IMRT QA in the USA

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Outline

- Why is IMRT QA necessary?
- Initial QA for a Clinic
- Routine QA for IMRT
- Future of Patient IMRT QA
- Resources:
  - Red Journal (Int. J. Radiat. Oncol. Biol. Phys. 51, 880-914 (2001)
  - ASTRO (“White” paper)
  - AAPM (IMRT Subcommittee Guidance Document)

Why is IMRT QA Necessary?

- What QA?
- Dosimetry
  - Monitor Units
  - Linear Accelerator (delivery)
- Patient Treatment
  - Treatment Plan (quality)
  - Treatment Plan (errors)
  - Patient Positioning

MUs

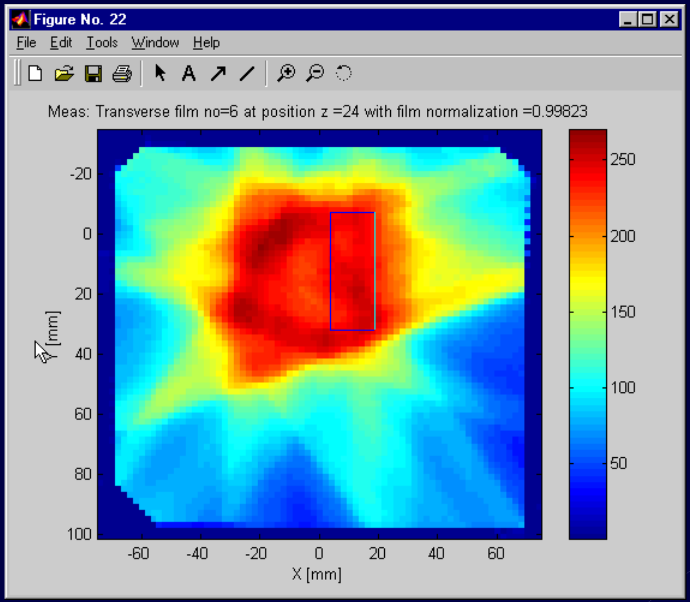
- Intuitive/straightforward dose-to-MU relationship lost
- Measurement or calculation necessary to validate

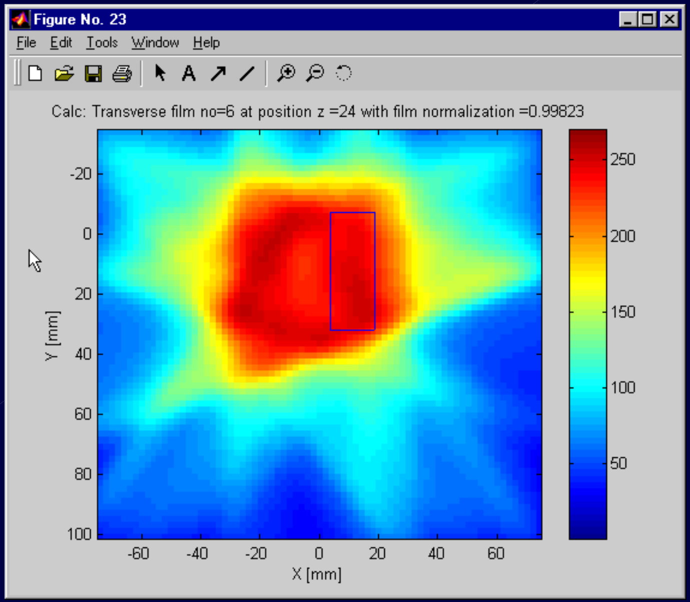
Prostate treatment

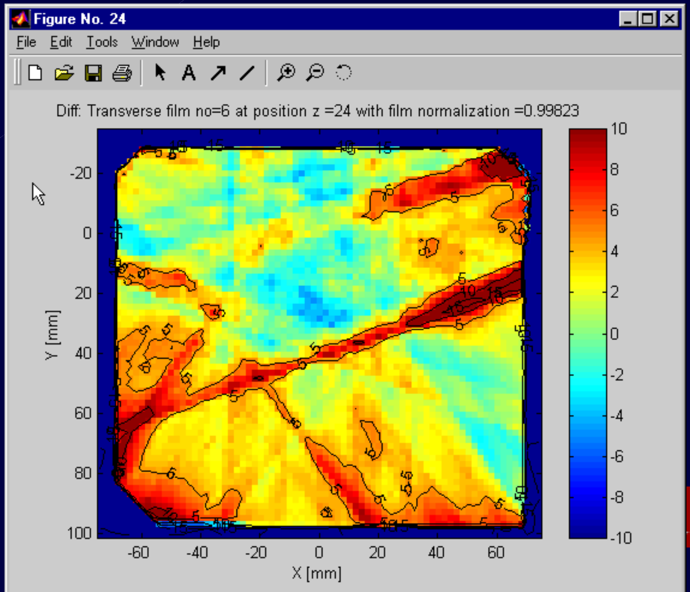
Total 200 cGy
899 MUs

Gantry Angle	MUs	
36°	214	
108°	154	100% LAO
180°	189	
252°	258	168% RAO
324°	149	

Delivered Dose



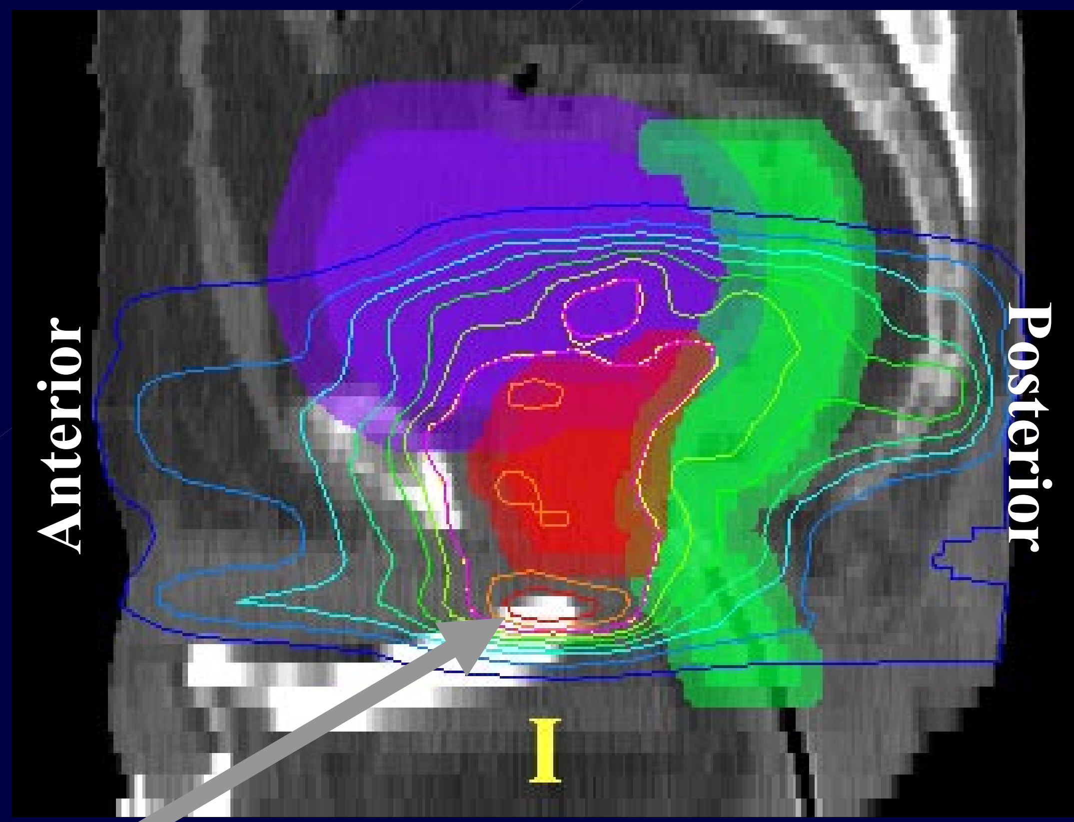




Treatment Plan QA: Penile Bulb

10.0	%	10.49	Gy
20.0	%	20.97	Gy
30.0	%	31.46	Gy
40.0	%	41.94	Gy
50.0	%	52.43	Gy
60.0	%	62.92	Gy
70.0	%	73.40	Gy
80.0	%	83.89	Gy
90.0	%	94.37	Gy
70.5	%	73.93	Gy

Superior



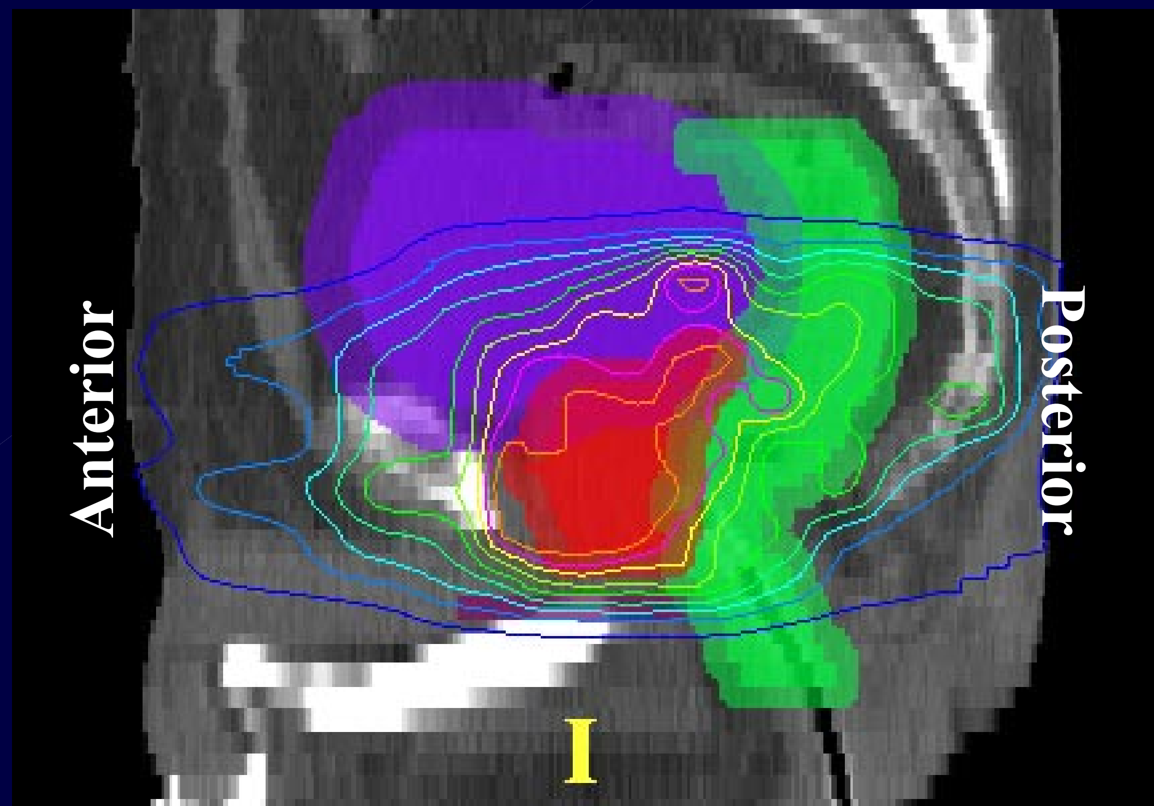
Inferior

94 Gy !!!

Penile Bulb Delineated

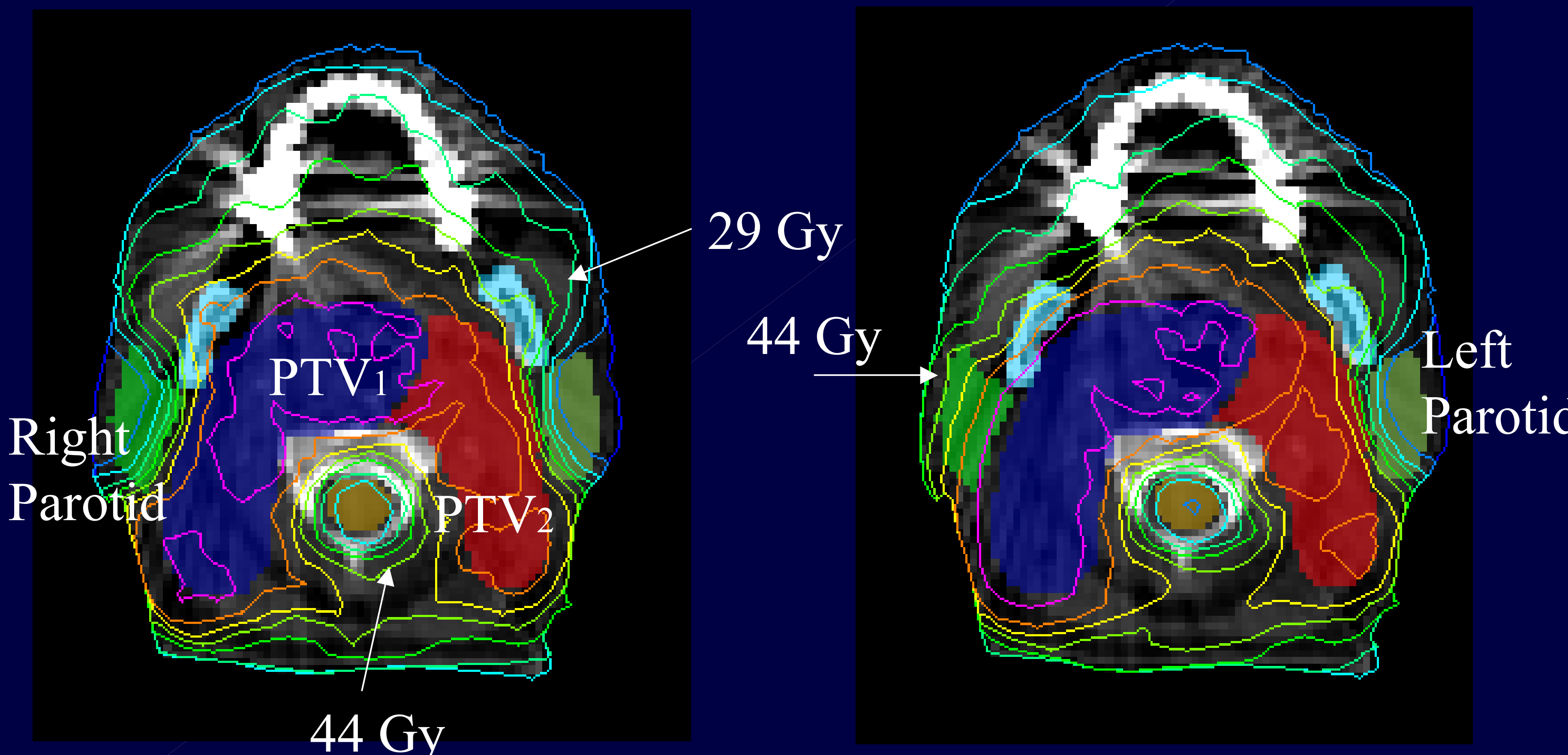
10.0	%	9.87	Gy
20.0	%	19.73	Gy
30.0	%	29.60	Gy
40.0	%	39.47	Gy
50.0	%	49.33	Gy
60.0	%	59.20	Gy
70.0	%	69.07	Gy
80.0	%	78.93	Gy
90.0	%	88.80	Gy
75.0	%	74.00	Gy

Superior

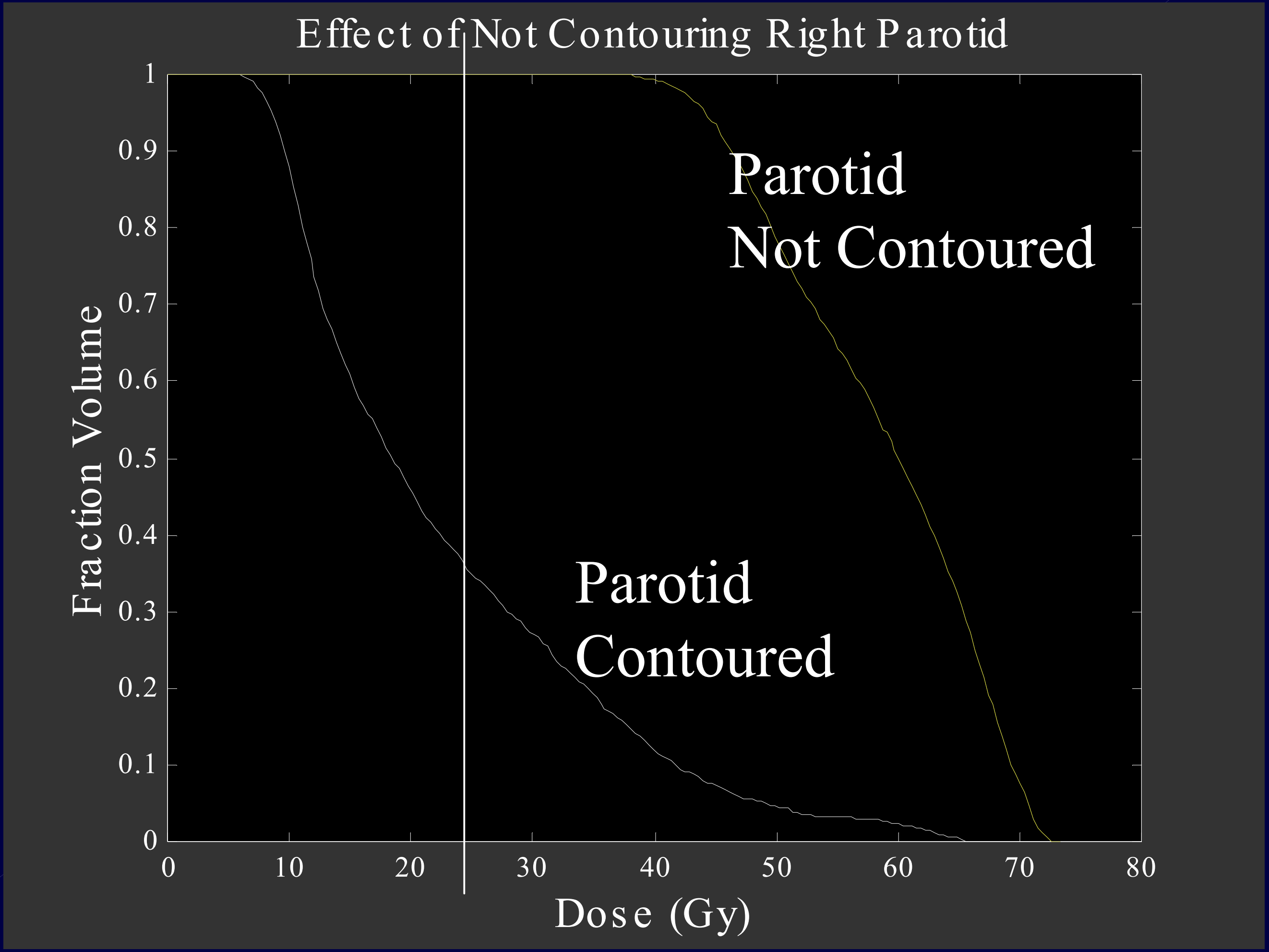


Inferior

Thorough Delineation of Critical Structures



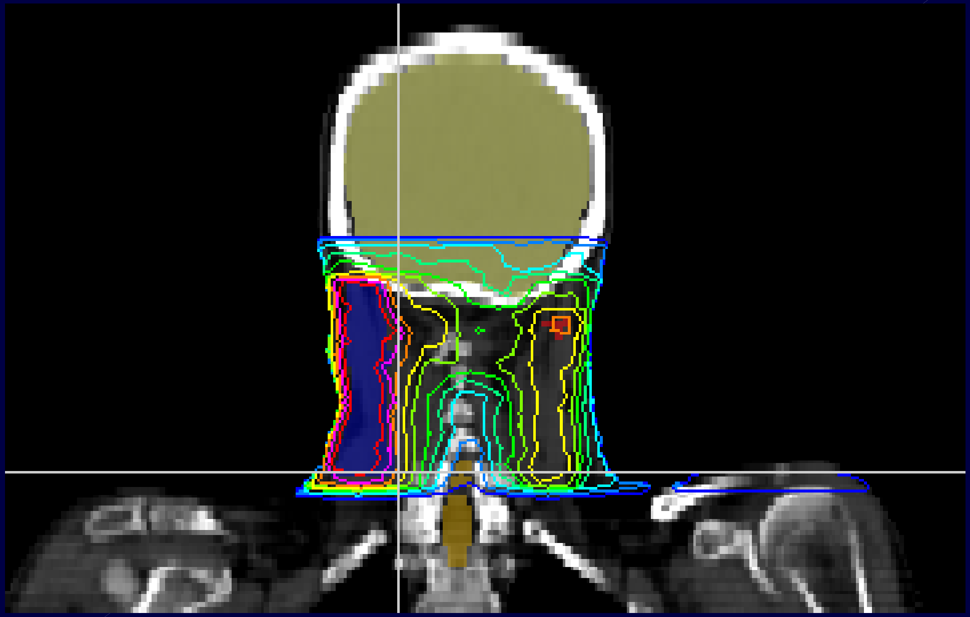
Missing Contour DVH

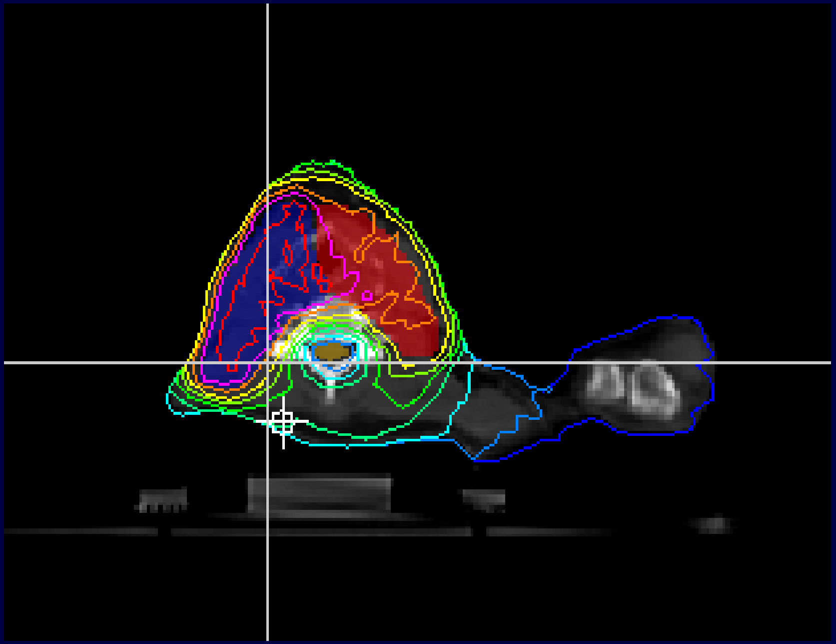


Mobile Structures

TPS modifies fluence to compensate for shoulder

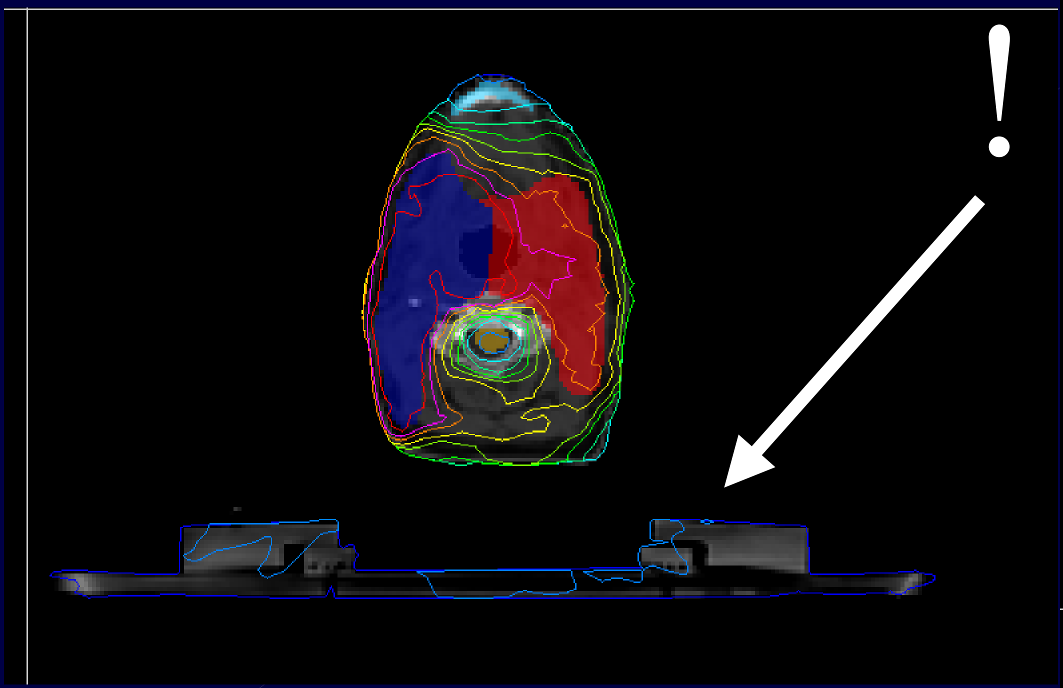
"External Avoidance" structure can remove fluence from specific directions

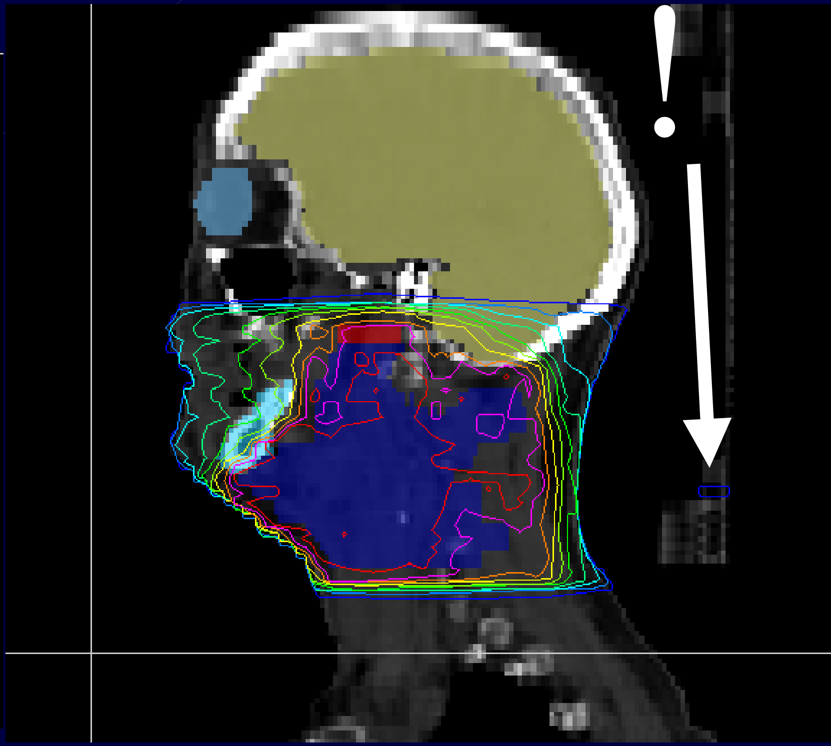




Error Monitoring

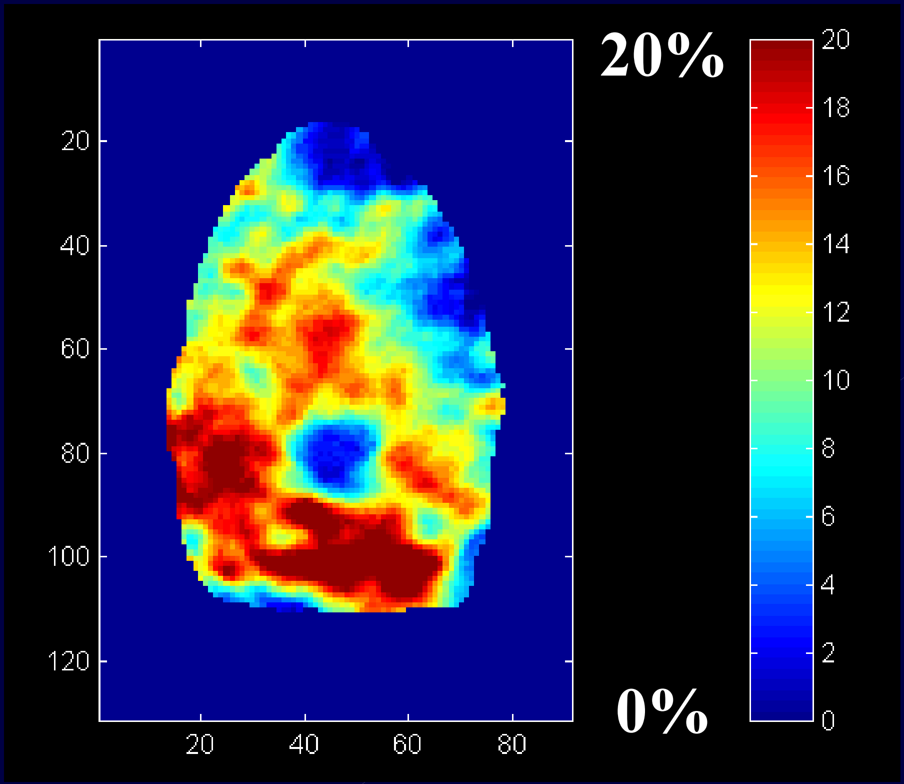
Fluence compensates for "couch"





Error Monitoring

Important to understand dose calculation algorithm!



Dose Error (%)

Machine: Barnes Clinac 600C/D (350deg/1cm)
Approval #: 44217

Table Angle: 180°

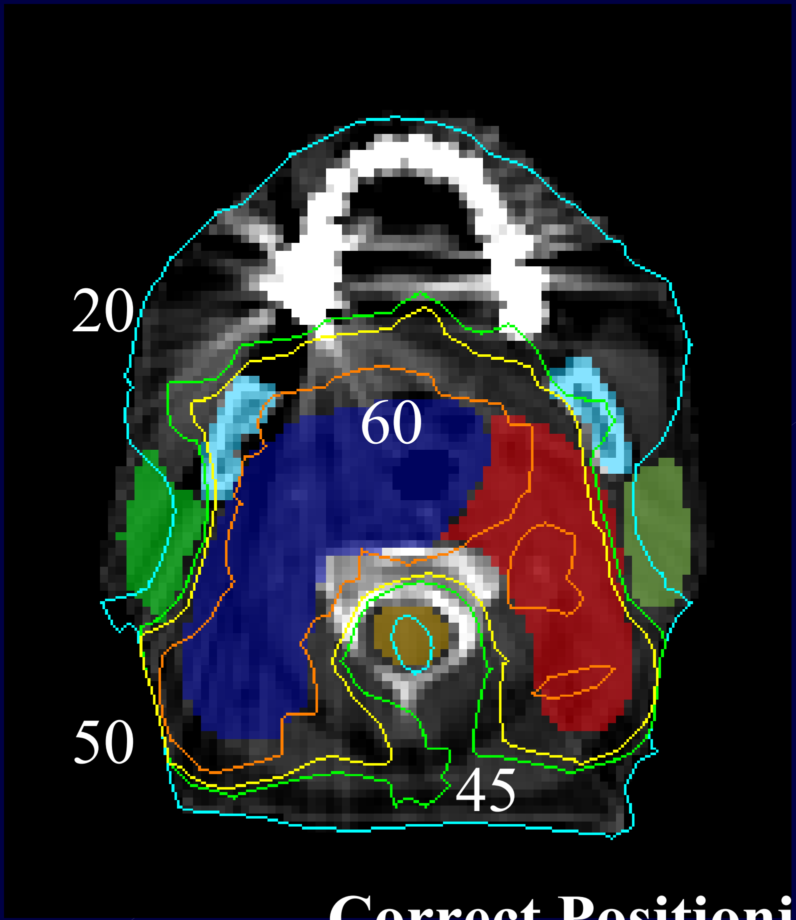
Couch Movement Instructions	Gantry Start	Gantry End	MU Total	MU Per°	Rot Cnt
I 34.40	350°	10°	488	1.44	1
I 51.20	350°	10°	471	1.39	1
I 68.00	350°	10°	466	1.37	1
I [illegible]	350°	10°	[illegible]	[illegible]	1
I 101.60	350°	10°	645	1.90	1
I 118.40	350°	10°	593	1.74	1
I [illegible]	350°	10°	[illegible]	[illegible]	1
I 152.00	350°	10°	507	1.49	1

Machine: Barnes Clinac 600C/D (350deg/1cm)
Approval #: 29369

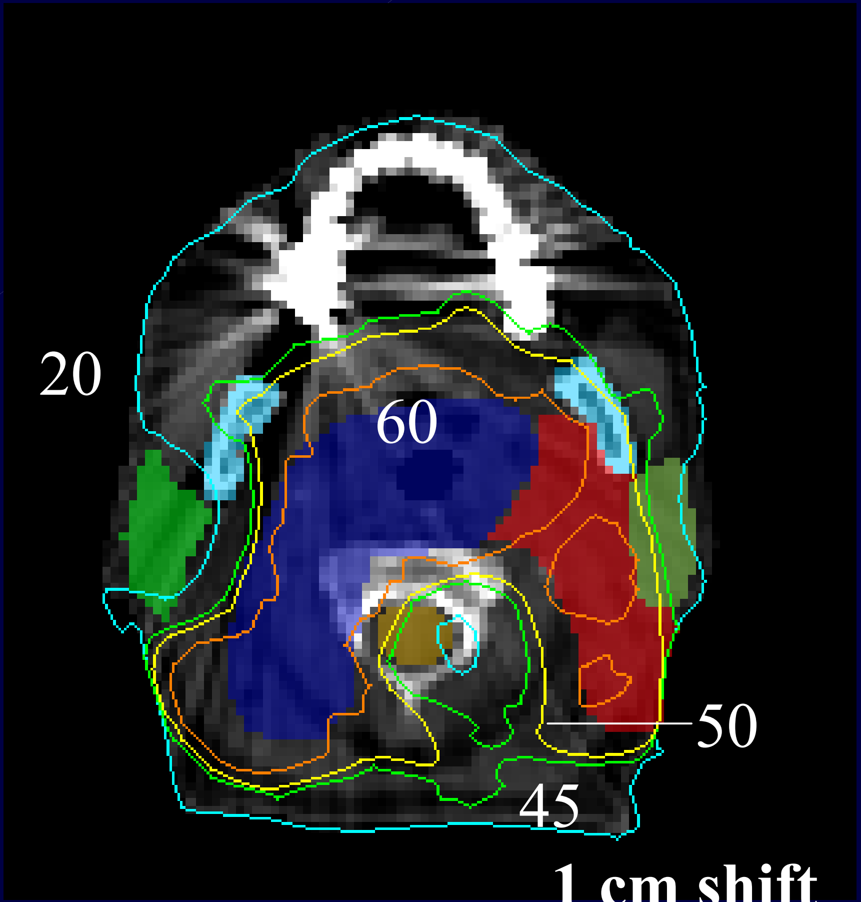
Table Angle: 180°

Couch Movement Instructions	Gantry Start	Gantry End	MU Total	MU Per°	Rot Cnt
I 34.40	350°	10°	488	1.43	1
I 51.20	350°	10°	471	1.39	1
I 68.00	350°	10°	466	1.37	1
I [illegible]	350°	10°	[illegible]	[illegible]	1
I 101.60	350°	10°	442	1.30	1
I 118.40	350°	10°	438	1.29	1
I 135.20	350°	10°	425	1.25	1
I 152.00	350°	10°	504	1.48	1

High Conformality: Spatial Positioning QA

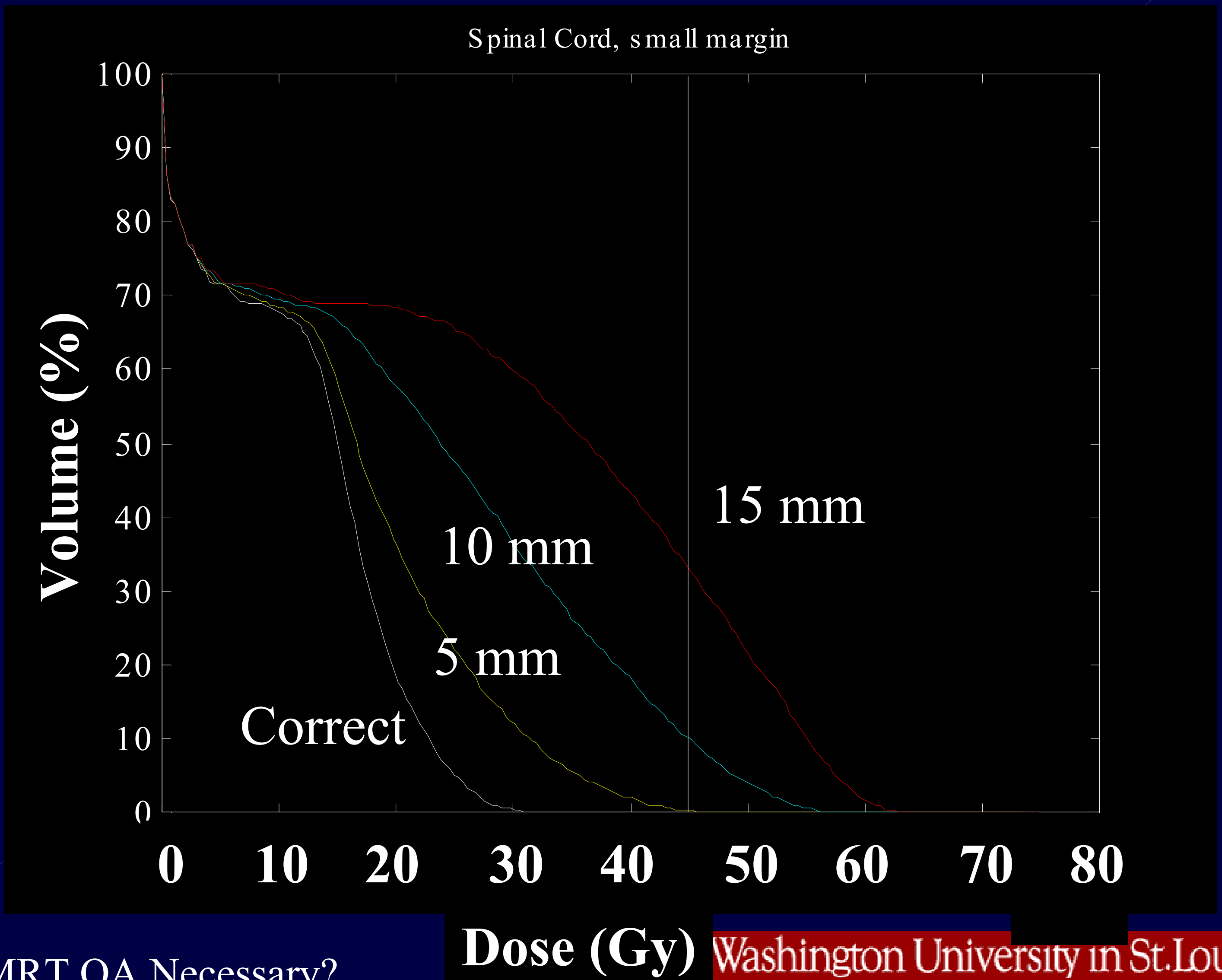


Correct Positioning

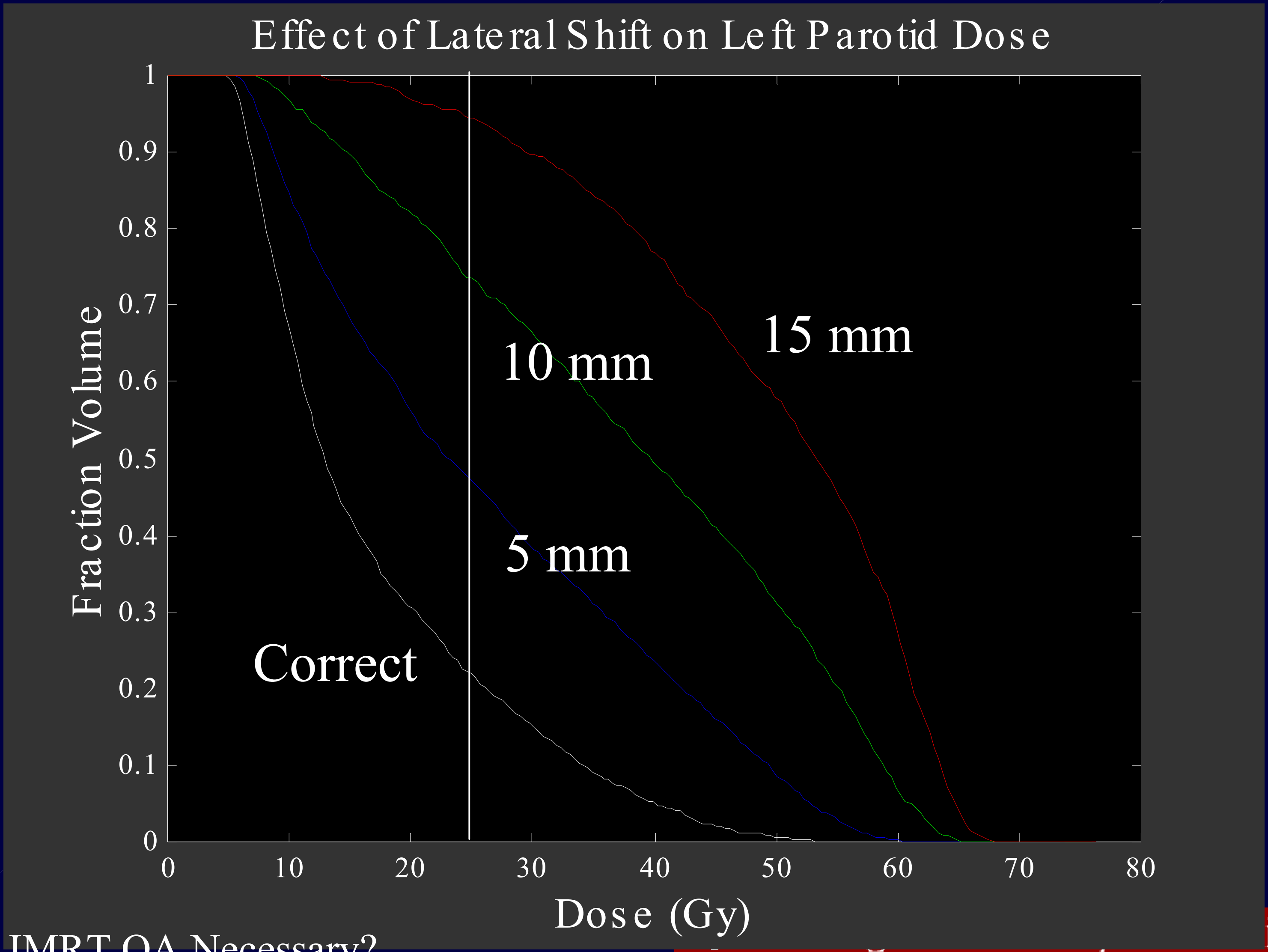


1 cm shift

Spinal Cord, Small Margin



Left Parotid

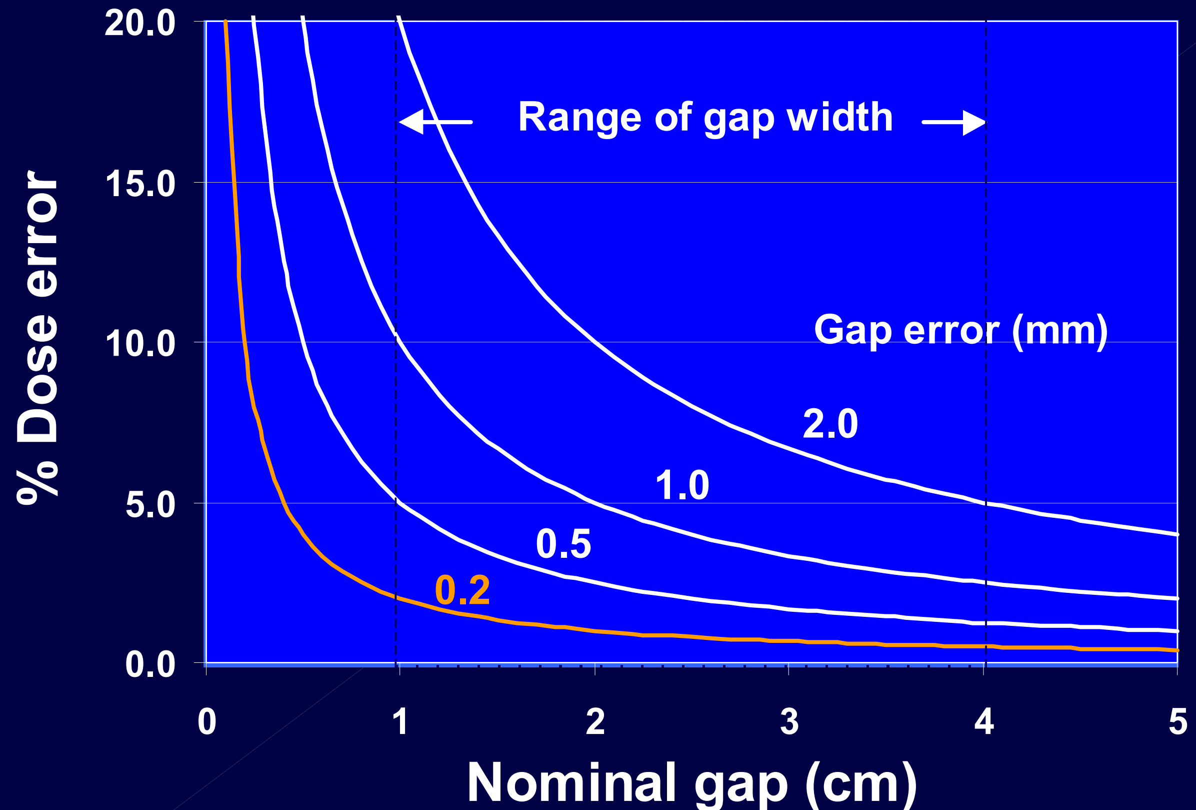


Initial QA for a Clinic

- Delivery System
- Treatment Planning System
- Process

Why Delivery QA?

Gap error ⟶ Dose error



Bottom line: Leaf calibration errors = dose delivery errors in target
Maintenance needs to understand this!

Slide courtesy of T. LoSasso

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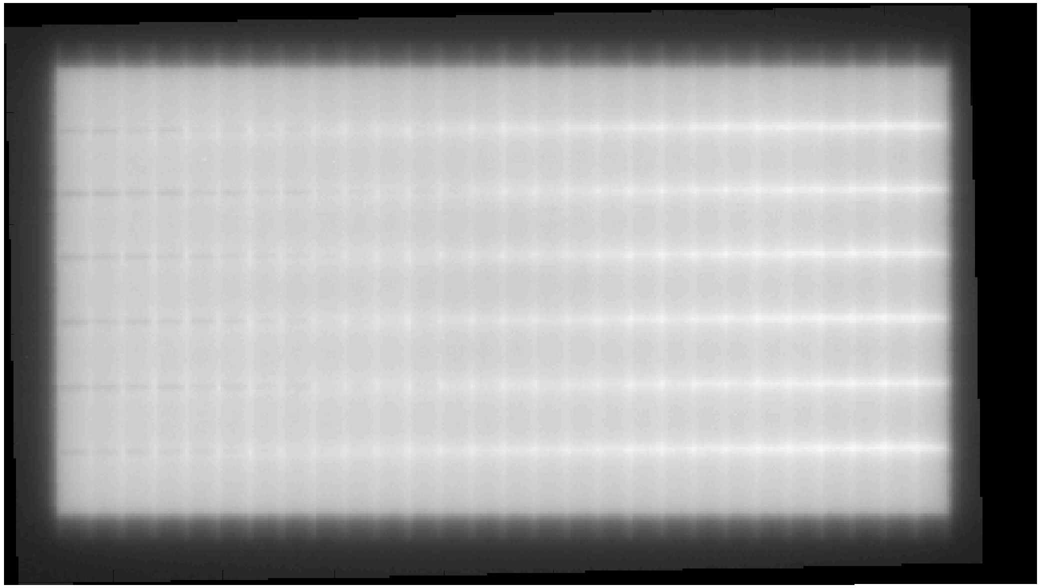
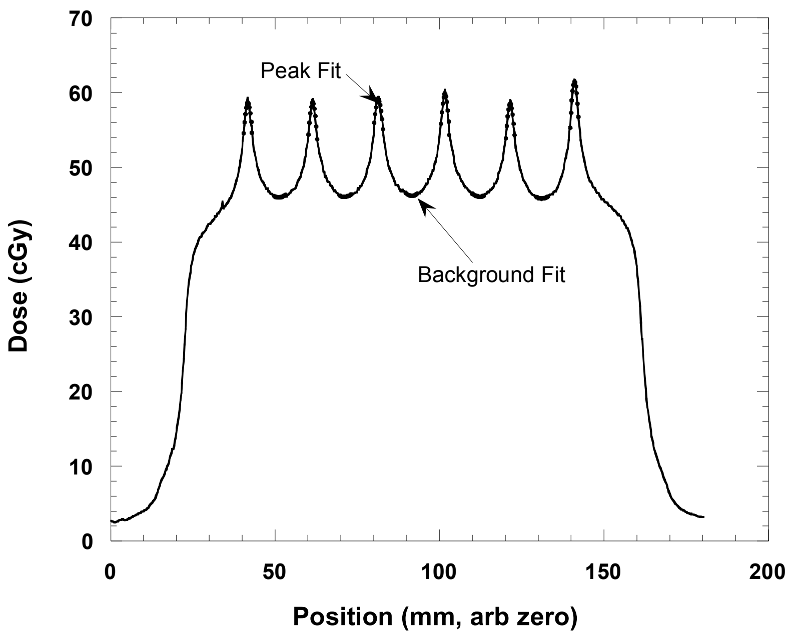
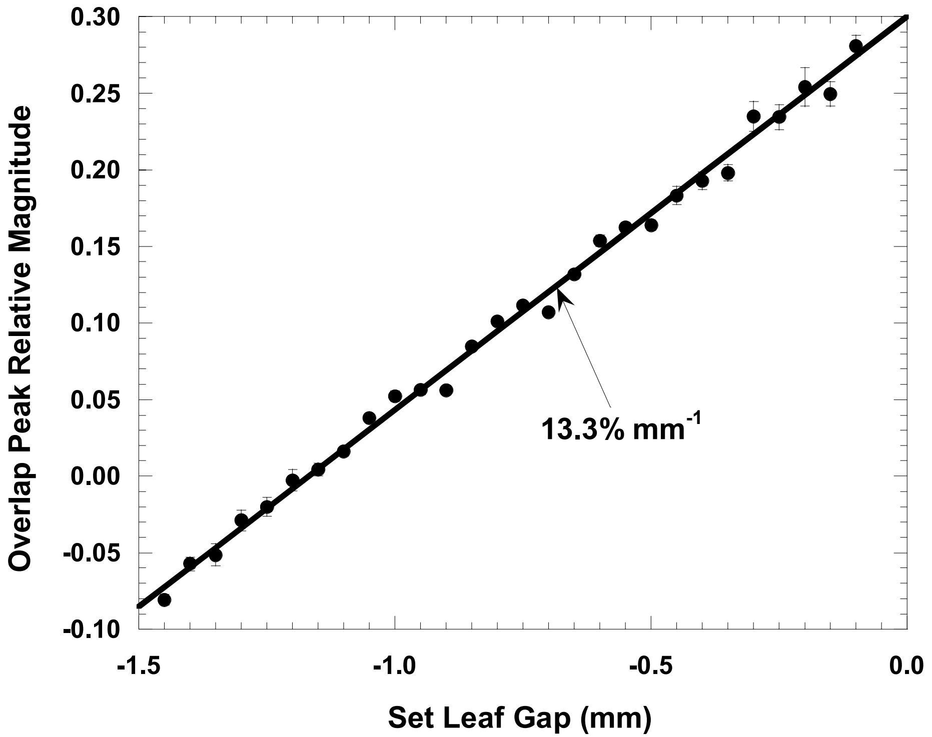
Why Delivery QA?



SMLC mismatch = Dose Error

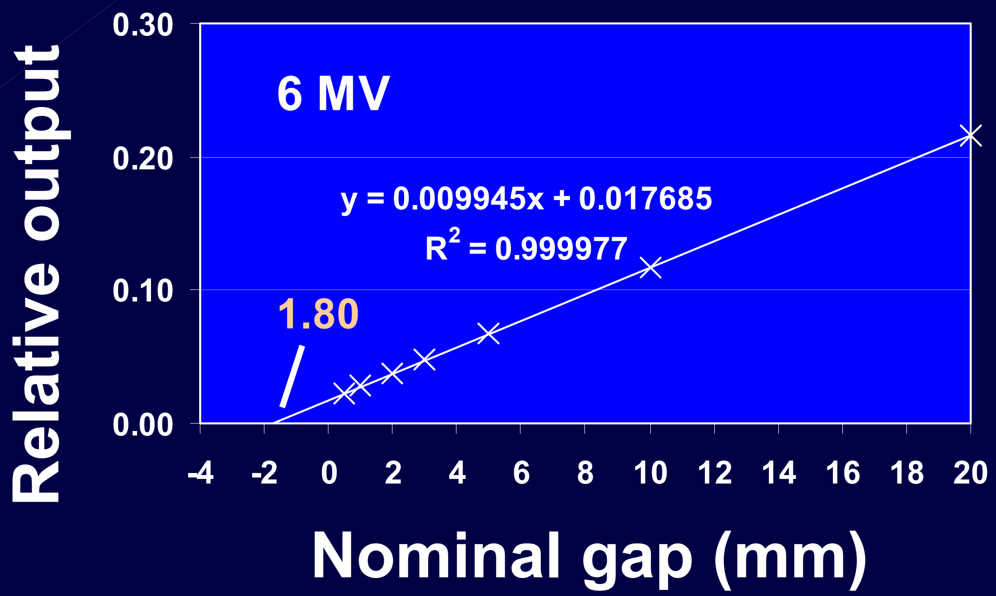




Initial QA for a Clinic

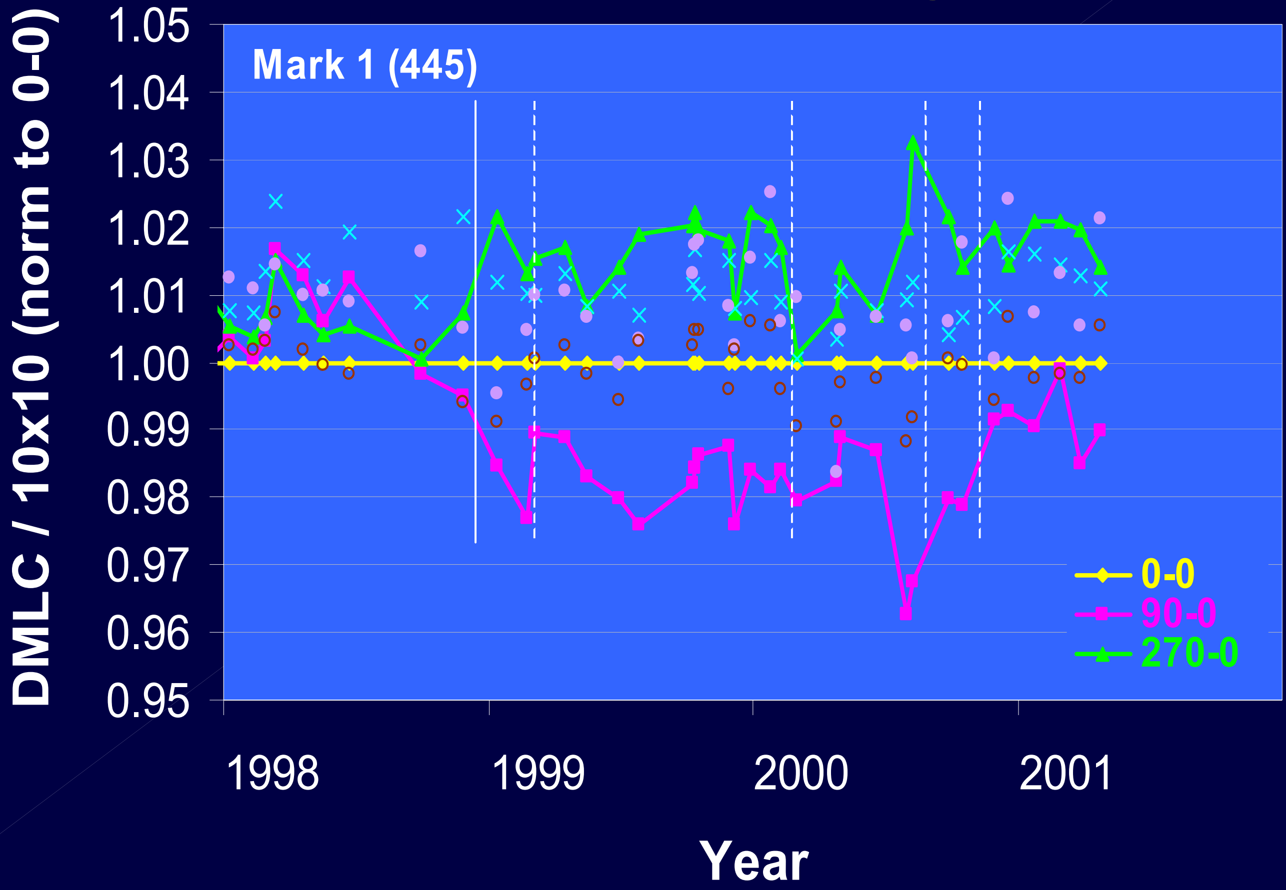
QA of Delivery System

- MLC calibration – Dynamic
  - Leaf offset (definition of leaf position)
  - Series of scanning fields (changing field width)
  - Extrapolation to 0 dose, provides offset
  - Offset function of beam energy
  - Check wrt gantry angle
- Other parameters
  - Leaf transmission
  - Interleaf leakage
  - Leaf penumbra



Data courtesy of LoSasso

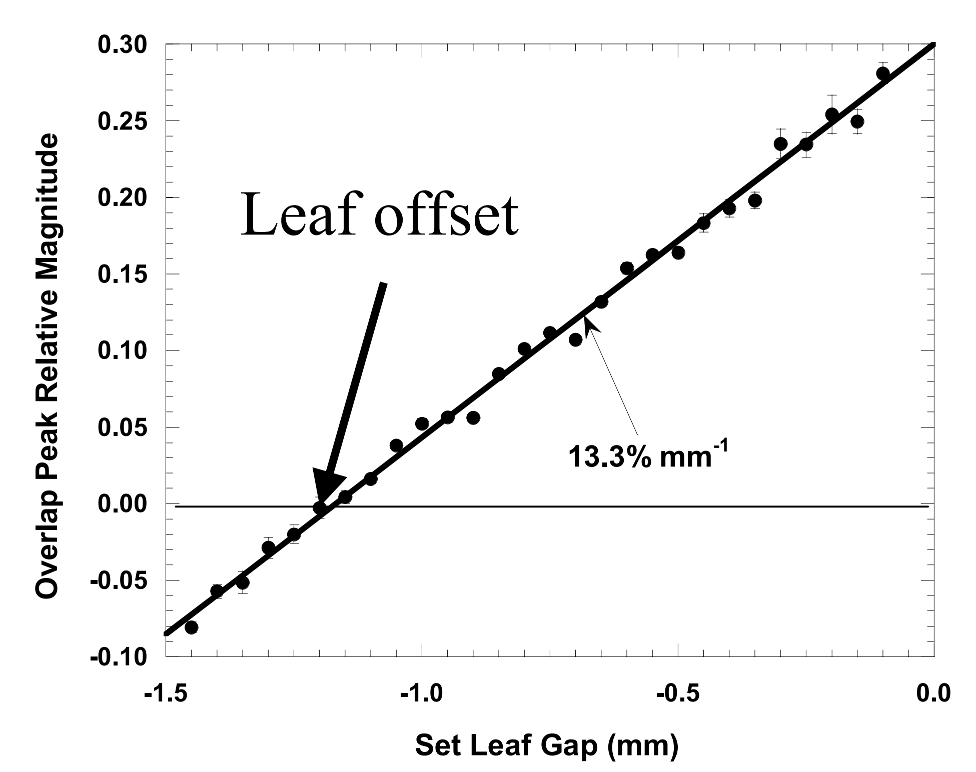
DMLC Output Stability
Time and Angle



Slide courtesy of LoSasso

QA of Delivery System

- MLC Calibration – Static
  - Leaf offset
  - Series of static fields (changing abutment)
  - Overlap regions scanned
  - Compromise between overdose and underdose (rounded leaf ends)
  - Check wrt gantry/collimator angle/beam energy



QA of Planning/Delivery System

- Two are linked
- Plans (if available by TPS)
  - Open fields (dose per MU and PDD)
  - More complex fluences
  - Used to check user input data

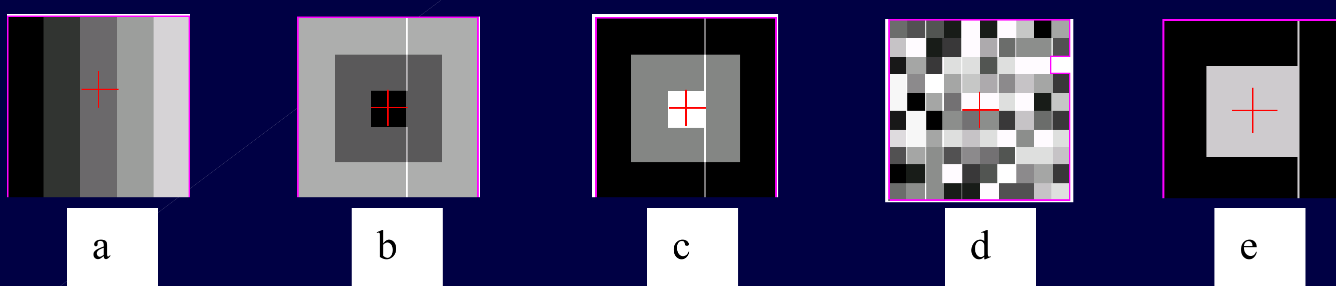
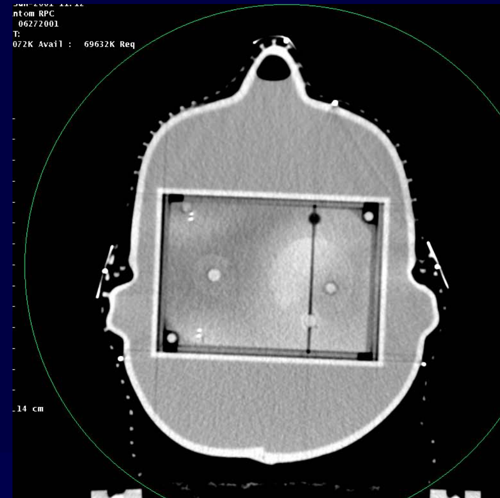


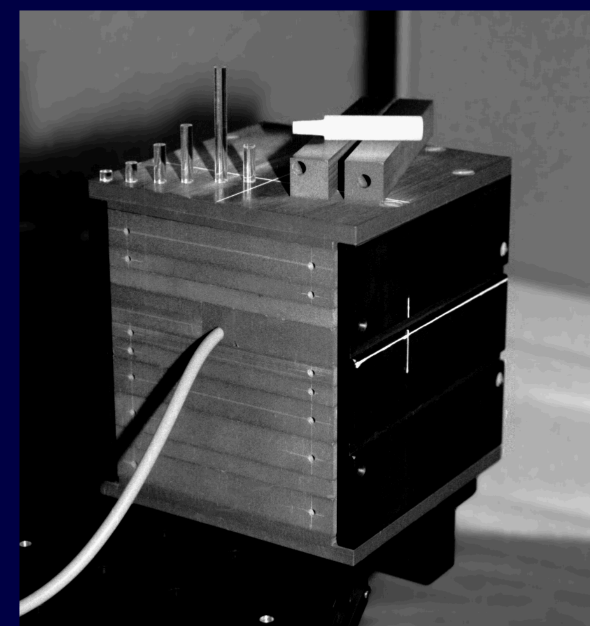
Figure 3.3 Examples of user-controlled intensity shapes used for commissioning tests.

Initial QA: Process

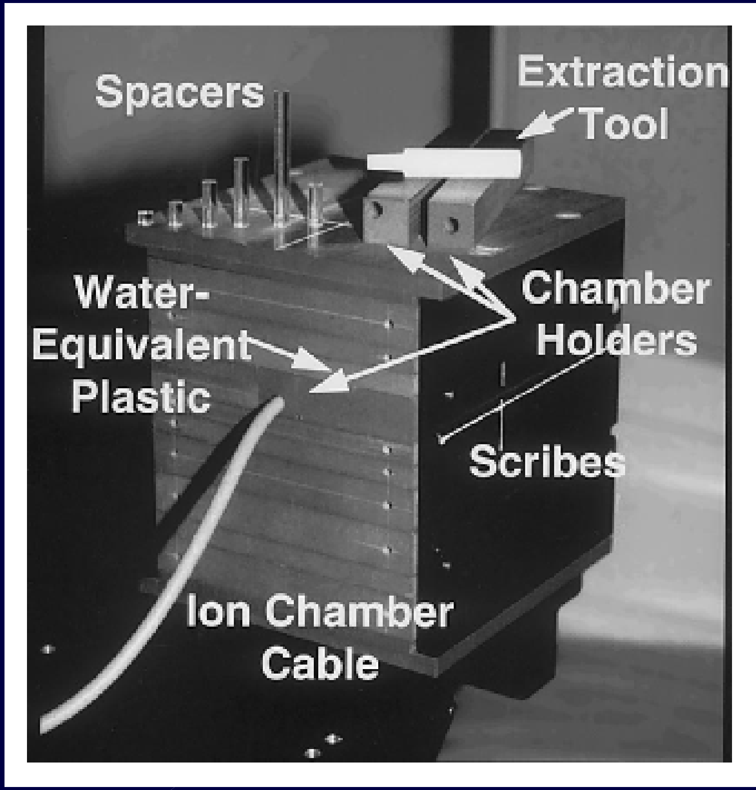
- Important to validate dose (magnitude and position) prior to first treatment
- All items in common with 3DCRT (e.g., patient name, gantry angles, orientations…) should be validated
- Direct dose verification is most novel with IMRT
- Phantoms
  - Anthropomorphic
  - Geometrically regular
- Scanned, planned, treated (target volumes and CS)
- Unambiguous geometry
- Independent spatial registration
- Quantitative dose comparisons

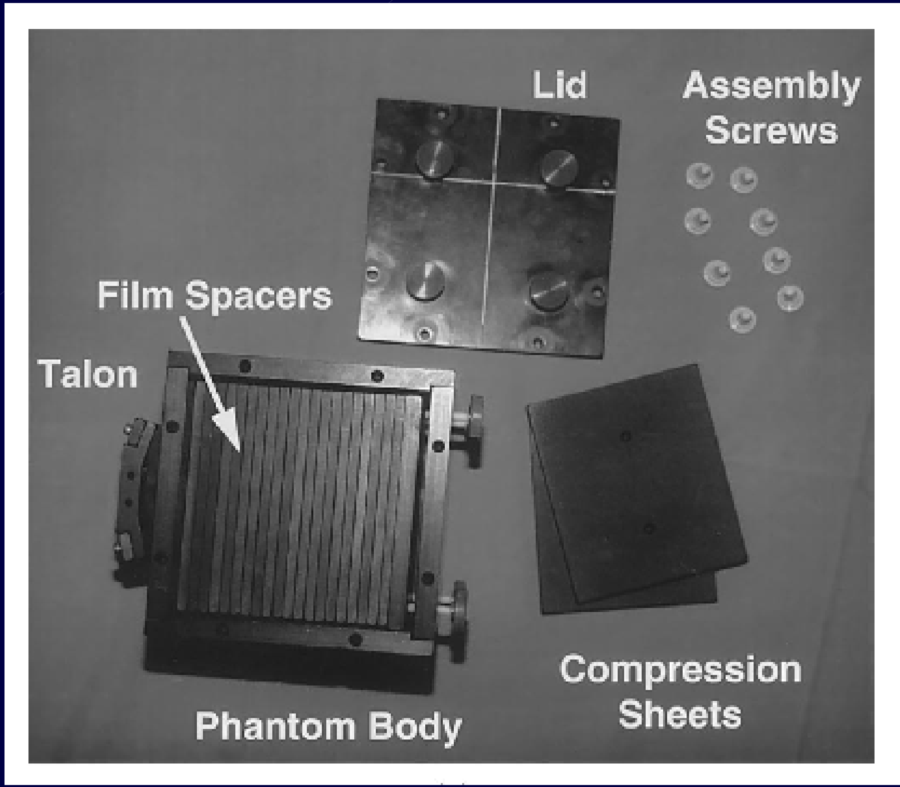


- Anthropomorphic
  - Internal heterogeneities are anatomically correct
  - Heterogeneities may make dose measurements and comparisons complicated
  - Multiple dosimeter comparisons difficult
  - Geometric alignment may be difficult
- Geometrically Regular
  - Alignment straightforward
  - Internal construction precise
  - Multiple dosimeters straightforward



Phantoms For IMRT QA





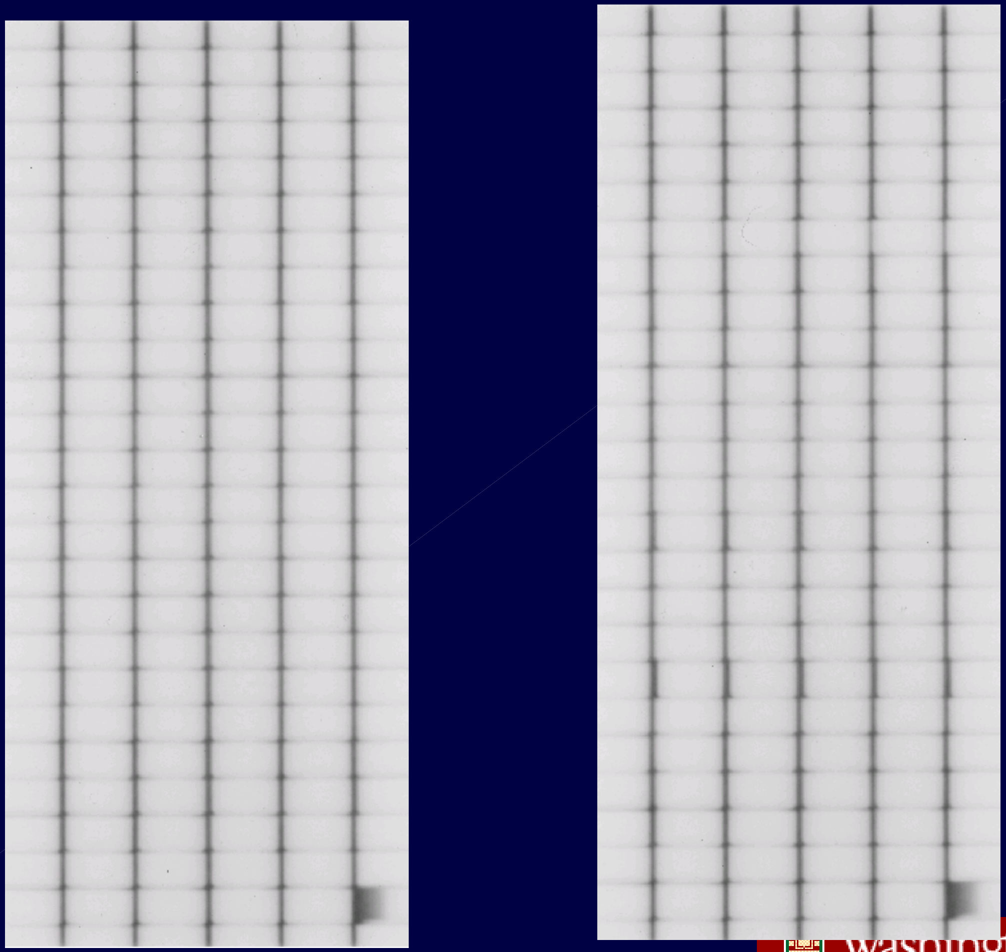
Routine QA for IMRT

- Delivery Systems
  - More qualitative (films by eye)
  - More sparse (e.g., CAX msmts)
  - More frequent checks (risk vs effort)
- Treatment Planning Systems
  - SMLC
  - DMLC

Routine Delivery QA Examples

Film test

1 mm bands **errors introduced**



← - 0.5 mm

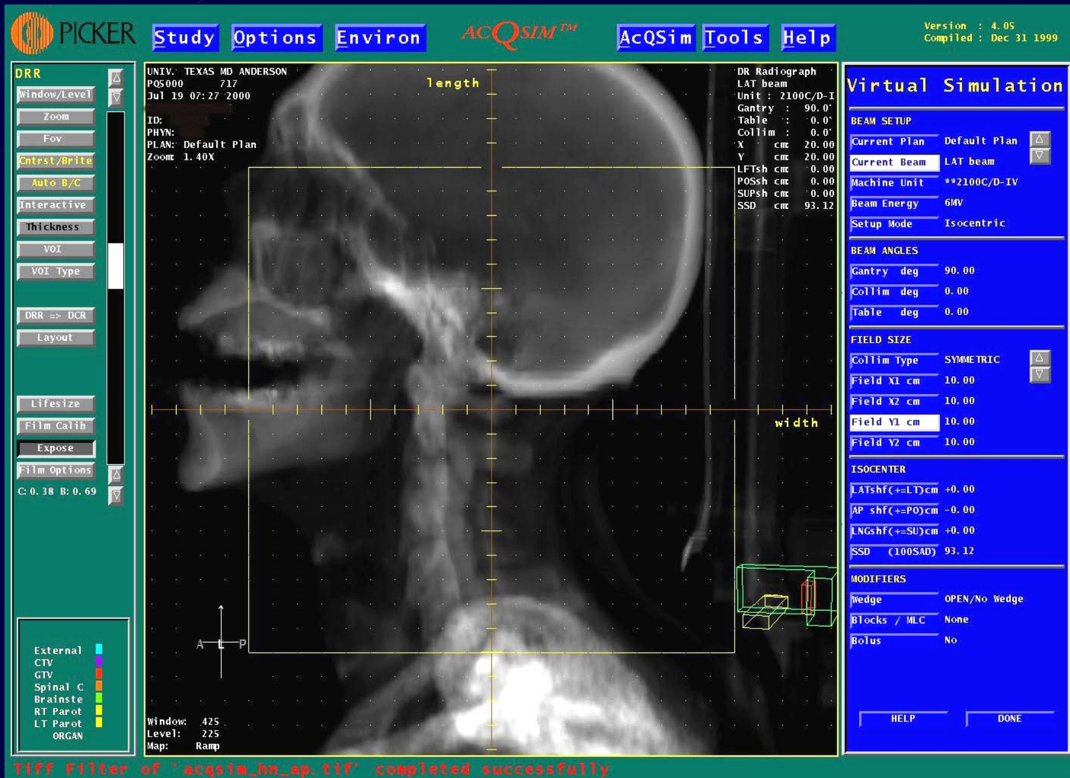
← - 0.2 mm

← + 0.2 mm

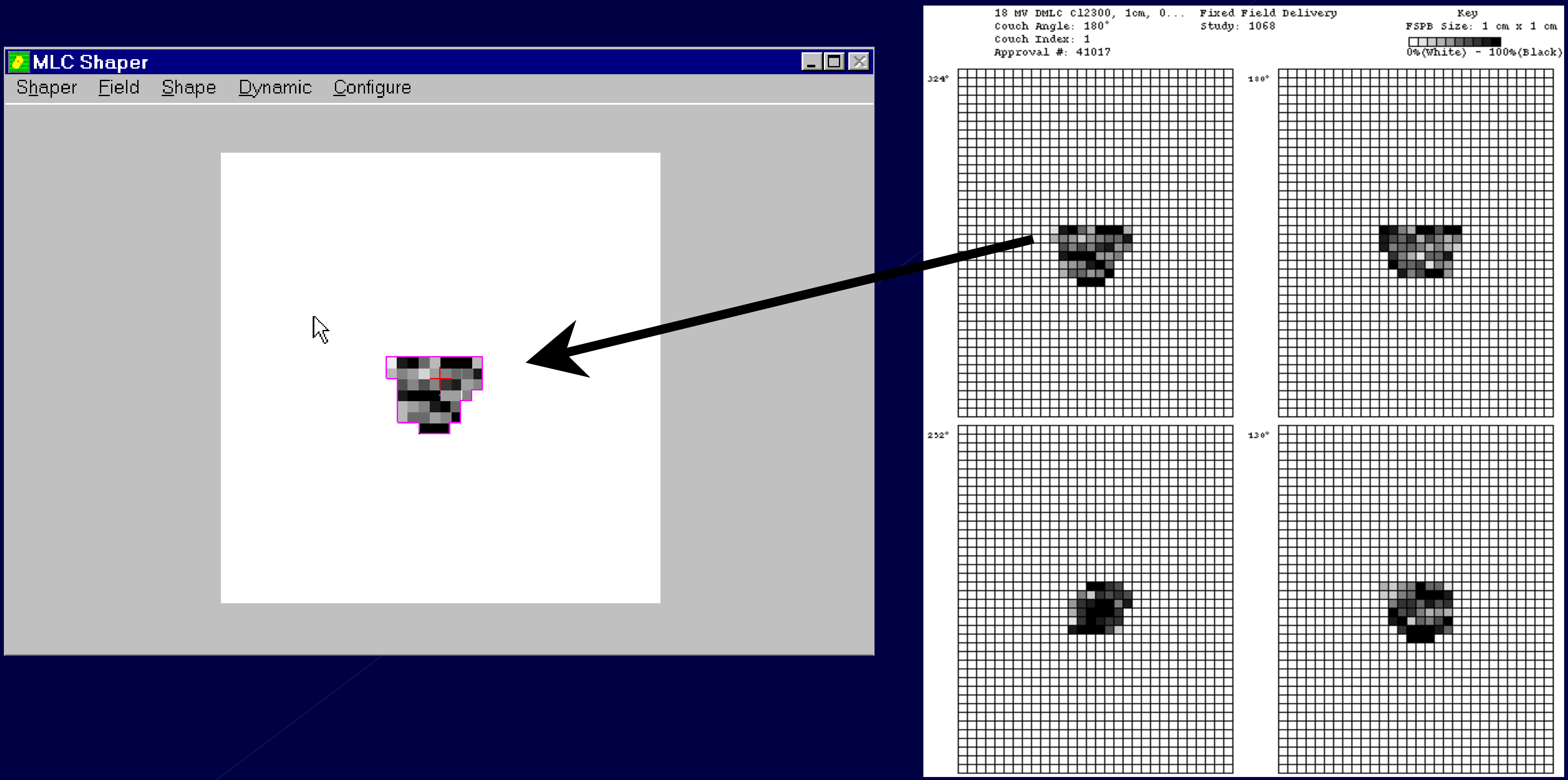
← + 0.5 mm

Patient-Specific QA

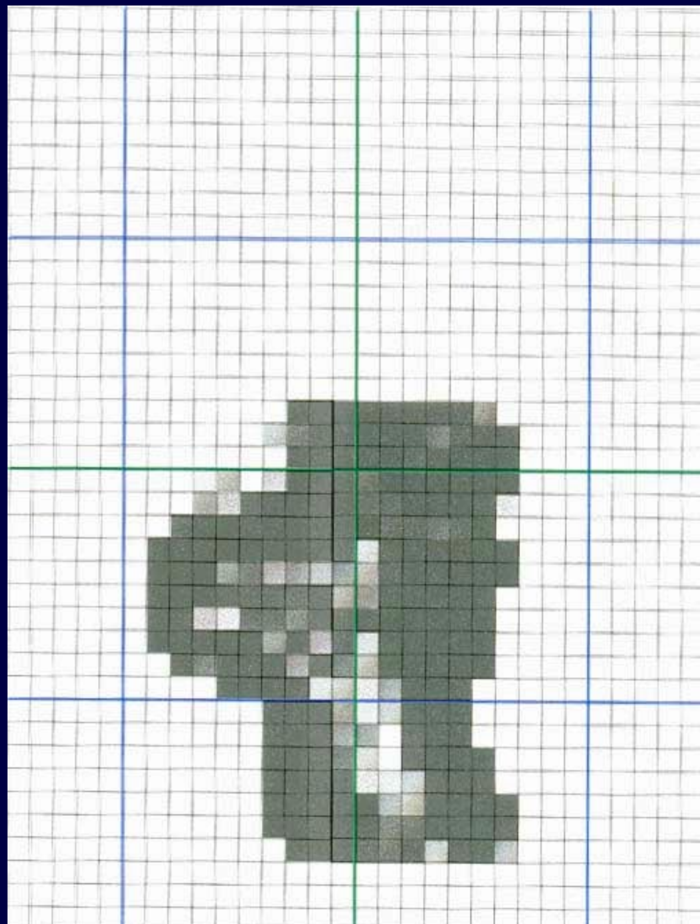
- Positioning and Immobilization
  - Inter-fraction motion similar to 3DCRT
  - Intra-fraction motion unique to IMRT
  - No definitive guidelines for immobilization yet (some studies being conducted to identify effect of motion on IMRT delivery)
  - Current advice: minimize where possible, no IMRT in lung, liver without breath-hold/gating
  - Use same technology as 3DCRT (orthogonal films/ portal images)



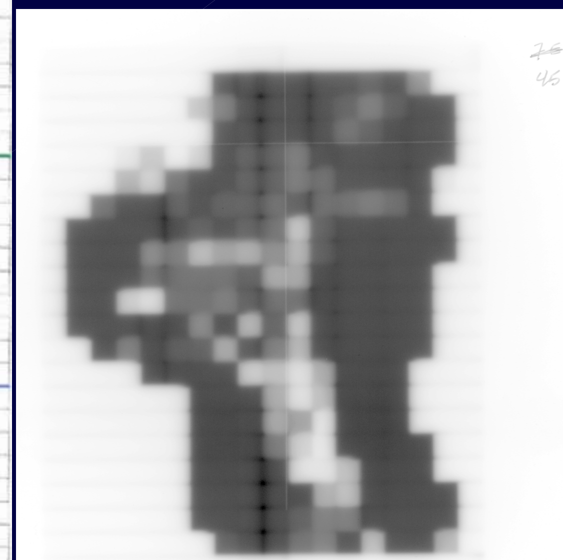
QA of Machine Instructions & R&V System



Qualitative Film Measurement



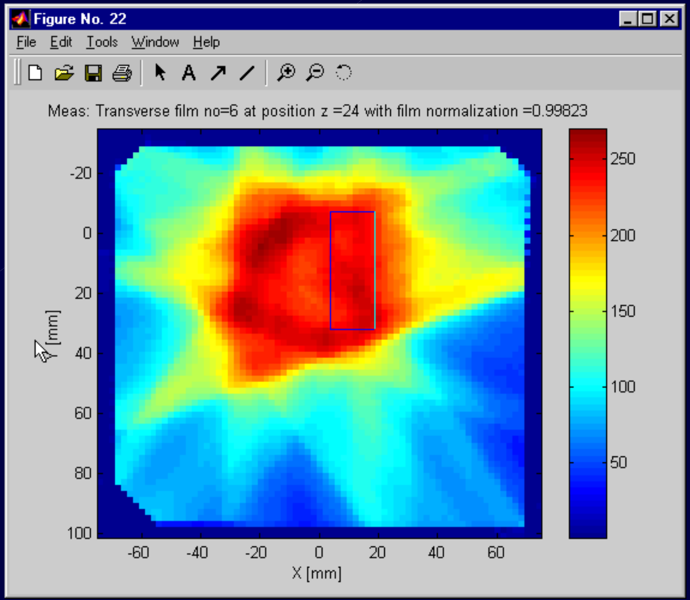
Corvus Plan Output (combined)



Film Measurement
(100cm SFD, 2cm buildup)

Slide courtesy of Lei Dong
Routine QA for IMRT

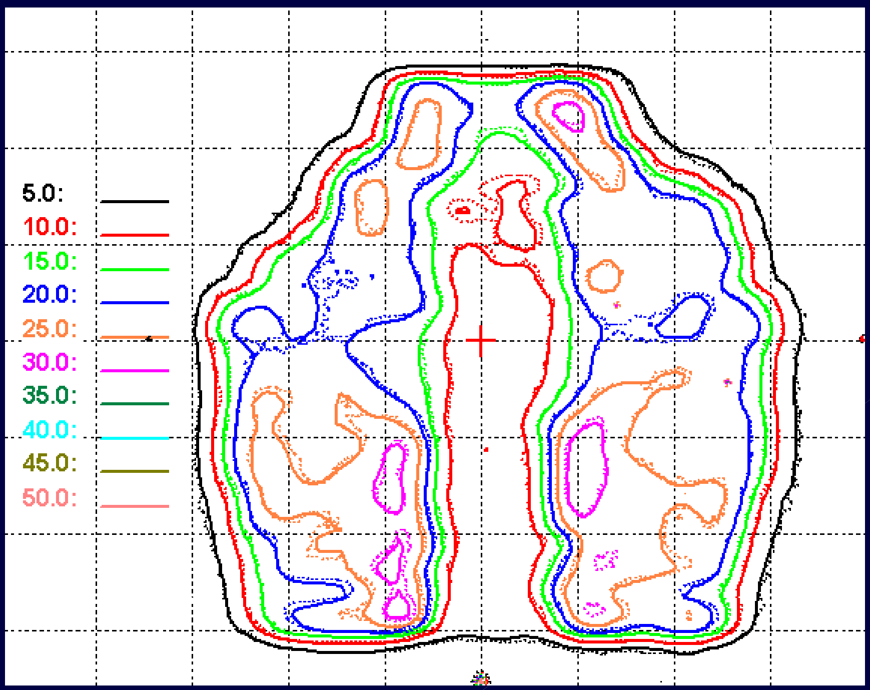
Dose/MU Validation

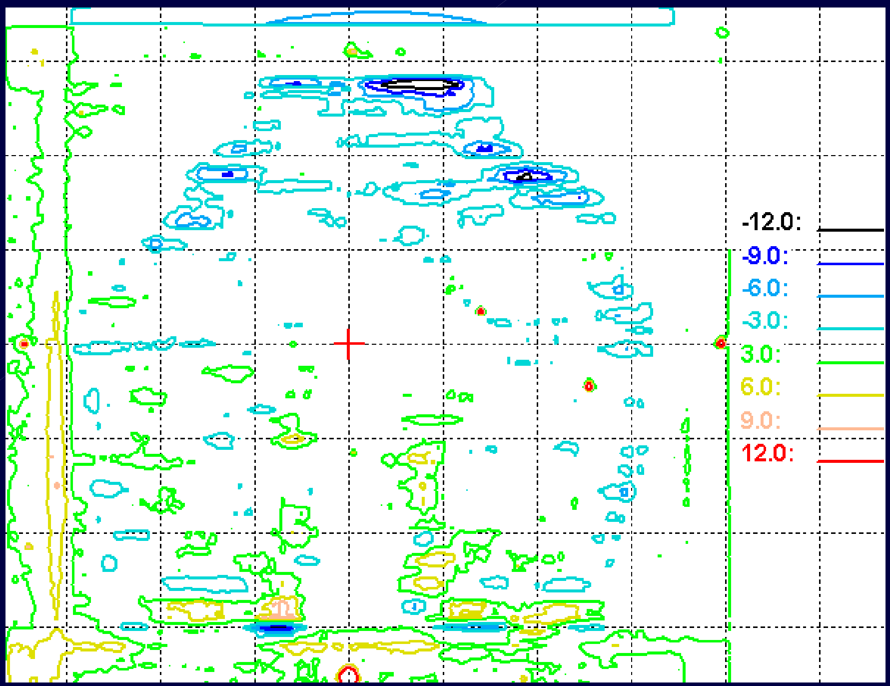


- Measurement based
  - Phantom plan
  - Irradiation
  - Dosimeters
    - Ionization chamber (quantitative, sparse)
    - Radiographic film (more qualitative, 2-dimensional)

Single Field – Flat Phantom

Nasopharynx - PA field





Overlay

Plan

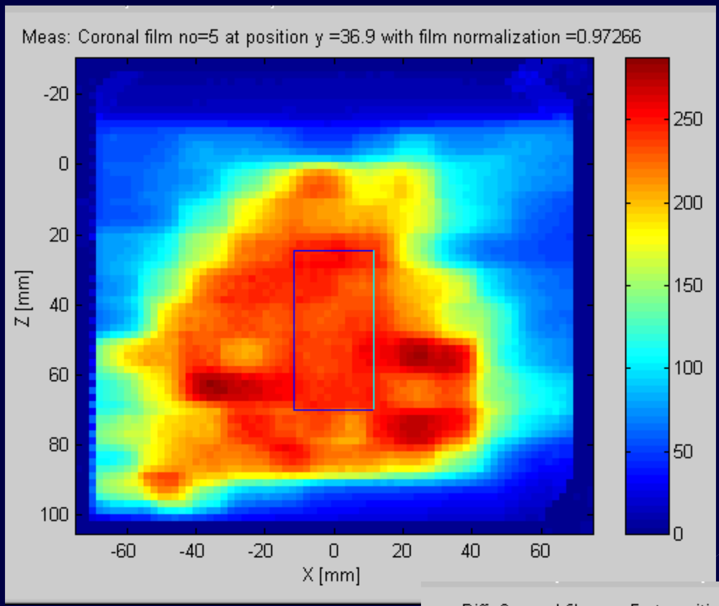
Film

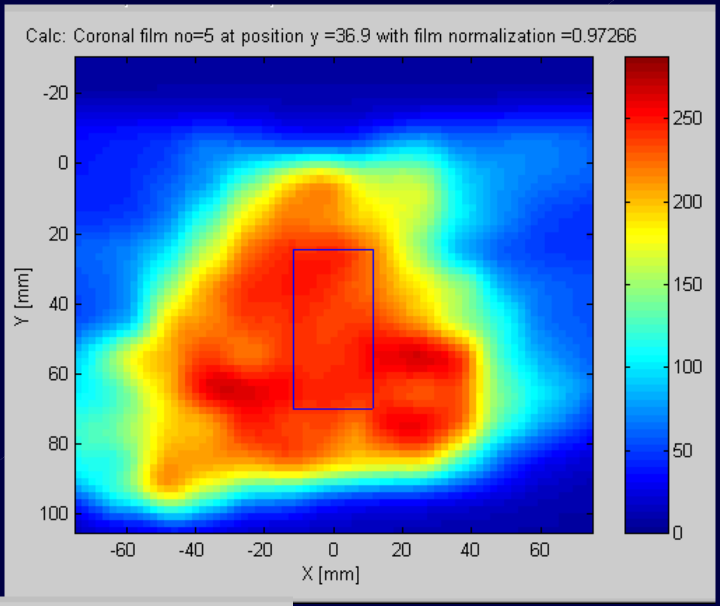
Dose difference

Film - plan

Slide courtesy of LoSasso

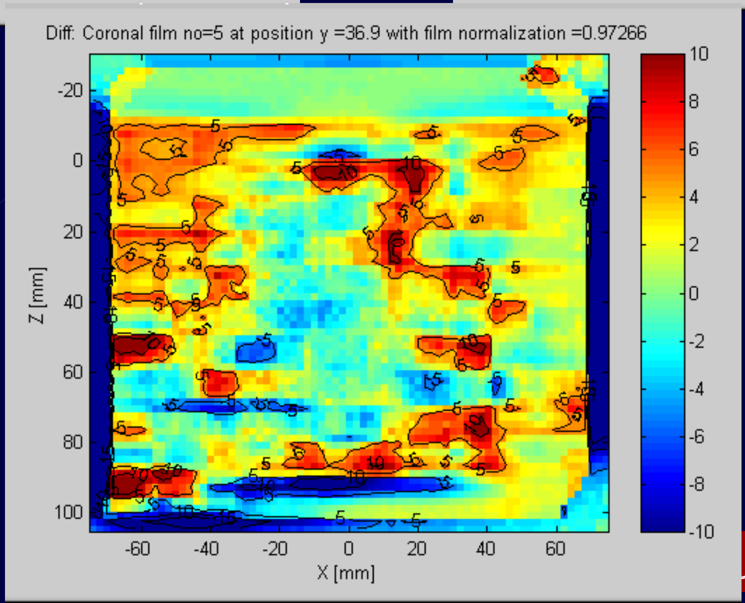
Multiple Field – In Phantom





Measurement

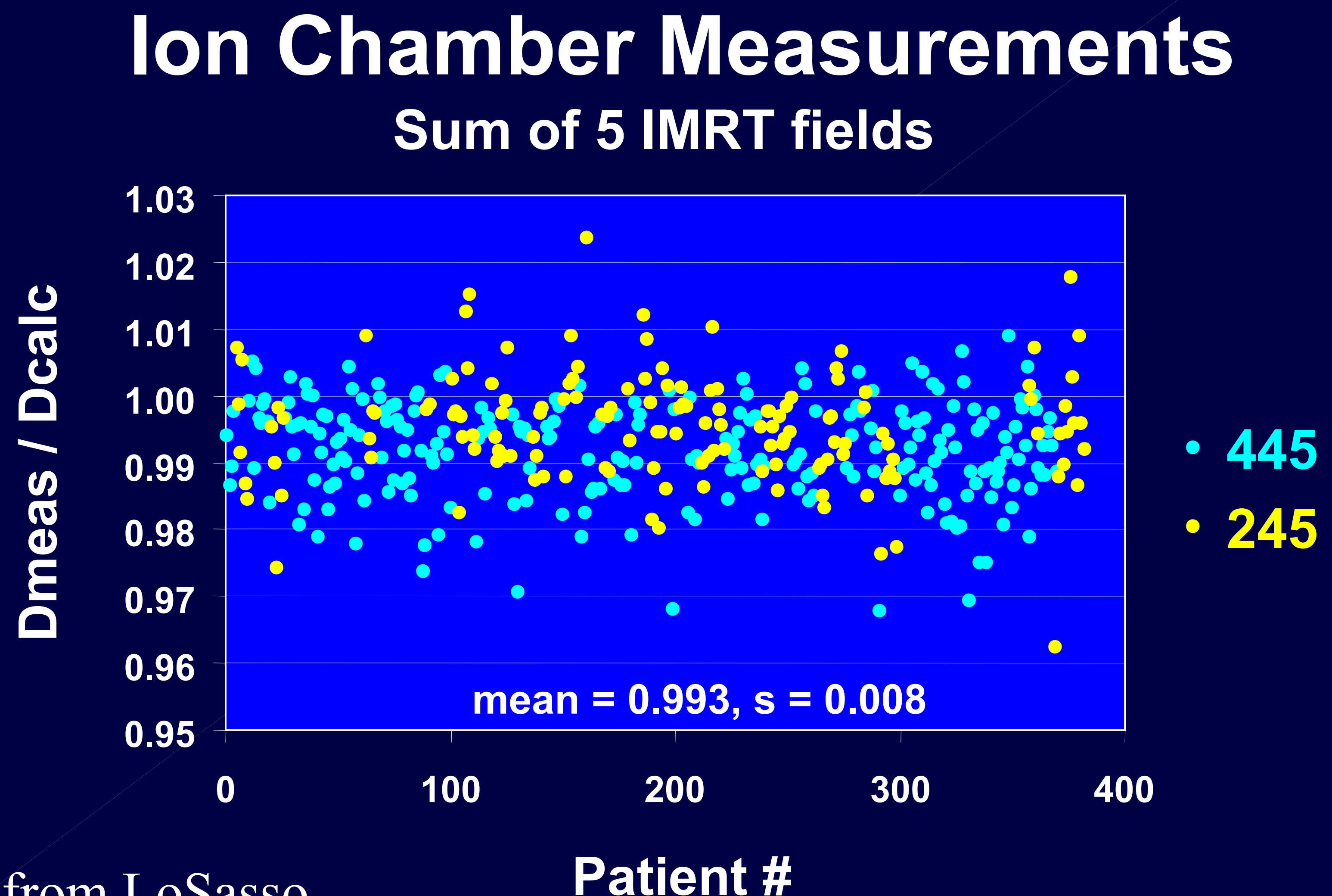
Calculation



Coronal

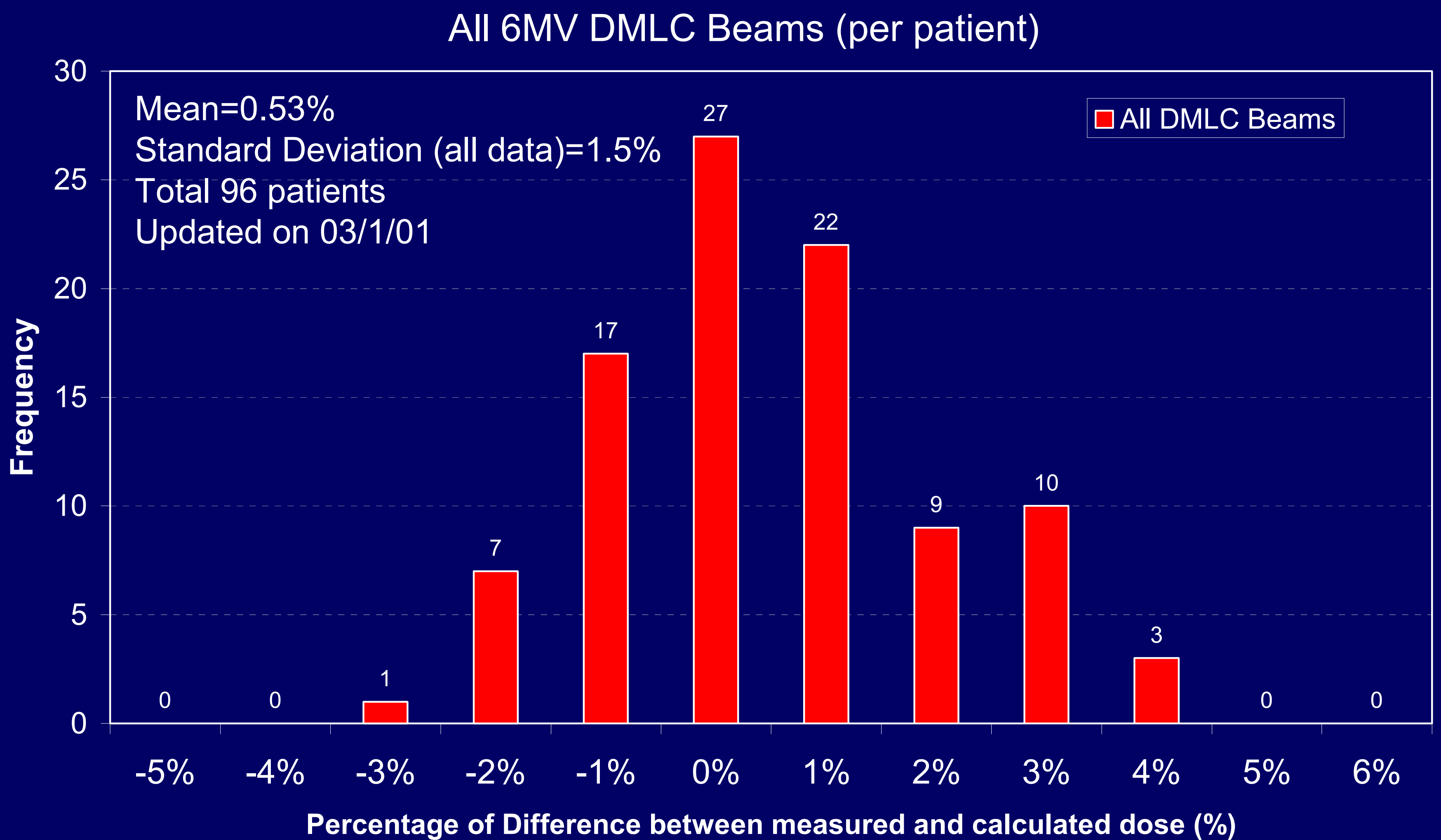
Difference

Ionization Chamber Statistics



Data from LoSasso

Ionization Chamber Statistics

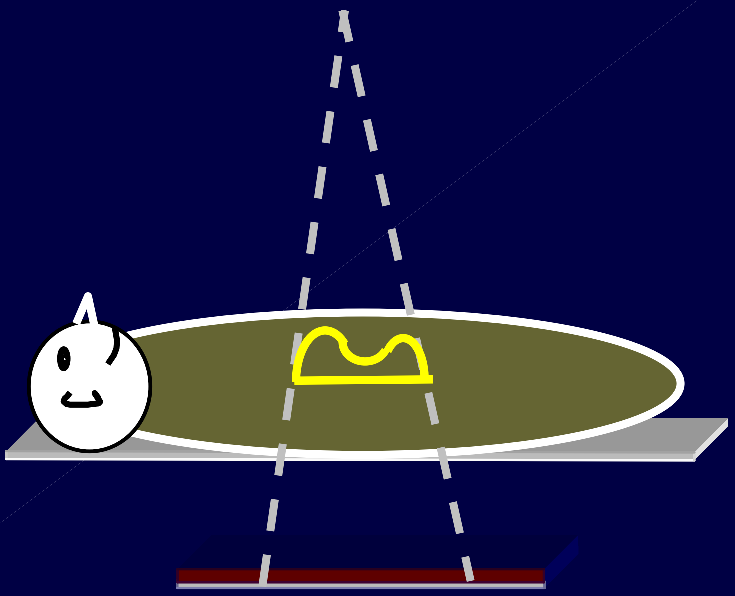


Slide courtesy of Lei Dong

Fluence (Fluence-Dose) Validation

- Principally used with EPIDs
- Provides some level of confidence that
  - Correct beams associated for patient
  - Correct position/orientation of beam
  - Limited verification of total delivered dose

EPID



EPID Readings

EPID calibration to portal dose rate

Dose integration to measured profile & dose

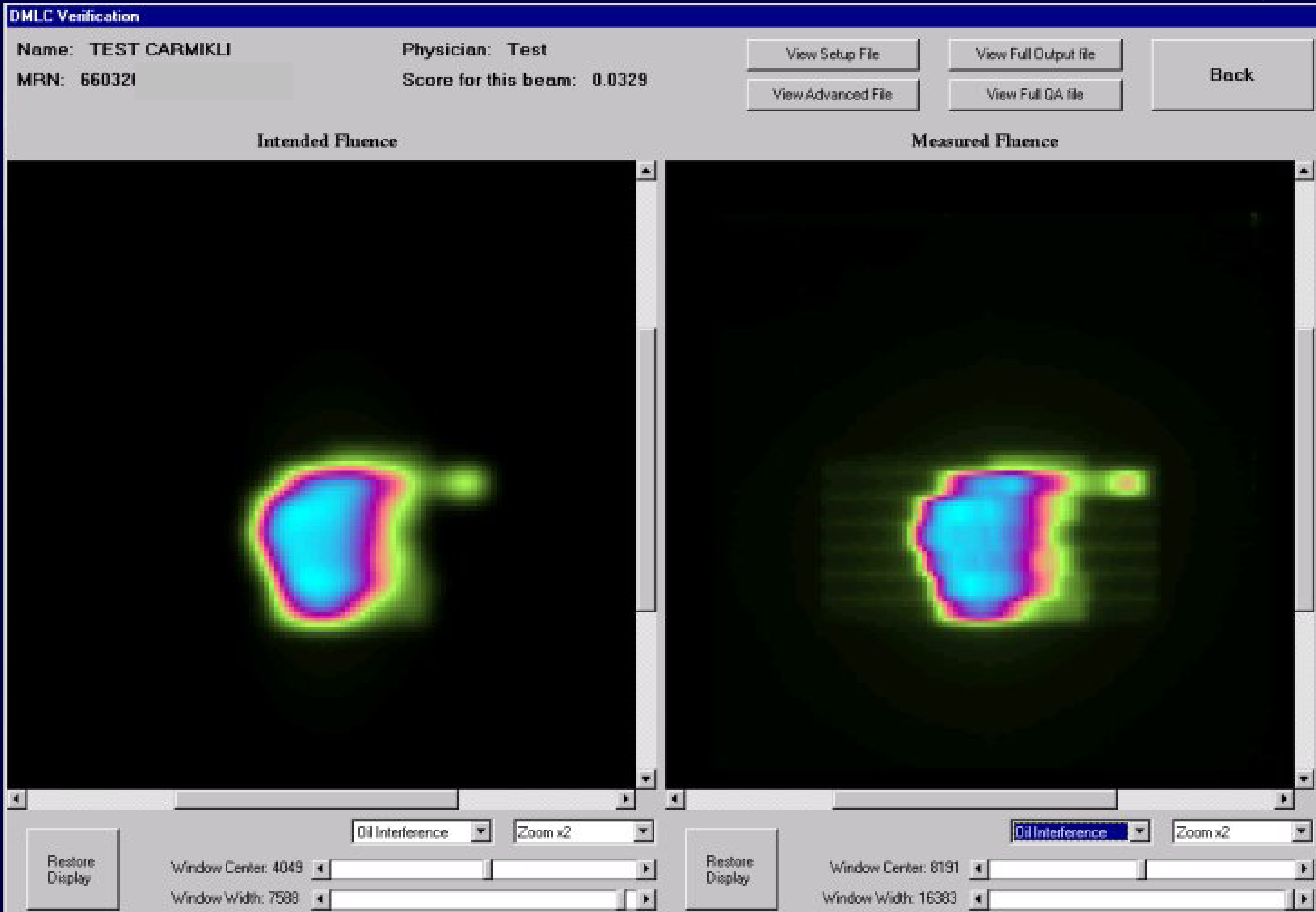
Comparison: Linear Regression

Intended profile & dose

Profile and dose verification

Slide courtesy of LoSasso

EPID



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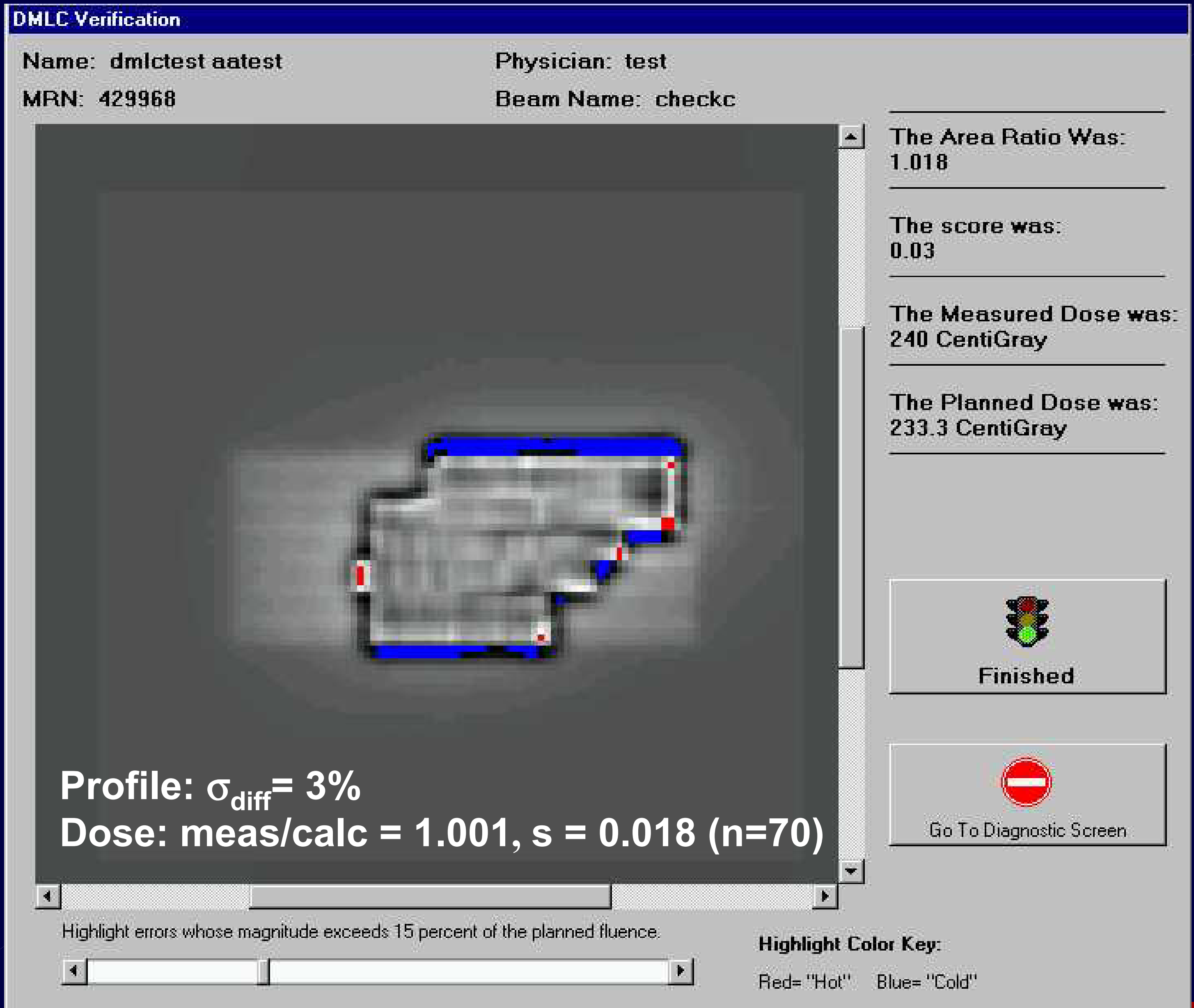
EPID



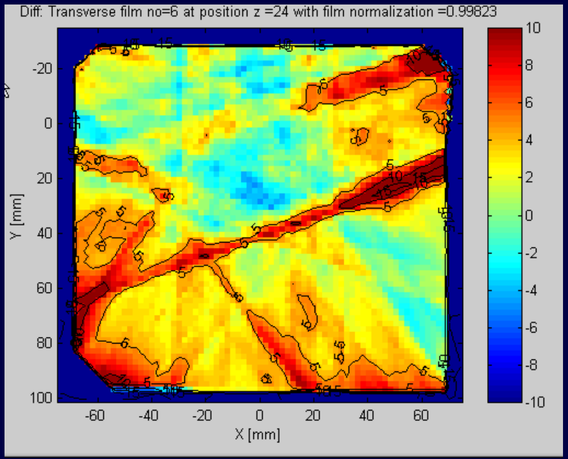
Profile: σ_{diff}= 3%

Dose: meas/calc = 1.001, s = 0.018 (n=70)

Slide courtesy of LoSasso

Discrepancy Analysis 1

- TPS:
  - Input data (penumbra, PDD, outputs, leaf offsets)
  - Accelerator model inaccurate
  - Dose calculation algorithm limitation
  - Leaf sequencing algorithm
- Experiment
  - MLC information transfer
  - Experimental setup
    - Geometry
    - Irradiation (wrong patient/field/MUs…) – >30 params for each irradiation
    - Bad HD curve
    - Bad processing



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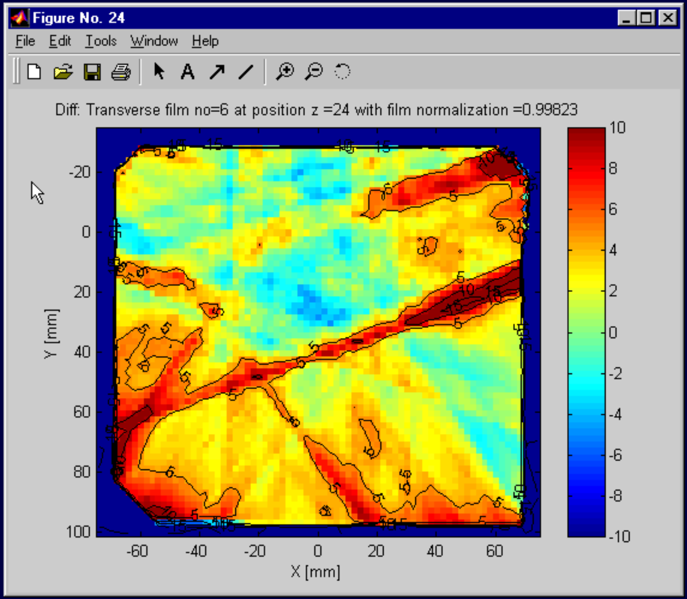
Discrepancy Analysis 2

- Delivery
  - Incorrect MLC calibration (readout vs position)
  - Incorrect accelerator operation (e.g. sticking leaf)
- Analysis
  - Film scanning/readout
    - Densitometer artifacts
    - User-input data (film position, etc.)
    - Incorrect registration

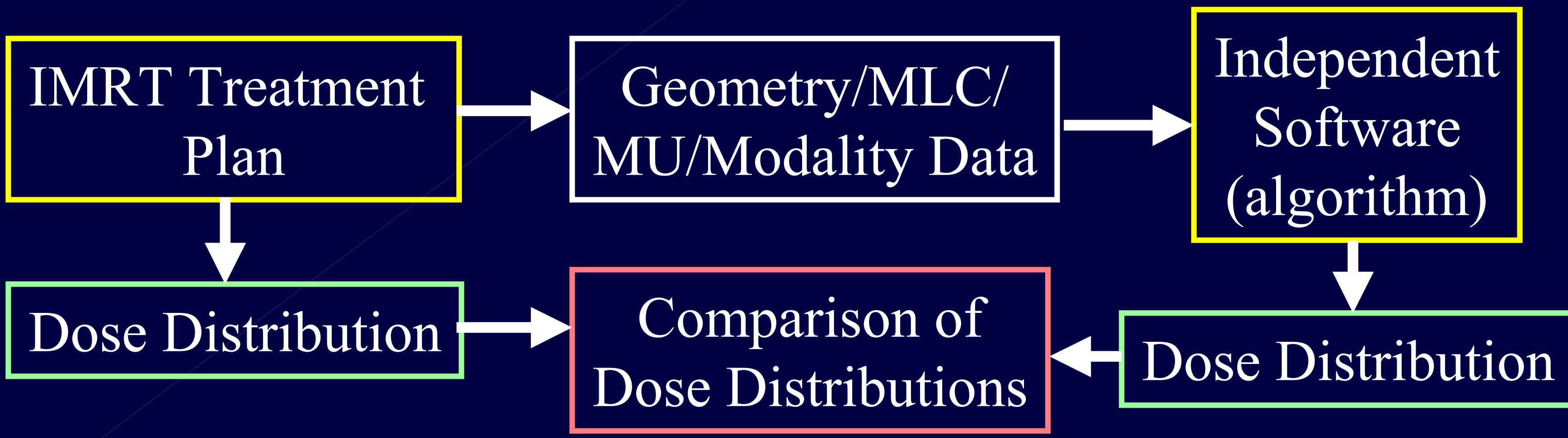
Criteria

- What constitutes an “acceptable” QA result?
  - Answer function of local dose gradient and magnitude (van Dyk)
    - Shallow gradient = dose difference
    - Steep gradient = distance-to-agreement
    - Overall = γ
    - Acceptable discrepancies function of dose
    - Should be function of location (structure)
      - Evaluations should be based on dvhs of structures!



Future of Patient QA

- Move from measurement to calculation based
- In US, some clinics implement calculation-based MU checks
  - Typically single points (CAX)



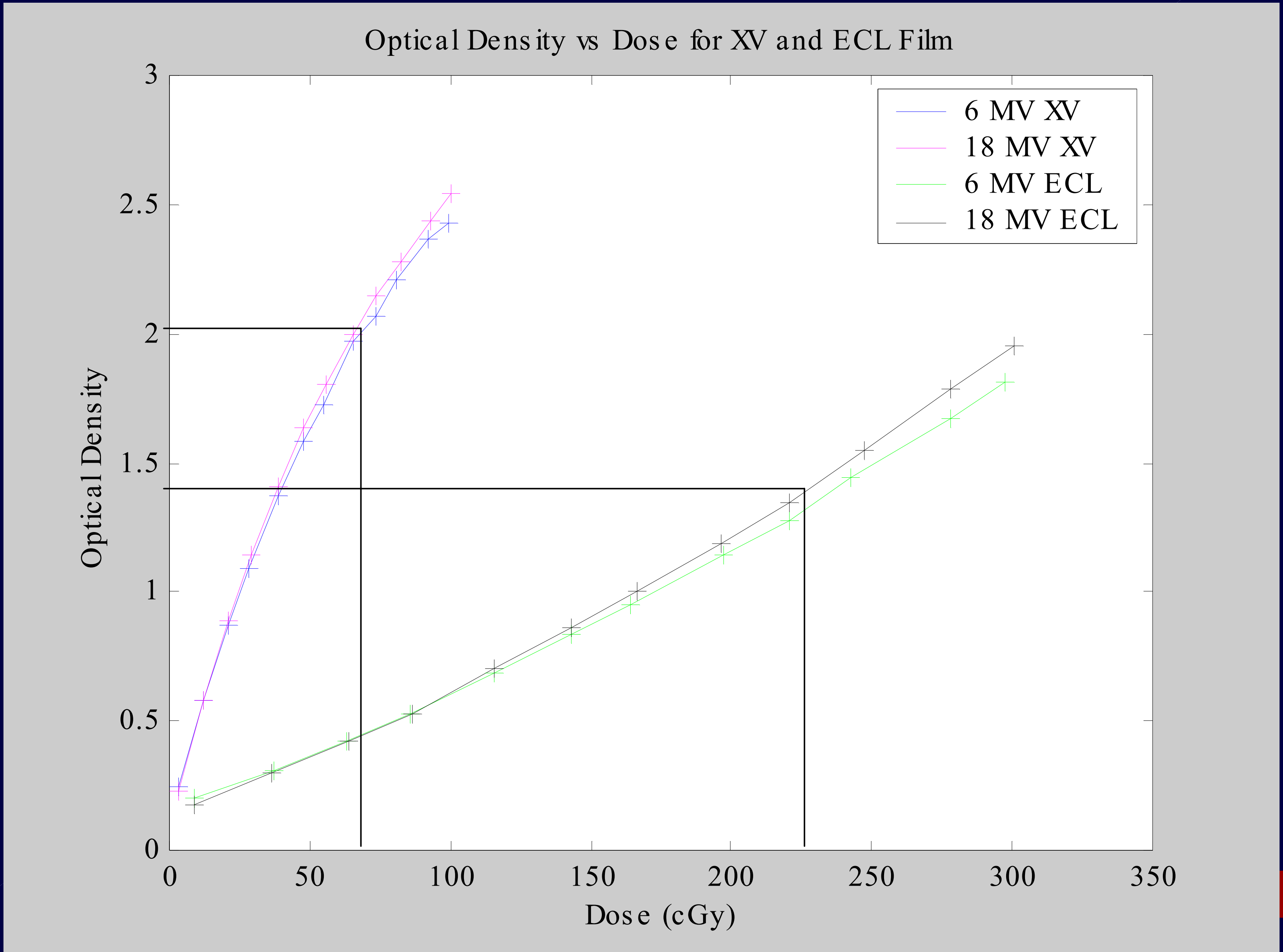
(MSKCC technique)

Does not guarantee the plan is correct!

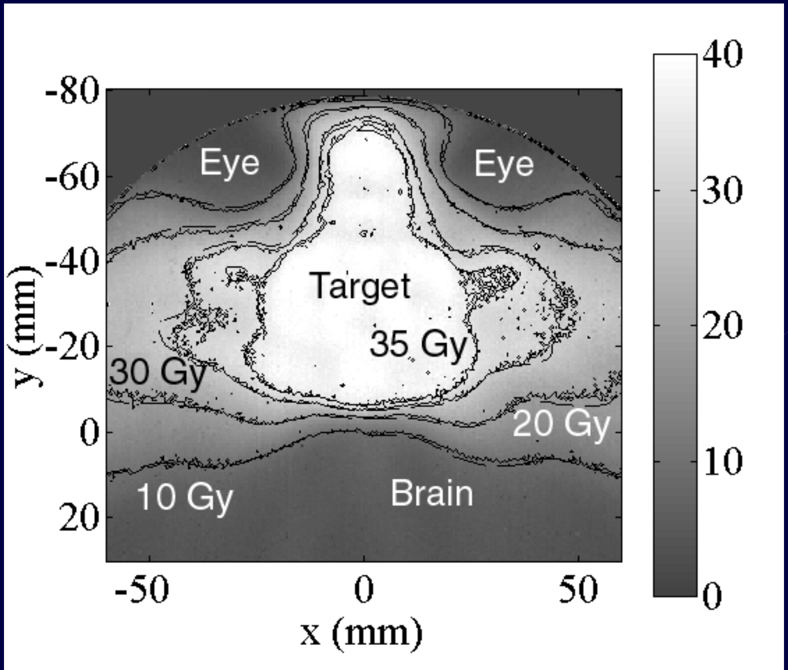
Future of Dosimetry

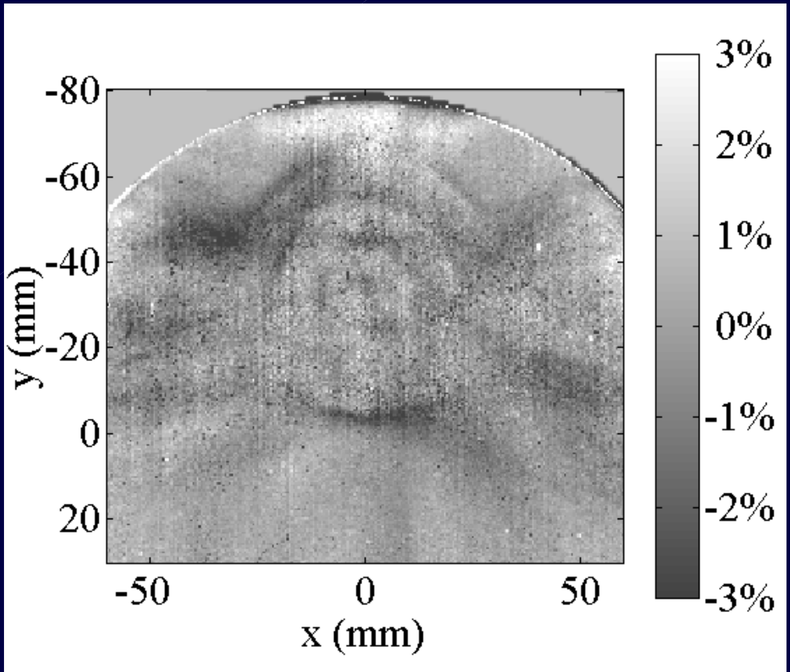
- Slower radiographic film (EDR2)
- More quantitative 2-D dosimeter
  - Radiochromic film
  - More sensitive film (2-10 Gy) being developed
  - Very good accuracy if used correctly
- 3-D dosimeters
  - Fricke gel
  - PAG gel (BANG)

Kodak EDR2


Optical Density vs Dose for XV and ECL Film
Optical Density
Dose (cGy)
6 MV XV
18 MV XV
6 MV ECL
18 MV ECL
0
0.5
1
1.5
2
2.5
3
0
50
100
150
200
250
300
350

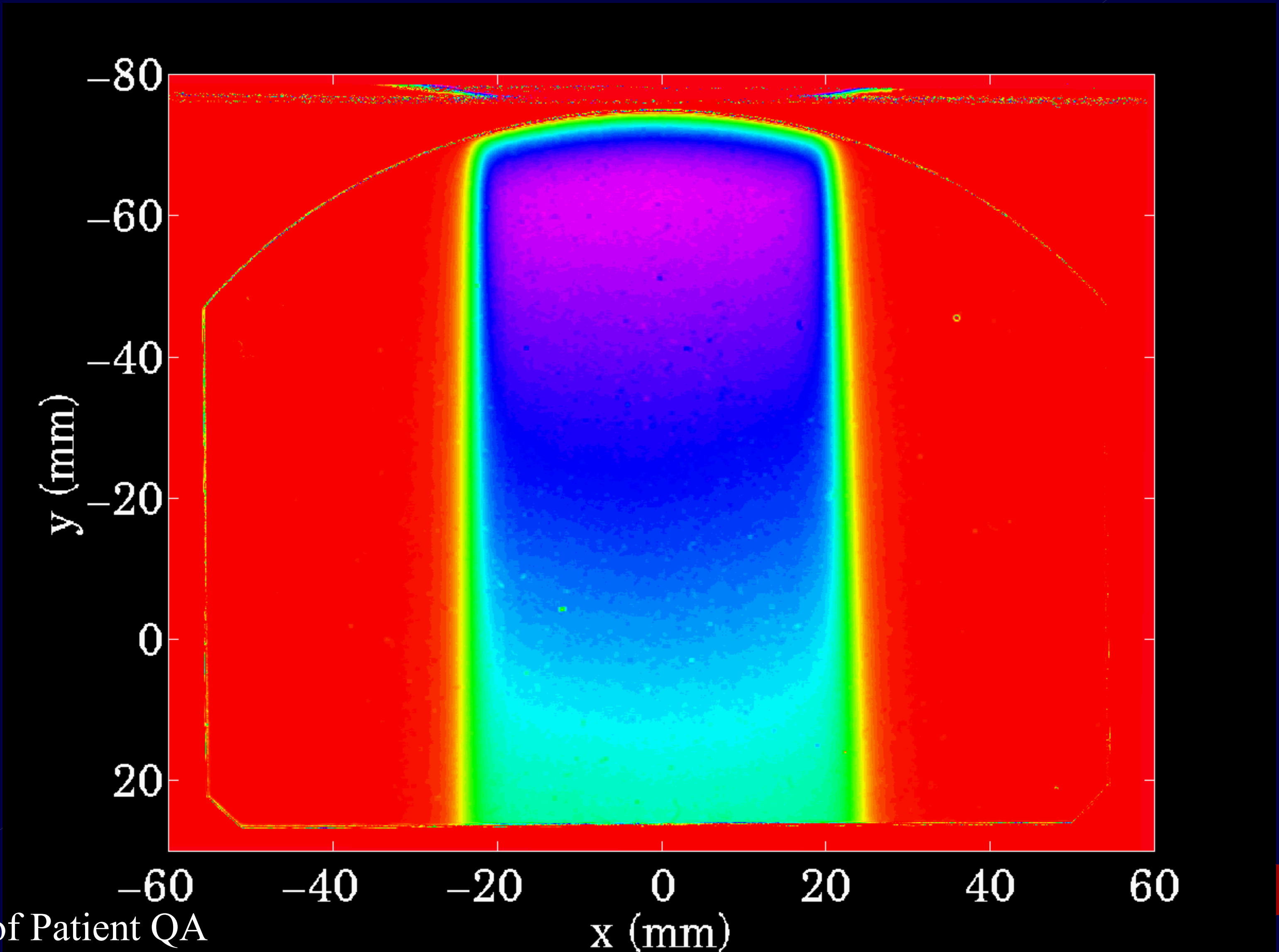
Radiochromic Film



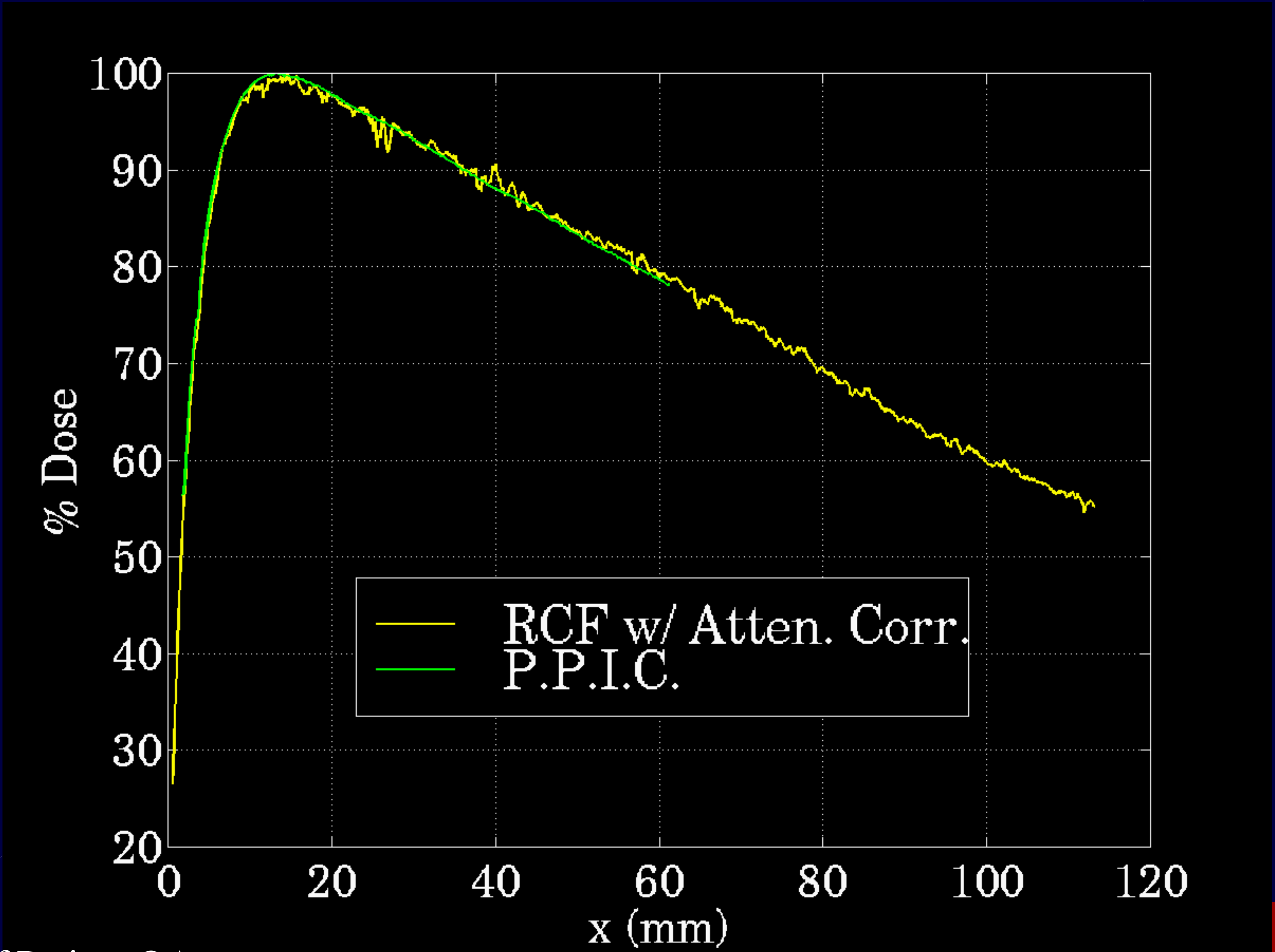


0.001 mm^3 measurement volumes!

Quantitative Tests

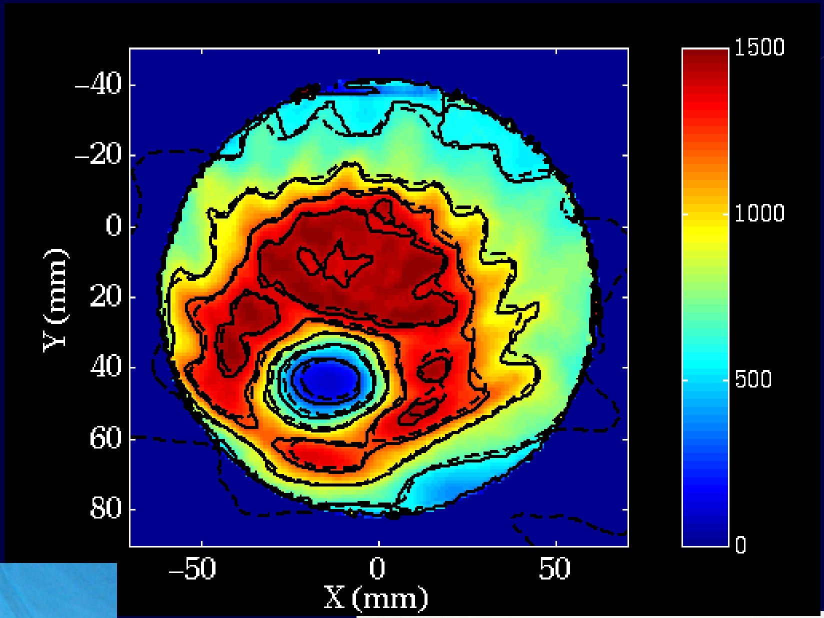


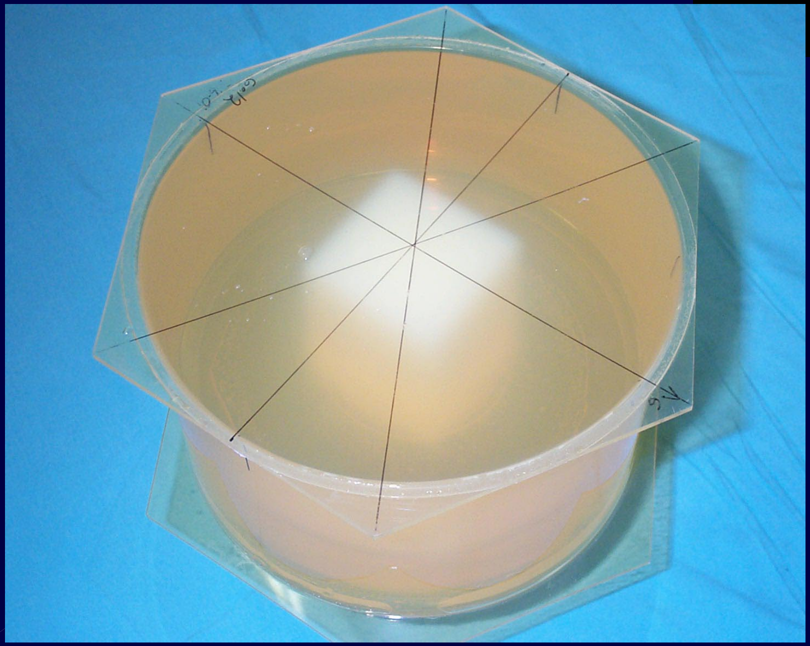
CAX Profiles

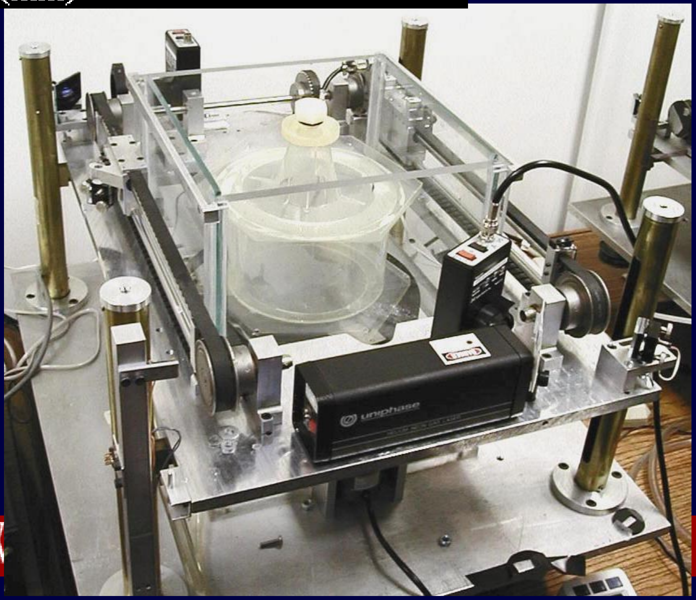


3-D Dosimetry

- 3d
  - –PAG gels
    - MRI
    - Optical







Summary

- Commissioning
  - Accelerator TPS data acquisition (penumbra, pdd…)
  - Accelerator operation (leaf calibration and operation)
  - Standard 3D tests
  - Check simple enface fields (square…)
  - Full treatment plans to phantoms (checks process)
    - Individual beams or total treatment plans

Summary

- Phantom plans for patients
  - Measurement-based comparisons (film & ion chamber)
  - [Calculation based verification]
- Position/Orientation verification (port film)
- Routine Linac QA
  - Leaf calibration
  - Leaf operation