Scan Time Reduction and X-ray Scatter Rejection in Dual Modality Breast Tomosynthesis

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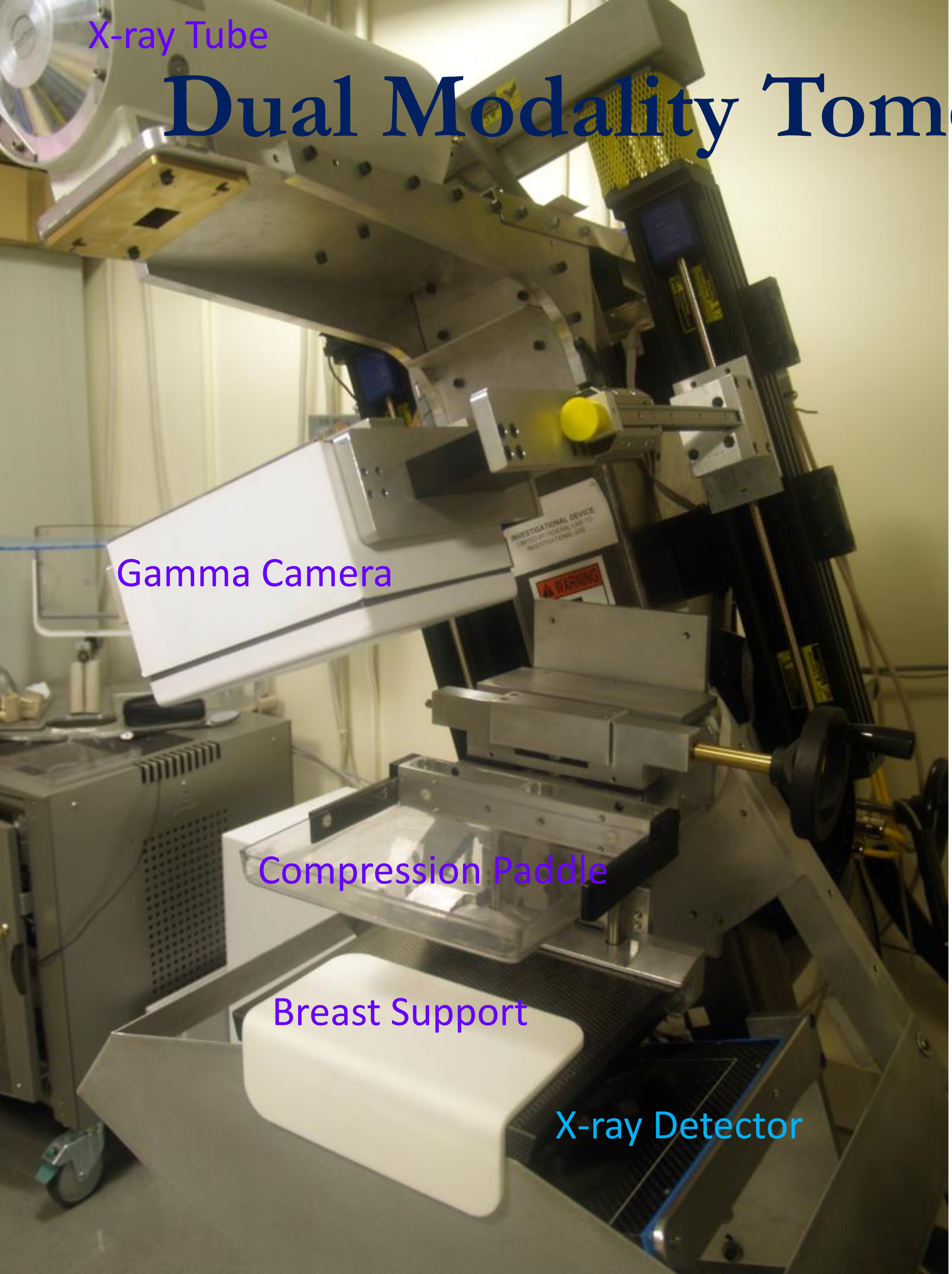
Breast Cancer Statistics

- Second most common cancer after skin cancer
- Second leading cause of cancer death in women, after lung cancer.
- It is estimated that about 39,620 women will die from breast cancer this year
- Mortality rates are decreasing – believed to result from providing better treatment and finding the cancer earlier.

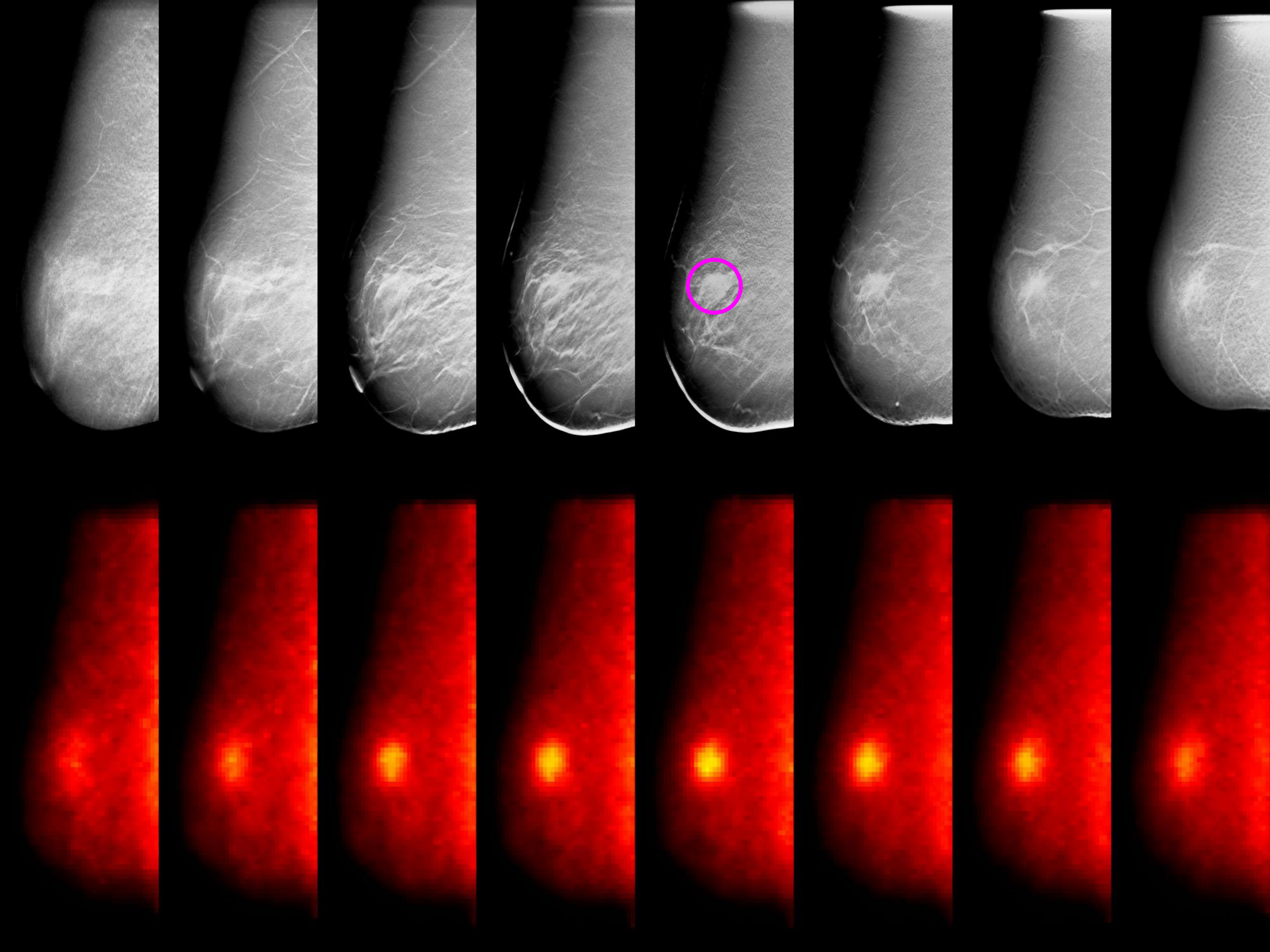
Methods of Early Detection

- 2-Dimensional (2D) X-ray mammography – Single planar image
  - Standard method
  - Large amount of compression
- X-ray Tomosynthesis – 3D volume reconstructed from several 2D images taken from different angles
  - Becoming new standard
  - Removes obscuration due to overlapping tissue
  - Not as much compressive force required
- Gamma ray emission tomosynthesis – currently being researched by our lab
  - Requires radioactive tracer – typical tracer is Tc-99m
  - 3D Functional Information
  - Gamma camera used to visualize radiotracer distribution

Dual Modality Tomosynthesis (DMT)

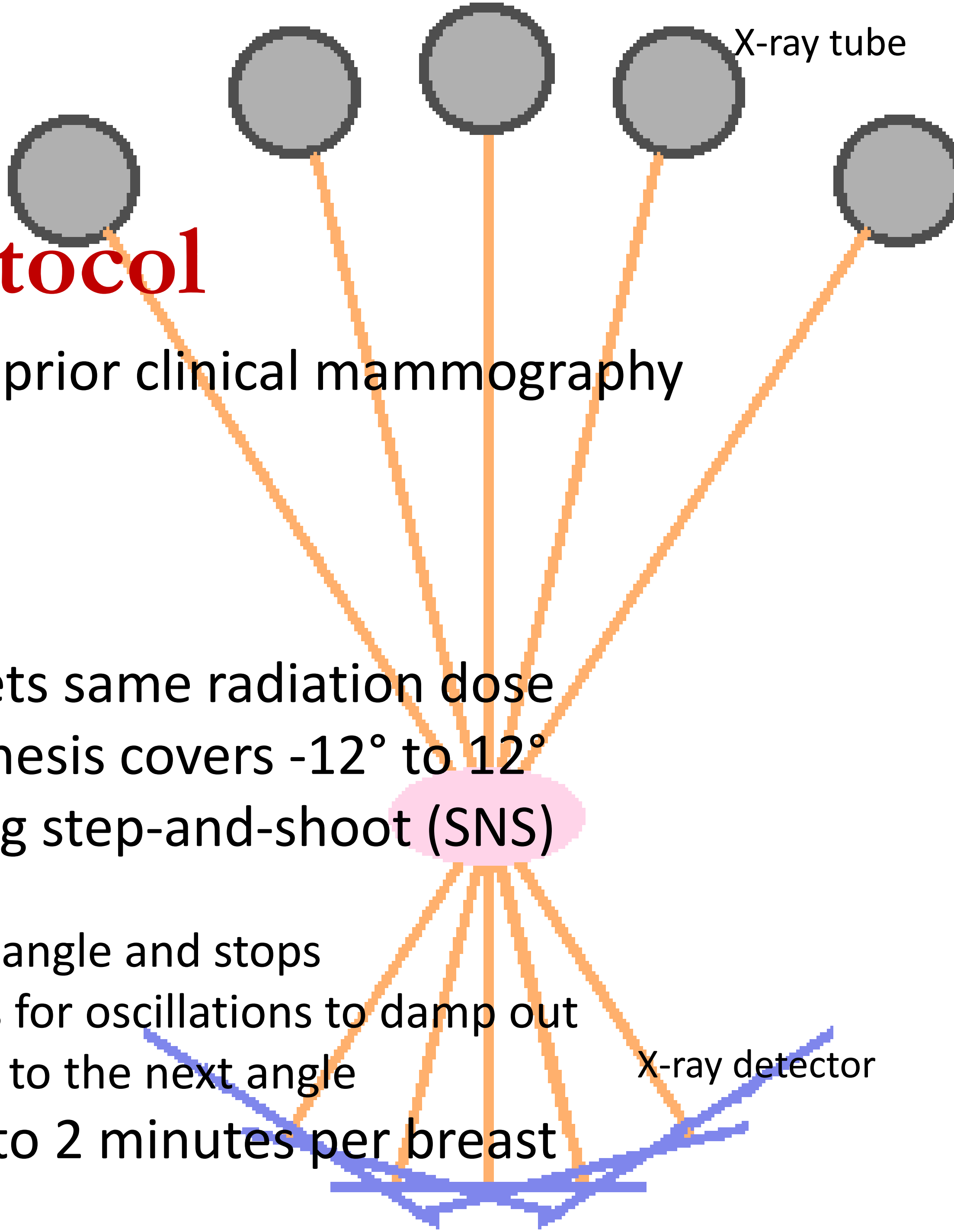


- Patient injected with radiotracer
- Breast placed and kept stationary at axis of rotation (AOR)
- X-ray imaging done first
- Then gamma imaging done with the breast in the same configuration

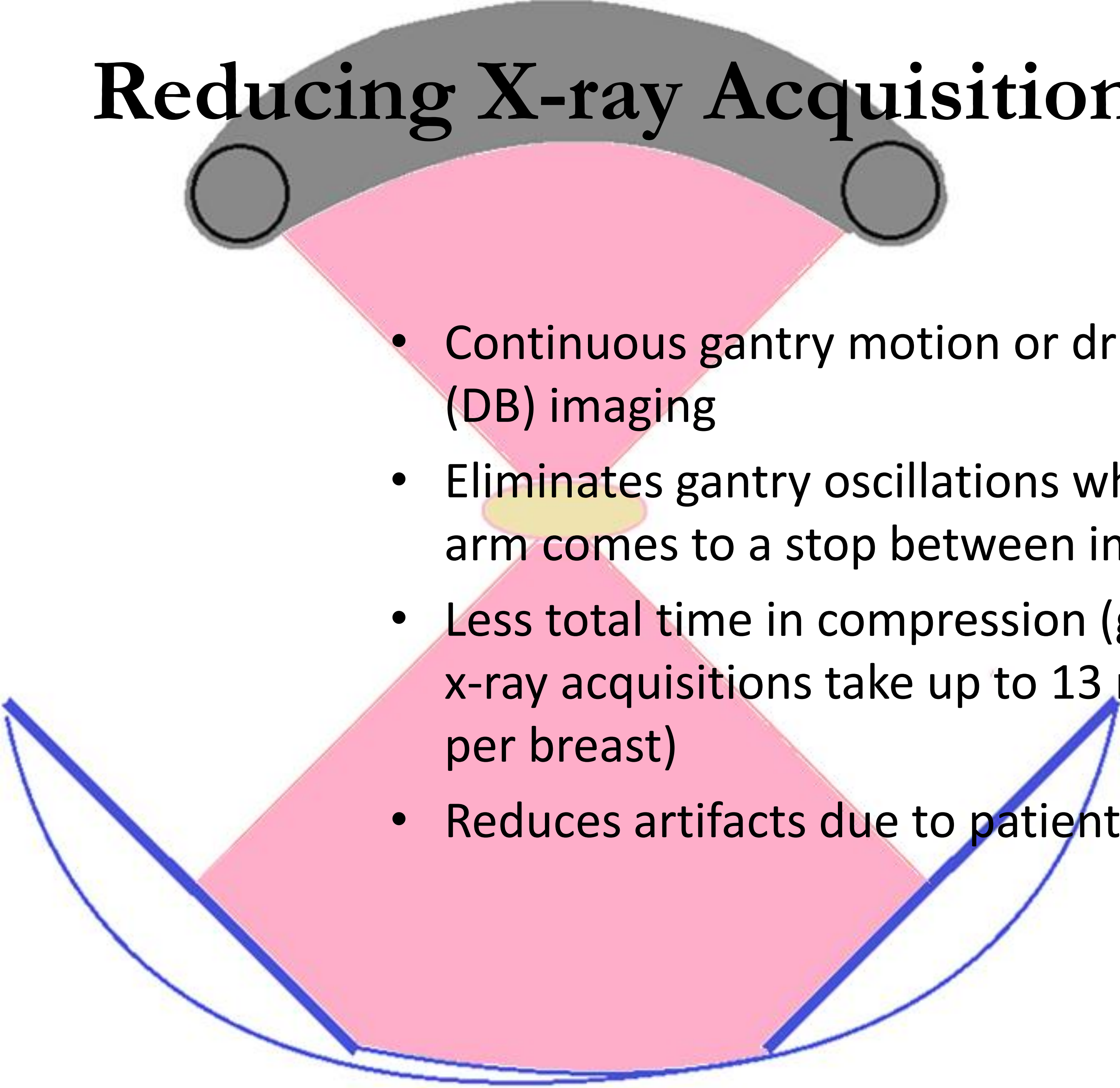


Current X-ray Acquisition Protocol

- Dose set using subject's prior clinical mammography exam:
  - Exposure
  - Density
  - Compressed thickness
- Every projection view gets same radiation dose
- Limited angle tomosynthesis covers -12° to 12°
- 13 projection views using step-and-shoot (SNS) method
  - Gantry moves to desired angle and stops
  - Pause for couple seconds for oscillations to damp out
  - Image taken and then on to the next angle
- Full X-ray scan takes up to 2 minutes per breast



Reducing X-ray Acquisition Time

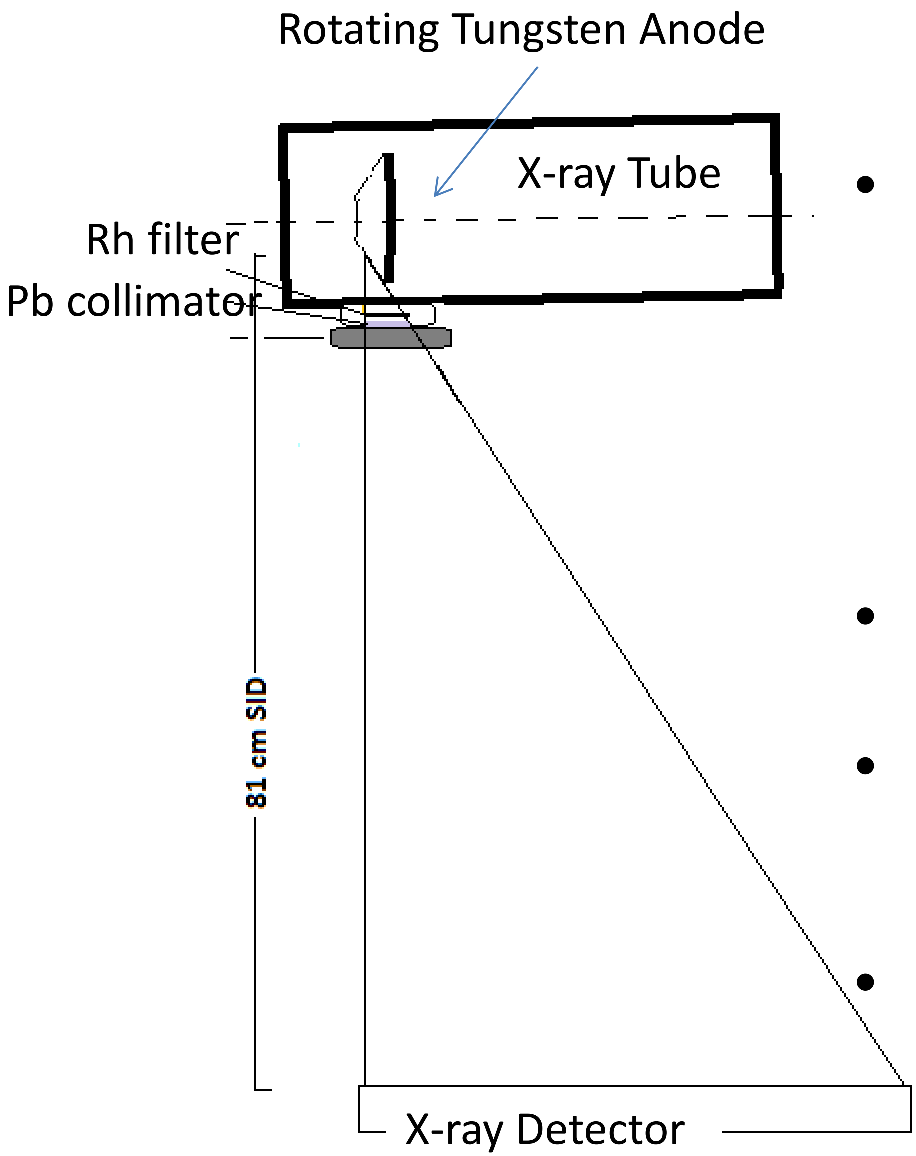


- Continuous gantry motion or drive-by (DB) imaging
- Eliminates gantry oscillations when gantry arm comes to a stop between images
- Less total time in compression (gamma + x-ray acquisitions take up to 13 minutes per breast)
- Reduces artifacts due to patient motion

Feasibility

- Hardware capabilities – images taken at a faster rate in DB imaging
  - Turning x-rays on and off quickly
  - Taking images at higher frame rate
- Ability to synchronize all components
  - No wasted radiation
  - Need to image at specific gantry angles
- Maintaining image quality

X-ray Beam



- Parameters that determine x-ray output
  - W Target and Rh filter
  - Tube voltage: 20 - 40 kVp
  - Tube current: 5 – 250 mA
  - Exposure time: 40 – 500 ms
- Tube voltage sets photon energy
- Product of current and exposure time (mAs) determines fluence
- Generator is capable of short exposures and short gaps between exposures

X-ray Detector

- 2923MAM from Dexela, a PerkinElmer Co
- CMOS active pixel sensor
- High resolution CsI scintillator
- 290.8 mm x 229.8 mm active area
- 75µm pixel size

- 14 bit digital output
- High Dynamic Range (HDR) Mode
- High Sensitivity (HS) Mode
- Capable of acquiring up to 17 frames per second (fps)

Determining Motion Based on Blur

- Blur caused by projection of single point over more than one point on the detector within an exposure
- Point within x-ray beam that would experience the most blur will limit gantry speed
- Need to know maximum angle gantry arm can traverse within an exposure to limit blur b to one detector element (pixel size = 75 microns)
- Keeping angular speed fixed during imaging for now
- Can calculate required speed v when given:
  - $\Delta\theta$ = maximum angle that gantry can traverse
  - t_{exp} = Exposure time

320 ms exposure of tungsten (10 deg/s gantry angular speed)

- Treated detector and tube as fixed
- Calculation performed on points inside x-ray field of view (FOV), but consider only:
  - Locations of beam that will potentially have tissue
  - Points furthest from AOR will have most blur
- Using Eqs. (1)-(4) to solve for Δθ

$$\begin{bmatrix} x_{rot} \\ y_{rot} \end{bmatrix} = \begin{bmatrix} \cos\Delta\theta & -\sin\Delta\theta \\ \sin\Delta\theta & \cos\Delta\theta \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \quad (1)$$

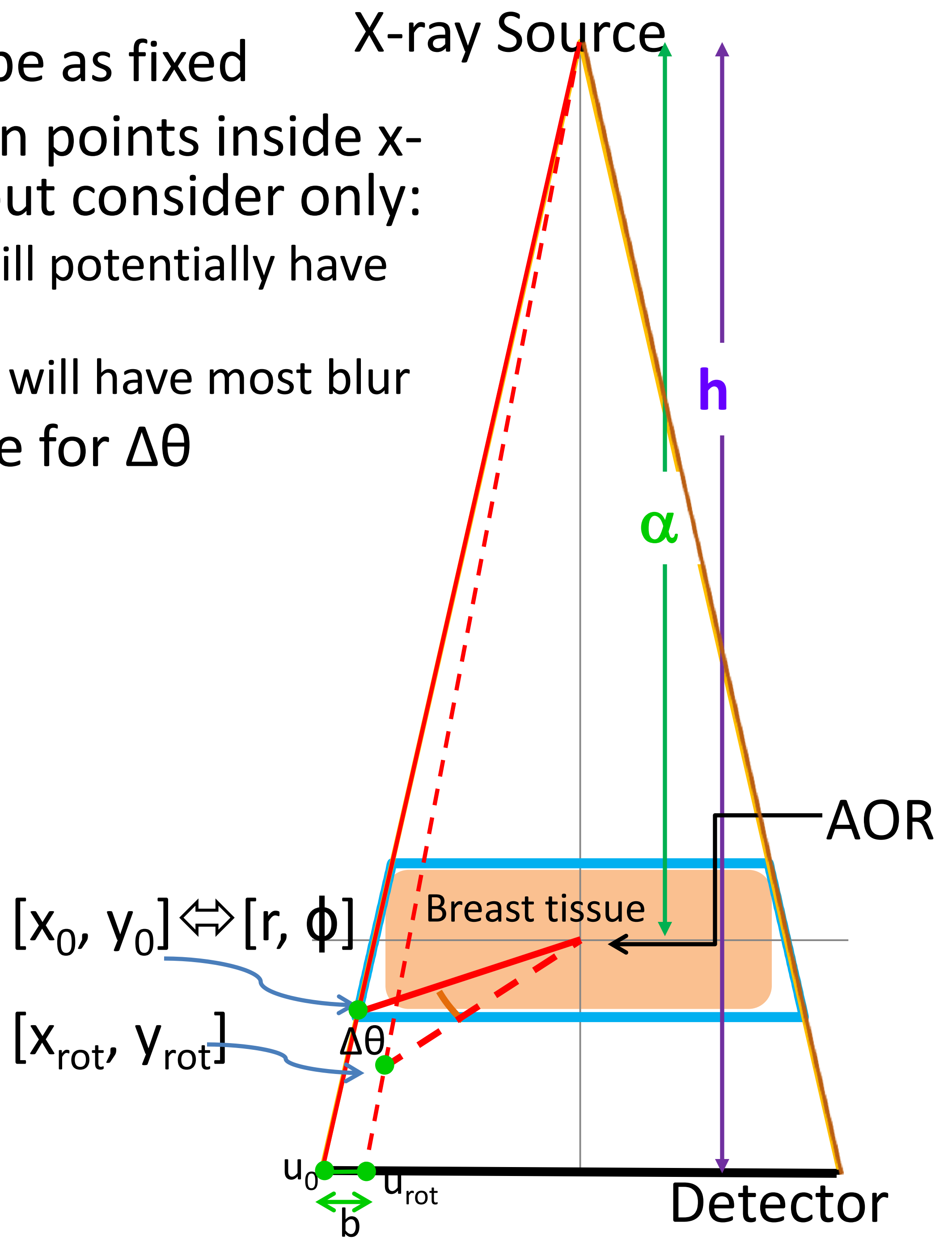
$$u_0 = \frac{x_0}{(\alpha - y_0)} * h \quad (2)$$

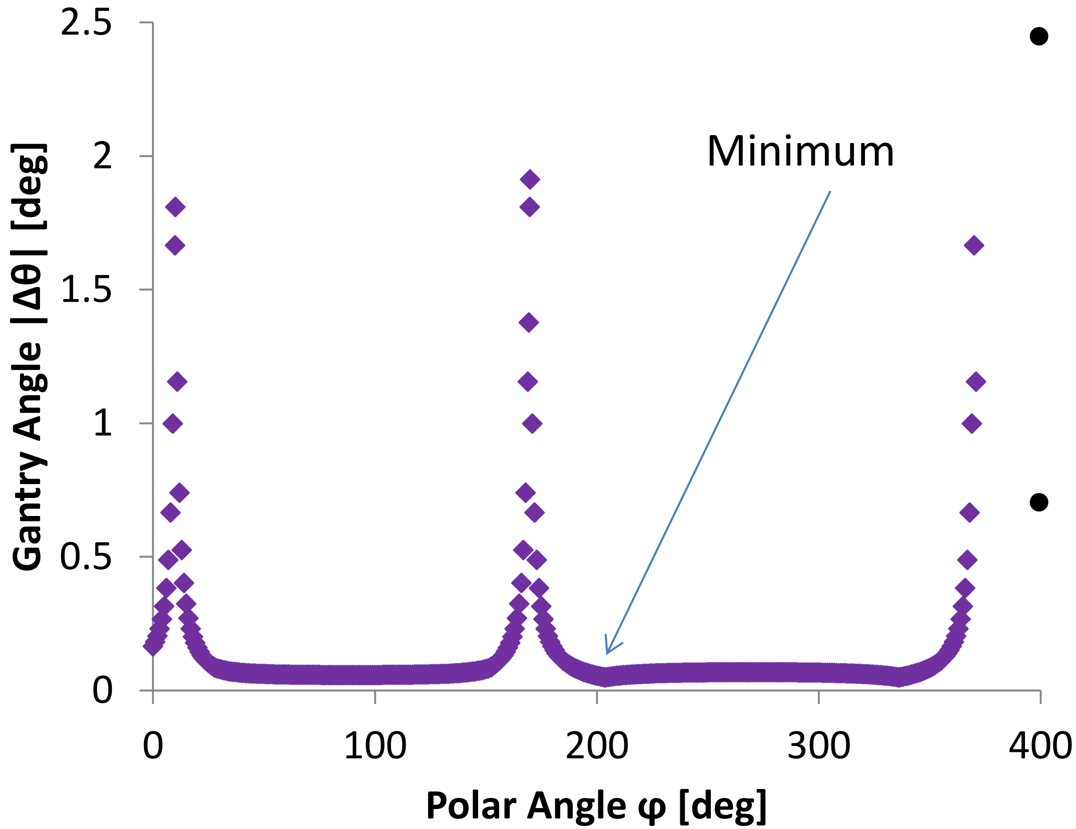
$$u_{rot} = \frac{x_{rot}}{(\alpha - y_{rot})} * h \quad (3)$$

$$b = |u_0 - u_{rot}| \quad (4)$$

$$b \leq \text{pixel size} \quad (5)$$

$$\nu = \frac{\Delta\theta}{t_{exp}} \quad (6)$$





- Points that limit speed are bottom left-hand and right-hand corners of blue outline (smallest value of $\Delta\theta = 0.048°$)
- Angular range and exposure time determine total acquisition time

Resulting Scan Times

- For confining blur to a pixel size of 0.075 mm and given a 24 deg angular range in worst case scenario:
  - 40 ms (speed = 1.2°/s)→ 20 sec scan
  - 320 ms(speed = 0.15°/s) → 160 sec scan

Factors to Consider

- Limited tube current (250 mA maximum)- may not be able to compensate for reduced exposure time
  - Average mAs/view used in DMT x-ray tomo studies ~40 mAs
  - Maximum mAs/view with 40 ms exposure is 10 mAs
- This will reduce exposure level per view

- Must maintain image contrast while being less susceptible to system noise
- Need to gauge detector performance for range of entrance exposures

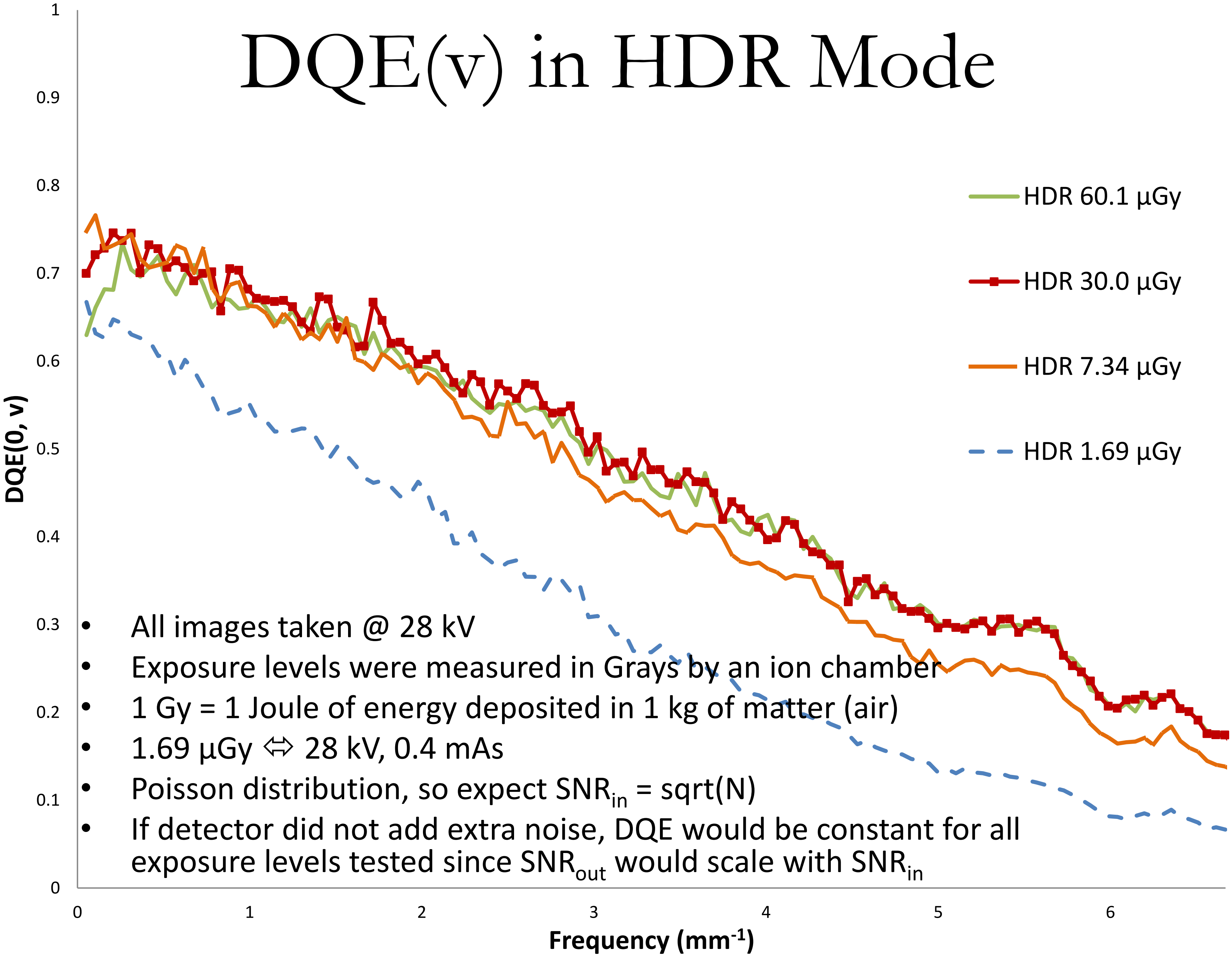
Detective Quantum Efficiency (DQE)

- Spatial frequency dependent function
- Indicates how efficiently the detector can process the input x-ray signal:

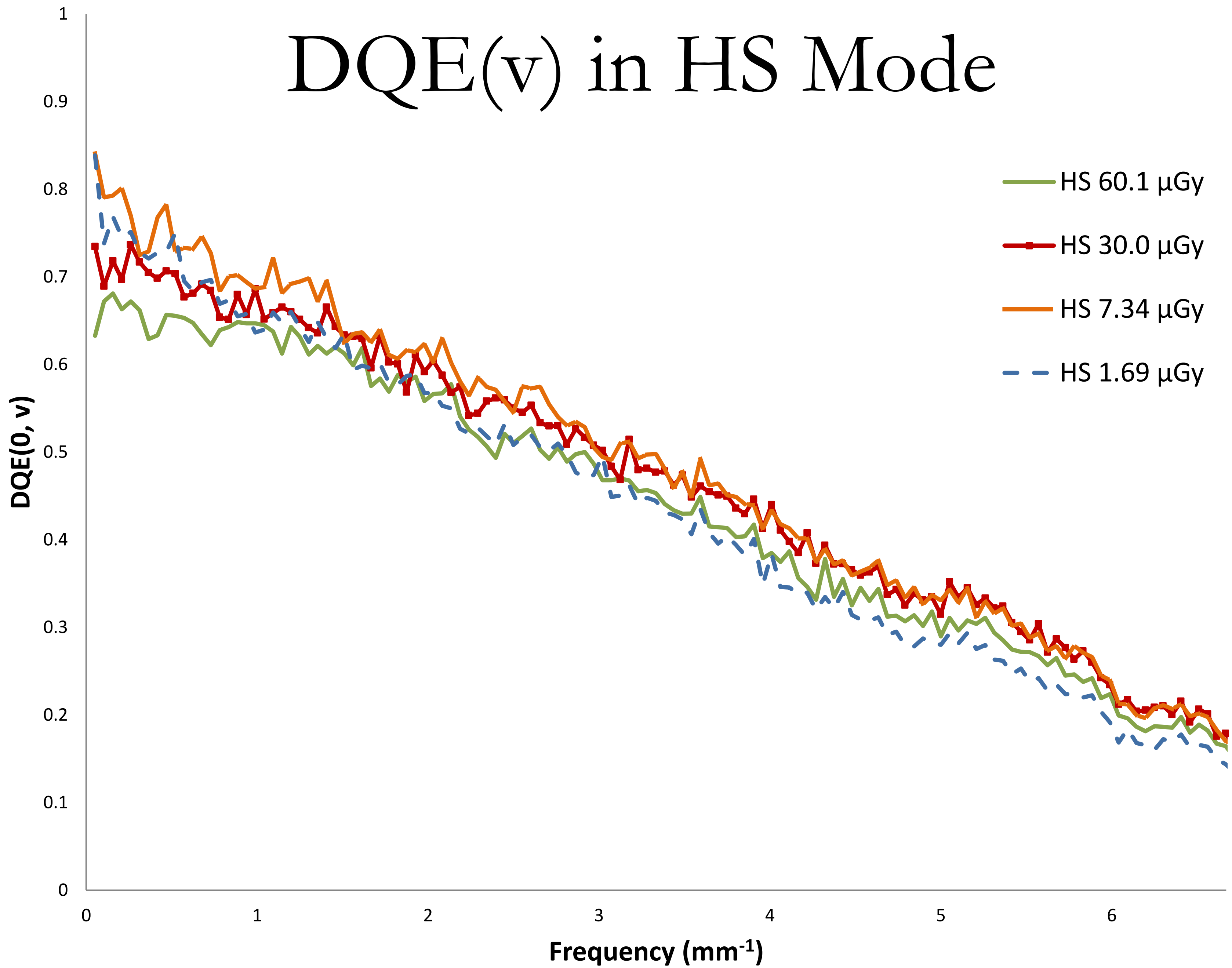
$$DQE(u,v) = \frac{SNR_{out}^2(u,v)}{SNR_{in}^2(u,v)} \qquad (1)$$

- Spatial frequency coordinates
  - u ⇔ x-direction ⇔ image rows
  - v ⇔ y-direction ⇔ image columns
- SNR_{in} is signal to noise ratio at input of detector, SNR_{out} is obtained from the output image
- Standardized protocol provided means of determining $SNR_{in}^2(u,v)$

DQE(v) in HDR Mode



- All images taken @ 28 kV
- Exposure levels were measured in Grays by an ion chamber
- 1 Gy = 1 Joule of energy deposited in 1 kg of matter (air)
- 1.69 µGy ⇔ 28 kV, 0.4 mAs
- Poisson distribution, so expect SNR_{in} = sqrt(N)
- If detector did not add extra noise, DQE would be constant for all exposure levels tested since SNR_{out} would scale with SNR_{in}

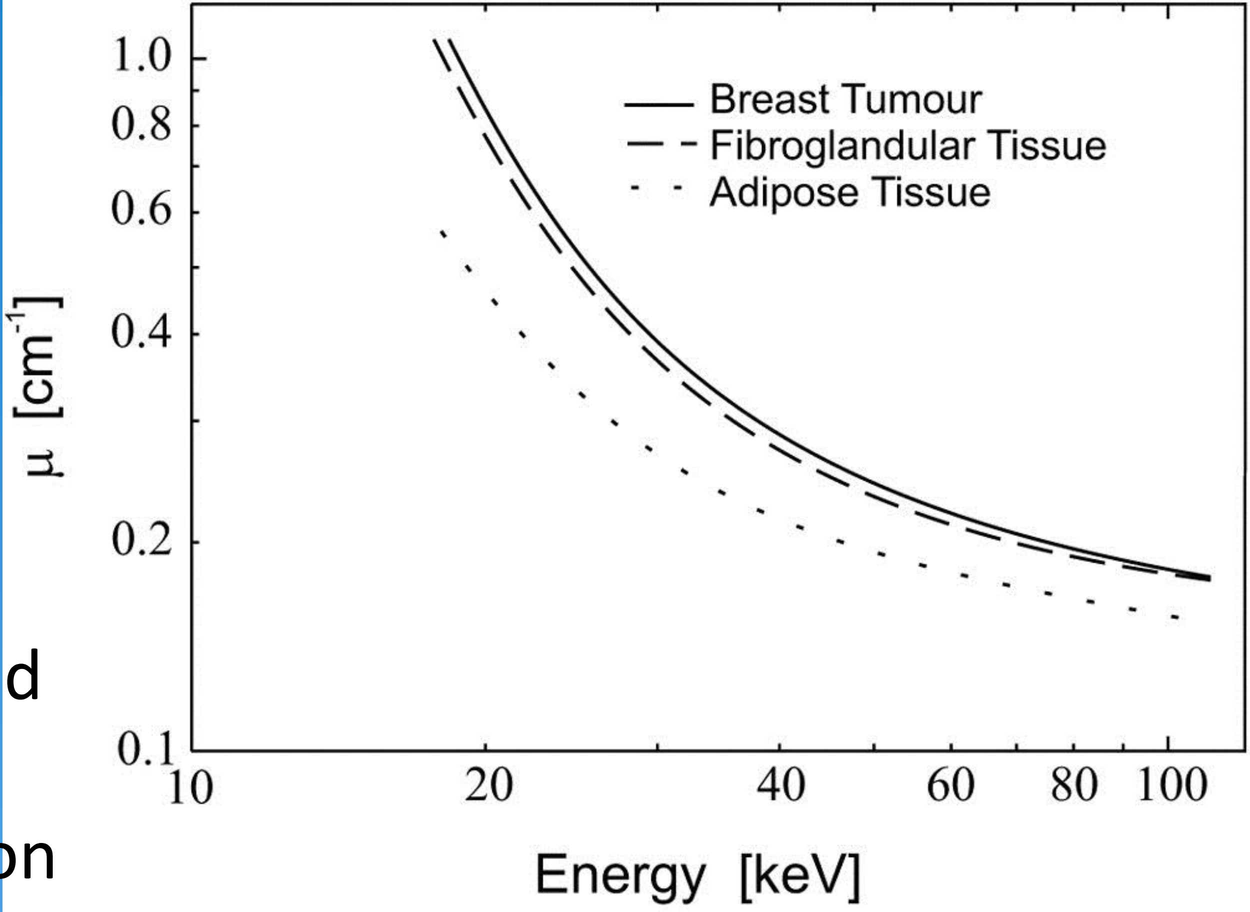


DQE(v) in HS Mode
DQE(0, v)
Frequency (mm-1)
HS 60.1 µGy
HS 30.0 µGy
HS 7.34 µGy
HS 1.69 µGy
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6

Results of DQE Analysis

- Worse detector performance in HDR mode for low exposures below 7 µGy
- Nearly constant DQE over the full range of exposure levels tested between for HS mode
- Short, fast exposures are possible without image quality degradation due to system noise
- However, this analysis does not include effect of scatter on image quality

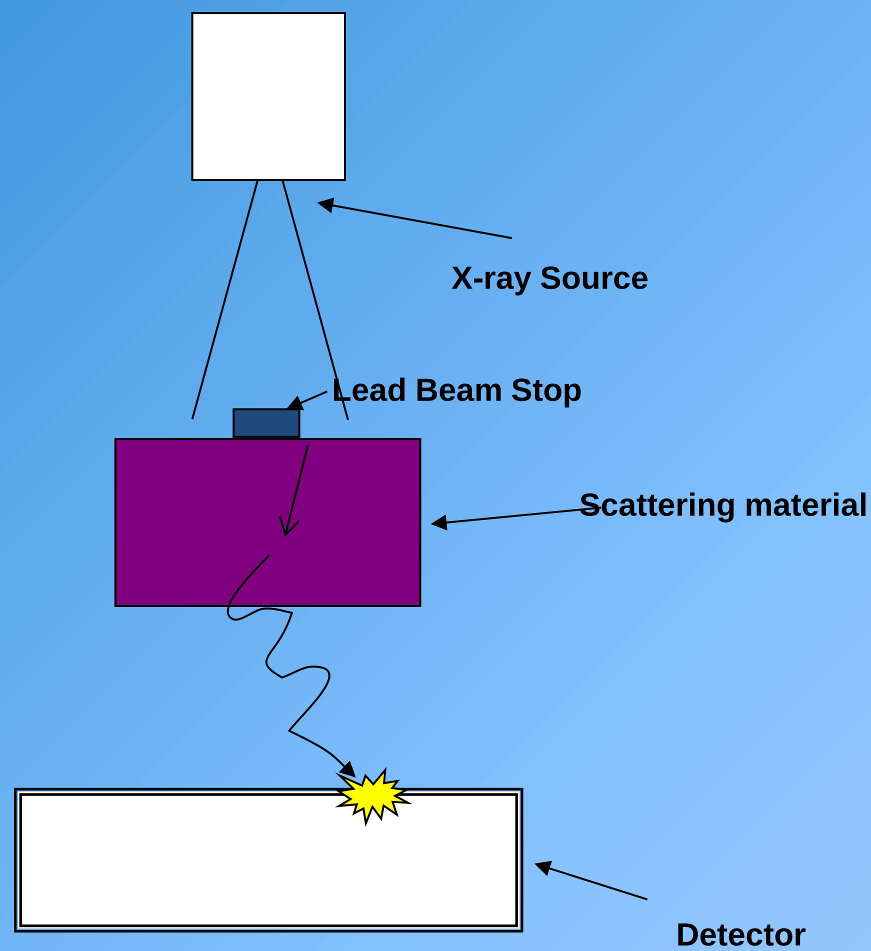
X-ray Scatter

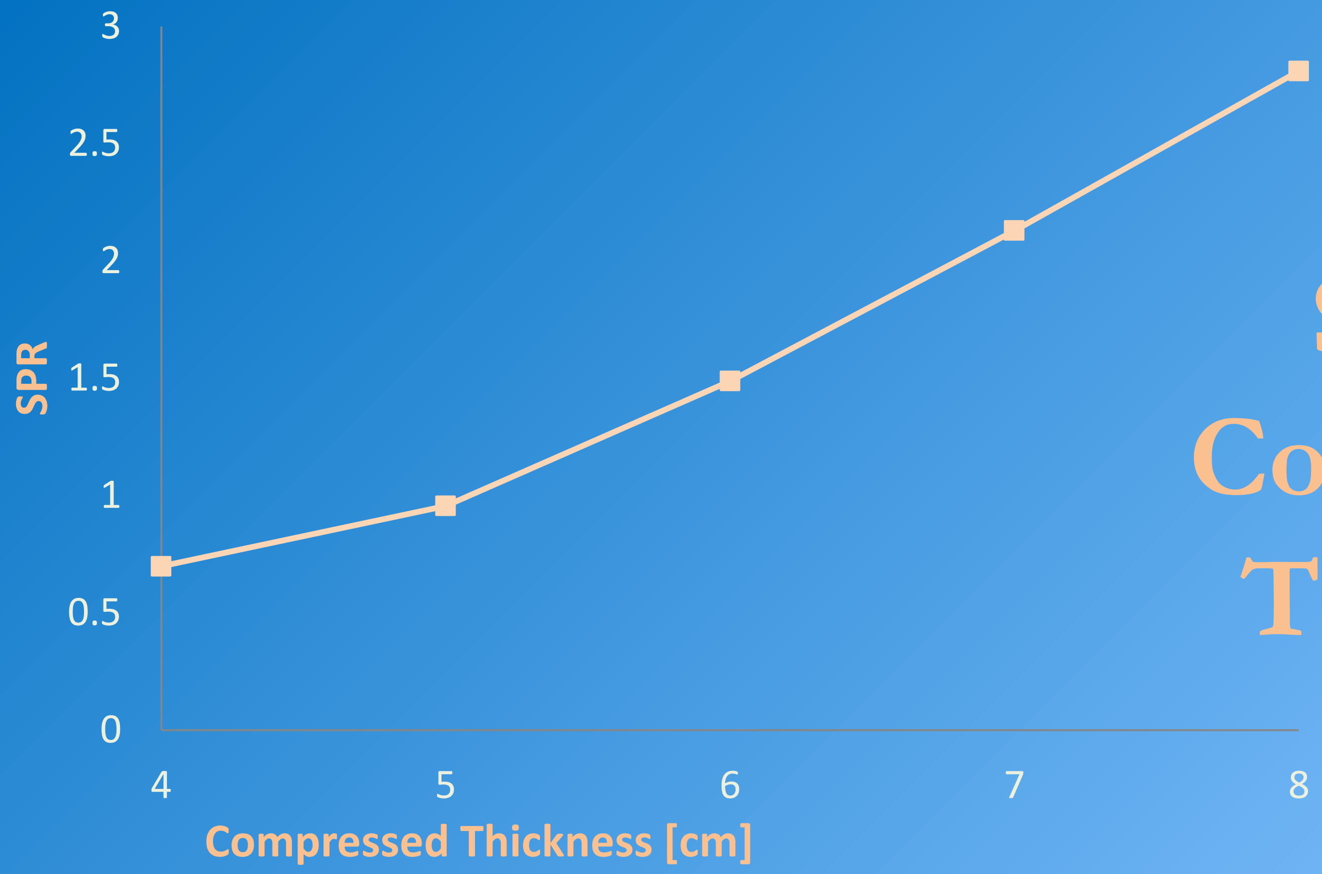


- Compton scatter
- Healthy tissue and tumors have similar attenuation
- Scatter decreases image contrast
- Degradation worsens with more scattering material
- Average compressed thickness: 7.7 cm

Measuring Relative Scatter

- Beam stop experiment to quantify scattered x-rays relative to primary x-rays in images
- Using circular lead blockers to attenuate primary beam
- Place scattering material (mimics breast tissue) between blocker and detector
- Scattered x-rays would result in non-zero mean pixel values observed behind blocker
- Use mean pixel values in images to obtain scatter to primary ratios (SPRs)



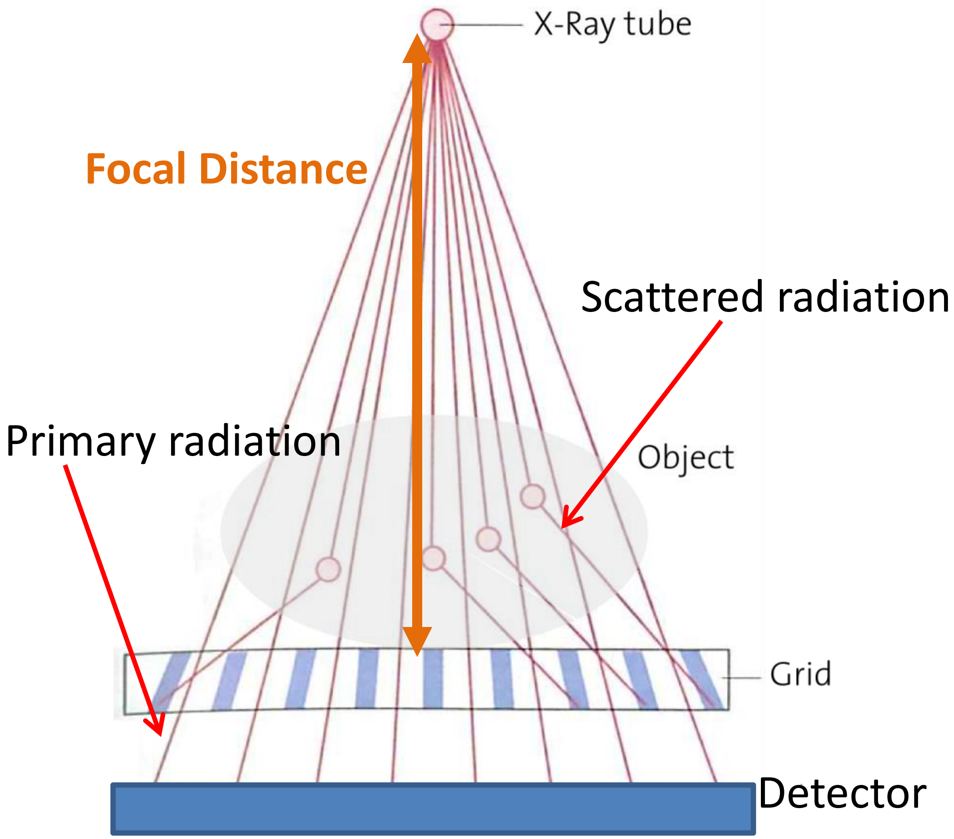


SPR vs. Compressed Thickness

- SPR values for each compressed thickness
- Large amount of scatter present
- Essential to cut out as much scatter for improving contrast
- Require an anti-scatter grid

Focused Anti-Scatter Grid

- Scattered radiation is more likely to be in a different direction from primary photons
- Grid walls made of material with high atomic number for attenuating majority of scattered radiation
- Grid placed between scattering material and detector at focal distance
- Focused anti-scatter grid for higher primary x-ray transmission out of cone beam



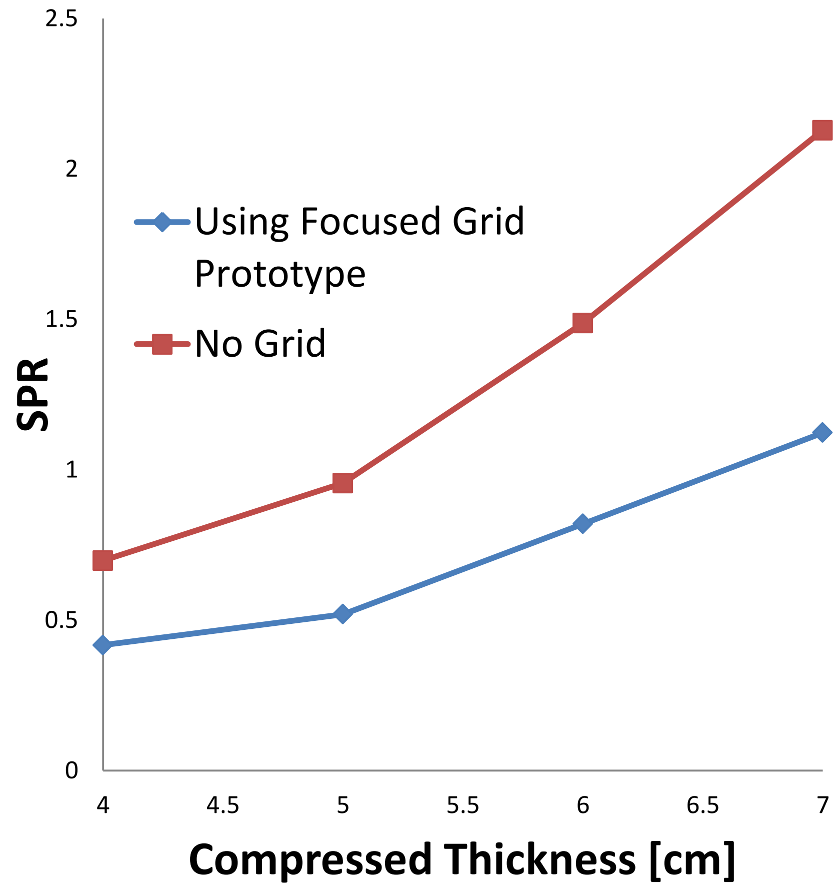
http://miac.unibas.ch/PMI/01-BasicsOfXray.html#(28)

Grid Prototype

- Tungsten-polymer focused anti-scatter grid fabricated by MIKRO Systems
- 2D grid
- 80 cm focal distance
- Active area dimensions: 18 x 26 cm
- Spacing: 1 mm
- Wall thickness: 0.1 mm
- Open area fraction: 83%

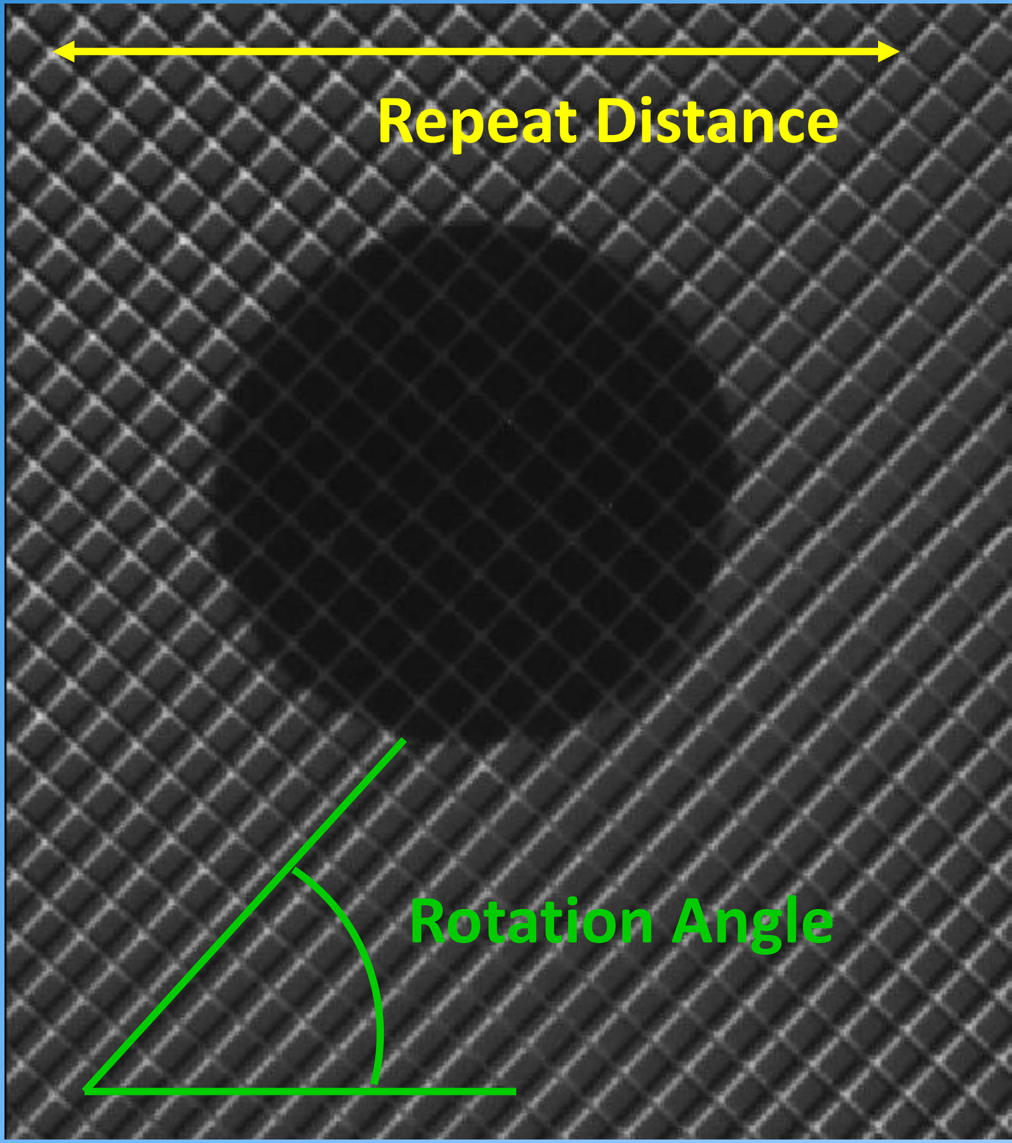
SPR with Grid in Beam

- Tungsten-polymer grid placed directly on detector beneath x-ray focal spot (XFS)
- SPR values found using same experimental setup and techniques as for no grid
- Grid significantly decreases scattered radiation



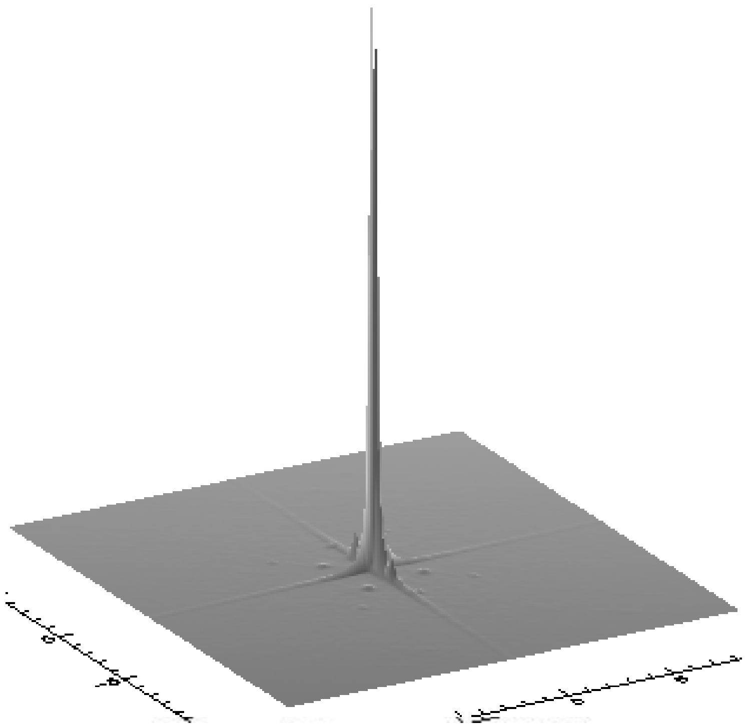
Grid Lines

- Grid shows up in image when kept stationary
- Must move grid during exposure to blur grid lines
- Lines are not parallel to image rows and columns
- Grid rotation angle- (47° for prototype)
- Repeat distance (19.4 mm for prototype)



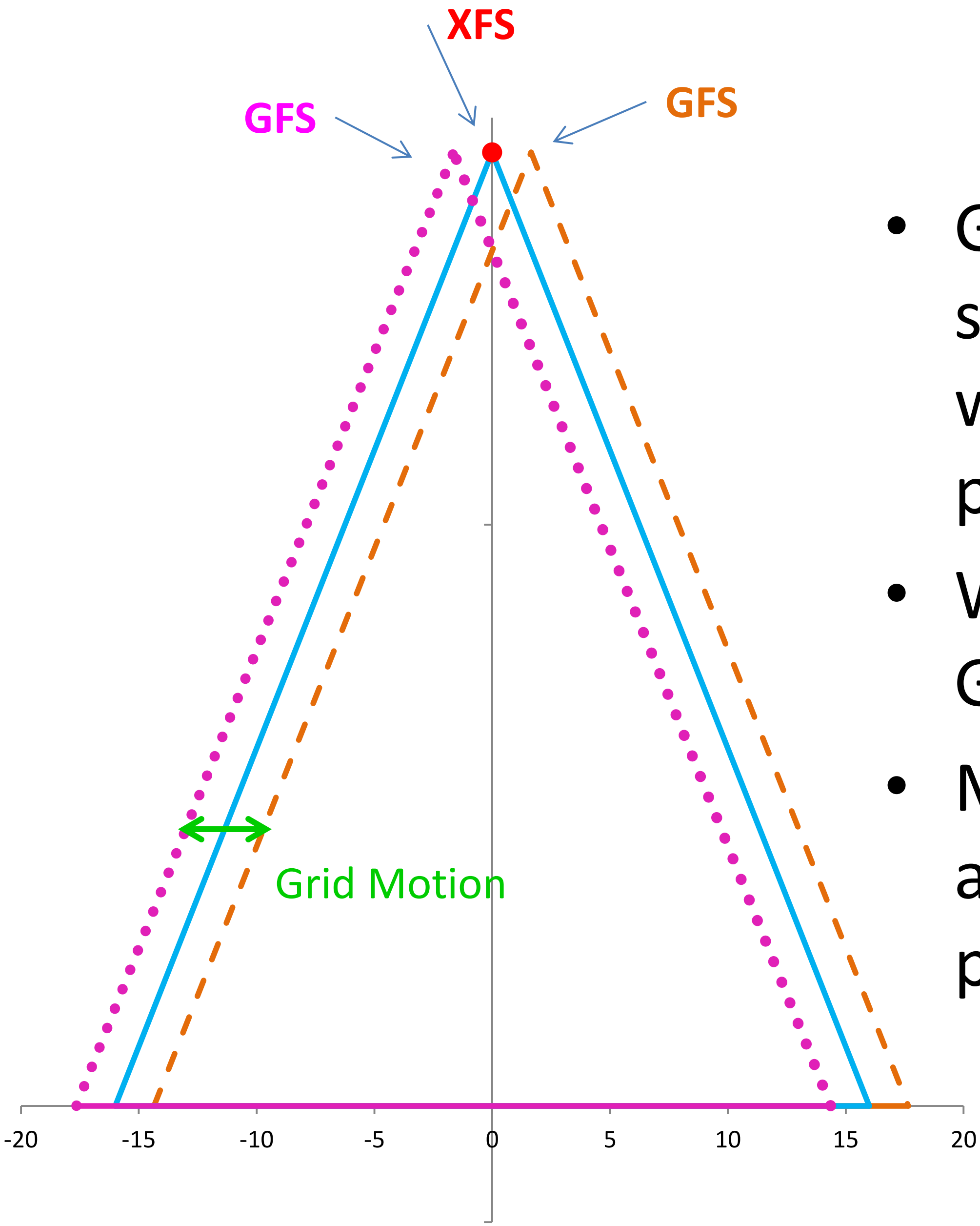
Blurring Grid Lines

- Image noise power spectrum (NPS) analysis
- NPS(u,v) = |FFT(Image)|^2
- Found that translating grid by at least 1 repeat distance during exposure works best

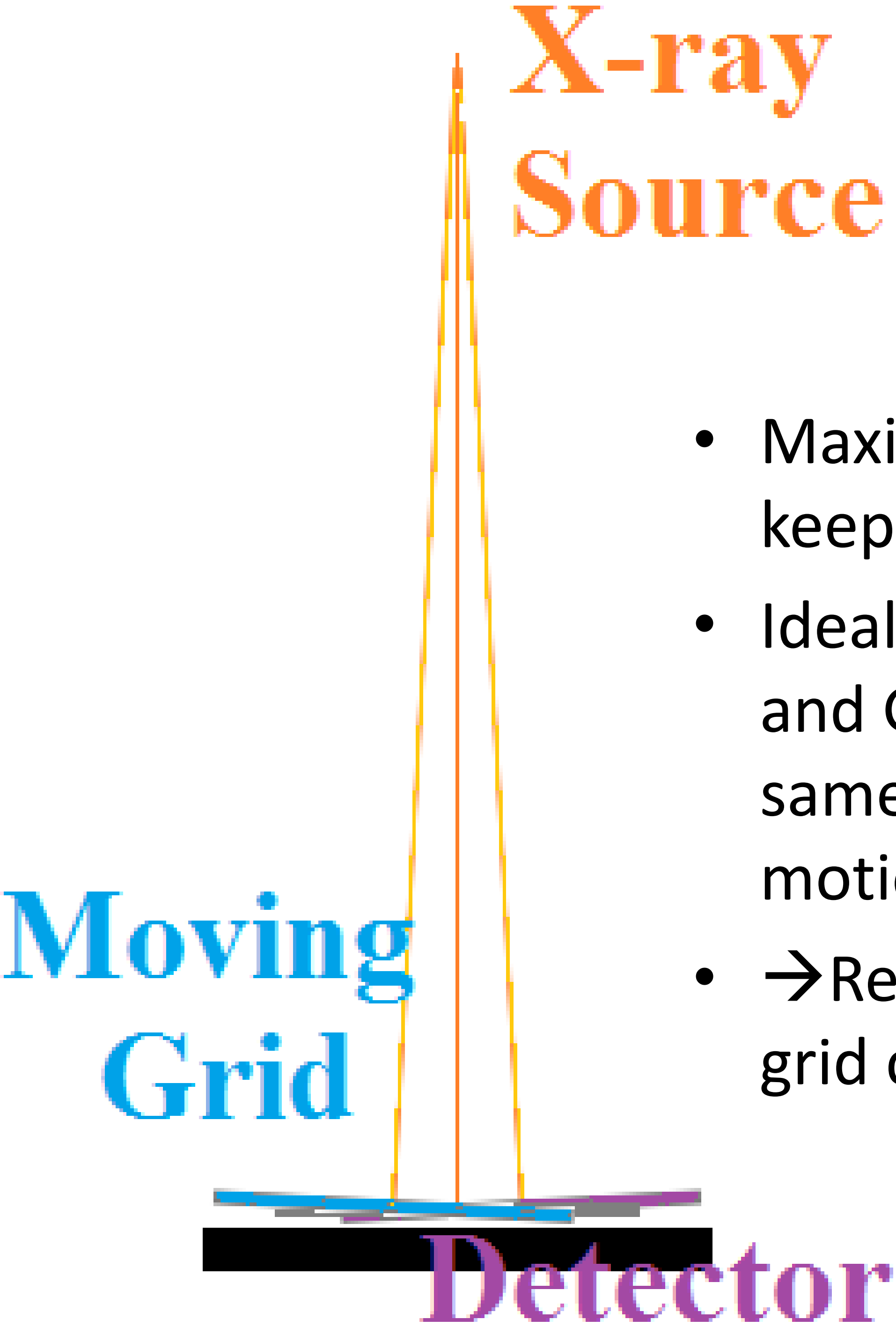


Grid moving full repeat distance during exposure

Decrease in Beam Intensity

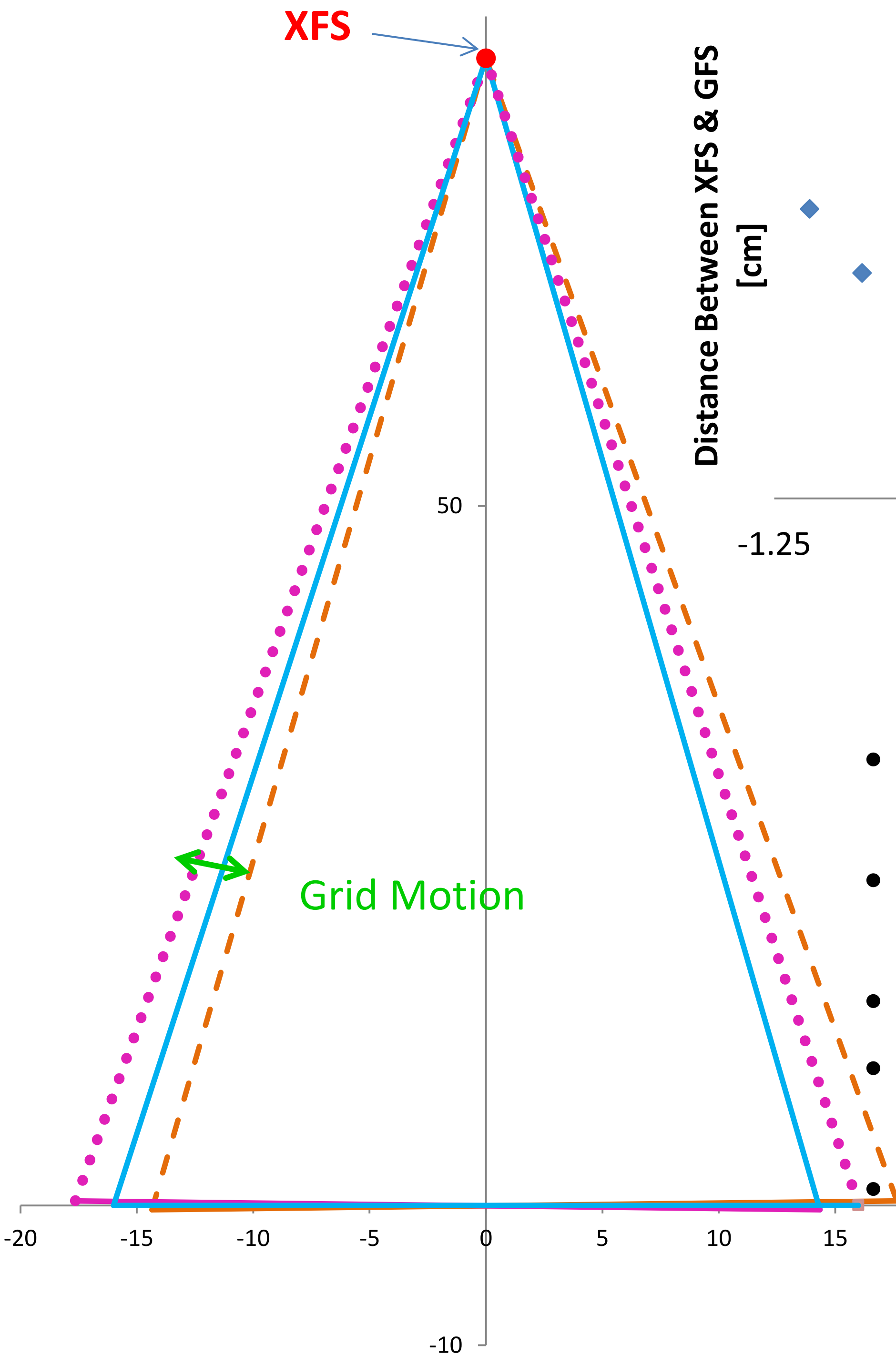


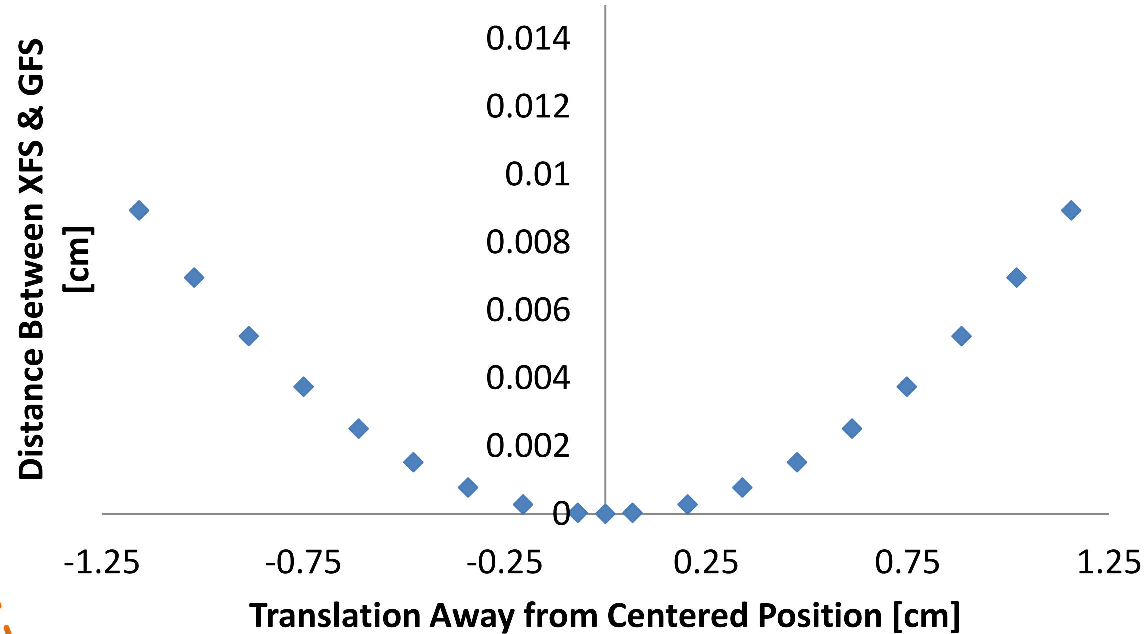
- Grid focal spot (GFS) is the single point in space to which all grid holes are pointing
- When placed correctly, the GFS is right on top of (XFS)
- Moving only side to side attenuates more primary photons



Ideal Trajectory

- Maximize primary transmission by keeping grid pointing towards XFS
- Ideal trajectory is where both XFS and GFS are always kept at the same point in space throughout motion
- →Results in circular trajectory of grid center with an 80 cm radius





- Room for translation is limited to 2.5 cm
- Taking leftmost point of grid – radius of circular trajectory is 83 cm
- Can approximate arc by straight line
- Move grid edge along line that is tangent to circle
- Relative reduction in intensity should be smaller than for translation only motion

- Obtain motor and evaluate image quality with tangent line trajectory of grid
- If significant improvement, order new final anti-scatter grid
- Synchronize grid motion with gantry motion
- Determine optimum velocity profiles for shortest scan time (acceleration between views?)
- Do phantom studies to evaluate image quality

Next Steps

Thank you!