

3

IMRT in clinical practice at the
UMC-Utrecht

Clinical use of IMRT

- **Improvement of local control without increased incidence of normal tissue complications**
 - **Dose escalation in the prostate**
- **Step-and-Shoot delivery with Elekta linacs with MLC**
- **Inverse planning with PLATO-ITP**

Dilemma:

- **Increase dose to target**
And
- **Avoid normal tissue**
And
- **Don't reduce margins around target**

Outline

- **Planning**
- **Dosimetric verification of treatment plan**
- **position verification using fiducial gold markers**

Planning: partial boosting

- **Dose escalation in conventional plan is not possible because of high toxicity for normal tissue**
- **Reducing margins around the CTV is unsafe because of uncertainties in target position**



- **Increase the dose to an area inside the target and mimic the old dose distribution outside**

Partial boost Treatment of the Prostate

- **Dose escalation in GTV up to 76 Gy**
- **35 identical fractions, no separate boost**
- **Mimic conventional dose distribution outside GTV:**
 - **Rate of toxicity as in conventional treatment**
 - **Local control at least equal to conventional treatment**
- **Position verification with fiducial gold markers**

Contours for Inverse Planning

transversal

sagittal

CTV

PTV

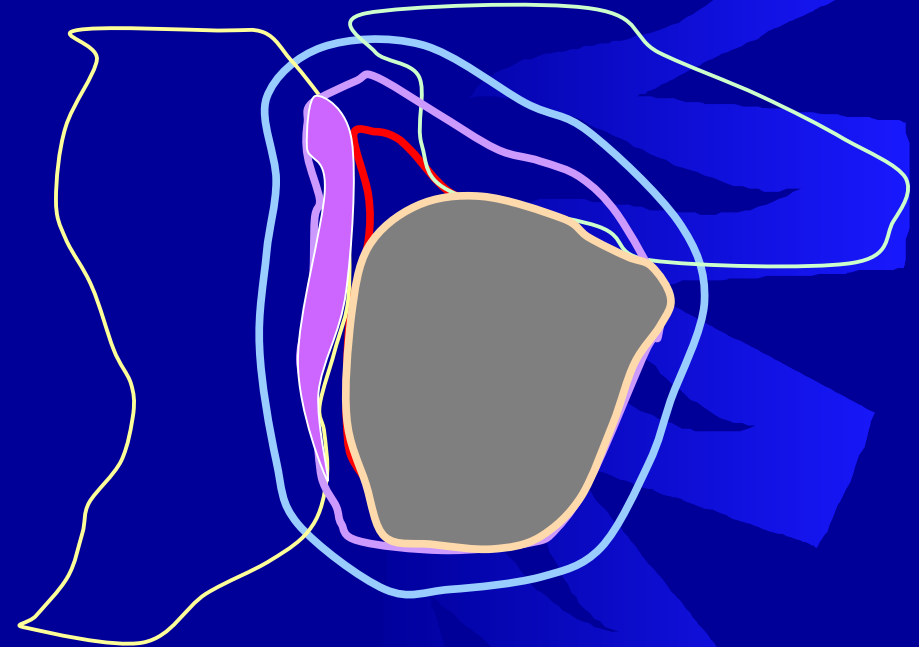
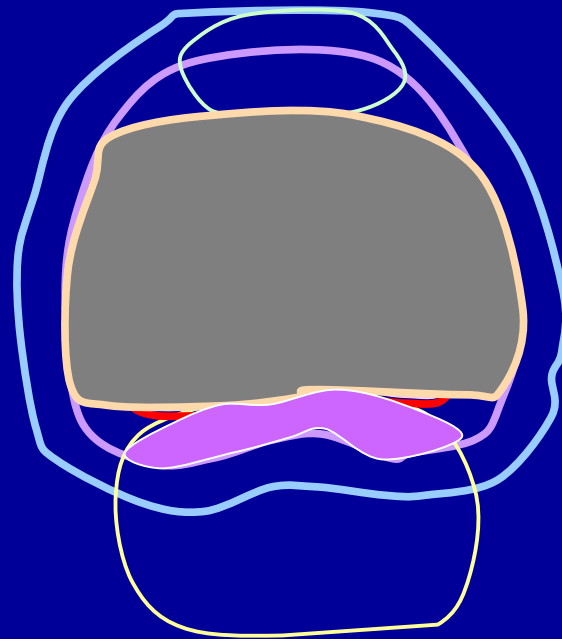
TV

rectum

bladder

Extended Boost Volume

Overlap PTV-Rectum



Dose prescription

Optimization Parameters (Total dose; values in Gy)

VOI	On/off	Overlap Priority	Organ Type	Max Dose	Weight	Min Dose	Weight	DVH Points
PTV	<input checked="" type="checkbox"/>	5	T O I	69.0	100.0	69.0	100.0	<input type="checkbox"/>
EBV	<input type="checkbox"/>	1	T O I	76.0	20.0	76.0	30.0	<input type="checkbox"/>
TV	<input checked="" type="checkbox"/>	6	T O I	66.0	100.0	0.0	0.0	<input type="checkbox"/>
PTVrect	<input type="checkbox"/>	2	T O I	68.0	100.0	68.0	50.0	<input type="checkbox"/>

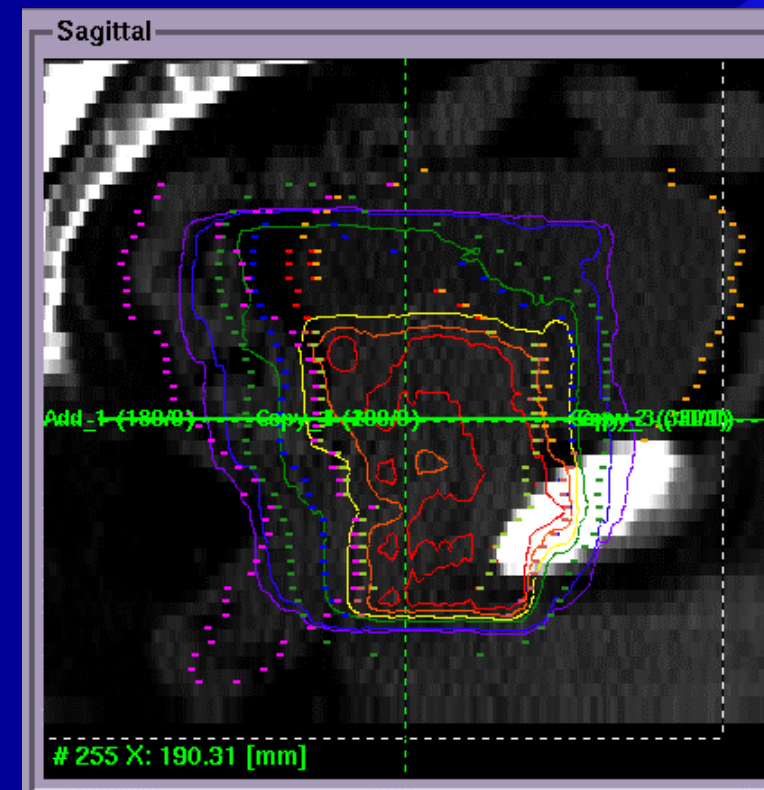
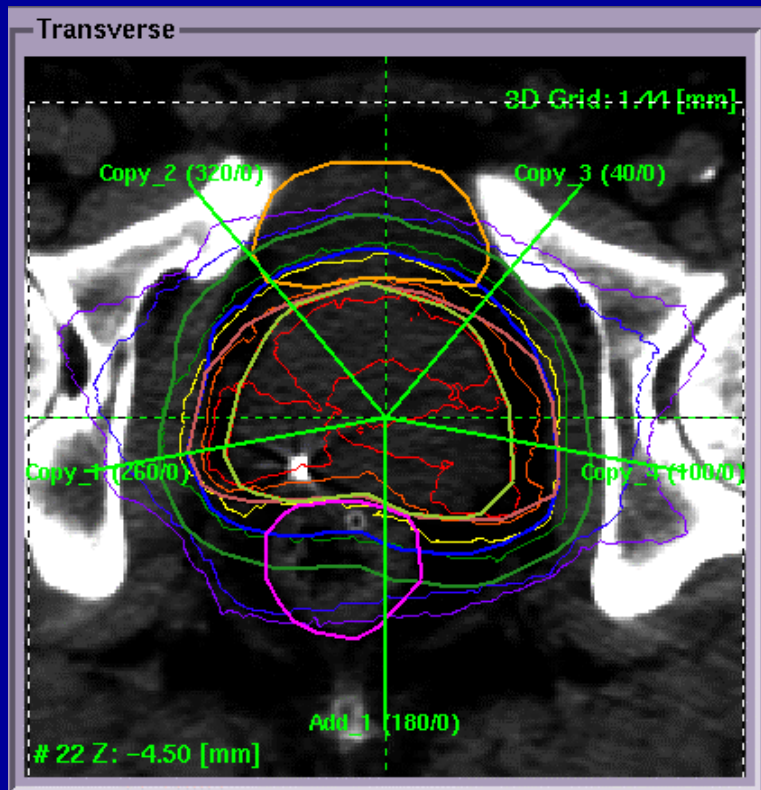
Organs at risk

body	<input checked="" type="checkbox"/>	17	T O I	45.0	5.0	0.0	0.0	<input type="checkbox"/>
rectum	<input checked="" type="checkbox"/>	3	T O I	50.0	3.0	0.0	0.0	<input type="checkbox"/>

OK Cancel

Dose Distribution

<input checked="" type="checkbox"/>	45.00	<input type="checkbox"/>	68.00	<input type="checkbox"/>	72.00	<input checked="" type="checkbox"/>	76.00
<input checked="" type="checkbox"/>	50.00	<input type="checkbox"/>	69.00	<input type="checkbox"/>	73.00		
<input checked="" type="checkbox"/>	66.00	<input checked="" type="checkbox"/>	70.00	<input checked="" type="checkbox"/>	74.00		
<input type="checkbox"/>	67.00	<input type="checkbox"/>	71.00	<input type="checkbox"/>	75.00		

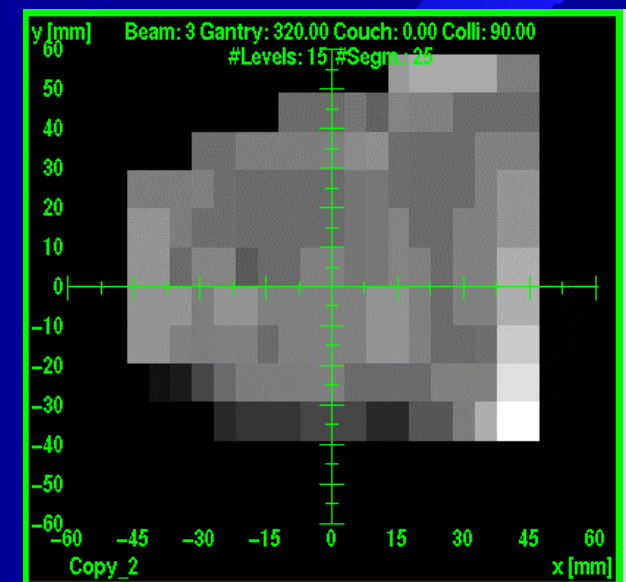
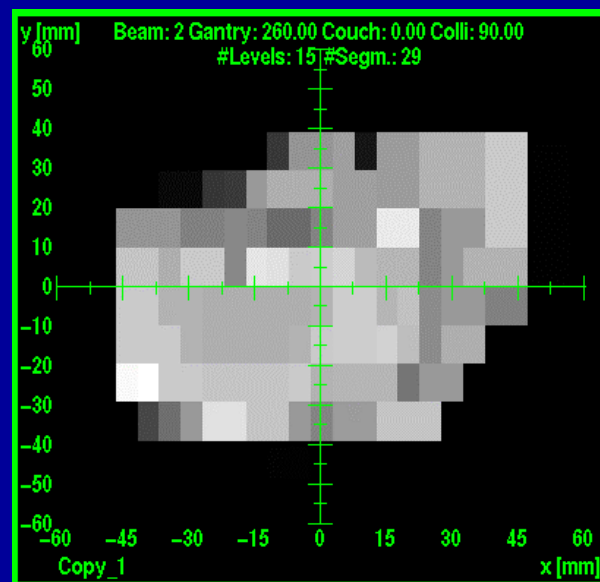
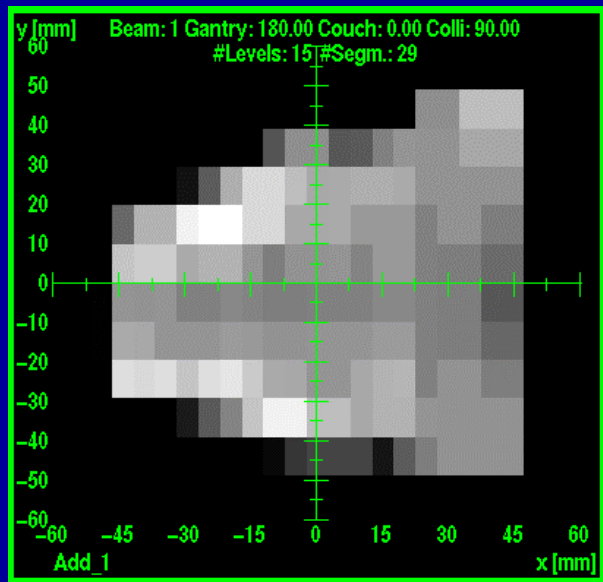


Optimized fluence

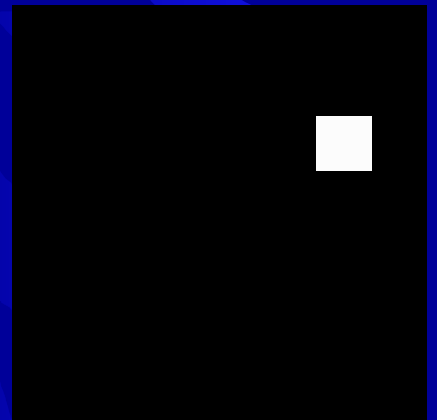
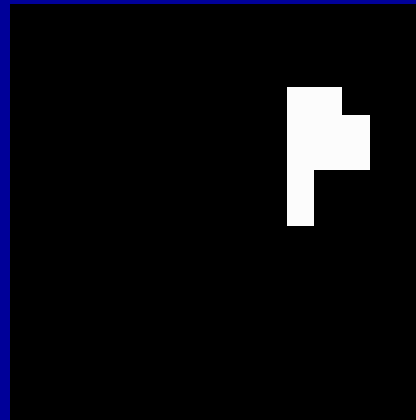
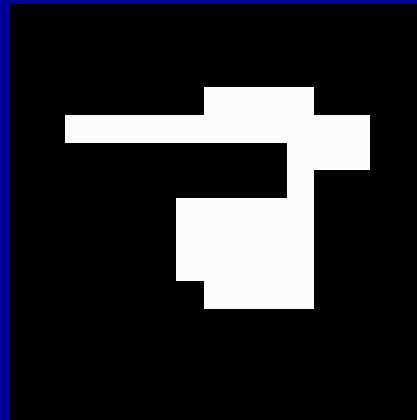
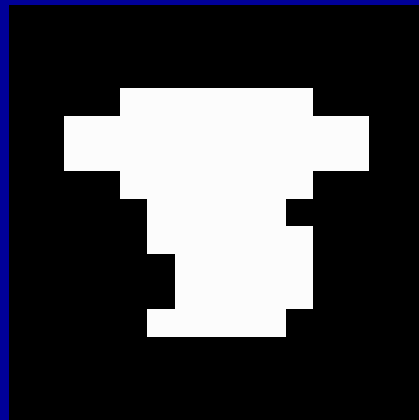
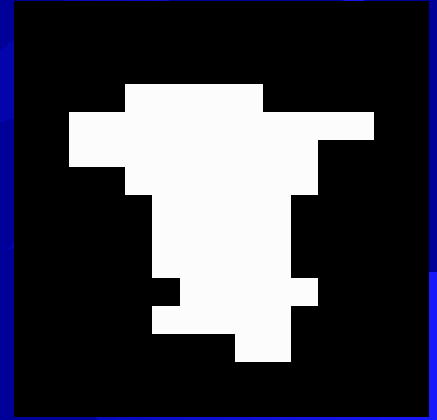
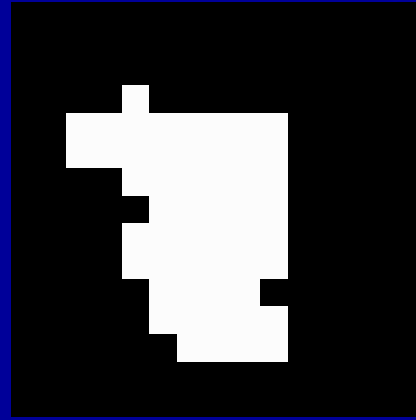
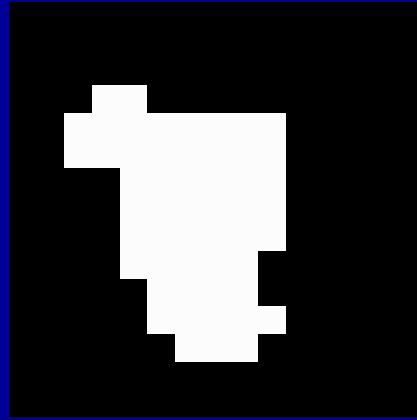
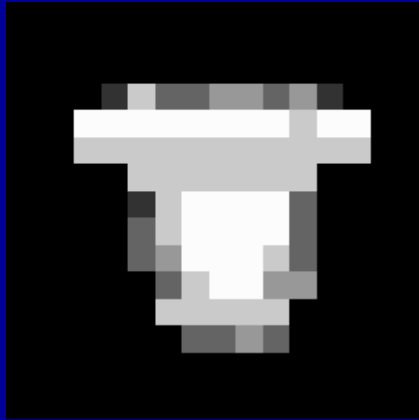
PA

260

320



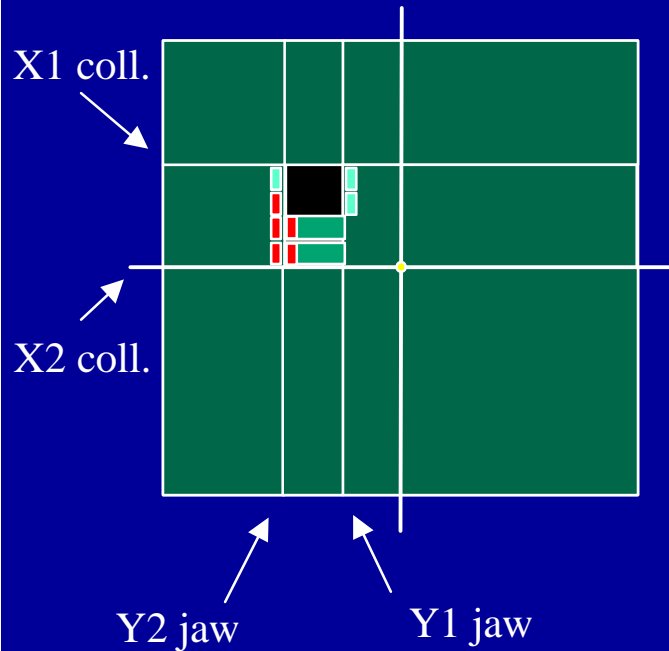
Sequencing



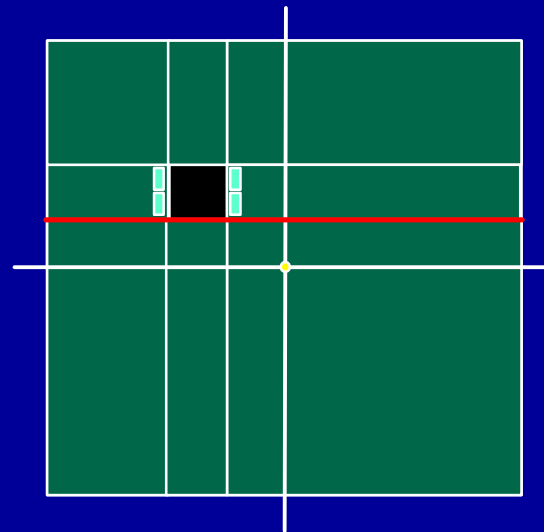
Sequencing for the Elekta MLC

Off-axis fields

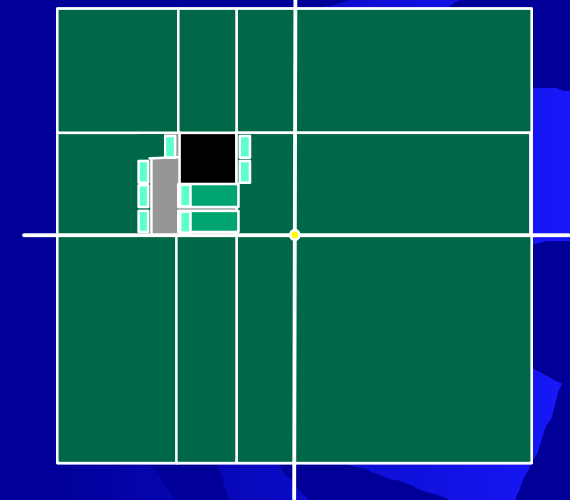
Collision between leaves



X collimator crosses 0



Transmission through back-up jaw

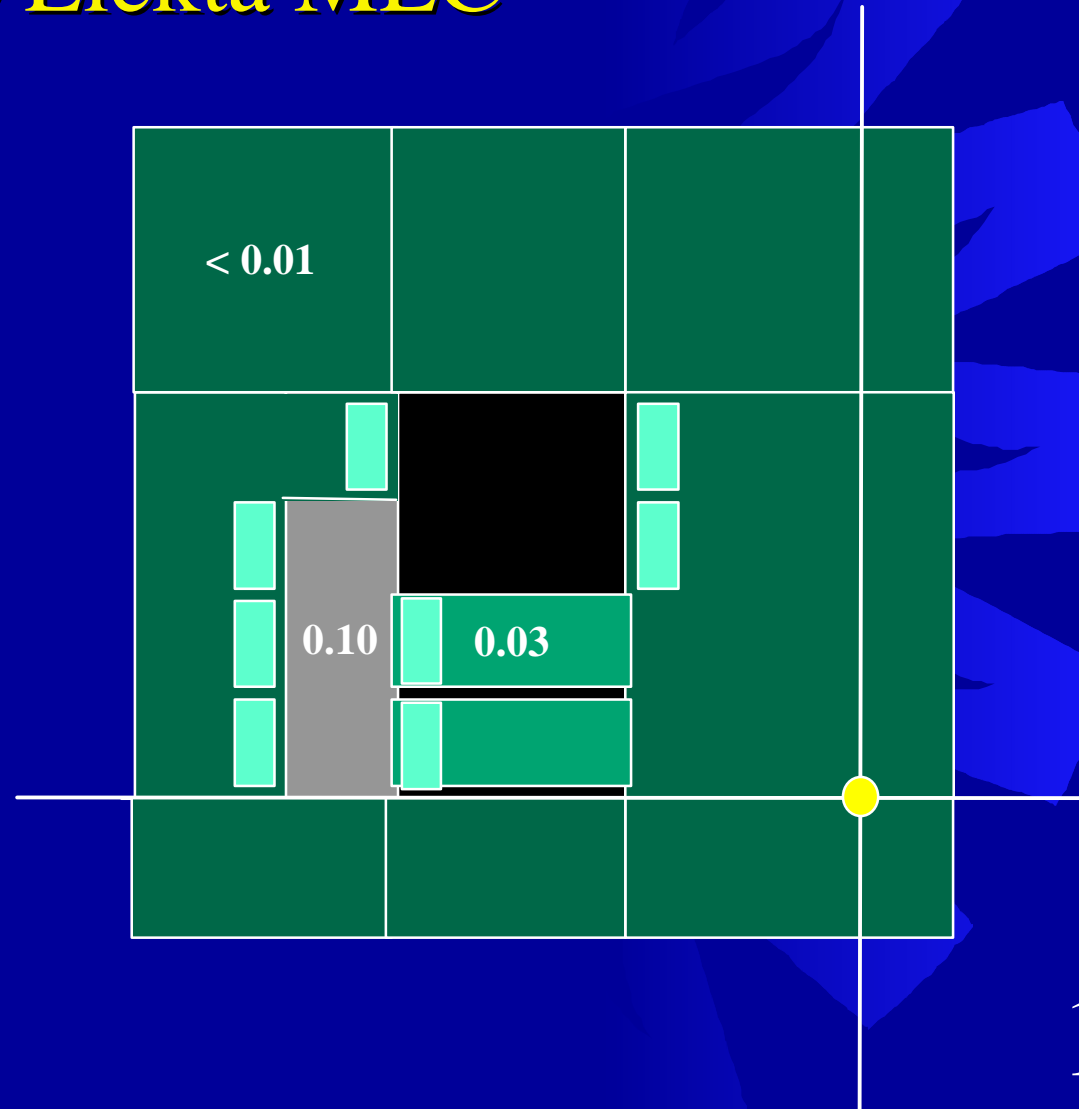


Sequencing for the Elekta MLC

'Flag pole' effect

Transmissions

- **X-jaw** **0.005**
- **Y-jaw** **0.10**
- **Leaves** **0.03**

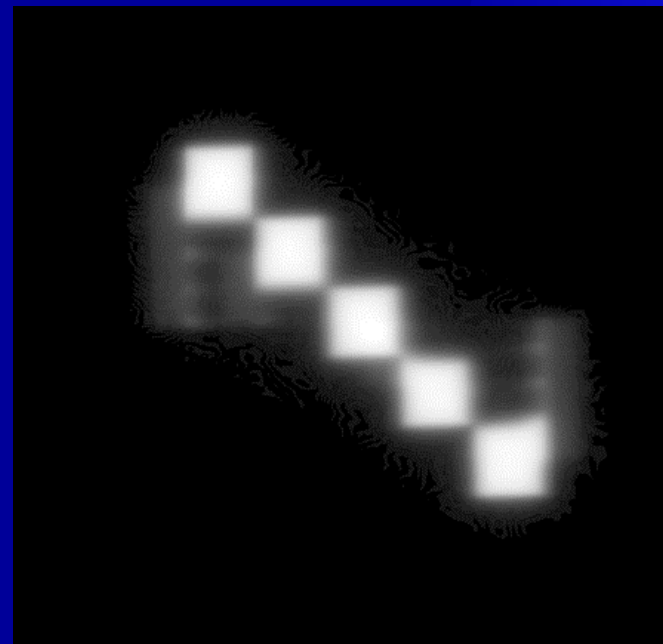


Sequencing for the Elekta MLC

Deliverable fluence
(1 level, 5 segments)



Film
(1 level, 5 segments)



UMC-U Sequencer for Elekta in PLATO ITP

- **Recursive algorithm**
- **Collimator and leaf transmissions are considered**
- **Fixed stratification**
- **Tongue/groove underdosage is prevented**
- **Sliding window and close-in modality possible**
- **Normalization of total deliverable fluence to total required fluence**

Quality assurance for IMRT

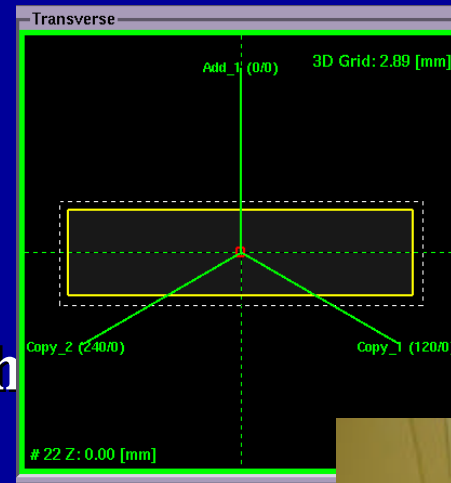
- **Dose check**
- **Position verification and correction**

Dose check

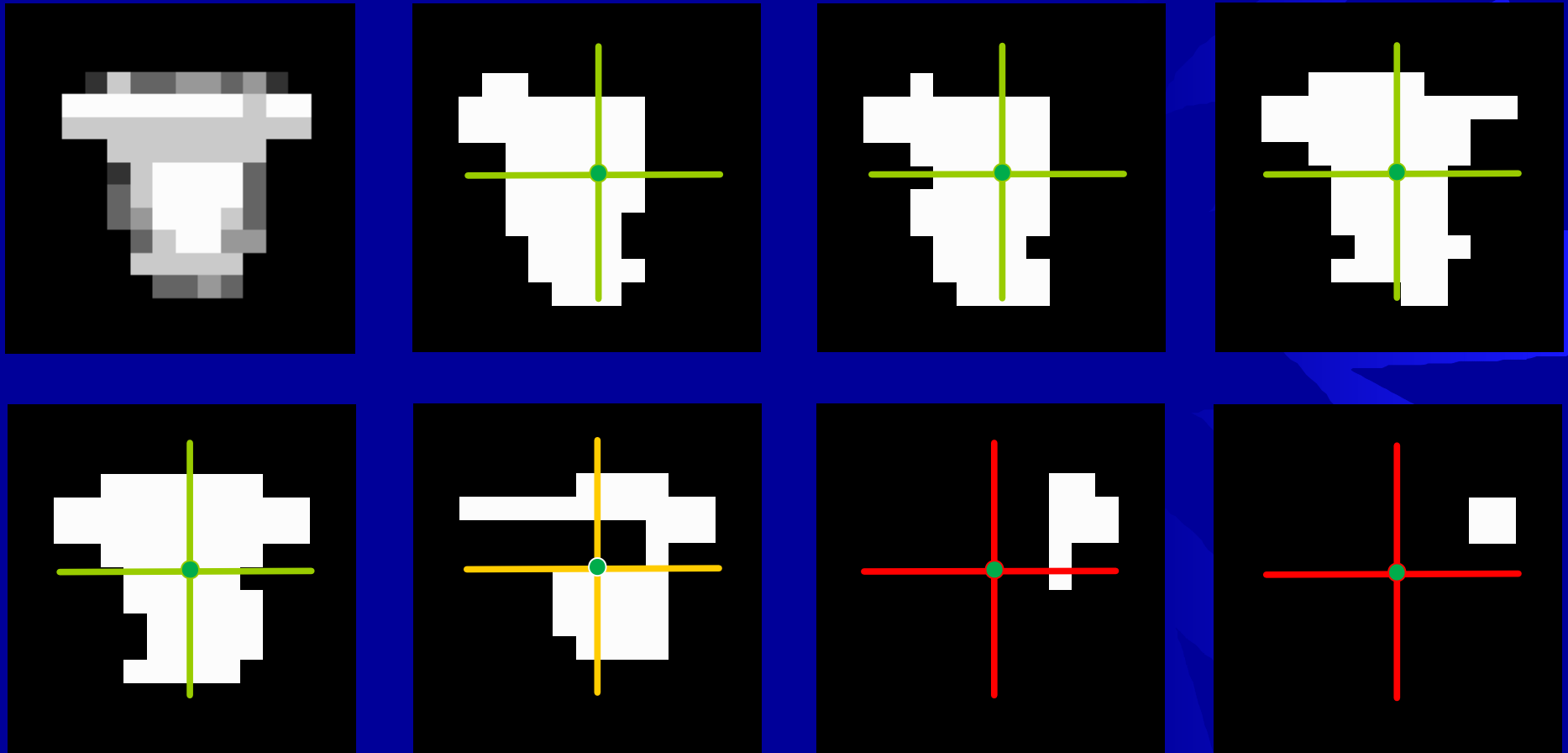
- **point dose measurement of isocenter dose**
- **film measurement of coronal plane**

Dose check: ionization chamber in phantom

- Transfer IMRT plan to polystyrene phantom
- Calculate dose
- Measure isocenter dose with IC04 ionization chamber

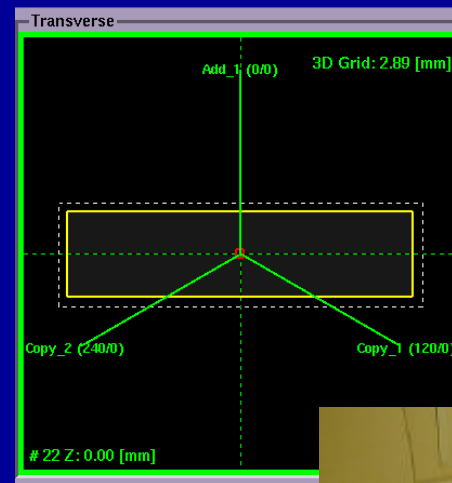


Ionization chamber measurement in irregular fields



Verification of delivered dose on film

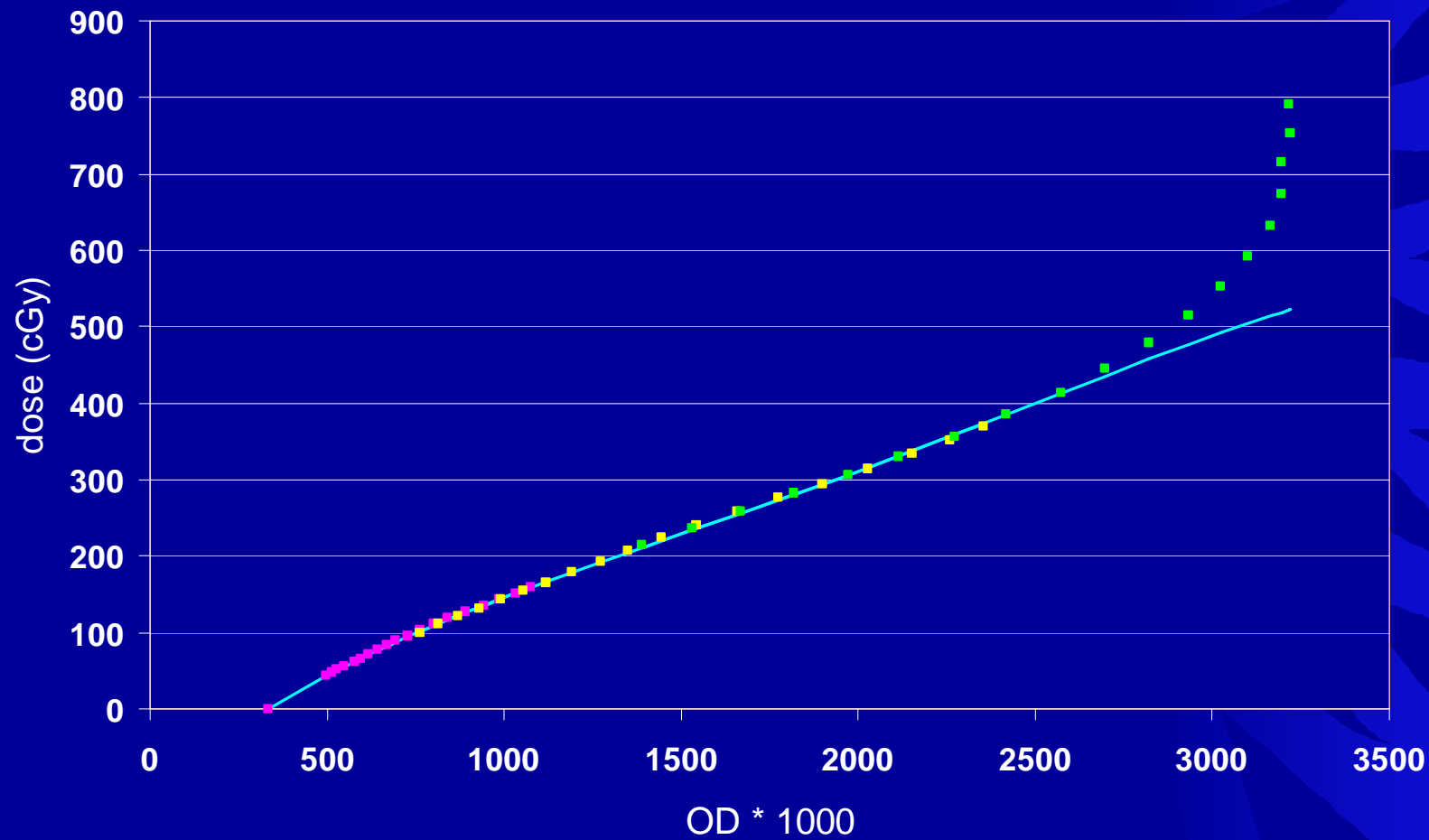
- **Transfer IMRT plan to polystyrene phantom**
- **Calculate dose**
- **Measure coronal plane dose on film**



Calibration ionization chamber and film

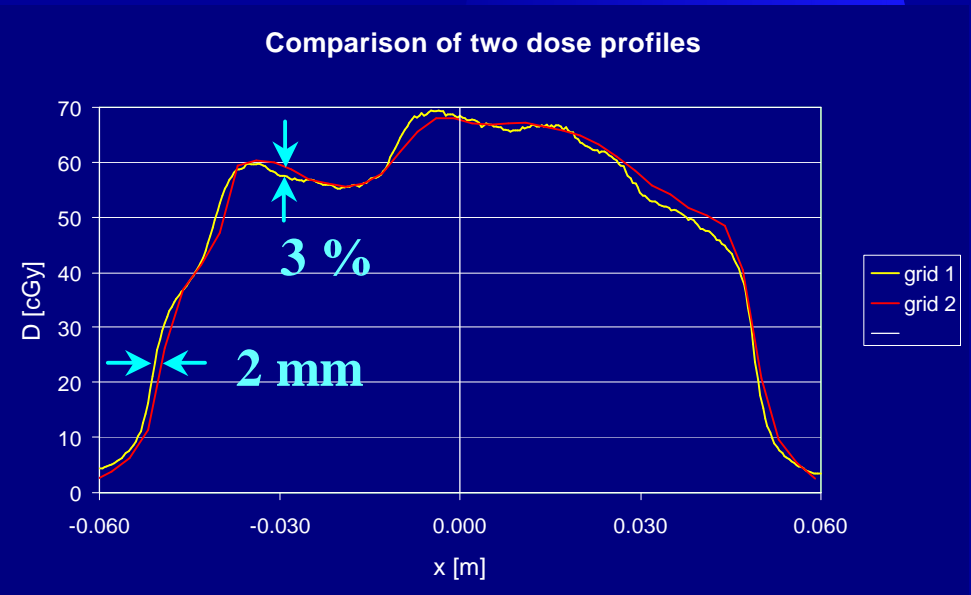
- **Calibration ionization chamber**
 - reference field 10x10 cm, depth 5 cm, SSD
- **calibration**
 - 20x20 cm wedge fields, depth 5 cm, SSD 100, collimator 90 and 270° 300, 700 and 1500 MU,
 - fit OD-dose curve to 4th order polynomial

Calibration Kodak EDR2 film



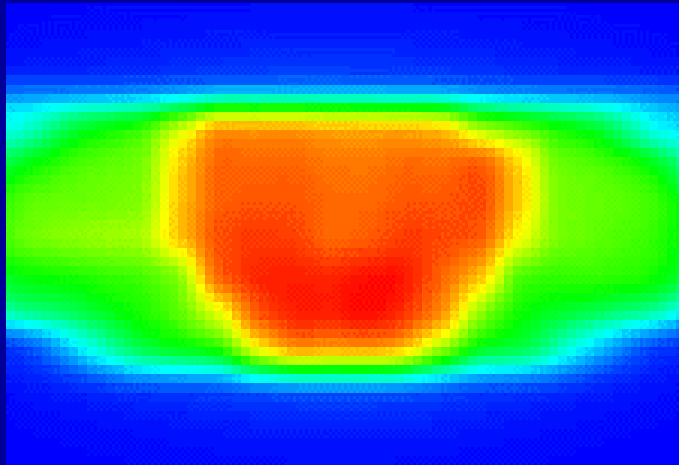
Quantitative Comparison of Dose Distributions

- **% Difference on plateau**
- **mm difference on gradient**
- **Generalize to 2D (film) and 3D (dose calculation)**

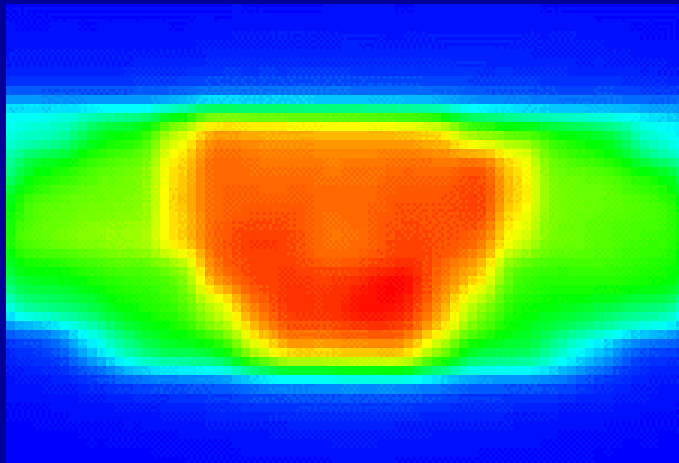


Quantitative comparison of dose distribution

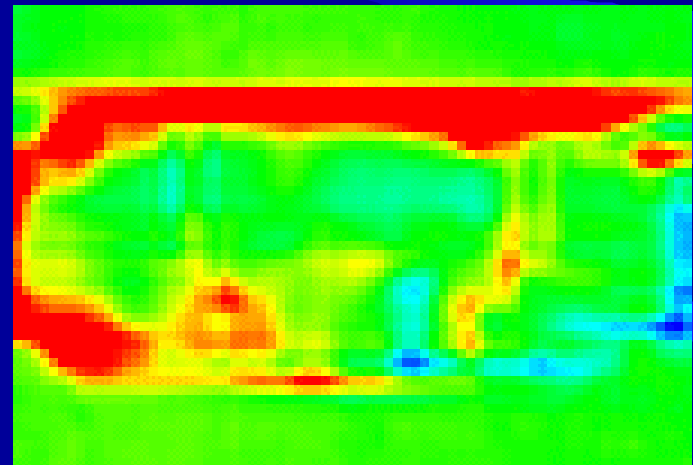
RTS



film

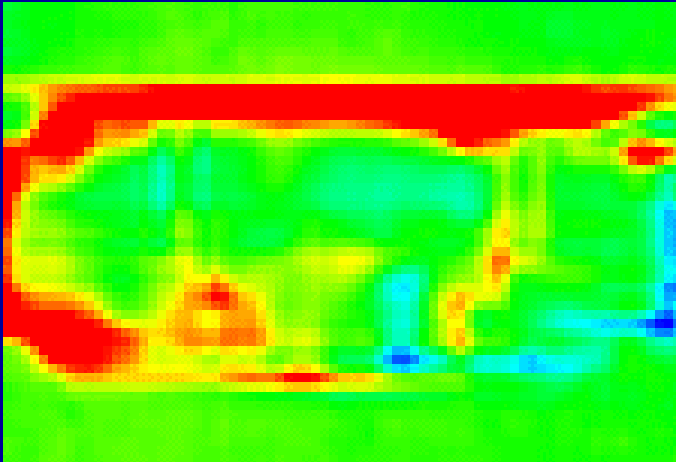


Difference
-5 to 5%

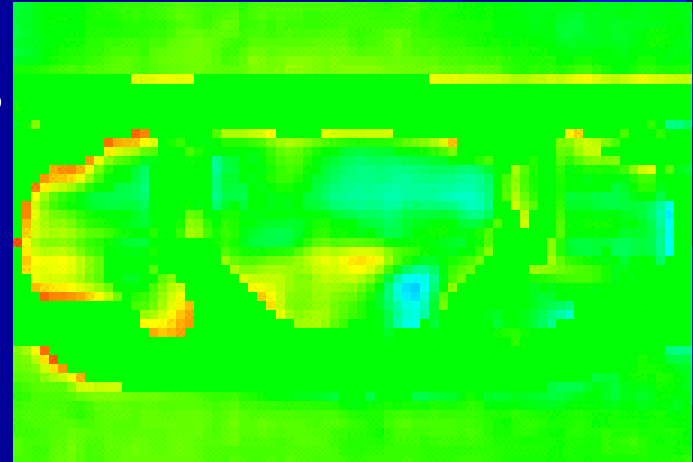


Quantitative comparison of dose distribution

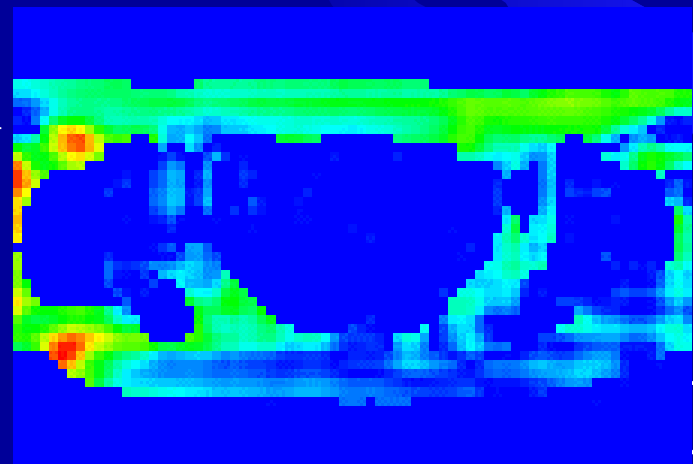
Difference
-5 to 5%



% diff
-5 to 5%

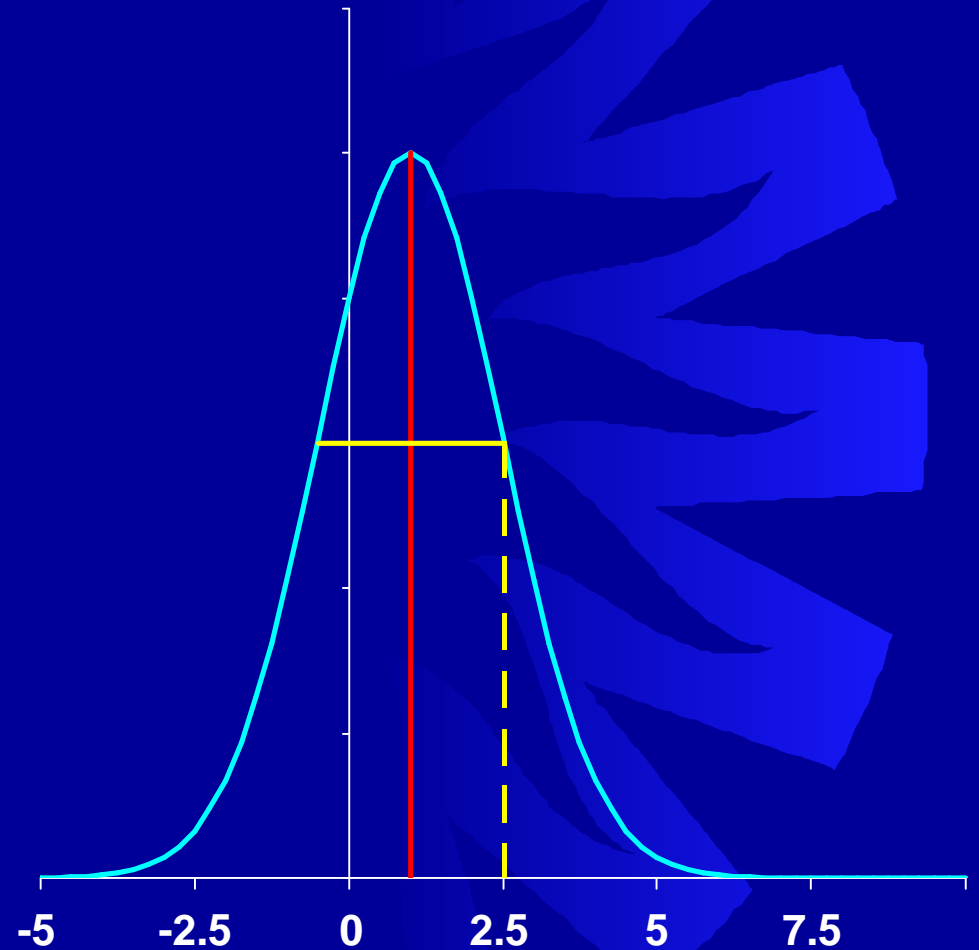


mm diff
0 to 5 mm



Quantitative comparison of dose distribution

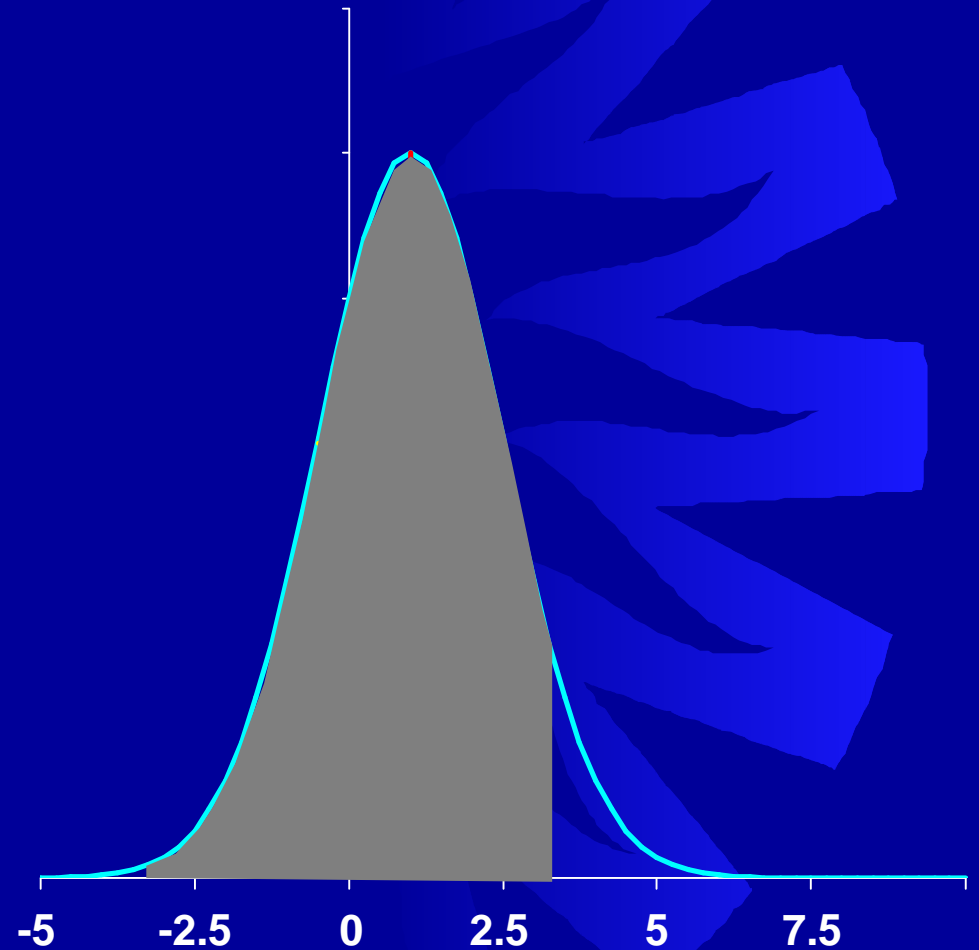
- **Statistics:**
 - average difference d_{av}
 - standard deviation s_d



Quantitative comparison of dose distribution

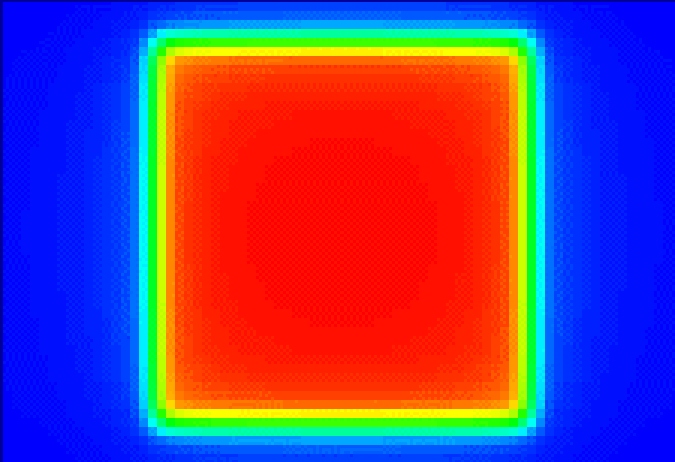
- **Statistics:**
 - average difference d_{av}
 - standard deviation s_d
 - confidence limit

$$D = |d_{av}| + 1.5 s_d$$

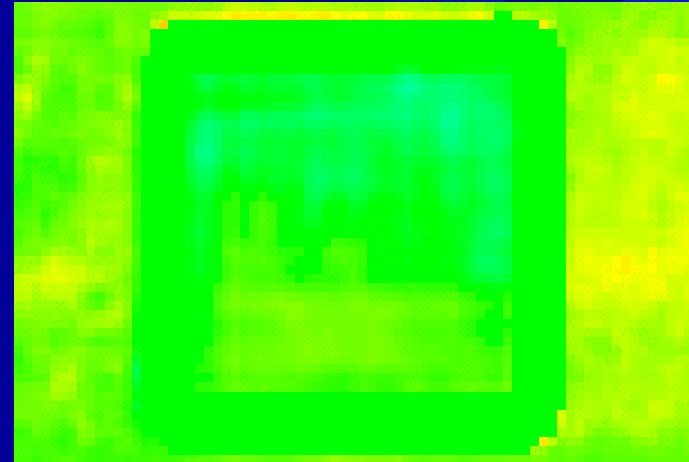


open field 10x10

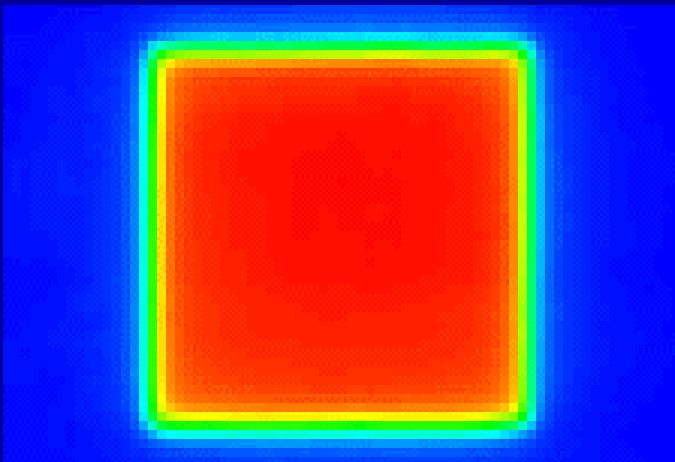
RTS



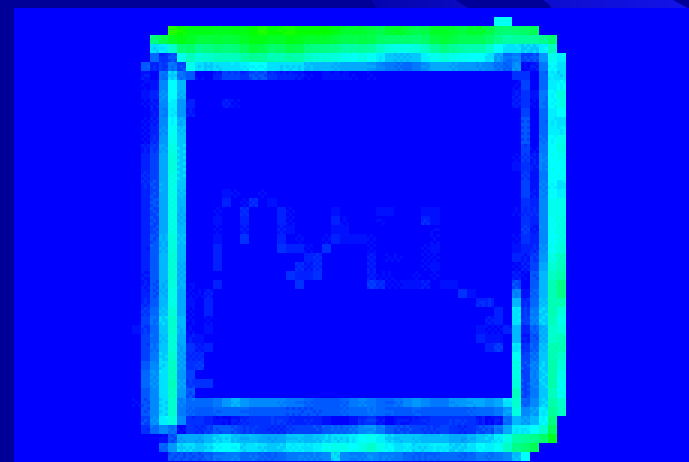
% diff
 $\Delta 2.3$



film

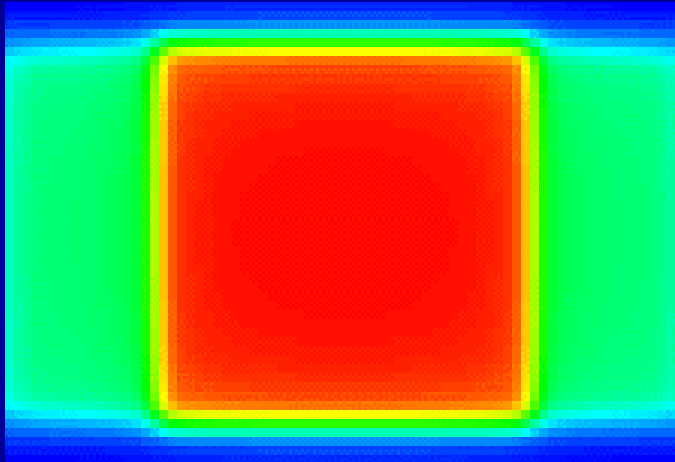


mm diff
 $\Delta 1.5$

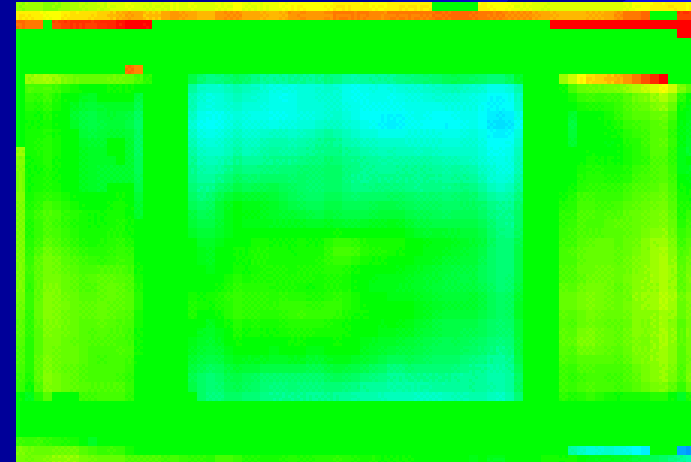


3 beam geometry, open fields

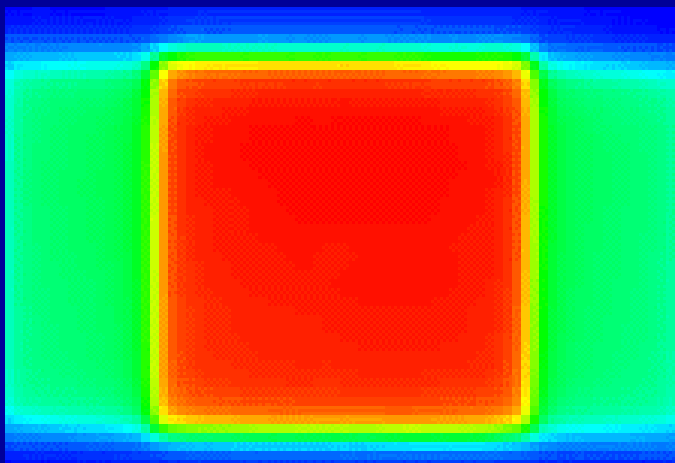
RTS



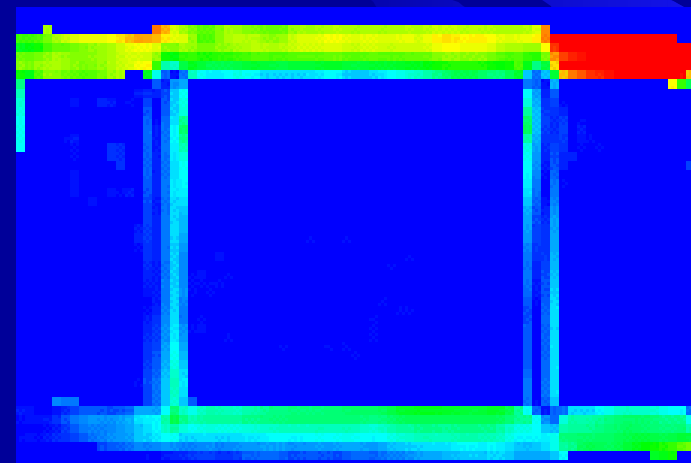
% diff
 $\Delta 2.3$



film

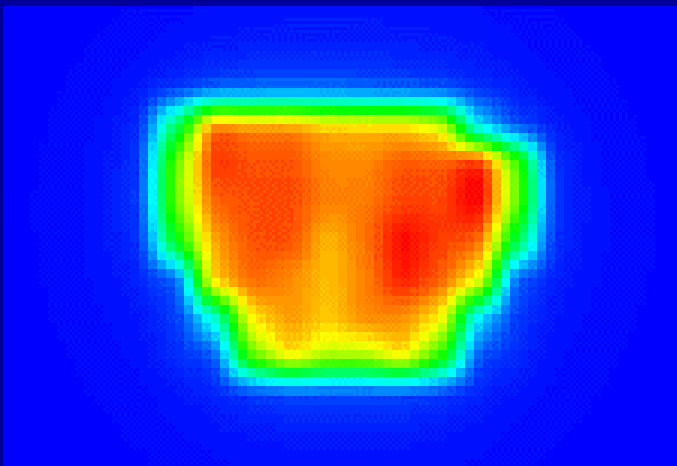


mm diff
 $\Delta 3.1$

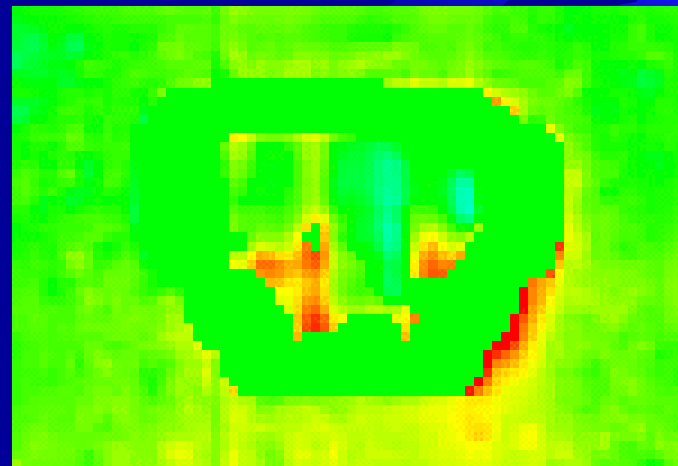


IMRT prostate, AP only

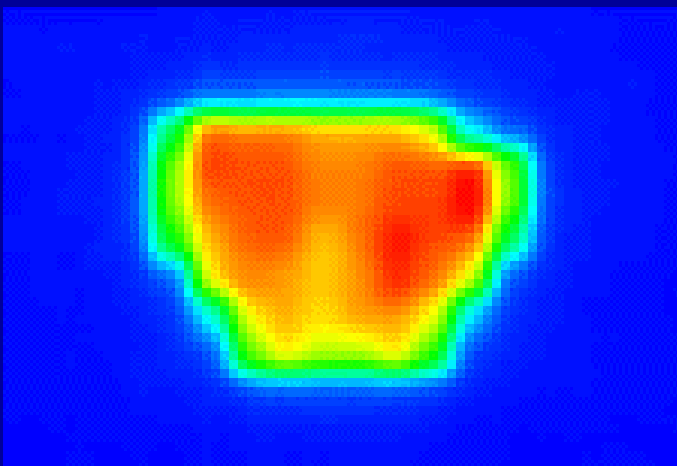
RTS



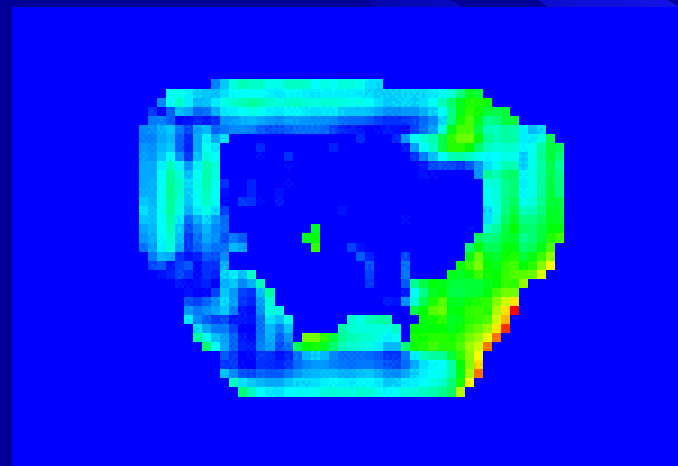
% diff
 $\Delta 2.5$



film

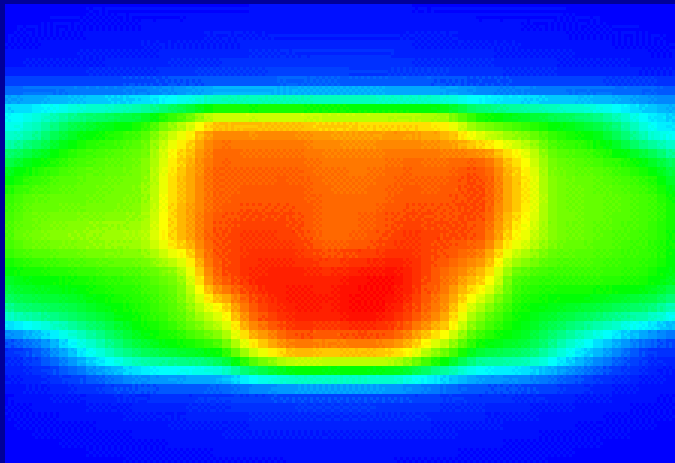


mm diff
 $\Delta 2.6$

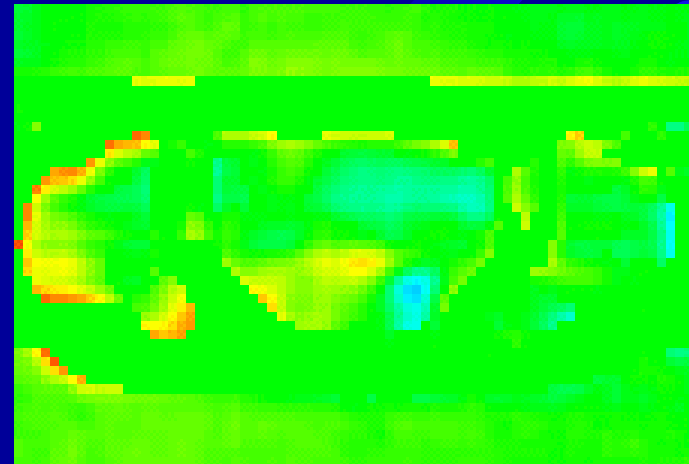


IMRT prostate

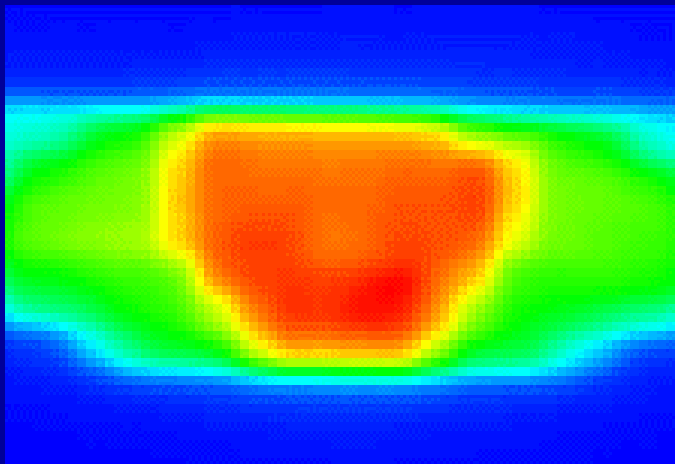
RTS



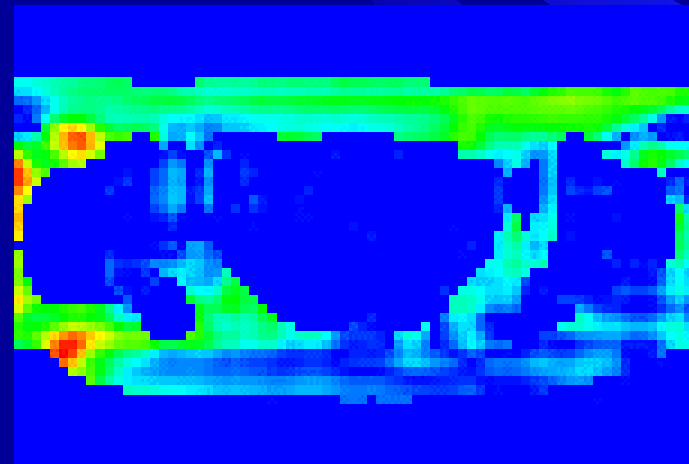
% diff
 $\Delta 2.0$



film



mm diff
 $\Delta 2.2$



Results dose check

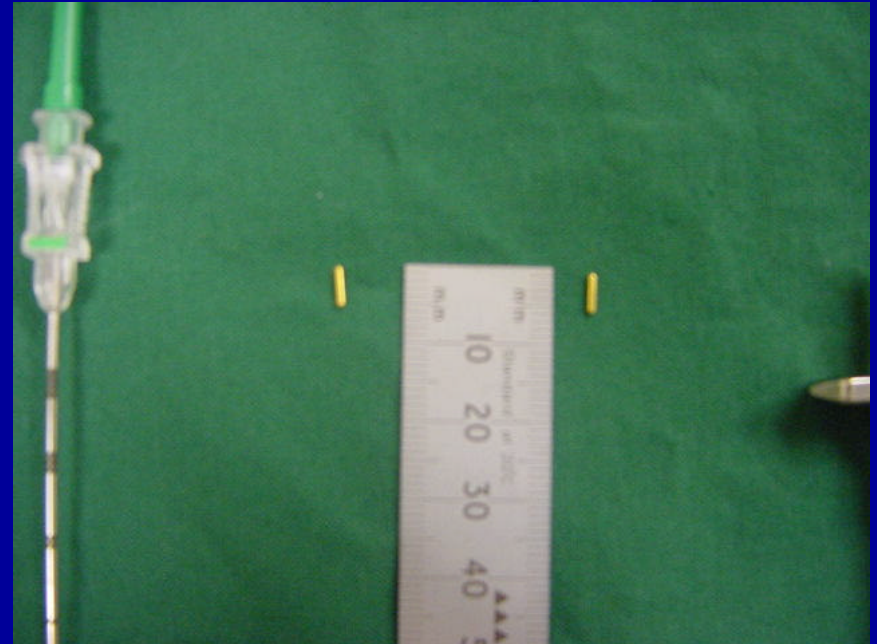
- **Isocenter dose**
 - **calculation - ionization chamber: -1.6%**
- **film measurement confidence limits**
 - **3.0% or 2.5 mm**

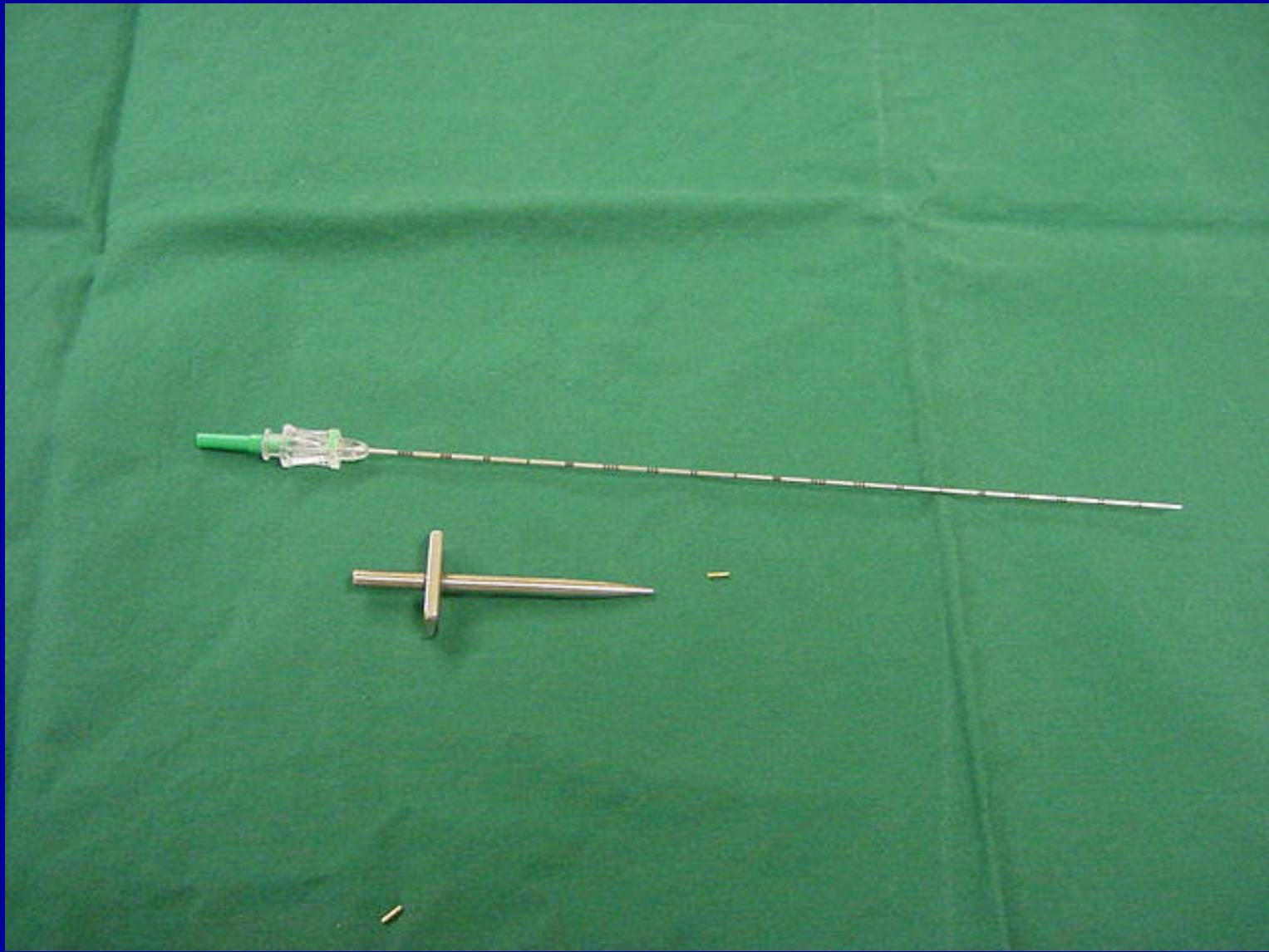
Position verification and correction

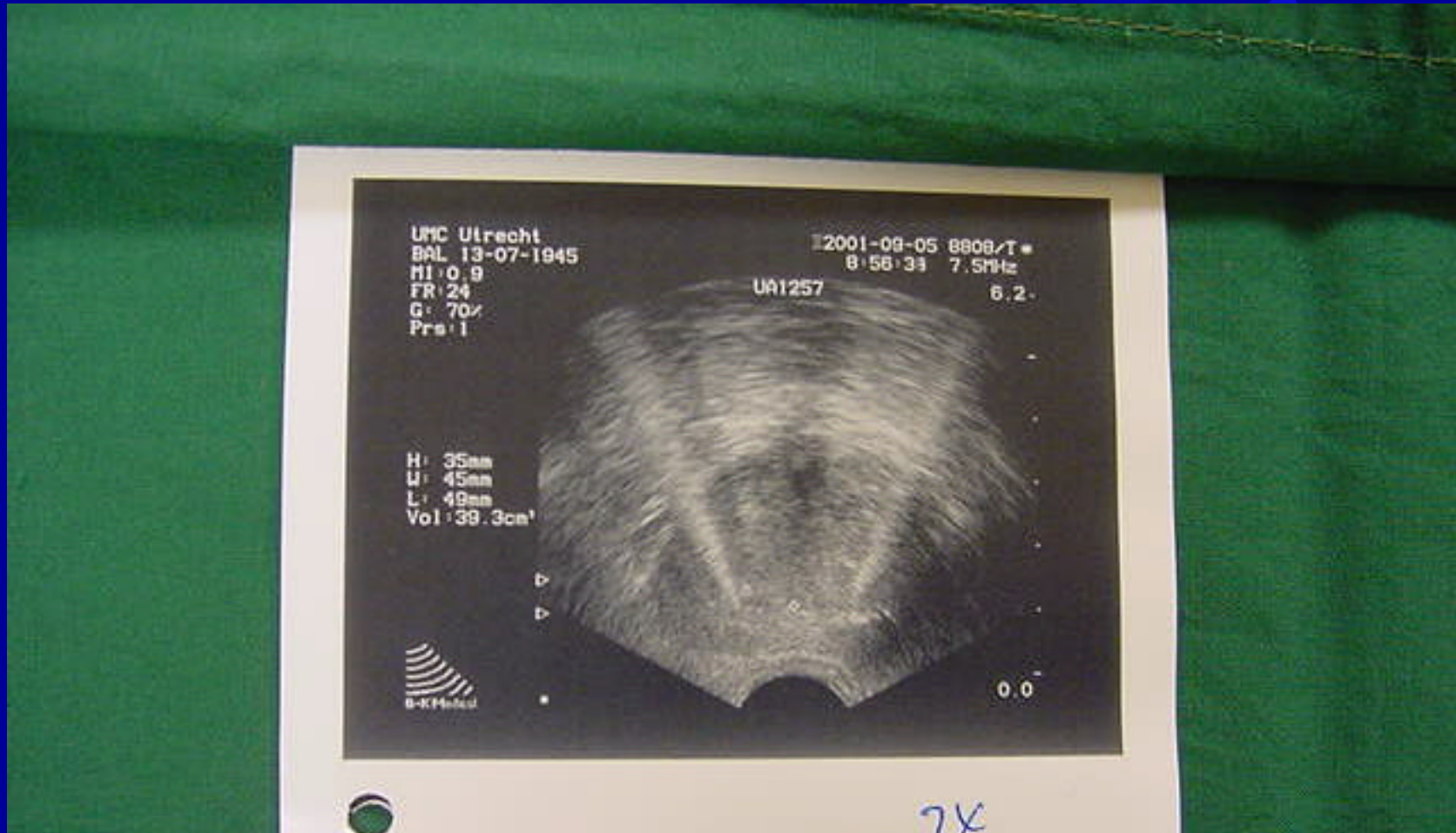
- **daily portal imaging of all treatment fields**
- **detection of position of gold markers**
- **shrinking action level correction protocol**

Implantation of Gold Markers

- **Lithotomy Position**
- **Transrectally Ultrasound Guided**
- **Iodine Implantation Needle**
- **Two Markers, One in each lateral Lobe**







Feasibility study:

Toxicity

- **Mild Transient Hematuria & Rectal Bleeding**
- **No Extra Pain**

Stability of markers inside prostate

- **Markers Migration**
- **Prostate contour changes**

Markers Study: materials

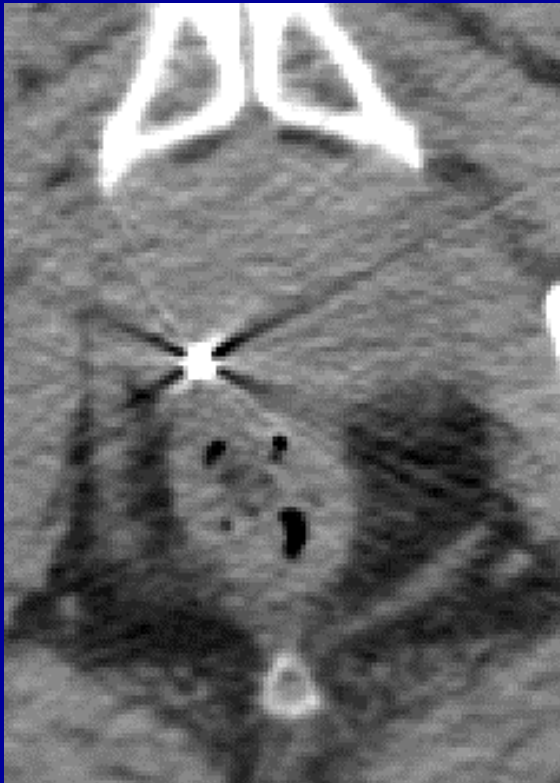
- **10 Patients**
- **1-3 Gold seeds**
- **Sequential CT Scans (0, 3, 6) week of treatment**
- **Daily a-Si Flat Panel Portal Image**

Marker study: methods

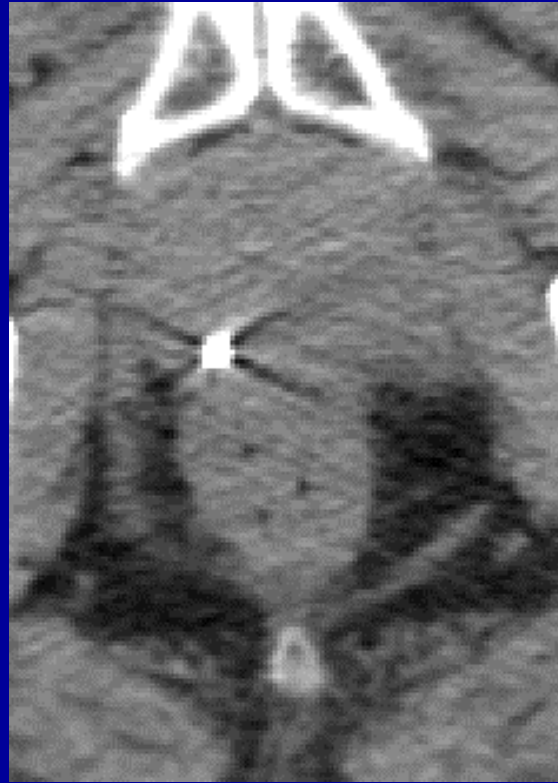
- **Measuring position of markers in repeat CT scans**
- **Compare similarity between prostate contours in repeat CT scans**
- **Measuring distance between two markers in Epid image**

Repeated CTs

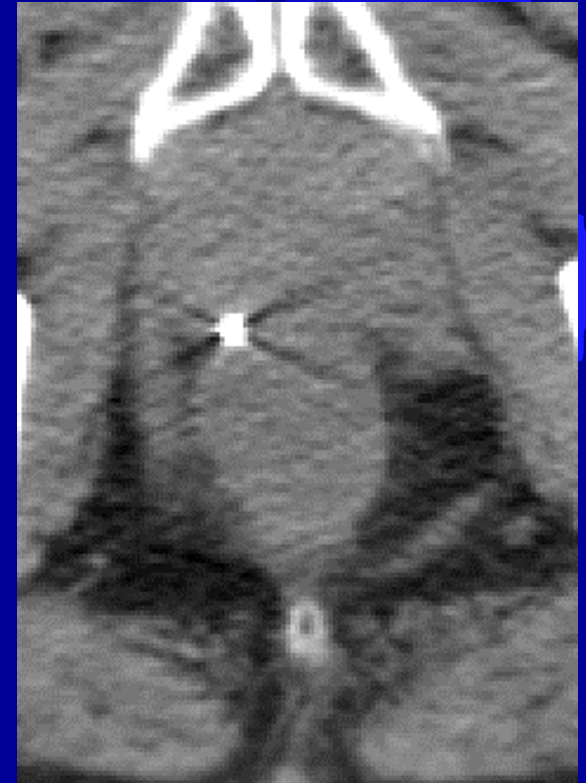
week 0



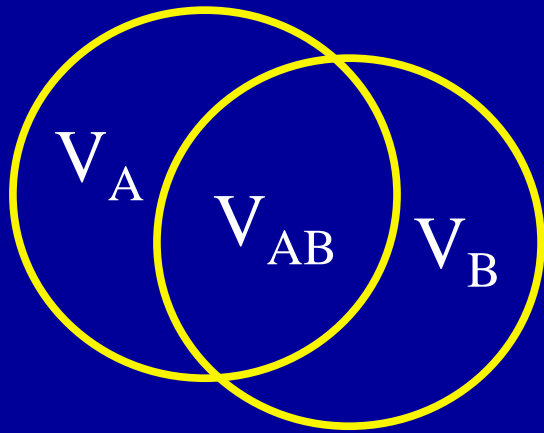
week 3



week 6

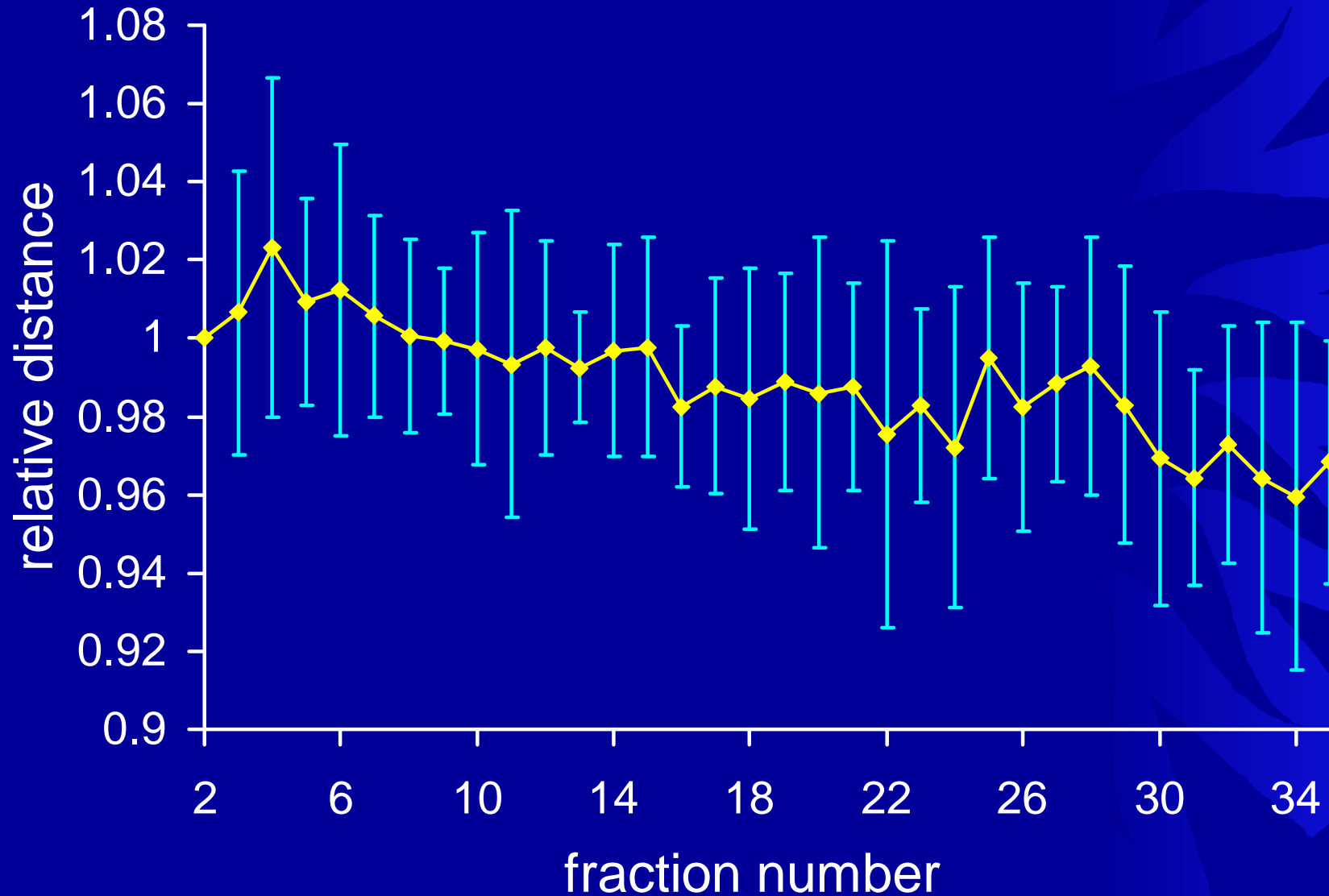


Similarity measures

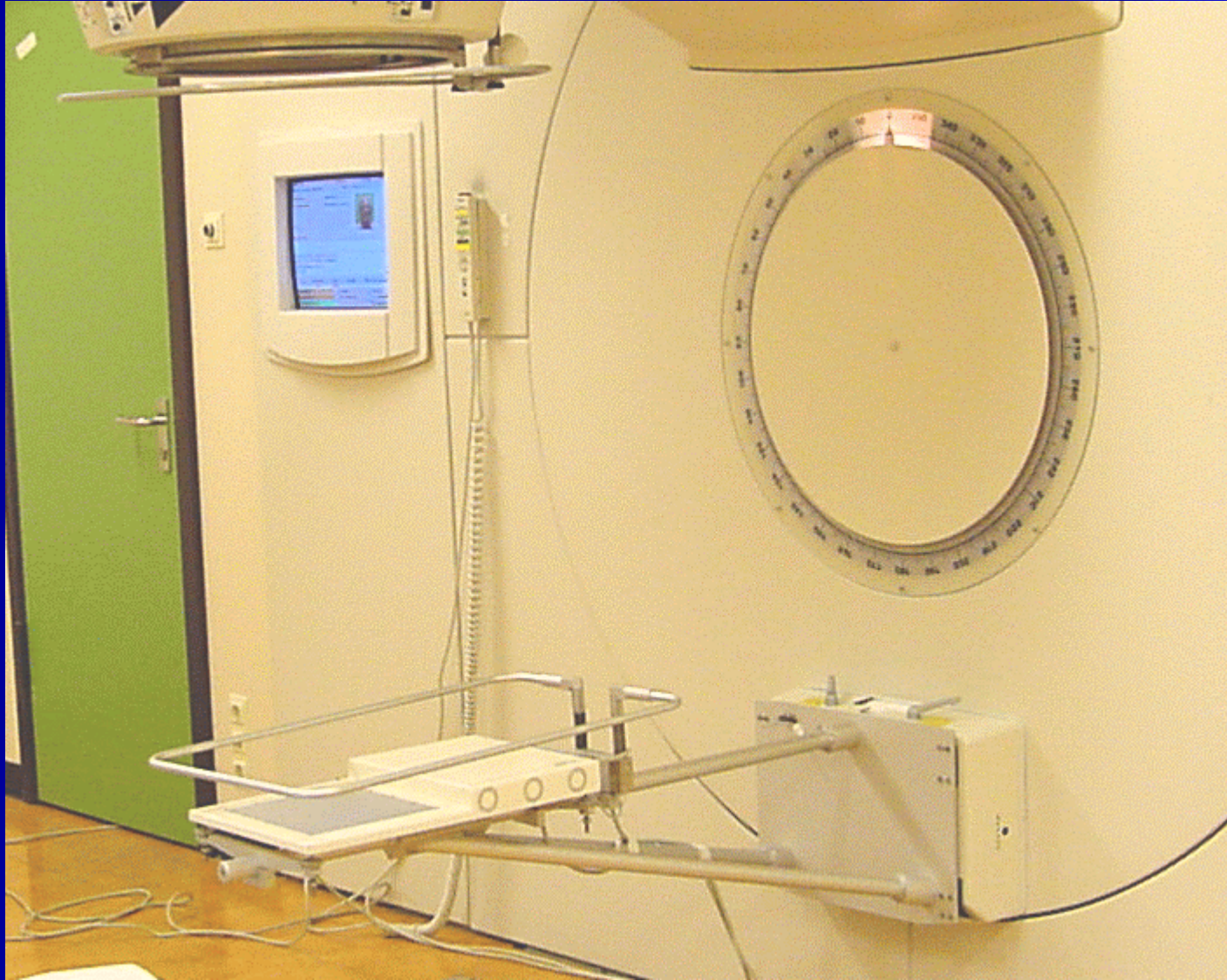


	$V_A \setminus V_B$	$V_{AB} \setminus V_A$ *	$V_{AB} \setminus V_B$
CTV	0.98 " 0.04	0.85 " 0.10	
Prostate corpus	0.98 " 0.04	0.96 " 0.04	

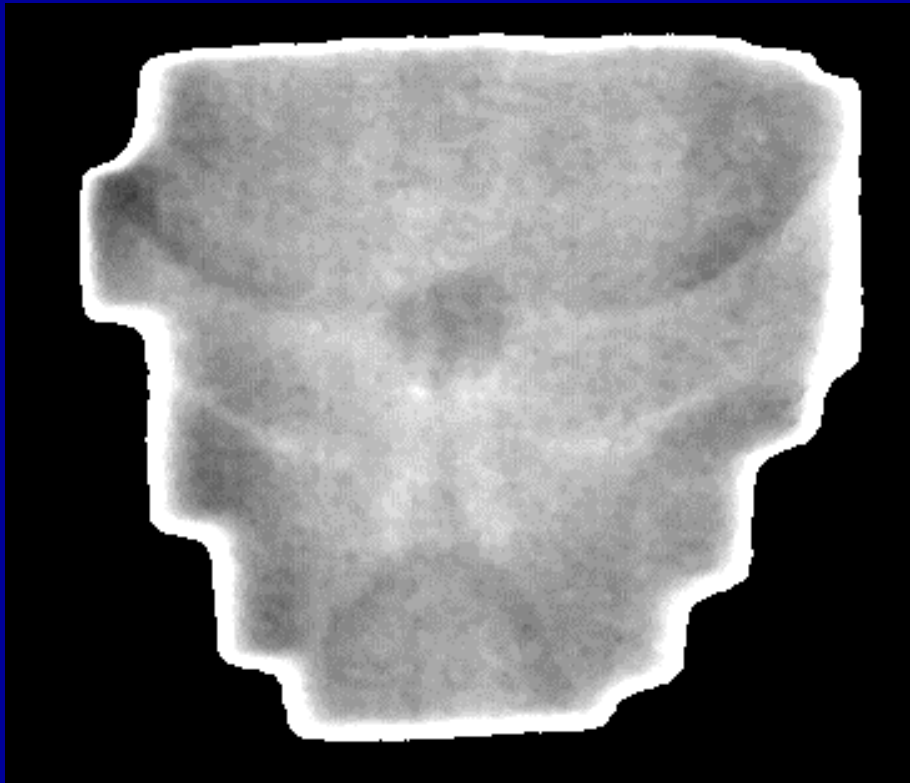
Relative distances between markers during treatment



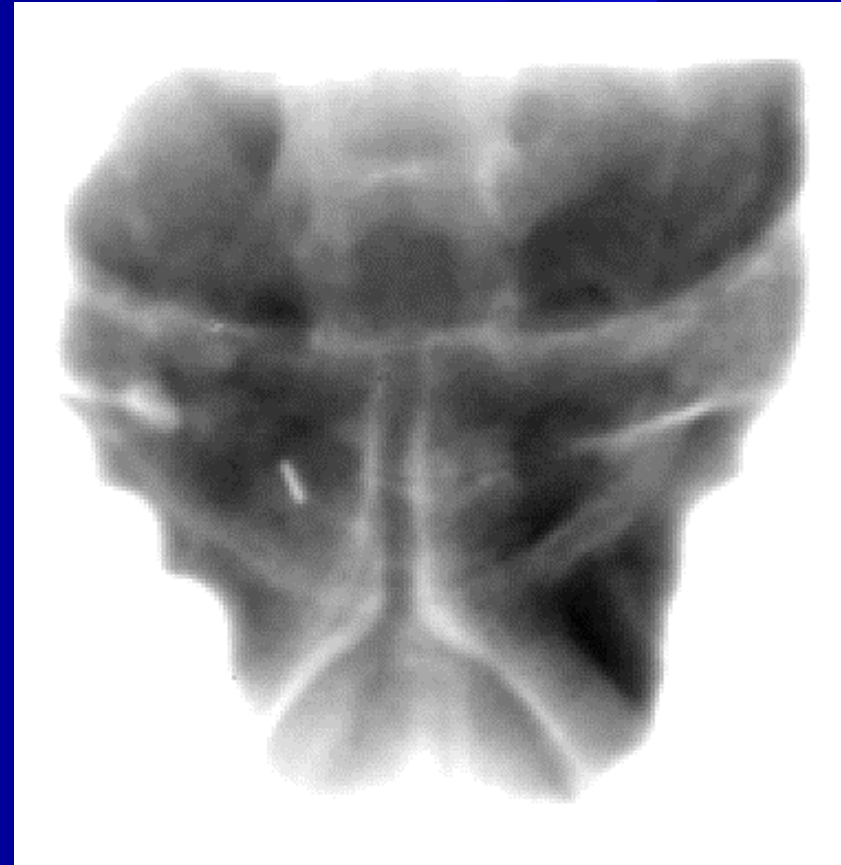
Flat-Panel Imager



Comparison iView camera based and FPI: AP prostate field

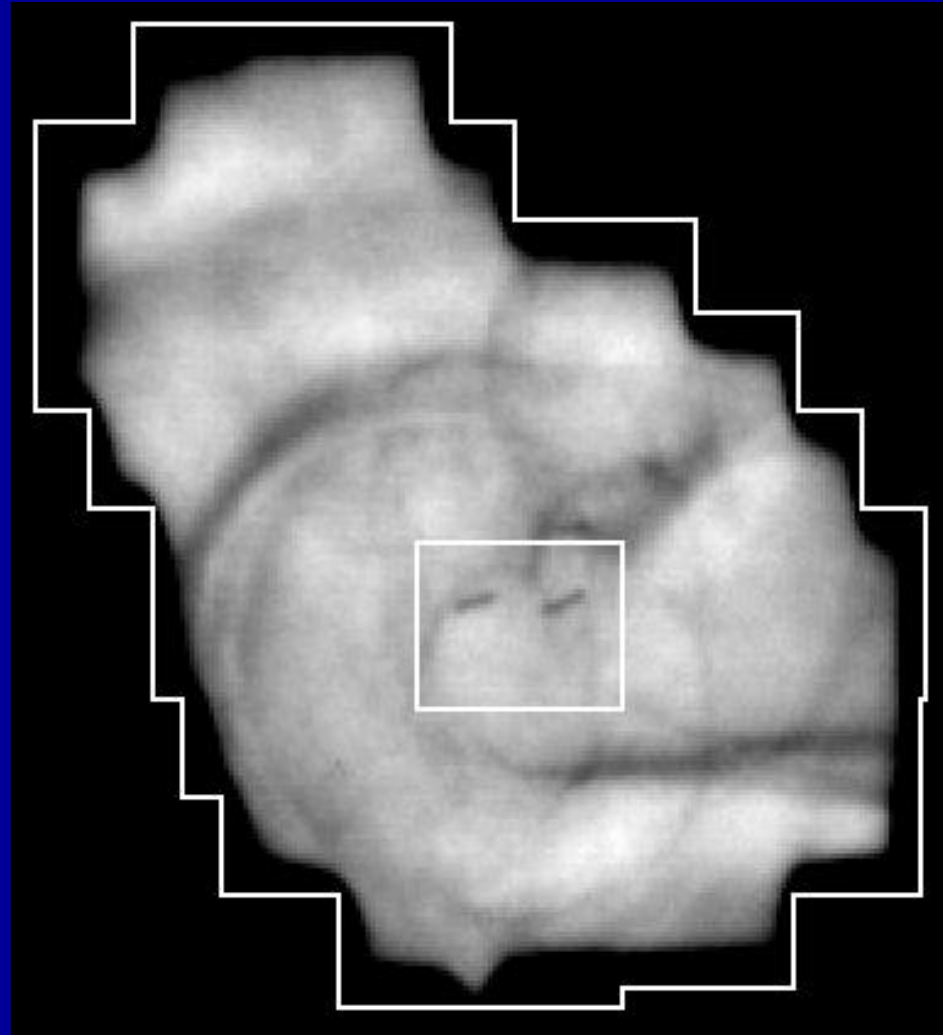


camera based



a-Si

Prostate Motion From Day to Day



1.5 cm

Variations in position

- **Variations in prostate position occur due to**
 - **internal organ motion**
 - **set-up variations**
- **random deviations**
- **systematic deviations**

- **First goal: minimize systematic deviations**

'Shrinking Action Level' correction protocol

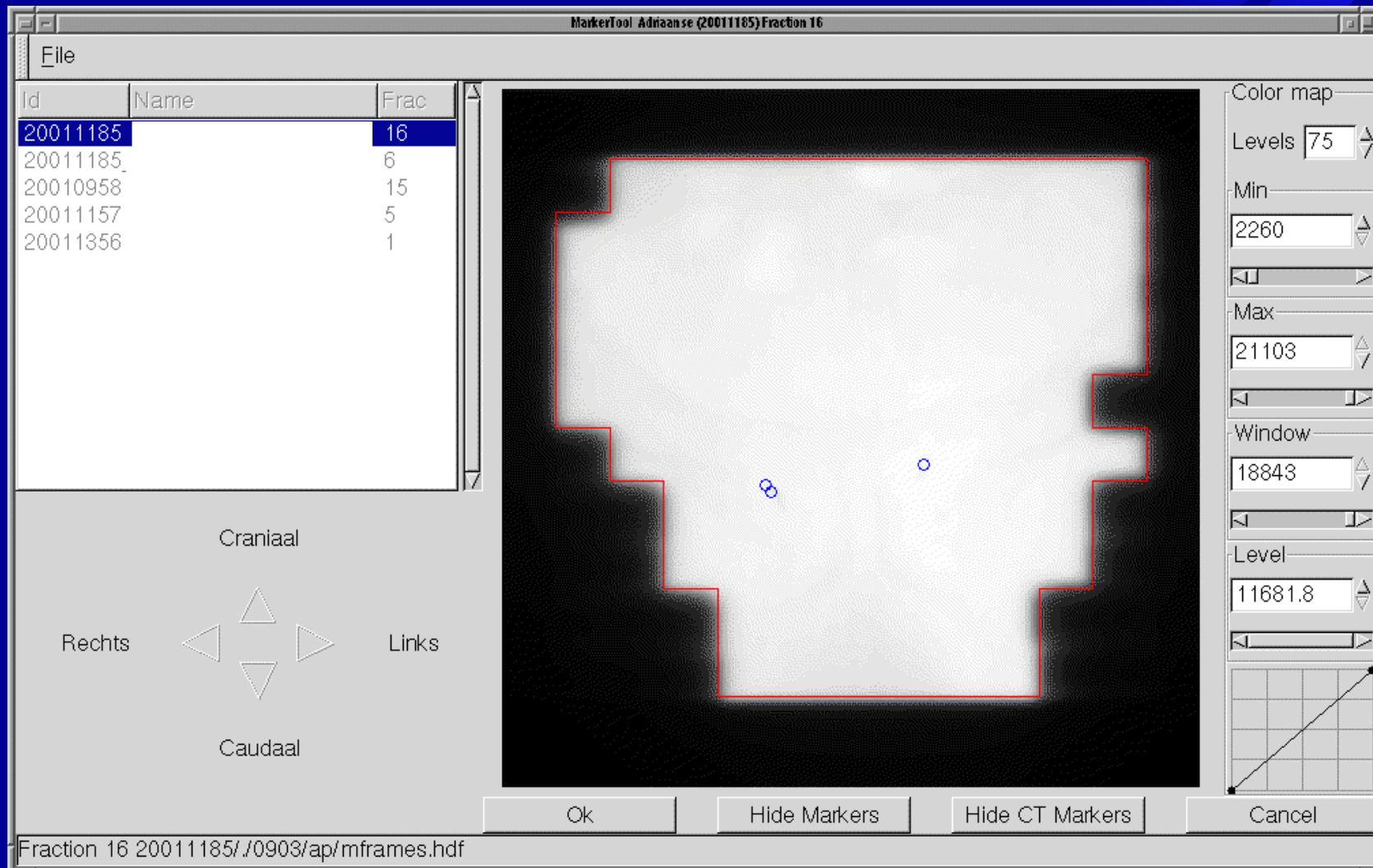
- Correction is applied if the displacement **AVERAGED** over previous fraction exceeds the 'action level'
- The action level is large at first
- The action level shrinks when more fractions were delivered without position correction

* *Bel et al. IJROBP 35(2) 321-332*

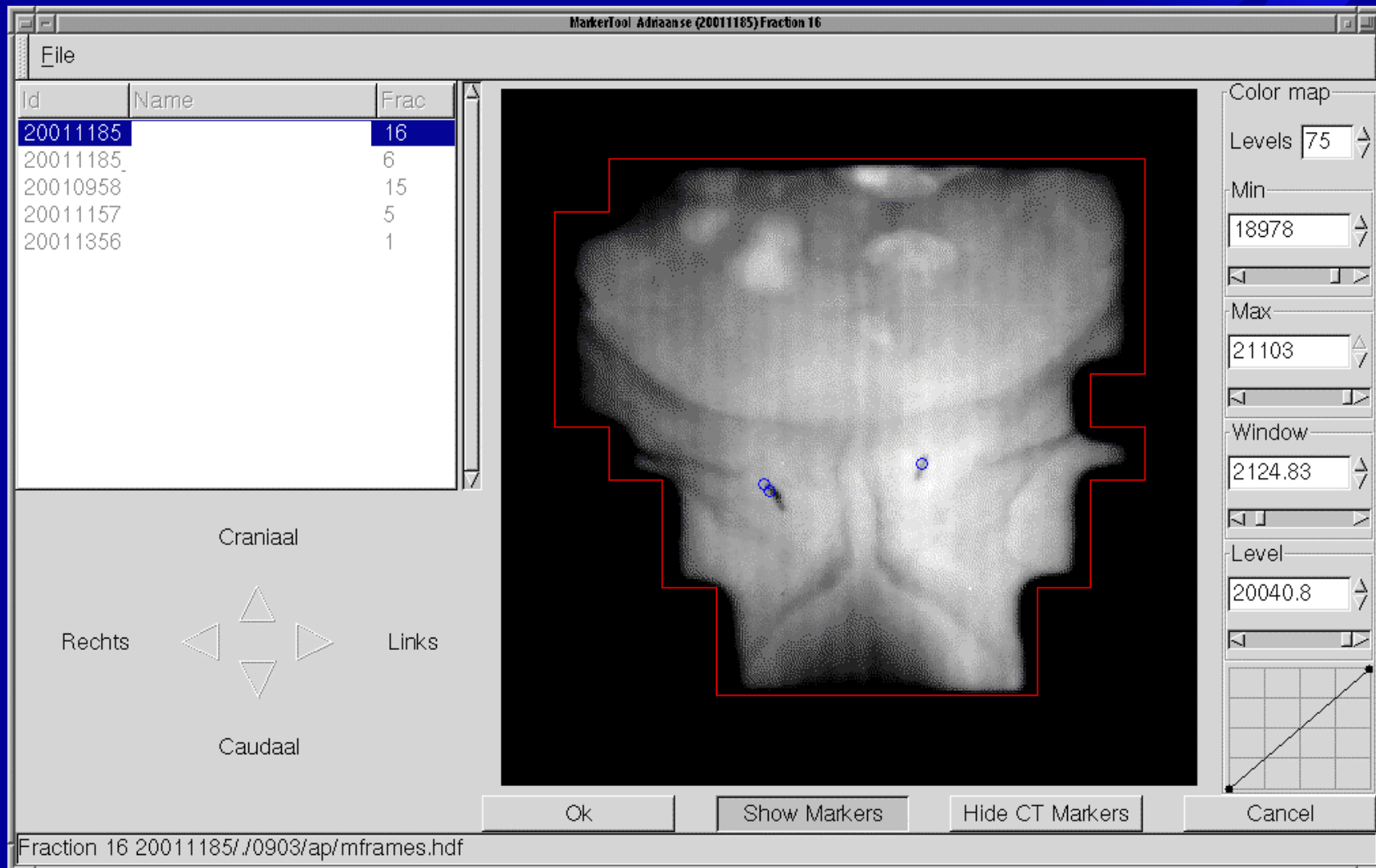
SAL correction for prostate IMRT

- Longitudinal, lateral and vertical directions are considered independently
- Action level per direction
 - 1st fraction: 6.0 mm
 - 2nd fraction: 4.2 mm
 - 3d fraction: 3.5 mm
 - 4 and higher: 3.0 mm
- After a correction:
go back to action level of 1st fraction

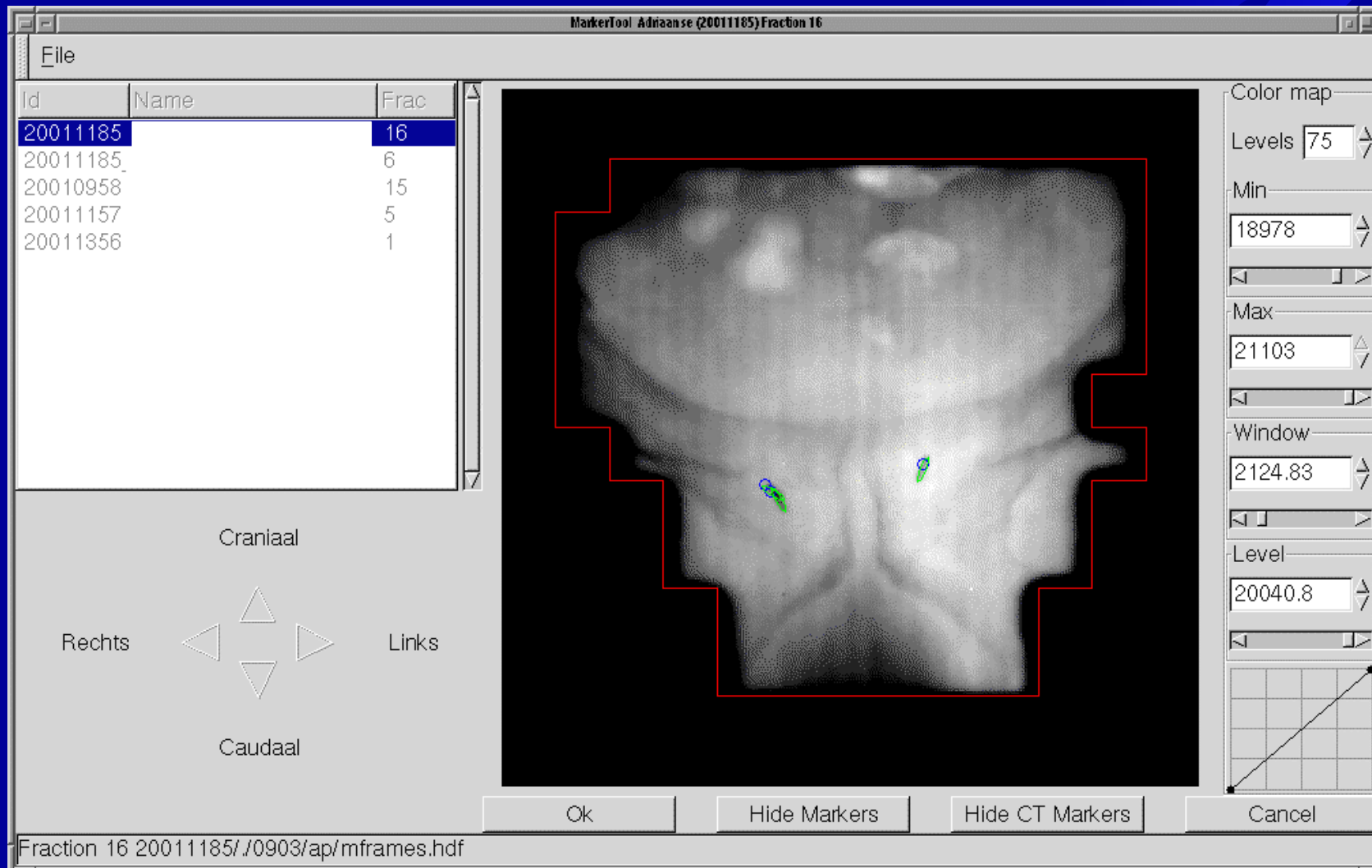
markerTool: field edge detection



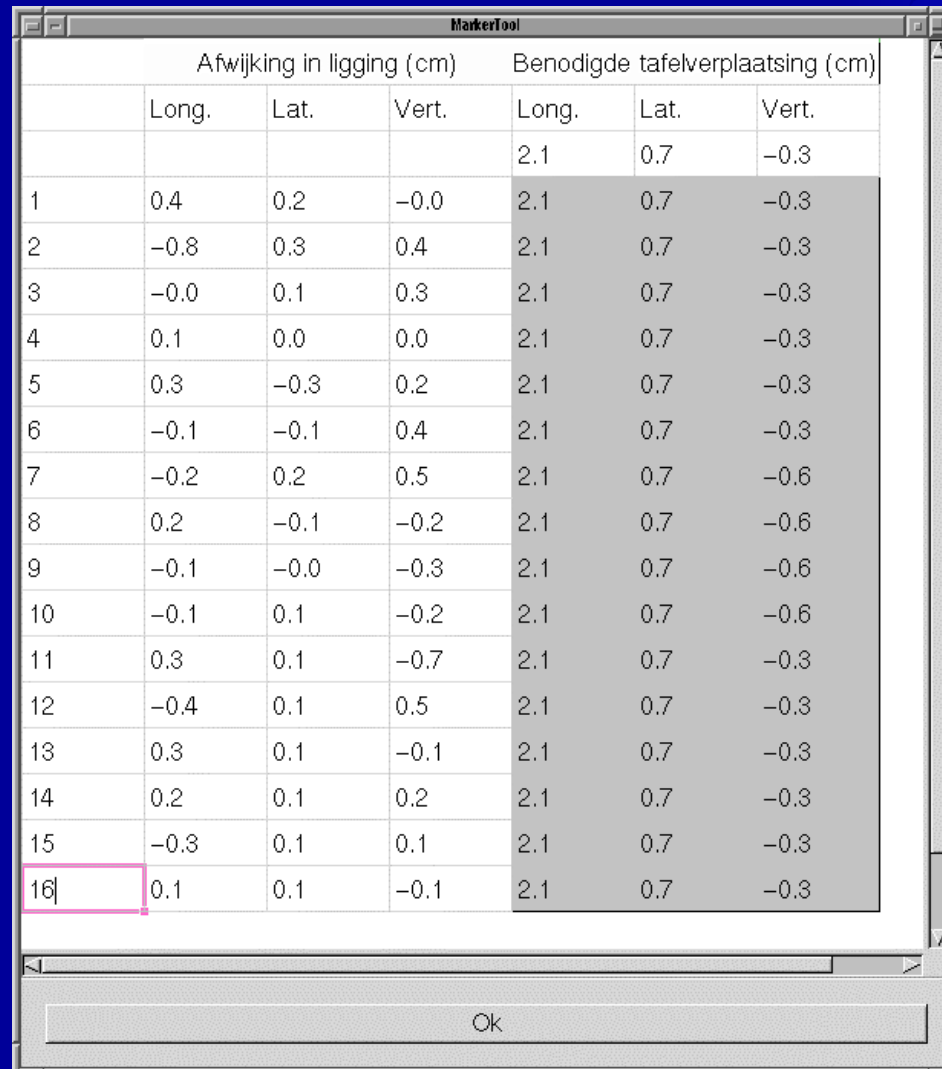
markerTool: marker detection



markerTool: marker detection



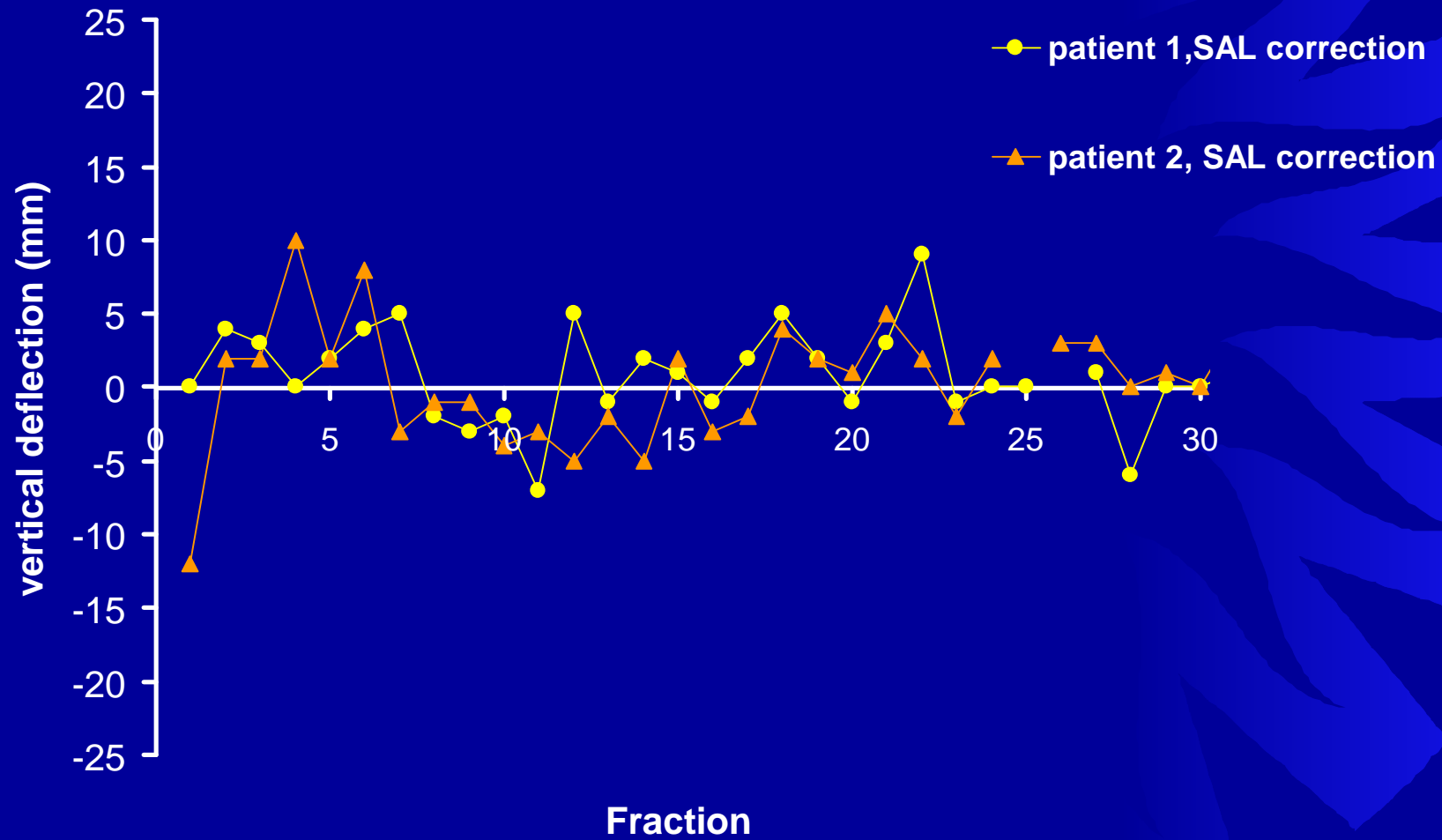
Correction protocol



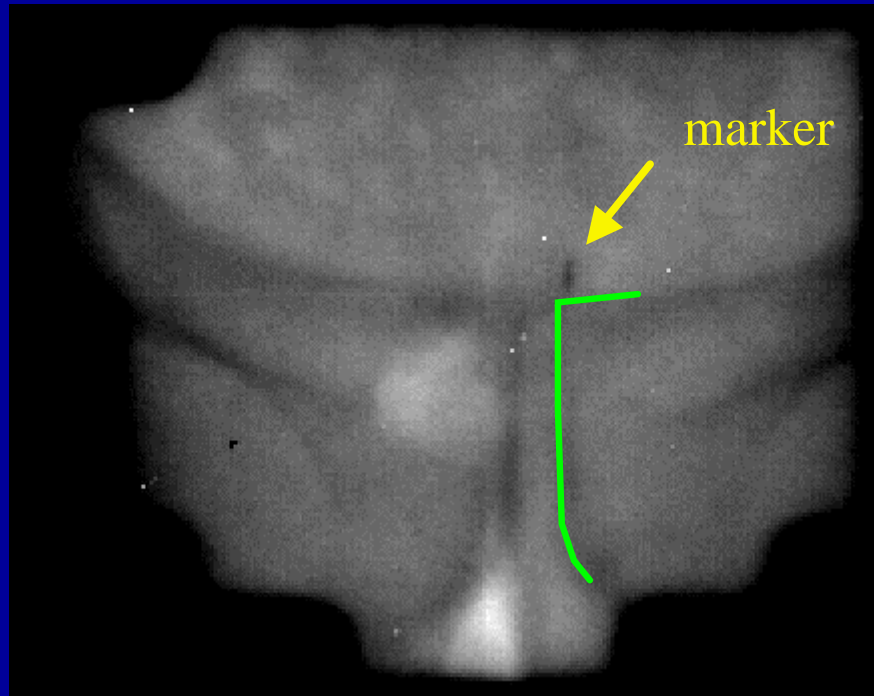
	Afwijking in ligging (cm)			Benodigde tafilverplaatsing (cm)		
	Long.	Lat.	Vert.	Long.	Lat.	Vert.
				2.1	0.7	-0.3
1	0.4	0.2	-0.0	2.1	0.7	-0.3
2	-0.8	0.3	0.4	2.1	0.7	-0.3
3	-0.0	0.1	0.3	2.1	0.7	-0.3
4	0.1	0.0	0.0	2.1	0.7	-0.3
5	0.3	-0.3	0.2	2.1	0.7	-0.3
6	-0.1	-0.1	0.4	2.1	0.7	-0.3
7	-0.2	0.2	0.5	2.1	0.7	-0.6
8	0.2	-0.1	-0.2	2.1	0.7	-0.6
9	-0.1	-0.0	-0.3	2.1	0.7	-0.6
10	-0.1	0.1	-0.2	2.1	0.7	-0.6
11	0.3	0.1	-0.7	2.1	0.7	-0.3
12	-0.4	0.1	0.5	2.1	0.7	-0.3
13	0.3	0.1	-0.1	2.1	0.7	-0.3
14	0.2	0.1	0.2	2.1	0.7	-0.3
15	-0.3	0.1	0.1	2.1	0.7	-0.3
16	0.1	0.1	-0.1	2.1	0.7	-0.3

Ok

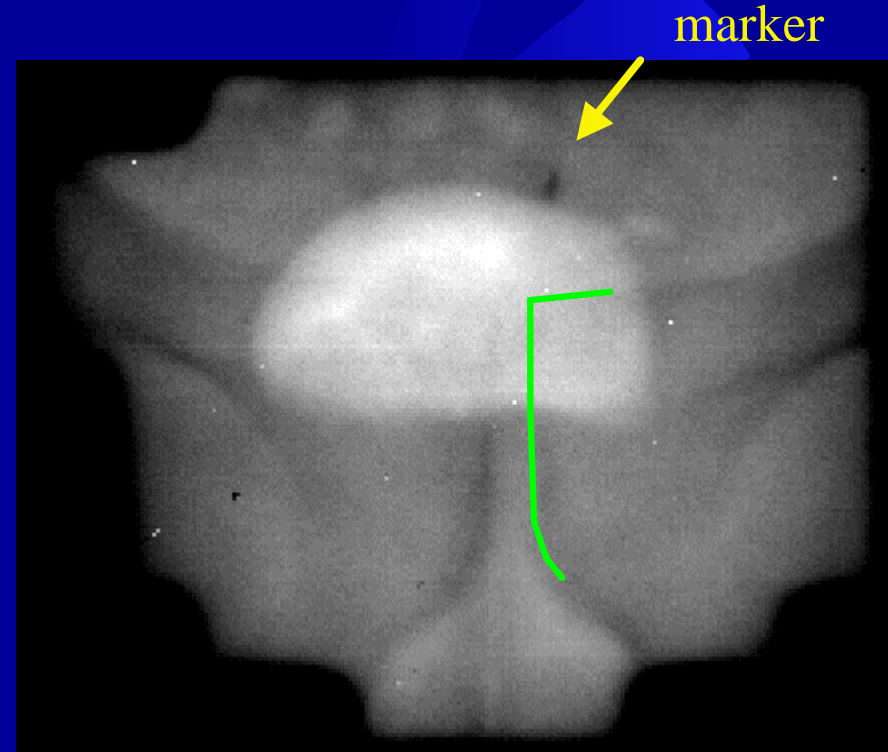
Position variation (vertical)



Misalignment target and bones: prostate

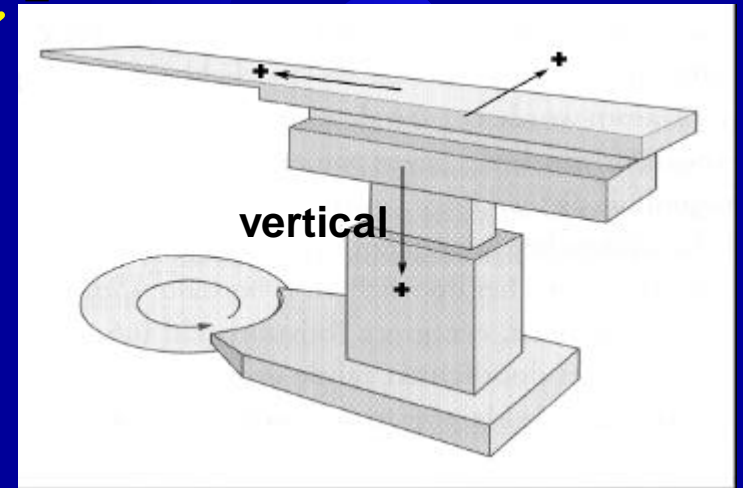
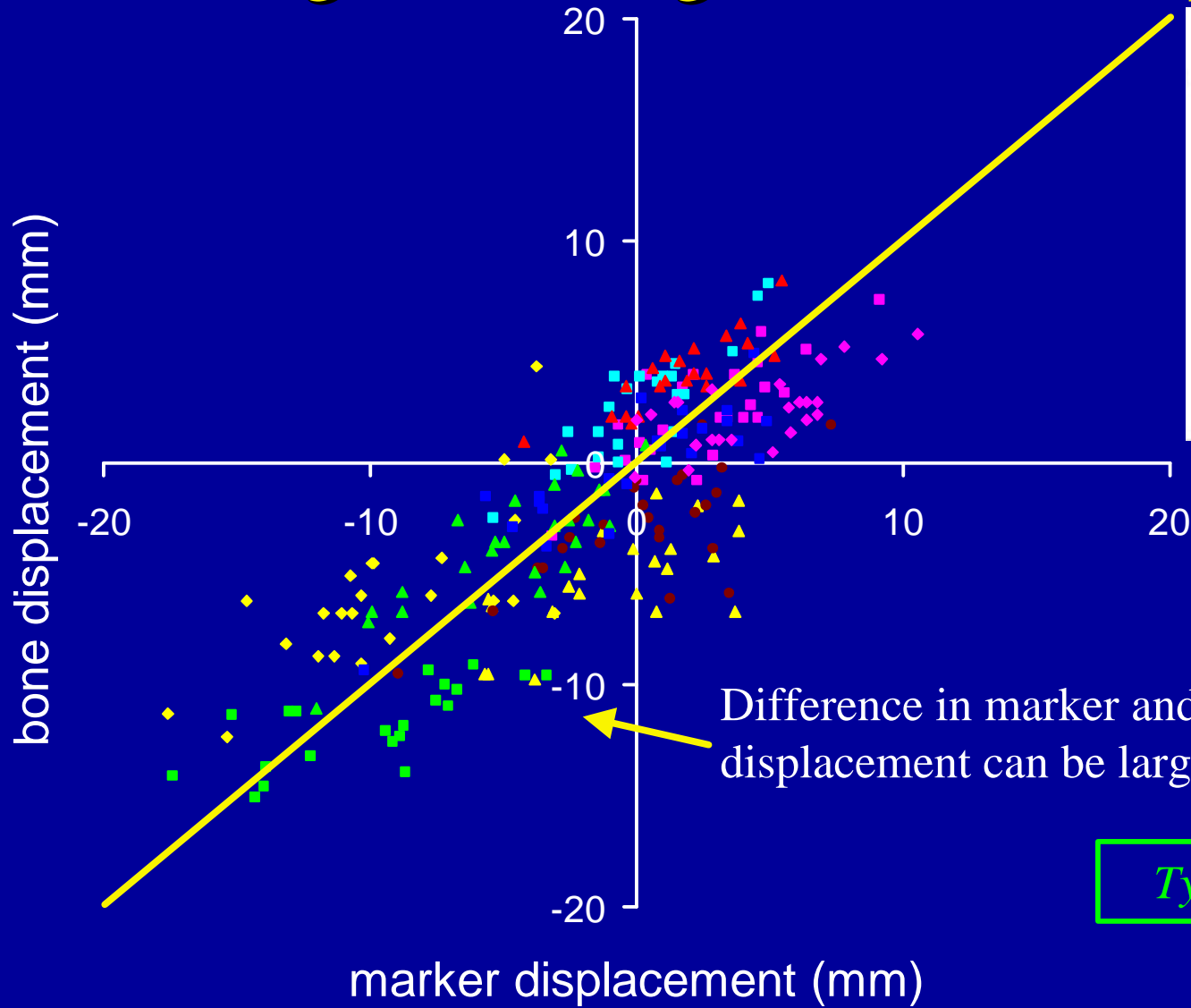


fraction 8



fraction 22

Misalignment target and bones: prostate

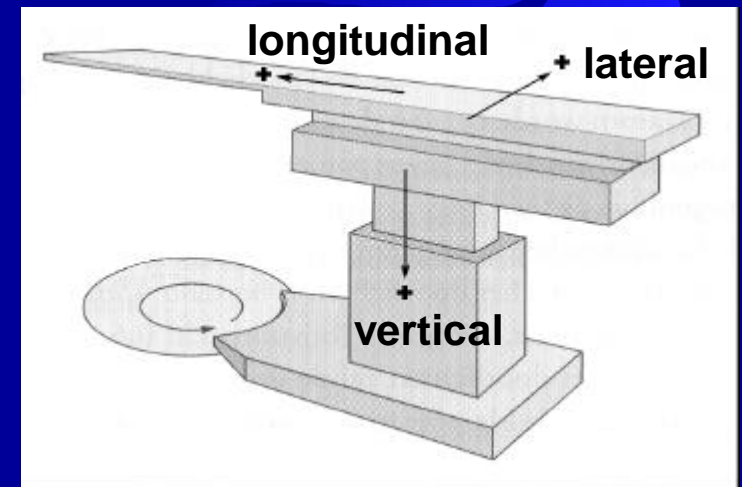


Typical for all pelvic tumours

Position verification and correction

Longitudinal (cm)

	averages	maxima	minima
average	0.00	0.08	-0.05
sd	0.33	0.59	0.20
	0.00	0.00	0.00
margin sys	0.10	0.21	0.01
margin rnd	0.23	0.42	0.14
margin tot	0.26	0.42	0.18

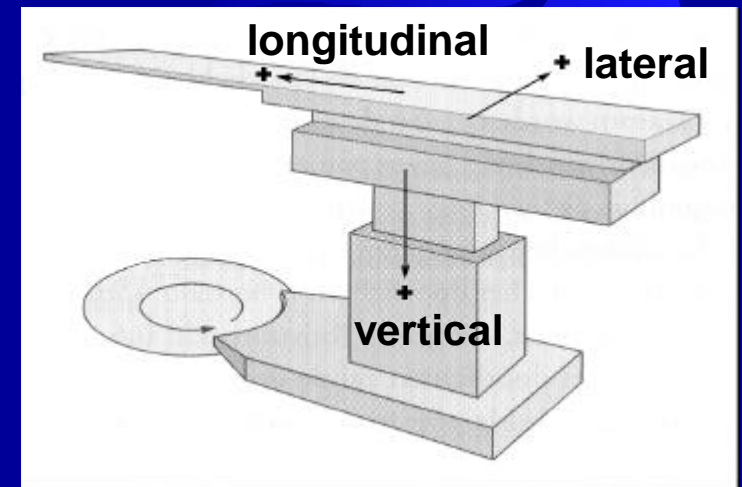


Average number of corrections: 2.5 (0 - 8)

Position verification and correction

Lateral (cm)

	averages	maxima	minima
average	0.01	0.08	-0.08
sd	0.22	0.31	0.13
	0.00	0.00	0.00
margin sys	0.12	0.22	0.02
margin rnd	0.16	0.21	0.09
margin tot	0.20	0.31	0.10

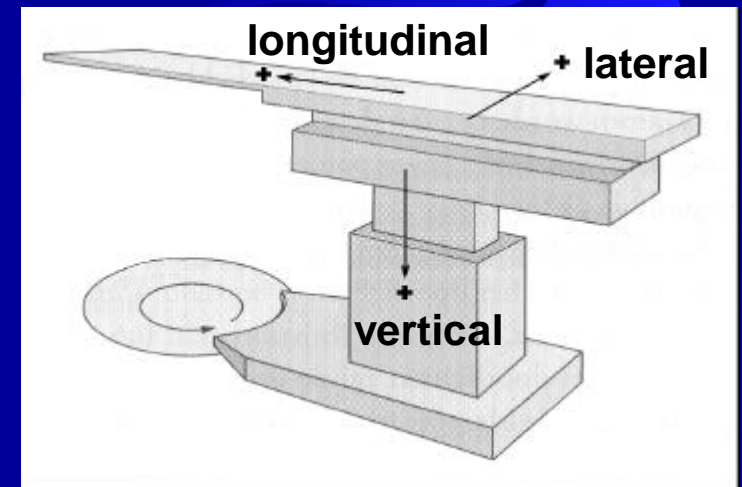


Average number of corrections: 0.9 (0 - 3)

Position verification and correction

Longitudinal (cm)

	averages	maxima	minima
average	0.01	0.08	-0.11
sd	0.42	0.60	0.30
	0.00	0.00	0.00
margin sys	0.10	0.31	0.01
margin rnd	0.30	0.42	0.21
margin tot	0.33	0.43	0.22



Average number of corrections: 4.7 (1 - 9)

Summary

- **Dose escalation to prostate without increase in toxicity**
- **Quality assurance involves routine measurement of dose in phantom**
- **Gold fiducial markers are convenient and effective for position verification and correction**

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