# THE CNAO EXPERIMENTAL LINE & FUTURE DEVELOPMENTS

Marco Pullia

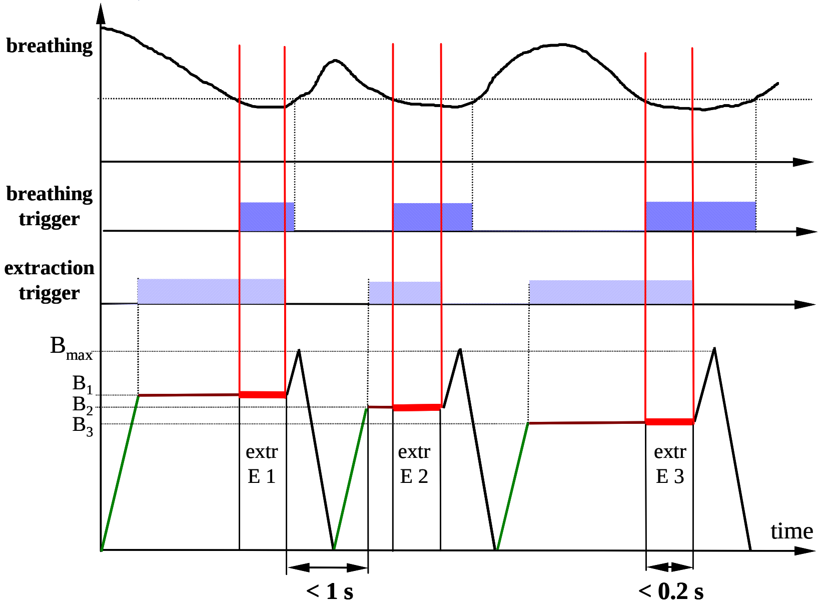
# Future and R&D

# R&D activities

- Gating

# On-line imaging

“Minimal” choice: breathing synchronisation (already applied in Chiba and HIT, planned at CNAO)




Interesting also for IMRT: lots of efforts and devices

*(Review in Riboldi et al, Lancet Oncology 2012)*

External surrogates with correlation models

X-rays

Ultrasound, MRI

Particle radiography


(Courtesy of Medical Intelligence)

# R&D activities

- Gating
- Cycle Shortening

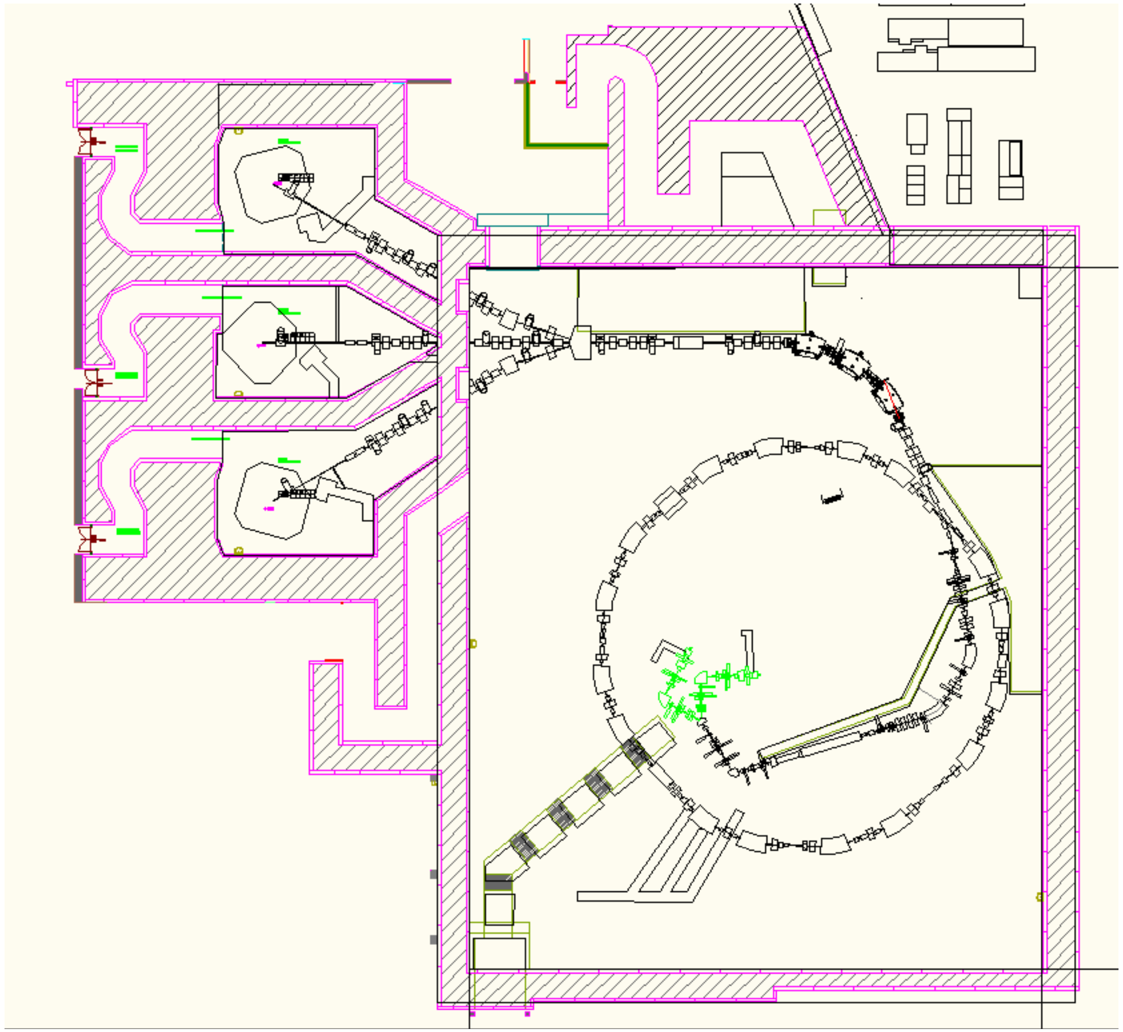
# Cycle shortening

- Reduce delays
- Long flat top (to avoid repetitions with faint spots)
- Dynamic betatron
- Chopstop/end of charge
- Smaller hysteresys cycle for protons

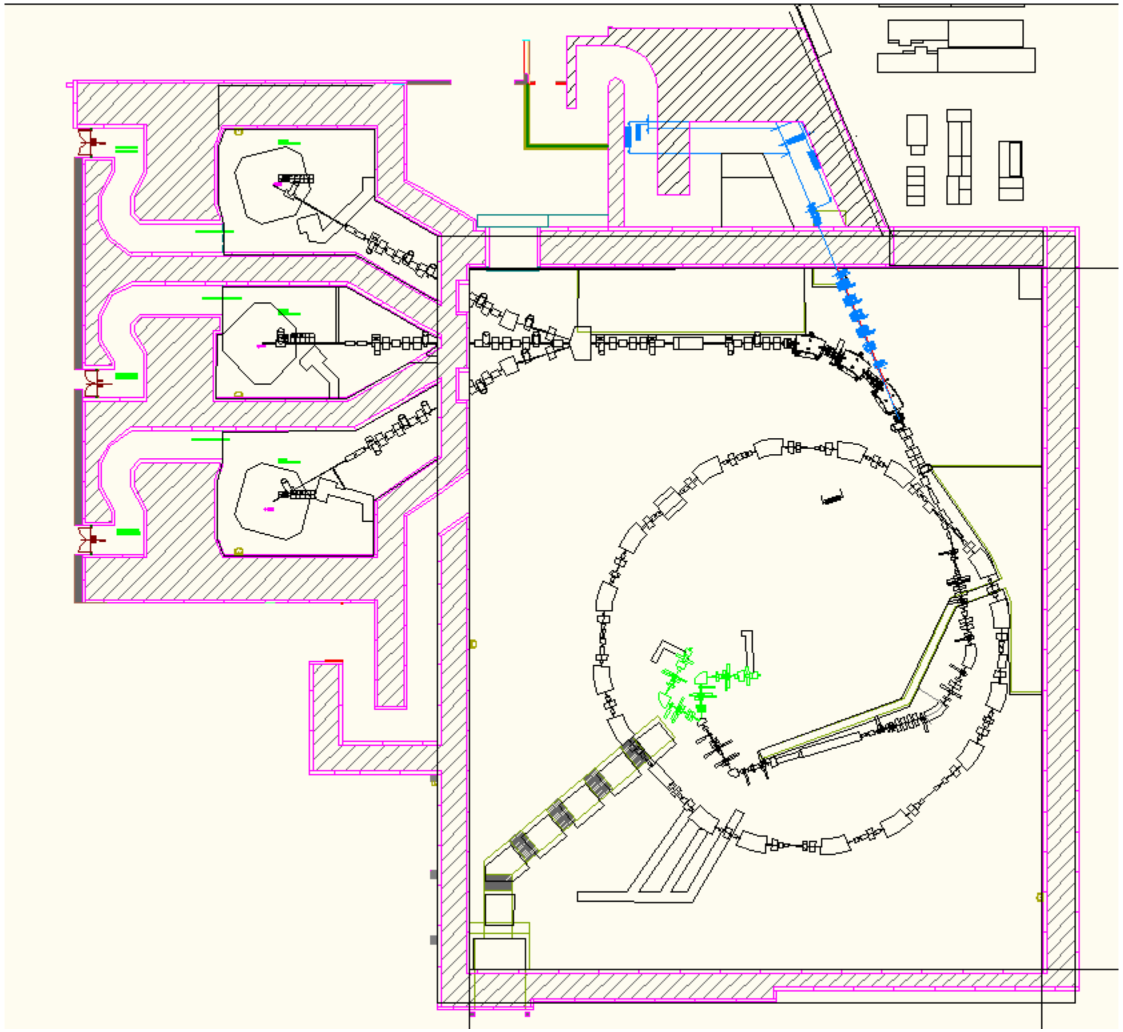
# R&D activities

- Gating
- Cycle Shortening
- Experimental room
  - High energy beam line
  - New ion species ($1 < Z < 8$)
  - Medium energy beam line

# Present



# Experimental room

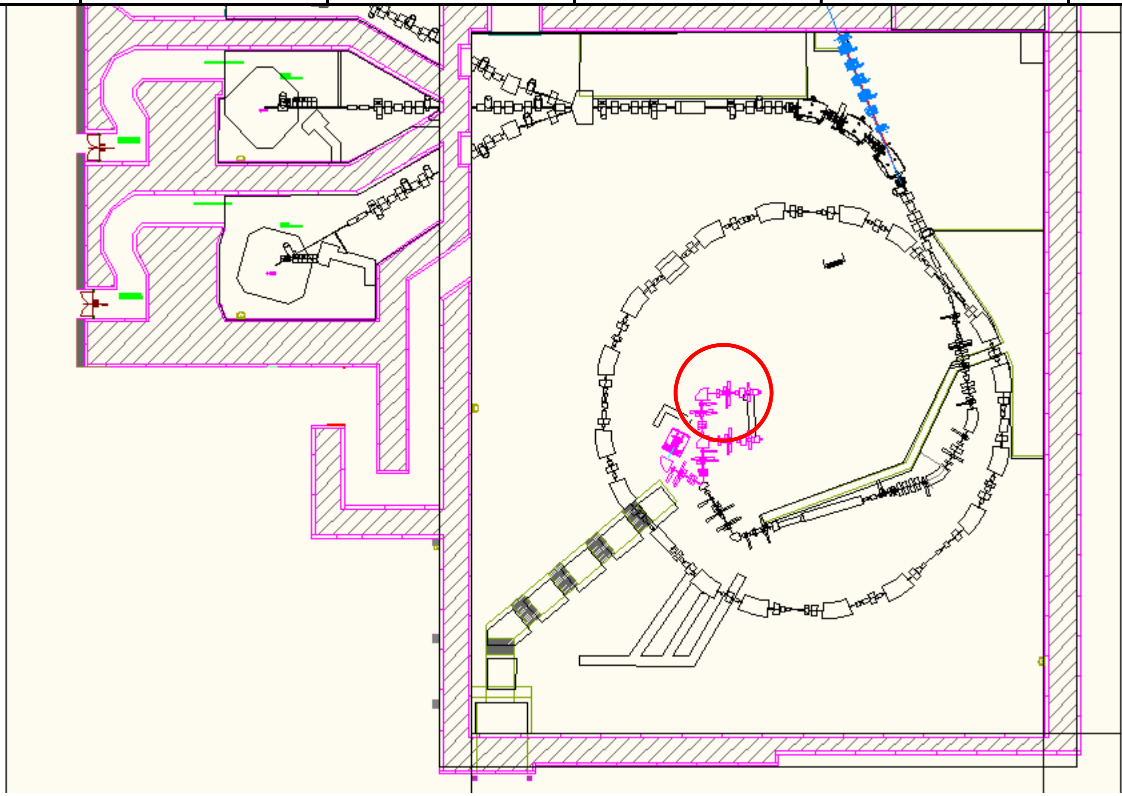


# New source/new particles (1)

Additional ion species

| | H | He | Li | C | O |
|---|---|---|---|---|---|
| Z | 1 | 2 | 3 | 6 | 8 |
| I (p/s) | 1.00E+10 | 2.50E+09 | 1.11E+09 | 2.78E+08 | 1.56E+08 |
| K (MeV/u) | 250 | 250 | 250 | 400 | 400 |

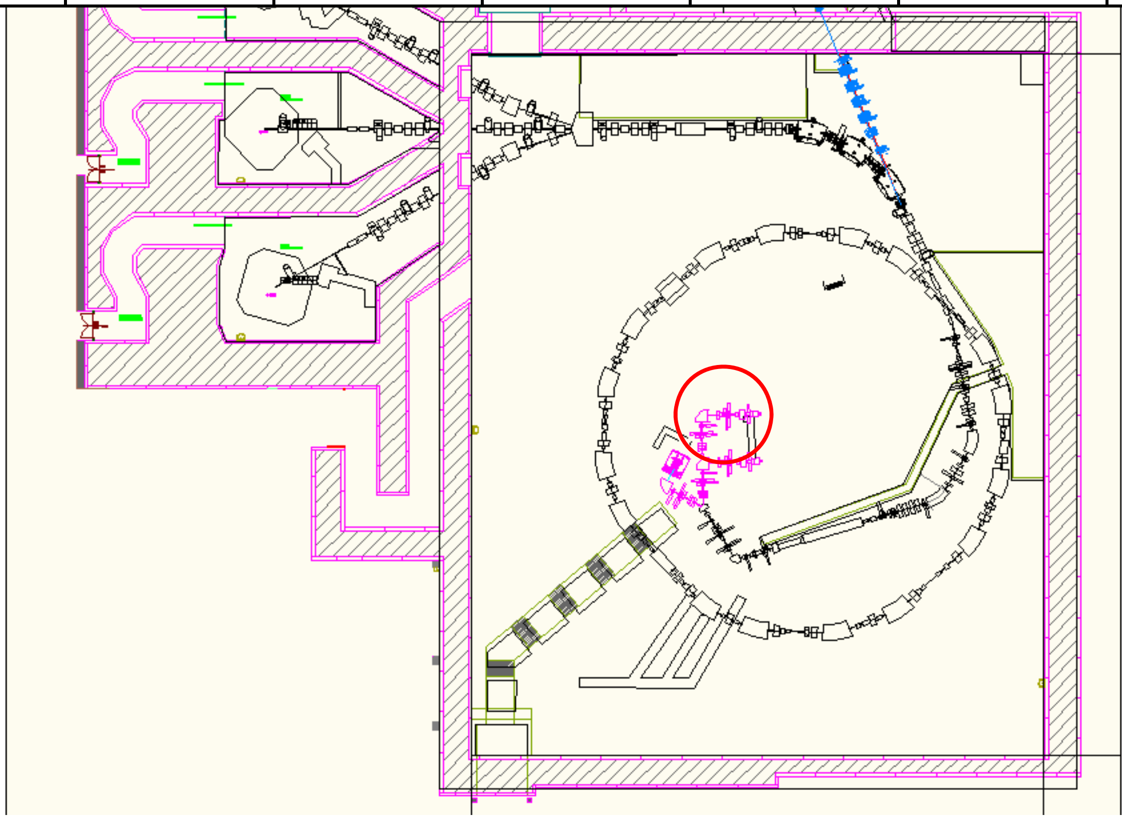
Higher energy He for radiography



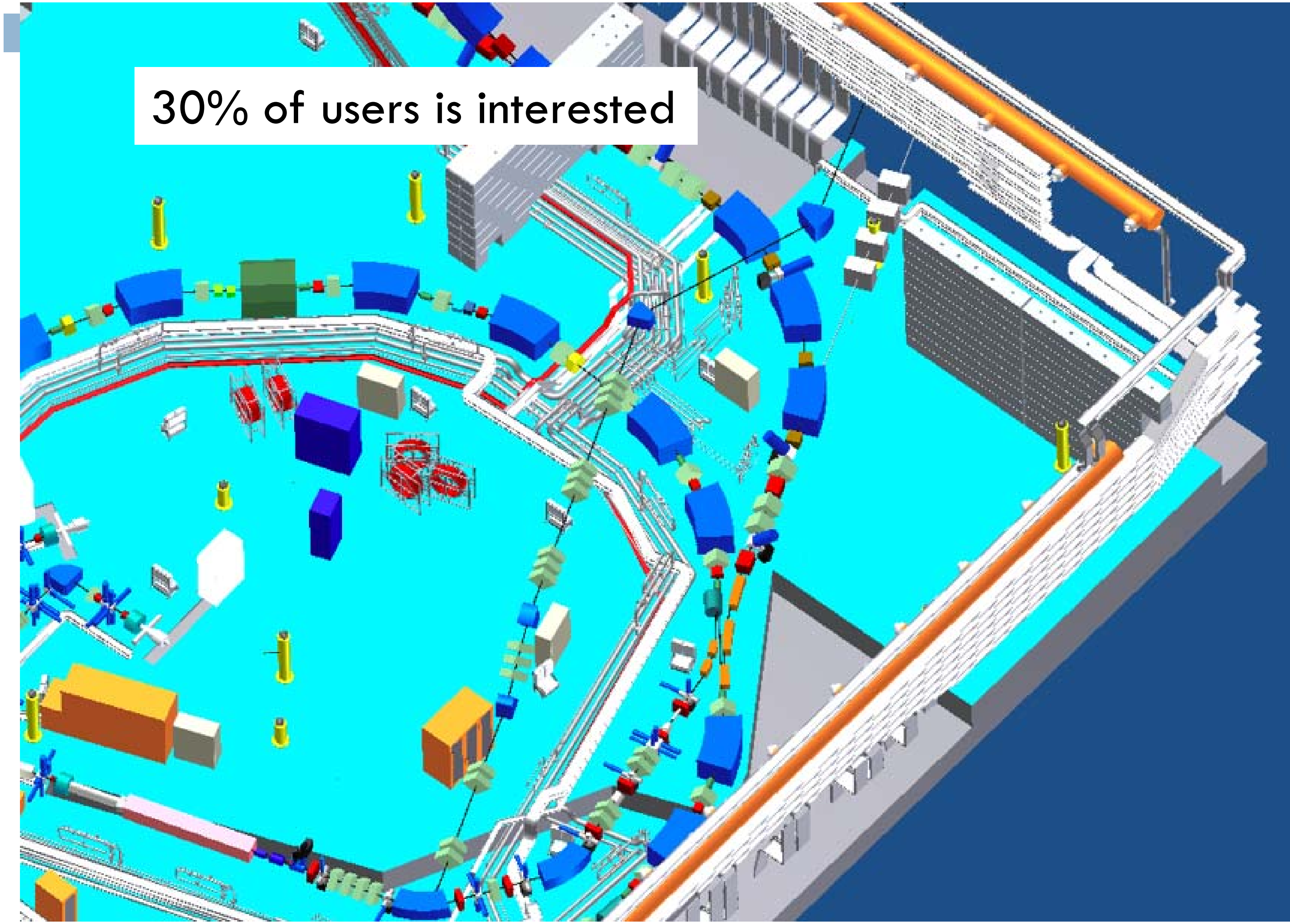
# New source/new particles (2)

Additional ion species

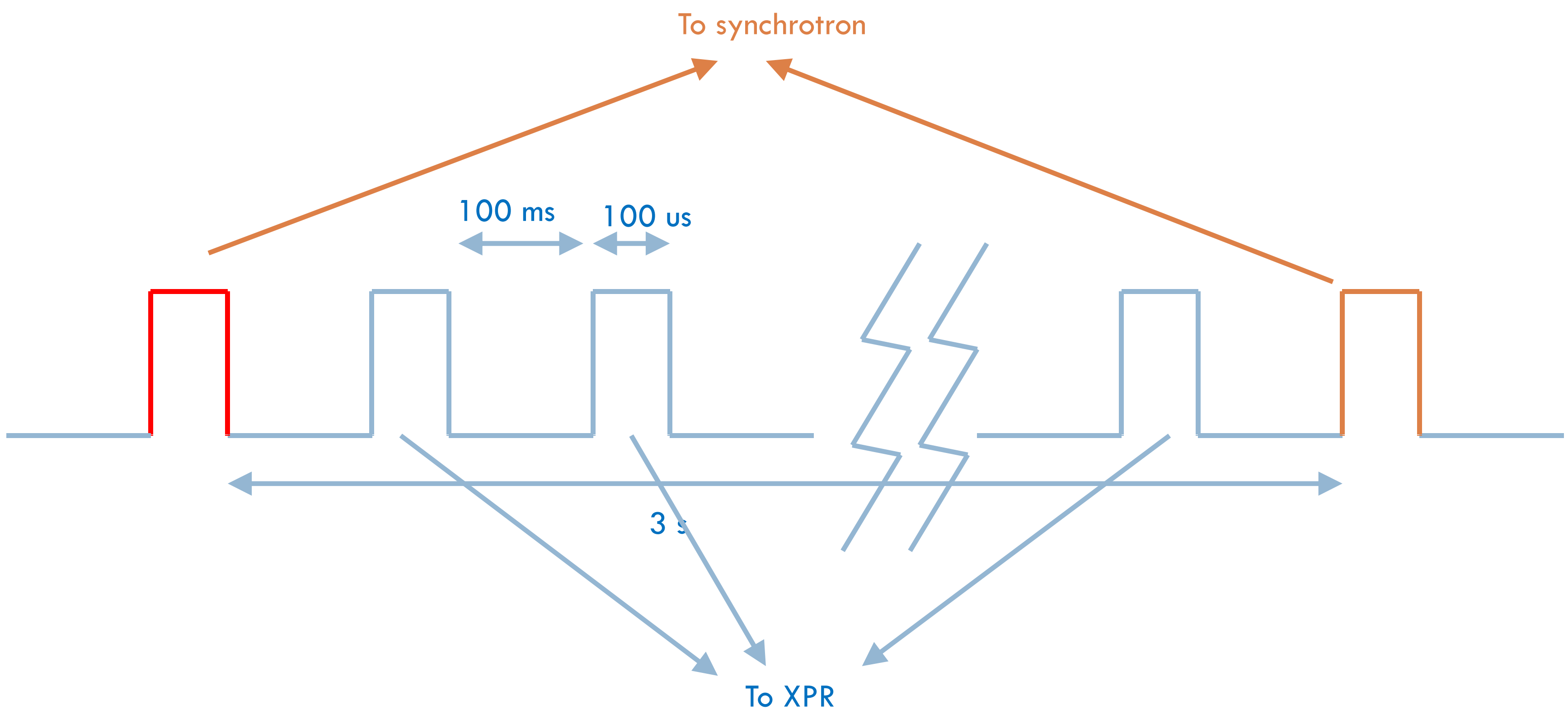
| | H | He | Li | Be | B | C | N | O |
|---|---|---|---|---|---|---|---|---|
| Z | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| I (p/s) | 1.00E+10 | 2.50E+09 | 1.11E+09 | 6.25E+08 | 4.00E+08 | 2.78E+08 | 2.04E+08 | 1.56E+08 |
| K (MeV/u) | 330 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |



# Further in future: 7 MeV/u beam?



# Parasitic operation



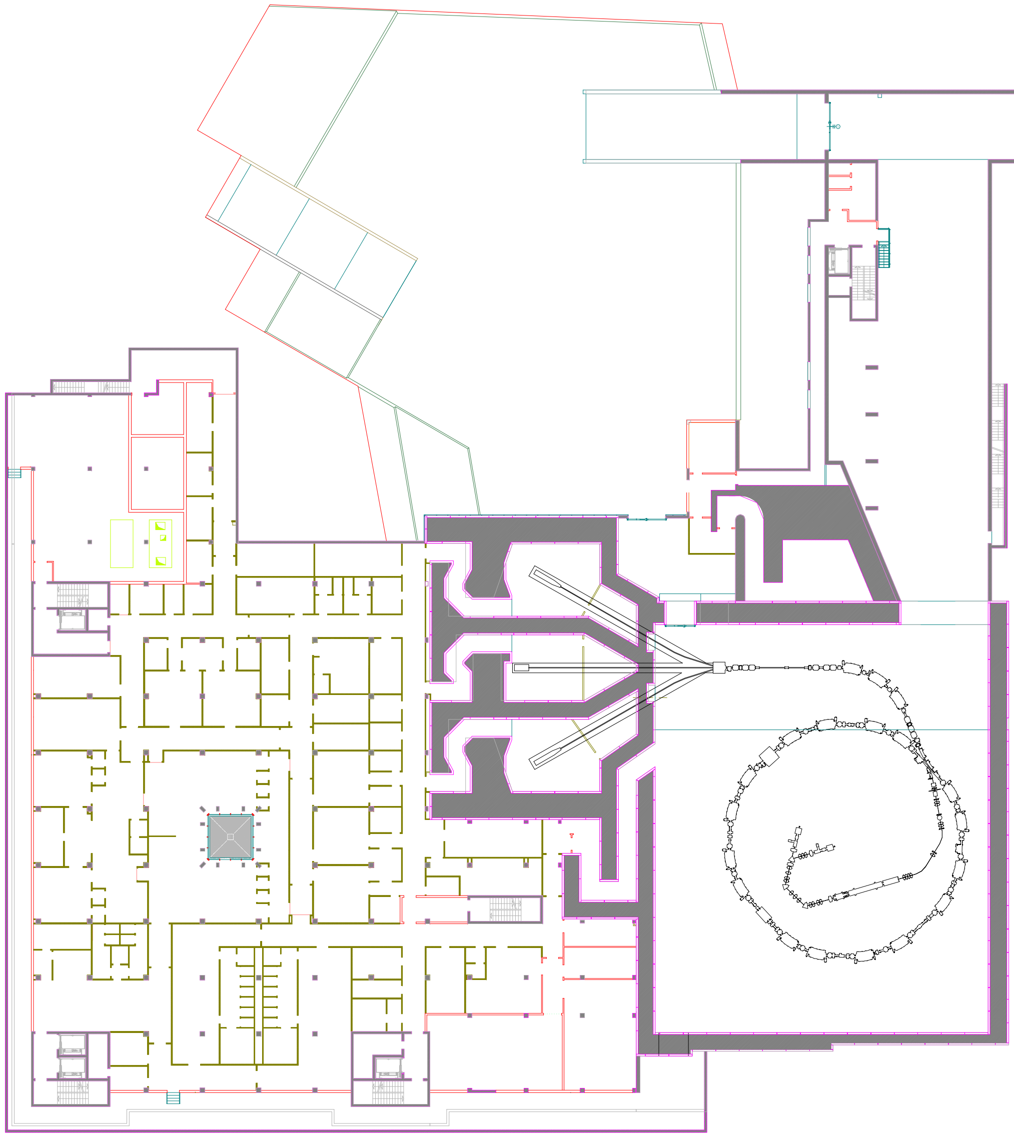
# R&D activities

- Gating
- Cycle Shortening
- Experimental room
  - High energy beam line
  - New ion species ($1 < Z < 8$)
  - Medium energy beam line
- Gantry

# Further in future: gantries

- Expansion foreseen in the design

# Phase 1 (2003)



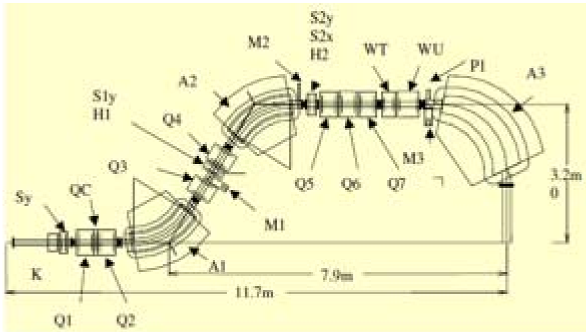
# Phase 2 (2003)

# SETTO DI PROTEZIONE (lavori di espansione)

# Size and magnetic rigidity

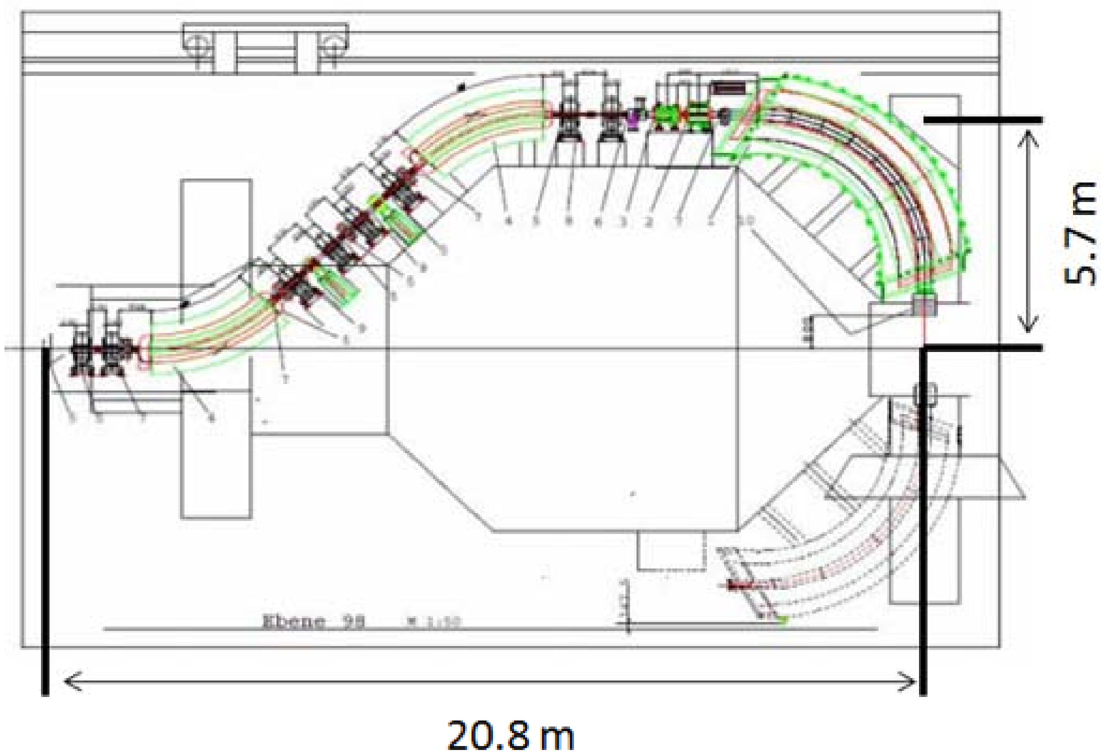


Conventional RT




Proton Gantry
$B\rho < 2.4$ Tm

Carbon Ion Gantry
$B\rho < 6.4$ Tm



# ULICE WP6 Cooperation



**Istituto Nazionale di Fisica Nucleare (INFN)**

ETOILE (France)

IFIC (Spain)

| Work package number | 6 | Start date or starting event: | | | M1 |
|---|---|---|---|---|---|
| Work package title | Carbon Ion Gantry | | | | |
| Activity Type | RTD | | | | |
| Participant id | 1 CNAO | 4 CERN | 5 MEDA | 6 Etoile | 18 INFN |
| Person-months per beneficiary | 117 | 9 | 6 | 4 | 18 |

**CNAO Partnership**

- **Necchi Monica (100%)**
- **Savazzi Simone (100%)**
- **Viviani Claudio (100%);** from the 1st September 2010 substituted by **LanteValeria**
- **Osorio Moreno Jhonnatan (100%) – PARTNER** Project WP21

Involvement of industrial partners has been pursued, other institutional and academic partners are participating, as well, **totally for free**

CERN (Switzerland)

CNAO (Italy)

GSI (Germany)

Universitaetsklinikum Heidelberg (Germany)

Karolinska Institutet (Sweden)

TERA (Italy)

IBA (Belgium)

EBG MedAustron (Austria)

The ULICE project is co-funded by the European Commission under FP7
Grant Agreement Number 228436.

# Firms involved

## Schär

They built the two **protons gantry at PSI** (Villigen)
**PPS** and **PVS** for the treatment rooms at **CNAO** (Pavia)

❖ feasibility of the mechanical structure of a mobile isocentre gantry
❖ dimensions equal to 2/3 with respect to a fixed isocentre gantry
❖ total structure cost 20% less than a fixed isocentre gantry

## MT Mechatronics

It is an experienced international specialist in designing and constructing turn-key precision mechatronics structures including drive control hard- and software. They built **the only** existing carbon ion **gantry** in **Heidelberg:** turn-key supply including development, engineering, fabrication, erection, measurement and adjustment, commissioning and test.

❖Critical issues discussion
❖ Inputs useful for the treatment cabin design
❖ Comparison of costs for the 3 different mechanical structures

## Kone

They have competences in special lifts (e.g. escalators and autowalks); they set the standard for safety, reliability, visual design, space savings and environmental performance. They revolutionized the elevator industry through their sustainable, energy-efficient designs.

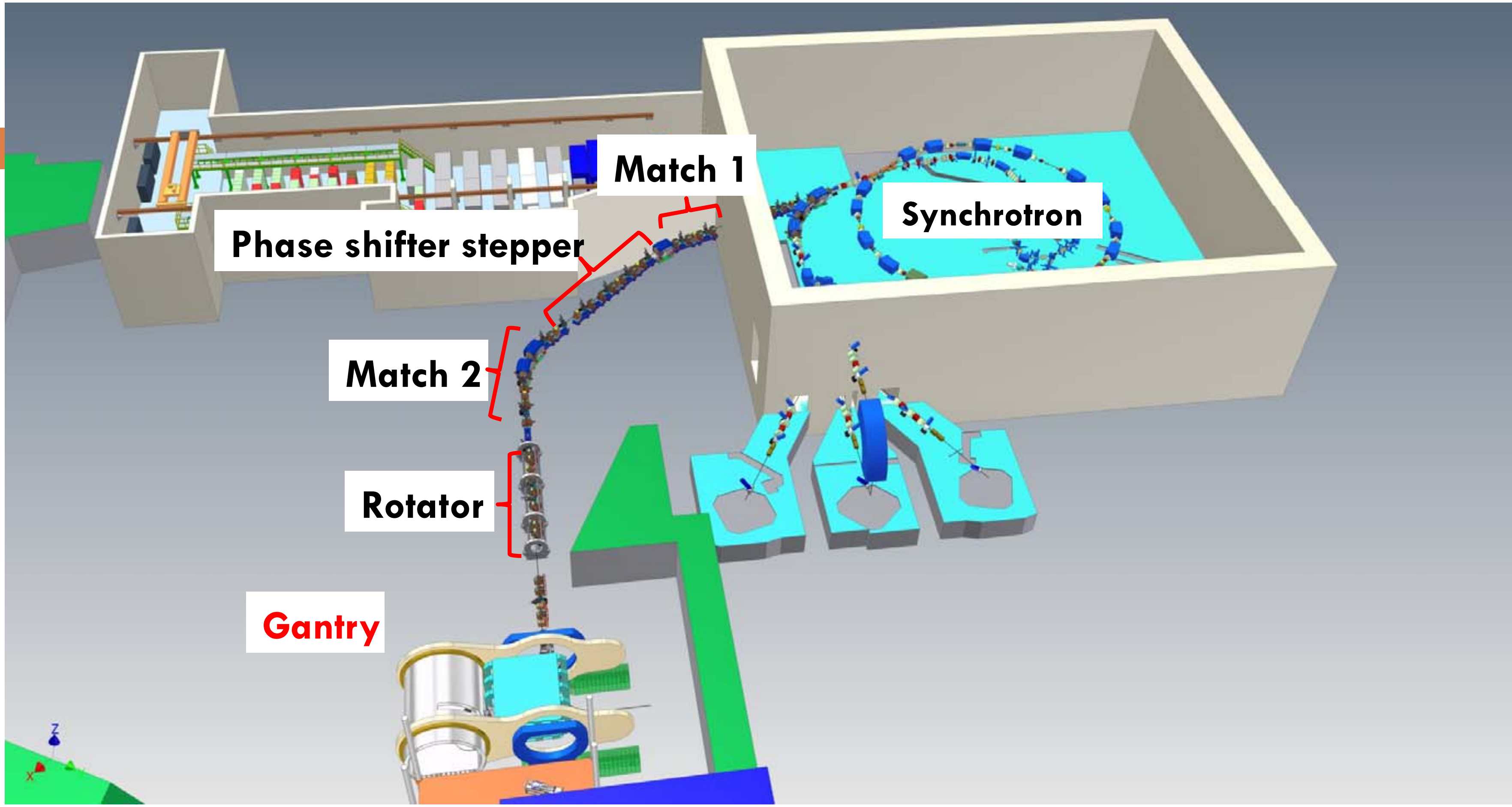
❖Design and study for the platform and service lift system
❖ Cost estimate for the complete system

## *iba*

IBA has pioneered proton therapy. With proven efficacy in more than 50,000 patients worldwide, more than 50% of the world's PT clinical centres designed and equipped by IBA.
Their Universal Nozzle provides 4 delivery modes with millimetre precision, including Pencil Beam Scanning

❖Critical issues discussion
❖ Inputs useful for the treatment cabin design
❖ Technical details of gantries

# Beam line




**Synchrotron**
- particle Beam source
- Initial beam conditions

→

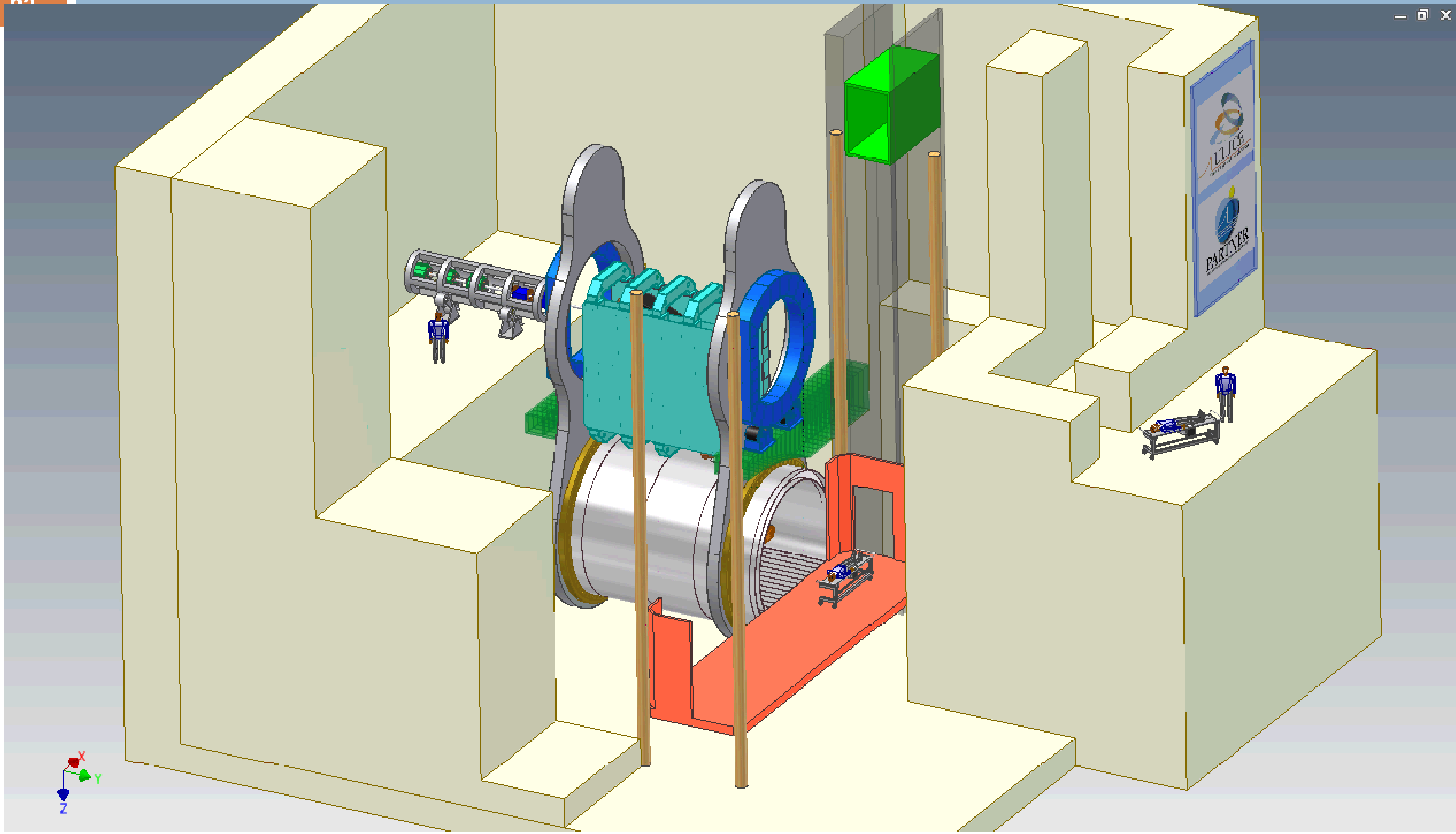
**Match**
- Adjust the beam parameters to the following elemets

→

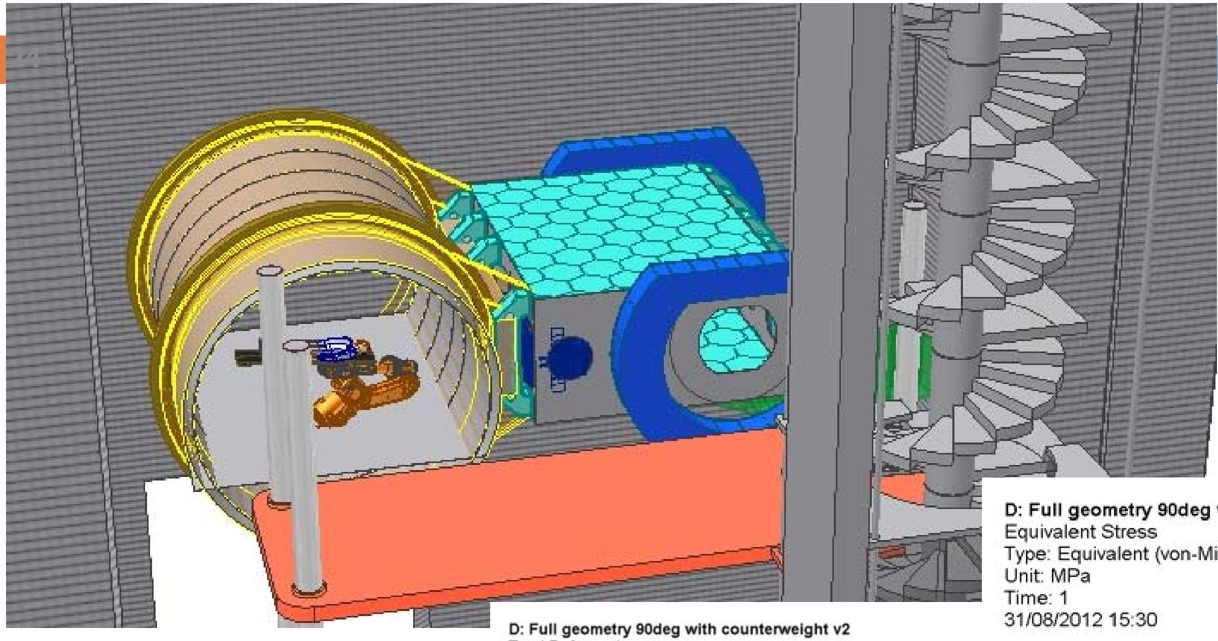
**Phase shifter stepper**
- Adjust the beam dimensions at the isocenter

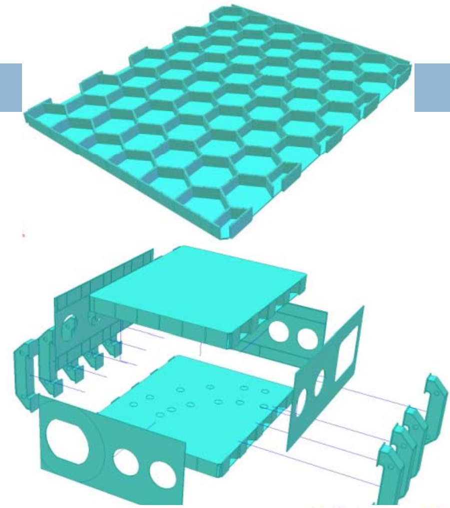
→

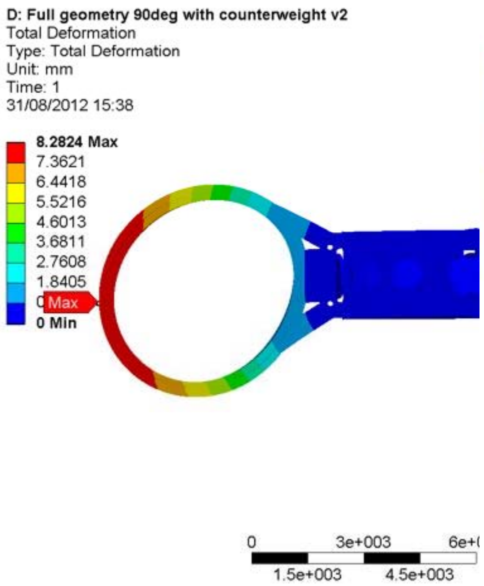
**Telescope**
- Final Match
- Rotator
- Gantry

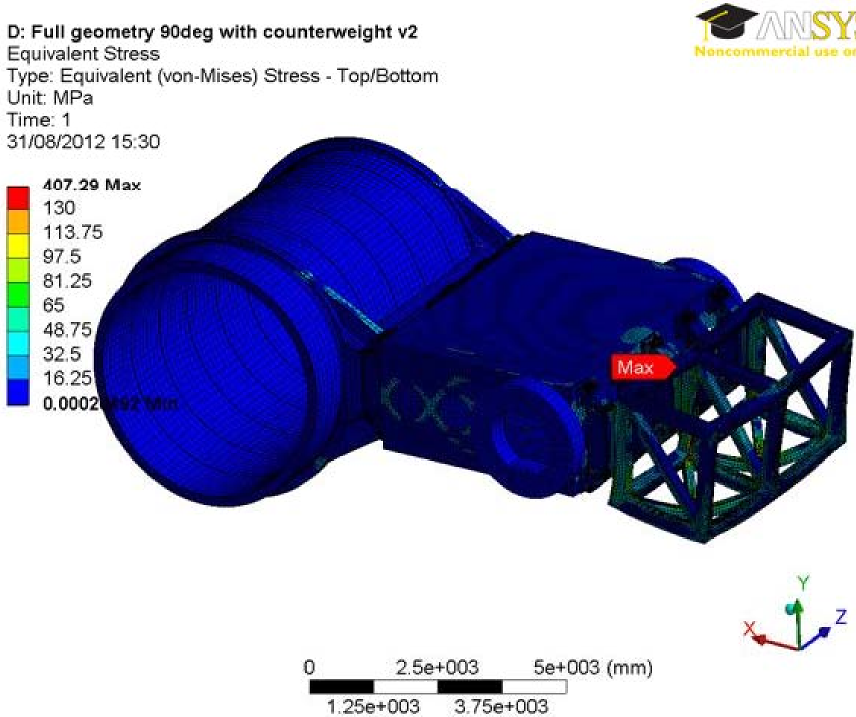

ALICE
PARTNER
X
Y
Z

# The ULICE gantry: mechanical structure without brackets



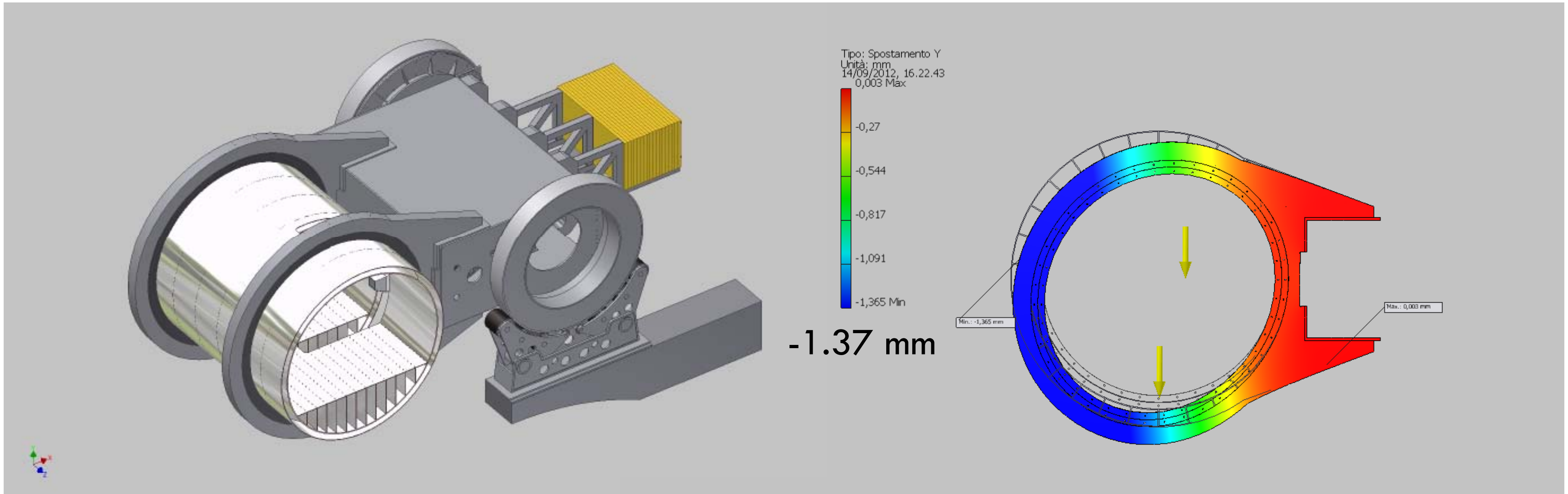


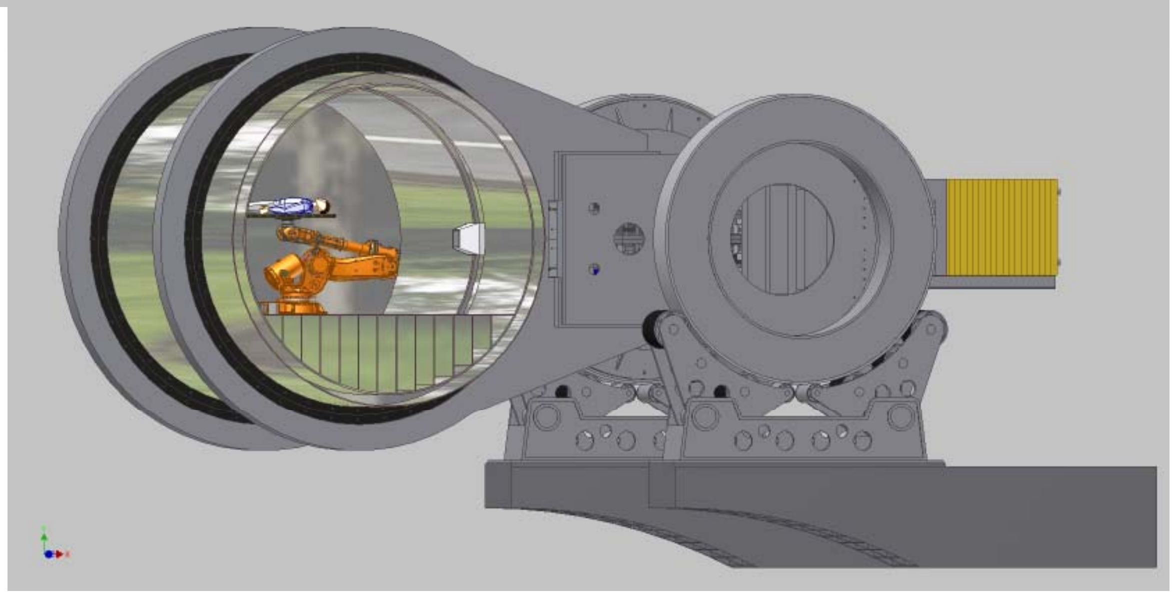




ANSYS
Noncommercial use only

# The ULICE gantry: mechanical structure with half brackets



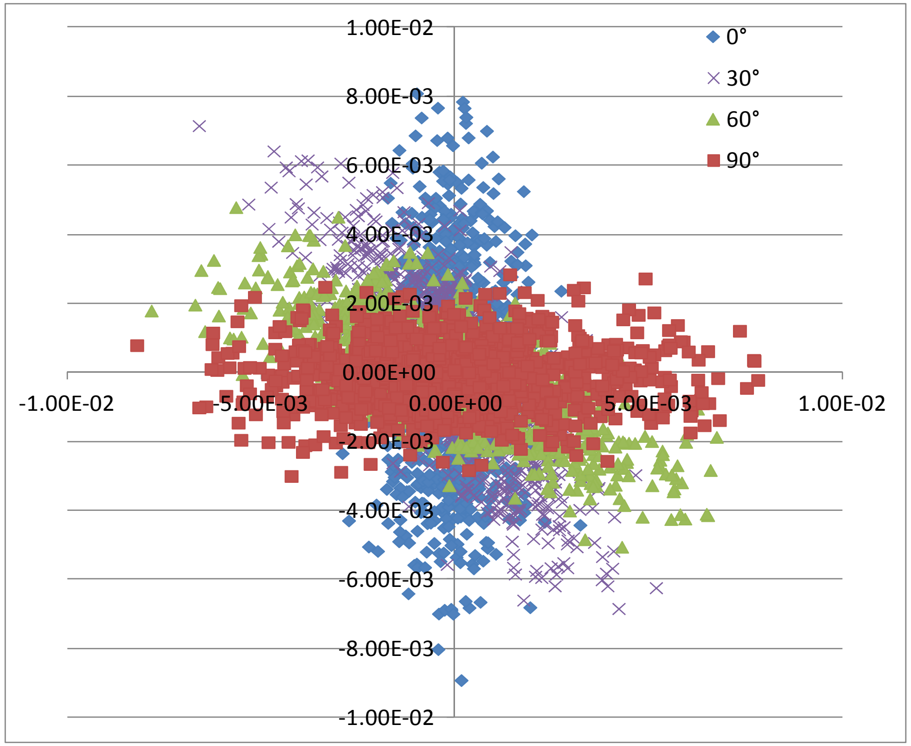

Gantry mass: 350 t



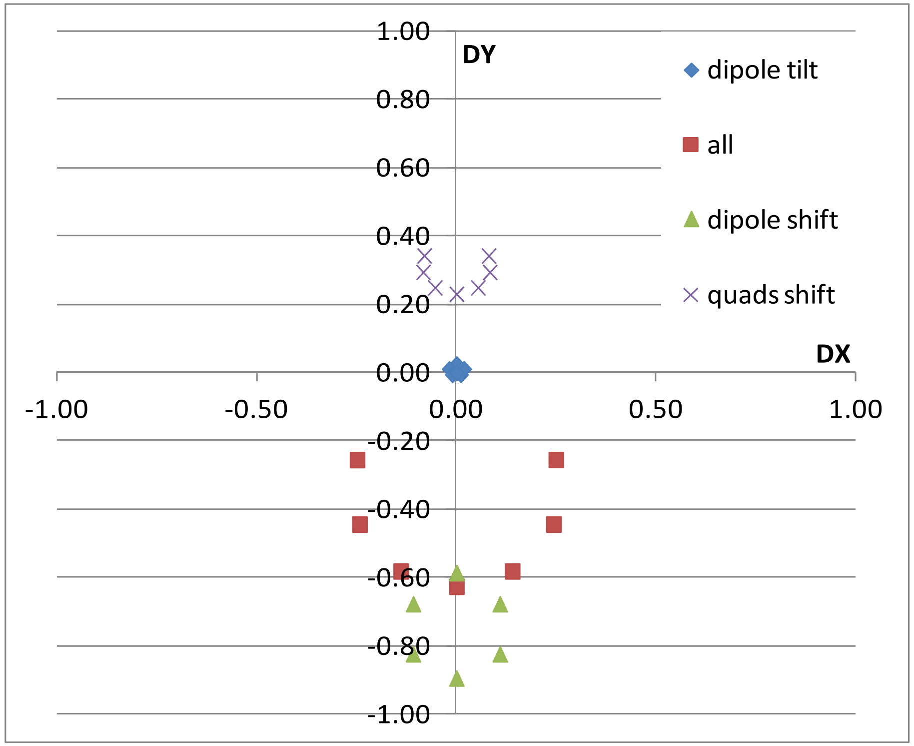
# Magnet misalignment effect



Isocenter displacement for random magnet alignment errors in the gantry




Isocenter displacement for structure deformation at various gantry angles

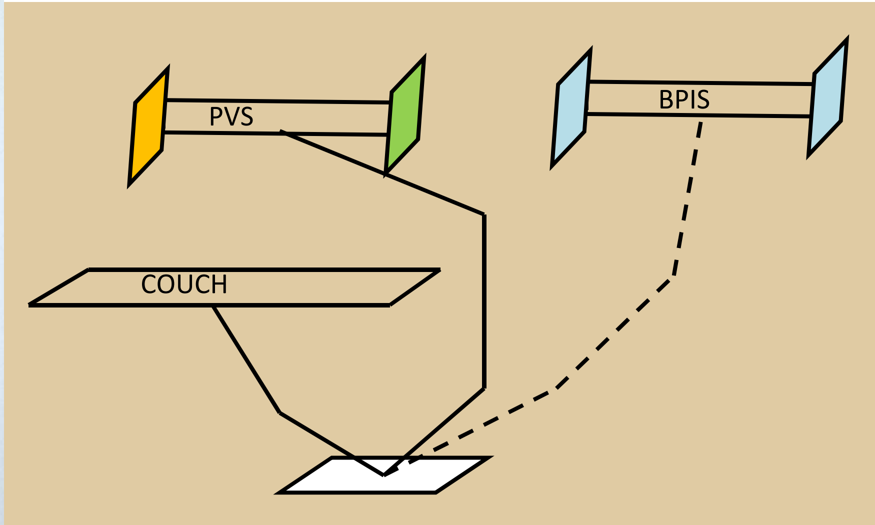


# The ULICE gantry: Beam Based Alignment



CNAO treatment room #2: PPS and PVS

Measure where the beam is and put the isocenter there…




One robot arm with two “tools”

# Parasitic dose to patient



- Measurement have been performed shooting four spills against water tanks simulating the preliminary beam position measurement
- The dose measured 0.5 m on the side of the target was less than 10 uSv for both protons and carbon ions.

# The ULICE gantry: cost estimates



| | |
|---|---|
| **Magnets (k€)** | 1705 |
| **Magnets PS (k€)** | 975 |
| **Mechanical structure & assembling (k€)** | 5920 |
| **Patient cabin & PPS (k€)** | 3960 |
| **PVS (k€)** | 1360 |
| **Patient handling (k€)** | 225 |
| **Gantry building (k€)** | 1500 |
| **TOTAL (k€)** | **15645** |

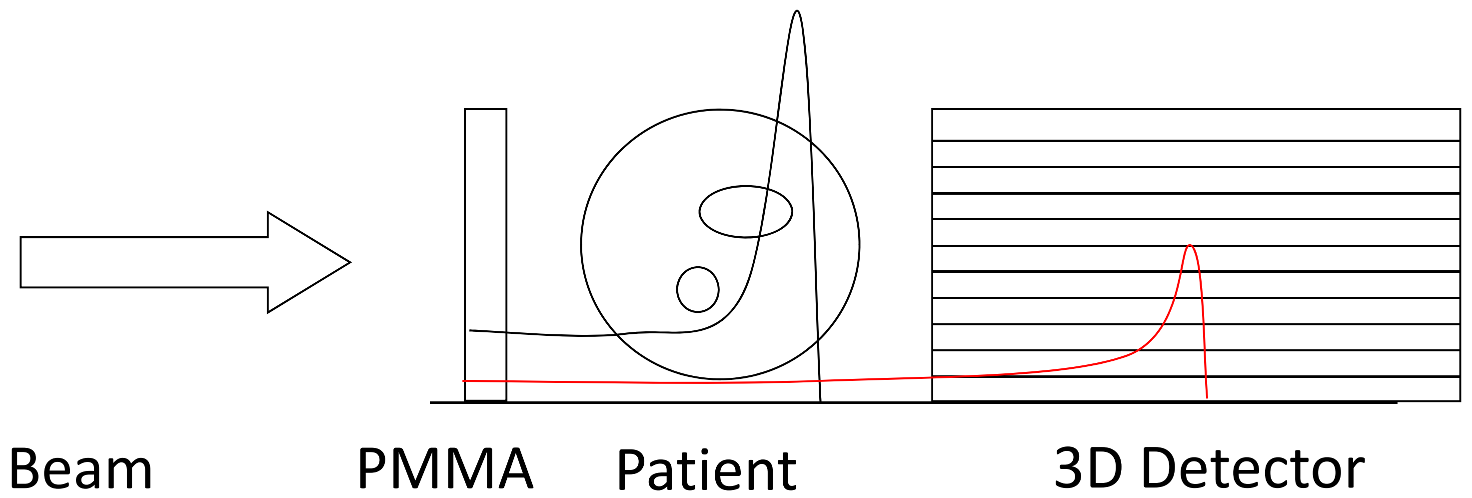
+ conventional plants, cooling and ventilation, access control…
common to any solution

# R&D activities

- Gating
- Cycle Shortening
- Experimental room
  - High energy beam line
  - New ion species ($1 < Z < 8$)
  - Medium energy beam line
- Gantry
- HeCheck

# HeCheck

- Simultaneously accelerate 99.9% C and 0.1%He (in Dose)




- Real time ~radiography and patient thickness (range) verification

# Conclusions

- R&D is fundamental in a plant like CNAO
- A dedicated facility for experimental activities is being designed
- Facility construction can be scheduled in stages (HEBT, source, MEBT, Gantries, …)
- Many possible studies possible both for improving the machine and for general advances


That's all Folks!