Clinical and Radiobiological considerations in Proton Radiotherapy

Alejandro Carabe, Ph.D.
`Assistant Professor

December 14, 2016

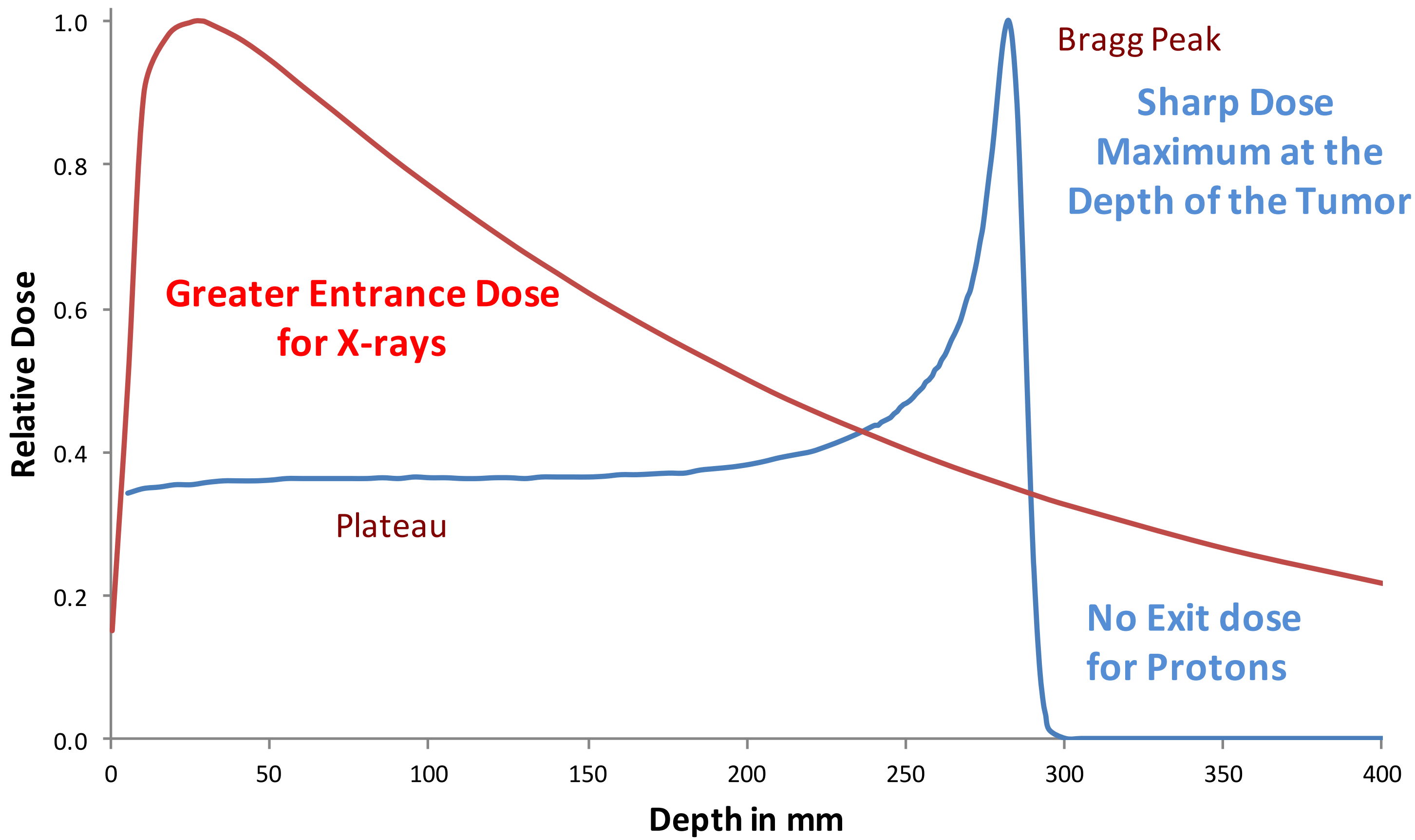
PENN RADIATION ONCOLOGY
Penn Medicine

Summary

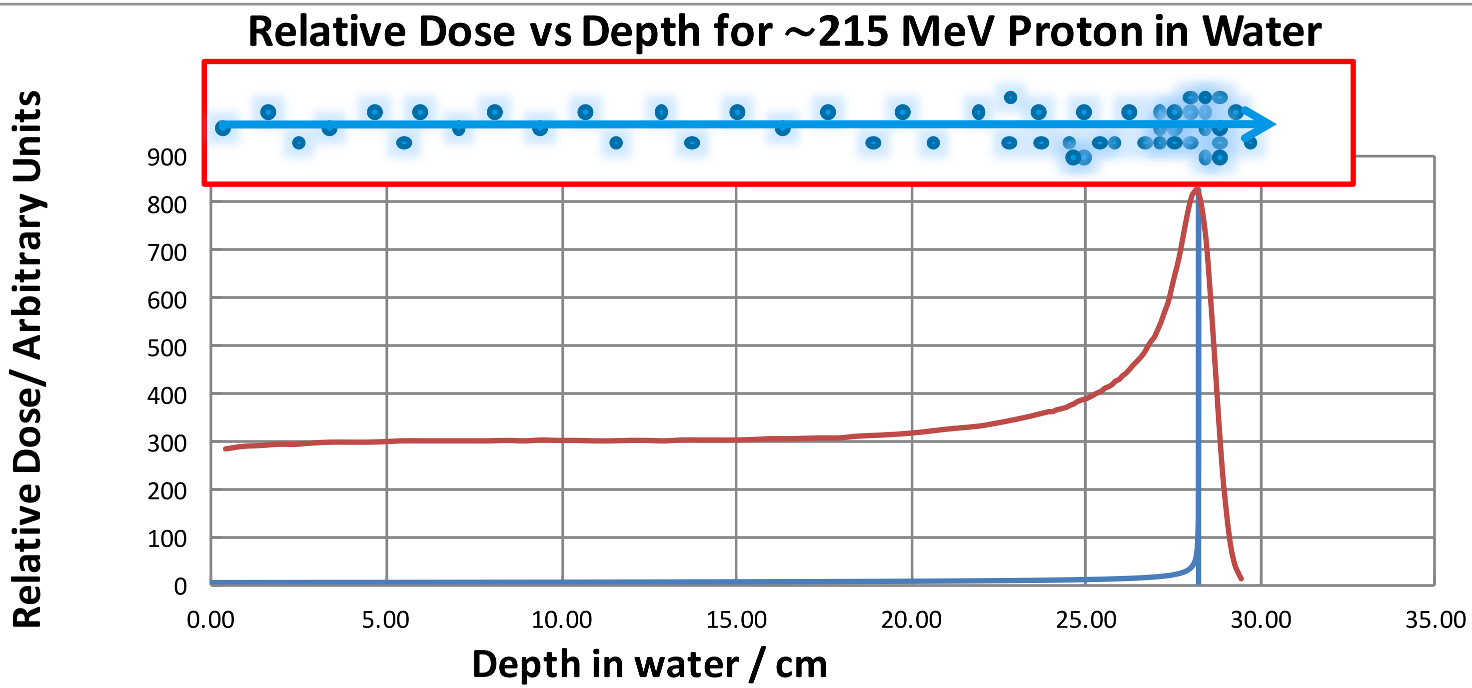
- Physical and biophysical properties of protons
- Proton delivery techniques: What do their physical differences mean in terms of clinical plans?
- Uncertainties in proton therapy: How are they accounted for with passively scattered beams vs scanned beams?
- General beam angle selection guidelines
- Site-specific beam arrangement considerations
- Clinical examples of unique proton techniques
- What is the way forward in proton radiotherapy?

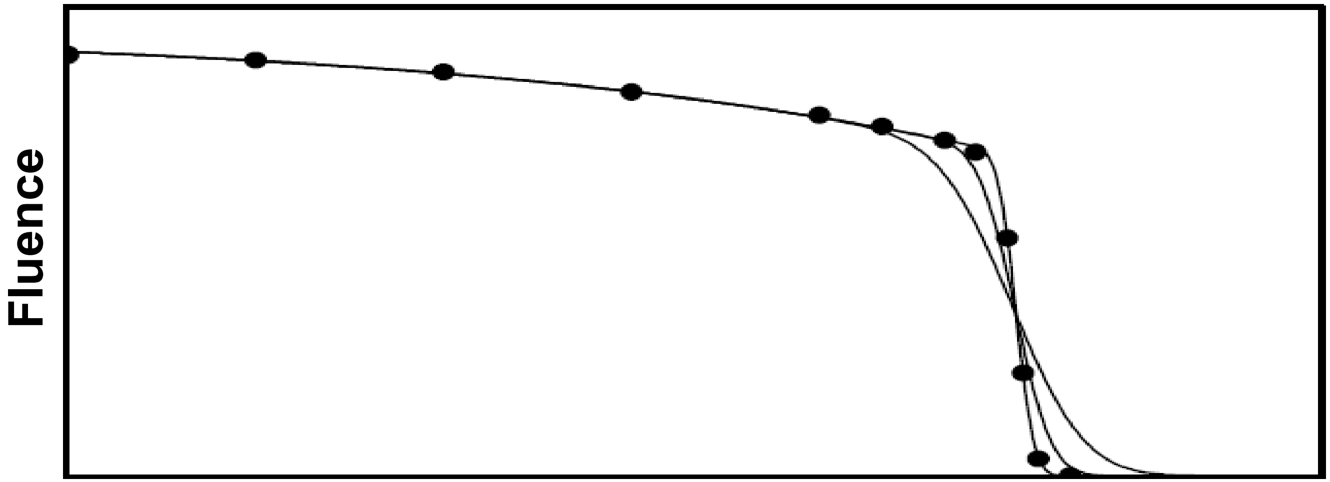
COMPARISON OF PROTON AND PHOTON DEPTH DOSE CHARACTERISTICS

There are three important differences to note in comparing these curves

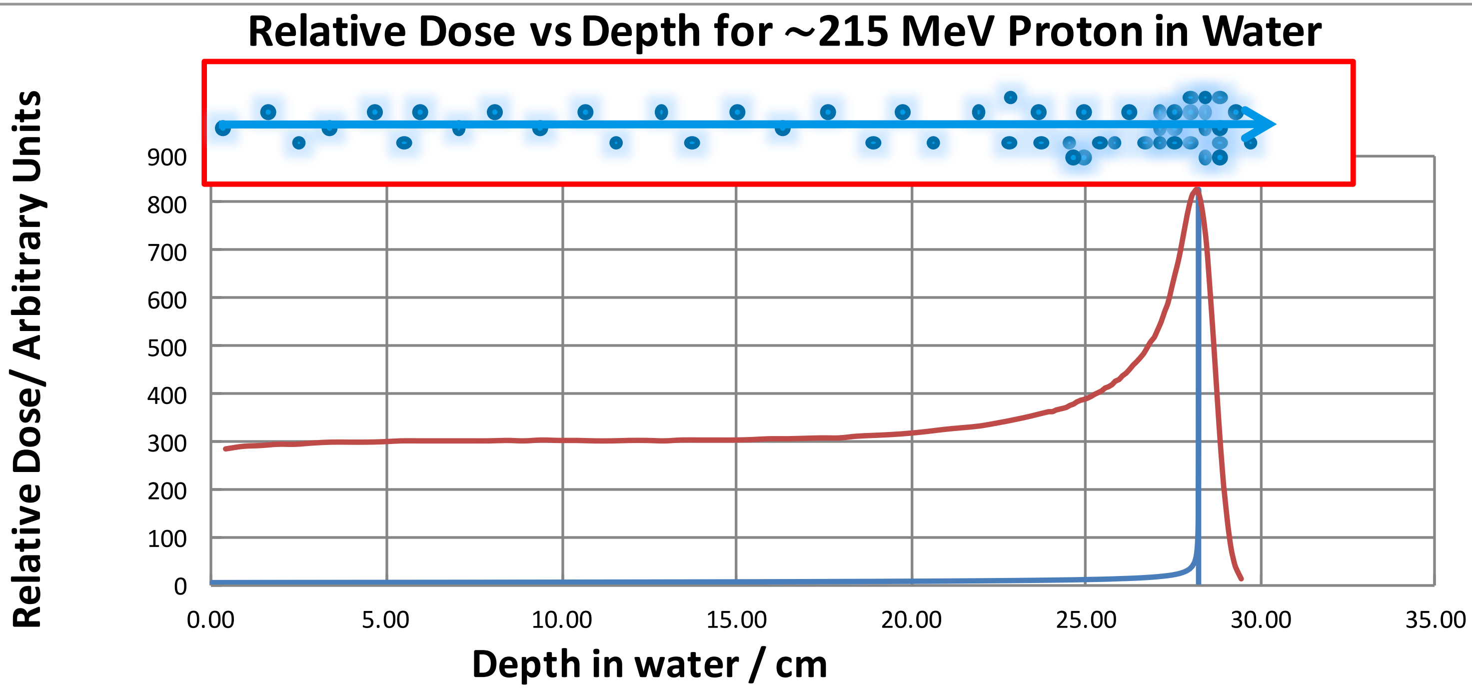


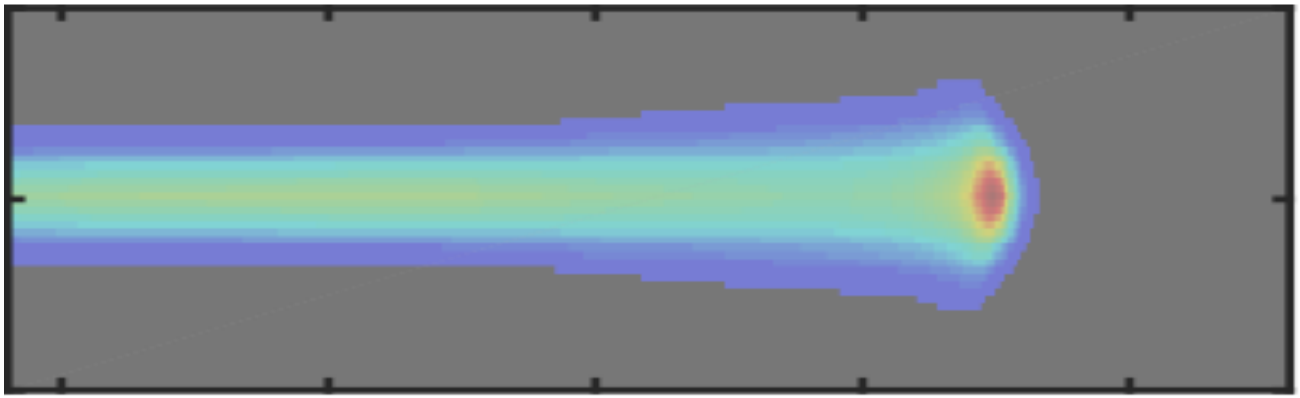
THE BRAGG PEAK



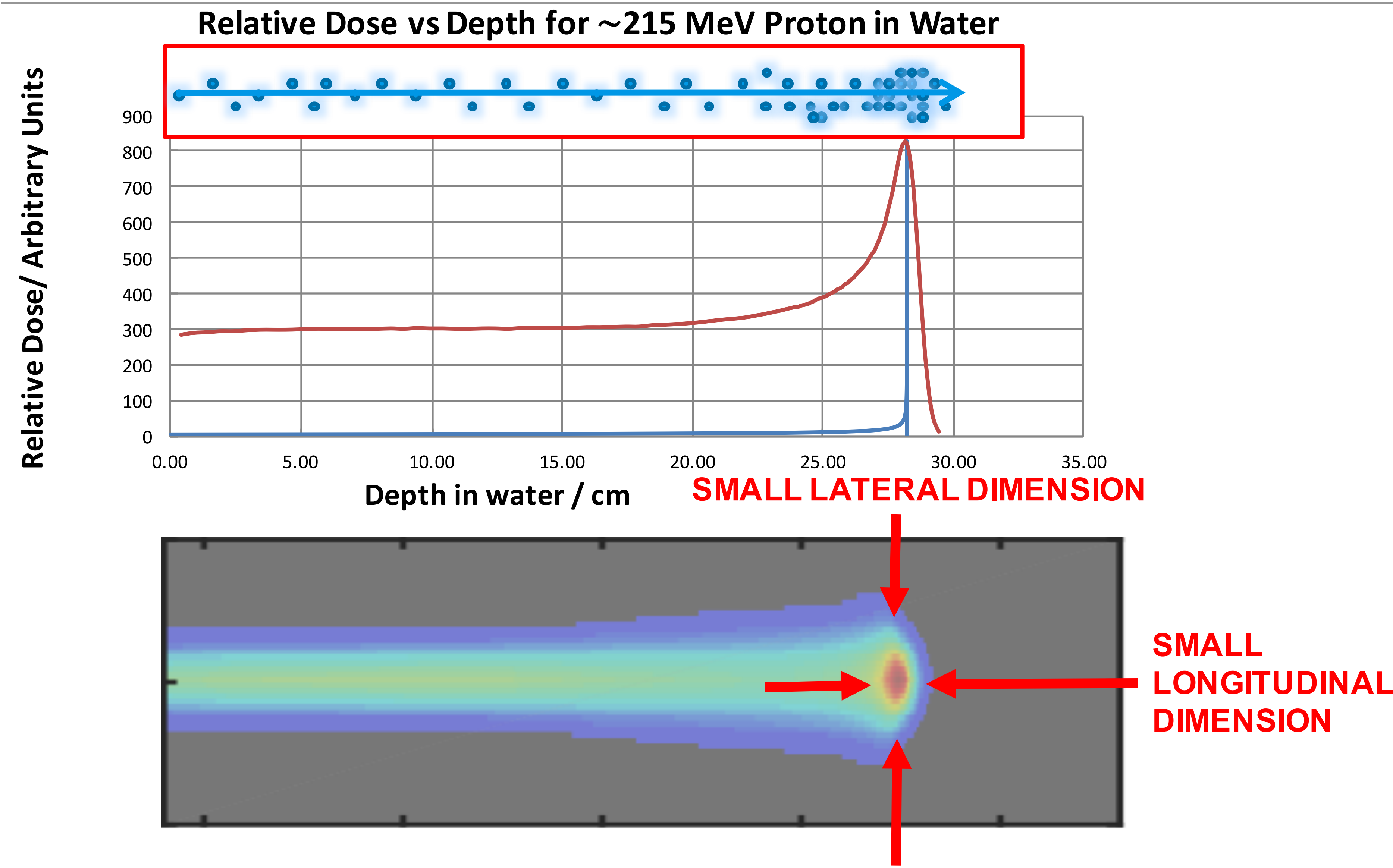


THE BRAGG PEAK



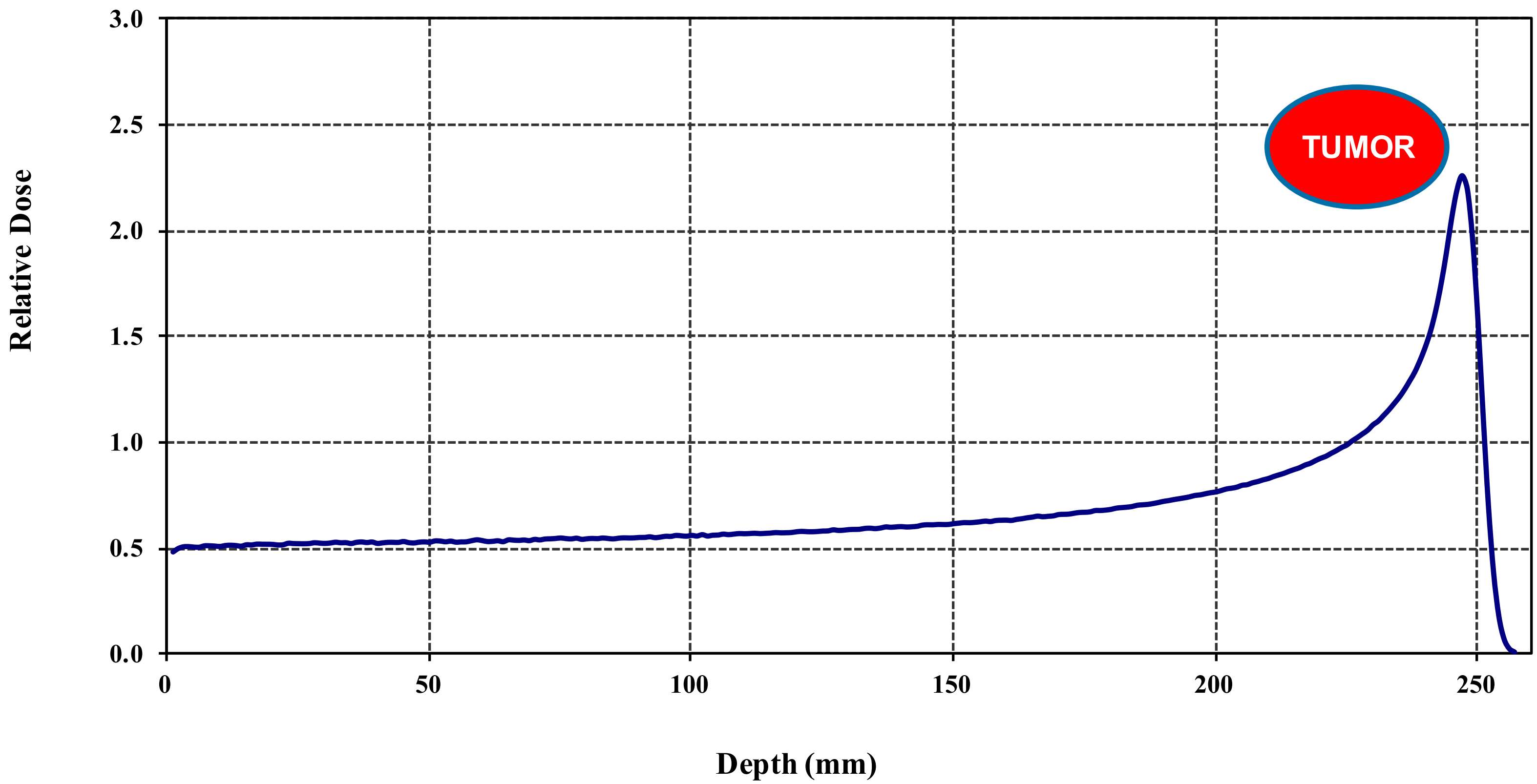


THE BRAGG PEAK



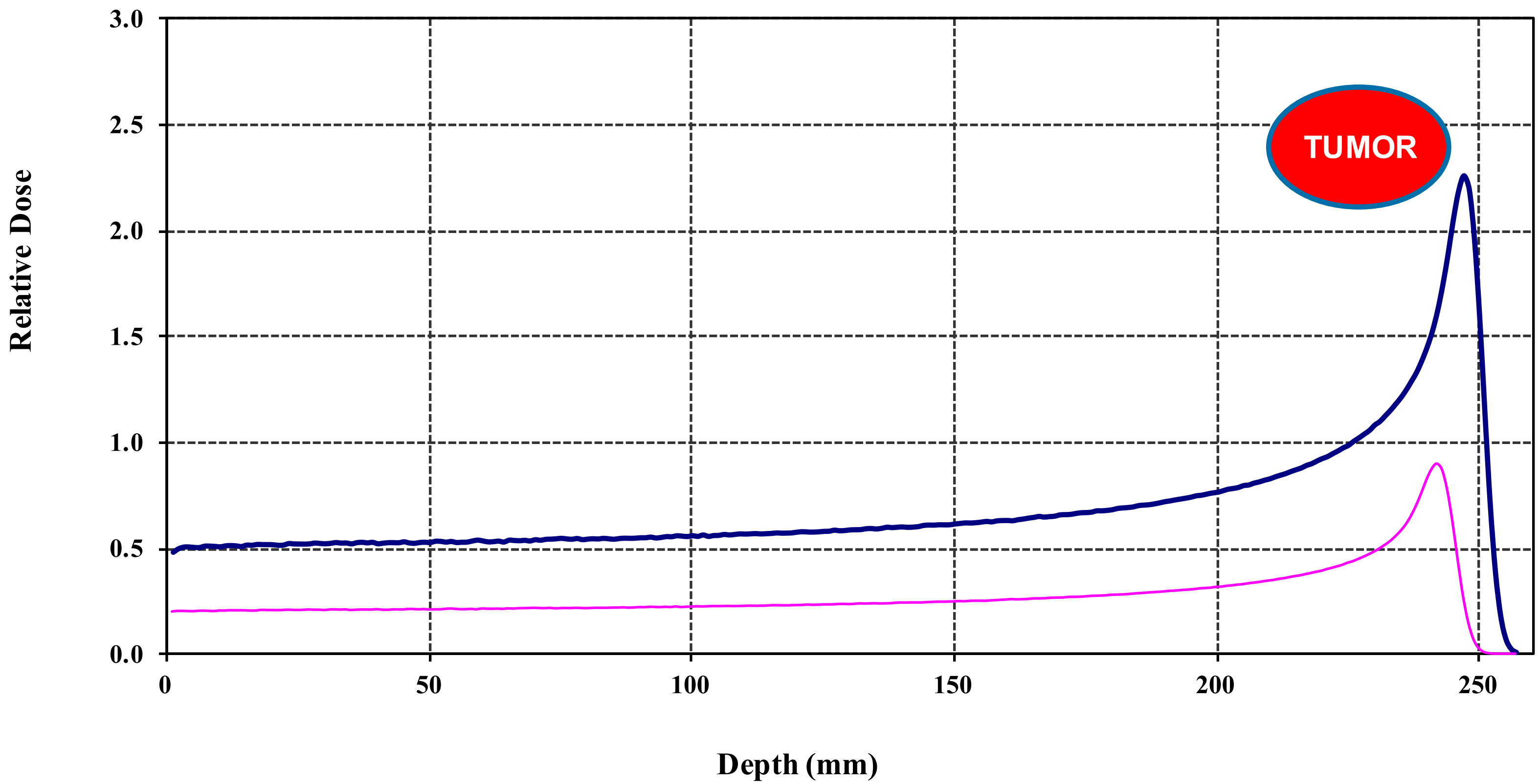
HOW TO SPREAD THE BRAGG PEAK LONGITUDINALY? THE SPREAD OUT BRAGG PEAK (SOBP)

- The dimensions of a typical tumor are very much greater than the width of the pristine Bragg peak



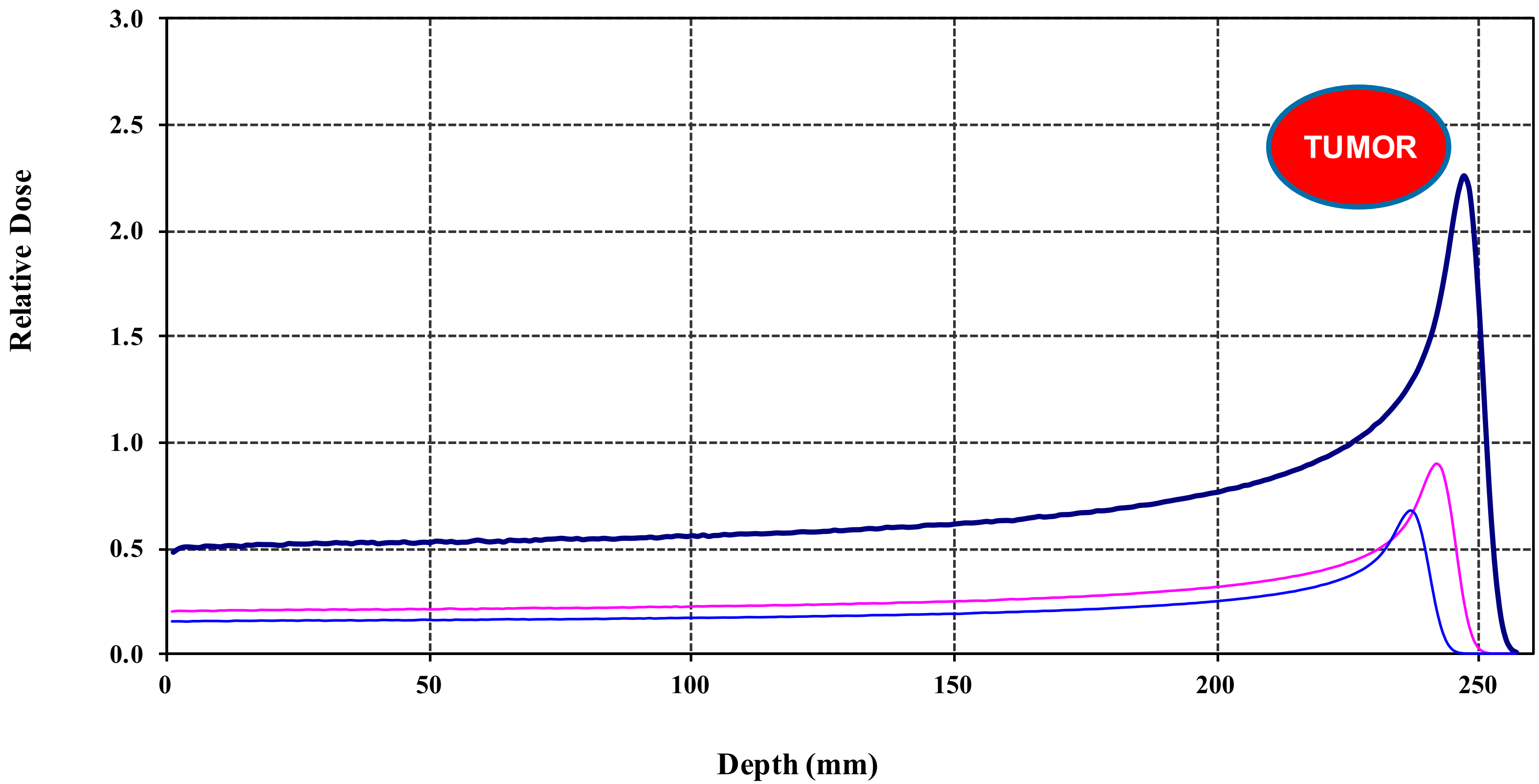
CONSTRUCTING A SOBP

- Bragg peaks with a range of different penetrations (proton beam energies) and intensities are combined



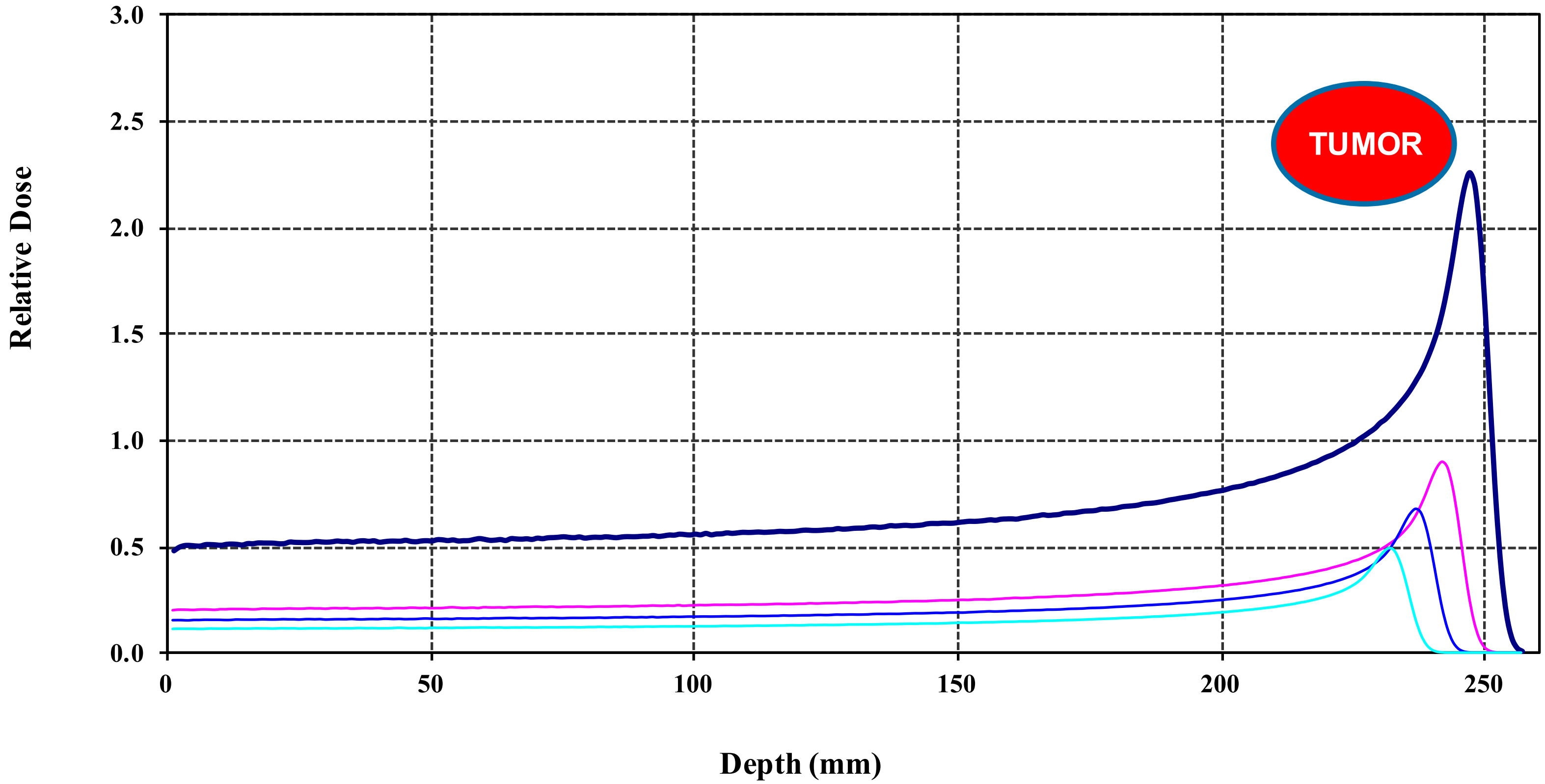
CONSTRUCTING A SOBP

- Bragg peaks with a range of different penetrations (proton beam energies) and intensities are combined



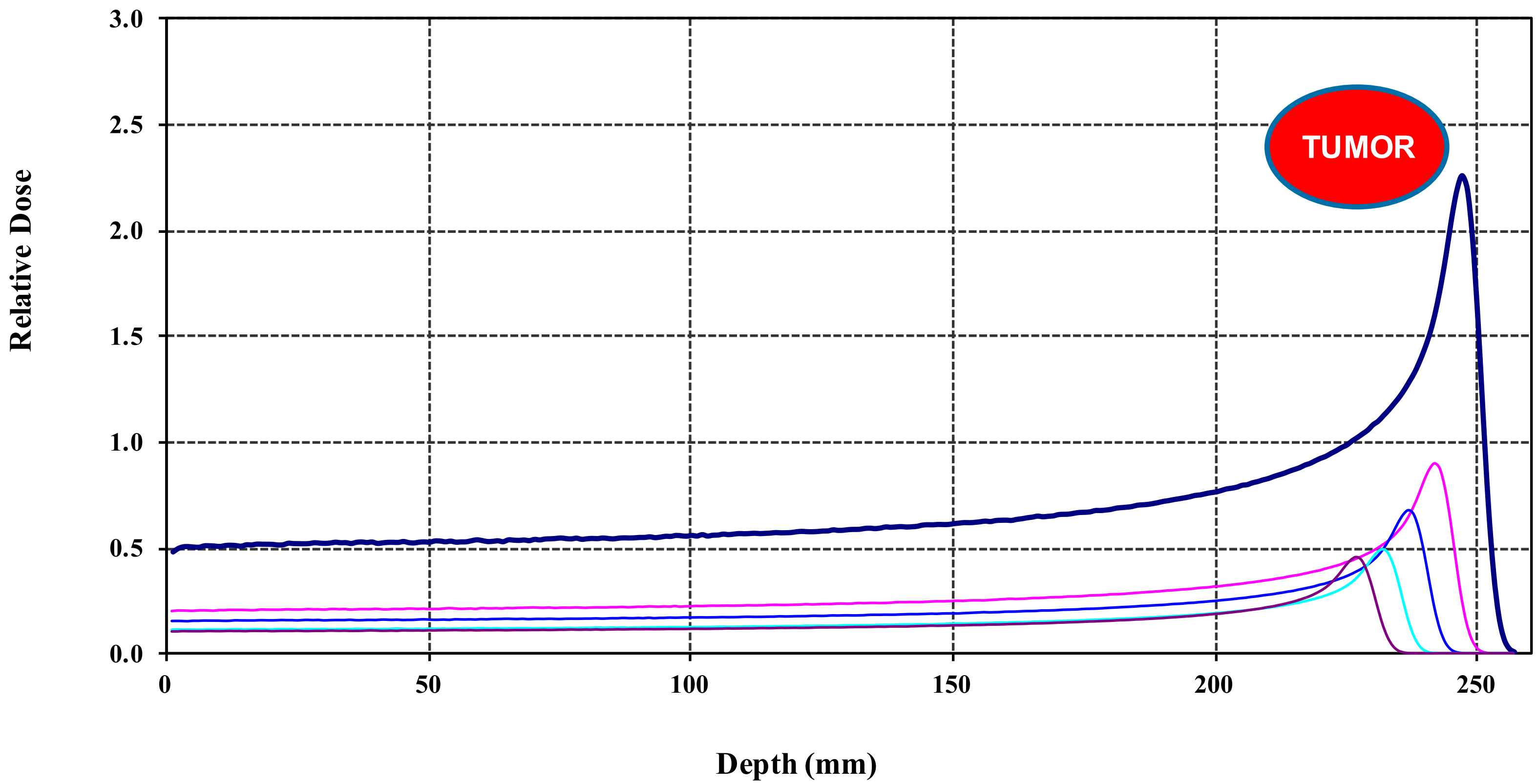
CONSTRUCTING A SOBP

- The range of different penetrations span the tumor volume



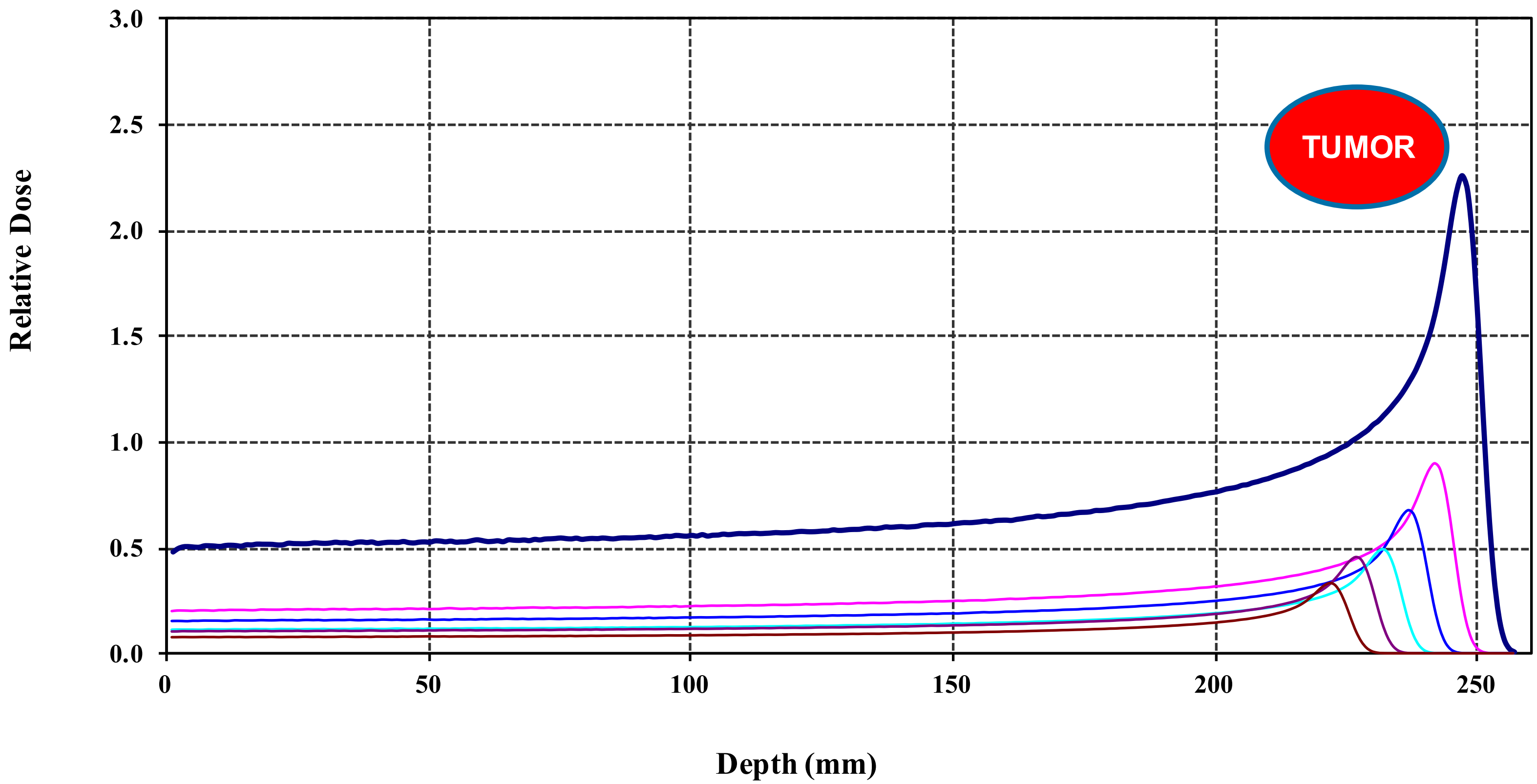
CONSTRUCTING A SOBP

- The range of different penetrations span the tumor volume



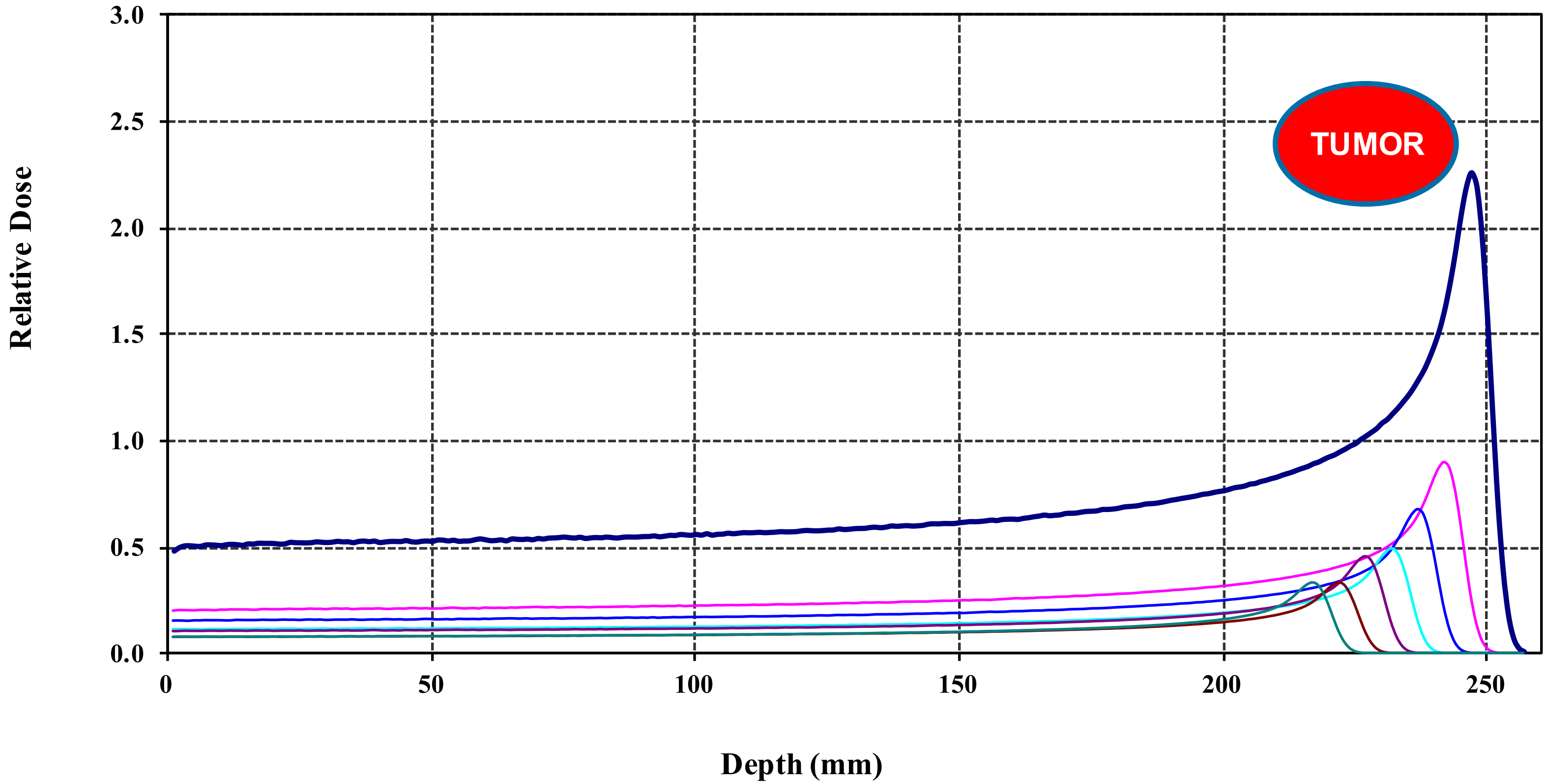
CONSTRUCTING A SOBP

- The range of different penetrations span the tumor volume



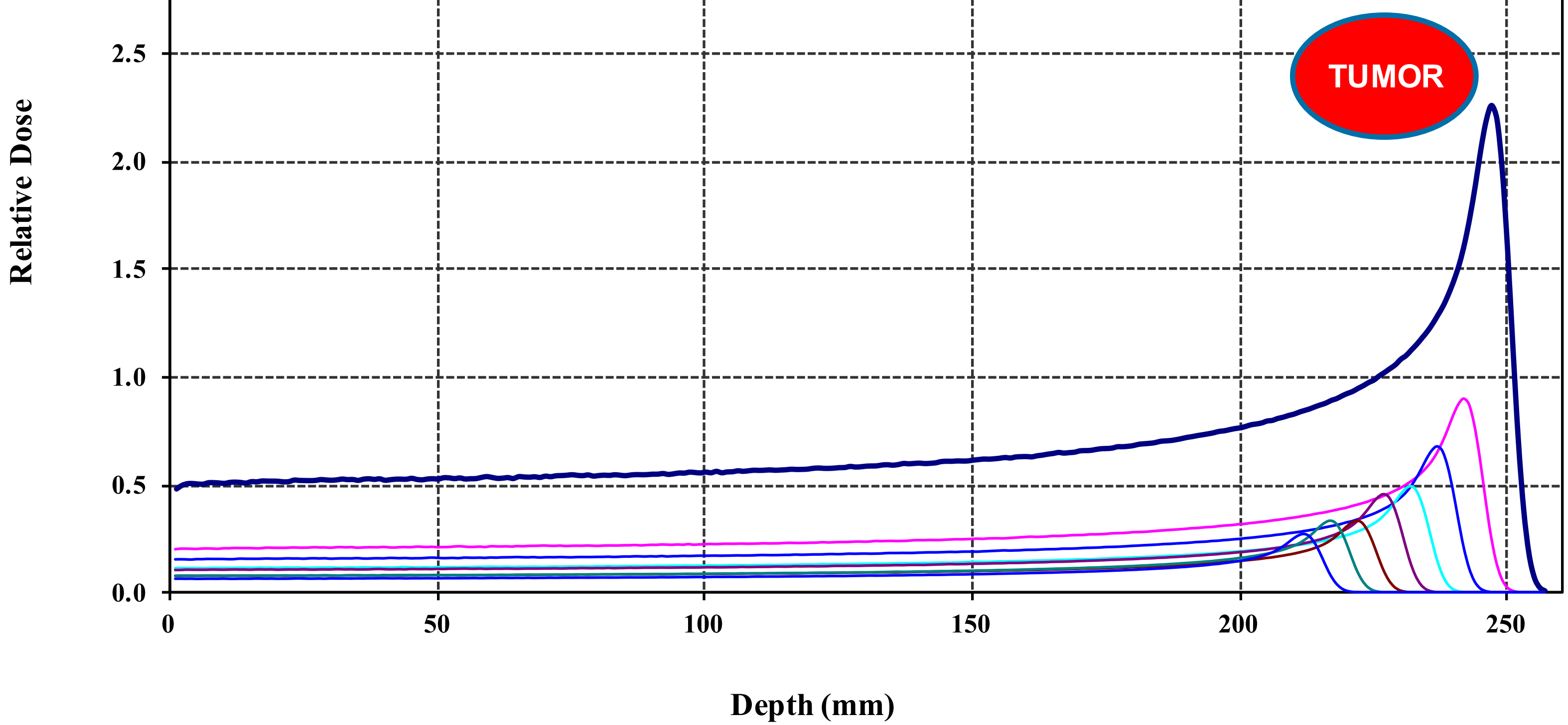
CONSTRUCTING A SOBP

- When all the Bragg peaks are delivered and summed the result is the SOBP.



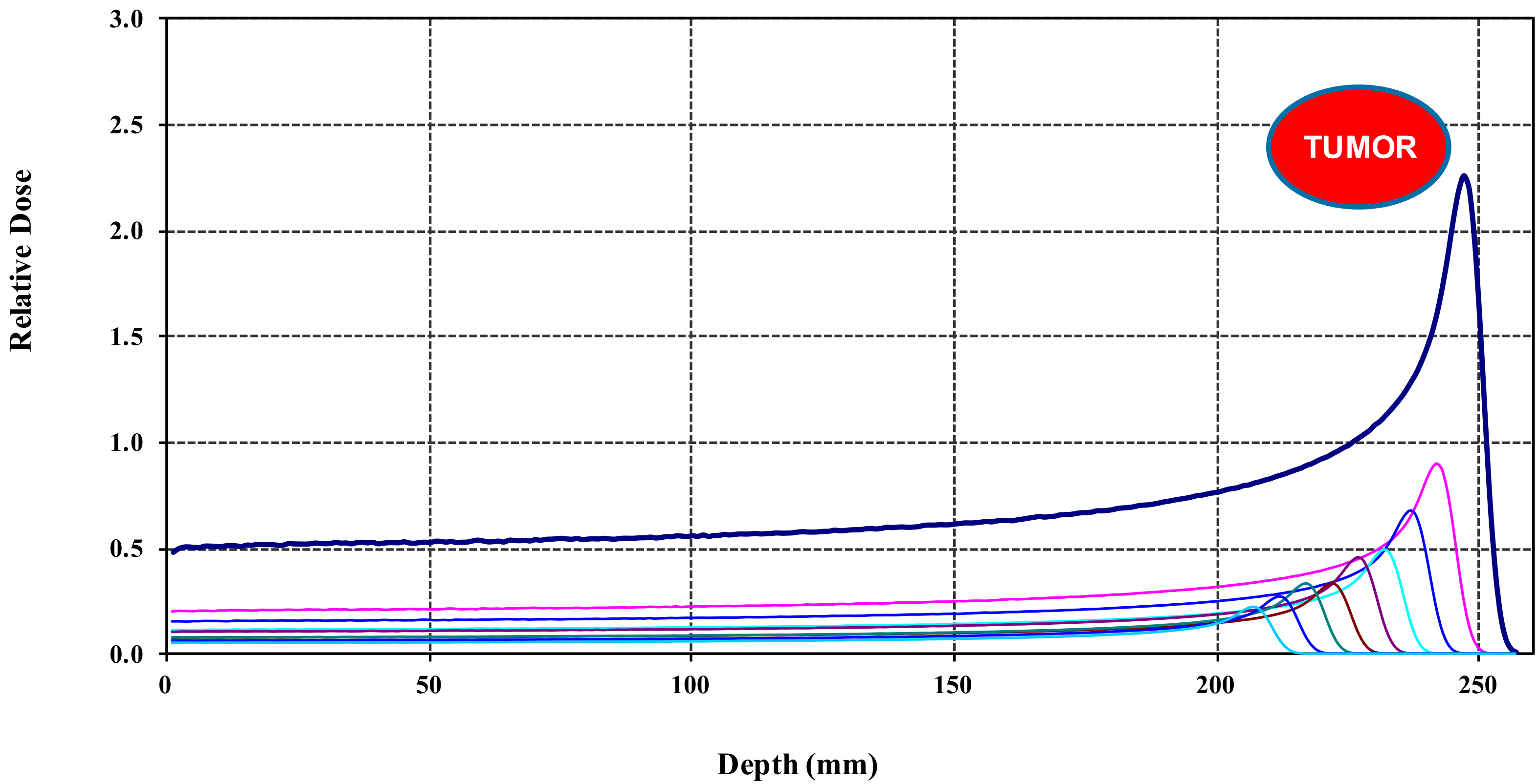
CONSTRUCTING A SOBP

- When all the Bragg peaks are delivered and summed the result is the SOBP.



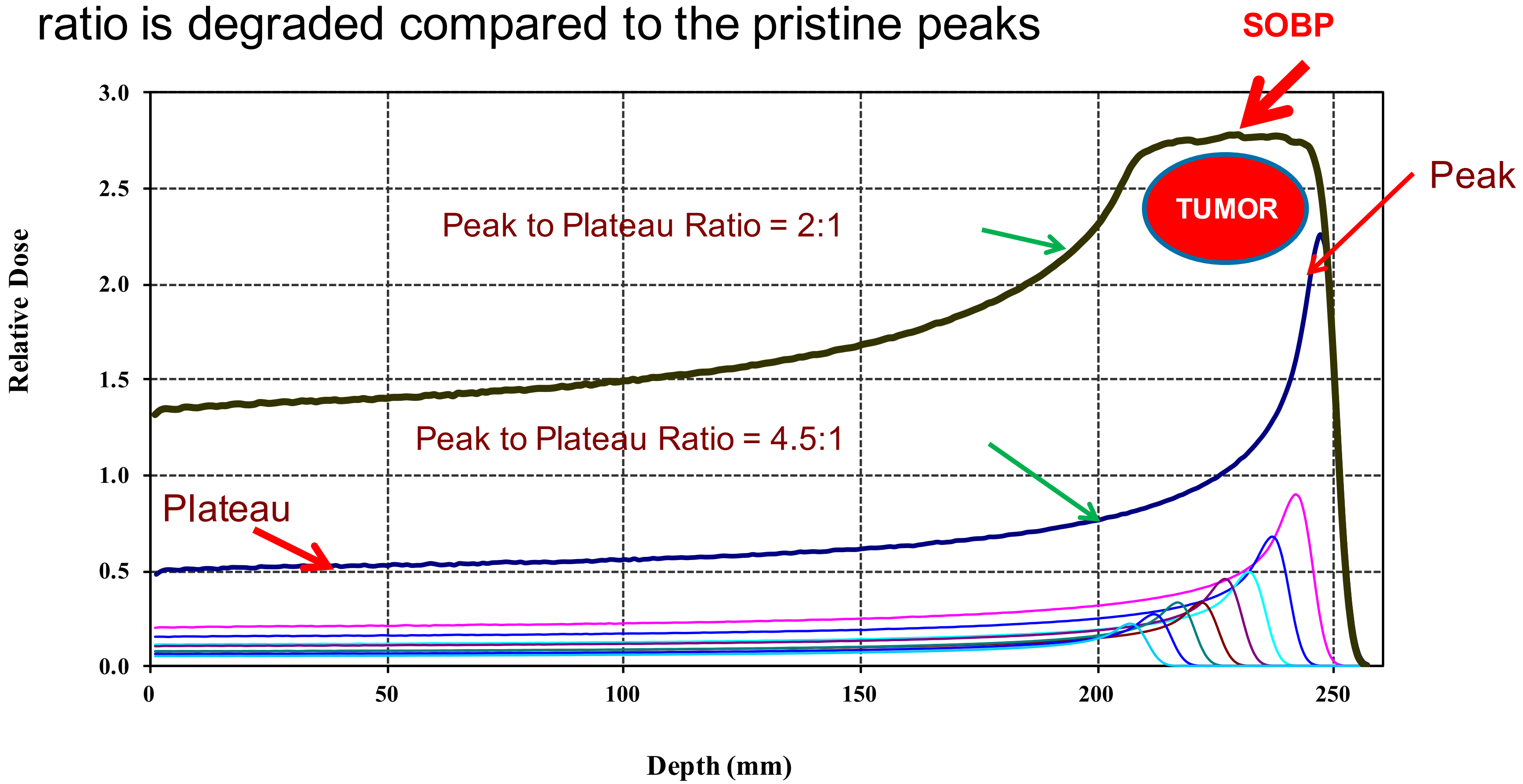
CONSTRUCTING A SOBP

- When all the Bragg peaks are delivered and summed the result is the SOBP.



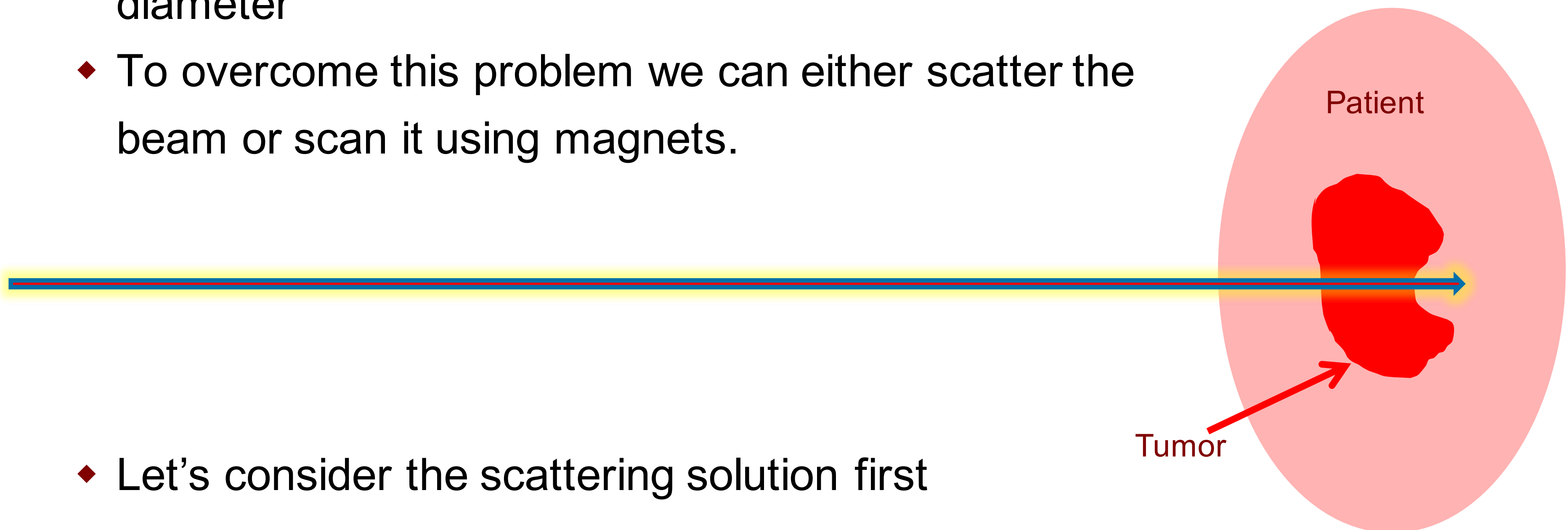
THE SOBP

- The SOBP has flat dose distribution across the tumor volume
- A result of the summing process is that the peak to plateau dose ratio is degraded compared to the pristine peaks



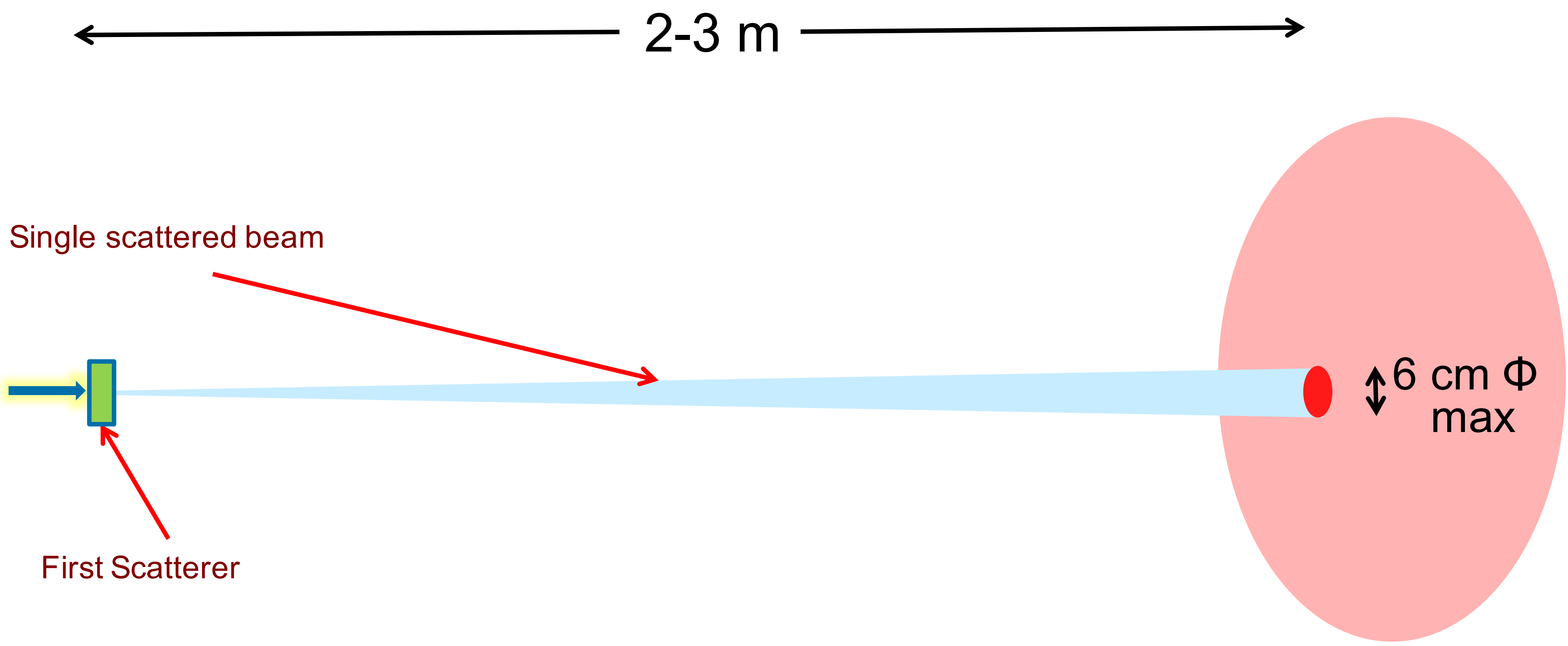
ANOTHER PROBLEM

- So we have solved the problem of how to cover the tumor volume in depth with the narrow Bragg peak
- But there is another problem. The proton beam emerging from the beamline also has small lateral dimensions, being only about 10 mm in diameter
- To overcome this problem we can either scatter the beam or scan it using magnets.



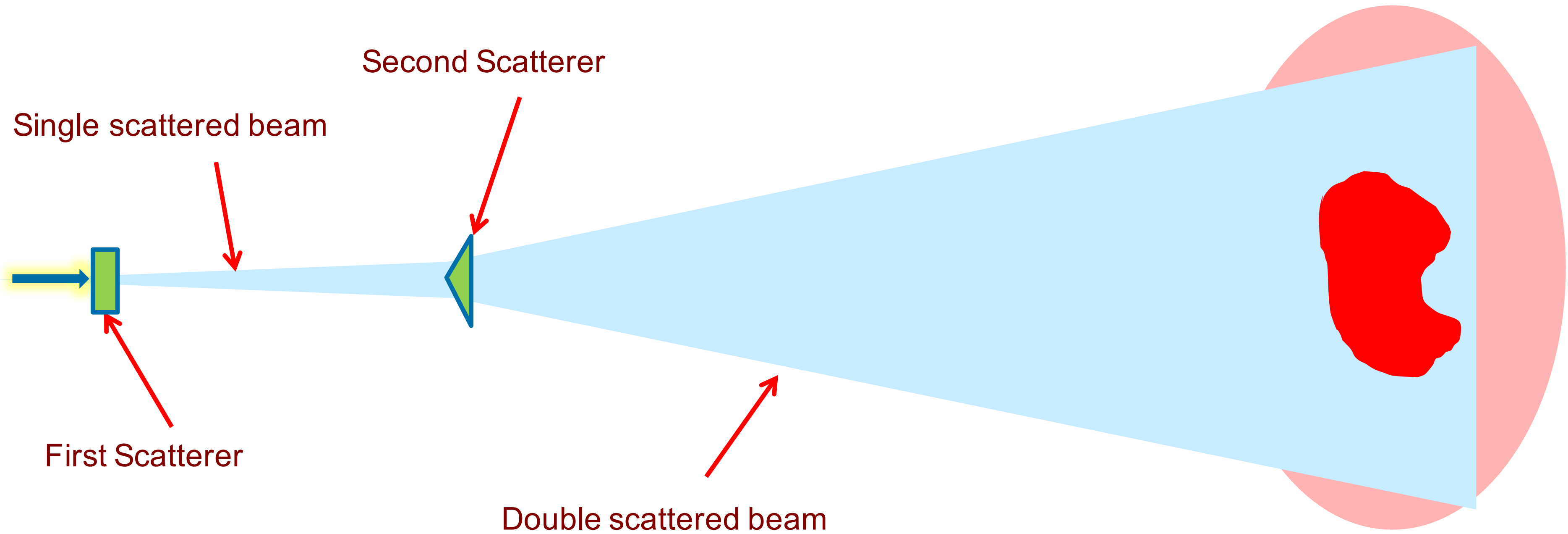
- Let's consider the scattering solution first

SINGLE SCATTERING



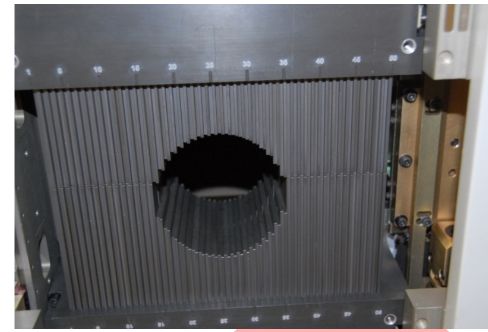
DOUBLE SCATTERING

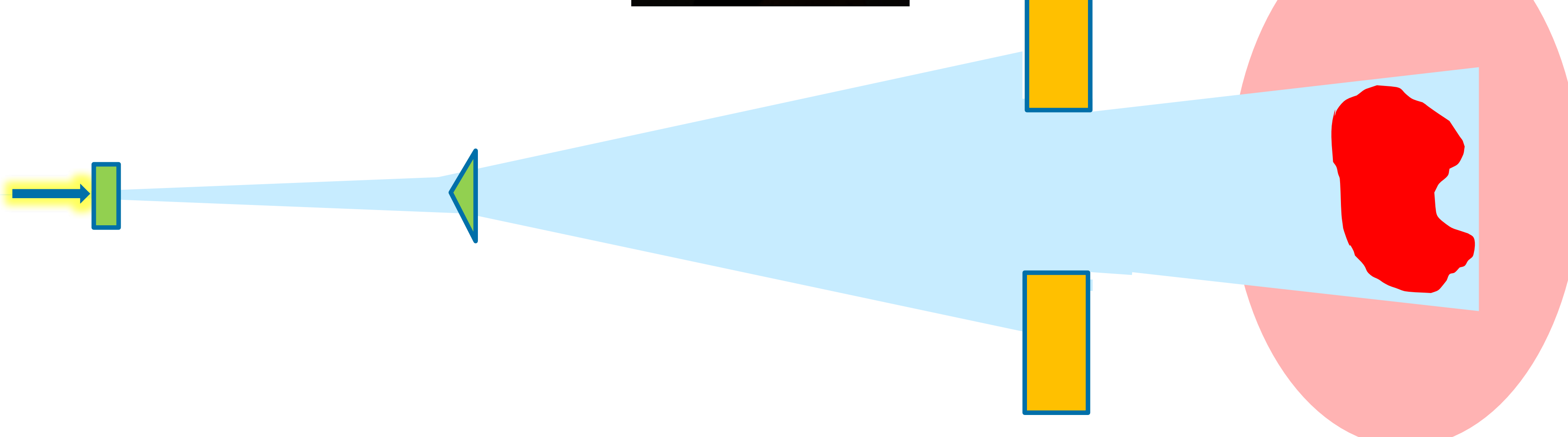
- To get large field sizes two scatterers must be used
- But there is still a field size limitation of ~ 22-25 cm



APERTURE

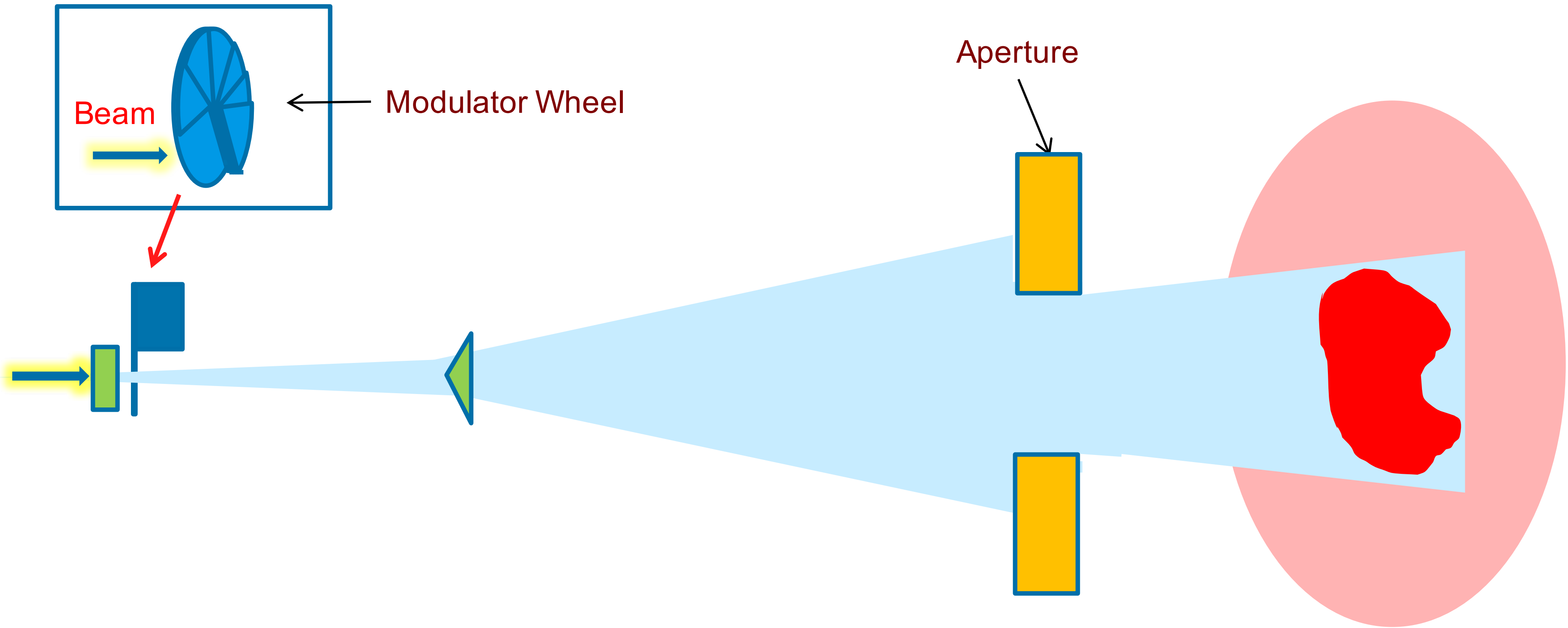
- An aperture shapes the beam in the lateral dimensions.



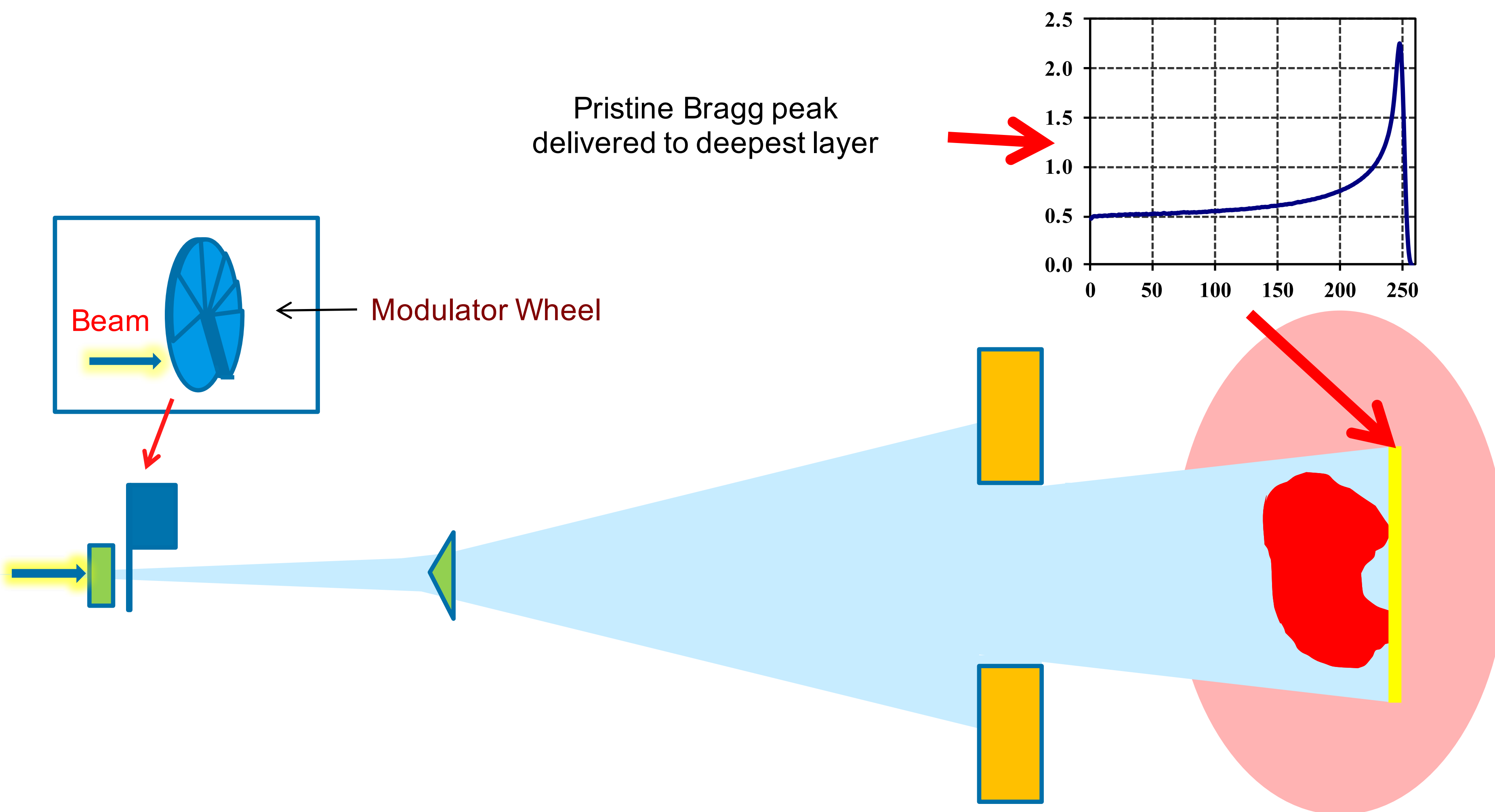


RANGE MODULATOR

- A modulator wheel with steps of different thickness is rotated in the beam path to spread the beam in depth across the tumor.

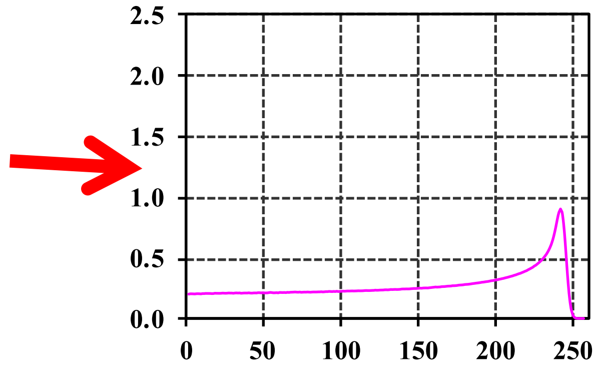


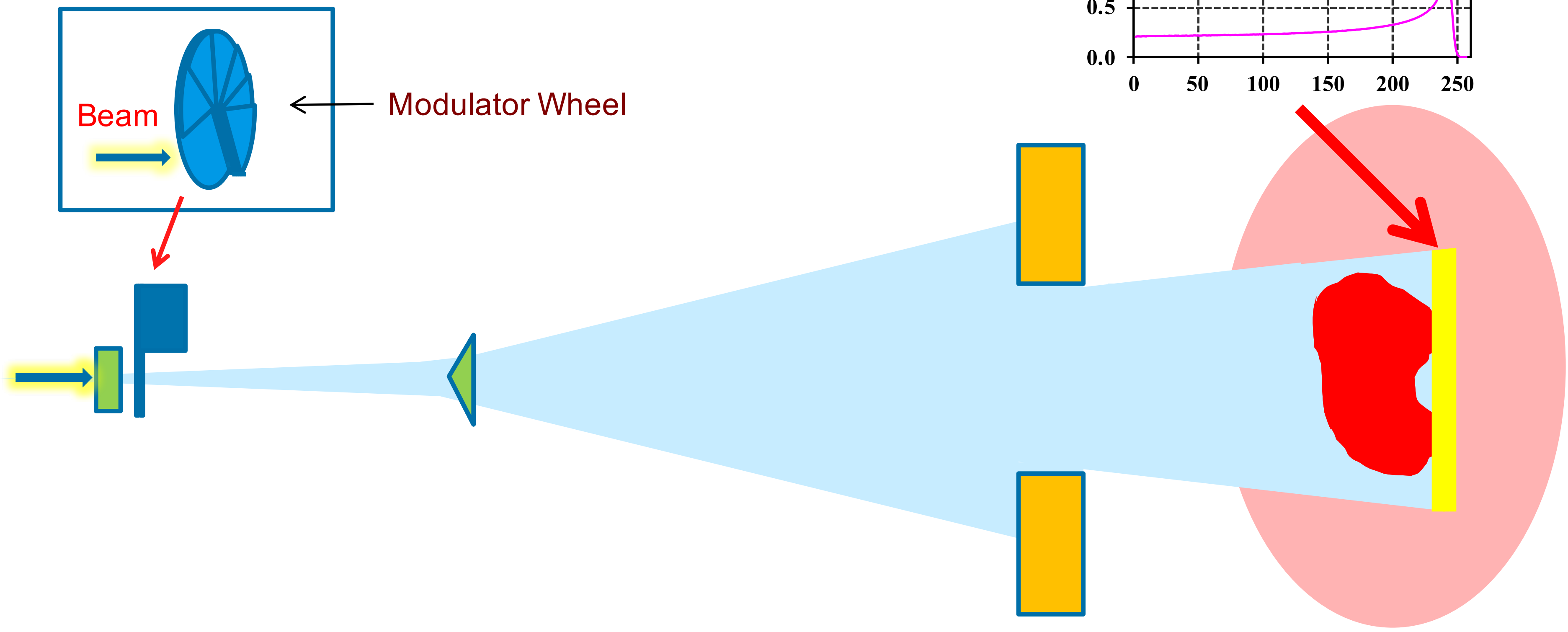
RANGE MODULATOR



RANGE MODULATOR

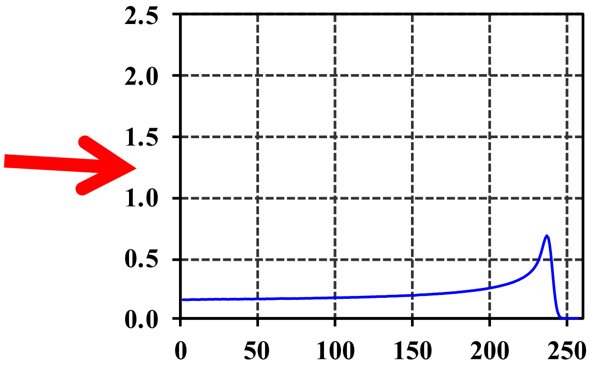
A second pristine Bragg peak
is delivered to the target volume
with less intensity

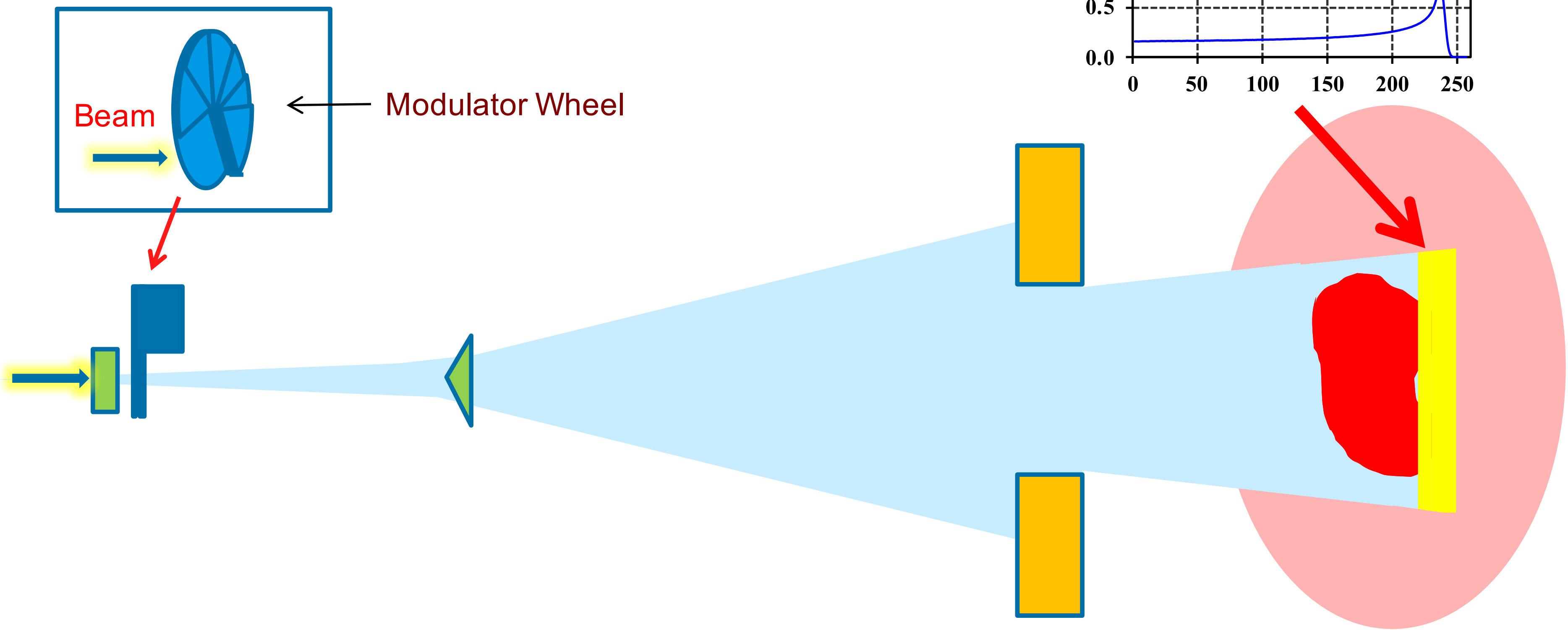




RANGE MODULATOR

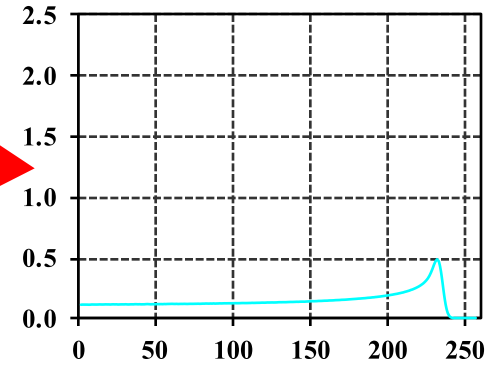
A third pristine Bragg peak
is delivered to the target volume
with less intensity

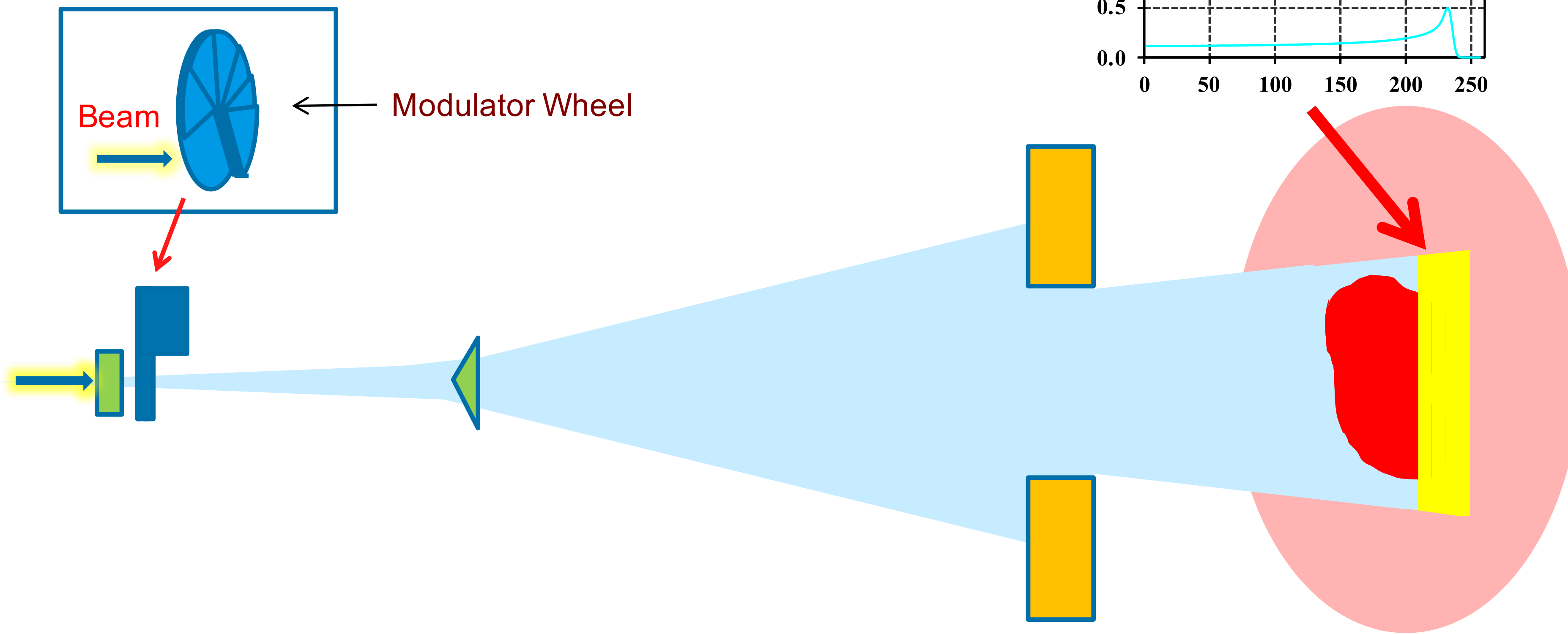




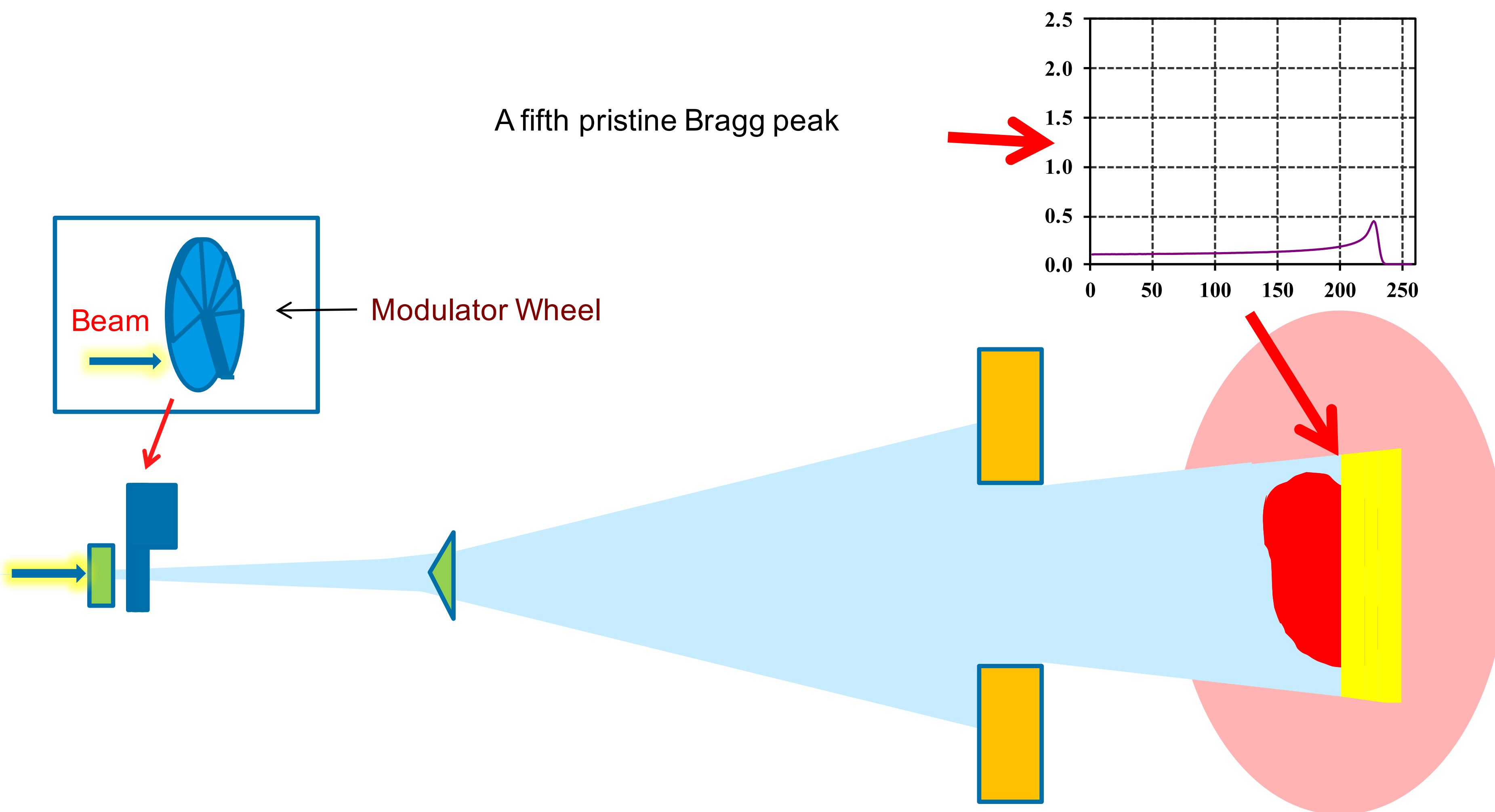
RANGE MODULATOR

A fourth pristine Bragg peak
is delivered to the target volume
with less intensity

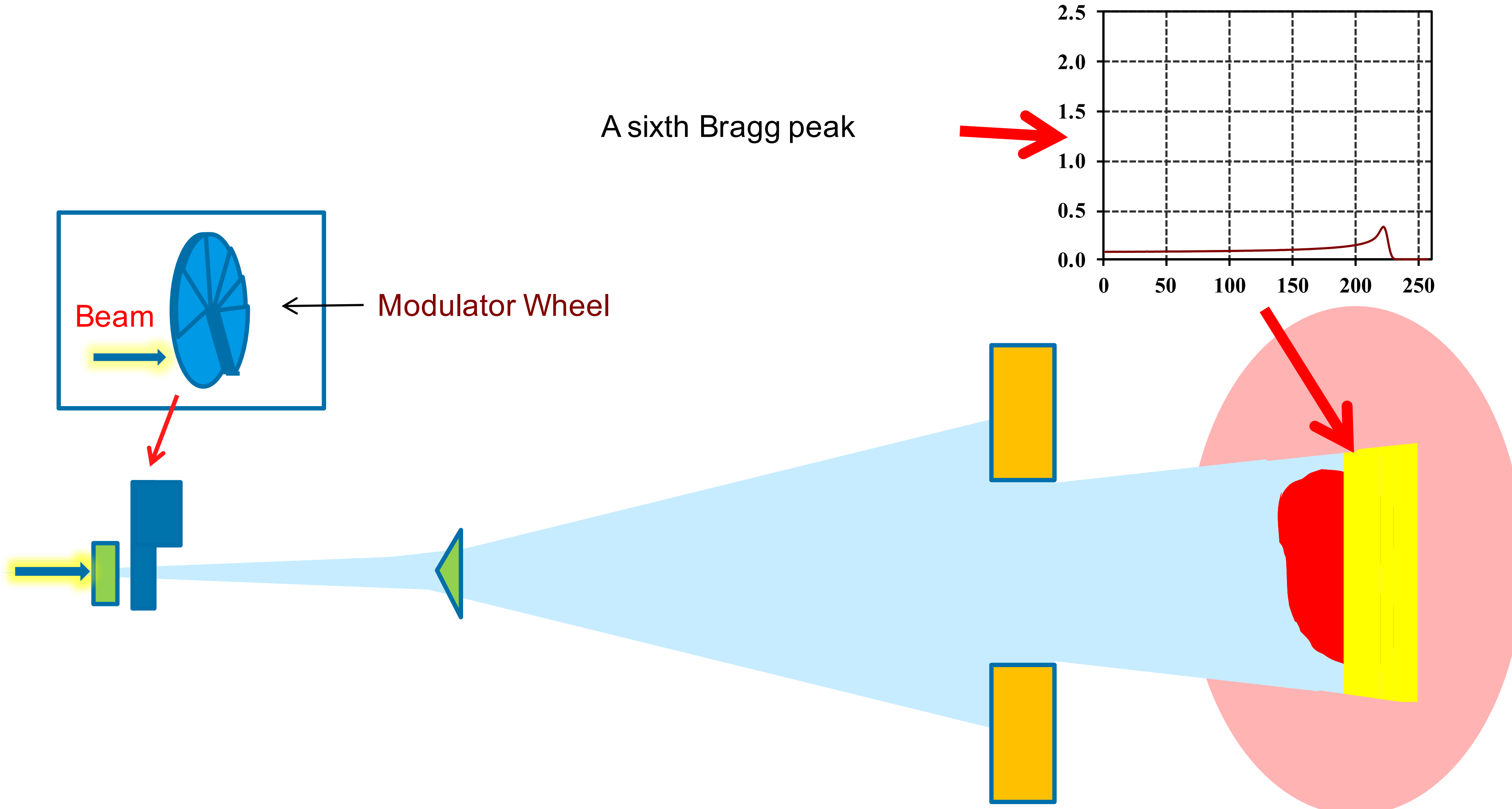




RANGE MODULATOR

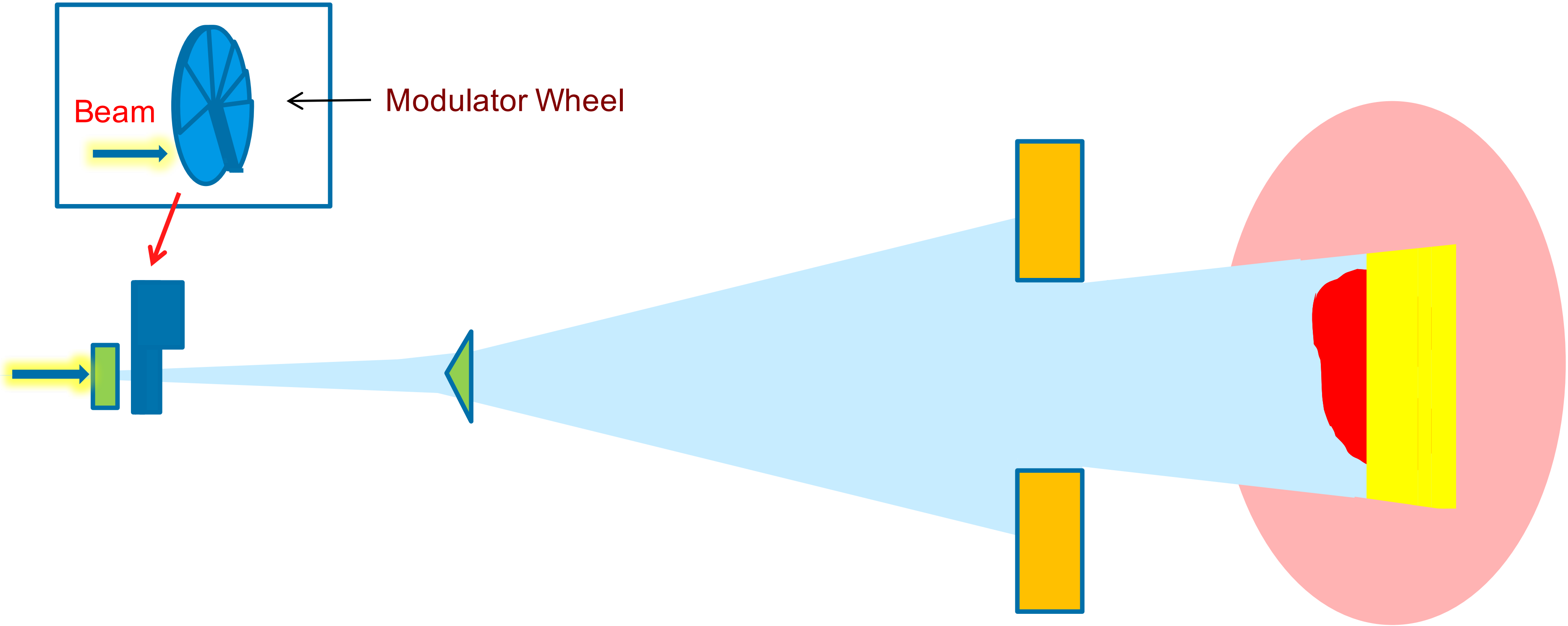


RANGE MODULATOR



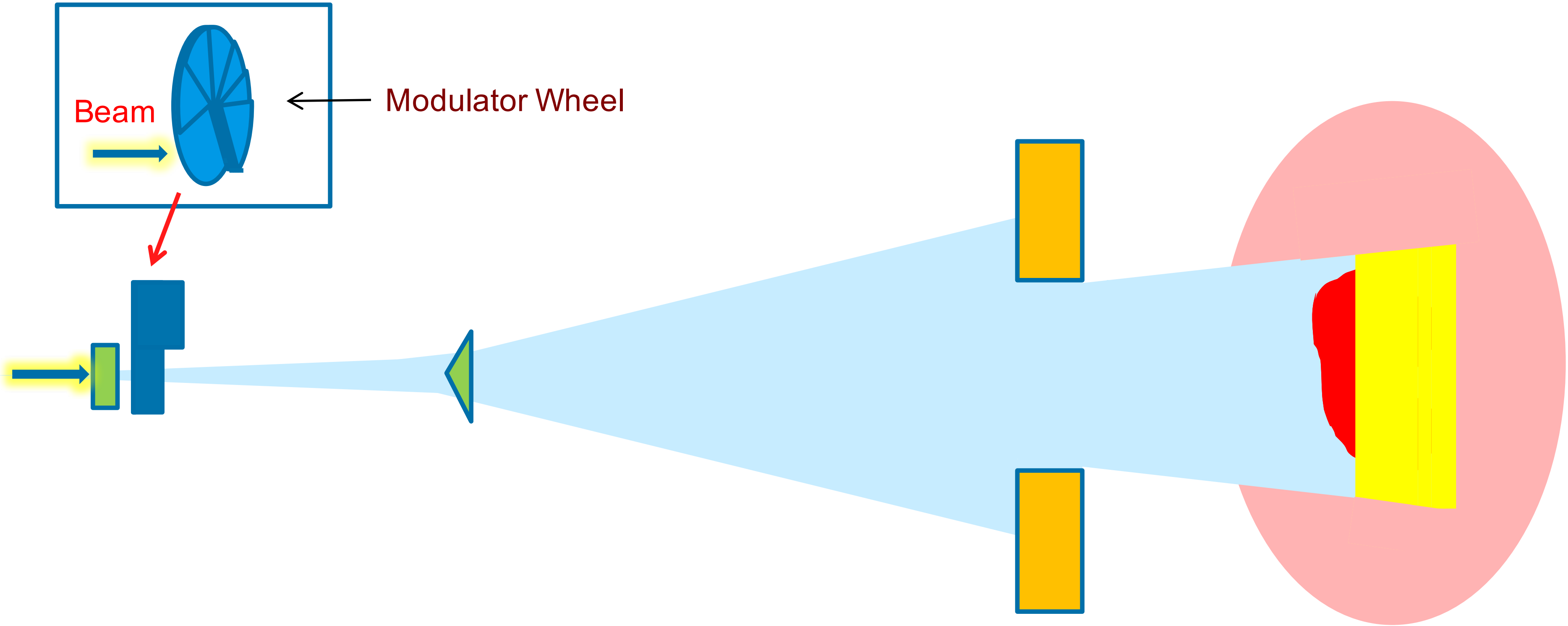
RANGE MODULATOR

And so on



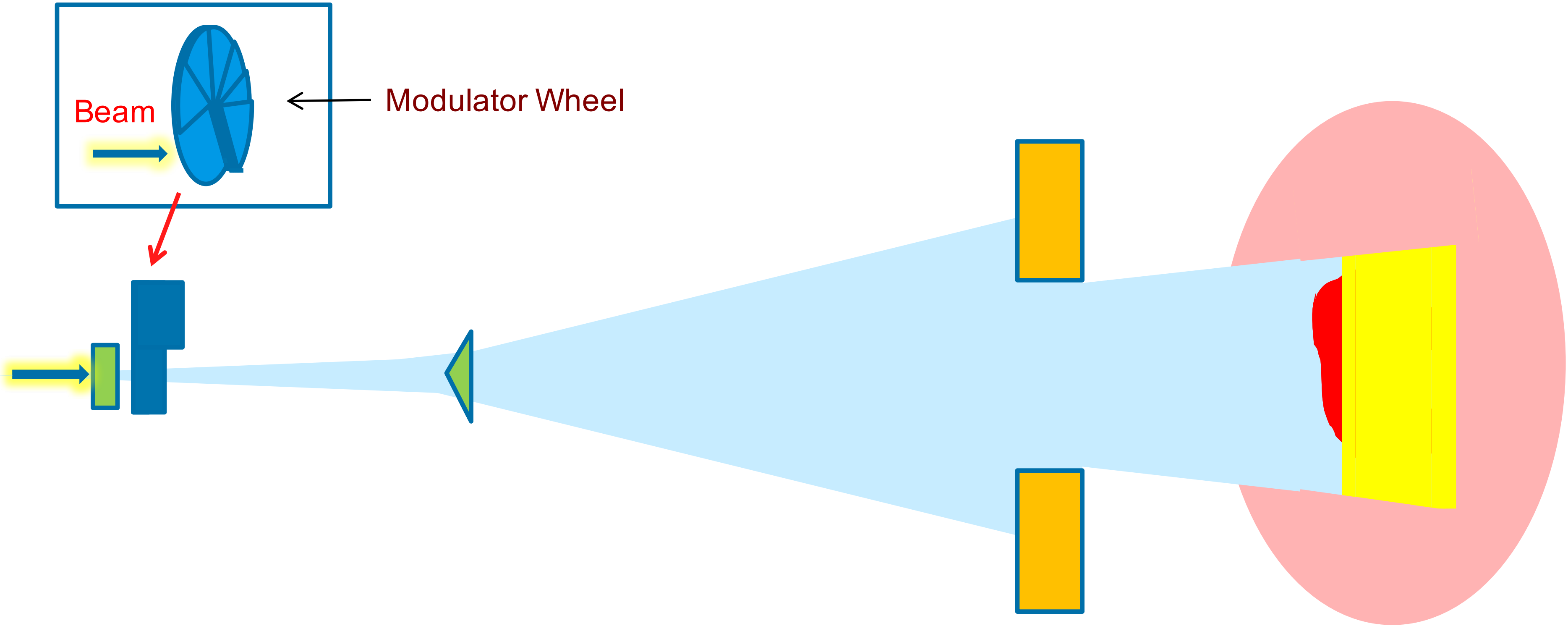
RANGE MODULATOR

And so on, and on …



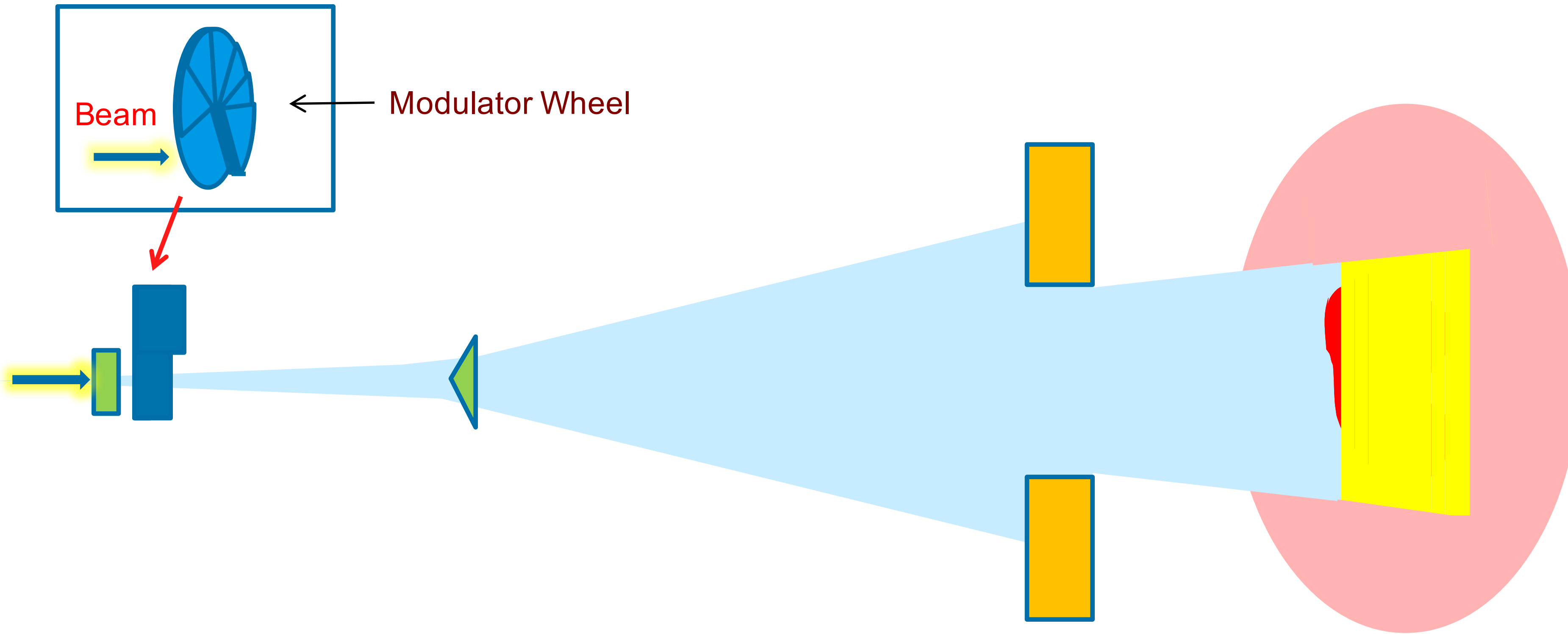
RANGE MODULATOR

And so on, and on, and on …



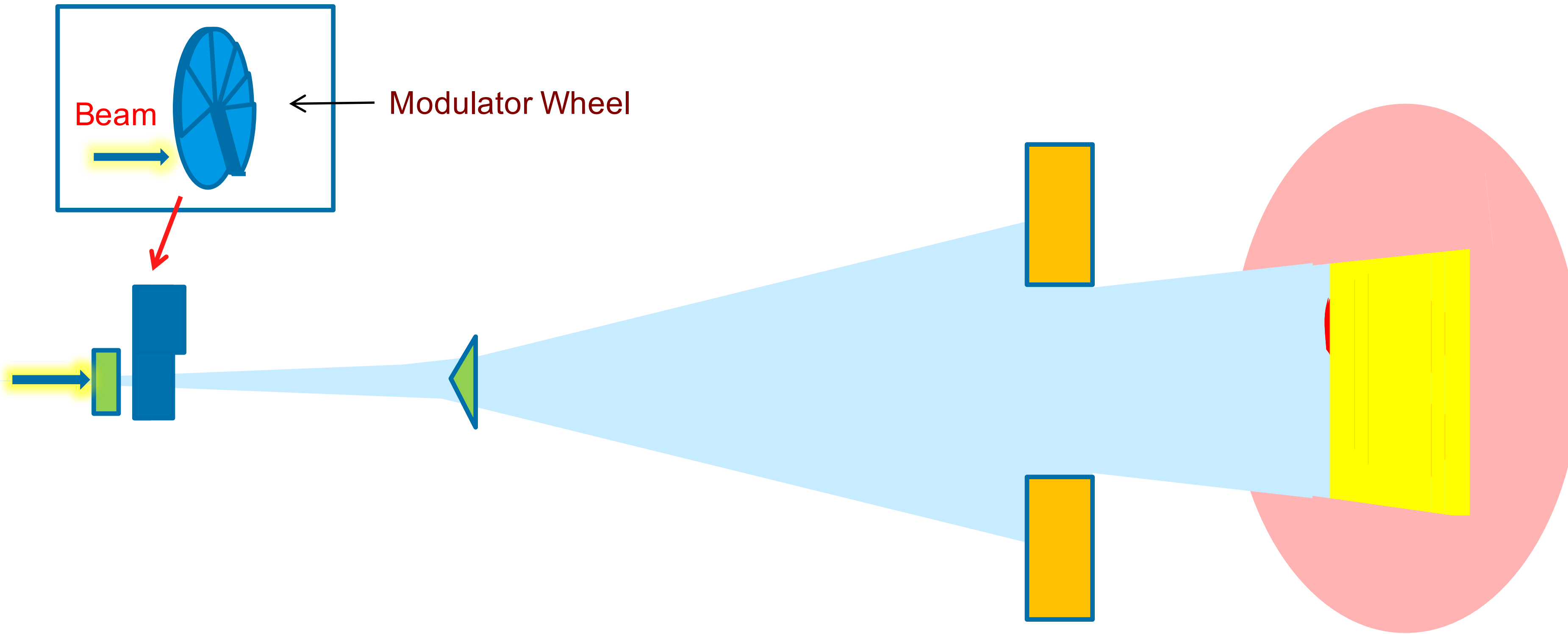
RANGE MODULATOR

And so on, and on, and on, and on …



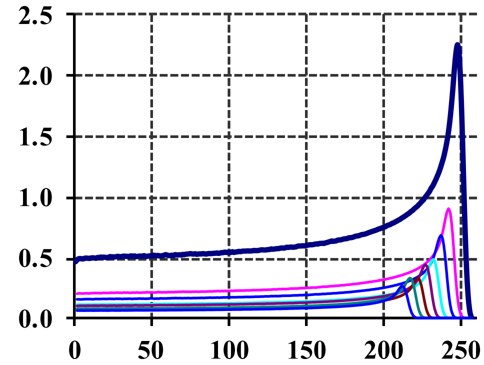
RANGE MODULATOR

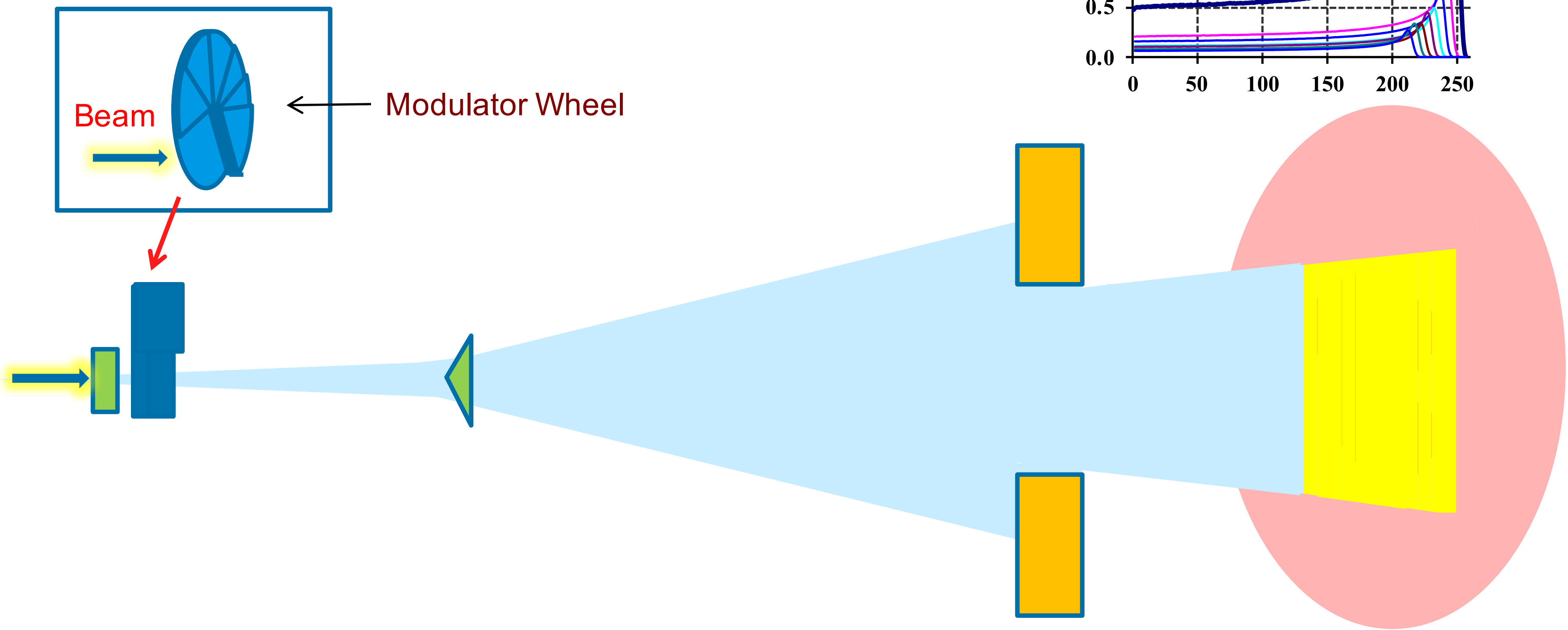
And so on, and on, and on, and on, and on …



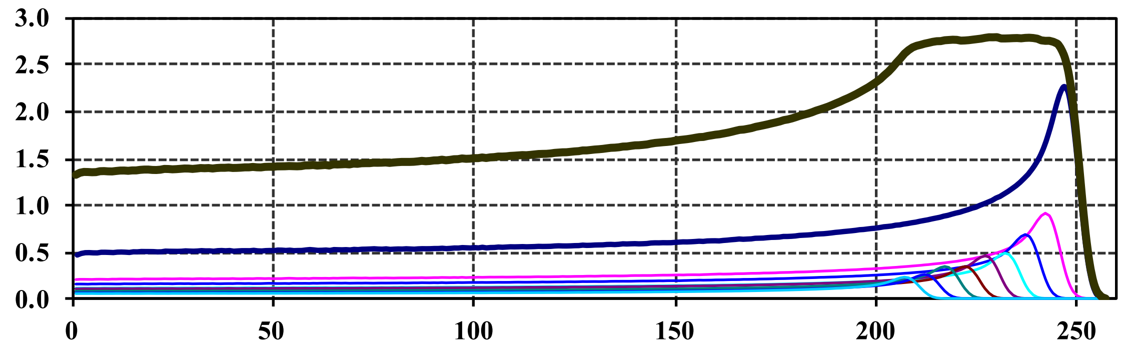
RANGE MODULATOR

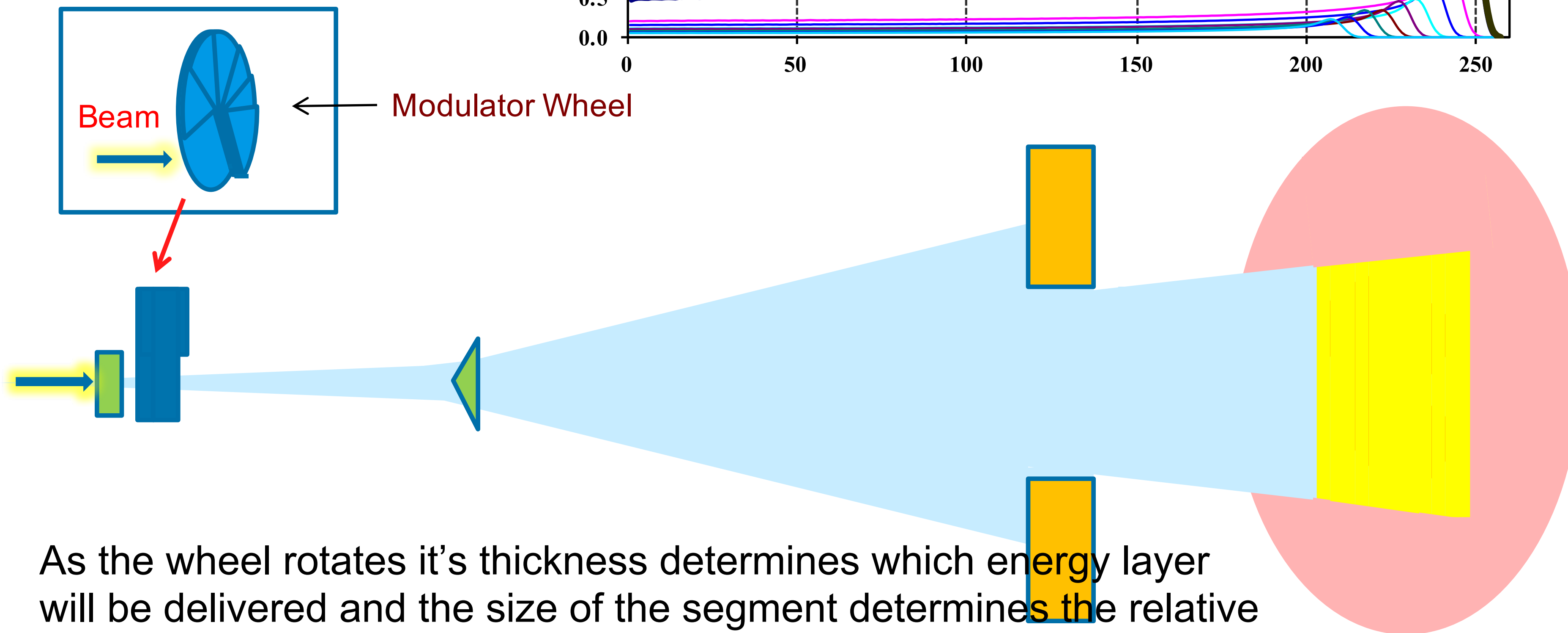
Until all the peaks are delivered





RANGE MODULATOR

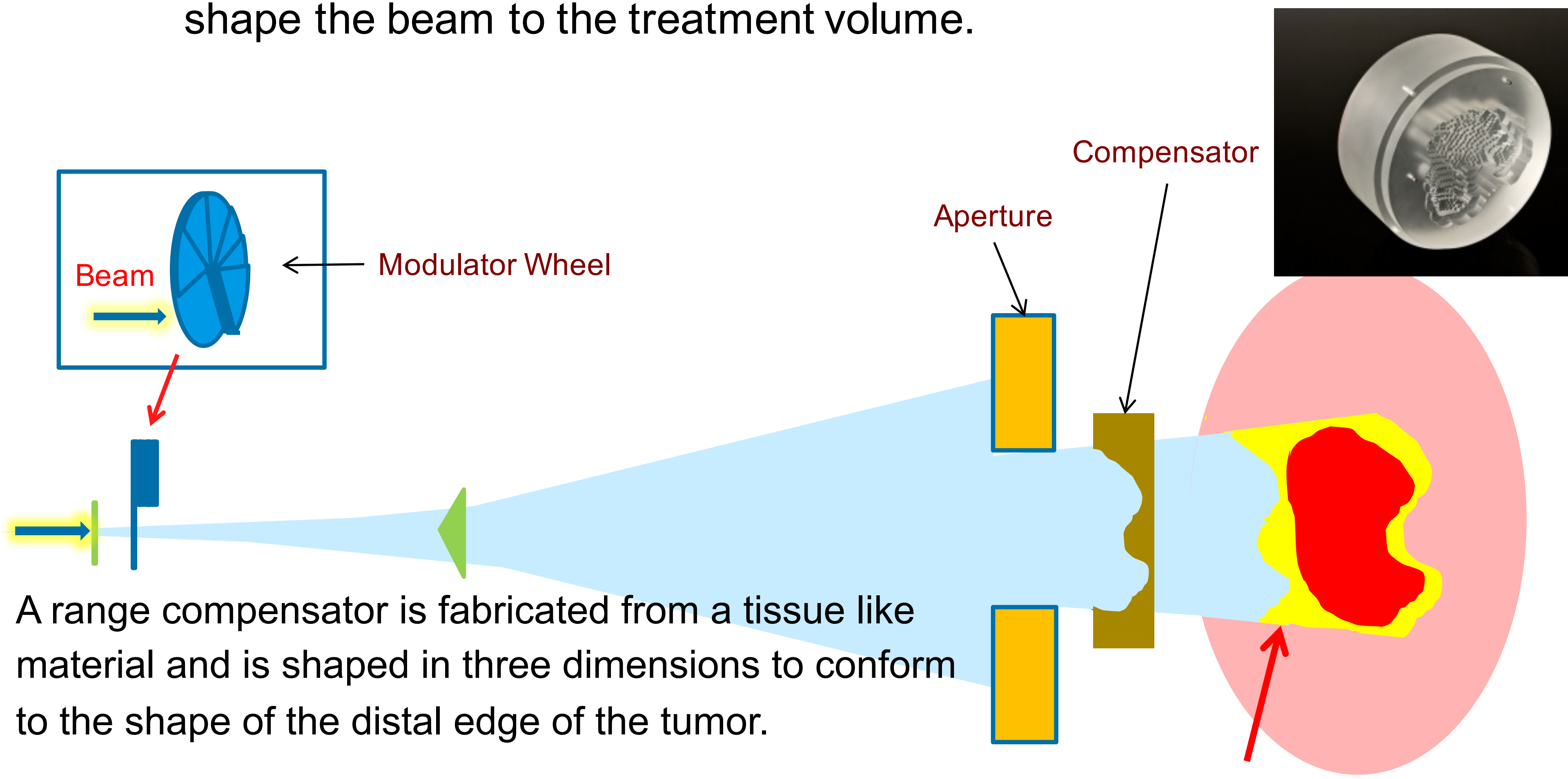




As the wheel rotates it’s thickness determines which energy layer will be delivered and the size of the segment determines the relative intensity of the peak delivered at that depth, provided the wheel spins at a constant rate and the incident proton beam intensity is also constant.

RANGE MODULATOR, APERTURE, COMPENSATOR

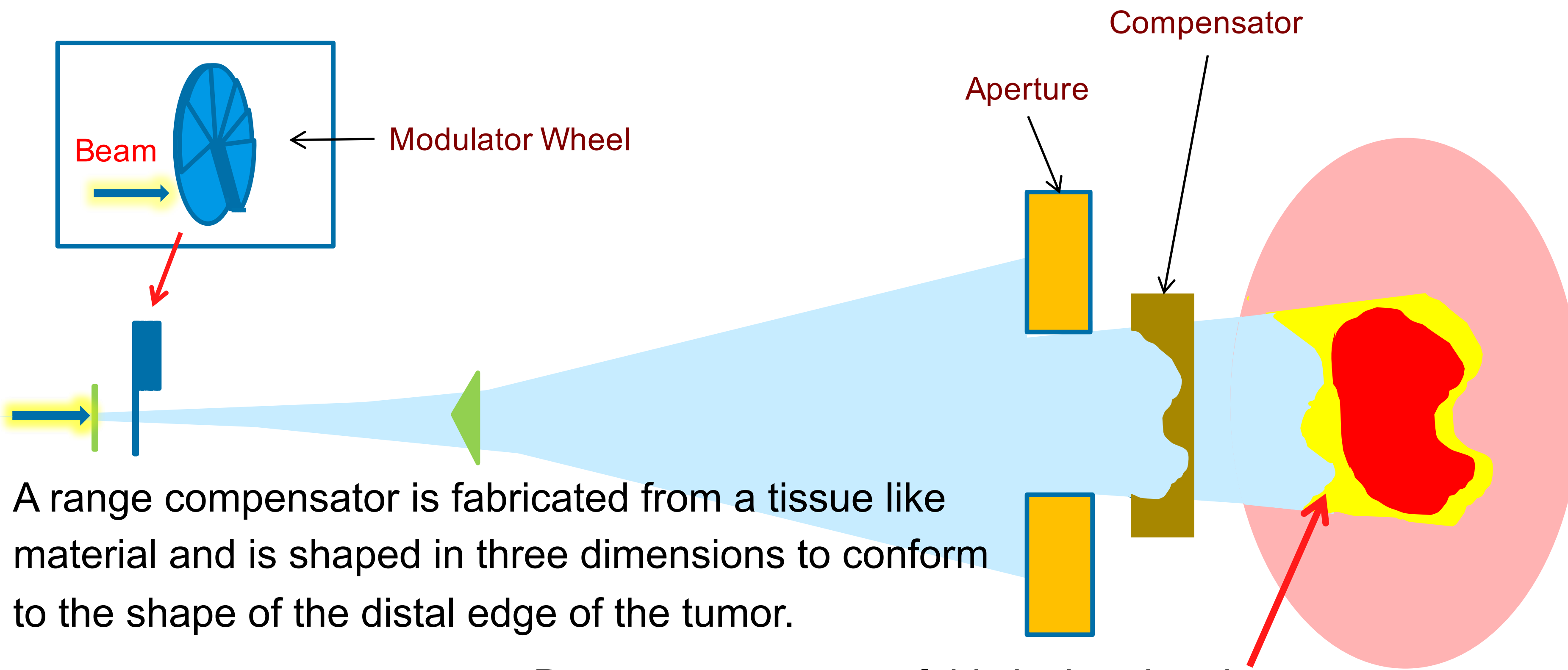
- A modulator wheel, aperture and compensator must be used to shape the beam to the treatment volume.



A range compensator is fabricated from a tissue like material and is shaped in three dimensions to conform to the shape of the distal edge of the tumor.

RANGE MODULATOR, APERTURE, COMPENSATOR

- A modulator wheel, aperture and compensator must be used to shape the beam to the treatment volume.
- An aperture shapes the beam in the lateral dimensions.

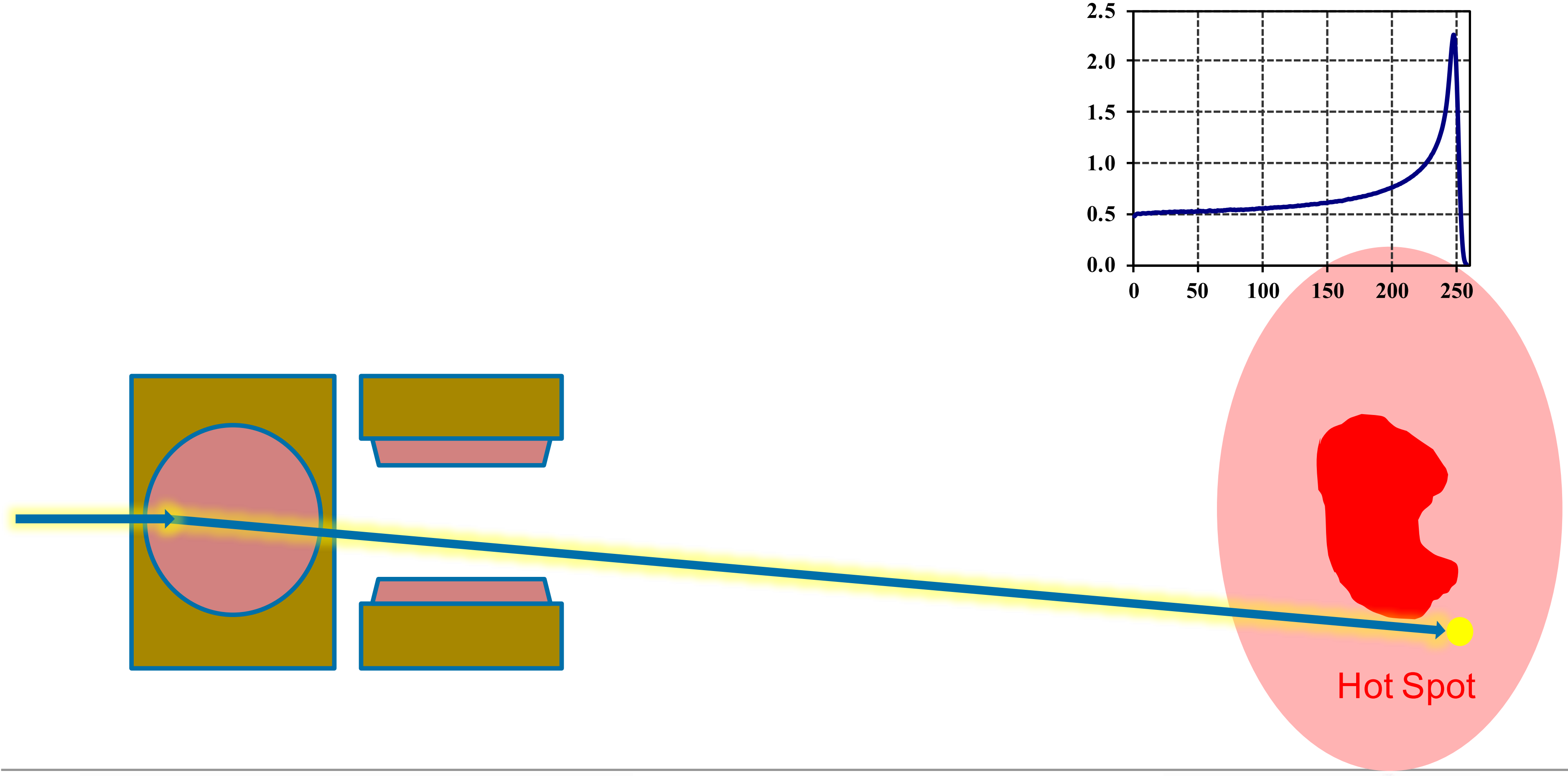


A range compensator is fabricated from a tissue like material and is shaped in three dimensions to conform to the shape of the distal edge of the tumor.

But a consequence of this is that that the same shape is impose on the proximal edge of the dose distribution

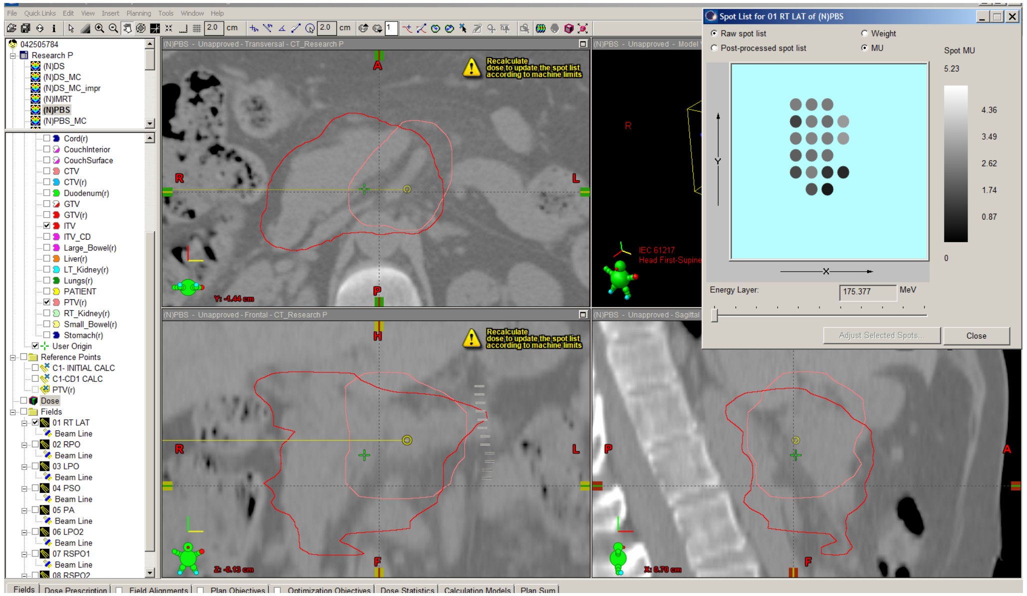
ALTERNATIVE DELIVERY: PENCIL BEAM SCANNING (PBS)

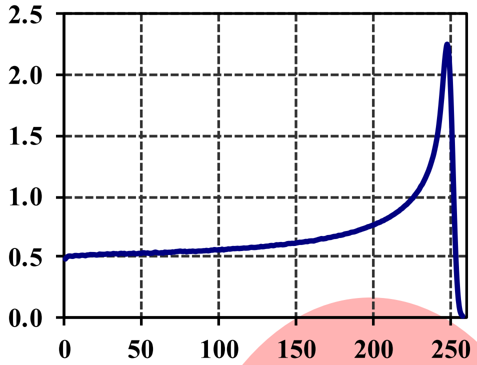
- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage



PBS

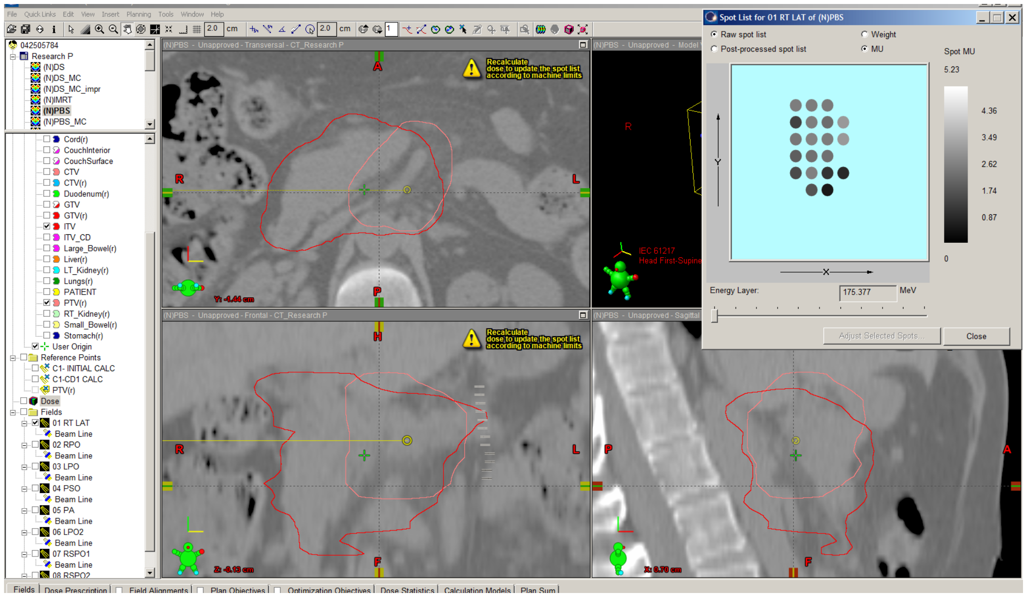
- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage

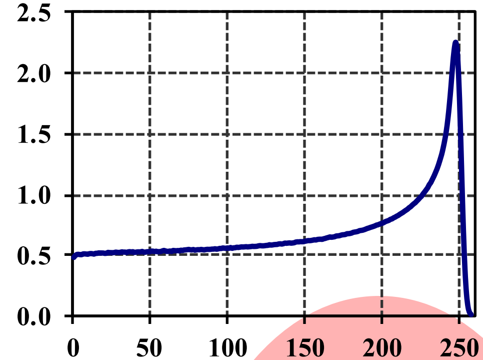


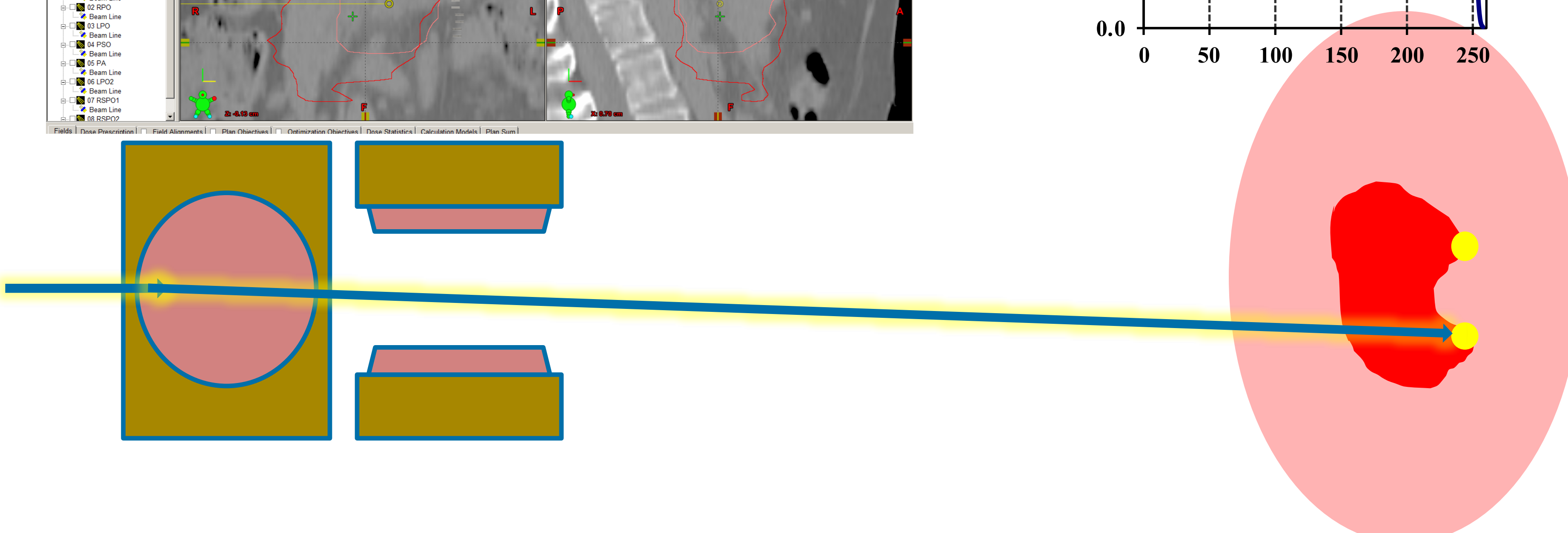


PBS

- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage

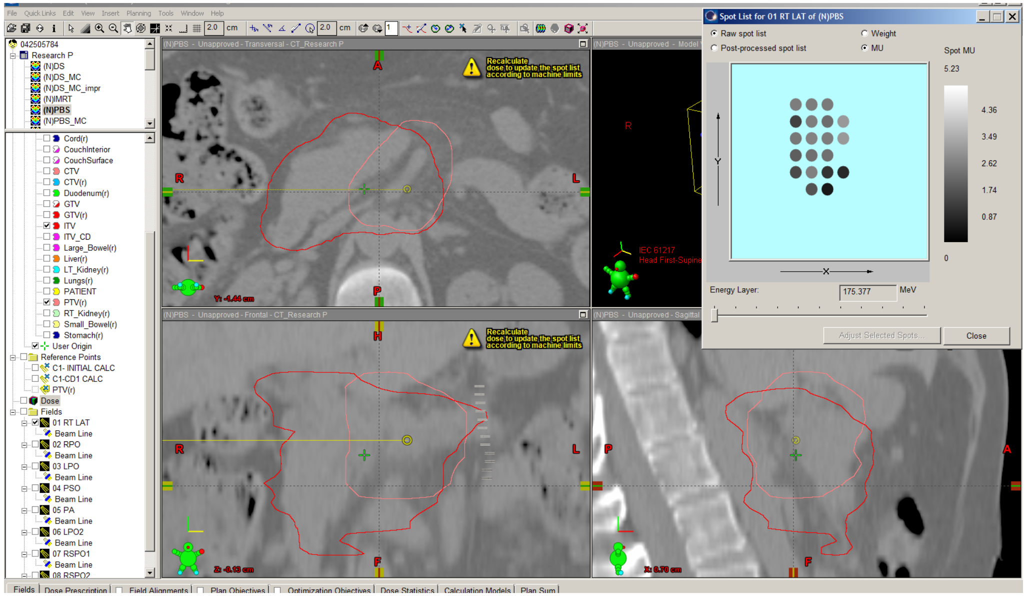


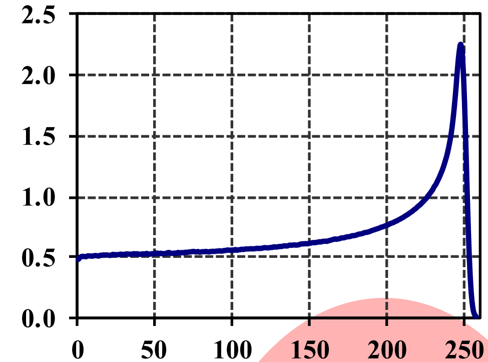


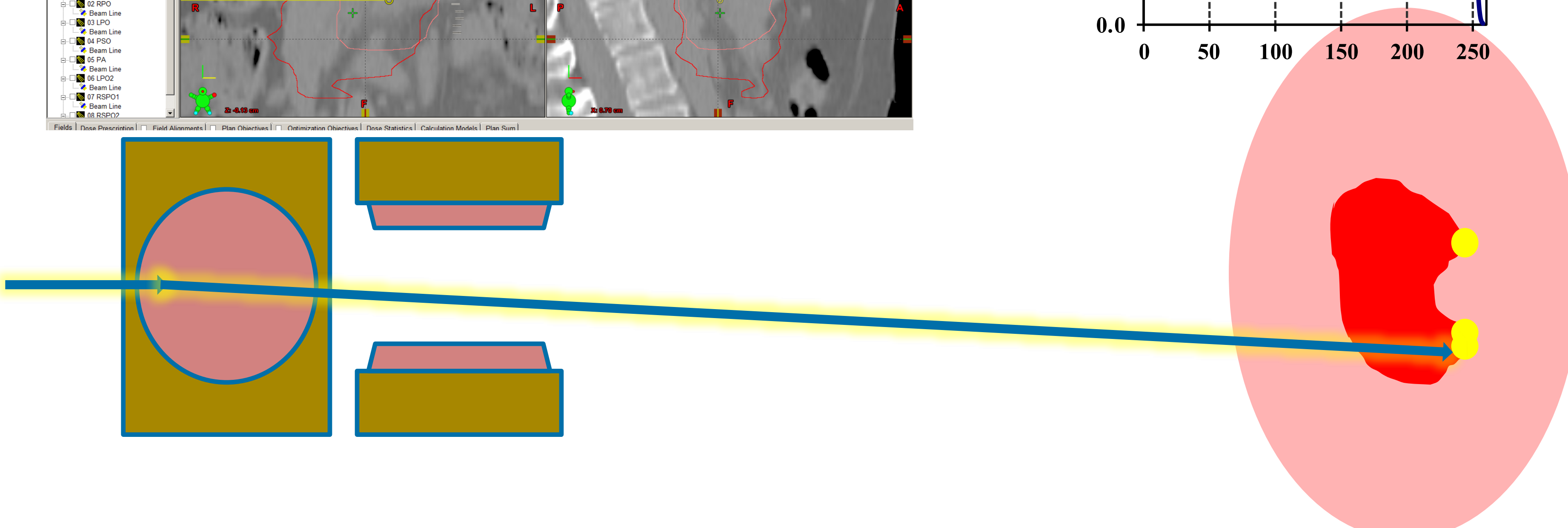


PBS

- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage

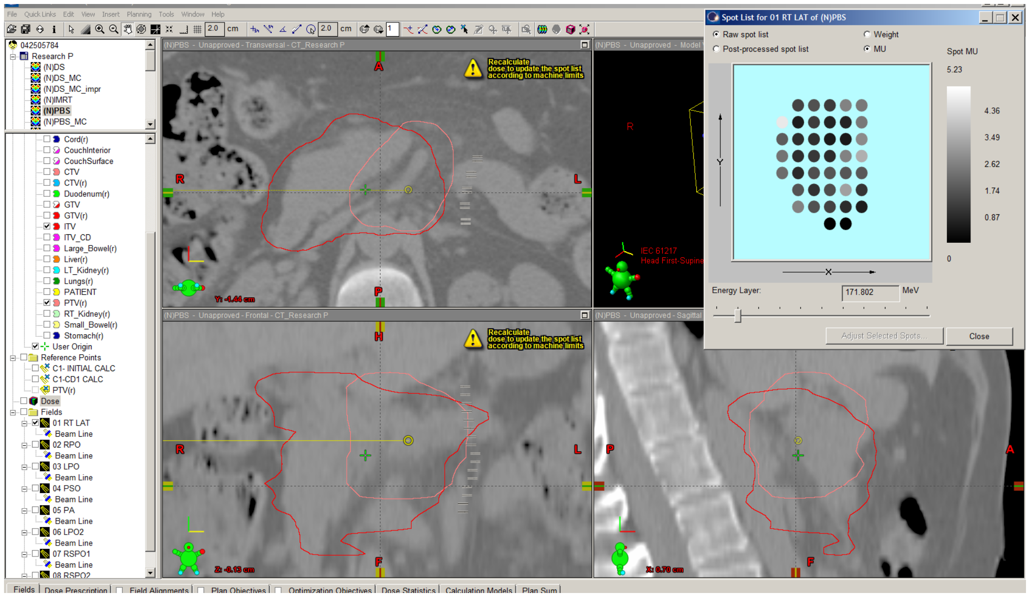


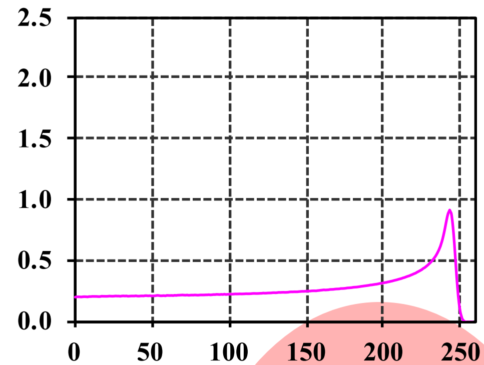




PBS

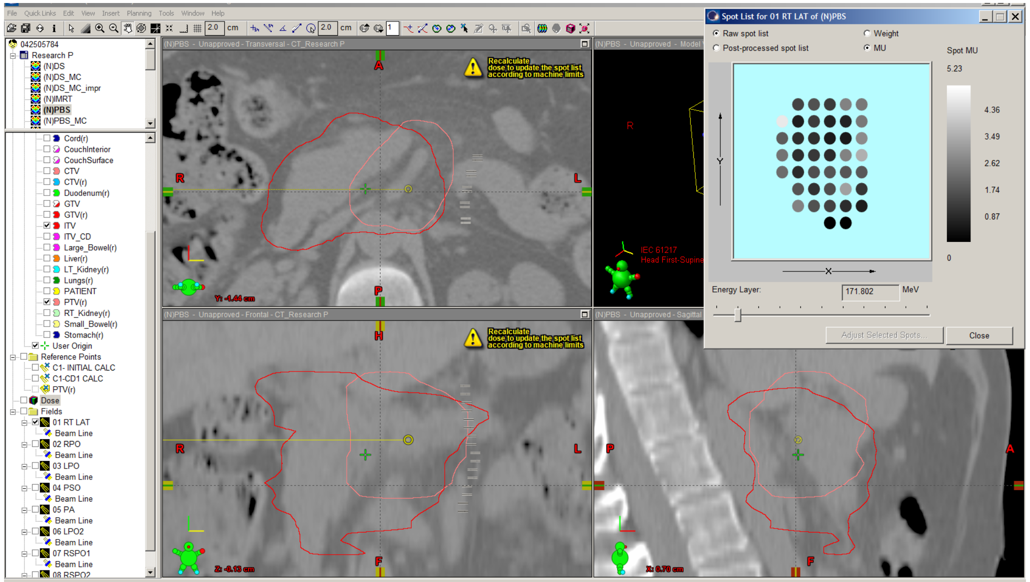
- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage

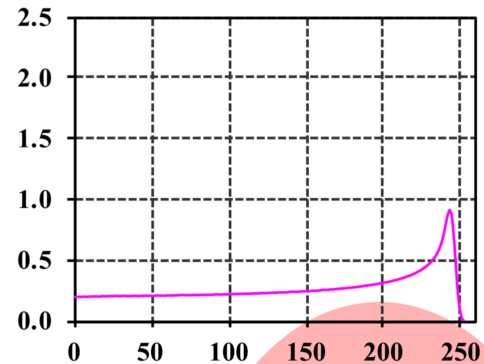


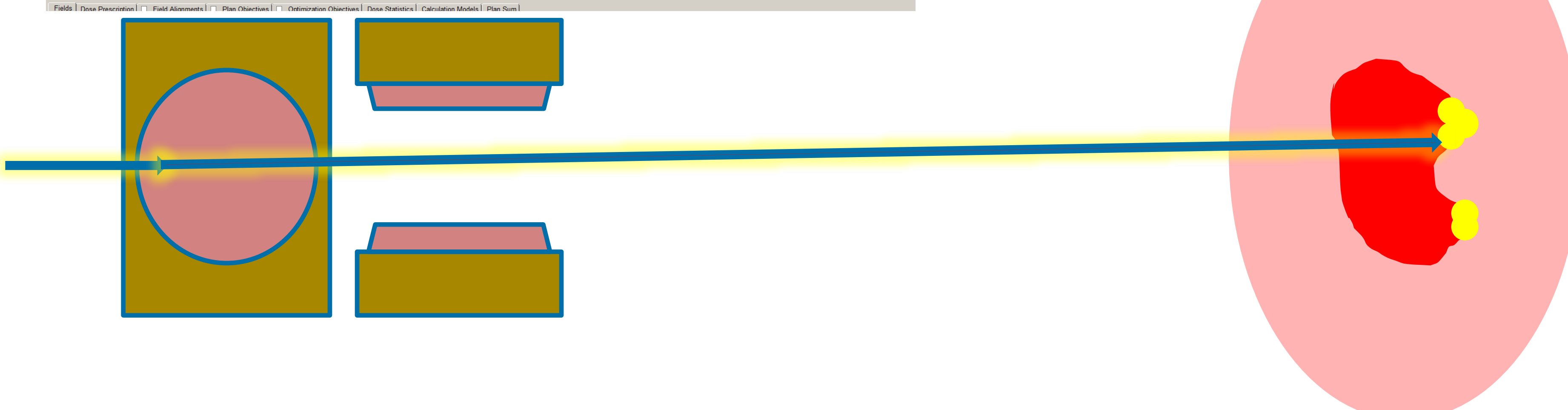


PBS

- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage

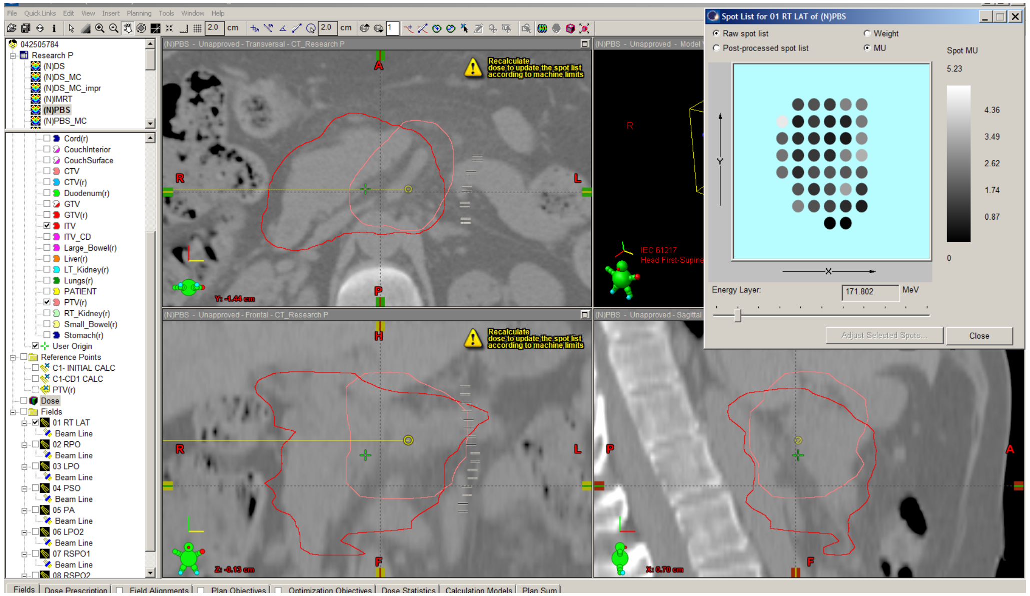


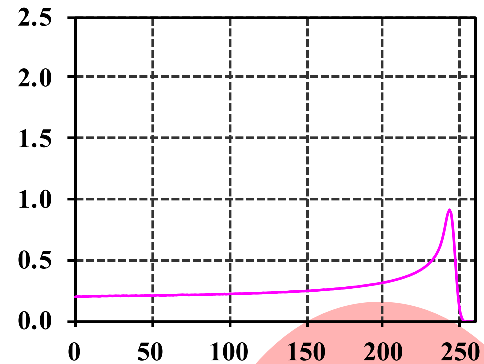


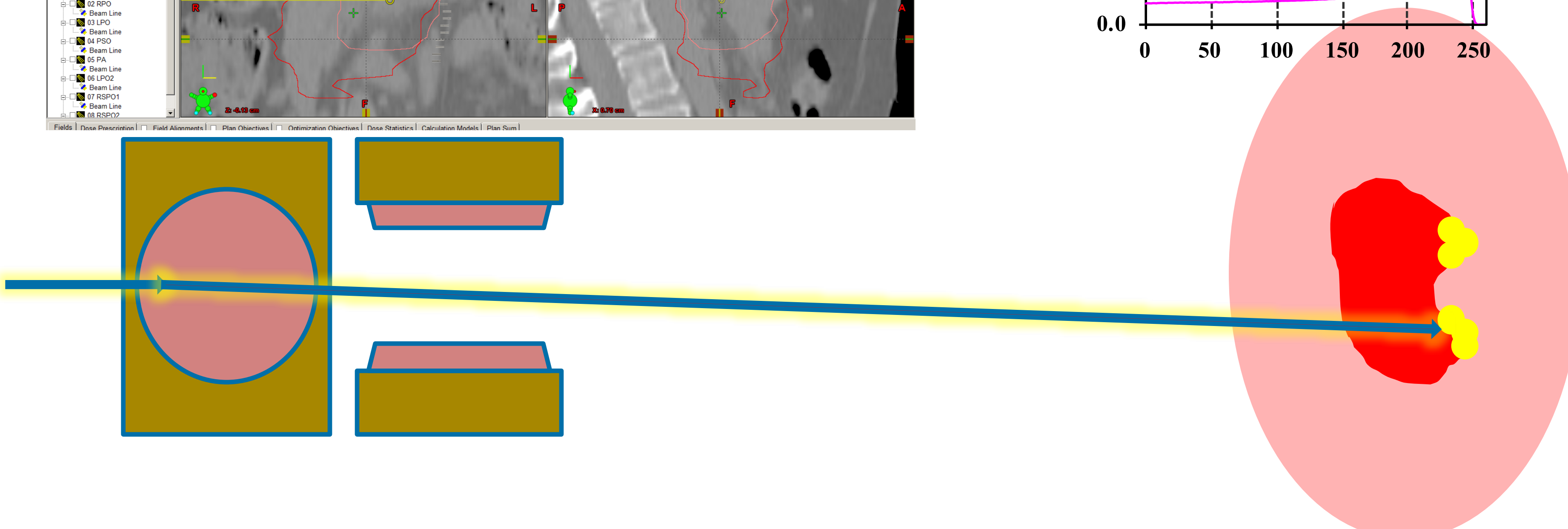


PBS

- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage

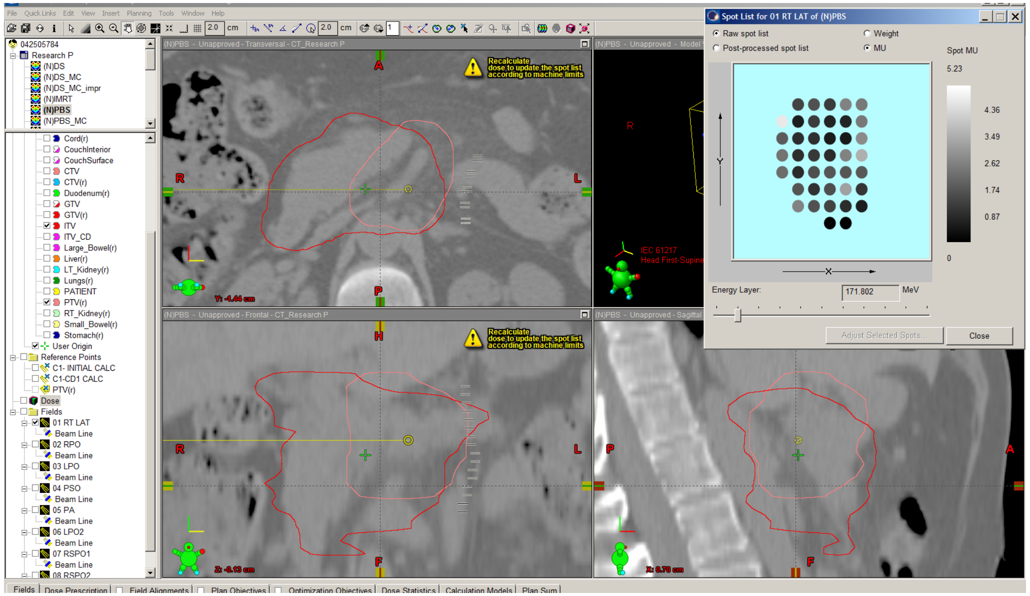


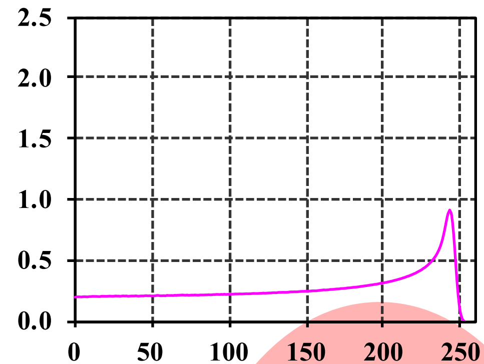


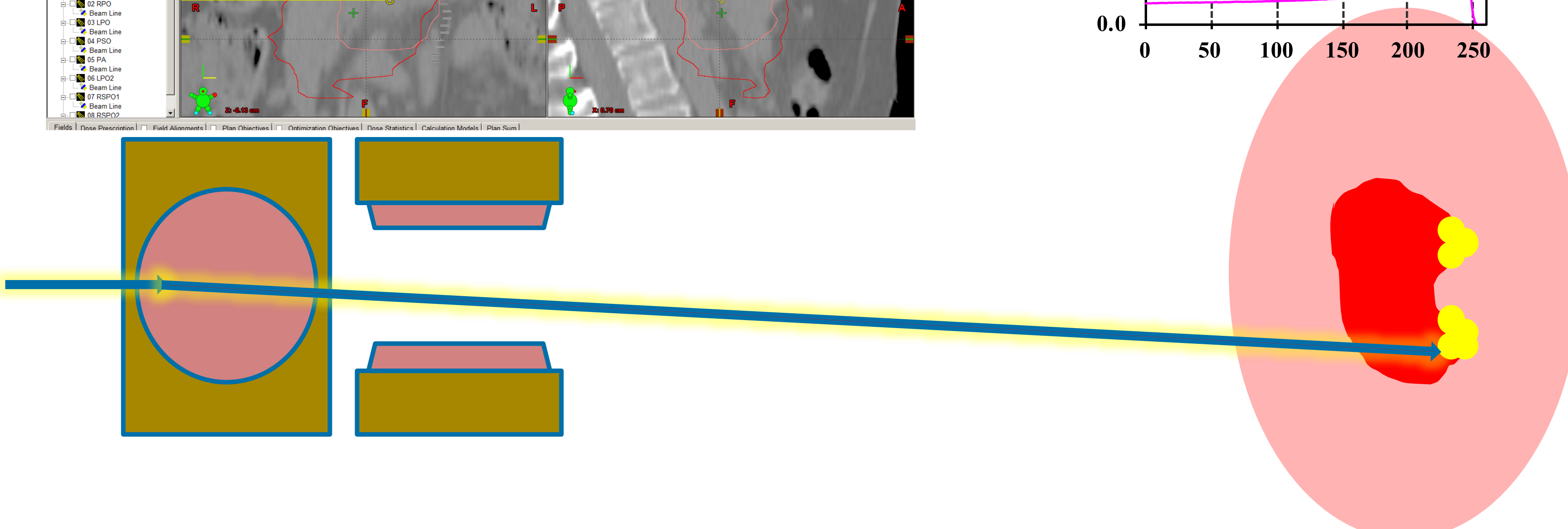


PBS

- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage

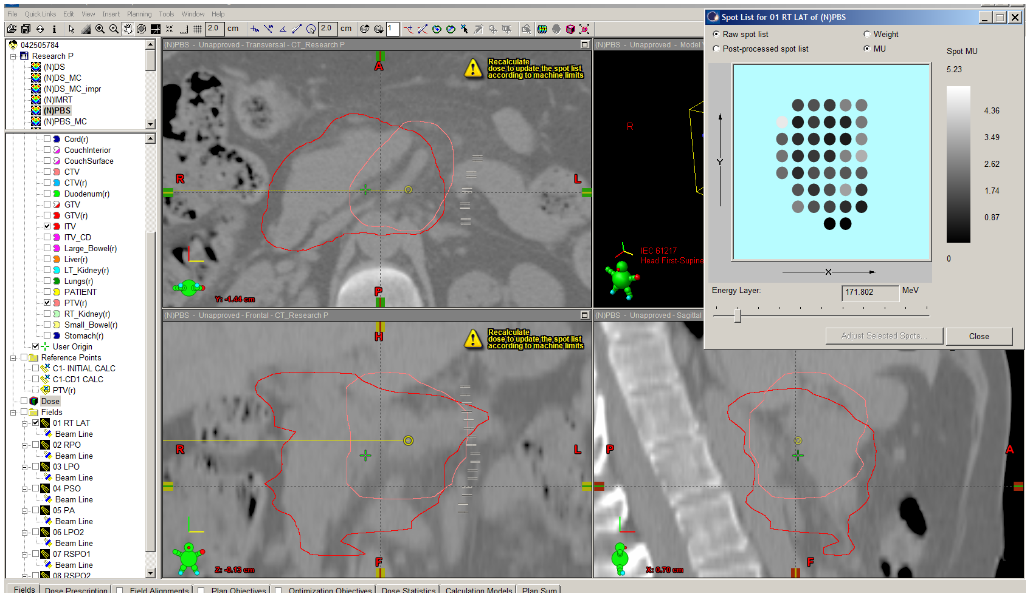


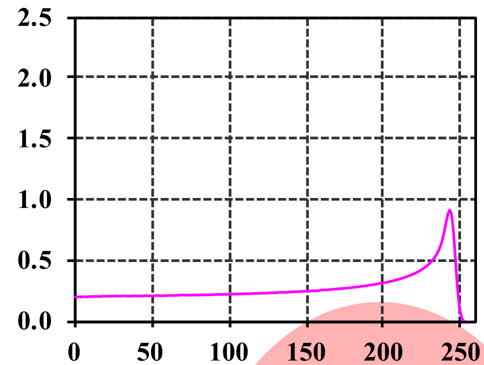


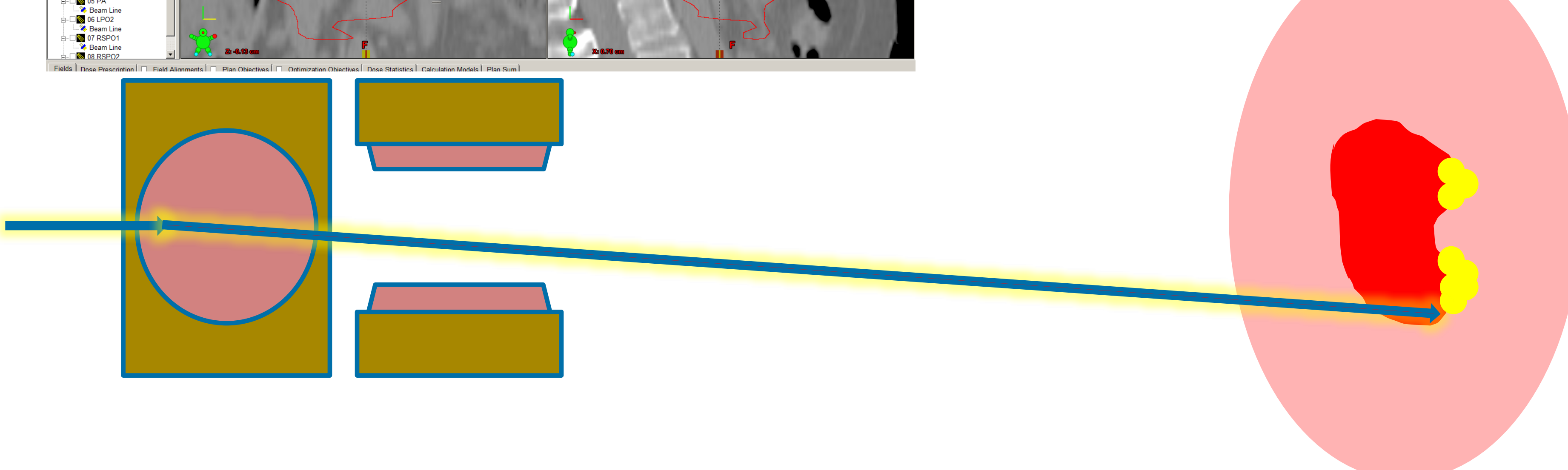


PBS

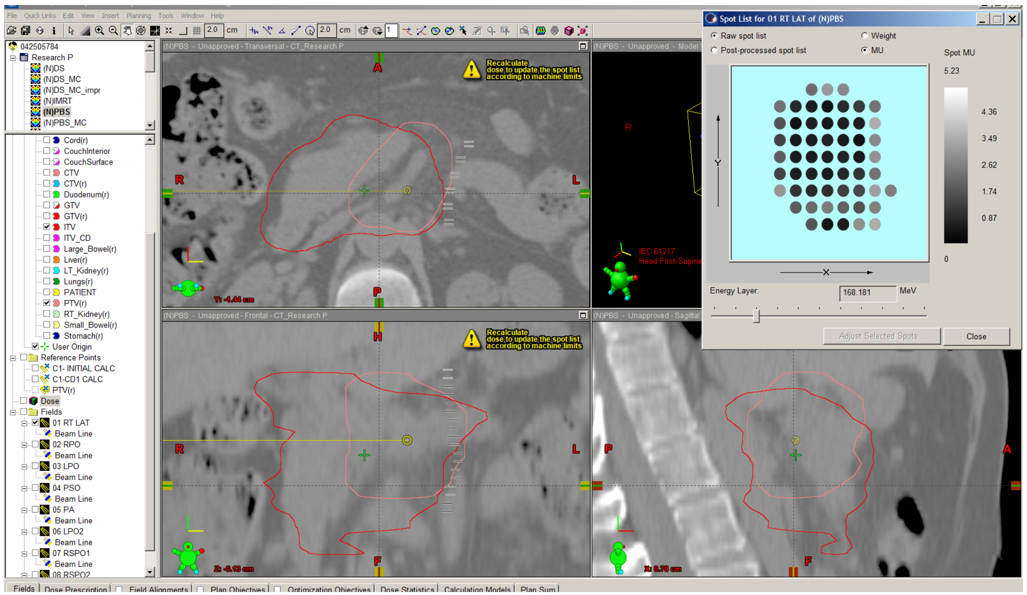
- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage



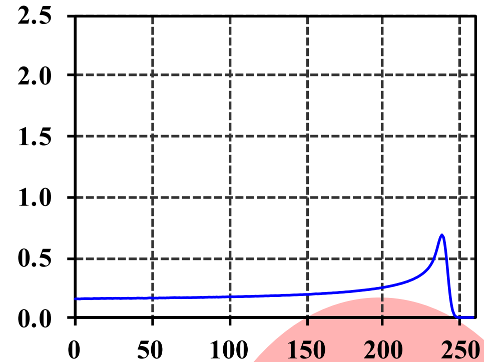




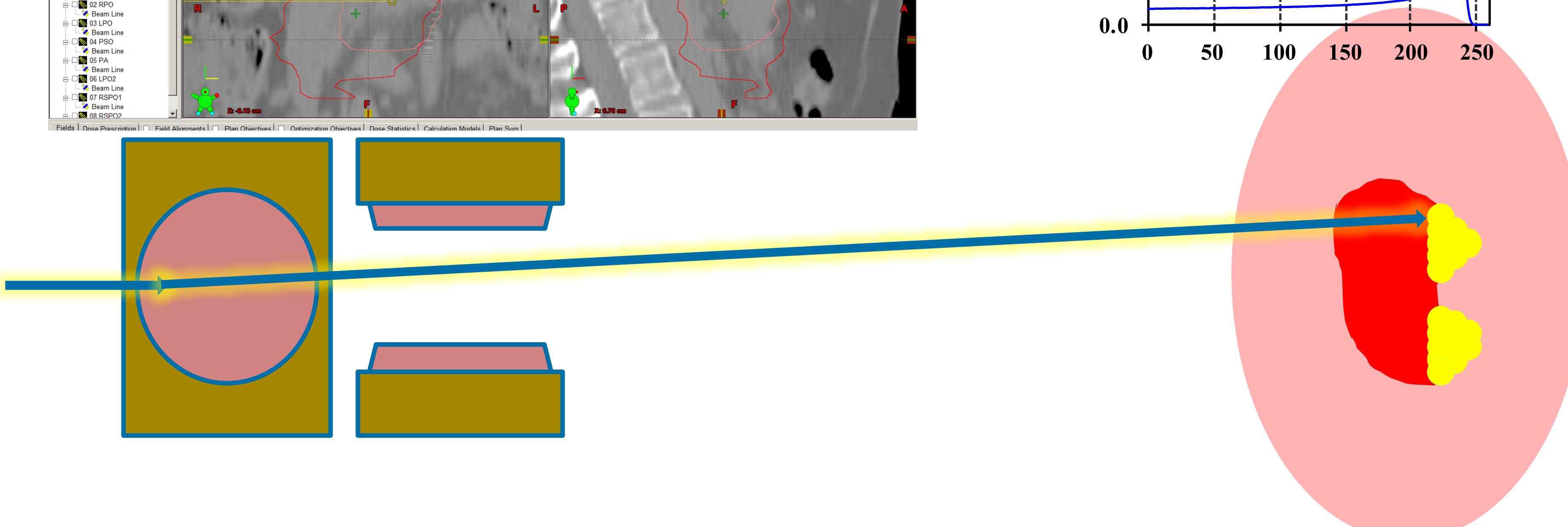
PBS



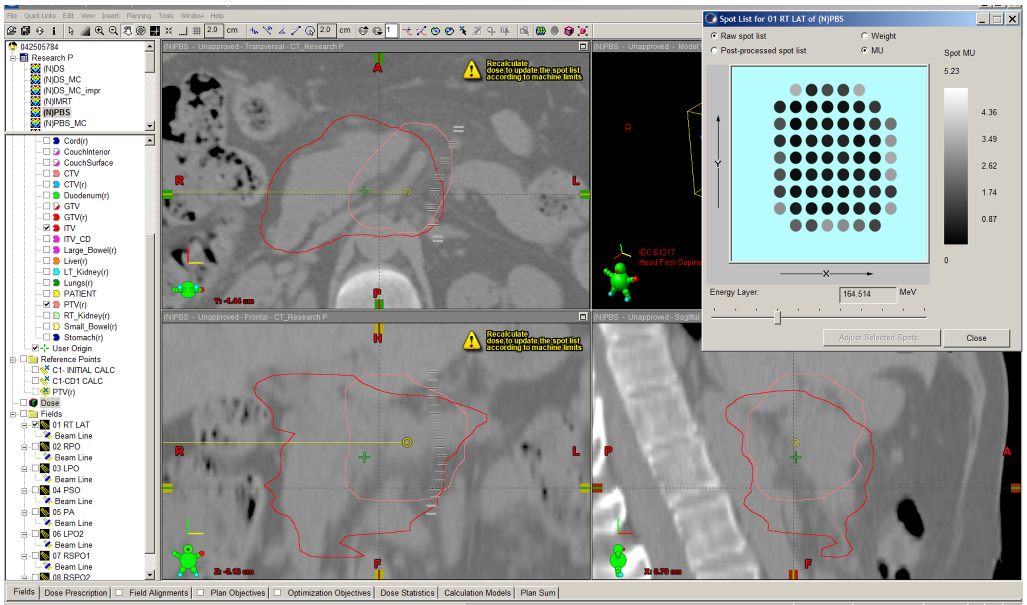
Spot List for 01 RT LAT of (N)PBS
Raw spot list
Post-processed spot list
Weight
MU
Spot MU
Energy Layer:
168.181
MeV
Adjust Selected Spots
Close
Recalculate dose to update the spot list according to machine limits

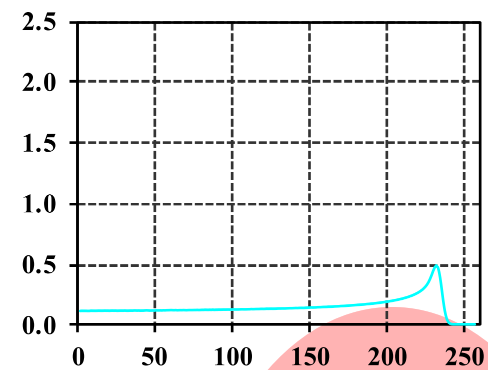


2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250

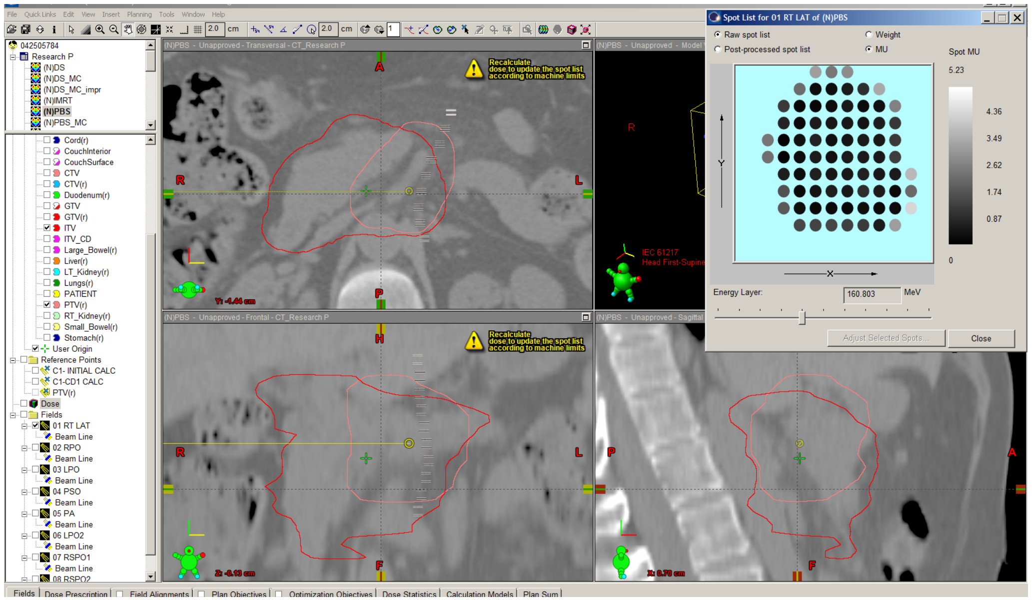


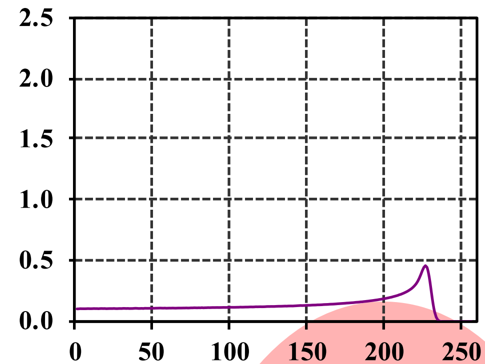
PBS

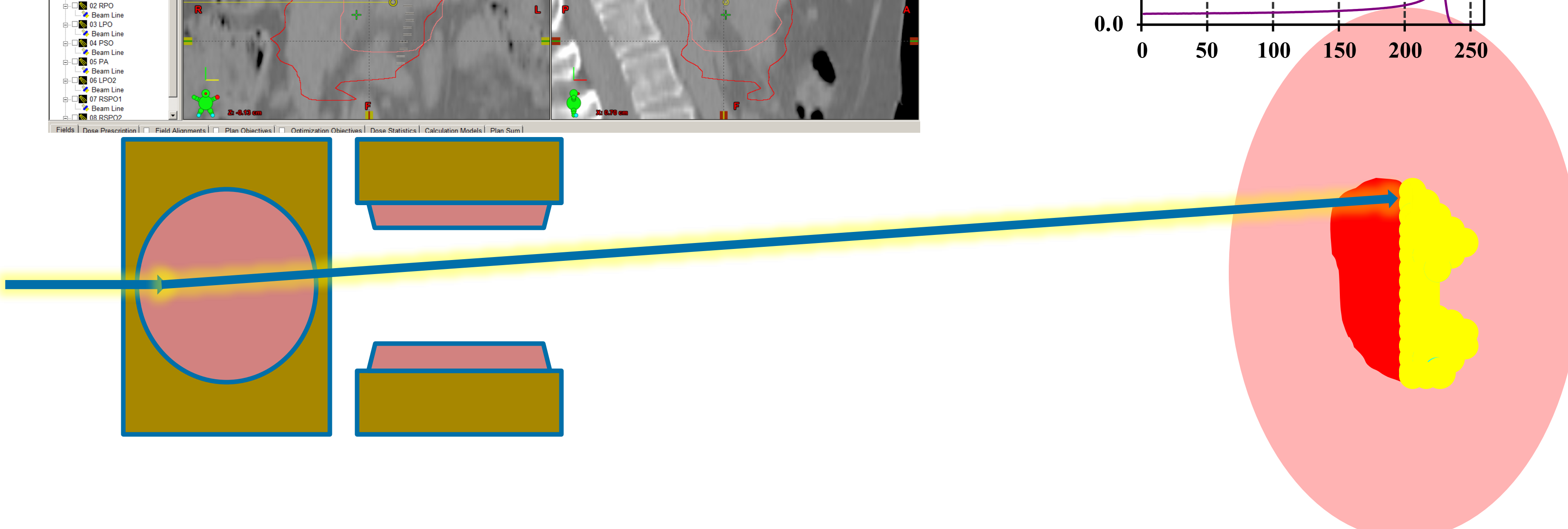

Spot List for 01 RT LAT of (N)PBS
Raw spot list
Post-processed spot list
Weight
MU
Spot MU
Energy Layer:
164.514
MeV
Adjust Selected Spots...
Close
Recalculate dose to update the spot list according to machine limits


2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250

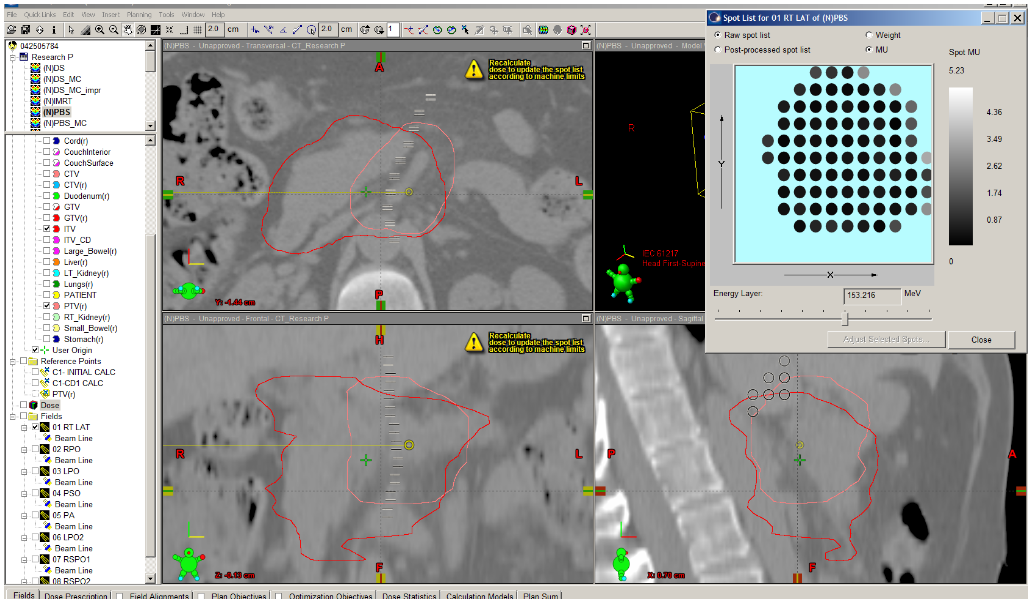
PBS


Spot List for 01 RT LAT of (N)PBS
Raw spot list
Post-processed spot list
Weight
MU
Spot MU
5.23
4.36
3.49
2.62
1.74
0.87
0
Energy Layer:
160.803
MeV
Adjust Selected Spots
Close
Recalculate dose to update the spot list according to machine limits
Fields
Dose Prescription
Field Alignments
Plan Objectives
Optimization Objectives
Dose Statistics
Calculation Models
Plan Sum

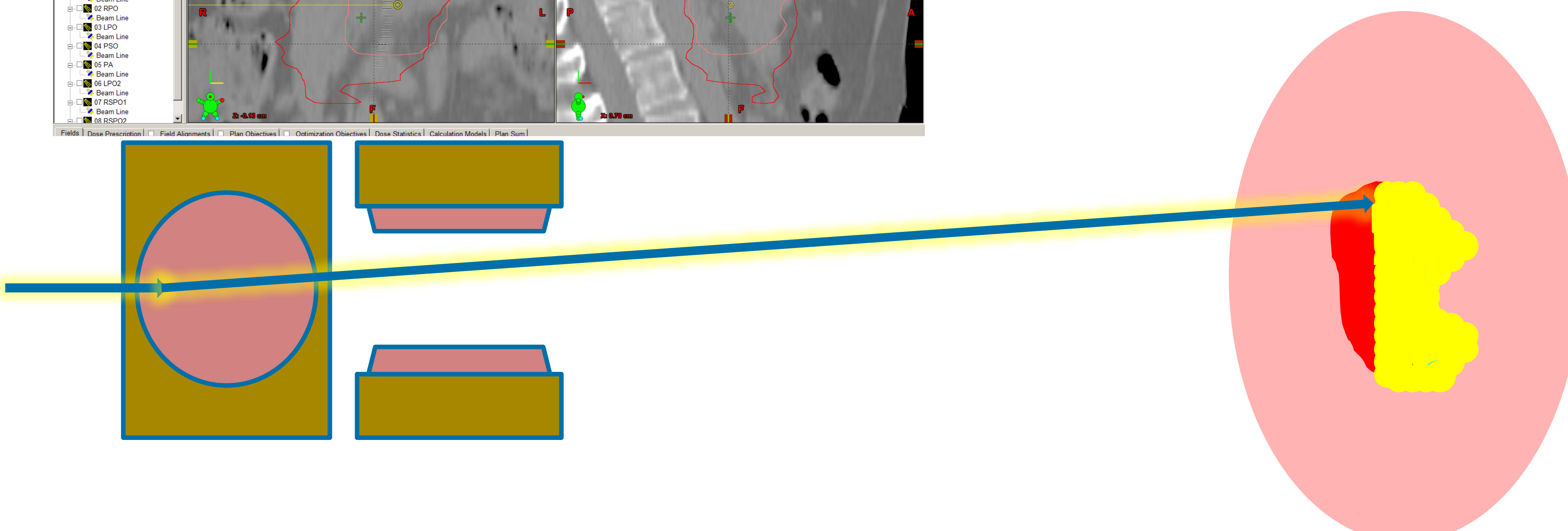

2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250



PBS

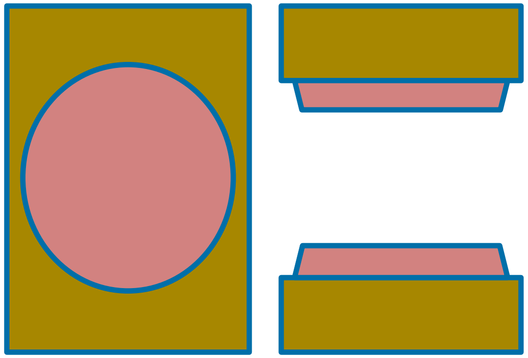


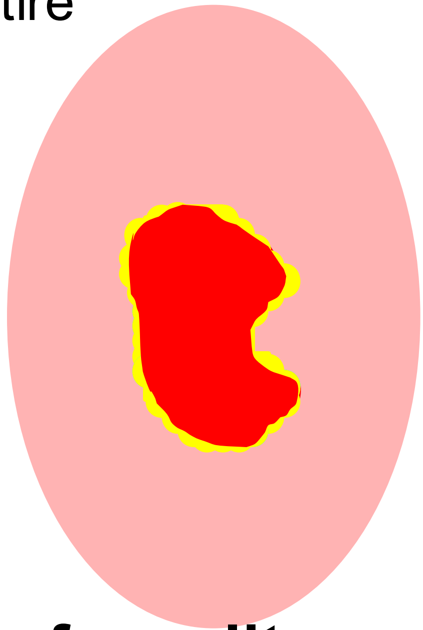
Spot List for 01 RT LAT of (N)PBS
Raw spot list
Post-processed spot list
Weight
MU
Spot MU
Energy Layer:
153.216
MeV
Adjust Selected Spots
Close



PBS

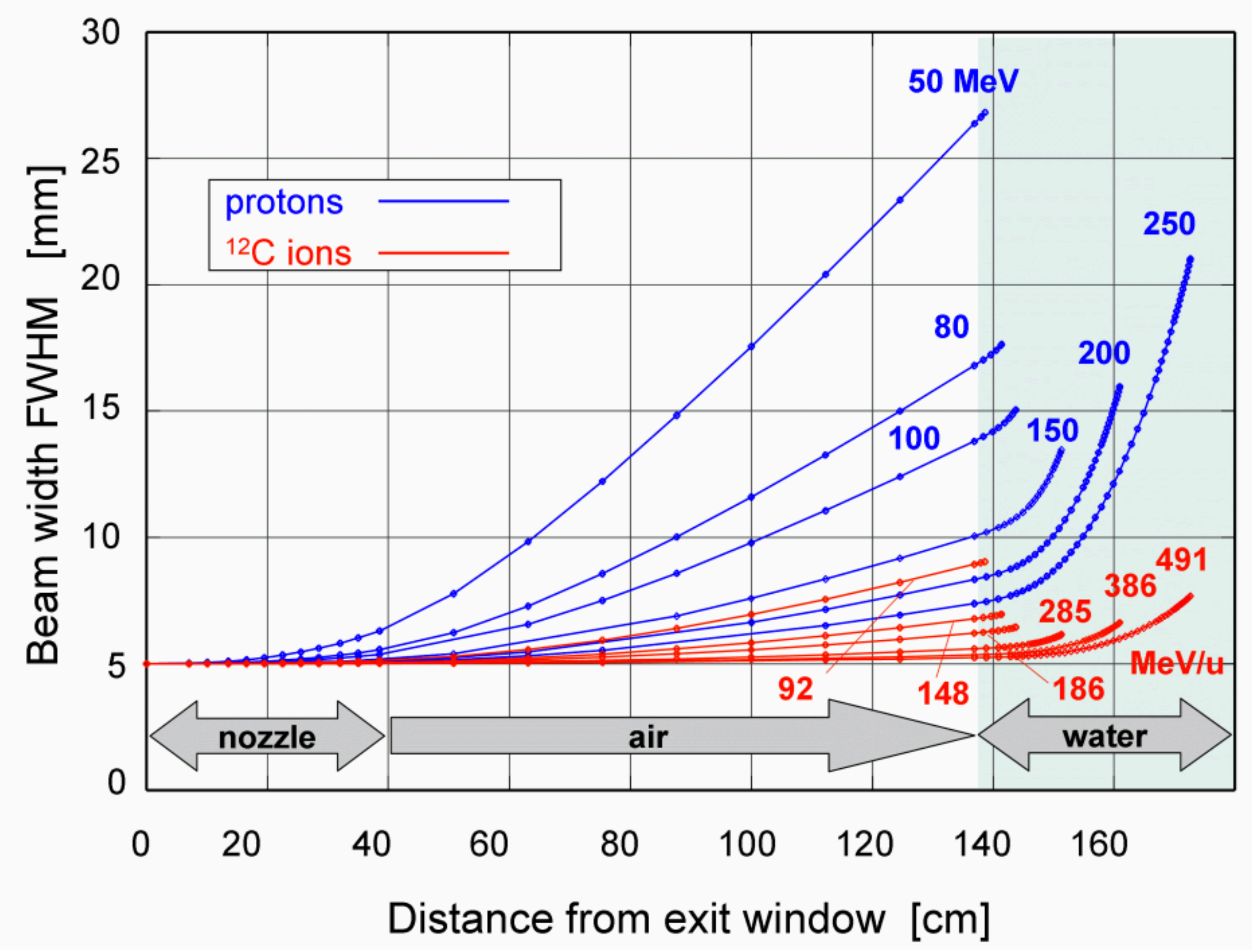
- By using two magnets to scan the beam at orthogonal angles we can achieve lateral tumor coverage and place relatively small pixels of dose (~ 1 cm spheres) anywhere we want them in a given plane.
- We can then reduce the beam energy and “pull back” the pixels to deliver another layer.
- And repeat the process until we have covered the entire treatment volume.





Using this method we can achieve dose conformality on both the distal and proximal sides of the tumor

Do we have control over the spot size?

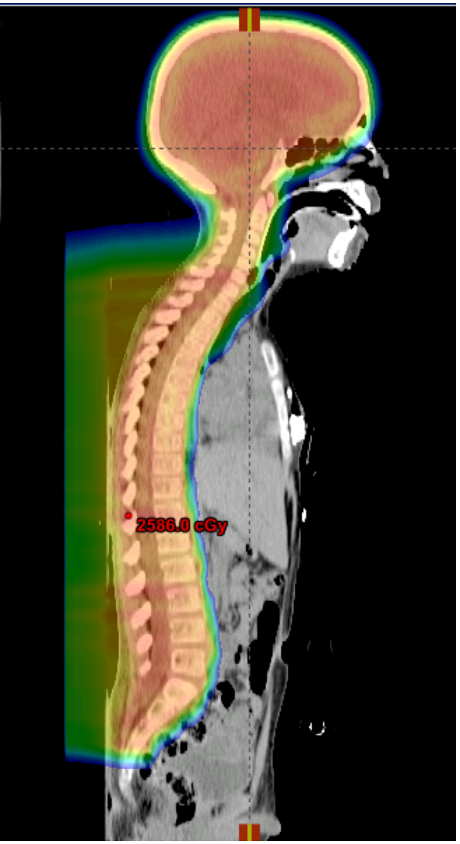


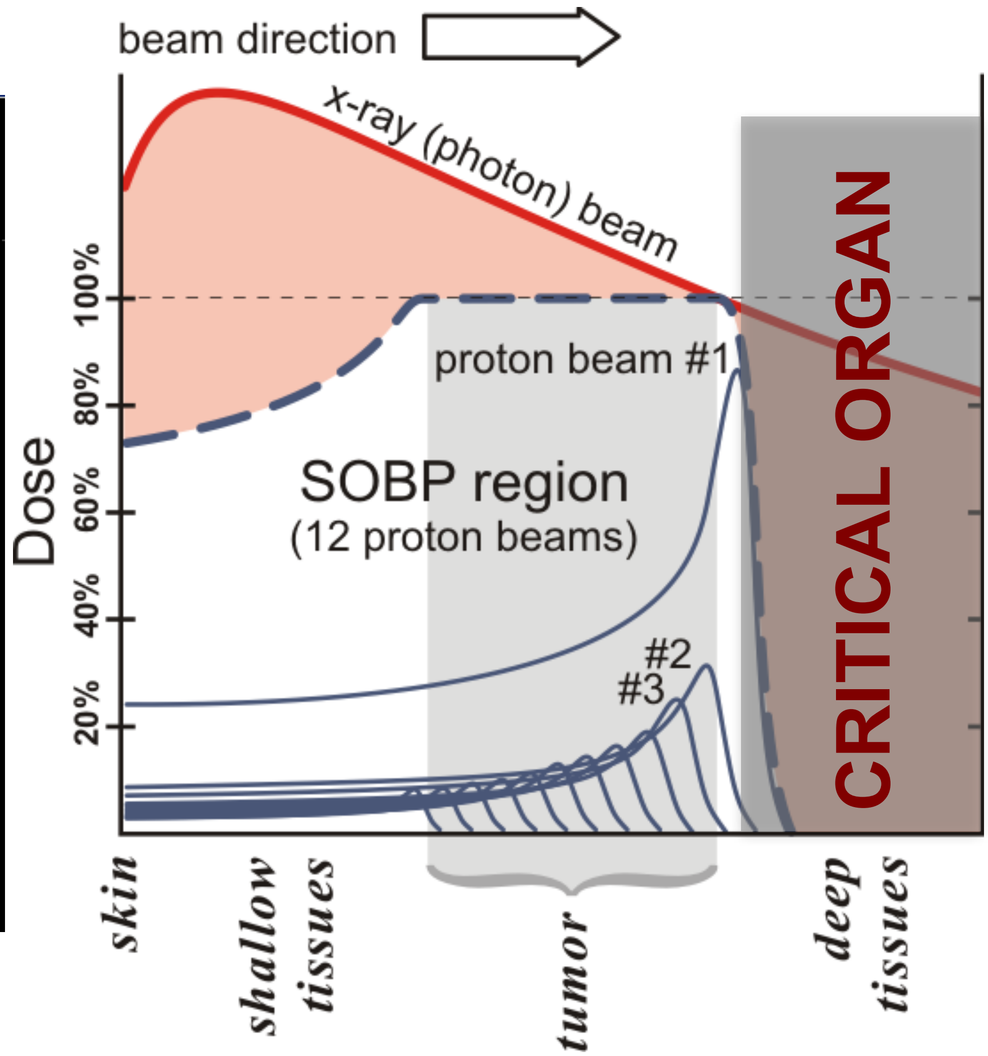
Weber & Kraft (Cancer J 2009;15:325)

Biophysical advantages of proton radiotherapy

- **Protons have a clear physical advantage over photons**

Proton

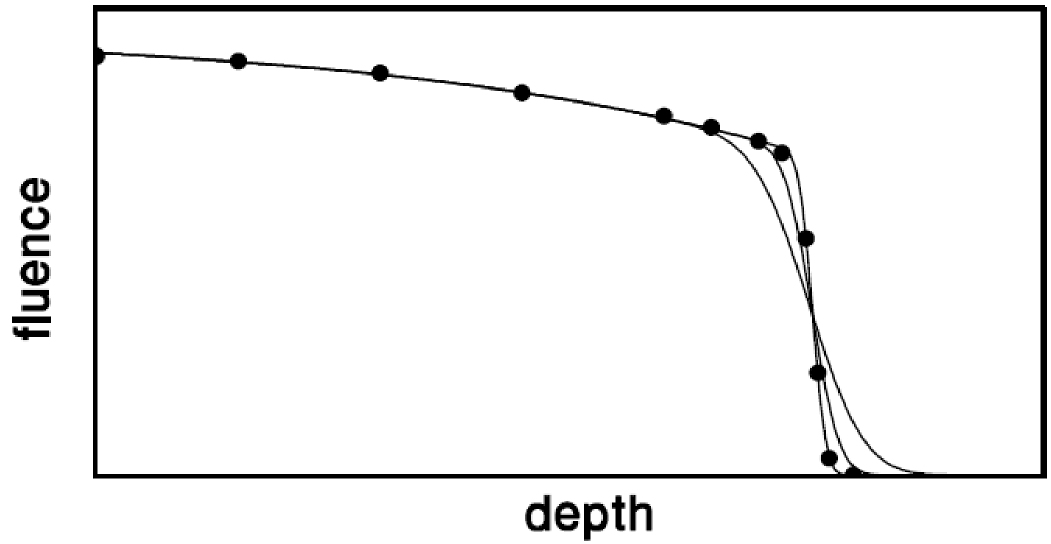


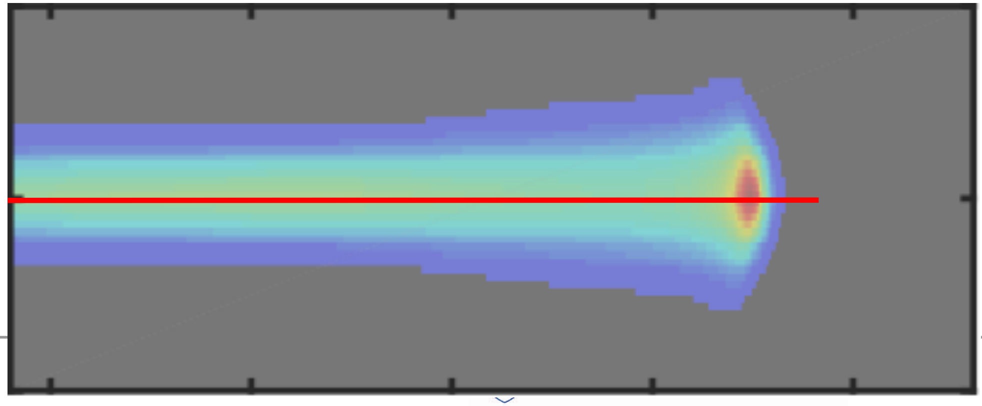


Photon

Biophysical advantages of proton radiotherapy

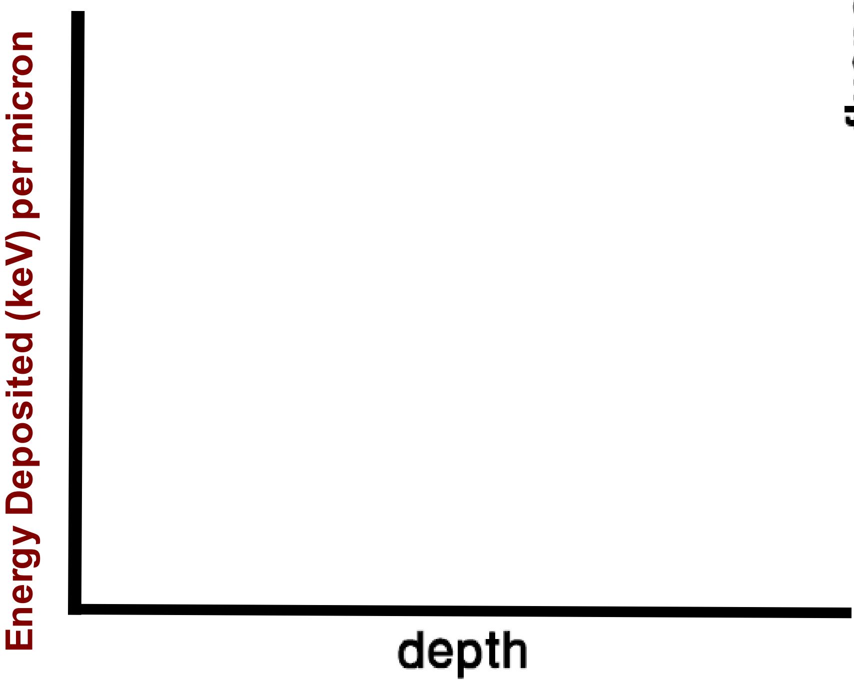
- Protons have a clear physical advantage over photons
- Do protons have any biological advantage over photons?

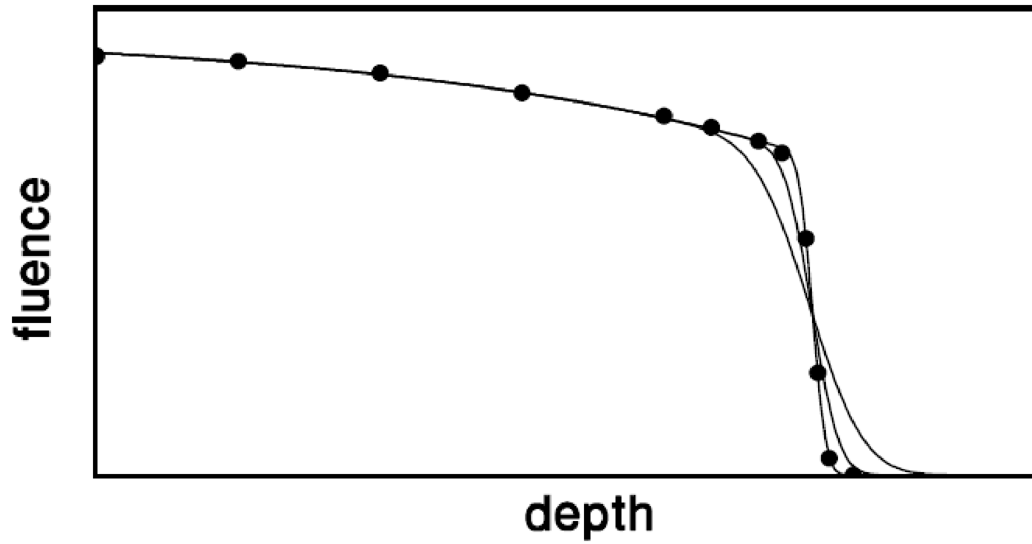


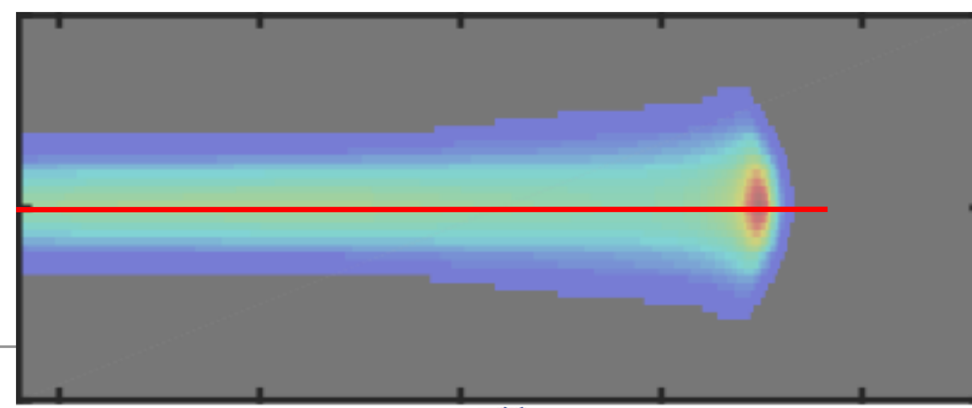


Biophysical advantages of proton radiotherapy

- Protons have a clear physical advantage over photons
- Do protons have any biological advantage over photons?

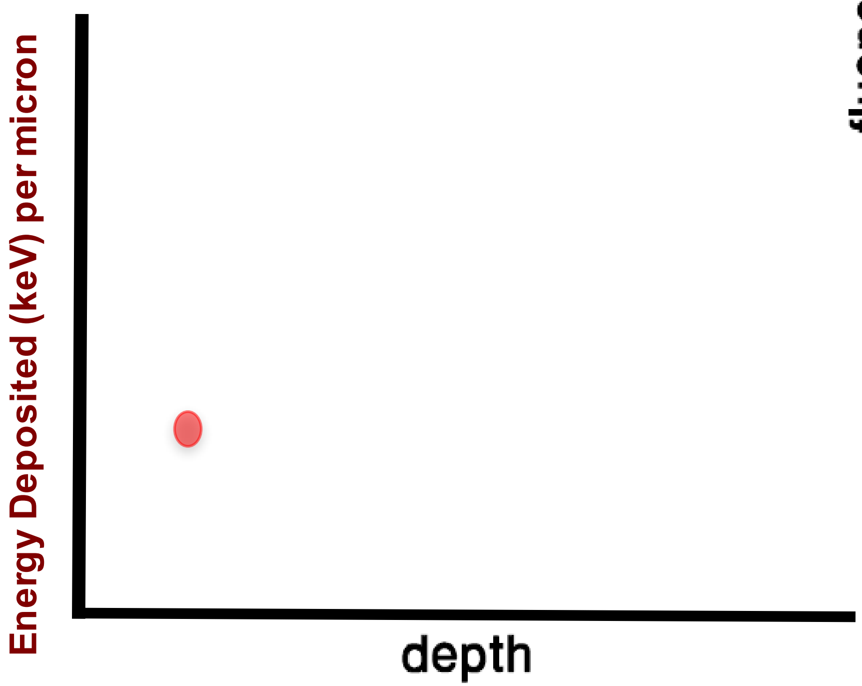


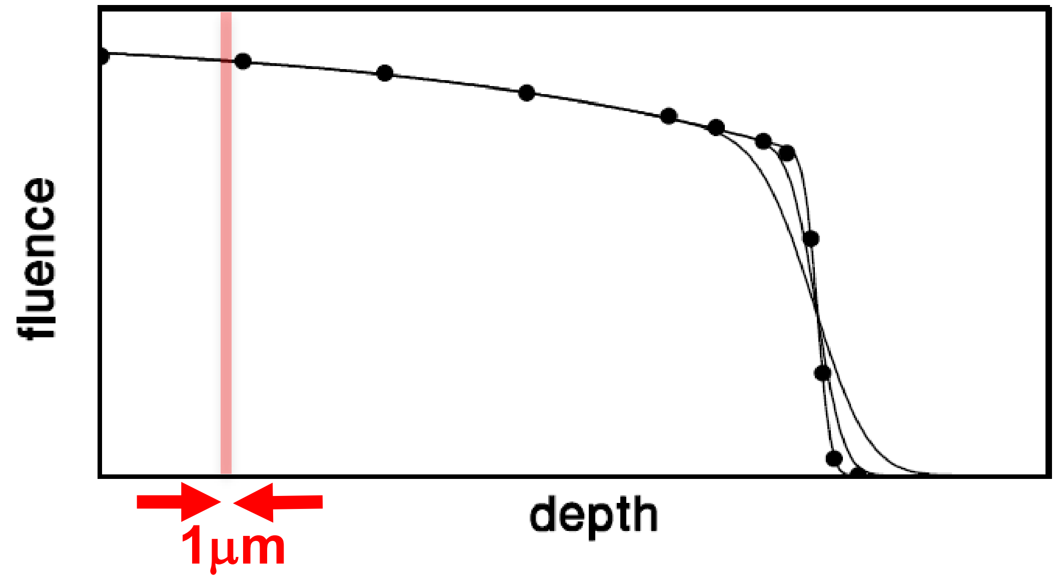


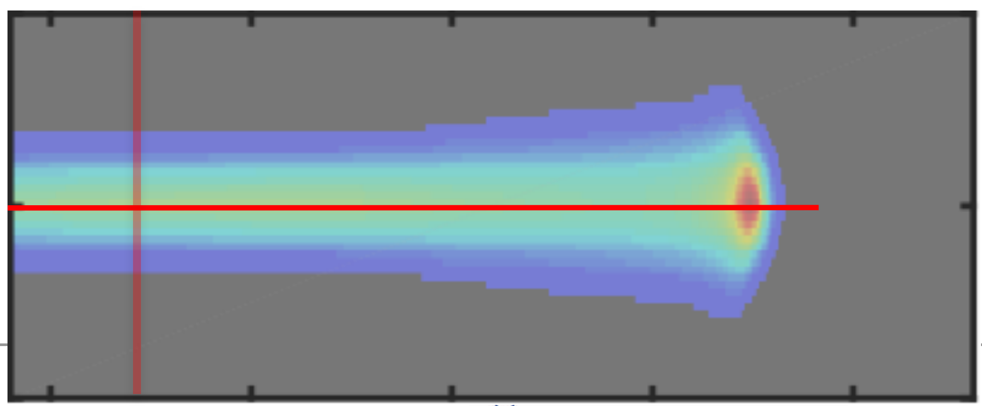


Biophysical advantages of proton radiotherapy

- Protons have a clear physical advantage over photons
- Do protons have any biological advantage over photons?

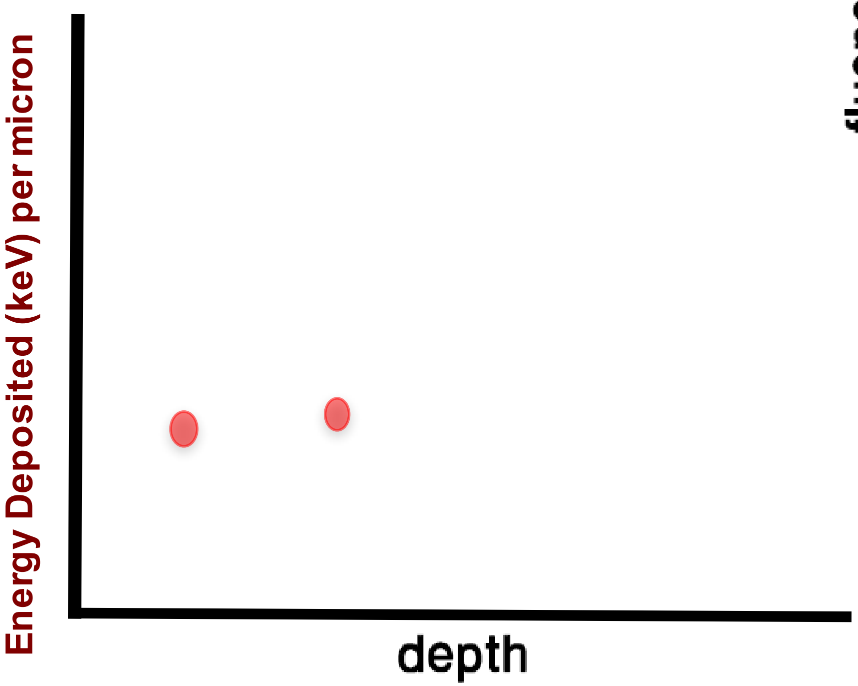


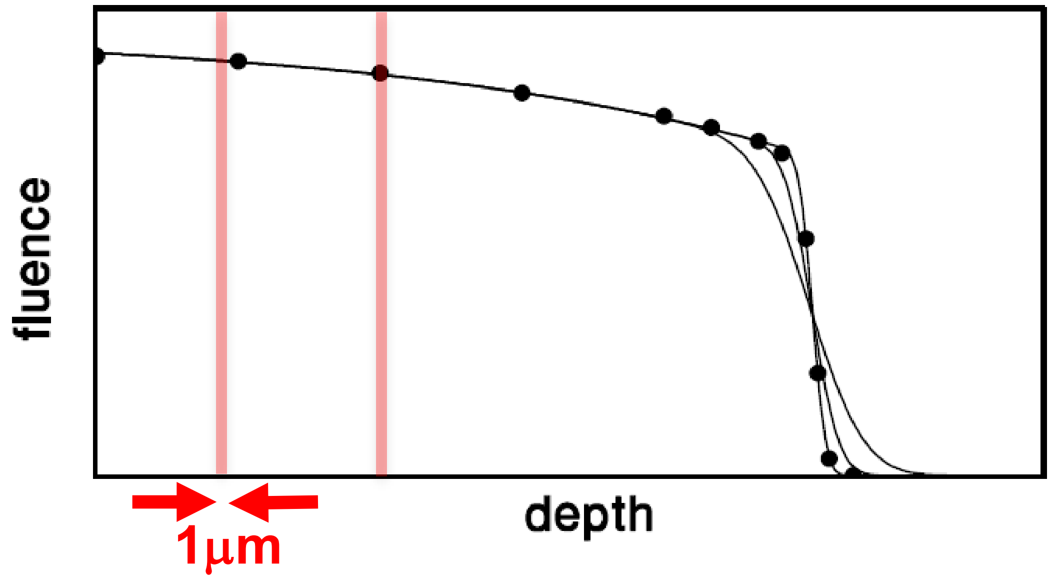


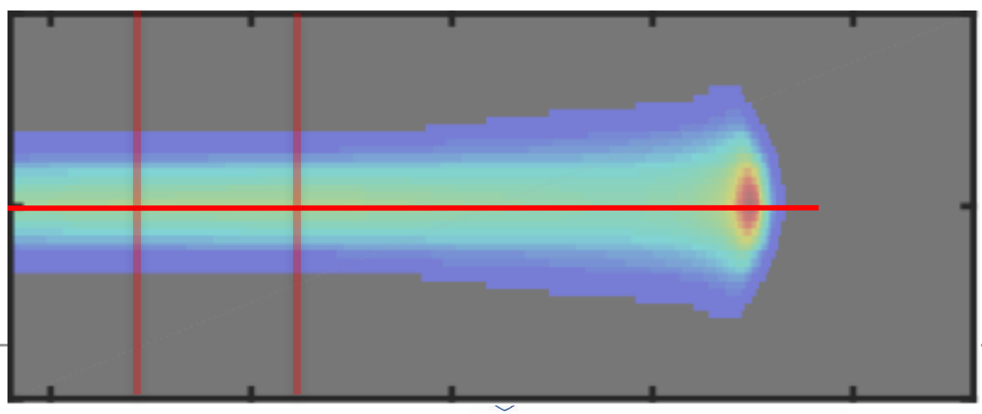


Biophysical advantages of proton radiotherapy

- Protons have a clear physical advantage over photons
- Do protons have any biological advantage over photons?

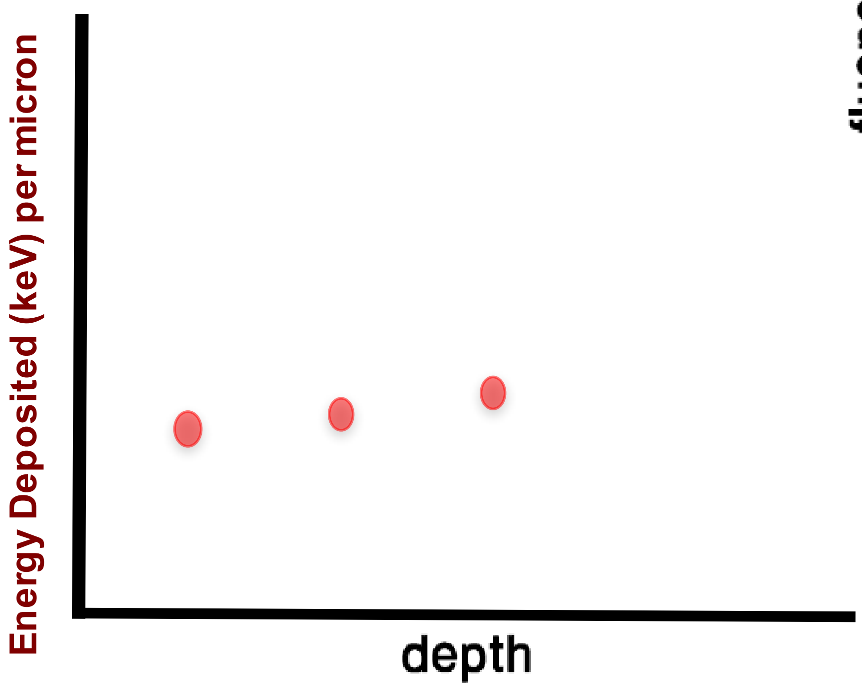


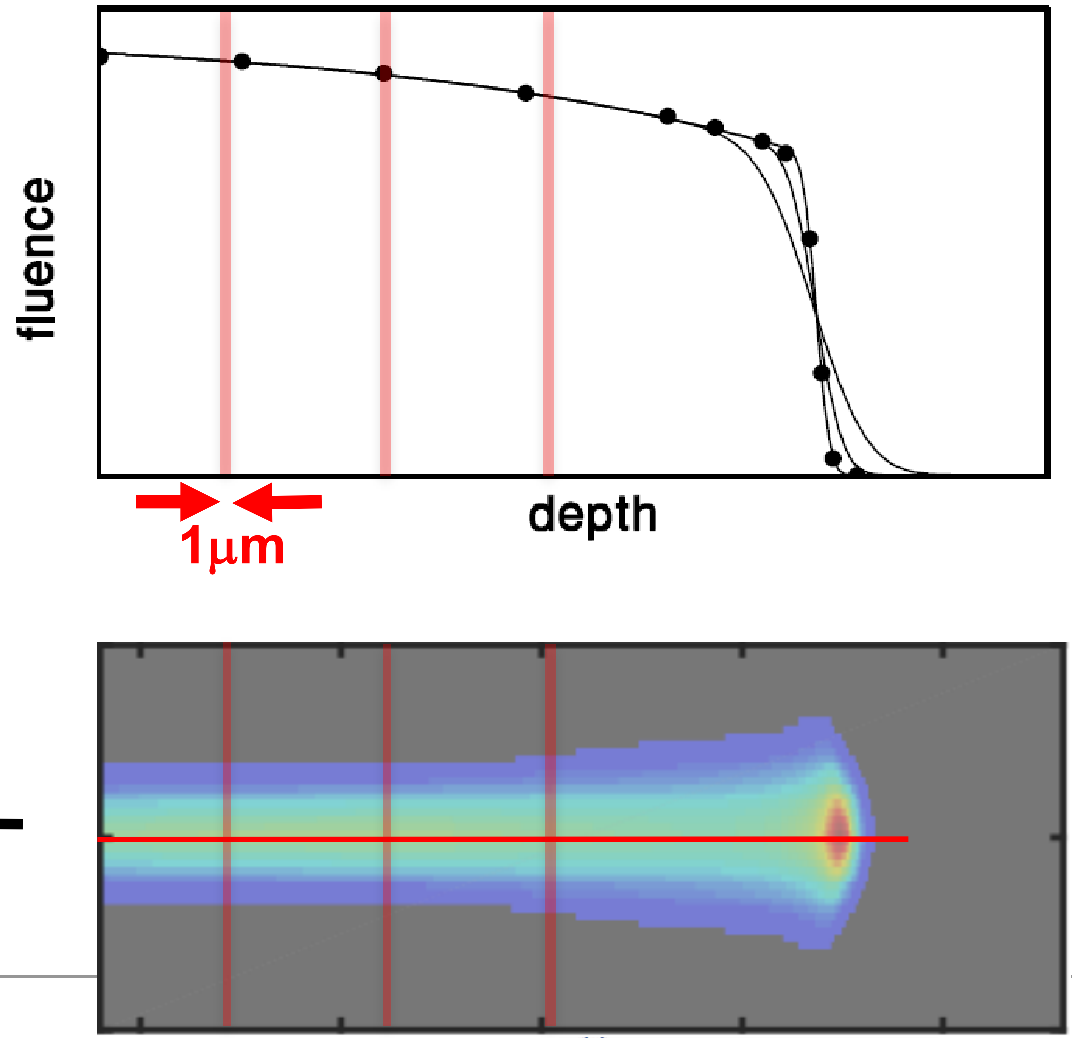




Biophysical advantages of proton radiotherapy

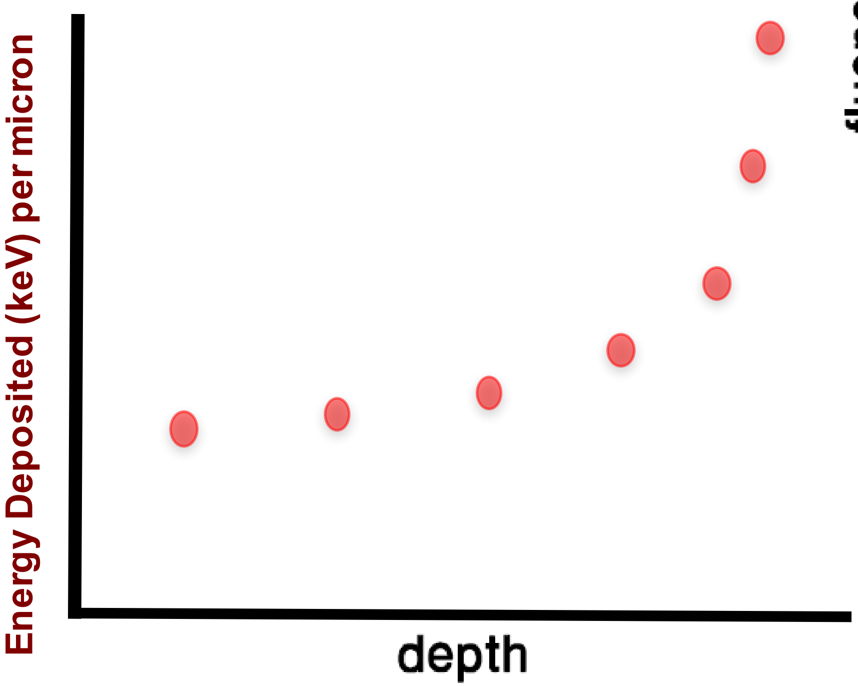
- Protons have a clear physical advantage over photons
- Do protons have any biological advantage over photons?

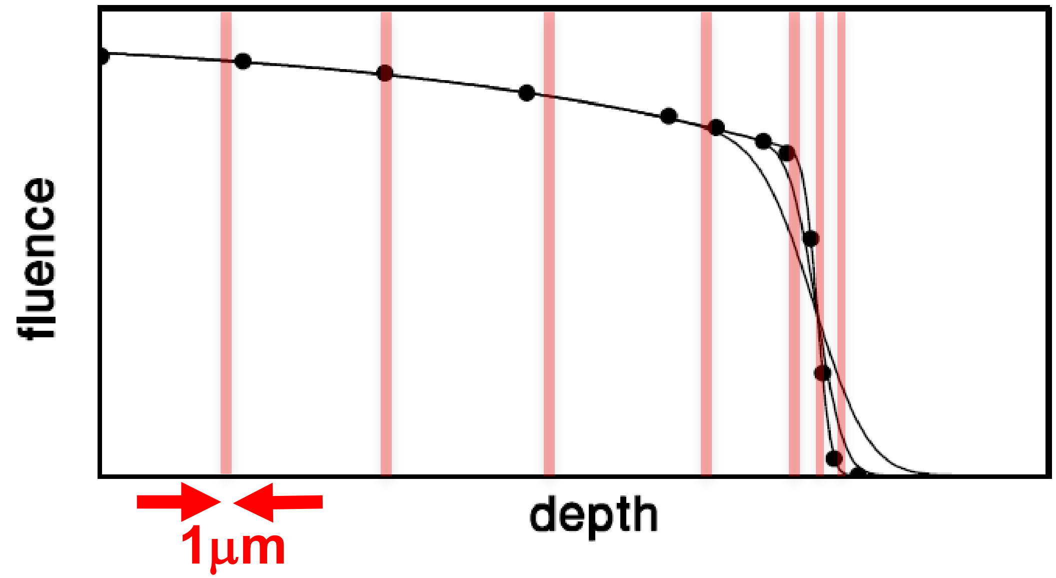


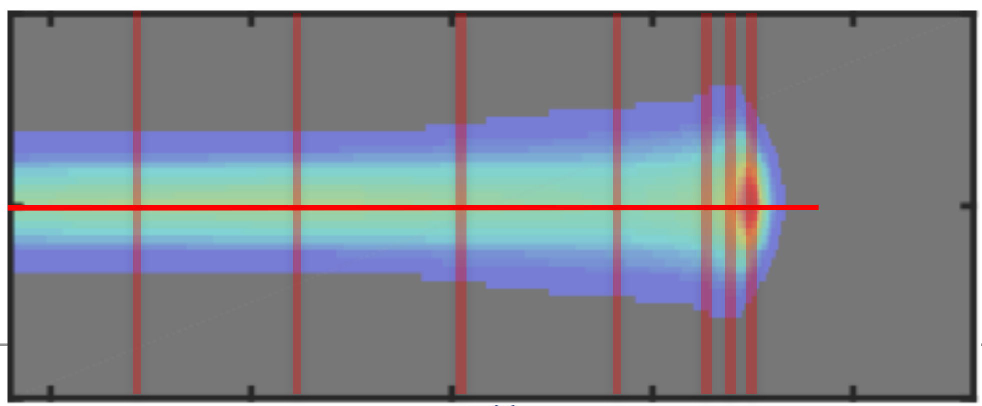


Biophysical advantages of proton radiotherapy

- Protons have a clear physical advantage over photons
- Do protons have any biological advantage over photons?



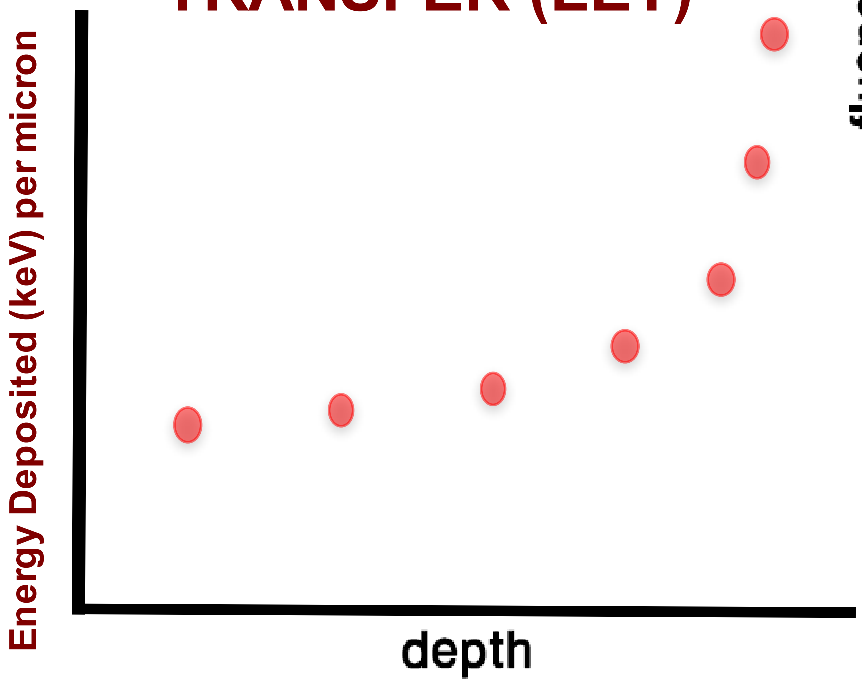


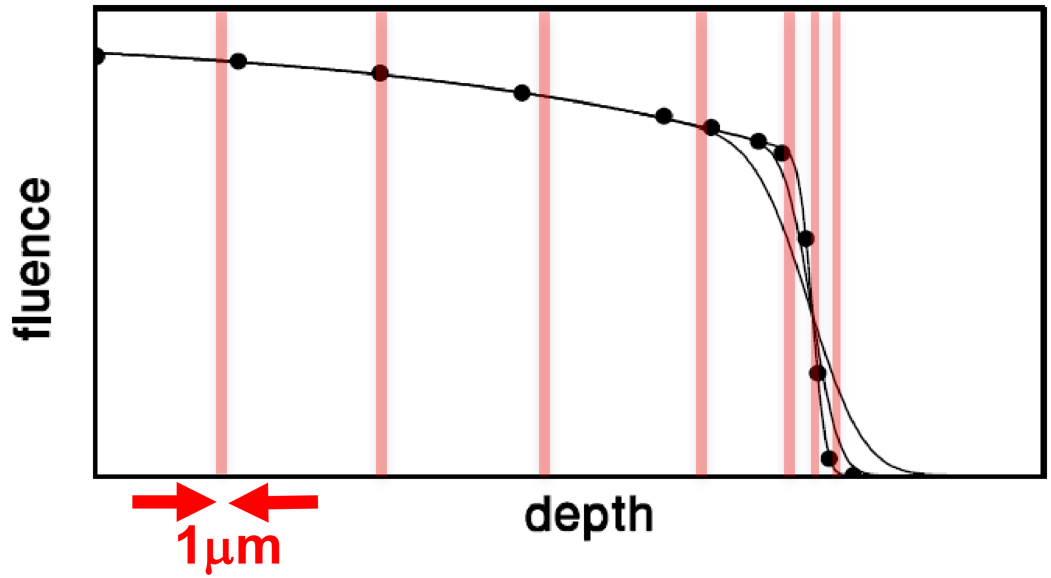


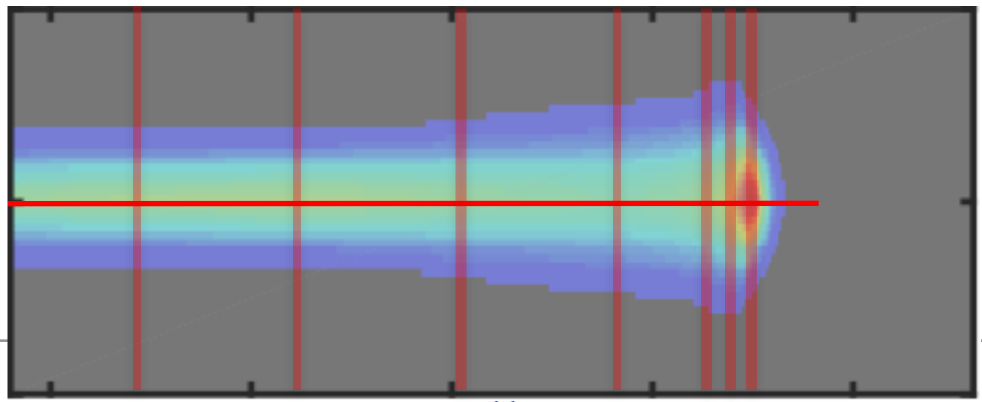
Biophysical advantages of proton radiotherapy

- Protons have a clear physical advantage over photons
- Do protons have any biological advantage over photons?

LINEAL ENERGY TRANSFER (LET)







Biophysical advantages of proton radiotherapy

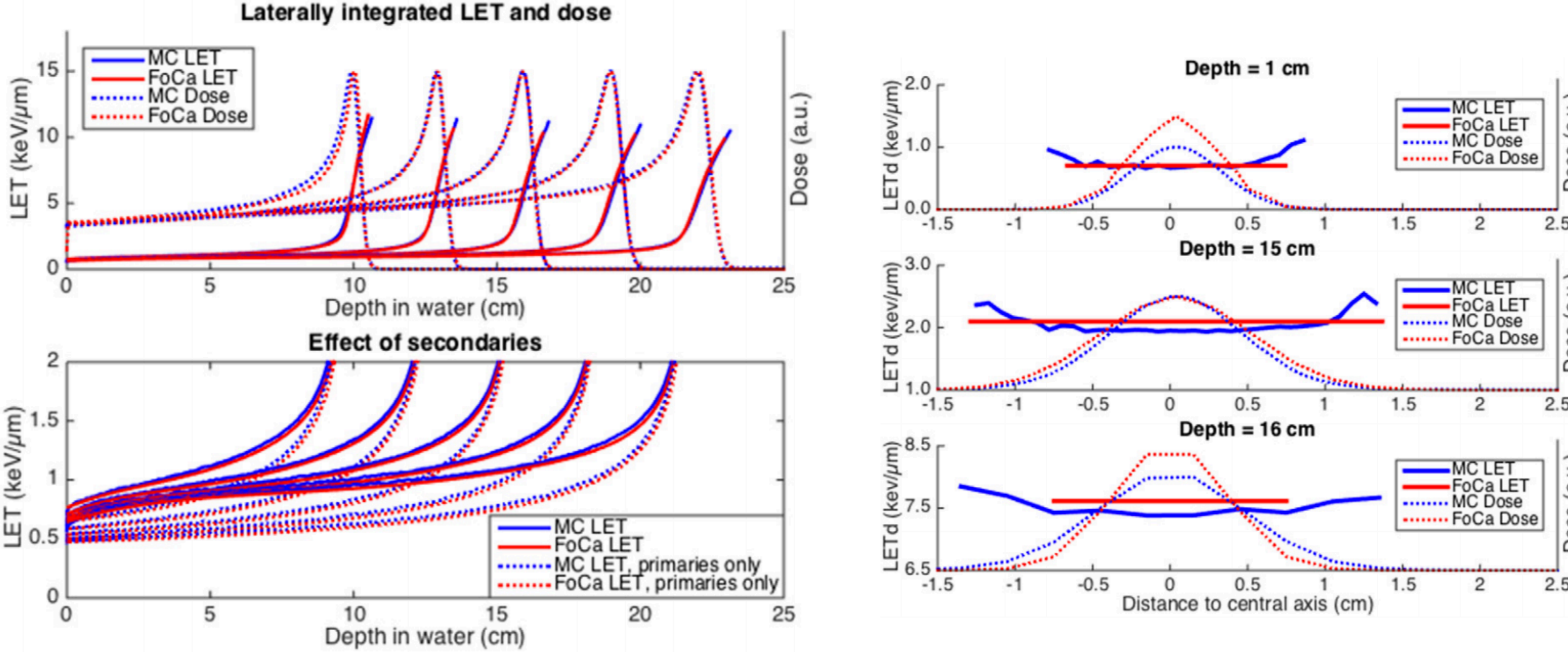
Phys Med Biol. 2016 Feb 21;61(4):1705-21. doi: 10.1088/0031-9155/61/4/1705. Epub 2016 Feb 3.

Analytical calculation of proton linear energy transfer in voxelized geometries including secondary protons.

Sanchez-Parcerisa D[1], Cortés-Giraldo MA, Dolney D, Kondrla M, Fager M, Carabe A.

Author information

[1]Department of Radiation Oncology, Hospital of the University of Pennsylvania, Philadelphia, PA 19104, USA.



Biophysical advantages of proton radiotherapy

IOP Publishing | Institute of Physics and Engineering in Medicine Physics in Medicine & Biology

Phys. Med. Biol. **60** (2015) 2645–2669 doi:10.1088/0031-9155/60/7/2645

A critical study of different Monte Carlo scoring methods of dose average linear-energy-transfer maps calculated in voxelized geometries irradiated with clinical proton beams

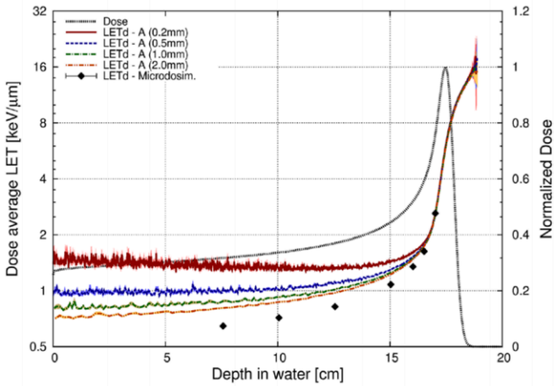
M A Cortés-Giraldo[1] and A Carabe[2]

[1] Department of Atomic, Molecular and Nuclear Physics, Universidad de Sevilla, Seville, Spain

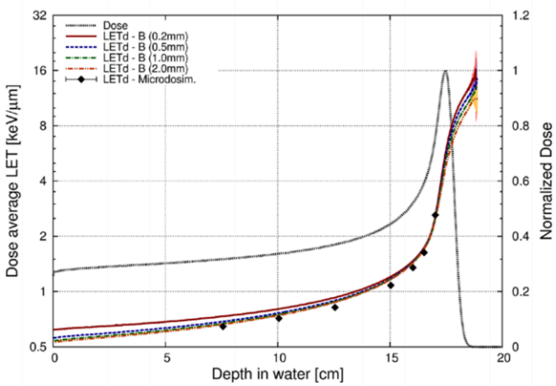
[2] Department of Radiation Oncology, Hospital of The University of Pennsylvania, Philadelphia, PA, USA

E-mail: miancortes@us.es

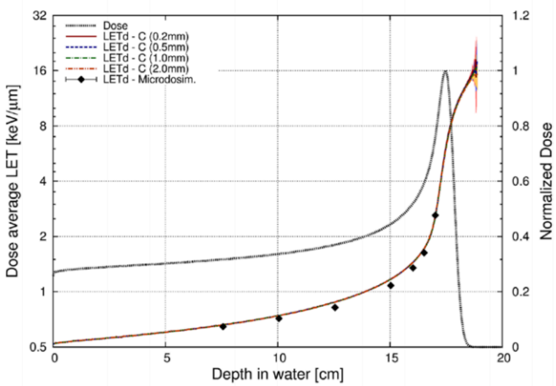
$$\overline{L}_{\mathrm{d}} = \frac{\sum_{n=1}^{N}\sum_{s=1}^{S_n}\omega_n \frac{\varepsilon_{sn}^2}{l_{sn}}}{\sum_{n=1}^{N}\sum_{s=1}^{S_n}\omega_n\, \varepsilon_{sn}}$$



$$\overline{L}_{\mathrm{d}} = \frac{\sum_{n=1}^{N}\left[\omega_n \frac{\left(\sum_{s=1}^{S_n}\varepsilon_{sn}\right)^2}{\sum_{s=1}^{S_n} l_{sn}}\right]}{\sum_{n=1}^{N}\left[\omega_n \sum_{s=1}^{S_n}\varepsilon_{sn}\right]}$$



$$\overline{L}_{\mathrm{d}} = \frac{\sum_{n=1}^{N}\sum_{s=1}^{S_n}\omega_n\, L_{sn}\, \varepsilon_{sn}}{\sum_{n=1}^{N}\sum_{s=1}^{S_n}\omega_n\, \varepsilon_{sn}}$$



Microdosimetric Measurements: 3D microdetectors

First Silicon Microdosimeters Based on Cylindrical Diodes

[1] C. Guardiola, [1] A. Carabe, [2] F. Gómez, [3] G. Pellegrini, [3] C. Fleta, [3] S. Esteban, [3] D. Quirion, [3] M. Lozano

[1] Department of Radiation Oncology, University of Pennsylvania, Philadelphia, PA 191004, USA

[2] Departamento de Física de Partículas, Universidad de Santiago de Compostela (USC), Santiago de Compostela, E-15782, Spain

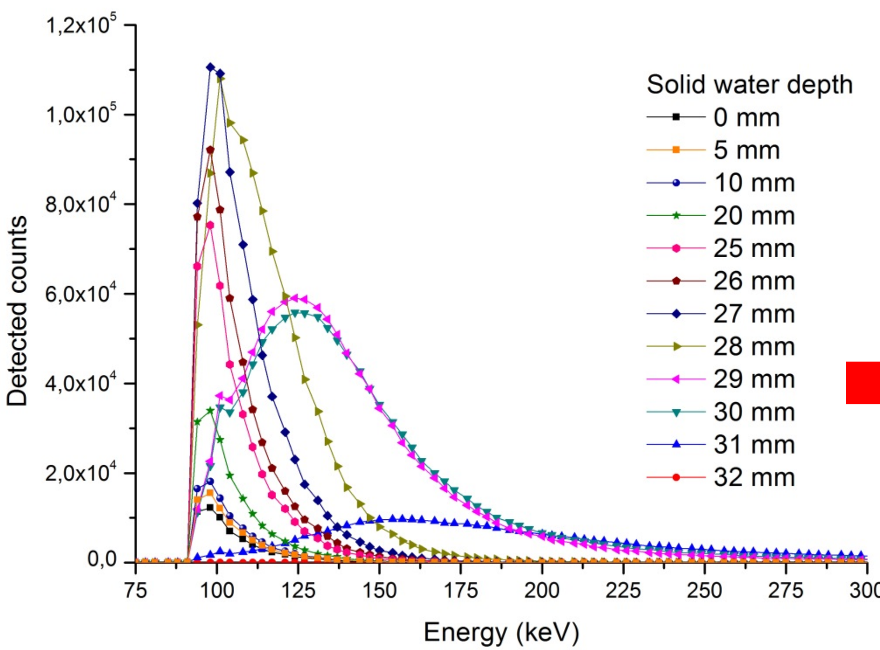
[3] Instituto de Microelectrónica de Barcelona (IMB-CNM, CSIC), Bellaterra, E-08193, Spain

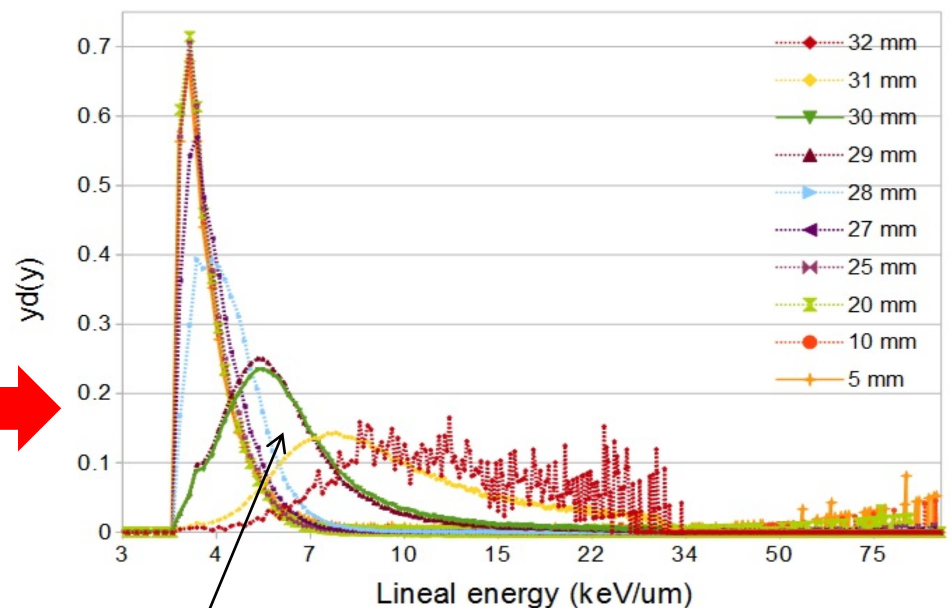
E-mail: GuardioC@uphs.upenn.edu

Centre Nacional de Microelectrònica IMB

ALIBAVA SYSTEMS

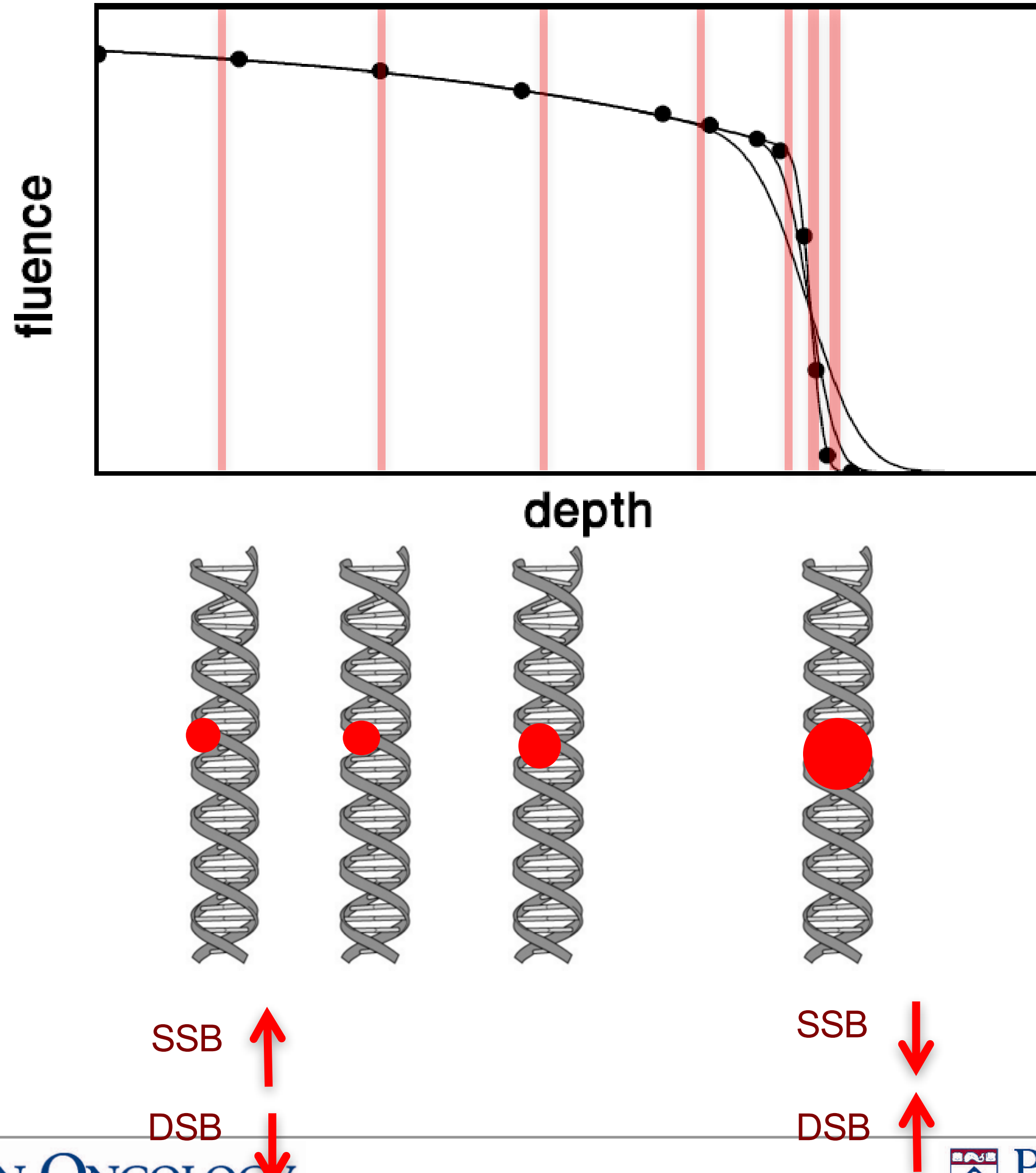
Received: 19 September 2014 /Accepted: 28 November 2014 /Published: 31 December 2014

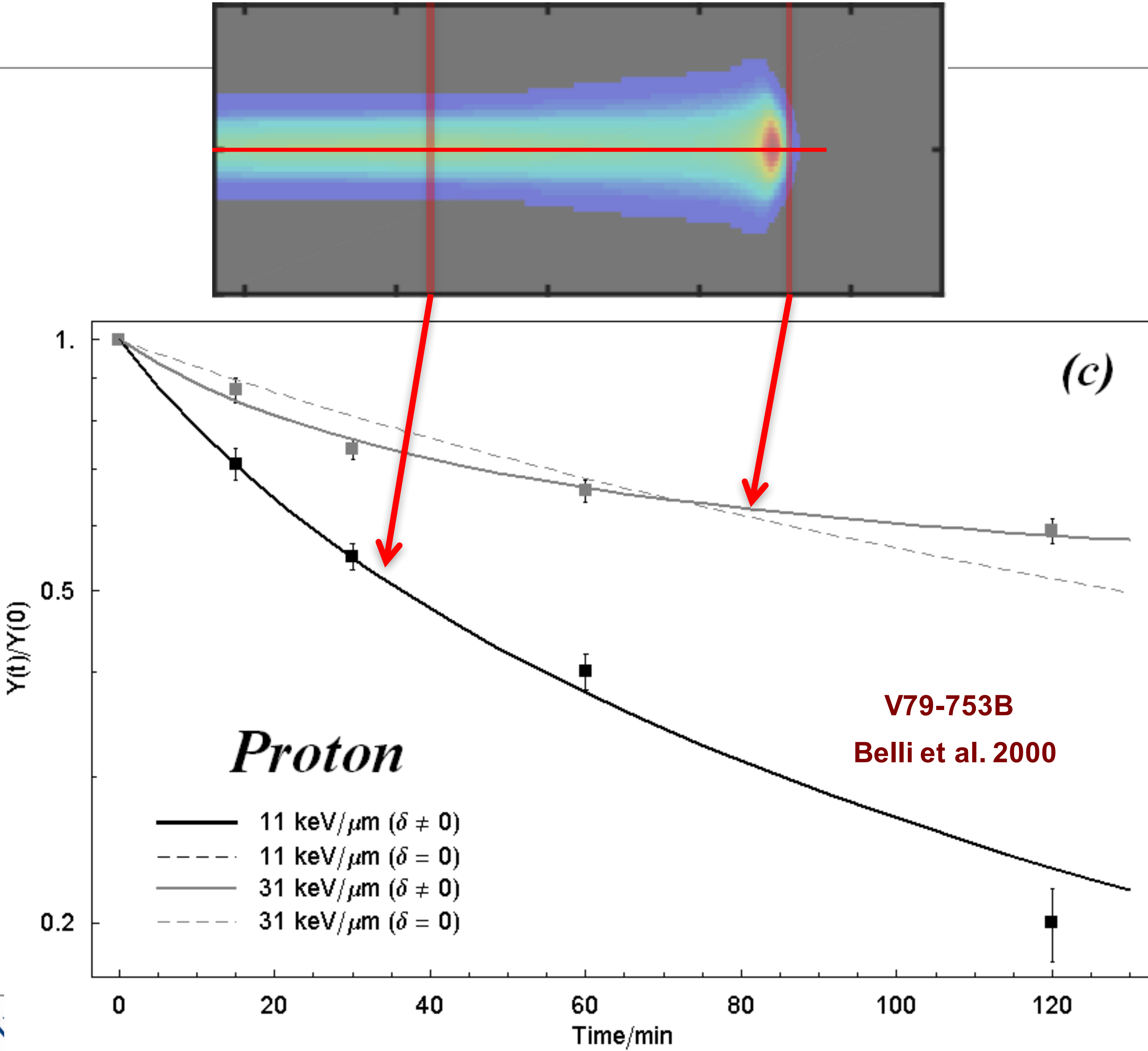




LET ~ average area under the curve

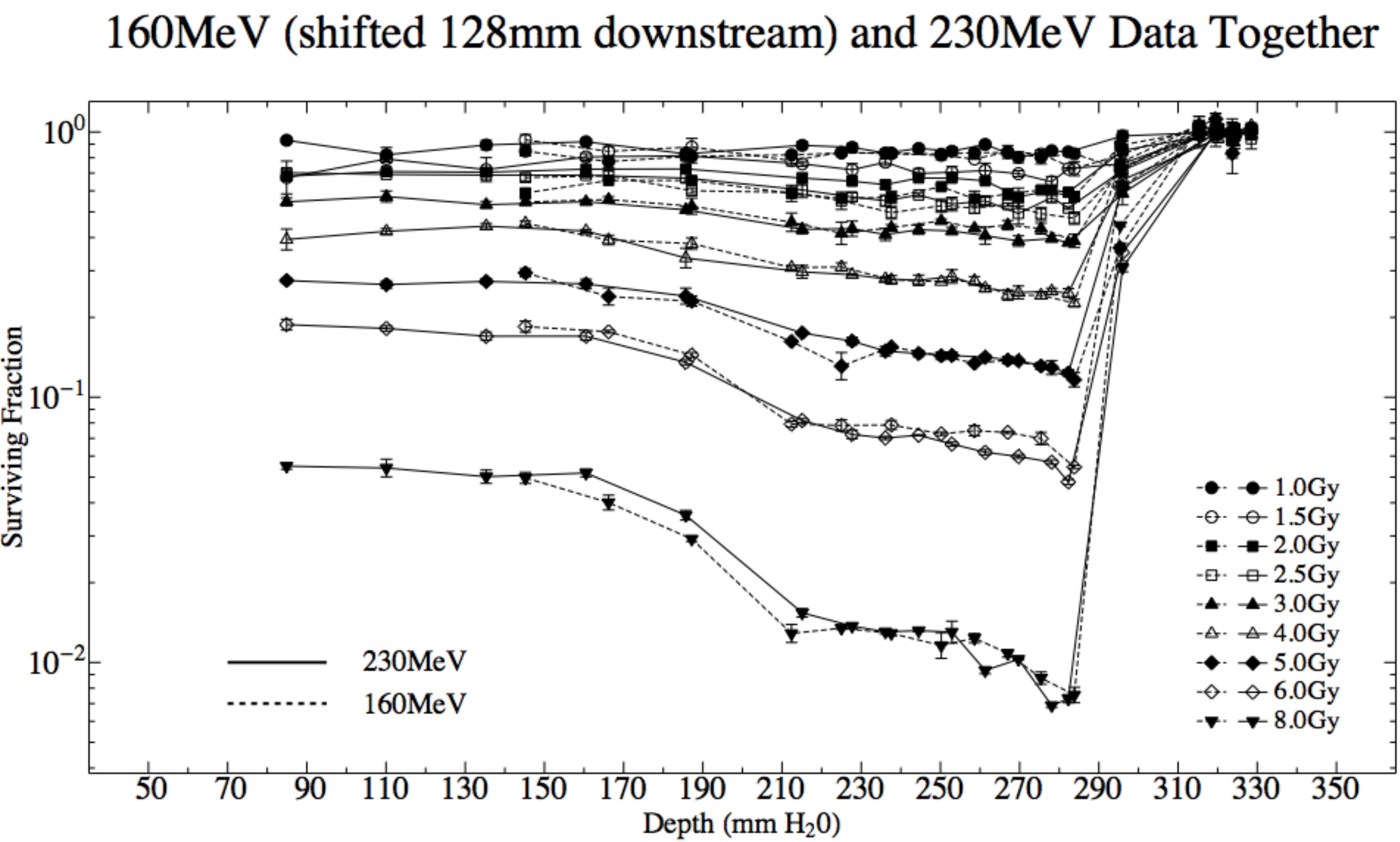
Biophysical advantages of proton radiotherapy





(c)
Proton
V79-753B
Belli et al. 2000
11 keV/μm (δ ≠ 0)
11 keV/μm (δ = 0)
31 keV/μm (δ ≠ 0)
31 keV/μm (δ = 0)
Y(t)/Y(0)
Time/min
1.
0.5
0.2
0
20
40
60
80
100
120

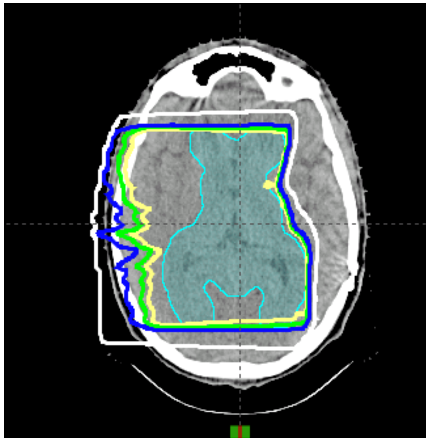
Biophysical advantages of proton radiotherapy

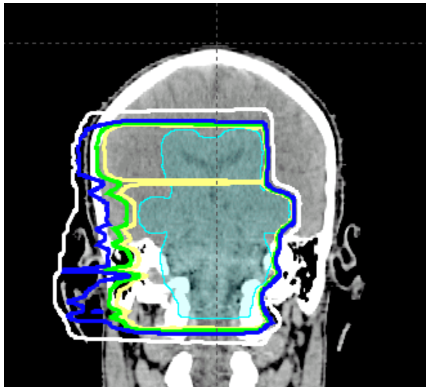


Wouters et al. Rad Res 2015 Feb; 183(2):174-87

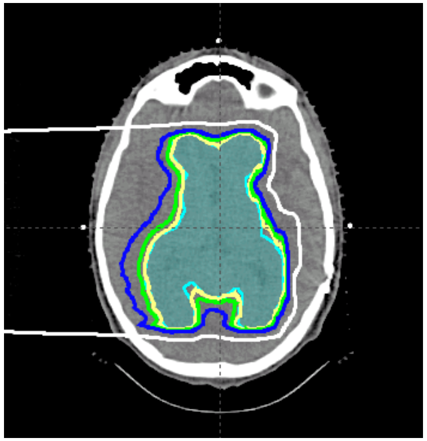
Proton Delivery Techniques

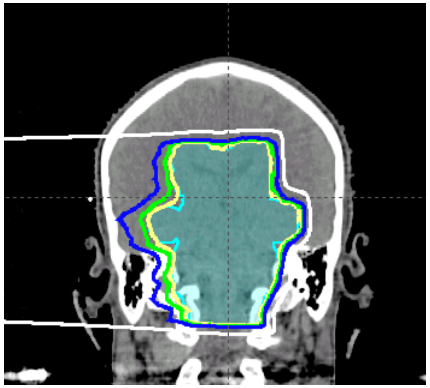
- The width of the SOBP for passively scattered beams is determined by the widest part of the target in depth





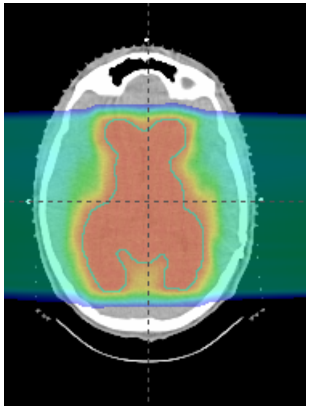
- The width of the SOBP for PBS beams is determined by the width of the target in depth along each line of spots

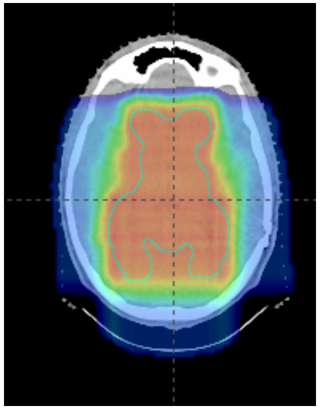




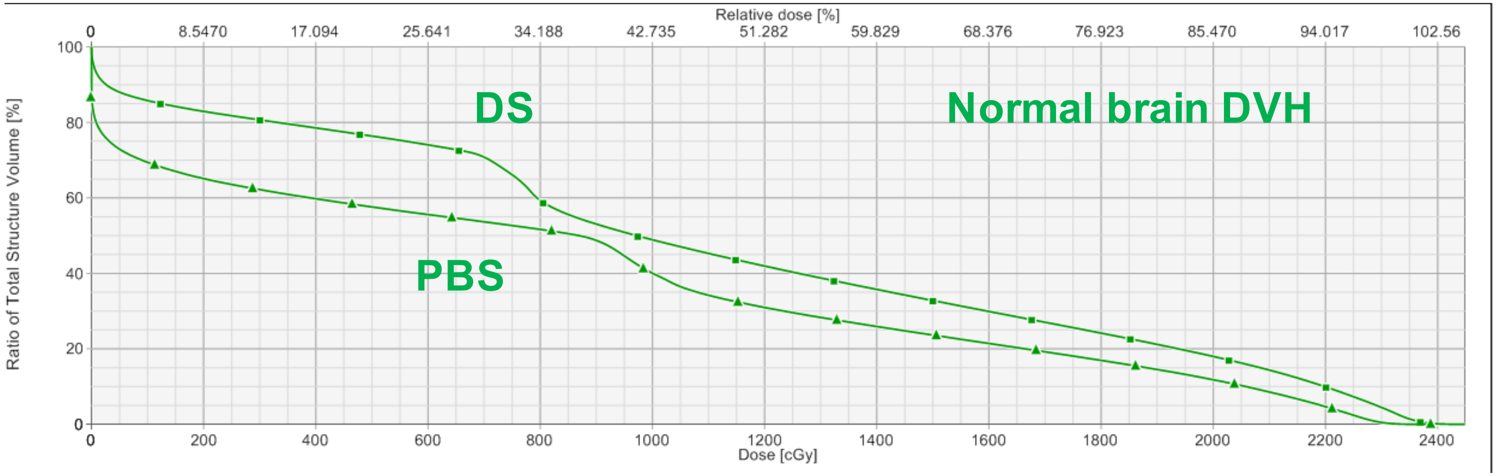
Proton Delivery Techniques

- **By adding multiple beams, you can achieve a similarly conformal plans with passively scattered beams**





- **Generally, the integral dose will be higher with DS**



Uncertainties in Proton Therapy

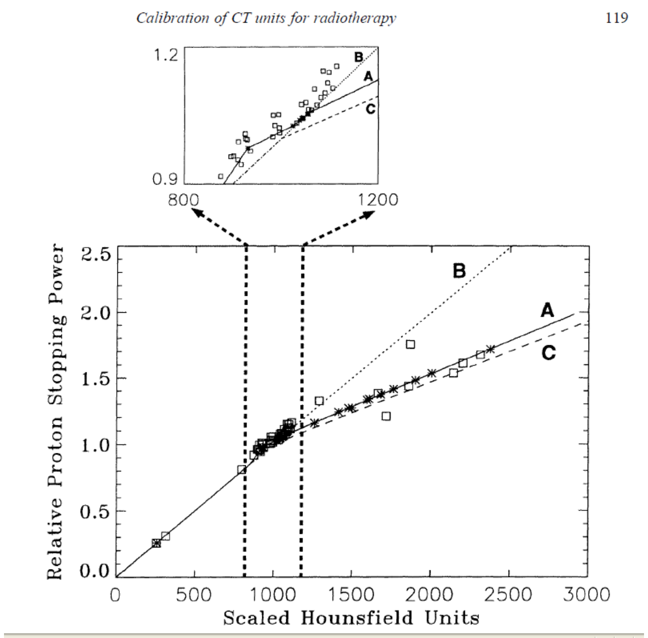
Systematic Range Uncertainty

- The HU value must be correlated with the relative proton stopping power through a calibration curve in the treatment planning system

- Different tissue compositions which have the same HU can have different proton stopping powers

- The uncertainty in conversion from HU to sopping power introduces ~1-2% uncertainty in the range of the beam

- Beam hardening and image artifacts in CT scans introduce additional uncertainty

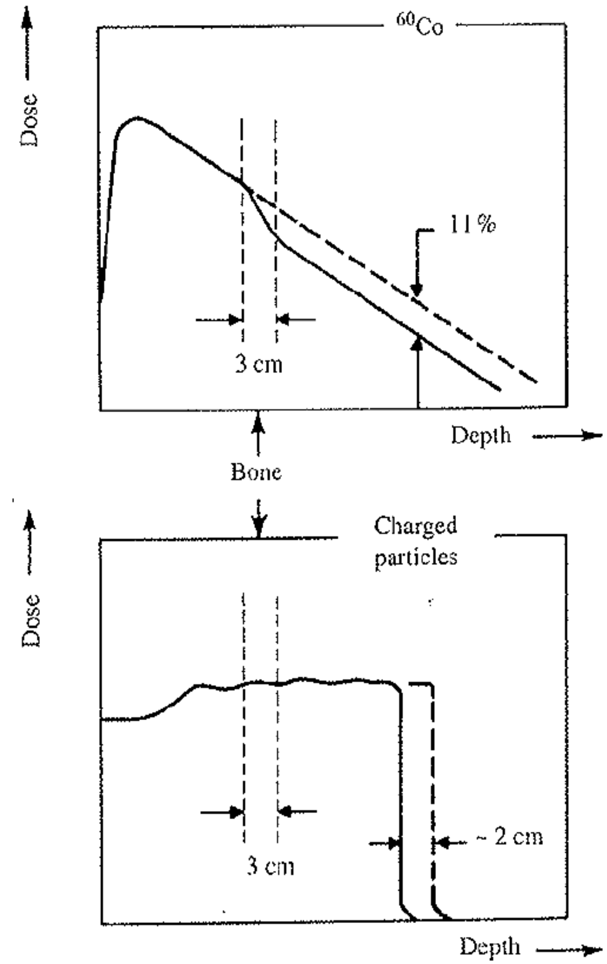


Schneider, et al. The calibration of CT Hounsfield units for radiotherapy treatment planning

Uncertainties in Proton Therapy

- **Why is range uncertainty such a big deal?**

- Dose from protons falls off steeply at the end of the proton range
- Failure to account for a higher density structure along the proton path may result in a near zero dose in a distal segment of the target due to reduced range of the protons
- Neglecting to account for an air cavity upstream of the target can result in higher doses delivered to normal structures distal to the target

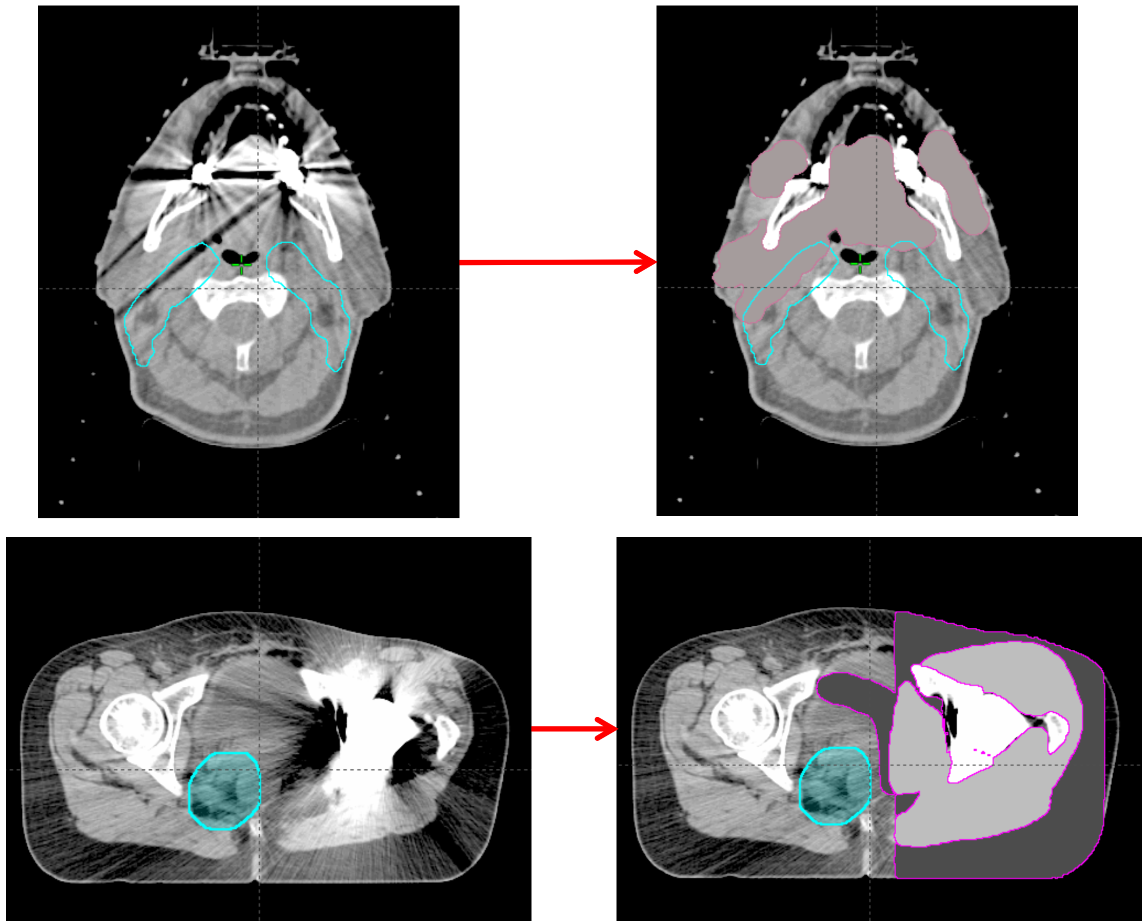


Goitein, et al., Med Phys

Uncertainties in Proton Therapy

Reducing HU Uncertainty

- Uncertainties introduced by image artifacts can be reduced by overriding the artifacts with manually set HU



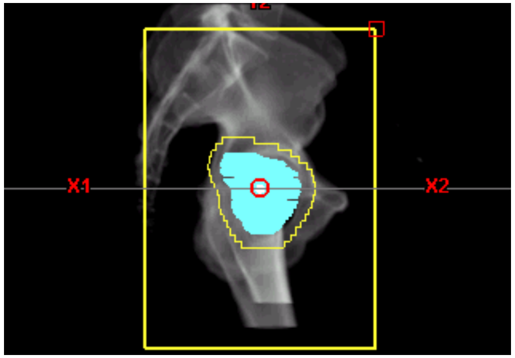
Uncertainties in Proton Therapy

- **Uncertainties perpendicular to the beam direction**
  - Patient setup uncertainty
  - Target motion
    - Same philosophy as photon margins

- **Uncertainties in the beam direction**
  - Uncertainty in range due to uncertainty in HU and conversion to proton stopping power
  - Uncertainty in the path of the beam through heterogeneous tissue due to setup uncertainty
    - Margin considerations are specific to the beam direction and beam path, so PTV concept is not relevant

Treatment Planning – Scattered Beams

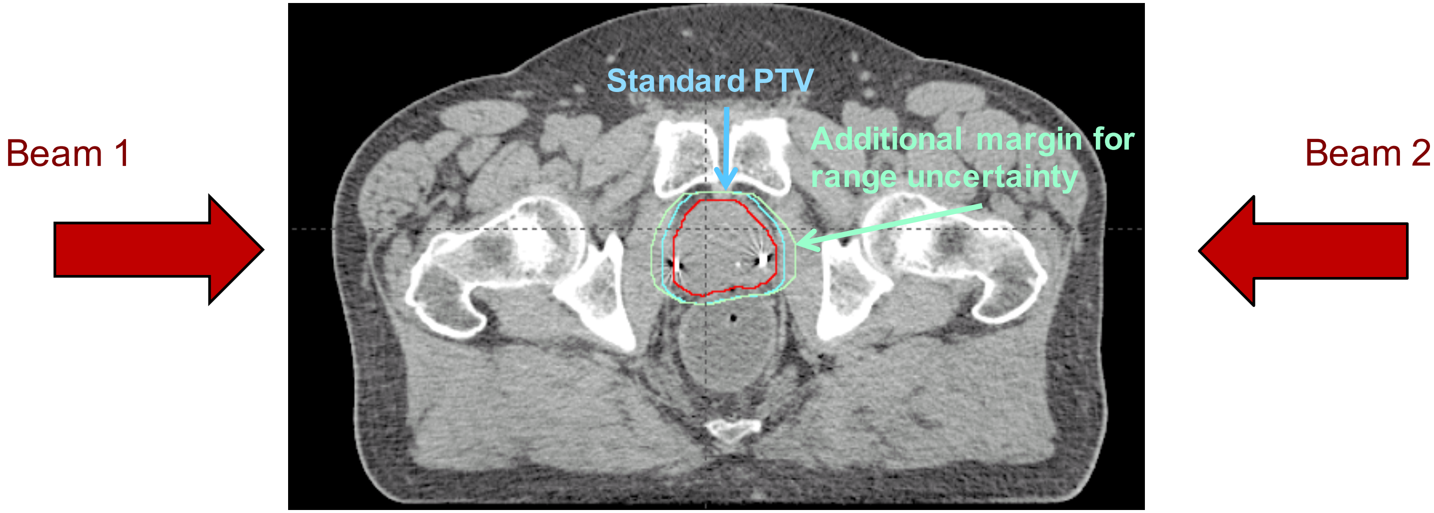
- Uncertainty perpendicular to the beam - apply sufficient margin to the collimating aperture from the CTV to account for setup and motion uncertainty



- Range uncertainty – expand the SOBP by 3.5% of the range plus 3mm distally and proximally, smear the compensator
  - 3.5% for uncertainty in HU and conversion to proton stopping power
  - 3mm for beam delivery uncertainty, compensator milling uncertainty and compensator positioning uncertainty
  - Smearing ensures coverage in the presence of motion or anatomical change along the beam path

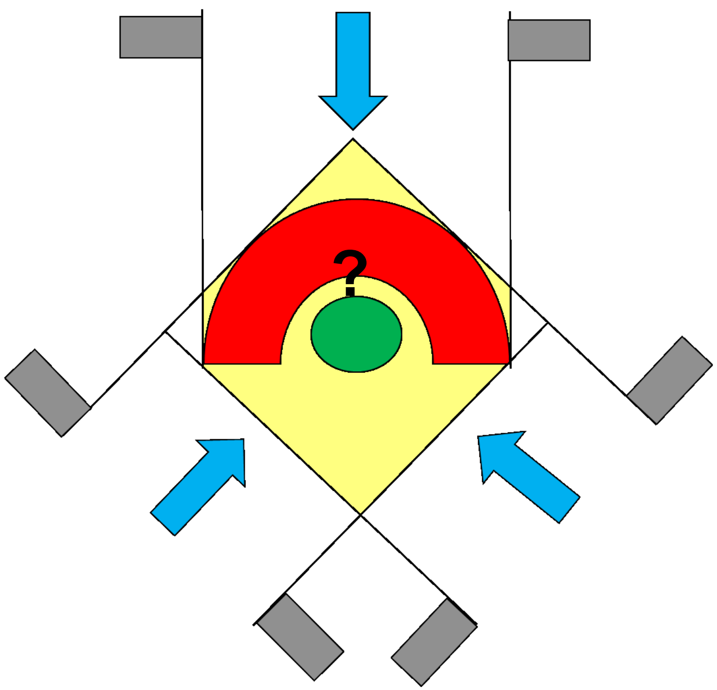
Treatment Planning – Scanned Beams

- **Inverse planning requires either:**
  - Incorporating uncertainty margins into an optimization structure
  - Explicit robust optimization
- **Structures can be created with additional margin in the beam direction in order to account for range uncertainty**

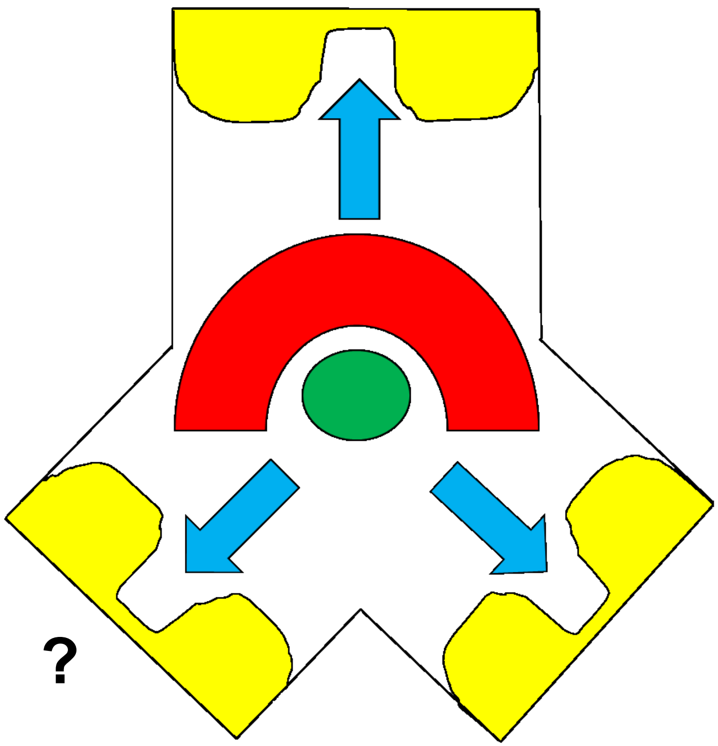


Treatment Planning – Scanned Beams

- **PBS treatment plans are optimized using inverse planning techniques which allow for variation in <u>position</u>, <u>intensity</u> and *<u>energy</u>* of each spot**



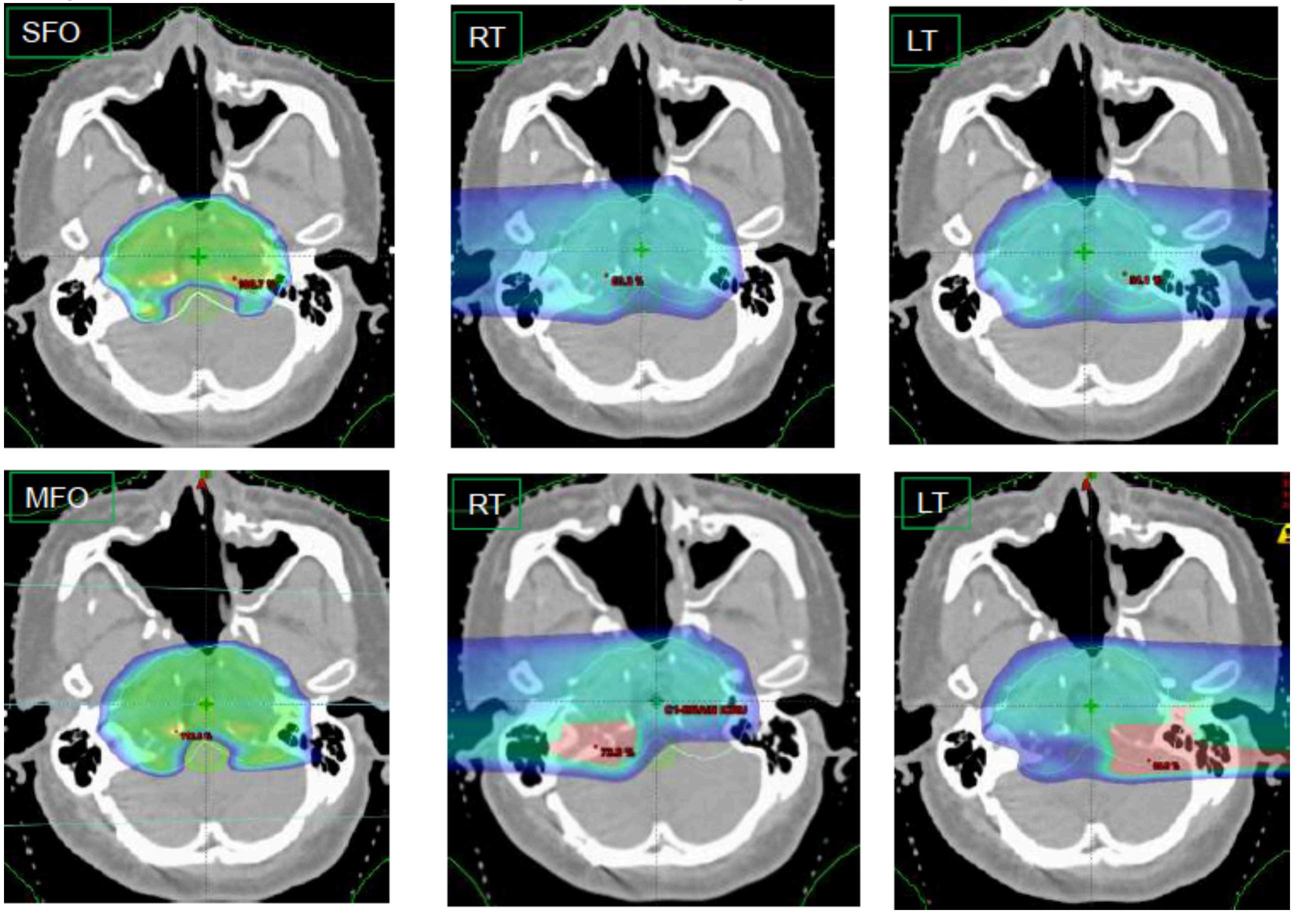
3D Forward planning



PBS: Inverse planning

Treatment Planning – Scanned Beams

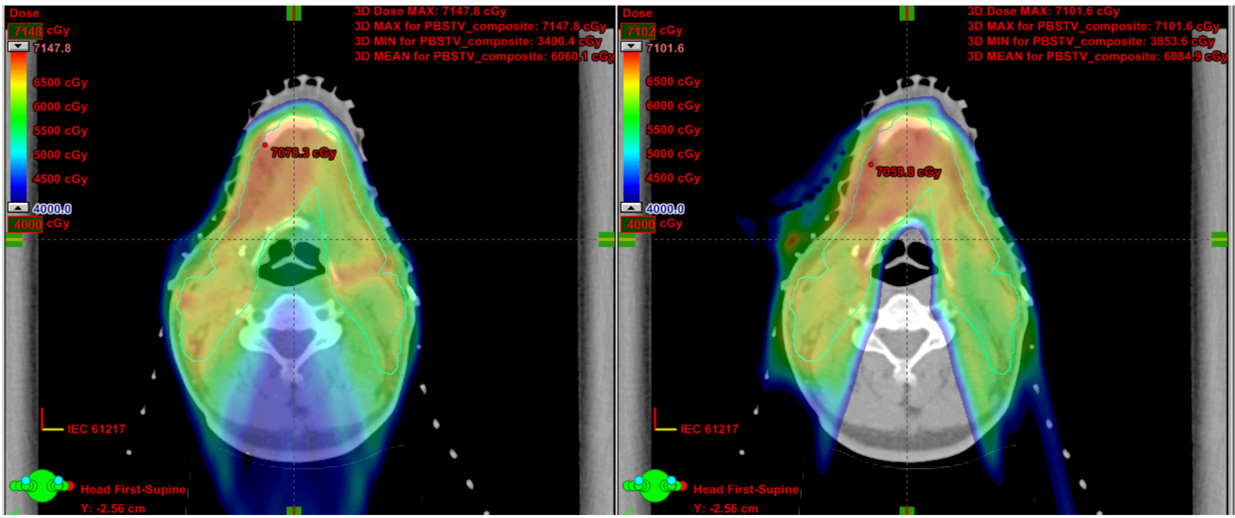
- PBS plans can be optimized such that each of the beams covers the target uniformly with dose (single field optimization SFO) or such that the sum of all beams covers the target uniformly with dose (multi-field optimization MFO)



Treatment Planning – Scanned Beams

- MFO provides more degrees of freedom to optimize a treatment plan and can provide better normal tissue sparing

SFO MFO

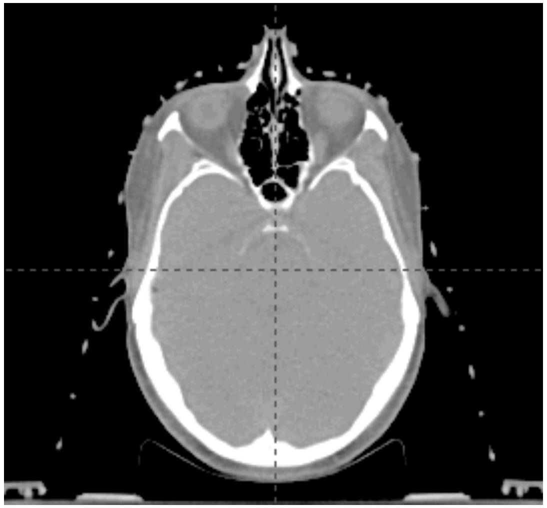


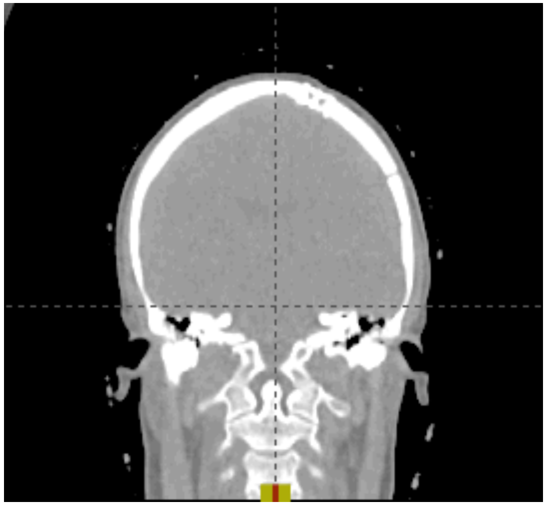
- The higher degree of modulation in the spot maps causes MFO plans to be less robust to uncertainty

General Beam Angle Selection Guidelines

- **Shortest beam path to the target**
  - Protons STOP, so their major advantage is sparing dose to tissue distal to the target
  - A shorter path to the target results in less overall range uncertainty
- **Most homogeneous and reproducible path to the target**
  - Proton range is highly sensitive to heterogeneities along its path
- **Beams that stop just proximal to serial critical organs should be avoided**
  - Systematic range uncertainty could lead to a much higher dose to an OAR that is close distal proximity to the beam fall-off than is calculated in the nominal plan
  - Uncertainty in relative biological effectiveness in the distal fall-off

Site-specific Beam Angle Considerations



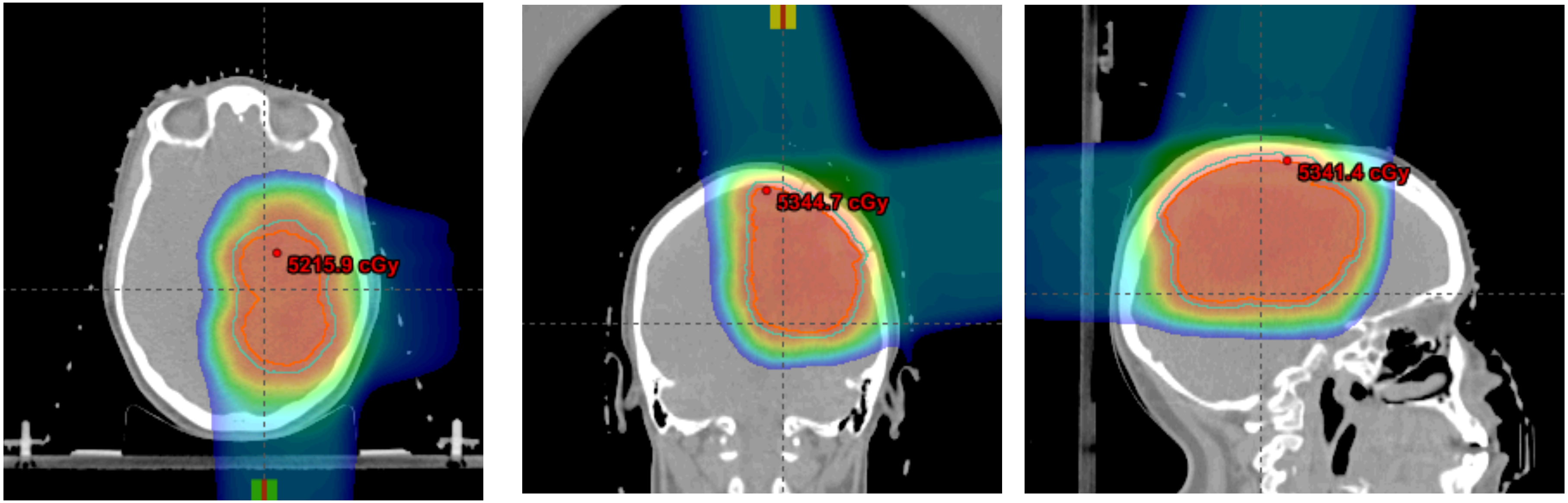


Brain

- Avoid beams passing through heterogeneous sinuses and base of skull
- Shortest beam paths to reduce integral dose to normal brain tissue
- Large angle of separation between beams helps reduce skin dose
- Multiple non-coplanar beams to avoid range and RBE uncertainties pointed toward critical structures

Site-specific Beam Angle Considerations

Example Brain Plan



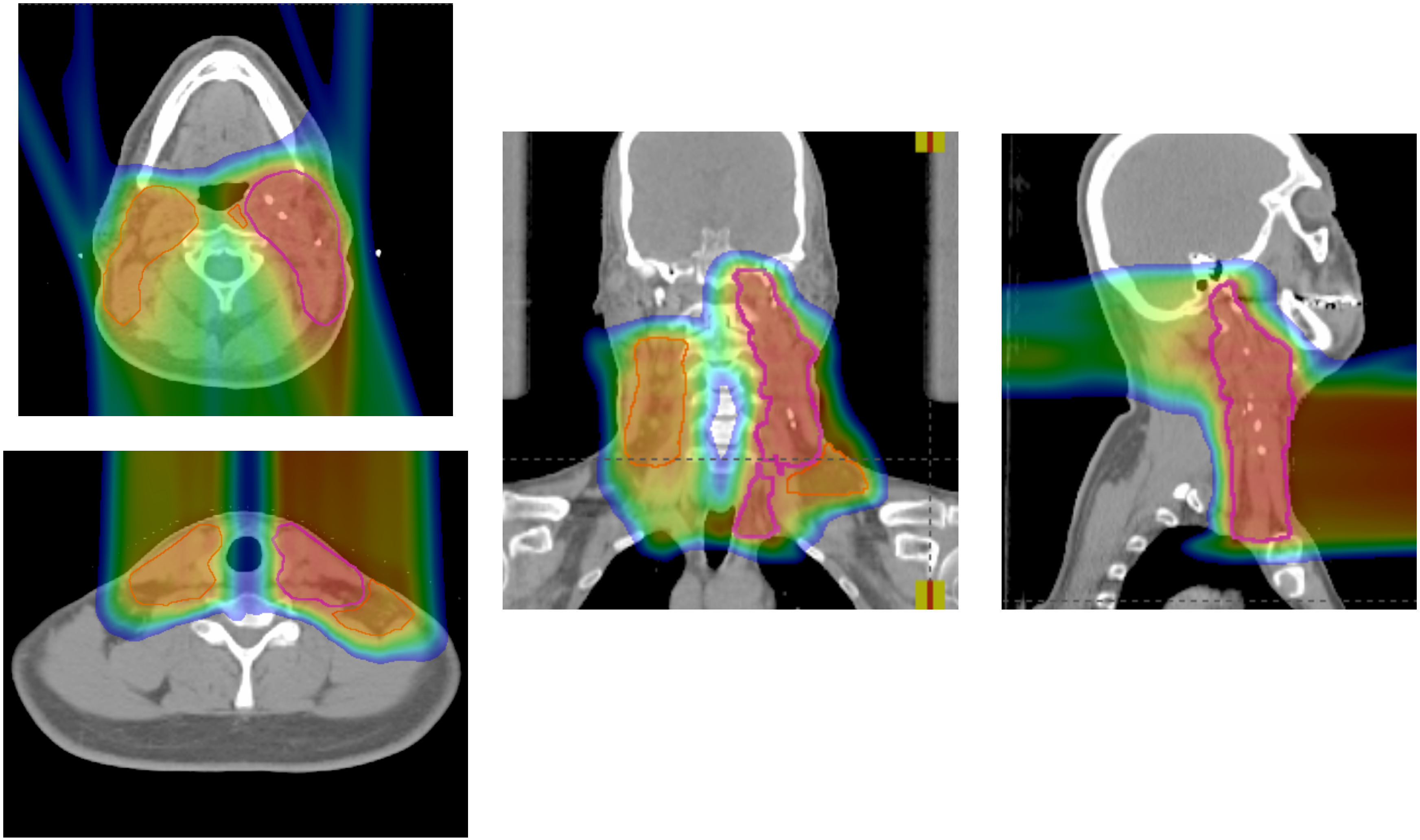
Site-specific Beam Angle Considerations

Head and Neck

- Avoid anterior beams through areas of uncertainty in the mouth
  - Metal dental work
  - CT artifact caused by teeth and dental work
  - Tongue positioning
- Avoid posterior beams through the neck in the presence of loose tissue and skin folds
- Shoulder alignment is critical when treating neck nodes with posterior beams

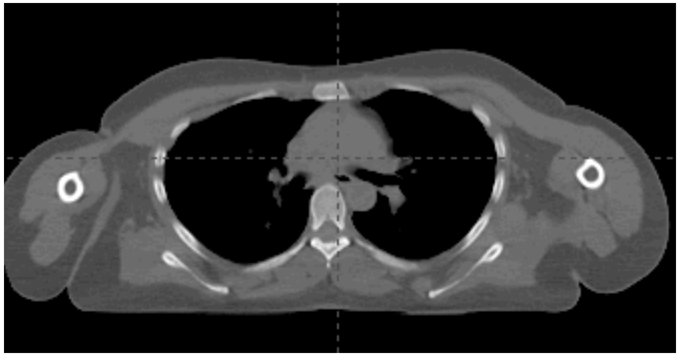
Site-specific Beam Angle Considerations

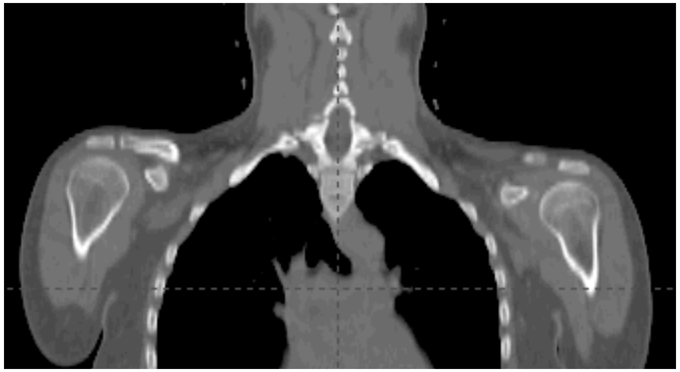
Example H&N Plan



Site-specific Beam Angle Considerations

Mediastinum

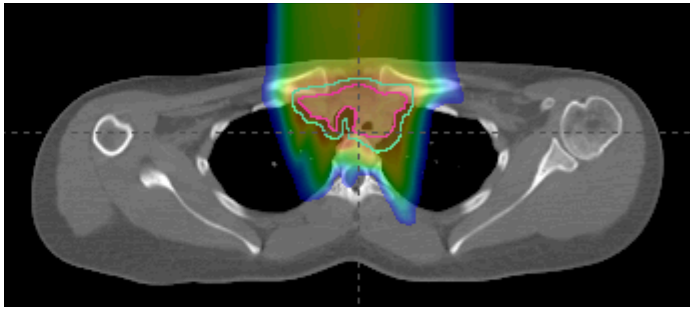


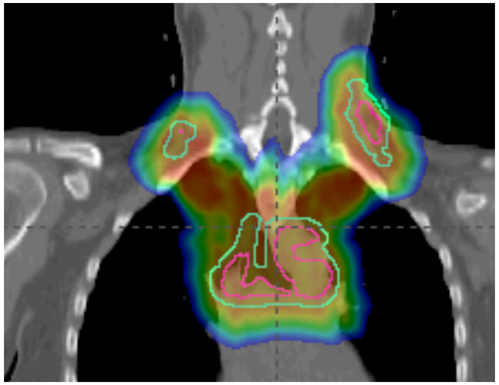


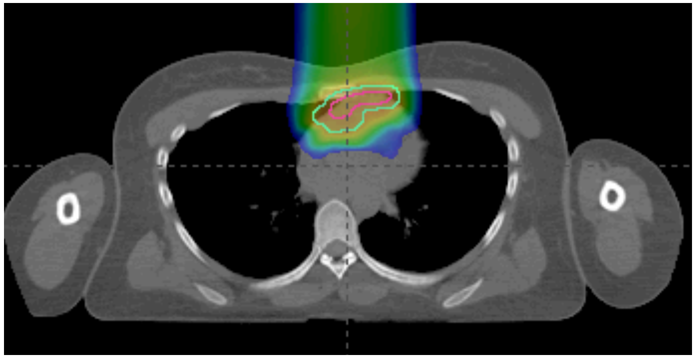
- Generally anterior or posterior beams are used depending on target geometry since they best spare lung dose
- Posterior beams can spare heart and breast tissue when target is more posterior
- Anterior beams can spare heart and cord when target is more anterior

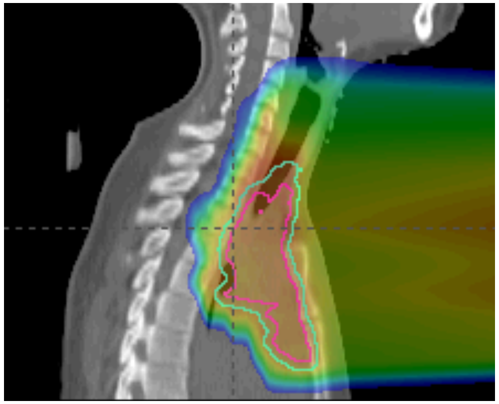
Site-specific Beam Angle Considerations

Example Hodgkin's Plan

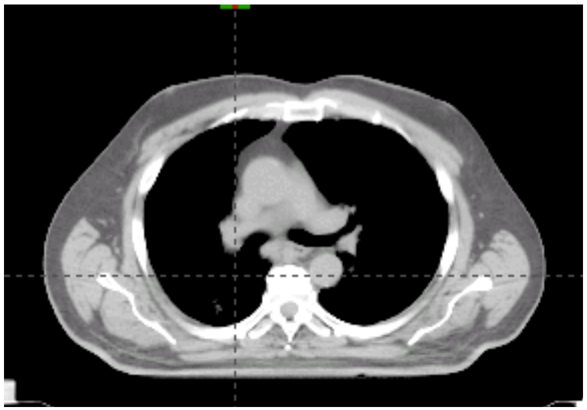






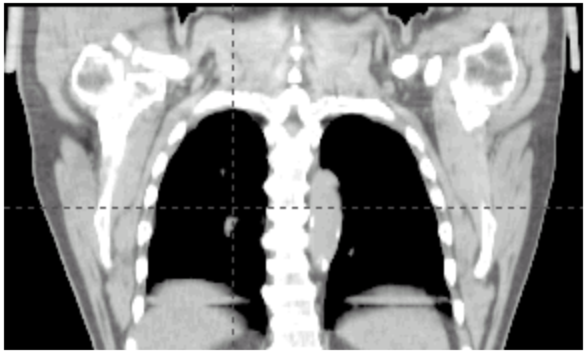


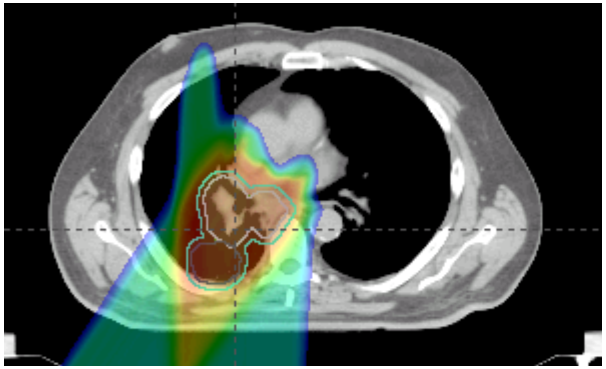
Site-specific Beam Angle Considerations



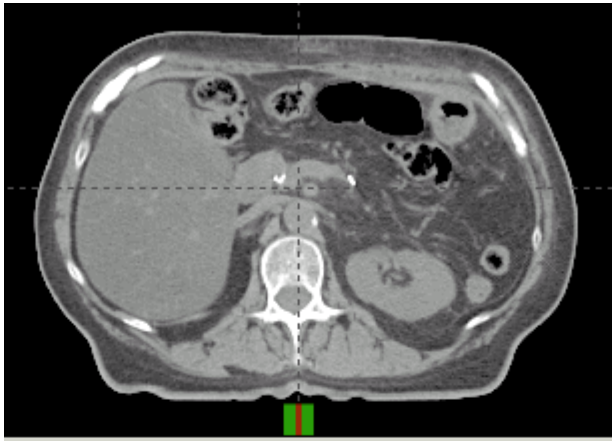
Lung

- A posterior beam is often the most stable
- Generally the posterior beam is combined with a posterior oblique beam that blocks the spinal cord



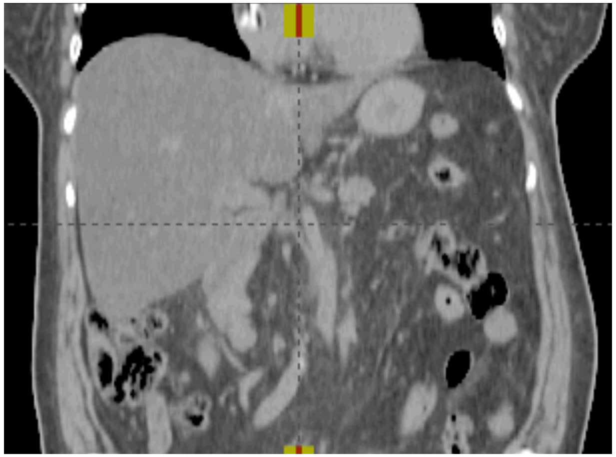


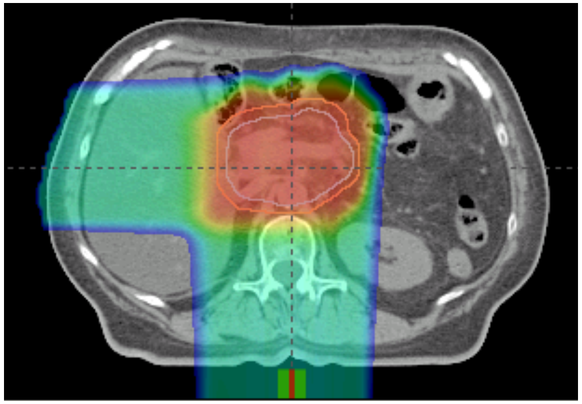
Site-specific Beam Angle Considerations

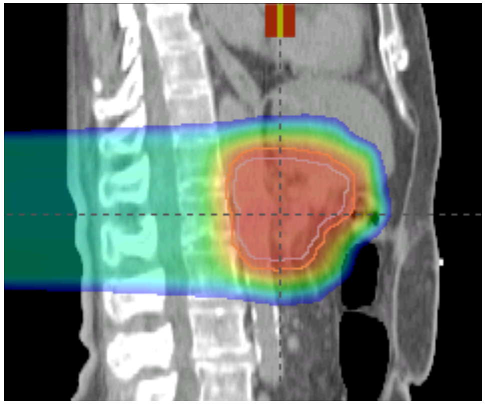


Abdomen

- Posterior and right-sided beams are the most stable
  - Reproducible setup
  - Homogeneous path, avoid bowel gas
  - Have to manage mean liver, kidney doses

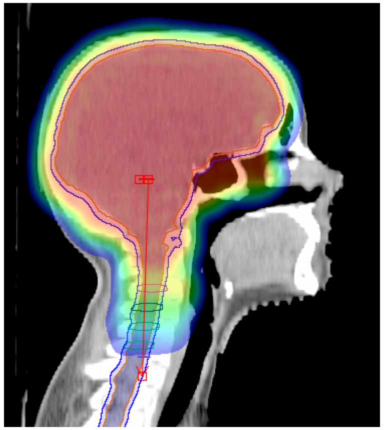


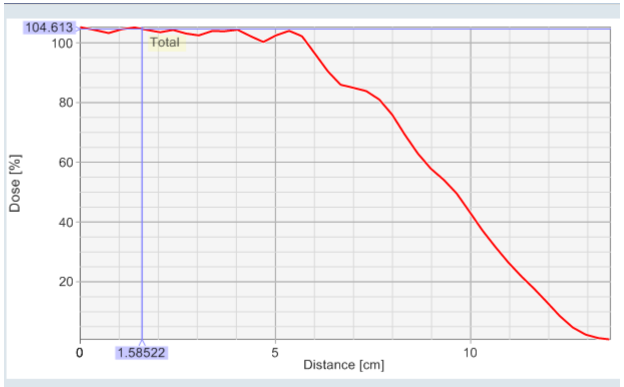


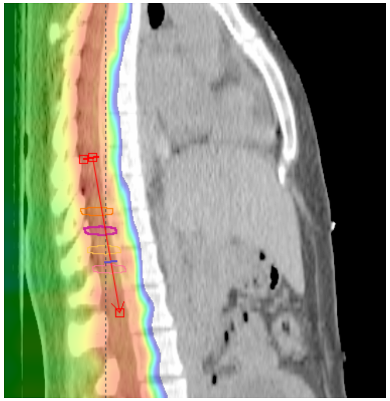


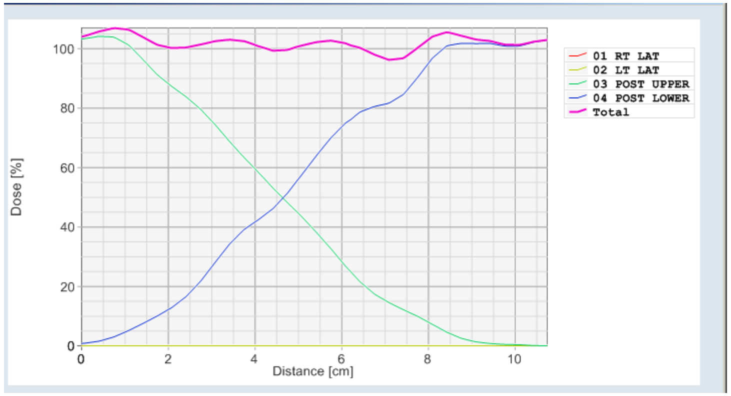
Clinical Examples

- **Field Matching with PBS**
  - Overlapping fields with shallow gradients to smear the match
  - Example: Craniospinal matches



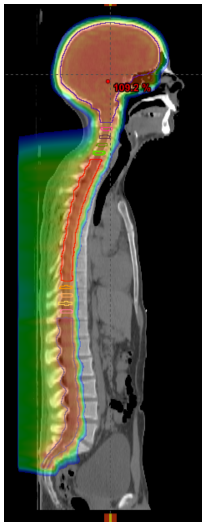


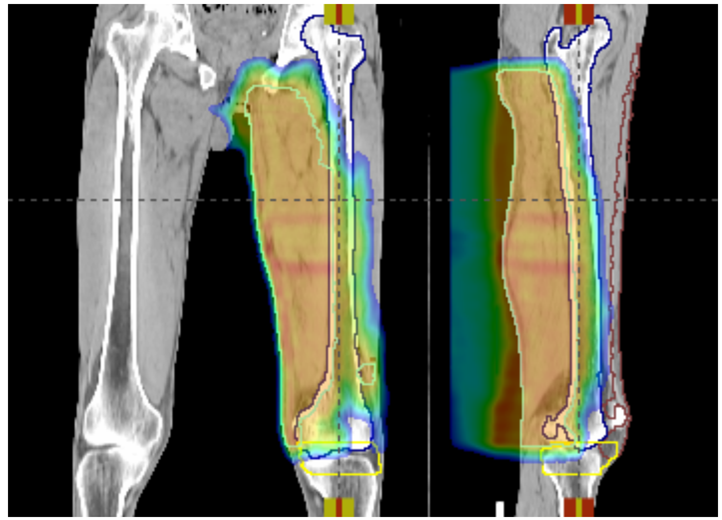


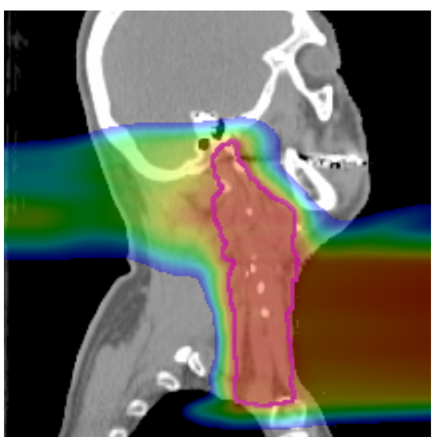


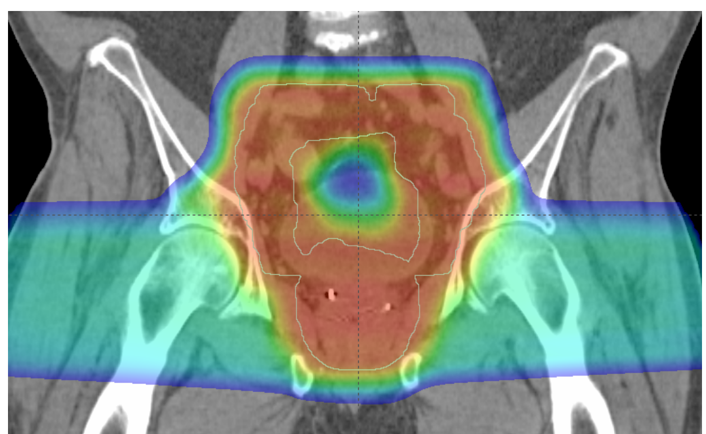
Clinical Examples

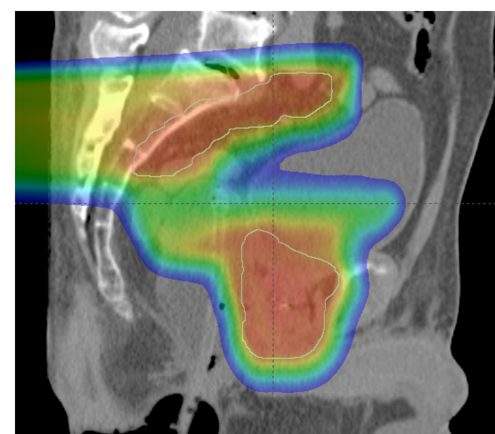
- **Field Matching with PBS**
  - Results in homogeneous safe matches between fields





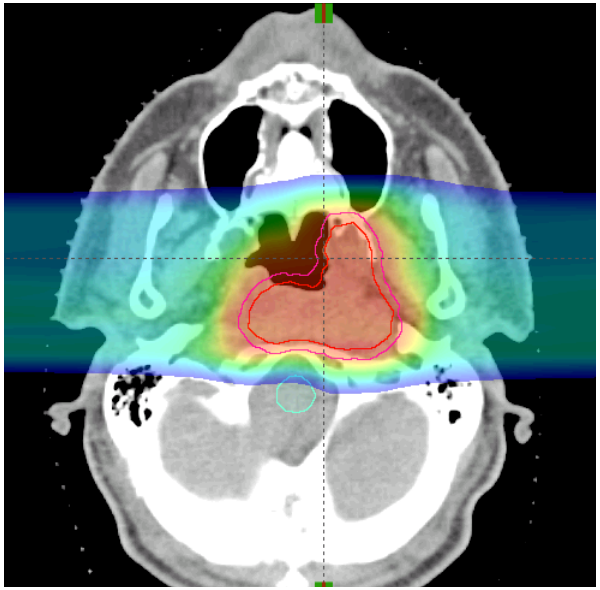


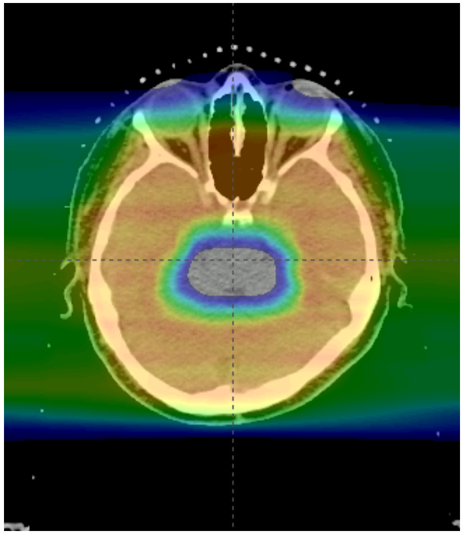


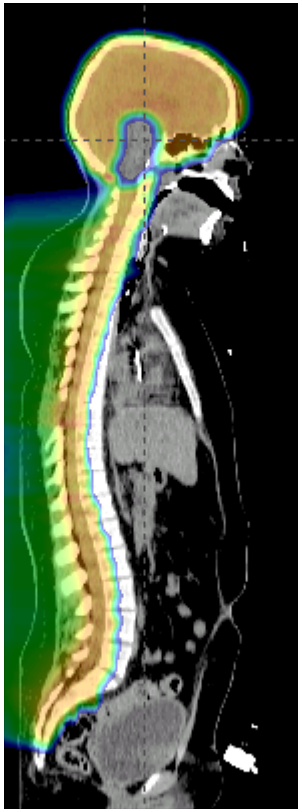


Clinical Examples

- **Retreatment**
  - Protons provide the potential to treat recurrences while avoiding even low dose to previously irradiated normal tissues

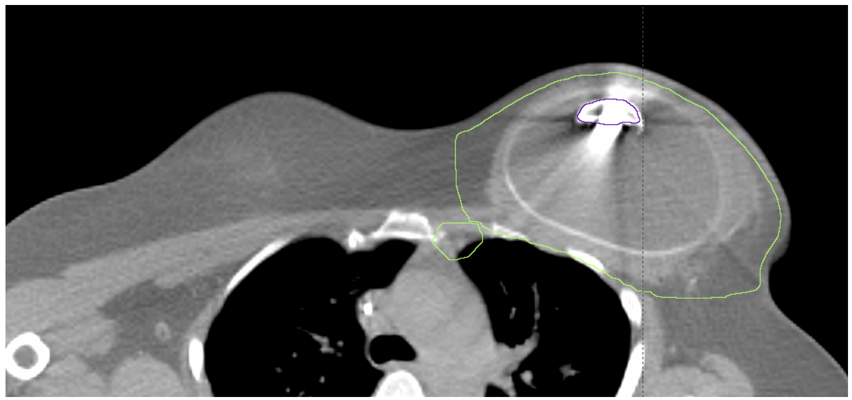


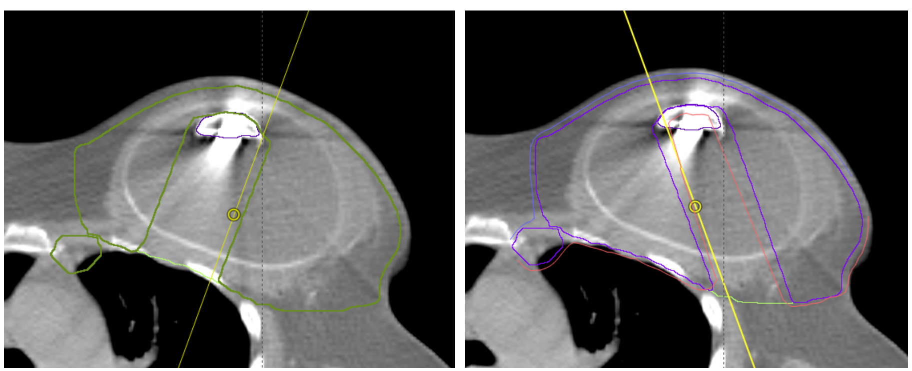


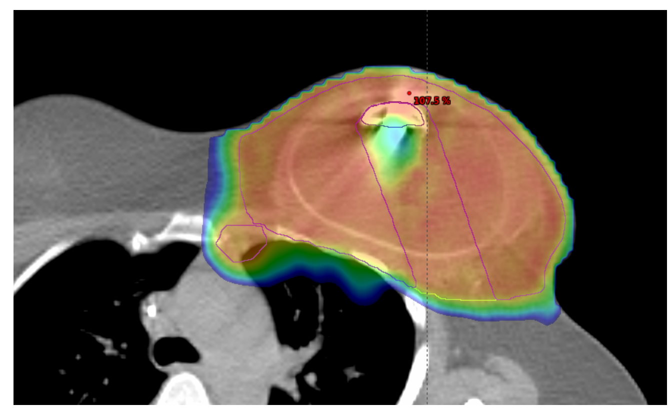


Clinical Examples

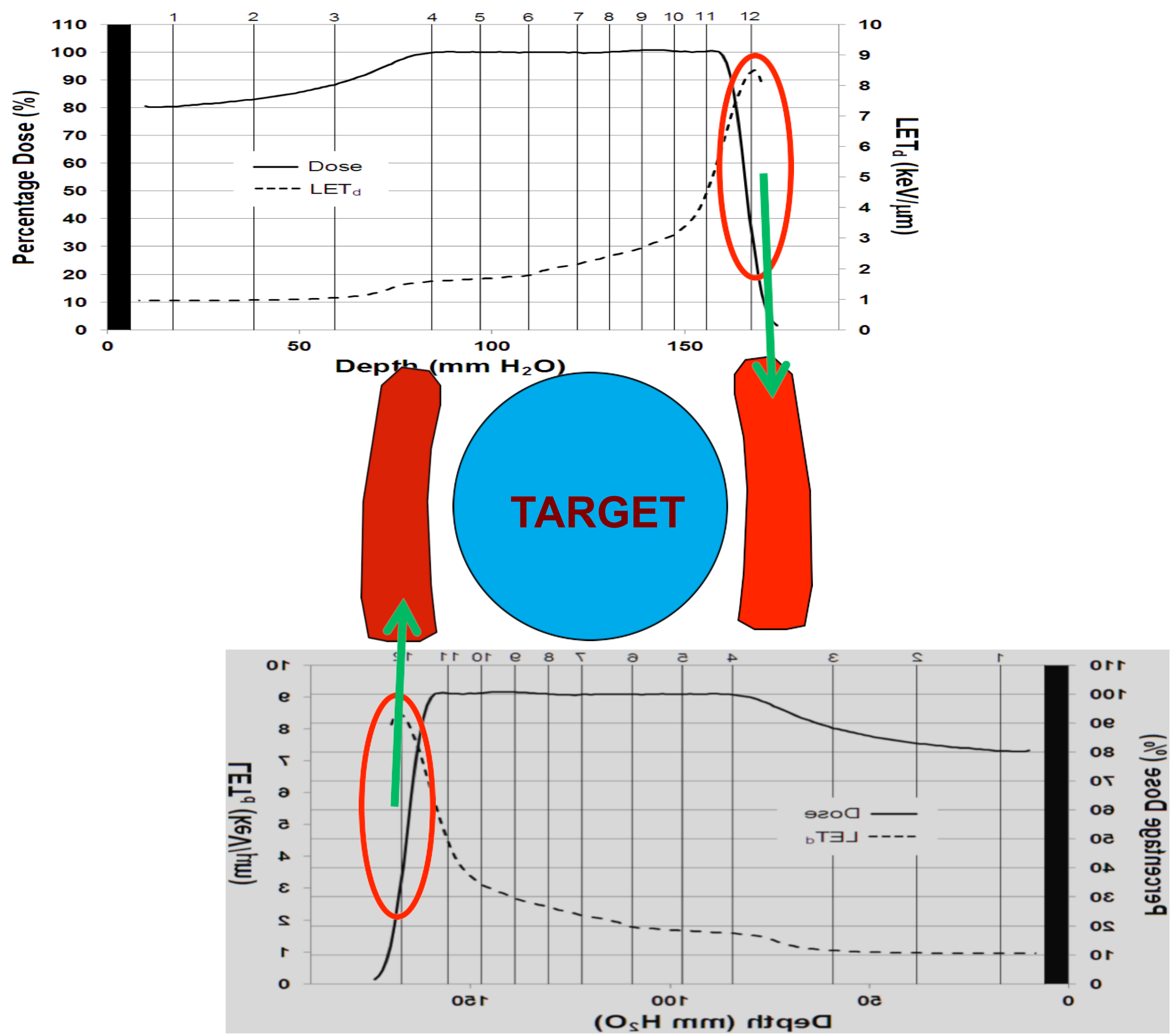
- **Avoidance of Metal in the target area**
  - MFO with PBS can allow treatment of targets containing metal without sending protons through the metal



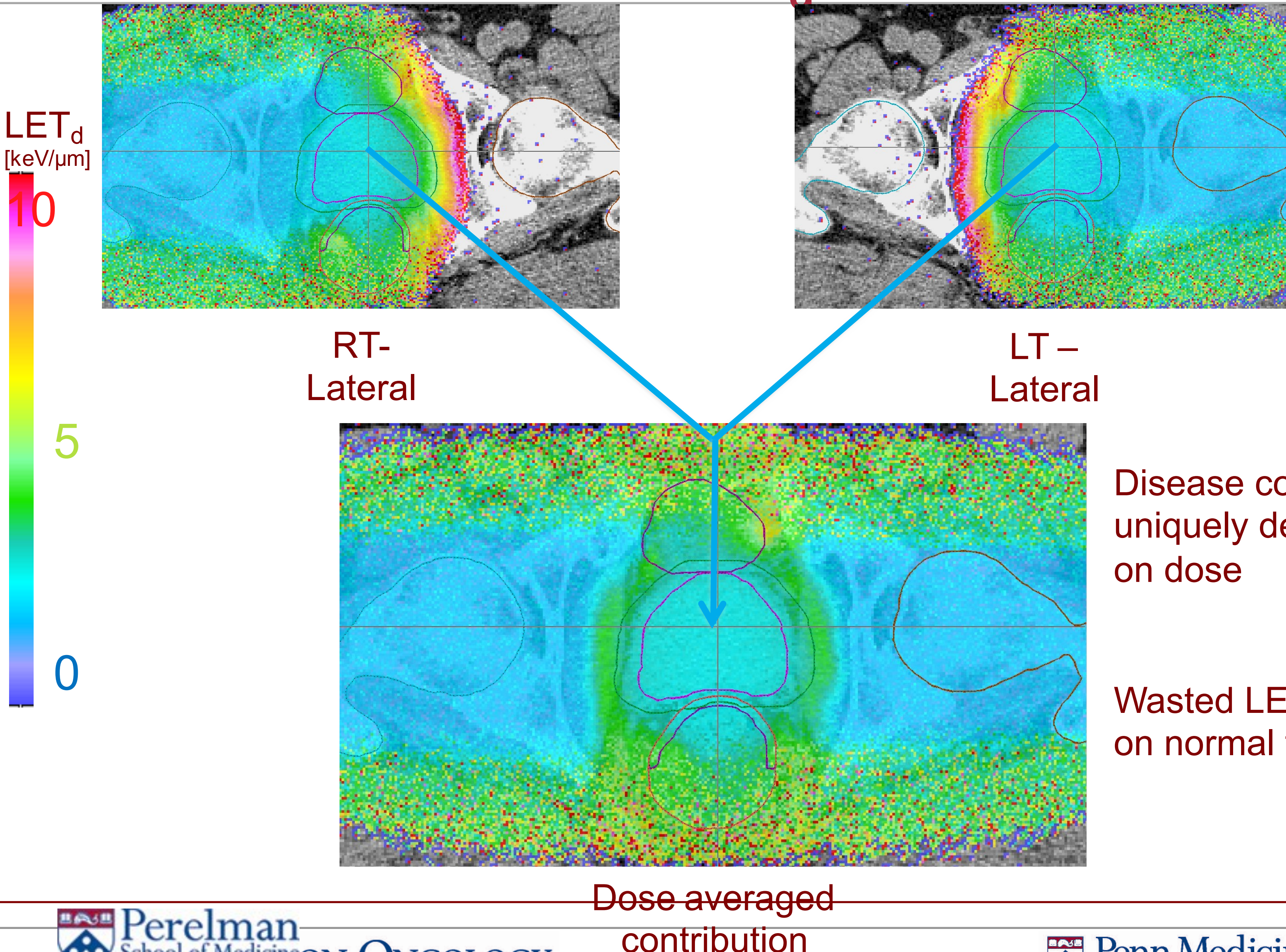




Biophysical aspects of current proton treatment planning approaches



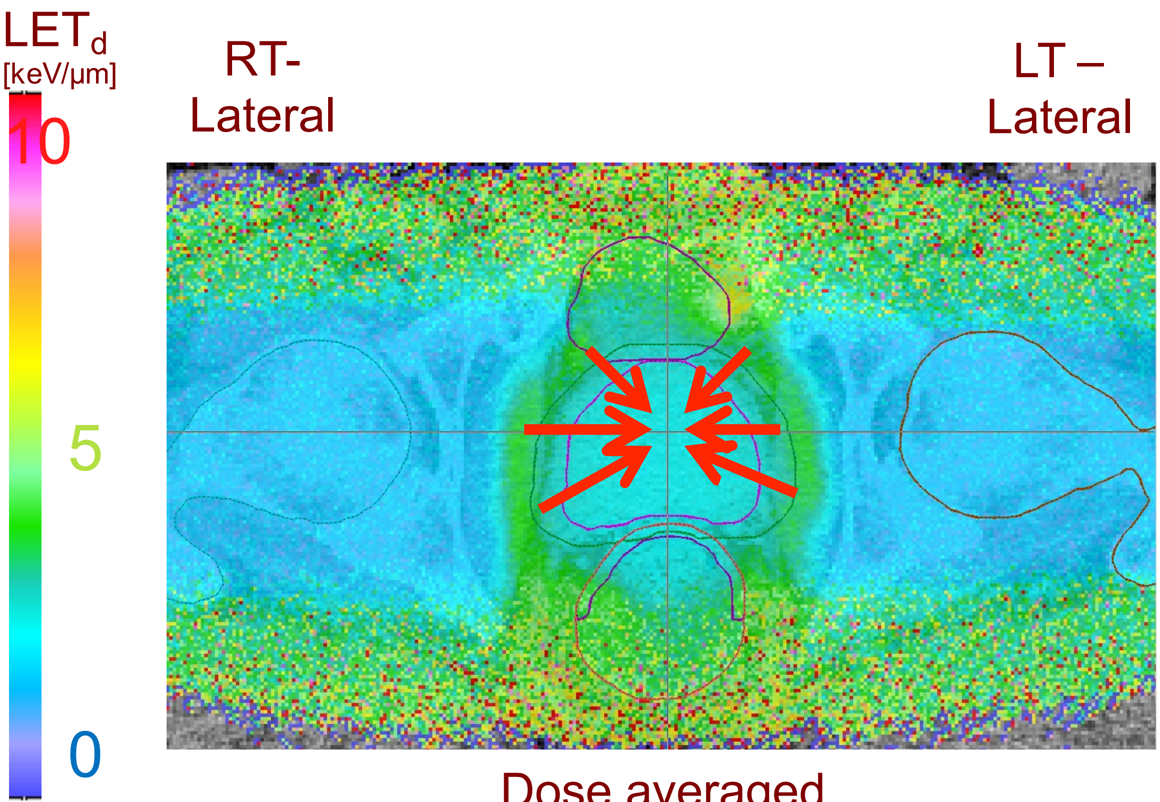
Standard treatment LET_d distributions



Disease control uniquely depends on dose

Wasted LET effect on normal tissue

planning approaches



Dose averaged contribution

Disease control will depend on dose **and LET**

Normal tissue shielded from the region of the beam with enhanced biological effectiveness

Can we exchange dose for LET while maintaining the same biological effect in the target volume?

If we can, that would mean:

1we could decrease the required prescribed dose (or even the number of fractions) of the treatment without loosing its biological effectiveness.

2reduce the dose (by default from 1) in the normal tissue

3reduce the LET in the normal tissue

Work done by: Marcus Fager – University of Pennsylvania

International Journal of
Radiation Oncology
biology • physics

www.redjournal.org

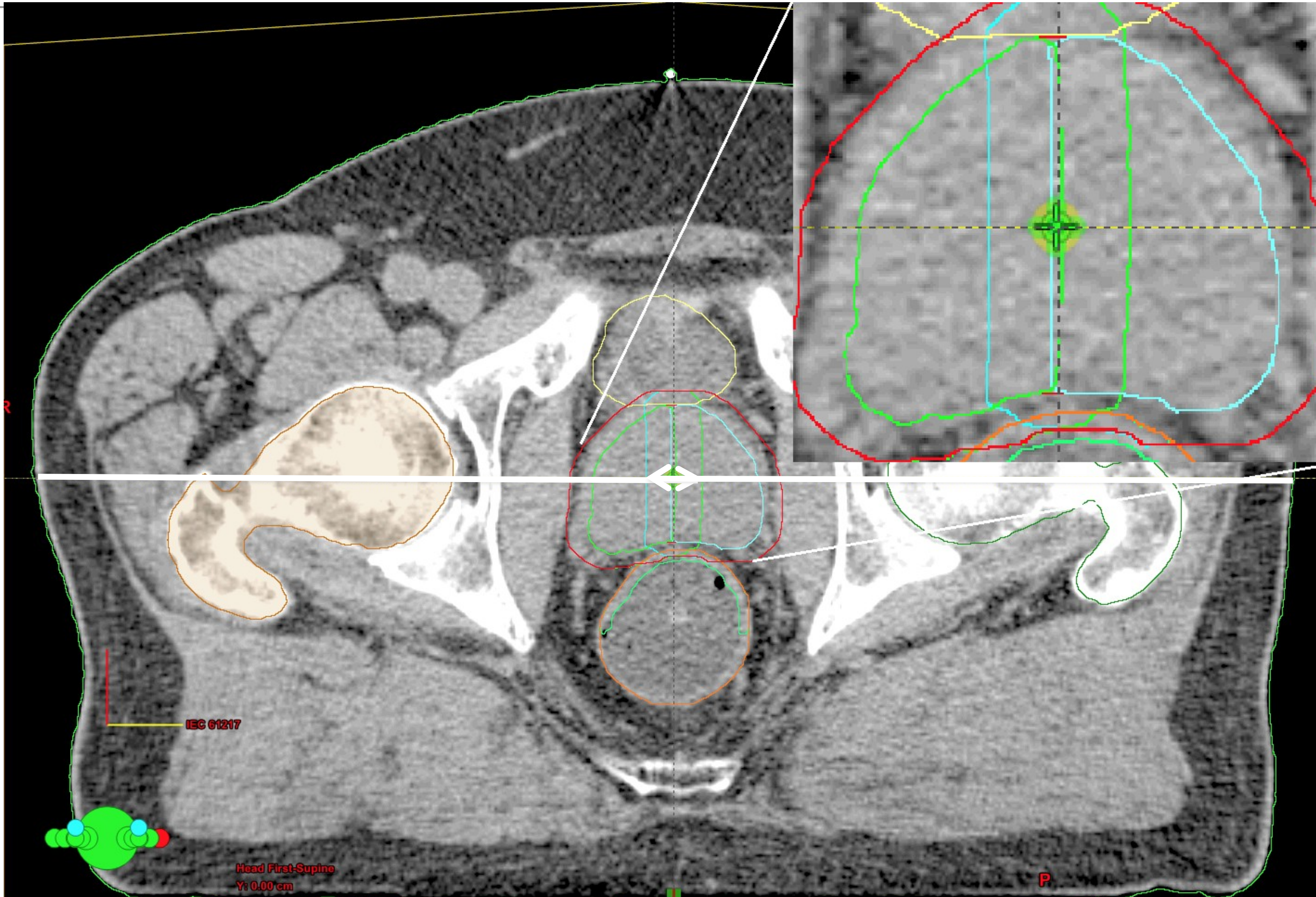
Physics Contribution

Linear Energy Transfer Painting With Proton Therapy: A Means of Reducing Radiation Doses With Equivalent Clinical Effectiveness

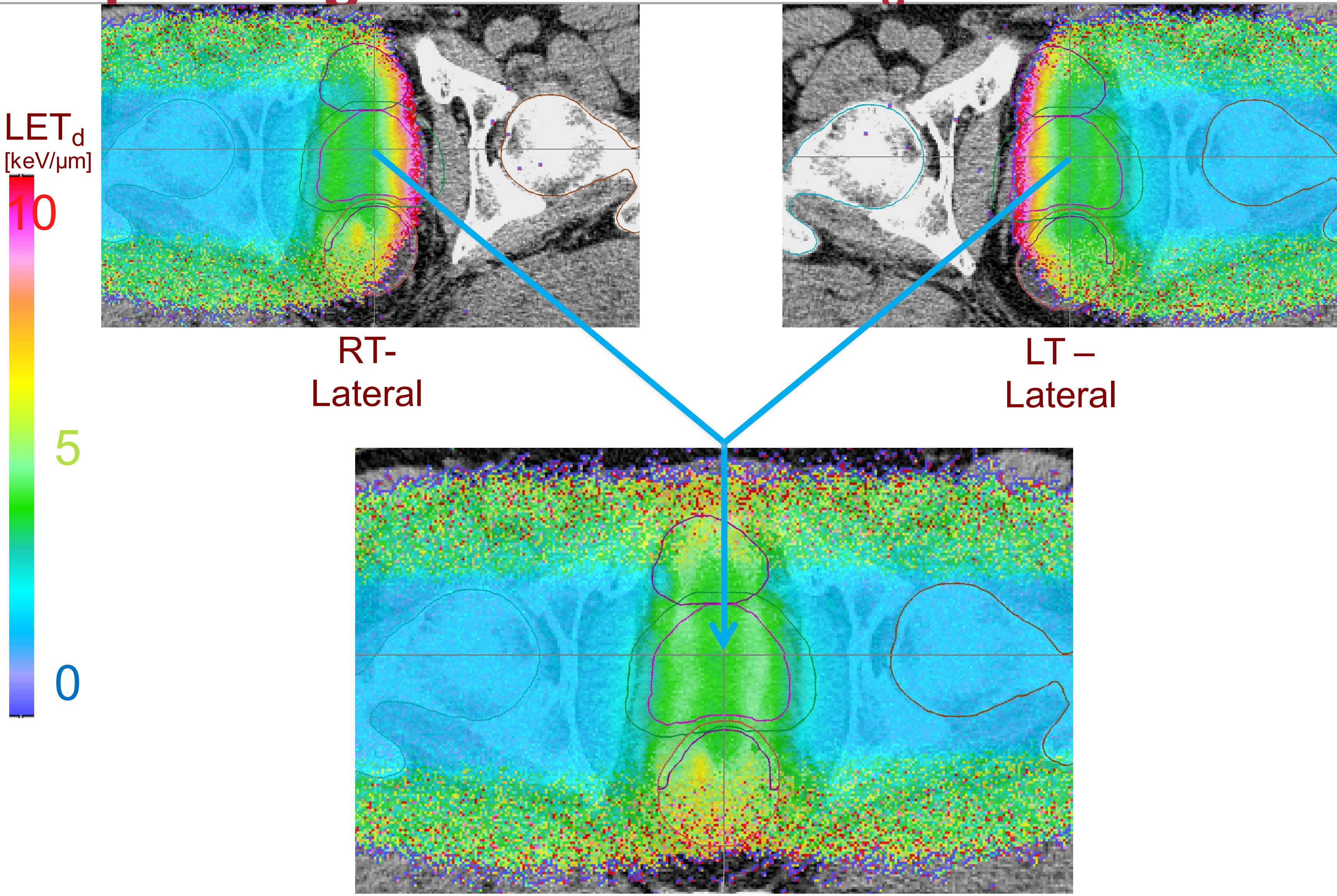
Fager Marcus, MSc,* Toma-Dasu Iuliana, PhD,† Kirk Maura, MSc,* Dolney Don, PhD,* Diffenderfer Eric, PhD,* Vapiwala Neha, MD,* and Carabe Alejandro, PhD*

*Department of Radiation Oncology, School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania; and †Stockholm University and Karolinska Institutet, Stockholm, Sweden

Received Mar 10, 2014, and in revised form Dec 19, 2014. Accepted for publication Dec 29, 2014.

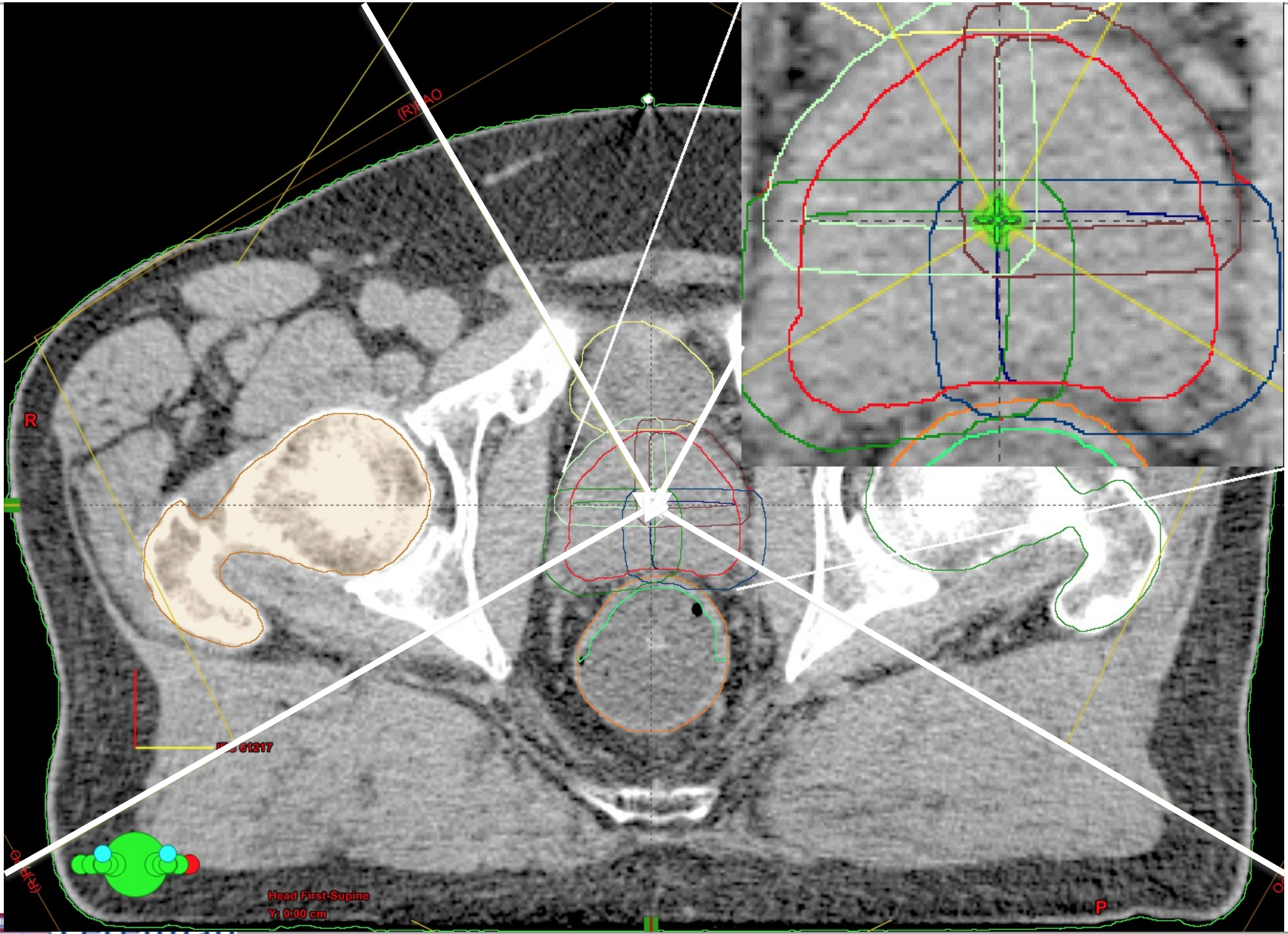

R
IEC 61217
Head First-Supine
Y: 0.00 cm
P

Split Target – 2 Field - LET_d distributions

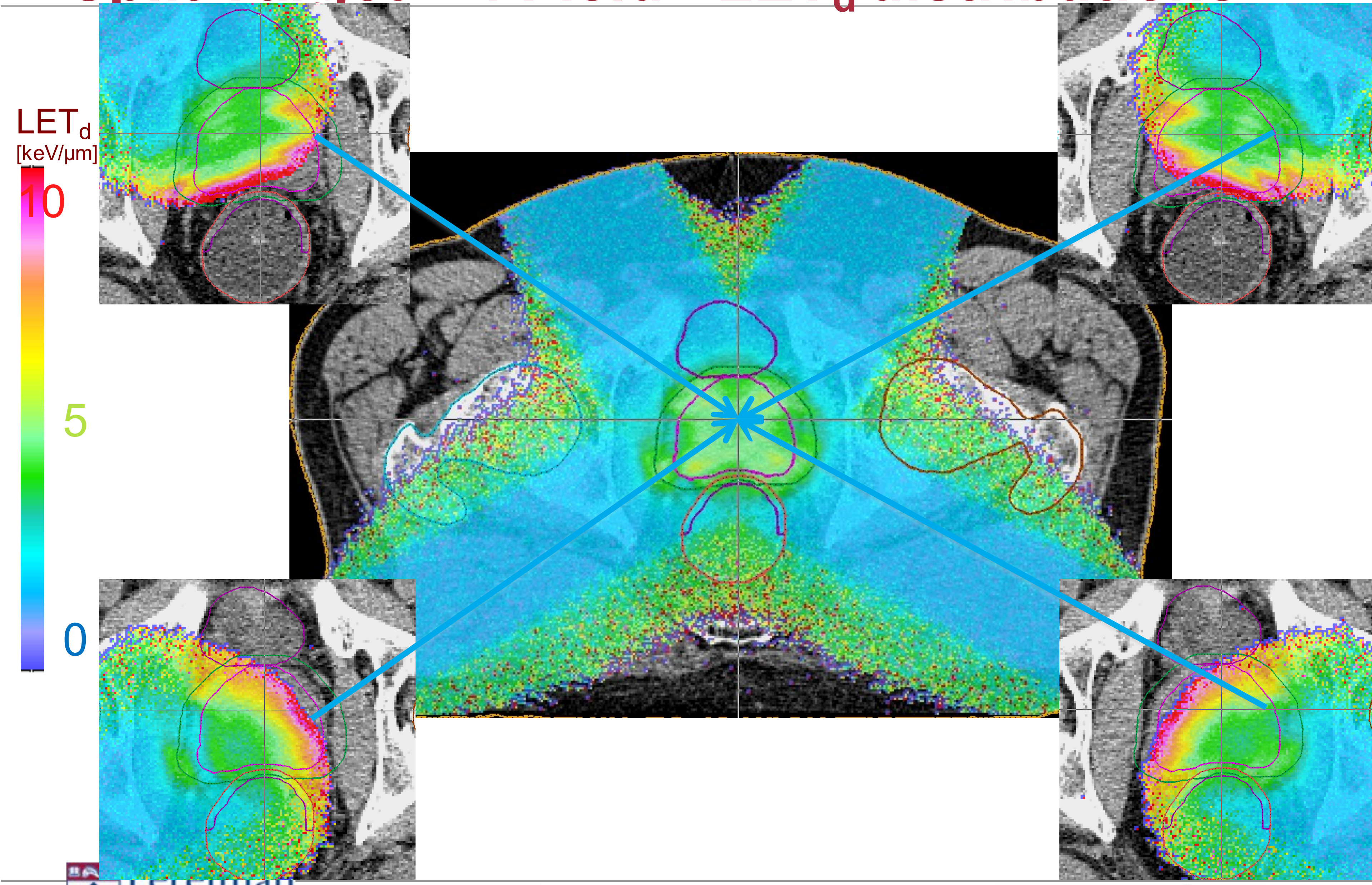


Dose averaged
contribution

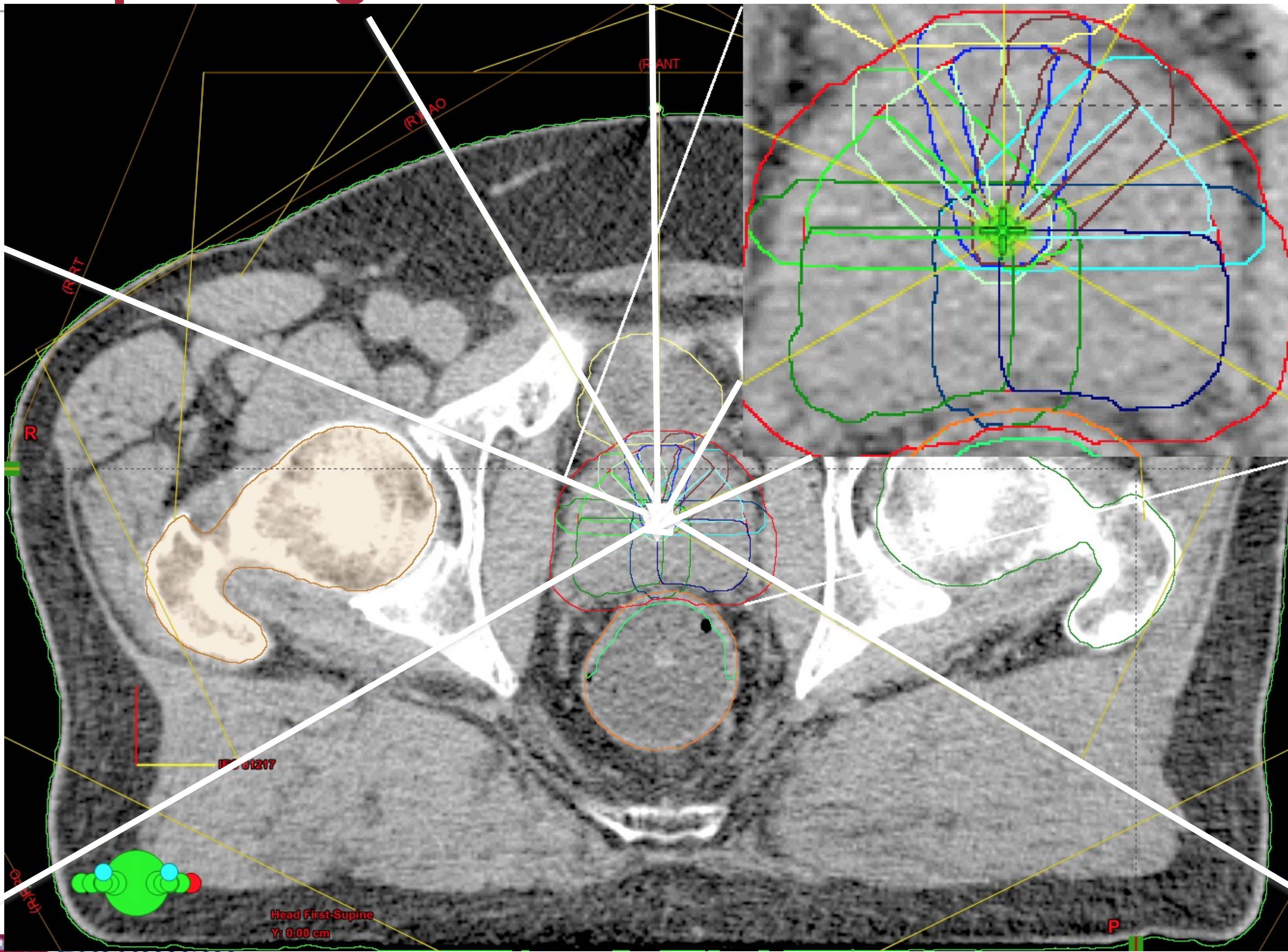
Split Target – 4 Field – CTV



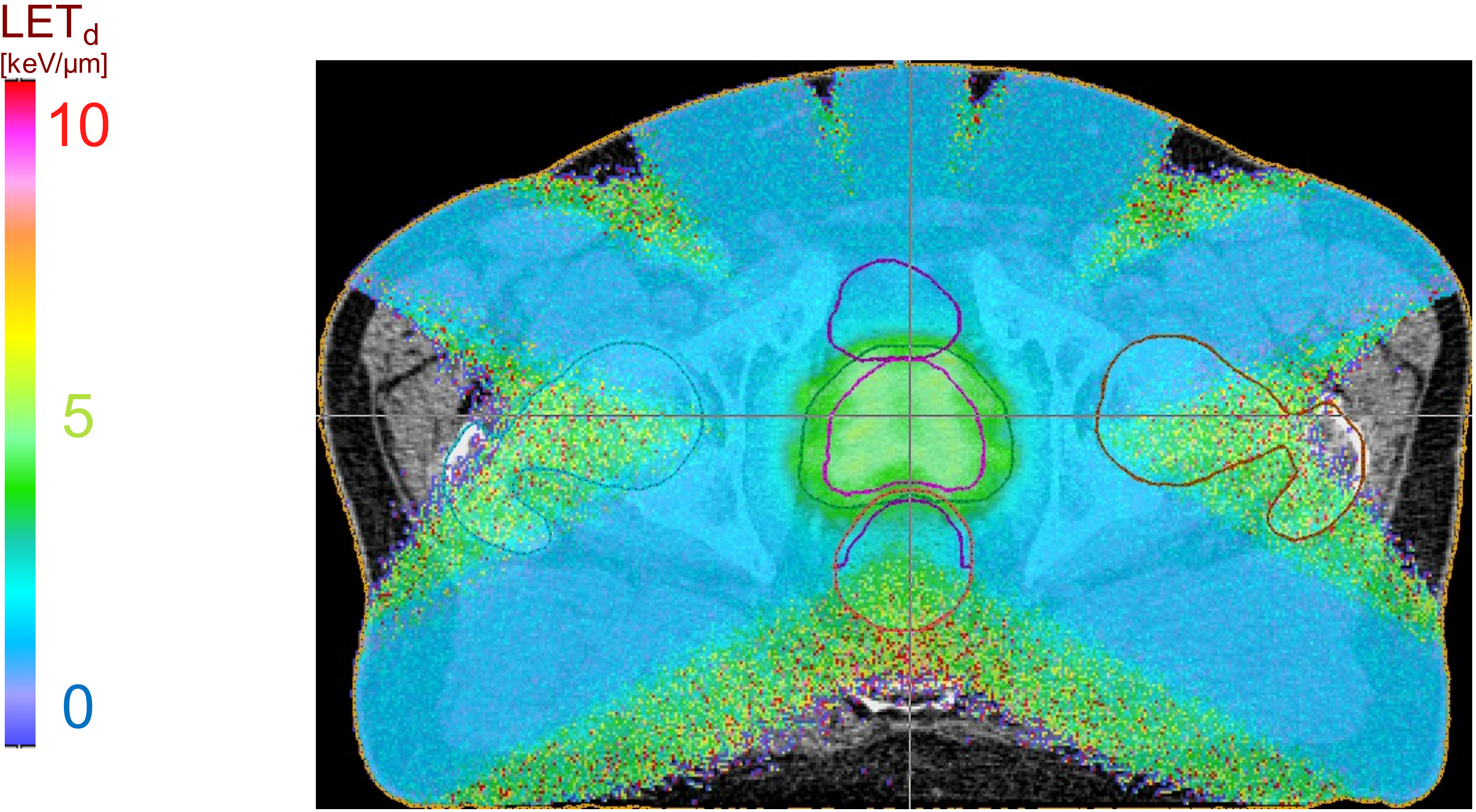
Split Target – 4 Field - LET$_d$ distributions



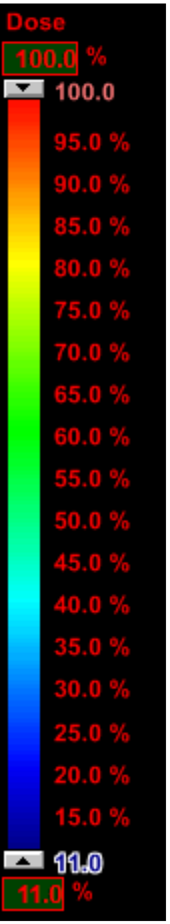
Split Target – 7 Field – CTV – PBSTV



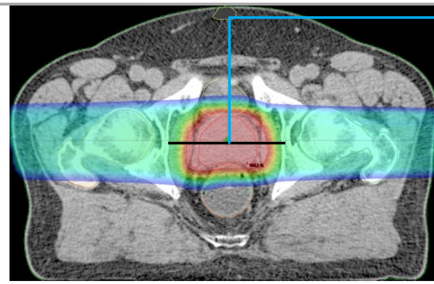
Split Target – 7 Field - LET_d distributions

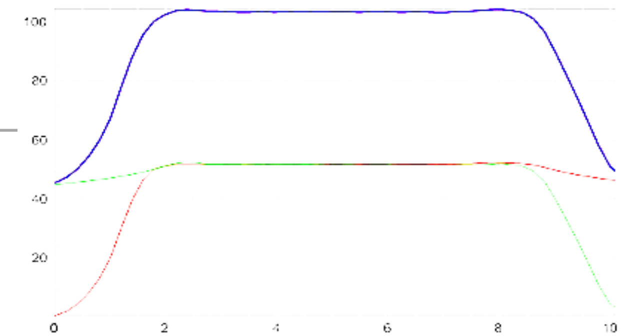


Dose Comparison

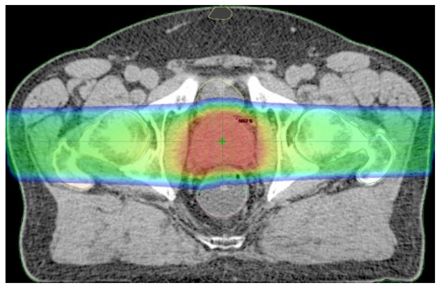


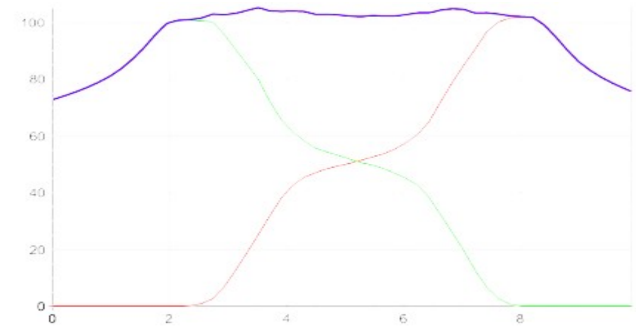
Standard Full Target



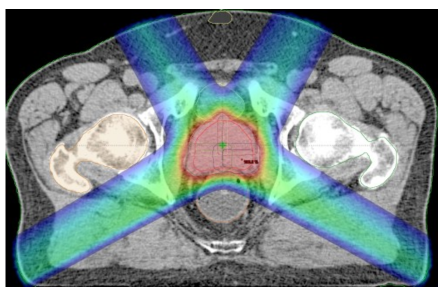


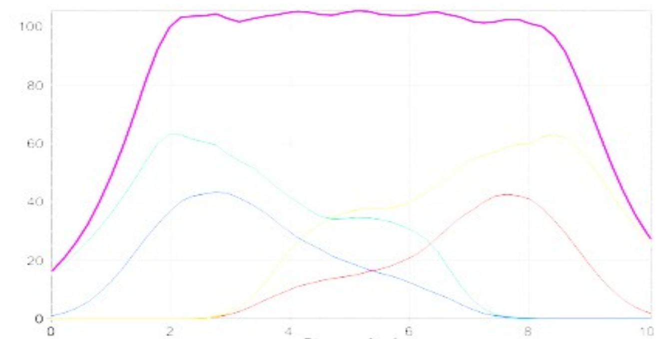
2 Field Split Target



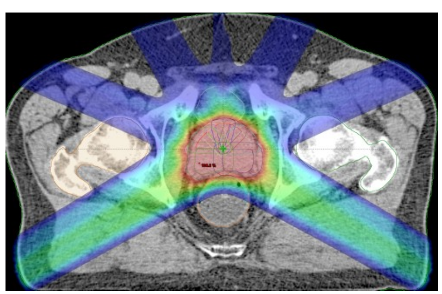


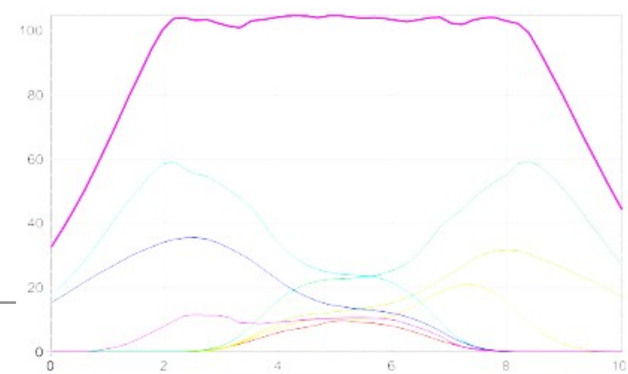
4 Field Split Target



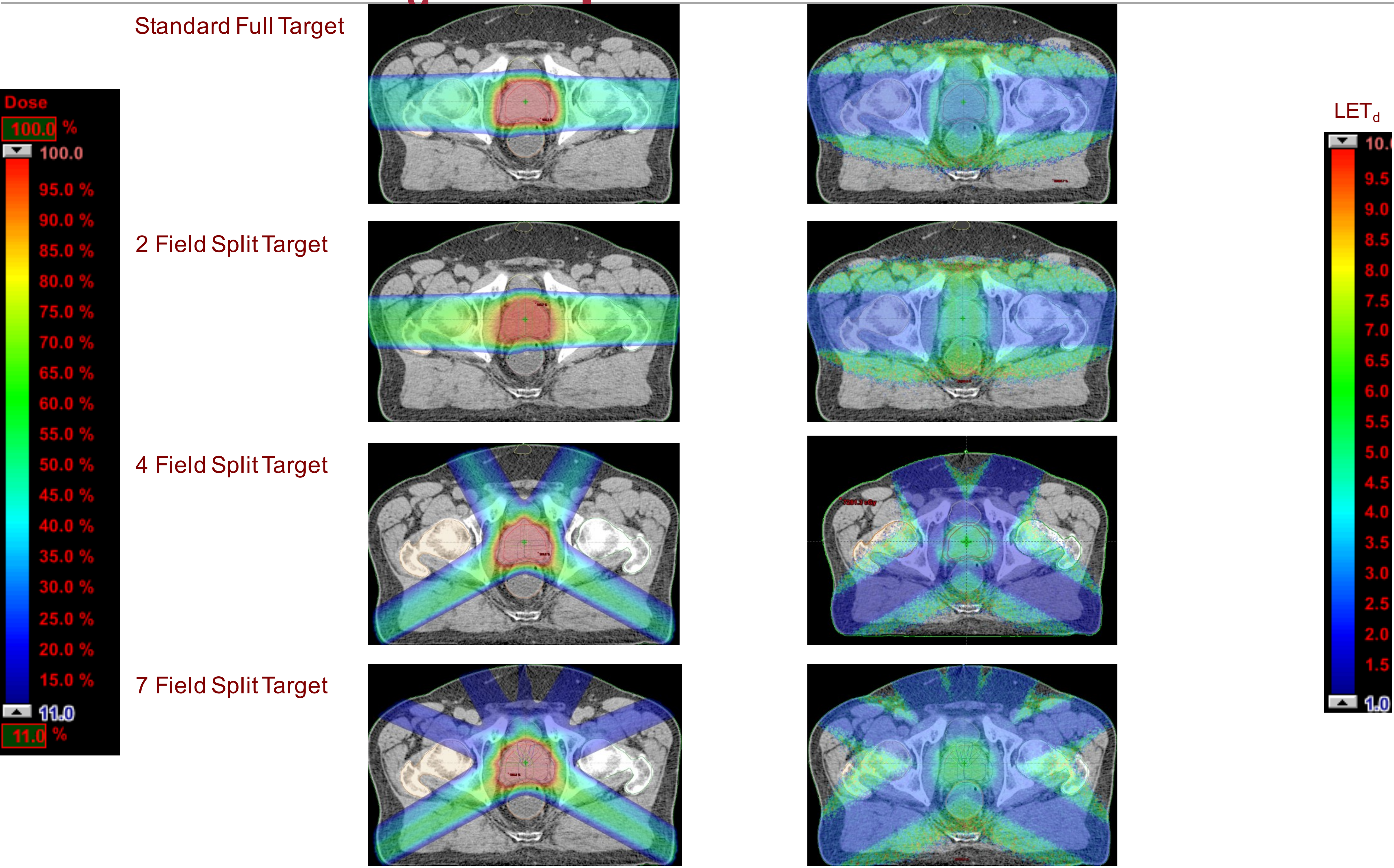


7 Field Split Target

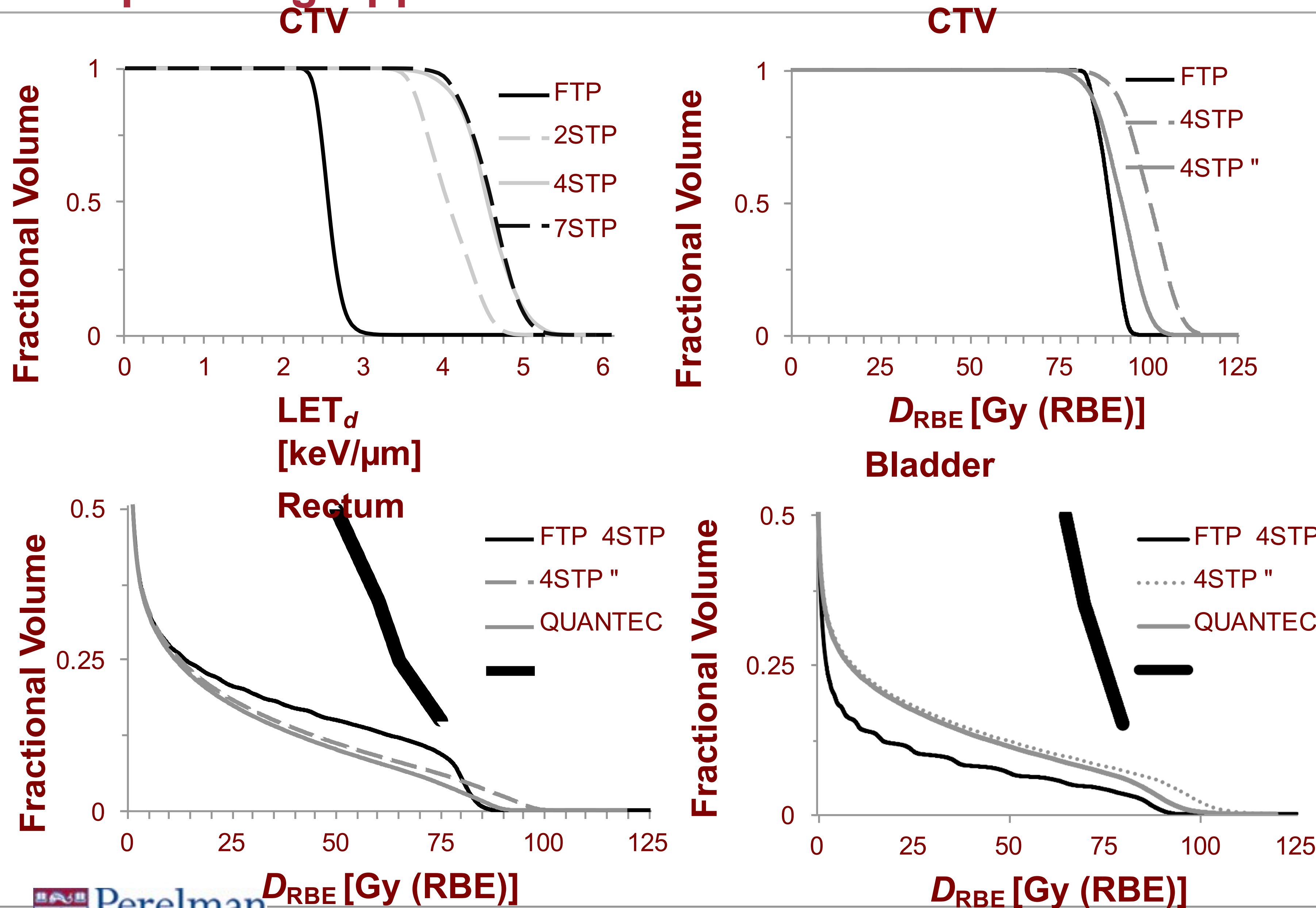




Dose – LET_d Comparison



Biophysical aspects of current proton treatment planning approaches



planning approaches

Purpose: To propose a proton treatment planning method that trades fractional physical dose (d) for dose-averaged Linear Energy Transfer (LET_d) while keeping the radiobiological weighted dose D_{RBE} to the target the same.

Methods: The target is painted with LET_d by using 2, 4 and 7 fields aimed at the proximal segment of the target (split target planning, STP). As the LET_d within the target increases with the increasing number of fields, the physical dose per fraction decreases to maintain the D_{RBE} the same as the conventional treatment planning method using beams treating the full target (full target planning, FTP).

Results: The LET_d increased inside the target by 61% for 2STP, 72% for 4STP and 82% for 7STP, compared to FTP. This increase in LET_d led to a decrease of d with 0.16±0.01Gy for 2STP, 0.2±0.03Gy for 4STP and 0.21±0.01Gy for 7STP keeping the D_{RBE} constant to FTP.

Conclusions: LET_d painting offers a method to reduce prescribed dose at no cost for the biological effectiveness of the treatment.

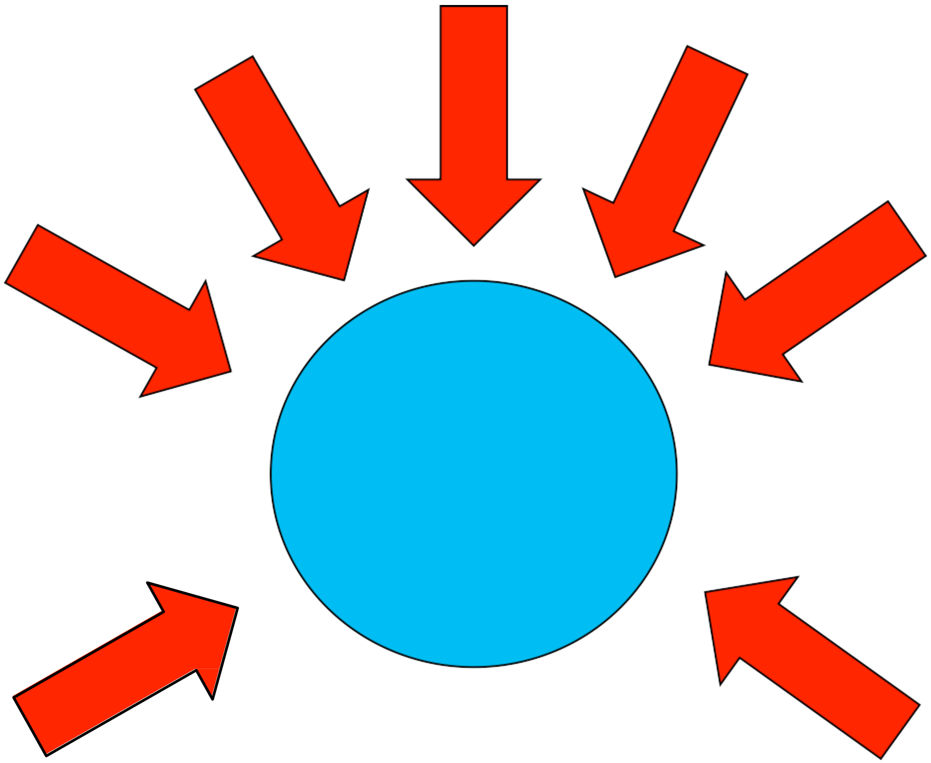
2STP: 9% (1.8GyE)

4STP:11% (1.8GyE)

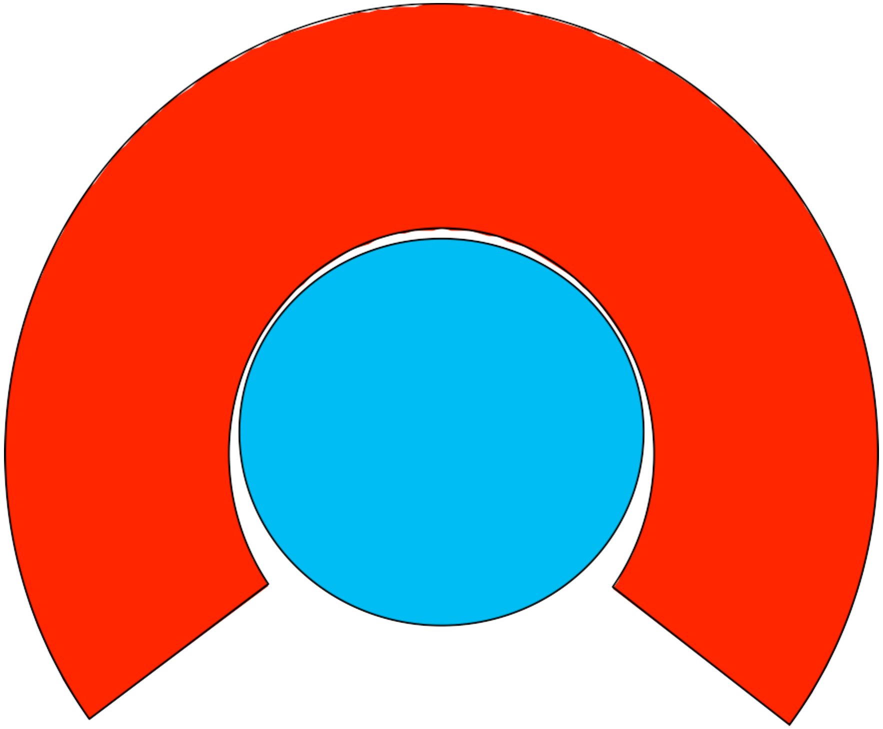
7STP:12% (1.8GyE)

Fager et al., 2014 (submitted)

What dose decrease percentage can we get if we go from discrete beams to…



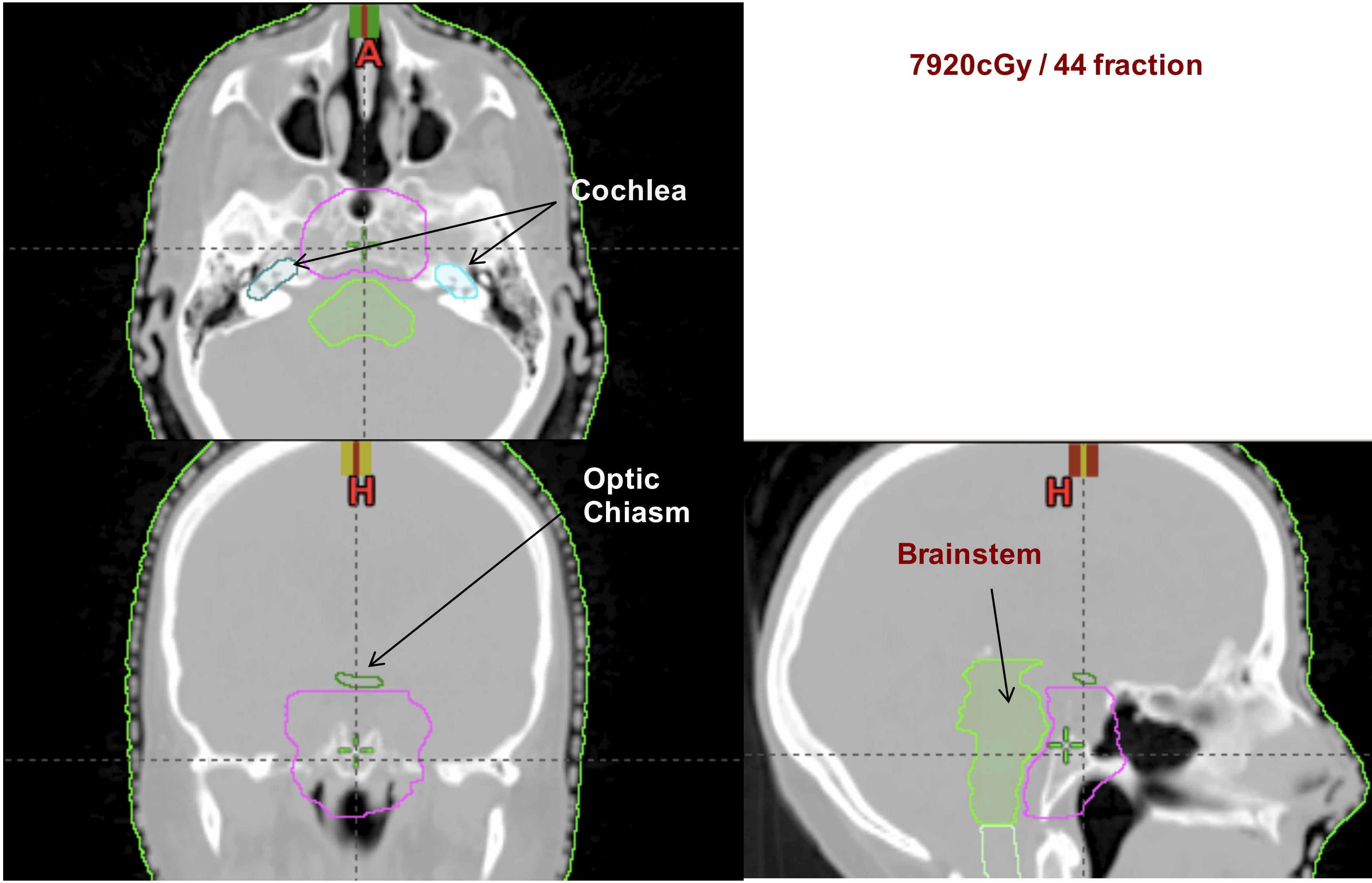
… continuous beam delivery



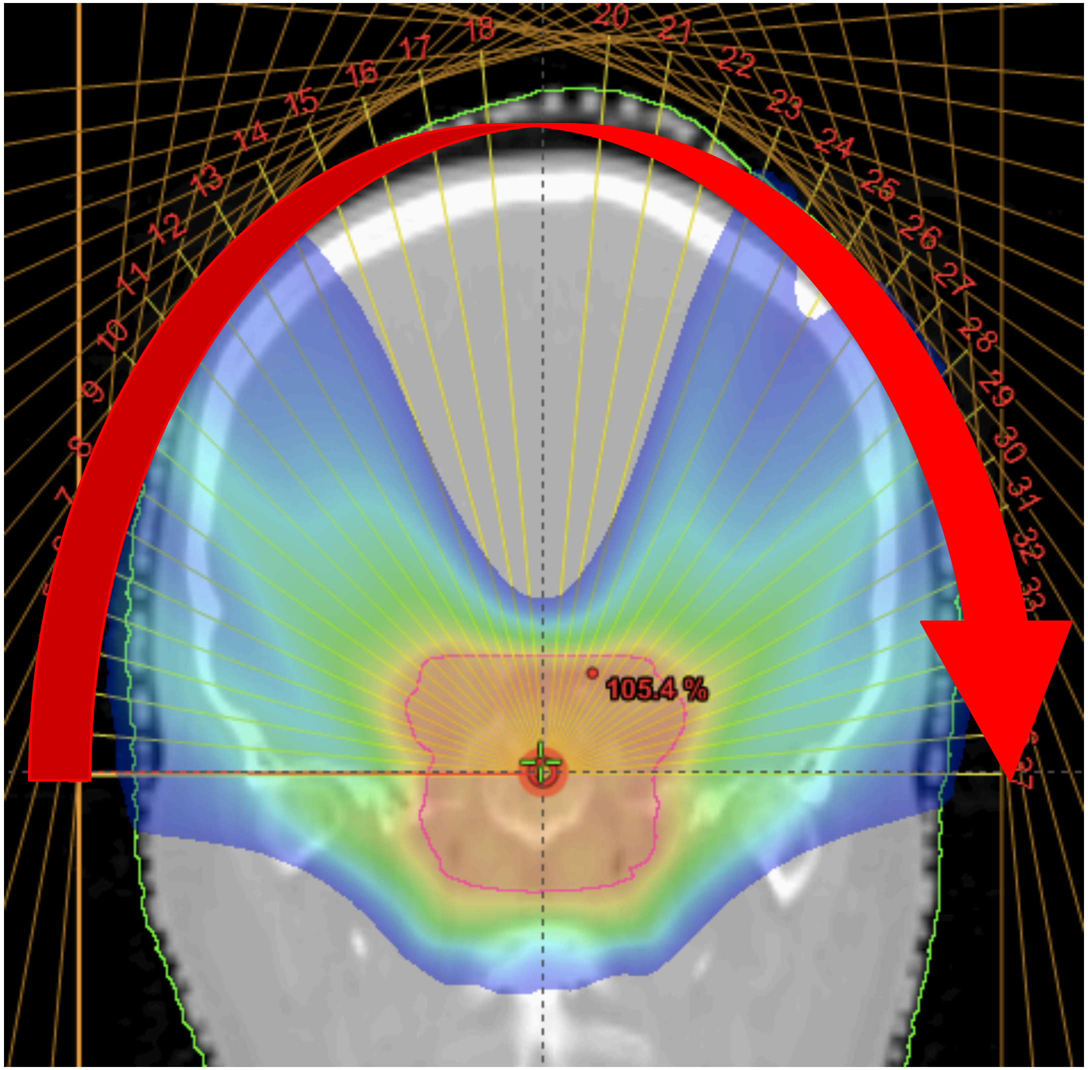
PROTON MODULATED ARC THERAPY (PMAT)

PMAT vs PBS treatment of Brain tumor

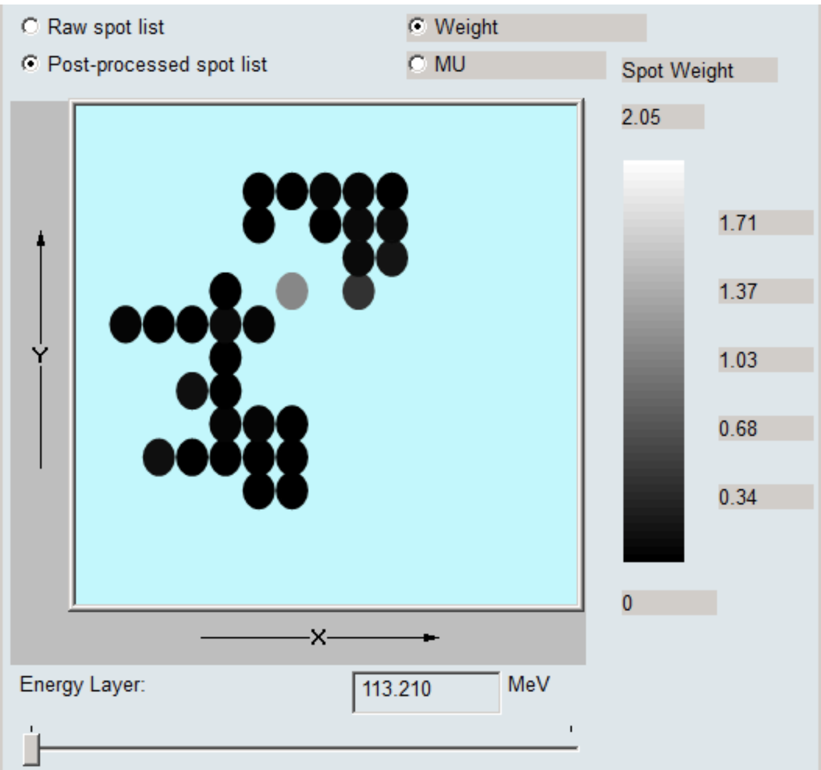
7920cGy / 44 fraction



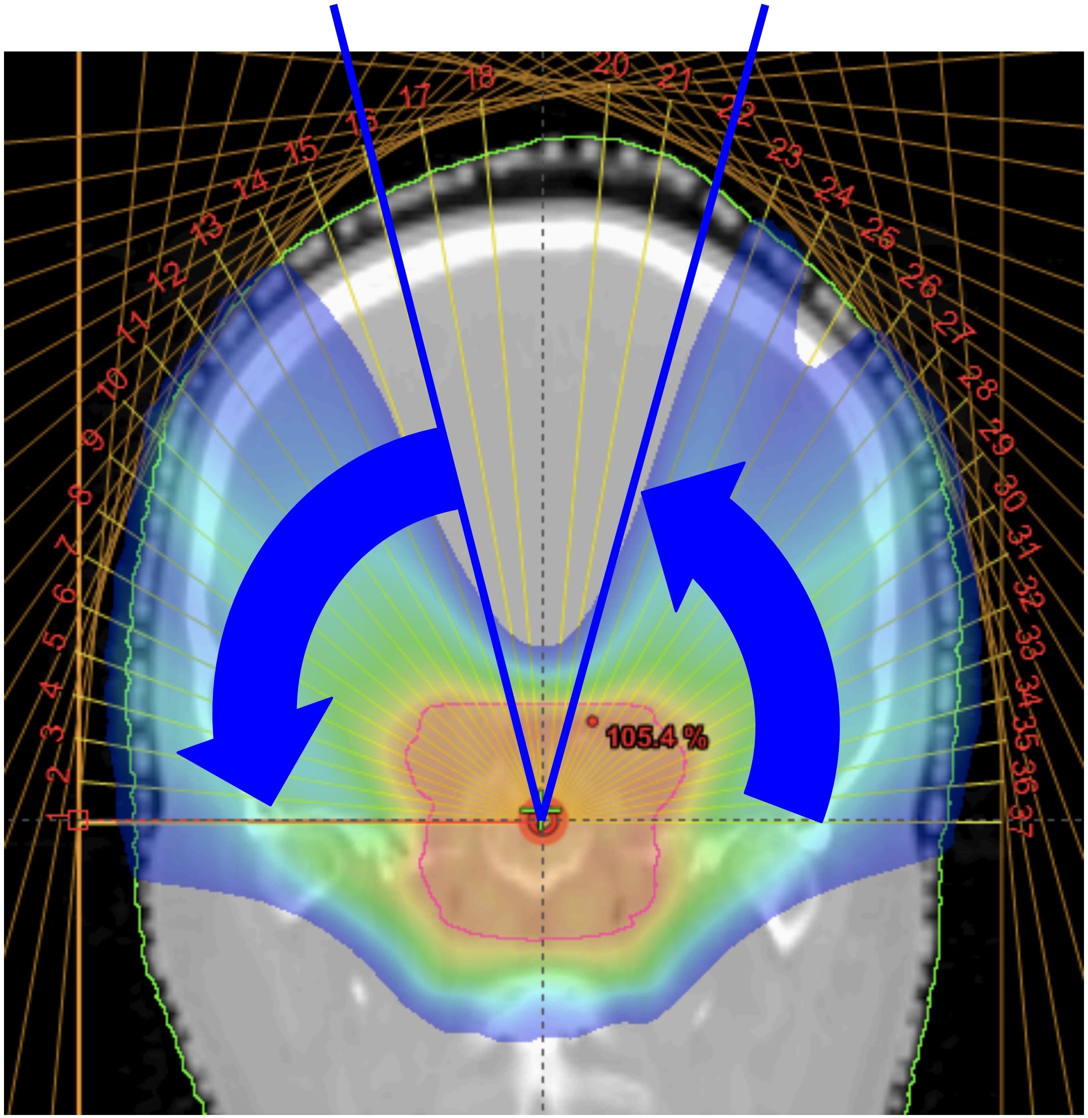
PMAT in Brain tumor



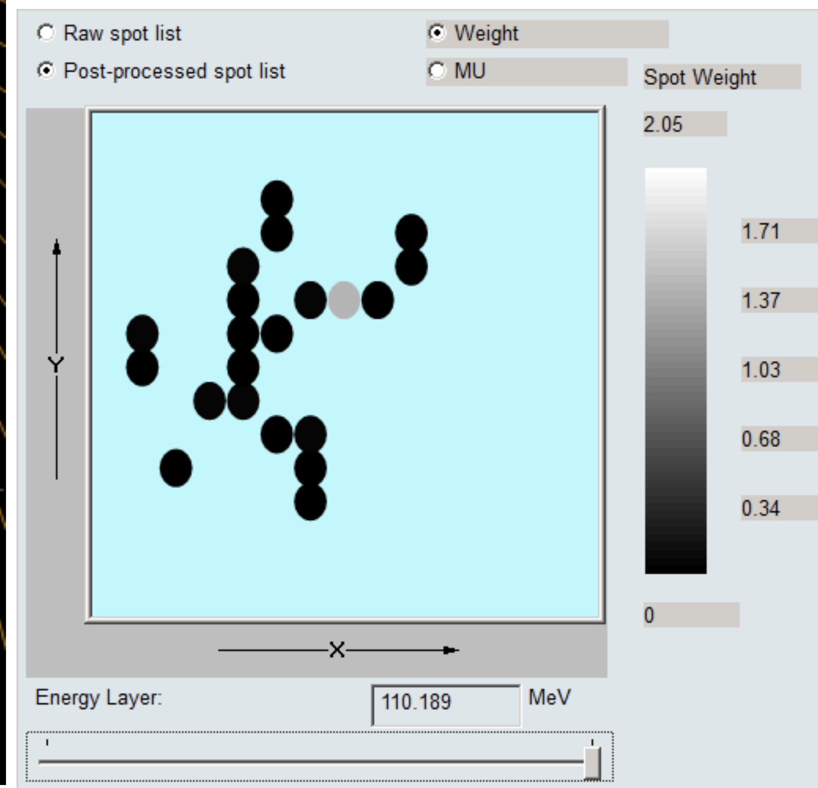
ARC 1
(E_1=113.2MeV)



PMAT in Brain tumor

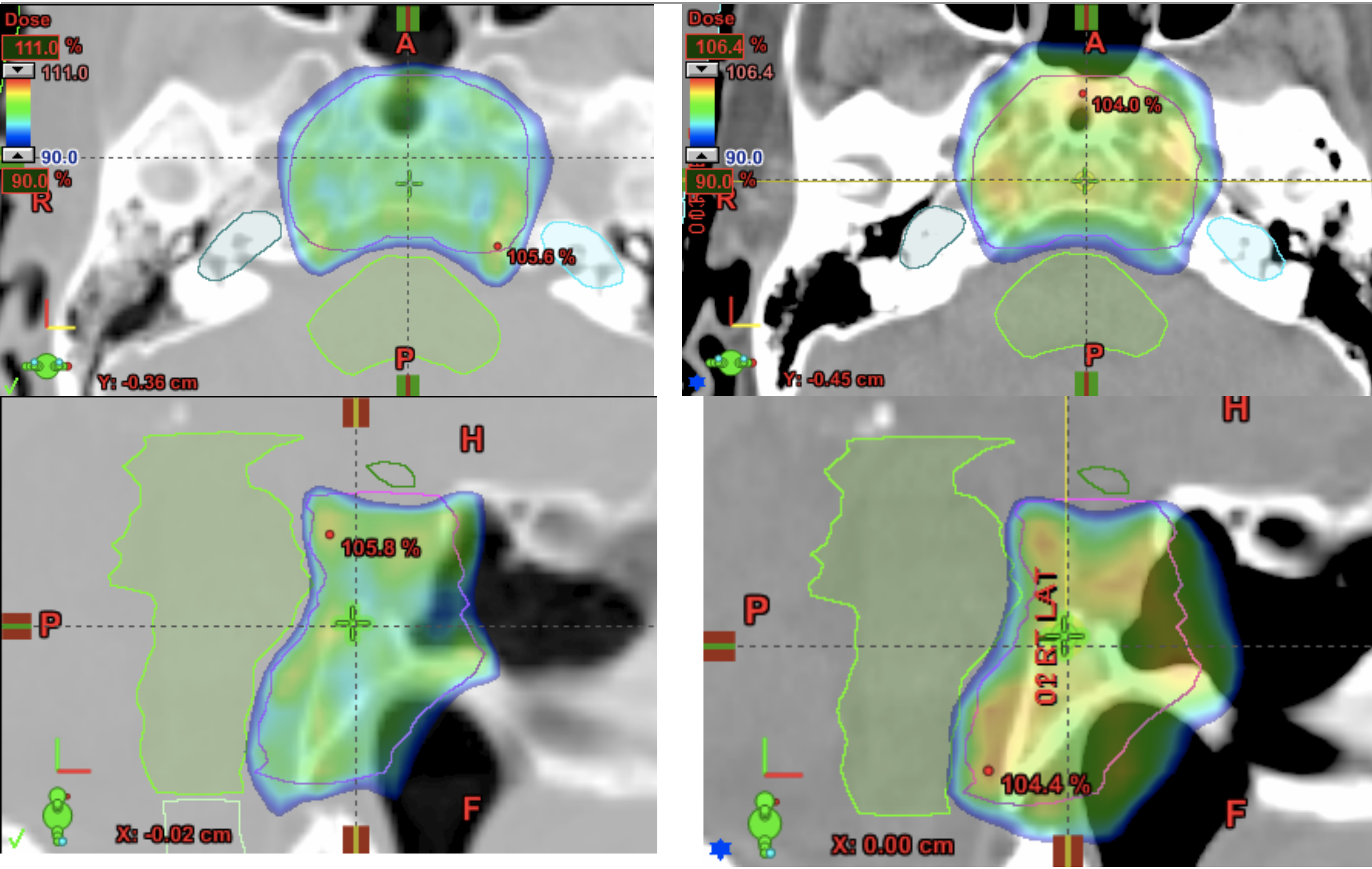


ARC 2
(E_1=110.2MeV)

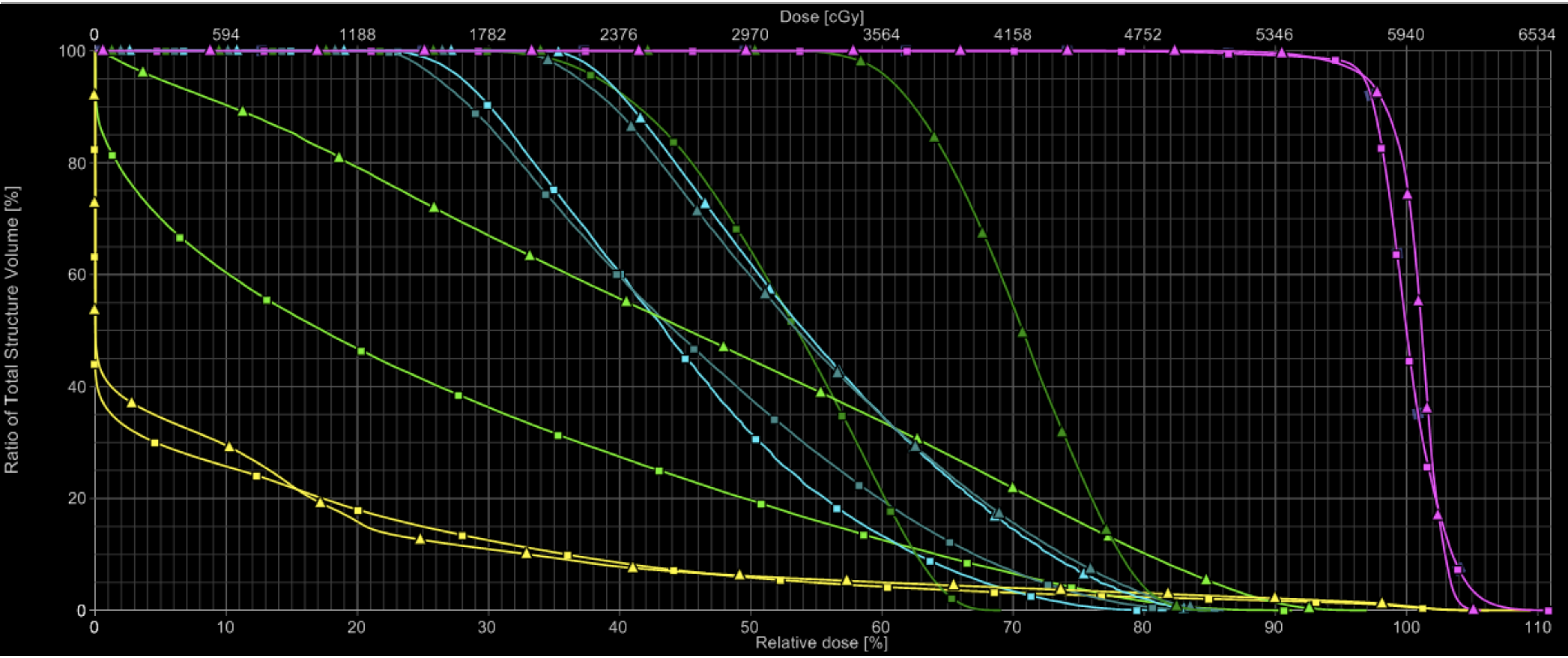


PMAT-DOSE

PBS-DOSE



PMAT vs PBS: DVH

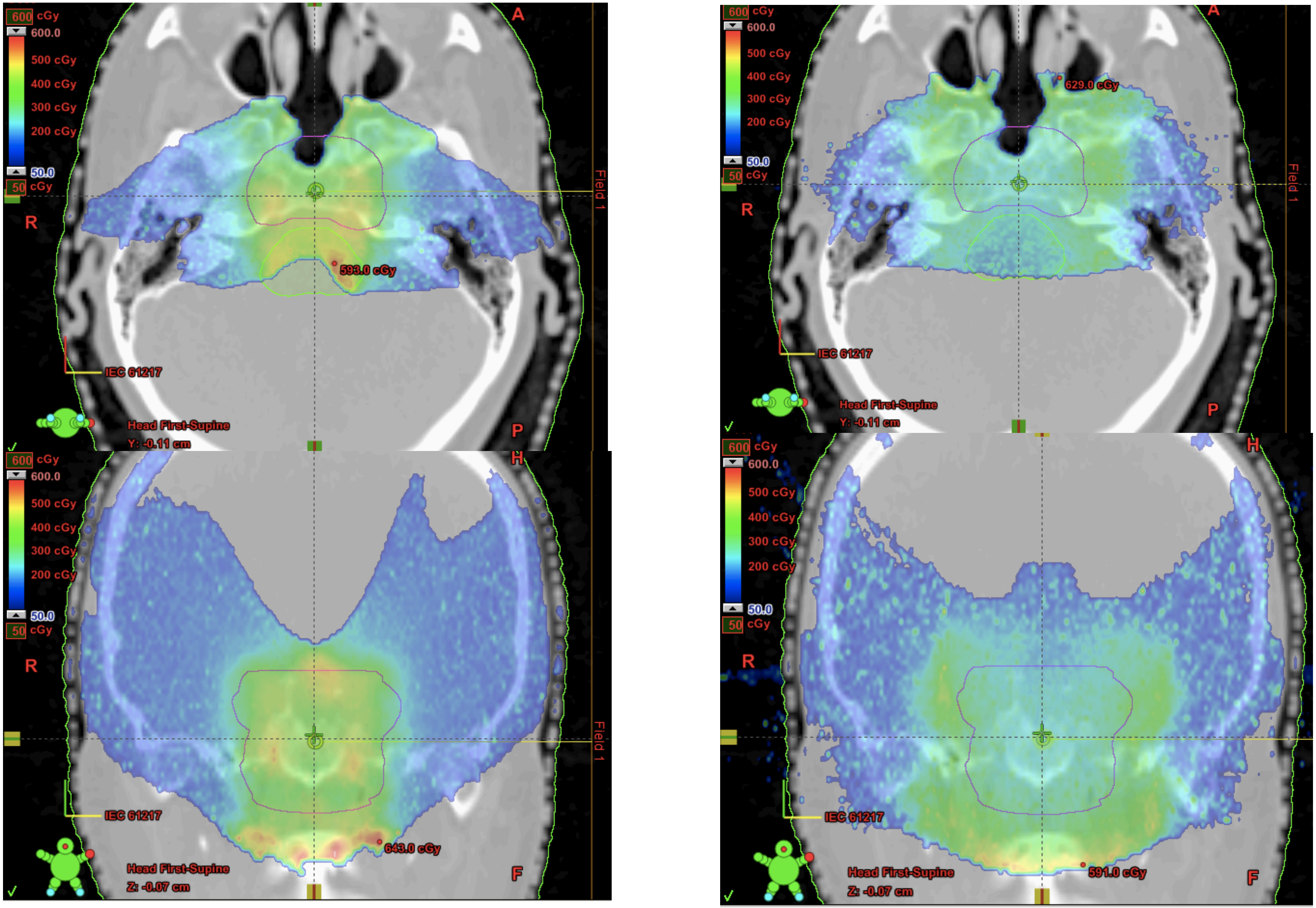


BRAINSTEM
Brain
COCHLEA_L
COCHLEA_R
OPTIC CHIASM
CTV 59.4 rev

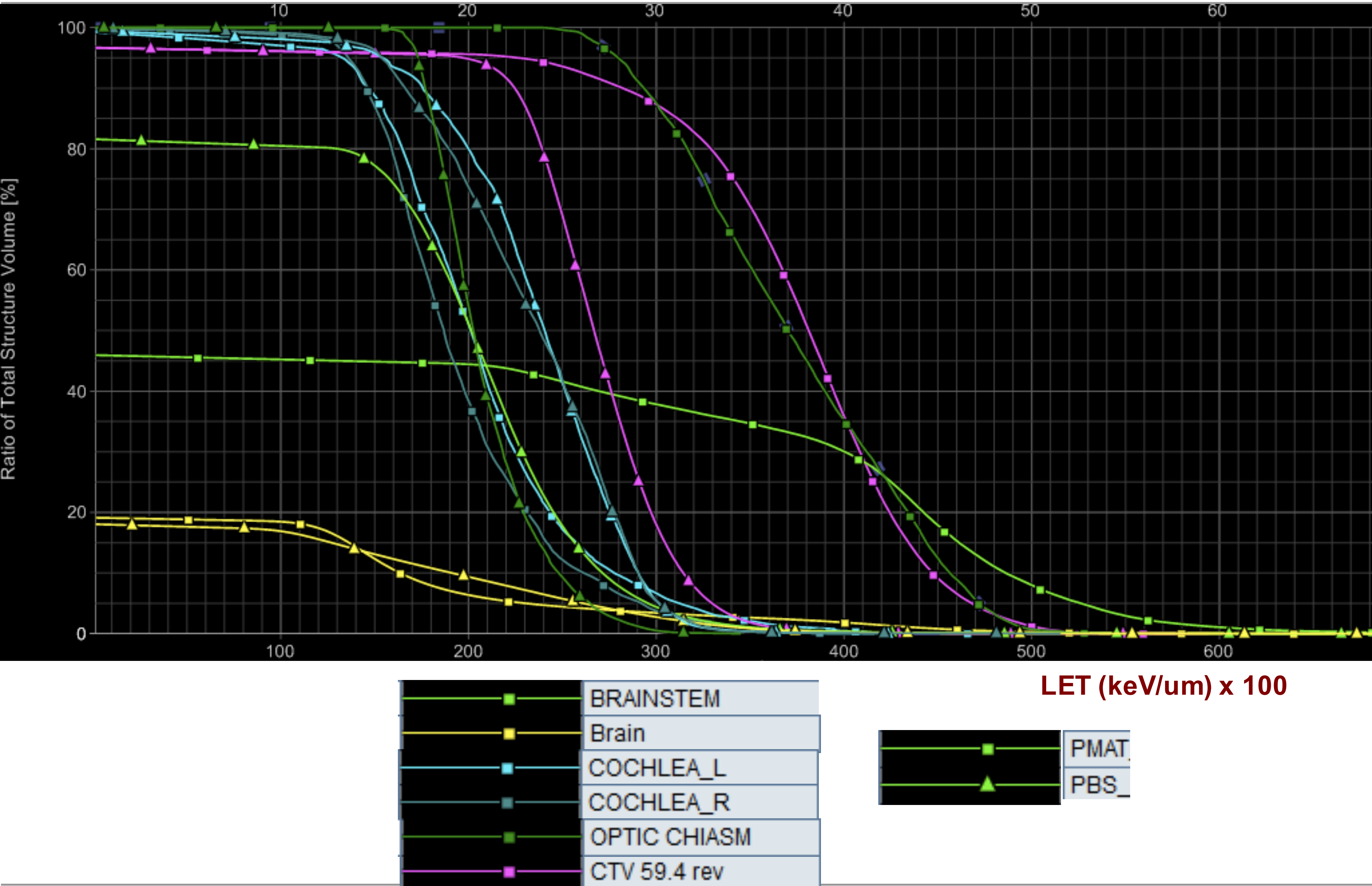
(R)37_Min_950
INI_PBS

PMAT-LET

PBS-LET



PMAT vs PBS: LET-VH



Summary

- Physics of proton therapy allows for sparing of additional normal tissue compared with photon therapy for a number of treatment sites
- Uncertainties in proton therapy must be addressed to ensure target coverage and safe doses to normal tissue structures
- Careful beam selection and robust planning help to maximize the potential benefits of proton therapy
- There biophysical properties in proton beams different than those present in conventional radiations
- The biophysical properties of proton beams will play an important role in the near evolution of proton radiotherapy delivery techniques

Thank you