# De "2D", a Radioterapia 3D Conformal y a Intensidad Modulada (IMRT)

## Una progresión

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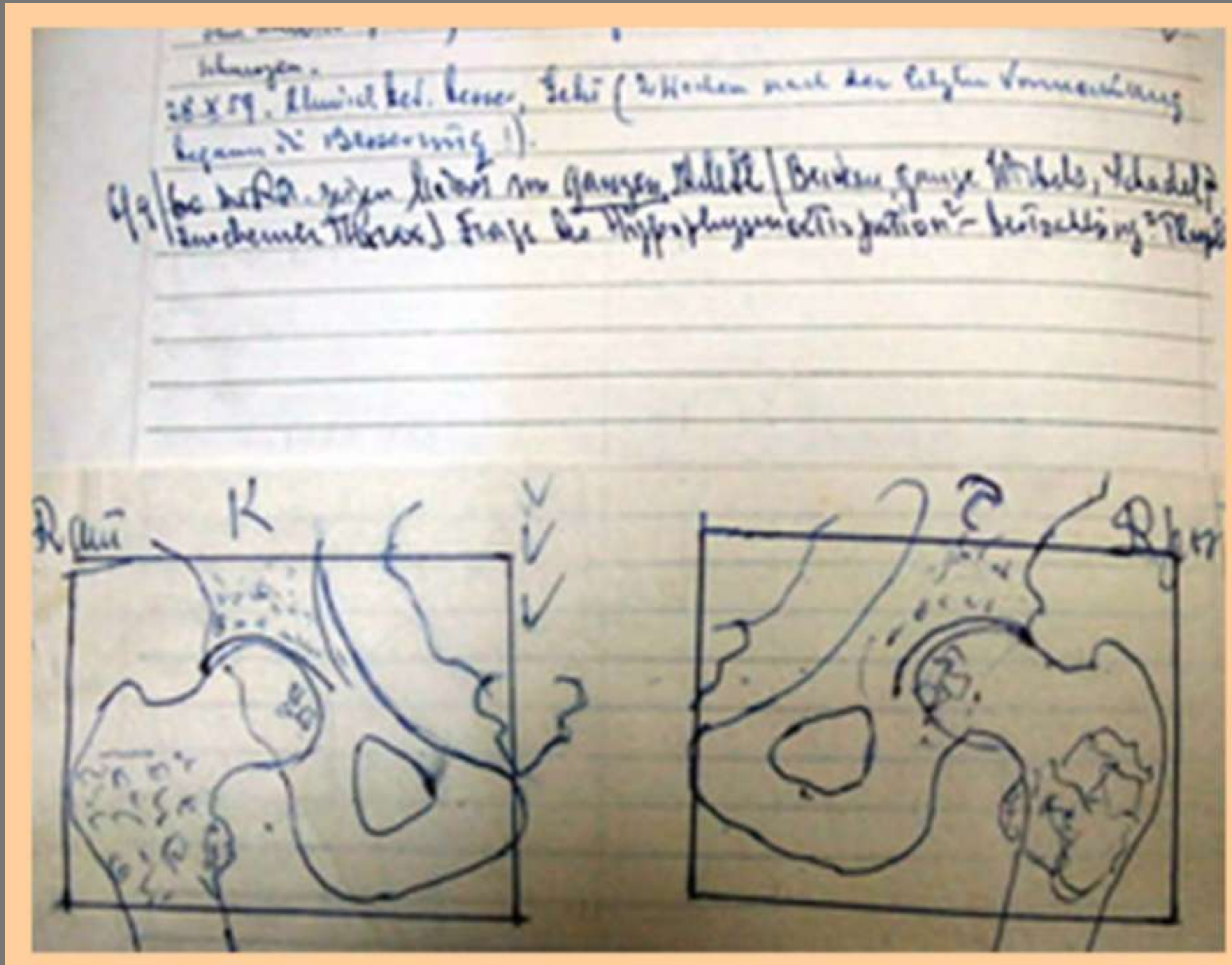


**Radiation therapy simulation… a note and a diagram in the chart**
**The Italian Hospital – Haifa- circa 1940**

# The 2D era classics…

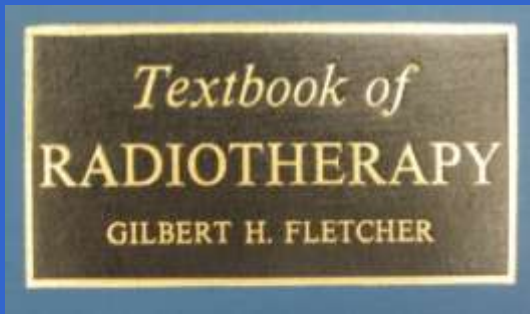



FIG. 3–54. Female, age 61, was seen with a retromolar trigone-anterior faucial pillar squamous cell carcinoma, grade III. There were no palpable nodes. From November 2, 1969 to December 19, 1969, 6400 rads tumor dose was given at 5 cm; 7400 rads tumor dose at 3 cm was given in 4½ weeks with 1:1 loading 18-MeV x-rays and electron beam. There was a portal reduction at 6000 rads at 3-cm depth. The entire right neck received 5500 rads given dose in 4½ weeks with 9-MeV electron beam.

FIG. 3–85. Diagram of the fields employed for the irradiation of supraglottic squamous cell carcinoma with no clinical metastasis in the neck. The upper and midjugular nodes are electively irradiated with 5000 rads in 5 weeks. (From Goepfert et al.: Laryngoscope 85:14, 1975.)



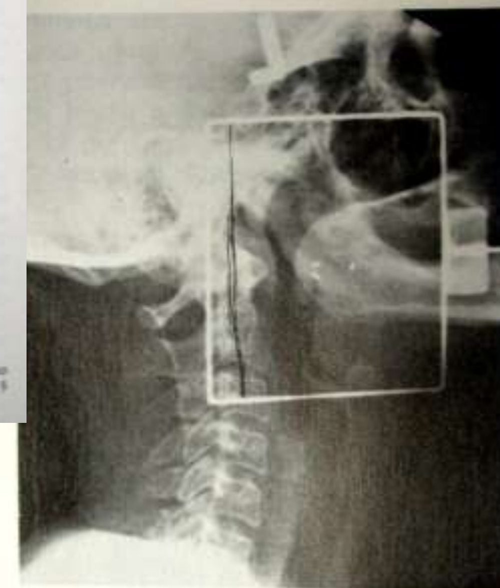


FIG. 3–55. Female, age 48, was seen January 26, 1976, with a lesion centered on the left anterior tonsillar pillar, extending to the retromolar triangle laterally, to the third molar area anteriorly, and down over the inner aspect of the gum. It extended along the edge of the pillar to about 2 cm from the midline and to within 1 cm of the junction of the hard and soft palate. Biopsy revealed squamous cell carcinoma, grade II. The lesion was classified as T2N0 of the left anterior tonsillar pillar.

Between January 28, 1976 and March 9, 1976, the patient received a 6500-rad tumor dose at 4-cm depth using half 18-MeV electron beam

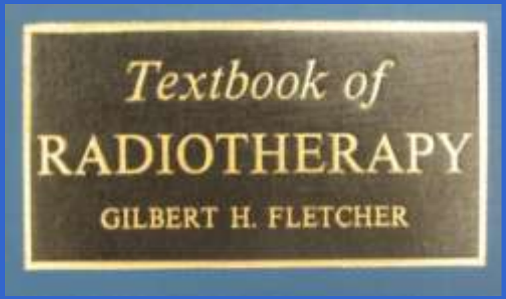
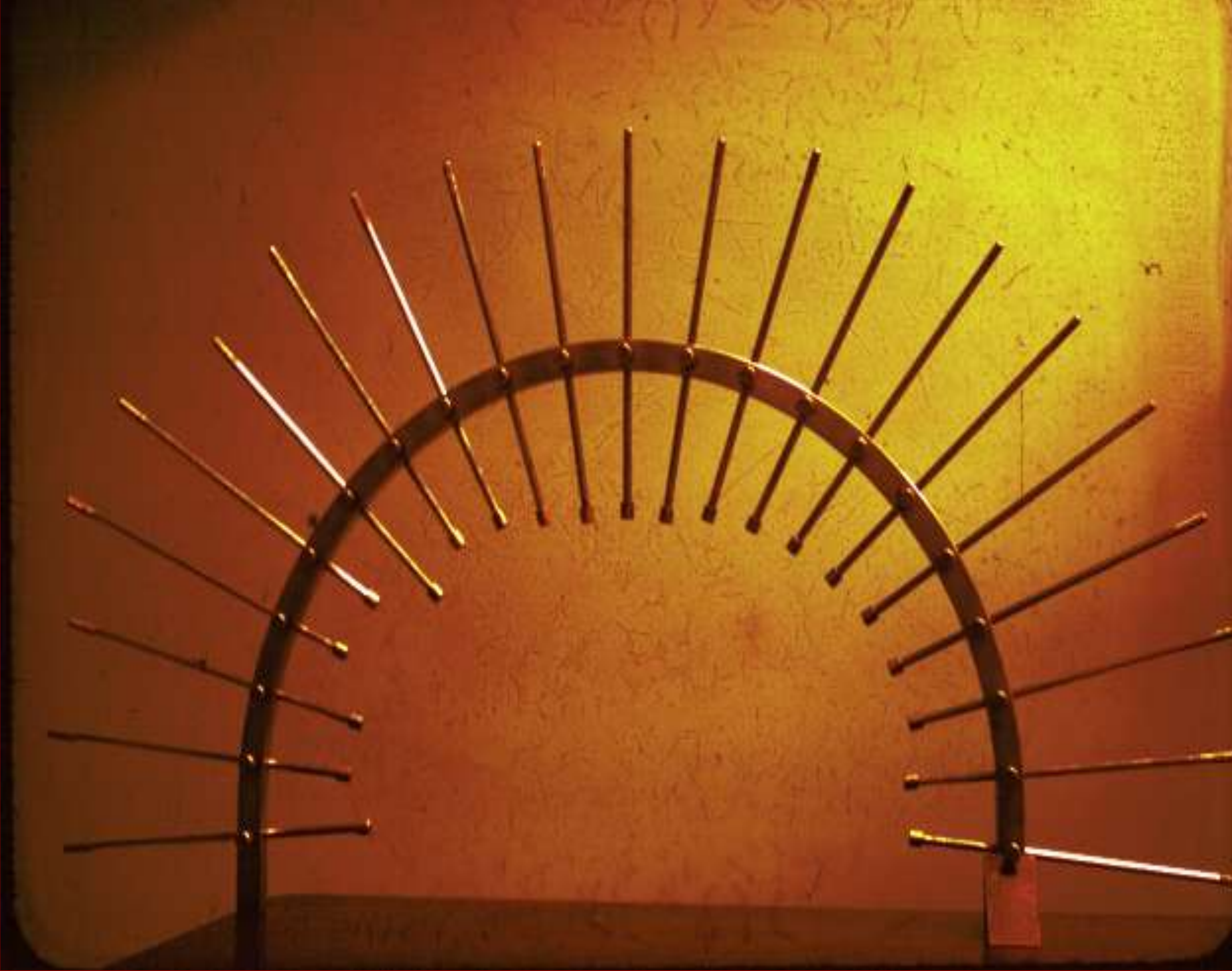




FIG. 11–37. A. Projection of vaginal disease onto the surface of the body. The cervical localizer, seen on the left side of the tray, consists of a plastic rod with a lead plug at its tip and a fluid level to assure its horizontal position. The plastic rod is introduced into the vagina, guided by the examining finger until contact is made with the lowest palpable vaginal disease. As the rod is then attached to the stand at exactly this level, the vertical pointer, which is in line with the tip of the rod, will project the location of the lowest palpable vaginal disease onto the surface of the body. The lower margin of the portal is drawn 2 cm below that projection. A verification film is taken immediately and adjustments are made until the field includes approximately 1 cm of tissue below the lead plug, which means that there will be at least 2 cm of normal vaginal tissues in the irradiated field.

Also seen on the tray are the compression cone for the 22-MeV betatron with the lead blocks to shield respectively 2 and 4 cm of tissue at 10-cm depth. The end of compression cone for the $^{60}Co$ unit is made of copper mesh to minimize secondary electron emission. The lead blocks can slide sideways to fit the isodose curves of the individual radium system.


FIG. 11–37. C. The same procedure used for the localization of the lowest palpable disease is also used to determine the center of the lateral portals. A Lucite bridge used for daily treatment duplication is also shown.



Calculo disimétrico típico = Calculo de TIEMPO para un tratamiento con una unidad de Cobalto-60

April 1, 1969

Co-60 TREATMENT TIME and "SKIN" DOSAGE CHART
at
The Long Island Jewish Hospital
270-05 76th Avenue
New Hyde Park, N.Y. 11040

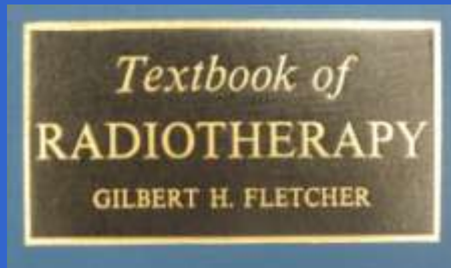
80 CM. S.S.D.

Time in Minutes to give 100 rads tumor dose at depth and Max.r "skin" dose for 100 Rads at depth for period April 1, 1969 through June 30, 1969.

Output 104.8 r/Min. at 80 Cm. S.S.D.

| | AREA IN SQ. CM. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | | 50 | | 100 | | 200 | | 400 | |
| Depth in CM. | Max. Rads | Min. | Max. Rads | Min. | Max. Rads | Min. | Max. Rads | Min. | Max. Rads | Min. |
| .5 | 100 | .97 | 100 | .96 | 100 | .96 | 100 | .94 | 100 | .94 |
| 1.0 | 103 | 1.00 | 102 | .98 | 102 | .97 | 102 | .96 | 102 | .95 |
| 2.0 | 110 | 1.06 | 108 | 1.00 | 107 | 1.02 | 107 | 1.00 | 106 | .99 |
| 3.0 | 117 | 1.13 | 115 | 1.10 | 113 | 1.08 | 112 | 1.05 | 111 | 1.04 |
| 4.0 | 125 | 1.22 | 122 | 1.17 | 120 | 1.14 | 118 | 1.11 | 117 | 1.10 |
| 5.0 | 134 | 1.30 | 130 | 1.25 | 127 | 1.21 | 125 | 1.18 | 124 | 1.16 |
| 6.0 | 145 | 1.40 | 139 | 1.35 | 136 | 1.30 | 133 | 1.25 | 131 | 1.23 |
| 7.0 | 156 | 1.51 | 150 | 1.44 | 145 | 1.39 | 141 | 1.33 | 139 | 1.30 |
| 8.0 | 169 | 1.63 | 161 | 1.55 | 156 | 1.49 | 151 | 1.42 | 147 | 1.38 |
| 9.0 | 183 | 1.78 | 174 | 1.68 | 167 | 1.59 | 161 | 1.52 | 156 | 1.46 |
| 10.0 | 198 | 1.92 | 188 | 1.82 | 180 | 1.72 | 172 | 1.62 | 165 | 1.55 |
| 11.0 | 215 | 2.08 | 202 | 1.90 | 193 | 1.84 | 184 | 1.74 | 176 | 1.65 |
| 12.0 | 233 | 2.25 | 218 | 2.11 | 207 | 1.98 | 197 | 1.84 | 188 | 1.76 |
| 13.0 | 252 | 2.44 | 236 | 2.29 | 223 | 2.12 | 210 | 1.98 | 200 | 1.87 |
| 14.0 | 273 | 2.64 | 254 | 2.47 | 239 | 2.28 | 225 | 2.10 | 212 | 1.99 |
| 15.0 | 296 | 2.86 | 275 | 2.66 | 257 | 2.45 | 239 | 2.25 | 226 | 2.12 |
| 16.0 | 319 | 3.08 | 298 | 2.87 | 276 | 2.63 | 256 | 2.40 | 240 | 2.25 |
| 17.0 | 345 | 3.33 | 320 | 3.08 | 296 | 2.83 | 274 | 2.57 | 257 | 2.40 |
| 18.0 | 371 | 3.59 | 345 | 3.33 | 318 | 3.03 | 293 | 2.74 | 272 | 2.55 |
| 19.0 | 402 | 3.90 | 373 | 3.68 | 343 | 3.27 | 313 | 2.93 | 289 | 2.71 |
| 20.0 | 436 | 4.23 | 402 | 3.88 | 368 | 3.51 | 334 | 3.12 | 306 | 2.87 |

Lillian E. Jacobson



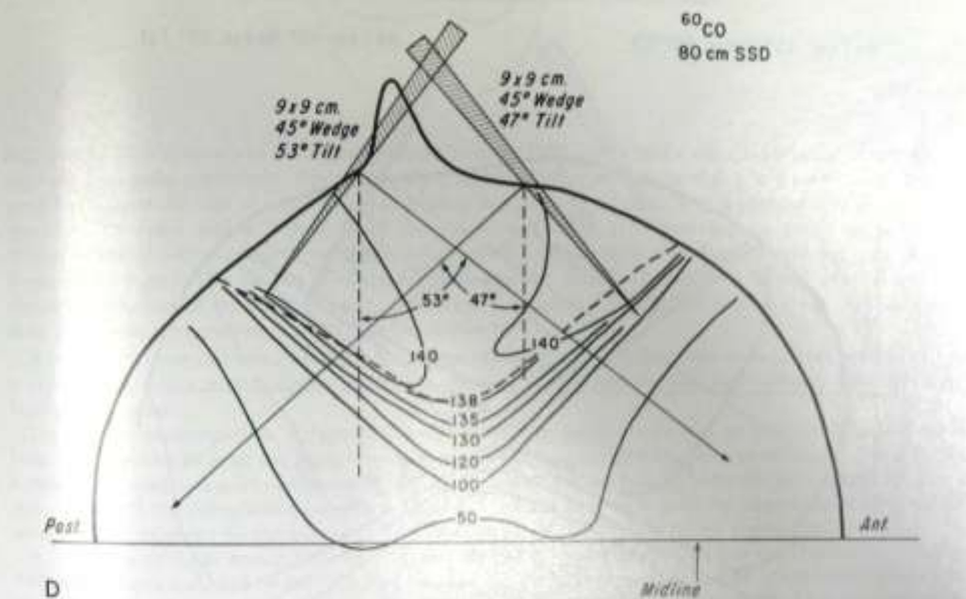




FIG. 3–124 (cont'd). C. Treatment for the ipsilateral neck. The anterior $^{60}$Co field extends from the lower border of the parotid field.
D. Isodose distribution of $^{60}$Co wedges. The tumor dose is taken at the 138% curve. The tissue volume included in the high dose range is not excessive.

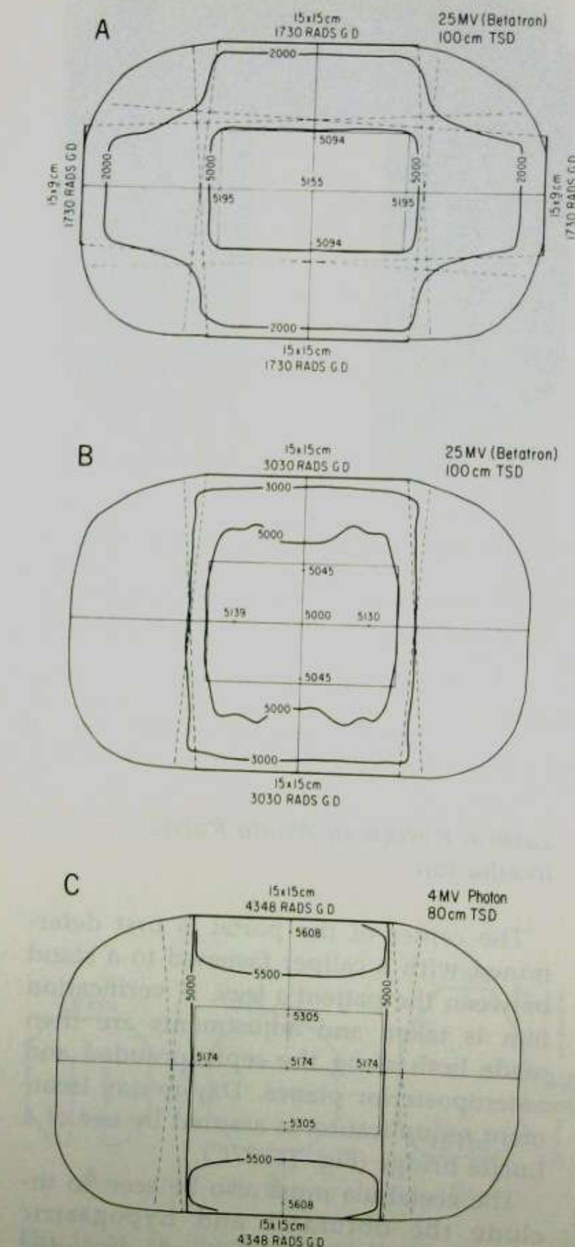



**FIG. 11–36.** **A.** Box pattern, 15 × 15 × 9 cm (approximately 2000 cm³) with 25 MeV. **B.** Parallel opposing 15 × 15 × 22 (AP diameter) cm (approxi-

# Les puedo confiar un secreto?

- La verdad es que nunca tratamos pacientes con Radioterapia en 2D…
- Solo se tenia información de 2D
  - En radiografías que colapsan el cuerpo sobre una película
  - En representación de solo un plano por vez
- Pero los pacientes … toditos de 3D

# In “2D” radiotherapy

- The target is defined in relation to anatomic landmarks - heavy reliance on bony anatomy

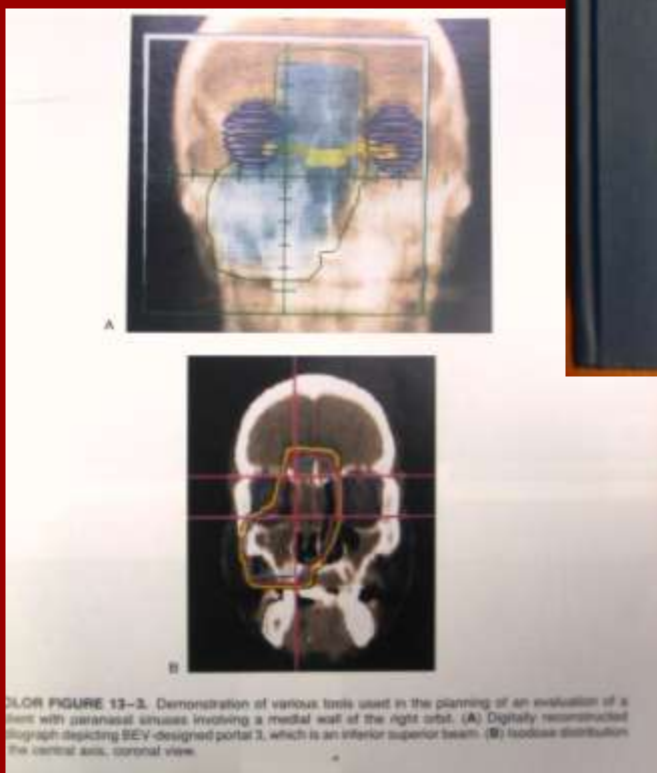
- The extent of fields is driven by knowledge of anatomy and by disease pathways

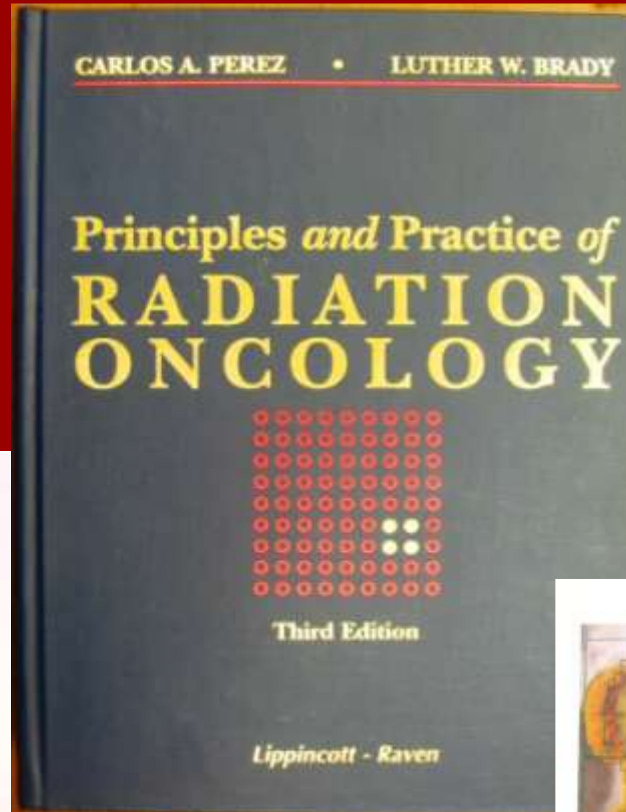
- Extensive use of physical examination, palpation and physical measurements of the patient.

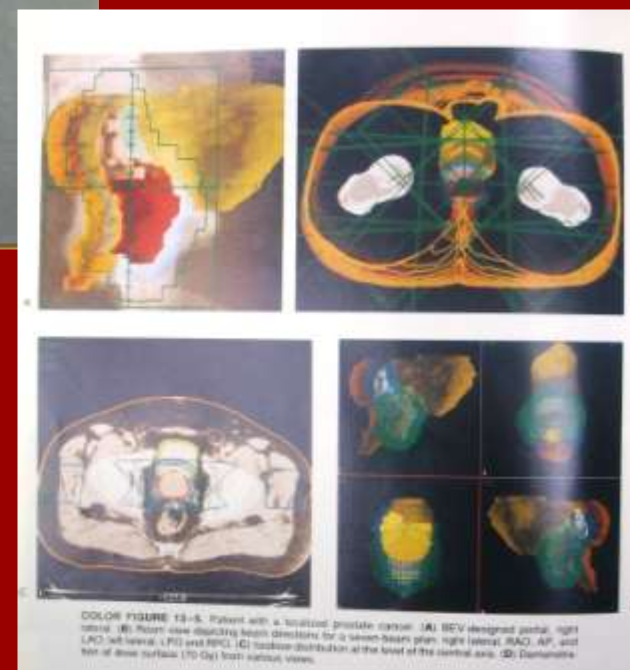
- Dose distribution information limited to single plane of major significance in order to cover the target. Energy selection is very important.

- Protection of critical organs set by experience

# The 90's – the era of 3D





Perez and Brady - Principles and Practice of Radiation Oncology-1998, and others…

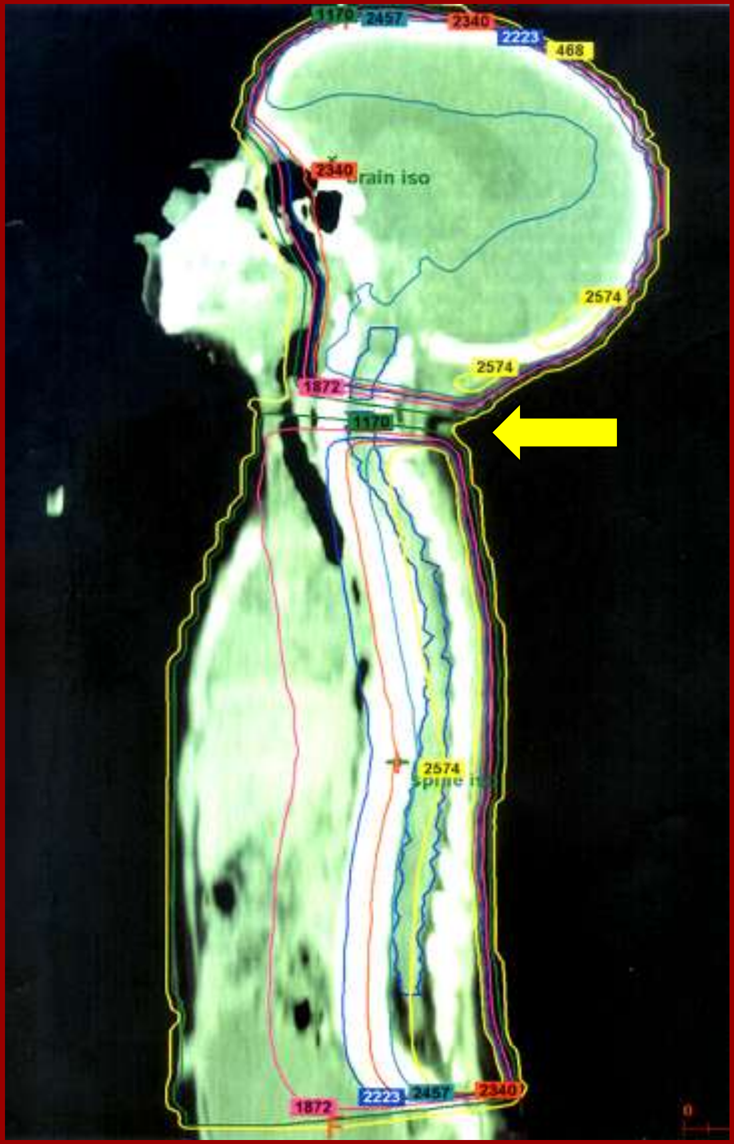
# 3-D Conformal RT
# Essential use of CT information

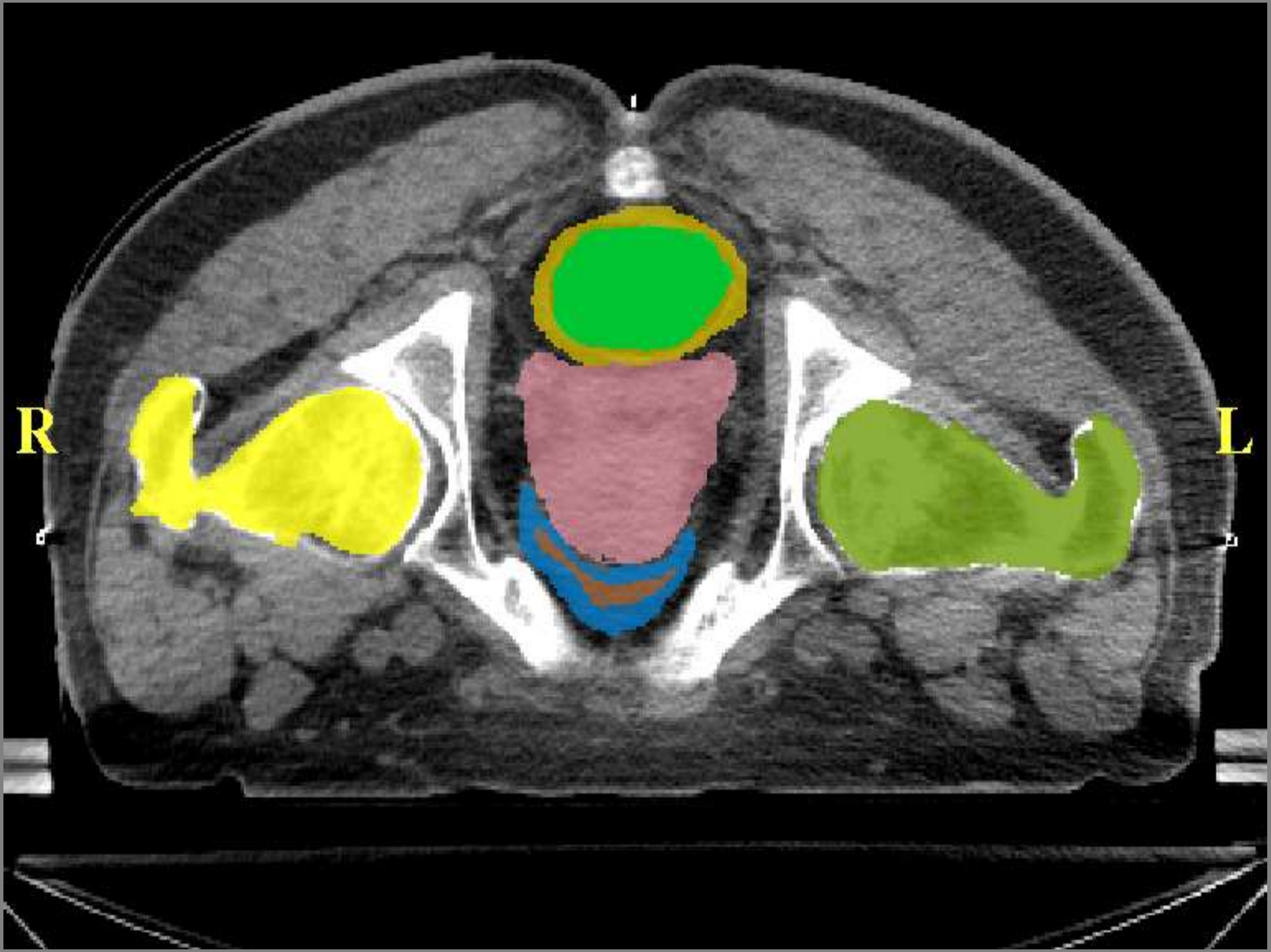
- Major increase in the use of CT information enables the construction of volumetric data sets
- The targets are constructed slice by slice from knowledge of anatomy and by disease pathways but aided by visualization of organs and boundaries between them and the targets. Physical examination, palpation and other tests are complemented with cross sectional images.
- The fields outlines are "conformed" to the BEV of the targets
- Physical measurements of the patient are substituted by digital image measurements tools.
- The target is still defined in relation to anatomic landmarks – significant reliance on bony anatomy. Use of DRR's

# 3-D Conformal RT - cont.

- Dose distribution information expanded to multiple planes
- Accounting for dose contributions from other planes is made possible by better beam models. Increased weight given to doses to critical organs
- New tools required to describe target and critical organ doses (DVH) and for plan evaluation
- DVH of critical organs start to generate Organ dose tolerance information and partial volume dose tolerance
- Multiple beam directions and non-coplanar arrangements reduce the dependence on beam energy

# Irradiacion cranio-axial

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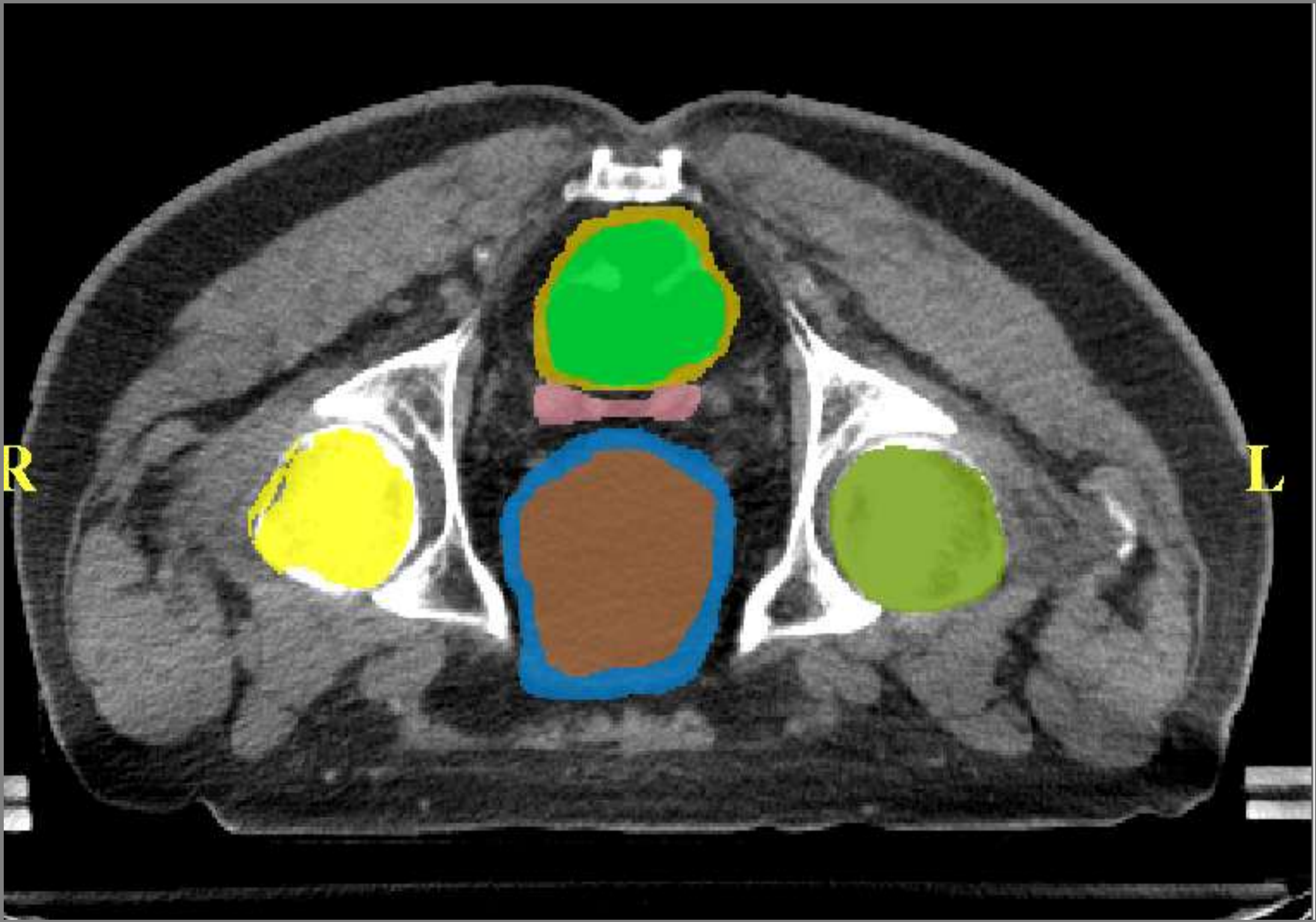
R
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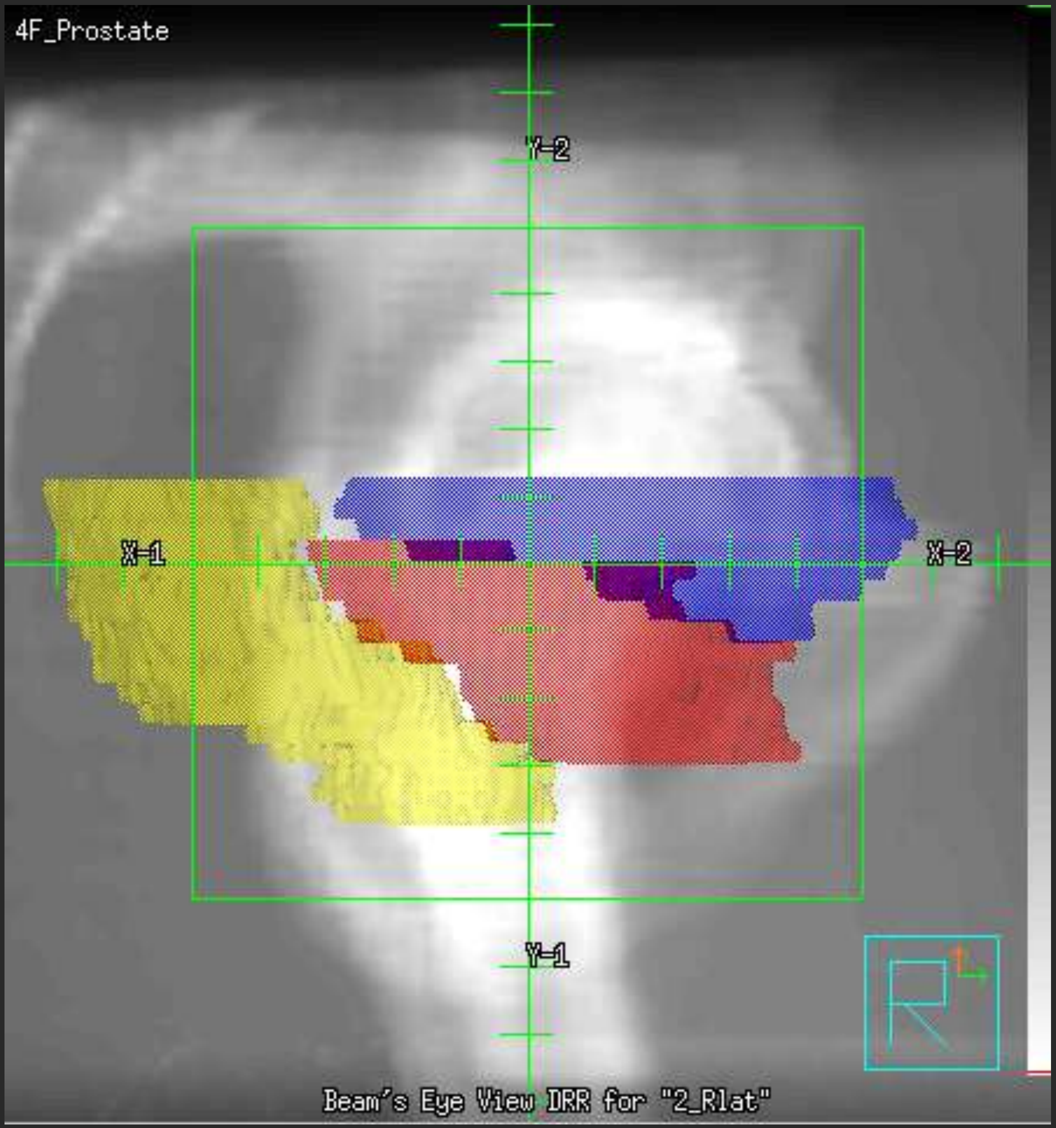
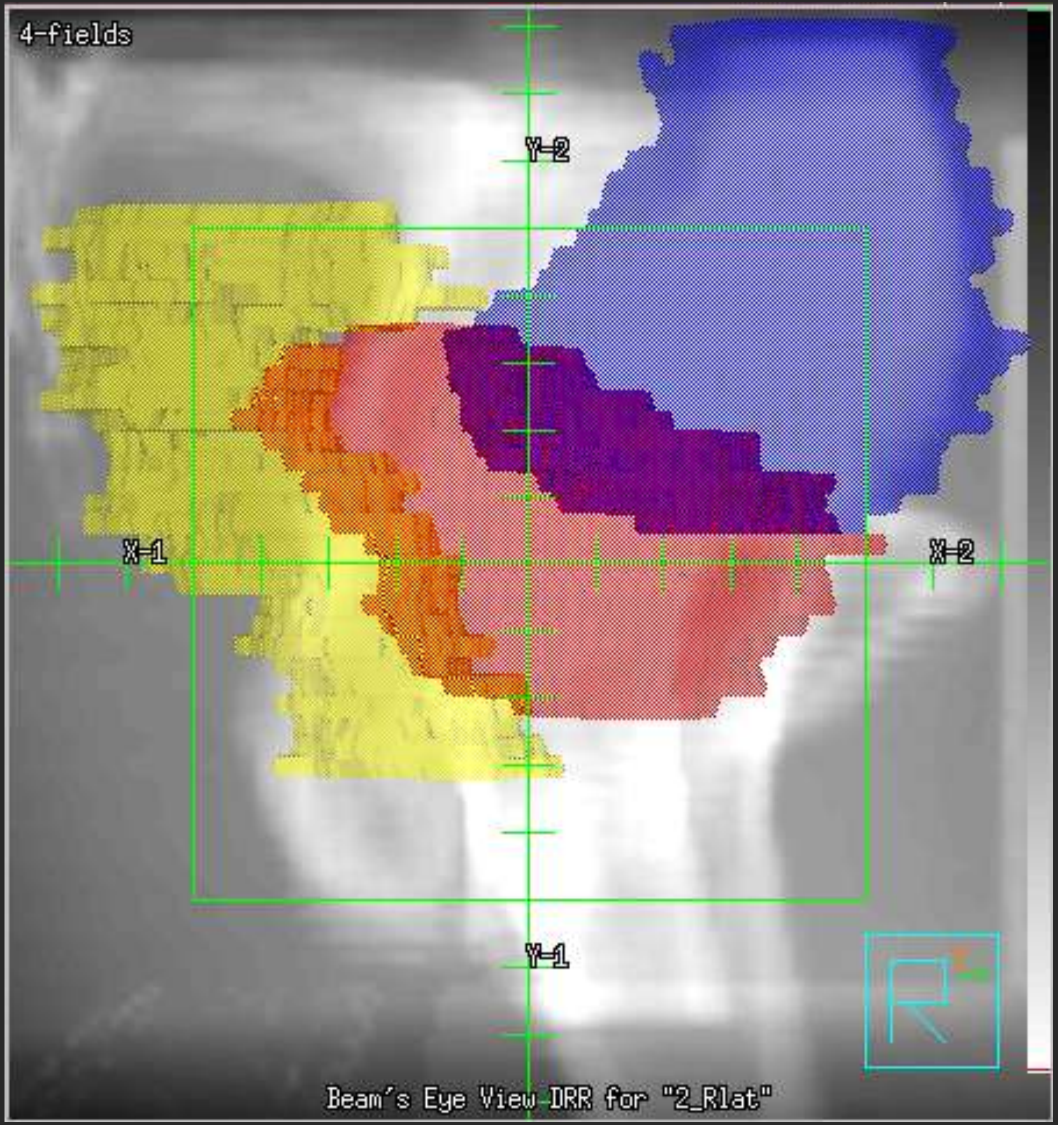
# Four fields+arcs for a <u>small</u> Prostate EBT

Total prescription 65 Gy to Isocenter



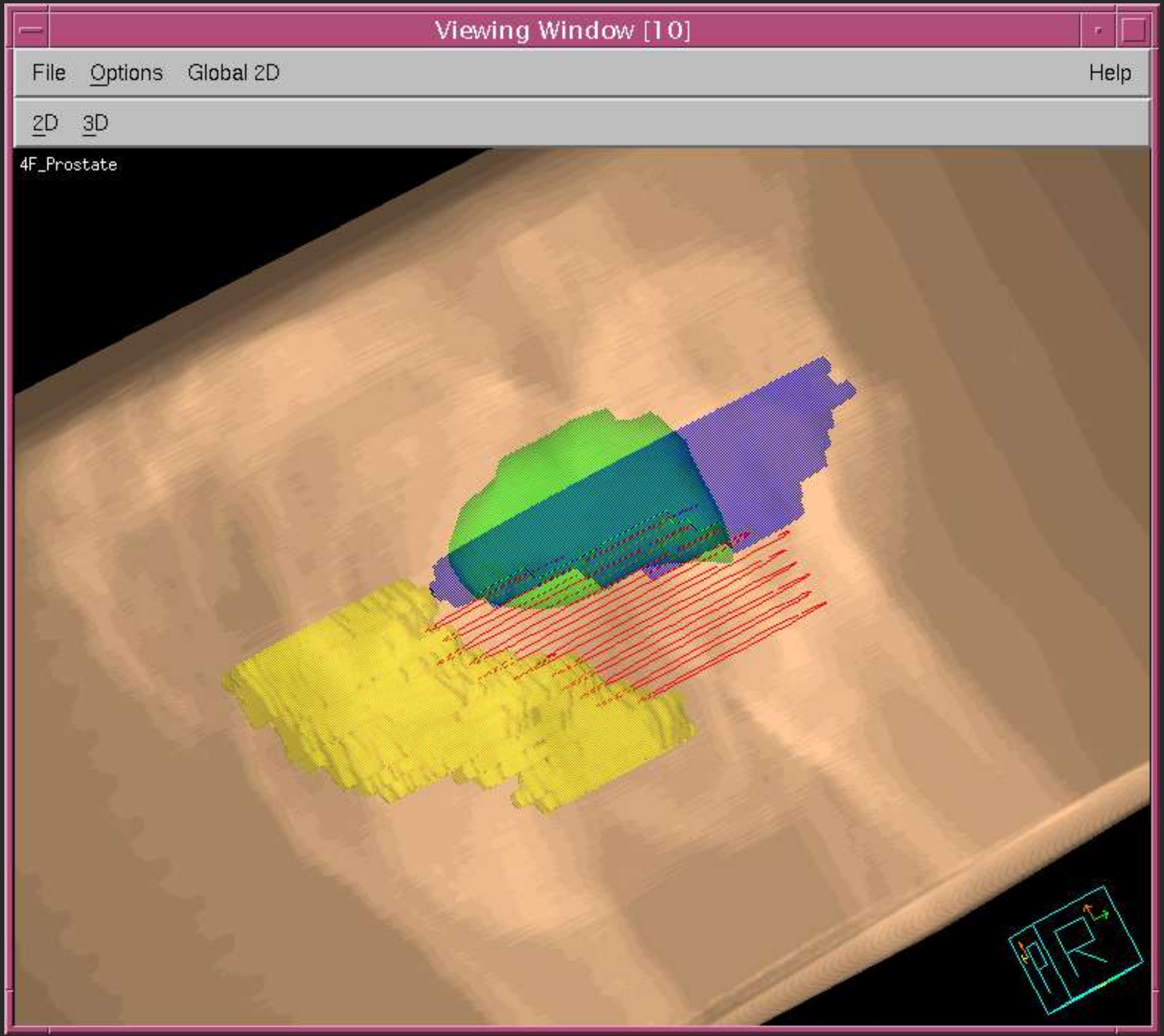
# Four fields+arcs for a LARGE Prostate EBT

Total prescription 65 Gy to Isocenter



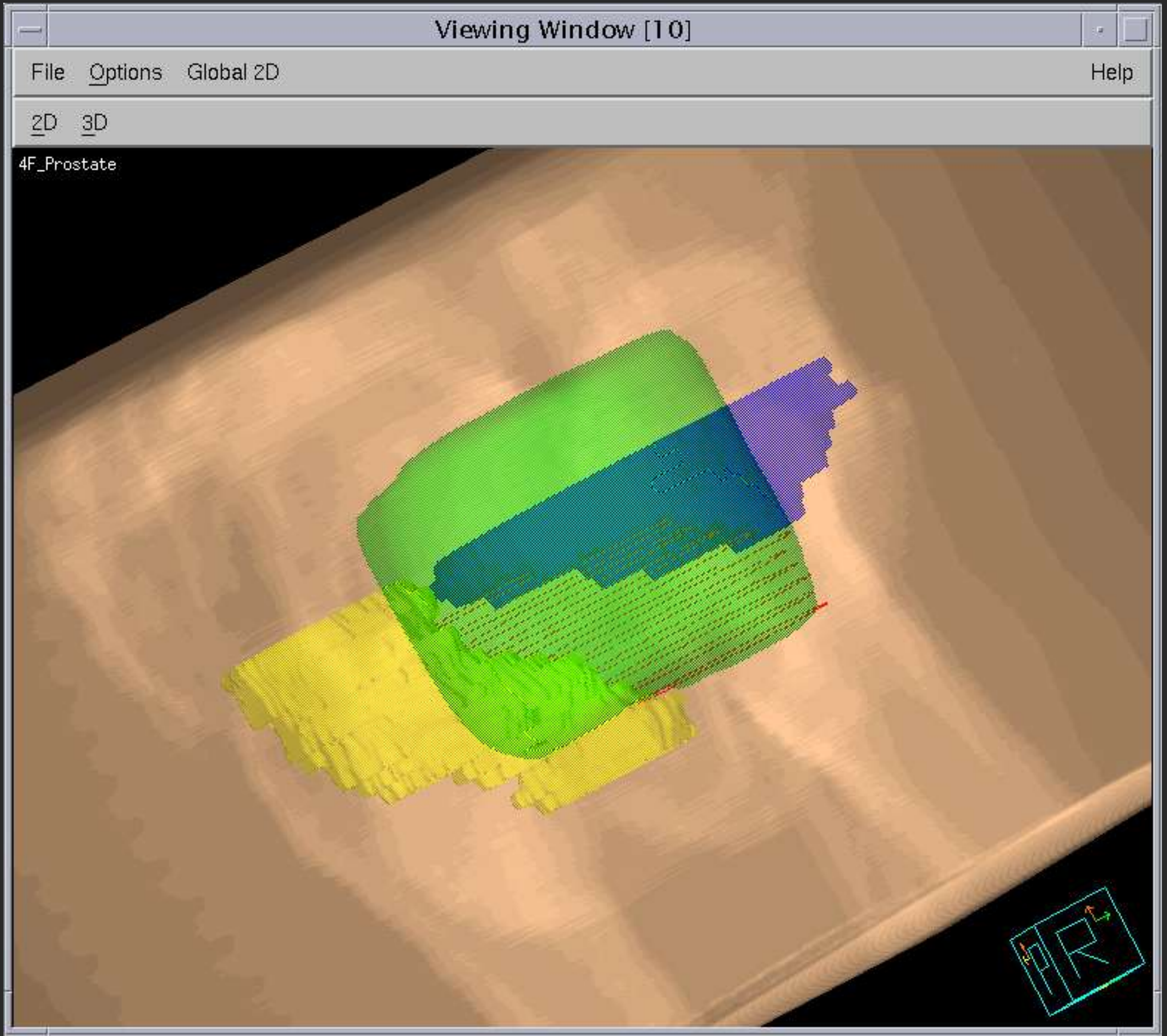
# Green Dose Cloud for four fields plus arcs for the small prostate

Isodose is the 65 Gy prescription



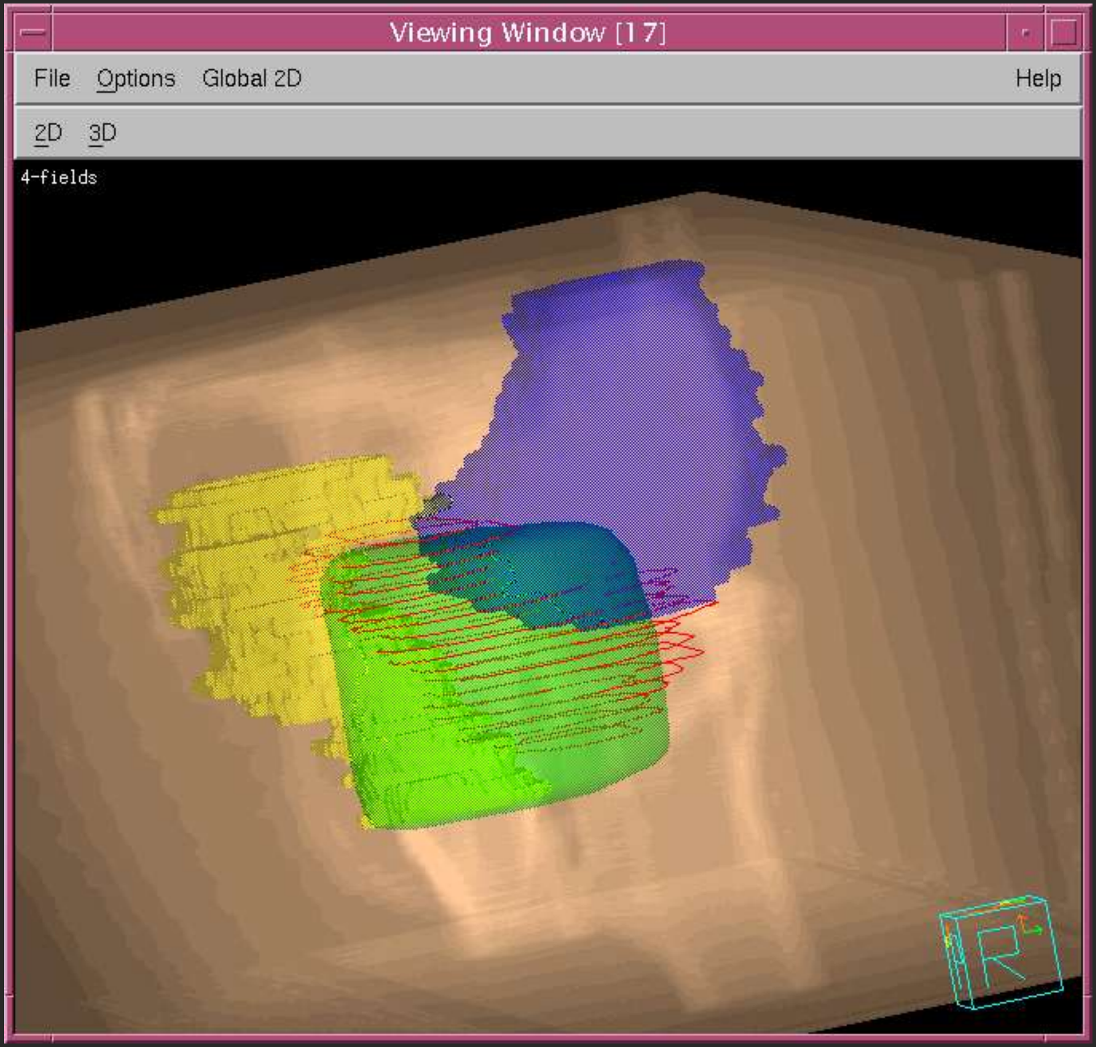
# Dose Cloud for four fields plus arcs for the same small prostate PTV

Isodose is now 97% of isocenter prescription ( 63 Gy)



# Same Green Dose Cloud for four fields plus arcs for the LARGE PTV

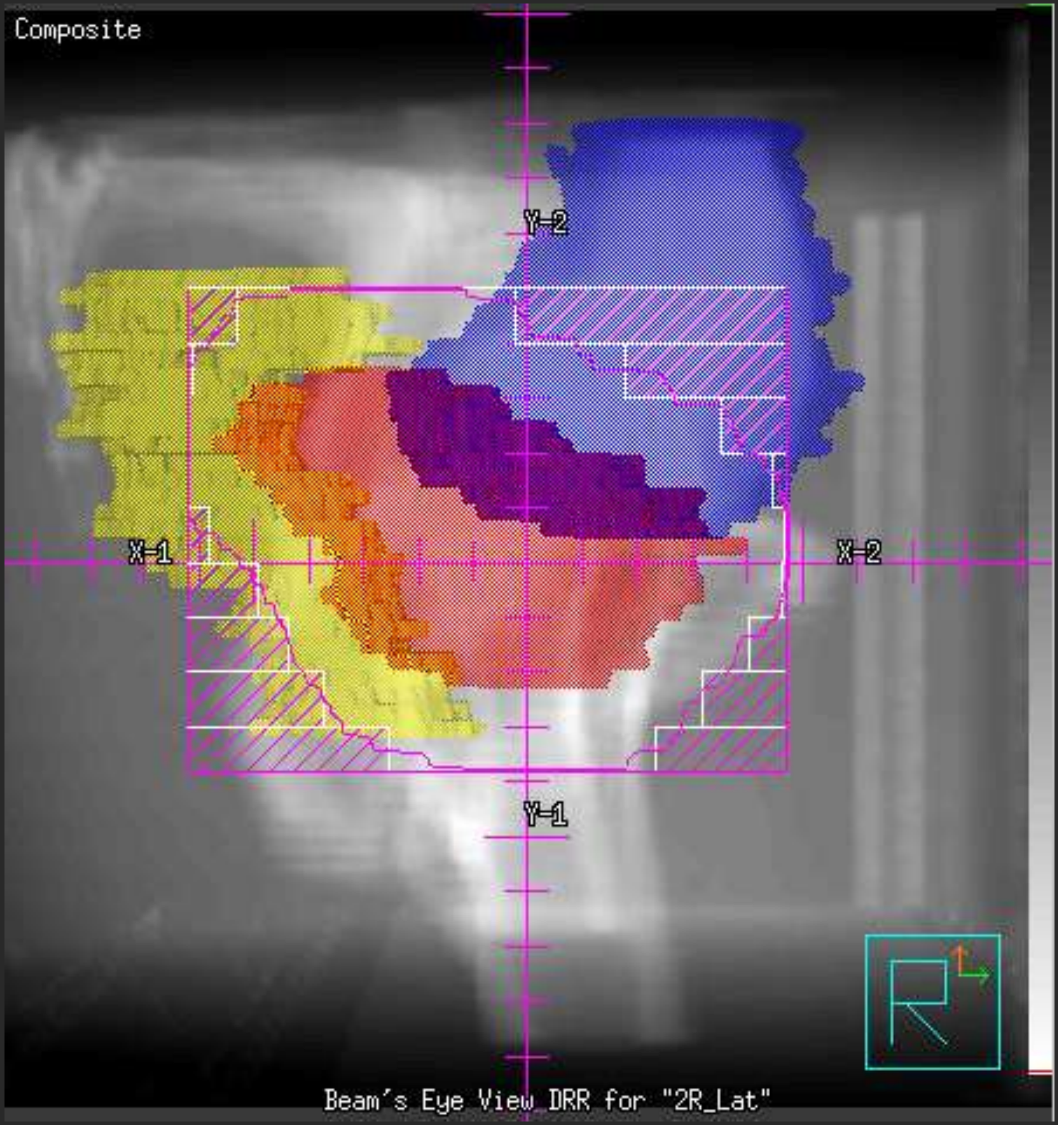
Isodose is 97% of isocenter prescription – 63 Gy



# CT guided Conformal Plan

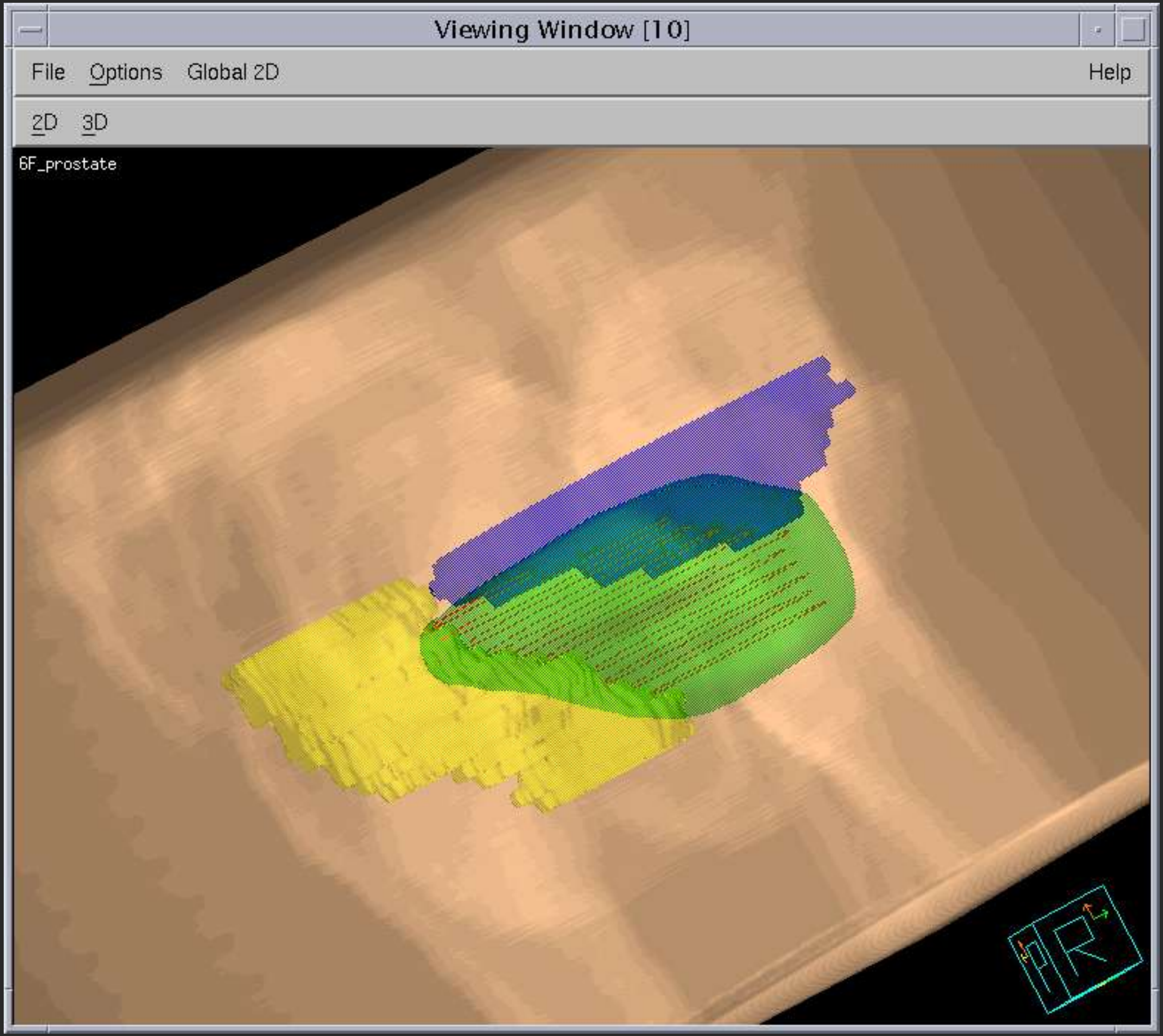
## One of Six fields

## Prescription 77.4Gy to PTV



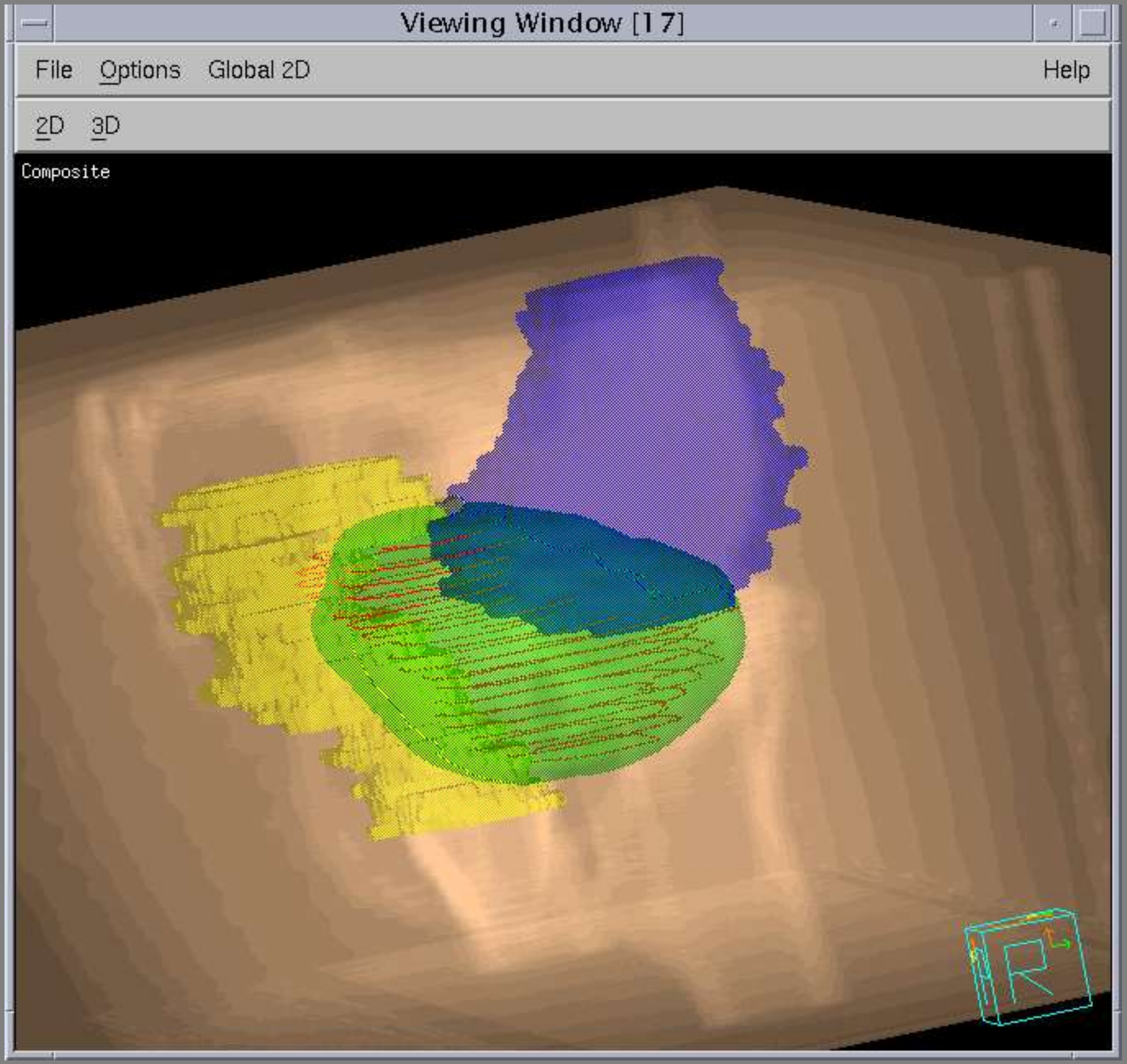
# Dose Cloud for a Six Fields CRT

## Prescription Isodose 77.4 Gy – small PTV



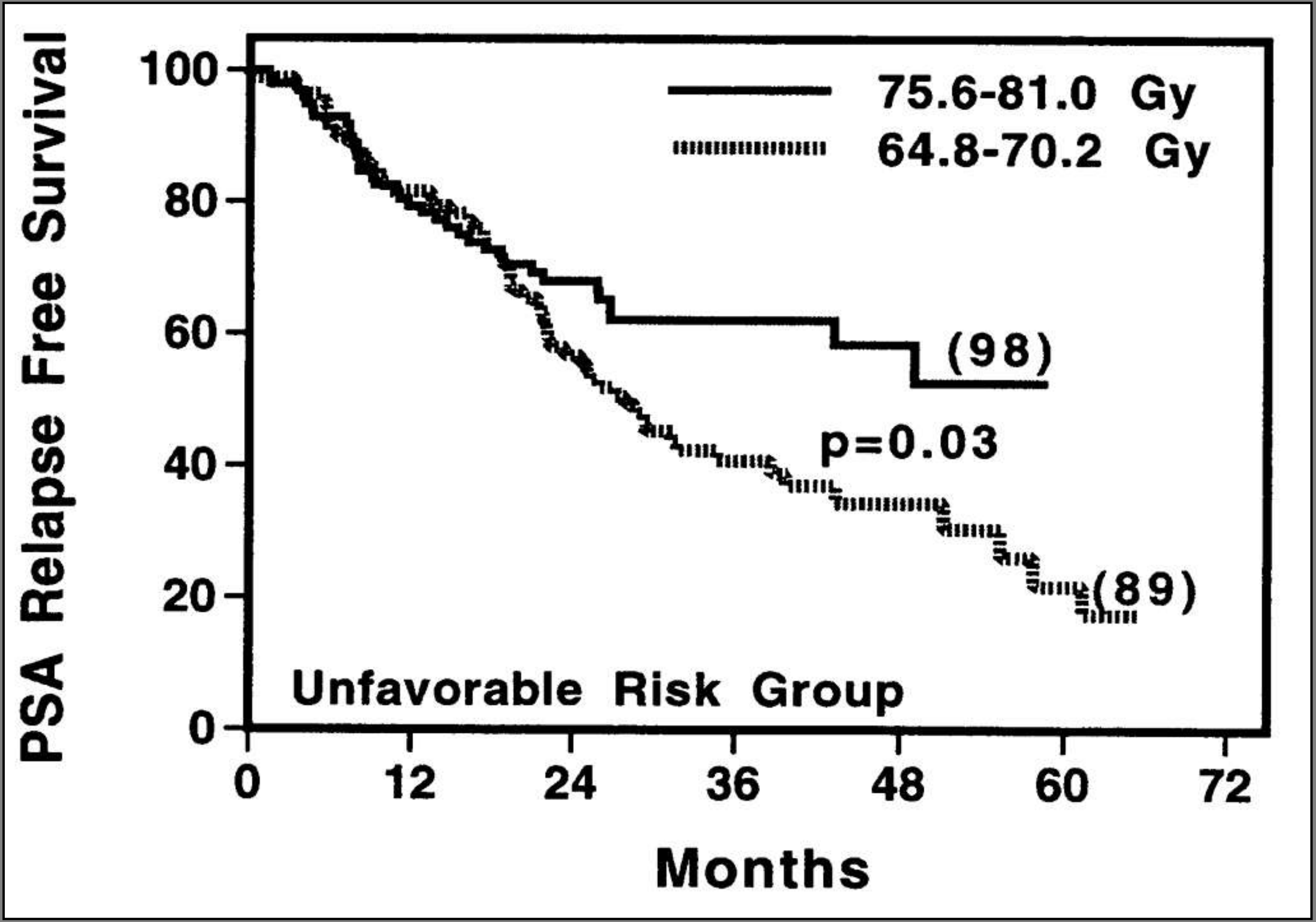
# Dose Cloud for Six Fields CRT

## Prescription Isodose 77.4 Gy – LARGE PTV



# Comparative Dose-Volume Histograms

# RFS vs. DOSE - RT alone




From: M.J.Zelefsky et. al.; IJROBP June 1998

# RFS vs. DOSE - RT alone

## 657 patients treated in 1994-95

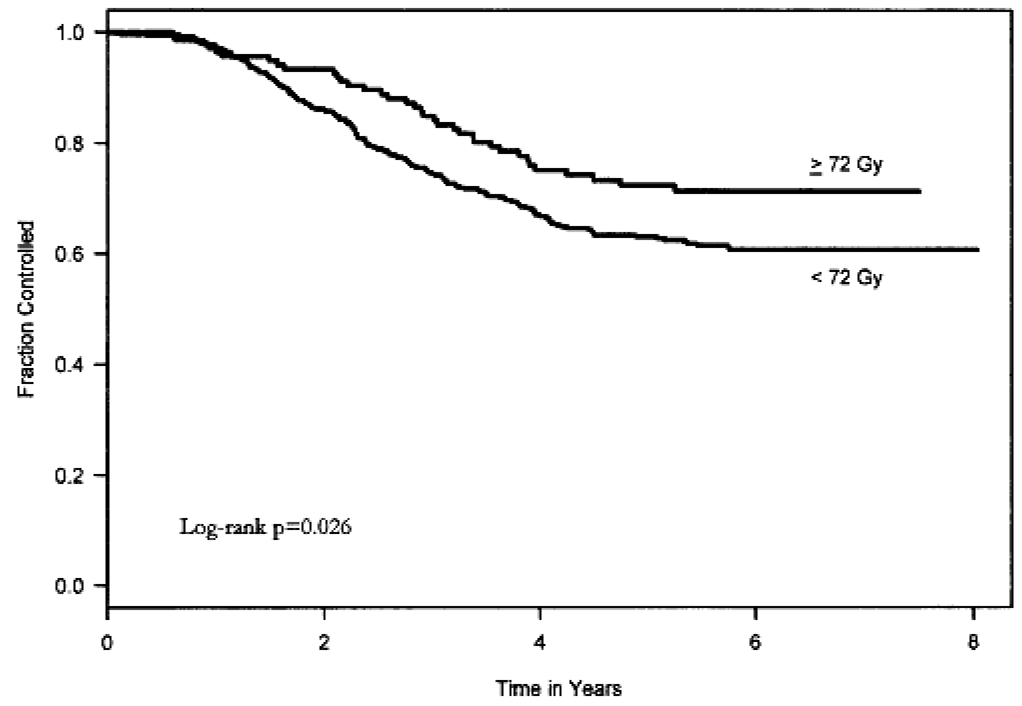



Fig. 2. Kaplan-Meier prostate-specific antigen (PSA) disease-free survival curves of patients with intermediate-risk tumors (T1b, T1c, T2a, GS ≤6 and PSA >10 ng/mL but ≤20 ng/mL or T2b, GS ≤6 and PSA ≤20 ng/mL or GS 7 and PSA ≤20 ng/mL).

**From: P. Kupelian et. al.; IJROBP Feb 2005**

# IMRT

- Por que molestarse y complicar las cosas?
- Que es IMRT?
- Como se hace?
- Que hacer y que no…
- Que mas?

# Dose Response

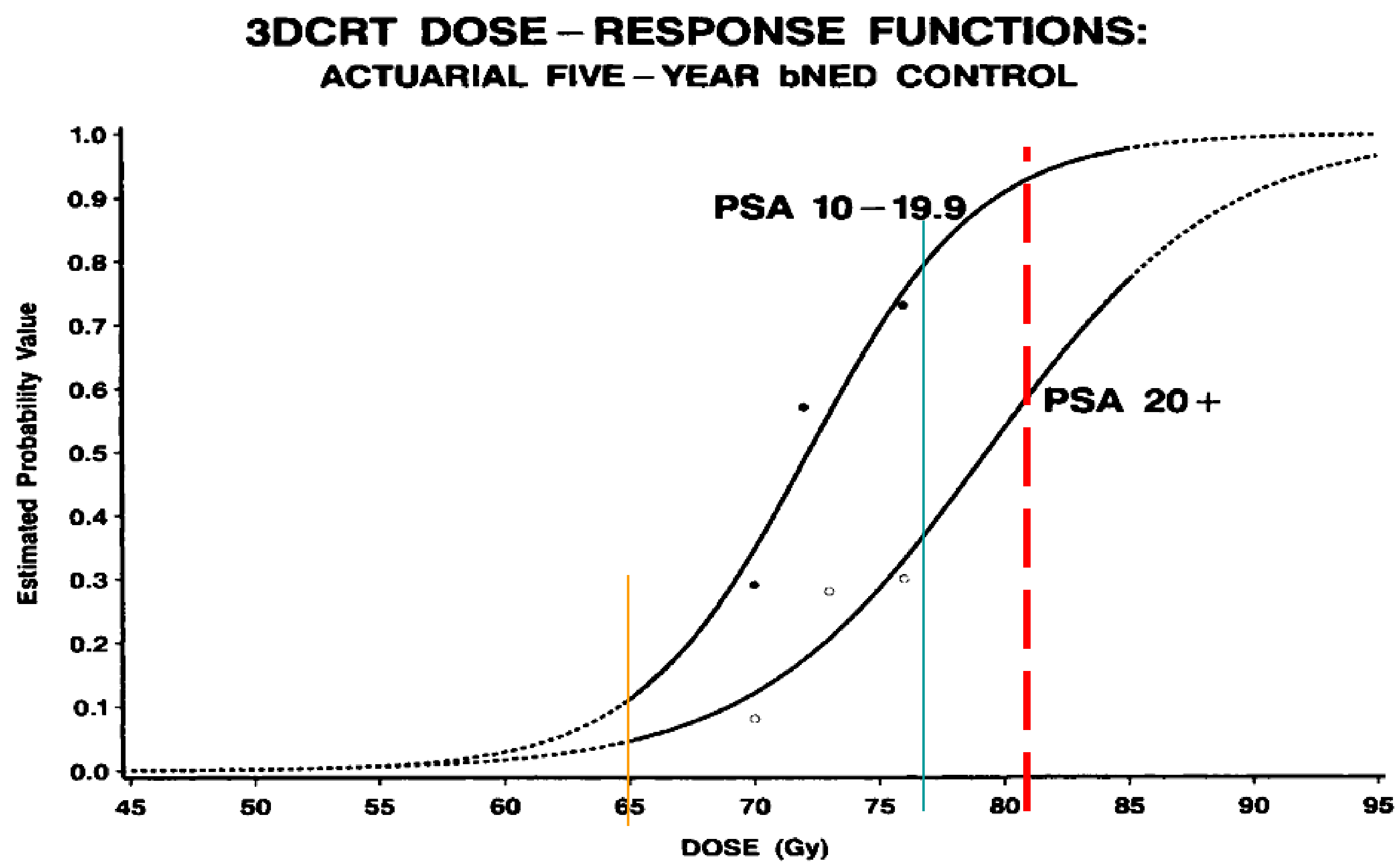



Fig. 2. Logistic response models for bNED for two pretreatment PSA groups.

- From: G.E.Hanks et. al., IJROBP, June 1998

# Morbidity vs. Dose

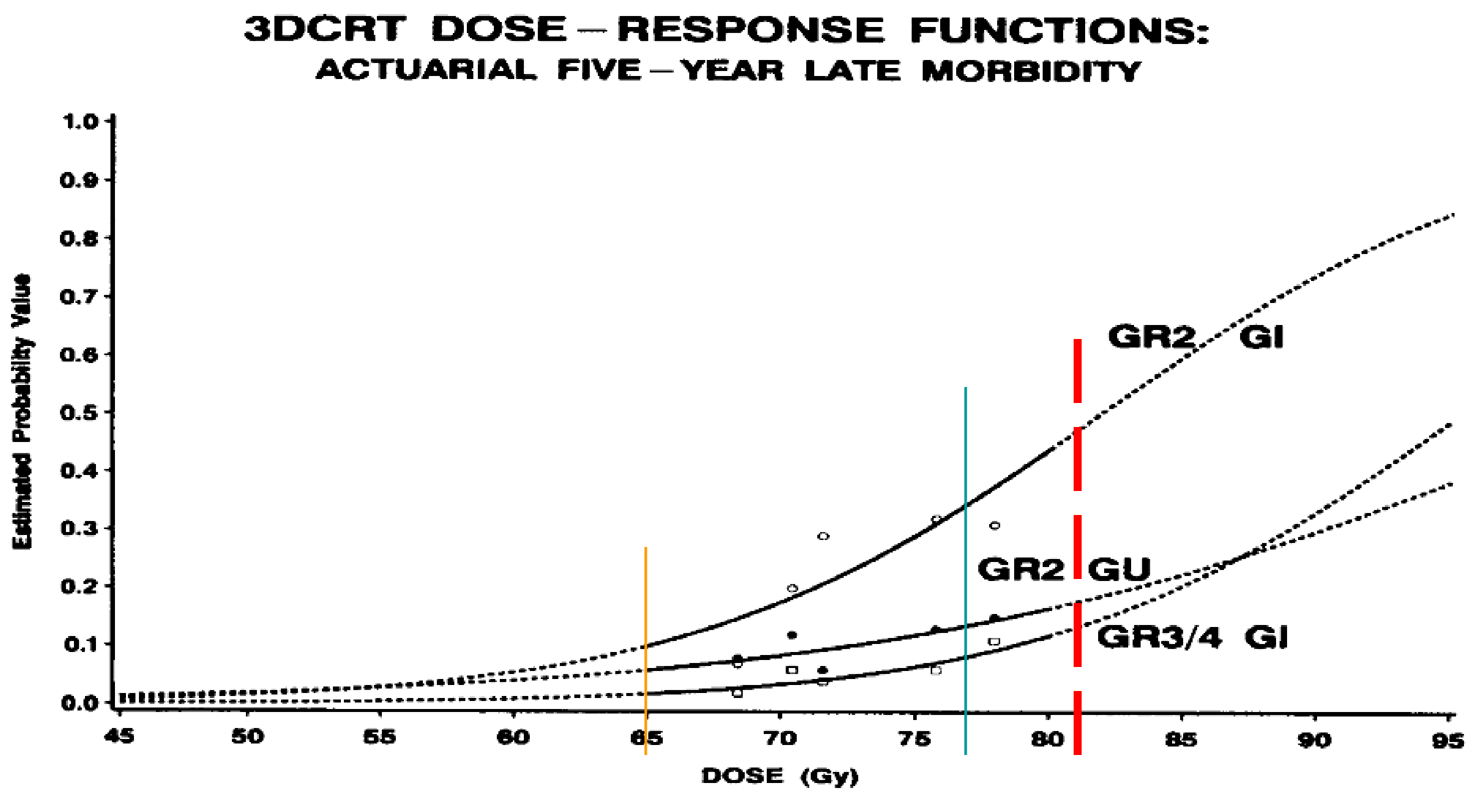



Fig. 5. Logistic response models for gastrointestinal and genitourinary radiation sequelae.

From:G.E.Hanks et. al., IJROBP, June 1998

# IMRT *is* CONFORMAL THERAPY

**Conforms (high) dose to the target volume for improved tumor control**

Conforms (low) dose to sensitive structures to reduce complications

**AND**

***Adds modulation to the geometric shaping of the beam***

# Methods of Intensity Modulation

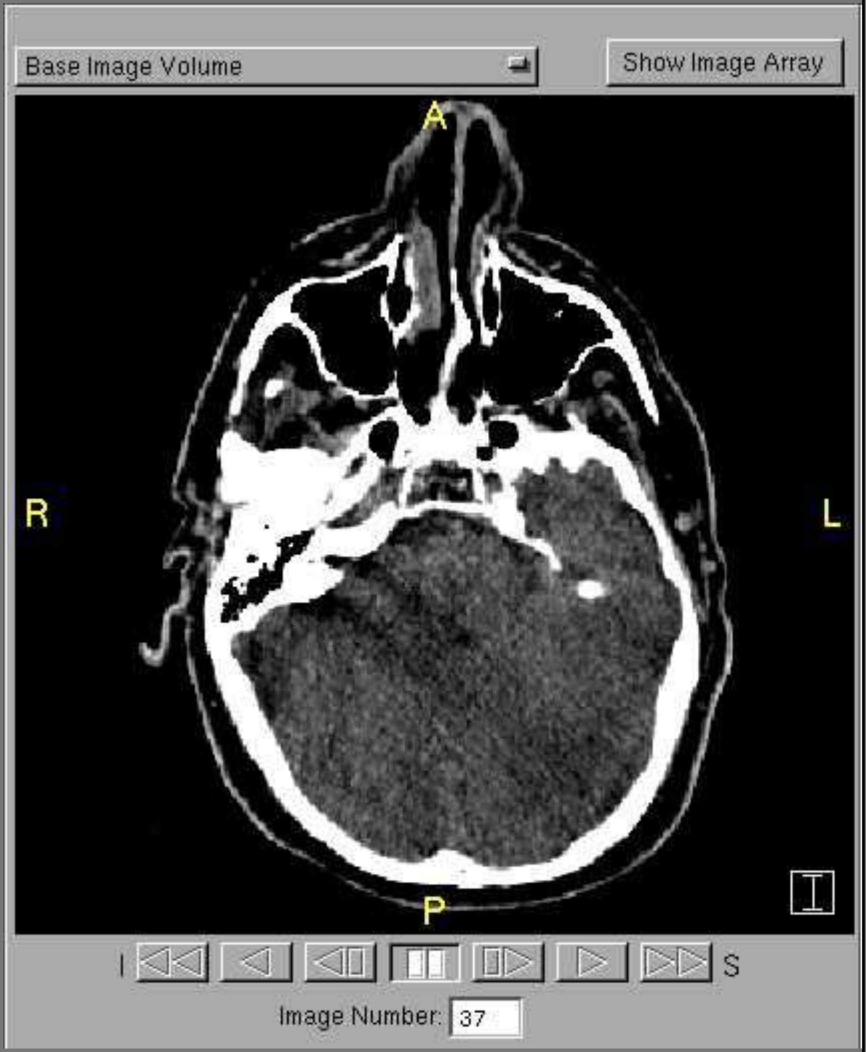
- **Wedge** ***(1-D linear intensity-modulation)***
- **Compensator** ***(2-D intensity-modulation)***
- **Coned-down boost field** ***(bi-level intensity-modulation)***
- **Dynamic Collimation**
  - *Independent Jaws*
  - *Multileaf :* ***discrete, continuous***
  - *Slit field :* ***Peacock, Tomotherapy***

# How is IMRT different from 3D-CRT?

- Definition of the prescription
- Optimization (Inverse Planning)
- Delivery Method
- Dose Calculation
- Quality Assurance requirements
- Treatment Delivery and Verification

# A new perspective on what is "the prescription"

- **Identification of the Target is a "must"**
- **Definition of the <u>desired</u> Target DVH**
- **Determine the <u>desired</u> DVH's for Sensitive Structures**
- **Assign Uncertainties to the Volumes**
- **Set *Goals* and *Priorities* or *Penalties***

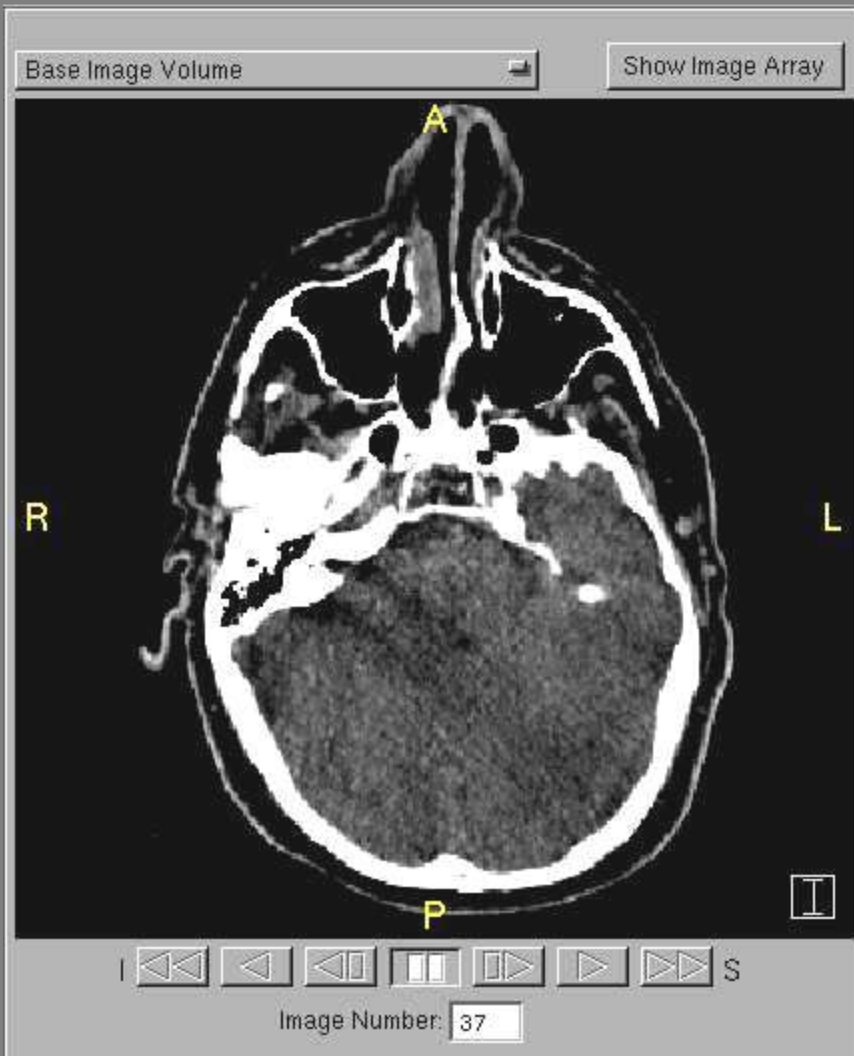


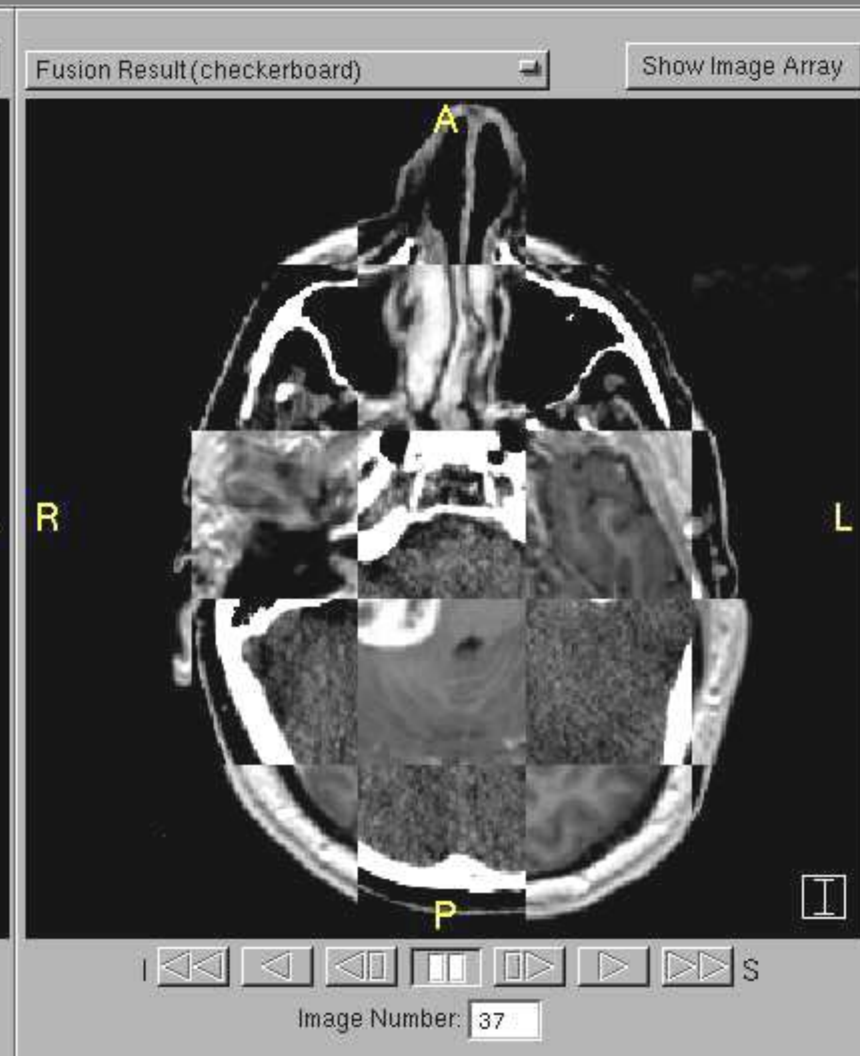

Acoustic neuroma not visible on
CT image


Acoustic neuroma not visible on CT image

Mass clearly seen on reformatted MRI image after fusion with CT

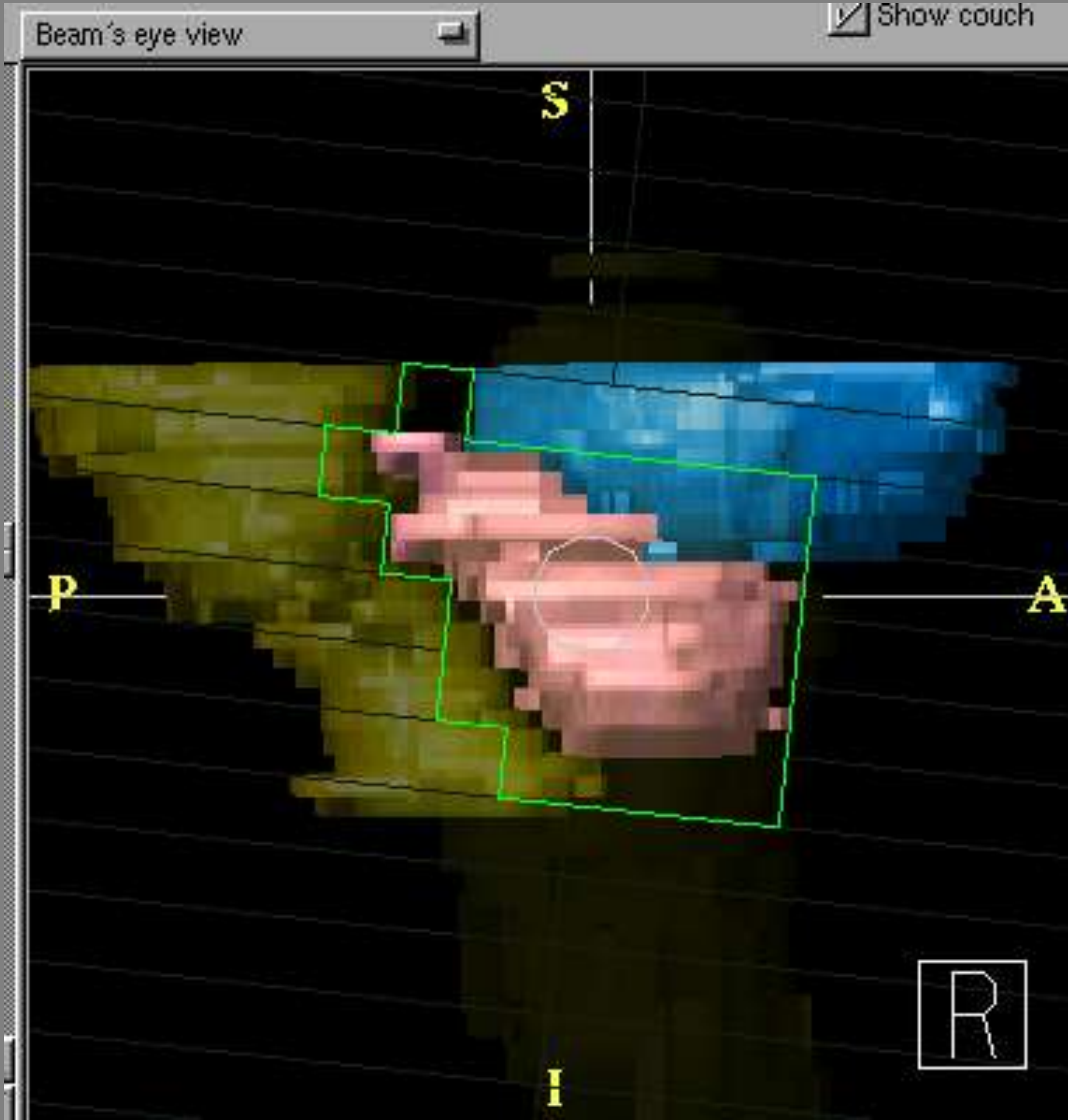
# Image fusion can play a useful role




a-CT image

b-CT and MRI checkerboard combination


Beam's eye view
Show couch
S
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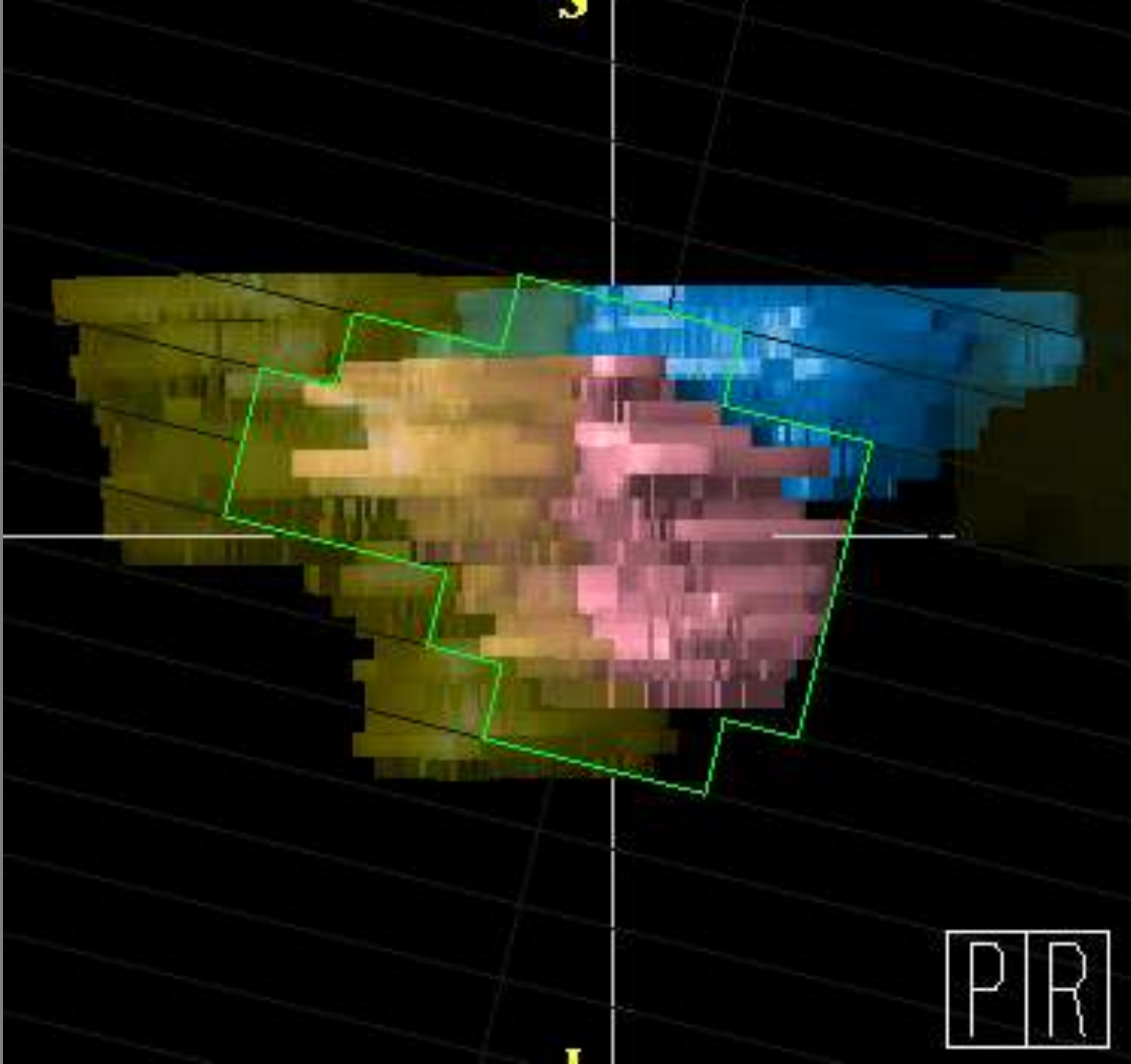
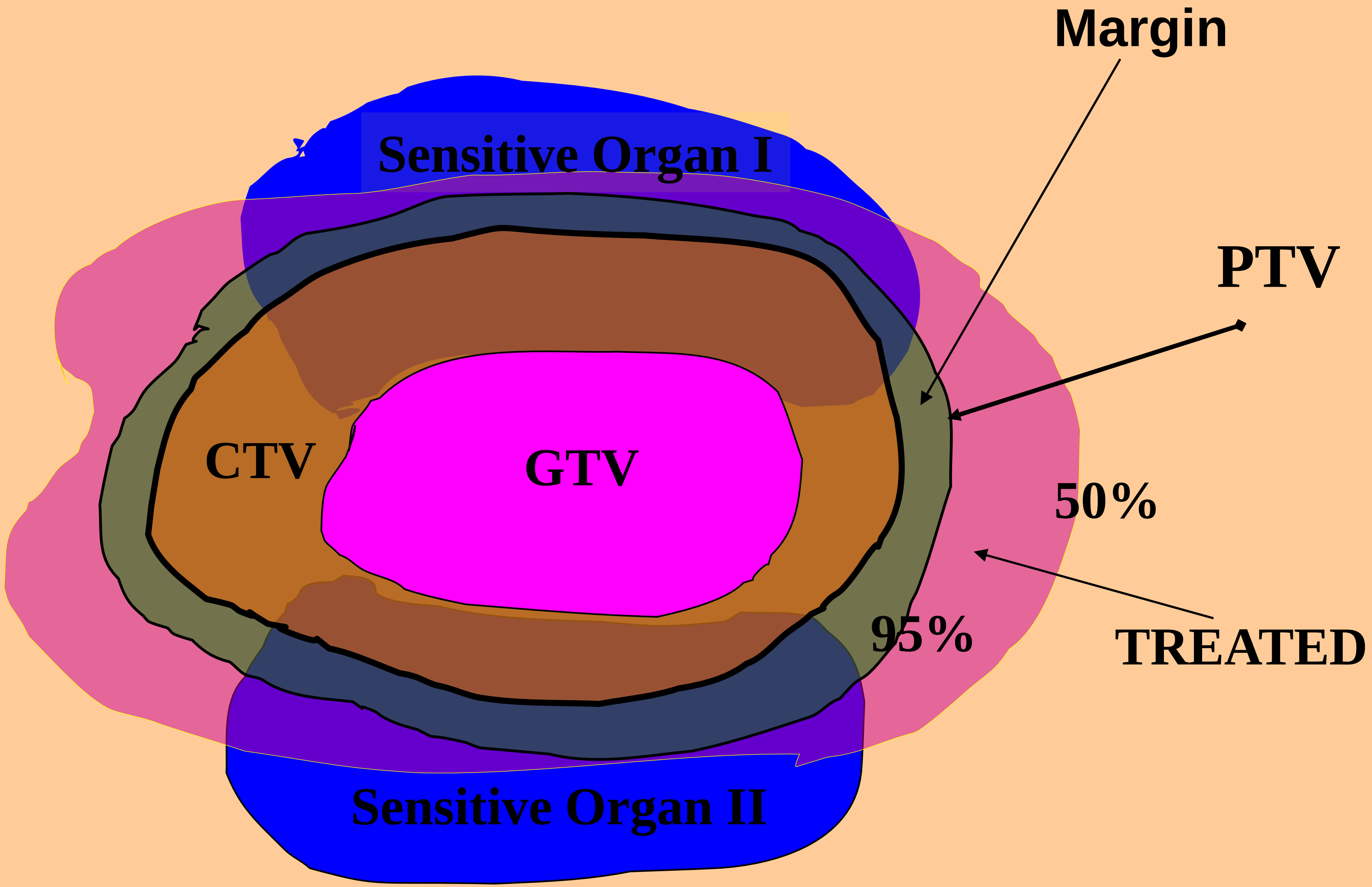


P
R

# El “drama” de la Radioterapia?

- Podemos dar dosis de radiación tan altas que podemos esterilizar cualquier tumor… y “curar” todo cáncer localizado…
- …si no fuese por esos otros órganos y tejidos intrusos que se meten en el camino para molestar…

# Relation between Volumes




ICRU-50 and ICRU-62

# The new "craze" in prescriptions

**Optimization**

**Structures and Constraints**

| Structure | Constraint | | | | | | |
|---|---|---|---|---|---|---|---|
| CTV | | Volume [cc]: | 142 | Points: | 7150 | Resolution [mm]: | 3.00 |
| | Upper | Volume [%]: | 10.0 | Dose [cGy]: | 5700.0 | Priority: | 80 |
| | Upper | | 5.0 | | 5950.0 | | 90 |
| | Lower | Volume [%]: | 100.0 | Dose [cGy]: | 5400.0 | Priority: | 110 |
| Cooling Ring | | Volume [cc]: | 657 | Points: | 33574 | Resolution [mm]: | 3.00 |
| | Upper | Volume [%]: | 10.0 | Dose [cGy]: | 2600.0 | Priority: | 85 |
| | Upper | | 0.0 | | 3000.0 | | 95 |
| Cord | | Volume [cc]: | 11 | Points: | 2876 | Resolution [mm]: | 1.72 |
| | Upper | Volume [%]: | 2.0 | Dose [cGy]: | 4200.0 | Priority: | 85 |
| External | | Volume [cc]: | 3213 | Points: | 135528 | Resolution [mm]: | 3.00 |
| L cochlea | | Volume [cc]: | 1 | Points: | 1314 | Resolution [mm]: | 1.00 |
| | Upper | Volume [%]: | 50.0 | Dose [cGy]: | 2050.0 | Priority: | 100 |
| | Upper | | 10.0 | | 4300.0 | | 75 |
| L optic nerve | | Volume [cc]: | 1 | Points: | 1287 | Resolution [mm]: | 1.00 |
| | Upper | Volume [%]: | 20.0 | Dose [cGy]: | 4000.0 | Priority: | 75 |
| LT Eye | | Volume [cc]: | 8 | Points: | 2552 | Resolution [mm]: | 1.52 |
| | Upper | Volume [%]: | 20.0 | Dose [cGy]: | 1500.0 | Priority: | 80 |
| PTV 3mm | | Volume [cc]: | 185 | Points: | 8965 | Resolution [mm]: | 3.00 |
| | Upper | Volume [%]: | 10.0 | Dose [cGy]: | 5950.0 | Priority: | 80 |
| | Upper | | 5.0 | | 5950.0 | | 90 |
| | Lower | Volume [%]: | 95.0 | Dose [cGy]: | 5400.0 | Priority: | 100 |
| | Lower | | 98.0 | | 5100.0 | | 95 |
| R cochlea | | Volume [cc]: | 1 | Points: | 646 | Resolution [mm]: | 1.00 |
| | Upper | Volume [%]: | 50.0 | Dose [cGy]: | 2050.0 | Priority: | 100 |
| | Upper | | 10.0 | | 4300.0 | | 85 |
| R optic nerve | | Volume [cc]: | 1 | Points: | 941 | Resolution [mm]: | 1.00 |

Add Upper Constraint | Add Lower Constraint | Delete

# Inverse Planning Problem

Dose to point i:

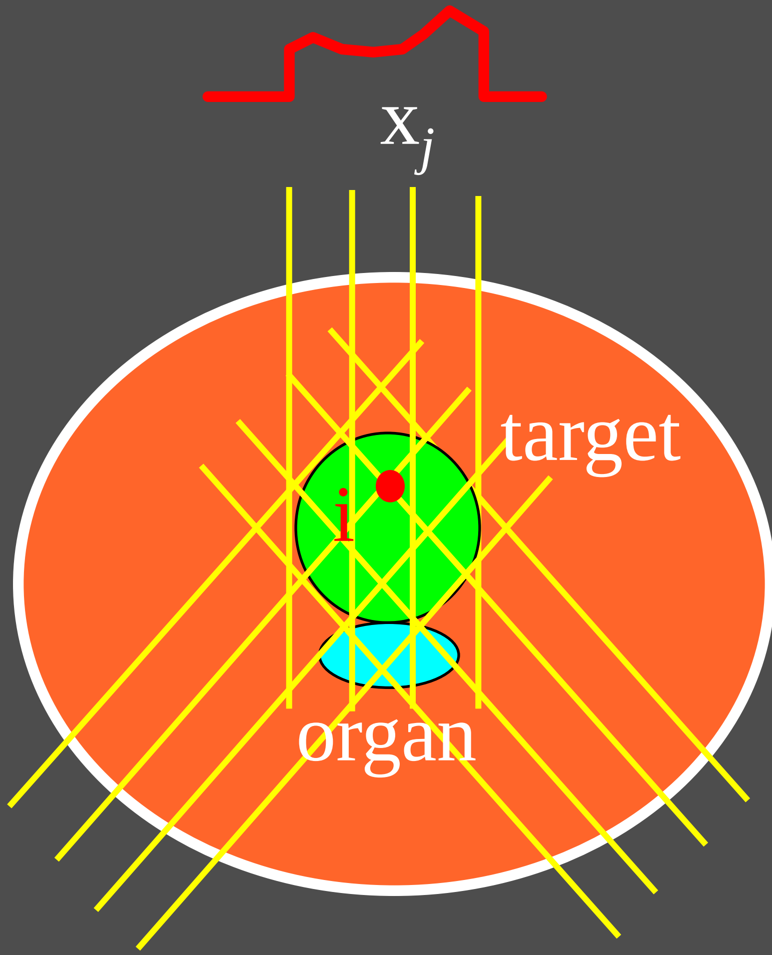
$$D_i = x_1 d_{1i} + \bullet\bullet\bullet + x_J d_{Ji}$$
$$= \mathbf{x} \bullet \mathbf{d}_i$$

Objective function:

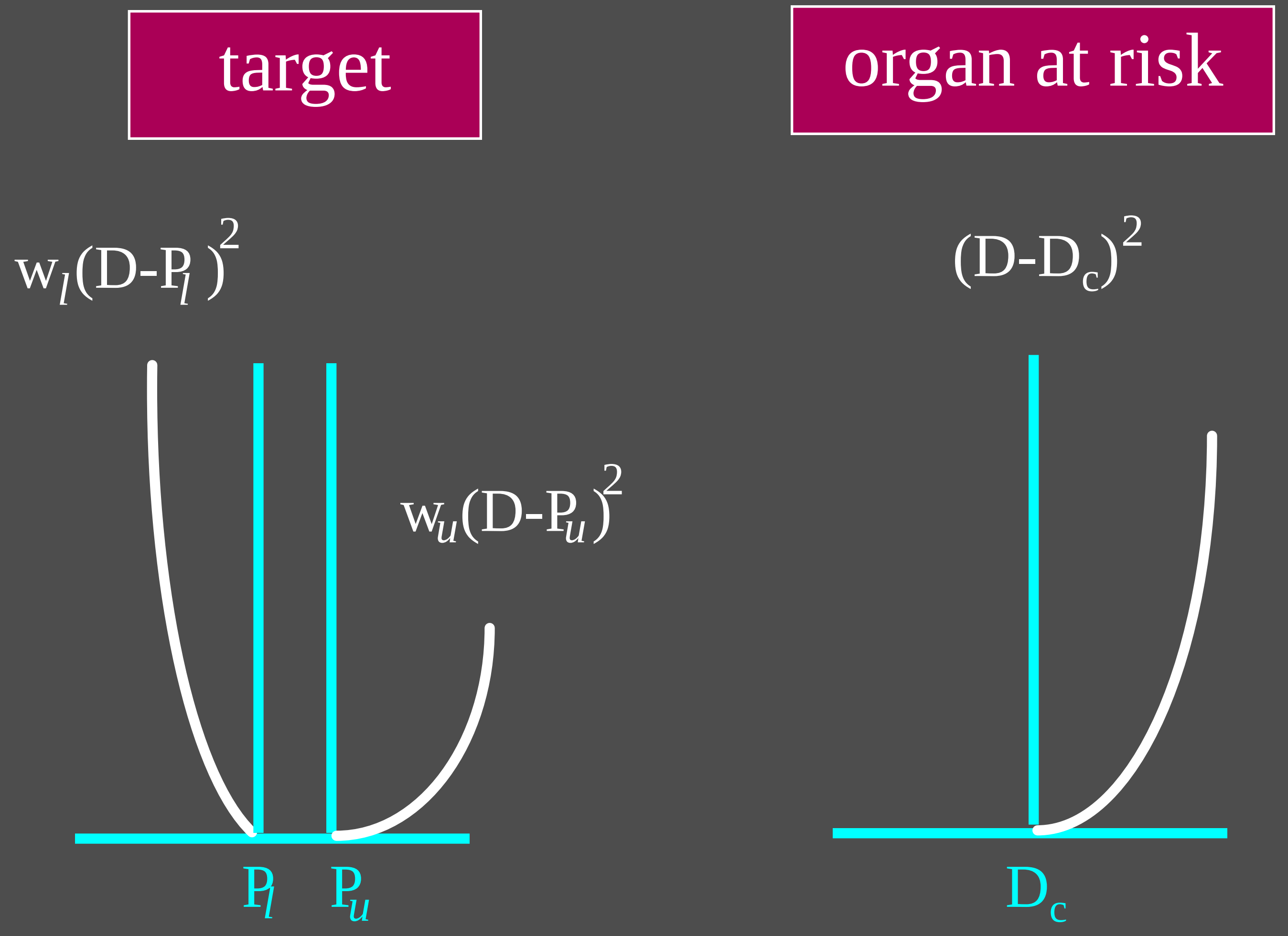
$$F(\mathbf{x}) = \sum_i w_i \bullet (D_i - P_i)^2$$

Minimize F(x):

$$\nabla F(\mathbf{x}) = 2 \sum_i w_i \bullet (D_i - P_i)\, \mathbf{d}_i = 0$$



# Types of Objective Functions



# How is the Modulated Intensity Calculated?

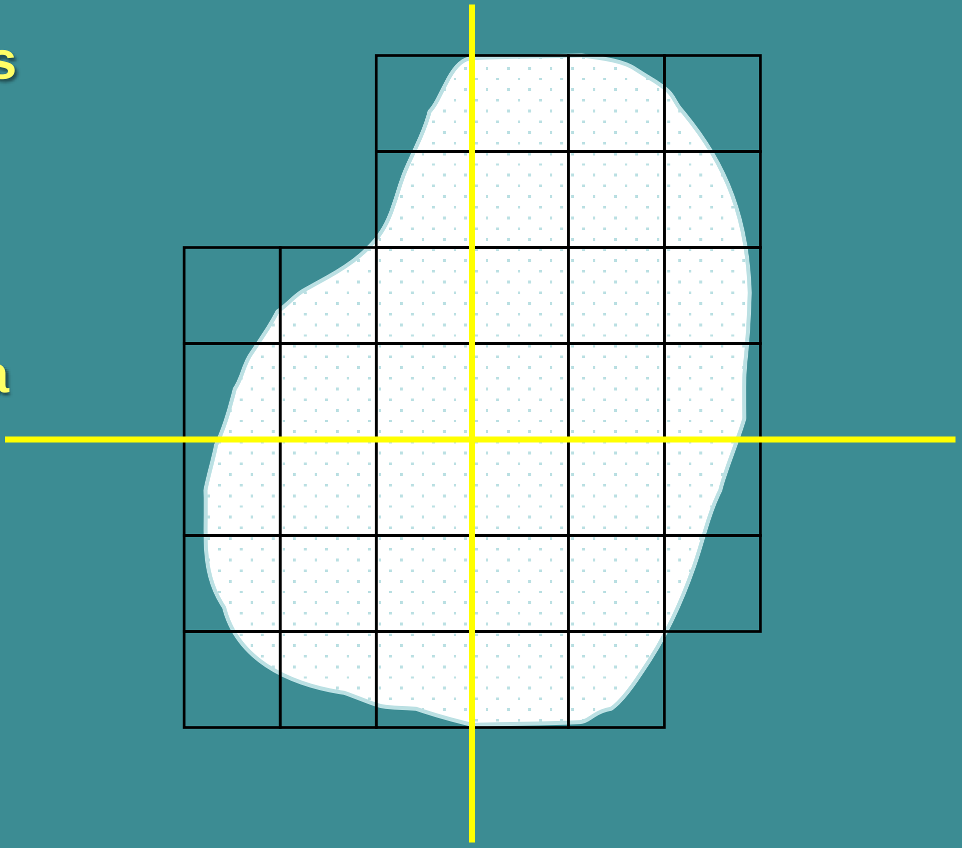
- “Dividing” each beam into many small beamlets

- Each beamlet can have an intensity from 0 - 100 %

# Plan Optimization

Conceptually, plan optimization proceeds as follows:

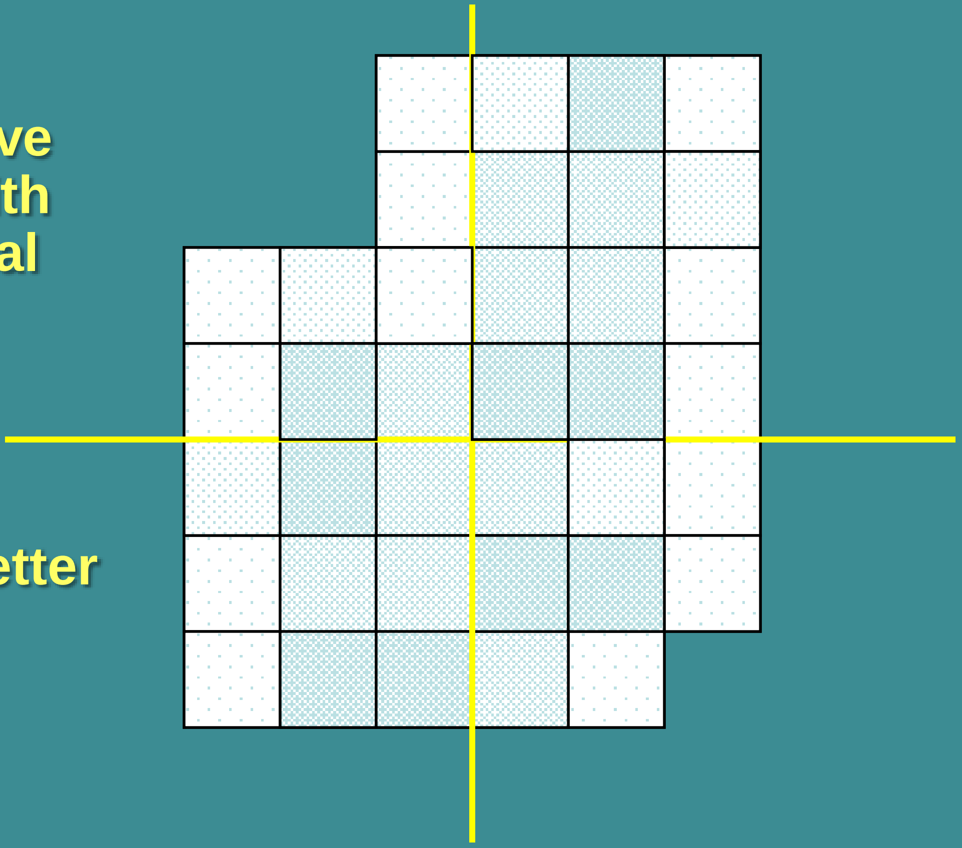
- For each treatment field, a beam's-eye-view of the target is used to divide the field into pencil-beams.
- For simplicity, assume the pencil-beams are centered on a 1 cm x 1 cm grid.



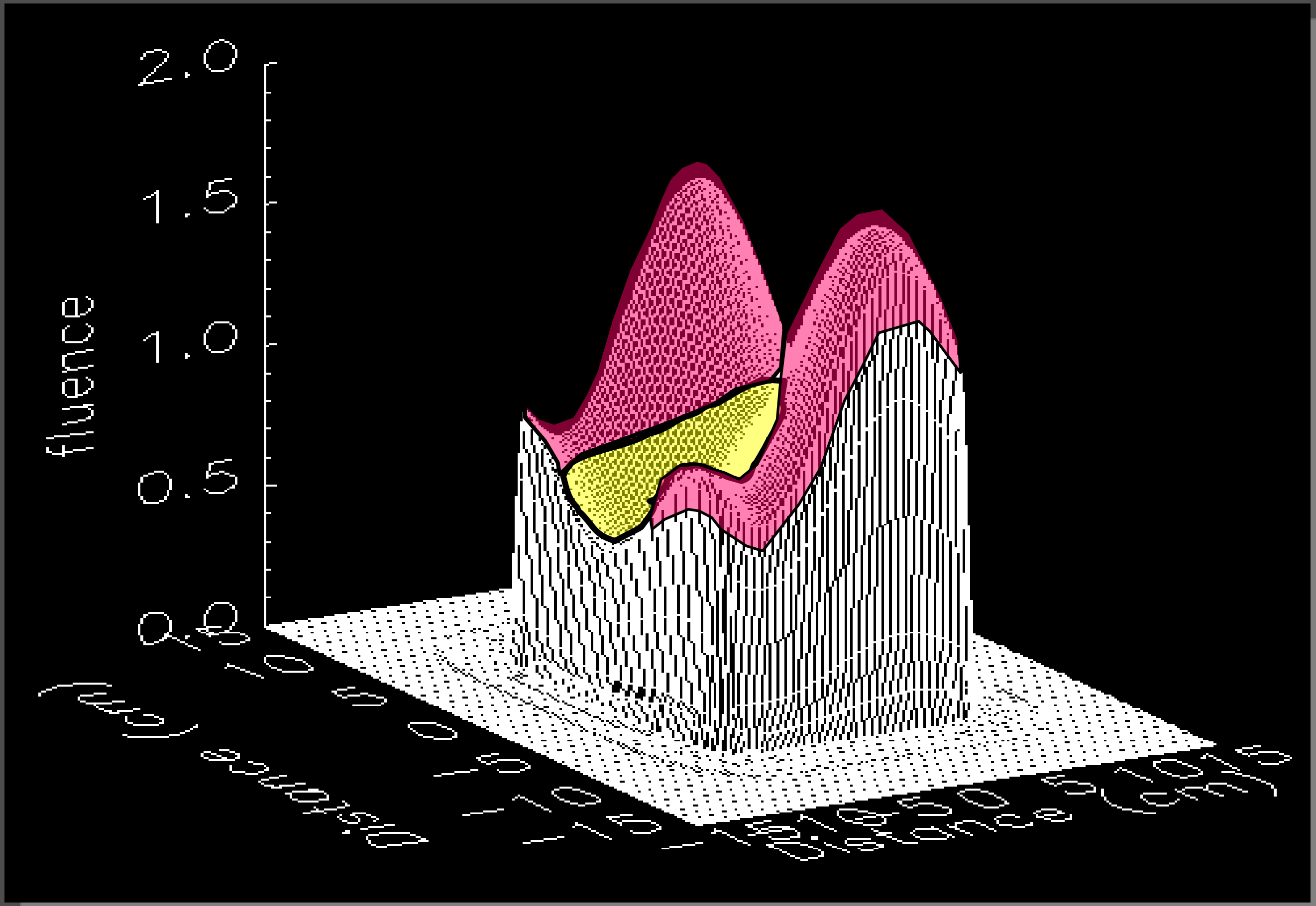
# Plan Optimization

**During optimization:**

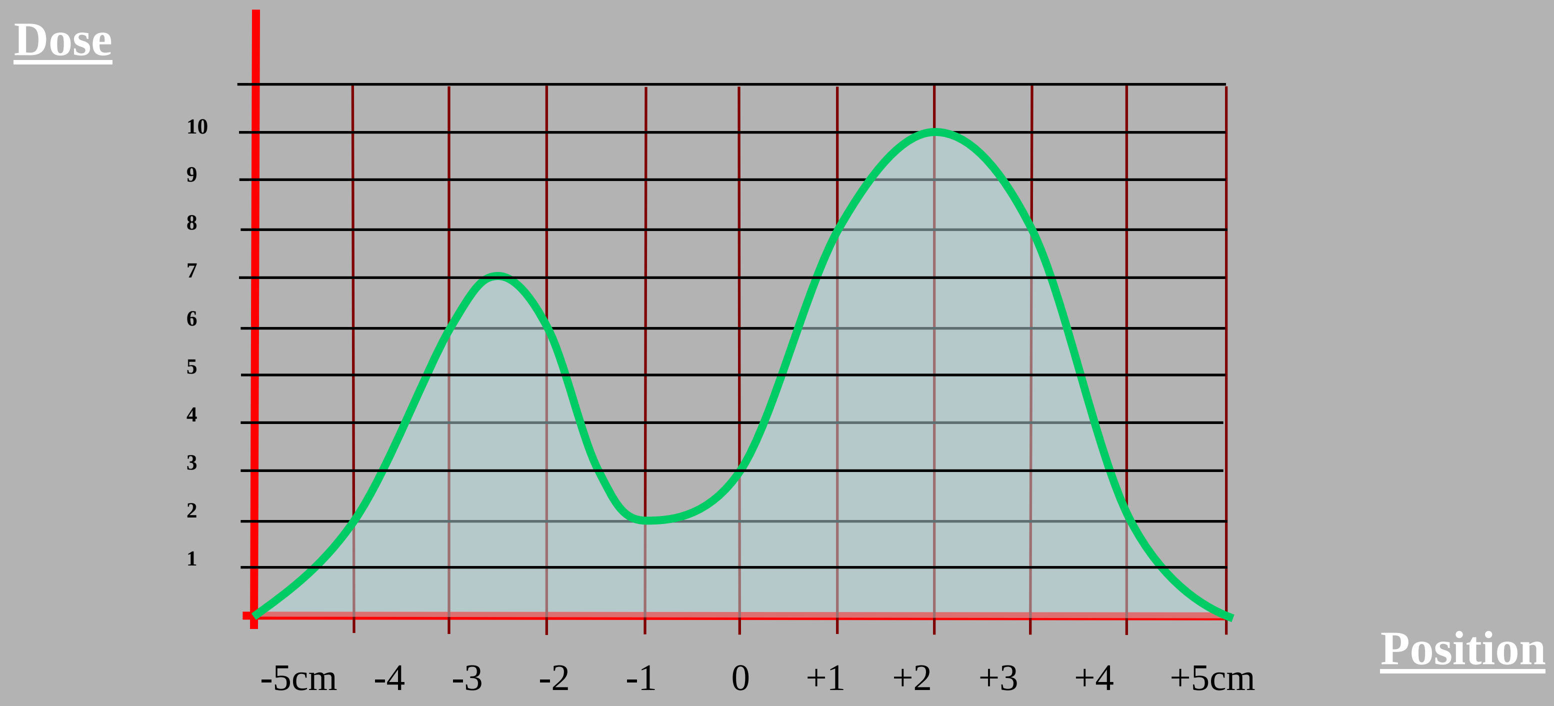
- **The weight of each pencil beam in each field is changed during each iteration.**
- **After each iteration, the objective function is calculated, along with the DVH of the target and critical structures.**
- **The optimization iterations continue until the objective function is no-longer getting better or the maximum number of iterations has been achieved.**



# Prostate Posterior Field Intensity Profile



# How Can We Make Any Intensity Shape?




Dose
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-3
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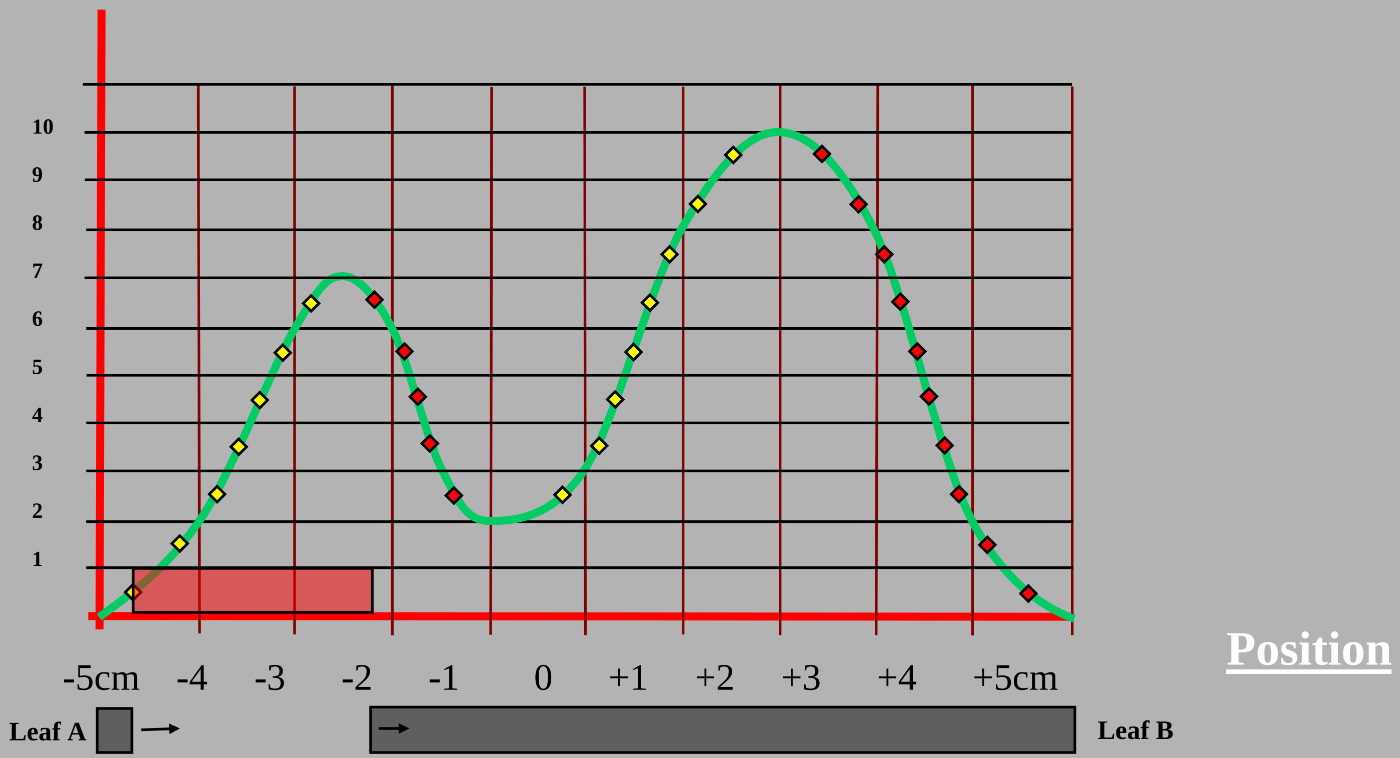
-1
0
+1
+2
+3
+4
+5cm
Position



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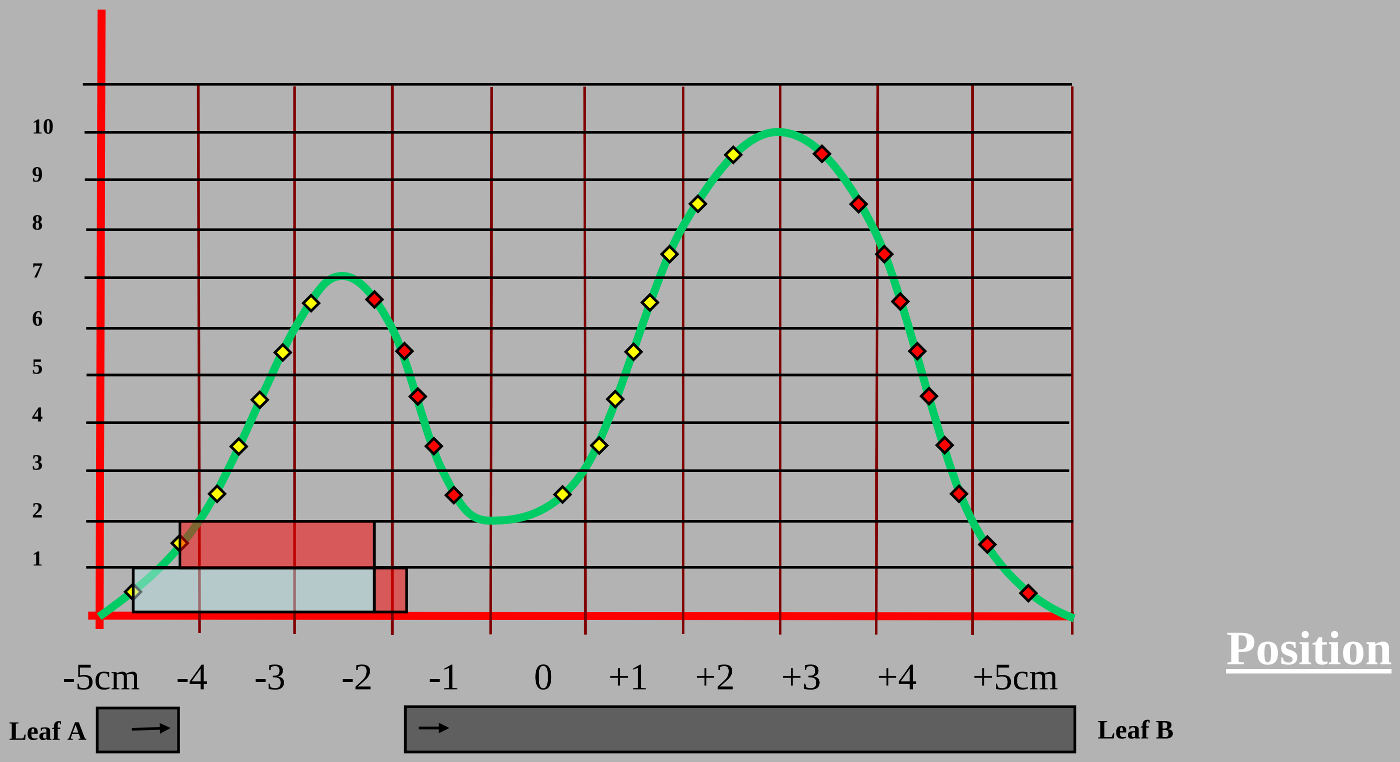
+3
+4
+5cm
Position
Leaf A
Leaf B



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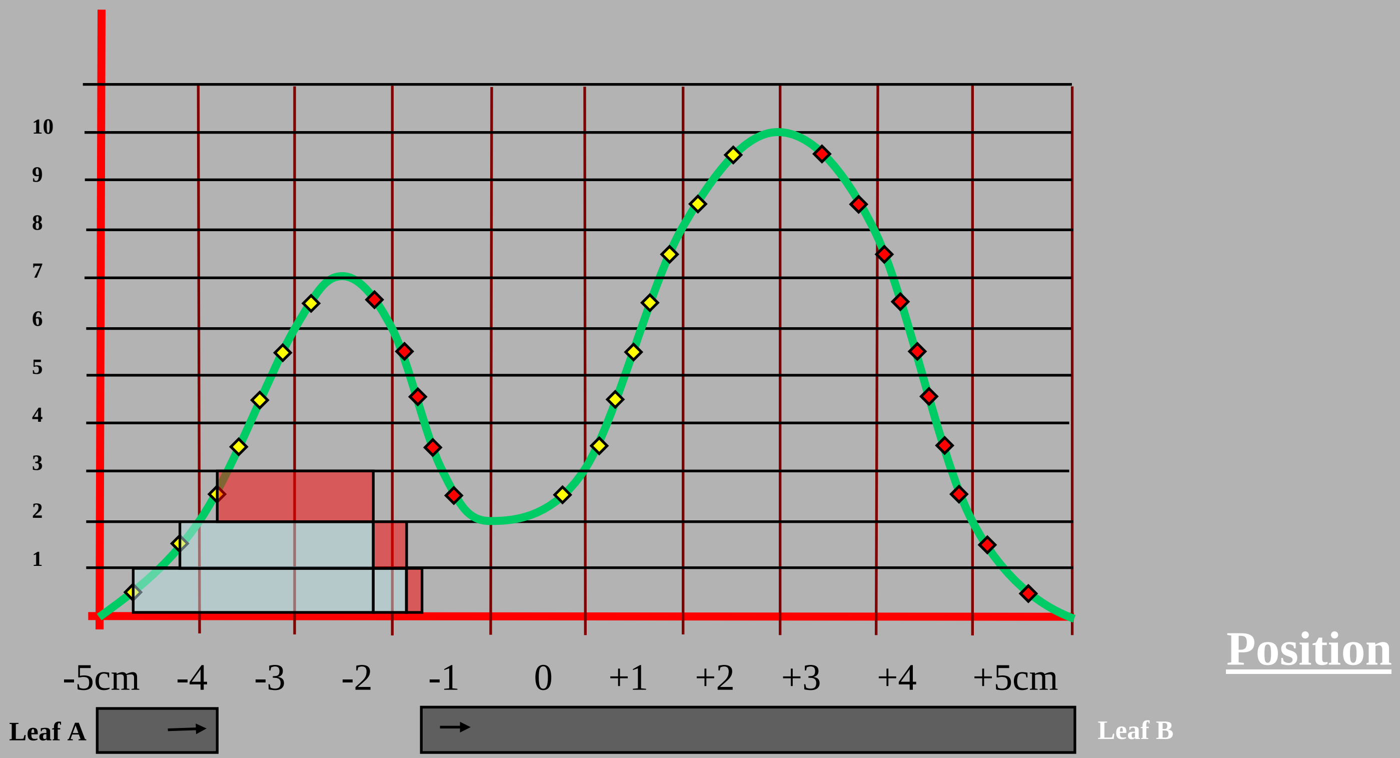
+1
+2
+3
+4
+5cm
Position
Leaf A
Leaf B



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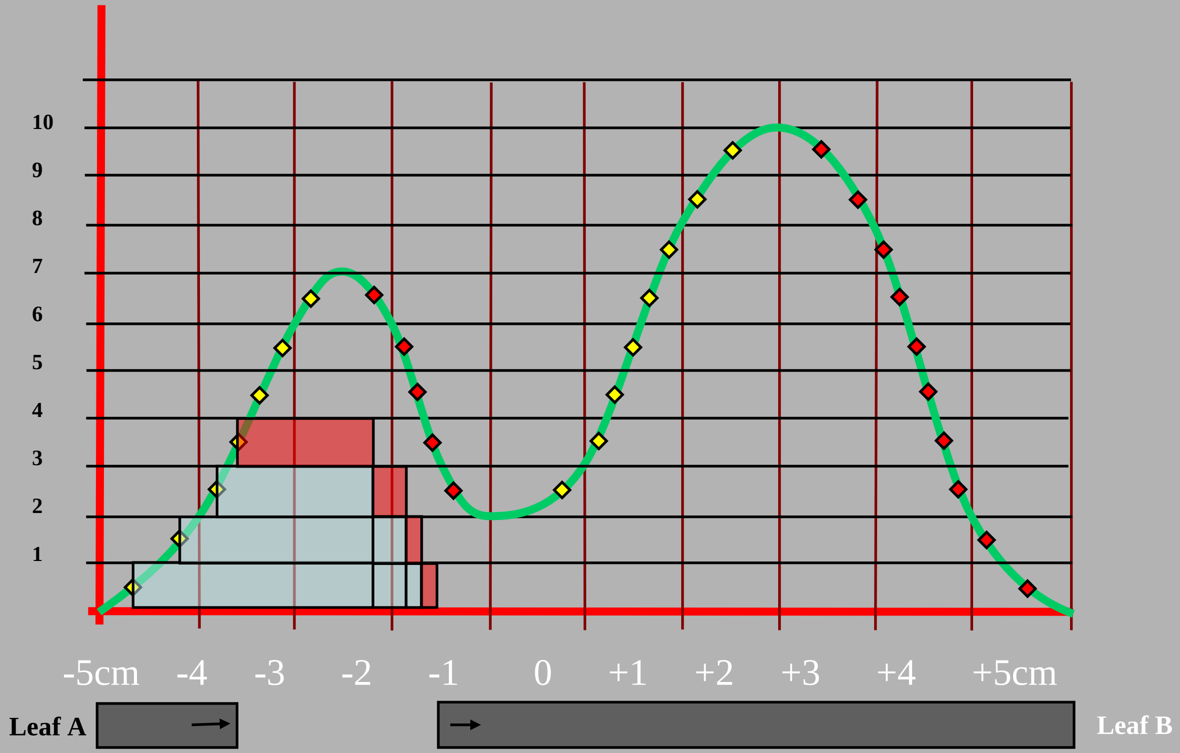
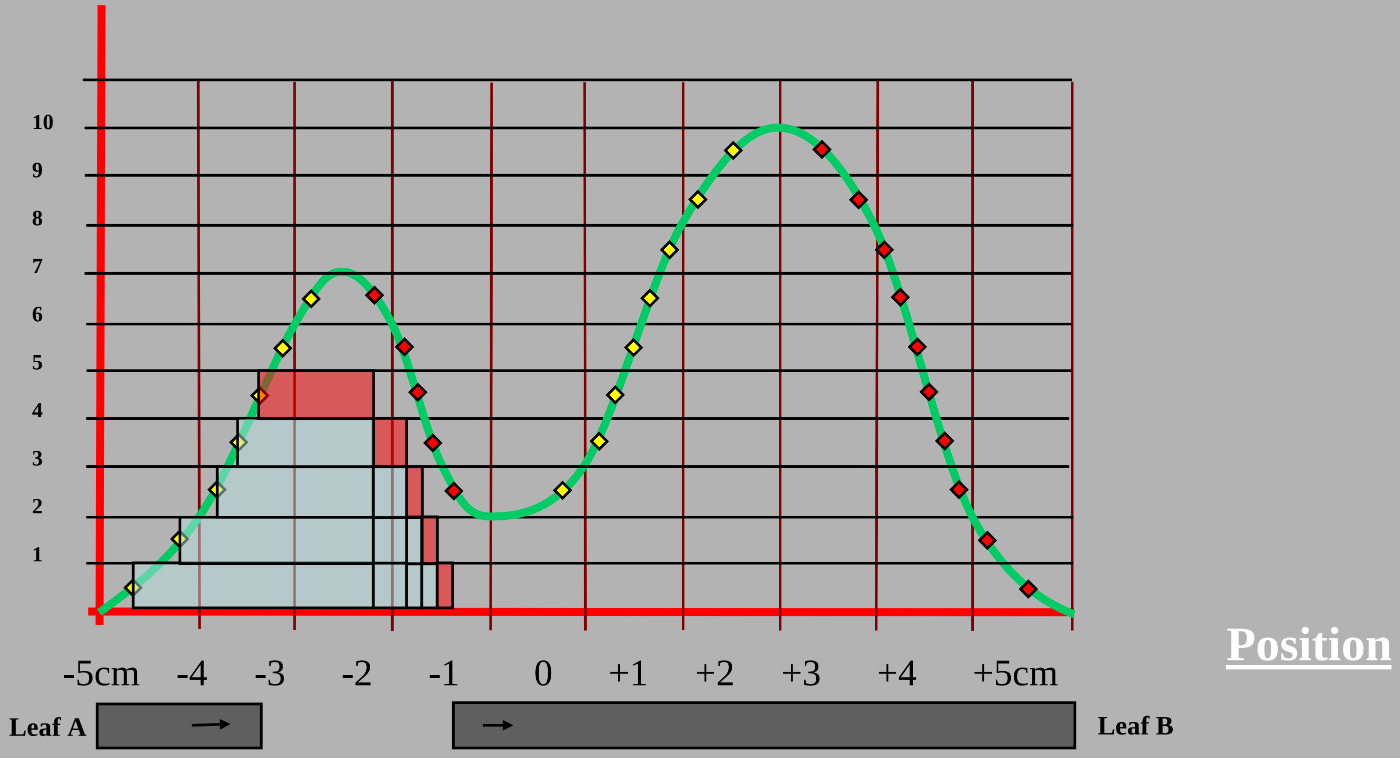
+5cm
Position
Leaf A
Leaf B




**Position**



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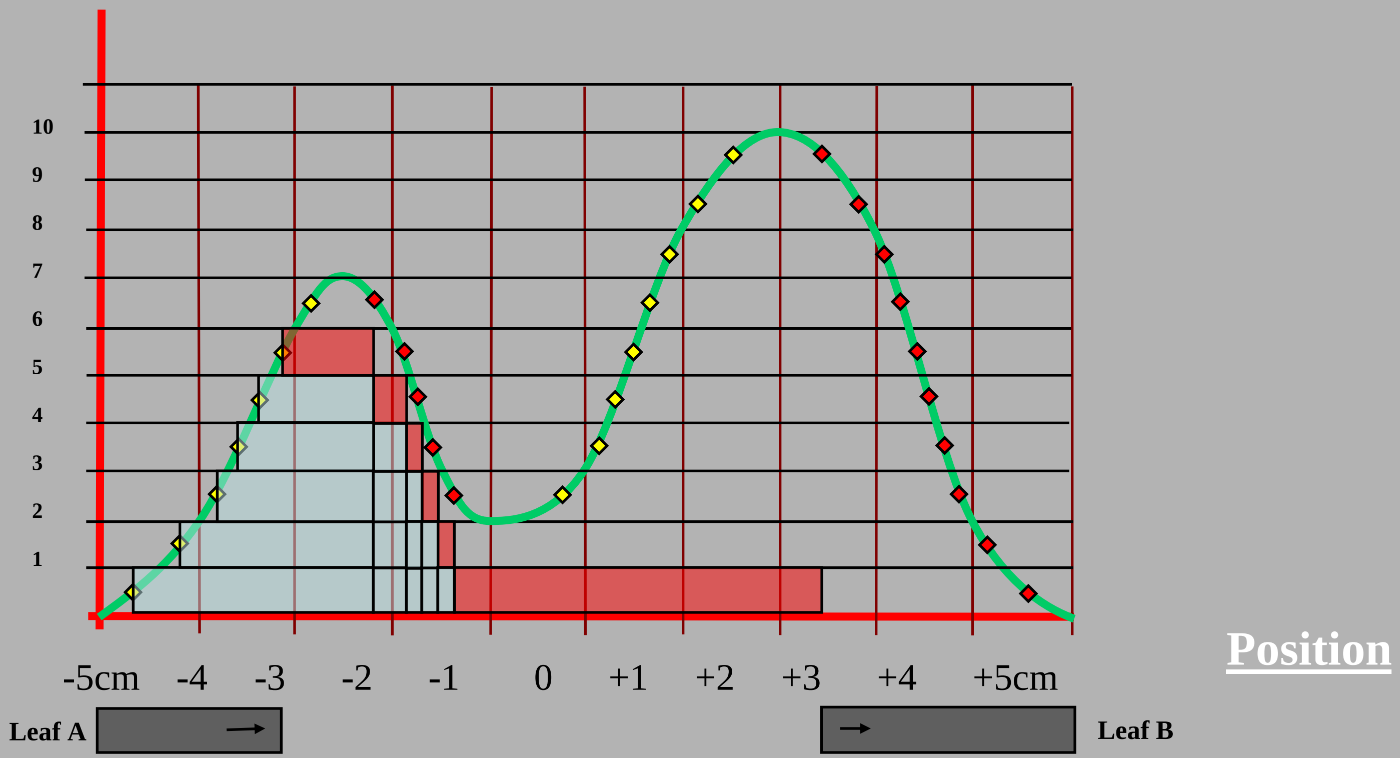
+5cm
Position
Leaf A
Leaf B



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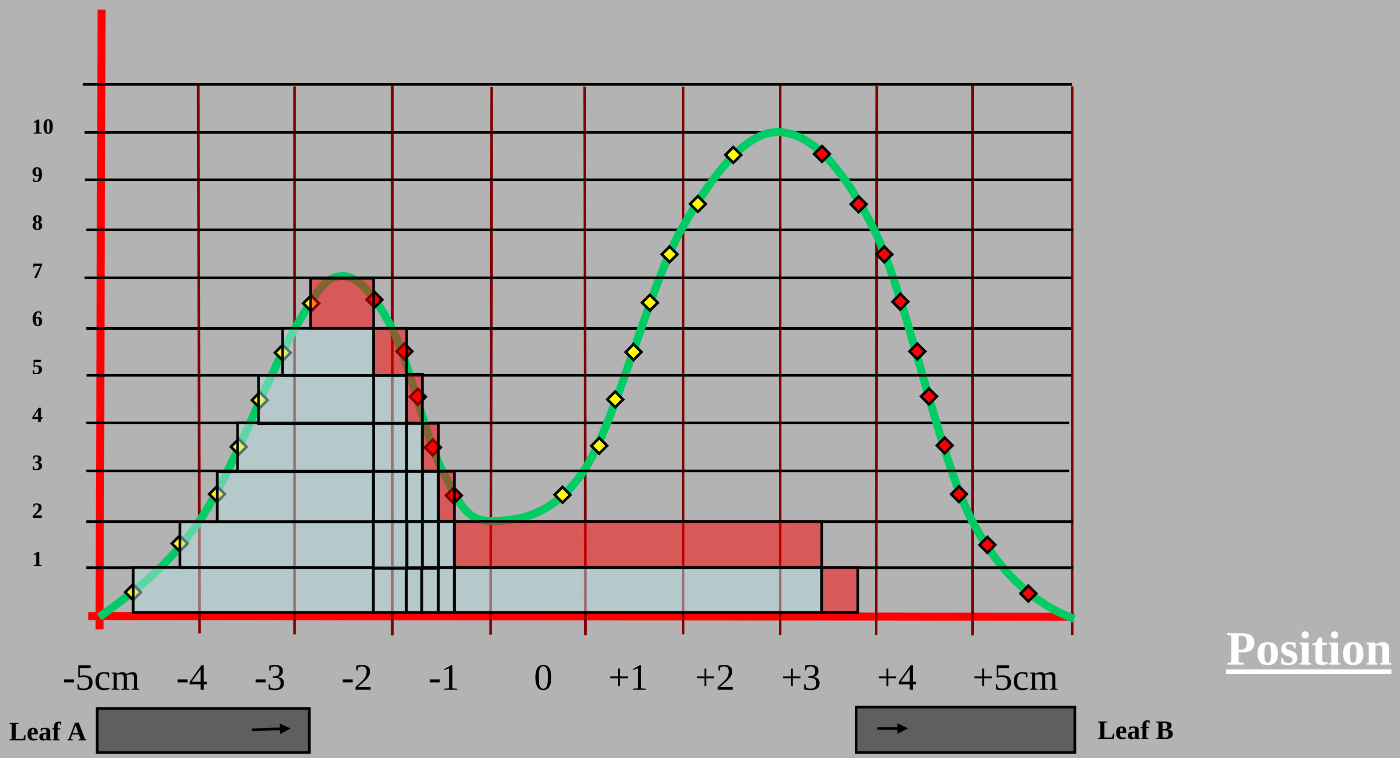
+5cm
Position
Leaf A
Leaf B



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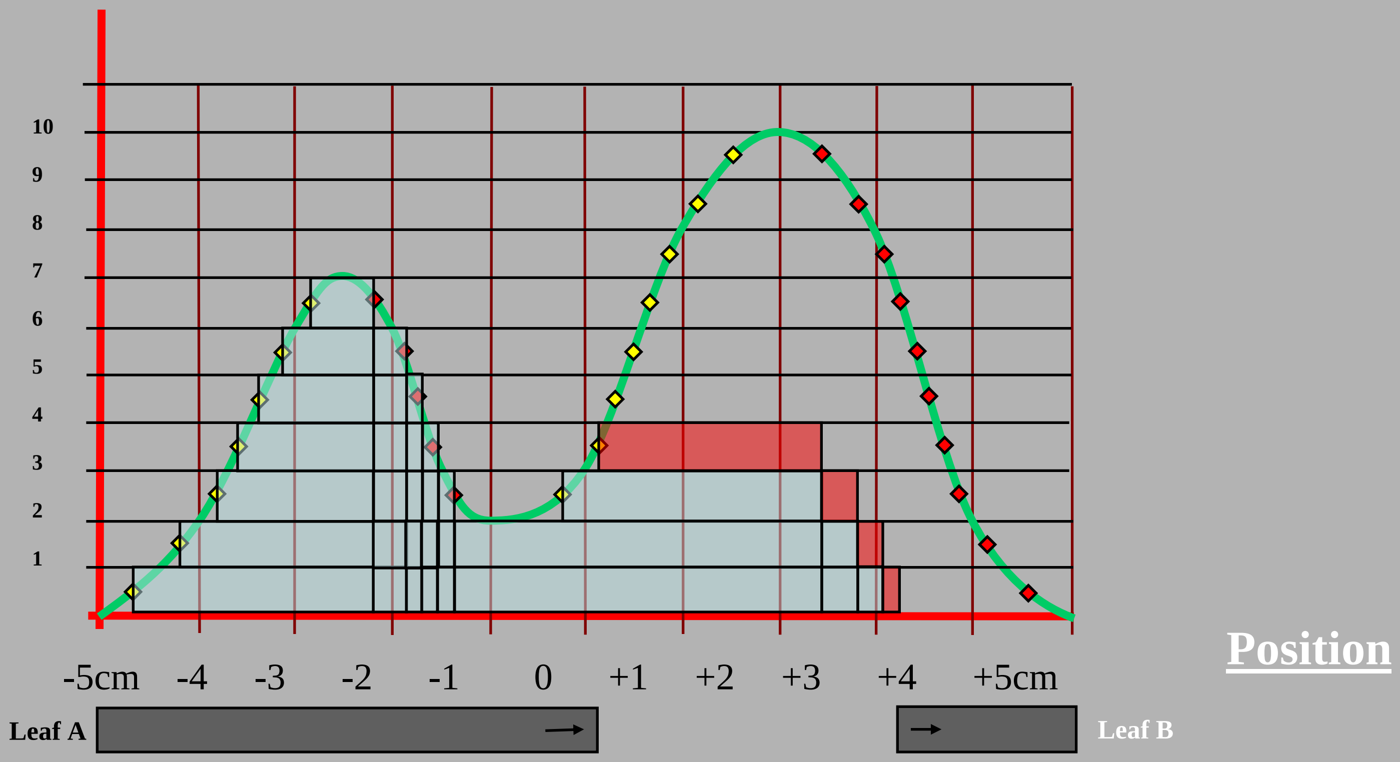
Position
Leaf A
Leaf B



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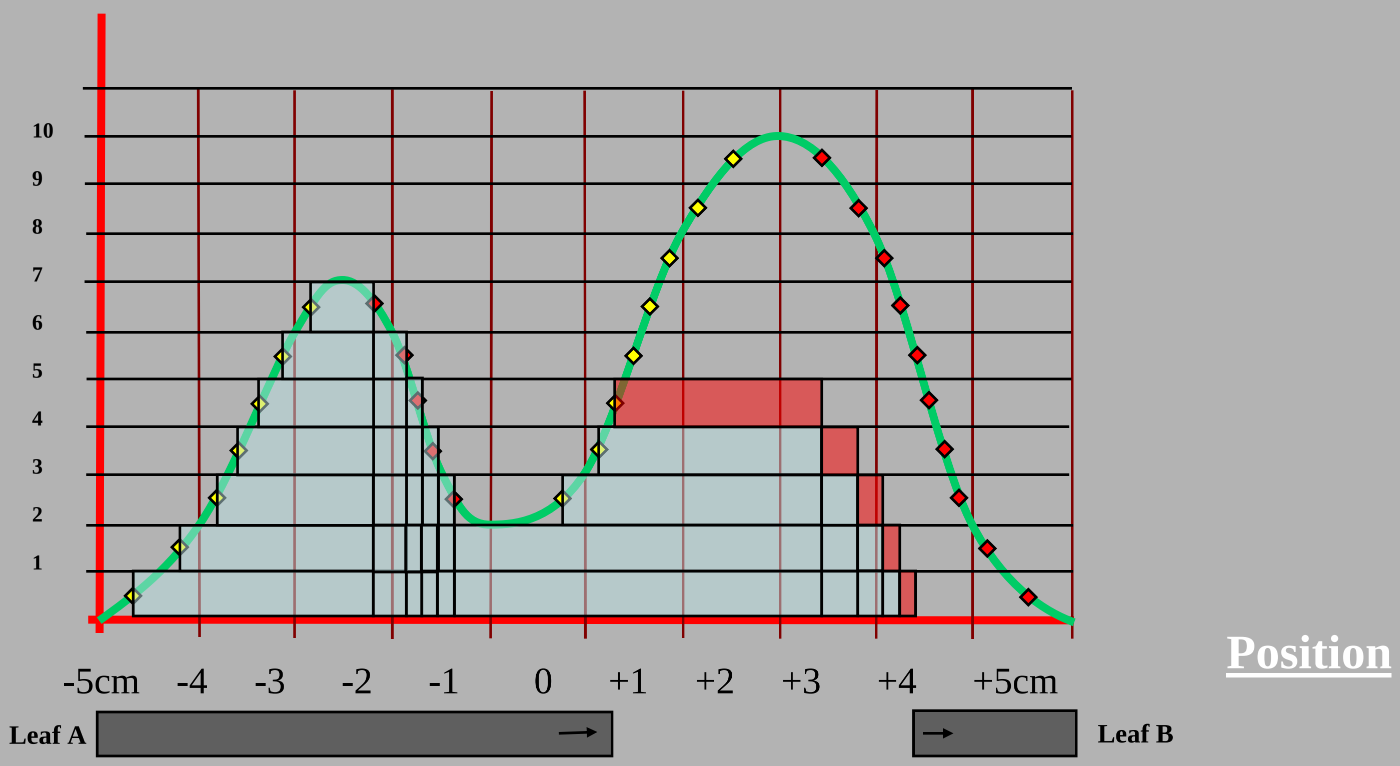
+5cm
Position
Leaf A
Leaf B



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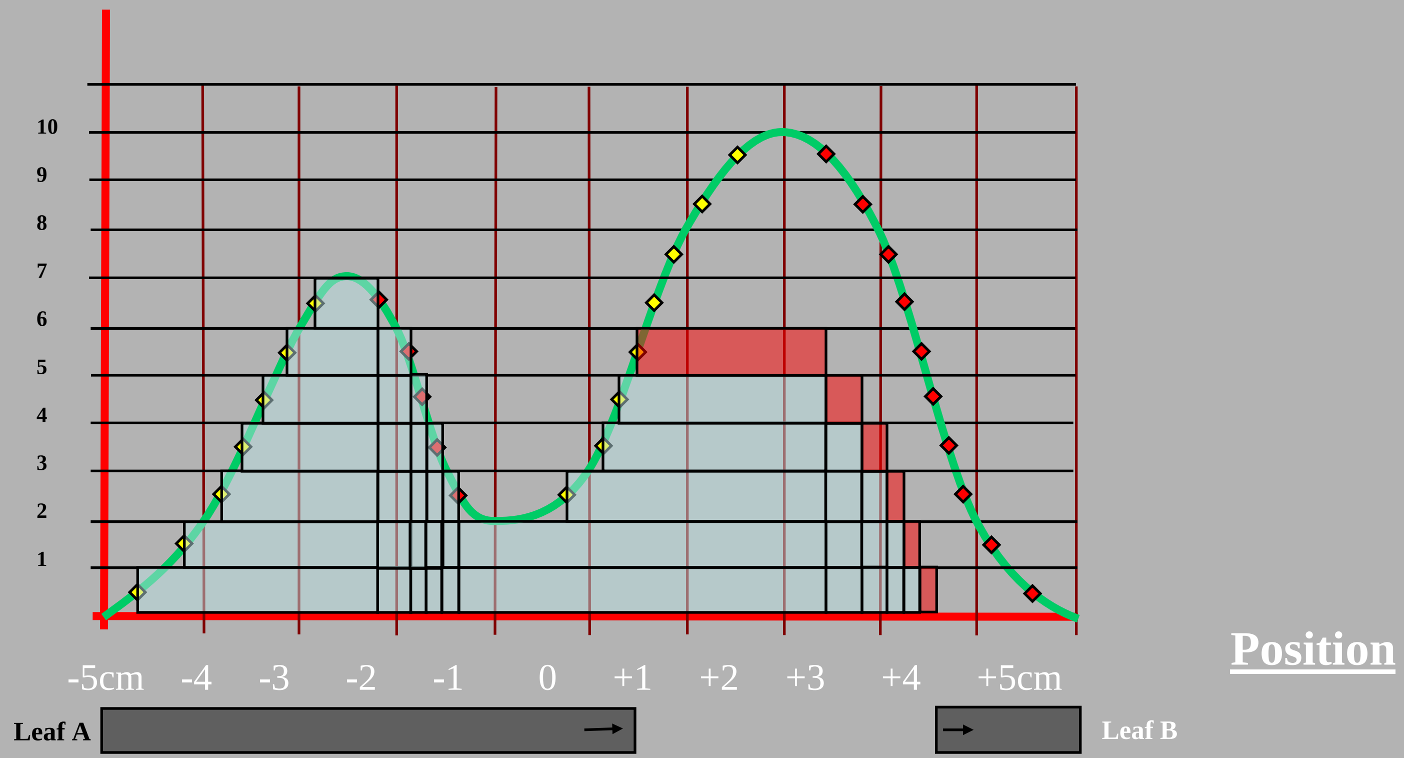
Position
Leaf A
Leaf B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-1
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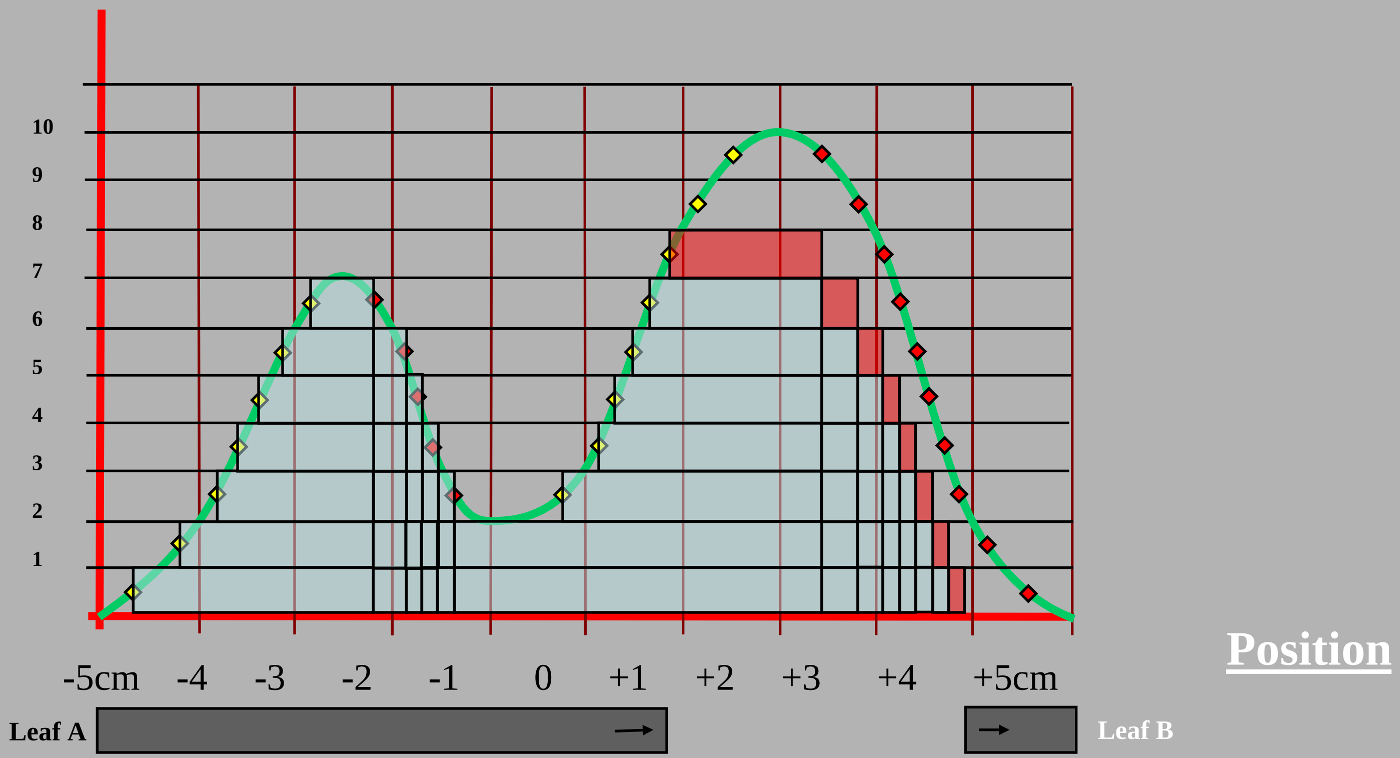
+1
+2
+3
+4
+5cm
Position
Leaf A
Leaf B



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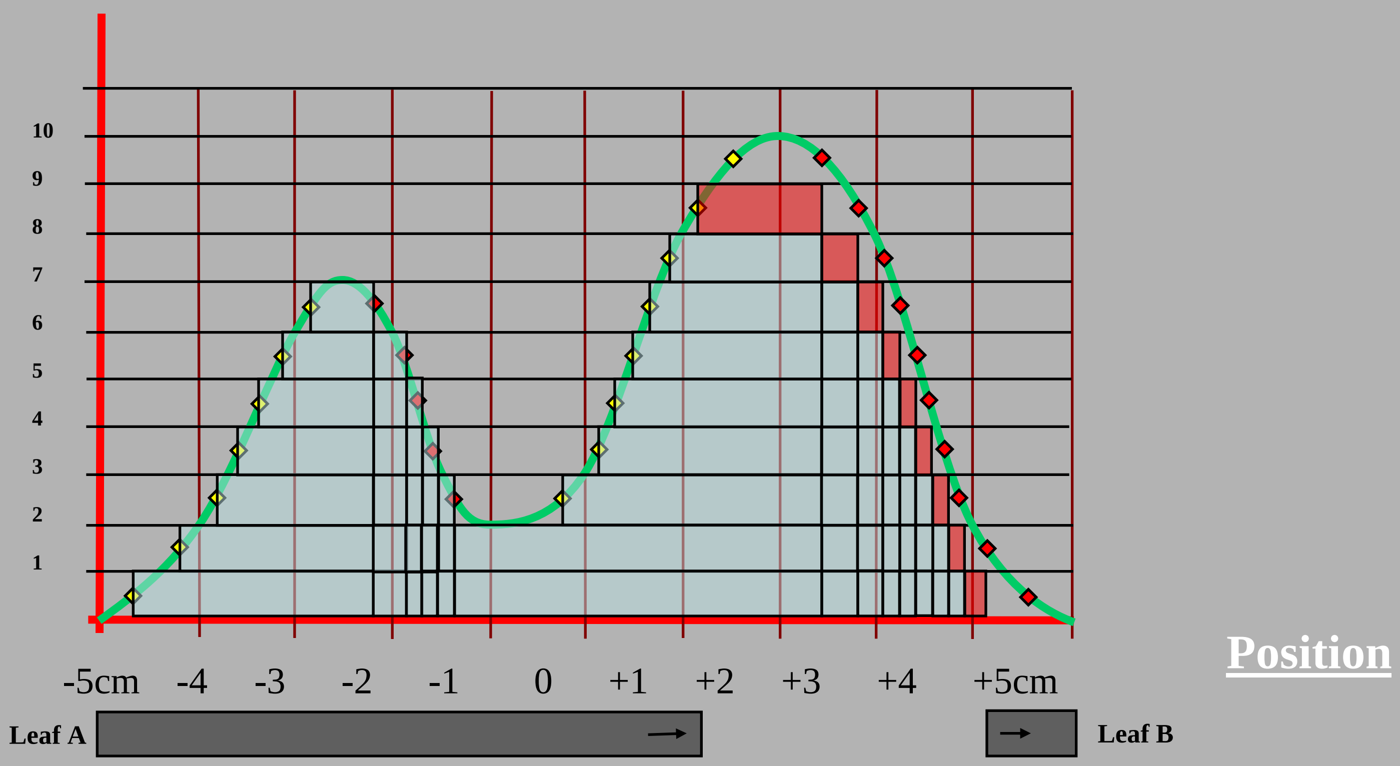
Position
Leaf A
Leaf B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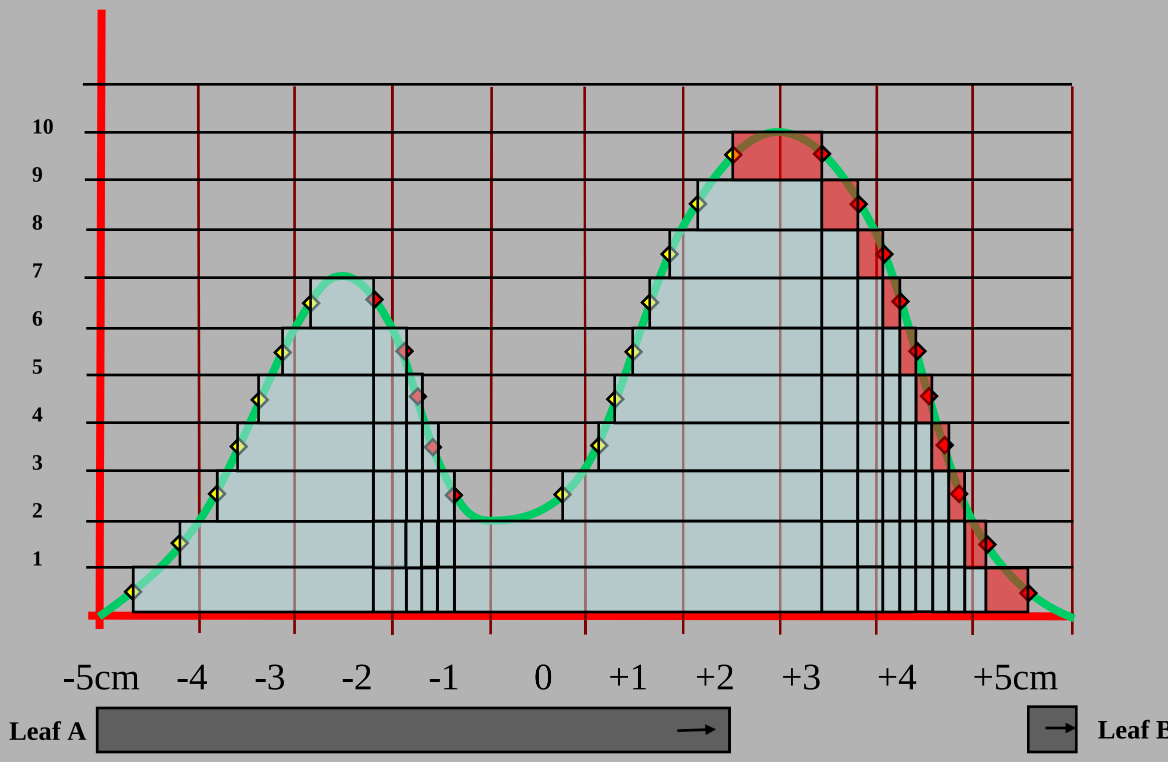
Position
Leaf A
Leaf B



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-5cm
-4
-3
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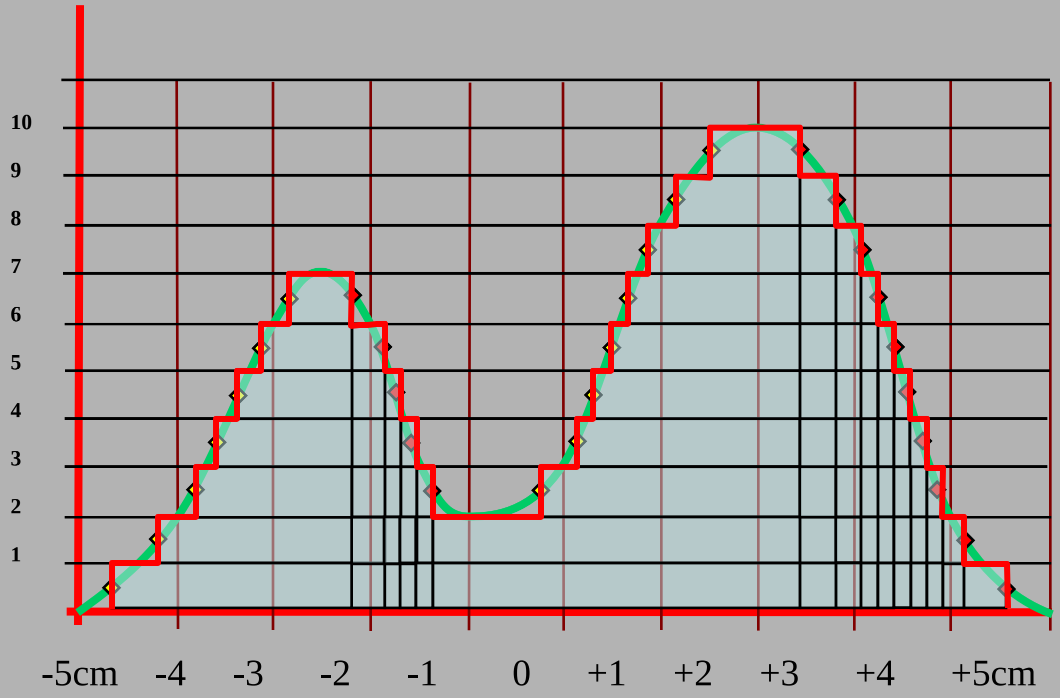
-1
0
+1
+2
+3
+4
+5cm
Leaf A
Leaf B

# Done!

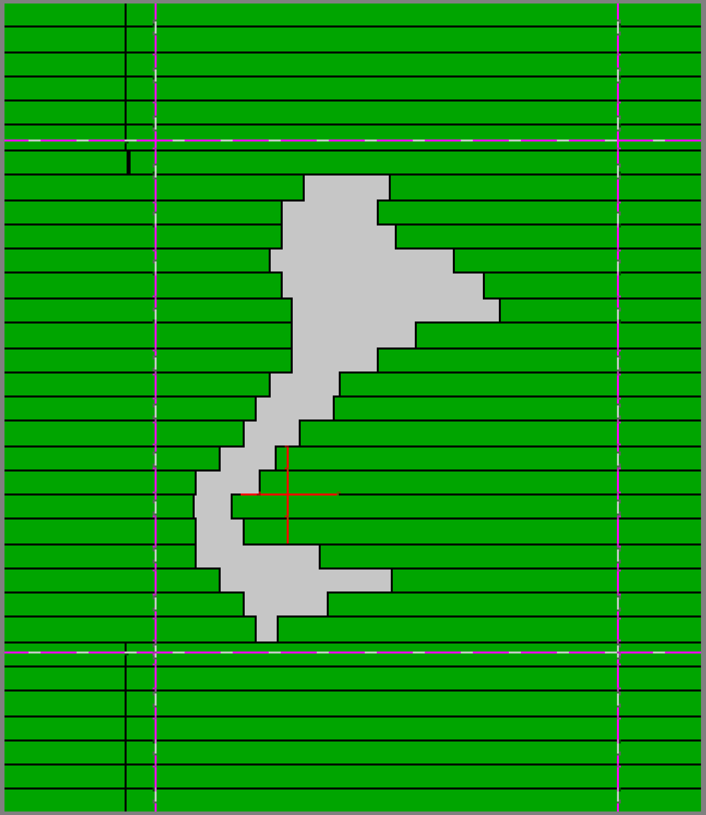


# The Leaf Motion Calculator™

## Creates the control file that orchestrates the dance between the beam control and the motion of the MLC leaves

- **Leaf end shape (geometric penumbra)**
- **Leaf Transmission**
- **"Tongue and Groove" effect**
- **Jaw transmission**

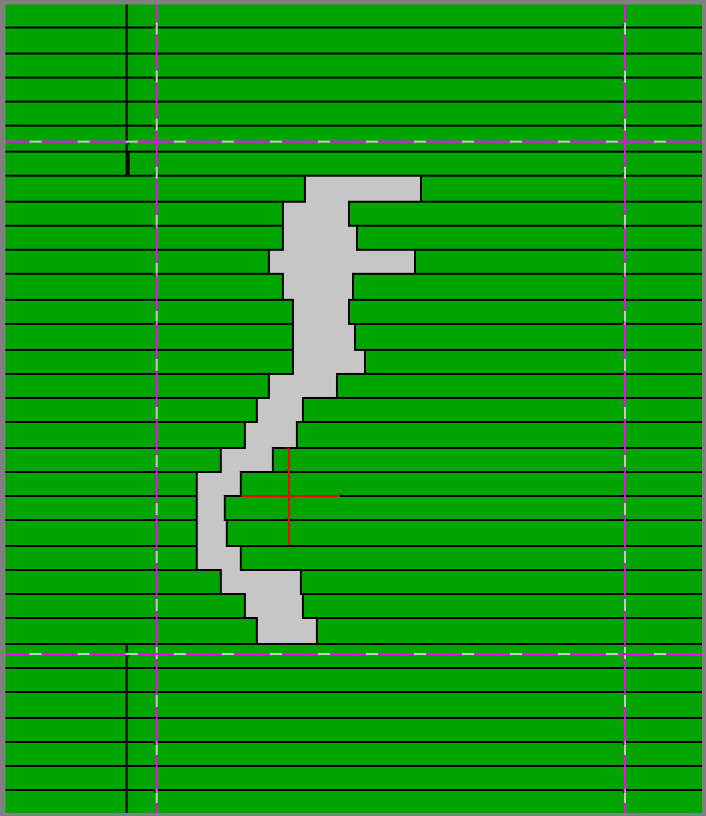
**"Step and Shoot"**



# The Leaf Motion Calculator™

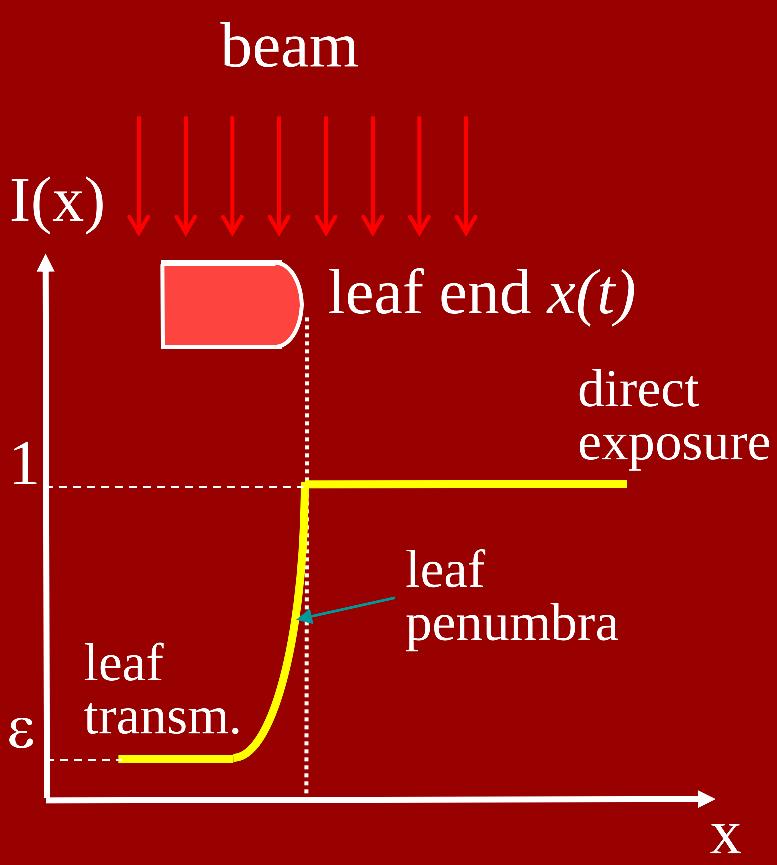
"Sliding Window"

- Leaf end shape (geometric penumbra)
- Leaf Transmission
- "Tongue and Groove" effect
- Jaw transmission
- Leaf speed and acceleration



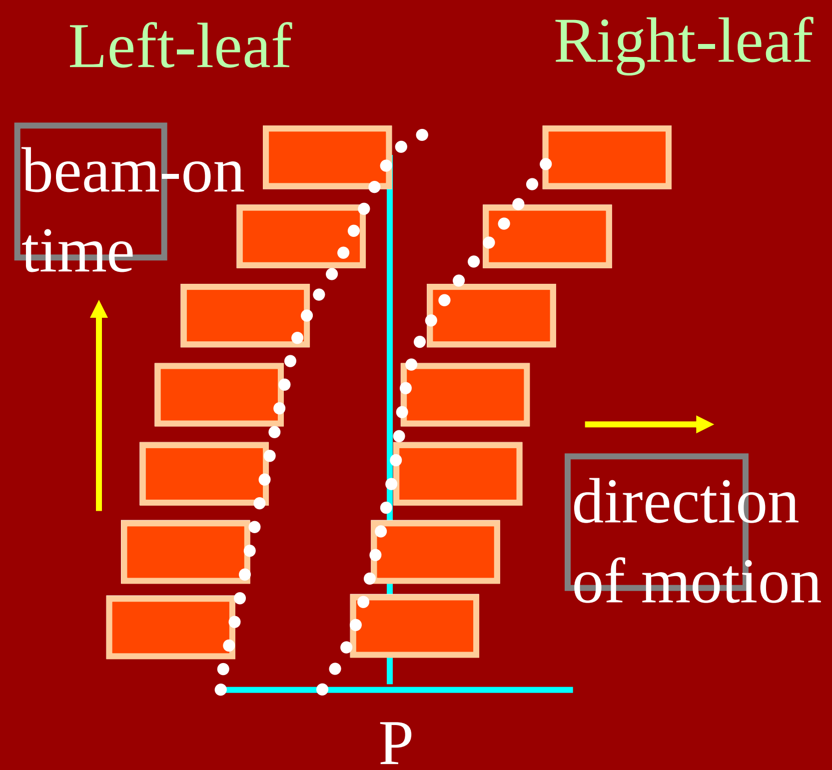
# Effects of Rounded Leaf-End and Leaf Transmission

Intensity as a function of position from the leaf end



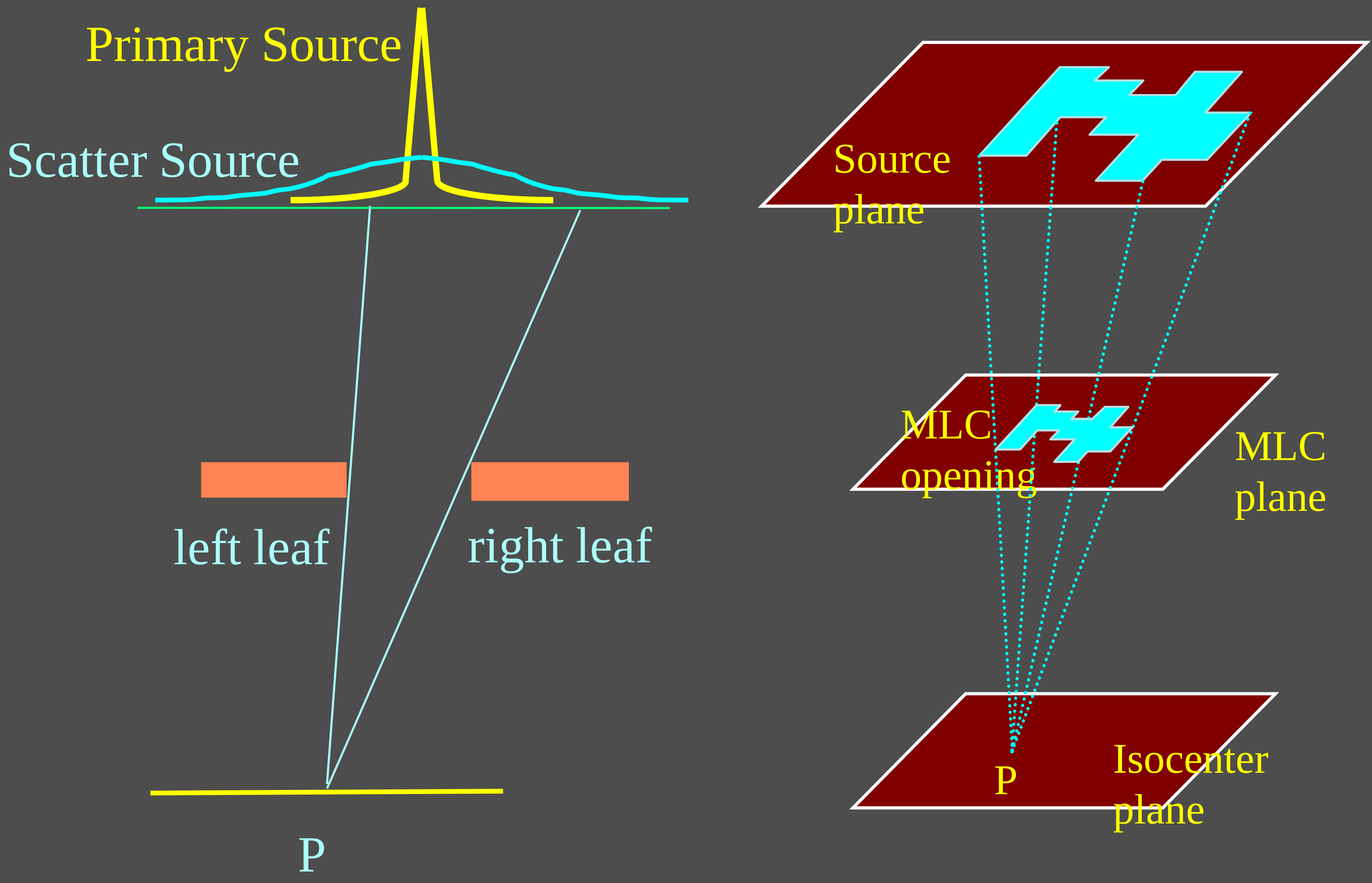

Total intensity at P :

$$\phi_p = \int_{t=0}^{T} I(x_r(t)-p)\, I(p-x_l(t))\, dt$$



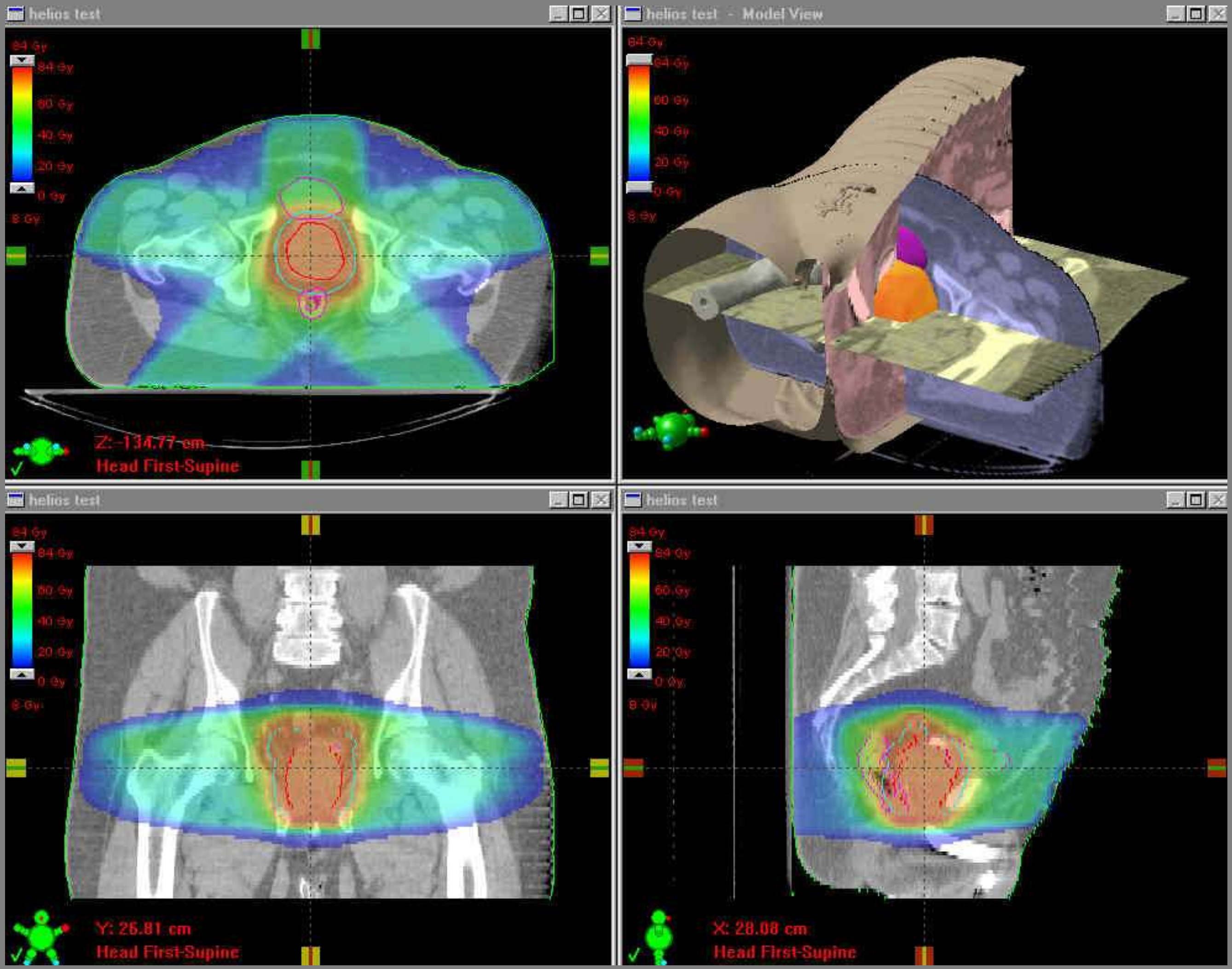
# Variation of Output with Field Shape/Size

*Backprojection to the Source Plane*



# Plan Review: Isodose Distributions

- **Isodose distributions are reviewed in axial, sagittal and transverse displays.**
- ***The same as you would for a 3-D plan, but many more structures and details***



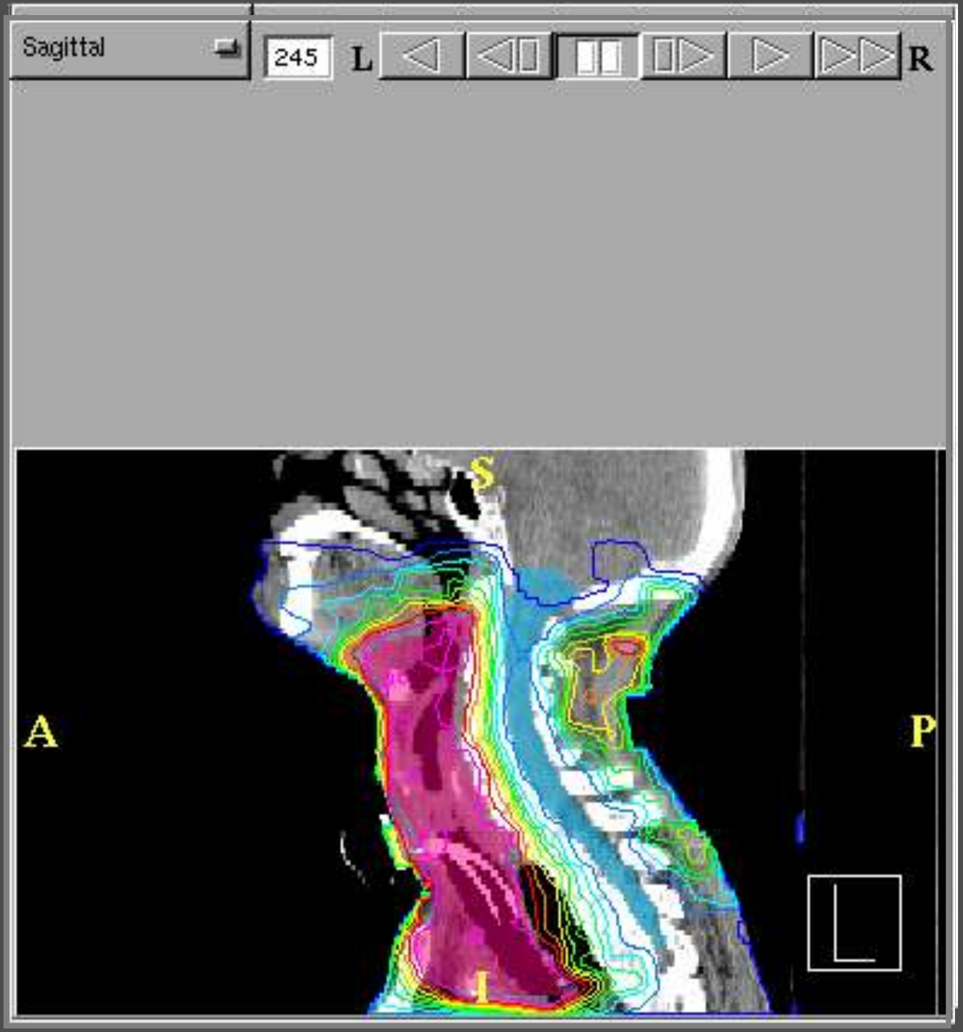
# Plan Review: Isodose Distributions

**Isodose distributions are reviewed in axial, sagittal and transverse displays.**

- ***The same as you would for a 3-D plan, but much more detail of complex structures and dose levels***

**Isodose lines in the figures are 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%.**

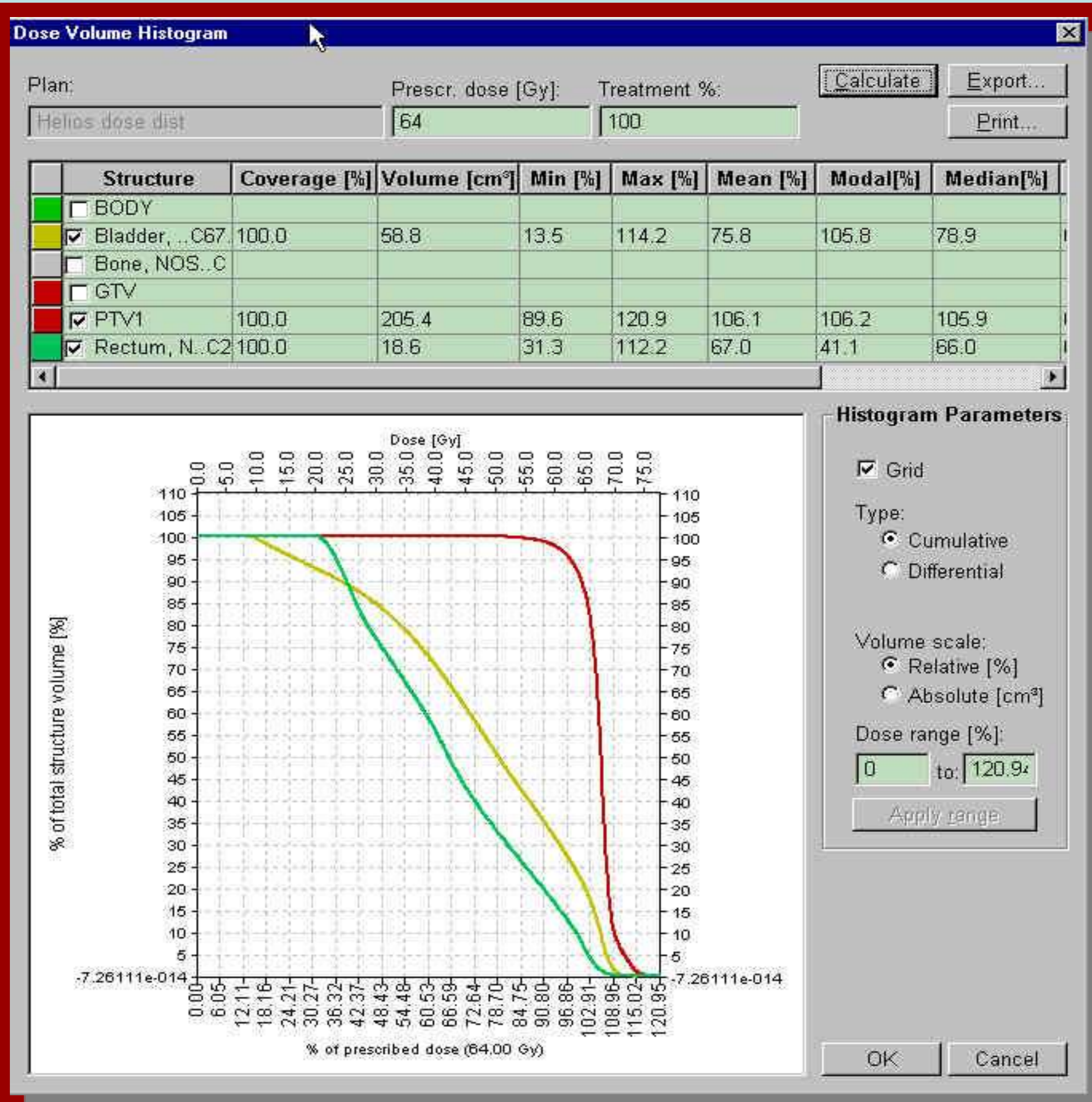
**(Click the mouse to page through isodose images.)**



# Plan Review: Dose Volume Histograms

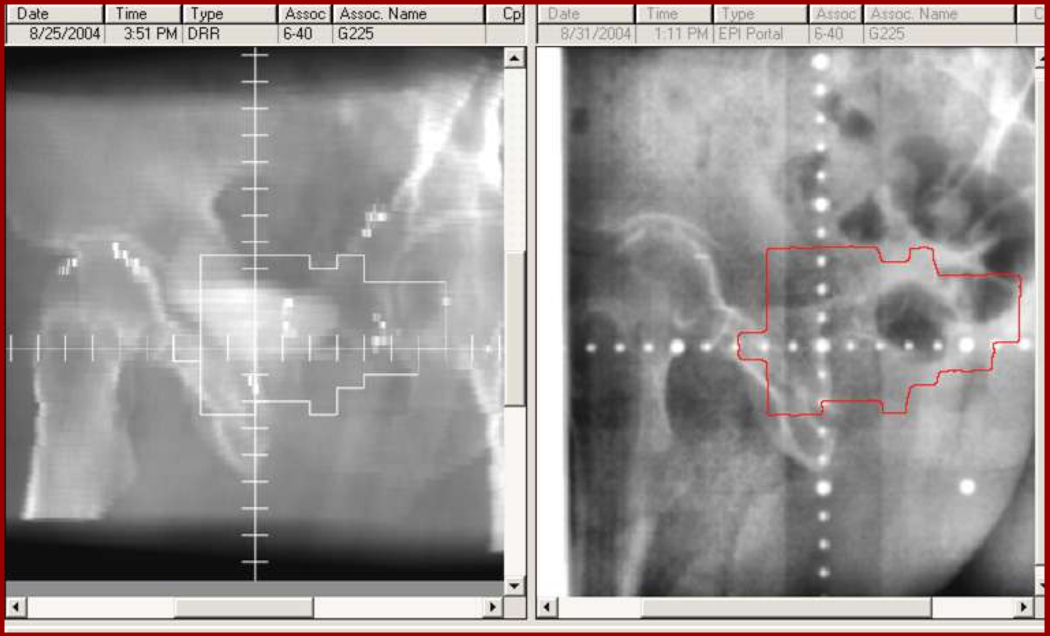
- **Dose Volume Histograms of the target and critical structures are reviewed**

- ***The same as you would for a 3-D plan, but more structures***



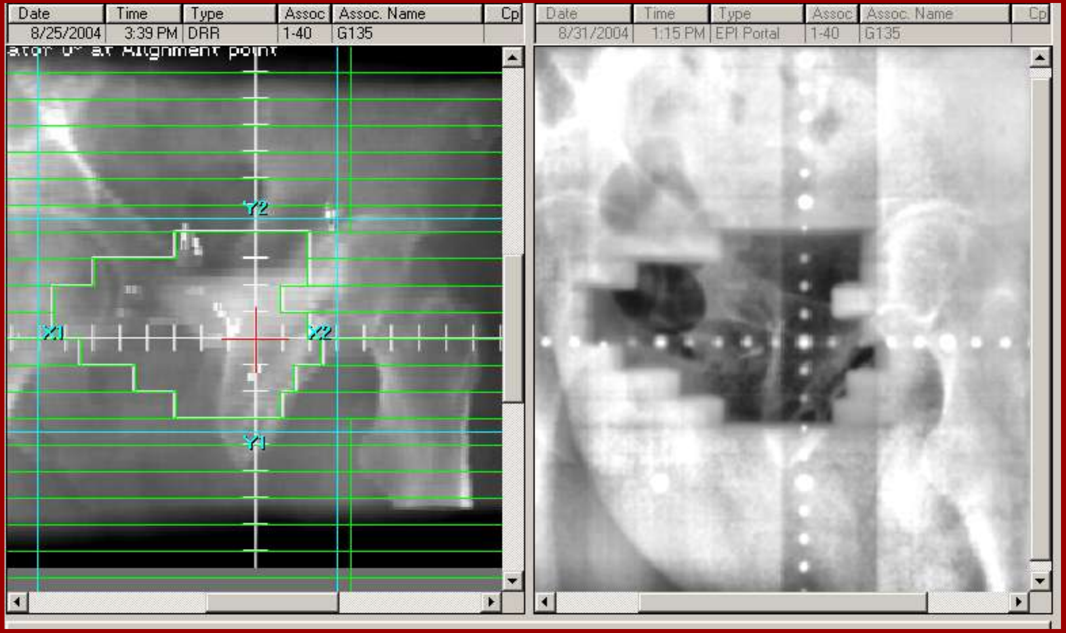
# Do We Deliver the Dose Distribution that we calculated ?

- Patient specific Quality Assurance
  - Distribution of radiation applied to a phantom
  - Measurements and analysis of individual fields
  - Performance of the d-MLC




*How do we know if the dose is delivered to the right place… and does it cover the target?*

DRR with planned aperture (left) is compared with the outline of the exposed port (CIAO-on the right) obtained with the portal imager




MLC position displayed on DRR has to match the planned aperture (left).

Portal image of the exposed port (CIAO) on the right

# Do We Deliver the Correct Dose Distribution for Treatment Every Time ?

- Associate the d-MLC files to the fields in the Record and Verify system
- Verify start positions for each field
- Periodic QA of the d-MLC
- Audit the d-MLC motion history for the treatment

# Do We Deliver the Same Treatment Every Time ?

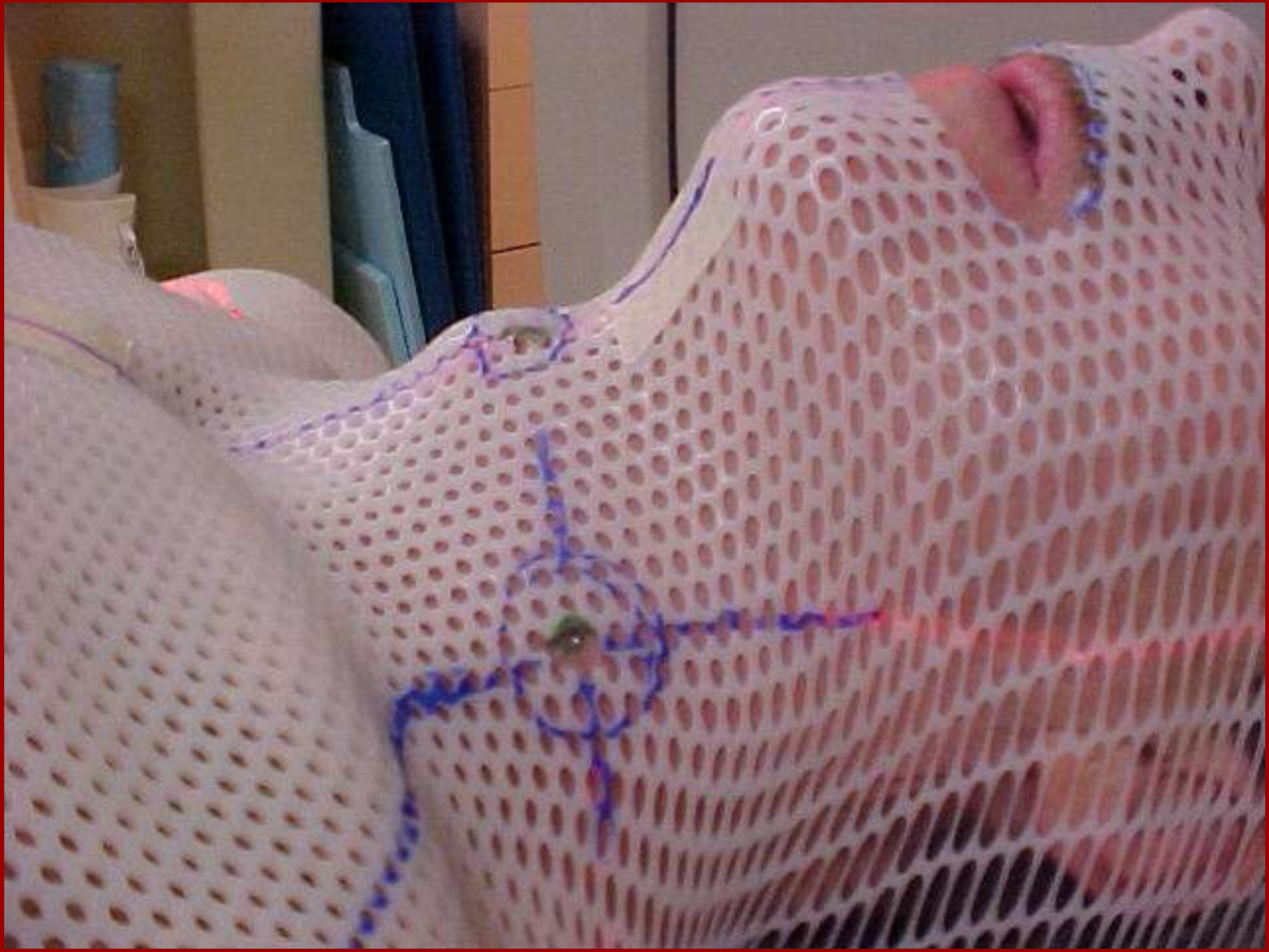
With an 80 leaf MLC,there are about 2,000 parameters and 15,000 leaf positions per day, that have to be "just right"….
…every day.

Record and Verify systems should be an integral part of IMRT delivery !

# Targeting Accuracy and Localization

- Targets Move
  - Patient positioning
  - Limits on delivery system
- Implication:
  - Increased risk of complications seen with dose escalation
- SOLUTIONS
  - Minimize Uncertainty in Target Organ Location, perhaps on a daily basis
  - Use Image guided localization of the target or a reliable surrogate
  - Use gated beam delivery

# Immobilization is only a part of the solution



# Summary

- Advanced imaging, planning and delivery tools, such as 3D TPS, ITP and IMRT, allow the creation of highly conformal dose distributions
- The overall treatment is only as good as the ability to know where the target and the sensitive structures are at all times
- Margins to the target volume should account for uncertainties in localization, for patient repositioning and immobilization and for organ motion.

# The big challenges!

**The better we can "fix" the target and be sure where we deliver the dose, the more we can reduce the margin required to convert CTV to PTV, and spare dose to sensitive structures!**

## However…

**The tighter the dose distribution, the better we must know where the target is at all times!**

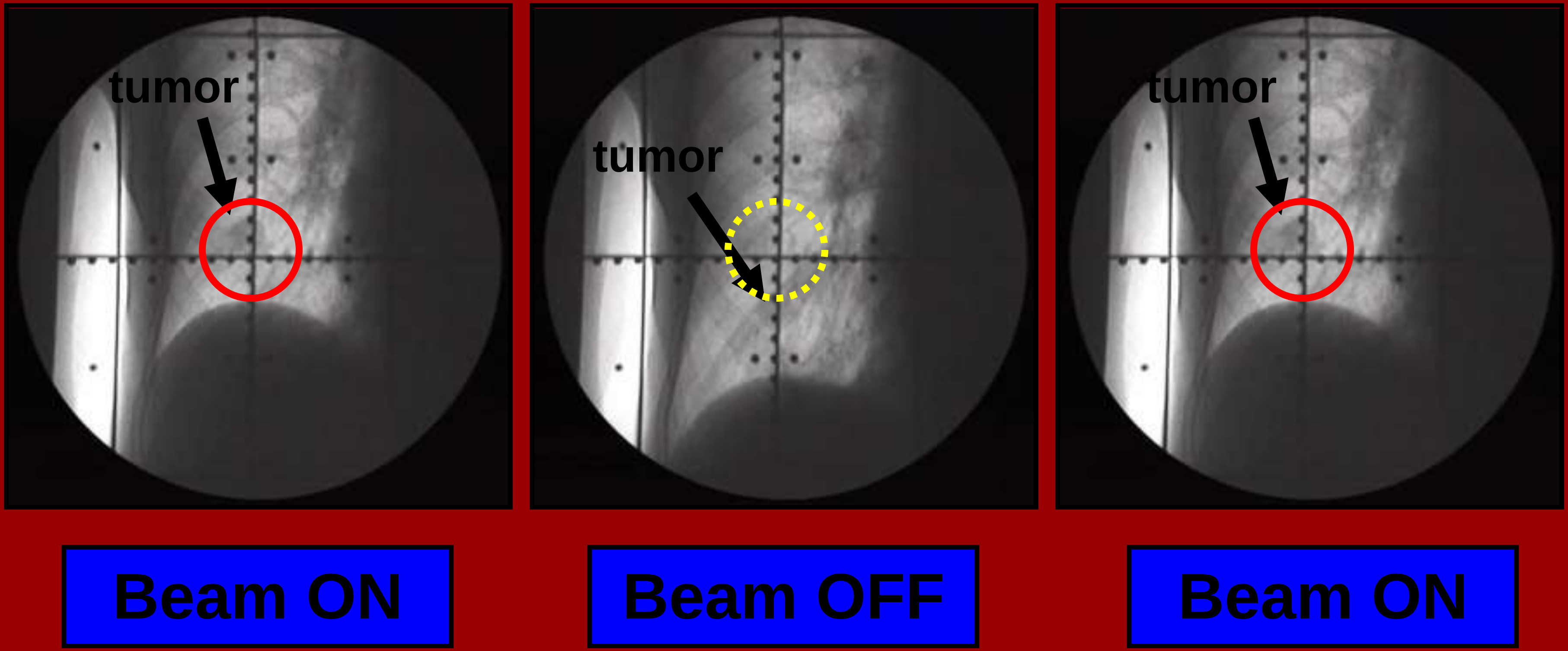
# So, what else…

- Reduction of localization uncertainties
- Definition (Expansion?) of CTV based on function
- Plan Optimization based on TCP and NTCP data
- Data on partial volume tolerances is needed
- Smoother integration of functions and subsystems
- On-line dose verification with EPID's
- Image based patient/target positioning (IGRT) (e.g.:EPID, US or IR surrogate based corrections, Beam gating, CBCT), with or without On-line correction
- Adaptive RadioTherapy (ART)
- Monte Carlo based dose calculation

# *Synchronization of radiation treatment with respiration*

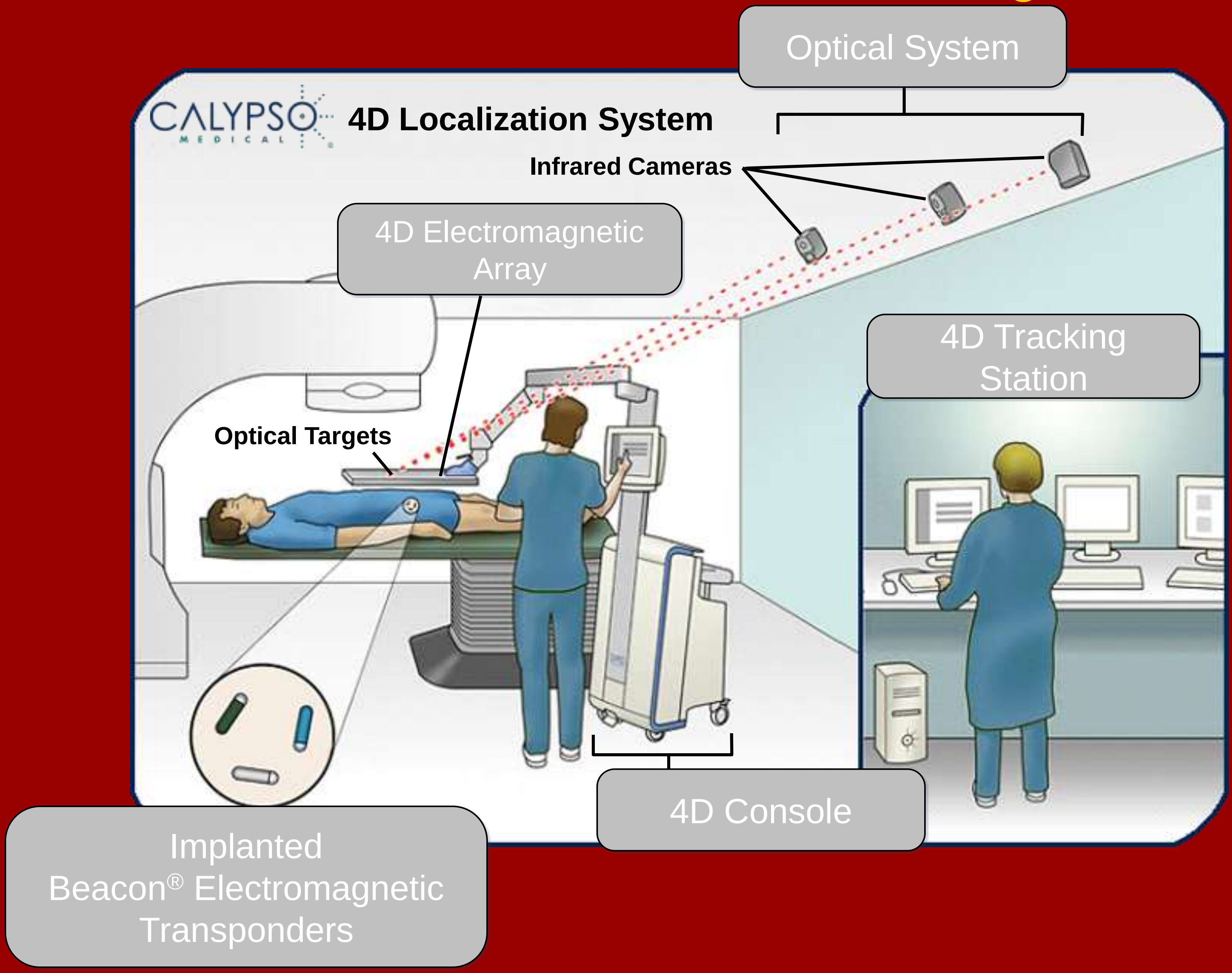
- *An implicit assumption is that the tumor and organ motion is correlated to respiration motion.*
- *Motion range of up to 3 cm with respiration possible*
  - *PTV increases significantly with motion*
  - *Increased PTV limits use of radiotherapy for some disease sites*

# *Respiratory gating is ...*




***...synchronizing the radiation beam with the respiratory cycle***

# Localization and 4D Tracking

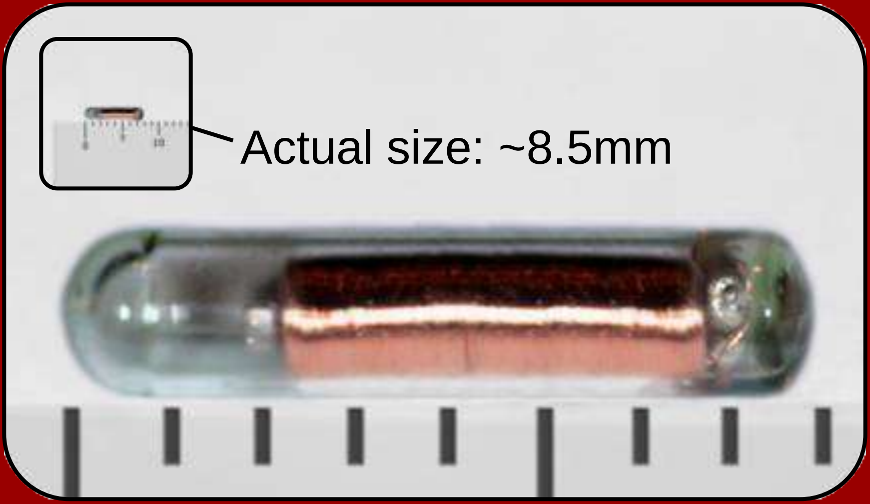


# Radiationless 4D target tracking (Calypso)

## GPS for the Body®

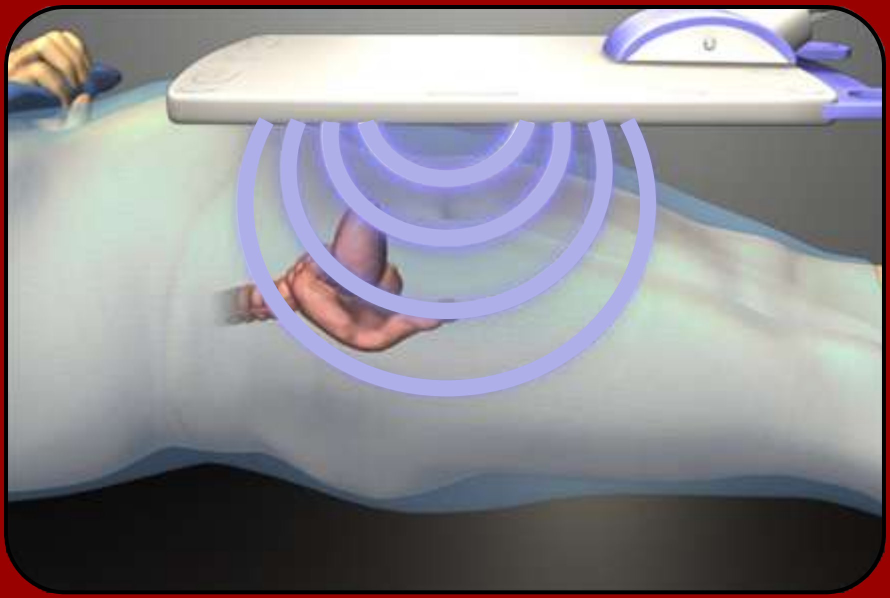
Wireless miniature **Beacon® Electromagnetic Transponders**

Accurate, objective guidance for target localization and continuous, real-time tracking

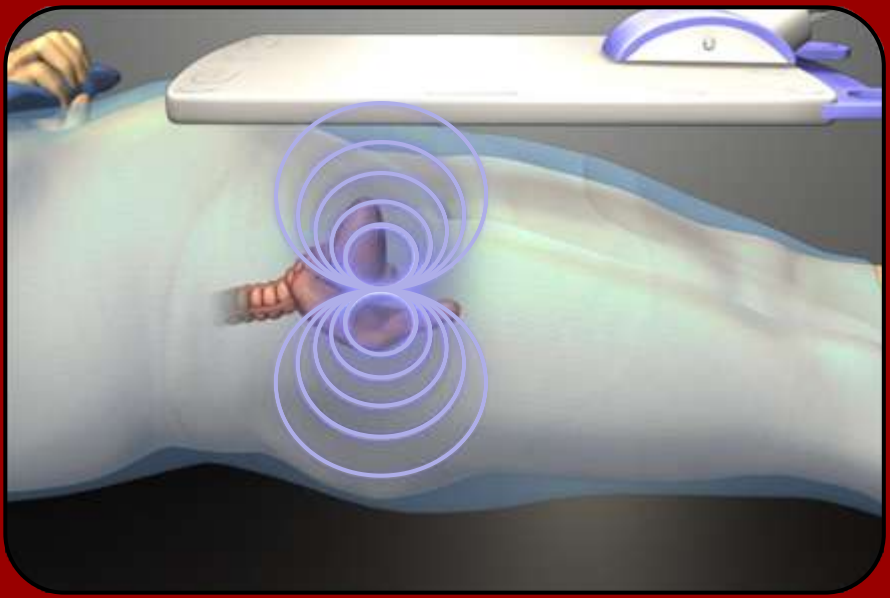



***Beacon® Electromagnetic Transponder***

# Electromagnetics Locate and Track Continuously



**Step 1**



**Step 2**

# 3D Variable Motion