ULICE Gantry Design

WP6

Presented by M. Pullia

OVERVIEW

- **ULICE WP6: *Carbon Ion Gantry***
- **Selection and hiring of 3 full time persons**
- **Training on the main aspects of accelerator physics, hadrontherapy and beam delivery**

- **First milestone:**
- **1. Online survey written with the collaboration of CNAO physicians**
- **2. Answers collection and analysis**

  3. Definition of the functional specifications → First deliverable (June 2010)

- **Status and plan of the second milestone**

  1. Different gantry typologies and geometries survey and analysis; training on "new tools" (WINAGILE, MAD8, COCU, COMSOL3.5a, MCNPX)

  2. Meeting with ULICE WP6 collaboration on the 7th September 2010 at CERN (status of work, planning of the next steps and sharing the work according to the competences each of us can provide)

  3. Gantry typology choice (1 or 2)

  4. Gantry conceptual design.

CERN (Switzerland)

ETOILE (France)

CNAO (Italy)

IFIC (Spain)

GSI (Germany)

Universitaetsklinikum Heidelberg (Germany)

Karolinska Institutet (Sweden)

TERA (Italy)

IBA (Belgium)

EBG MedAustron (Austria)

Work package number	6	Start date or starting event:		M 1	
Work package title	Carbon Ion Gantry				
Activity Type[29]	RTD				
Participant id	1 CNAO	4 CERN	5 MEDA	6 Etoile	18 INFN
Person-months per beneficiary:	117	36	6	4	18

CNAO Partnership

- **Necchi Monica (100%)**
- **Savazzi Simone (100%)**
- **Viviani Claudio (100%);**

from the 1st September 2010 substituted by **Lante Valeria**

Deliverables	Description	Month of delivery
JRA 6.1	A report describing the optimised functional specifications	M9
JRA 6.2	Conceptual design of the gantry explaining the choices made	M30
JRA 6.3	Final design of the gantry describing the device, the design strategy and the performances achieved. It includes the papers published, the preliminary design of those magnets, power supplies, mechanical structure aspects that are considered to be more critical.	M36

Done

Work in progress

Online survey

ULICE WP6 Hadrontherapy Survey > Survey > Respond to this Survey

Survey : Respond to this Survey

First Name

Family Name

1.Concerning field size

1a. Dealing with the field sizes, what are the minimum useful field sizes of irradiation required for a treatment line?

- 7.5 x 7.5 cm
- 10 x 10 cm
- 10 x 15 cm
- 10 x 20 cm
- 15 x 15 cm
- 15 x 20 cm
- 20 x 20 cm
- other

by Audrey Ballantine

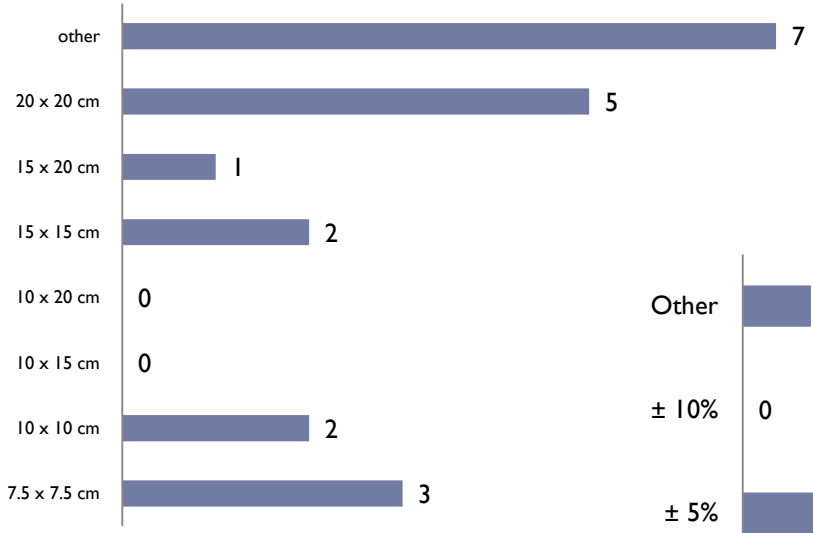
1b. Dealing with the field sizes, what are the reference field sizes of irradiation required for a treatment line?

- 10 x 10 cm
- 10 x 15 cm
- 10 x 20 cm
- 15 x 15 cm
- 15 x 20 cm
- 20 x 20 cm
- 30 x 30 cm

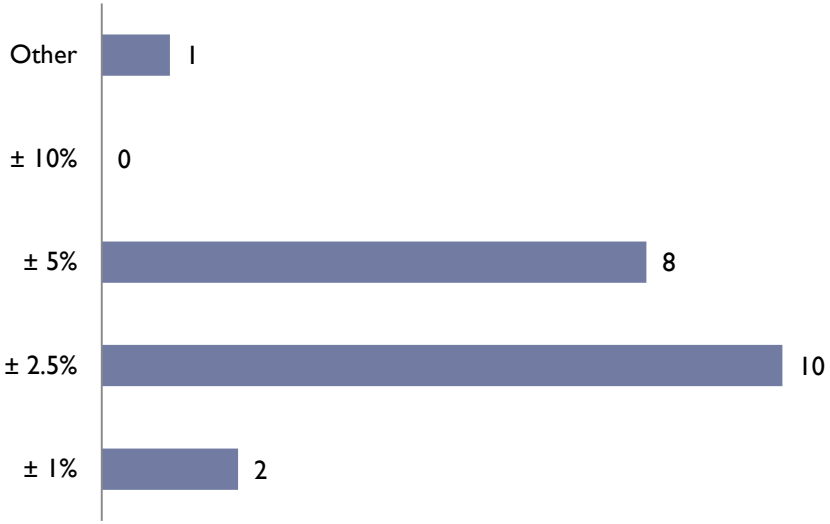
https://espace.cern.ch/project-ULICE-WP6-Hadrontherapy-Survey/Lists/ULICE%20WP6%20Questionnaire/AllItems.aspx

Survey answers analysis

1a minimum field sizes



6. dose uniformity



Final results from answers analysis

Gantry functional specifications	
Field size	15 x 15 cm^2 or 10/15 x 20 cm^2
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
Required space around isocentre	60 cm
Achieved beam directions	ALL

"Deliverable Report JRA6.1 – Functional specifications", June 2010

Field size: 20 x 20 cm ^{2} is the "optimum" but 10 x 10 cm^2 is accepted by the hadrontherapy community, also. A field size as large as possible will increase size and costs of a gantry, so, a good compromise could be a field of **15 x 15 cm^2** → reduction of magnets size and treatment of almost all the typical tumors. Costs of both magnet and power supply have to be considered for the final choice. A **rectangular field** can permit to reduce the gap size of the last bending magnet and consequently the power consumption. In case of larger tumor areas **IMPT** technique could be employed.

SAD: **4 meters** (or more) permits to consider the beam quasi-parallel, allowing for the employment of a commonly used TPS and limiting at the same time the skin dose/area increase.

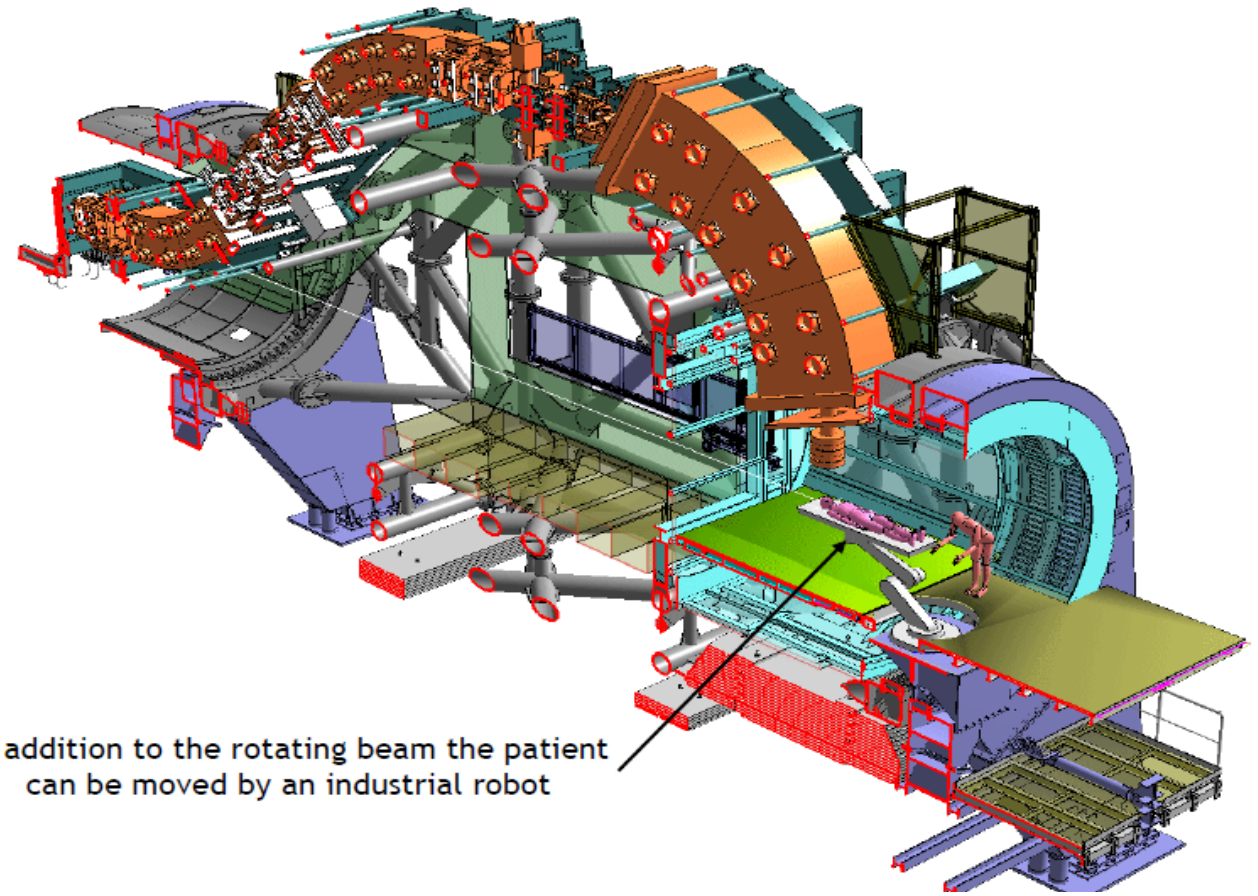
Achievable beam directions: All. To be able to reach all the irradiation directions a complete rotation of the gantry (360°) is desirable, but this could be accomplished also by means of a 180° rotation (from 90° to -90°) together with a 180° rotation of the couch around the vertical axis (without considering pitch and roll)

Towards the second milestone: ***conceptual design of the gantry*** (April 2012)

In progress…

- Beam transport line and magnet simulations (WINAGILE, MAD8, COCU, COMSOL3.5, …)
- Gantry typologies choice and conceptual designs
- Shielding: preliminary studies in radioprotection aspects (MCNPX)

The reference: HIT



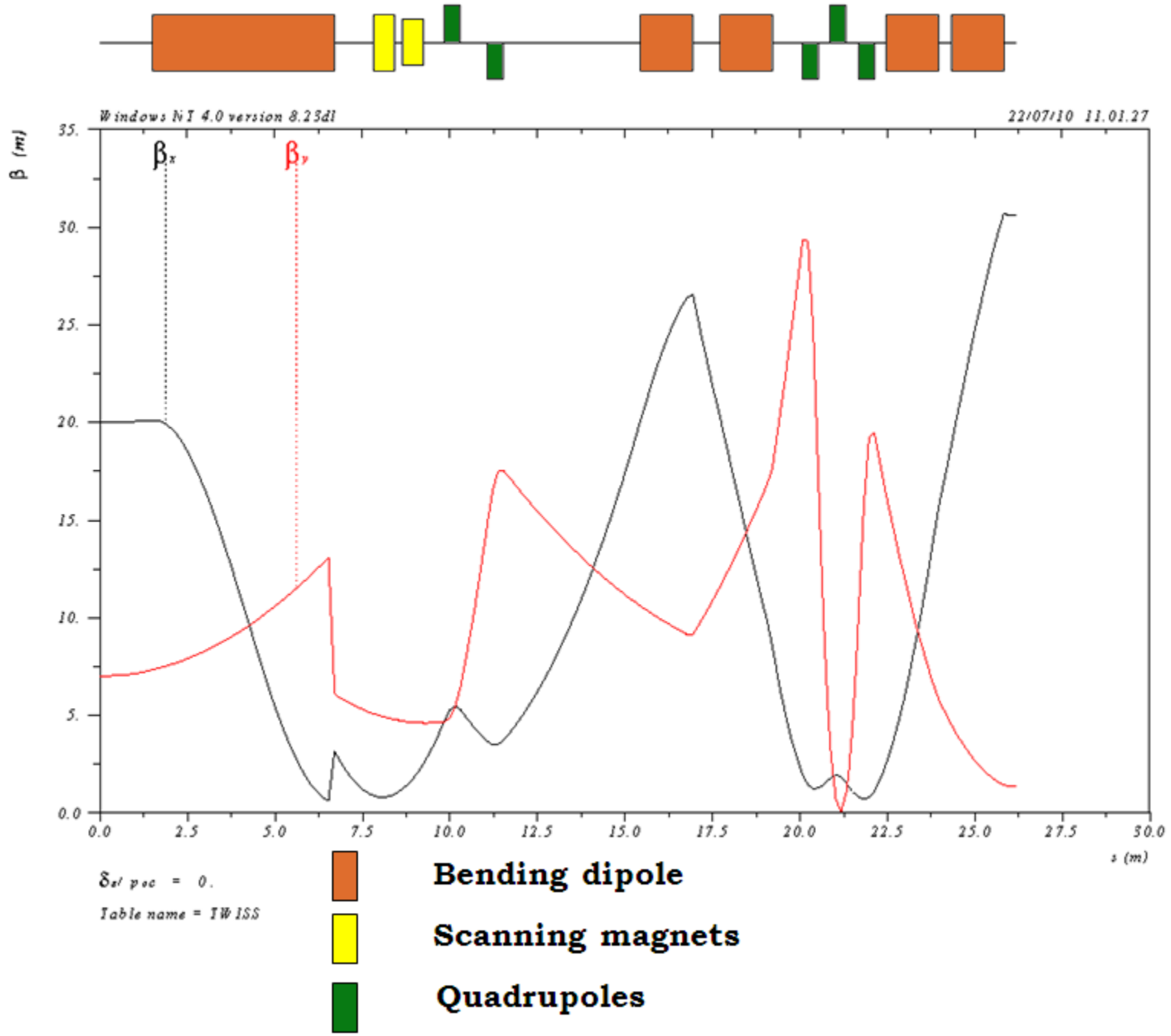
- In addition to the rotating beam the patient can be moved by an industrial robot

Allows patient treatment from different directions, the gantry can be rotated ± 180° with a max. speed of 3°per second

Dimension: 25 m long and 13 m in diameter

Weight: 600 tons, the rotating parts have 420 tons, the magnets have 140 tons

Andreas Schnegg, Survey and alignment of the world's largest gantry for cancer therapy, IWAA 08, Tsukuba, Japan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22/07/10 11.01.27
β (m)
β_x
β_y
35.
30.
25.
20.
15.
10.
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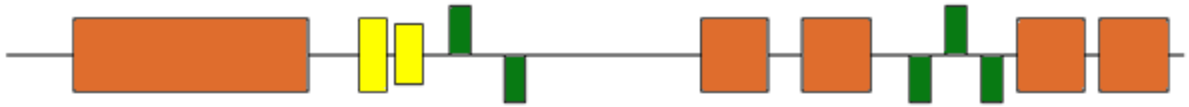
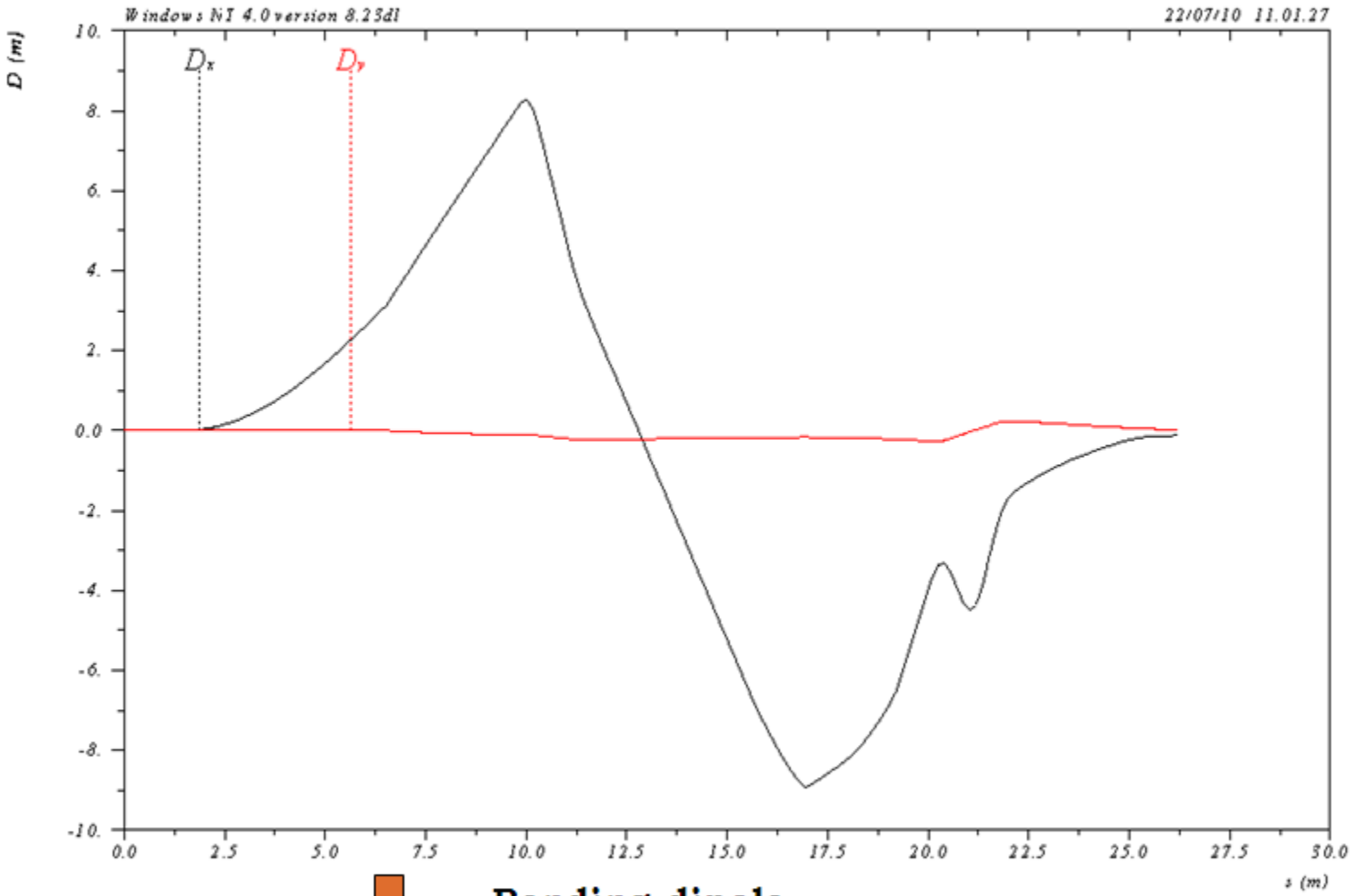
15.0
17.5
20.0
22.5
25.0
27.5
50.0
s (m)
$\delta_{s/\,poc}$ = 0.
Table name = TWISS
Bending dipole
Scanning magnets
Quadrupoles





$\delta_{s/\,poc}$ = 0.

Table name = TWISS

Bending dipole

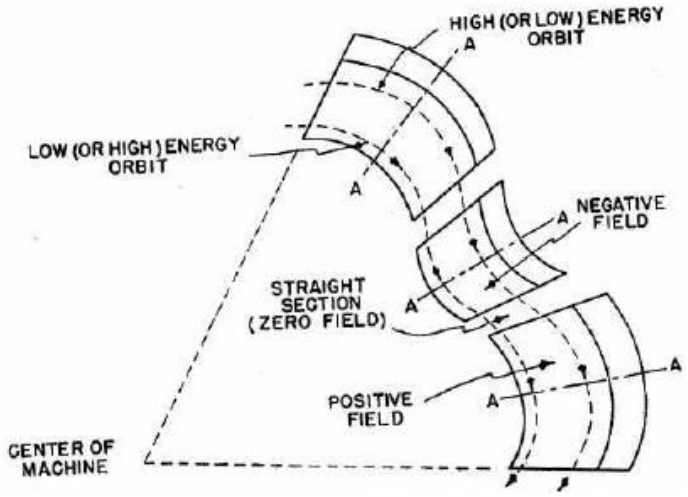
Scanning magnets

Quadrupoles

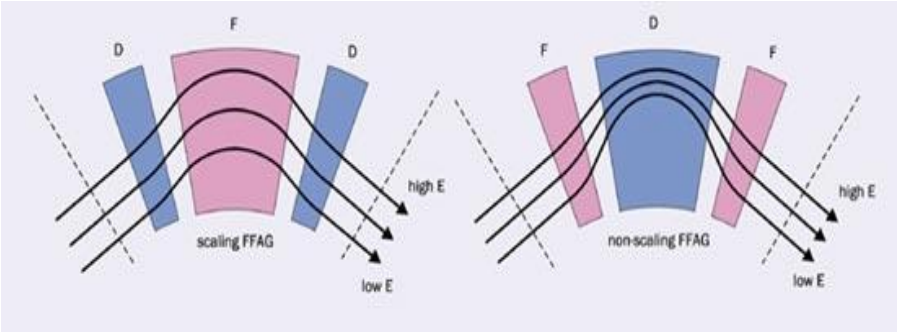
Aspects and ideas to be considered

- SAD and scanning magnets position
- 360° vs 180°
- Field patching
- Fixed or mobile isocenter
- Superconducting magnets
- FFAG gantry
- Divergent scanning
- ...

What is an FFAG?



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

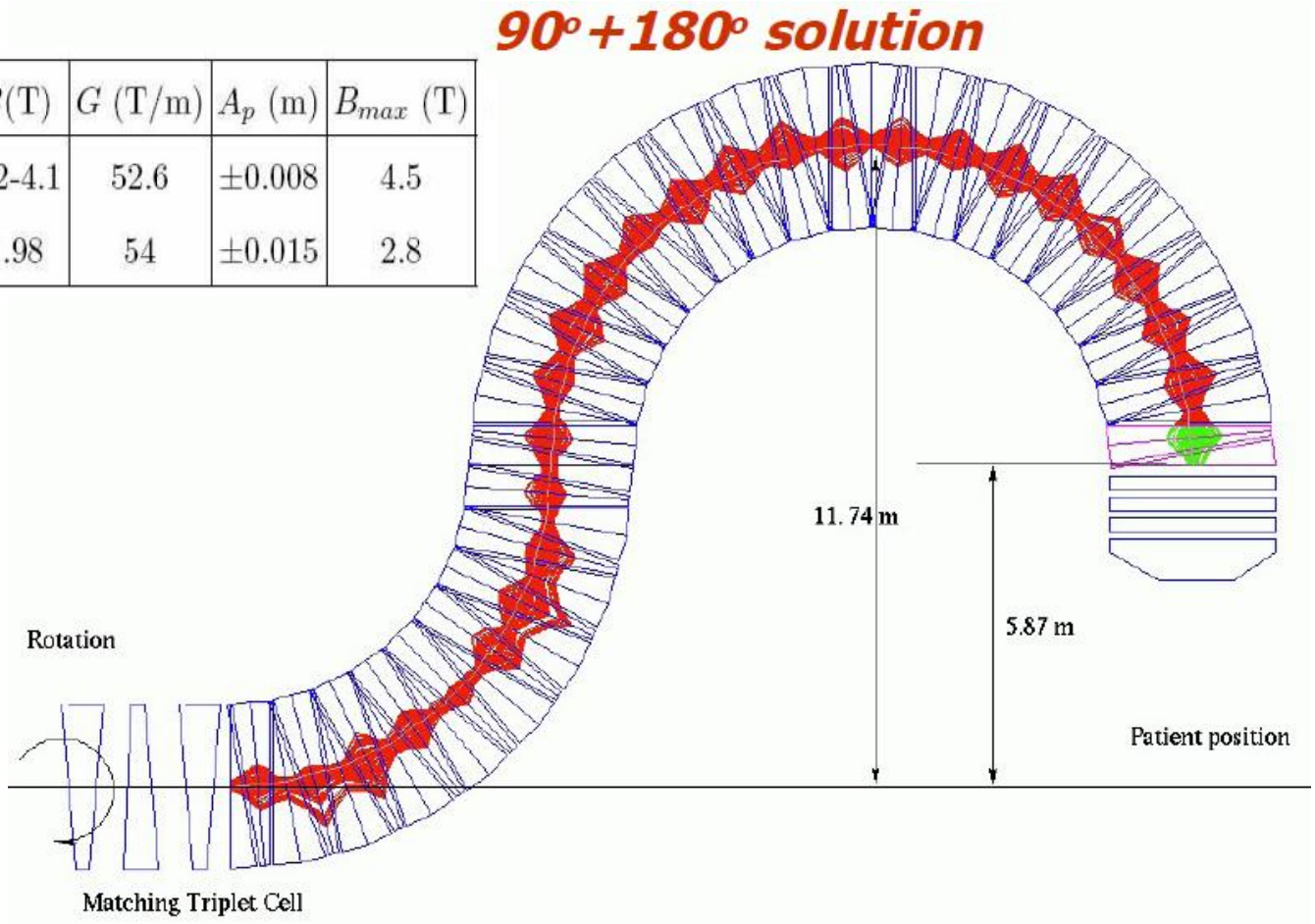


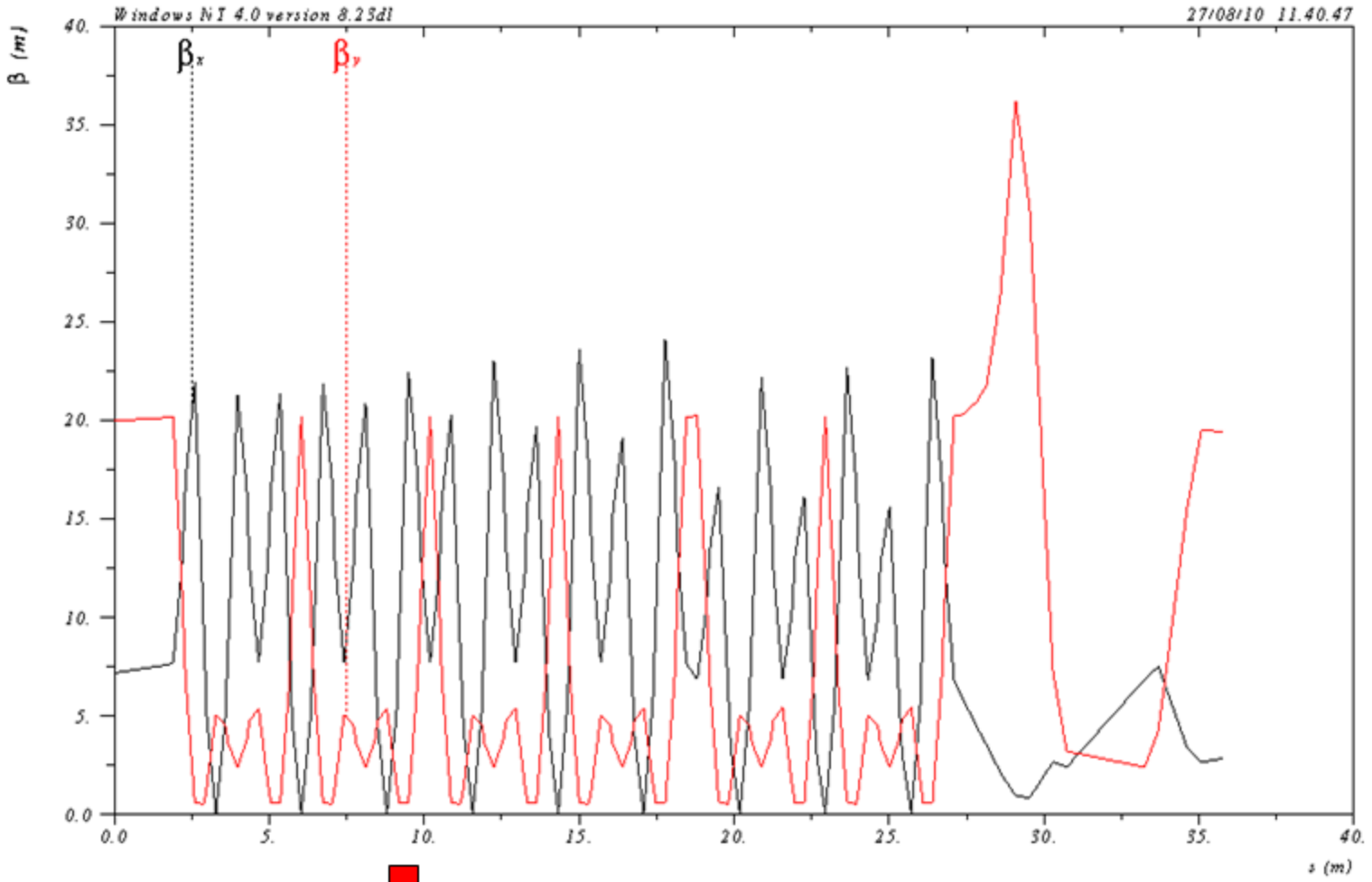
Basic characteristics:

1. **FIXED MAGNETIC FIELD**
2. **Spiral orbits** → wider magnets and vacuum chambers
3. **Large acceptances**
4. **High beam current**

Fixed isocentre gantry with FFAG

Magnet	L(m)	B(T)	G (T/m)	A_p (m)	B_{max} (T)
BD	0.38	3.2-4.1	52.6	$\pm$0.008	4.5
BF	0.40	1.98	54	$\pm$0.015	2.8

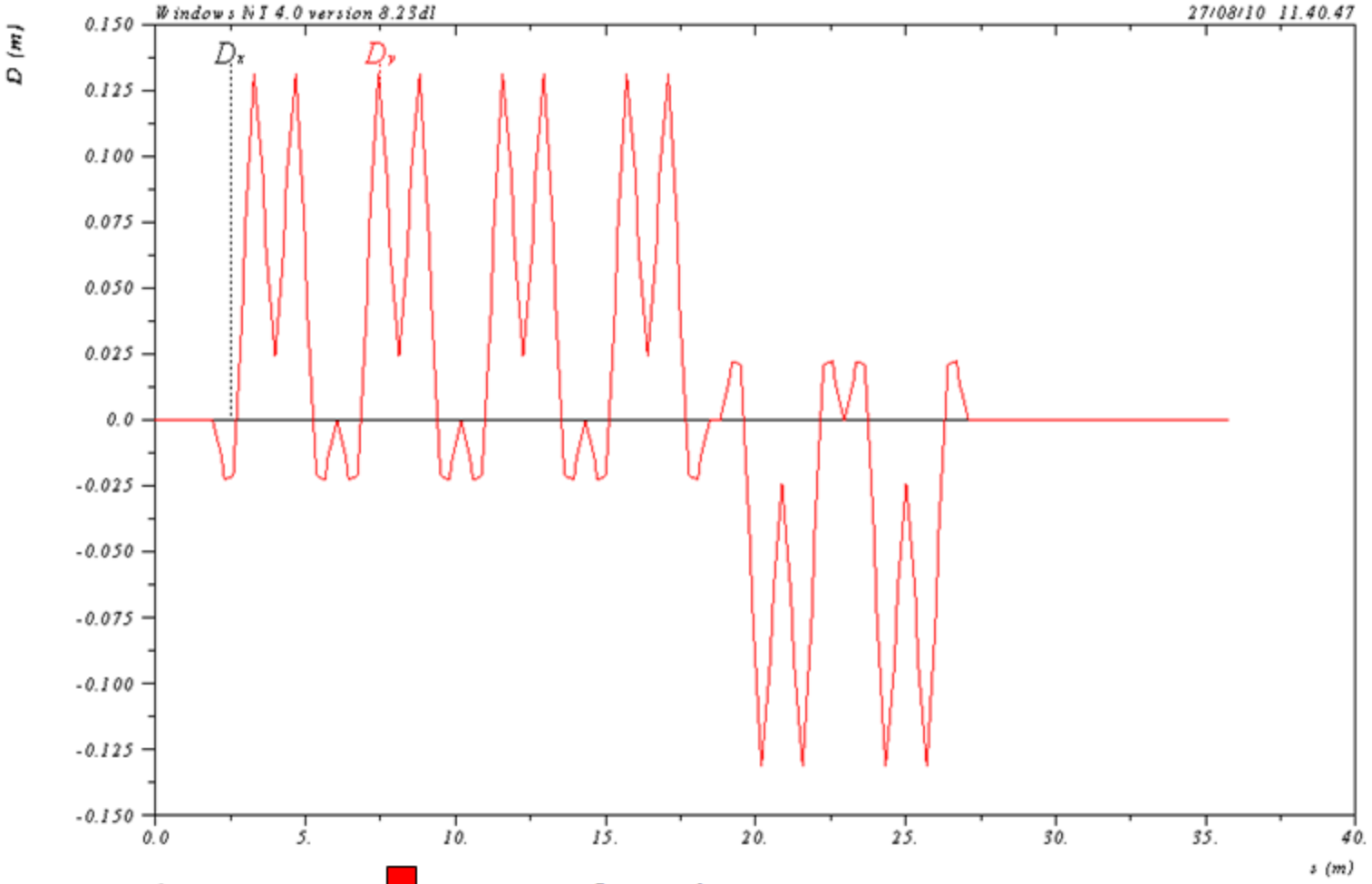




Defocusing magnets

Focusing magnets

Quadrupoles



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Defocusing magnets

Focusing magnets

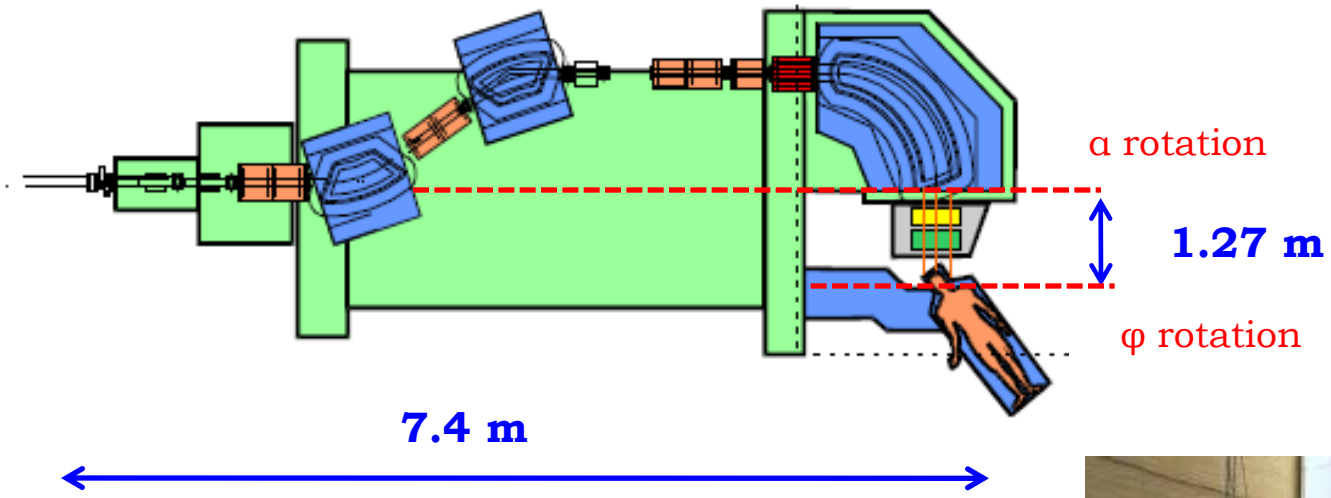
Quadrupoles

Main features

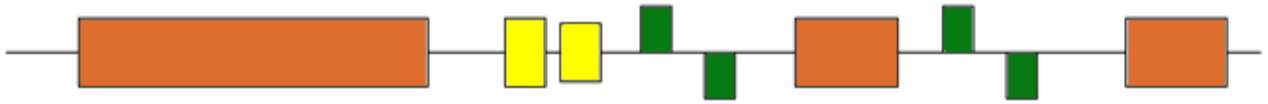
Normal fixed isocentre gantry	
Radius	~ 6.5 m
Isocentre-last magnet dist.	~ 3 m
Scanning magnets	upstream
Effective SAD	~ ∞
Maximum bending field	~ 1.6 T
Length	~ 22 m

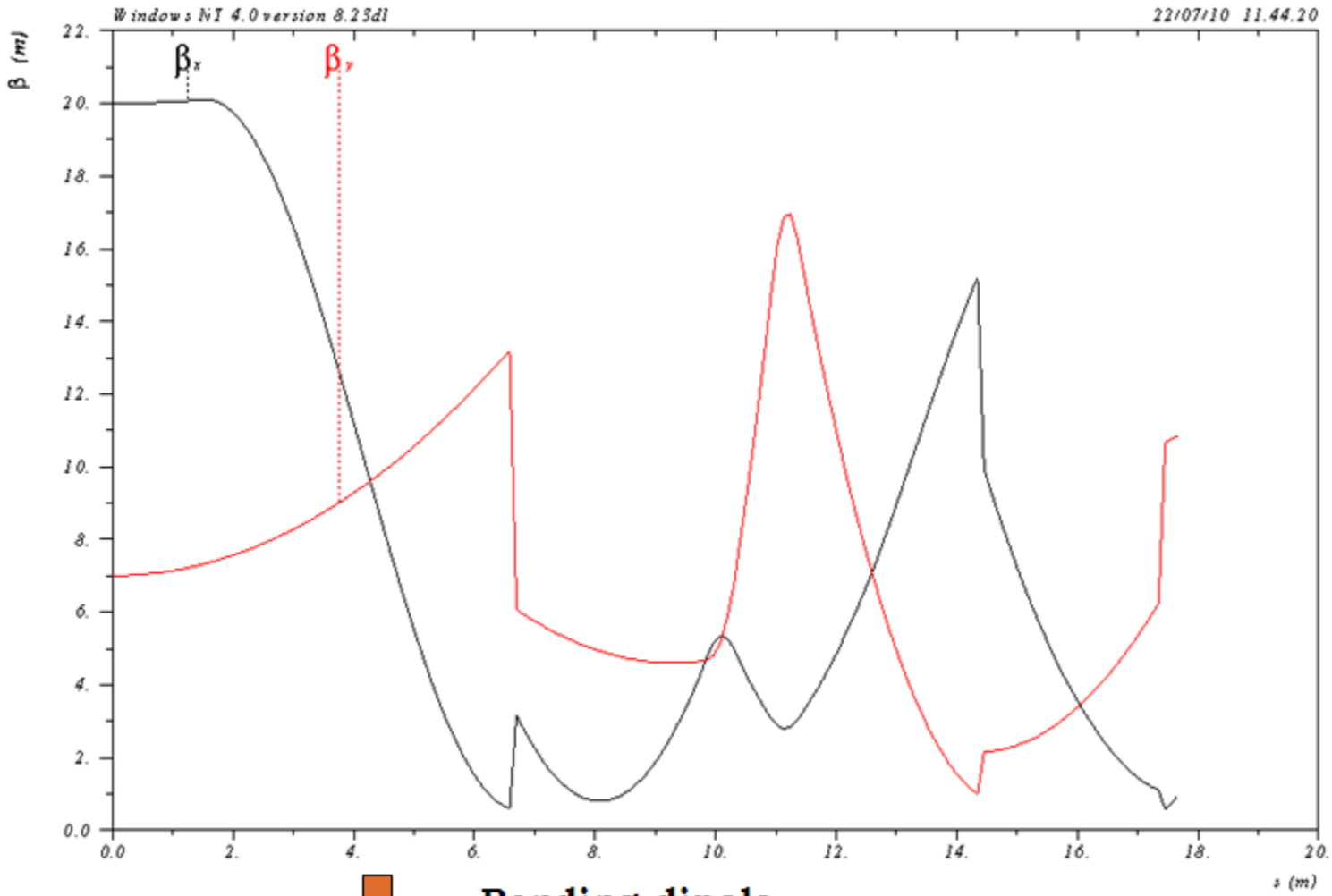
FFAG Fixed isocentre gantry	
Radius	~11 m
Isocentre-last magnet dist.	~ 6 m
Defocusing mean field	-3.8 T
Defocusing maximum field	-4.5 T
Defocusing gradient	-27.17
Focusing mean field	1.64 T
Focusing maximum field	2.4 T
Focusing gradient	29.64
Length	~ 25 m

Mobile isocentre gantry: PSI gantry 1 (Protons)



E. Pedroni, Center for Proton Radiation Therapy Paul Scherrer Institute
PSI, 8 August 2007

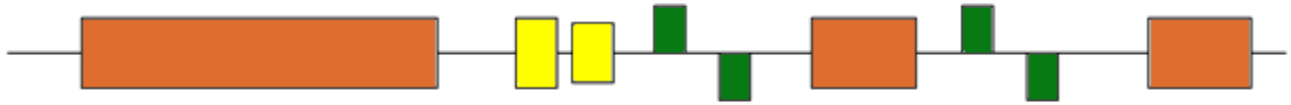


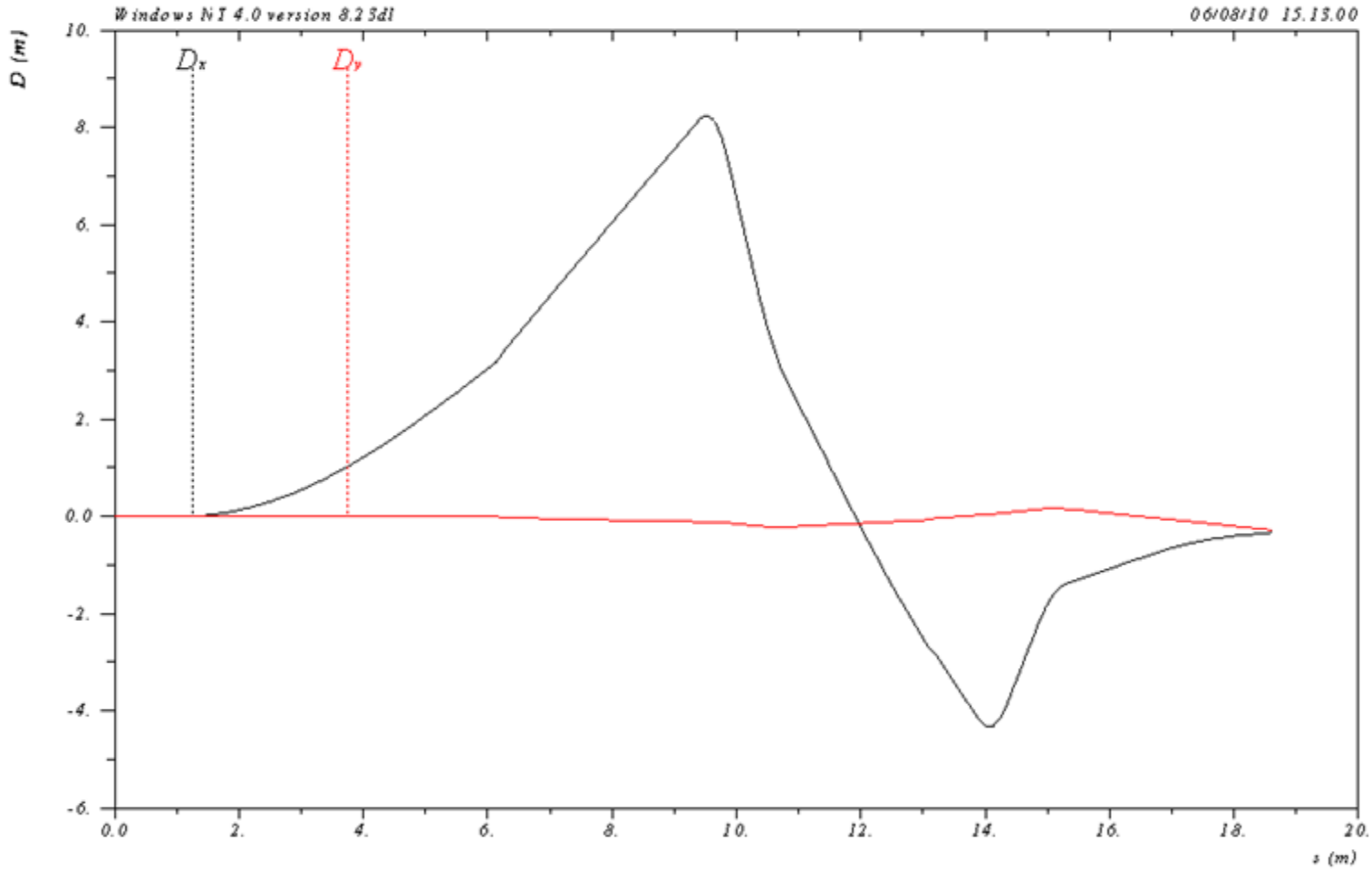


Bending dipole

Scanning magnets

Quadrupoles





$\delta_{ref\ pos}$ = 0.

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Bending dipole

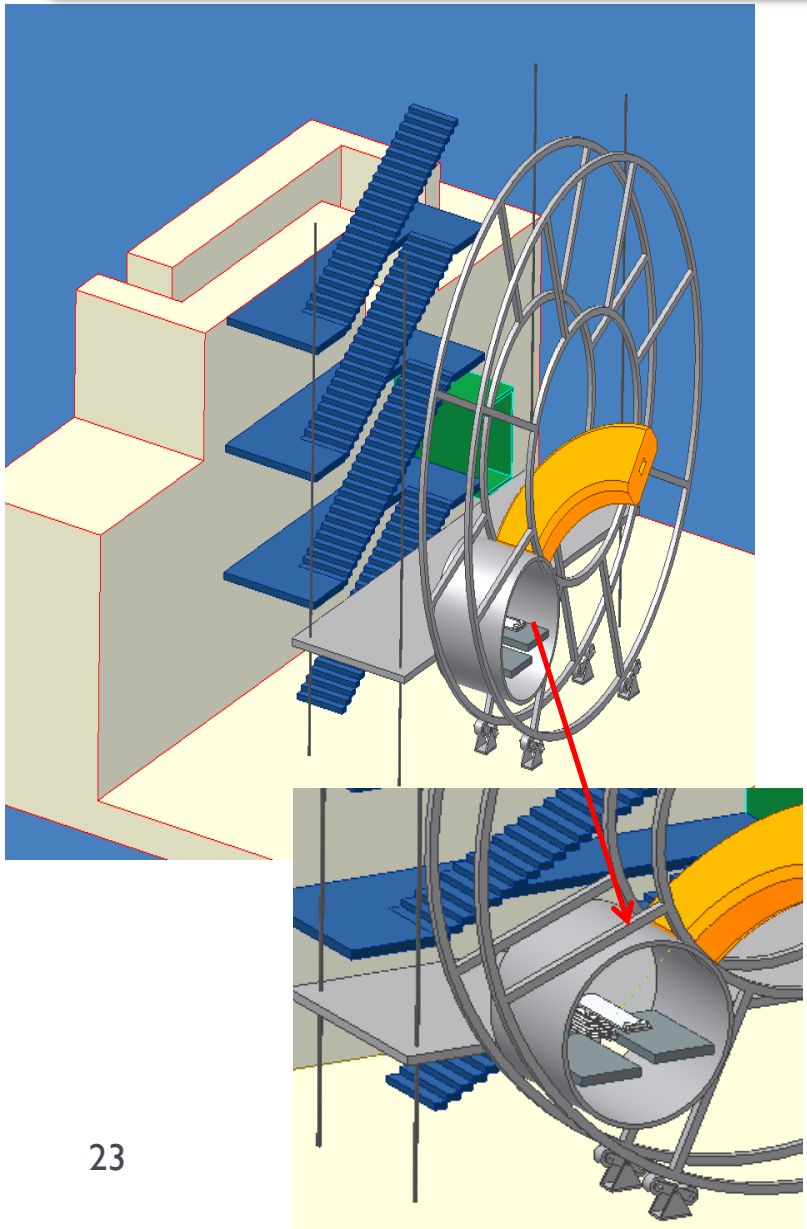
Scanning magnets

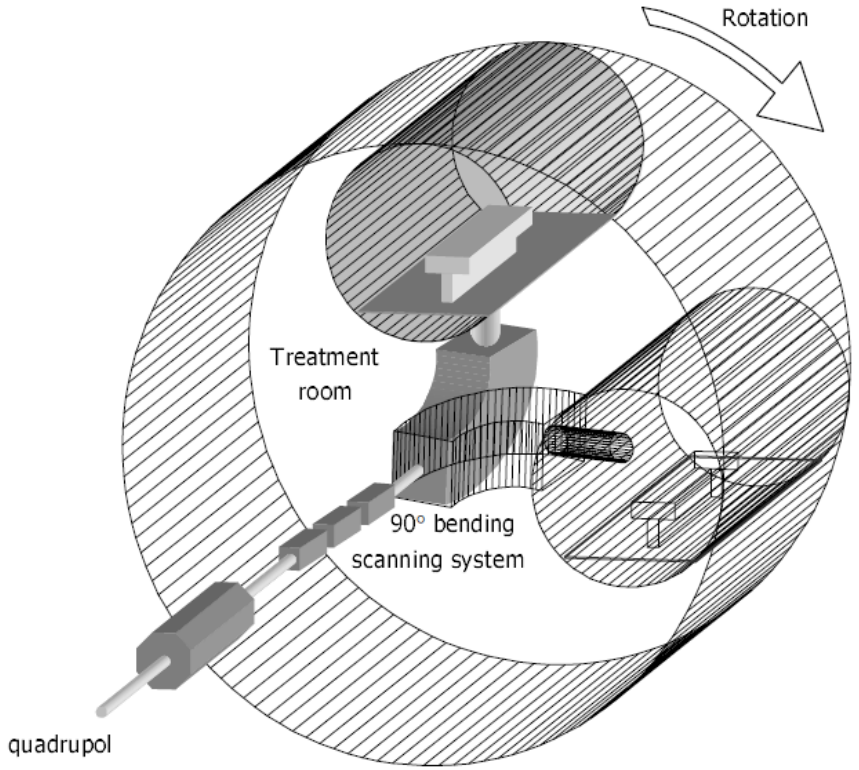
Quadrupoles

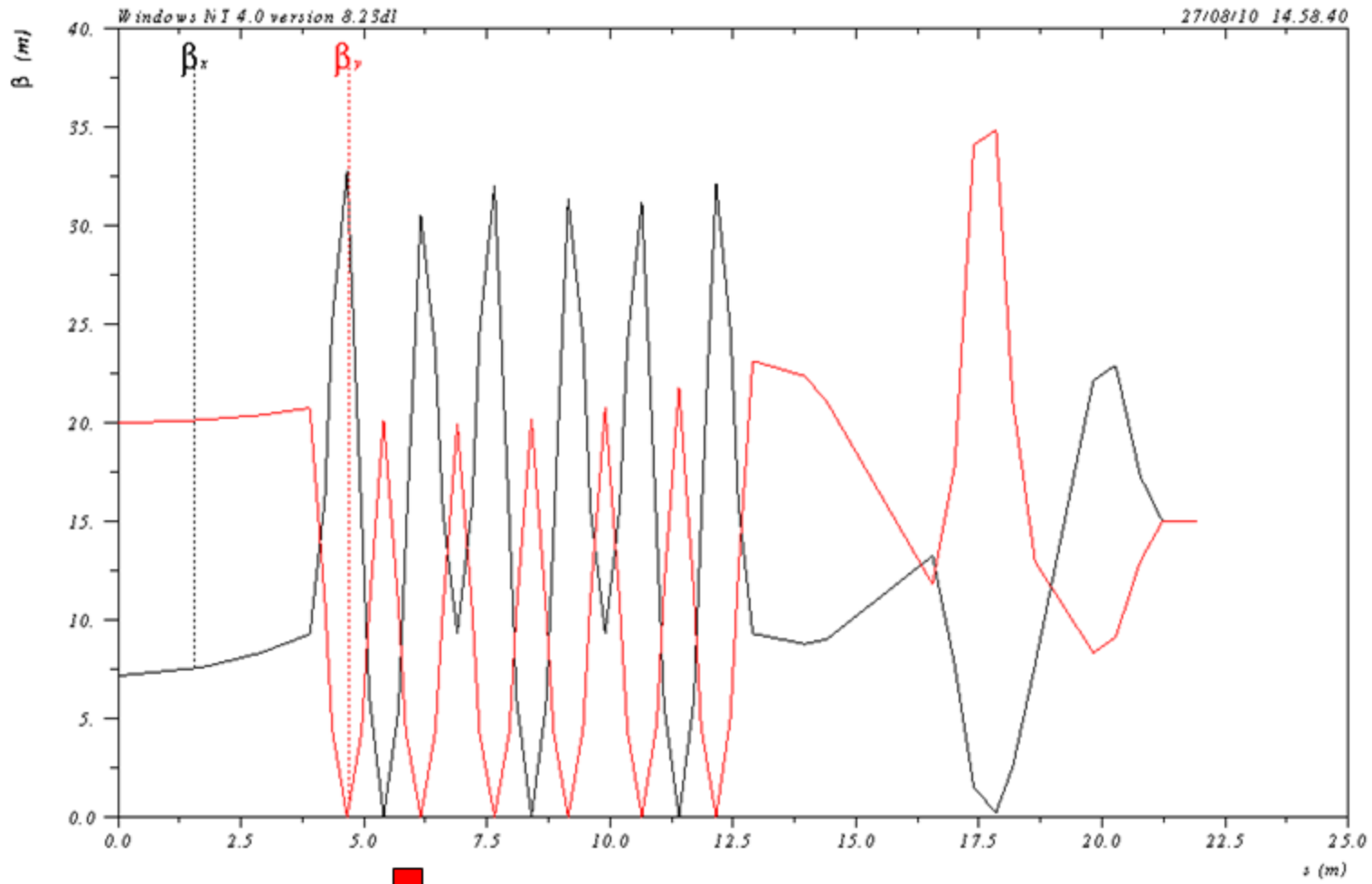
Main features

Mobile isocentre gantry	
Radius	~ 4.5 m
Isocentre-last magnet dist.	~ 3 m
Scanning magnets	Upstream
Effective SAD	~ ∞
Maximum bending field	~ 1.6 T
Length	~ 18 m

Mobile isocentre gantry: Riesenrad



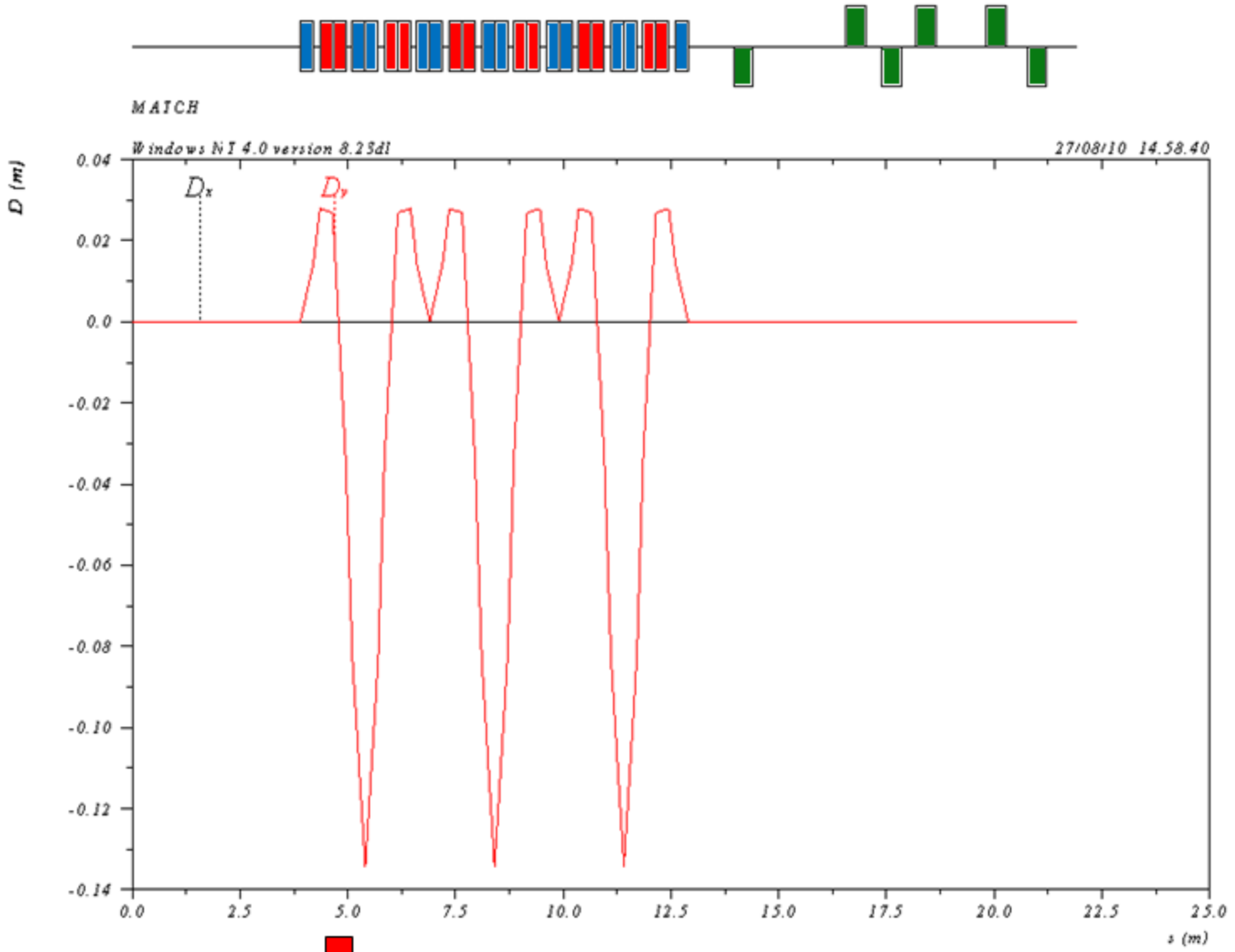




Defocusing magnets

Focusing magnets

Quadrupoles



Defocusing magnets

Focusing magnets

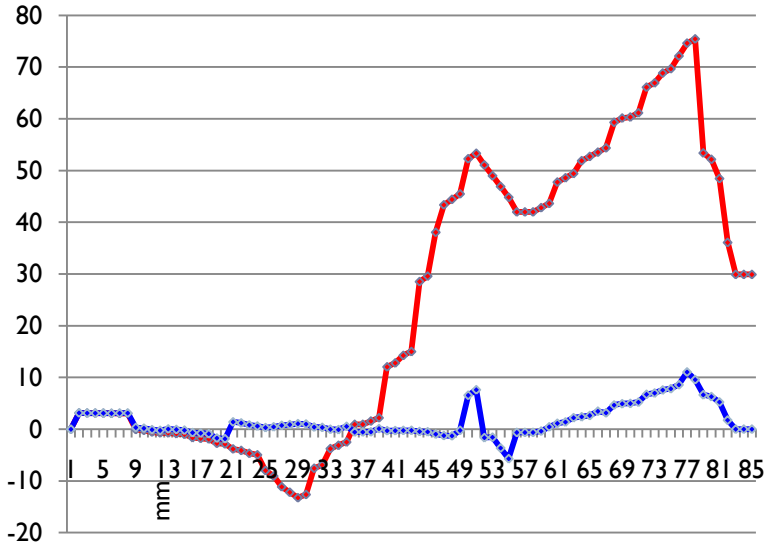
Quadrupoles

Main features

FFAG Riesenrad-like gantry	
Defocusing mean field	-3.8 T
Defocusing maximum field	-4.4 T
Defocusing gradient	-25.144
Focusing mean field	1.64 T
Focusing maximum field	2.4 T
Focusing gradient	31.165
Vertical dispersion	+3 cm/-13 cm

Misalignments and steering

- Study on misalignments has just started



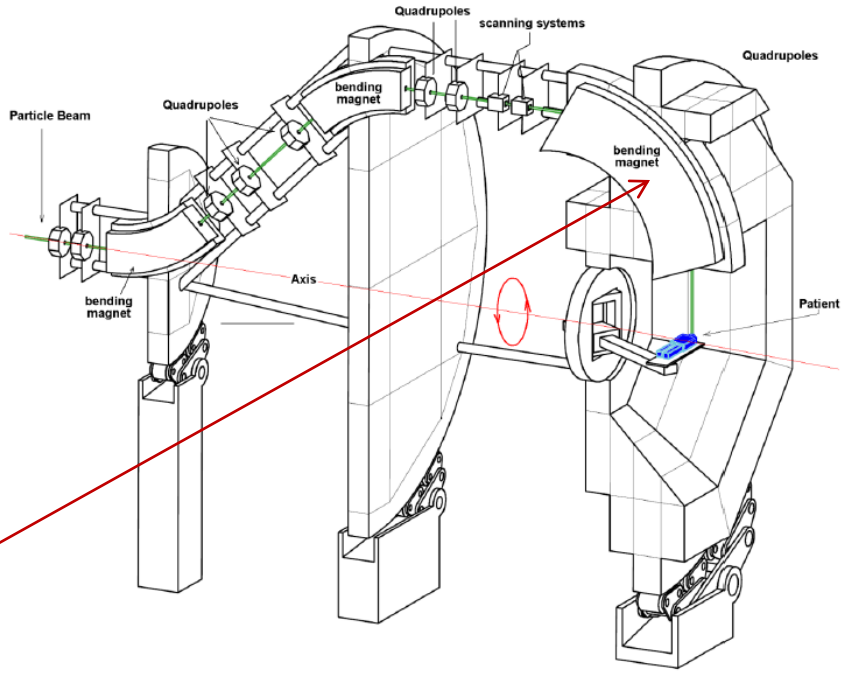
Example of steering:
beam position **before** (**red**) and **after** (**blu**) corrections

Element number along the line

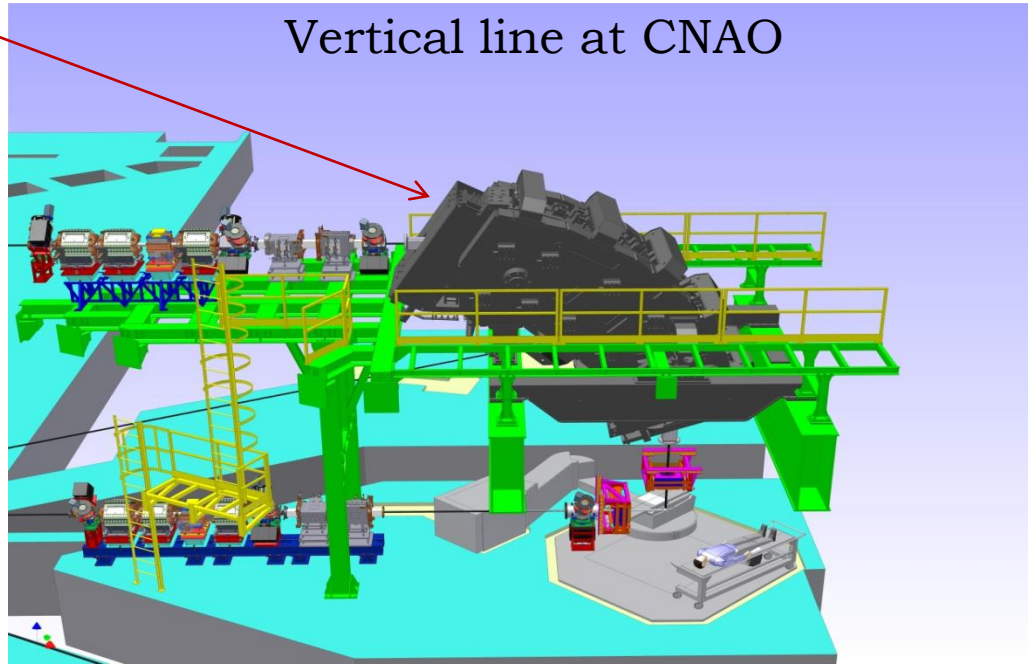
MAGNET STUDY AND DESIGN

- Optics studies need a deep analysis of magnets design and behavior (both for conventional and SC ones).
- Magnets analysis started with simulations by means of a finite elements software, **COMSOL**, which allows geometries to be modeled and imported (from Inventor® or Autocad®, for example) and electromagnetic features to be investigated
- As a first step, the “well known” 90° dipole of CNAO vertical line has been modeled and results have been compared with already existing ones (obtained by means of OPERA software)

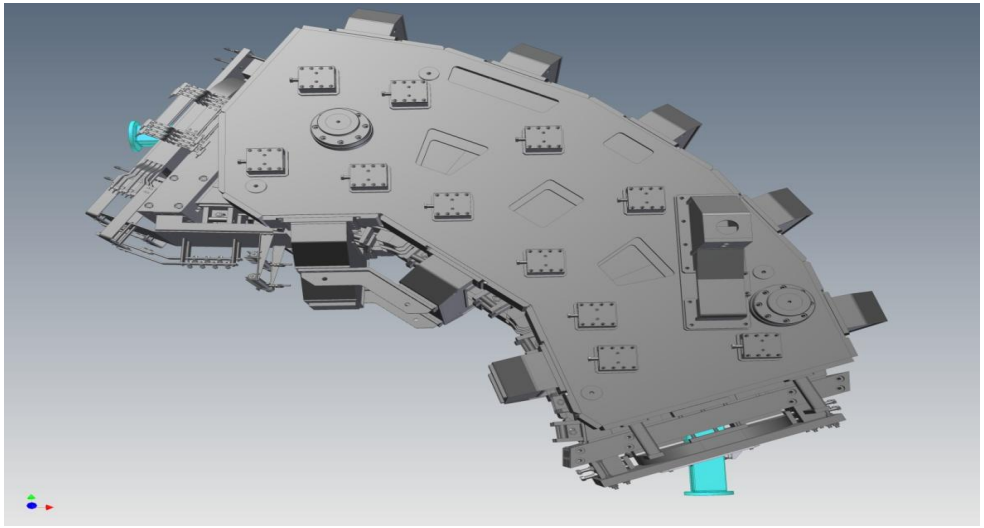
Typical concept of carbon ion gantry :
isocentric and barrel structure



Bending magnet

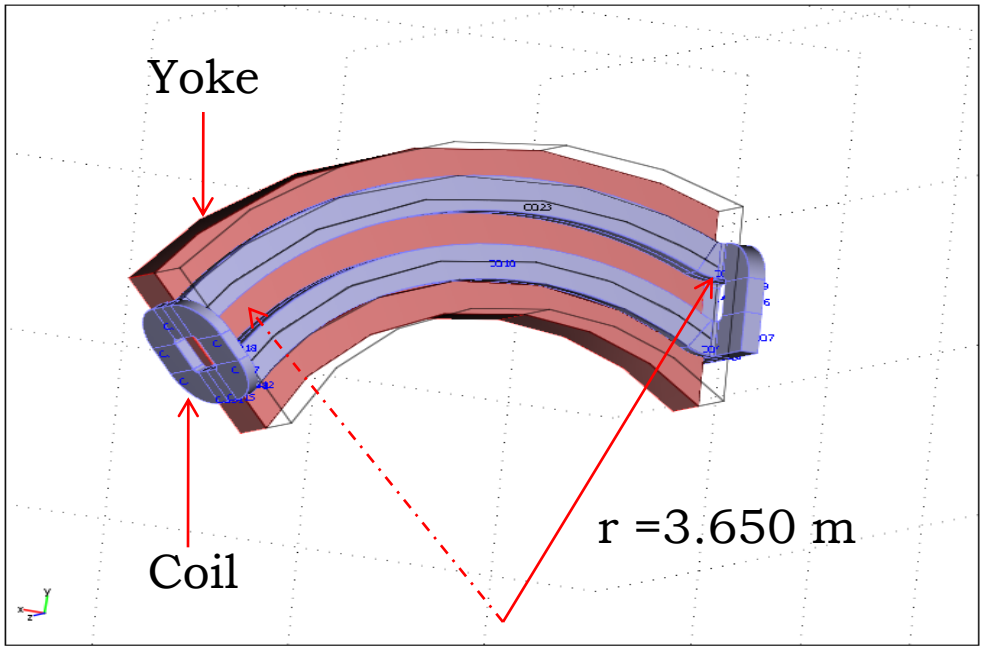


Last bending magnet

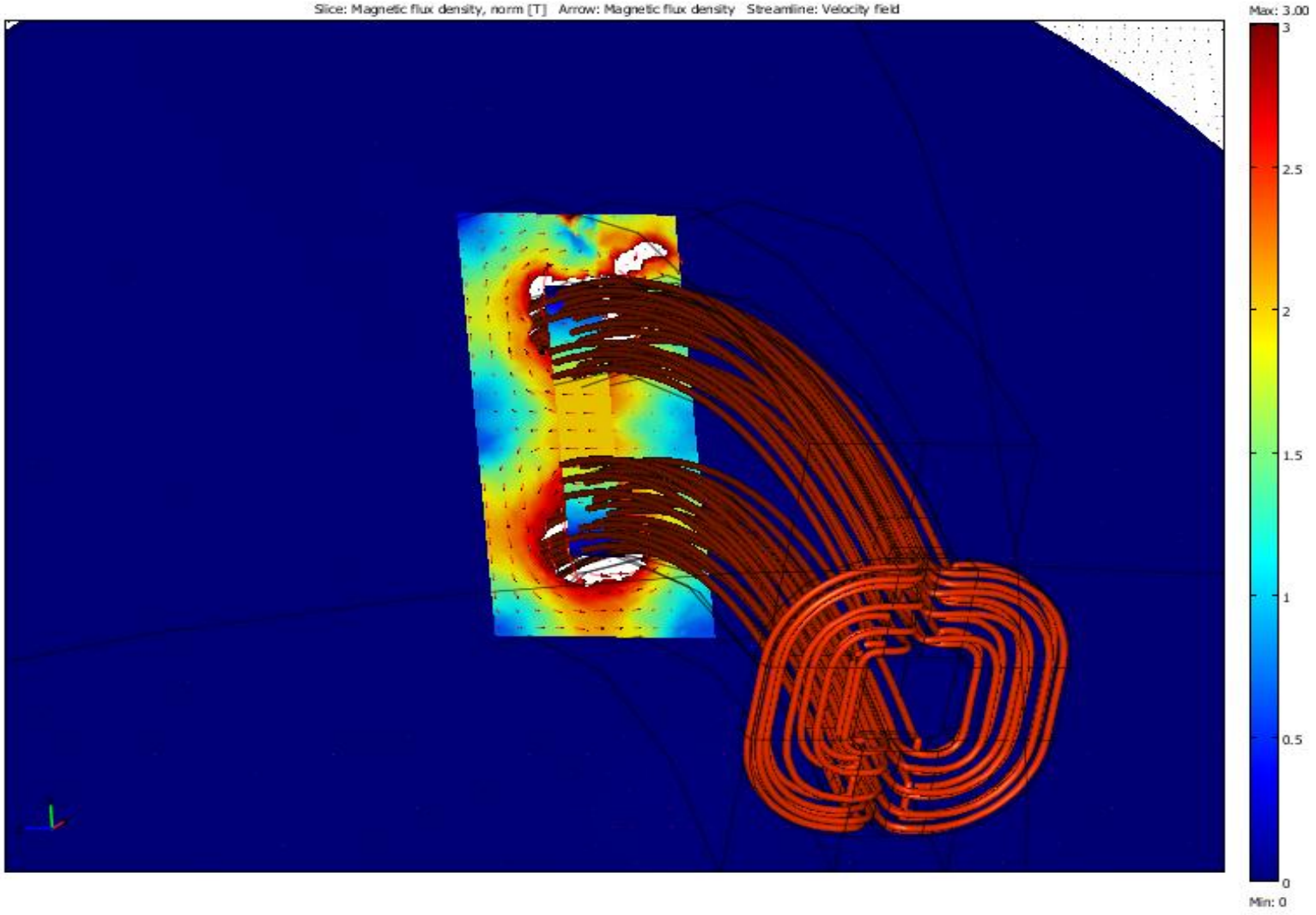


Magnet characteristics:
Nominal Field: 1.81T
Turns per pole: 80
Nominal current: 2280 A

Simplified geometry adopted for COMSOL simulation



Magnetic flux density (slice and arrows)

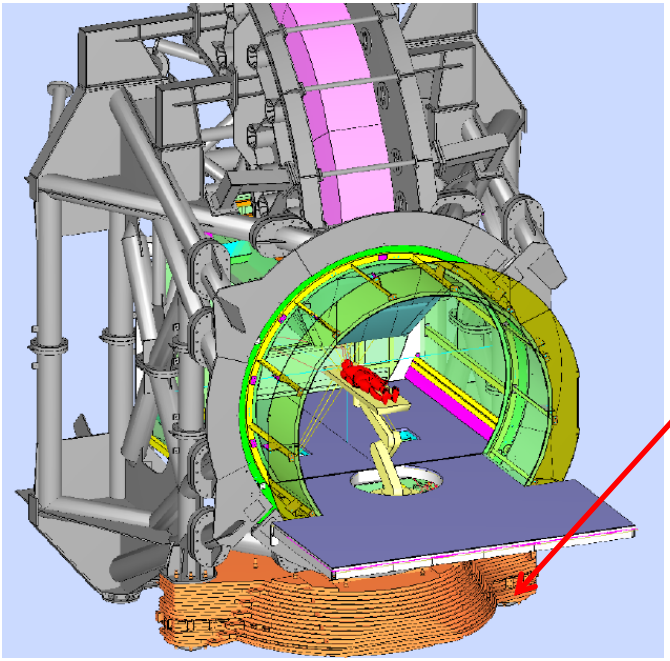


COUNTERWEIGHT & SHIELDING

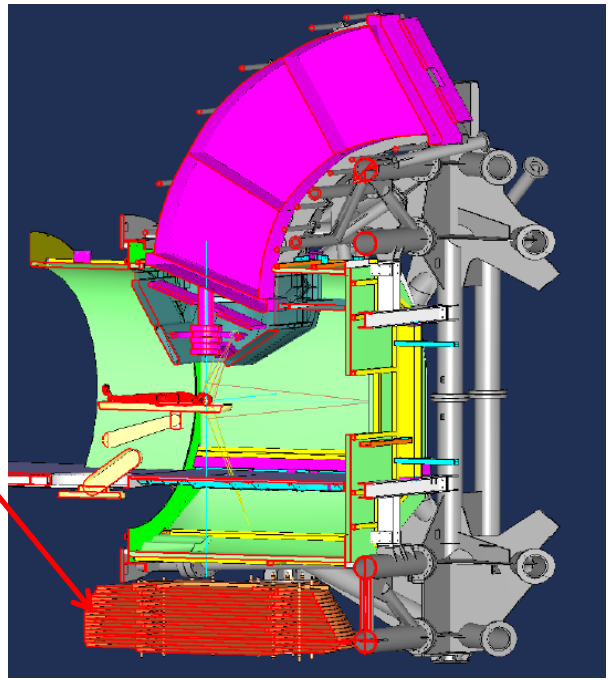
Radiation has to be shielded outside the gantry room. This aspect is directly related with the beam direction given by the gantry geometry. A heavy counterweight contributes to the shielding in the beam direction and influences the treatment rooms configuration and the quantity (typology, also) of shielding material(s) in the walls.

Preliminary studies in radioprotection aspects

In some designs, the gantry **counterweight** (made of large thicknesses of steel) acts as a stopper in the beam direction, but it covers a limited angle.



Counterweight



Pics courtesy of
MT Mechatronics

CONCLUSIONS

- WP6 is proceeding as scheduled
- First deliverable completed
- Specifications more or less standard
- Survey and examination of the alternatives ongoing
- In a few days the next collaboration meeting to plan next actions
- The gantry design is starting