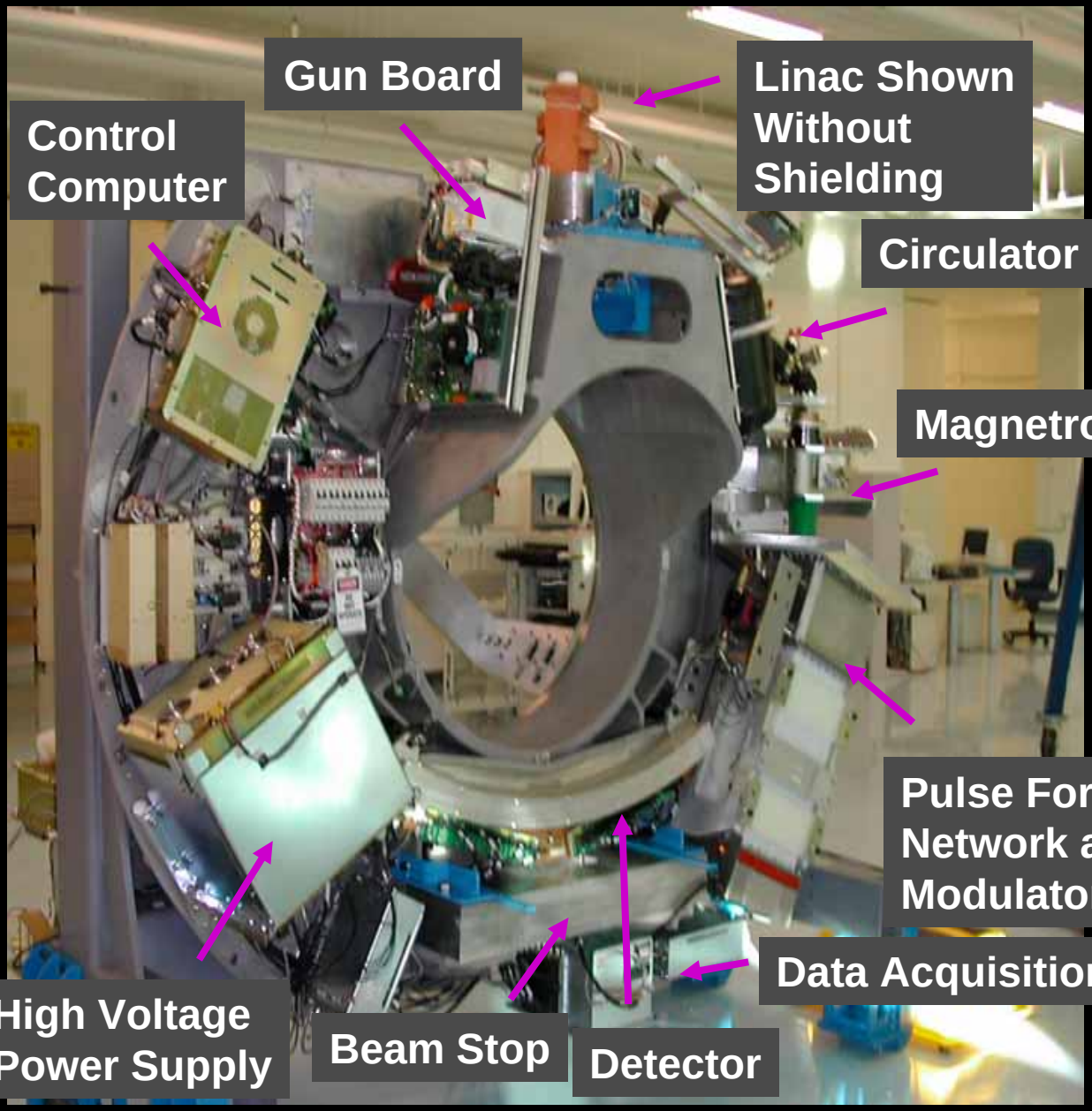
Daily Localization III: Tomotherapy

Sanford L. Meeks, Ph.D
Director of Physics

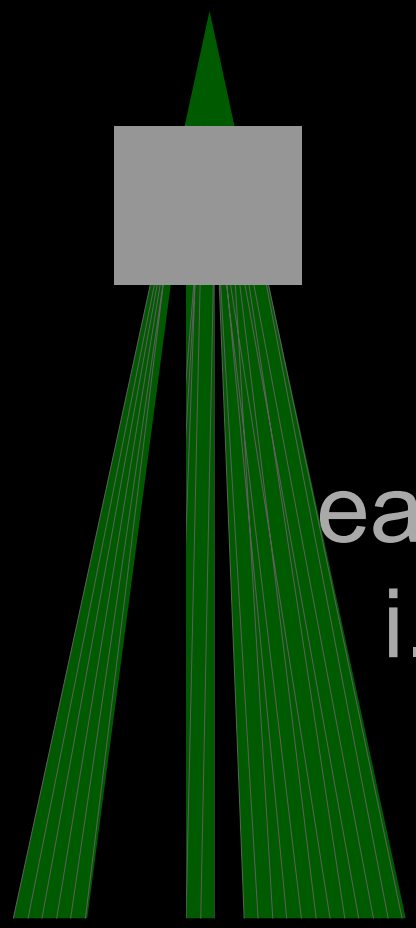
Outline

- Physical Characteristics
- Quality Assurance
- Image Quality
- Overview of Clinical Application
- System Limitations
- Future Developments
  - Adaptive Tomotherapy
  - “Topo”therapy

TomoTherapy HI-ARTII



TomoTherapy

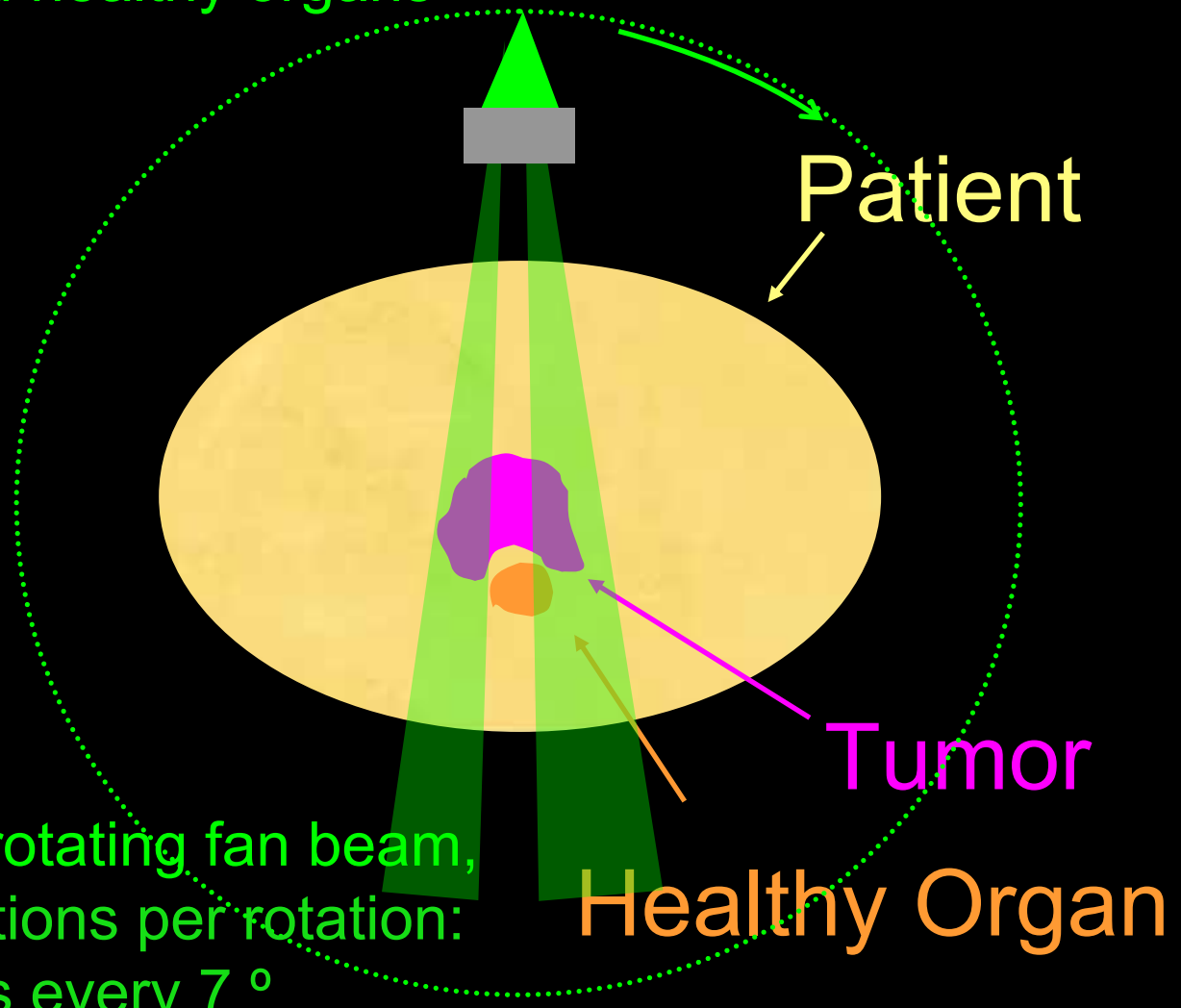


Divides beam into 64 beamlets using binary mlc

each beamlet can be on/off i.e. temporal modulation

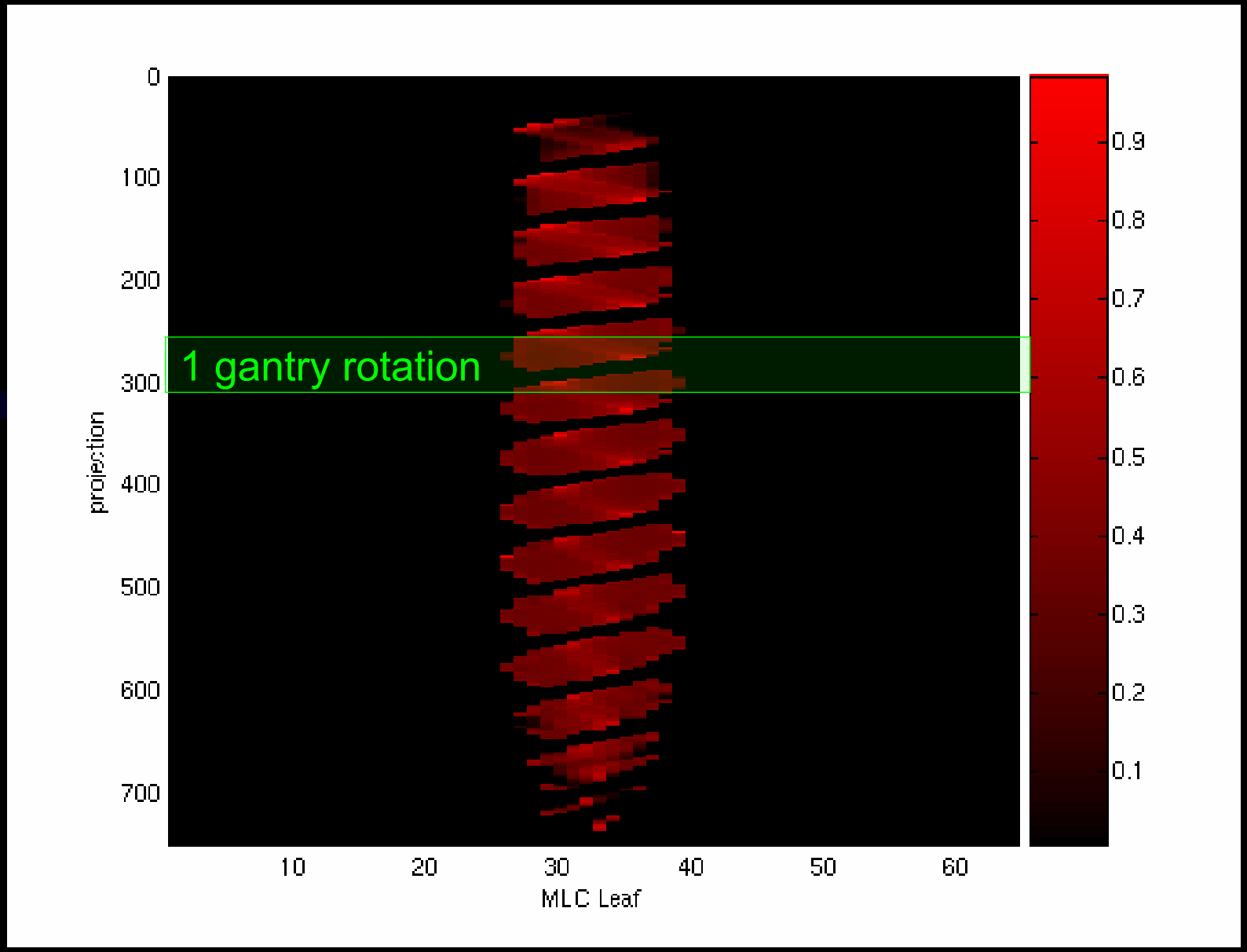
TomoTherapy

Beamlets are turned on or off depending on intersection with tumor and healthy organs

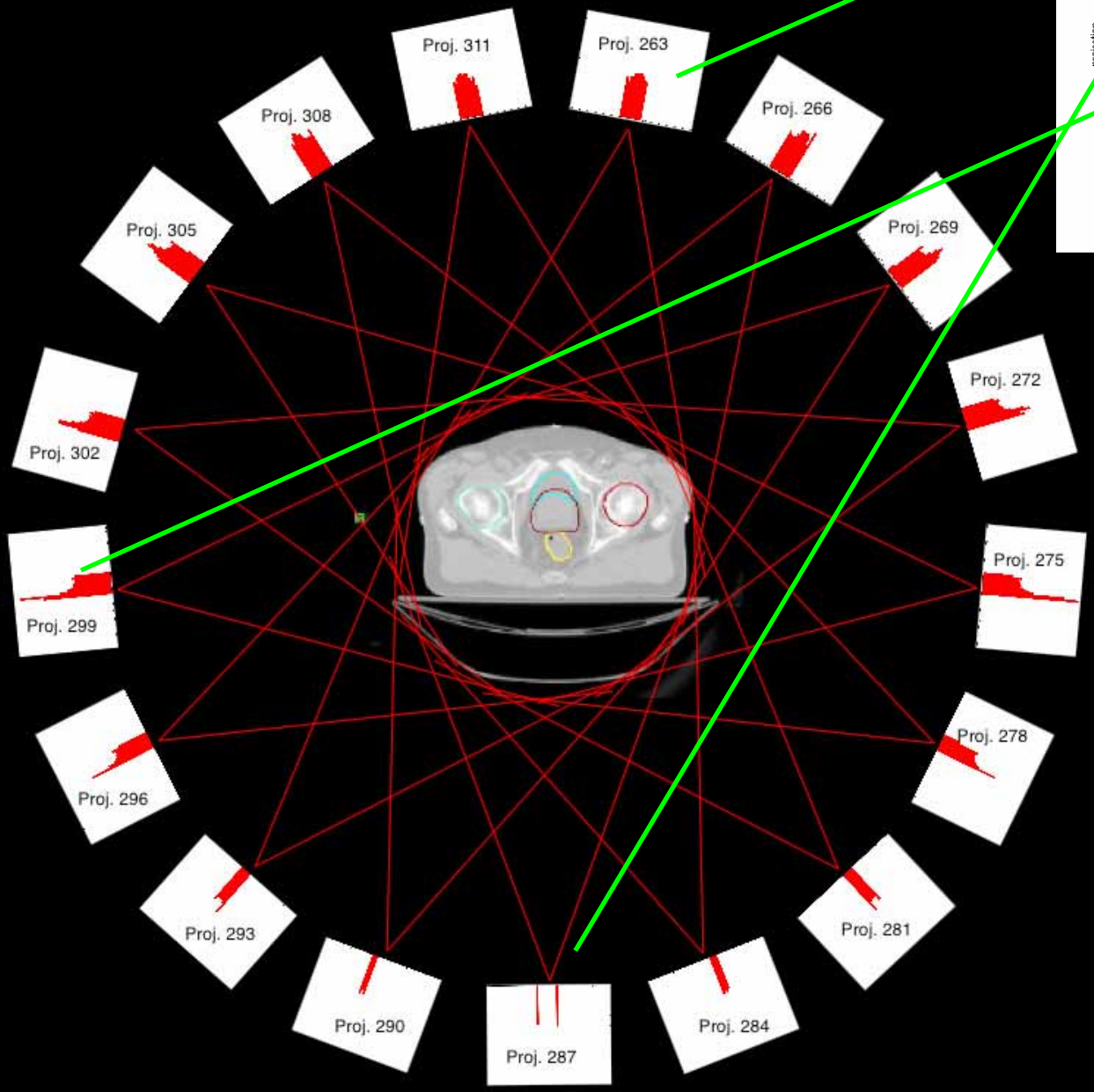


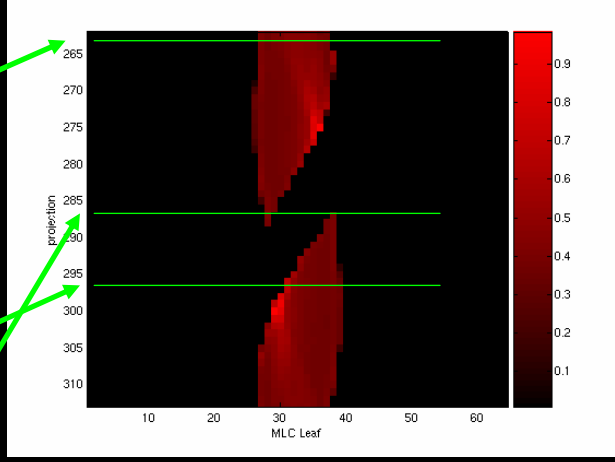
Continuously rotating fan beam, with 51 projections per rotation: beam changes every 7 º

Delivery Instructions (Sinogram) for Prostate Delivery



Sinogram

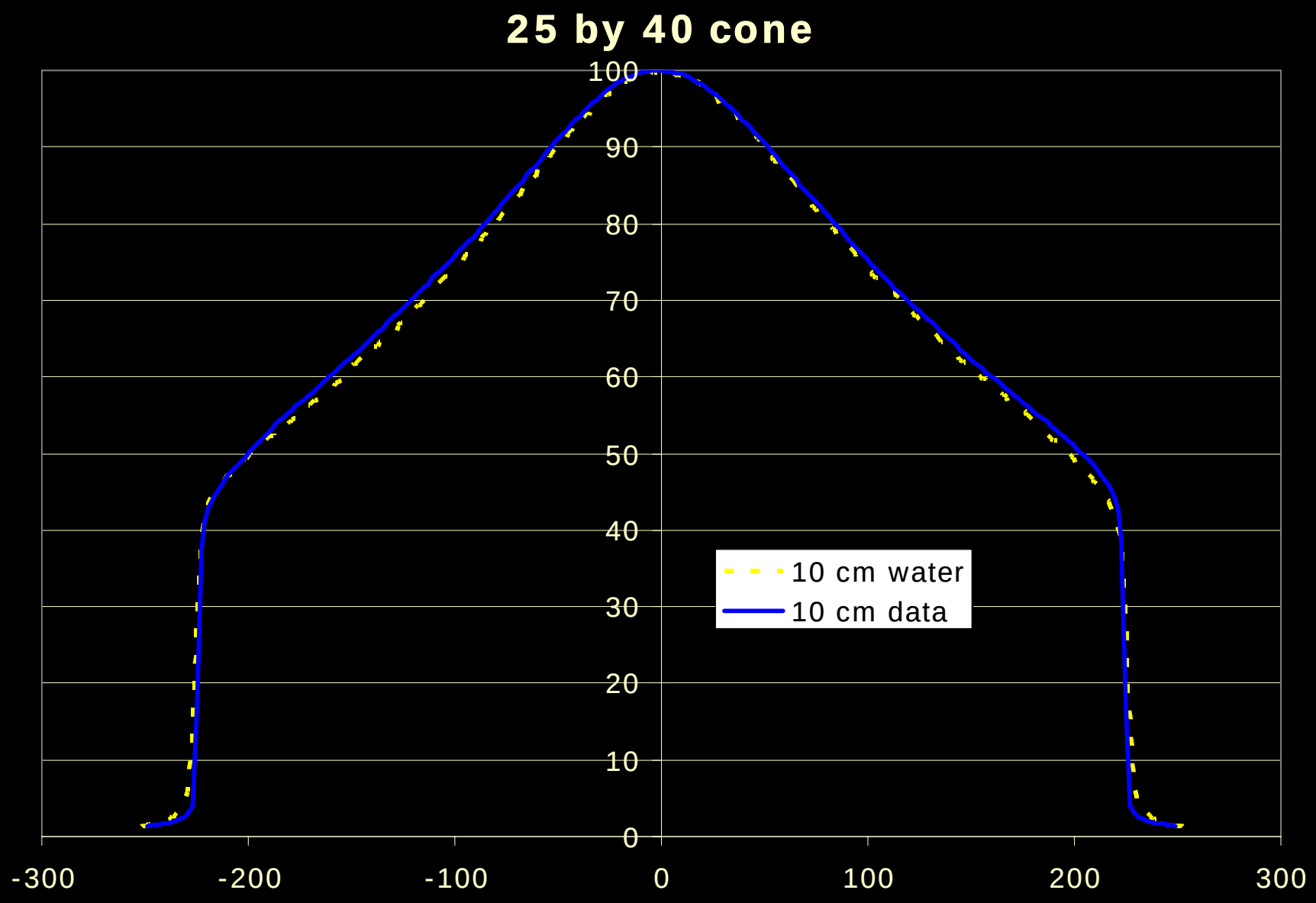

Proj. 311
Proj. 263
Proj. 308
Proj. 266
Proj. 305
Proj. 269
Proj. 302
Proj. 272
Proj. 299
Proj. 275
Proj. 296
Proj. 278
Proj. 293
Proj. 281
Proj. 290
Proj. 287
Proj. 284


projection
265
270
275
280
285
290
295
300
305
310
10
20
30
40
50
60
MLC Leaf
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

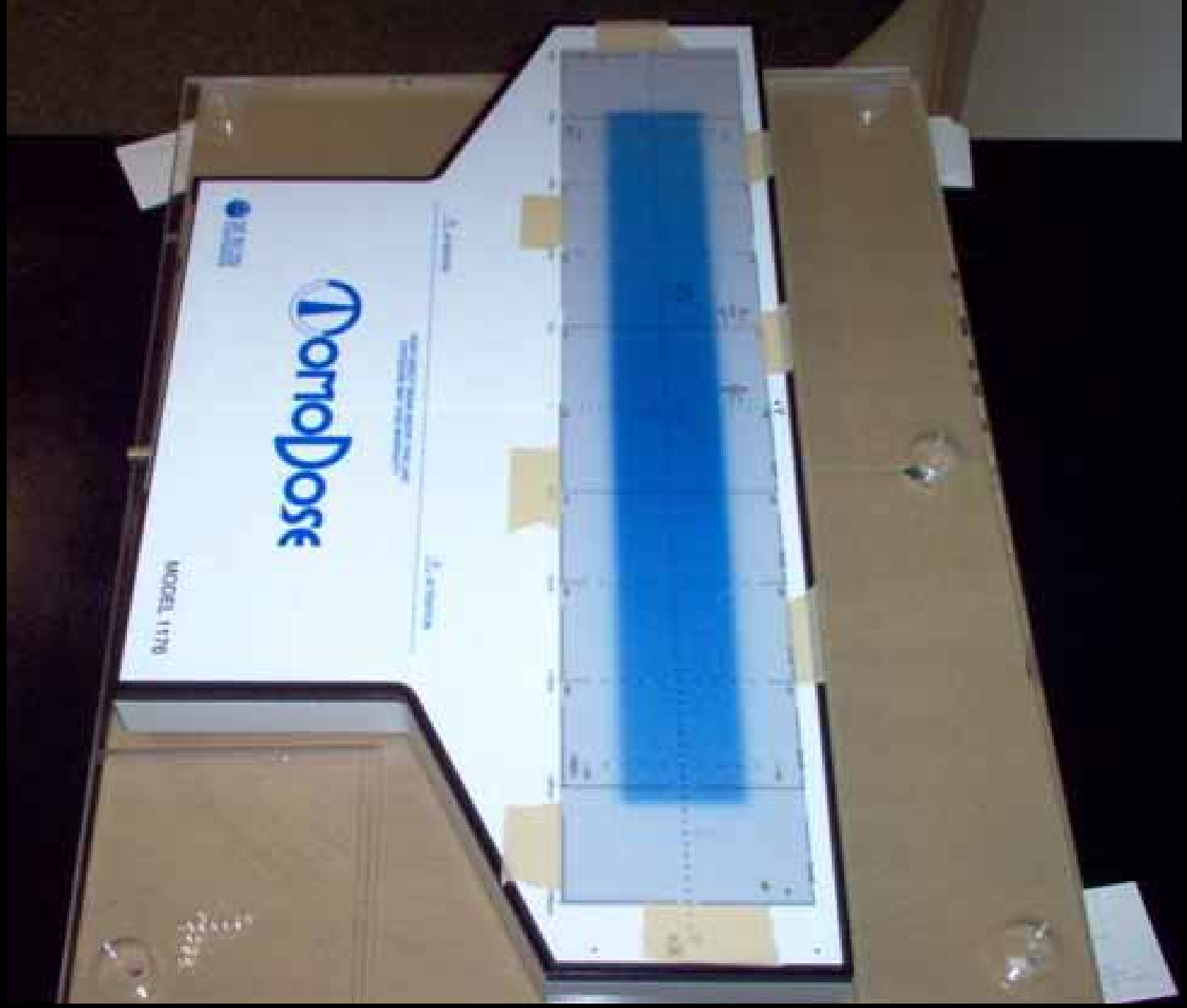
MDACCO QA Program

- Daily
  - Lasers at home position
  - Static output and energy constancy
  - Air scan for CT detector calibration
  - Table readout constancy
  - DQA using ion chamber and film for every patient treated
- Monthly
  - Lasers – movement accuracy using image registration
  - Absolute Output with different chamber
  - Symmetry (TomoDose)
  - Table motion accuracy
  - Interlocks/emergency offs, etc.
- Annual
  - Scanning static fields
  - Independent output verification in static field (RPC TLDs)
  - End-to-end tests with rotational fields

Compare Scan Data with Model



Compare Scan Data with Model



Langen KM, Meeks SL, Poole DO, et al. Med Phys, 32(11):3424, 2005.

TomoDOSE

File Edit Data Setup Log Help

Start Stop Background : No Dose : None Calibration : 11_feb.cal Data: Normalized

Standard: GoldStandard_2p5cm.txt UnZoom

TomoDOSE Devi...
25jul06_2_5cm.txt
GoldStandard_2...

X Axis

-19cm -15cm -10cm -5cm 0cm 5cm 10cm 15cm 19cm

25jul06_2_5cm.txt

-110mm(32/76)
Left Val: 68.9
Right Val: 68.7
Point Sym: 0.25%

Normalized

cm - TomoDOSE Coordinates

XSym YSym %diff

Mirror Symmetry: X Axis

%

cm - TomoDOSE Coordinates

Y Axis: 0cm

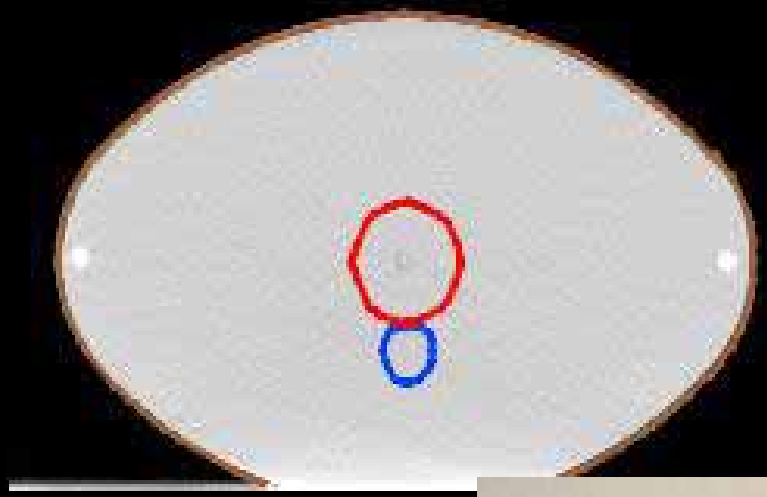
Normalized

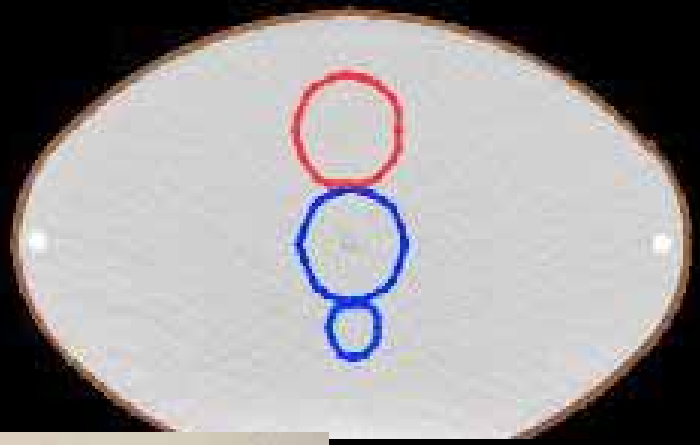
cm - TomoDOSE Coordinates

End-to-End Tests

2 Gy or 2.5 Gy to the target

50 or 100 cGy to
Center Structure





Ion Chamber Measurements

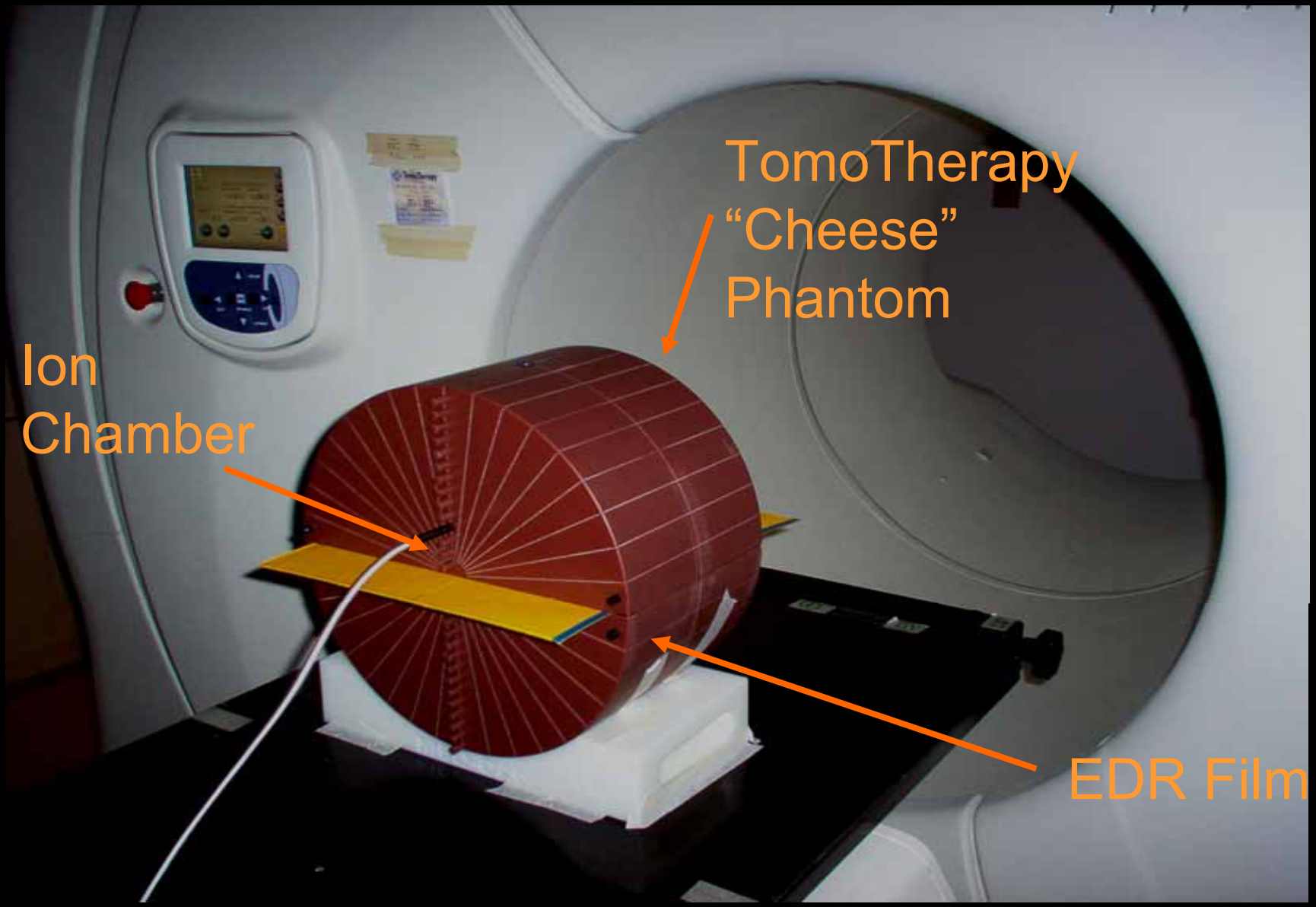
Acceptance Measurements

Optimizer dose (cGy)	Expected dose (cGy)	Mean IC dose (cGy)	Ratio
215.0	215.00	213.97	**0.995**
81.6	83.73	83.26	**0.994**
42.8	44.92	44.35	**0.987**

Measurements after change to 2.1.1

Optimizer dose (cGy)	Expected dose (cGy)	Mean IC dose (cGy)	Ratio
210.0	210.00	215.7	**1.027**
209.0	83.73	213.7	**1.022**
25.5	25.5	25.7	**1.007**
53.04	53.04	54.6	1.03

Integrated Quality Assurance



DQA – Point Dose Measurement

M. D. Anderson Cancer Center Orlando
TomoTherapy
Patient Dose Verification

Patient Name	**RTOG**
Date	3/30/2005 15:49
Plan Name	Plan_03

TomoTherapy Point Dose Verification

Temperature	**22.0**	^{0}C
Pressure	**755.6**	mm Hg
CTP	**1.006**	
Electrometer	Inovision 35040	
Chamber	Exradin A1SL, SN 30566	
Phantom	Solid H_20 ("Cheese" Phantom)	
System Calibration Factor (C21)	0.550	[Gy/nC]
Ion Chamber Position In Phantom	1 below film	
Electrometer Reading for Phantom Irradiation	2.975	[nC]
$Dose_{plan}$	**1.603**	[Gy]
$Dose_{meas}$	**1.646**	[Gy]
Ratio (D_{meas}/D_{plan})	**1.027**	**Pass**

TomoTherapy Planning Station -- M D Anderson - Orlando

Patient: 09_HN,H0022_show
DOB: Jan 27, 2004 Sex: M
ID: HNrtogIMRT
Plan date: Mar 11, 2005 10:36:12 AM
Oncologist:

No Photo

Plan: Plan_03
Plan status: Approved
DQA plan: Plan_01
Patient position: HFS

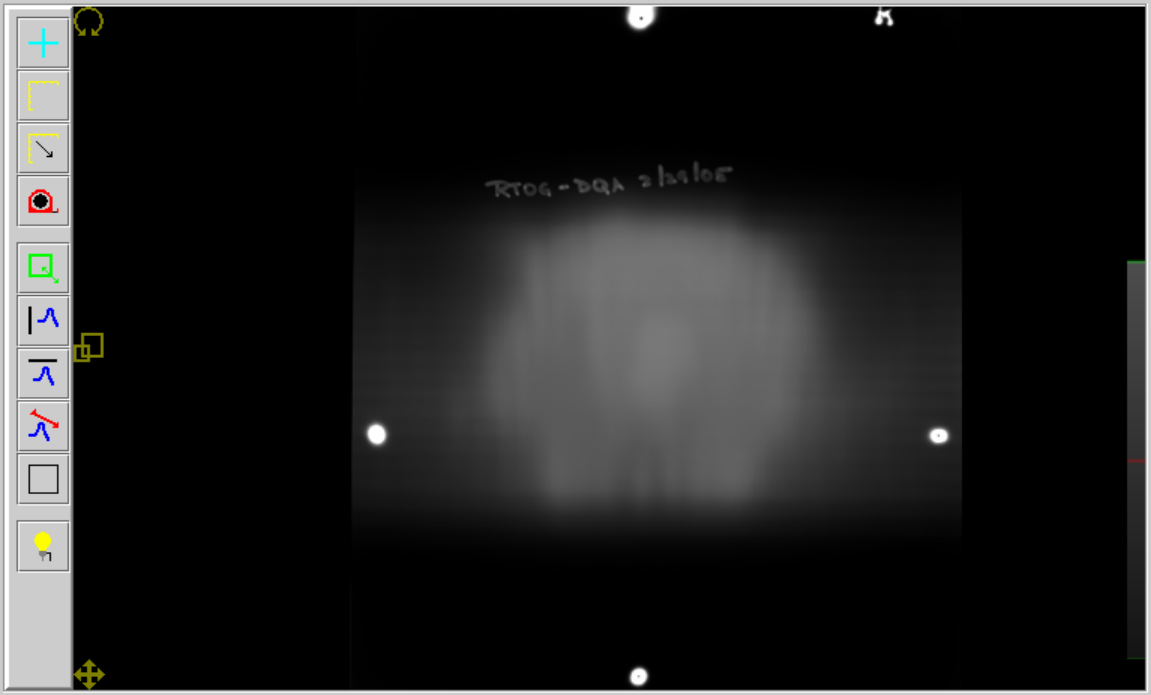
What's Next

Save DQA Data

- Click **Save Film Data** to save current data for this procedure.
- Click **Save POIs** to save POI data.

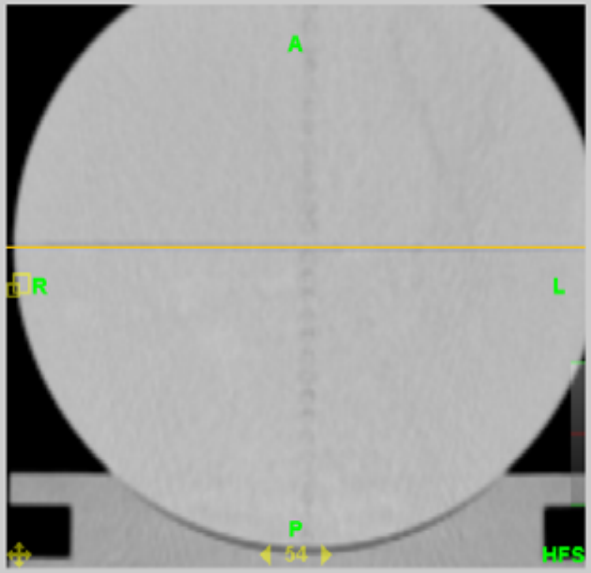
User: Physicist

ROIs | Optimization | Fractionation | Delivery QA Setup | Delivery QA Analysis



Phantom Registration

Click on the image to set a horizontal line that best approximates the position of the plane of the film with respect to the phantom. You may select any slice. When satisfied, click the 'Accept Vertical Position' button to end this step of film registration.



Accept Vertical Position | Cancel

Select Procedure

Reference dose: 2.22 Gy

Proc number: 0

Read Film File

Read Cal File

Convert To Dose

Plot Cal Table

Extract Dose Plane

Flip Image

Scale Film Dose

Dose Display

☑ Isodose

1.5
1.425
1.35
1.2
1.05
0.75
0.6

Film Registration

Register Film Position

Registration type: CORONAL ORIENTATION patient slice: 117

Film registration succeeded. You may now compare calculated and measured doses.

Accept Point | Cancel Registration

Save Film Data

Save POIs

DTA tolerance (cm): 0.3

Dose tolerance (Gy): 0.0666 Change

Points of Interest

Add Point of Interest

Remove Selected POI

Show Selected POI

Move Selected POI

Name	Comment	Color	x	y	z	Calc Dose	Meas Dose	Diff (Gy)

TomoTherapy Planning Station -- M D Anderson - Orlando

No Photo

Patient: 09_HN,H0022_show
DOB: Jan 27, 2004 Sex: M
ID: HNrtogIMRT
Plan date: Mar 11, 2005 10:36:12 AM
Oncologist:

Plan: Plan_03
Plan status: Approved
DQA plan: Plan_01
Patient position: HFS

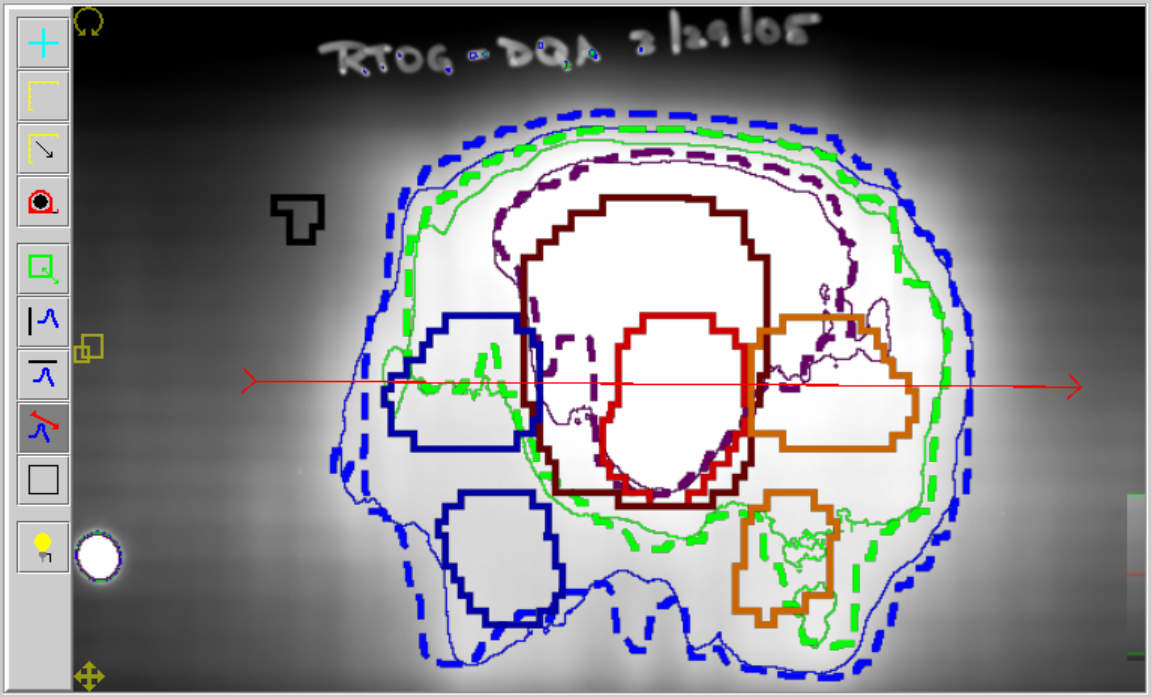
What's Next

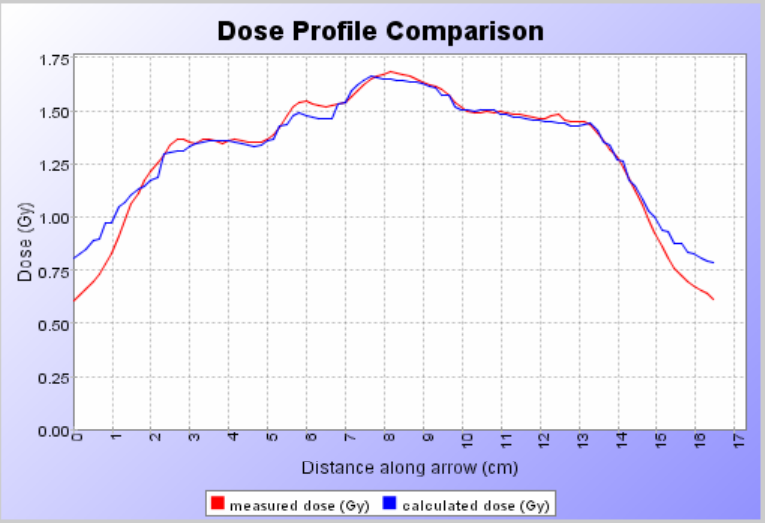
Save DQA Data

- Click **Save Film Data** to save current data for this procedure.
- Click **Save POIs** to save POI data.

User: Physicist

ROIs | Optimization | Fractionation | Delivery QA Setup | Delivery QA Analysis





Select Procedure

Reference dose: 2.22 Gy

Proc number: 0

Read Film File

Read Cal File

Convert To Dose

Plot Cal Table

Extract Dose Plane

Flip Image

Scale Film Dose

Dose Display

☑ Isodose

1.5

1.35

1.2

Name	Color	Display?
patient		☐
tumor		☐
ptv1		☑
ptv2		☑
ptv3		☑
ptv4		☑
rtpar		☑

Select All | Select None

Display Options

- ○ No contours
- ○ Show gamma
- ◉ Show these contours:
- ☑ Show film contours
- ☑ Show calc contours
- ☑ Show patient ROIs

Save Film Data

Save POIs

☑ Show film profile ☑ Show calc profile

☑ Show background?

- ◉ Film background
- ○ Phantom background

Stop Gamma Calc

Calculate Gamma

Gamma Histogram

Search distance: (cm): 0.3

DTA tolerance (cm): 0.3

Dose tolerance (Gy): 0.0666 Change

Points of Interest

Add Point of Interest

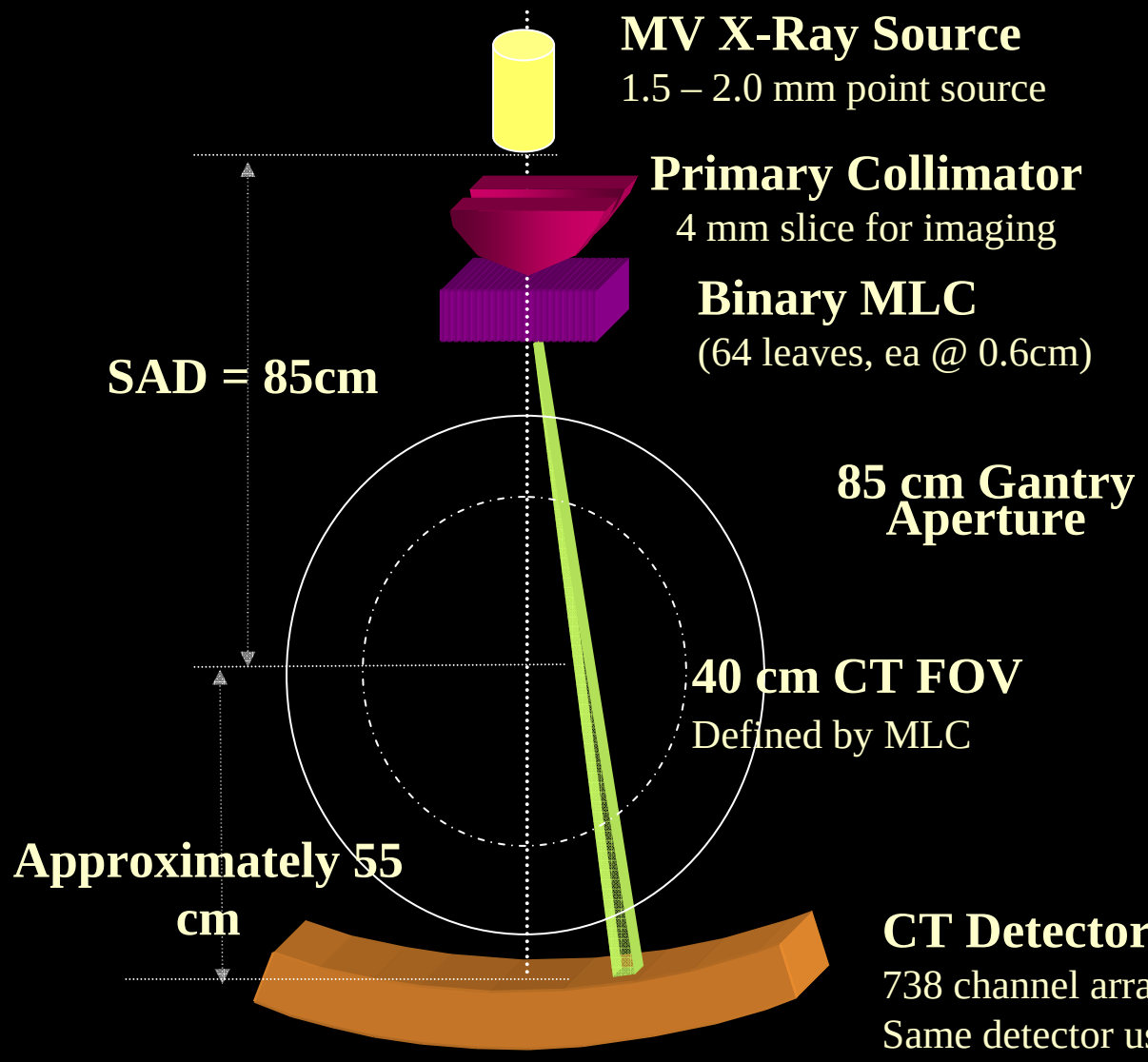
Remove Selected POI

Show Selected POI

Move Selected POI

Name	Comment	Color	x	y	z	Calc Dose	Meas Dose	Diff (Gy)
POI_00	PTV 66.6 Gy		0.844	2.803	1.219	1.603	1.646	-0.043
POI_01	Spinal Cord		0.844	2.803	-3.844	0.753	0.759	-5.517e-003

TomoTherapy MVCT Imaging Chain



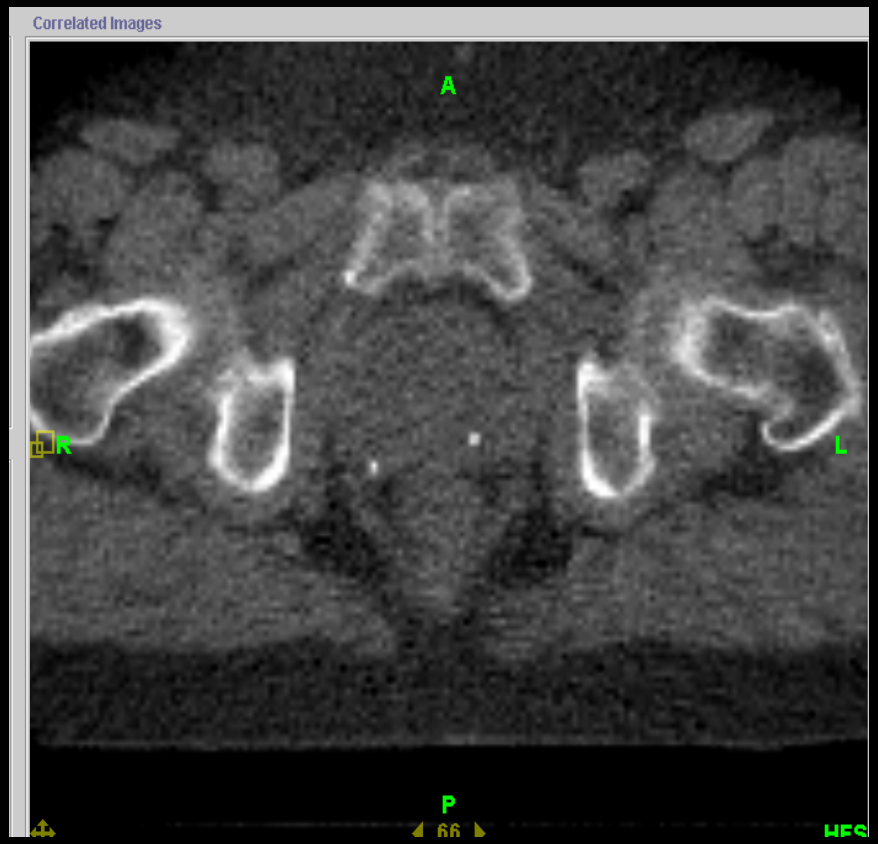
Spatial Resolution Limits

Matrix	0.05 MTF (lp/mm)	Nyquist Limit (lp/mm)	Resolved Diameter Hole Pattern (mm)	lp/mm Associated with Hole Pattern Visualization
256	0.105	0.32	>1.75	<0.29
512	0.42	0.64	1.25	0.40
768	0.51	0.96	1.00	0.50

Patient Images: Prostate

Diagnostic (kV) CT

Tomotherapy (MV) CT



MVCT Imaging Characteristics

- Uniformity is comparable to diagnostic CT scanners while noise is worse
- MVCT numbers are consistent – suitable for dose calculations
- Spatial resolution using 512x512 matrix is ~1.5 mm
- Dose: ~1.1 cGy for 5-mm slice width and pitch of 1; dose decreases with “looser” pitch
- Energy ~ 3.48 MV
  - Slightly softer than treatment beam → smaller spot size, improved penumbra & contrast resolution

- **Image Quality is acceptable for patient alignment and is also acceptable for delineation of many soft tissue structures.**

Meeks et al., *Med Phys* 32(8):2673, 2005

Treatment Planning

- No
  - beam angles to specify
  - field sizes to specify
  - length limit
  - Energy choices (only 6 MV)
- Available optimization parameters
  - Jaw setting : 1 – 5 cm (most often 2.5 cm)
  - Pitch – (p=0.86*1/n) n=1,2,3,4…
  - Modulation factor – higher means more modulation
  - Structure importance
  - Penalties (used to drive specific DVH points)

ROIs | Optimization | Fractionation | Delivery QA Setup | Delivery QA Analysis

Prescription

% Vol / Stats — For: PTV70gy — 95.0 % will receive ..... **70.0 Gy**

Field Width: 2.56 cm - Jaws(1.15,-1.85) — Pitch: 0.300 — Dose Calc Grid: Normal — Batch beamlets

Tumor Constraints

Name	Display	Color	Blocked	Use?	Importance	Max Dose [	Max Dose Pen.	DVH Vol [	DVH Dos	Min Dose [(	Min Dose Pen.
PTV70gy	✓		None	✓	120	70.0	1000	95.0	70.0	70.0	1000
PTV57gy	✓		None	✓	100	57.0	900	96.0	57.0	57.0	900
CordSup	✓		None								
CordInf	✓		None								

Sensitive Structure Constraints

Name	Display	Color	Blocked	Use?	Importance	Max Dose	Max Dose Pen.	DVH Vol	DVH Dose [Gy]	DVH Pt. Pen.
Lt Parotid	✓		None	✓	25	57.0	250	15.0	20.0	250
CordMargin	✓		None	✓	20	40.0	200	80.0	35.0	200
OralCavity	✓		None	✓	15	55.0	100	80.0	50.0	100
Brainstem3mm	✓		None	✓	15	45.0	50	30.0	35.0	50

Dose Display

✓ Isodose

73.5
70
66.5
57
45
40

Density Image Viewer

Density Image

Optimize

Mode: Beamlet

Modulation Factor: 2.000

Initiate Full Dose after 20 iterations.

Start

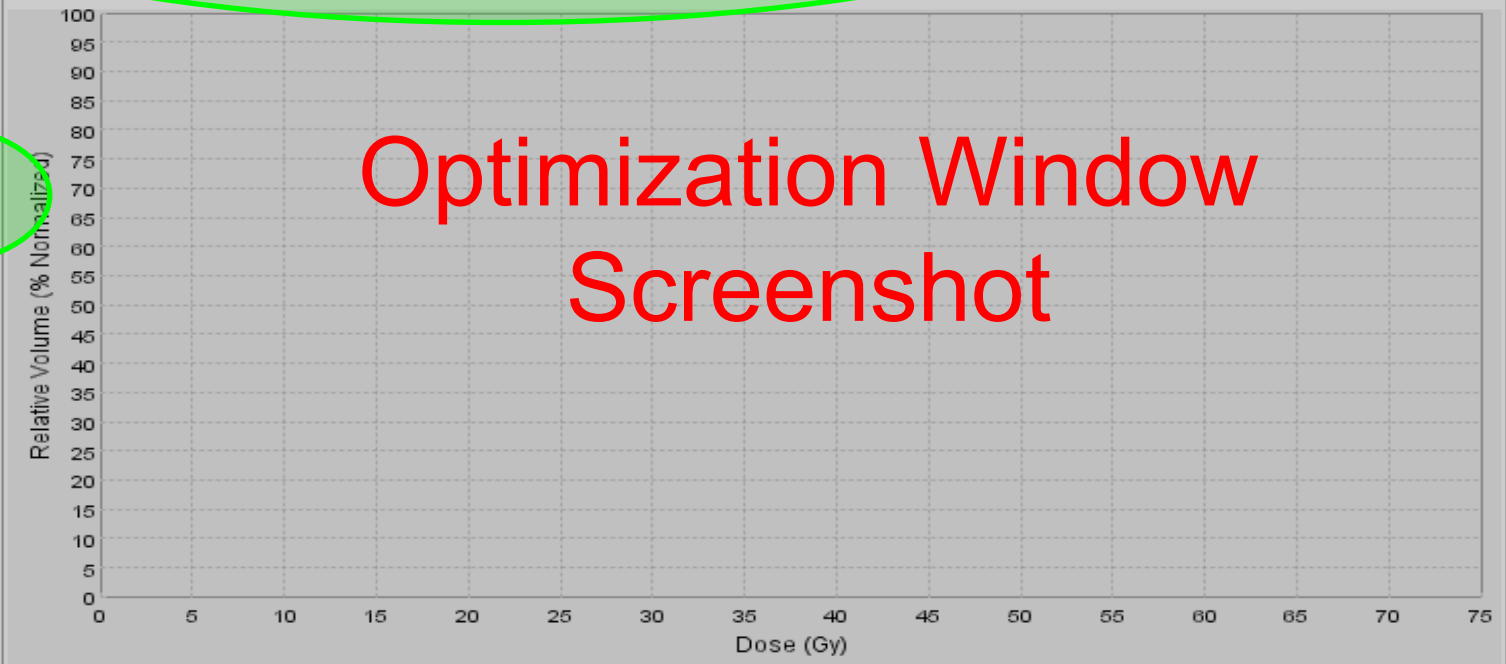
Pause

Resume

Get Full Dose

Cancel

Dose-Volume Histogram - Cumulative Mode Relative



Vol Min < 0.0 > | Vol Max < 100.0 | Gy Min < 0.0 > | Gy Max < 75.0 >

Optimization Window Screenshot

Tips for Optimization

- Optimization is an interactive iterative optimization requiring user intervention.
- Work first on adequate PTV coverage. This should be achieved in 25-35 iterations. After achieving acceptable dosimetry, increase the penalty of the target structures.
- Next work on one sensitive structure at a time by greatly increasing the penalty of the sensitive structure.

Treatment planning time

1. Step: Calculate Beamlets

20 - 30 min for prostate - 1-2 hours for Head and Neck
can be batched, I.e. overnight

2. Step: Optimize plan

0.5 - 1 hour for prostate (30-50 iterations)
1- several hours for Head and Neck
(50-several hundred iterations)

TomoTherapy Operator Station -- Tomotherapy Inc.

No Photo

Patient: **MRI Plan (GHO)**
DOB: Jan 1, 2000 Sex: Unknown
ID:
Plan date: Apr 30, 2004 2:28:28 PM
Oncologist: GHO

Plan: Plan_01
Plan status: Unapproved
DOA plan:
Patient position: HFS

What's Next

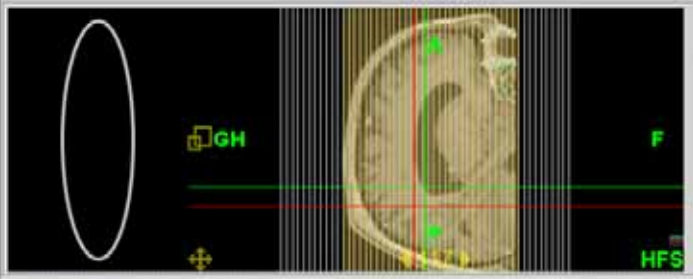
Prepare Scan
Click **Prepare Scan.**
(details)

User: Gene Genesis

Acquire Image | Create Fast Plan | Speed Planner | Demo Scan | Demo Img

Scan | Register | Treat | Calibrate

Slice Selector



Slice Thickness
- Fine
- Normal
- Coarse

Clear Selected Slices

Accept slices

TomoImage

Plan procedures:

Type	Status	Date	Time
TomoImage	Performed	Apr 30, 2004	3:53:43 PM
TomoImage	Performed	Apr 30, 2004	4:14:18 PM
TomoImage	Performed	Apr 30, 2004	4:57:22 PM
TomoImage	**Scheduled**	**May 1, 2004**	**8:40:30 AM**

Prepare scan

Show Auxiliary Machine Data

Scan Status

Scan Progress Time (seconds)

Elapsed	Remaining

Couch Position (millimeters)

IEC Ty (longitud.)	IEC Tz (vertical)
332.0	197.3

Monitor Chamber 1 (Dose Monitor Units)

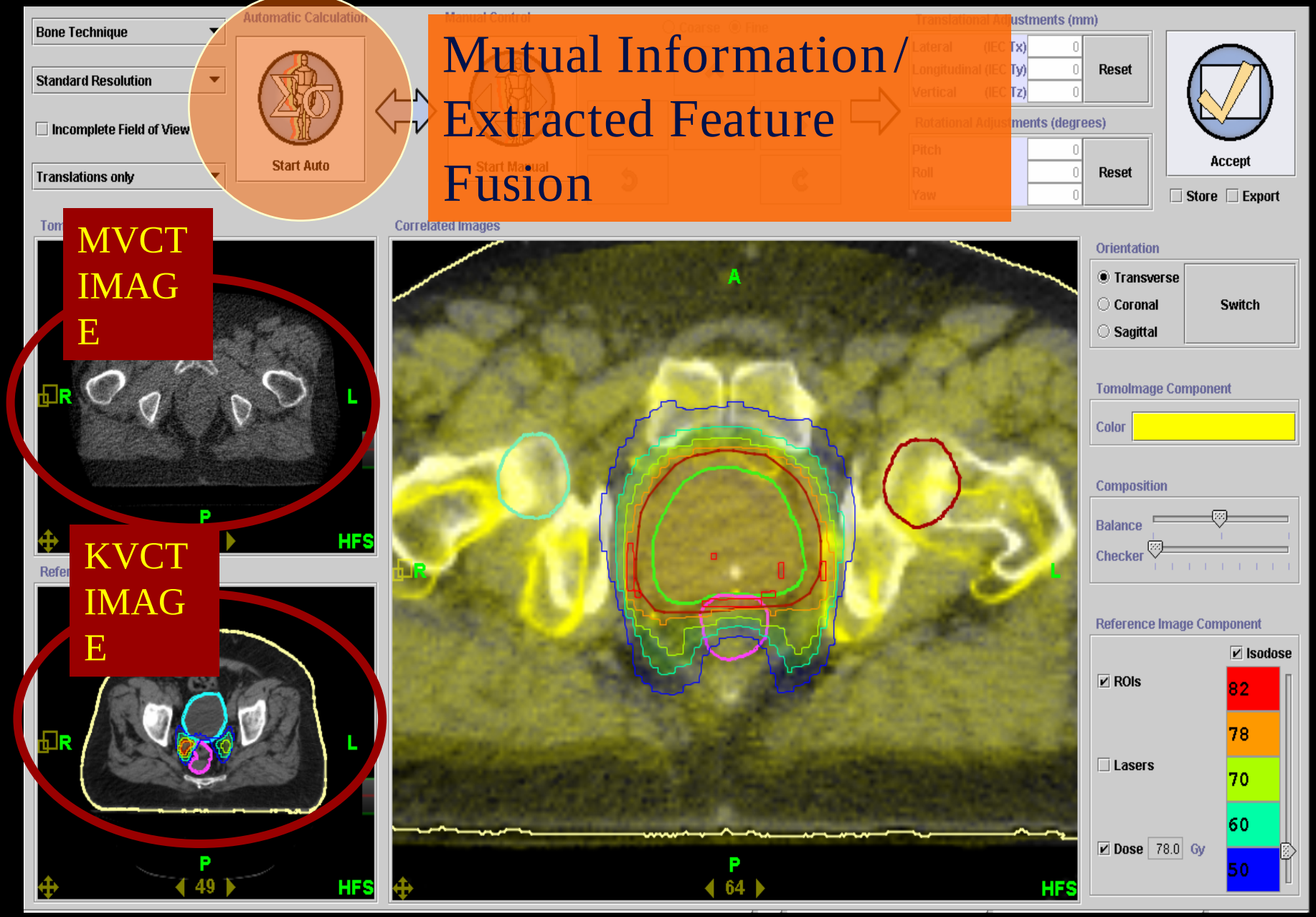
Cumulative (mu)	Rate (mu/min.)

Monitor Chamber 2 (Dose Monitor Units)

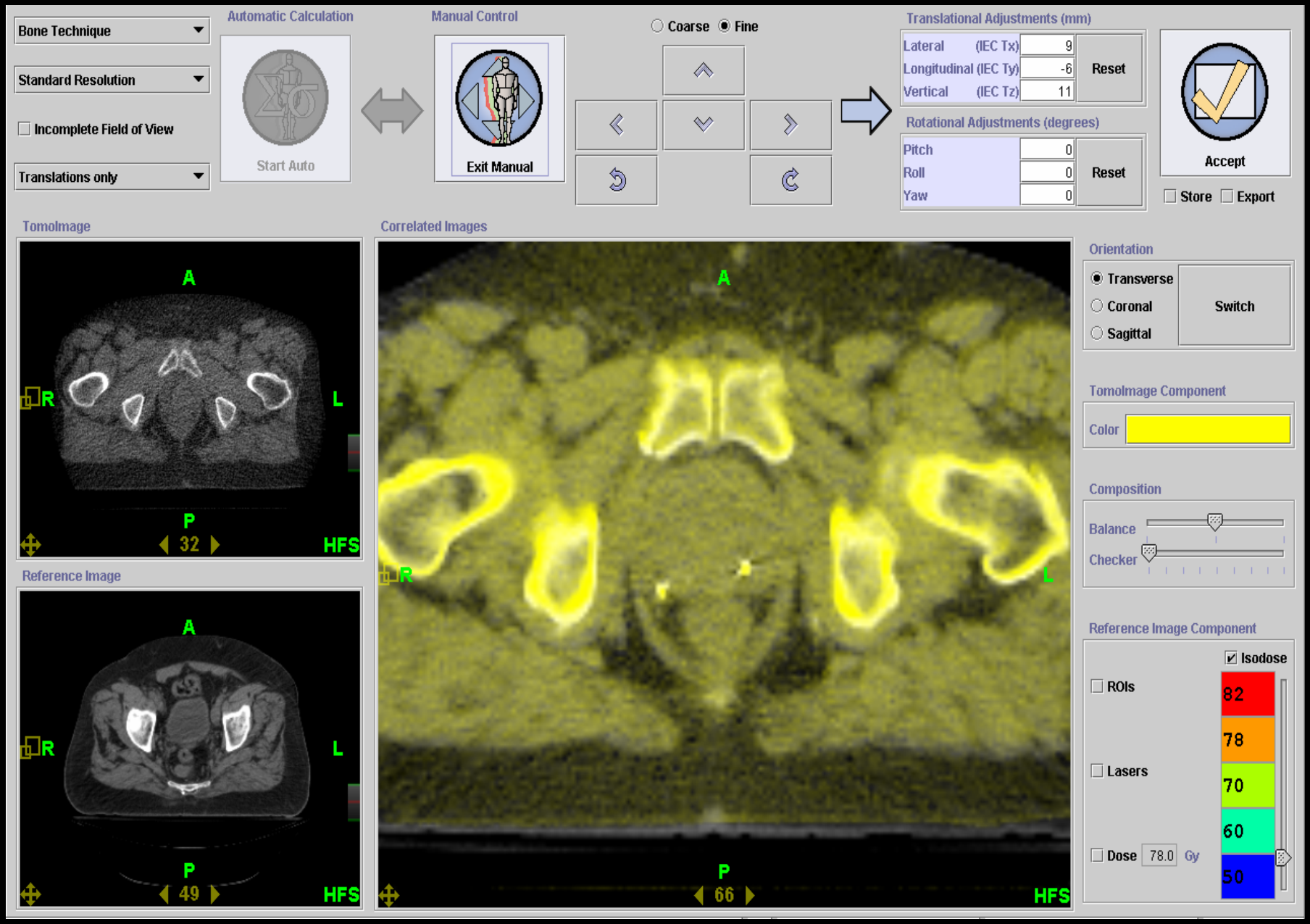
Cumulative (mu)	Rate (mu/min.)

Ready for scanning. | Saturday, May 1, 2004 | 08:54:55

Prostate Helical Tomotherapy



Transverse, aligned



Average In-Room Times

- 5 minutes for setup
- 3-5 minutes MVCT scan
- 5 minutes reconstruction and registering MVCT to KVCT and shift patient
- 4-10 minutes beam on time (H&N, prostate)

17-25 minutes total for IGRT and IMRT

System Limitations

- Reliability
- Inability to deliver non-coplanar beams
- No electrons
- Simple treatments no longer simple and maybe not better
  - Parallel opposed fields
  - Tangent breast

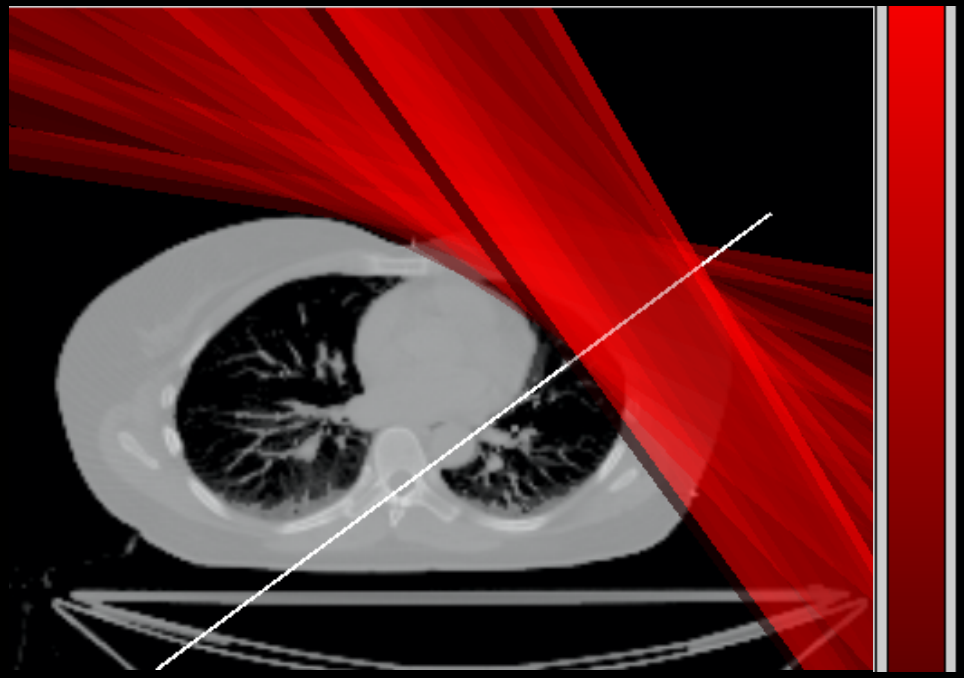
System Reliability

- 2005 uptime was actually very good **(Meeks calc) = 244/255 days = 96%**
- TomoTherapy, Inc. Service
  - Very responsive
  - Diagnostic tools are improving
  - Recent improvements in local parts inventory/distribution.
- Major component reliability still an issue.
- Aggravation factor
  - System interrupts
  - Couch

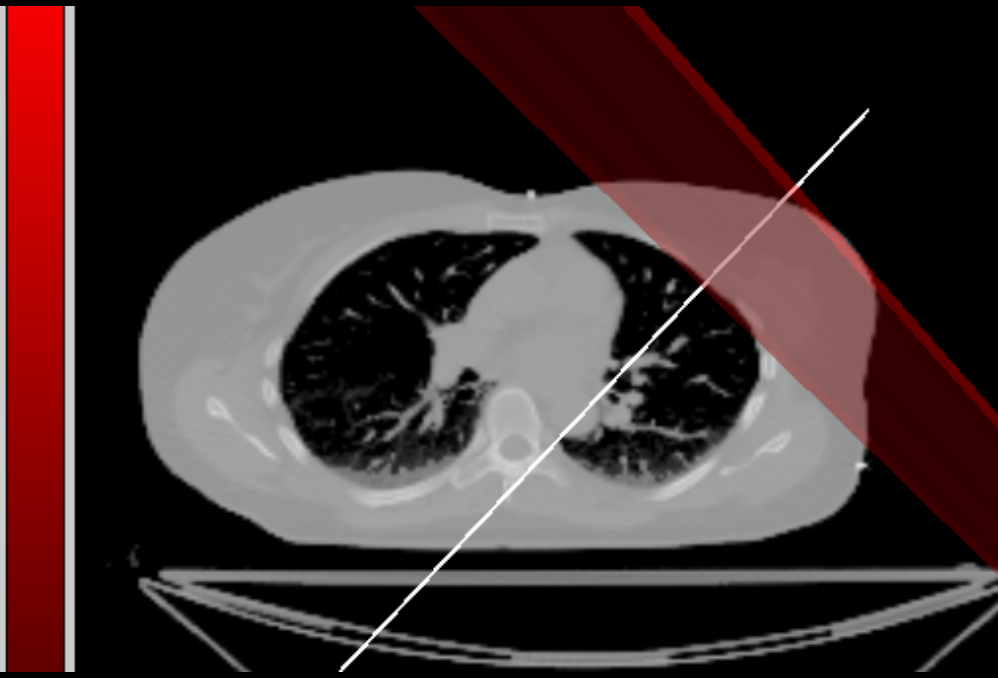
Simple Treatments now hard

What about “TopoTherapy” as a future solution? Static modulated slit beam with continuous couch translation through beam.

Breast tomotherapy



Breast topotherapy (opposed tangents)



Gonzalez VJ, Buchholz DJ, Langen KM, et al. Int J Radiat Oncol Biol Phys 65(1):284, 2006.

Future Development

Adaptive Tomotherapy

- Daily Image Guidance
- Dose Recalculation
- Deformable Image Registration
- Dose Accumulation
- Plan Re-optimization

Dose Recalculation

Use pre-treatment MVCT

↓

Recalculate plan based on planned MLC pattern

↓

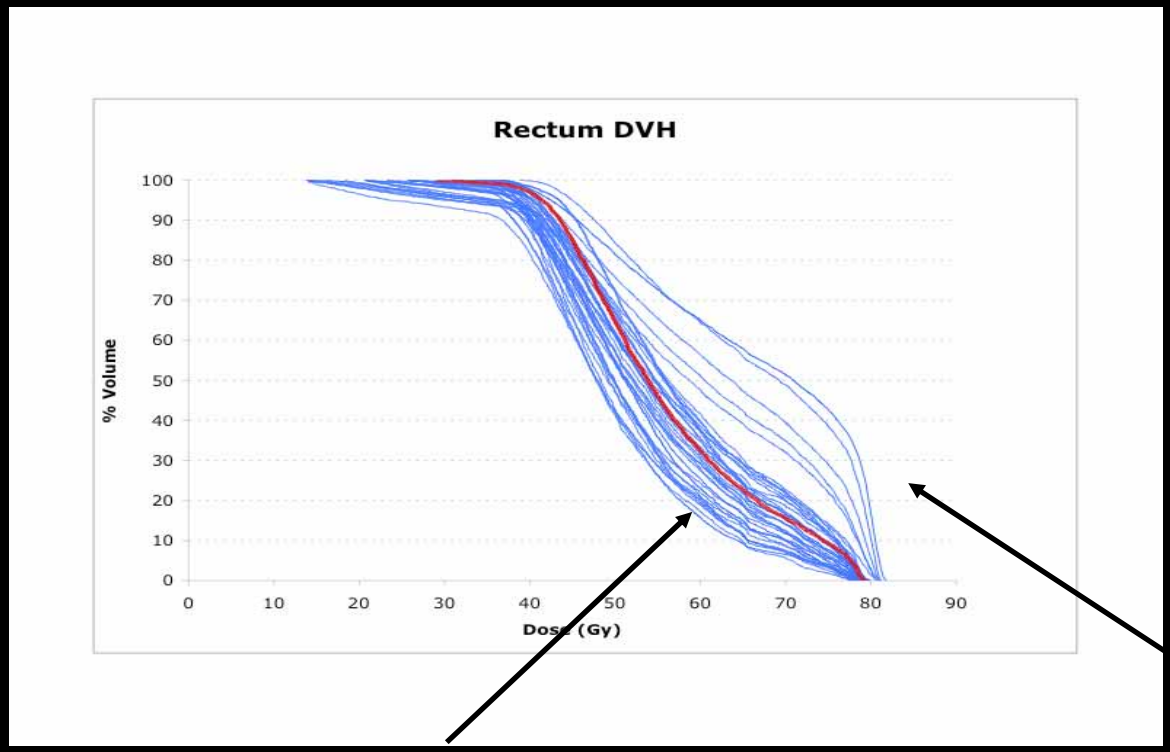
Recalculate Dose on MVCT image

MVCT Images for Dose Calculation
Summary

- MVCT numbers are reproducible
- MVCT to electron density calibration is reliable
- Phantom end-to-end test results are within 1 % of plan results
- MVCT images can be used for reliable dose computations

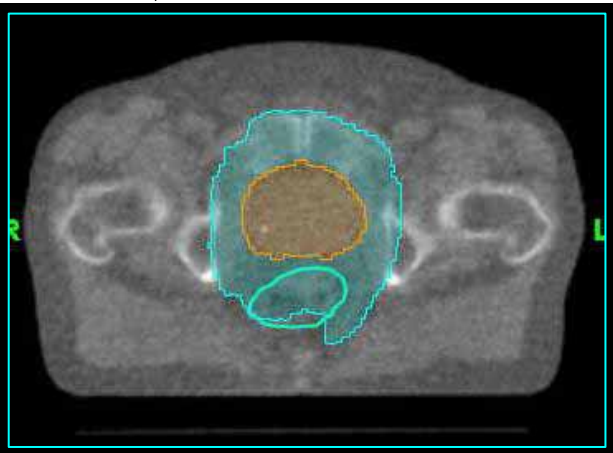
Langen et al. : Use of megavoltage CT (MVCT) images for dose computations. PMB, 50, pp 4259

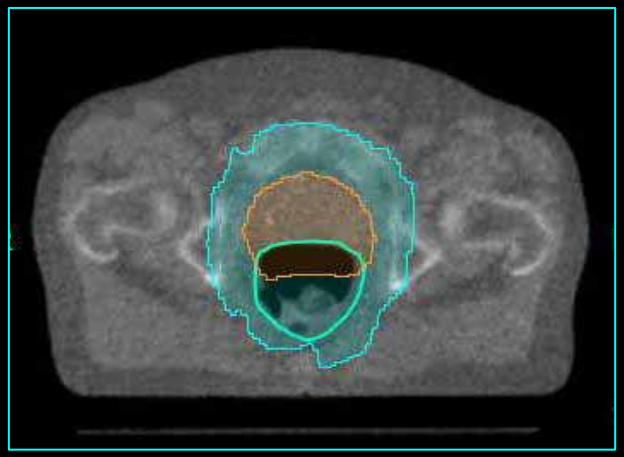
DVH Recalculation

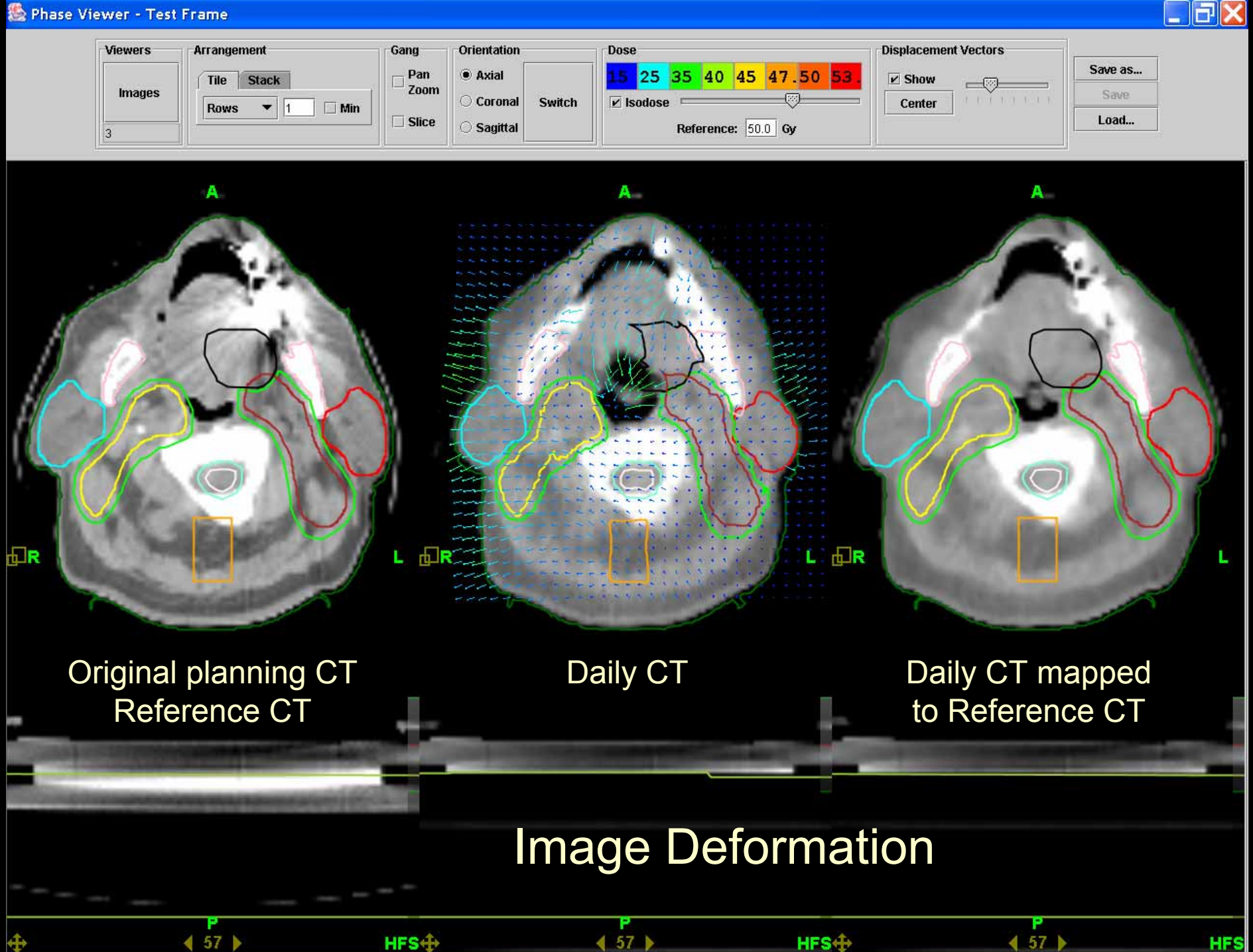


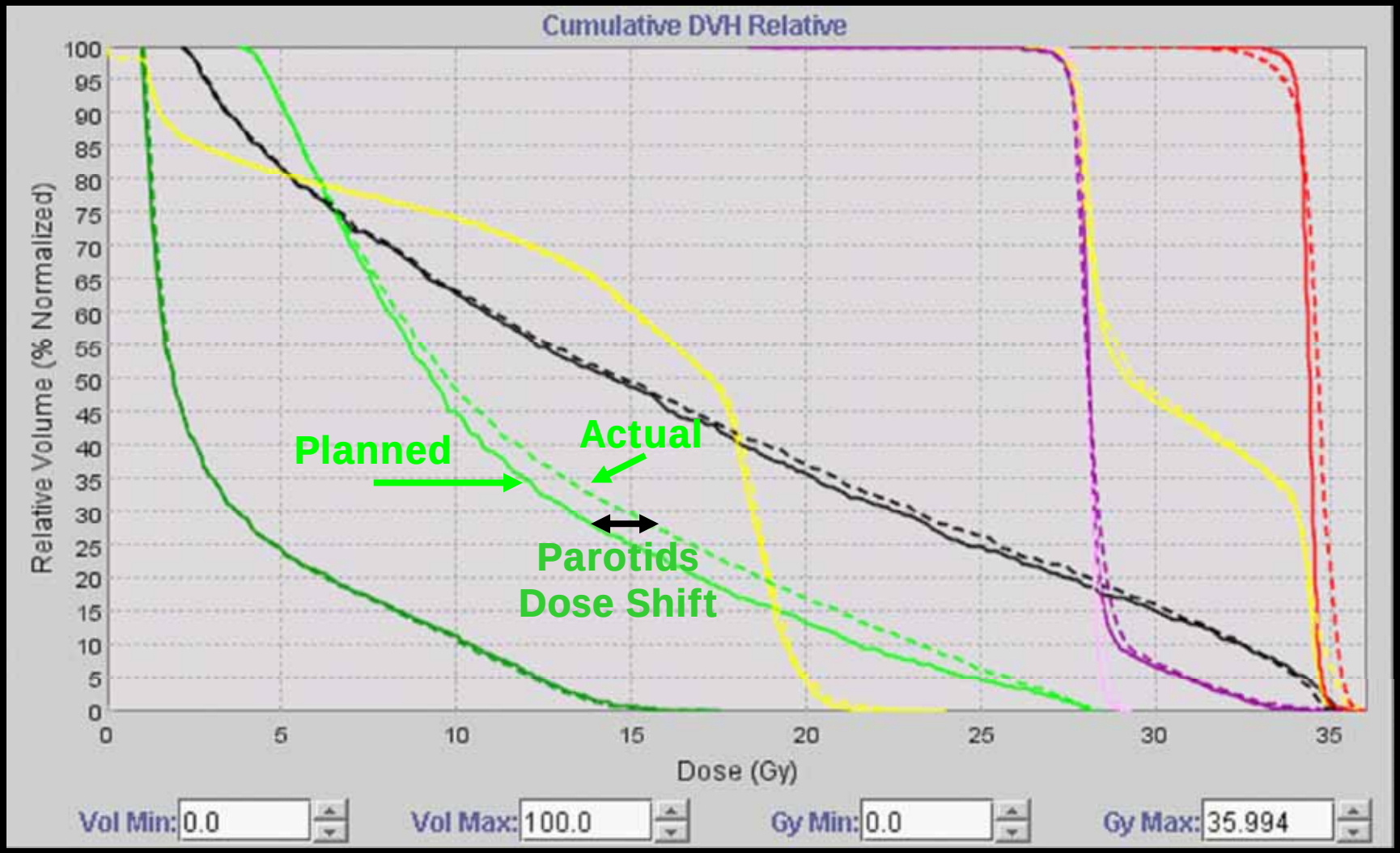
Plan DVH

39 “true” DVHs





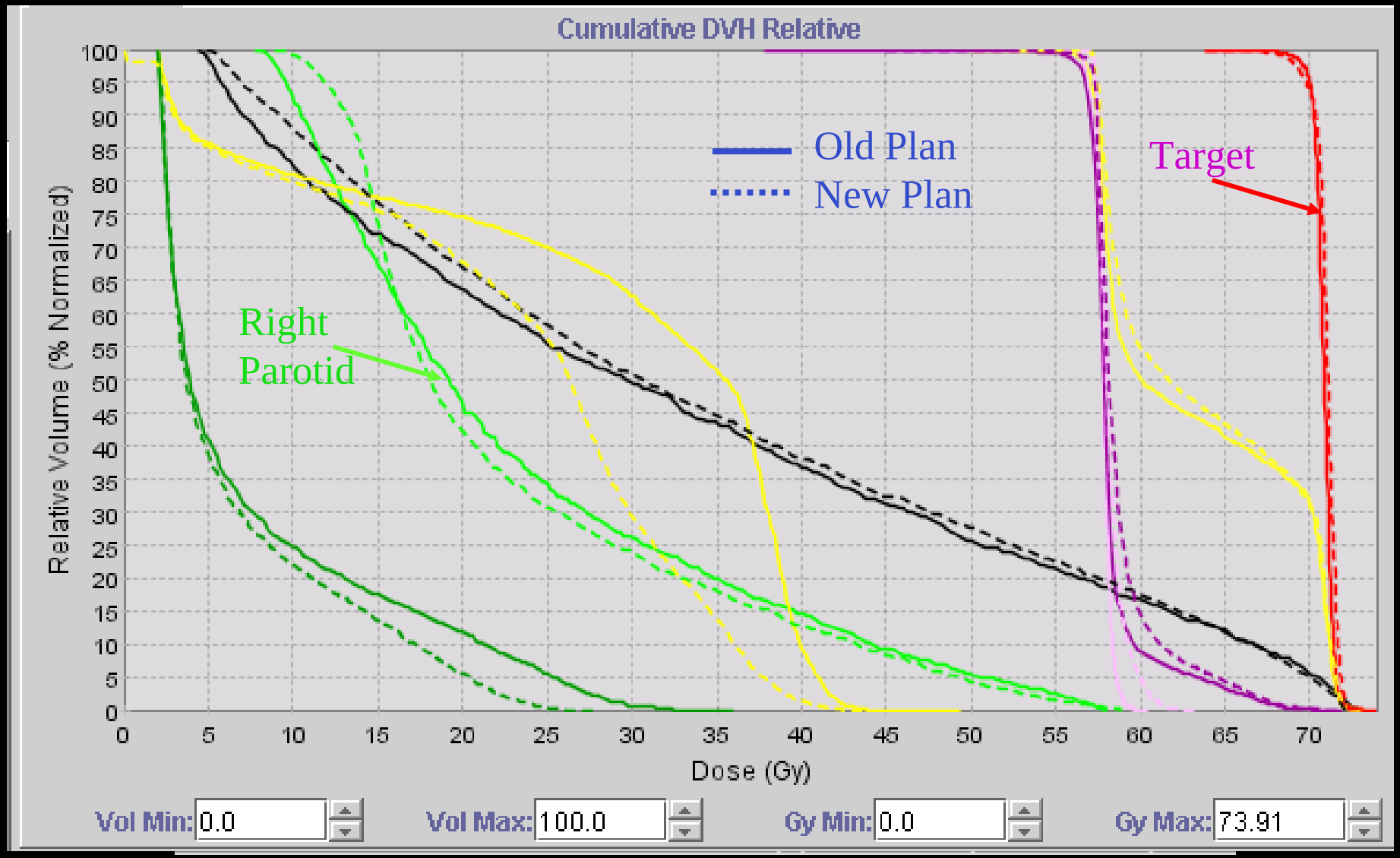

Phase Viewer - Test Frame
Viewers
Images
3
Arrangement
Tile
Stack
Rows
1
Min
Gang
Pan
Zoom
Slice
Orientation
Axial
Coronal
Sagittal
Switch
Dose
15 25 35 40 45 47.50 53.
Isodose
Reference: 50.0 Gy
Displacement Vectors
Show
Center
Save as...
Save
Load...
A
R
L
P
57
HFS
Original planning CT
Reference CT
Daily CT
Daily CT mapped
to Reference CT
Image Deformation


Cumulative DVH Relative
Relative Volume (% Normalized)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
Dose (Gy)
Planned
Actual
Parotids
Dose Shift
Vol Min: 0.0
Vol Max: 100.0
Gy Min: 0.0
Gy Max: 35.994

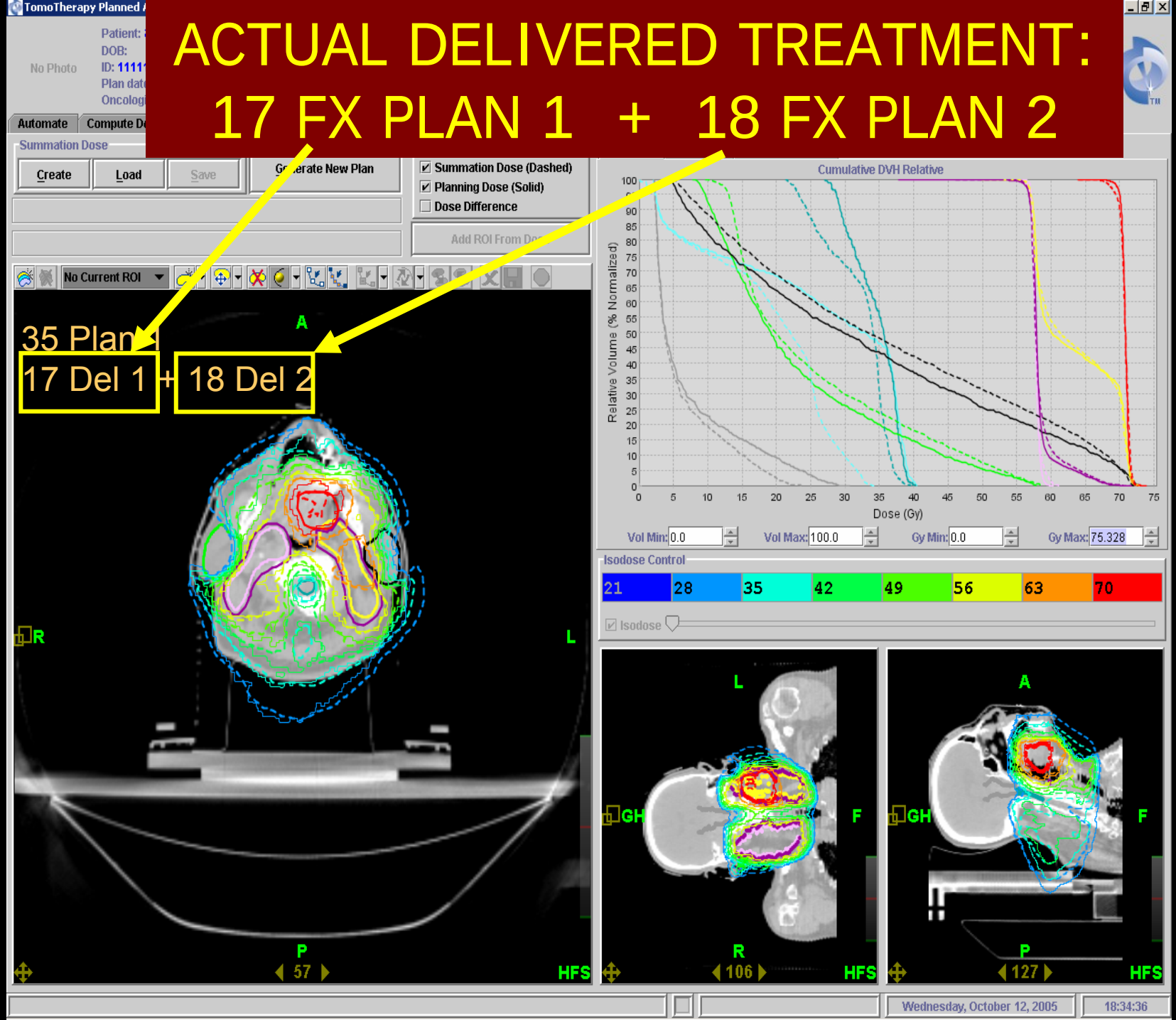
Composite Delivery after Re-Plan

New plan on new CT, based on the accumulation of doses from 17 of 35 total fractions

AIM: REDUCE PAROTID DOSE - 4 Gy colder over remaining 18 fractions



ACTUAL DELIVERED TREATMENT:
17 FX PLAN 1 + 18 FX PLAN 2



Acknowledgements

MDACCO

- Doug Burch, CMD
- Rob Burkavage, CMD
- Bobby Chauhan, CMD
- Patrick Kupelian, MD
- Katja Langen, PhD
- Choonik Lee, PhD
- Rafael Mañon, MD
- Amish Shah, PhD
- Robert Staton, PhD
- Thomas Wagner, PhD
- Twyla Willoughby, MS
- Omar Zeidan, PhD

University of Wisconsin/TomoTherapy

- Quan Chen, PhD
- Rupak Das, PhD
- Jason Haimerl, PhD
- Weiguo Lu, PhD
- Rock Mackie, PhD
- Gustavo Olivera, PhD
- Ken Ruchala, PhD
- Wolfgang Tome, PhD