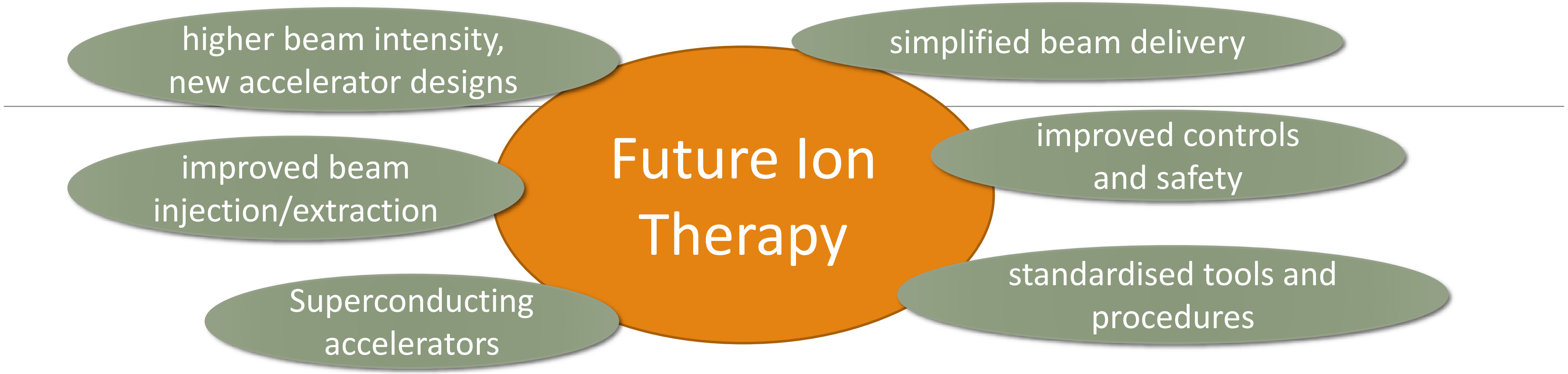
Introduction to Joint Research Activities

MAURIZIO VRETENAR, CERN (PILLAR COORDINATOR)

MARBURG, 23 MAY 2024

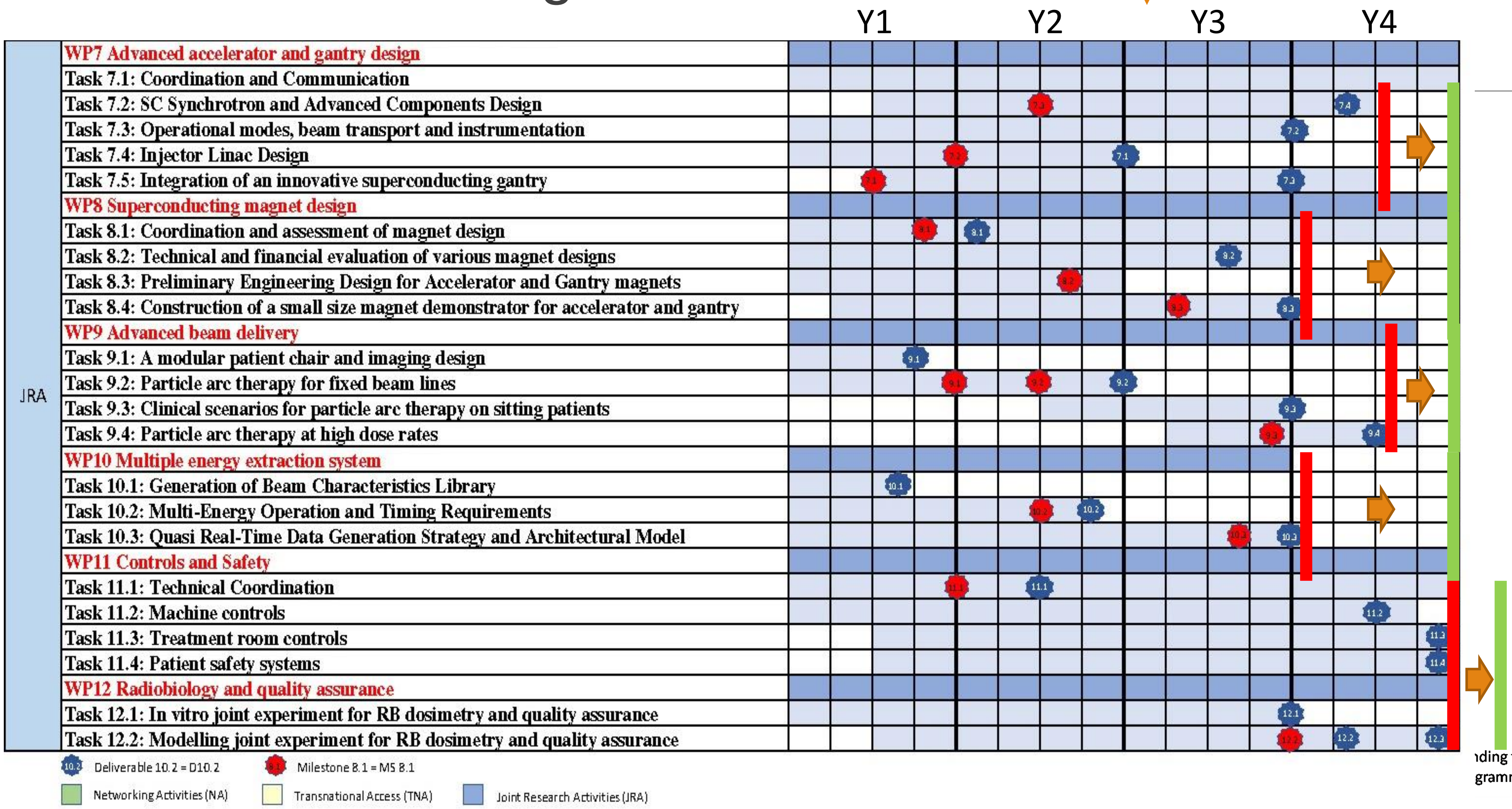
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548

The 6 JRA's: a set of strategic directions to advance Heavy Ion Therapy



WP	Title	Coordinator	Goals
7	Advanced accelerator and gantry design	M. Vretenar (CERN)	Develop technologies and designs for synchrotron, gantry
8	Superconducting magnet design	E. De Matteis (INFN)	Assessment and preliminary design of SC magnets
9	Advanced beam delivery	C. Graeff (GSI)	Develop new patient chair and related arc therapy
10	Multiple energy extraction system	T. Haberer (HIT)	Develop strategy and tools for multiple en. extraction
11	Controls and Safety	D. Perusko (Cosylab)	Design controls and safety for increased intensity
12	Radiobiological Dosimetry and QA	U. Schötz (MIT)	Dosimetry standardization for radiobiological experiments

The JRA Work Programme



The 6 month project extension has moved all Deliverables and WP end dates by 6 months or more. Activity to be completed in:

- 4 years for WP7, WP8, WP9, WP10
- 4.5 years for WP11, WP12

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gramme under grant agreement No 101008548

Summary of HITRIplus JRA status at end of P2

WP7: helium synchrotron design progress, completed injector linac design, definition gantry design – **D7.1**

WP8: decision of the technical design aspects of the final demonstrator (Curved Canted Cosine Theta based on NbTi superconductor): a) conductor; b) impregnation; c) manufacturing procedure; d) assembly procedure; e) iron yoke. Evaluation and test of procedures – **MS8**

WP9: Conceptual Design Report completed for chair (vertical axis rotation + vertical imaging), demonstrator and studies for arc therapy – **D9.2, D9.3**

WP10: Design of an accelerator control system capable of executing multi-energy operation (control of real-time data) – **D10.2**

WP11: Advanced study of control system needs (Del. next period).

WP12: associations between various physical doses and their effects induced on cellular level, comparison of data from clinical centres, finalizing radiobiological experiments at partners (Del. next period).

Heavy Ion Therapy Research Integration

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Heavy Ion Therapy Research Integration

WP7 - Advanced accelerator and gantry design

MAURIZIO VRETENAR, CERN (WP COORDINATOR)

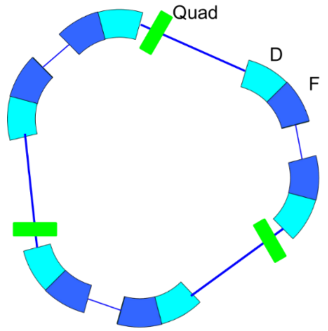
ELENA BENEDETTO, SEEIIST/TERA-CARE (DEPUTY WP COORDINATOR)

MARBURG, 23 MAY 2024

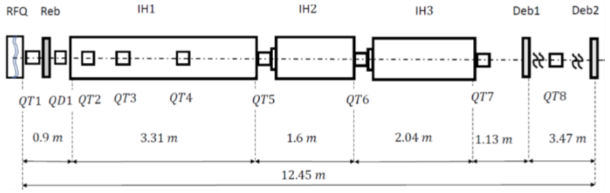
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548

WP7 Main objectives and goals

To design solutions to **improve performance** of the existing accelerators for heavy ion research and therapy: multiturn injection for higher beam intensity, improved extraction and beam transport – in particular for new FLASH therapy modality, and **new linac injector** for higher intensity and parallel production of isotopes for research and therapy.

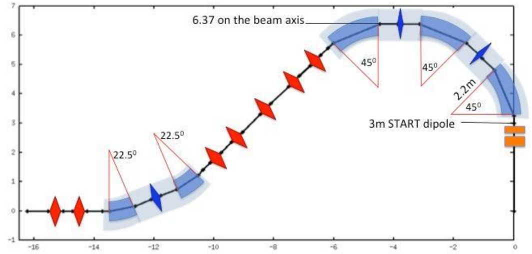


To combine these accelerator solutions with the superconducting (SC) magnets developed in WP8 to develop the **conceptual design of a compact and innovative SC heavy ion synchrotron** for cancer research capable of operating with multiple ion species.



To convert the most promising of the existing conceptual designs for **superconducting gantries** into a detailed technical design integrating all components.

→ New (after suggestion of EC Officer in December 2022)



Investigation of **accelerators designs for alternative ions to carbon, in particular helium** – important synergies between the design of a SC synchrotron for carbon and a NC synchrotron for helium.

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WP7 contractual obligations and status

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS7	Linac and Gantry conceptual design, and SC synchrotron main parameters	4 - CERN	12	Choice of conceptual design and basic parameters of the innovative superconducting gantry and Selection of basic linac design: frequency, layout. Definition of key parameters for the superconducting synchrotron

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D7.1	Linac injector design	2 - BEVA	Report	Confidential, only for members of the consortium (including the Commission Services)	24
D7.2	Gantry design	1 - CNAO	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D7.3	SC synchrotron design	13 - SEEIIST	Report	Public	40

MS7: achieved on schedule (basic design choices)
D7.1 achieved (September 2023)
D7.2 on schedule for M42 (September 2024)
D7.3 ongoing, for M46 (February 2025).

Regular meetings, all partners contributing with some readjustments of work between partners, integration of a new partner TERA-CARE.

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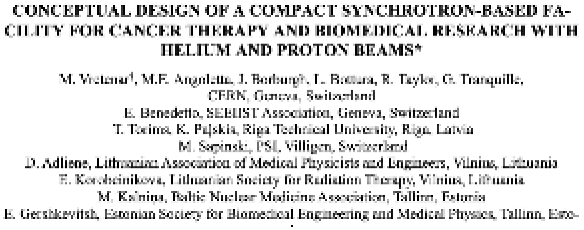
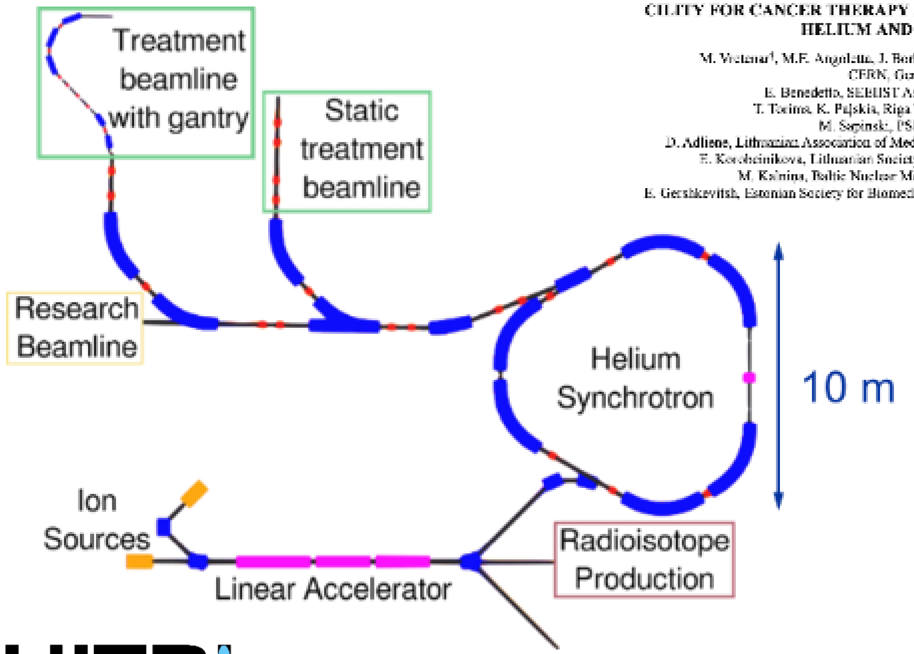
Task 7.2 Synchrotron and advanced components design (SEEIIST, CERN, CNAO, MEDA)

The initial design of a triangle-shaped compact superconducting synchrotron led to the idea of using the same layout with normal-conducting magnets to accelerate protons and helium ions (4He2+) in a compact facility.



CONCEPTUAL DESIGN OF A COMPACT SYNCHROTRON-BASED FACILITY FOR CANCER THERAPY AND BIOMEDICAL RESEARCH WITH HELIUM AND PROTON BEAMS*

M. Vretenar[1], M.E. Angoletta, J. Borburgh, L. Bottura, R. Taylor, G. Tranquille, CERN, Geneva, Switzerland
E. Benedetto, SEEIIST Association, Geneva, Switzerland
T. Torims, K. Pajskis, Riga Technical University, Riga, Latvia
M. Sapinski, PSI, Villigen, Switzerland
D. Adliene, Lithuanian Association of Medical Physicists and Engineers, Vilnius, Lithuania
E. Korobeinikova, Lithuanian Society for Radiation Therapy, Vilnius, Lithuania
M. Kalnina, Baltic Nuclear Medicine Association, Tallinn, Estonia
E. Gershkevitsh, Estonian Society for Biomedical Engineering and Medical Physics, Tallinn, Esto-

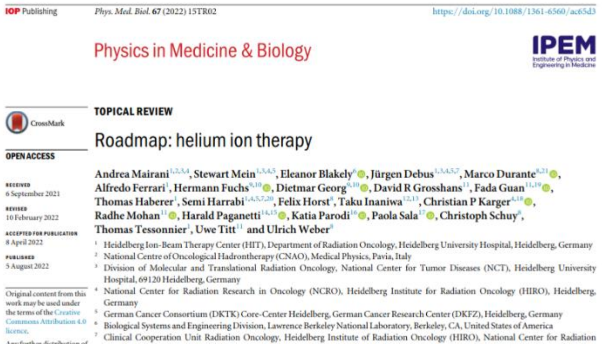


- 2 beamlines treatment
- 1 beamline research.
- Surface ~2,000 m2

Main features:

- rigidity 4.6 T/m: 4He2+ at 220 MeV/u (33 cm pen.).
- 4 x 10^{10} ions, to irradiate 1 litre tumour with 2 Gy.
- RF/KO slow extraction, multiple energies, FLASH extraction (100-200 ms) with phase displacement.

Renewed interest in He treatment (superior conformality) led by the Heidelberg team



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Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

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TOPICAL REVIEW

Roadmap: helium ion therapy

Andrea Mairani[1,2,3,4], Stewart Mein[1,3,4,5], Eleanor Blakely[6], Jürgen Debus[1,3,4,5,7], Marco Durante[8,21], Alfredo Ferrari[1], Hermann Fuchs[9,10], Dietmar Georg[9,10], David R Grosshans[11], Fada Guan[11,19], Thomas Haberer[1], Semi Harrabi[1,4,5,7,20], Felix Horst[8], Taku Inaniwa[12,13], Christian P Karger[4,18], Radhe Mohan[11], Harald Paganetti[14,15], Katia Parodi[16], Paola Sala[17], Christoph Schuy[8], Thomas Tessonnier[1], Uwe Titt[11] and Ulrich Weber[8]

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4 National Center for Radiation Research in Oncology (NCRO), Heidelberg Institute for Radiation Oncology (HIRO), Heidelberg, Germany
5 German Cancer Consortium (DKTK) Core-Center Heidelberg, German Cancer Research Center (DKFZ), Heidelberg, Germany
6 Biological Systems and Engineering Division, Lawrence Berkeley National Laboratory, Berkeley, CA, United States of America
7 Clinical Cooperation Unit Radiation Oncology, Heidelberg Institute of Radiation Oncology (HIRO), National Center for Radiation

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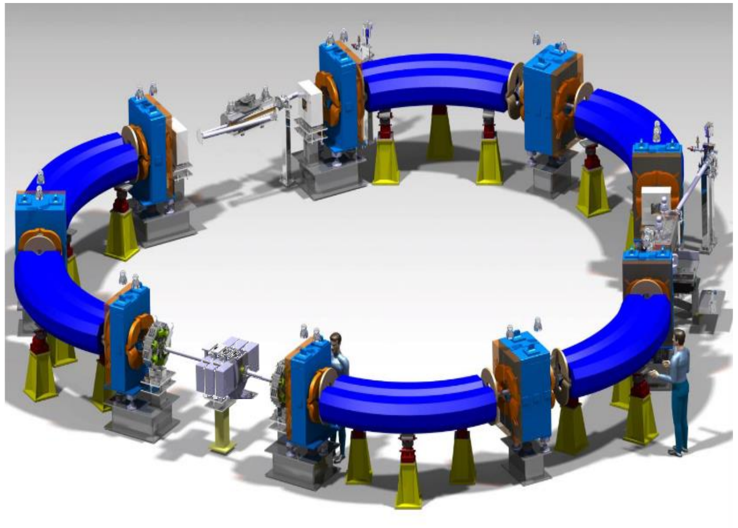
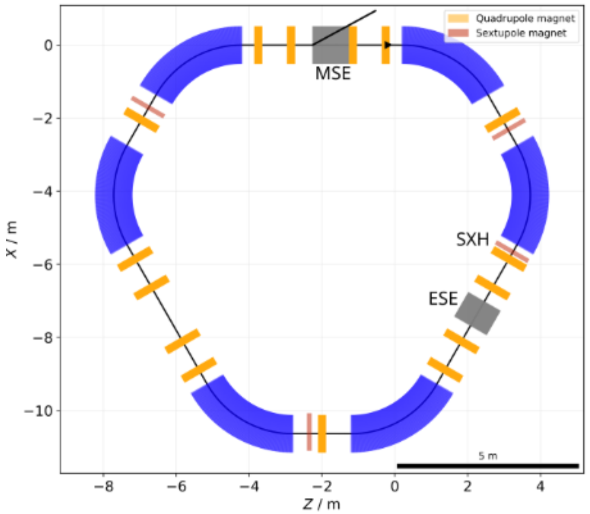
This project has re
research and inno

Design of HeLICS (Helium Light Ion Compact Synchrotron)

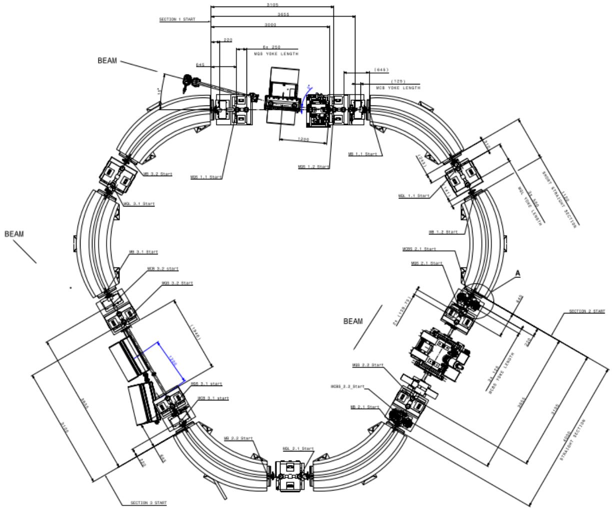
- Magnet field 1.65 T, combined-function gradient with 30^0 pole face angles, 6 magnets at 60^0, 33m circumference
- RF-KO extraction analysed for both Helium and SC Carbon synchrotrons.
- New detailed beam optics, particle tracking ongoing.



3D integration



Lattice



Complete Layout

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Similar lattice developed for SC synchrotron

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Task 7.3 Operational modes, beam transport and instrumentation (SEEIIST, CERN, CNAO, MEDA)

Beam trasport lines

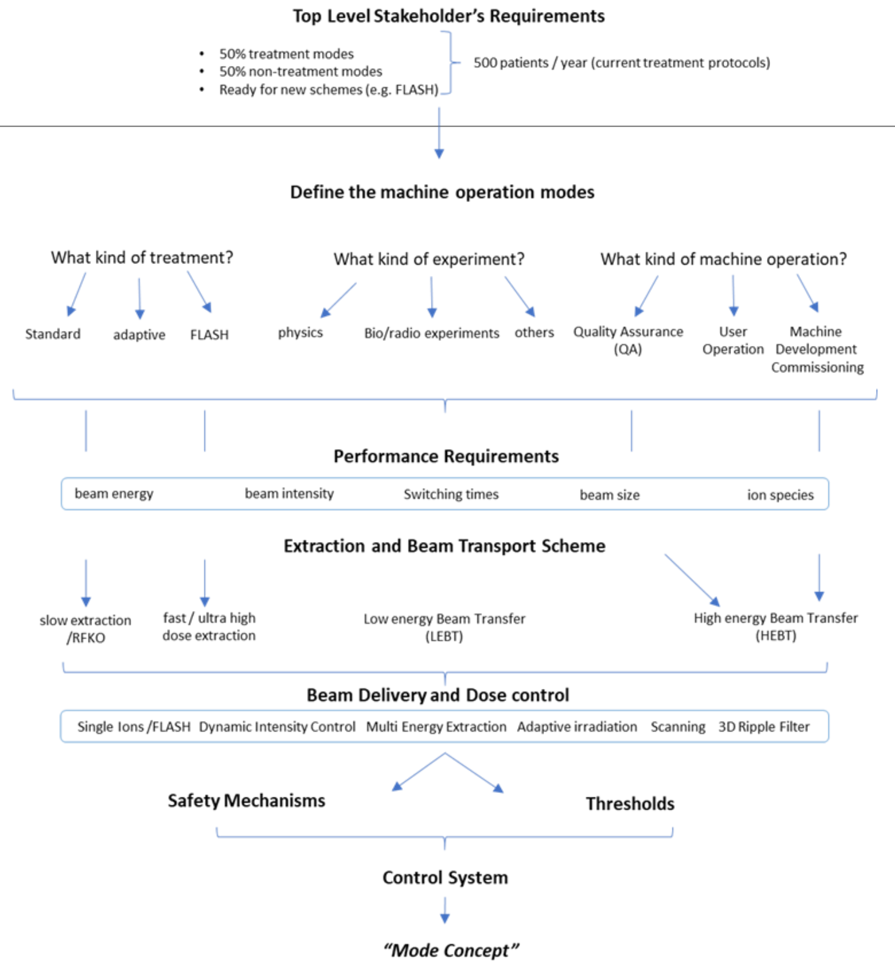
→ completed (CERN-NIMMS Note 9)

Beam instrumentation

→ in progress (IPAC22 paper)

Operational modes

→ progress on a document (SEEIIST) with requirements and proposed solutions for research and treatment operation.



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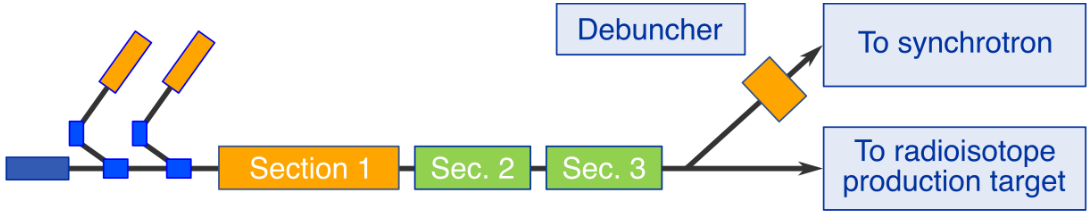
Task 7.4 - Injector Linac Design (BEVA, CERN, SEEIIST)

Comparison of 2 injector designs: 217 MHz IH-based (BEVA), 352 MHz DTL-based (CERN)

Based on a common general layout covering both injection of C, He, p and production of radioisotopes.



Sections 2 and 3 are powered **only** for isotope production

Maximum duty cicle: **10%**

3 Ion Sources:

- $^{12}C^{4+}$, 0.6 mA, 45 kV
  0.25 π·mm·mrad
- $^{4}He^{2+}$, 0.5 mA,
  0.3 π·mm·mrad
- $^{1}H^{+}$ or $^{2}H^{+}$, 5 mA,
  0.2 - 0.3 π·mm·mrad

LINAC sec. 1:

- A/q = 3
- W_{in} = 15 keV/u
- W_{out} = 5 MeV/u

Baseline: **217 MHz**
Alternative: **352 MHz**

LINAC sec. 2:

- A/q = 2
- W_{in} = 5 MeV/u
- W_{out} = 7.1 MeV/u

LINAC sec. 3:

- A/q = 2 or 1
- W_{in} = 7.1 MeV/u
- W_{out} = 10 MeV/u

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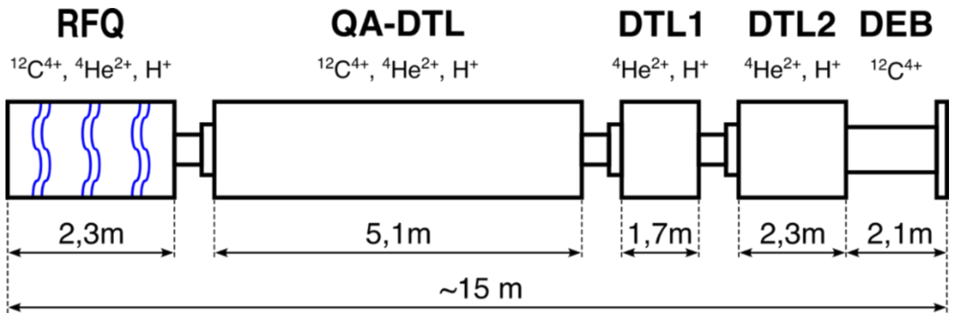
Development of the 352 MHz version and comparison

Quasi-Alvarez DTL structure (F0D0 focusing with 100% transmission, 2/3 drift tubes smaller for higher efficiency, 1/3 drift tube containing a permanent magnet quadrupole).

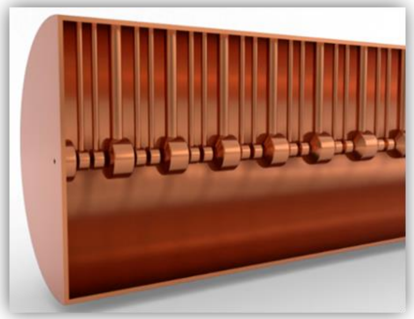
Standard DTL (Alvarez) for last 2 tanks

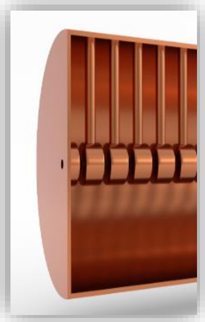


COMPARISON OF LINAC DESIGNS

Parameter	217 MHz design	352 MHz design	
Length	9.4	11.3	m
RF power	1’340	1’370	kW

- Slight advantage in power for 352 MHz
- For C4+ only, 217 MHz more advantageous.
- For C4+ and He, might merge two designs: RFQ + IH at 176 MHz, followed by 2 DTL tanks at 352 MHz.





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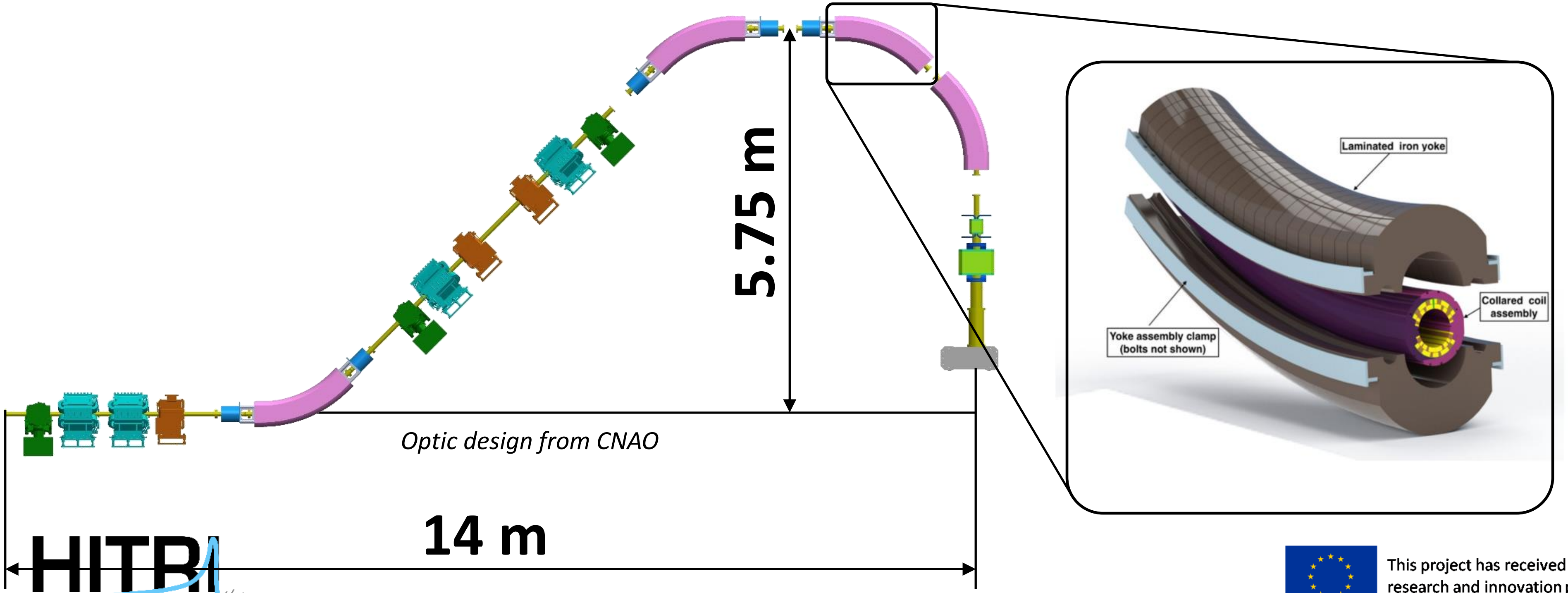
Task 7.5 - Integration of an innovative superconducting gantry: optics, mechanics, beam delivery (CNAO, CERN, SEEIIST, MEDA, RTU)

Decision after P1: Layout with 4 identical 45^0 4 T SC magnets, downstream scanning, complete rotation ±180^0



Optic design from CNAO

Features of Superconducting Dipole	
Material	Nb-Ti
Dipole Field	4 T
Aperture	80 mm
Length	1.3 m
Bending angle	45 °
Bending radius	1.65 m
Mass	**1500 kg**

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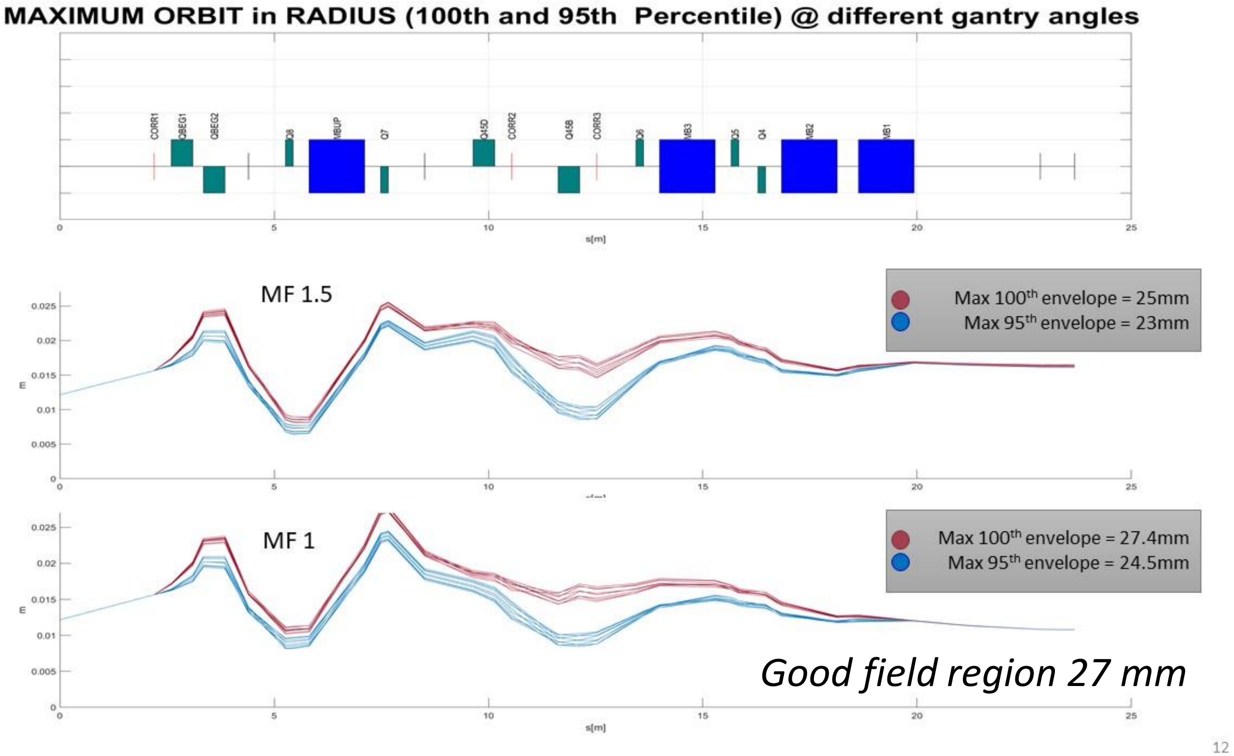
Beam optics studies (CNAO, G. Frisella, S. Savazzi, E. Felcini, M. Pullia)

- Description of curved dipoles inside beam optics code refined using thin multipolar lenses.
- Optimization algorithms developed to derive best position of quadrupoles, orbit correctors, monitors and minimize space occupied by beam in magnets.
- Accurate study of misalignment errors (cold-warm supports, vacuum vessel, backlash, deformation of gantry structure) to compare configurations (ongoing).



Maximum space occupied by the beam in the configuration with 0 T/m of quadrupole gradient in the SC dipoles. The lines represent the envelopes corresponding to eight different gantry angles and the two magnification factors: in red are shown the maximum envelopes, in blue the envelopes corresponding to the 95th percentile.

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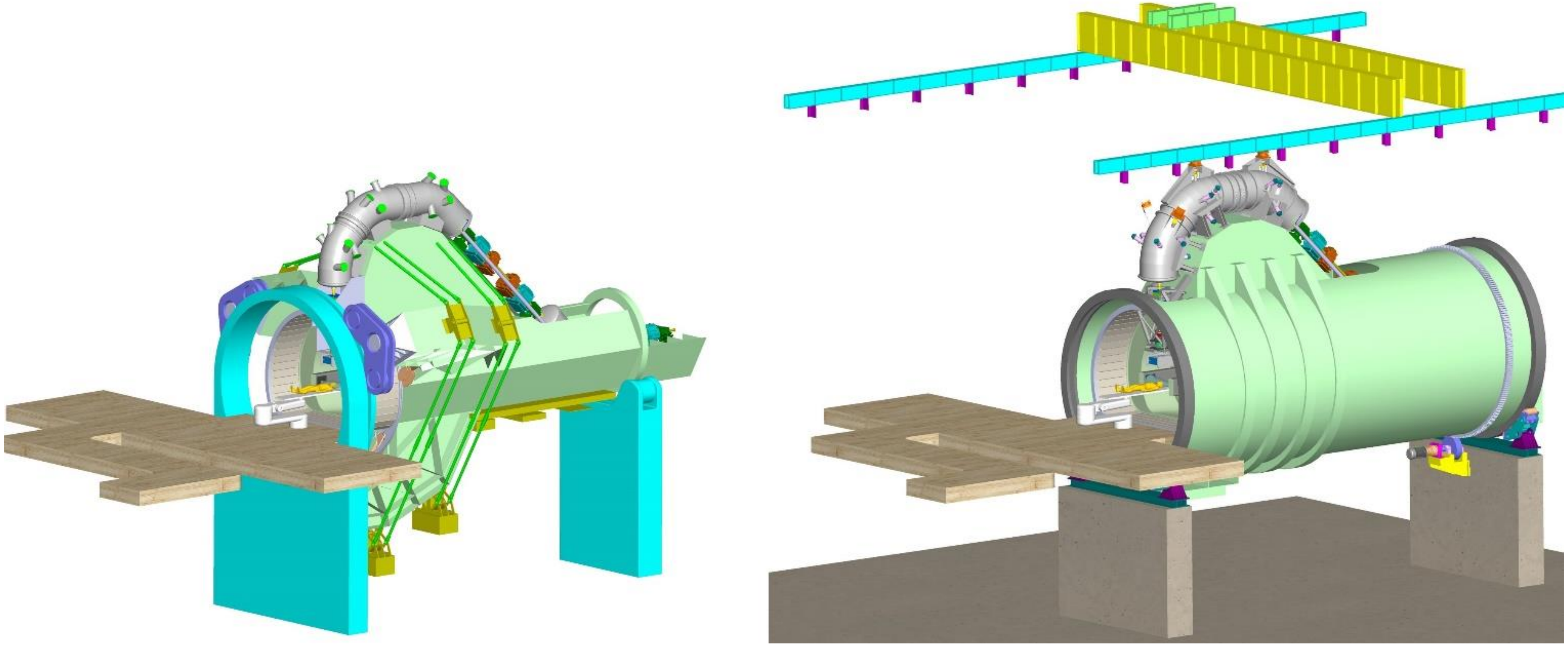
Mechanical structure (RTU: L. Piacentini, A. Ratkus, CERN: L. Dassa)

- Additional tension structures to minimize deformations.
- Preference given to stiff barrel structure (right).
- Improvement of supports to reduce mass.



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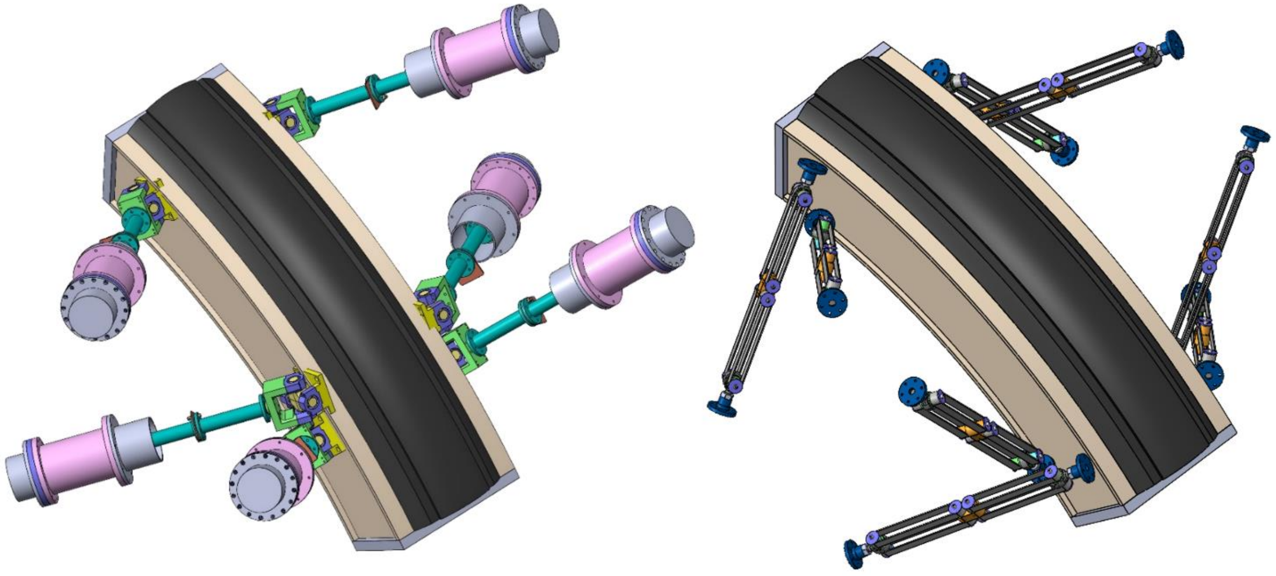
SC magnets support and risk analysis

- Two alternatives for suspension system of SC elements, with 6 or 8 supports.
- Genetic algorithm to select (minimum misalignment and heat-load to cold mass).



Working Group set-up for risk management study of gantry (failure analysis during clinical operation and risk assessment of the hazardous situations) – to be completed for Deliverable.

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Thank you for your attention and thanks to all WP7 colleagues:

SEEIIST: P. Grübling
TERA-CARE: E. Benedetto, L. Garolfi
CNAO: M. Pullia, E. Felcini, G. Frisella, A. Mereghetti, M.G. Pullia, S. Savazzi
BEVA: U. Ratzinger, B. Koubek
RTU: L. Piacentini, T. Torims, A. Ratkus
MEDA: M. Pivi
GSI: Y. Foka
CERN: L. Dassa, D. Perini, L. Nikitovic, M. Vretenar, F. Asvesta, H. Huttinen, R. Taylor

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