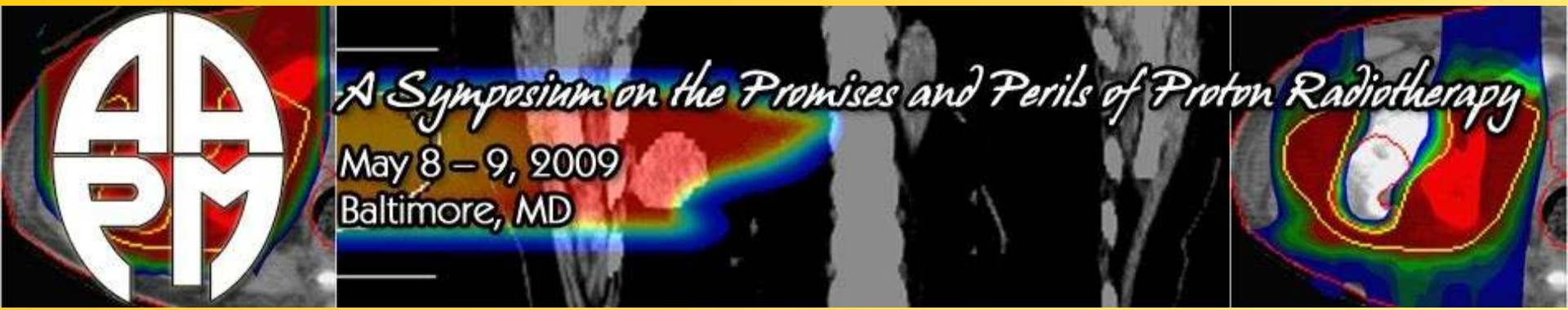


Promises and Perils of Proton Therapy

Beam Delivery (Implications)

or *Towards 'Cost Effective' Particle Therapy*

Jay Flanz

MGH/FBTC

Harvard Medical School

What is a Beam Delivery?

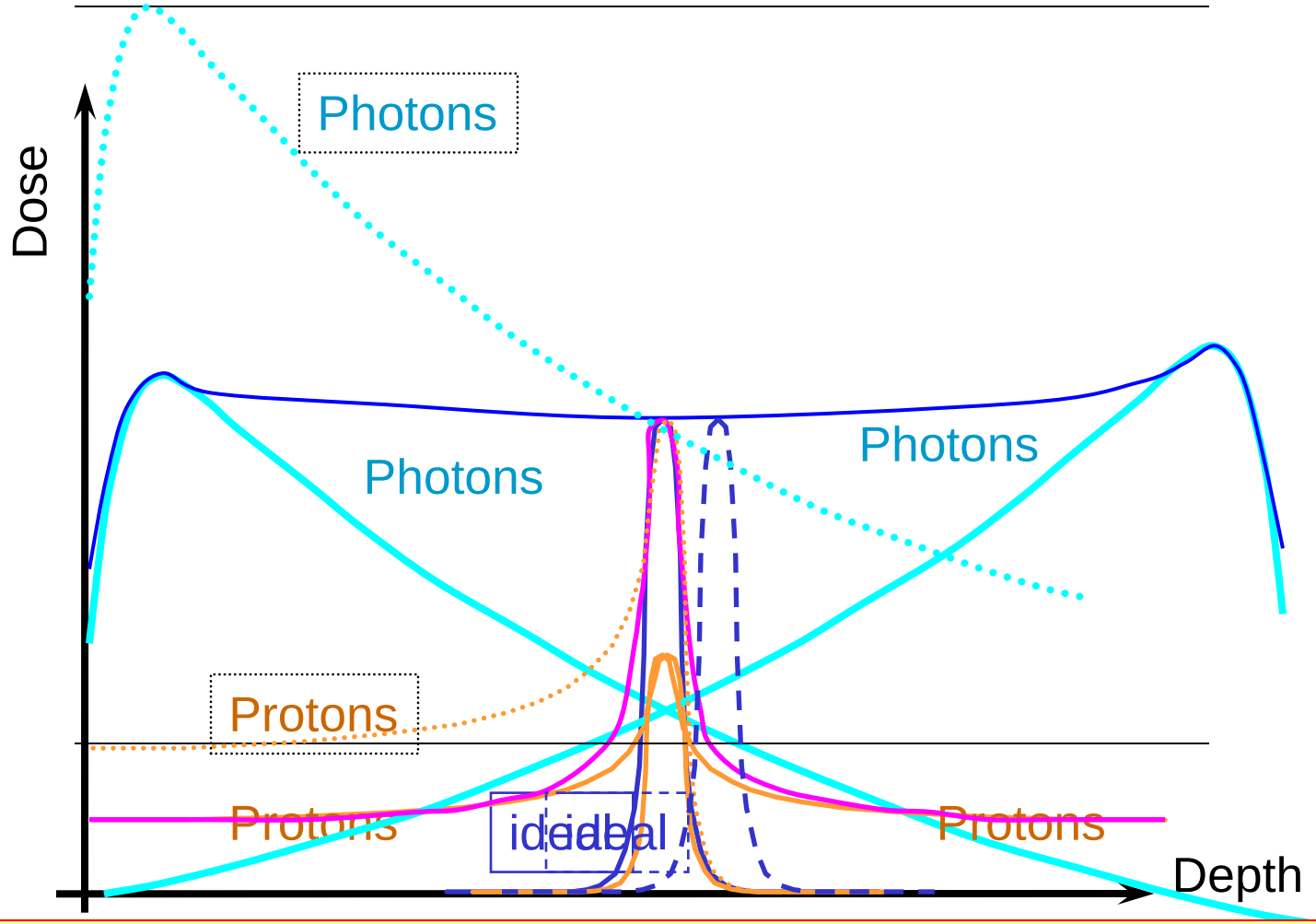
- Start with an *accelerator beam*.
- Convert the *raw* accelerator beam to a *clinical treatment beam*.
  - What are the parameters needed for a clinical beam?
    - **Spread out the beam (5d)** on the target according to prescription (Conformal)
    - Deliver the prescribed **dose** **in each of the 5 dimensions**
  - What are the associated accelerator beam parameters?
    - See Below, but not Usually discussed: Beam timing, Emittance
  - Direct the treatment beam to the Target in **desired orientation** (part of 5d)

These are connected!

- Monitor the parameters of the treatment beam.

Accelerator Beam	Treatment Beam
○ Beam Energy	○ Beam Range
○ Beam Size	○ Dose Distribution
○ Beam Shape	○ Dose Distribution
○ Beam Current	○ Dose Rate
○ Beam Timing	○ Many effects

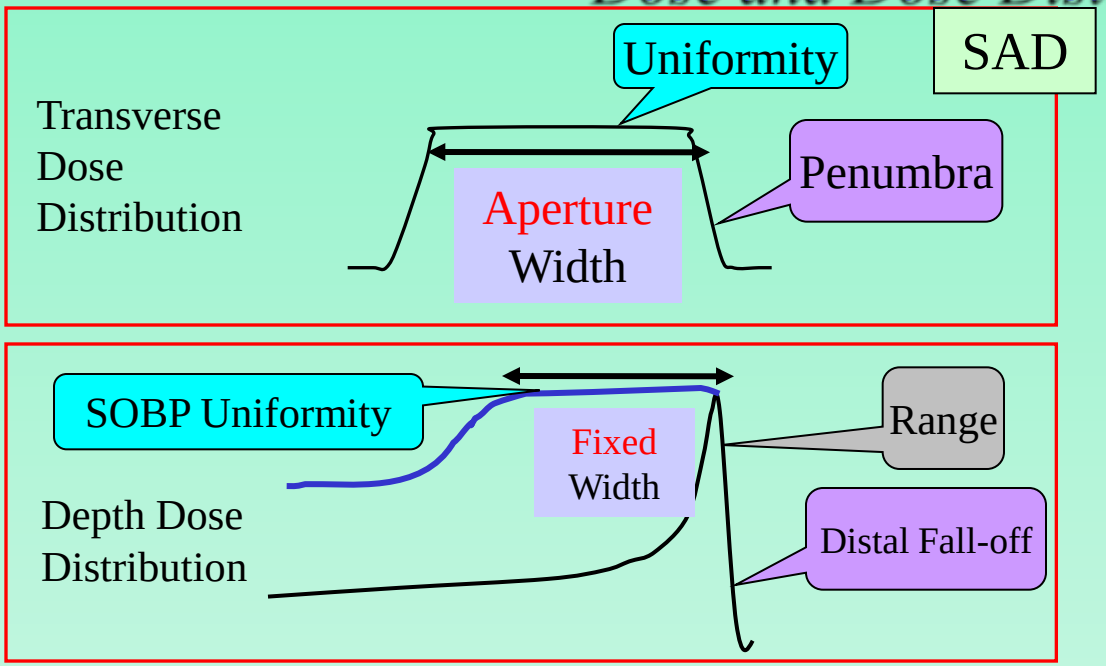
The Ideal Depth Dose Distribution



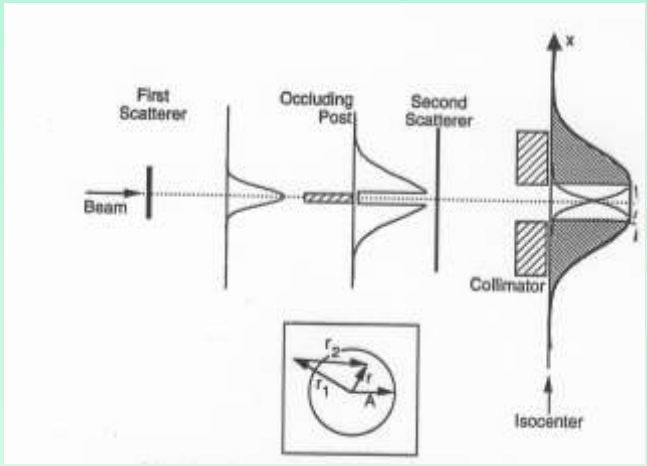
Beam for Beam you can always do a better job with Particles (except at the Surface).

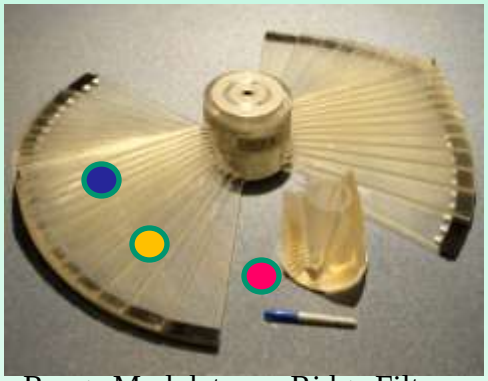
What is Scattering? Proton Beam Parameters

Dose and Dose Distribution



- Tranverse
  - Scatterers
  - Single Scattering
  - Double Scattering
- Longitudinal
  - Range Modulator
  - Ridge Filter





Range Modulator or Ridge Filter

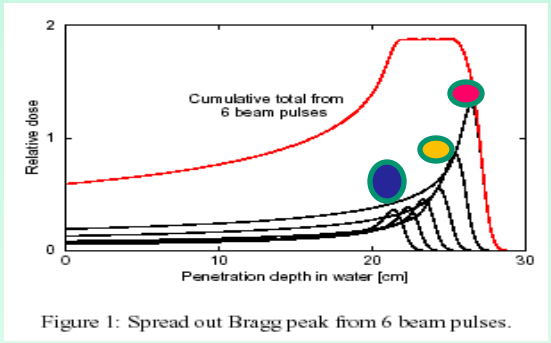


Figure 1: Spread out Bragg peak from 6 beam pulses.

Errors for the most part average out, or are easily detectable.

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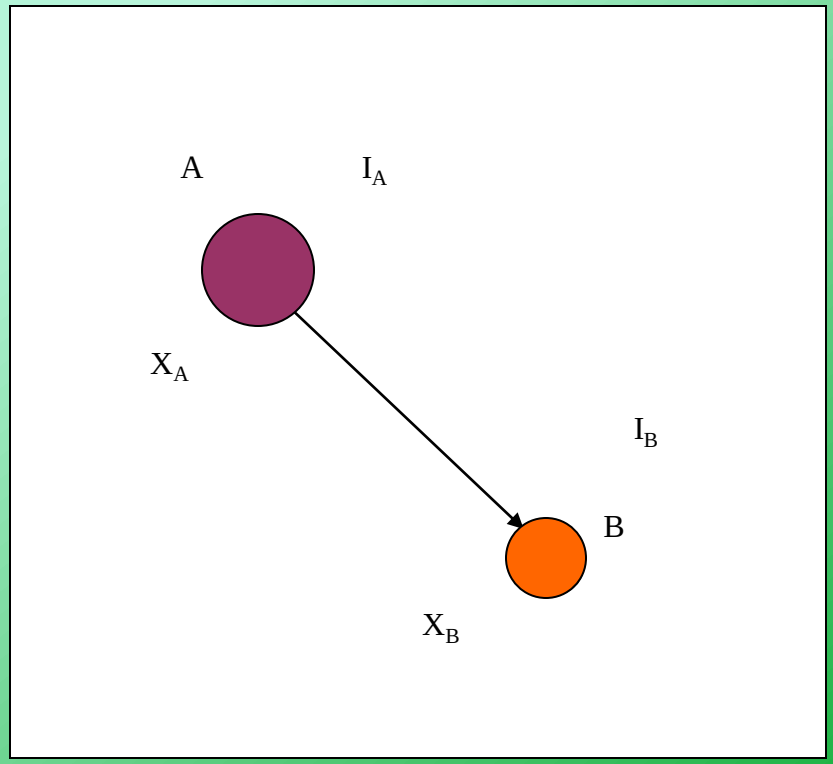
General Description of Scanning

General Description of Scanning: Pictorially, figure 1 describes the scanning process.

A beam at position A, at coordinate $\mathbf{X_A}$, is characterized by its current $\mathbf{I_A}$ and it's beam size $\boldsymbol{\sigma_A}$. The beam deposits a dose $\mathbf{D_A}$ at location A. After that dose is deposited at location A, taking a time $\mathbf{t_A}$, the beam is moved to location B. The time it takes to move from location A to location B is $\mathbf{t_{AB}}$. The beam current during that movement is $\mathbf{I_{AB}}$. The velocity that the beam moves from position A to B is $\mathbf{v_{AB} = (x_B - x_A)/t_{AB}}$, and the current change between A and B is $\mathbf{dI/dt = (I_B - I_A)/t_{AB}}$. In this way we have defined all the terms that are necessary in the delivery of beam scanning.

- 1978-9: Spot Scanning at NIRS - 30 Patients
  - Range Modulator (Fast) + Lateral 2d Spot
- 1992 ish: B&W Scanning at BNL
- mid 1990's: Spot Scanning at PSI
- mid 1990's: Scanning at GSI
- 2008: Scanning at MDA (with Hitachi)
- 2008: Scanning at MGH (with IBA)



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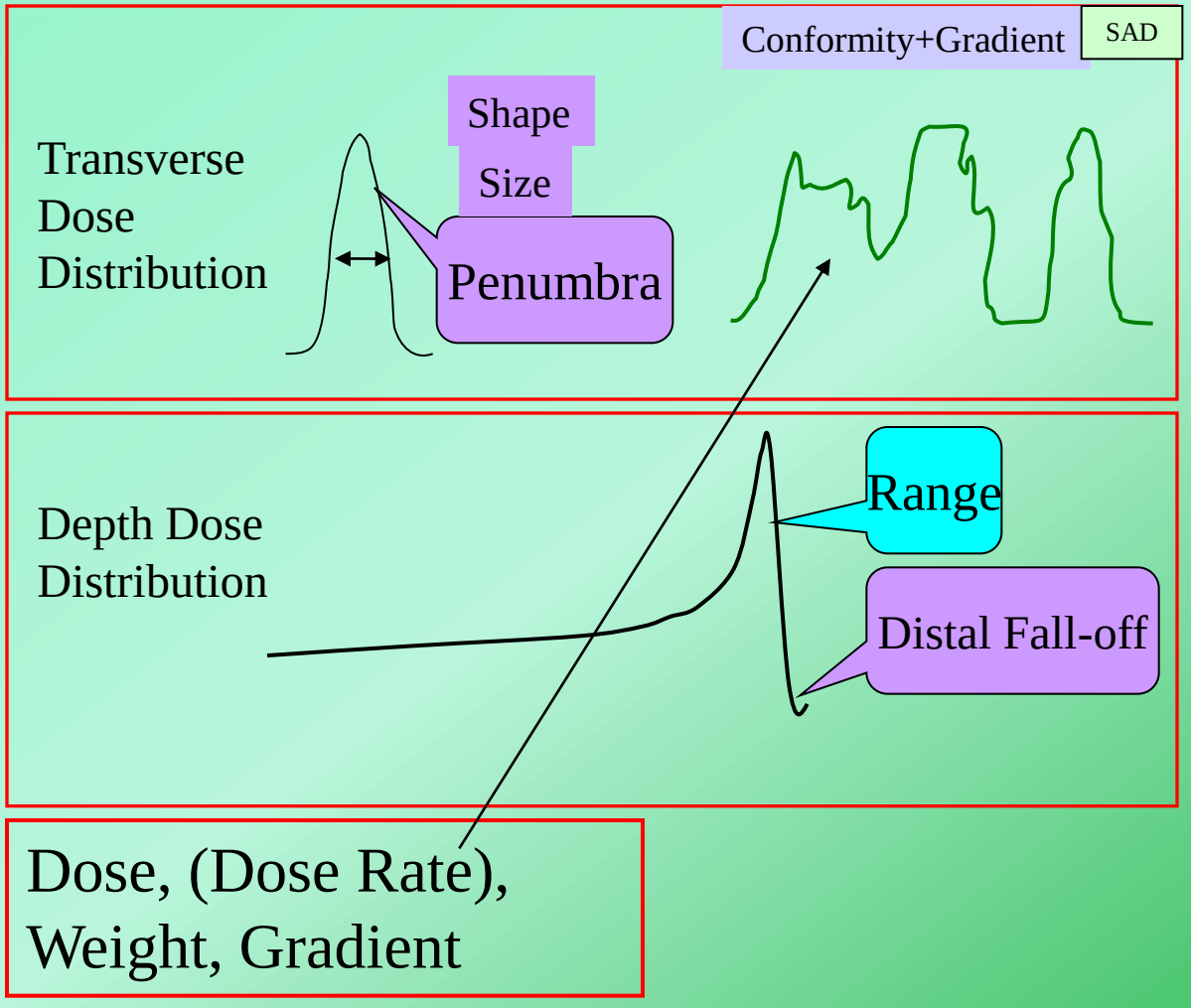
Scanning Proton Beam Parameters
Dose and Dose Distribution



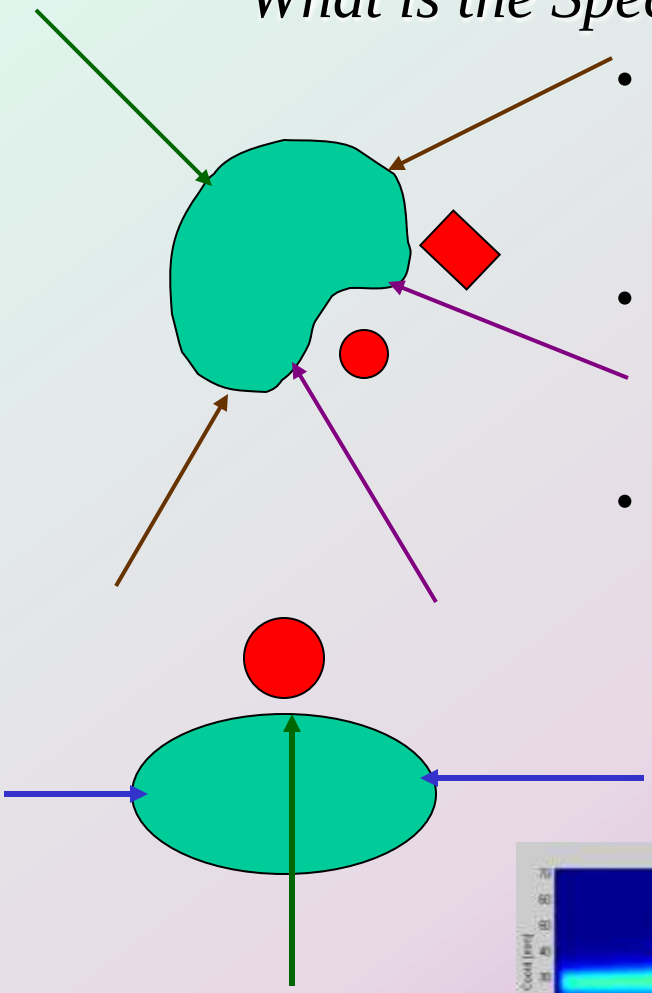
- Generalized Scanning
- Uniform Scanning
- Wobbling

Errors are less 'intuitive' and may not average out. (Harder to measure?) Need a basis for estimating the effects of errors and tolerances !

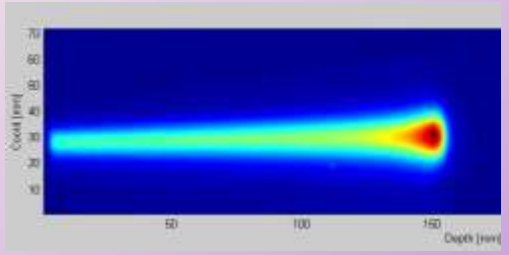
Scanning Beam Parameters:

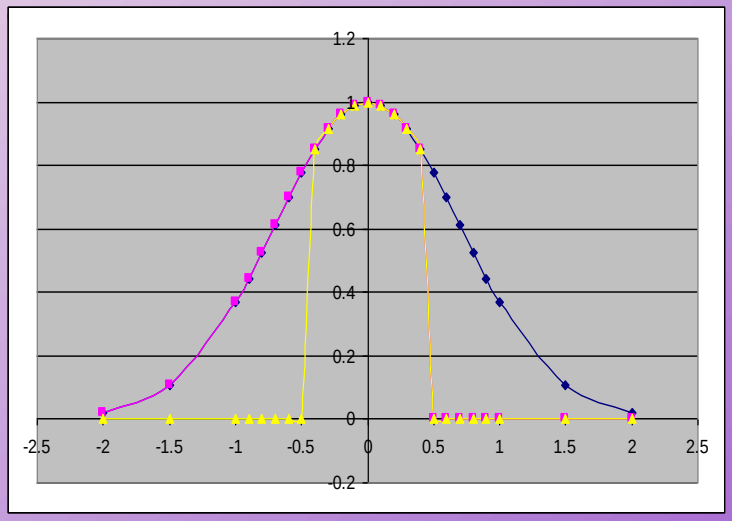
What is the Spec? Beam Sigma or Beam Edge

One of them.



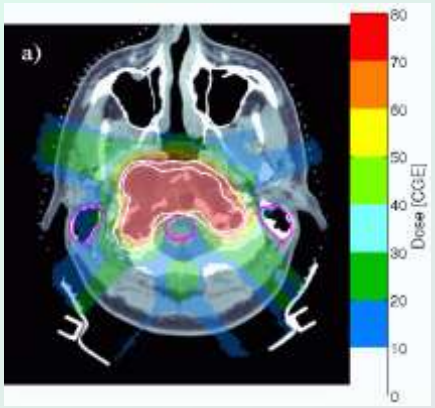
- When is a smaller beam size needed ???
  - when absolutely necessary to pass BETWEEN two critical structures on Surface. (What is the percentage of these cases?) Then one needs small*er* sigma.
- Use Is a Sharp edge needed??
  - To minimize penumbra on Surface. For cases of penetration less than 5cm (MCS).
- How to achieve sharp edge?
  - Small sigma
  - Use the Distal Edge
  - Modified MLC
  - ANOTHER WAY





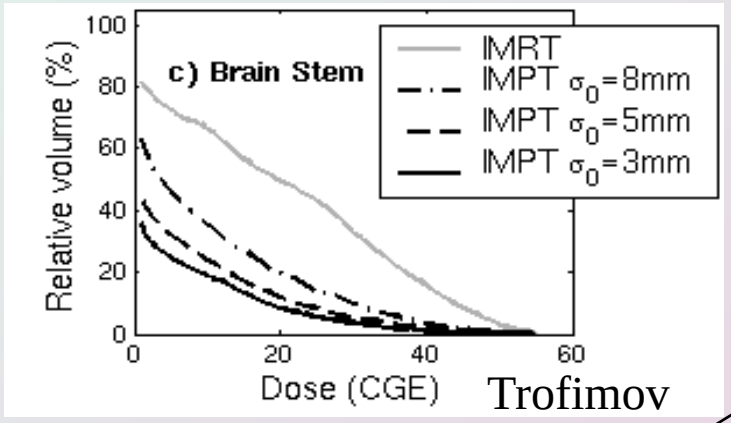
Tolerance:10% variation in sigma --> 2% VARIATION IN DOSE !

Beam Sigma or Penumbra ?



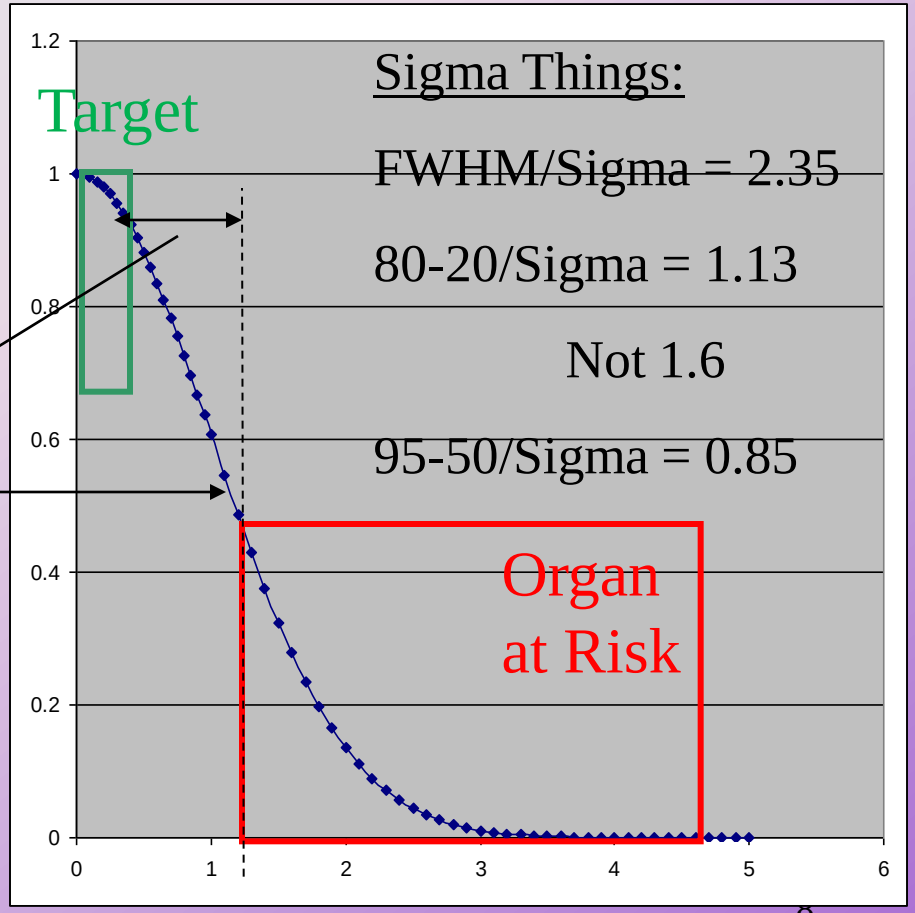
$$y = e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2}$$

Assume: Dose to Target within +/- 2.5% and Organ at Risk < 50%

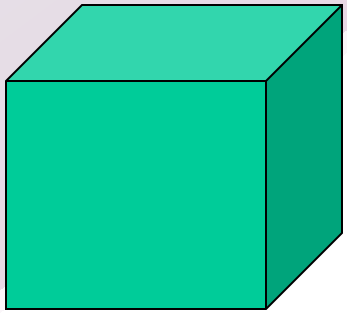


Trofimov

Therefore, if we have a 5mm spacing, we need a sigma of 6mm (FWHM=12mm)

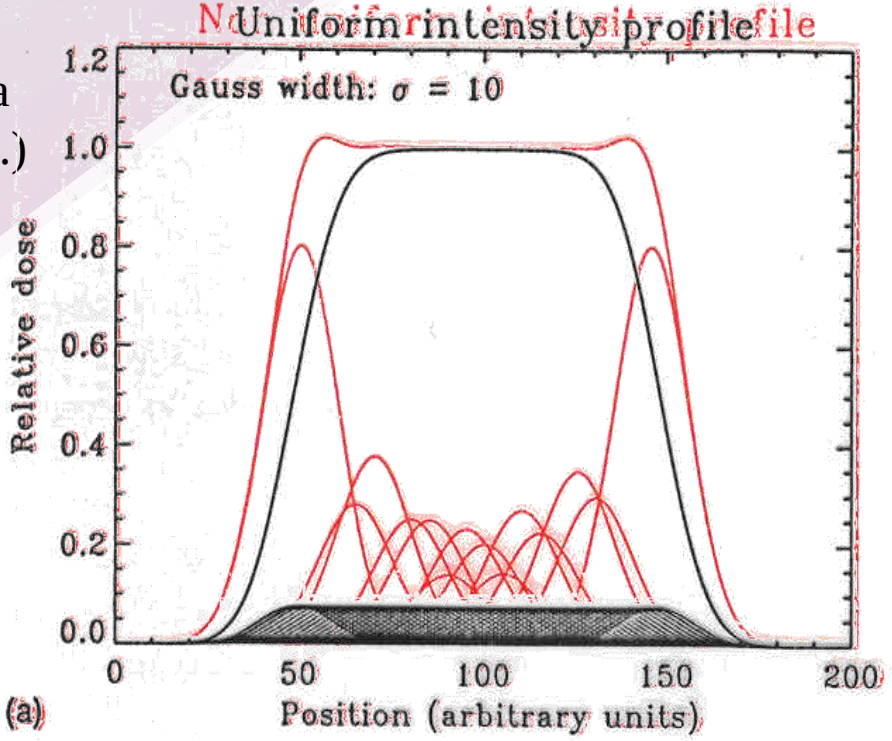


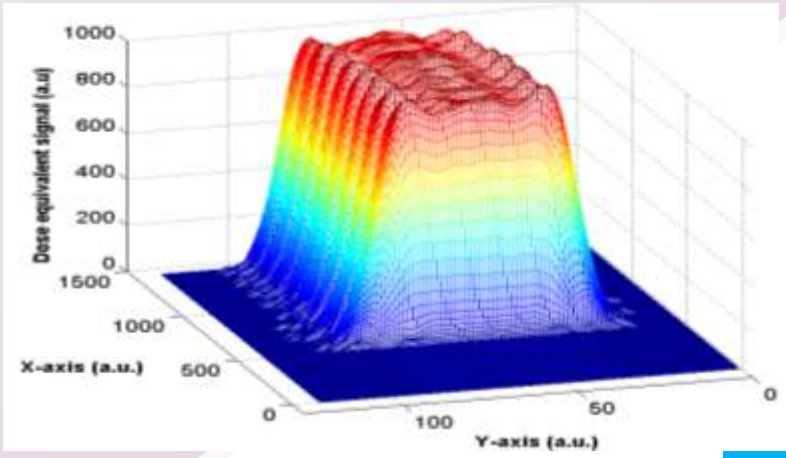
Penumbra Optimization



- Cube of $12_{(50\%)}$x$12_{(50\%)}$ x10 cm
- Planned with ASTROID
  - Penumbra Optimization (ala PSI/Berkeley)
  - This results in a balance between penumbra and overall uniformity. (There will be ears.)
  - TPS provides the map which must be compared with the measurement

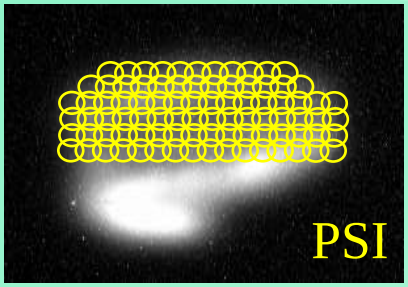
Pedroni et. al.



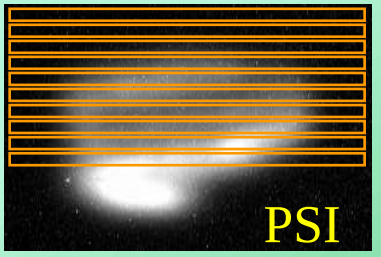


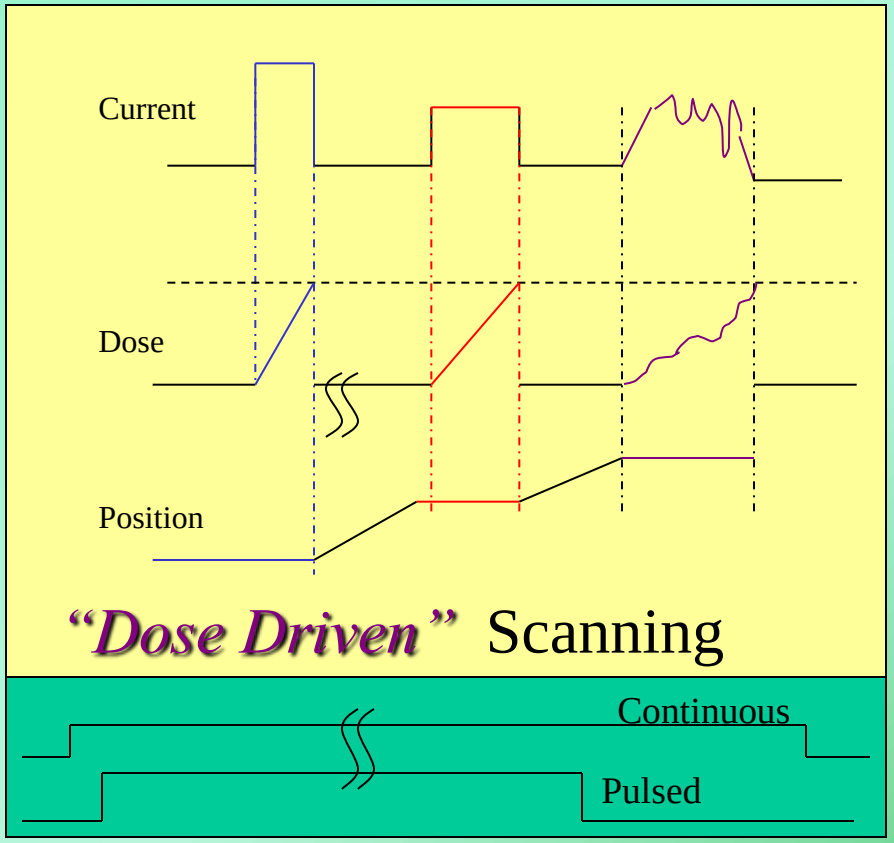
Therefore "Fluence Modulation" is required for optimized Uniform Dose !

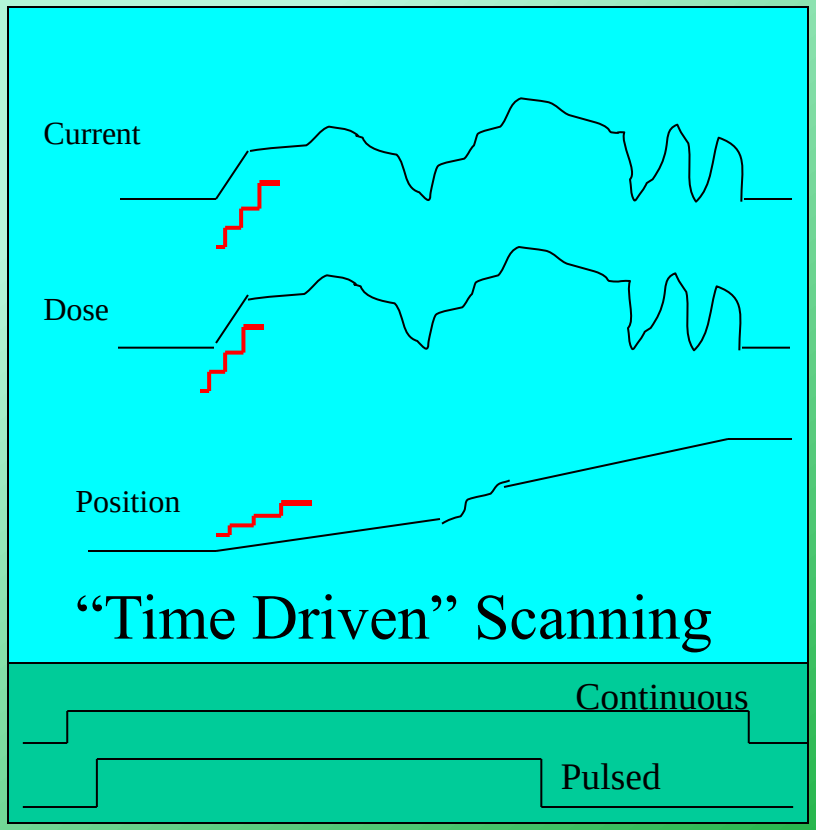
Time Structure in Pencil Beam Scanning



- Dose Drive "Spot"
- Time Driven "Spot" with time increments dt
- -- $\text{Lim}_{(dt \text{ --> } 0)}$ of ***time driven mini-spot*** = continuous





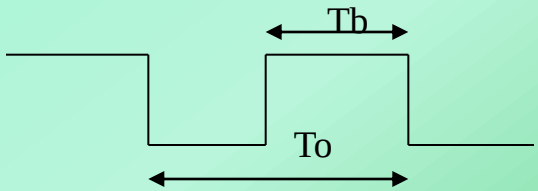


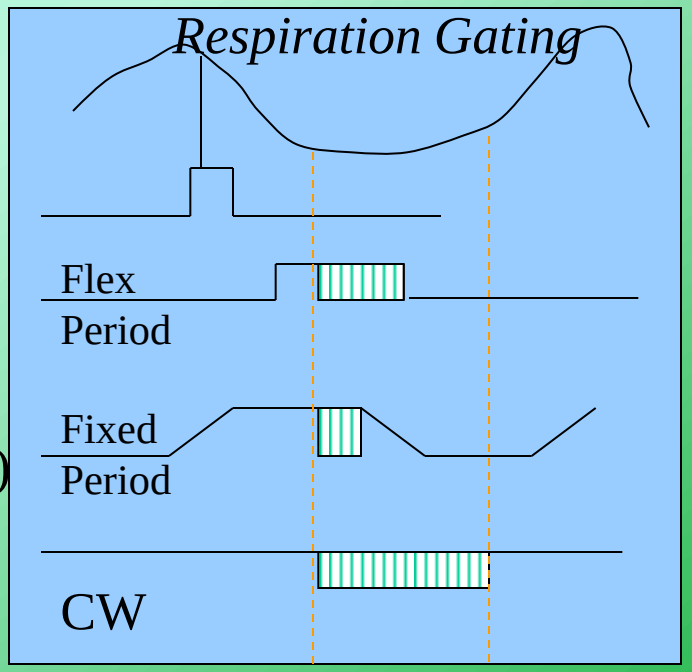
Continuous Stable/Unstable. Pulsed Short or Long

More on Time; Never enough Time?

- What if the beam is continuous?
  - No change from previous slide
- What if the beam is pulsed?
  - Example: 6cm x 6cm x 6cm = 0.21 liters
  - Example: 8cm x 8cm x 8cm = 0.5 liters
  - Beam Size 3.3mm
  - Bragg peak width 3.3mm
  - Assume Dose Driven Spot Scanning
  - #Spots = 6000, 14250
  - @ 30 pps → 200 seconds = 3.3 minutes (Once)
  - @ 30 pps → 500 seconds = 8 minutes (Once)

This ASSUMES VOXEL by VOXEL Painting!!



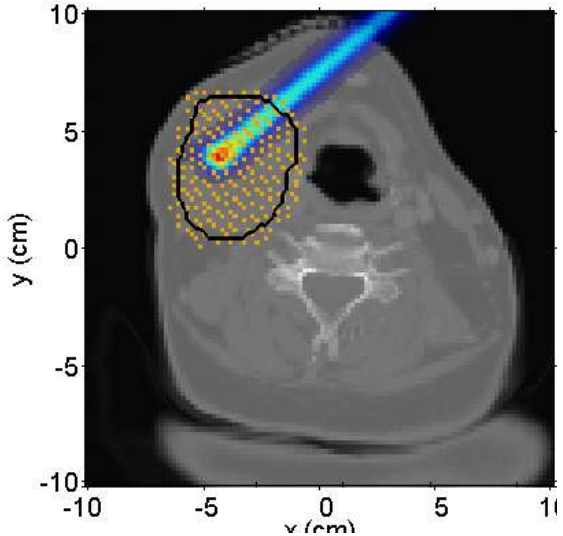


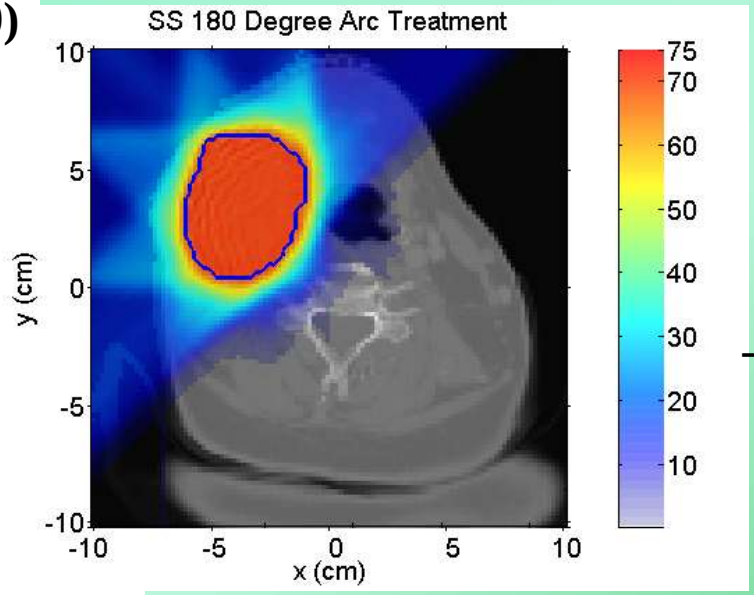
RadioBiology Time Effects? (sec, nsec, psec)

e.g. Scanning with E then x, or x then E, Short pulses vs. Rf structure

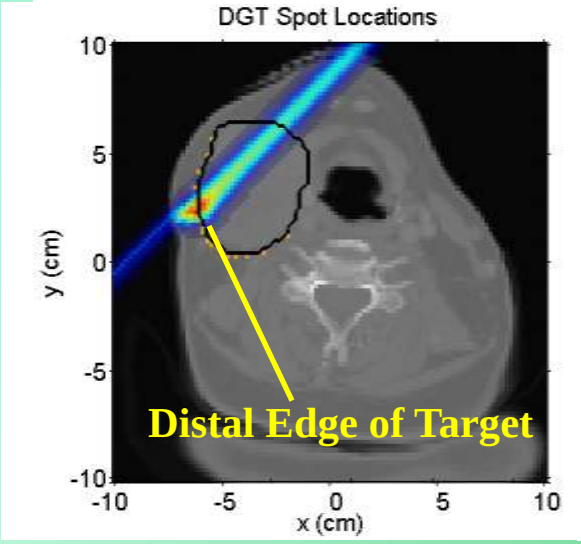
Methods of Dose Driven Scanning: DSS and DET

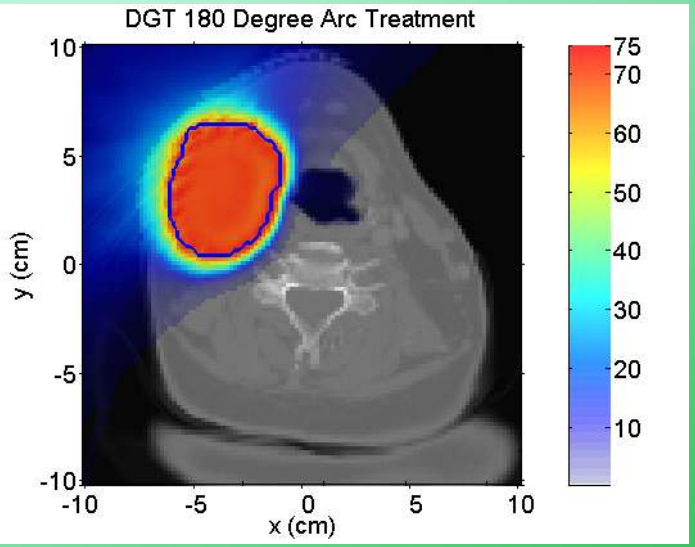
SS Spot Locations (~300)





DET Spot Locations (~20)





- **For DET multiple directions or arc therapy and intensity modulation required to obtain uniform dose distributions.** *(End of Range very important)*

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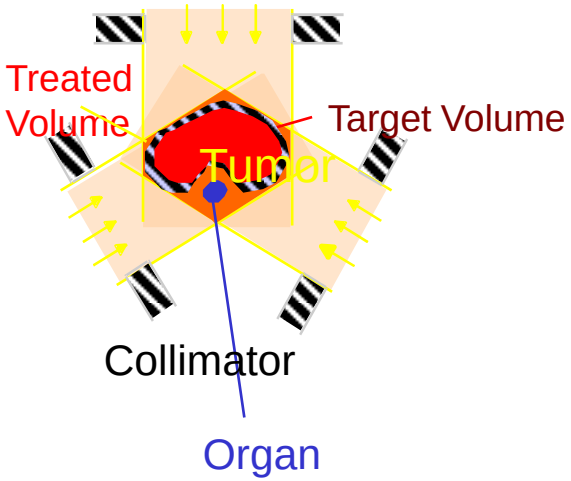
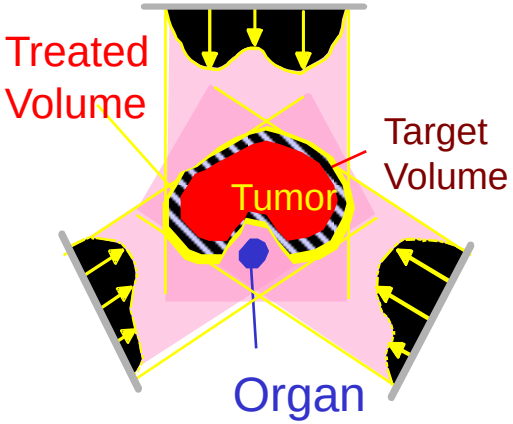
Mackey

Evolution of Conformation

"Classical" Conformation



Intensity Modulation

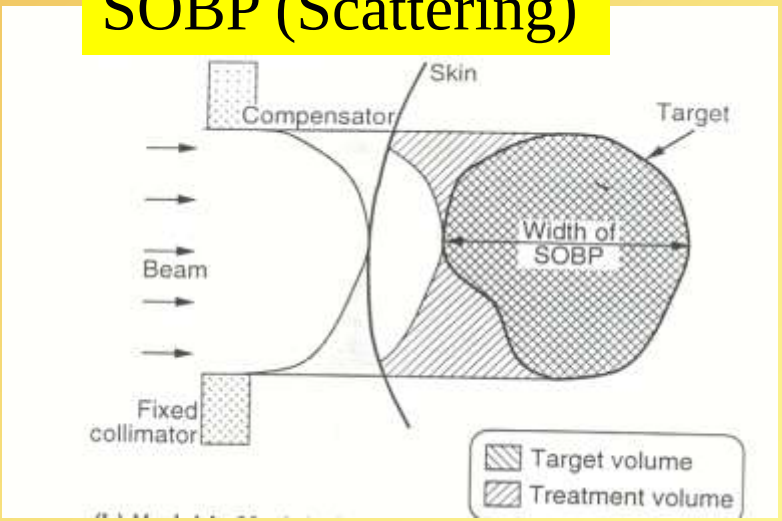


Photon Conformal: Multiple fields up to dynamic arc

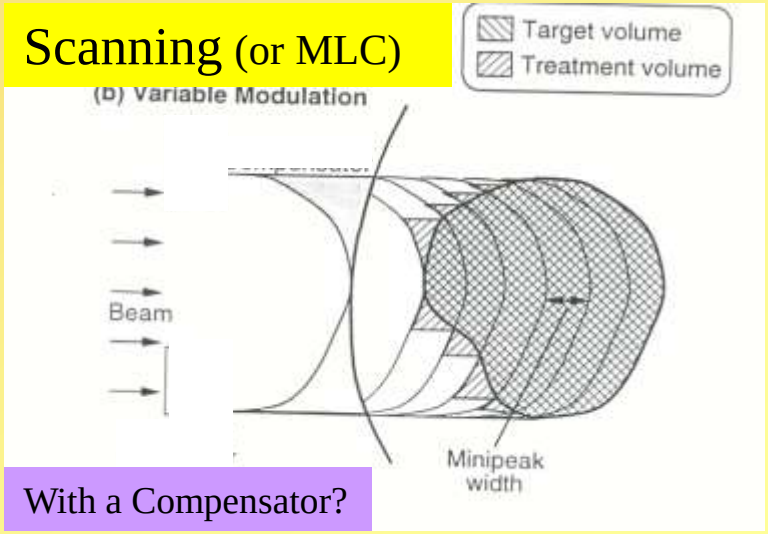
vs.

Charged Particle: Single or few fields?

SOBP (Scattering)



Scanning (or MLC)



With a Compensator?

Can also use multiple angles.

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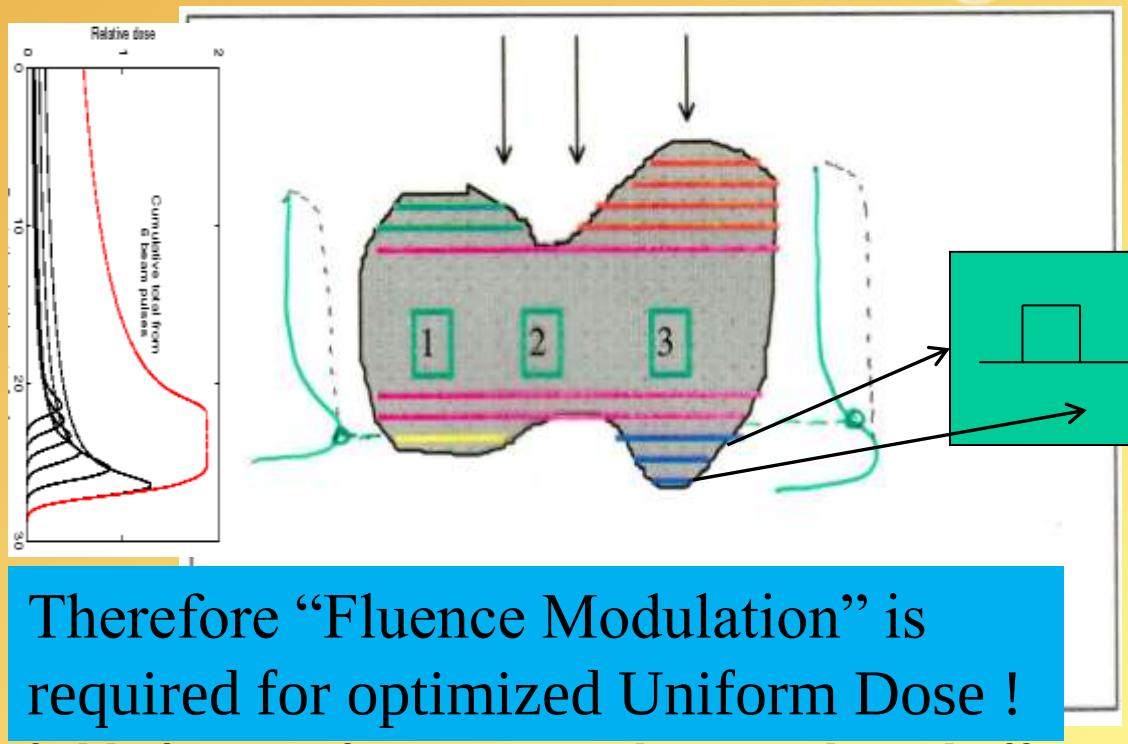
What are the some features of Proton Beam Scanning?

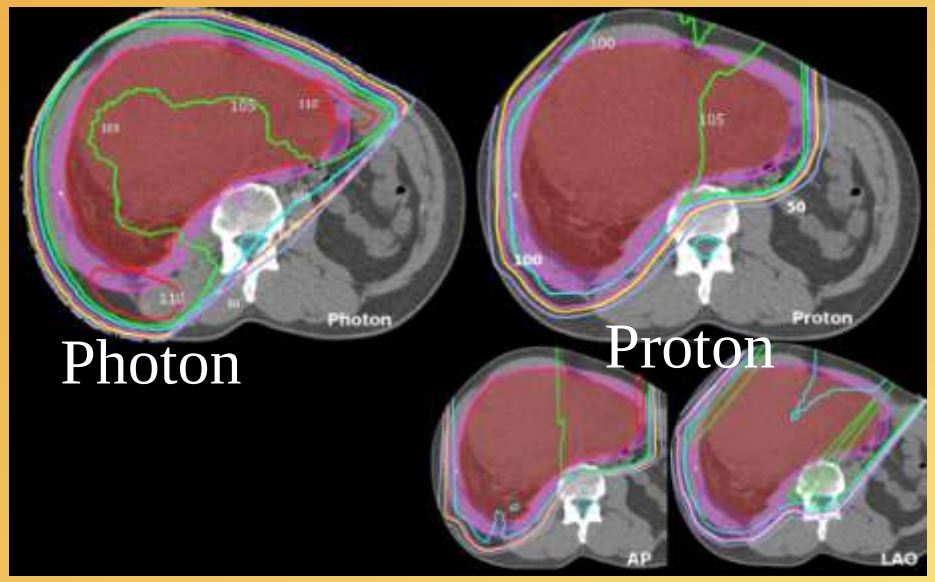


Example without a Compensator

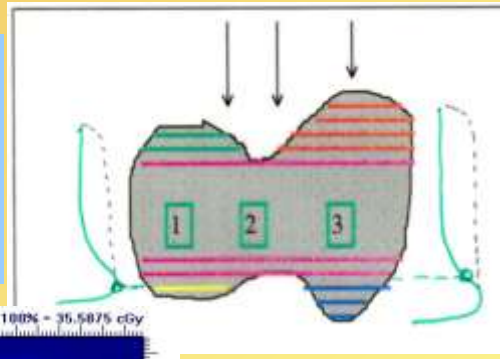
Therefore "Fluence Modulation" is required for optimized Uniform Dose !

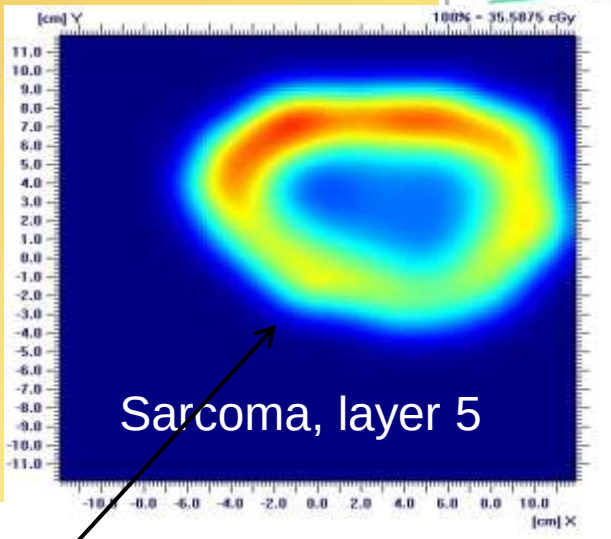
- *Reduce* # fields for a uniform Dose Delivery (Clinical effects?).
- *Reduce* unwanted Dose (e.g. Proximal Primary Dose)
- *Reduce* the need for Patient Specific Equipment
  - Apertures
  - Compensators
- *Reduce* radiation from primary beam intercepting machine components (n)
- *Allow* a non-uniform Dose Delivery

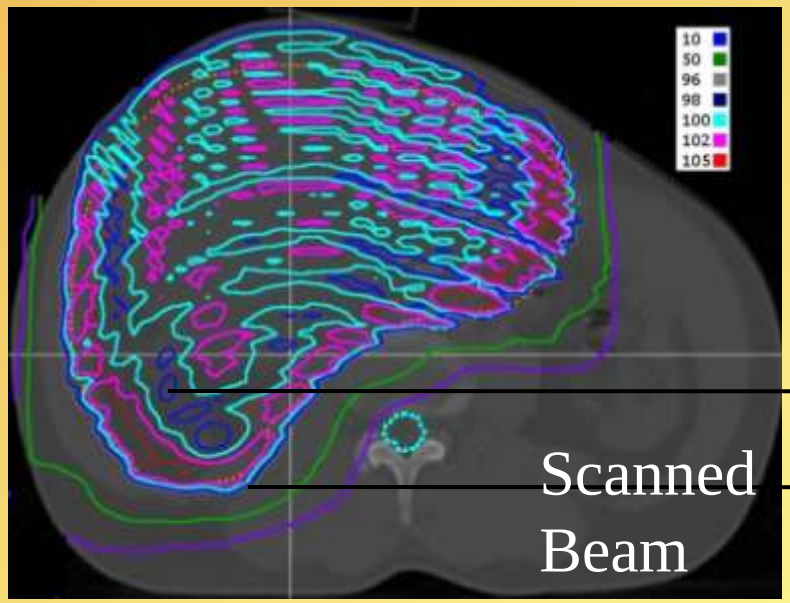
First Patient Treatment – 4 liter Sarcoma

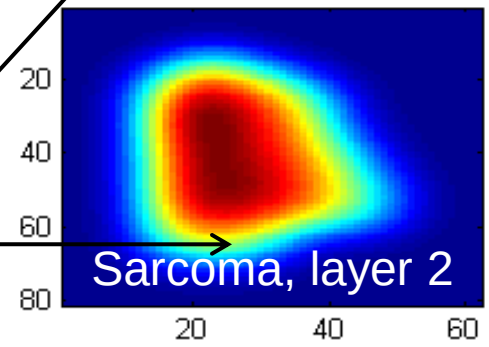


Kooy,
Delaney,
Clasie, et. al.





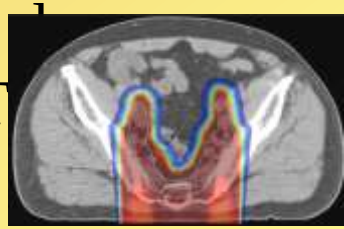




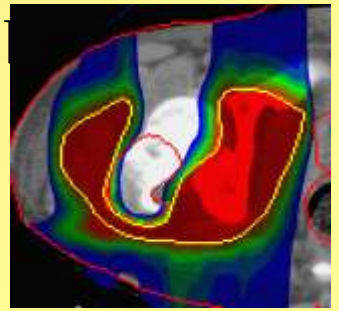
Full Irradiation from ONE direction and no PSH

Proton Beam Scanning (PBS) is NOT (Just) IMPT

- IMRT ≡ multiple fields of non-uniform dose delivery to obtain an overall conformal uniform dose distribution.
- Particle Beam Scanning, can create a highly conformal d distribution with ONE field, but layers or pencils (DET *non-uniform fluence* are required.



  - ***Highly Conformal distributions with ONE field – NOT IMRT (EOR)***
  - ***Dose Modulation can be required for uniform field – NOT IMRT***
- Non-uniform (single field) dose distributions using proton beam scanning can be delivered like IMXT if needed, l general fewer fields are needed.



  - ***Fewer (IMPT) fields 'are' needed for highly conformal distributions – NOT IMXT***
- ***Using the Term IMPT does NOT convey the power of PBS***
  - ***Power = Efficiency, conformality, Tx speed, "Cost Effectiveness", etc.***

The Evolution of the Medical Accelerator

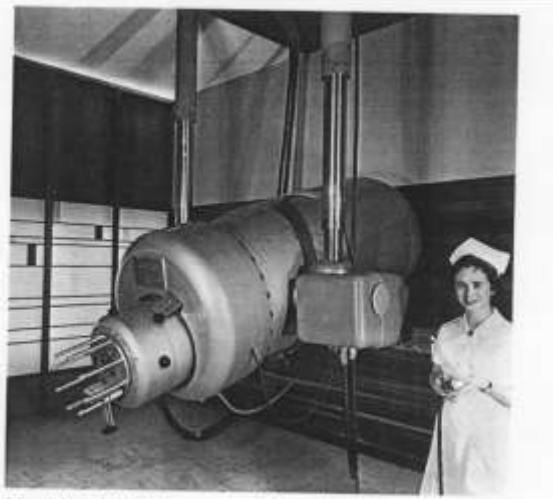
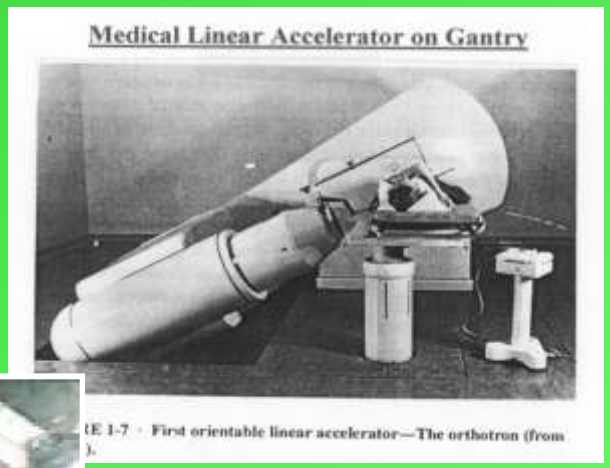


Fig. 6-8.—A Van de Graaff generator used for radiation therapy at the University Pennsylvania Hospital. (Courtesy of the University of Pennsylvania and High Volts Engineering Corporation.)



(E 1-7 · First orientable linear accelerator—The orthotron (from).

Figure 4-4. Photograph of Allis-Chalmers 25 MeV betatron installed in the Ontario Cancer Institute.

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Beam angles needed DEPEND on:

Beam Modality (e.g. Scanning) ; Anatomy; Patient Orientation

- Lying, Sitting, (Standing)
- Reproducibility (Day to Day?)
- How long can position be maintained (sec, min??)
- Knowledge of existing anatomy/tumor location and shape and required treatment plan du jour
- **Imaging, True adaptive planning**

Siemens

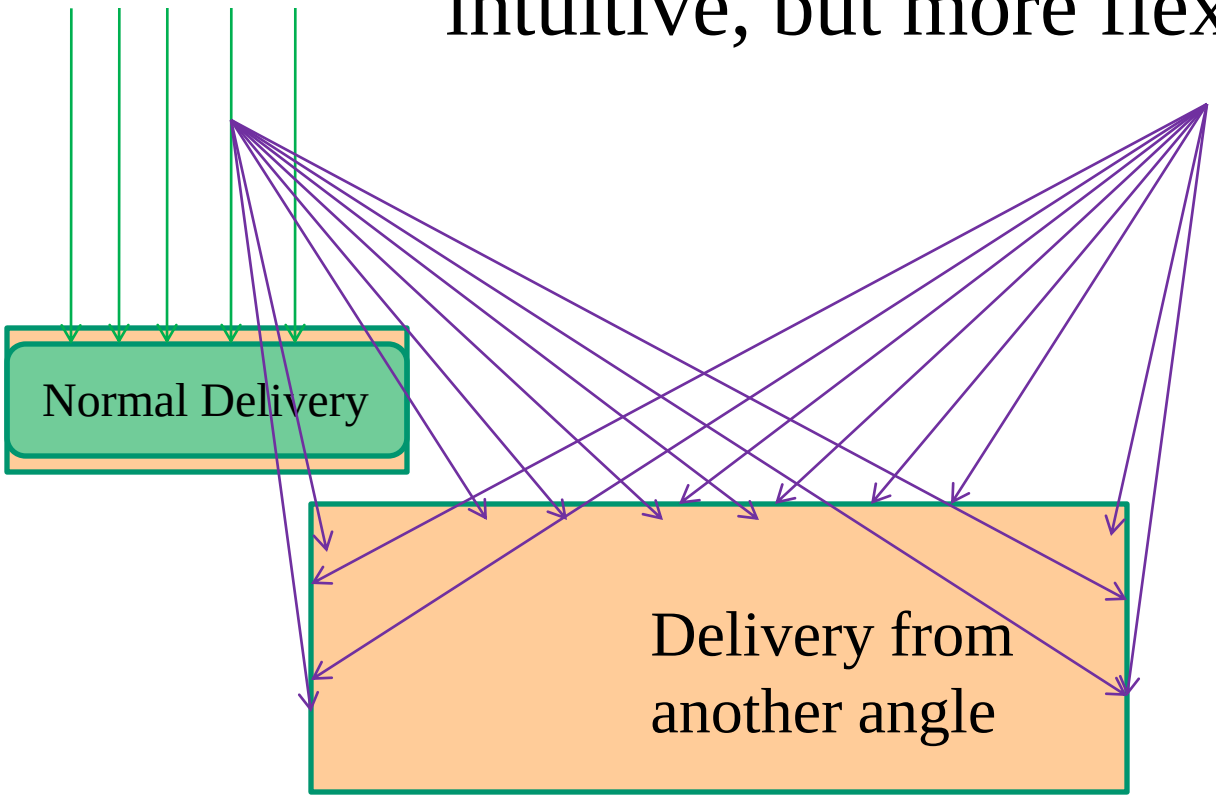
ProCure

Another Way Scanning Can Help? Adaptive Treatment Delivery

- Without the use of Patient specific equipment, and with a totally flexible beam delivery – all that is needed is a file from a treatment plan – each treatment beam can be different from the one before with no additional time required (Other than whatever is being used to generate that different plan) i.e. Adaptive Treatment Delivery
- For use in
  - Positioning du Jour
  - Changing Target Geometry
  - Etc.

More on Beam Angles

With scanning, Geometry becomes less intuitive, but more flexible

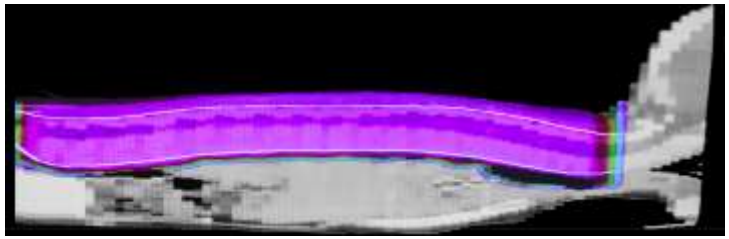


Angle of entry does not have to be as constrained as with Scattered beams, and can still have a 'square' edge and uniform dose. (Proximal dose is shifted.)

- Matching
- *SAD may not be as much of an issue*

Move Patient to Beam? or

Move Beam to Patient?



Proximal Dose issue?: *Alternate Field Directions Via Patient Location*

Another way Scanning can help? Tracking organ motion

PTCOG XXXVI

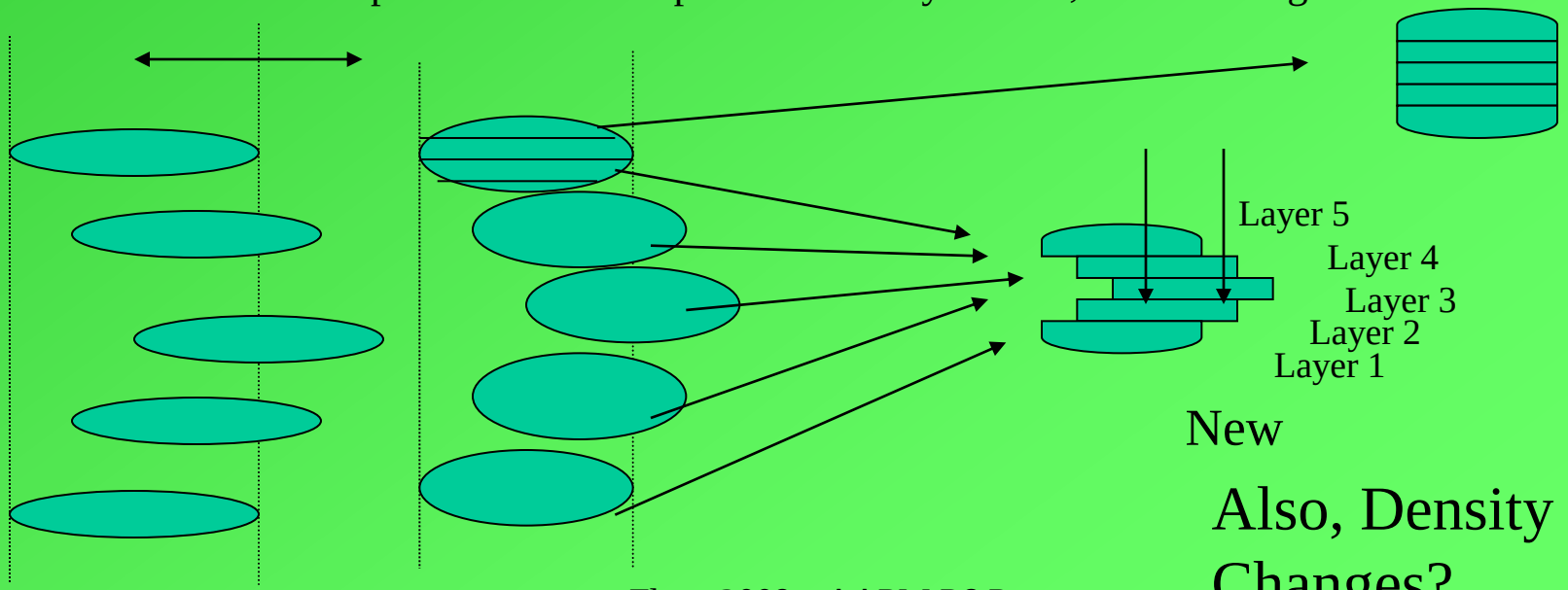
Target Motion

Target Motion - What should we do about it? What kind of scanning is best?

Time of motion?

Is a 200msec window fast enough for locating a target's edges?

Is motion reproducible wrt respiration or body motion, or something?

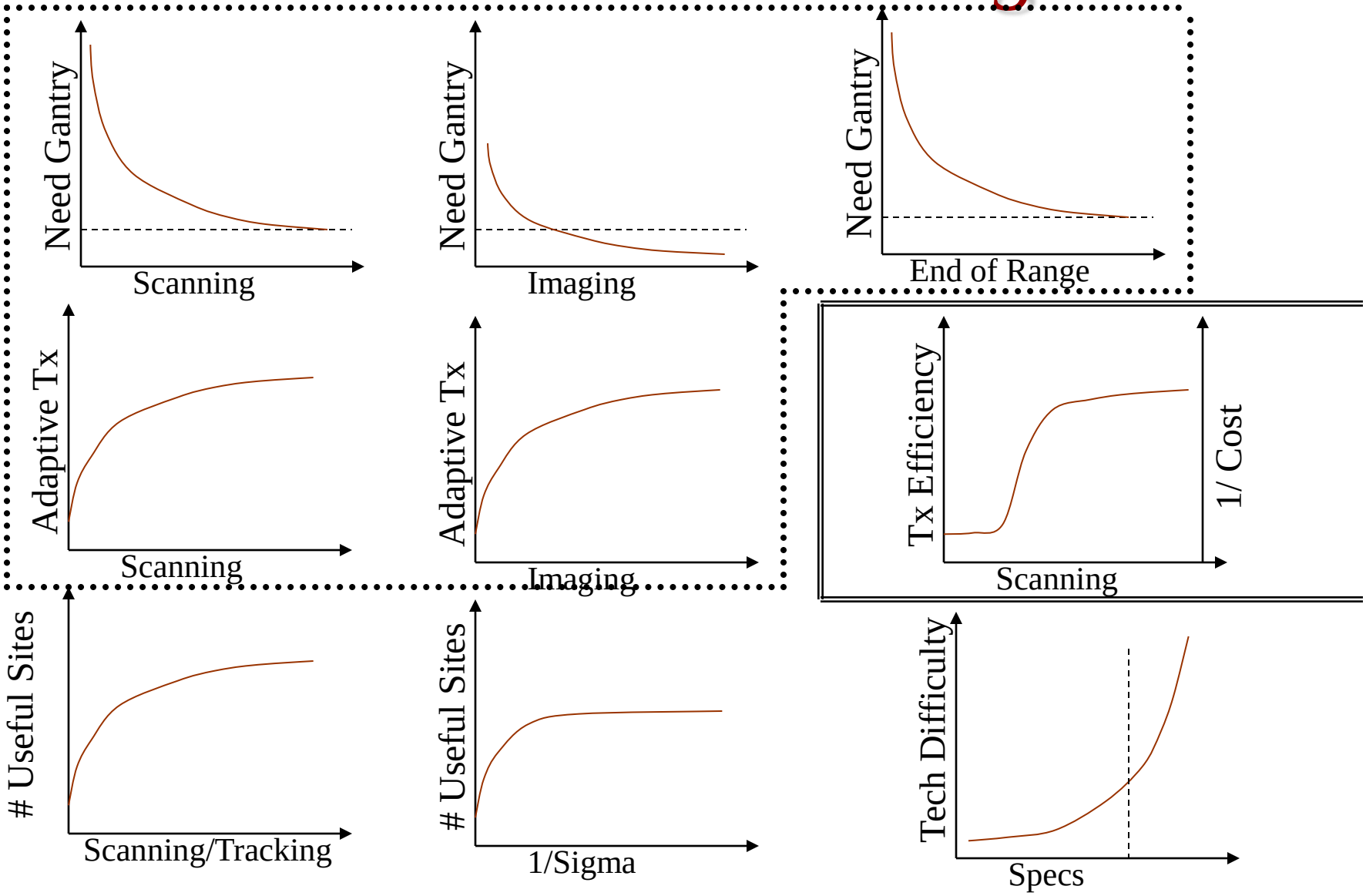


New

Also, Density Changes?

Flanz 2009 – AAPM P&P

Promises & Challenges



Promises and Perils

Promises	Perils
• Ultimate Treatment – Better Conformality – Simple? Radiobiology	• Multiple Parameter Choices – Tolerances/Sensitivities
• Scanning – Ultimate Conformality – Large range of applicability – Will enable Adaptive Tx	• Scanning – Technical Implementation – Expense ~ Specs: e.g. 1/Beam Size – Often shown for H&N? – Confused with IMRT (IMPT) – Lose sight of other sites/techniques
• Gantry – All Angles/All Sites – Scanning may reduce need	• Gantry – Expensive, Big (Drives equip $)
• Machines Choices – Smaller, Bigger – Cheaper, Expensive	• Machine Choices – Choose Delivery Modality, Timing

***IMPT** is not a good term for Proton Scanning unless it is **IM**proved **P**roton **T**herapy*

Bortfeld Suggestion

The Francis H. Burr Proton Therapy Center

Thank You !