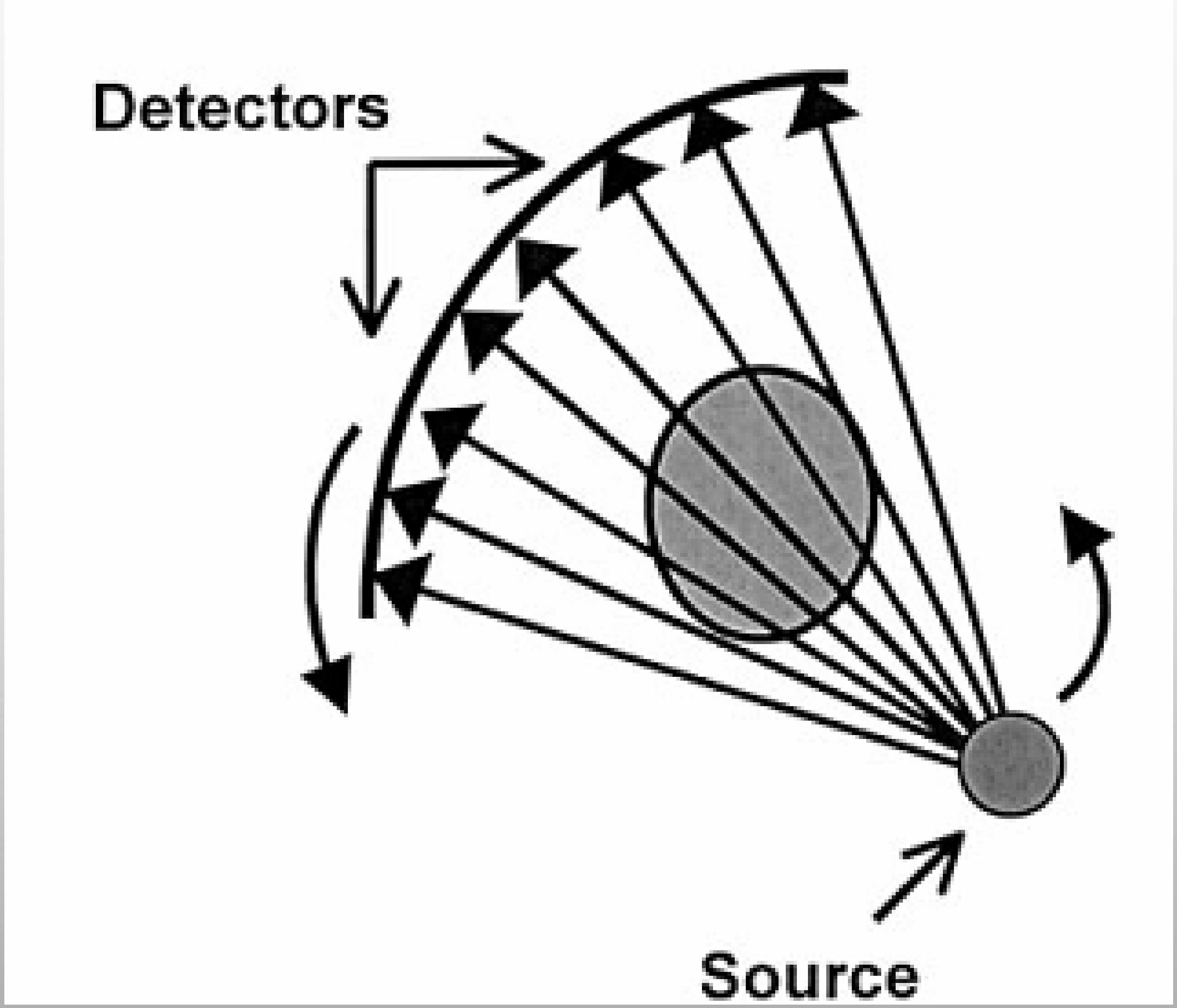
Second CT

- Pros: reducing scan time
- The trunk could be imaged
- By adding detectors angularly displaced , several projections could be obtained in a single translation
- Early versions: 3 detectors each displaced by1°
  - Since each detector viewed the x-ray tube at a different angle , a single translation produced 3 projections
  - The system could rotate 3° to the next projection rather than 1°
  - make only 60 translations instead of 180 to acquire a complete section
  - Scan times were reduced X 3
- Later versions: up to 53 detectors
  - Fast enough (tens of seconds)to permit acquisition during a single breath hold
  - First designs to permit scans of the trunk
  - Because rotating anode tubes could not

Third Generation

- Design: larger array of detectors
  - (300-700detectors, usually circular
  - Shorter scanning time (2 sec)
  - Designers: pure rotational scanning motion could be used , then it would be possible to use higher-power ,rotating anode x-ray tubes and thus improve scan speeds in thicker body parts
- "Slam-bang translational motion" was replaced with smooth rotational motion
  - higher-output rotating anode x-ray tubes could be used
  - greatly reducing scan times
- X-ray tube is collimated to a wide x-ray beam (fan-shaped)
- Directed toward an arc-shaped row of detectors
- Tube and detector array rotate around patient
- Different projections are obtained during rotation by pulsing x-ray source or by sampling the detectors at a very high rate

Third Generation CT



Third CT

- Improvement in detector and data acquisition technology
  - detector array with enough, high spatial resolution cells to allow measurement of a fan-beam projection of entire patient cross-section
- Sampling considerations required scanning an additional arc of one fan angle beyond 180°, although most scanners rotate 360° for each scan.
- Current helical scanners are based on modifications of rotate-rotate designs
- Scan times = few seconds or less, and recent versions are capable of subsecond scan times
- Imaging process is significantly faster than 1st or 2nd generation systems

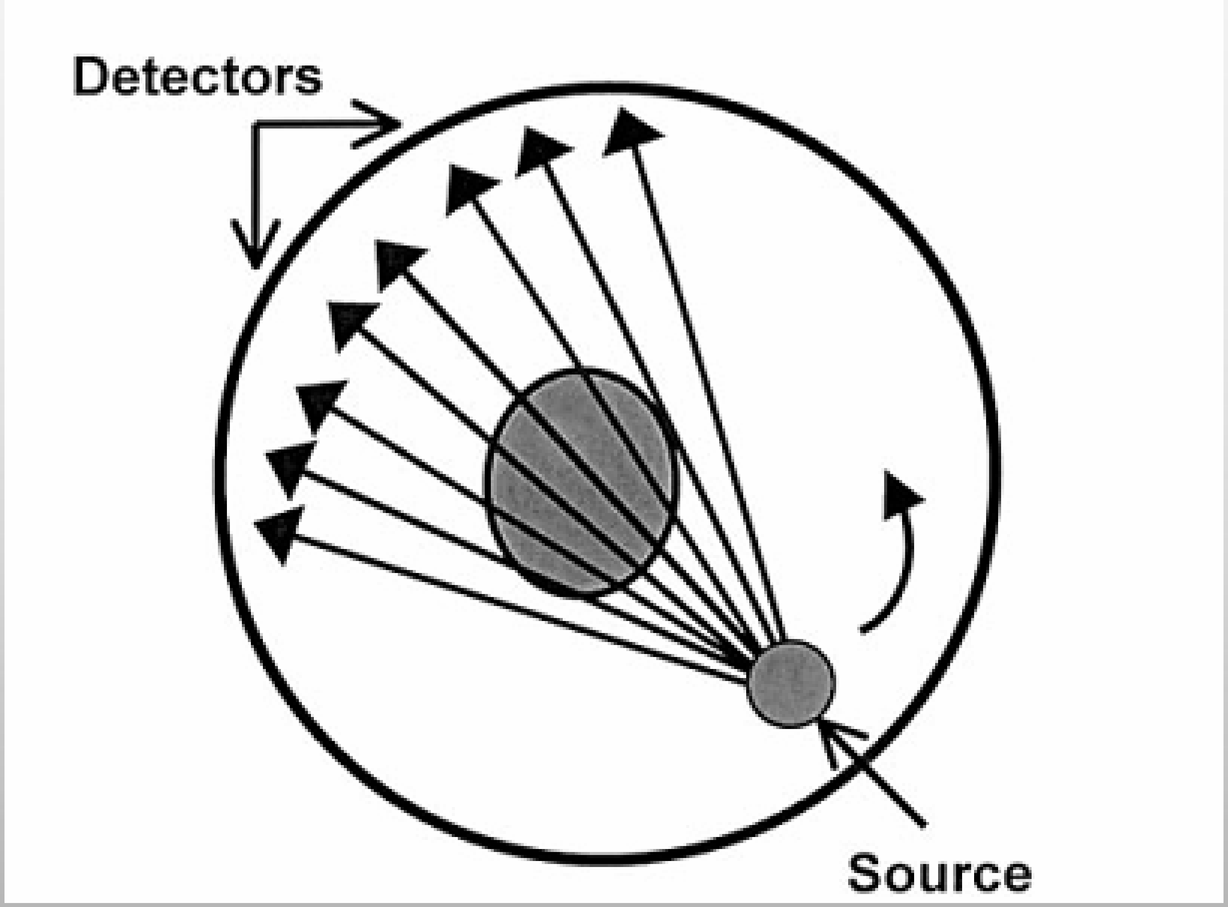
Rotate/rotate, wide fan beam

- Number of detectors increased substantially (to more than 800 detectors)
- Angle of fan beam increased to cover entire patient
  - Eliminated need for translational motion
- Mechanically joined x-ray tube and detector array rotate together
- Newer systems have scan times of ½ second
- Cons: very high performance detectors are needed to avoid ring artefacts and the system is more sensitive to aliasing than 1st or 2nd generation scanners

Fourth Generation

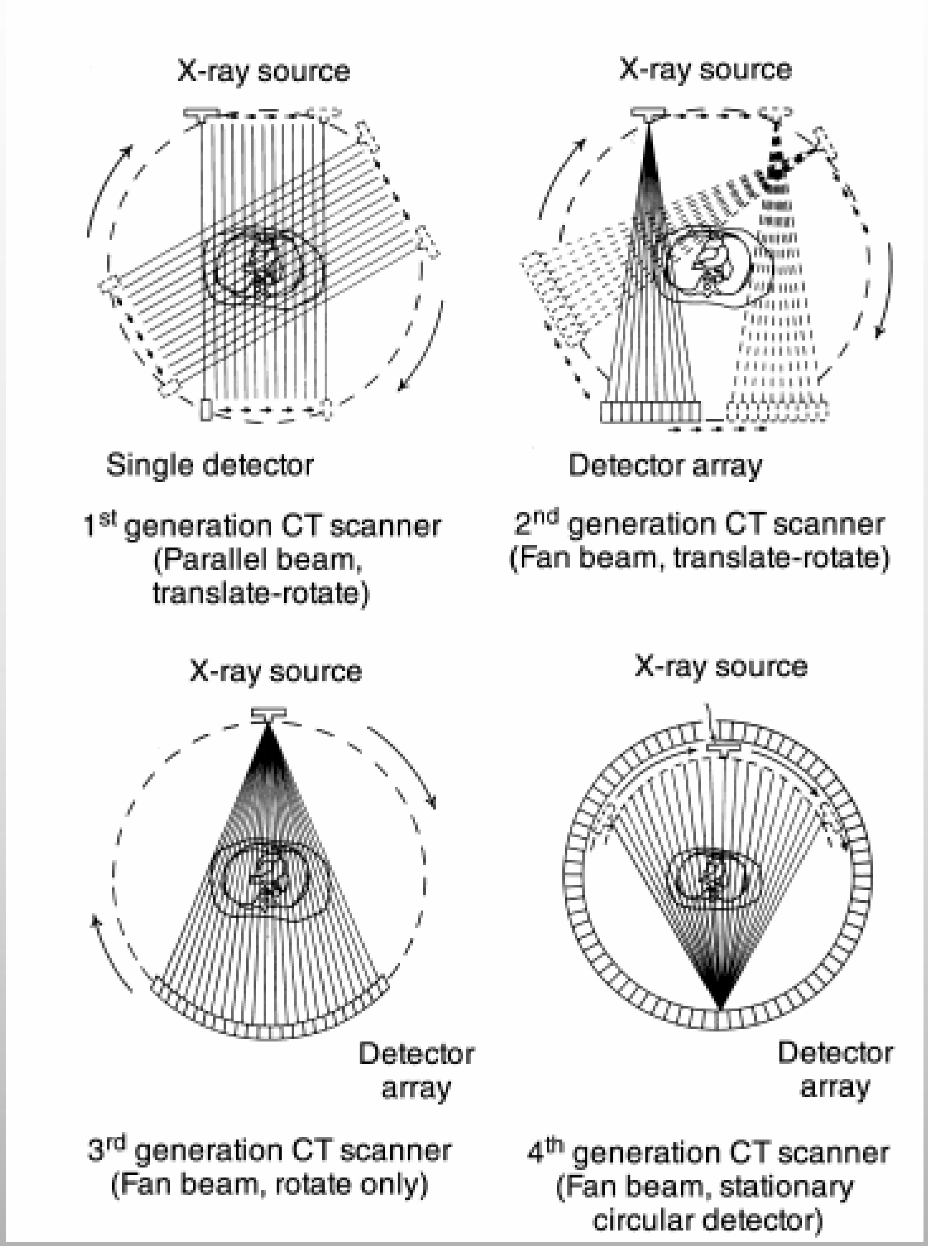
- Design: stationary detector ring & rotating X-ray tube
- Reduced motion resulted in reduction in complexity
- Stationary detector requires a larger acceptance angle for radiation, and is therefore more sensitive to scattered radiation than the 3rd generation geometry
- Require larger number of detector cells and electronic channels (higher cost) to achieve the same spatial resolution and dose efficiency as a 3rd generation system
- a rotate-stationary or rotate only geometry

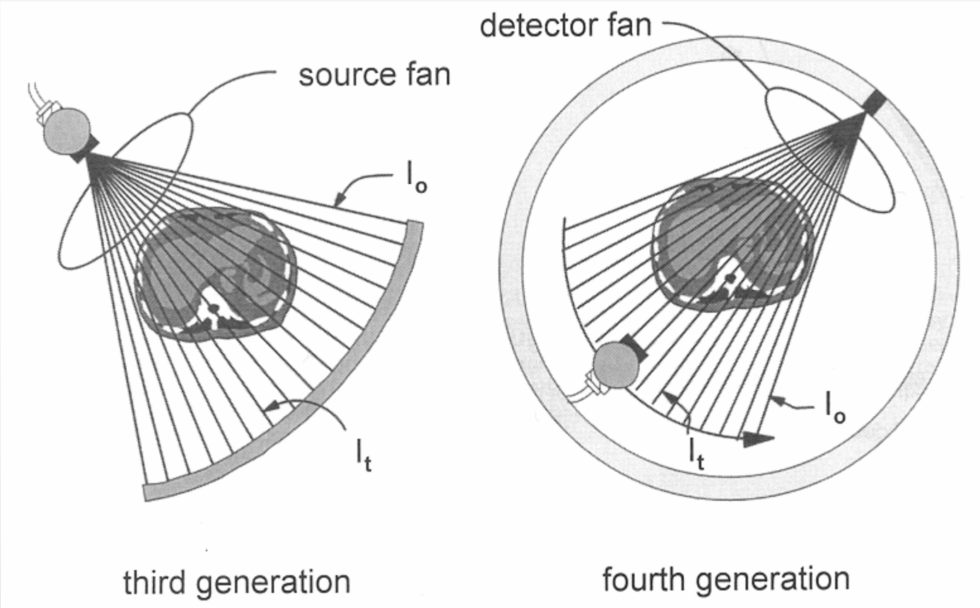
Fourth CT



Fourth Generation CT

- Design: also eliminated translate-rotate motion
  - Circular array of FIXED detectors
  - Source only rotates within a stationary ring of detectors
- Larger fan beam
- Shorter scanning time
- Early versions: had some 600 detectors
- Later versions: had up to 4,800
- Limitation: less efficient use of detectors , less than 1/4 are used at any point during scanning
- Only the x-ray generator and tube rotate at 360 ,thus shortening the scanning time even more


X-ray source
Single detector
1st generation CT scanner
(Parallel beam,
translate-rotate)
X-ray source
Detector array
2nd generation CT scanner
(Fan beam, translate-rotate)
X-ray source
Detector
array
3rd generation CT scanner
(Fan beam, rotate only)
X-ray source
Detector
array
4th generation CT scanner
(Fan beam, stationary
circular detector)

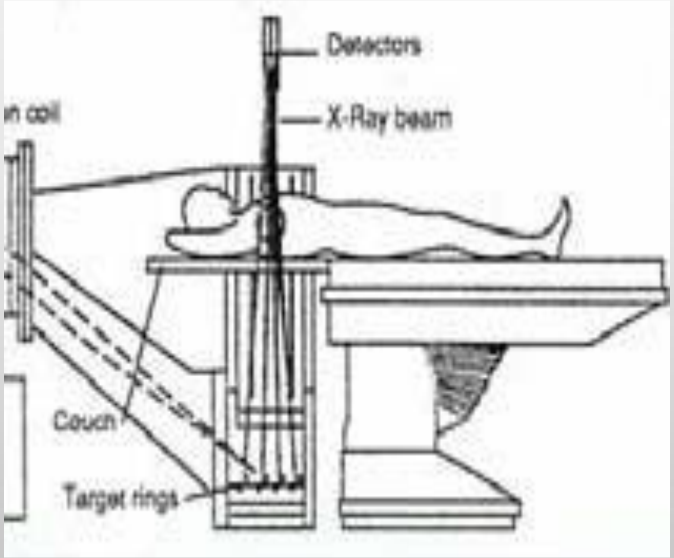


source fan
I_o
I_t
third generation
detector fan
I_o
I_t
fourth generation

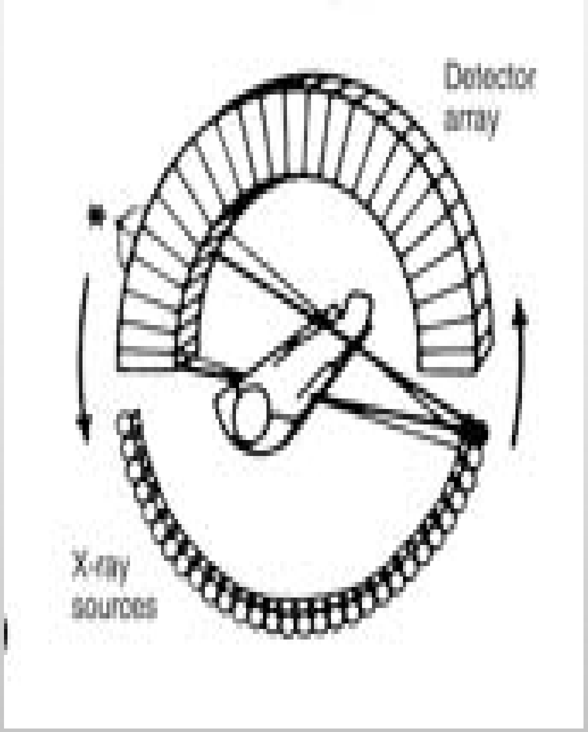
5th Generation

- *Design: x-ray tube is* a large ring that circles patient, opposed to detector ring
- *Use:* for cardiac tomographic imaging **"cine CT"**
- X - rays produced = high - energy electron beam
- No moving parts to this scanner gantry
- It is capable of 50 - millisecond scan times and can produce 17 CT slices/second
- *stationary/stationary geometry*

Fifth CT



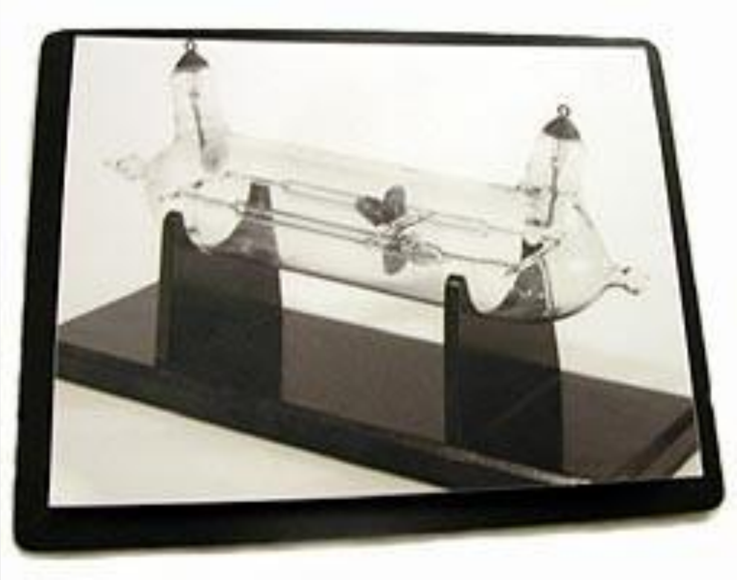
Detectors
X-Ray beam
n coil
Couch
Target rings

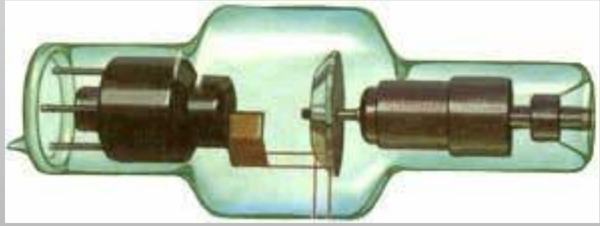


Detector
array
X-ray
sources

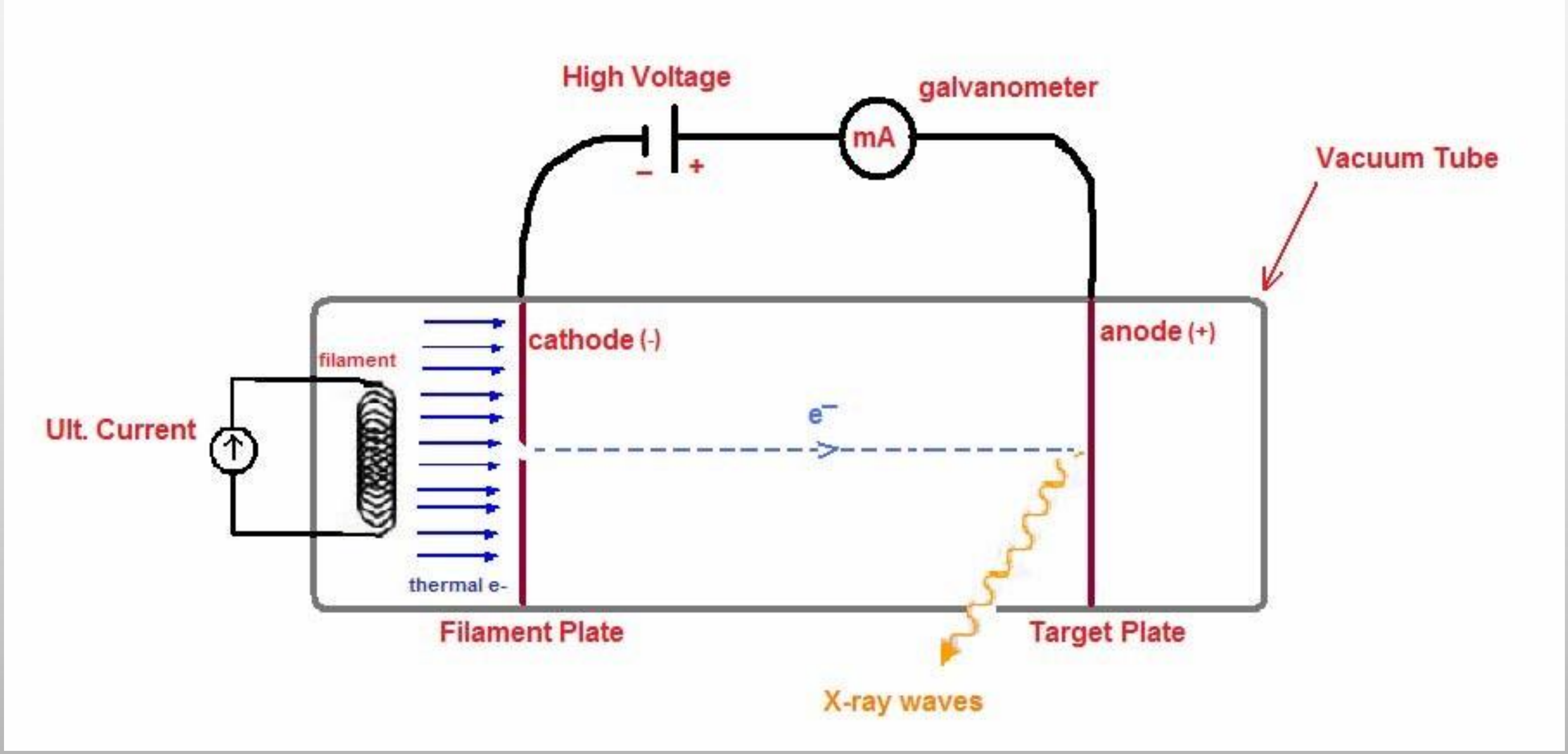
X-Ray Tube

- Vacuum
  - Accelerating electrons
  - e^- will travel faster
- Filament
  - Alternating current
  - Thermal electrons
- Cathode (-)
  - Filament plate with a tiny slit
  - Connected to high voltage battery source
- Target/Anode (+)
  - Electrons collide with target
  - Produce x-ray
  - Must have high melting point (Tugnsten)





Simplified X-Ray Tube



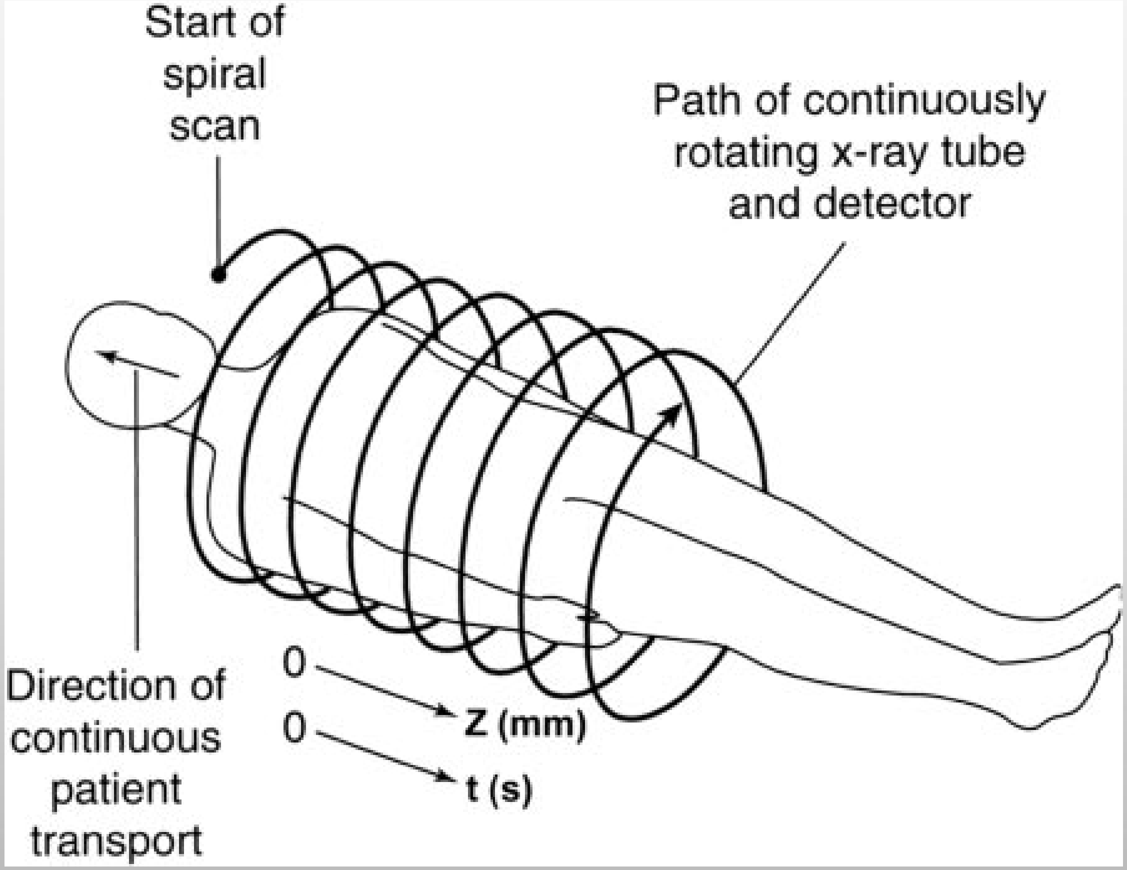
Sixth Generation

- 1990,Significant advancement in technology
- Allowed 3D image acquisition within a single breath hold

Spiral/Helical CT

- Design: x-ray tube rotates as patient is moved smoothly into x-ray scan field
- Simultaneous source rotation, table translation and data acquisition
- Produces one continuous volume set of data for entire region
- Data for multiple slices from patient acquired at 1sec/slice

Spiral CT



Start of spiral scan
Path of continuously rotating x-ray tube and detector
Direction of continuous patient transport
0
Z (mm)
0
t (s)

Advantages of Spiral

- **Speed:** patient movement continuous . shorter exam time ; entire abdomen or chest: 30 sec (1BH)
- **Improved detections:** differences in BHs in standard CT, small lesions fall out of plane for each continuous slice
- **Improved contrast:** image a region in a short period, contrast can be timed
- **Improved reconstruction & manipulation:** volume of data collected, transverse data can be reconstructed in any plane- strip away skin, muscles, etc….

Spiral/Helical CT

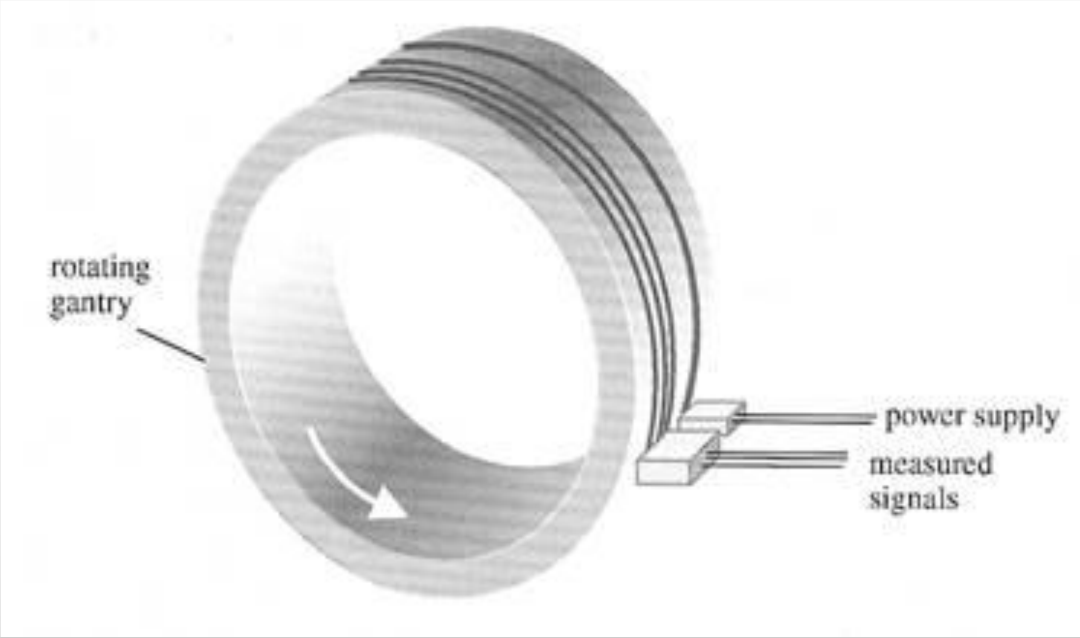
Three technological developments:

1. Slip-ring gantry designs
2. Very high power x-ray tubes
3. Interpolation algorithms to handle projection data

1. Slip-Ring Technology

- Alternative to cabling system = slip-ring
- 1989 Kalender
- Electromechanical devices: circular electrical conductive rings and brushes
- Transmit electrical energy across a moving interface
- All power and control signals from the stationary parts of the scanner system are communicated to the rotating frame through slip ring
- Allow scan frame to rotate continuously with no need to stop between rotations to rewind system cables

Slip Ring



2. High Power X-ray Tube

- Thermal load in CT
- 1st and 2nd, stationary tube(low heat, slow scans)
- Oil cooling thermal systems around tube, fast scans
- scan time vs. Heat capacity increased x 5
- thermal demands on the x-ray tube
- Tubes with much higher thermal capacities were required to withstand continuous operation over multiple rotations
- New design: ceramic insulators ,oil cooling of bearing, compact metal envelop
- Expected life of tube 10,000-40,000 hrs vs. 1000 regular one

3. Interpolation Algorithms

- Kalender developed interpolation methods to generate projections in a single plane
- Overlapping sections generated by math, not beam, improve z-axis with no increase in dose
- Improved image quality

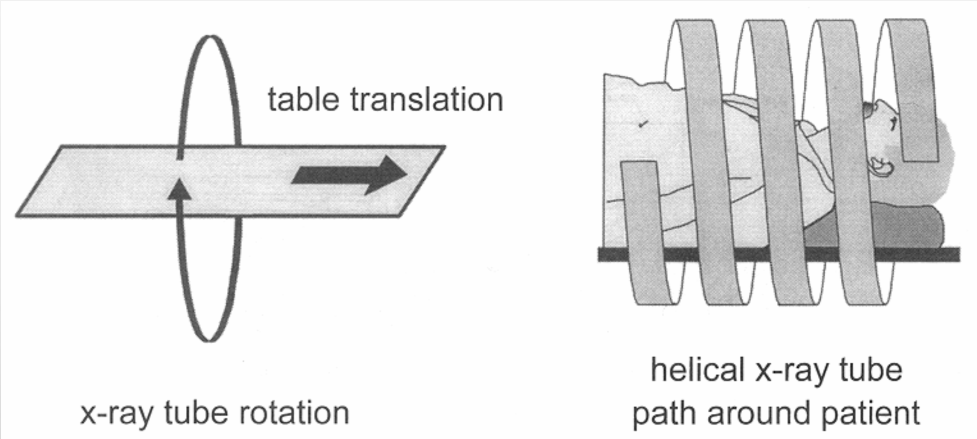


table translation
x-ray tube rotation
helical x-ray tube
path around patient

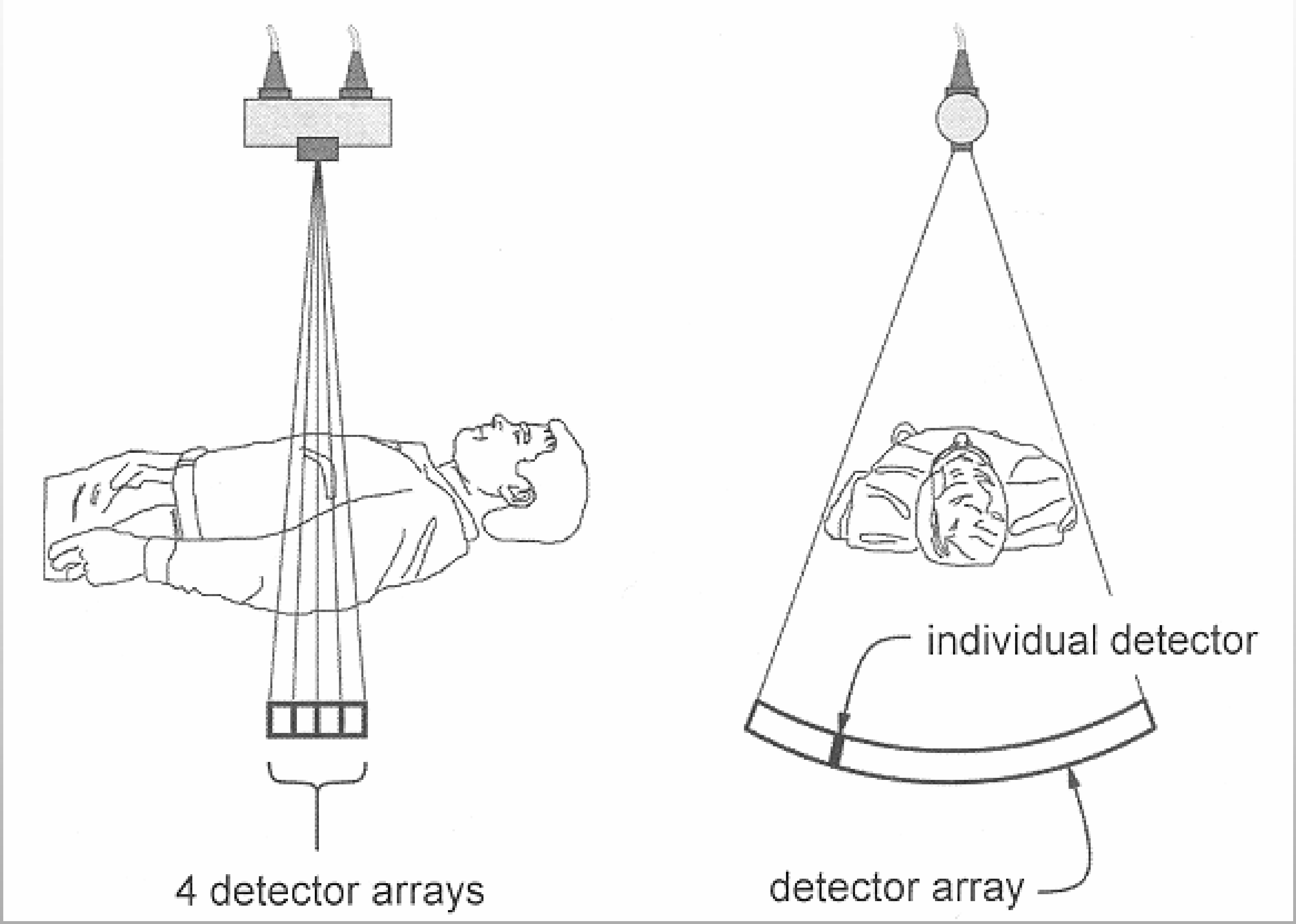
Seventh Generation

- New Technology, single row had its limitation
- Design: multiple detector array
- The collimator spacing is wider and more of the x-rays that are produced by the tube are used in producing image data
  - Opening up the collimator in a single array scanner increases slice thickness, reducing spatial resolution in the slice thickness dimension
  - With multiple detector array scanners, slice thickness is determined by detector size, not by the collimator

Seventh Generation CT

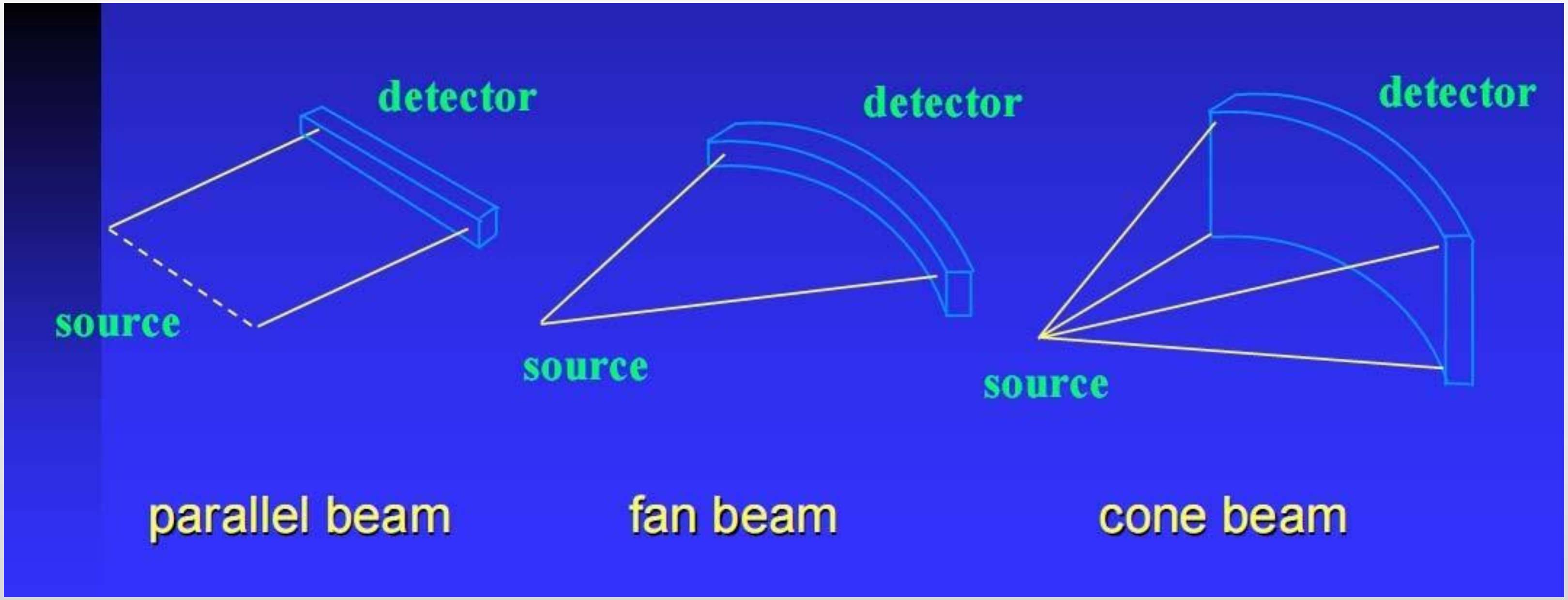
- "turbo-charged" spiral
- Up to 8 rows of detectors
- 4 rows, large volume of patient scanned 1 BH
- (thorax, abdomen, pelvis) at once
- Allows 1mm sections though chest in 20 sec
- Improvement in details
- Problem with PACS, stain on storage system

Seventh CT



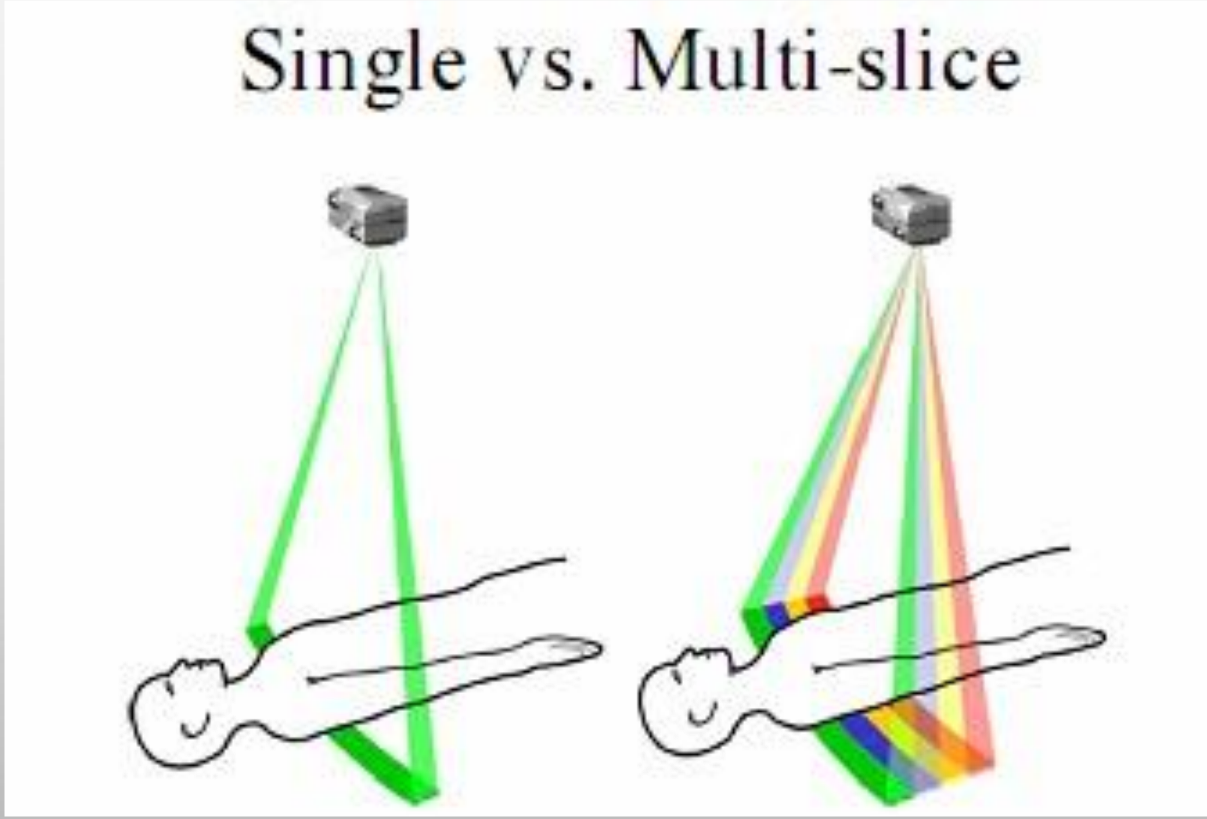
Seventh CT

- Cone Beam & multiple parallel rows of detectors
- Widened (z-direction) x ray beam & detector array to acquire multiple (4-64 slices simultaneously)
- Advantage: reducing scan time/ increase z-resolution
- Disadvantage: less scatter rejection compared to single slice, very expensive

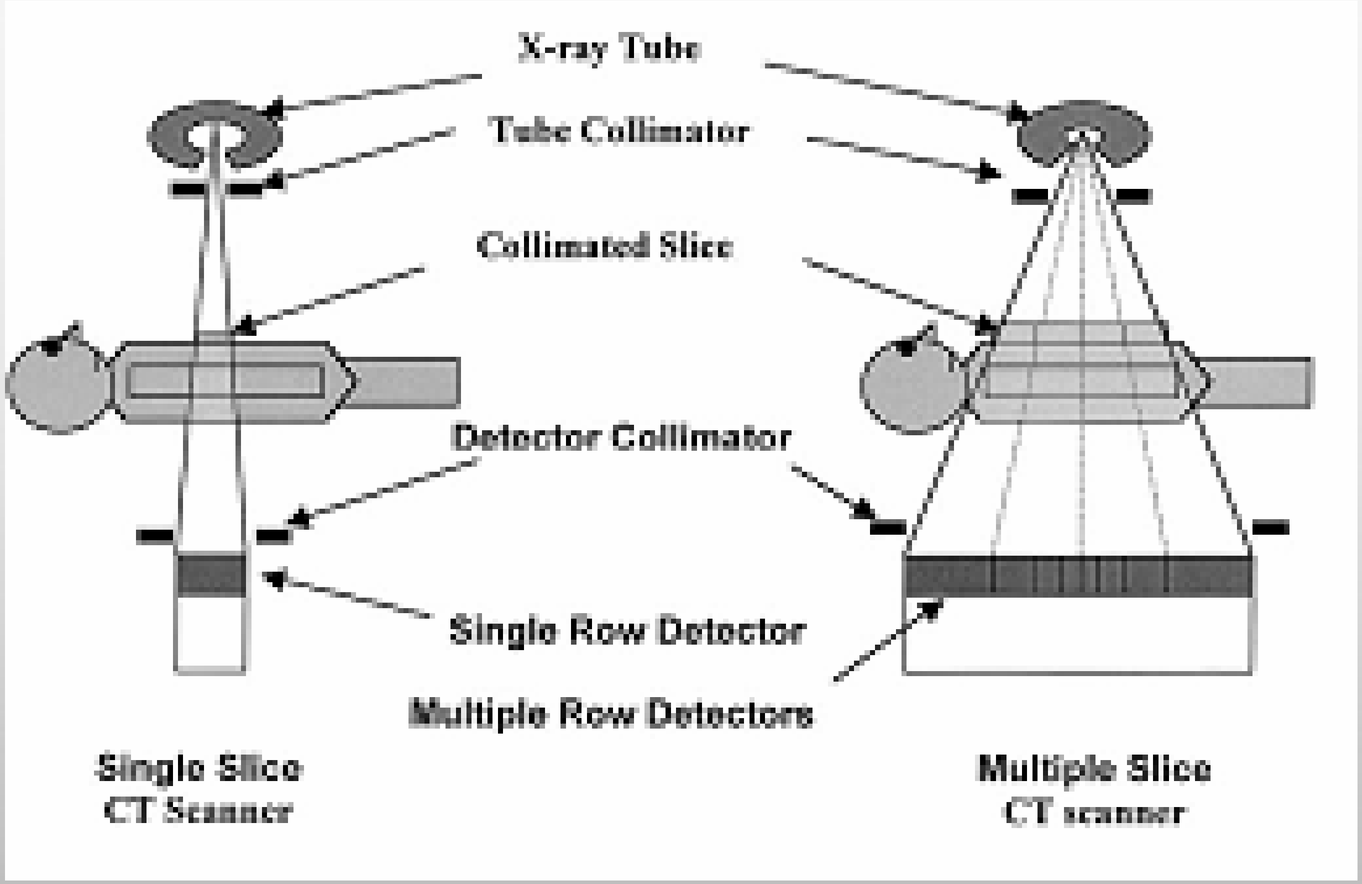

detector
source
parallel beam
detector
source
fan beam
detector
source
cone beam

Multiscanning

- Relates to the technique of double or triple rotation of the tube and detectors around the same axial plane
- Provides double of triple the volume per slice, upon which the final image can be derived
- In practice each rotation produces its own bank of raw data,
- Hence motion which may occur during one rotation can be averaged out from data of the remaining two rotations
- Multiscanning therefore reduces motion artifacts and consequently improves image quality

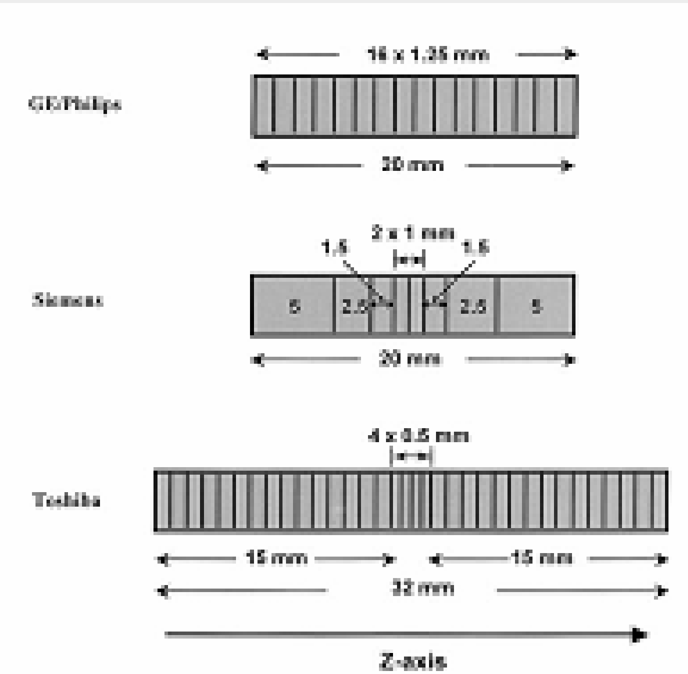

Single vs. Multi-slice

Seventh CT



X-ray Tube
Tube Collimator
Collimated Slice
Detector Collimator
Single Row Detector
Multiple Row Detectors
Single Slice
CT Scanner
Multiple Slice
CT scanner

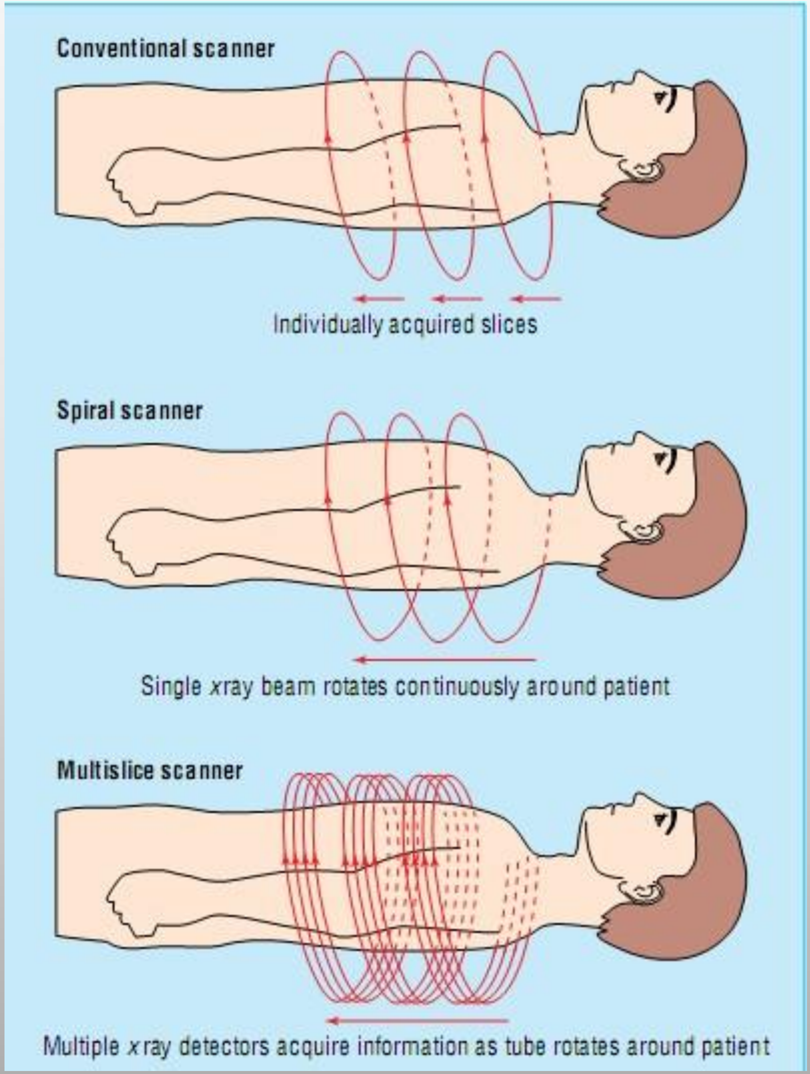
Multiple Array Design



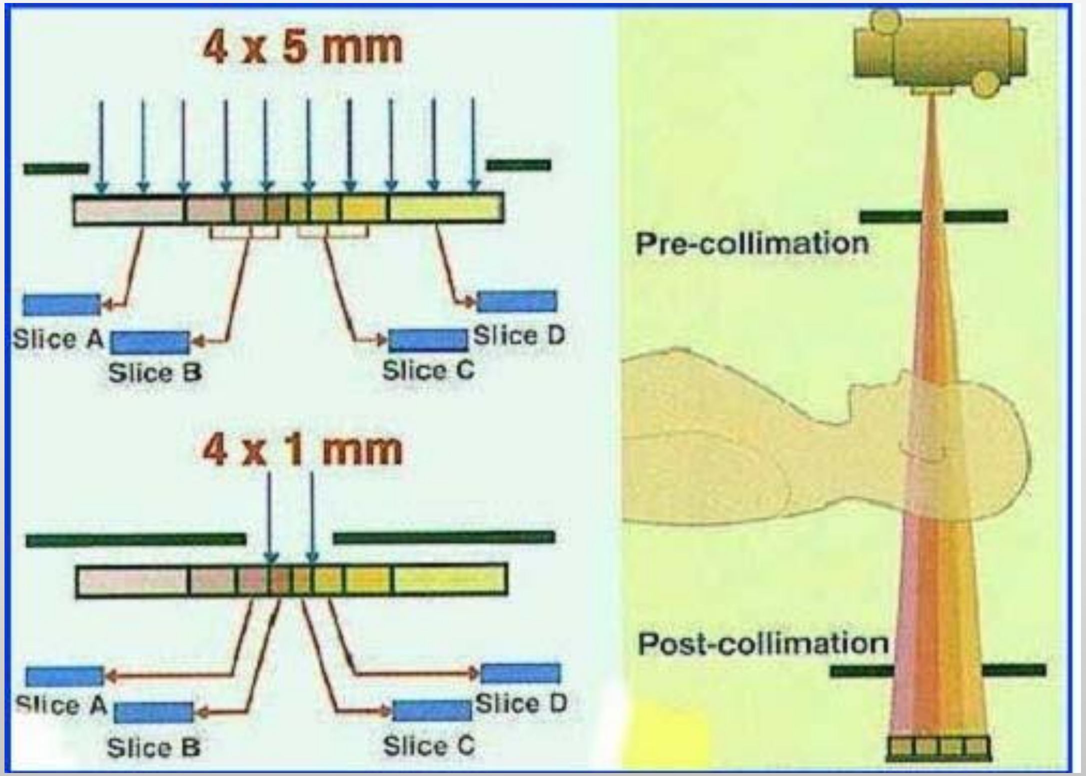
Combination of Section width

GE*/Philips	Siemens†	Toshiba‡
4 × 1.25	2 × 0.5	4 × 0.5
4 × 2.5	4 × 1	4 × 1
4 × 3.75	4 × 2.5	4 × 2
4 × 5	4 × 5	4 × 3
2 × 10	2 × 8	4 × 4
	2 × 10	4 × 5
		4 × 6
		4 × 7
		4 × 8

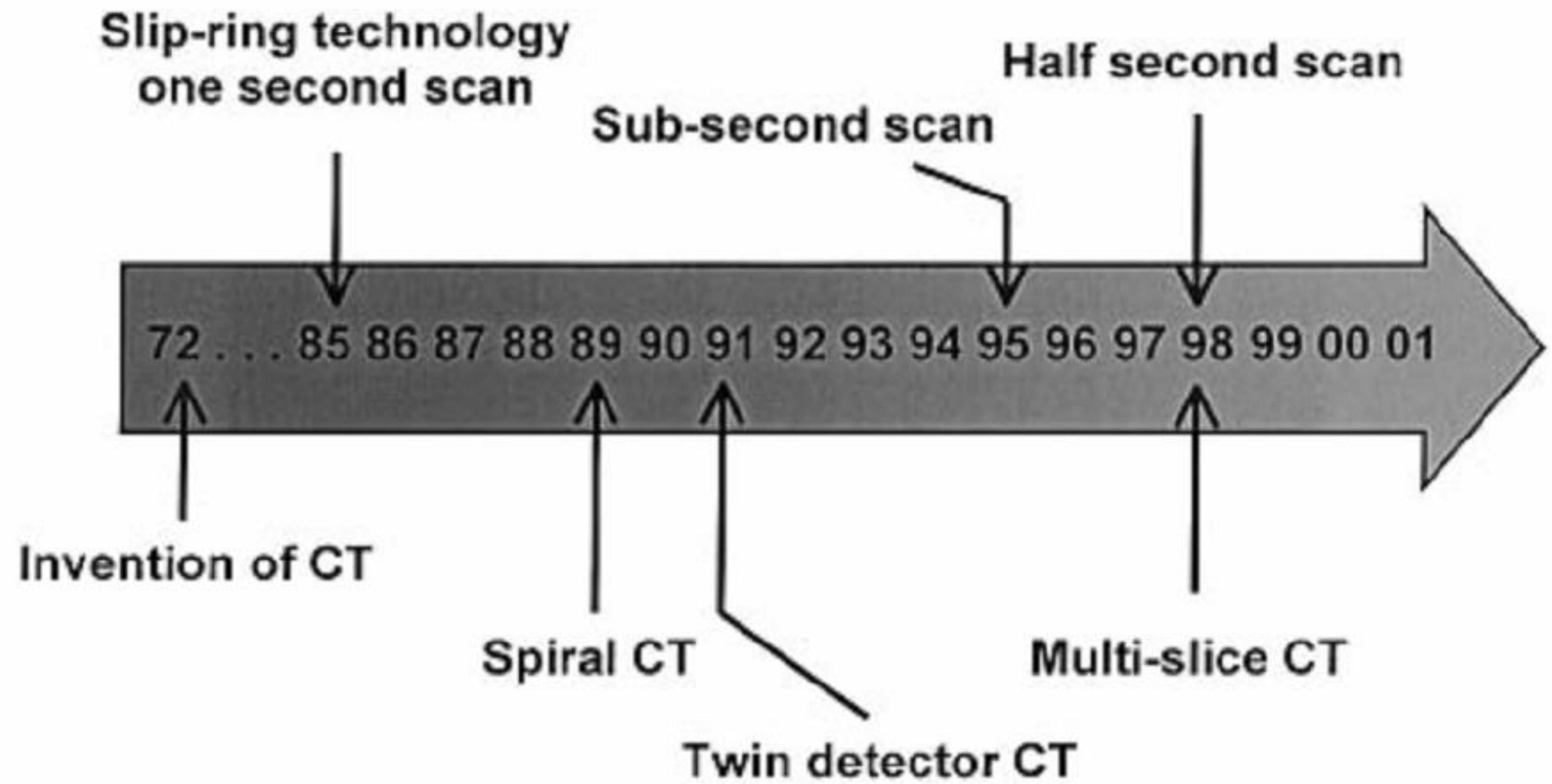
5^{th}, 6^{th} , 7^{th} G CT



Multislice Scanning



Generation	Source	Source Collimation	Detector
1st	Single X-ray Tube	Pencil Beam	Single
2nd	Single X-ray Tube	Fan Beam (not enough to cover FOV)	Multiple
3rd	Single X-ray Tube	Fan Beam (enough to cover FOV)	Many
4th	Single X-ray Tube	Fan Beam covers FOV	Stationary Ring of Detectors
5th	Many tungsten anodes in single large tube	Fan Beam	Stationary Ring of Detectors
6th	3G/4G	3G/4G	3G/4G
7th	Single X-ray Tube	Cone Beam	Multiple array of detectors


Slip-ring technology
one second scan
Sub-second scan
Half second scan
72 . . . 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01
Invention of CT
Spiral CT
Twin detector CT
Multi-slice CT

Main Commercially Available CT

MODEL	SCANNING AND GEOMETRY
Philips T60	rotate/rotate
Picker 1200	rotate/stationary
General Electric 9800	rotate/rotate
Siemens DRH	rotate/rotate
Toshiba 900S	rotate/stationary(slip ring)
Toshiba Xpress	rotate/rotate(slip ring)