Automated Image Analysis Software for Quality Assurance of a Radiotherapy CT Simulator

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Overview

- Radiotherapy imaging
- RT Imaging QA: problems and solution
- Describe features of auto analysis software
- Demonstrate application to CT-Sim and Sim-CT
- Outline experience to date

Imaging Modalities for RT

- Common
  - Simulator (fluoroscopy)
  - CT-simulator
  - Digitally Reconstructed Radiographs (DRRs)
  - Simulator-CT (single slice and cone-beam)
  - Electronic Portal Imaging Devices (EPIDs)
- ‘Emerging’
  - Ultrasound
  - MRI
  - PET
  - On treatment cone-beam CT and kV radiography

Integrated System

RT Imaging QA: Essential Tests

- Geometric Accuracy in 3D
  - In and out of image plane (pixel size, couch travel)
  - Mechanical alignments
  - Laser alignment
- Image quality
  - Sufficient for purpose?
  - Consistent over time
- Accurate physical information
  - CT number / HU calibration -> electron density
- Testing of overall system
  - Geometrical co-registration
  - Transfer of image data

The Problems…

- Different tests are specified for different modalities
- Range of ‘equivalent’ test objects
- Most tests are only semi-quantitative
- Operator dependency
- Frequent (daily/fortnightly) comprehensive testing is required BUT most tests are time-consuming
- Some imaging equipment performs too well!

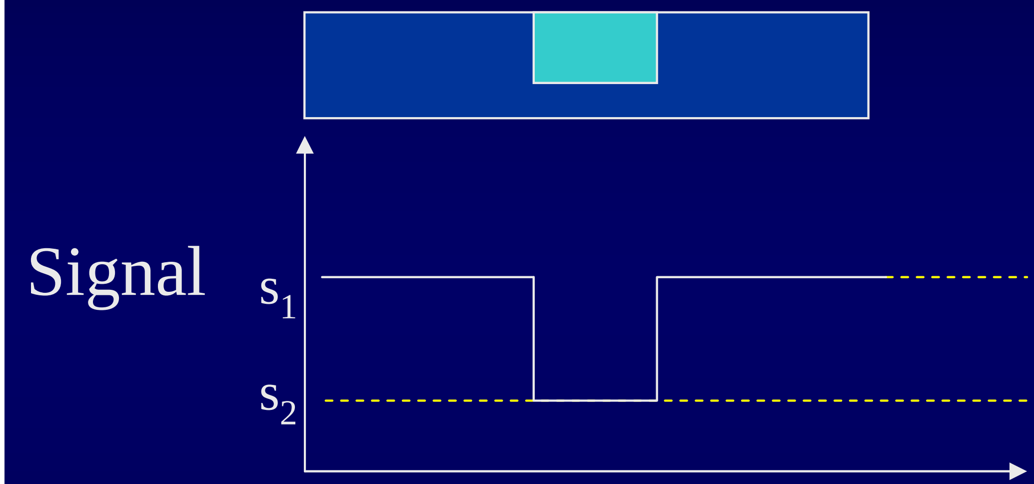
- Difficult to test integrated system.

The Solution…

- Develop single, uniform approach for all RT imaging modalities
  - + display devices, film processors, etc.
- Robust, fully objective and quantitative
- Analysis performed by computer
- Results automatically stored in database for trend analysis, etc.

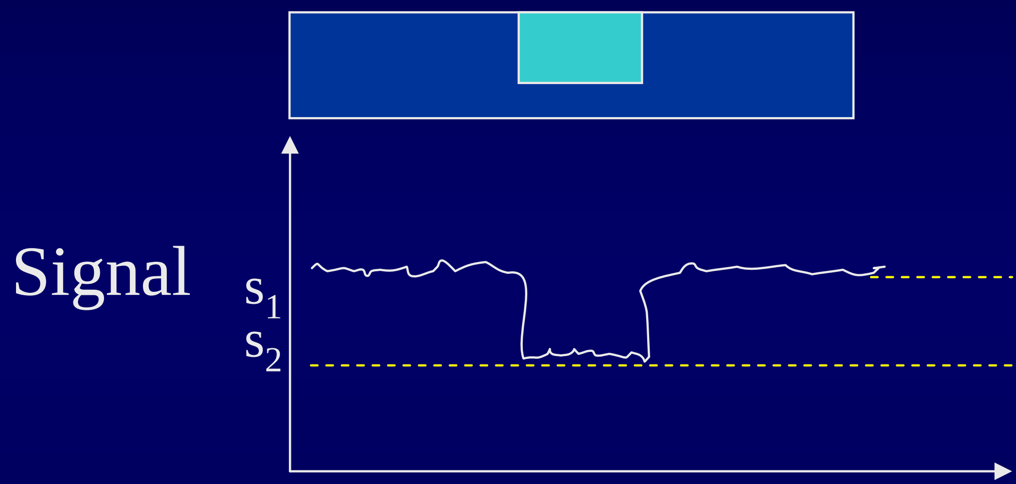
The Approach

1. Develop Appropriate Phantom



$SNR_{in} = s_1 / s_2$

2. Acquire Image of Phantom



$SNR_{out} = s_1 / s_2$

$$\left[\frac{SNR_{out}}{SNR_{in}}\right]^2 = DQE(f)$$

Determining the DQE

Modulation Transfer Function (Phantom)

$$DQE(f) = \boxed{K \cdot D} \cdot \frac{MTF^2}{NPS}$$

Dose and acquisition setting dependent.

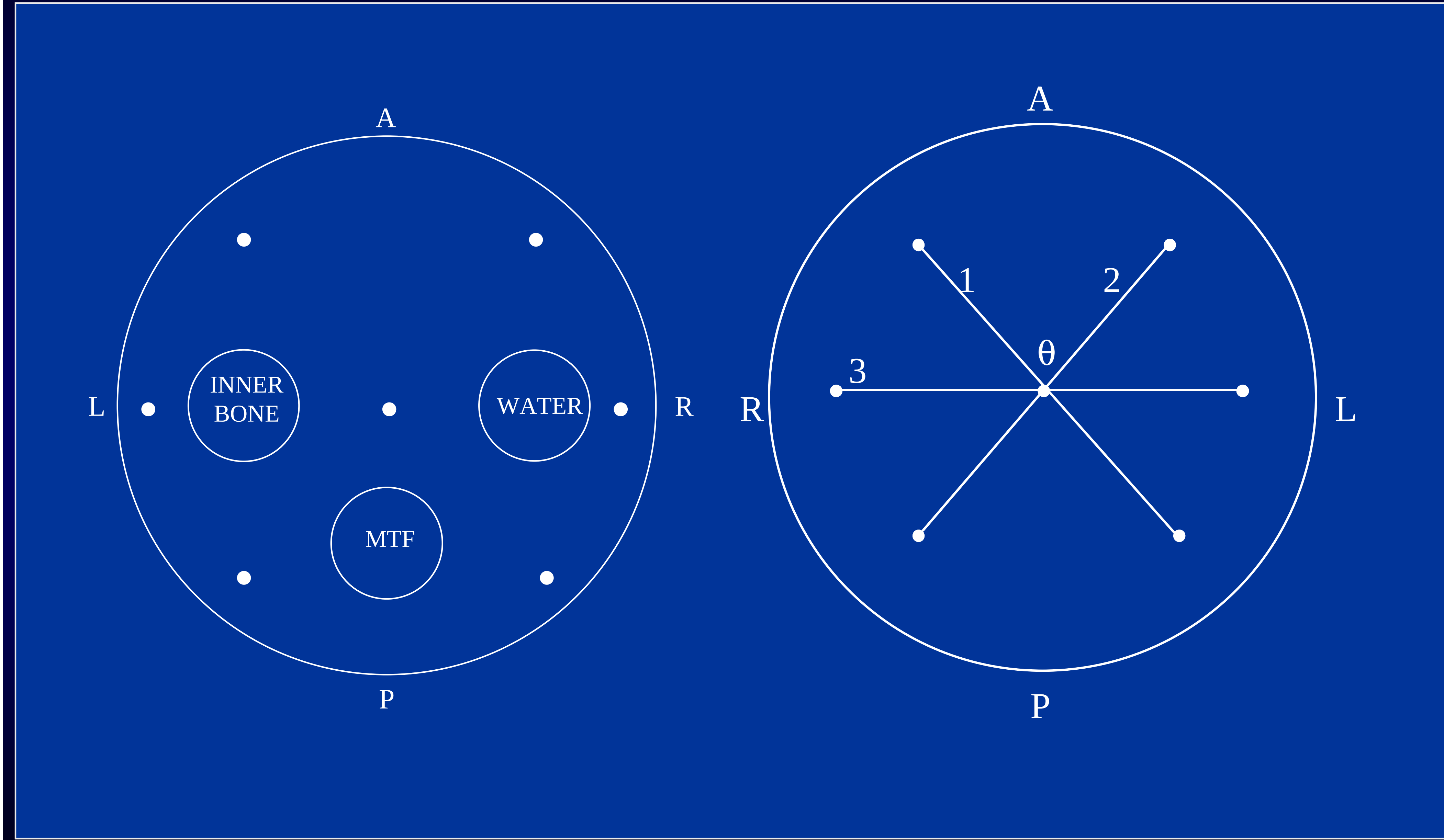
Noise Power Spectrum (Phantom)


HiSpeed

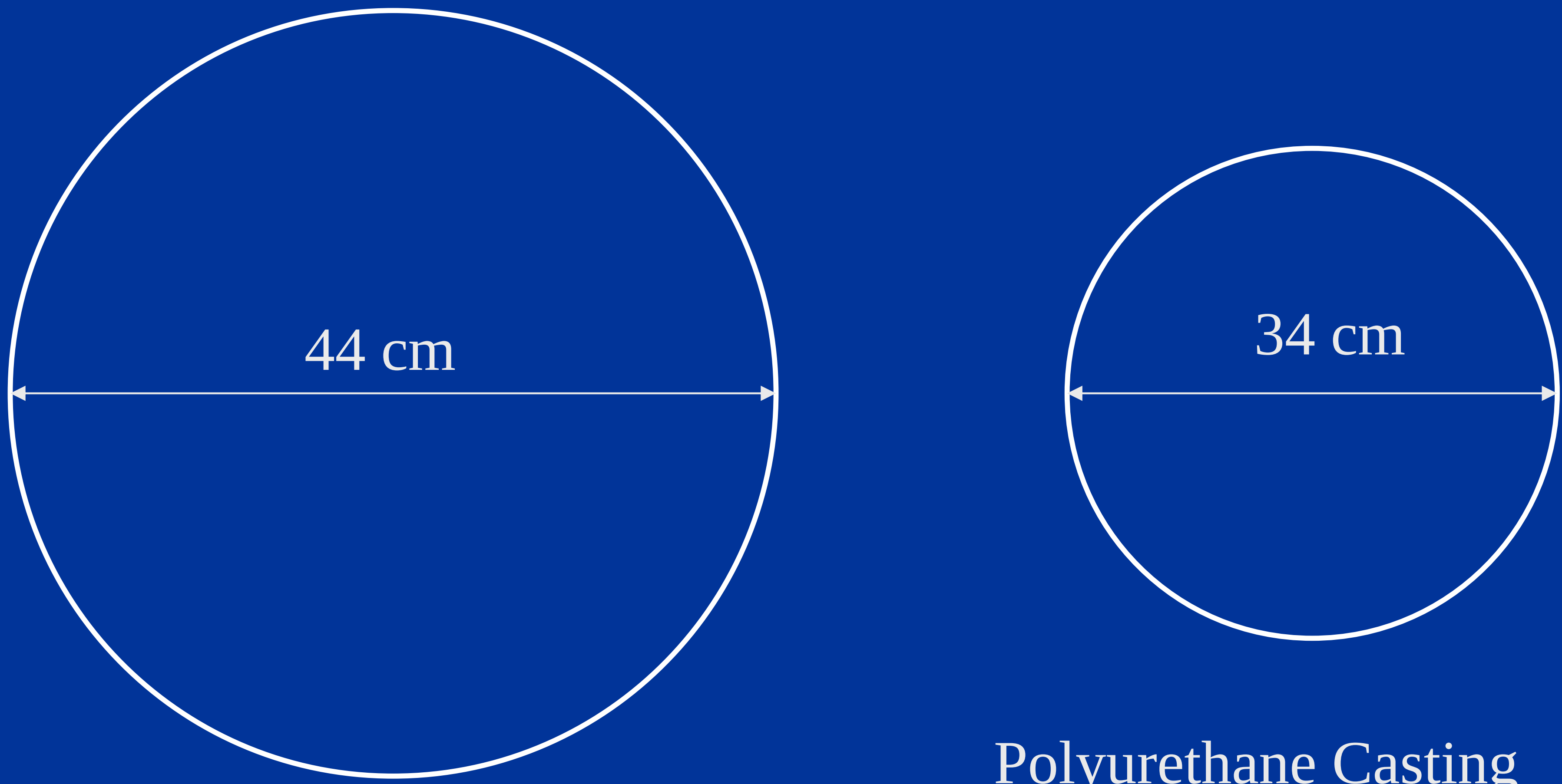
Varian Ximatron EX Sim-CT

Additional Collimators

Varian Performance Phantom



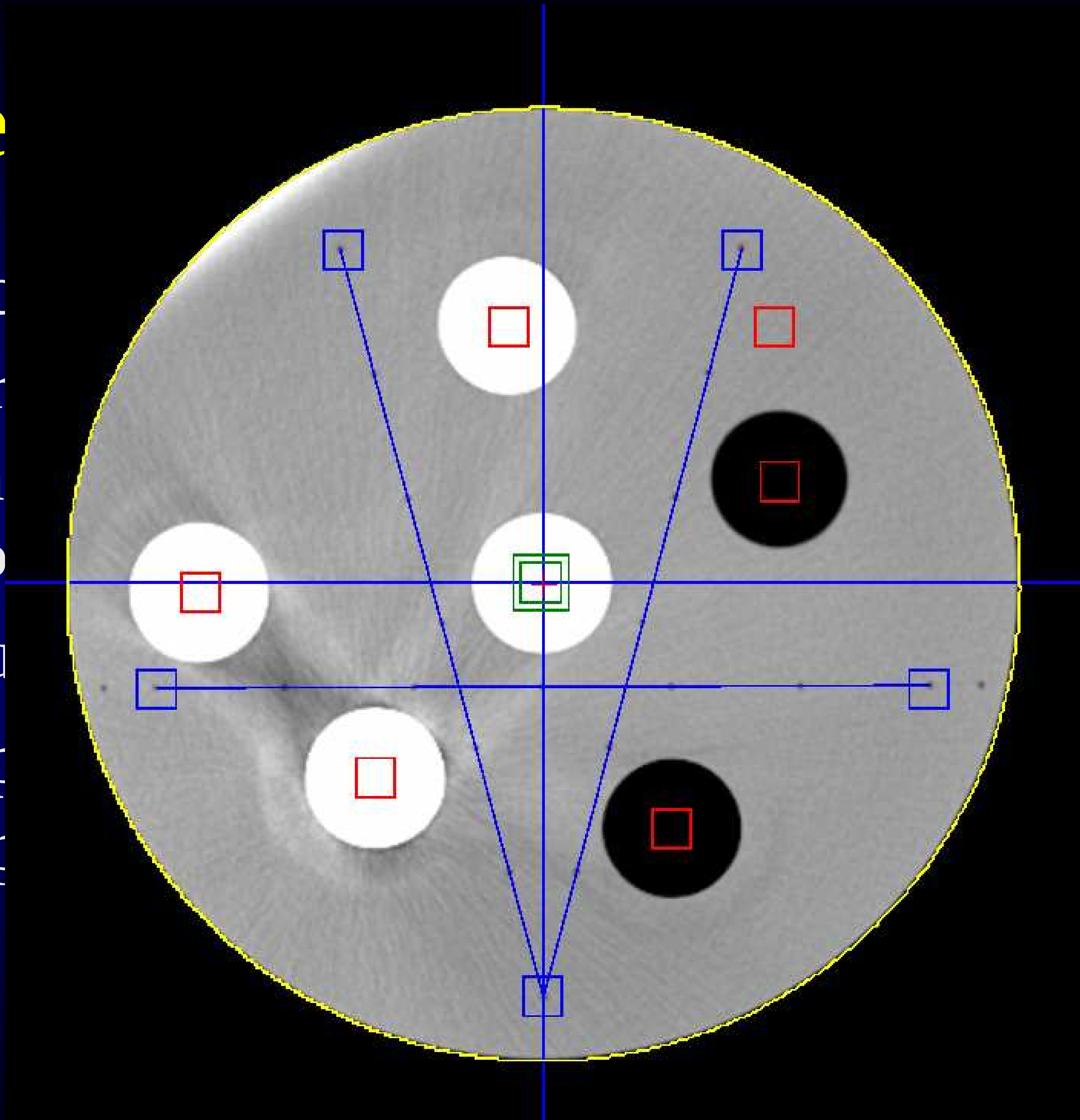
Varian Uniformity Phantoms

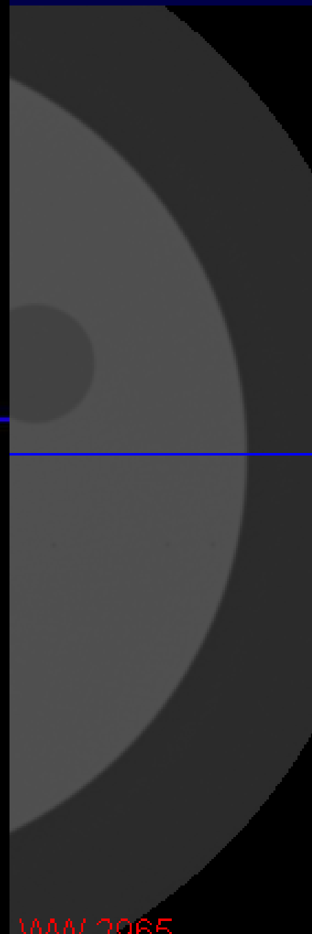


Polyurethane Casting
HU -580

Ge… nt

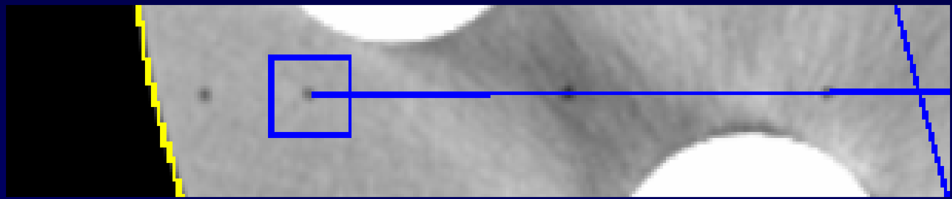
- Detec…
  - Thr…
  - Tra…
    cho…
- Calcu…
- Comp…
  zero p…

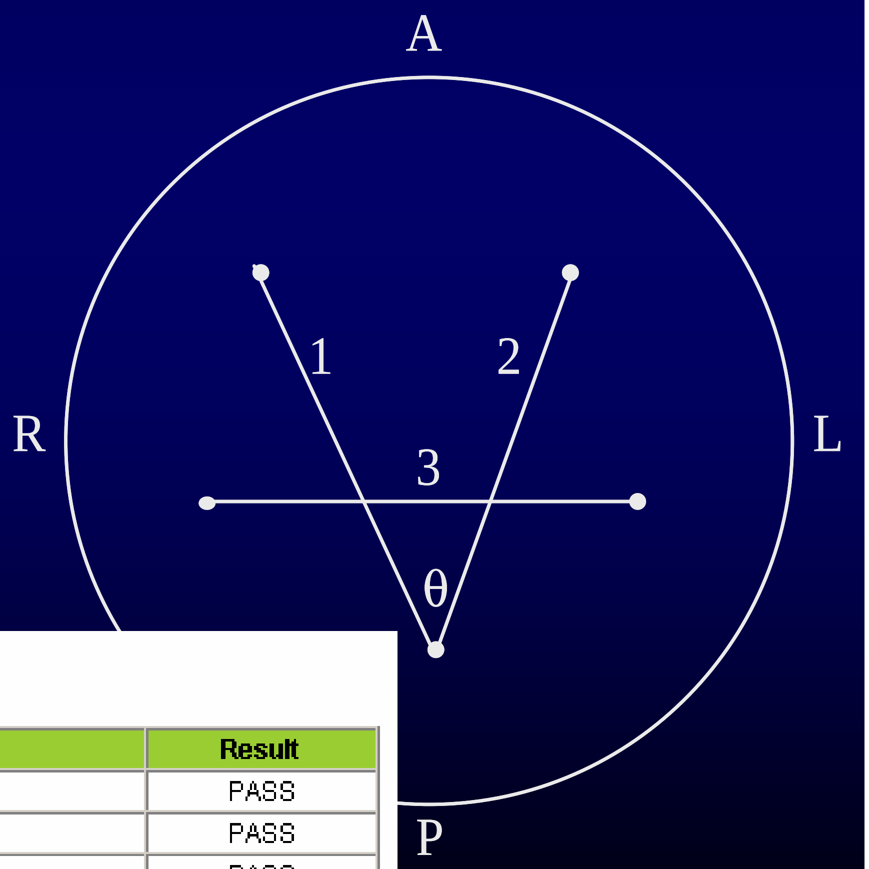




Geometry: Pixel Size

- Measure distance between holes
- Use centre of phantom and expected pixel size to identify 'seek area'
- Local minimum is centre of hole



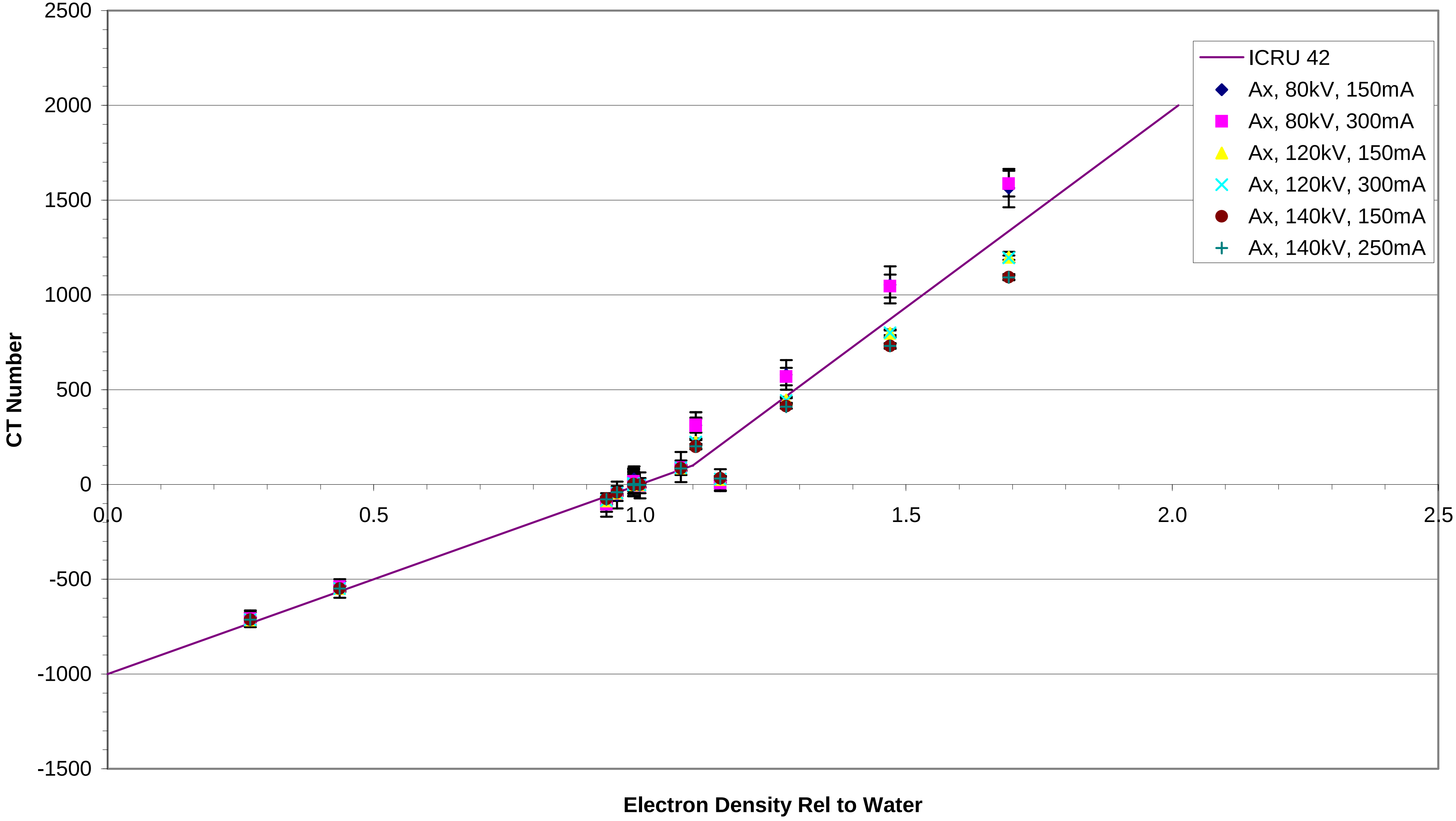


Geometric Distortion

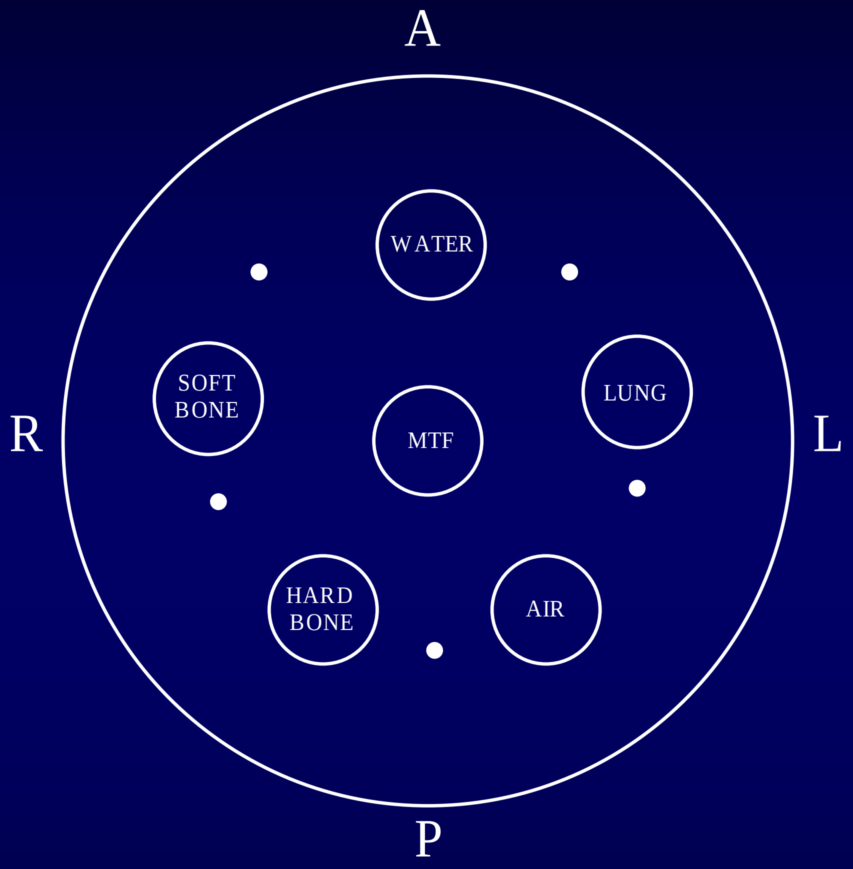
Line	Name	Length (mm)	Expected (mm)	Result
1	Line 1	301.6	300±2	PASS
2	Line 2	301.1	300±2	PASS
3	Line 3	300.8	300±2	PASS

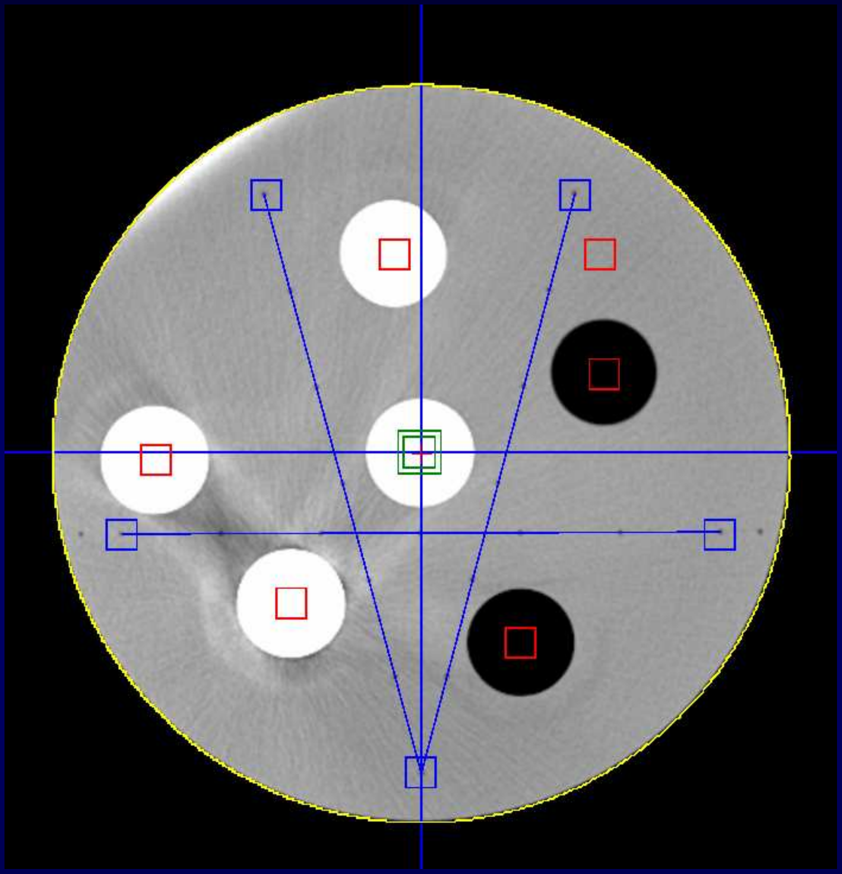
Hounsfield Unit Calibration

Baseline Values Measured During Commissioning



Hounsfield Unit Calibration





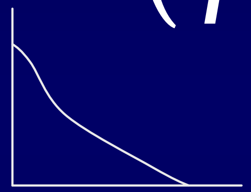
ROI Analysis

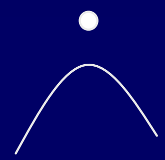
ROI	Name	Mean	Std Dev	Expected	Result
1	Water	-2.1	3.5	0±5	PASS
2	Lung	-732.1	2.4	-732±10	PASS
3	Air	-995.4	2.8	-1000±5	PASS
4	Cortical Bone	1298.7	8.6	1300±10	PASS
5	Inner Bone	185.5	5.0	189±10	PASS
6	Urethane	-579.8	2.6	-580±10	PASS

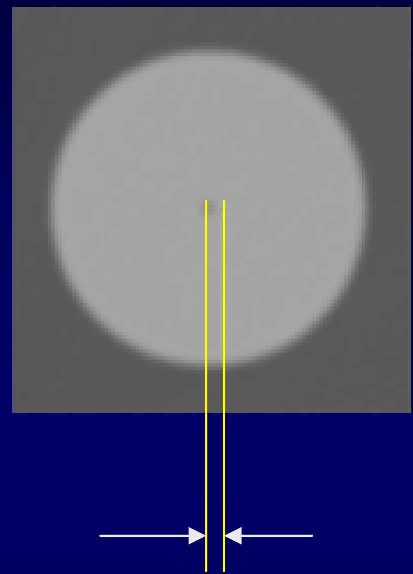
Modulation Transfer Function

- Calculate from impulse object

$$MTF(f) = \left| FT\{PSF(x)\} \right|$$







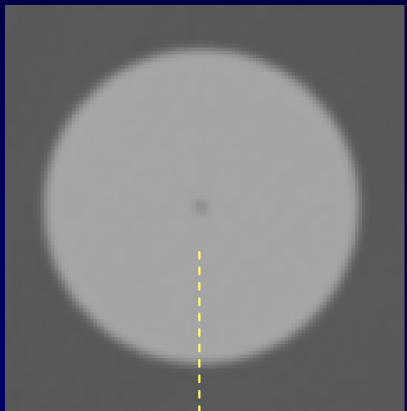
Finite size (DSF)

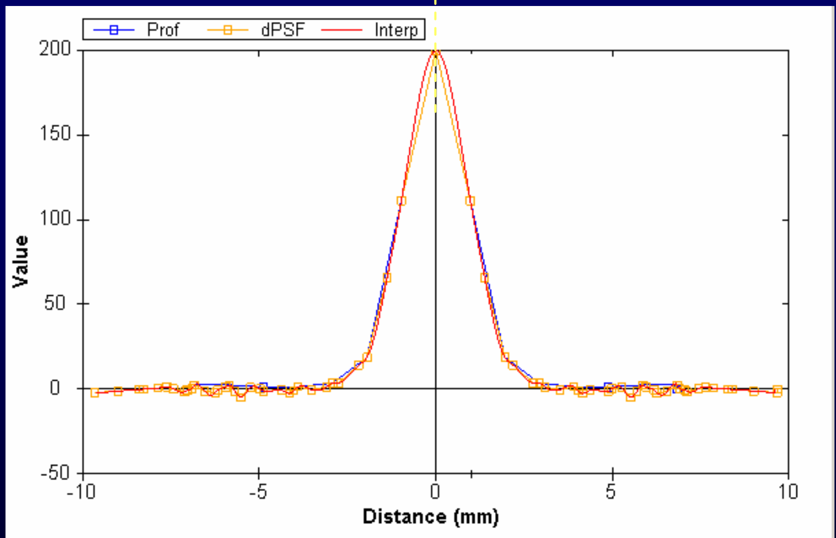
$$OSF(x) = PSF(x) \otimes DSF(x)$$

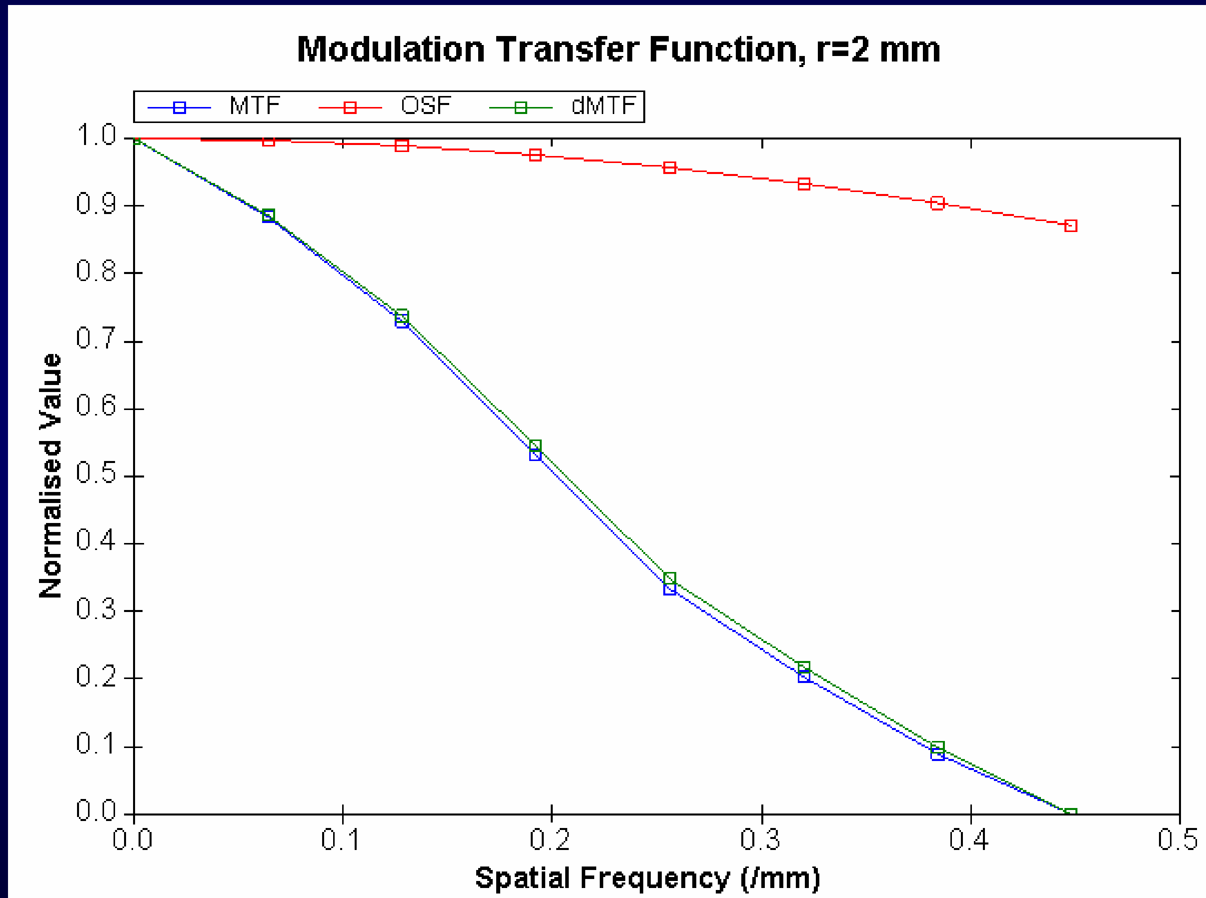
$$FT\{OSF(x)\} = FT\{PSF(x)\} \times FT\{DSF(x)\}$$

$$MTF(f) = \frac{FT\{OSF(x)\}}{FT\{DSF(x)\}}$$

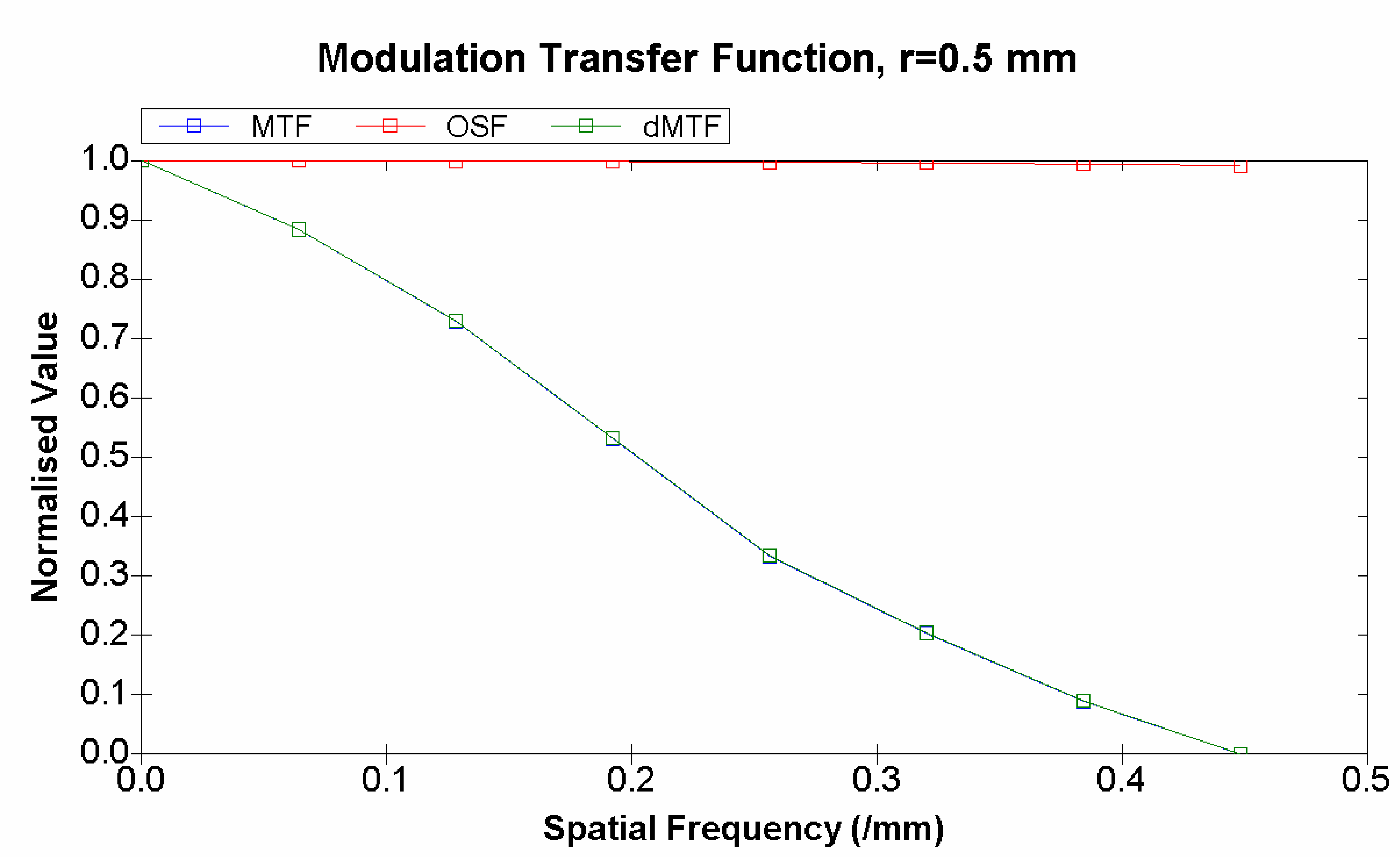
Calculation from Impulse Object







Object Spread Function
(From ALL pixels in ROI)


Modulation Transfer Function, r=0.5 mm
MTF
OSF
dMTF
Normalised Value
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4
0.5
Spatial Frequency (/mm)

Uniformity Phantom Analysis

- Define Useful FOV (UFOV) as 90% FOV
- Calculate:

$$\text{Coefficient of Variation}, CoV = \frac{\text{std dev}}{\text{mean}}$$

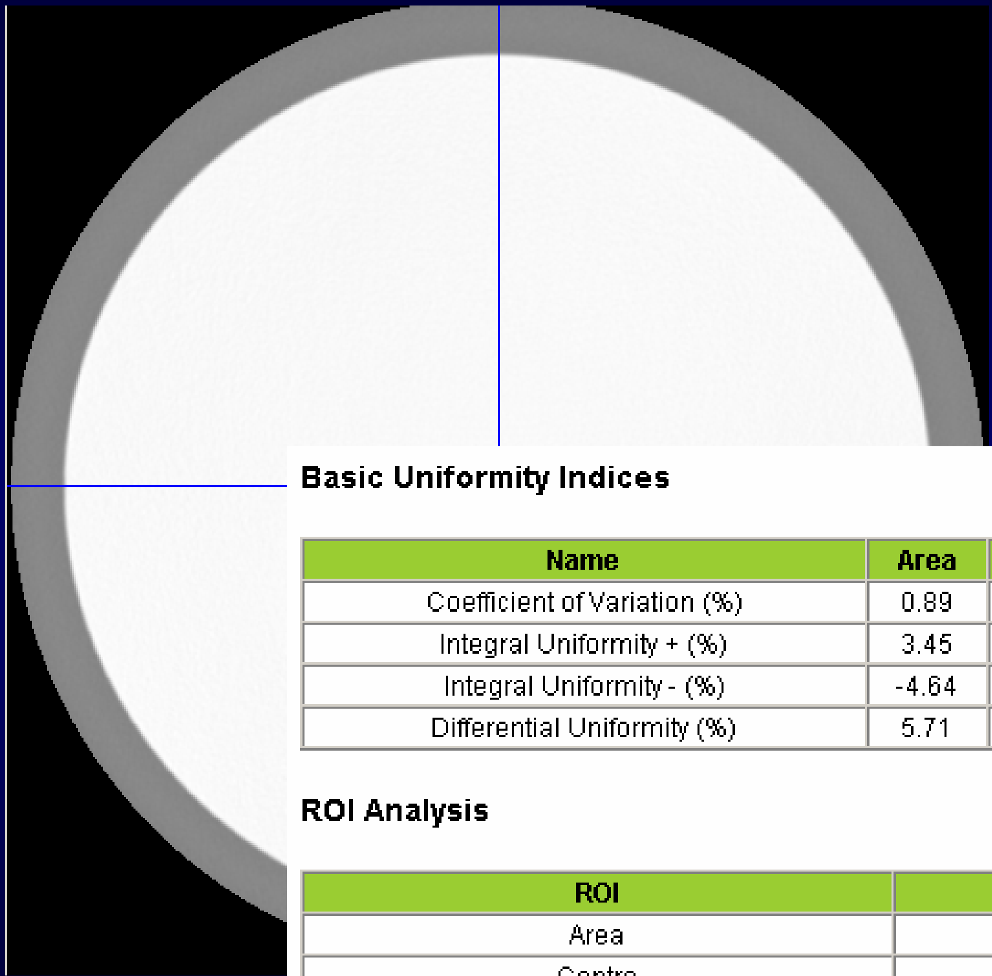
$$\text{Integral Uniformity}, U_{+} = \frac{p_{\max} - mean}{mean}$$

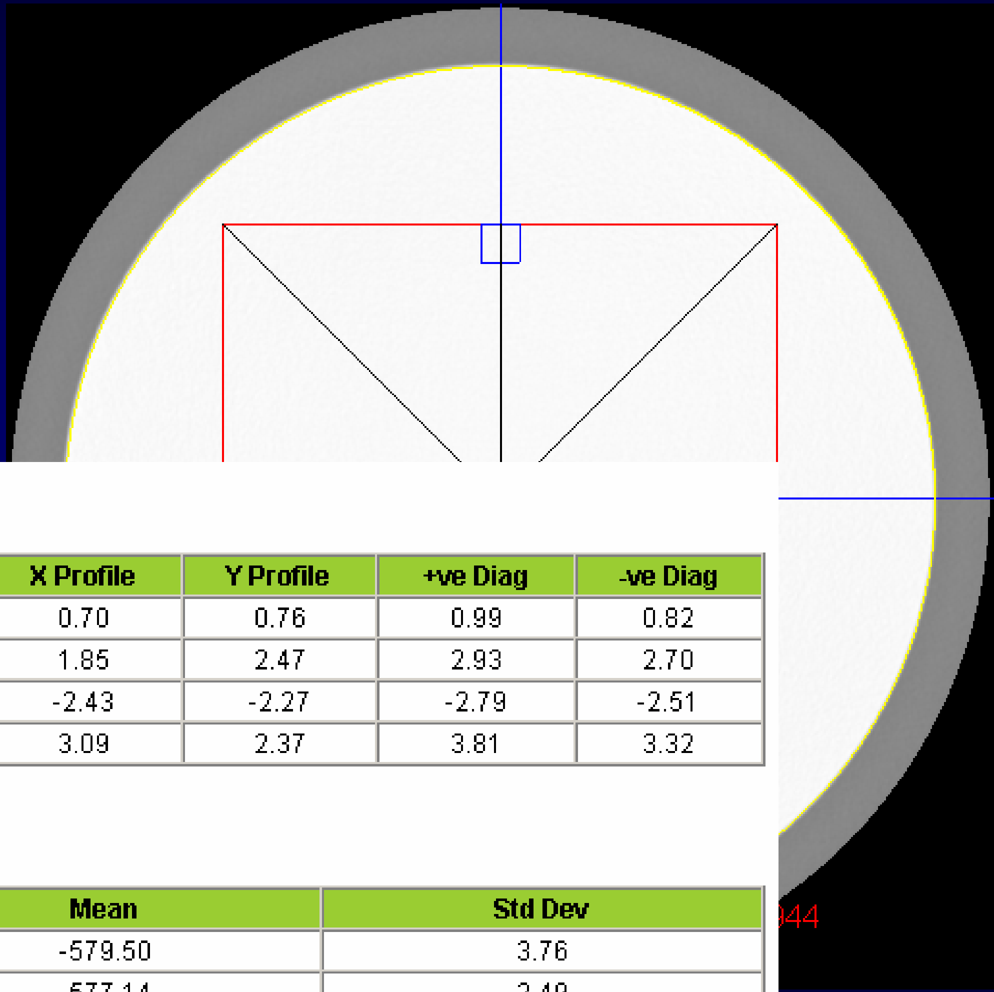
$$\text{Integral Uniformity}, U_{-} = \frac{p_{\min} - mean}{mean}$$

$$\text{Differential Uniformity}, U_{d} = \frac{\Delta p_{\max}}{mean}$$

$$\text{Uniformity Index}, U_{CT} = \frac{centre - \langle periphery \rangle}{1000}$$

Uniformity Phantom Analysis





Basic Uniformity Indices

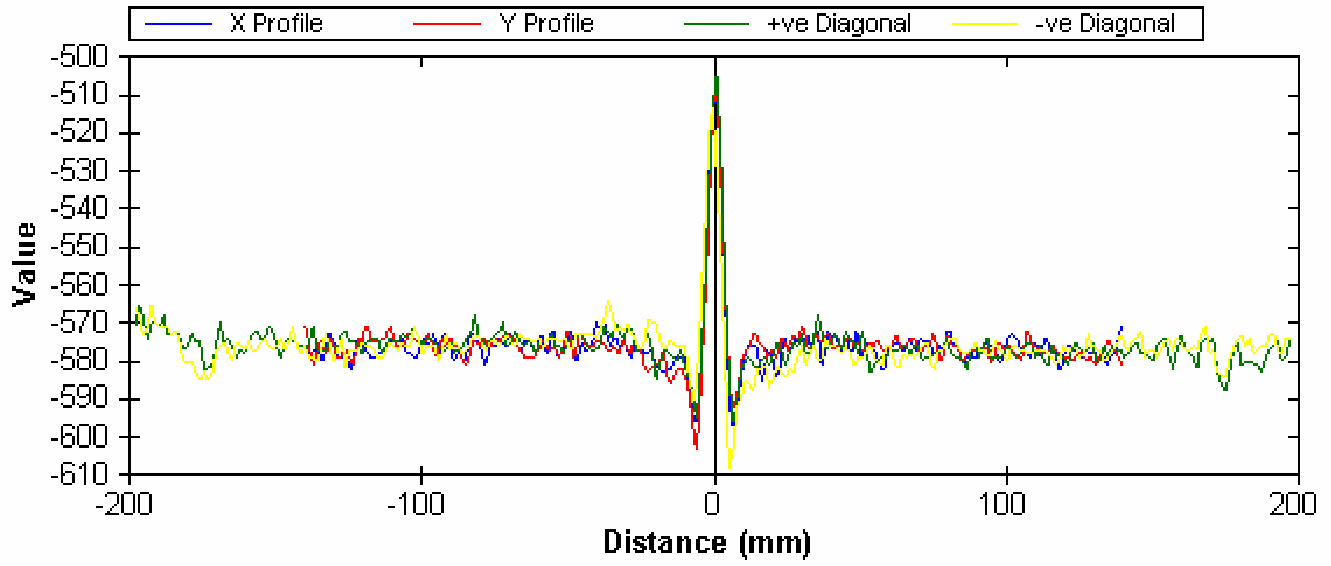
Name	Area	X Profile	Y Profile	+ve Diag	-ve Diag
Coefficient of Variation (%)	0.89	0.70	0.76	0.99	0.82
Integral Uniformity + (%)	3.45	1.85	2.47	2.93	2.70
Integral Uniformity - (%)	-4.64	-2.43	-2.27	-2.79	-2.51
Differential Uniformity (%)	5.71	3.09	2.37	3.81	3.32

ROI Analysis

ROI	Mean	Std Dev
Area	-579.50	3.76
Centre	-577.14	2.49
3 O'Clock	-580.22	3.59
6 O'Clock	-580.86	3.81
9 O'Clock	-578.91	4.12
12 O'Clock	-579.87	3.46

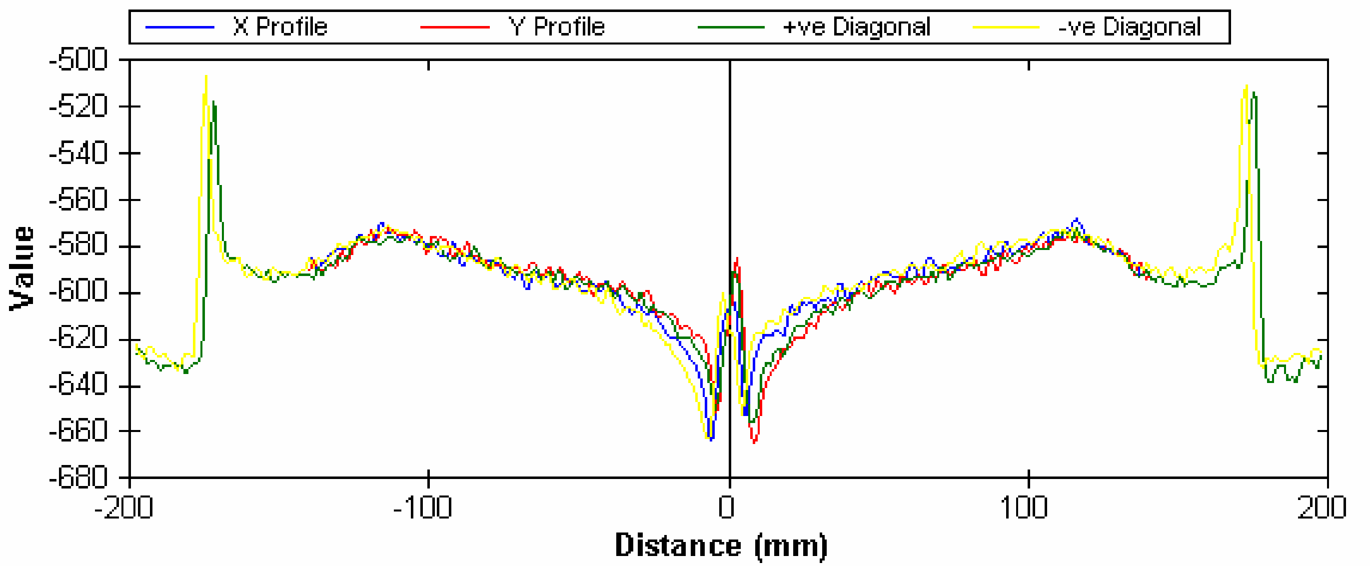
Index of Uniformity: 0.28 %

Uniformity Profiles



Sim-CT

Urethane Norm



Air Norm

Noise Power Spectrum

- Region of Interest from Uniformity Phantom
- Remove DC component (subtract mean value)
- Perform 2D FFT

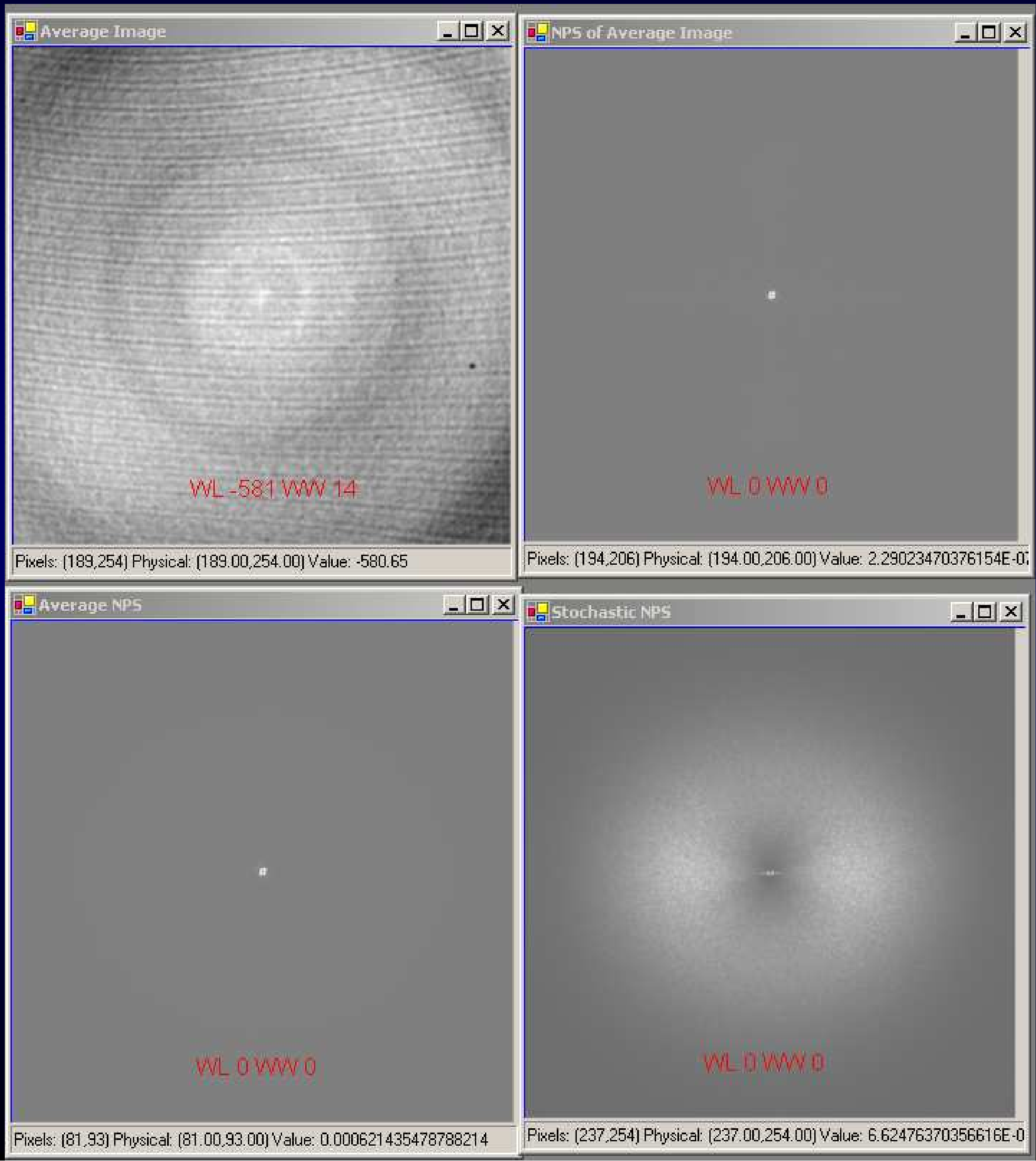
$$NPS(u,v) = \frac{\mathrm{Re}(u,v)^2 + \mathrm{Im}(u,v)^2}{area}$$

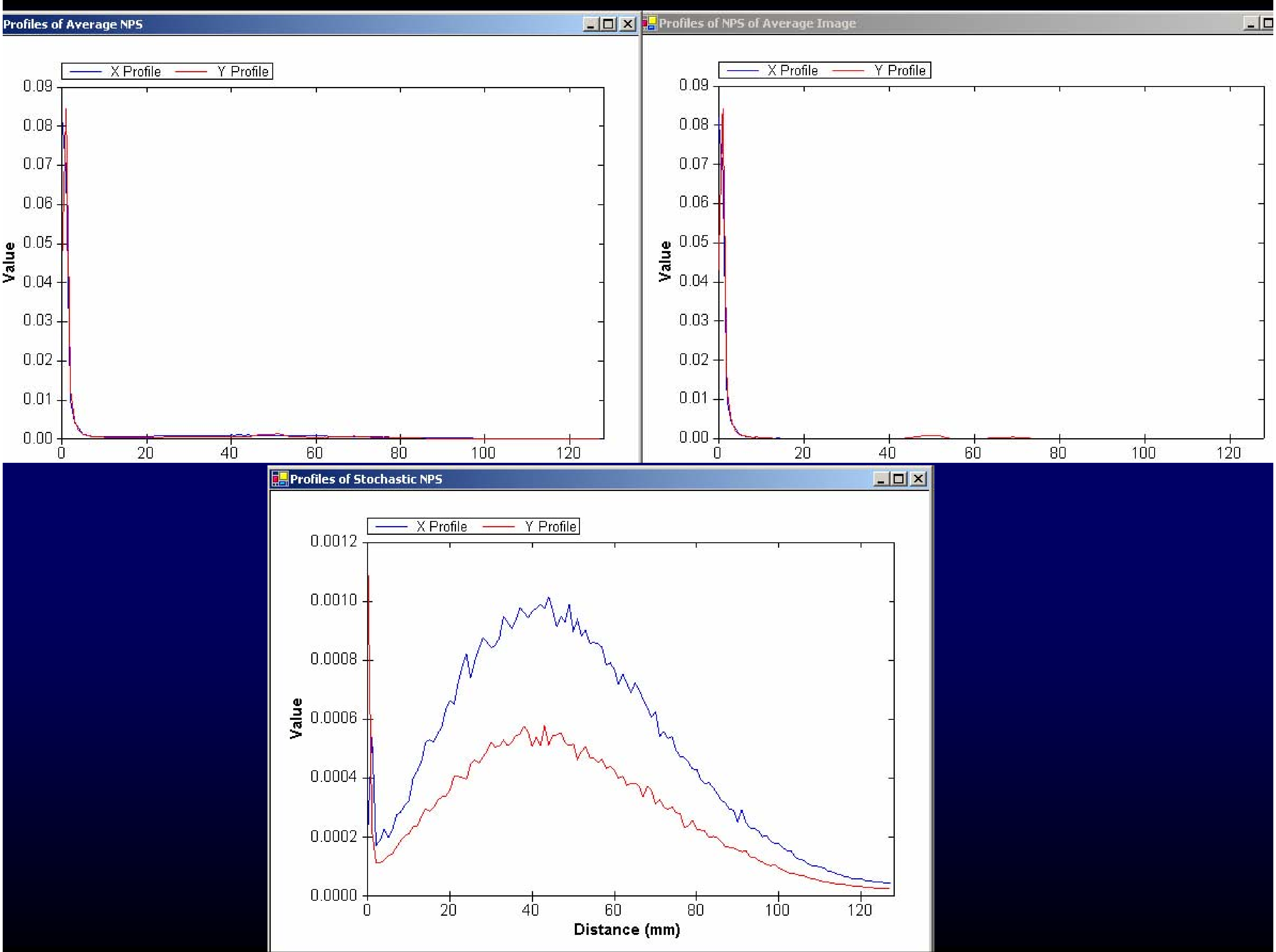
- Separation of stochastic noise

$$NPS_s = \frac{\sum_n NPS}{n} - NPS\left(\frac{\sum_n ROI}{n}\right)$$

NPS Example

- 100 images of Uniformity Phantom, 50 cm FOV

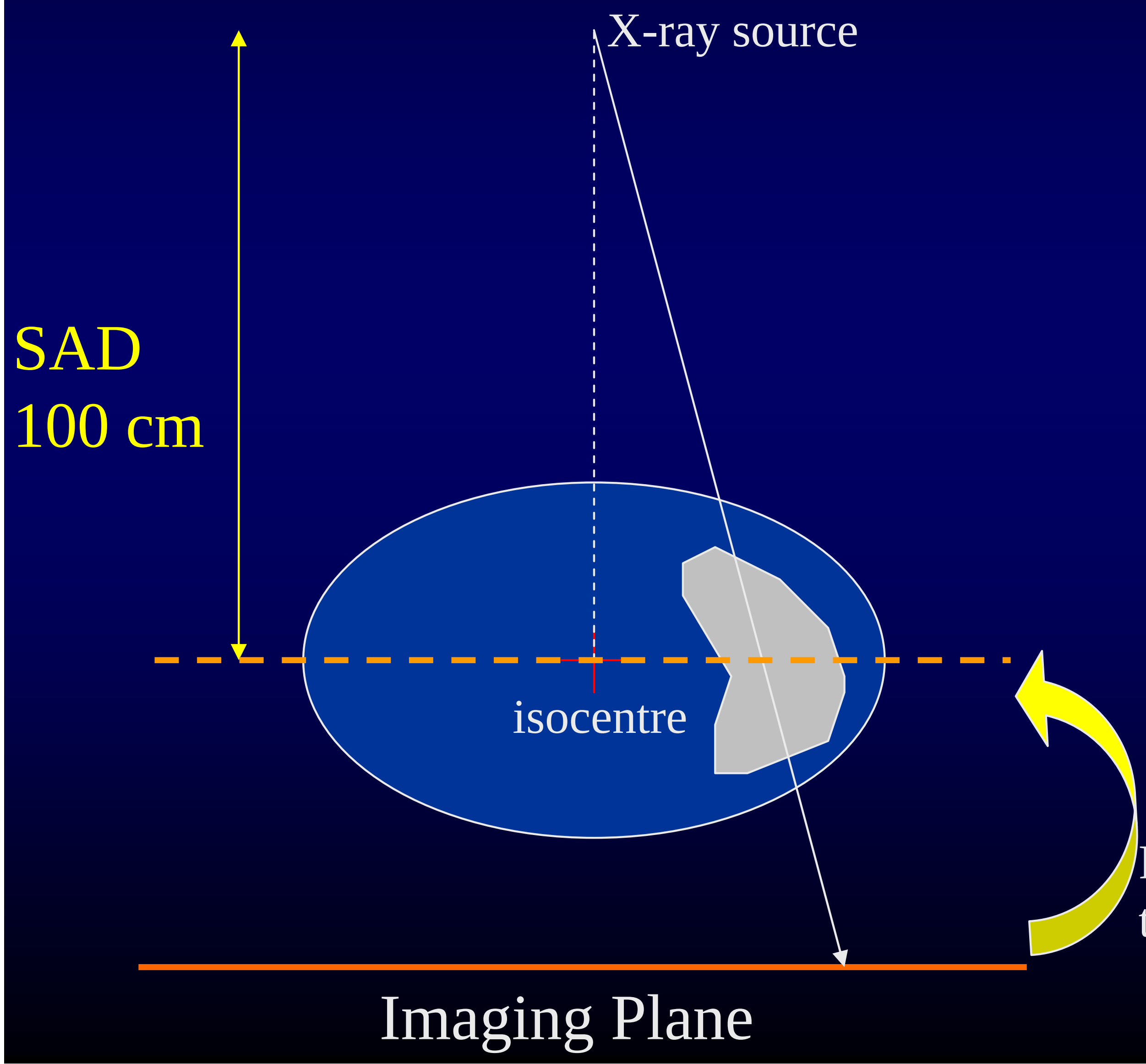


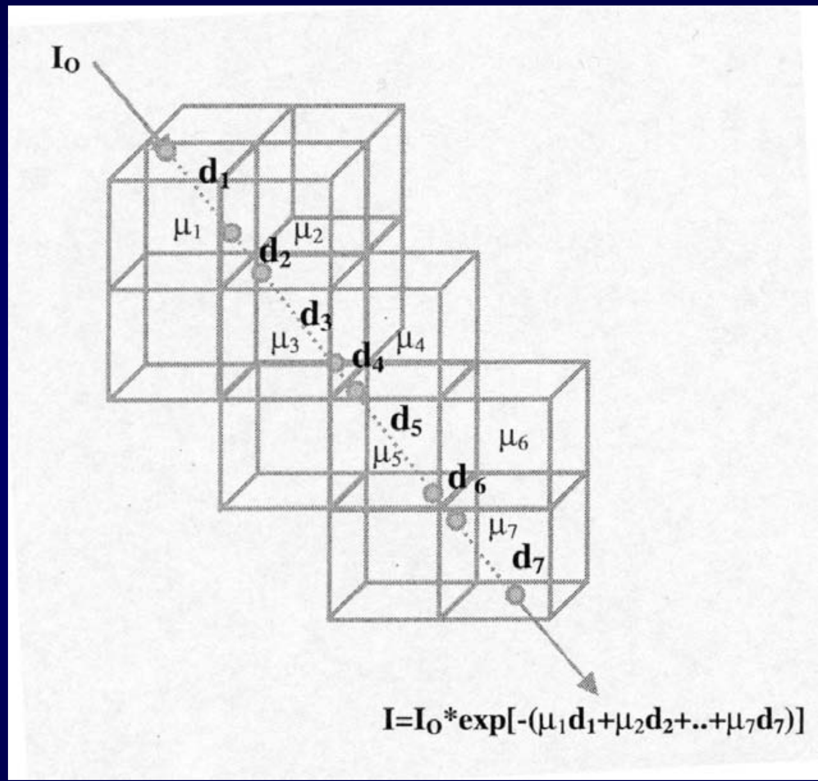


Profiles of Average NPS
X Profile
Y Profile
Value
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
20
40
60
80
100
120
Profiles of NPS of Average Image
X Profile
Y Profile
Value
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
20
40
60
80
100
120
Profiles of Stochastic NPS
X Profile
Y Profile
Value
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0
20
40
60
80
100
120
Distance (mm)

Production of DRRs

- Ray trace from virtual source of x-rays through stack of CT slices and model attenuation of beam.

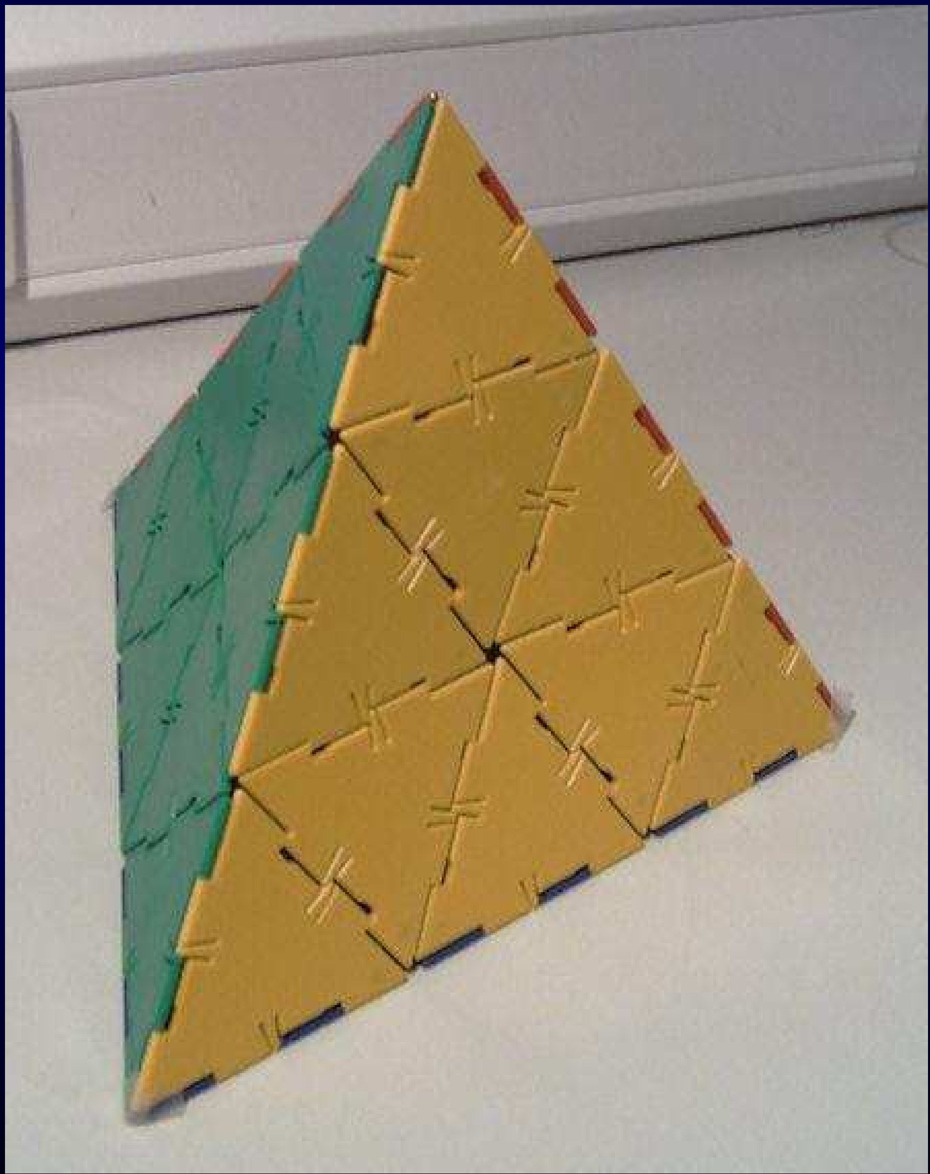


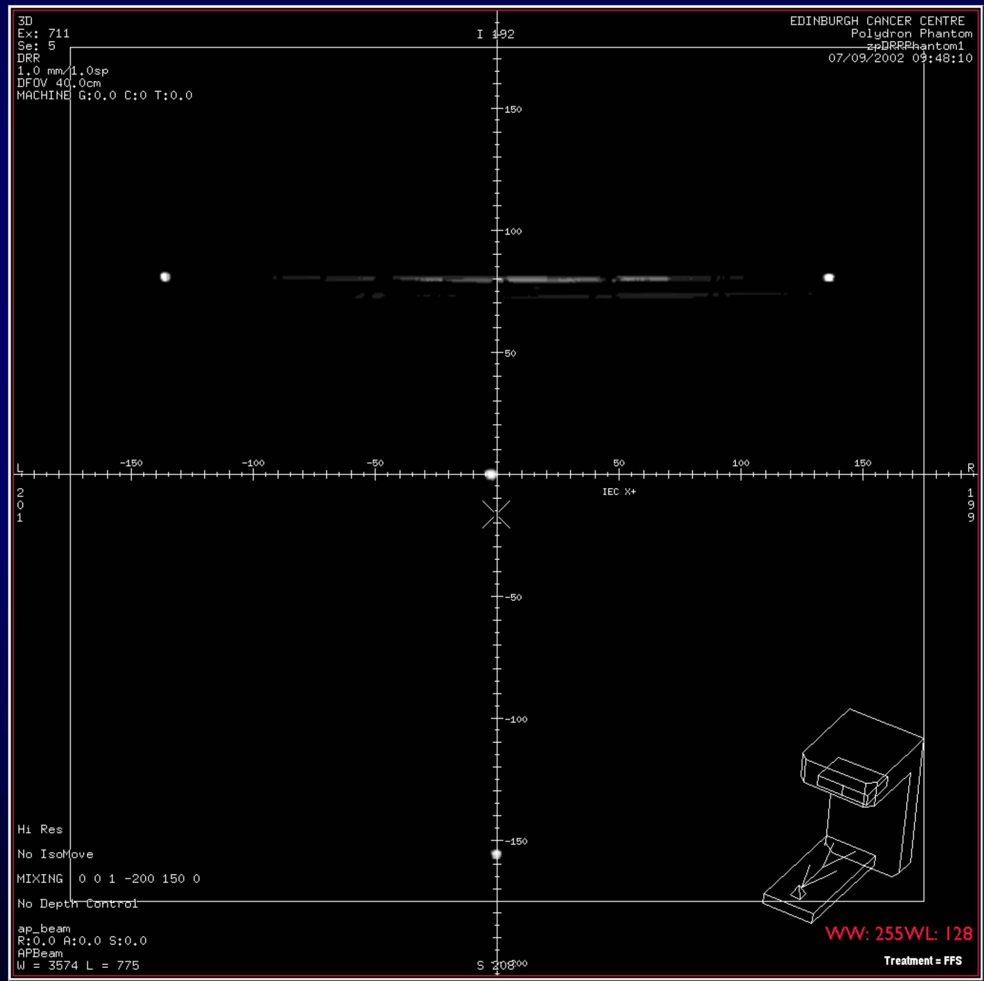


Reference: Milickovic *et al*,
Physics in Medicine and Biology (2000) 45:10;2787-2800

DRR Production Example

Edinburgh DRR Phantom





Software Demo

Experience & Conclusions

- New approach appears complicated, but…
- Significantly faster than previous methods
- More robust, fully objective and quantitative
- Greater confidence in results
- New ability to follow trends

- Need to finalise DRR phantom
- Expand to include other RT imaging modalities