Northwestern Medicine®
Chicago Proton Center

AAPM2015
REINVIGORATING
SCIENTIFIC EXCELLENCE

Proton Treatment Planning

SAM Educational Session

Mark Pankuch, PhD
Northwestern Medicine Chicago Proton Center

Today's objectives

- Discuss the general planning tools used in proton planning
  - Aperture / Compensator based delivery
  - Pencil Beam delivery
- Review the unique handling of CTV / ITV / PTV when treating with protons
- Understanding the benefits of PBS and some additional concerns
- PBS patient specific QA

Aperture / Compensator based Planning Strategies

- Cover the target with appropriate margins

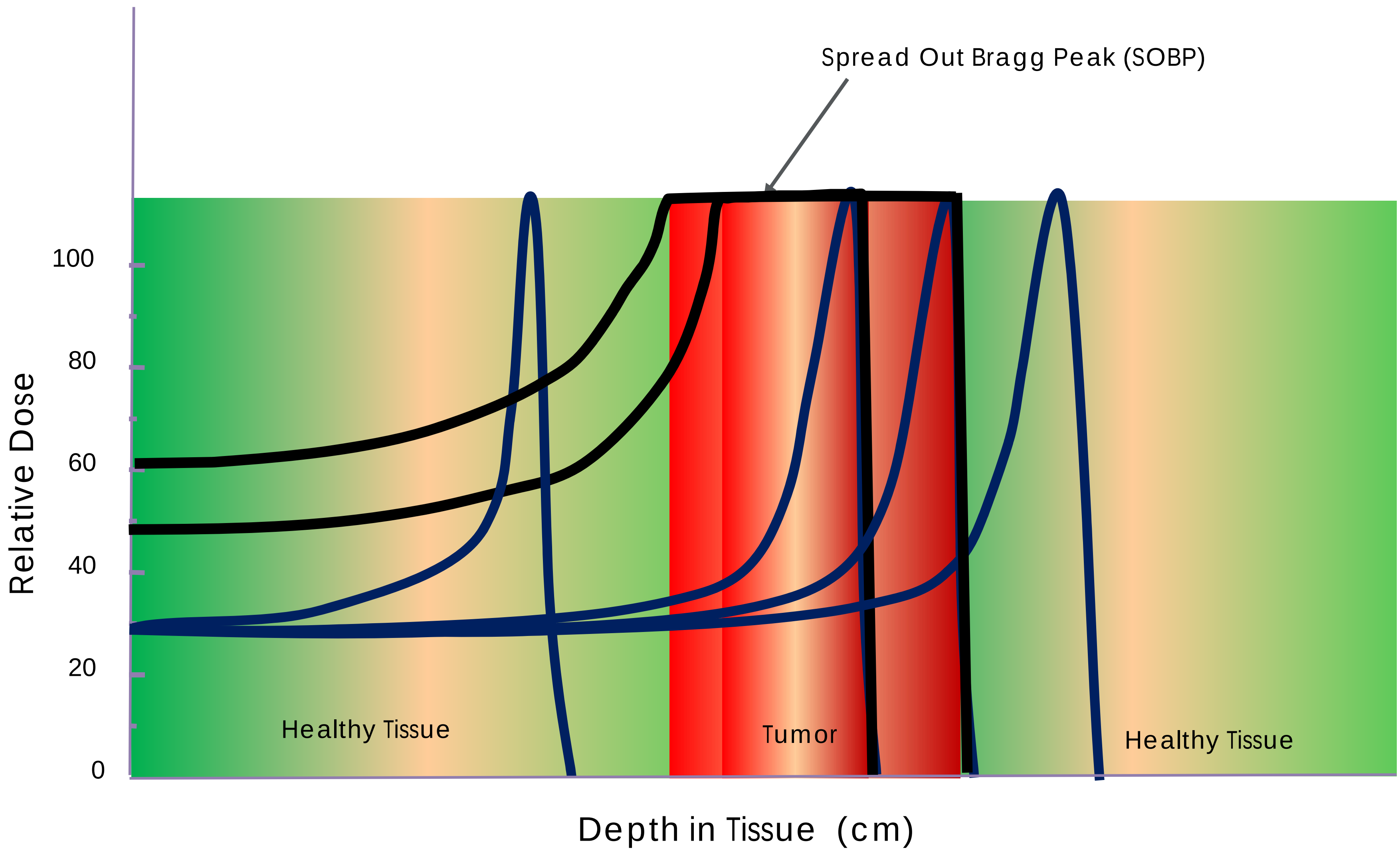
- Spare the critical structures

- Plan with fields that deliver the most "robust" plan

Tools to do our job

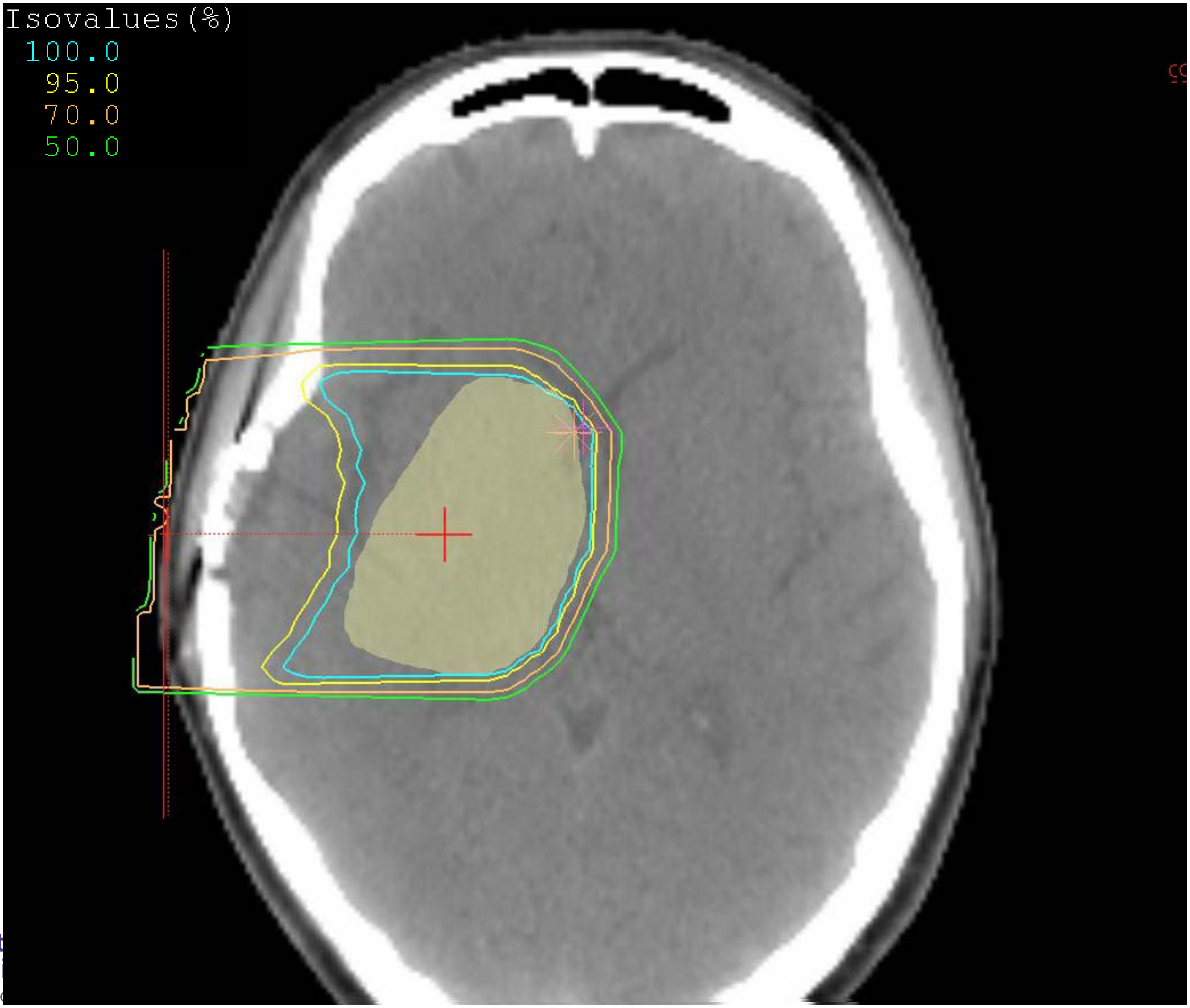
- Protons
  - Range : The depth of the Bragg peak (D90%)
  - Modulation : The spread of the Bragg peak
  - Apertures : Shaping the beam perpendicular to the path
  - Compensators : Distal Shaping
  - Patch Fields : Distal Edge to Lateral Edge Matching

The Physics of Protons

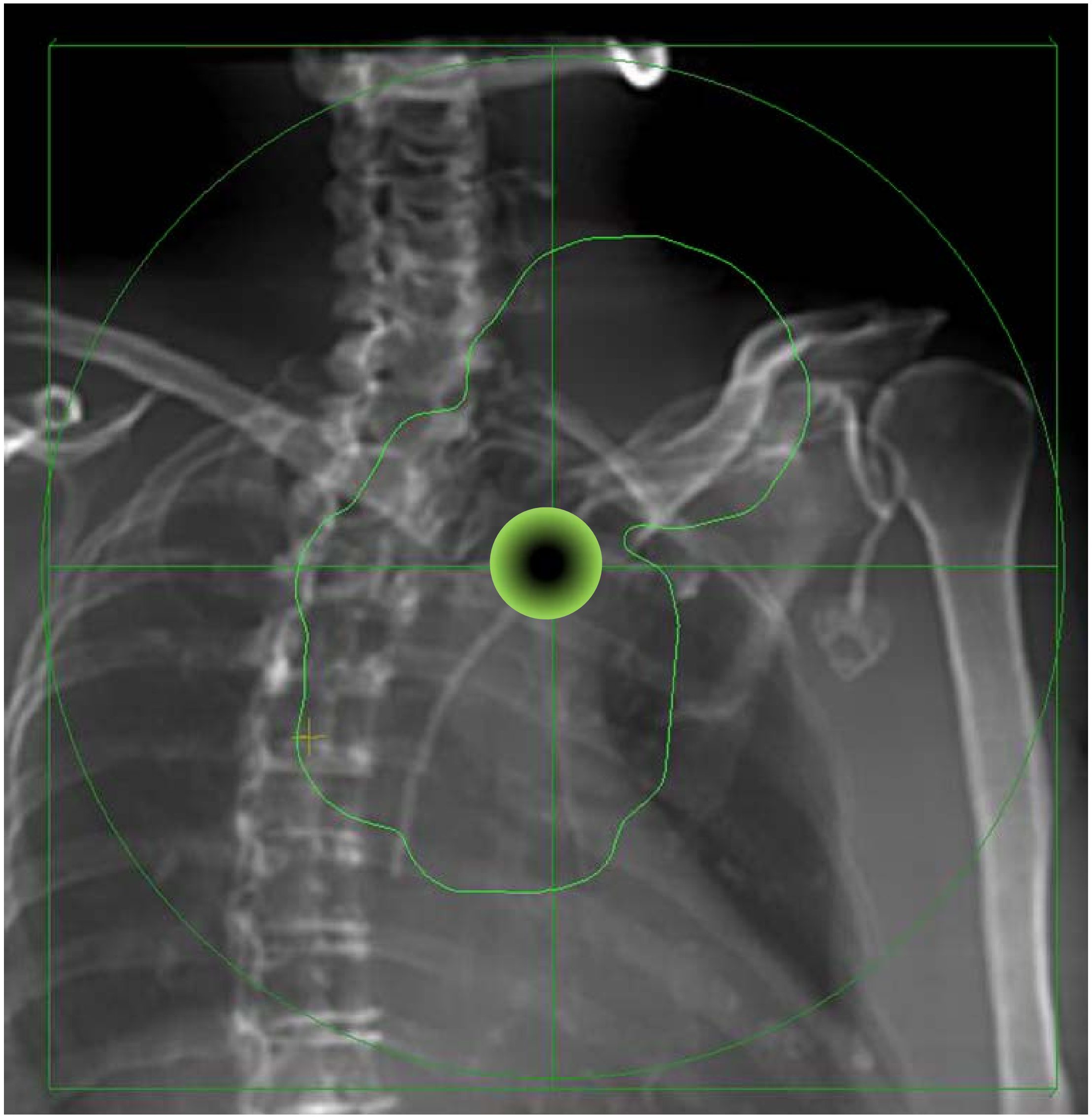


Northwestern Medicine®
Chicago Proton Center

Range and Modulation

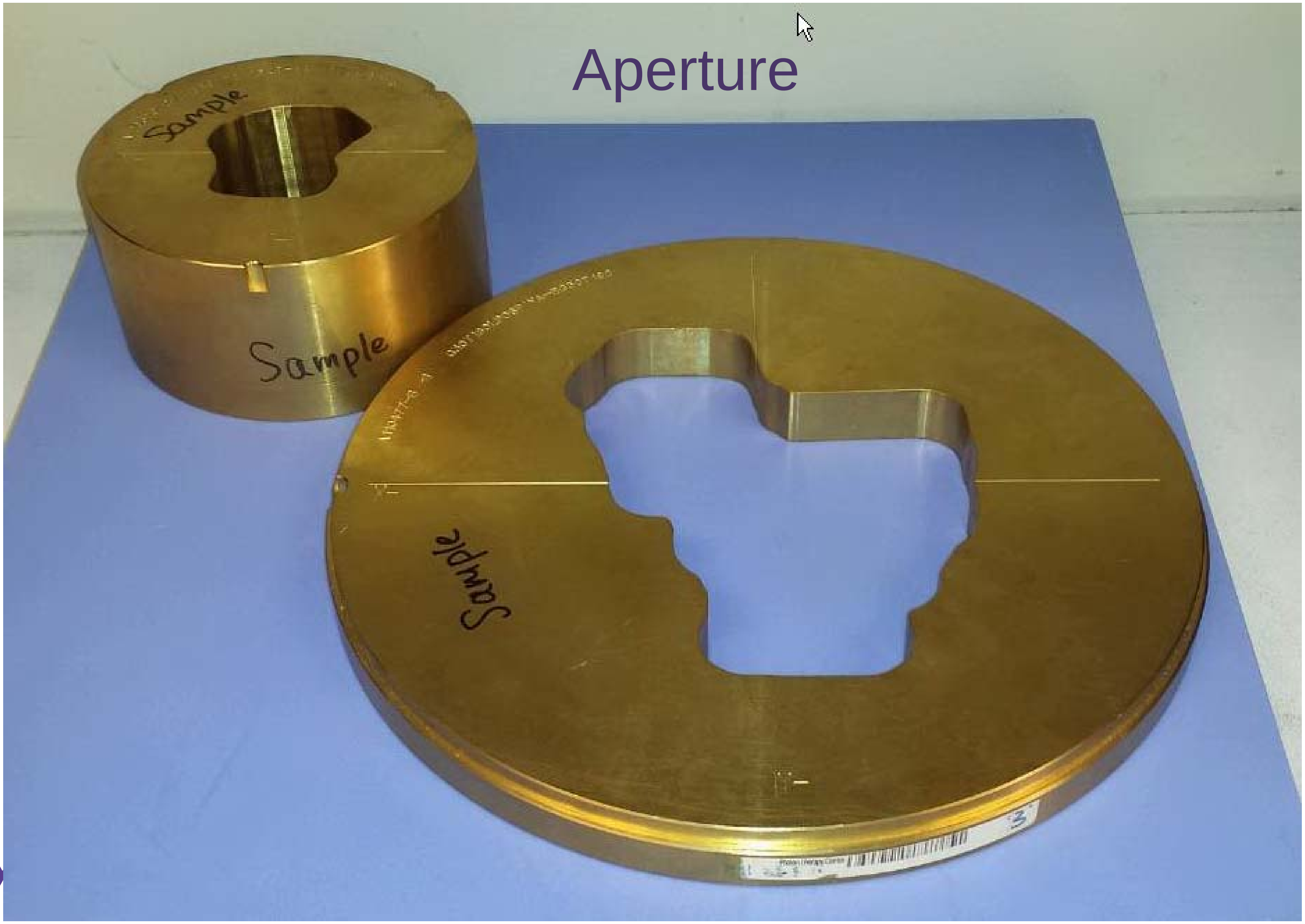


Spreading the beam across the field

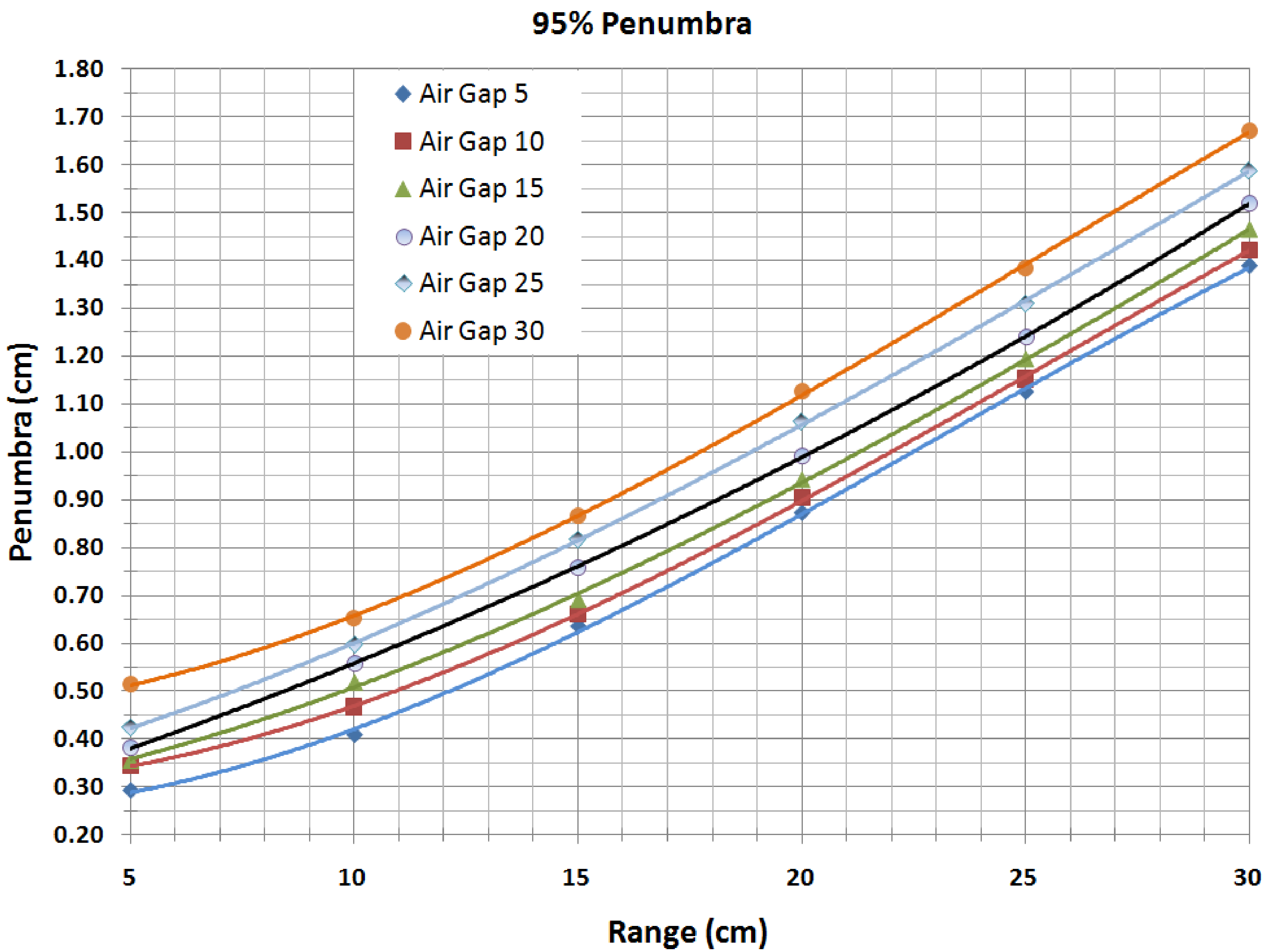


Northwestern Medicine®
Chicago Proton Center

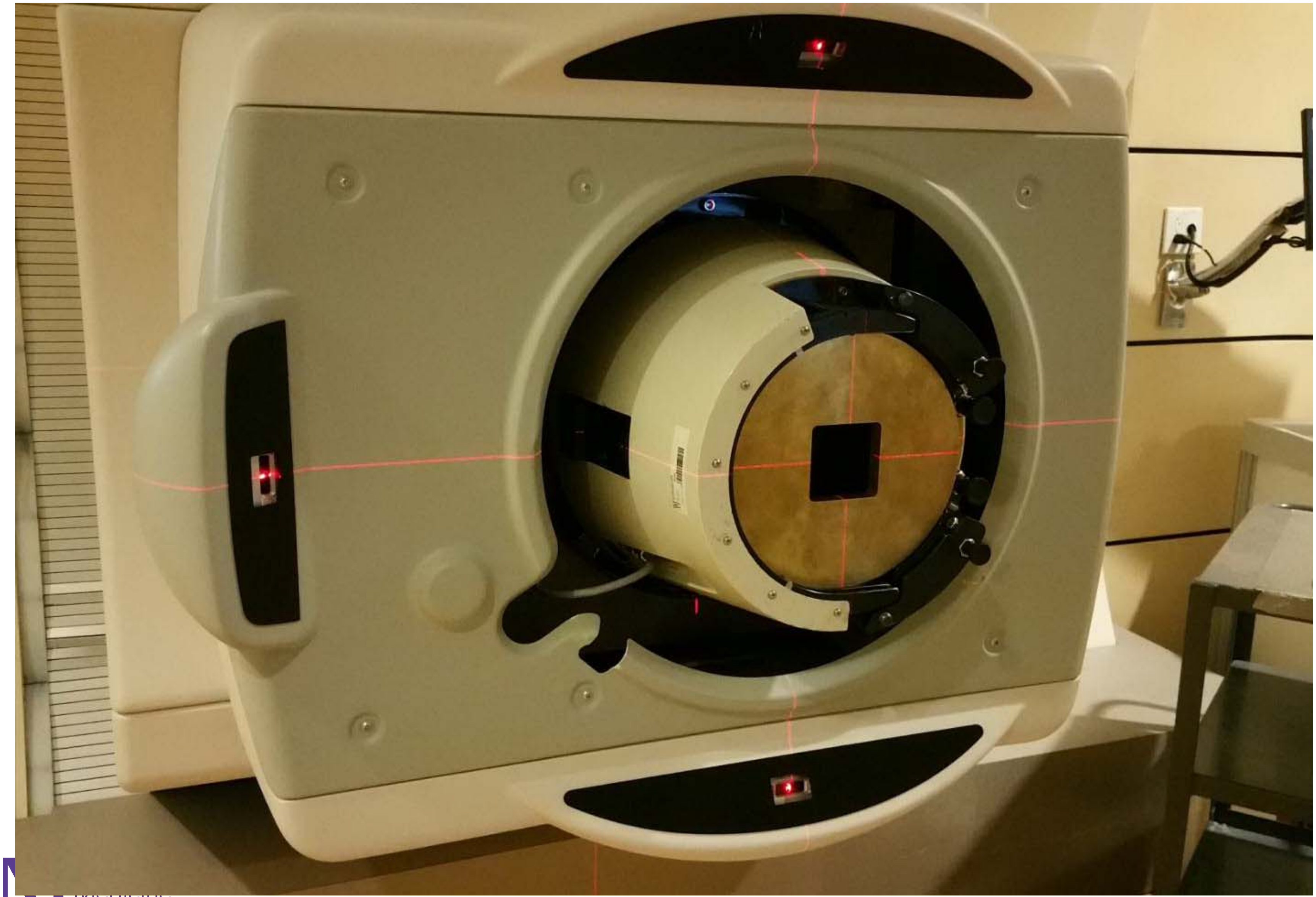
Patient Specific Devices



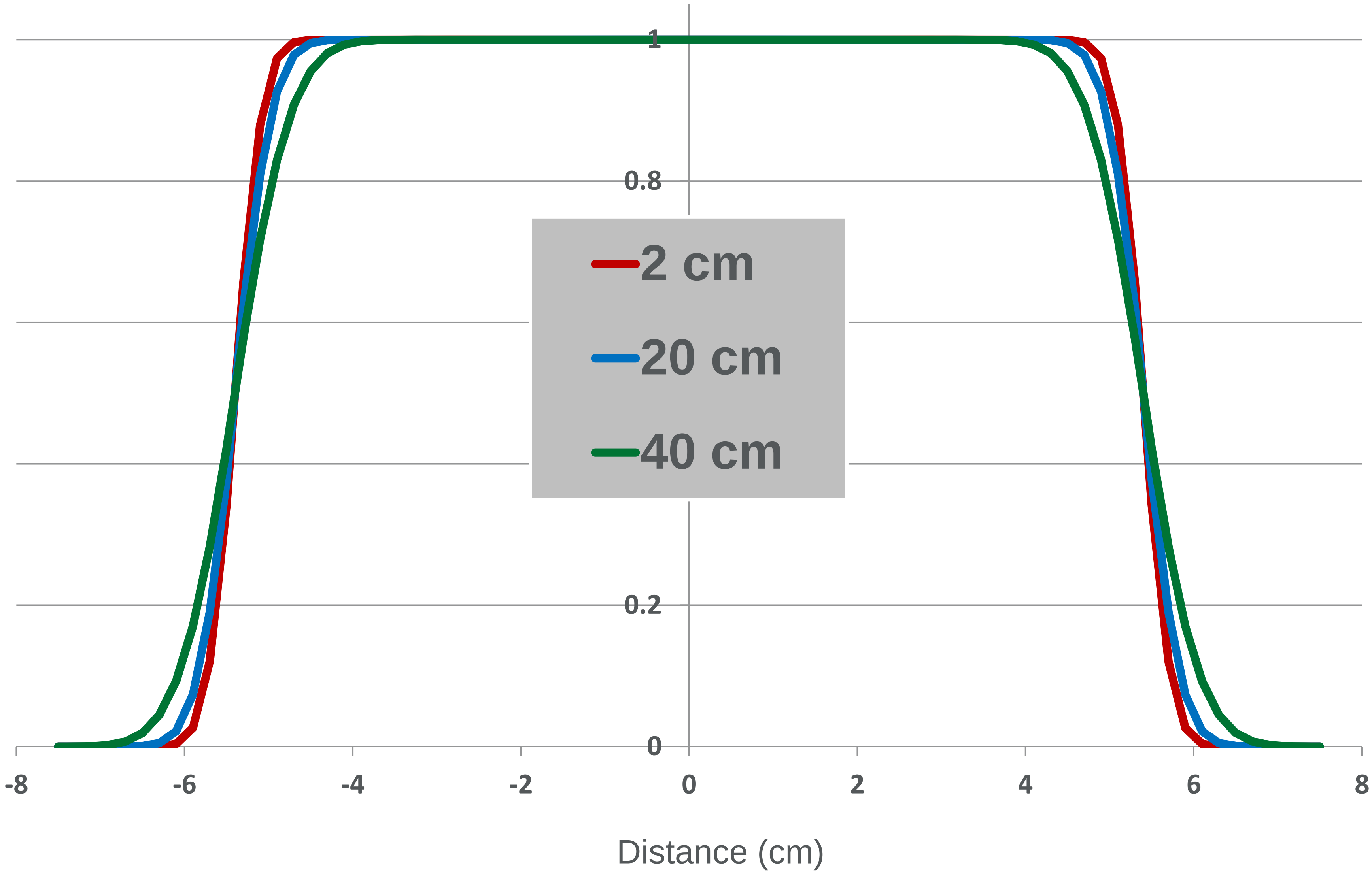
Aperture Design



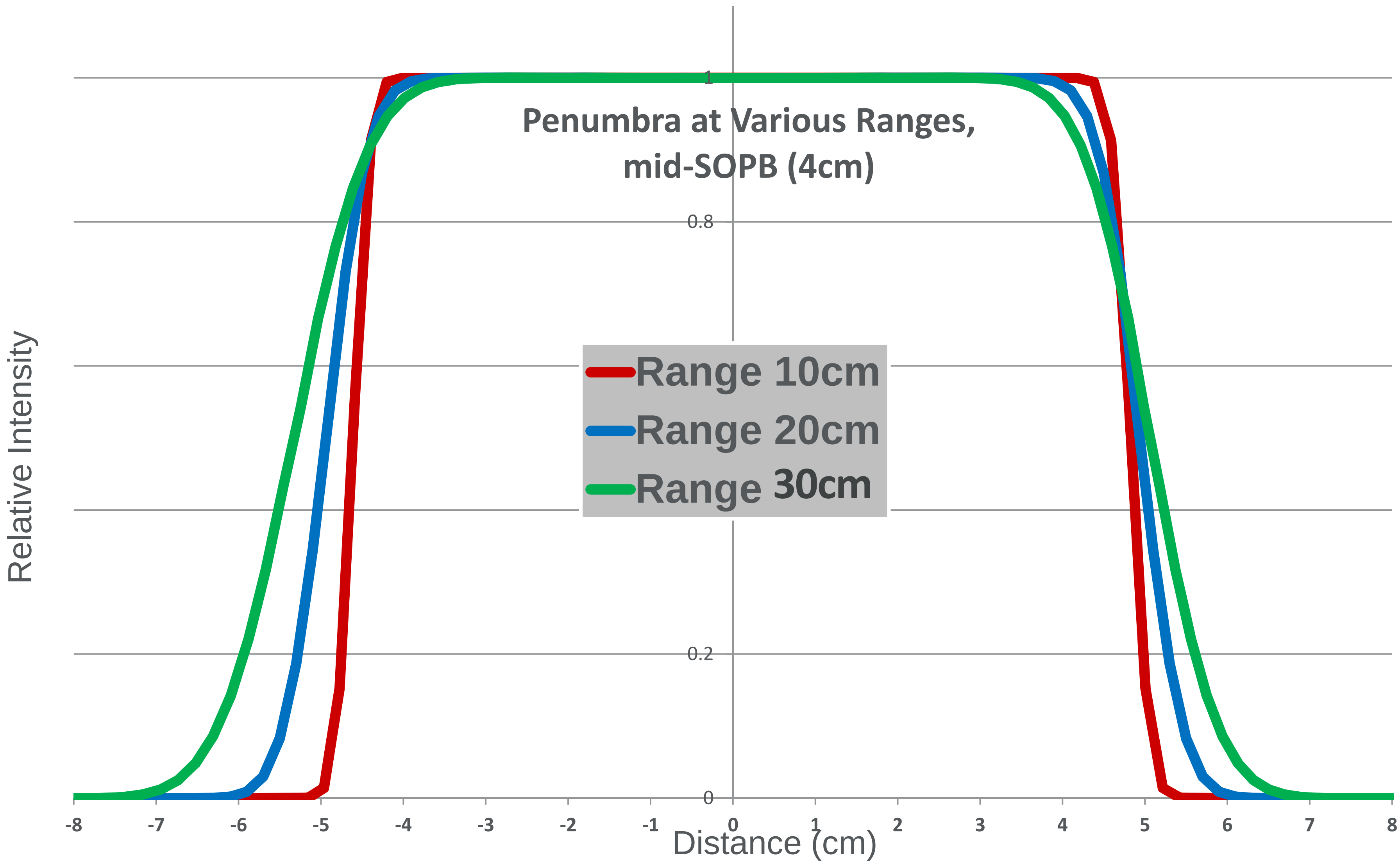
Brass Aperture mounted in Treatment Snout



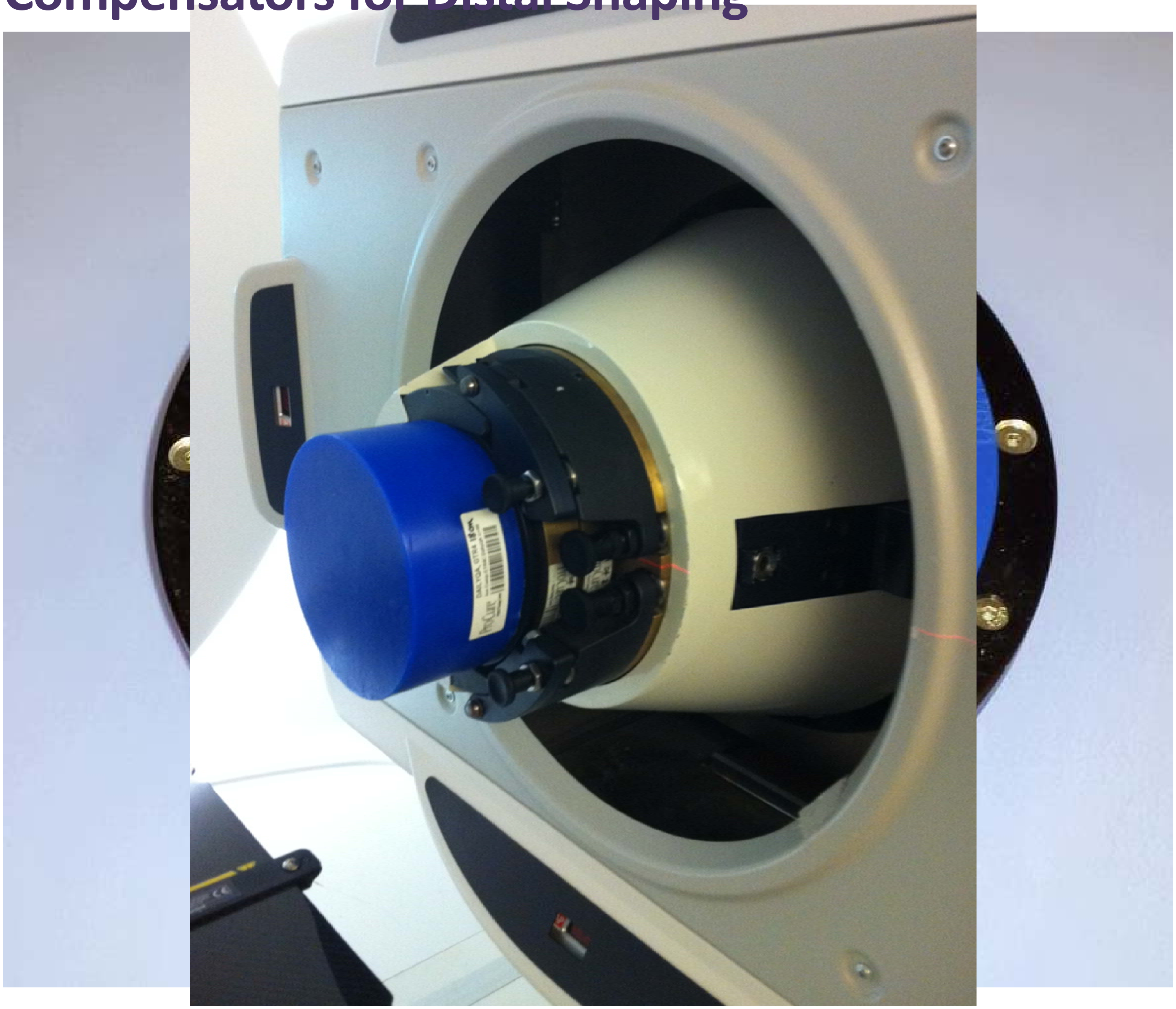
Penumbra at Various Air Gaps



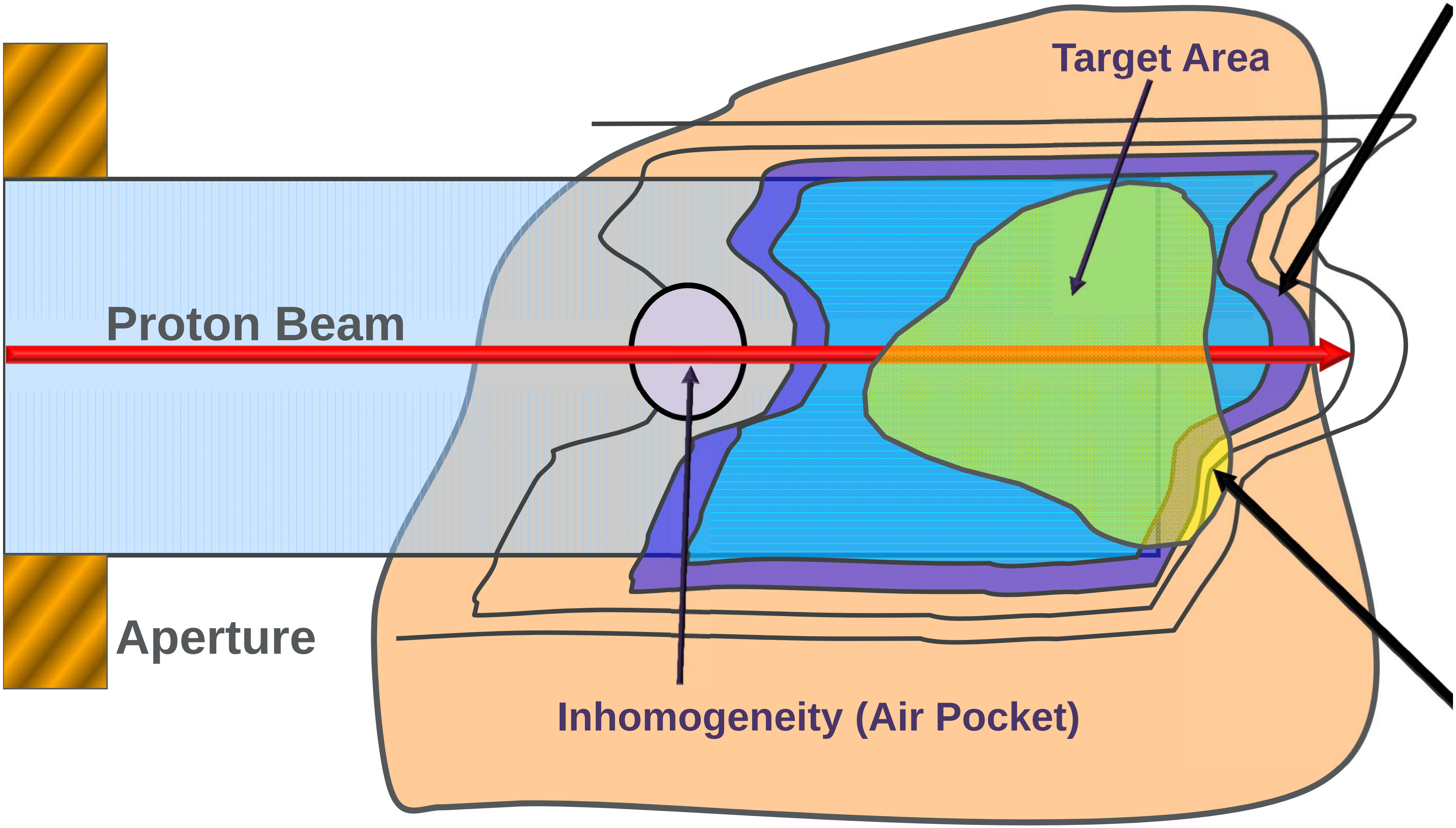
Penumbra as Mid SOBP at various ranges



Compensators for Distal Shaping

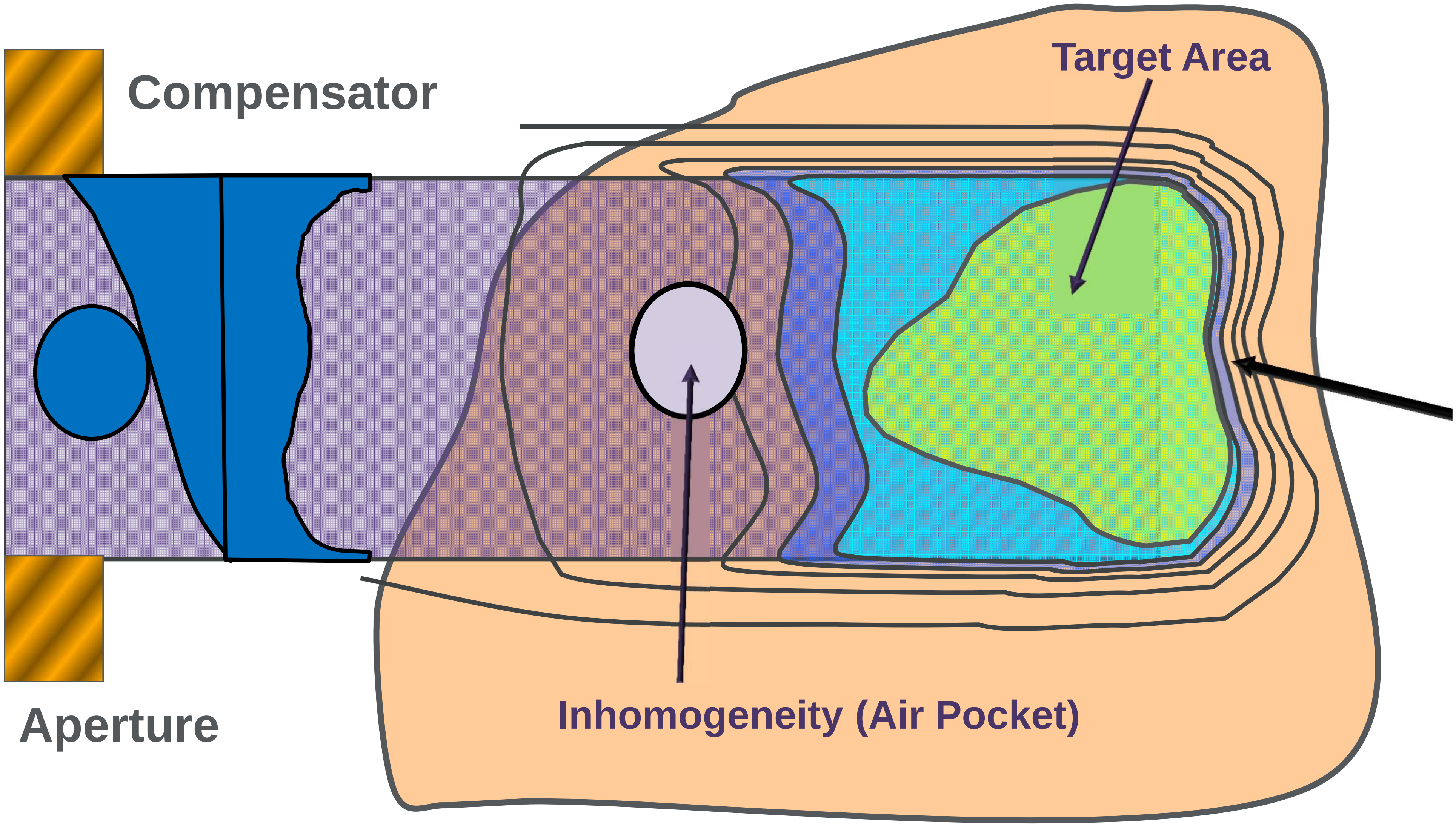


No Compensator

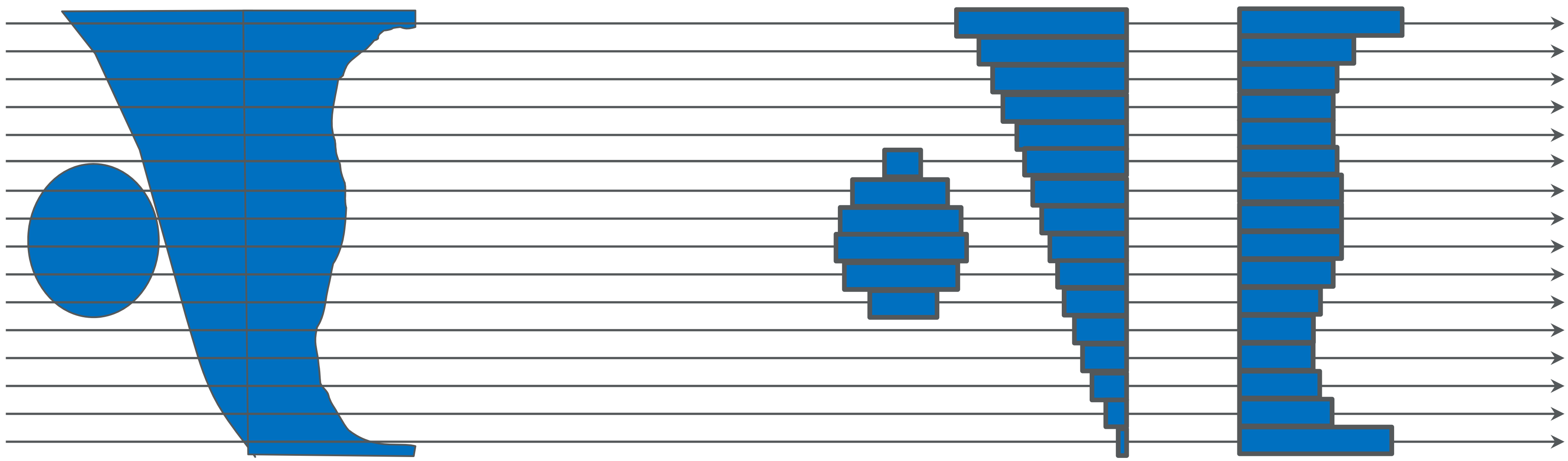


Northwestern Medicine®
Chicago Proton Center

With Compensator



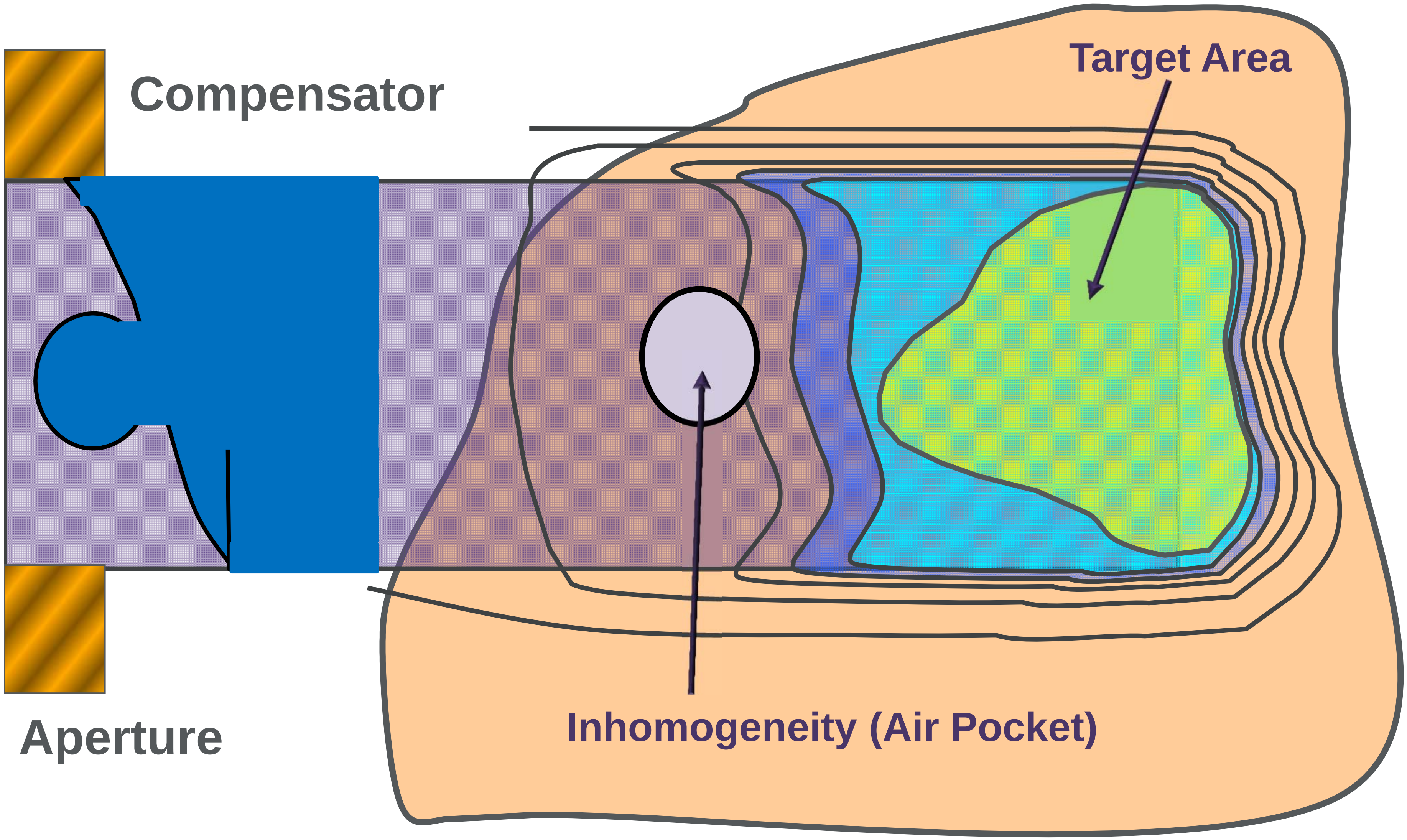
Design of the compensator



Northwestern Medicine®
Chicago Proton Center

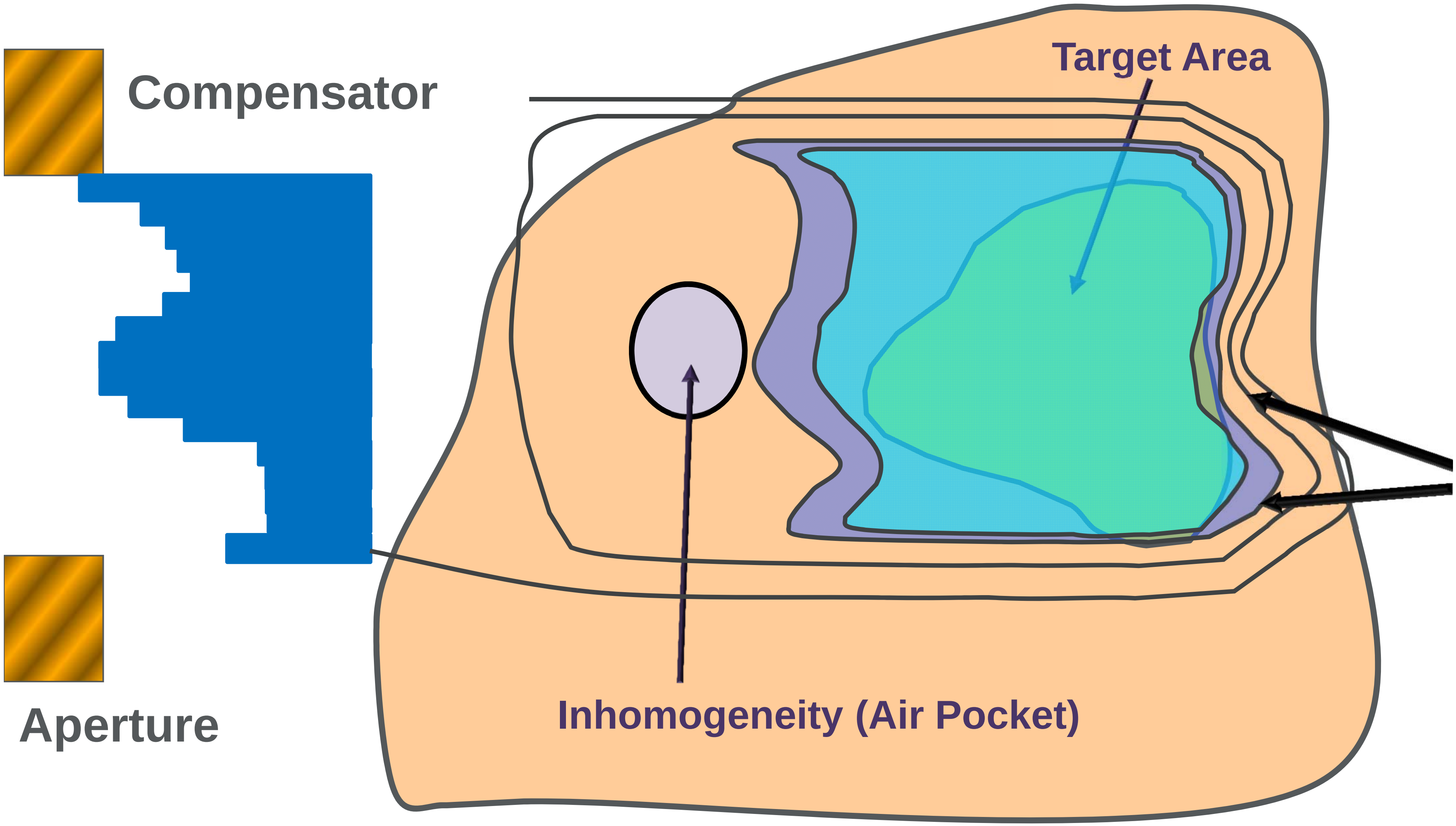
Design of the compensator

With Discrete Compensator

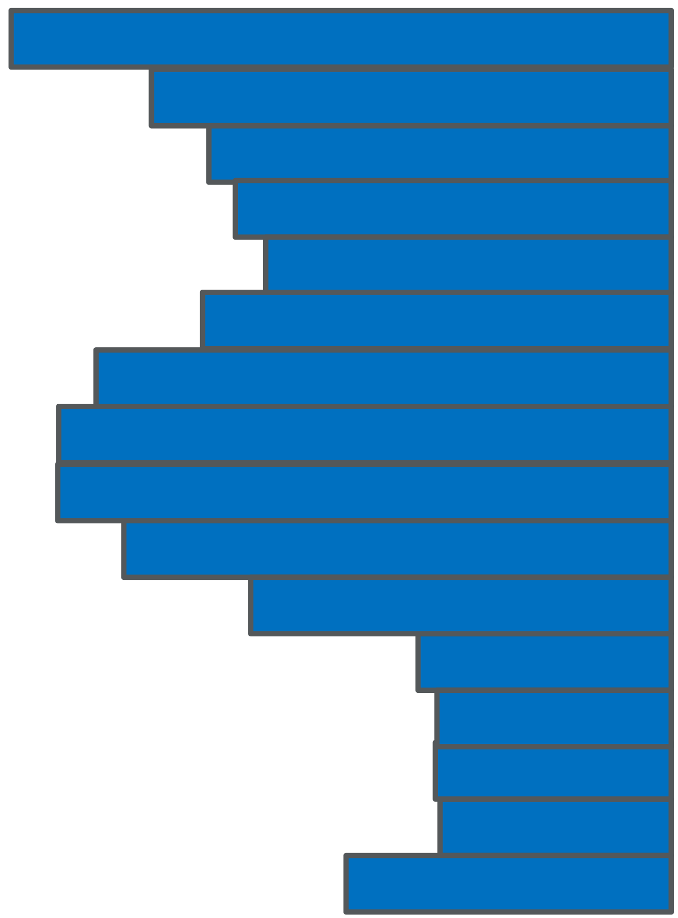


Northwestern Medicine®
Chicago Proton Center

With Discrete Compensator



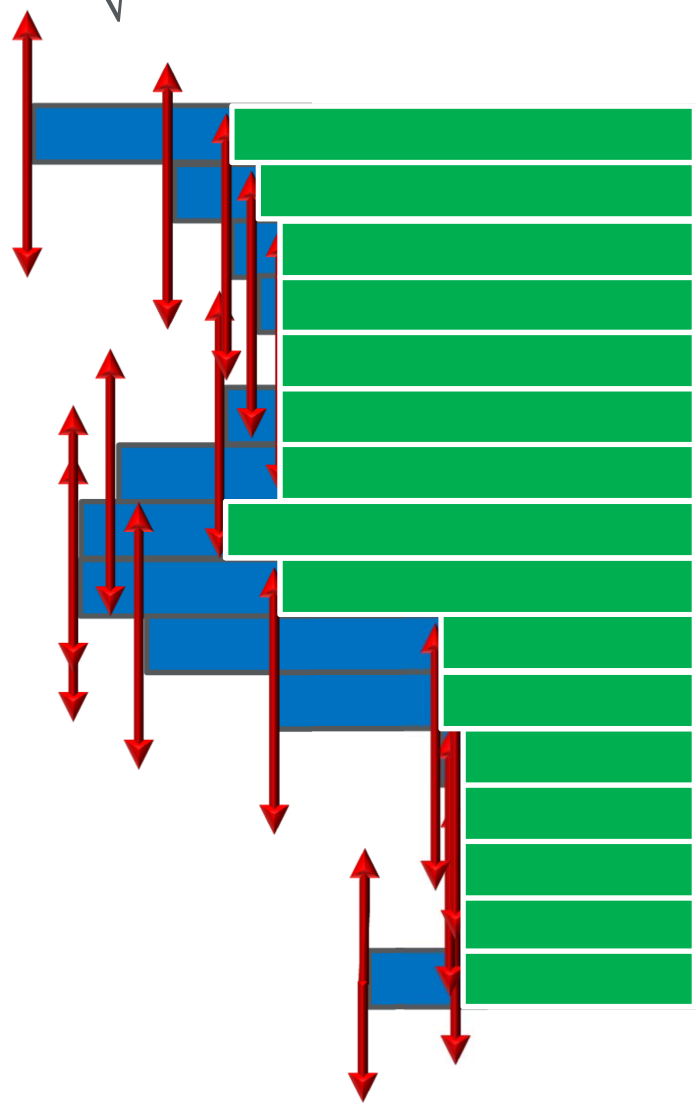
Smearing



Northwestern Medicine®
Chicago Proton Center

Smearing

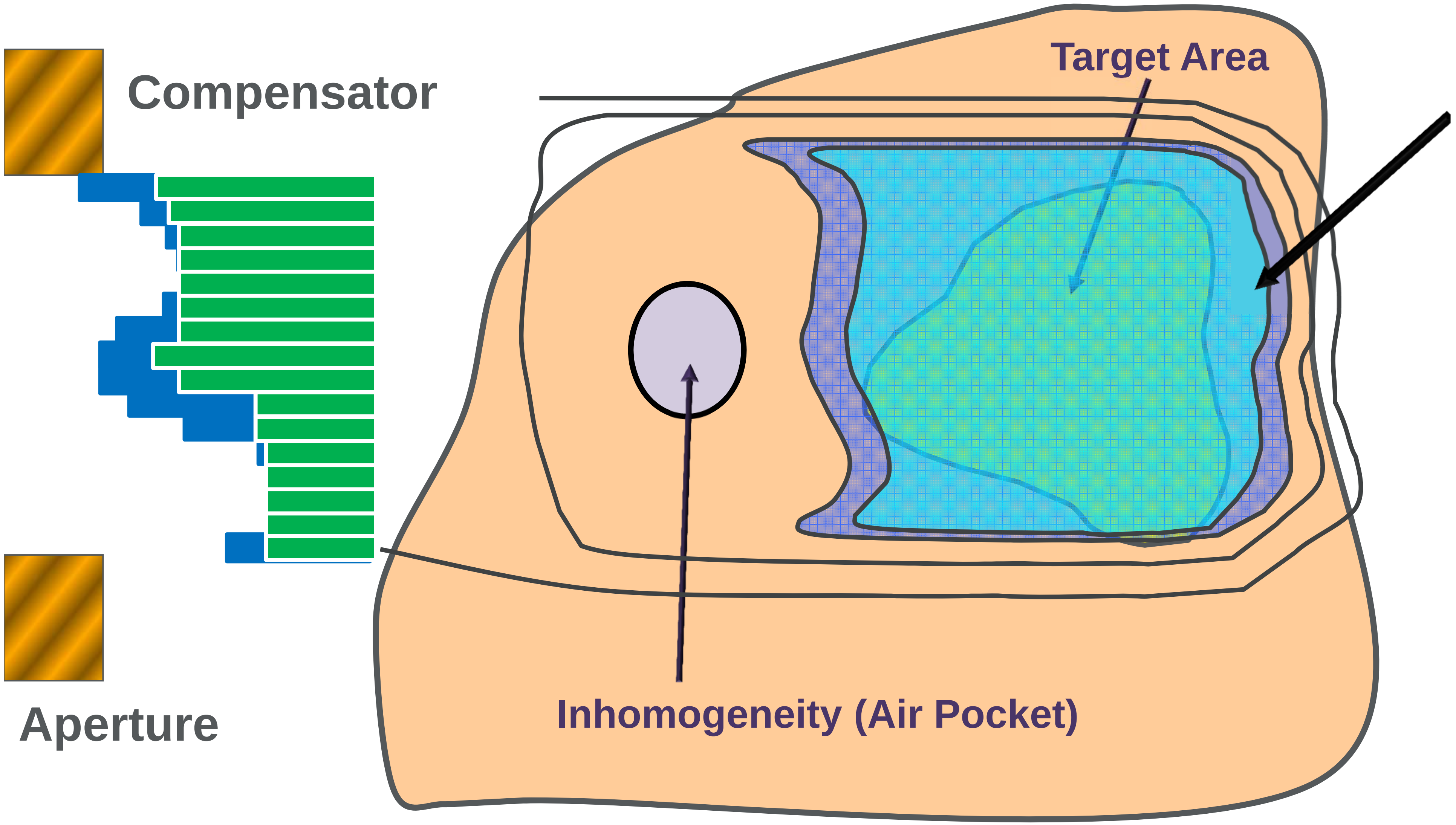
$$\text{Smearing Radius}^* = \sqrt{(\text{Set up Margin})^2 + (\text{Int Motion})^2 + (0.03 * \text{Depth})^2}$$



Northwestern Medicine
Chicago Proton Center

* Moyers, et.al I.J. Rad Onc Bio Phy, 2001

With Discrete Compensator



Smearing

- Sacrificing distal conformity to ensure you have enough range (and modulation) to cover the target
- Accounts for the fact that treatment path lengths may be different than planned path lengths due to set-up errors and internal motion.
- Can easily be built into compensator design
- Not directly accounted for in PBS

Question 1

Which statement is true regarding the smearing radius in compensator based proton therapy?:

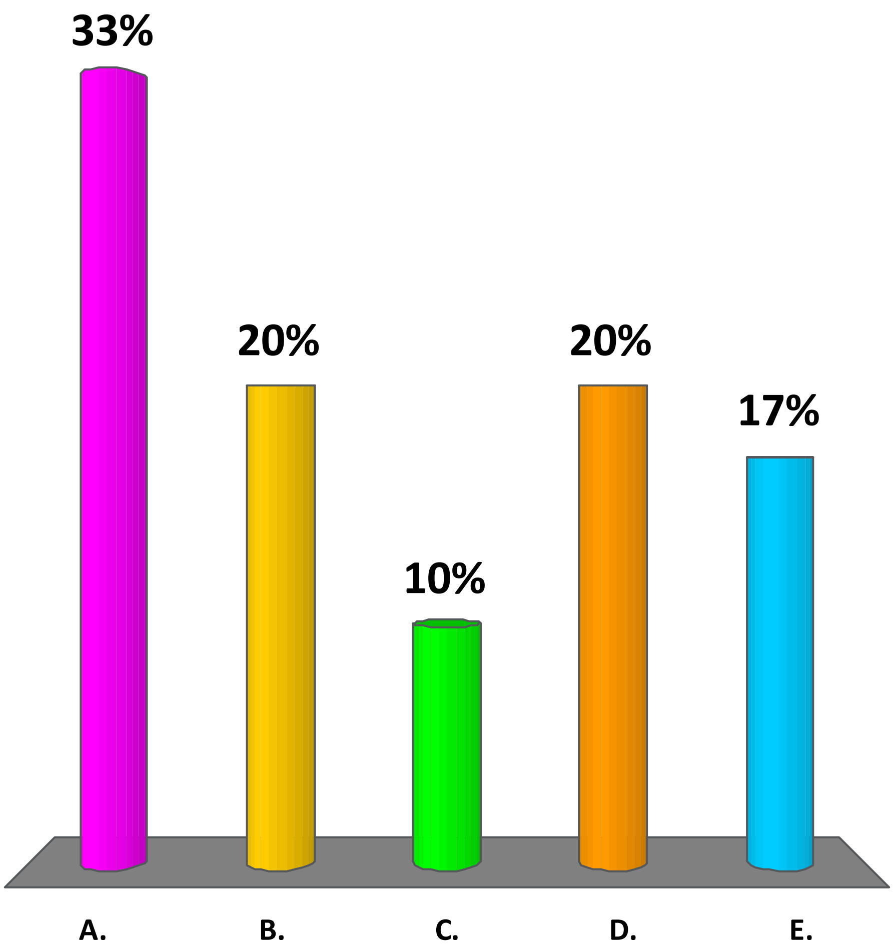
A. Smearing helps to increase dose conformity to the target.

B. Smearing decreases range uncertainty

C. Smearing is not necessary is inhomogeneous regions

D. The magnitude of the smearing radius is related to the expected set-up errors , the internal motion and the range of the proton beam

E. Smearing is directly applicable to photon treatments as well



Northwestern Medicine® Chicago Proton Center

Question 1

Which statement is true regarding the smearing radius in compensator based proton therapy?:

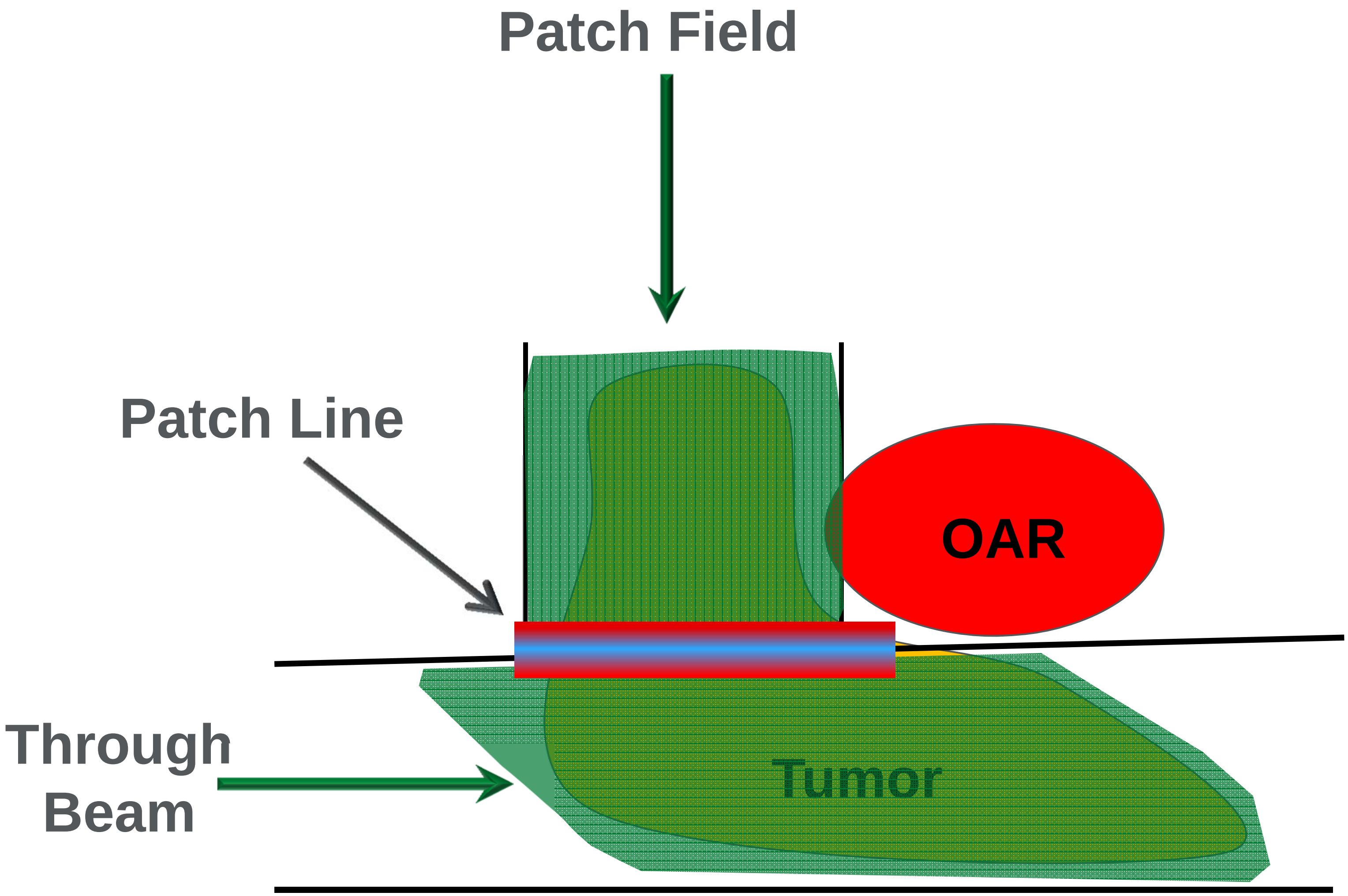
a) Smearing helps to increase dose conformity to the target.
b) Smearing decreases range uncertainty
c) Smearing is not necessary is inhomogeneous regions
d) The magnitude of the smearing radius is related to the expected set-up errors , the internal motion and the range of the proton beam
e) Smearing is directly applicable to photon treatments as well

Correct Answer (d) : The magnitude of the smearing radius is related to the expected set-up errors , the internal motion and the range of the proton beam

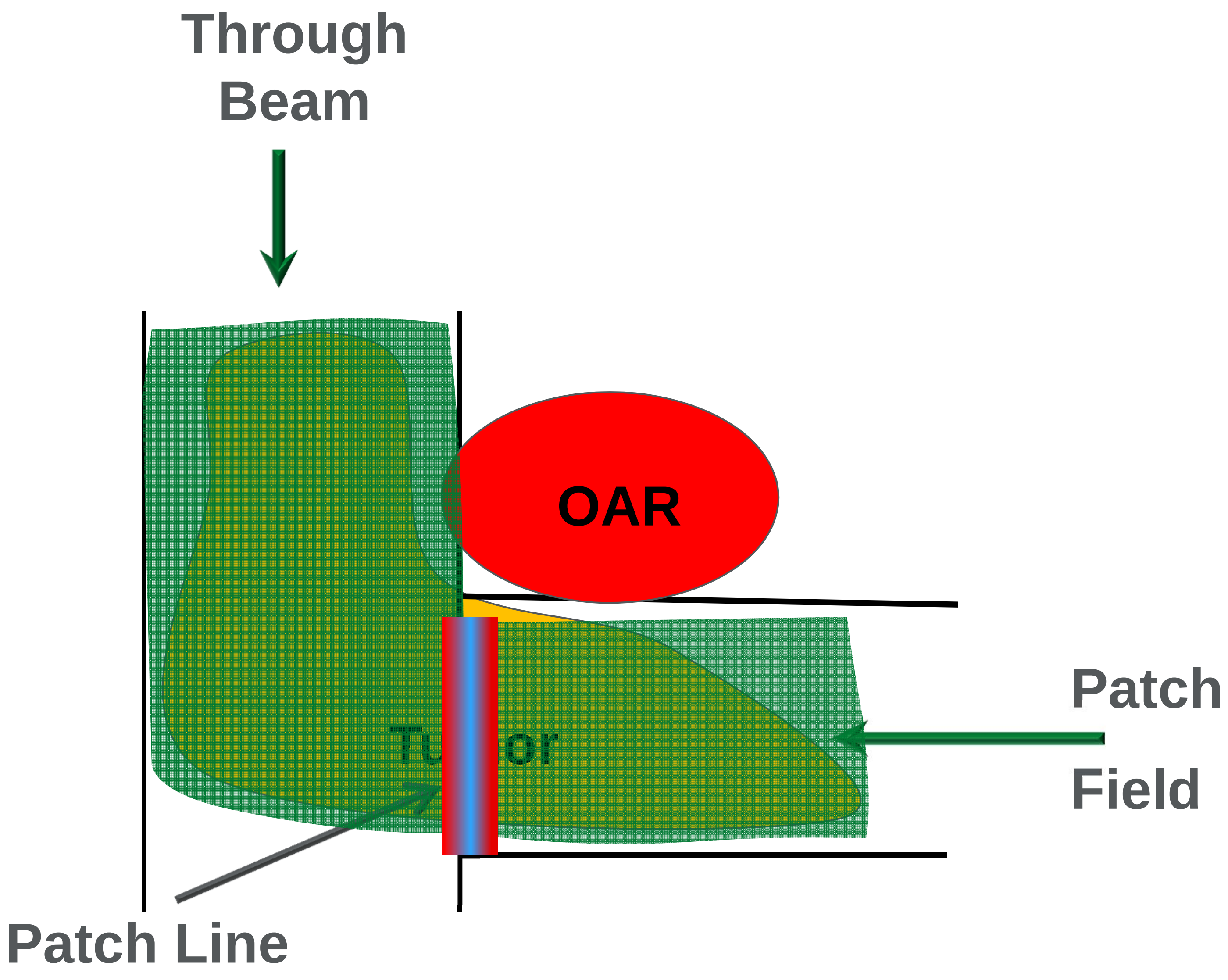
Reference : Moyers, et.al I.J. Rad Onc Bio Phy, 2001
ICRU 78

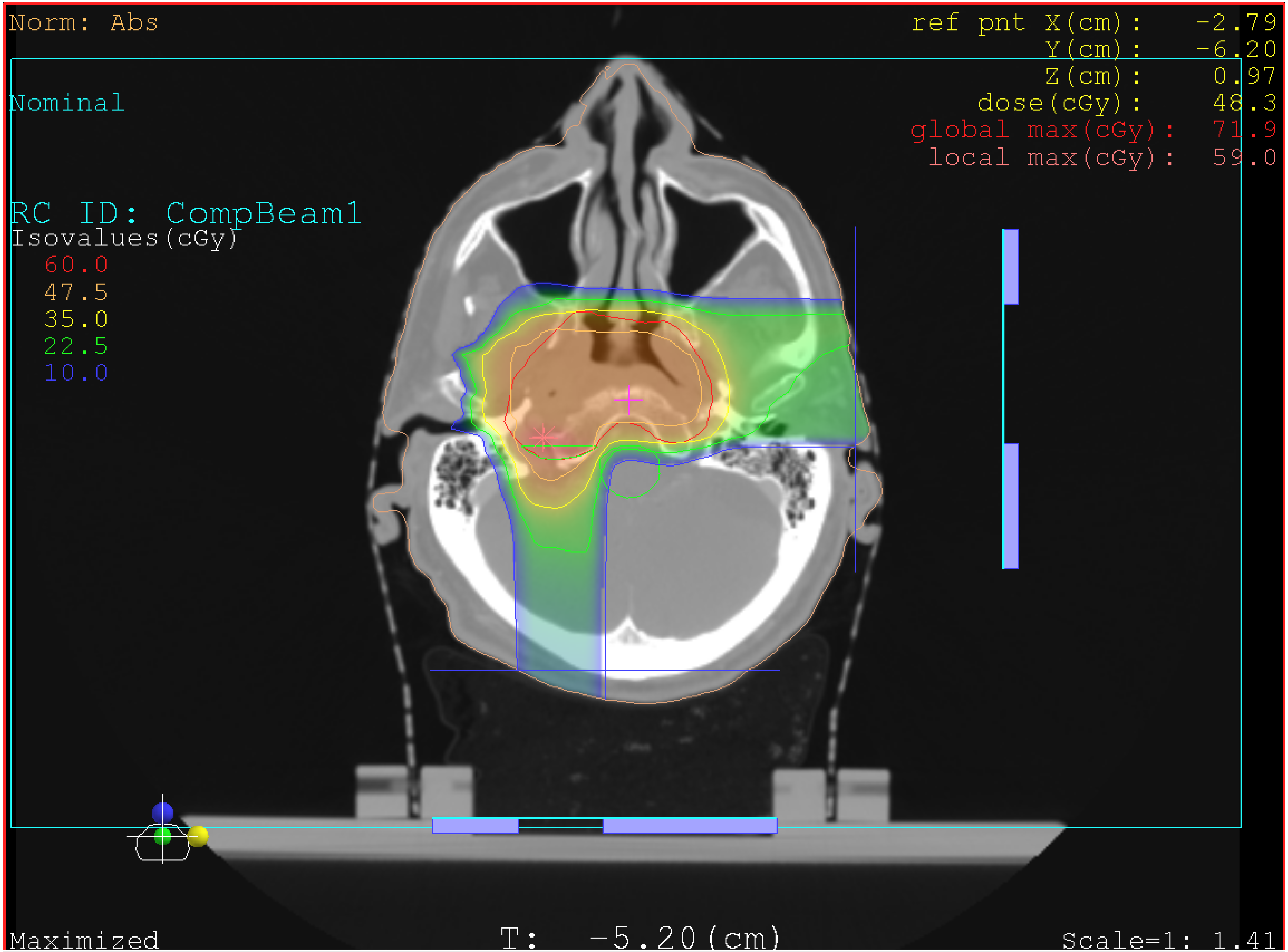
Northwestern Medicine®
Chicago Proton Center

Patch Field Technique



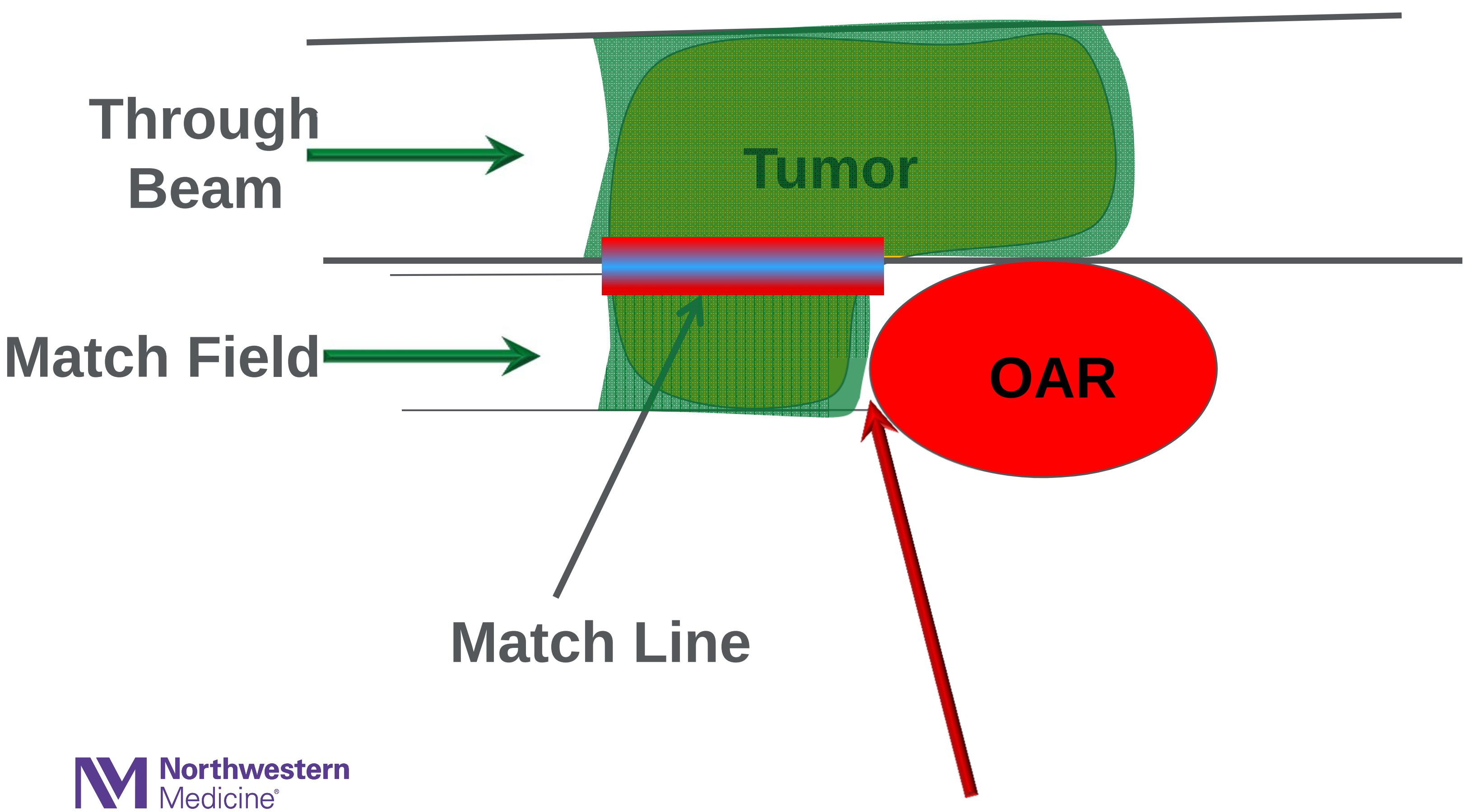
Patch Field Technique : Match Line Change

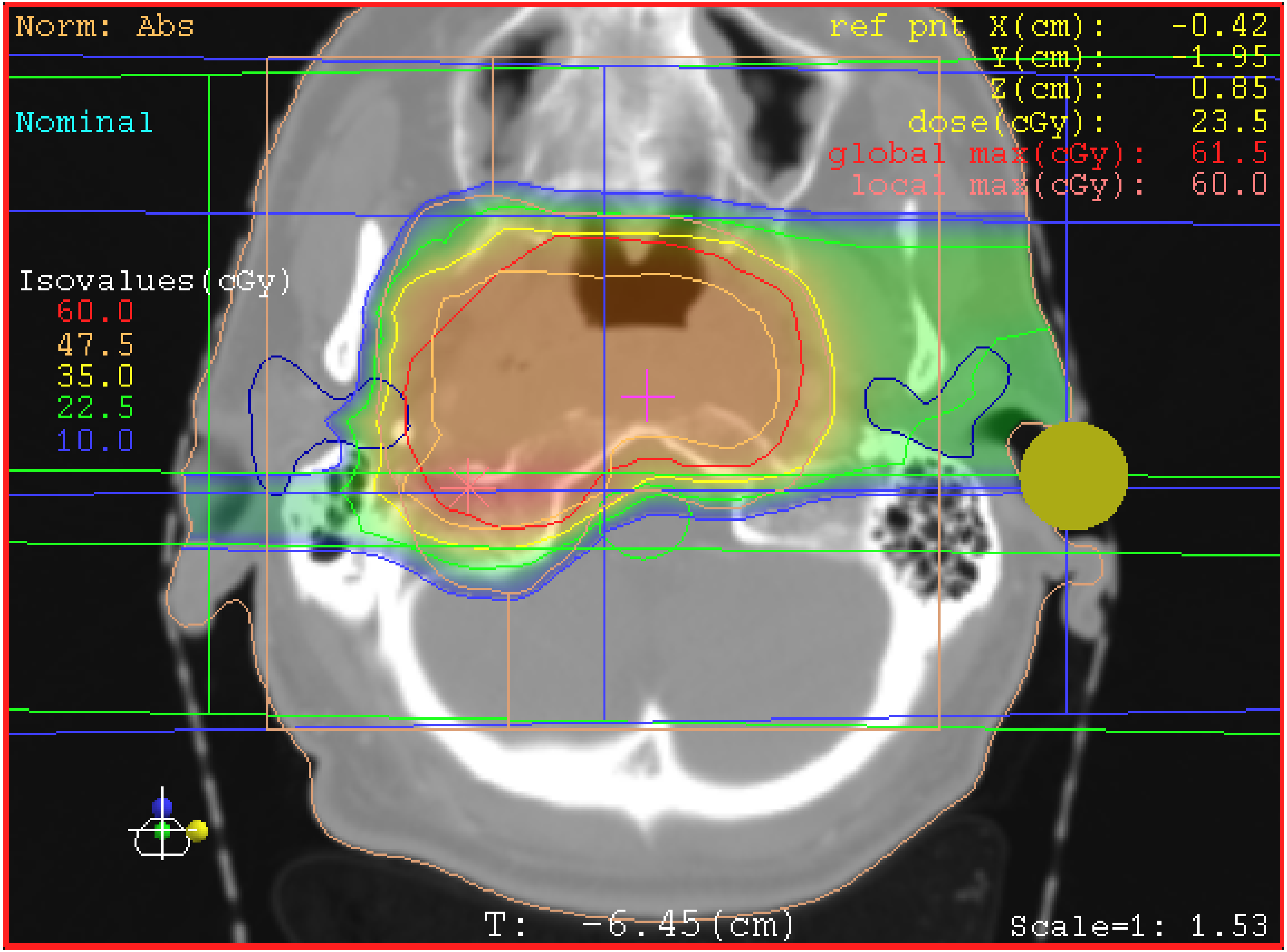




Norm: Abs
Nominal
RC ID: CompBeam1
Isovalues(cGy)
60.0
47.5
35.0
22.5
10.0
ref pnt X(cm): -2.79
Y(cm): -6.20
Z(cm): 0.97
dose(cGy): 48.3
global max(cGy): 71.9
local max(cGy): 59.0
Maximized
T: -5.20(cm)
Scale=1: 1.41

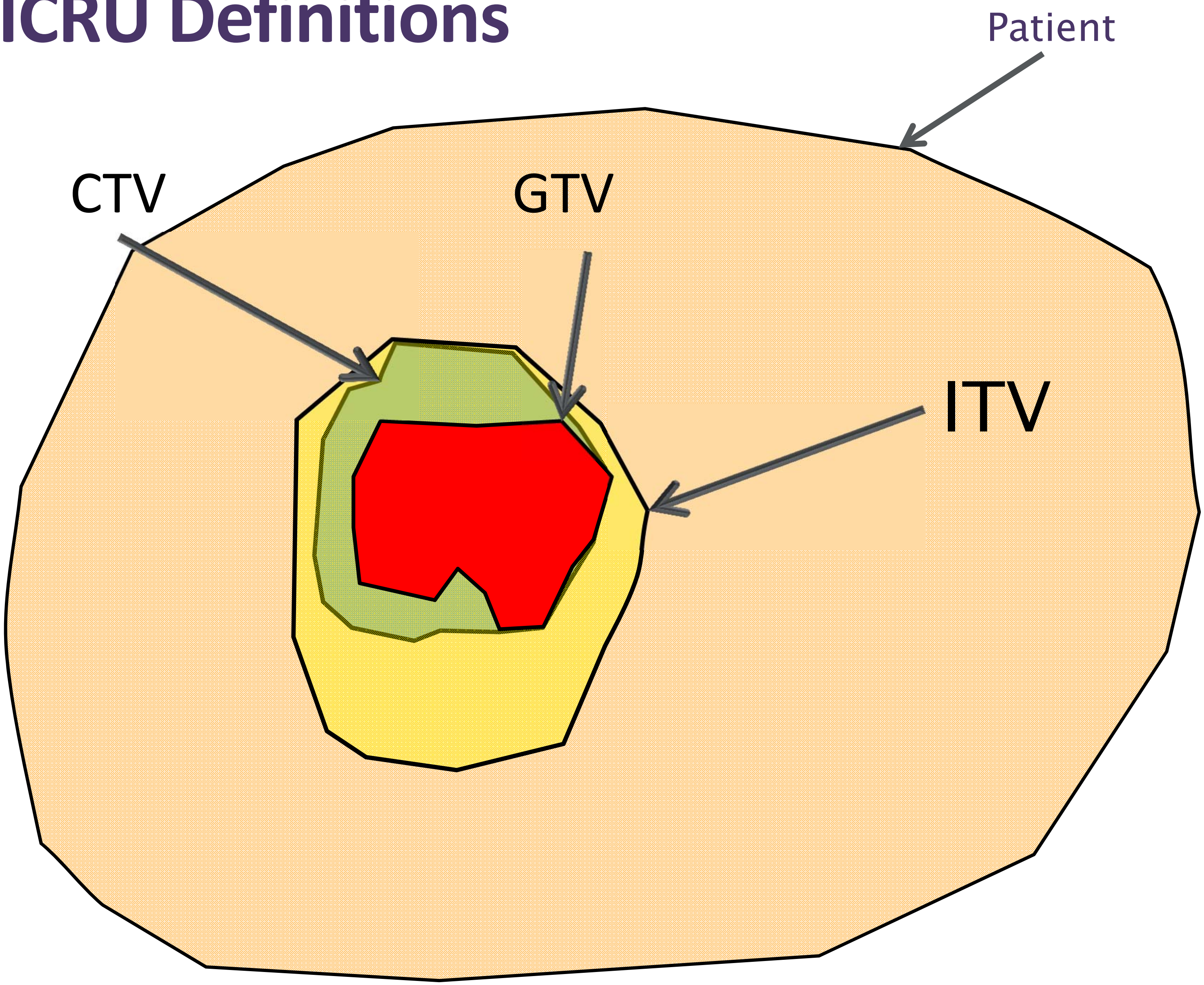
Match Technique



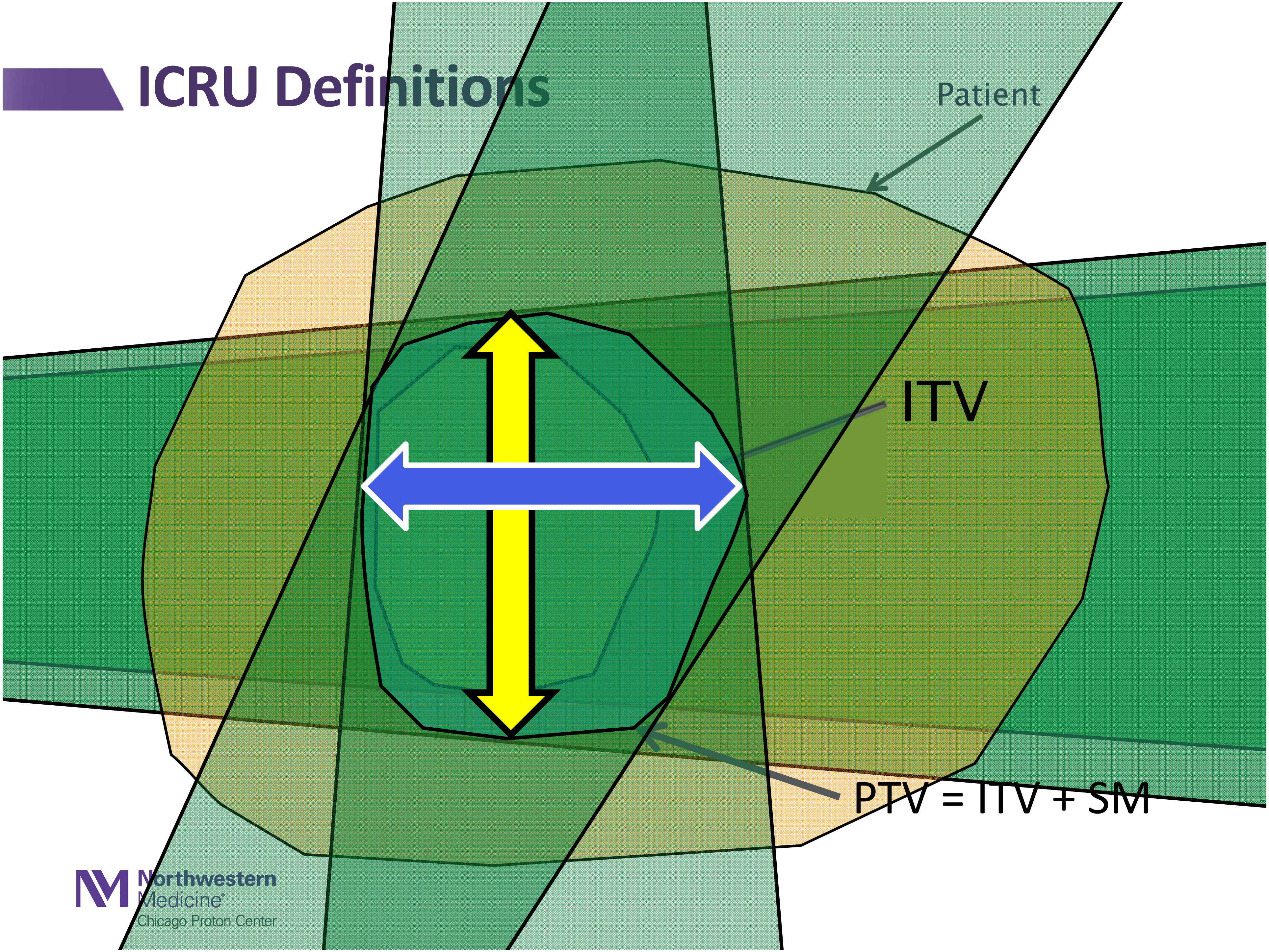


Norm: Abs
Nominal
ref pnt X(cm): -0.42
Y(cm): -1.95
Z(cm): 0.85
dose(cGy): 23.5
global max(cGy): 61.5
local max(cGy): 60.0
Isovalues(cGy)
60.0
47.5
35.0
22.5
10.0
T: -6.45(cm)
Scale=1: 1.53

ICRU Definitions

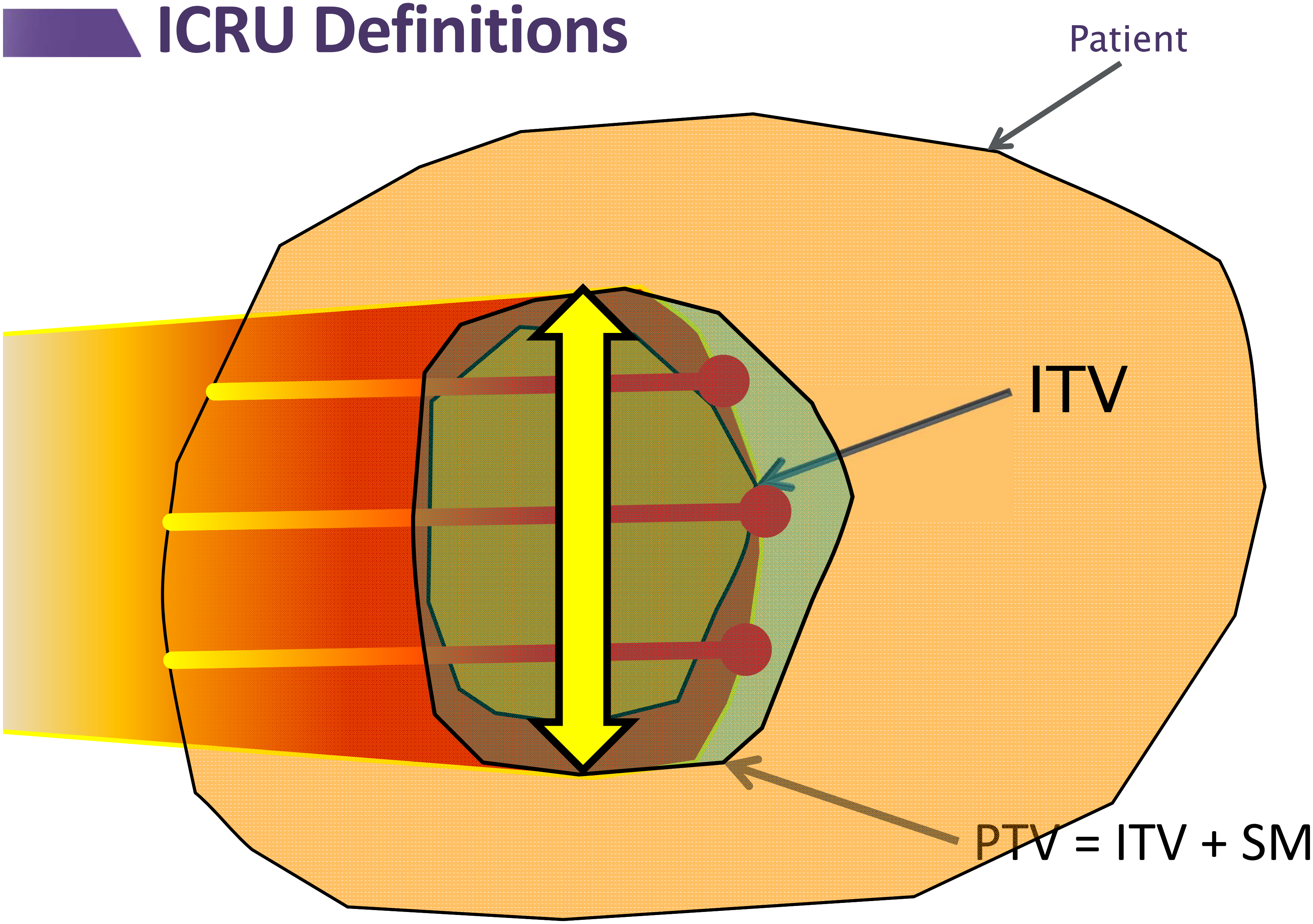


ICRU Definitions



Northwestern Medicine®
Chicago Proton Center

ICRU Definitions



Protons need no distal Set-up margin?

But…. What about

Range Uncertainties

Where do range uncertainties come from ??

- De

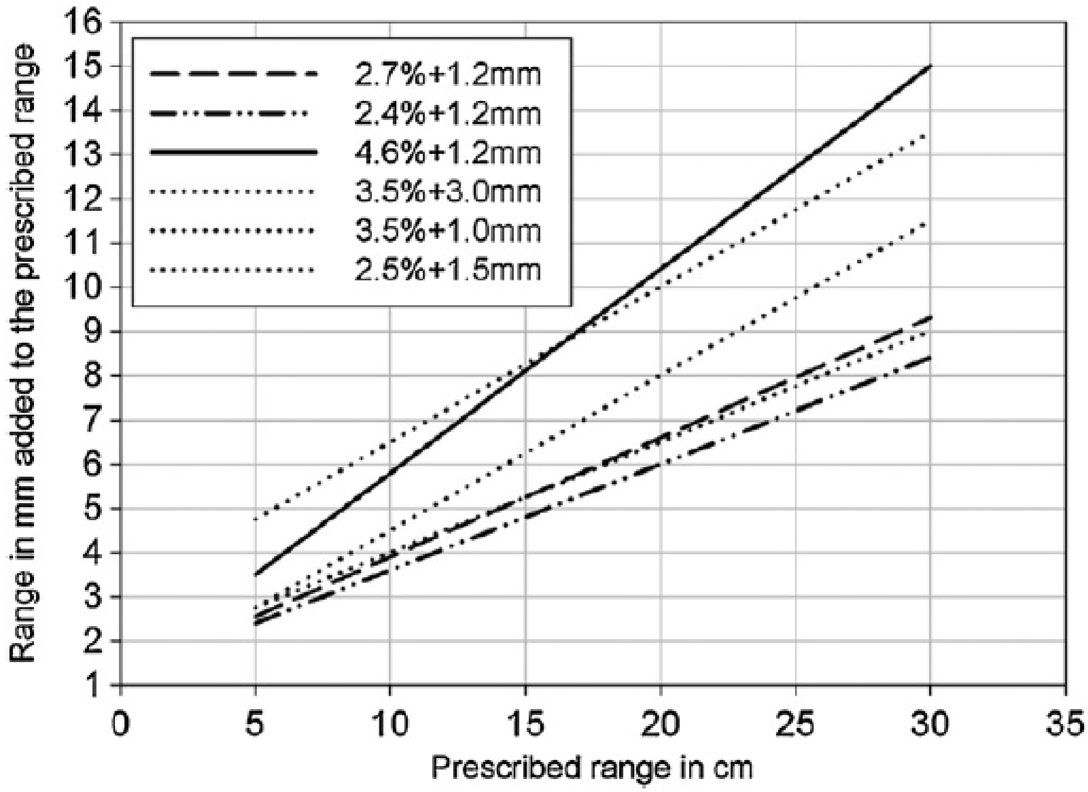


Figure 12. Dotted lines: typically applied range uncertainty margins in proton therapy treatment planning as currently typically applied at the MGH (3.5% + 1 mm), the MD Anderson Proton Therapy Center in Houston (3.5% + 3 mm), the Loma Linda University Medical Center (3.5% + 3 mm), the Roberts Proton Therapy Center at the University of Pennsylvania (3.5% + 3 mm) and the University of Florida Proton Therapy Institute (2.5% + 1.5 mm). Note that these centers may apply bigger margins in specific treatment scenarios. Dashed line: estimated uncertainty without the use of Monte Carlo dose calculation. Solid line: estimated uncertainty for complex geometries without the use of Monte Carlo dose calculation. Dashed-dotted line: estimated uncertainty with the use of Monte Carlo dose calculation.

Nortl
Medi
Chicago Proton Center

Paganetti, Phys. Med Biol (57), 2012

Moyers : Ion Stopping Powers and CT Numbers

Table 7. Summary of estimated uncertainties in treatment planning due to CT numbers and stopping powers

Cause	Uncertainty Before Mitigation	Mitigation	Uncertainty After Mitigation	Possible Future Uncertainty
Scanner calibration for standard conditions	±0.3% day-to-day	Patient-specific scaling	±0.0%	±0.0%
kVp, filter, and FOV selection	±2.0% PMMA, PC > ± 2.0% bone	Use only calibrated conditions	±0.0%	±0.0%
Volume and configuration scanned	±2.5%	Patient-specific scaling	±0.0%	±0.0%
Position in scan	±1.5% water ±2.5% tissue > ± 3.0% bone	—	±1.5% water* ±2.5% tissue > ± 3.0% bone*	±0.5% water^{DE*} ±0.8% tissue^{DE} > ± 1.0% bone^{DE*}
Metal implants	100%	z ≤ 22 – MVXCT z > 22 - substitution	±5.0% metal*	±5.0% metal*
Stopping power of water	±1.0%	—	±1.0%	±0.5%
RLSP of tissues and devices	±0.0 to 3.0%	Contour and substitute	±1.0%	±1.0%
WEQ *vs*. RLSP (soft tissues only)	±1.6%	—	±1.6	±1.6
Energy dependence of RLSP for low Z	±1.2%	—	±1.2	±0.5^{MC}
Total (soft tissues only)	—	—	±3.5	±2.2

Abbreviations: DE, dual-energy CT; MC, Monte Carlo calculations.
*Not considered in total.

Northwestern Medicine®
Chicago Proton Center

Moyers, Medical Dosimetry(35), 2010

Yang : Comprehensive analysis of proton range uncertainties related to patient stopping power ratio estimation using the stoichiometric calibration

Table 8. Estimates of uncertainties (1σ) in patient SPR estimation in current clinical practice.

	Uncertainties in SPR estimation (1σ)		
Uncertainty source	Lung (%)	Soft (%)	Bone (%)
Uncertainties in patient CT imaging	3.3	0.6	1.5
Uncertainties in the parameterized stoichiometric formula to calculate theoretical CT numbers	3.8	0.8	0.5
Uncertainties due to deviation of actual human body tissue from ICRU standard tissue	0.2	1.2	1.6
Uncertainties in mean excitation energies	0.2	0.2	0.6
Uncertainties due to energy dependence of SPR not accounted by dose algorithm	0.2	0.2	0.4
Total (root-sum-square)	5.0	1.6	2.4

Table 9. Median, 90th percentile and 95th percentile of composite range uncertainties and th corresponding percentile when the range uncertainty is 3.5% at different clinical sites.

	Composite range uncertainty (%)			
Tumor site	Median	90th percentile	95th percentile	Percentile when range uncertainty = 3.5%
Prostate	1.3	2.5	3.0	98%
Lung	1.5	2.9	3.4	96%
Head and neck	1.3	2.6	3.0	98%

Yang, Phys. Med. Biol, (57) 2012

Paganetti : Range uncertainties in proton therapy and the role of Monte Carlo simulations

Source of range uncertainty in the patient	Range uncertainty without Monte Carlo	Range uncertainty with Monte Carlo
Independent of dose calculation		
Measurement uncertainty in water for commissioning	± 0.3 mm	± 0.3 mm
Compensator design	± 0.2 mm	± 0.2 mm
Beam reproducibility	± 0.2 mm	± 0.2 mm
Patient setup	± 0.7 mm	± 0.7 mm
Dose calculation		
Biology (always positive) ^	$+\sim 0.8\%$	$+\sim 0.8\%$
CT imaging and calibration	$\pm 0.5\%$[a]	$\pm 0.5\%$[a]
CT conversion to tissue (excluding I-values)	$\pm 0.5\%$[b]	$\pm 0.2\%$[g]
CT grid size	$\pm 0.3\%$[c]	$\pm 0.3\%$[c]
Mean excitation energy (I-values) in tissues	$\pm 1.5\%$[d]	$\pm 1.5\%$[d]
Range degradation; complex inhomogeneities	-0.7%[e]	$\pm 0.1\%$
Range degradation; local lateral inhomogeneities *	$\pm 2.5\%$[f]	$\pm 0.1\%$
Total (excluding *, ^)	$2.7\% + 1.2$ mm	$2.4\% + 1.2$ mm
Total (excluding ^)	$4.6\% + 1.2$ mm	$2.4\% + 1.2$ mm

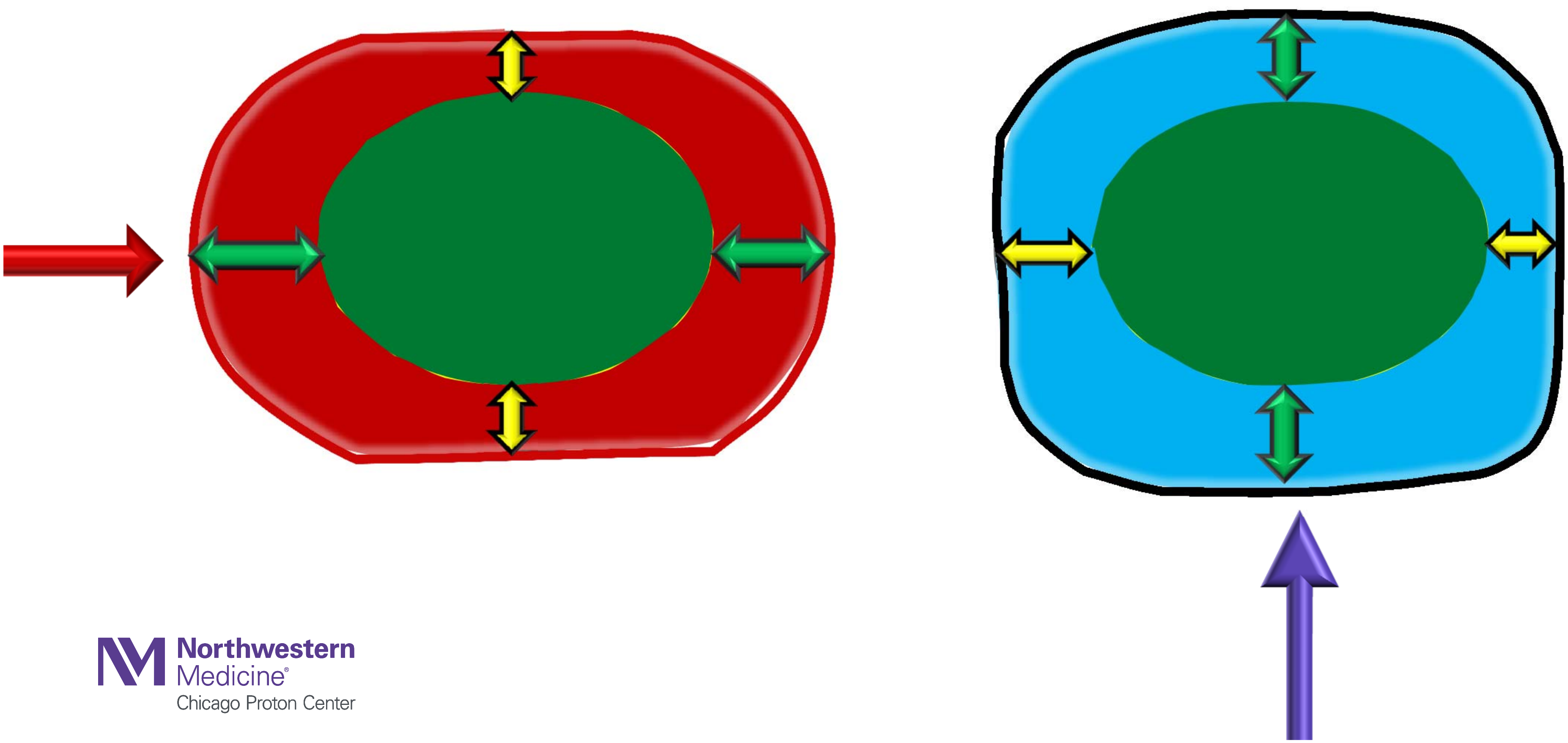
Northwestern Medicine
Chicago Proton Center

Paganetti, Phys. Med Biol (57), 2012

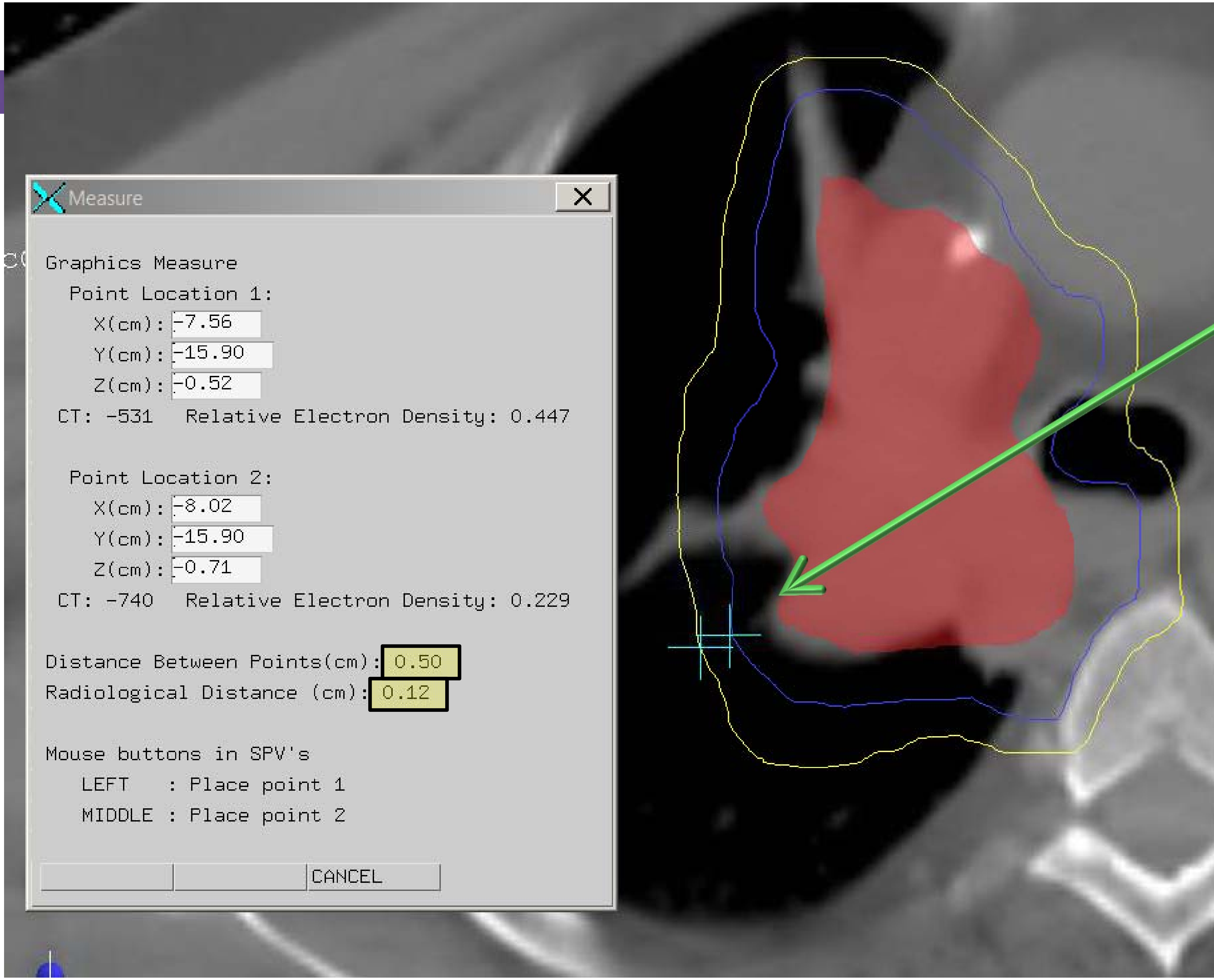
Adding Setup and Range Uncertainty with Protons

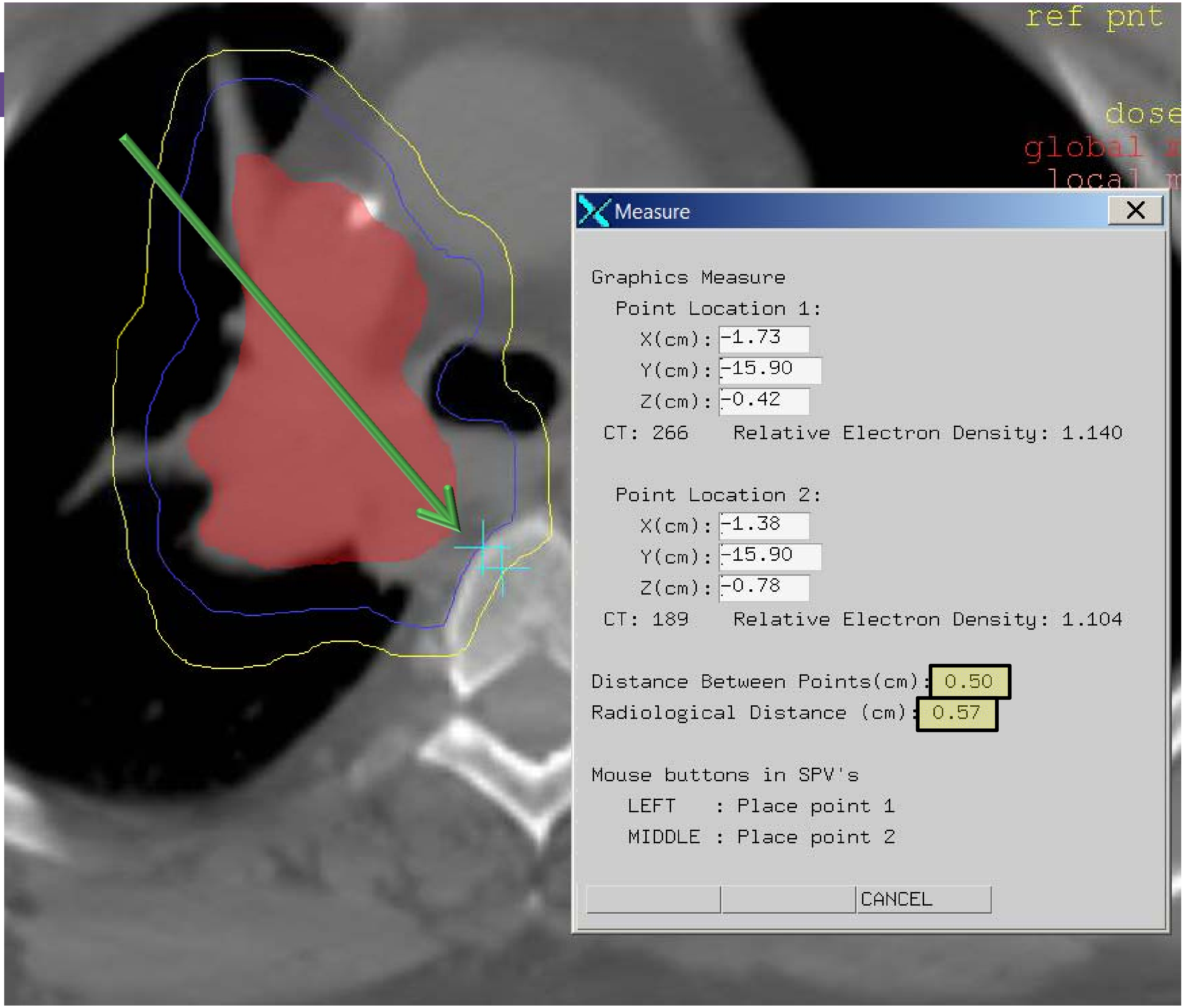
Perpendicular Expansion
Physical Distance
(cm)

Parallel Expansion
Radiobiological Depth
(WET)



Northwestern Medicine®
Chicago Proton Center


Measure
Graphics Measure
Point Location 1:
X(cm): -7.56
Y(cm): -15.90
Z(cm): -0.52
CT: -531 Relative Electron Density: 0.447
Point Location 2:
X(cm): -8.02
Y(cm): -15.90
Z(cm): -0.71
CT: -740 Relative Electron Density: 0.229
Distance Between Points(cm): 0.50
Radiological Distance (cm): 0.12
Mouse buttons in SPV's
LEFT : Place point 1
MIDDLE : Place point 2
CANCEL


ref pnt
dose
Measure
Graphics Measure
Point Location 1:
X(cm): -1.73
Y(cm): -15.90
Z(cm): -0.42
CT: 266 Relative Electron Density: 1.140
Point Location 2:
X(cm): -1.38
Y(cm): -15.90
Z(cm): -0.78
CT: 189 Relative Electron Density: 1.104
Distance Between Points(cm): 0.50
Radiological Distance (cm): 0.57
Mouse buttons in SPV's
LEFT : Place point 1
MIDDLE : Place point 2
CANCEL

Question 2

Which statement is true about range uncertainty of a proton beam?

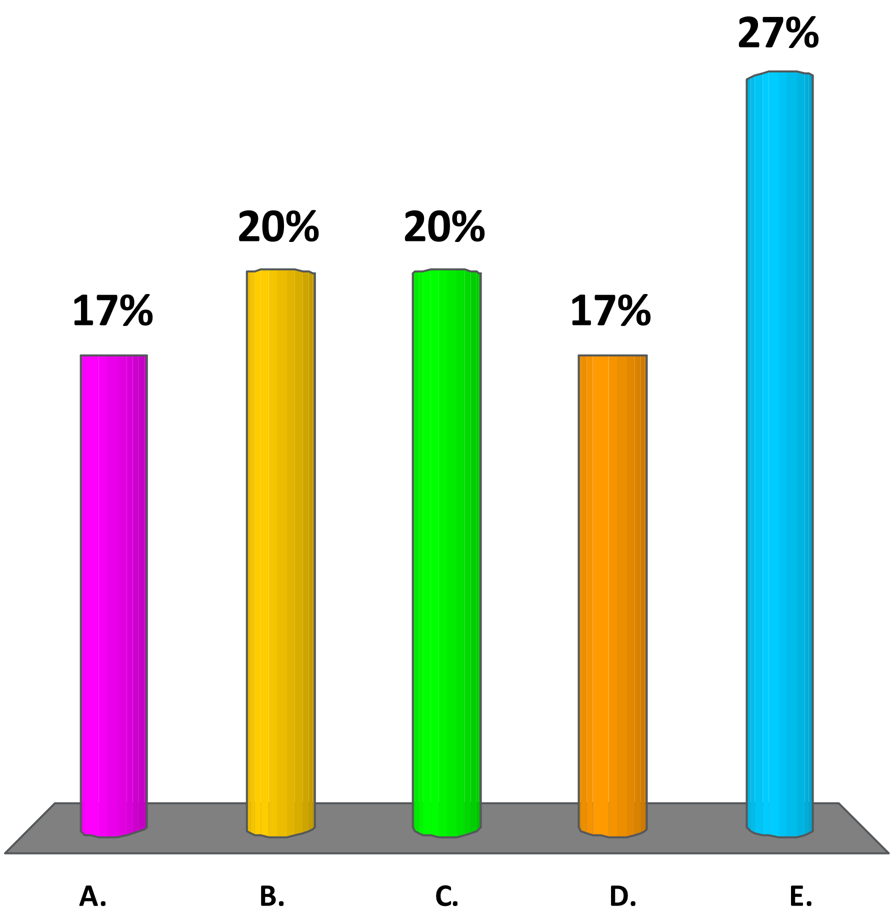
A. Range Uncertainty can not be quantified.

B. Range Uncertainty Is very poorly understood

C. Range Uncertainty can be accounted for by adding a beam specific distal and proximal margins

D. Range Uncertainty will completely eliminate the benefits of decreased integral dose given to the patient by a proton treatment

E. Range Uncertainty will lead to lower tumor control rates for proton patients



Question 2

Which statement is true about range uncertainty of a proton beam?

a) Range Uncertainty can not be quantified.

b) Range Uncertainty Is very poorly understood

c) Range Uncertainty can be accounted for by adding a beam specific distal and proximal margins

d) Range Uncertainty will completely eliminate the benefits of decreased integral dose given to the patient by a proton treatment

e) Range Uncertainty will lead to lower tumor control rates for proton patients

Correct Answer (c) : Range Uncertainty can be accounted for by adding a beam specific distal and proximal margins

References : Moyers MF, et.al. : **Med Dosim. 2010 Autumn;35(3):179-94.**
Yang M, et.al : **Phys Med Biol. 2012 Jul 7;57(13):4095-115.**
Paganetti, H : **Phys Med Biol. 2012 Jun 7;57(11):R99-117.**

Northwestern Medicine® Chicago Proton Center

HU Unit conversions

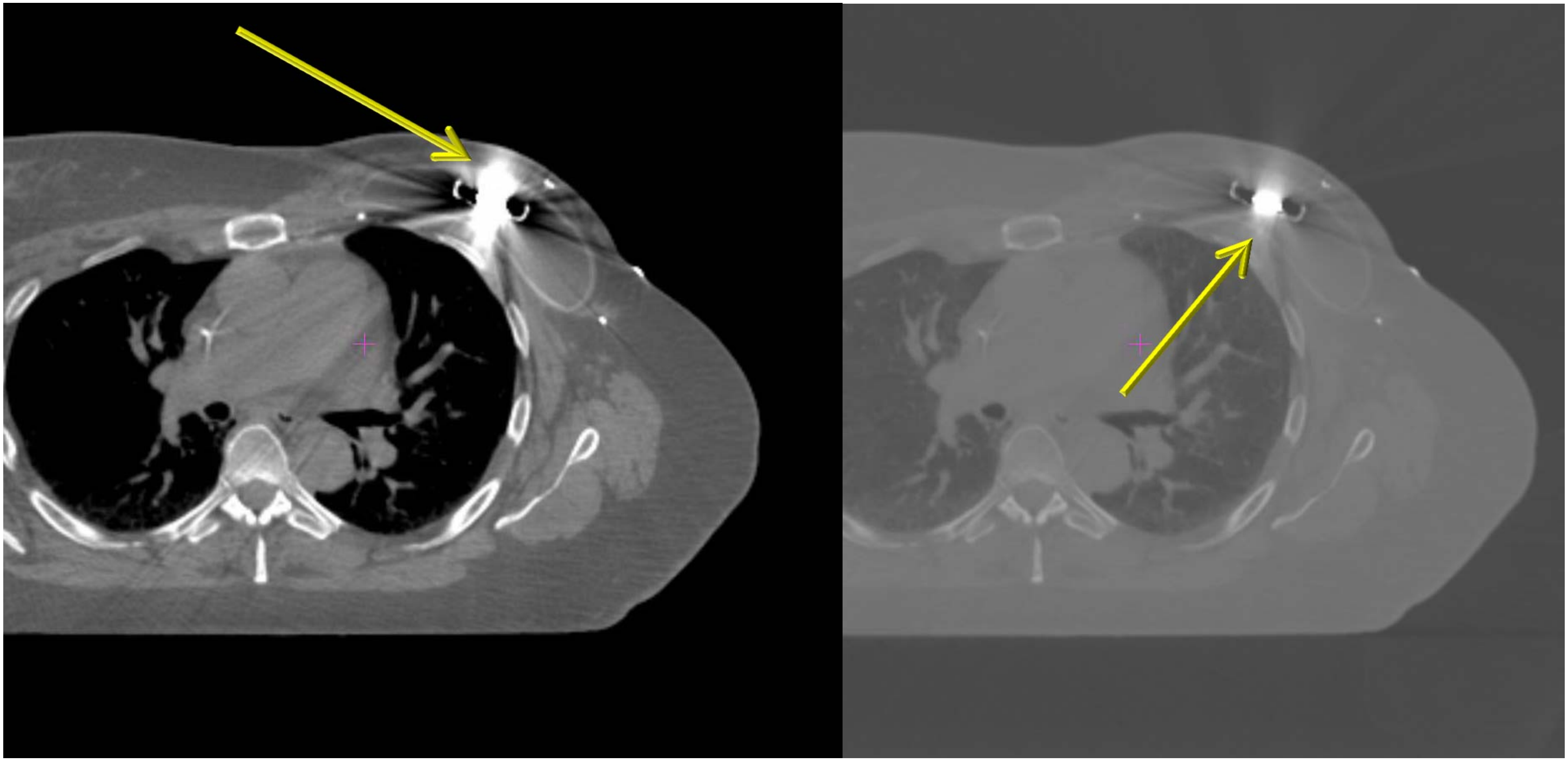
- Conversion from HU to RSP has inherent problems
  - Noise
  - Beam hardening

- Trying to make our CT scanner a spectrometer
  - Two tissues can have same HU but different RSP

- Anything not natural can have large errors.
  - Contrast
  - Fillings
  - Implants

Northwestern Medicine® Chicago Proton Center

Chestwall Expander



Breast Prosthesis

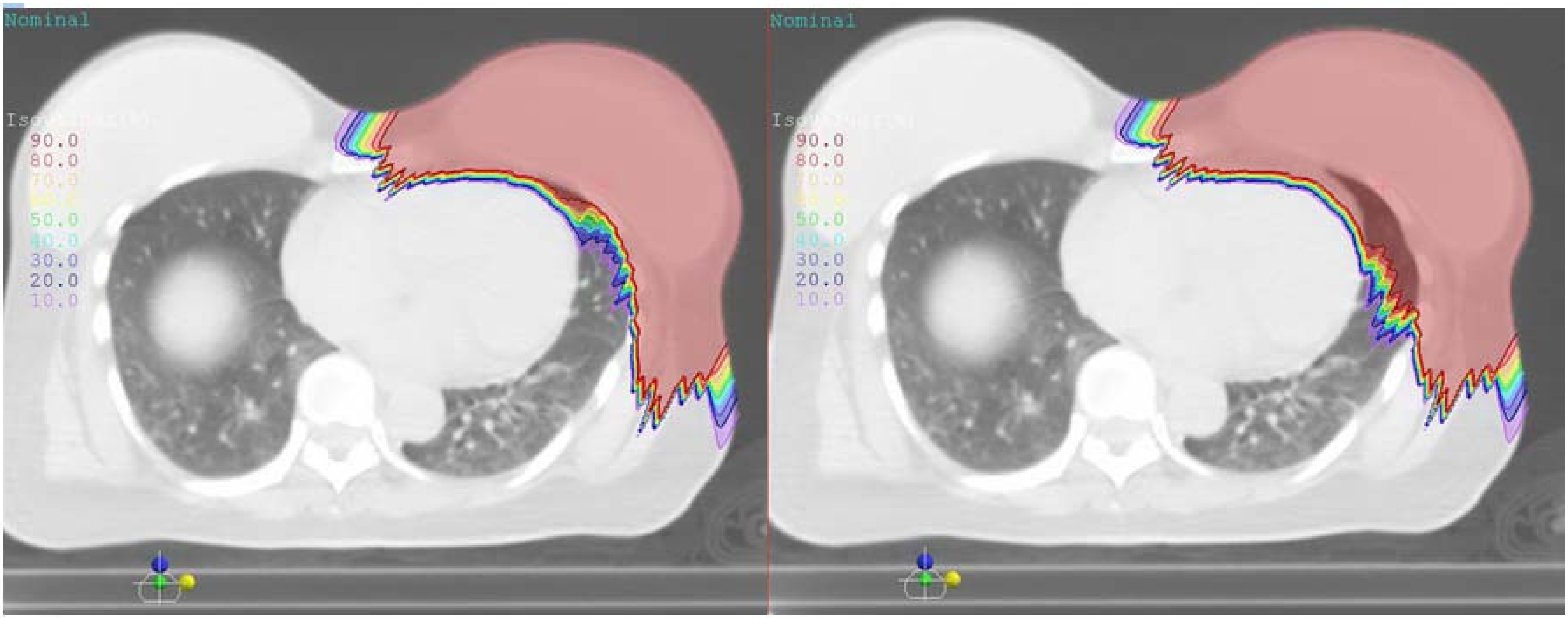


Fig. 3: Treatment plan for patient with silicone breast prosthesis. (a) Planned dose distribution without RLSP reassignment. (b) Delivered dose distribution if planned without proper pRLSP assignment.

Northwestern Medicine®
Chicago Proton Center

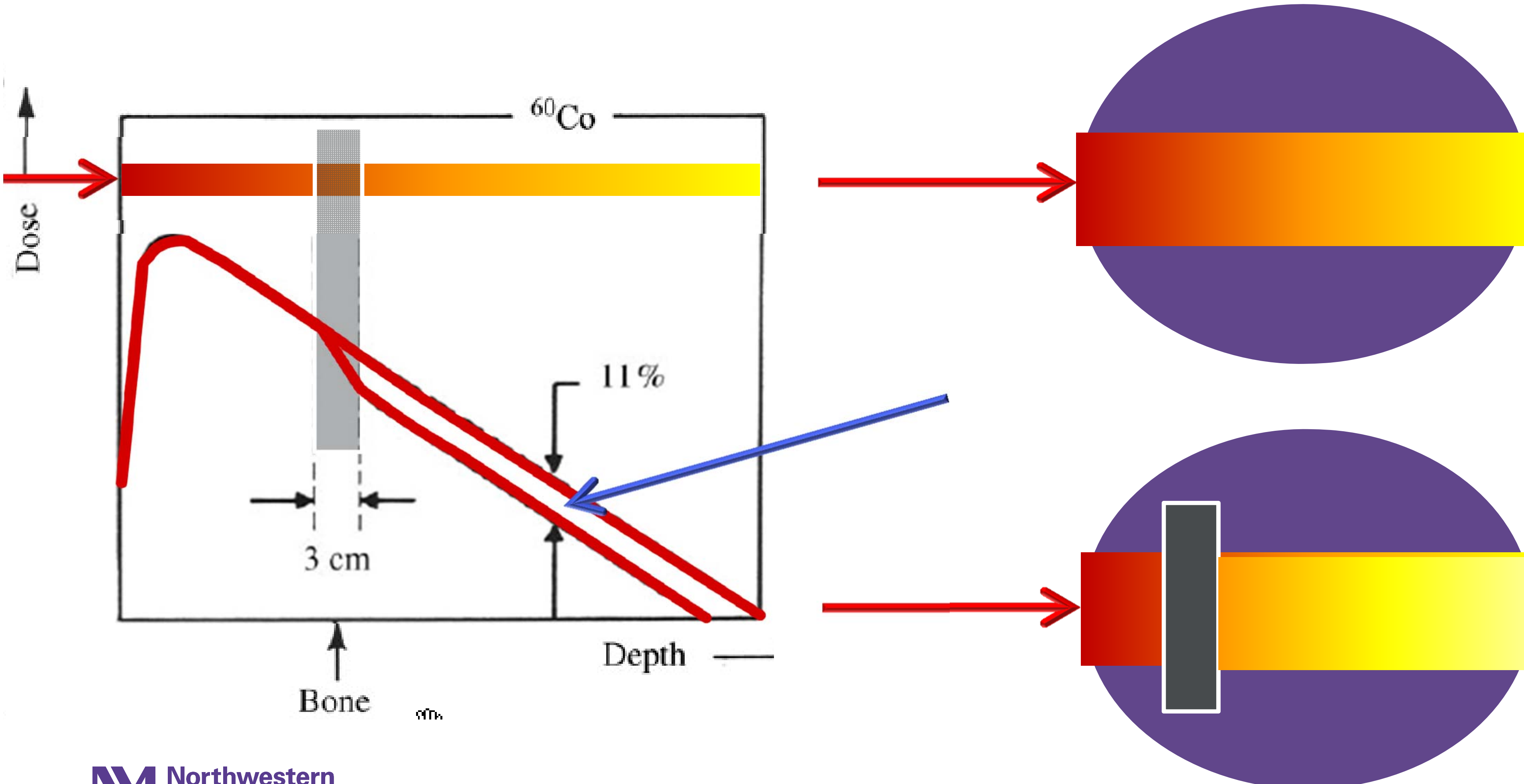
Is there any hope for improvements?

- Dual Energy CT (kV / MVCT)
- Proton activation (PET/SPECT) Tomography
- Prompt Gamma verification
- Proton Radiography
- Proton Tomography

Importance of Image Guidance (IGRT)

- Image Guidance critical to avoid a geometric miss if the target
- For protons, verification of proton path length equivalence is essential.

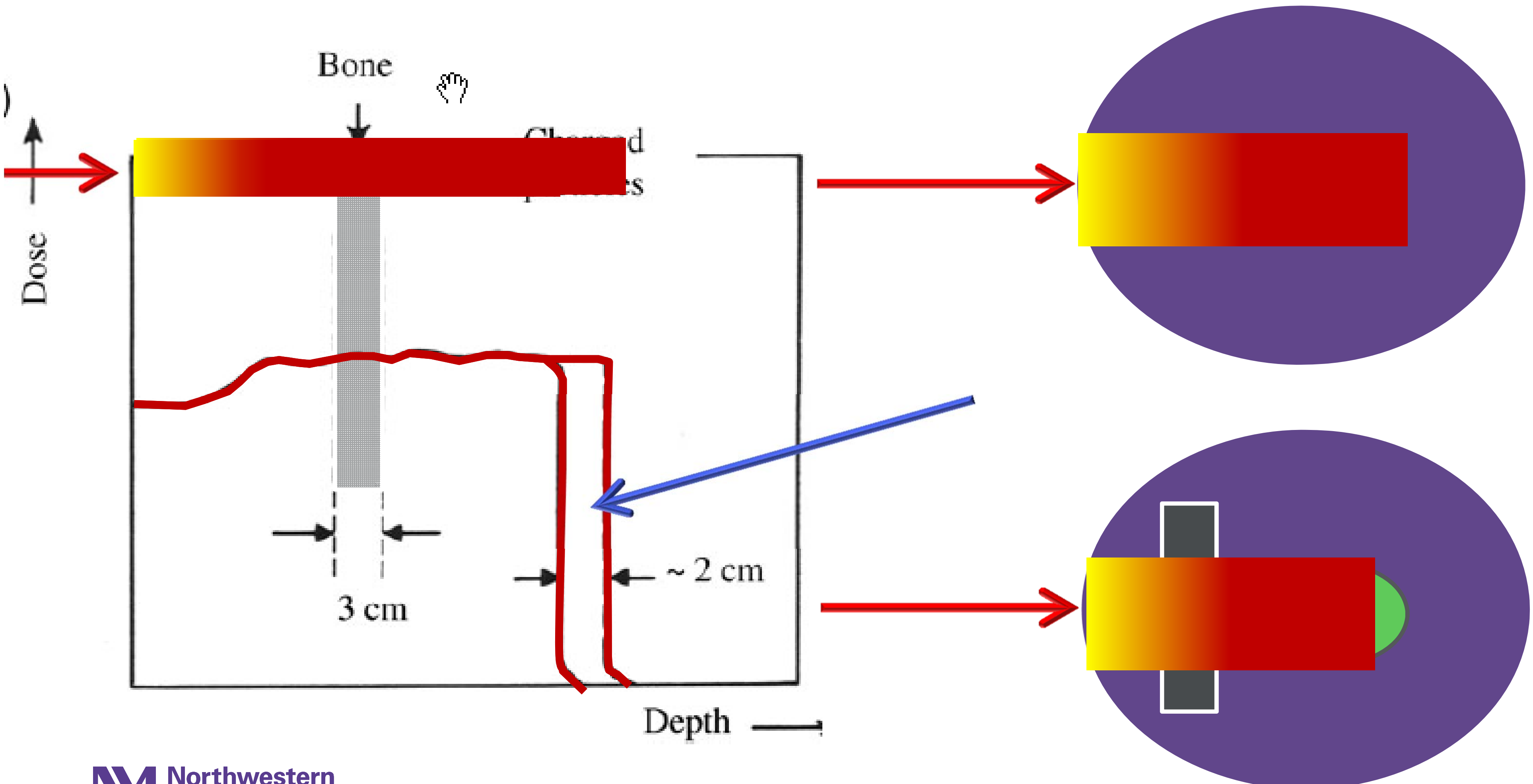
Effect of Path Length Variances : Photons



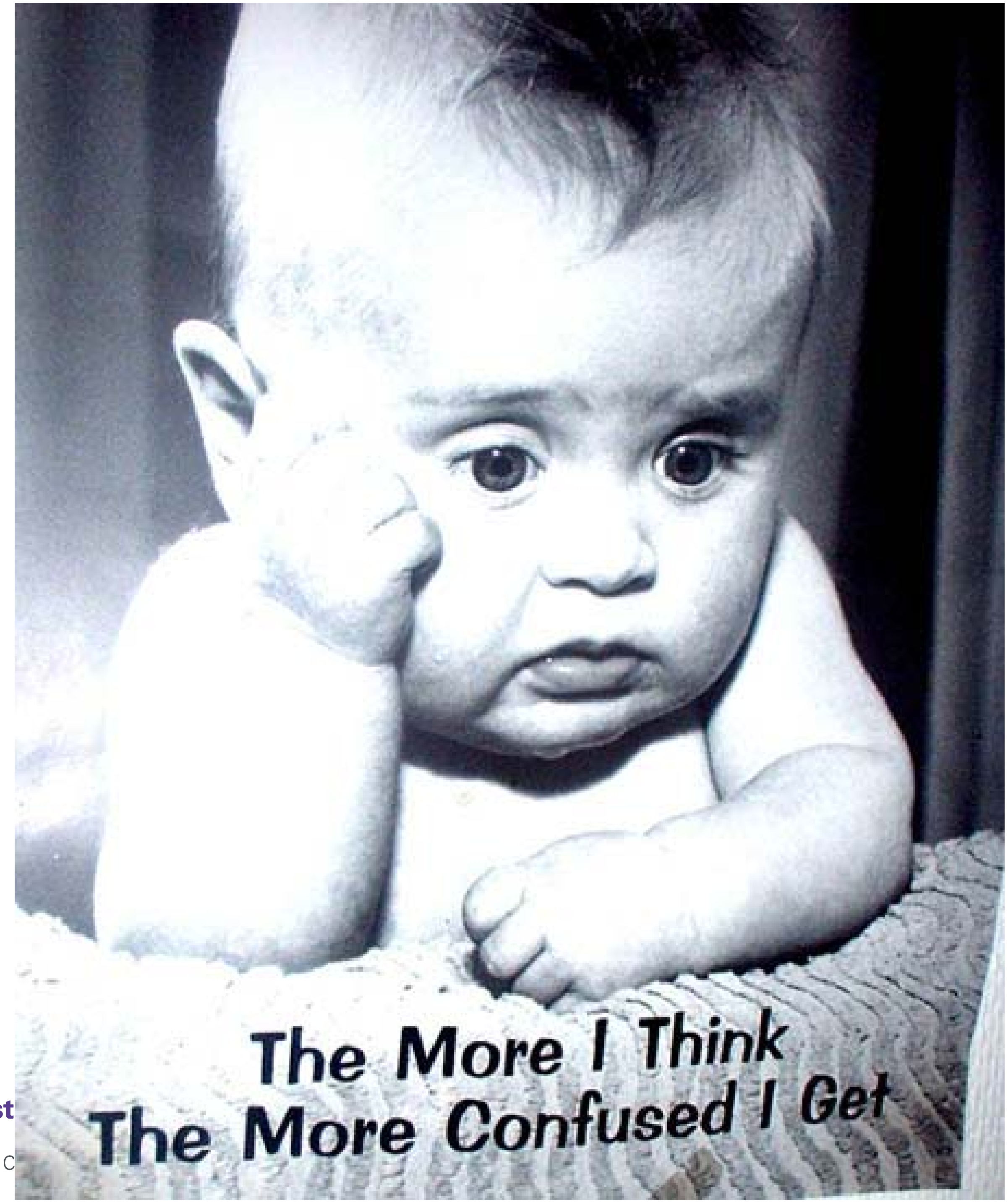
Northwestern Medicine® Chicago Proton Center

From ICRU 78

Effect of Path Length Variances
Protons



From ICRU 78



Northwest
Medicine®
Chicago Proton C

Pencil Beam Delivery / Planning

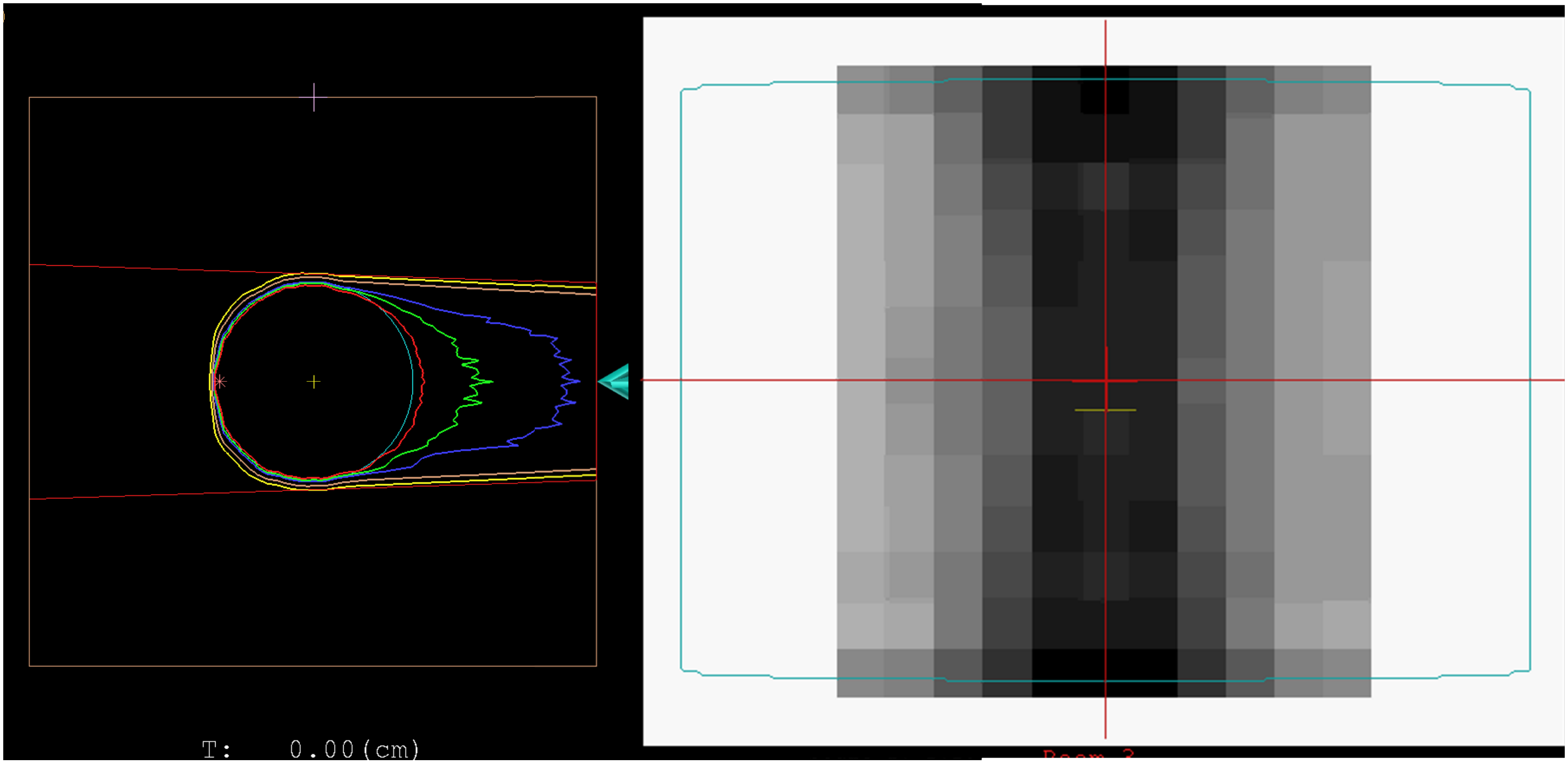
- Layers of spot patterns delivered over the target volume

- Variable Intensity Control
  - Dose uniformity
  - Simultaneous Intergraded Boost

- Distal <u>AND</u> Proximal conformity

- The ability to perform Multi-Field Optimizations

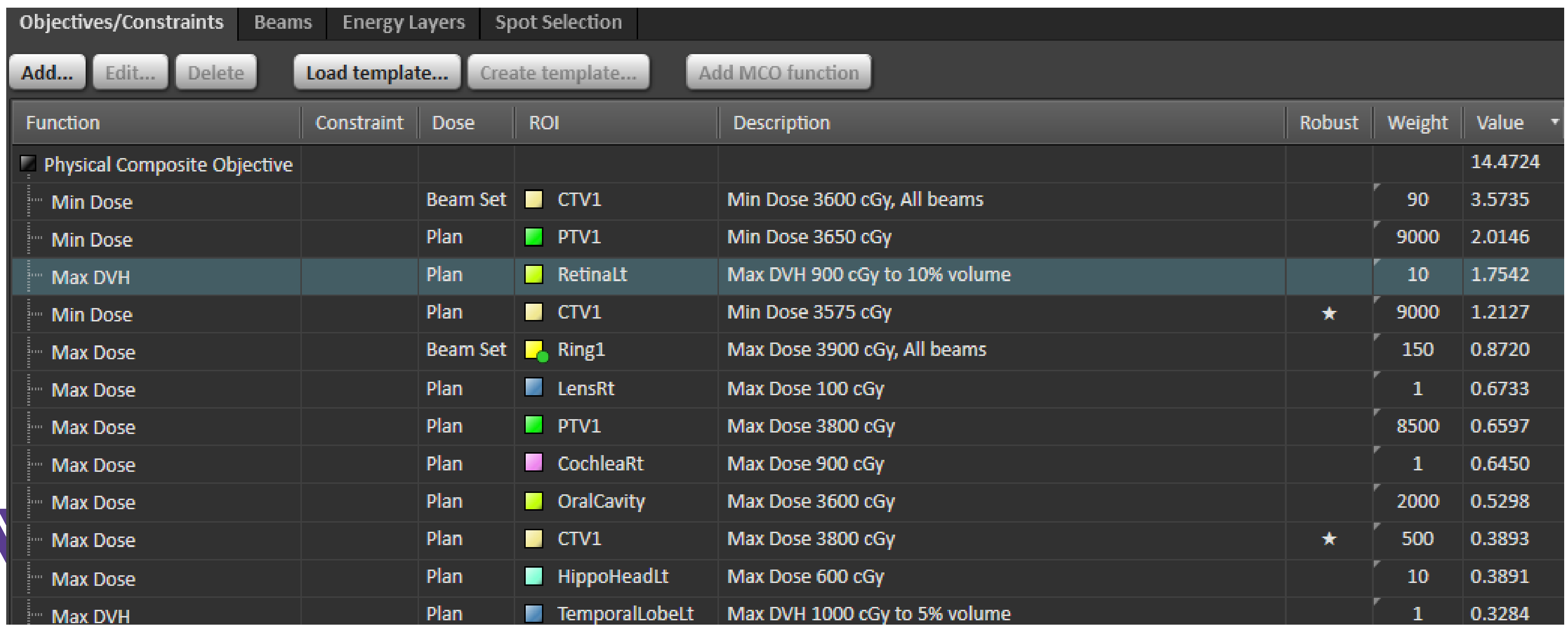
Spot Intensity for SFUD plan



BEV of the Intensity patterns

Spot Positions and Intensity

- Impossible to manually define spot positions and intensities and hope they relate to each other.
- Inverse planning is required
- Objective function is defined
- An iterative process is used to minimize the objective function

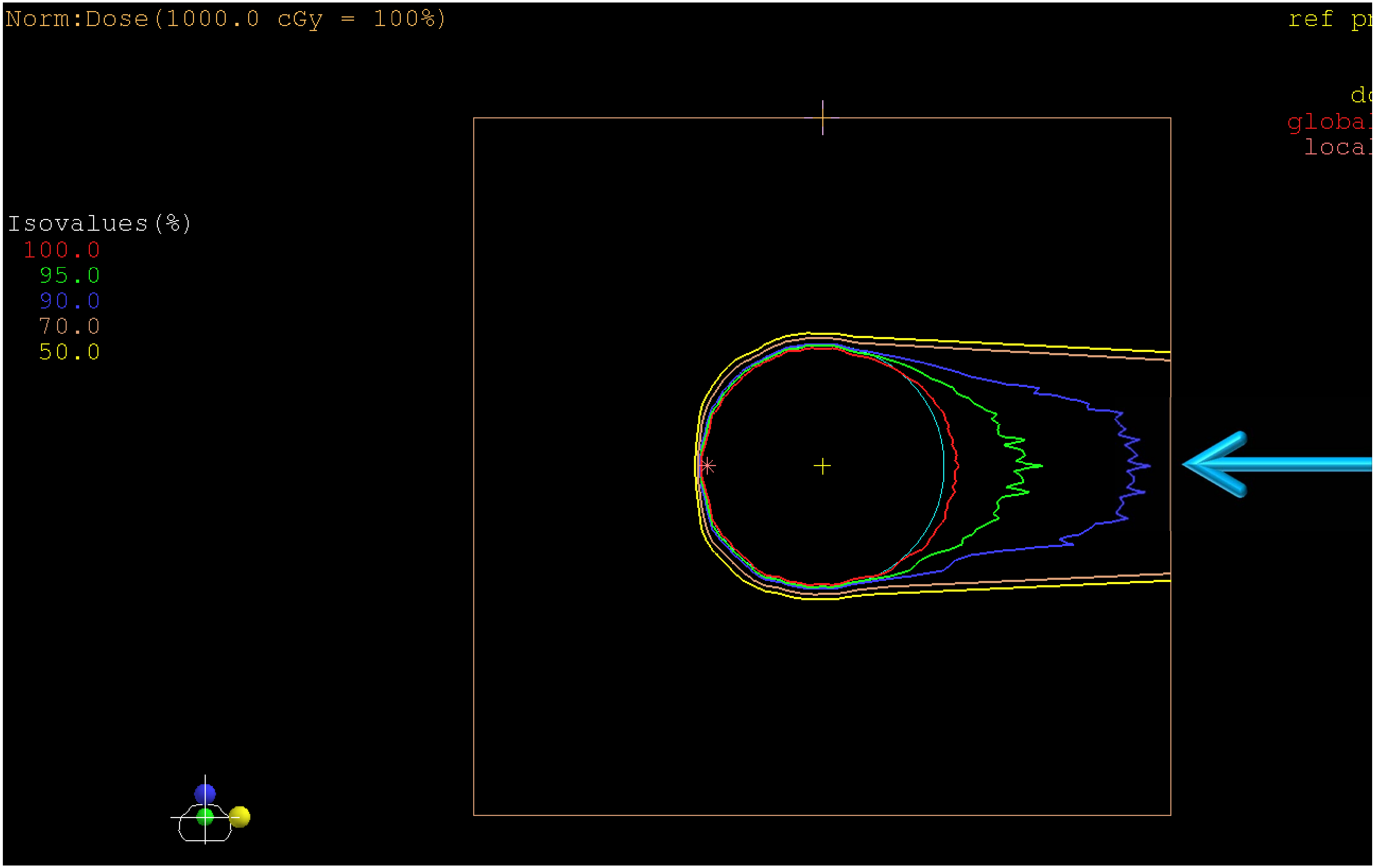


Objectives/Constraints | Beams | Energy Layers | Spot Selection

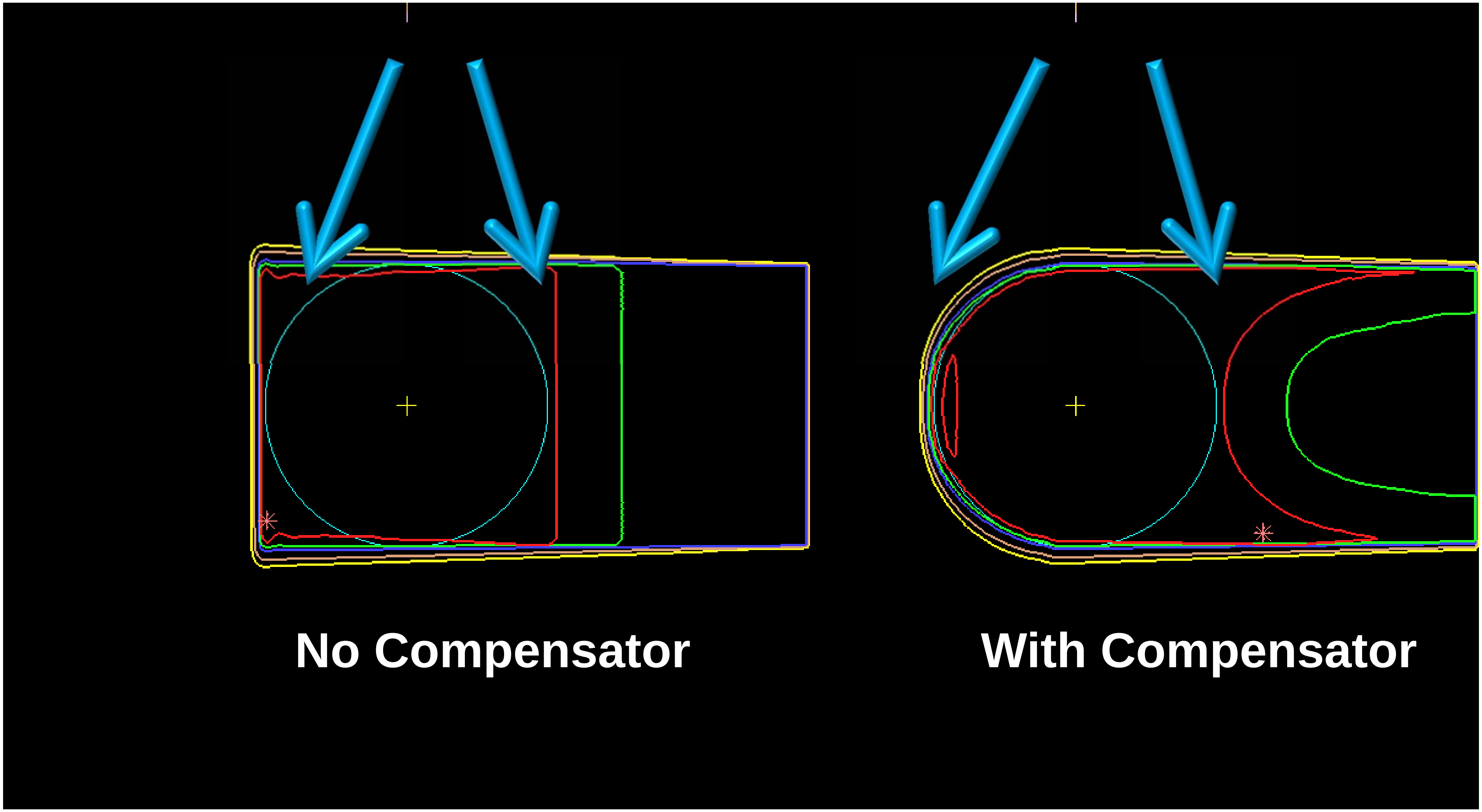
Add... | Edit... | Delete | Load template... | Create template... | Add MCO function

Function	Constraint	Dose	ROI	Description	Robust	Weight	Value
Physical Composite Objective							14.4724
Min Dose		Beam Set	CTV1	Min Dose 3600 cGy, All beams		90	3.5735
Min Dose		Plan	PTV1	Min Dose 3650 cGy		9000	2.0146
Max DVH		Plan	RetinaLt	Max DVH 900 cGy to 10% volume		10	1.7542
Min Dose		Plan	CTV1	Min Dose 3575 cGy	★	9000	1.2127
Max Dose		Beam Set	Ring1	Max Dose 3900 cGy, All beams		150	0.8720
Max Dose		Plan	LensRt	Max Dose 100 cGy		1	0.6733
Max Dose		Plan	PTV1	Max Dose 3800 cGy		8500	0.6597
Max Dose		Plan	CochleaRt	Max Dose 900 cGy		1	0.6450
Max Dose		Plan	OralCavity	Max Dose 3600 cGy		2000	0.5298
Max Dose		Plan	CTV1	Max Dose 3800 cGy	★	500	0.3893
Max Dose		Plan	HippoHeadLt	Max Dose 600 cGy		10	0.3891
Max DVH		Plan	TemporalLobeLt	Max DVH 1000 cGy to 5% volume		1	0.3284

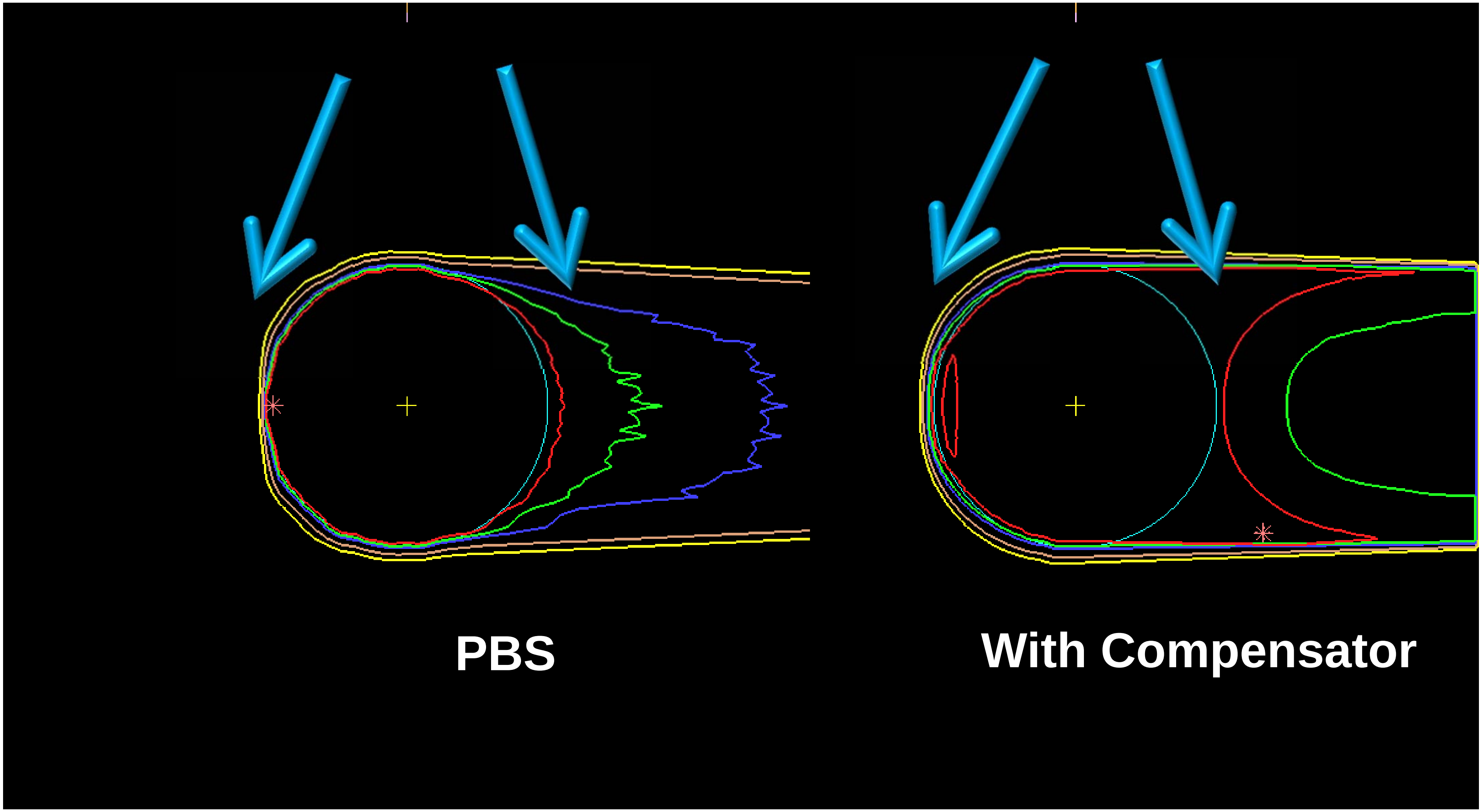
Aperture/Compensator vs. PBS



Advantage of a Compensator



Advantage of a Compensator



PBS Planning is lacking critical tools that are easily available in Aperture /Compensator delivery:

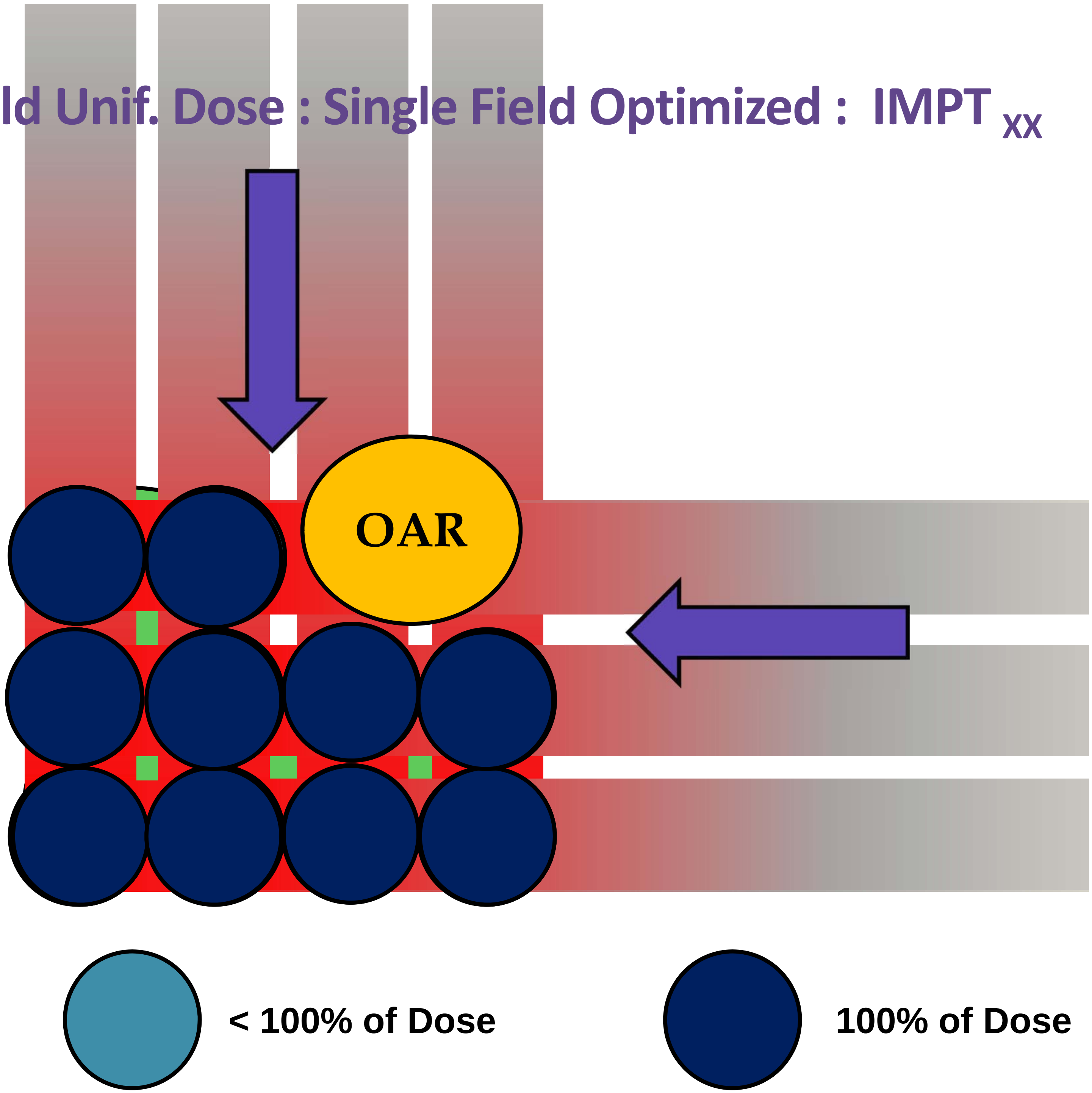
How do we account for?

- **Smearing**
  - Set-up errors
  - Internal motion and inconsistent anatomy
  - No physical device (compensator)

- Range Uncertainties

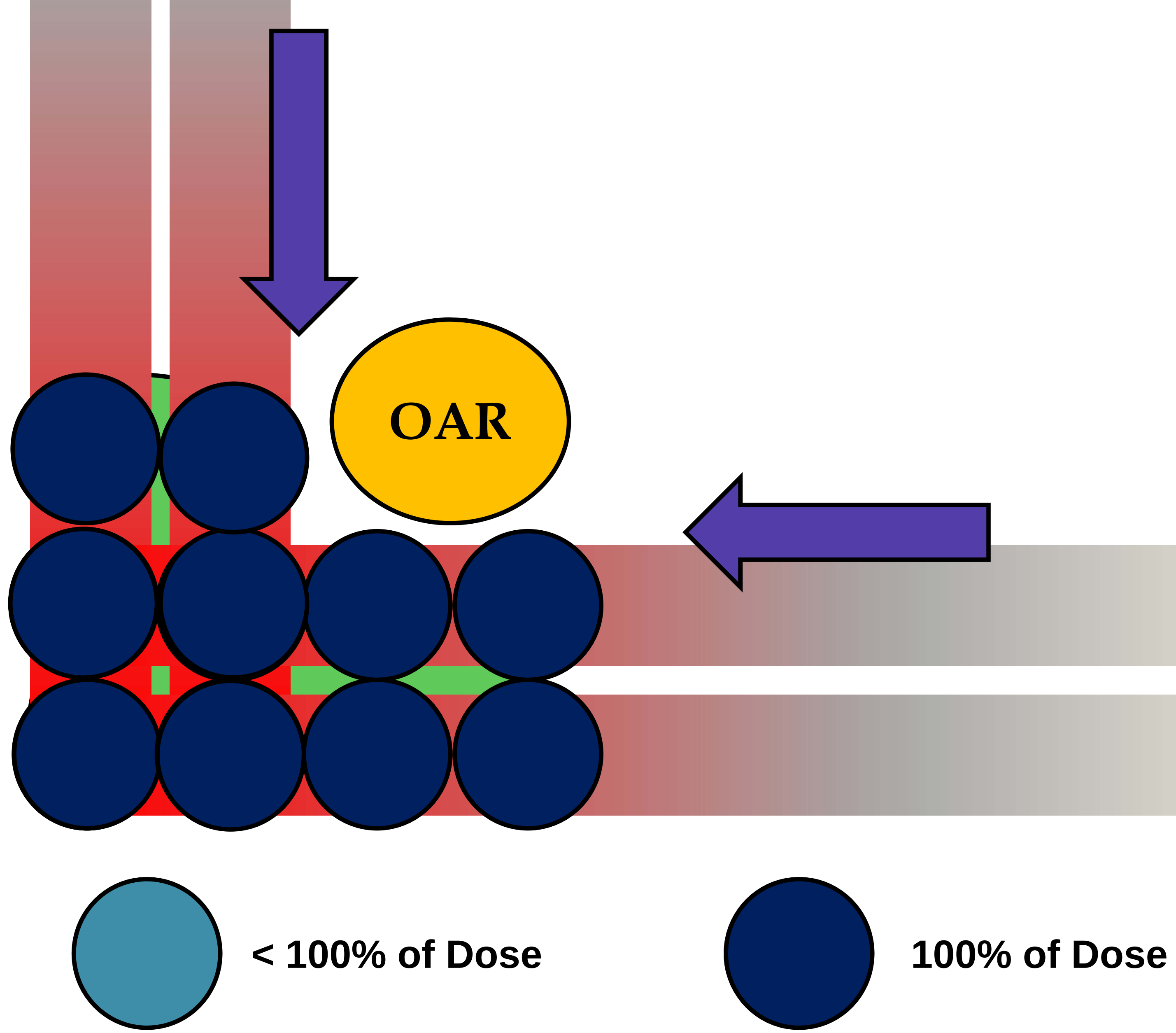
Northwestern Medicine®
Chicago Proton Center

Single Field Unif. Dose : Single Field Optimized : IMPT $_{XX}$



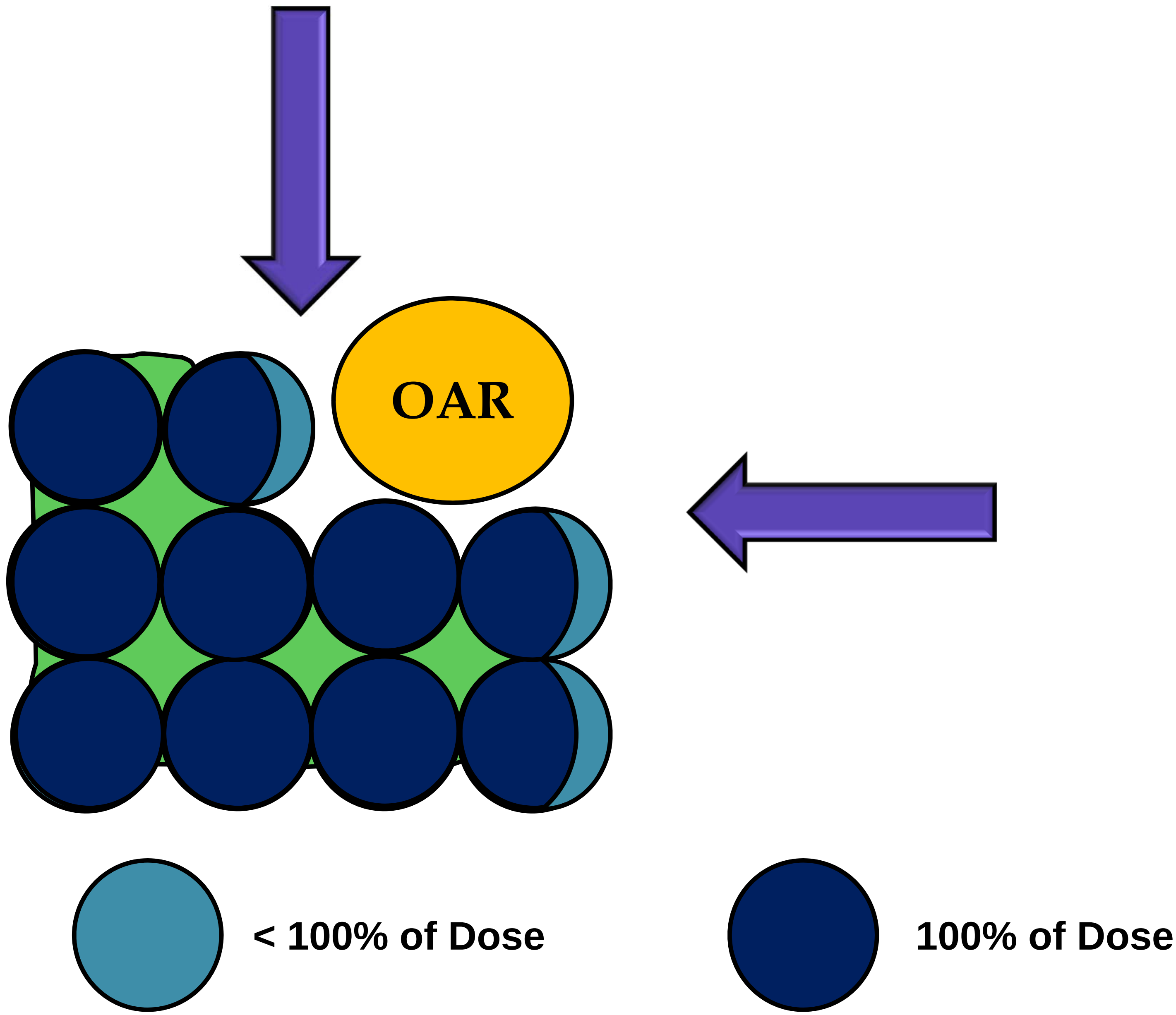
Northwestern Medicine®
Chicago Proton Center

Multi-Field Uniform Dose : (IMPT $_{FULL}$)



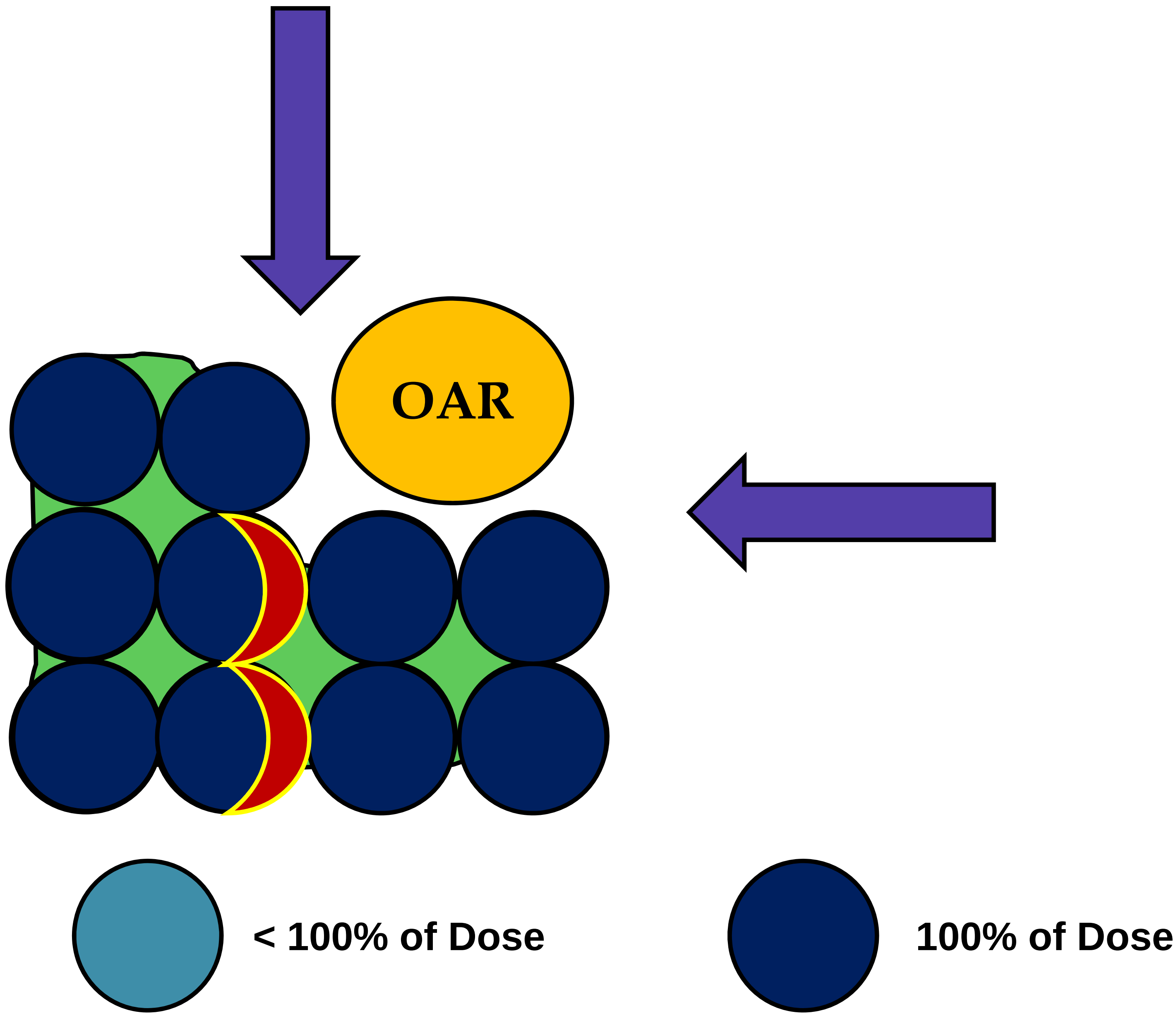
Northwestern Medicine®
Chicago Proton Center

SFUD with range error



Northwestern Medicine®
Chicago Proton Center

Multi Field Optimized with a range error

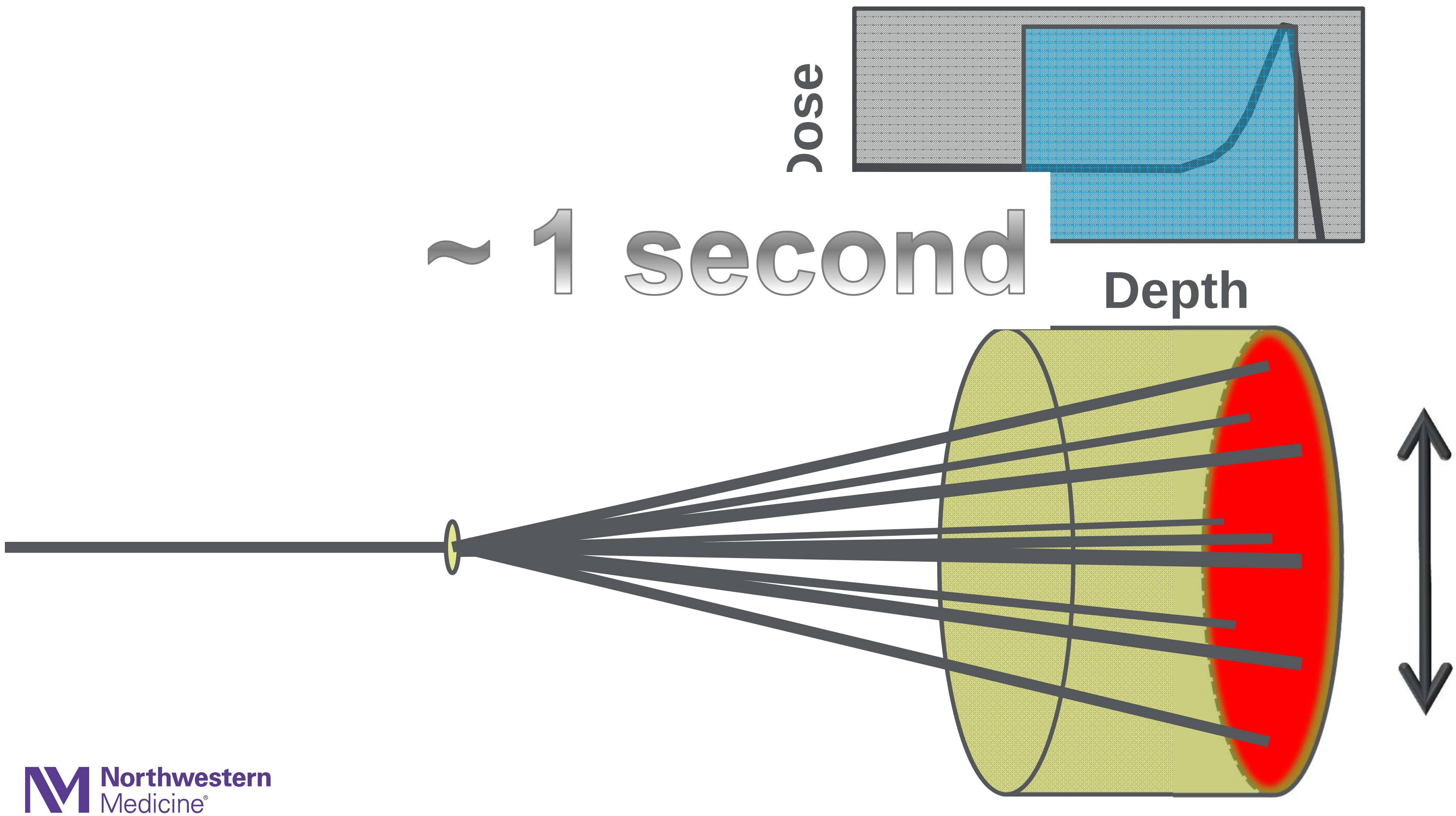


Northwestern Medicine®
Chicago Proton Center

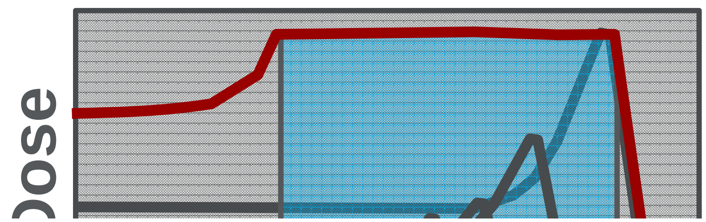
Delivery timing of your PBS delivery system and method need to be understood

- PBS Beam delivery method
  - Delivery speed perpendicular to incident beam
  - Delivery speed parallel to incident beam

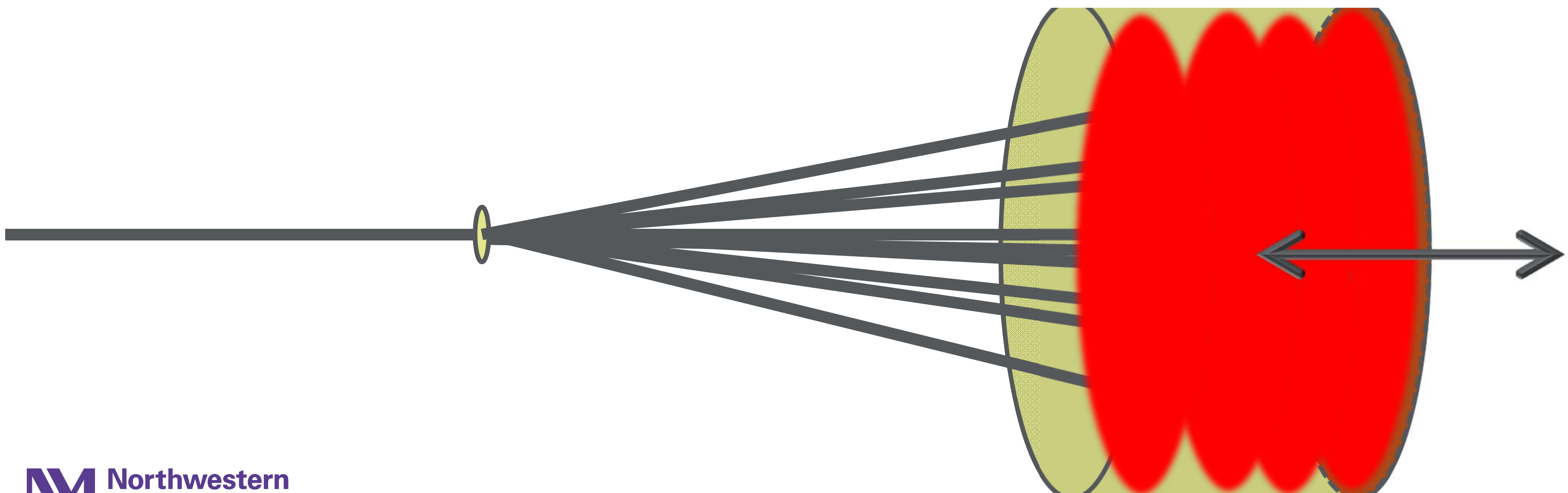
Delivery perpendicular to incident beam



Delivery parallel to incident beam



Not Quick ~ 2-5 second

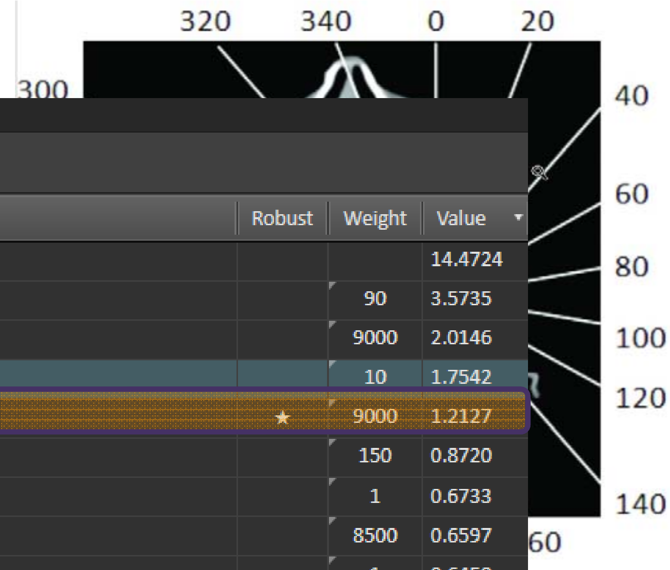


Northwestern Medicine®
Chicago Proton Center

With PBS we need to consider Robustness:

- Quantify the sensitivity of the PBS plan to :
  - Set-up errors
  - Internal Motion
  - Range Uncertainties

- Two methods to do this:
  - Prospectively : Robustness Optimization
  - Retrospectively : Robustness Evaluation



5256. MDA

- Evalu
  - E
  - C
- Addi
  - C th
  - A p p
  - ..
  - T
- 4-D R

N

Objectives/Constraints | Beams | Energy Layers | Spot Selection

Add... | Edit... | Delete | Load template... | Create template... | Add MCO function

Function	Constraint	Dose	ROI	Description	Robust	Weight	Value
Physical Composite Objective							14.4724
Min Dose		Beam Set	CTV1	Min Dose 3600 cGy, All beams		90	3.5735
Min Dose		Plan	PTV1	Min Dose 3650 cGy		9000	2.0146
Max DVH		Plan	RetinaLt	Max DVH 900 cGy to 10% volume		10	1.7542
Min Dose		Plan	CTV1	Min Dose 3575 cGy	★	9000	1.2127
Max Dose		Beam Set	Ring1	Max Dose 3900 cGy, All beams		150	0.8720
Max Dose		Plan	LensRt	Max Dose 100 cGy		1	0.6733
Max Dose		Plan	PTV1	Max Dose 3800 cGy		8500	0.6597
Max Dose		Plan	CochleaRt	Max Dose 900 cGy		1	0.6450
Max Dose		Plan	OralCavity	Max Dose 3600 cGy		2000	0.5298
Max Dose		Plan	CTV1	Max Dose 3800 cGy	★	500	0.3893
Max Dose		Plan	HippoHeadLt	Max Dose 600 cGy		10	0.3891
Max DVH		Plan	TemporalLobeLt	Max DVH 1000 cGy to 5% volume		1	0.3284
Max DVH		Plan	Ring1	Max DVH 3000 cGy to 10% volume		1000	0.2820
Max Dose		Plan	CochleaLt	Max Dose 2300 cGy		1	0.2515
Max Dose		Plan	HippoTailRt	Max Dose 600 cGy		10	0.2242
Max DVH		Plan	ParotidLt	Max DVH 2000 cGy to 80% volume		200	0.2086
Max DVH		Plan	OralCavity	Max DVH 600 cGy to 70% volume		70	0.1790
Uniform Dose		Plan	CTV1	Uniform Dose 3650 cGy		100	0.1654
Max DVH		Plan	Brain	Max DVH 500 cGy to 10% volume		5	0.0712
Max DVH		Plan	ParotidRt	Max DVH 400 cGy to 50% volume		10	0.0382
Max DVH		Plan	TemporalLobeRT1	Max DVH 1000 cGy to 5% volume		1	0.0064
Max DVH		Plan	OralCavity	Max DVH 2900 cGy to 30% volume		1	0.0023
Max Dose		Plan	Brain	Max Dose 3600 cGy		50	0.0013
Max Dose		Plan	OpticNerveLt	Max Dose 3600 cGy		1	7.1147E-4
Max DVH		Plan	OralCavity	Max DVH 3600 cGy to 15% volume		4	9.9509E-5
Max Dose		Plan	Brainstem	Max Dose 3600 cGy		1	2.4875E-5
Max Dose		Plan	LensLt	Max Dose 175 cGy		0	0.0000
Max Dose		Plan	OpticNerveRt	Max Dose 3600 cGy		1	0.0000
Max DVH		Plan	RetinaRt	Max DVH 300 cGy to 10% volume		0	0.0000
Max DVH		Plan	Brainstem	Max DVH 1800 cGy to 40% volume		1	0.0000

Robustness Analysis

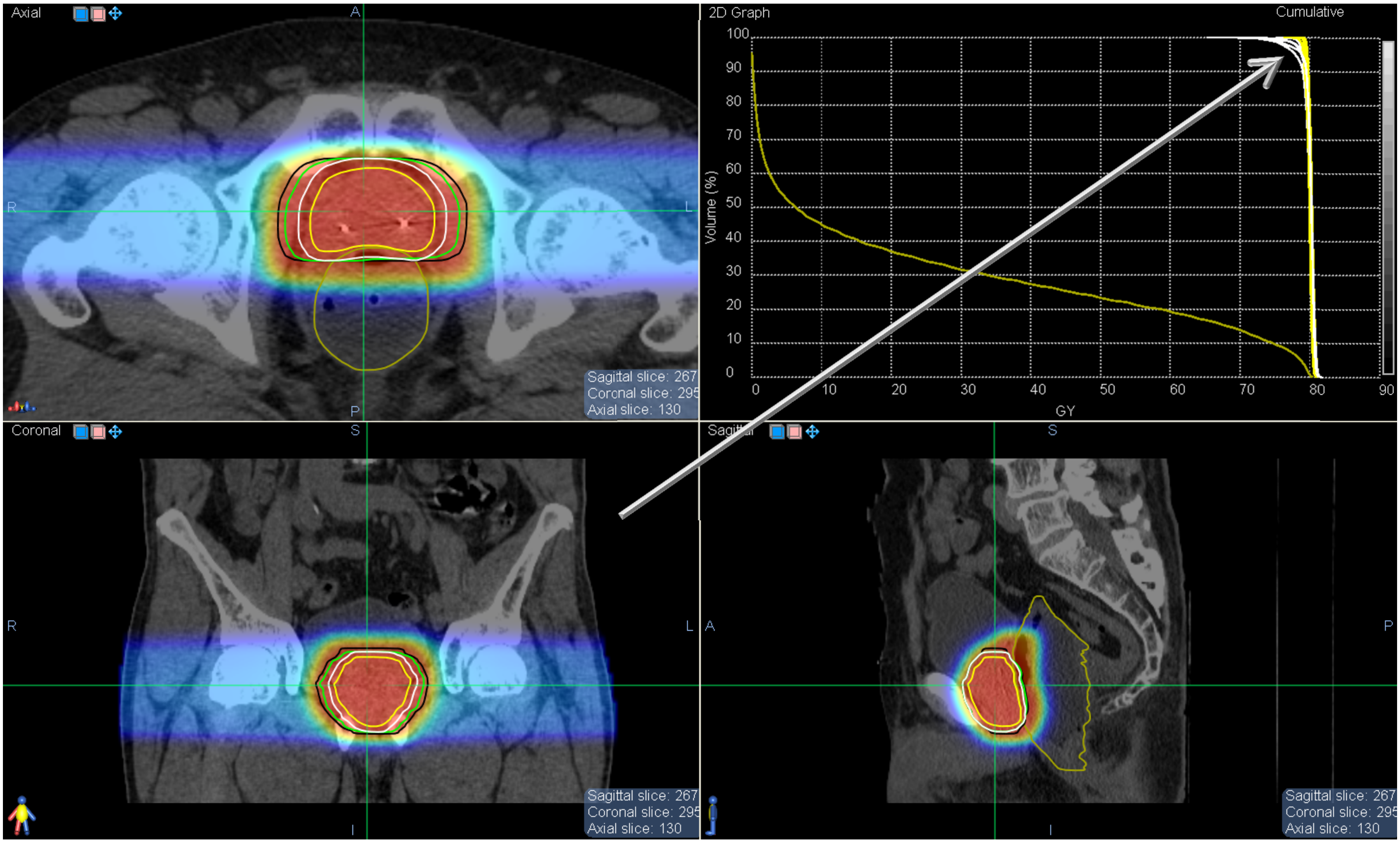
Process of evaluating several potential scenarios to understand potential "worse case" results

- Translate and/or rotate individual fields and recalculate
  - Mimic Set-up errors

- Re-assign shifted HU conversion curves and recalculate
  - Mimic HU conversion errors

- Move Target structures and recalculate
  - Mimic Internal Motion

Anterior Plan: Simple DVH



Question 3

Which statement s true about robustness evaluations?

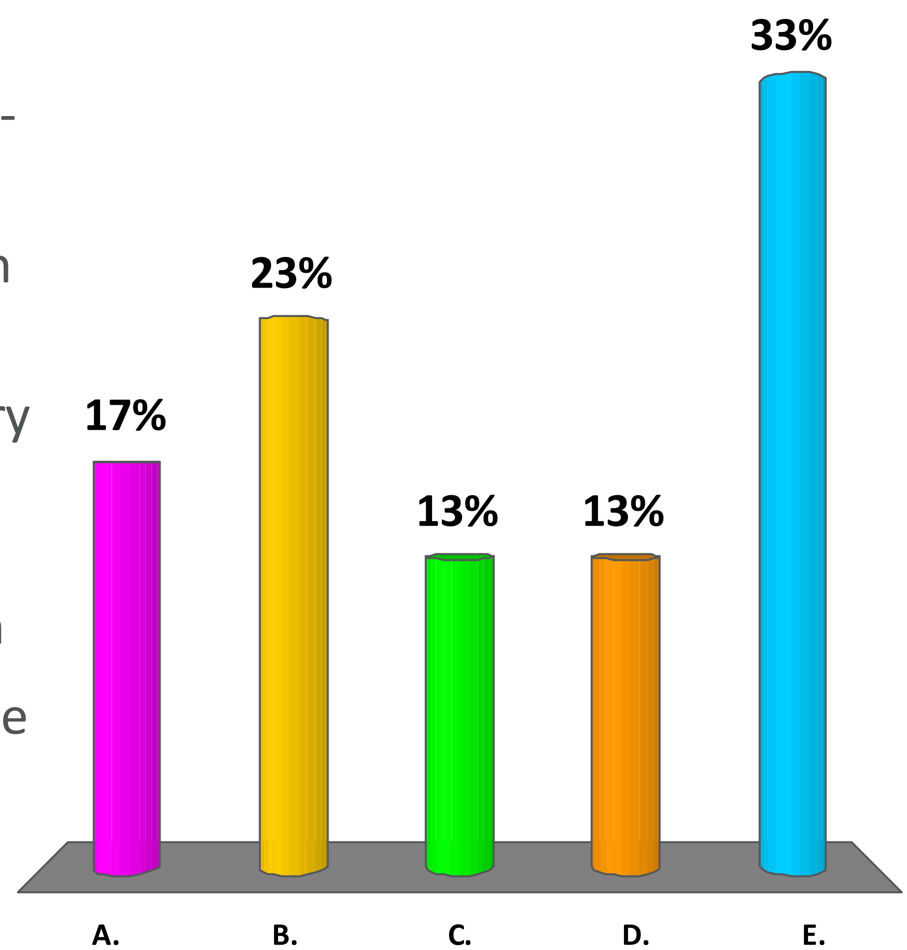
A. Robustness evaluation quantity potential differences in dose distributions of PBS plans caused by set-up and/or range uncertainties.

B. Robustness evaluation compare proton and photon plans

C. Robustness evaluation are not necessary for Multi Field Optimized proton plans

D. Robustness evaluation should be different to the nominal treatment plan

E. Robustness evaluation will speed up the planning process



Northwestern Medicine®
Chicago Proton Center

Question 3

Which statement s true about robustness evaluations?

a) Robustness evaluation quantity potential differences in dose distributions of PBS plans caused by set-up and/or range uncertainties.
b) Robustness evaluation compare proton and photon plans
c) Robustness evaluation are not necessary for Multi Field Optimized proton plans
d) Robustness evaluation should be different to the nominal treatment plan
e) Robustness evaluation will speed up the planning process

Correct Answer (a) : Robustness evaluation quantity the differences in dose distributions of PBS plans caused by set-up and/or range uncertainties.

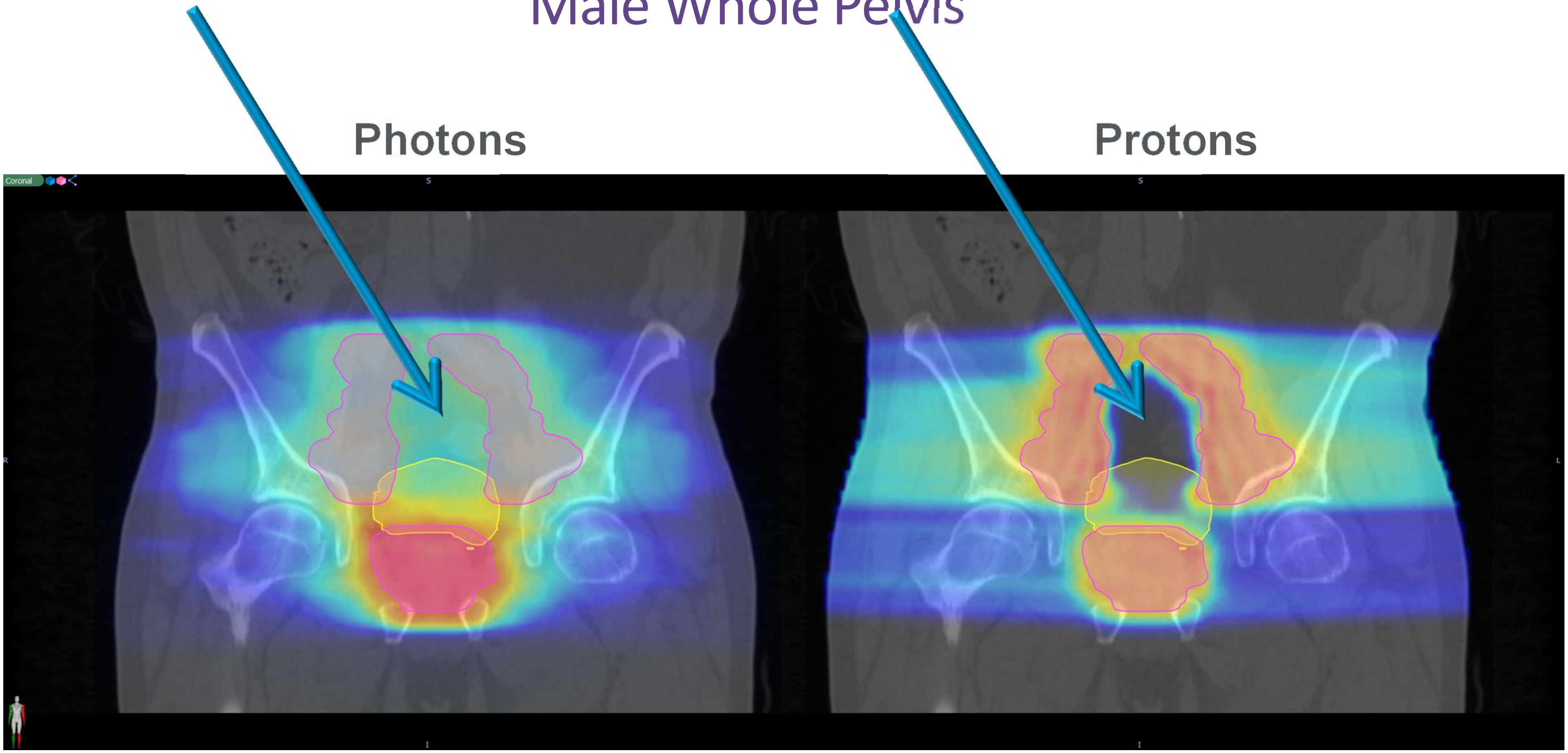
References : Pugh TJ, et al. : Med Dosim. 2013 Autumn;38(3):344-50.

Answer (A)

Northwestern Medicine®
Chicago Proton Center

A few cases where PBS was beneficial:

Male Whole Pelvis

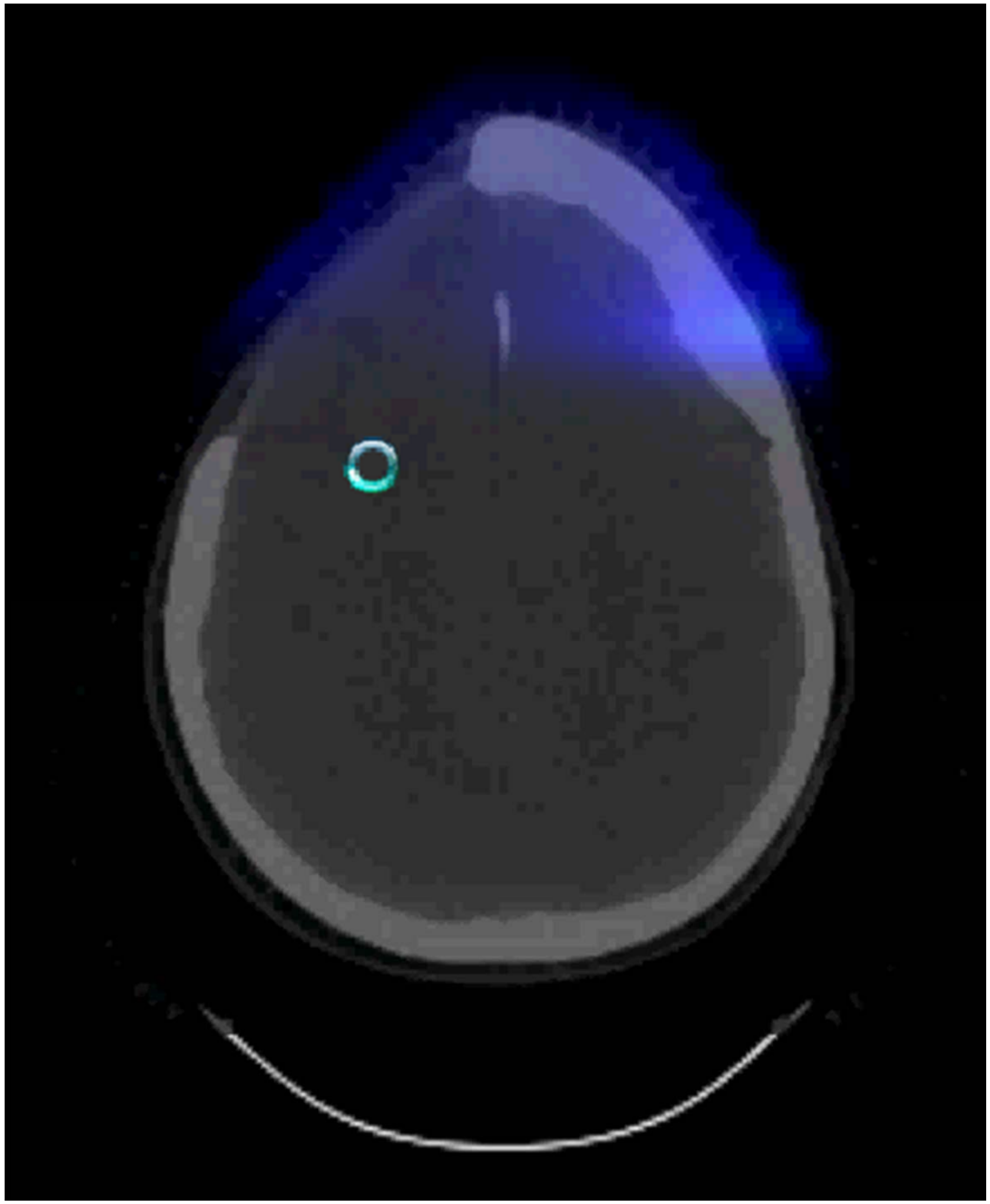


Northwestern Medicine®
Chicago Proton Center

Retreat Meningioma

59.4Gy(RBE)

0.0Gy(RBE)



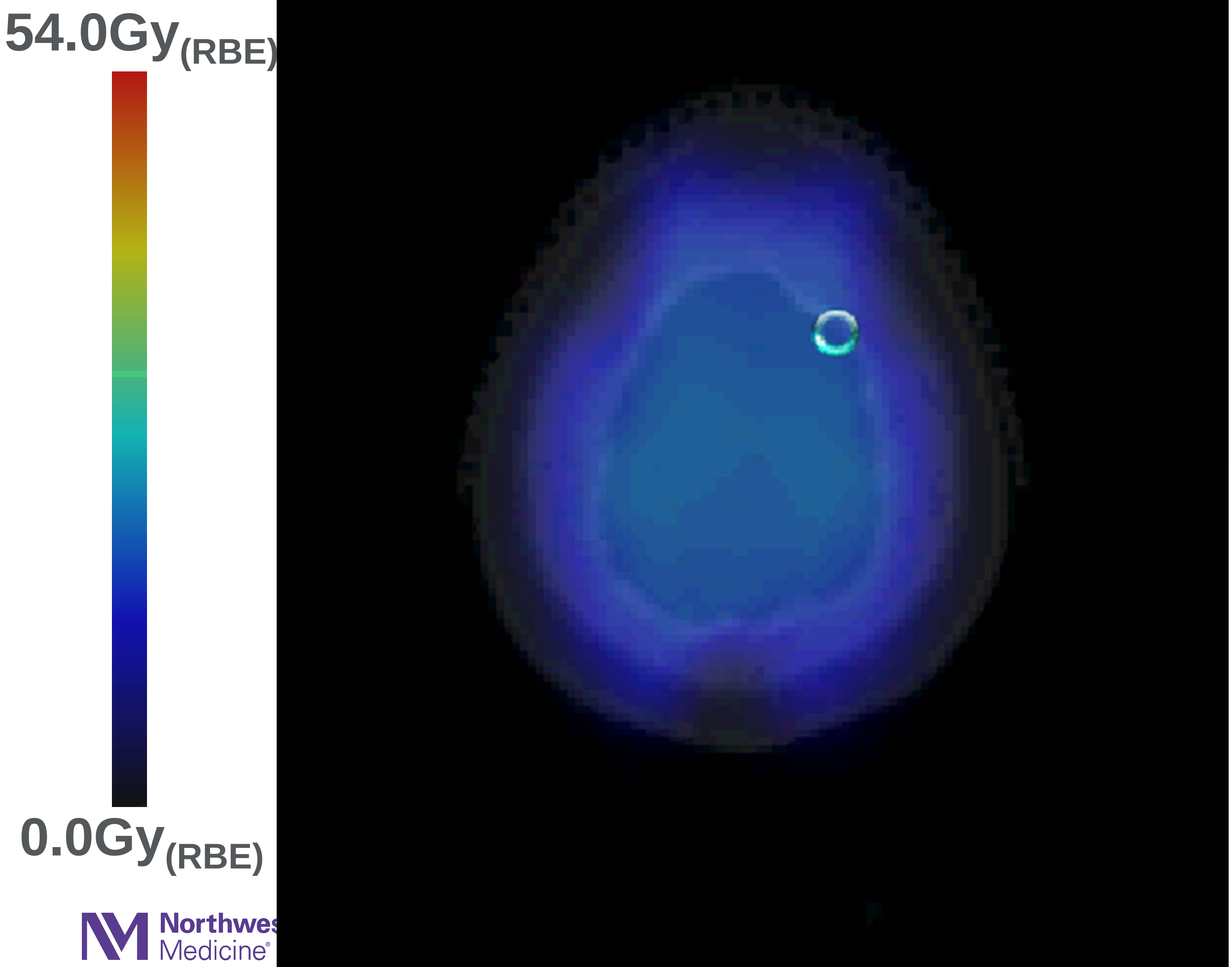
40 y/o Male History of Brain irradiation at age 2 for acute lymphoblastic leukemia.

50.4Gy(RBE)

Boost to 59.4Gy(RBE)

Northwestern Medicine®
Chicago Proton Center

Pineal Blastoma



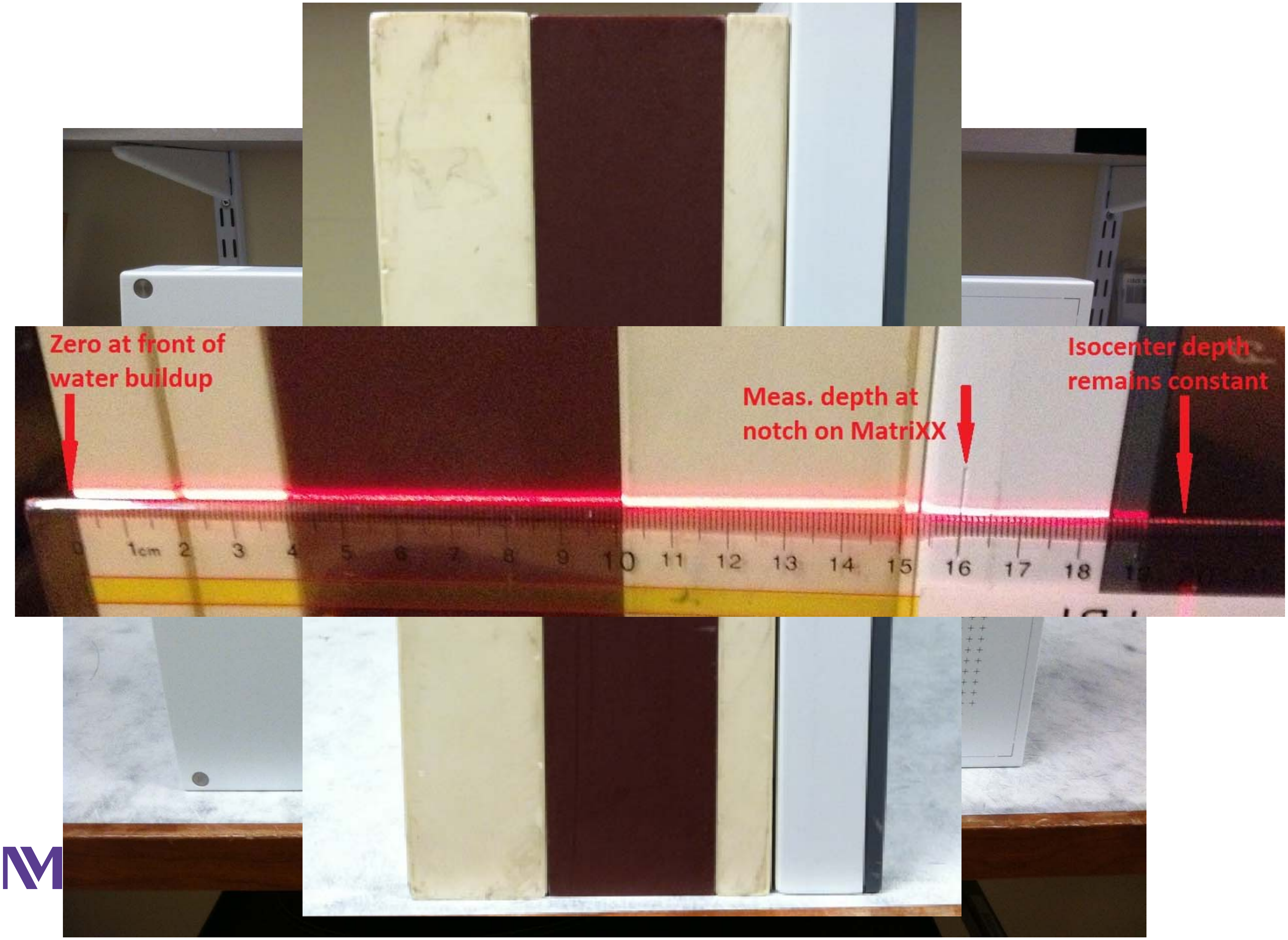
13 y/o Male
Germinoma :
Pineal Region

PBS Patient Specific QA

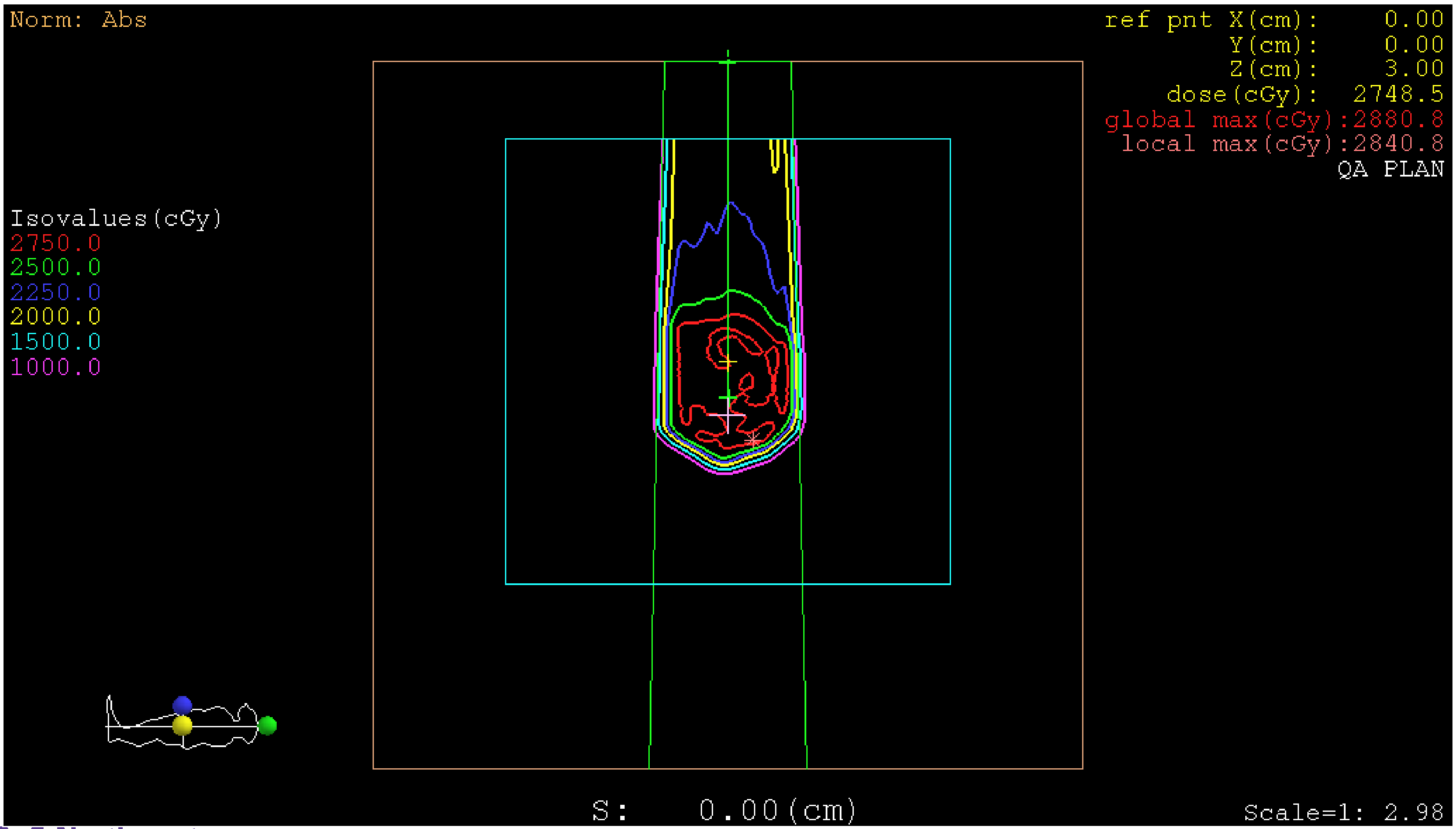
- Secondary independent measurement of planned fluence onto a uniform phantom
  - With protons :
    - 3-dimensional dose distribution
    - A profiles at one depth does not predict the profile at other depths

- Profile Measurements : Must obtained at various depths
  - How many is enough?
    - Initially obtained at least 4 depths
    - Distal portion of CTV
    - Center portion of CTV
    - Proximal portion of CTV
    - Depth = 10cm or less : Plateau region

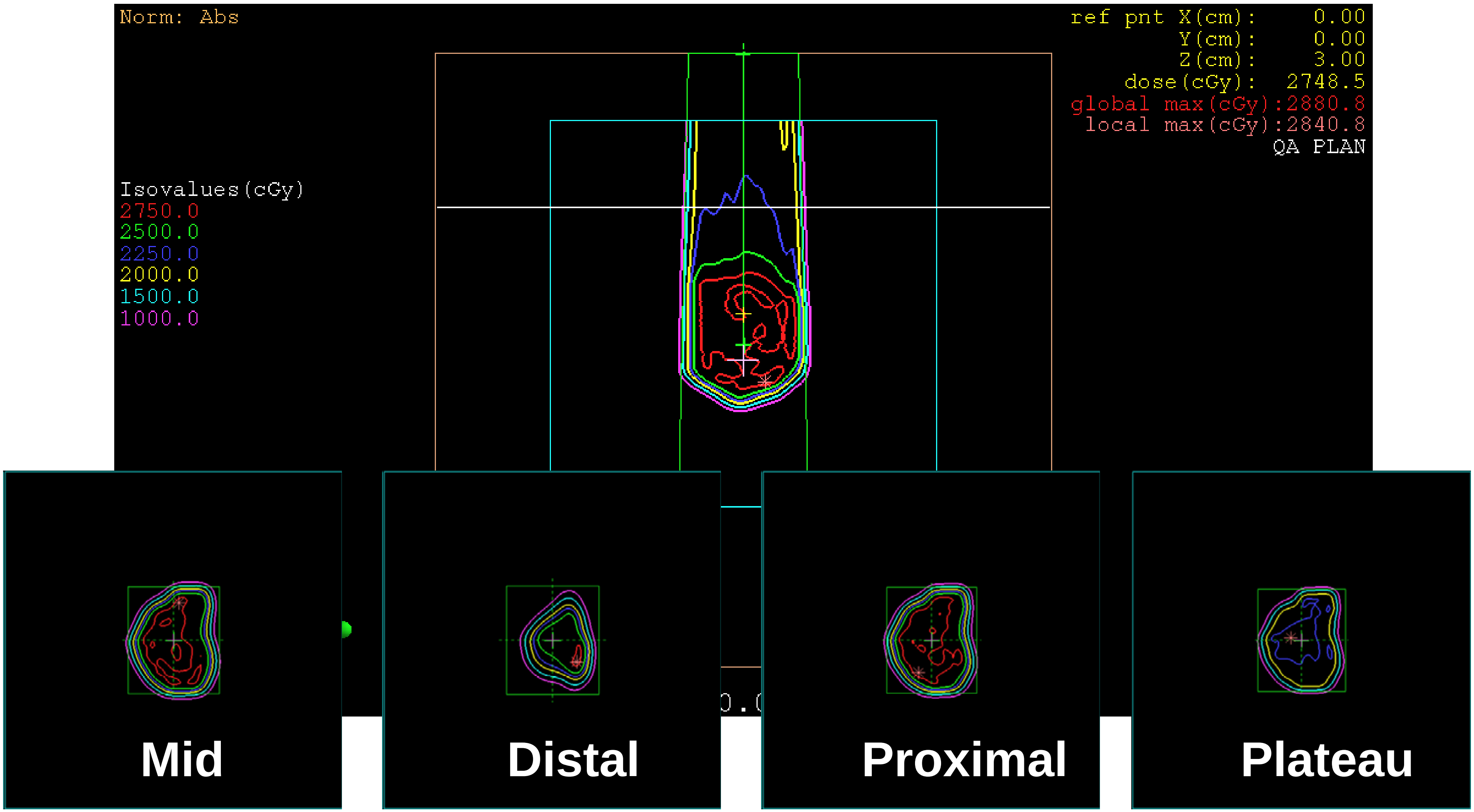
Patient Specific PBS QA S/U



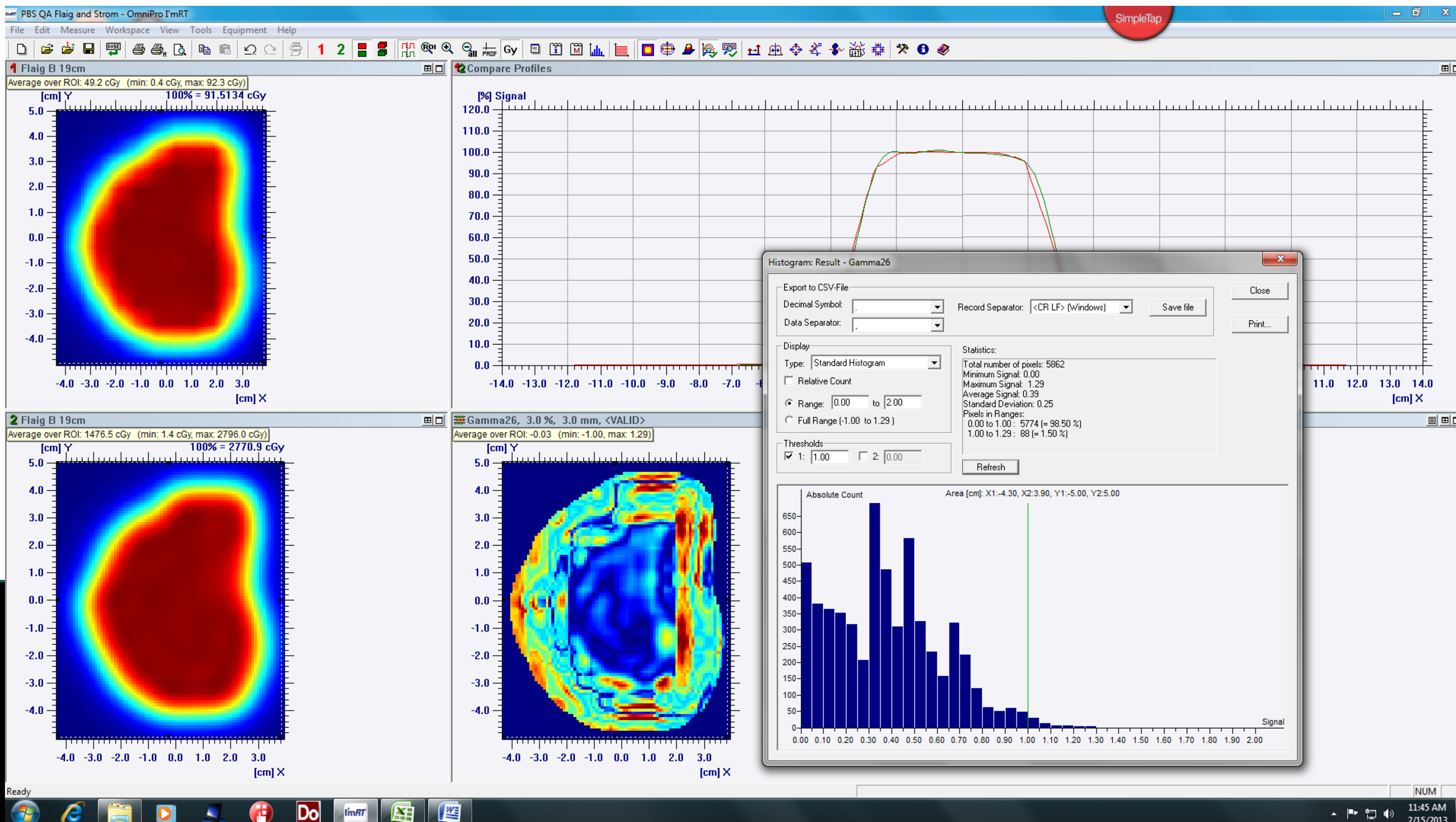
PBS Patient Specific QA Process



Obtain expected planned dose planes



Profile evaluation of calculated vs. measured profiles



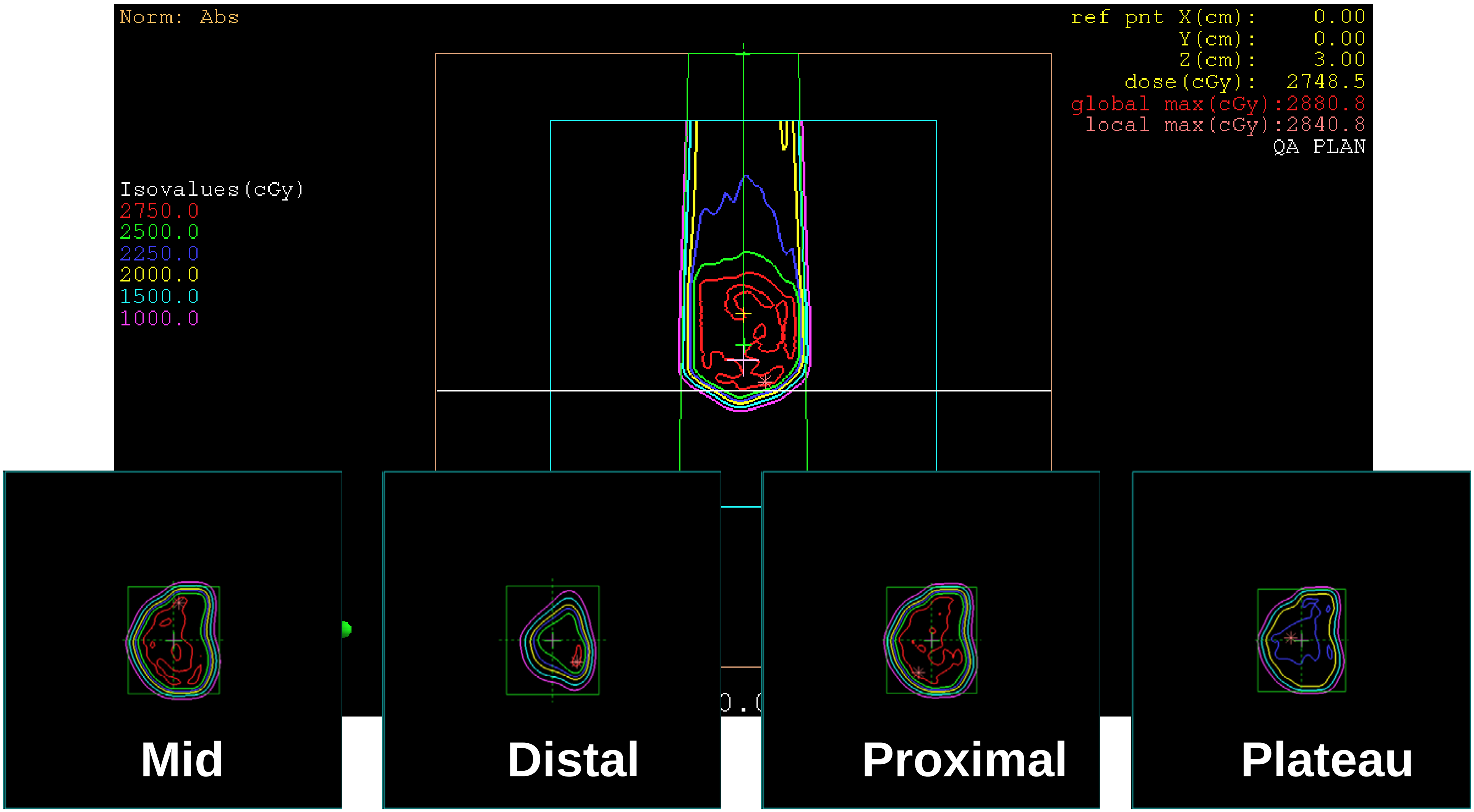
Mid

Distal

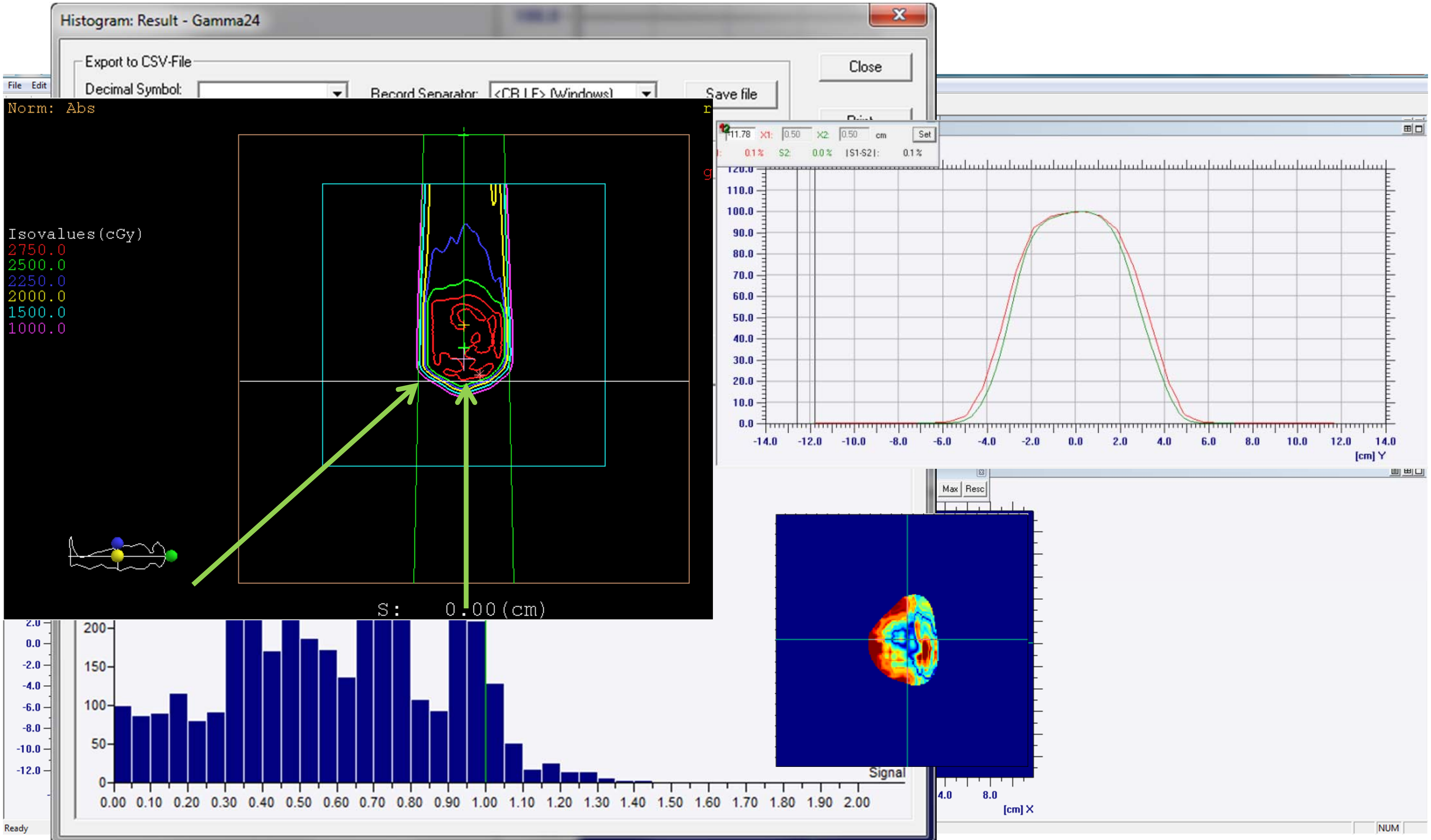
Proximal

Plateau

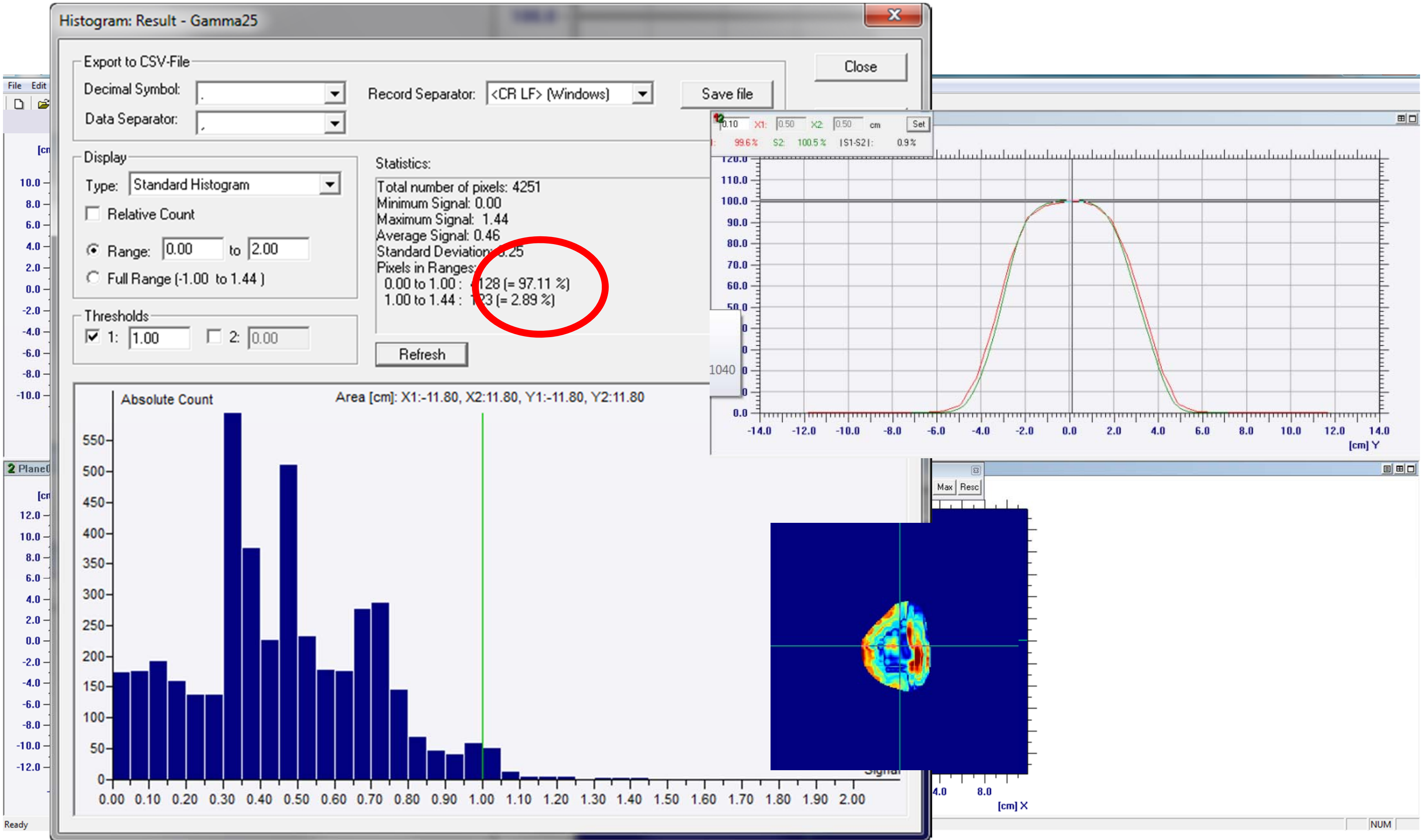
Obtain expected planned dose planes



Distal Edge Evaluation

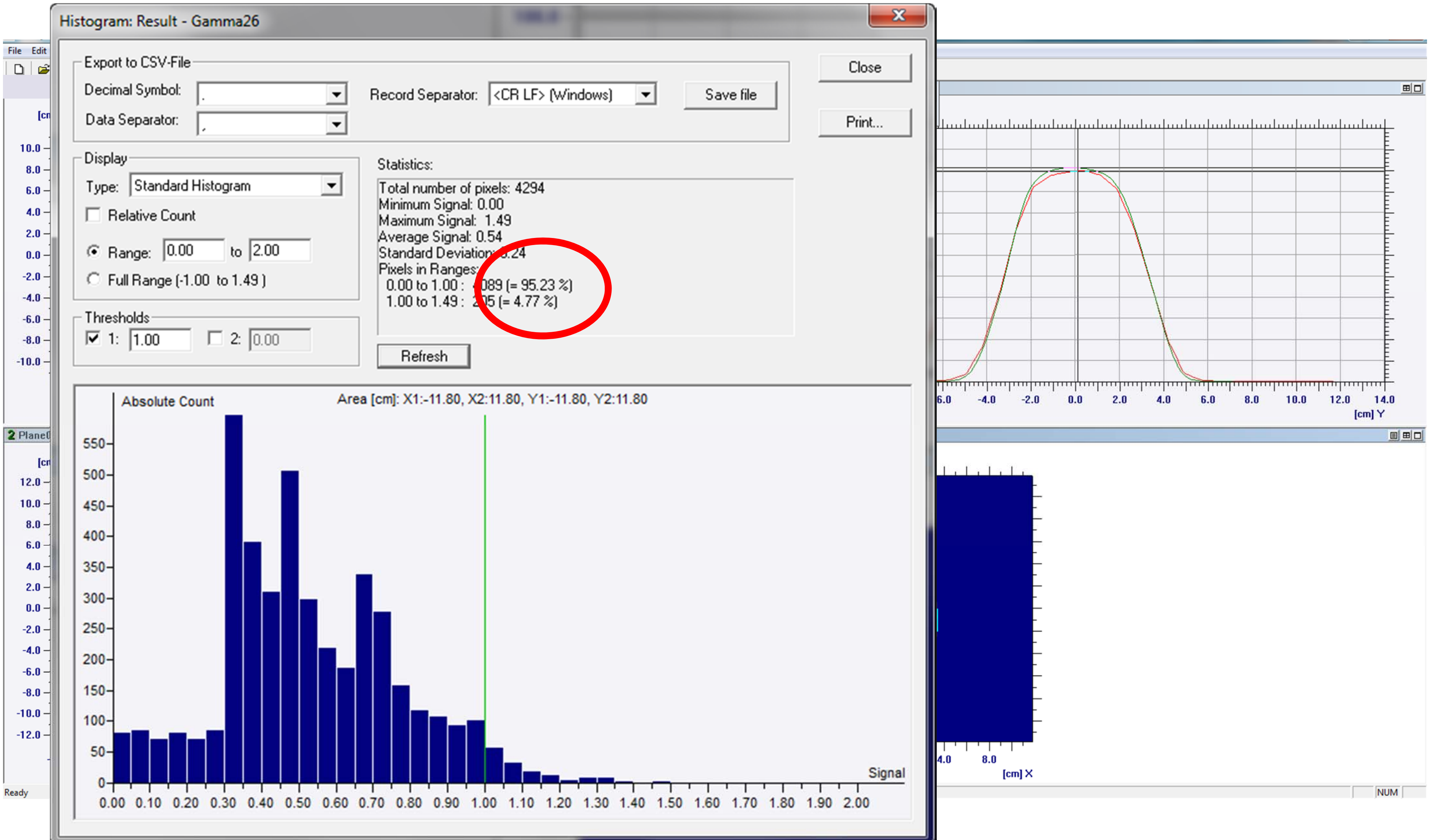


Distal Edge Evaluation



Chicago Proton Center

Distal Edge Evaluation



In Conclusion : Is it too hard?? Should we give up??

No way !!

The true benefit of proton is in the difference in integral dose. Make the best of this !!

Northwestern Medicine®
Chicago Proton Center

Thank You for listening!

Northwestern Medicine®
Chicago Proton Center