HITRI+ and I.FAST:
next Eu programs for SC heavy ion therapy machine

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HITRI+ and I.FAST

HITRI

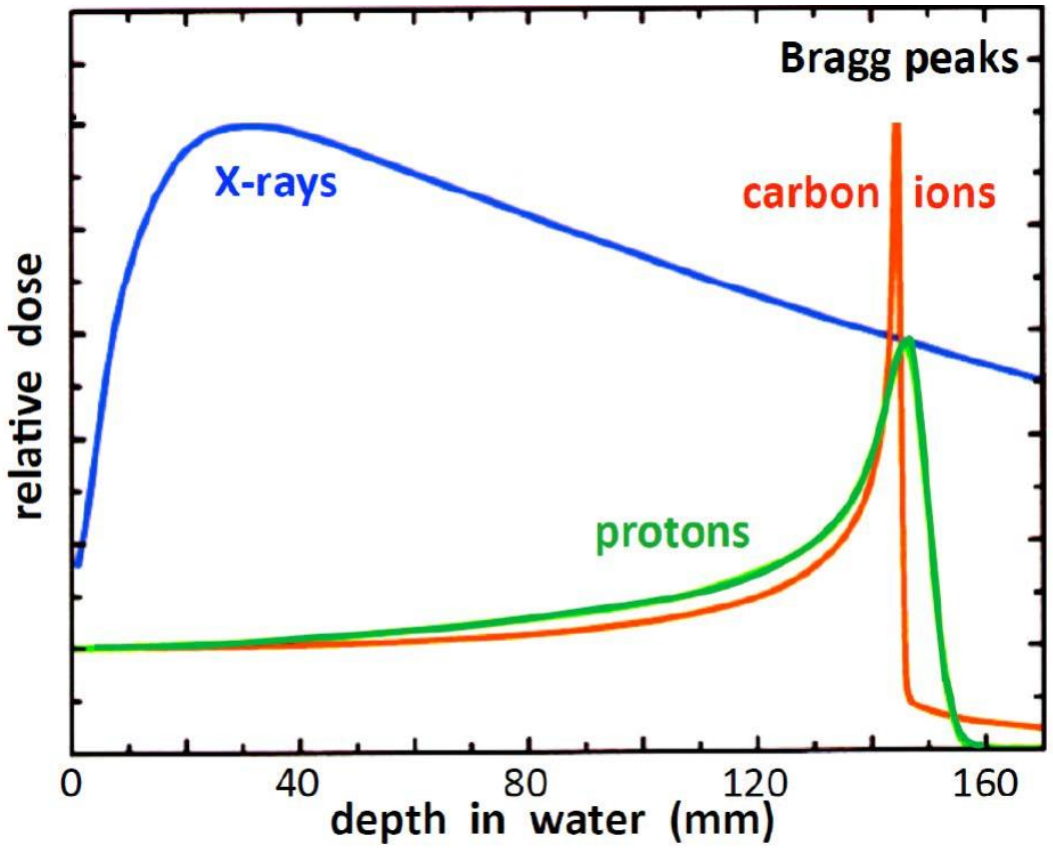
I.FAST

Content

- Status of ion therapy in Europe
- SEEIST initiative
- CNAO & MedAustron driven initiative
- Roadmap
- HITRI -> HITRI+
- I-FAST

Hadrontherapy via carbon ions

- Hadrons, proton and ions, are clinically better than X-rays, because they spare surrounding tissue (Bragg peak)
- Proton therapy is expanding fast, while C-therapy is much behind
- Carbon and other ions are **much more precise and effective** than protons especially for the so-called «radioresistant tumors».

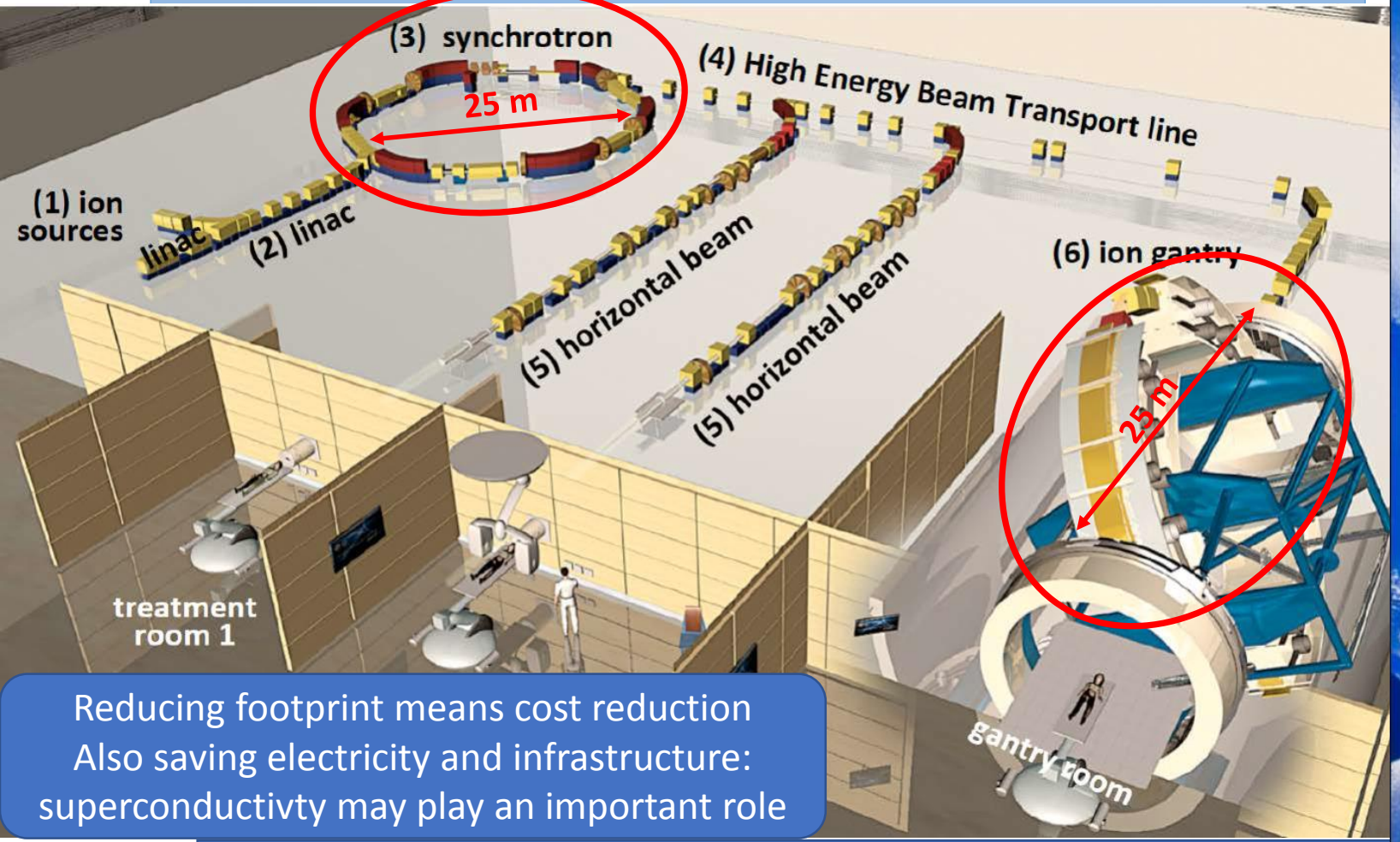


Hadrontherapy centers

- Hadrontherapy started beginning of 90's
- 250,000 patients irradiated
  - 30,000 with carbon ions (5,000/y)
- World: ~ 100 hadron centers (160 by 2025)
  - 12 C-ions centers (Asia, especially Japan leading)
- Europe:
  - 28 hadrontherapy centers
    - 4 C-ions centers

Courtesy of ENLIGHT

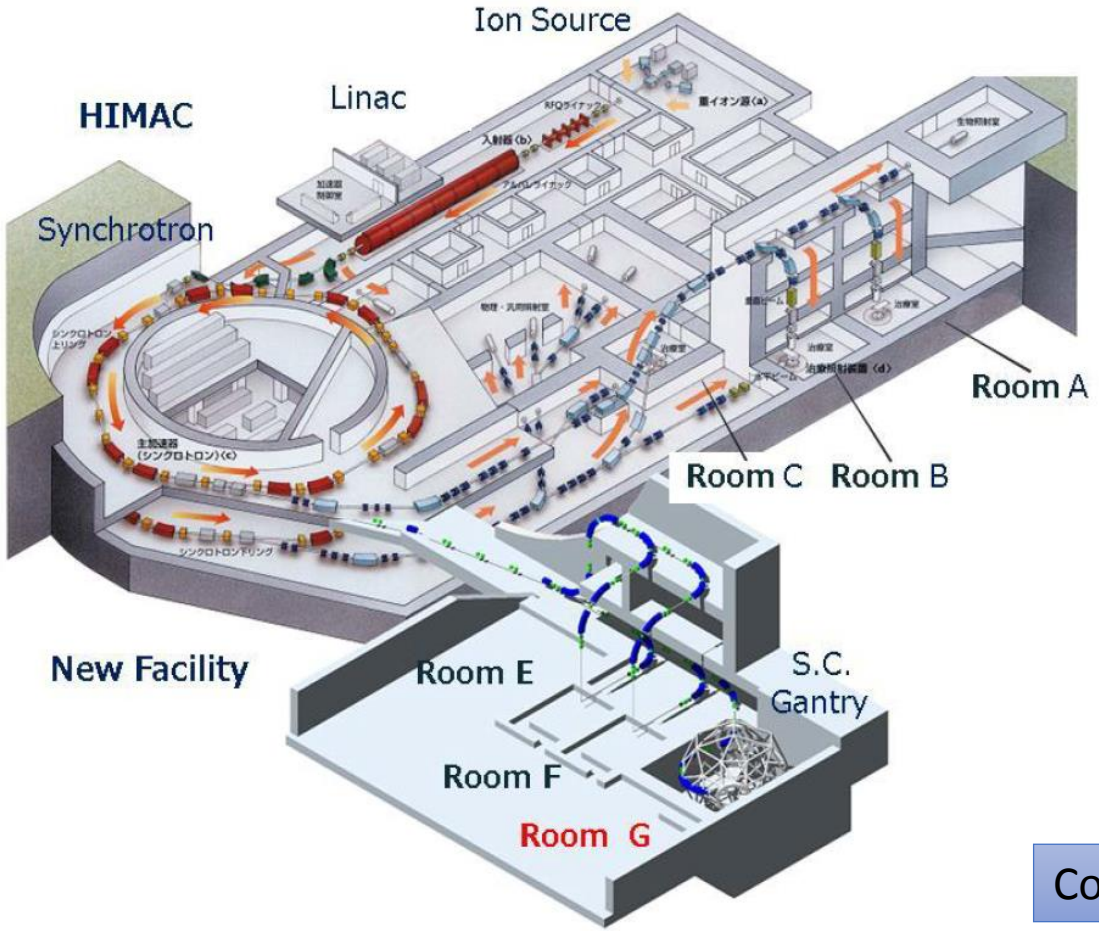
HIT - Heidelberg Ion Beam Therapy Center (first in EU)

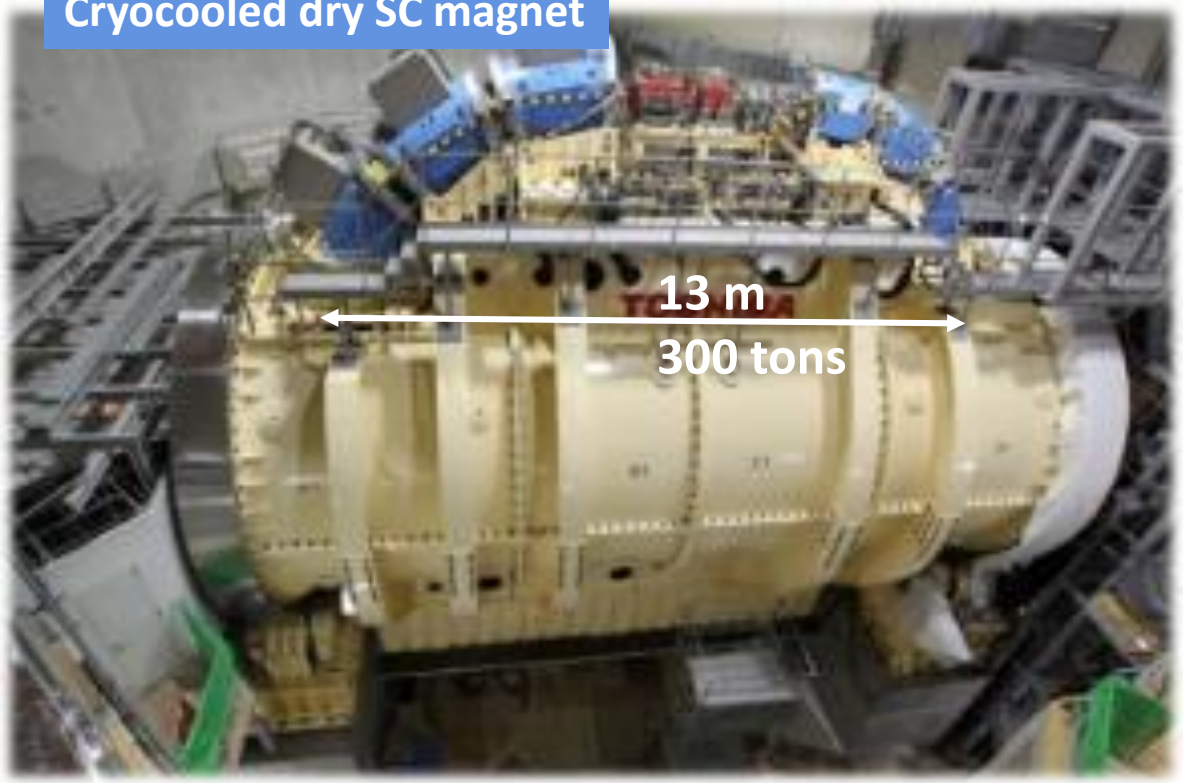


Reducing footprint means cost reduction
Also saving electricity and infrastructure: superconductivty may play an important role

25 m long
13 m diameter
600 tons rotation
670 tons total

Japan: HIMAC at QST-NIRS
First SC Gantry in operation 2018

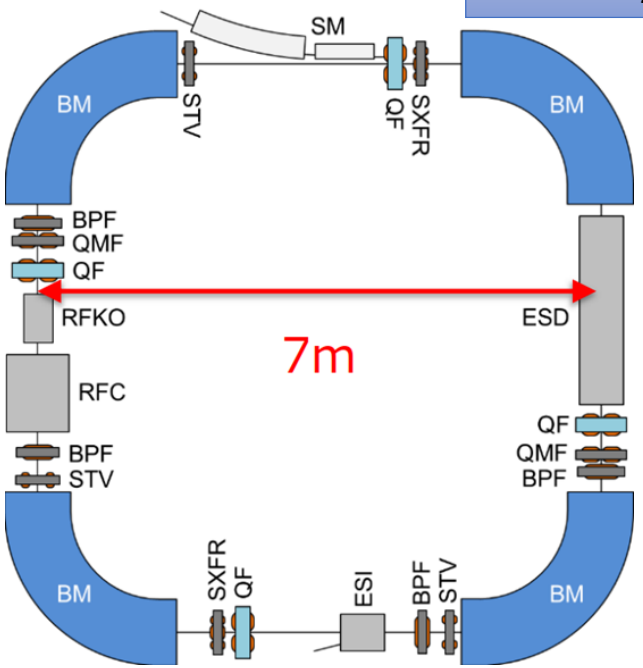




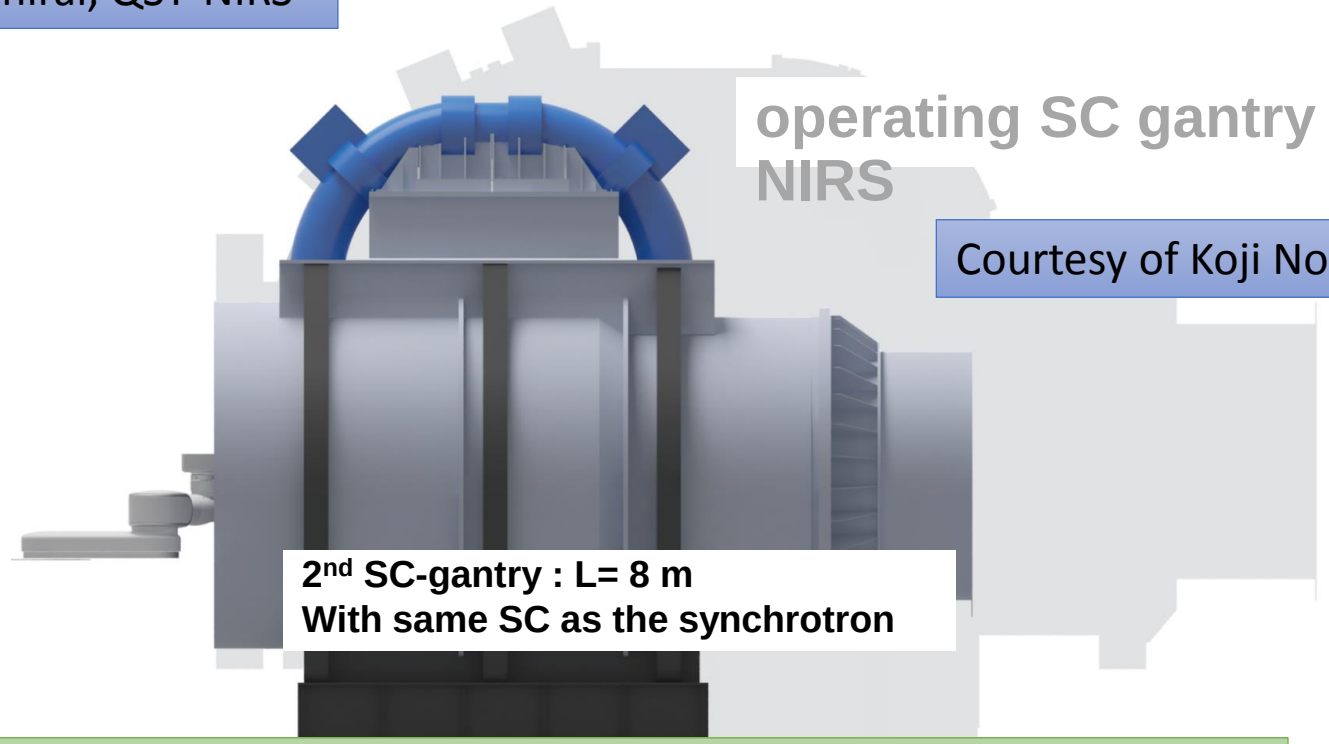
Courtesy of T. Shirai, QST-NIRS

Japan: HIMAC at QST-NIRS strong push toward SC technologies

Courtesy of T. Shirai, QST-NIRS



B0 = 3.5 T reducing accelerator dia. 20 → 7-10 m



Courtesy of Koji Noda, QST-NIRS

Dip. Field: 2.9→ 3.5 → ~ 5 T
Ramp time: 60 → 5 → 3 s
Op. Temp. : 4-5 K …….→ 10-20 K this requires HTS

SEEIIST

South East European International Institute for Sustainable Technologies

Fighting against cancer

Nuclear medicine as crucial component of future personalised cancer care

Develop advanced cancer therapy with ion beams and isotopes

Two Strategic Objectives – One initiative

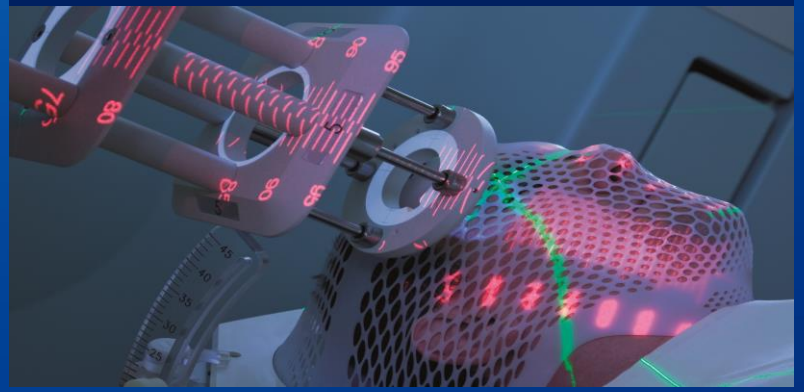
Building international cooperation and scientific capacity in South East Europe

Advance European integration, reverse brain drain, connect to Europe

Comprehensive Dimension: both Cancer Therapy and Research Center with 50% of the beam time dedicated to research – other Unique Selling Points

MULTI-DISCIPLINARY RESEARCH WITH HEAVY IONS

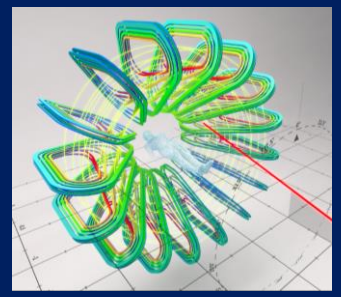
- Pre-clinical (medical, radiobiology)
- Clinical, including clinical trials
- Industrial research (microelectronics)
- Material research
- Ultra-high dose rates (FLASH)



Cutting-edge innovative and novel research in any of these topics driven by novel technological opportunities
Complementary to all existing facilities

BREAKTHROUGH IN TECHNOLOGY

- Multi-ion synchrotron (beyond presently used p and C-ions)
- More compact and much cheaper Superconducting synchrotron
- Superconducting gantry
- Higher beam intensity, faster extraction; Real time imaging



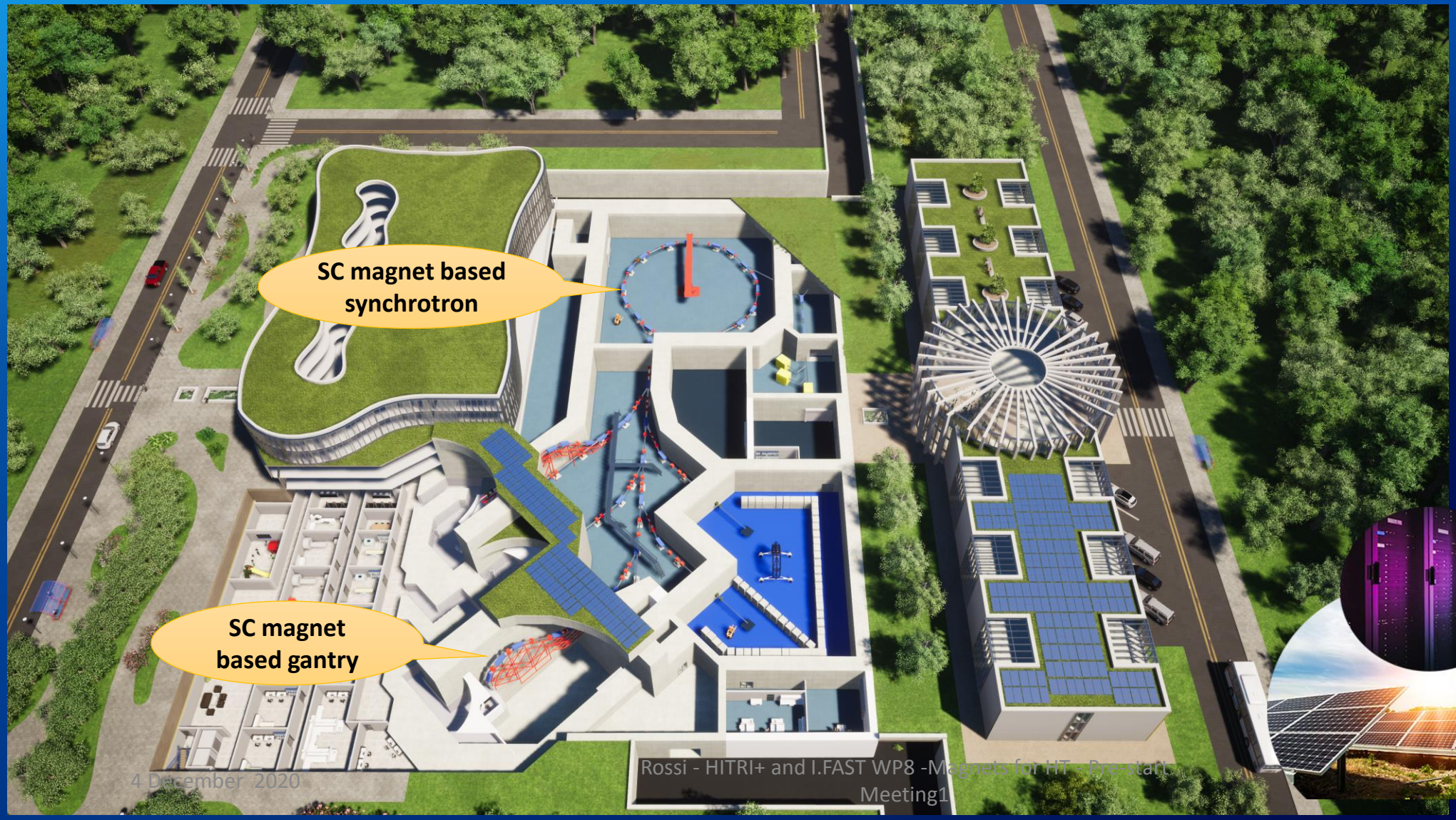
Will make cancer treatment with ions accessible to a large fraction of the European population and bring back Europe the lead position in this field

SCIENCE DIPLOMACY

- Declaration of Intent signed at CERN in October 2017 by 8 SEE countries
- MoC signed by 6 Prime Ministers of the SEE Region in July 2019, at the Summit of Berlin Process, Poznan
- Political support by the Swiss Government to establish SD roadmap

With the strong supporting consortium of 18 European research centers and clinics the SEE region is trying to revive its technological tradition

SEEIIST – First Green Infrastructure in line with Horizon Europe Cancer Mission



collaboration CERN-CNAO-MedAustron-INFN on C-ion GANTRY

- Improve the efficiency (medical effectiveness and treatment time) of the present facilities
  - CNAO (Pavia, IT)
  - MedAustron (Vienna, AT)
- Design a gantry compatible with the present layout without large civil engineering and infrastructure investment
- Leveraging the design capability and technology infrastructure of HEP community (CERN) to strenghten the medical technology in EU.
  → NIMMS program at CERN led by M. Vretenar
- TRIGGERED by GaTOROID of L. Bottura in 2019

Collaboration CERN-CNAO-MedAustron-INFN on C-ion SC GANTRY (started end 2019)

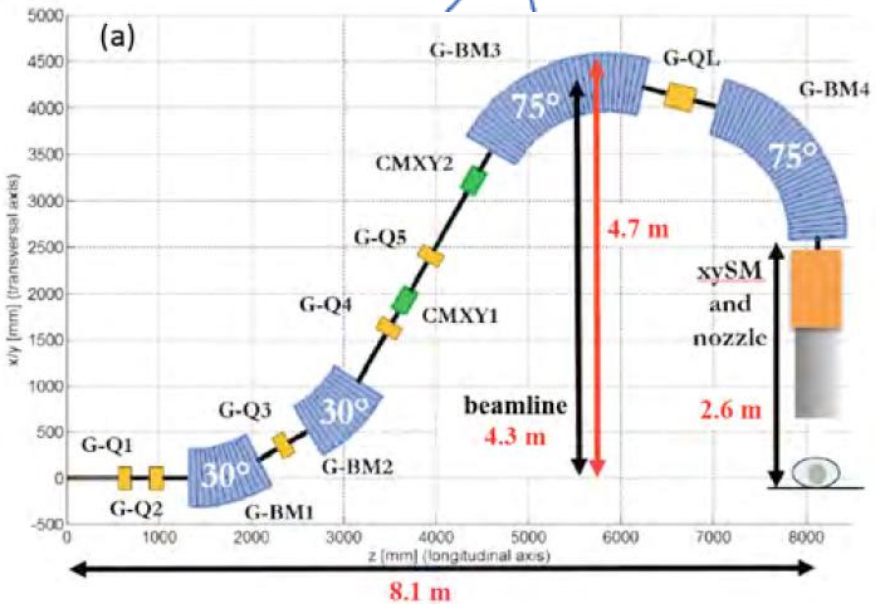
- Scope: design a SC gantry and demonstrate technology to allow its construction in 7-8 year
- Exploring two lines:
  - *Light rotating gantry*, weight ~ 10-20% of HIT gantry (40-! of of HIMAC-JP)
    - Based on work driven by **TERA foundation** in collaboration with CERN
    - Now mainly driven by NIMMS program at CERN, with TERA
  - *Static toroidal gantry* of new design based on a CERN patent

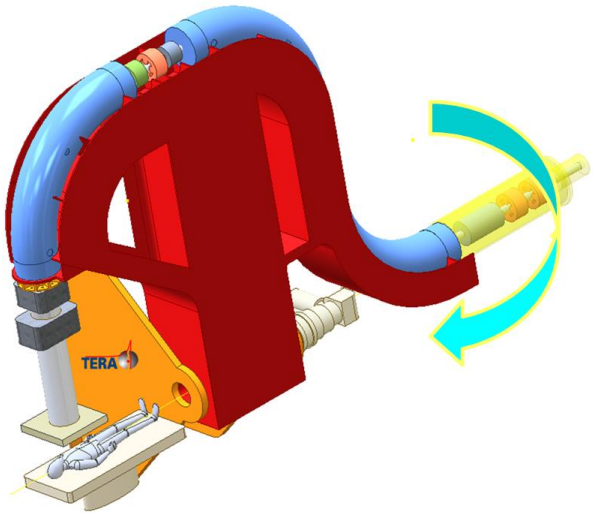
TERA
Fondazione per Adroterapia Oncologica

L. Bottura, "A Gantry and apparatus for focussing beams of charged particles," Patent, EP 18173426.0., May 2018
E. Felcini, phD thesis (EPFL Lausanne and CERN, 2020)

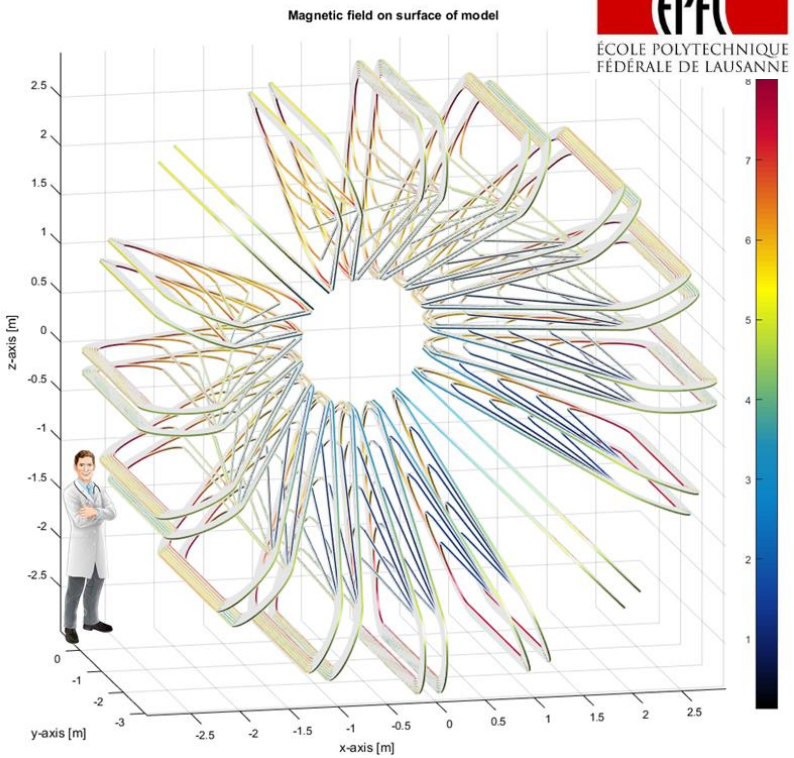
Collaboration CERN-CNAO-MedAustron-INFN on C-ion SC GANTRY

Light rotating gantry





Toroidal gantry



End 2020: decision on design based on International panel assessment. GOING on right now…

Exploring all SC technologies for next generation HEP colliders for advancing in Hadrontherapy

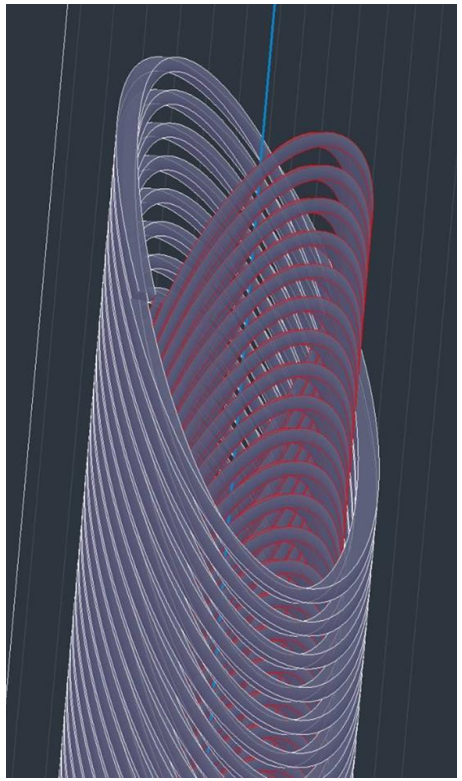
- Nb-Ti remains the workshorse of superconductivity: first solution

- For *HiLumi LHC*, now, and *FCC-hh*, in the near future, CERN and HEP communty is developing
  - **Nb_3Sn technologies for collider quality** magnets. Next talks (CERN and USA)! (Requirements for HEP colliders slighty ≠ for sweeping synchrotrons)
  - **Canted Cosine Theta dipoles** (Nb-Ti for *HiLumi LHC*, CERN and IHEP Beijing, Nb_3Sn for *FCC-hh*, PSI and LBNL). Self-funded initative by Uppsala U.and Scaditronix (CERN coll.)
- For *FCC-hh* HEP is also exploring HTS coils for accelerator quality magnets:
  - in Europe via mainly the EC funded *FP7-EuCARD2* and *H2020-ARIES*
  - In USA mainly in LBNL (in the frame of accelerator R&D for next collider).

Nb-Ti CCT: p-gantry and HiLumi LHC

LBNL: CCT coil prototype for large acceptance proton gantry ∅ = 400 mm: Successfully tested to 3.5 T; segmented former

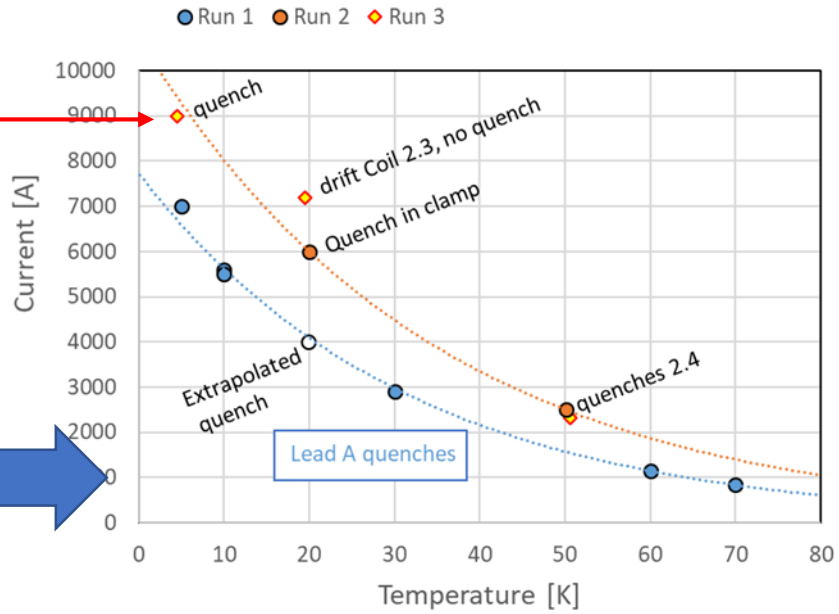
HiLumi LHC: CERN has designed, built and tested a dual 3 T, 2 m long - ∅ = 90 mm, straight CCT. Now IHEP Beijing producing 2x13 units



HTS for accelerator magnets: status in EU

CERN Feather_M2: flare end race track, REBCO Roebel cable, 40 mm bore

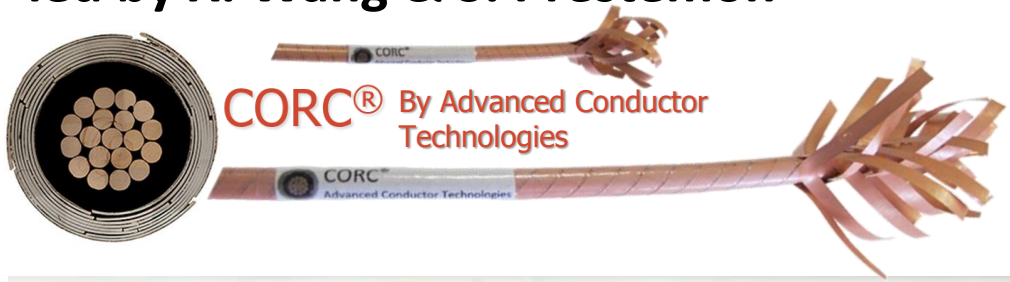
> 3 T in 2017; 1st magnet
> 4.5 T in 2019; 2nd magnet
~ 6-7 T in 2021; 3rd magnet, hopefully!



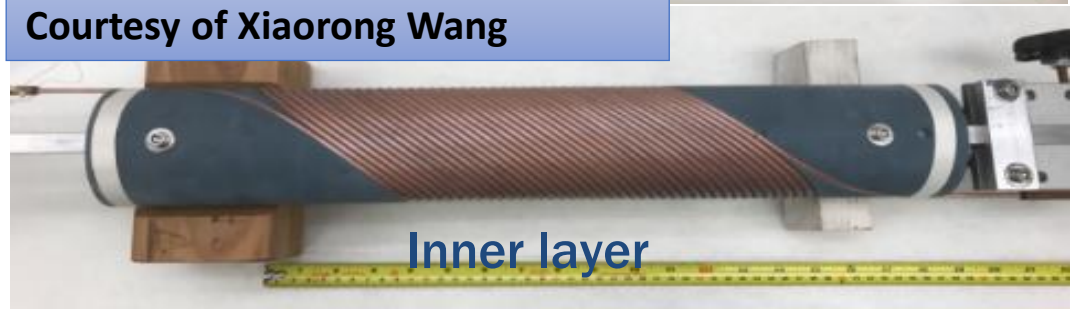
CEA HAS ASSEMBLED a cosϑ dipole, 40 mm bore, with REBCO Roeble cable: test in 2021

LBNL effort on HTS accelerator magnets

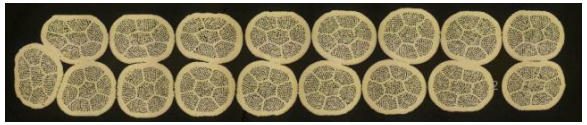
Program based on CORC and CCT layout led by X. Wang & S. Prestemon

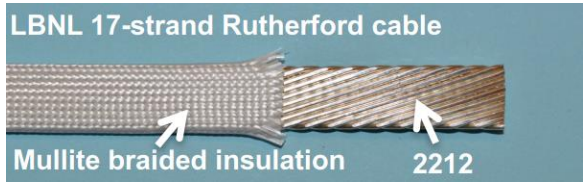


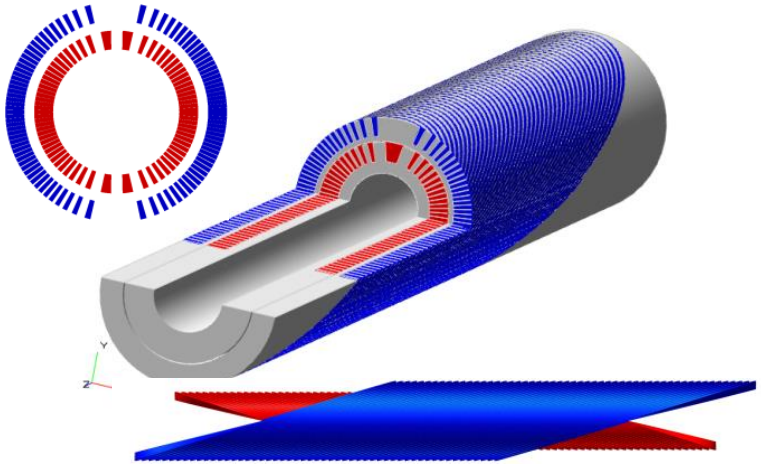
Courtesy of Xiaorong Wang



Program on use of Bi-2212 Rutherford cable with race track and CCT layout led by T. Shen and S. Prestremon







Courtesy of Tengming Shen

The EC H2020 funded program - 1

- HITRI: Prapared in May-June 2019 and submitted to EU in Nov.2019
  - Heavy Ion Therapy Research Infrastructure
  - Scope: design study mainly (if not purely) for SEEIIST
  - Magnet WP scope:
    - to produce an assessment and a design between CCT and CT for synchrotron and between CT/CCT/Toroid for gantry
    - To build two protos one in HTS
- Should have started in Summer 2020.
  - Not approved: info in February 2020, official communication March 2020): weak in medical part and use… (**Physics part OK**)

The EC H2020 funded program - 1

I.FAST

- Is the *omnibus* program following CARE, Eucard, Eucard2, ARIES to integrate accelerator R&D across EU labs: It si about 10 ME form EU, many WPs…
- Each reasearch theme has been pre-selected by a TIARA/ARIES committee
  - Proposal to the selection committee in July 2019. Programs were then defined in June-July 2019.
  - Decision in October 2019 to be submitted in March 2020 and to start in May 2021 (after ARIES end)
  - Proposals: 1) develop CCT for HT **(approved);** 2)to develop Toroids for HT (**NOT approved**)
- **WP8 on Innovative Superconducting Magnets**
  - Conceived as after-HITRI: fostering innovation: → exploring HTS cable and new magnet layout
  - **Involve Industry in the know how build up is a key goal for the WP.**
  - CCT made of: CORC® ?, stacked tapes? Roebel? Or Bi-2212 Rutherford cable? Other magnet layout?
  - The WP8 fosters also a panel to steer HTS for accelerator magnets in EU and the development of a HTS cable suitable for low losses - large size - fast cycling - synchrotrons (led by GSI)
  - **Applied in May 2020; Approved 3rd of November 2020!**

The EC H2020 funded program - 1

- **HITRI*plus* (Hitri+)**
  - Once applied for I.FAST in March 2020 extension of 3 months of deadlines
  - Opportunity to re-apply, withut too much effort a renewed HITRI program
  - Medical part improved, scope expanded not only to SEEIIST (still most prominent project in EU). Physics part, **MAGNETS, same as HITRI**
  - **Infrastructure (not DS): 4 year long. Magnet program is stil foreseen in 3 years**
  - **WP8 on Magnet Design**
    - **overview and assessment of various conductors** (LTS, HTS, various types of cables) and magnet layouts (cosϑ, CCT, racetracks – split coils or flare ends – etc…).
    - Both for Synchrotrons (main dipole and extraction channel) and Gantry
    - Design construction and **test of 1 demontrator ~500 mm long (either LTS or HTS)**
    - **Very much CCT oriented!**
  - **Applied in May 2020; Approved 3rd of November 2020!**

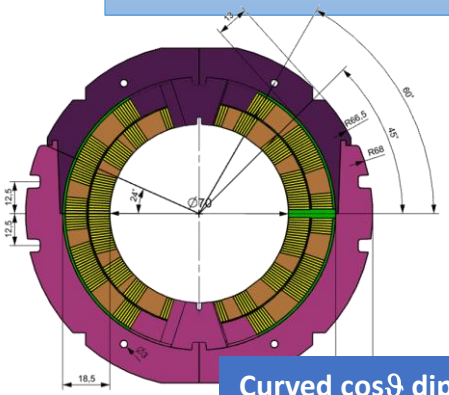
The EU roadmap for enabling a full SC C-ion facility: synchrotron + gantry

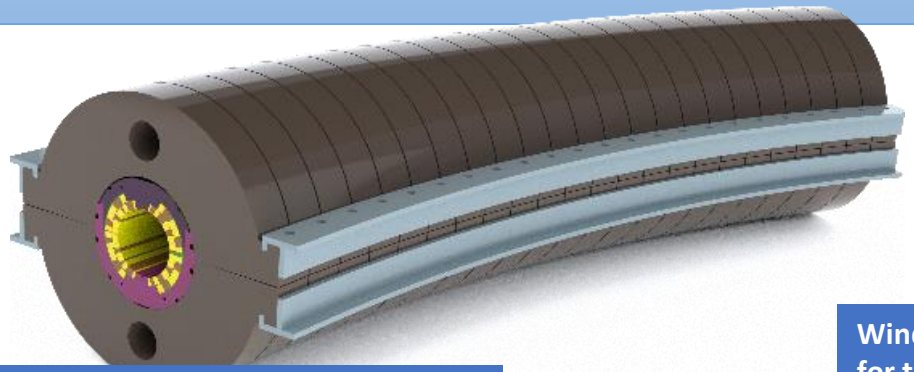
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CERN-CNAO-MedAustron-INFN collab. for Gantry													
SEEIIST													
H2020-HITRIPlus & I.FAST			LTS										
			HTS										
HE program for R&D ??			HTS			?	?	?	?	?	?		
	Conceptual study		Proto & Design		Construction		Installation & Commissioning						

Disclaimer: roadmap to be reviewed with stakeholders

I think we should not wait too much to prepare the next step: a large magnet program in HE …

A few ideas (just as list…)

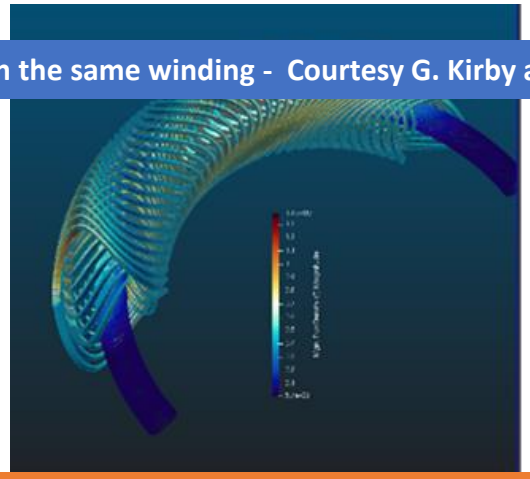


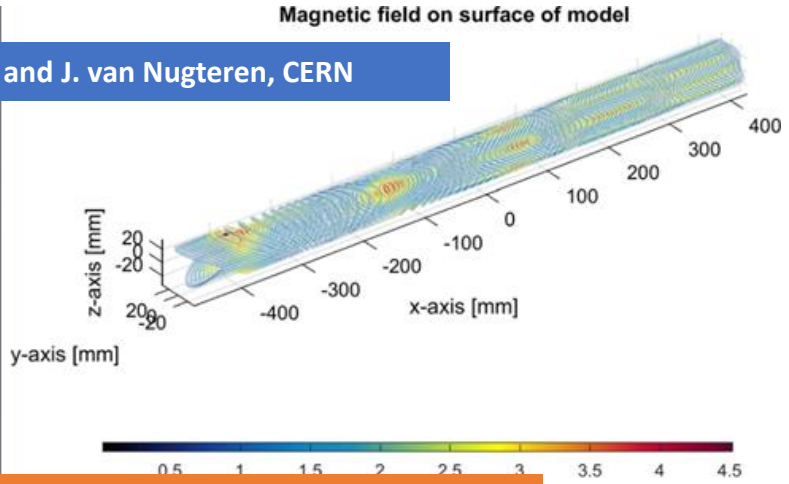


Curved cosϑ dipole with H-split yoke with assembly clamps - Courtesy Mikko Karppinen, CERN

Winding plate of the HTS 0.5 m wide HTS demonstrator toroid for the Ga-Torroid; courtesy E. Felcini and G. de Rijk, CERN

Solution for curved and straight CCT coils combining dipole and quadrupole in the same winding - Courtesy G. Kirby and J. van Nugteren, CERN





The challenge is not the field level, rather designing for ramping field and cryocooled magnets…

HITRI+ WP8 Magnet Design (with construction and test of a demonstrator)

Member	Person-months	Total costs	EC funds	Institute matching funds
CEA	20	192,500	86,625	105,875
CERN	10	161,250	70,538	90,713
CIEMAT	22	145,000	65,250	79,750
INFN	32	357,000	160,650	196,350
PSI	2	29,750	13,388	16,363
UU	8	79,750	35,888	43,863
Wigner RCP	12	39,250	17,663	21,588
SEEIIST	8	65,625	15,094	50,531
Total	**114**	**1,070,125**	**465,094**	**605,031**

INFN is two units (MI-GE). Sentronis is associate to SEEIIST

INFN is the WP8 – Magnet Coordinator
CEA is the deputy coordinator

I.FAST WP8 Innovative SC Magnet. Demonstrators in Industry!!!

Members	Person-months	EC funding	Institute matching funds	TOTAL Funds
CEA	10	42,188	76,705	118,892
CERN	11	190,153	345,732	535,884
Wigner RCP	24	24,638	44,795	69,433
INFN	14	112,613	204,750	317,363
CIEMAT	12	26,438	48,068	74,506
UU	5	31,500	57,273	88,773
PSI	6	28,688	52,159	80,847
BNG	10	64,313	116,932	181,244
Scanditronix	10	59,938	108,977	168,915
Elytt	15	59,938	108,977	168,915
Sigmaphi	15	59,938	108,977	168,915
Grand Total	**132**	**700,340**	**1,273,345**	**1,973,685**

INFN is the WP8 – Magnet Coordinator; CEA is the deputy Coord.
The budget includes 50 kE (placed at CERN) of the ESG and workshops; it does not include the 200 kE of GSI-UT-IEE-ILK for ramped cable