GANTRIES

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Educational Session 54th Annual Conference of the Particle Therapy Co-Operative Group, May 20, 2015

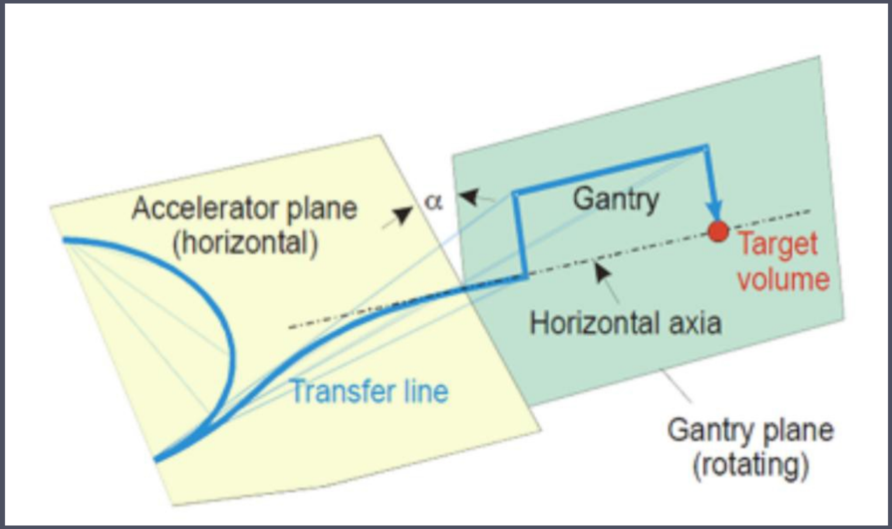
Outline

- Motivation and general concepts
- Brief history of gantries
- Gantry properties and considerations
- PSI Gantry 2 : Example gantry at the state-of-art
- Some future directions

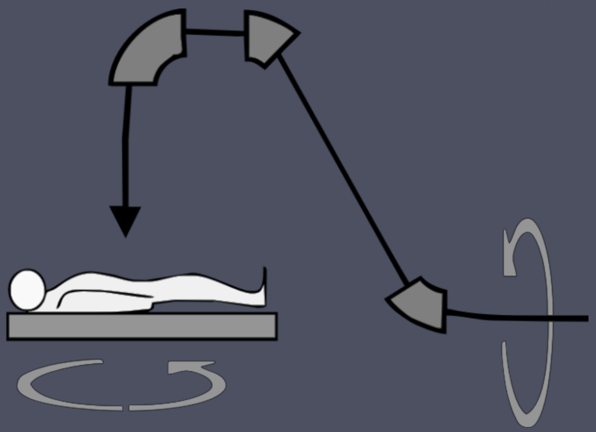
Motivation and general concepts

What is a Gantry?

- Gantry is a *rotating beam transport line* that focuses and directs the particle beam to the desired position in the patient target volume, at *any angle* required by the treatment plan.
- Gantry rotation and rotation of the patient table (patient positioning system – PPS) allow a full *4π solid angle* coverage.
- Patient in *supine* position.

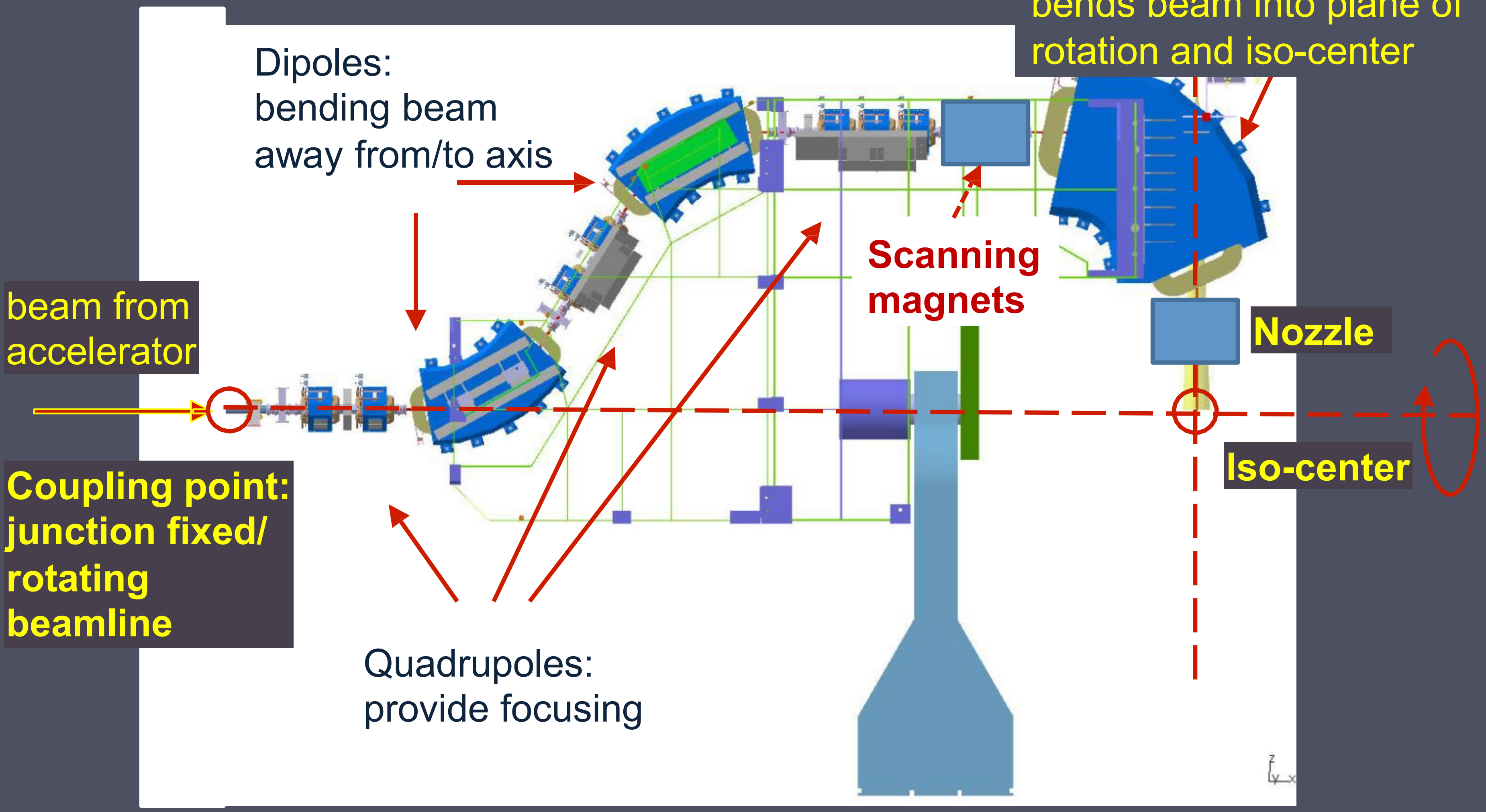


PIMMS Vol 1, CERN



Anatomy of a gantry

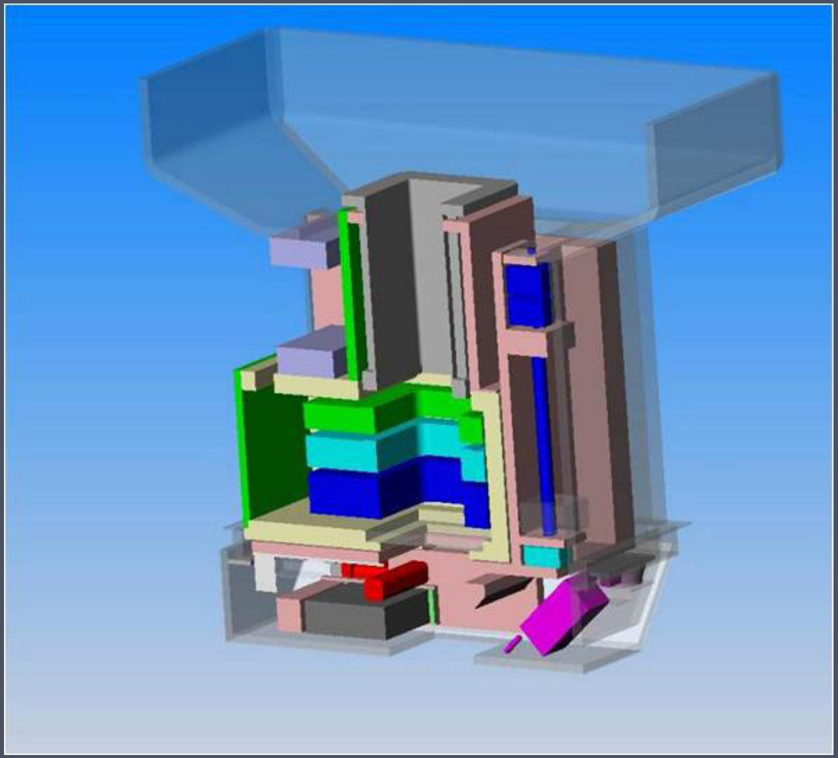
Example PSI Gantry 2*



*E. Pedroni, et. al. Eur. Phys. J. Plus (2011) 126: 66

Nozzle (radiation head)

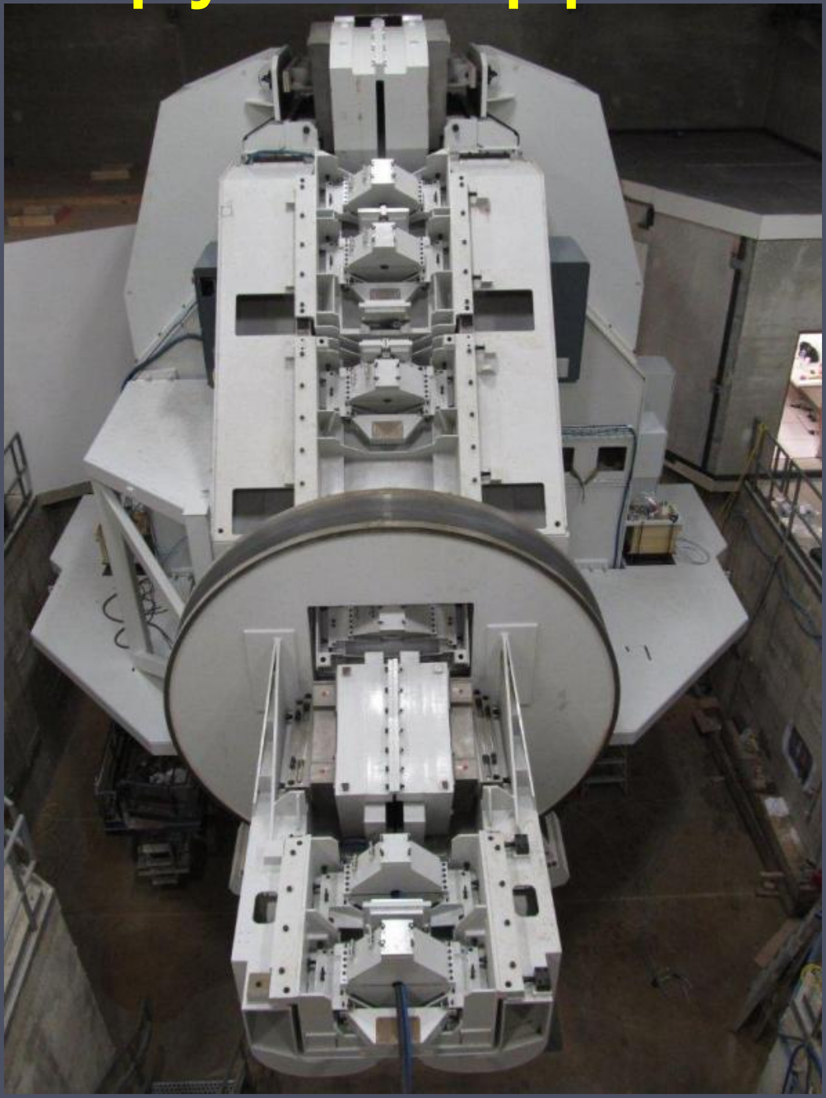
- Measure dose
- Beam position
- Beam shape
- Range shifter



Examples of existing proton gantries

Varian Particle Therapy / Scripps

ProBeam™ Delivery System
Rotational Gantry



Gantry

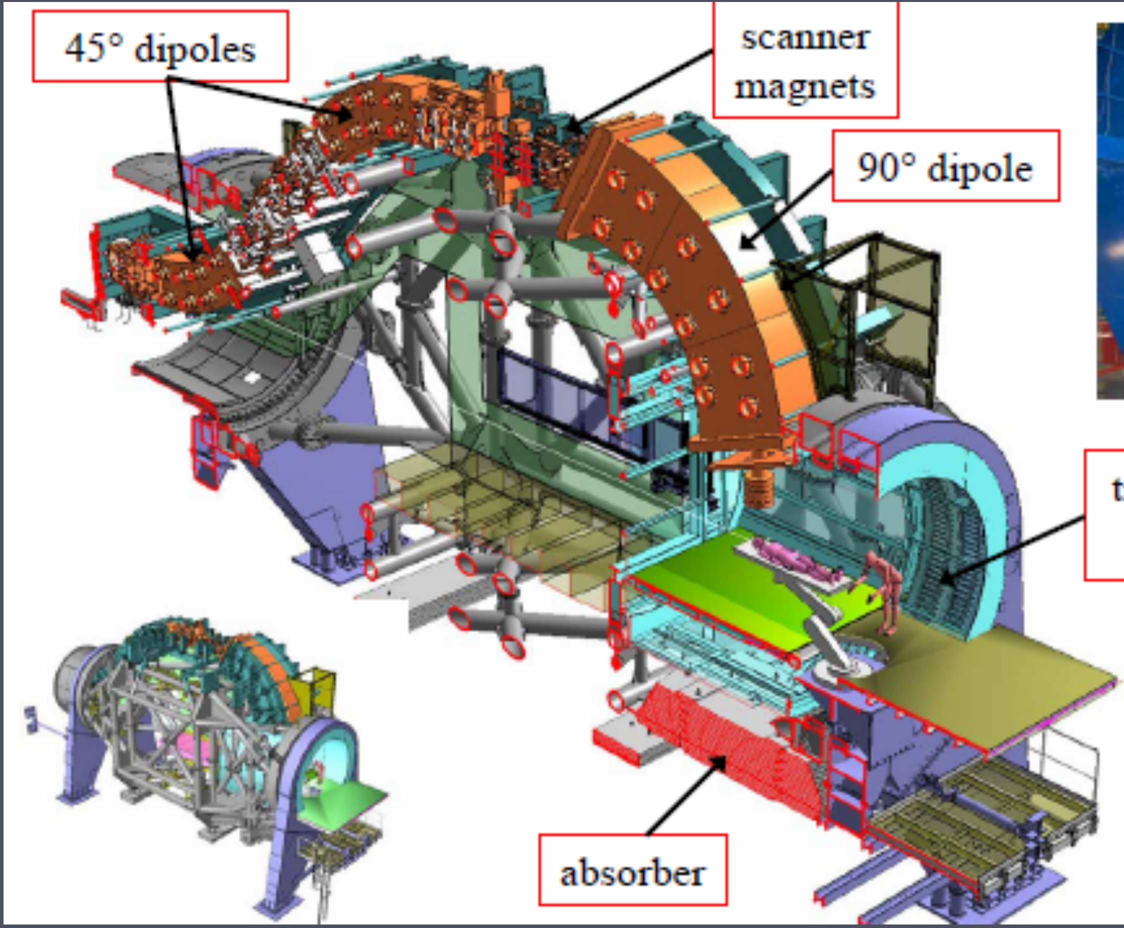
- 380°rotation, 1 RPM
- Angular position precision ±0.1°
- Moving floor
- 10.8m diameter, 10.2m length
- Room dimensions 36 x 47 ft

Varian Particle Therapy
Scripps

Artist Rendering

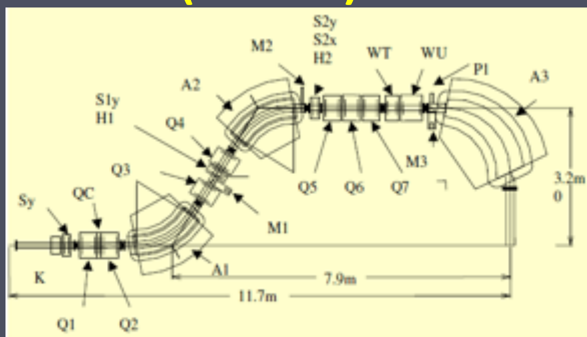
Heidelberg Ion Therapy Carbon Ion Gantry

Only Carbon Gantry Worldwide



Gantries are Large

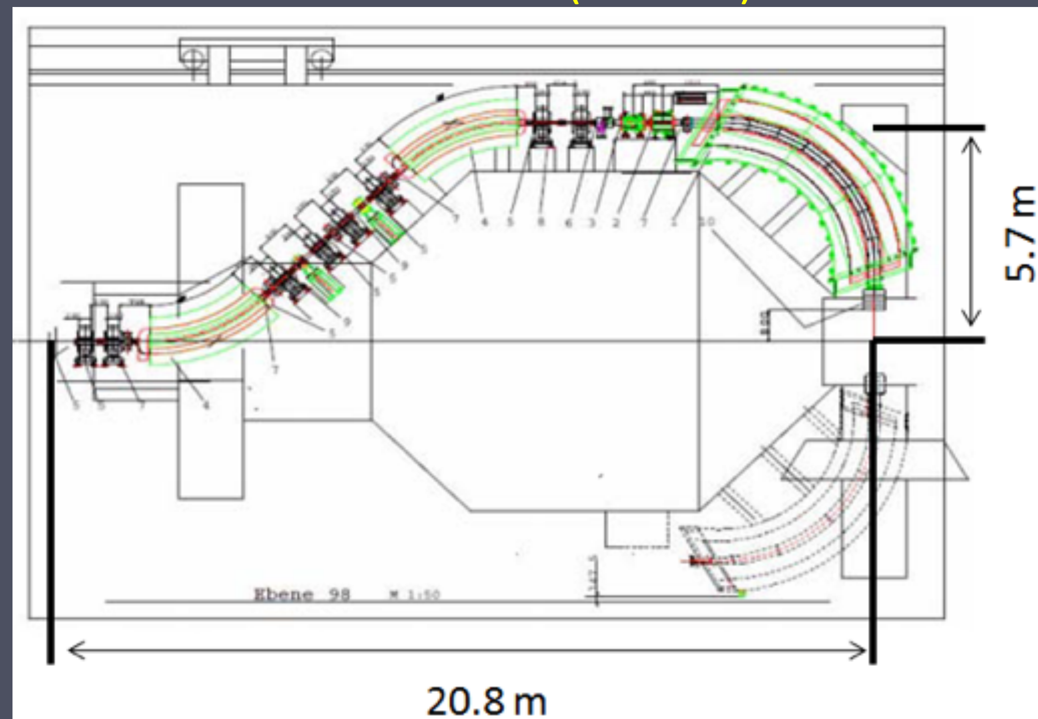
PSI Gantry 2
(Proton)



~8 m

~12 m

HIT
(Carbon)



~13 m

~22 m

Weight

- Proton gantries weight about **100 tons**
- HIT carbon gantry weighs **600 tons**

1/10 of the Eiffel Tower

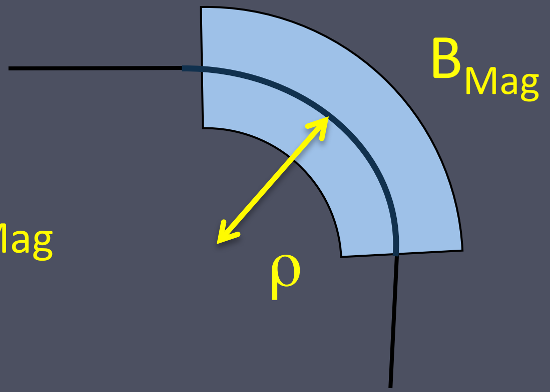
Why Carbon Gantries Are Bigger

Carbon Ion beams are harder to bend

- Difficulty to bend measured by magnetic rigidity, $B\rho$ [T m]

- Bending radius, ρ, is :

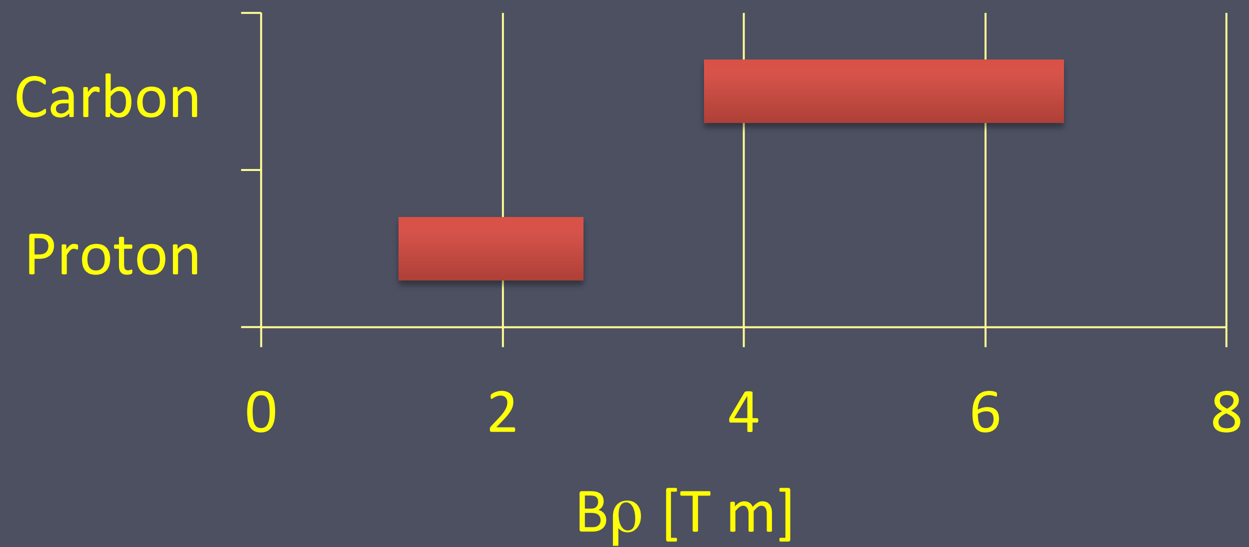
$$\rho = B\rho/B_{Mag}$$



- For the same penetration depth
  - Magnetic Rigidity is ~2.6 times higher for Carbon Ion Beams

Magnetic Rigidity

Magnetic rigidity for 3 – 30 cm penetration depth

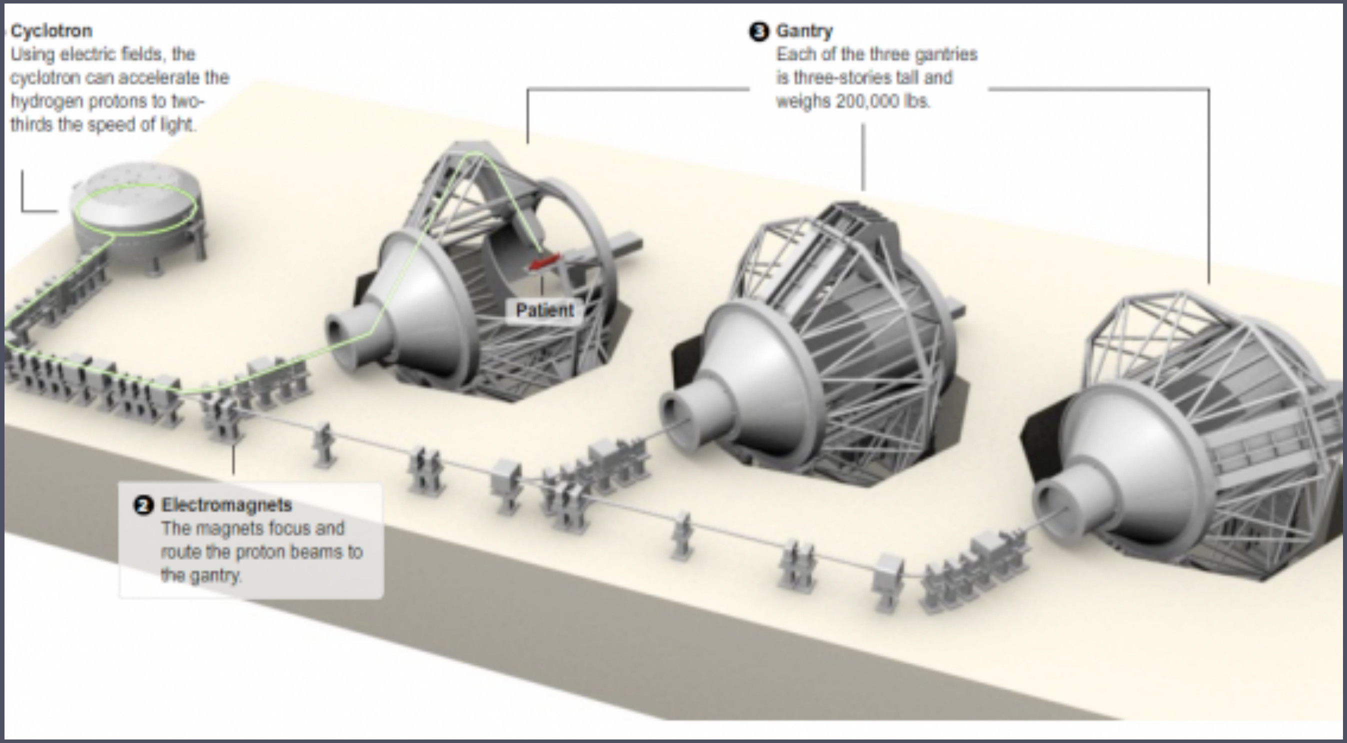


Example : HIT 90° Dipole

Field Strength is 1.81 Tesla

Bending radius is 3.67 m for Bρ is 6.64 Tm

Proton Therapy Center



Gantries are larger than the proton cyclotron

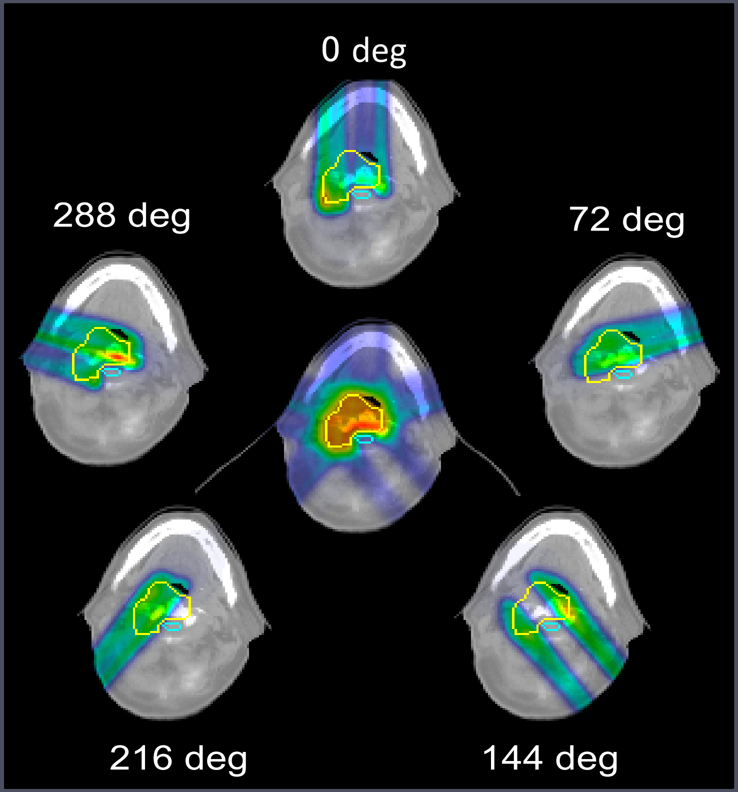
Heidelberg Ion Therapy (HIT) Facility

Gantry is 3 stories tall

http://idw-online.de/pages/de/news504069

Why Gantries?

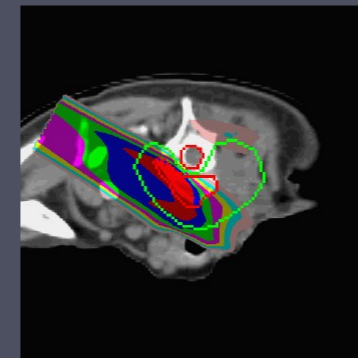
- Gantries facilitate treatment planning
- Multiple beam directions help to
  - *Avoid* sensitive organs (*OAR*)
  - *Spare* surrounding *tissue*
  - *Conform more closely tumor shape*



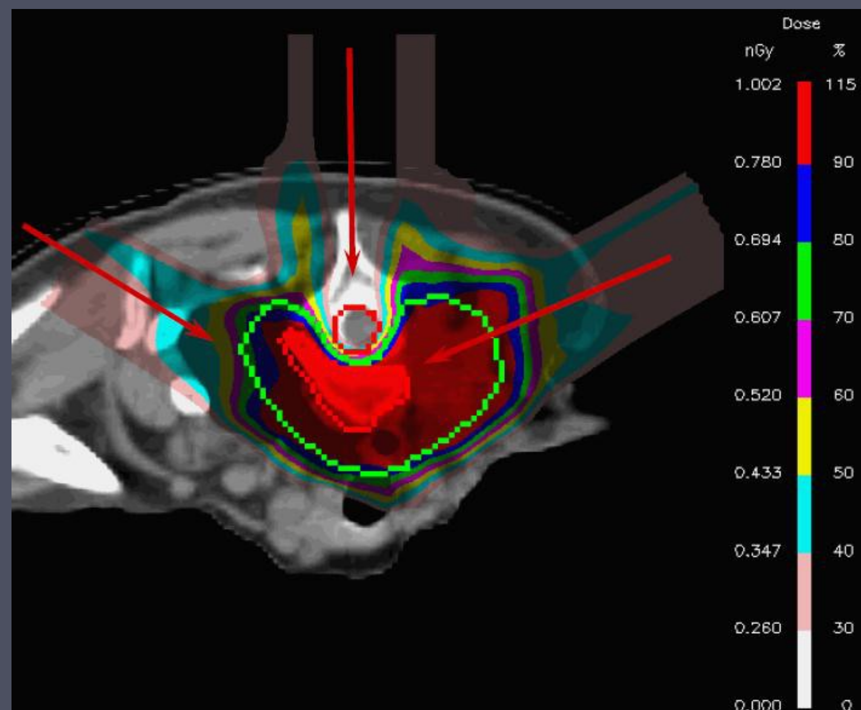
Thesis, B.Schaffer, PSI

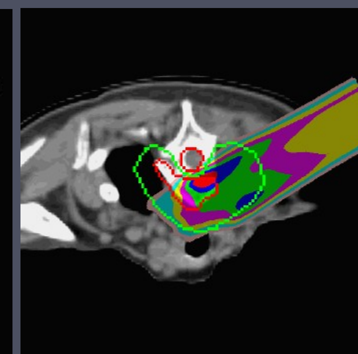
Combining gantries and scanning

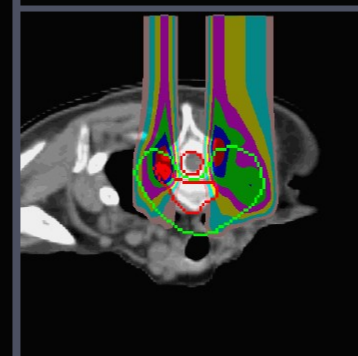
- IMPT (intensity modulated particle therapy)
  - Simultaneous optimization of dose fields
  - Superposition of non-homogenous dose fields



- Requires the use of a ***gantry***
  - Need to apply all fields in the same session
- Requires ***scanning***



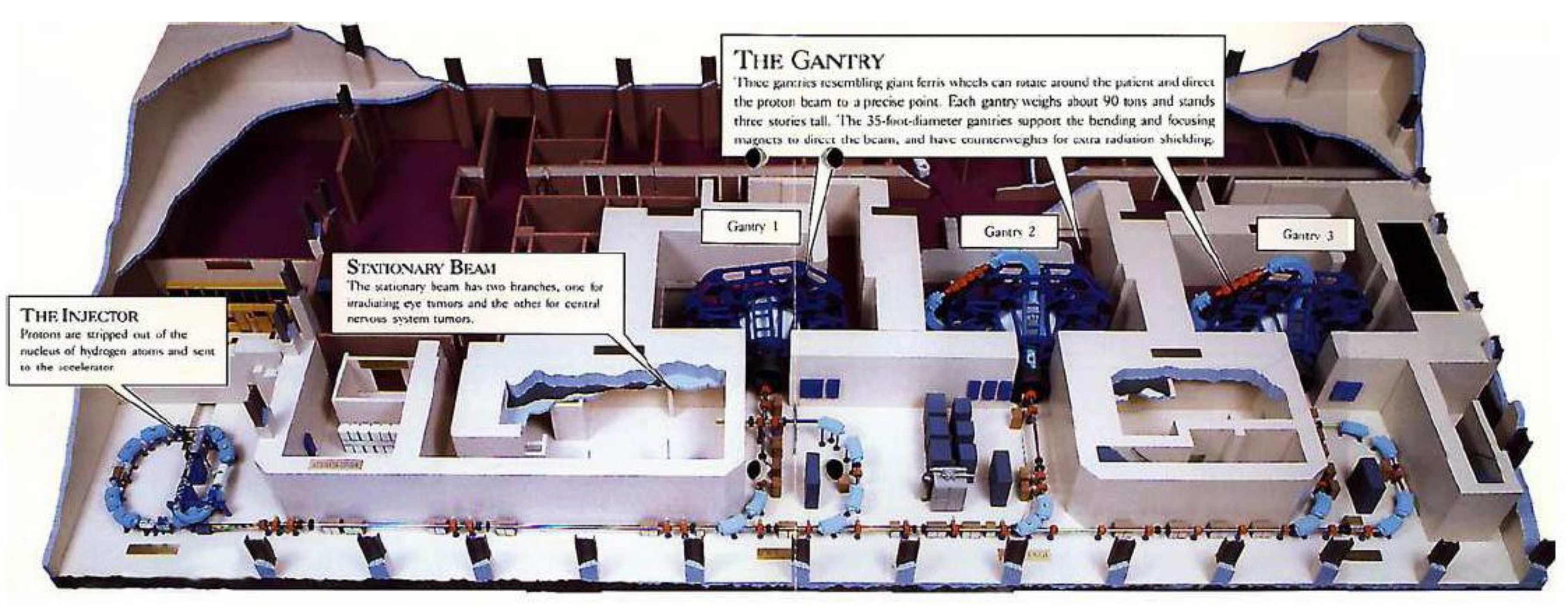




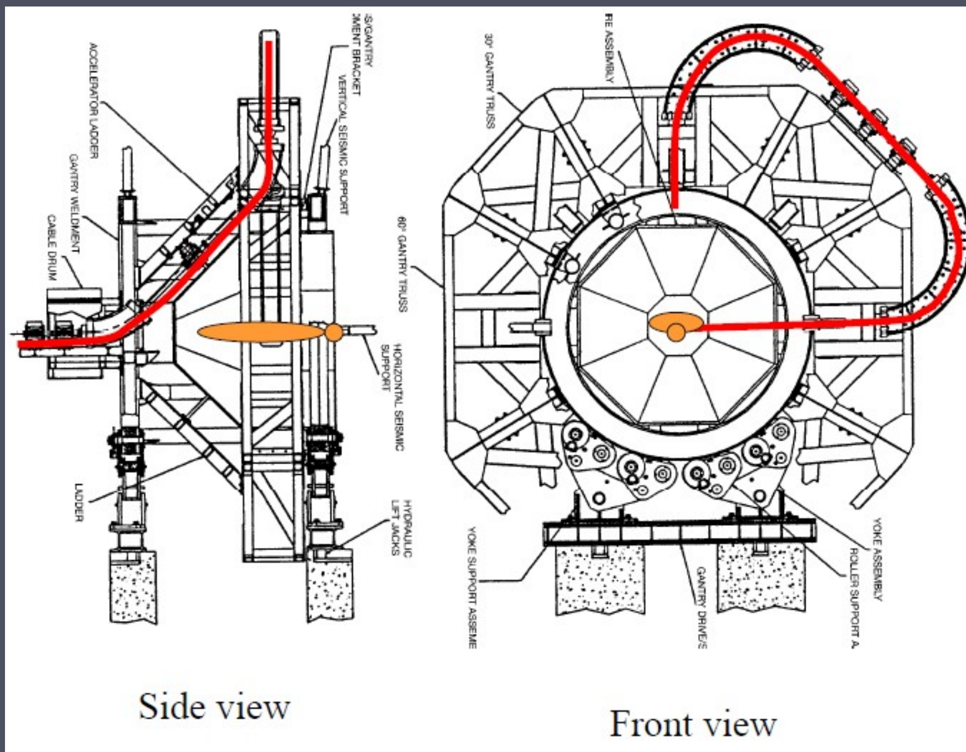
Brief history of gantries

1991 – Loma Linda University

- First hospital-based proton therapy facility
  - Synchrotron based (Fermilab technology – Optivus)
  - 3 Gantries, 2 fixed horizontal beam rooms
  - Passive scattering

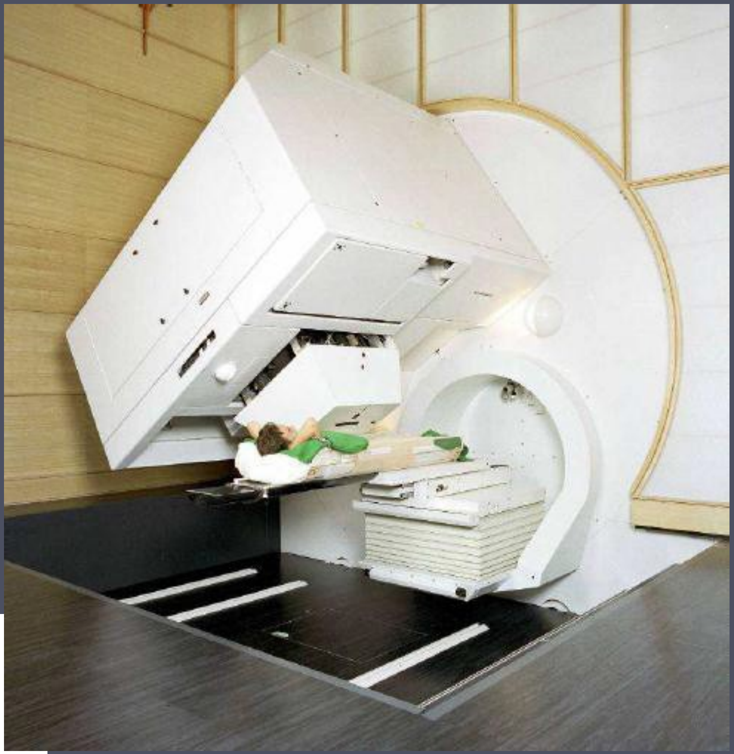


Loma Linda – Corkscrew Gantry

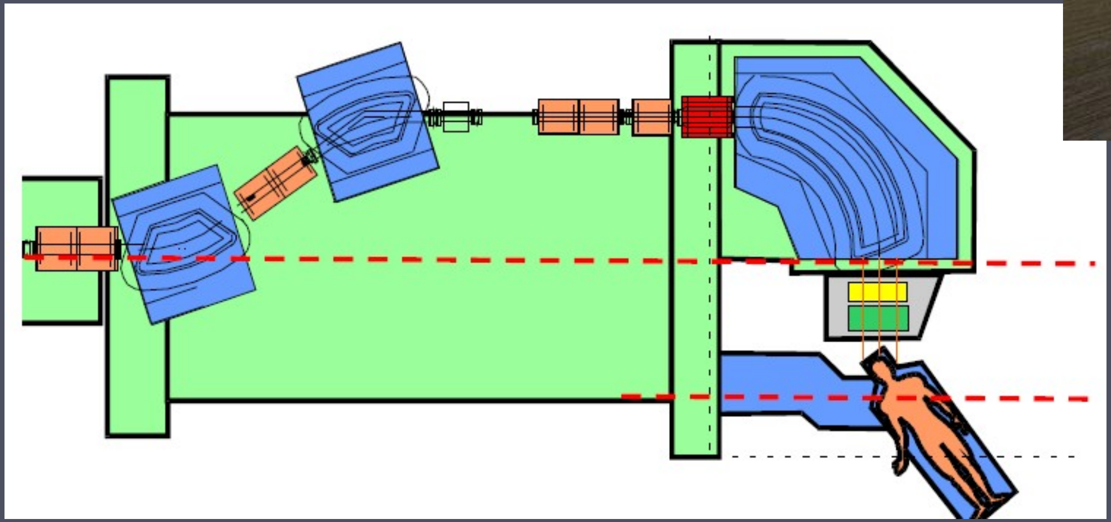


The first proton gantry

1992 – PSI Gantry 1

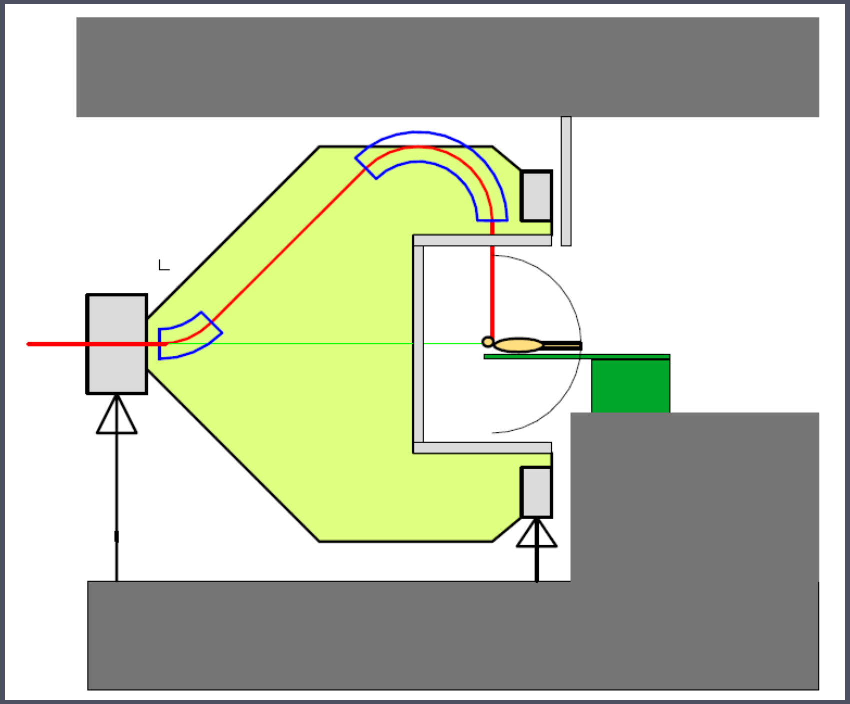


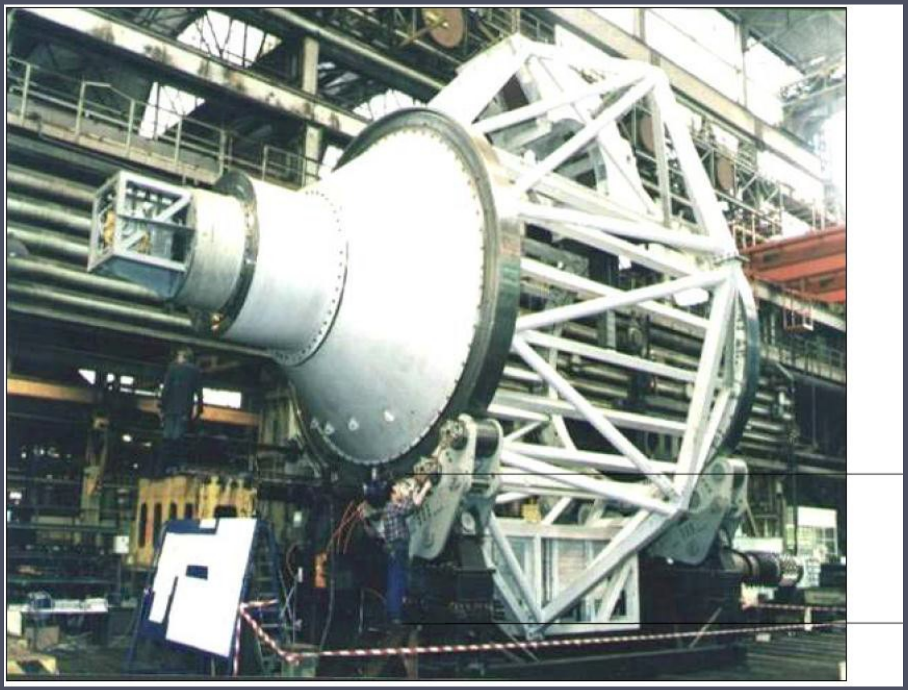
- The first ***scanning*** Gantry in the world
- Characteristics
  - ***Upstream parallel scanning***
  - Gantry radius only ***2m***
  - Eccentric mounting of patient table on front Gantry wheel



One plane is scanned magnetically, the other via table motion (like field patching)

Commercial solutions end of 90s





Example IBA

- Last bend 135°
  - Short path up-down, short length
  - Cylindrical treatment cell, gantry pit
- Passive scattering, nowadays also scanning

First commercial scanning systems 2008

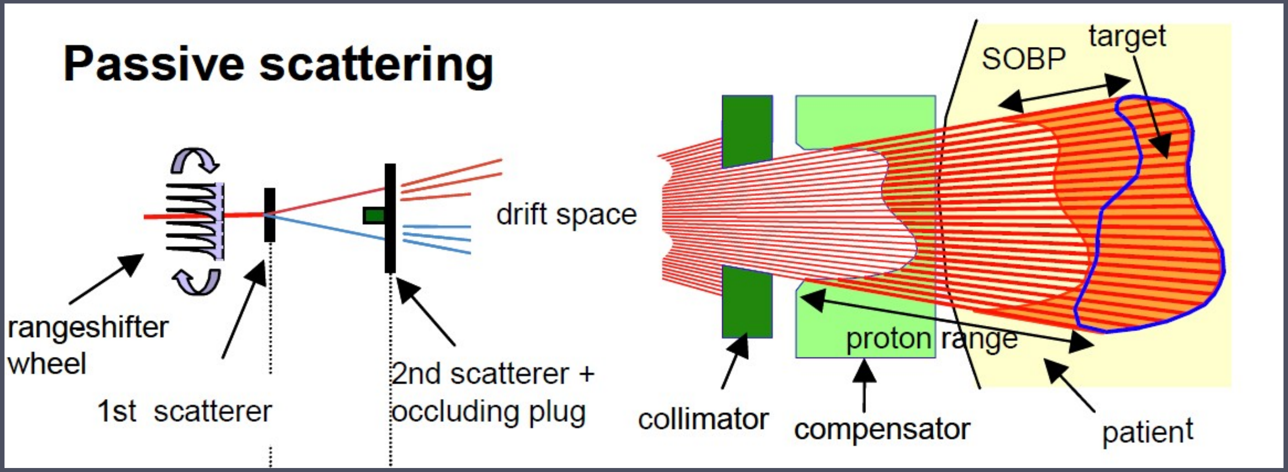
- MD Anderson (Hitachi)
- Followed by RPTC Munich (Varian) and MGH Boston (IBA)

Gantry properties and considerations

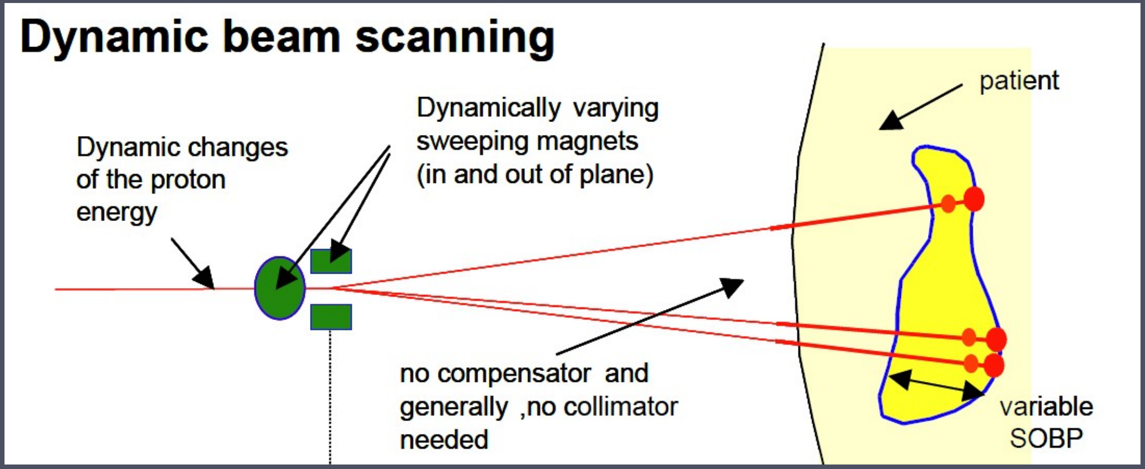
Some Gantry Properties and Considerations

1. Beam delivery modalities: Active Scanning versus Scattering
2. Fast Depth Scanning
3. Size of the Good-Field Region
4. Source to Axis Distance (SAD)
5. Fixed versus Mobile Isocenter

Beam delivery modalities (Passive scattering versus scanning)



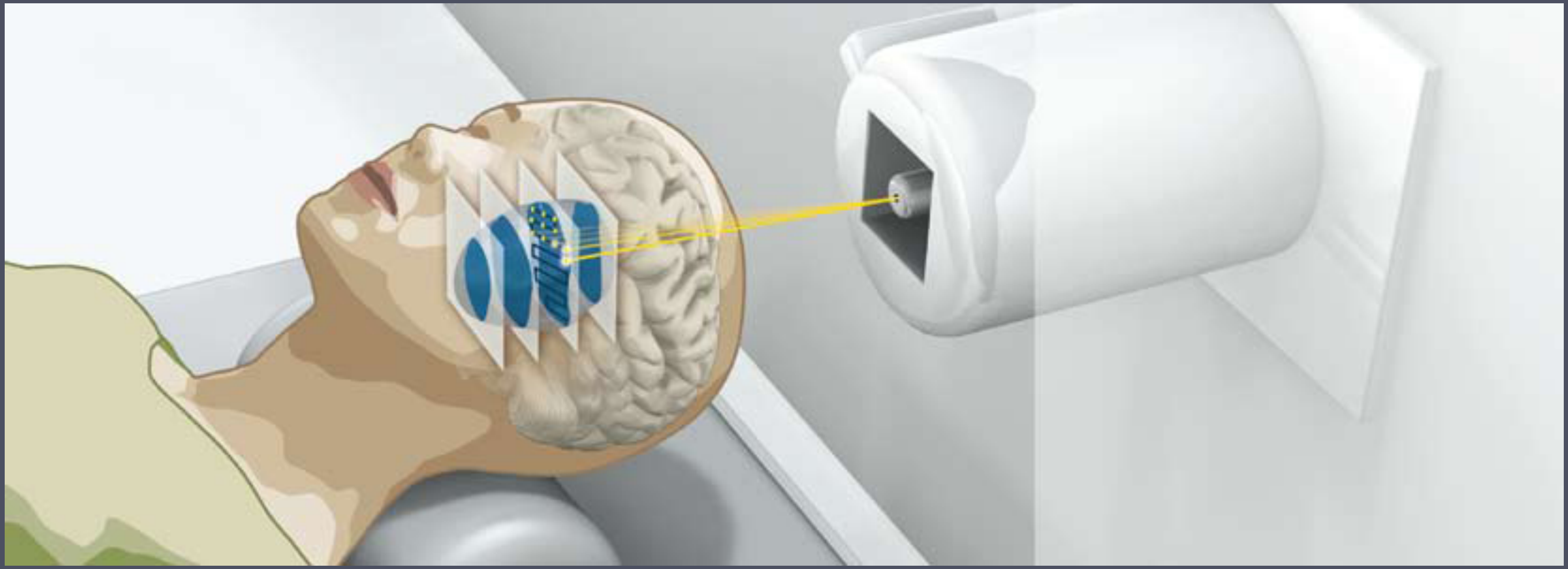
Will not talk about this technique further, however many installed (proton) Gantries still use this technique



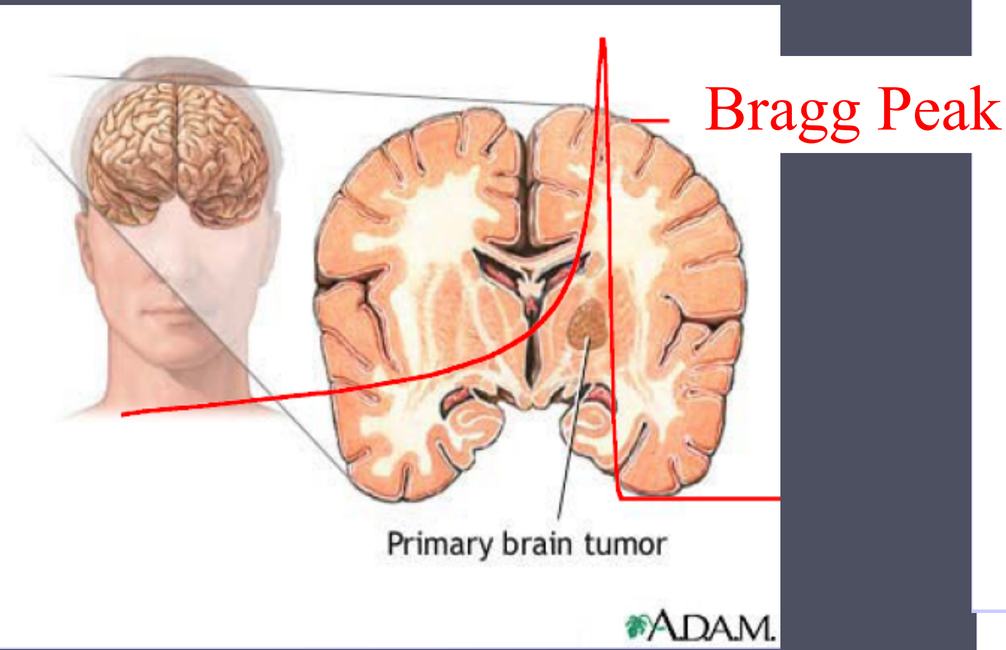
Active Scanning: State-of-the art nowadays. Allows intensity modulated therapy. No patient-specific hardware needed.

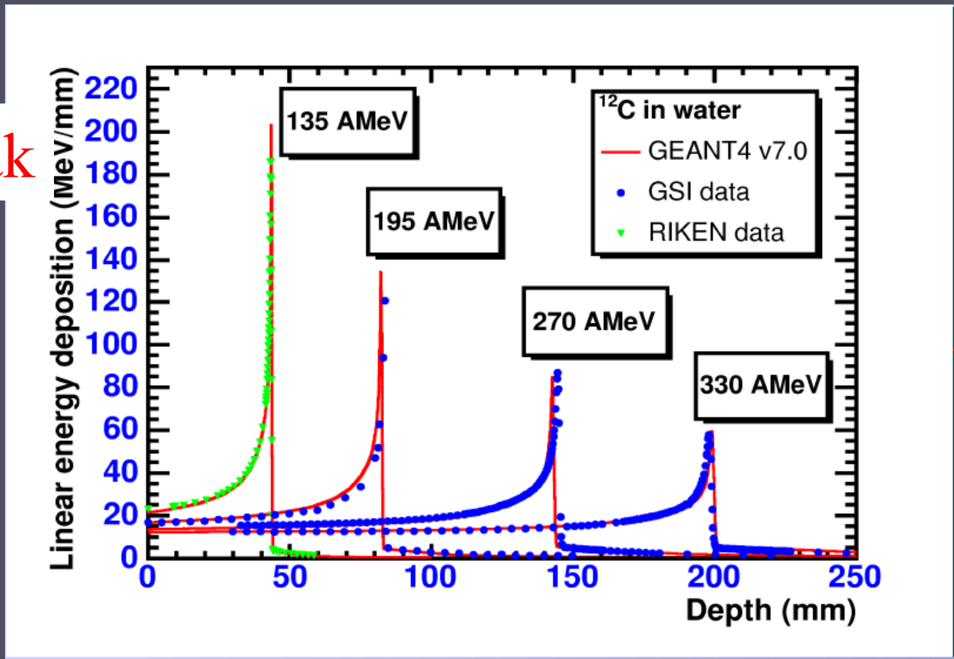
1. Active Scanning

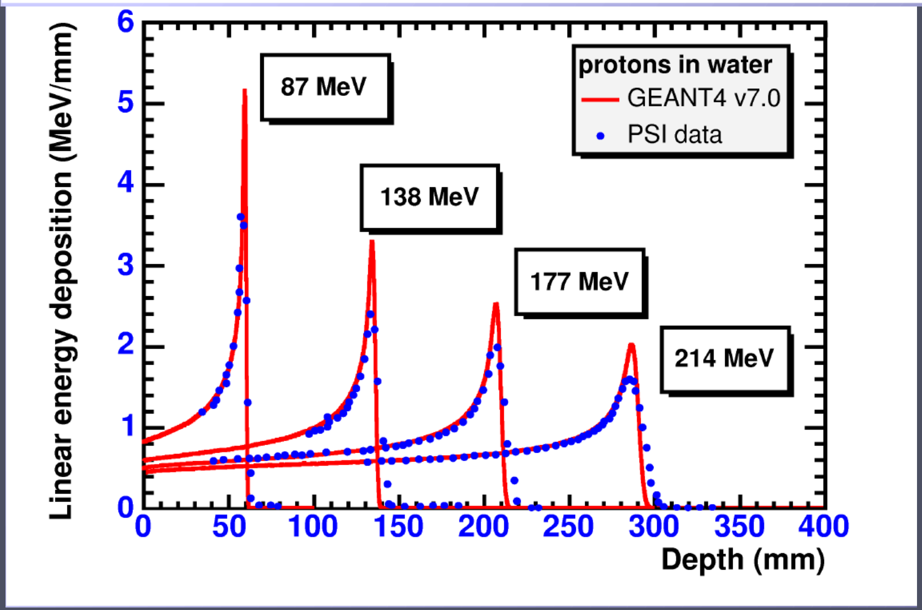
- Active spot or pencil scanning - the desired dose is delivered by scanning a small (few millimeters) beam in all 3-dimensions



2. Fast depth scanning







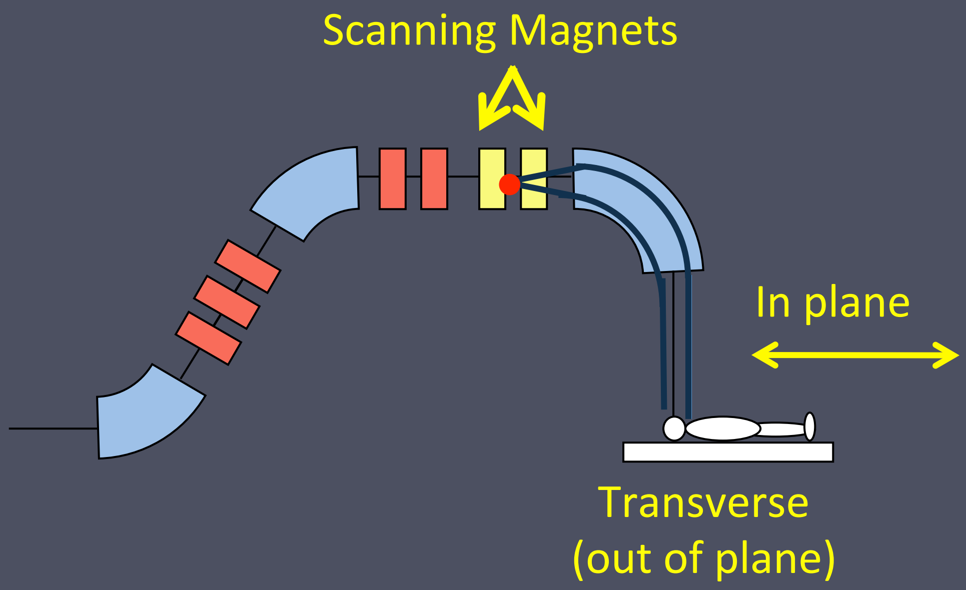
- **The depth of the energy deposition peak (Bragg peak) can be efficiently tuned by changing the ion energy**
- **Most gantries require changing the magnet fields**

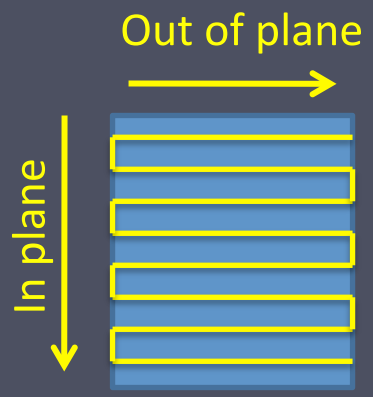
5mm depth change requires a 1% field change (on average)

3. Good Field Region

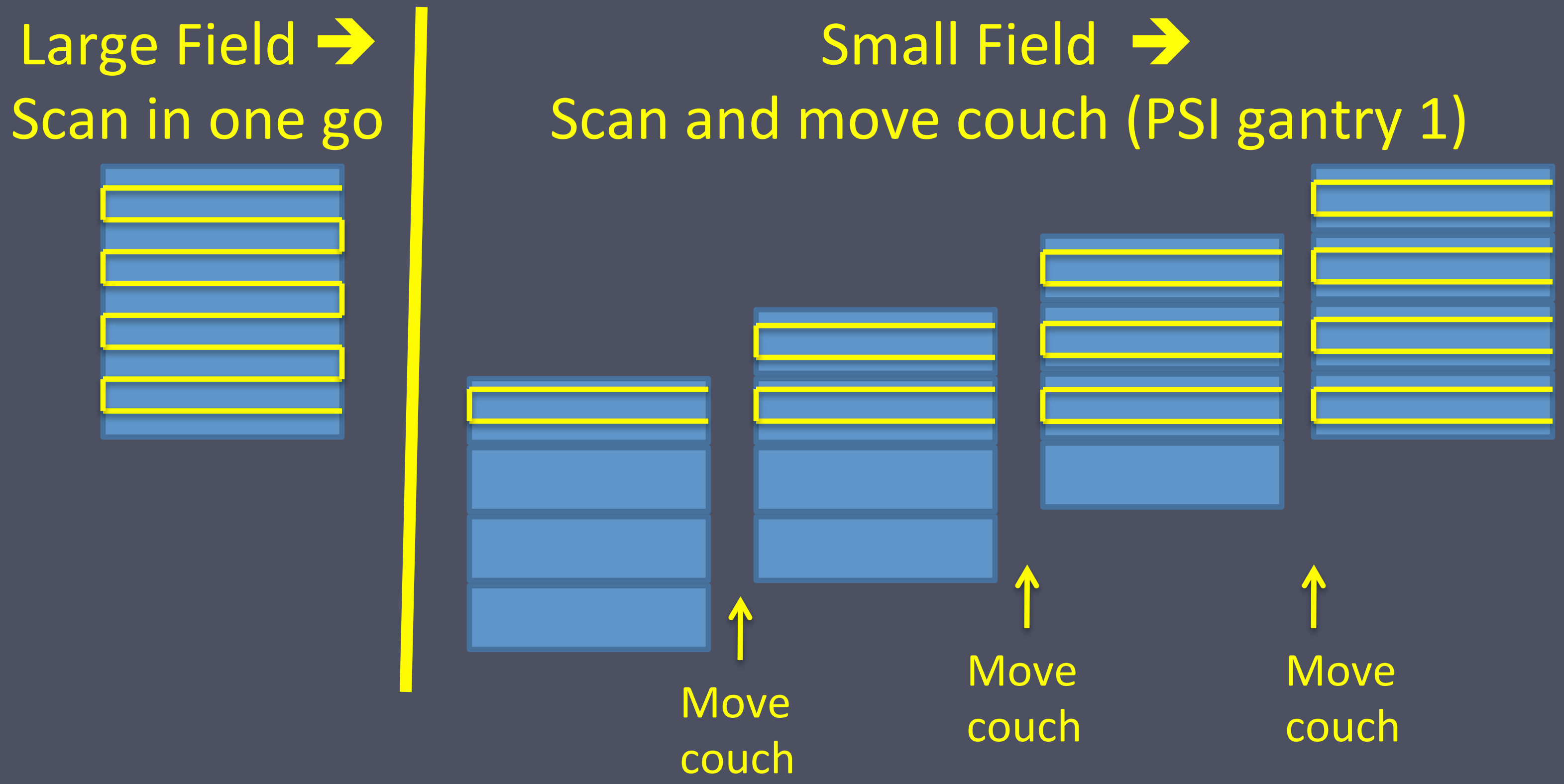
Good field region is the lateral region that can be scanned without moving the gantry or patient

Lateral plane (In plane and Out of plane Dimensions)





Field Patching

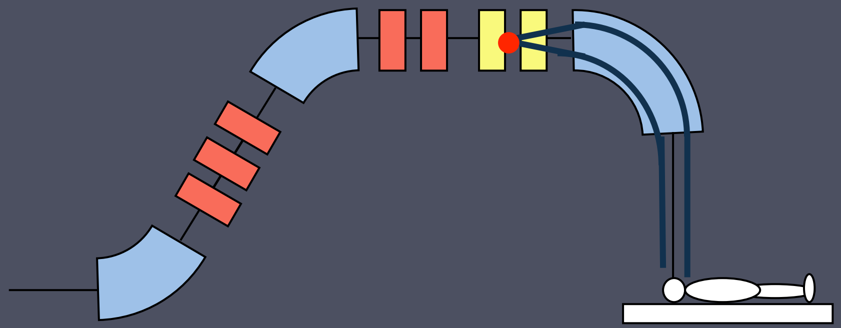


- Field patching is slower
- Large field may require larger magnet apertures and higher costs

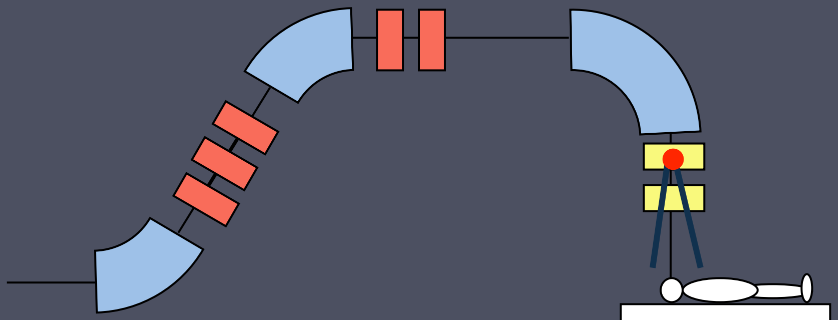
What is an optimal size for the good field region?

4. Parallel versus Angular Scanning

- To minimize normal tissue dose → Parallel scanning is preferable



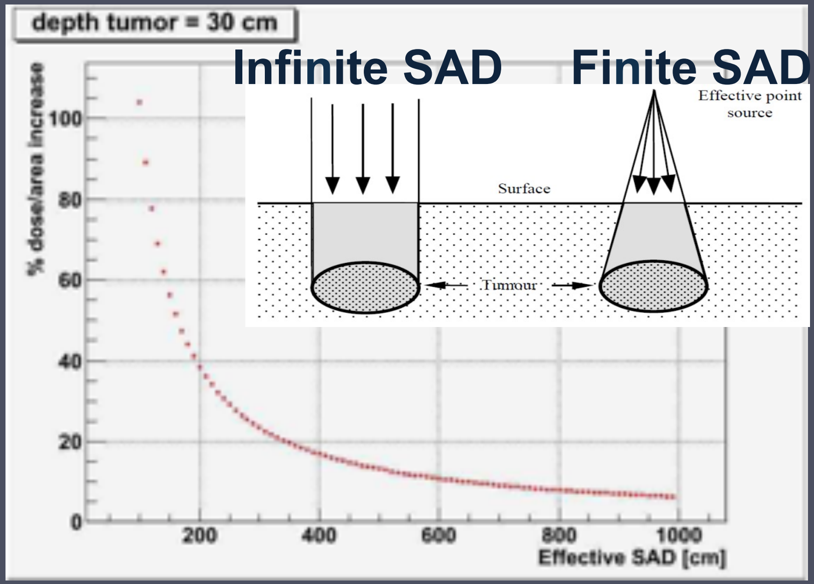
- But some small angle might be acceptable

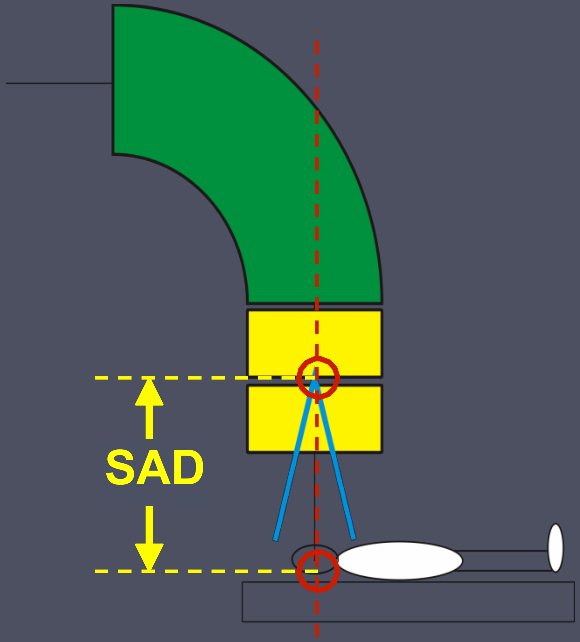


- Source to Axis Distance (SAD)

Considerations for smaller SADs

- Higher relative skin dose
- More complex planning an dosimetry



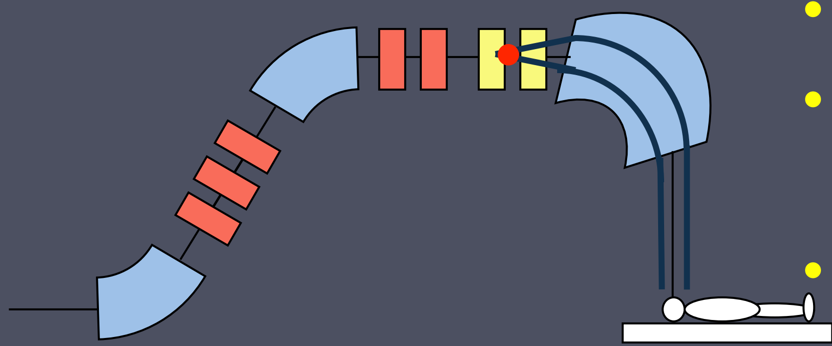


What is the Minimal Acceptable SAD?

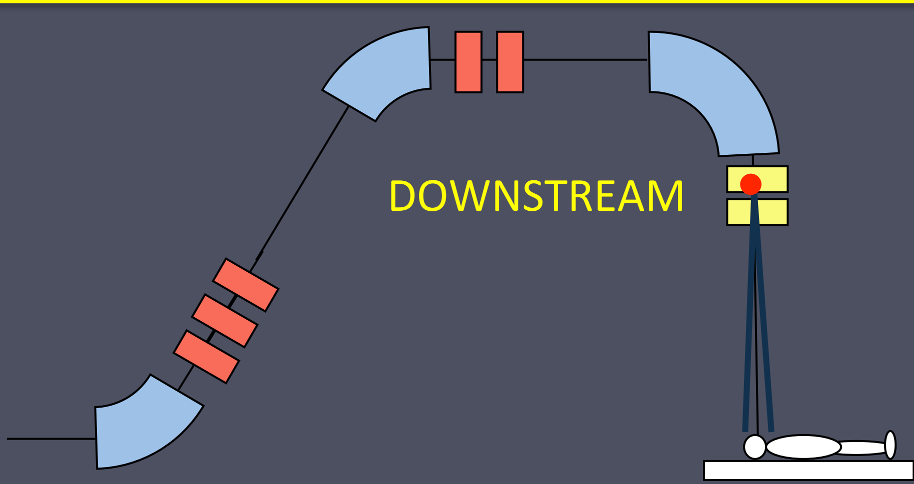
Scanning Magnets Location

Upstream or Downstream of Final Bend?

UPSTREAM

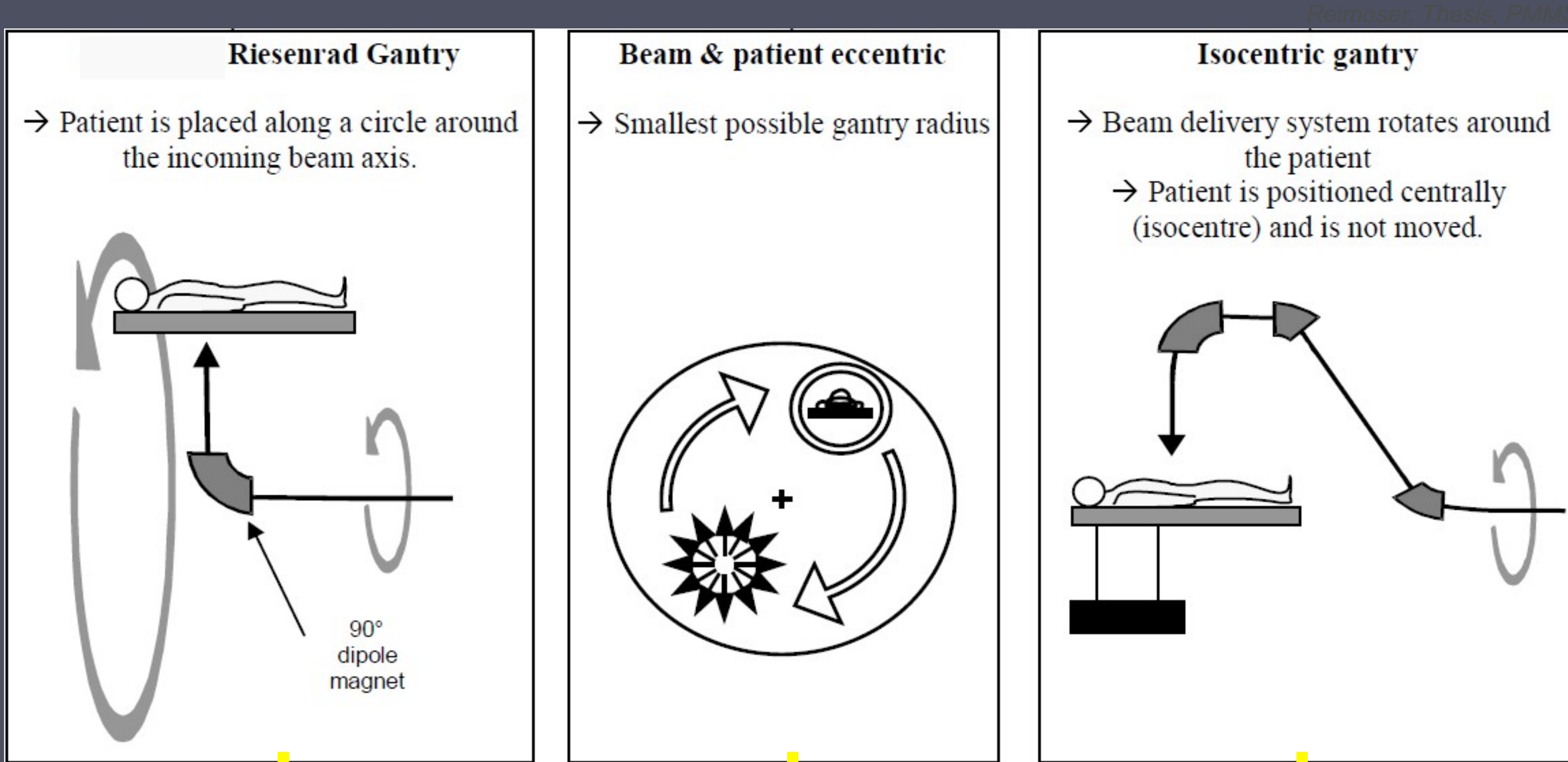


- Large aperture magnet
- Emphasis on magnet field quality
- Higher operating costs



- Larger gantry radius
- Larger room size

5. Mobile versus fixed Isocenter



Has not been built yet

PSI Gantry 1

Most Gantries in the world

Gantry functional specifications

Example (ULICE* survey)

- As part of the Union of Light Ion Centers in Europe (ULICE), physicians and medical physicists from CNAO and other European facilities completed a survey

- Some of the survey results are shown on the next page are useful in understanding the carbon ion **gantry functional specifications**

*ULICE Report JRA6.1 (2010). A 565 (2006) 430.

Gantry functional specifications	
Minimum good field size	**15 x 15 cm^2**
Maximum number of fields per session	**4**
Penetration depth (range)	**3 – 30 cm (corresponding energy: p = 60 - 220MeV; C ion = 120 – 430 MeV/u)**
Voxel dose accuracy	**±1%**
Dose uniformity	**±2.5%**
Voxels characterization	**3 x 3 x 3 mm^3**
Voxels out of range	**1%**
Field position accuracy	**±0.5 mm**
SAD	**4 m**
Maximum treatment time	**30 min**
Minimum required space around isocenter	**60 cm**
Achieved beam directions	**4π**

What is the present state-of-art?

Present state-of-art

- Fast Conformal Scanning with Volumetric Repainting
- Active and Parallel (large SAD)scanning
- Short (few minute) treatment time per field (including repaintings)
- Reasonably large Lateral Good-Field Regions
- Fixed Isocenter
- Field position accuracy ~1mm
- Full 4π angular coverage

PSI Gantry-2 and HIT are good examples

Both are derivatives of the same design - Pavlovic

Pavlovic Type Gantry Design

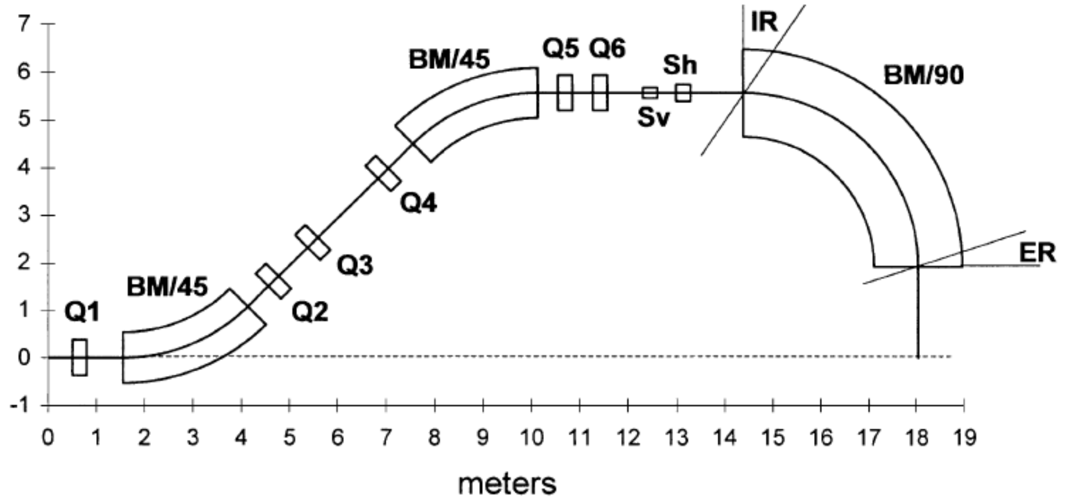


Fig. 3. Layout of the gantry with the minimum number of quadrupoles: Q1–Q6 = quadrupoles, BM/45 = 45° bending magnet, BM/90 = 90° bending magnet, Sh = horizontal scanner, Sv = vertical scanner, IR = input pole face rotation (30°), ER = exit pole face rotation (21°).

Radially very compact by having the last magnet a 90 degree magnet. All the other magnets – quadrupoles, dipoles, and steering magnets, do not take up additional radial space.

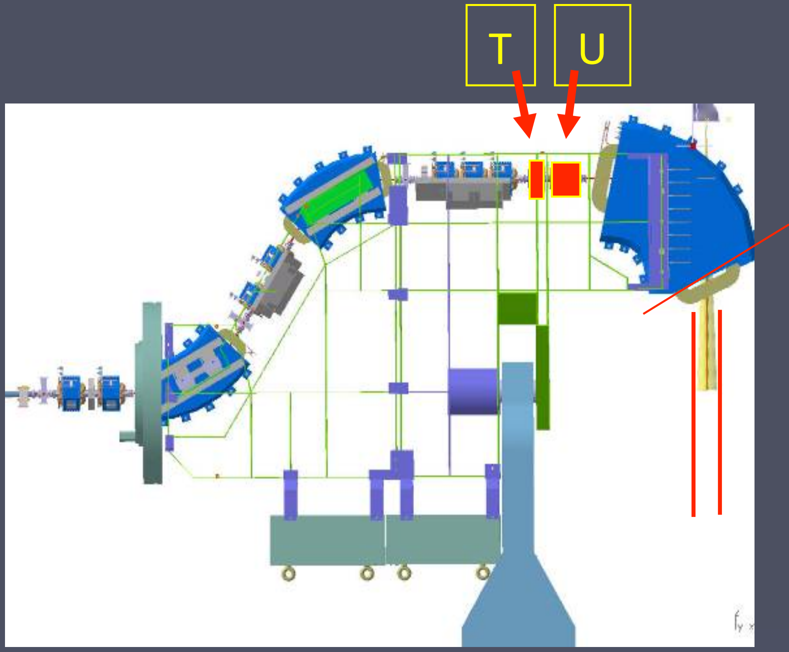
The radial size is determined by only three things –
(1) the space between the patient and the last magnet,
(2) the bending radius of the 90 degree dipole, and
(3) the outer diameter of the magnet.

M. Pavlovic, et al, Nucl. Inst. and Meth A 545 (2005) 412-426

Example – PSI Gantry 2

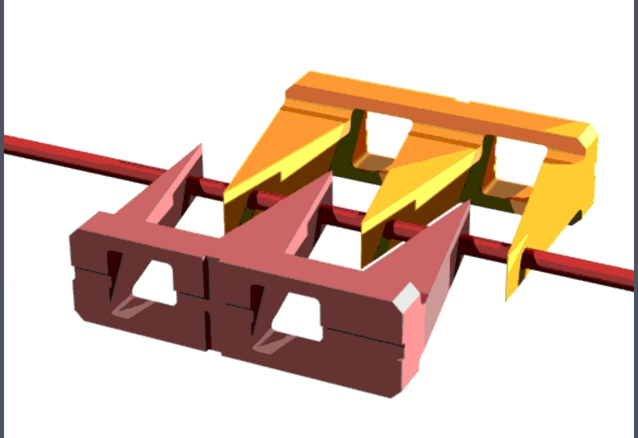
- Good Field Region 12 cm x 20 cm
- Fast double parallel scanning
  - Lines ~10 ms
  - Lateral Plane (one energy) <200 ms (20 lines)
  - Beam Intensity Modulation (BIM)
- Quick Depth Change
  - 100 ms per 5 mm
- Repainting of iso-layers
  ~ 7 seconds per cubic liter (20 energies)
- Volumetric repainting capability
  - 10 repaintings / liter in 1 (**2**) minutes

Lateral Scanning

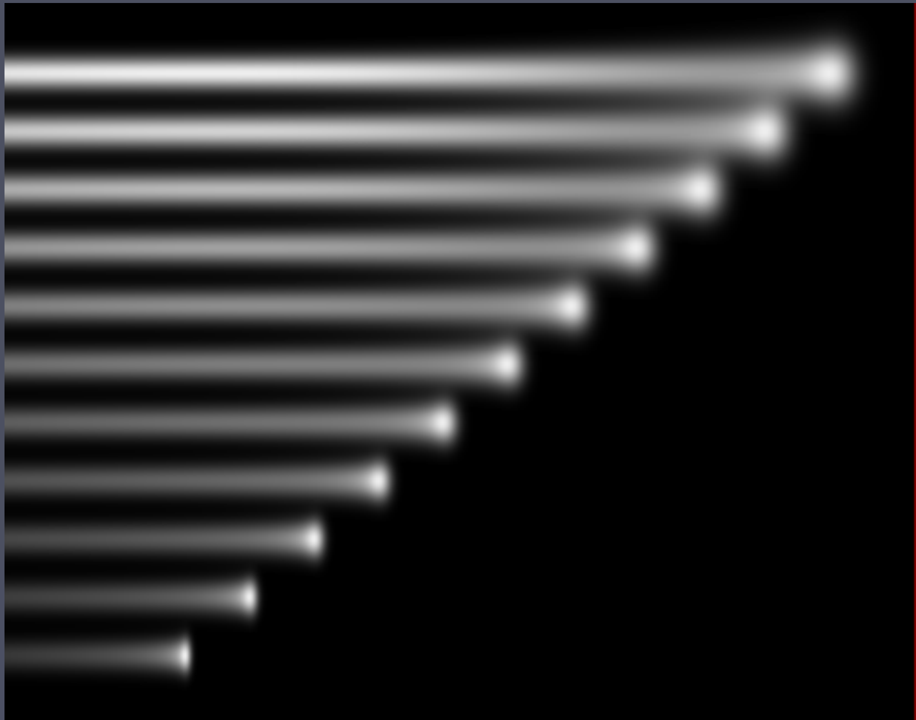


Fast beam energy changes

Carbon wedges moving against each other in the beam



Fast energy changes
with degrader and beam line
(including GANTRY 2 magnets)
Aiming at 100 ms dead time for range steps of 5 mm
Achieved 80 ms !!



Future developments

Potential For Improvement

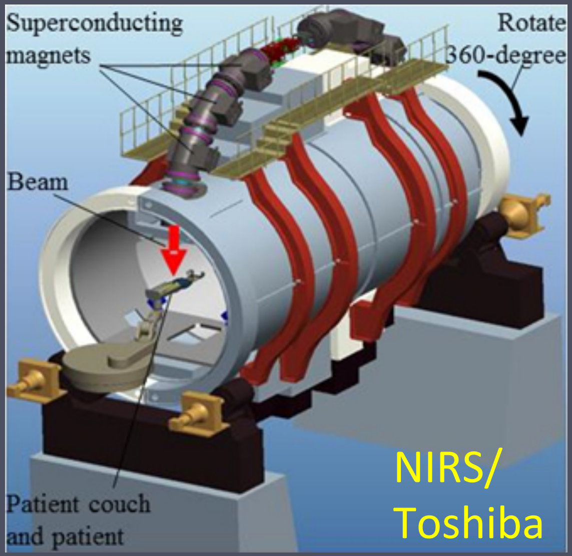
- Gantries are expensive
  - Large structures
  - Requiring big heavily shielded (~5m thick) rooms
  - Substantial operating costs (up to 0.8 MW for HIT Gantry)

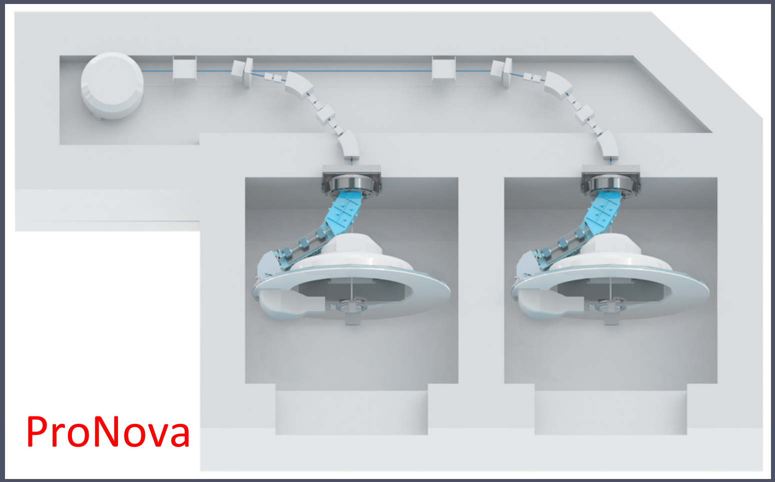
- Advantages of gantries are such that many new proton facilities are being built with multiple gantries

- Gantry development has potential for achieving significant gains in size reduction, cost, and improved performance

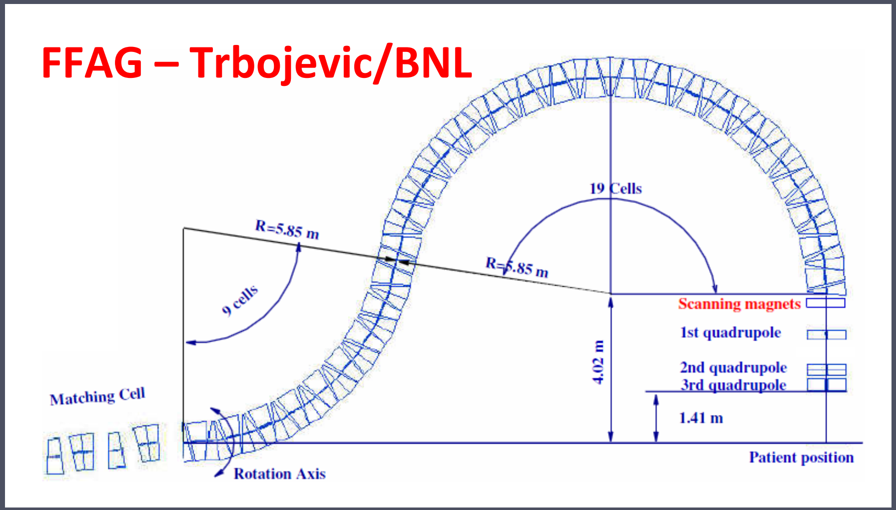
Potential for lighter and higher performance gantries

1. More compact gantries using superconducting magnets (Y. Iwata)

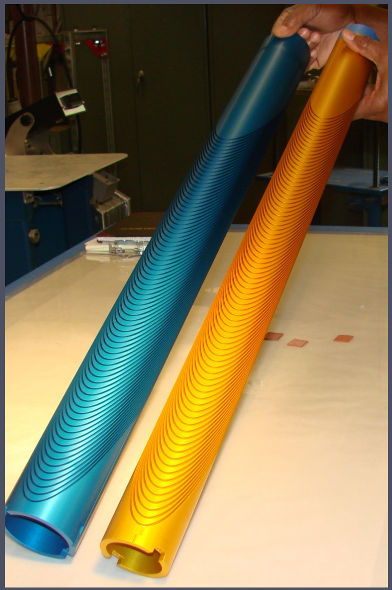


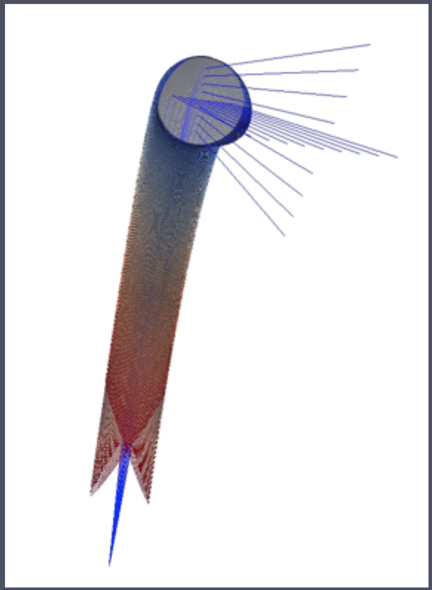


2. **Faster energy scanning**



Superconducting CCT magnets – Caspi/LBL





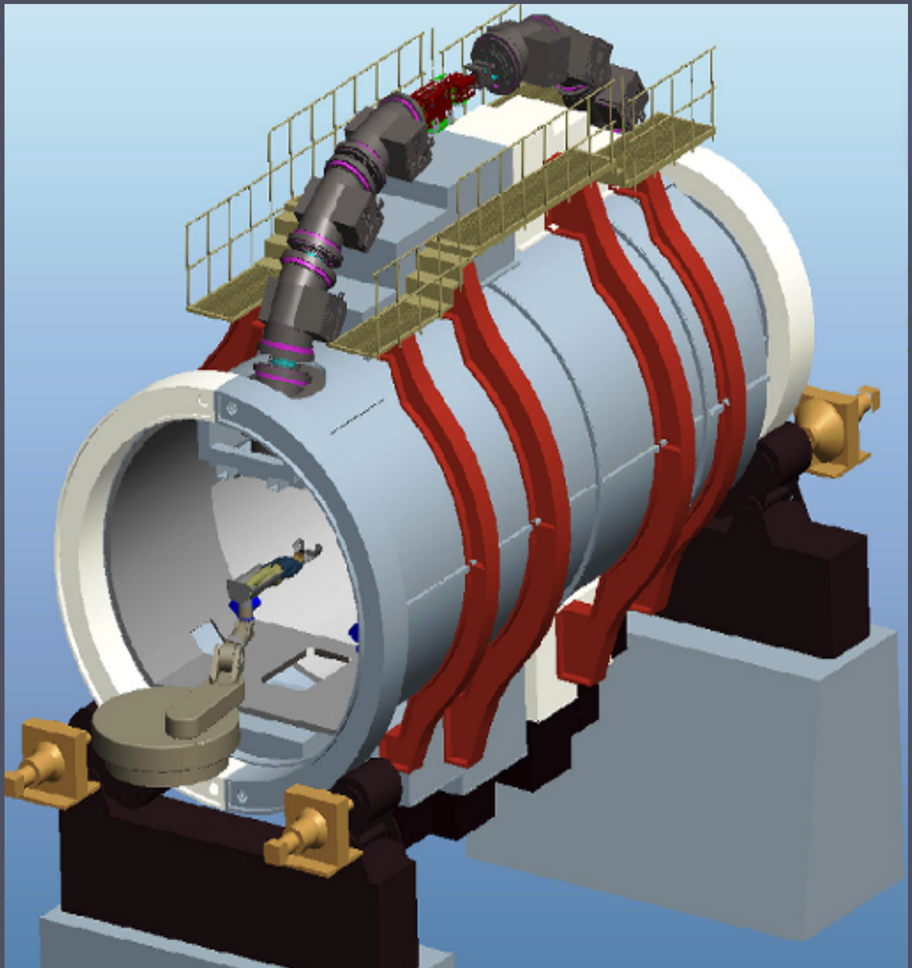
Superconducting Magnets

- Attraction
  - Superconducting magnets can achieve many times the magnetic field strength compared with normal conducting magnets

    – *more compact lighter systems*

- Some major challenges such as
  - Rotatable cryogenic systems
  - Rapid field changes for scanning depth

Superconducting rotating-gantry (NIRS/TOSHIBA)



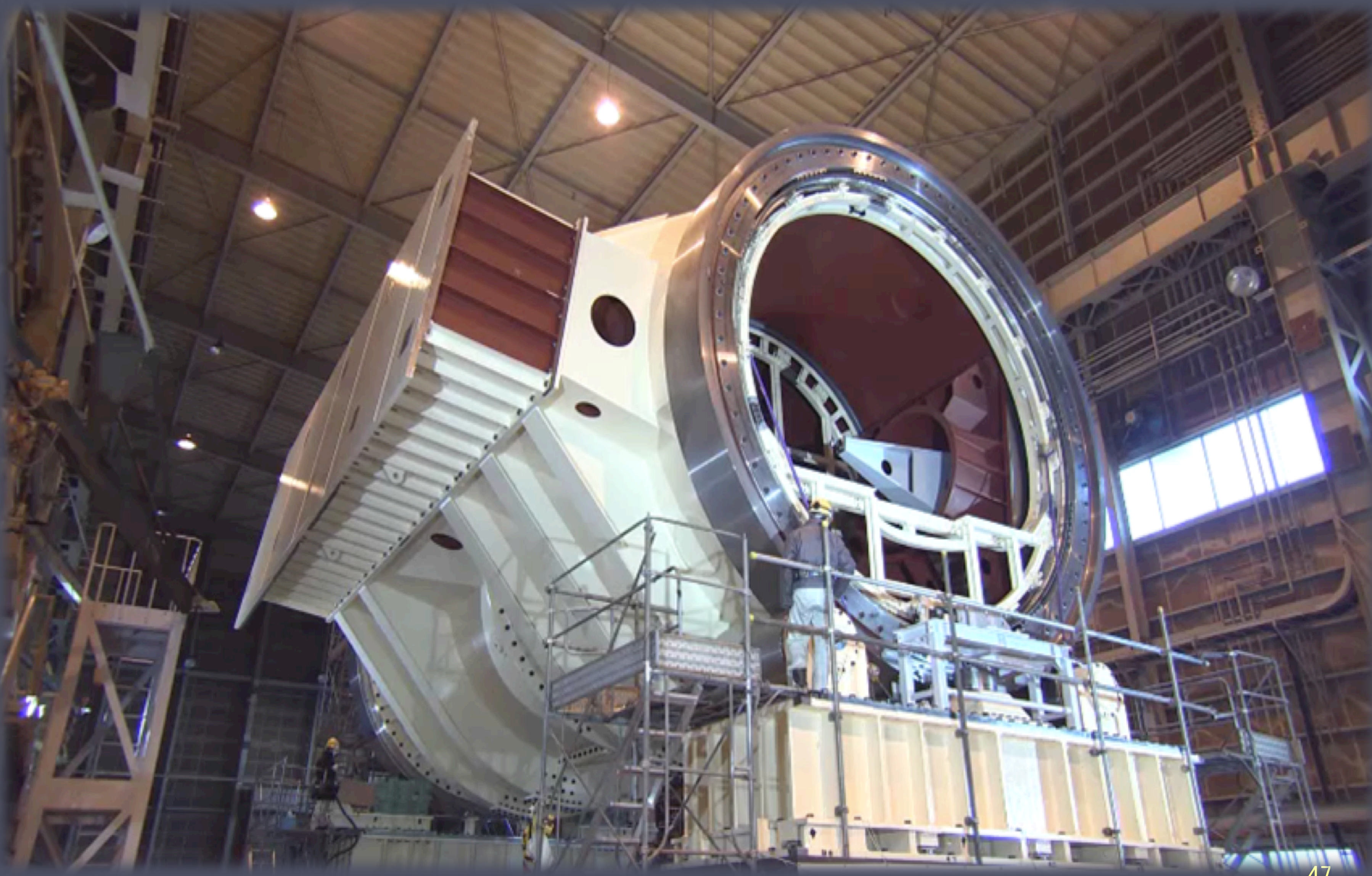
Weight: order of 300 tons

Use of superconducting (SC) magnet

Ion kind : ^{12}C
Irradiation method: 3D Scanning
Beam energy : 430 MeV/n
Maximum range : 30 cm in water
Scan size : 200×200 mm^2
Beam orbit radius : 5.45 m
Length : 13 m

The size and weight are considerably reduced

Rotation tests at the Toshiba factory

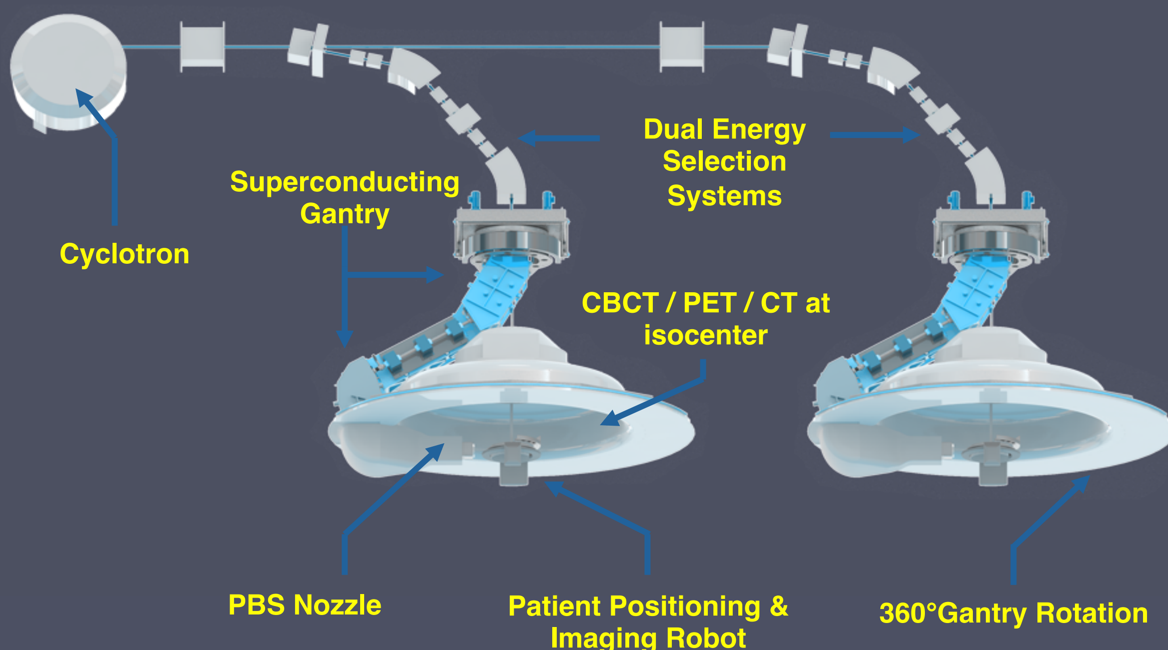


Summary (NIRS/TOSHIBA)

- **Superconducting rotating-gantry**
  - **World's first superconducting gantry**
  - **Compact (~proton gantries)**
- **Future plan**
  - **Construction will complete by this summer**
  - **Beam commissioning will be made in this autumn**
  - **Treatment using the gantry (~March, 2016)**

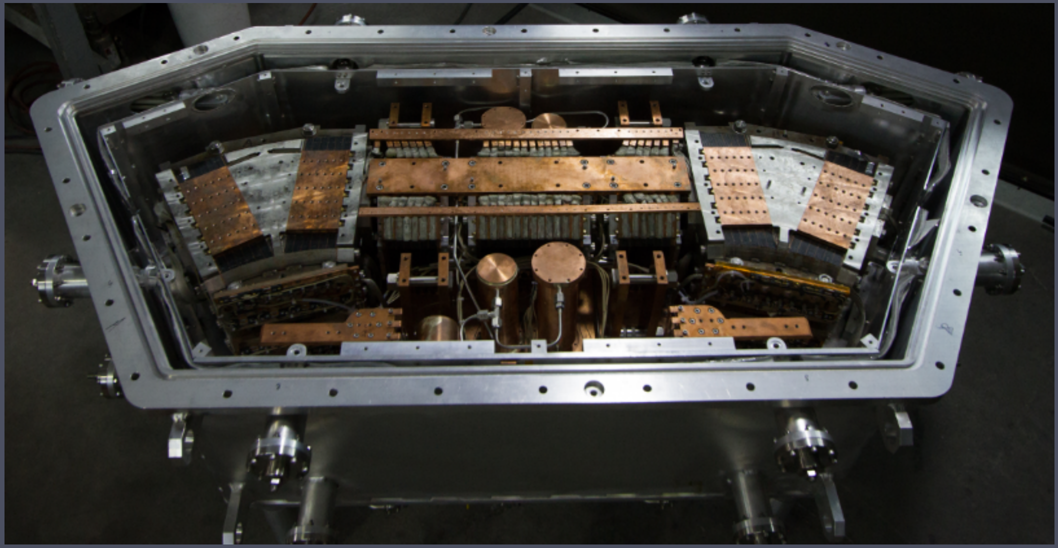
PRONOVA SC360 SUPERCONDUCTING GANTRY

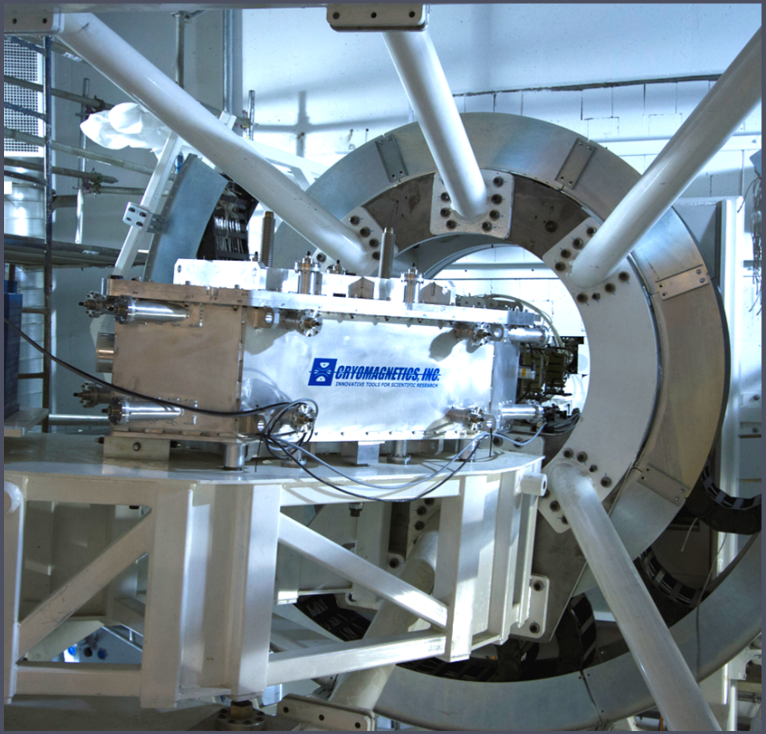
- 4T Achromatic 60 and 150 deg bends
- Lightweight and compact design allows:
  - 360 rotation in compact vault
  - Rectangular treatment room
  - Cantilever nozzle – open isocenter
  - Space for full 360 dual energy CBCT at isocenter
  - Low operating power



ProNova Superconducting Achromat

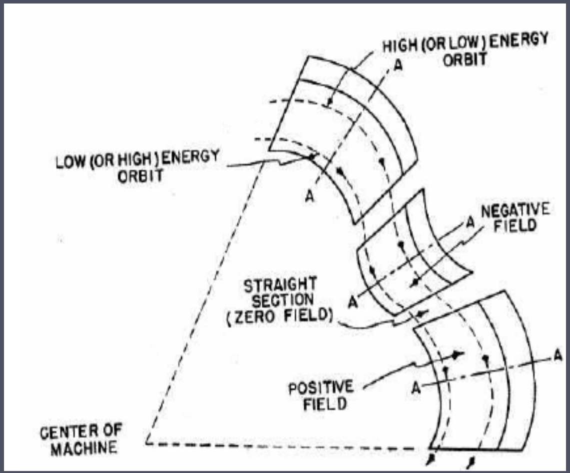
- Achromat status
  - SC achromat US Patent issued
  - Exceeds ramp rate, full field, and rotational test requirements
  - Mounted and tested at full field on gantry
  - In production for early 2016 shipments



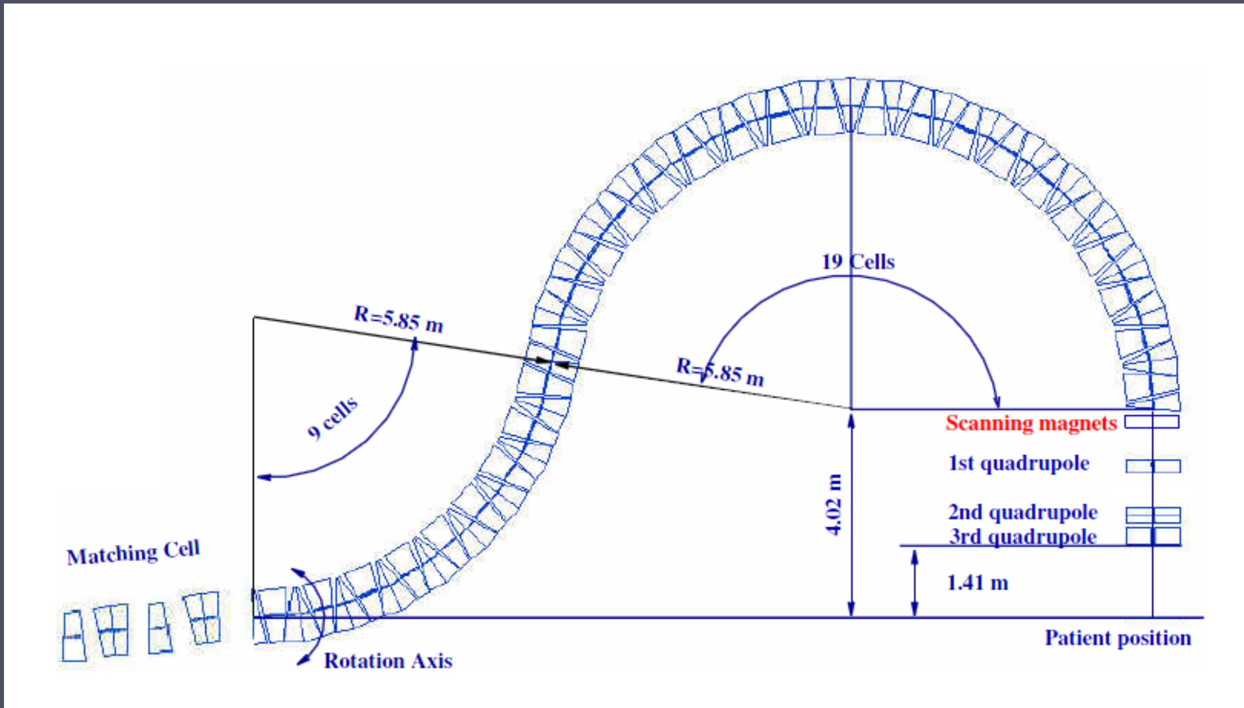


Larger momentum acceptance - Achromat allows to scan the beam energy over some range without changing the magnet field

Fixed Field Alternating Gradient Gantry



Dejan Trbojevic, Workshop on Hadron Beam Therapy of Cancer, Erice 2009



Fixed Field Alternating Gradient Design

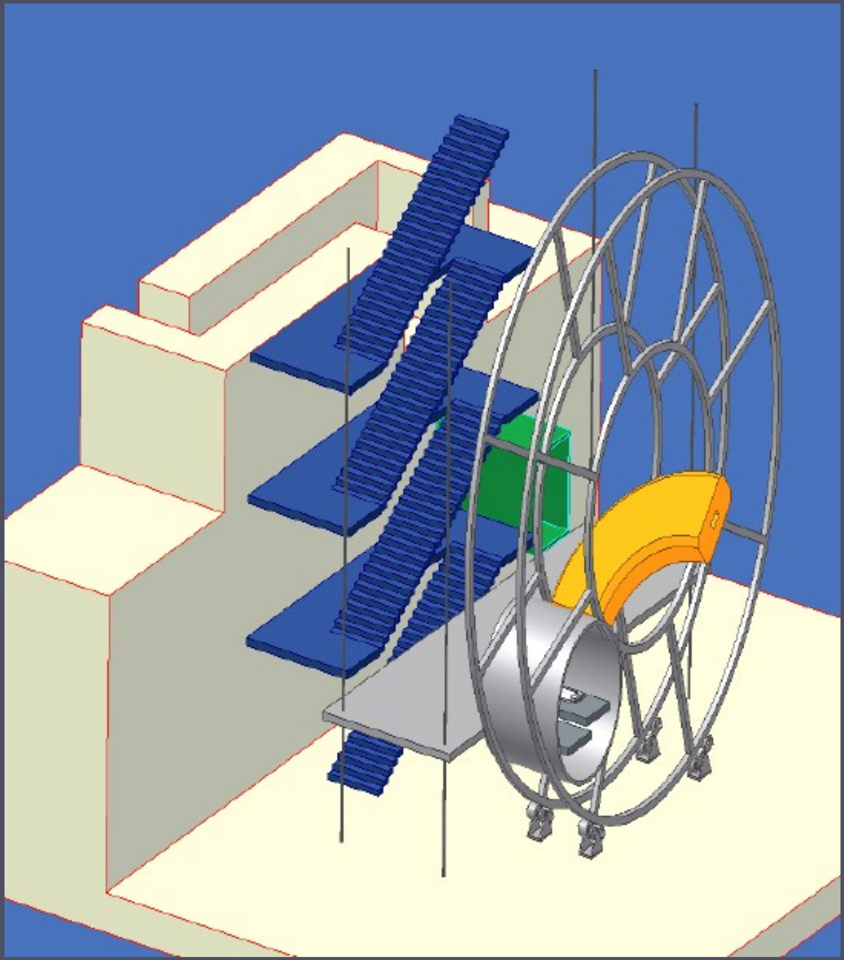
- Small aperture high gradient dipoles

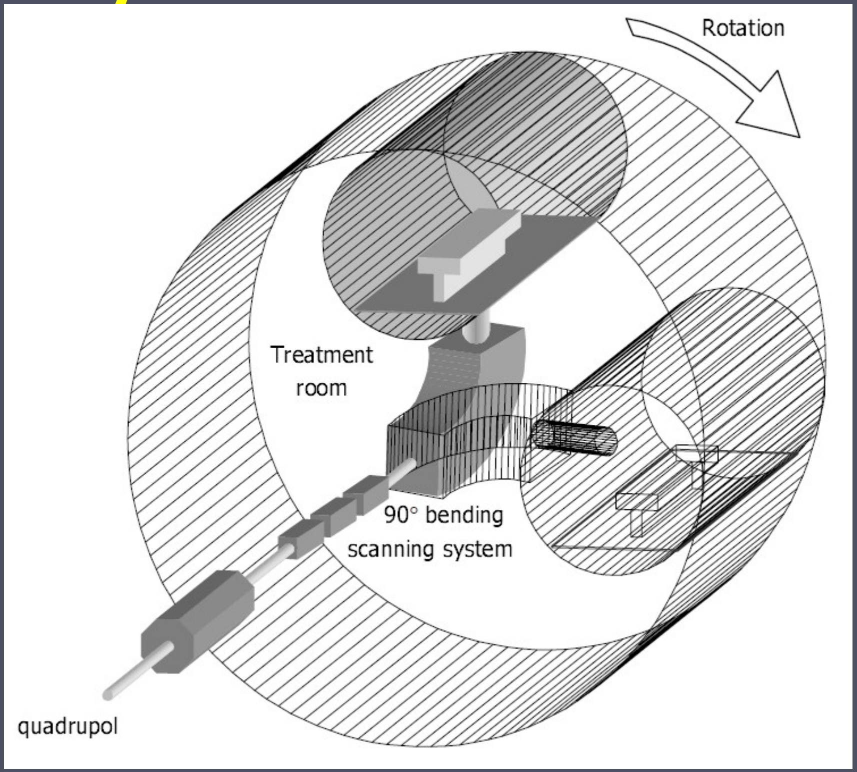
The potential for very fast depth scanning

A Potential Major Advantage

- Large Energy/Momentum Acceptance
  - May not need to change field while scanning depth
  - Potential to enable very fast depth scanning

Mobile Isocenter – The Riesenrad Gantry





The main rotating structure is the room with the patient (lighter than the 600t of HIT).

Summary

- Gantries are essential for optimizing PT
- Performance of existing gantries is impressive
- Gantry development can have significant impact on the performance and cost of the facility


THANK YOU