Clinical Monte Carlo: Photon Beams

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What is Monte Carlo?

A mathematical method using random sampling

What is Monte Carlo ?

- The originators : Neumann and Ulam 1949
- The method : Random sampling from pdf's to construct solutions to problems.

John Von Neumann

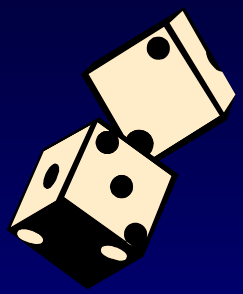
(1903-1957)

Stanislow M. Ulam

(1909-1984)

Why call it Monte Carlo?

After the city in the Monaco principality ...



What is Monte Carlo Radiation Transport?

- Random sampling of particle interactions

  a good supply of random numbers

  probability distributions governing the physics processes

- Information obtained by simulating large number of histories

Why Use Monte Carlo for Radiotherapy Treatment Planning

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)

The Accuracy Requirement for Treatment Planning Dose Calculation

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

and

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

then

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

CPU time required

1 Gy => 1 billion electrons **(1cmx1cm field)**

1% uncertainty for 0.3 cm cubes requires a few million electrons (hours on a PC)

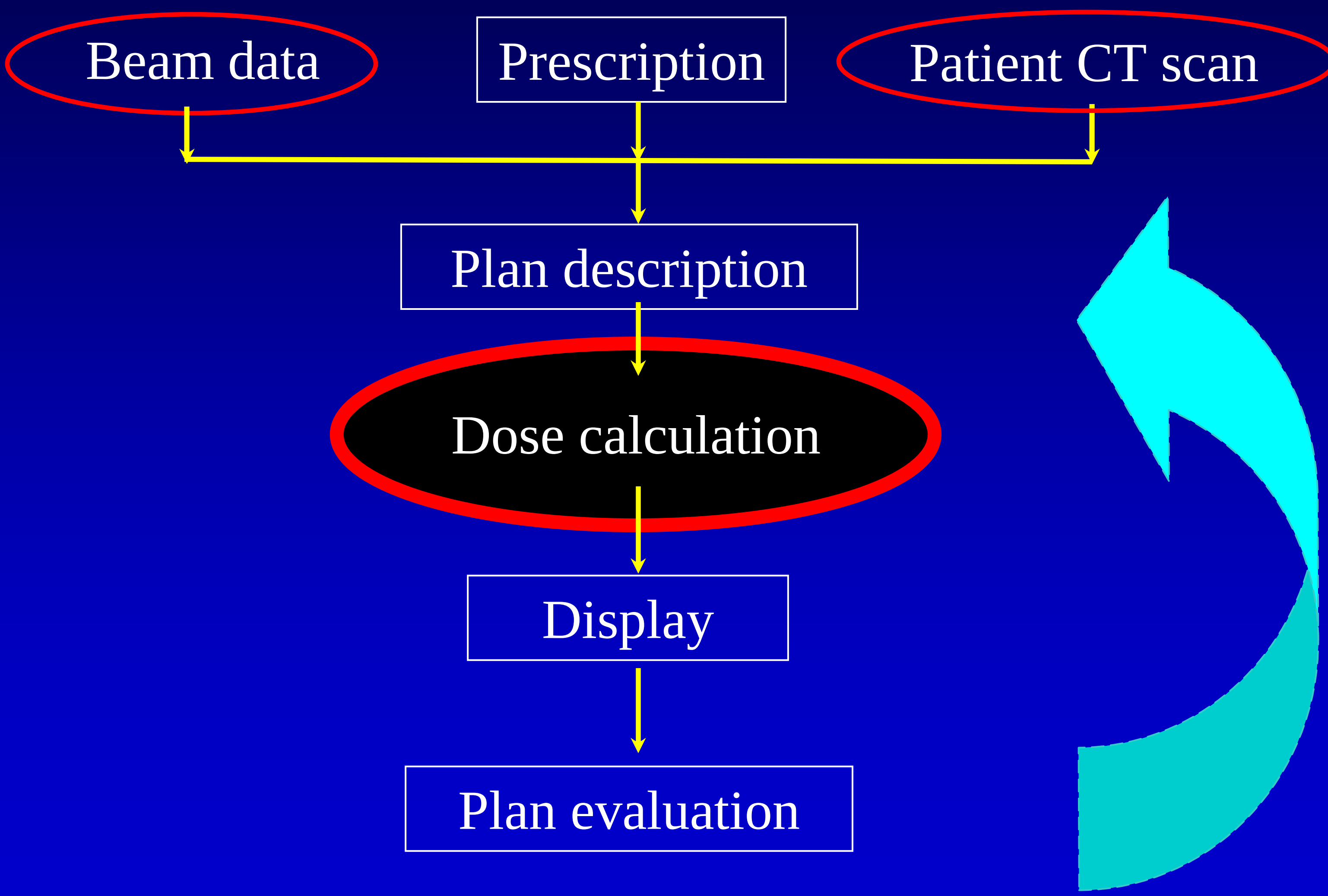
1 Gy => 1000 billion photons **(1cmx1cm field)**

1% uncertainty for 0.3 cm cubes requires up to a few billion photons (days on a PC)

Applications of M-C in radiotherapy

- Fluence and spectrum calculations
- Dosimetric parameters (stopping powers, etc.)
- Correction factors (BSF, HS, PS, P/S ratio...)
- Dosimeter response simulations
- Treatment head simulations
- Treatment planning dose calculations

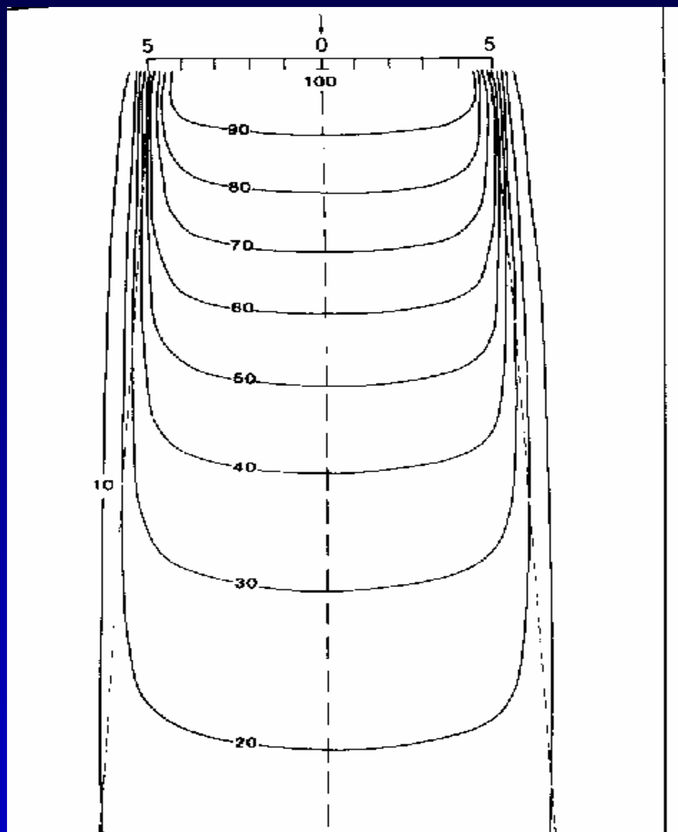
Radiotherapy treatment planning

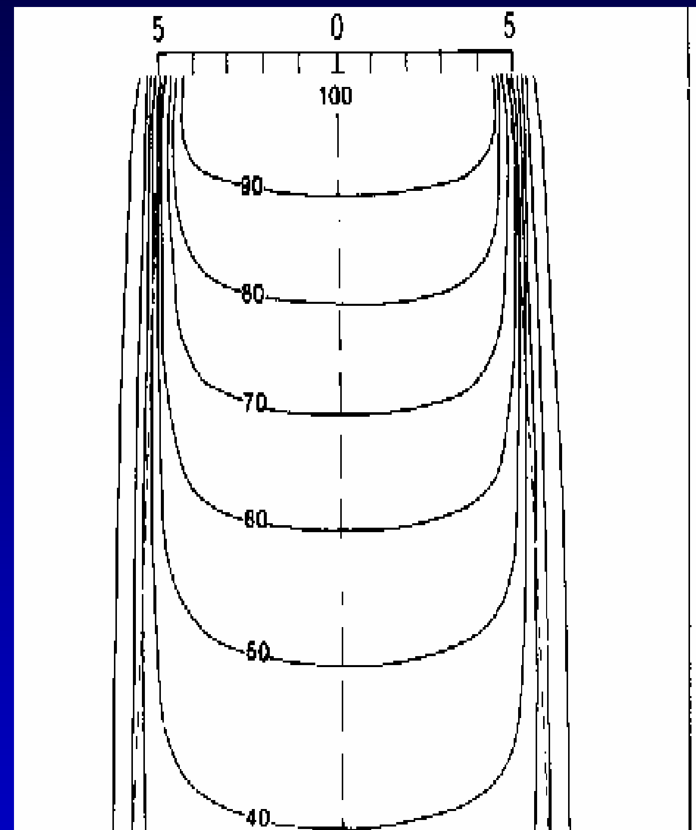


Dose algorithms for RTP

- Photon beams
  - Clarkson
  - FFT, FSPB, superposition convolution
  - super MC, XVMC
  - Monte Carlo
- Electron beams
  - 3D pencil beam
  - MMC, super MC, VMC
  - Monte Carlo

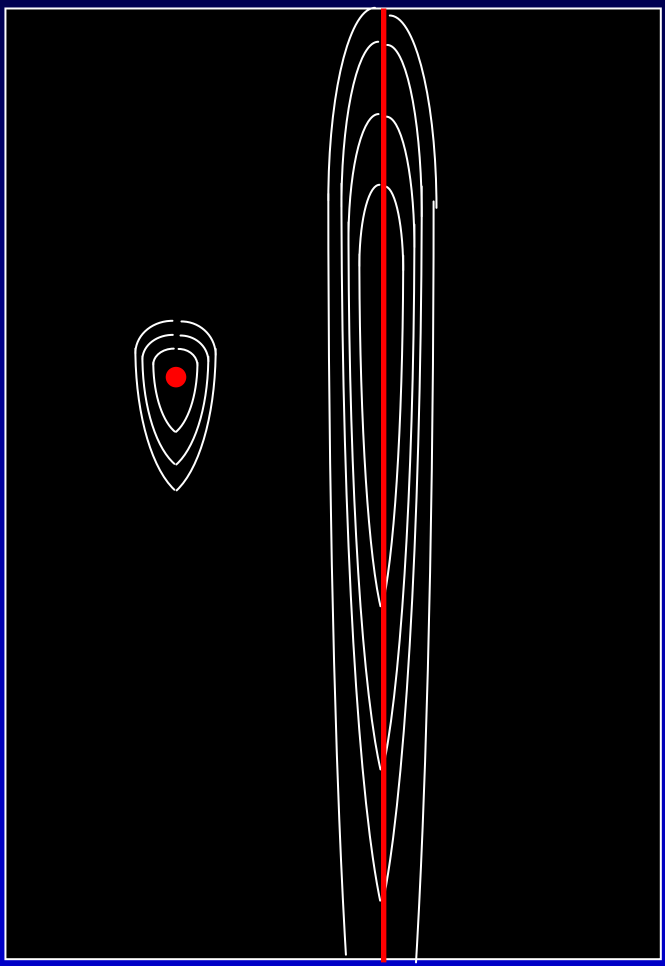
Equivalent Pathlength Correction



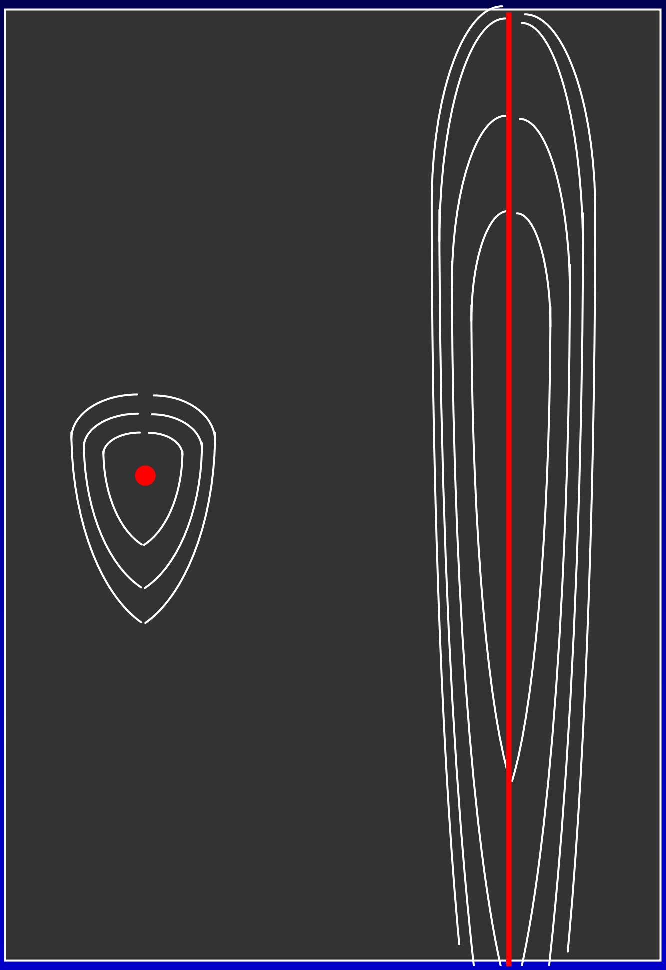


High-density medium **Low-density medium**

Variation of Dose Kernels with Density

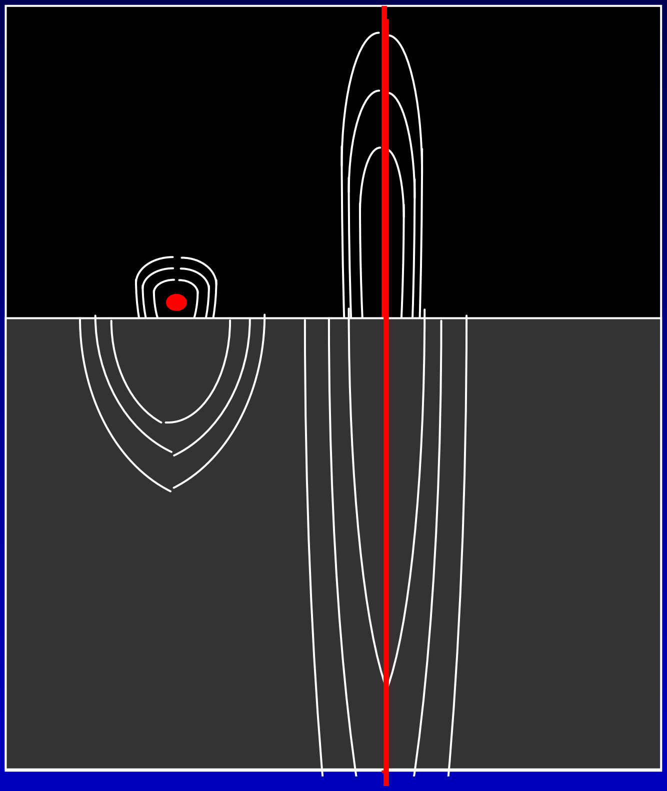


High-density medium



Low-density medium

Variation of Dose Kernels with Density

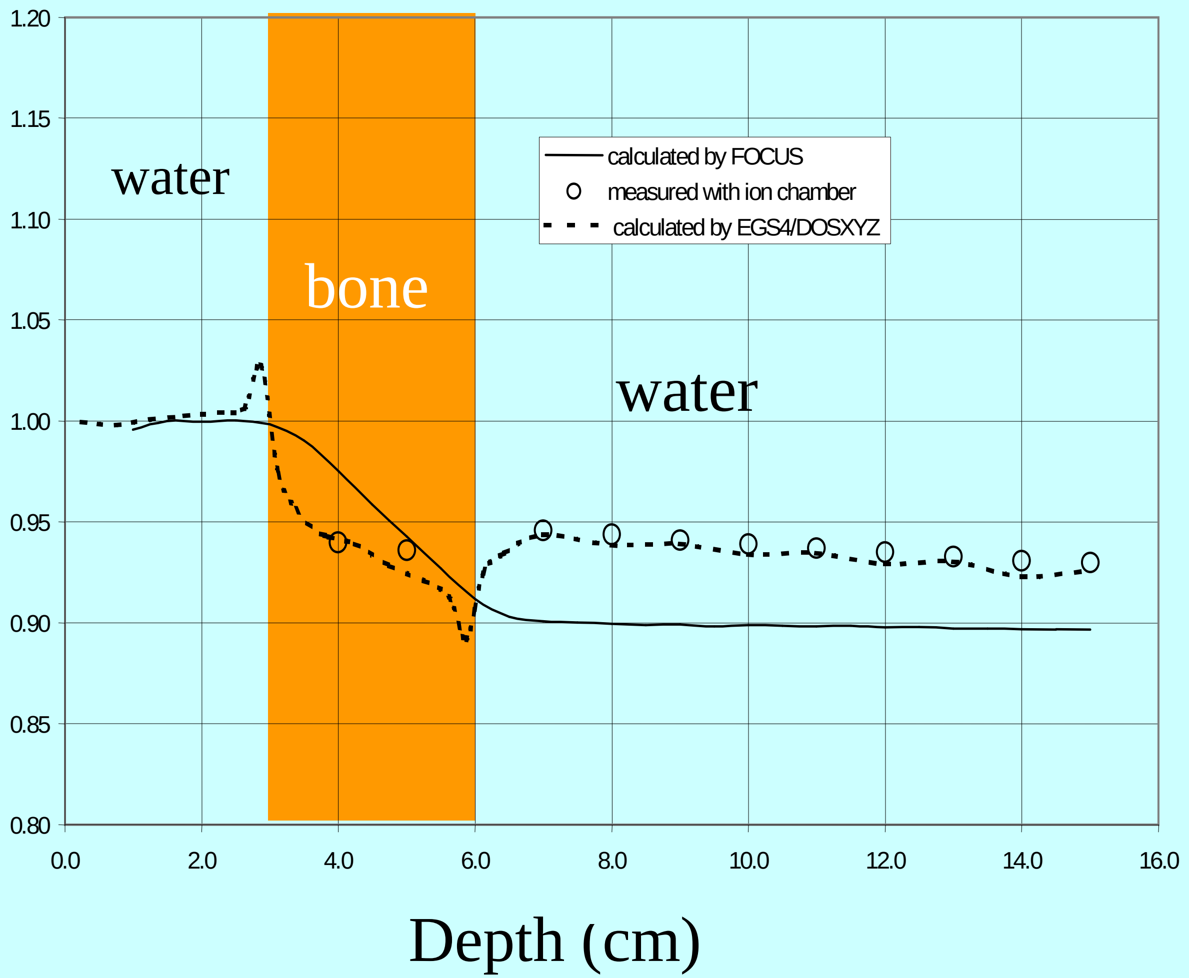


High-density medium

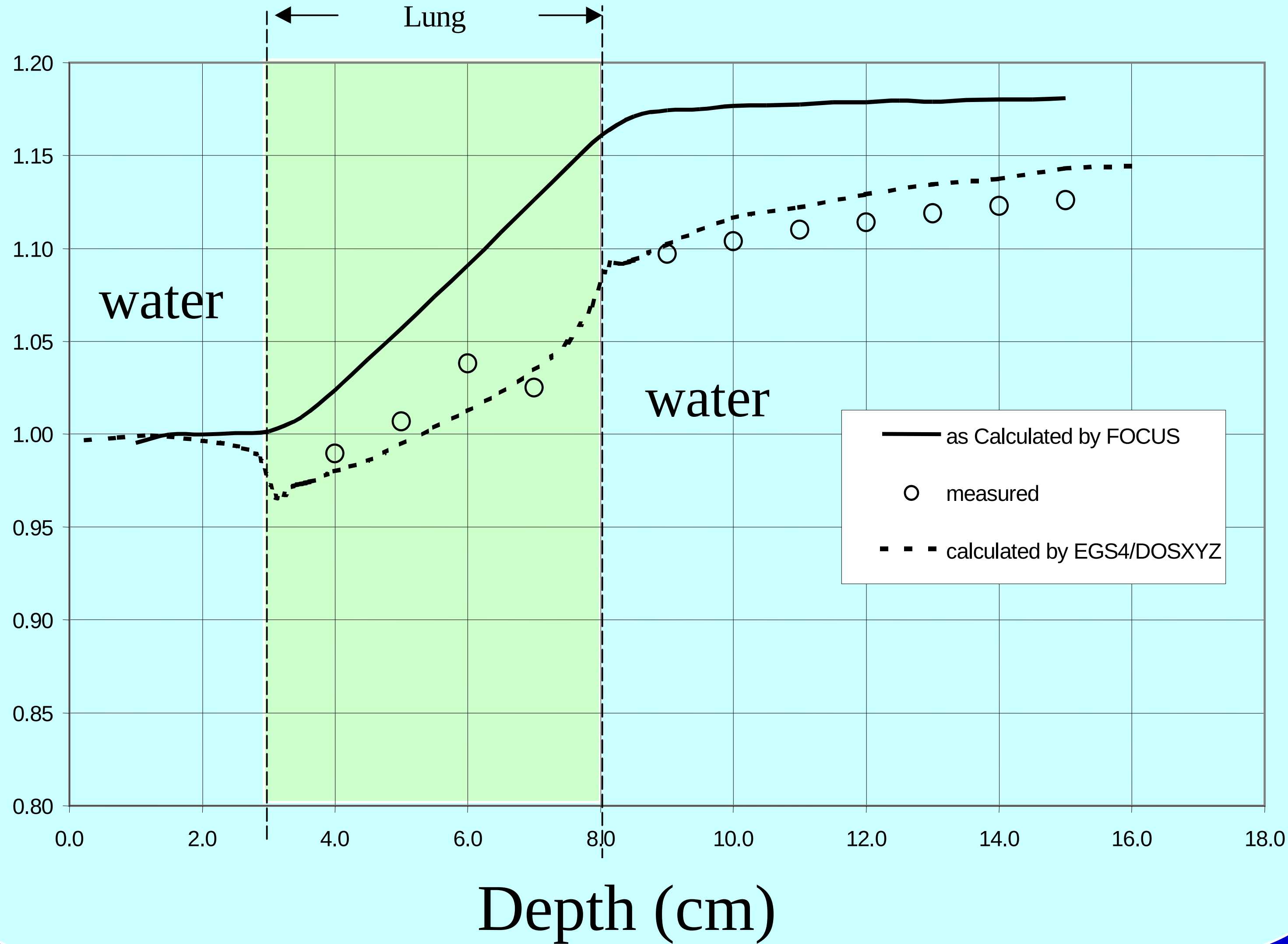
Low-density medium

The accuracy depends on how it is implemented.

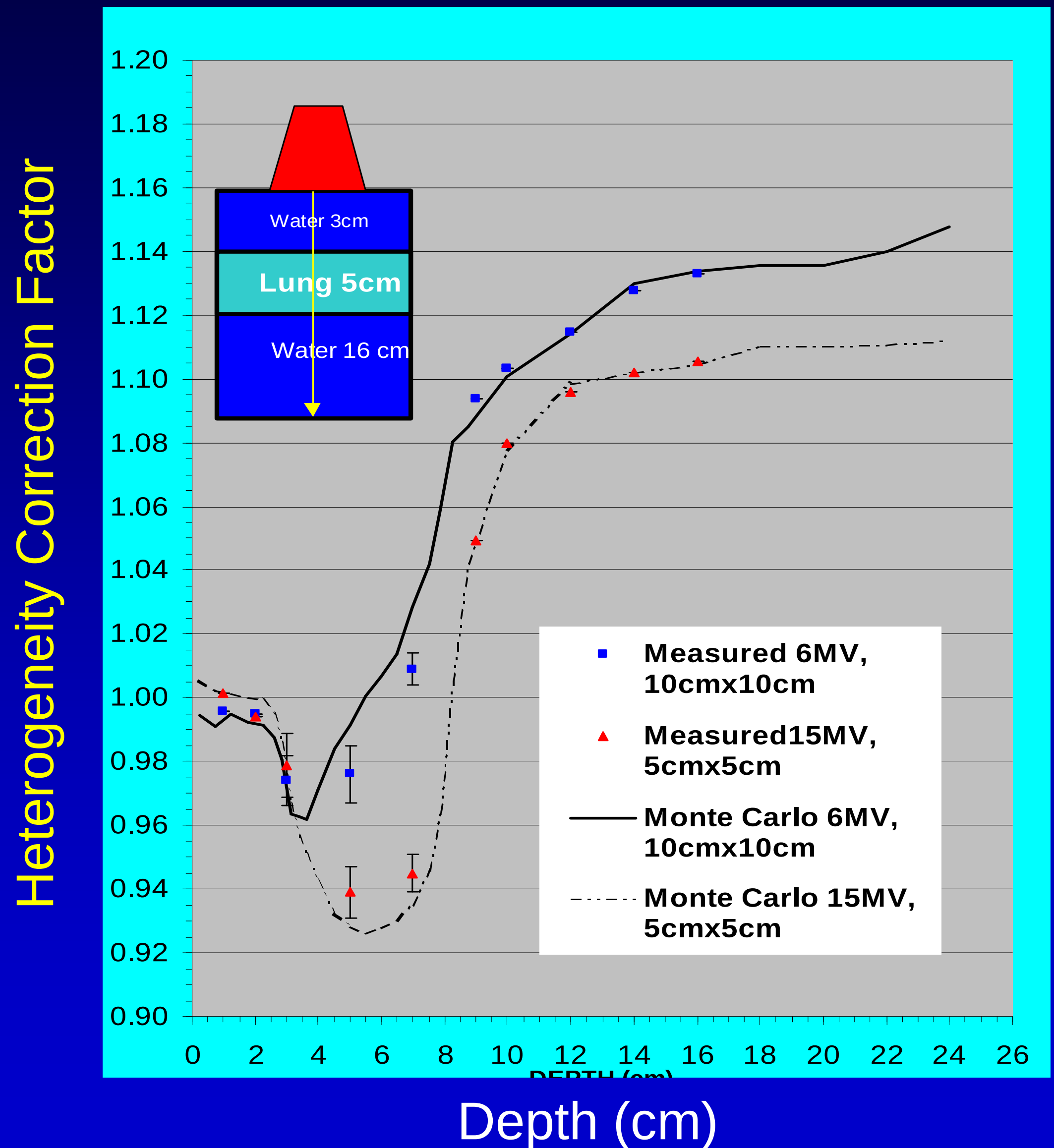
Correction factor for bone for 6 MV photons



Correction factor for lung for 6 MV photons



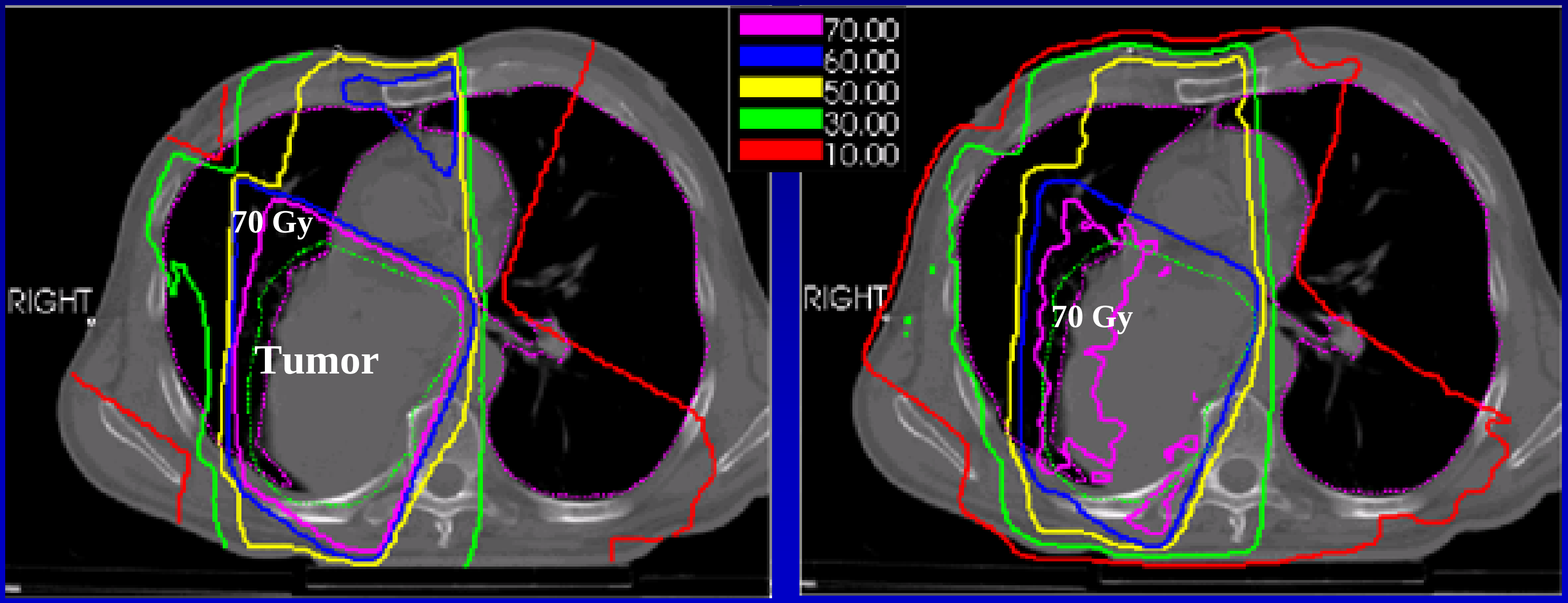
Layered Lung Phantom



Comparisons of Pencil Beam and Monte Carlo

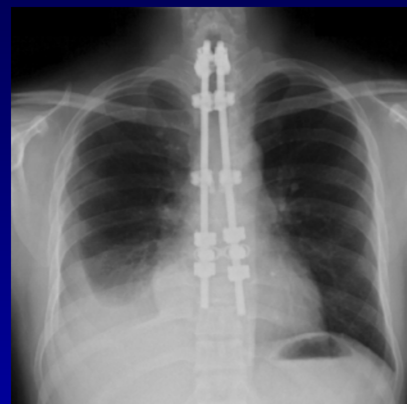
Mohan et al (1997)

Conventional Method (Pencil Beam) | **PEREGRINE**

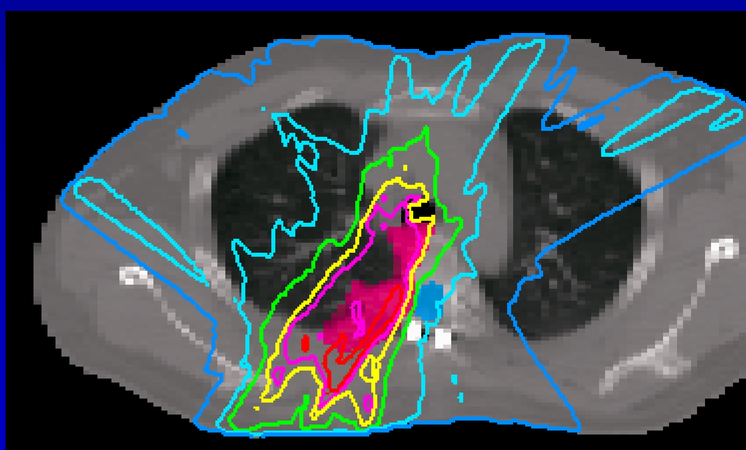


Dose Verification for IMRT

(Pawlicki et al 2000)



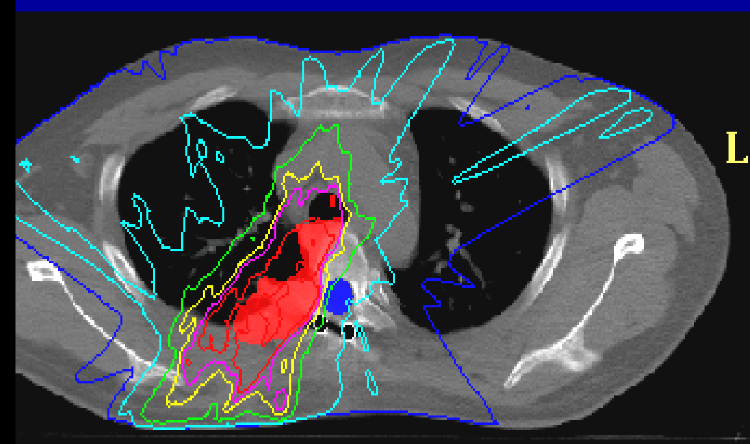
Monte Carlo



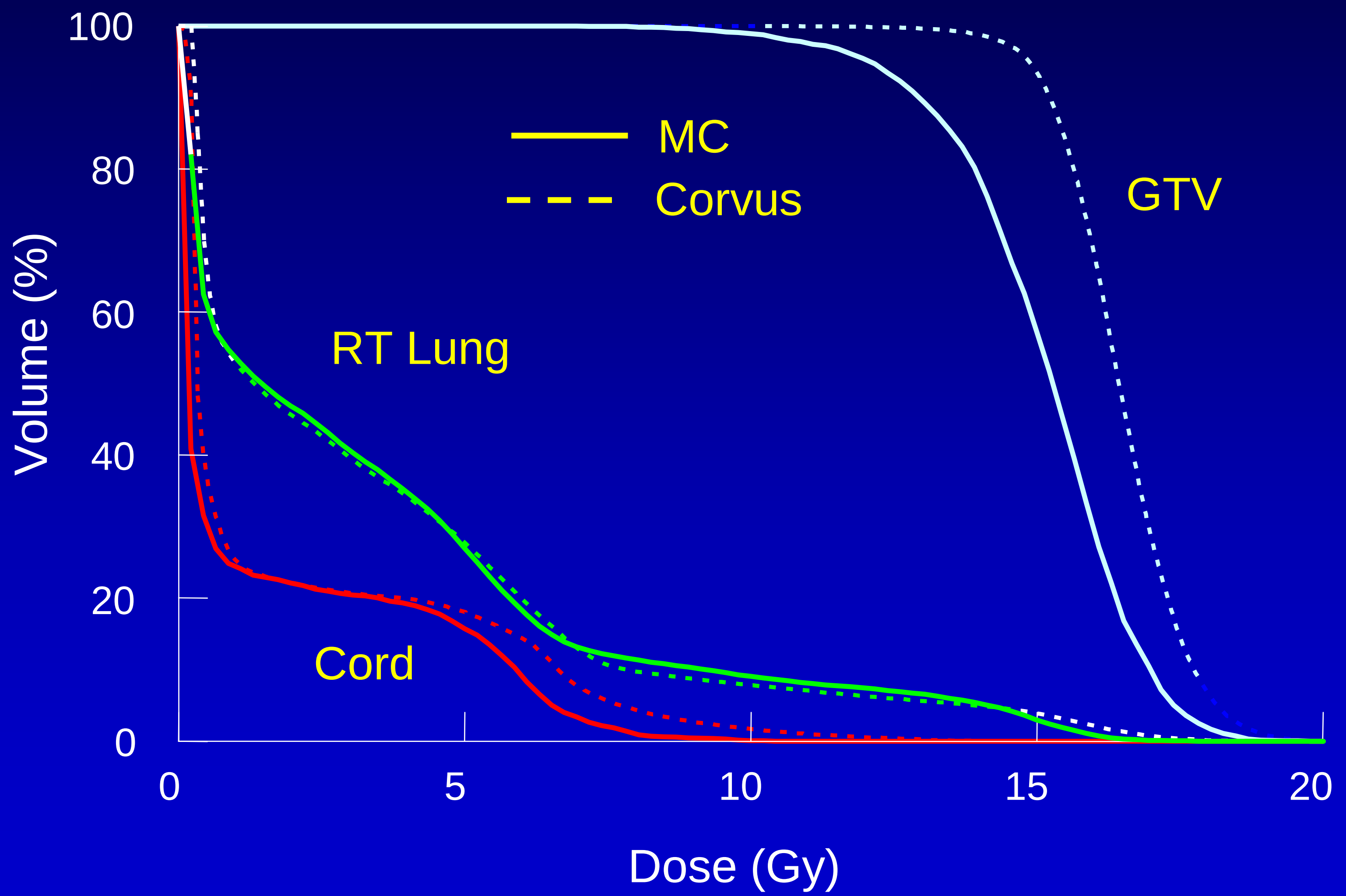
Gy

16.2
14.4
12.6
9.0
5.4
1.8

Corvus



DVH Comparison



Monte Carlo Algorithms

- Electron beams reported
  - VMC
  - DOSXYZ
  - MCDOSE/MCSIM
  - PENELOPE
  - MCRTP
  - DPM
- Photon beams reported
  - XVMC
  - PEREGRINE
  - MCNP
  - DOSXYZ
  - MCDOSE/MCSIM/MCRS

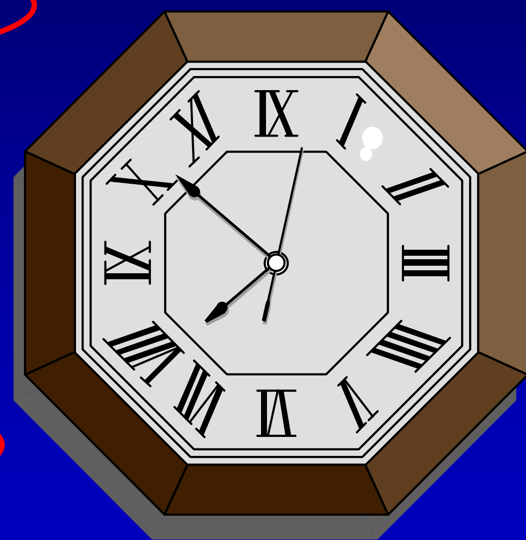
Current Status of MCTP

Accuray

NumeriX?

NOMOS

Nucletron



DOSIGRAY

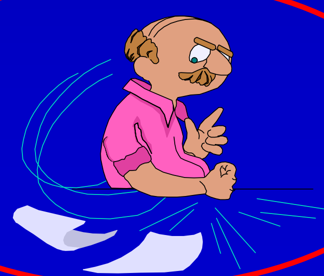
CMS

ADAC

Varian/BrainLab

FCCC...

MCV...

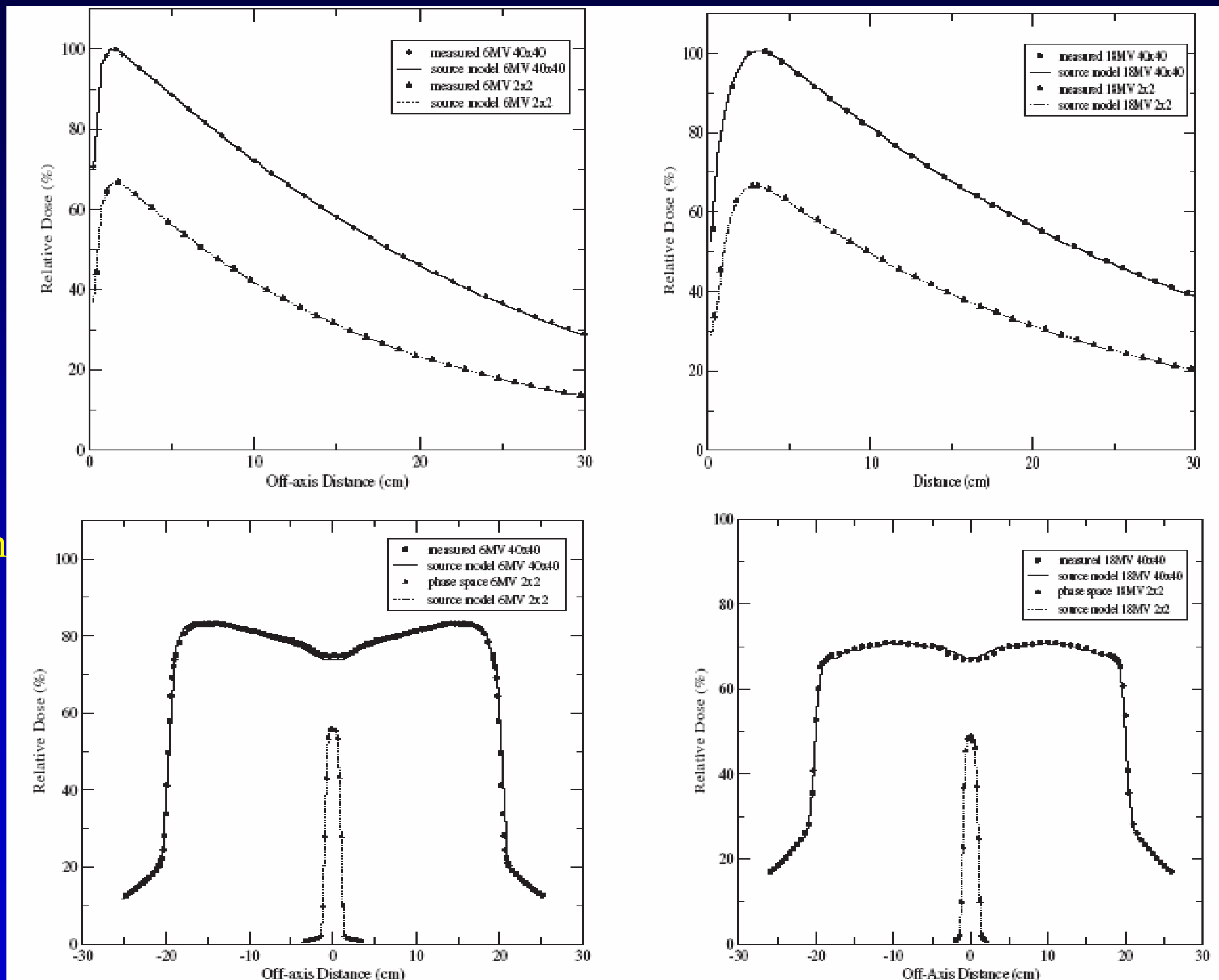


Implementation of MCTP

- Accelerator simulation
- Source modeling
- Beam commissioning
- CT data conversion and phantom setup
- Dose calculation algorithms
- Data processing and plan evaluation
- Plan optimization

Measured vs MC Reconstructed Dose Distributions

6 MV
40cmx40cm



18 MV
40cmx40cm

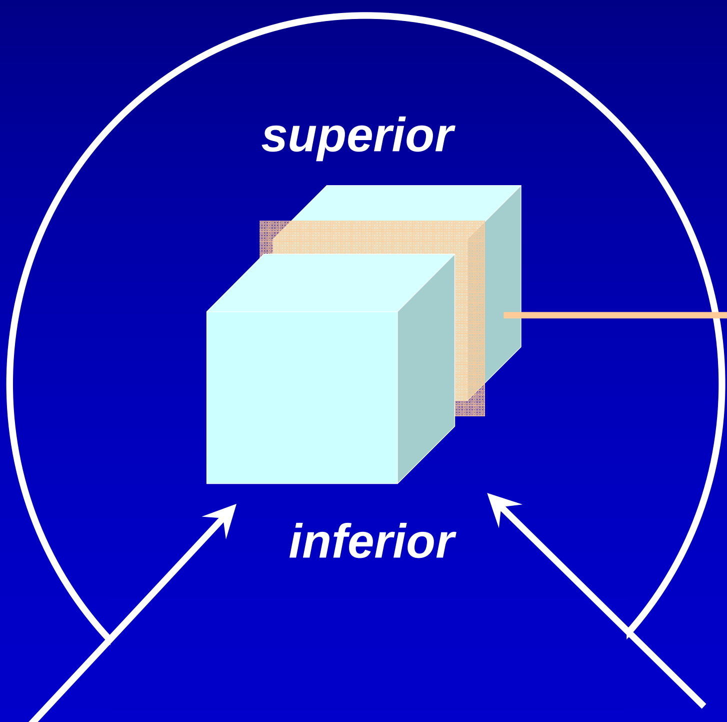
Yang et al, *Phys Med Biol* (2004) 49: 2657-73

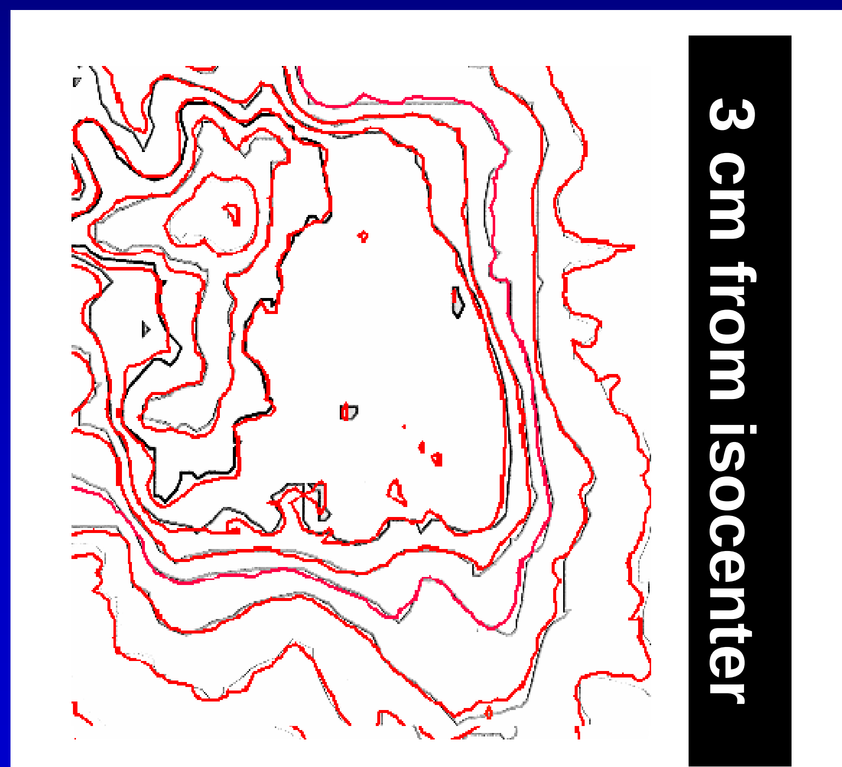
Combined Dose Distribution: Film vs Monte Carlo

Patient plan (Corvus)

Delivery in film phantom

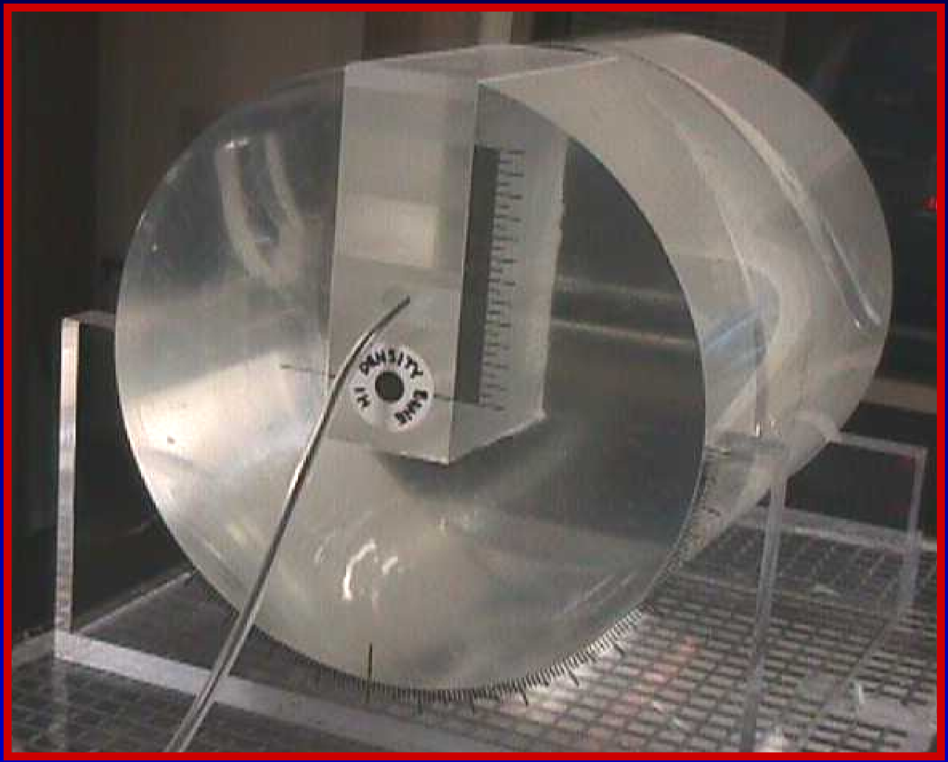
Monte Carlo dose calculation

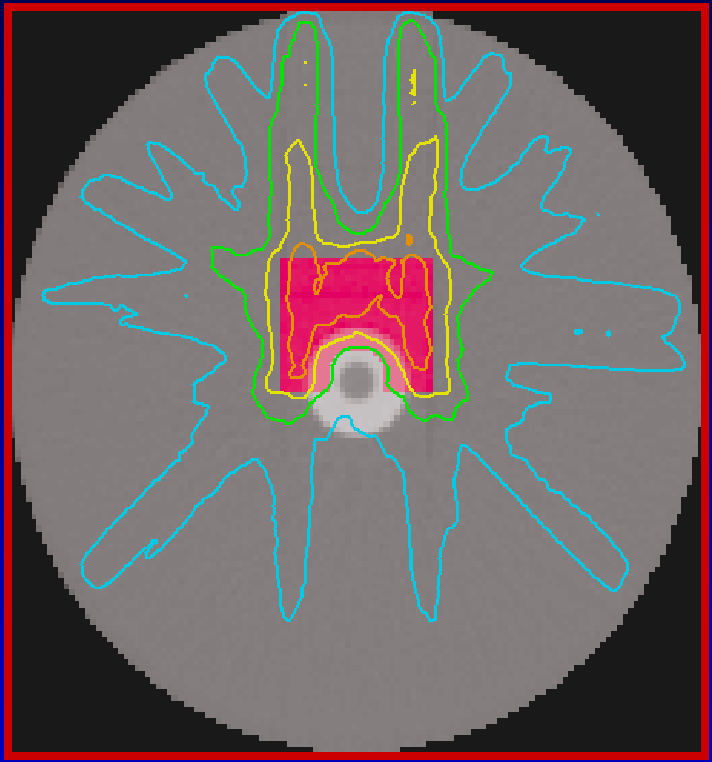




Lee et al (2001)

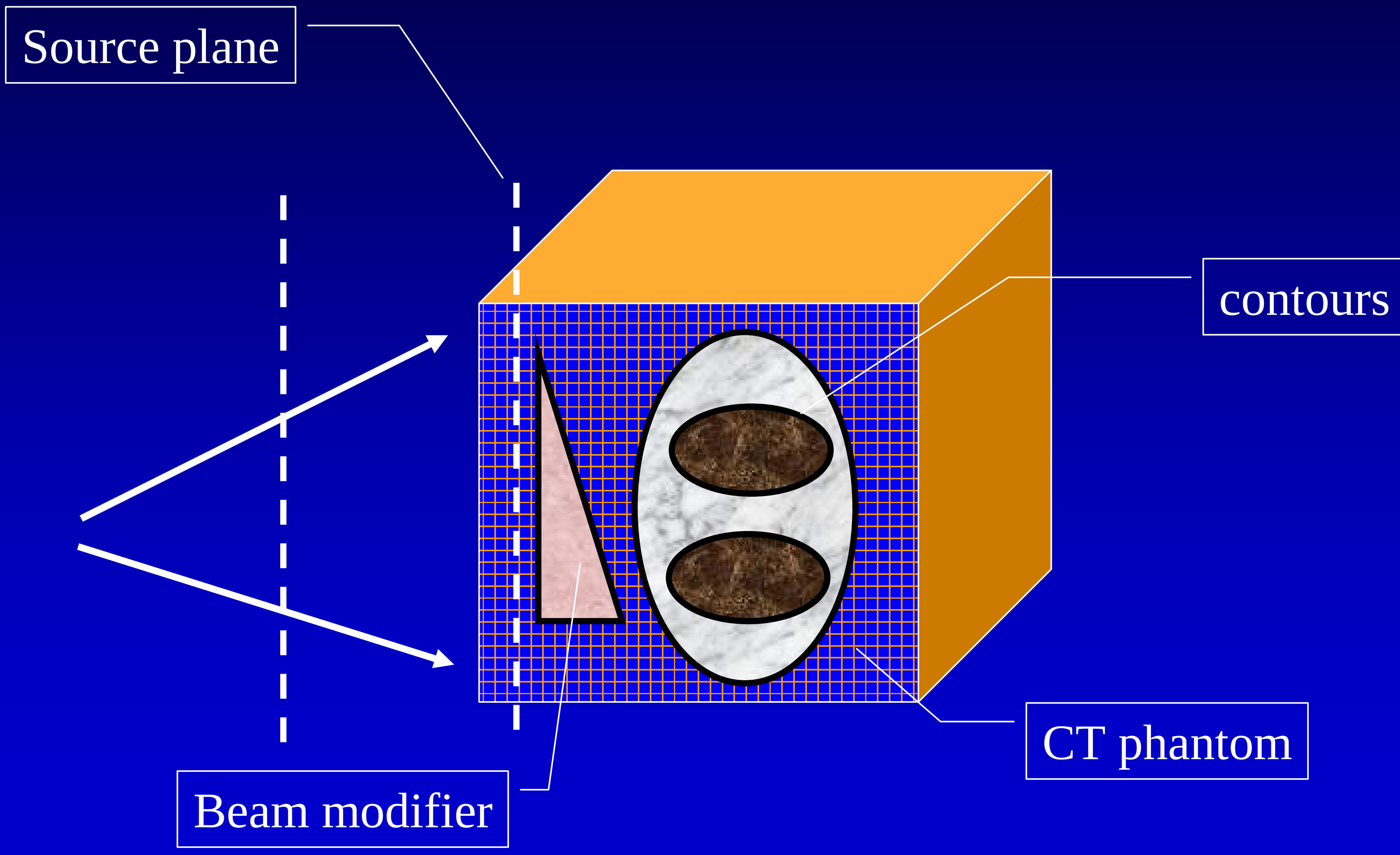
Calculations vs. Measurements





Energy	M-C	Meas	CORVUS
4 MV	2.177 Gy	2.177 Gy	2.201 Gy
15 MV	2.146 Gy	2.161 Gy	2.276 Gy

M-C Simulation Geometry



CT Number to Medium Conversion

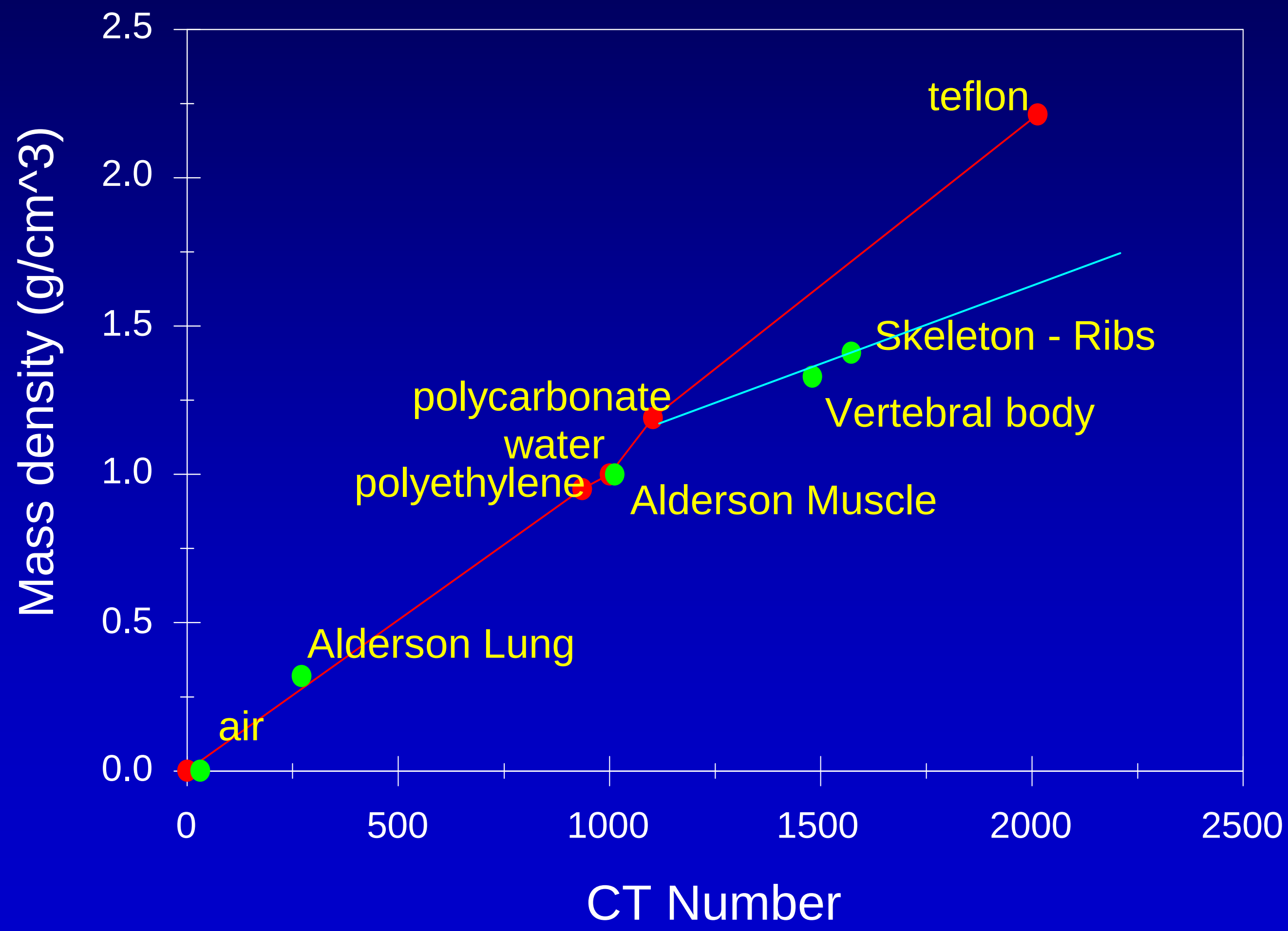
2000~2.088g/cm3

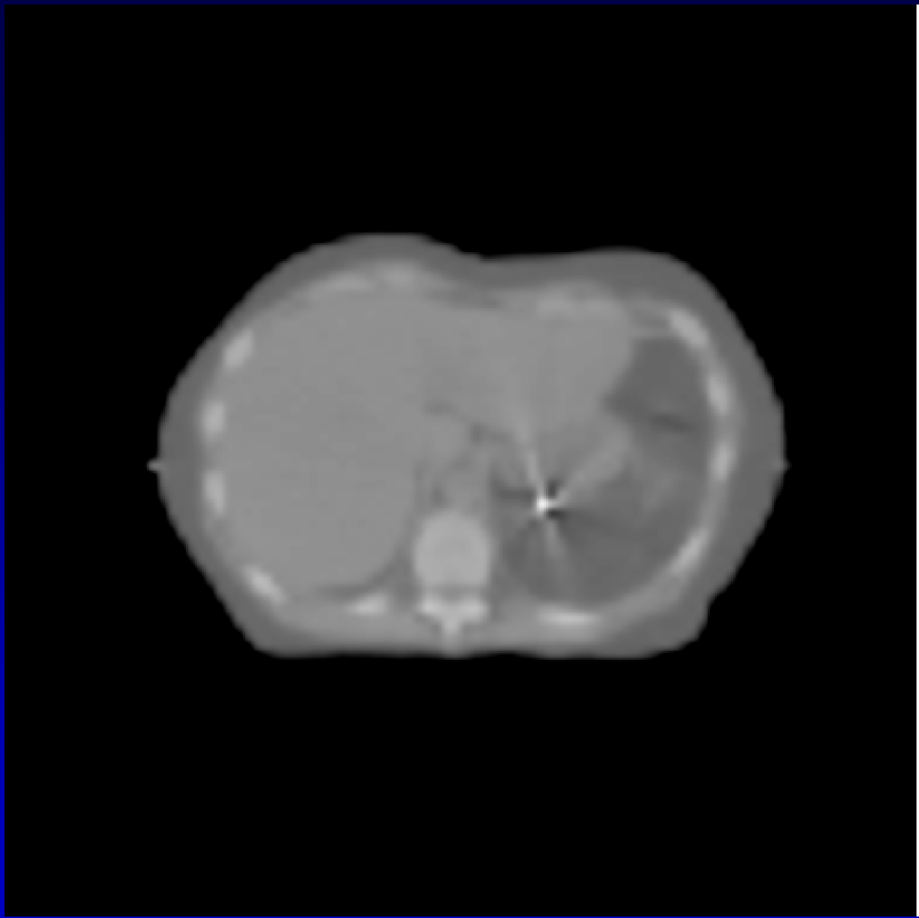
125~1.101g/cm3

-700~0.302g/cm3

-950~0.044g/cm3

-1000~0.001g/cm3





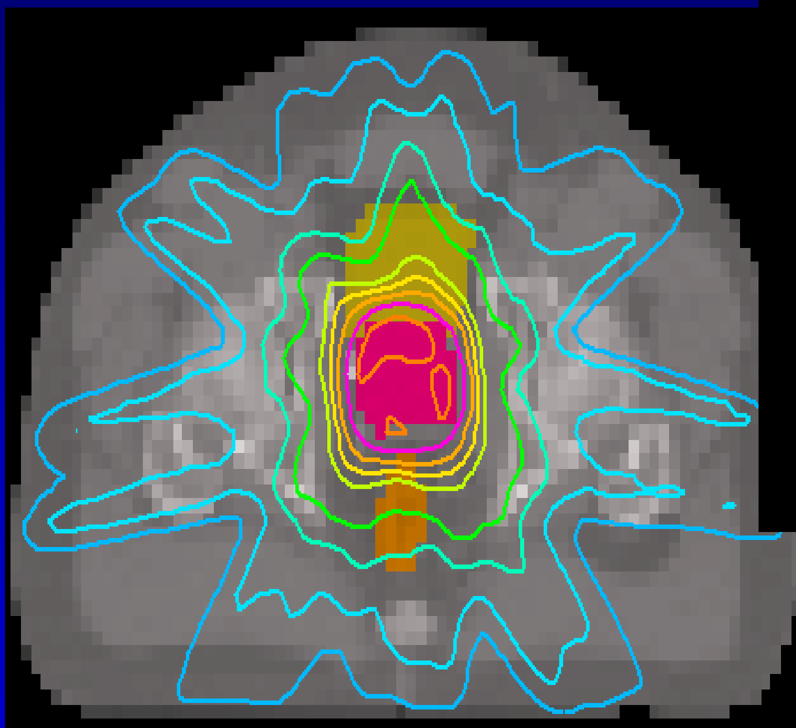
Density map

Medium map

Treatment Plan Comparison

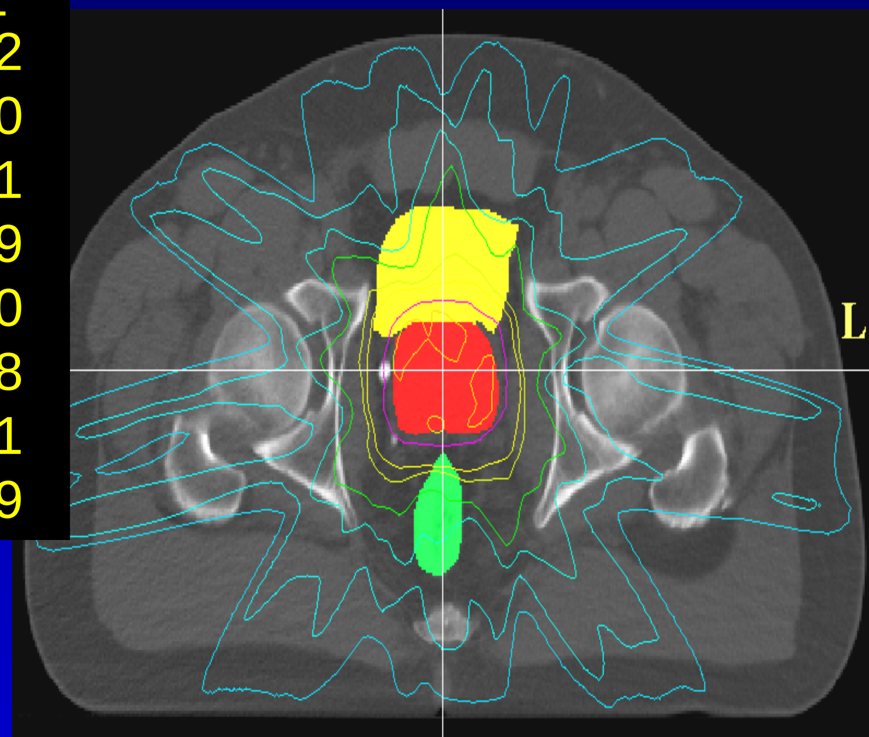
Prostate

Monte Carlo

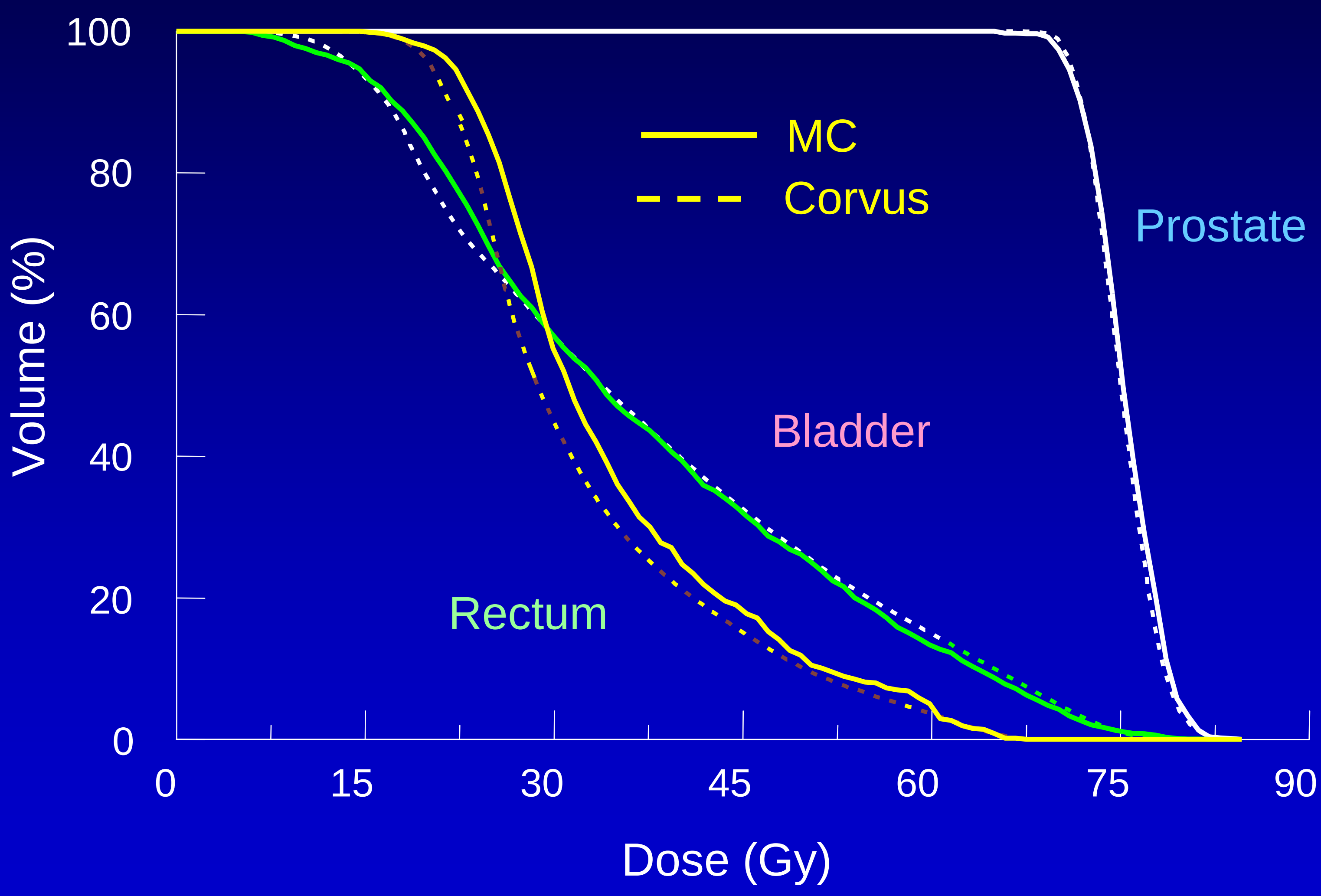


Gy
77.2
70.0
56.1
48.9
35.0
27.8
21.1
13.9

Corvus

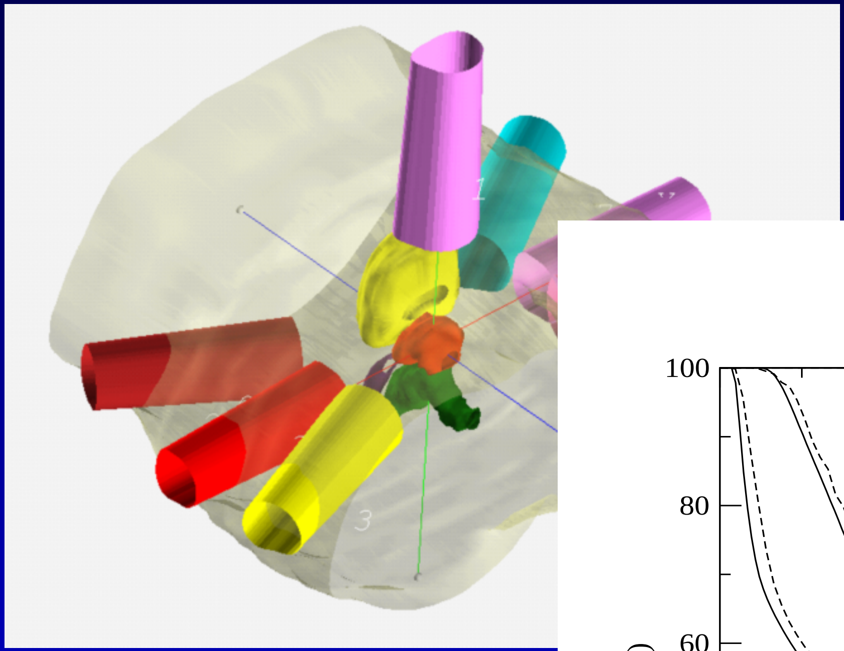


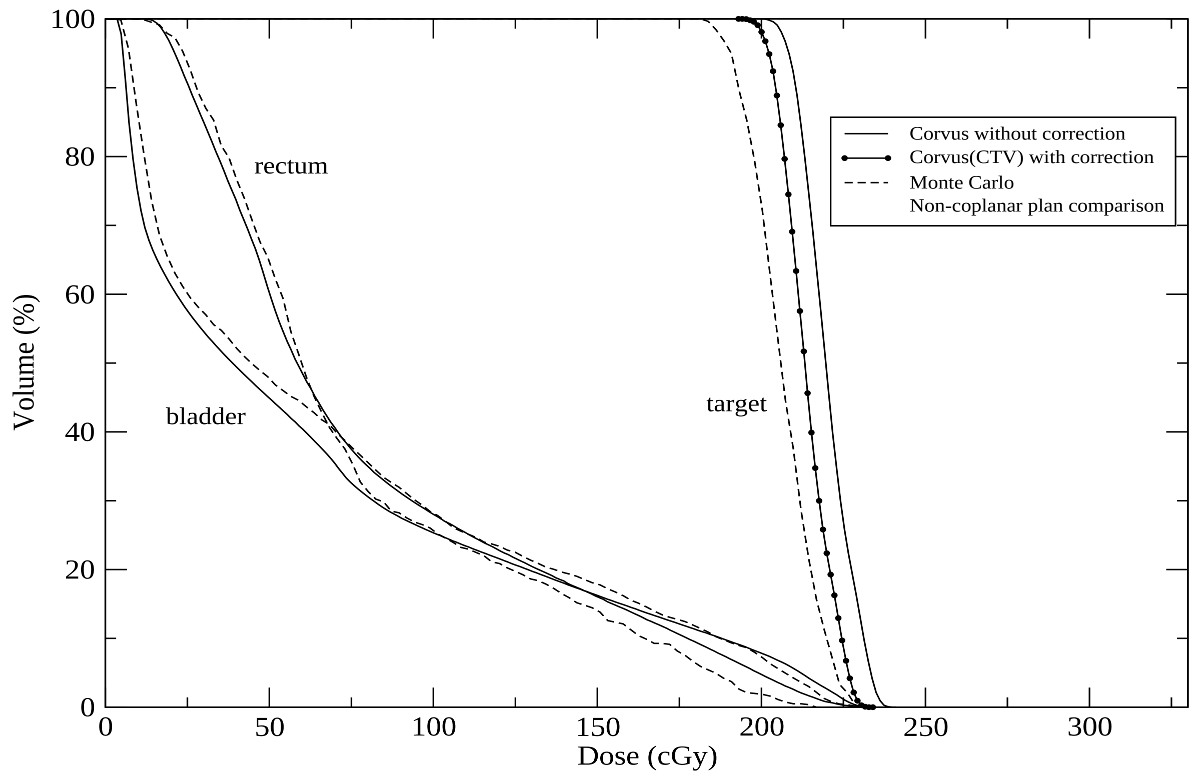
Prostate



100
80
60
40
20
0
Volume (%)
0
15
30
45
60
75
90
Dose (Gy)
MC
Corvus
Prostate
Bladder
Rectum

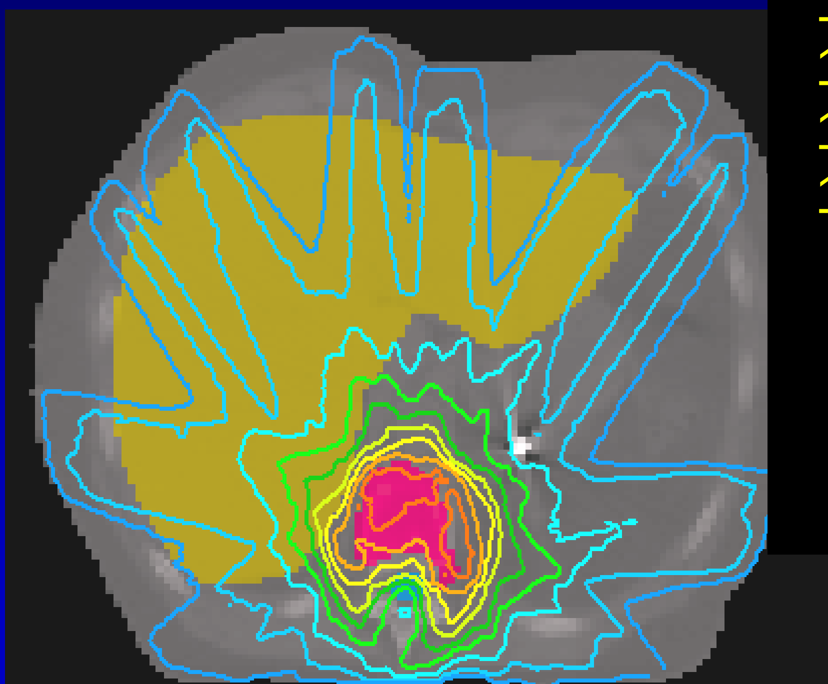
Dose Verification for Non-coplanar Prostate IMRT





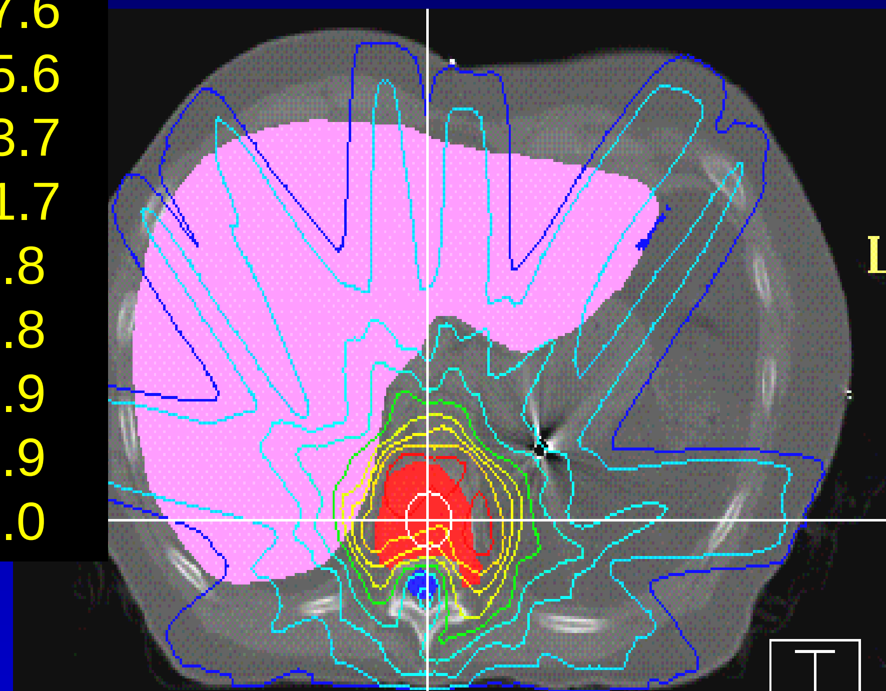
T11-L1 Vertebra

Monte Carlo

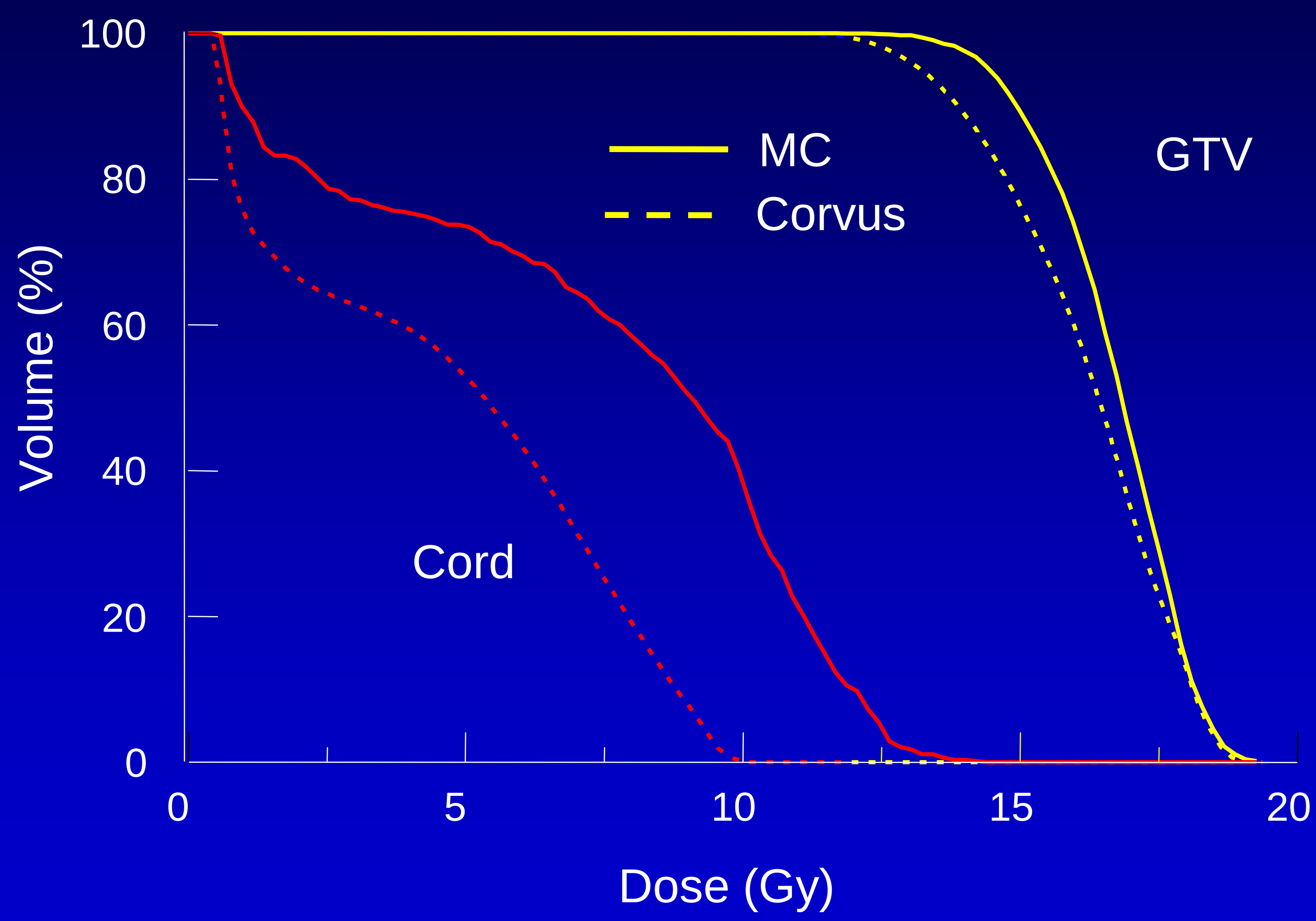


Gy
17.6
15.6
13.7
11.7
9.8
7.8
5.9
3.9
2.0

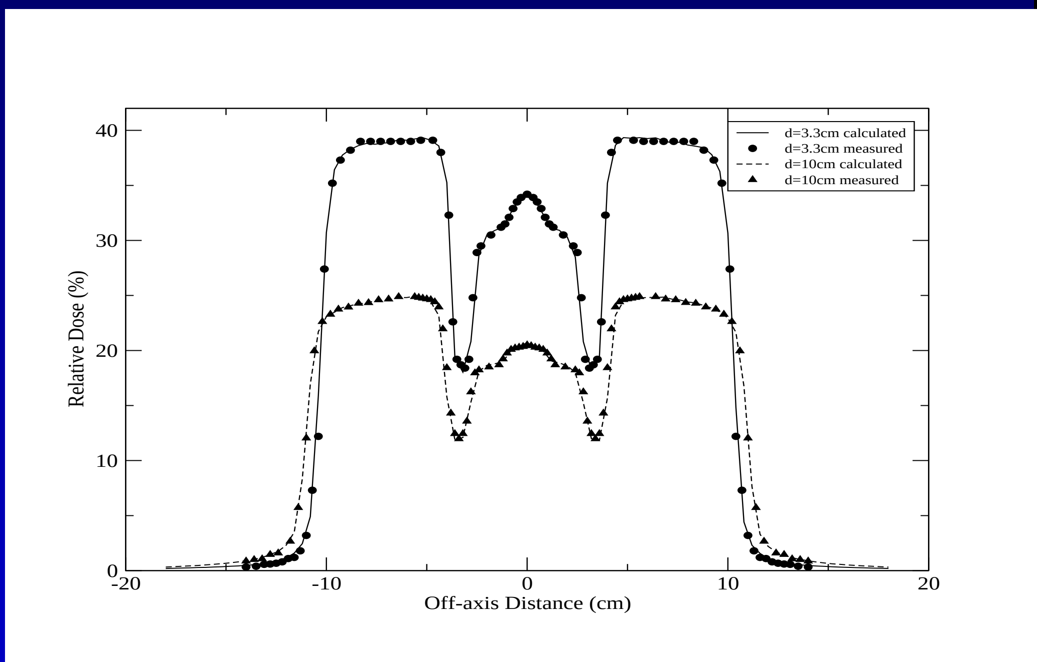
Corvus



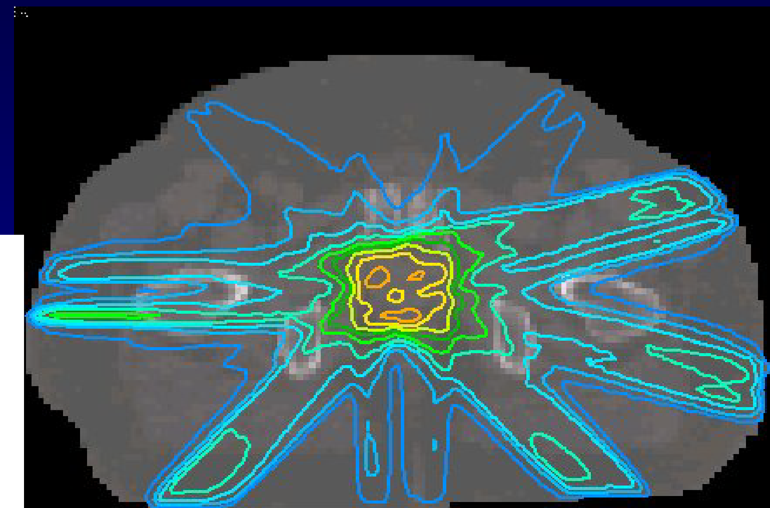
T11-L1 Vertebra



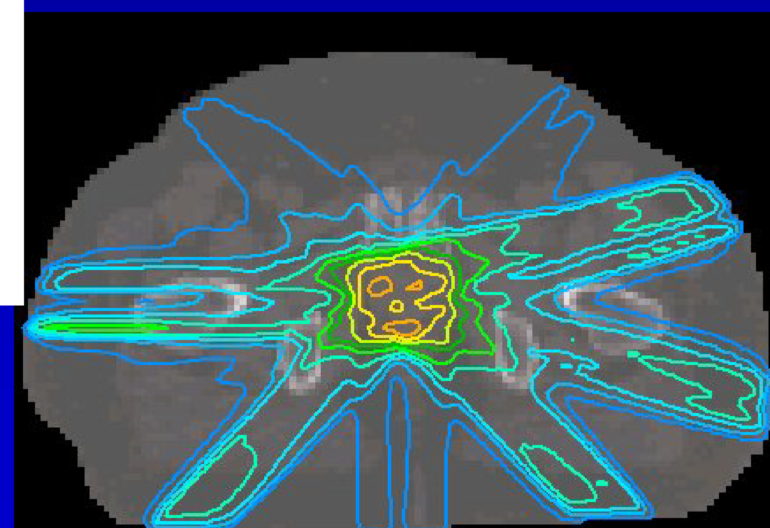
Effect of Couch Bar on IMRT Dose Distribution



MC vs film measurement



Without bar

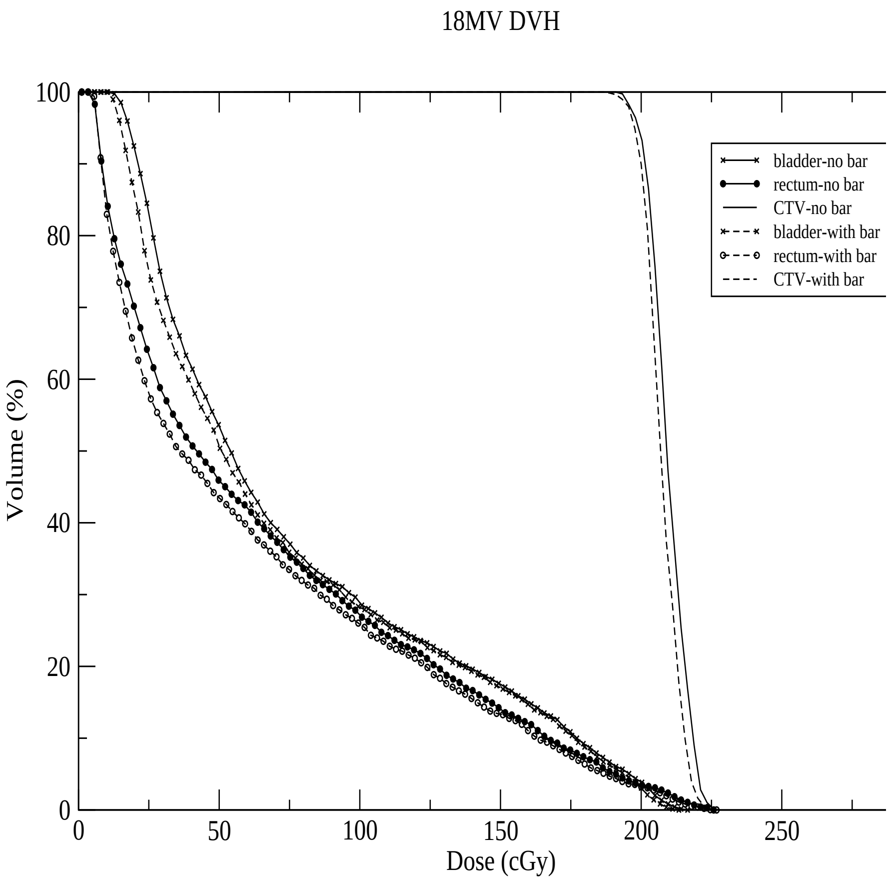


With bar

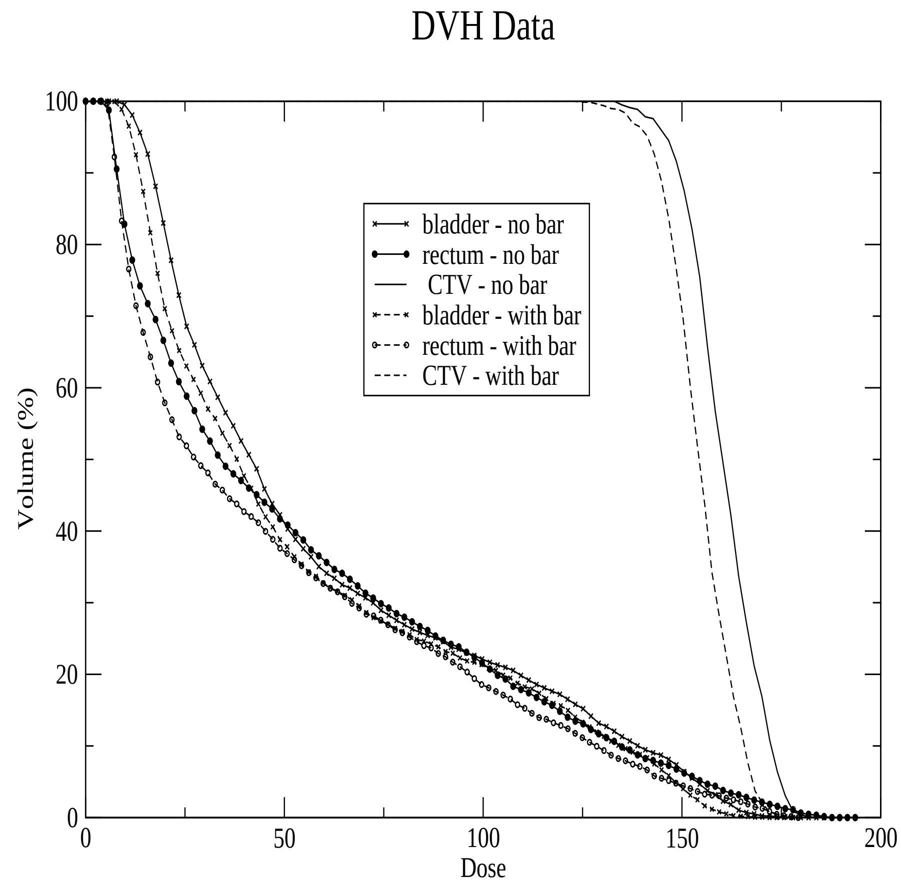
Yang et al 2005

Effect of Couch Bar on IMRT Dose Distribution

IMRT using 18 MV photons

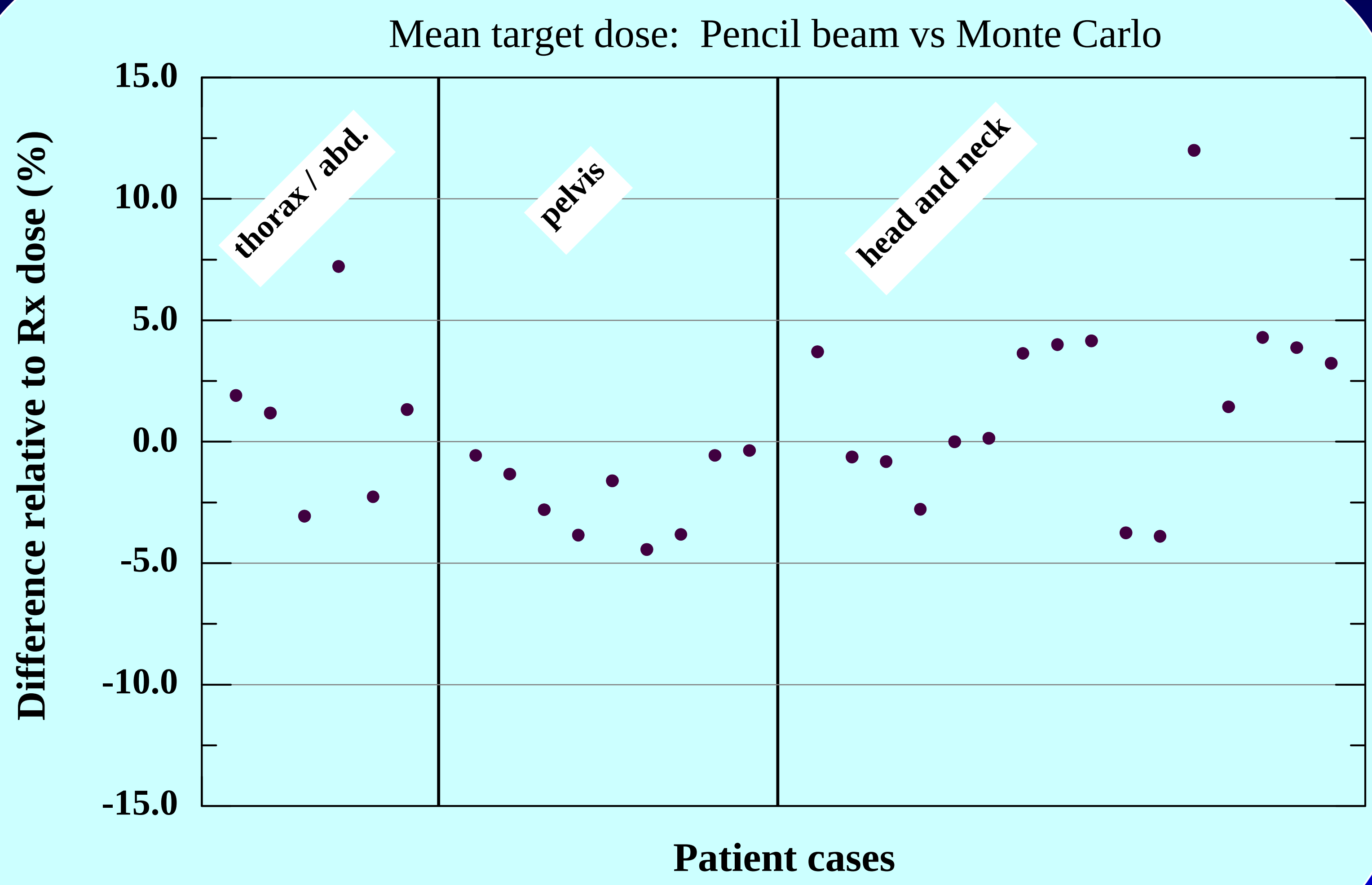


IMRT using 6 MV photons

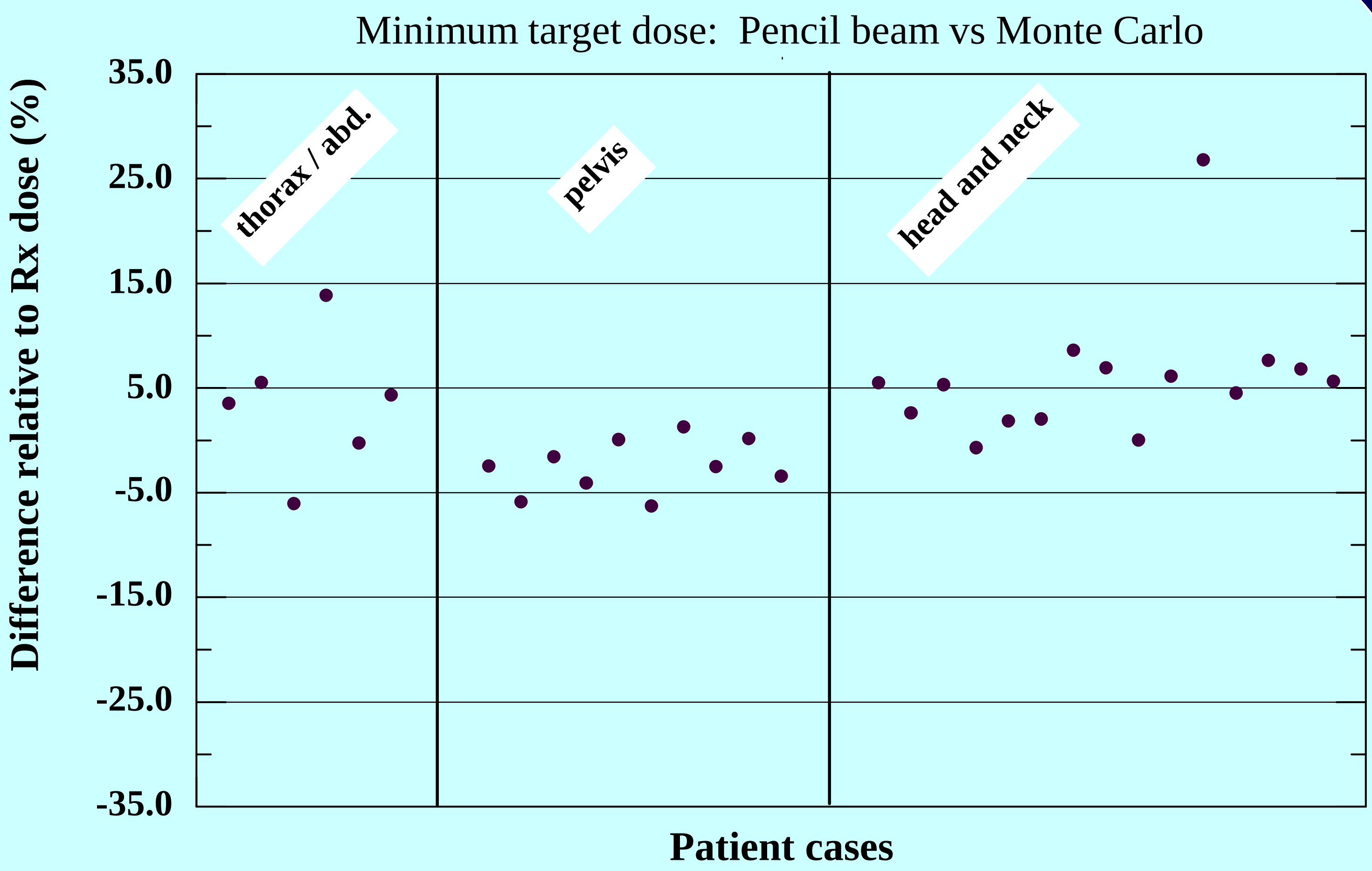


Yang et al 2005

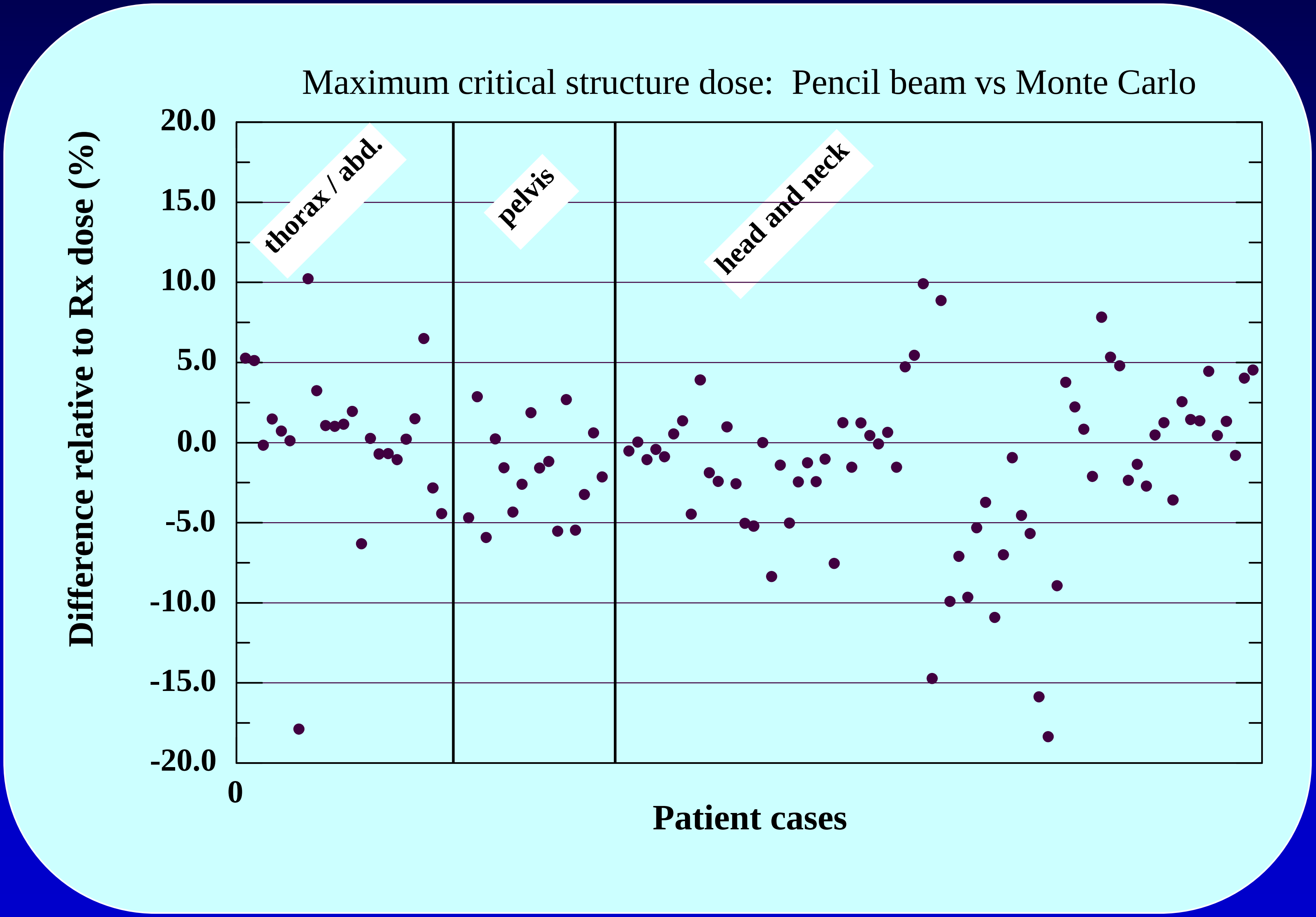
Mean Target Dose (BP vs MC)



Minimum Target Dose (BP vs MC)

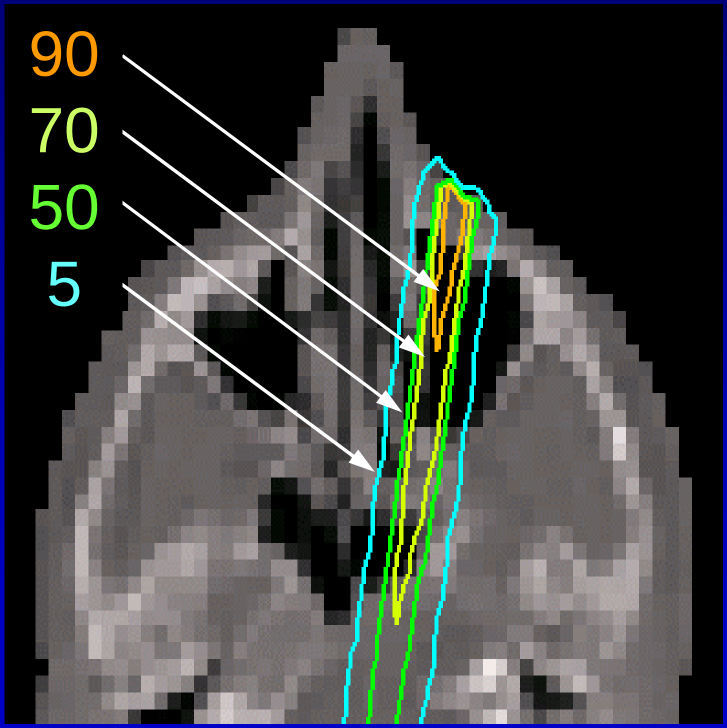


Max. Critical Structure Dose (BP vs MC)

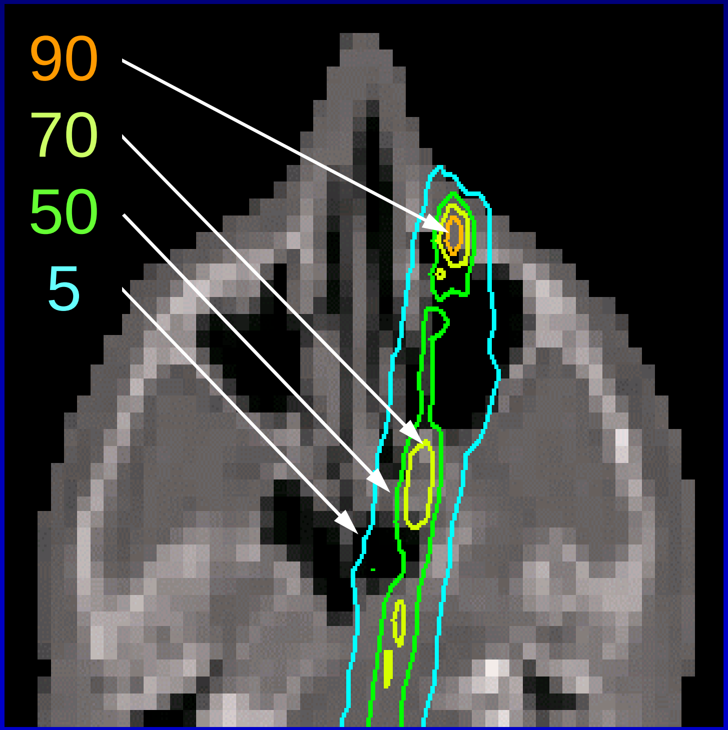


Beamlet Dose Distributions

FSPB

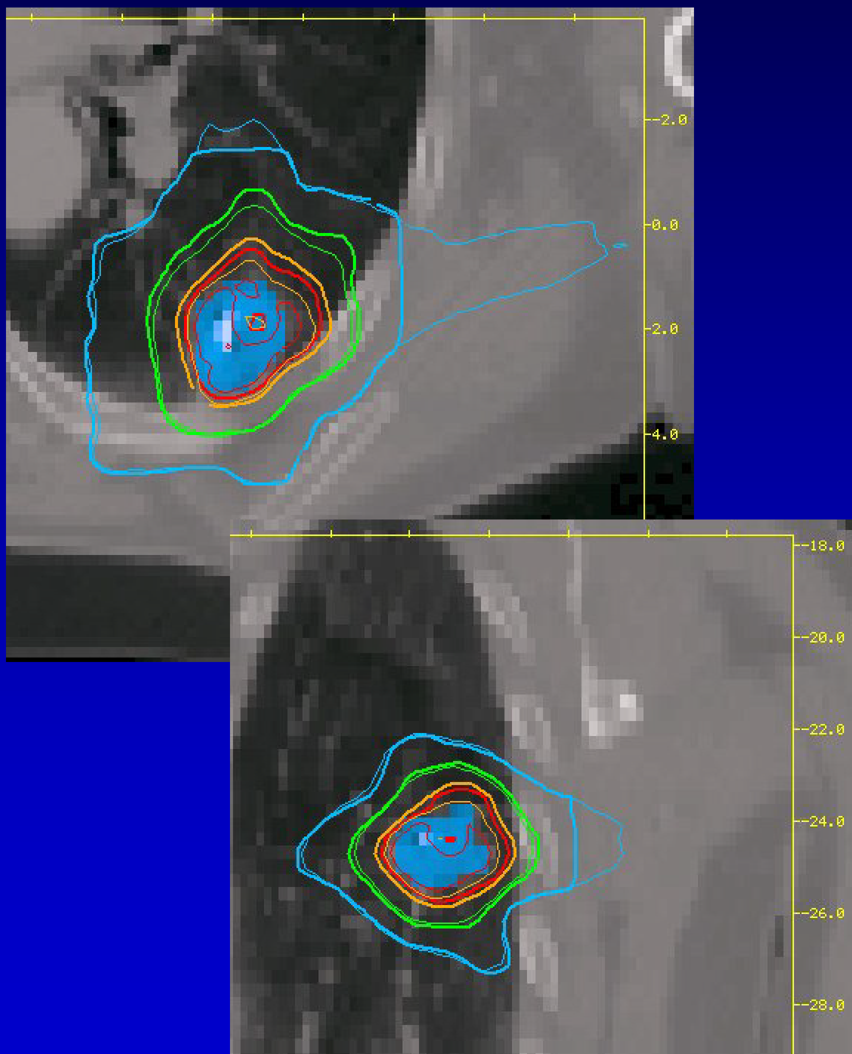


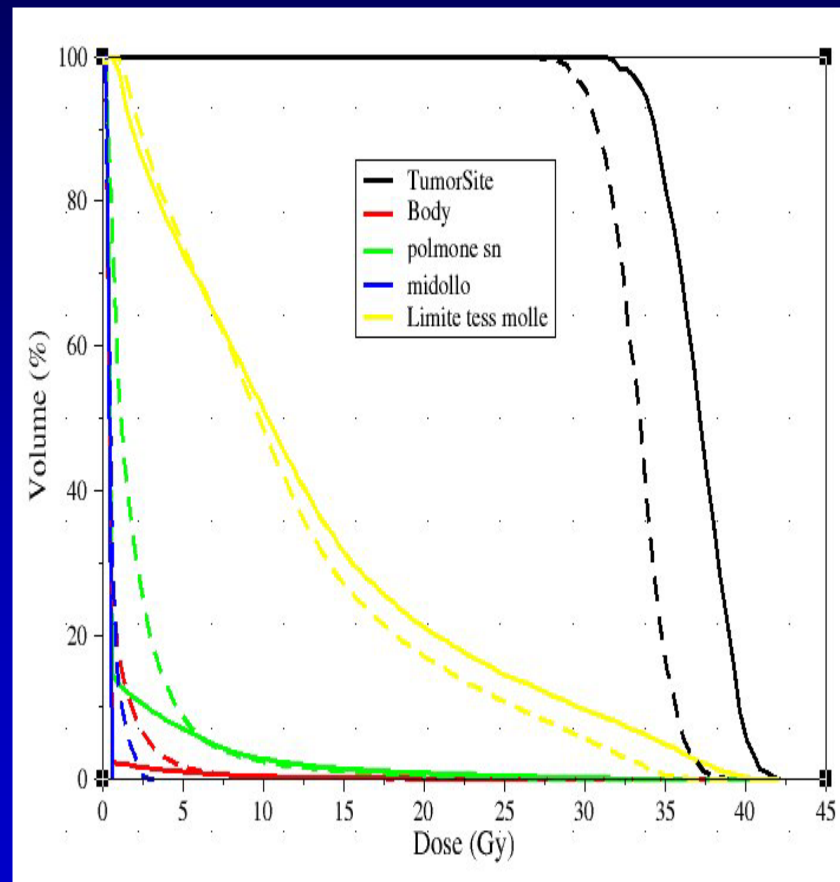
Monte Carlo



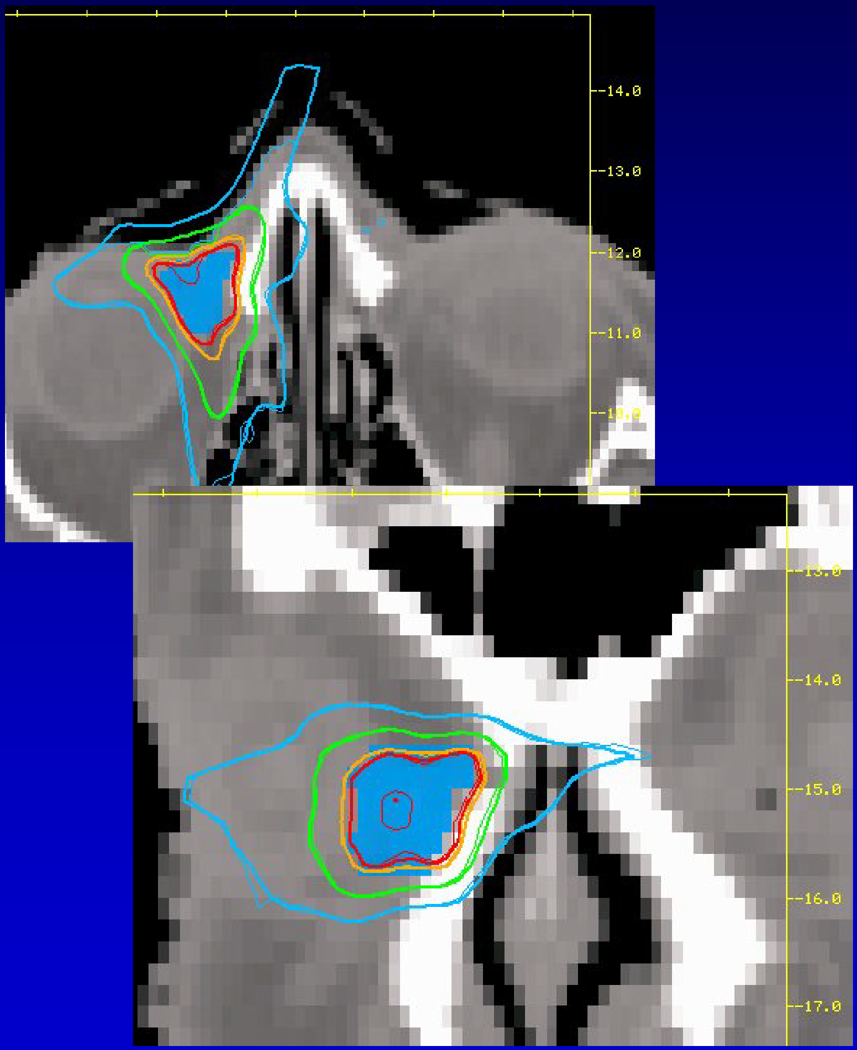
Pawlicki and Ma (2001)

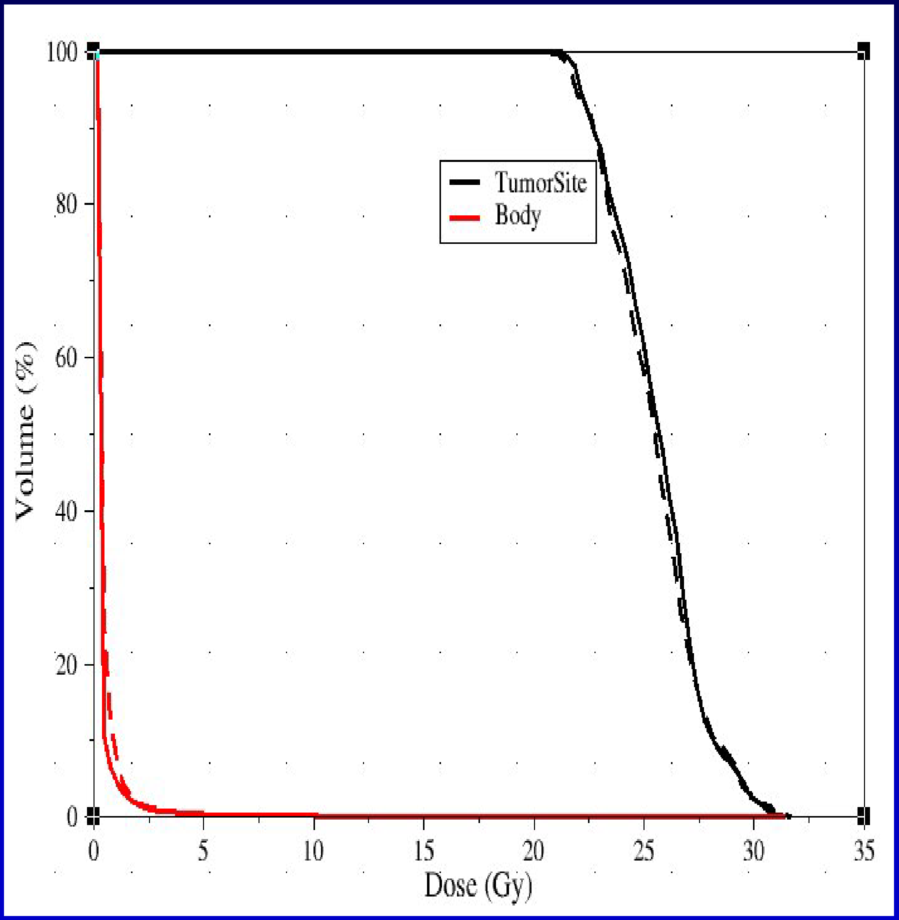
CyberKnife Monte Carlo





CyberKnife Monte Carlo





Summary

- MC dose calculation is becoming a practical tool for advanced radiotherapy treatments
- The accuracy of MC dose calculation depends on the implementation
- The potential of MC dose calculation remains to be explored

Acknowledgments

The FCCC/Stanford Monte Carlo Team

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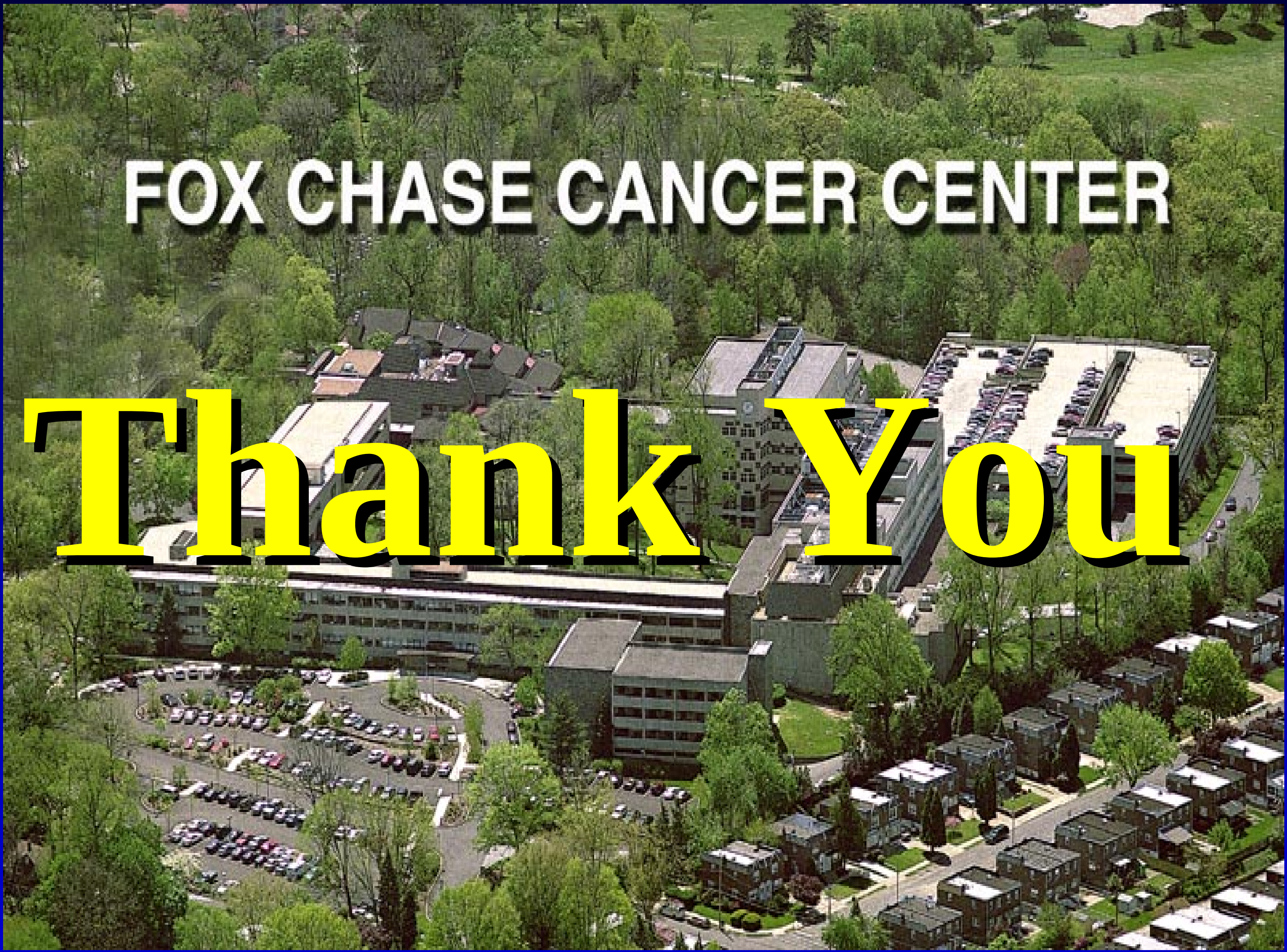

FCCC Monte Carlo courses, April 2010