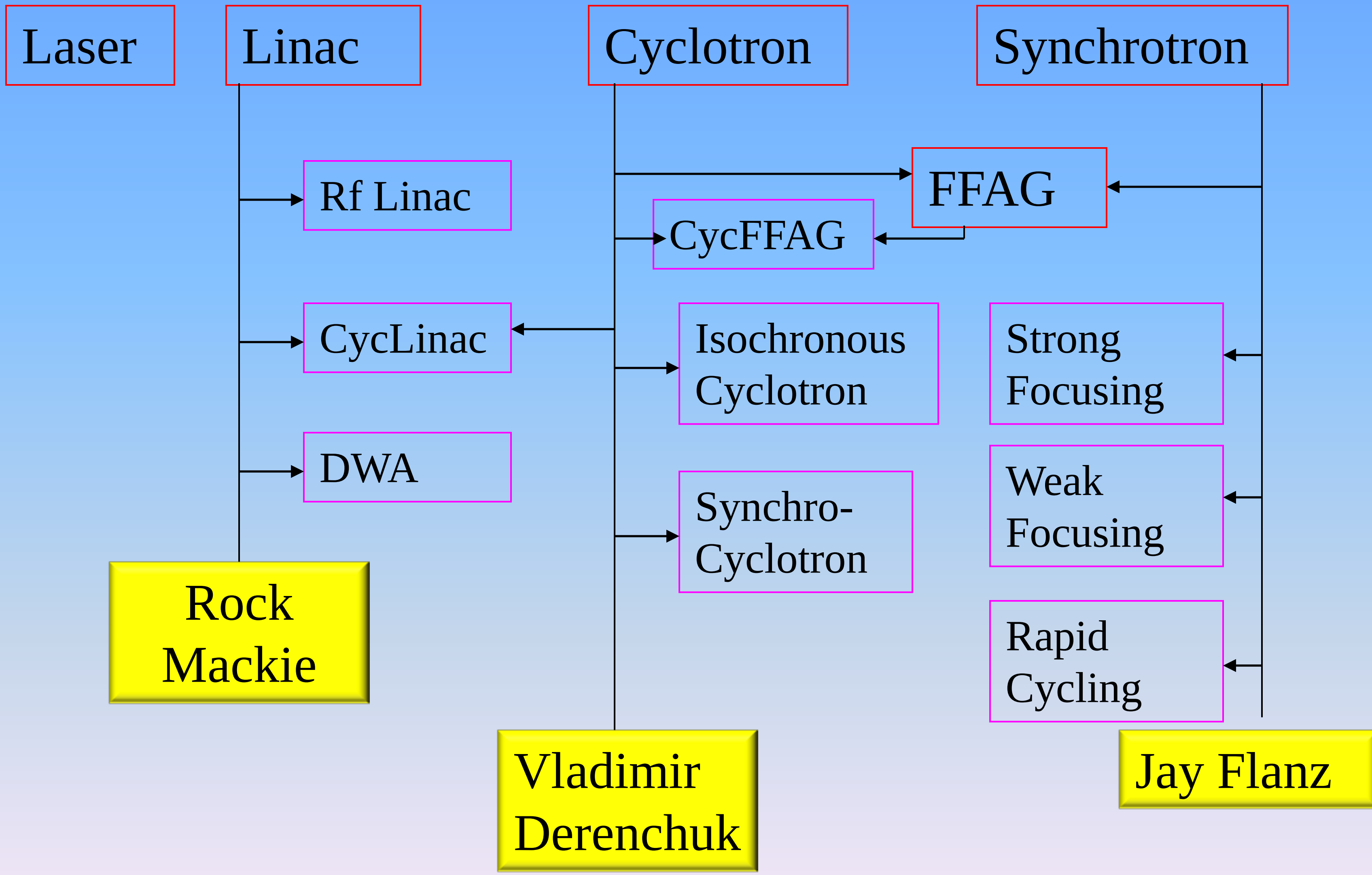
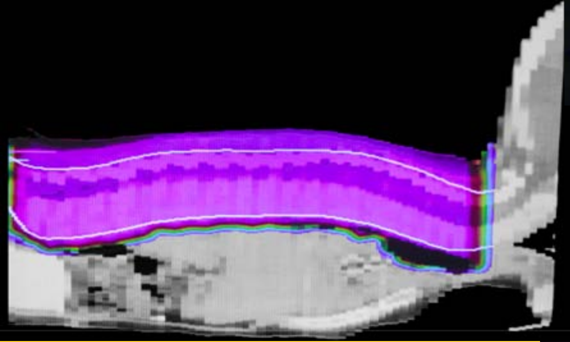
Particle Beam Technology and Delivery

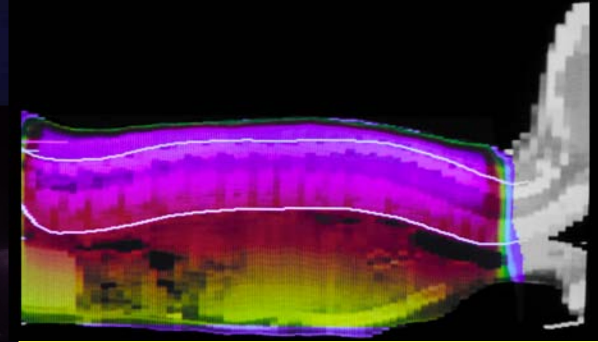
AAPM

Particle Beam Therapy Symposium

Types of Accelerator Systems







Particle Beam Technology & Delivery

Synchrotrons

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Harvard Medical School

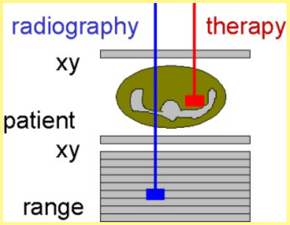
Ongoing Themes in Field of Particle Therapy

Examples for CONTEXT of Technology and Delivery:

1. *Pencil Beam Scanning (PBS)*
   - Impact on: Beam Parameters from Accelerator + Delivery
   - Scanning "type"; Beam Size; etc.
2. *Image Guided Therapy (IGRT)*
   - Impact on: Imaging; Beam Alignment
   - PROTON Radiography/Tomography ????
3. *Organ Motion*
   - Impact on: Beam Parameter timing; Beam Tracking
4. *End of Range* ® - Proton Range vs. HU ?
5. *Field Directions*(θ,φ,ψ): How to treat specific sites?
6. *Lower Capital Costs $$$*
7. *Increased Throughput*
   - Positioning, Aligning, Field-to-field time, Beam time

X-ray Simulation   Proton Radiography Simulation

Joao Seco, MGH



These may not be new concepts, but they are the current foci owing to the fact that the 'first' round of system specs have been satisfied. (i.e. the Berkeley/MGH report of 20 years ago.)

Separated Themes may not lead to system solutions!

Need System Solutions

- How to deliver a Rx non-uniform dose distribution to a moving target with a desired conformance?

  vs. e.g. Continuous Beam Scanning: with 3mm Sigma

  – *This involves beam parameter TIMING issues, beam trajectory and range manipulation, Apertures (or not), etc.*

- How to deliver quality treatment to the appropriate number of patients at an affordable cost?

  vs. e.g. Out of room setup; Energy Change in 2 seconds

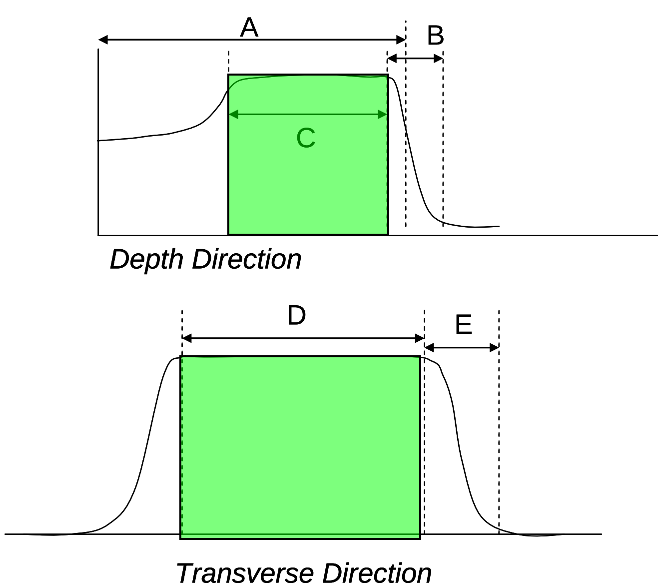
  – *This involves automated remote operations*
    - *Imaging and Analysis and Correction of Position*
    - *Go from Field to Field without delays (e.g. Moving things remotely)*

It's not just the accelerator. It's the other components and how the accelerator works with the other components !

Goal of Particle Radiotherapy

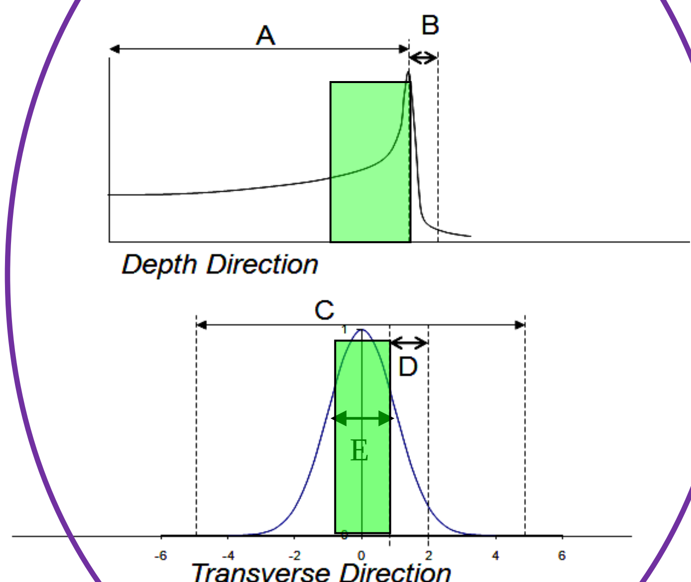
- Deliver required dose to a target in a reasonable time
- Deliver the correct dose distribution to the correct location
  - Minimize the dose outside the target

Dosimetric Regions of Interest (Scattering)



- C&D = desired dose
- A+B+E = unwanted dose

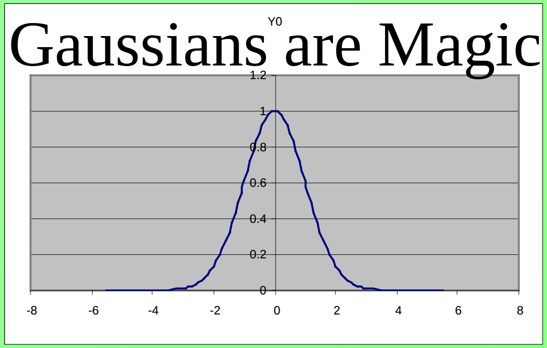
Dosimetric Regions of Interest (Scanning)

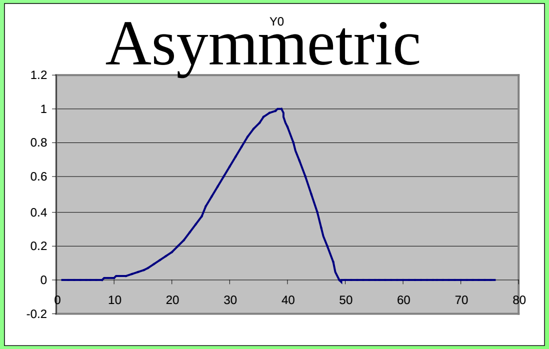


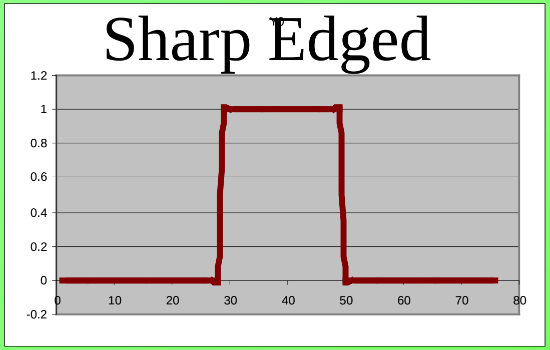
Use this as the building blocks to deliver dose

- E, B&part of A= desired dose
- Some of A+(C-E) = unwanted dose

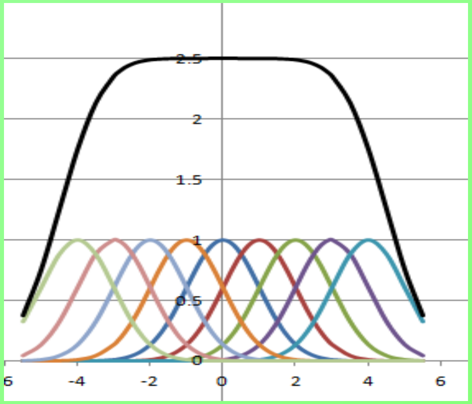
Spread out Transverse Dose with Scanned beam spots

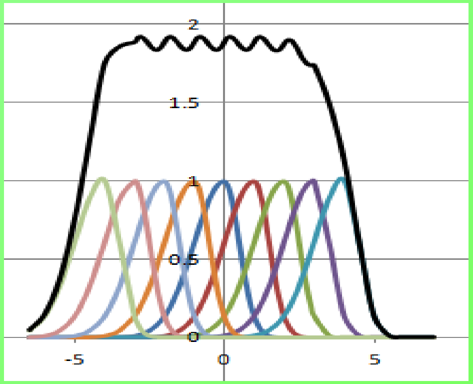




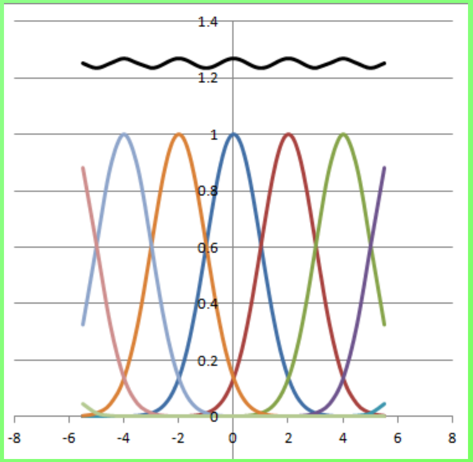


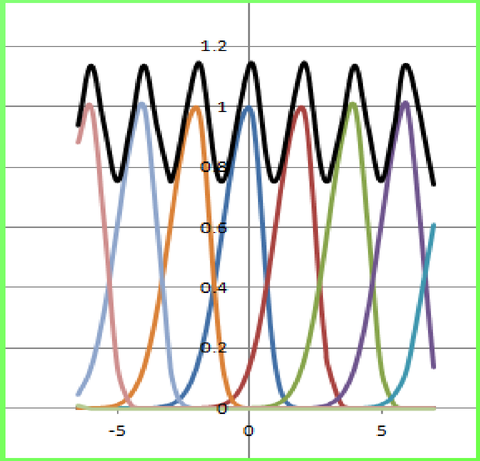
Spacing: 1 sigma

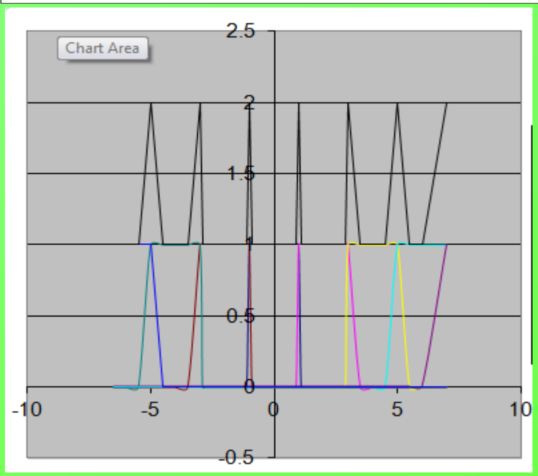




Spacing: 2 sigma





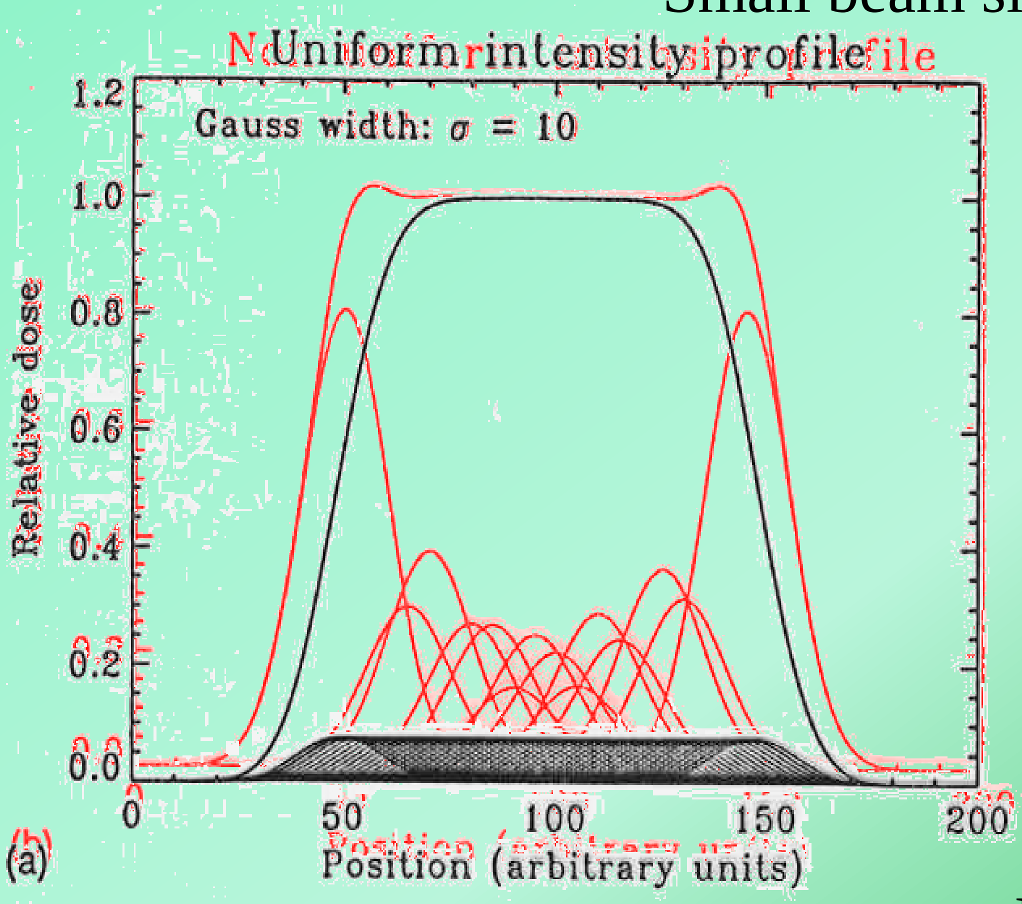


Transverse spreading using superposition of unmodified beams.

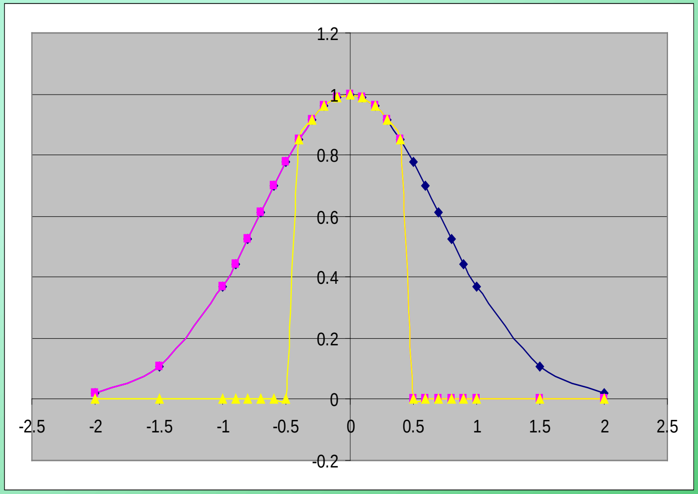
Uniform dose scenario.

Scanning – *The "Penumbra" of a scanned beam*

Small beam sigma vs. Cut off edges.



PSI/Berkeley



In this case the Technology required has to deliver a dose modulated distribution

In this case the Technology required has to produce a different beam profile (where it counts).

Materials in the Beam Path – Including the Patient

The Raw beam shape is NOT the only contributing factor

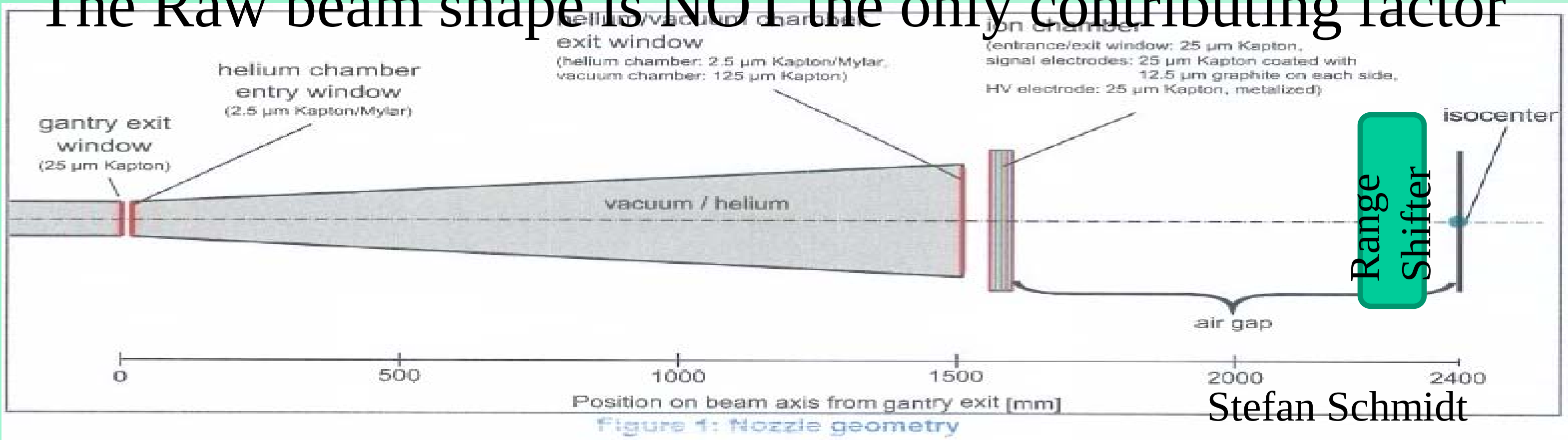


Figure 1: Nozzle geometry

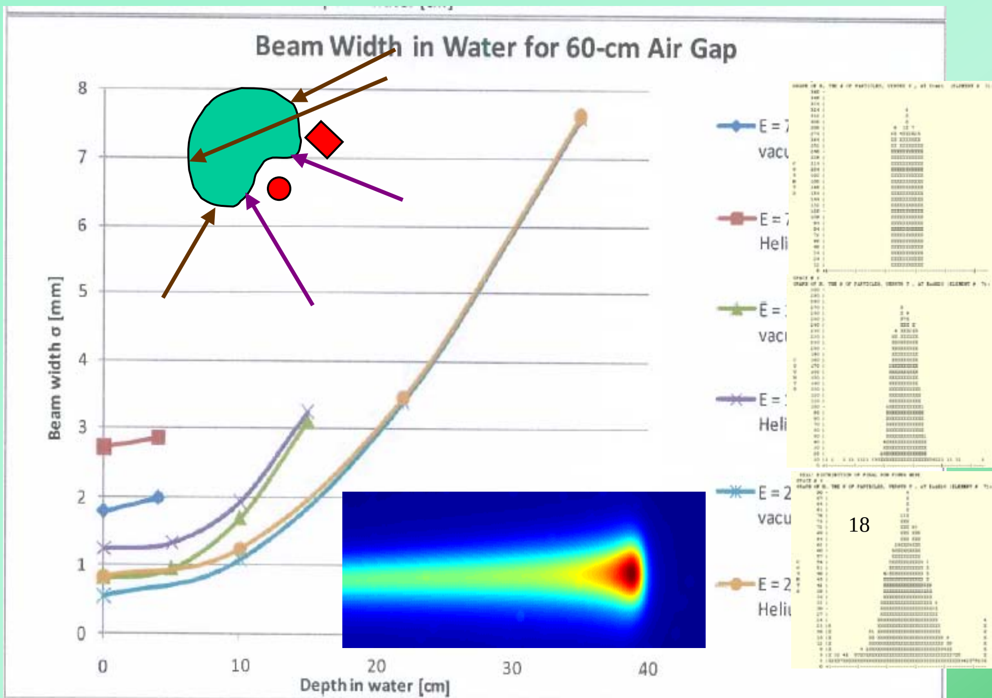
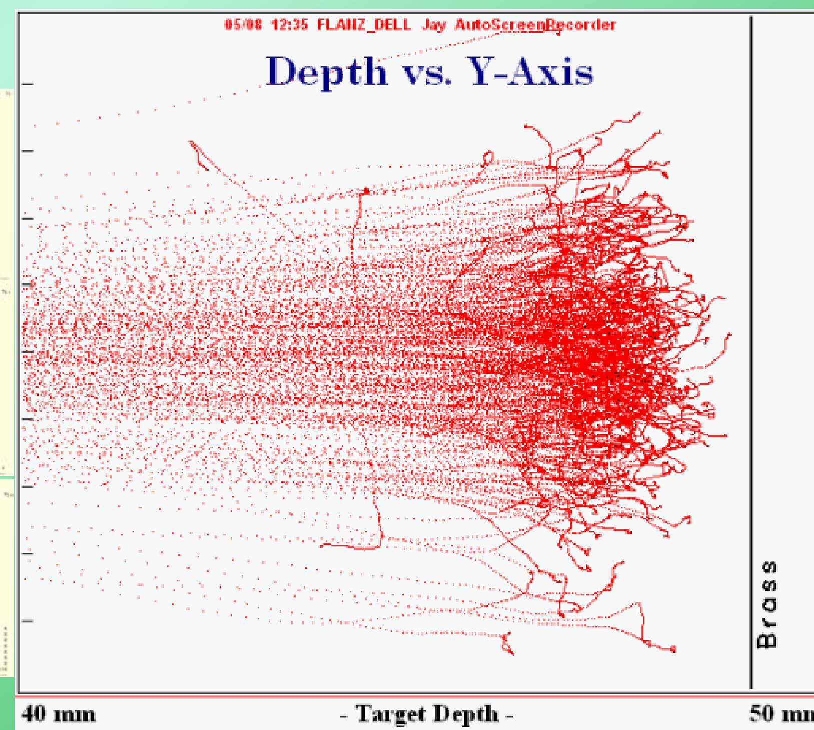
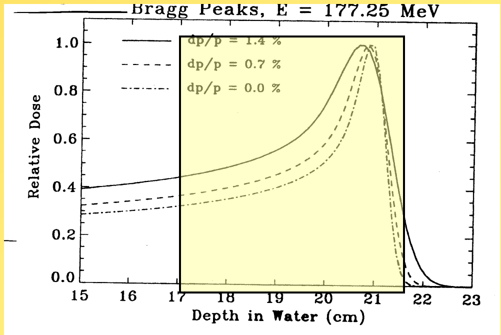


Figure 7: Beam width in water for 80 and 60-cm air gap



Dose / Dose Rate

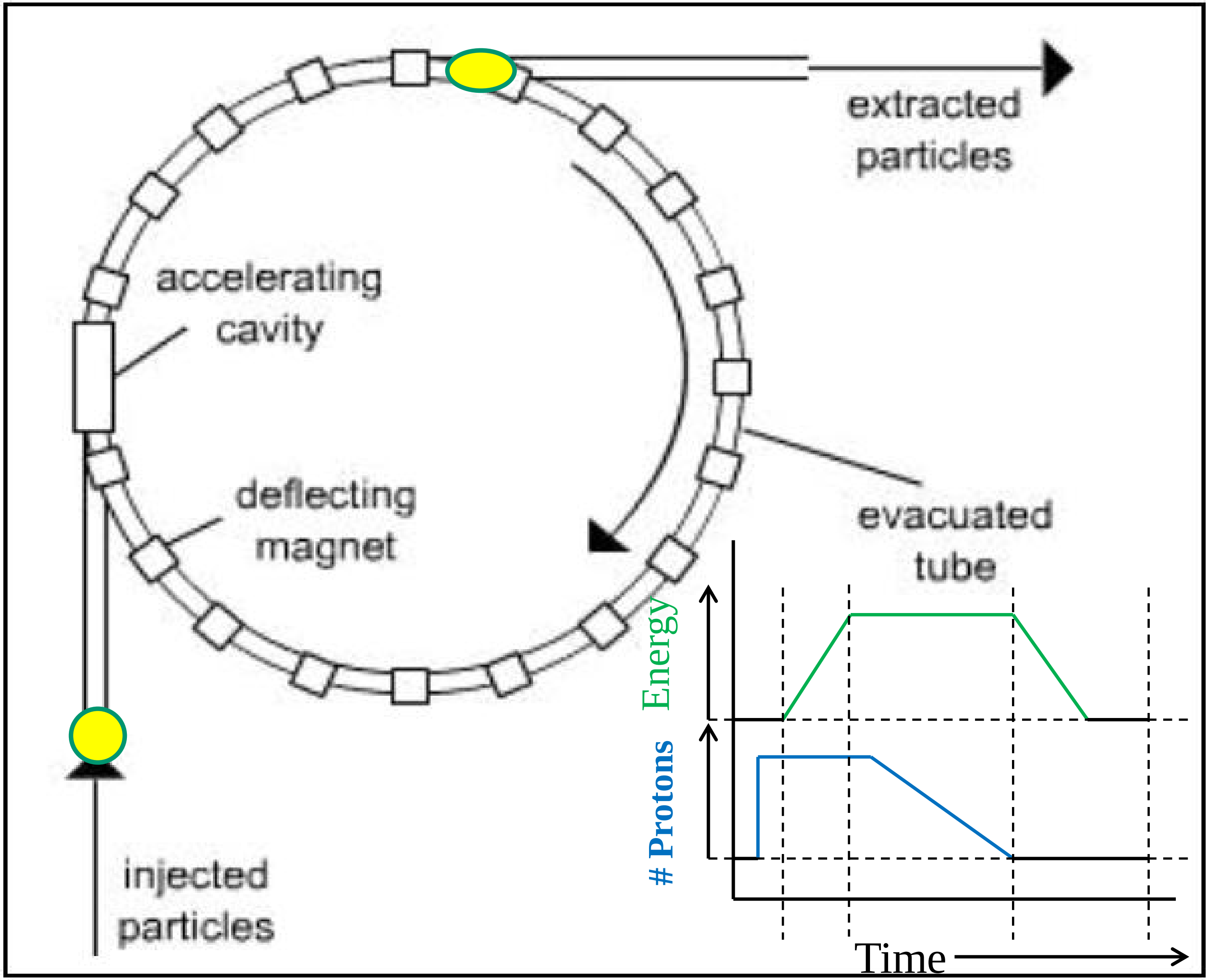
- Power = Joules/sec = Energy * Current
  - e.g. → 150 MeV * 1 nA = *0.15 Watts*
- Dose = Joules/kg ≡ Gray (Gy)
  - Dose = (Power* seconds) /kg
  - e.g. → 150 MeV * 1 nA * 60 sec = *9 Joules*

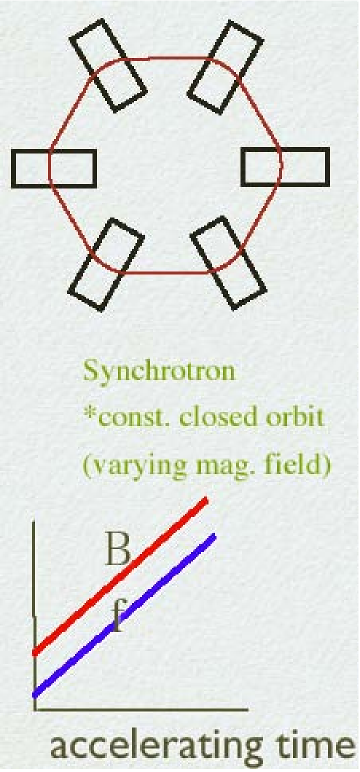


- Water → 1kg/1000cc = 1kg/liter
- Dose = 9 Joules /1kg (in a liter)
- ➔ 150 MeV, 1nA == 9 Gy in 1 liter in 1 minute
- But not all energy goes into the target (see Bragg peak)→ *3-6 Gy in 1 liter in 1 minute*

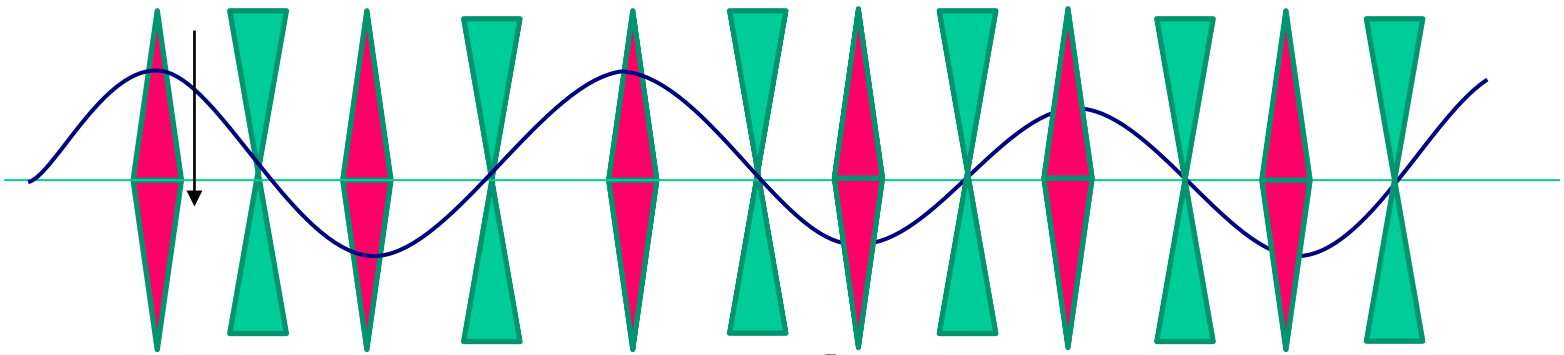
- *Therefore, for 1Gy in 1 liter we need ~ 120 GigaProtons*
  - *(120 GP/min ➔ ~ 0.3nA)*

What is a Synchrotron?

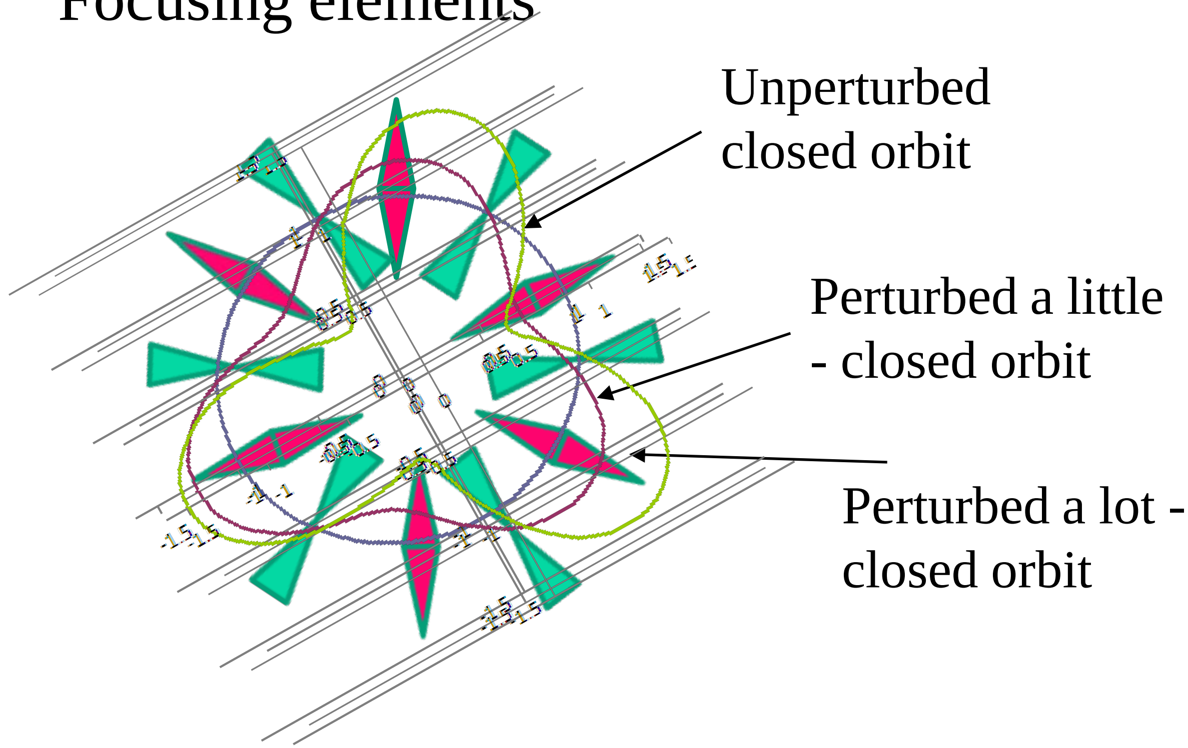




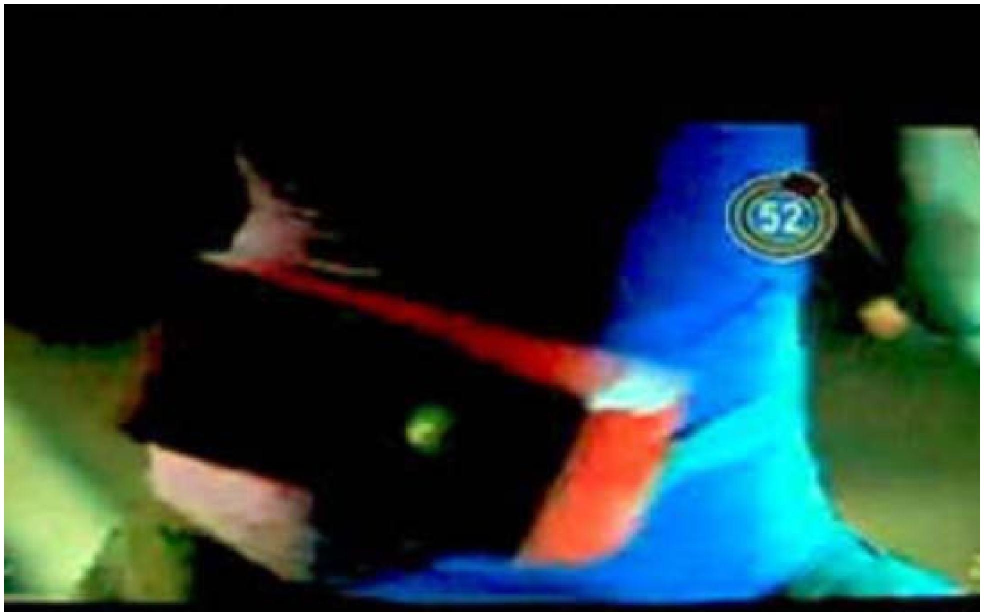
Ring Orbit – Alternating Focusing

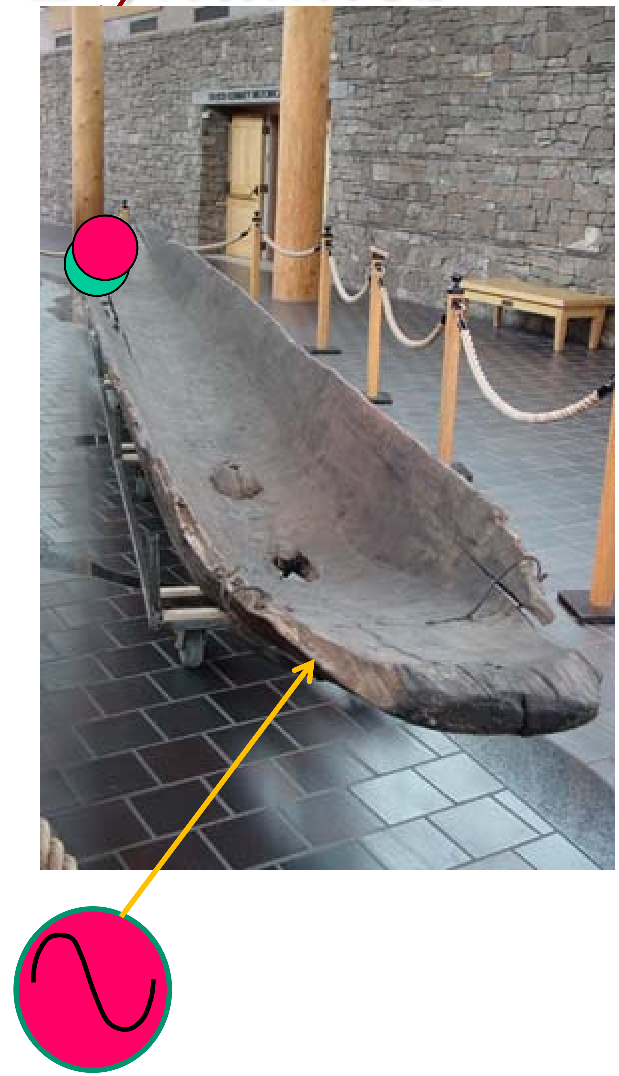


Focusing elements

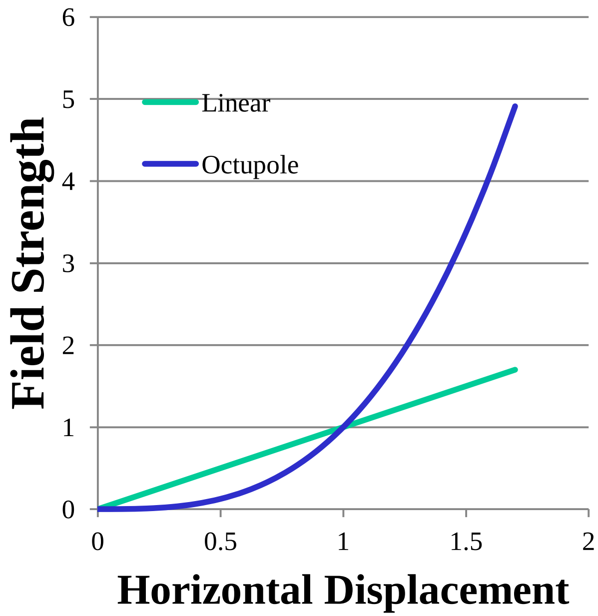


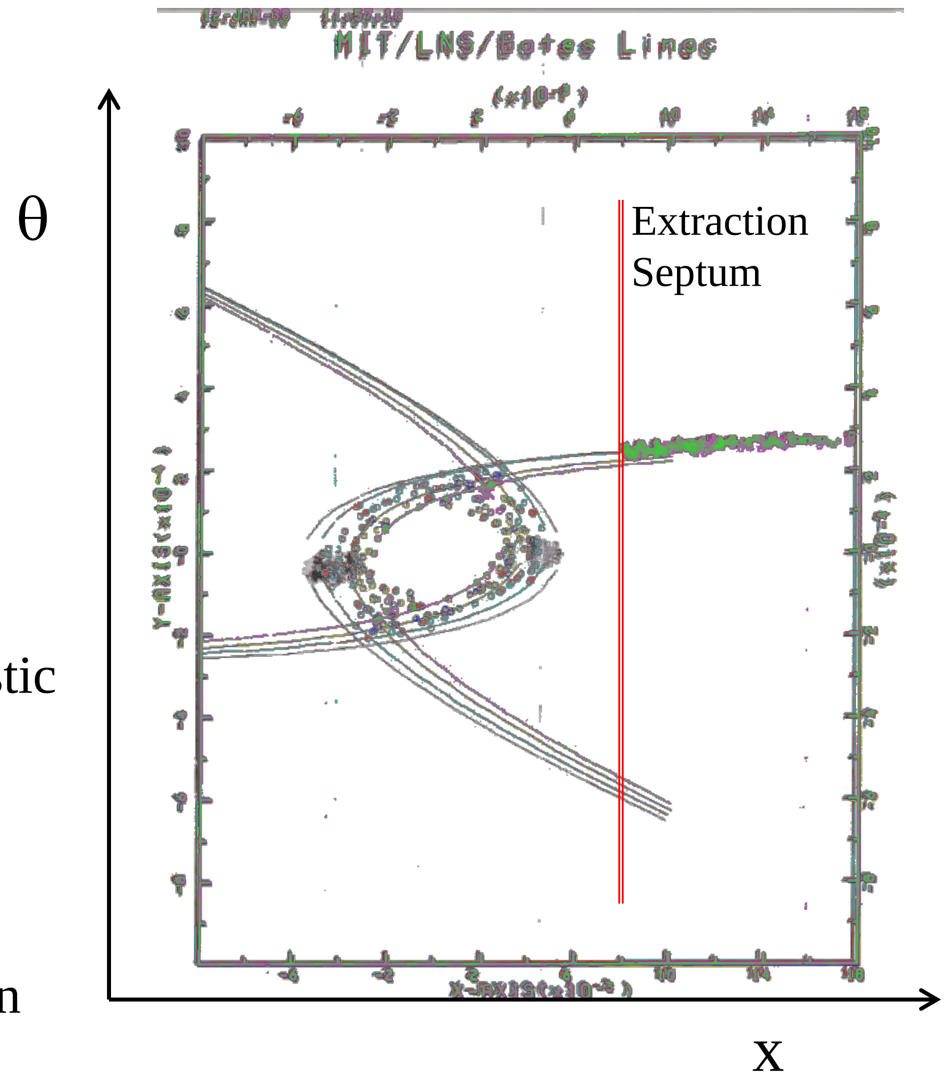
Synchrotron Beam Dynamics





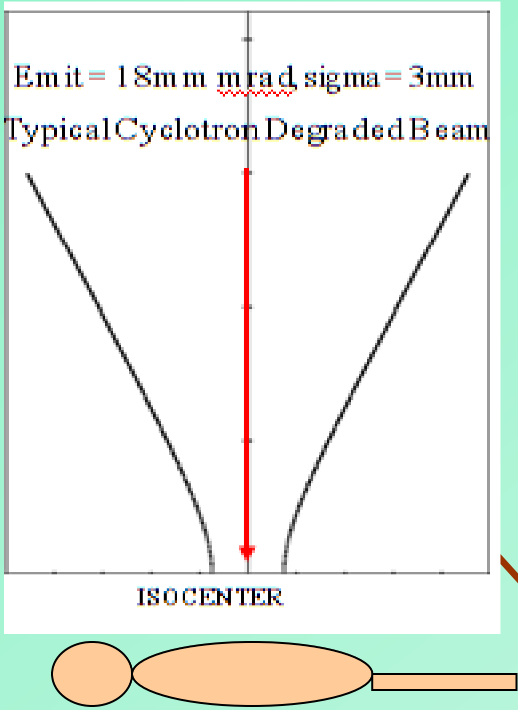
Resonant Extraction (one method)

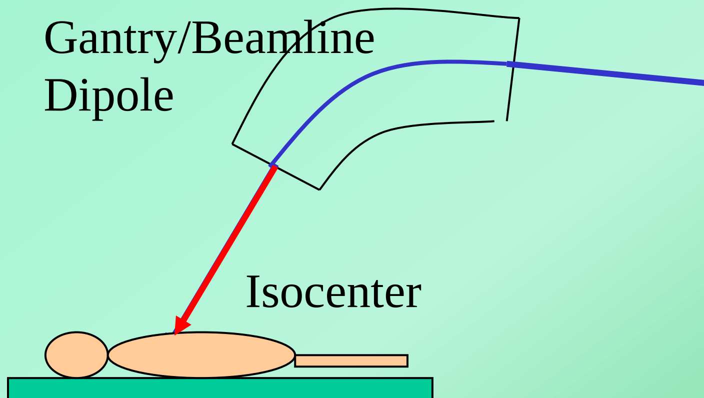


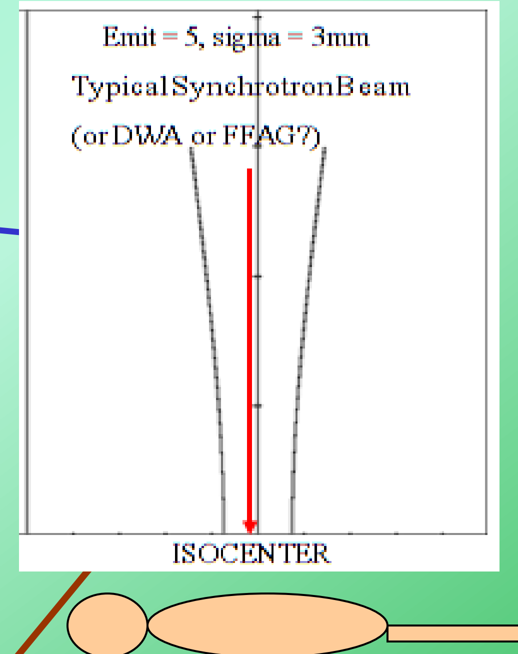


- The process is partly stochastic (uncorrected time structure is not smooth)and
- The extracted beam phase space is NOT Gaussian in the extraction plane (depending on the type of extraction).

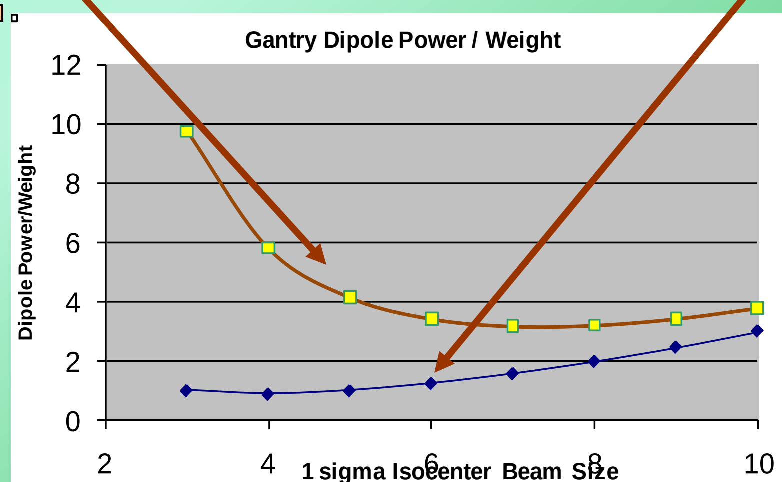
Beam size from the last magnet to Isocenter?







PS Current ~ Gap (2.1 sigma)
Magnet weight ~ gap ^{2}
Power ~ Current ^{2} ~ gap ^{2}

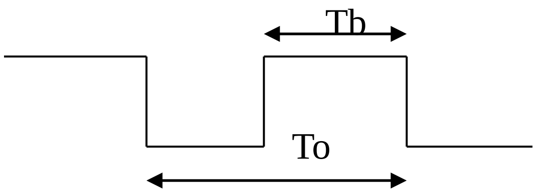


Treatment Time Contributions

Synchrotron

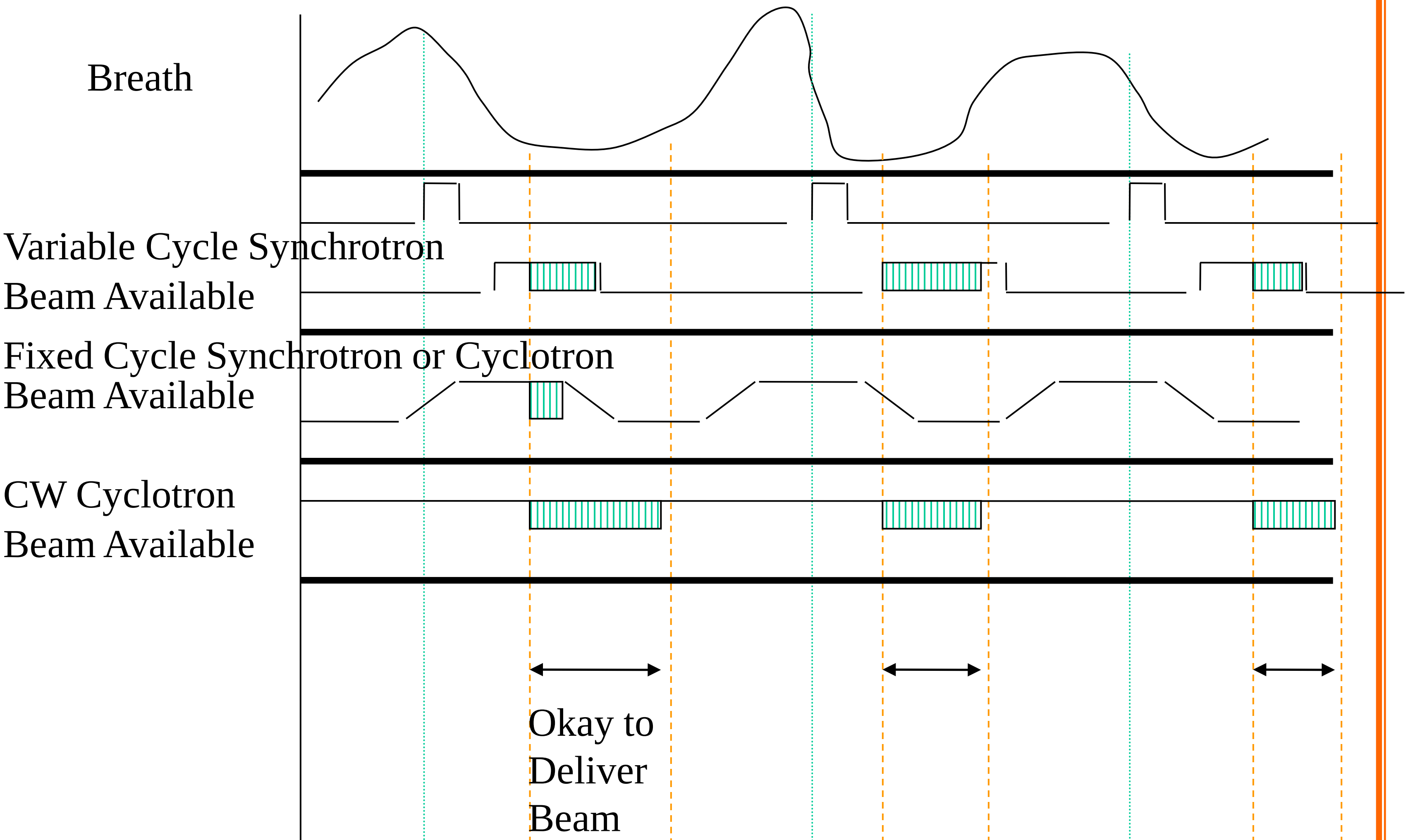
If more particles are needed or change energy

- Time to Inject
- Time to Accelerate
- Time needed to <u>wait until the patient is ready</u> for particles (e.g. gating)
- Time needed to extract particles
  - Instrumentation will only allow a finite number of particles per unit time
- Time needed to Decelerate



<u>Additional 'cycle' times</u> are needed if there are not enough protons in the ring to deliver the required dose at a given range.

Time needed to wait until the patient is ready for particles



Comparison of Beam Utilization for Treatment Requiring Synchronization

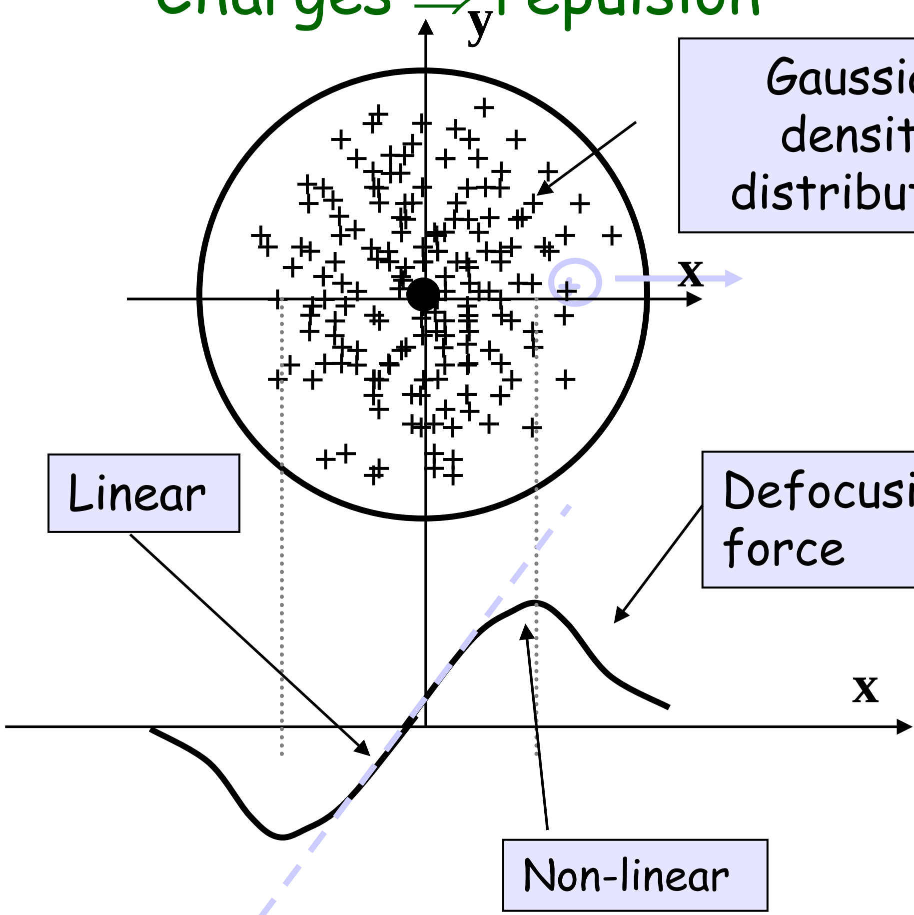
Effective Dose Rate may depend upon accelerator time structure

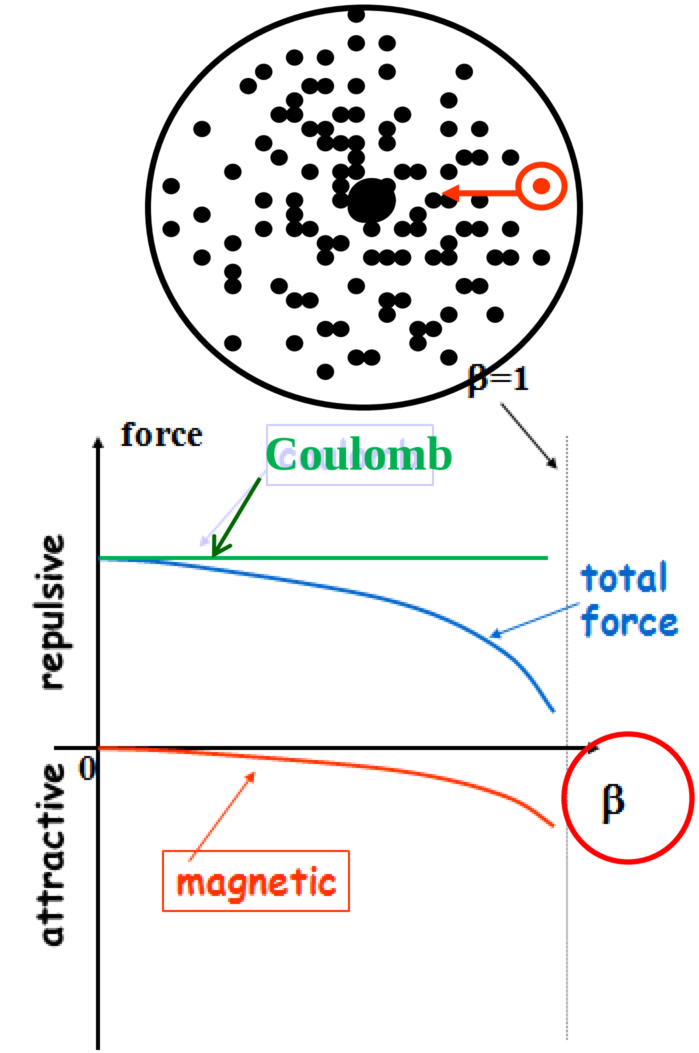
Are additional cycle times needed?

Accelerator Physics: Space Charge effects

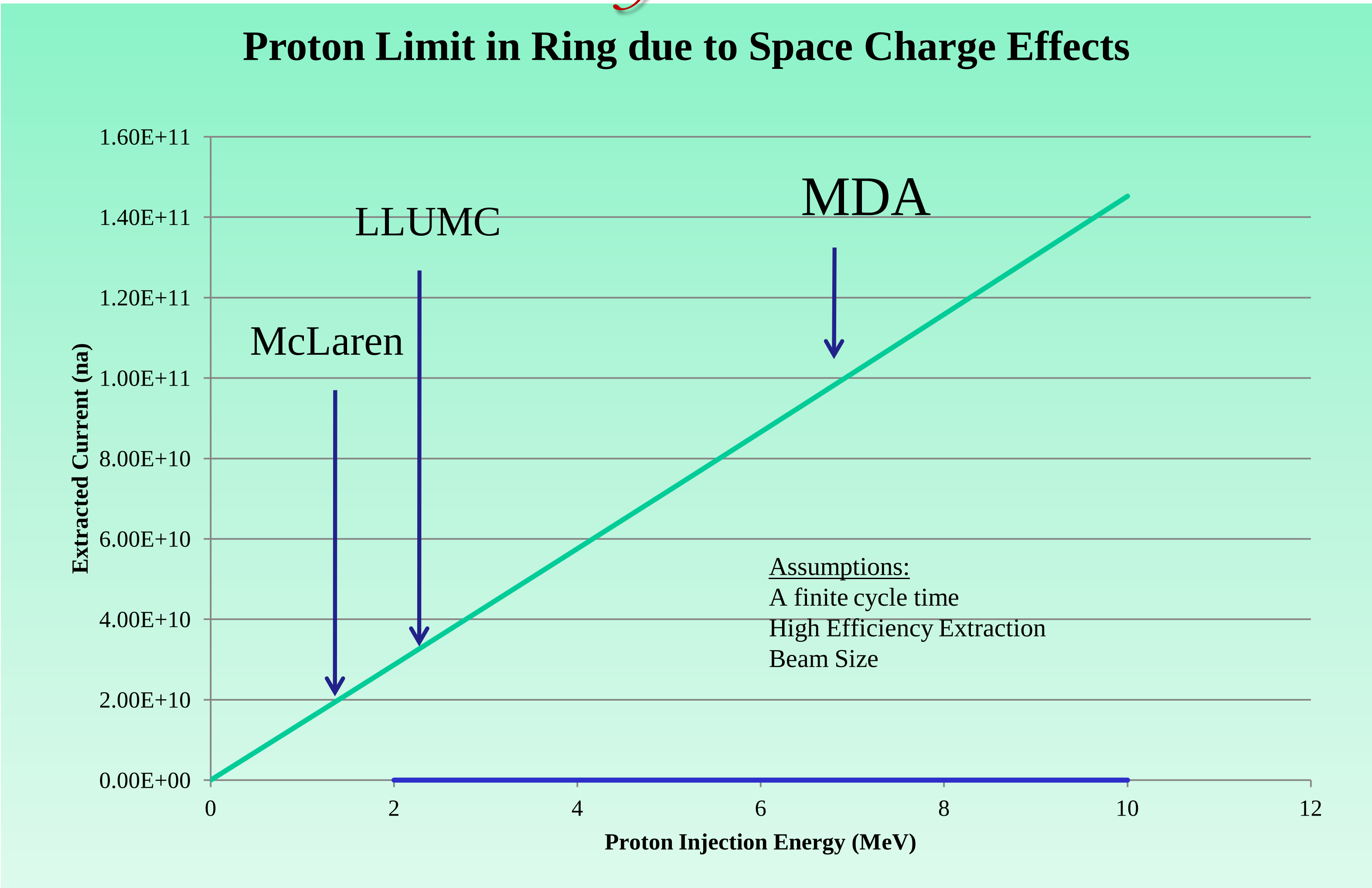
How many protons can be stuffed into a Ring?

Charges ⇒ repulsion   Parallel currents ⇒ attractive





How many protons can be stuffed in a ring? How many are needed?

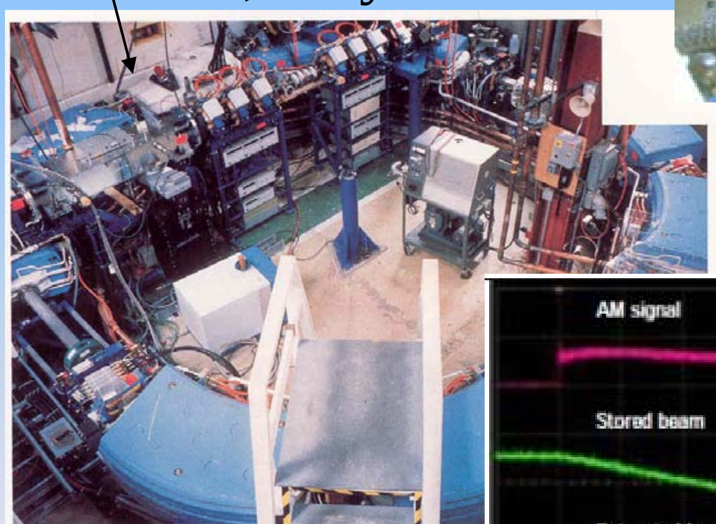


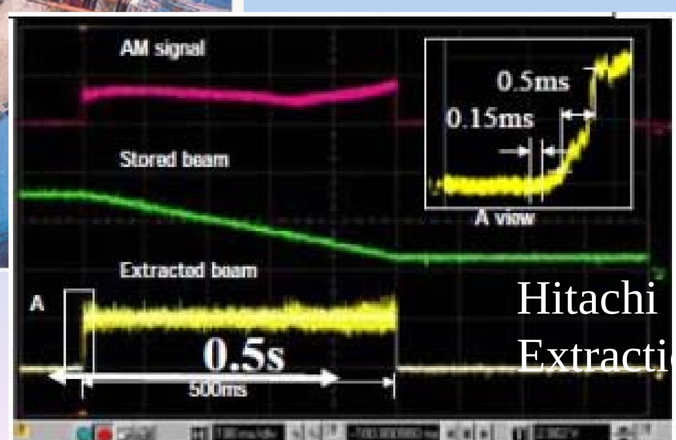
Also 1Gy/min in a liter ➔ 113GigaProtons/min ➔ <3Gp/cycle

First Proton Therapy Synchrotrons

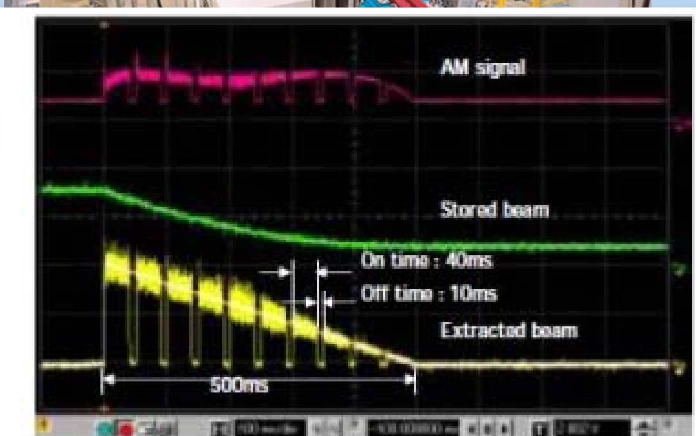
Optivus® Fermilab MITSUBISHI ELECTRIC HITACHI Inspire the Next PROTOM proton therapy technologies

LLUMC, Tsukuba,
MD Anderson, Shizuoka,
Wakasa, HIMAC, Hyogo,
McLaren, Mayo …





Hitachi
Extracti



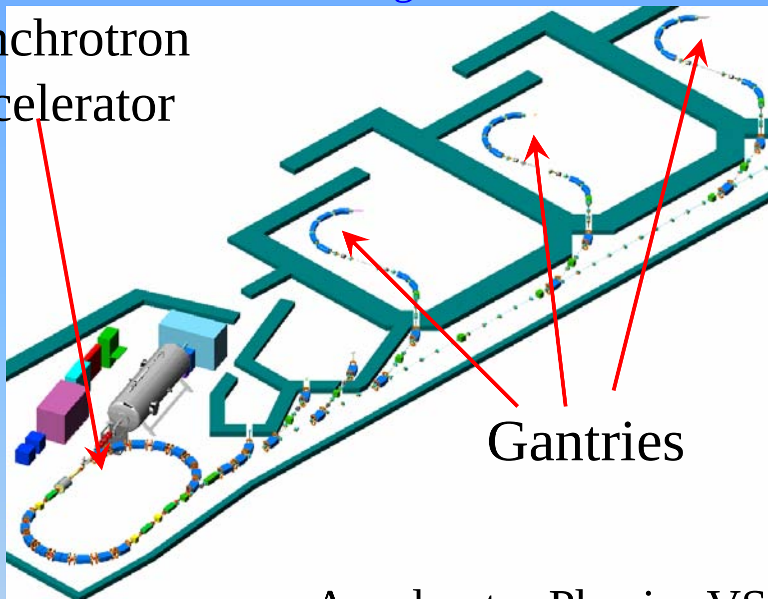
Faster/Bigger

Synchrotron Extremes

Smaller / Cheaper

Rapid Cycling Medical Synchrotron

the second generation



"Compact" Medical Synchrotron

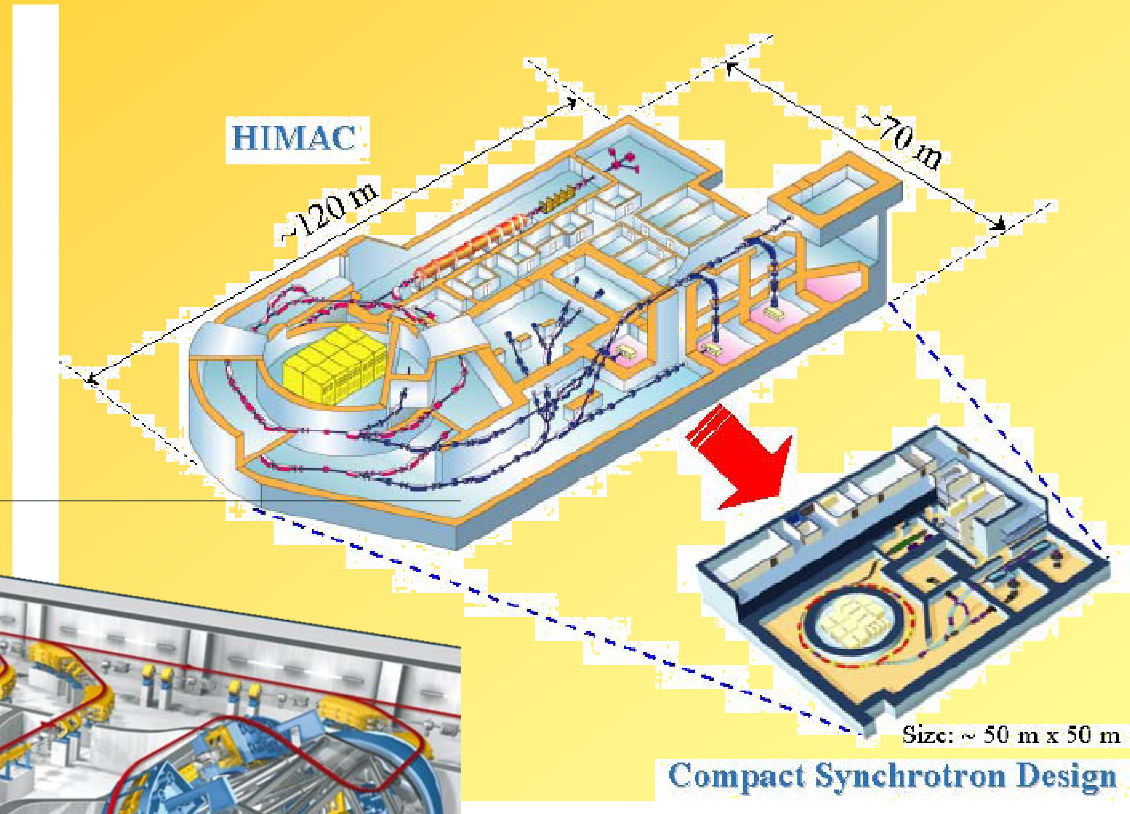
Accelerator Physics VS. ANTI-Accelerator Physics?

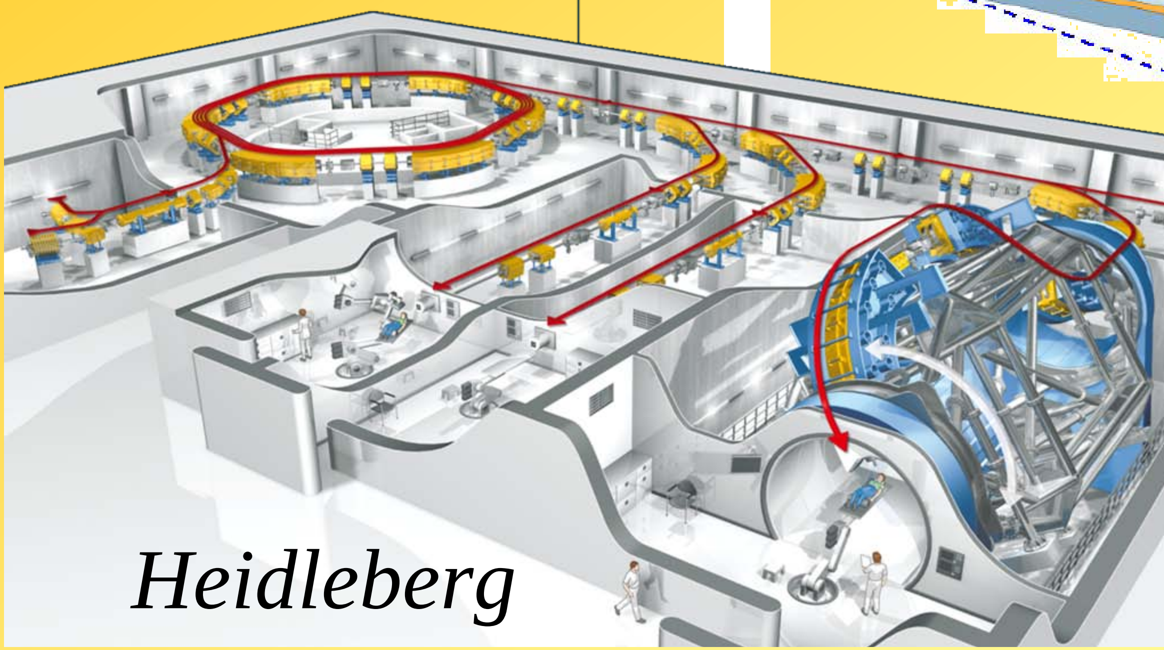
- Current (~<nA?).
- Beam Time Structure (maybe) - Scanning (not line?) / Organ Motion
- Lower Emittance – Good for beamlines and Gantries
- Energy Change time linked to acceleration time (Faster?)
- At 30 Hz in 120 sec ==> 3600 pulses ! (What can be done ?)
    - 10x10x10cm (@3mm spot) ~ 10,000 spots (ONE pulse/spot)

Heavy Ion Accelerators and Facilities - Conventional

Remember:
400MeV/nucleon:

Could be big and Expensive! But they are shrinking also !





NIRS Japan

What might someone do with a Blank Slate?

- **How to deliver a Rx non-uniform dose distribution to a moving target with a desired conformance?**
  - Scanning beams with adjustably sharp edges
  - Accelerator with timing consistent with Scanning and organ motion (Flexible timing)
  - Appropriate on-line imaging
- **How to deliver quality treatment to the appropriate number of patients at an affordable cost**
  - Accelerator Design:
    - Make it INEXPENSIVE, Simple
      - Design only what's needed
        - » What Energy is needed? (Treatment, Tomography, …)
        - » What Current is needed? (Scattering, Scanning, Losses …)
    - Simplify the Optics
  - Minimize Building costs; e.g. Some Shielding Requirements
    - No 'designed' sources of BEAM LOSS
      - Chose a Beam delivery like Scanning

Gratuitous Comments:

- *Treating with particles requires a system approach.*
- *The various subsystems interact with each other and depend upon each others capabilities.*
- *Trade-offs include size, speed, intensity, of everything, (equipment, beam etc.)*
- *More and more demand for affordable particle therapy solutions is apparent.*
- *New Approaches are being fueled by both accelerator interests, and by the more and more demanding requirements of particle therapy.*

The Francis H. Burr Proton Therapy Center

Thank You !