# Gantry Design for the Heavy-Ion Therapy Medical Application

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Luca Piacentini

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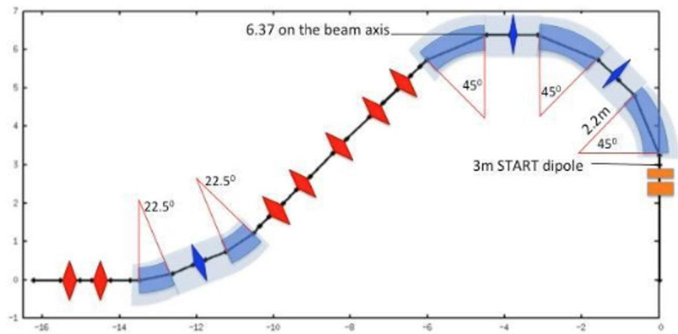
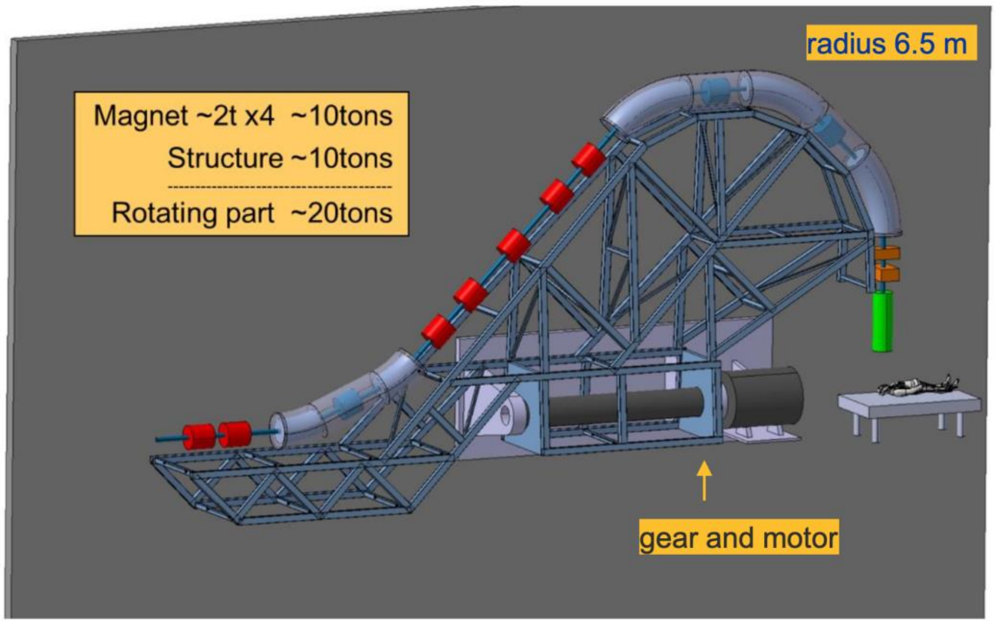
# Gantry Mechanical Design

- **Gantry** – Rotating beam line sending the beam to precise positions to the patient




CNAO Centro Nazionale di Adroterapia Oncologica

CNAO: **Marco Pullia**

1862 RĪGAS TEHNISKĀ UNIVERSITĀTE

CERN team: Mechanical & Materials Engineering (MME) **Diego Perini**, **Luca Dassa**

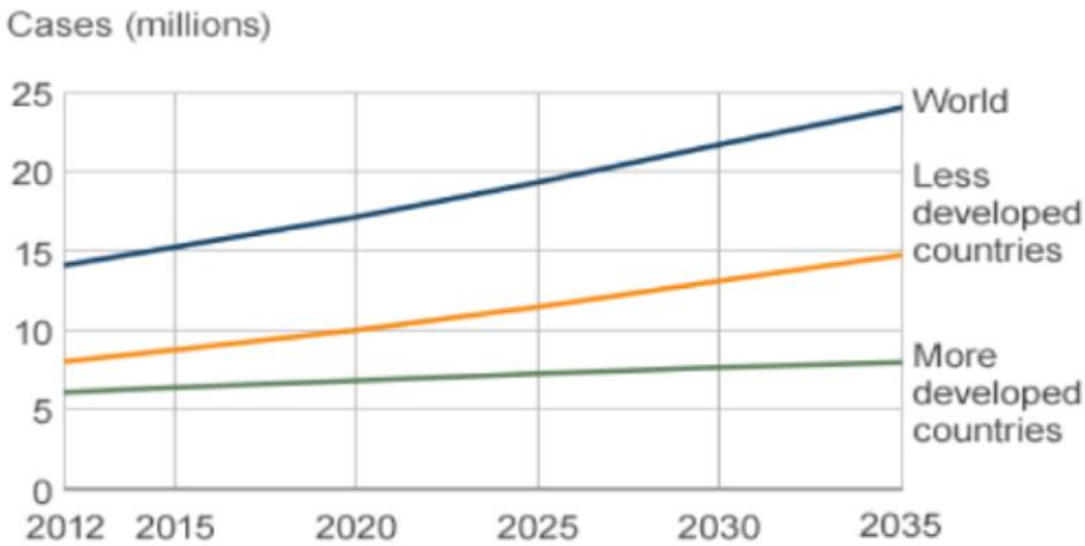
RTU Team: **Andris Ratkus**, **Toms Torims, Jānis Vilcāns, Luca Piacentini**

CERN

# Fighting against Cancer

- Cancer is the **second** leading cause of death globally
- Globally, nearly 1 in 6 deaths is due to cancer (WHO)

Predicted Global Cancer Cases




Source: WHO GloboCan

**Timeline:** 4 year, started
1st of April 2021

Heavy Ion Therapy Research Integration

**H**eavy **I**on **T**herapy **R**esearch **I**ntegration ***plus***

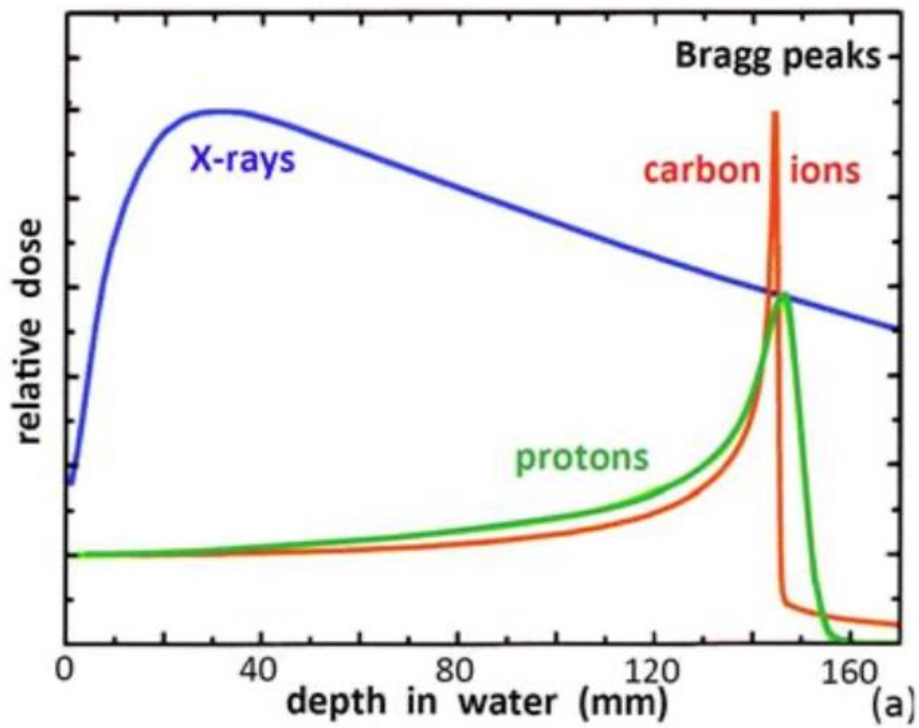
# Why hadron therapy (proton or ions)

Different from X-rays or electrons, protons (and ions) deposit their energy at a given depth inside the tissues, **minimising dose to the organs close to the tumour,** sparing nearby organs.

## Physical phenomena:

**X-ray Radiation Therapy is improving as well**

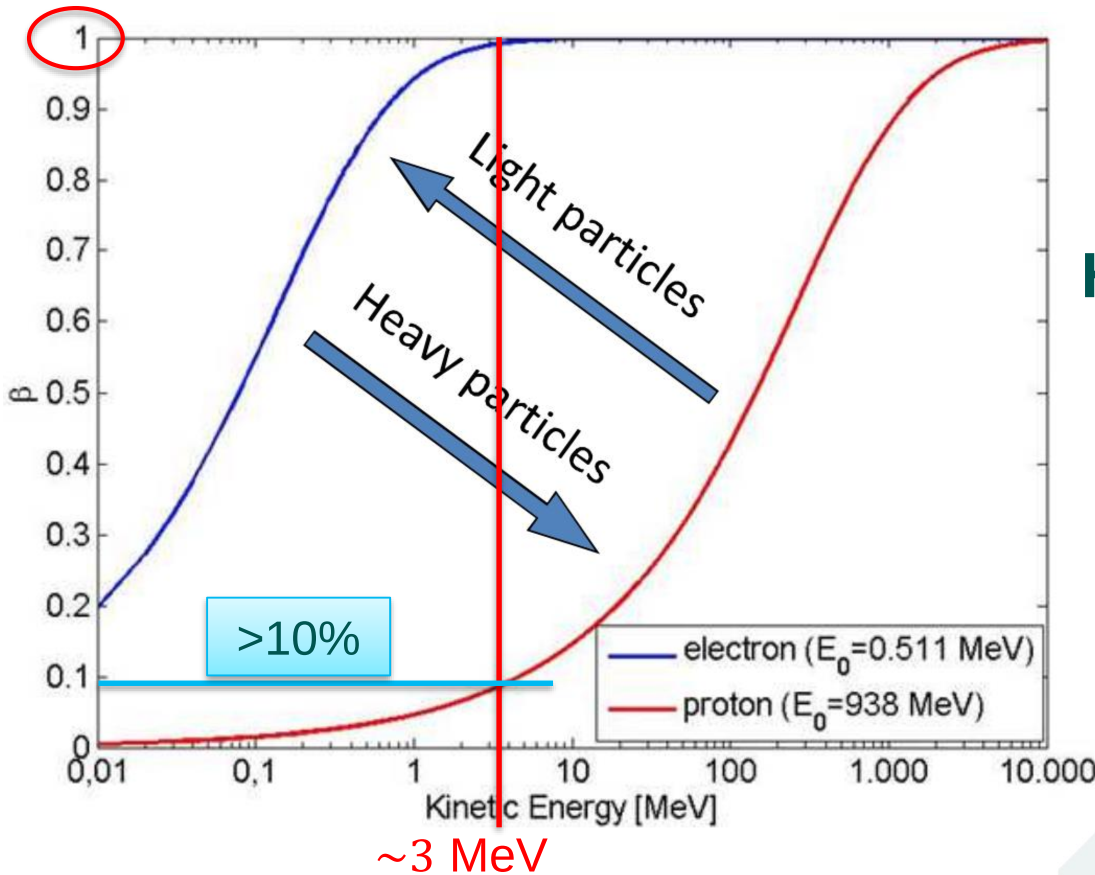
**Proton therapy** is mainly recommended for:
- Some specific tumours close to critical organs
- Niche therapy




Source: Maurizio Vretenar CERN

# Circumstances to be taken into account

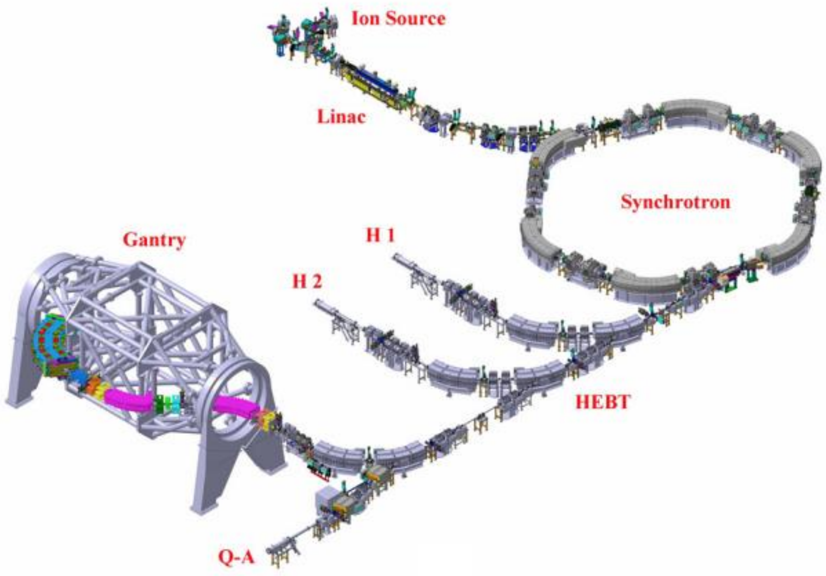
- A proton is approx. **1800 times heavier** than an electron.
- Higher energy is needed to accelerate protons and Ions




**Higher energy – LARGER SIZE !!!**

Source: David Alesini CAS

# Existing facilities



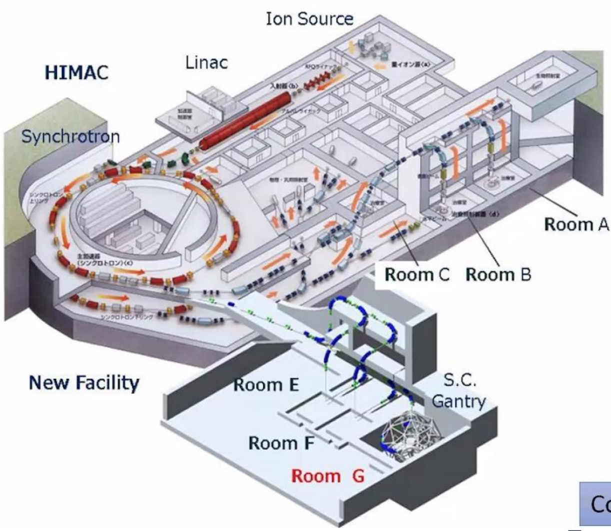

The Heidelberg Ion Therapy Facility gantry (**RT magnets**):
L=25 m, F = 13 m, **600 tons**

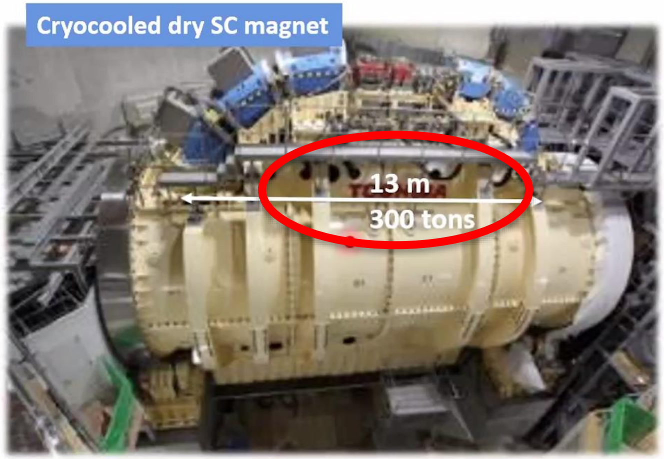
## Japan: HIMAC at QST-NIRS
## First SC Gantry in operation 2018

QST

NIRS HIMAC

Source: The Heidelberg Ion Therapy Facility (HIT)




Courtesy of T. Shirai, QST-NIRS

HIT Heidelberger Ionenstrahl-Therapiezentrum

CNAO Centro Nazionale di Adroterapia Oncologica

MedAustron

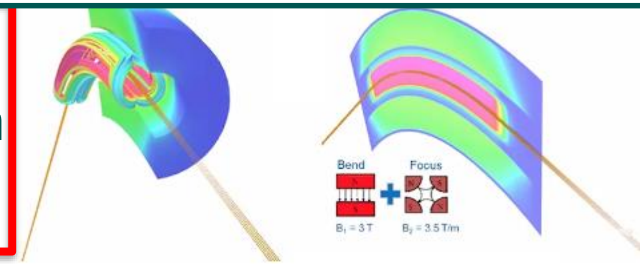
HITRI plus Heavy Ion Therapy Research Integration

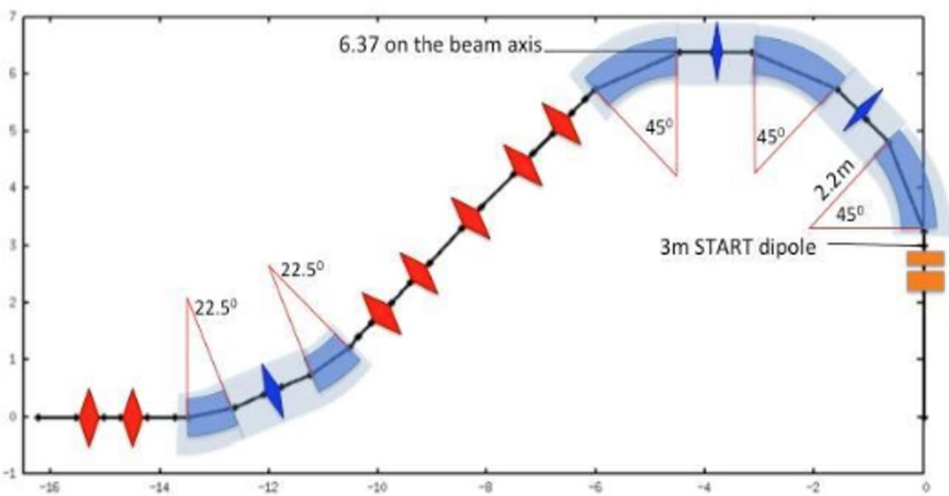
# New generation of compact ion therapy accelerators

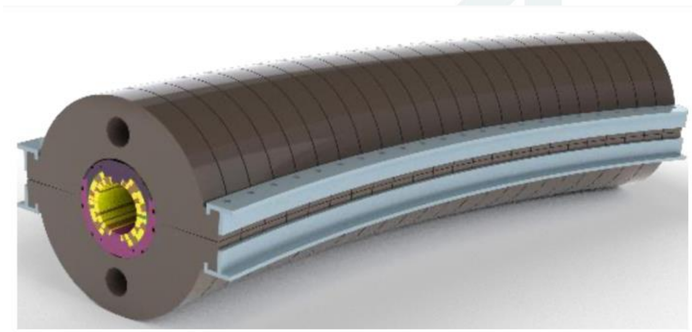
## NIMMS–
### Next Ion Medical Machine Study
by Elena Benedetto

WP 7 (*One WP of 14 WP*) Challenges

- New superconducting magnets
- Optimised beam transport and instrumentation
- Higher accelerating gradient
- **Lower costs**
- **Weight lower than 100 tons and length below 16 metres**



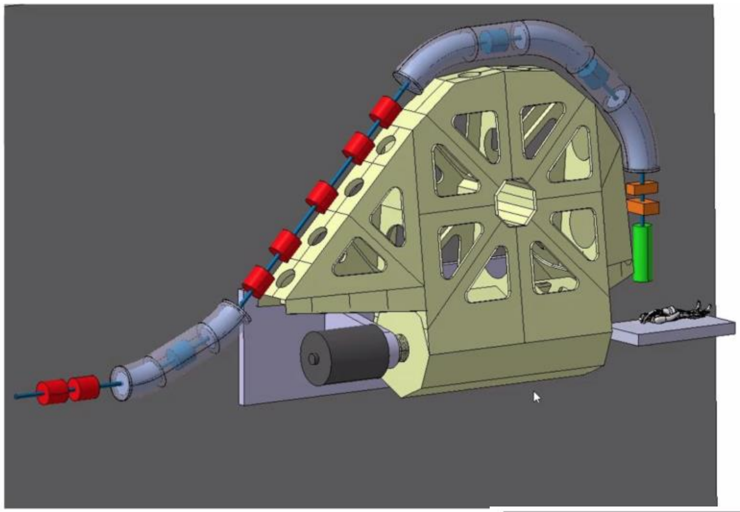



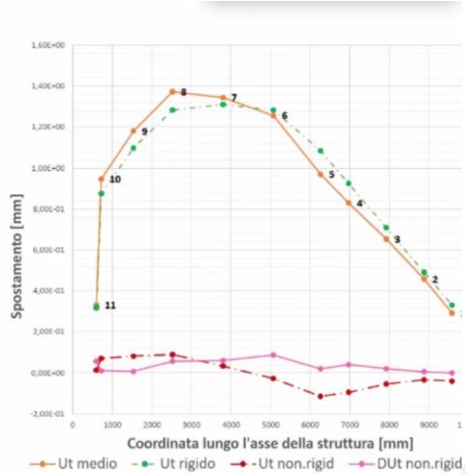



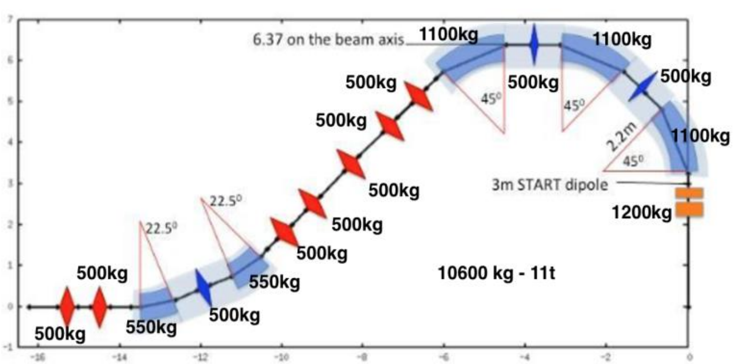
Source: Maurizio Vretenar CERN

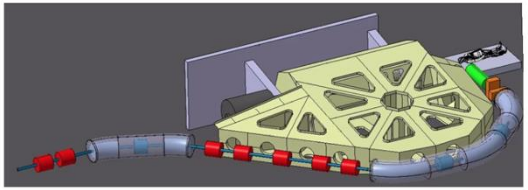
# Assumptions/ calculation I

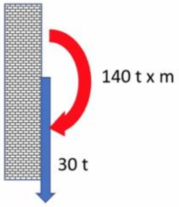
- ~~360º~~ ⟶ 220º to reduce dimensions
- Remove drive from axis

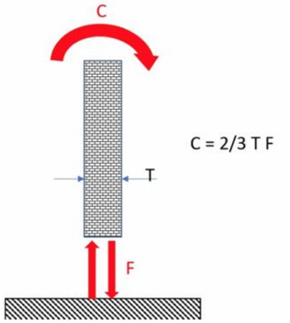


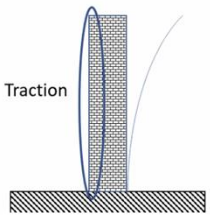


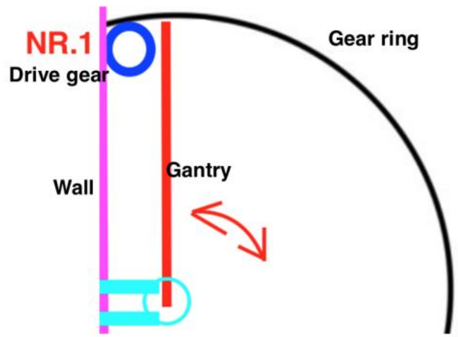


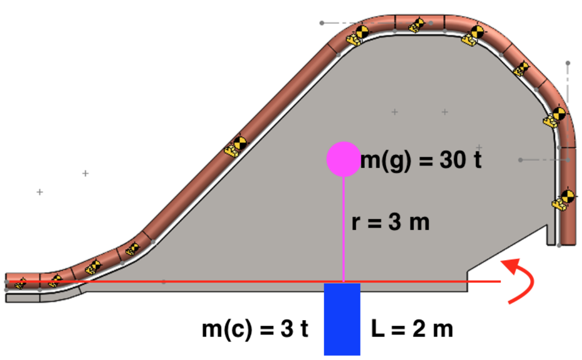



# Assumptions/ calculation II

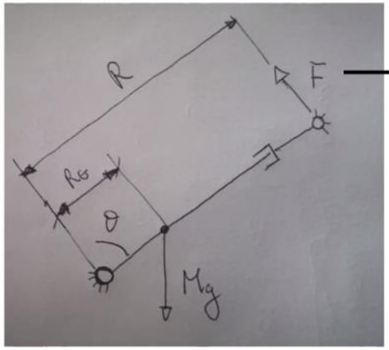
- Gears
- Inertia
- Torques etc.




| Wt (kN) 150x3 | S45C tensil str. 628/3 (N/mm^2) | Module (mm) | Dp 1/mod (mm^-1) | F Face width of gear (mm) | with TWO drive gearsF Face width of gear/ 2 (mm) | Y Lewis Factor | Number of tooth | Small gear contacting pich circle diameter (mm) |
|---|---|---|---|---|---|---|---|---|
| 450 | 209 | 16 | 0,0625 | 340 | 170 | 0,396 | 40 | 640 |
| 450 | 209 | 16 | 0,0625 | 350 | 175 | 0,384 | 38 | 608 |
| 450 | 209 | 16 | 0,0625 | 360 | 180 | 0,374 | 34 | 544 |
| 450 | 209 | 16 | 0,0625 | 370 | 185 | 0,364 | 30 | 480 |
| | | | | | | | | |
| 450 | 209 | 20 | 0,05 | 290 | 145 | 0,371 | 34 | 680 |
| 450 | 209 | 20 | 0,05 | 300 | 150 | 0,359 | 30 | 600 |
| 450 | 209 | 20 | 0,05 | 310 | 155 | 0,347 | 26 | 520 |
| 450 | 209 | 20 | 0,05 | 320 | 160 | 0,336 | 22 | 440 |




$\uparrow 10\%\ \boldsymbol{Weight}$ $\uparrow 1.5\%\ \boldsymbol{Inertia}$

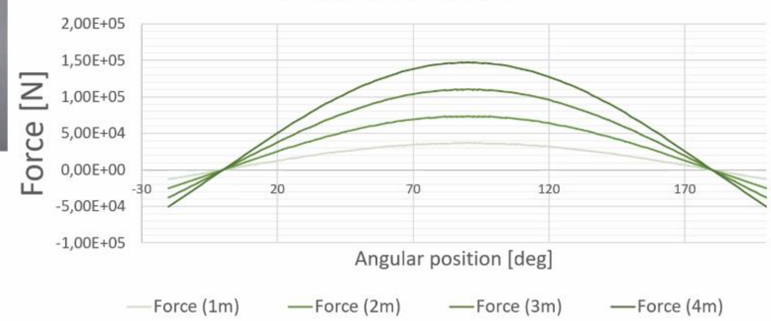



$$F = Mg\frac{R_G}{R}\sin\theta$$

R = 8 m

RG = 1 - 4m

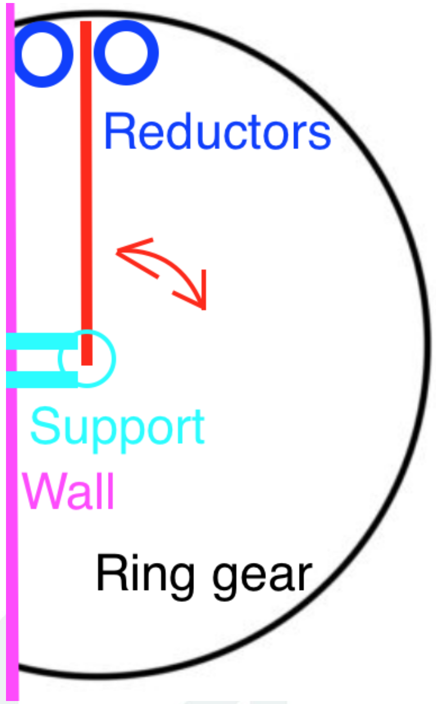
Comparison between forces with the COG at different radial distances



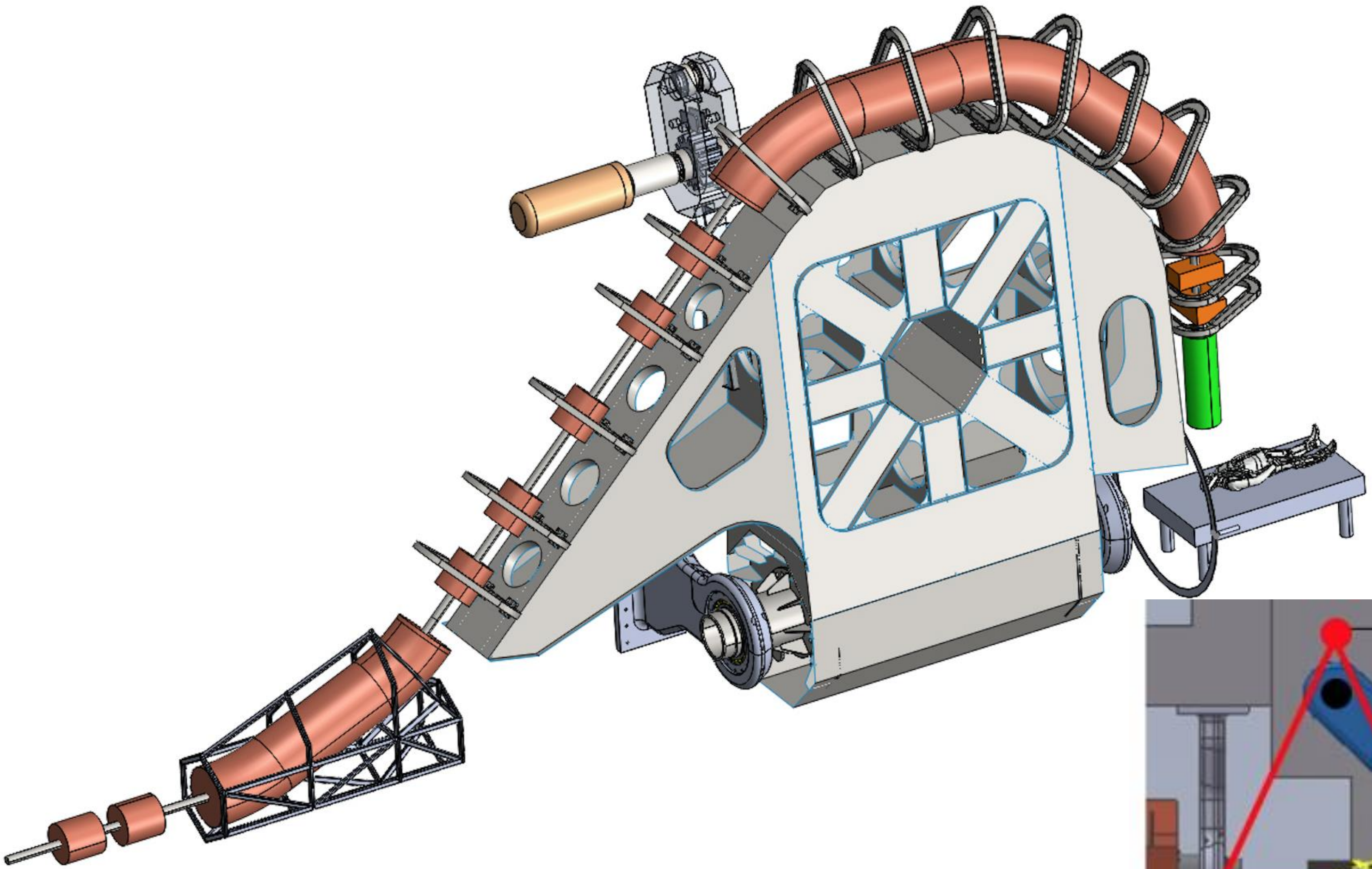
# Assumptions/ calculation III

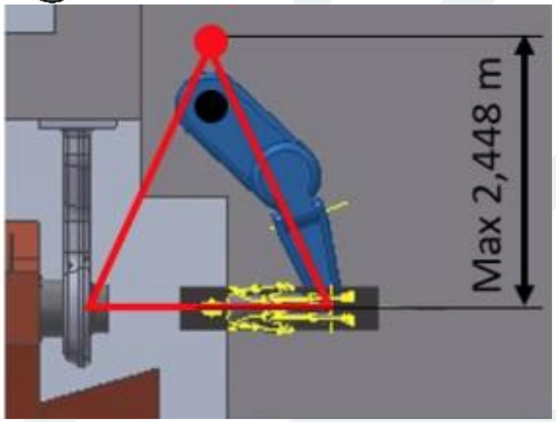
Gantry speeds:

- Target speed – 1 rpm >> 30 sec.
- 1 rpm – average speed value with steps:
  - “Soft start”
  - ”Accelerating stage”
  - **“MAX speed”**
  - “Deaccelerating stage”
  - “Positioning stage”
- ”MAX speed” > 1rpm



# Iteration process





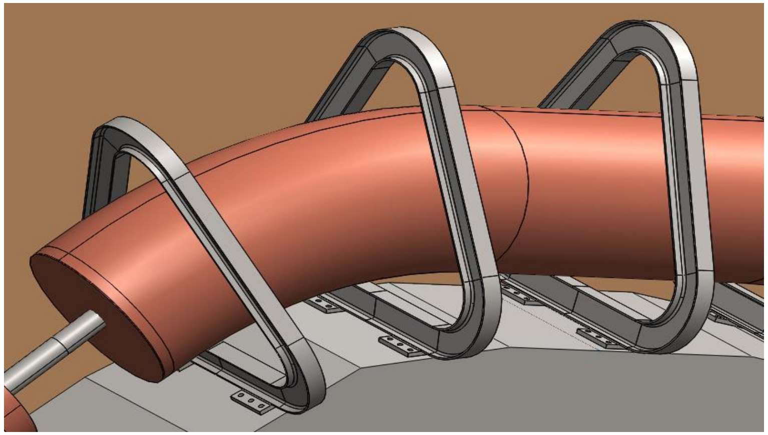
# Evaluation of solutions

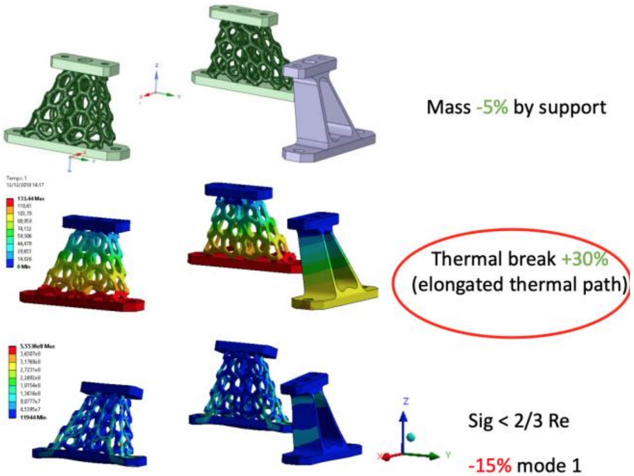
| Config | Pros | Cons | wearables | Safety | Deformation Performances | Moving Mass | Inertia | Loads on wall | Brakes position | green |
|---|---|---|---|---|---|---|---|---|---|---|
| Large gear | 1. Brakes on the outside<br>2. Driven from outside<br>3. Available components on the market<br>4. Reduction<br>5. Multiple braking system points | 1. High load on teeth<br>2. Difficult to manufacture or expensive<br>3. Constrain complexity<br>4. Reduction<br>5. (Accuracy of the large gear) | 1. Gears<br>2. Motor<br>3. Bearings<br>4. Brakes | | | | N/A | | | |
| Double piston | 1. Accumulator possibility<br>2. Available components on the market | 1. Space<br>2. Size of the pistons (length)<br>3. Brakes still on the axis<br>4. Accuracy<br>5. S... | 1. Sealings<br>2. Bearin... | | | | | | | |
| | | | ...Motor<br>6. Pulleys, rollers<br>7. Ropes<br>8. Brakes<br>9. Fluid | | | | N/A | | | |
| Motor-reduction | 1. Compact solution<br>2. (compensation of rigid rotation) | 1. Reversibility due to reduction<br>2. Accuracy from reductor play<br>3. deformations | 1. Gears<br>2. Motor<br>3. Bearings<br>4. Brakes | | | | N/A | | | |

**Solutions evaluation and Feasibility check should be continued**

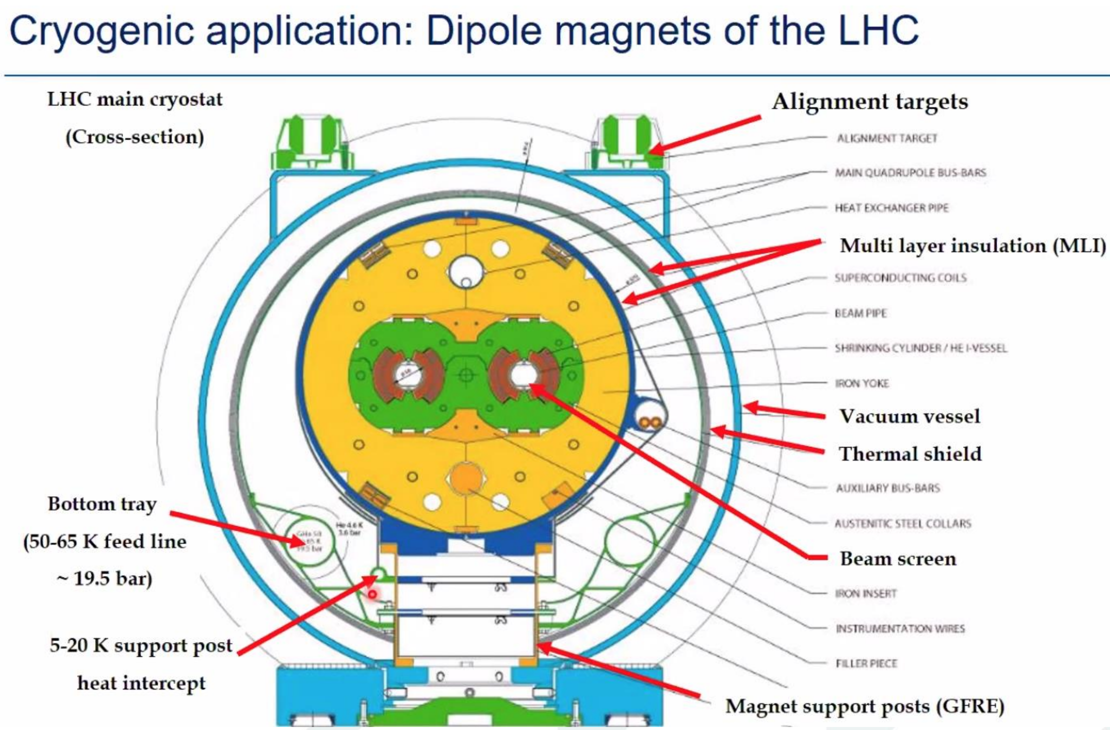
# Future steps

- The gantry design
- Cryogenic – vacuum "tube" fix to to the gantry
- Magnet fix in cryogenic "tube"






Source:Y. Jan (CERN)




Source: T. Koettig CERN TE/CRG

# Team and PhD thesis

CERN: Mechanical & Materials Engineering (MME) **Diego Perini**, **Luca Dassa**

RTU: **Toms Torims, Andris Ratkus** and two PhD students **Jānis Vilcāns, Luca Piacentini**

- **Jānis Vilcāns**

*Development of the rotational (mobile) cryostat system for the superconducting magnets in the hadron therapy installations.*

- **Luca Piacentini**

*Gantry design integration and development*

# Thanks