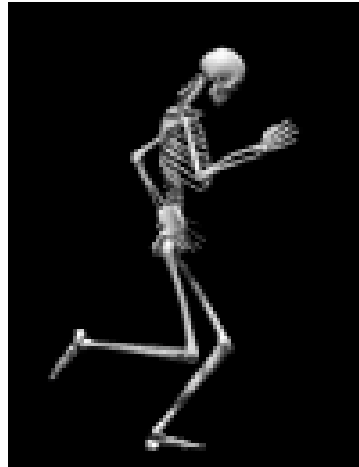


# CT-Generations

RAD309

Dr. Eng. Sarah Hagi



# Definition of Generation

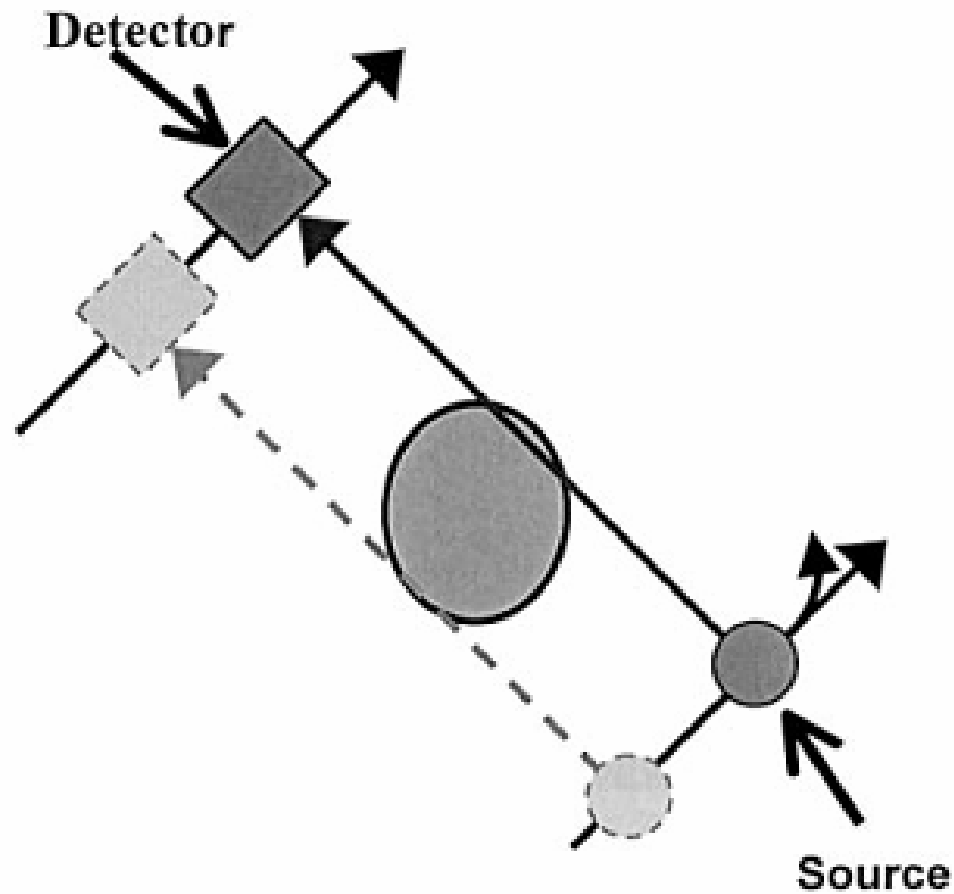
- Classification of computed tomography (CT) based upon: arrangement of components and mechanical motion required to collect data
- “Generation” the order in which CT scanner design has been introduced, and each has a number associated with it
- NOTE: higher generation number NOT a higher performance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

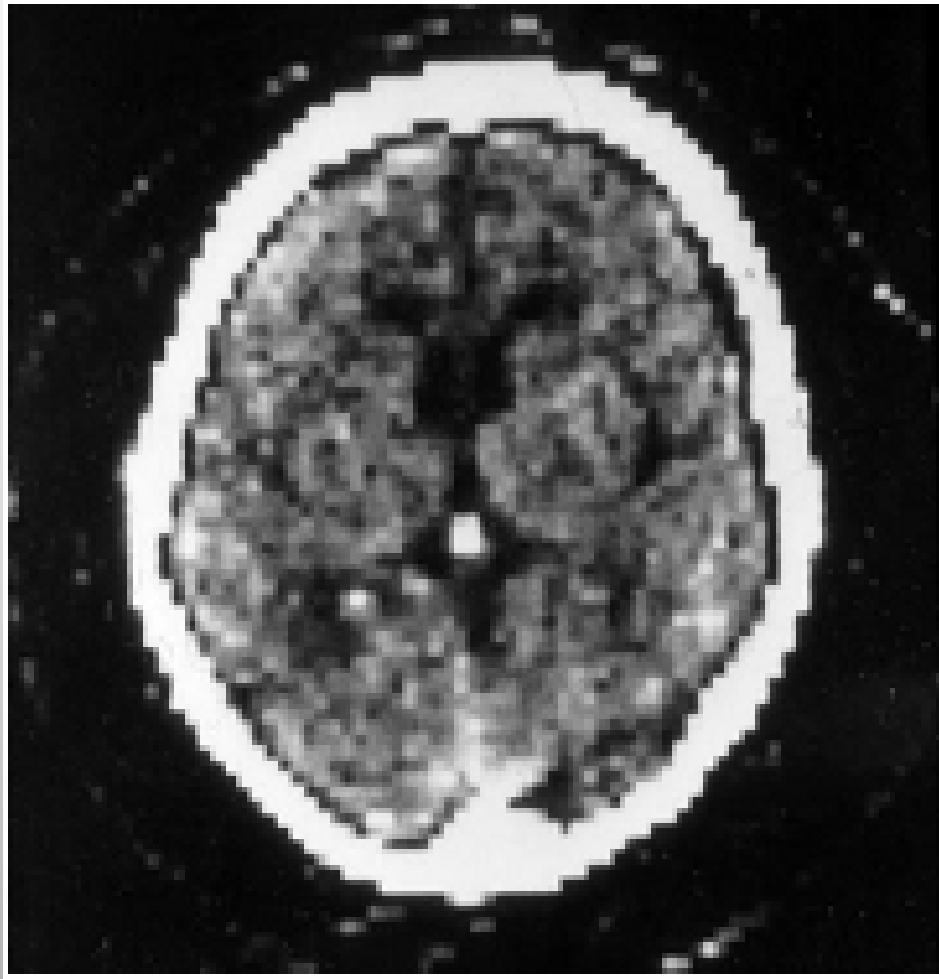
# First Generation CT

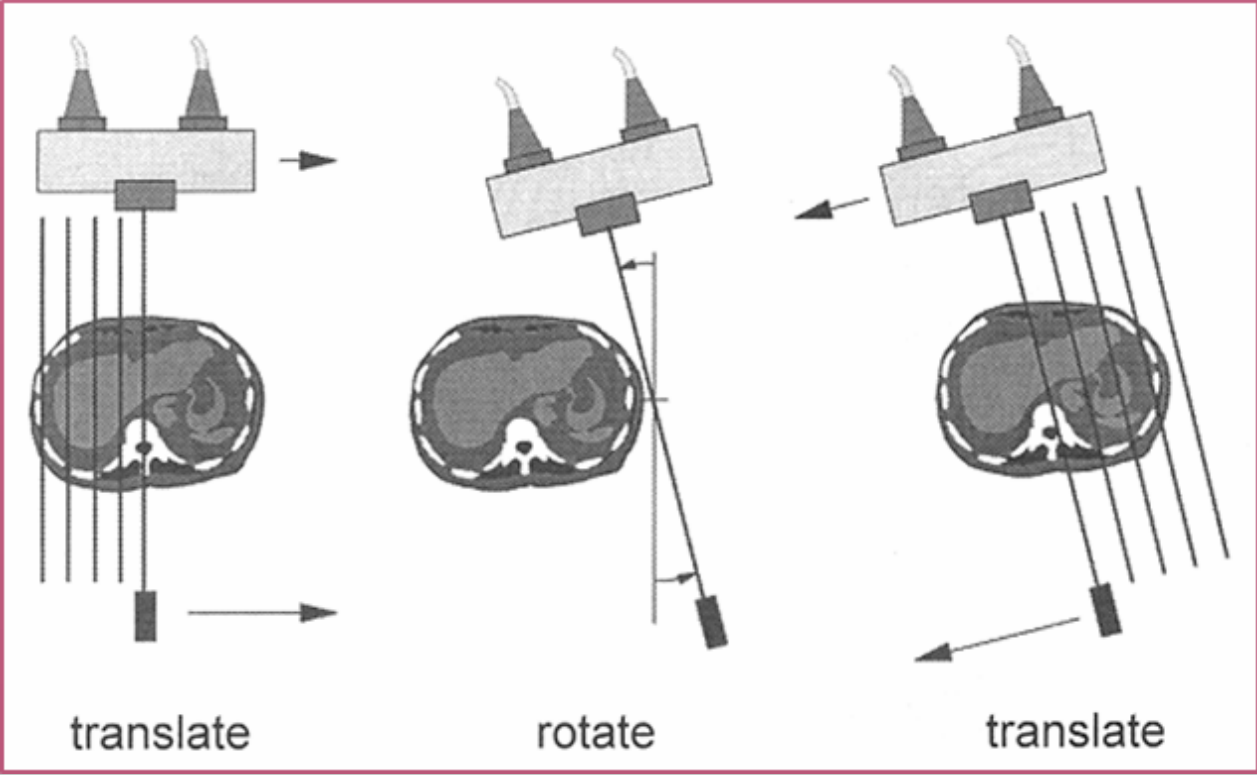


# First CT

- 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 somewhat 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

# 1<sup>st</sup> CT Generation Image



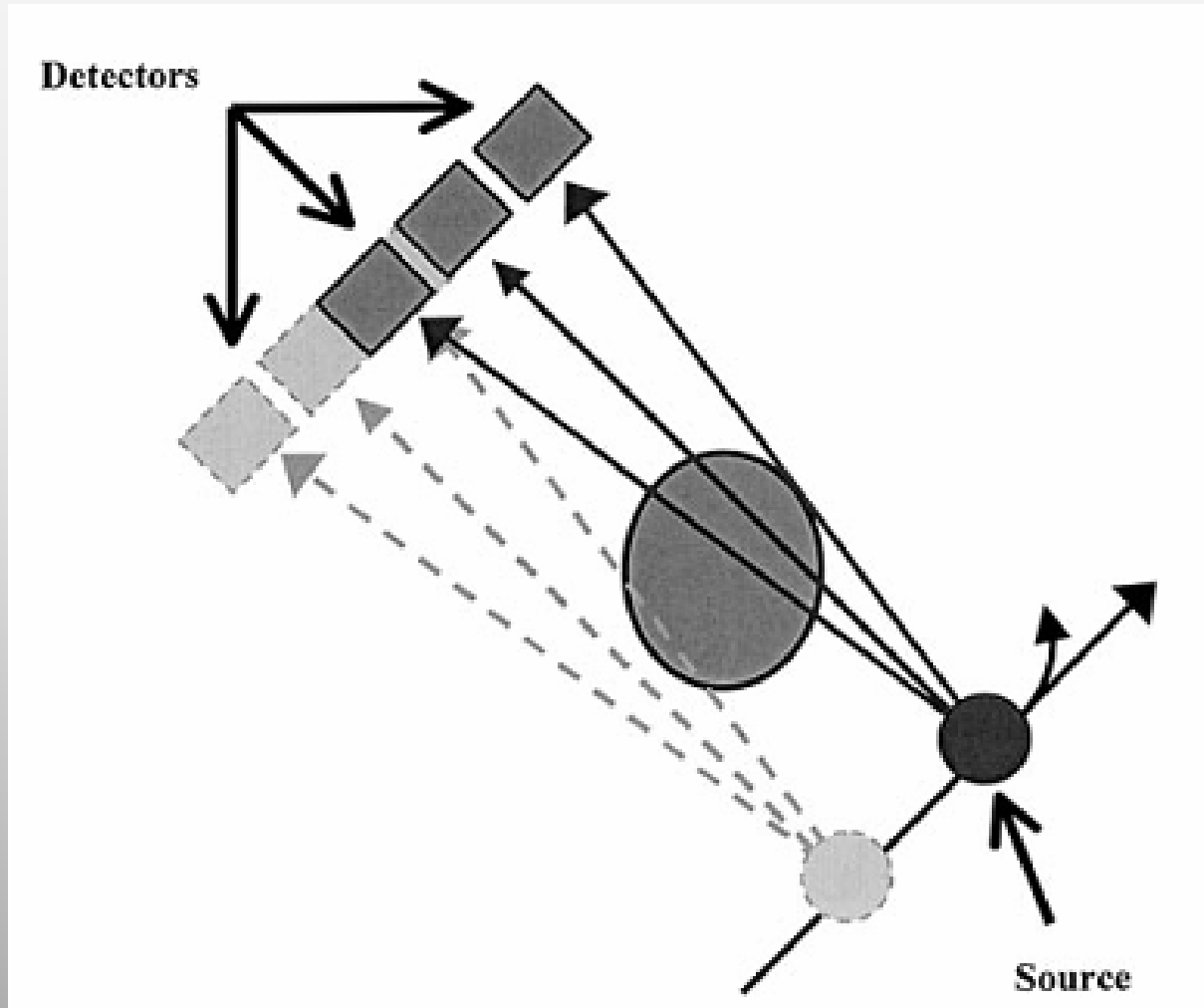


# Second Generation

- 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



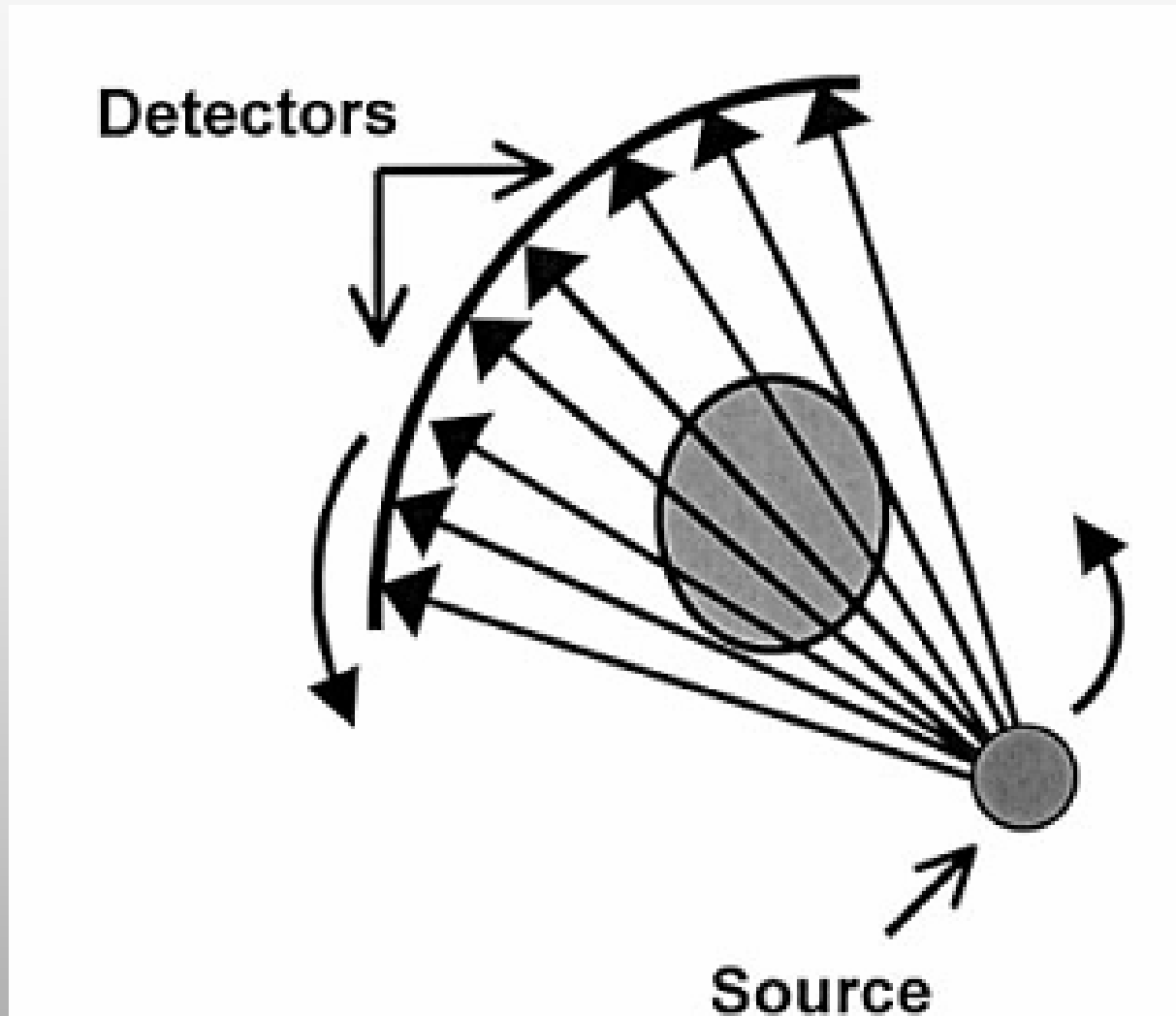
# Second CT

- 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 by  $1^\circ$ 
  - Since each detector viewed the x-ray tube at a different angle, a single translation produced 3 projections
  - The system could rotate  $3^\circ$  to the next projection rather than  $1^\circ$
  - 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  $180^\circ$ , although most scanners rotate  $360^\circ$  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

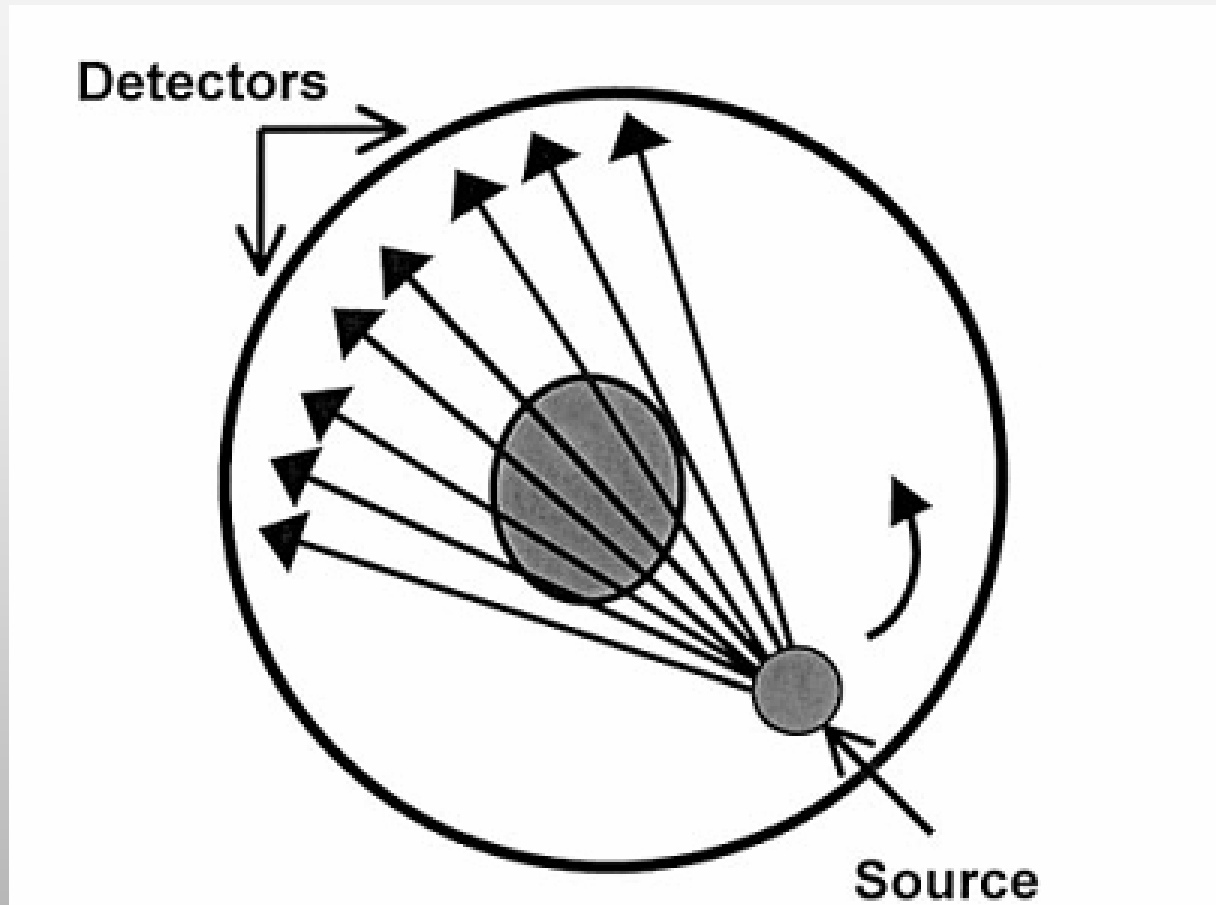
# Rotate/rotate, wide fan beam

- 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  $\frac{1}{2}$  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

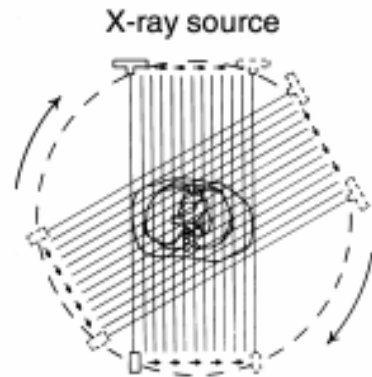
# Fourth CT





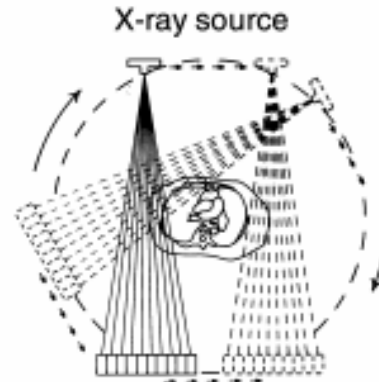
# Fourth Generation CT

- 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



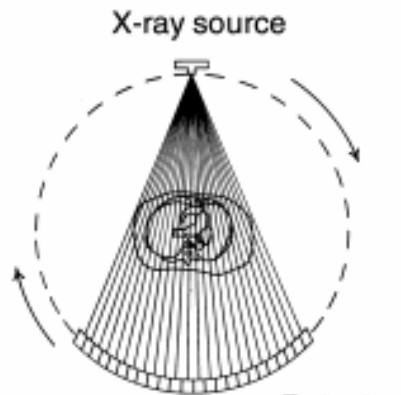
Single detector

1<sup>st</sup> generation CT scanner  
(Parallel beam, translate-rotate)



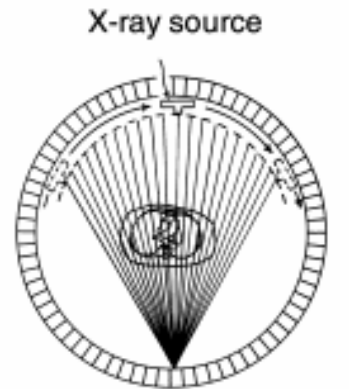
Detector array

2<sup>nd</sup> generation CT scanner  
(Fan beam, translate-rotate)



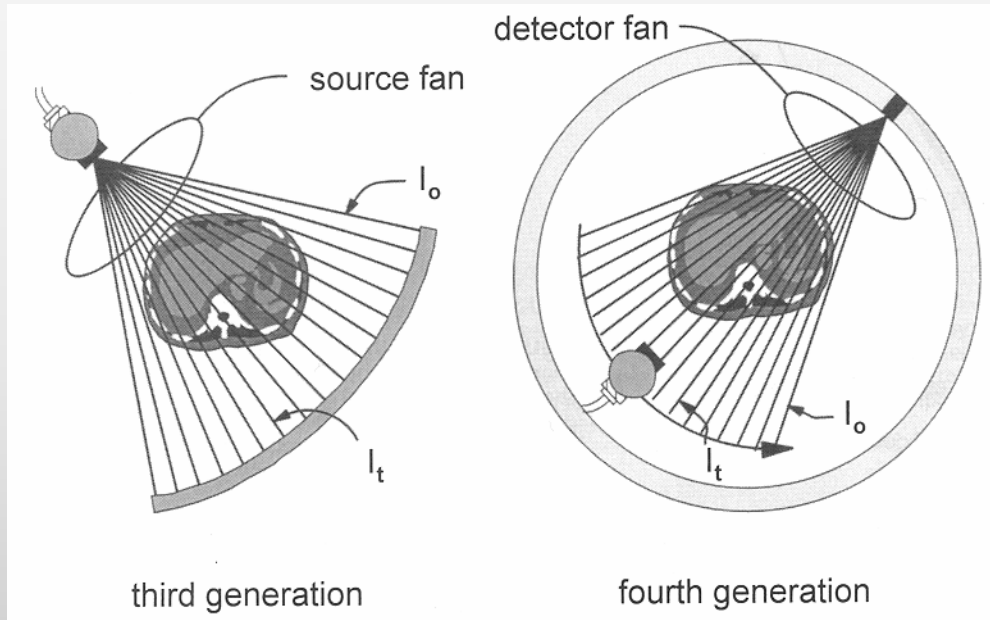
Detector array

3<sup>rd</sup> generation CT scanner  
(Fan beam, rotate only)



Detector array

4<sup>th</sup> generation CT scanner  
(Fan beam, stationary circular detector)



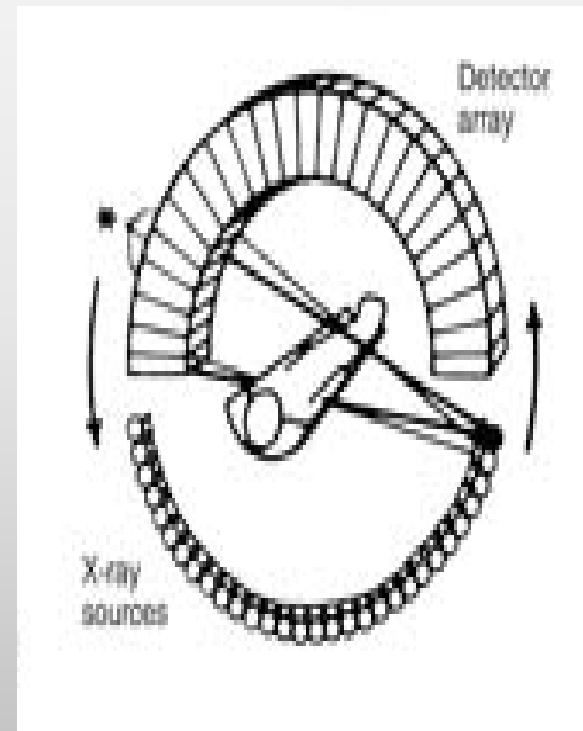
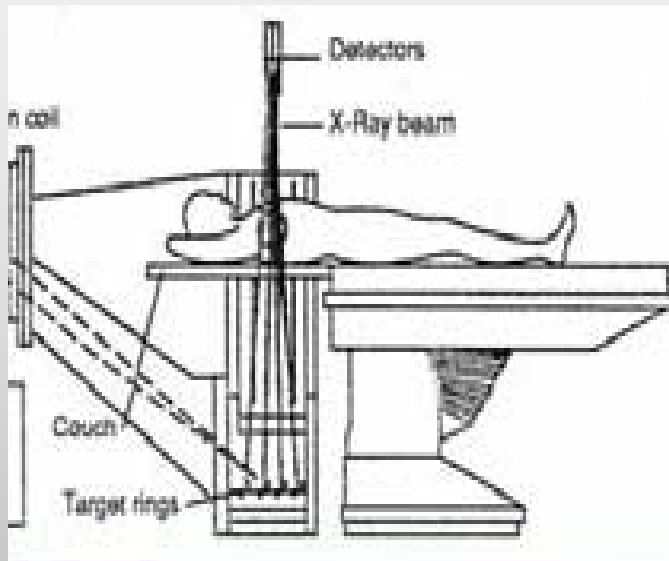
# More Categories

- Several other CT scanner geometries which have been developed and marketed do not precisely fit the above categories

# The So Called 5<sup>th</sup> Generation

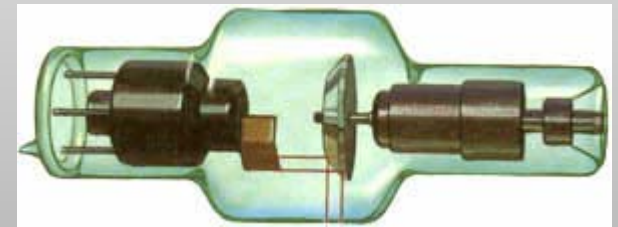
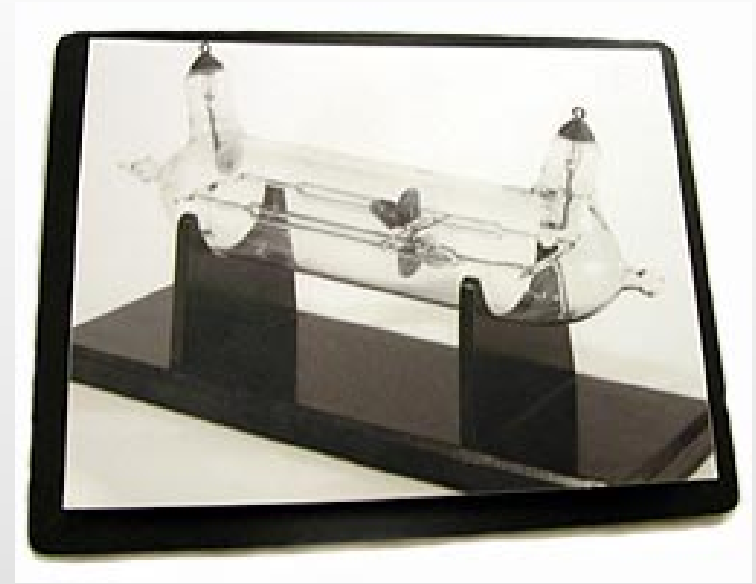
- *Design: x-ray tube is a large ring that circles patient, opposed to detector ring*
- *Use: for cardiac tomographic imaging “**cine CT**”*
- *X - rays produced = high - energy electron beam*
- *No moving parts to this scanner gantry*
- *It is capable of 50 - millisecond scan times and can produce 17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

# Fifth CT

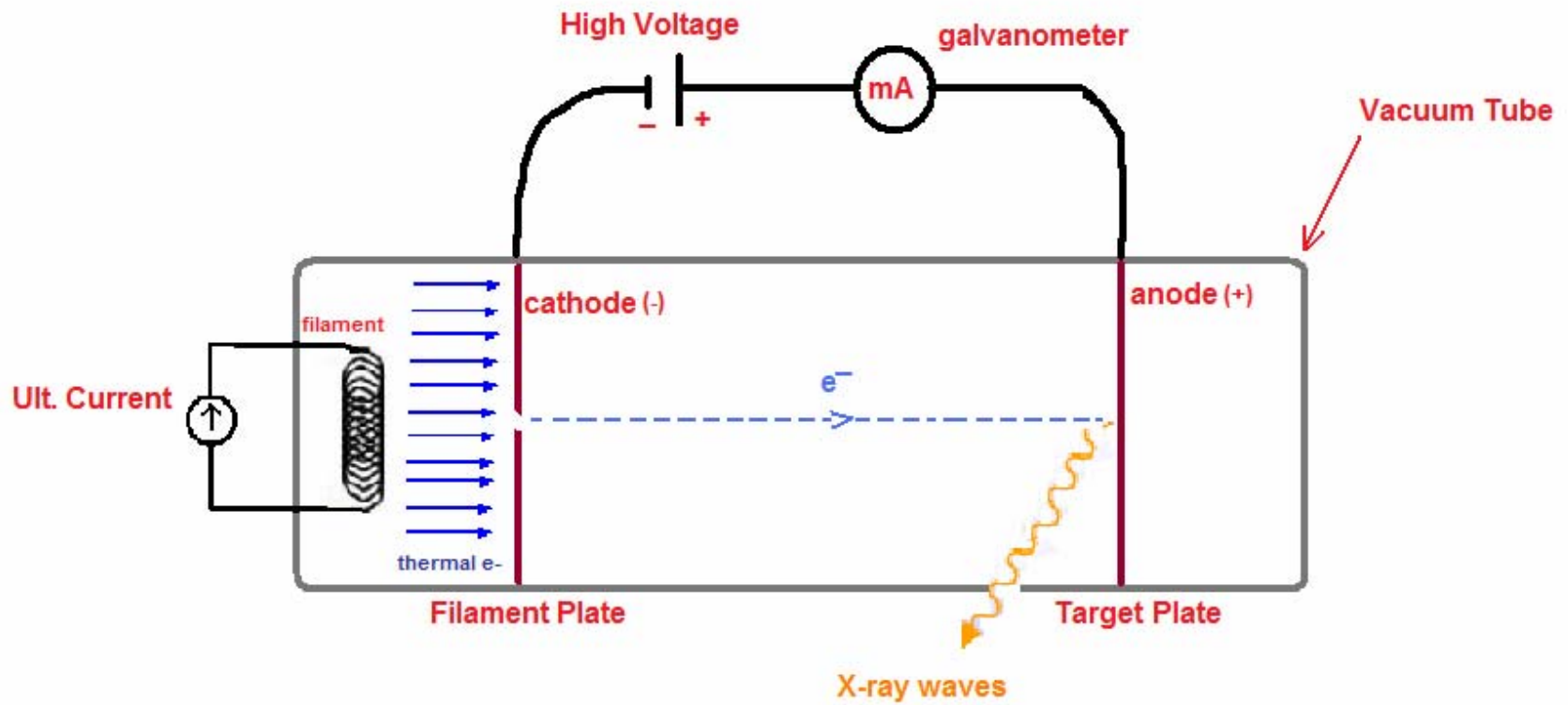


# X-Ray Tube

- 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 (Tungsten)



# Simplified X-Ray Tube





# The cine CT system

- No mechanical scanning motion
- X-ray detector and tube anode are stationary
- Anode, is a very large semicircular ring that forms an arc around the patient scan circle
- Source of X-rays is moved around the same path as a fourth generation CT scanner by steering an electron beam around the X-ray anode
- Terms millisecond CT, ultrafast CT and electron beam CT have also been used, although the latter can be confusing since the term suggests that the patient is exposed to an electron beam

# Cont.

- Very fast scanner ,data collection for 1slice is 50-100 ms
- Requires no mechanical motion to acquire data
- Sweeps an intense electron beam across a large, stationary anode target which surrounds the patient
- X-rays are emitted from the point where electrons strike target
- X-rays transmitted through object are measured by a stationary array of detectors
- Cine CT systems, have higher noise level and lower spatial resolution but are ideal for some clinical application
  - cardiac imaging with and without the use of contrast agents, lung imaging, and paediatric studies

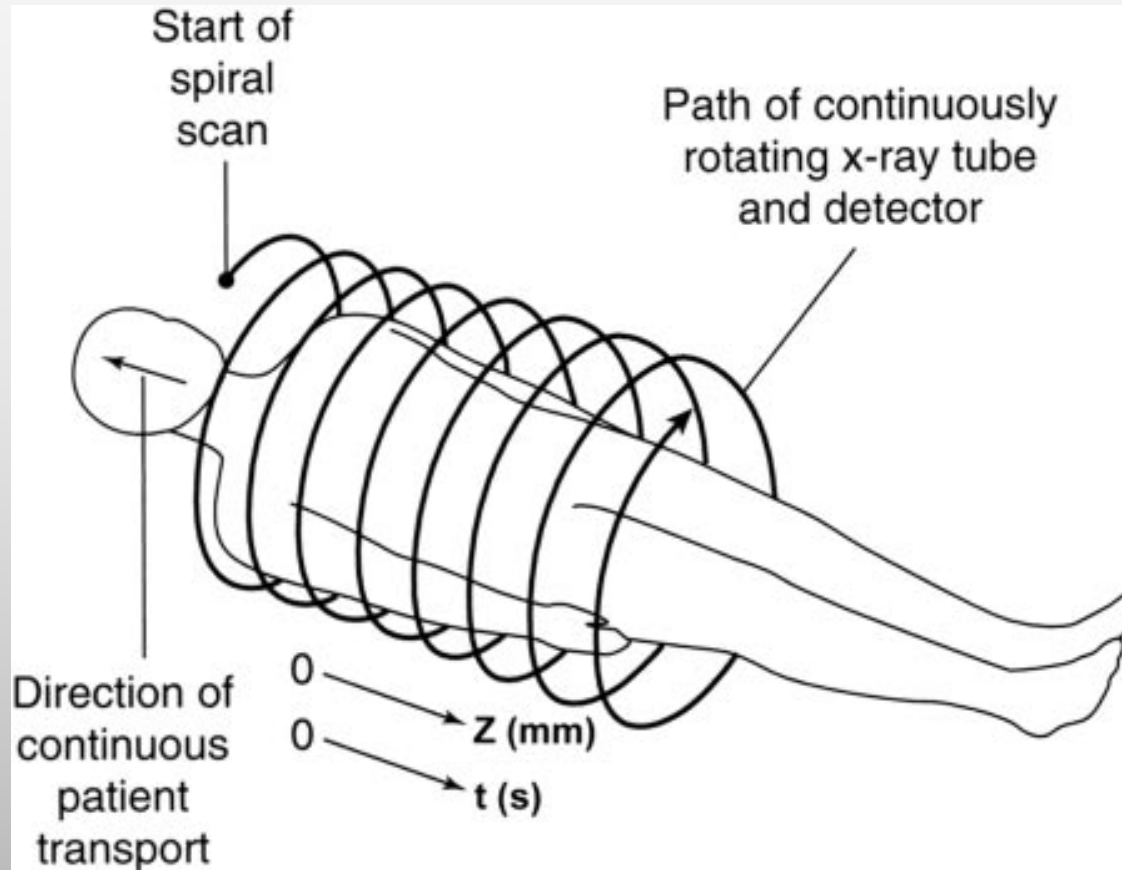
# Sixth Generation

- 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



# 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:

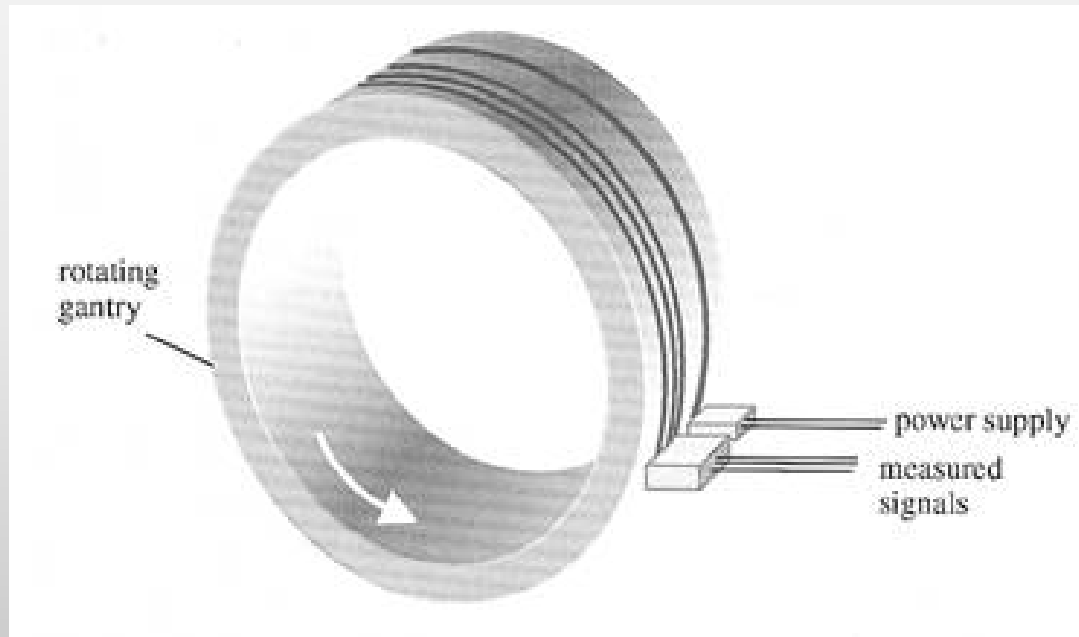
1. Slip-ring gantry designs
2. Very high power x-ray tubes
3. Interpolation algorithms to handle projection data

# 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

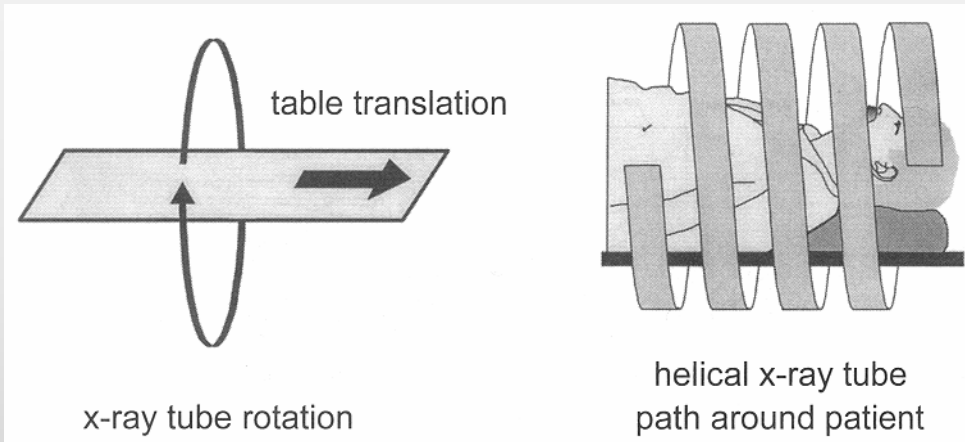


## 2. High Power X-ray Tube

- Thermal load in CT
- 1<sup>st</sup> and 2<sup>nd</sup>, 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



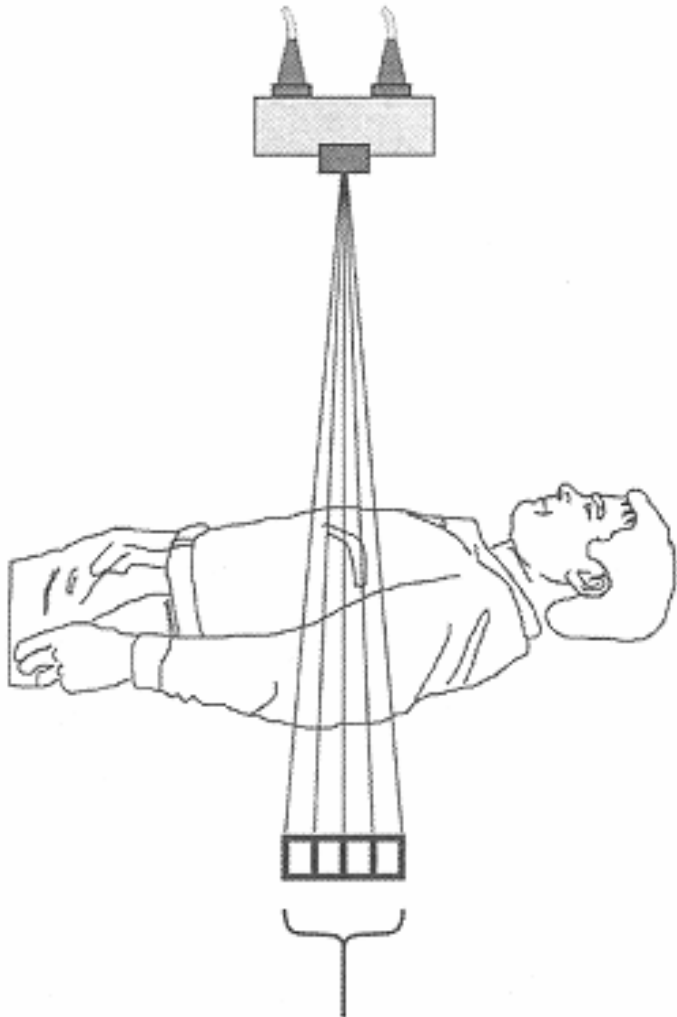
# Seventh Generation

- 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

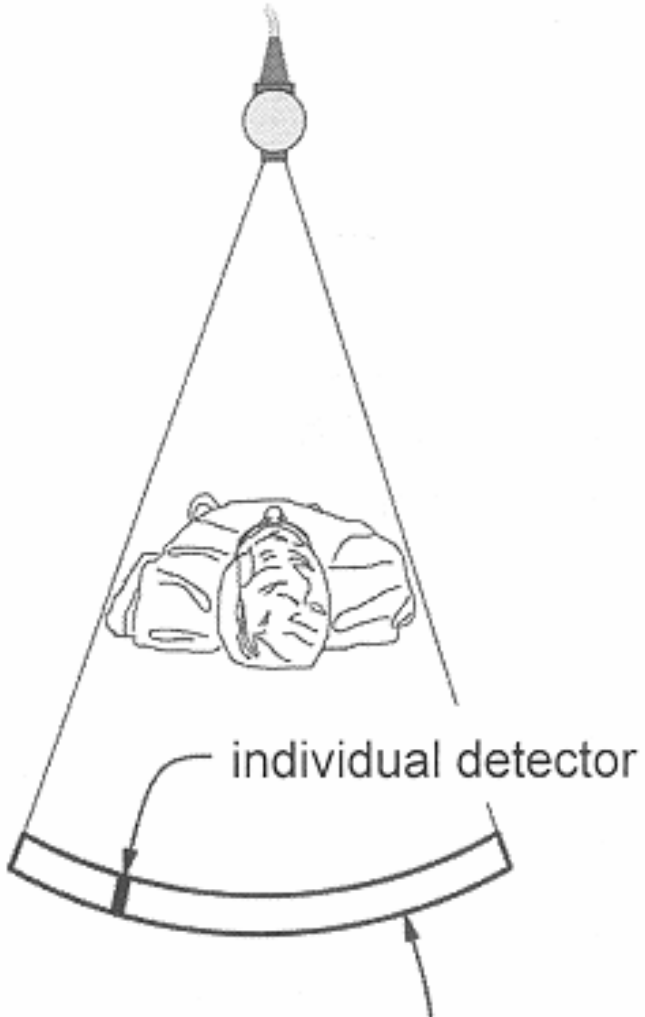
# Seventh Generation CT

- “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 through chest in 20 sec
- Improvement in details
- Problem with PACS, stain on storage system

# Seventh CT



4 detector arrays

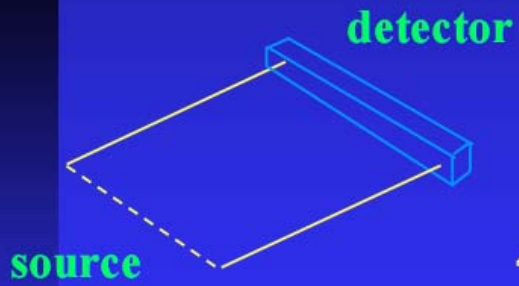


detector array

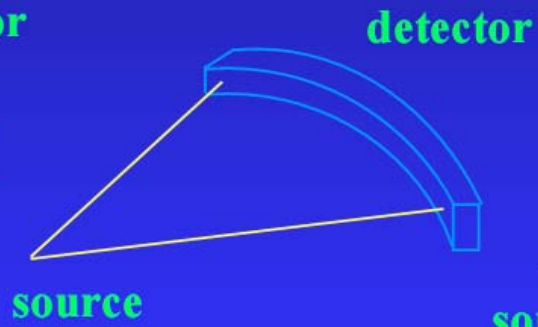
# Seventh CT

- 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

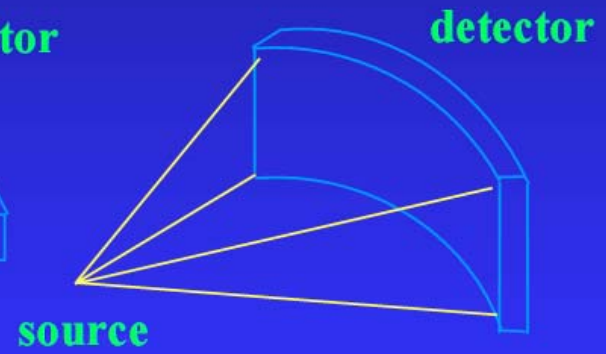




parallel beam



fan beam

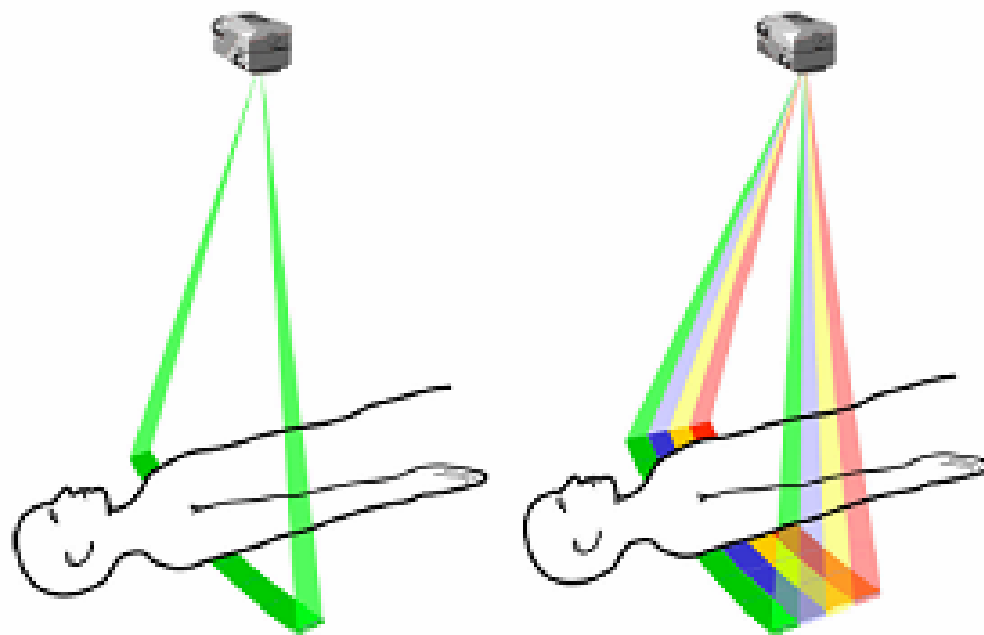


cone beam

# Multiscanning

- Relates to the technique of double or triple rotation of the tube and detectors around the same axial plane
- Provides double or 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

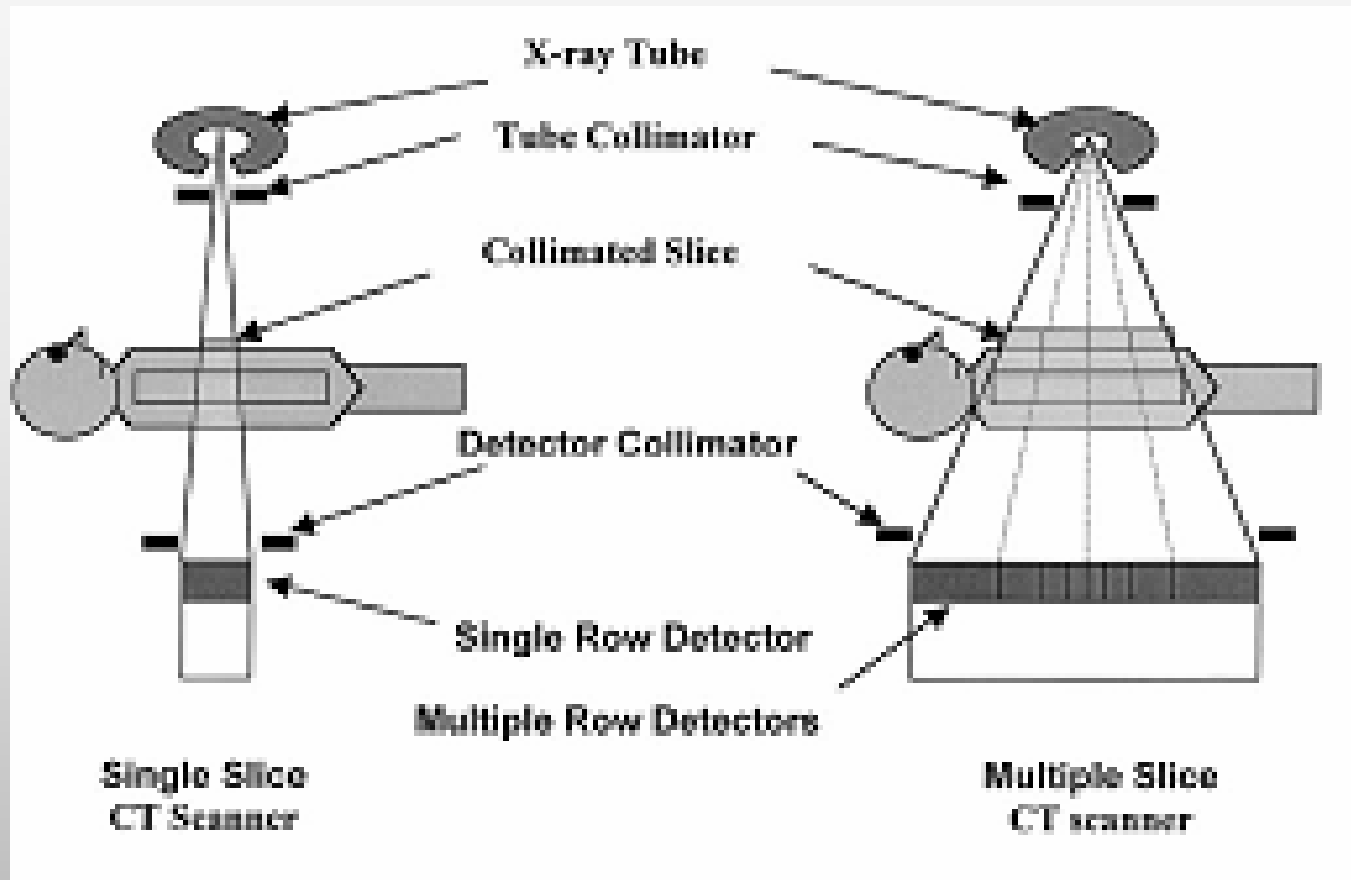
## Single vs. Multi-slice



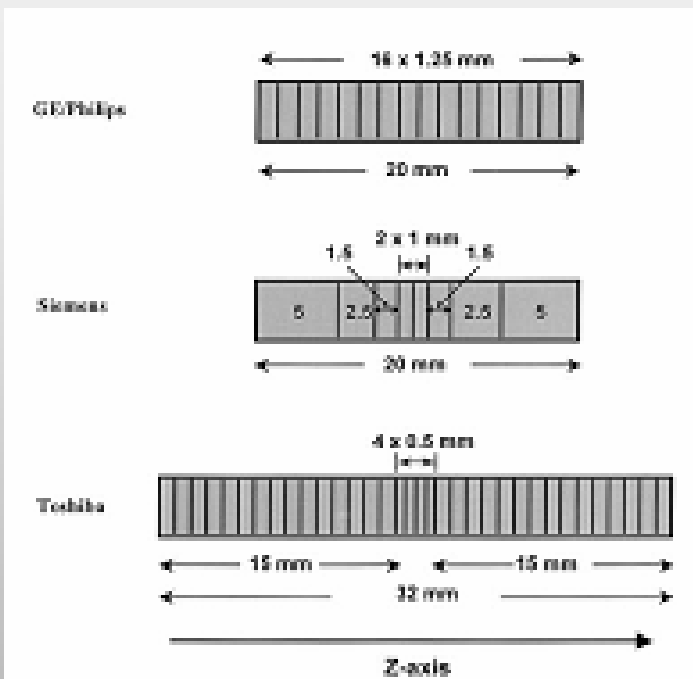
# MSCT

- 1998 all major manufacturers introduced multislice CT, simultaneous acquisition of four slices, providing a great improvement.
- 4 slice, not fast enough to avoid venous overlay assuming a cerebral circulation time of less than 5 sec
- In 2000, 8 slice CT were presented, followed by 16 slice in 2001
- Most modern generation of MSCT is 64 slices per rotation, enabling a whole body CTA with 1,500mm scan range in 22-25seconds
- Future announced 256slices
- Components: tubes and detector measurement systems, large influence on performance
- Development in software and computer capacity lead to processing and reconstruction in a short time

# Seventh CT



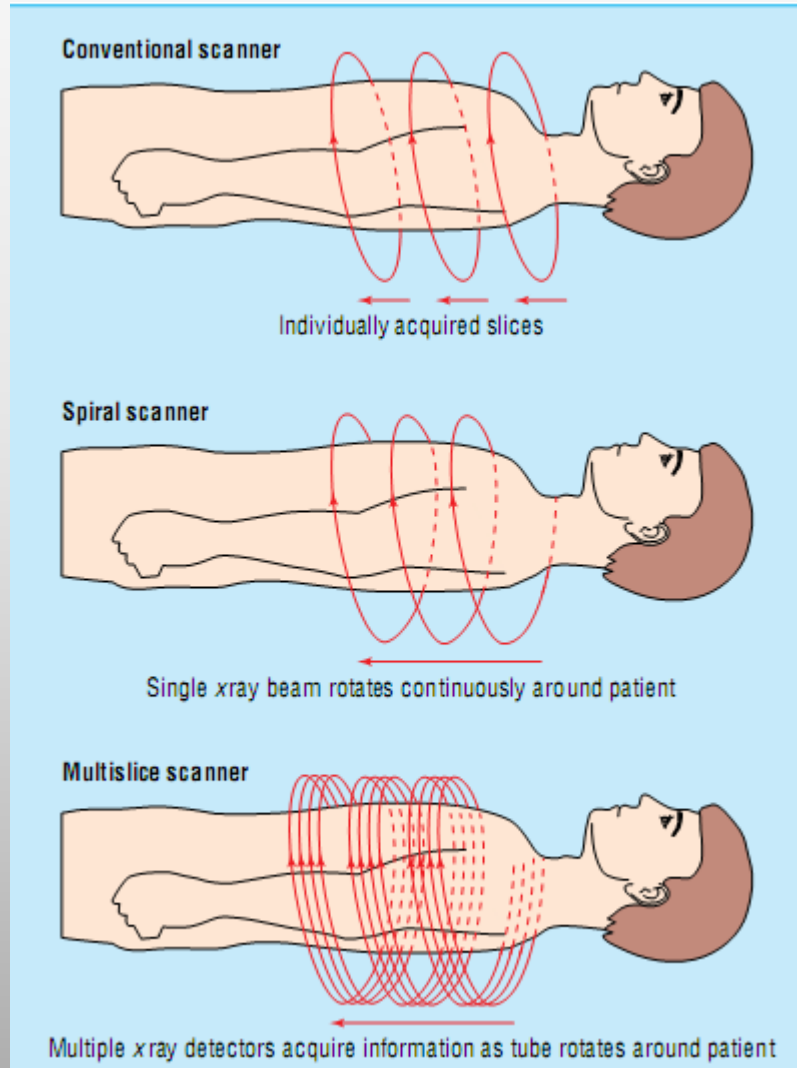
# Multiple Array Design



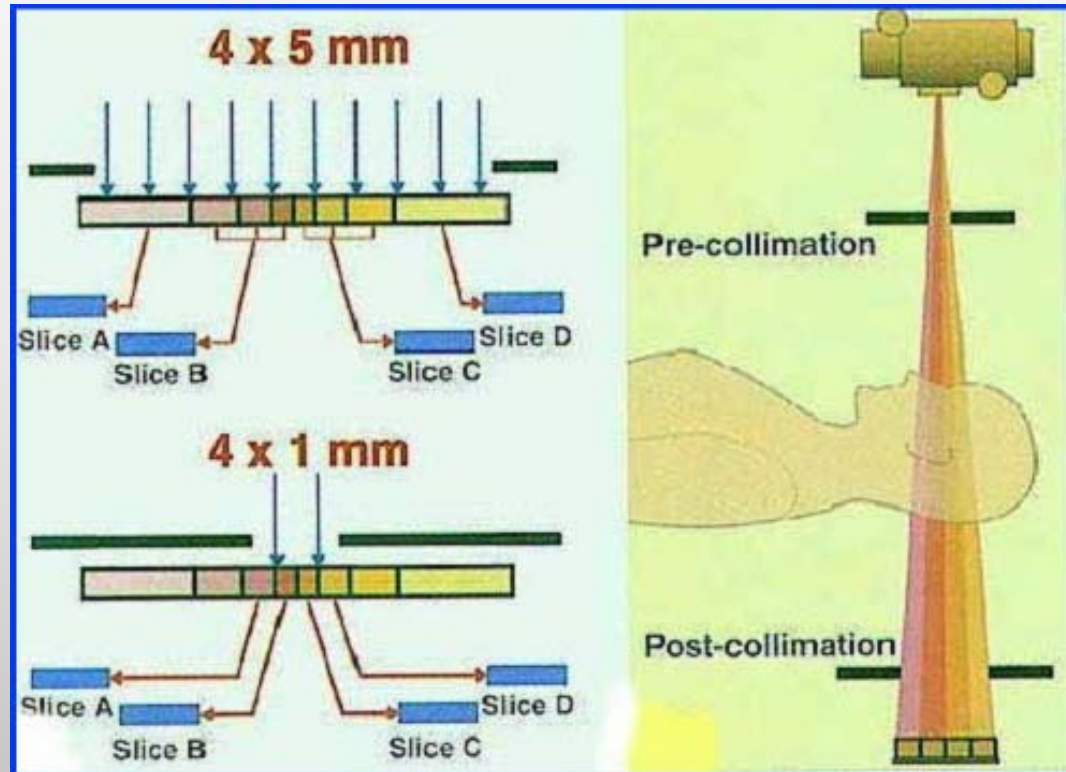
| GE* / Philips | Siemens† | Toshiba‡ |
|---------------|----------|----------|
| 4 X 1.25      | 2 X 0.5  | 4 X 0.5  |
| 4 X 2.5       | 4 X 1    | 4 X 1    |
| 4 X 3.75      | 4 X 2.5  | 4 X 2    |
| 4 X 5         | 4 X 5    | 4 X 3    |
| 2 X 10        | 2 X 8    | 4 X 4    |
|               | 2 X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

Combination of Section width

# 5<sup>th</sup>, 6<sup>th</sup>, 7<sup>th</sup> G CT

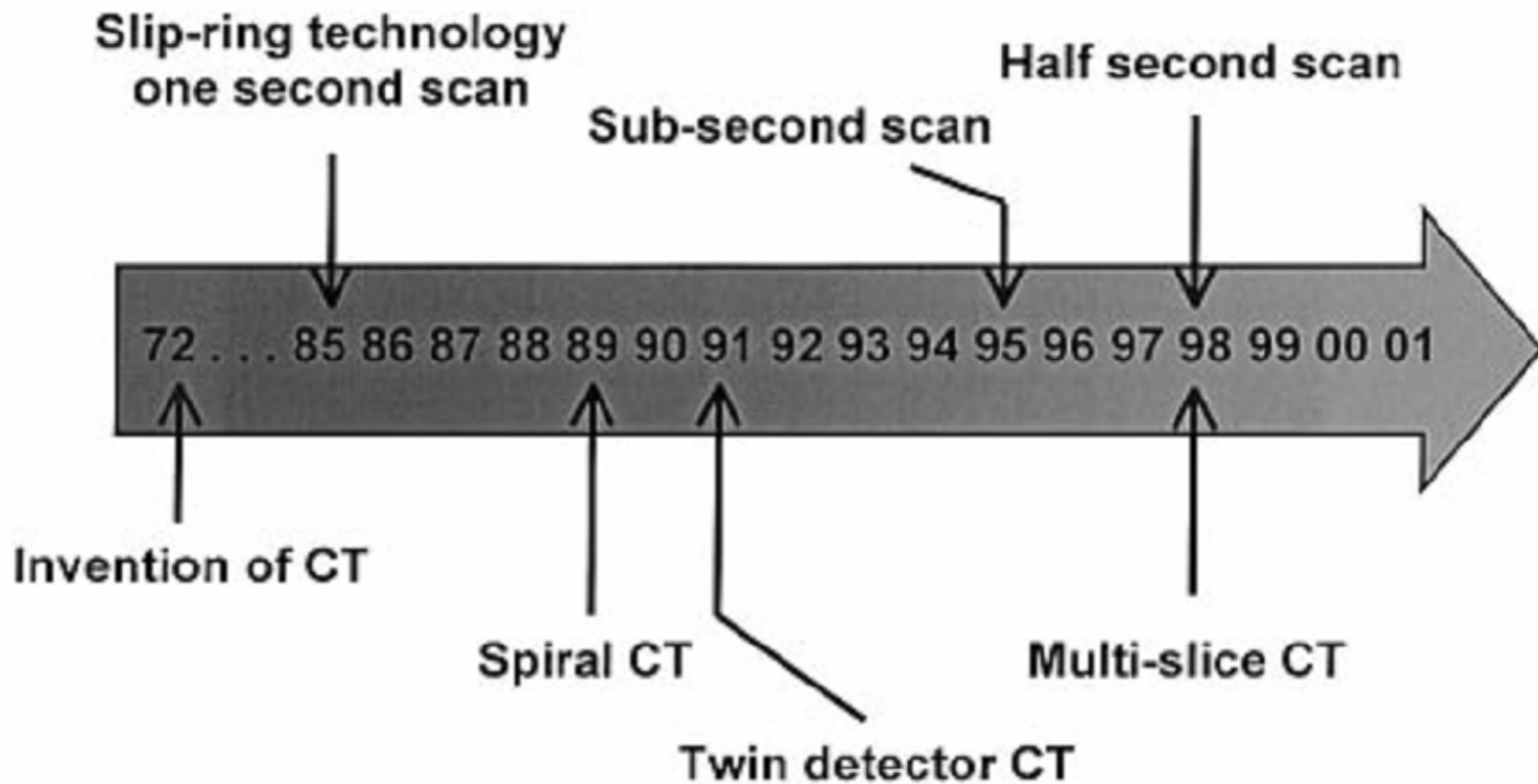


# Multislice Scanning





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



# 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)     |