HTS for Accelerators
Status, Needs and Perspective

L. Bottura, CERN

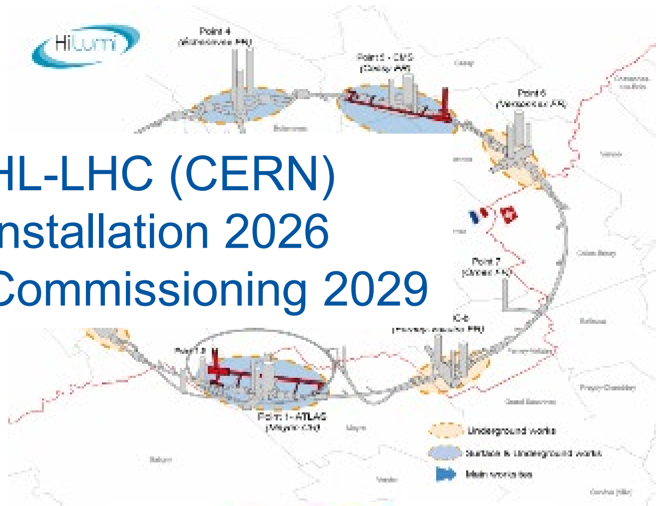
1MSpeOr3-01
ASC 2022, Honolulu, Hawaii, October 2022

IEEE-CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), March 2023. Presentation 1MSpeOr3-01 was given at Applied Superconductivity Conference, Honolulu, HI, USA, October 23-28, 2022.

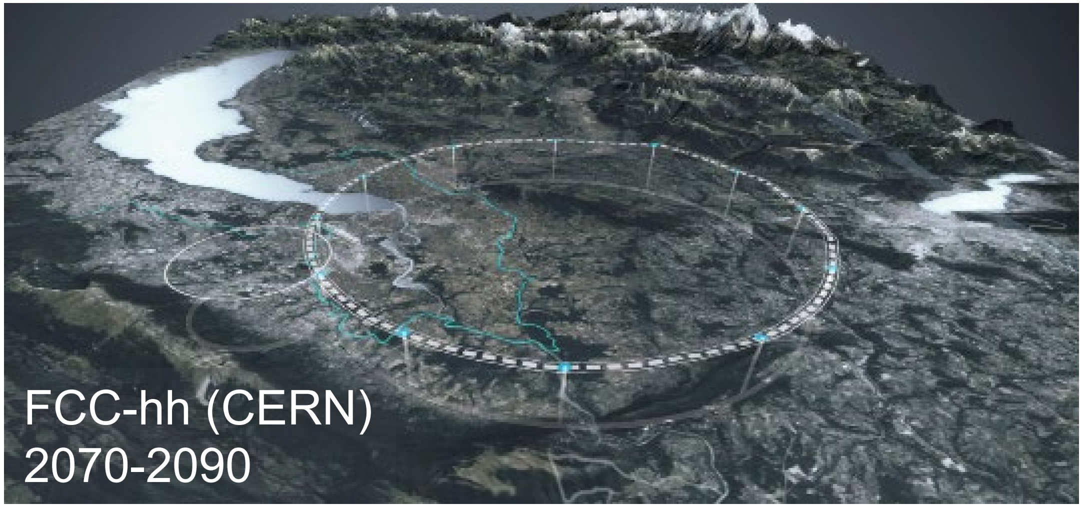
Outline

- Accelerator landscape and needs
  - The need for high fields
  - The need for energy
  - The need for economics
- HTS for accelerators
- HTS for more accelerators
- Summary

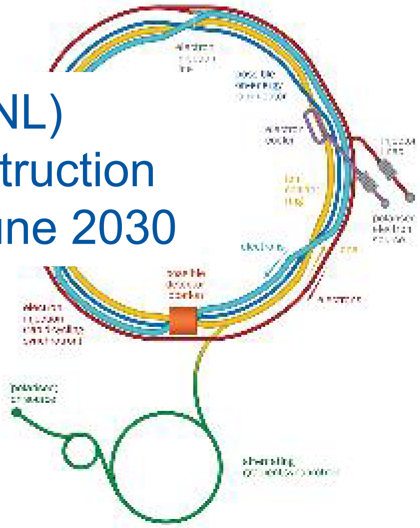
HEP Landscape - Circular Colliders



HL-LHC (CERN)
Installation 2026
Commissioning 2029

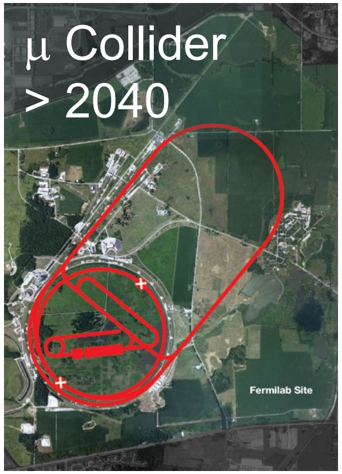


FCC-hh (CERN)
2070-2090



EIC (BNL)
In construction
CD4 June 2030

SppC (IHEP)
> 2040



μ Collider
> 2040

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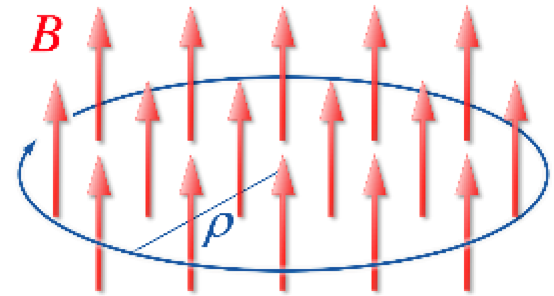
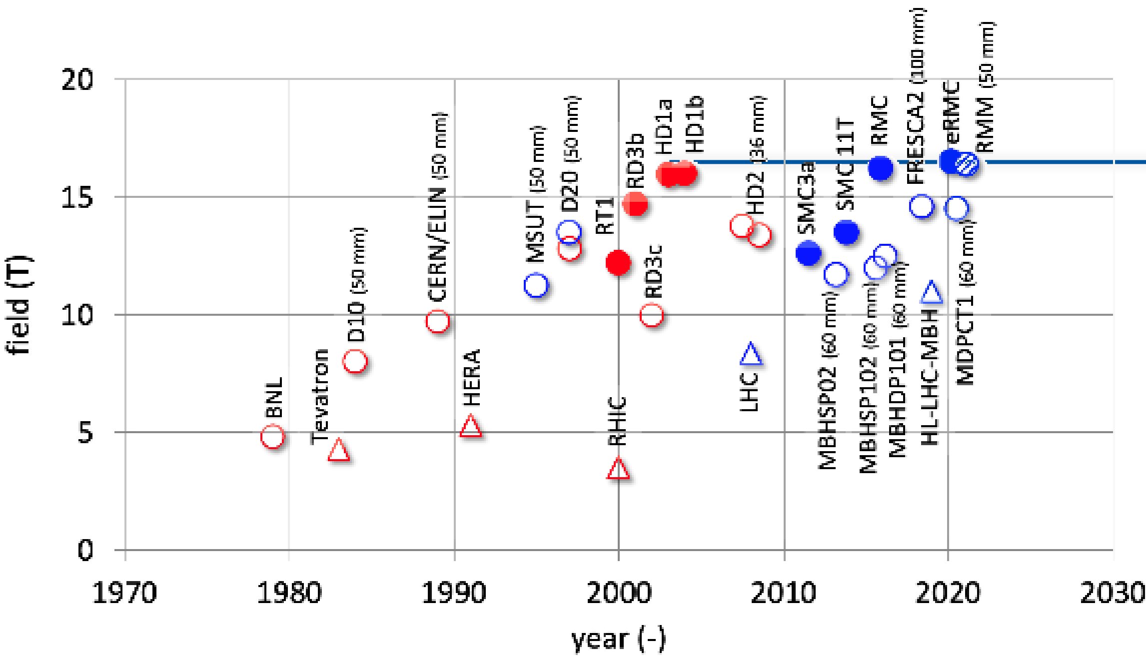
High field dipoles (FCC-hh)

Beam energy — Bending radius — Dipole field

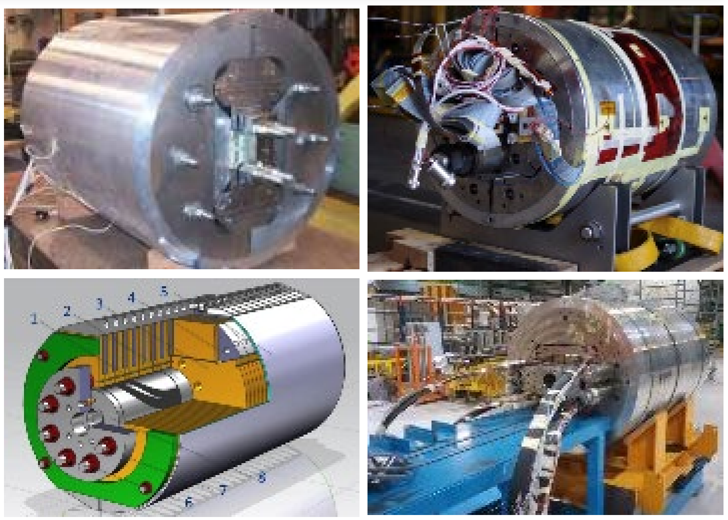
$$E[GeV] = 0.3\,B[T]\,\rho[m]$$



This is the reason for the steady call for **higher fields** in accelerator magnets



Upper limit of LTS (Nb_3Sn)



HTS is the only path beyond 16 T

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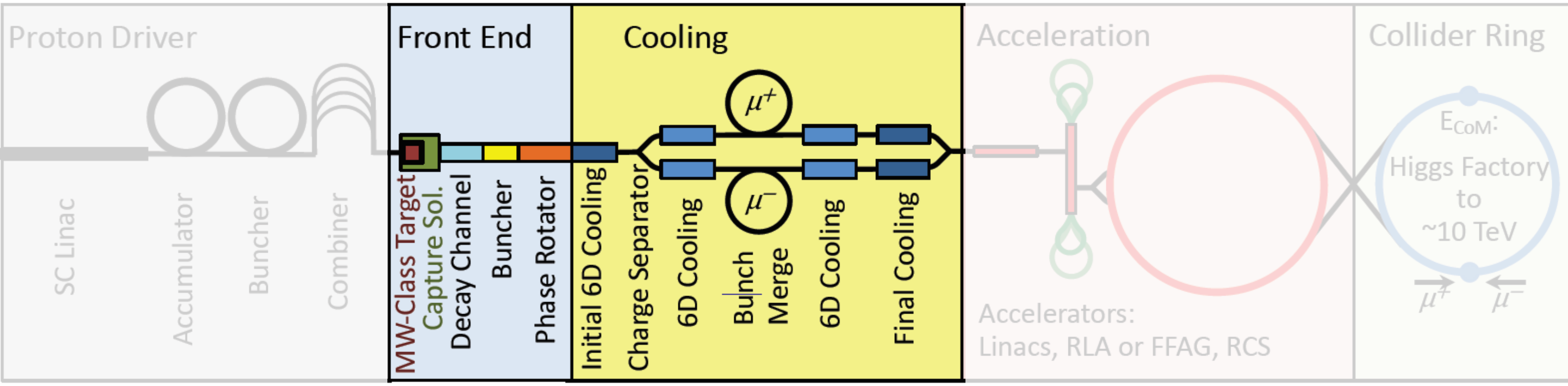
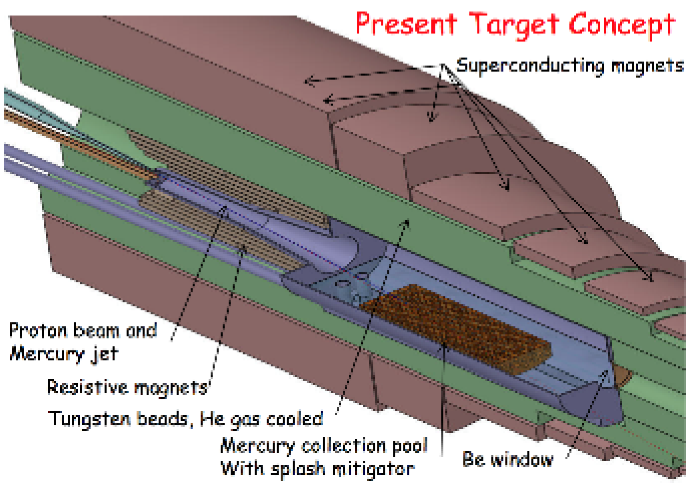
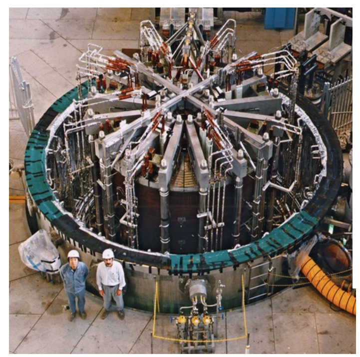
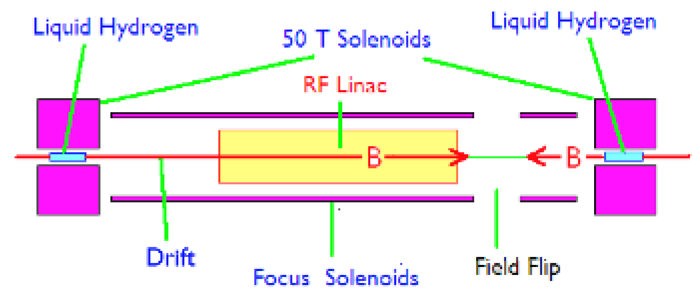
High field solenoids (Muon Collider)



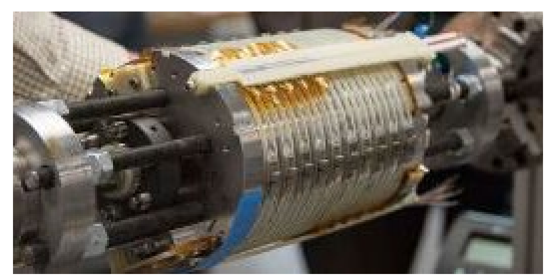


20 T, 150 mm, 100 kW





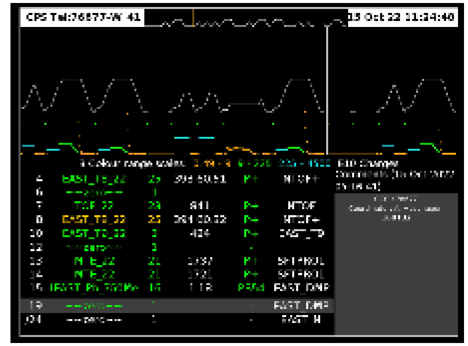
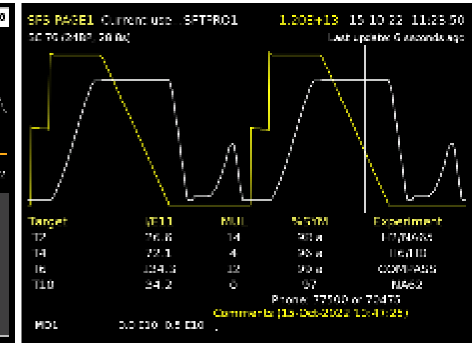
30…50 T, 50 mm

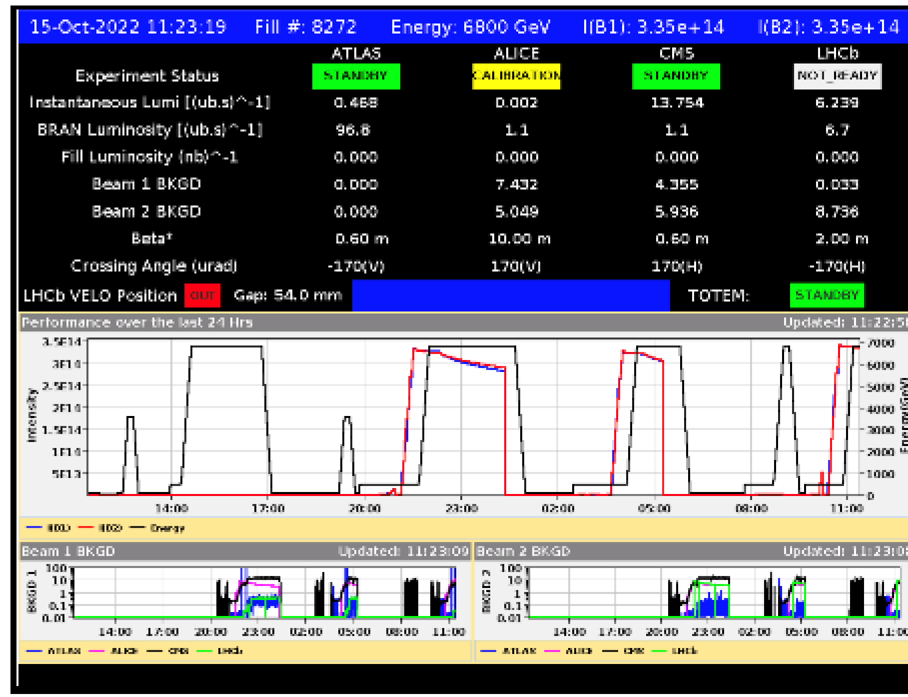


HTS may be the only path towards a muon collider

The need for energy

- CERN uses today **1.3 TWh** per year of operation, with peak power consumption of **200 MW** (running accelerators and experiments), dropping to **80 MW** in winter (technical stop period)
- Electric power is drawn directly from the French 400 kV distribution, and presently supplied under agreed conditions and cost
- **Supply cost, chain and risk** are obvious concerns for the present and future of the laboratory



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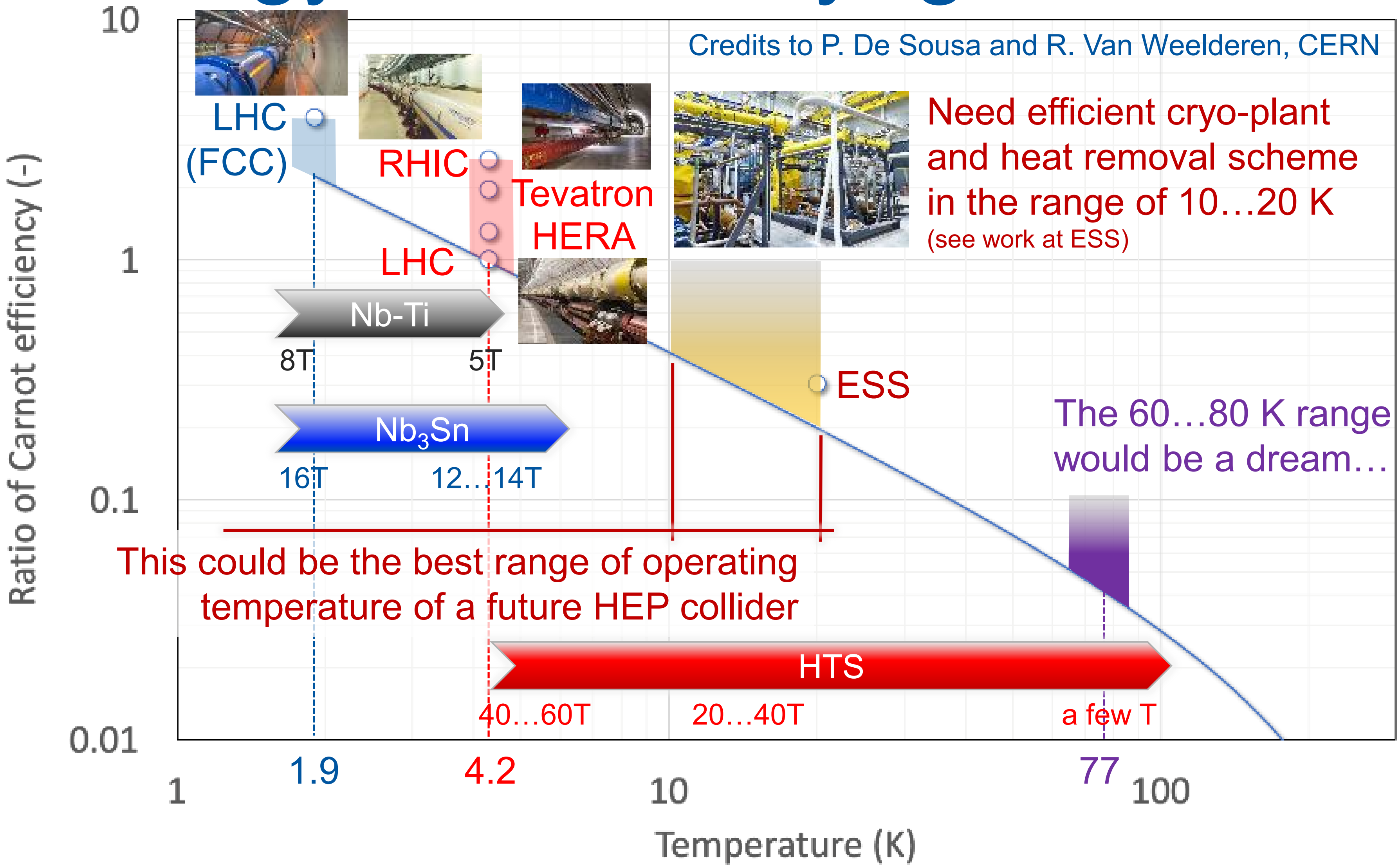
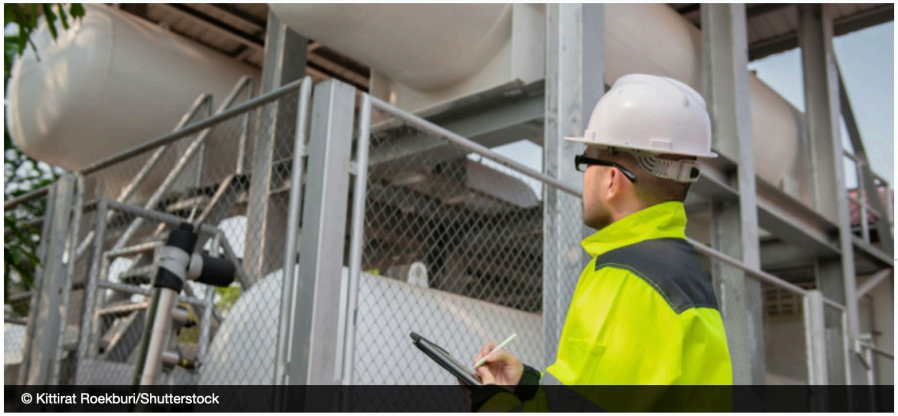
Energy efficient cryogenics



HTS may be the only path towards a future collider

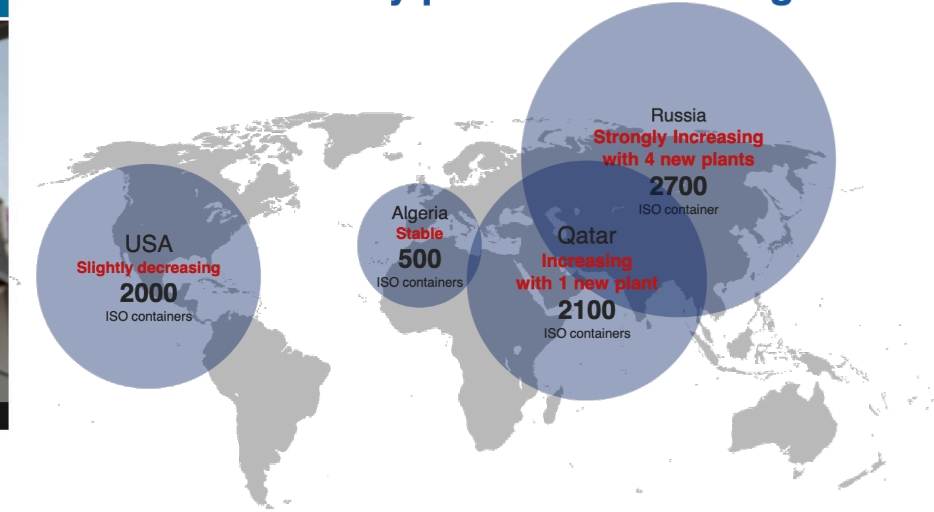
16 JUIN 2022 **Publications** Briefings de l'Ifri



Aurélien REYS, Vincent BOS

Hélium : les nouvelles géographies d'une ressource critique
Briefings de l'Ifri, 16 juin 2022

Helium is a **by-product of natural gas**



Tentative forecast in 2026 based on public announcements of new capacities available in quantity of Iso container of 4.5 tonnes

TE CRG

Future helium **supply is limited** and entails a substantial economical and availability **risk**

Consequences

Current situation

- Market shortage is affecting industrial and scientific customers
- Manufacturing industry contracts are impacted with volume limitations
- Large scientific instrument cannot do so & rely on established industrial partnership

Helium market still at risk in 2023 and for the coming years

- Uncertainty on the effective Russian production capacity and market access
- Algerian gas production transferred using pipeline instead of LNG
- No more back-up from the US federal authorities, Cliffside for sale ! (C&en News)

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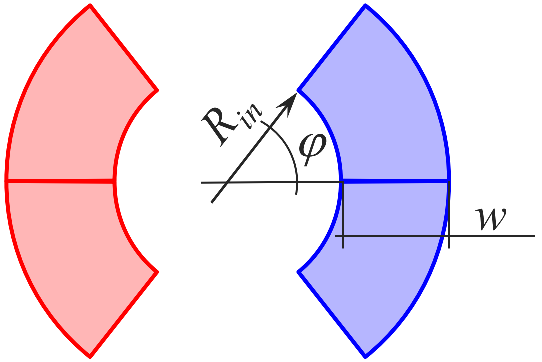
The need for economics

- A large component in the magnet cost is the **amount of superconductor** (coil cross section)
- High-field superconductors are (significantly) more expensive than *good-old* Nb-Ti
- Need to work in two directions:
  - **Reduce the coil cross section (increase *J* !)**

$$B = \frac{2\mu_0}{\pi} J w \sin(\varphi)$$

$$A_{coil} = 2\varphi(w^2 + 2R_{in}w) \sim \frac{1}{J^{1.5}}$$



  - **Reduce unit conductor cost**

HTS may offer both

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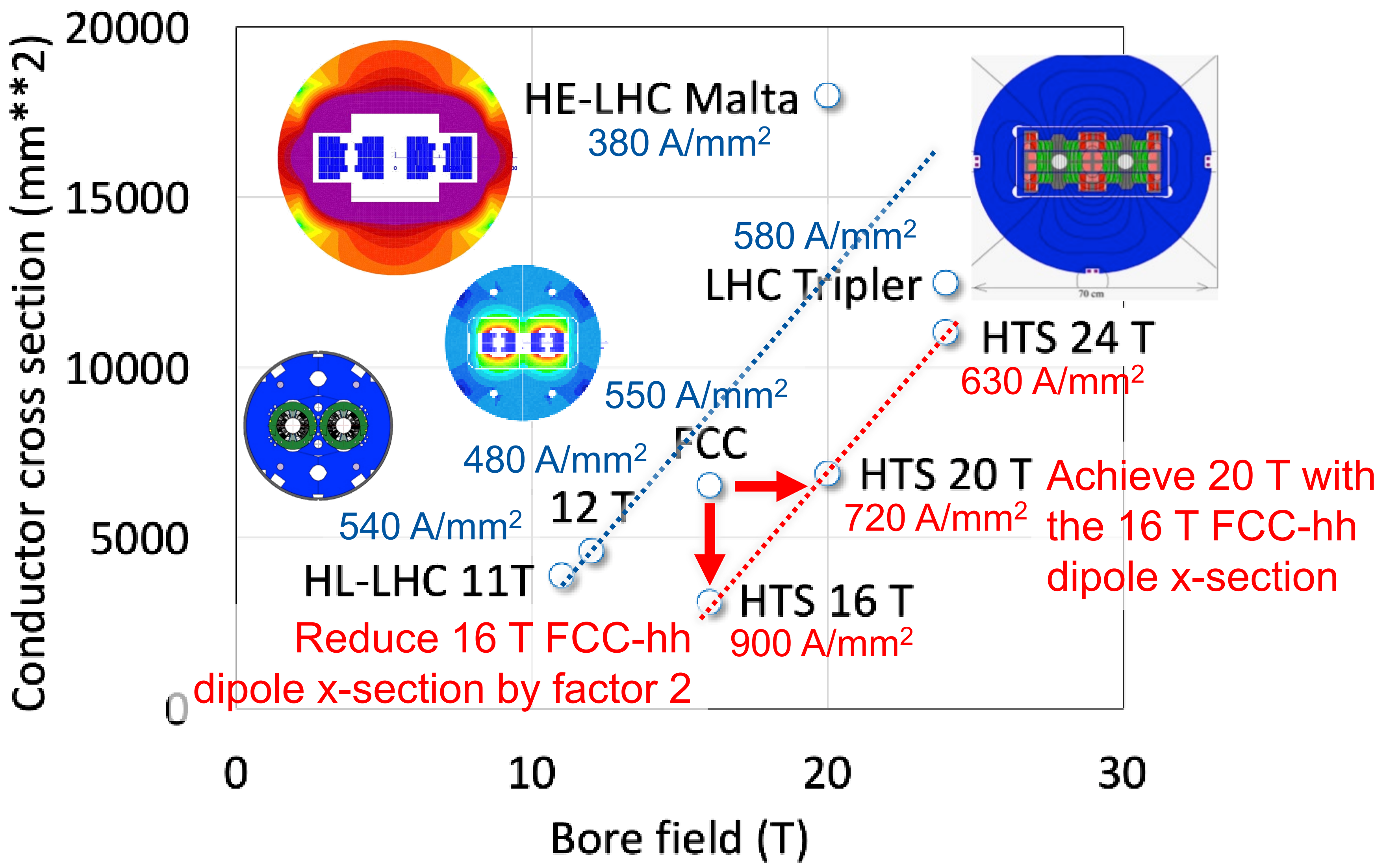
On a slimming diet !



Single coil conductor cross section
Multiply by ≈20 for kUSD/m

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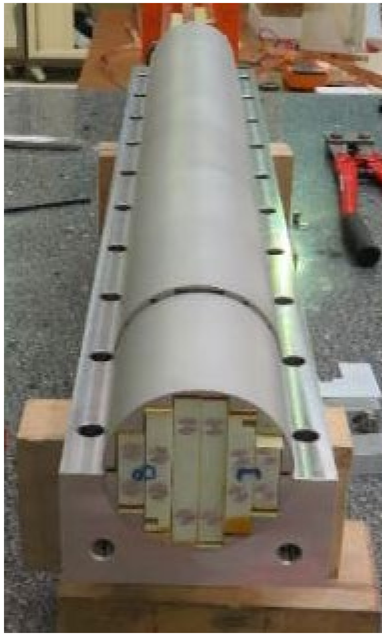
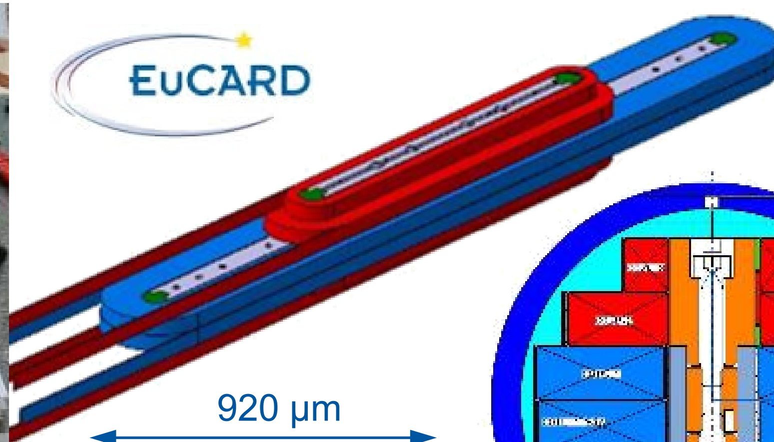
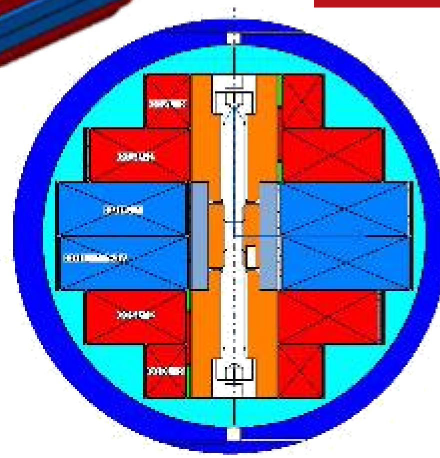
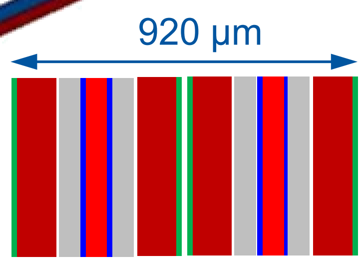
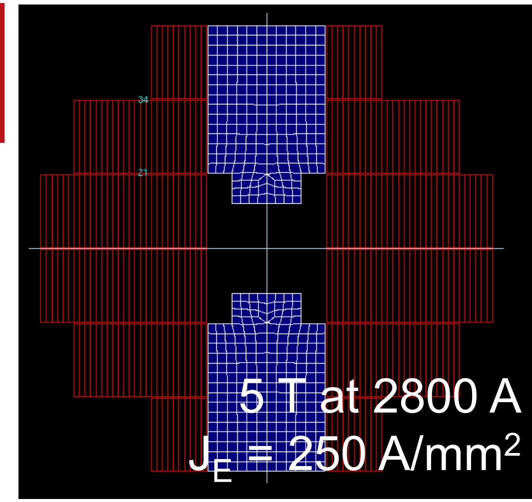
New winding technology is needed

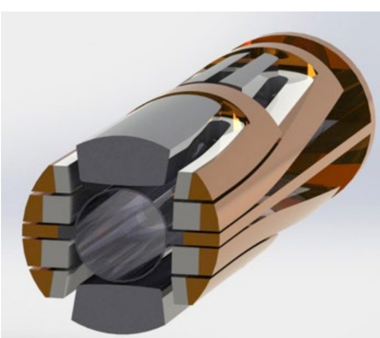


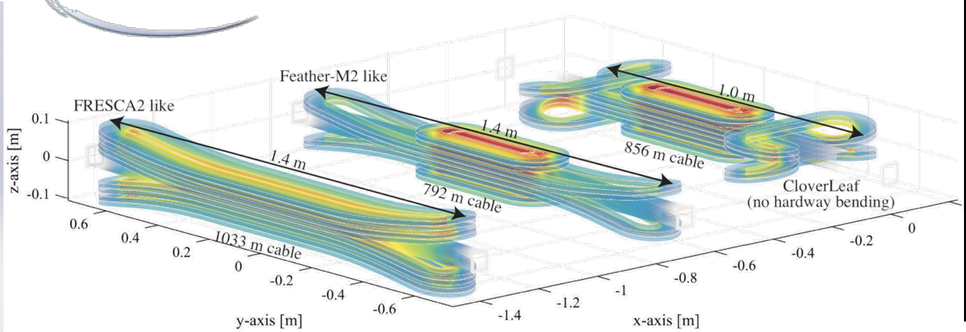


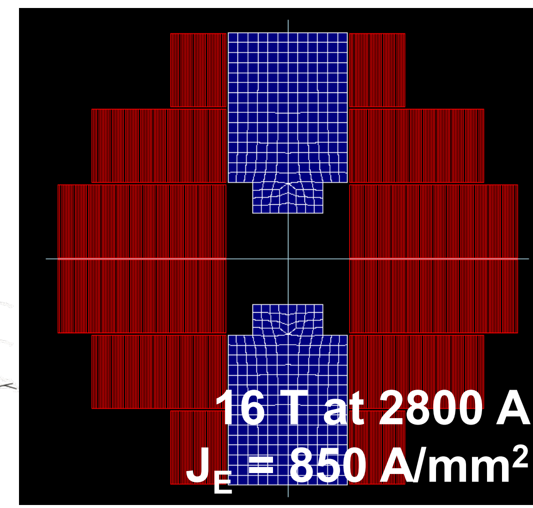








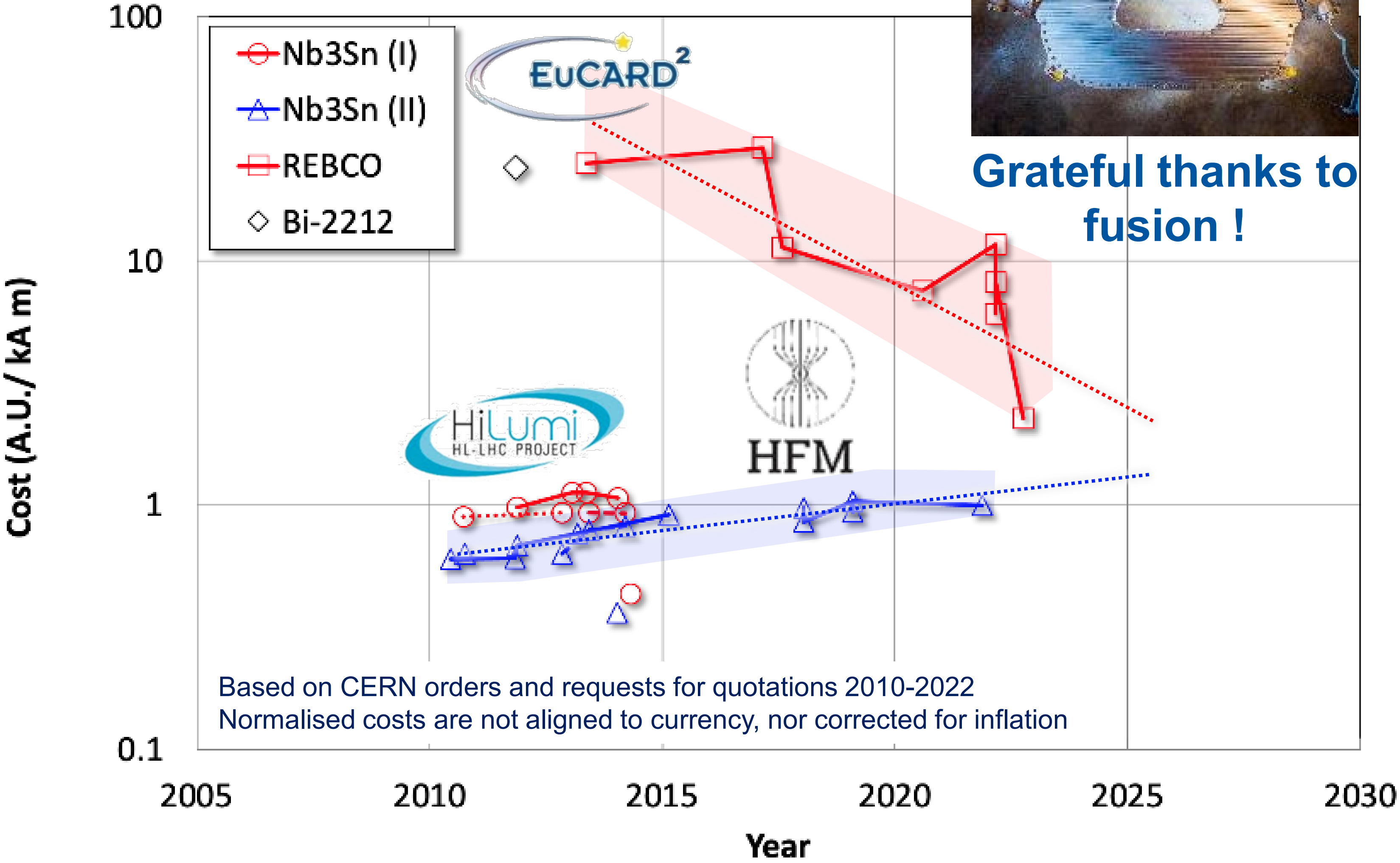




HTS windings can profit from “NI” technology

Conductor cost

Grateful thanks to fusion !



Impressive cost reduction in HTS !

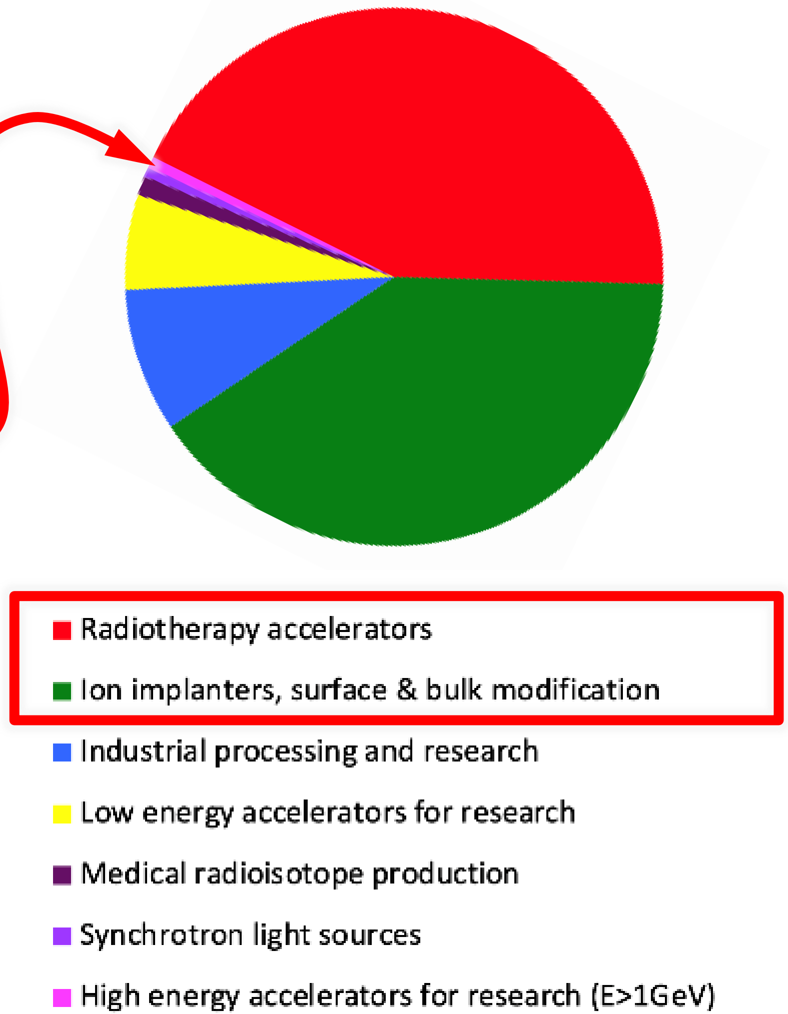
HTS for accelerators – an attempt

		Specification	Target
Minimum J_{non-Cu} (4.2 K, 20 T)	(A/mm^2)	1500	3000
Minimum J_{non-Cu} (20 K, 20 T)	(A/mm^2)	600	1250
$\sigma(I_C)$	(%)	10	5
Unit length UL	(m)	150	500
Minimum bending radius	(mm)	10	
Allowable $\sigma_{longitudinal\ non-Cu}$	(MPa)	800	1000
Allowable compressive $\sigma_{transverse}$	(MPa)		400
Allowable tensile $\sigma_{transverse}$	(MPa)		25
Allowable shear $\tau_{transverse}$	(MPa)		20
Allowable peel σ_{peel}	(MPa)		
Allowable cleavage $\sigma_{cleavage}$	(MPa)		
Range of allowable $\varepsilon_{\lambda ongitudinal}$	(%)	-0.1…0.4	-0.1…+0.5
Internal specific resistance $\rho_{transverse}$	($n\Omega/cm^2$)		20

Substrate (non-magnetic alloy): 40…60 μm
Copper stabilizer (total): 20…40 μm

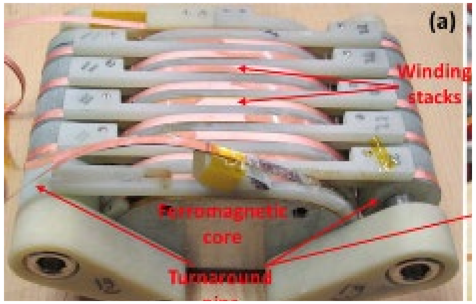
Accelerator landscape

- Accelerators for HEP are discovery machines of large dimension, cost and complexity, often in scientific and public news
- There are more than 35,000 particle accelerators in the world. Most of them are used for therapy and industrial applications

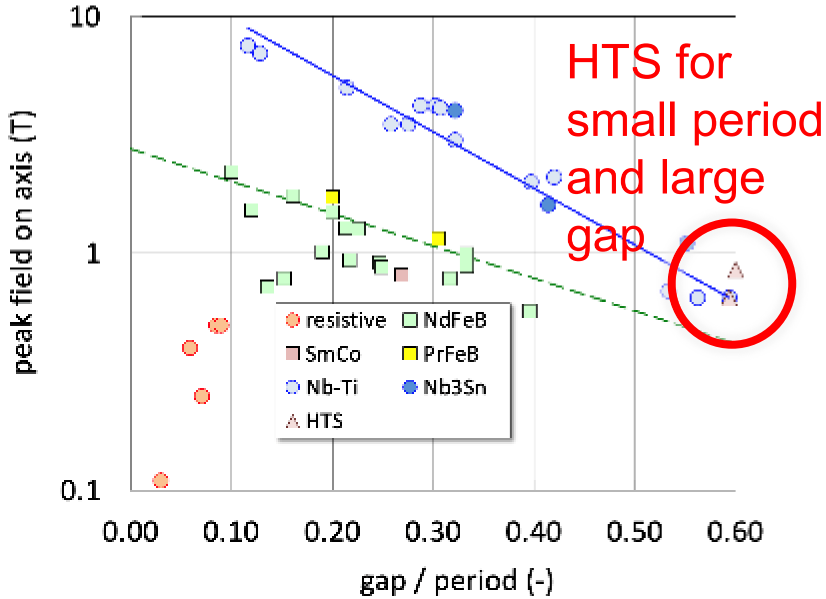


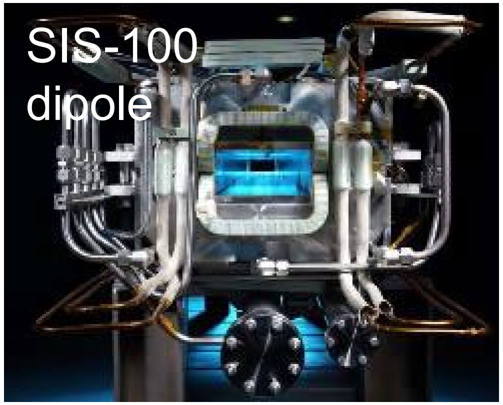
HTS for more accelerators

Light sources may profit from HTS insertion devices



M Calvi, 2020 SUST 33 014004   I. Kesgin, 2017 SUST 30 04LT01





Analysis of the FAIR complex (approx. 2008) projected an energy break-even for a total magnet loss of 15 W/m at 4.2 K loss per unit length. At 77 K this would be obtained for a loss per unit length > 100 W/m

Compact medical and industrial accelerator applications (1…3 T) will profit from significantly improved power balance

This would obviously require a proper analysis

Summary

- The next step at the energy frontier of high energy physics needs
  - High fields (dipoles and quadrupoles from 16 T up to 20 T, solenoids from 20 T up to 40 T and more)
  - Energy efficiency (increase operating temperature to profit from Carnot, *minimal cryogen* usage)
  - Economics (high J_E, compact magnets, to reduce construction costs, sustainable Maintenance and Operation)
- **HTS may offer it all, provided…**
  - **We develop a new magnet technology palette**, higher current density, higher operating temperature (large degree of innovation required), using present conductor: do not wait for better
  - **Deploy rapidly for users**: they get to know the features of the new devices, cope and (may) adapt demands
  - **Profit from cost reduction**: one more "factor two reduction" possible ? That would be disruptive (HTS/LTS cross over)

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