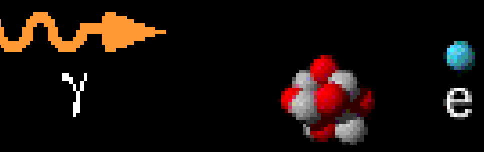
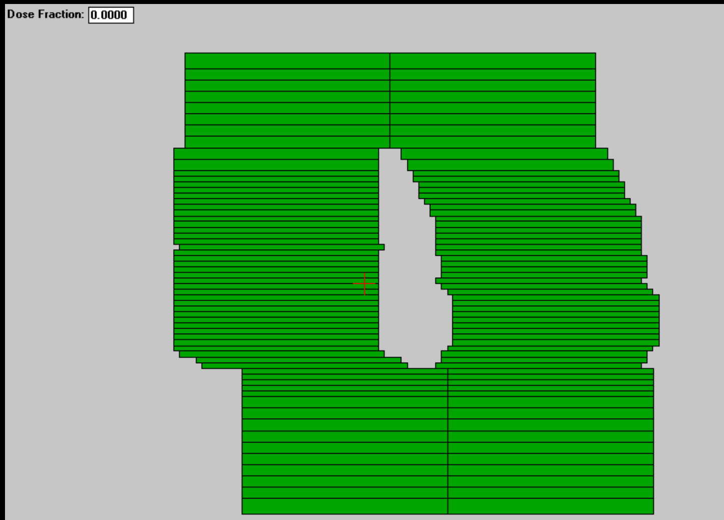
The Department of Radiation Oncology
Virginia Commonwealth University

Application of Monte Carlo to Intensity Modulated Radiation Therapy

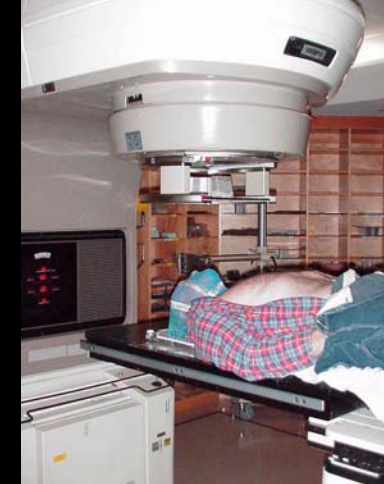
J.V. Siebers and P.J. Keall
Virginia Commonwealth University
Medical College of Virginia Hospitals
Richmond, Virginia USA

Radhe Mohan
M.D. Anderson Cancer Center
Houston, Texas





Outline

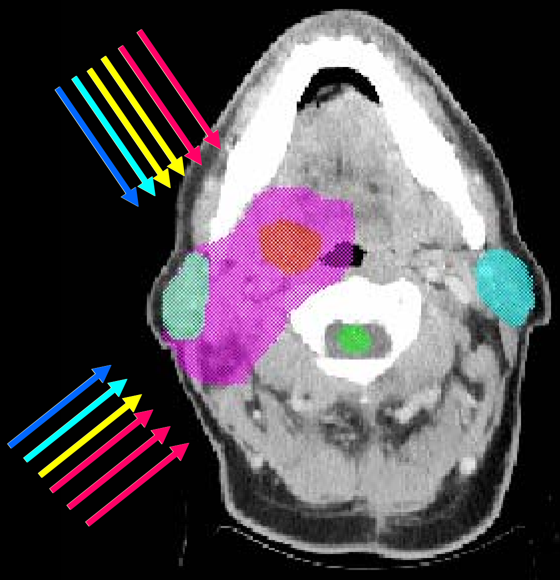


- **What is (different about) IMRT?**
  - **Why can (conventional) dose algorithms be inaccurate?**
- **Why is Monte Carlo better?**
- **Application of Monte Carlo to IMRT**
  - **Quality Assurance**
  - **Patient case study**
  - **IMRT optimization**

Intensity Modulated Radiation Therapy (IMRT)

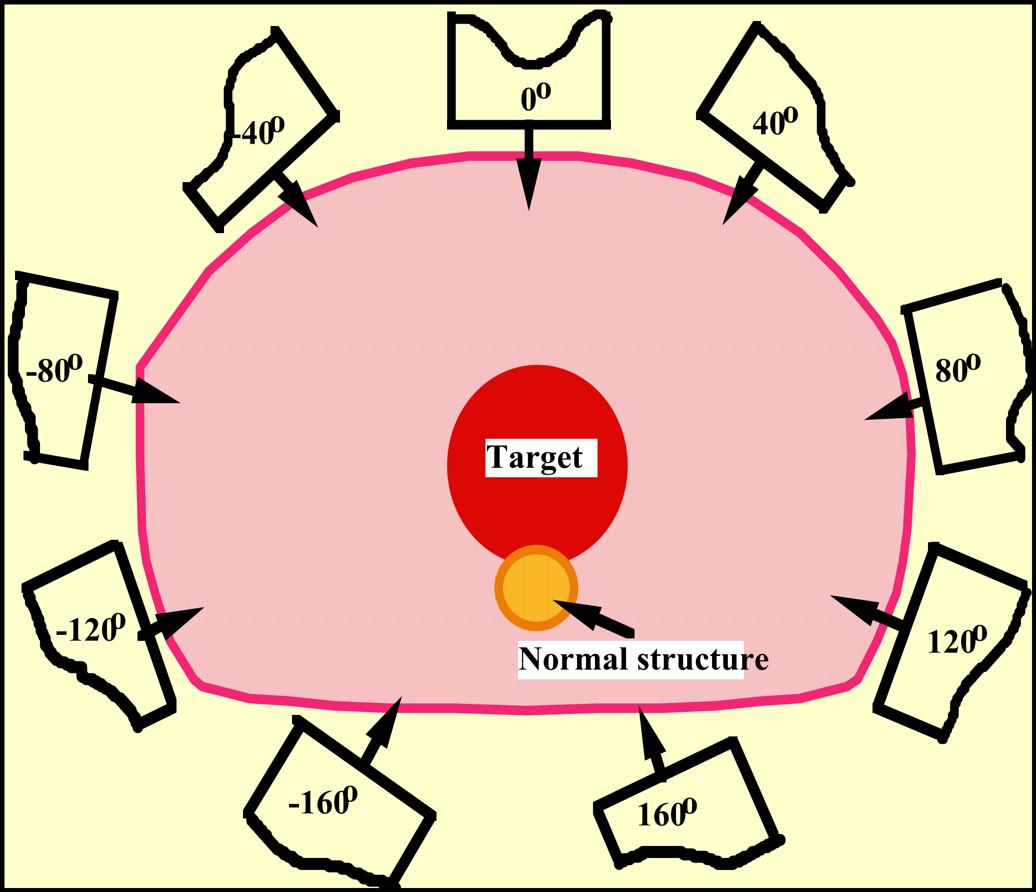
Tx Objective:

- 70 Gy to 95% of PTV1 (Tumour)
- 54 Gy to 90% of PTV2
- <20 Gy to 50% of Left Parotid
- <40 Gy to 99% of Cord

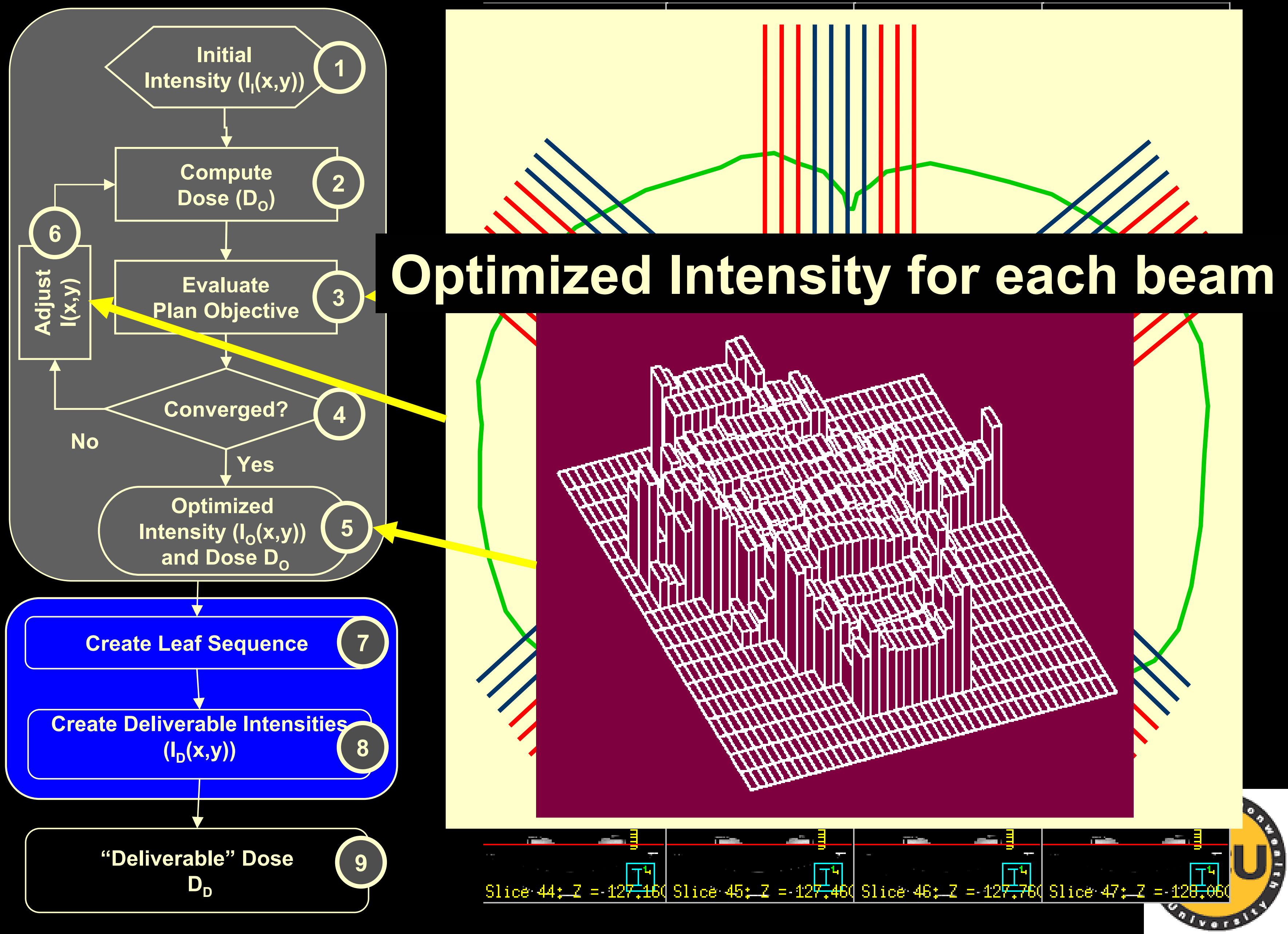


Intensity Modulated Radiation Therapy (IMRT)

Assignment of non-uniform intensities (i.e., weights) to tiny subdivisions of beams ("beamlets" or rays) to maximize dose to target while minimizing dose to normal structure

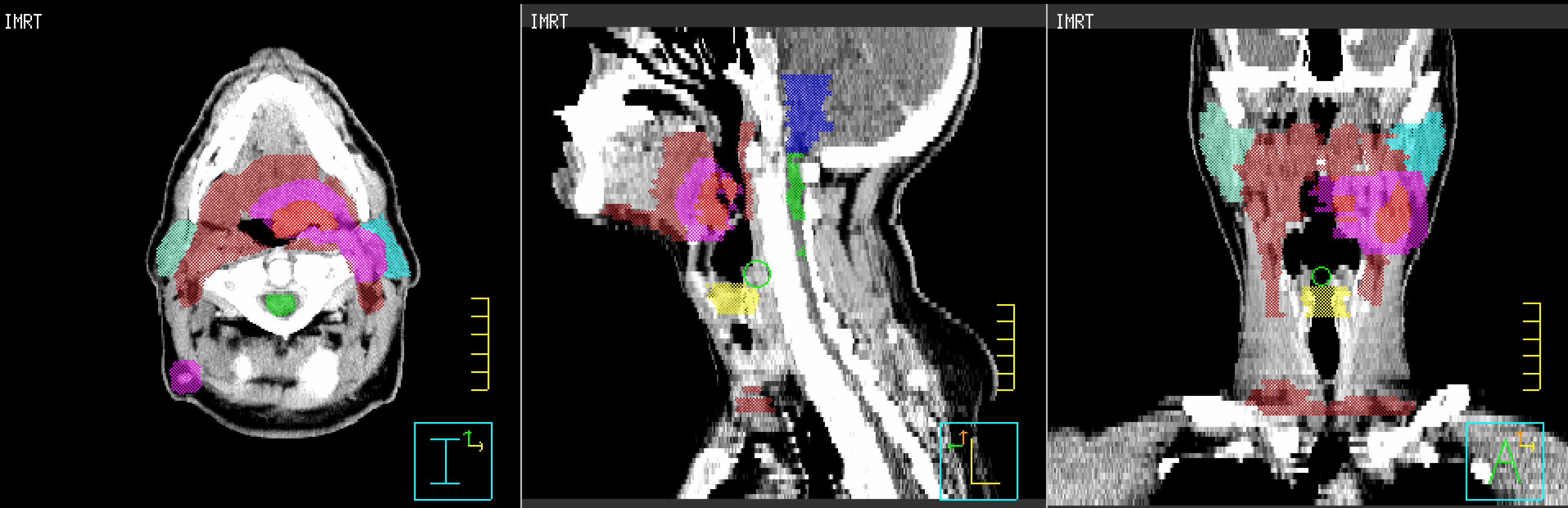


Intensity Modulated Radiation Therapy

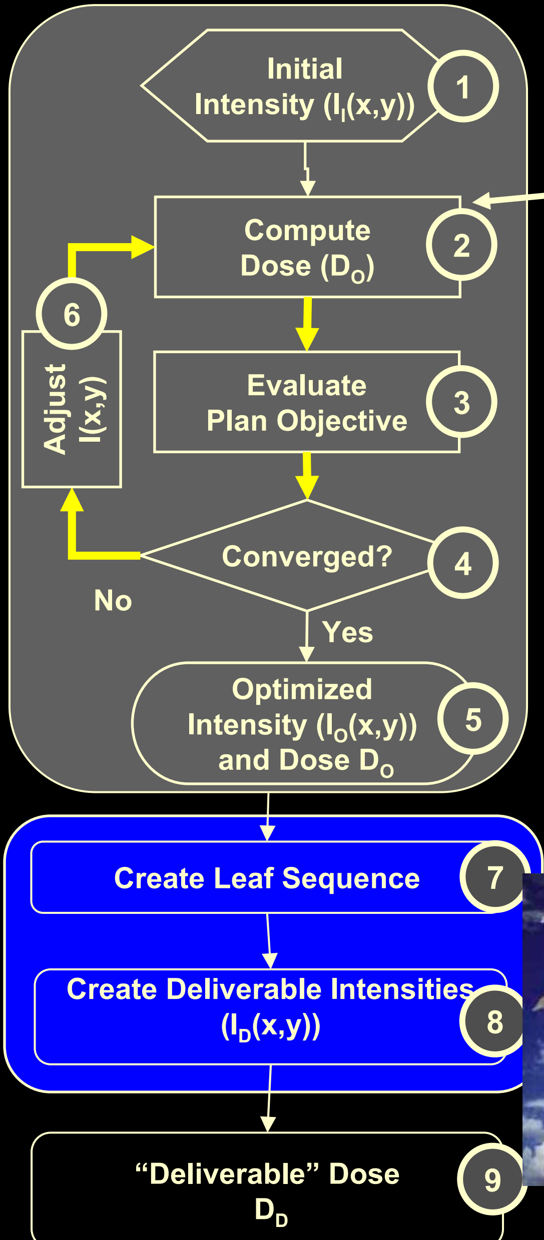


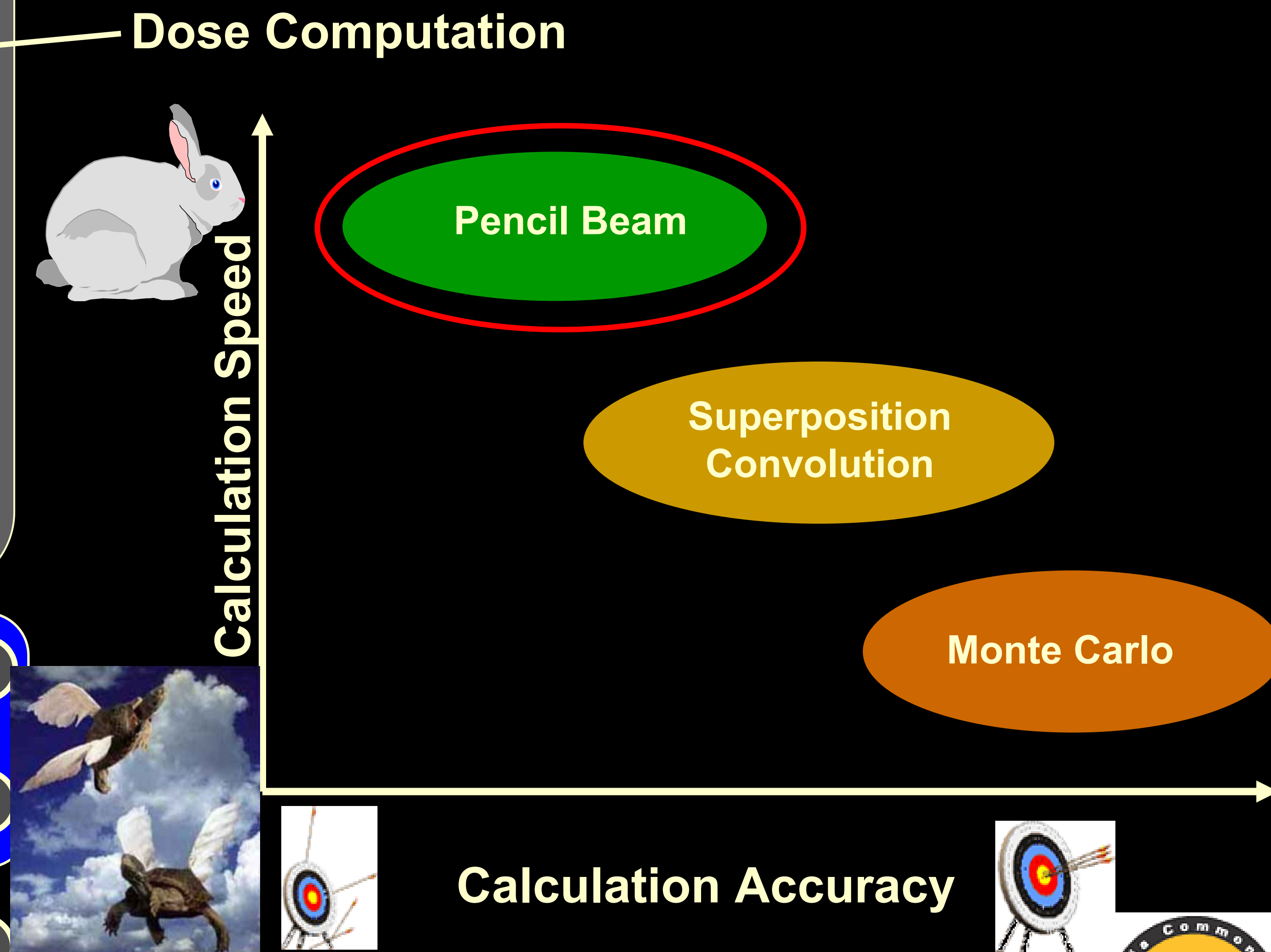
What

is different about IMRT?

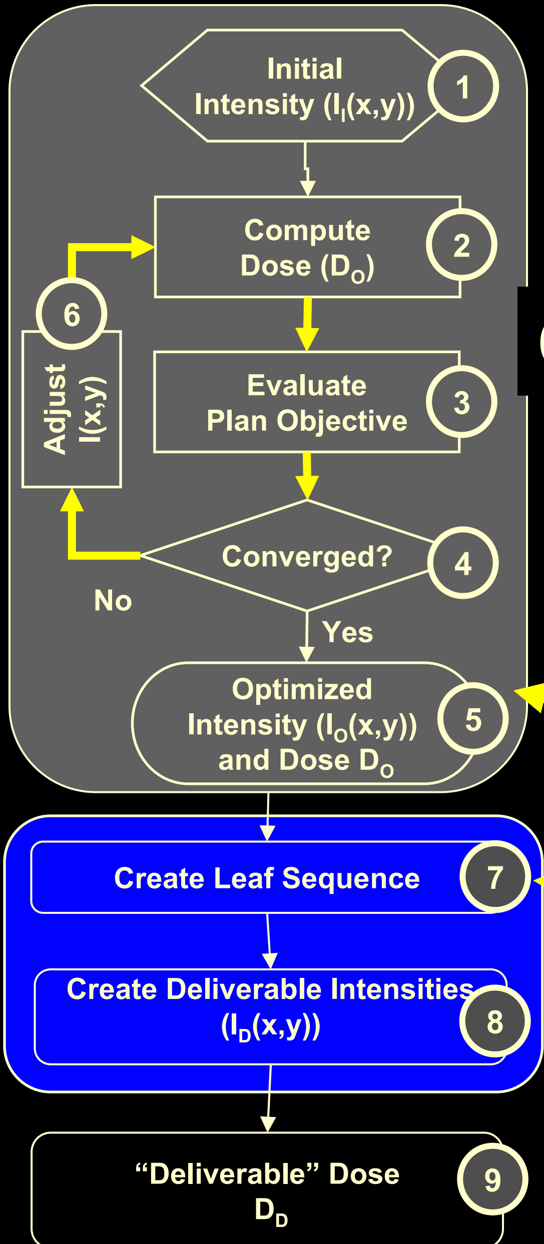


Iterative process

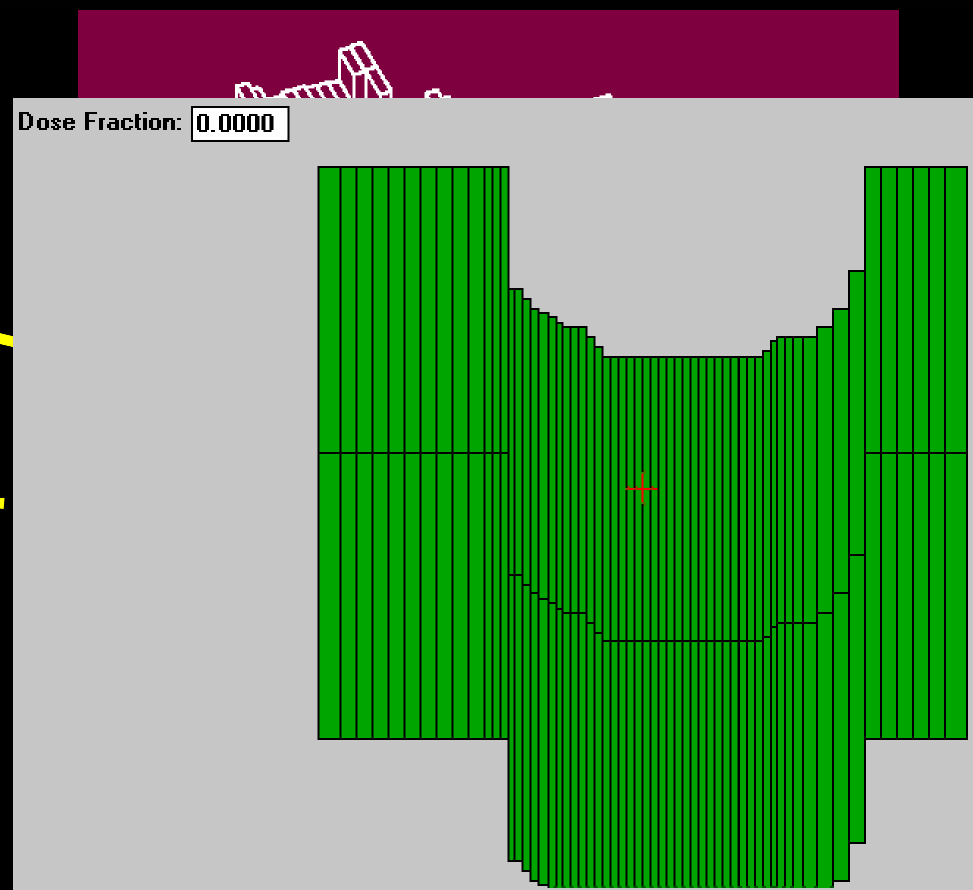




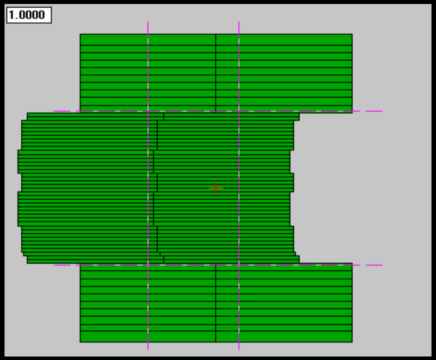
Leaf Sequences

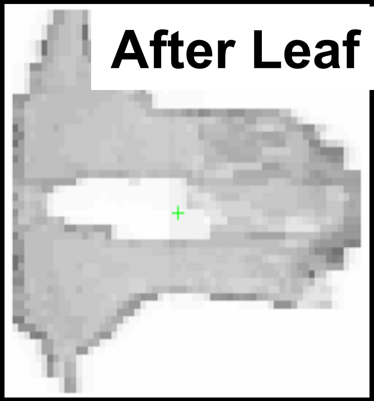


Optimized Intensity for each beam



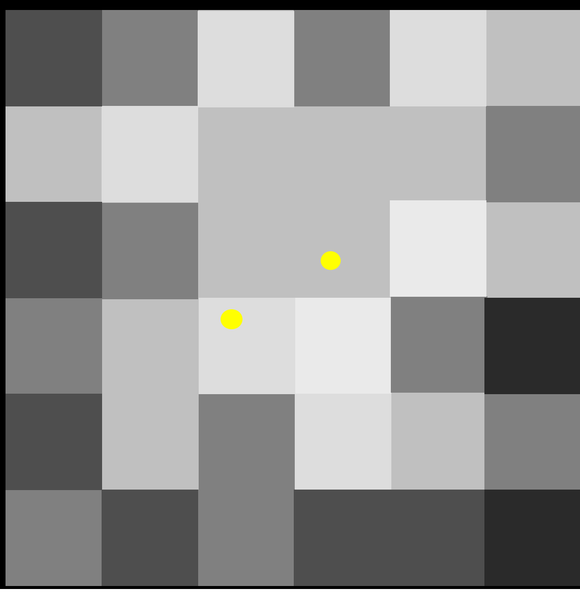
How is MLC included in “conventional” dose algorithm?

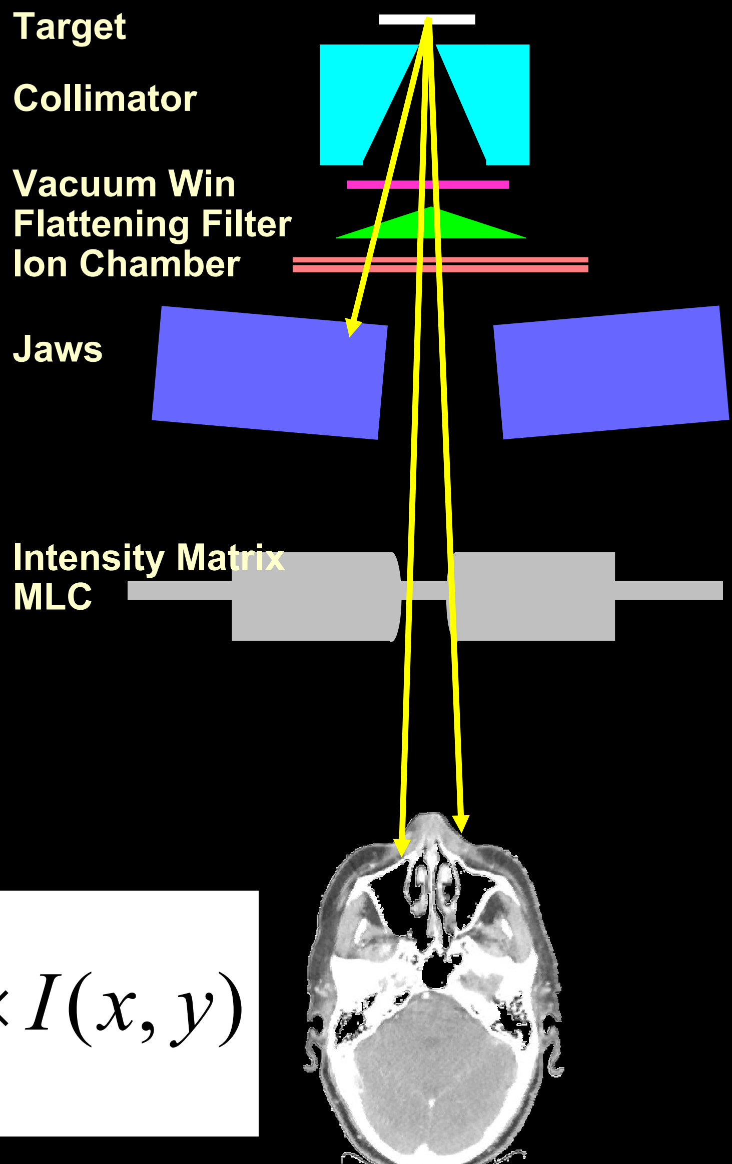




After Leaf Sequencer

MLC in conventional dose calculation

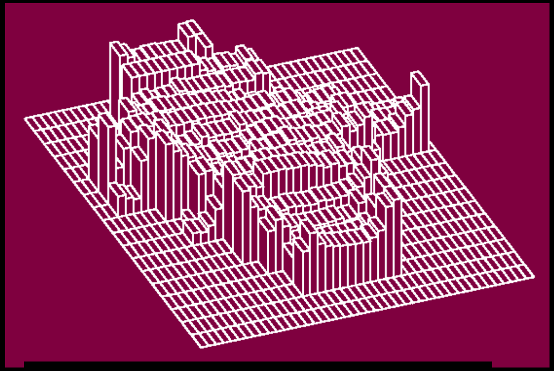




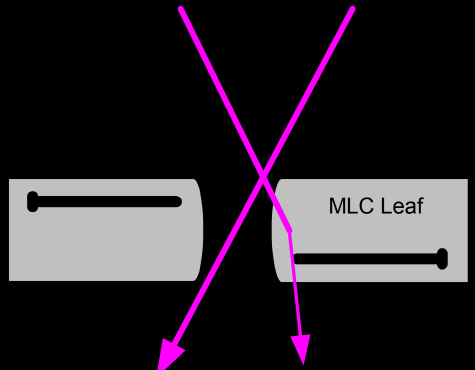
$$\Psi(x,y)_f = \Psi(x,y)_i \times I(x,y)$$

What really happens?
MLC Effects on IMRT Field

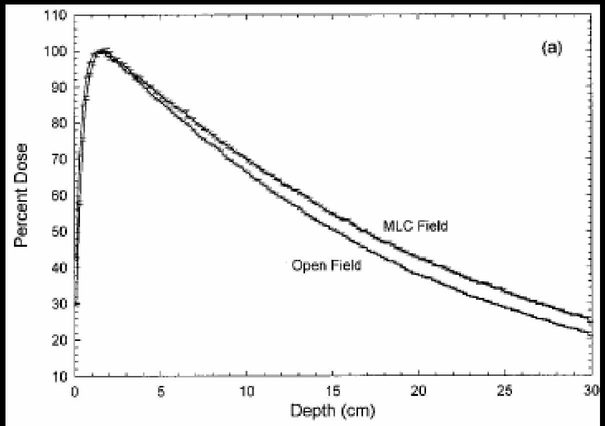
- **Intensity variation**
  - Details difficult to predict due to complexities of leaf geometry



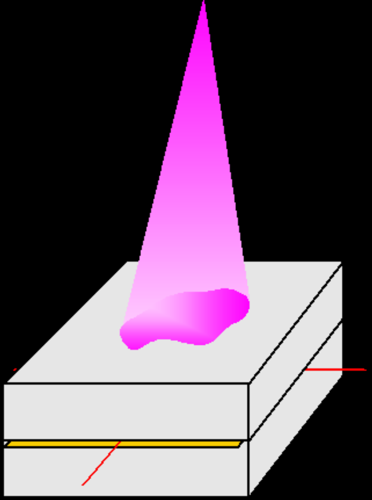
- **MLC scatter**

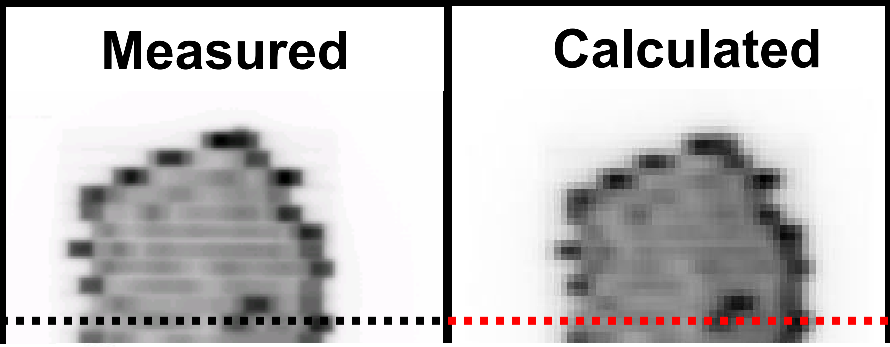


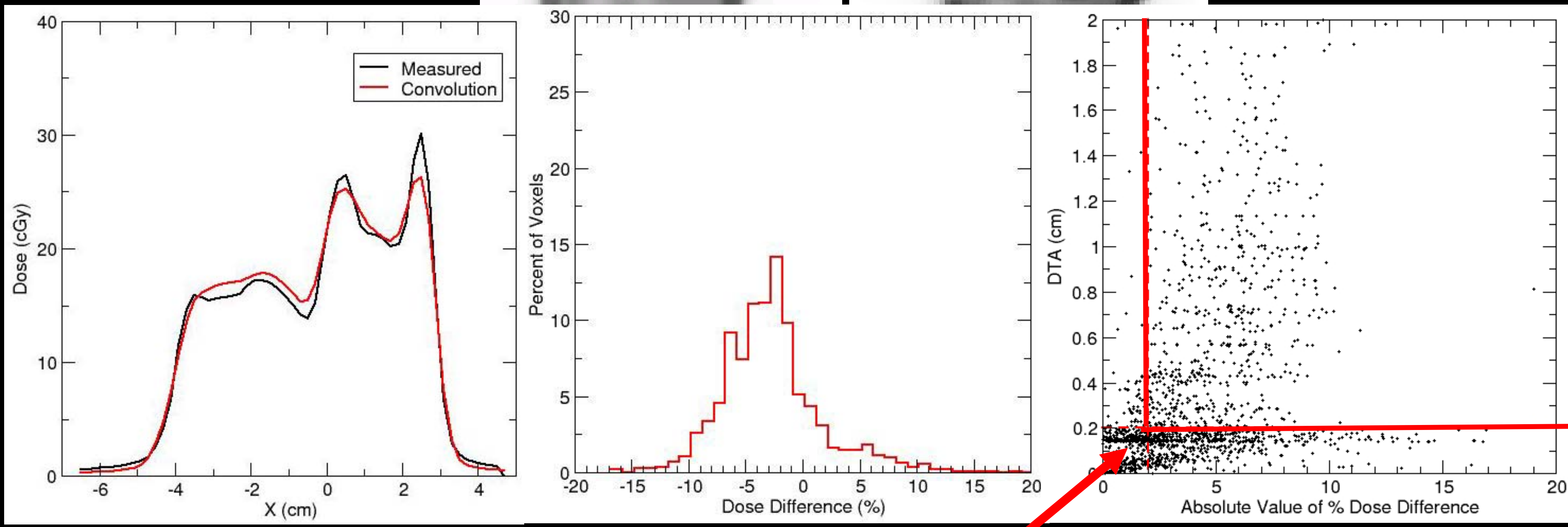
- **Beam hardening**



Conventional algorithm







54% of points have a dose difference <2% or a DTA <2 mm

Conventional dose algorithms can be inaccurate for

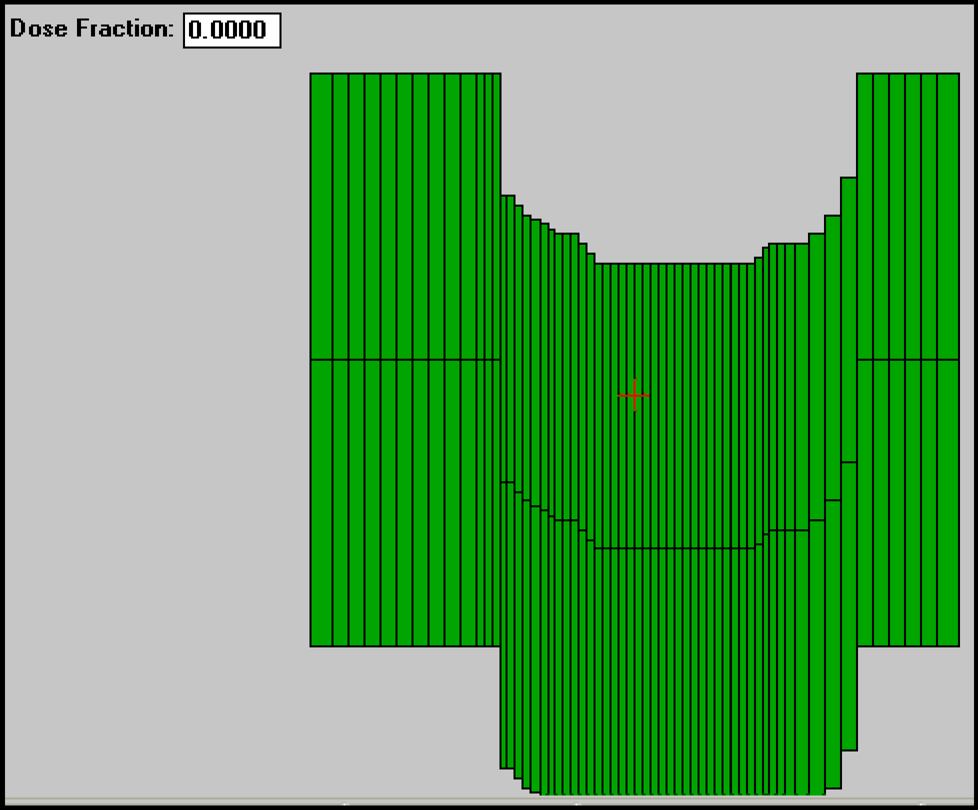
- Small fields
- Regions of dose gradients (radiation disequilibrium)
- Heterogeneous conditions

IMRT is typically delivered through a sequence of small static fields or with a dynamically moving aperture with a small width. Dose gradients are common place in IMRT fields.

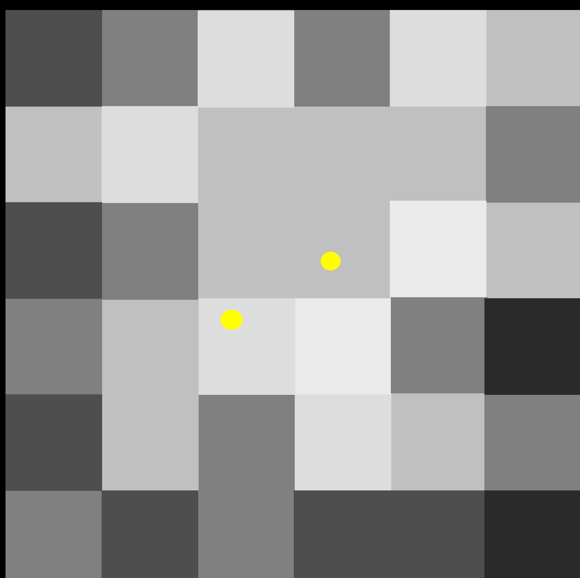
Why
is Monte Carlo better?

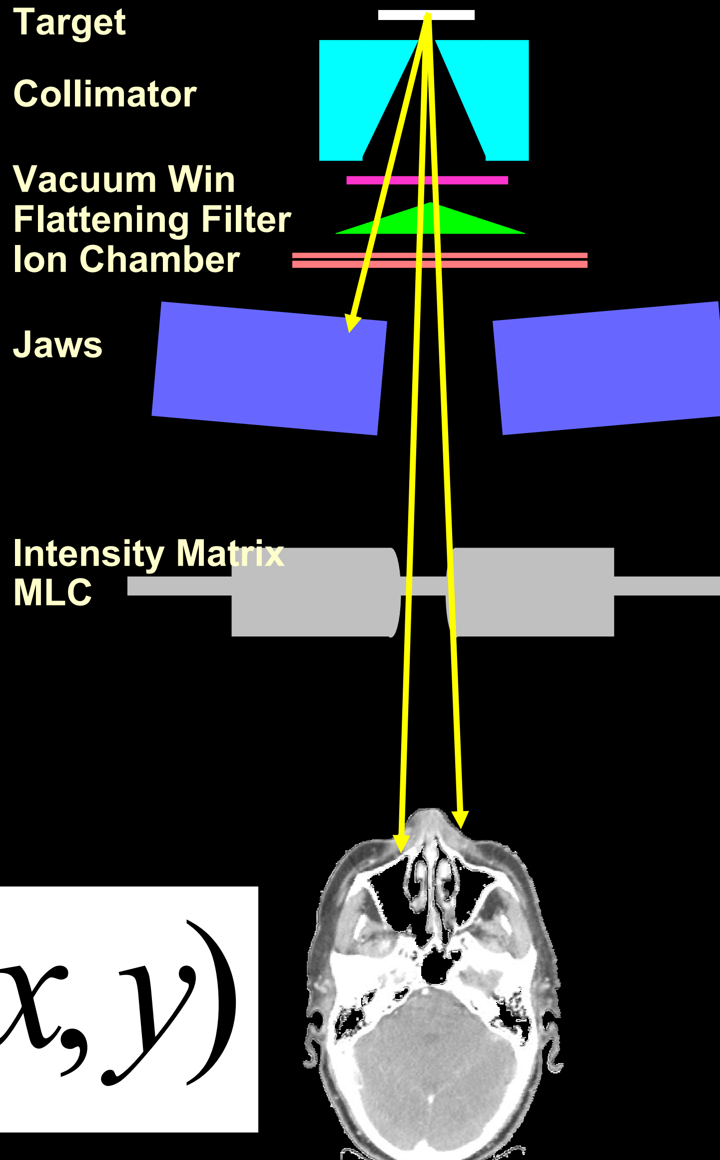
- MC makes no assumptions regarding equilibrium
  - MC can be accurate for very small field sizes
- MC transports in patient materials
  - MC is accurate in heterogeneities
- MC can transport through MLC

How do MLC for Monte Carlo?



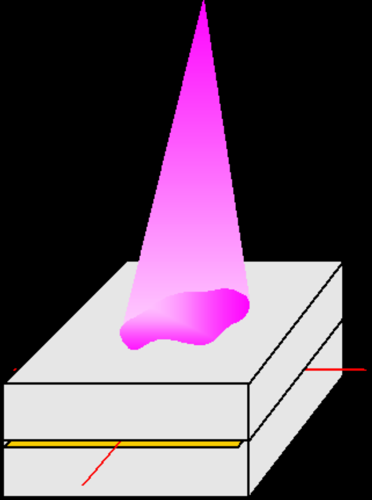
Can use Intensity Matrix

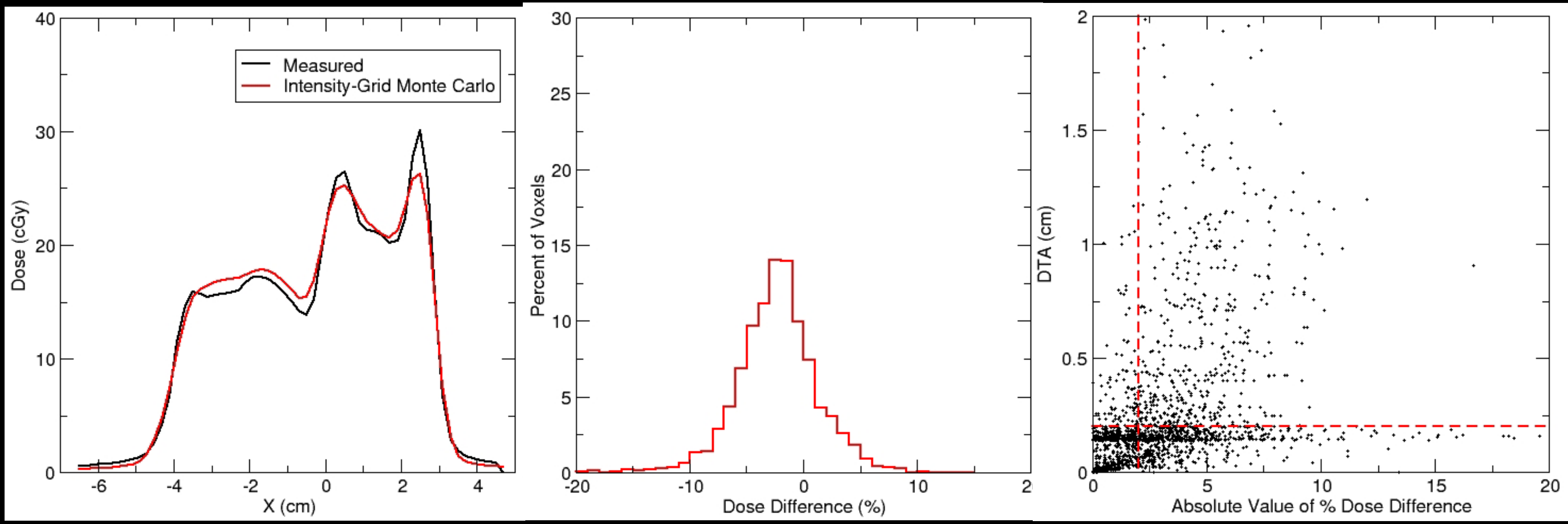




$$W_f = W_i \times I(x,y)$$

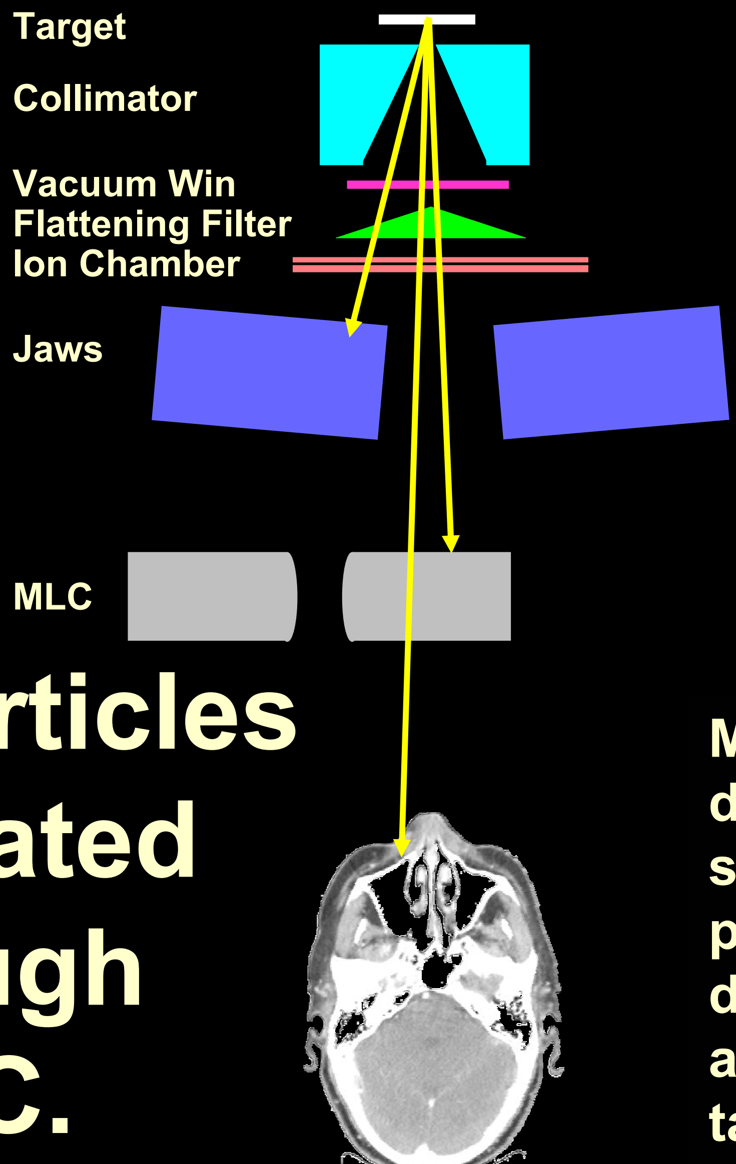
Measurement Compared to MC using Intensity Matrix method





Effects of MLC on fluence are approximated
Ignores MLC scatter, beam hardening, …

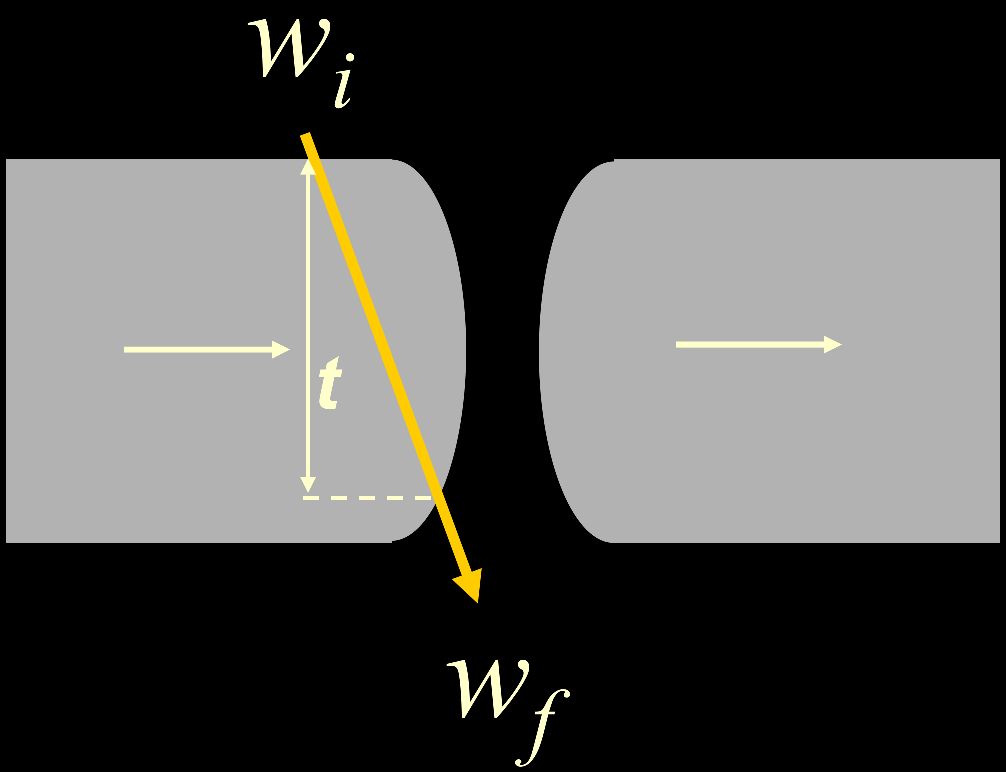
Direct Particle Transport



Individual particles can be simulated directly through (moving) MLC.

MLC geometric details, leakage, scatter, and particle energy dependent effects are inherently taken into account

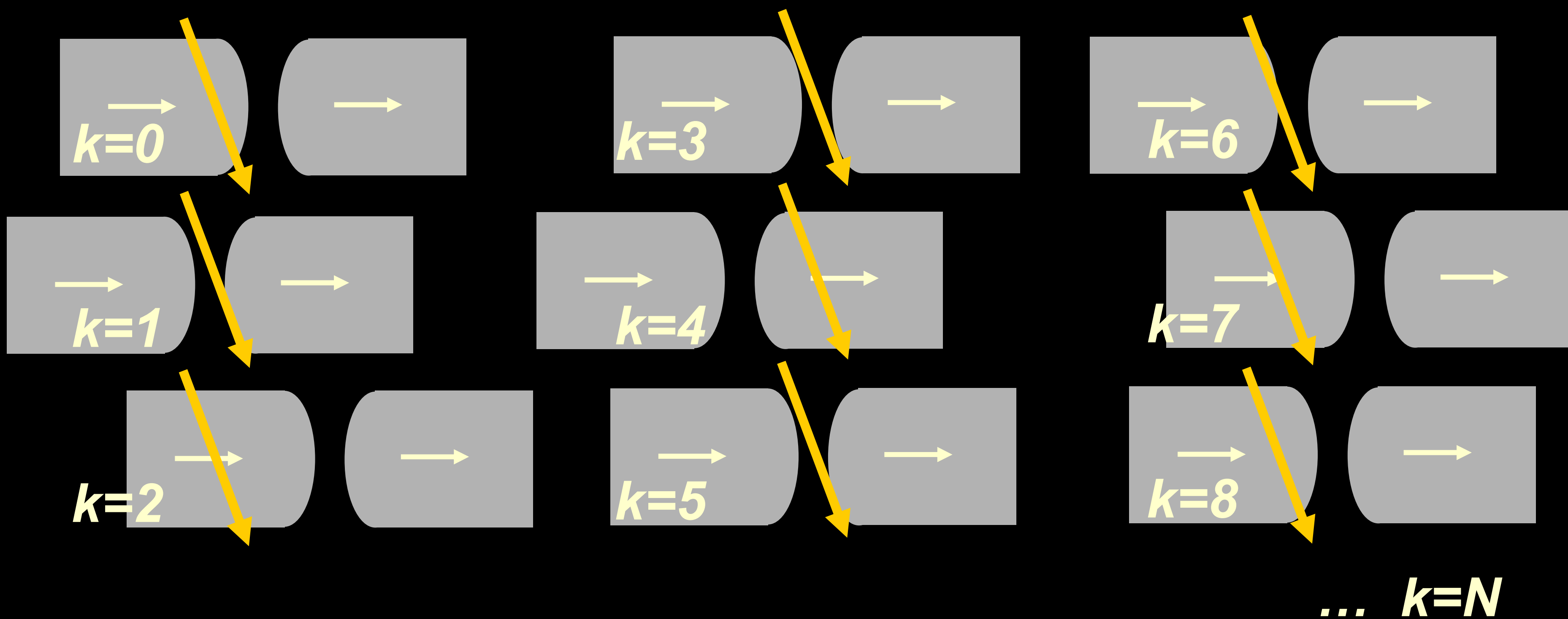
Attenuation from One Sample



At random "times" determine thickness t

$$w_f = w_i e^{-\mu(E)t/\cos\theta_z}$$

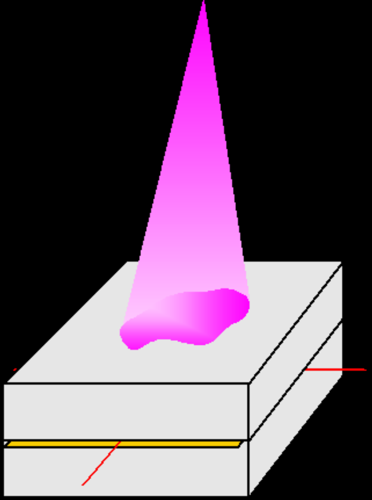
Multiple Samples

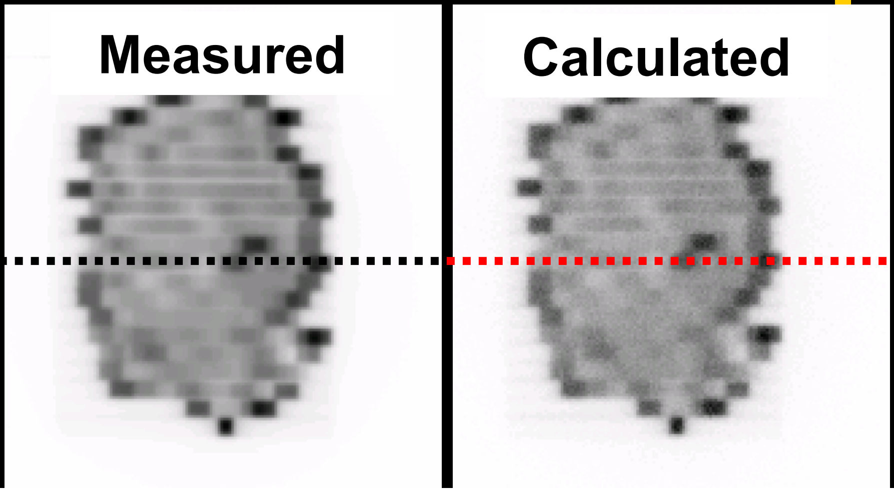


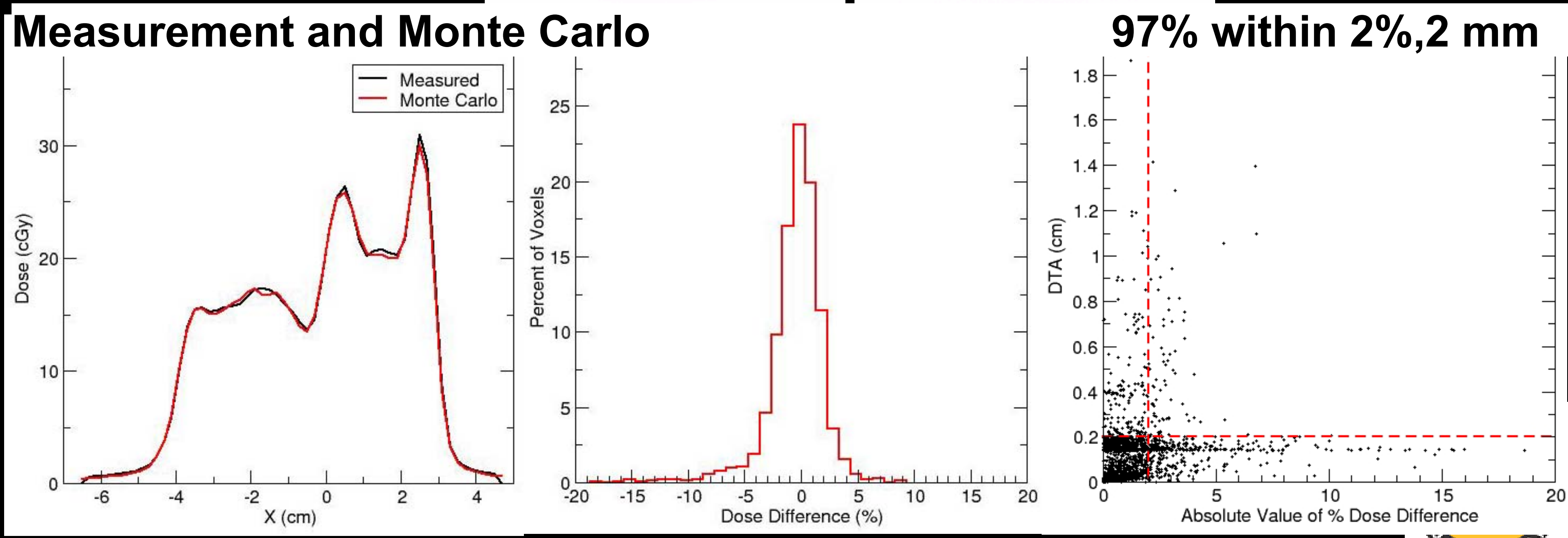
Determine overall probability by sampling at multiple random "times".

$$w_f = \frac{w_i}{N} \sum_{k=1}^{N} e^{-\mu(E) t_k / \cos\theta_z}$$

MC with MLC to Measurement Comparison







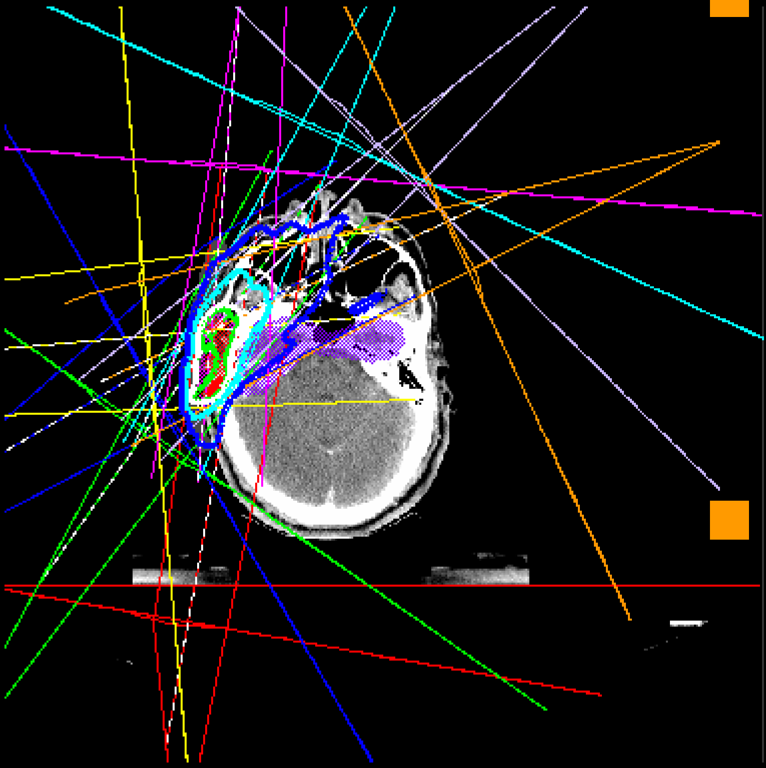
Application

of Monte Carlo to IMRT…

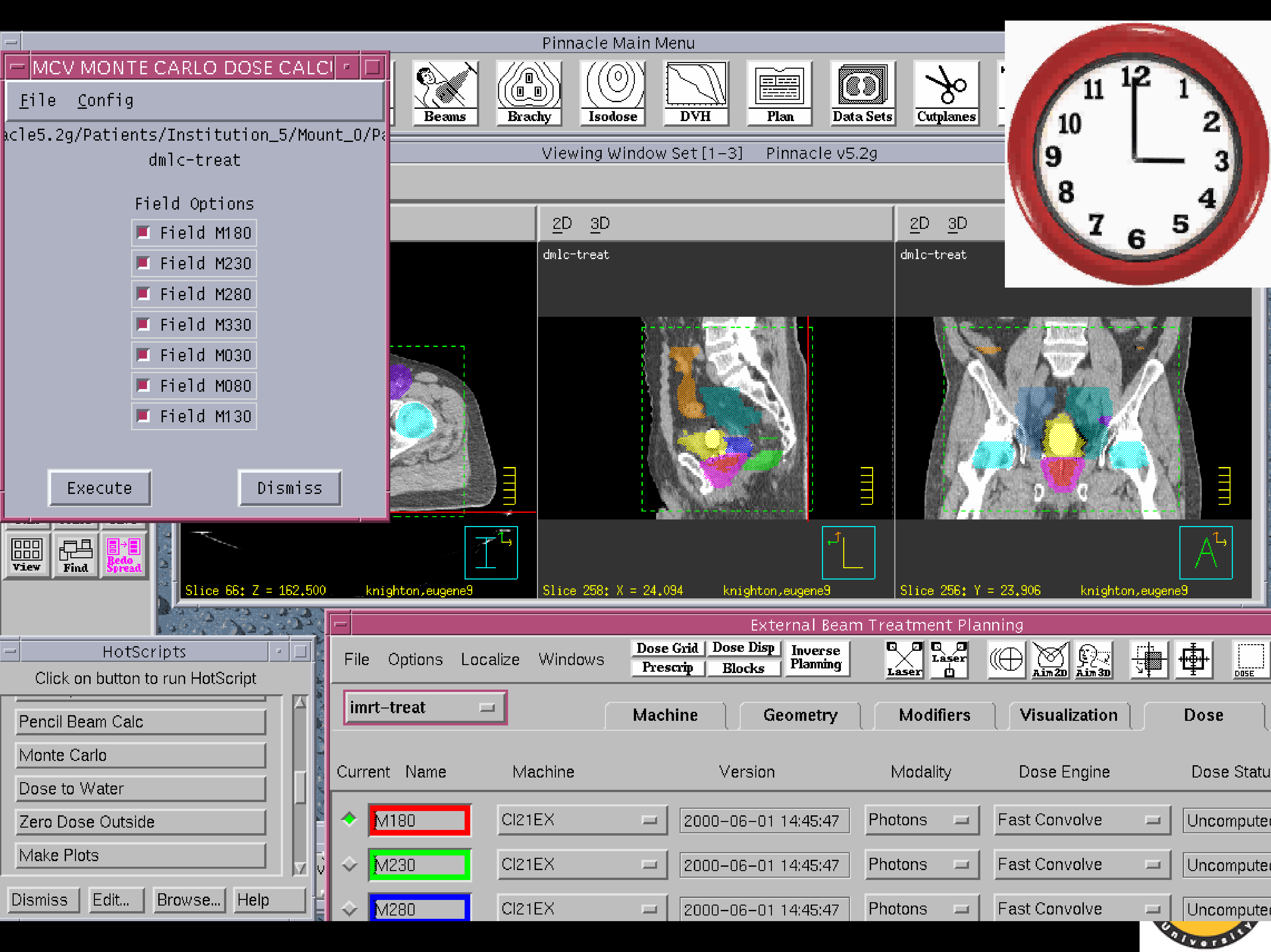
Monte Carlo

For Patient Dose Verification

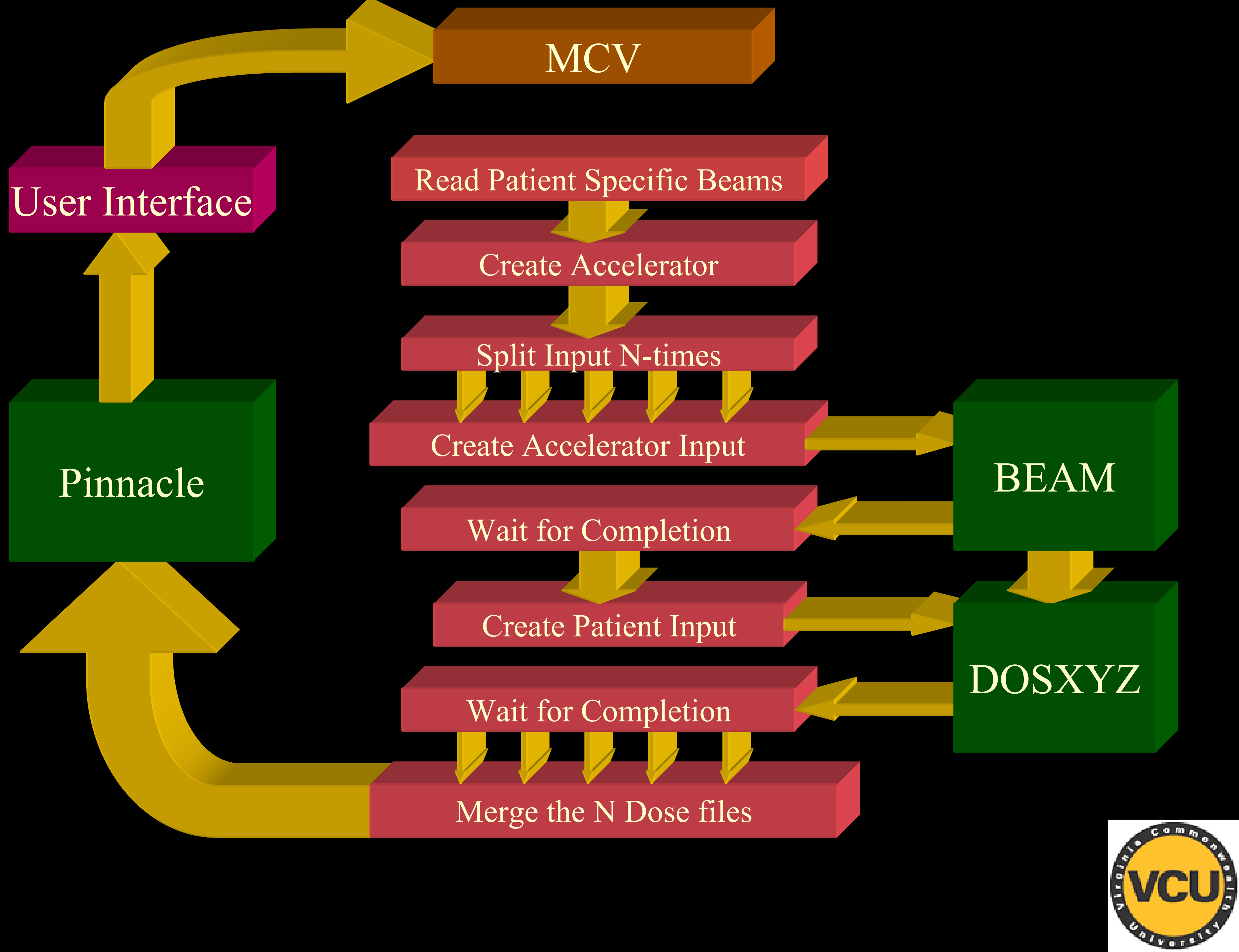
Beams on Patient

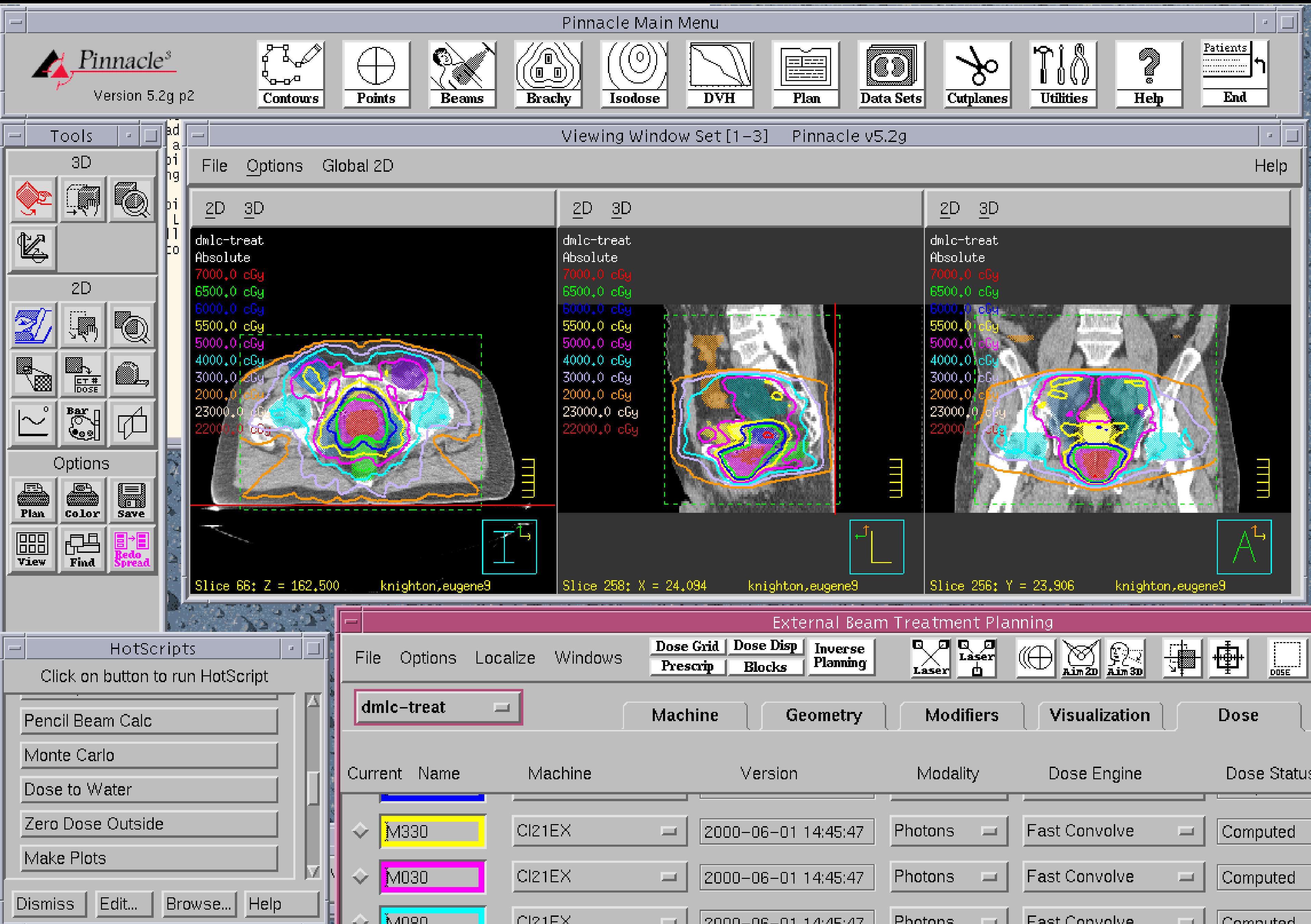


- Use Monte Carlo to recompute beams
  - Use MLC sequence files sent to accelerator to generate intensity modulation
- Compare DVHs with Planning Systems convolution calculation

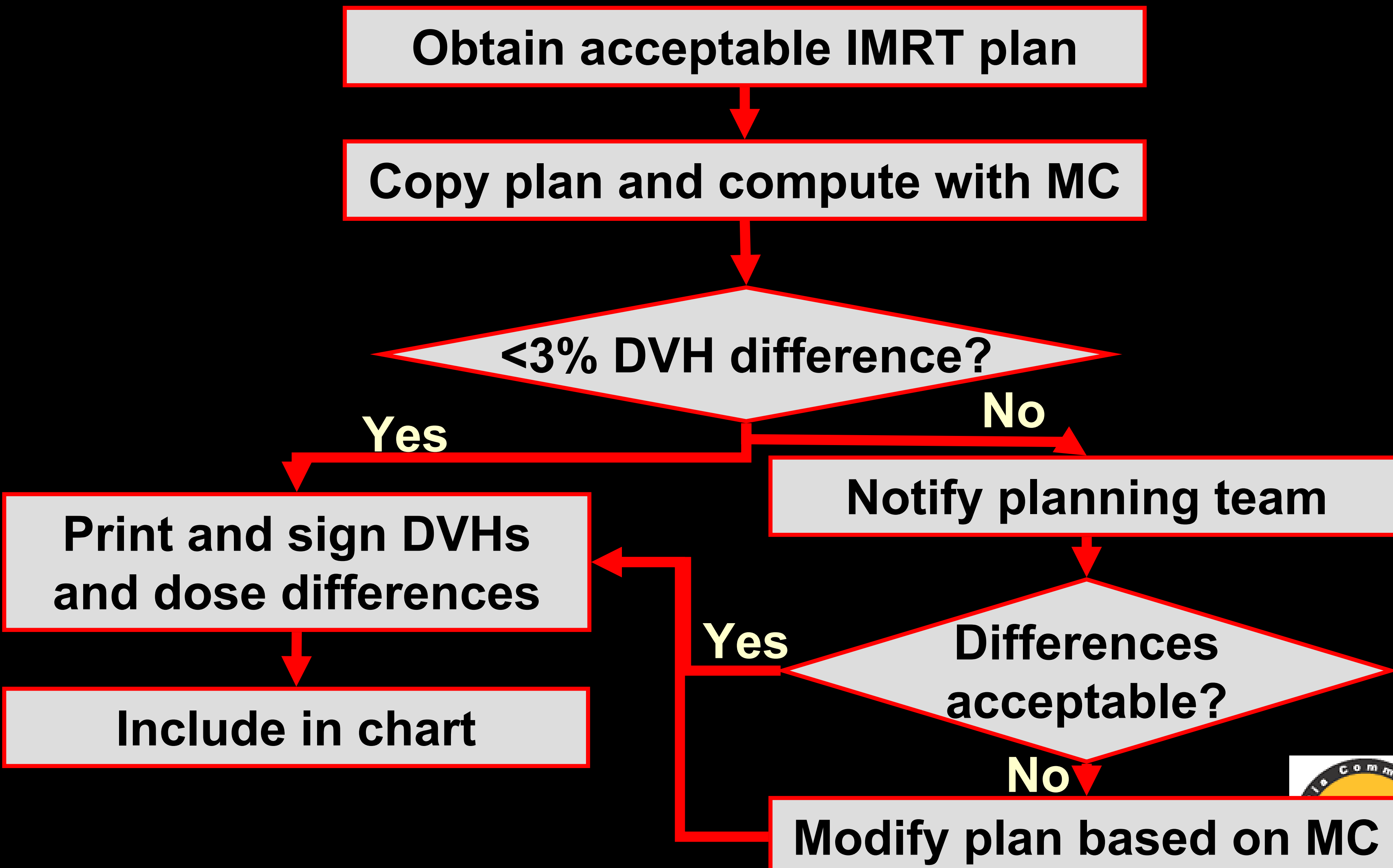


Pinnacle Main Menu
MCV MONTE CARLO DOSE CALC
File Config
acle5.2g/Patients/Institution_5/Mount_0/Pa
dmlc-treat
Field Options
Field M180
Field M230
Field M280
Field M330
Field M030
Field M080
Field M130
Execute
Dismiss
Beams
Brachy
Isodose
DVH
Plan
Data Sets
Cutplanes
Viewing Window Set [1-3] Pinnacle v5.2g
2D 3D
dmlc-treat
View
Find
Redo Spread
Slice 66: Z = 162.500 knighton,eugene9
Slice 258: X = 24.094 knighton,eugene9
Slice 256: Y = 23.906 knighton,eugene9
HotScripts
Click on button to run HotScript
Pencil Beam Calc
Monte Carlo
Dose to Water
Zero Dose Outside
Make Plots
Dismiss
Edit...
Browse...
Help
External Beam Treatment Planning
File Options Localize Windows
Dose Grid
Dose Disp
Prescrip
Blocks
Inverse Planning
Laser
Aim 2D
Aim 3D
imrt-treat
Machine
Geometry
Modifiers
Visualization
Dose
Current Name Machine Version Modality Dose Engine Dose Statu
M180 Cl21EX 2000-06-01 14:45:47 Photons Fast Convolve Uncompute
M230 Cl21EX 2000-06-01 14:45:47 Photons Fast Convolve Uncompute
M280 Cl21EX 2000-06-01 14:45:47 Photons Fast Convolve Uncompute

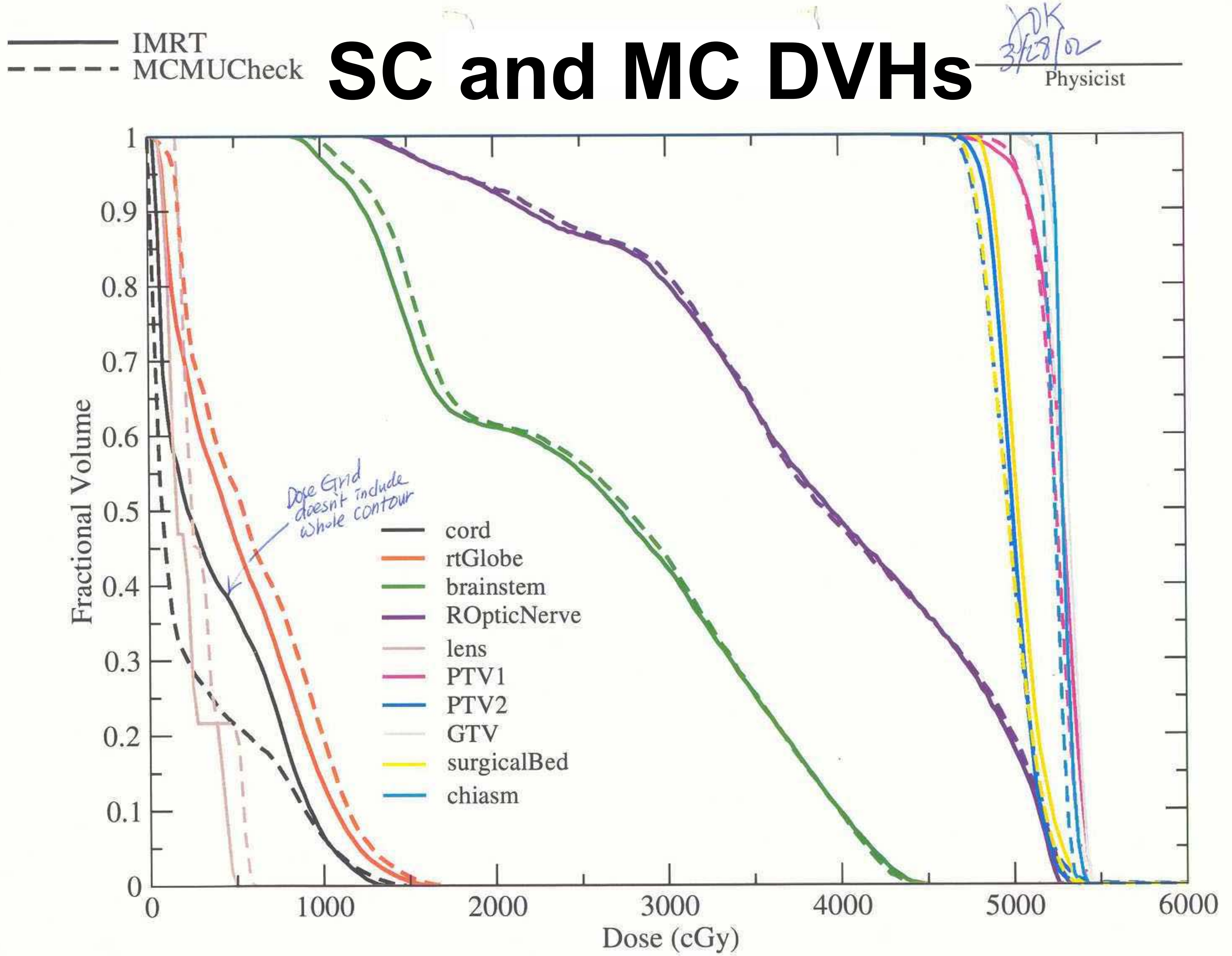

MCV
User Interface
Read Patient Specific Beams
Create Accelerator
Split Input N-times
Create Accelerator Input
Pinnacle
BEAM
Wait for Completion
Create Patient Input
DOSXYZ
Wait for Completion
Merge the N Dose files
VCU
Virginia Commonwealth University


Pinnacle Main Menu
Pinnacle3
Version 5.2g p2
Contours
Points
Beams
Brachy
Isodose
DVH
Plan
Data Sets
Cutplanes
Utilities
Help
Patients
End
Tools
3D
2D
Options
Plan
Color
Save
View
Find
Redo Spread
Viewing Window Set [1-3] Pinnacle v5.2g
File Options Global 2D
Help
2D 3D
dmlc-treat
Absolute
7000.0 cGy
6500.0 cGy
6000.0 cGy
5500.0 cGy
5000.0 cGy
4000.0 cGy
3000.0 cGy
2000.0 cGy
23000.0 cGy
22000.0 cGy
Slice 66: Z = 162.500 knighton.eugene9
Slice 258: X = 24.094 knighton.eugene9
Slice 256: Y = 23.906 knighton.eugene9
HotScripts
Click on button to run HotScript
Pencil Beam Calc
Monte Carlo
Dose to Water
Zero Dose Outside
Make Plots
Dismiss
Edit...
Browse...
Help
External Beam Treatment Planning
File Options Localize Windows
Dose Grid
Dose Disp
Prescrip
Blocks
Inverse Planning
Laser
Aim 2D
Aim 3D
dmlc-treat
Machine
Geometry
Modifiers
Visualization
Dose
Current Name Machine Version Modality Dose Engine Dose Status
M330 Cl21EX 2000-06-01 14:45:47 Photons Fast Convolve Computed
M030 Cl21EX 2000-06-01 14:45:47 Photons Fast Convolve Computed
M080 Cl21EX 2000-06-01 14:45:47 Photons Fast Convolve Computed

Monte Carlo IMRT verification

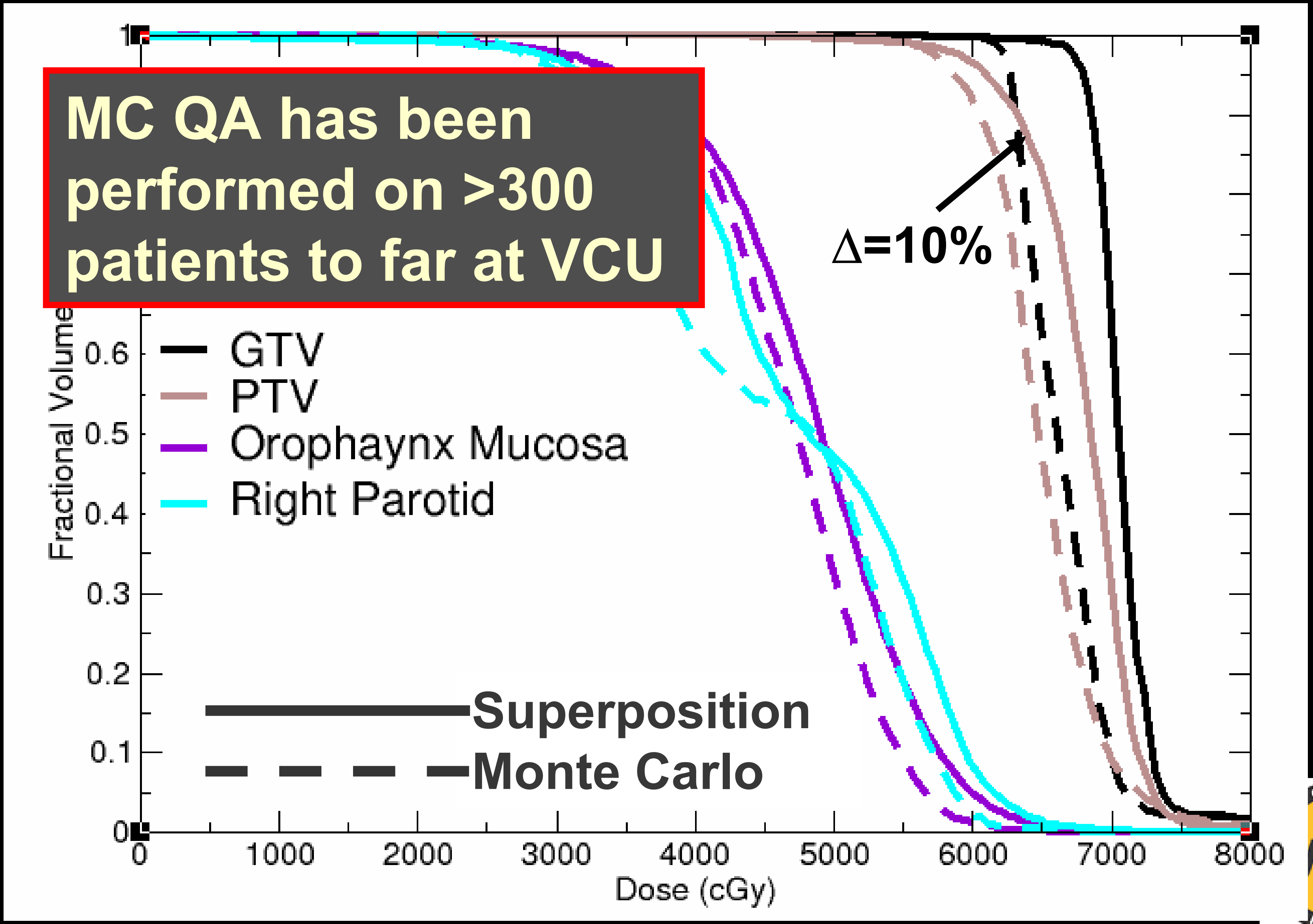


SC and MC DVHs



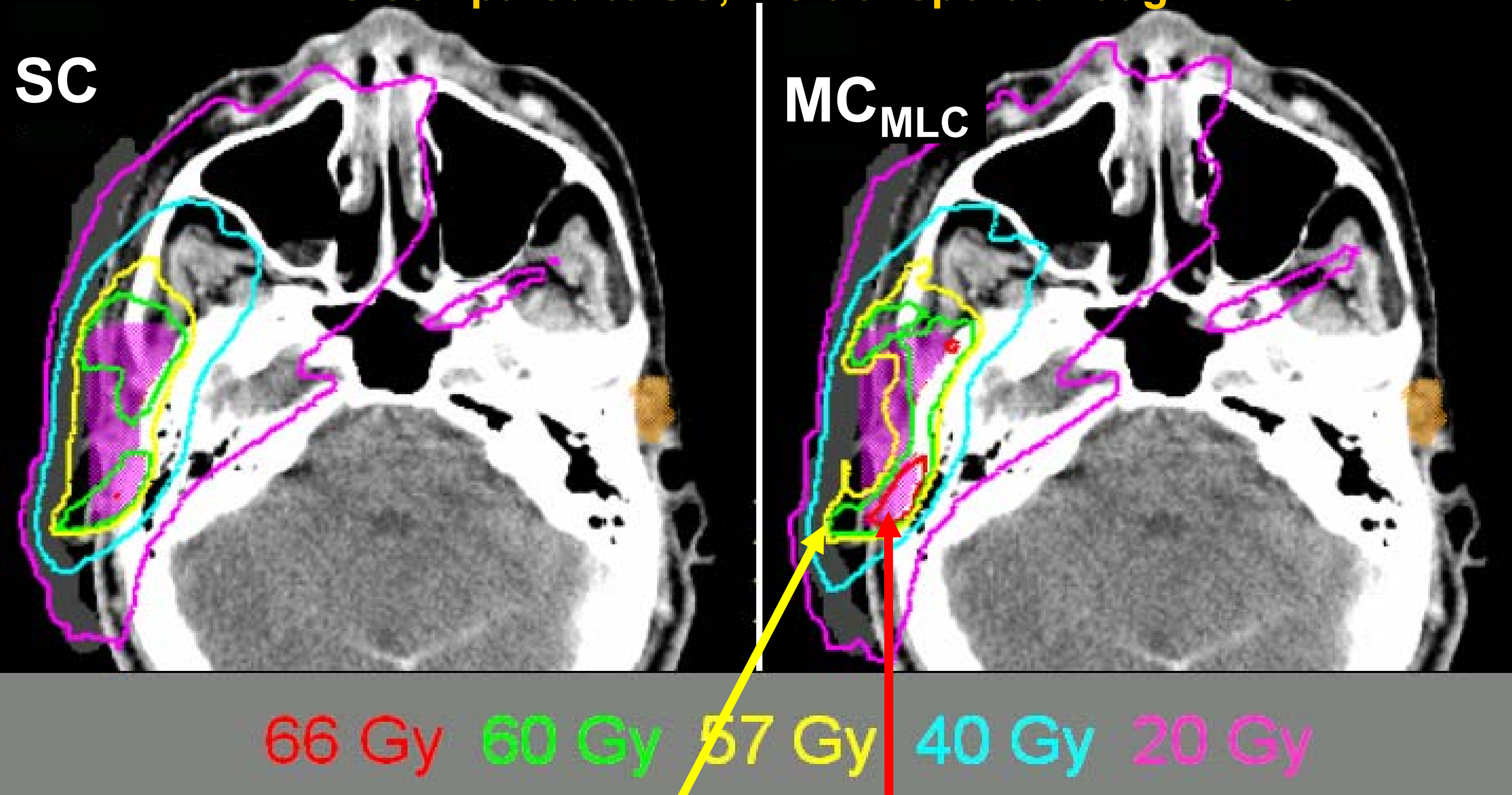
IMRT Plan Verification

VCU IMRT QA



IMRT Plan Verification

MC compared to SC, MC transport through MLC

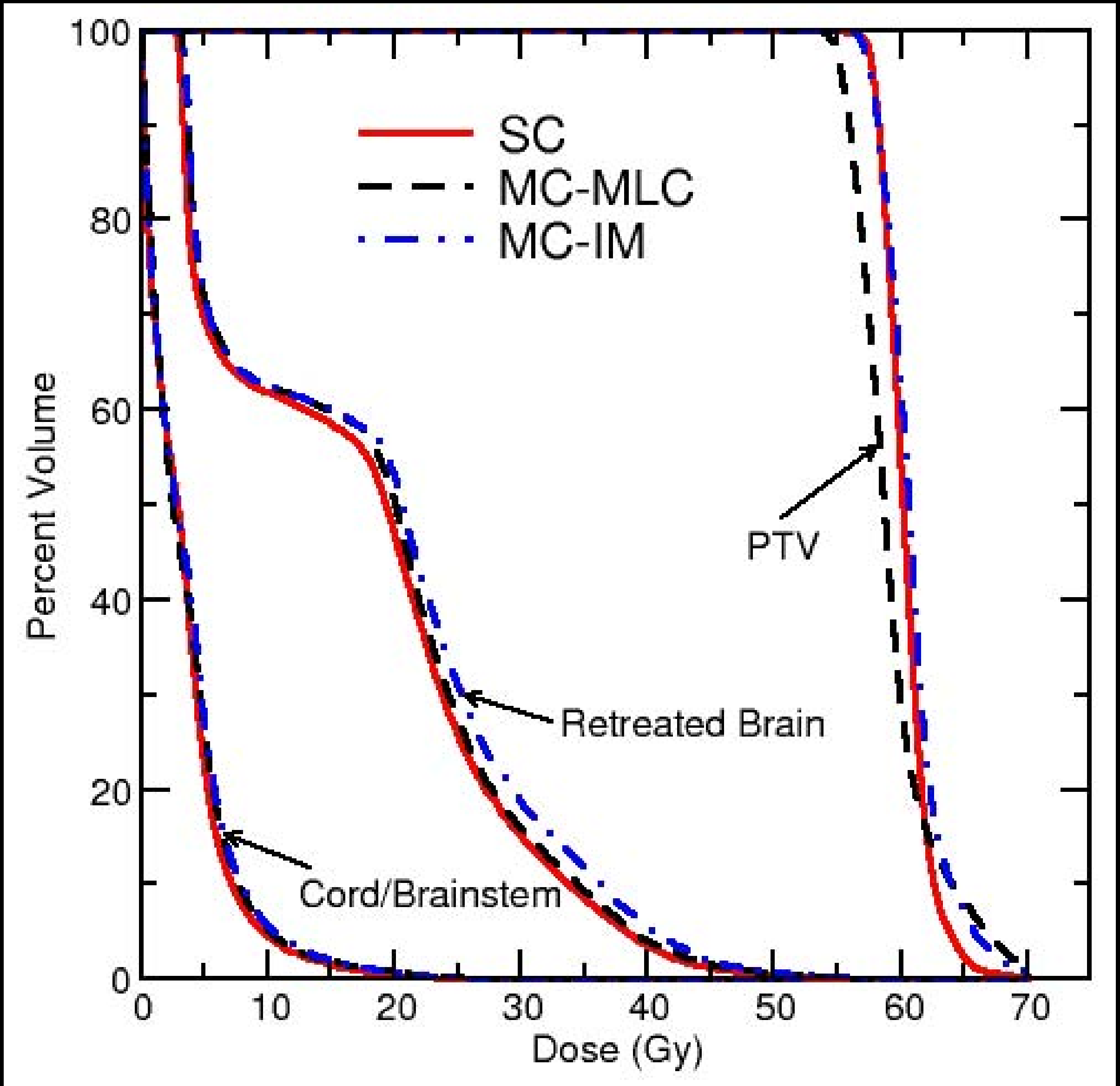


66 Gy Hot-Spot

57 Gy line not cover PTV

IMRT Plan Verification

MC compared to SC



Results from 28 Head and Neck Treatment Plans

- 21/28 had ΔD > 3% for Target Structures
  - 4/28 ΔD > 5%
- 5/28 exceeded critical structure (cord) tolerance dose due to ΔD

What

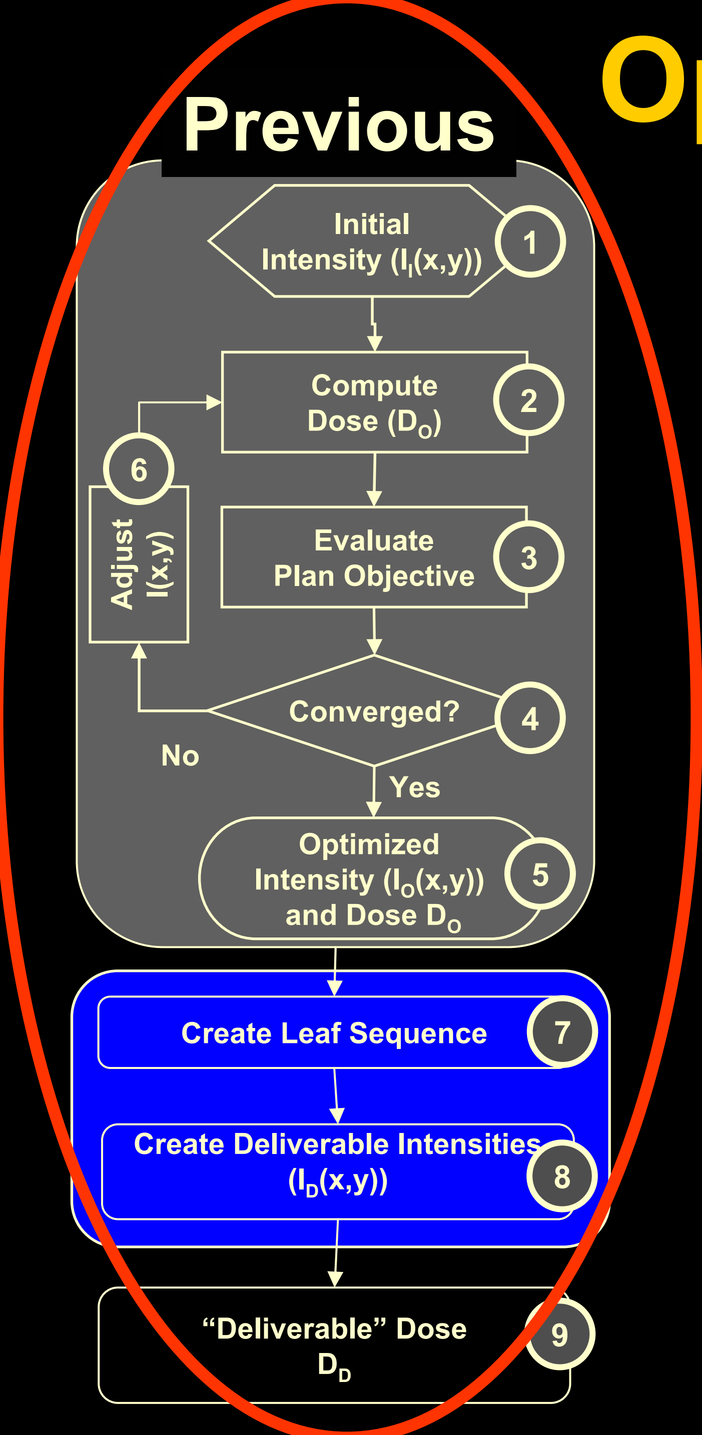
about using Monte Carlo for IMRT optimization?

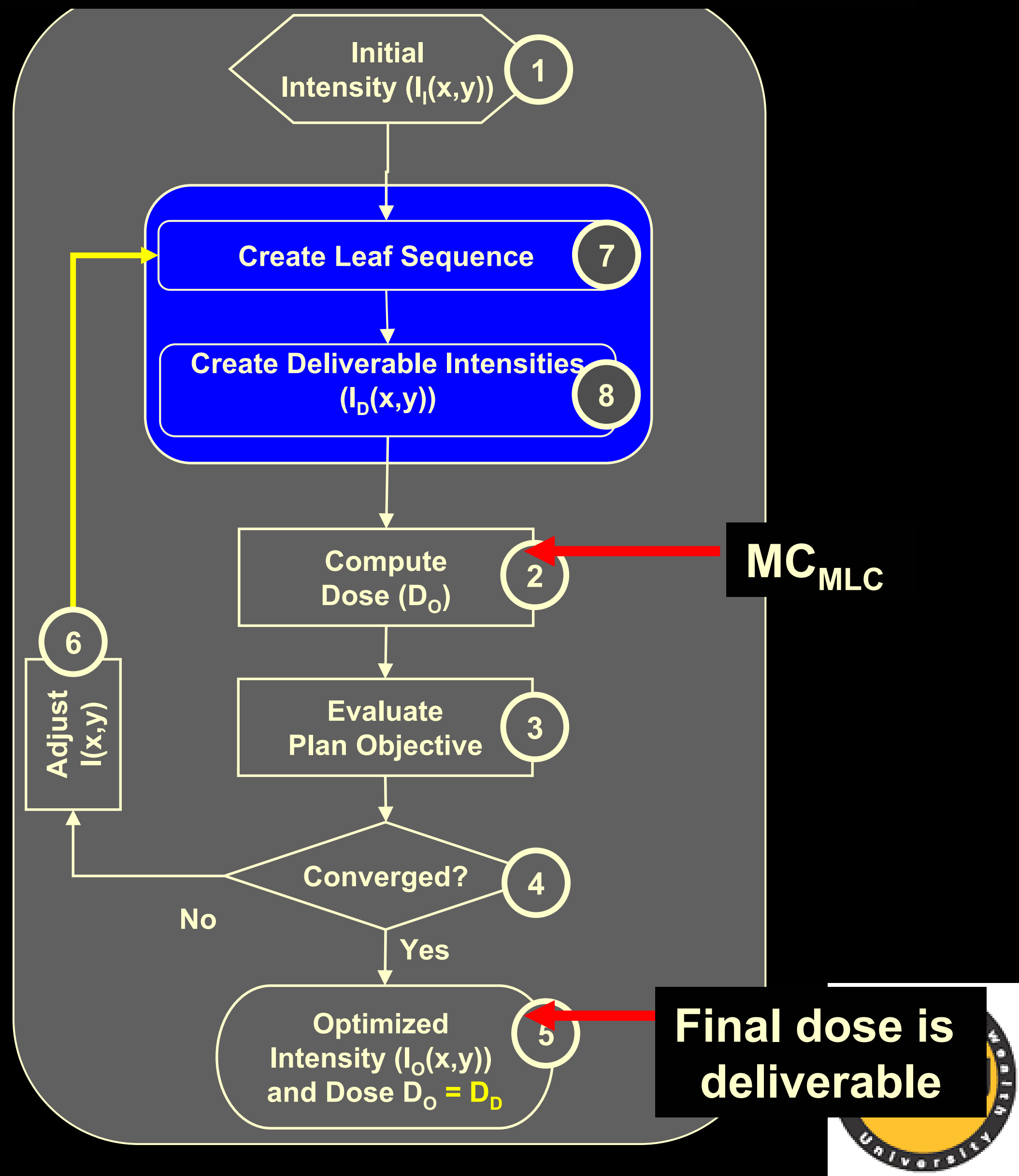
Can

Monte Carlo result in a better plan for the patient?

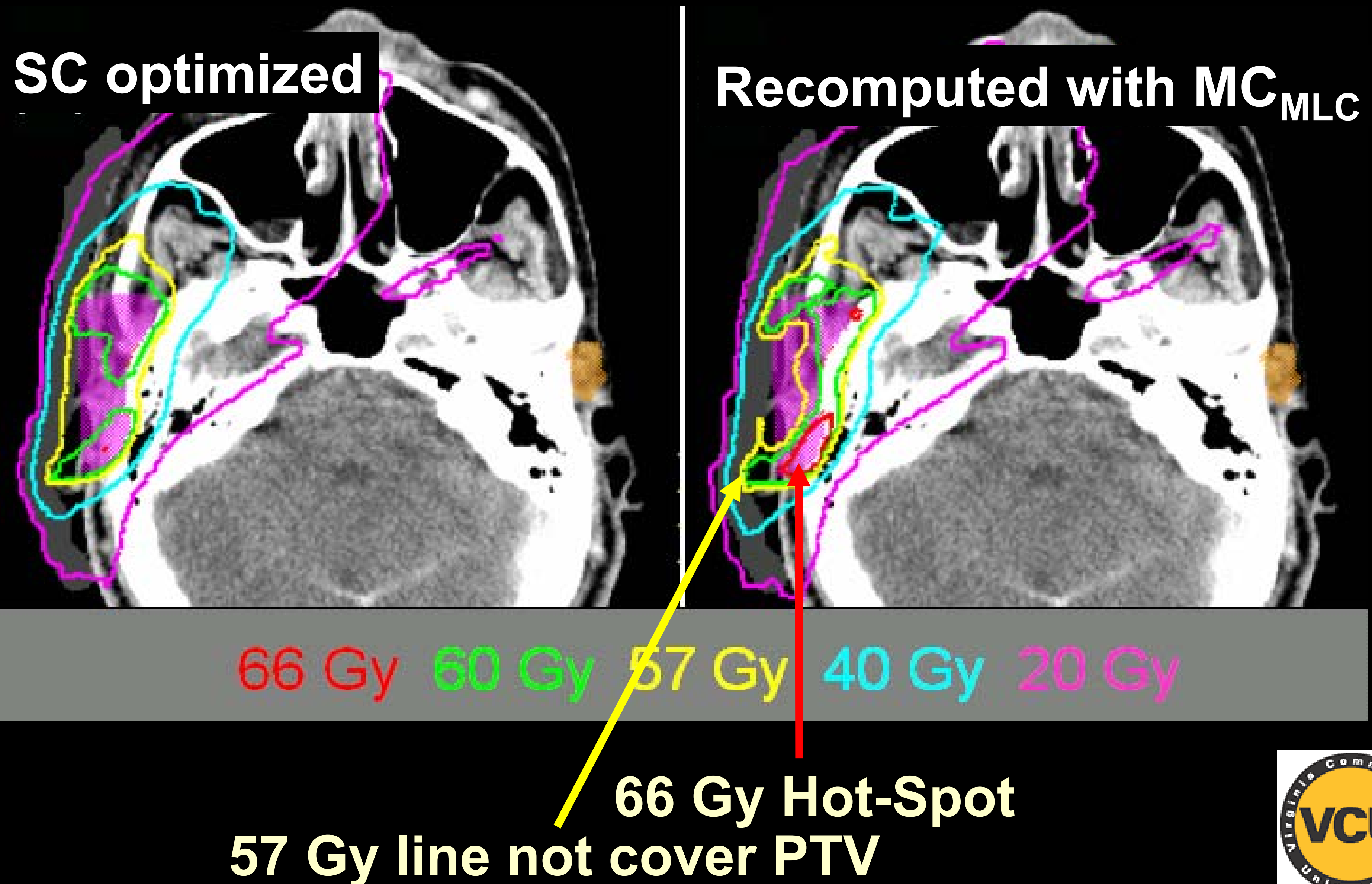
Optimization Process

MC Deliverable Optimization



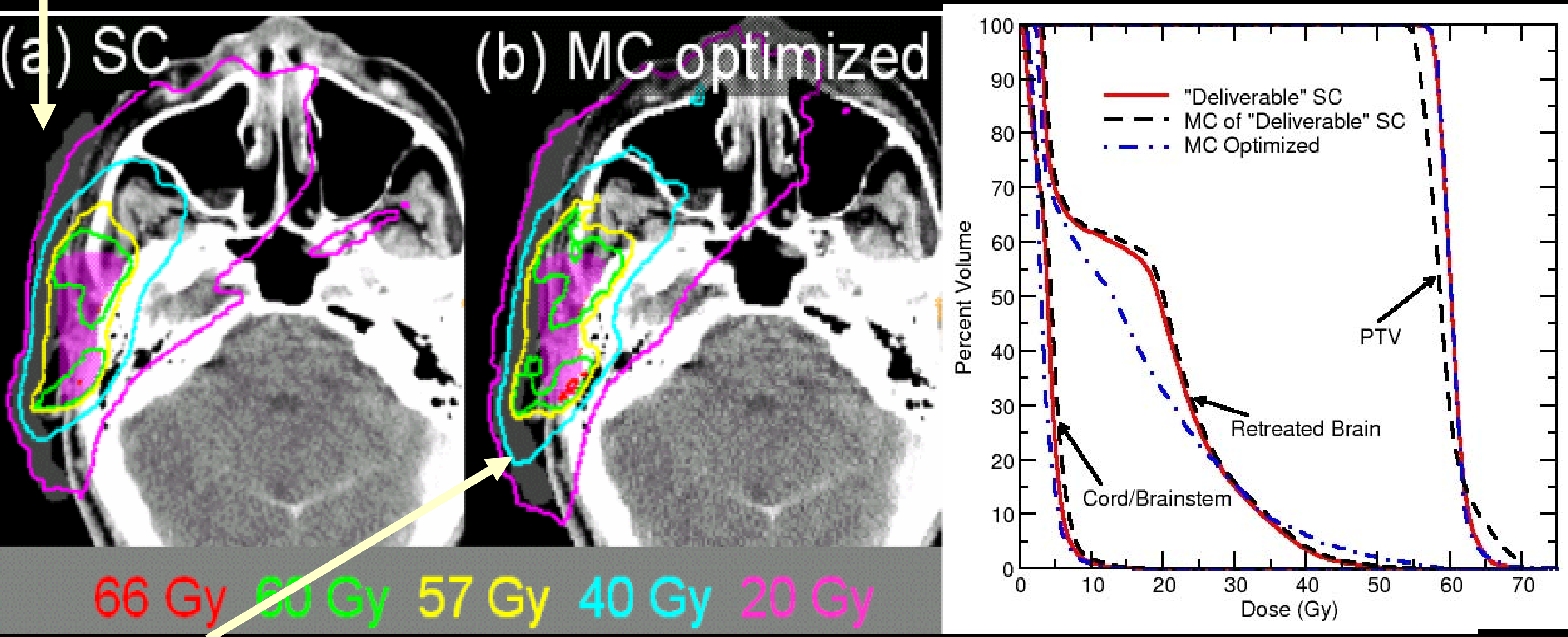


Isodose coverage



Optimized with MC

(a) Approved plan that did not agree with MC



(b) MC optimized plan restores target coverage

Initial desired dose distribution was achievable, but it required different intensities / leaf sequences than predicted by SC to be achieved in the patient

Problem

- MC dose calculation takes too long for iterative IMRT dose computation
- Possible Solutions
  - Faster MC codes
  - Negative weight particle method
  - Hybrid dose calculations
  - Smoothing / Denoising MC distributions

What is a Hybrid Algorithm?

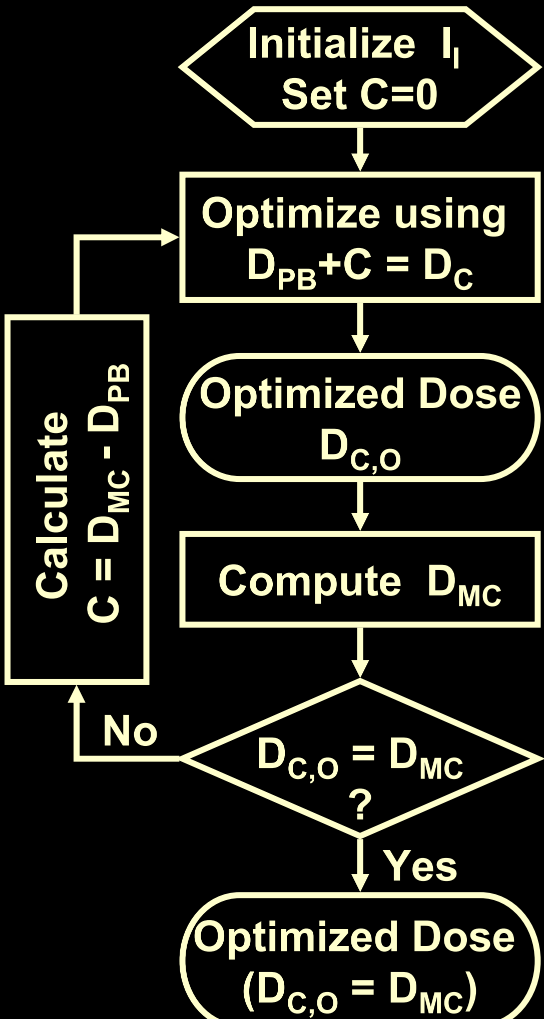
- Combining or mixing of different dose calculation algorithms
- Useful for iterative IMRT calculation

What are the objectives of using hybrid algorithms?

- Decrease (wall clock) time required to do plan optimization
- Final optimized result as good as if accurate algorithm used for all iterations

Hybrid Dose Calc Methods

Correction Method



$$I_n = I_{C_{MC}} + \Delta I_n$$

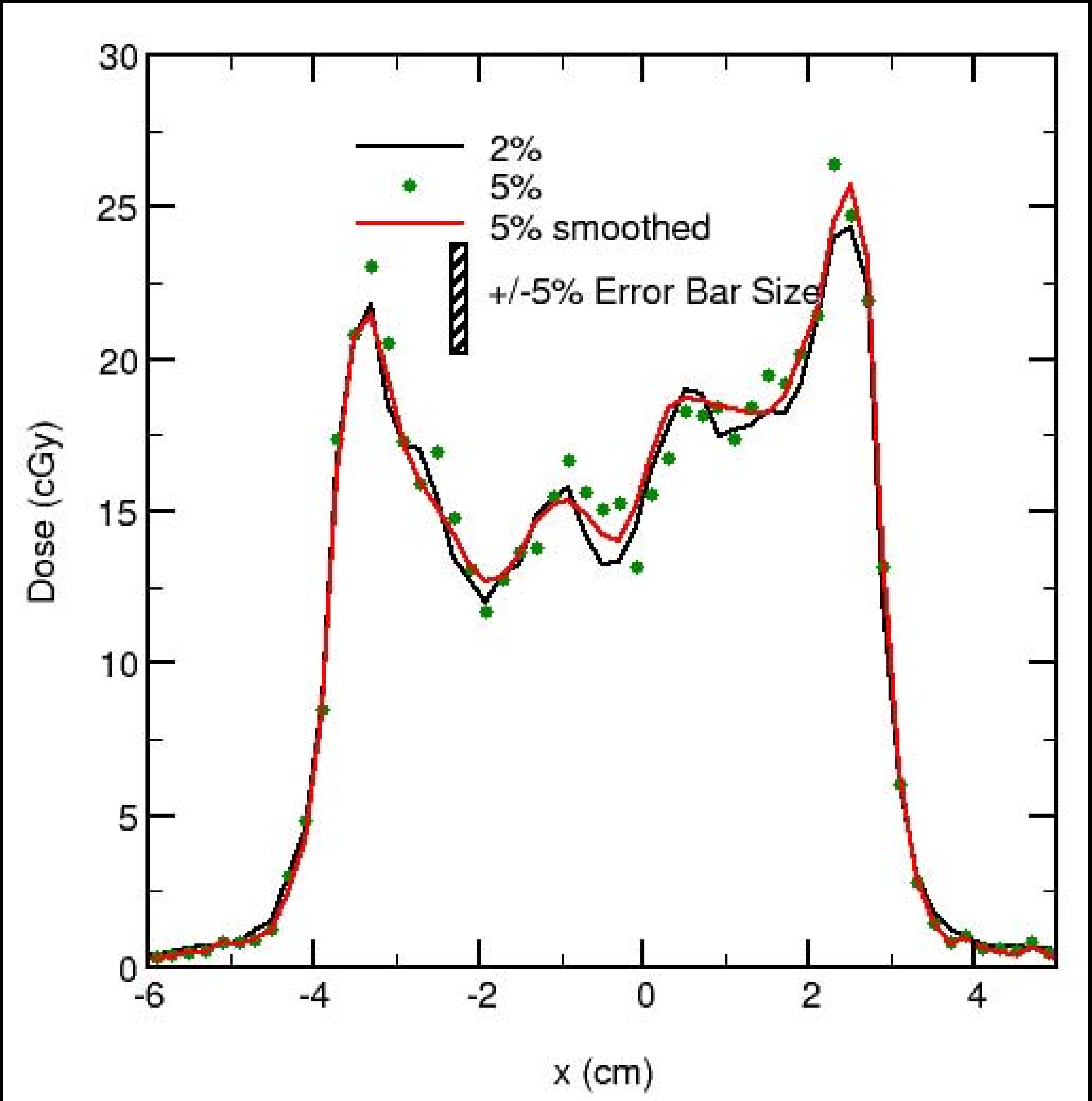
$$D_C = \left(T_{I_n} \otimes K\right) + C = \left(T_{I_{C_{MC}}} \otimes K\right) + \left(T_{\Delta I_n} \otimes K\right) + C = D_{MC} + \left(T_{\Delta I_n} \otimes K\right).$$

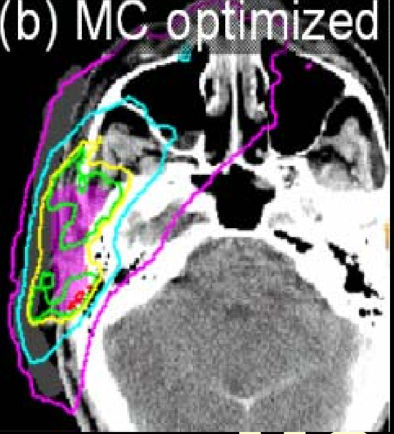
$$(\Delta I_n \rightarrow 0),\ D_C \rightarrow D_{MC}$$

Smoothing / Denoising

- Approaches
  - Smoothing via fitting
    - Kawrakow, Fippel
  - Wavelets to remove high frequencies
    - Deasy
- Can reduce #particles by ~8x

Smoothing / Denoising





Conclusions

- MC reveals dose discrepancies cause by
  - Heterogeneities
  - Fluence
- MC useful for IMRT plan verification
  - Practical
- In future will be used for plan optimization
  - Requires Fast MC