Dielectric Wall Accelerator (DWA) and Distal Edge Tracking Proton Delivery System

Rock Mackie
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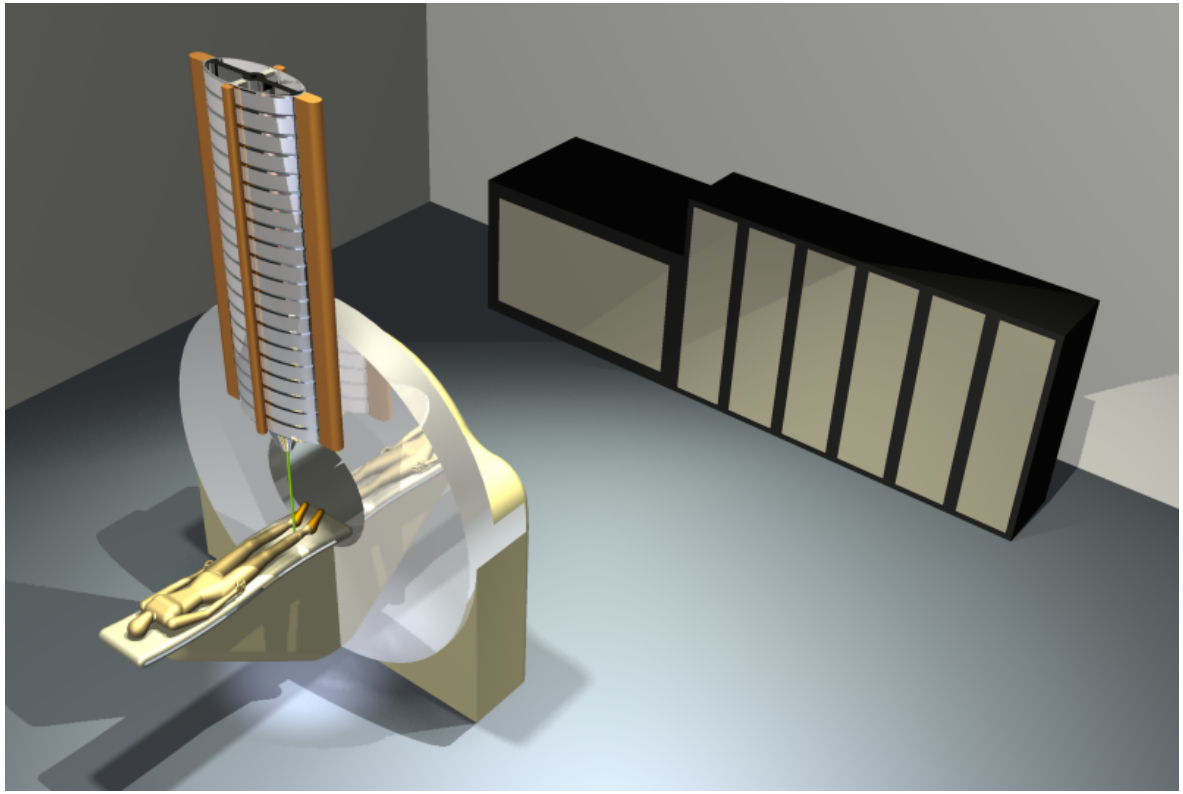
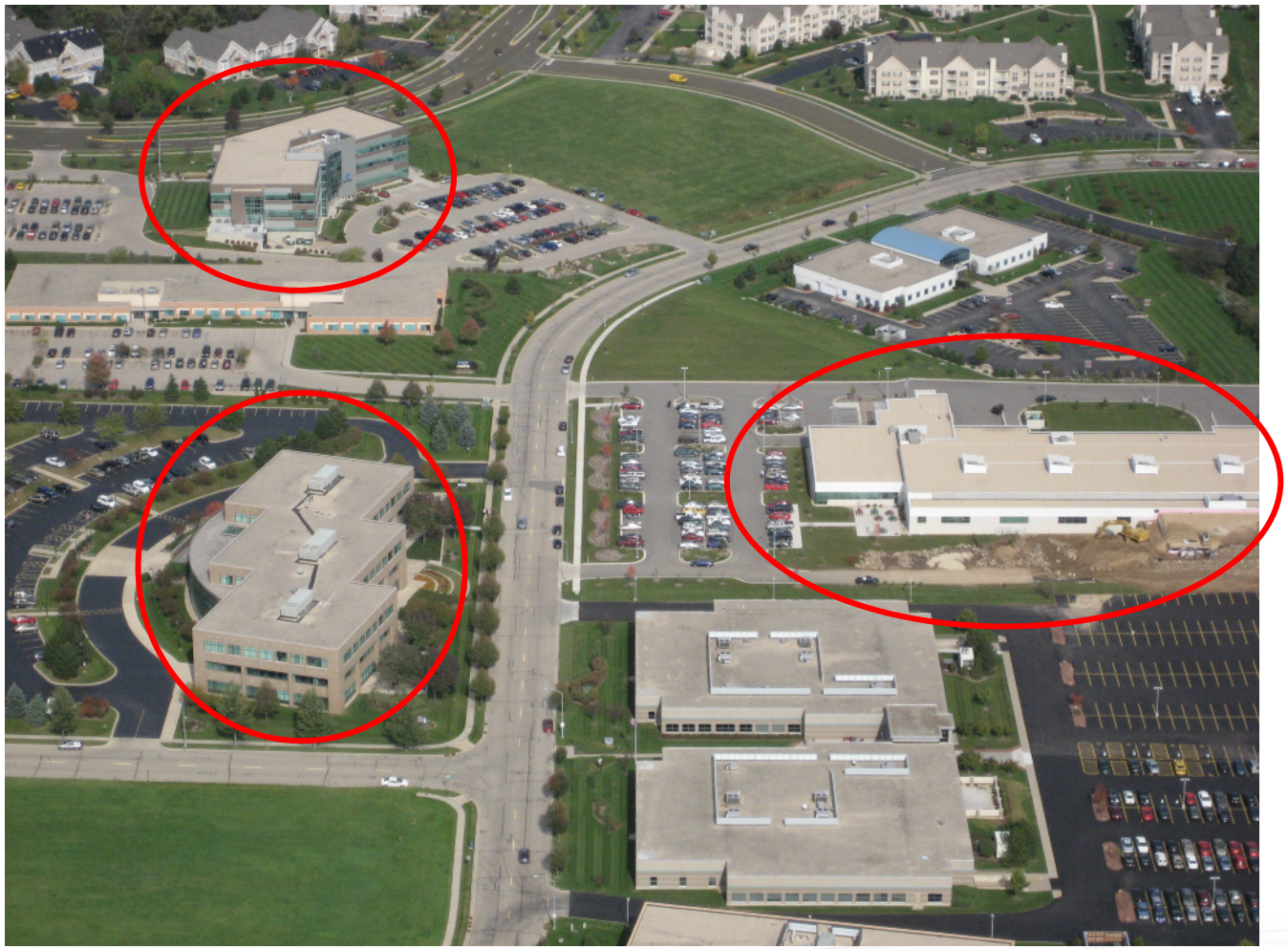
Co-Founder and Chairman of the Board or TomoTherapy Inc



I have a conflict of interest due to a financial interest in TomoTherapy Inc, which is involved in commercializing the dielectric wall accelerator.

TomoTherapy Headquarters: Madison Wisconsin

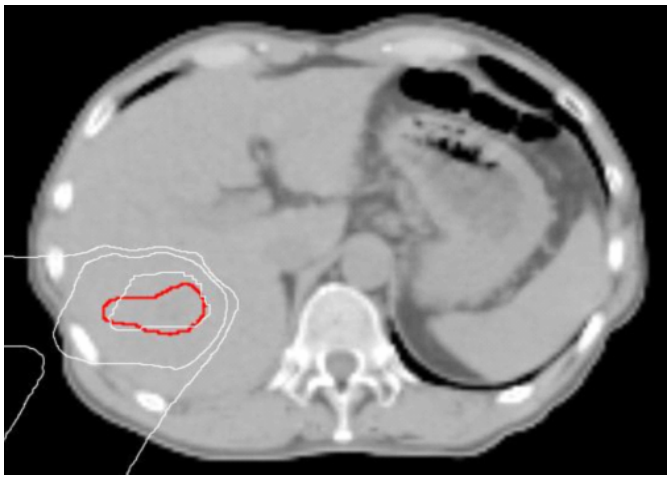


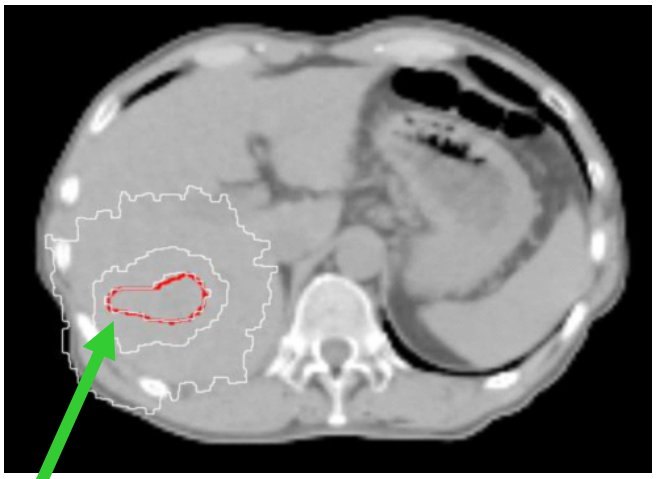
Overview

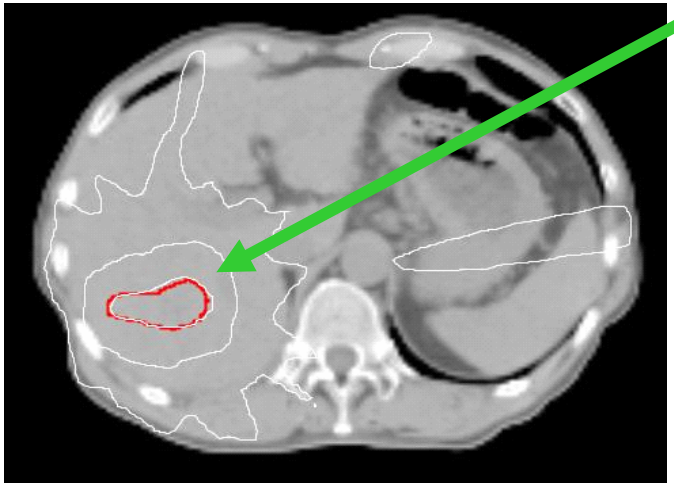
- Comparison of protons with IMRT
- The need for a compact unit.
- The dielectric wall accelerator.
- The desirability of intensity modulated proton therapy (IMPT) and rotational delivery.
- Compact Particle Acceleration Corporation (CPAC)

IMRT Vs Conventional Protons

Conventional Protons Are Delivered With Only A Few Fields



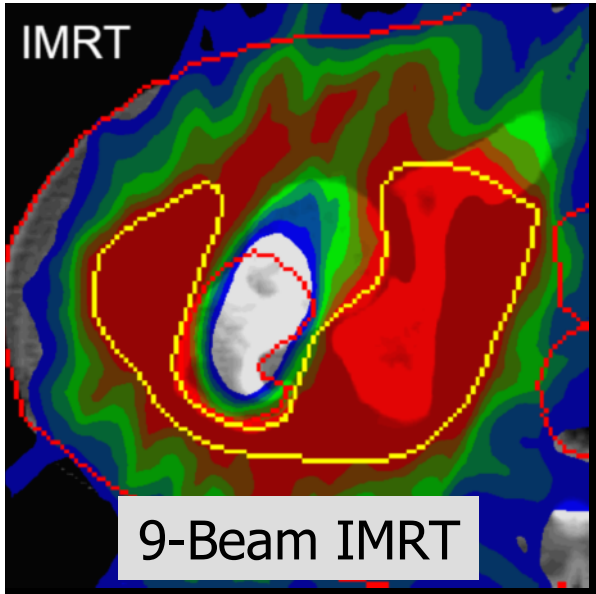




Greater high dose conformity with IMRT…

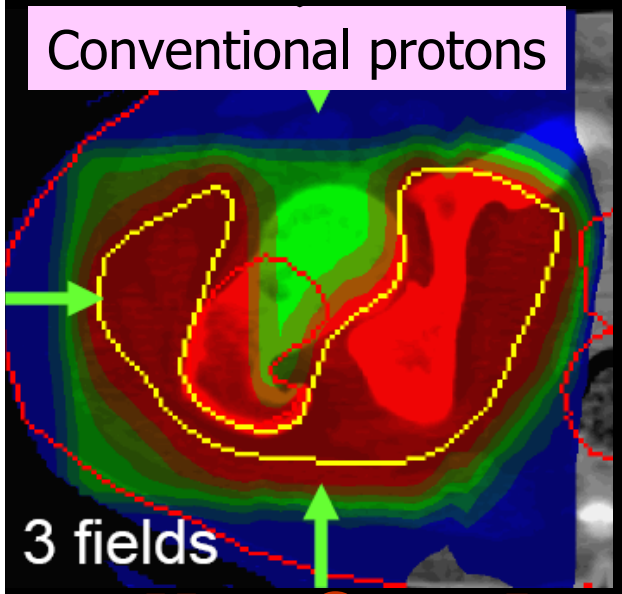
Proton	Tomo
Pinnacle IMRT	Case 2 (Isodose Lines:15, 30, and 60Gy)

…but less integral dose with protons.

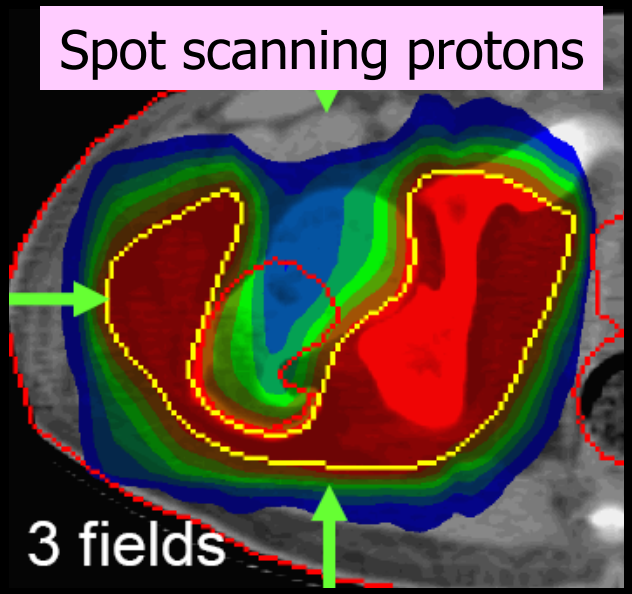


- Conventional (passive scattering) proton therapy provides questionable improvement over IMRT
- IMPT is clearly superior to IMRT

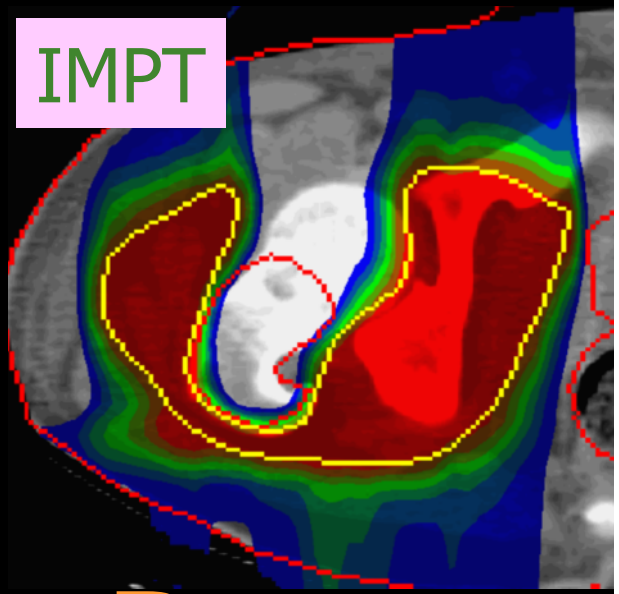
⇒IMPT capability is essential to justify large cost differential over high-end x-ray equipment



Not Good



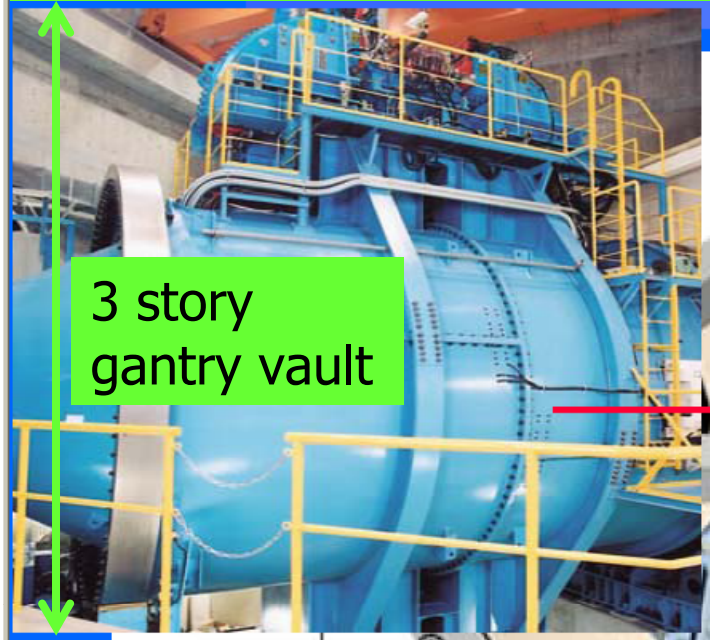
OK

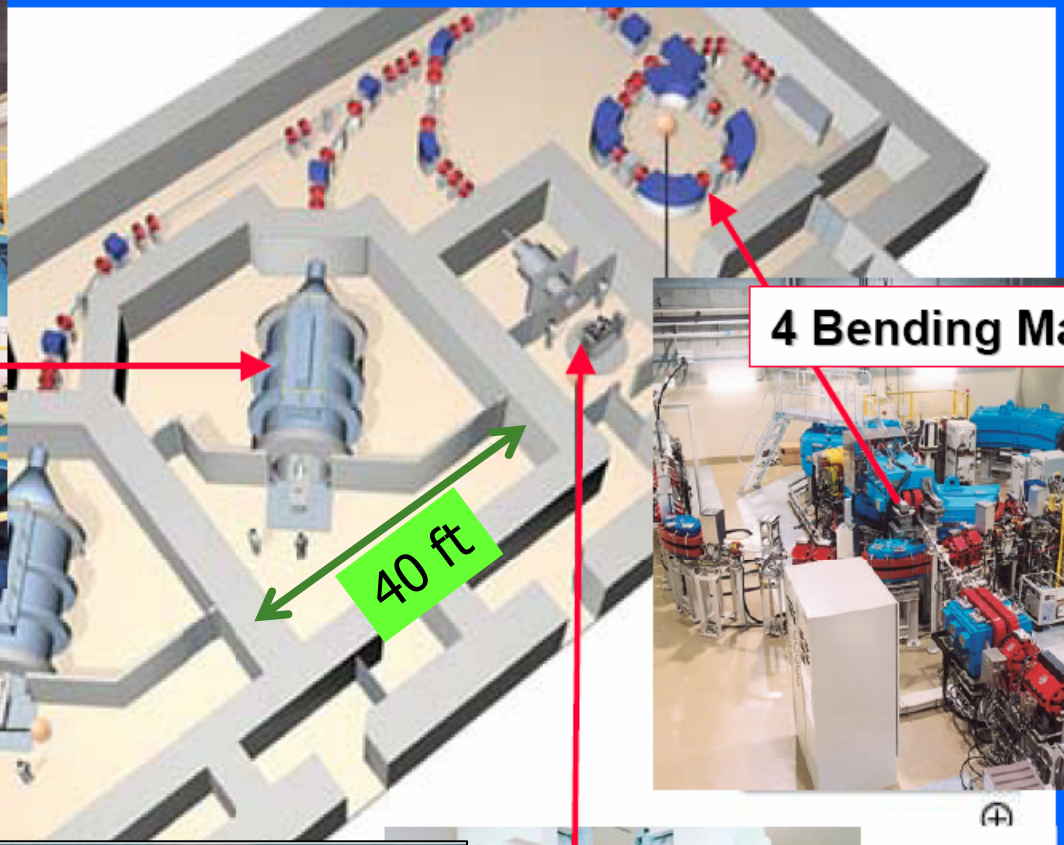


Better

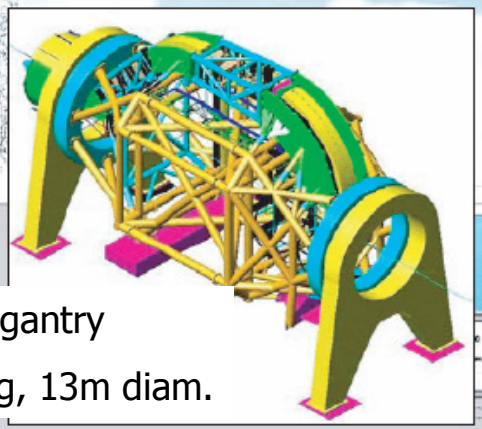
Shizuoka Proton Center, Japan

Mitsubishi solution



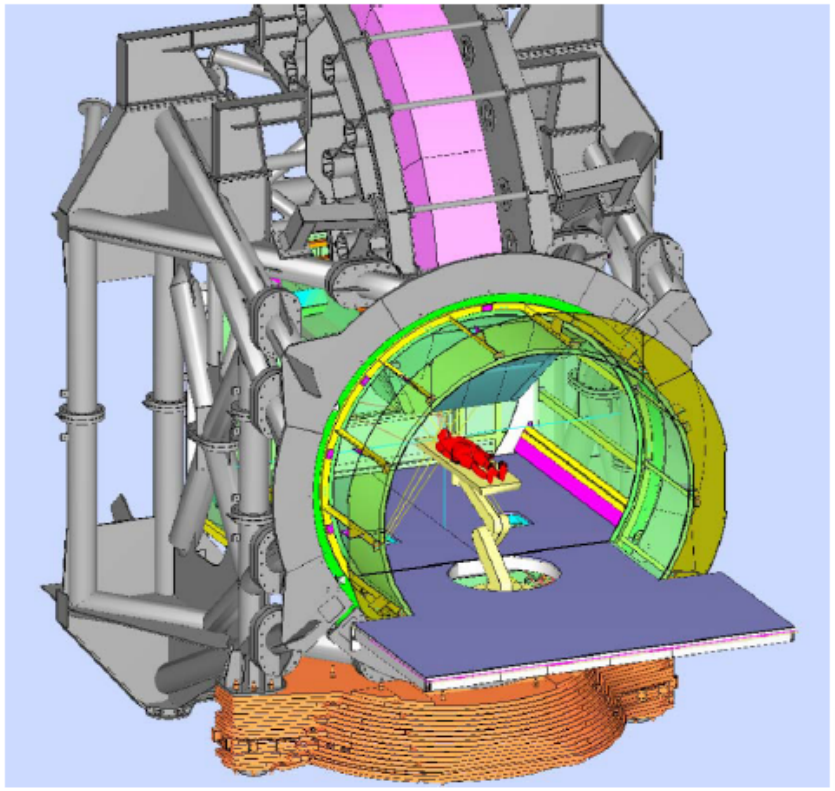


Heidelberg Ion Therapy Center



600 ton gantry

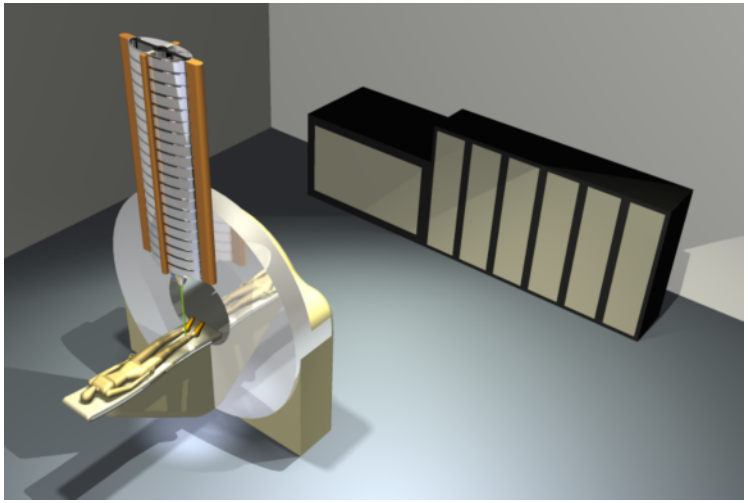
25m long, 13m diam.



Detail Drawings

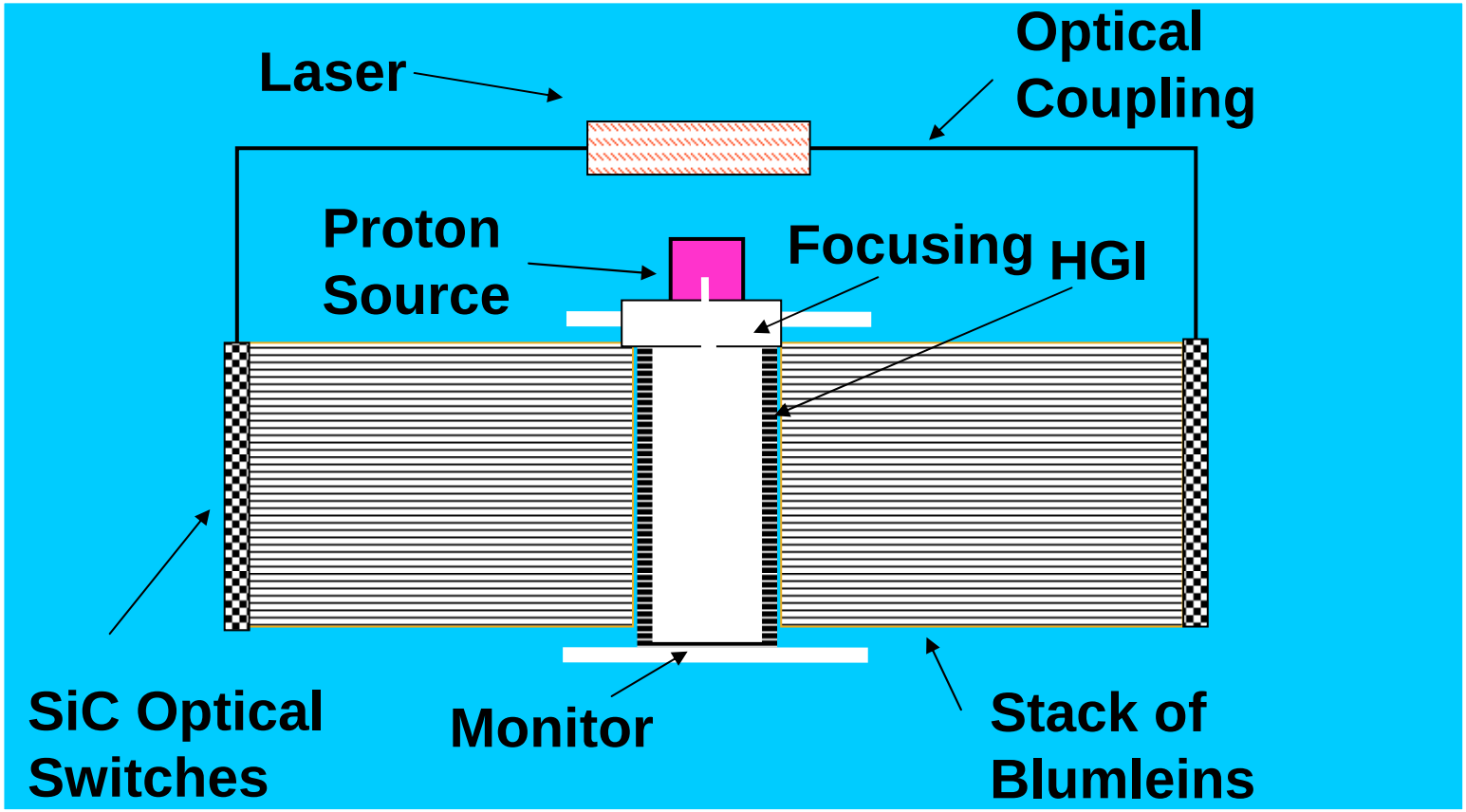
Click To Access Concept Drawings

TomoTherapy Next Generation



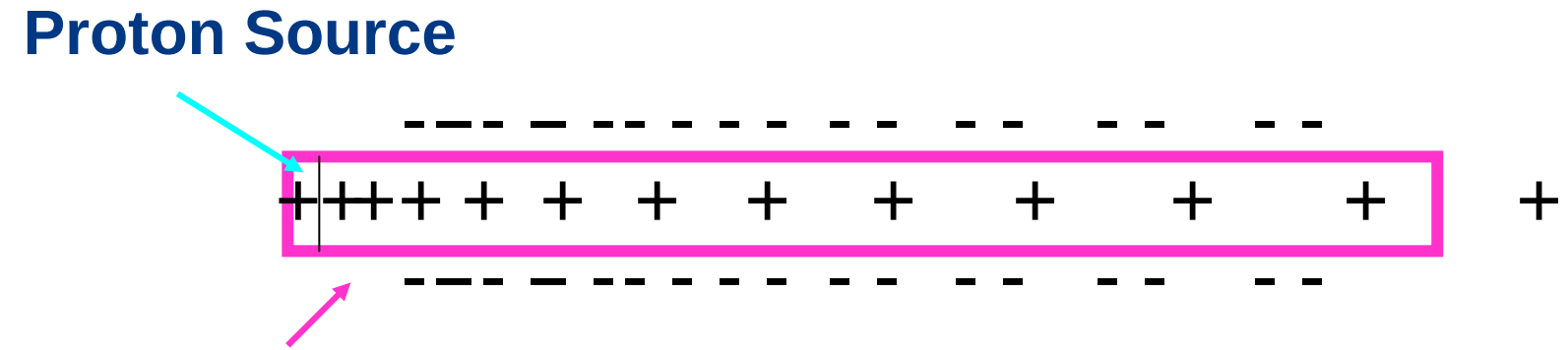
- Both systems clinically complement each other.
- Both based on rotation delivery.
- Natural evolution to TomoTherapy® Hi·Art®.
- TomoTherapy has/owns core competencies to produce/build proton systems.

Proton System Based on Dielectric Wall Accelerator (DWA)* Technology



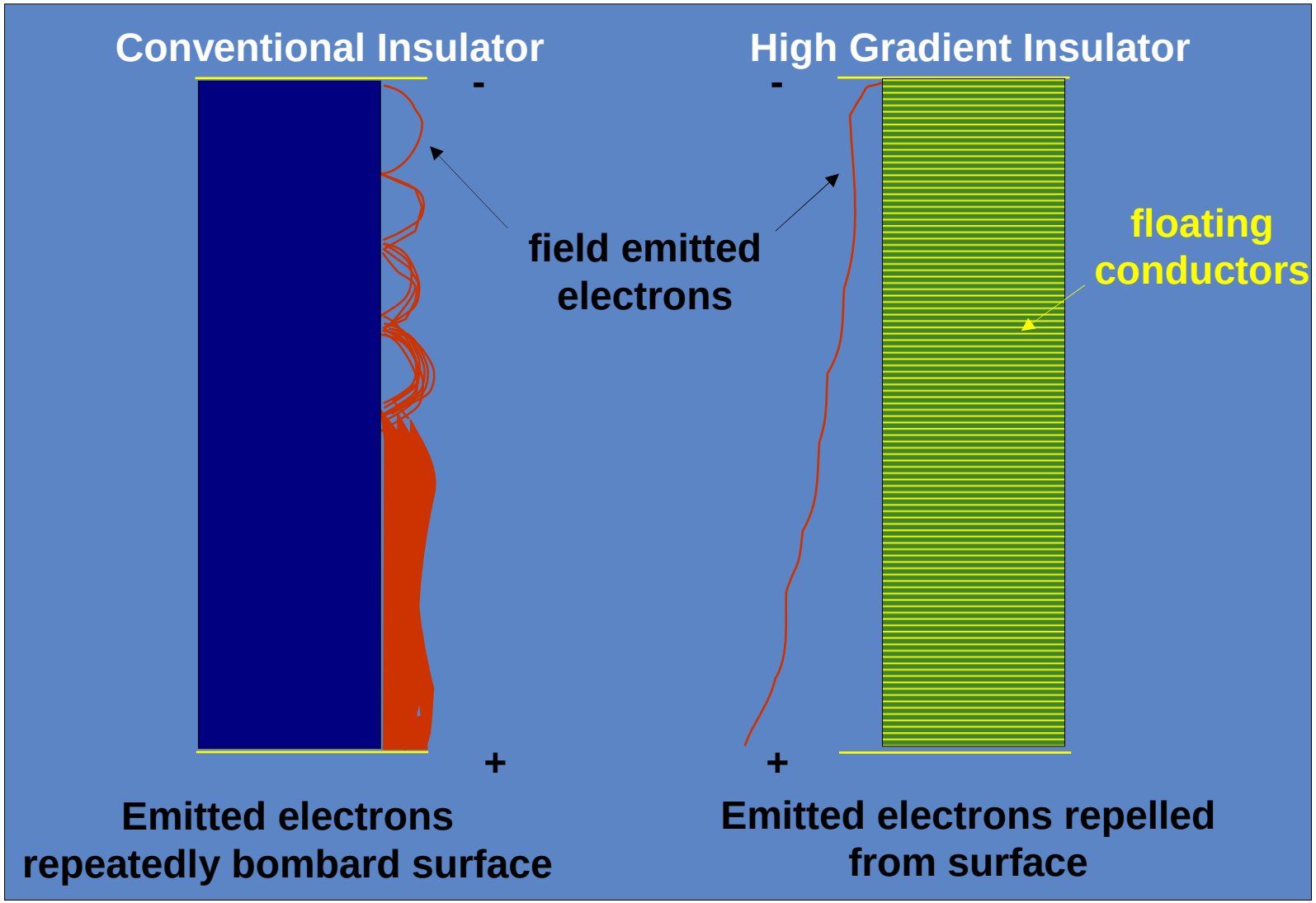
*Lawrence Livermore National Laboratory, Livermore CA

Matching Phase Velocities

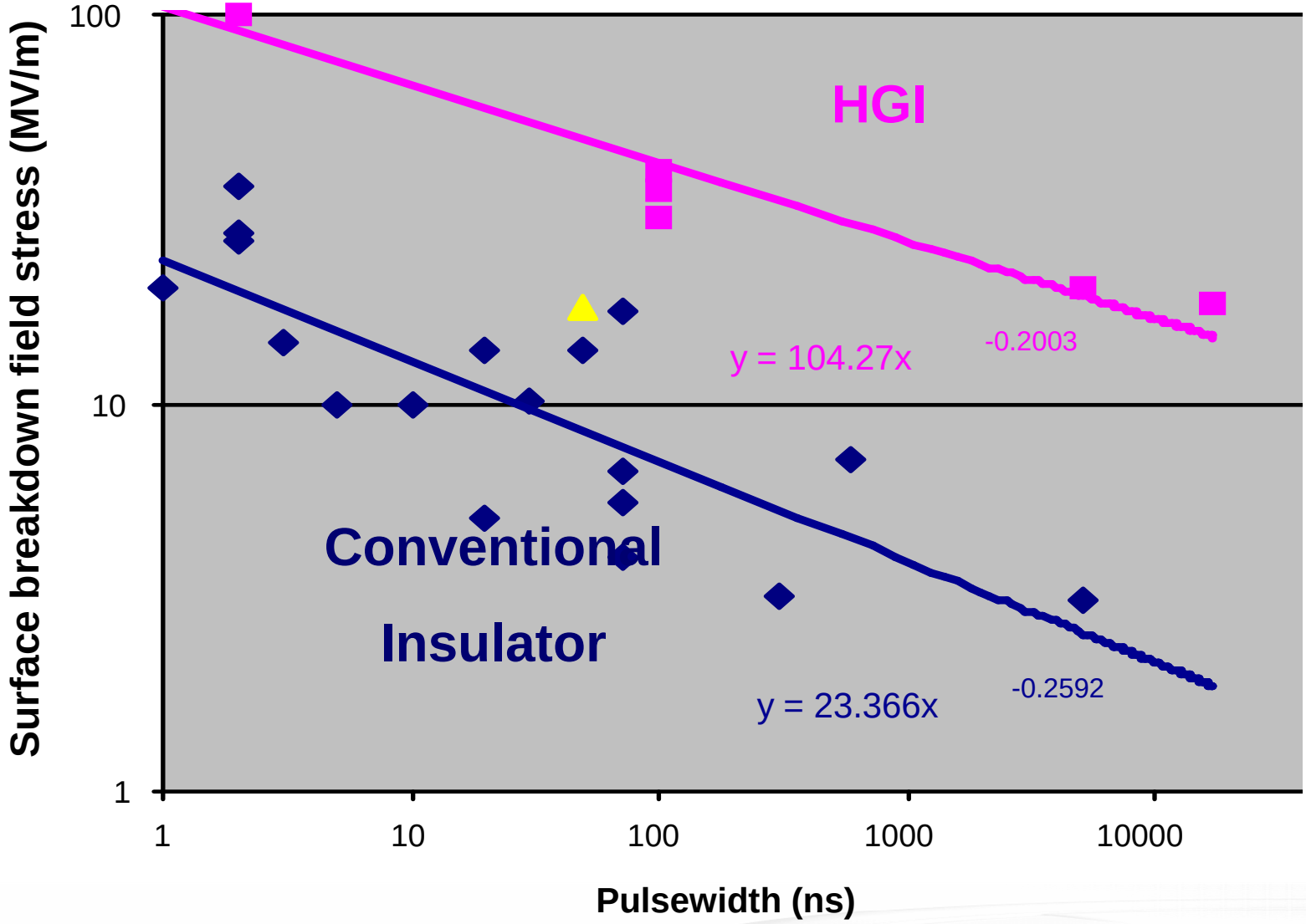


- **The phase of the first Blumlein firing has to match the proton source**
- **The phase velocity of Blumlein firings have to match the proton velocity throughout the accelerator**

How High Gradient Insulators Work

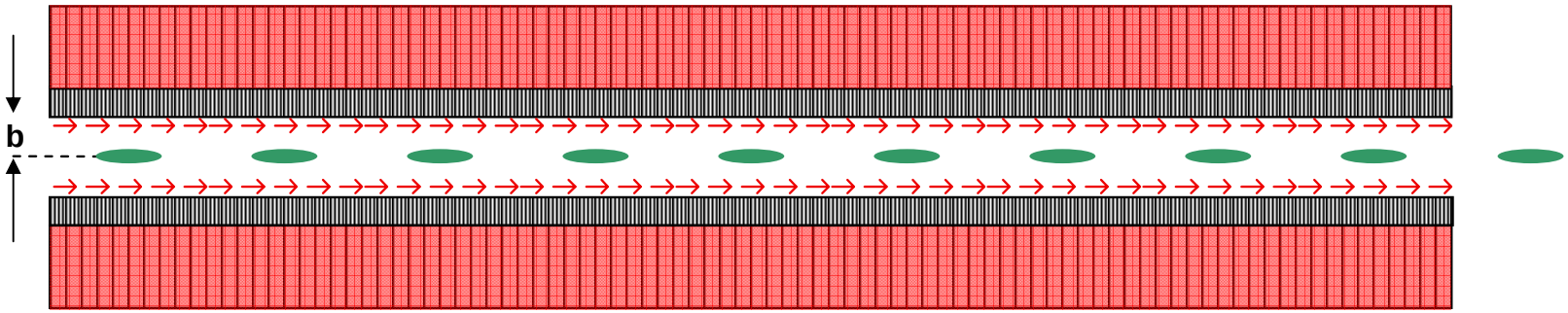


Breakdown Voltage Increases As the Pulsewidth Decreases



DWA in the Traveling Wave Mode*

HGI characteristics imply that the highest gradients will be attained for the shortest pulses



Along the wall $E_z\ r,t,z \quad E_z\ r,$

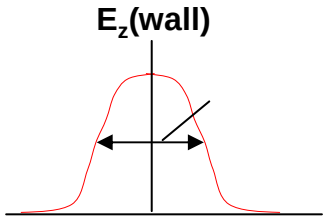
$$t \quad z/u$$

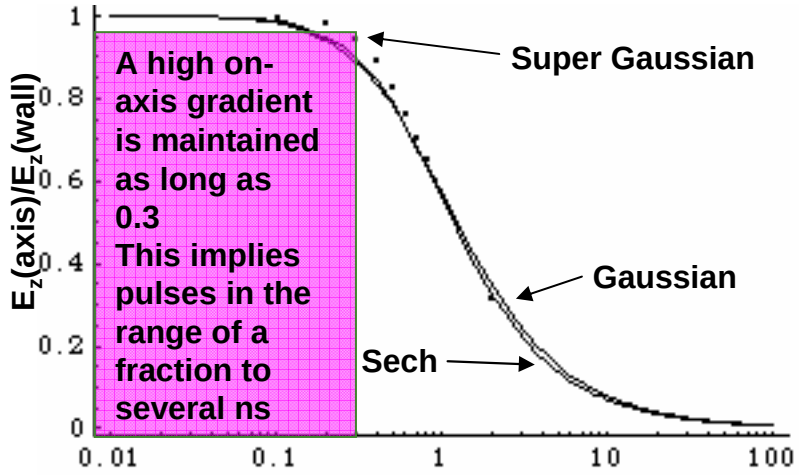
$$\frac{1}{\sqrt{1 \quad u^2/c^2}}$$

= full width at half maximum

***u* = speed of wall excitation**

= Lorentz factor



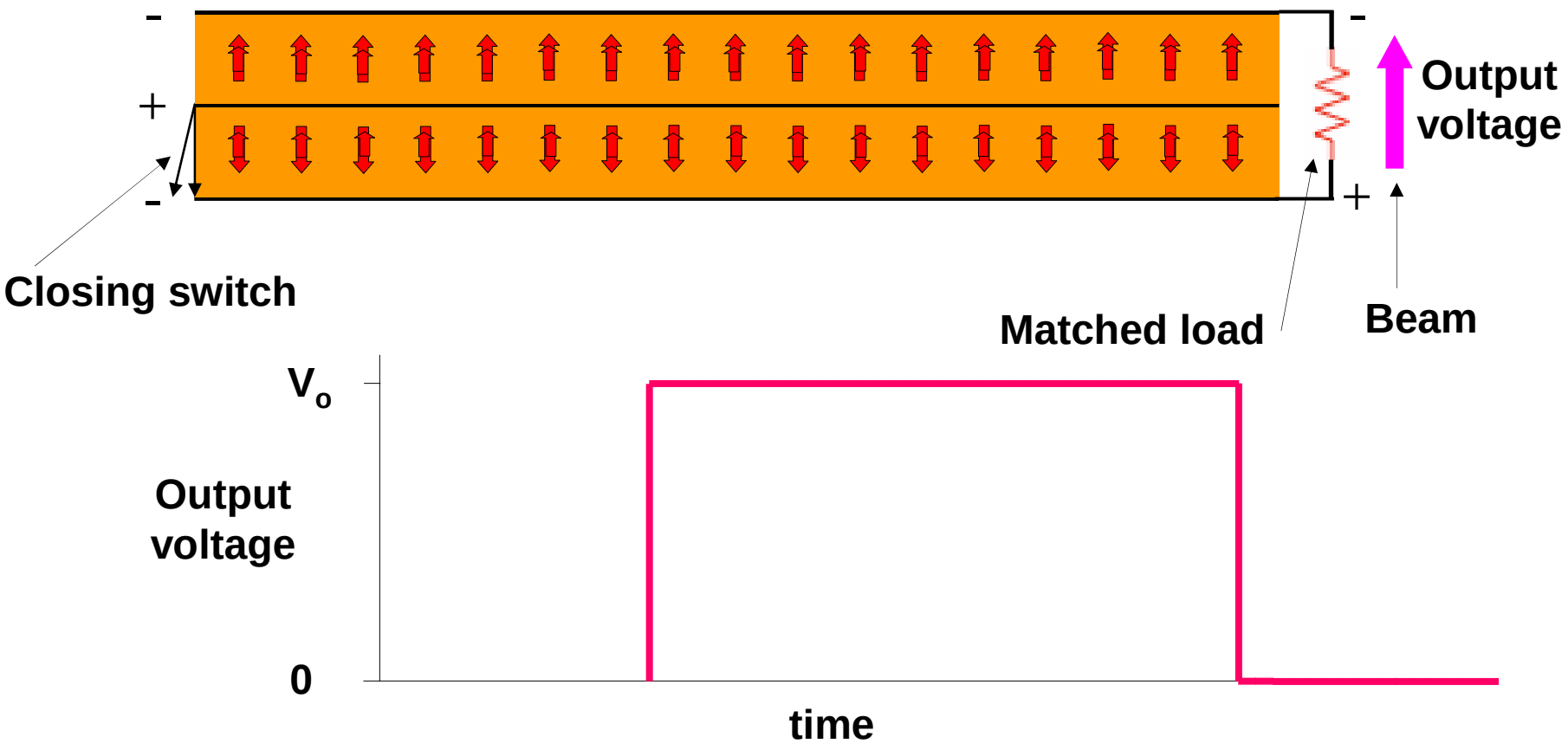


$$\frac{b}{u}$$

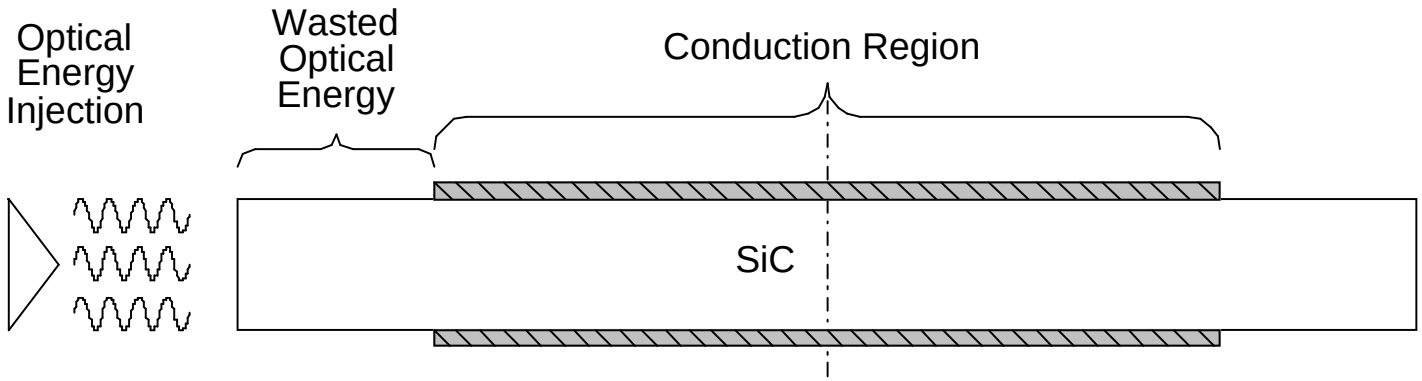
This accelerator can work for any charged particle

***patent pending**

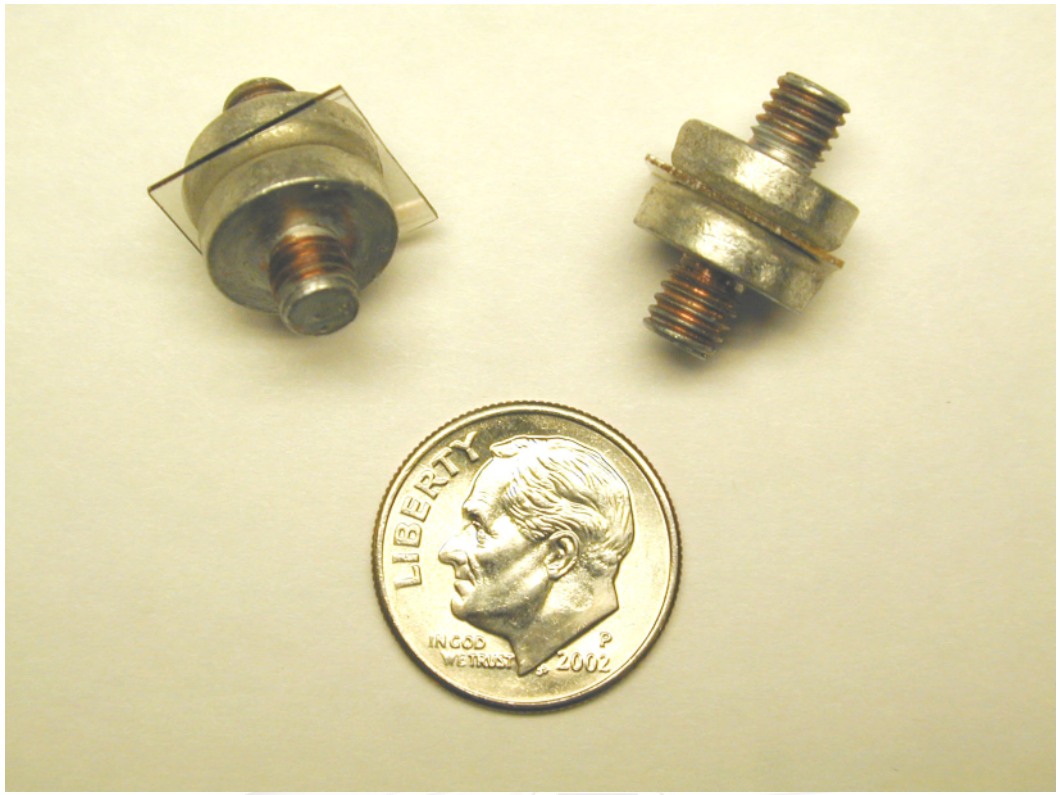
Operation of a Basic Blumlein



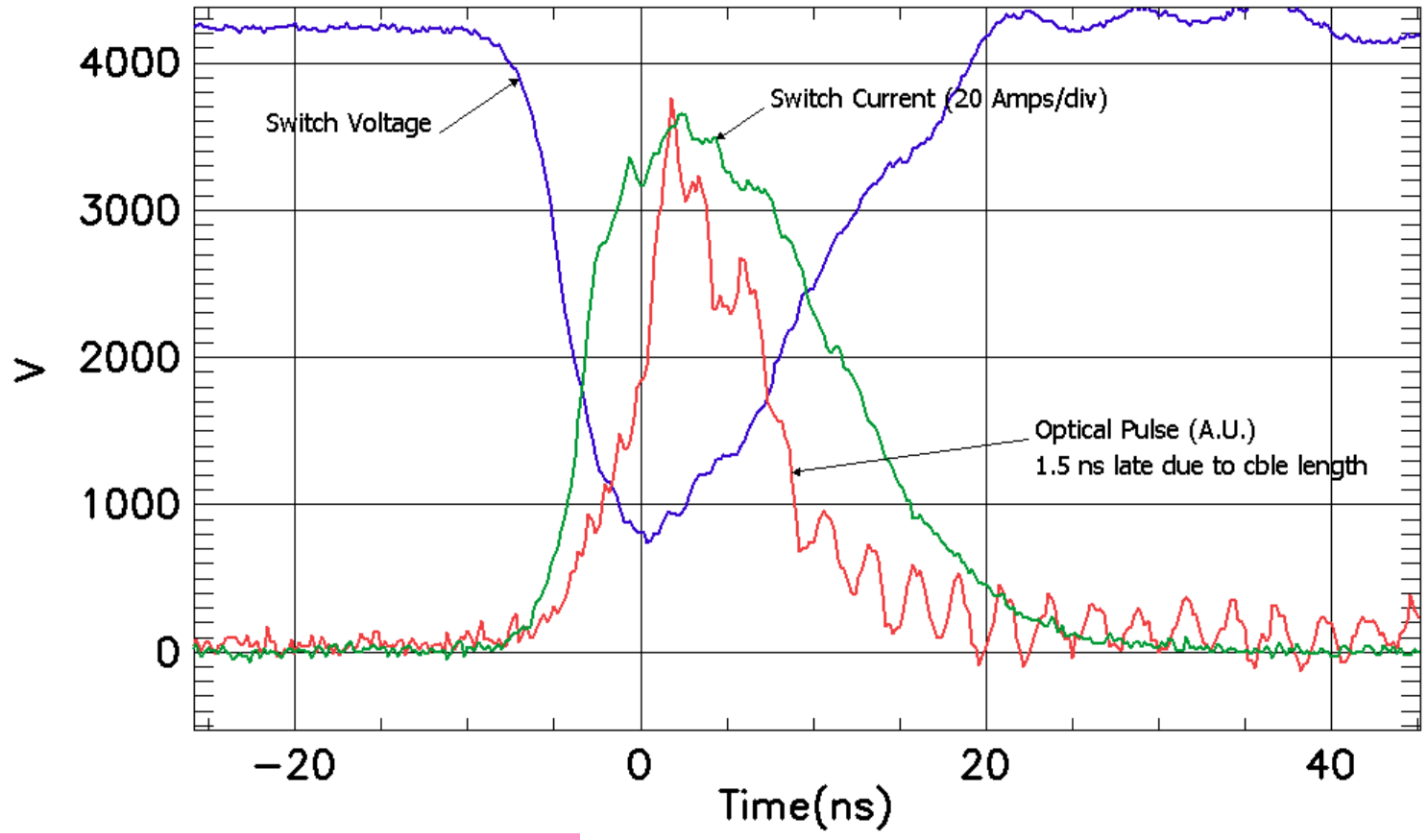
SiC Optical Switches



With the absorption of light the optical switch rapidly transitions from electrically open to closed.



Optical Switches

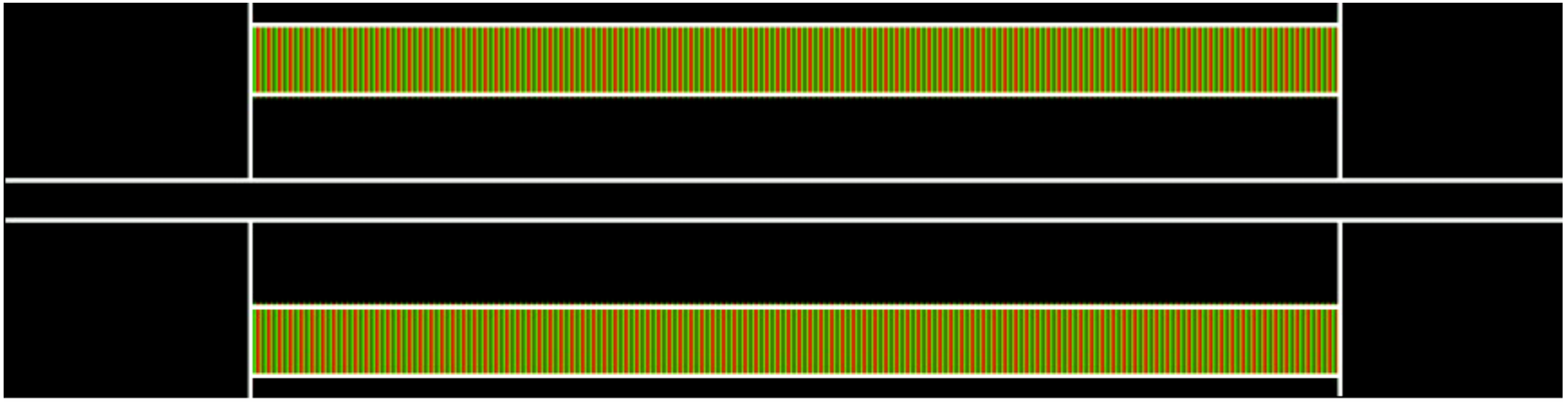


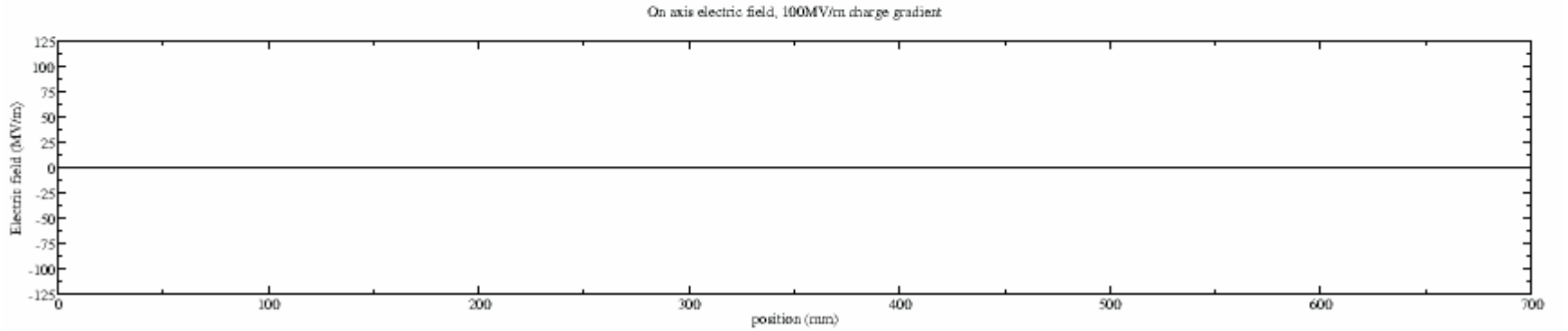
SiC offers high voltage, high current operation at elevated temperature with long lifetime, low jitter and fast risetime

***Patent pending**

DWA supports a virtual traveling wave by continuous wall excitation* accelerator

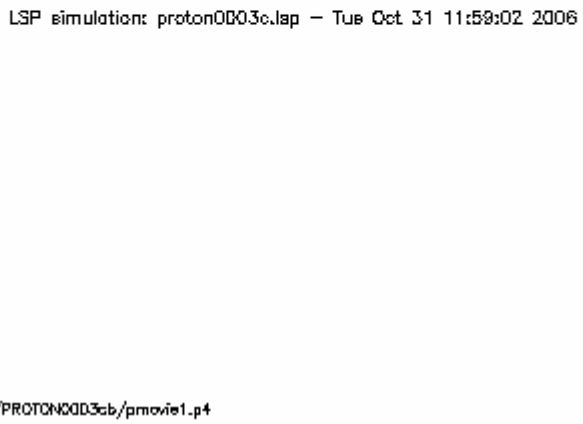
Longitudinal Electric Field Plot





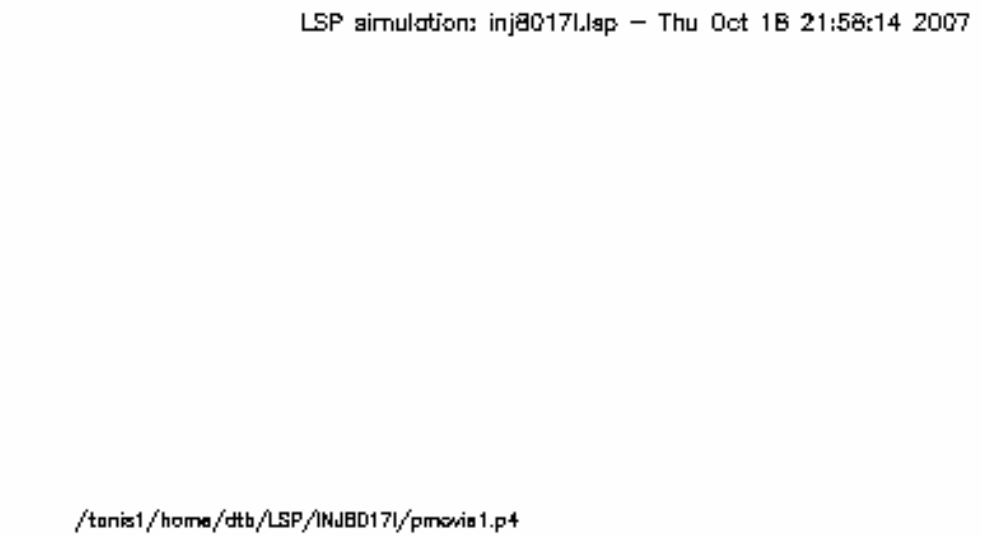
*patent pending

Beam capture into the DWA



Focusing to Change the Beam Spot Size

DWA Can Eliminate Deuteron Contamination



Basic Specifications

- 200 MeV protons in 2 meters
- Energy, intensity and spot width variable pulse to pulse
- Nanosec pulse lengths
- At least 200 degrees of rotation
- 50 Hz pulse repetition rate
- 20 ft x 20 ft x 14 ft high vault
- Less neutron dose (neutrons still produced in the patient)

How is the dielectric wall accelerator proposed to work?

20%	1.	It uses radiofrequency power just like all other accelerators to produce a standing electric field.
20%	2.	It is based on a cyclotron straightened out to be a linear accelerator.
20%	3.	It has an isotropic source that is Lorenz contracted to not be isotropic.
20%	4.	It uses transmission lines to supply a traveling electric field to a high gradient insulator.
20%	5.	It uses a laser-pumped plasma to push the protons along the surface an insulator.

How is the dielectric wall accelerator proposed to work?

1. It uses radiofrequency power just like all other accelerators to produce a standing electric field. No RF source is used.

2. It is based on a cyclotron straightened out to be a linear accelerator. Not physically possible.

3. It has an isotropic source that is Lorenz contracted to not be isotropic. Out of context correction applied to moving charges to correct for space charge effects.

4. ***It uses transmission lines to supply a traveling electric field to a high gradient insulator.*** The accuracy of switching the transmission lines is key to the design.

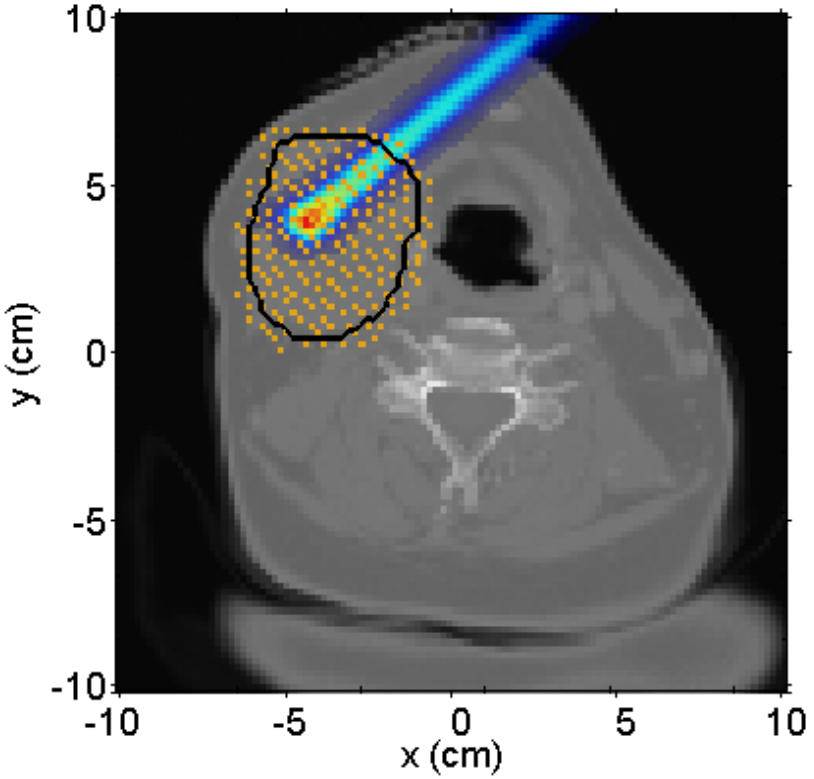
5. It uses a laser-pumped plasma to push the protons along the surface an insulator. Confuses the plasma wake field accelerator systems.

Distal Edge Tracking (DET)
"Tomotherapy for Protons"

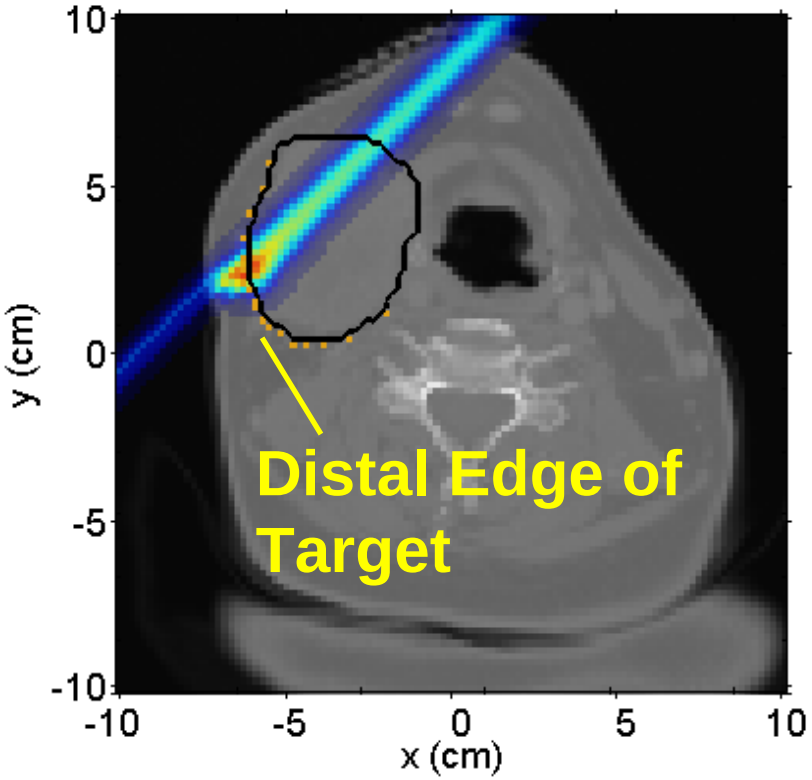
- Utilize energy modulation to allow the Bragg peak to only follow the distal edge of the target.
- Provide intensity modulation to control the dose homogeneity in the target and avoid normal tissues.
- Need a very large number of treatment directions to enable it (i.e., arc or rotational therapy)
- Bortfeld et al. have shown that DET provides the lowest normal tissue dose for a given target dose.

Spot Scanning and DET

SS Spot Locations (~300)

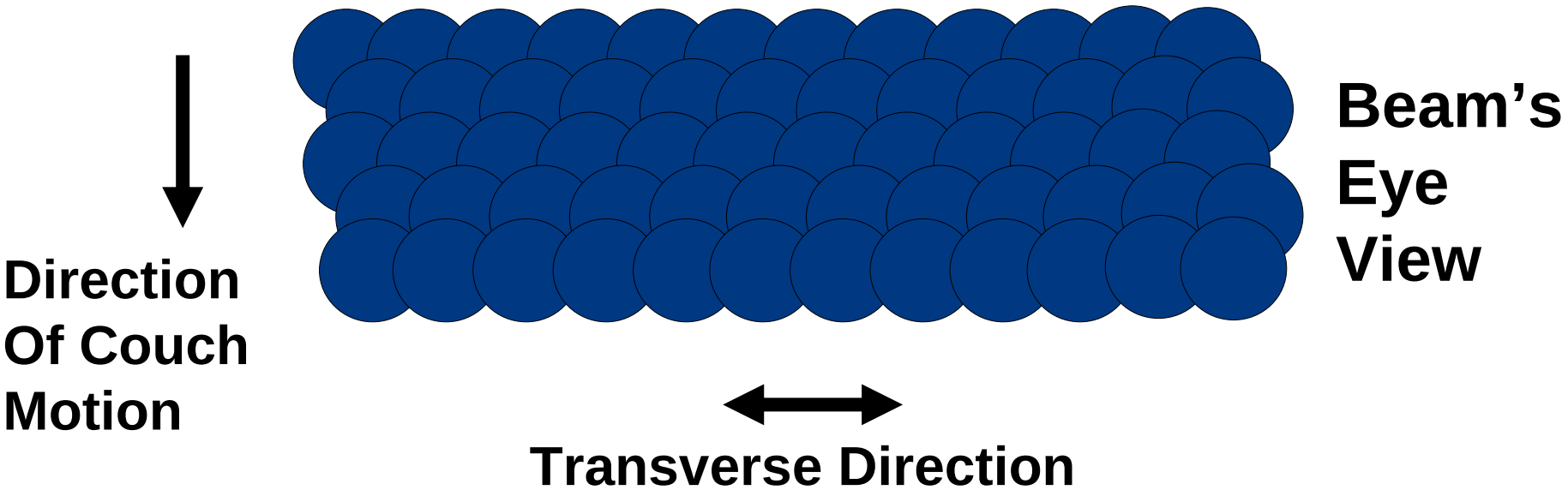


DET Spot Locations (~20)



- For DET multiple directions or arc therapy and intensity modulation required to obtain uniform dose distributions.

How the Spots May Be Scanned

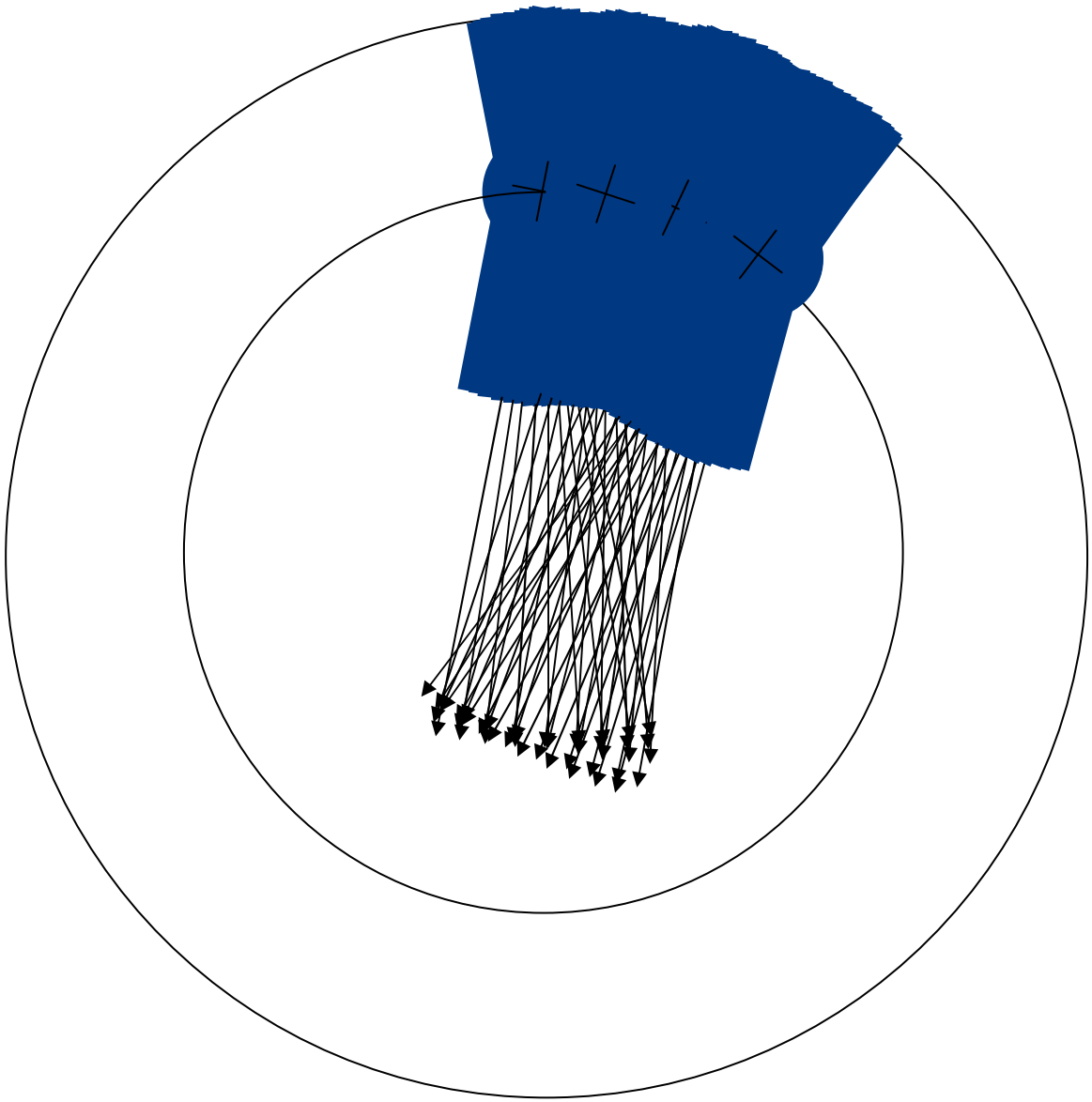


- Magnetic scanning is the fastest spot movement.
- At 50 Hz, the time between spots is 20 ms.
- Possible to track the beam longitudinally to manage motion.

Gantry Rotation

Gantry rotation is the slowest scanning motion.

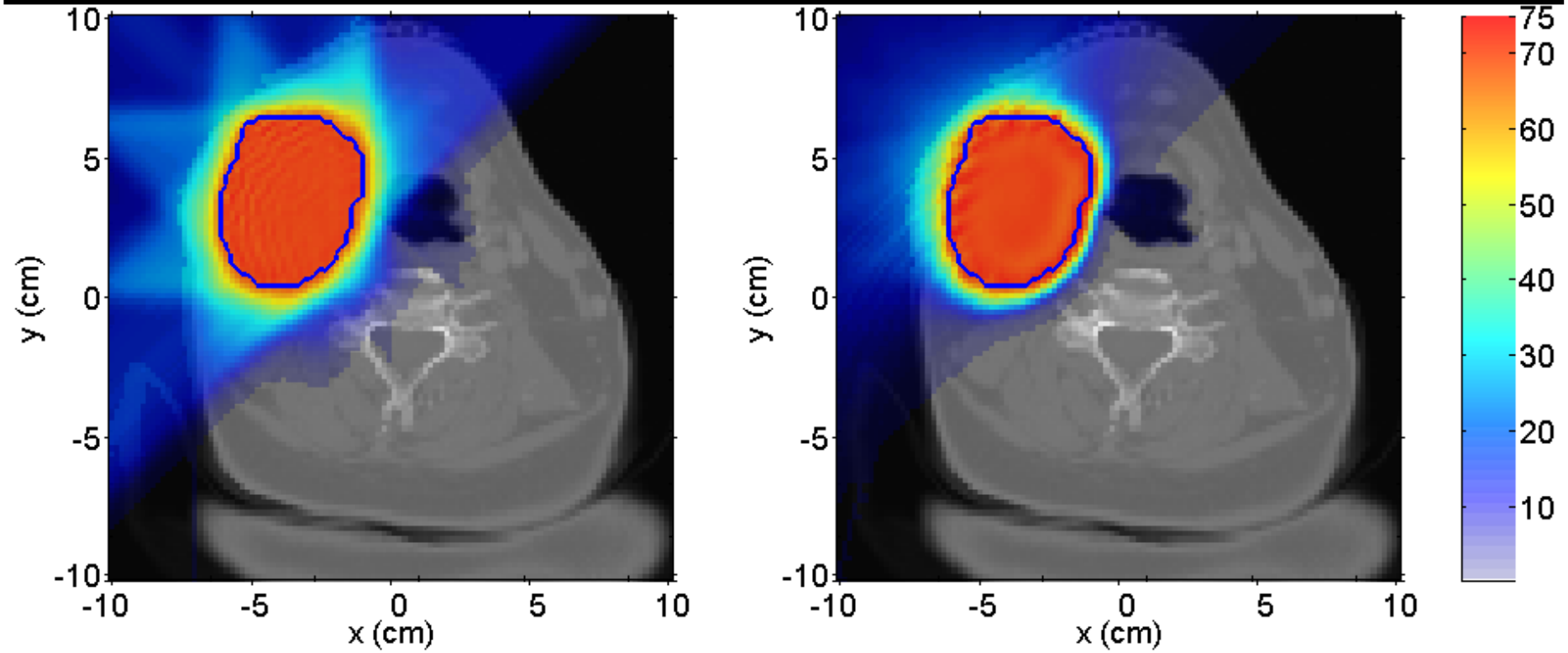
While not show here gantry rotation is occurring simultaneously with scanning.



Spot Scan and DET Distributions

SS Dose Distribution, 5 directions

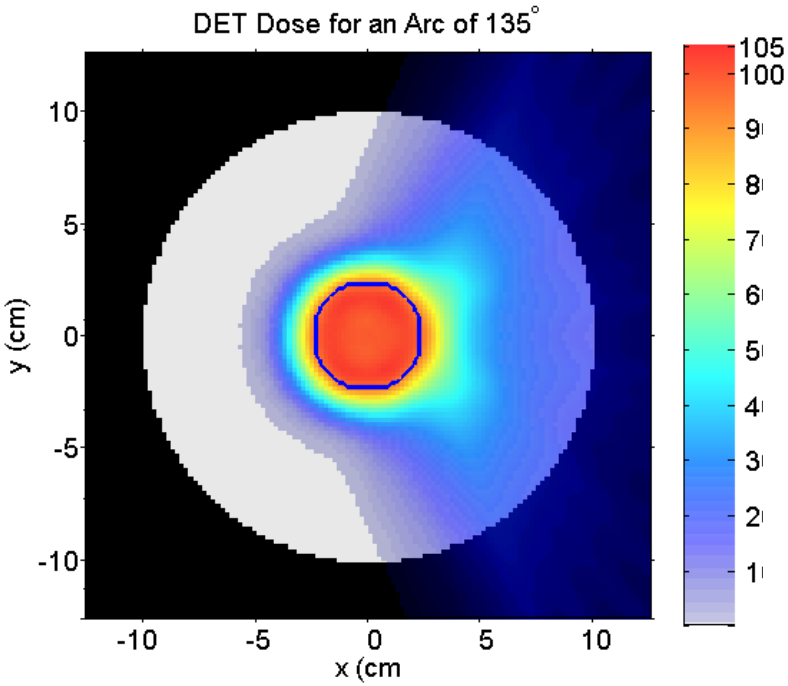
DET Dose Distribution, 25 directions

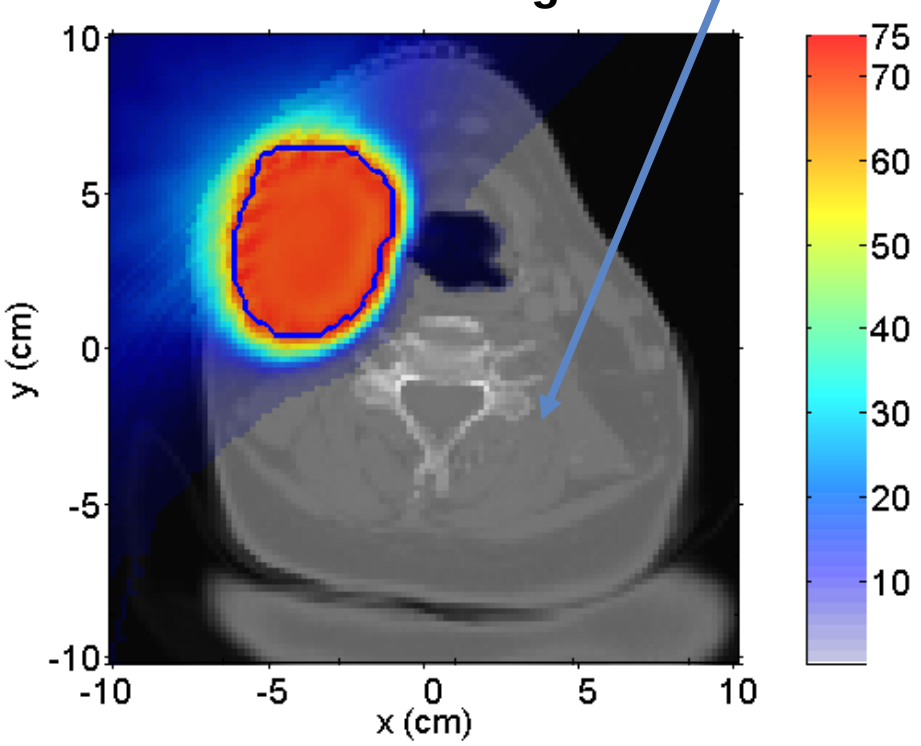


- DET can be delivered with limited arc therapy.
- On average, arc therapy enables lower proton energy to be delivered.

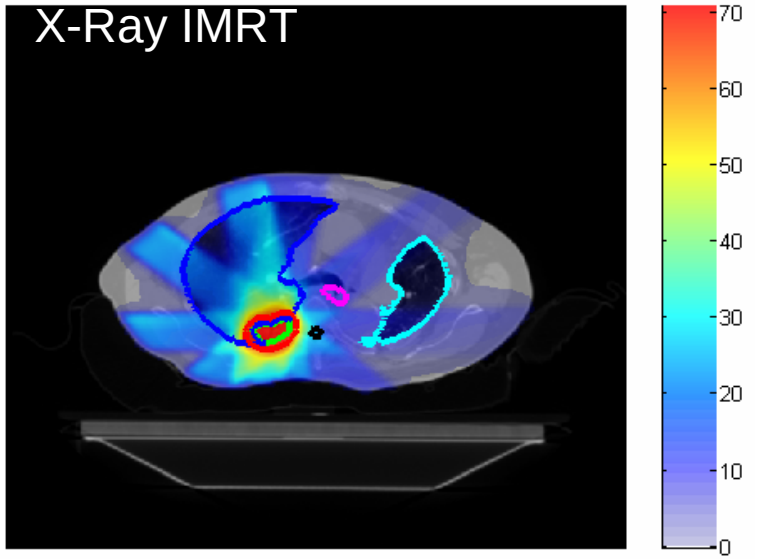
Intensity Modulated Protons Can Be Done With Limited Angle DET Arcs

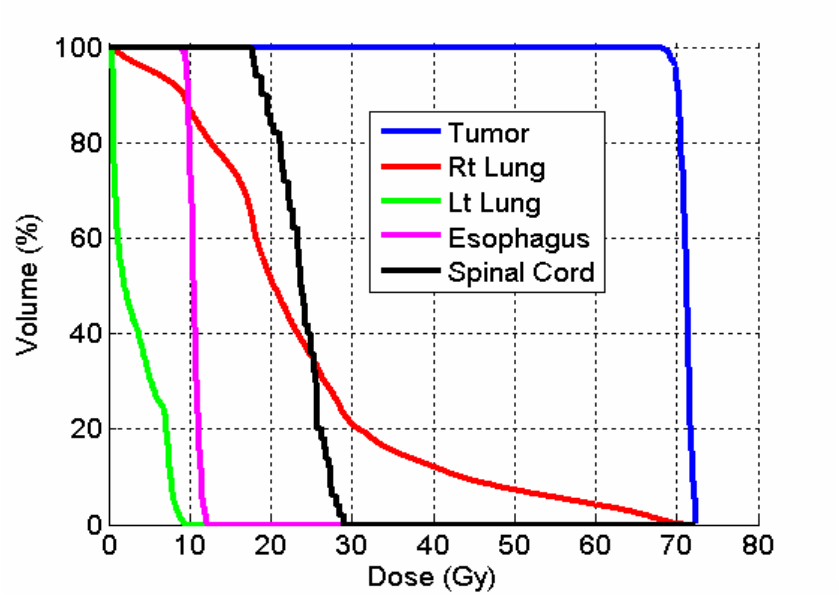
Limited arc delivery means large volume of the patient is at ~0 dose.

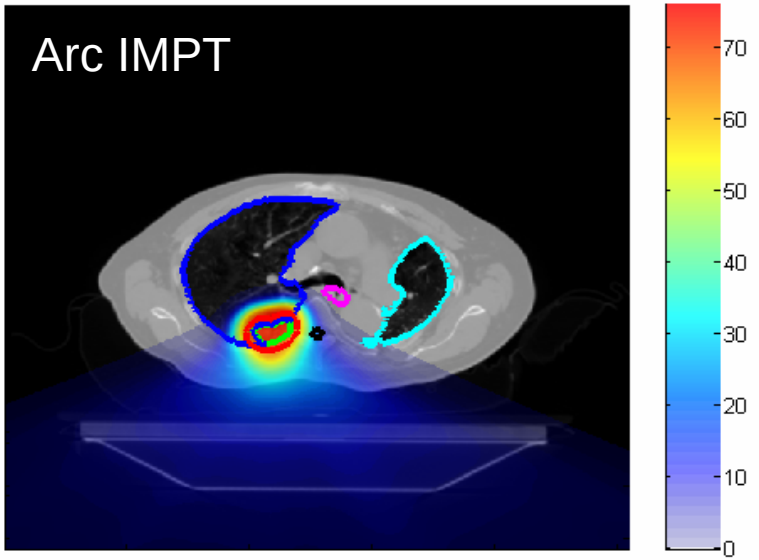


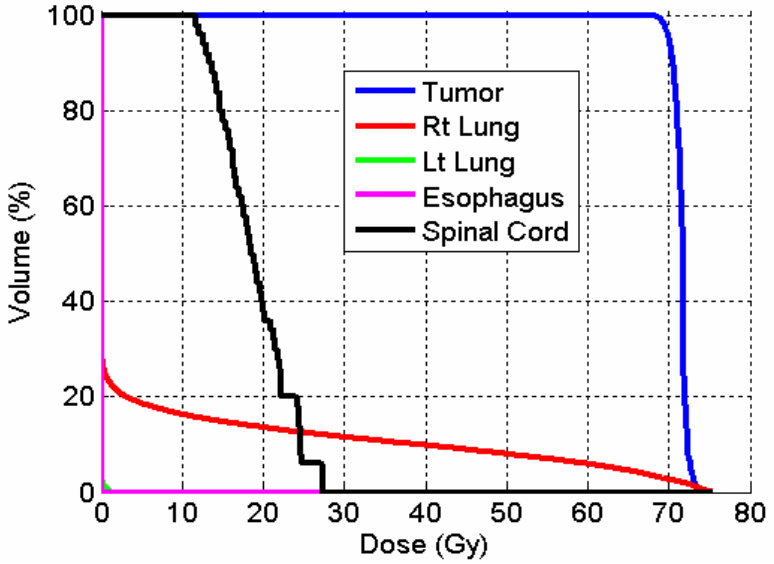


5 Field X-Ray IMXT Vs Arc IMPT









What is distal edge tracking?

20%	1.	Instead of portal imaging, it tracks where the Bragg peak falls.
20%	2.	It is an IMPT method that despite generating more integral dose is faster to deliver.
20%	3.	It is a slower but provides a more homogeneous dose than conventional spot scanning.
20%	4.	A form of IMPT that places the Bragg peak on the distal side of the target volume and is faster to deliver.
20%	5.	It reduces the uncertainty of Bragg peak placement.

What is distal edge tracking?

1. Instead of portal imaging, it tracks where the Bragg peak falls. Protons do not produce portal images. CT is required.

2. It is an IMPT method, that despite generating more integral dose, is faster to deliver. No DET generally has the lowest integral dose of any IMPT method.

3. It is slower but provides a more homogeneous dose than conventional spot scanning. It is faster and provides a homogeneous dose equivalent to other IMPT methods.

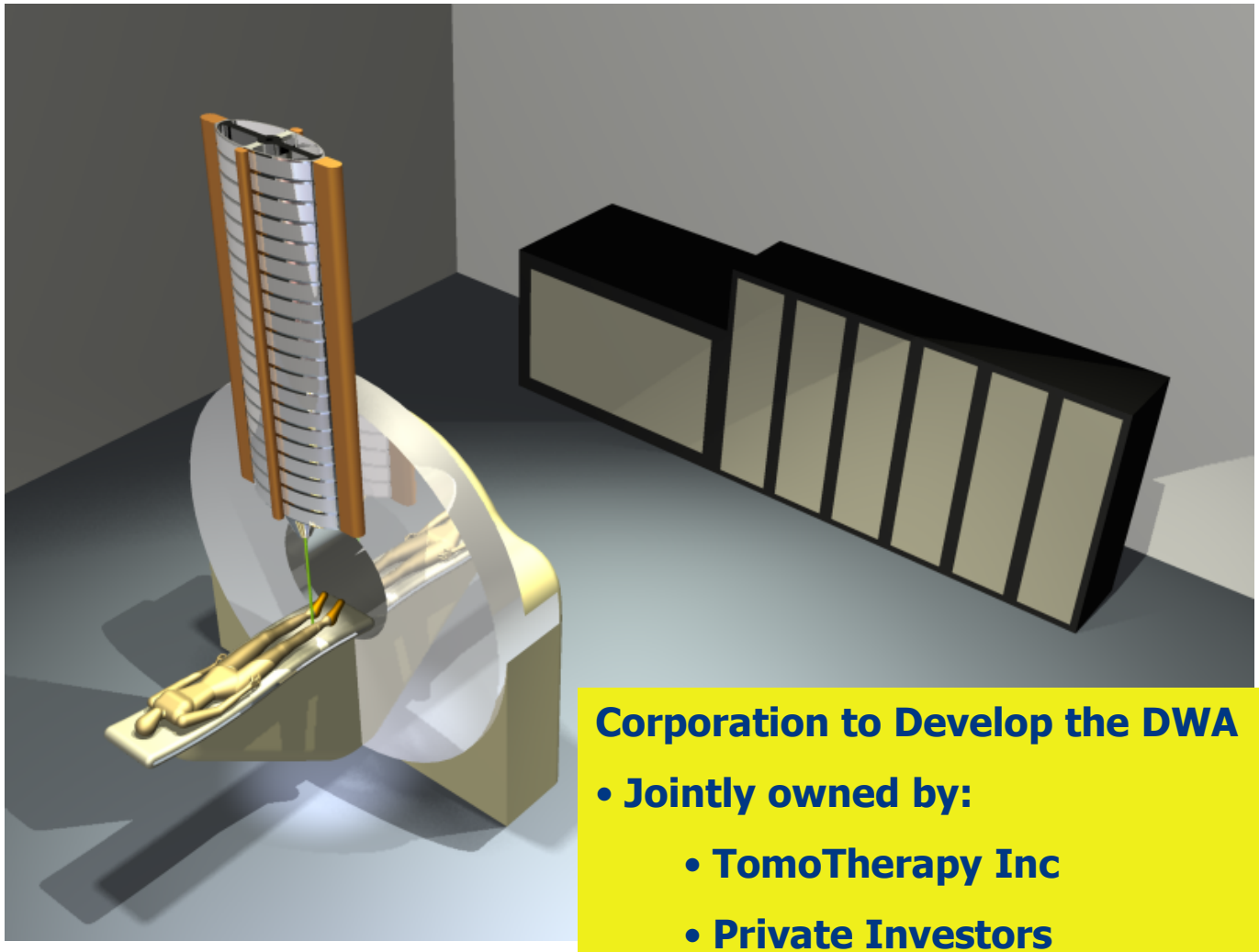
4. ***A form of IMPT that places the Bragg peak on the distal side of the target volume and is faster to deliver.*** Intensity modulation produces dose uniformity in the target volume.

5. It reduces the uncertainty of Bragg peak placement. It actually increases the delivery uncertainty, however, the system will be CT guided to ensure the Bragg peaks fall on the distal side of the target volume.

Conclusions

- **DWA is a multistage inductive accelerator under development at Lawrence Livermore National Lab.**
- **Acceleration gradient of 100 MV/m possible.**
- **200 MeV protons in 2 meters.**
- **Beam energy, intensity and spot size variable pulse-to-pulse.**
- **IMPT can be achieved with spot scanning or distal edge tracking through limited arcs.**

Compact Particle Accelerator Corporation



Corporation to Develop the DWA

- **Jointly owned by:**
  - **TomoTherapy Inc**
  - **Private Investors**
  - **Radiation Oncology Centers**