Radiotherapy optimization methods for modulated beams in Monte Carlo treatment planning

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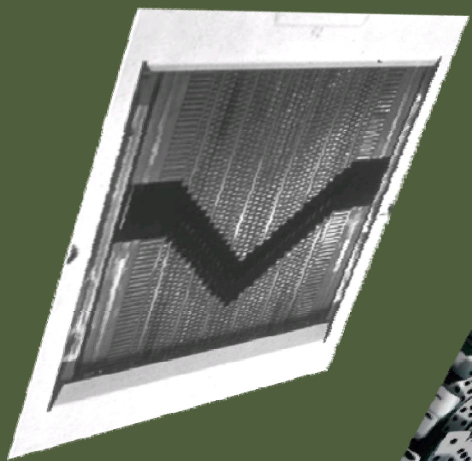
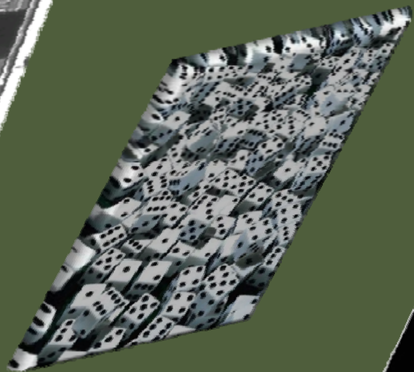
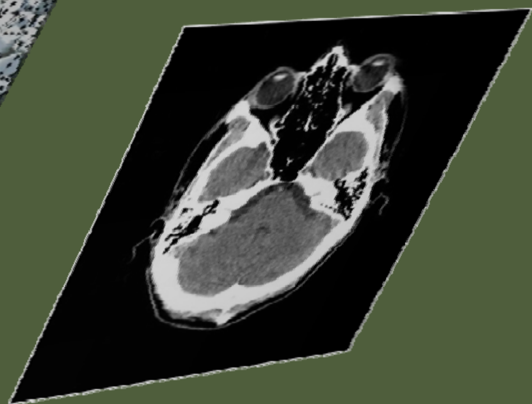
2 Hosp. Univ. Virgen Macarena, Serv. Radiofísica/Radioterapia, Sevilla







ISI Web of Knowledge℠

Radiotherapy Techniques to be used from now on:

Latest 3 years

From the point of view of procedure

- Shaping by MLC.
- Modulation by MLC.
- Collimation device integrated in the planning system.

290 references MLC

From the point of view of Radiation protection

- Less shielding possible for just the necessary MUs (few fields instead of sliding windows).

50 references DAO

From the point of view of the administration

- More treatments with high dose rate.
- Hypofractionation where possible.
- Simultaneous irradiation volumes.

170 references APBI

55 references SIB

Hardware for these techniqes:

- Robust Multileaf collimation device.
- Good positioning system (IGRT).

Software for these techniques:

- A system able to give solutions with the required precision.
- A system with the correct input sources.
- A system able to consider the actual interactions with the collimation devices.
- A system able to consider the inhomogeneities in the dose calculation.

Problems in Radiotherapy (utopian goal: dual objetive):

- Dose calculation in the patient.
- Fluence map for IMRT.
- To find the MLC segments or apertures.

Mathematical solutions:

- Numeric method for dose calculation (Monte Carlo)
- Optimization procedure to find the weights.
- Sequencer to obtain the apertures.

"An accuracy of about 5% in dose delivery is required to effectively treat certain types of cancers and to reduce complications".

ICRU Reports 24 (1976) and 42 (1988)

$$\sigma^2=\sigma^2_{calib}+\sigma^2_{dose}+\sigma^2_{setup}+\sigma^2_{motion}+\dots$$

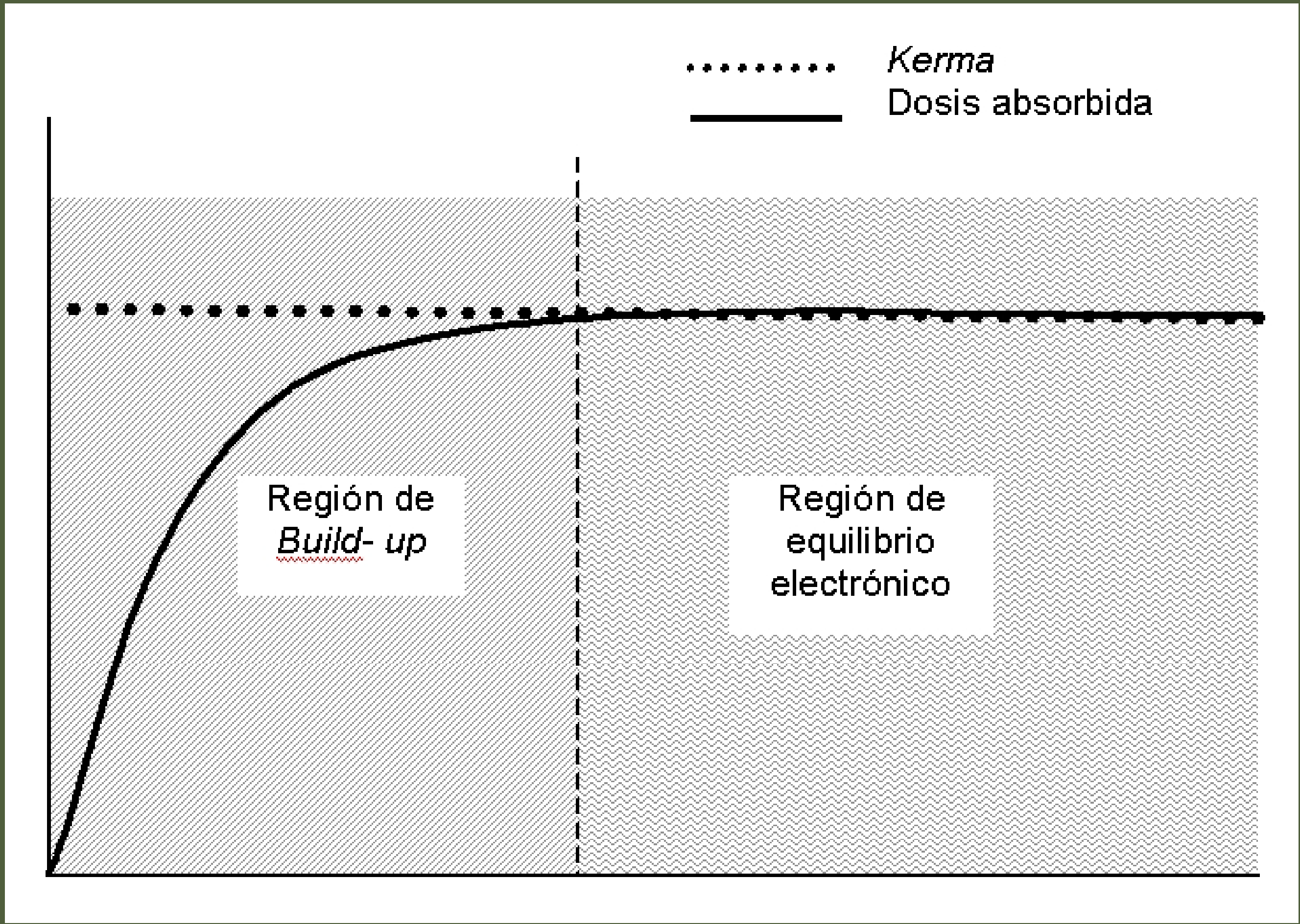
and

$$\sigma \geq 2\sigma_{dose}=5\%$$

then

$$\boldsymbol{\sigma_{dose}=2.5\%}$$

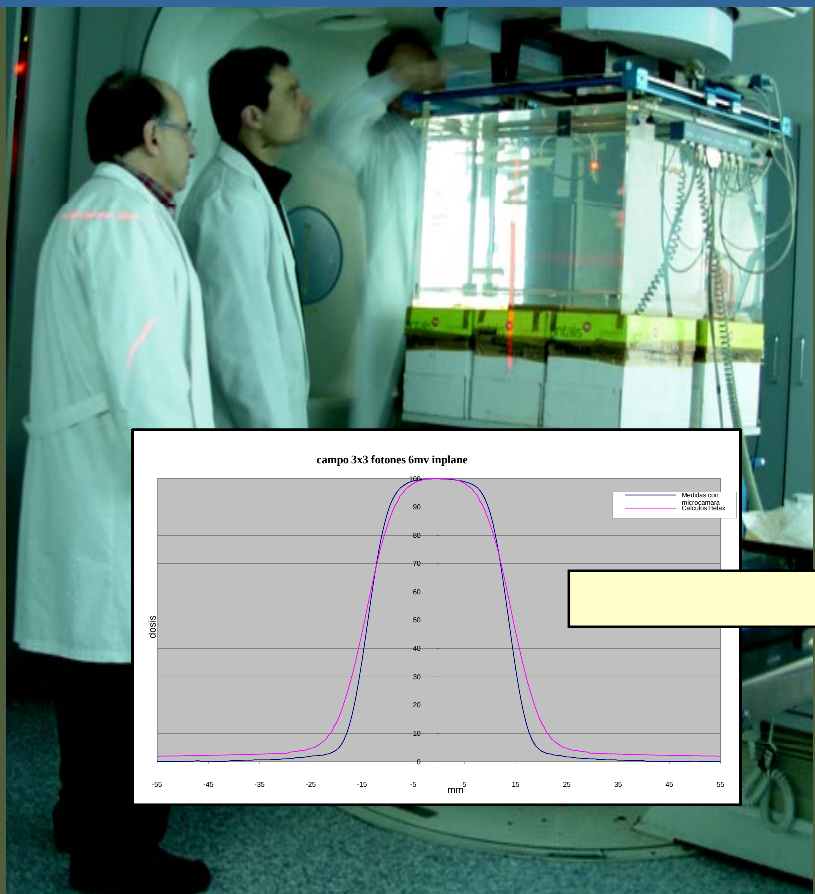
General problem: No local energy deposition

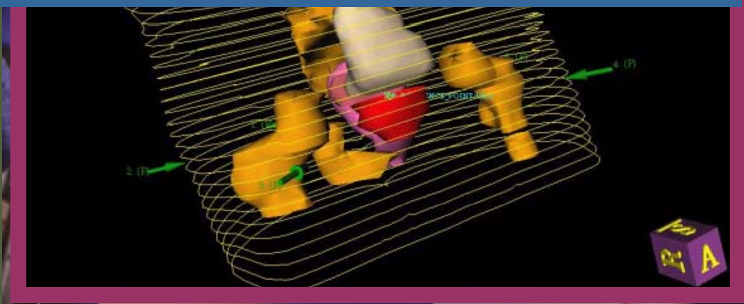


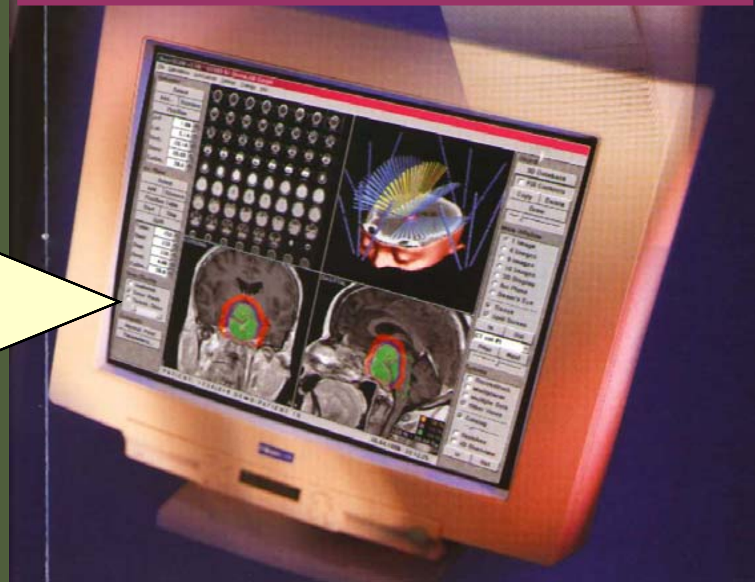
KERMA: Kinetic Energy Released in MAterial

Uncertainty linked to measurements

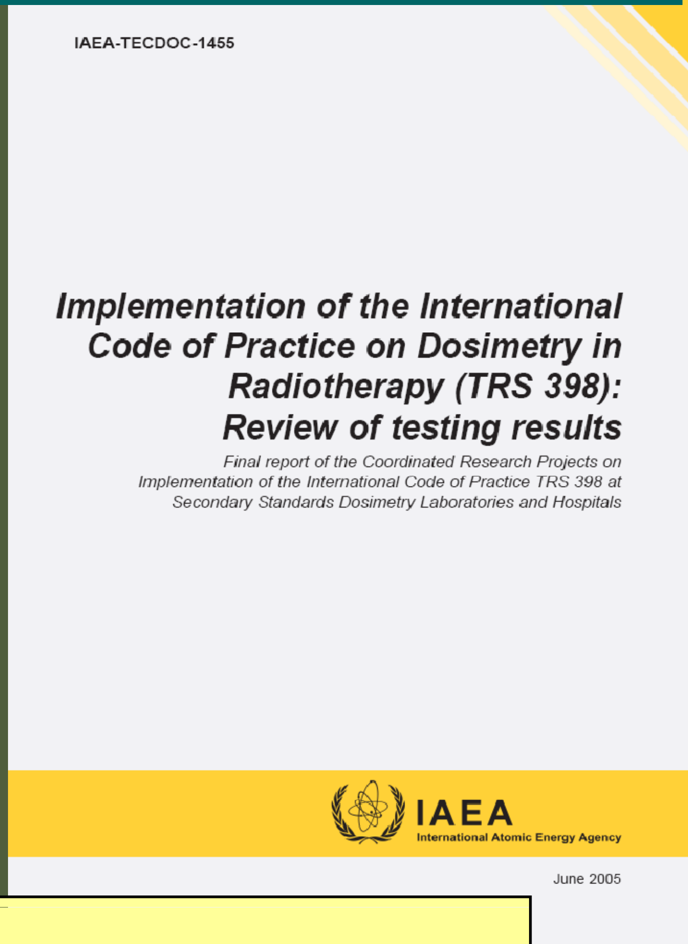
The best analytic algorithm needs experimental measurements for the relative dose in a conventional TPS







What about a protocol for non standard fields (IMRT, Radiosurgery) ?... Capote et al. IAEA



IAEA-TECDOC-1455

Implementation of the International Code of Practice on Dosimetry in Radiotherapy (TRS 398): Review of testing results

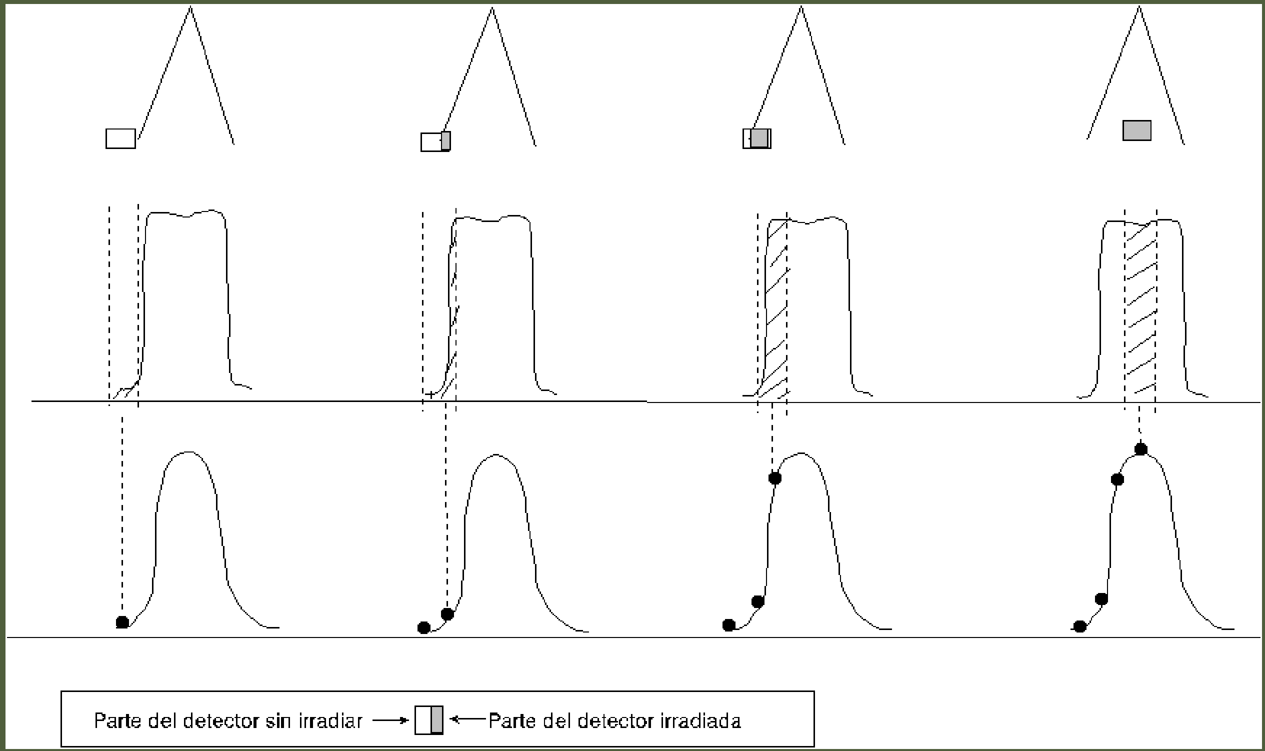
Final report of the Coordinated Research Projects on Implementation of the International Code of Practice TRS 398 at Secondary Standards Dosimetry Laboratories and Hospitals

IAEA
International Atomic Energy Agency

June 2005

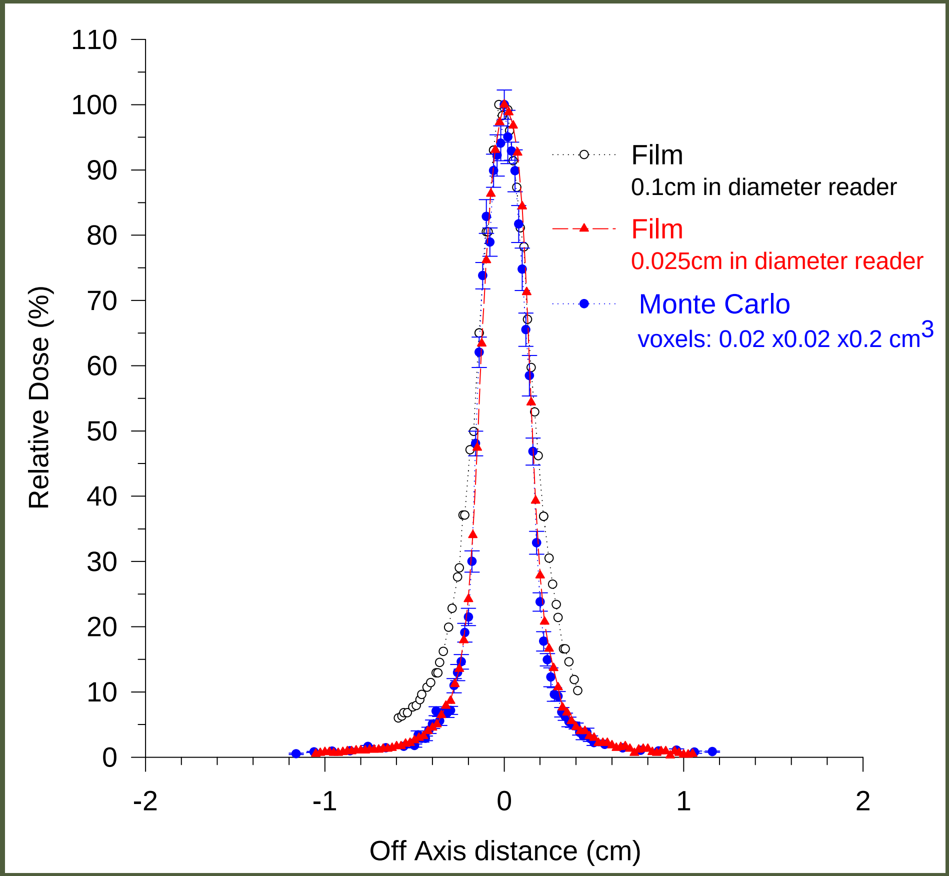
$$D_{water} = D_{air} \cdot s_{w,air} \cdot p_{cav} \cdot p_{dis} \cdot p_{wall} \cdot p_{cel}$$

The smaller detector is too big to measure penumbra of small fields



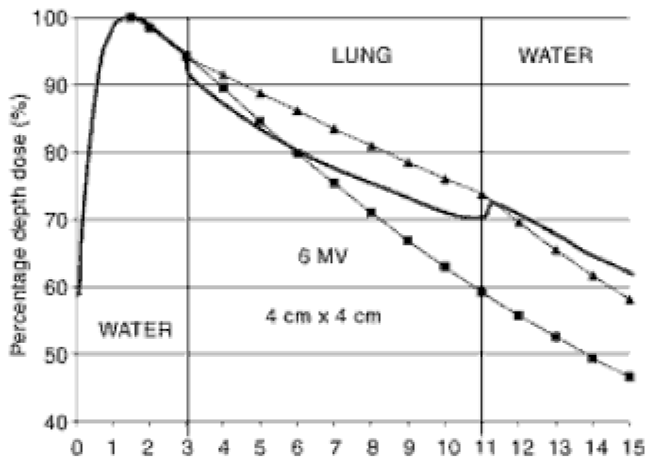
Resolution? ⟶ Reader size

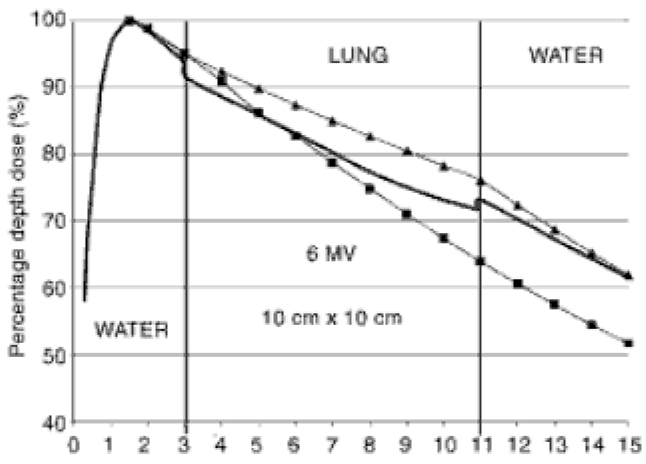
Radiotherapy optimization methods for modulated beams in Monte Carlo treatment planning



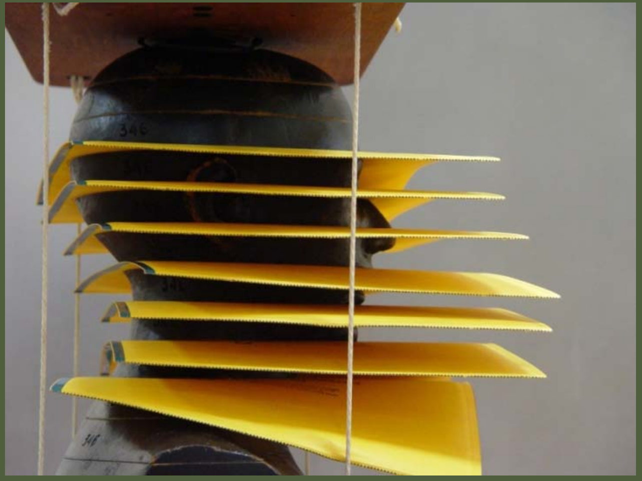
Heterogeneities considerations:

-How is considered the build-up region?
-What about rebuild effect?





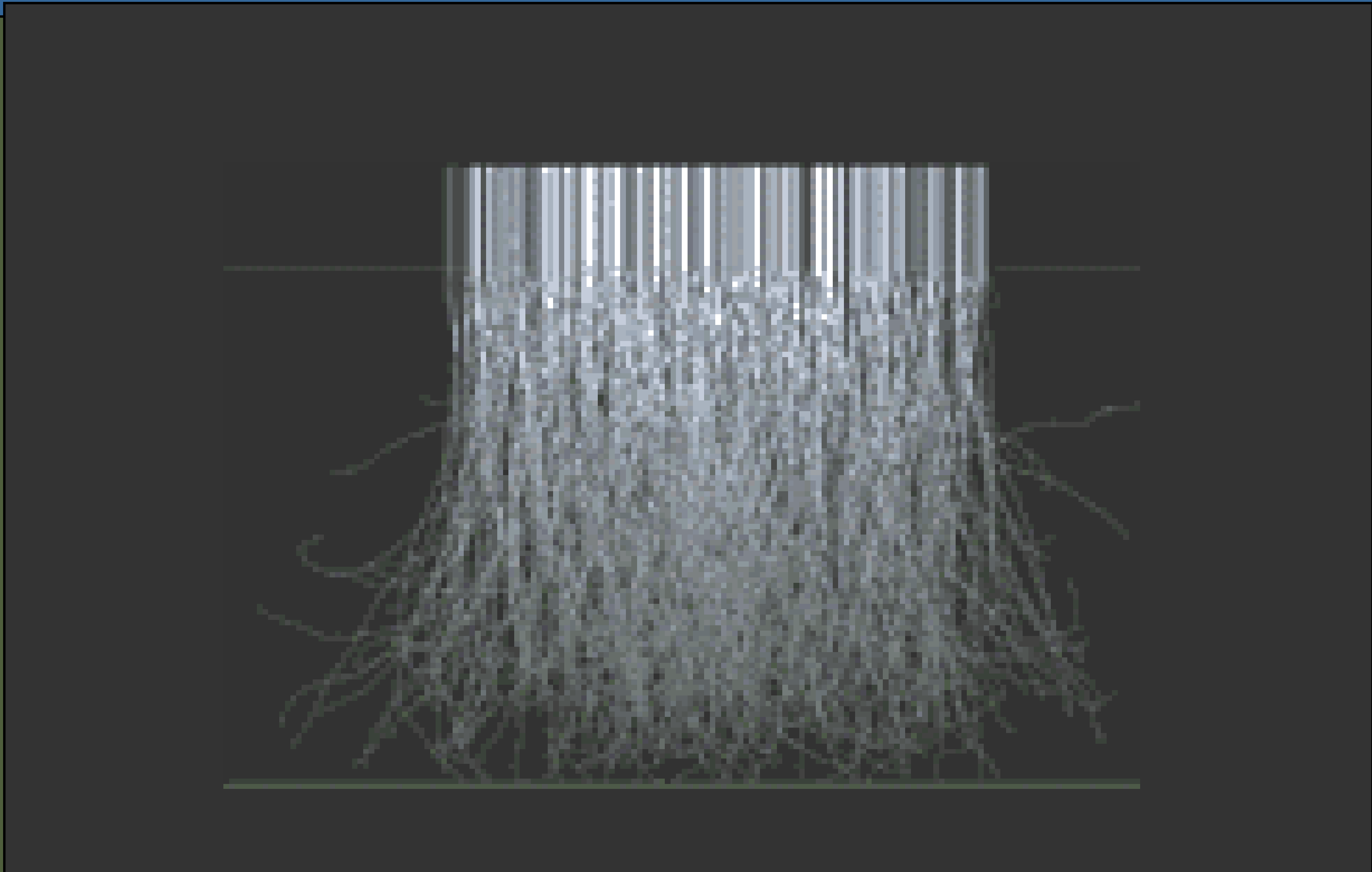
Handbook of radiotherapy physics: theory and practice Escrito por Philip Mayles,Alan E. Nahum,Jean-Claude Rosenwald



Patients do not let us do certain things

Monte Carlo

EGS (Electron Gamma Shower)



Inventors: Neumann and Ulam 1949

John Von Neumann

(1903-1957)

Stanislow M. Ulam

(1909-1984)

Random numbers → Monte Carlo → Results

Physical Problem → Probability Functions (well defined) → Monte Carlo

Statistical Error $\frac{1}{\sqrt{N}}$

- Conventional algorithm:

Radiotherapy: Treatment Planning system (TPS)

Pencil beam

Collapsed cone

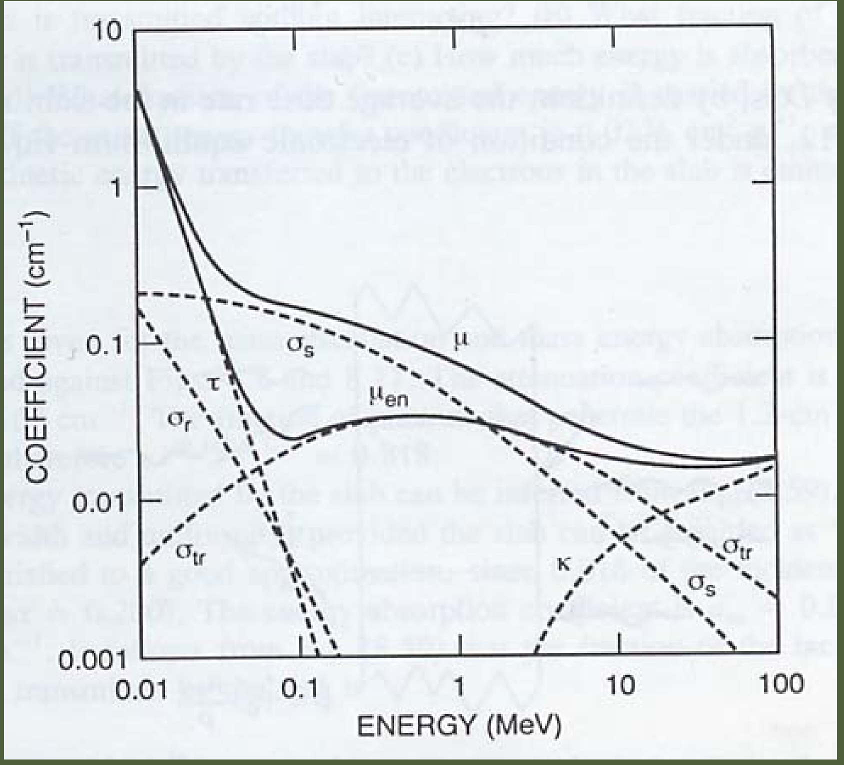
- Monte Carlo Method:
  - Physical problem described by probability well known.
  - Random numbers linked to parameters of the functions.
  - Average values from the sampling with high N.
  - Dose Variance (σ^2). The higher N the lower σ $\sigma^2 = 1/N$
  - Efficiency (€) $\varepsilon = 1/(\sigma^2 T)$ T (CPU time)

Radiation transport

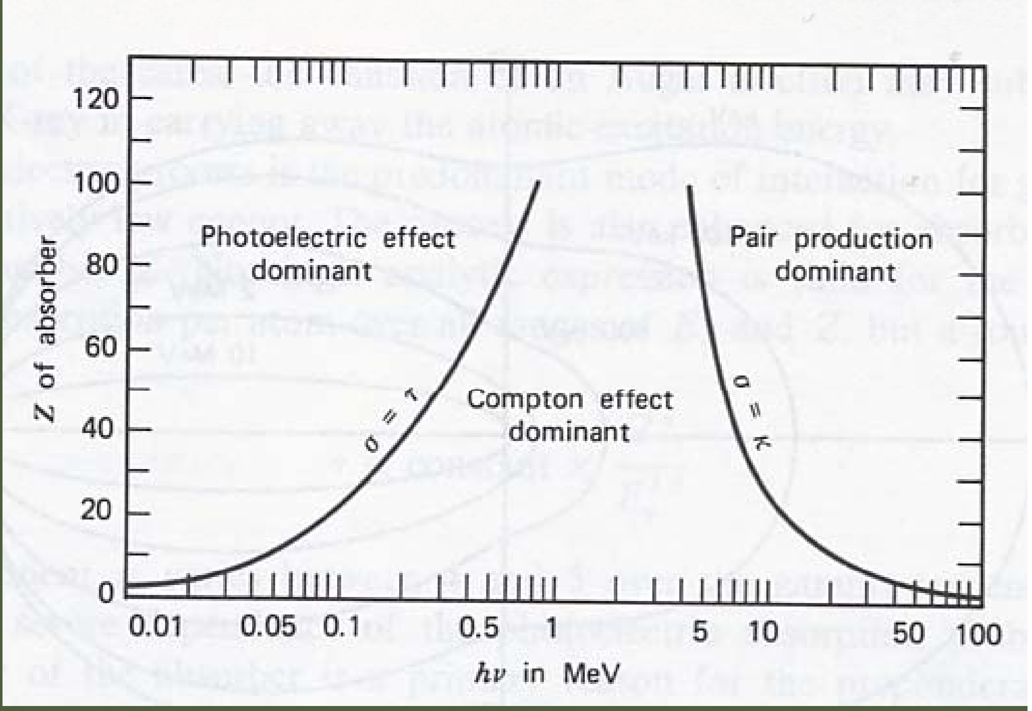
- Photon events
  - Rayleigh scattering
  - Photoelectric effect
  - Compton scattering
  - Pair production

Energy value Atomic number (Z)

- Electron events
  - Inelastic collision with e-
  - Bremsstrahlung
  - Electron-positron annihilation
  - Elastic collisions with atomic nucleus



Attenuation coefficients depending on the incident energy photon in water



Essential cross sections corresponding to clinical energy values

Clinical implementation of Monte Carlo

- F Hasenbalg, H Neuenschwander, R Mini and E J Born. Collapsed cone convolution and analytical anisotropic

"Issues associated with clinical implementation of Monte Carlo-based photon and electron external beam treatment planning"
Med Phys: 34 (2007) 4818-4853

AAPM TG 105 report

IJ Chetty, B Curran, J Cygler, J DeMarco, G Ezzell, B Faddegon, I Kawrakow, P Keall, H Liu, C-M Ma, DWO Rogers, D Sheikh-Bagheri, J Seuntjens, JV Siebers

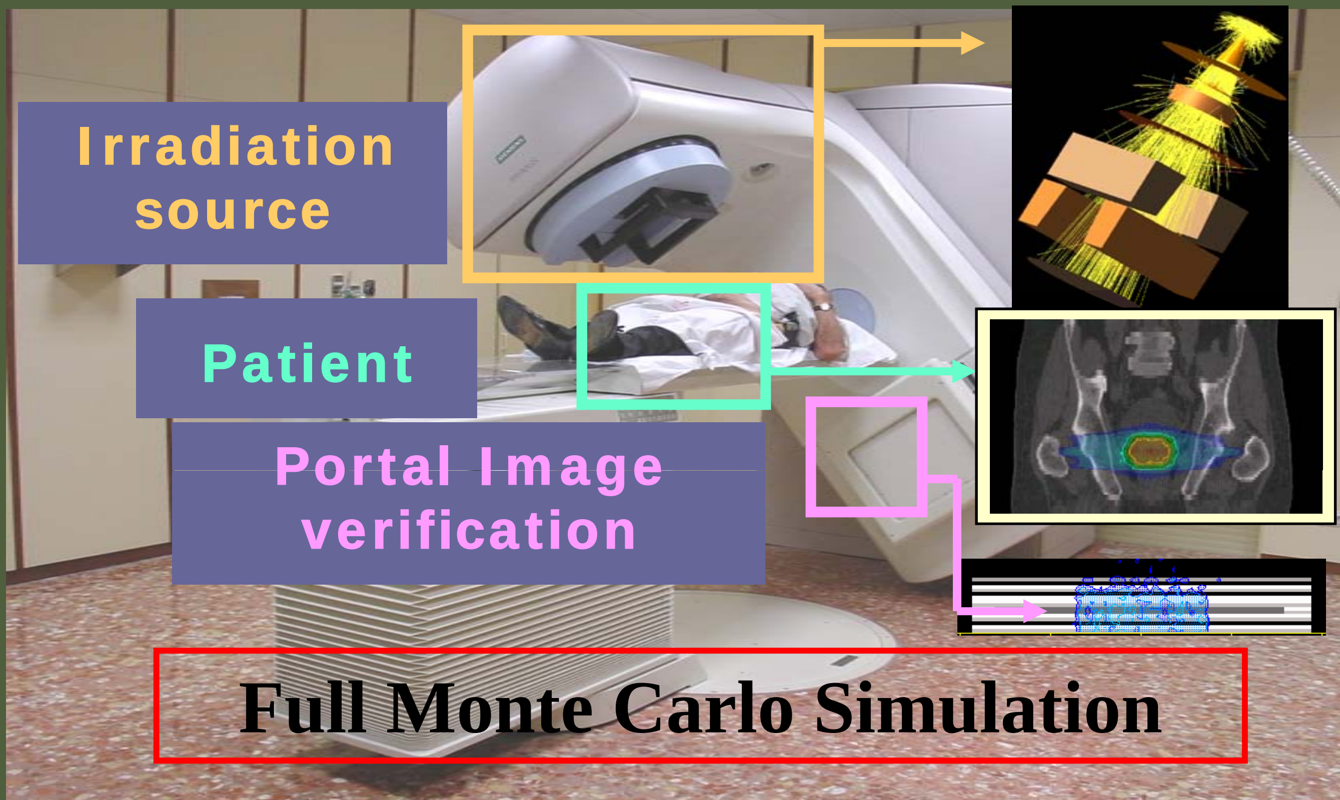
calculation method for photon beams".

- Krieger T, Sauer OA. Phys. Med. Biol. 2005, Vol.50,Iss.5, 859-868. " Monte Carlo- versus pencil-beam-/collapsed-cone-dose calculation in a heterogeneous multi-layer phantom".

Monte Carlo dose engines are already implemented in commercial TPS.

- Monte Carlo calculations of dose in a patient phantom VMC++ in MDS-Nordion (Kawrakow and Fippel).

- Several MCTP home made system and no more:



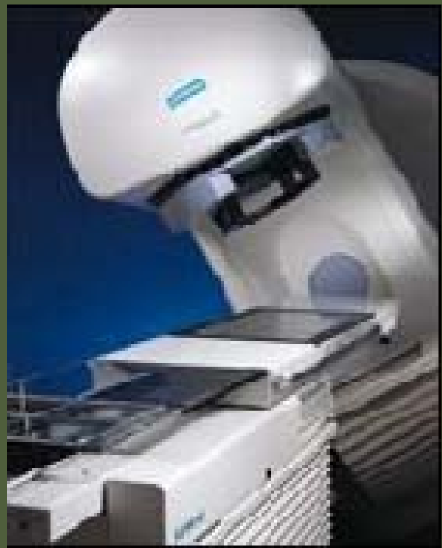
Linacs simulated by the Medical Physics Sevilla group

Elekta

SL-18

Siemens

Primus



Varian

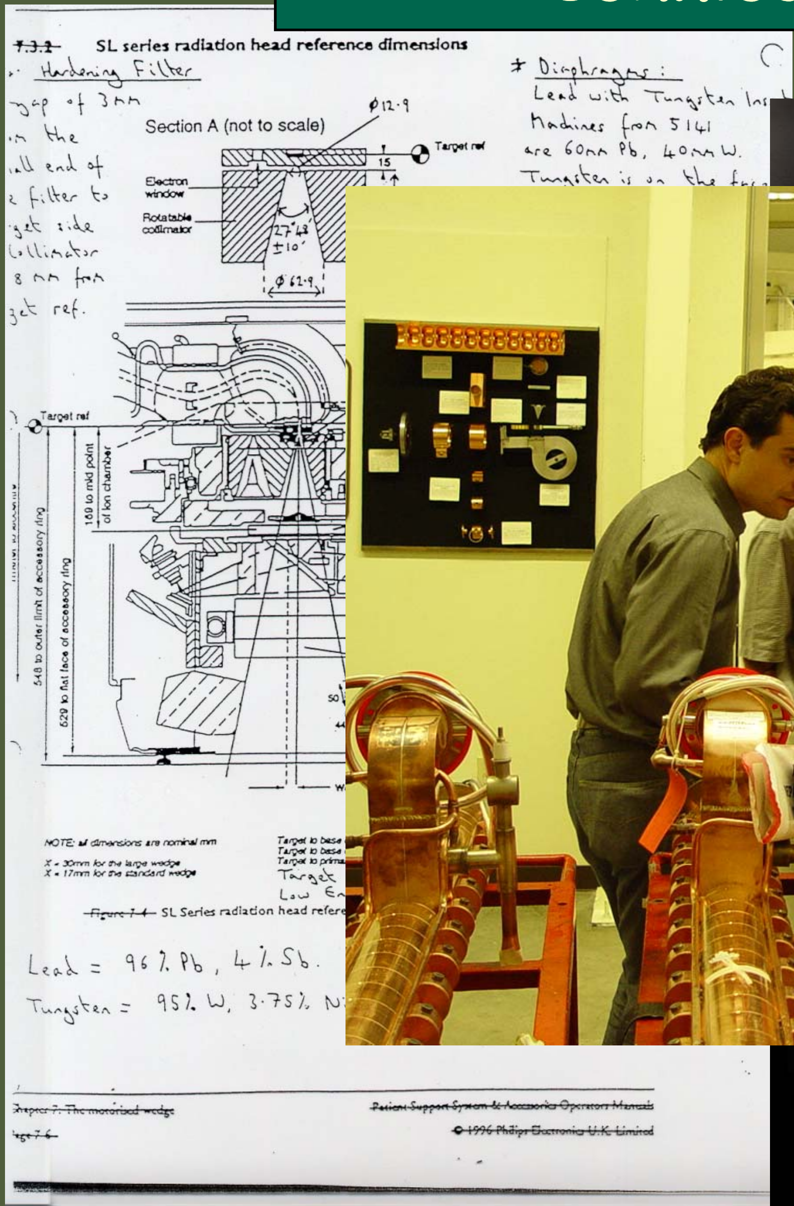
Varian 2100 DC

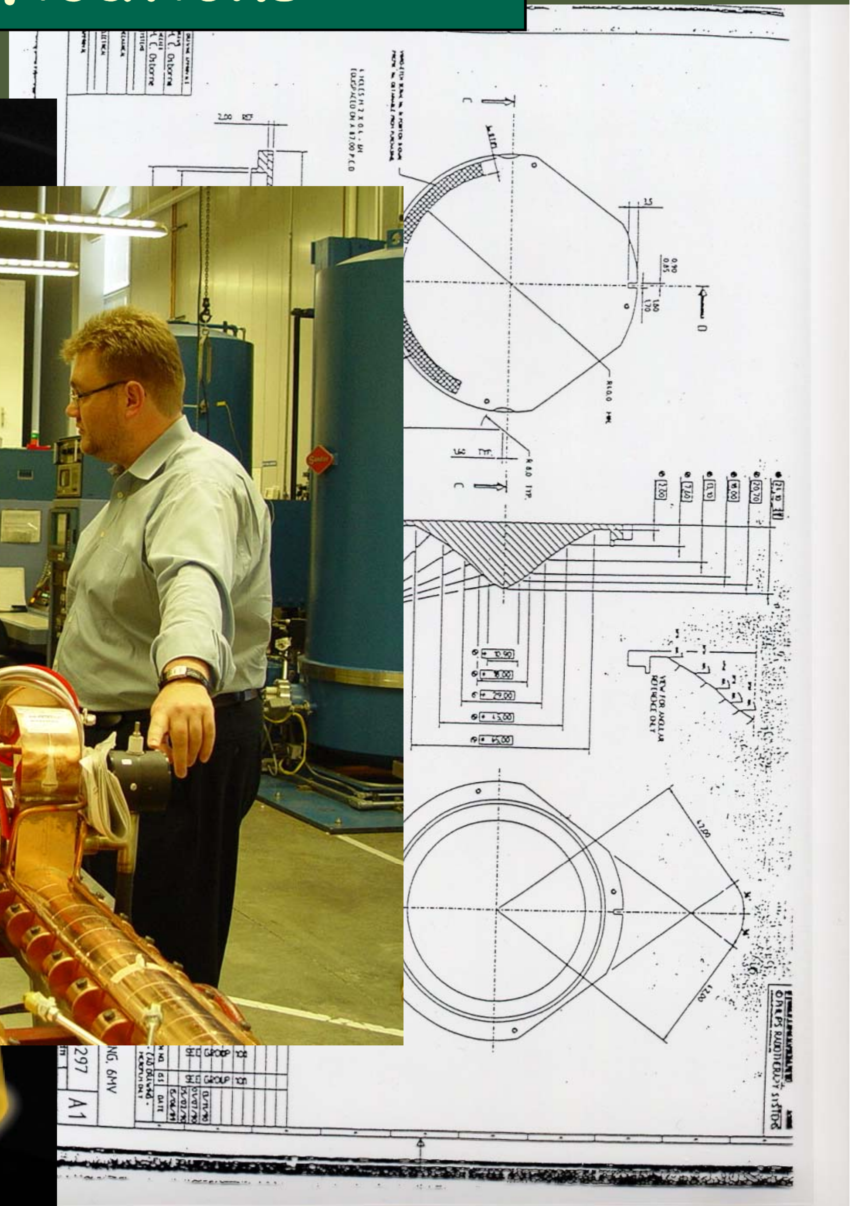
Radiosurgery

IMRT Step & Shoot

IMRT Dynamic

Technical specifications



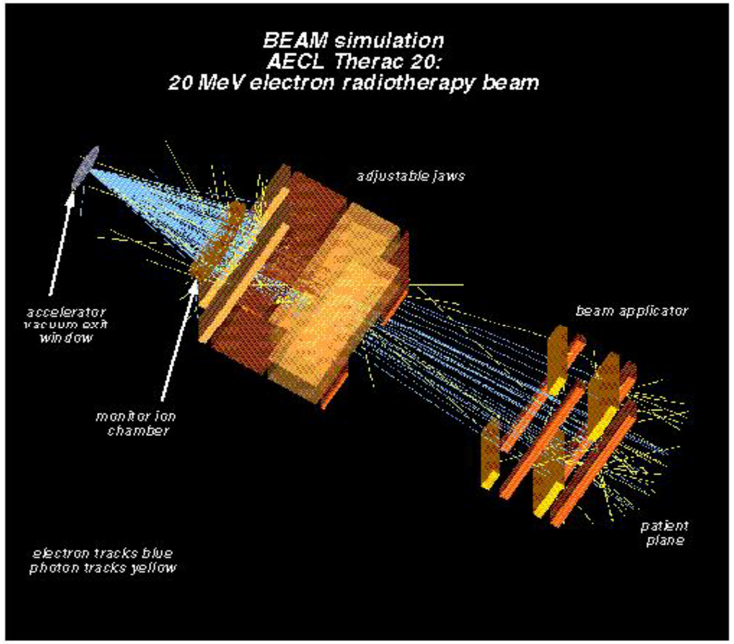


BEAMnrc/EGSnrc

BEAM Users Manual

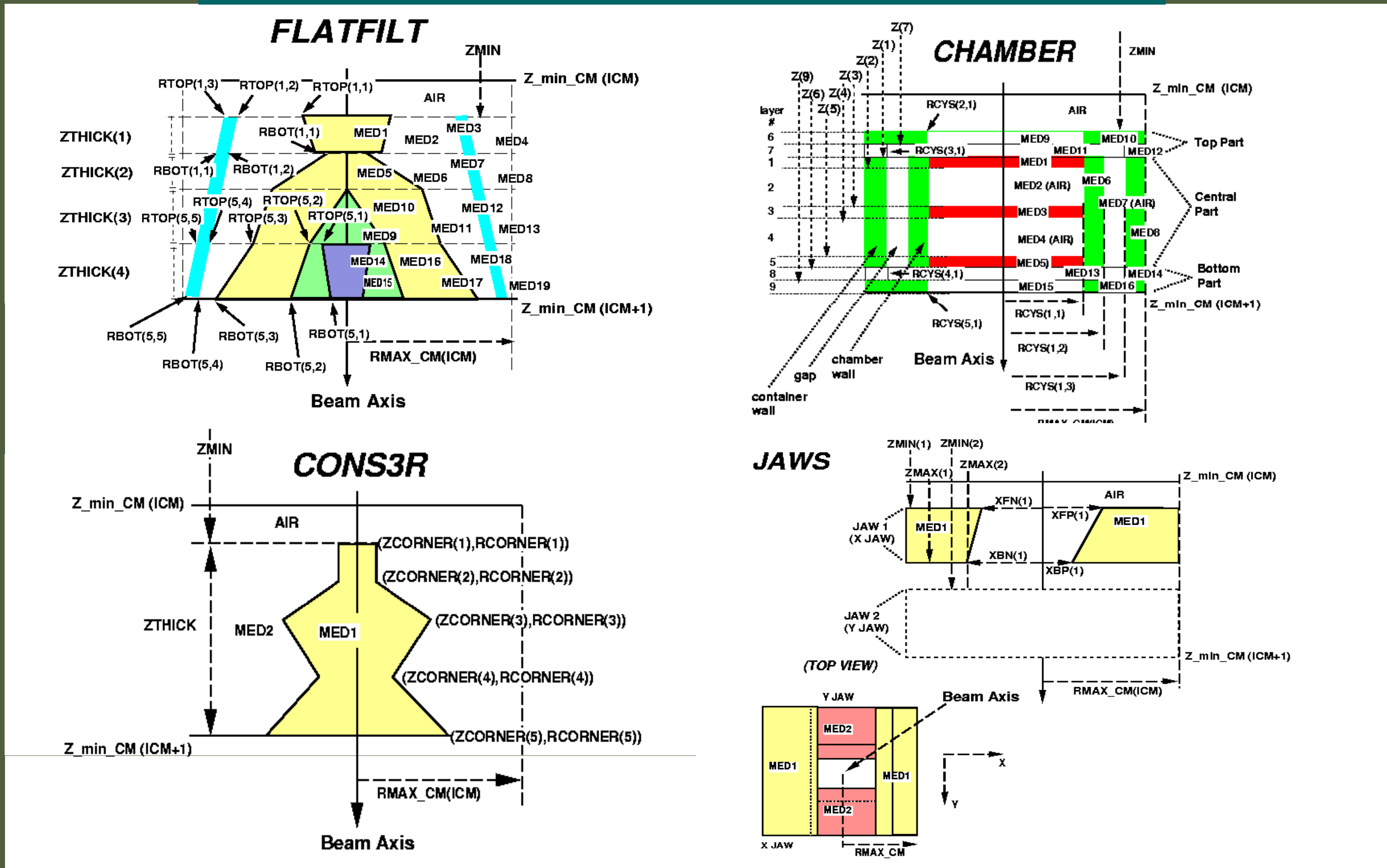
D.W.O. Rogers, C.-M. Ma, G.X. Ding and B. Walters
Ionizing Radiation Standards
National Research Council of Canada
Ottawa, K1A 0R6
dave@irs.phy.nrc.ca

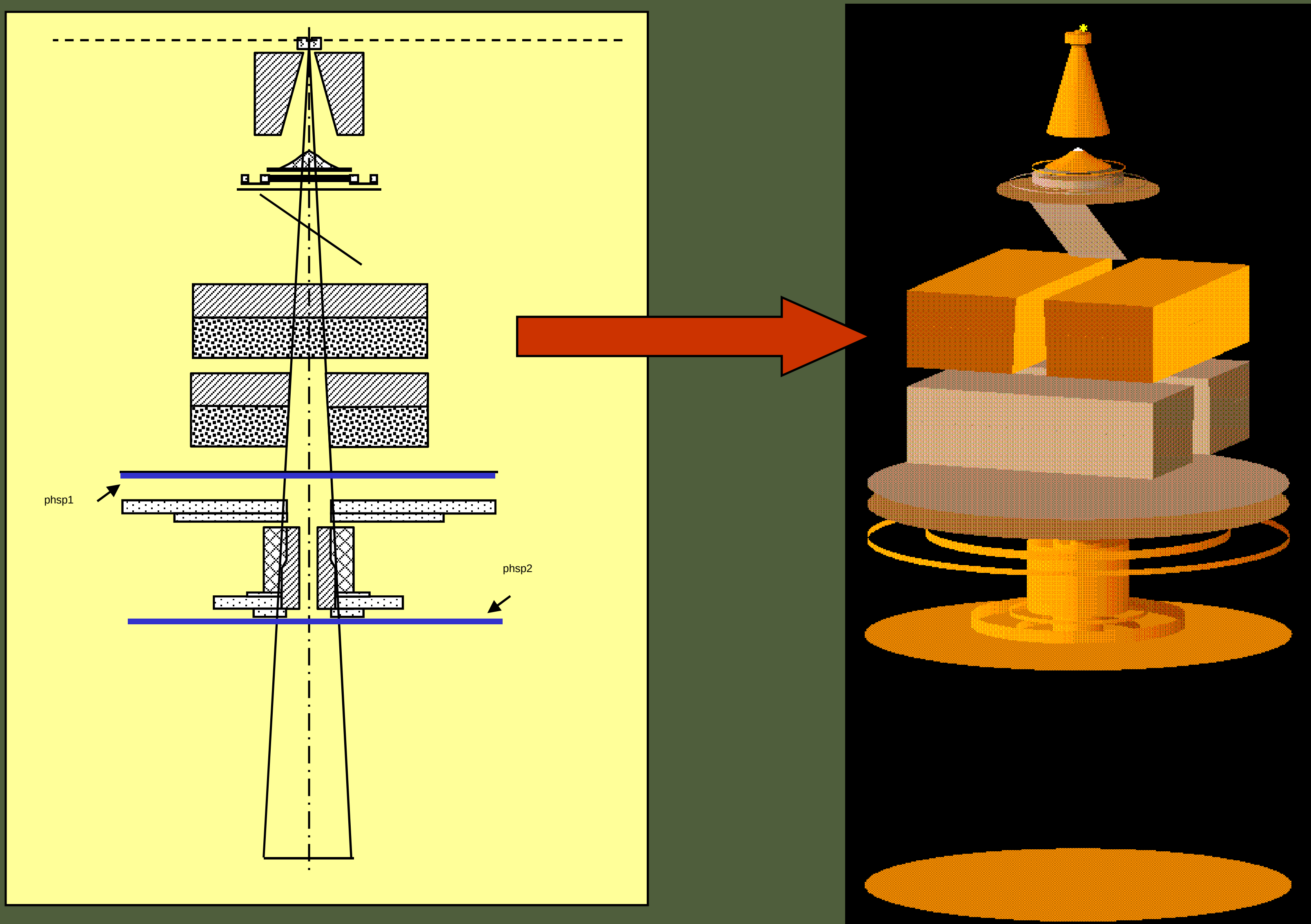
Printed: September 30, 1997(last edited: 28 Sep 1997)
NRCC Report PIRS-0509(A)revB



Source tex file is: $OMEGA_HOME/doc/beam_um/beam_um.tex
Available on-line for authorized users via:
http://www.irs.inms.nrc.ca/inms/irs/BEAM/beamhome.html

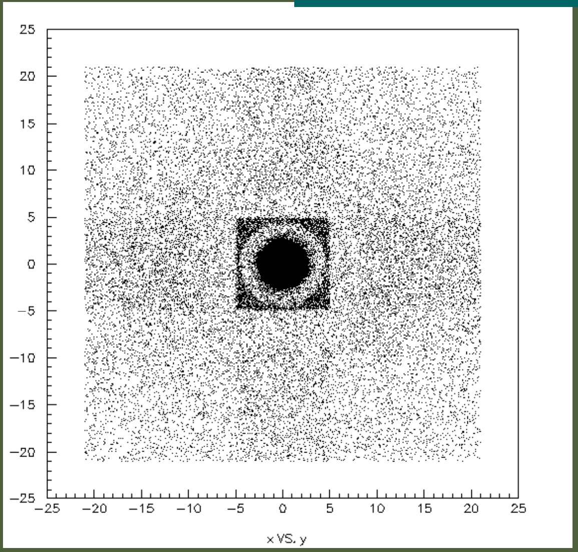
Component modules

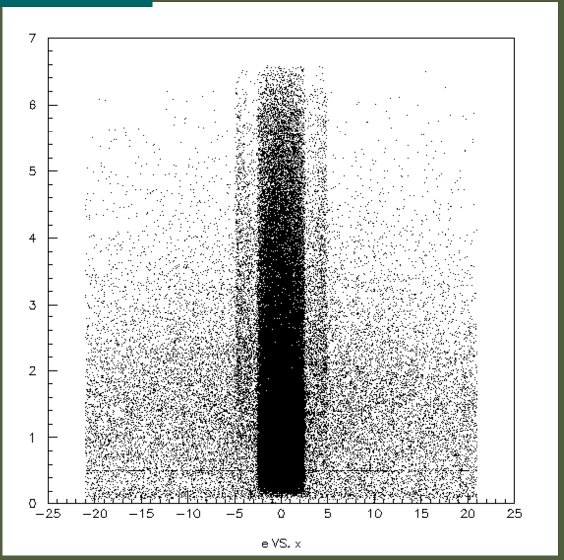


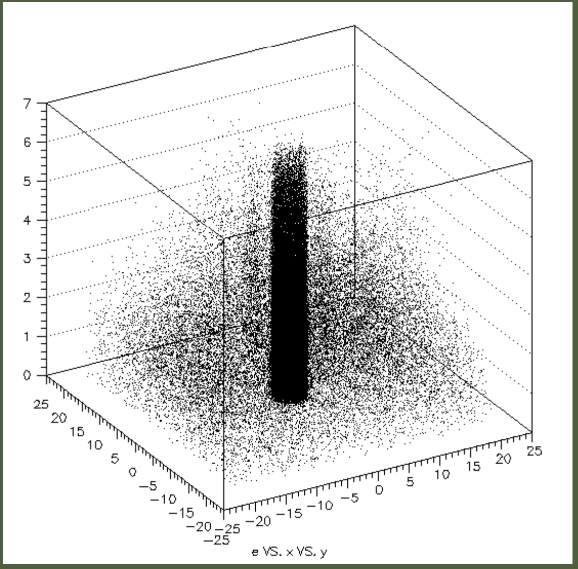

phsp1
phsp2

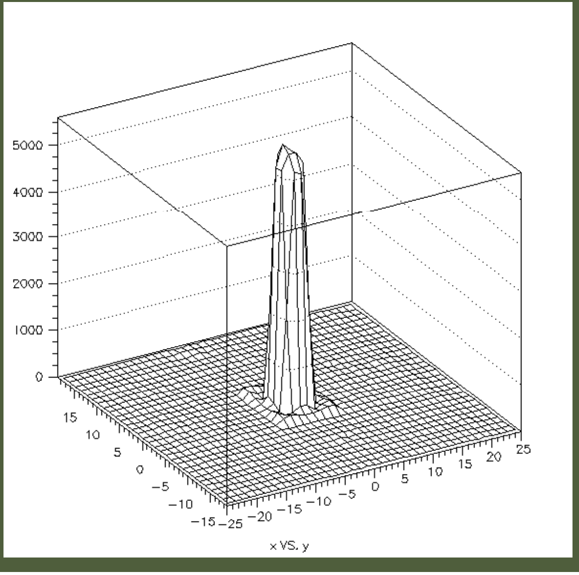
Radiosurgery

Radiosurgery









IMRT: Effect of the interaction with the MLC

- This study is not feasible using conventional TPS :

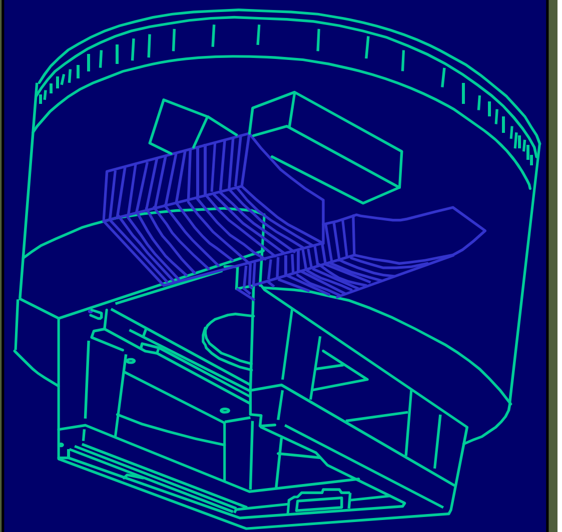
Experimental data is needed as input

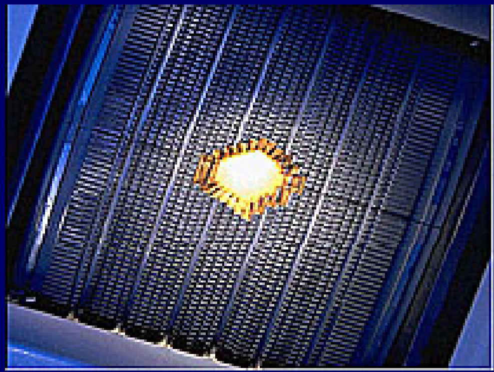
-Accurate, universal and portable results:

TPS independent dose distribution

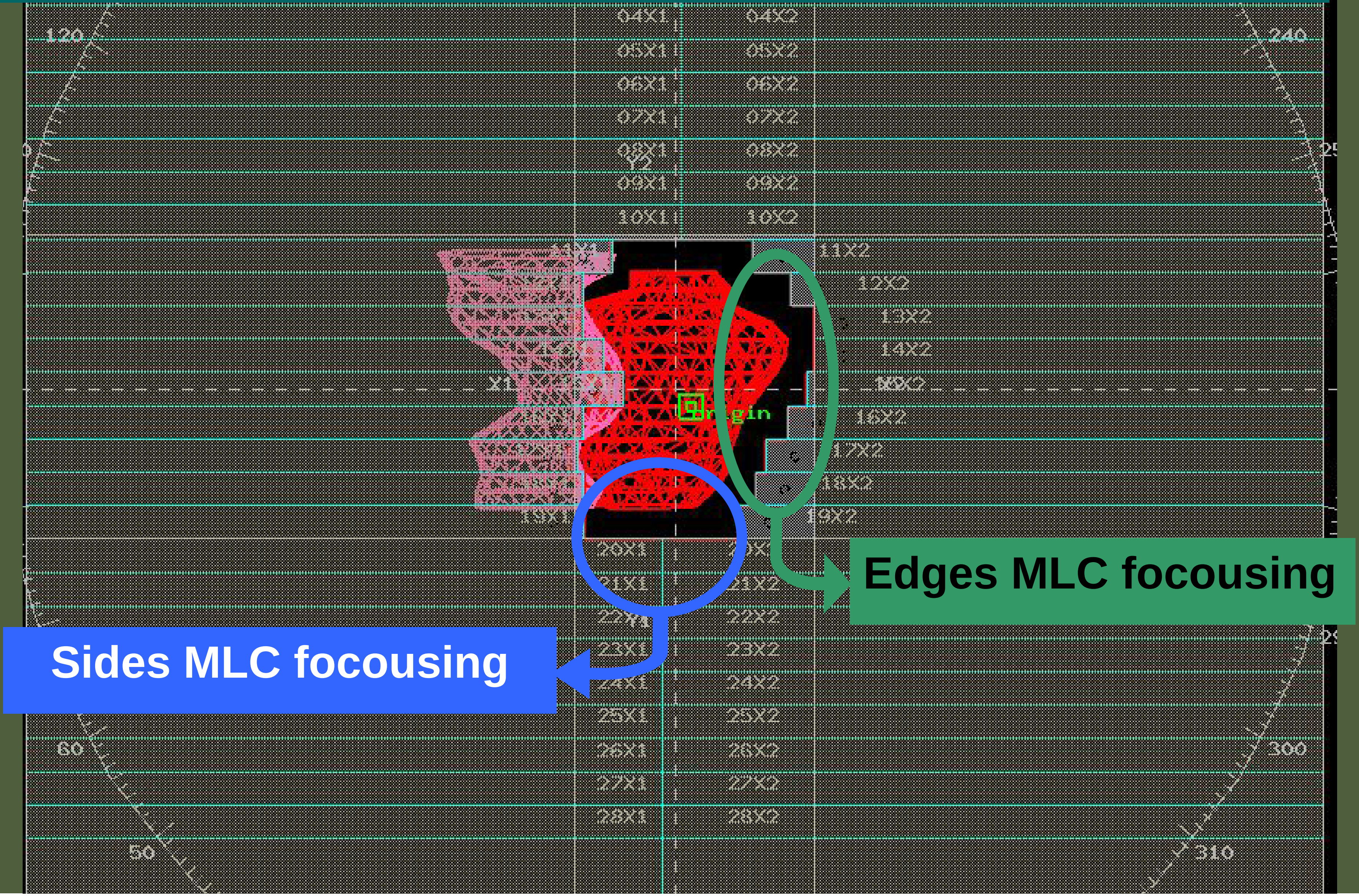
- Flexible geometrical specifications :

Dose differences can be associated with any specific MLC geometric variations.

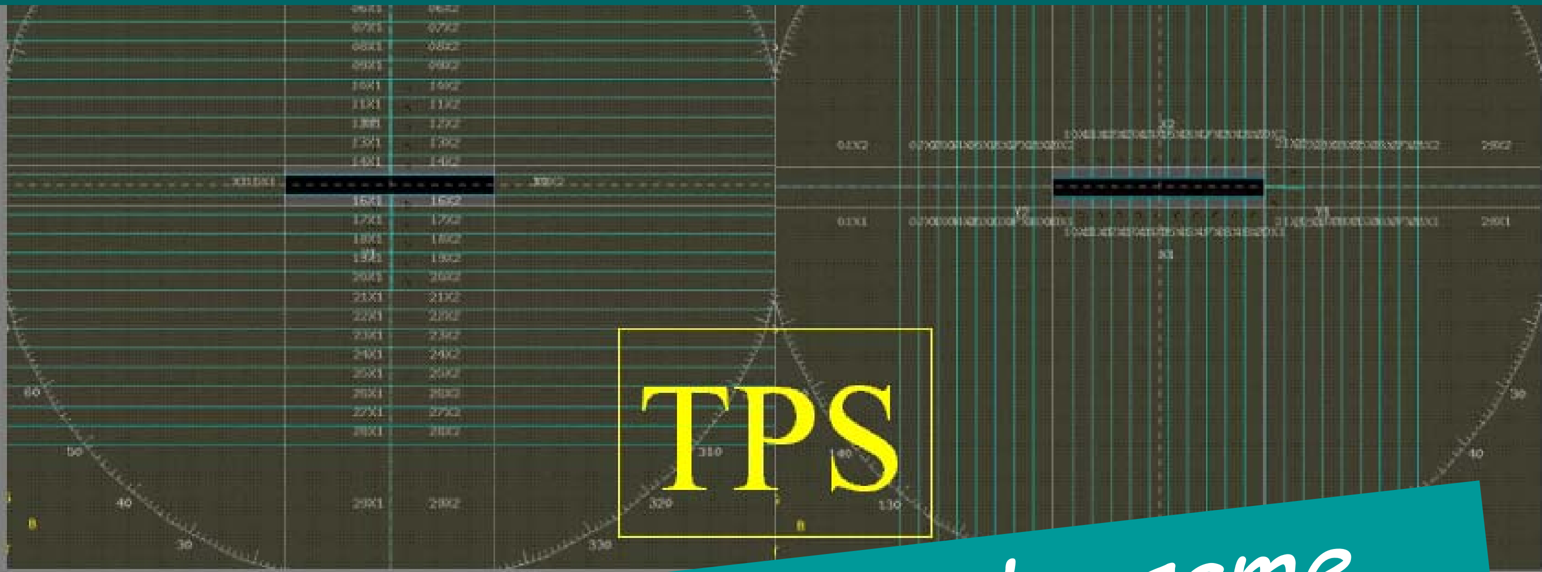




IMRT: Effect of the interaction with the MLC



IMRT: Effect of the interaction with the MLC

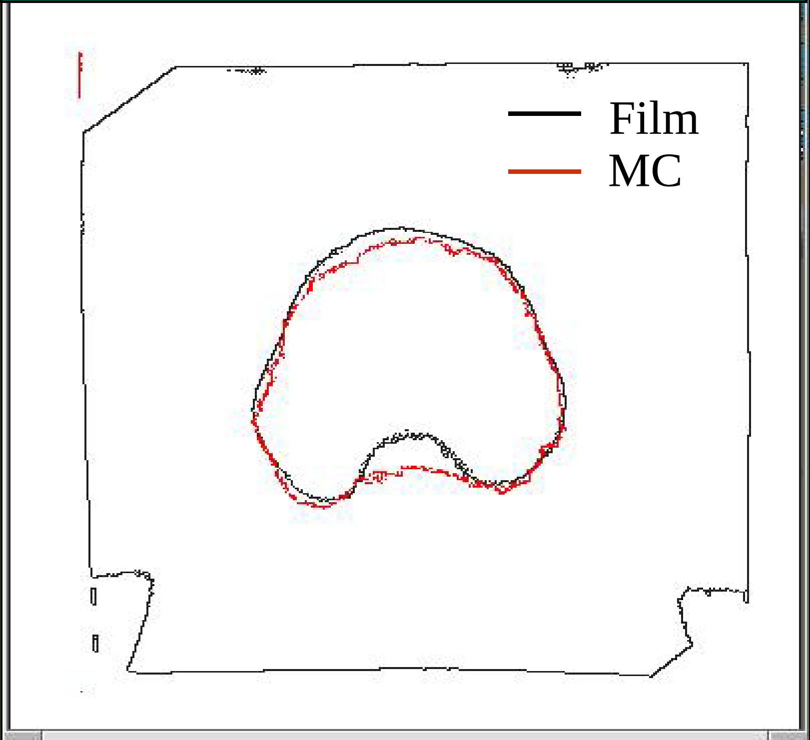


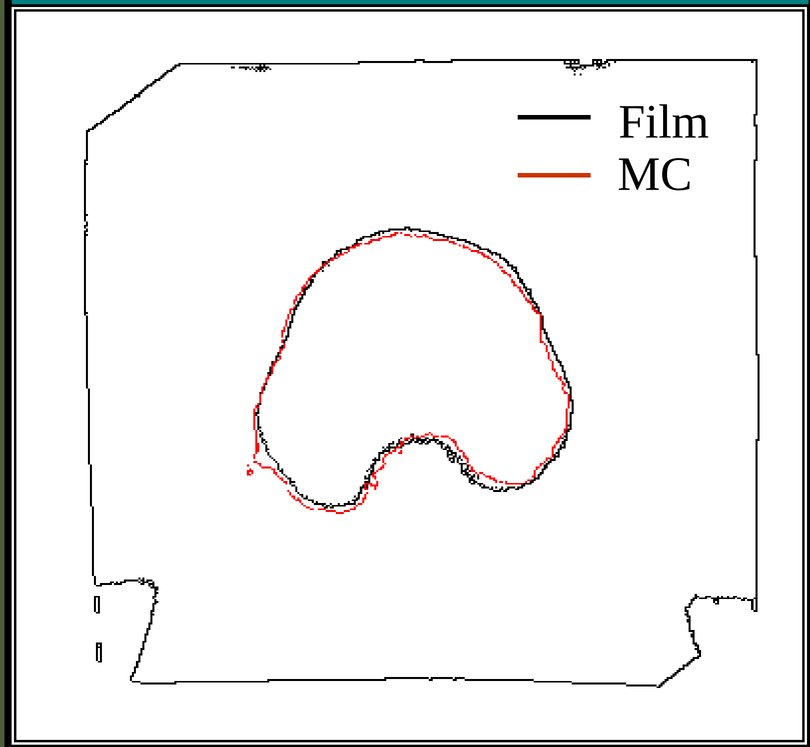
Fluence map is the same

Built with the leaf's SIDE   Built with the leaf's END

IMRT: Effect of the interaction with the MLC

MC(single focus) versus Film	MC(double focus) versus Film
85 %	**85 %**

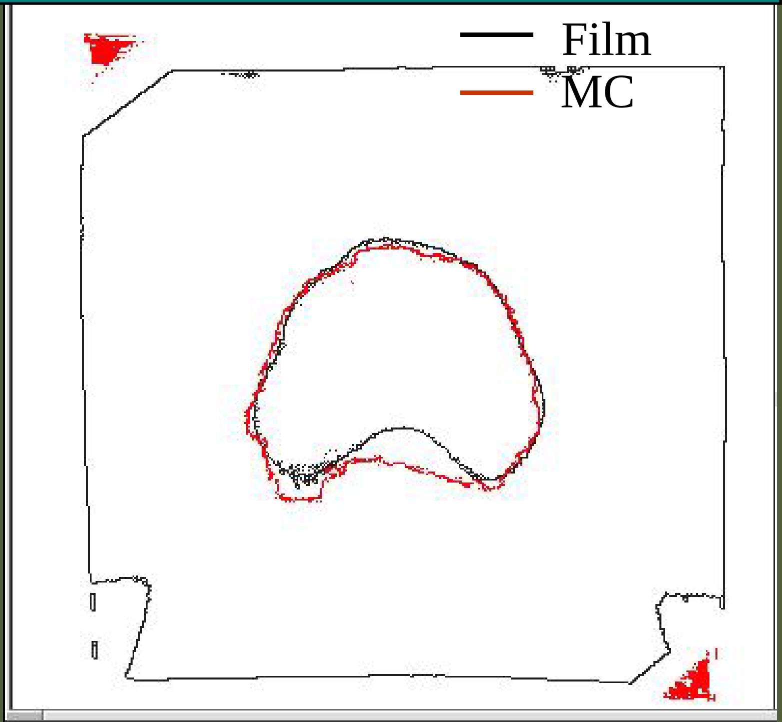




IMRT: Effect of the interaction with the MLC

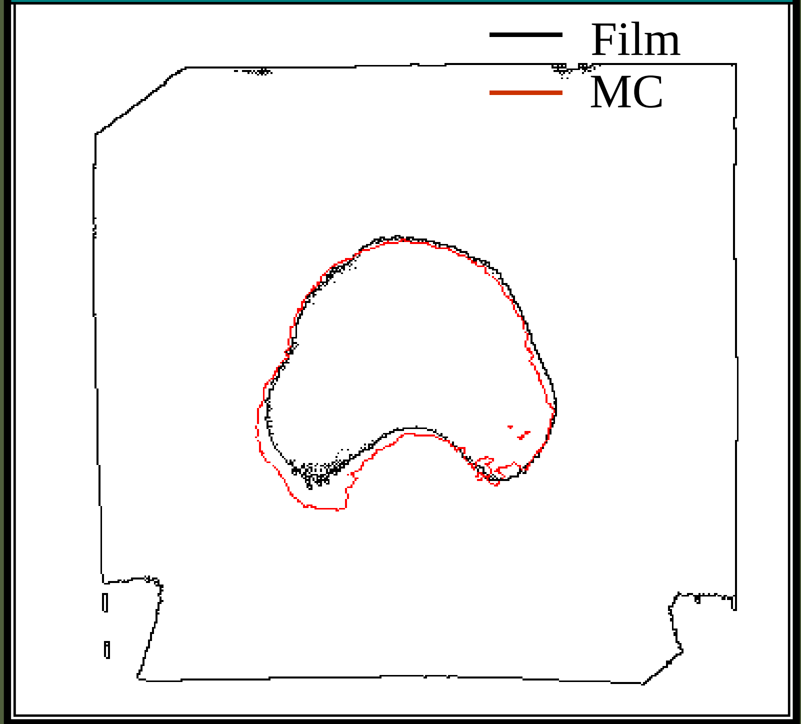
MC(single focus) versus Film

90 %

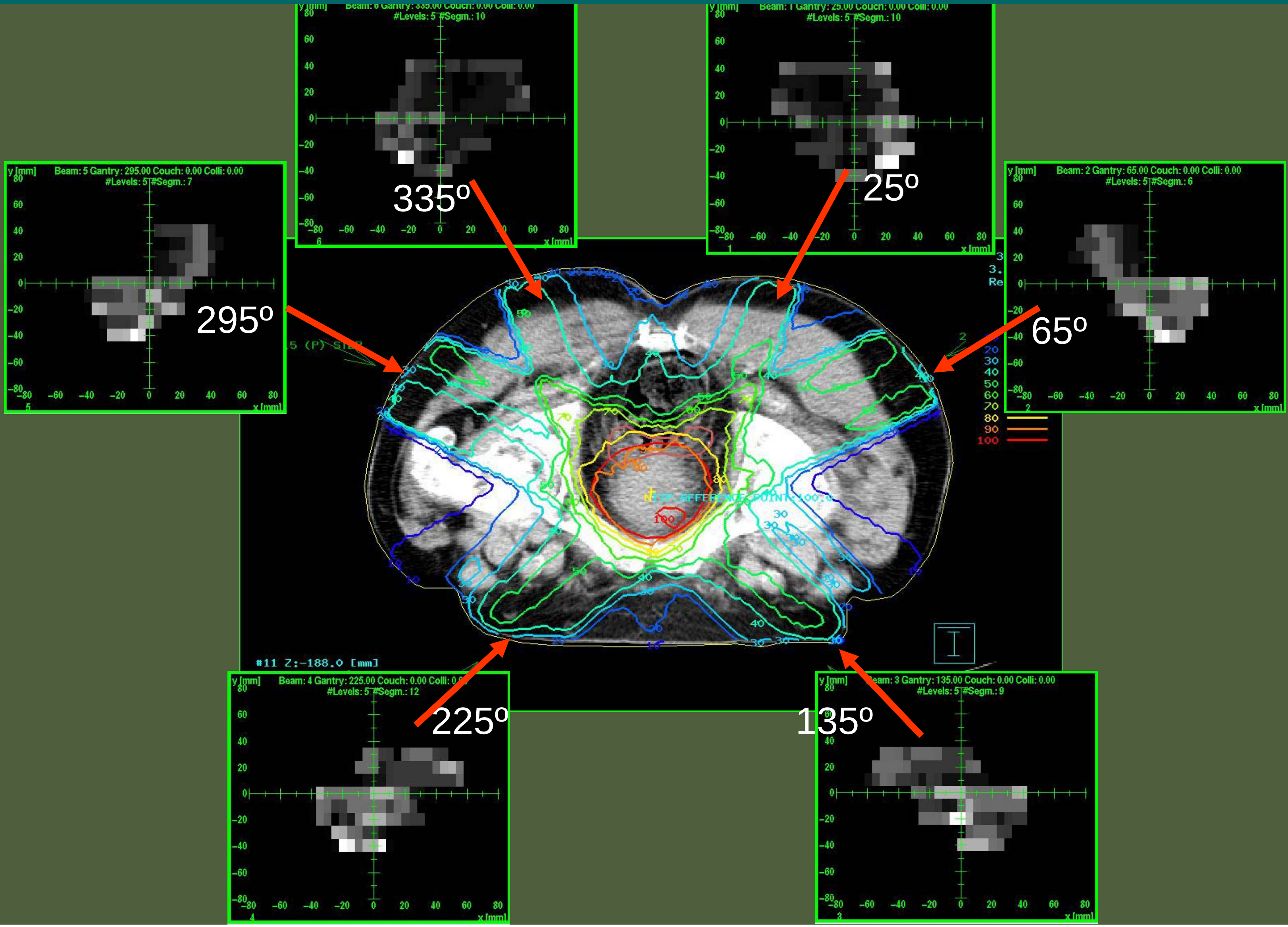


MC(double focus) versus Film

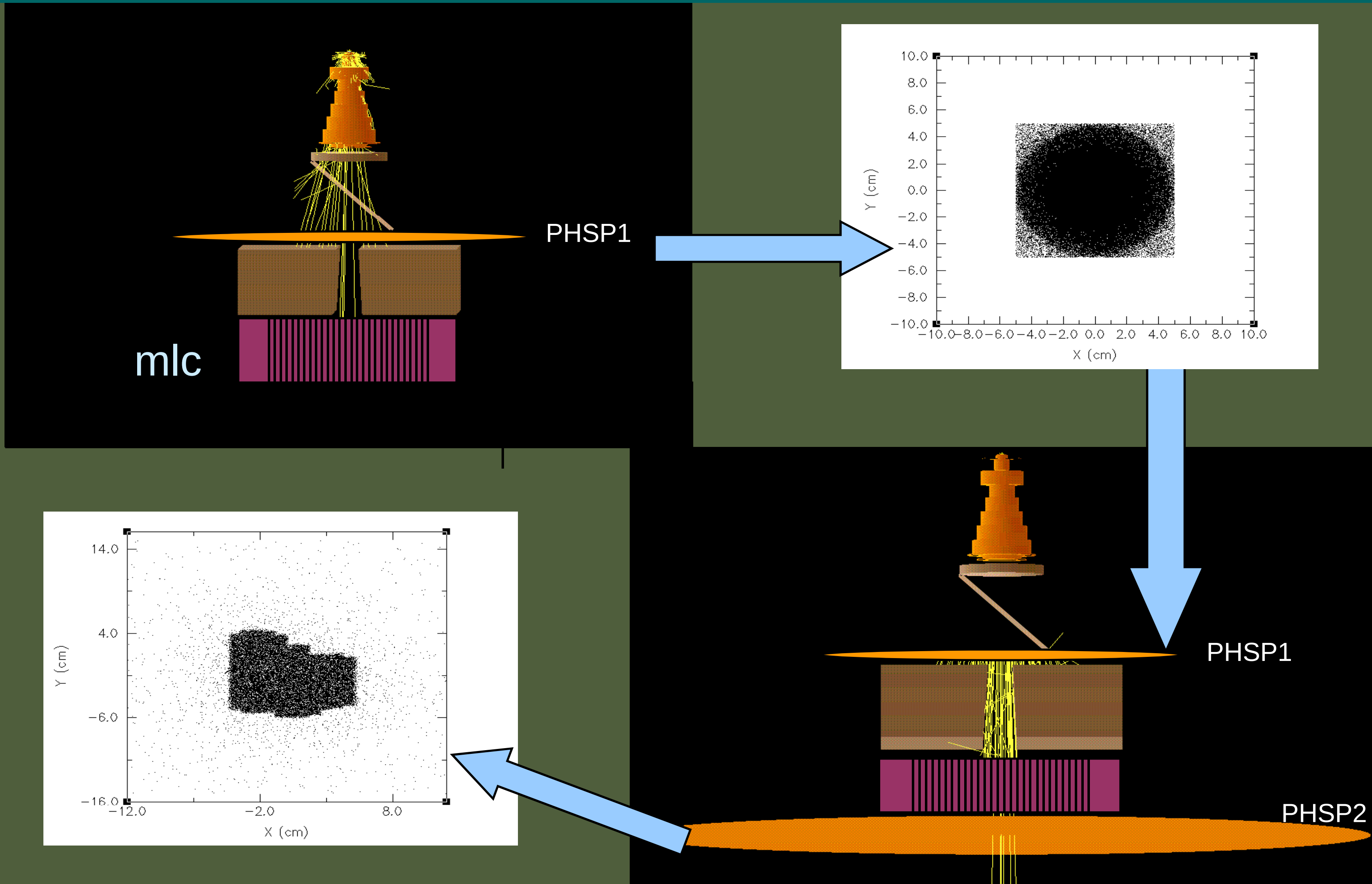
90 %



IMRT simulations

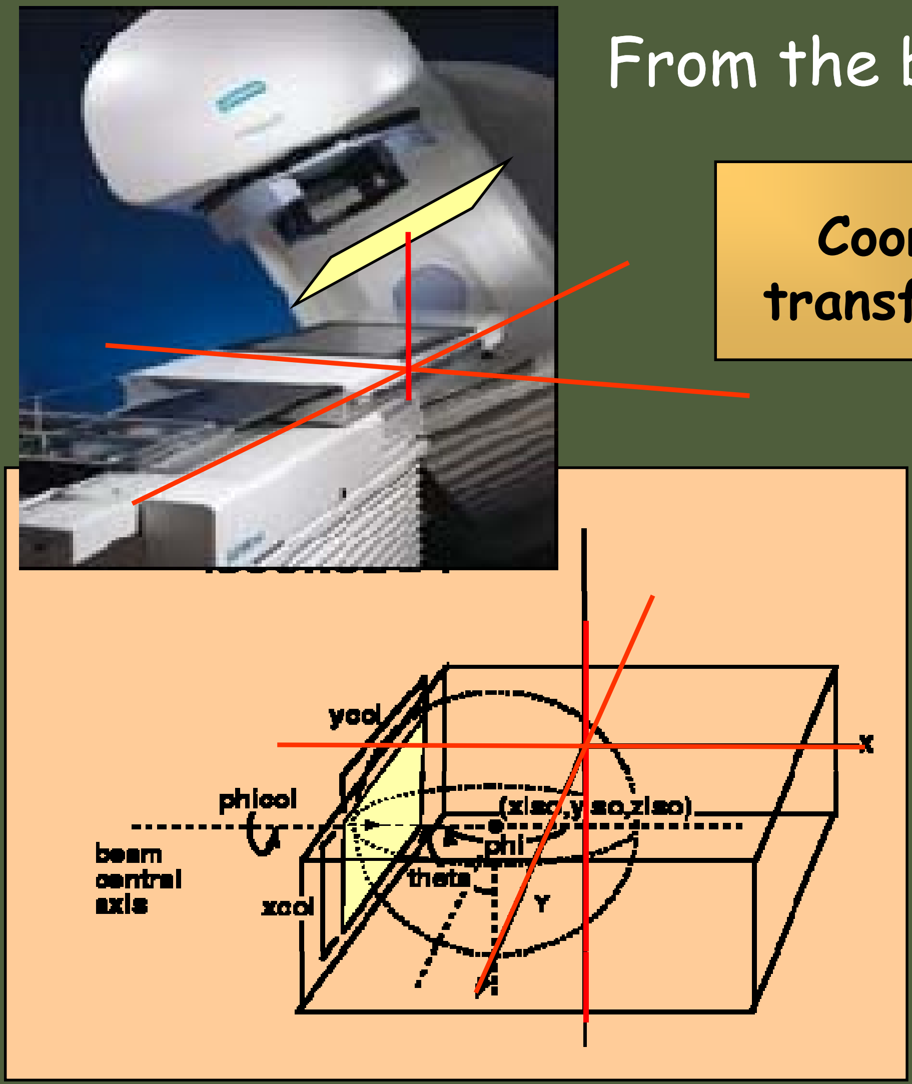


IMRT simulations



IMRT simulations

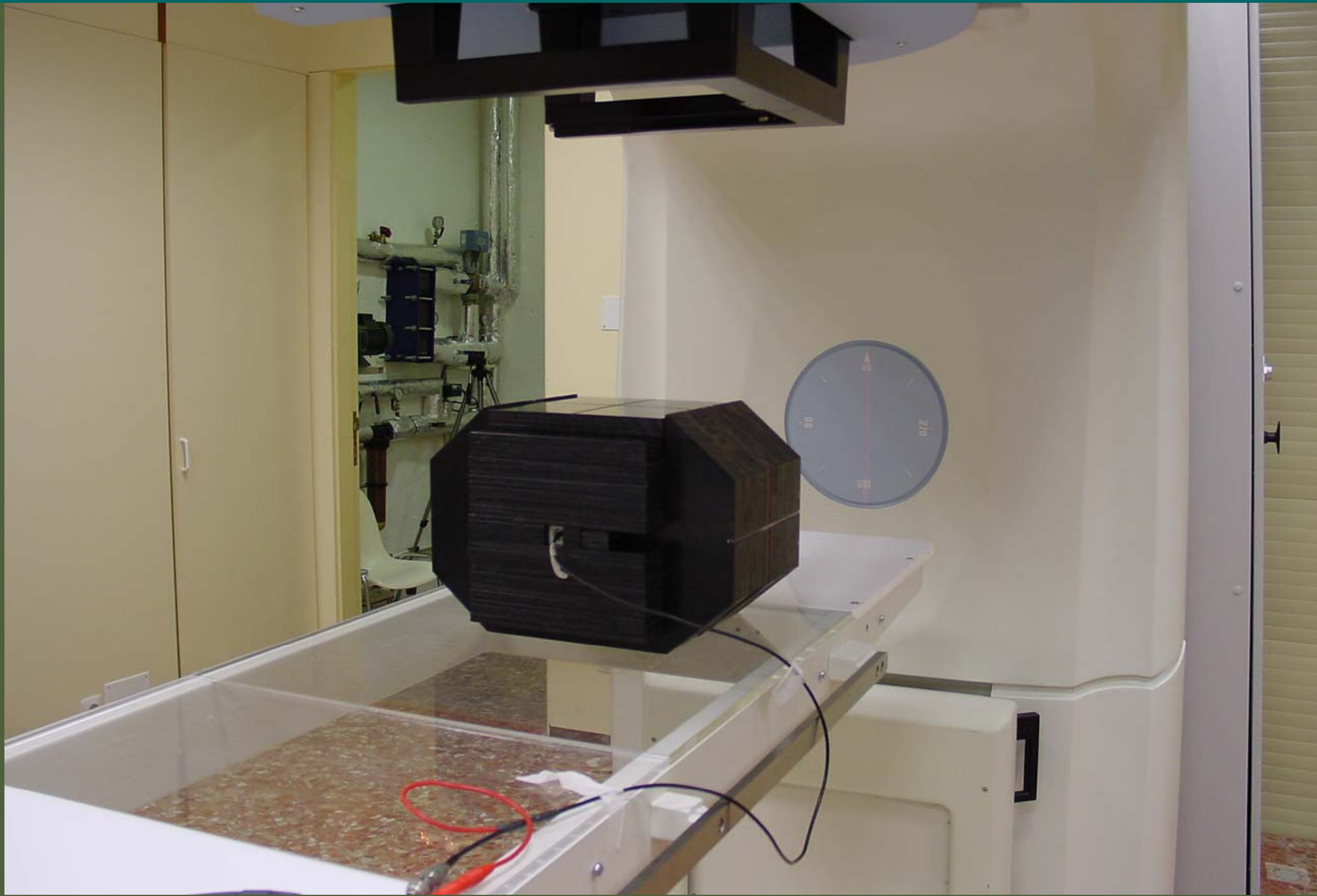
From the bunker to the MC system



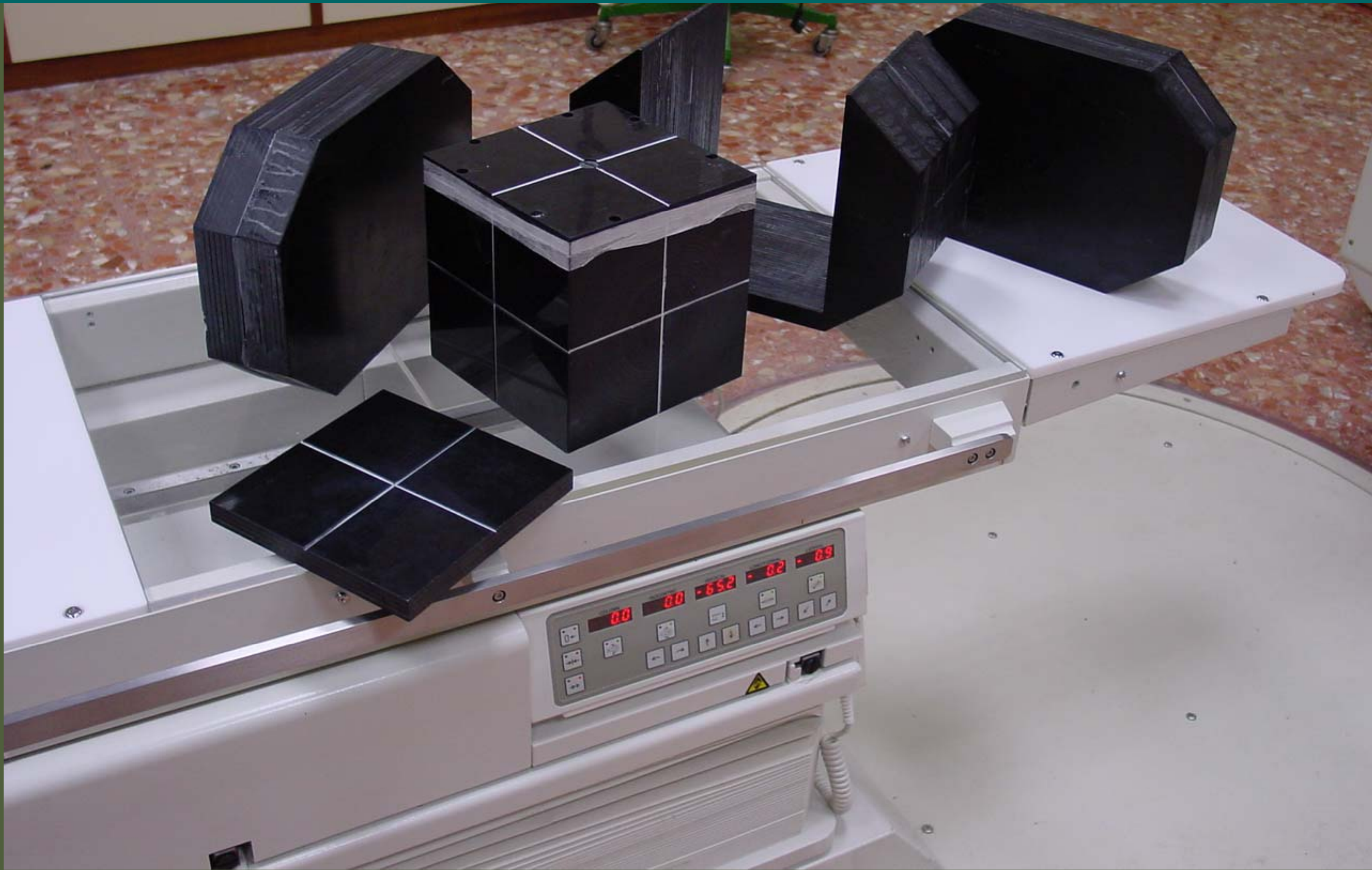
Coordinates transformations

Changing parameters for a whole treatment simulation

Verification of IMRT simulations

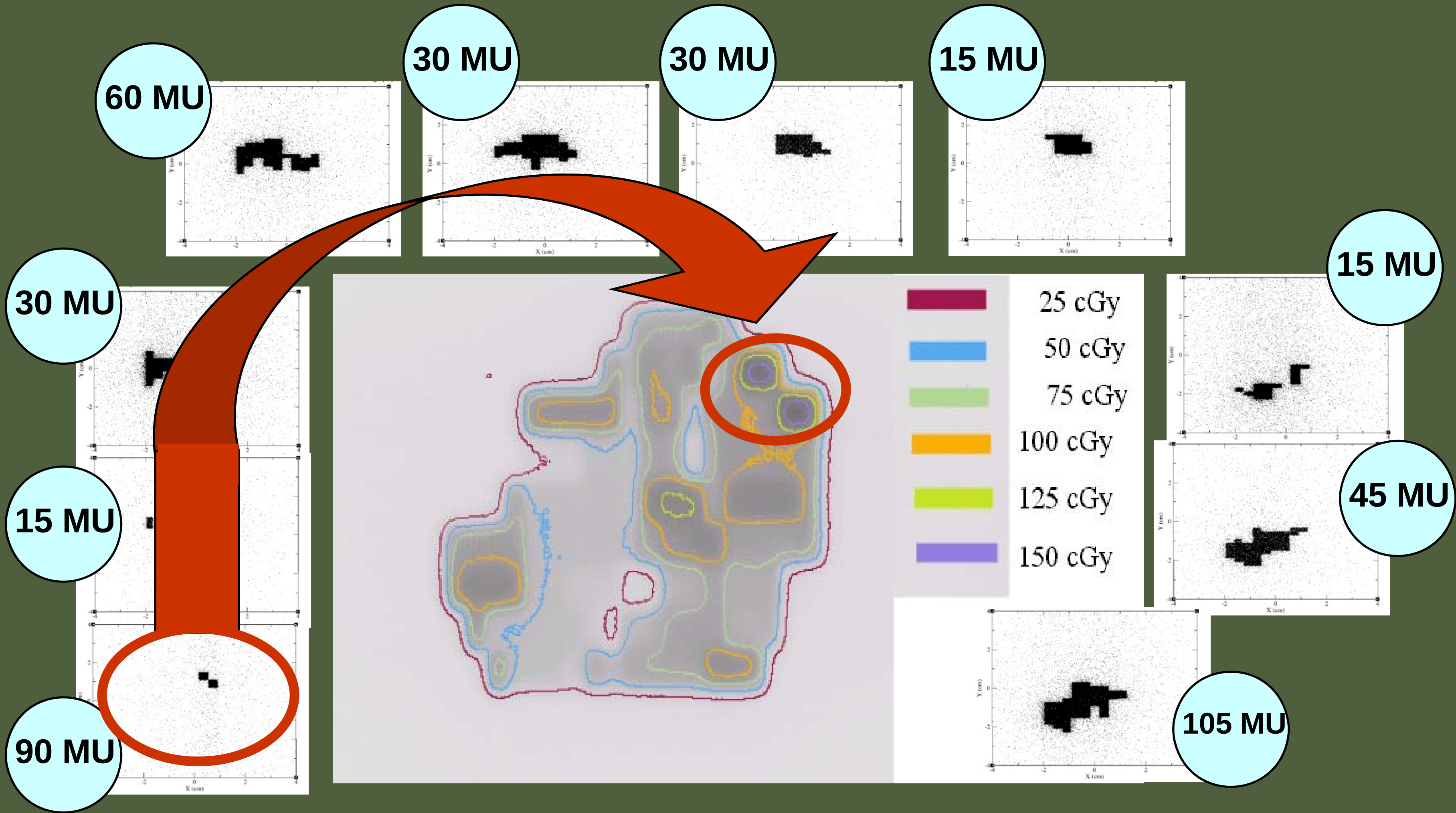


Verification of IMRT simulations

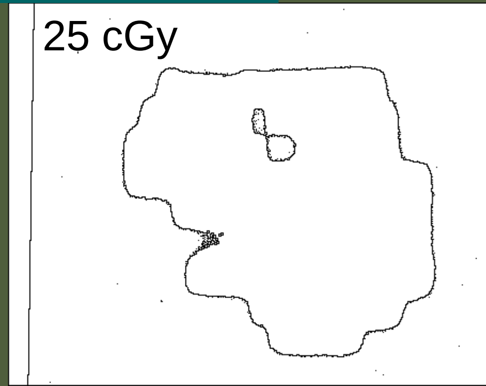


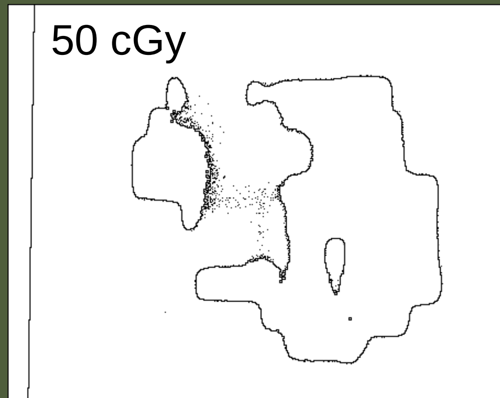
Verification of IMRT simulations

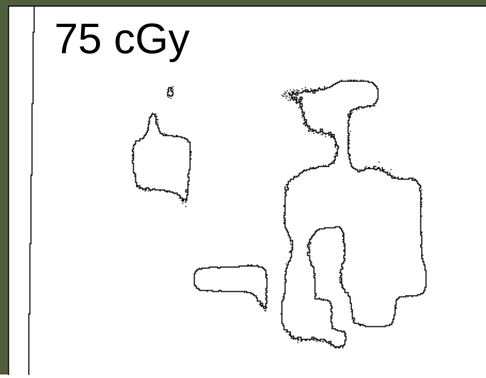
Verification of IMRT simulations

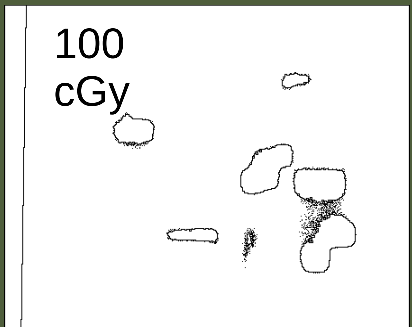


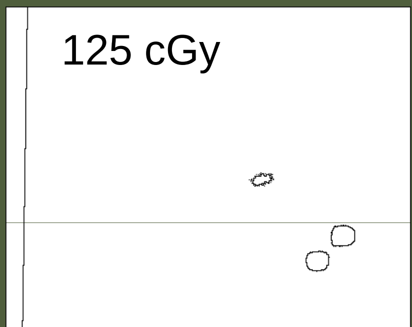
Verification of IMRT simulations

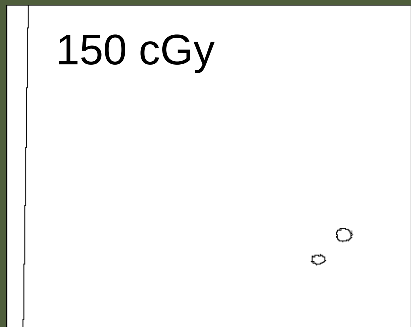




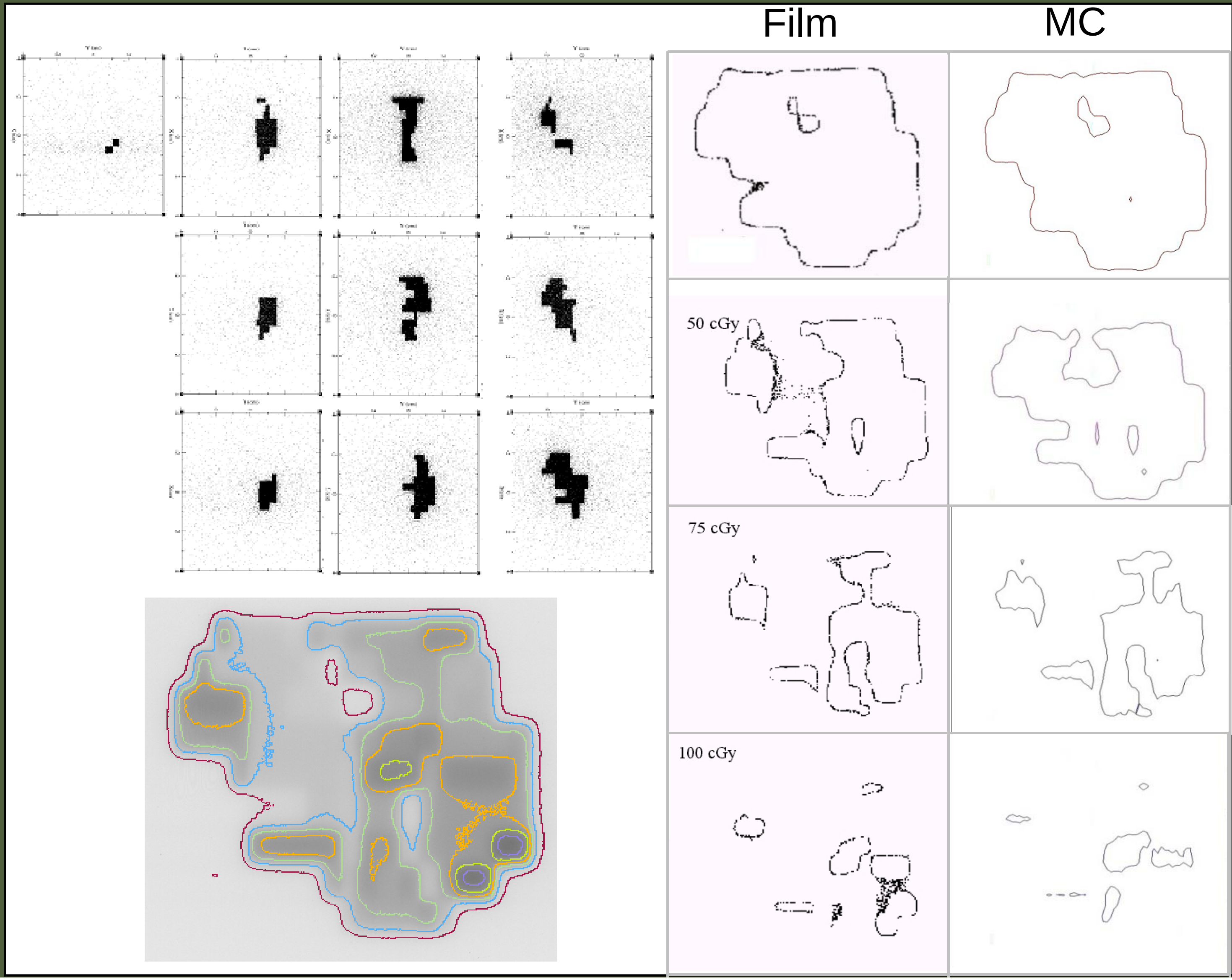






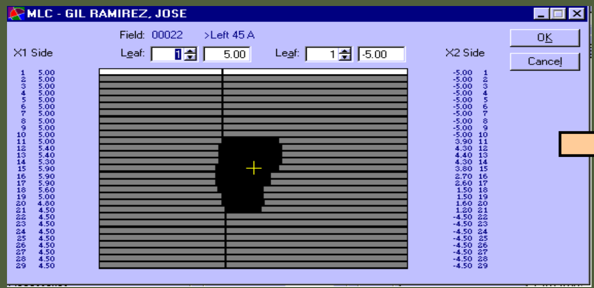


Verification of IMRT simulations

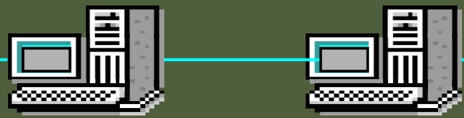


Automatic prodcedure

TPS



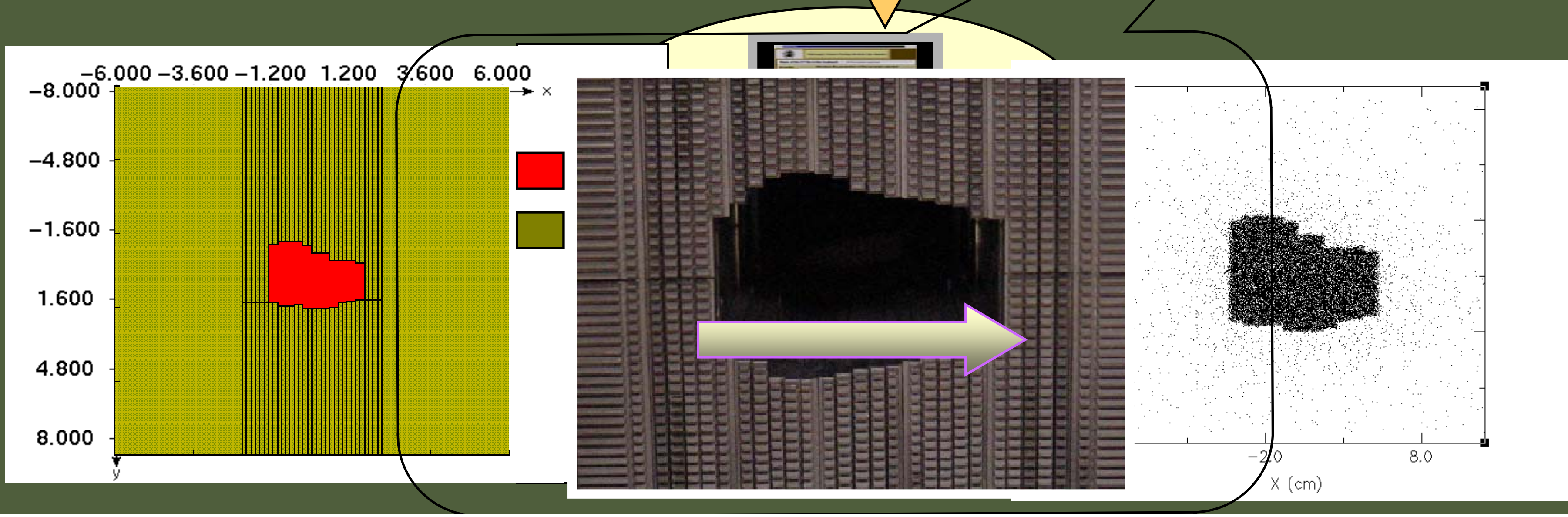
Network



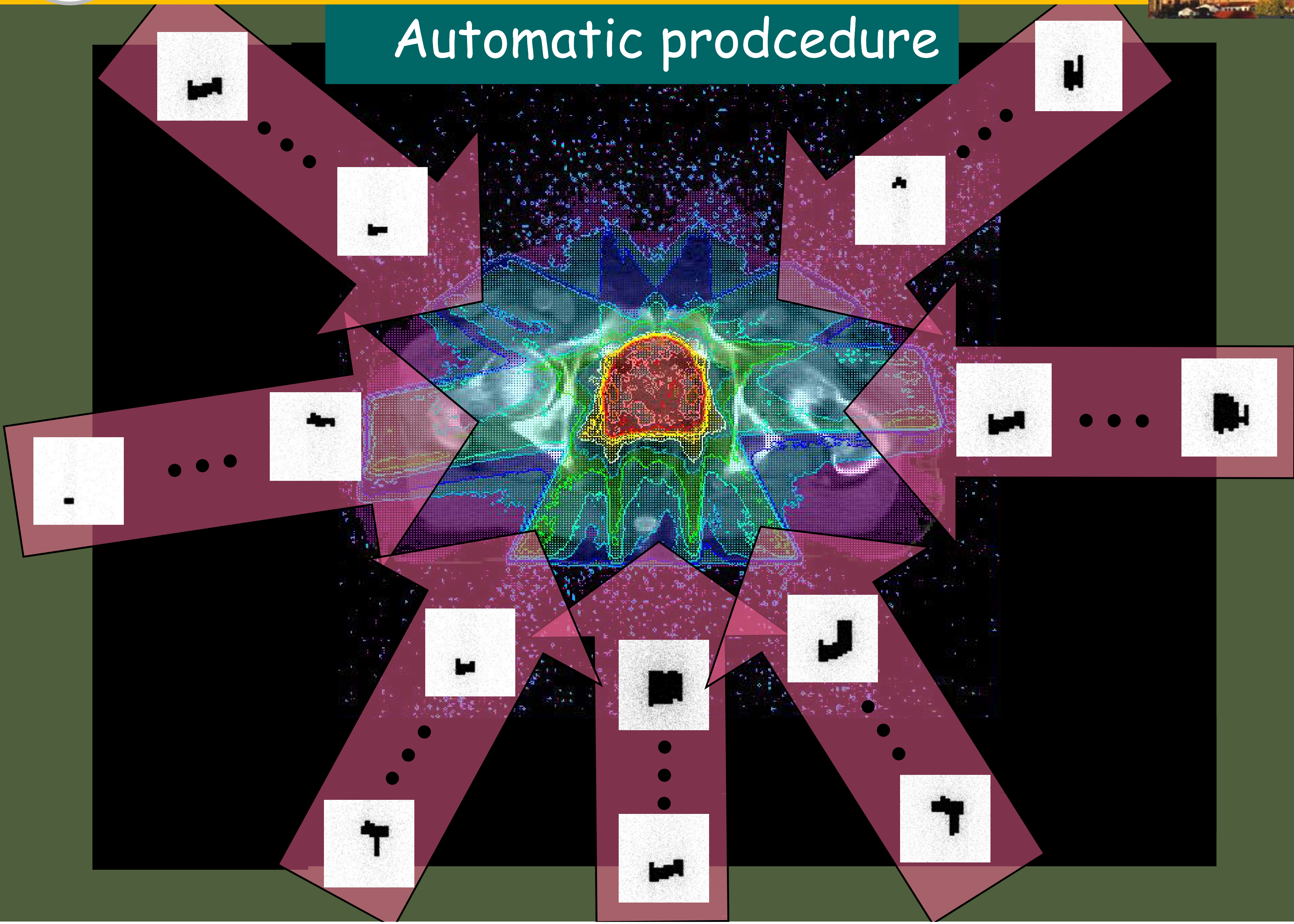
DATA
X y cos
8,34,5,6678, 45 67 46 4634 7856 567W45
W4,56,89 745 346 656 3446 43
99H,675,32, 89 456235 45
986 78 6743 9 8 263 02449237 94 7349
40457 5 5235 6 5634534557 235RTNHJ
4515 31451 3435

LINAC

MONTE CARLO



Automatic prodcedure



Two histories are statistical independent

SERVERS

6 Pentium IV 3 GHz, 1 GB RAM, HD – 250 GB

----

144 CPUs PIII (72) – PIV (72)

432 GHz, 60.4 GB RAM

HD: 9 TB

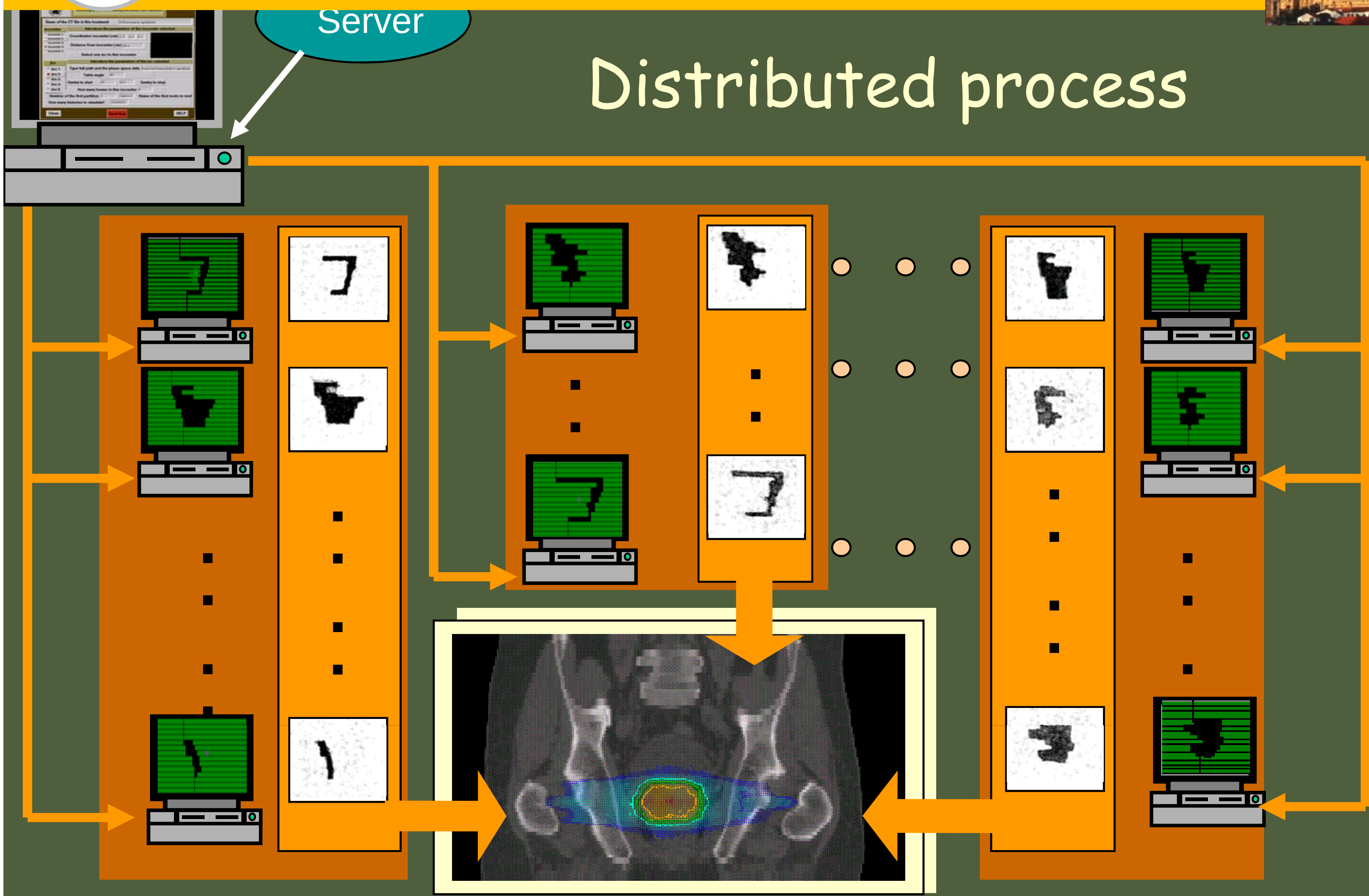
3 Switch 3Com

48 - 10/100 Mbps

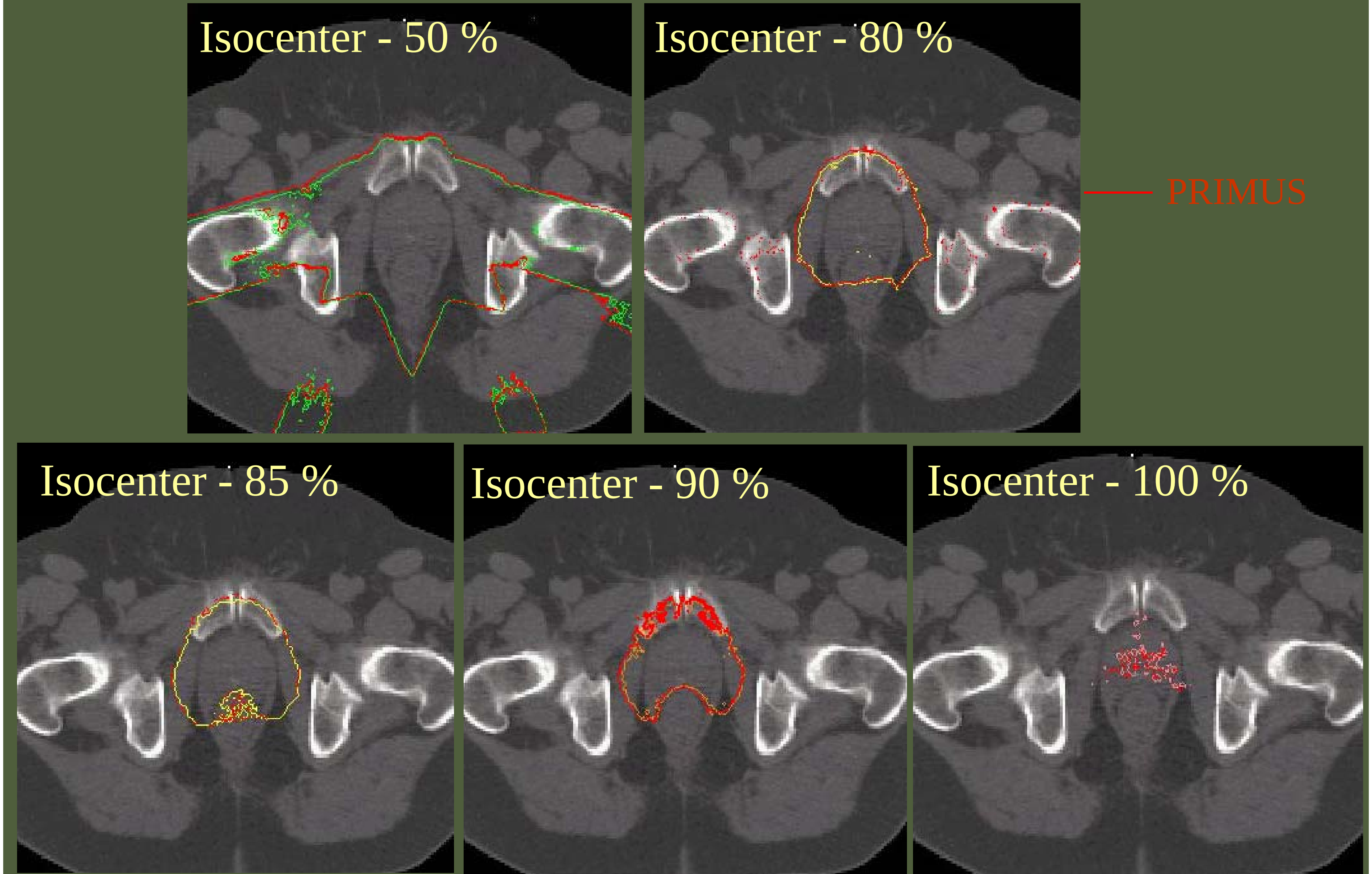
24 – 1Gbps

6 – 1 Gbps to Server

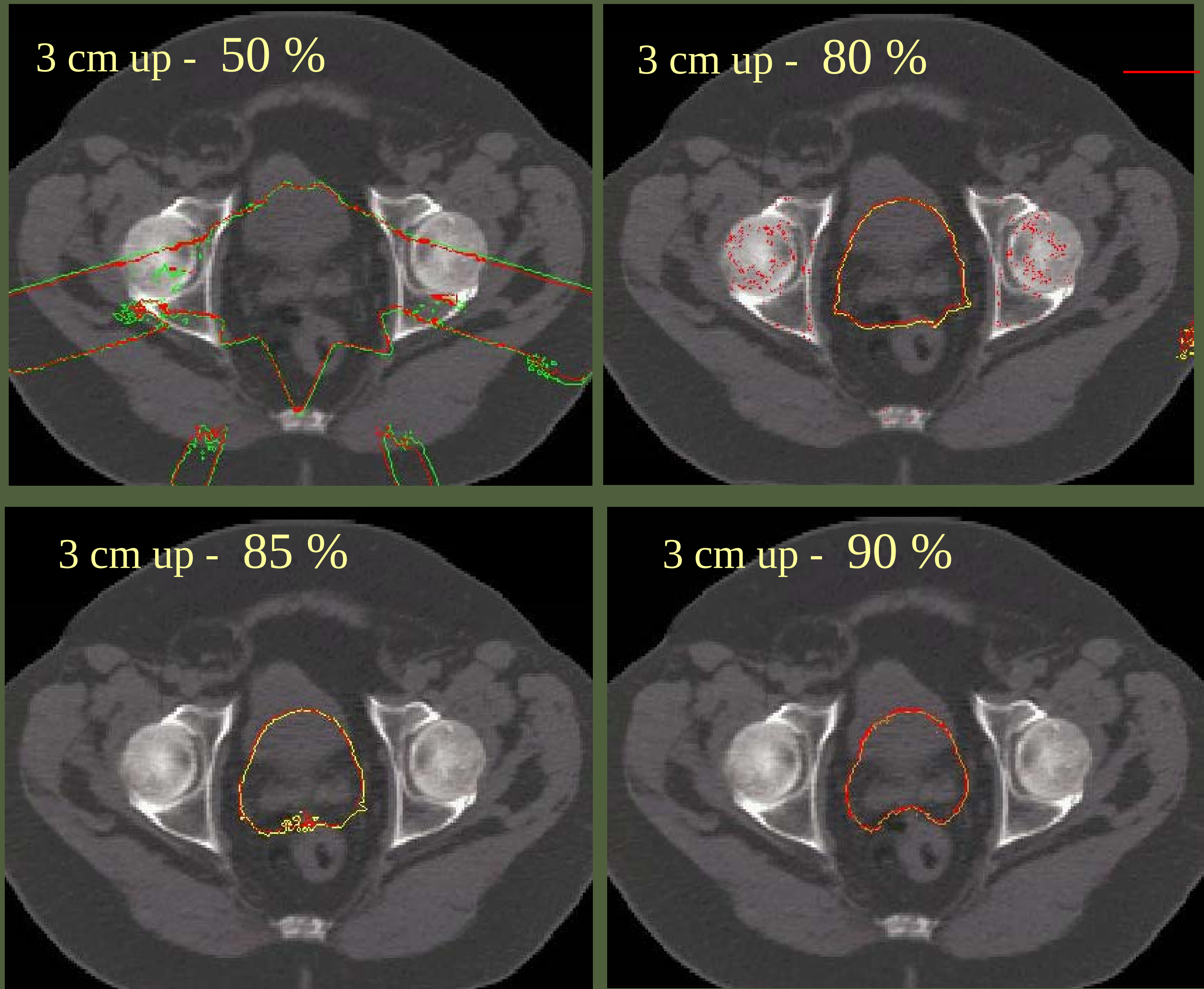
Distributed process



Routine IMRT verification by means of an automatic MC simulation system.
Leal et al. *Int. J. Rad. Oncol. Biol. Phys.* 2003; 56(1):58-68

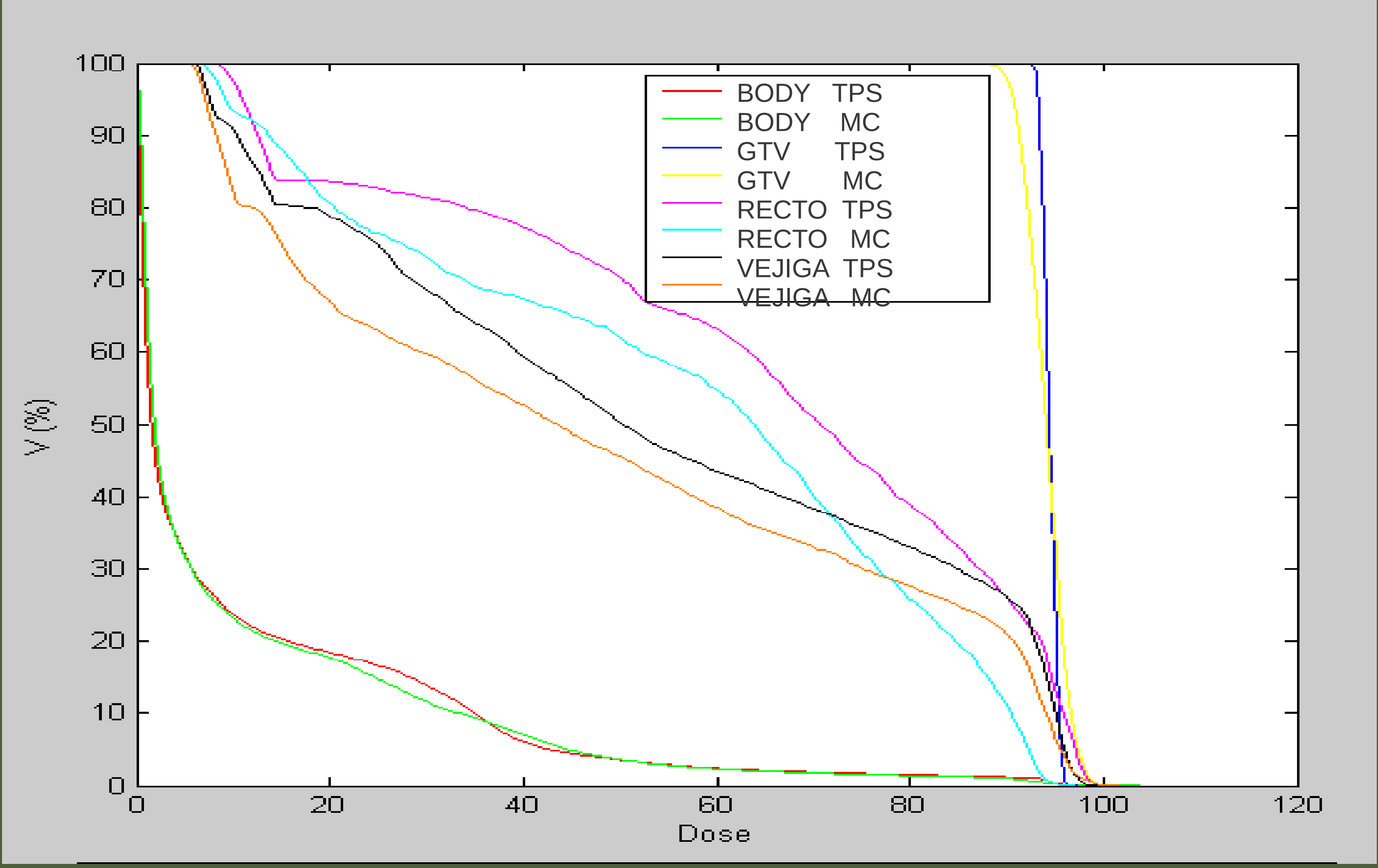

Isocenter - 50 %
Isocenter - 80 %
PRIMUS
Isocenter - 85 %
Isocenter - 90 %
Isocenter - 100 %

Radiotherapy optimization methods for modulated beams in Monte Carlo treatment planning

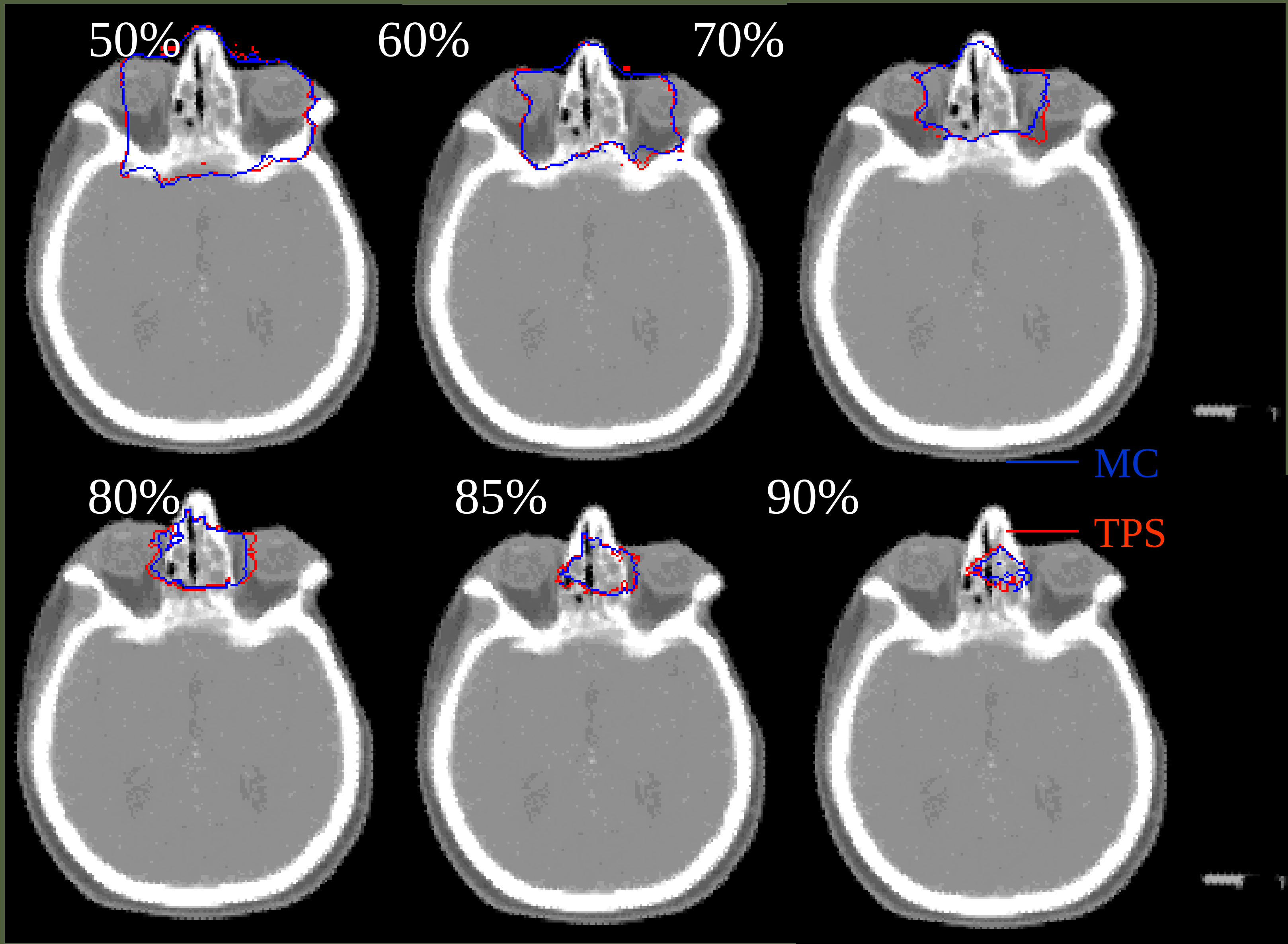


PRIMUS

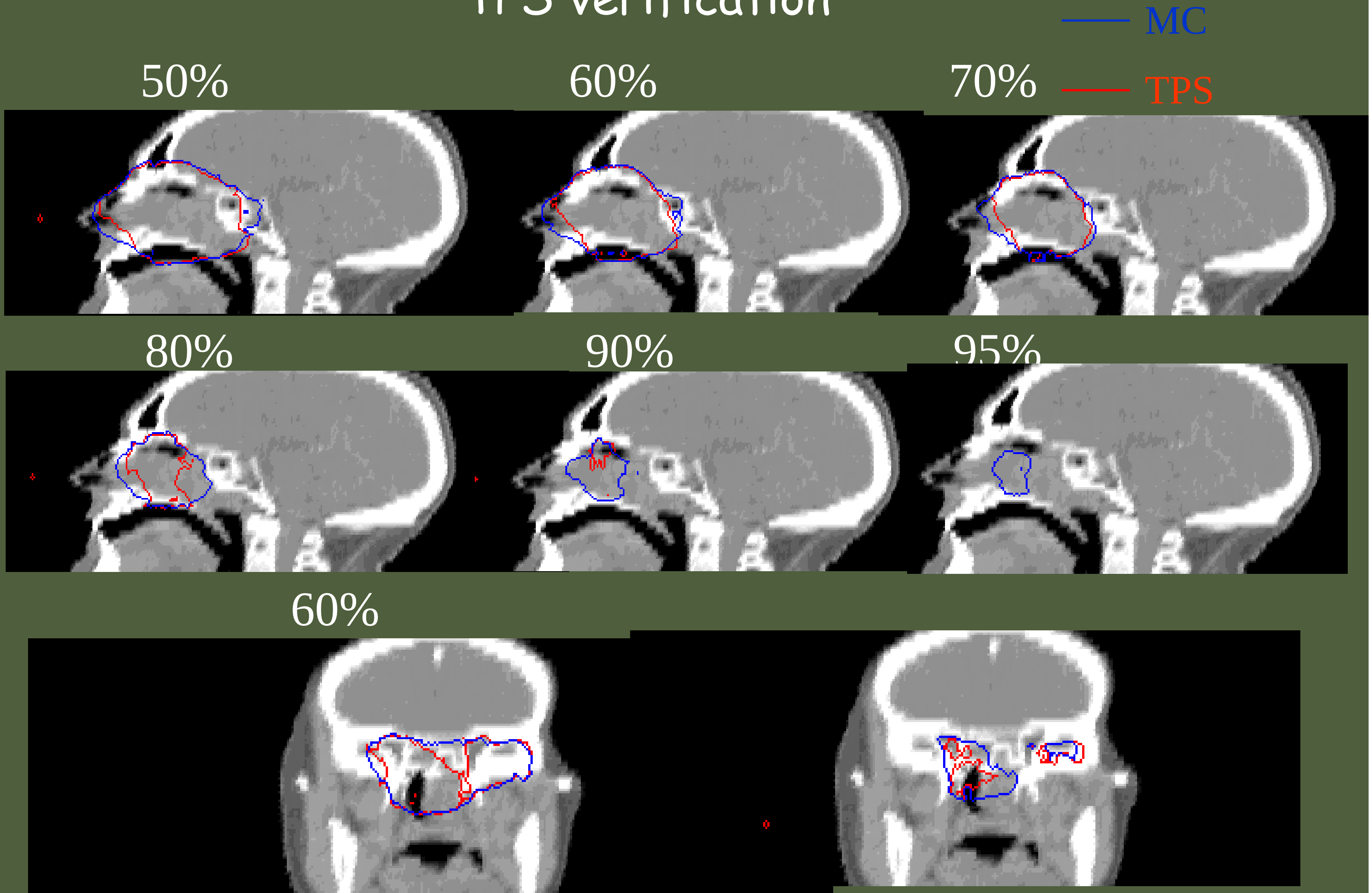
TPS verification



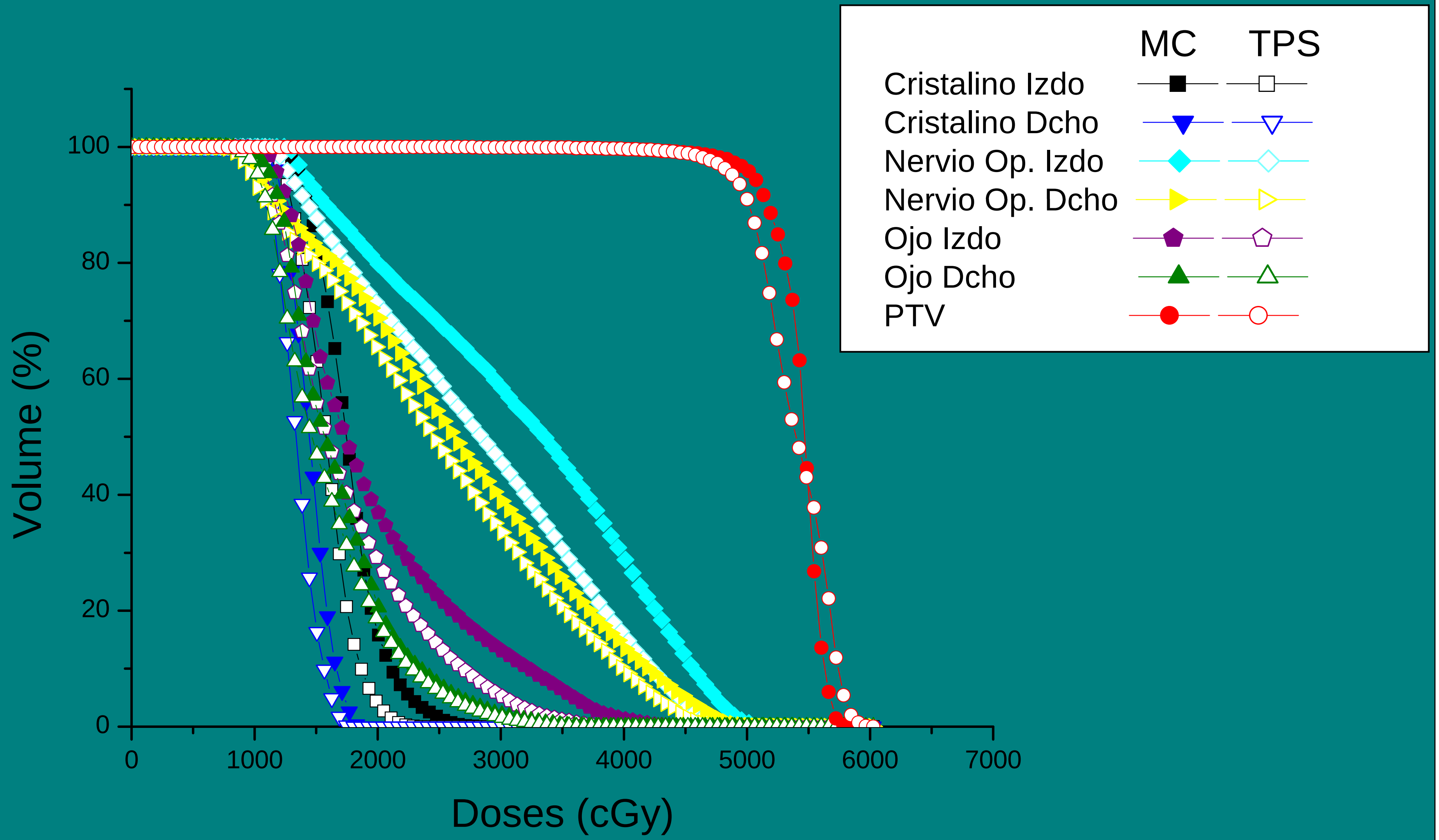
TPS verification



TPS verification



TPS verification



Modulated electron Radiotherapy (MERT)

"there is no alternative treatment to electron beam therapy"

G. H. Fletcher, "Clinical applications of the electron beam," N. Tapley, ed. (New York, Wiley), 1976:1.

R. Mohan, T. D. Brown, D. Kuban, …..

Shallow Tumors (< 7 cm depth)

Chest wall and no deep breast cancer (< 7 cm)

- Accelerated Partial Breast Irradiation (APBI)

Head and Neck

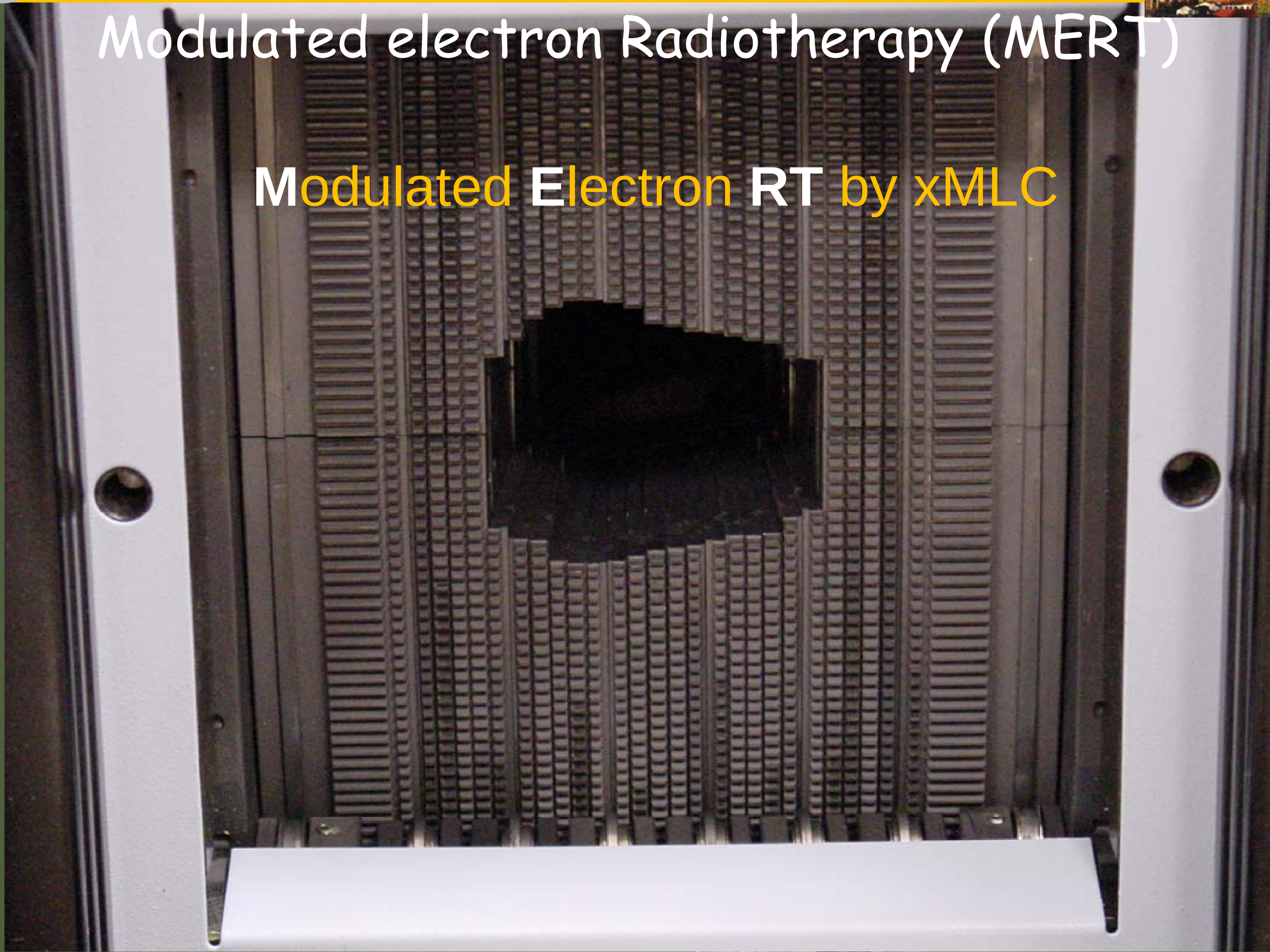
Lip and skin

Boost to nodes

Potential combination with photon IMRT

- Simulatenous Irradiated Boost (SIB)

Modulated electron Radiotherapy (MERT)



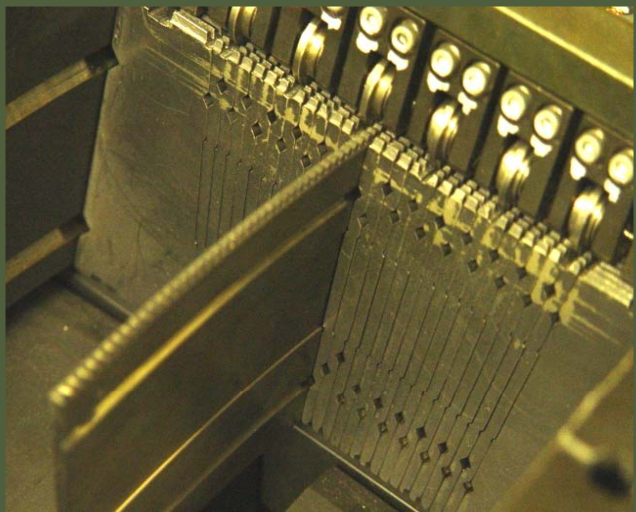
Modulated Electron RT by xMLC

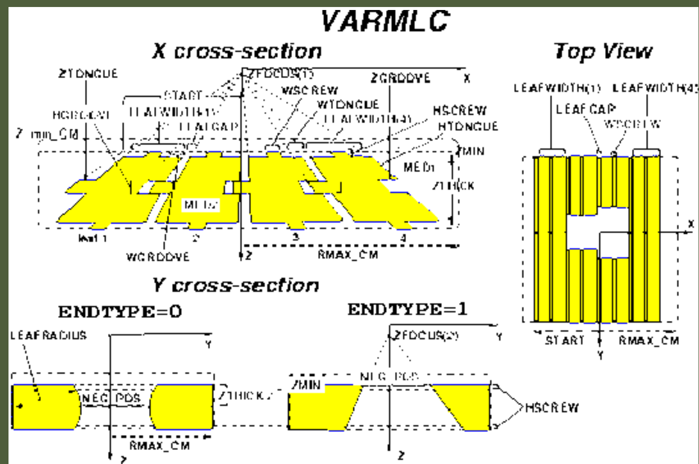
Modulated electron Radiotherapy (MERT)

Kudchadker et al. stated the xMLC as the ***"most attractive"*** option for the future when ***"electron scattering from leaf ends, leaf leakage, and bremsstrahlung production, were taken into account in the computation of dose".*** Int J Radiat Oncol Biol Phys, 53(4):1023–37, 2002.

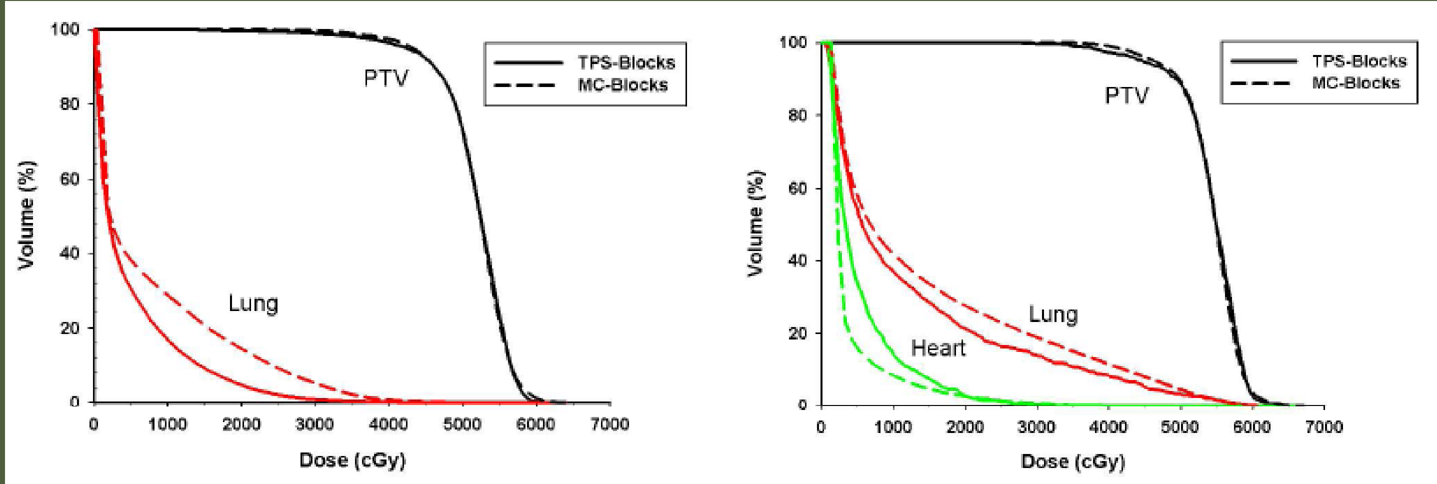
The solution is MERT by means of MCTP:

- Full MC simulation
- Not ray-tracing method.

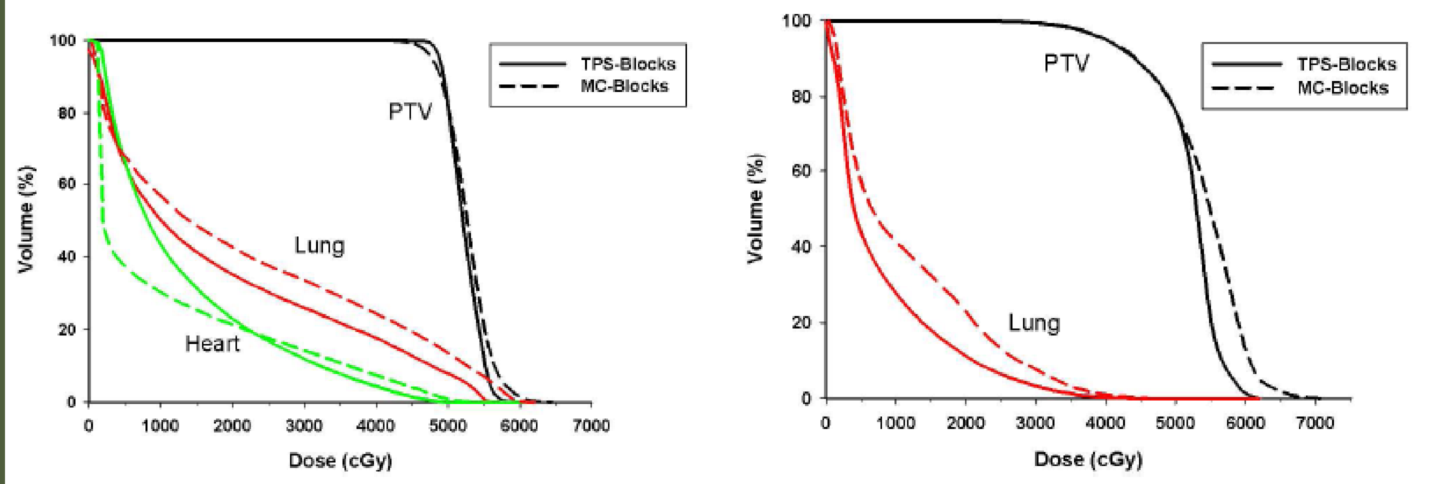




Monte Carlo Treatment Planning is required for shaped electron beams

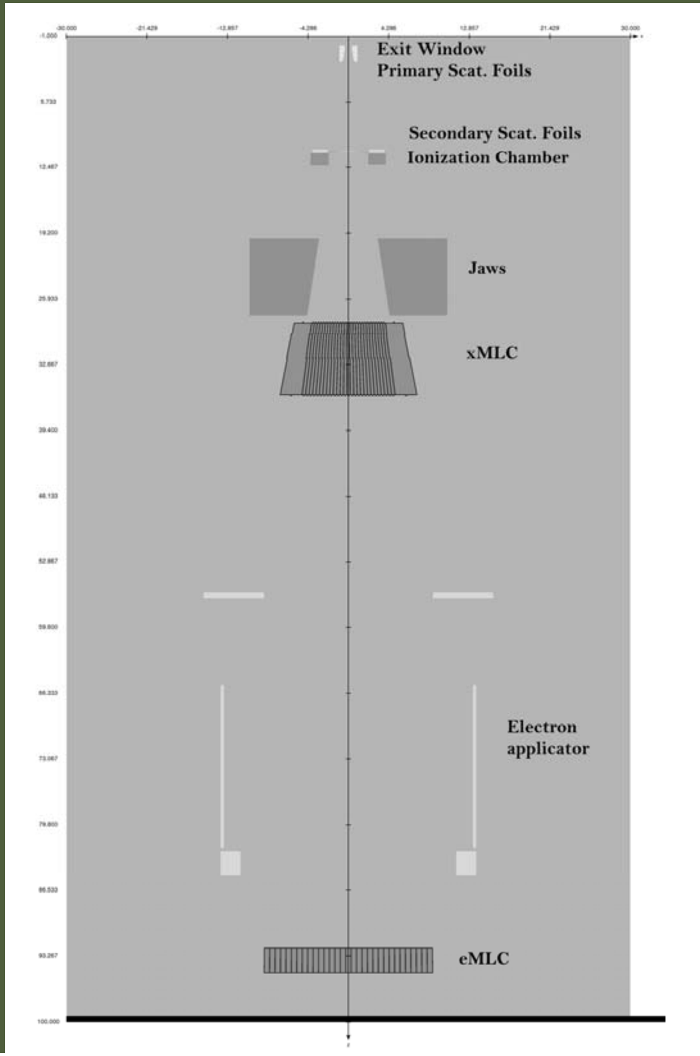


TPS(pencil beam) vs MC

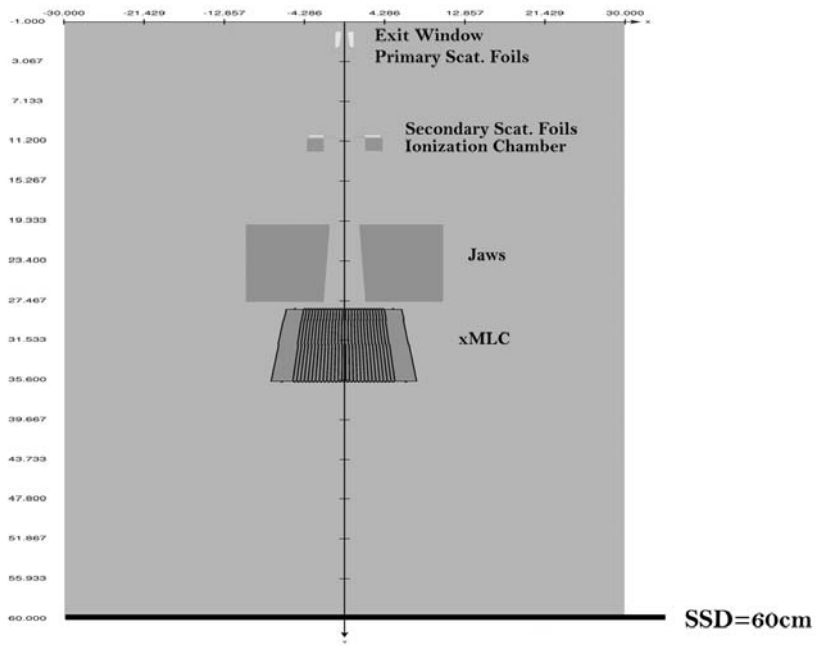


Monte Carlo Treatment Planning for MERT + IMRT

IMRT setup

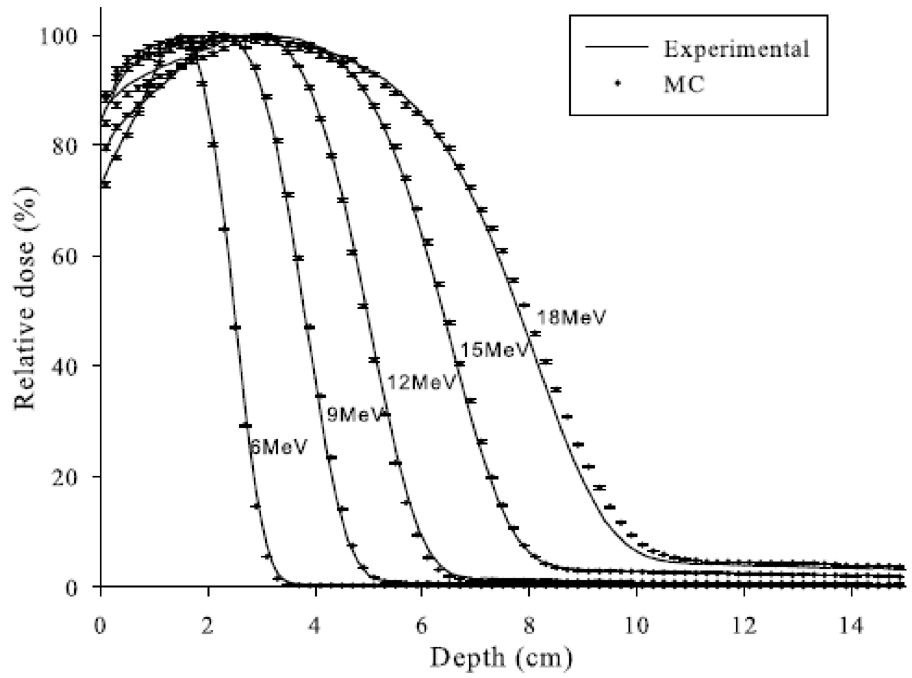


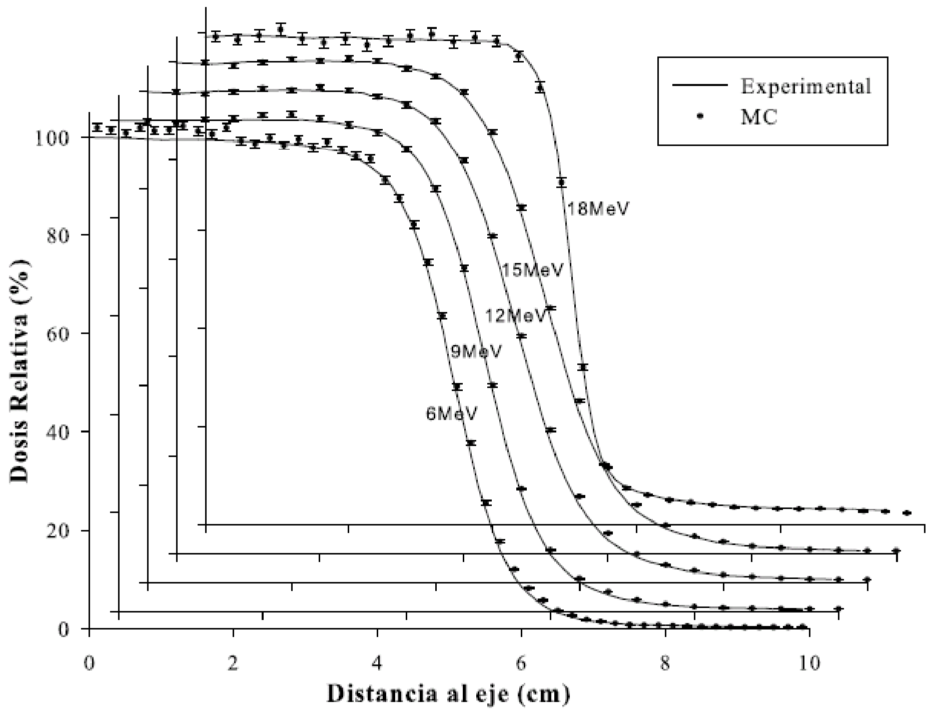
MERT setup



Monte Carlo Treatment Planning for MERT + IMRT

MC simulation and experimental data fit
SSD= 60cm (9x9 cm^2)





Monte Carlo Treatment Planning for MERT + IMRT
Feasibility of the xMLC for electron beams

0.6x0.6 cm^2

Energy (MeV)	$\%D_s$	$\%D_x$	R_{90}	R_{50}	R_p	G
6	94.9(97.8)	0.8(0.1)	1.3(0.5)	2.3(1.1)	3.1(1.9)	2.2(1.4)
9	93.5(96.3)	2.5(0.6)	1.5(0.7)	2.9(1.7)	4.5(2.9)	1.5(1.4)
12	92.7(95.7)	3.3(0.9)	1.5(0.7)	3.3(1.9)	4.9(3.3)	1.4(1.3)
15	86.4(96.8)	8.0(2.2)	1.7(1.1)	3.9(2.3)	5.7(3.5)	1.4(1.4)
18	91.3(94.1)	6.7(3.6)	1.7(1.3)	3.7(2.7)	5.3(4.1)	1.4(1.4)

3.0x3.0 cm^2

Energy (MeV)	$\%D_s$	$\%D_x$	R_{90}	R_{50}	R_p	G
6	81.5(80.5)	0.1(0.1)	1.7(1.7)	2.3(2.3)	3.7(2.9)	2.6(2.5)
9	91.1(84.8)	0.2(0.3)	2.5(2.5)	3.5(3.5)	4.7(4.7)	2.4(2.2)
12	93.1(87.2)	0.5(0.6)	2.7(2.9)	4.5(4.5)	5.9(5.9)	2.0(2.2)
15	91.3(87.2)	1.5(1.9)	2.9(3.5)	5.3(5.3)	7.7(7.3)	1.7(2.0)
18	90.2(87.2)	2.8(3.8)	3.5(4.1)	6.3(6.3)	8.9(8.5)	1.6(1.8)

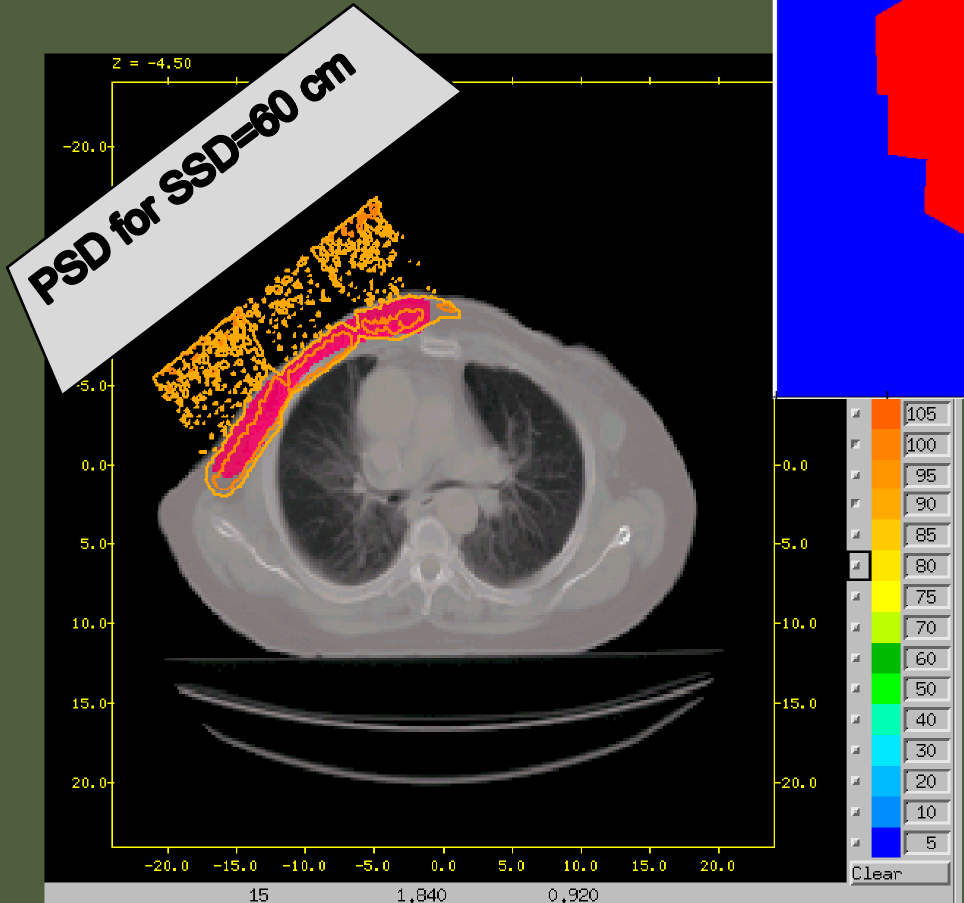
5.4x5.4 cm^2

Energy (MeV)	$\%D_s$	$\%D_x$	R_{90}	R_{50}	R_p	G
6	75.0(76.2)	0.1(0.1)	1.9(1.7)	2.3(2.3)	3.1(2.9)	2.7(2.5)
9	78.6(82.4)	0.2(0.3)	2.9(2.9)	3.7(3.7)	4.7(4.7)	2.9(2.9)
12	82.7(86.2)	0.4(0.6)	3.7(3.7)	4.9(4.9)	5.9(5.9)	2.9(3.0)
15	86.8(89.2)	1.5(2.1)	4.5(4.5)	6.1(6.3)	7.7(7.5)	2.6(3.0)
18	85.7(88.5)	3.1(3.9)	5.1(4.9)	7.5(7.7)	9.7(9.5)	2.4(2.5)

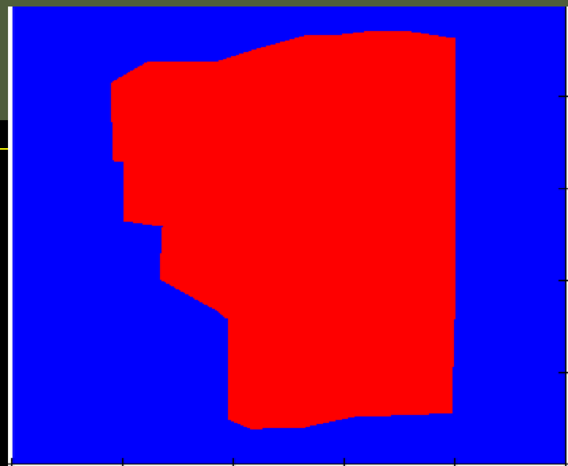
9.0x9.0 cm^2

Energy (MeV)	$\%D_s$	$\%D_x$	R_{90}	R_{50}	R_p	G
6	72.7(73.8)	0.1(0.1)	1.9(1.7)	2.3(2.3)	3.1(2.9)	2.8(2.5)
9	78.1(78.6)	0.3(0.3)	2.9(2.9)	3.7(3.7)	4.7(4.5)	2.9(2.8)
12	83.4(79.8)	0.5(0.6)	3.9(3.7)	4.9(4.7)	5.9(5.7)	3.0(3.1)
15	88.2(86.2)	1.7(2.2)	4.9(4.7)	6.3(6.3)	7.7(7.5)	3.0(3.1)
18	88.3(86.7)	3.3(4.0)	5.5(5.5)	7.9(7.9)	9.7(9.5)	2.9(3.1)

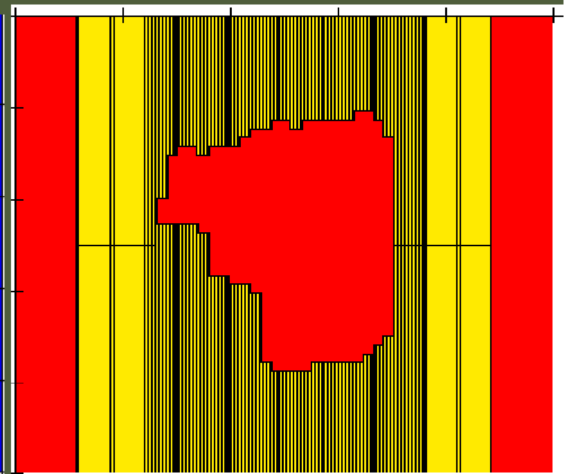
xMLC segments with SSD=60cm instead of cut-outs with SSD=100cm



Cut-out



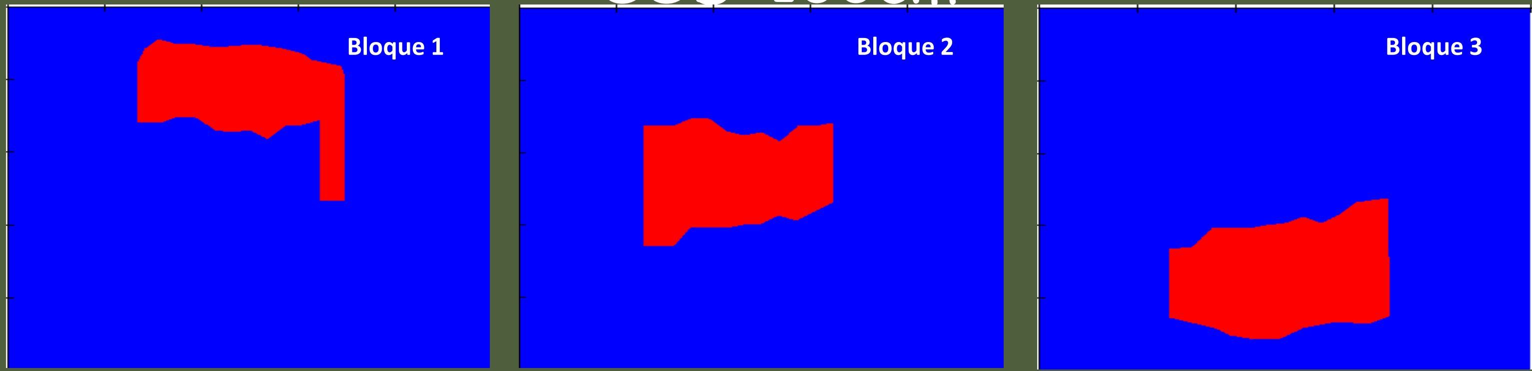
xMLC



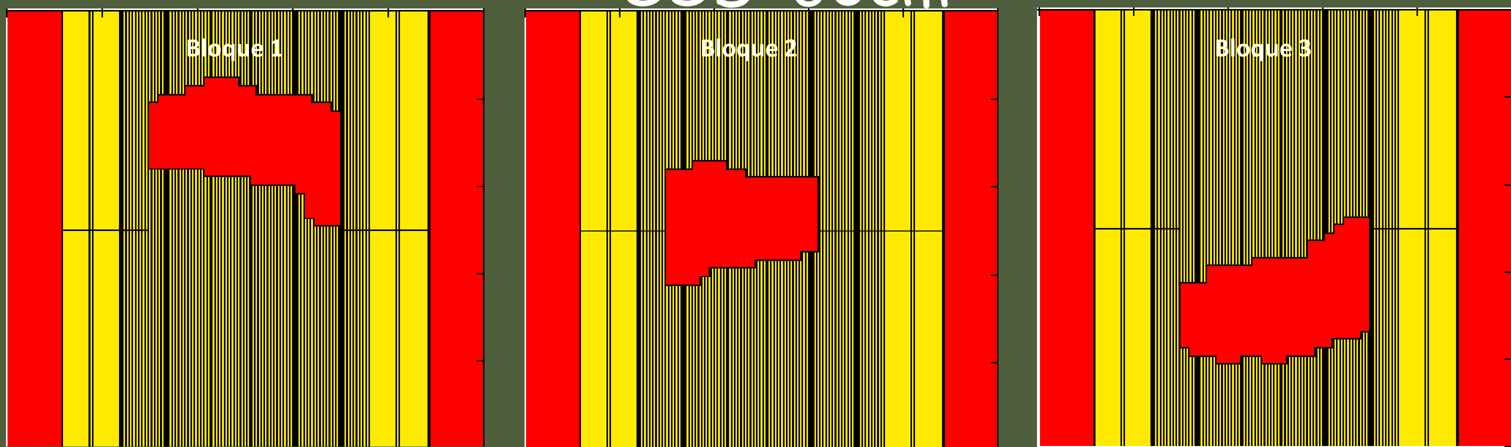
Chest wall

3 cut-outs
One with 6 MeV
Two with 9 MeV
Prescribed dose:
50 Gy at 90%

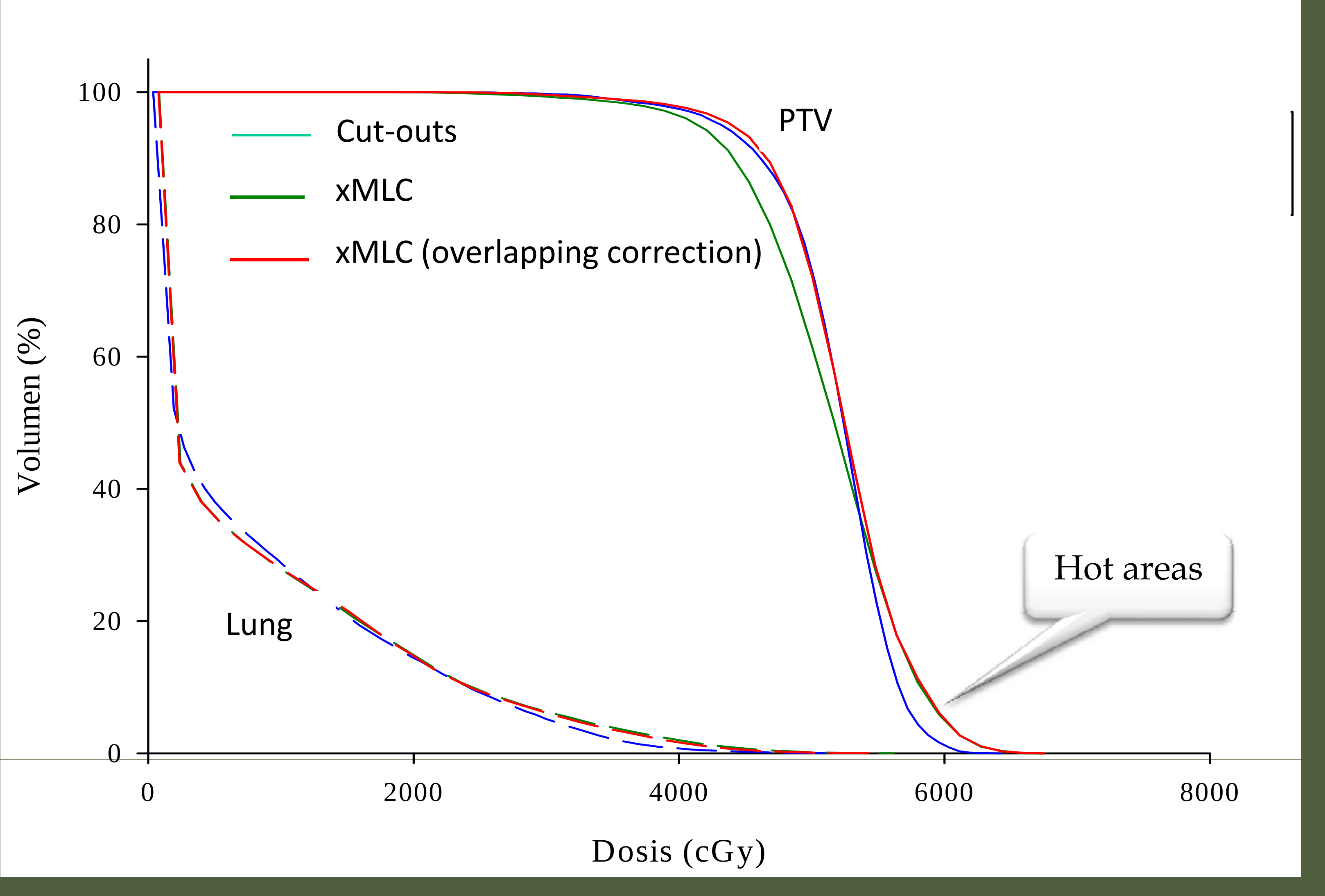
Cut-outs with BEAMnrc (Block CM)
SSD=100cm

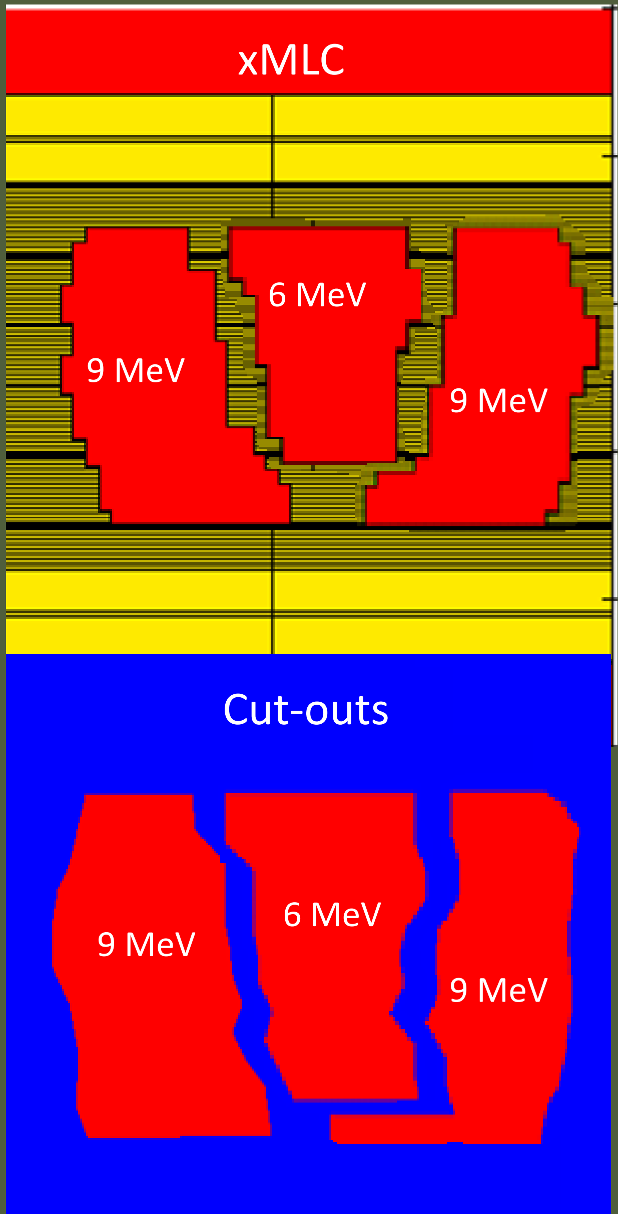


xMLC segments with BEAMnrc (VARMLC CM)
Divergence correction
SSD=60cm

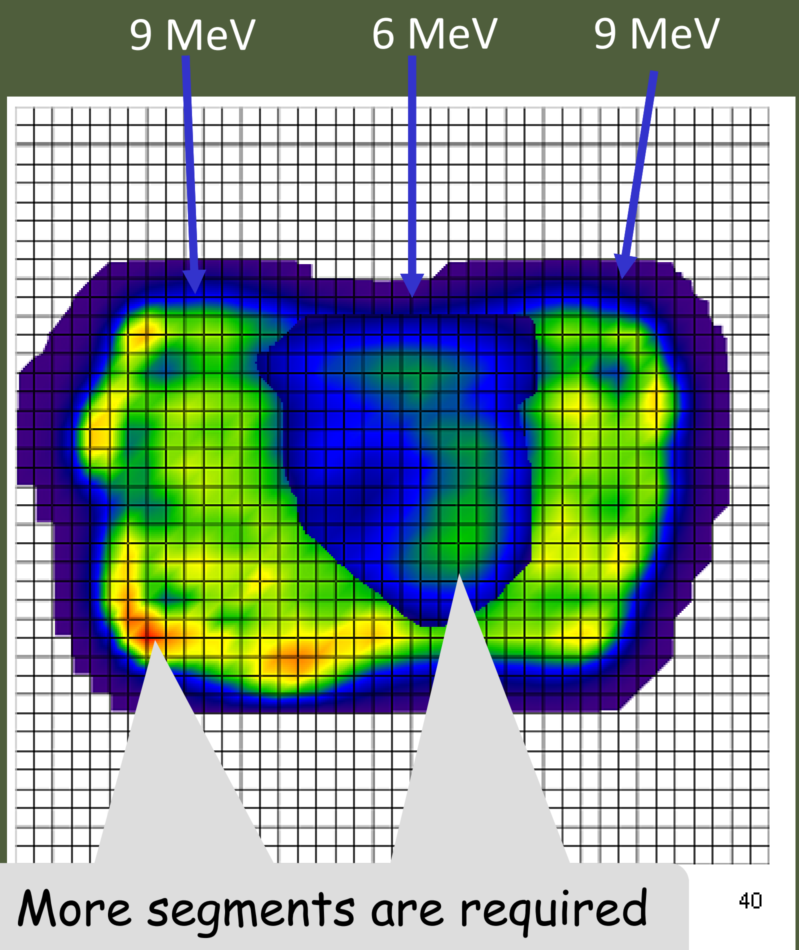


Larger distance from the MLC to the patient





Optimised beamlets to get a better dose distribution



More segments are required

Segments for weighting optimization process.

Options:

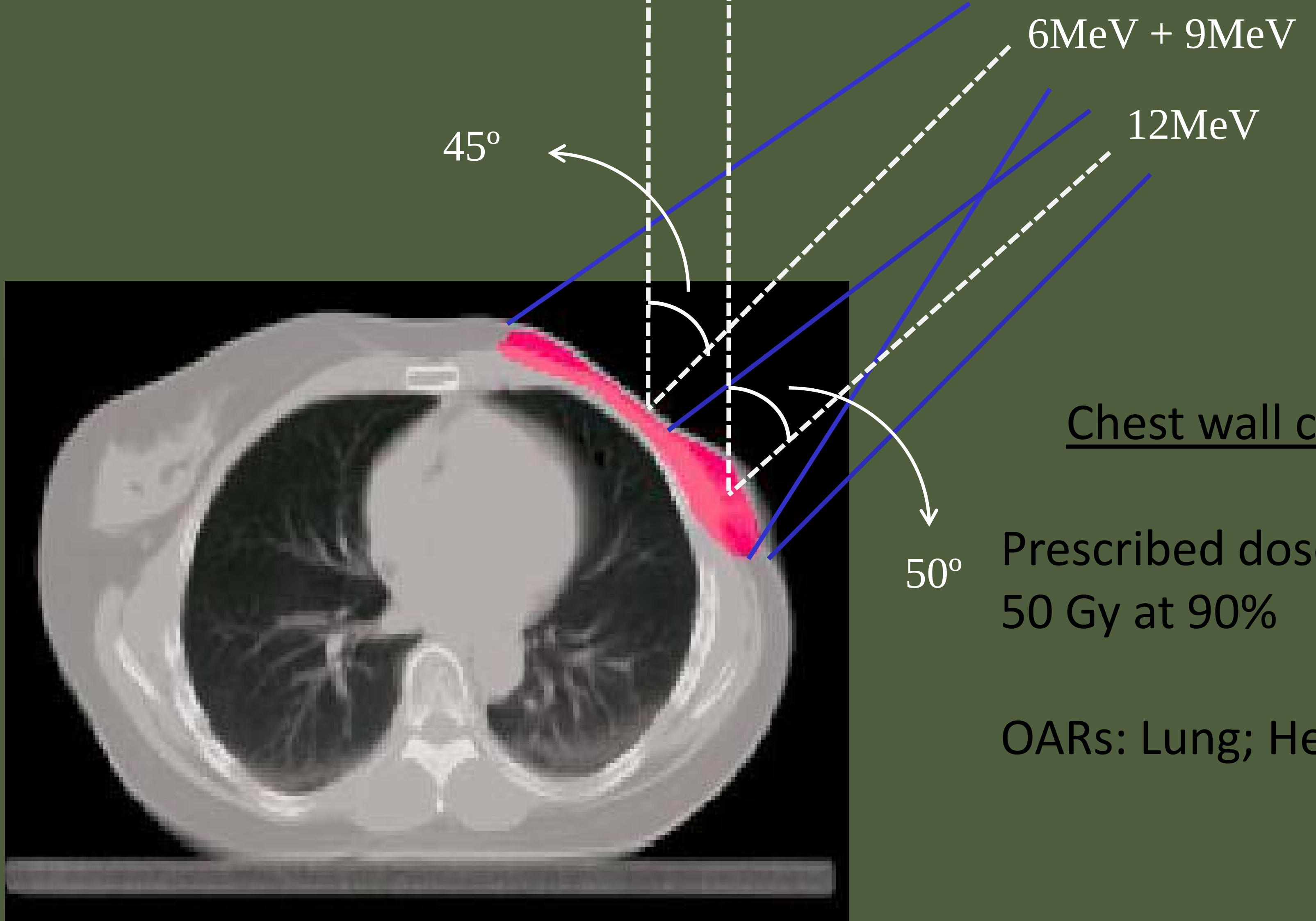
1. Inverse planning optimization procedure: (beamlets weighted for a sequencer)

2. Class solutions based on the experience: (Direct Aperture optimization)

3. A hybrid optimization system (Under construction)

Inverse planning optimization

1° Stage: Incidence angle and energy beams selection



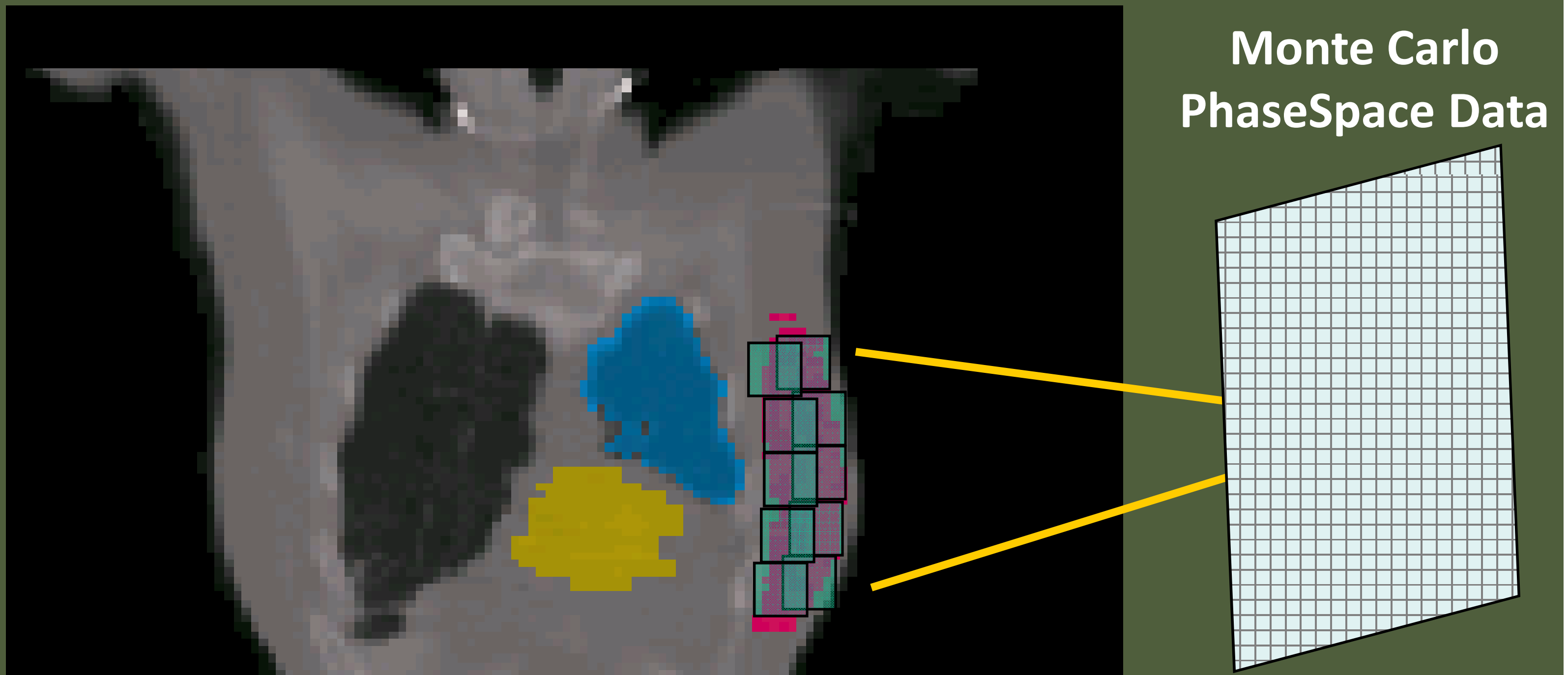
Chest wall case

Prescribed dose:
50 Gy at 90%

OARs: Lung; Heart

Inverse planning optimization

2° Stage: Optimised Beamlets distribution



$$\text{mín} \quad \left\{ F = \theta_{\mathcal{O}} \sum_{(x,y,z)\in\mathcal{O}} \sum_{p=1}^{N} \omega_p D_p(x,y,z) + \theta_{\mathcal{P}} \sum_{(x,y,z)\in\mathcal{P}} \sum_{p=1}^{N} \omega_p D_p(x,y,z) \right\} :$$

$$d_{max} \geq D(x,y,z) \geq d_{min} \quad \forall (x,y,z) \in \mathcal{P},$$

$$\omega_m \leq \frac{\alpha}{N} \sum_{p=1}^{N} \omega_p, \quad m = 1,2,\ldots,N,$$

$$\omega_p \geq 0$$

Inverse planning optimization

2° Stage: Optimised Beamlets distribution

$$\text{mín} \quad \left\{ F = \theta_{\mathcal{O}} \sum_{(x,y,z)\in\mathcal{O}} \sum_{p=1}^{N} \omega_p D_p(x,y,z) + \theta_{\mathcal{P}} \sum_{(x,y,z)\in\mathcal{P}} \sum_{p=1}^{N} \omega_p D_p(x,y,z) \right\} :$$

$$d_{max} \geq D(x,y,z) \geq d_{min} \quad \forall (x,y,z) \in \mathcal{P},$$

$$\omega_m \leq \frac{\alpha}{N} \sum_{p=1}^{N} \omega_p, \quad m = 1, 2, \ldots, N,$$

$$\omega_p \geq 0$$

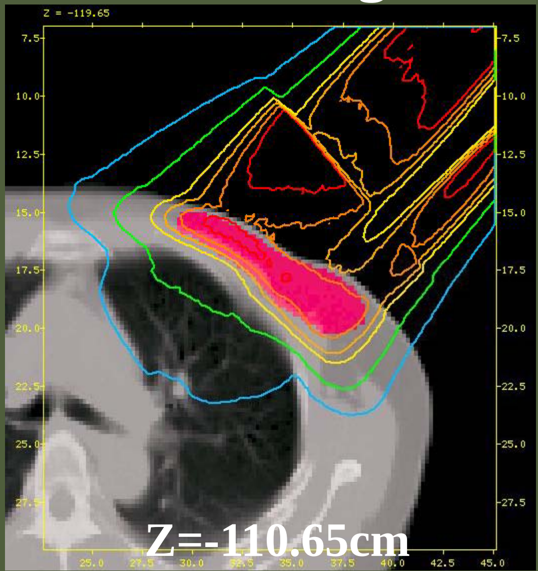
Nonlinear programing (commercially implemented):

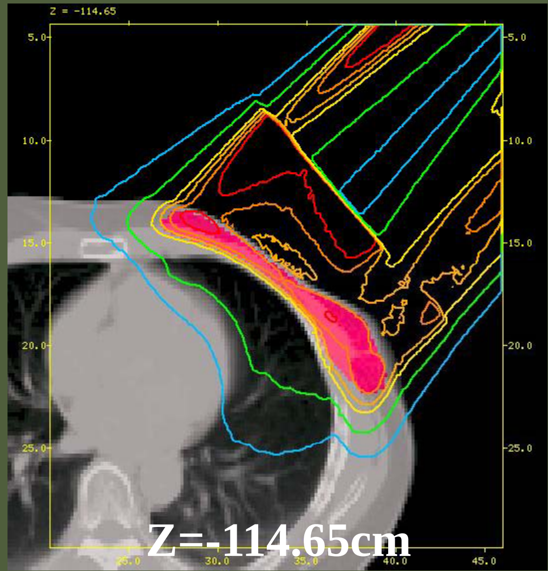
Optimization algorithms:

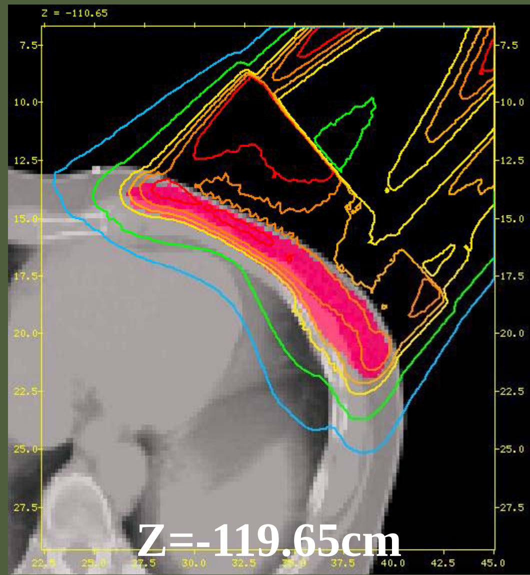
- Gradient method: Newton method; maximun gradient method (Bortfeld 1999, Hristov et al. 2002, Zhang et al. 2004)
- Stocastic algorithm: Simulated annealing method (Rosen et al. 1995, Wu et al. 2000)

Inverse planning optimization

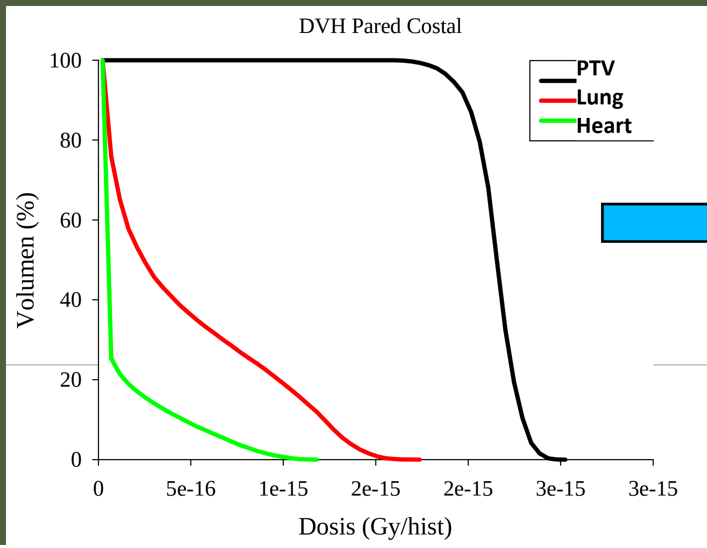
2° Stage: Optimised Beamlets distribution







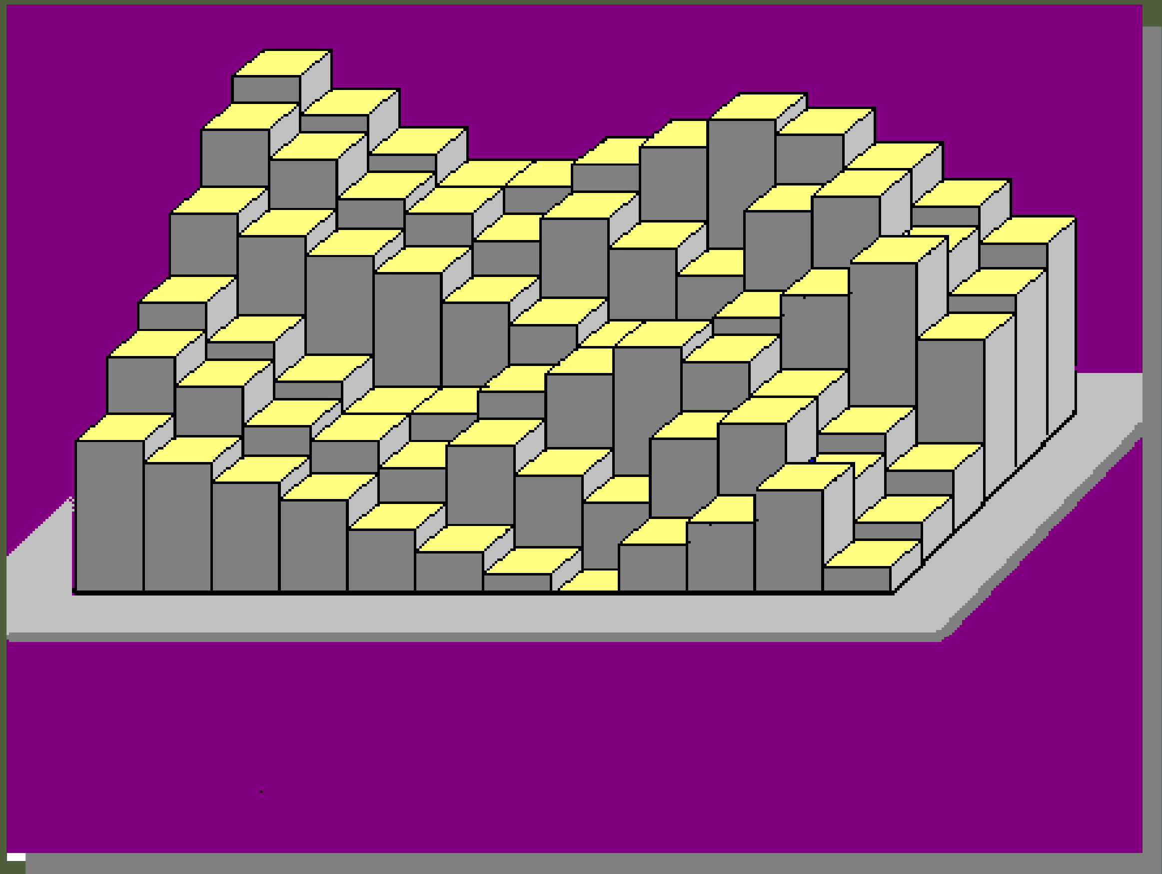
Theoretical DVH with beamlets



Sequencer for the actual segments

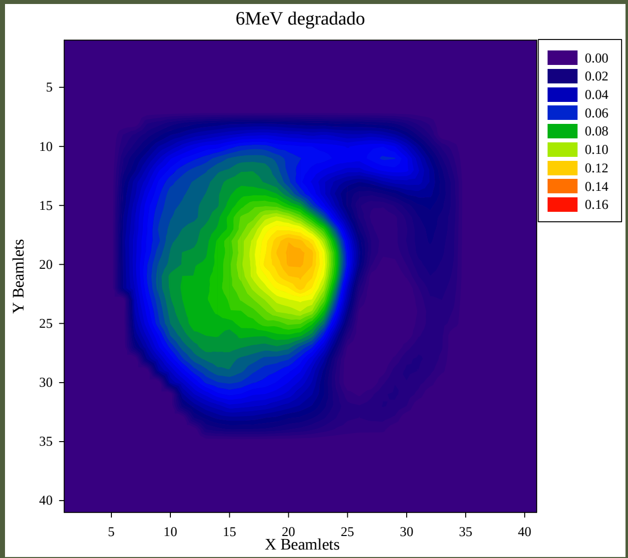
Inverse planning optimization

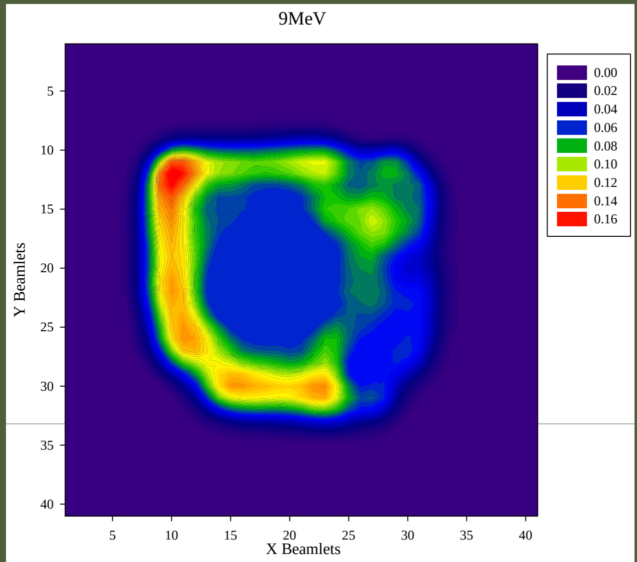
Previous MC analysis for the sequencer

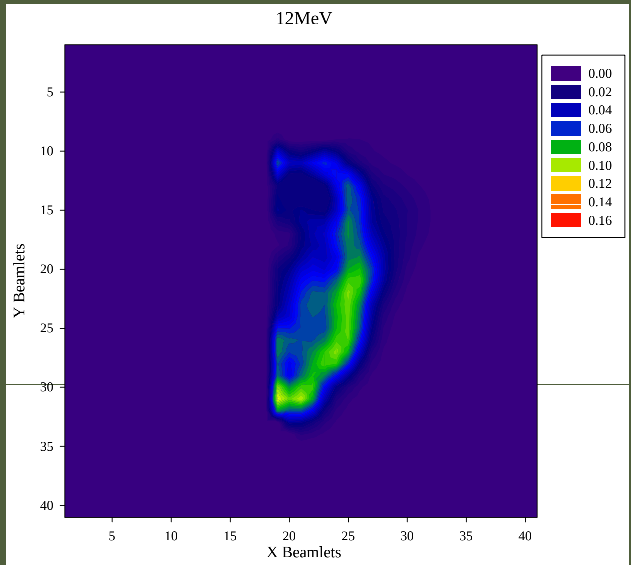


Inverse planning optimization

Fluence maps from the weighted beamlets

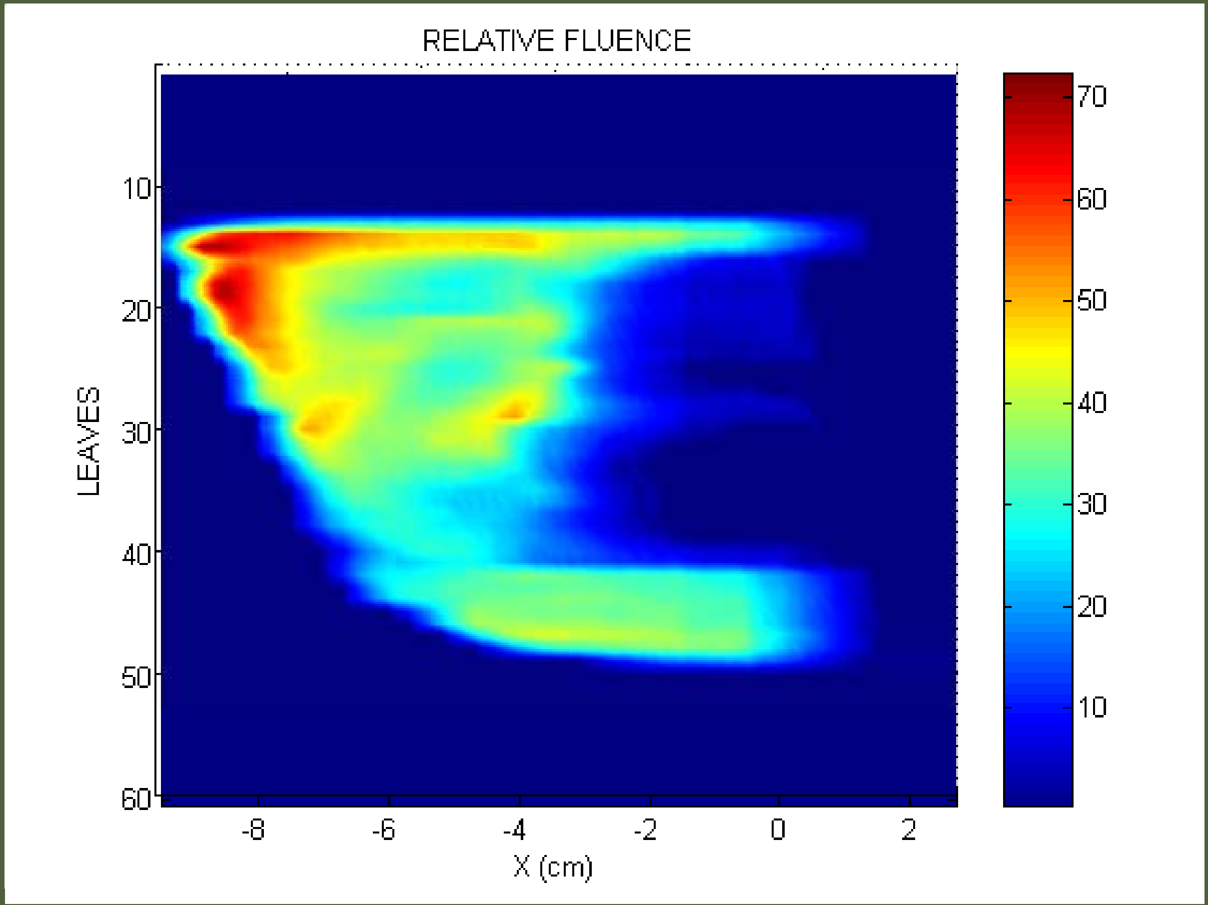






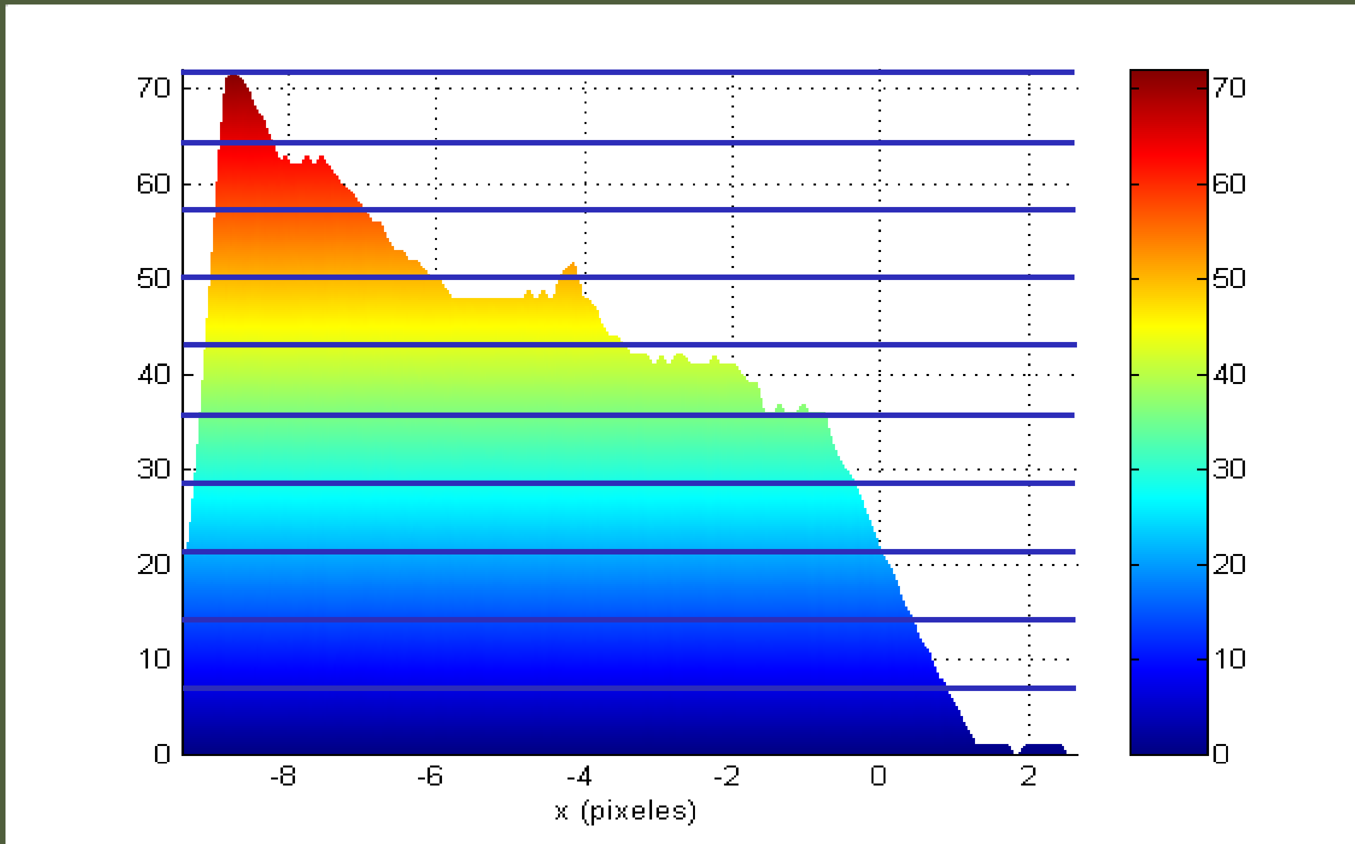
Inverse planning optimization

3° Stage: Segmentation procedure



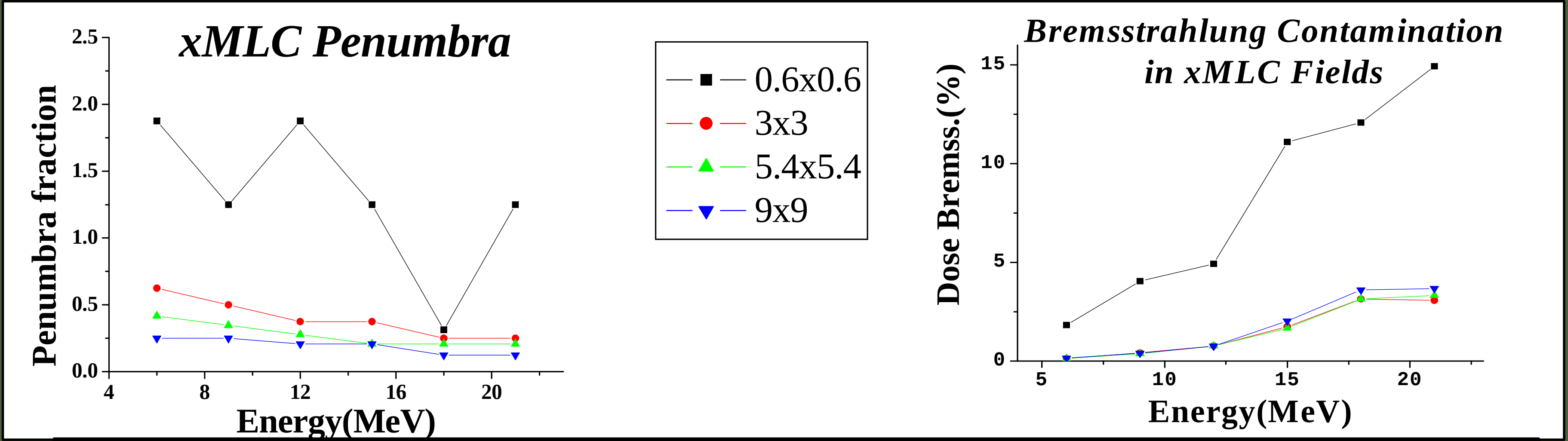
Inverse planning optimization

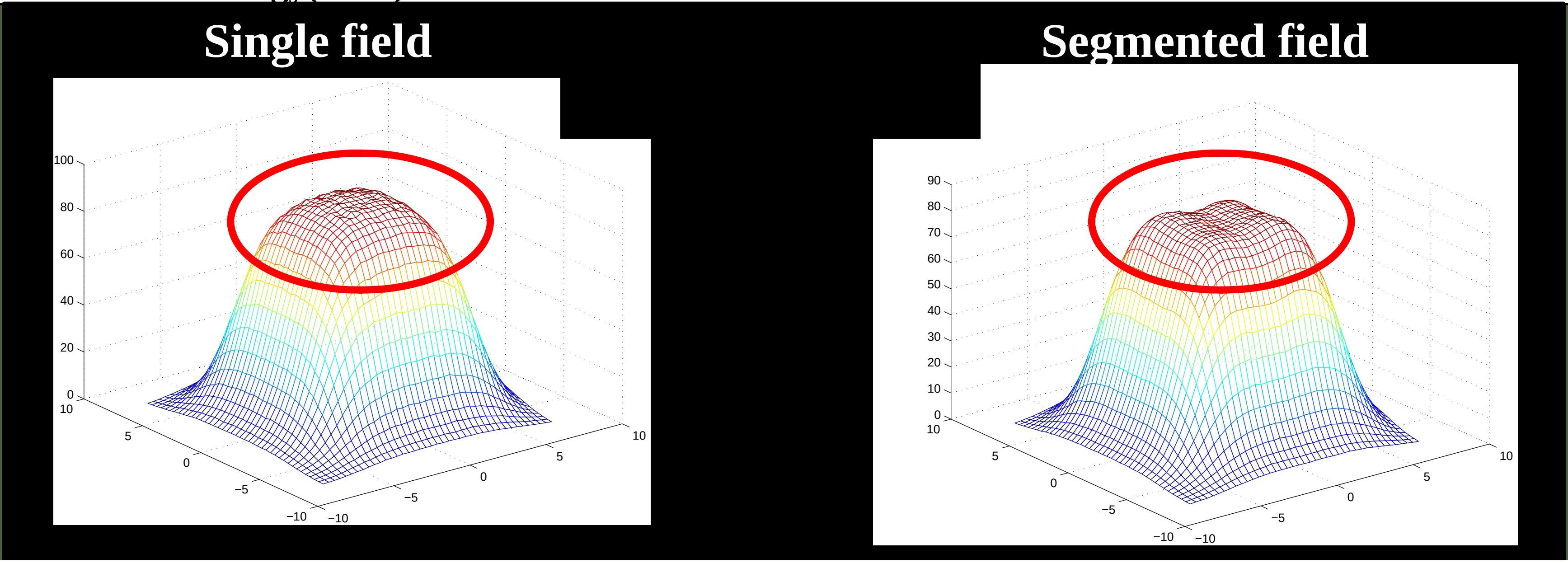
3° Stage: Segmentation procedure



Inverse planning optimization

Previous MC analysis for the sequencer

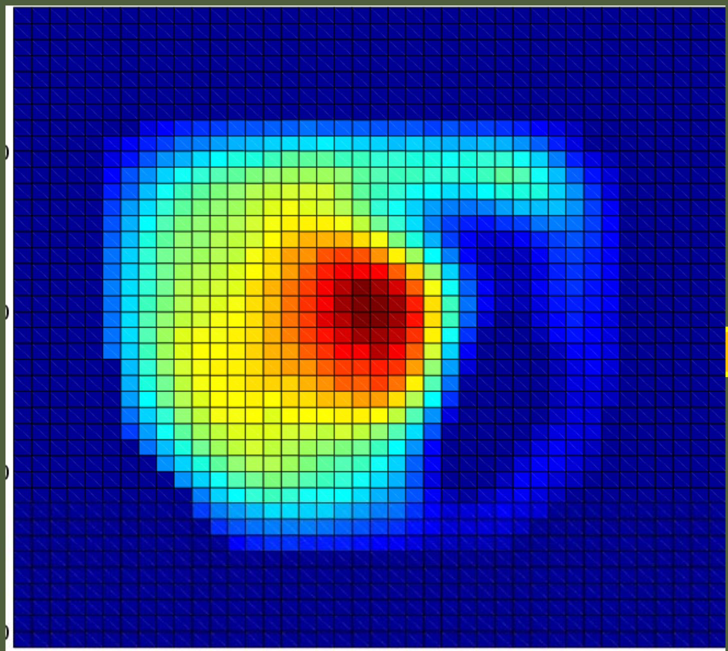


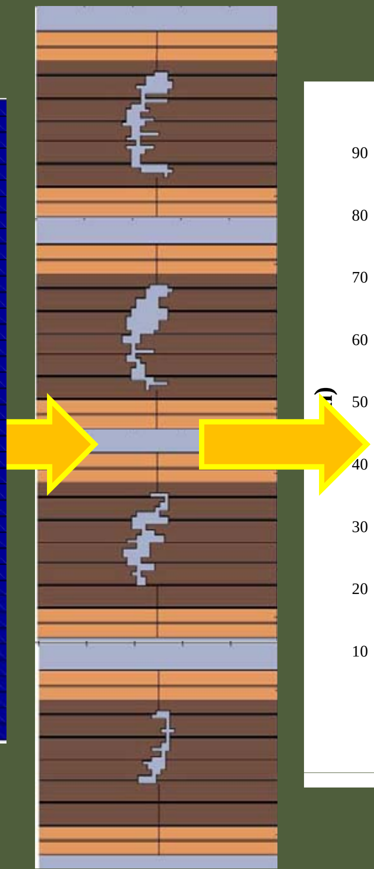


Inverse planning optimization

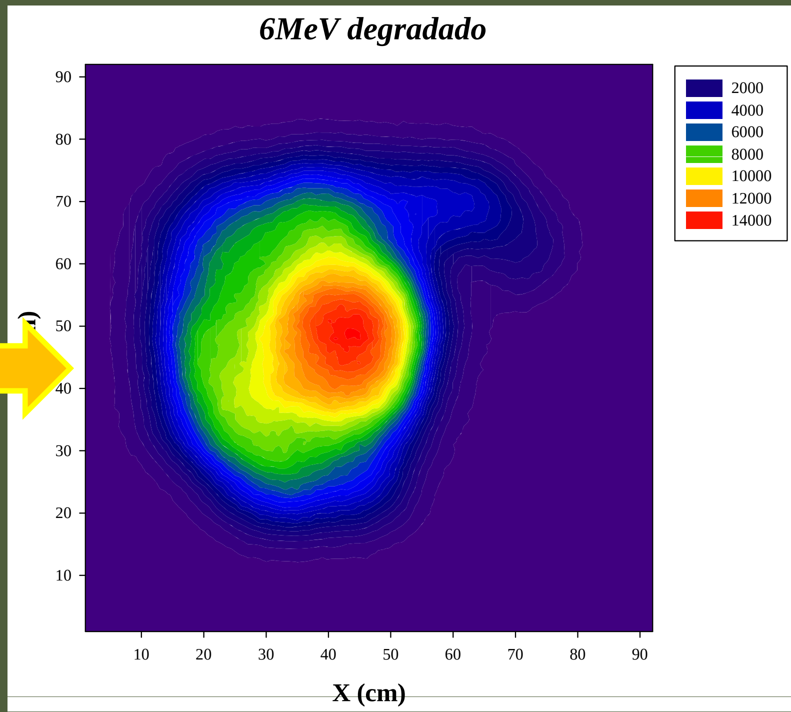
3° Stage: Segmentation procedure

Beamlets fluence





Segments fluence

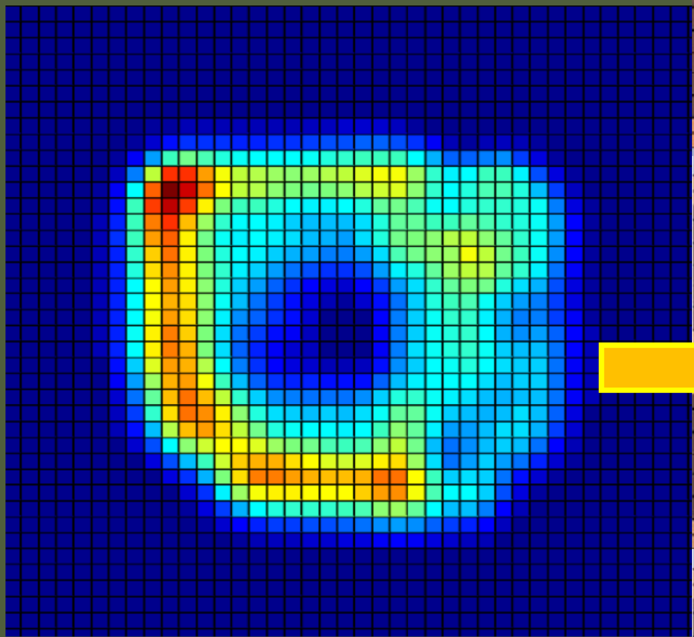


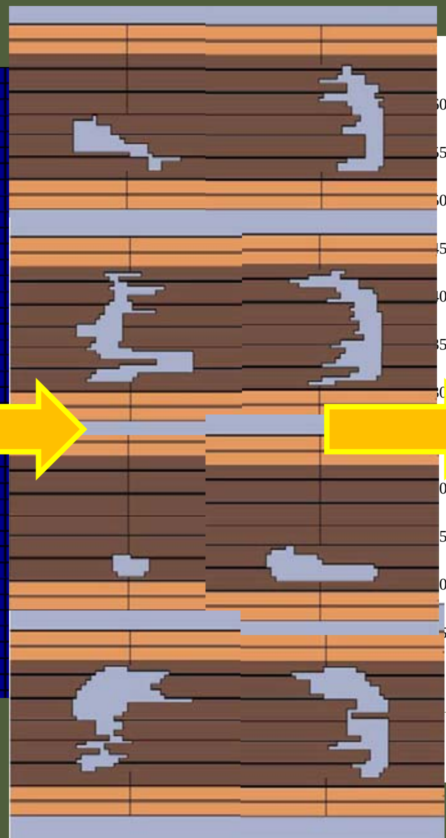
Inverse planning optimization

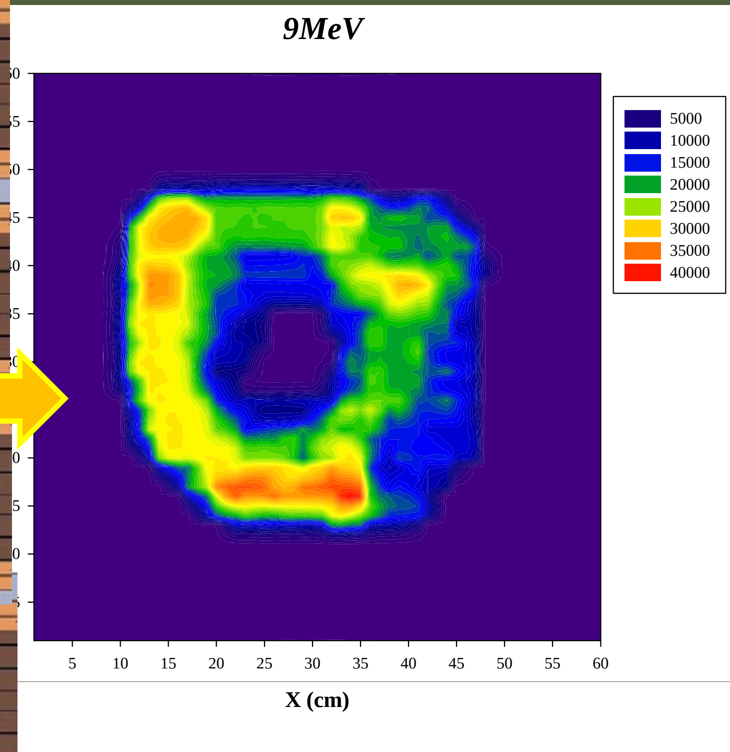
3° Stage: Segmentation procedure

Beamlets fluence

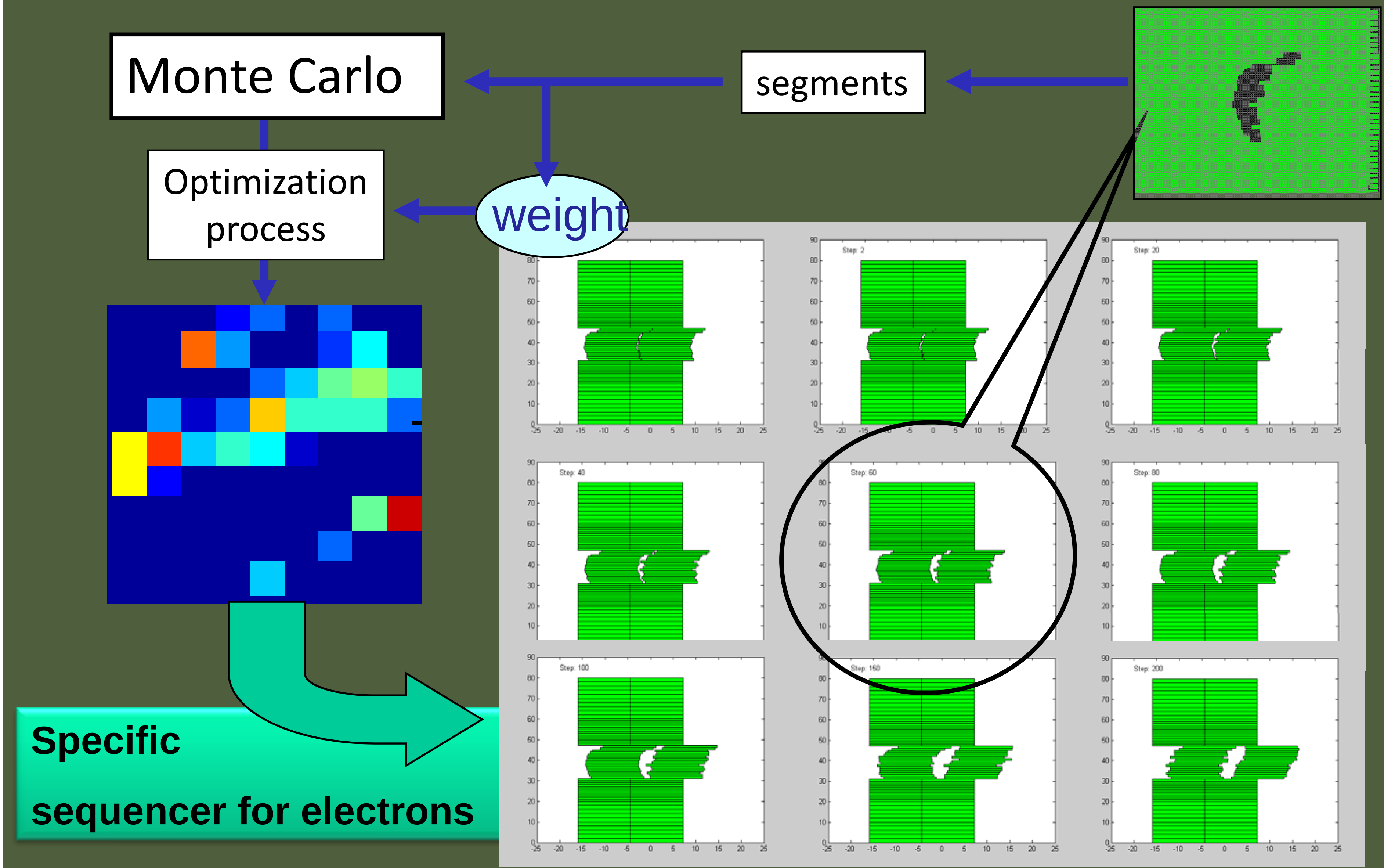
Segments fluence



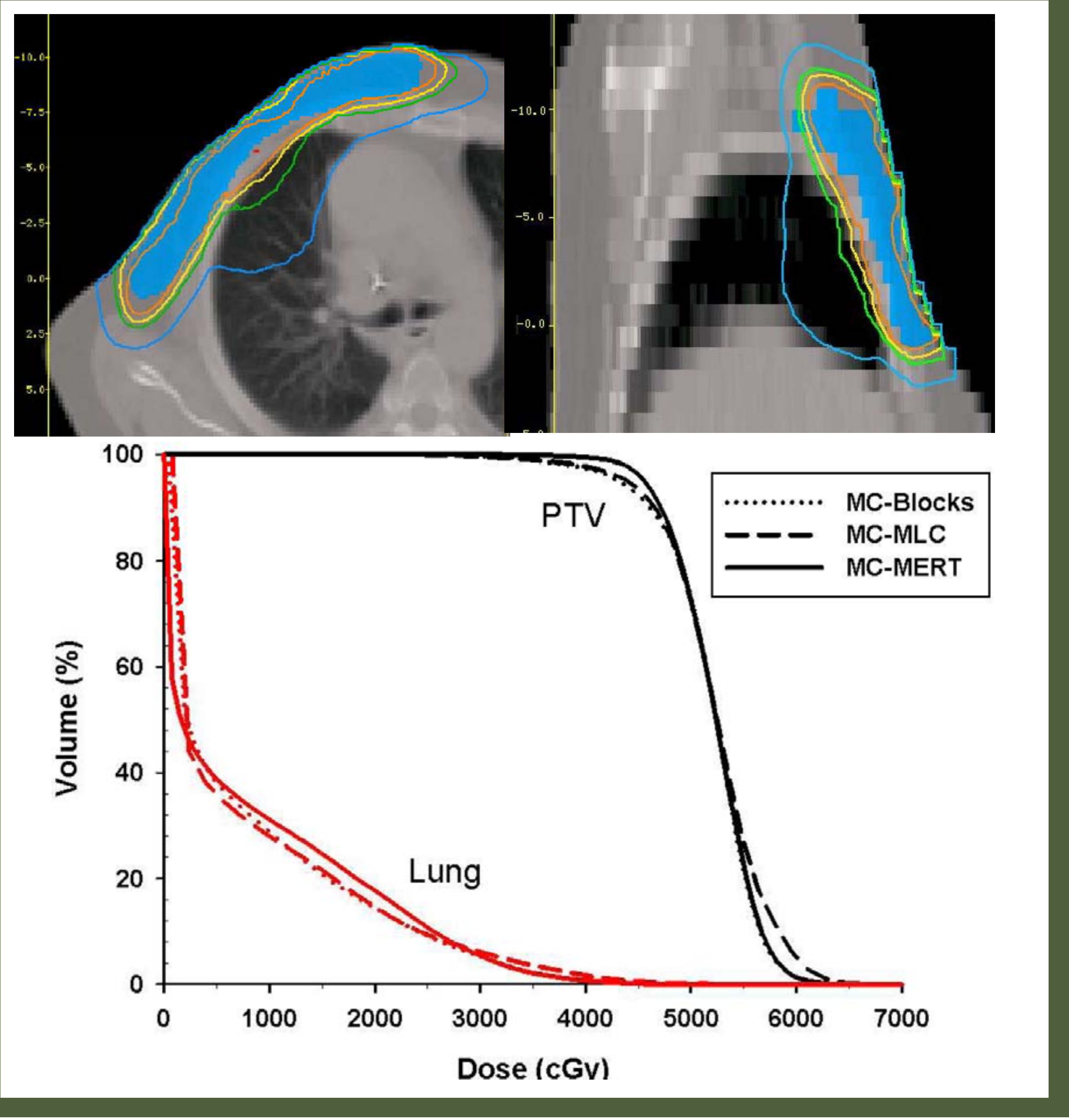




Inverse planning optimization

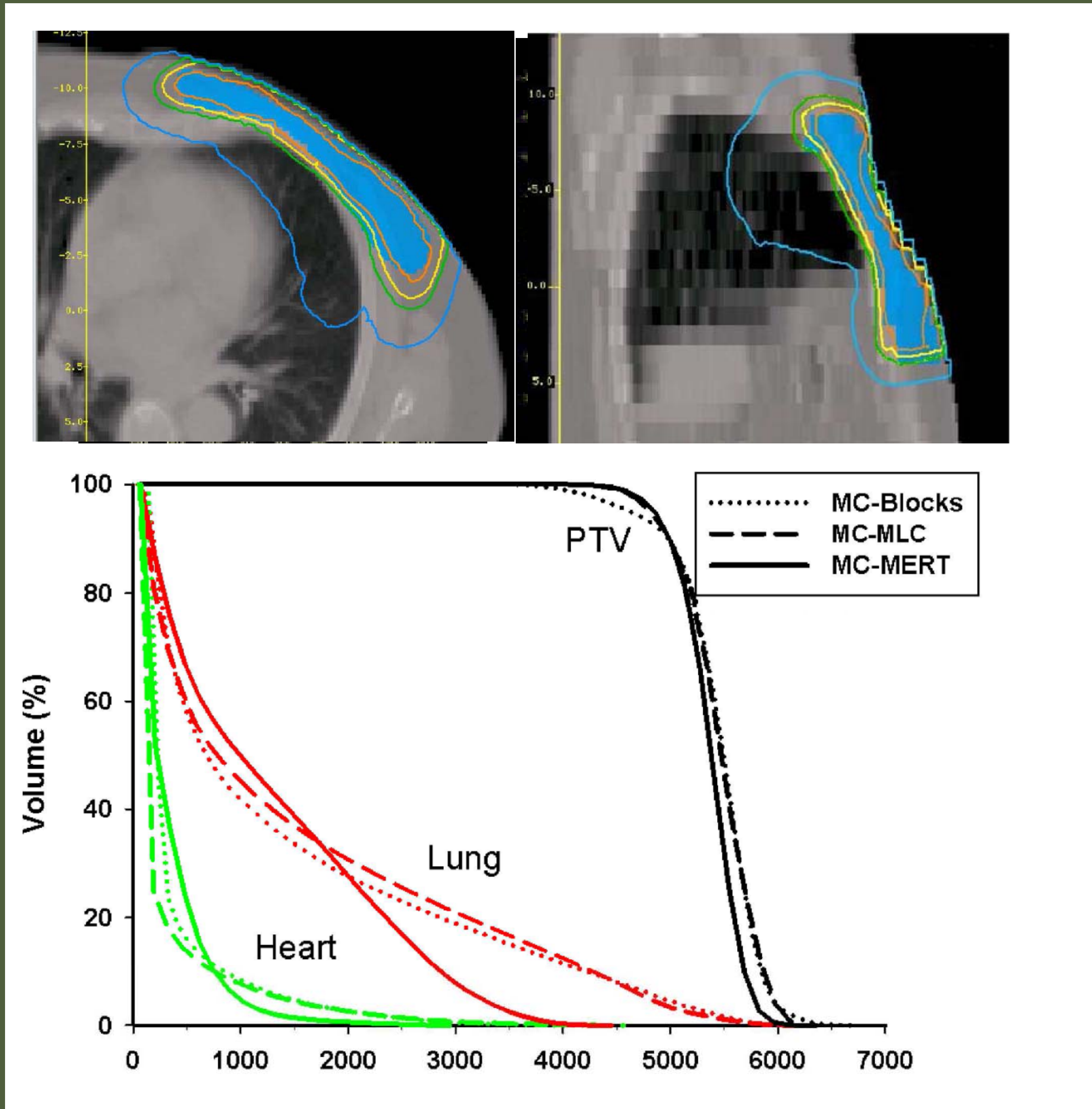


Chest Wall cases by MERT with our MCTP



Deep region:
9 MeV y 15 MeV

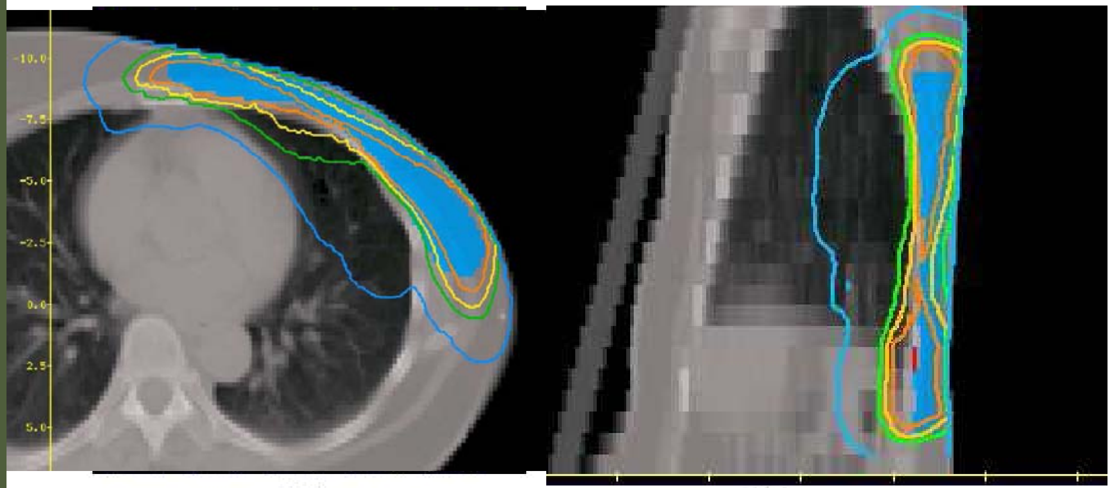
Chest Wall cases by MERT with our MCTP



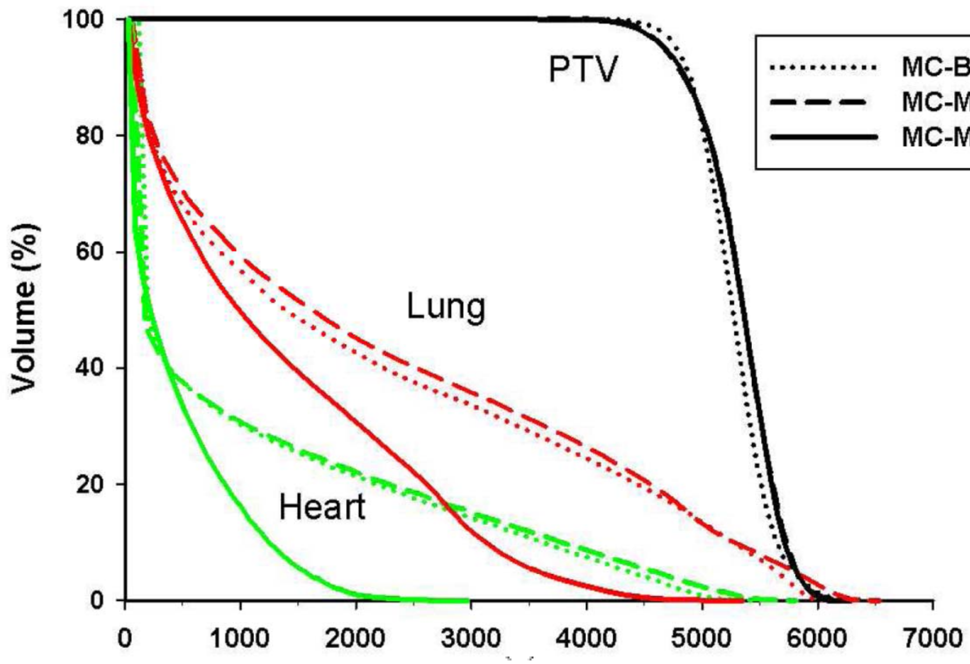
Deep region:

9 MeV y 15 MeV

Chest Wall cases by MERT with our MCTP



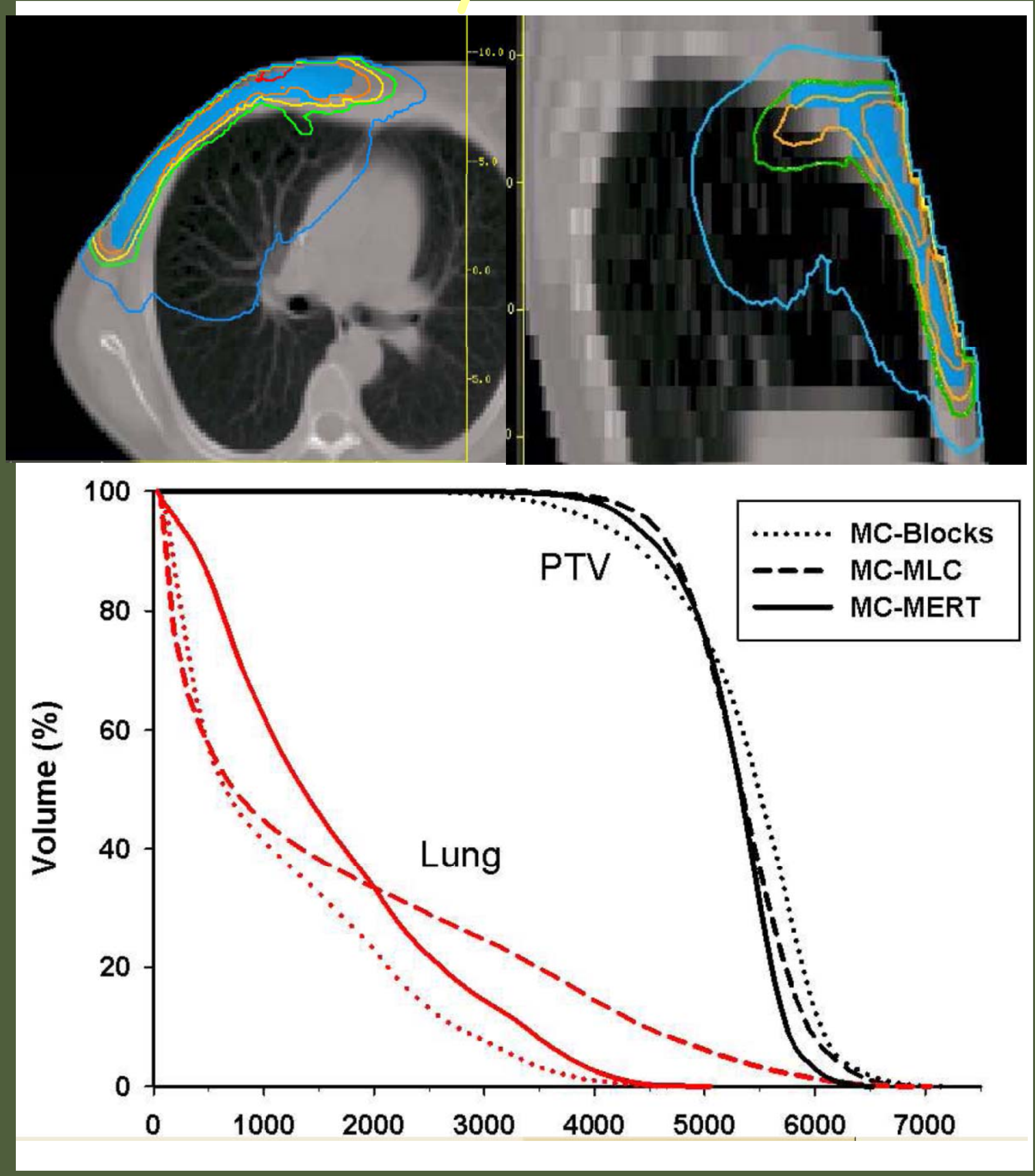
(a) (b)



Shallow region:
Degrader slice

6 MeV degrader
6 MeV and 9 MeV

Chest Wall cases by MERT with our MCTP



Big PTV

SSD=70 cm
6 MeV, 9 MeV an
12 MeV

Chest Wall cases by MERT with our MCTP

Irradiation parameters used for the presented chest wall cases.

Patient P1	Angle	E(MeV)	Number of segments	Total MU
MC-Blocks	325	6 + 9	1 + 2	196 196
MC-MLC	325	6 + 9	1 + 2	73 + 73
MC-MERT	325	6 + 9	4 + 9	121 + 233

Patient P2	Angle	E(MeV)	Number of segments	Total MU
MC-Blocks	35	9 + 15	1 + 1	206 + 206
MC-MLC	35	9 + 15	1 + 1	79 + 79
MC-MERT	35	6 + 9 + 15	4 + 4 + 5	95 + 82 + 68

Patient P3	Angle	E(MeV)	Number of segments	Total MU
MC-Blocks	35	6 + 9	1 + 1	193 + 193
MC-MLC	35	6 + 9	1 + 1	139 + 139
MC-MERT	35	6 + 9 + 12	7 + 3 + 6	224 + 127 + 232

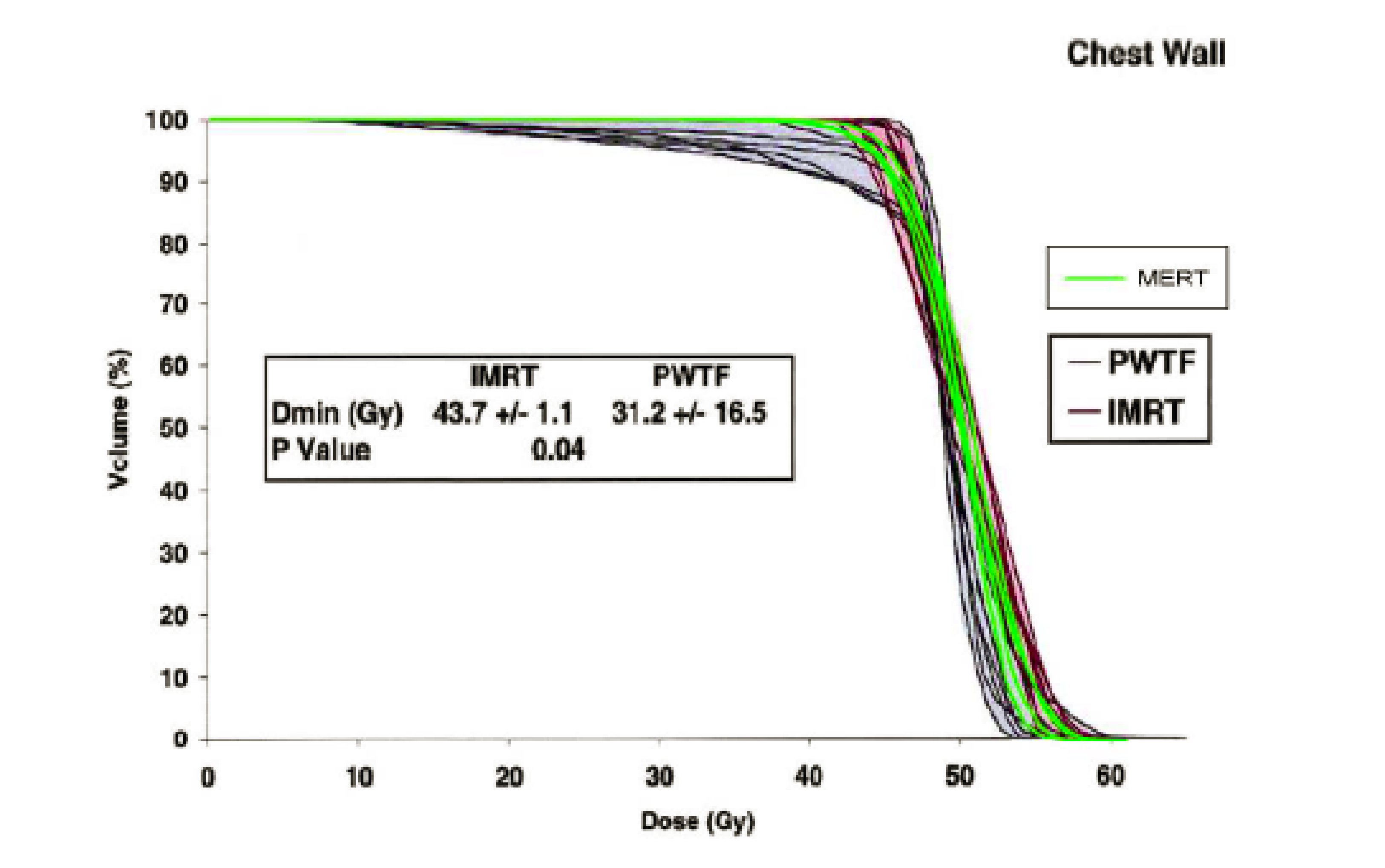
Patient P4	Angle	E(MeV)	Number of segments	Total MU
MC-Blocks	327	6 + 9 + 12	1 + 1 + 1	191 + 191 + 191
MC-MLC	327	6 + 9	1 + 1	195 + 195
MC-MERT	315	6deg + 12	3 + 11	185 + 275

Modulated electron radiotherapy treatment planning using a photon multileaf collimator for post-mastectomized chest walls. *Salguero et al. Radiother & Oncol. 2009 Dec;93(3):625-32.*

Chest Wall cases by MERT with our MCTP

DVH Comparison (I)

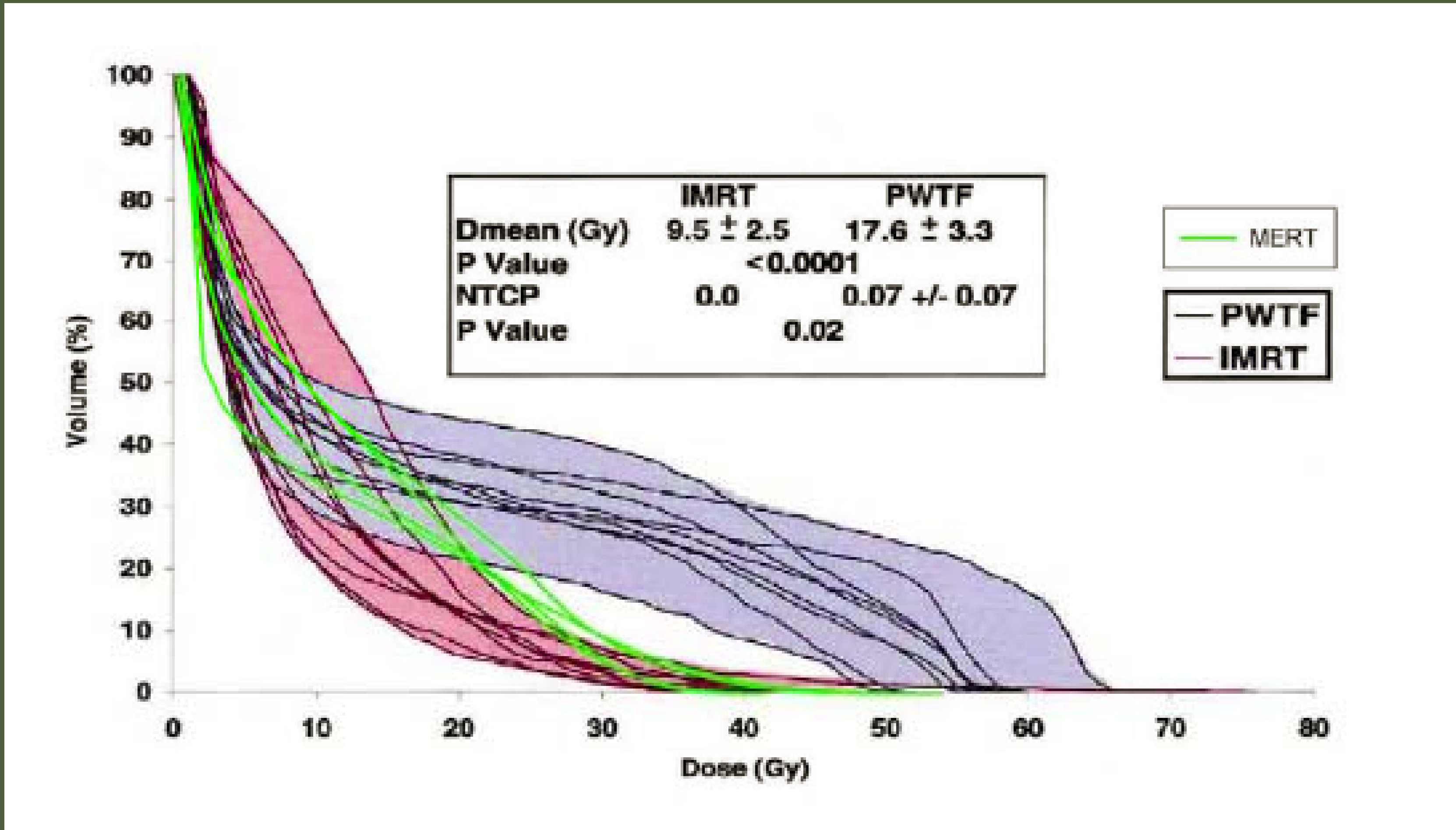
Data from: EA Krueger at al. Int.J.Radiat.Oncol.*Biol.*Phys. Vol. 56, Nº4, pp1023-1037



Chest Wall cases by MERT with our MCTP

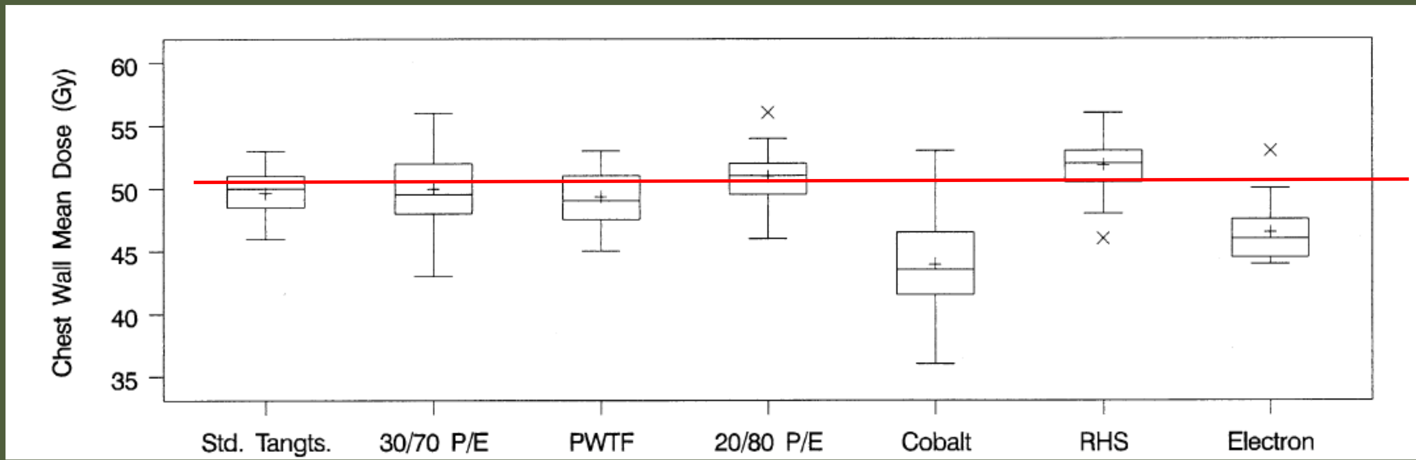
DVH Comparison (II)

Data from: EA Krueger at al. Int.J.Radiat.Oncol.*Biol.*Phys. Vol. 56, Nº4, pp1023-1037

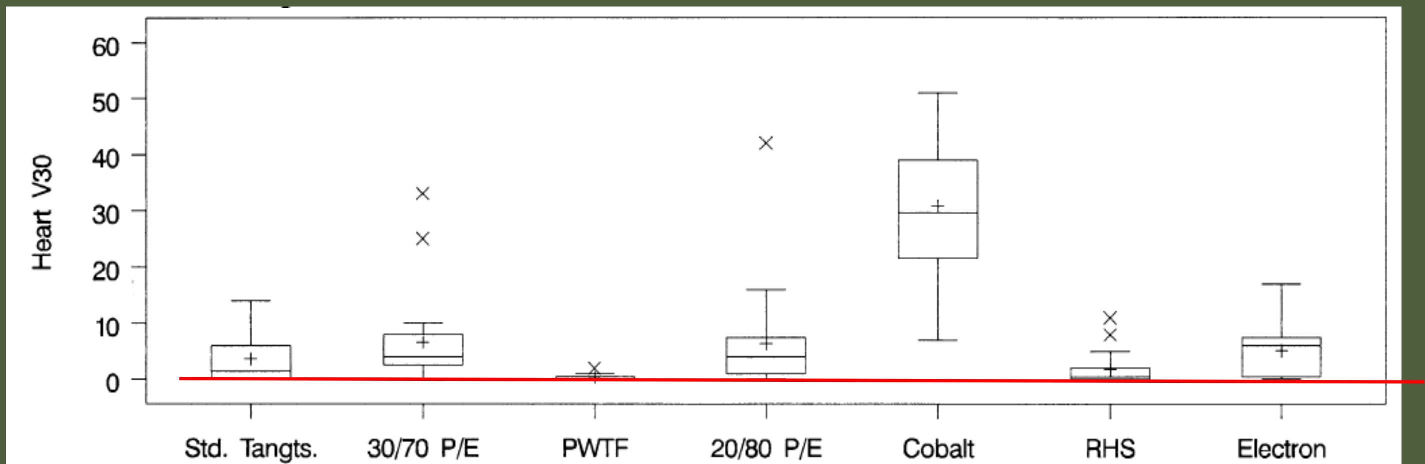


Chest Wall cases by MERT with our MCTP Comparison (III)

Int.J.Radiat.Oncol.*Biol.*Phys. Vol. 52, Nº5, pp1220-1230



Average Dose in PTV=50.5Gy

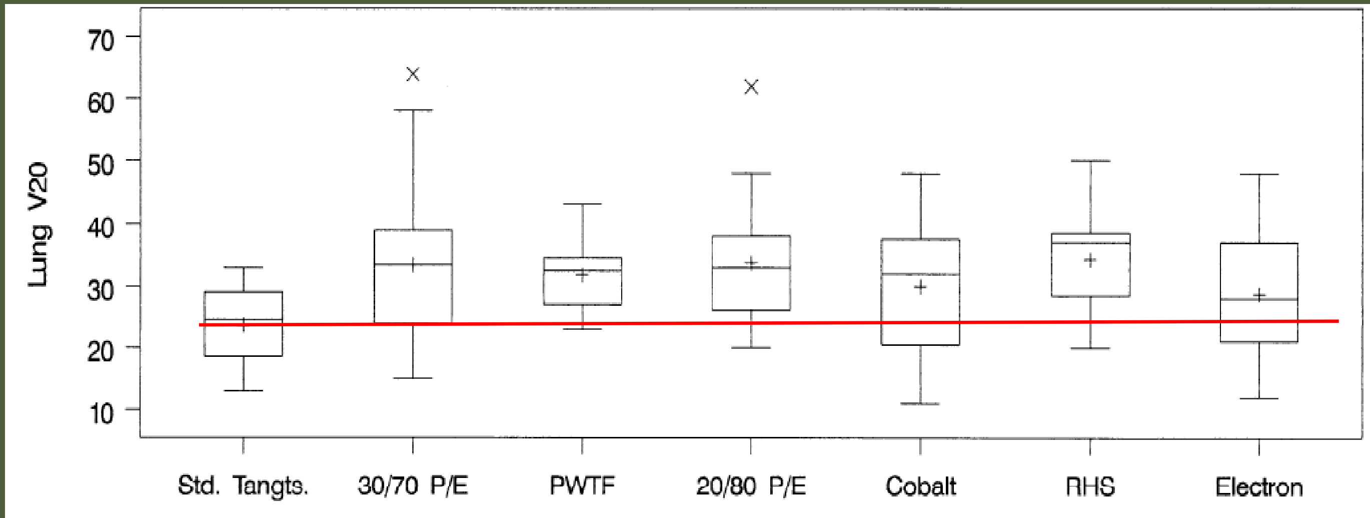


V30 of Heart: 0.03%

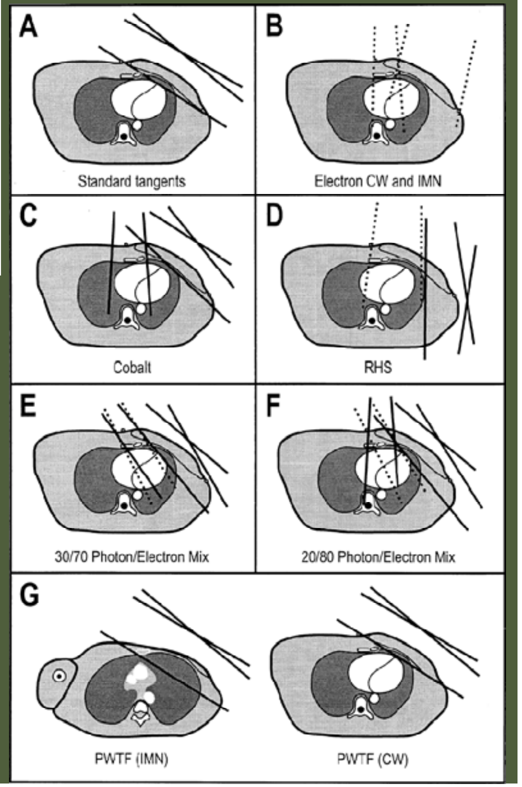
Chest Wall cases by MERT with our MCTP

Comparison (IV)

Int.J.Radiat.Oncol.*Biol.*Phys. Vol. 52, Nº5, pp1220-1230



V20 lung: 23.5%

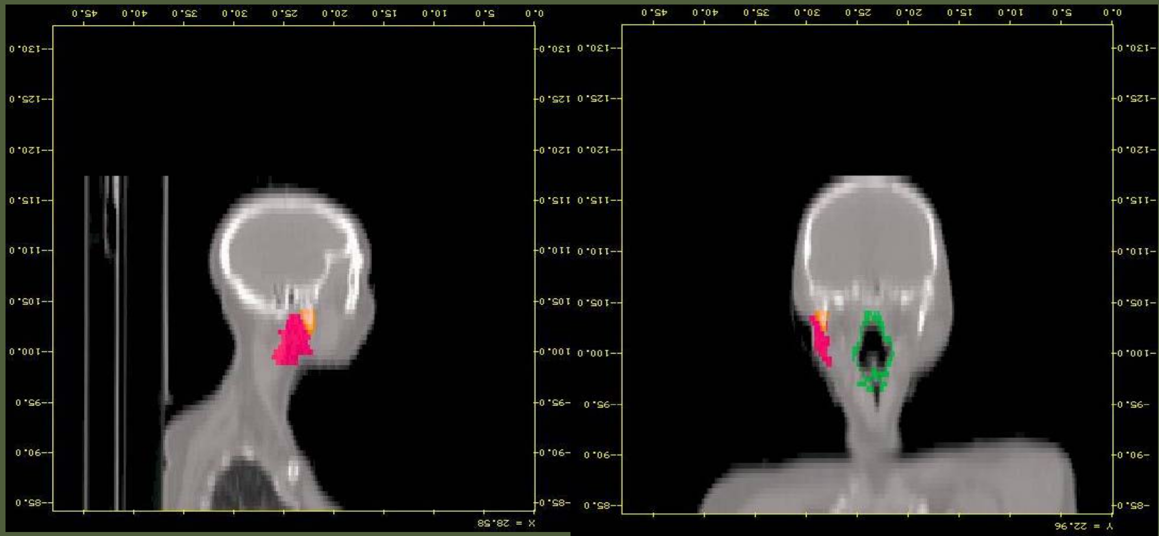


Standard Tangents
Photon and electron (30%/70%)

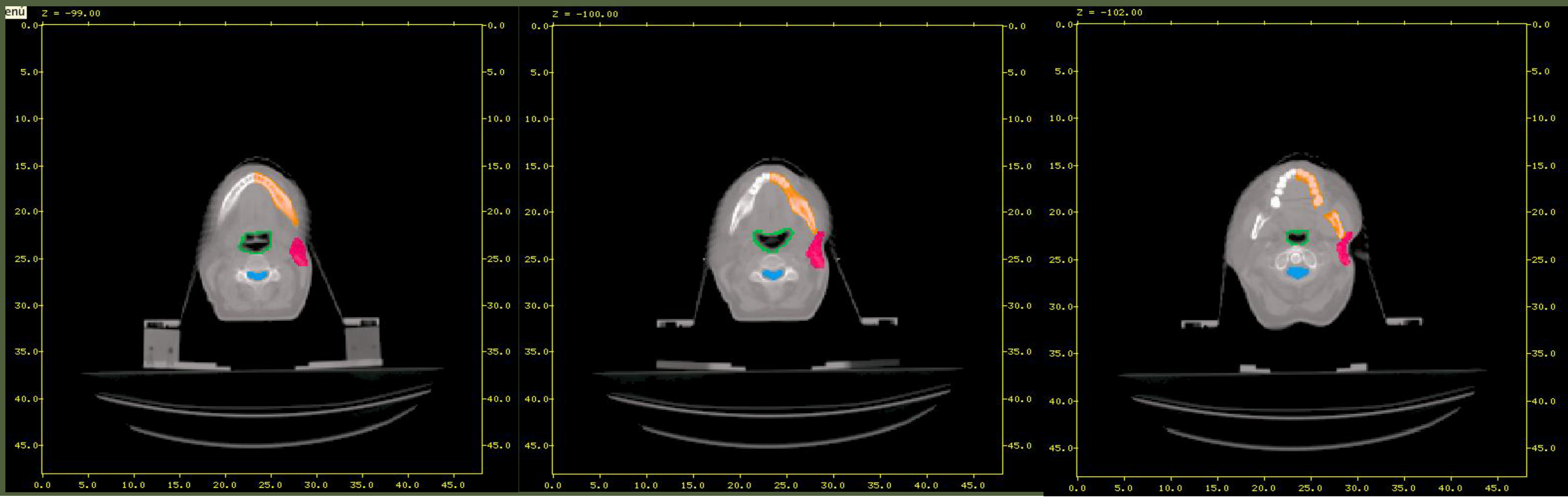
Partially wide tangent fields (PWTFs)
Photon and electron (20%/80%)
Cobalt
Reverse hockey stick (RHS)
9 and 12-MeV electron field (Electron)

H&N shallow tumors by MERT with our MCTP

Parotid glands case



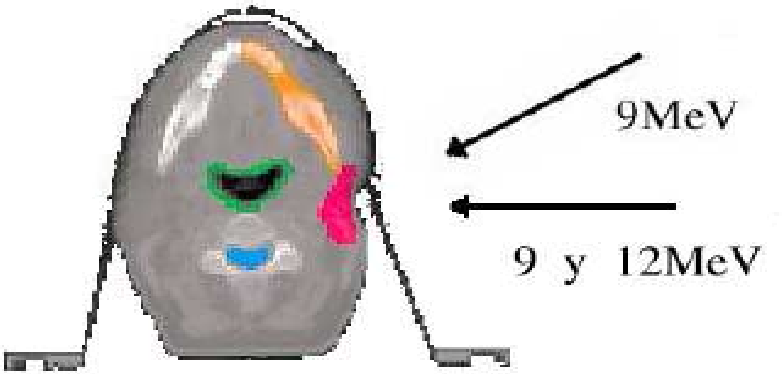
- PTV
- Hemi-jaw
- Larinx mucous
- Marrow

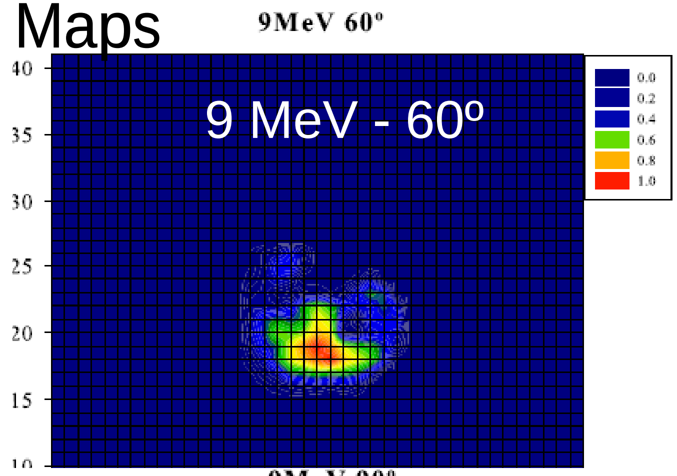


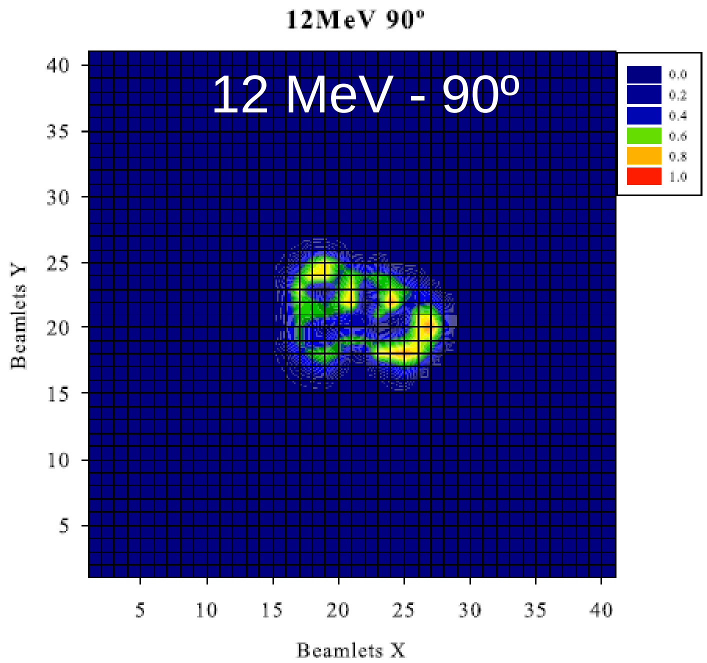
H&N shallow tumors by MERT with our MCTP

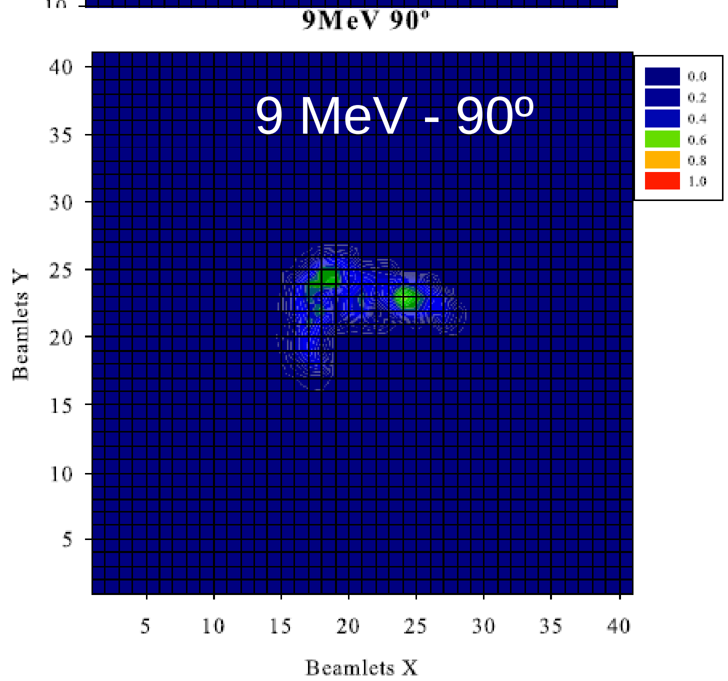
Parotid glands case

Beamlets Fluence Maps





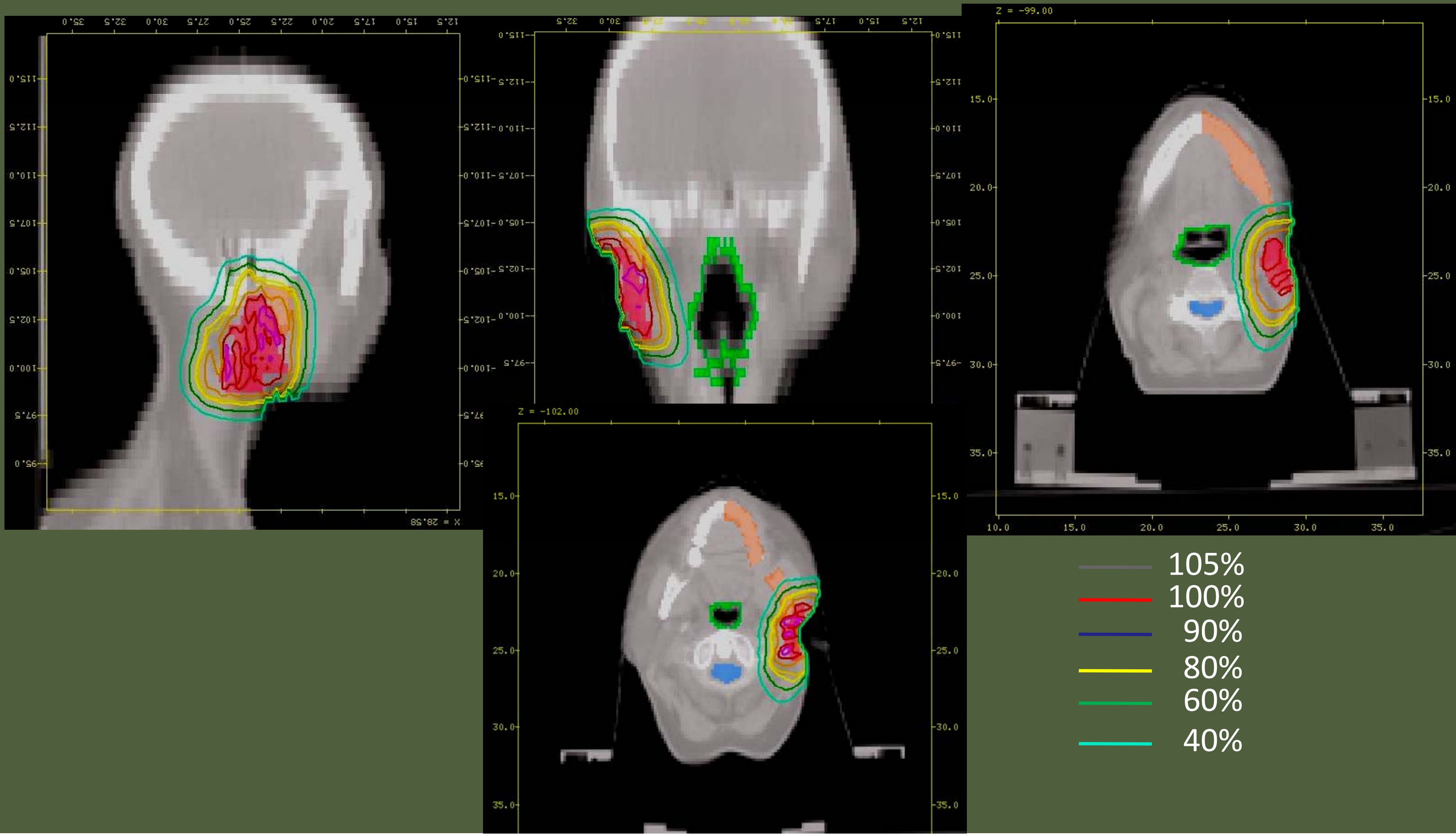




H&N shallow tumors by MERT with our MCTP

Parotid glands case

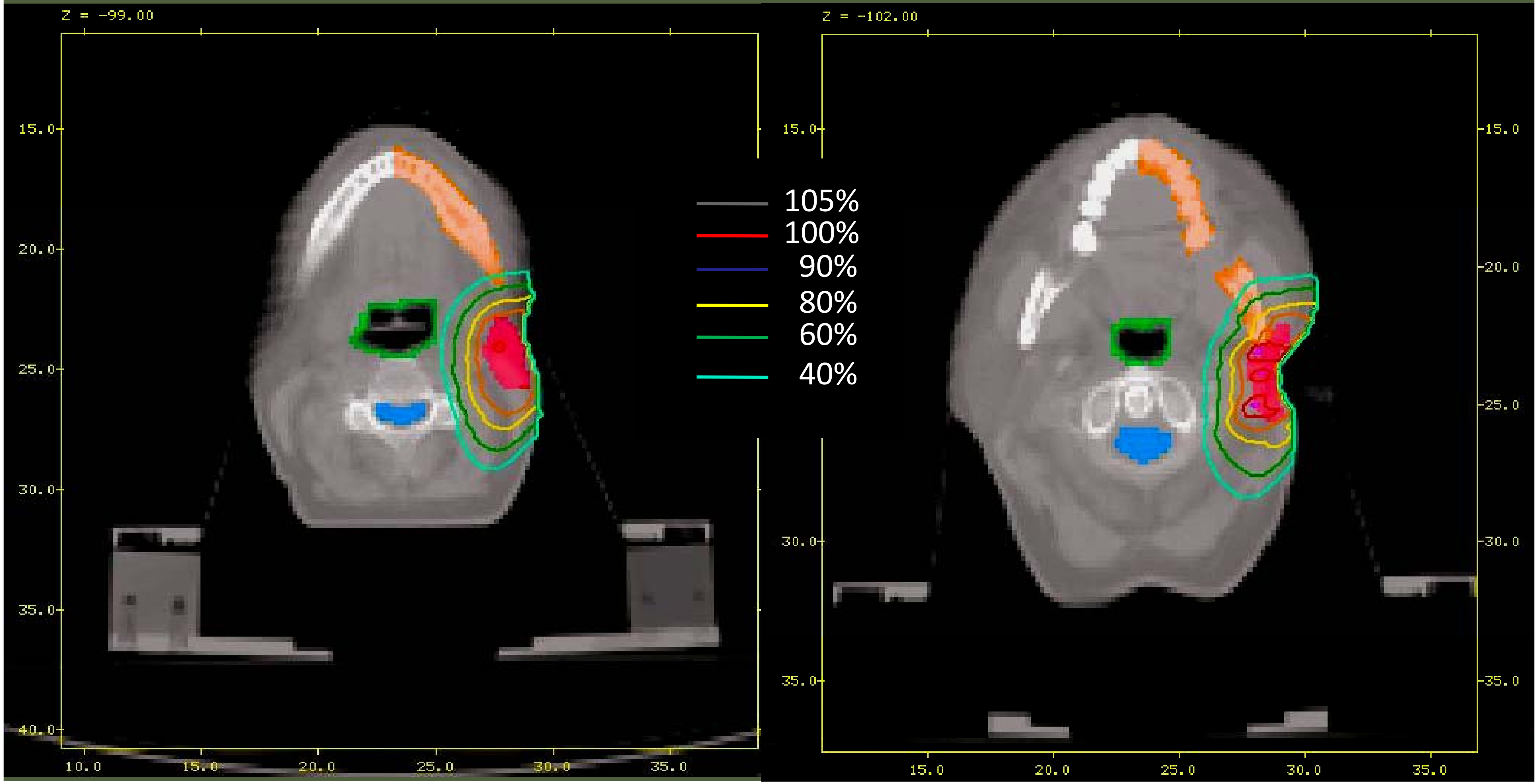
Final dose distribution



H&N shallow tumors by MERT with our MCTP

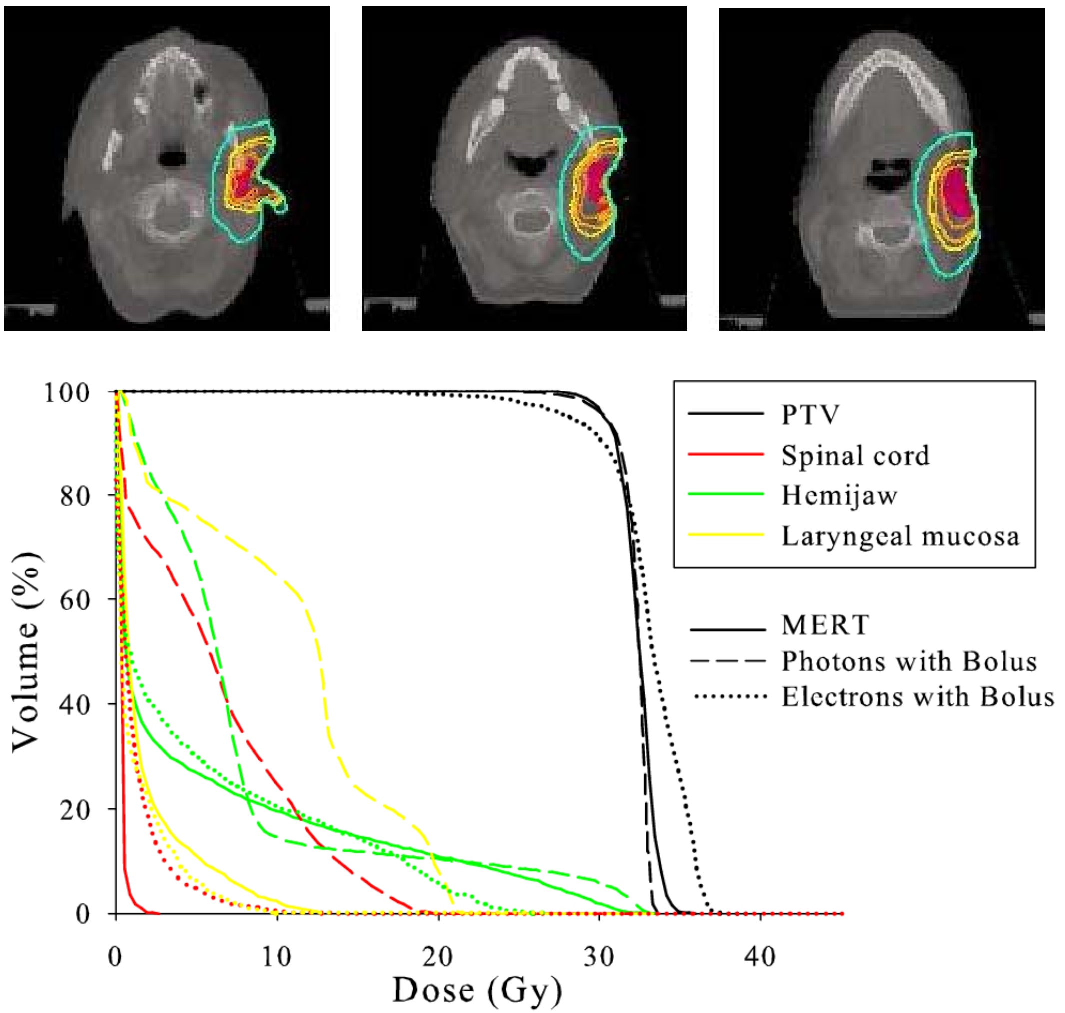
Parotid glands case

Beamlets dose distribution



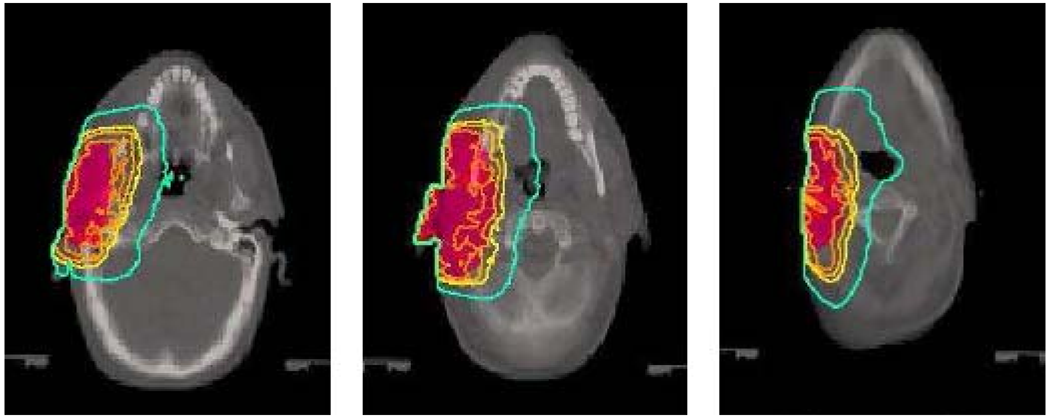
H&N shallow tumors by MERT with our MCTP

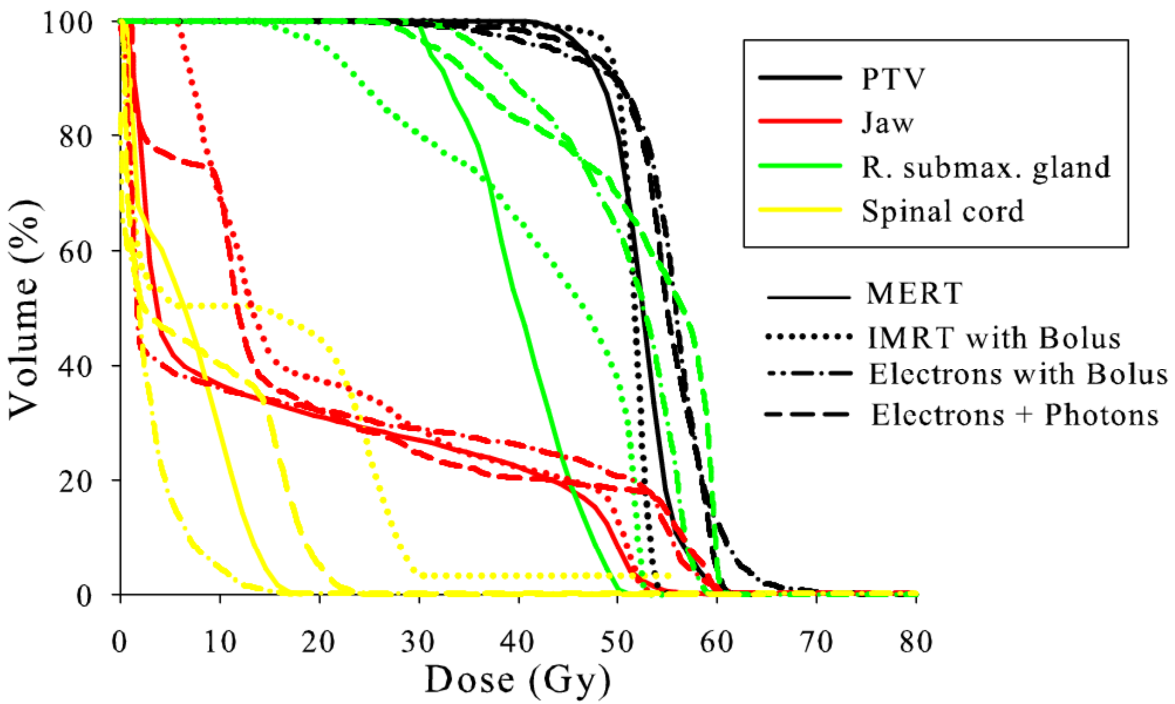
Parotid glands case



H&N shallow tumors by MERT with our MCTP

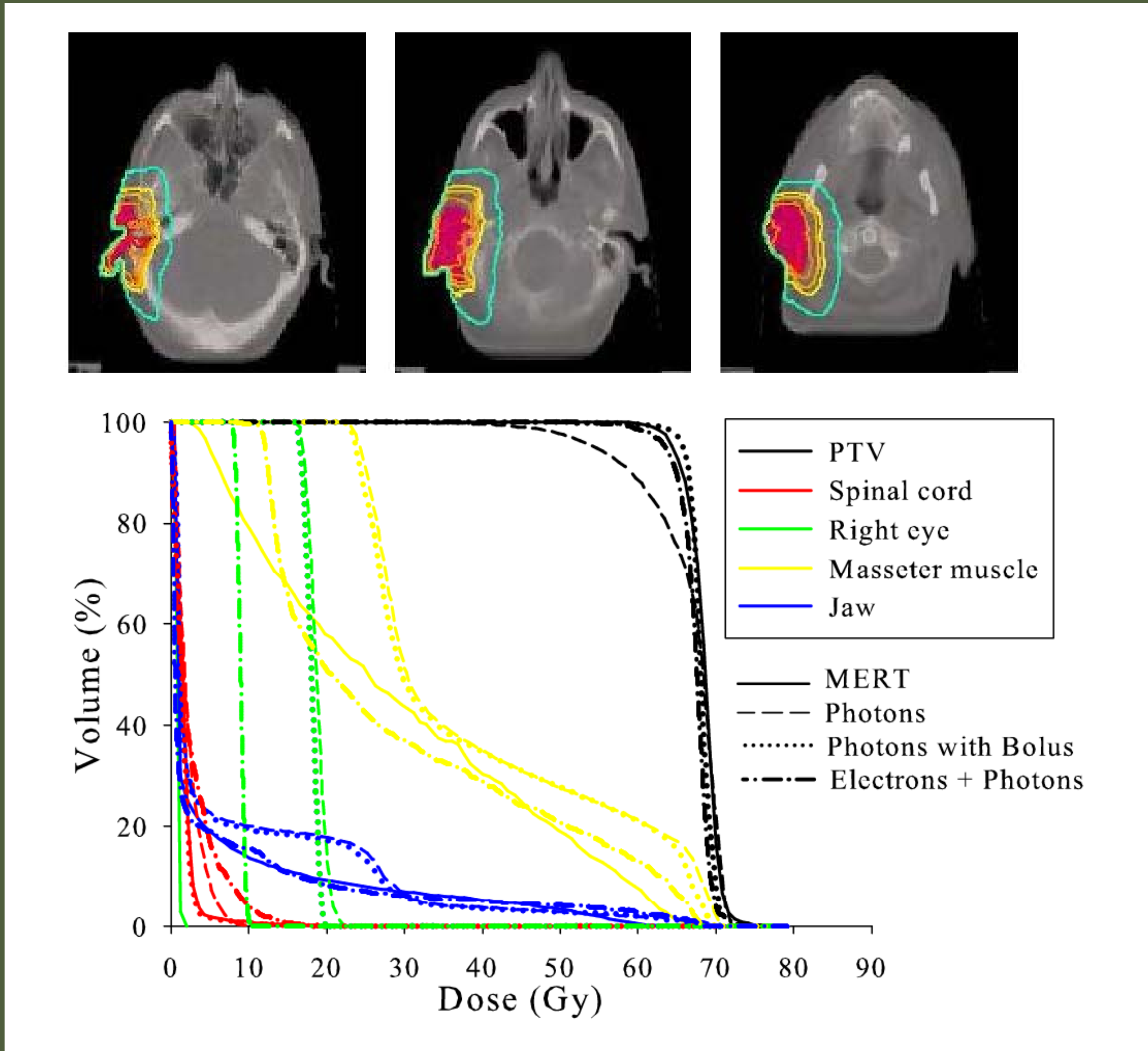
Parotid glands case





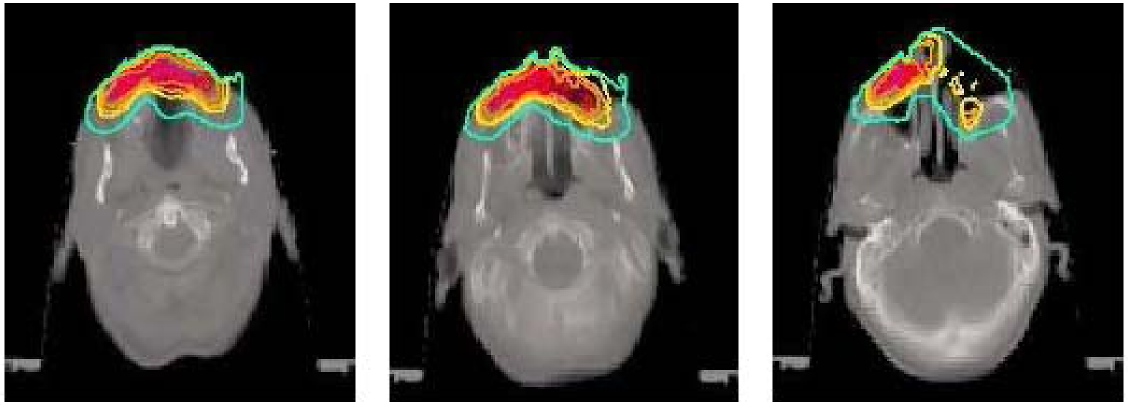
H&N shallow tumors by MERT with our MCTP

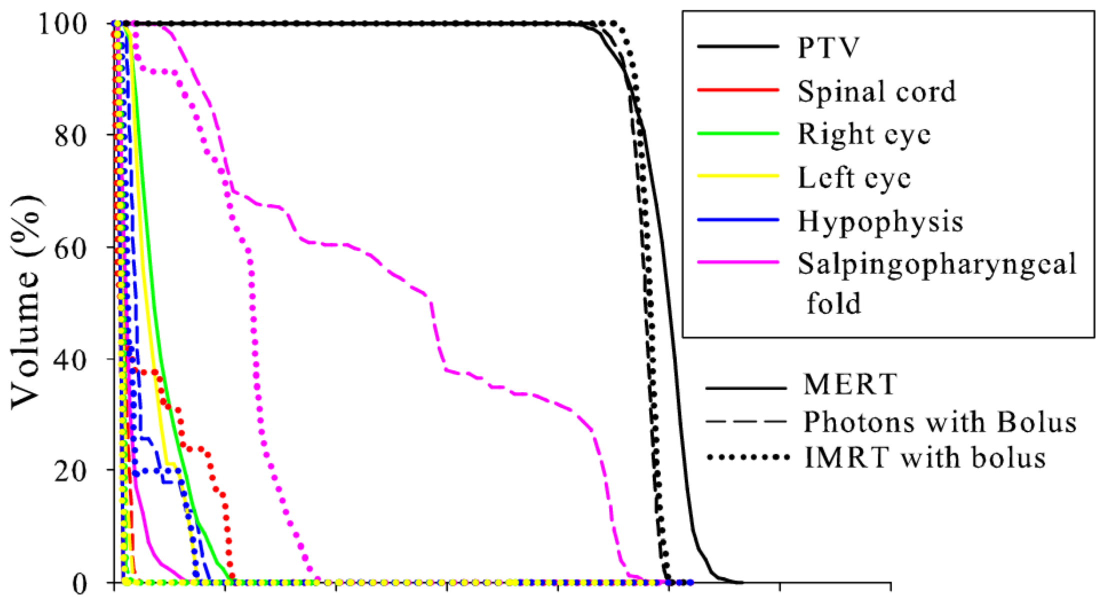
Ear tumor case



H&N shallow tumors by MERT with our MCTP

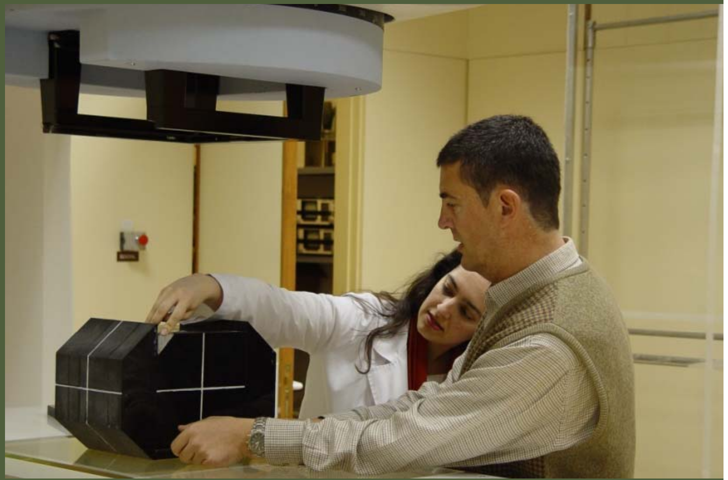
Oropharinge case



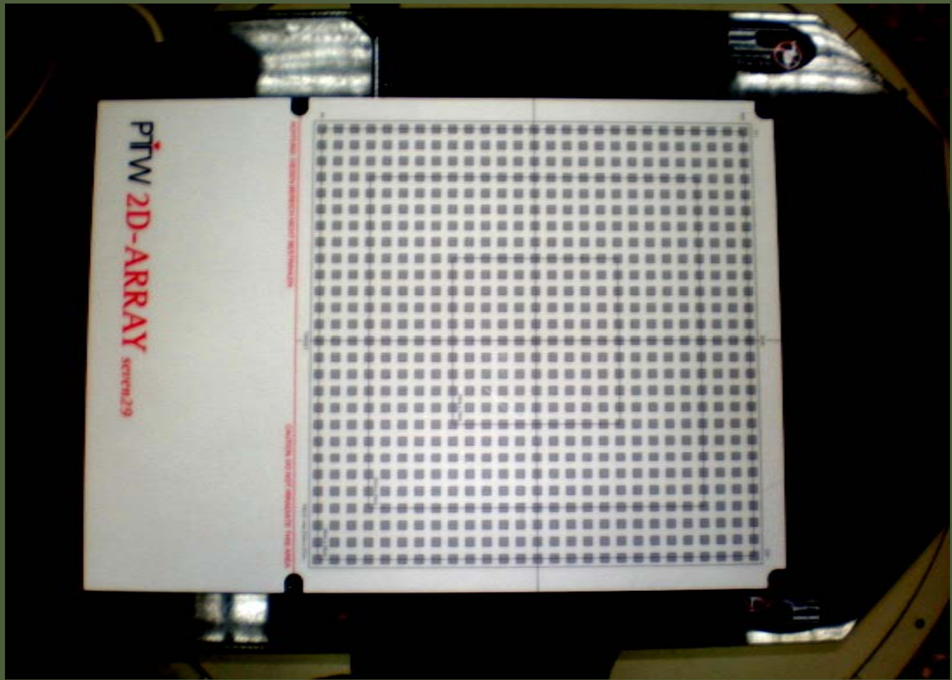


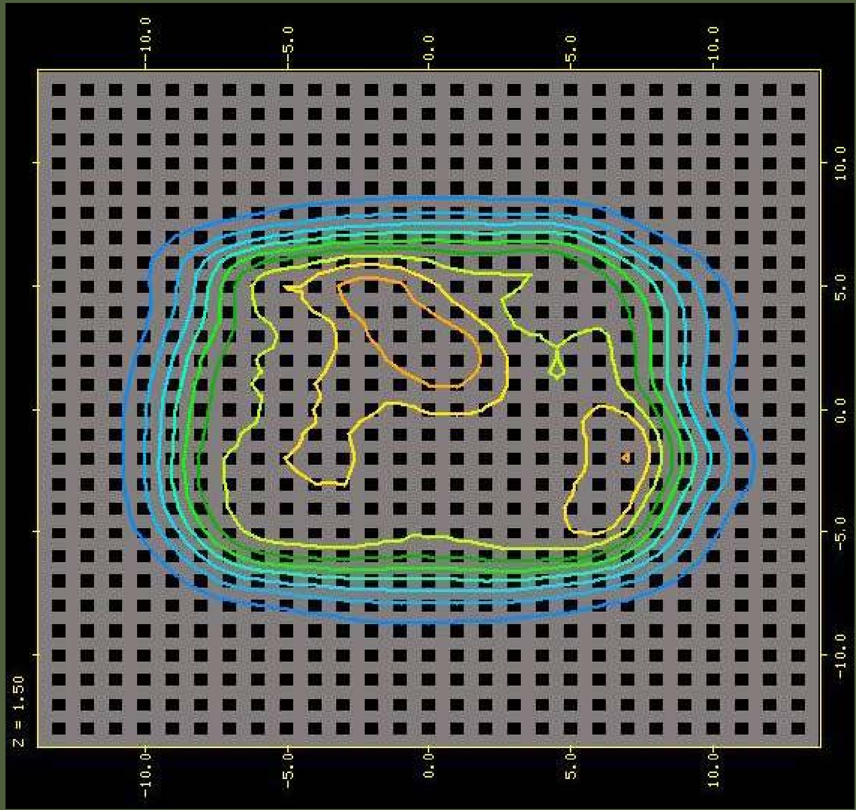
Intensity- and energy-modulated electron radiotherapy by means of an xMLC for head and neck shallow tumors. *Salguero et al. Physics in Medicine and Biology.* 55, 5 (2010)

Experimental verification

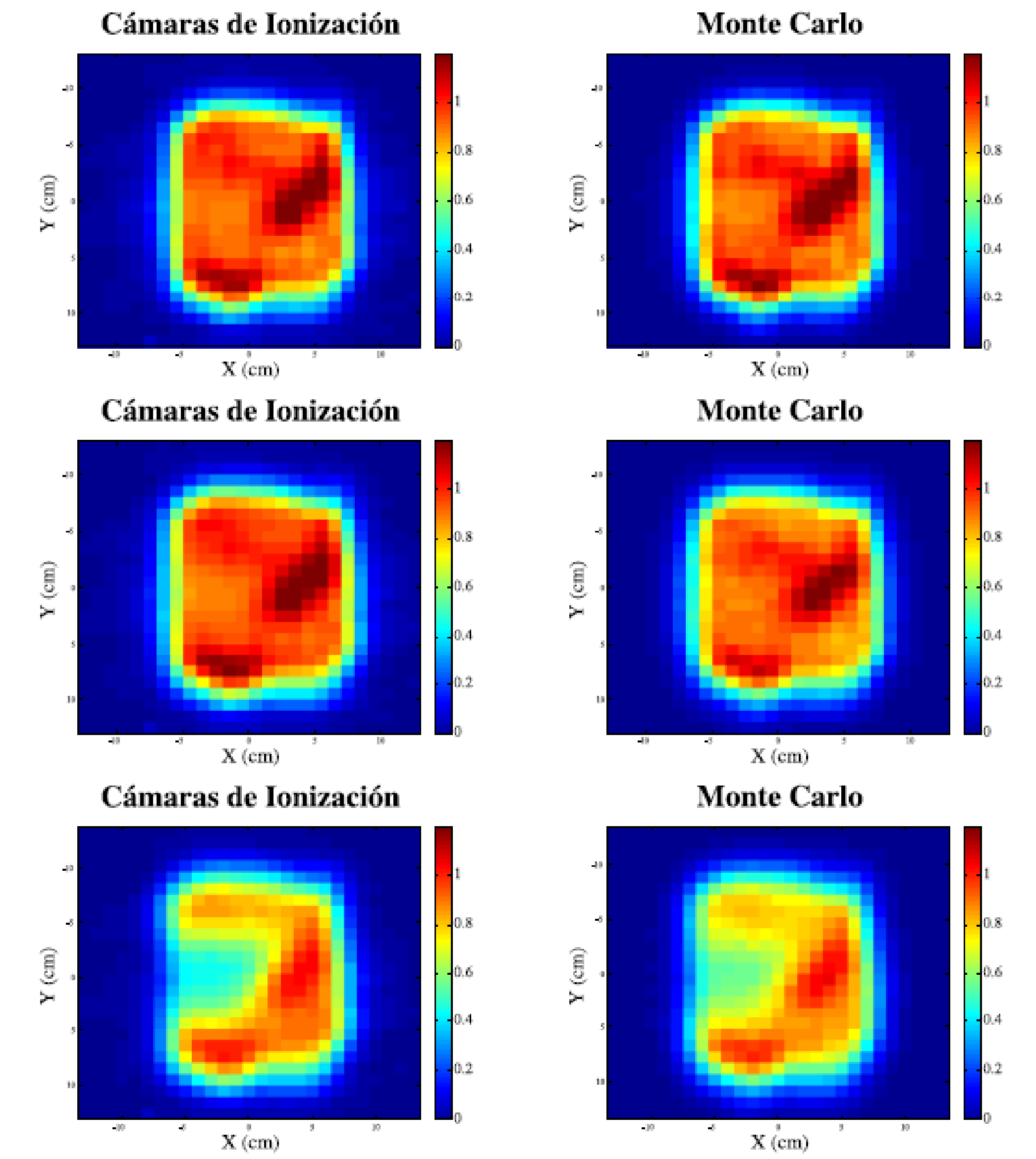


Experimental verification



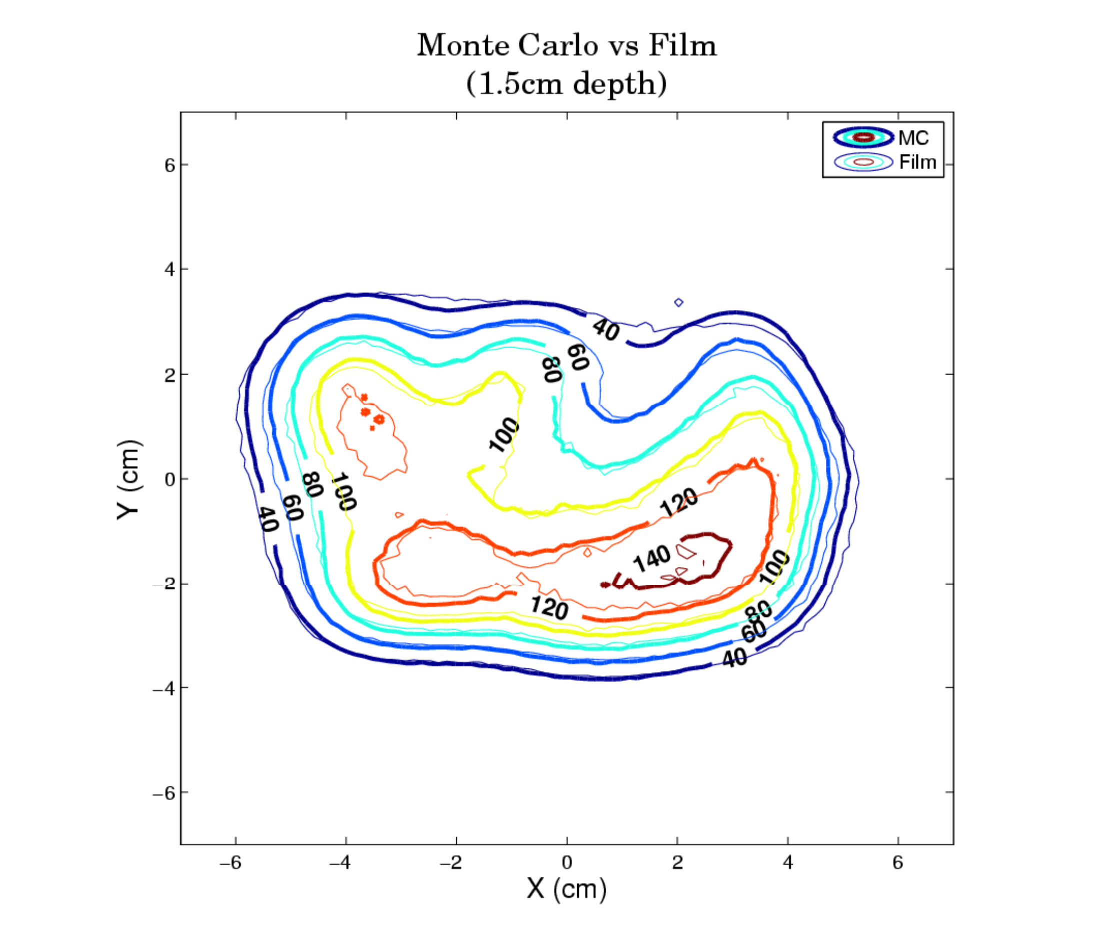


Experimental verification



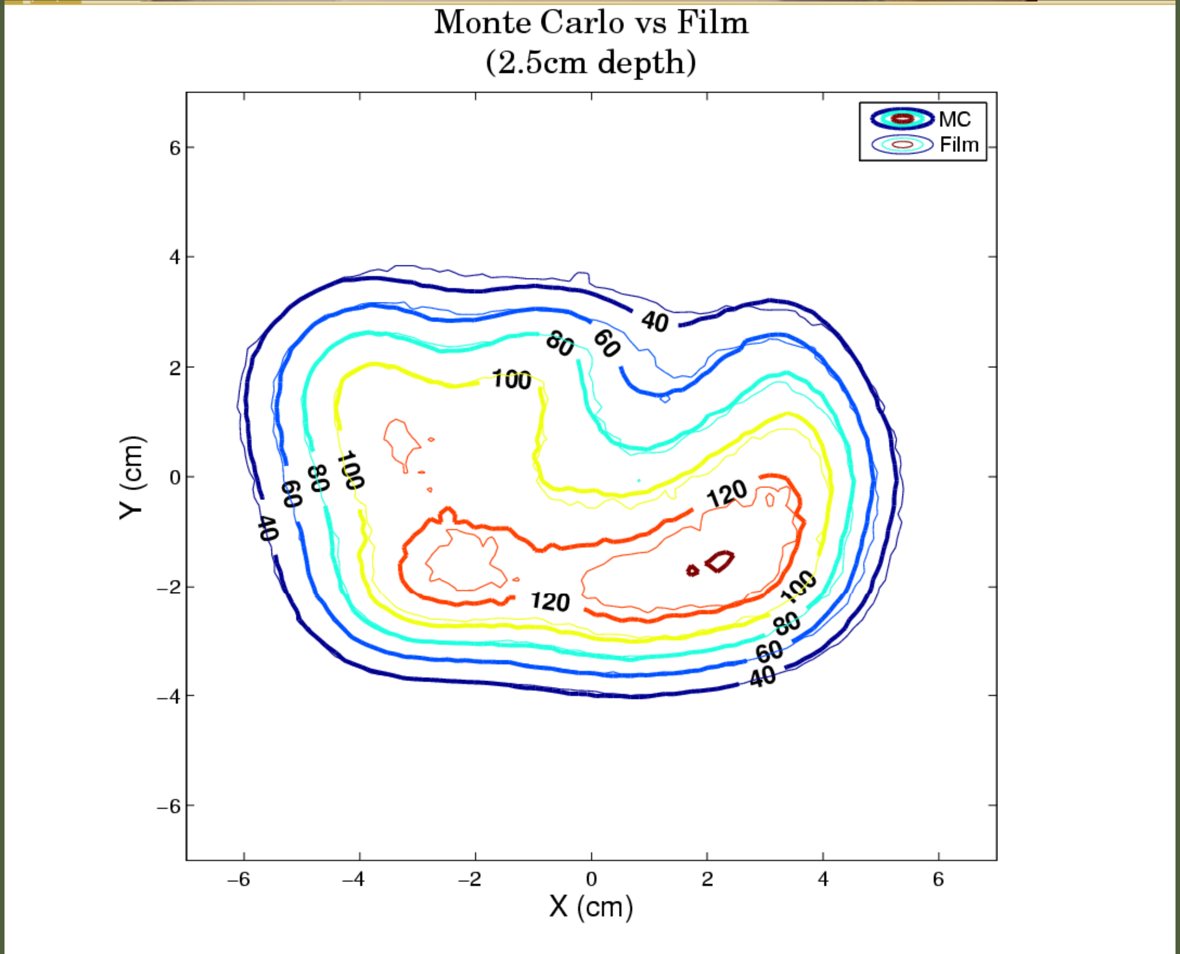
Experimental verification

Relative dose verification: Radiochromic films



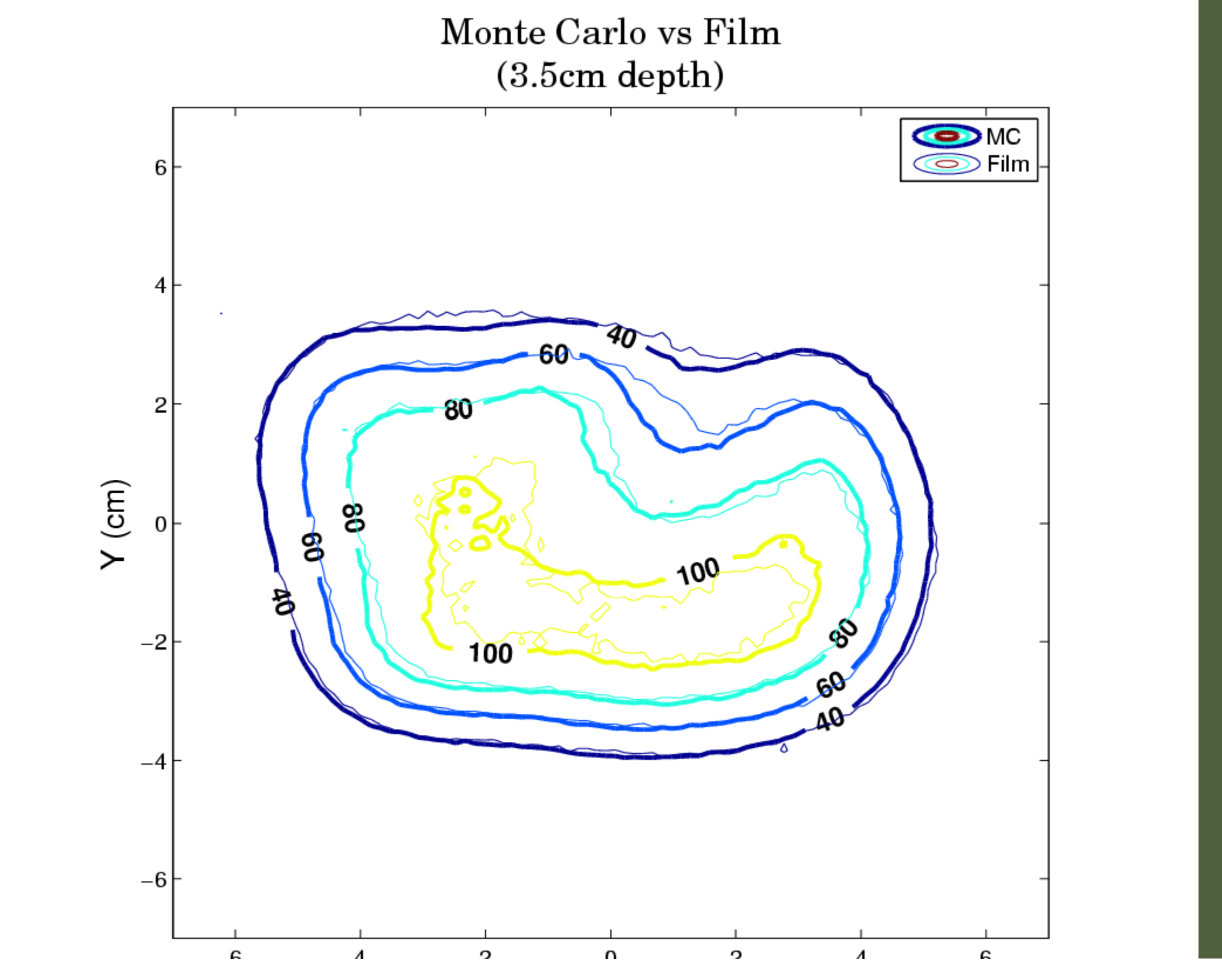
Experimental verification

Relative dose verification: Radiochromic films



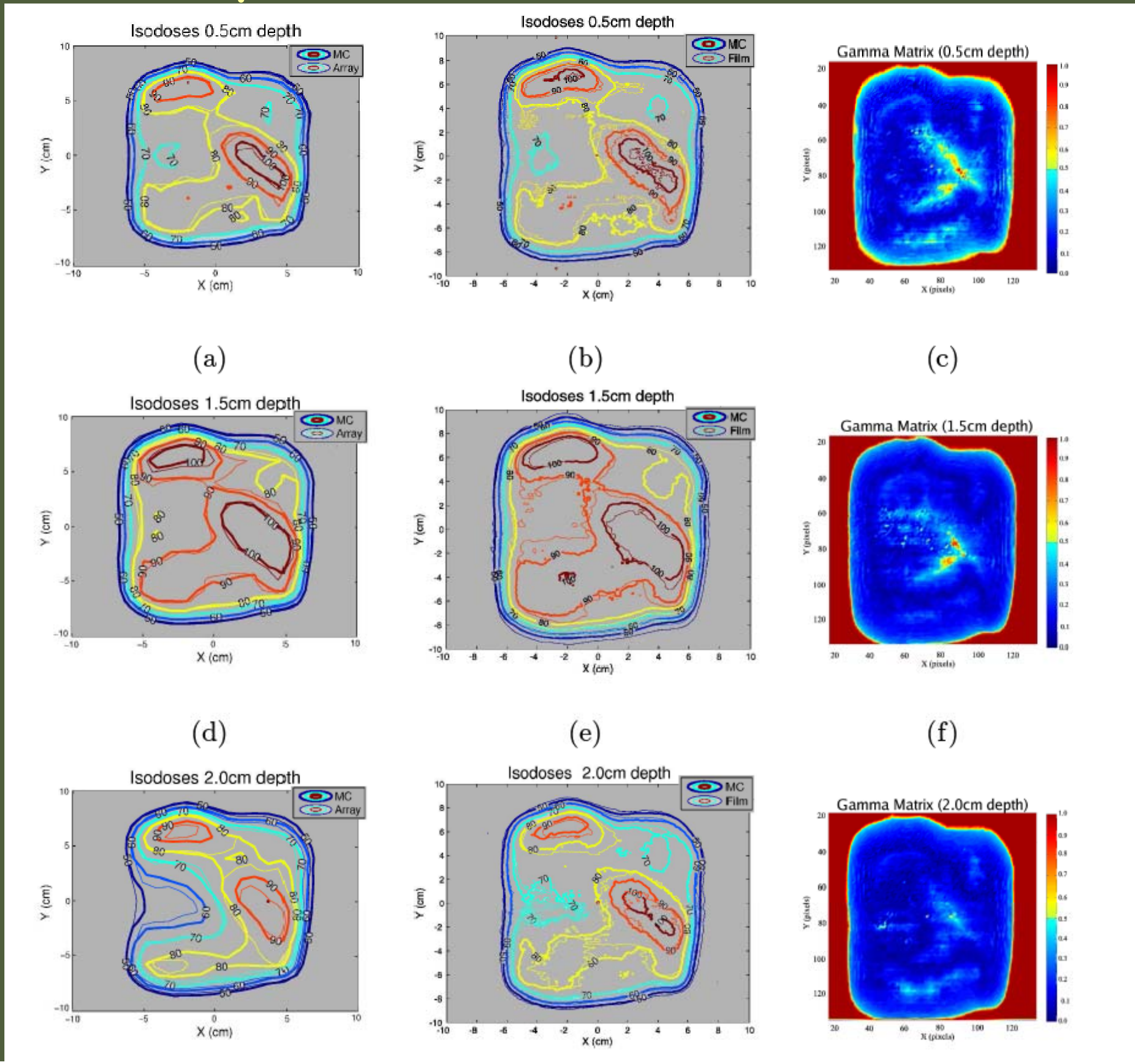
Experimental verification

Relative dose verification: Radiochromic films



Experimental verification

Gamma analysis



Experimental verification

Absolute dose verification: Plane-parallel ion chamber

Chest wall cases

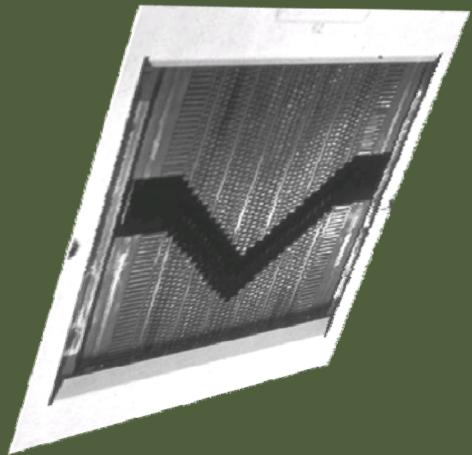
Case	Experimental dose (cGy)	MC dose (cGy)	Difference
P1	217.5	217.2	-0.1%
P2	219.1	221.2	+1.0%
P3	216.2	213.2	-1.4%
P4	157.5	153.1	-2.9%

Shallow H&N cases

	Experimental dose (cGy)	Monte Carlo dose (cGy)	Difference
Case 1	201.1	204.1	-1.47%
Case 2	255.9	253.2	+1.07%
Case 3	231.9	233.0	-0.47%
Case 4	245.2	242.7	+1.03%

Can we extend the model ? Yes, IMRT+MERT

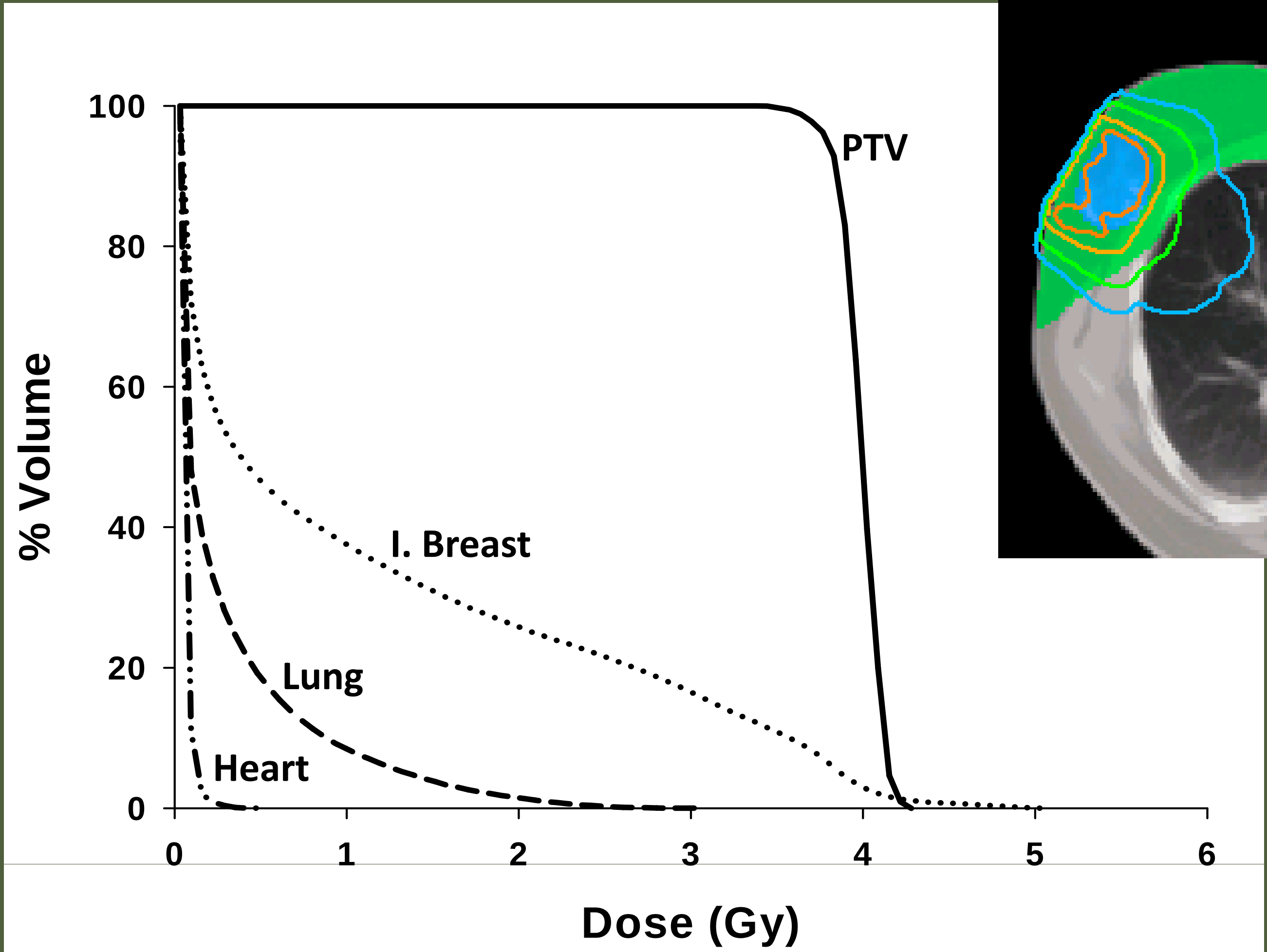
-We have the same collimation device for both type of particles.

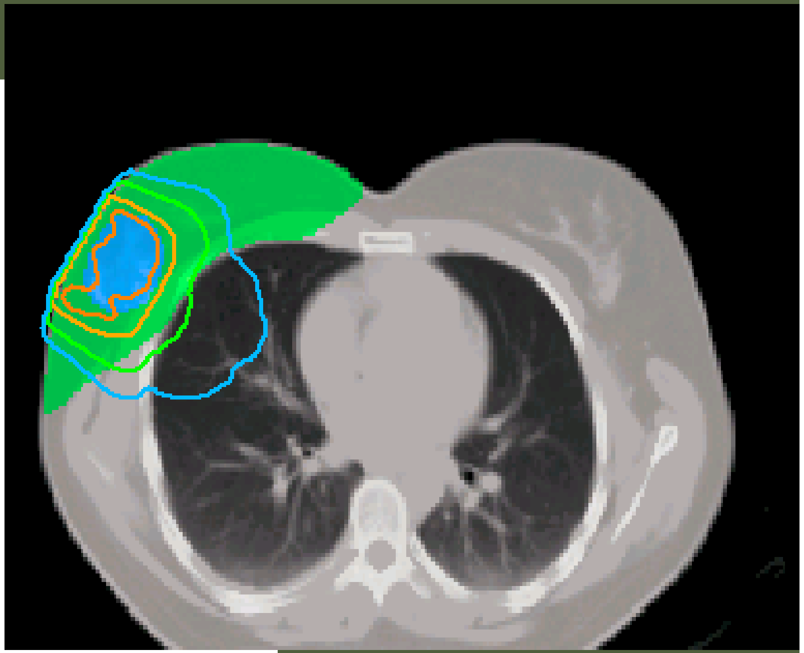


- We have the same algorithm to calculate the dose with the wished precisition:

MCTP

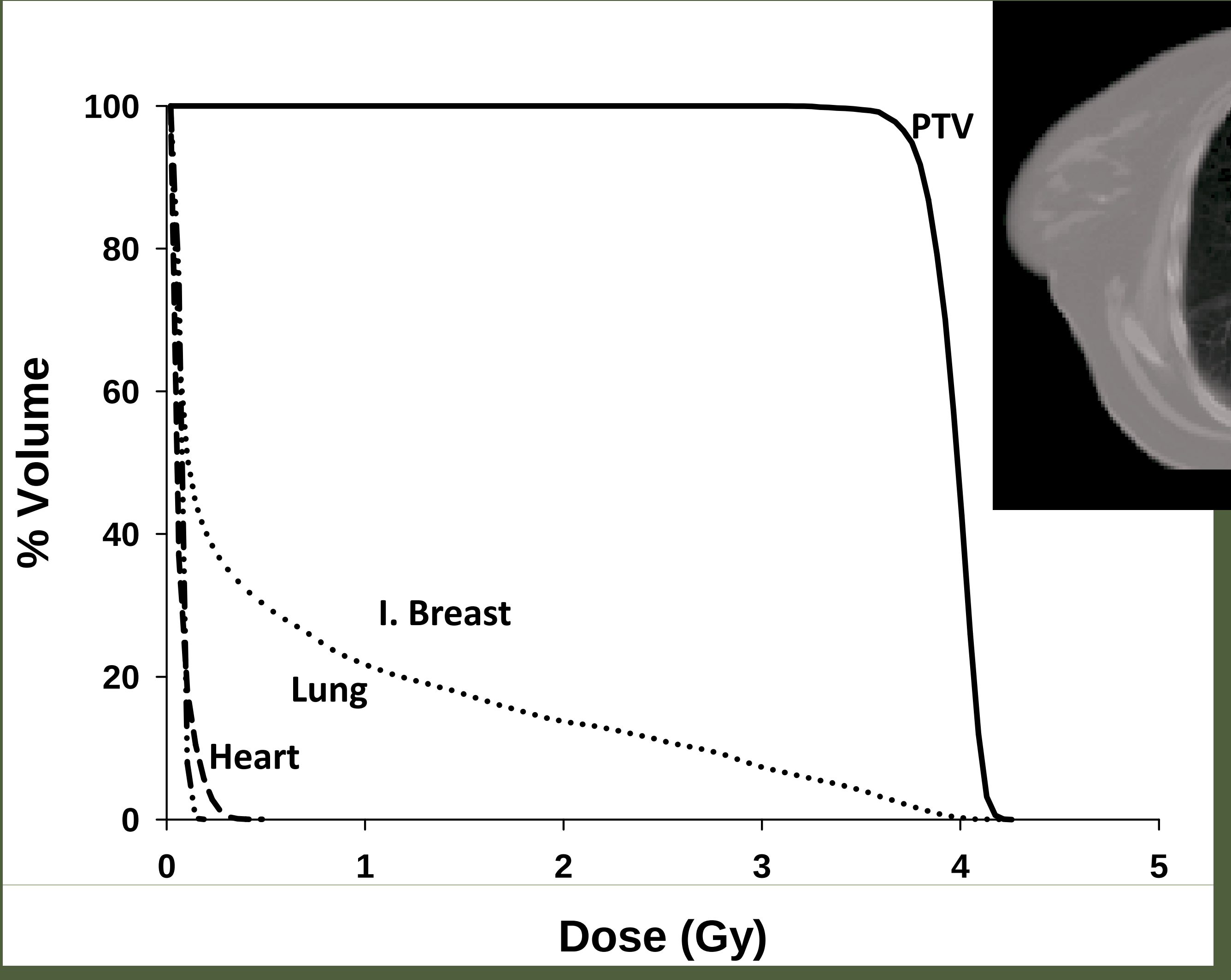
Combination IMRT+MERT
Accelerated Partial Breast Irradiation

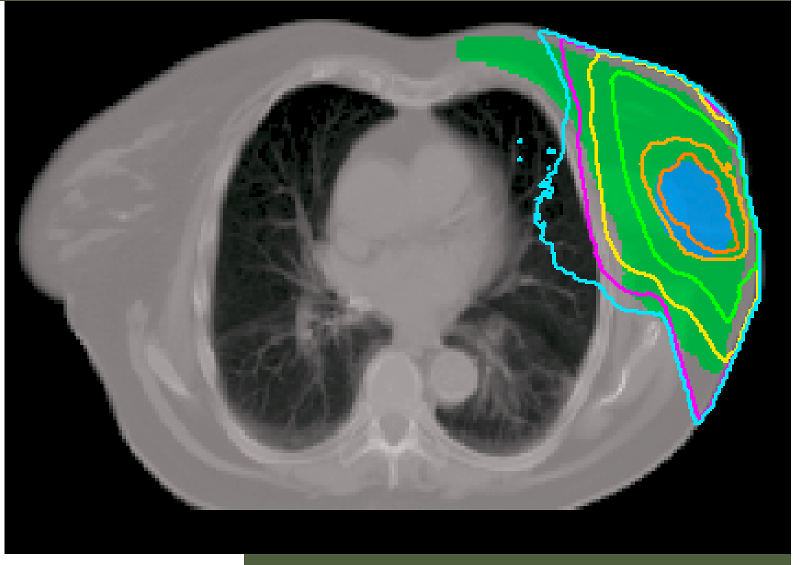




20, 50, 90, 100, 110% isodose lines.
Prescrition : 38.5 Gy
10 fractions.

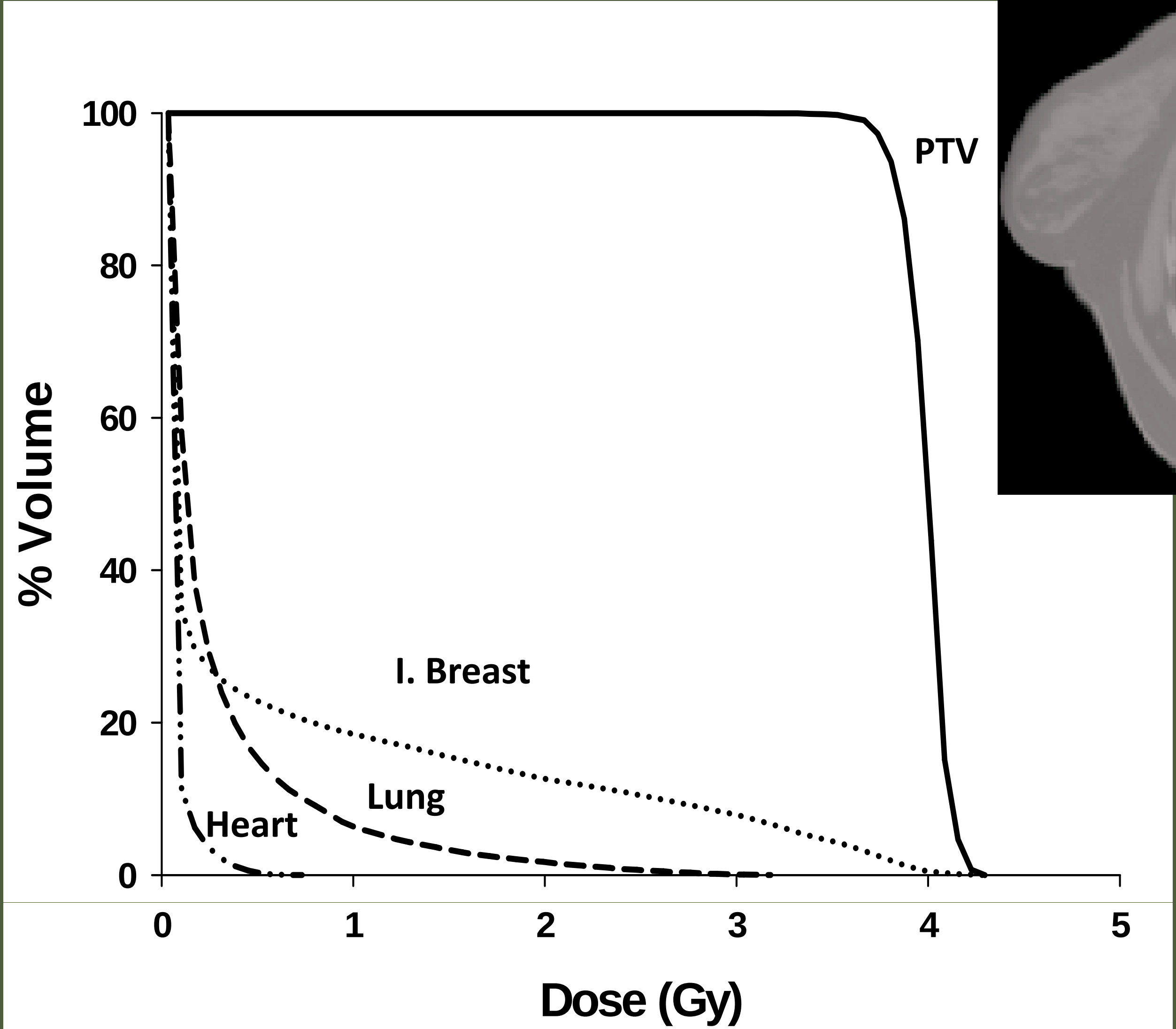
Combination IMRT+MERT
Accelerated Partial Breast Irradiation

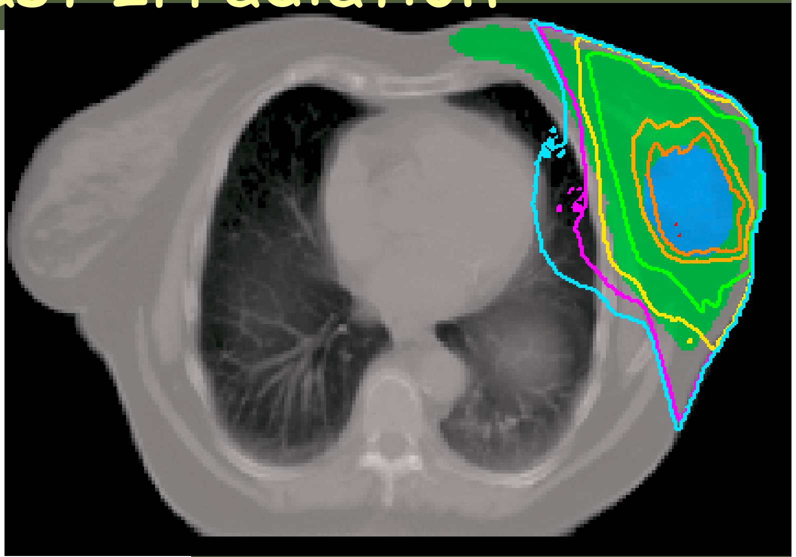




5, 10, 20, 50, 90, 100, 110, 120% isolines
Prescription: 38.5 Gy
10 fractions.

Combination IMRT+MERT
Accelerated Partial Breast Irradiation



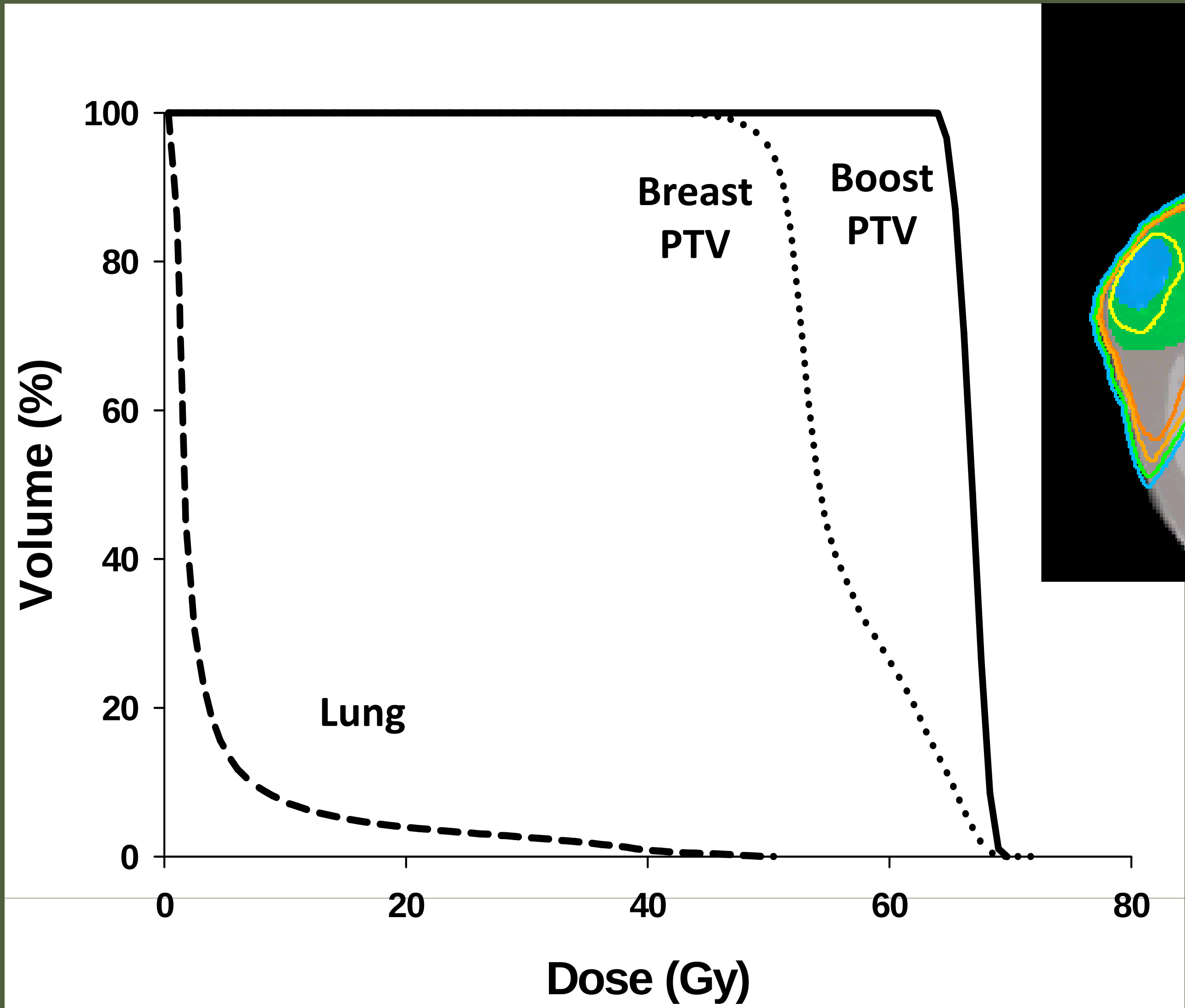


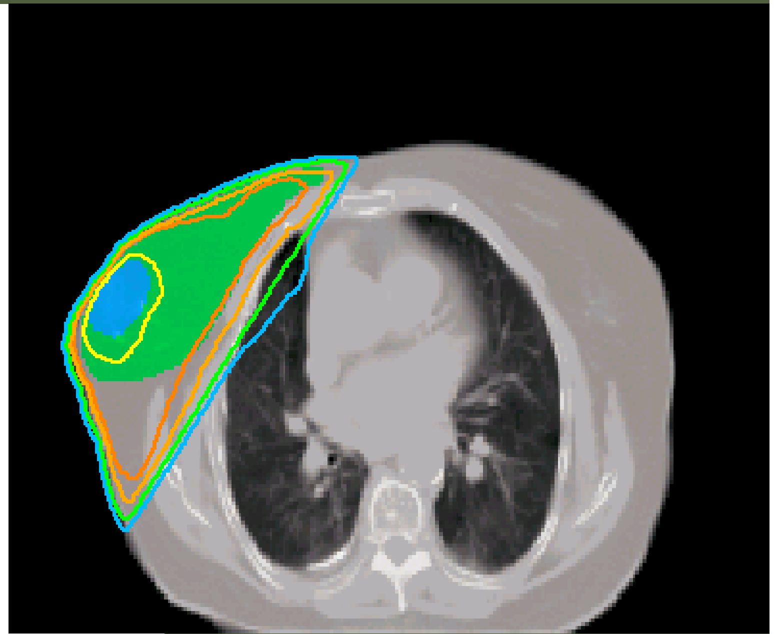
5, 10, 20, 50, 90, 100, 110, 120% isolines

Prescription: 38.5 Gy

10 fractions.

Combination IMRT+MERT
Simultaneous Irradiated Boost





20, 50, 90, 100 y 128% isolines.
Prescription PTV: 50.4 Gy
Prescription CTV: 64.4 Gy

Combination IMRT+MERT

Technique	Case	Beam type	Energy (gantry angle)	Number of segments	Monitor Units
PBI	P1	Electrons	12 MeV (295º)	3	28.0, 75.5, 59.7
			15 MeV (295º)	4	60.5, 28.1, 33.3, 32.9
	P2	Electrons	18 MeV (90º)	4	5.4, 11.2, 25.4, 12.6
		Photons	6 MV (342º)	4	20.3, 16.8, 33.9, 62.1
			6 MV (150º)	2	209.0, 0
	P3	Electrons	12 MeV (320º)	4	60.4, 50.1, 3.5, 39.4
			15 MeV (320º)	6	32.3, 37.5, 38.4, 5.2, 30.9, 34.8
SIB	P3	Electrons	12 MeV	1	19.4
		Photons	6 MV (39º)	2	95.3, 10.1
			6 MV (213º)	2	96.4, 9.7

TCP and NTCP for PBI cases

* El fraccionamiento es igual a 2 Gy debido a que se convirtió la dosis a dosis equivalente del fraccionamiento convencional.

	Dosis (Gy)/Frac	a	TD50	γ	γ/β	P1 EUD	P1 TCP (%)	P2 EUD	P2 TCP (%)	P3 EUD	P3 TCP (%)
Breast TCP	2 (*)	-7.2 (1)	36.24 (2)	2 (3)	3 (4)	56.39	97.17	56.42	97.18	55.95	96.99
					4 (5)	56.09	97.05	56.11	97.06	55.67	96.87
					4.6 (6)	55.96	96.99	55.97	97.00	55.54	96.82
				0.88 (2)	4 (5)	56.09	82.31	56.11	82.33	55.67	81.92

NTCP	Dosis (Gy)/Frac	γ/β	a	TD50	γ	P1 EUD	P1 NTCP (%)	P2 EUD	P2 NTCP (%)	P3 EUD	P3 NTCP (%)
Pneumonitis	2 (*)	3 (4, 8-10)	1 (3)	24.5 (7) 30.8 (8)	2 (3)	0.74	0.00	3.00	0.00	2.82	0.00
Pericarditis			3 (3)	50 (7) 52.3 (9)	3 (7) 1.28 (9)	0.86	0.00	0.77	0.00	1.20	0.00
Fibrosis			0.78 (4)	60 (10)	3.4 (6) 4 (3)	5.94	0.00	11.79	0.00	5.23	0.00
				65 (10)	4 (3)						
				70 (7)	3.4 (6)						

Our group is committed with few fields and with just the necessary MUs :

Leakage issue:

MUs in the beam delivery can be reduced :

Dose prescription to the target and as lower as possible integral dose

ISI Web of Knowledge℠

Latest 3 years

Few fields?...

Intensity Modulated Arc Therapy (IMAT):

Average MUs with IMAT is lower than with IMRT but the dynamic version one.

Step&Shoot IMRT is slower than IMAT but similar MUs

- RapidArc of Varian is based on DAO (Otto K 2007) — 65 references

- Volumetric Modulated Arc Therapy (VMAT) — 45 references

ERGO++ :
<u>MLC shapes are given by anatomic relationship between PTV and OARs</u>

Few fields?...

Not always new techniques and simpler to use are the best.

?

Smart sequencer

Hybrid optimization model (our proposal) :

Weights calculation under Linear Programming:
- The problem is reduced to the necessary voxels
- Dose-volume restrictions are not always necessary.
- The calculation time is faster.

Class solutions in an automatic way:
- Few beamlets for the optimization procedure.
- Aperture can be defined from the begining but…

Why don´t we use the benefit of our sequencer?

Linear Programming formulation to find weights

Objective function

$$f.o. = P\sum_{i=1}^{N_{ptv}} x_i + Q_{PTV}\sum_{i=1}^{N_{ptv}} y_i + R_{OAR}\sum_{i=N_{ptv}+1}^{N} x_i$$

Initial conditions

$$\begin{cases} \sum_{j=1}^{M} B_{ij}\omega_j - x_i \le D^{max} & i = 1,\dots,N_{ptv} \\ \sum_{j=1}^{M} B_{ij}\omega_j + y_i \ge D_{min} & i = 1,\dots,N_{ptv} \\ \sum_{j=1}^{M} B_{ij}\omega_j - x_i \le d^{max} & i = N_{ptv}+1,\dots,N \end{cases}$$

$$con \quad x_i, y_i \ge 0 \quad \forall i$$

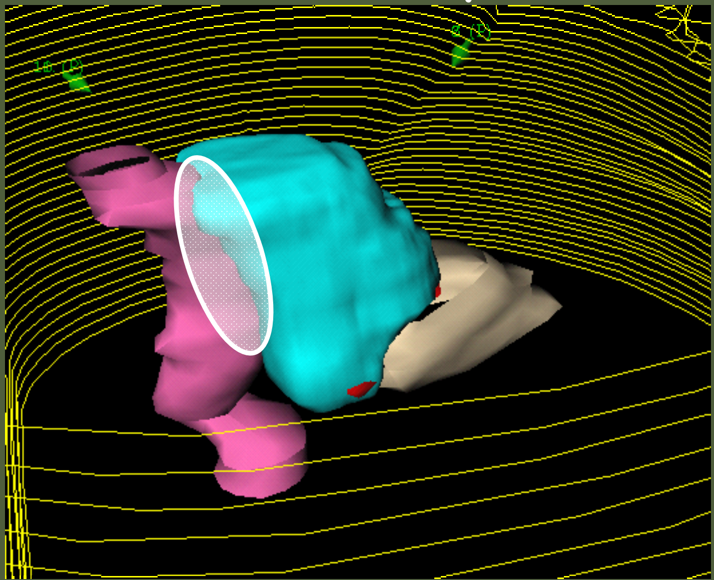
nº of equations: $N + N_{PTV}$

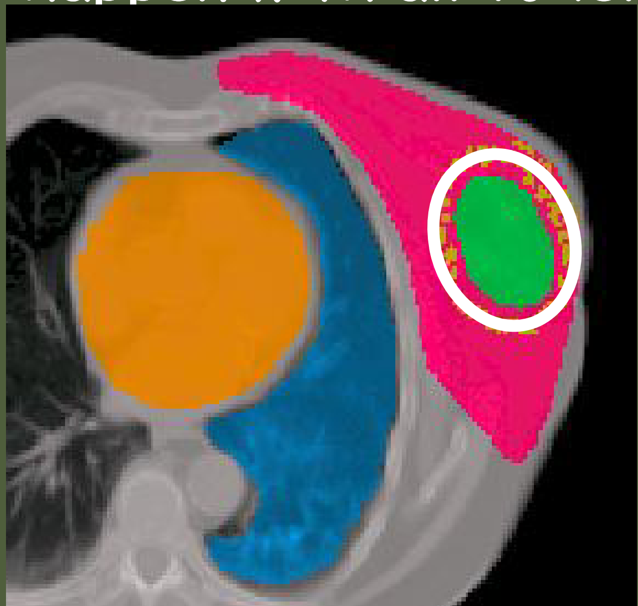
nº of unkowns: $M + (N + N_{PTV})$

LP is not feasible for all the potential beamlets but it is the fastest method if the initial problem is adequately reduced.

Linear Programming for a reduced intial problem

1. Voxel reduction:
   Is it necessary to know what happen with all voxels?

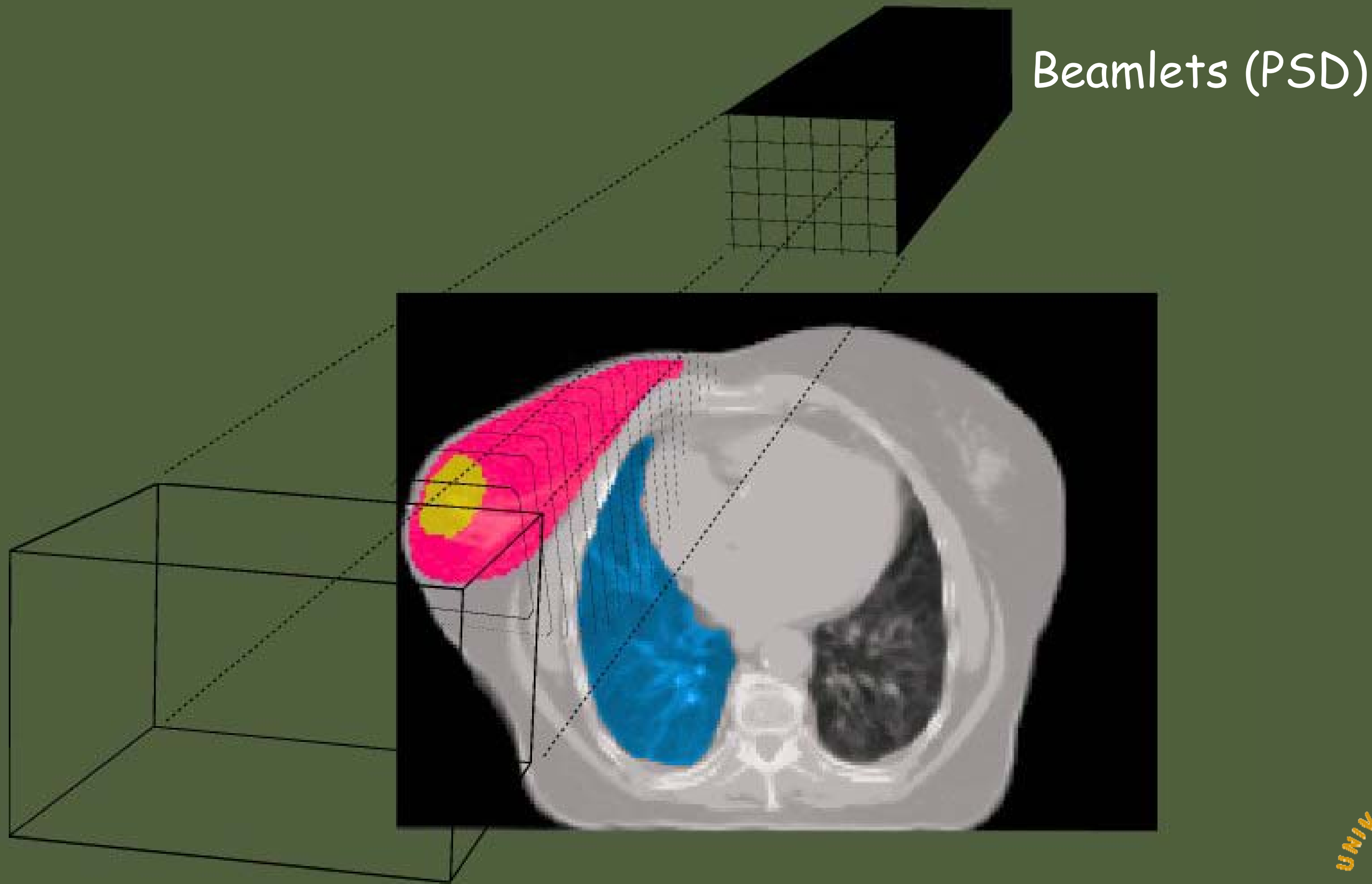




2. Grouping of beamlets:
   We need to find the apertures susceptible for weighting.

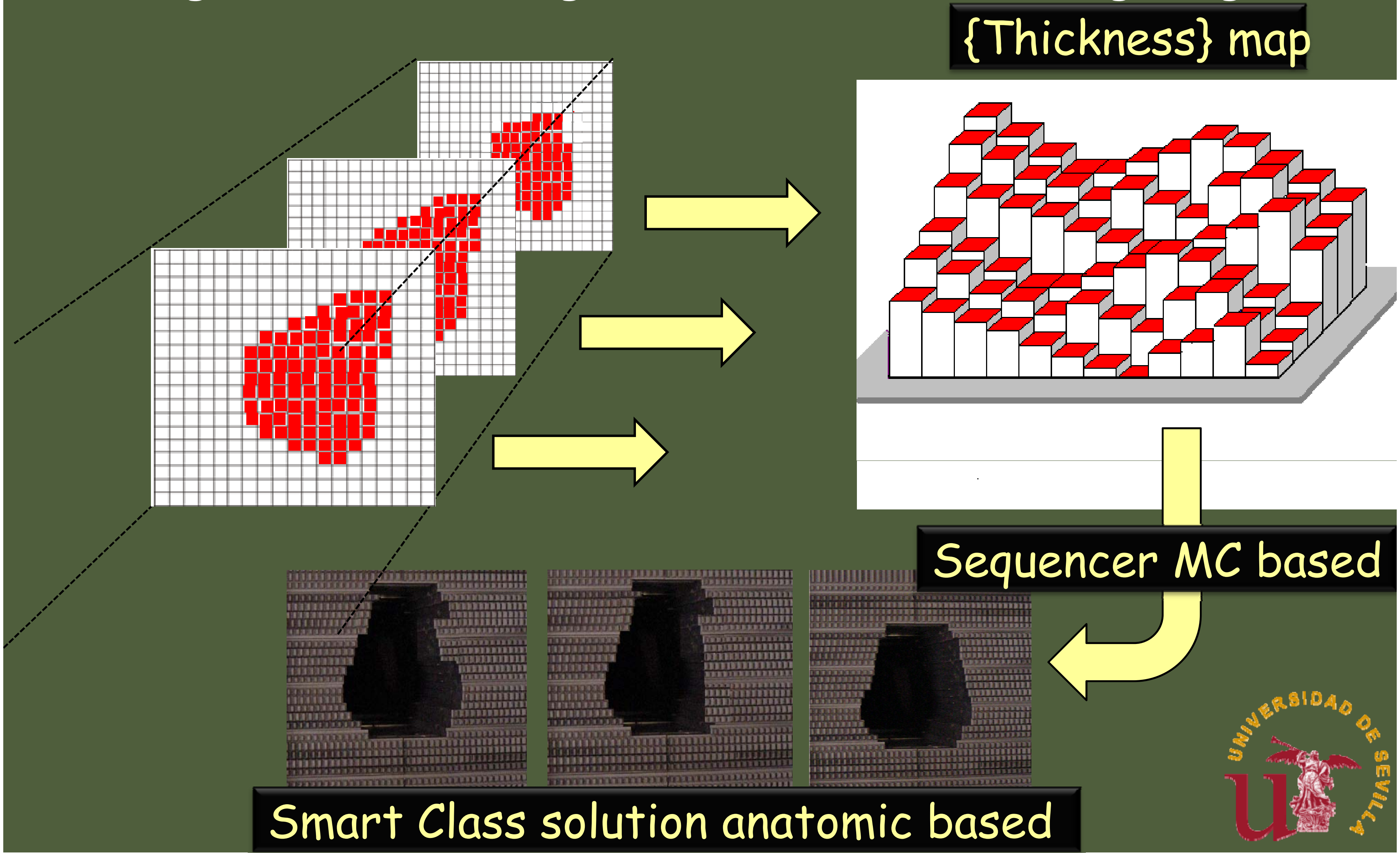
Smart sequencer for LP optimization

Looking for freedom degrees for the fluence weighting.

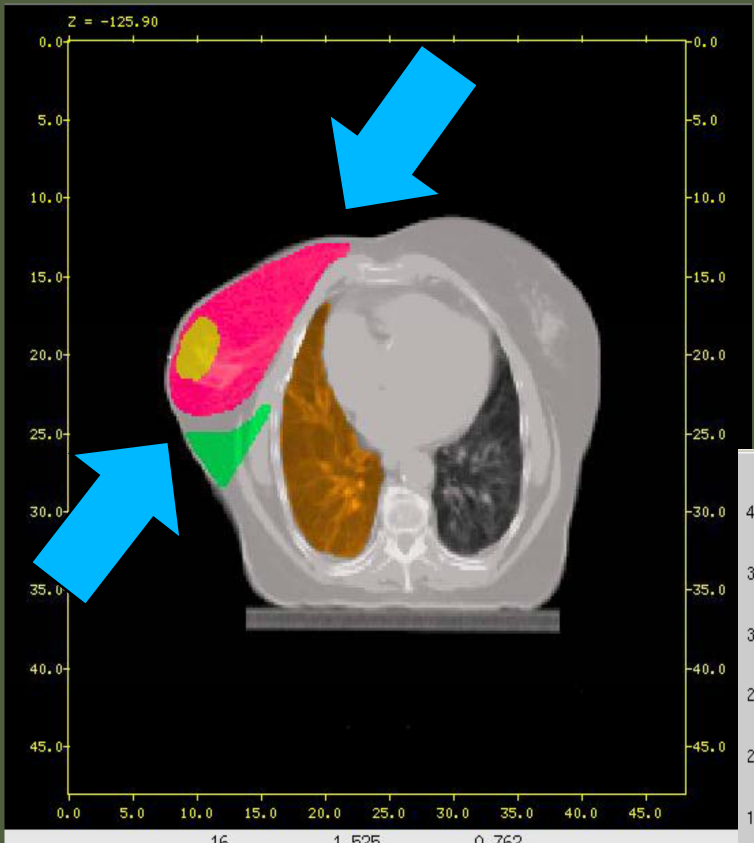


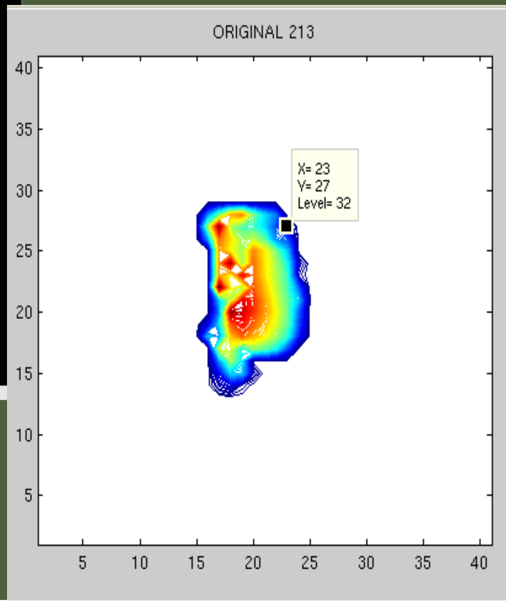
Smart sequencer for LP optimization

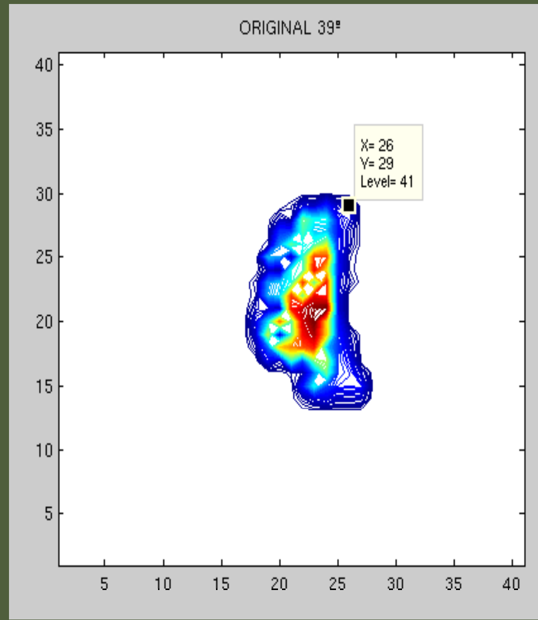
Looking for freedom degrees for the fluence weighting.



Finding freedom degree for weighting photon beams in a SIB case

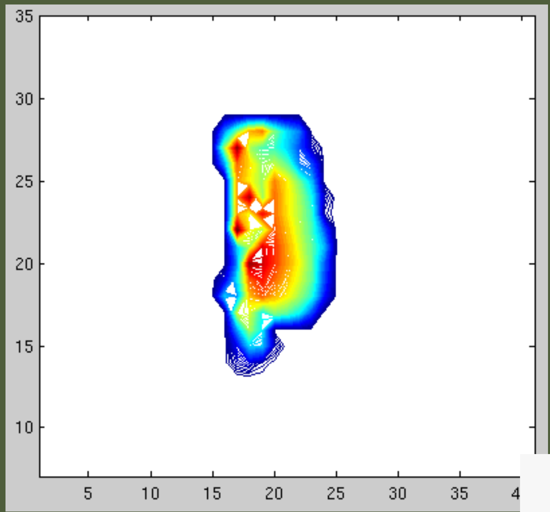






{Thickness} map

Metabolic map??



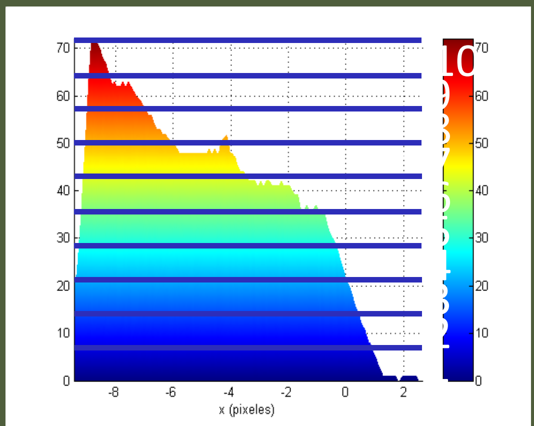
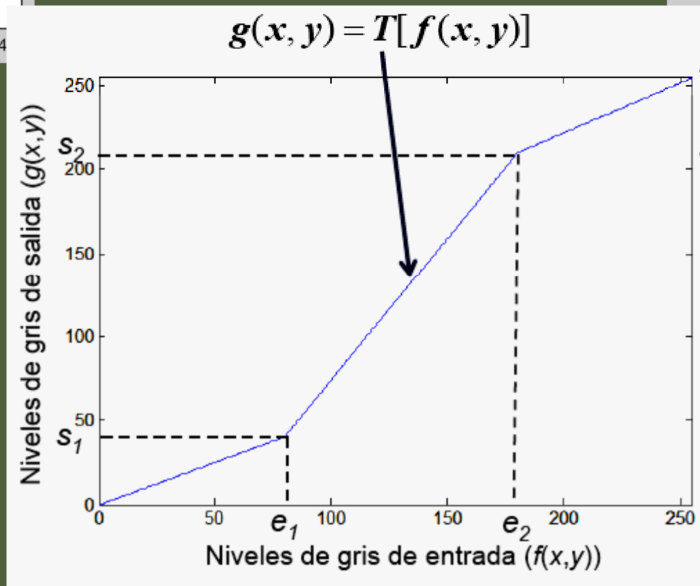
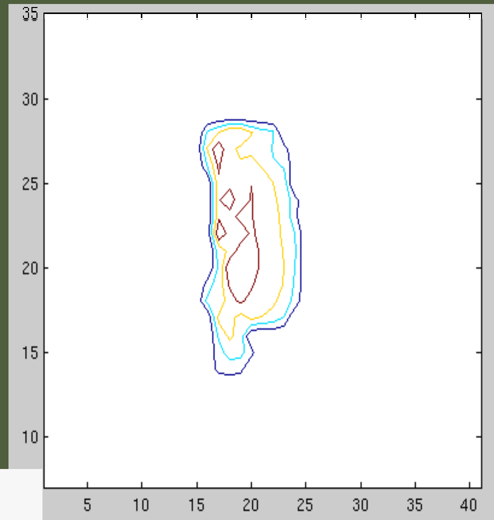


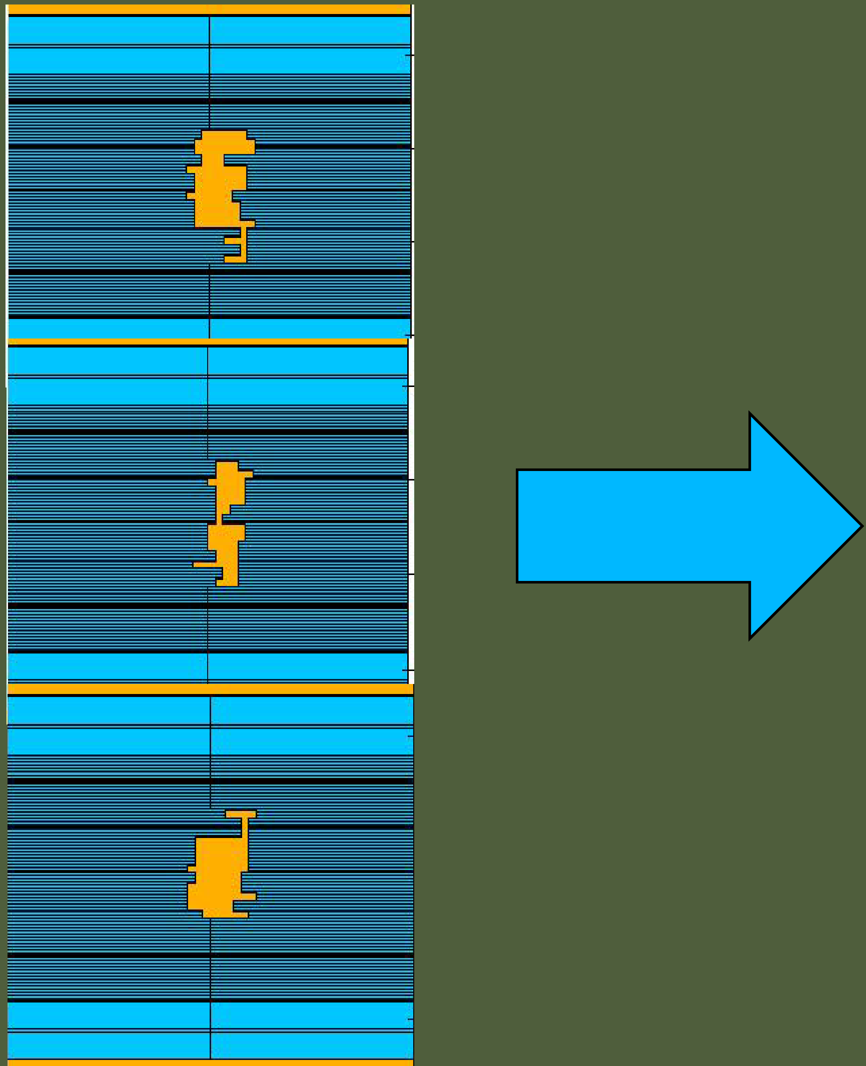
Image processing

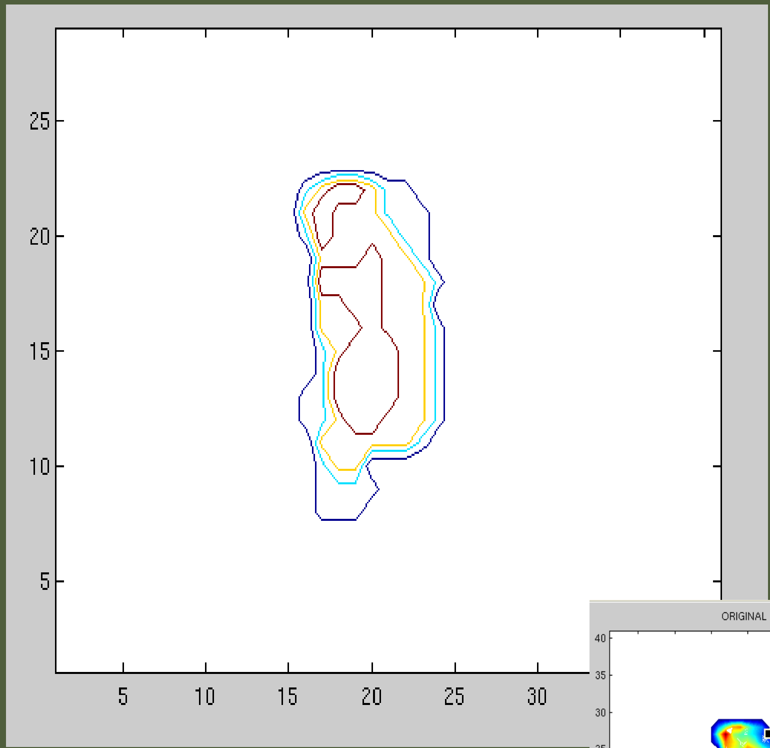


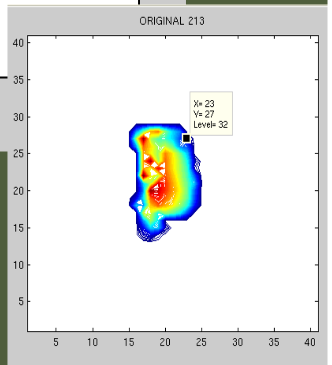
Matrix for the sequencer



Direct aperture from a sequencing process !!!



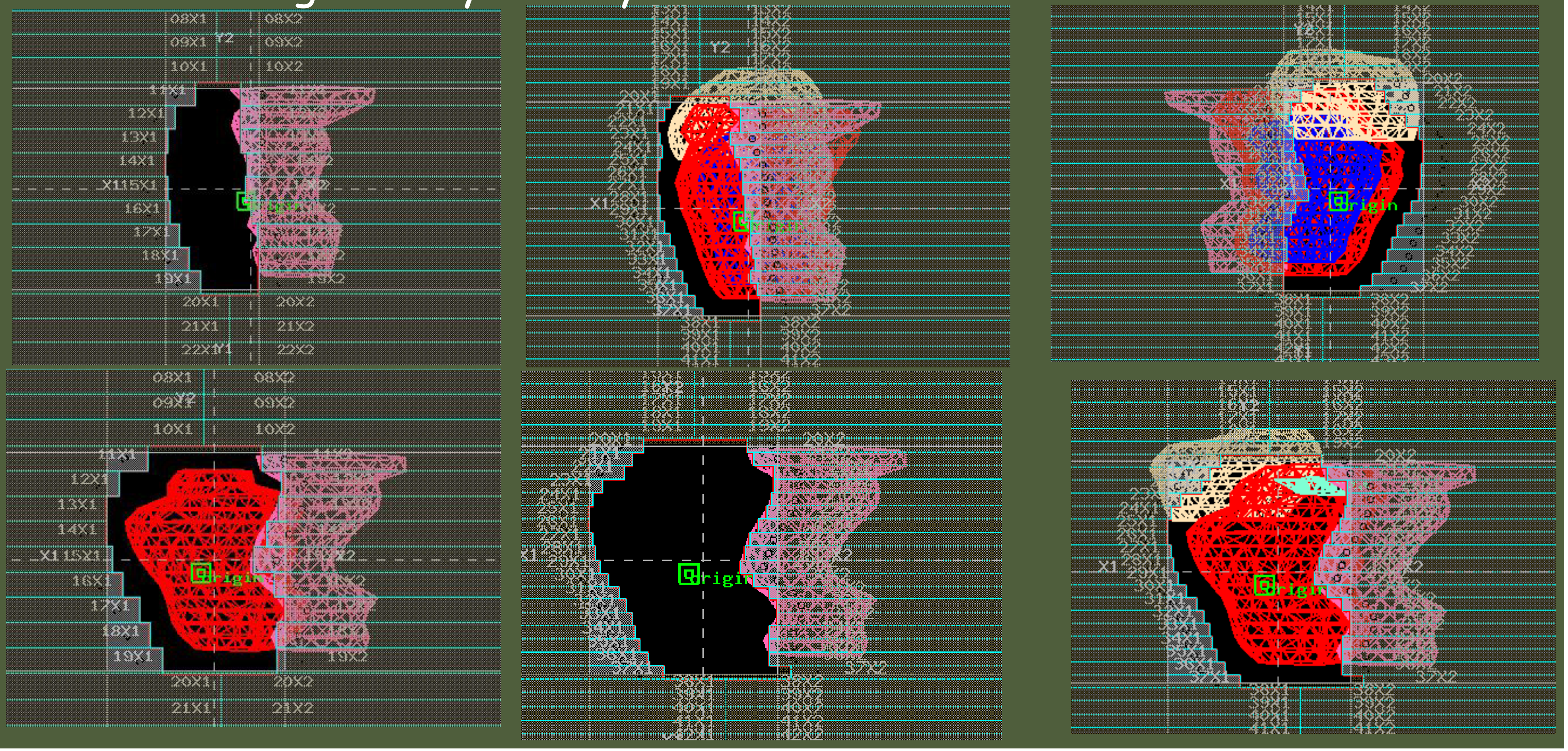




- Thickness map with the information of structures can be "sequenced" to obtain the smart aperture to be weighted.

- Few "beamlets" linked to "regions of voxels of interest" will allow a fast LP solution with the best set of weights.

- These few segments yes they are worth full simulated MC.



Thanks for your attention

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