Gantries

M. Pullia

CAS, Accelerators for Medical Applications, 26 May – 5 June 2015, Vösendorf, Austria

fondazione CNAO
Centro Nazionale di Adroterapia Oncologica

What is a gantry?

- A tall metal frame that supports heavy machines such as cranes, railway signals, or other equipment
- A support for a barrel lying on its side.

THIS MODEL CAN BE BUILT WITH MECCANO OUTFIT No. 10 — Leaflet No. 10

MECCANO

Automatic Gantry Crane

(MODEL No. 10.10)

SPECIAL FEATURES

Entirely automatic operation of the traversing trolley and lifting and lowering the load, are attractive features of the fine Gantry Crane described in this Leaflet. A Meccano E15R type Electric Motor provides the driving power.

The attractive Gantry Crane that forms the subject of this Leaflet is a very interesting and instructive model that will give much pleasure to anyone who builds it. The main feature of the model is an ingenious automatic reversing mechanism, by means of which the trolley is made to travel to and fro along the gantry rails and reverse its direction on reaching each end, entirely without attention. The motive power is provided by a Meccano E15R type Electric Motor.

Cranes of this type are used mainly in metal stock yards, foundries and coaling yards, where they are capable of handling great or small loads over wide areas. They are also to be seen sometimes on quaysides. The actual cranes of course are not fitted with automatic reversing mechanisms, and the trolley is controlled by the driver, who is usually located in a control cabin that forms part of the trolley itself.

FIG. 1
This fine Gantry Crane is fitted with a special mechanism that raises and lowers the load automatically as the trolley moves to and fro along the gantry

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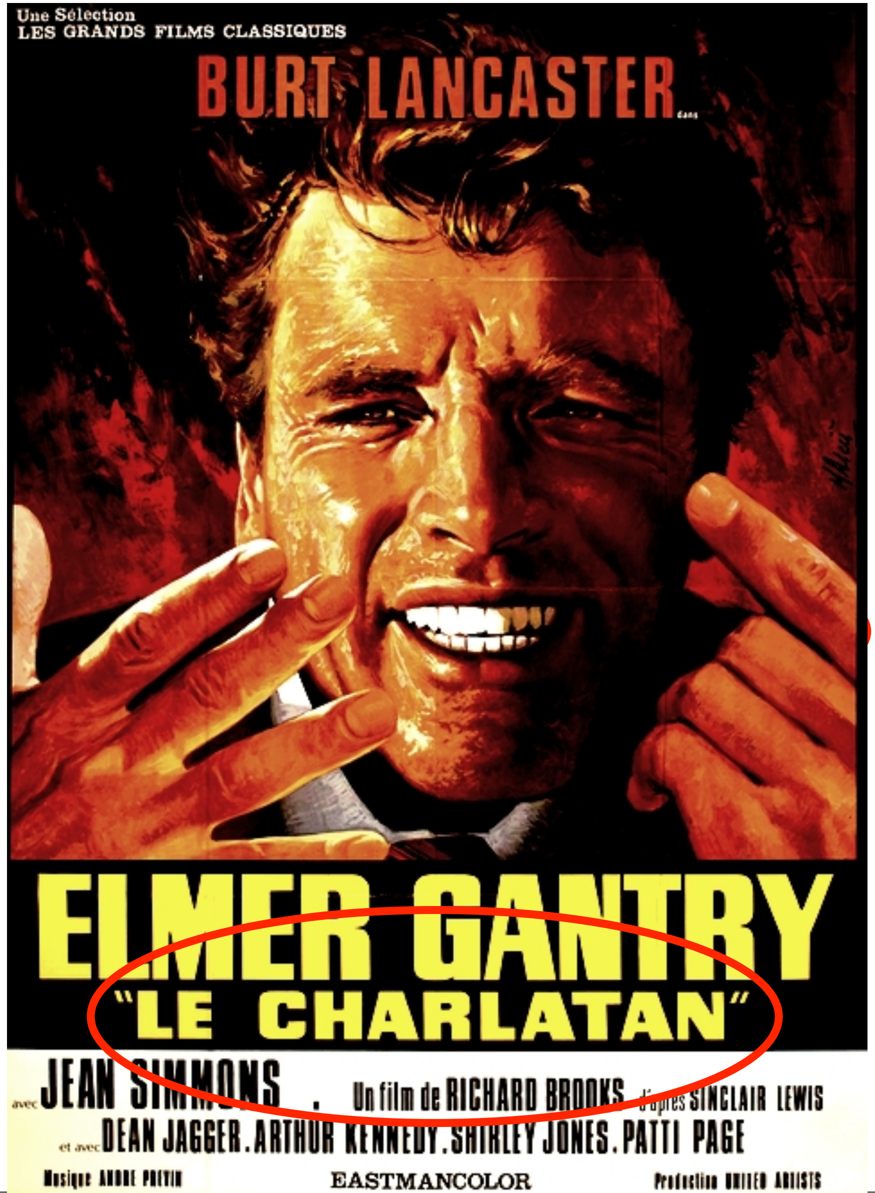
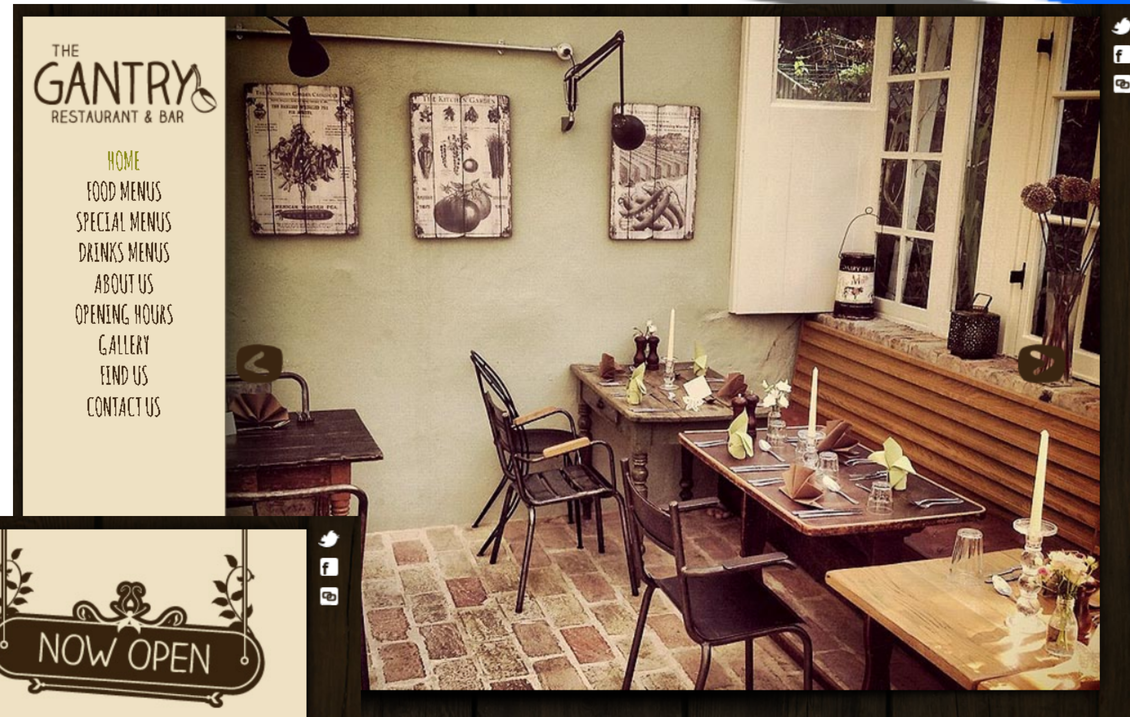
Gantry at cinema



Hopefully not in our case...

Gantry food


THE GANTRY
RESTAURANT & BAR
HOME
FOOD MENUS
SPECIAL MENUS
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CONTACT US
NOW OPEN
WELCOME TO THE GANTRY
COME AND SIT AT THE BAR, RELAX IN FRONT OF THE FIREPLACE, DINE INDOORS AND IN THE CONSERVATORY OR JUST SOAK UP THE FRESH AIR IN OUR HIDDEN GARDEN.
020 8469 0043
188 BROCKLEY ROAD, BROCKLEY, LONDON SE4 2RE
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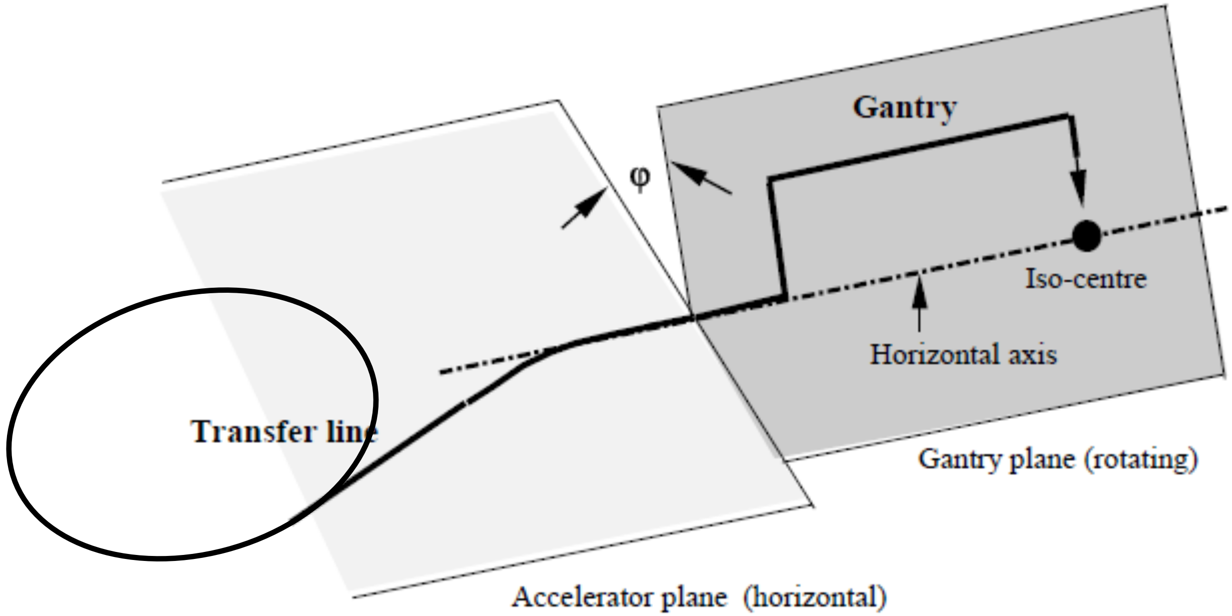
Gantry in music

- I could not find a picture, but I think I remember of an english group called The Gantry...

... but for us

- **A gantry is a section of beamline that can rotate around the isocenter in order to direct the beam onto the patient from any direction**



Why a gantry?

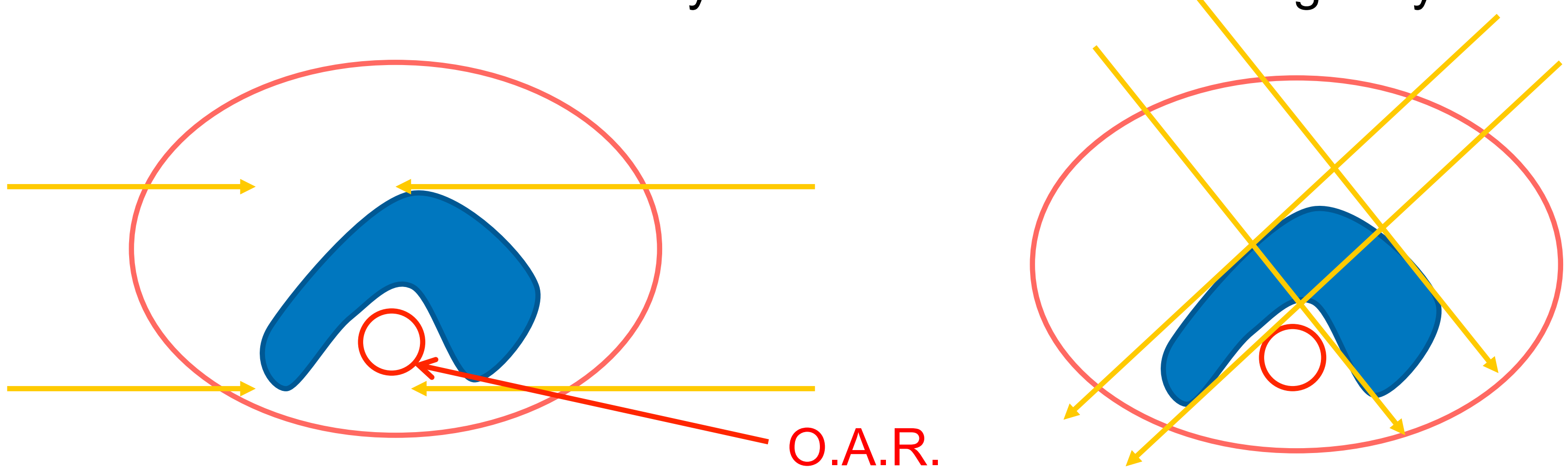
- To treat patients in supine position (eventually prone) in the same position in which CT, PETand MRI were acquired. Patient rotation only around gravity to preserve internal organs and soft tissue geometry.
- To provide the maximum flexibility in selecting the irradiation direction when optimising the dose delivery.
- To allow a “robust” treatment planning. Exploiting the sharp distal fall off can be risky in some cases and a gantry helps in avoiding fields directed towards an Organ At Risk (OAR).
- Avoid density heterogeneities
- Minimize SOBP extension (less energies required and better peak to plateau ratio)

Why a gantry

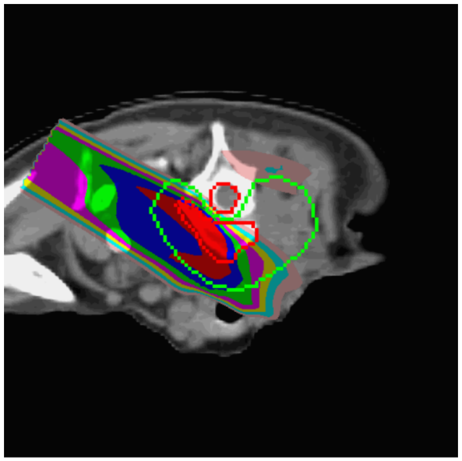
Allows better, more robust planning:
e.g. minimize fields pointing towards
OAR (Organ At Risk)

With horizontal line only

With gantry



Treatment planned with gantry



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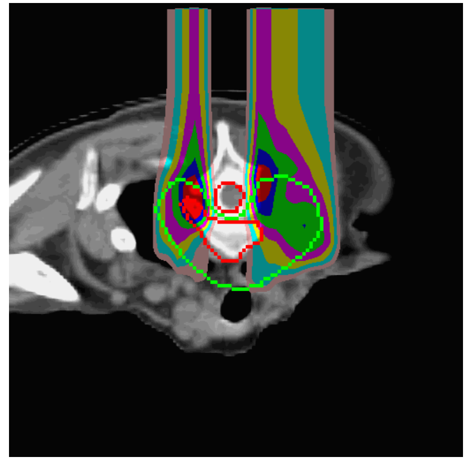

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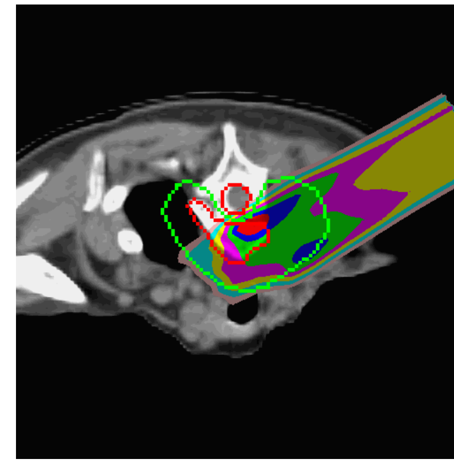

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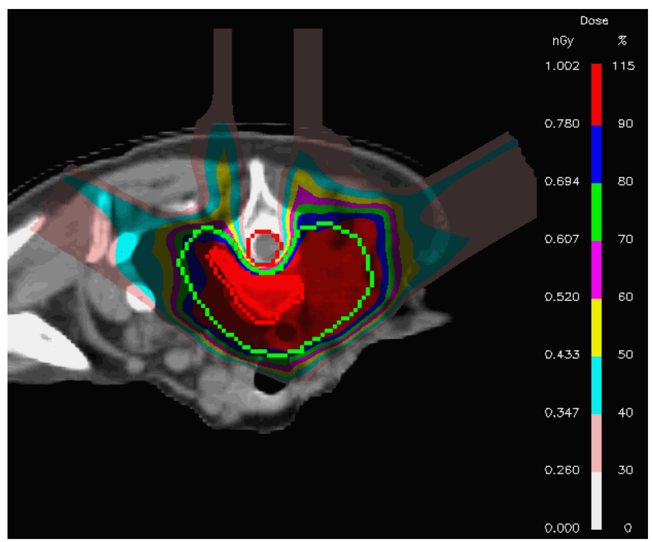
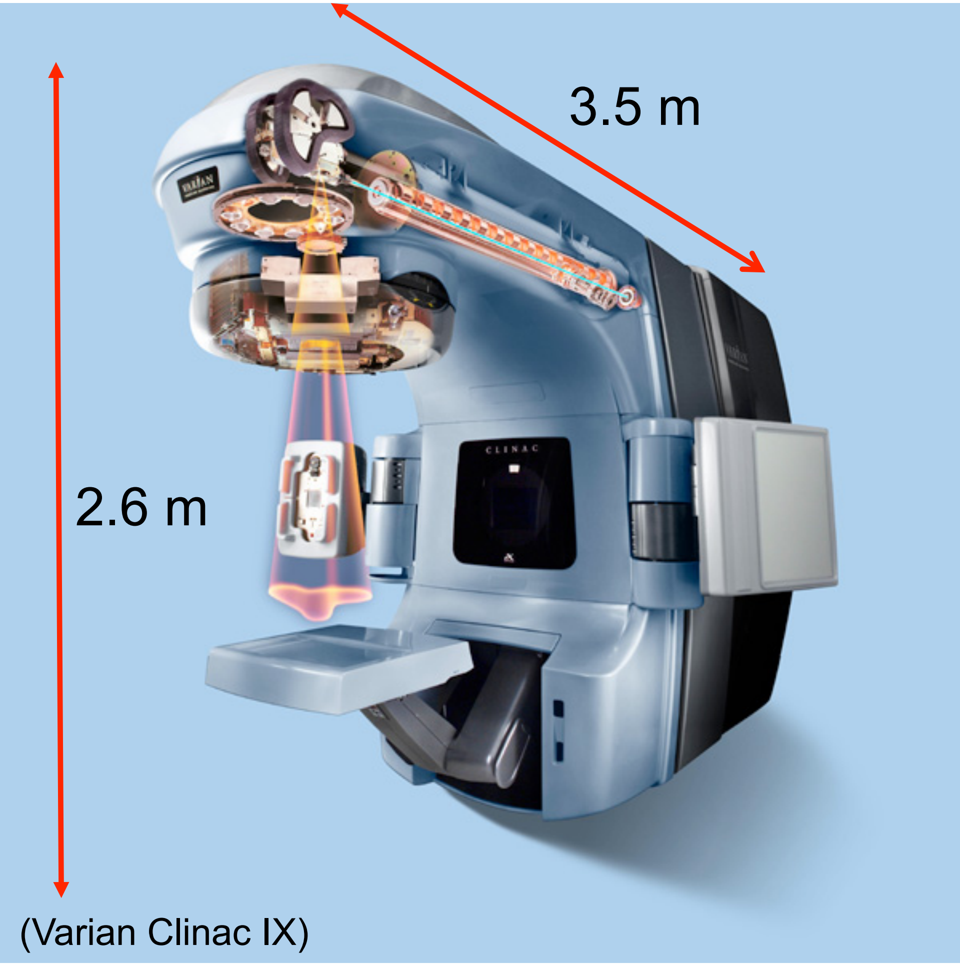


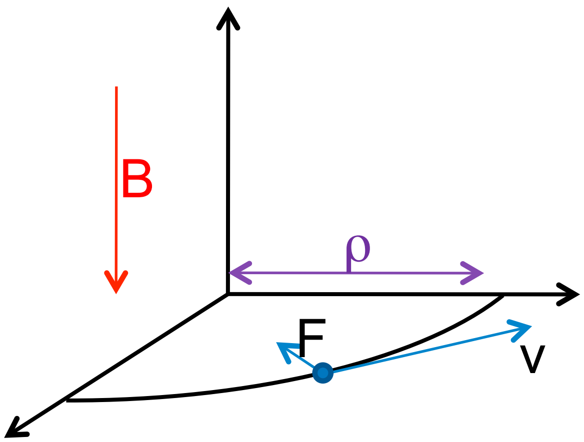
IMPT: each spot has an individually specified number of particles. The sum of the various fields is flat (or as required by clinics).

Gantry in conventional radiotherapy

- **The whole linac is inside the gantry**
- **The gantry head can pass between patient and floor for irradiation from below**



Magnetic rigidity



$$qvB = \frac{mv^2}{\rho} \Rightarrow B\rho = \frac{p}{q}$$

Electron, 20 MeV: Bρ = 0.068 T m

In practical units:

Protons, 60 MeV: Bρ = 1.14 T m

0.2998 *B* [T] ρ [m] = *p* [GeV/c]/*q* [e]

Protons, 250 MeV: Bρ = 2.43 T m

↑

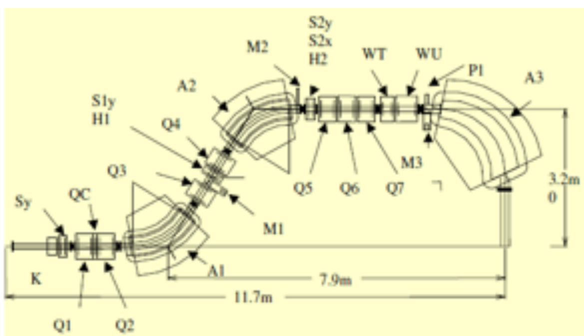
"Zero comma *c*"

Carbon, 120 MeV/u: Bρ = 3.25 T m

Carbon, 400 MeV/u: Bρ = 6.35 T m

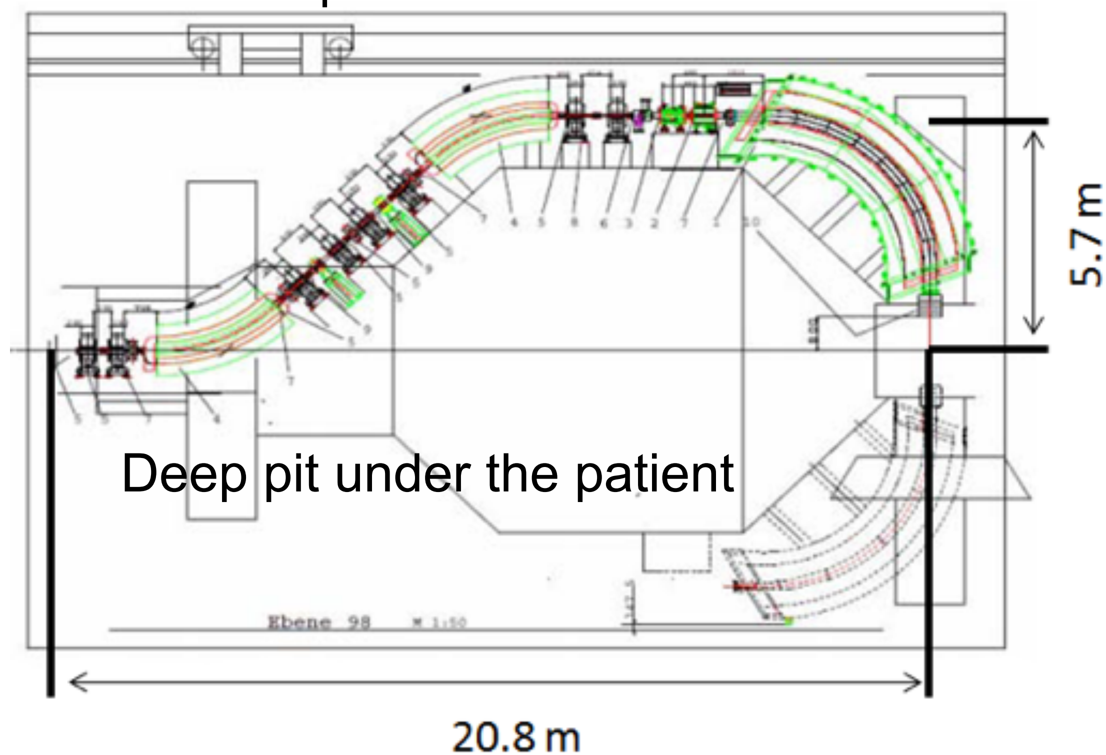
Size and magnetic rigidity

Conventional RT 



Proton Gantry
Bρ < 2.4 Tm

Carbon Ion Gantry
Bρ < 6.4 Tm



Deep pit under the patient

Proton gantry

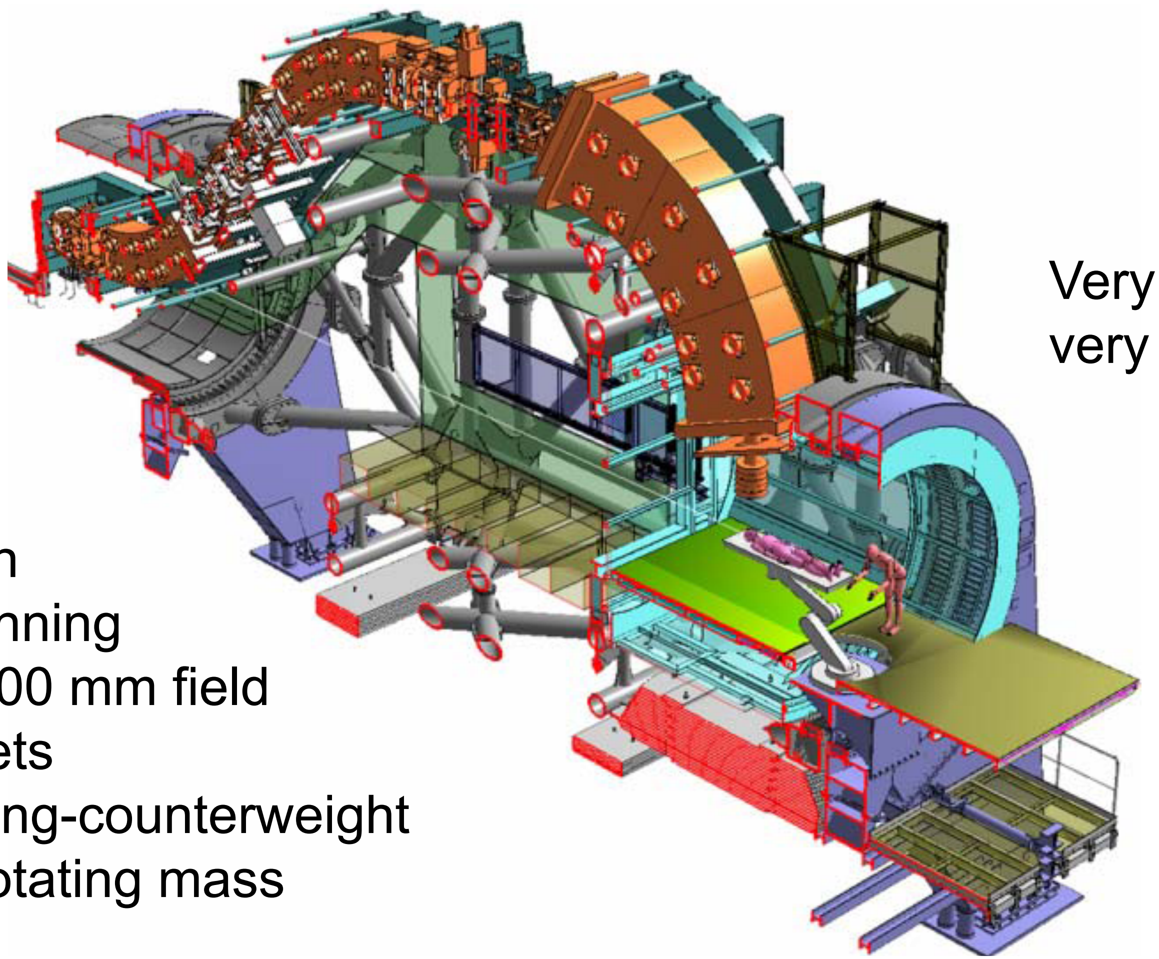
Mitsubishi

Hitachi

IBA

Carbon ion gantry

Only one C gantry worldwide: L = 25 m x ϕ = 13 m, 600 t



Very large, very heavy, very expensive

360° rotation
Parallel scanning
200 mm x 200 mm field
140 t magnets
120 t shielding-counterweight
600 t total rotating mass

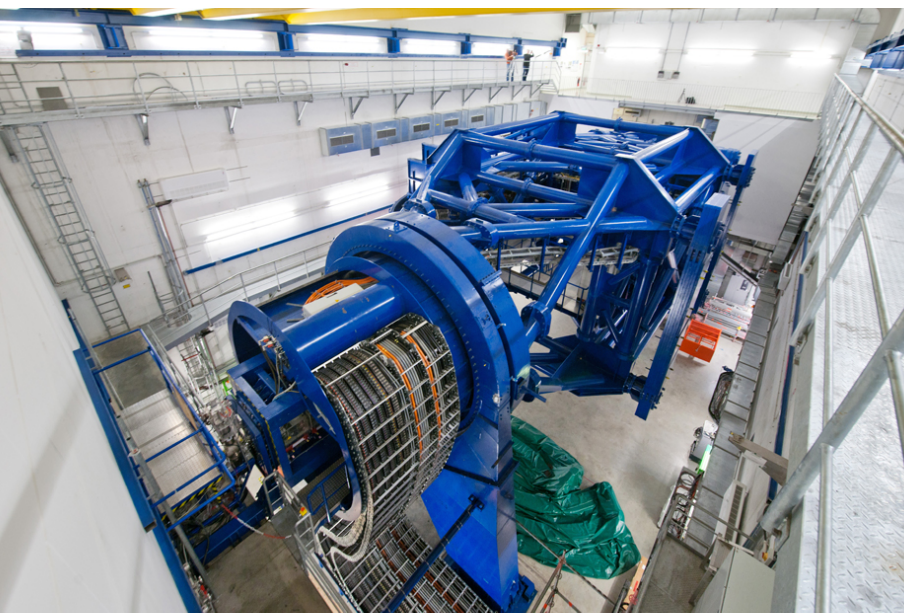
(Udo Weinrich, GSI)

The CNAO 90° magnet during installation in the vertical line. The size is the same as for a gantry final magnet.

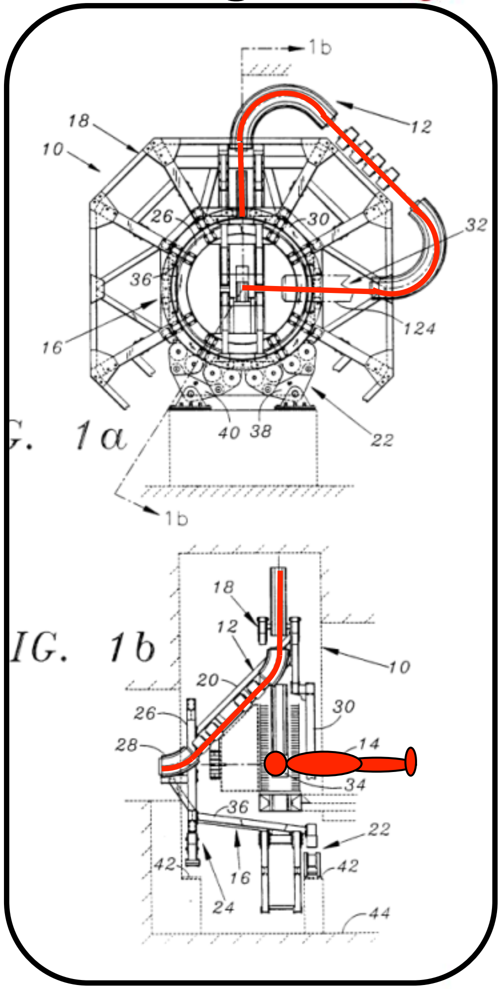
Carbon Ion Gantry

- **The HIT Gantry:**
  the only operational C Gantry

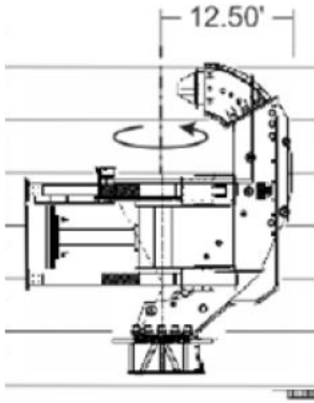
  L = 25 m x ϕ = 13 m,
  600 t rotating mass



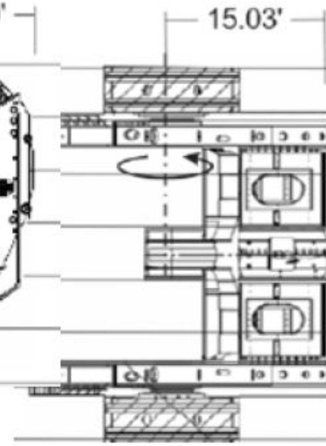
Proton gantries, many geometries used



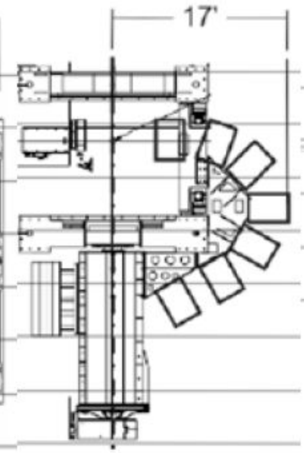
Corkscrew gantry at LLUMC



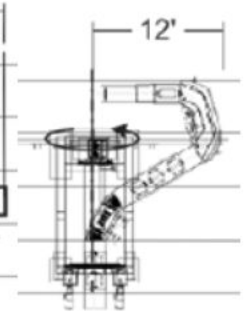
IBA Proteus One



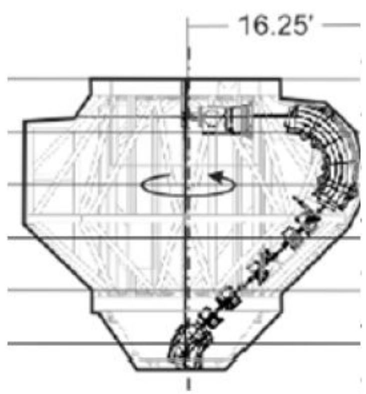
MeVIon



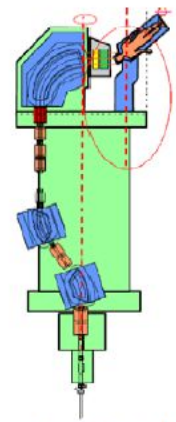
ProTom



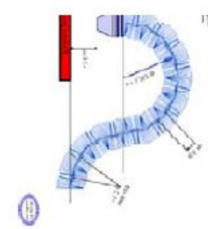
ProNova



IBA/SHI/ Hitachi In-Plane



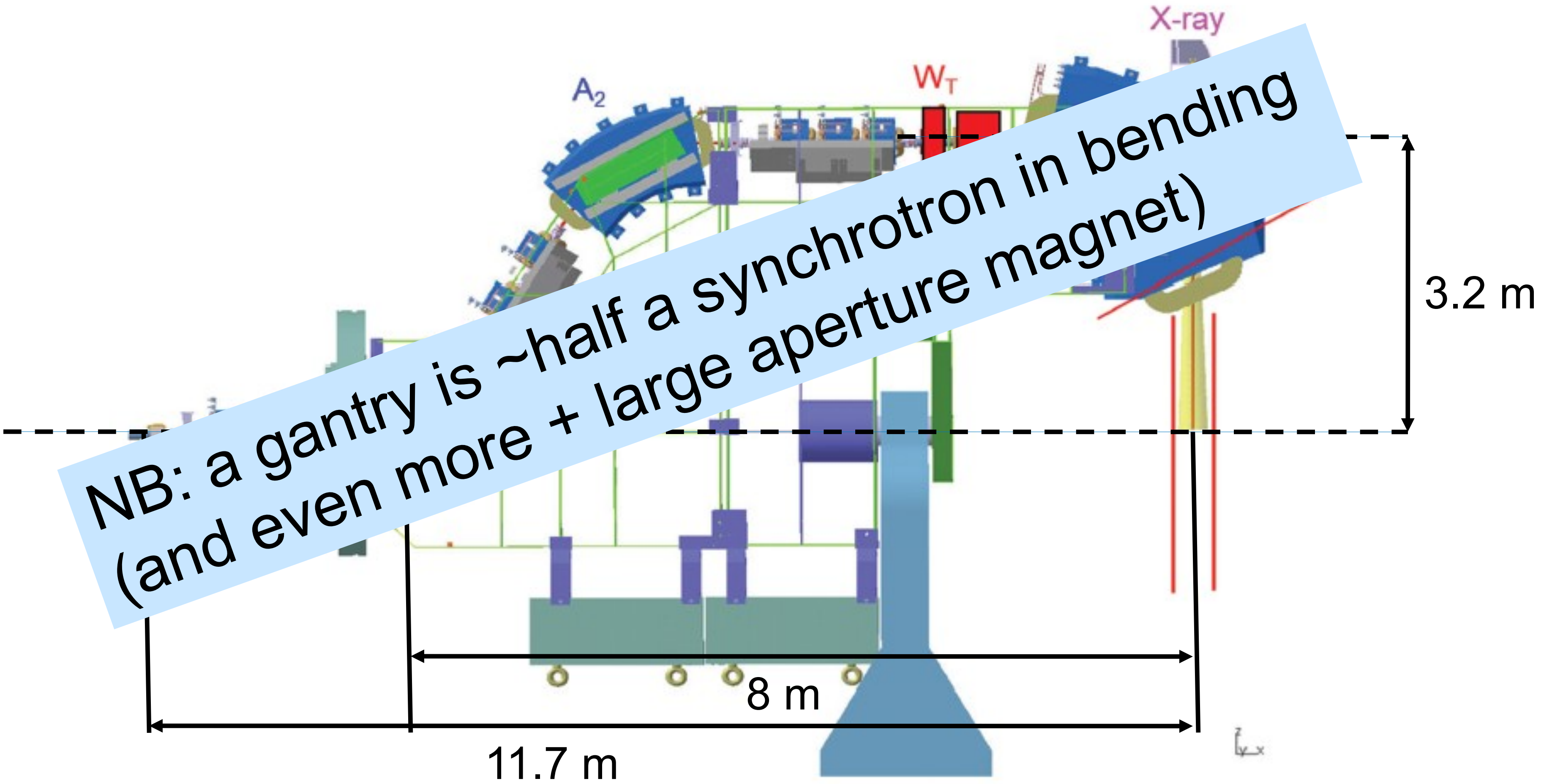
PSI 1 shortest radius



FFAG is the lightest

(Adapted from a slide of J. Flanz)

PSI gantry 2 (we will see it at MedAustron)



- **Thus gantries are useful, but especially carbon gantries are huge, expensive, difficult etc.**

- **CAN WE DO BETTER?**

Aspects and possibilities to consider in a gantry

- **Space around isocenter for patient dimensions and couch orientation**

Space around patient

- Patient size
- Walk around patient
- Imaging in situ
- Couch rotation

- Typical
  ~ 45 – 65 cm
  ~ 2 m opposite to nozzle

- Scattering, air and distance degrade beam quality

(Photon gantry used for illustration only, text refers to particles)

Aspects and possibilities to consider in a gantry

- Space around isocenter for patient dimensions and couch orientation
- Field size

Field size

- Area that can be irradiated
- Trade off between performace and gantry cost/size
- Larger field requires thicker vacuum window.
- Typically

  20x20 in europe to

  30x40 cm^2 in the US

(Photon gantry used for illustration only, text refers to particles)

Aspects and possibilities to consider in a gantry

- **Space around isocenter for patient dimensions and couch orientation**
- **Field size**
- **Active or passive beam delivery (scattering or scanning)**

Scanning or scattering

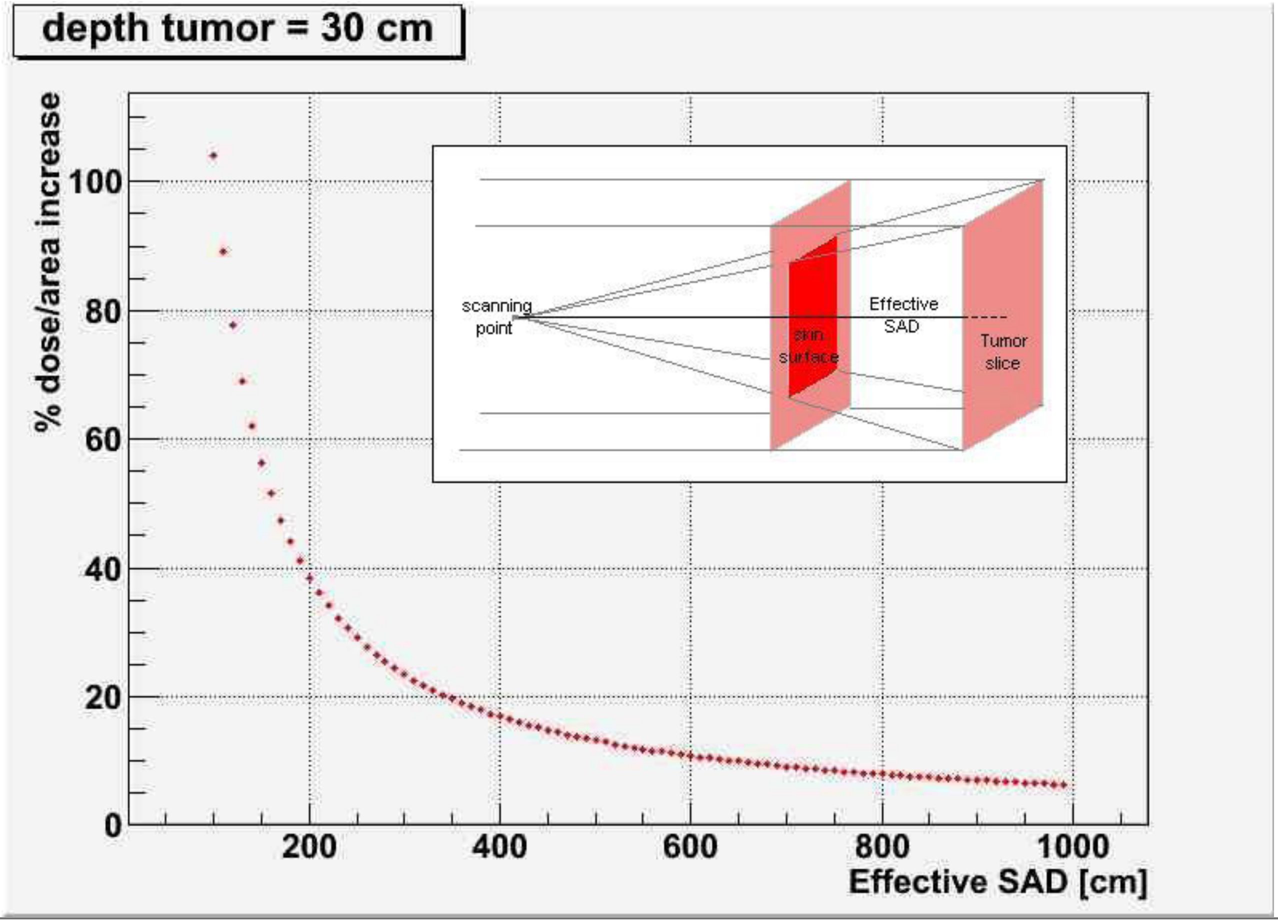
- **Scattering is the most used spreading technique, but it is not suitable for carbon beams and anyway the trend is towards scanning also for protons.**
- **Let’s assume scanning in the following**

Aspects and possibilities to consider in a gantry

- Space around isocenter for patient dimensions and couch orientation
- Field size
- Active or passive beam delivery (scattering or scanning)
- Source to Axis Distance (SAD)

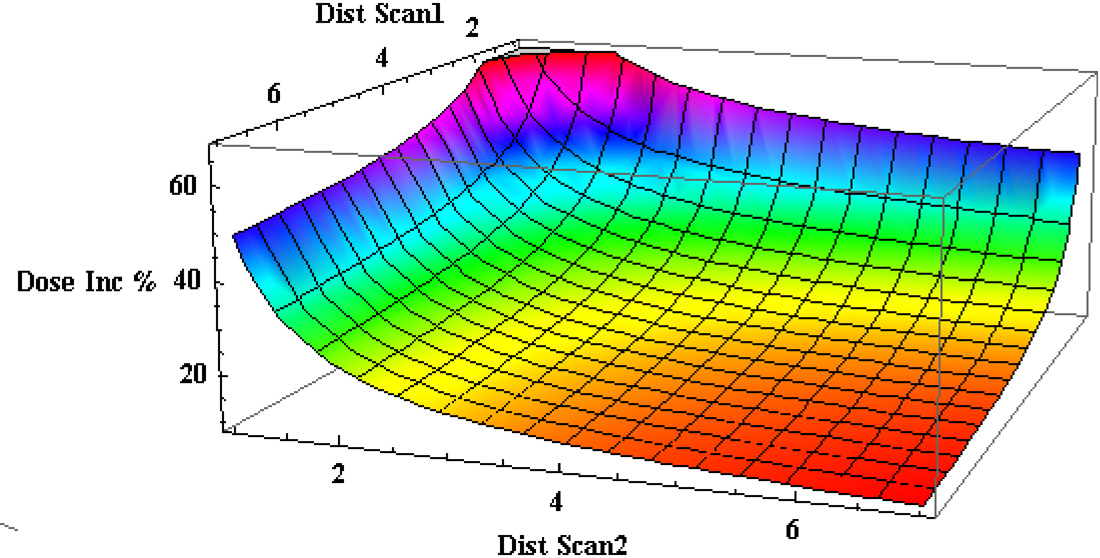
SAD

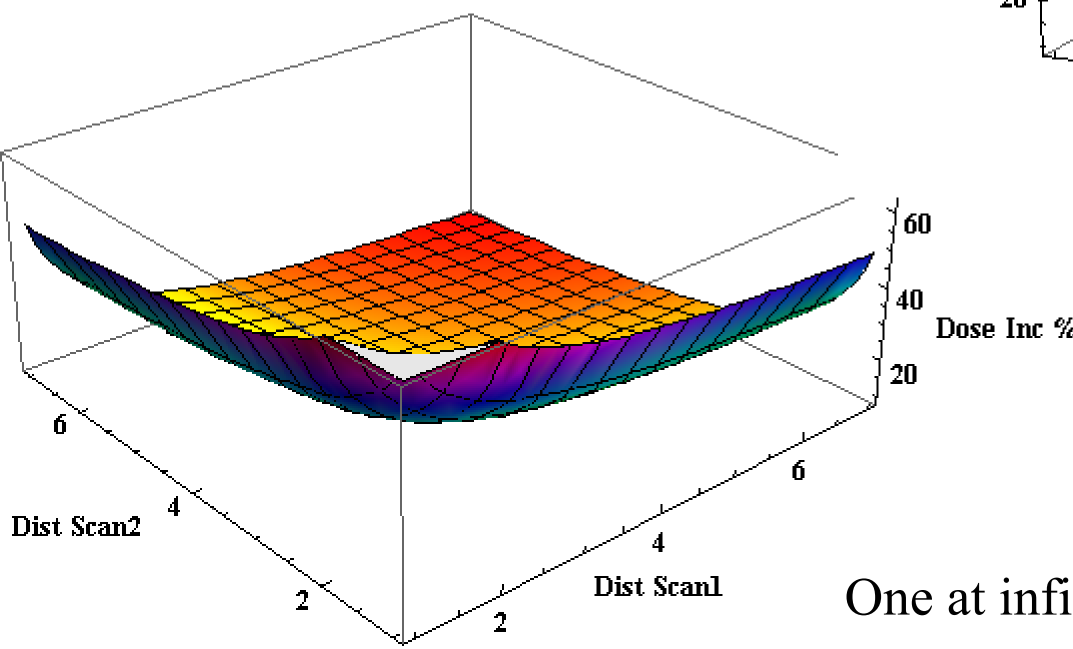
- Treatment plans (at least many of them) consider parallel scanning
- Dose increase to the skin, which is a radiosensitive organ



Sistema Sanitario Regione Lombardia
fondazione CNAO Centro Nazionale di Adroterapia Oncologica

SAD for separated scanners





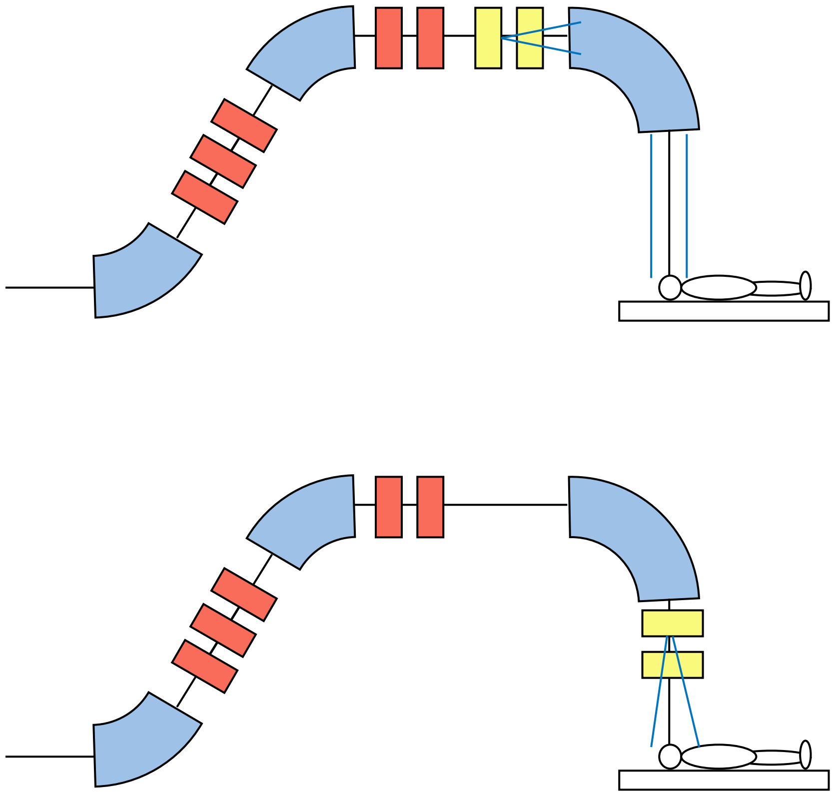
One at infinity, SAD=3.40 d=0.3 DoseInc=10%

One at infinity, SAD=1.83 d=0.3 DoseInc=20%

Aspects and possibilities to consider in a gantry

- Space around isocenter for patient dimensions and couch orientation
- Field size
- Active or passive beam delivery (scattering or scanning)
- Source to Axis Distance (SAD)
- Scanning magnets position

Scanning magnets position



- Large aperture dipole: weight and power consumption
- Large gantry radius and large room size

One scanning magnet upstream and one downstream is often proposed

Aspects and possibilities to consider in a gantry

- Space around isocenter for patient dimensions and couch orientation
- Field size
- Active or passive beam delivery (scattering or scanning)
- Source to Axis Distance (SAD)
- Scanning magnets position
- 180° or 360°

360° vs 180°

- **By rotating the couch by 180°, all the beam directions are possible also with only 180° of rotation of the gantry**

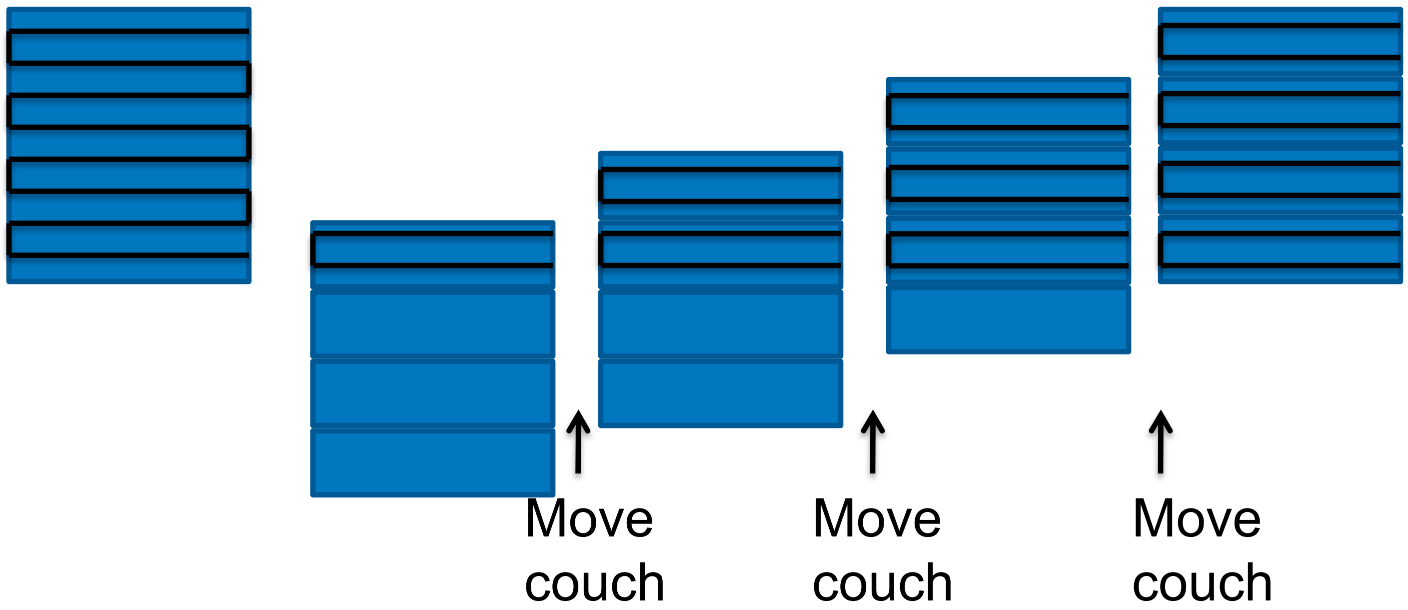
Rotation of the couch may require position verification (time and XRays),
But it saves space and requires less shielding on the wall "not irradiated".

Aspects and possibilities to consider in a gantry

- Space around isocenter for patient dimensions and couch orientation
- Field size
- Active or passive beam delivery (scattering or scanning)
- Source to Axis Distance (SAD)
- Scanning magnets position
- 180° or 360°
- Field patching

Field patching

Scan in one go — Scan and move (~PSI gantry 1)

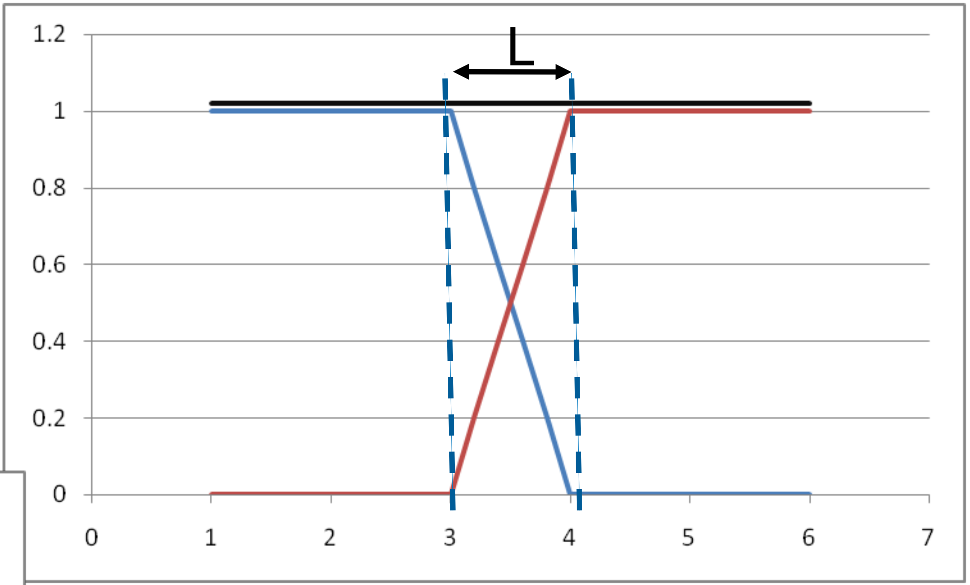


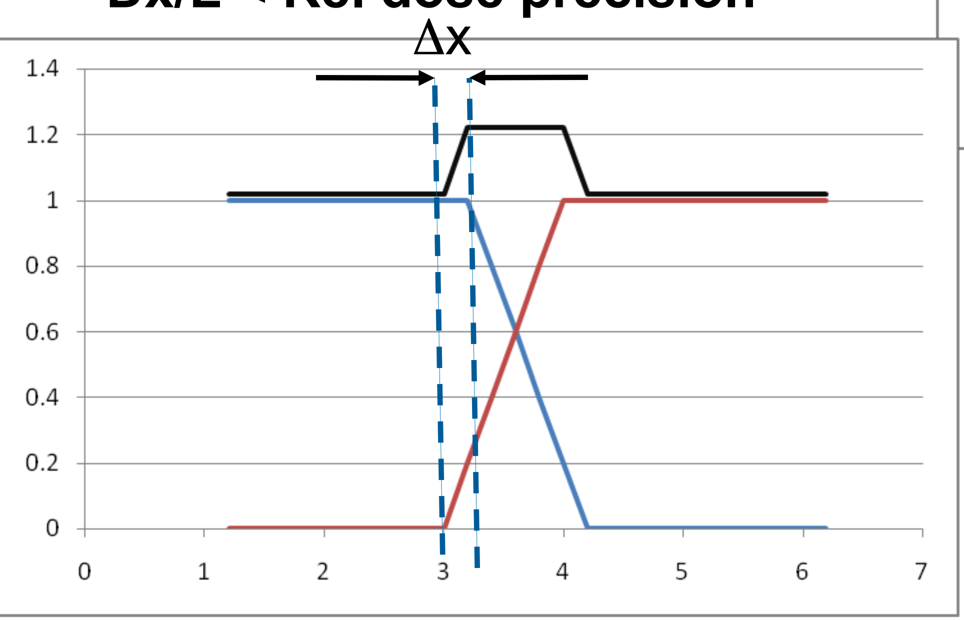
Reduced magnet aperture, but slower procedure and difficulties somehow similar to simultaneous optimisation of multiple fields with IMPT

Field patching

- **Fields have to be tapered (possible with active scanning)**
- **Alignment required**

Dx/L < Rel dose precision





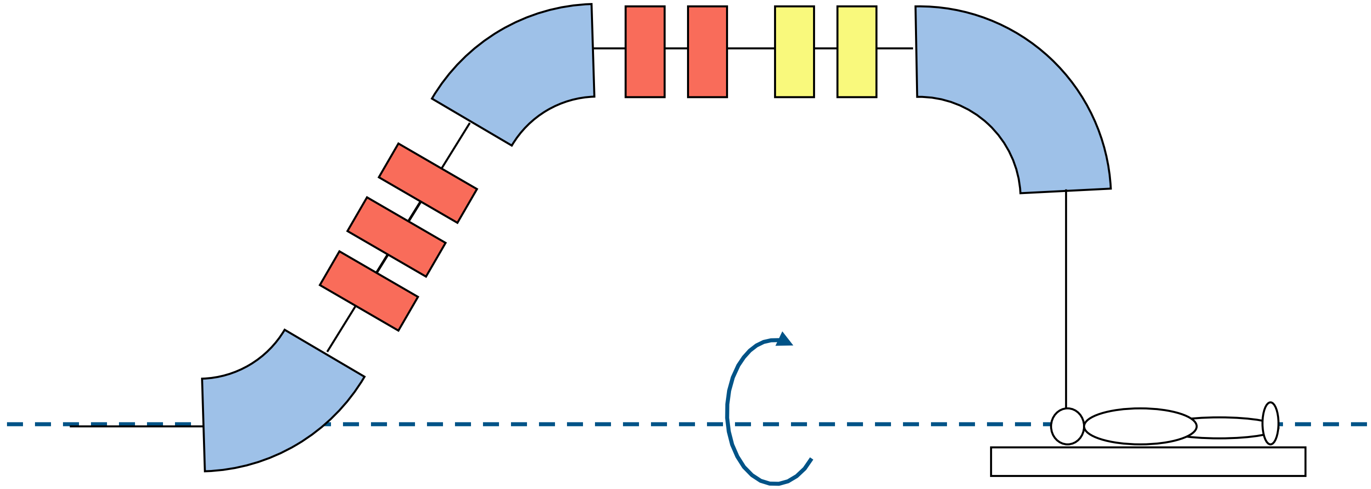
0.5mm/2cm = 2.5%

Aspects and possibilities to consider in a gantry

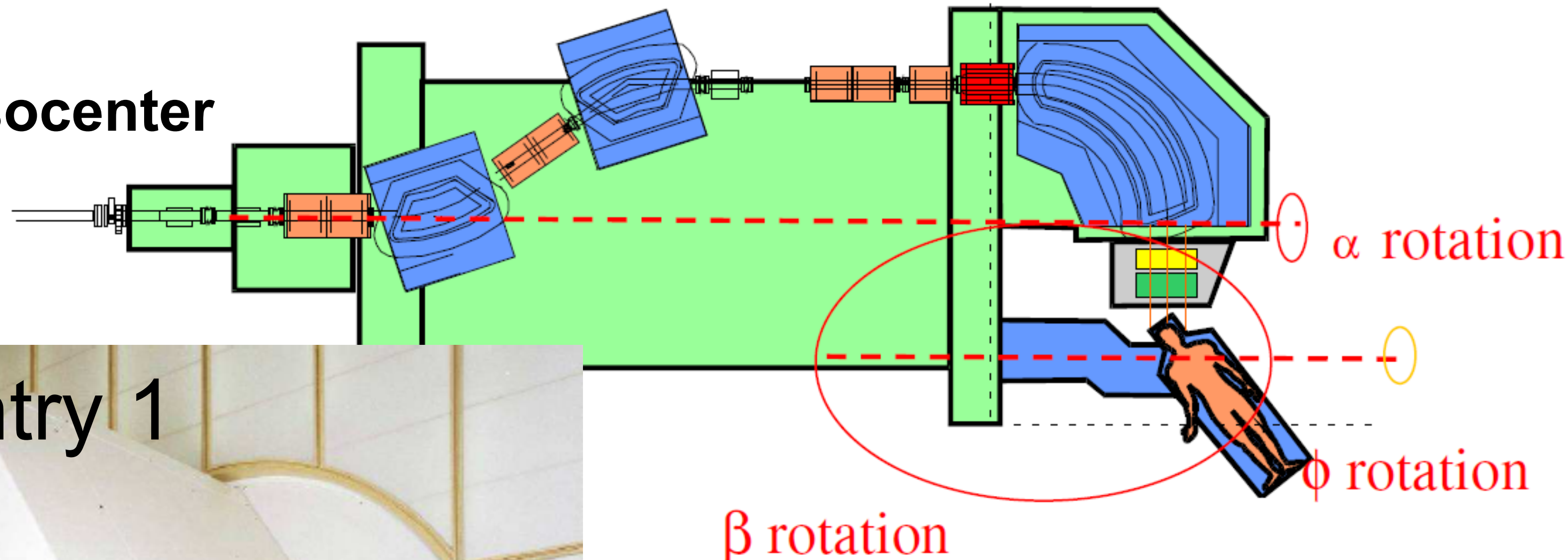
- Space around isocenter for patient dimensions and couch orientation
- Field size
- Active or passive beam delivery (scattering or scanning)
- Source to Axis Distance (SAD)
- Scanning magnets position
- 180° or 360°
- Field patching
- Fixed or mobile isocenter

Fixed or mobile isocenter

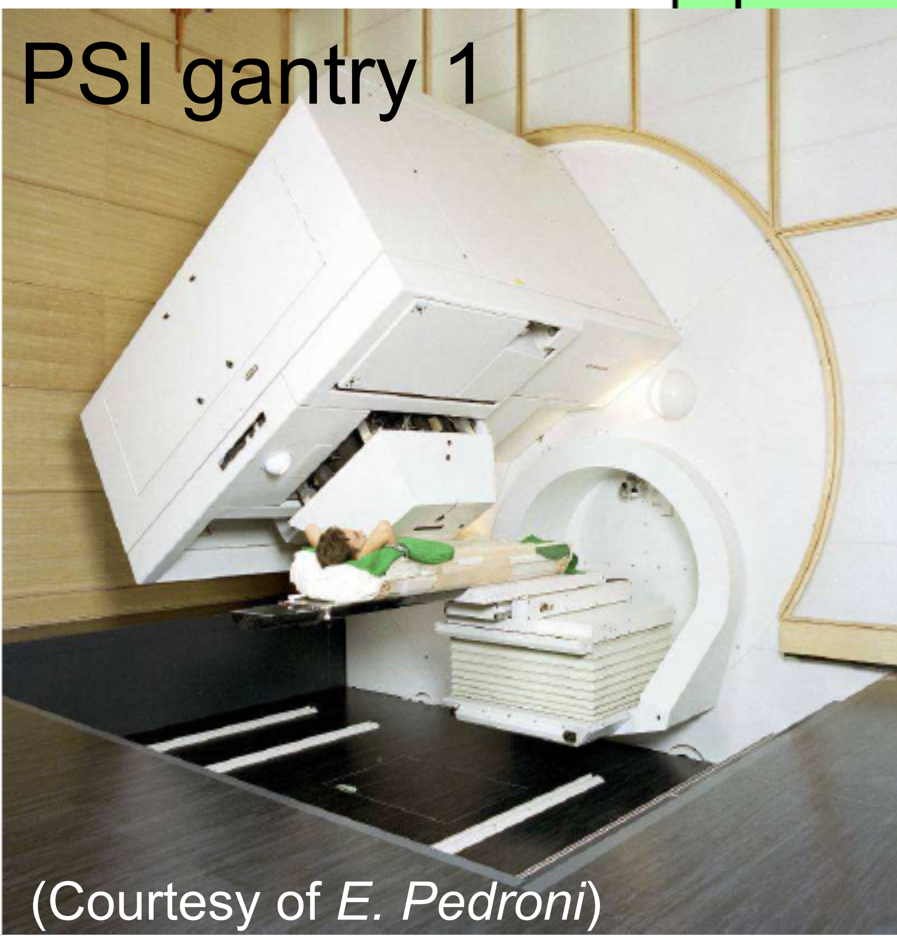
- **Most of the existing gantries have a fixed isocenter on the rotation axis of the gantry. This implies large masses rotating at large radius.**



Mobile isocenter



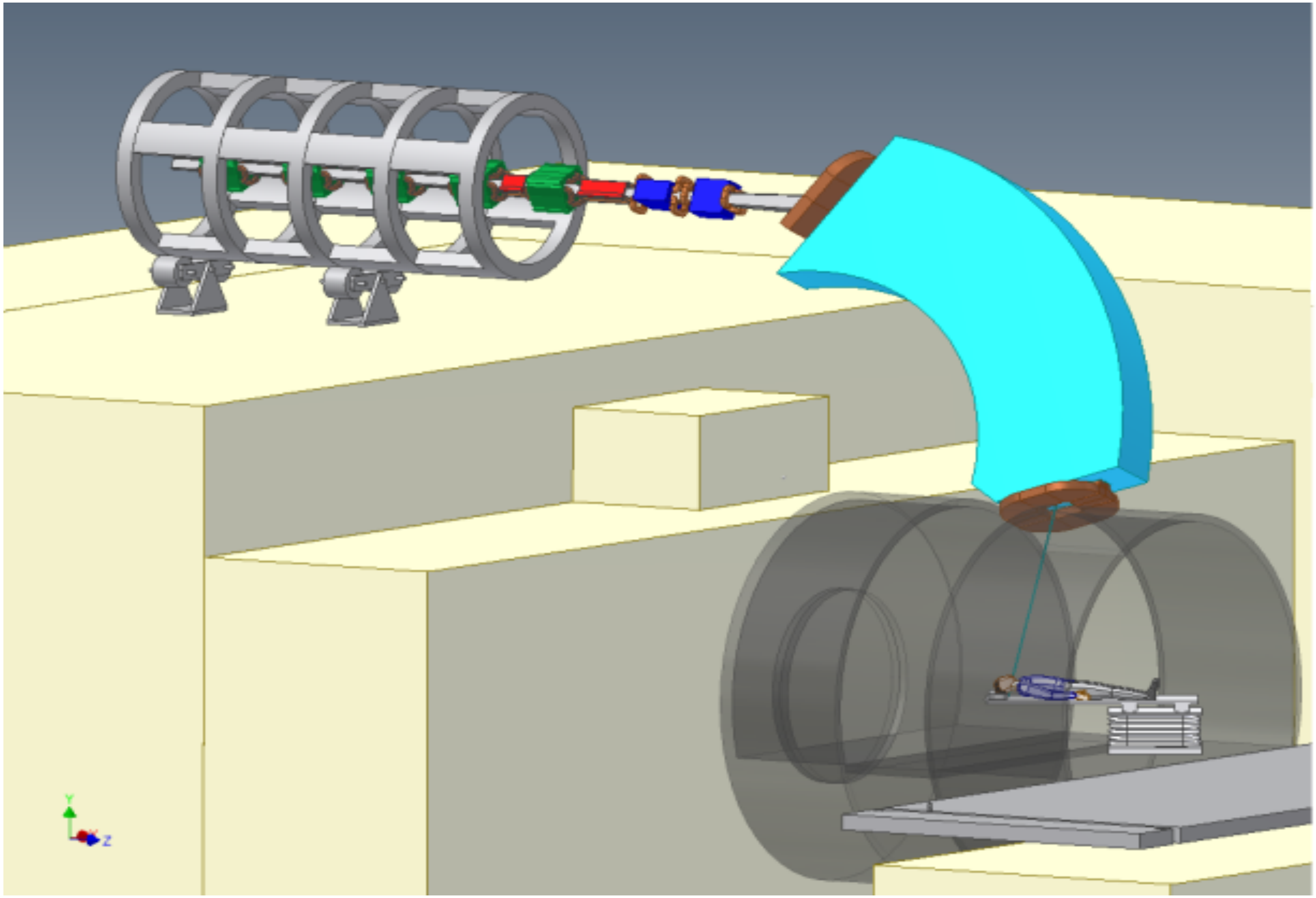
First scanning gantry worldwide



(Courtesy of *E. Pedroni*)

An isocenter, through which all the directions pass, exists but its position depends on gantry orientation.

ULICE mobile isocenter gantry (“Riesenrad”)



90° bending magnet

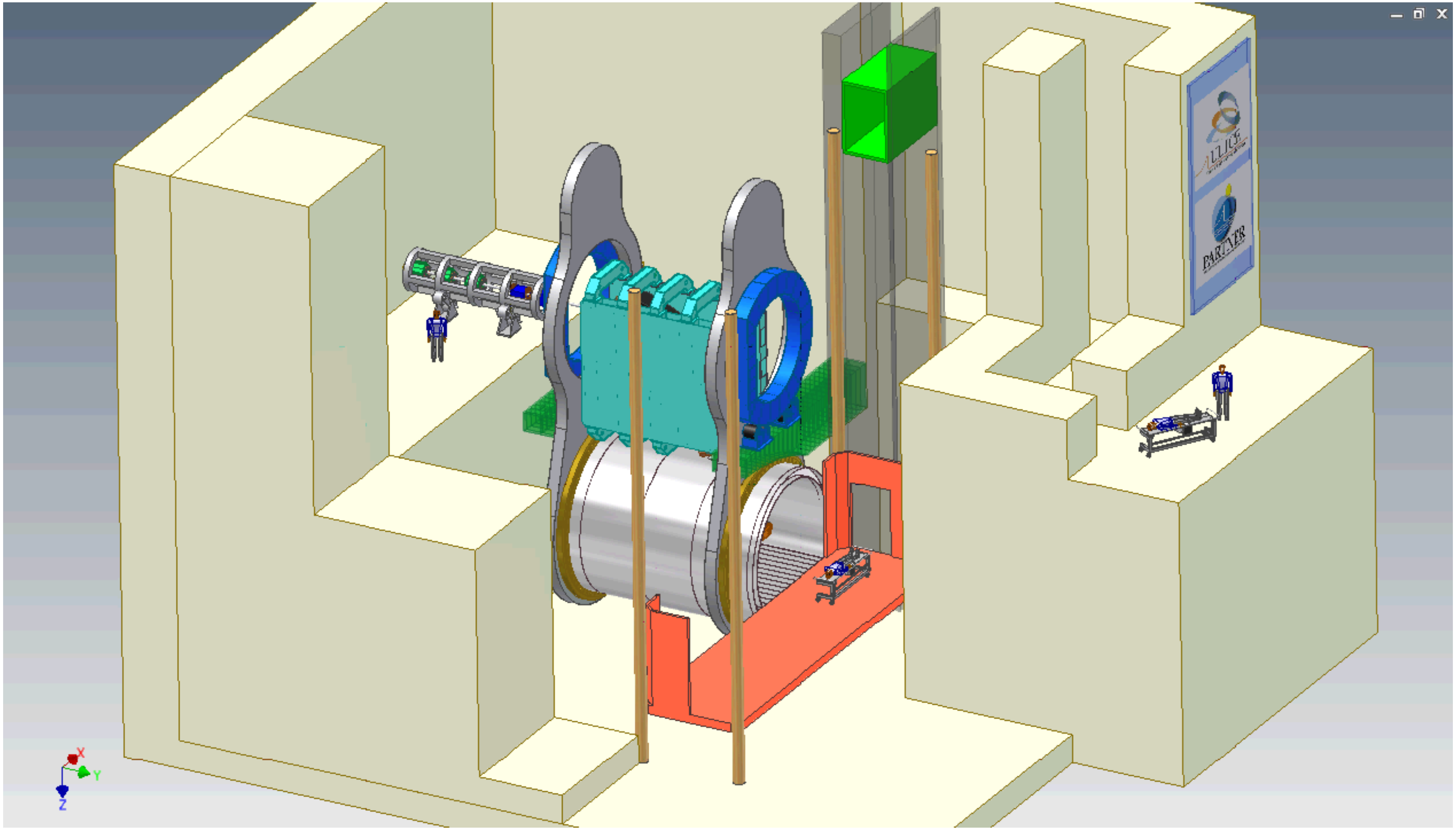
Scanning magnets

Quadrupoles

Corrector magnets

London Eye

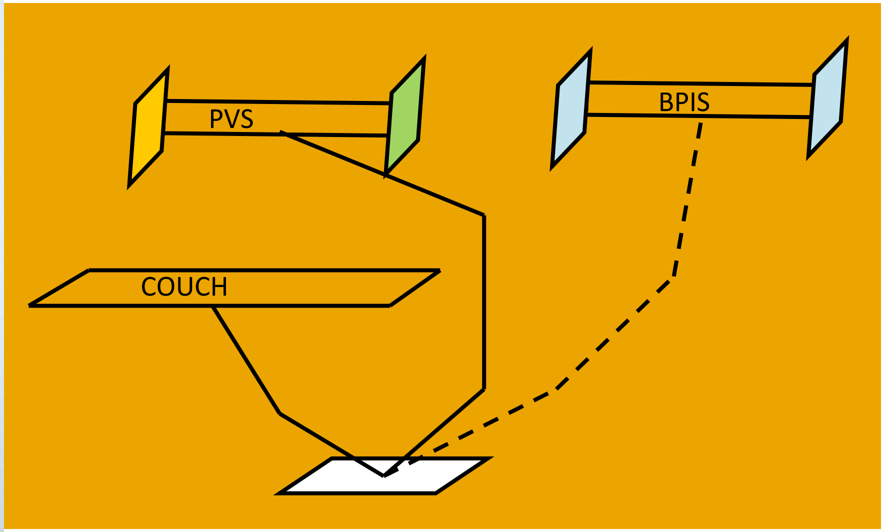
ULICE mobile isocenter gantry (“Riesenrad”)



Beam Based Alignment

Isocenter position moves and is not easy to measure/verify/define

Measure where the beam is and put the isocenter there…



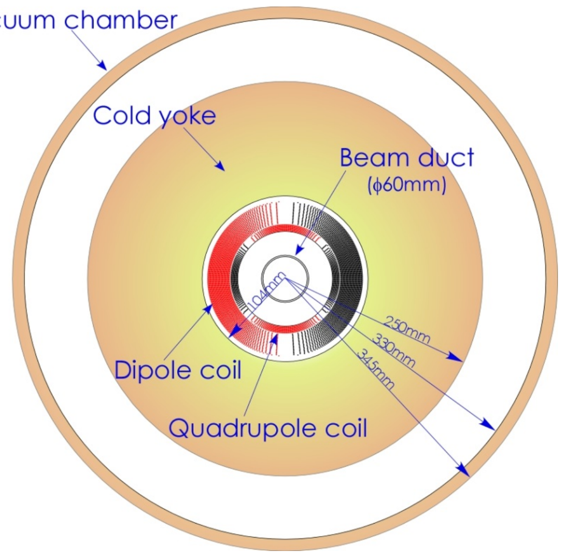
One robot arm with two "tools"

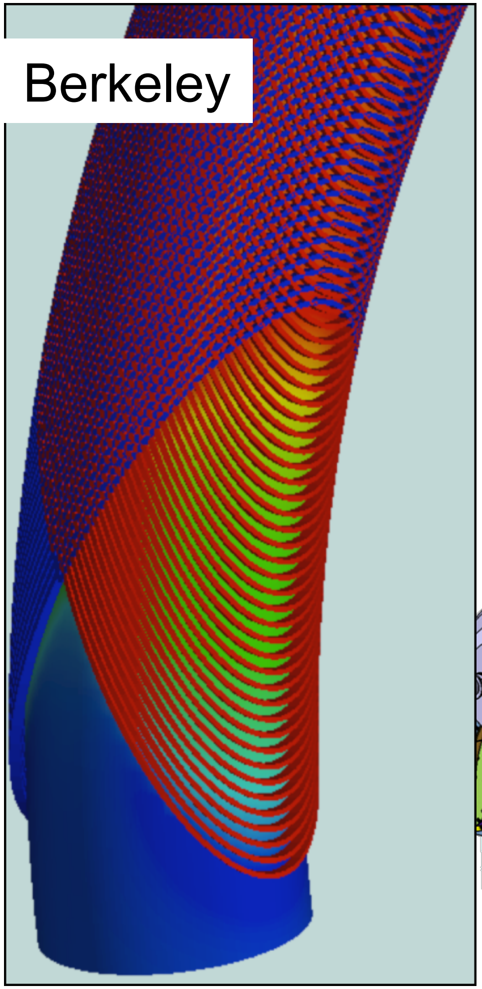
CNAO treatment room #2: PPS and PVS

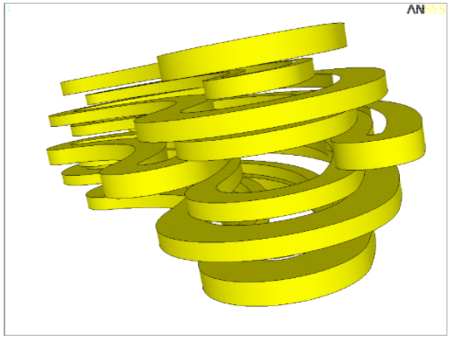
Aspects and possibilities to consider in a gantry

- Space around isocenter for patient dimensions and couch orientation
- Field size
- Active or passive beam delivery (scattering or scanning)
- Source to Axis Distance (SAD)
- Scanning magnets position
- 180° or 360°
- Field patching
- Fixed or mobile isocenter
- Superconducting magnets

Superconducting magnet studies

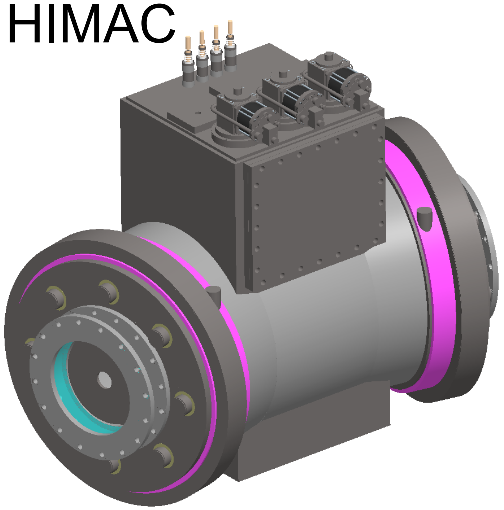


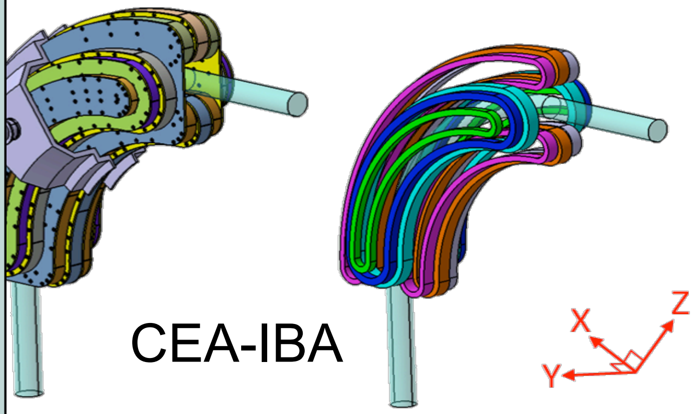




INFN-CNAO

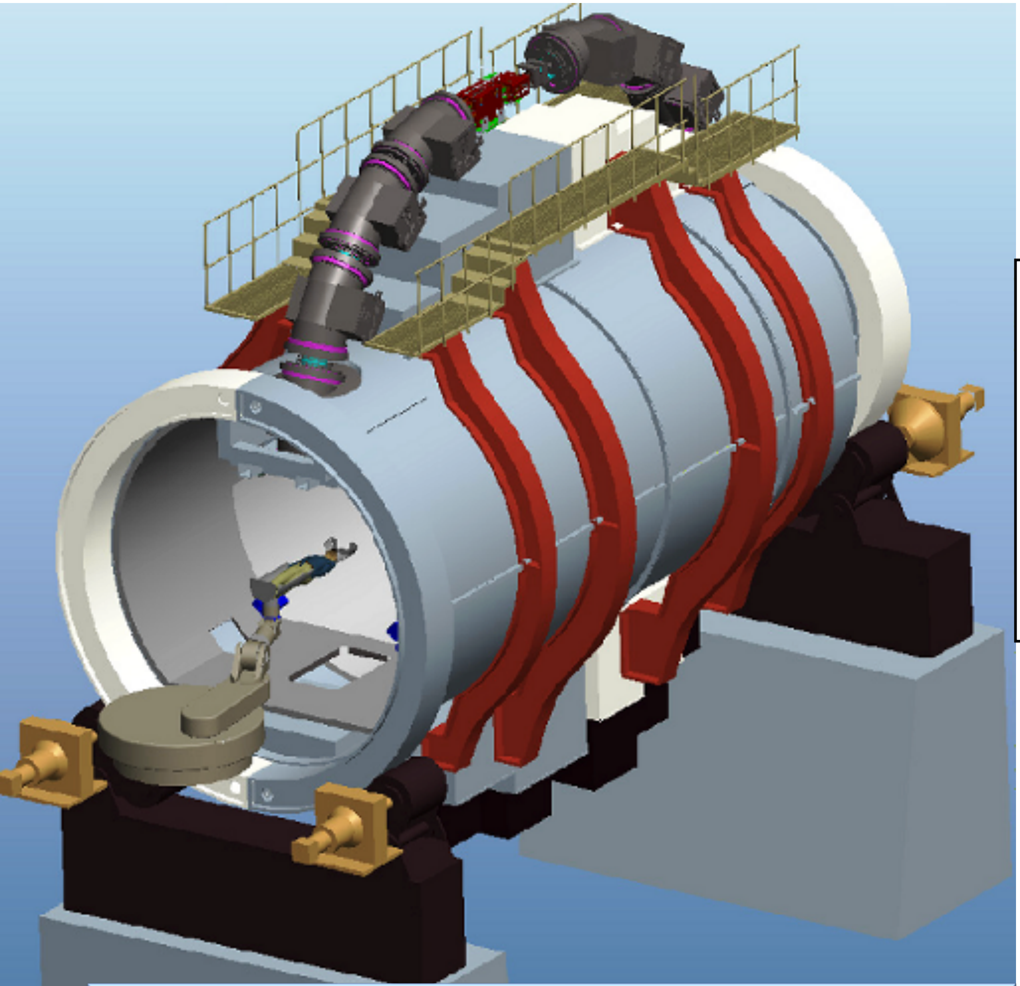
HIMAC





CEA-IBA

HIMAC superconducting gantry (under construction)



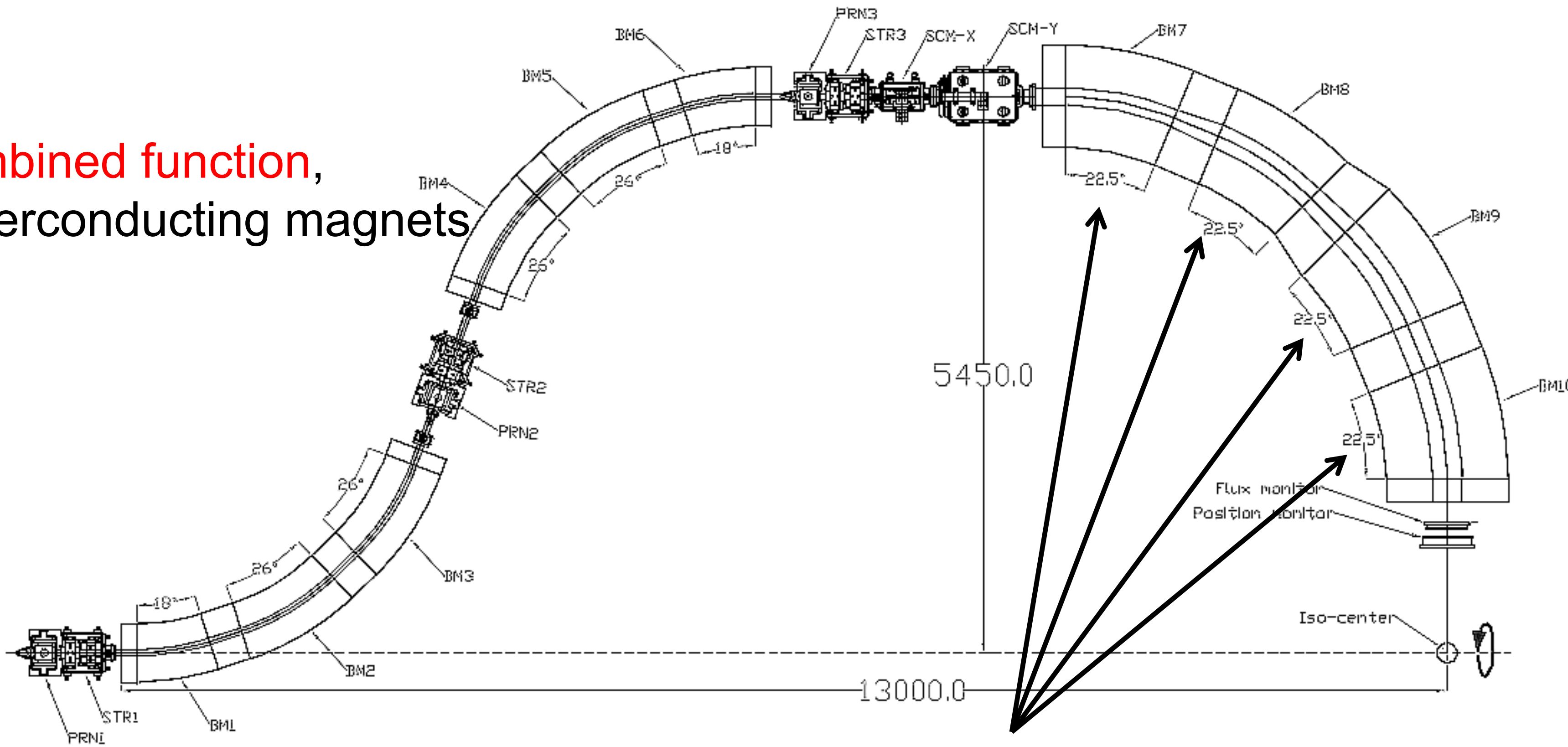
Ion kind	: ^{12}C
Irradiation method	: 3D Scanning
Beam energy	: 430 MeV/n
Maximum range	: 30 cm in water
Scan size	: □200×200 mm^2
Beam orbit radius	: 5.45 m
Length	: 13 m

Weight: order of 300 tons

(Courtesy of Y. Iwata)

Superconducting Gantry (HIMAC)

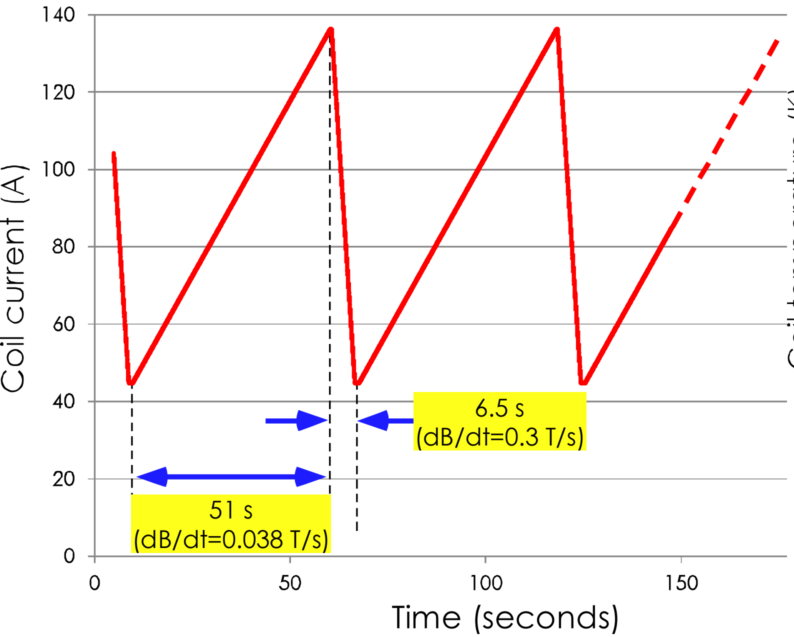
Combined function,
Superconducting magnets

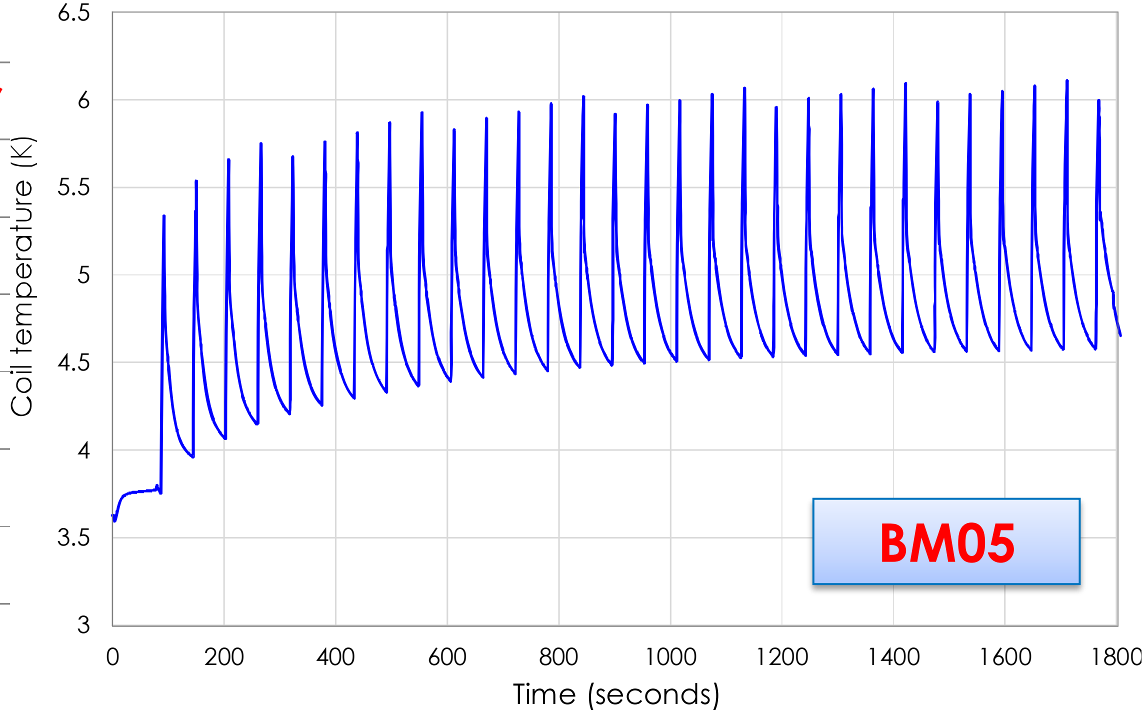


Progressively increasing perture

Ramping tests

- **Tests with maximum slew-rate**
- **I=45~136 A (E=56~430 MeV/u)**
- **No quench observed**
- **Average temperature converged below Tc~6.8 K**





Aspects and possibilities to consider in a gantry

- Space around isocenter for patient dimensions and couch orientation
- Field size
- Active or passive beam delivery (scattering or scanning)
- Source to Axis Distance (SAD)
- Scanning magnets position
- 180° or 360°
- Field patching
- Fixed or mobile isocenter
- Superconducting magnets
- 3D tumor tracking

- **If one wants to follow a tumor moving in range one needs a fast energy changing machine (or an active energy degrader) and a gantry with fast magnets or...**

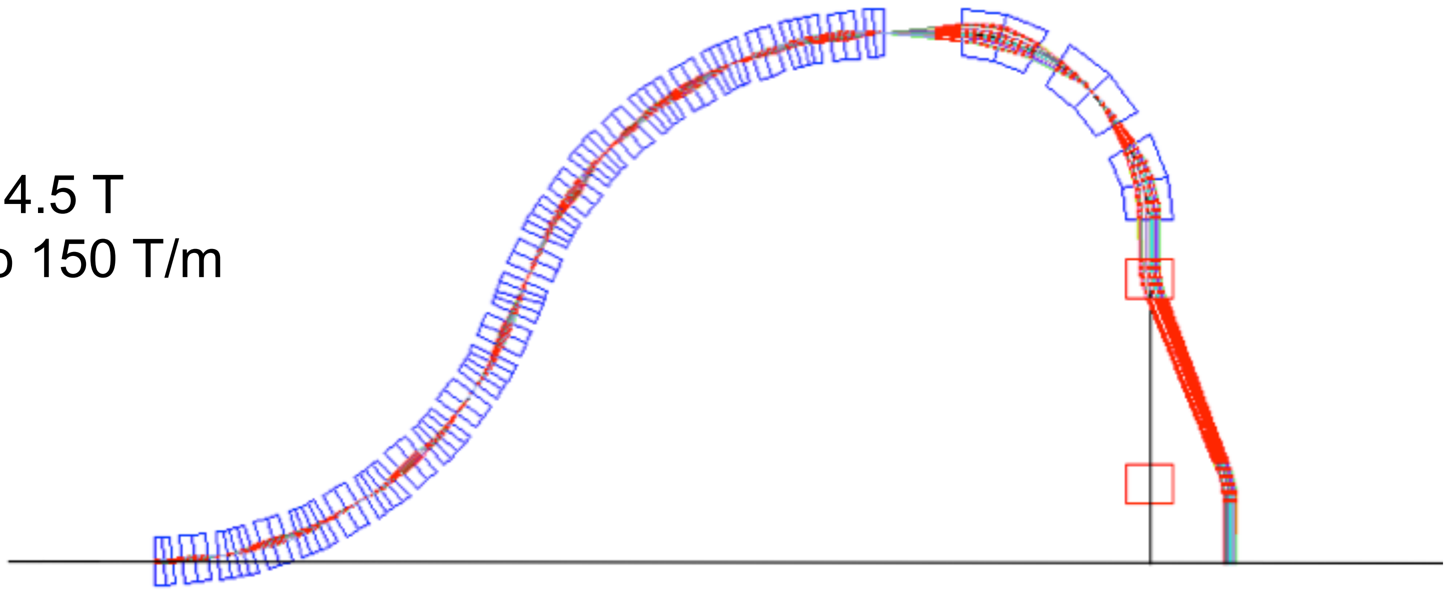
FFAG Gantry

What if dispersion is so small that $\Delta p/p = \pm 35\%$ goes through?

p 142 MeV
C 245 MeV

CARBON GANTRY height 4.091m

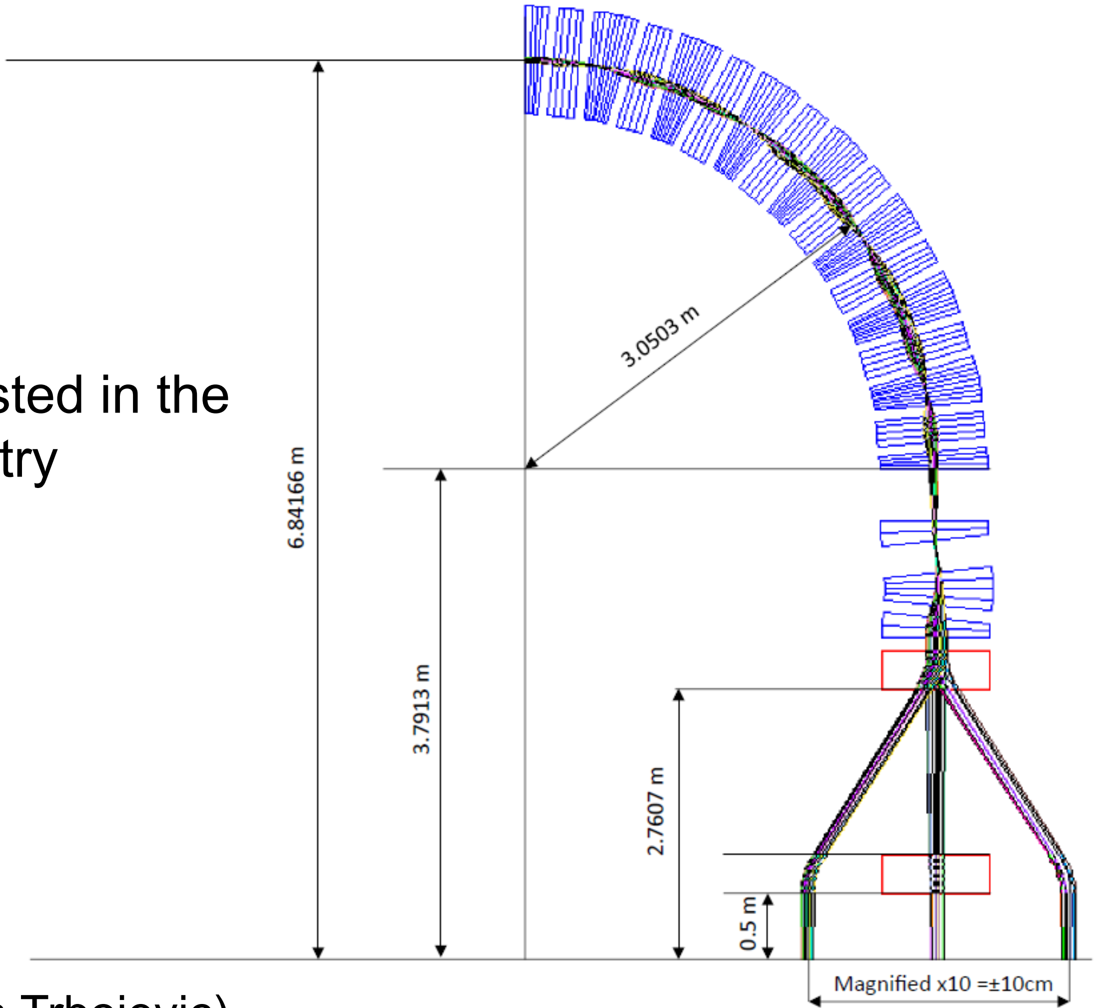
Bdip ~ 4.5 T
g up to 150 T/m



(Courtesy of Dejan Trbojevic)

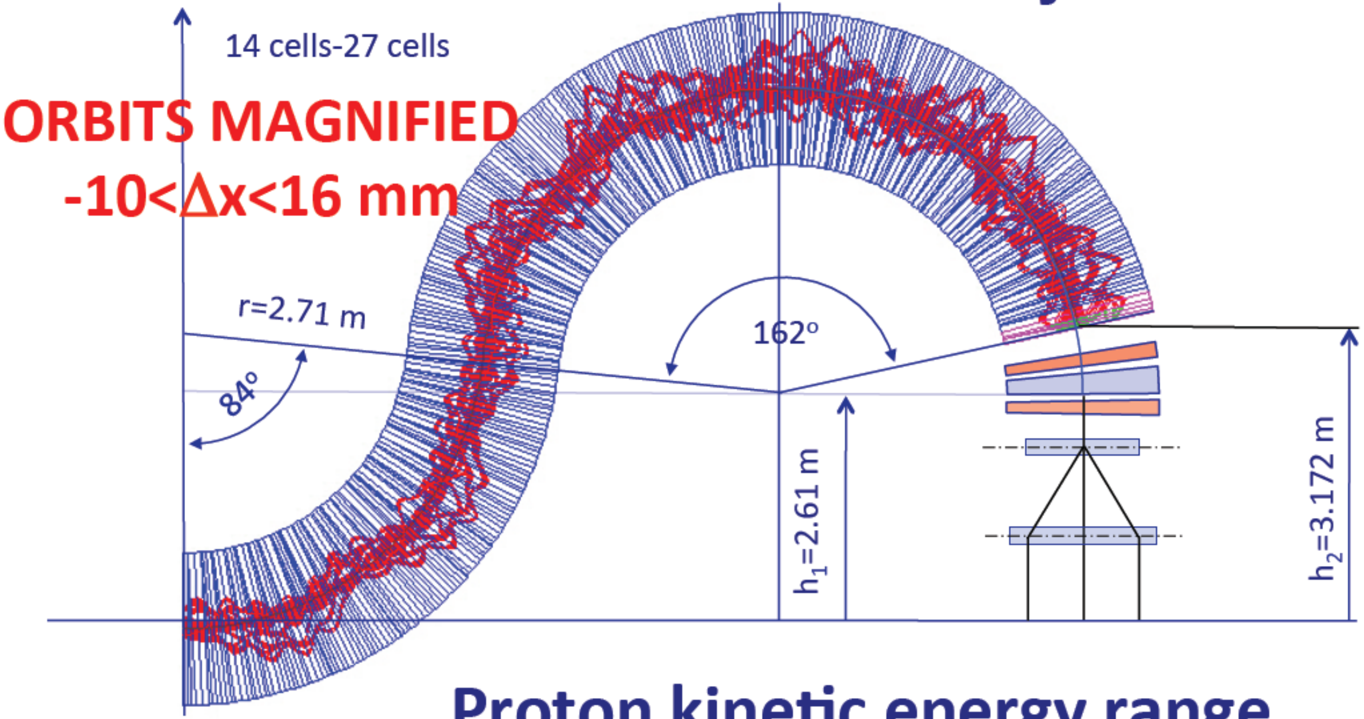
FFAG mobile isocenter

Can be hosted in the ULICE gantry



(Courtesy of Dejan Trbojevic)

Permanent Halbach Magnet NS-FFAG Proton Gantry



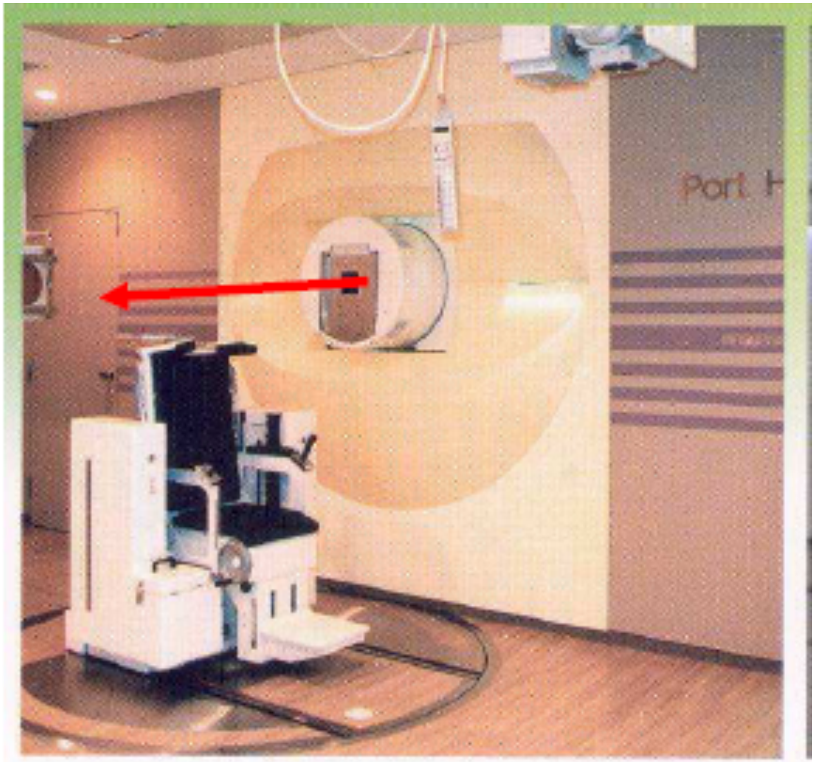
Proton kinetic energy range 30 – 250 MeV

(Courtesy of Dejan Trbojevic)

Alternatives

- Chair (with vertical CT)

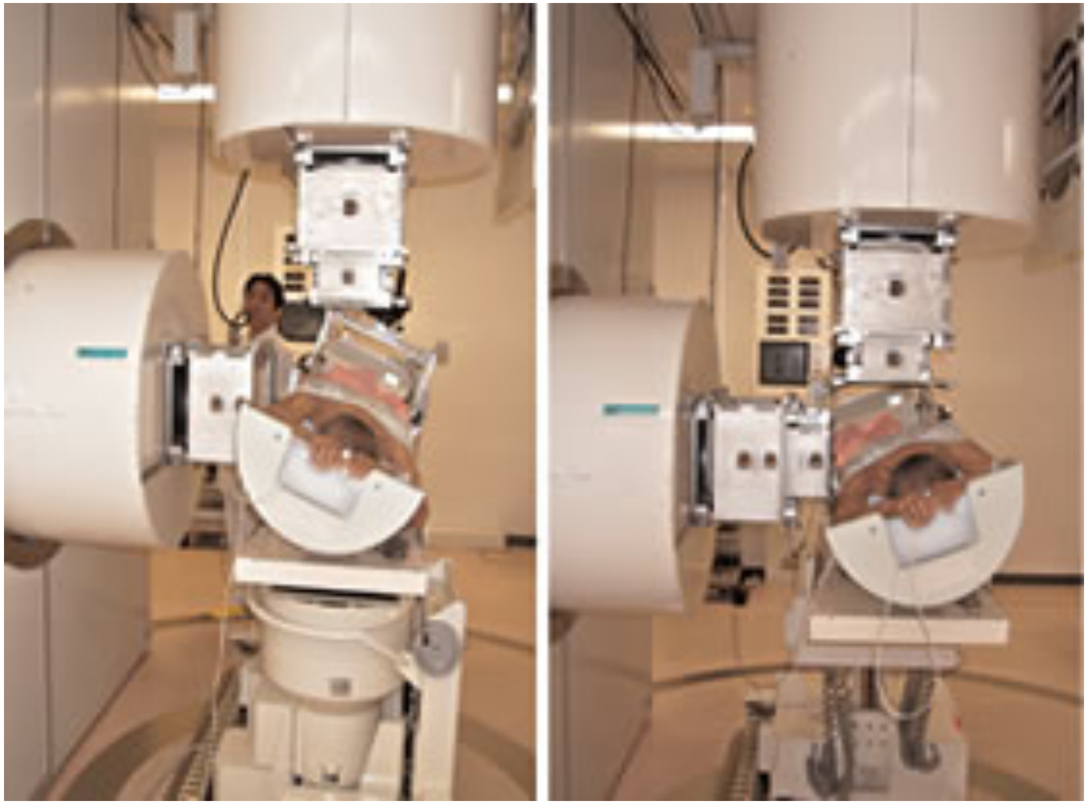
- **Chair at Hyogo**



Alternatives

- Chair with vertical CT
- Some patient rotation with 6d couch

- **Cradle couch at HIMAC**

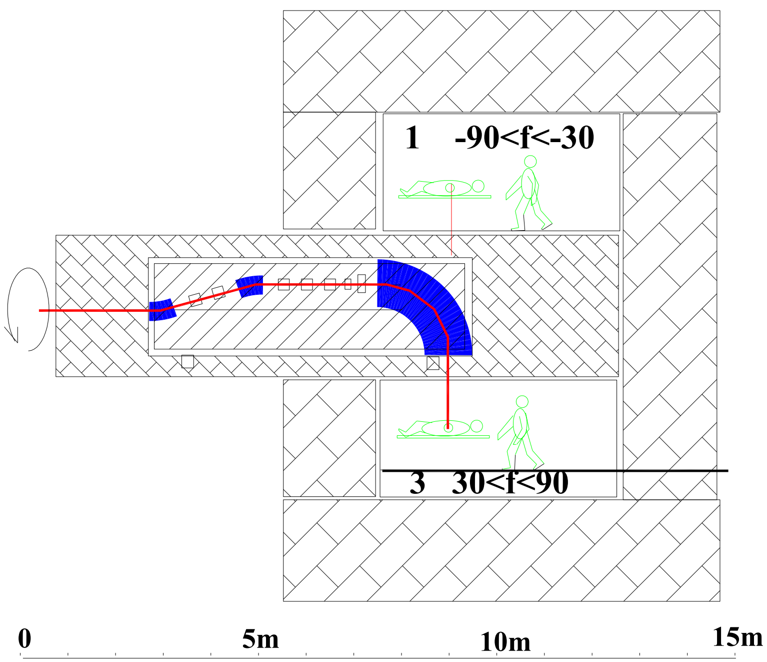


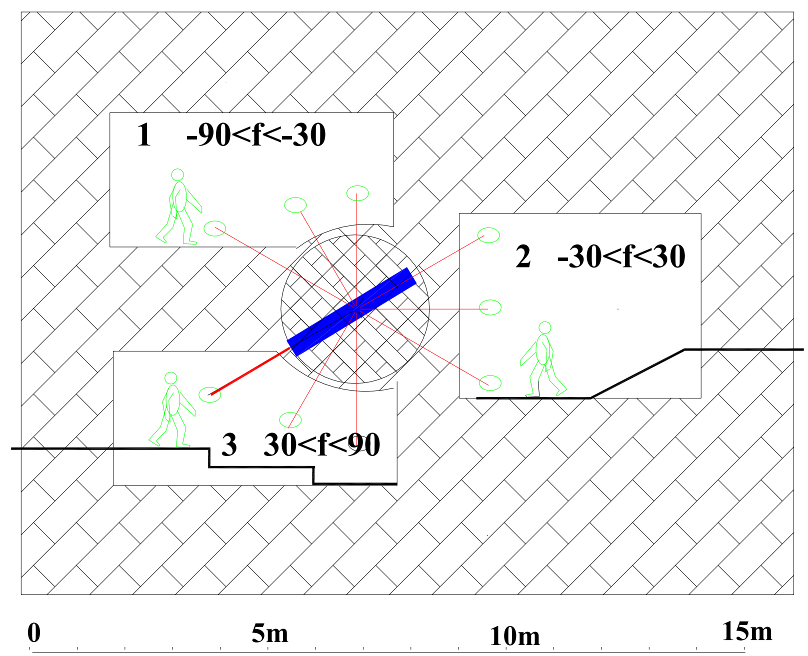
Alternatives

- Chair with vertical CT
- Some patient rotation with 6d couch
- Multi room system

Multi-room system

- **Proposed by A.Brahme**





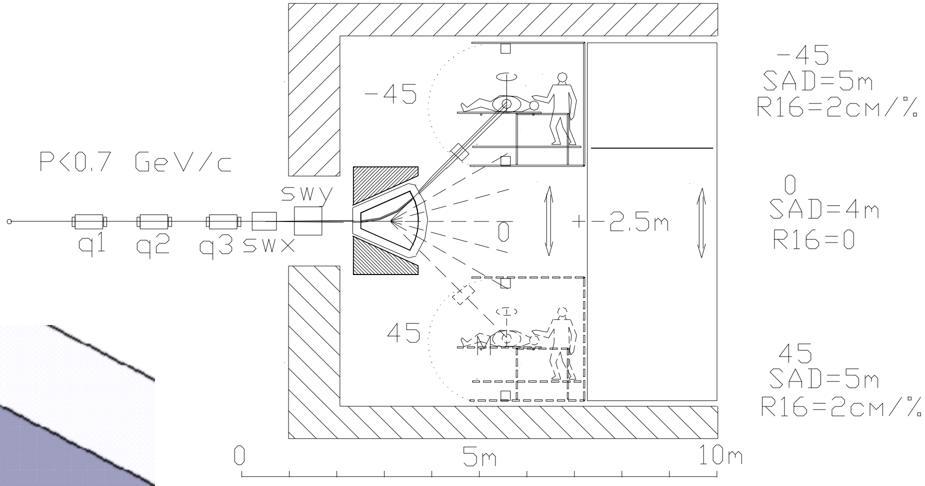
(*M. Kats*)

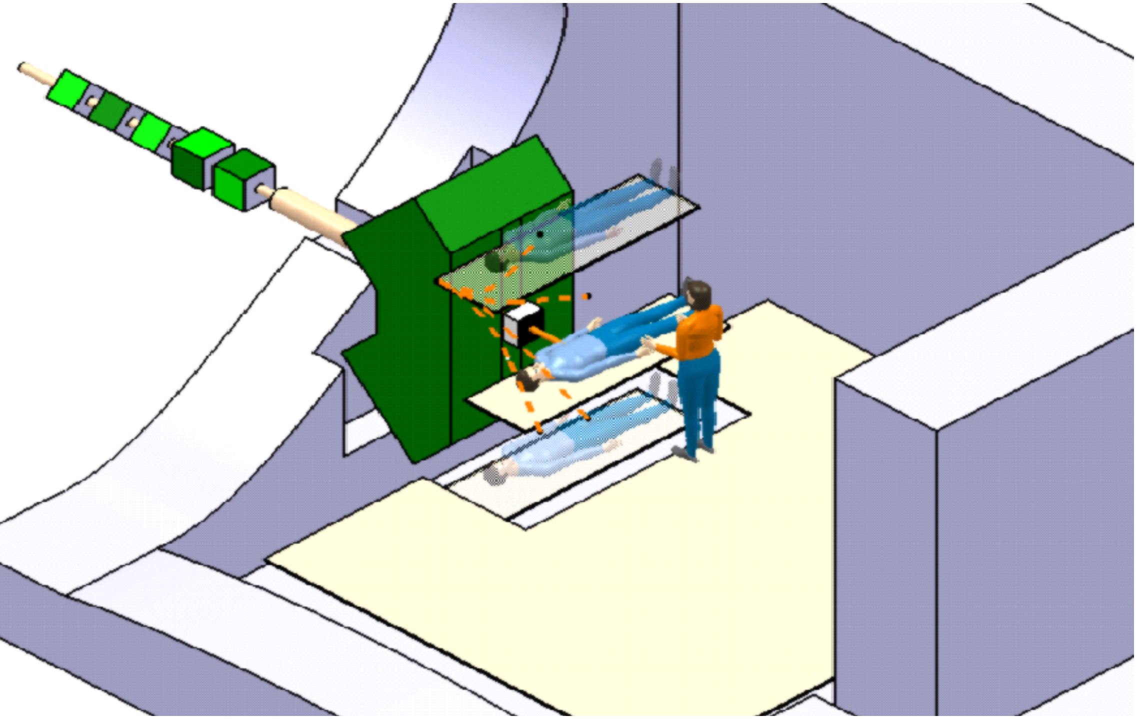
Alternatives

- Chair with vertical CT
- Some patient rotation with 6d couch
- Multi room system
- Planar system

Planar System

- **Proposed by M. Kats**

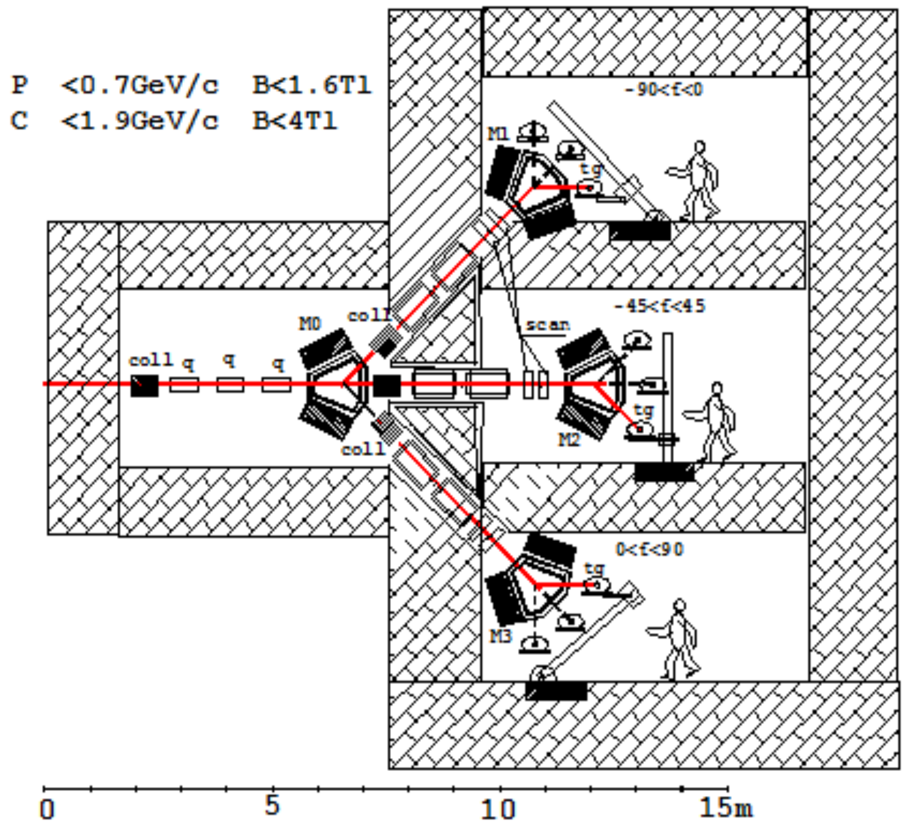




Circular exit face with center on beam entry position. Exit edge angle equals half bending angle.

Multi room planar system

- **Proposed by M. Kats**



Conclusions

- Carbon ion gantries are needed
- There are margins to improve the present schemes
- There are new ideas for new schemes
- There are large margins for compromise solutions and combinations of ideas

- Many aspects must be considered when designing a gantry

Conclusions

- Space between isocenter and last magnet for patient, beam delivery system (monitors and evetually scanning magnets), SAD
- Space downstream isocenter for patient and to go around patient
- Space for in situ position verification

- Gantry size depends on the space above plus bending radius plus magnet with supporting structure size.
- If mobile isocenter, the patient cabin will determine the gantry radius.
- Access to patient

Conclusions

- The gantry dimensions define the gantry room size and cost (digging, concrete, ventilation, climatization, shielding)
- No columns, thus single span roof. Generally roof thickness is defined more by radiation protection than by structural reasond, but anyway pre-built beams are likely to be necessary.
- Tumor tracking in energy
- And many others...

Thank you for your attention

“Physics is like sex: sure, it may give some practical results, but that's not why we do it. ”

R. Feynmann

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