MID 42330

PART III:

Particle therapy of cancer

The HOLY GRAIL of Radiation Therapy

Ideal Situation

Provide a lethal dose to the tumor

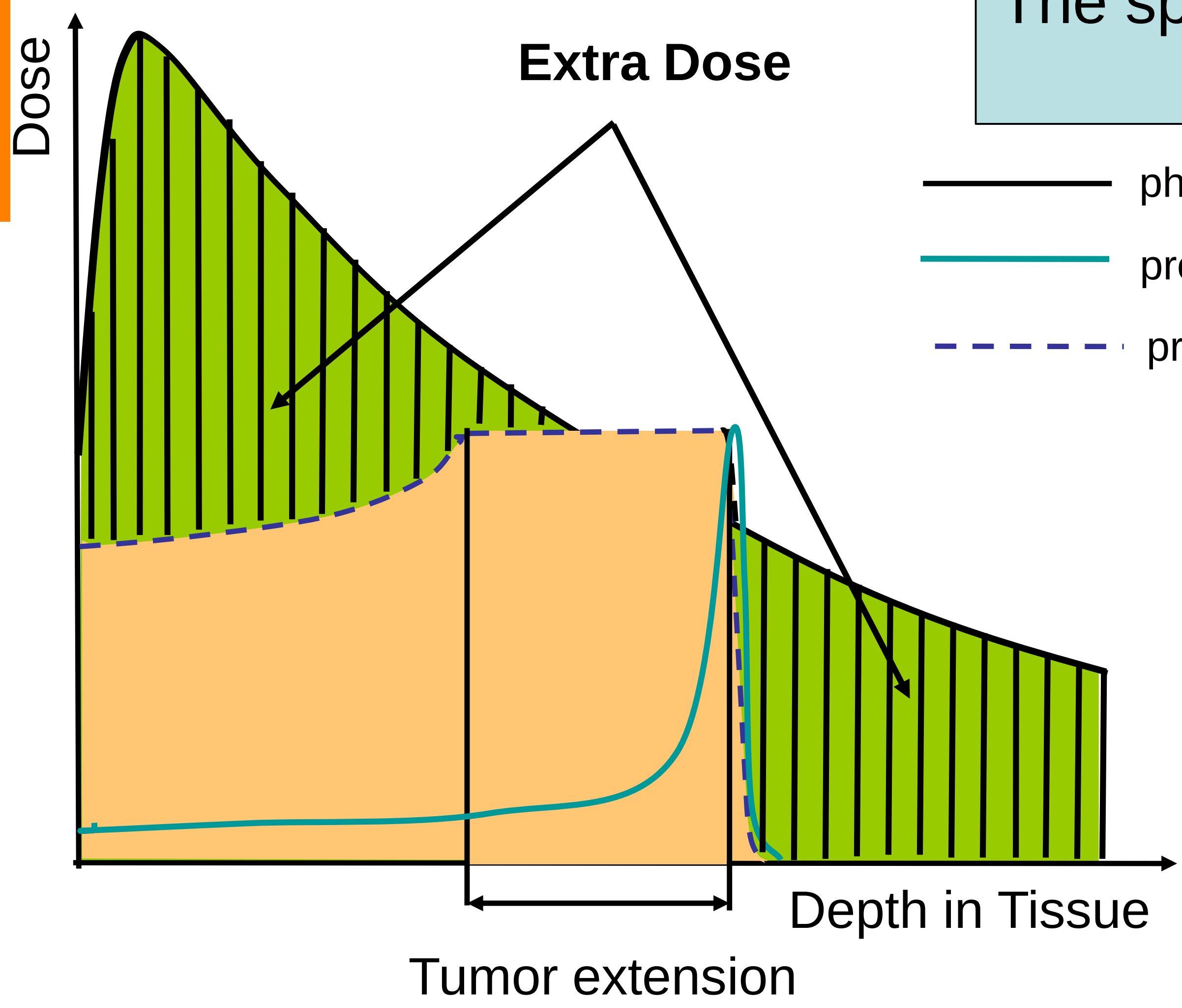
and

Spare perfectly the surrounding healthy tissue

In Practice

Deposit the radiation dose more precisely in the target volume with less dose in the surrounding healthy tissues.

Photon-Proton dose distribution comparison



The spread out Bragg peak (SOBP)

- Position of the Bragg peak depends on beam energy
- Incomming energy modulation $\Rightarrow$ SOBP
- No dose downsteam of tumor
- Lower dose upstream of tumor

Main requirements for a proton therapy system

1. **Ability to reach the tumor**

- Range in patient: up to 32 g/cm²
- Range modulation:up to full range, with steps of 0.5 g/cm²
- Field size: up to 30 x 40 cm

2. **Ability to reach the from any selected direction**

- Isocentric Gantry
- Precise, robotic patient positioner

3. **Ability to reach the tumor accurately**

- Penumbra: maximum 2 mm at skin
- Distal dose falloff: maximum 1 mm above physical limit
- Patient positioner accuracy and reproducibility: 0.5 mm for small displacements
- Gantry accuracy and reproducibility: 1 mm radius circle of confusion
- Patient alignment methods: lasers, light fields, X-rays

4. **Ability to verify and control the dose deposition using IC's**

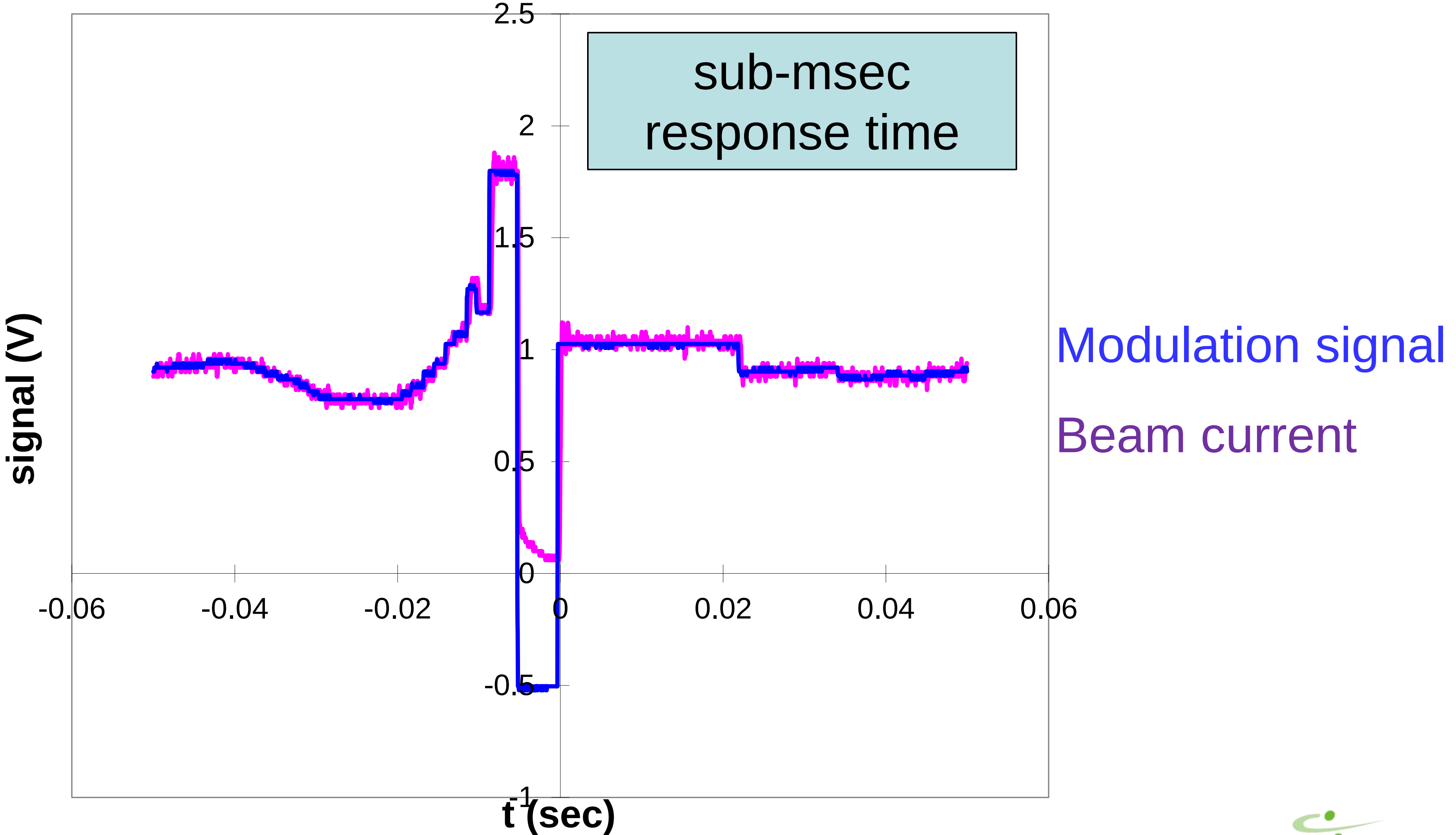
Accelerator parameters driving the technology choice

- Energy: defines the range in the patient (230 MeV enough)
- Energy definition: defines the range accuracy and the distal falloff
- Beam current: defines the dose rate (10^{11} p/sec enough (10 nA))
- Beam current stability and noise: defines ability to use wobbling and scanning
- Accurate and fast beam current control: needed for conformal therapy

Cyclotrons for Proton & Carbon therapy?

- In 1991, when IBA entered in PT, the consensus was that the best accelerator for PT was a synchrotron
- IBA introduced a very effective cyclotron design, and today the majority of PT centers use the cyclotron technology (Not only IBA but also Varian, Mevion, SHI)
- Over the last 20 years, users came to appreciate the advantages of cyclotrons:
  - Simplicity & reliability
  - Intense, continuous (non pulsed) beam current
  - Lowest cost and size
  - But, most importantly, the ability to modulate rapidly and accurately the proton beam current

Real oscilloscope measured signals



Why is fast current modulation important?

- A big issue with scanned beam is the motion of the target during irradiation
- If you cannot control accurately and rapidly the current ,or if the beam is slowly pulsed , your only choice is step-and-shoot (spot scanning)
- Assuming a 10 mm (FWHM) beam spot size, a 50% overlap and a 20 Hz pulse rate, the maximum scanning speed will be 0.2 m/sec
- With this speed, for a large size tumor, repainting many time each layer is not really an option
- In contrast, with a cyclotron you can scan at 20 m/sec and rescan many times each layer

Change of energy?

- Cyclotrons are simpler at fixed energy
- Energy change by graphite degrader at waist after cyclotron exit, followed by divergence slits and energy analyzer
- This very effectively decouples the accelerator from the patient
- Fragmentation products are effectively eliminated in slits and ESS
- Yes, neutrons are produced, but ESS is well shielded and the average beam currents are very low > little activation
- How fast? 5 mm step in energy in 100 msec. Respiration cycle is 2…4 seconds => 100 msec is fine

Accelerators for proton therapy: two alternatives

Small synchrotron

+ *Advantages*
  + Naturally variable energy
– *Disadvantages*
  – Current limited if low energy injection
  – Beam current stability & low noise is difficult on small synchrotrons
  – Fast and accurate beam current control difficult to achieve
  – More complex with negative impact on availability

Compact cyclotron

+ *Advantages*
  + No physical current limitation
  + Beam current stability & noise specifications currently achieved on small cyclotrons
  + Fast and accurate beam current control over 1000/1 range easy to achieve
  + Low complexity, resulting in highest availability
– *Disadvantages*
  – Variable energy requires external Energy Selection System

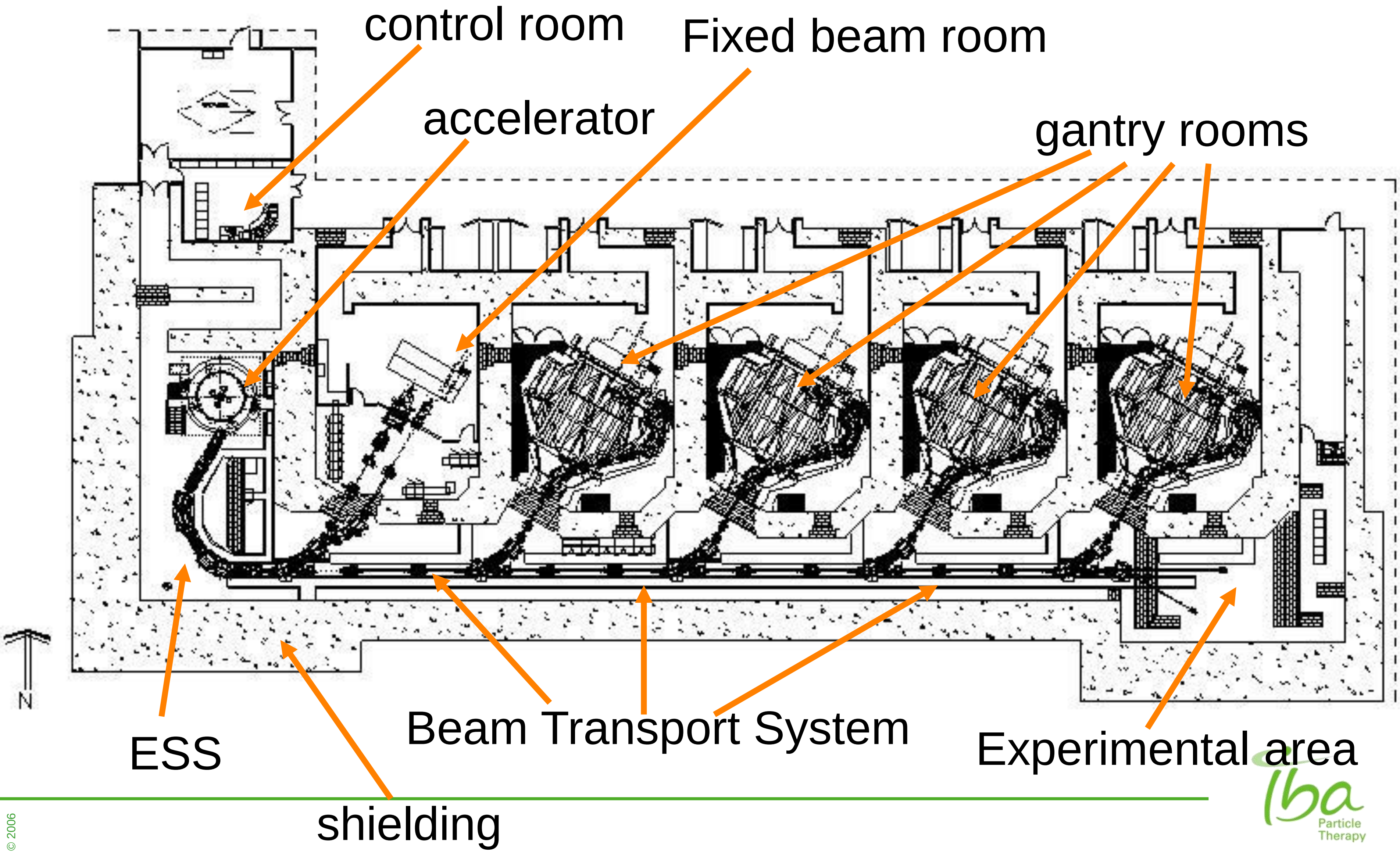
A Proton Therapy Facility is like a small Hospital

- A proton therapy system is much more than only an accelerator
- It is a complex, multi-room system, filling a hospital building.
- The total investment is around 100 M€, of which 45 M€ for the equipment
- Many people (doctors, therapists, physicists, nurses) work daily in a PT facility
- A PT facility can treat 1500 patients/year and generate revenues in the order of 30 M€/year!

Main Sub-systems of a cyclotron based PT facility

- 230 MeV isochronous cyclotron
- Energy Selection System (ESS)
- Beam Transport and Switching System
- Isocentric Gantries (typically 3) and one Fixed Beam Line
- Nozzles for matching the beam wrt the required treatment (scattering, wobbling or scanning, diagnostics)
- Robotic Patient Positioners
- Software Control and Safety System

Typical Proton Therapy Facility Layout



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The 230 Mev Cyclotron at MGH/NPTC in Boston

Protons only

Fixed energy

200 tons

∅ = 4.7 m

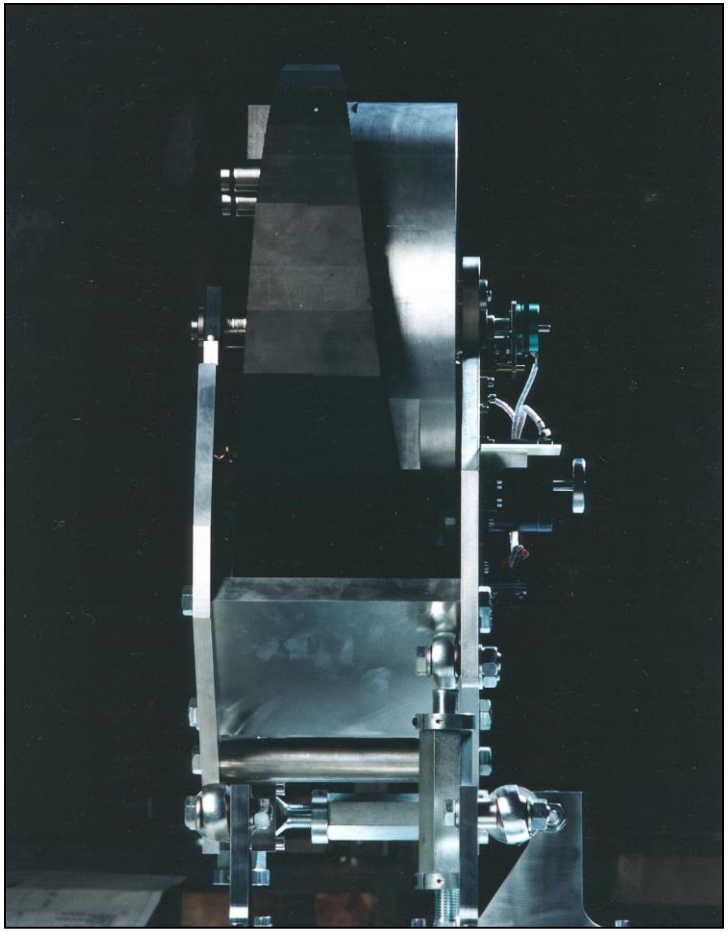
C230 inside view: spiral sectors with elliptical gap

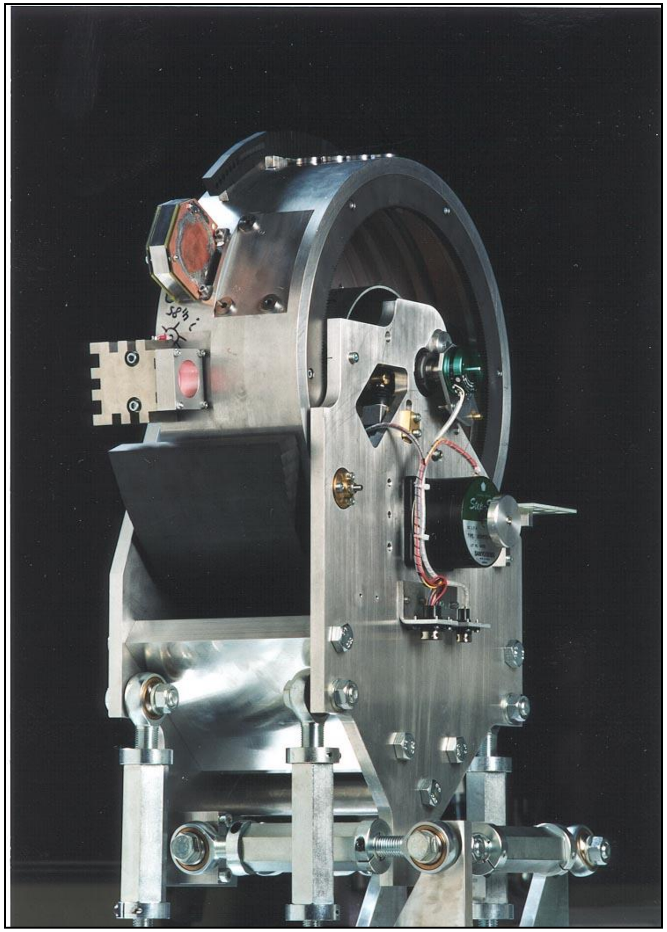
Spiral sectors => better vertical focusing
Elliptical gap => high B-field and easier extraction

The Energy Selection System

- Carbon wedge is used for coarse energy definition
- Emittance slits are used to define the emittance of the transmitted beam
- Analyzing magnet system defines accurately the range at nozzle entrance
- Laminated magnets and quads allow 10% energy change in 2 seconds

The carbon wedge degrader





IBA PT subsystems : the beam transport lines.

The energy selection system. WPE, Essen, 2010.

The Beam Transport and Switching System

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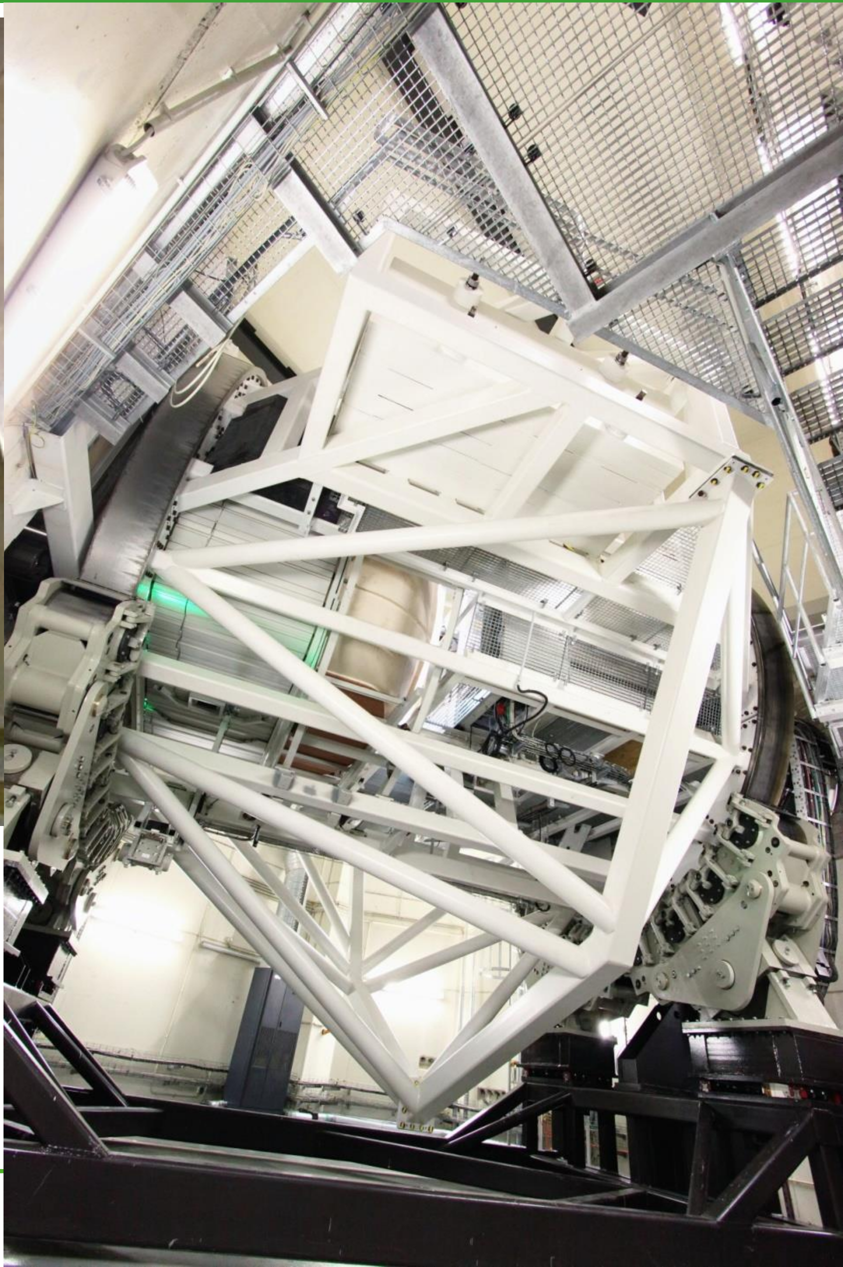
The isocentric gantry => about 10 m high.

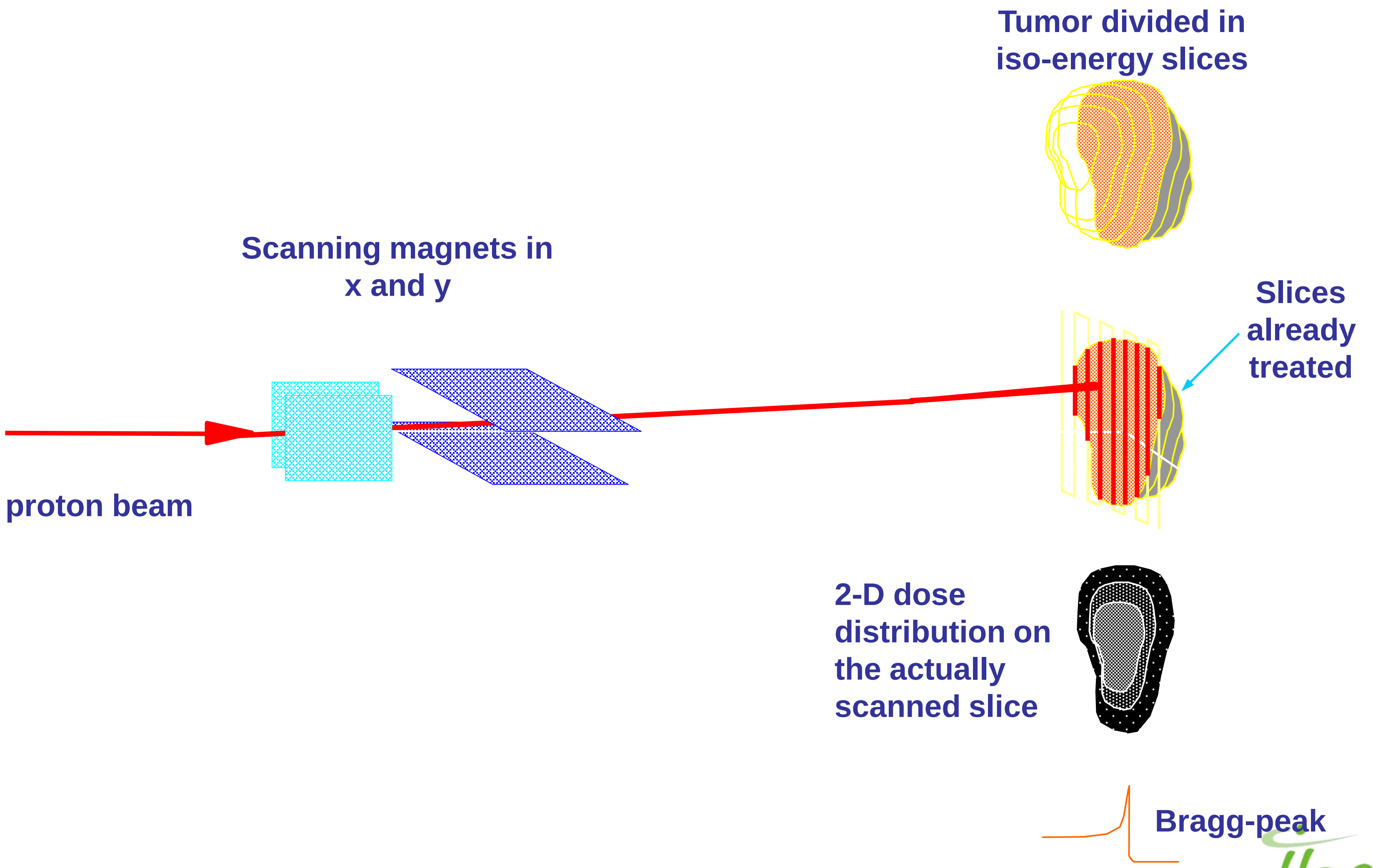


Good alignment is of crucial importance

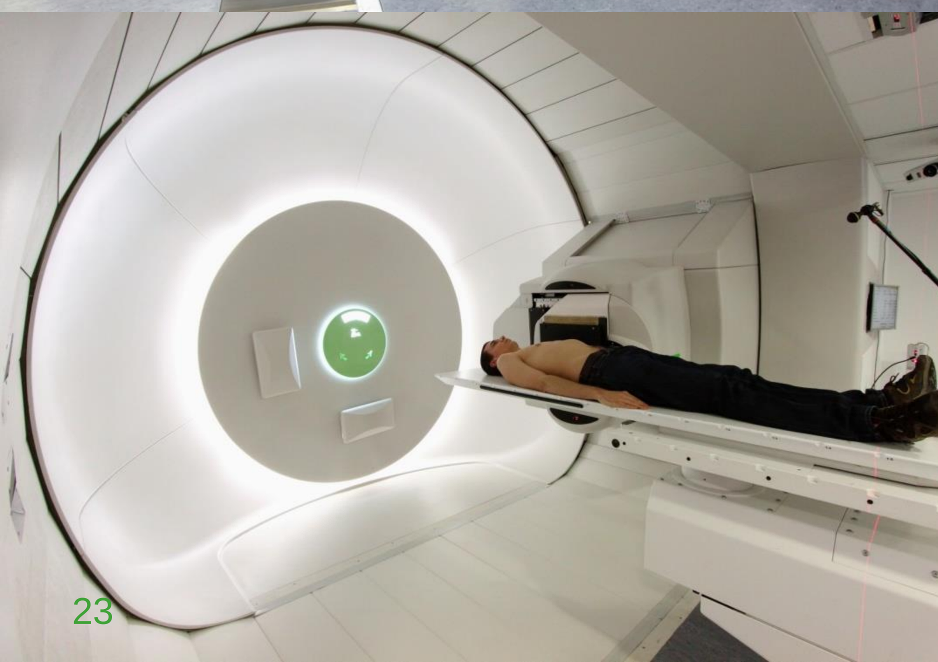
The purpose of the nozzle

- Modulate the proton energy (range in patient)
- to spread the proton beam to obtain a uniform dose distribution in a large volume
  - Double scattering for small to moderate fields
  - Wobbling for the largest and deepest fields
  - Pencil Beam Scanning for the most precise conformal mapping
- to measure accurately the dose delivered to the patient
- Provide alignment of the patient with the proton field

IMPT: Pencil Beam Scanning principle



A patient friendly treatment room is important



The UPHS Particle Therapy Centre, Philadelphia

- One of the largest Particle Therapy centre to date!
- 4 Gantry Rooms
- 1 Fixed Beam Room
- 1 Experimental Room
- Beam since July 2008

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