Accumetra

Computational Approach to Validating Image Quality in A Screening Program

Ricardo S. Avila

June 13, 2016

Outline

- CT Lung Screening Protocol Challenge
- Challenge Methods
- Challenge Results & Findings

CT Lung Cancer Screening Protocol Challenge

- **Goal**
  - To quantitatively determine the most effective lung cancer screening CT scanners and protocols using an ultra-low cost, crowd-sourced approach.
  - In addition, to identify the best protocols for combined lung cancer and COPD screening.

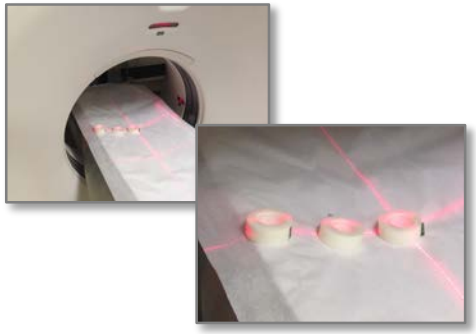
Free CT Image Quality Report

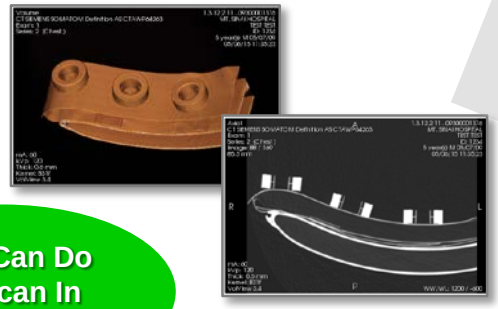
Can Be Replaced With Calibrated Object

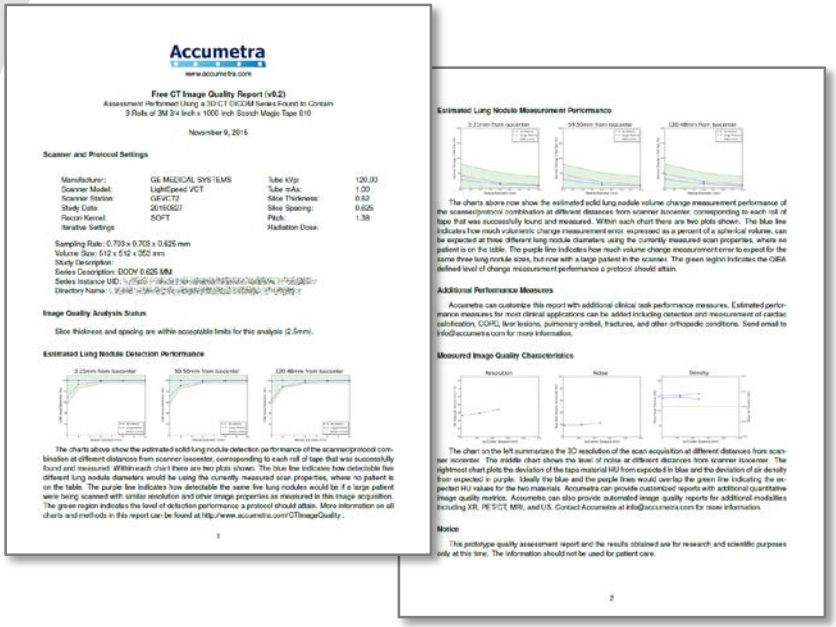
Accumetra.com

Email

Upload



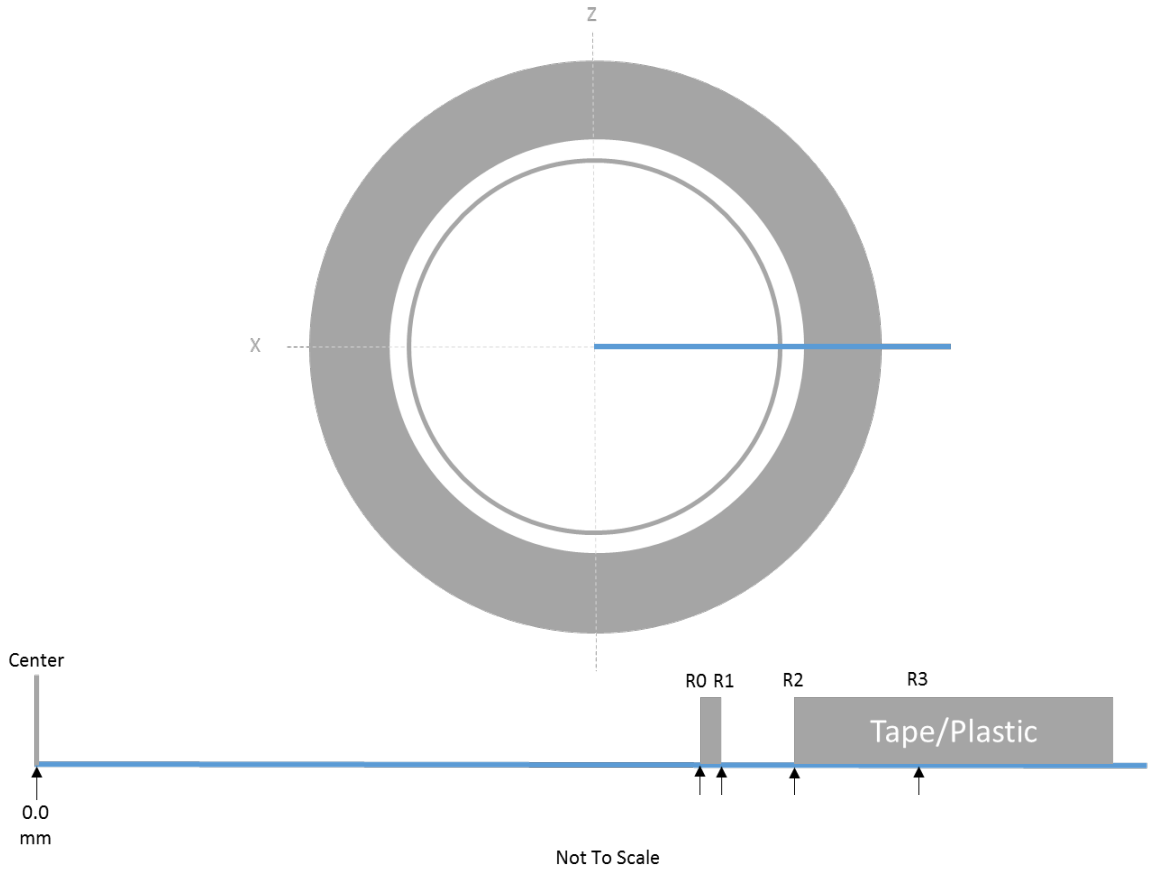




Tech Can Do The Scan In < 5 Minutes

3M Scotch Magic Tape

- Short Cylinders Have Multiple Geometric Advantages



- High Precision
- Low Cost ($1.33)
- Simple Geometry

Radiology Focused Image Quality Reports

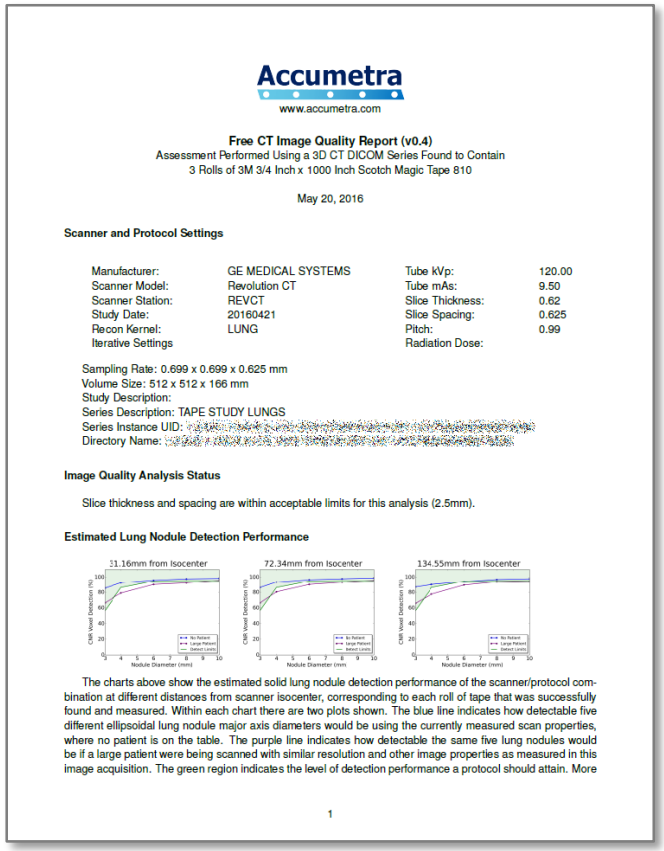
Protocol Settings

Analysis Status

Lung Nodule Detection

Lung Nodule Δ Measurement

Fundamental Properties



Accumetra
www.accumetra.com

Free CT Image Quality Report (v0.4)
Assessment Performed Using a 3D CT DICOM Series Found to Contain
3 Rolls of 3M 3/4 Inch x 1000 Inch Scotch Magic Tape 810

May 20, 2016

Scanner and Protocol Settings

Manufacturer:	GE MEDICAL SYSTEMS	Tube kVp:	120.00
Scanner Model:	Revolution CT	Tube mAs:	9.50
Scanner Station:	REVCT	Slice Thickness:	0.62
Study Date:	20160421	Slice Spacing:	0.625
Recon Kernel:	LUNG	Pitch:	0.99
Iterative Settings		Radiation Dose:	

Sampling Rate: 0.699 x 0.699 x 0.625 mm
Volume Size: 512 x 512 x 166 mm
Study Description:
Series Description: TAPE STUDY LUNGS
Series Instance UID:
Directory Name:

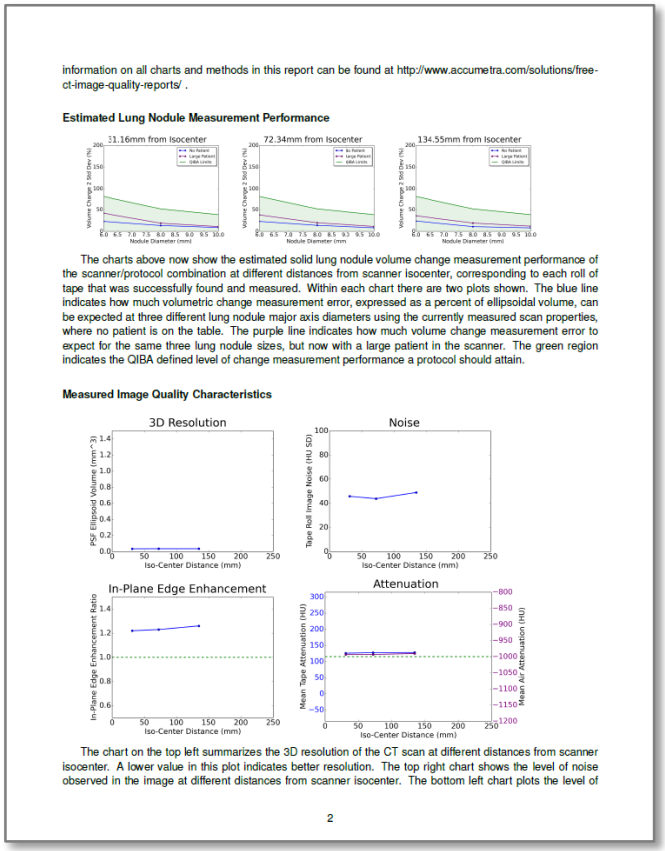
Image Quality Analysis Status

Slice thickness and spacing are within acceptable limits for this analysis (2.5mm).

Estimated Lung Nodule Detection Performance

The charts above show the estimated solid lung nodule detection performance of the scanner/protocol combination at different distances from scanner isocenter, corresponding to each roll of tape that was successfully found and measured. Within each chart there are two plots shown. The blue line indicates how detectable five different ellipsoidal lung nodule major axis diameters would be using the currently measured scan properties, where no patient is on the table. The purple line indicates how detectable the same five lung nodules would be if a large patient were being scanned with similar resolution and other image properties as measured in this image acquisition. The green region indicates the level of detection performance a protocol should attain. More

1



information on all charts and methods in this report can be found at http://www.accumetra.com/solutions/free-ct-image-quality-reports/ .

Estimated Lung Nodule Measurement Performance

The charts above now show the estimated solid lung nodule volume change measurement performance of the scanner/protocol combination at different distances from scanner isocenter, corresponding to each roll of tape that was successfully found and measured. Within each chart there are two plots shown. The blue line indicates how much volumetric change measurement error, expressed as a percent of ellipsoidal volume, can be expected at three different lung nodule major axis diameters using the currently measured scan properties, where no patient is on the table. The purple line indicates how much volume change measurement error to expect for the same three lung nodule sizes, but now with a large patient in the scanner. The green region indicates the QIBA defined level of change measurement performance a protocol should attain.

Measured Image Quality Characteristics

The chart on the top left summarizes the 3D resolution of the CT scan at different distances from scanner isocenter. A lower value in this plot indicates better resolution. The top right chart shows the level of noise observed in the image at different distances from scanner isocenter. The bottom left chart plots the level of

2

Team

- Accumetra
  - Challenge Leadership
  - Image Assessment Technology
- Prevent Cancer Foundation
  - National Cancer Patient Advocacy
  - Lung Cancer Workshop XIII
- Lung Cancer Alliance
  - National Cancer Patient Advocacy
  - > 300 Framework Sites
- I-ELCAP
  - Largest Ongoing International Lung Cancer Screening Study
- COPD Foundation
  - National COPD Patient Advocacy

Challenge Schedule

- April – May 31 CT Data Submission
- June 1 – 10 Data Analysis & Review
- June 13 LCW XIII Results Presentation
- ~August 1 Manuscript Submission

Challenge Methods

Lung Nodule Volumetric Error

Patient Characteristics

1. Lesion Size
2. Lesion Margin
3. Patient Size
4. Attachment
5. Local Conditions
6. High HU Objects
7. Metal Implants
8. Motion
9. …

Scan Specification

1. Detector Rows
2. mAs
3. kVp
4. Slice Thickness
5. Recon Kernel
6. Iterative Recon
7. Dual Source
8. Auto mA & kVp
9. …

CT Acquisition

Acquired Images

Semi-Automated Software

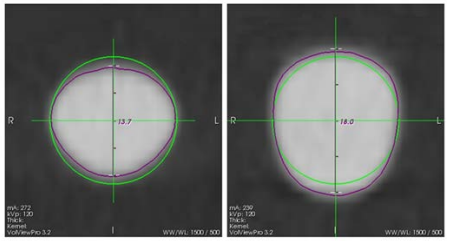
Detection & Measurement

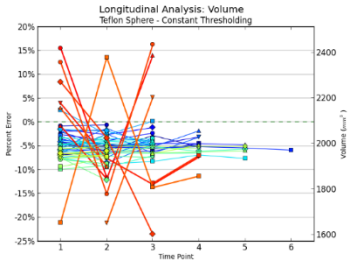
Challenges

1. Internal Structures
2. Large Complex Borders
3. Changing Presentation
4. Very Large Patients

Issues

1. Large & Growing # Parameters
2. Constantly Changing
3. Operator Preferences/Errors
4. Difficult to Fully Reproduce





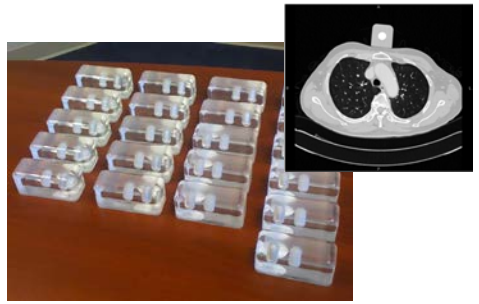
1 Object

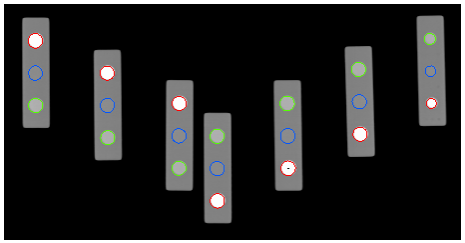
2 Scanner

3 Software

Volumetric Performance

Estimating The Scanner Model





1 Object → 2 Scanner

Precisely Made Real Object

- Background Material
- Foreground Material
- Shape Geometry

→ 1 →

Real Scanner

1. Sampling Rate
2. Position
3. Orientation
4. Background Density
5. Foreground Density
6. Image Noise
7. 3D PSF

→ 1 → Real Images

Virtual Object

- Background Material
- Foreground Material
- Shape Geometry

→

Optimizer

Virtual Scanner

1. Sampling Rate
2. Position
3. Orientation
4. Background Density
5. Foreground Density
6. Image Noise
7. 3D Gaussian PSF

→ Simulated Images → RMSE

→ Optimizer

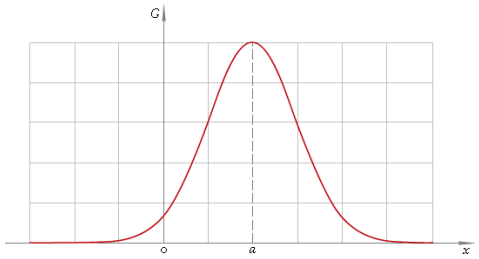
Image Quality Characteristics

- CT Image Quality
  - 3D Resolution (3D PSF)
  - Image Noise (HU SD)
  - Edge Enhancement (Ratio)

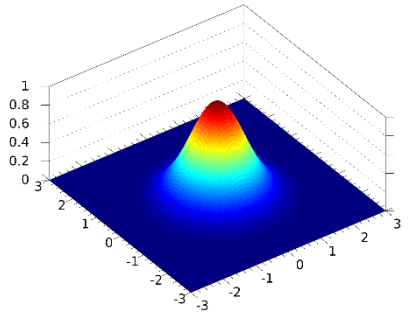
- These Metrics Are Evaluated Across The CT Table FOV Using 3 Rolls of Tape
  - Averaging used for comparisons

Resolution: 3D PSF Sigma Ellipsoid Volume

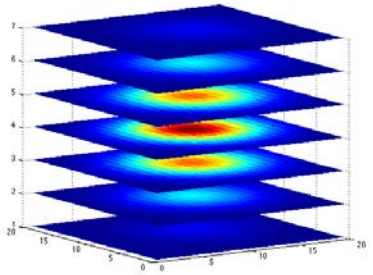
1D Gaussian



2D Gaussian

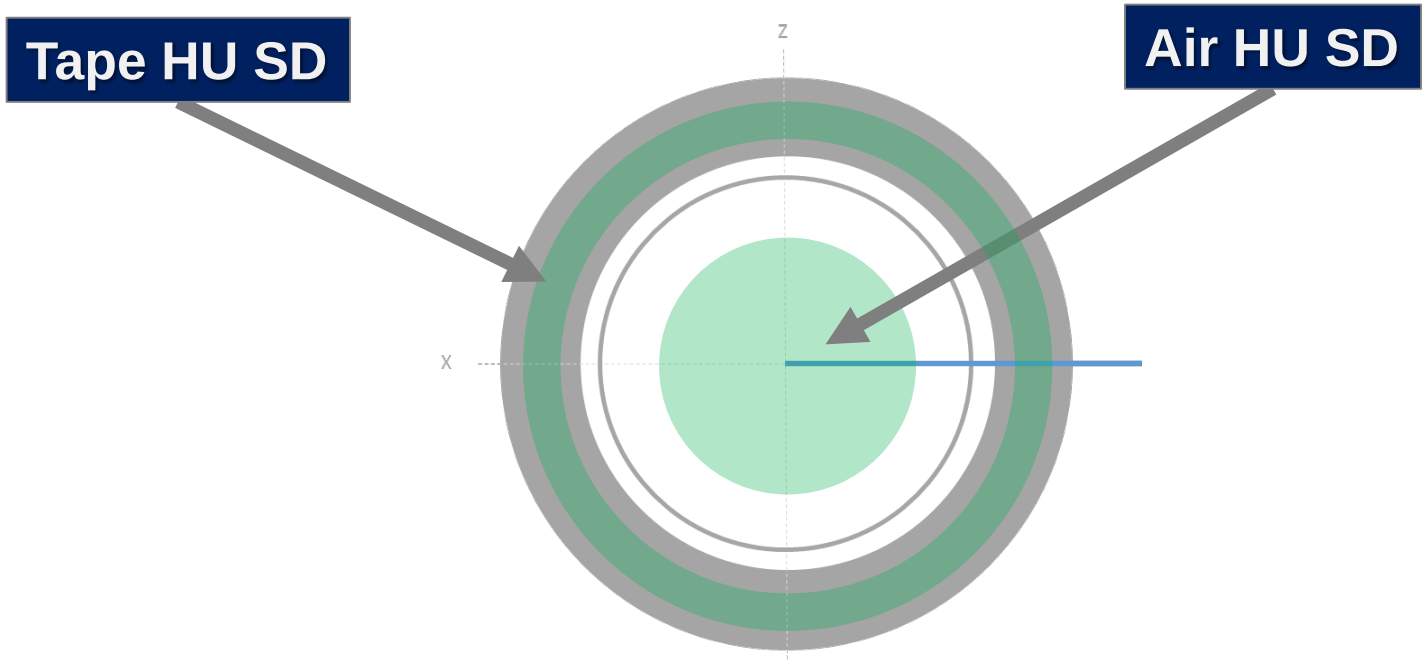


3D Gaussian

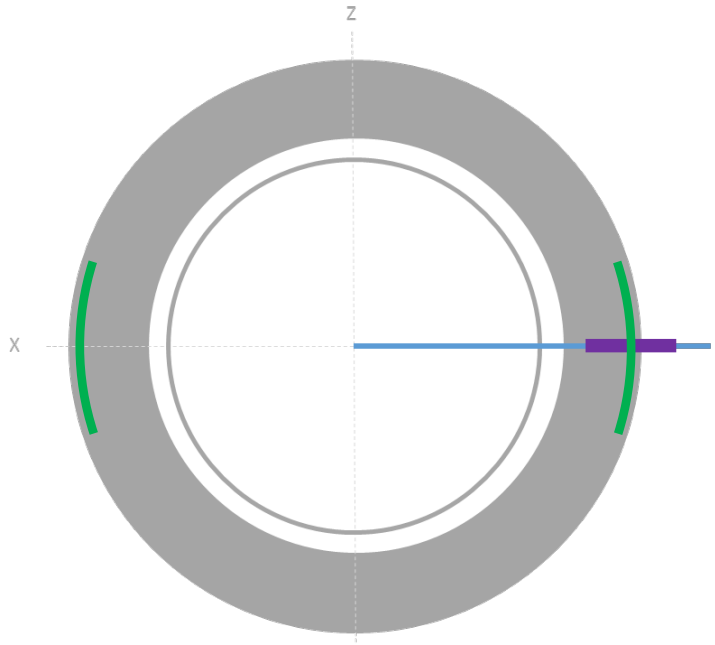


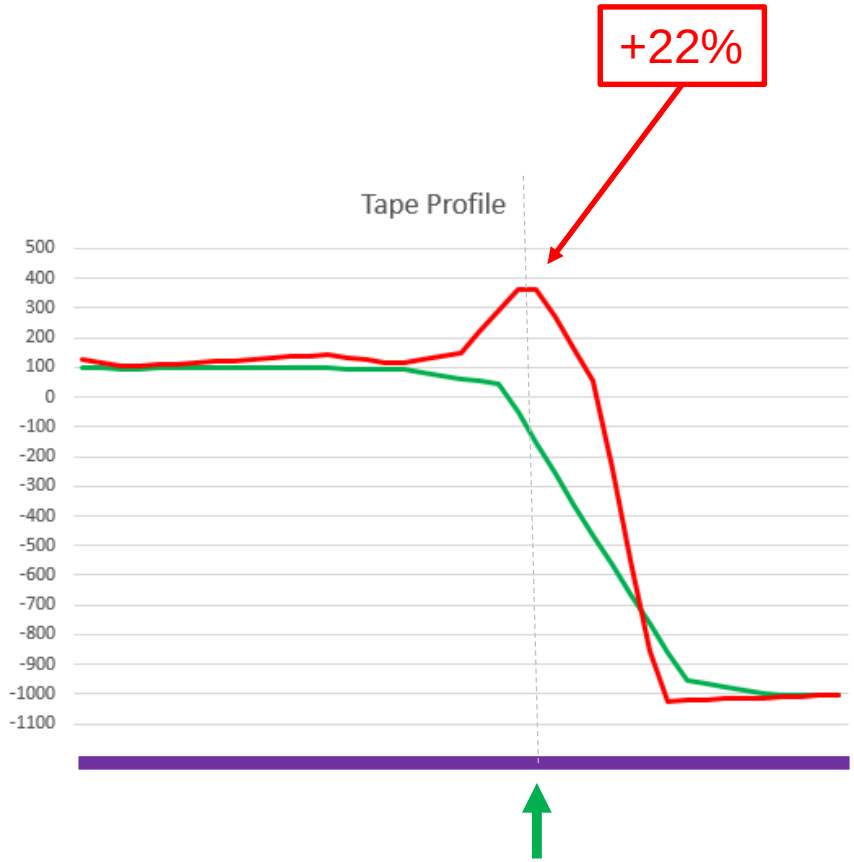
3D Gaussian PSF along with sampling rate represents the resolution of the system

Measuring Image Noise

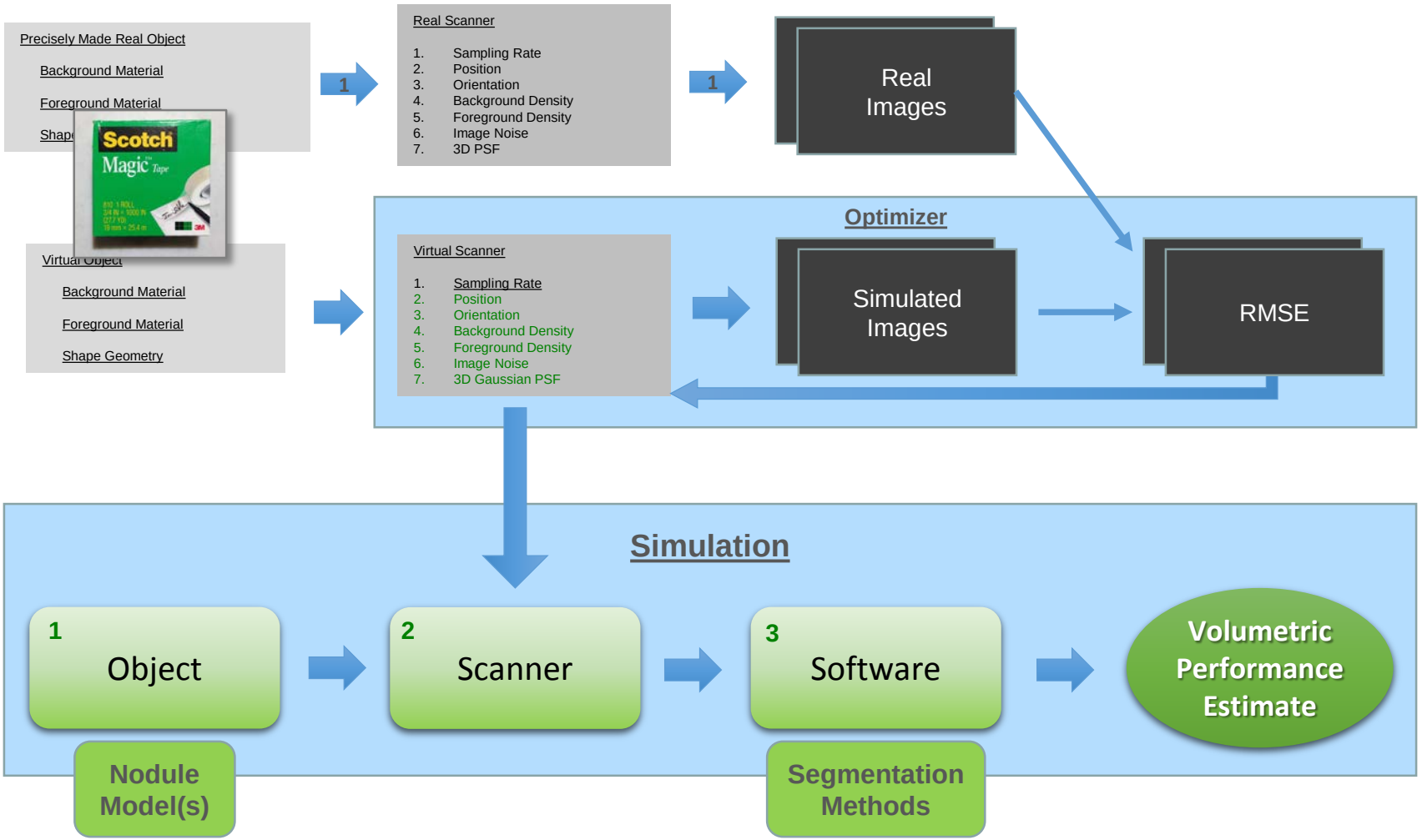


Measuring In-Plane Edge Enhancement





Estimating Scanner/Protocol Performance



Ellipsoid Scanning Simulation

Simulated Object

Object Contrast	Object Position	Object Orientation
215 HU	Any	Any

Object Size

4.0 mm x 3.0 mm x 2.25 mm	6.0 mm x 4.5 mm x 3.375 mm	8.0 mm x 6.0 mm x 4.50 mm	10.0 mm x 7.50 mm x 5.625 mm	12.0 mm x 9.00 mm x 6.75 mm

Simulated Scanner

CT Linearity	Resolution (PSF σ)	Sampling Rate	Noise
Perfect	0.798 x 0.798 x 0.697	0.89 x 0.89 x 1.25	40 HU SD

Simulated Images

Challenge Results & Findings

Challenge Data Analysis Panel

• Rick Avila	Accumetra
• Heather Chen-Mayer	NIST
• Nick Petrick	FDA
• Sheila Ross	Lung Cancer Alliance
• David Yankelevitz	Mount Sinai
• Gudrun Zahlmann	Roche

Disclaimer

General

- This information presented here is preliminary data that needs further review, validation, and study. The initial findings presented here may need to be revised over time.

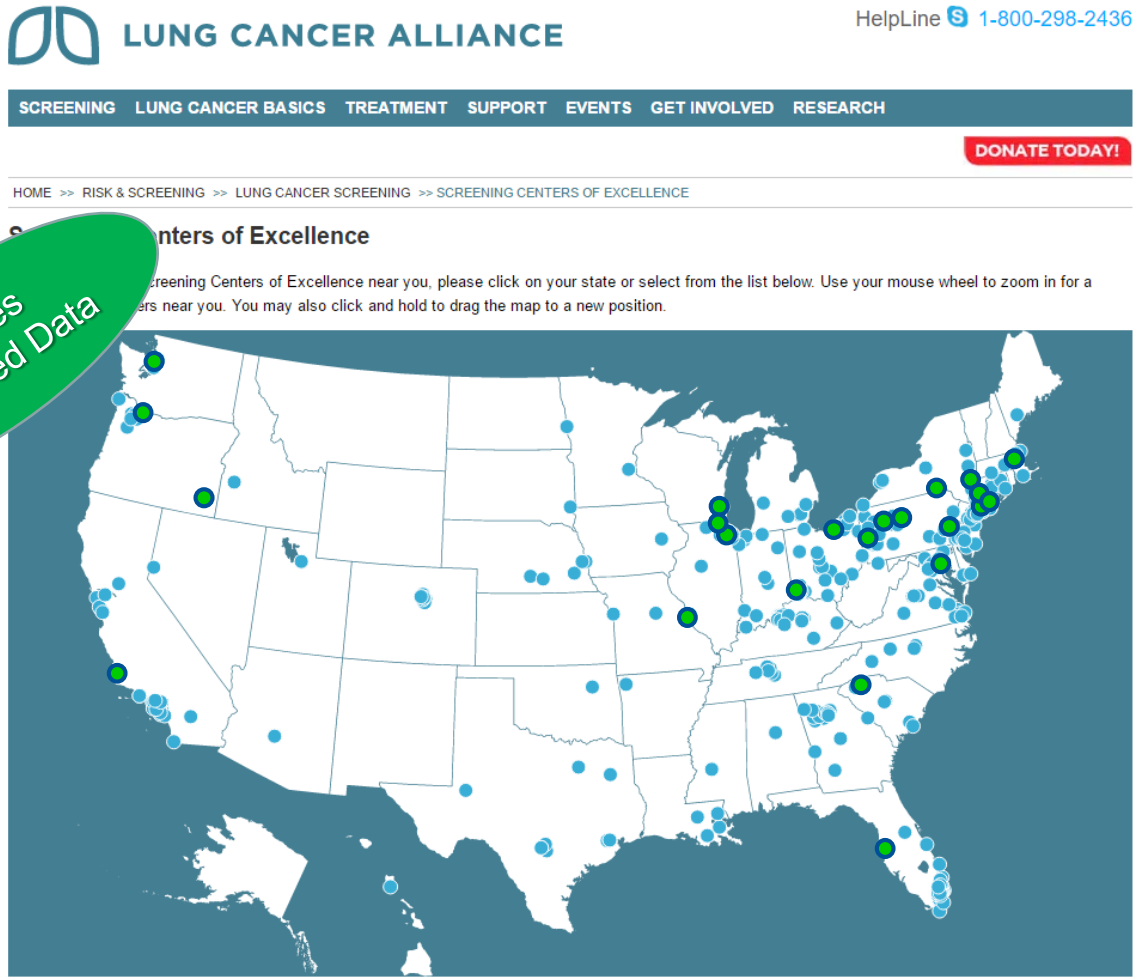
FDA

- The mention of commercial products, their sources, or their use in connection with materials reported herein is not to be construed as either an actual or implied endorsement of such products by the Department of Health and Human Services.

NIST

- Any mention of commercial products within this document is for information only; it does not imply recommendation or endorsement by NIST.

CT Scanning Site Participants



26 Sites Submitted Data

- China
- Spain (2)
- Israel

Fully Automated Measurements

Fundamental Image Quality Metrics

- **CT Linearity**
  - Air, Tape
- **3D Gaussian PSF**
  - X, Y, Z Sigma
- **Sampling Rate**
  - X, Y, Z Distance
- **Image Noise**
  - Tape HU SD
- **Edge Enhancement**
  - Max Mean Edge HU / Mean Tape HU

Estimated Clinical Task Metrics

- **Small Nodule Detection**
  - 3, 4, 6, 8 10 mm ellipsoids
- **Small Nodule Change Measurement**
  - 4, 6, 8, 10 mm ellipsoids

Data Analysis Steps

1. Remove highly edge enhancing reconstruction kernels

2. Separate into requested slice thickness and spacing categories

3. Review 3 tape points in resolution vs noise space

4. Review 3 tape points in detection and change measure space

Future Analysis

CT Scanners (26 sites)

GE (19% = 10/53)	BrightSpeed8	8	1
	LightSpeed VCT	64	5
	Discovery CT750 HD	128	2
	Revolution CT	256	2
Siemens (50% = 27/53)	Sensation 16	16	2
	Biograph40	40	1
	Sensation64	64	4
	SOMATOM Definition	64	4
	SOMATOM Definition AS	40, 64, 128	6
	SOMATOM Definition AS+	128	4
	Definition AS+ 128	128	1
	Definition Edge 128	128	1
	SOMATOM Definition Flash	256	4
Philips (23% = 12/53)	Brilliance64	64	4
	IngenuityCT	128	5
	iCT 256	256	3
Toshiba (8% = 4/53)	Aquilion	64	1
	Aquilon ONE	320	3
4 Manufacturers	18 Models		53 CT Scanners

CT Lung Screening Protocol Guidelines

	CT Acquisition			
	Detectors >=	Thickness <=	Spacing <=	Kernel
2016 RSNA/QIBA Small Nodule Profile (19% to 42%)	16	1.25	1.25	Highest Res.
2016 I-ELCAP Guidelines	64	1.25	1.25	Highest Res.
2015 European Society of Radiology	16	1.0	0.7	No Pref.
2015 American College of Radiology (10 Pillars Publication)	16	2.5, 1.0 pref.	No Pref.	No Pref.
2016 AAPM Lung Cancer Screening Protocols	16	2.5, 1.0 pref.	2.5, 1.0 pref.	Range Not Easy

Our Specification: >= 16 detector rows, <=1.25 thickness , <=1.25 spacing

Detection Slice Thickness & Recon Kernel

Need to Verify With Sites

Slice Thickness	Sites	Low	Medium	High
<= 0.625	4 (15%)	0	3	1
0.8, 1.0, 1.25	12 (46%)	6	2	4
>= 1.5	10 (38%)	6	3	1

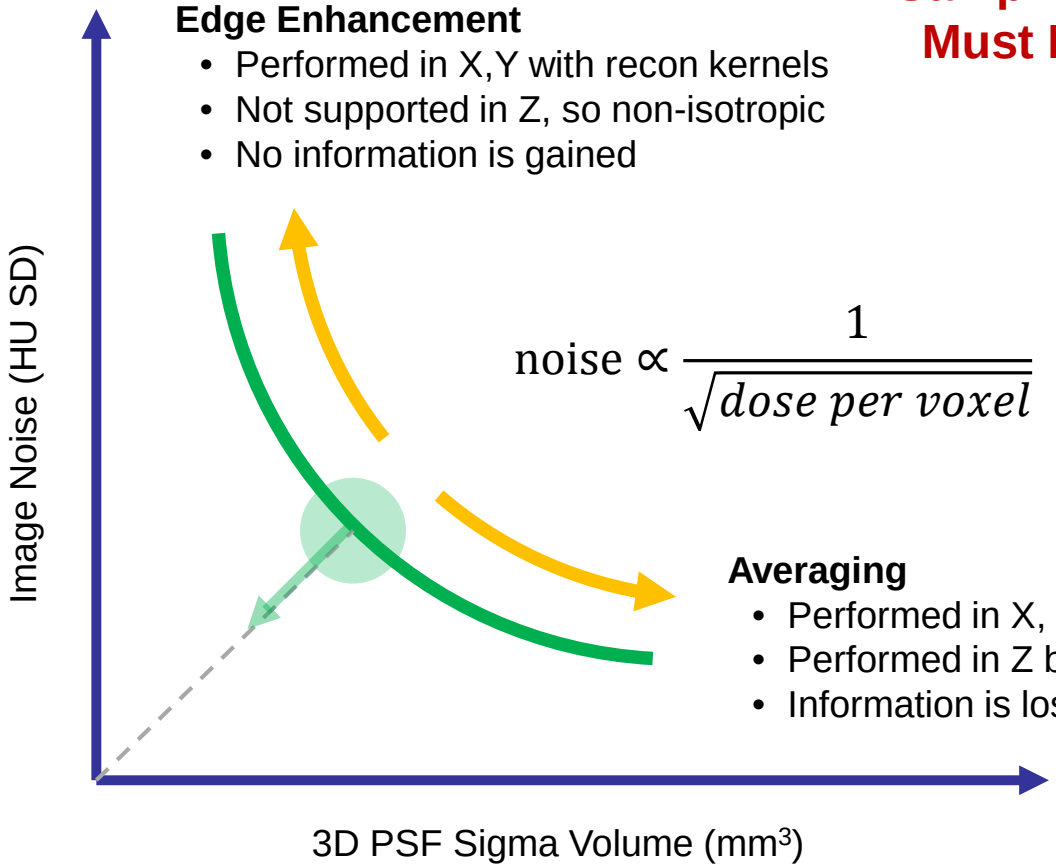
3 used 2mm ST & 1mm spacing

Resolution vs Noise

Edge Enhancement

- Performed in X,Y with recon kernels
- Not supported in Z, so non-isotropic
- No information is gained

Sampling Rate Also Matters Must Be Compatible With Resolution



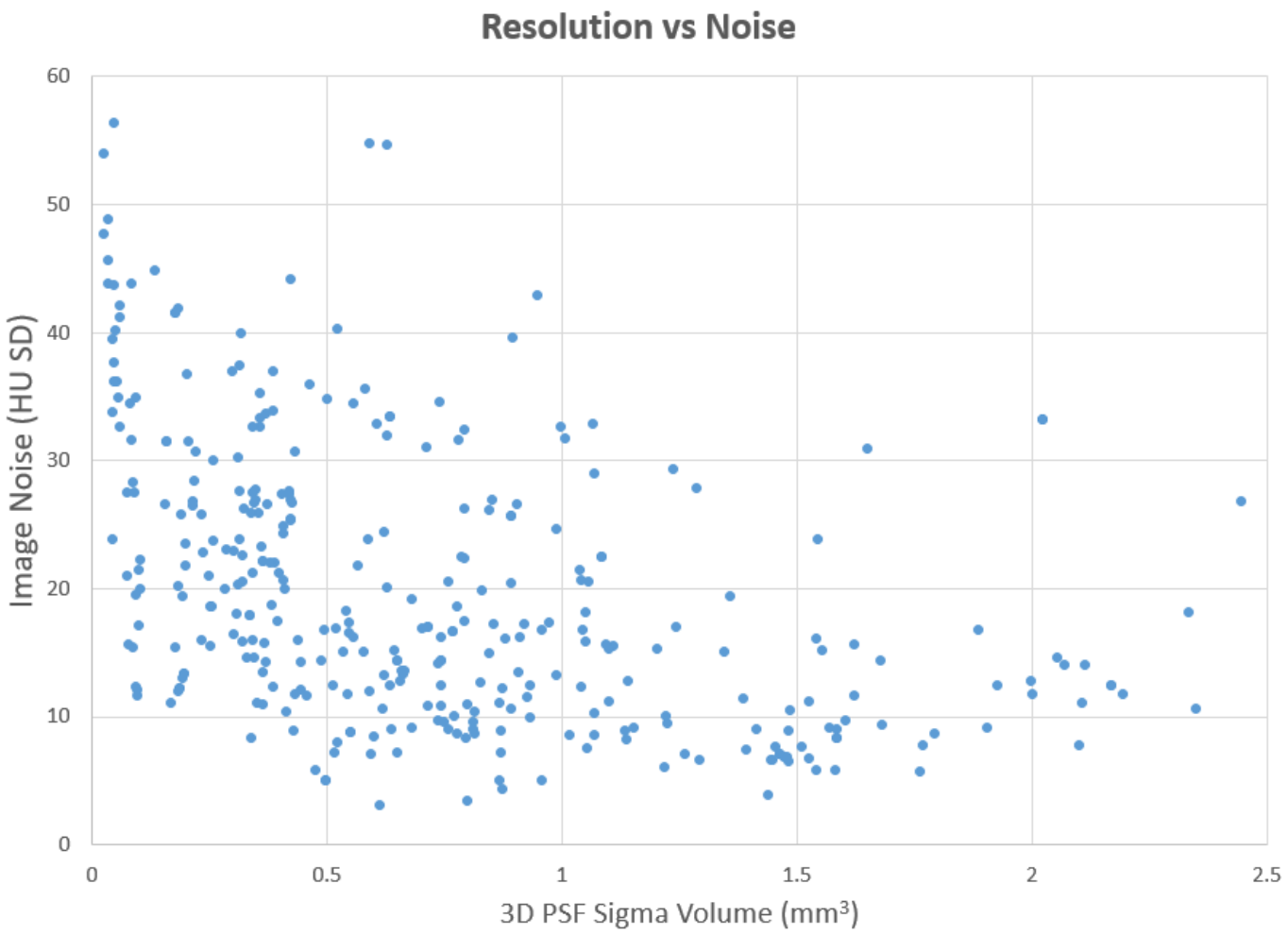
$$\text{noise} \propto \frac{1}{\sqrt{dose\ per\ voxel}}$$

Averaging

- Performed in X, Y by recon kernels
- Performed in Z by slice thickness
- Information is lost

Dose Normalization Is Needed (mAs)

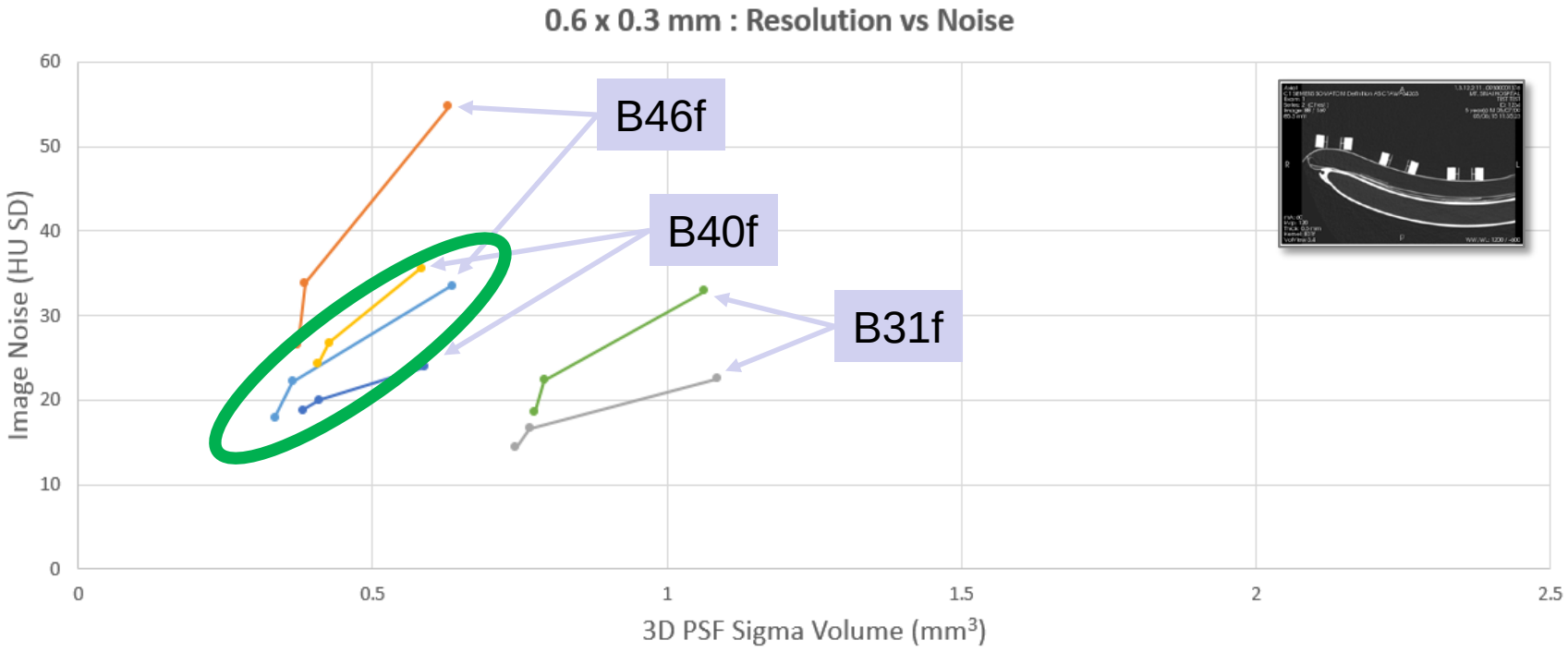
Step 0: Assemble All Data



Step 1: Remove Edge Enhancing Kernels
Step 2: Separate Into Relevant Slice Thicknesses

Step 3: Review 3 Tape Points
0.6 mm Slice Thickness x 0.3mm Slice Spacing

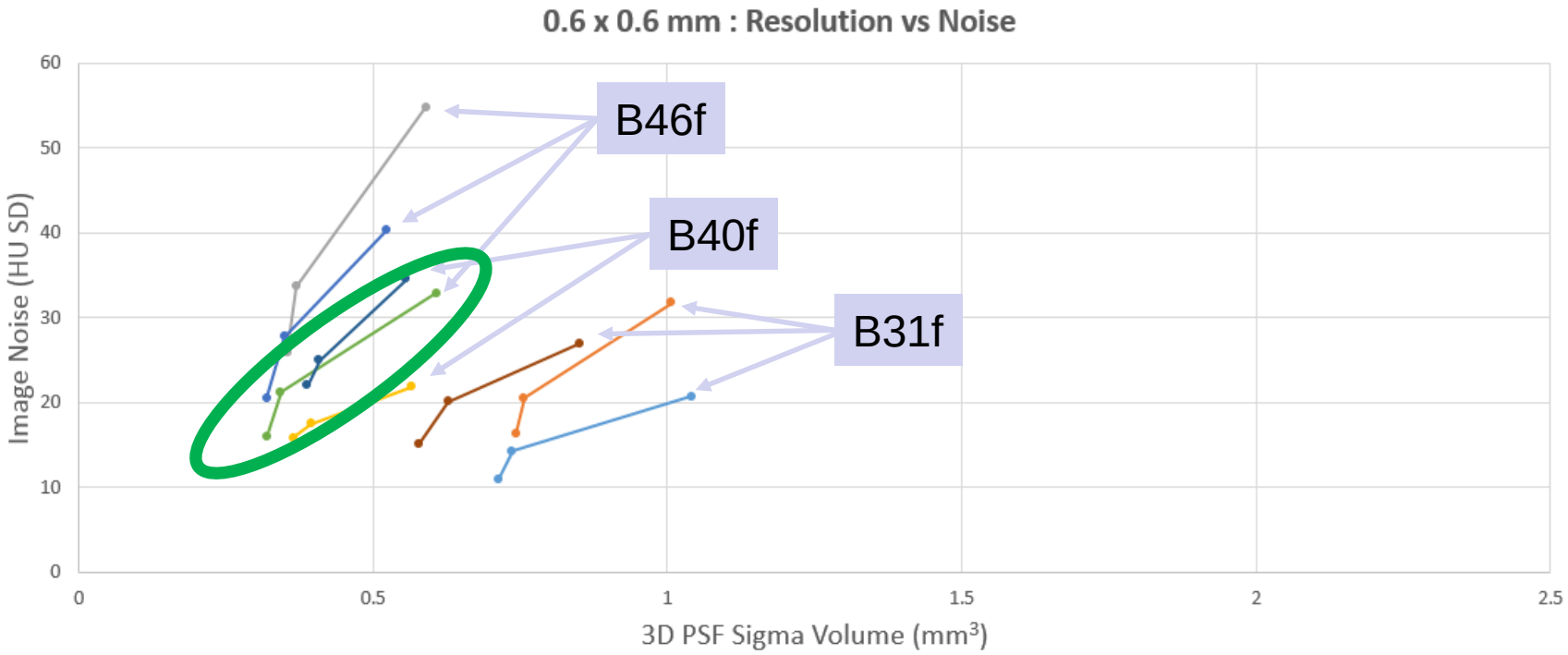
1000 Slices!
Outside Guidelines



All Data from One **Siemens SOMATOM Definition** CT Scanner
Pitch 0.8, 0.5s/rotation, 120 kVp, 21 or 64 mA

Step 3: Review 3 Tape Points
0.6 mm Slice Thickness x 0.6mm Slice Spacing

500 Slices!

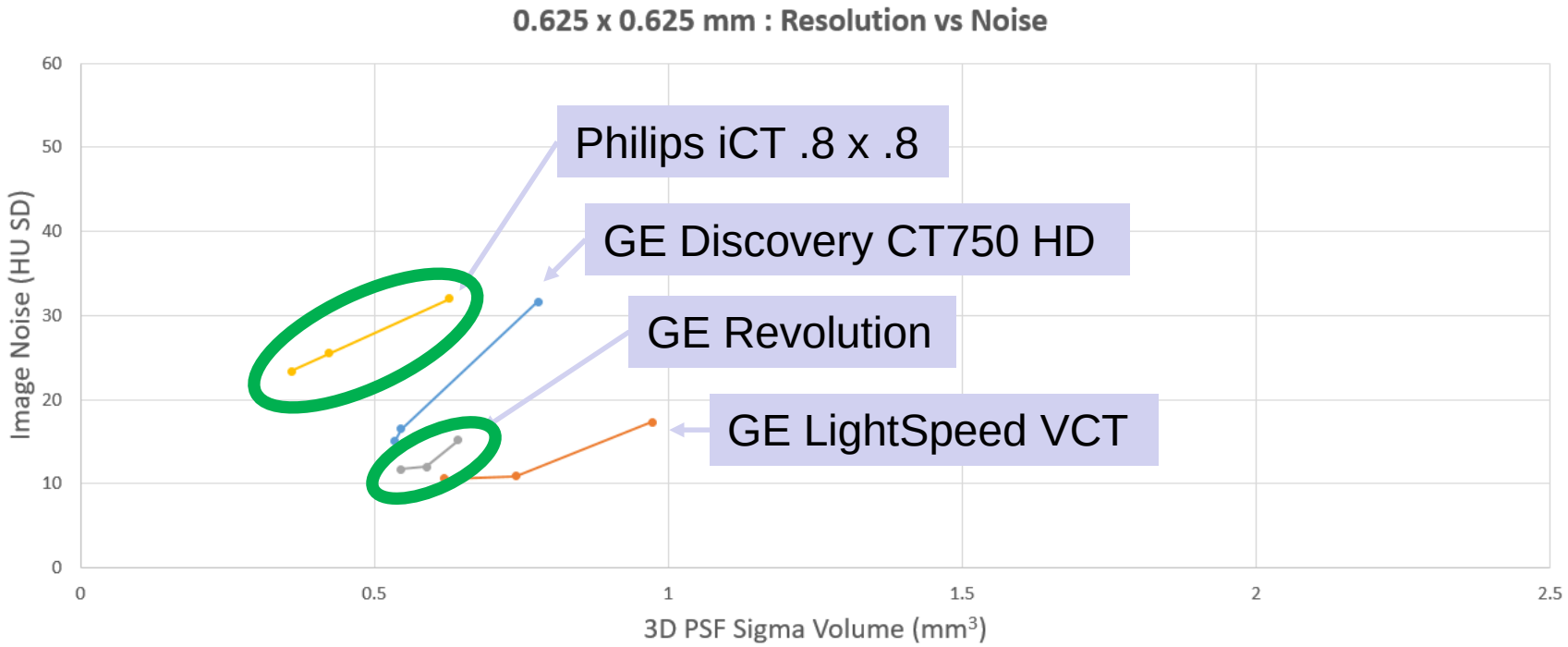


All Data from One **Siemens SOMATOM Definition** CT Scanner
Pitch 0.8, 0.5s/rotation, 120 kVp, 21 or 64 mA

AND a **Biograph40** with a Similar Protocol Except Pitch = 1.2

Step 3: Review 3 Tape Points
.625 mm Slice Thickness x .625 mm Slice Spacing

480 to 375 Slices!

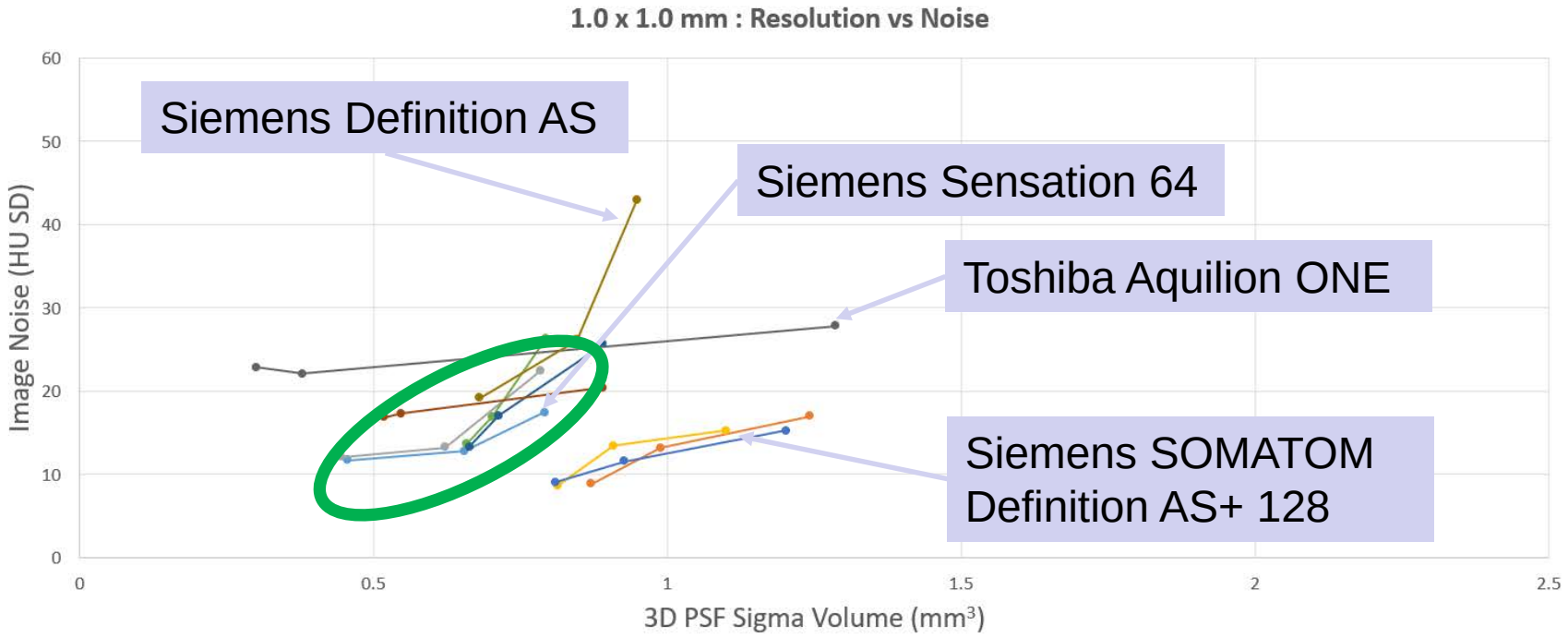


Best data so far from a **GE Revolution** CT Scanner
Pitch 1, 0.5s/rotation, 120 kVp, 19 mA, STANDARD kernel

AND a **Philips iCT** with a Similar Protocol Except 0.827 s/rot, F Kernel

Step 3: Review 3 Tape Points
1.0 mm Slice Thickness x 1.0 mm Slice Spacing

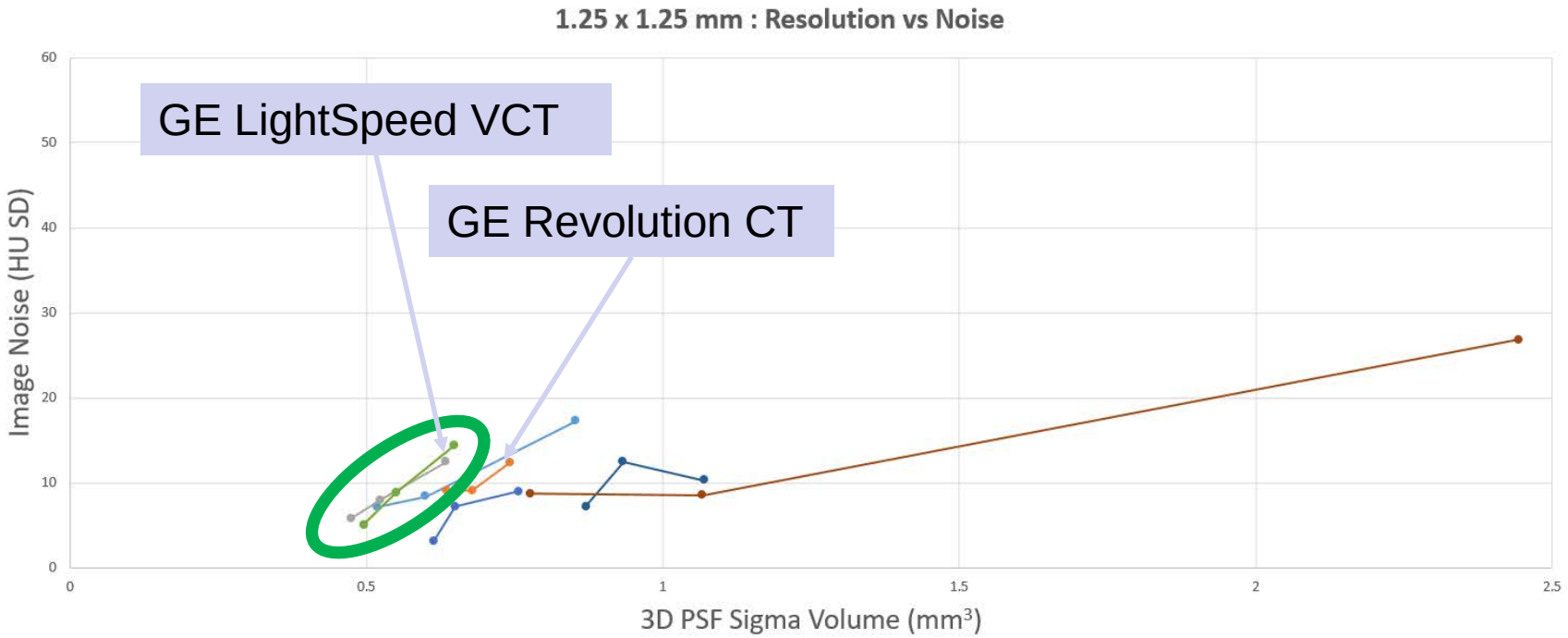
300 Slices



Best data so far from a **Siemens Sensation 64** CT Scanner
Pitch 1, 0.5s/rotation, 120 kVp, 70 mA, B31f kernel

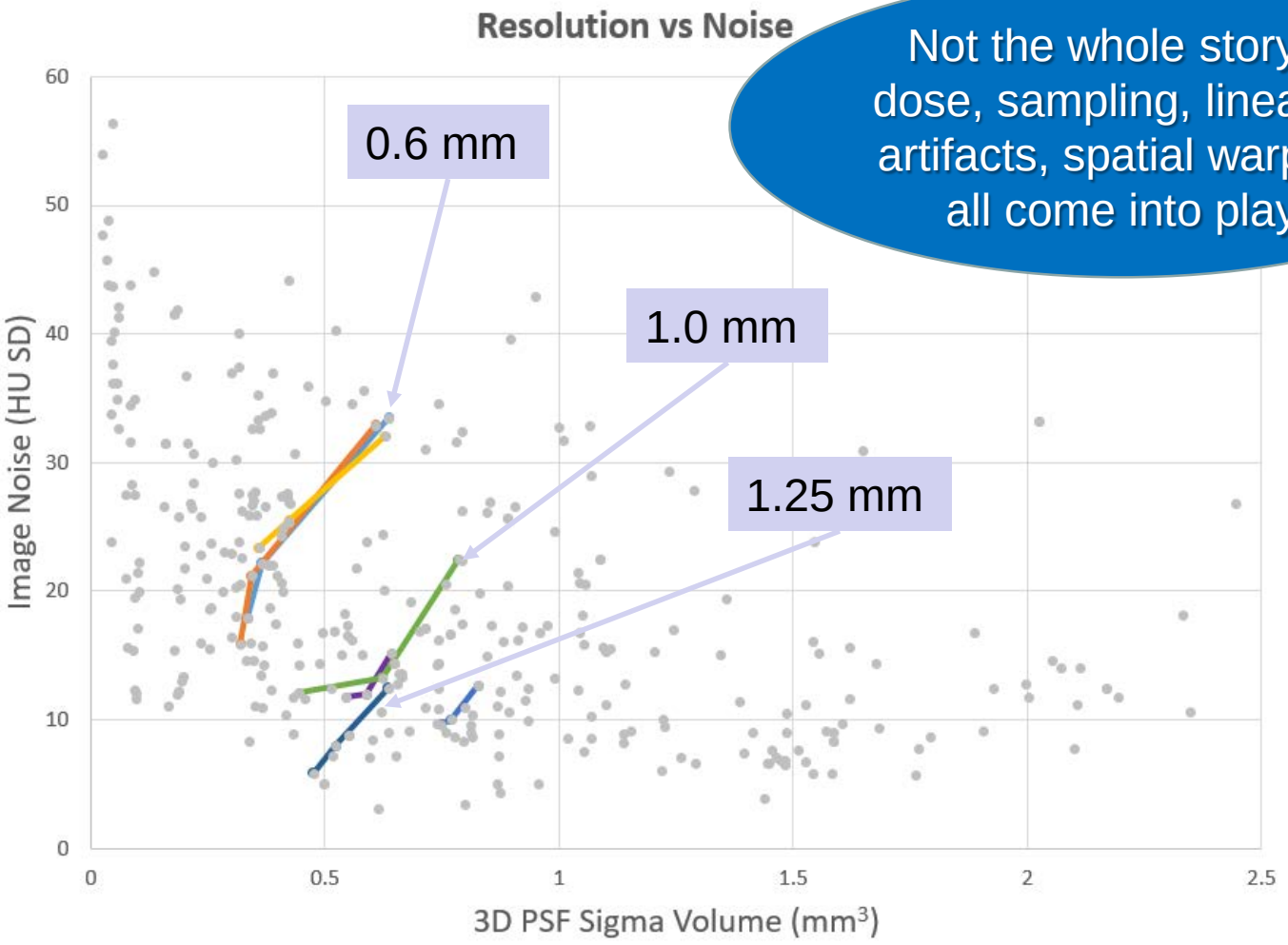
Step 3: Review 3 Tape Points
1.25 mm Slice Thickness x 1.25 mm Slice Spacing

240 Slices



Best data so far from **GE LightSpeed VCT** CT Scanners
Pitch 1, 0.5s/rotation, 120 kVp, 50 mA, STANDARD kernel

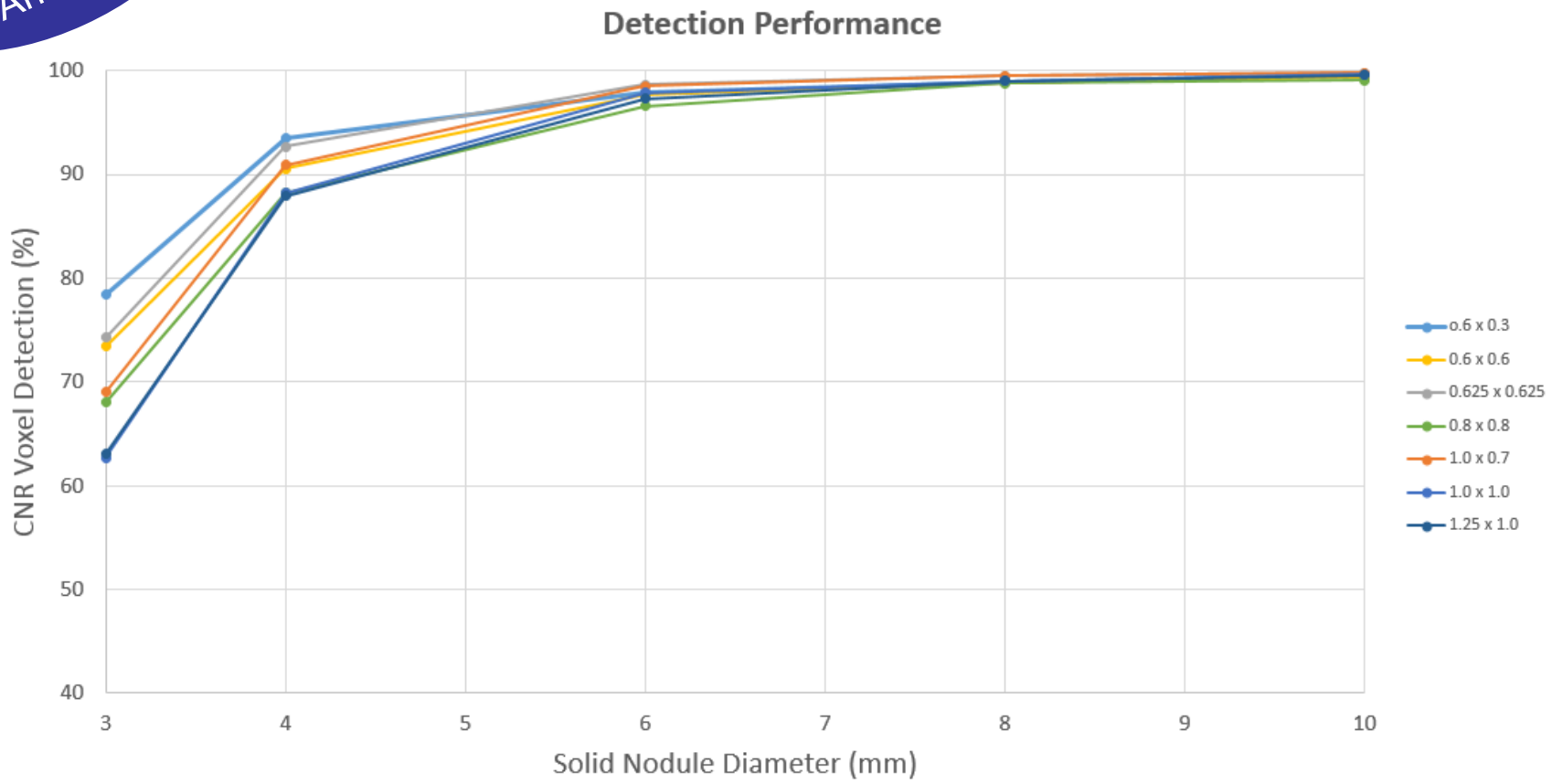
Step 3: Review 3 Tape Points



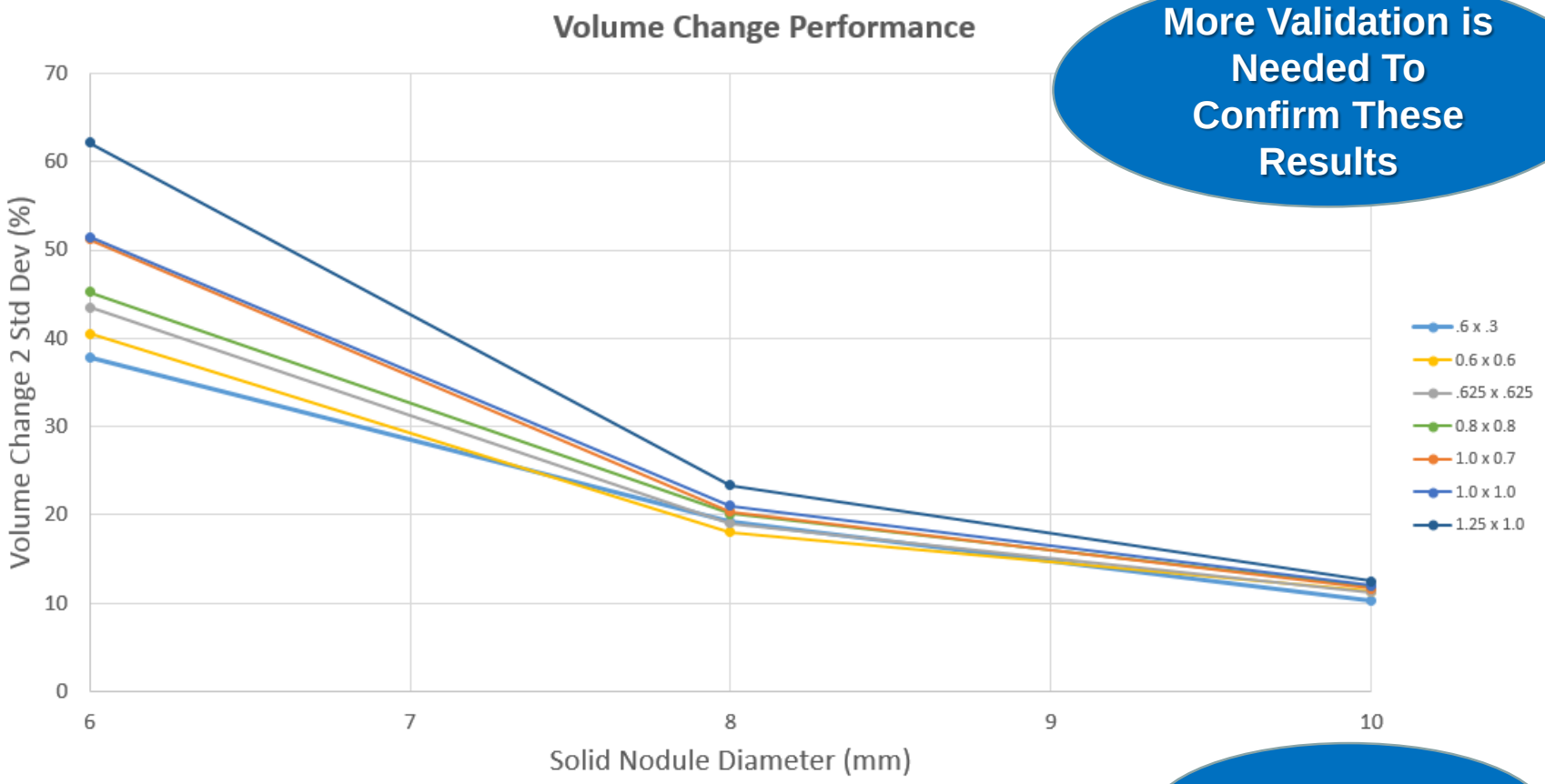
Not the whole story – dose, sampling, linearity, artifacts, spatial warping all come into play

Step 4: Review Clinical Detection Task Estimates

For Future Analysis



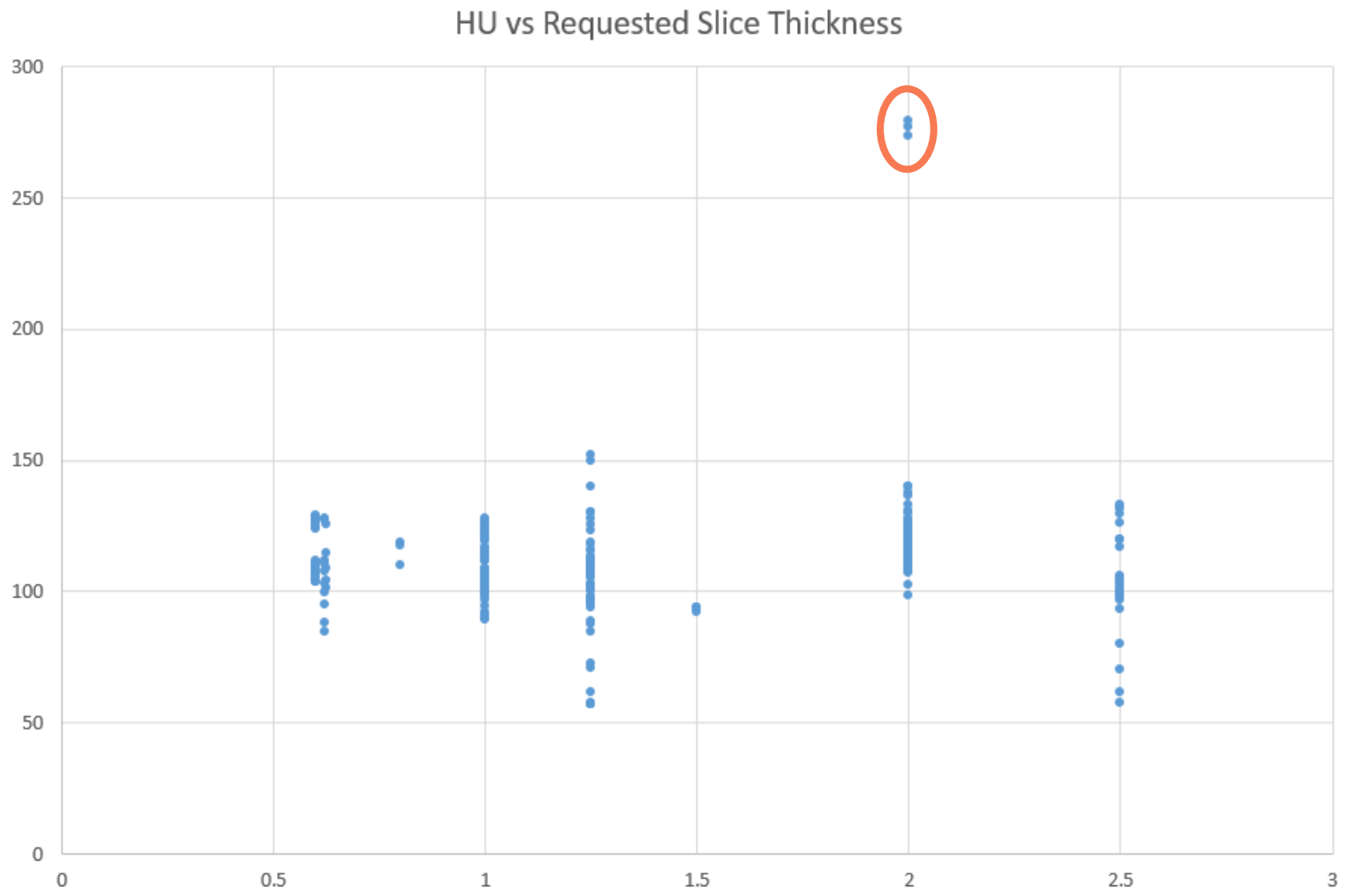
Step 4: Review Clinical Volume Change Measure Estimates



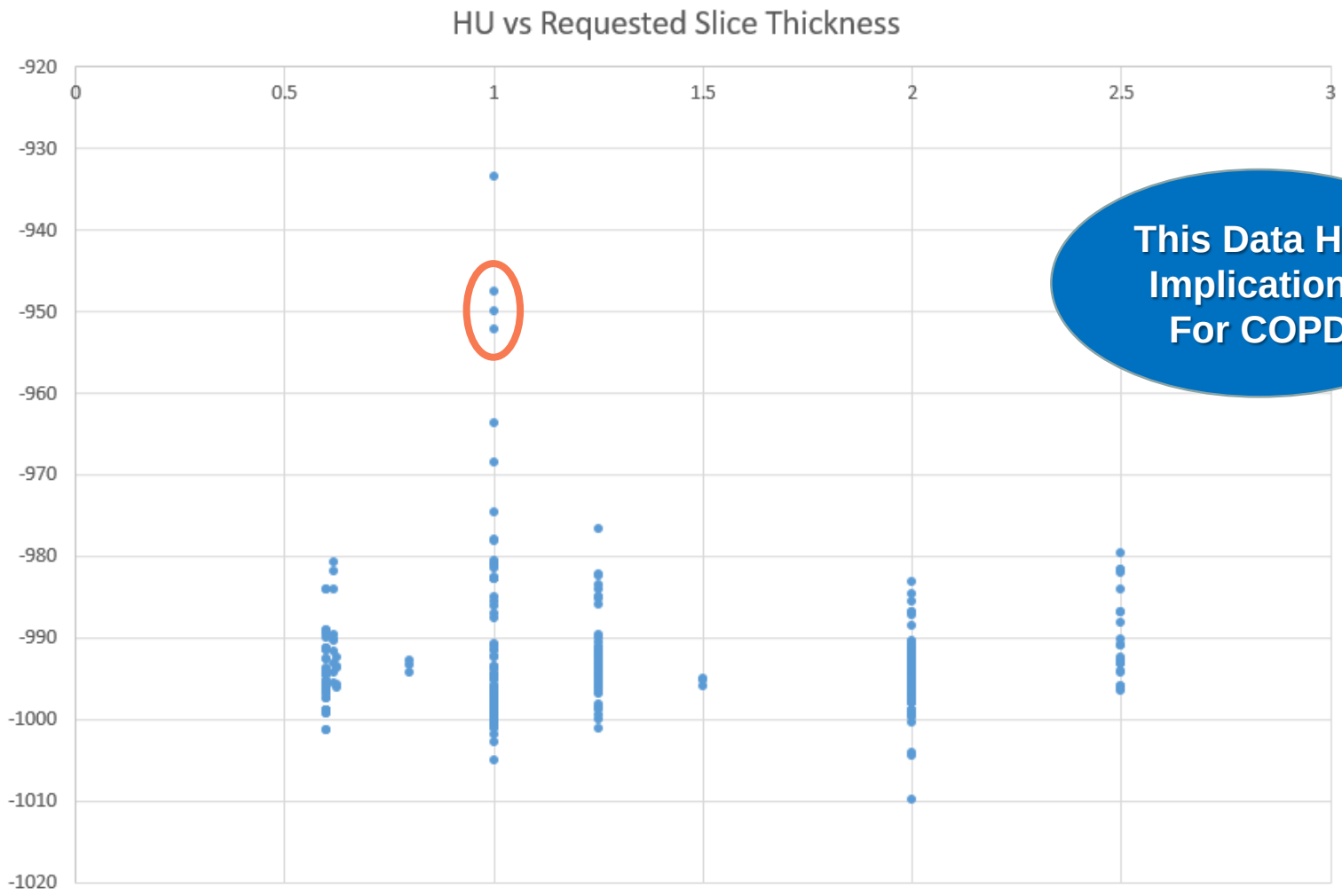
More Validation is Needed To Confirm These Results

1024 x 1024

Future: HU Stability - Tape



Future: HU Stability - Air



Recommendation Recommendation

- Proposal
  - Always acquire at least 2 CT series
    1. A high resolution CT scan for CAD/quantitative imaging/Radiomics purposes
    2. A retrospective reconstruction for individual radiologist preferences

Challenge Results & Findings

- We Have A New Low Cost Approach For Measuring and Monitoring CT Imaging Performance
  - With The Potential for Constantly Updated Protocol Guidance
- Many Scanners and Protocols Are Capable of Reaching Guidelines But Many Sites Are Choosing Not To Do It
- We Need More Contributed Data For Individual Slice Thickness Analysis To Arrive at Best Scanners/Protocols
- As Screening Sites Achieve Guidelines And Use Better Scanning Protocols The Data and Statistics Will Improve

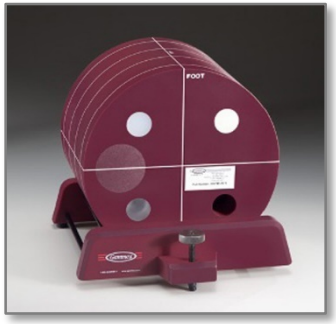
Challenge Results & Findings

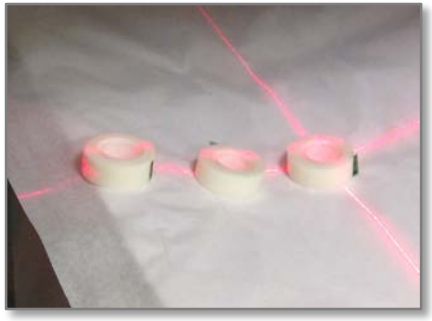
- Multiple Opportunities To Improve Performance
  - All Scanners Need to Support
    - Simple and Accurate DICOM Reported mAs Values
    - 1024 x 1024 Matrix Size
  - Each Current Scanner Model Can Be Further Optimized
    - Better Kernel Guidance Can Be Quickly Provided
    - Slice Thickness Is A Big Issue – Need to Address
  - Some Protocols Should Be Avoided
  - Maintaining High Performance Over Full FOV is Challenging

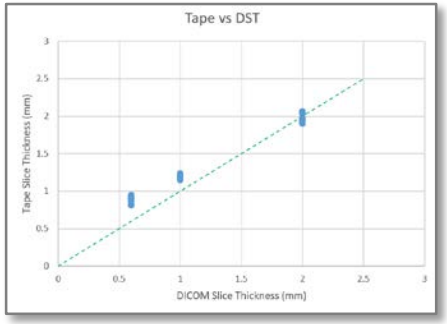
Thank You

Validation Studies

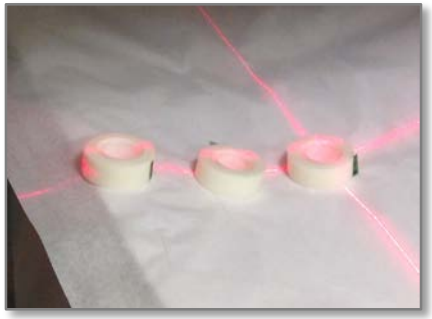
- ACR Phantom and Tape Comparison

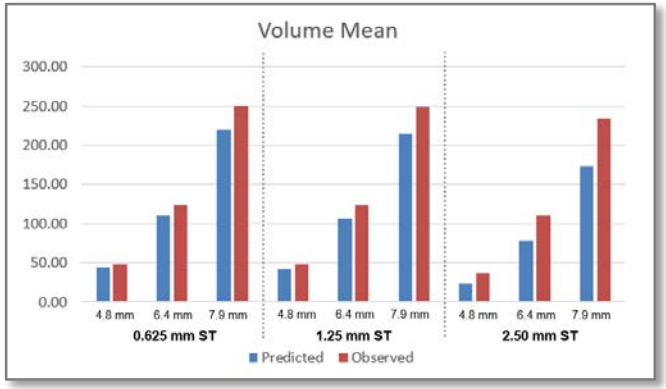






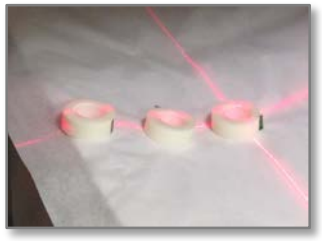
- Clinical Task Prediction Performance



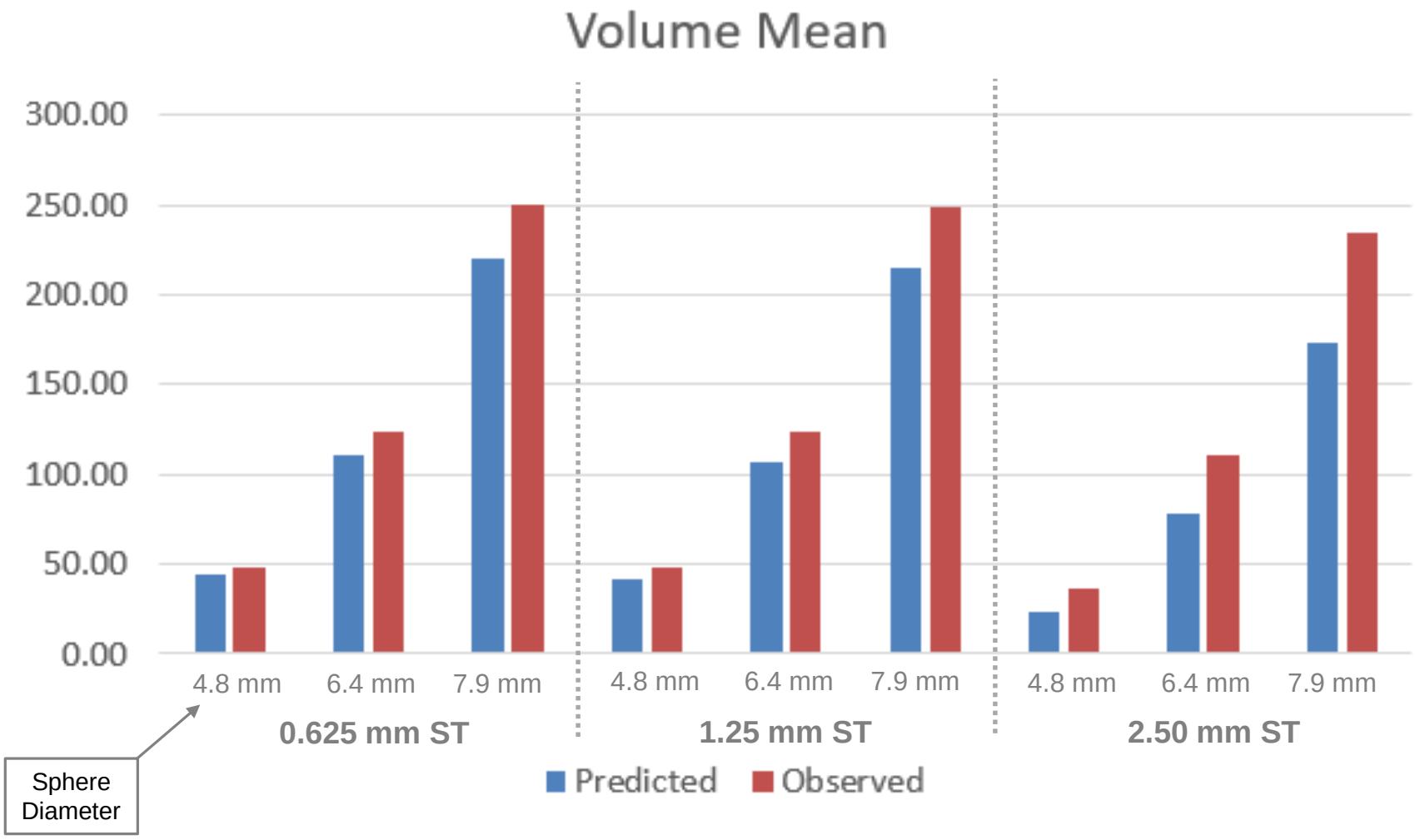


Validation Study: Predicted vs Measured

- CT Scanner
  - GE LightSpeed VCT
- Scan Protocol
  - Lung screening protocol with standard kernel, 0.625, 1.25, and 2.5mm slice thickness and spacing
- Objects
  - 1 scan of 3 rolls of 3M Scotch Tape ¾ x 1000 inch
  - 10 scans of Teflon spheres inside low density foam inside an anthropomorphic chest phantom, phantom was moved slightly each time
- Analysis
  - Automated analysis of scotch tape scan including estimated volume measurement performance
  - Independent algorithm for the detection and volume measurement of spheres
- Comparison
  - Plot predicted volume performance vs actual measurements



Predicted vs Observed Sphere Volume



Predicted vs Observed Sphere Volume