The NIMMS Programme and the He Synchrotron

Elena Benedetto, SEEIIST Association
Maurizio Vretenar, CERN

20th September 2022, ITRF Kickoff meeting

The CERN **Next Ion Medical Machine Study (NIMMS)** leverages on CERN expertise to develop **technologies and designs** for a new generation of medical accelerators with ion beams

nimms

- NIMMS launched (funded) as a Knowledge Transfer initiative in 2018.
- Started ~20y after PIMMS, on which CNAO/MedAustron are based.
- Federating large number of partners and supported by EU programs: HITRI*plus* and iFAST.
- Focuses on developments for ions – protons covered by industry
- Partners can use the NIMMS technologies to assemble their own optimized facility.

HF Linac
Synchrotron
Gantry
Magnets
AI/ML*
R-isotopes*

* in preparation

International partners collaborating with NIMMS:
- ❑ SEEIIST Association (Switzerland)
- ❑ 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.)

Next generation ion therapy synchrotrons

✧ **Reduced size, weight, cost**

- SC magnets an option

✧ **Multi-ions treatment Vs. optimization for a single ion**

- p, He, C, O, all species for research Vs. Helium (and protons) only

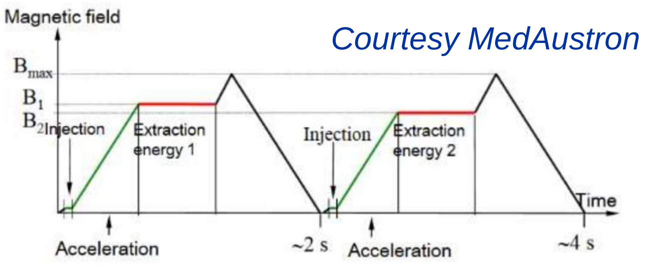
✧ **Higher (x20) beam intensity for flexible delivery:**

- deliver full beam at Multi-Energy in one cycle (Vs. limitation of SC magnet ramp)
- ready for FLASH treatment modalities

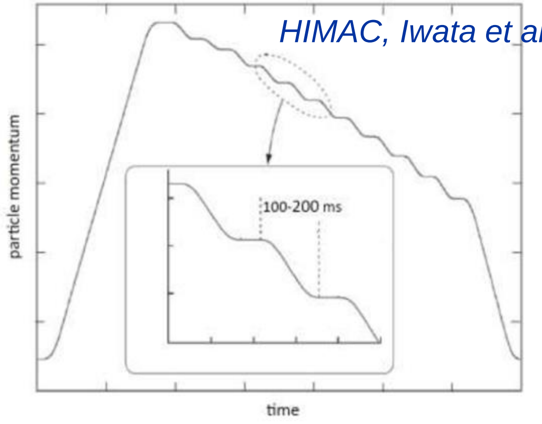
✧ **Energy efficient**

- *Check out: G. Bisoffi et al, IPAC22*

Flexible beam delivery requires x20 higher intensity



TODAY: Every change of energy → A different cycle



Multi-Energy Extraction going down (up) within same cycle

FLASH: deliver the entire *high intensity* in <200 ms

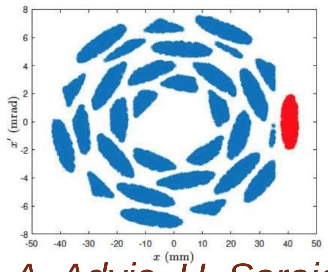
Deliver* 2 Gy in 1 liter tumour

Protons	2.6e11	*U. Amaldi*
Helium	8.2e10	
Carbon	2e10	

* factor ~2 (efficiencies in dose delivery)

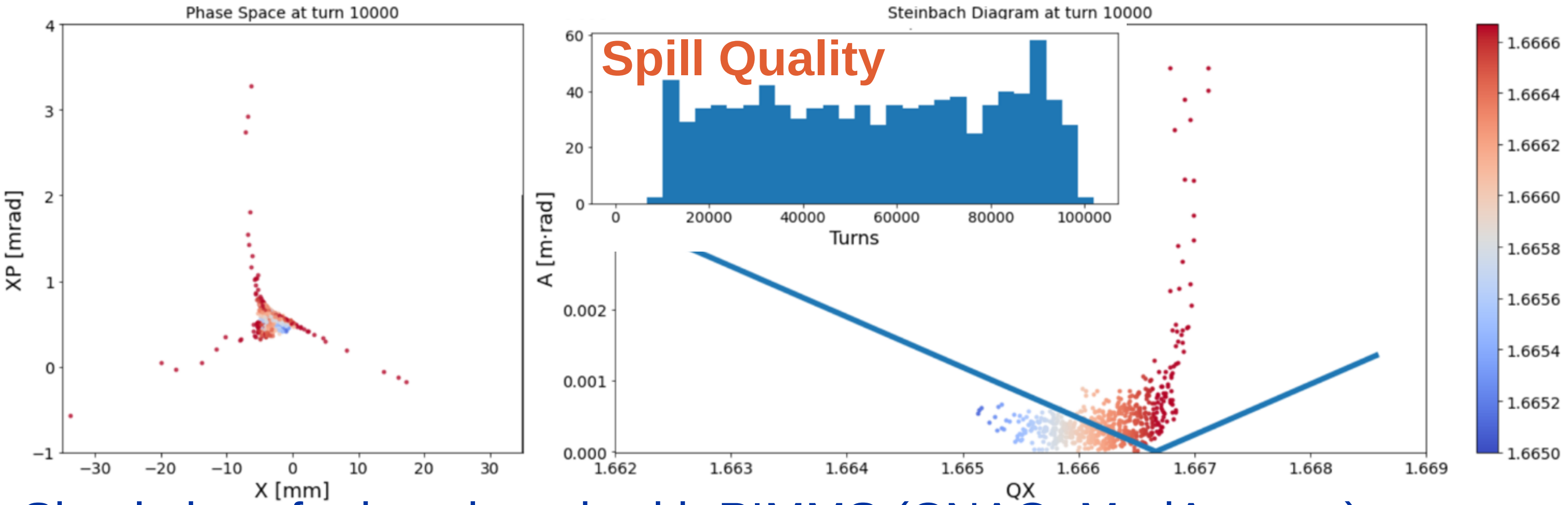
Need:

- ❑ Multi-turn injection optimized
- ❑ High-current sources (R&D)
- ❑ High-transmission in source/RFQ/linac



A. Advic, U. Sarajevo (2019)

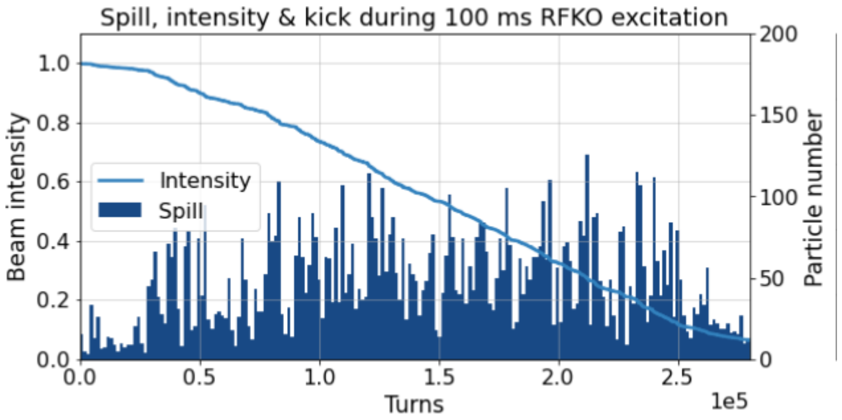
“Fast” slow extraction on the 3rd order resonance



Rebecca Taylor,
CERN/Imperial College

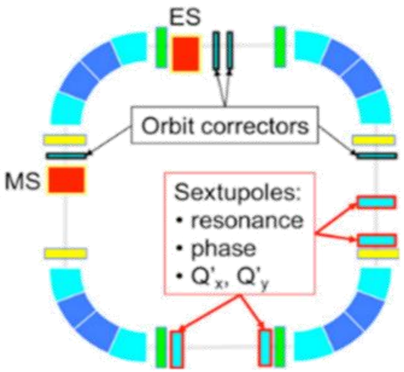
Simulations for benchmark with PIMMS (CNAO, MedAustron)

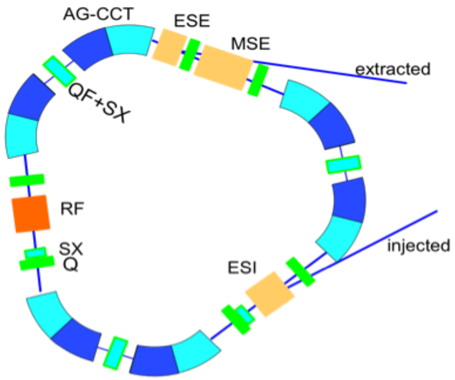
FLASH regime, RF-KO extraction
Preliminary simulations foresee exciter voltage ~1kW for 10urad (10x beyond hardware capability)



SC-magnet compact ring for C-ions

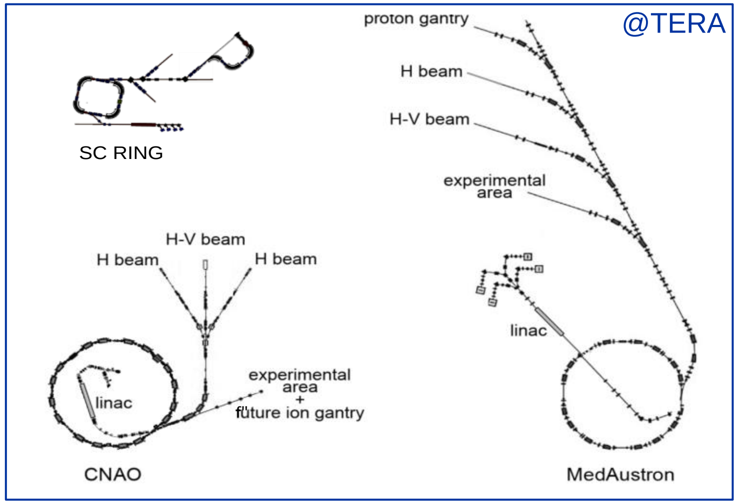
HITRI*plus* Heavy Ion Therapy Research Integration



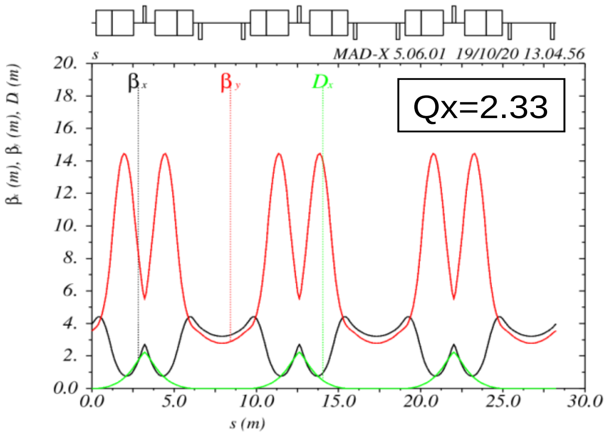


Developed within HITRI*plus* (E. Benedetto)
Evolved to triangular, with 3.5 T 60^0 magnets and a SC quadrupole in between.
No-dispersion in straight sections (inj, extr, RF)

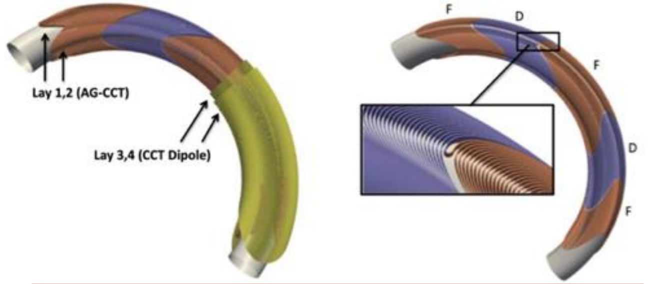
TERA E.Benedetto et al. 2018
https://arxiv.org/abs/2105.04205



~30m length. Optics is flexible with small quads for tune adjustment, carring sextupole + orbit correctors



AG-CCT magnets allow periodic focusing while bending, reducing beta function (and beam size)



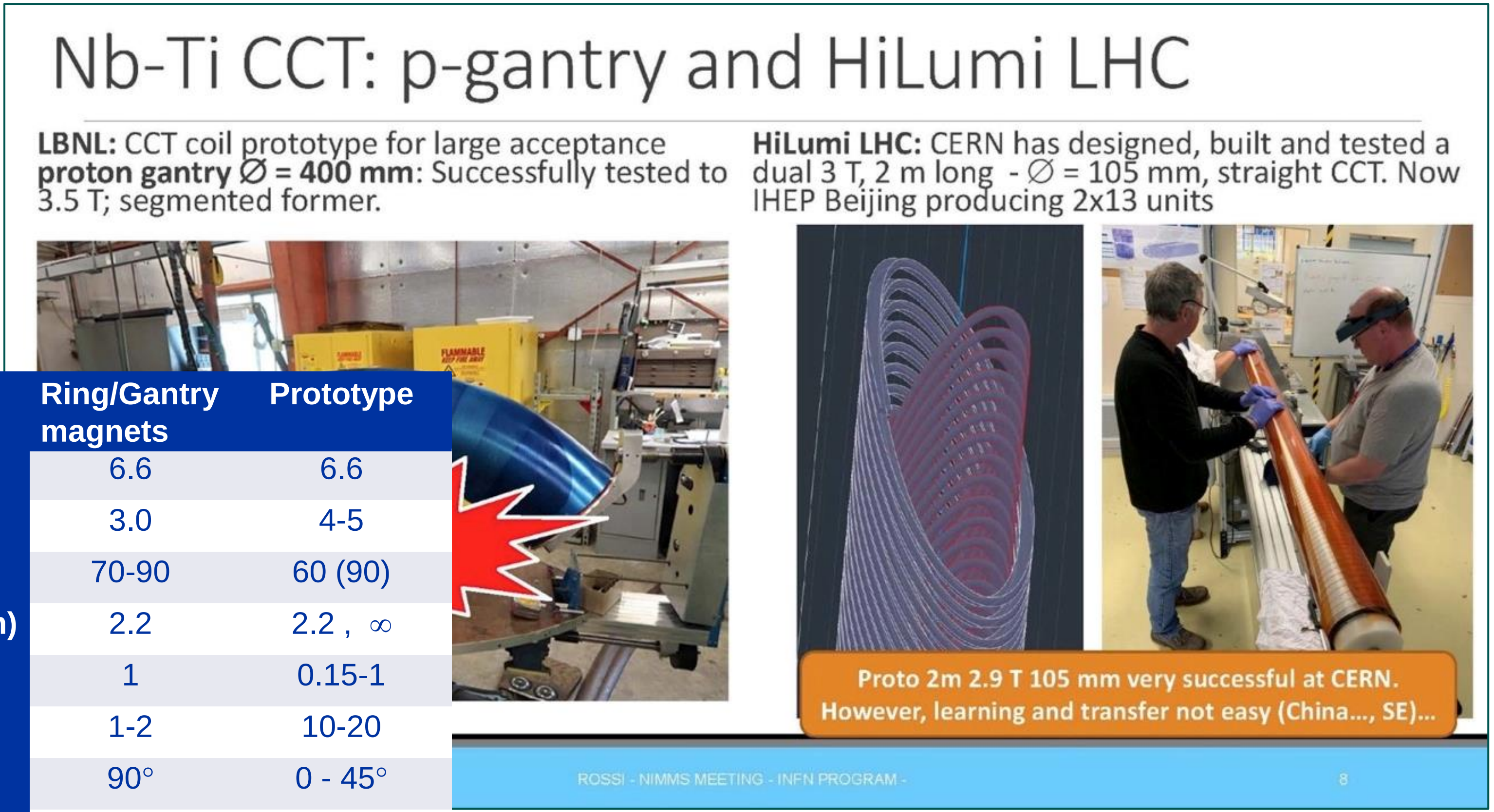
IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 27, NO. 4, JUNE 2017

Design of an Achromatic Superconducting Magnet for a Proton Therapy Gantry

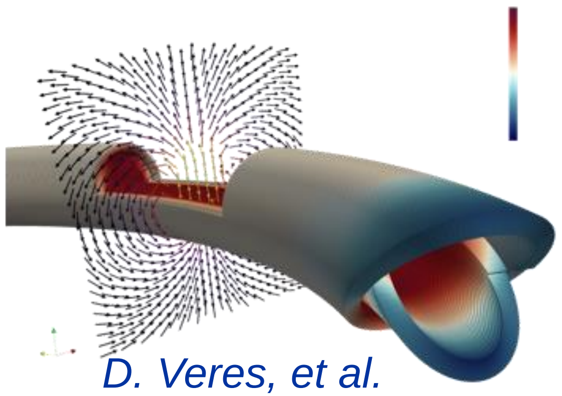
L. Brouwer, S. Caspi, R. Hafalia, A. Hodgkinson, S. Prestemon, D. Robin, and W. Wan

SC Strongly-Curved CCT magnets

L. Rossi



Parameter	Ring/Gantry magnets	Prototype
Bρ (Tm)	6.6	6.6
B_0 dipole (T)	3.0	4-5
Coil apert. (mm)	70-90	60 (90)
Curvature radius (m)	2.2	2.2 , ∞
Ramp Rate (T/s)	1	0.15-1
Field Quality (10^{-4})	1-2	10-20
Deflecting angle	90°	0 - 45°
Alternating-Gradient	yes (triplet)	N/A
Quad gradient (T/m)	40	40
B_{quad} peak (T)	1.54- 1.98	1.2
B_{peak} coil (T)	4.6 - 5	5.6-7
Current (kA)	< 6	< 5
Temperature (K)	5 (8)	5 (20)
Superconductor	NbTi	NbTi (curved), HTS (straight)



D. Veres, et al.

Several prototypes will be built in ~3y from now

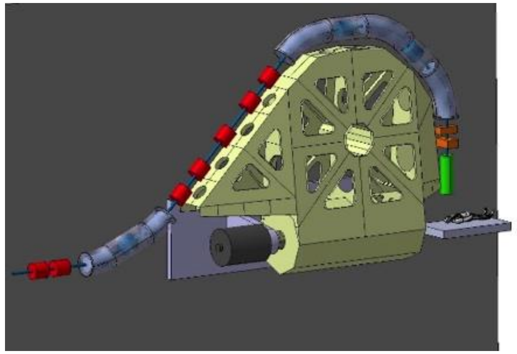
Field Quality in strongly curved magnets (& modeling challenges)

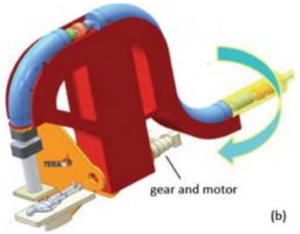
Study group HITRI*plus* E.Benedetto, D.Barna

→ use generalized gradients Vs. multipoles

SC-magnet compact gantry for C-ions

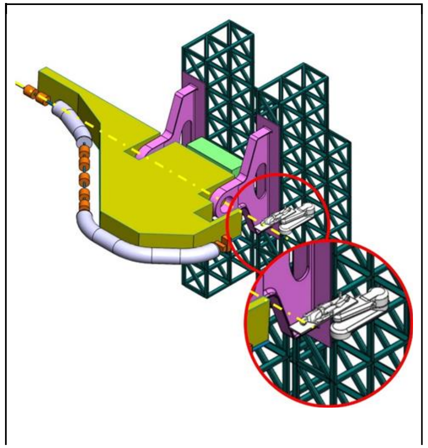
- Gantries for Carbon ions are huge, two SC gantry in Japan, studies in Europe.
- Objective: Develop a superconducting gantry with weight lower than 100 tons and length below 16 metres.
- Subject: a «SIGRUM» type gantry selected by an expert committee in Dec. 2020.
- Development ongoing within HITRI*plus*

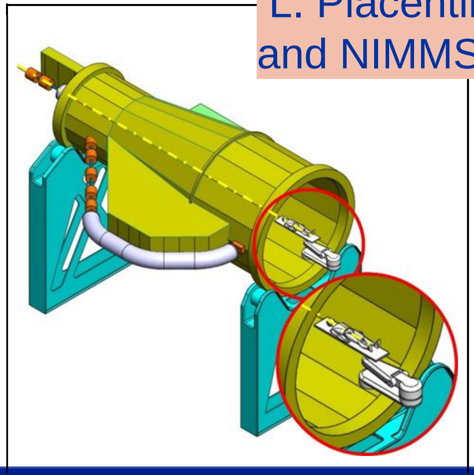




E.Benedetto et al, TERA, https://arxiv.org/abs/2105.04205
U. Amaldi, et. al, TERA + CERN, NIMMS-Note-002

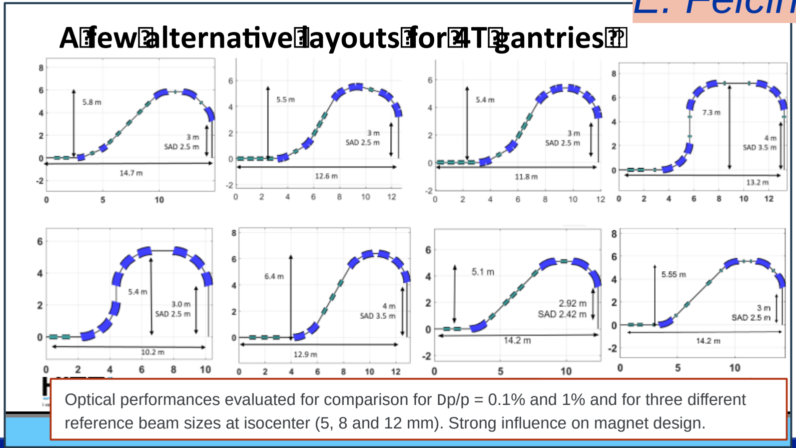
L. Piacentini, Riga U. and NIMMS





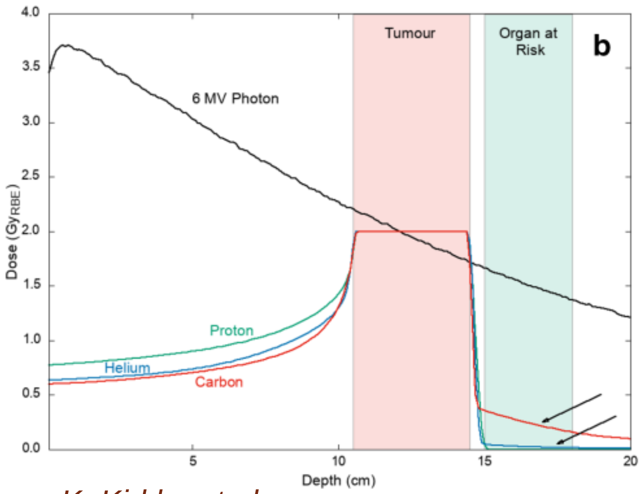
HITRI*plus*
Heavy Ion Therapy Research Integration

E. Felcini, CNAO

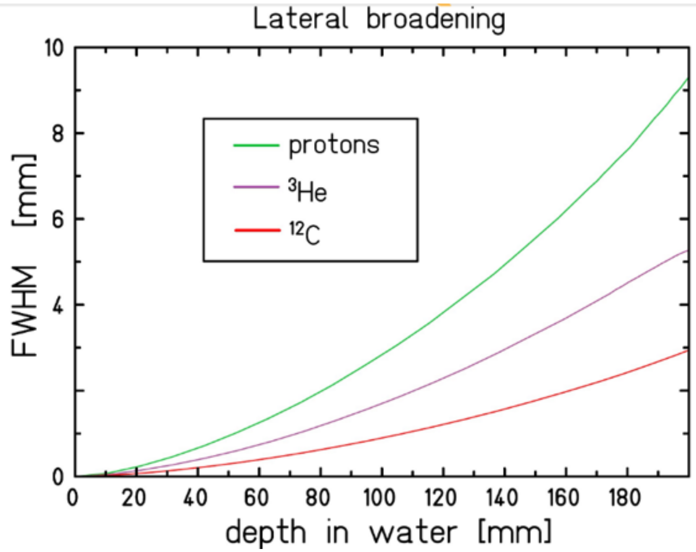


…Why a synchrotron for Helium

M. Vretenar et al., IPAC22



K. Kirkby et al., https://doi.org/10.1259/bjr.20200247



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

Why Helium?

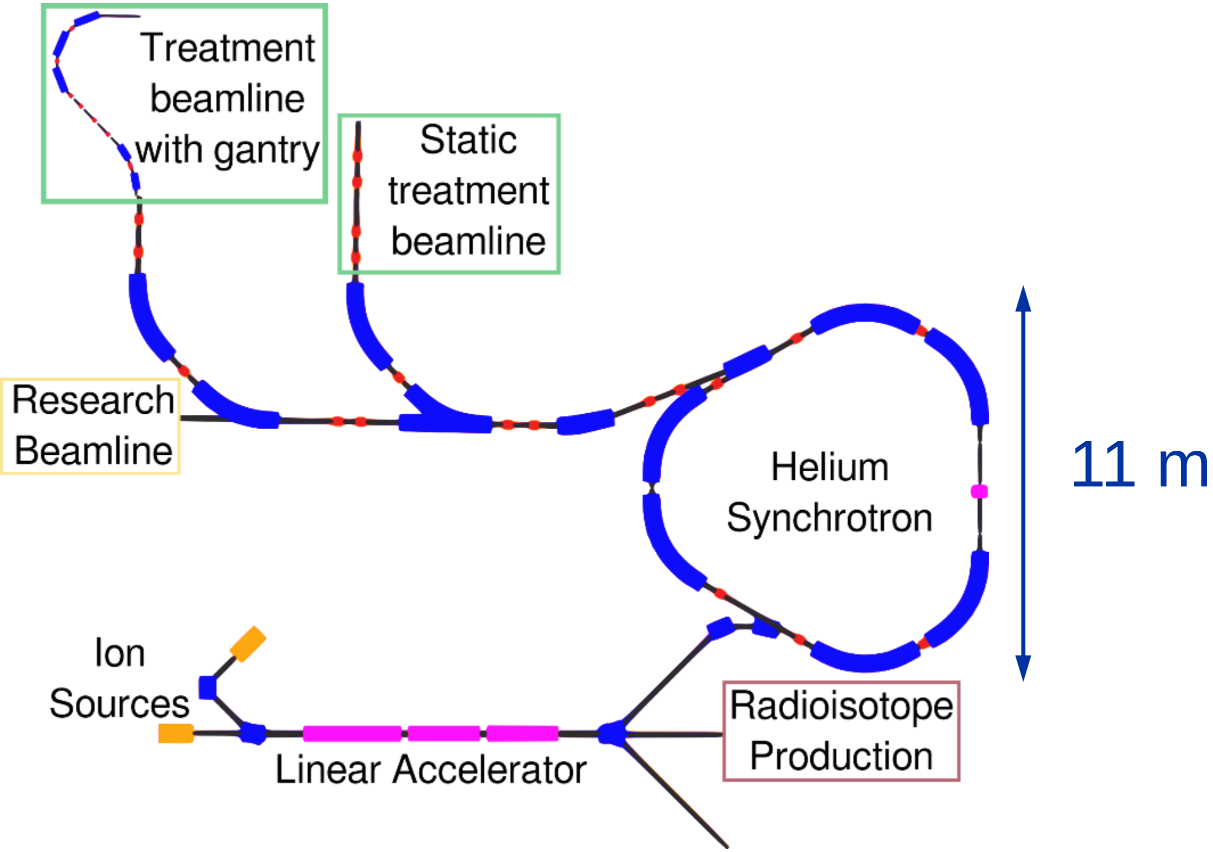
- reduced lateral scattering than p
- lower fragmentations than C
- lower neutron dose than p or C
- could treat some radioresistant tumours

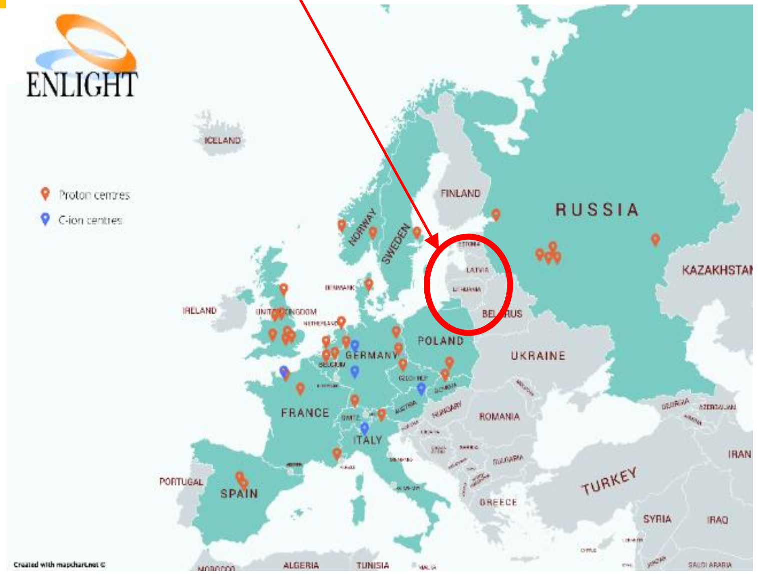
- Max. beam rigidity Brho = 4.5 Tm (~intermediate between p and C)

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

Helium facility

Considered for a recently proposed Advanced Particle Therapy Centre for the Baltic States.



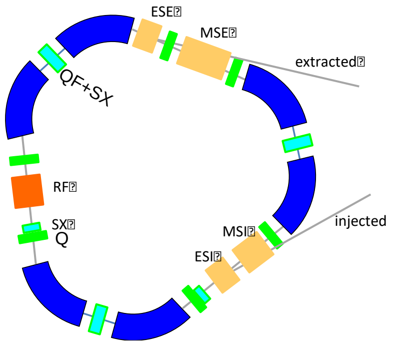


Particle therapy in Europe. ENLIGHT, 2020

- 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

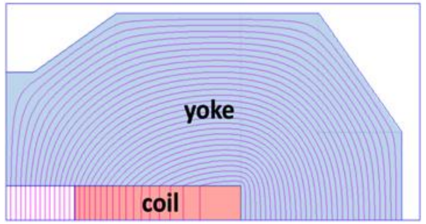
The Helium synchrotron

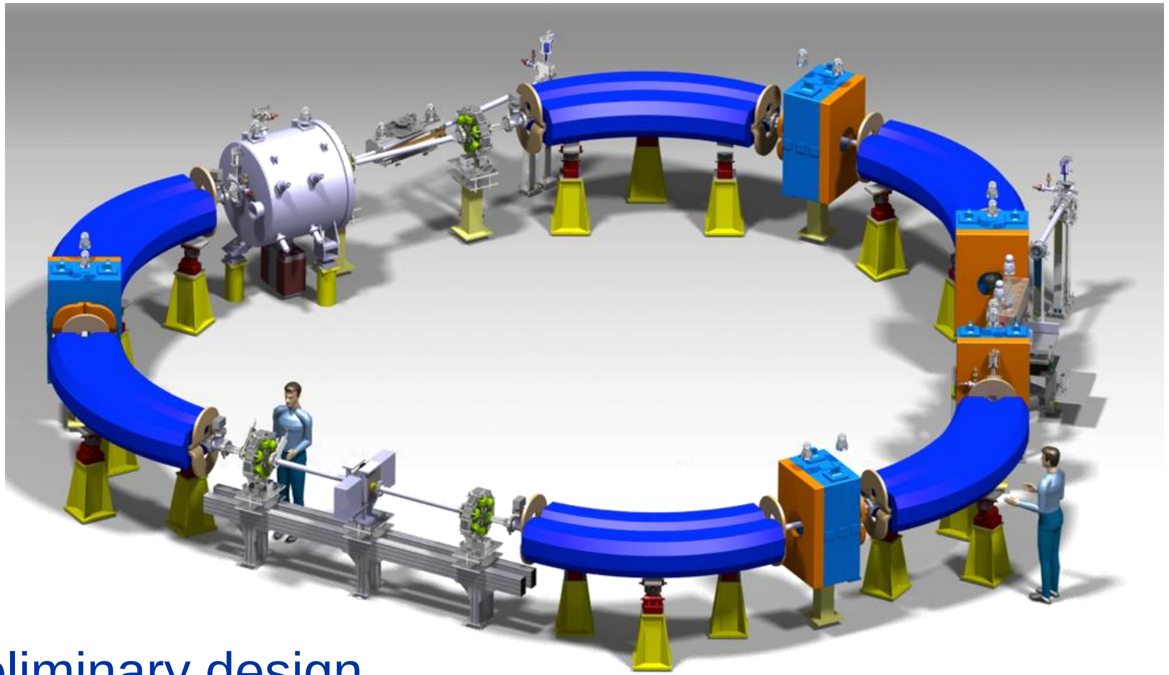
Proven technology – warm magnets - , compact & upgradable

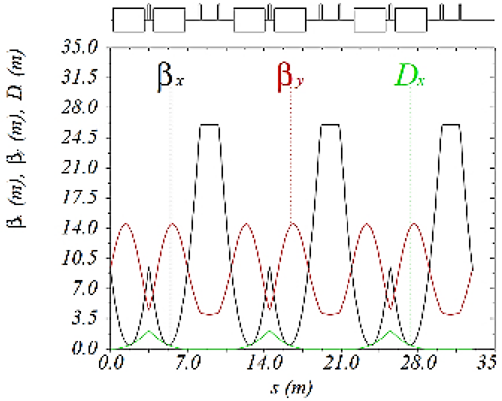


Three straight sections (injection, extraction, RF)

“Conservative” dipole field of 1.65 T (minor impact on ring size), with window-frame magnets.







Preliminary design, circumference 33 m

Injector linac at 352.2 MHz, based on CERN Linac4 design.

CERN experience in small synchrotrons (LEIR, ELENA)

Similarities with SC synchrotron for C- ions, e.g. in the straight sections

Conclusions

At NIMMS we are designing

- Compact synchrotrons based on warm- and SC- magnet technology
- Flexible beam delivery, for conventional irradiation and FLASH

We are looking forward to working with you!

SEEIIST advanced design

South East Europe International Institute for Sustainable Technologies, consortium of 10 countries, facility for cancer in South East Europe.

- ✓ Science for peace
- ✓ Scientific excellence
- ✓ Education & Training

Strategic partner of NIMMS and part of HITRIplus, iFAST

- ➢ Research and therapy with ions: p, He, C, O,… up to Ar
- ➢ Synchrotron baseline is PIMMS layout, option of a compact SC-magnet machine
- ➢ Flexible extraction (multi-energy slow-ex and FLASH)
- ➢ Intensity x20(*) EU facilities

(*)To deliver 2 Gy Carbon ions to 1 liter in one cycle

	p	He	C
Intensity	2.6 e11	8.2 e10	2.0 e10
Inj. Energy (MeV/u)	7-10	5	5
Extr. Energy (MeV/u)	60-250	60-250	100-430
Beam rigidity max (Tm)	2.42	4.85	6.62
Ring diameter (m)		~25m	
Spill duration (s)		0.1 - 60	
Ripple@1kHz (I_{max}/I_{ave})		<1.5	

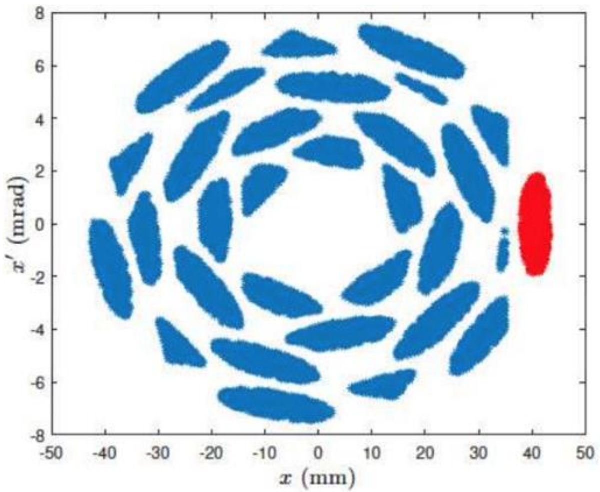
✧ Higher (x20) intensity: MT inj of 2e10 C-ions

Commercially available ECR source ~200 uA C+4

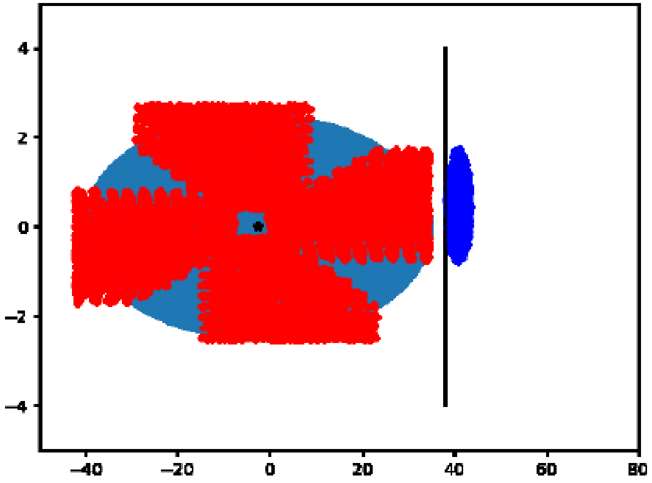
Next generation ECR (e.g. AISHA, Catania) ~600 uA C+4 (in 0.3 mm mrad rms)

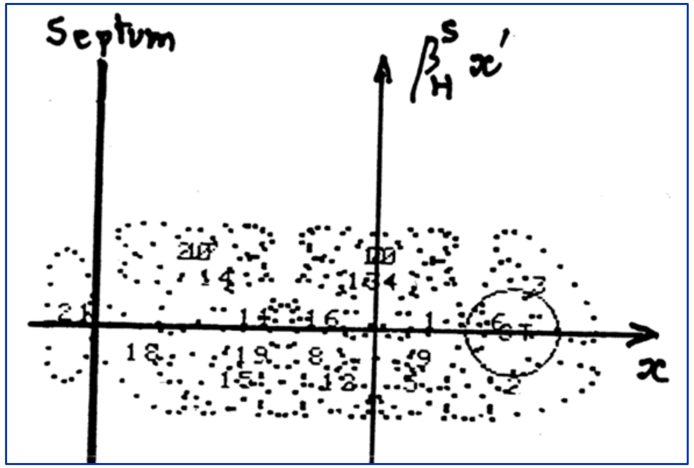
~similar #turns for He-ions (source 1mA)

Injecting @ 5 MeV/u in a 70 m circumference
With 90% (high!) efficiency from source to injection → 13 “effective turns” needed (x2 for the compact)
Final emittance of ~5mm mrad (rms normalized)



A. Advic, U. Sarajevo (2019)


EB, playing to increase brightness



LEIR injection (S.Maury, C.Carli, D. Mohl)