Development of innovative particle therapy technologies at CERN: the Next Ion Medical Machine Study

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About CERN

CERN ("Conseil Européen pour la Recherche Nucléaire") was founded in 1954 to promote "science for peace".

Today an International Organisation with 23 member states, is the largest particle physics laboratory in the world.

~ 2600 staff
~ 1800 other paid personnel
~ 14000 scientific users

Budget (annual) ~ 1300 MCHF

Member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom

Associate Members: Cyprus, Estonia, Slovenia, Croatia, India, Latvia, Lithuania, Pakistan, Türkiye, Ukraine

Finland is a member state since 1991

The mission of CERN

- Push back the frontiers of knowledge

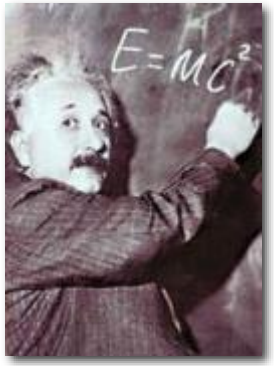
  the secrets of the Big Bang …what was the matter like within the first moments of the Universe's existence?

- Develop new technologies for accelerators and detectors

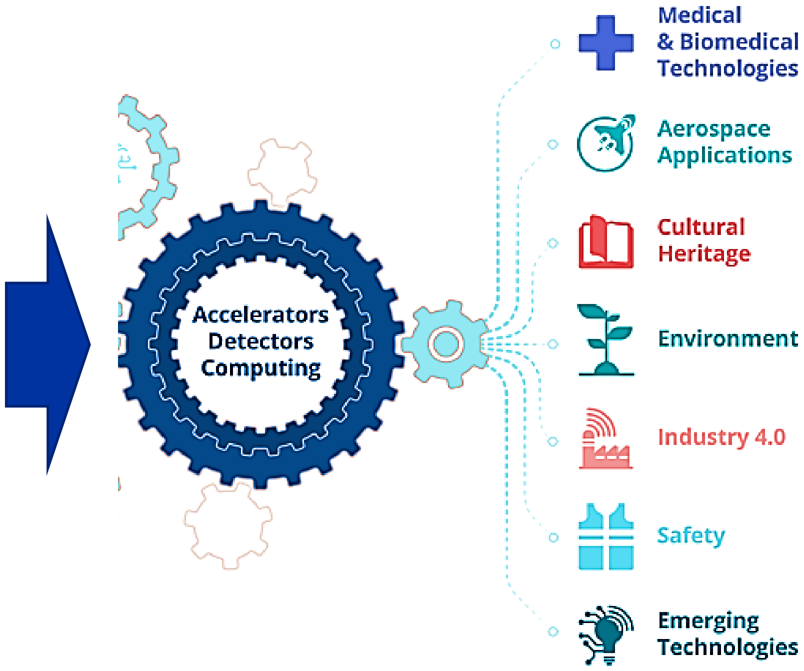
- Train scientists and engineers of tomorrow

- Unite people from different countries and cultures

The 27-km Large Hadron Collider (LHC), built and operated at CERN, is the largest particle accelerator in the world



From the Large Hadron Collider to medicine



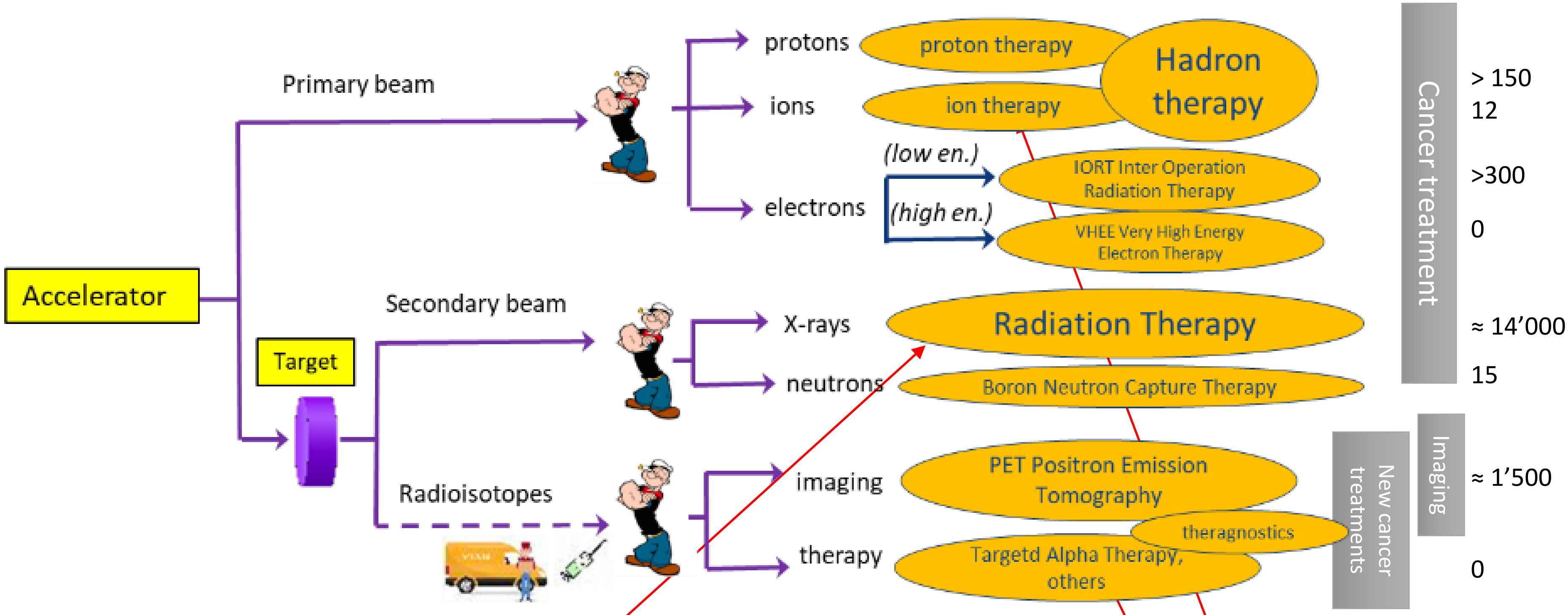
CERN and Society

- Huge experience in all technologies related to acceleration and detection of particles
- Engaged to maximise the return to society and to demonstrate the impact of major investments as the Large Hadron Collider.

- MedTech is the main field of application of CERN technologies for the benefit of society.
- The subatomic world made accessible using particle accelerators can lead to substantial advances in many fields of medicine: treatments with particles, isotopes, advanced diagnostics,…
- Developing these technologies requires a strong collaboration across physics, biology, medicine - and CERN can provide a fertile collaborative ground for them to grow.

Particle accelerators, a formidable tool for medicine

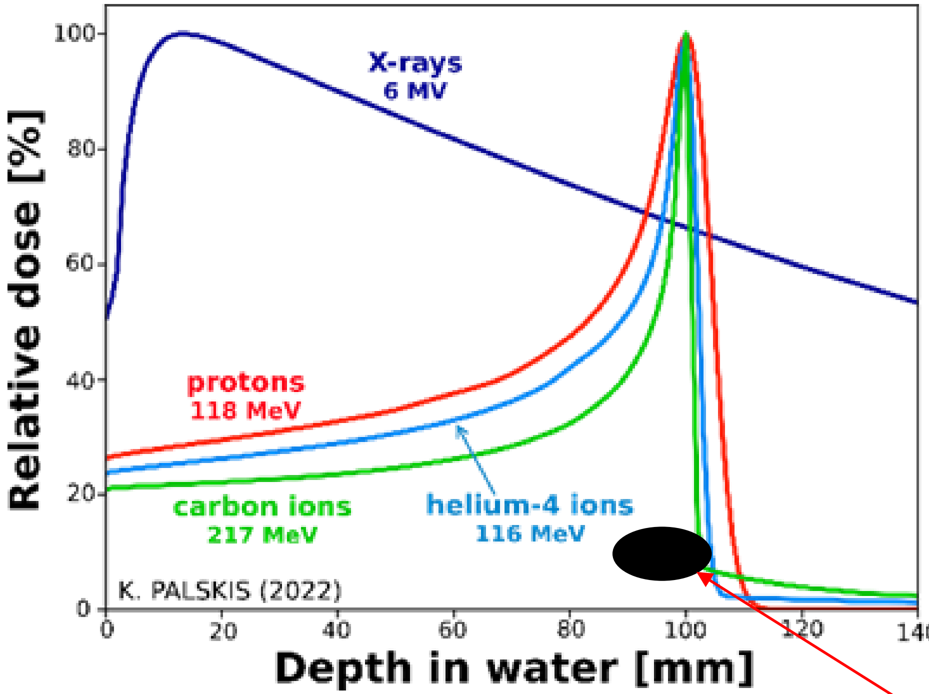
Accelerators produce particles (photons, protons, ions) that can penetrate into the body to treat diseases and to observe internal organs without using surgical tools.



14,000 electron linear accelerators worldwide for X-ray therapy of cancer

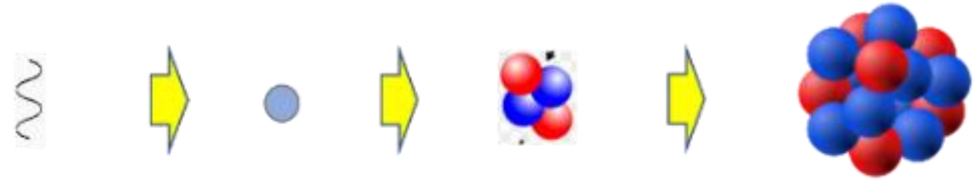
Reference domains for the Baltic Advanced Particle Therapy Centre

Treating cancer with particle beams



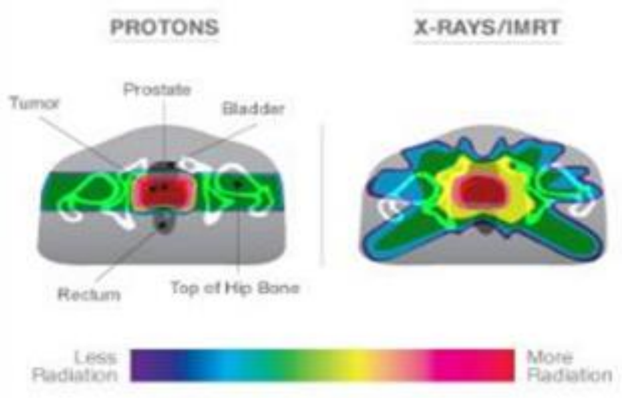
tumour position

Bragg peak:
Different from X-rays, protons and heavier ions deposit their energy at a defined (energy dependent) depth inside the tissues, **minimising the dose to the organs close to the tumour**.



Photon (X-ray) no mass | **Proton** mass: 1 m_0 | **Helium** ion mass: 4 m_0 | **Carbon** ion mass: 12 m_0

m_0= 1.67 × 10^{-27} kilograms



Comparison of dose for prostate cancer (protons vs. X-rays)

Particle therapy recommended for **cancers close to critical organs and paediatric**. Many ongoing clinical trials to assess benefits for different types of cancer in terms of **side effects** and **recurrencies**.

Today only protons and carbon ions **are licensed for treatment**. Trials with helium ions (intermediate between the two) are starting at HIT Heidelberg.

The EU particle therapy landscape

Particle therapy centres in Europe. Courtesy of ENLIGHT, 2020

Most European countries are now equipped for particle therapy, and others are rapidly following (Spain has just signed a contract for 10 proton therapy centers).

Only two regions are not covered;
- Baltic countries and Finland
- South East Europe

Worldwide, >150 proton therapy centres, 12 carbon therapy

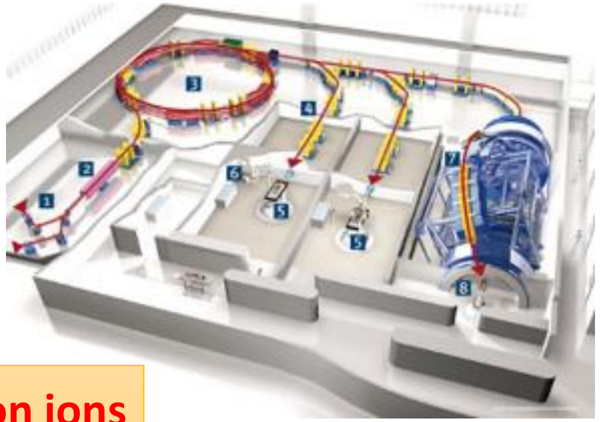
Comparing accelerator designs

Heavier ions are more effective because they deliver more energy to the tissues, but need more energy to enter the body → factor 2.8 in accelerator diameter from protons to carbon

Linac, X-rays
~50 m^2
~few M€

courtesy IBA

Cyclotron, protons
~500 m^2
~40 M€



Synchrotron, carbon ions
~5,000 m^2
~250 M€

Commercially available

Specially designed and built

Range to explore: compact synchrotron for light ions

The CERN Next Ion Medical Machine Study

- **Proton** therapy is now commercial, and CERN, as an international organisation, cannot interfere with a mature commercial market.
- **Ion** therapy is still in an early phase despite its advantages, limited by:
  - ✓ **Size and cost of the accelerator**;
  - ✓ **Lack of experimental data**.
- New demands from the medical community and new opportunities from accelerator technologies can be integrated in a newly designed ion therapy facility.

nimms

Approval in 2019 of the **Next Ion Medical Machine Study (NIMMS).**

In line with CERN mission, the goal of NIMMS is to build on CERN expertise to develop a portfolio of technologies that can be used in a next generation facility, more than developing a single design (NIMMS as a «toolbox»).

NIMMS as an international collaboration

NIMMS is an international collaboration based at CERN to develop new technologies for the future generation of accelerators for cancer therapy with ions.

- Building on the CERN experience in small accelerators and in accelerators for medicine;
- Federating partners to develop innovative designs and technologies;
- **Partners** can use the NIMMS technologies to assemble their own optimized facility.

NIMMS collaboration in 2023 (19 partners)

- SEEIIST (South-East European International Institute for Sustainable Technologies)
- TERA/TERA-CARE Foundation (Italy/CH)
- Riga Technical University (Latvia)
- GSI (Germany)
- INFN (Italy)
- CIEMAT (Spain)
- Cockcroft Institute (UK)
- University of Manchester (UK)
- CNAO (Italy)
- Imperial College (UK)
- MedAustron (Austria)
- U. Melbourne (Australia)
- ESS-Bilbao (Spain)
- Sarajevo University (Bosnia &H.)
- University of Thessaloniki (Greece)
- PARTREC (Netherlands)
- TENMAK (Türkiye)
- ITRE (Slovenia)
- University of Malta

NIMMS Funding:

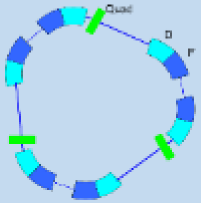
- CERN Knowledge Transfer
- SEEIST, RTU and TERA (personnel at CERN)
- European projects HITRIplus and I.FAST
- Donations

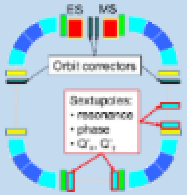
In 2022/23 NIMMS has supported:

- 8 PhD Students
- 3 Post-Docs
- 2 Master students

The four NIMMS Work Packages

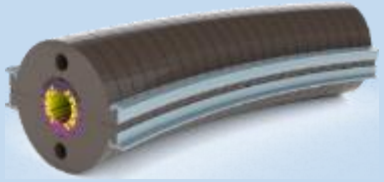
1. Small synchrotrons for particle therapy





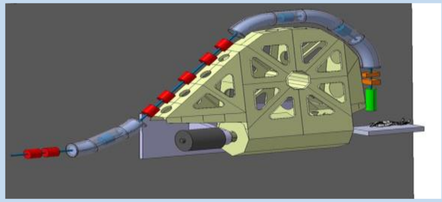
Reduced dimensions with improved performance (injection, extraction)

2. Curved superconducting magnets for synchrotrons and gantries



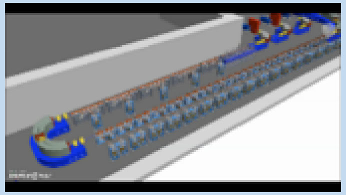
Canted Cosine Theta, NbTi or HTS

3. Superconducting gantries



Precise beam delivery on multiple angles

4. Linear accelerators for ions



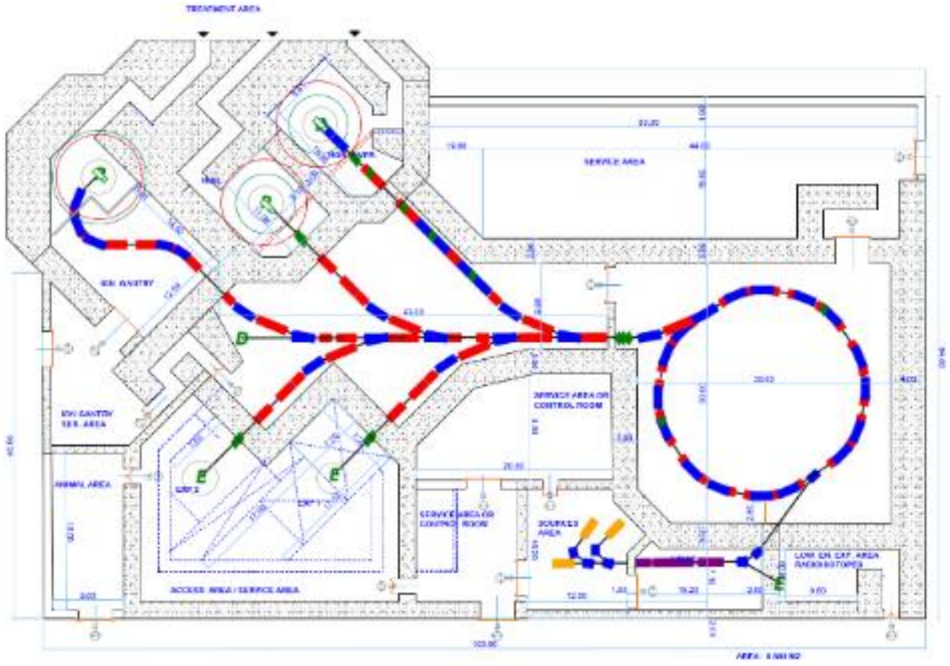
Compact bent full-linac
Synchrotron injector with isotope production

NIMMS supported designs: SEEIIST carbon ion therapy and research facility

Intensive design work in 2019/20 for a **modern facility for research and therapy with protons and carbon ions**

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.
5. Multiple energy extraction (multiple flat-tops) for faster treatment.



Total 5,400 m^2
(including shielding)

Estimated cost (2020): 240 M€

SEEIIST (South East Europe International Institute for Sustainable Technologies): a new international partnership aiming at the construction of a new Research Infrastructure for cancer research and therapy in South East Europe (11 member countries).

Goals are to develop a new advanced design and to build international cooperation and scientific capacity in a region that will join EU but is less develop and still divided, in the line of "science for peace".

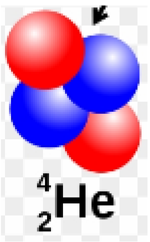
SEE ST
South East European International Institute for Sustainable Technologies

NIMMS supported designs: compact research and therapy facility with p and He

Recent interest in treatment with He beams:

- reduced lateral scattering than protons
- lower fragmentations than carbon
- lower neutron dose
- could treat some radioresistant tumours
- well suited for FLASH treatment

First patient treated at Heidelberg, clinical trials in preparation



Physics in Medicine & Biology

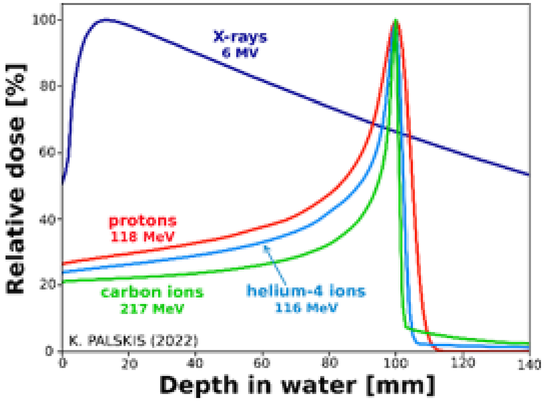
IPEM

TOPICAL REVIEW

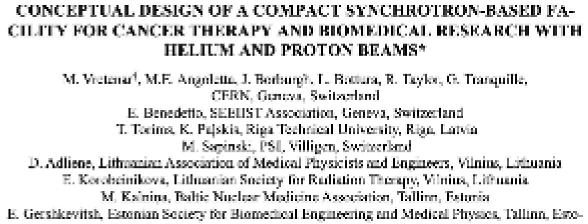
Roadmap: helium ion therapy

Andrea Mairani, Stewart Mein, Eleanor Blakely, Jürgen Debus, Marco Durante, Alfredo Ferrari, Hermann Fuchs, Dietmar Georg, David R Grosshans, Fada Guan, Thomas Haberer, Semi Harrabi, Felix Horst, Taku Inaniwa, Christian P Karger, Radhe Mohan, Harald Paganetti, Katia Parodi, Paola Sala, Christoph Schuy, Thomas Tessonnier, Uwe Titt and Ulrich Weber

Heidelberg Ion Therapy, 2022

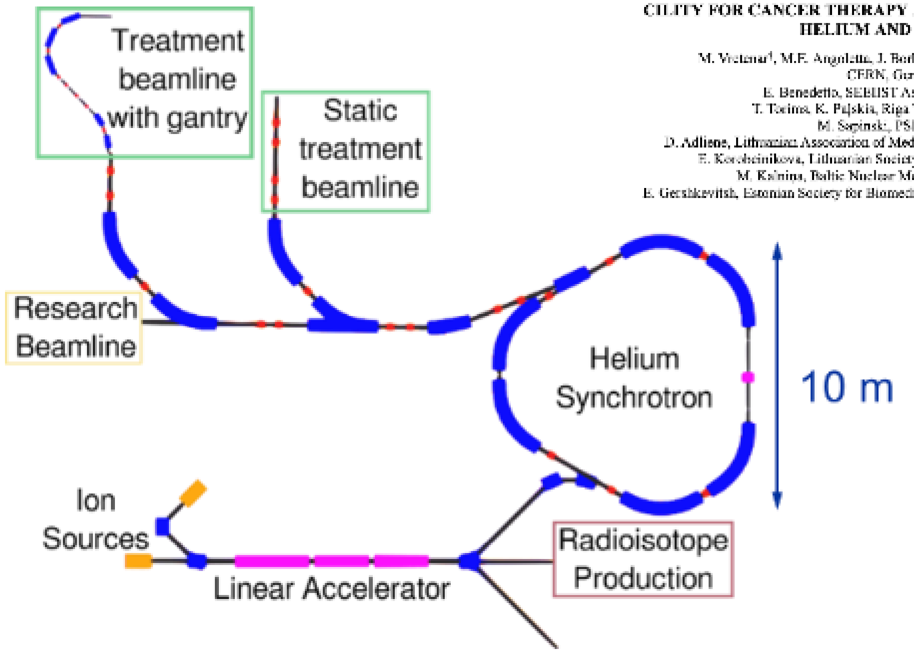


Conceptual design of a facility for research and therapy with protons and helium beams



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

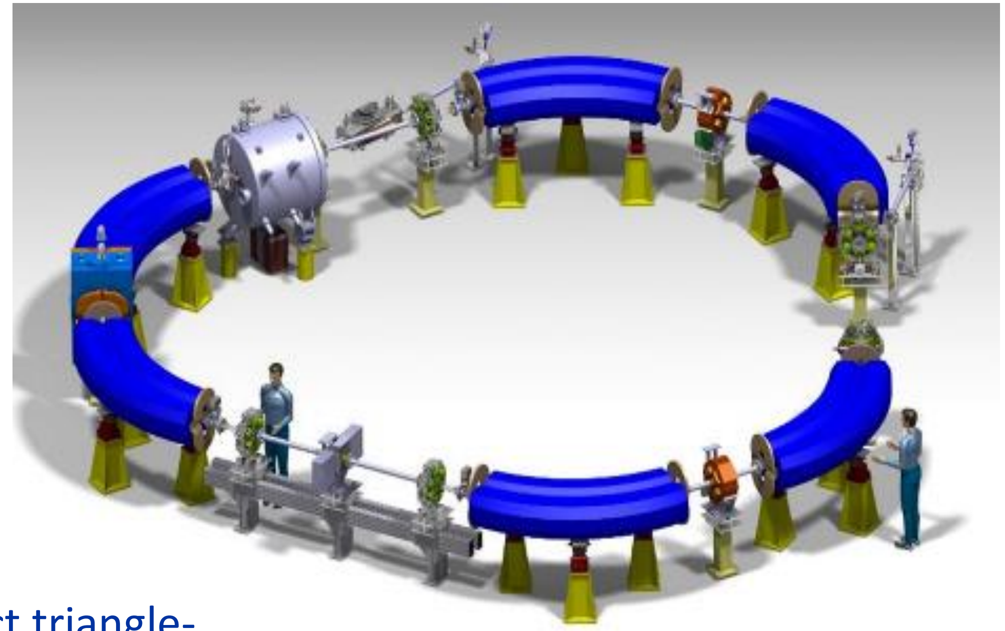
M. Vretenar[1], M.E. Angoletta, J. Borburgh, L. Bottura, R. Taylor, G. Tranquille, CERN, Geneva, Switzerland
E. Benedetto, SEEIIST Association, Geneva, Switzerland
T. Torims, K. Palskis, Riga Technical University, Riga, Latvia
M. Sapinski, PSI, Villigen, Switzerland
D. Adliene, Lithuanian Association 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

1. **Cancer t**reatment with **protons** or **helium**
2. **P**rotons at higher energy for **on-line radiography**
3. **Experimental programme with p, He, C, O**.
4. **FLASH** extraction and **mini-beams**.
5. Parallel production of **radioisotopes** (e.g. 211At)

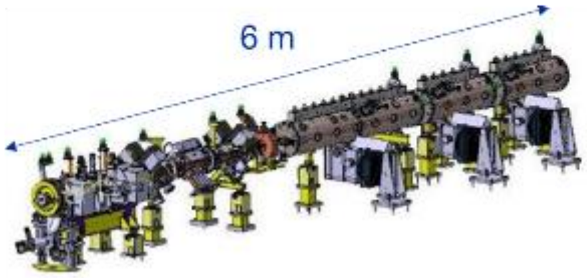
The accelerator elements of the facility



Compact triangle-shaped synchrotron

Design is based on ELENA, a synchrotron for deceleration of antiprotons recently built at CERN

Ion linear accelerator for synchrotron injection and production of medical radioisotopes



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)

More details on the next presentations (Heli, Toms, Kristaps)

CERN

Thank you for your attention