Energy Modulated Radiotherapy (EMRT) using sub-MV beams

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Disclosures

- Staff physicist UNM Comprehensive Cancer, Albuquerque, NM
- Part-time contract Verus Research, Albuquerque, NM

Outline

1. Introduction
2. Initial work toward small field radiotherapy in a practical manner
3. Theory of energy modulation with sub-MV beams
4. EMRT planning/optimization routine
5. Future Work

Unraveling a thread…

- First collaboration with UNM Computer Science that is building basic radiotherapy research tools.
- We want to consider solutions that are—in the end practical—and can be implemented in conventional clinics
- Then also, build upon historical strategies that are known to be successful
- Work presented here was motivated by seeking what we have perceived as the frontier of radiation therapy, submillimeter radiotherapy techniques
- Not knowing what exactly we were going to find, we pulled the string…
- What we are presenting now is not what we initially set out to do, but its where we are at.

Radiotherapy Strategies

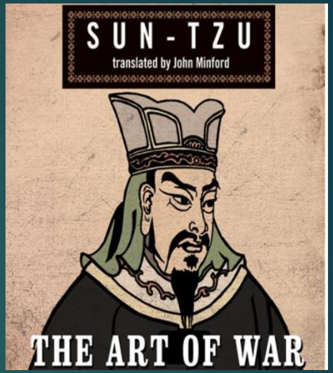
War-by-attrition
—Historical—
— Established biological models—
—Low impact weaponry—

Ablation
—More recent—
—Extreme impact—
—Advanced technology—

Both strategies have benefits/trade-offs that require different types of radiotherapy techniques

Treatment strategy: War-by-attrition

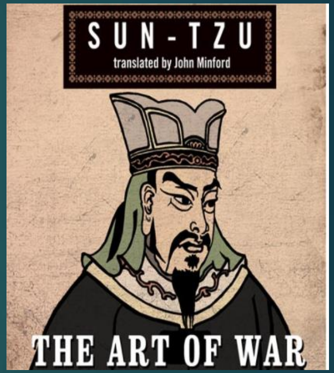
- "Military strategy in which belligerent attempts to win a war by wearing down the enemy to the point of collapse through continuous losses of personnel and materiel."
- Goal: limit losses to an acceptable level while maximize enemy's
- "The war is usually be won by the side with greater resources"
- Radiation is used to tip the odds in favor of normal tissue



Sun-Tzu Critique

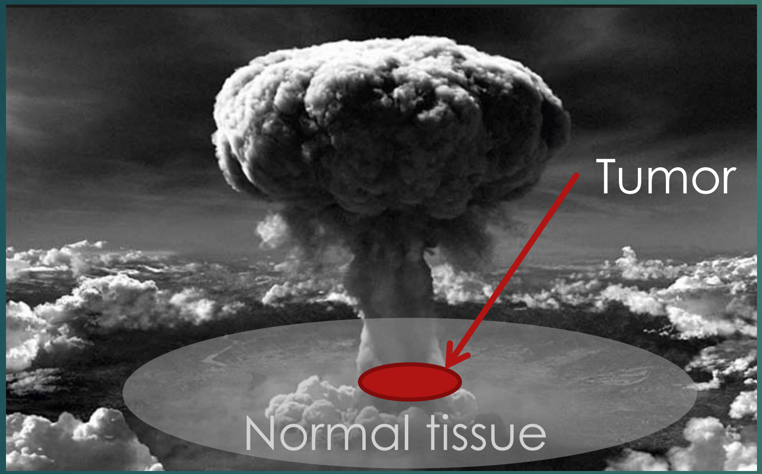
- Sun-Tzu viewed that attrition warfare is something to be avoided: represents the opposite principles of war where one attempts to achieve decisive victories by using minimal necessary resources.

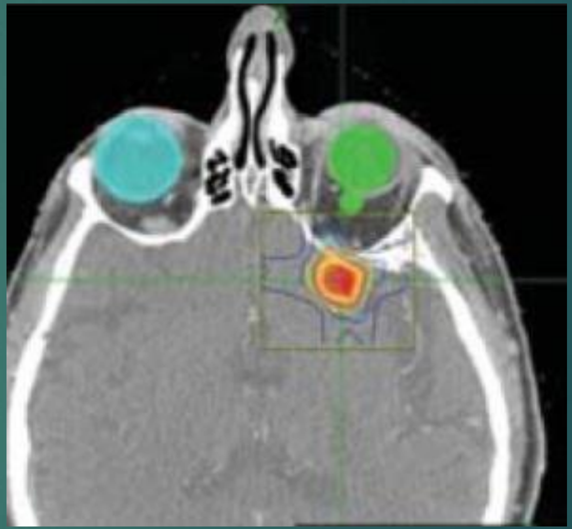
- Attritional methods are tried as a last resort when other strategy have failed or not feasible.



Treatment strategy: Ablation

- Large dose for a single or a few treatments to a small area
- Any tissue exposed, normal or cancer, will be destroyed
- Extremely focused delivery to tumor





Note: the use of such firepower requires more rigorous QA and accurate alignment tools

Trend: radiation therapy's footprint is getting smaller

Many-to-few:

- Decrease the total amount of treatments, while increasing the dose per fraction

Big-to-small:

- Reduce the size of the treatment fields to match the patient's anatomy, motion and the tumor's response
- With the help of PET imaging these treatment volumes are getting smaller and smaller

Radiation therapy's footprint is getting smaller: Multi-institutional studies challenging the amount of radiation a patient receives

This challenges the accuracy of the historical DNA damage/repair model that setup the current standard of care!

Need to explore the use of small fields and understand mechanisms behind the biological response

Sites include...

...of these studies ...ound superior ...results using ...tion!

CLINICAL INVESTIGATION — Breast

FRACTIONATION FOR WHOLE BREAST IRRADIATION: AN AMERICAN SOCIETY FOR RADIATION ONCOLOGY (ASTRO) EVIDENCE-BASED GUIDELINE

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Int. J. Radiation Oncology Bi...
doi:10.1016/j.ijrobp.2010.04.042

...and Correlates of the ...onated Whole-Breast Radiation ... the State of Michigan

...a Jagsi, MD, DPhil,* Kent A. Griffith, MS,* David Heimburger, MD,† Eleanor M. Walker, MD,‡ Inga S. Grills, MD,§ Thomas Boike, MD,|| Mary Feng, MD,* Jean M. Moran, PhD,* James Hayman, MD,* and Lori J. Pierce, MD*, on behalf of the Michigan Radiation Oncology Quality Consortium

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Received Jul 23, 2014, and in revised form Sep 16, 2014. Accepted for publication Sep 22, 2014.

BR001 A Phase 1 Study of Stereotactic Body Radiotherapy (SBRT) for the Treatment of Multiple Metastases — Open

GI001 Randomized Phase III Study of Focal Radiation Therapy for Unresectable, Localized Intrahepatic Cholangiocarcinoma — Open — III

1073 GOG-0258/Endorsed Study: "A Randomized Phase III Trial of Cisplatin and Tumor Volume Directed Irradiation Followed by Carboplatin and Paclitaxel vs. Carboplatin and Paclitaxel for Optimally Debulked, Advanced Endometrial Carcinoma" — Open — III

1119 Phase II Randomized Study of Whole Brain Radiotherapy in Combination With Concurrent Lapatinib in Patients With Brain Metastasis From HER2-Positive Breast Cancer: A Collaborative Study... — Open — II R

0618 A Phase II Trial of Stereotactic Body Radiation Therapy (SBRT) in the Treatment of Patients with Operable Stage I/II Non-Small Cell Lung Cancer

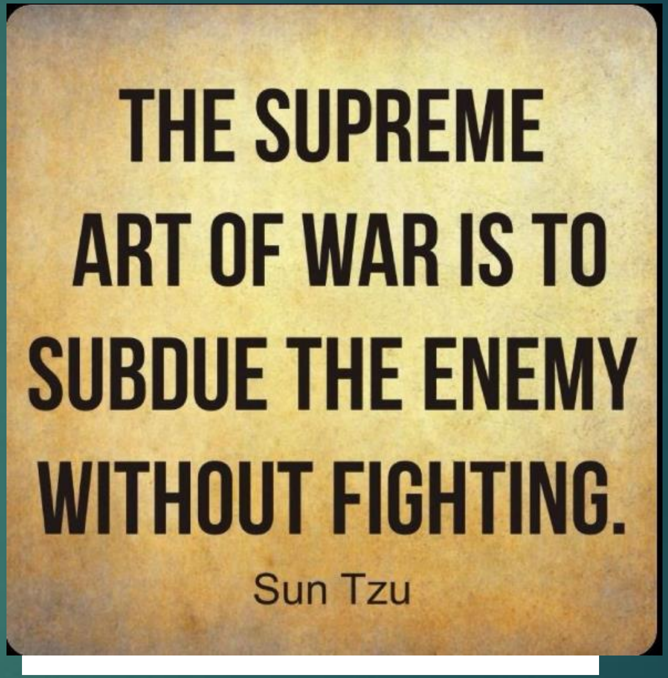
0123 A Phase II Randomized Trial With Captopril in Pati... +/ Chemotherapy for Stage II-IIIB Non-Sm... Lung Cancer—RTOG CCOP Study

0938 A Randomized Phase II Trial Of Hypofractionated... Cancer-RTOG CCOP Study

Next generation of radiation therapy: Submillimeter radiation therapy?

War-by-attrition

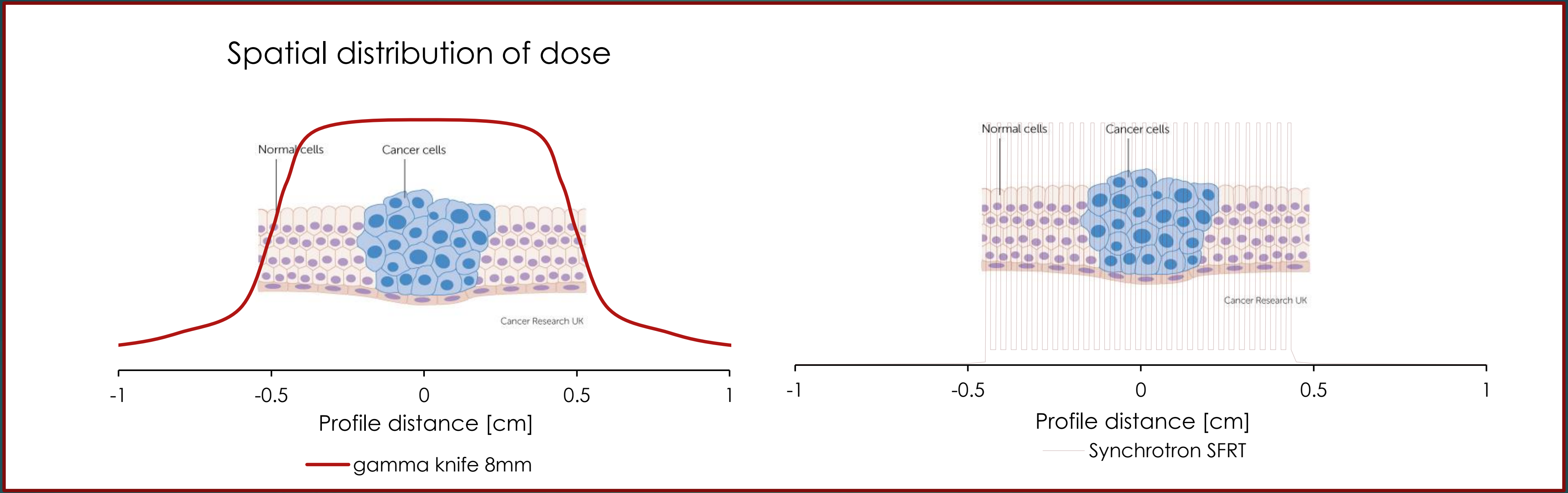
Ablation

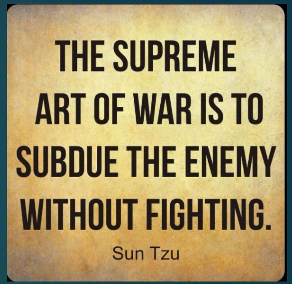


<u>"Very" small field sizes:</u>

- Extreme conformal avoidance
- Immune stimulation
- Unique genetic response
- Possibly more…

Example submillimeter technique: Microbeam Radiation Therapy(MRT)





Conventional Radiotherapy

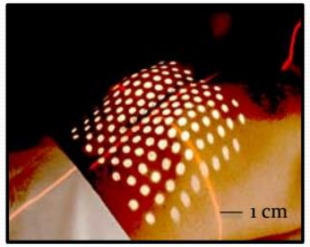
- Broad-beam geometry
- Treat entire tumor with uniform dose

Microbeam Radiotherapy

- Sharpe peaks and valleys
- Intentionally not irradiating entire region
- High-intensity peaks have treatment dose
- Valley regions are spared

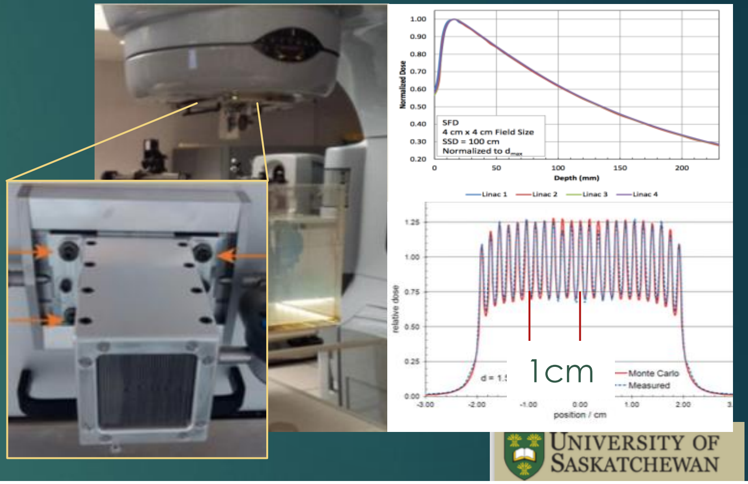
Evidence: Different biological response
Reason: Not fully known

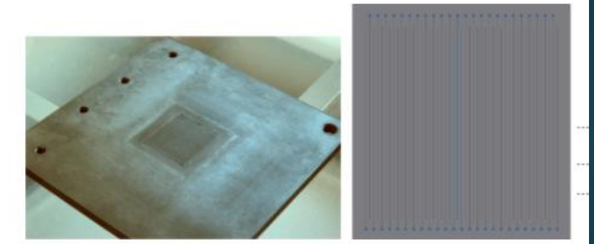
Future of radiation therapy: submillimeter radiation therapy techniques



Univ. of Kentucky, Arkansas, Maryland
Dr. Mohiuddin, M.

- "Submillimeter" includes the following variations in techniques:
  - "Grid therapy", "minibeam", "microbeam", "spatially fractionated"
  - Each are in their own stage of development from clinical trials "grid" therapy and pre-clinical "mini" and "micro" beam
  - Each claim different response characteristics than conventional radiotherapy
  - Variations also include:
    - Geometric arraignment of radiation source
    - Type of radiation used both photons and charged particles
- But despite these variations, there is a coherent message: Treating with small beams induces a different biological response than the conventional broad-beam radiation therapy

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A preclinical microbeam facility with a conventional x-ray tube
Stefan Bartzsch, Craig Cummings, Stephan Eismann, Uwe Oelfke
First published: 2 November 2016 Full publication history

Depth (mm)	1	5	10
Peak (mGy/s)	300 ± 20	230 ± 10	170 ± 10
Valley (mGy/s)	10.2 ± 0.5	11.2 ± 0.5	10.7 ± 0.5
PVDR	30 ± 3	21 ± 2	15.5 ± 1.5

Impact: submillimeter treatment mechanism, beyond ablation

- Stimulating immune system response: Kanagavelu, et al 2014
- Remarkable normal tissue tolerance

  Crosbie J et al Tumor cell response to synchrotron microbeam radiation therapy differs markedly from cells in normal tissues IJROBP 77 886-894 (2010)

  Dilmanian A et al Murine EMT-6 Carcinoma: high therapeutic efficacy of microbeam radiation therapy, Radiation Research 159, 632-641, 2003.
- Preferential tumorcidal genetic response

  Sprung, C et al, Genome-wide transcription responses to synchrotron microbeam radiotherapy, Radiation Research 178, 249-259 (2012)
- Potent tumor response to typically treatment resistant cancers, such as glioblastoma

  Bouchet, A et al Preferential effect of synchrotron microbeam radiation therapy on intracerebral 9L gliosarcoma vasculature networks IJROBP 78, 1503-1512 (2010)
- Similar responses can be documented in larger fields i.e. fields measured up to millimeters
  - Griffina R et al Microbeam Radiation Therapy Alters Vascular Architecture and Tumor Oxygenation and is Enhanced by a Galectin-1 Targeted Anti-Angiogenic Peptide

Implications: shrink the scale of treatments

Prostate

Brain lesion

Nerves, lymphatics, and blood vessels

IMRT
Very common, standard of care

SRS/SBRT
Common

May soon be possible

Outline

1. Introduction
2. Initial work toward small field radiotherapy, approach
3. Energy modulation with sub-MV beams
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Small field radiation therapy: potential is too good to ignore

- Indications that the historical DNA damage/repair model for radiobiology is incomplete.
- The use of small field sizes could offer another route to attack cancer.
- Furthermore, comparatively small, submillimeter fields are showing a different type of radiation response model that could be leverage
- Hence we launched our own study by finding the smallest field size we can generate from a clinical device.

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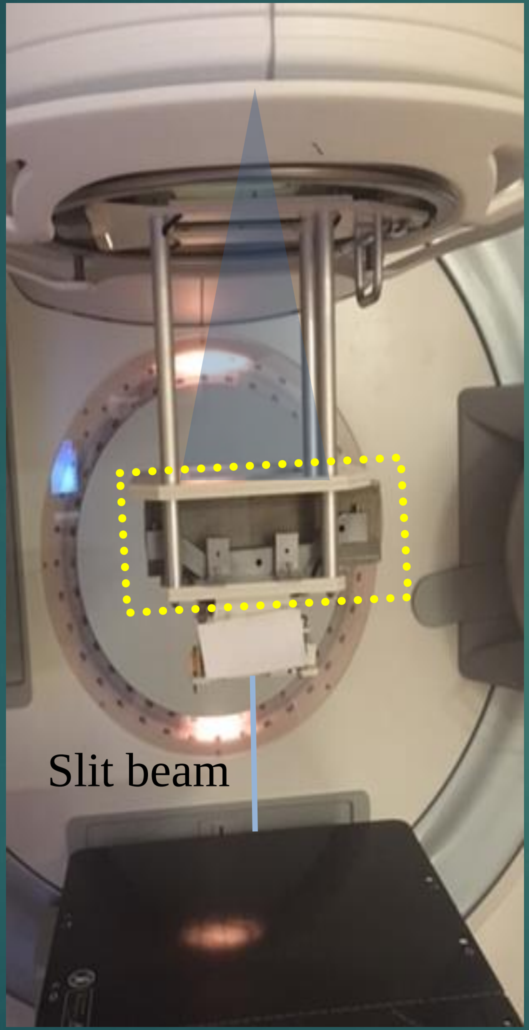
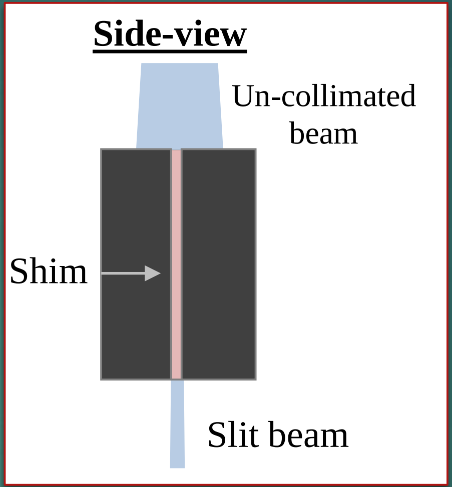
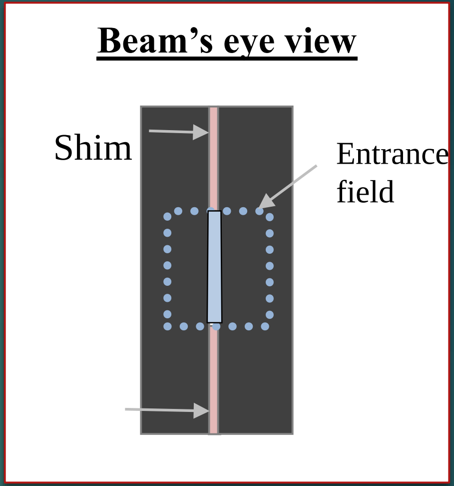
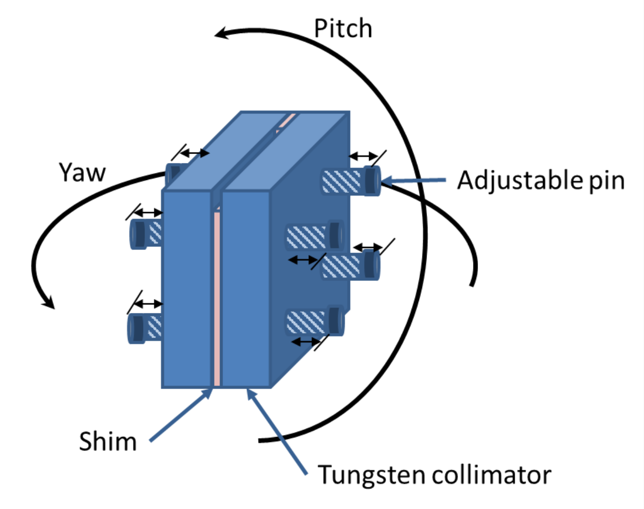
Linear accelerator



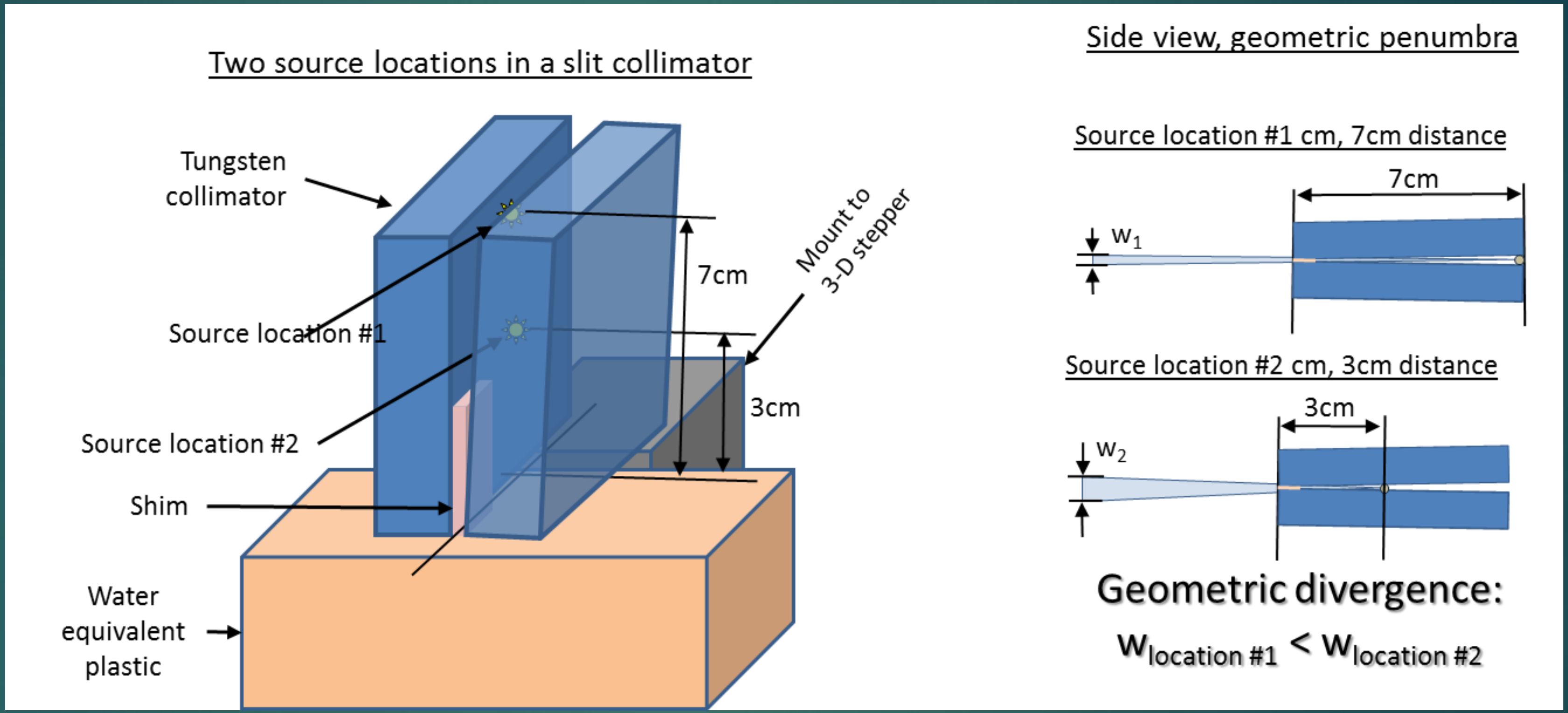






Collaborators:
Donna Siergiej
Rob Goodman

Ir-192, 380 keV photons



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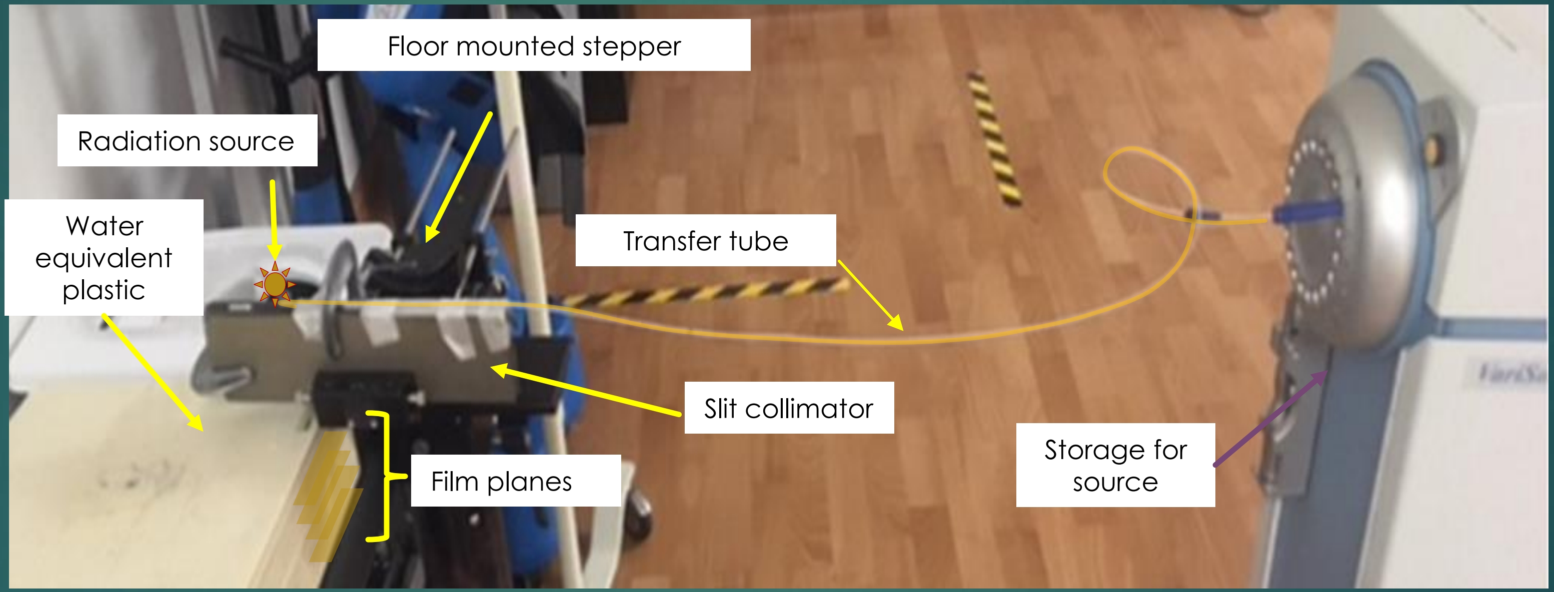
Ir-192 radioactive source



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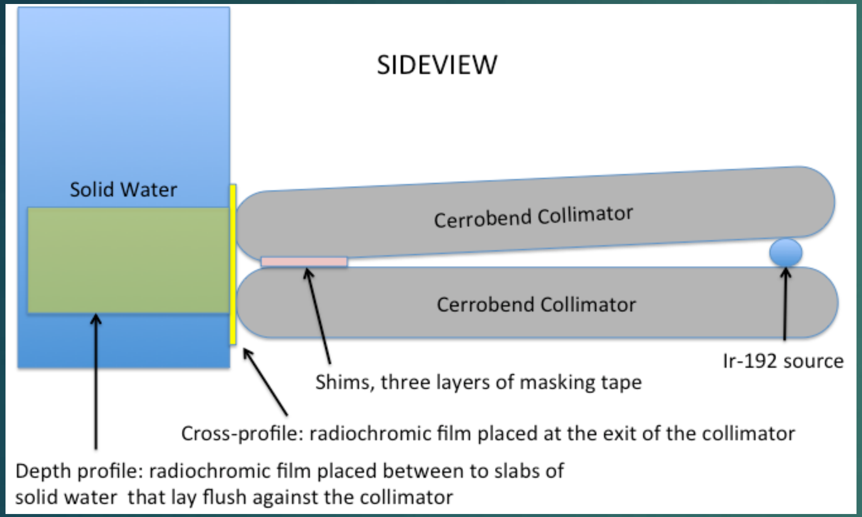
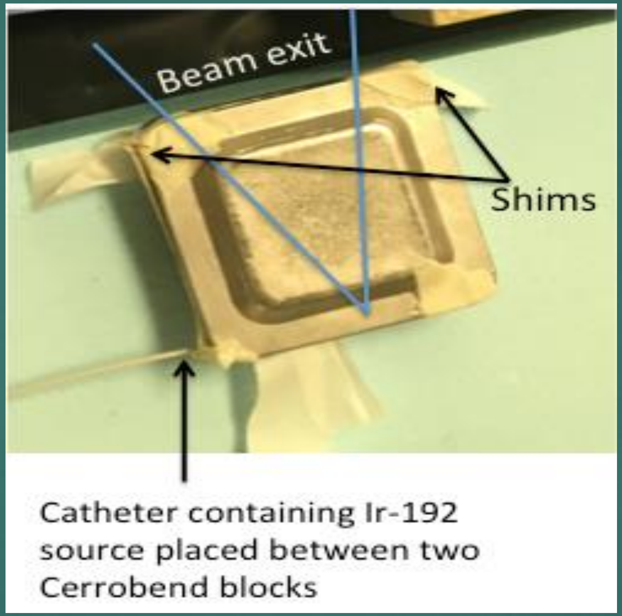
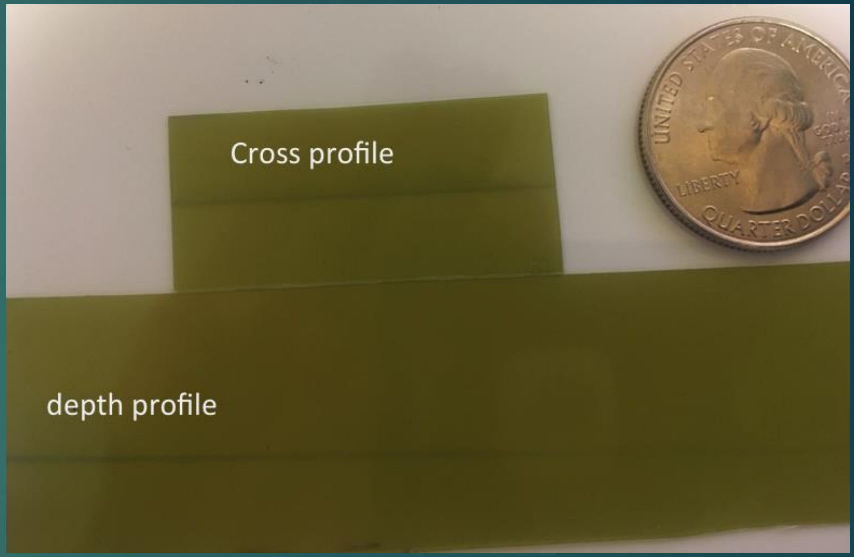
Further measurements with Ir-192







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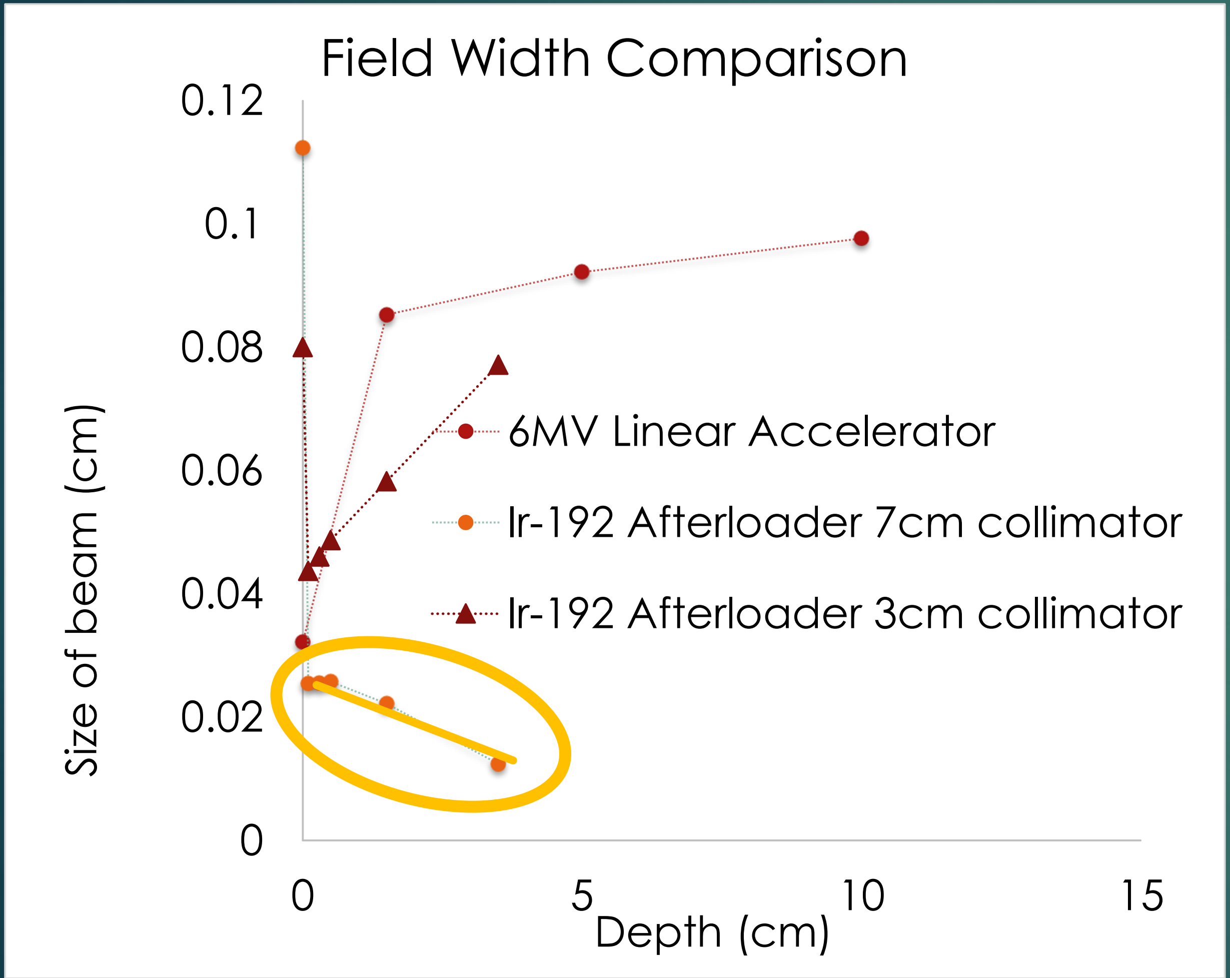
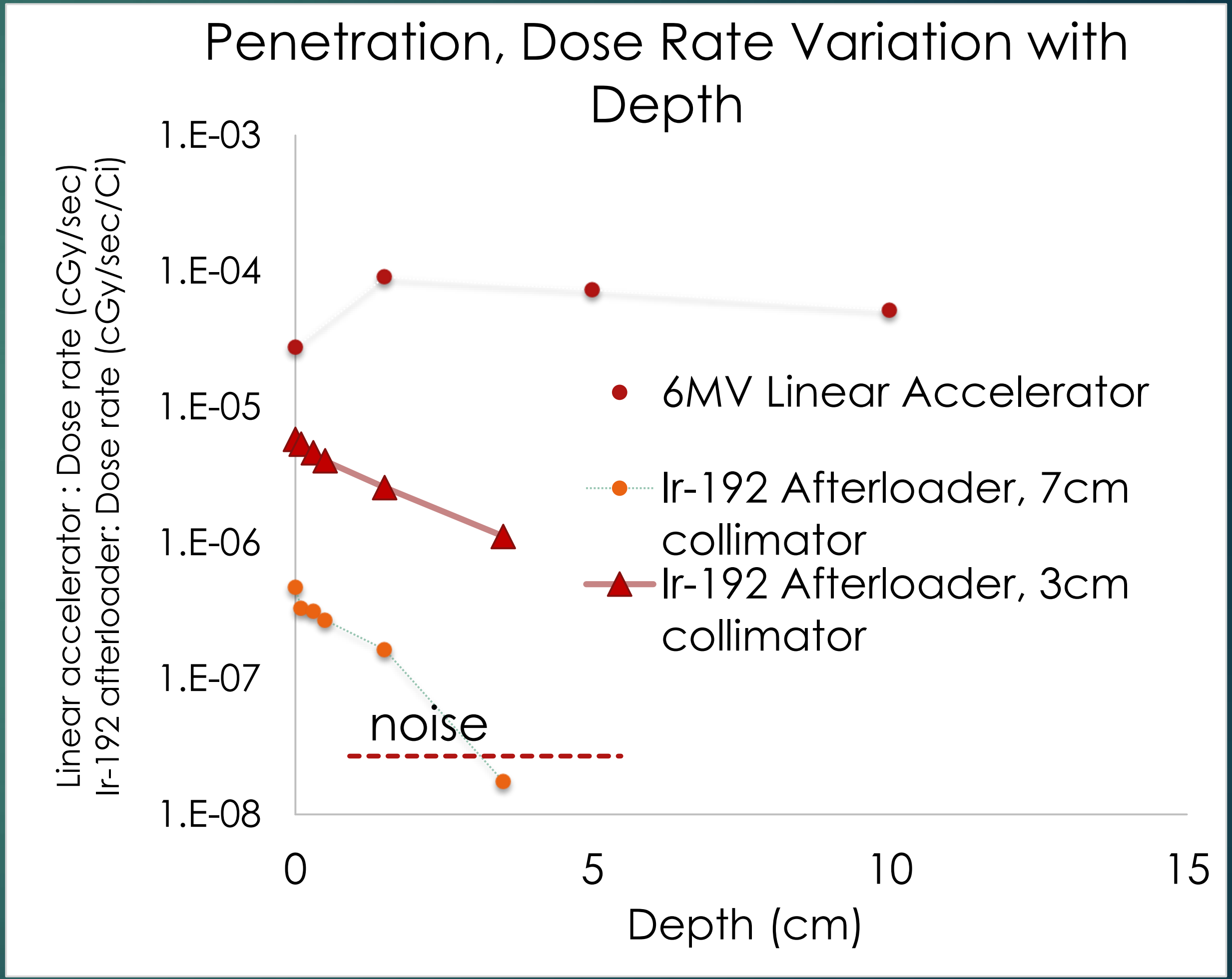
Results

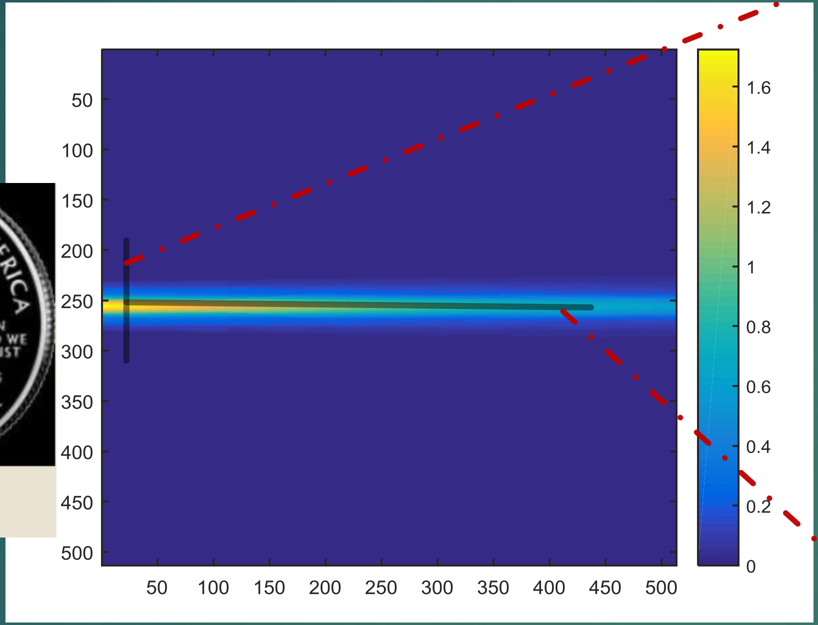


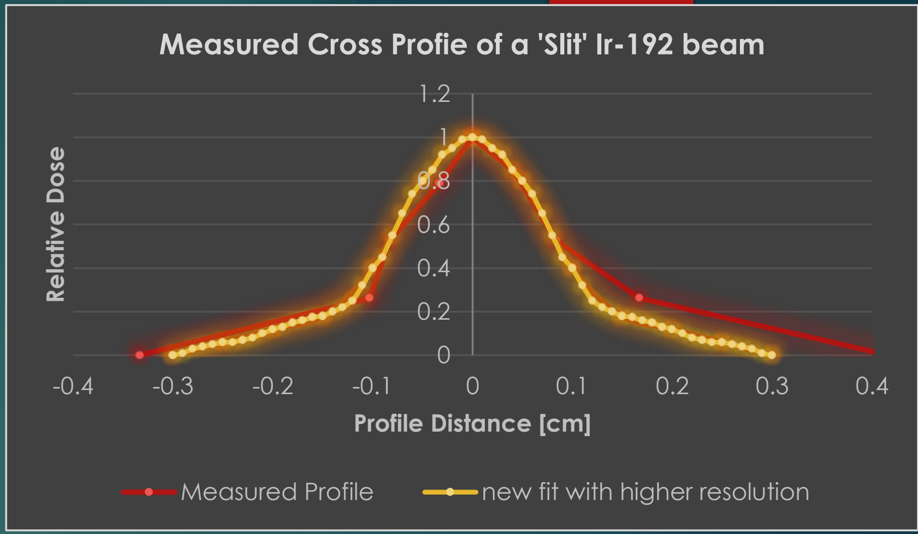
Field Width Comparison
0.12
0.1
0.08
0.06
0.04
0.02
0
Size of beam (cm)
0
5
10
15
Depth (cm)
6MV Linear Accelerator
Ir-192 Afterloader 7cm collimator
Ir-192 Afterloader 3cm collimator



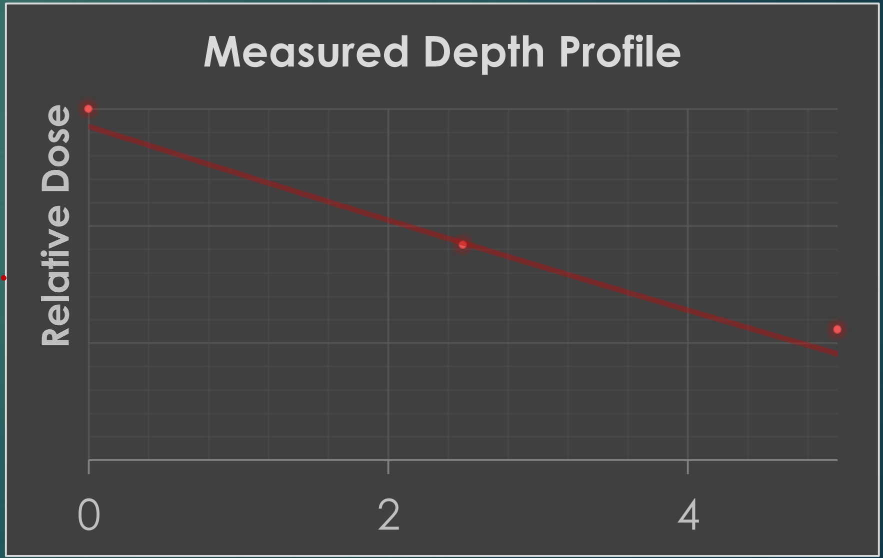
Penetration, Dose Rate Variation with Depth
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
Linear accelerator : Dose rate (cGy/sec)
Ir-192 afterloader: Dose rate (cGy/sec/Ci)
0
5
10
15
Depth (cm)
6MV Linear Accelerator
Ir-192 Afterloader, 7cm collimator
Ir-192 Afterloader, 3cm collimator
noise

Ir-192, single beam



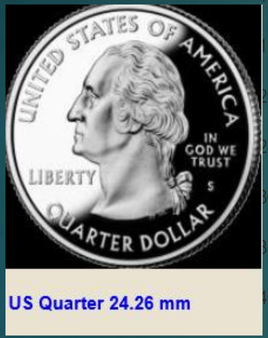


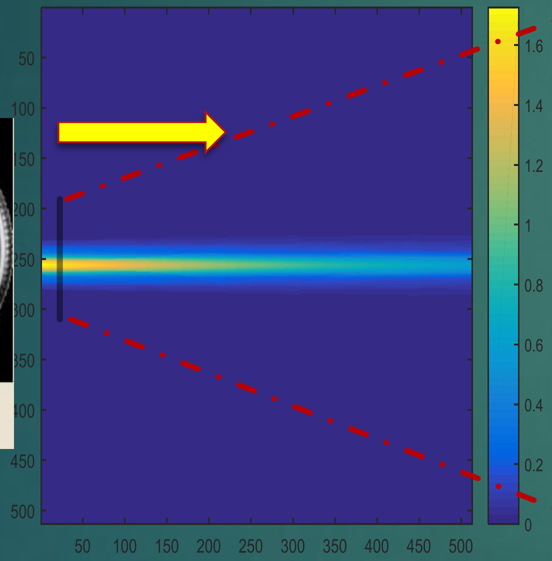
Note: the field size is larger than the prior setup



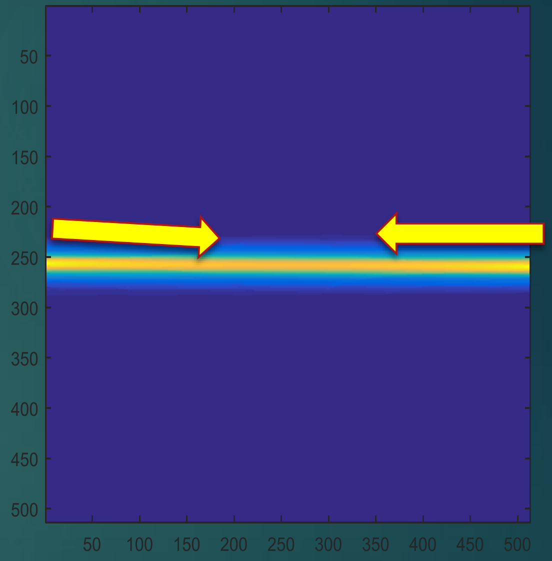
Note this is a exponential fit, the deeper the depth the larger the dose at the surface

Simulated opposing beam



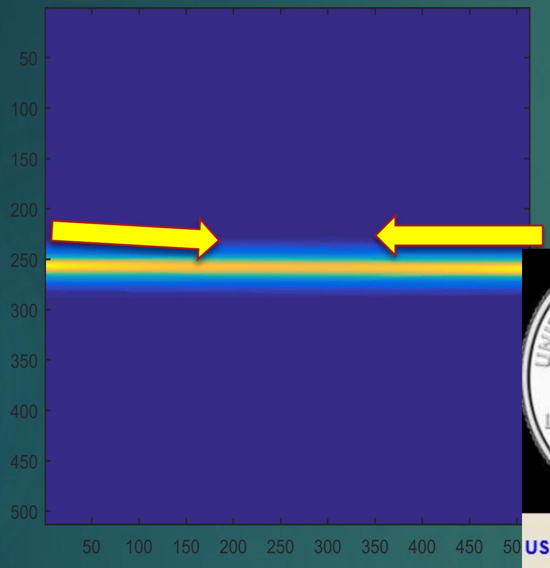


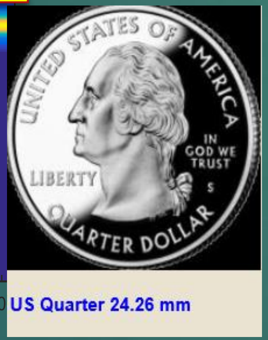
Simulated Ir-192 source



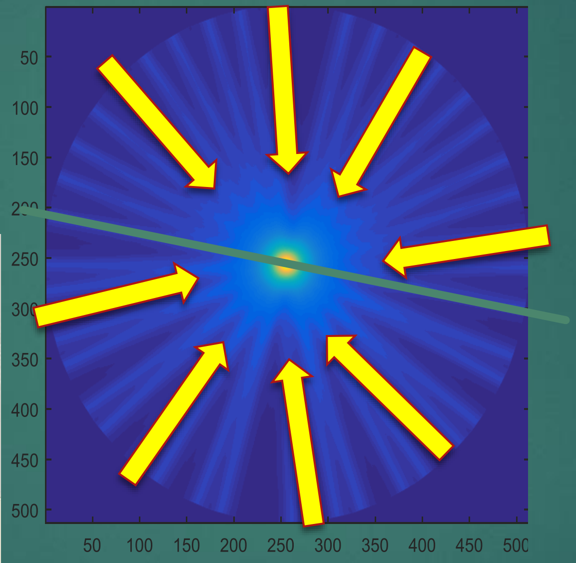
Opposing

Ir-192, rotational delivery to reduce collateral dose

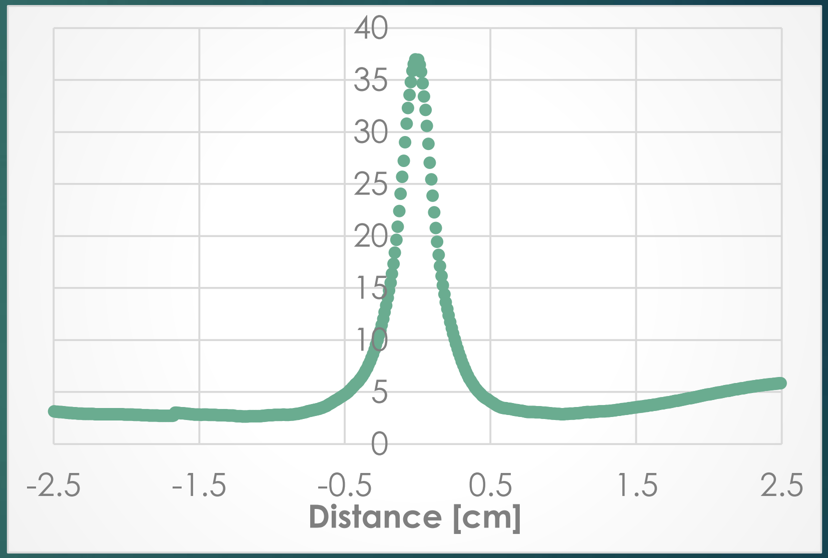




Opposing



Rotation



This show us that a relatively small field size can be delivered with a 400keV beam…
BTW, the dose fall off in this simulation is comparable to charge particle therapy

Outline

1. Introduction
2. Initial work toward small field radiotherapy, approach
3. Energy modulation with sub-MV beams
4. Planning/optimization routine for energy modulation
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Implications: if we want to make submillimeter treatments widely available, what is the most appropriate radiation to use?

Options

- ~~Electrons~~
- ~~Brachytherapy~~
- ~~Heavy charged particles~~
  - ~~Protons~~
  - ~~Heavier (i.e. Carbon~~)
- Photons

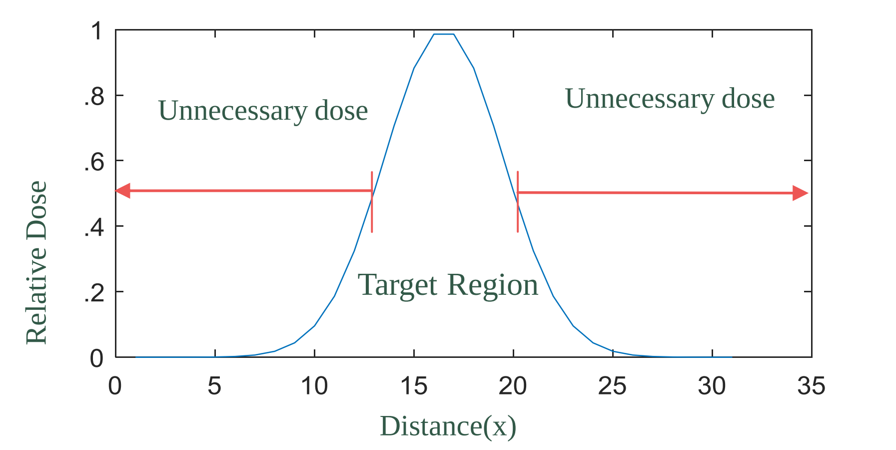
Considerations

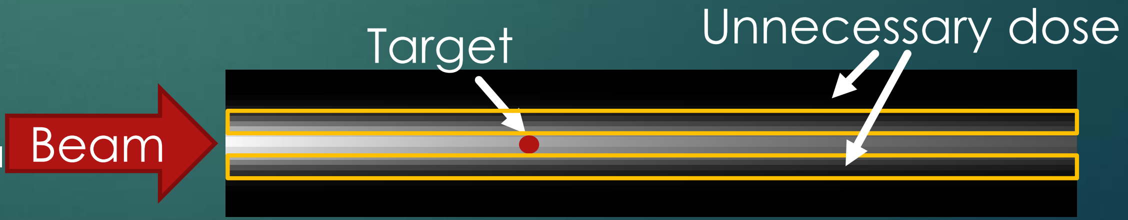
- If the tumor is not on or near surface, eliminates electron beam therapy.
- If we desire to have a non-invasive treatment, eliminates brachytherapy and orthovoltage units.
- For cost, eliminate charged particle therapy.
- Photons has tradeoffs… but may be the best practical type of radiation for therapy

Tradeoffs involved with selecting the most appropriate photon source (1)

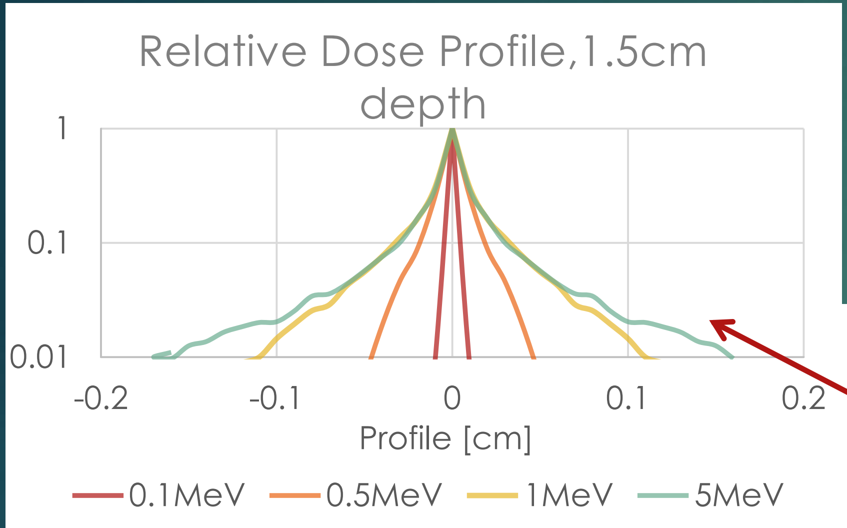
Field width

- Edges of the a photon beam is blurred by secondary interactions that spread dose outside of the edge of the beam's aperture.
- Certain treatments require very tight penumbra and field size to:
- 1.)achieve superior avoidance of nearby structures
- 2.) Reduce collateral dose to the patient
- For submillimeter therapy: tight penumbra's are required to create the unique biological response.
- A lower energy spectrum has smaller penumbra
- Implication:
  - Whatever beam has the smaller penumbra will have less integral dose.
  - This effect is more pronounced with beams that have less penetration

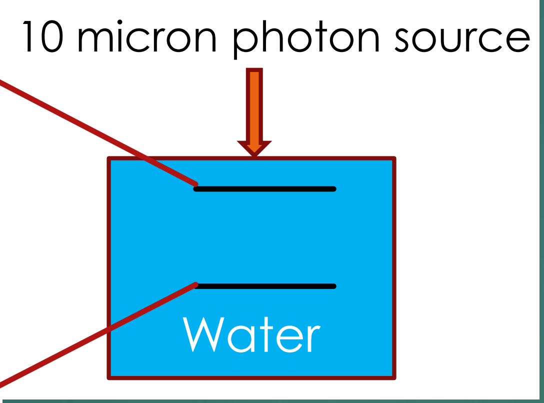


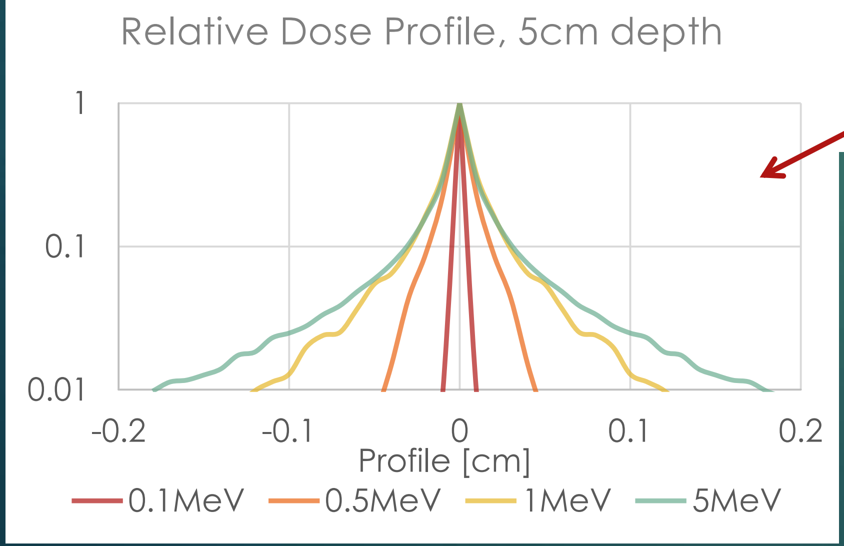


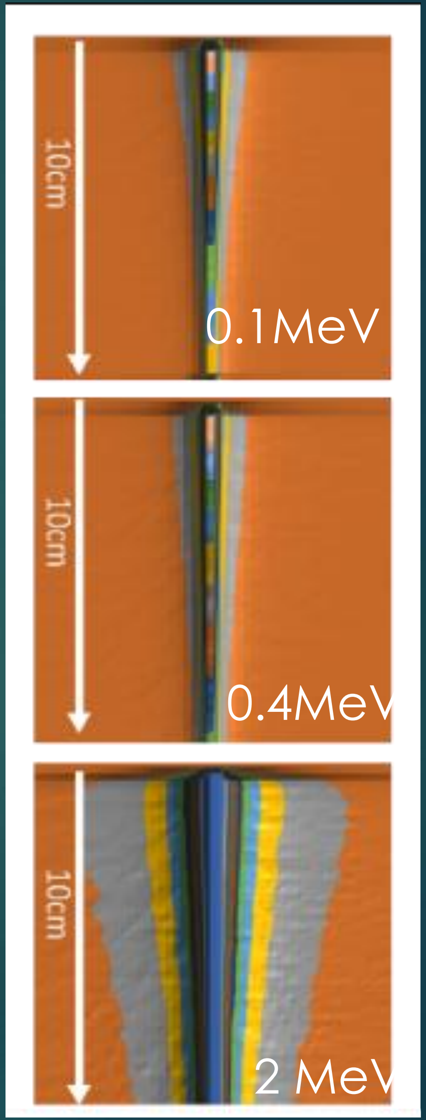
Penumbra size: What is the smallest treatment field?



- M Carlo Simulation
- Lower energy, smaller penumbra



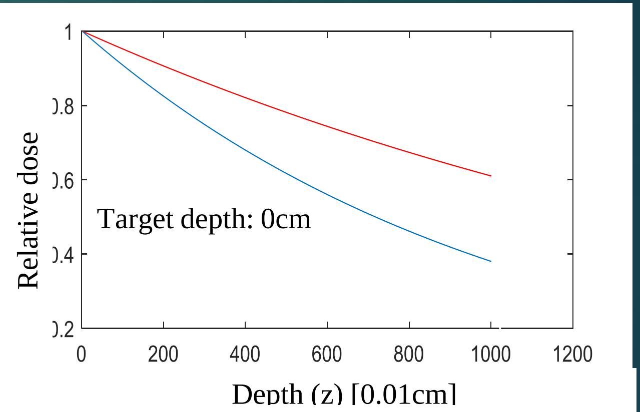


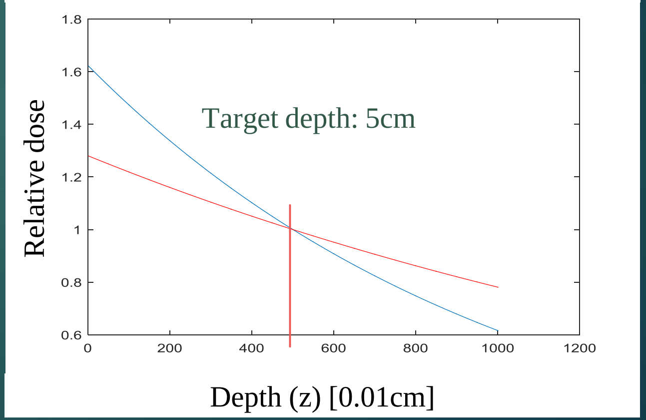


Tradeoffs involved with selecting the most appropriate photon source (2)

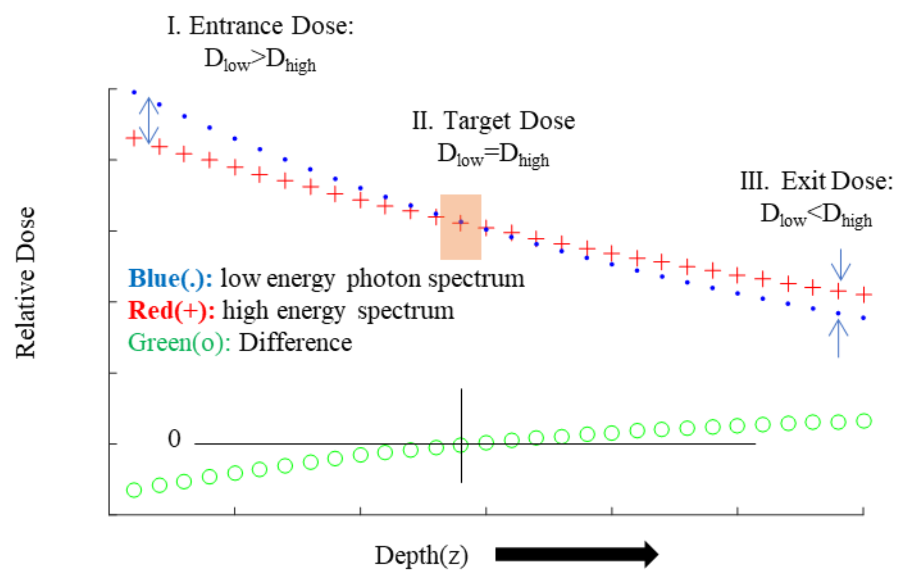
Penetration

- To obtain the same dose at depth, the less penetrating requires large dose at shallower depths and less at deeper depths
- Hence, lower energy beams will have greater skin dose but would have less exit dose.
- Blending high and low energy photon spectrum has been used with multi-energy radiotherapy LINACS to optimize beam's penetration into normal tissues and control skin dose
- In general, increasing beam energy also increases the beam's penetration





Ideal penetration to minimize patient dose, function of target depth

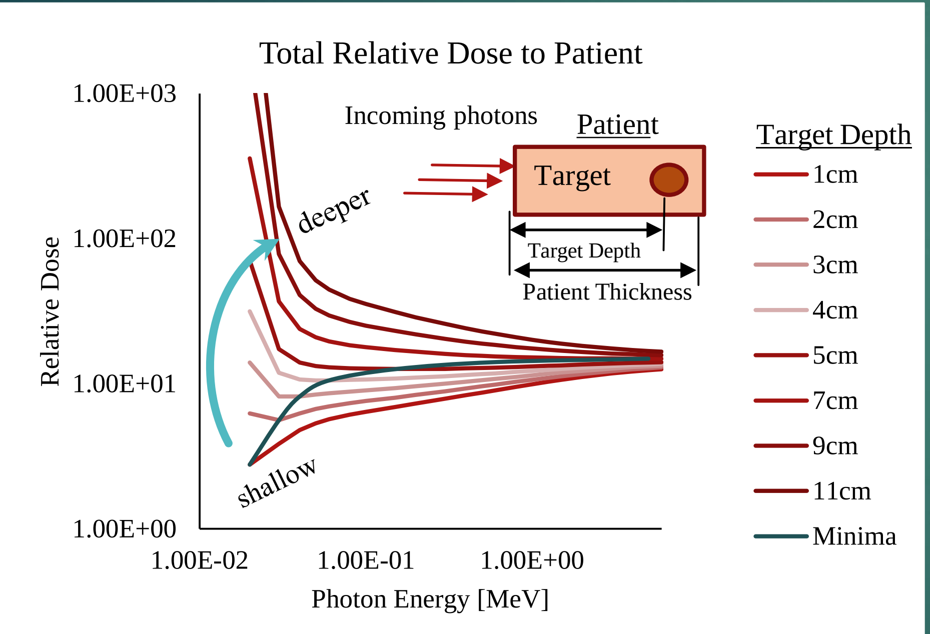


Dose at depth

- Relationship of the dose at depth

$$D\left(\mu_{(hv)}, z\right)_{CPE} = \frac{\mu(hv)_{en}}{\rho} \cdot hv \cdot \varphi_o \cdot exp\left(\mu(hv) \cdot \left(z - z_{target}\right)\right)$$

Ideal photon energy to reduce total dose to patient



Assume patient anatomy is 15cm thick

Total dose to patient 1-D model

Patient Thickness

$$Dose \sim \frac{(\exp(\mu(hv) \cdot depth))}{\mu(hv)} \cdot (1 - \exp(-\mu(hv) \cdot thickness))$$

Energy

Target depth

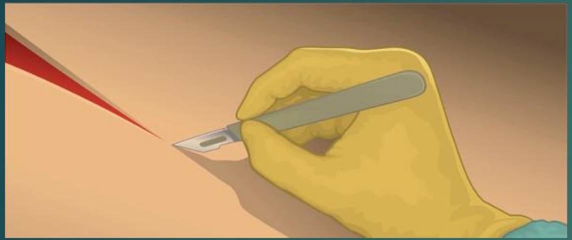
$\mu(hv)$ can be found by using NIST values

Tradeoffs: an opportunity to optimize

- Higher energy spectrums are more penetrating
  - (+) lower integral dose for deeper targets
  - (+) skin sparing
  - (-) broad penumbra
  - (-) larger exit dose
- Lower energy spectrums are less penetrating
  - (+)lower integral dose for shallow targets
  - (+)sharp penumbra
  - (-) large entrance dose

How can we get these tradeoffs compensate for each other?

Optimization analogy(1):



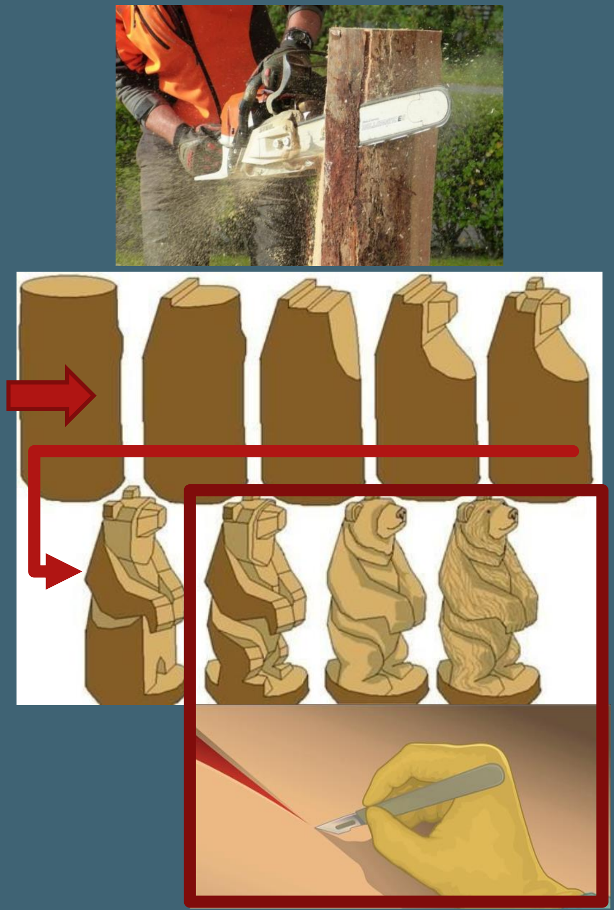
Sub- MV energy spectrum

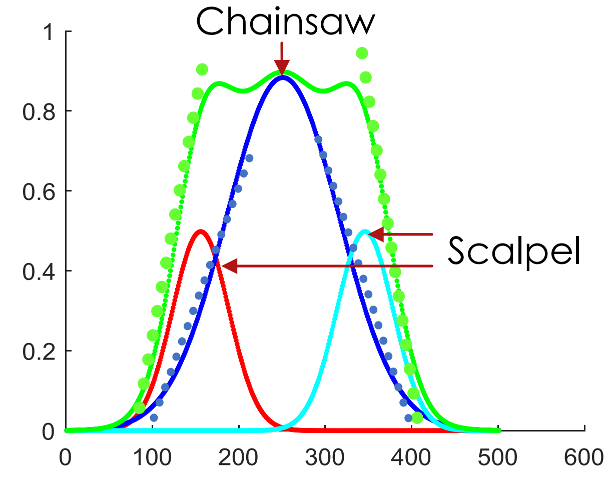
High energy spectrum

- Razor: very thin, limited penetration, make precise well thought out cuts that leaves neighboring tissues unharmed.
- Chain saw: relatively broad beam, made for efficiency and power
- Depending on the situation, you would want to have different tools
- The following discussion will use Gaussian distributions to approximate a small radiation field

Optimization analogy(2):

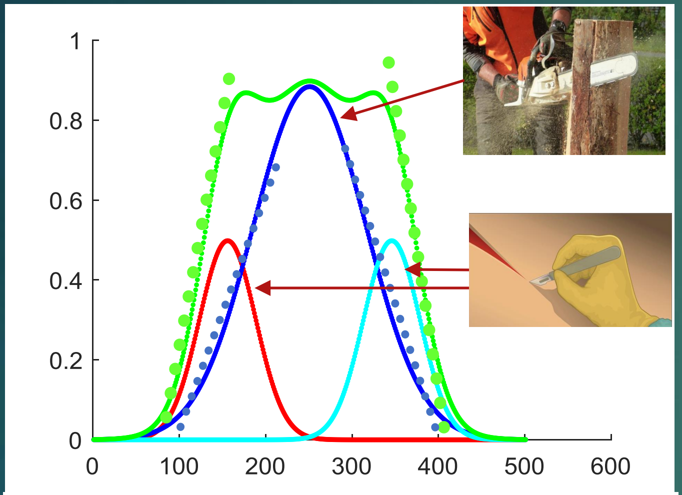
Starting point | Bear sculpture



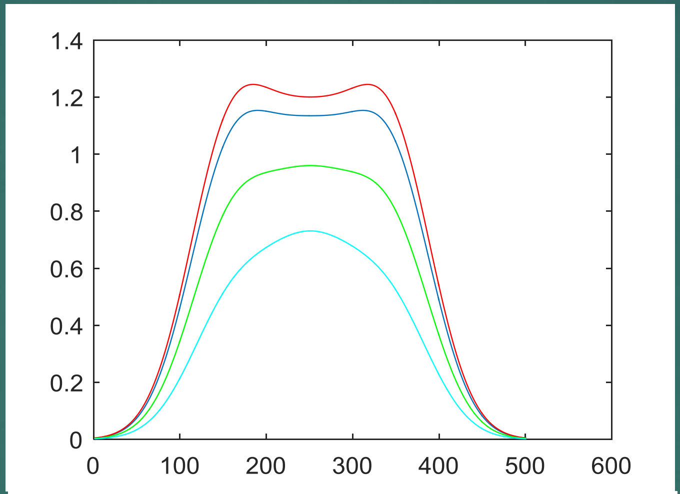


Red:
400keV, 0.5cm width, -1cm offset
Blue:
2MeV, 1.0cm width, 0 cm offset
Cyan:
400keV, 0.5cm width, +1cm offset

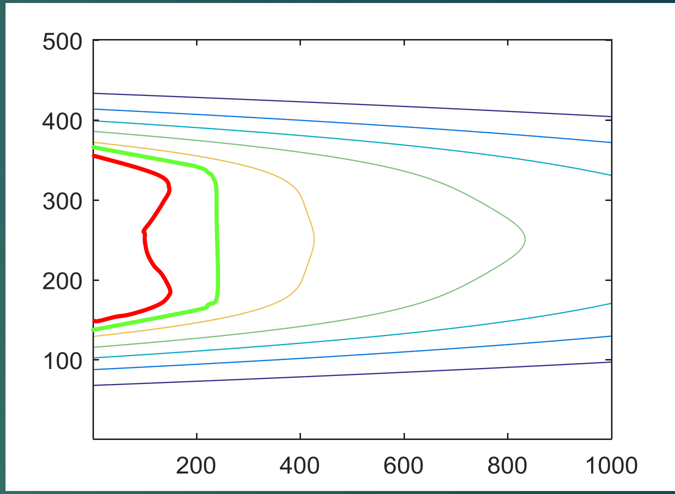
Changing profile with depth



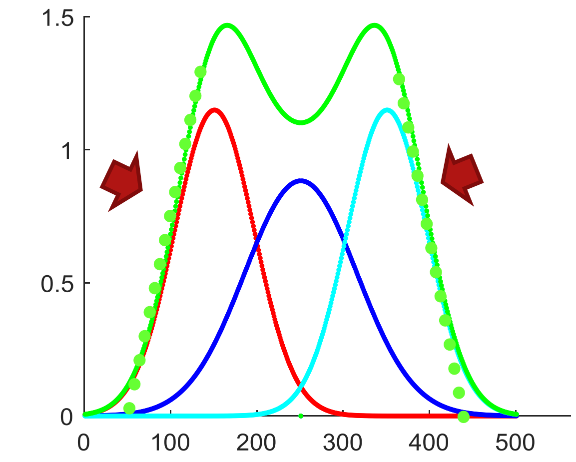
<u>Red:</u>
400keV, 0.5cm width, -1cm offset
<u>Blue:</u>
2MeV, 1.0cm width, 0 cm offset
<u>Cyan:</u>
400keV, 0.5cm width, +1cm offset



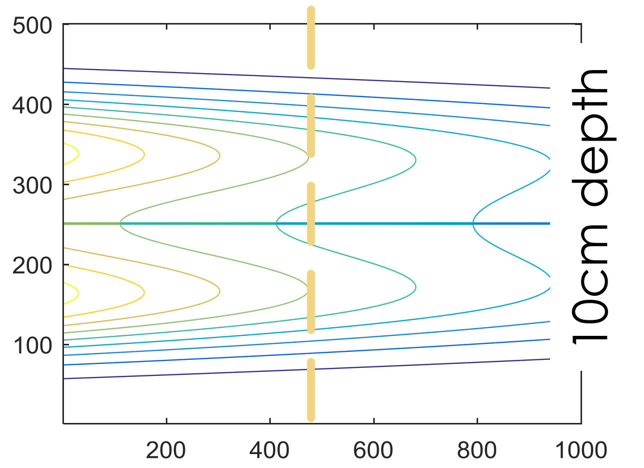
Red, depth = 1cm
Blue, depth = 2cm
Green, depth = 5cm
Cyan, depth = 10cm

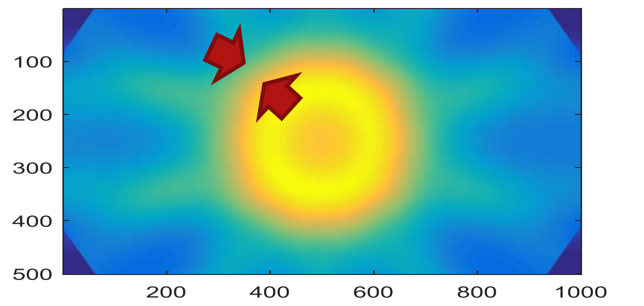


Other considerations

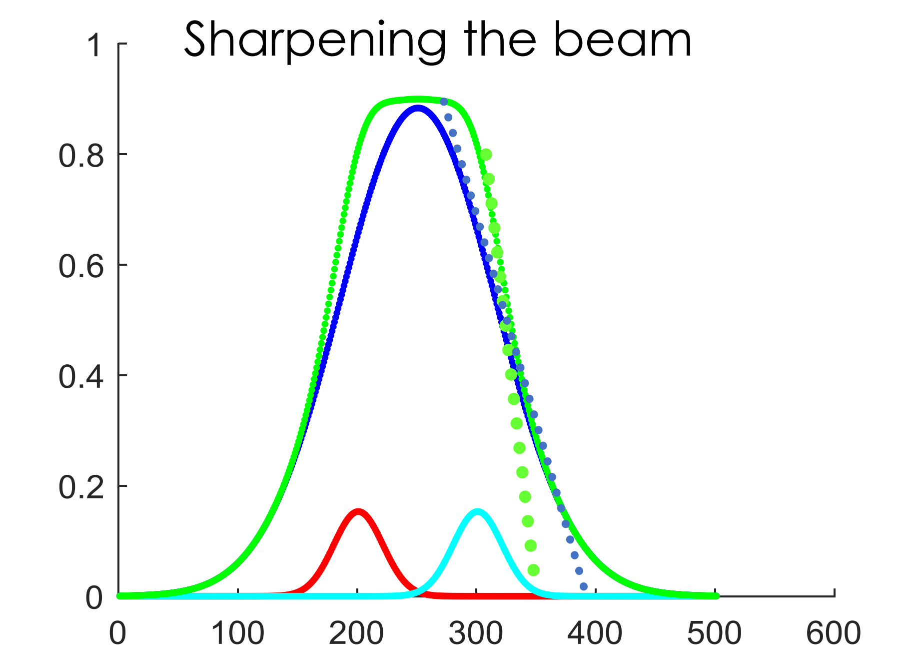


Red 400keV, 5mm FWHM, -1cm off axis
Blue 2MeV, 10mm FWHM
Cyan 400keV, 5mm FWHM,+1cm off axis
Intensity of 400keV is 50% larger than 2MeV, 5cm depth





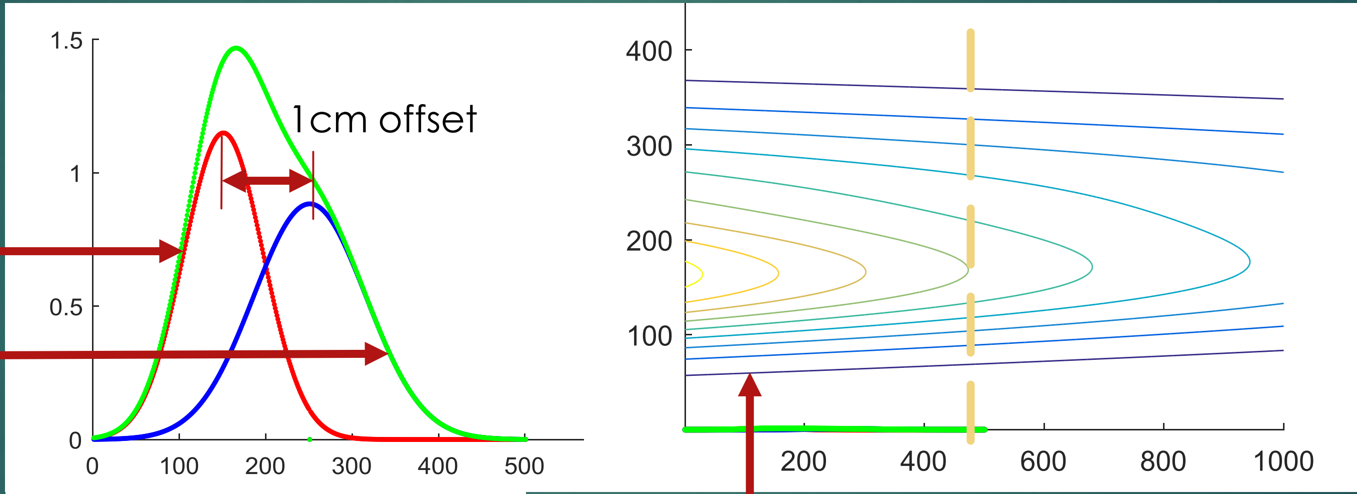
Penumbra of the sum, matches the penumbra of the thin beamlet



It doesn't take much to increase the dose gradient

We can now consider optimize weird dose distributions using different photon beams.

Far enough separation to match penumbra of the total dose



Red, 0.5 cm FWHM, 400 keV
Blue, 1.0 cm FWHM, 2 MeV
Green, sum

Intensity of 400keV is 50% larger than 2MeV, 5cm depth

Tight dose gradient

Outline

1. Introduction
2. Initial work toward small field radiotherapy, approach
3. Energy modulation with sub-MV beams
4. Planning/optimization routine for energy modulation
5. Future Work

How can we use this in optimization process

EMRT treatment planning

One time calculation per machine

- Monte Carlo simulation of beamlets through water
- Create polynomial fits to the data

↓

One time per plan

- Calculate dose distribution of beamlets that intersect with the target

↓

One time per optimization

- Create an initial guess to 'seed' iterative optimization

↓

Iterative optimization, subject to DVH dose constraints

- Randomly change the energy weighting
- Randomly change the intensity of each beamlet

EMRT treatment planning

One time calculation per machine

- Monte Carlo simulation of beamlets through water
- Create polynomial fits to the data

↓

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↓

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↓

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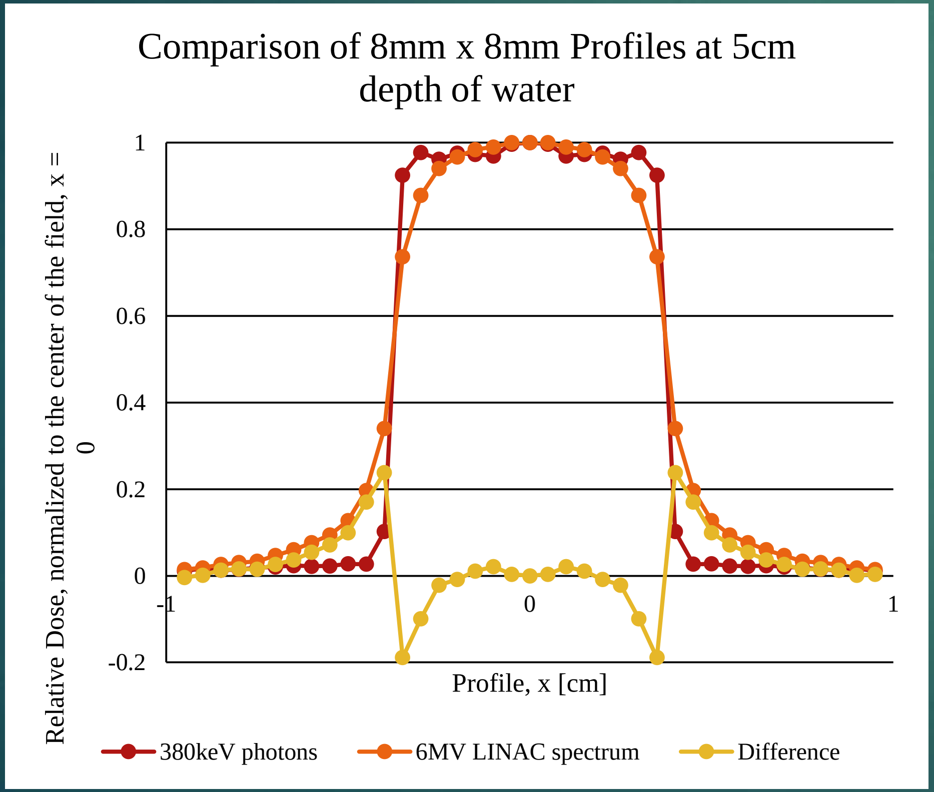
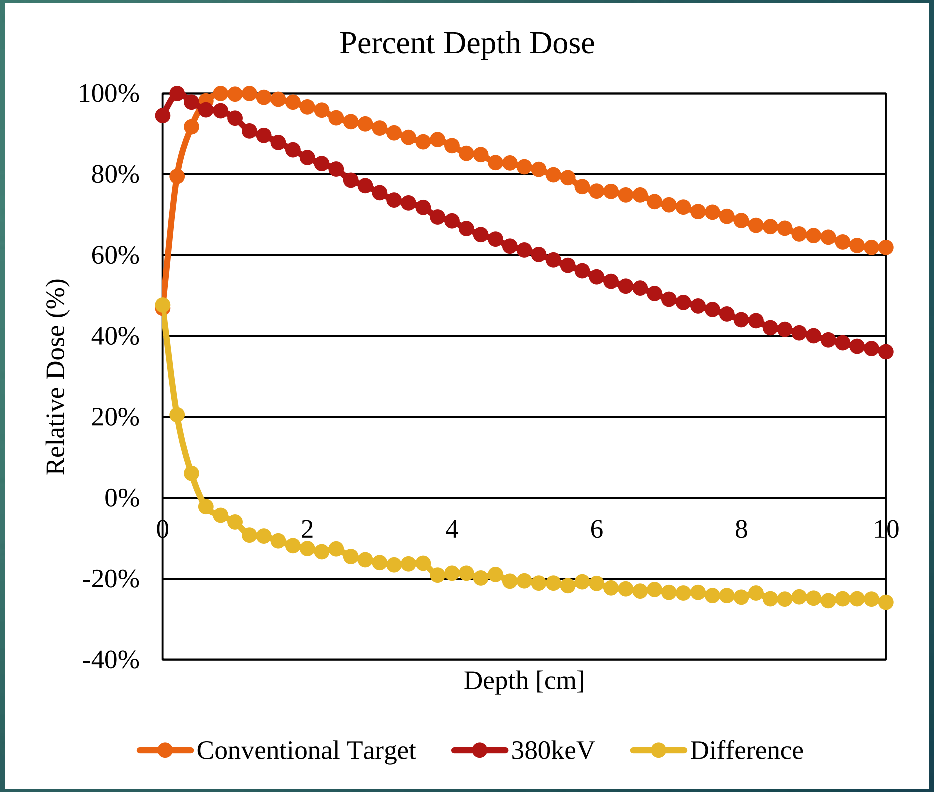
- Randomly change the intensity of each beamlet

Results of the MC

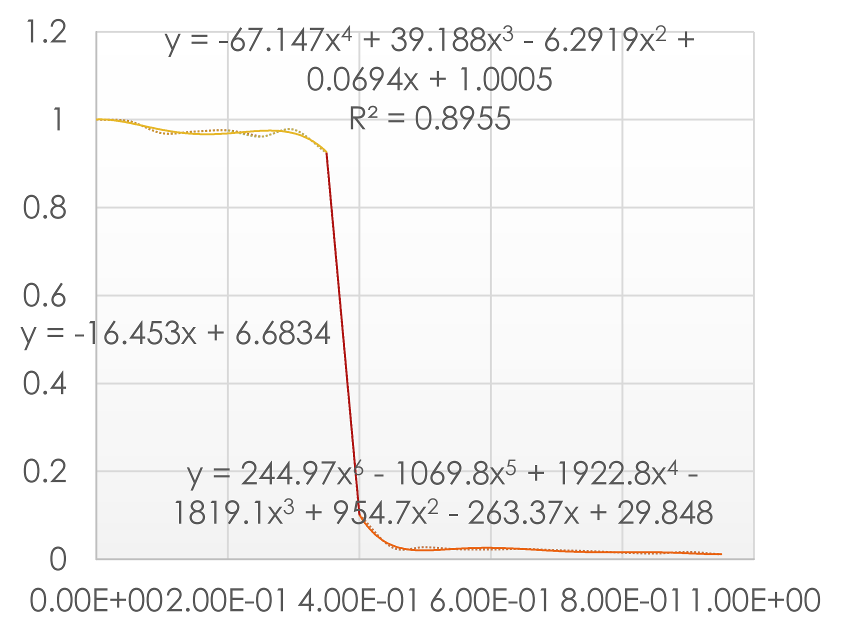
Profile

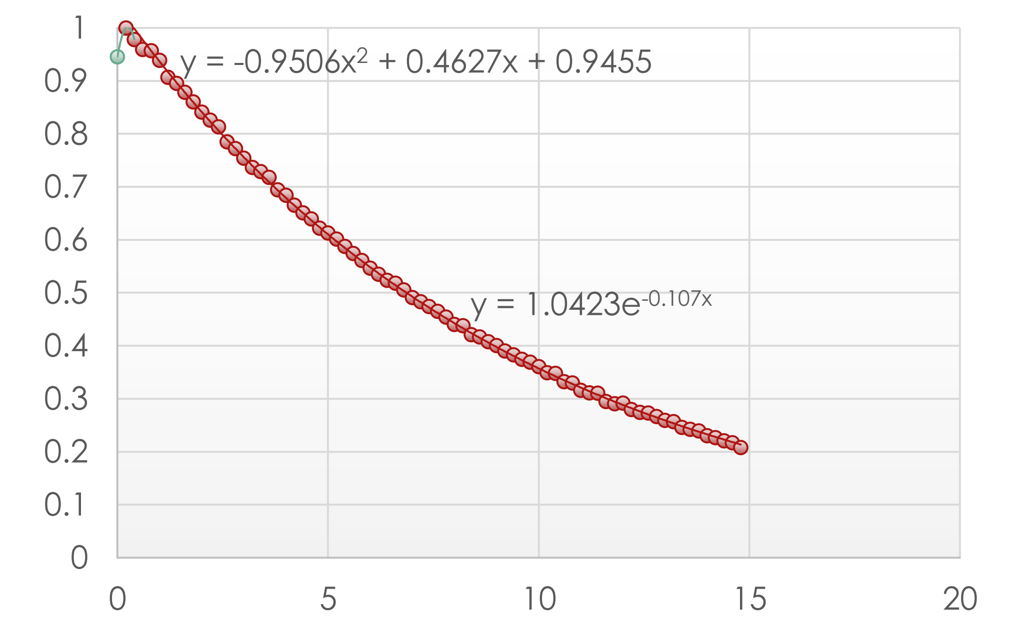


Depth dose



Generate piece-wise polynomial fit for each data set





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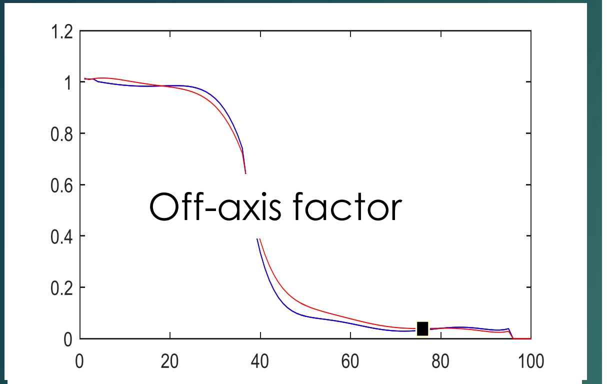
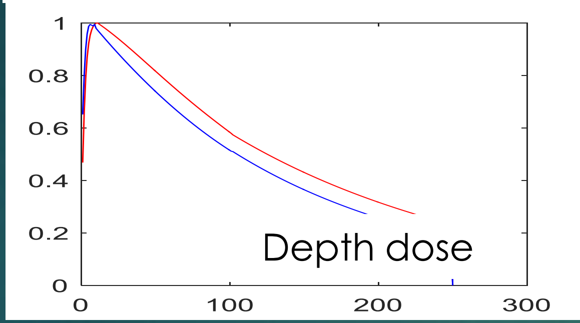
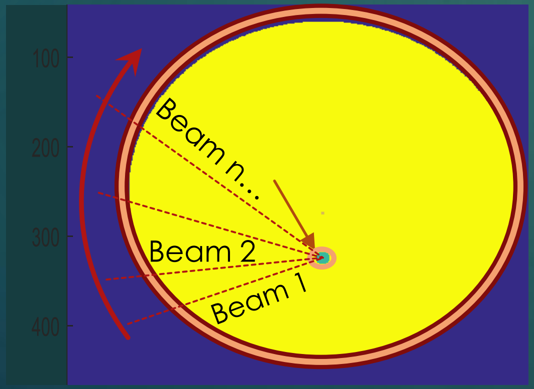
Iterative optimization, subject to DVH dose constraints

- Randomly change the energy weighting
- Randomly change the intensity of each beamlet

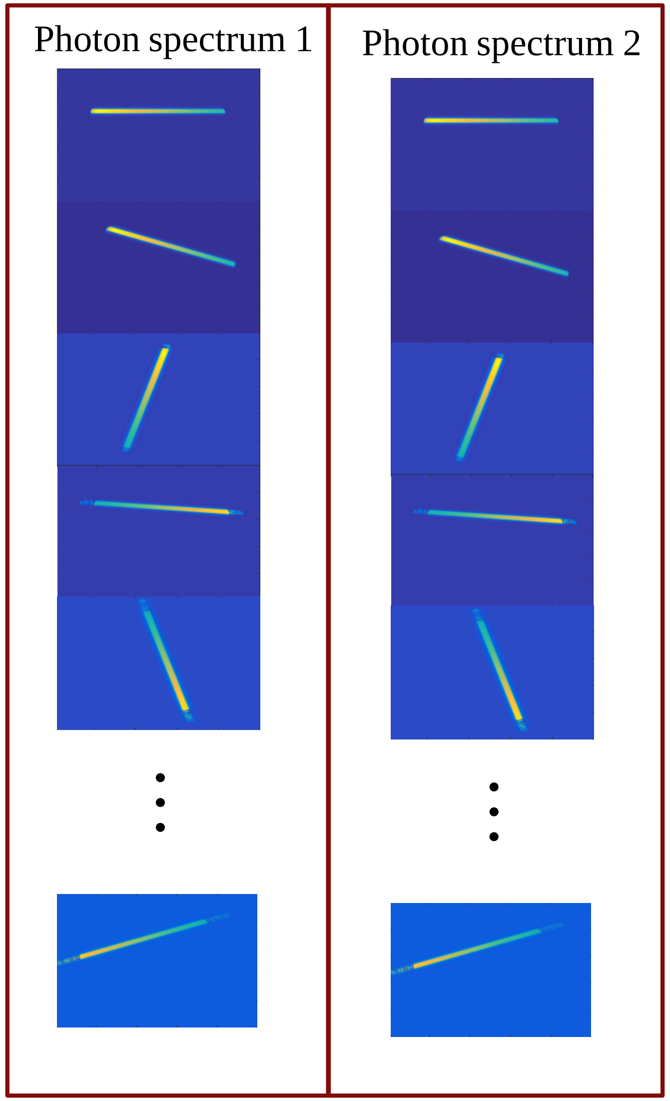
Patient beamlet calculation

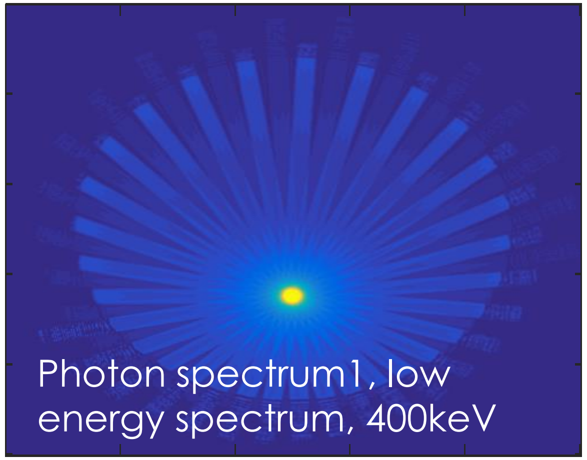


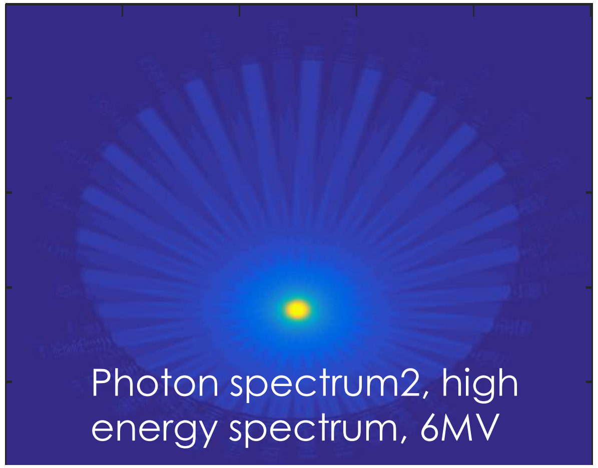




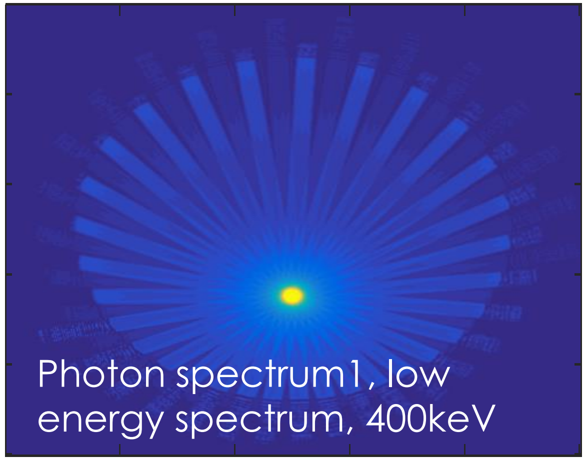
Dose calculation per beam



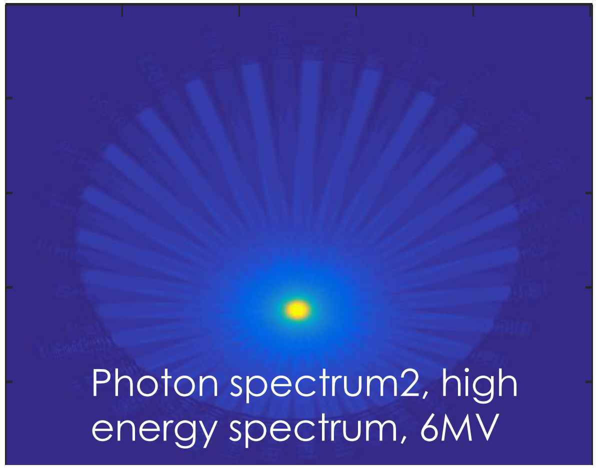




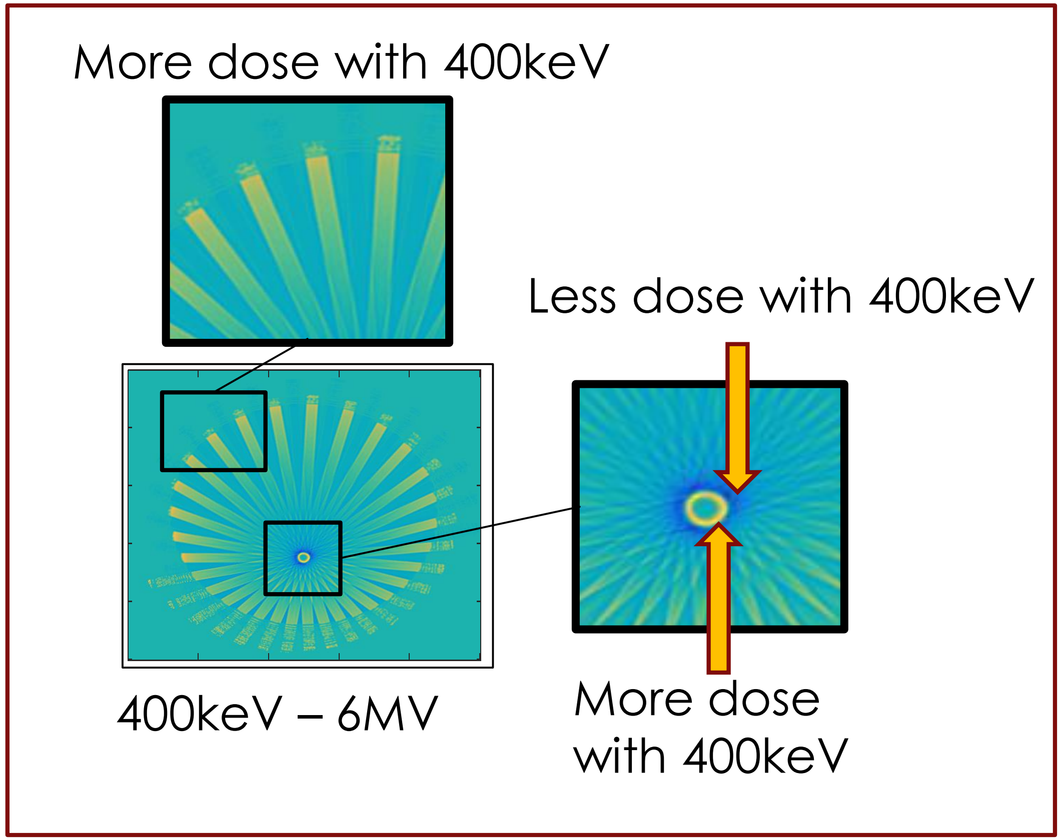
Comparison



Photon spectrum1, low
energy spectrum, 400keV



Photon spectrum2, high
energy spectrum, 6MV



More dose with 400keV
Less dose with 400keV
400keV – 6MV
More dose
with 400keV

EMRT treatment planning

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One time per plan

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One time per optimization

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Iterative optimization, subject to DVH dose constraints

- Randomly change the energy weighting
- Randomly change the intensity of each beamlet

Initial guess

- The better the initial guess, the faster and better the plan will become
- Options:
- 1.) set all intensity to a uniform value
- 2.) set all intensities to random number to the relative intensity
- 3.) Use built-in “nonnegative least-squares” routine:

lsqnonneg

Solve nonnegative least-squares constraints problem

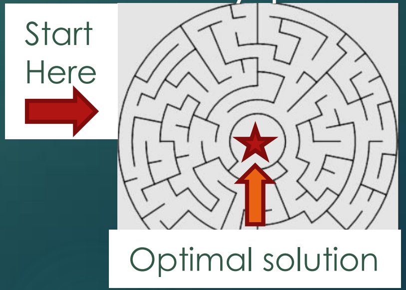
Equation

Solves nonnegative least-squares curve fitting problems of the form

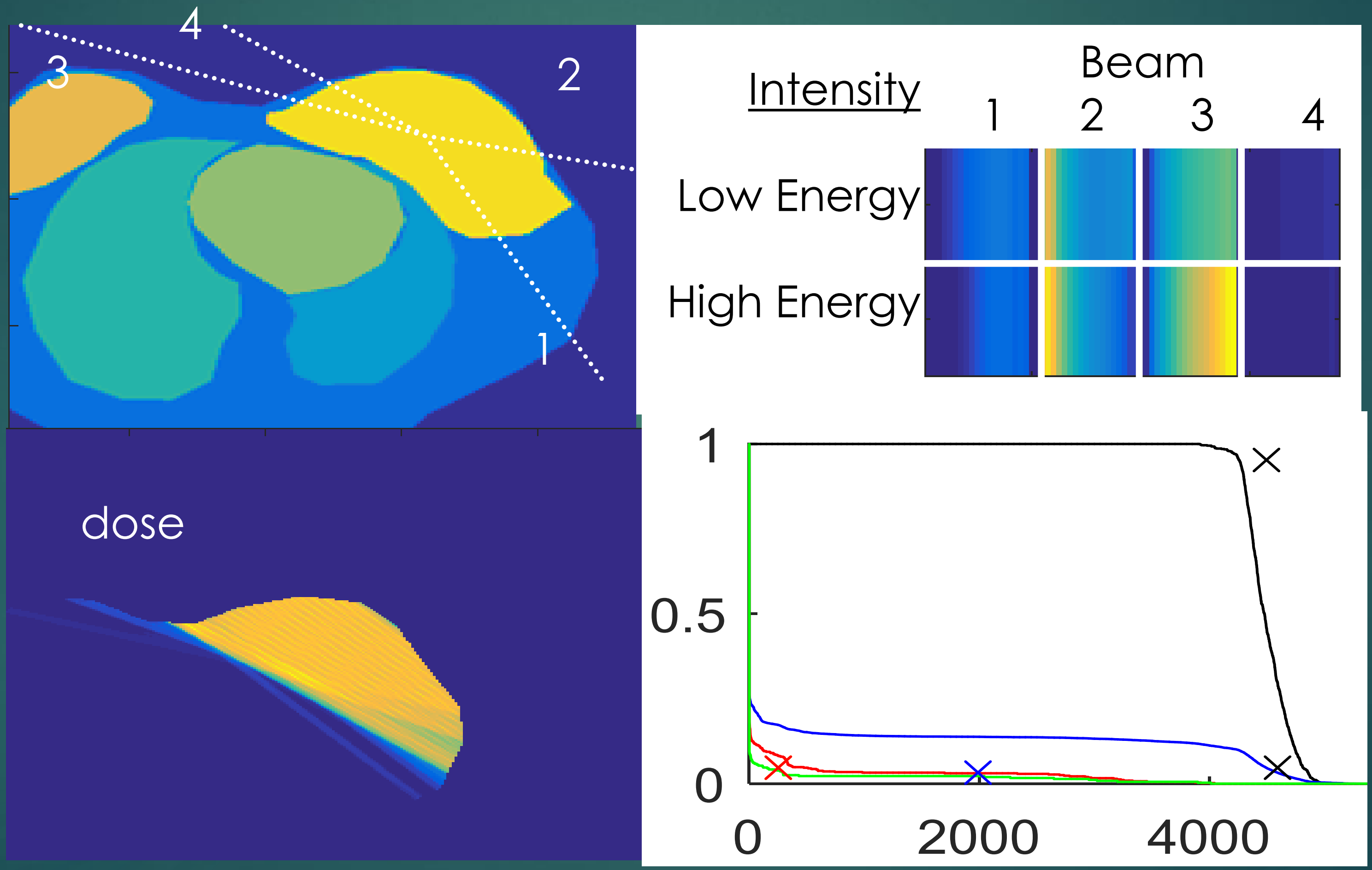
$$\min_{x} \|C \cdot x - d\|_2^2, \text{ where } x \geq 0.$$

Less sophisticated starting point, more complicated route to optimal intensity pattern

More sophisticated starting point, less complicated route to optimal intensity pattern



Initial Guess using Matlab's non-negative least squares(1)



EMRT treatment planning

One time calculation per machine

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- Randomly change the intensity of each beamlet

Iteration Step 1, Vary Energy Weight per angle

1. Calculate dose volume histograms, $DVHn(volume, dose)$, for each type of structures, n, on the current iterations' dose distribution

2. Calculate least squares (LSQ) on the dose volume histogram values of materials, n DVHn(volume, dose):

$$LSQ_o = \sum_{Structures,n} \left(\sum_{Constraints,i} k_i \cdot \left(DVHn(volume, dose)_{desired,i} - DVHn(volume, dose)_{actual}\right)^2 \right)$$

3. Find a percentage to change the relative weight of beam

$$\Delta w[\%] = random(0 \to 1)$$

Keep the same total intensity but exchange a certain percentage for low and high energy spectrums

4. For each angle/beam change the weighting of the low energy verses high energy

$$\boldsymbol{Intensity'_{low}} = \boldsymbol{Intensity_{o,low}} \cdot (\mathbf{1} - \Delta \boldsymbol{w})$$
$$\boldsymbol{Intensity'_{high}} = \boldsymbol{Intensity^{n}_{o,high}} \cdot (\mathbf{1} + \Delta \boldsymbol{w})$$

Evaluates the benefits of increasing the contribution of the **higher** energy spectra for the given beamlet.

5. Calculated dose from the new beam intensity distribution.

6. Calculate new dose volume histogram

7. Calculate new LSQ' for new distribution

8. If LSQ' <LSQ_o,keep new intensity distribution

--- *Repeat steps 1-8 but now multiply Δw by (-)1, effectively reversing the change in the weighting*

Evaluates the benefits of increasing the contribution of the **lower** energy spectra for the given beamlet.

Iteration Step 2, Vary Energy Weight per angle

1. Calculate dose volume histograms, $DVHn(volume, dose)$*, for each type of structures, n, on the current iterations' dose distribution*

2. Calculate least squares (LSQ) on the dose volume histogram values of materials, n DVHn(volume, dose):

$$LSQ_o = \sum_{Structures,n} \left(\sum_{Constraints,i} k_i \cdot \left(DVHn(volume, dose)_{desired,i} - DVHn(volume, dose)_{actual} \right)^2 \right)$$

3. Find a percentage to change the relative weight of beam

$$\Delta w[\%] = random(0 \rightarrow 1)$$

4. For each a given angle/energy change the Intensity:weighting of the low energy verses high energy

$$Intensity'_{low\ or\ high} = Intensity_{o,} \cdot (1 - \Delta w)$$

Changes the total intensity of the beam at that angle, regardless of which energy is being used

5. Calculated dose from the new beam intensity distribution.

6. Calculate new dose volume histogram

7. Calculate new LSQ' *for new distribution*

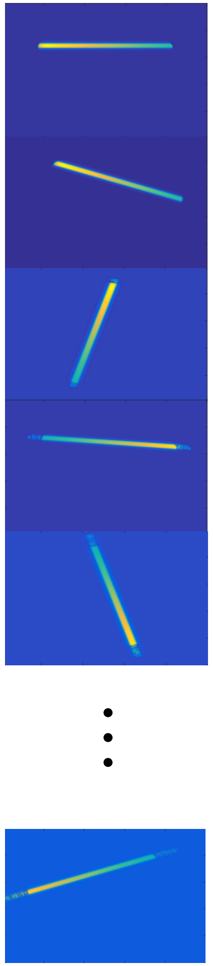
8. If $LSQ' < LSQ_o$*,keep new intensity distribution*

--- Repeat steps 1-8 but now multiply Δw *by (-)1, effectively reversing the change in the weighting*

GOAL: Find intensity distribution, I[hv,n], to meet dose constraints

Dose calculation per beam

Photon spectrum 1



× $I(hv_1)_1$

× $I(hv_1)_2$

× $I(hv_1)_3$

× $I(hv_1)_4$

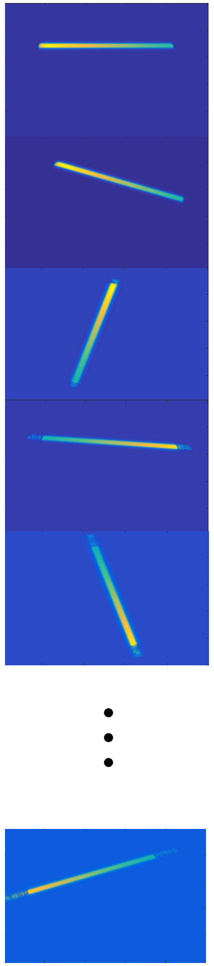
× $I(hv_1)_5$

⋮

× $I(hv_1)_n$

+

Photon spectrum 2



× $I(hv_2)_1$

× $I(hv_2)_2$

× $I(hv_2)_3$

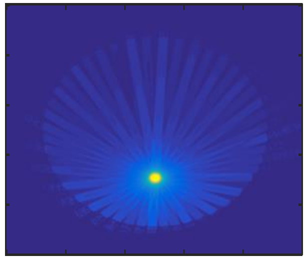
× $I(hv_2)_4$

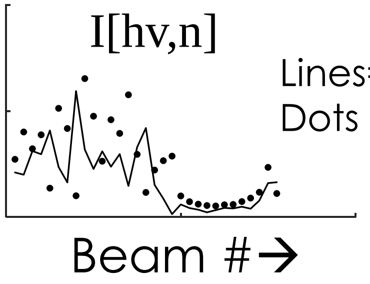
× $I(hv_2)_5$

⋮

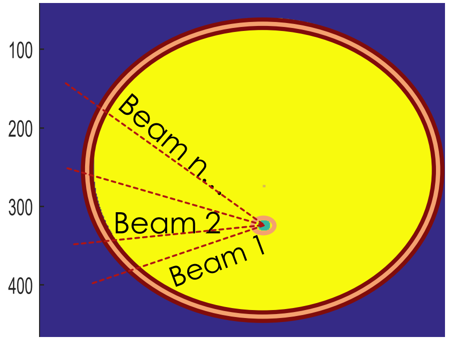
× $I(hv_2)_n$

=

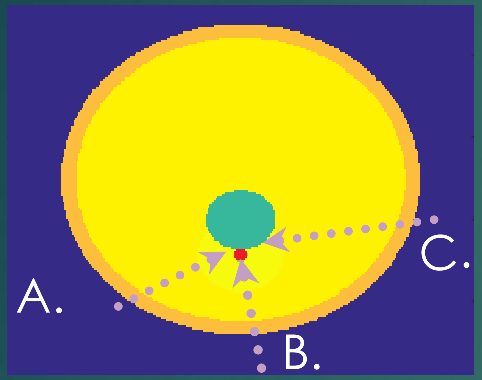




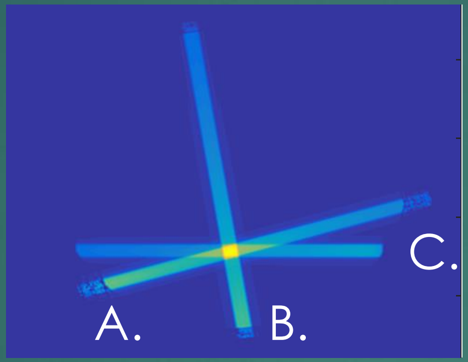
Lines=6MV
Dots = 400keV



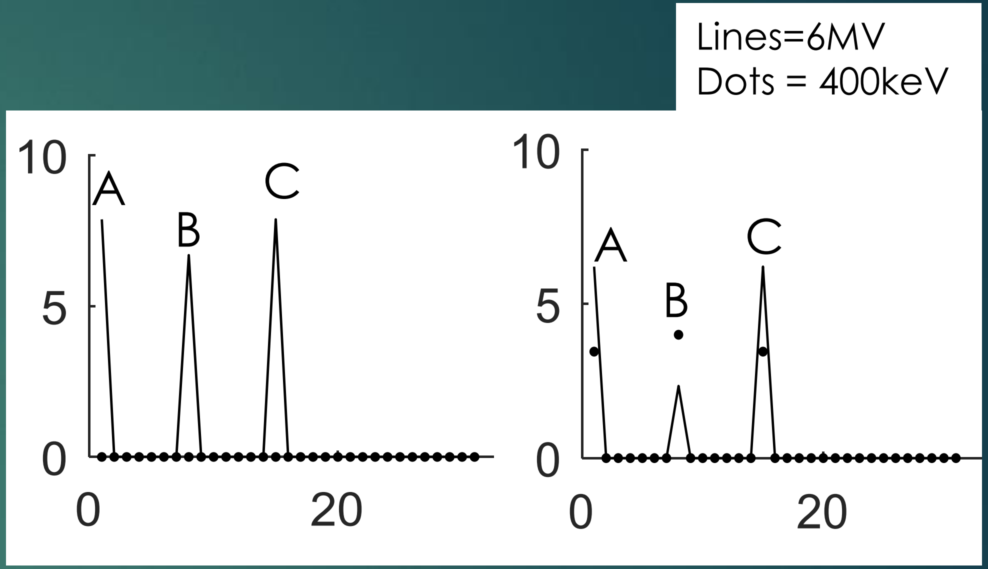
Simple multi-energy plan(1)



Step 1: calc dose per angle for each energy

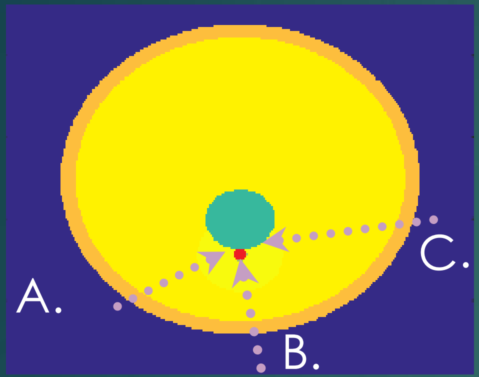


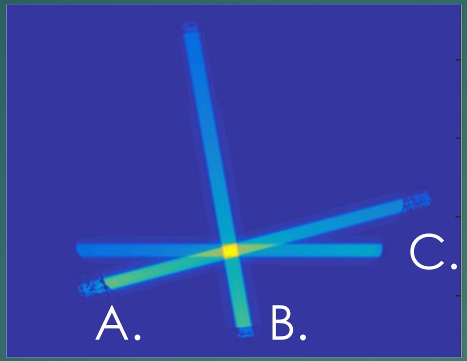
- Red, 8mm diameter target
- Green, avoidance structure
- Orange, 5mm skin surface contour
- Yellow, other tissue

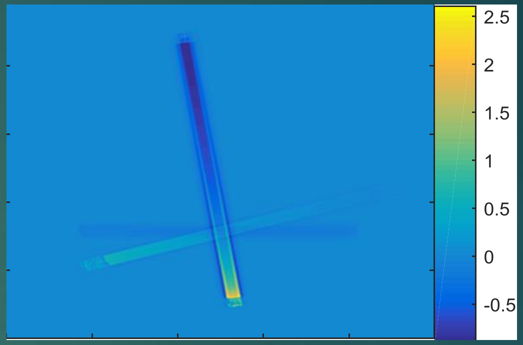


- Depth of target for beams B and C are equal
- Depth of target for A is shallower
- Hence to give equal contribution for each field, require more intensity from the laterals
- Send to inverse optimizer to find the most ideal intensity for each beam

Simple multi-energy plan(2)







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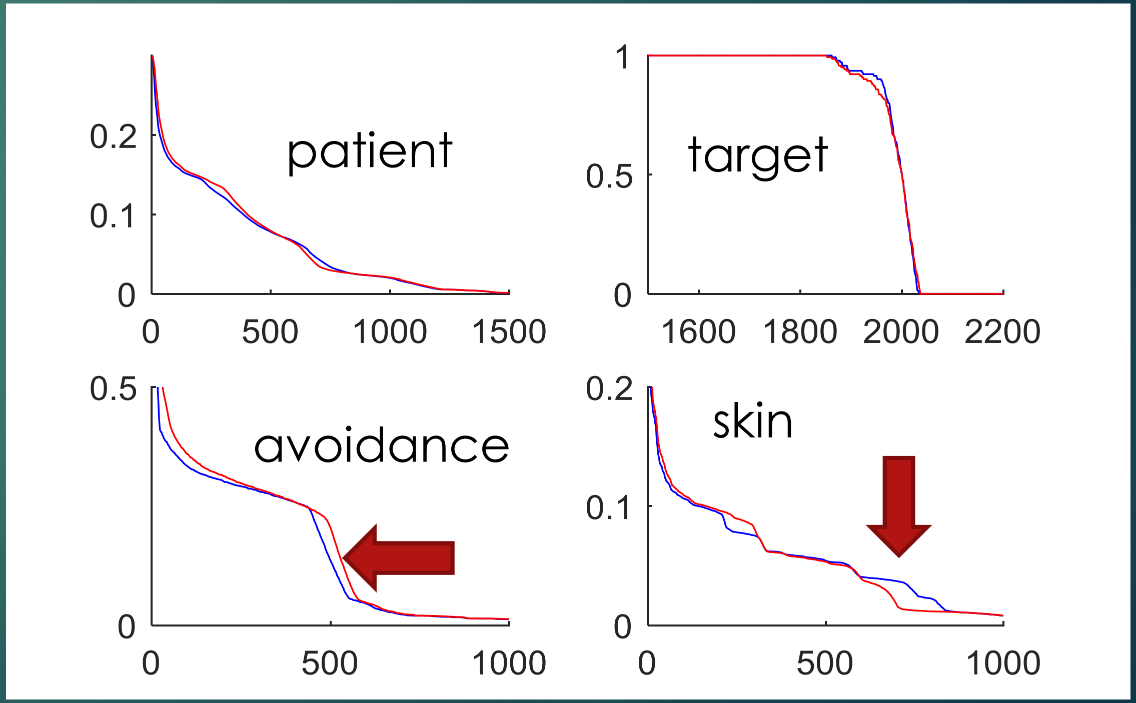
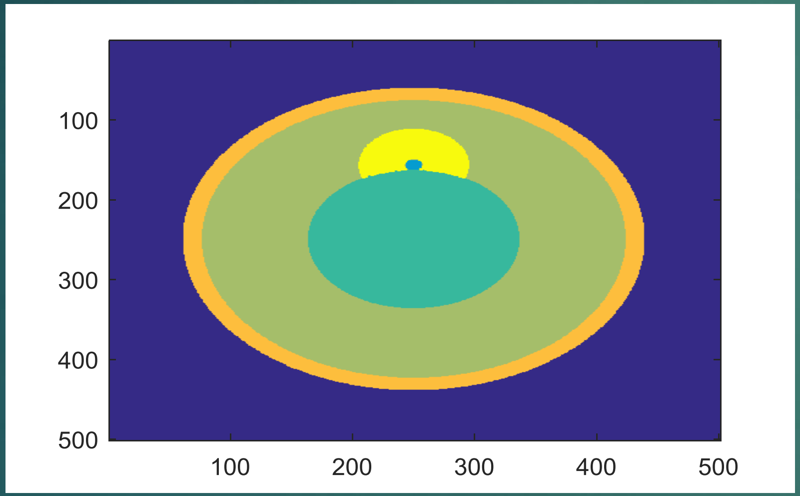
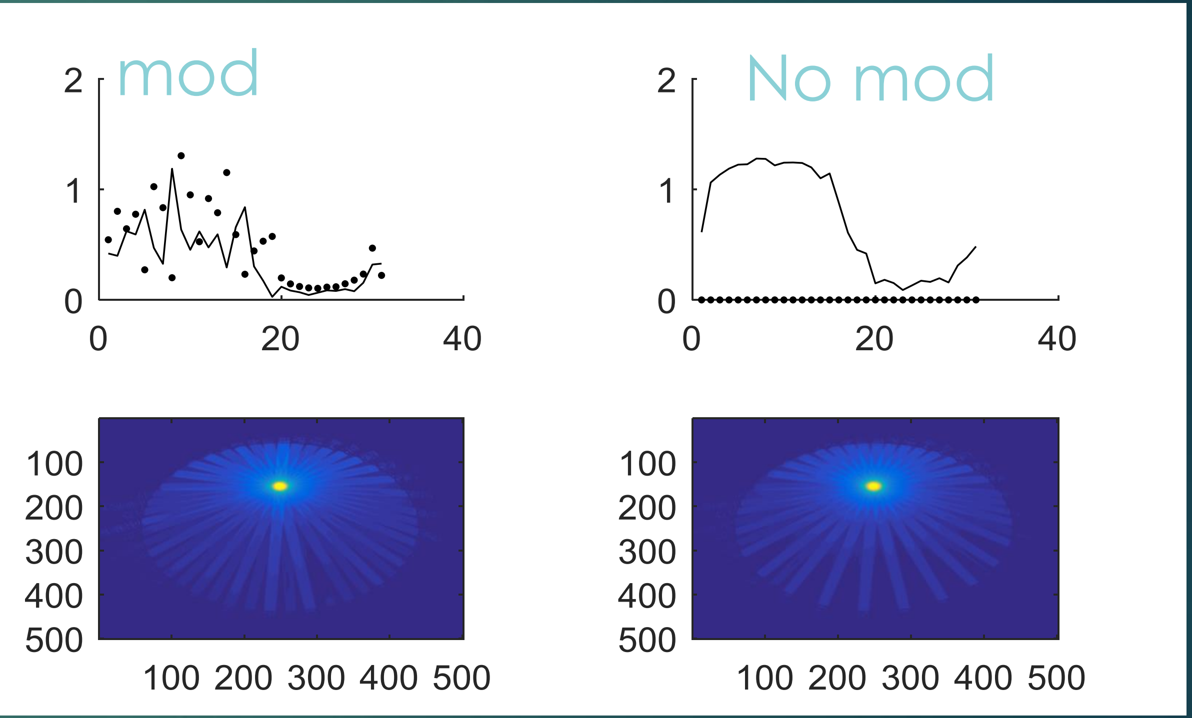


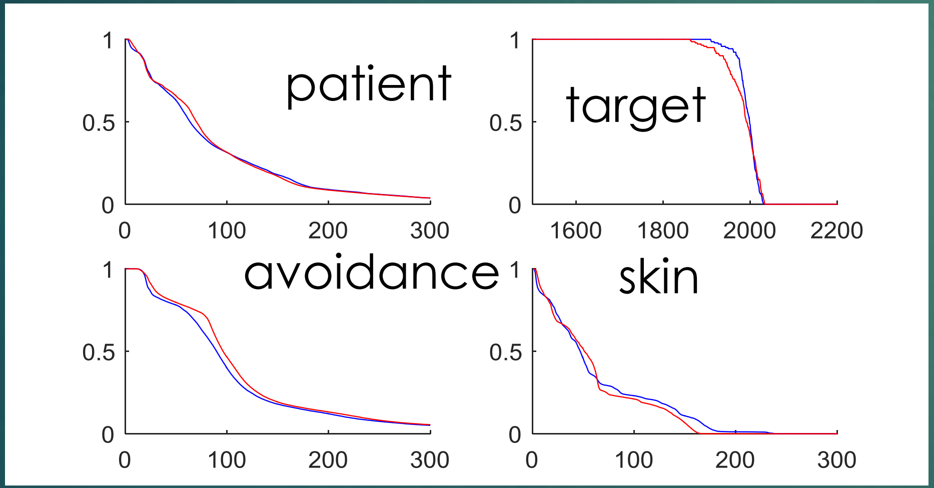
- Depth of target for beams B and C are equal
- Depth of target for A is shallower
- Send to inverse optimizer to find the most ideal intensity for each beam

Example 1

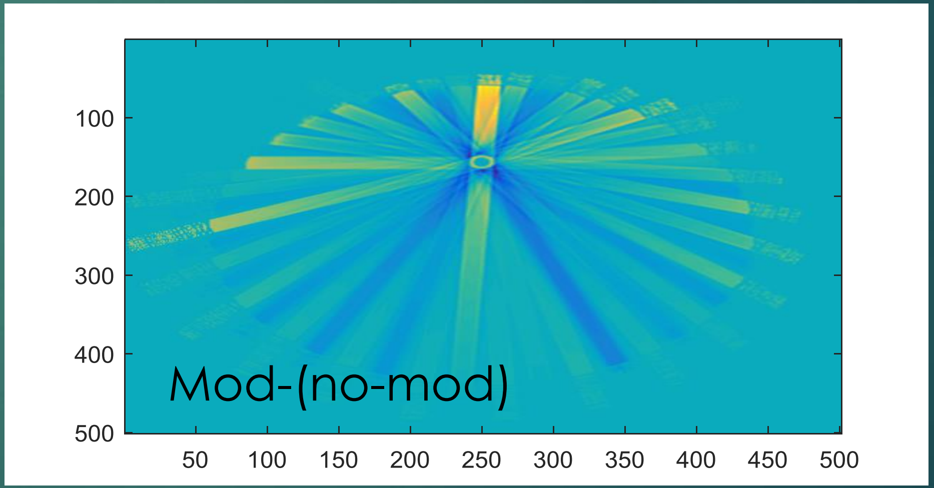
Lines=6MV
Dots = 400keV





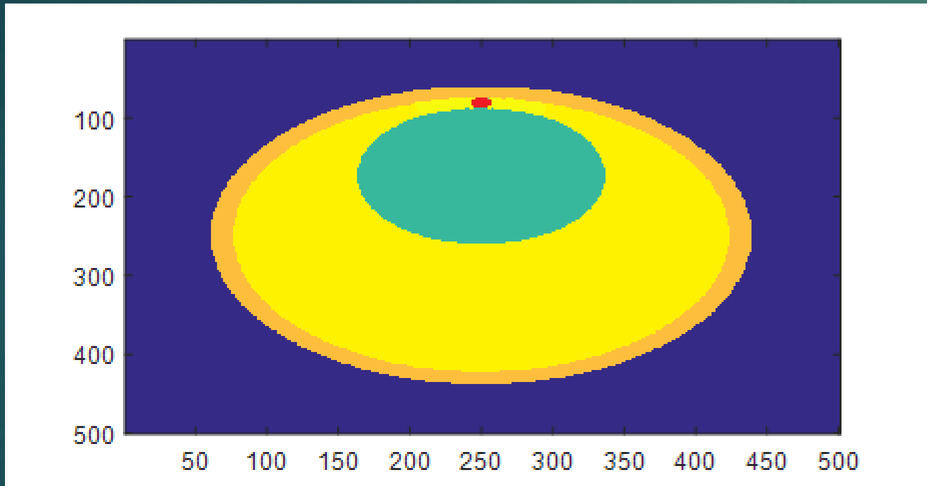


patient
target
avoidance
skin
1
0.5
0
100
200
300
1600
1800
2000
2200

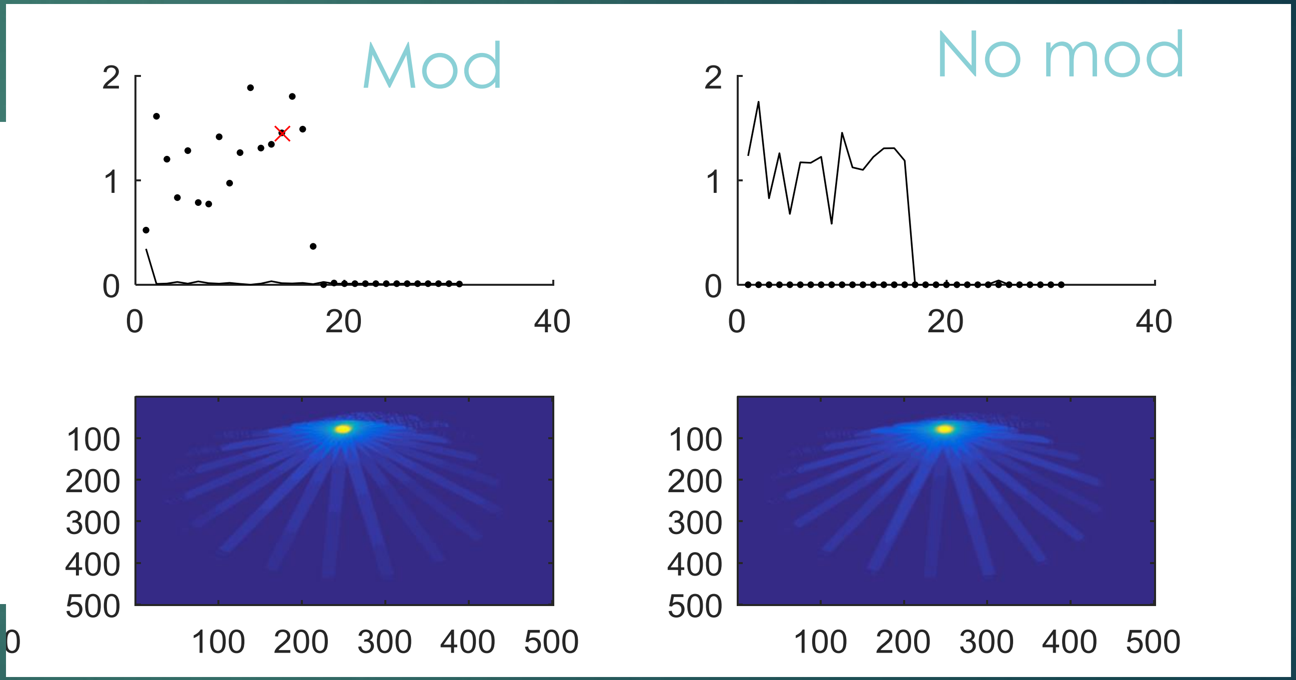


Mod-(no-mod)
100
200
300
400
500
50
150
250
350
450

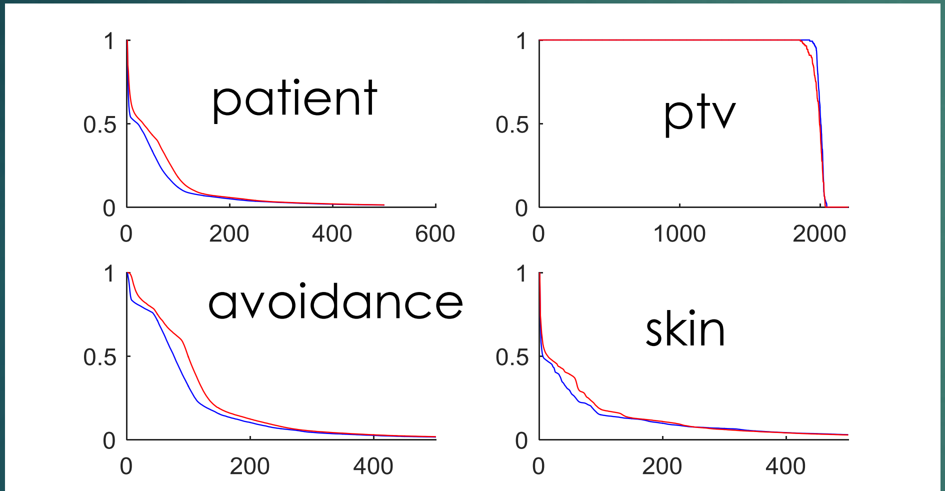
Example2

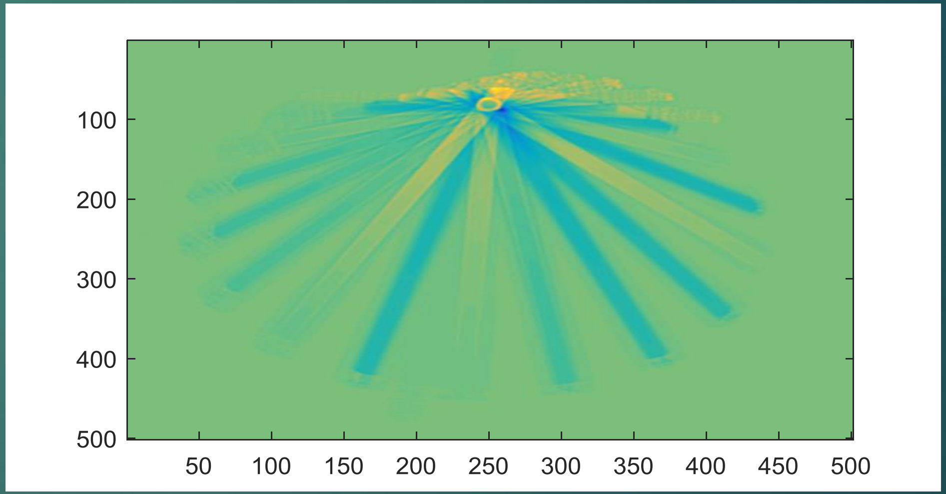


100
200
300
400
500
50
100
150
200
250
300
350
400
450
500



Mod
No mod
2
1
0
0
20
40
100
200
300
400
500





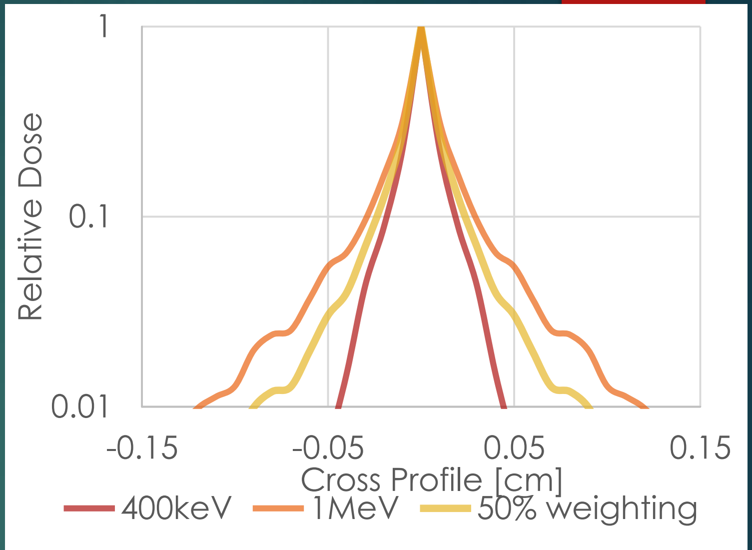
- Blue mod
- Red no mod

Lessons learned thus far…

- 400keV is used more than 6MV when target is close to the surface
- Some of the changes are not yet significant, reasons:
  - Insufficient resolution
  - Geometry is too perfect, no opportunity to really demonstrate capabilities to vary penetration
- We really see the impact of the use of energy modulation to create really small treatment fields

Future work

- Optimize with minimum field width, need more resolution with dose calculation, i.e. submillimeter voxels
- Seeking a planning system to commission with a lower energy spectrum
- Need to consider the device to deliver the radiation, this device should be practical to implement in a clinical setting



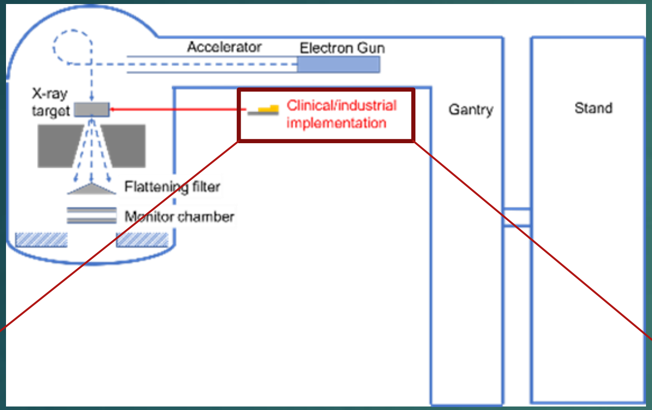
Need rigorous 3D planning tools that are common to all planning systems

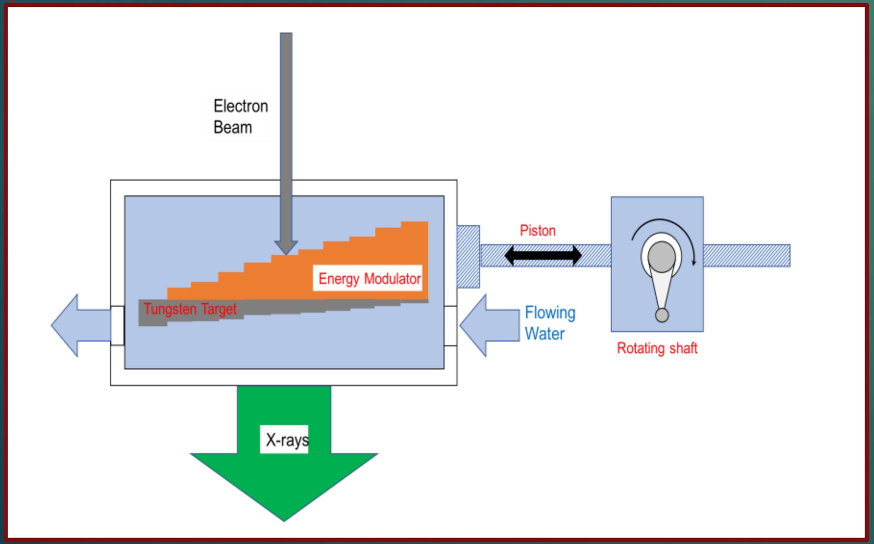
IMRT
Very common, standard of care

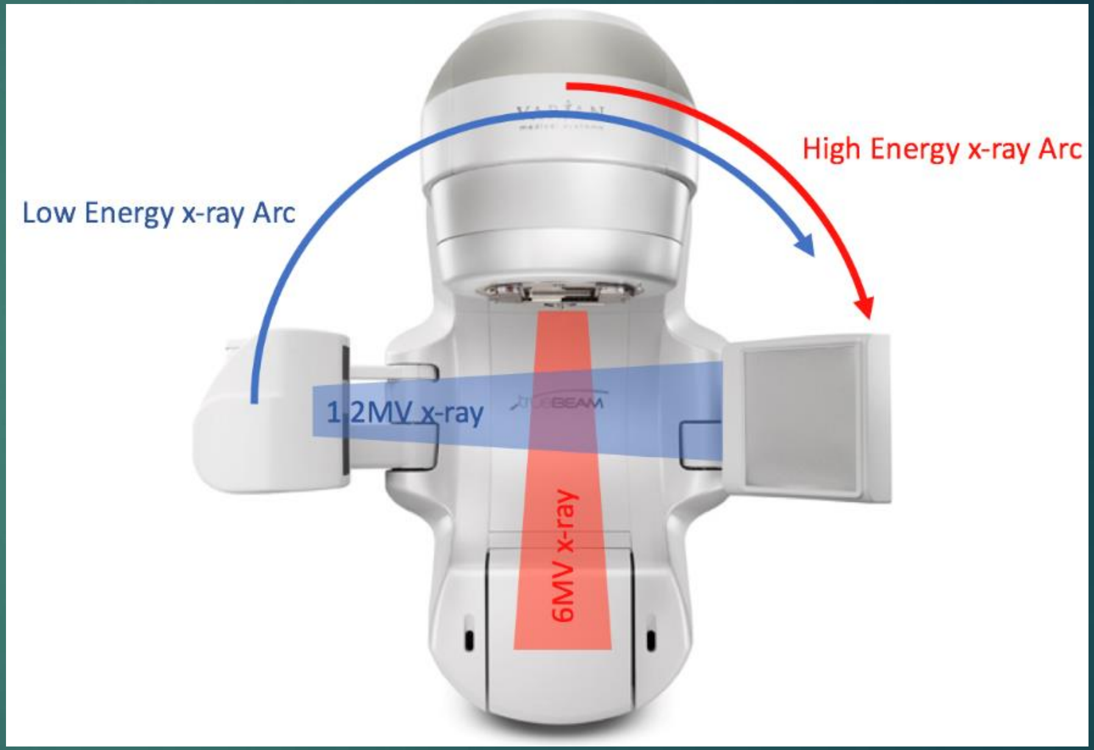
SRS/SBRT
Common

May soon be possible

Energy Modulated Arc Therapy







Unraveling a thread…

- Started pulling the thread on how we could make microbeam practical
- We found that the current devices treatment devices do not have characteristics to reproduce some other experiments
- Ideally we would need a new high intensity radiation source with lower energy capabilities
-
- First collaboration with UNM Computer Science that is building basic radiotherapy research tools.
- We want to consider solutions that are—in the end practical—and can be implemented in conventional clinics
- Then also, build upon historical strategies that are known to be successful

Thank you

COMPUTER SCIENCE

UNM COMPREHENSIVE CANCER CENTER