A Compact Synchrotron for Advanced Cancer Therapy with Helium and Proton Beams

M. Vretenar
CERN

IPAC'22

14 June 2022

M.Vretenar, M. E. Angoletta, G. Bisoffi[1], J. Borburgh, L. Bottura, K. Paļskis[2], R. Taylor[3], G. Tranquille, CERN, Geneva, Switzerland
E. Benedetto, M. Sapinski, SEEIIST Association, Geneva, Switzerland
[1] and INFN-LNL, I [2] and Riga Technical University, LV [3] and Imperial College, UK

The CERN Next Ion Medical Machine Study

Next Ion Medical Machine Study (NIMMS):

- Building on the experience of the PIMMS (proton-ion medical machine study) of 1996/2000;
- Federating a large number of partners to develop designs and technologies for next-generation ion therapy;
- Concentrating on technologies for ions – protons are covered by commercial companies;
- Partners can use the NIMMS technologies to assemble their own optimized facility.

nimms

Basic requirements of the next generation ion therapy accelerator:

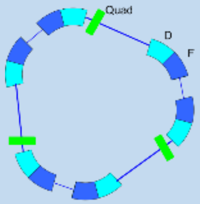
- ❑ Operation with multiple ions (protons, helium, carbon, oxygen, etc.) for therapy and research.
- ❑ Lower cost and dimensions, compared to present;
- ❑ Faster dose delivery with higher beam intensity and new delivery schemes (FLASH)
- ❑ A gantry device to precisely deliver the dose to the tumour.

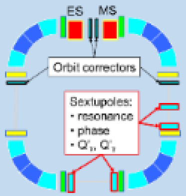
International partners collaborating with NIMMS:

- ❑ SEEIIST (South East European International Institute for Sustainable Technologies)
- ❑ TERA Foundation (Italy)
- ❑ 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)
- ❑ Riga Technical University (Latvia)
- ❑ Sarajevo University (Bosnia &H.)

Four NIMMS Work Packages

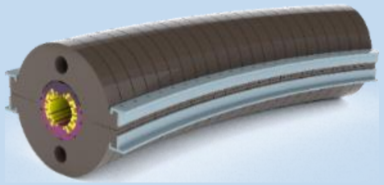
1. **Small synchrotrons for particle therapy**





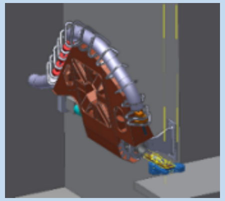
Reduced dimensions with improved performance (injection, extraction)

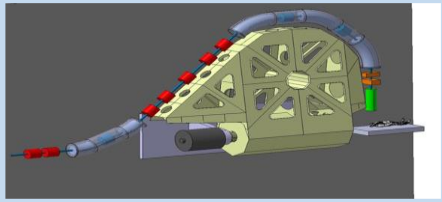
2. **Curved superconducting magnets for synchrotrons and gantries**



Canted Cosine Theta, NbTi or HTS

3. **Superconducting gantries**



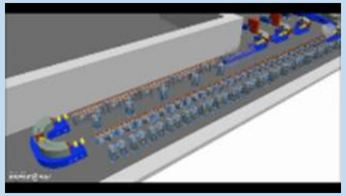


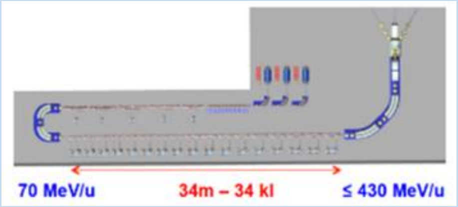
Precise beam delivery on multiple angles

HITRIplus EU project

IFAST EU project

4. **High-frequency ion linacs**



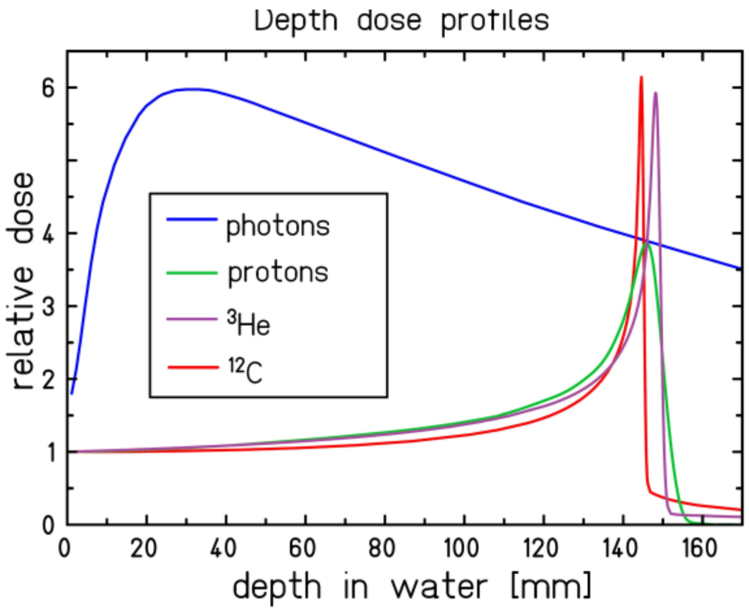


Compact bent layout

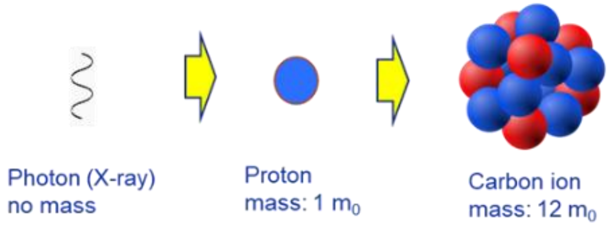
EU supporting initiatives

Modern particle therapy

Particle therapy aims at curing deep solid tumours with minimum damage to surrounding organs – promote health by improving quality of life after treatment



Durante, Debus & Loeffler, *Nat. Rev. Phys.* 2021



The Bragg peak gives a clear advantage to particles w.r.t. X-rays, but Bragg is not all: *biology is more complex than physics*

- Radiobiological effect **RBE** has a complex dependence on energy transfer and particle type: need of experimental work, complex models and sophisticated treatment plans.
- Practical dose delivery reduces ***effectiveness:*** longitudinal scan of tumour leads to higher dose in the penetration zone (Spread Out Bragg Peak),
- The precise dose distribution requires **comparable accuracy** in imaging of tumours and in compensation of organ motion.

Need for more **research**, with the two particles presently licensed for treatment (protons and carbon) and with other ions.

Accelerators for cancer therapy

Ions deliver more energy to the tissues but need more energy to enter the body → larger accelerators

Linac, X-rays
~50 m^2
~5 M€

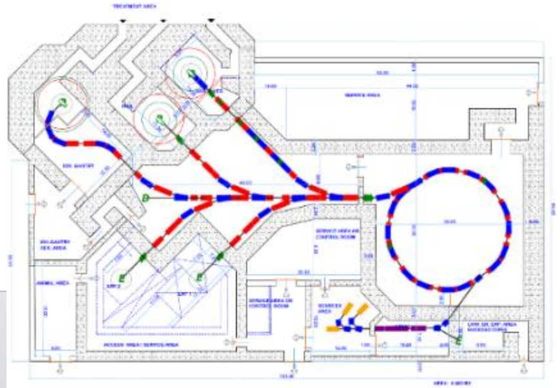
courtesy IBA

Cyclotron or synchrotron, protons
~500 m^2
~40 M€

Cnao , Pavia, Italy

Synchrotron, Carbon ions
~5,000 m^2
~200 M€

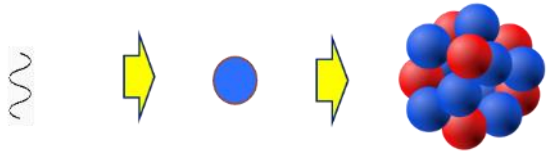
The proposed SEEIIST facility in South East Europe



Commercially available

Specially designed and built

Can we imagine something between protons and carbon?

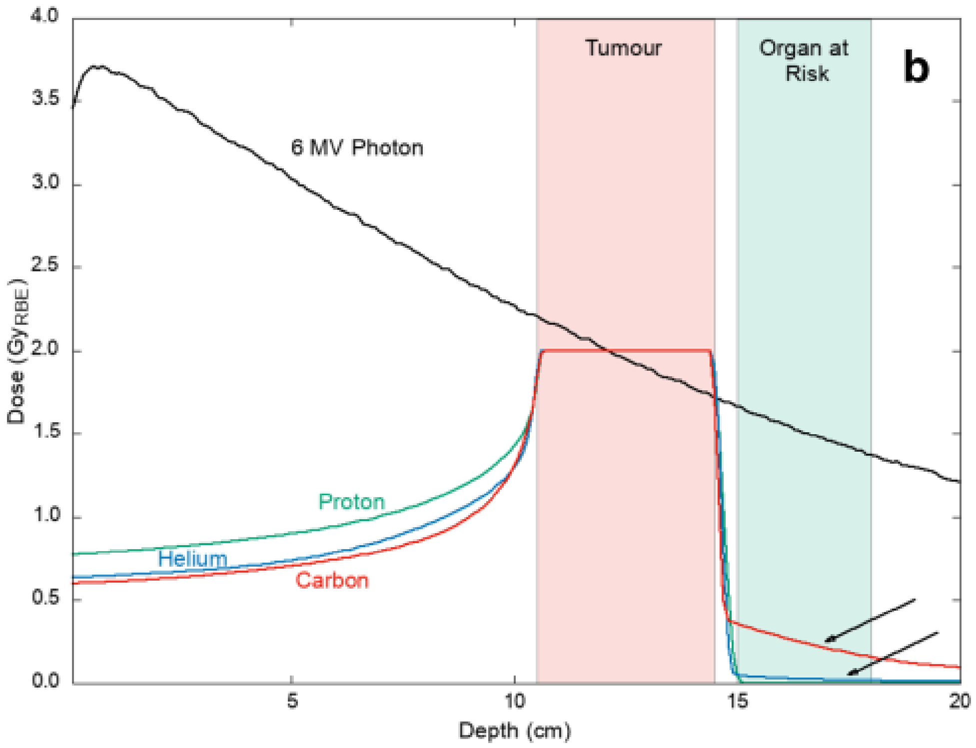


Photon (X-ray)
no mass

Proton
mass: 1 m_0

Carbon ion
mass: 12 m_0

Helium beams for cancer treatment



Spread-out Bragg peak for proton, helium, carbon compared to X-rays *(K. Kirkby et al., Heavy Charged Particle Beam Therapy and related new radiotherapy technologies, https://doi.org/10.1259/bjr.20200247)*

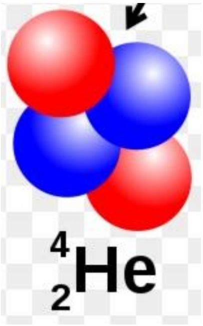
- Treatment with helium is under advanced study at carbon therapy centres.
- First patient treated in September 2021 at the Heidelberg Ion Therapy (D).
- Clinical trials ongoing, will be soon licensed for treatment.
- An accelerator designed for helium treatment can easily produce protons for standardised treatment, and be used for research with helium and heavier ions.

- ➢ reduced lateral scattering w.r.t. protons,
- ➢ lower fragmentations than carbon,
- ➢ lower neutron dose than protons or carbon, reducing risks in paediatric patients,
- ➢ could treat some radioresistant tumours at lower cost than carbon.

Main features of an accelerator for helium therapy

Synchrotron because of size, flexibility and cost:

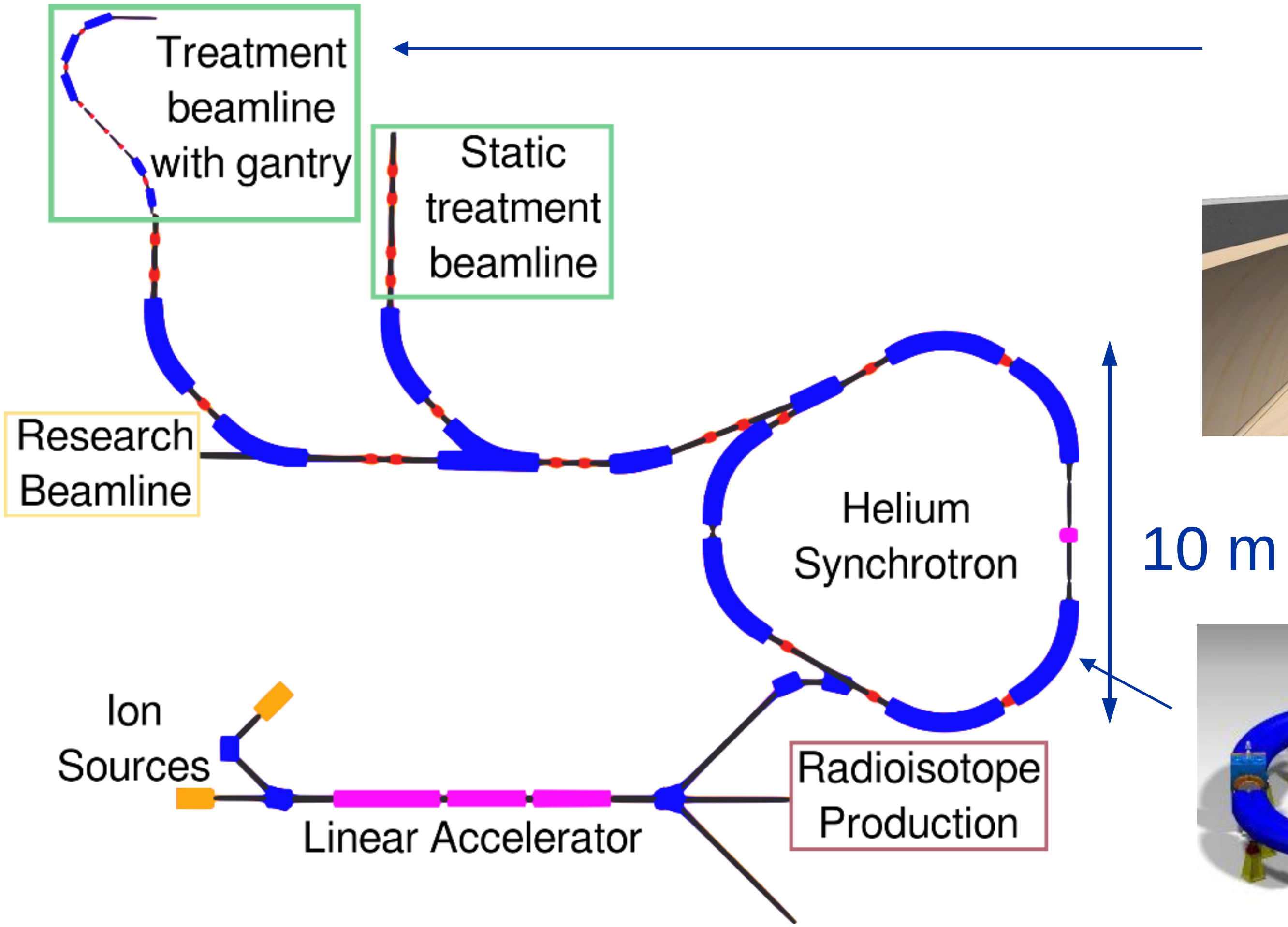
1. Can accelerate protons at treatment energy;
2. Can use protons at higher energy for full body on-line radiography;
3. Can accelerate other ions (carbon, oxygen) for biophysics experiments.
4. Can be equipped with modern FLASH extraction and can produce mini-beams.
5. The linac injector can be used in parallel (at higher duty cycle) for production of radioisotopes (e.g. 211At) using helium ions.

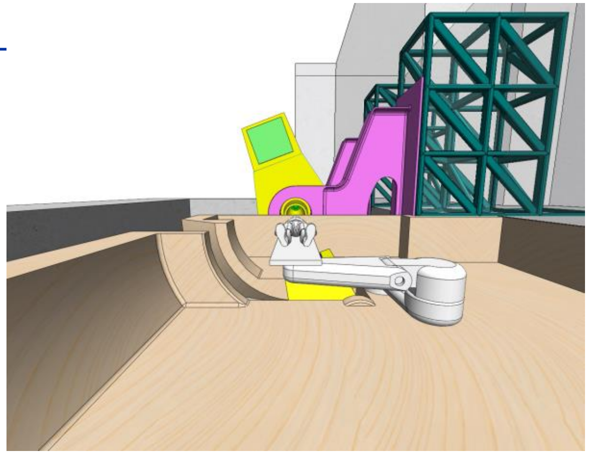


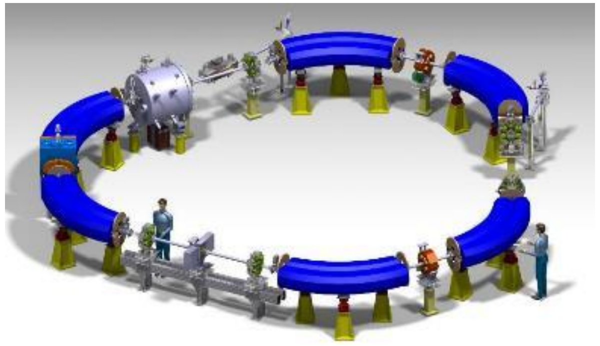
Main synchrotron parameters:

- maximum magnetic rigidity 4.5 Tm (**220 MeV/u** for 4He, penetration 30 cm in water).
- Source current 2 mA for **8 x 10^{10} ions injected**, to irradiate a 1 litre tumour with 2 Gy with a factor 2 margin for losses.
- Helium injection energy **5 MeV/u**. Additional linac tank to accelerate only **protons to 10 MeV**.

Layout of a facility for treatment and research with helium and protons







- Two beamlines for treatment, one for research.
- Rotating superconducting gantry (HITRIplus/SIG collaborations).
- Linac for parallel radioisotope production (211At for targeted alpha therapy)
- Surface ~1,600 m2

The synchrotron

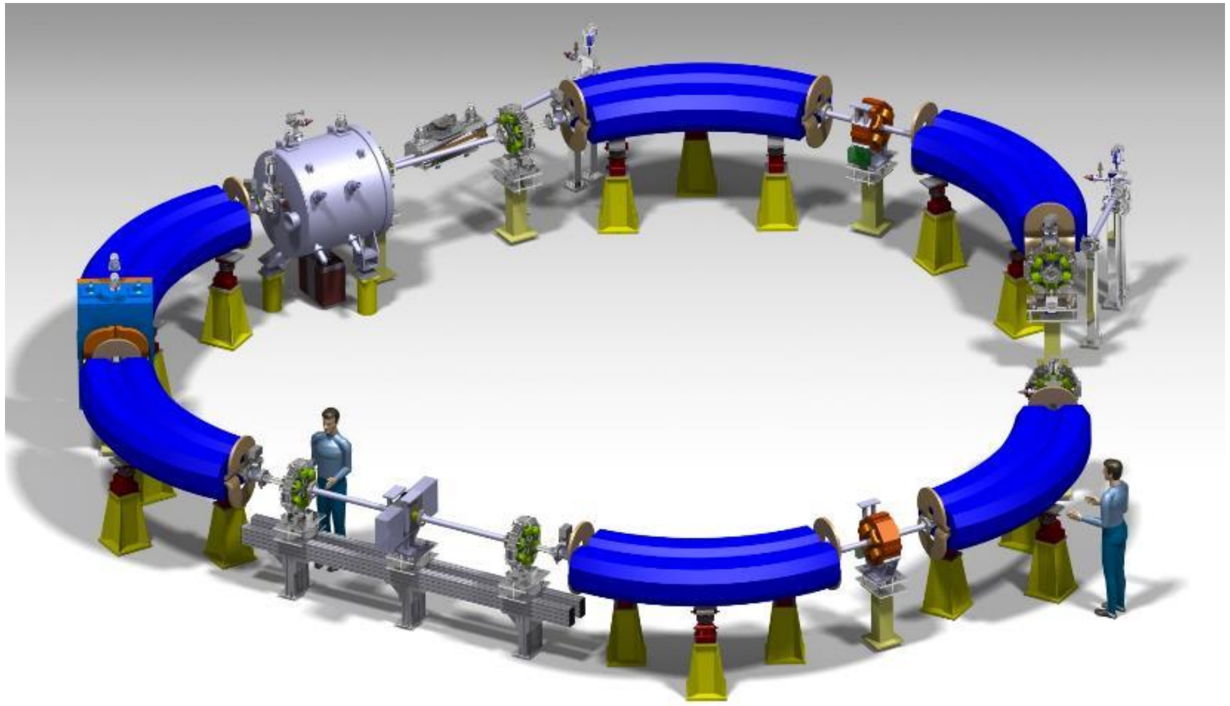
Design based on CERN experience in small synchrotrons (LEAR, LEIR, ELENA)

Three straight sections (injection, extraction, RF)

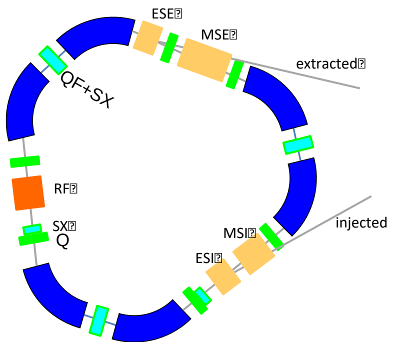
Conservative dipole field of 1.65 T (minor impact on ring size).

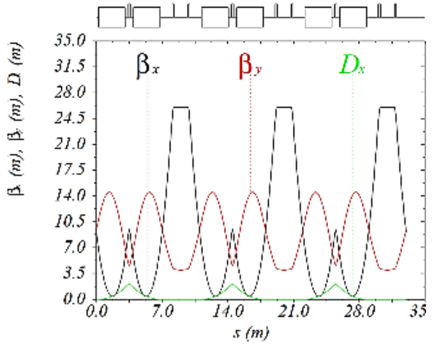
Estimated energy consumption ~430 kW (to be optimized).

Injector linac at 352.2 MHz, based on CERN Linac4 design



Preliminary design, circumference 33 m





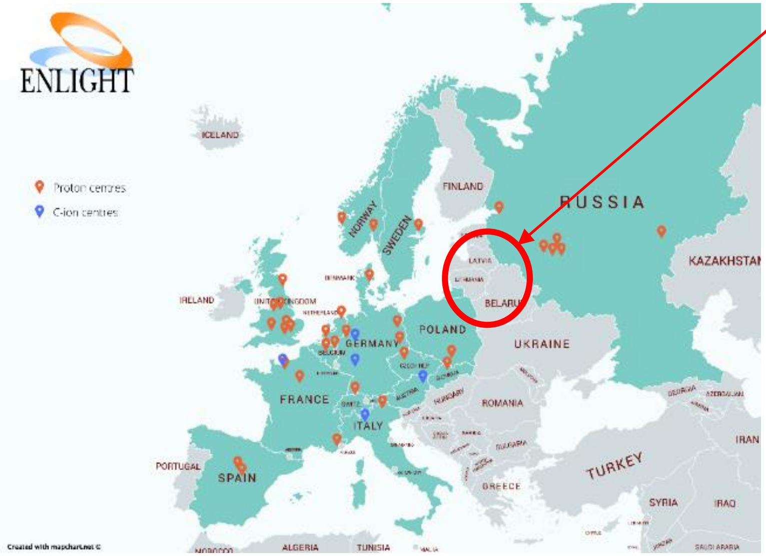
Same design (straight sections) to be used for a superconducting synchrotron for carbon ions

Conclusions

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

- Helium beams present a promising alternative for advanced cancer therapy.
- On top of new helium therapy, a helium synchrotron can provide conventional proton therapy with improved performance and can support a wide experimental programme.

This configuration is already being considered for new particle therapy initiatives, as the recently proposed Advanced Particle Therapy Centre for the Baltic States.



Particle therapy centres in Europe. Courtesy of ENLIGHT, 2020

Thank you for your attention,

and please visit our 6 related posters:

- **THPOMS019** Slow Extraction Modelling for NIMMS Therapy Synchrotrons
- **THPOMS022** Production of Radioisotopes for Cancer Imaging and Treatment With Compact Linear Accelerators
- **THPOMS011** Beam Optics Studies for a Novel Gantry for Hadrontherapy
- **THPOMS012** Explorative Studies of an Innovative Superconducting Gantry
- **THPOMS049** Energy Comparison of Room Temperature and Superconducting Synchrotrons for Hadron Therapy
- **THPOMS028**, Performance Study of the NIMMS Superconducting Compact Synchrotron for Ion Therapy with Strongly Curved Magnets