SEEIIST facility design and alternatives

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Hadron Therapy Workshop: status and perspectives, plans for next generation facilities

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Historical background – the SEEIIST accelerator

- 06/2018: “Archamps” Workshop on Ideas and technologies for a next generation facility for medical research and therapy with ions.
- 2019: CERN starts NIMMS (Next ion Medical Machine Study) for the design of next generation ion therapy facilities.
- 07/2019-07/2021: DLR contract to support SEEIIST design, with participation of GSI and CERN. NIMMS starts collecting a wide international collaboration supporting SEEIIST accelerator design.
- 04/2021: starts the HITRIplus project, a collaboration of European research institutions to push ion therapy forward, with a view to a future SEEIIST facility.
- 10/2021: the accelerator design group (CERN, SEEIIST and collaborators) contributes to the SEEIIST application for the ESFRI Roadmap.
- 07/2021: the ESFRI application is rejected (project not mature enough for implementation phase).
- End 2021: starts preparation for a CERN Yellow Report to disseminate the large amount scientific work done for SEEIIST (motivations, user communities, operation modality, accelerator design).
- October 2024: thanks to the immense work of the editing team (in particular, Y. Foka and P. Georgieva) the Yellow Report is sent to proofreading prior to publication in 2024.

The accelerator basic requirements

Requirements of the ion therapy community, expressed at the Archamps Workshop, June 2018

1. Concentrate on heavy ions (Carbon but also Helium, Oxygen, etc.) because proton therapy is now commercial (4 companies offer turn-key facilities) while ions have higher potential for treatment but lower diffusion.

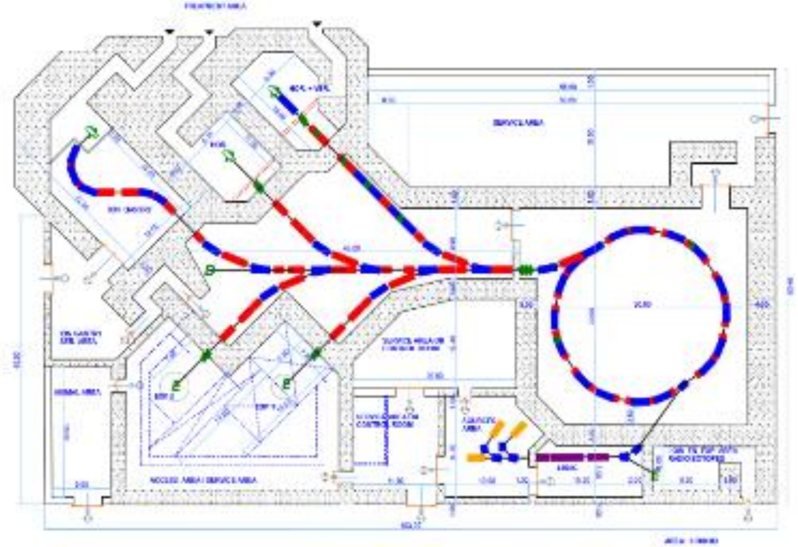
2. A next generation ion research and therapy accelerator must have:

- ❑ Lower cost, compared to present;
- ❑ Reduced footprint;
- ❑ Lower running costs;
- ❑ Faster dose delivery with higher beam intensity or pulse rate;
- ❑ A rotating gantry device to precisely deliver the dose to the tumour
- ❑ Allow operation with multiple ions, for therapy and research.

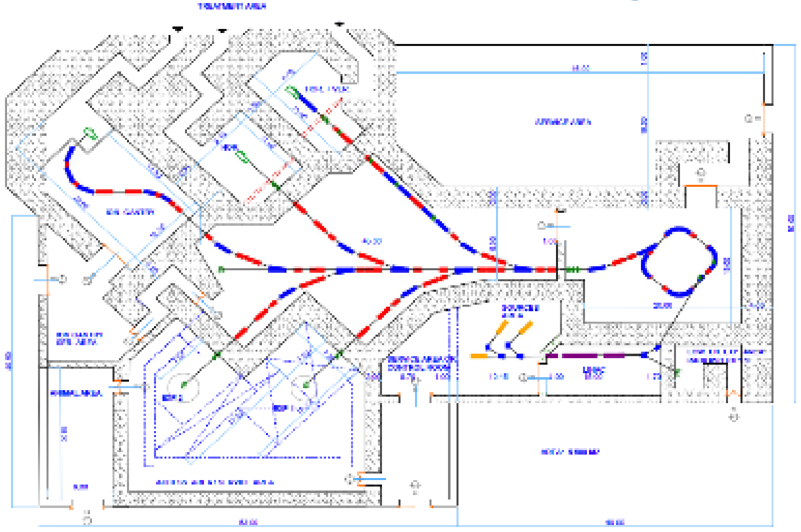
+ Specific requirements for SEEIIST:

- ❑ Easy Industrialization
- ❑ Reliability
- ❑ Simple operation
- ❑ Reduced risk
- ❑ Acceptable time to development

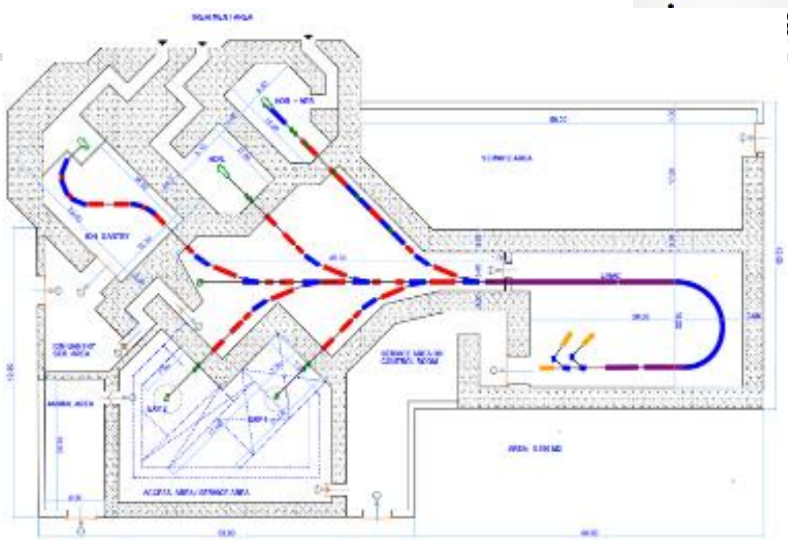
Comparison of accelerator designs for SEEIIST



RT synchrotron:
accelerator 1,200 m², facility 6,500 m²
estimated cost (acc. only): 42 M€



SC synchrotron:
accelerator 600 m², facility 5,500 m²
estimated cost (acc. only): 31 M€



Full linac:
accelerator 600 m², facility 5,500 m²
estimated cost (acc. only): 31 M€

SC synchrotron or linac allow 50% reduction in accelerator dimensions, 15% in overall facility dimensions, and 20% reduction in cost.

	Construction Cost	Operation cost	Footprint	Performance	Time to development	Risk of development	Treatment protocols	Gantry
Warm (new) synchrotron	Medium	Medium	Large	Good	Low	Low	Existing	Simple design
Superconducting synchrotron	Lower	Lower	Small	Good	Medium	Medium	Existing	Simple design
Linear accelerator	Lower	Lower	Small	Better	Long	Medium	To be developed	Complex design

Linac option discarded by SEEIIST because requires R&D, is not evolutive, and needs specific medical licensing.

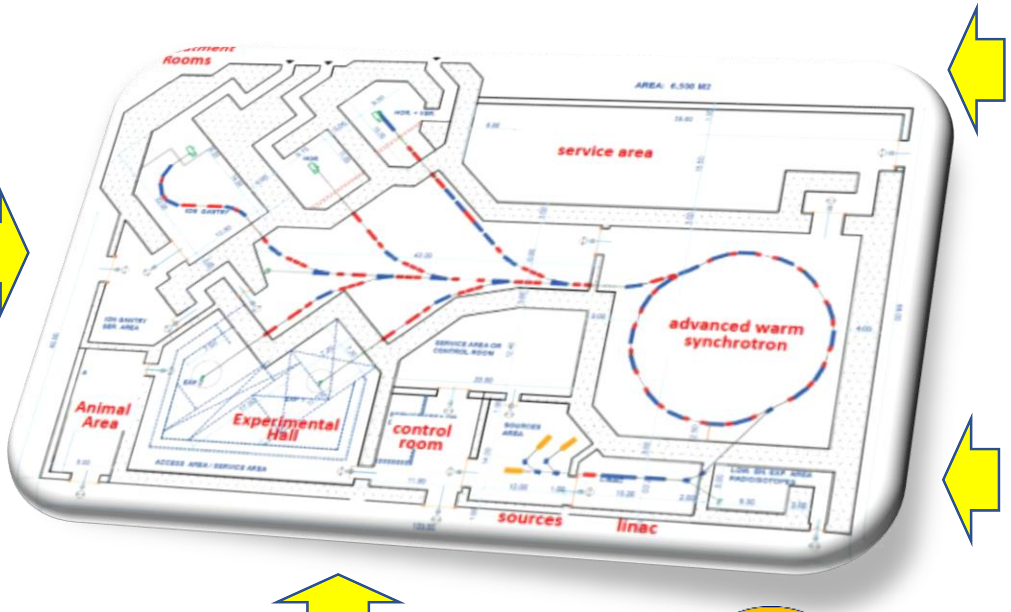
A 2020 study recommends the adoption as baseline configuration of a warm-magnet synchrotron with novel features. Development of superconducting magnets and adequate superconducting synchrotron designs should continue as an advanced alternative option. Because of its lower cost and smaller dimensions it might become the baseline in case preparation for construction of SEEIIST would take more time than foreseen and in case of success of the superconducting magnet development in HITRIplus.

The unique SEEIST ion therapy and research facility

The SEEIIST unique design, as presented in the ESFRI application and in the Yellow Report

A. Innovative SEEIIST features:

1. Optimised for 50% research and 50% patient treatment (~400 patients/year);
2. Providing 20 times higher beam intensity for carbon ions than present facilities;
3. Equipped with flexible extraction for operation in FLASH mode;
4. Equipped with dual mode linear injector capable of producing radioisotopes for cancer imaging and therapy.



C. Conservative SEEIIST feature:

The synchrotron adopts the well-established PIMMS design (known and available components, flexible layout for research);

D. Specific SEEIIST features:

1. Environmental strategy: minimise energy consumption, strategy for energy generation;
2. Conceived as a multiple-hub facility, to federate partners in different countries.

B. Advanced SEEIIST features (common to other advanced facilities):

1. Operation with multiple ions: protons, Helium, Carbon, Oxygen, Argon;
2. Multiple energy extraction for faster treatment;
3. Equipped with a compact superconducting gantry of novel design.

Layout of the complete SEEIIST-type facility

Research and Therapy Facility
(50% daily beam time for research, 50% for therapy)

Access for therapy

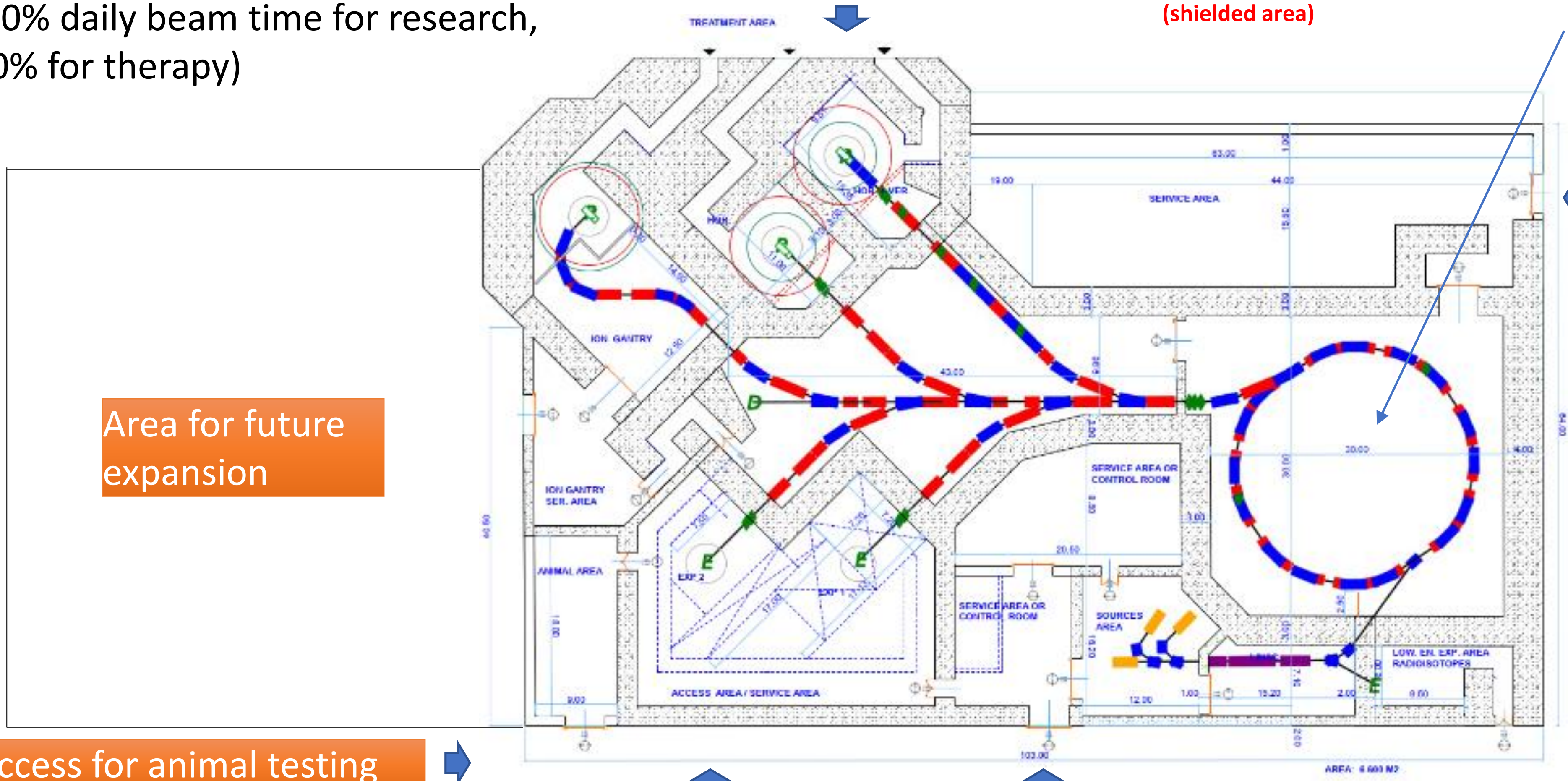
Total 5,400 m²
(shielded area)

The synchrotron can be replaced by an SC version if R&D successful

Equipment room and access to synchrotron

Area for future expansion

Target for isotope production



Access for animal testing

Reconfigurable experimental room

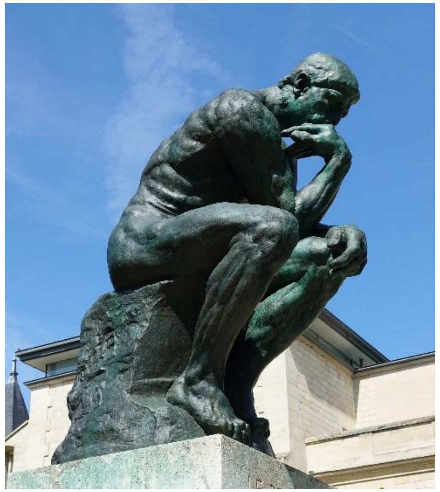
Access to experimental room and linac

SEEIIST as a green field facility

Roof of accelerator building is removed to show accelerator components

NIMMS strategy after 2021

- The delivery of the SEEIIST design in 2021 represented a milestone for NIMMS and started a thorough reflection on limitation and opportunities for new ion therapy facilities in Europe.
- Consideration #1: carbon ion therapy, with high costs and recommendation only for a small fraction of radioresistant tumours, is still perceived as “medicine for the wealthy”. There is financial and psychological resistance to new carbon facilities – only 3 ongoing projects worldwide – in particular for countries not yet equipped with a large number of X-ray therapy facilities and with proton therapy.
- Consideration #2: the implementation of the “full-carbon” SEEIIST is made difficult by the fact that it cannot be built in small stages. The investment is justified only by the final objective of carbon therapy. Justifying a large initial investment in countries that have still to build the required capacity might be politically challenging.

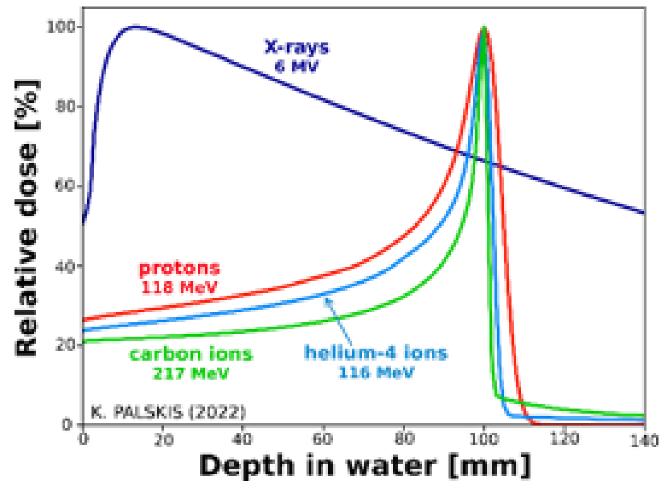


Idea:

Exploring alternatives at lower cost that could be implemented in stages, in parallel with setting up the required capacity in the host countries.

→ A compact accelerator for proton and helium

The helium & proton therapy and research facility



Therapy with **helium ions**, under development at HIT, may provide at an affordable accelerator cost maximum conformality with excellent effectiveness. Ideal in particular for paediatric patients.

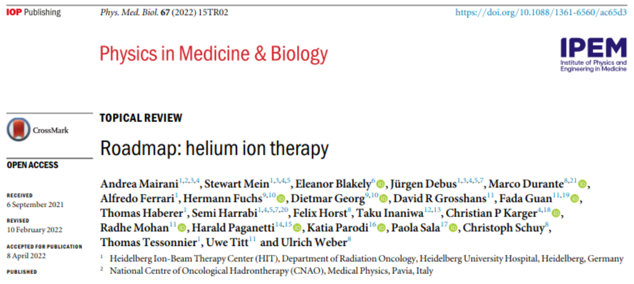
Minimum lateral scattering, best compromise between carbon (sharp Bragg peak) and protons (small fragmentation), low neutron dose.

New frontier for particle therapy.

A facility centred on a compact **helium synchrotron** based on CERN technology

A facility for cancer research and therapy with helium ions

- 2 beamlines for treatment, 1 for research.
- Slow and FLASH-type extraction.
- On-line radiography with protons or helium.
- Gantry or moving chair.
- Linac for parallel radioisotope production.
- Synchrotron circumference 33m
- Surface ~1,600 m2



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TOPICAL REVIEW

Roadmap: helium ion therapy

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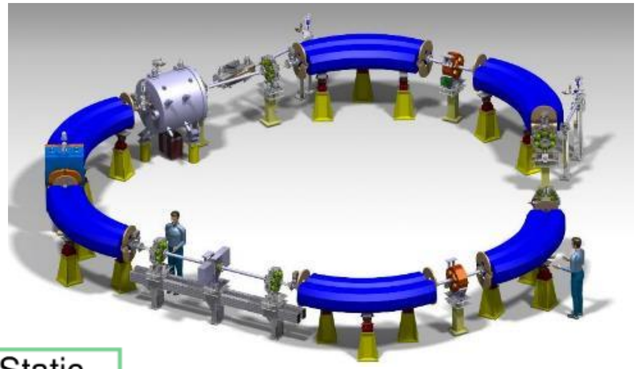
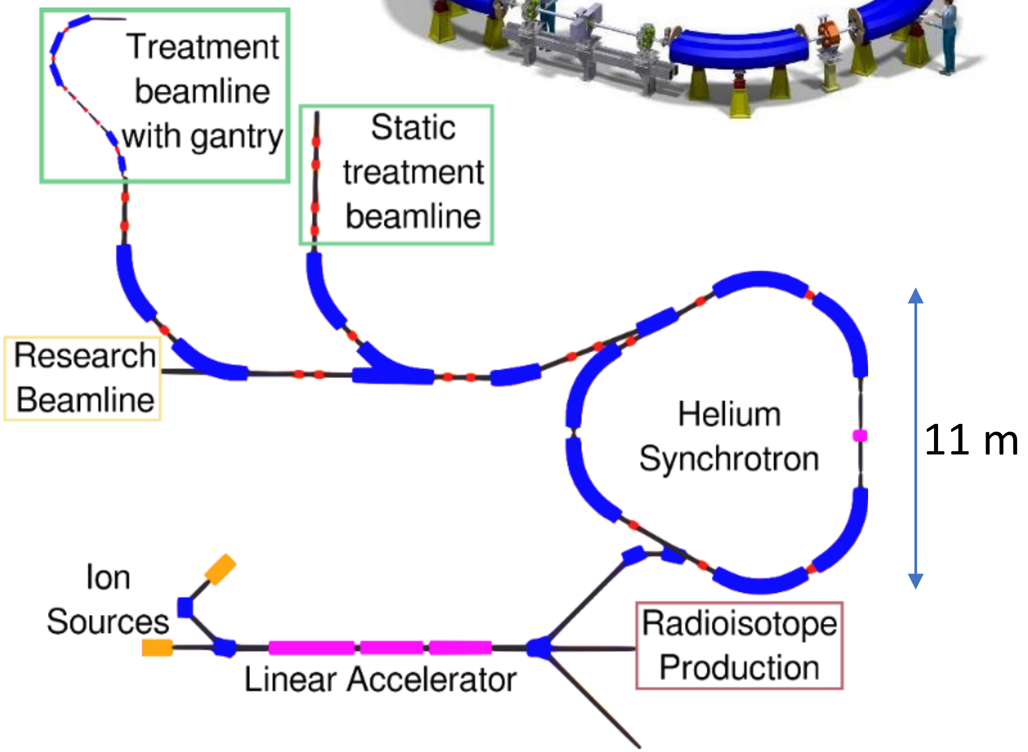
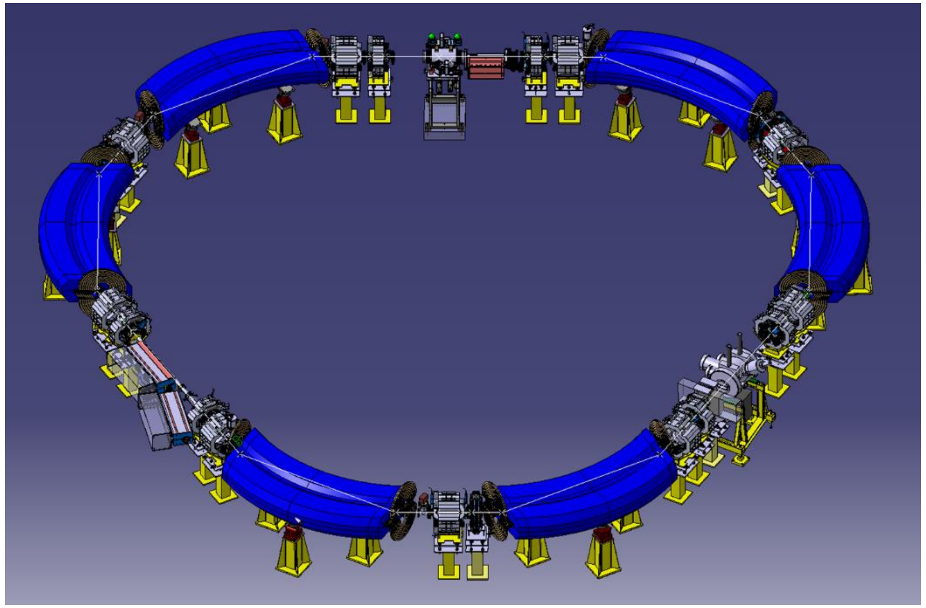




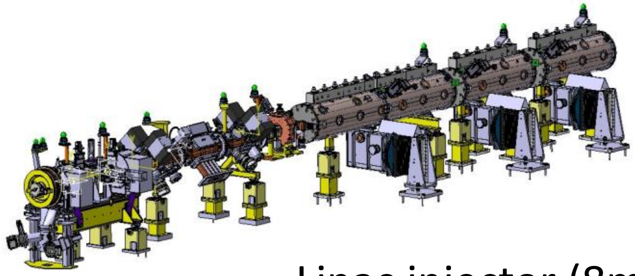
The accelerator



11 m

Compact triangle-shaped synchrotron

Synchrotron design under the responsibility of by E. Benedetto, formerly SEEIIST and now TERA-CARE

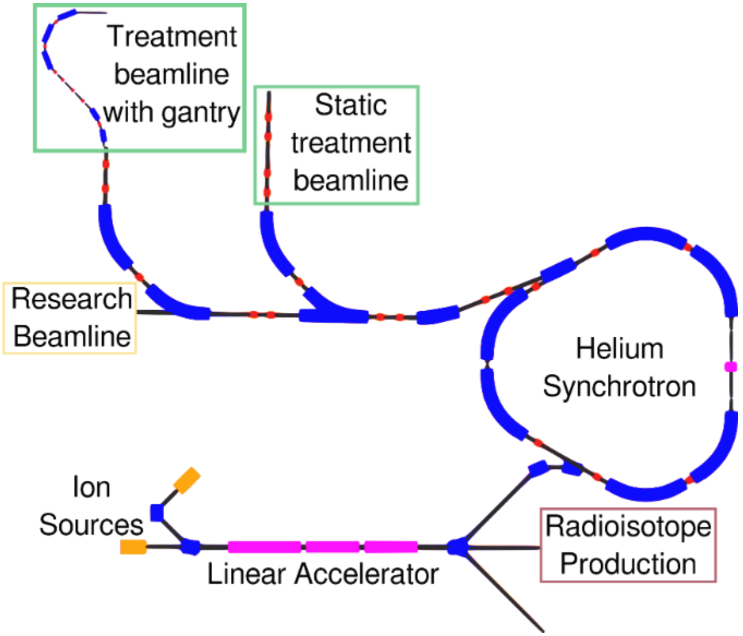


Linac injector (8m)

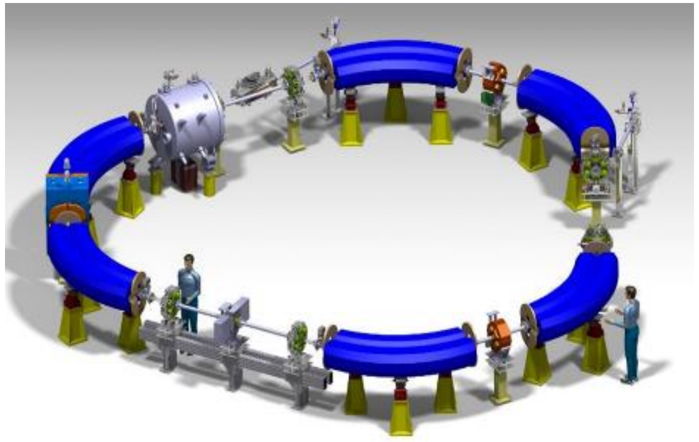
The design of the accelerator is progressing. Mechanical layout and main components are based on a synchrotron recently built at CERN for deceleration of antiprotons *(ELENA – image to the right)*

A staged approach

Step 1: ion source and injector test stand.
Step 2: linear accelerator for production of medical radioisotopes.
Step 3: synchrotron for research line.
Step 4: treatment with fixed beam.
Step 5: treatment with vertical room or gantry/chair.
….
Step 6: **replace the resistive magnets with superconducting magnets** to reach the field needed for carbon.



The accelerator lattice can be used with superconducting magnets, to obtain a carbon ion synchrotron with the same dimensions.
A HITRIplus deliverable with the preliminary design of the Superconducting synchrotron is in preparation (by E. Benedetto and her team)



- Large carbon therapy facilities are becoming commercial (Caen, Mayo).
- The HIMAC team in Japan is starting construction of a superconducting carbon ion synchrotron.
- To be competitive, a future carbon facility in Europe must use superconducting magnets (the CCT magnets developed in HITRIplus/IFAST, or a new generation of hybrid superferric magnets).

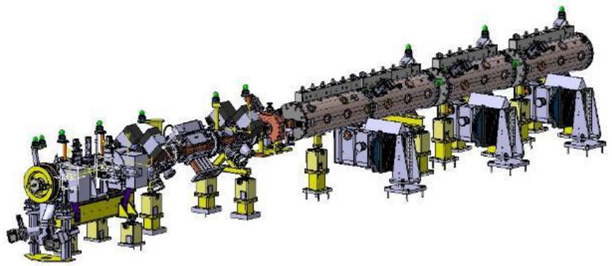
Linear accelerator for radioisotope production

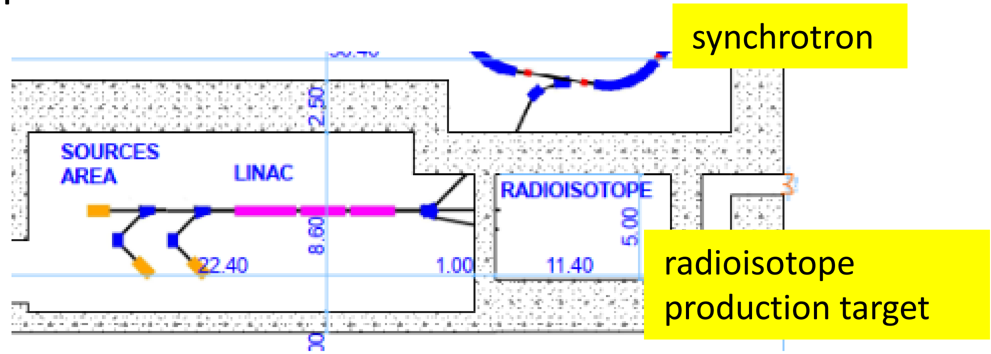
nimms

Coupling particle therapy with nuclear medicine

The linear injector of a helium therapy synchrotron can be used to produce radioisotopes for imaging and therapy, in parallel to operation for therapy.

Linear accelerators are more efficient and less demanding than conventional cyclotrons for operation with helium ions.





Radioisotope	Usage
Scandium-43, 44	Diagnostic – PET
Cobalt-57	Diagnostic – SPECT
Copper-64	Theranostic (β^-)
Copper-67	Theranostic (β^-)
Indium-111	Diagnostic – SPECT
Tin-117m	Theranostic (β^-)
Samarium-153	Theranostic (β^-)
Rhenium-186	Theranostic (β^-)
Astatine-211	Therapeutic (α)

Courtesy K. Palskis, RTU/CERN

Example: Targeted Alpha Therapy with Astatine 211

Alpha particles = Helium ions (2 protons, 2 neutrons) are the most dangerous radiation, short range and high toxicity!

The linear injector produces alpha-emitting therapeutic isotopes like 211At that are attached to antibodies and injected to the patient. The targeting vector accumulates the isotopes in the cancerous tissues where they selectively deliver their dose.

Advanced experimentation, promising for solid or diffused cancers (leukaemia).

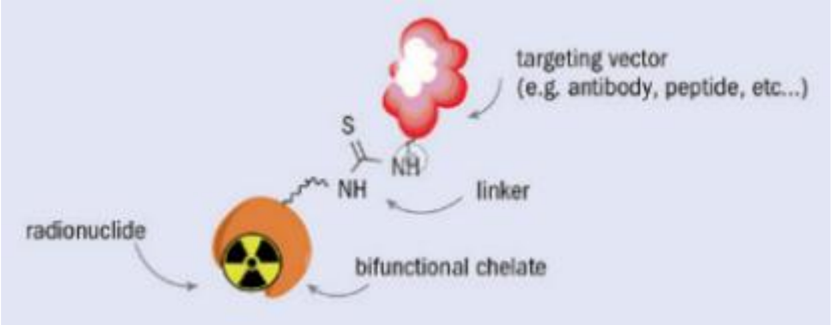
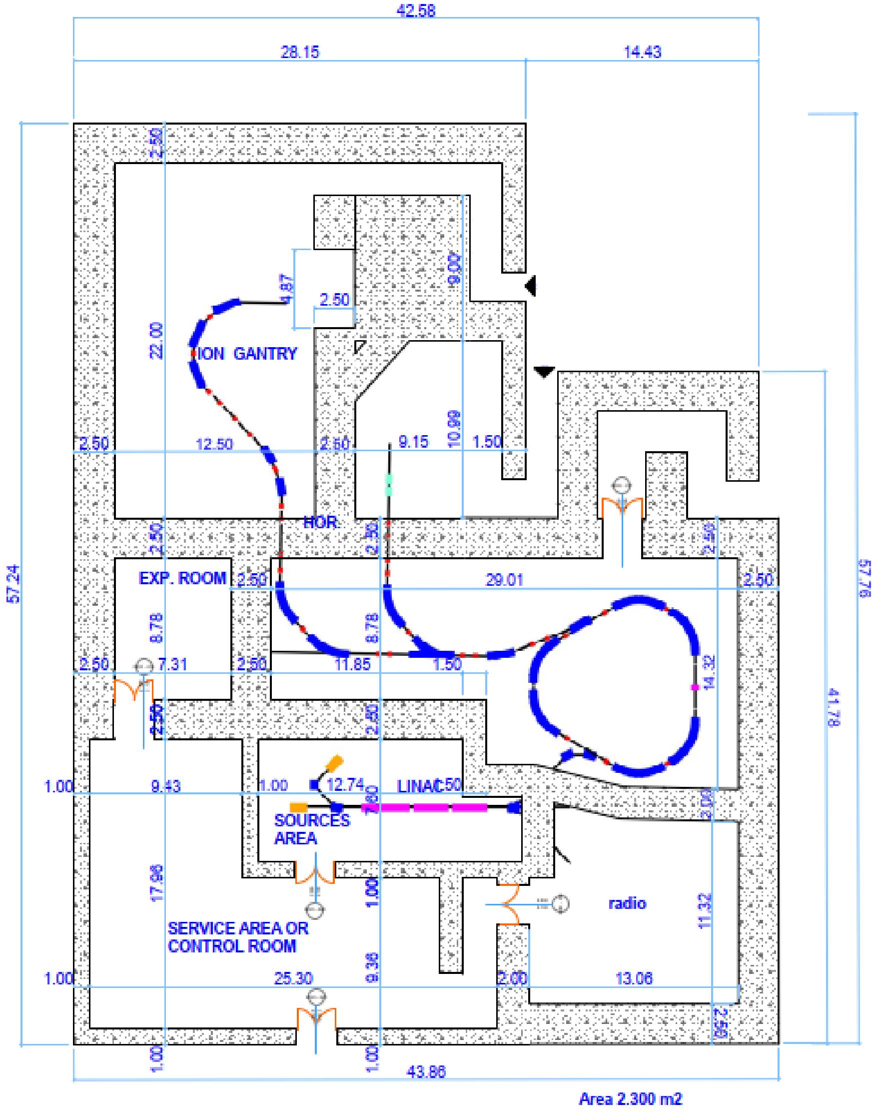


Image credit: CERN Courier

Potential users



1. Advanced Particle Therapy Centre for the Baltic States (APTCB)

Collaboration between Latvian, Estonian, and Lithuanian research institutions.

CERN Baltic Group

Draft concept-paper
Advanced Particle Therapy Center for the Baltic States

The Baltic Group has compared 5 options for a **new Research Infrastructure** for cancer therapy and research with particle beams in the region. The **Helium synchrotron** has been selected as the one giving the best combination of cost, innovation, scientific reach, treatment opportunities. Regional project with expected EC support.
The Baltic Group will prepare in 2025/26 a **Feasibility Study** covering medical, infrastructural, and economical aspects (business plan).

Implementation in the Baltic States

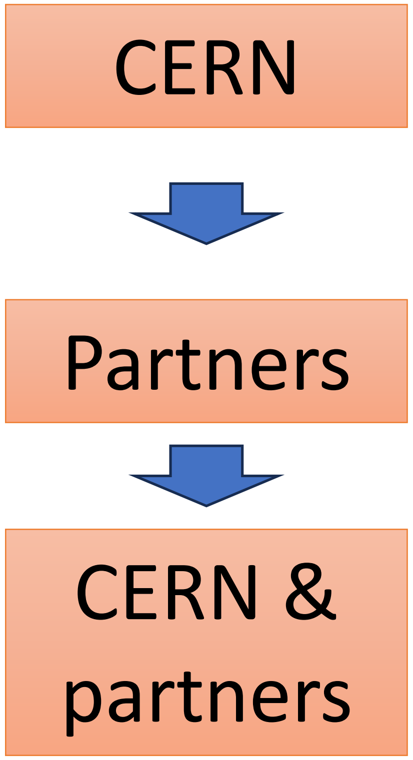
- The Baltic States are without a particle therapy centre. Support is growing in the region to construct such a facility.
- Incidence rate of 630 cases per 100 000 inhabitants: 34% receiving radiotherapy.
- 28 radiotherapy LINACs in region: **Sufficiently developed to move towards particle therapy.**
- Plans for head and neck tumours, sarcomas, complex localisations & paediatric cancers.
- Above treatment, provides **opportunities in accelerator technology, medical physics and (pre-)clinical research.**

2. Clinical Helium Facility for Switzerland (CHeFS)

Promoted by U. Amaldi and the TERA-CARE Foundation for construction in Switzerland.

NIMMS dissemination plan

1. NIMMS will prepare in June 2025 a preliminary Technical Design Report (TDR) for the helium therapy and research facility. It will be available to all NIMMS collaborators and other interested partners (priority to CERN Member and Associate Member States).
2. Partners willing to use the technologies described in the TDR can refer to this design for the proposal to their funding agencies and for their local implementation plan (as the Feasibility Study for the APTCB).
3. In case of approval, access to the NIMMS technologies will be defined with CERN at a later stage.



Thank you for your attention