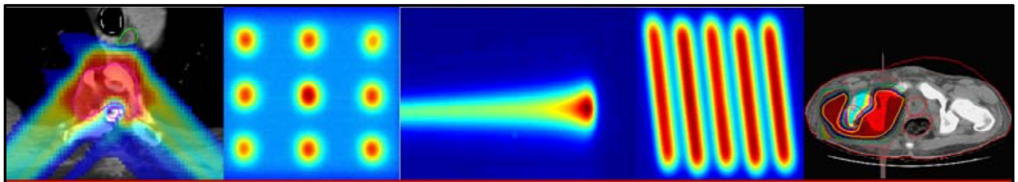

AAPM 2011: Overview of Proton Therapy Technology

Vancouver 2011

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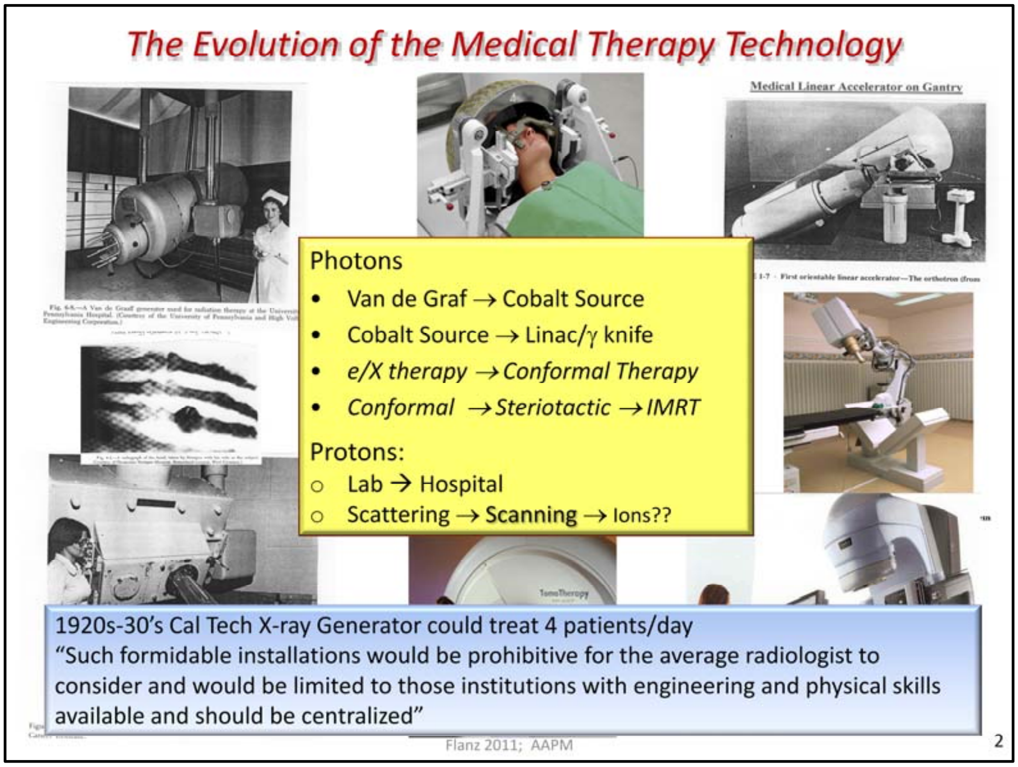
The Evolution of the Medical Therapy Technology
Medical Linear Accelerator on Gantry
Photons
• Van de Graf → Cobalt Source
• Cobalt Source → Linac/γ knife
• e/X therapy → Conformal Therapy
• Conformal → Steriotactic → IMRT
Protons:
○ Lab → Hospital
○ Scattering → Scanning → Ions??
1920s-30’s Cal Tech X-ray Generator could treat 4 patients/day
“Such formidable installations would be prohibitive for the average radiologist to consider and would be limited to those institutions with engineering and physical skills available and should be centralized”
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2

Goals of Radiotherapy

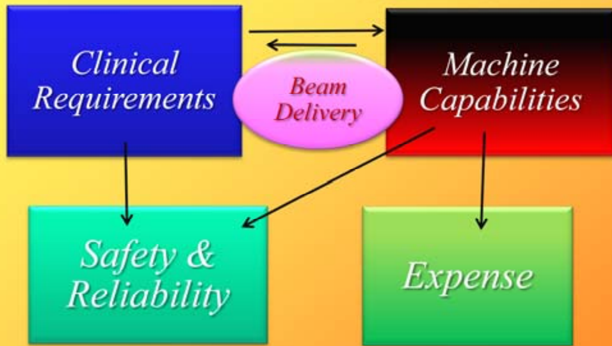
- *Deliver the Prescribed Dose.*
- *Deliver the Prescribed Dose Distribution.*
- *Deliver Dose Distribution to the right place.*

What is needed for Radiotherapy?

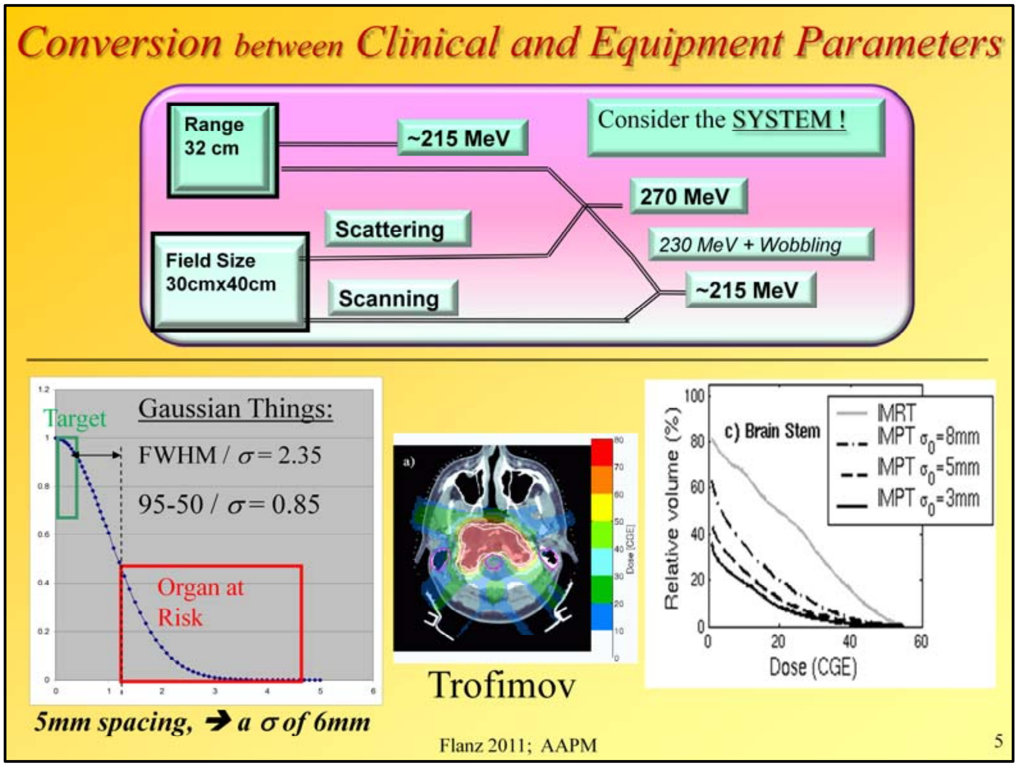
- *A Beam with the appropriate Range.*
- *A Beam with the appropriate timing.*
- *A way to control & measure Dose Distribution.*
- *A way to direct the beam to the right place.*
- *A way to find out where the right place is.*

What should be considered when thinking about Radio-Therapy Equipment?

Safely Spread out & control the beam in 5d: *x, y, depth, time, particle (e.g. X-ray, p, C)*

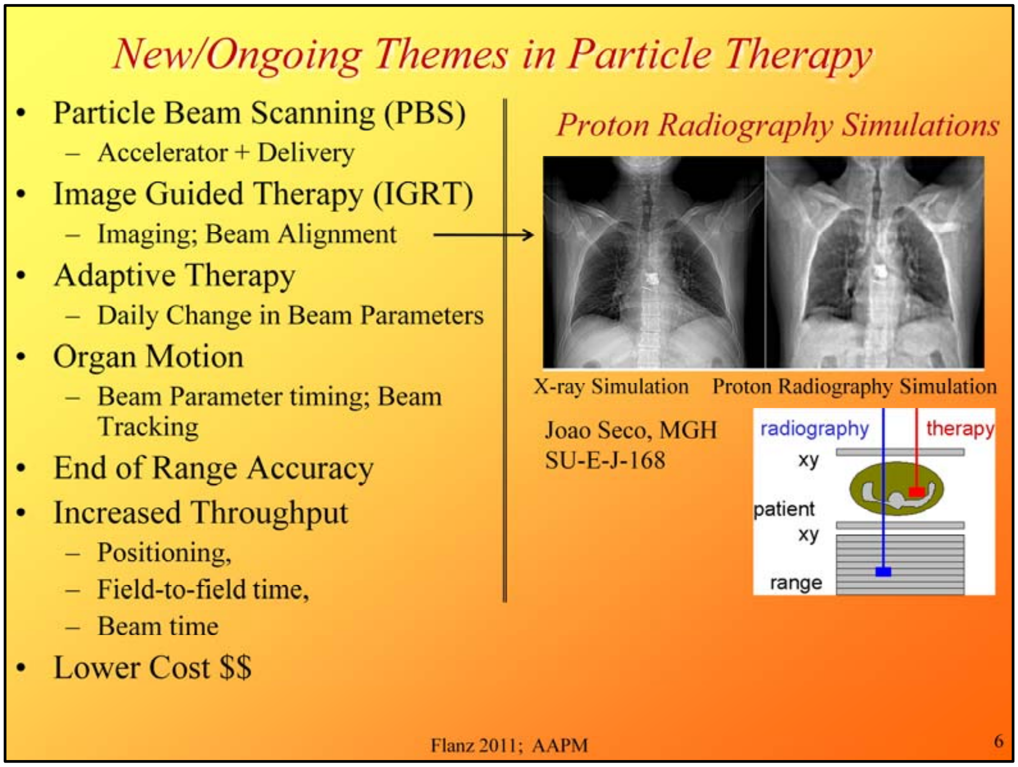


- Convert desired Clinical Performance to Equipment capabilities.
- Choice of Beam Delivery may affect the Rest of the Equipment
- Sometimes the Hardware Constraints will limit the Clinical Specs
- Always factor in Safety, Reliability and Cost.
- Is there a Balance among these Considerations?

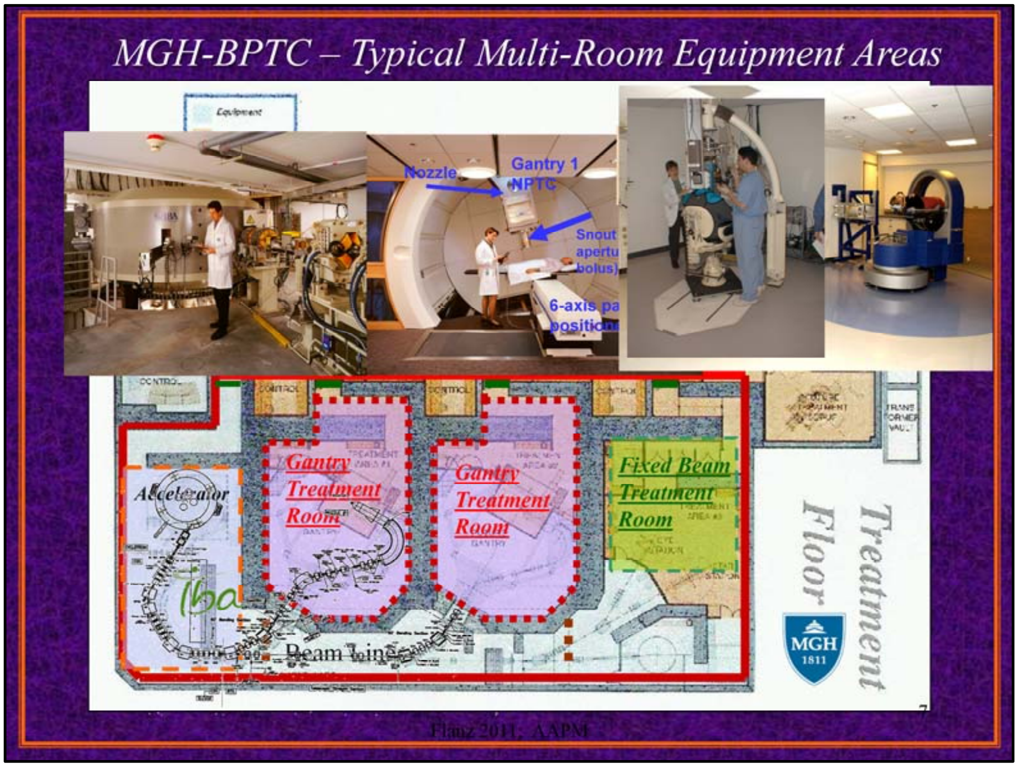


Upper Figure: If the clinical requirement is a range of 32cm, that would imply an unmodified beam energy of 215 MeV. However if one also required that the desired field size is greater than the unmodified beam size (which it will almost always be), then it depends on the type of beam spreading used. If Scattering is used, wherein material is put in the beam path to scatter the beam, then the energy is also degraded and the resulting beam energy requirement would be 270 MeV. Combination solutions are also possible.

Lower Figure: If the Scanning approach is used the penumbra can be simply the edge of the Gaussian beam. If there is a critical structure, say within 5 mm of the target edge, and we constrain the dose to be less than 50% of the target dose, then the sigma of the Gaussian beam would have to be less than 6mm. Alternatively, one can look at a realistic example. The DVH for this example shows the dose to the critical structure and compares that DVH for an IMRT plan and 3 scanning beam sizes. How much more would you pay for the 5mm beam sigma over the 8mm beam sigma? How much more would you pay for the 3mm sigma over the 5mm sigma?



Proton radiography is a potentially useful method for Proton Therapy, however to reach all sites sufficient energy (higher than normally needed for clinical application) is necessary. To date the only proton only machine with this capability is the ProTom synchrotron.


MGH-BPTC – Typical Multi-Room Equipment Areas
Nozzle
Gantry 1
NPTC
Gantry
Treatment
Room
Gantry
Treatment
Room
Fixed Beam
Treatment
Room
Accelerator
Beam Line
Treatment
Floor
MGH
1811
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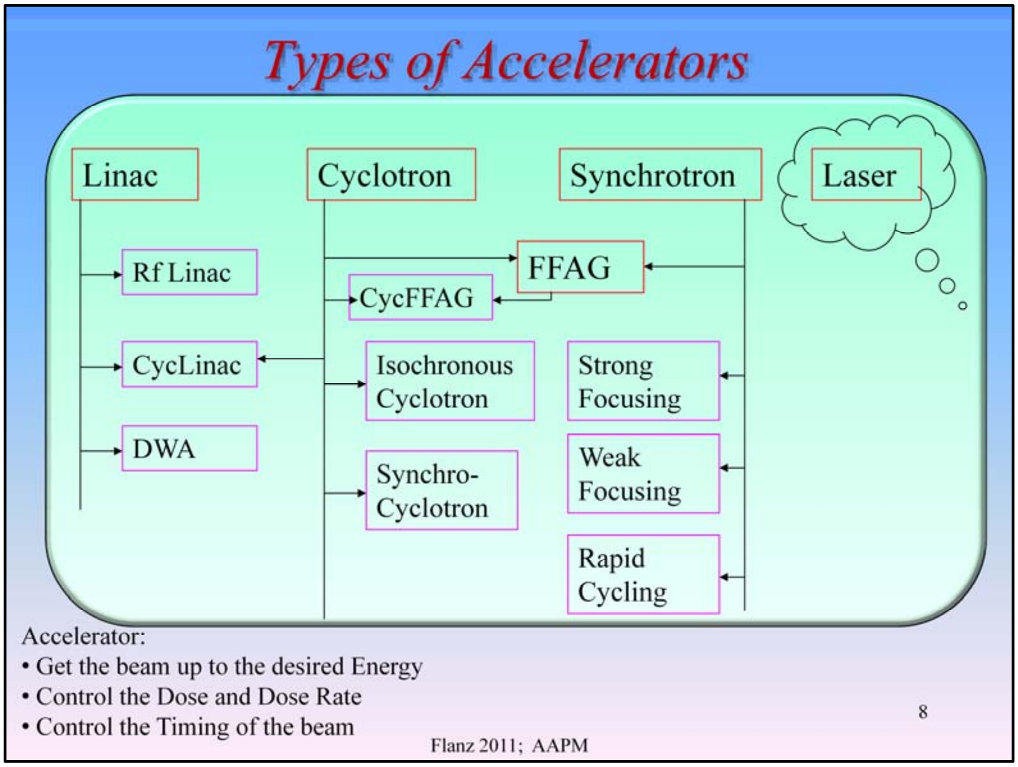
Types of Accelerators
Linac
Cyclotron
Synchrotron
Laser
Rf Linac
FFAG
CycFFAG
CycLinac
Isochronous Cyclotron
Strong Focusing
DWA
Weak Focusing
Synchro-Cyclotron
Rapid Cycling
Accelerator:
• Get the beam up to the desired Energy
• Control the Dose and Dose Rate
• Control the Timing of the beam
8
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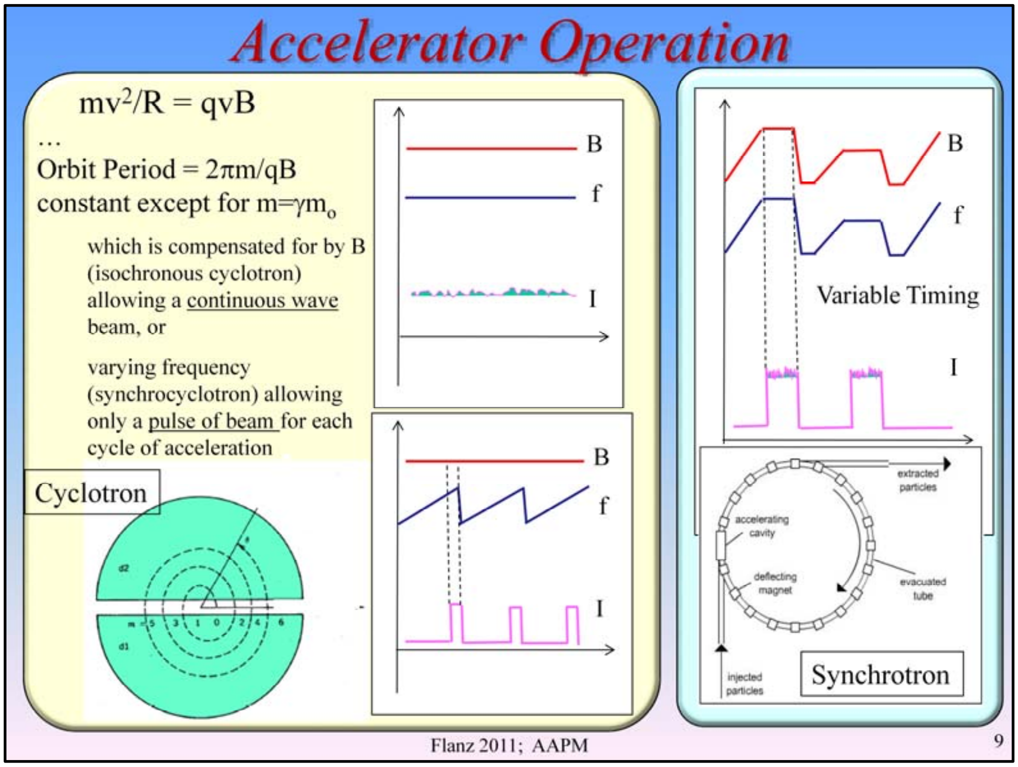


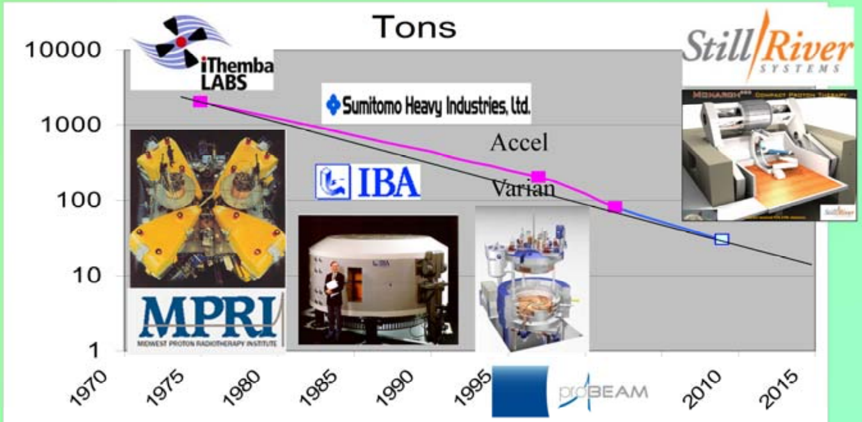
The time dependence of the beam is quite important from the point of view of how the beam will be delivered with a specific beam delivery modality, such as beam scanning.

In the case of a cyclotron, if the magnetic field and frequency are constant, then beam can be extracted continuously. In the case of a synchrocyclotron, when the frequency is cycled, then only a pulse of beam can be extracted at the end of each cycle.

In the case of the synchrotron, the beam can be extracted when the magnetic field and frequency are stabilized. The time extent of this period is variable.

Note that the constancy of the beam current extracted is not always as constant as one would like.

Proton Cyclotrons now can fit thru the Hospital door



- Lots of Current at High Energy, Fixed energy cyclotron needs it because..
- Degrader ➔Larger Emittance ? – Gantries and Beamline?
- Mixed results on Current Control?
- CW Beam always available when you need it - Scanning / Organ Motion
- SynchroCyclotrons have Short PULSED beam – Pulse rate IMPLICATIONS…

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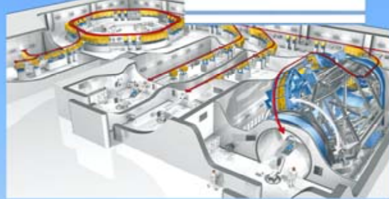
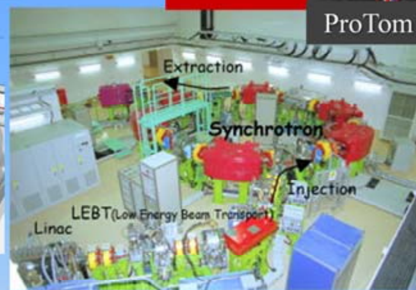
10

Proton Synchrotrons also in a "Hospital"



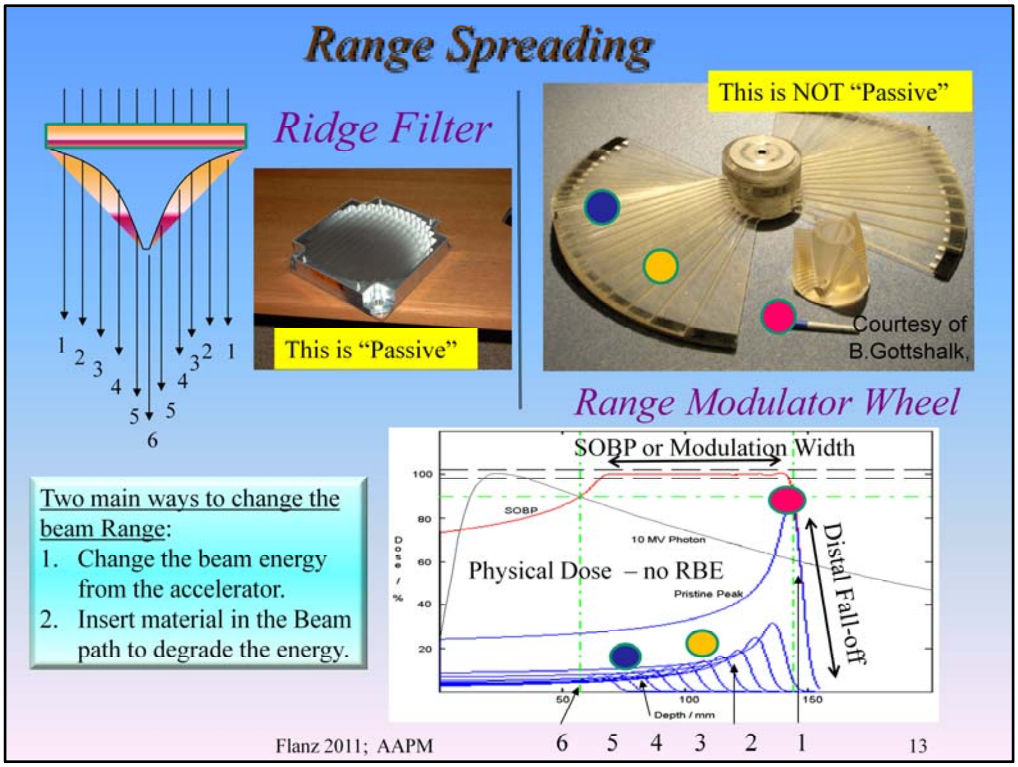


- No Degrader – Accelerate to desired energy.
- Mixed results on Current Control?
- Pulsed Beam – Variable pulse length
  - And can be synchronize with gating signal
- Energy Change Time limits ?
  - Governed by cycle time, or is it …
  - Or Rapid Cycling Synchrotron

Some *Goals of a Beam Delivery System*

- Create the Desired Dose Distribution in the Target:
  - The unmodified (***pencil***) beam does not match the shape of the target (e.g. tumor) so create the required distribution. (**Longitudinal AND Transverse**)
  - Direct the beam to the target and with the desired dose distribution
- Minimize Unwanted Dose:
  - Dose outside the target area is not good (from any particle- e.g. neutrons) (*Penumbra, Distal Falloff, …*)
- Optimize the Treatment Time:
  - Allow for an efficient treatment
- Beware of Sensitivities and Tolerances:
  - Use realistic tolerances of the incoming beam parameters (position, angle, timing)
- Consider Operational Efficiency & Cost:
  - Patient Specific Hardware
  - Number of fields required
  - QA

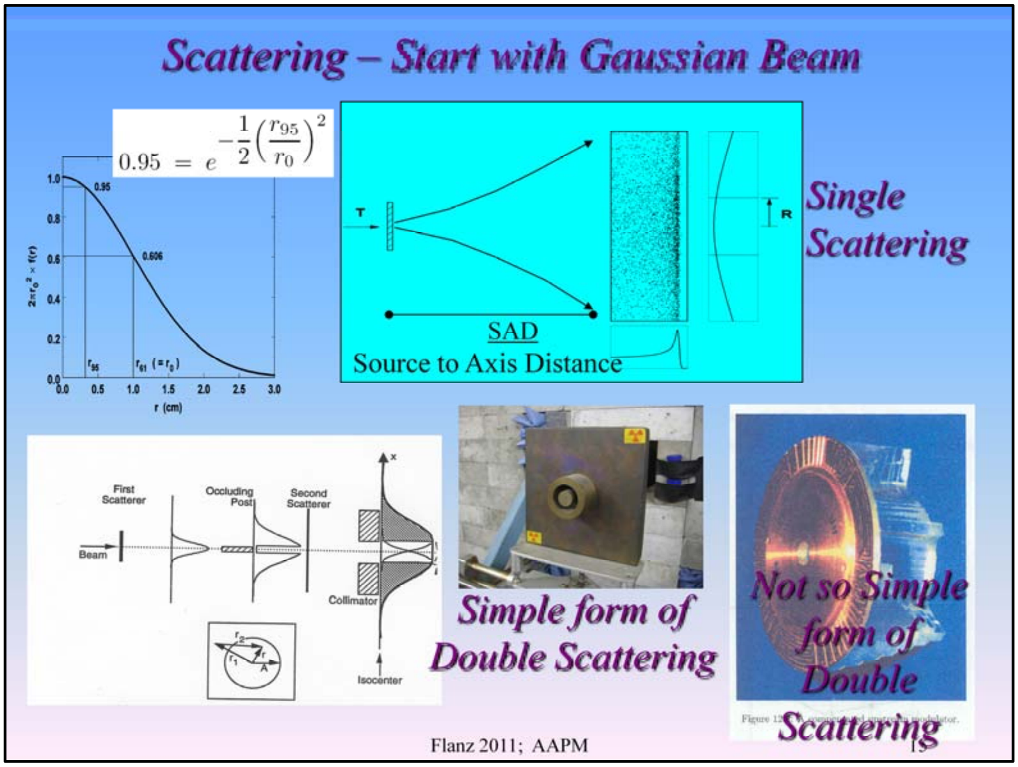
Challenges (see Palta's talk):
-- Conforming Dose
-- Moving Targets
-- Finite Penumbra and Range spread



Note that only systems with a ridge filter are Passive. Range modulators are spinning and in many cases the beam is either modulated or turned on and off during a wheel revolution and thus this delivery is NOT passive.

Transverse Spreading Options

- Scattering (Sometimes Passive, Sometimes not)
  - Single Scattering
  - Double Scattering
- Wobbling (Beam Scanning with Scattered beam)
- Pure Magnetic Scanning (unmodified, uncollimated beam)
- Combined Magnetic and Mechanical Scanning
  - Moving Magnet
  - Moving Patient


Scattering – Start with Gaussian Beam
$0.95 = e^{-\frac{1}{2}\left(\frac{r_{95}}{r_0}\right)^2}$
0.95
0.606
$2\pi r_0^2 \times f(r)$
r_{95}
r_{61} ($= r_0$)
r (cm)
T
R
SAD
Source to Axis Distance
Single Scattering
First Scatterer
Occluding Post
Second Scatterer
Beam
Collimator
Isocenter
Simple form of Double Scattering
Not so Simple form of Double Scattering
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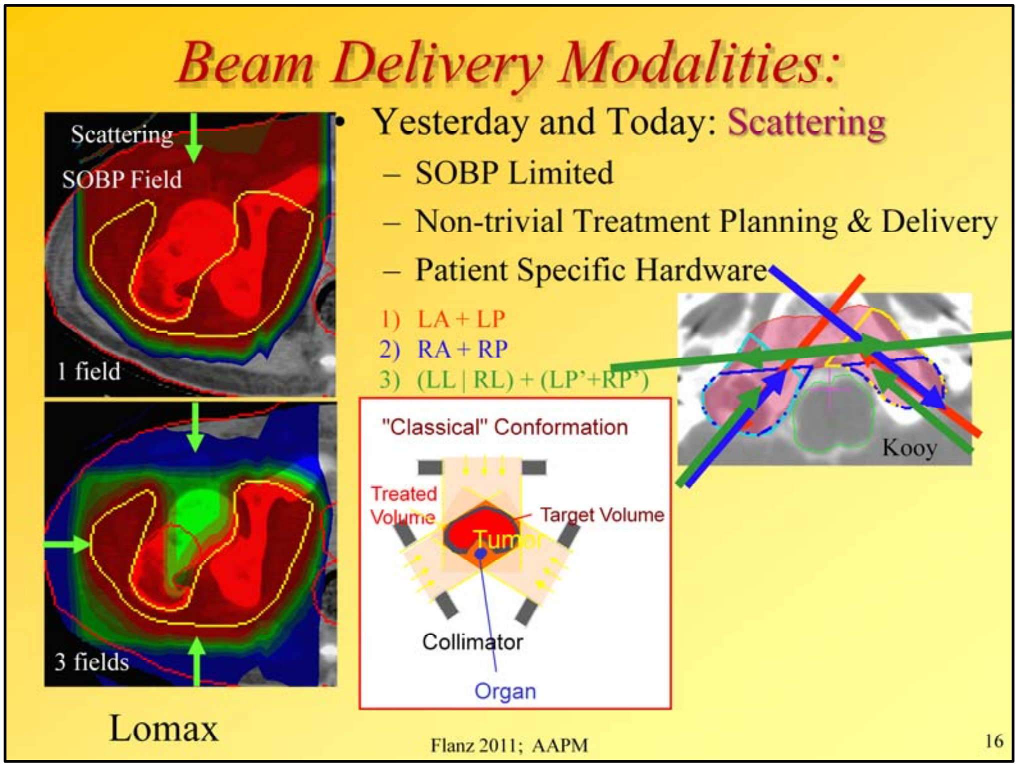
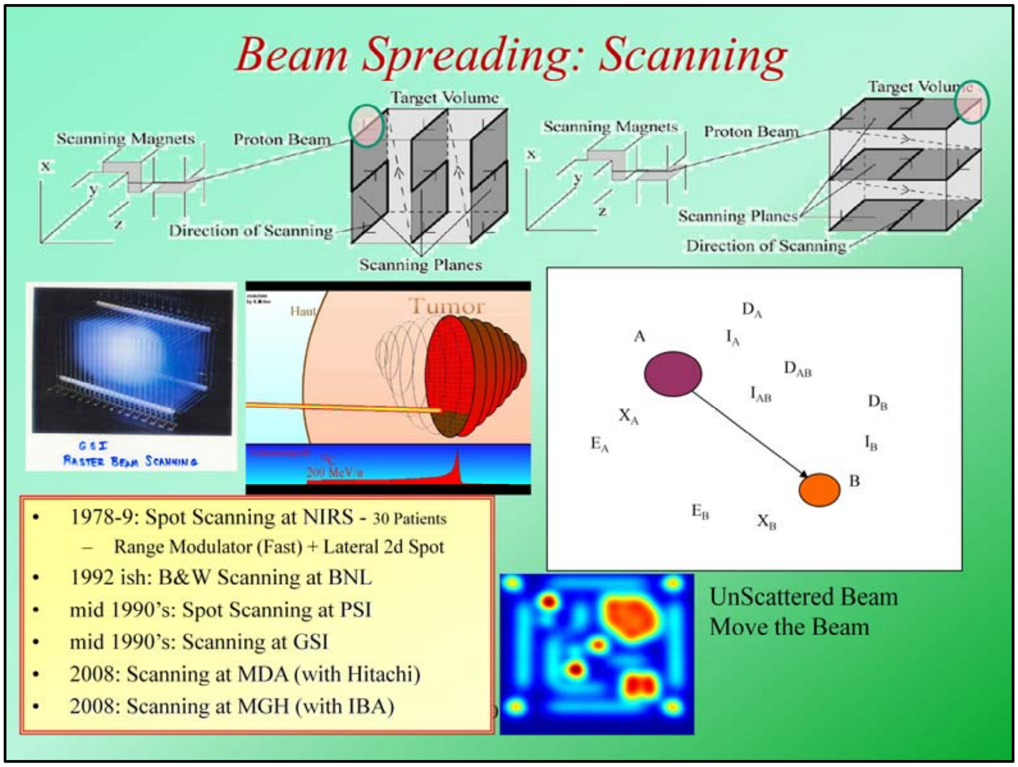


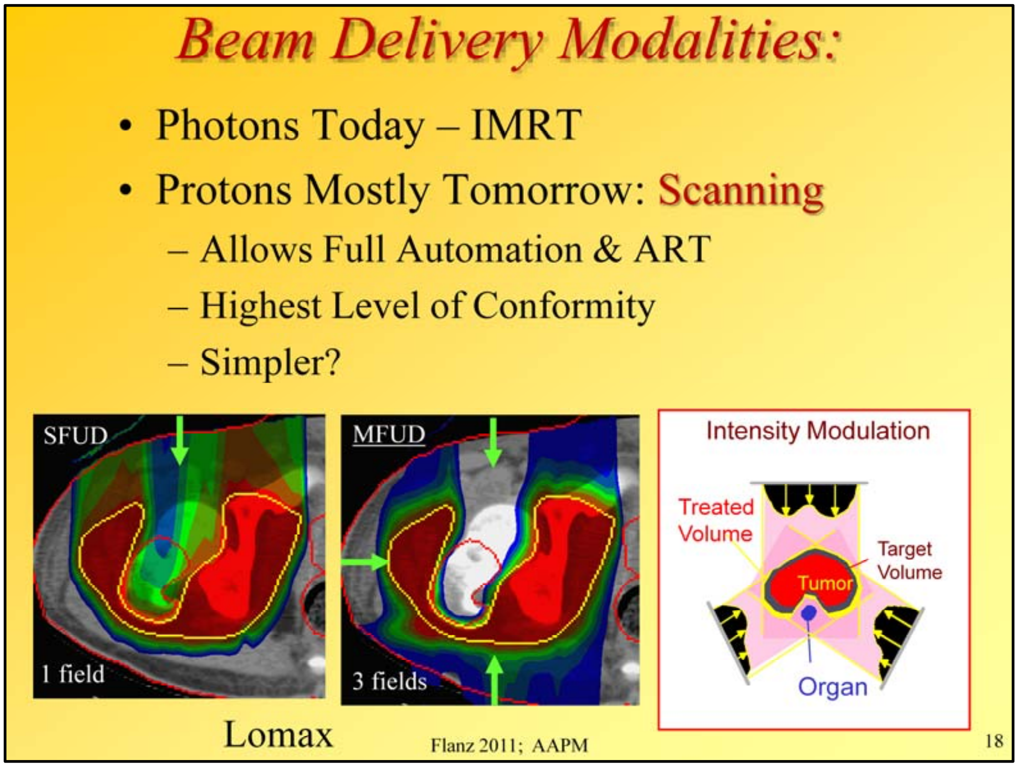
While, in principle the beam delivery modalities of classical conformal photon therapy and scattered SOBP fields are similar, in that the dose distribution across the field is constant. The way in which a particle beam can be combined is much more powerful and allows for a more conformal distribution.

On the other hand, the ways in which the SOBP beams are combined and planned are non-trivial as the beams are matched and patched sometimes abutting transverse edges and distal edges.

Thus while the beam delivery technique may seem similar between photon and particle beam delivery, there are significant differences in technique and conformality.

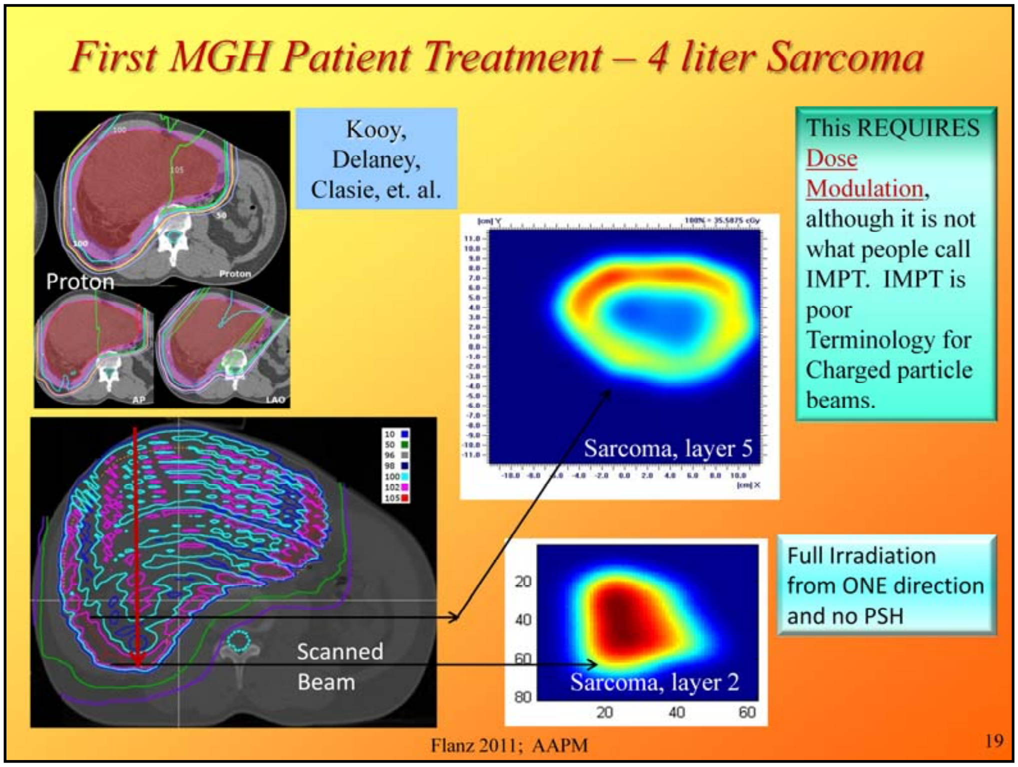


Beam Scanning is quite simply the act of moving the beam from place to place and perhaps changing the parameters. However, the details are quite detailed. The way in which the beam is moved, via spots or lines, via transverse or longitudinally spread, can be done in a variety of ways. However in all cases, incredible conformality is possible both distally and proximally. Although in the proximal direction, there is some dose which was deposited along the path when the distal dose was delivered.



Scanning beam delivery modality is similar to that of IMRT in that the dose distribution does not have to be constant across the target for each field. However for particles it is possible to achieve a uniform dose in one field or as a result of multiple fields in which each individual field delivers is non-uniform dose. Note that the degree of conformality possible with a single field of particles is quite high. This suggests that very high conformality is possible with much fewer beam fields than in the case of IMRT.

Also note that in beam scanning the intensity is not necessarily modulated, although it is possible to deliver a modulated dose profile so that it requires multiple fields to achieve an overall uniform dose (e.g. Multiple Field Uniform Dose – MFUD). We will also show in the next slide, that even for a single field uniform dose requires dose modulation. This makes scanning beam delivery quite a different modality than IMRT and these two should not be confused.



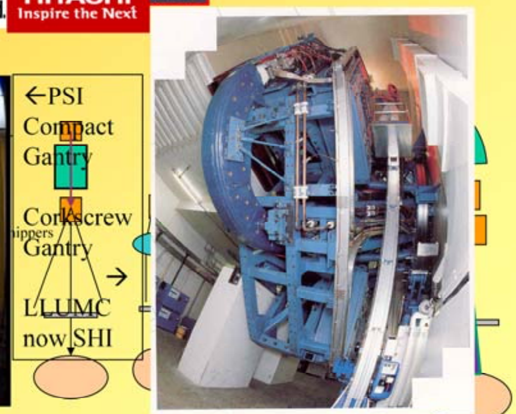
Note that when depositing the distal dose, some dose is deposited proximally. Therefore more proximal layers have a characteristic island of dose, or extreme dose modulation required in order to achieve a uniform dose in a single field. Thus dose modulation is required even in a single field unlike IMRT.

What do we need to move the Patient to the Beam, or vice-versa ?

- A Device to direct the beam at the appropriate angle.
- A Device to position the patient at the appropriate angle and position.
- Do we need a 360° Gantry for Everything?
- Are there enough patients to warrant special purpose, or limited purpose systems ?
  - Some Pediatrics
  - Steriotactic
  - Prostate
  - Eye …

But a Gantry is only part of the Story - it's the combination with other Systems that determines how the beam can be directed to the patient! (e.g. Including IMAGING)

In-plane Gantry Color Choices & Other Things



Gantries for Scattered Beams have dominated (Scatter after Bend)! Many more geometries possible for Scanning Gantries

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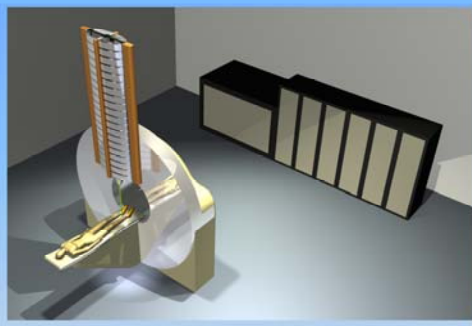
21

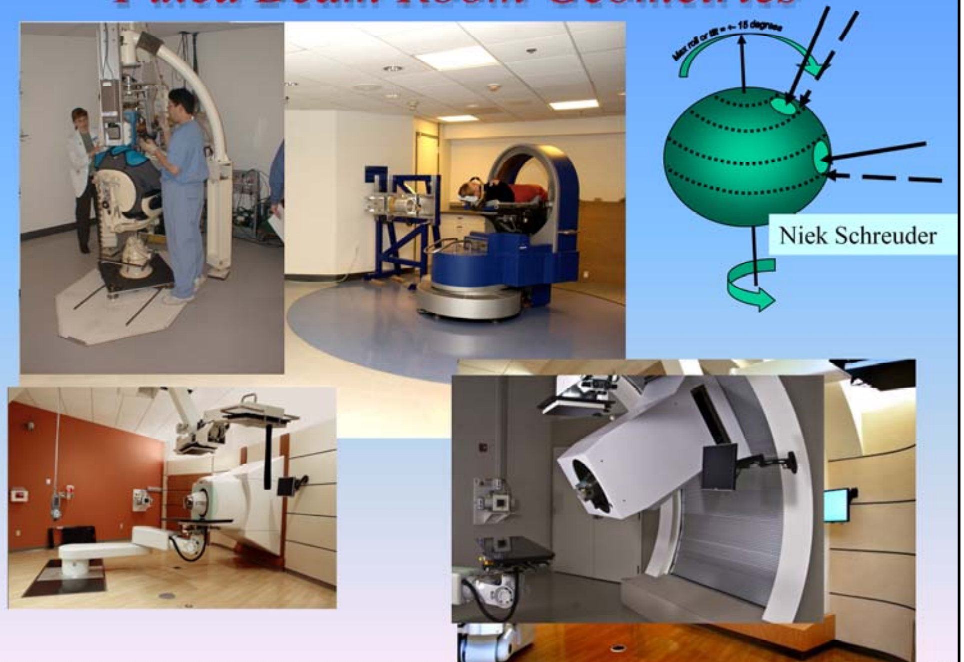
Accelerators on a Gantry



Superconducting Cyclotron Accelerator on a Gantry: Still River

Dielectric Wall Accelerator on a Gantry: CPAC

Fixed Beam Room Geometries



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Positioning – The Rise of the Robots

Integrated with Imaging Also !

External Setup

Imaging in Room using same Robot

etc. etc.

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24

Summary

- There are many options.
- There are many subtleties.
- There are many parameters.
- There is rapid evolution.
- Choice of the above is one way to address the issue of cost effectiveness.
- There is room for improvement still.
- Some terminology (e.g. IMPT, Passive Scattering, Raster Scanning …) can cause confusion. (AAPM TG 183)

The Francis H. Burr Proton Therapy Center

Thank You !

Change is a Constant !