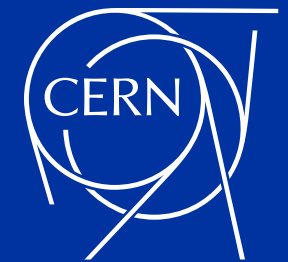


A Compact Synchrotron for Advanced Cancer Therapy with Helium and Proton Beams

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CERN

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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.



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.

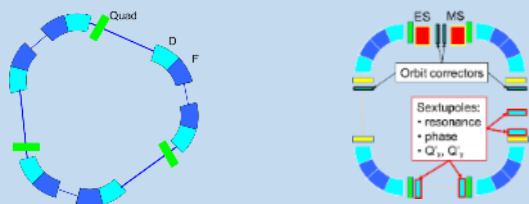
International partners collaborating with NIMMS:

- 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



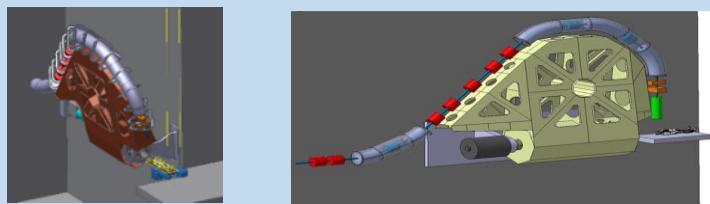
Reduced dimensions with improved performance (injection, extraction)

2. Curved superconducting magnets for synchrotrons and gantries



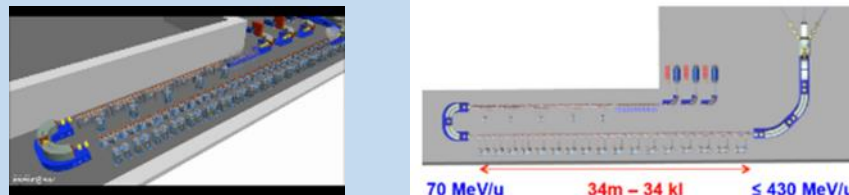
Canted Cosine Theta, NbTi or HTS

3. Superconducting gantries



Precise beam delivery on multiple angles

4. High-frequency ion linacs



Compact bent layout

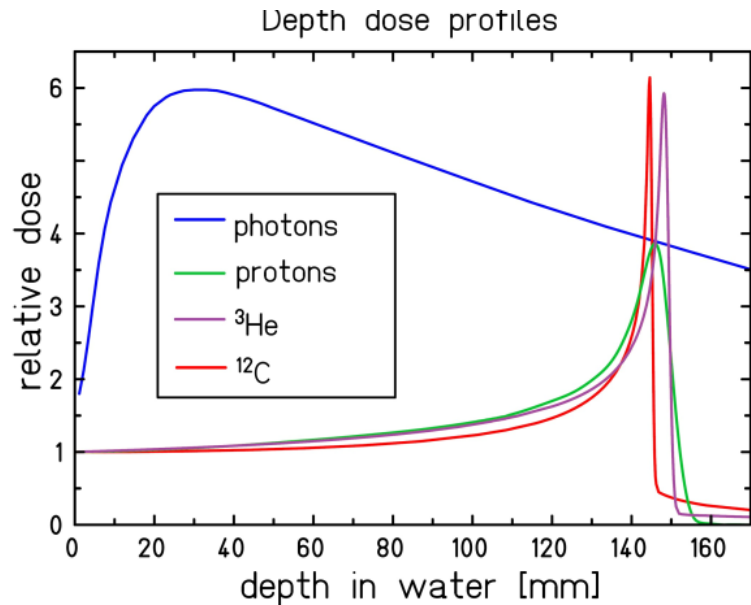
HITRIplus EU project

IFAST EU project

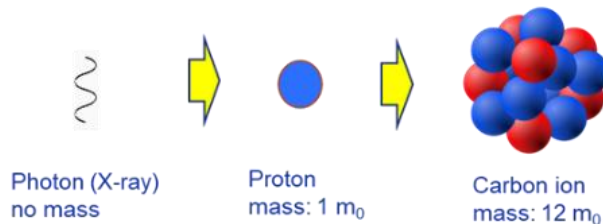
EU supporting initiatives

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

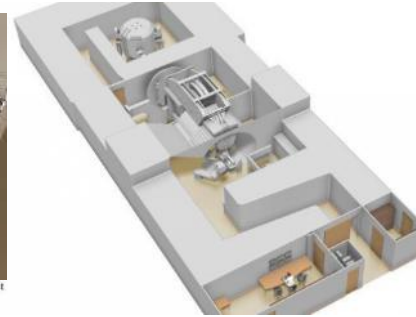
Ions deliver more energy to the tissues but **need more energy to enter the body** → larger accelerators



Linac, X-rays
~50 m²
~5 M€



Cyclotron or synchrotron, protons
~500 m²
~40 M€



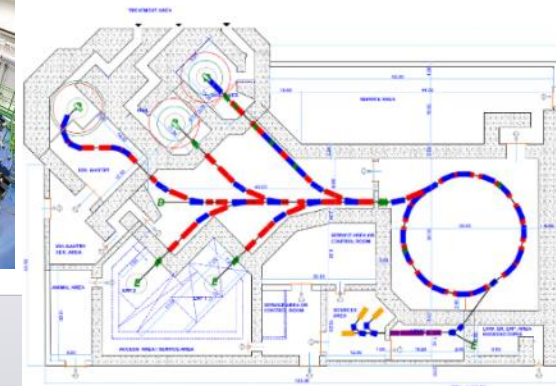
courtesy IBA

Cnao , Pavia, Italy



Synchrotron, Carbon ions
~5,000 m²
~200 M€

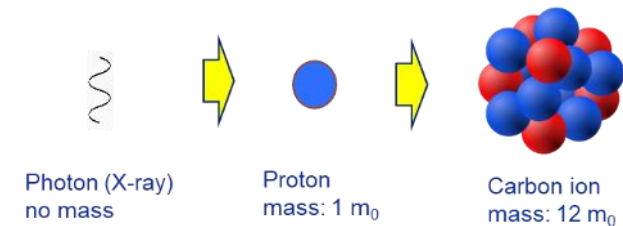
The proposed SEEIIST facility in South East Europe



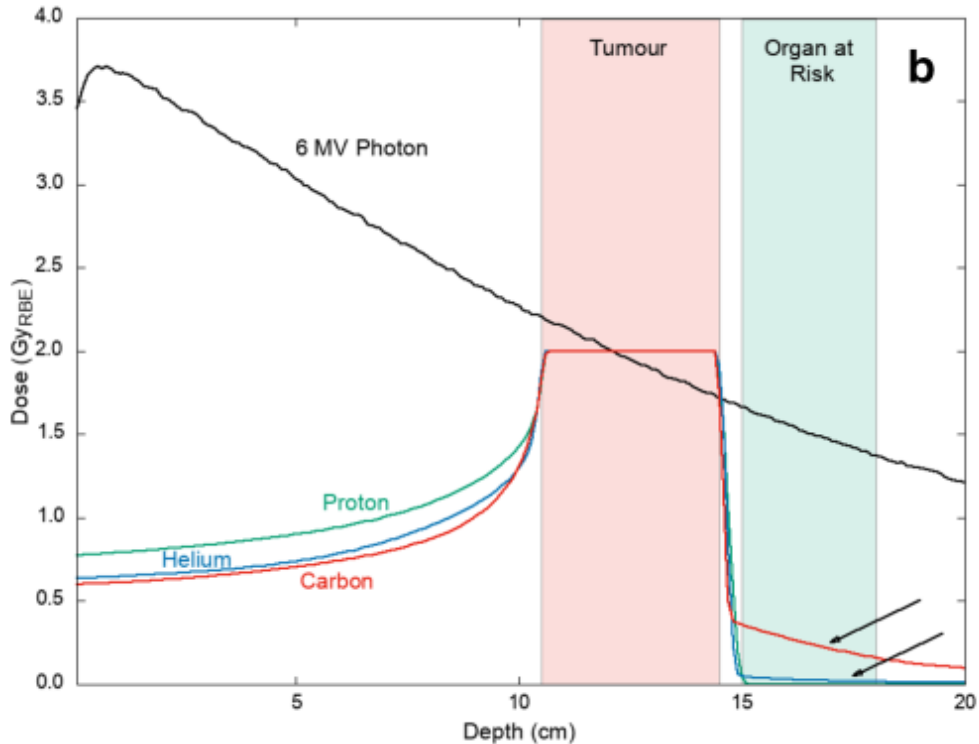
Commercially available

Specially designed and built

Can we imagine something between protons and carbon?



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>)

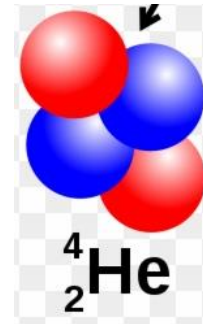
- Treatment with helium is under advanced study at carbon therapy centres.
- **First patient** treated in September 2021 at the Heidelberg Ion Therapy (D).
- **Clinical trials** ongoing, will be soon licensed for treatment.
- An accelerator designed for **helium treatment** can easily produce **protons**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

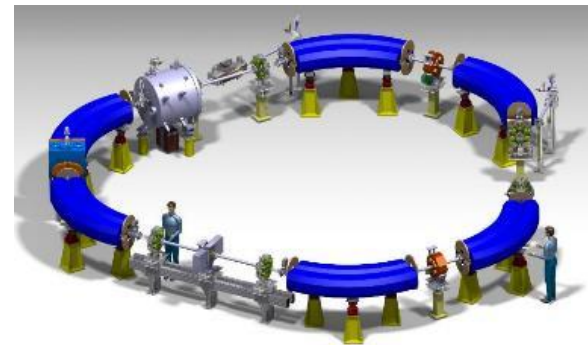
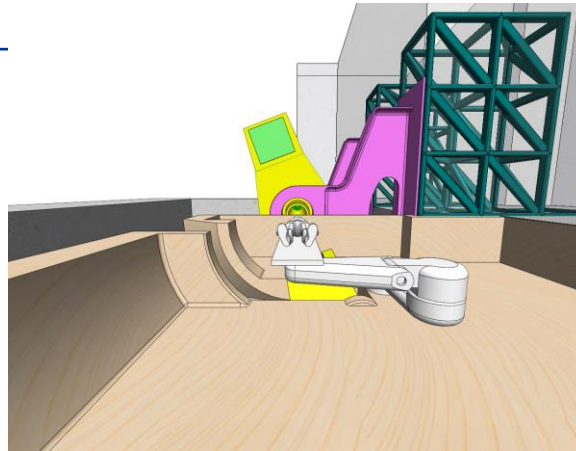
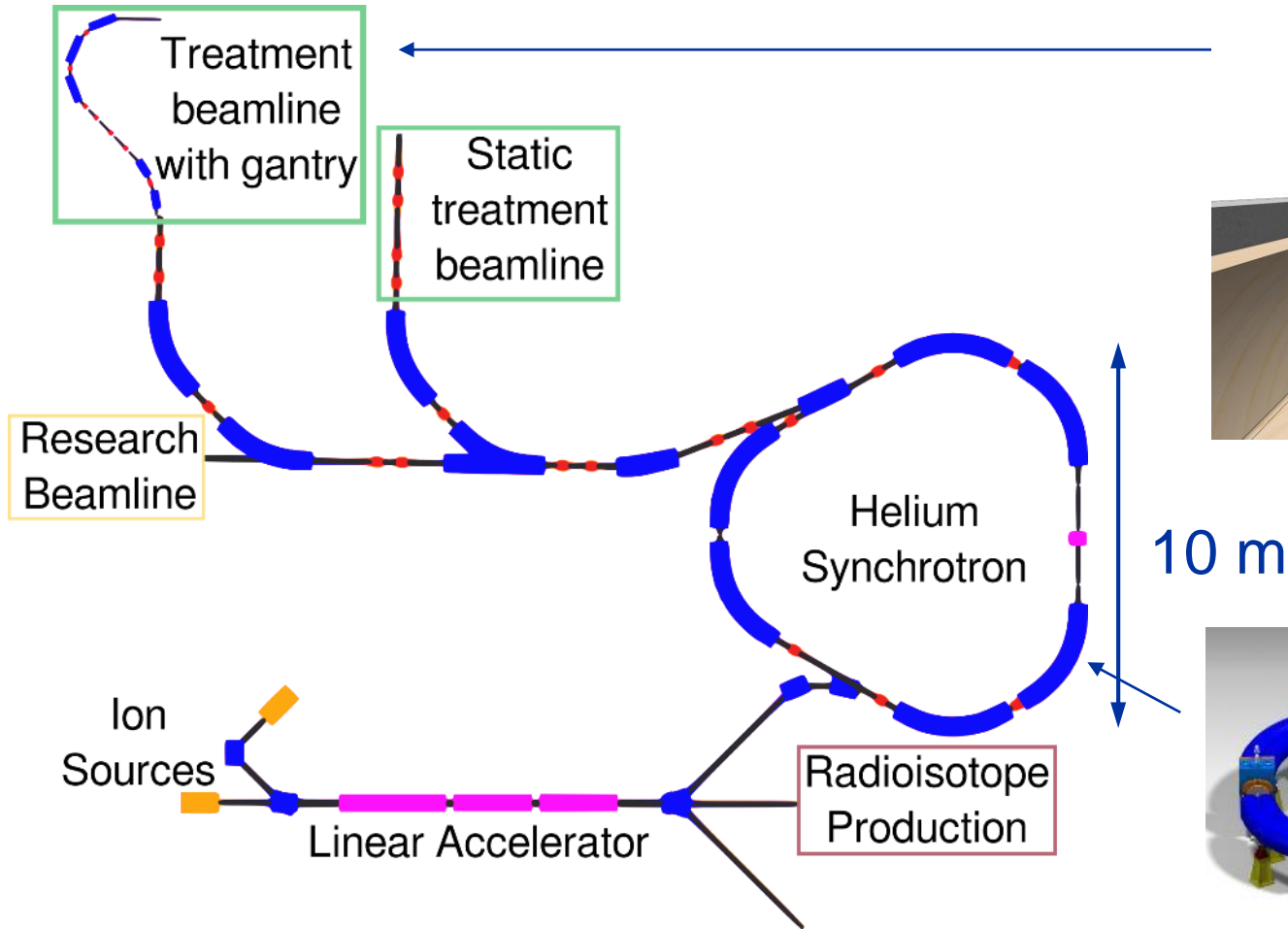
1. Can accelerate **protons** at treatment energy;
2. Can use protons at higher energy for full body **on-line radiography**;
3. Can accelerate **other ions** (carbon, oxygen) for biophysics experiments.
4. Can be equipped with modern **FLASH extraction** and can produce mini-beams.
5. The linac injector can be used in parallel (at higher duty cycle) for **production of radioisotopes** (e.g. ^{211}At) 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 **8×10^{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 (^{211}At for targeted alpha therapy)
- Surface $\sim 1,600 \text{ m}^2$

The synchrotron

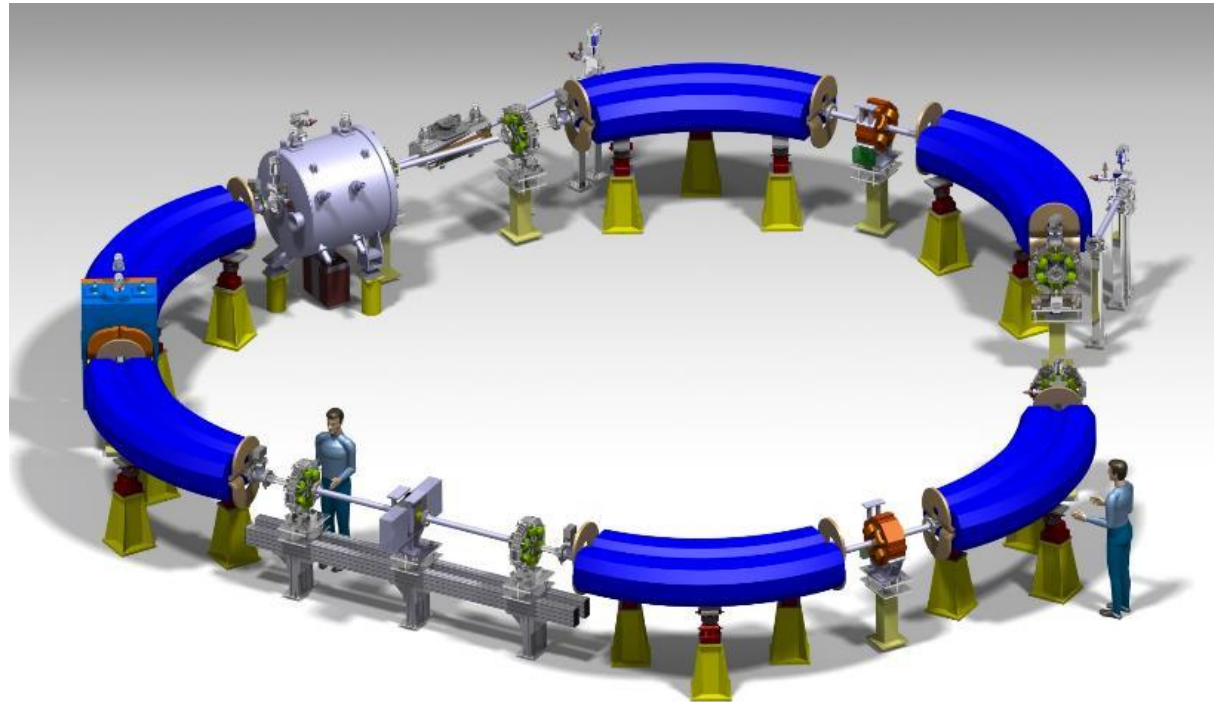
Design based on CERN experience in small synchrotrons (LEAR, LEIR, ELENA)

Three straight sections
(injection, extraction, RF)

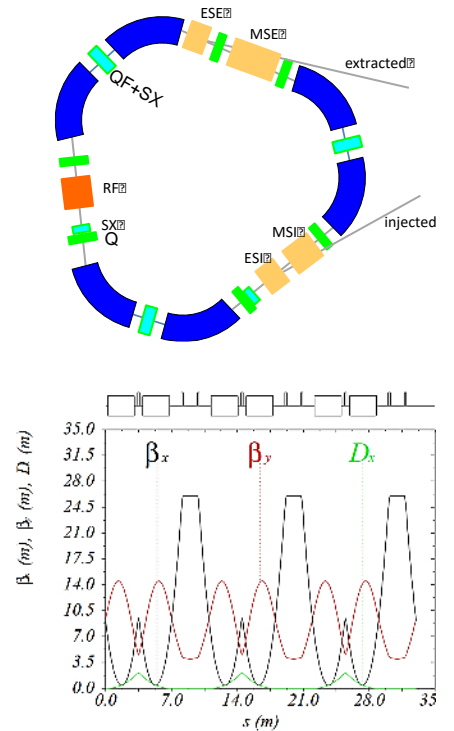
Conservative dipole field
of 1.65 T (minor impact
on ring size).

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

Injector linac at 352.2
MHz, based on CERN
Linac4 design



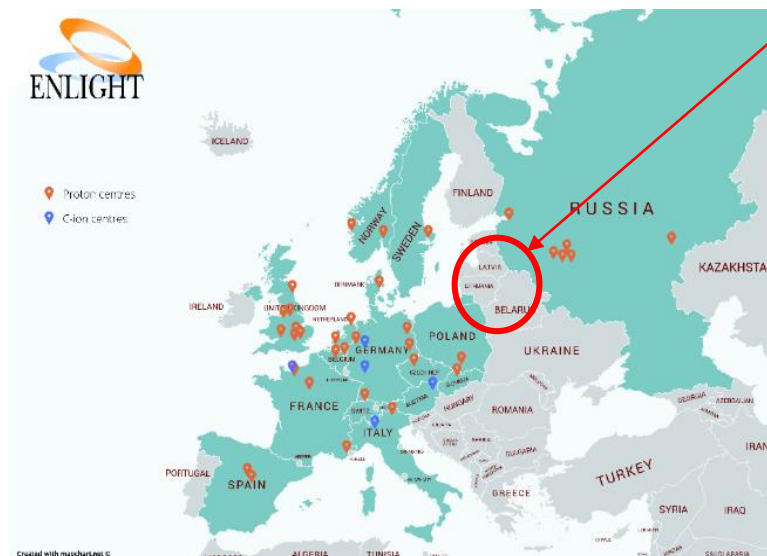
Preliminary design,
circumference 33 m



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

- 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