International
MUON Collider
Collaboration

MuCol

HFM
High Field Magnets

HFM – WP2.6
UHF Solenoids for the Muon Collider

Presented by L. Bottura, CERN
on behalf of the Muon Magnets Working Group

HFM annual meeting 2023, 30 October - 2 November 2023

CERN

Funded by the EU under Grant Agreement 101094300

Outline

- Magnet development targets
- HF and UHF solenoids
- R&D status and plans

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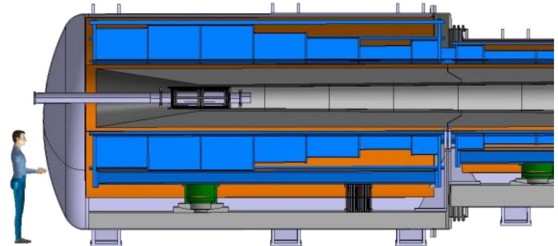
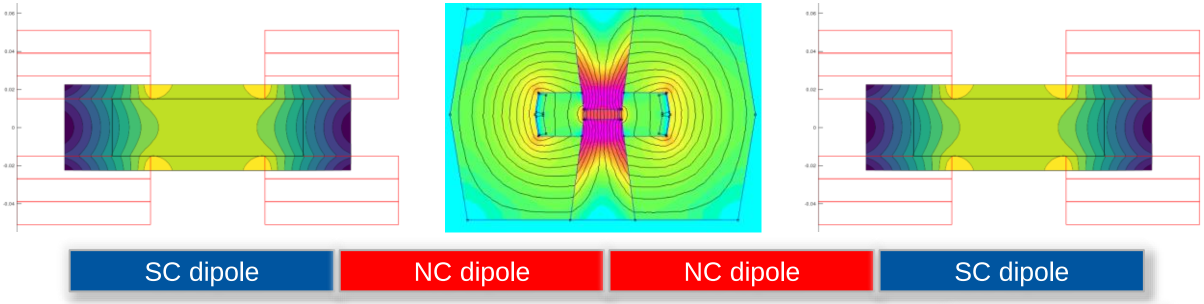
Muon Collider magnets

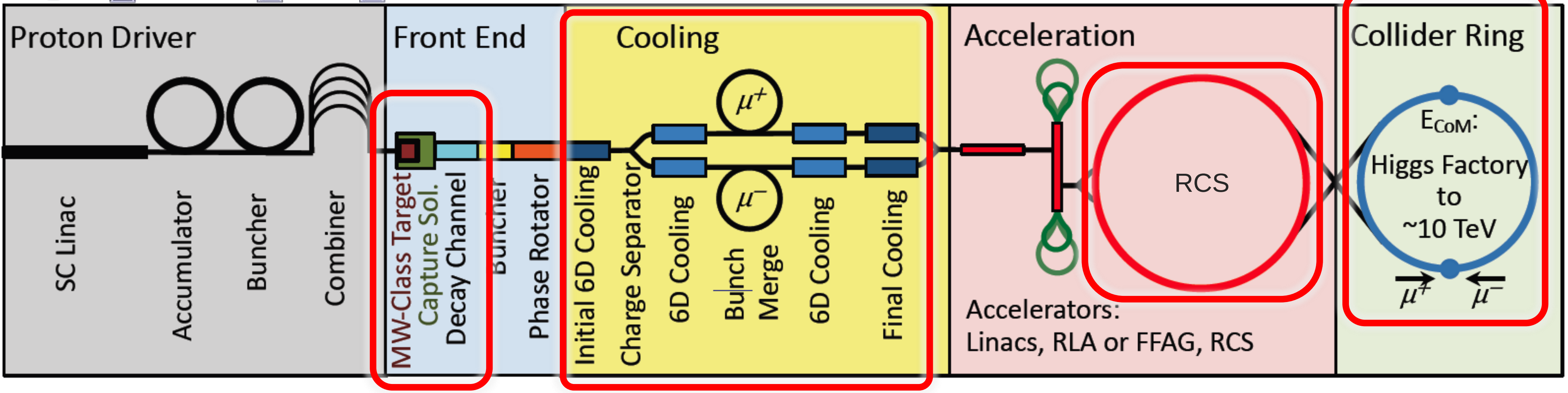
20 T, 200 mm
Radiation heat load ≈ 5…10 kW
Radiation dose: 80 MGy



NC ±1.8 T, 400 Hz
100 mm x 30 mm

SC < 10T
100 mm x 30 mm


SC dipole
NC dipole
NC dipole
SC dipole


Proton Driver
SC Linac
Accumulator
Buncher
Combiner

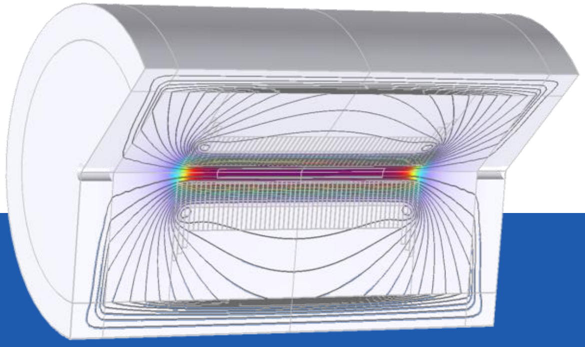
Front End
MW-Class Target
Capture Sol.
Decay Channel
Buncher
Phase Rotator

Cooling
Initial 6D Cooling
Charge Separator
6D Cooling
μ^+
μ^-
Bunch Merge
6D Cooling
Final Cooling

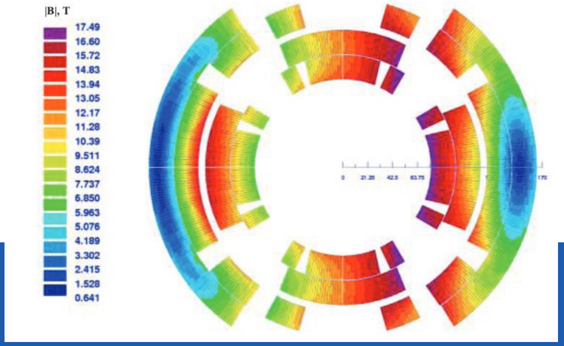
Acceleration
RCS
Accelerators:
Linacs, RLA or FFAG, RCS

Collider Ring
E_{CoM}:
Higgs Factory
to
~10 TeV
μ^+ μ^-

> 40 T, 60 mm



16 T peak, 160 mm
Radiation heat load ≈ 5 W/m
Radiation dose ≈ 20…40 MGy



Magnet development targets

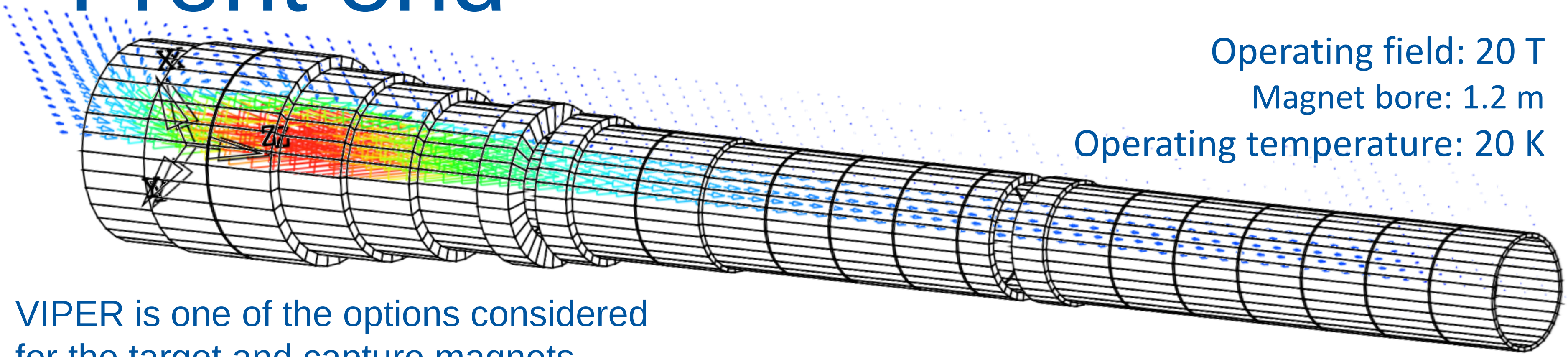
Complex	**Magnet**	**Aperture (mm)**	**Length (m)**	**Field (T)**	**Ramp rate (T/s)**	**Temperature (K)**
Target, decay and capture channel	Solenoid	1200	19	20	SS	20
6D cooling channel	Solenoid	90…1500	0.08…0.5	4…15	SS	4.2…20
Final cooling channel	Solenoid	50	0.5	> 40	SS	4.2
Rapid cycling synchrotron	NC Dipole	30x100	5	± 1.8	4200	300
Rapid cycling synchrotron	SC Dipole	30x100	1.5	10	SS	4.2…20
Collider ring	Dipole	160…100	4…6	11…16	SS	4.2…20

Outline

- Magnet development targets
- HF and UHF solenoids
- R&D status and plans

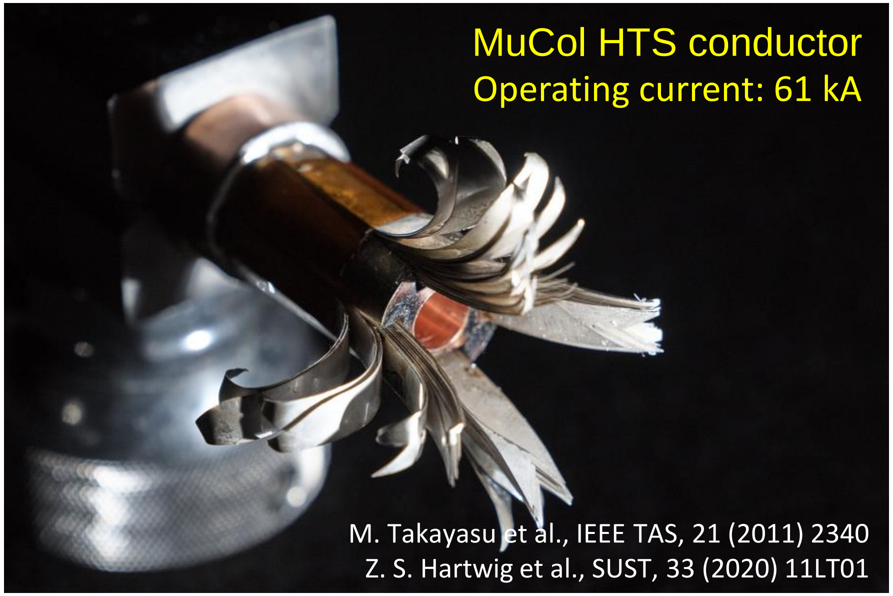
Front end

A Portone, P. Testoni, J. Lorenzo Gomez (F4E)
A. Kolehmainen, C. Accettura (CERN)



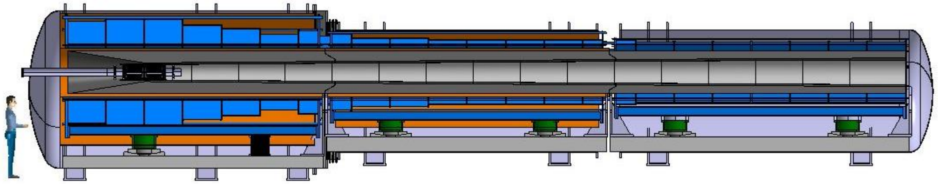
Operating field: 20 T
Magnet bore: 1.2 m
Operating temperature: 20 K

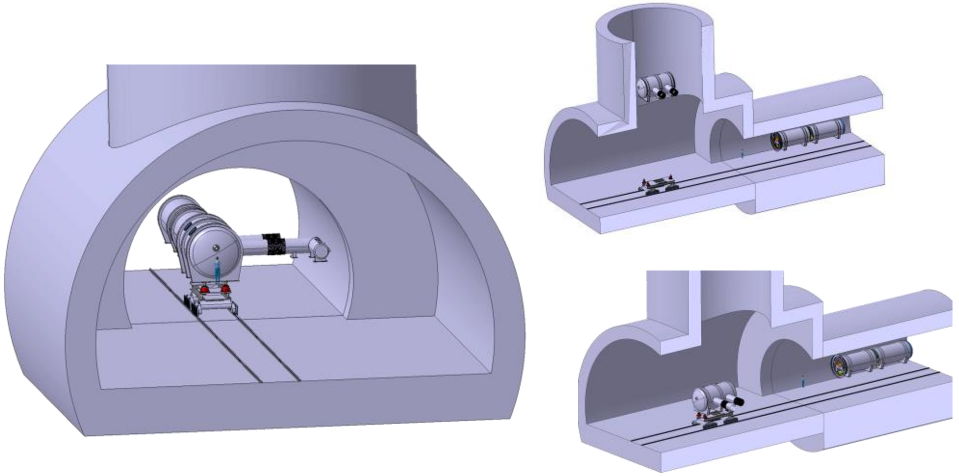
VIPER is one of the options considered for the target and capture magnets, providing a “feasible” solution



MuCol HTS conductor
Operating current: 61 kA

M. Takayasu et al., IEEE TAS, 21 (2011) 2340
Z. S. Hartwig et al., SUST, 33 (2020) 11LT01

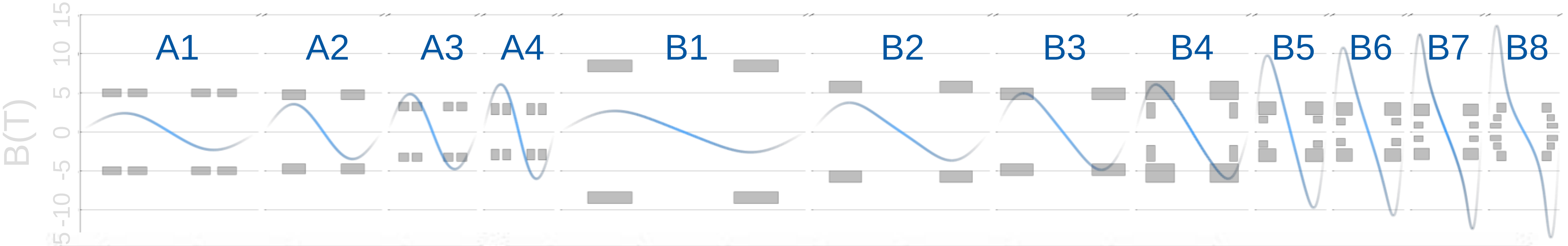




This looks more like a *fusion magnet*, not much synergy with HFM

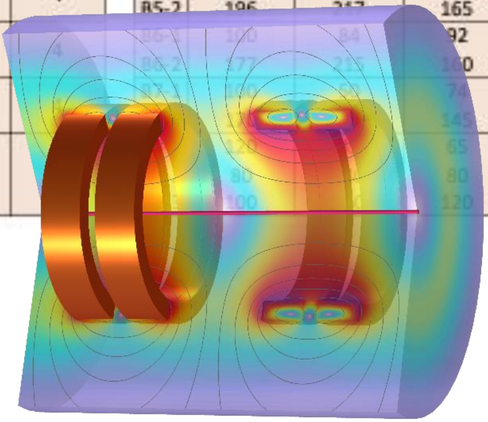
6D Cooling

J. Pavan (UMIL)
S. Fabbri (CERN)



Stage	Cell length	Peak axis B	Stored energy	Coils/cell
	(m)	(T)	(MJ)	(-)
A1	2	2.4	5.4	4
A2	1.32	3.5	15.4	2
A3	1	4.8	7.2	4
A4	0.8	6.1	8.4	4
B1	2.75	2.6	44.5	2
B2	2	3.7	24.1	2
B3	1.5	4.9	29.8	2
B4	1.27	6	24.4	4
B5	0.806	9.8	12	4
B6	0.806	10.8	8.2	4
B7	0.806	12.5	5.7	[illegible]
B8	0.806	13.6	1.4	[illegible]

Coil	Length	Radius	Thickness	Current density	Peak coil B	Hoop stress	Radial stress	Technology		
	(mm)	(mm)	(mm)	(A/mm^2)	(T)	(MPa)	(MPa)	Nb-Ti 4K	Nb$_3$Sn 4K	HTS 4K/20K
A1-1	210	450	100	63.25	4.1	34	-4.6	✓	✓	✓
A2-1	260	410	130	126.6	9.5	137	-28.3		✓	✓
A3-1	110	270	110	165	9.4	138	-28.5		✓	✓
A4-1	90	220	140	195	11.6	196	-49.4		✓	✓
B1-1	500	770	150	69.8	6.9	95	-13.5	✓	✓	✓
B2-1	360	500	150	90	8.4	114	-20.1		✓	✓
B3-1	370	410	150	123	11.2	174	-36.6		✓	✓
B4-1	92	175	200	94	9.2	231	-0.1/19.7		✓	✓
B4-2	320	410	240	70.3	7.8	66	-23.5		✓	✓
B5-1	100	113	88	157	13.9	336	-0.7/21.1		...	✓
B5-2	196	217	165	168	12.3	159	-55.7		✓	✓
B6-1	100	84	92	185	14.2	314	-1.4/22.3		...	✓
B6-2	177	215	160	155.1	10.3	118	-43.1		✓	✓
B7-1	100	60	74	198	14.3	244	-1.1/20.7		...	✓
[illegible]	[illegible]	[illegible]	145	155	10.1	119	-37.4		✓	✓
[illegible]	120	[illegible]	65	220	15.1	119	-3.0/22.1		...	✓
[illegible]	80	[illegible]	80	135	6.2	110	-2.4/4.5	✓	✓	✓
[illegible]	100	[illegible]	120	153	6.2	41	-22.9	✓	✓	✓



Coil size

Quench protection

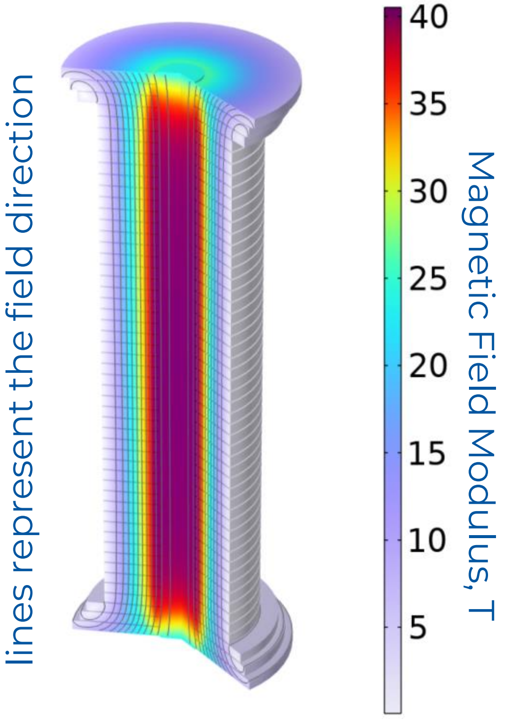
Margin

Mechanics

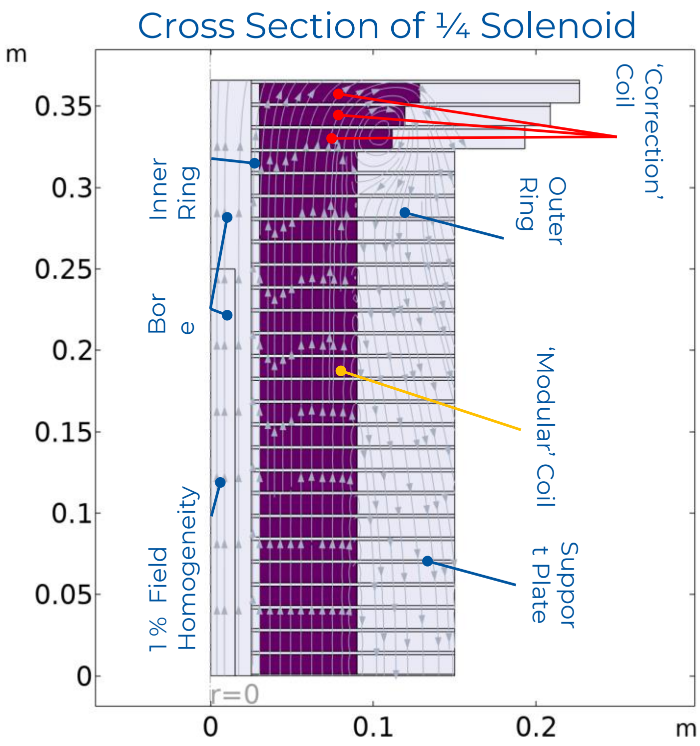
Courtesy of J. Pavan, UMIL, and S. Fabbri, CERN

Final cooling (40 T) magnetics

$$B_{max} = 2 \cdot \sqrt{\sigma_{max} \cdot \mu_0} \xrightarrow{\sigma_{max} = 600\ \text{MPa}} B_{max} \approx 55\ \text{T}$$



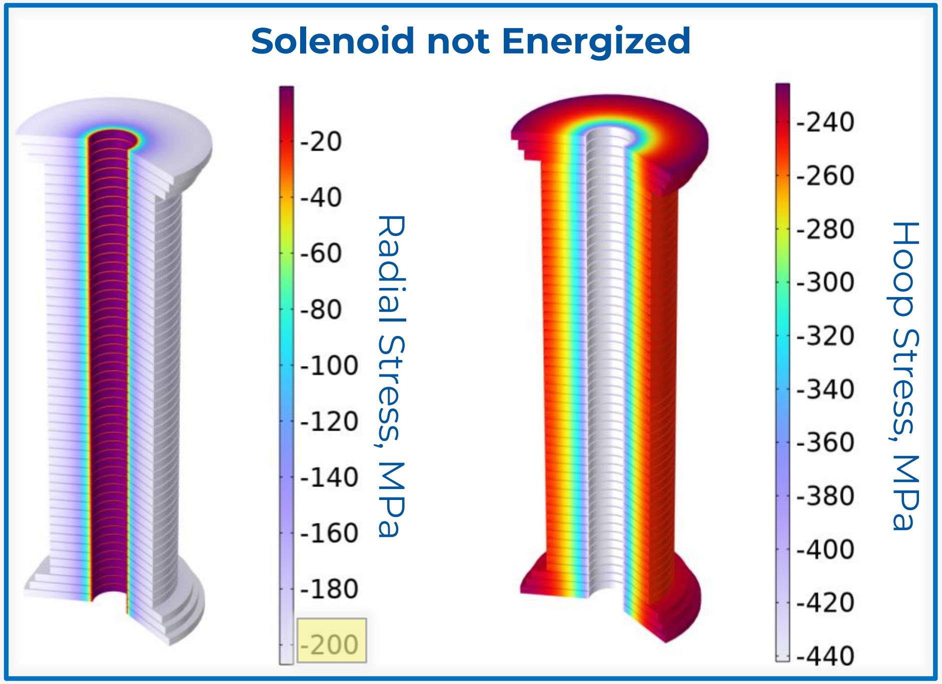
- **Modular** pancake design with supporting *ring and plates* to manage hoop, radial and vertical stresses
- Free bore **50 mm**
- Inner ring thickness 5 mm
- Coil **winding thickness 60 mm**
  - $J_e = 632\ \text{A mm}^{-2}$ → 40 T
- Outer ring thickness *60 mm*
  - **Outer radius 150 mm**
- Horizontal plate thickness 2 mm

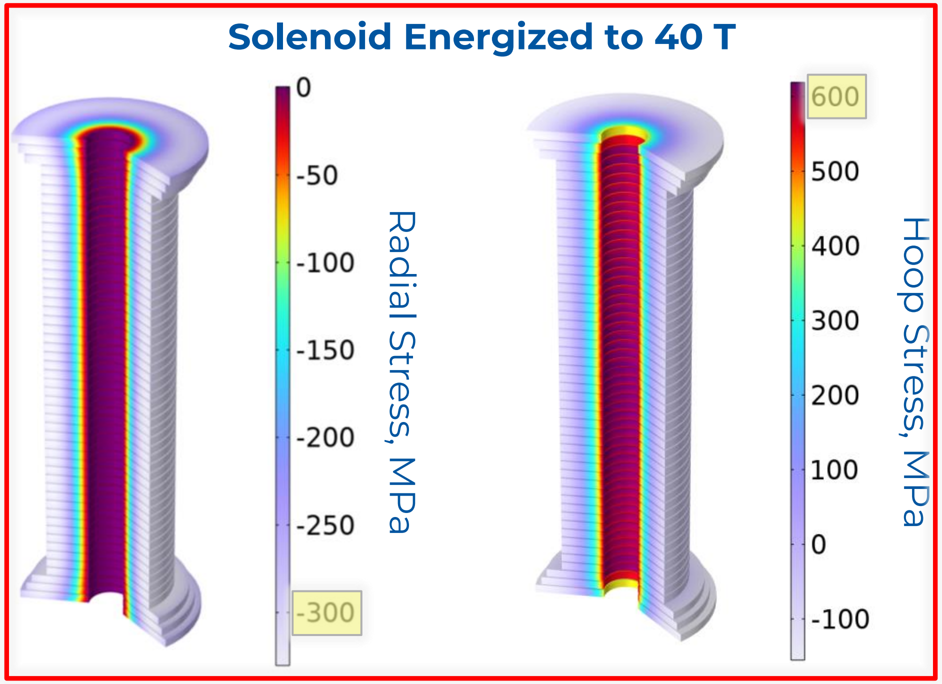


46 identical **'modular'** pancakes and **6 'correction'** pancakes are used to straighten the field lines at the solenoid ends

Courtesy of B. Bordini and A. Dudarev, CERN

Final cooling (40 T) mechanics


Solenoid not Energized

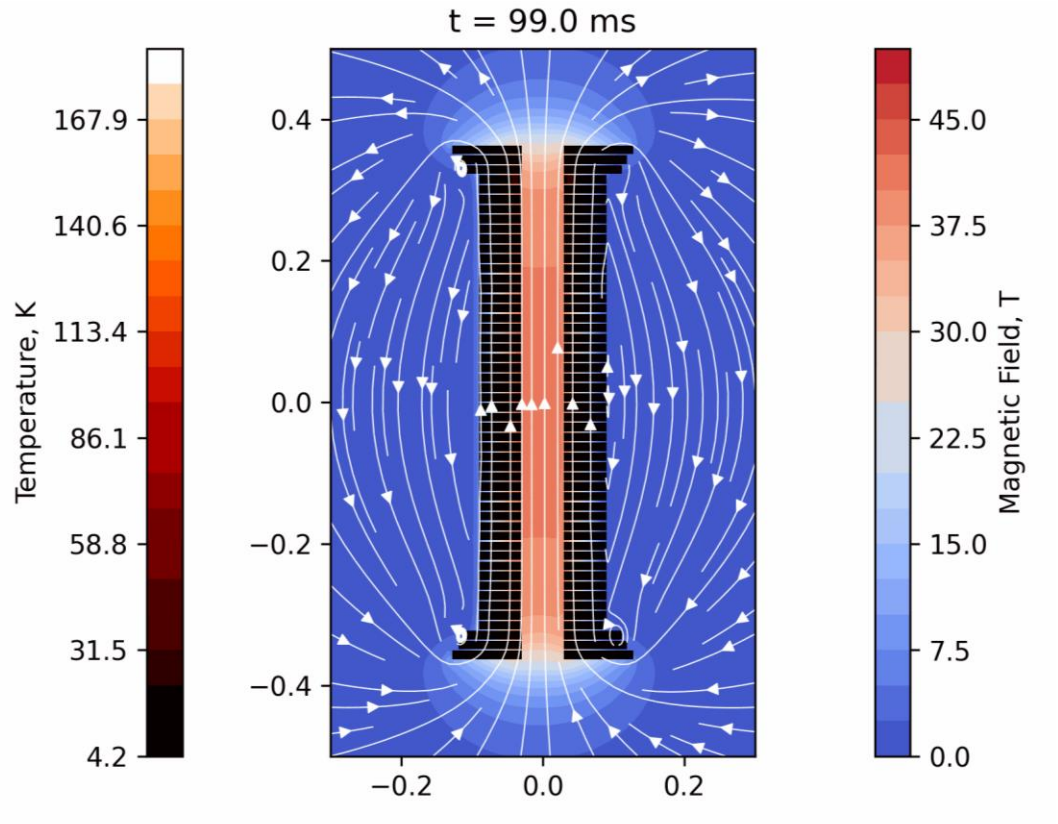

Solenoid Energized to 40 T

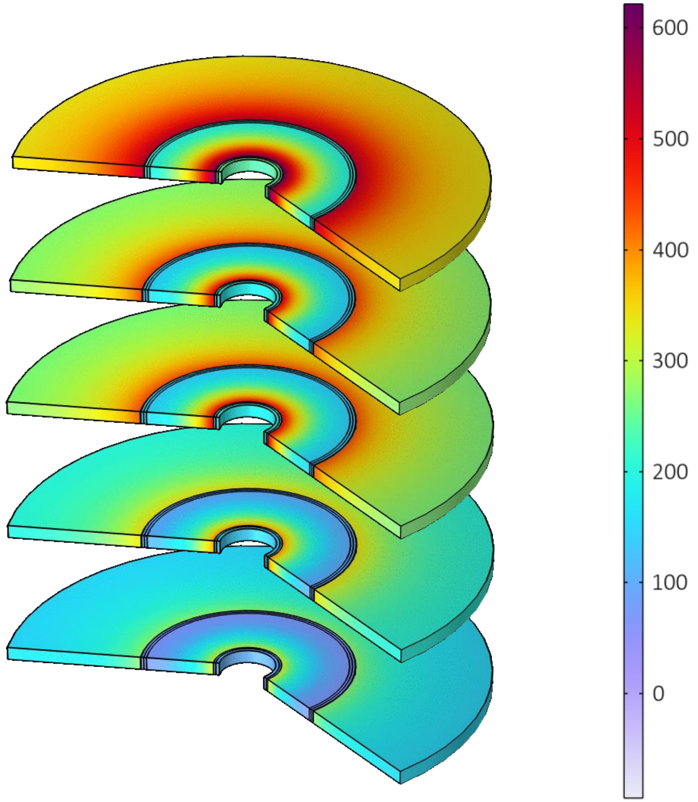
Preloading, a **radial precompression of ~ 200 MPa** is essential to limit the conductor hoop stress to acceptable values and to prevent tensile radial stress.

Electro-mechanical design and tests are in progress to validate the concept and identify issues/solutions towards assessing the performance limits.

Courtesy of B. Bordini and C. Accettura, CERN

Final cooling (40 T) quench





At this magnet scale (i.e. stored energy and size) a **non-insulated winding** seems to be a good option for quench management. Transverse resistance control in a range suitable for operation, balancing protection, mechanics, ramp time and field stability will be crucial (**priority R&D**)

Courtesy of T. Mulder and G. Vernassa, CERN

Outline

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- HF and UHF solenoids
- R&D status and plans

Funding: IMCC+MuCol

Conductor Testing

Initial set of samples collected from leading manufacturer to allow for initial screening and characterization measurements

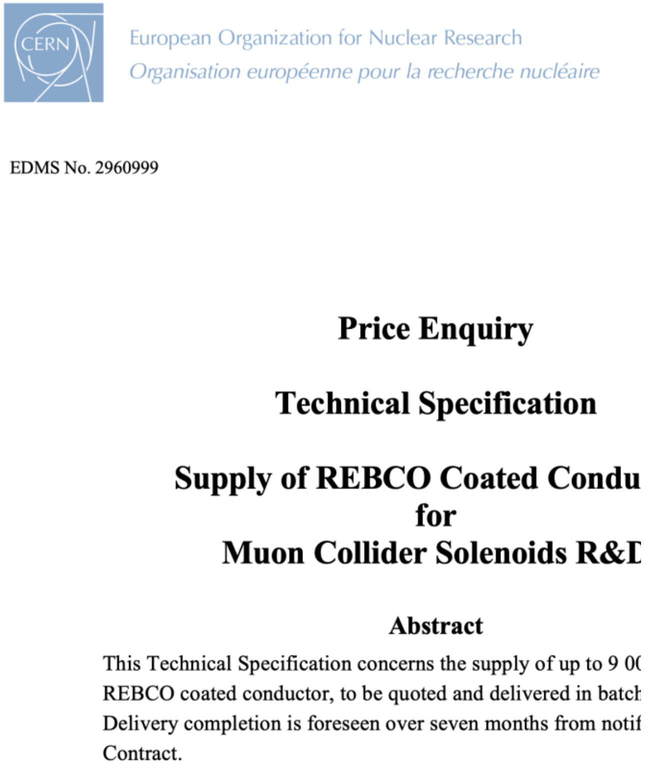
Manufacturer	Tape	length (m)	width (mm)
THEVA	TPL4421 - QS0037	414	4
SST	YP-448	25	12
Superpower	SCS12050-AP-M3-1221-9	100	12
SuperOx Japan	3209 N2	0.7	4
SST		25	4
SuperOx Japan	3155L_Cu_545_555	10	4
SuperOx Japan	2513C_Cu_106_116	10	4
SuperOx Japan	3625L_Cu_787_797	10	4
SuperOx Japan	3045R_Cu_1185_1195	10	4
SuperOx Japan	3661L_Cu_1468_1478	10	4
SuperPower	SCS4050-HM	10	4
Fujikura	FESC-SCH02	10.7	2

To be complemented with material presently in procurement at CERN and INFN

- University of Geneva
  - Critical current characterization at high field and scaling relations
  - Delamination experiments (see presentation from C. Senatore)
- University of Twente
  - Electro-mechanical tape characteristics in longitudinal and transverse stress/strain
  - Stack cable concept, design and characterization
- Southampton University
  - Insulated pancake manufacturing and testing à la EUCard2 (tape performance and quench characteristics) in field up to 10T/100mm bore and at temperatures between 77K and 4.2K vapour or liquid cooled

Funding: HFM

REBCO procurement



European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

EDMS No. 2960999

DO-33893/ATS
Group Code: ATS

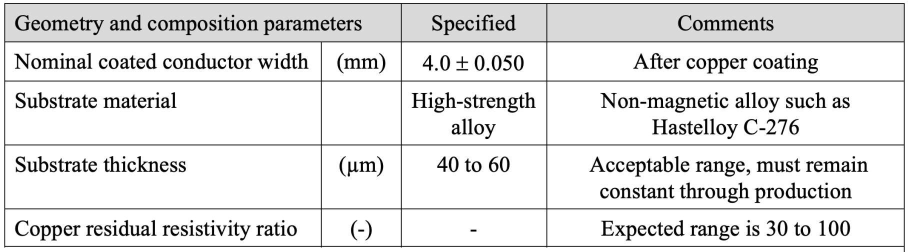
Price Enquiry

Technical Specification

Supply of REBCO Coated Condu
for
Muon Collider Solenoids R&

Abstract

This Technical Specification concerns the supply of up to 9 0
REBCO coated conductor, to be quoted and delivered in batc
Delivery completion is foreseen over seven months from noti
Contract.

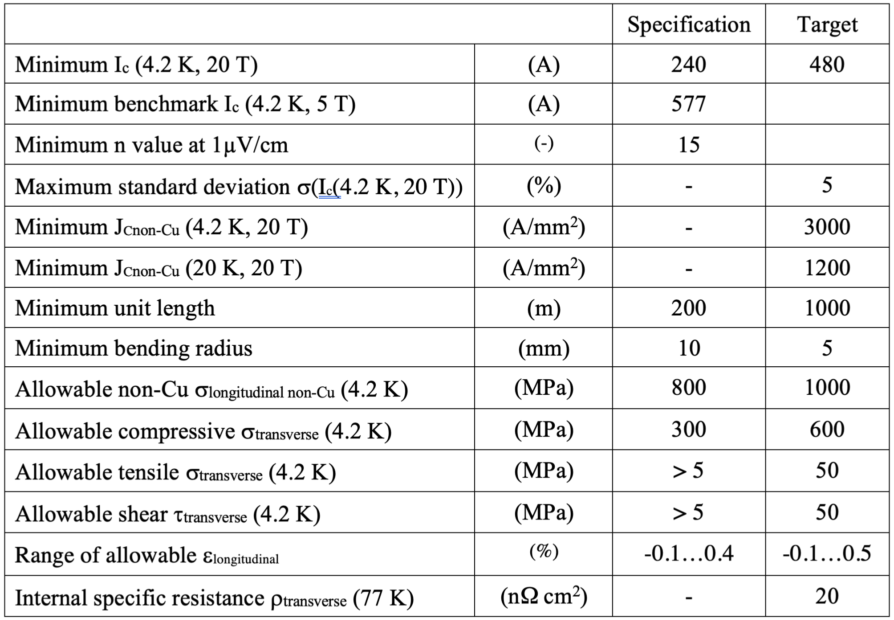


Geometry and composition parameters		Specified	Comments
Nominal coated conductor width	(mm)	4.0 ± 0.050	After copper coating
Substrate material		High-strength alloy	Non-magnetic alloy such as Hastelloy C-276
Substrate thickness	(µm)	40 to 60	Acceptable range, must remain constant through production
Copper residual resistivity ratio	(-)	-	Expected range is 30 to 100

ickness is intended as total,
twice the thickness of a
neous coating on both faces
f the coated conductor

ptable range, must remain
stant through production

must be no dog-boning and
ges after copper coating



		Specification	Target
Minimum I_c (4.2 K, 20 T)	(A)	240	480
Minimum benchmark I_c (4.2 K, 5 T)	(A)	577	
Minimum n value at 1 µV/cm	(-)	15	
Maximum standard deviation $\sigma(I_c(4.2\text{ K}, 20\text{ T}))$	(%)	-	5
Minimum $J_{C\text{non-Cu}}$ (4.2 K, 20 T)	(A/mm²)	-	3000
Minimum $J_{C\text{non-Cu}}$ (20 K, 20 T)	(A/mm²)	-	1200
Minimum unit length	(m)	200	1000
Minimum bending radius	(mm)	10	5
Allowable non-Cu $\sigma_{\text{longitudinal non-Cu}}$ (4.2 K)	(MPa)	800	1000
Allowable compressive $\sigma_{\text{transverse}}$ (4.2 K)	(MPa)	300	600
Allowable tensile $\sigma_{\text{transverse}}$ (4.2 K)	(MPa)	> 5	50
Allowable shear $\tau_{\text{transverse}}$ (4.2 K)	(MPa)	> 5	50
Range of allowable $\varepsilon_{\text{longitudinal}}$	(%)	-0.1…0.4	-0.1…0.5
Internal specific resistance $\rho_{\text{transverse}}$ (77 K)	(nΩ cm²)	-	20

DO 33893 published

up to 9 km of 4 mm REBCO tape, in batches of 3 km (option for additional 3 km), to be used to wind pancakes for solenoid R&D. The plan is to follow-up with 15 km of 4 mm REBCO tape in late 2024.

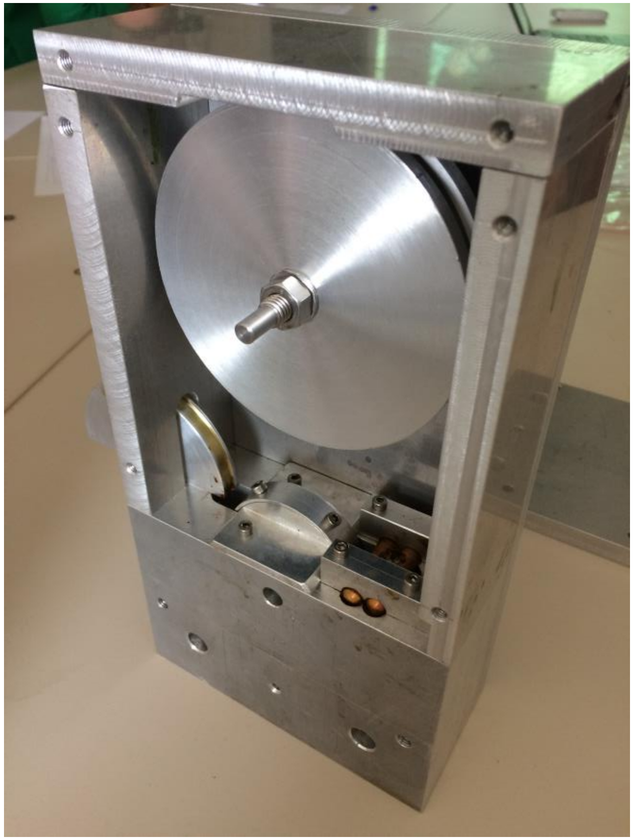
Funding: IMCC+MuCol

R&D Pancakes – 1/2

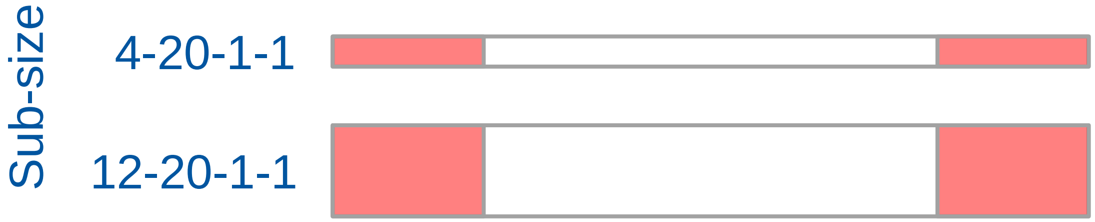
Singe and stacked pancake tests are planned to validate the concept and identify issues/solutions towards assessing the performance limits.

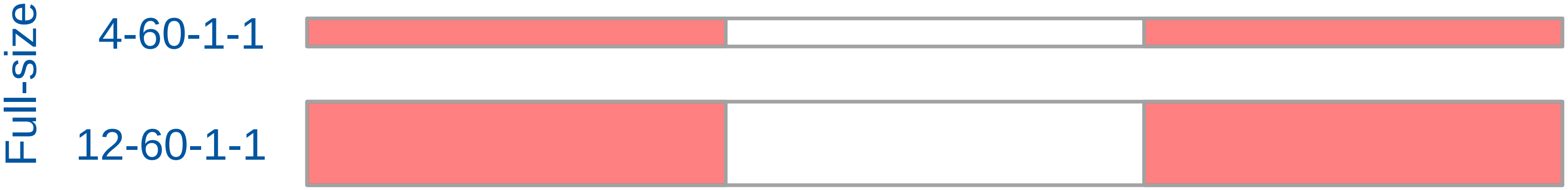
- 60 mm inner diameter
- 20 mm and 60 mm thickness
- 4 mm and 12 mm tape width
- Single and double pancakes winding
- One- and two-in-hand winding

Field reach: 15…25 T



Winding trials EP-ADO
Tooling and material test EN-MME



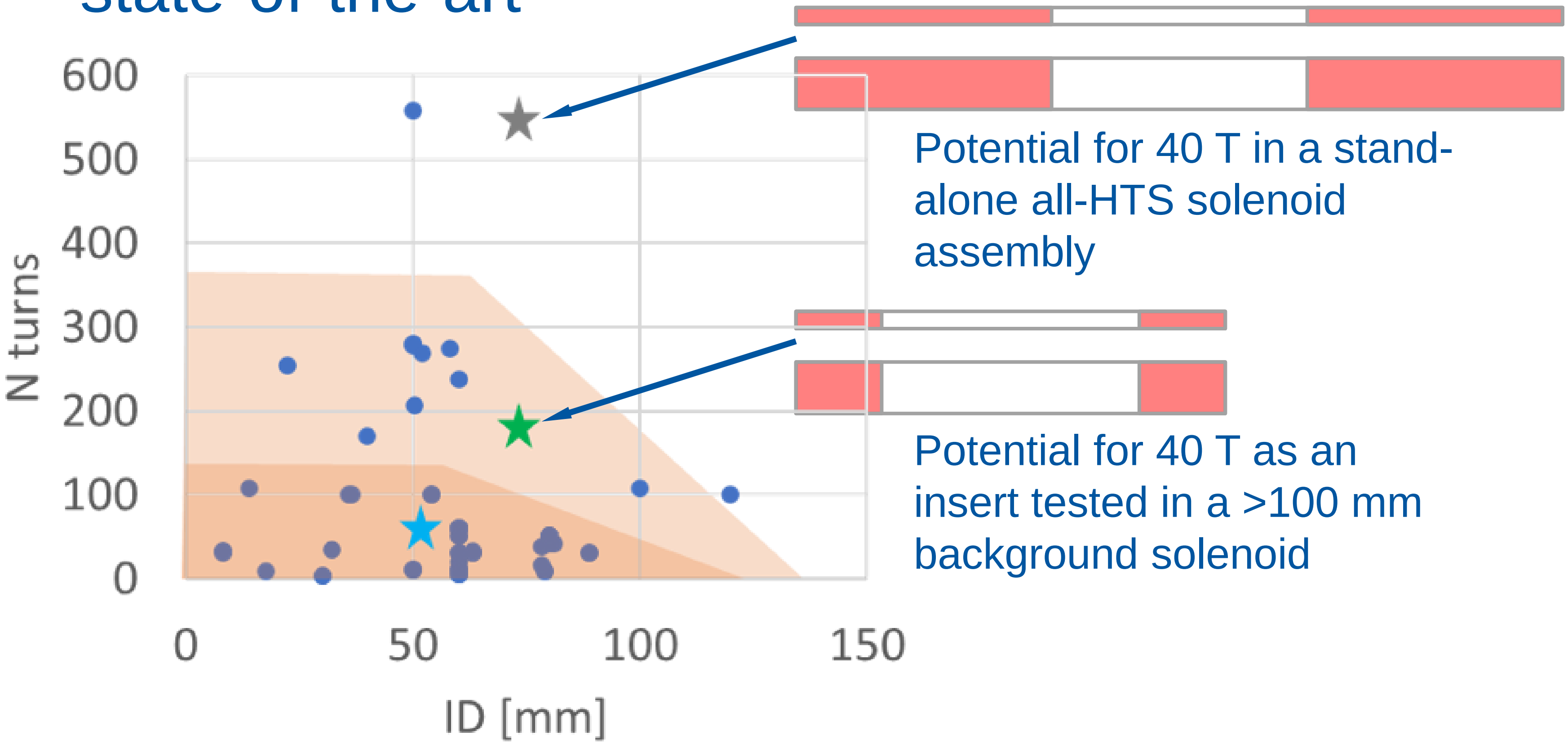


Prototype winding by courtesy of A. Dudarev, CERN

Funding: IMCC+MuCol

R&D Pancakes – 2/2

- The R&D pancakes will probe geometry and operating conditions well beyond the present state-of-the-art



Potential for 40 T in a stand-alone all-HTS solenoid assembly

Potential for 40 T as an insert tested in a >100 mm background solenoid

Courtesy of S. Sorti, UMIL and INFN LASA

Are solenoids relevant ?

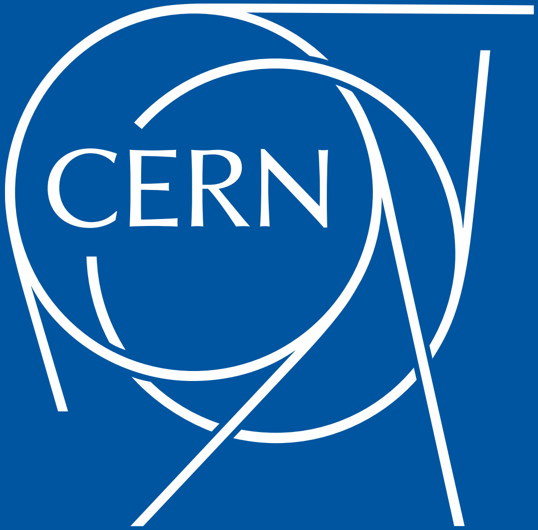
- Solenoid model coils built with modest conductor lengths and size (few km) can probe performance limits at extreme values:
  - Field (20 T…40 T) – high and ultra-high field characterization of the critical surface $J_C(B,T,\alpha)$
  - Force and stress (500 MPa…700 Mpa) – engineering test at levels relevant and beyond full-size accelerator magnets
  - Current density (600 A/mm^2…900 A/mm^2) and energy density (300 MJ/m^3) – quench detection and protection in a new regime, where present technical solutions may not work (detection time would be too short, quench heater power would be too high)
- “Simple” engineering, fast turnaround samples

Summary and perspective

- The magnet activities in the scope of the International Muon Collider Collaboration (IMCC) and the EU design study MuCol have a strong focus on HF and UHF HTS solenoids
  - We wish to **probe the limits of present technology**, and define the R&D required to achieve such performance (MuCol and ESPP deliverable)
  - **This work is instrumental** to achieving the muon collider luminosity targets (i.e. performance beyond US-MAP)
- This technology development connects directly to the R&D in the scope of HFM
  - Share technology challenges and advances, **and profit from capabilities within RD2 (e.g. KC4)**
  - Recall that **the technology developed is also relevant for other magnets**, such as arc dipoles and IR quadrupoles for the Muon Collider (steady state)
- HF and UHF HTS solenoids will be one of the leading themes in the upcoming INFRA-TECH EU call

Grateful thanks to many !

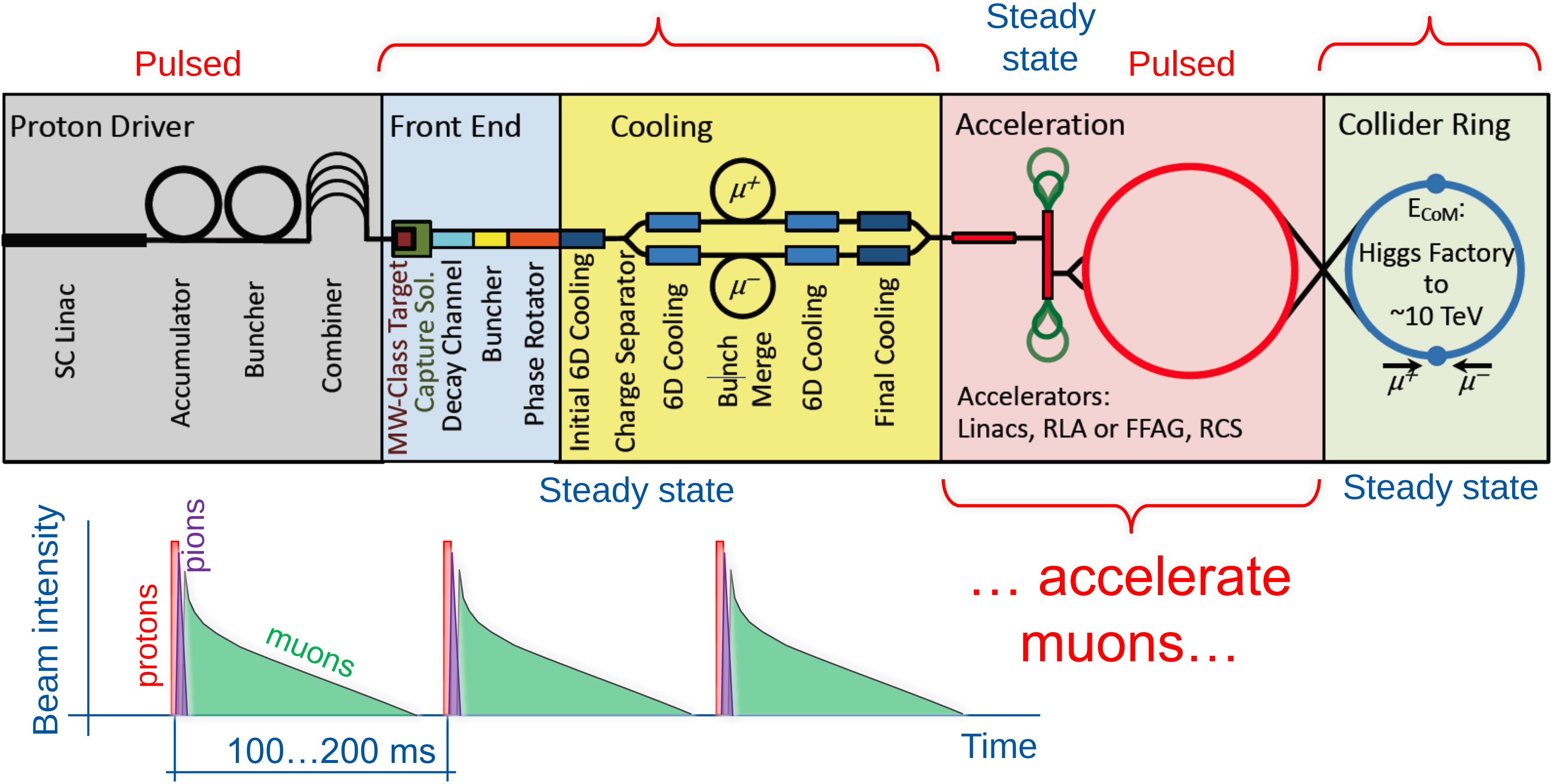
C. Accettura, N. Amemiya, B. Auchmann, J.S. Berg, A. Bersani, A. Bertarelli, F. Boattini, B. Bordini, M. Breschi, B. Caiffi, X. Chaud, F. Debray, A. Dudarev, M. Eisterer, S. Fabbri, S. Farinon, P. Ferracin, H. De Gersem, A. Kario, A. Kolehmainen, J. Kosse, J. Lorenzo Gomez, R. Losito, S. Mariotto, M. Mentink, T. Mulder, R. Musenich, D. Novelli, T. Ogitsu, M. Palmer, J. Pavan, H. Piekarz, A. Portone, L. Quettier, E. Rochepault, L. Rossi, T. Salmi, H. Schneider-Muntau, C. Senatore, M. Statera, P. Tavares, H.H.J. Ten Kate, P. Testoni, G. Vallone, A. Verweij, M. Wozniak, A. Yamamoto, Y. Yang, Y. Zhai, A. Zlobin, and the Muon Magnets Working Group


CERN

Proton-driven Muon Collider Concept

Produce a low emittance muon beam…

… collide !



… accelerate muons…

Risk register and mitigation (the plan)

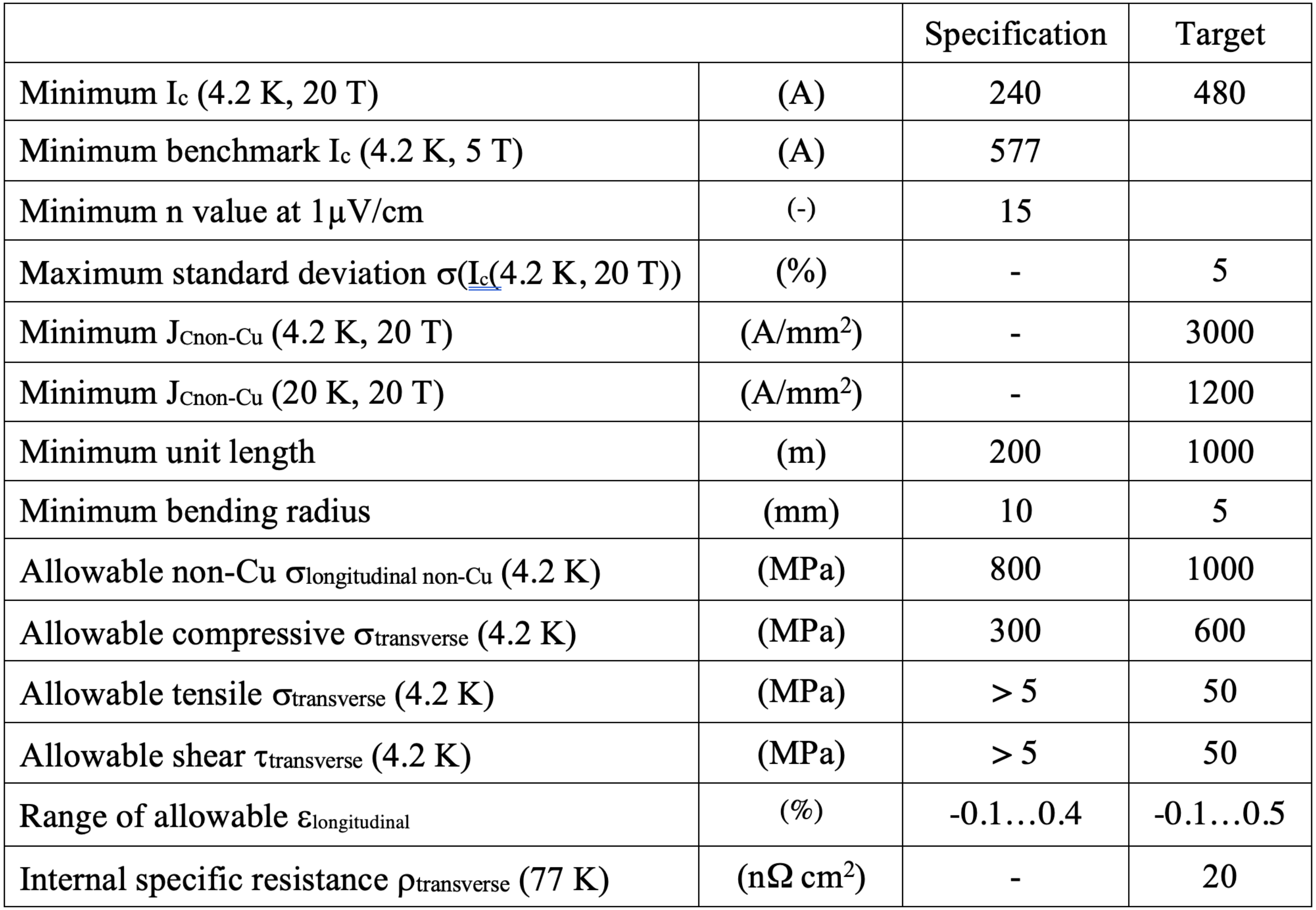
Risk	Mitigation action (program)	Tests (tape length)
Reaching field/sub-optimal performance	Use pancakes to test performance (force and thermal cycles) and compare to expected performance from characterized tapes (NOTE: need of complete Ic(B,T,angle) scaling)	10 sub-size (500) 5 full-size (1250)
Tape degradation during coil manufacturing	Test performance before/after winding at 77 K, partly covered by previous item. Dedicated tests to be performed for: soldering or potting, double pancakes and transitions, joints	10 sub-size (500)
Coil internal mechanics and mechanical properties	Instrumented stacks and dummy pancakes to verify stress components and distributions. Reinforcements and bonding of turns	20 stacks (200) 10 dummy (500) 10 sub-size loading (500)
Coil external mechanics and pre-load	Pre-loading structure development and tests	5 dummy (250) 5 sub-size loading (250) 5 full-size loading (1250)
Inter-turn resistance control and variants	Produce baseline windings (e.g. soldered, no insulation control) and variants introducing intrinsic and extrinsic resistance control	15 sub-size (750)
Joints resistance and stability	Produce test configuration for pancake joints and unit electrical/mechanical test. Integrate joints in pancakes and test resistance and stability (force and thermal cycles)	20 single joints (200) 10 sub-size (500) 2 full-size (500)
Quench detection	Introduce and test diagnostics in above tests. Select baseline (voltage ?) for comparison	Use above pancakes for dedicated tests
Quench protection	Test energy release and temperature increase in provoked and spontaneous quenches	Use above pancakes for dedicated tests
Coil dynamic forces	Test mini-coil stacks of pancakes	12 full-size (3000)

Total approximately 10 km of 4 mm tape

HTS tape specifications – 1/2

Geometry and composition parameters		Specified	Comments
Nominal coated conductor width	(mm)	4.0 ± 0.050	After copper coating
Substrate material		High-strength alloy	Non-magnetic alloy such as Hastelloy C-276
Substrate thickness	(µm)	40 to 60	Acceptable range, must remain constant through production
Copper residual resistivity ratio	(-)	-	Expected range is 30 to 100
Total copper coating thickness	(µm)	20 (2x10)	This thickness is intended as total, i.e. twice the thickness of a homogeneous coating on both faces of the coated conductor
Coated conductor thickness	(µm)	60 to 100	Acceptable range, must remain constant through production
Coated conductor thickness tolerance and homogeneity	(µm)	± 5	There must be no dog-boning and bulges after copper coating

HTS tape specifications – 2/2



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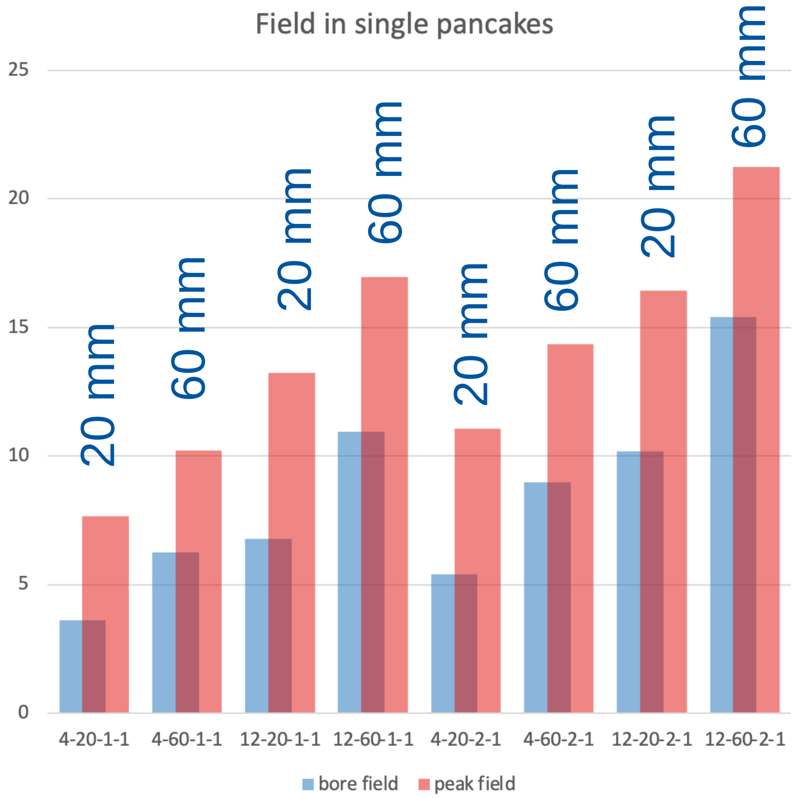
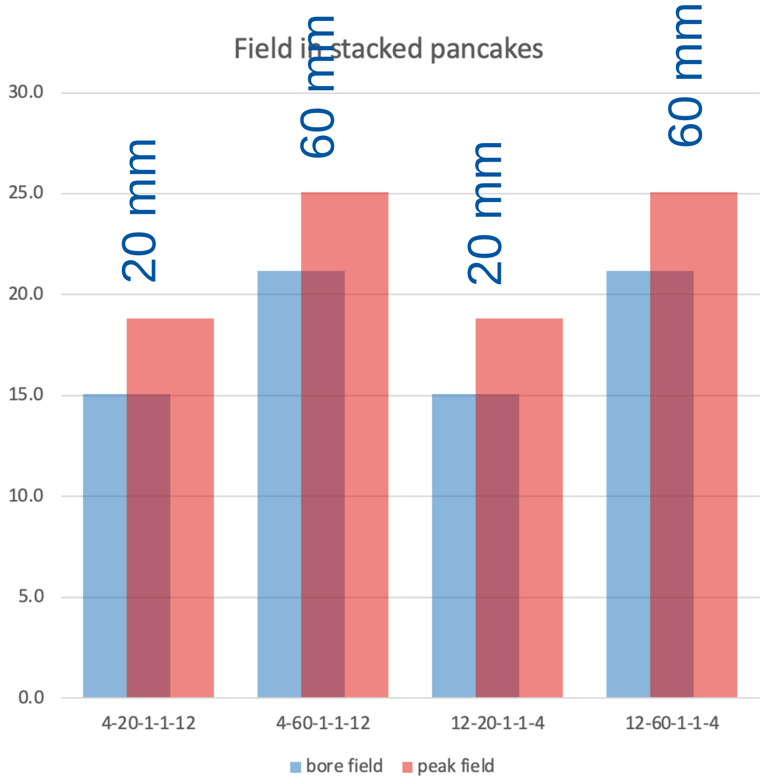
Minimum n value at 1 μV/cm	(-)	15	
Maximum standard deviation $\sigma(I_c(4.2\text{ K}, 20\text{ T}))$	(%)	-	5
Minimum $J_{C\text{non-Cu}}$ (4.2 K, 20 T)	(A/mm^2)	-	3000
Minimum $J_{C\text{non-Cu}}$ (20 K, 20 T)	(A/mm^2)	-	1200
Minimum unit length	(m)	200	1000
Minimum bending radius	(mm)	10	5
Allowable non-Cu $\sigma_{\text{longitudinal non-Cu}}$ (4.2 K)	(MPa)	800	1000
Allowable compressive $\sigma_{\text{transverse}}$ (4.2 K)	(MPa)	300	600
Allowable tensile $\sigma_{\text{transverse}}$ (4.2 K)	(MPa)	> 5	50
Allowable shear $\tau_{\text{transverse}}$ (4.2 K)	(MPa)	> 5	50
Range of allowable $\varepsilon_{\text{longitudinal}}$	(%)	-0.1…0.4	-0.1…0.5
Internal specific resistance $\rho_{\text{transverse}}$ (77 K)	(nΩ cm^2)	-	20

Magnetic field reach





4 mm tape

12 mm tape

4 mm tape

12 mm tape

Single pancakes

Double pancakes

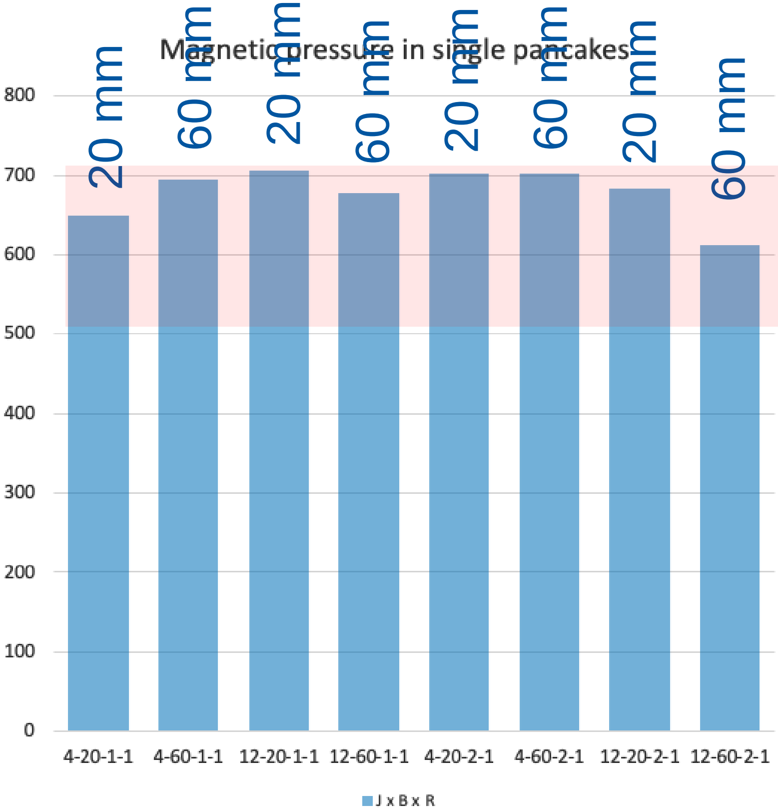
4 mm tape

12 mm tape

Stacked pancakes

MuC final cooling 40 T: ≈720 MPa

Magnetic pressure



4 mm tape

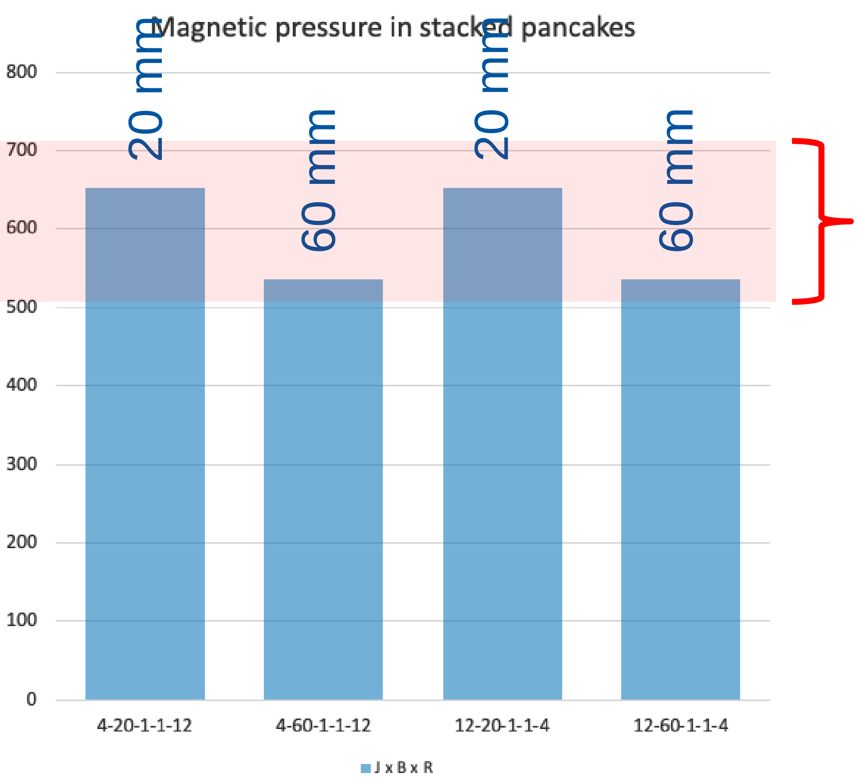
12 mm tape

4 mm tape

12 mm tape

Single pancakes

Double pancakes



500 to 700 MPa

4 mm tape

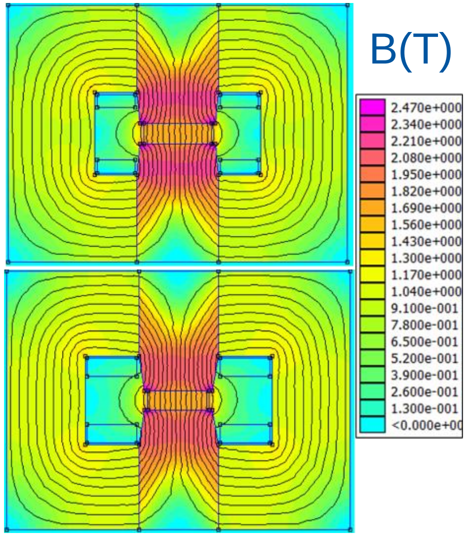
12 mm tape

Stacked pancakes

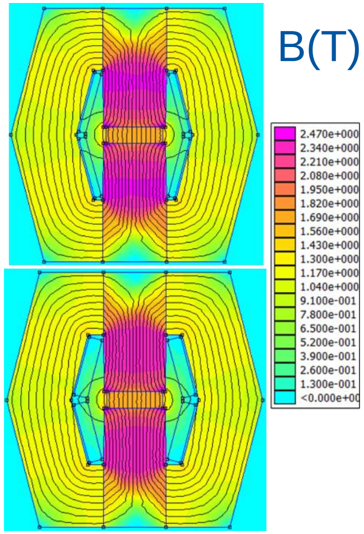
Accelerator magnets

NC dipoles

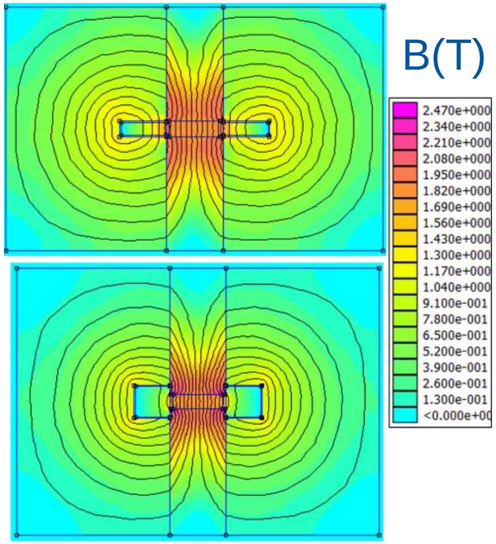
H-type



HG-type

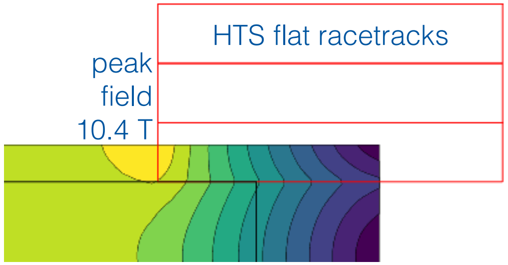


WF-type

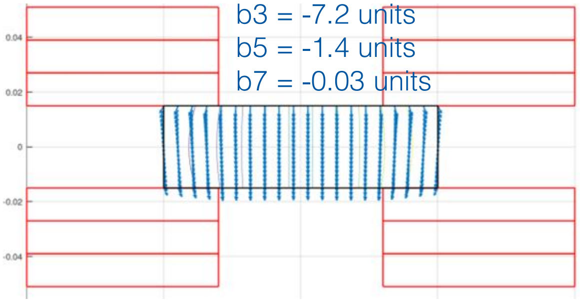


Minimum magnetic energy approximately 5.4 kJ/m (1.4 times the gap energy)
Minimum loss approximately 400 J/m cycle (about 2 kW/m)

SC dipoles



Rectangular magnet bore 100 mm x 30 mm



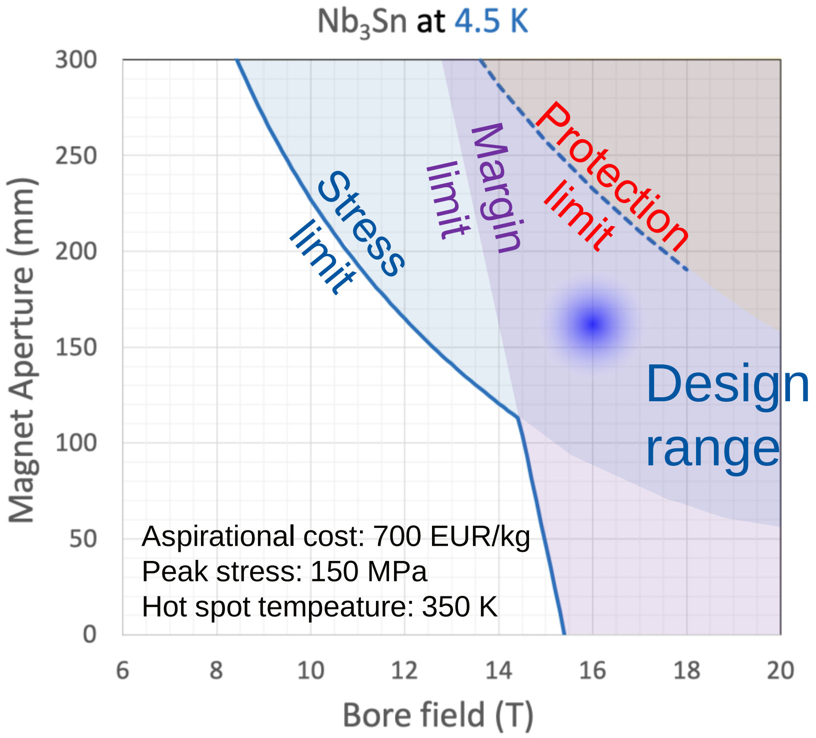
b3 = -7.2 units
b5 = -1.4 units
b7 = -0.03 units

A *simple* HTS racetrack dipole could match the beam requirements and aperture

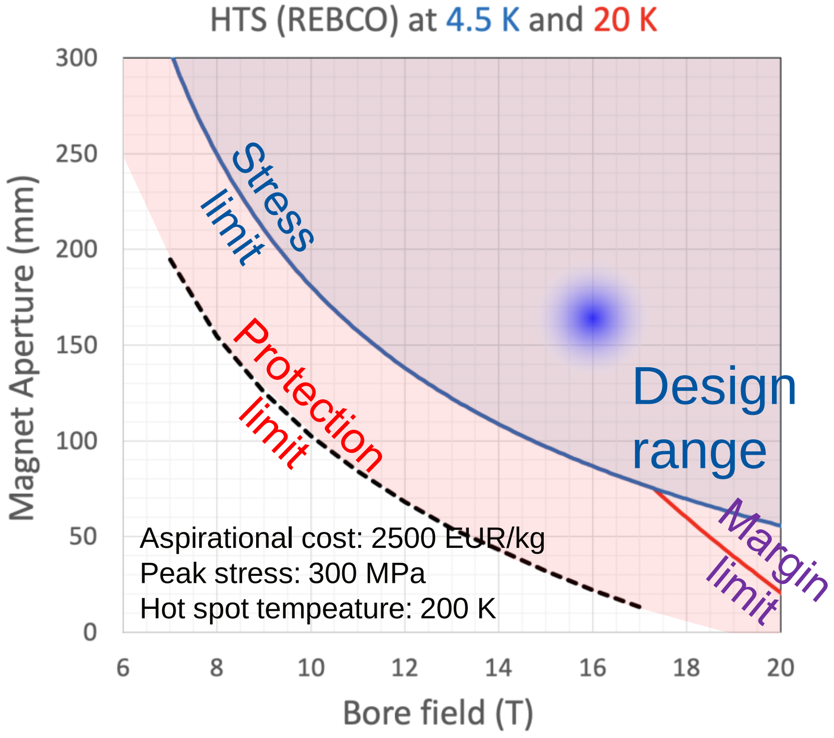
M. Breschi, L. Cavallucci, R. Miceli, P.L. Ribani (UniBO)
F. Boattini, S. Fabbri (CERN)

Courtesy of M. Breschi, P.L. Ribani, R. Miceli, UniBO

Collider magnets – A-B plots



Aspirational cost: 700 EUR/kg
Peak stress: 150 MPa
Hot spot tempeature: 350 K



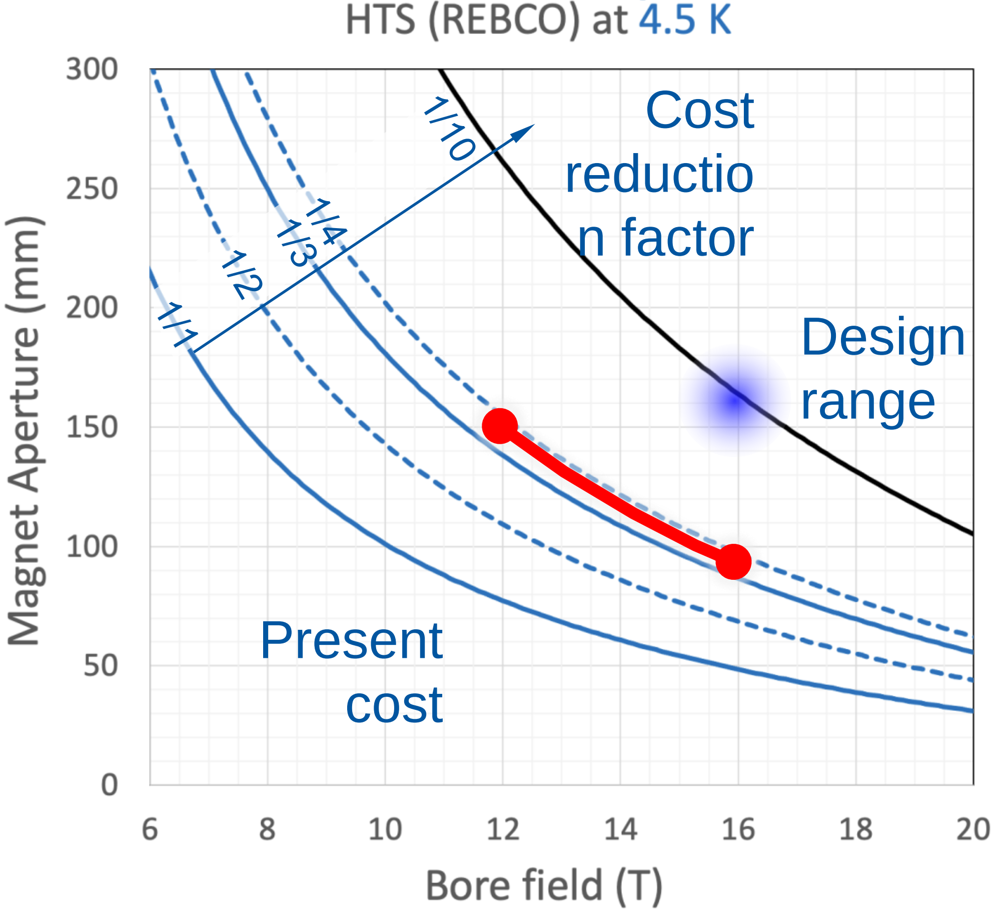
Aspirational cost: 2500 EUR/kg
Peak stress: 300 MPa
Hot spot tempeature: 200 K

- Work in progress to provide analytical expression for the magnet design limits (including protection and cost)
- Nb$_3$Sn falls short of required performance because of **operating margin** and peak stress (at affordable cost !)
- HTS falls short of required performance because of peak stress and protection (at affordable cost !) – **Need to devise alternative protection schemes**

D. Novelli, B. Caiffi, A. Bersani, S. Farinon (INFN), S. Mariotto (UMIL, INFN)
T. Salmi (TUT)

Courtesy of D. Novelli, S. Mariotto, B. Caiffi, INFN, and T. Salmi, TUT

Collider magnets – A-B range



- A reduction of HTS cost will result in wider design A-B range
  - Reducing unit cost by a factor four doubles the allowable magnet aperture at 16 T
  - A reduction of one order of magnitude would be required to reach (16 T, 150 mm)
- Operation in the range of temperature 10 K…20 K (above liquid helium) will reduce magnet aperture requirements
  - Acceptable heat loads is increased by a factor 2…4, thus reducing the need for shielding

- Iterate with beam physics as the nominal optics and adjust design targets in accordance.

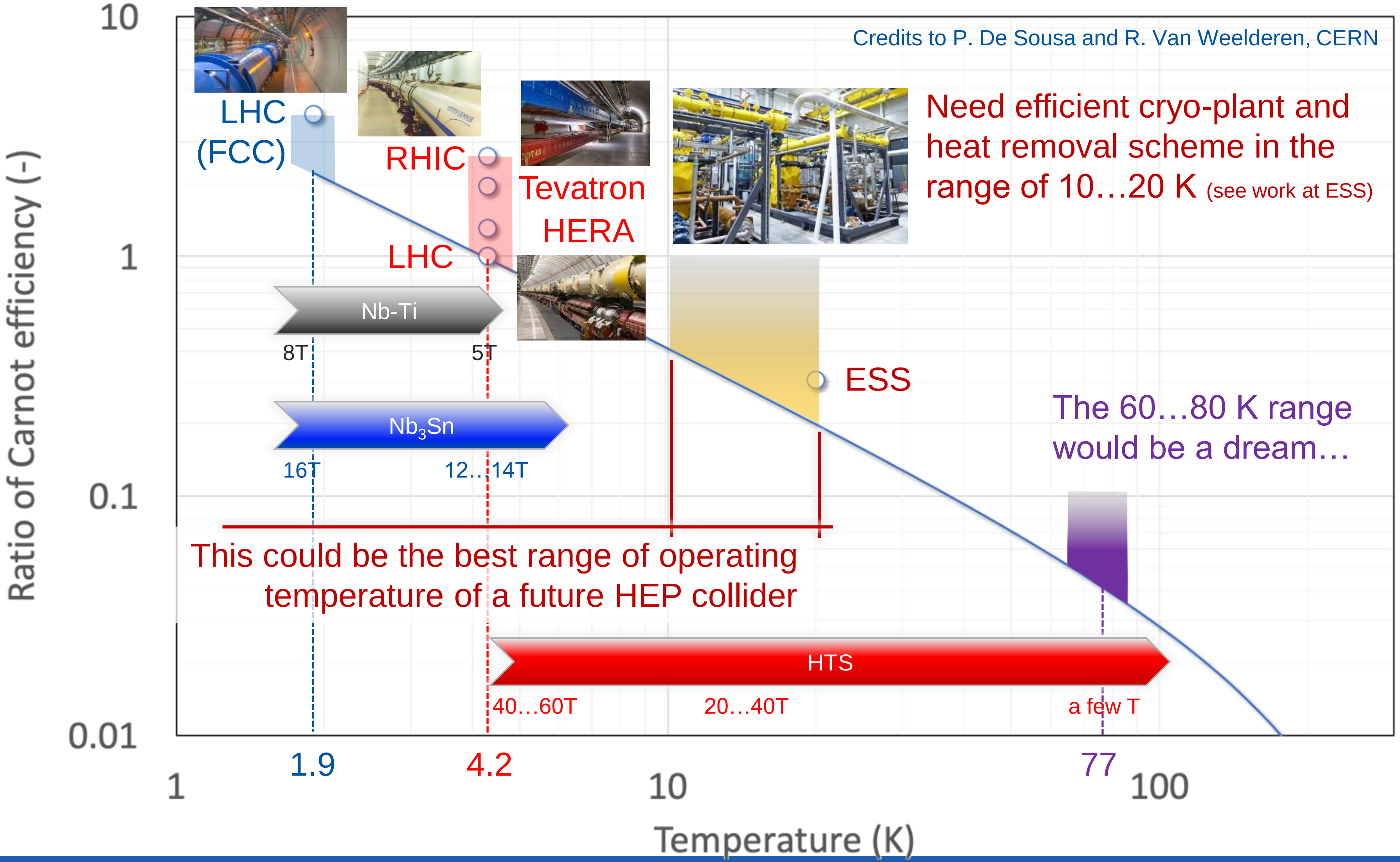
Typical A-B range can be (12 T, 160 mm) to (16 T, 100 mm)

- Include quadrupoles in the analytical evaluation of A-B limits

Courtesy of D. Novelli, S. Mariotto, B. Caiffi, INFN, and T. Salmi, TUT

Energy efficient cryogenics

$W/Q = (T_h - T_c)/T_c$



Credits to P. De Sousa and R. Van Weelderen, CERN

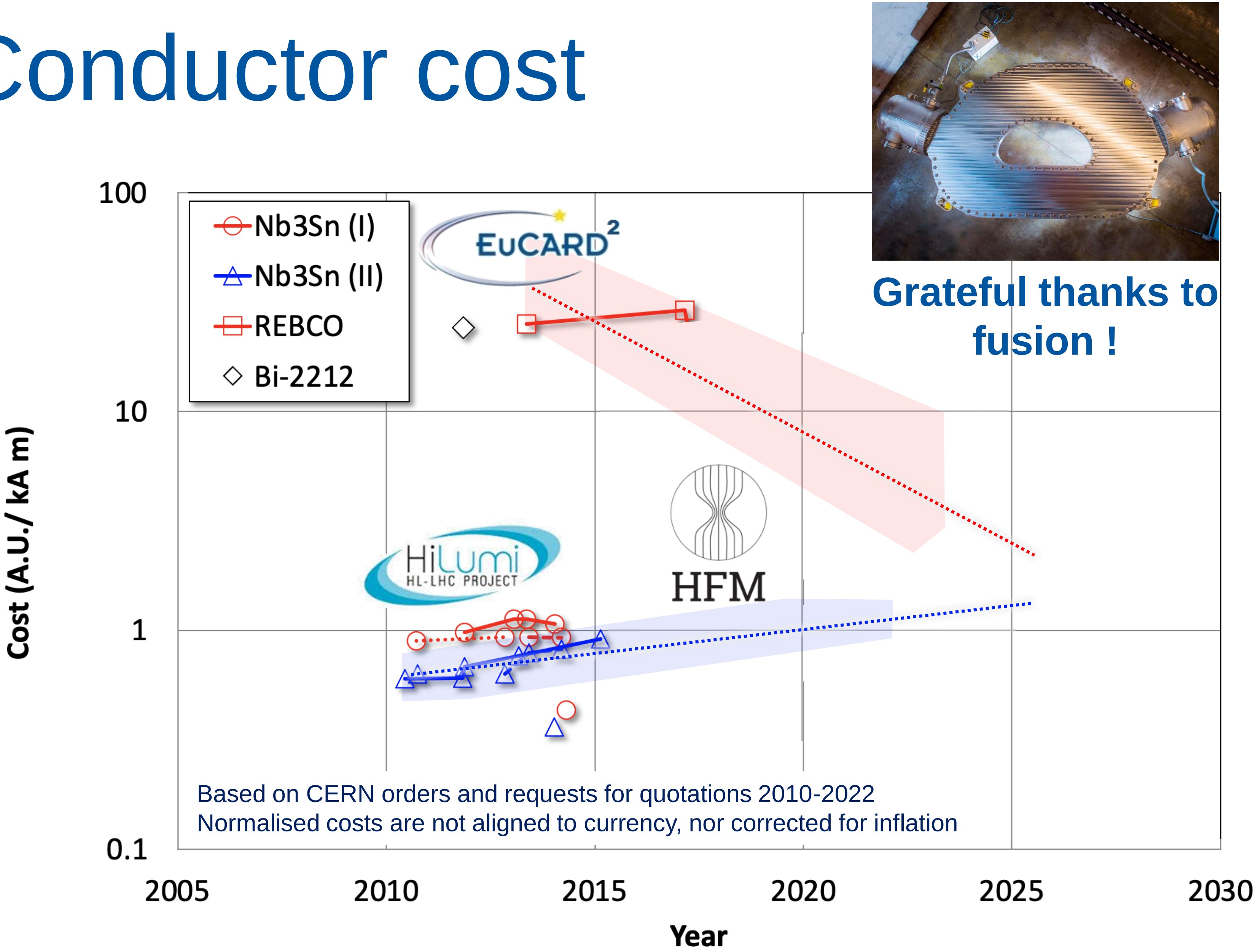
Need efficient cryo-plant and heat removal scheme in the range of 10…20 K (see work at ESS)

The 60…80 K range would be a dream…

This could be the best range of operating temperature of a future HEP collider

HTS may be the only path towards a future collider

Conductor cost

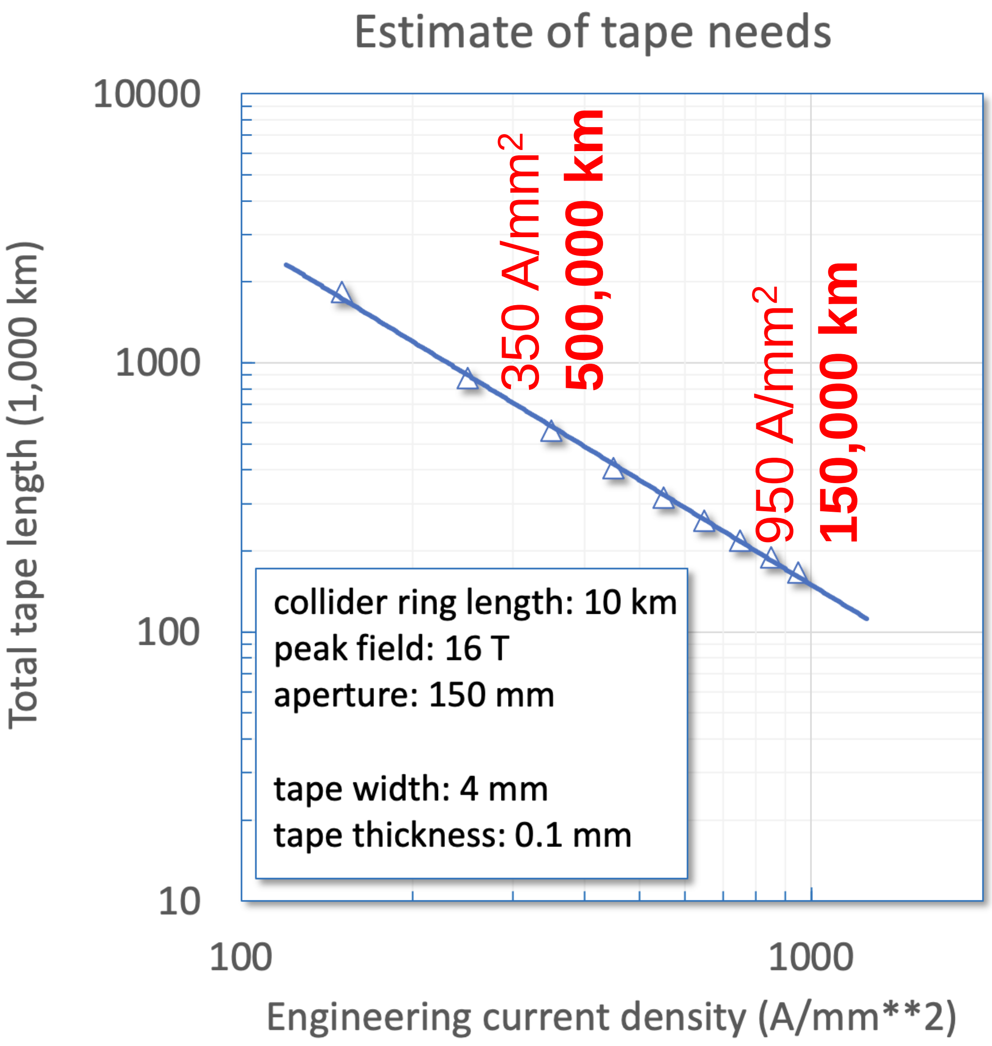


Grateful thanks to fusion !

Based on CERN orders and requests for quotations 2010-2022
Normalised costs are not aligned to currency, nor corrected for inflation

Impressive cost reduction in HTS !

Compact HTS windings



Need to increase the winding current density to fall in a *reasonable* range of tape length

Unresolved issues:

- Winding geometry for tapes and stacks (ends, alignment, transposition, …)
- **Mechanics** of coils under the exceptional electromagnetic loads (600 MPa longitudinal, 400 MPa transverse)
- **Quench management** at high current and energy density (up to 300 MJ/m^3)
- Radiation hardness of materials and coils (40…80 MGy and 10^{22} n/m^2)

The HEP push towards HTS

Reduce energy consumption
(FCC-ee 350 MW, FCC-hh 580 MW)

Operate SC magnets at *higher* cryogenic temperature (gas)

Increase energy efficiency
(COP at 1.9 K is about 1000)

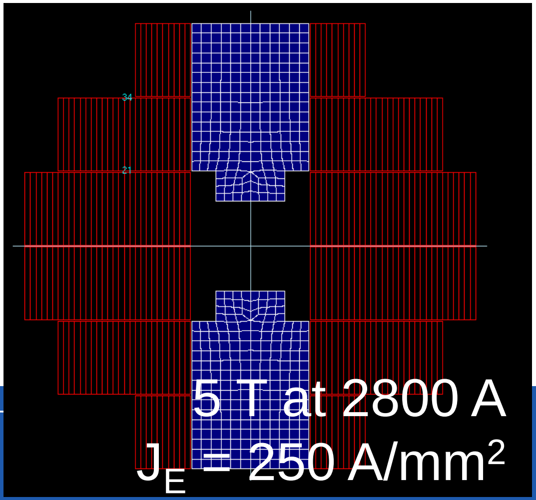
Risk with helium supply chain
(FCC-hh would require 900 tons of lHe)

Avoid large liquid helium bath and operate with gas (lower density)

Infrastructure (magnet) cost
(FCC-hh quoted at 9 BCHF)

Reduce SC cost per unit length and current

Increase coil current density to decrease conductor inventory

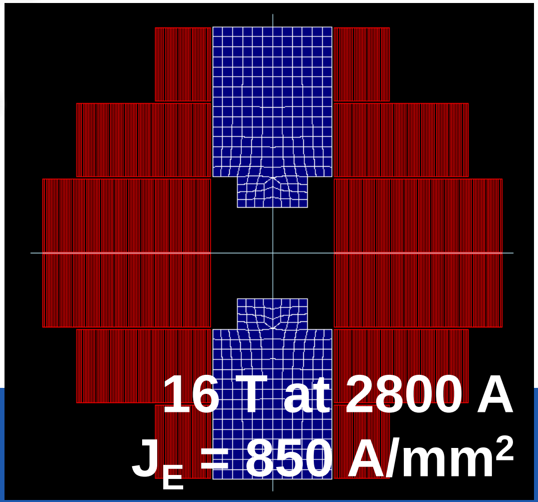


5 T at 2800 A
J_E = 250 A/mm^2

Calculation example
(T. Lecrevisse, CEA)

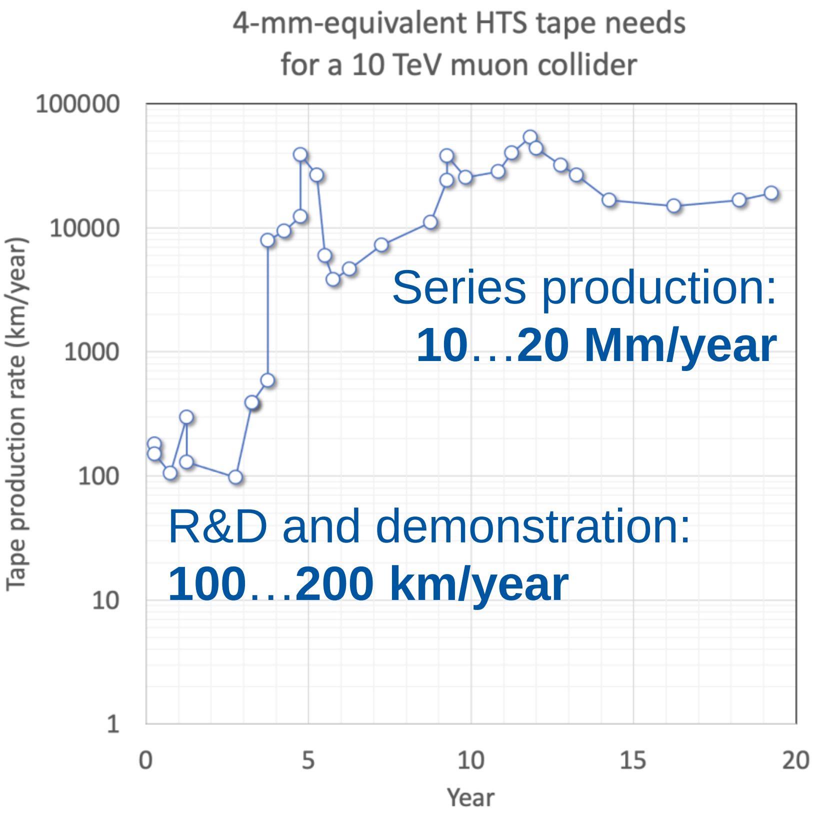
Compact HTS windings
- **Target J_E 1000 A/mm^2**

Operation in gaseous He
- **Range of 15…25 K**



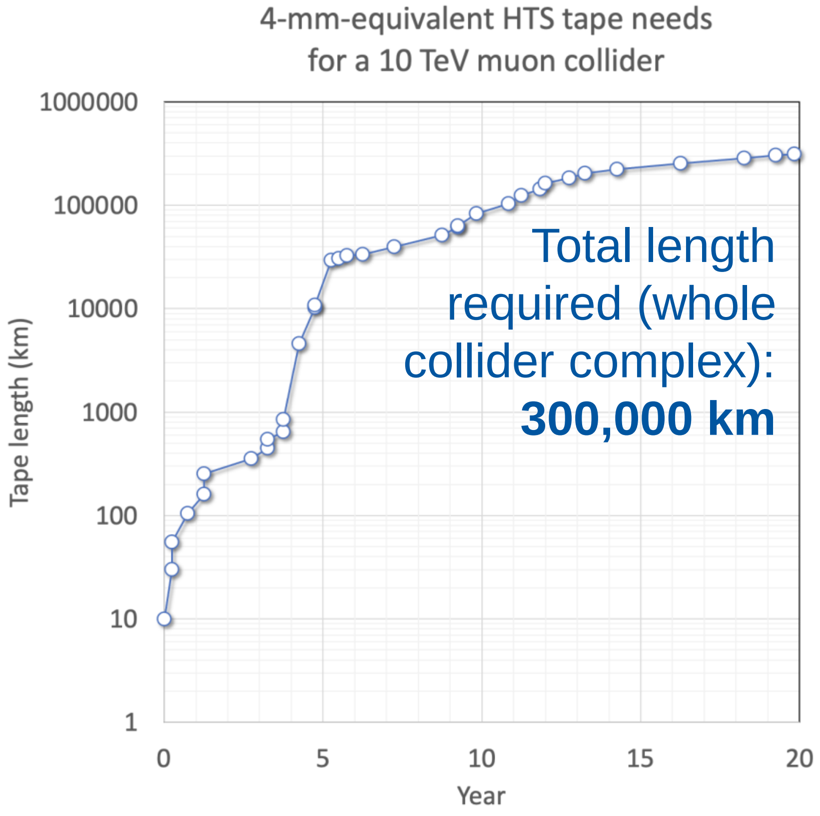
16 T at 2800 A
J_E = 850 A/mm^2

HTS needs for a muon collider



Series production:
10…20 Mm/year

R&D and demonstration:
100…200 km/year

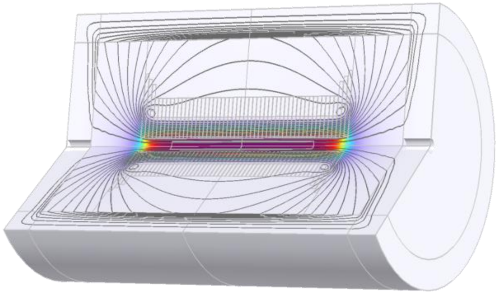


Total length
required (whole
collider complex):
300,000 km

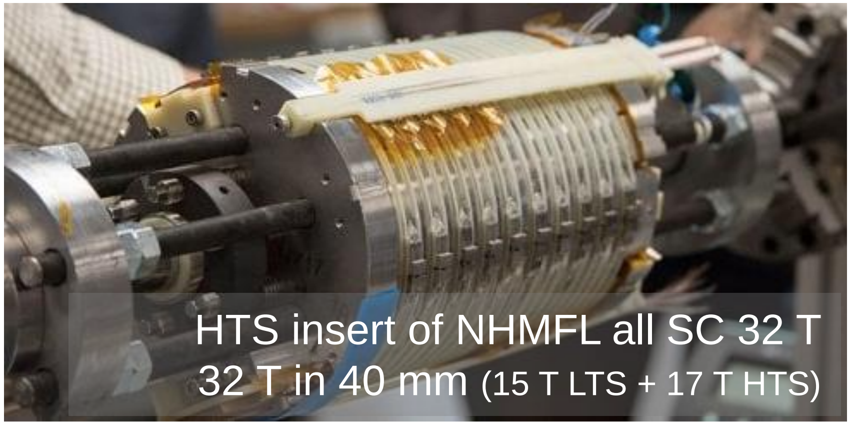
Massive, but not unreasonable: LHC wire was the same order of magnitude

Muon collider vs. high field magnets

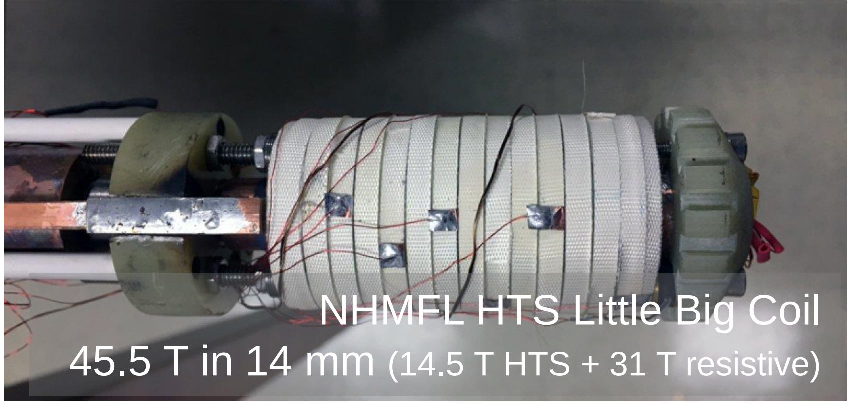
International
MUON Collider
Collaboration



Muon final cooling magnet
40 T at 4.2 K, 60 mm



HTS insert of NHMFL all SC 32 T
32 T in 40 mm (15 T LTS + 17 T HTS)



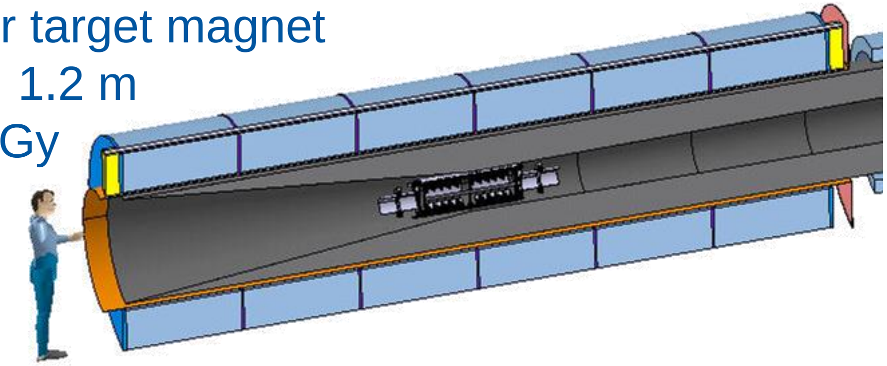
NHMFL HTS Little Big Coil
45.5 T in 14 mm (14.5 T HTS + 31 T resistive)

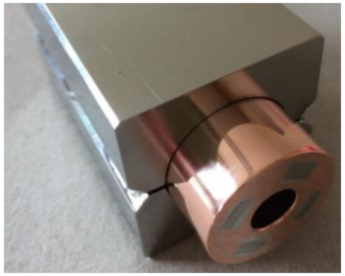
LNCMI/CEA Nougat
HTS insert
32.5 T in 50 mm
(12. 5 T HTS + 20 T
resistive)

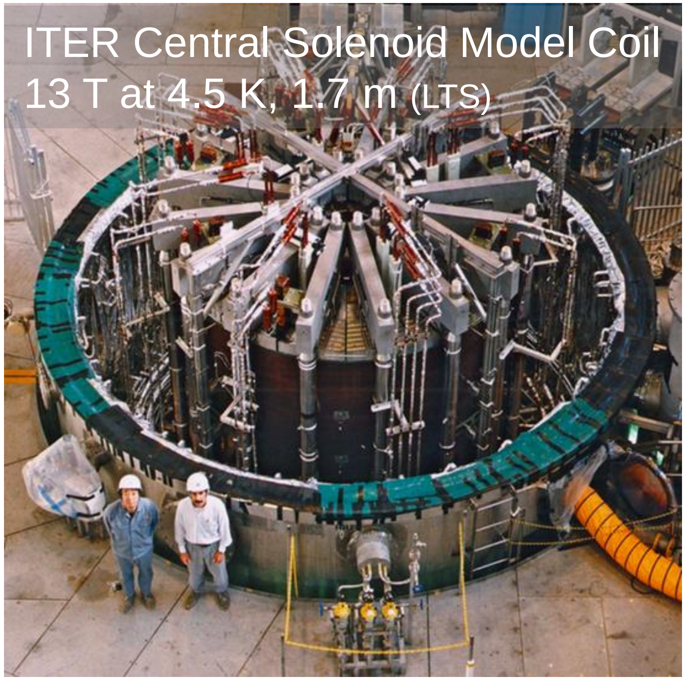
Sunam NI one-body
HTS magnet
26.4 T in 35 mm
(26.4 T HTS multi-width)

Muon collider vs. fusion

Muon collider target magnet
20 T at 20 K, 1.2 m
10 kW, 80 MGy







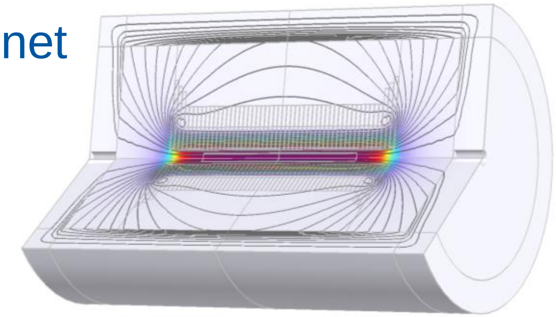
ITER Central Solenoid Model Coil
13 T at 4.5 K, 1.7 m (LTS)

MIT/CFS SPARC TF Coil prototype
20 T at 20 K (HTS)

Large bore solenoids, large heat and radiation

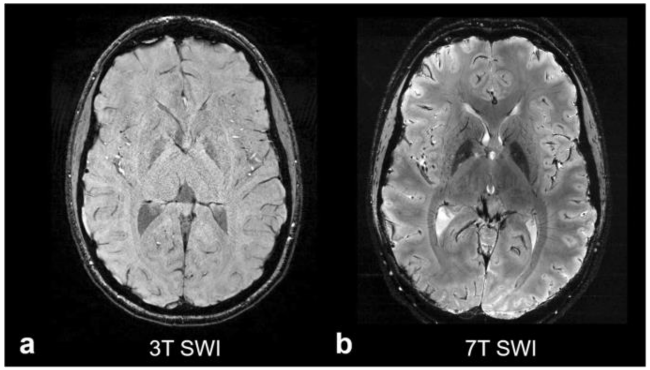
Muon collider vs. life science

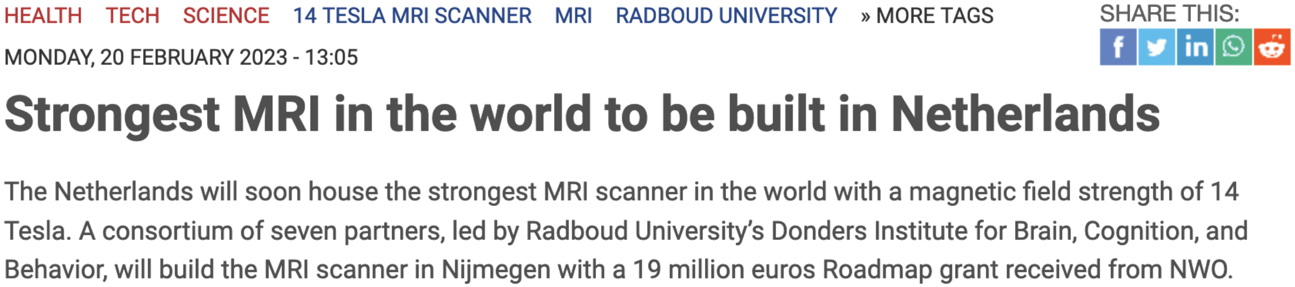
Muon final cooling magnet
40 T at 4.2 K, 60 mm



International
MUON Collider
Collaboration

14 T HTS MRI
800 mm





MONDAY, 20 FEBRUARY 2023 - 13:05

Strongest MRI in the world to be built in Netherlands

The Netherlands will soon house the strongest MRI scanner in the world with a magnetic field strength of 14 Tesla. A consortium of seven partners, led by Radboud University's Donders Institute for Brain, Cognition, and Behavior, will build the MRI scanner in Nijmegen with a 19 million euros Roadmap grant received from NWO.

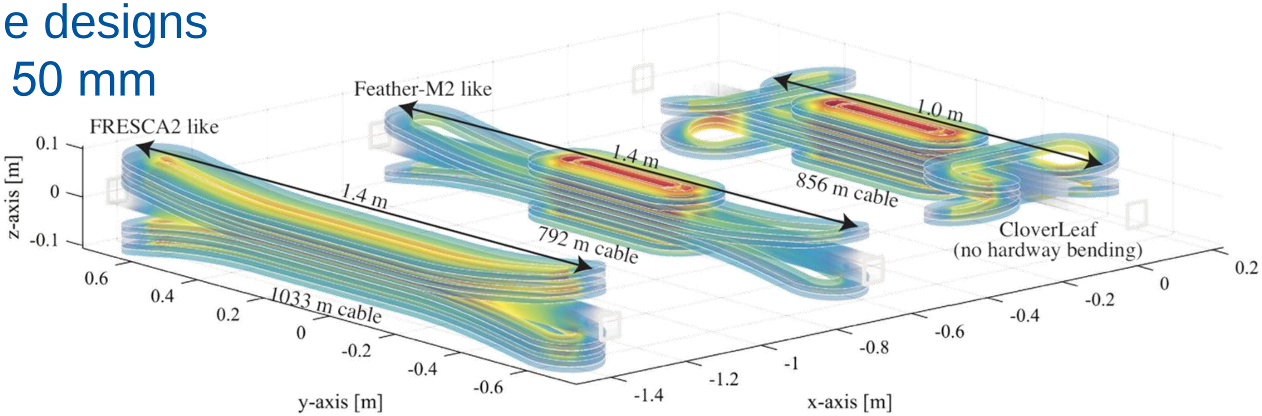
28.2 T LTS+HTS
54 mm

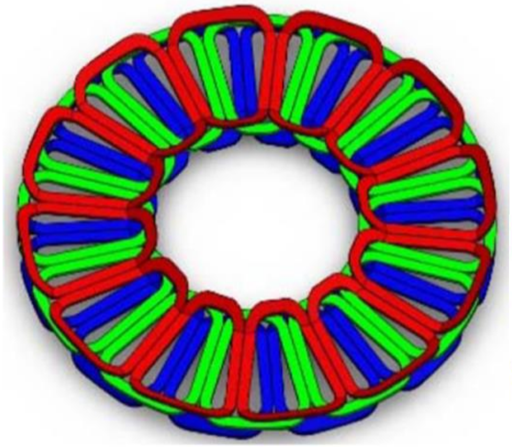
Fujikura and Bruker Collaboration: A 1.2 GHz NMR Magnet Built with Japanese HTS Tape Reaches Field at Bruker's Factory

Push field performance beyond state-of-the-art

Muon collider vs. power generation

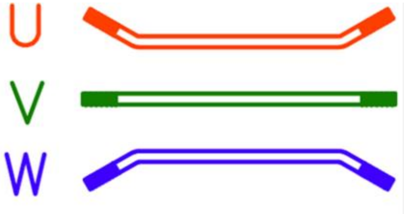
HTS dipole designs
10…20 T, 50 mm

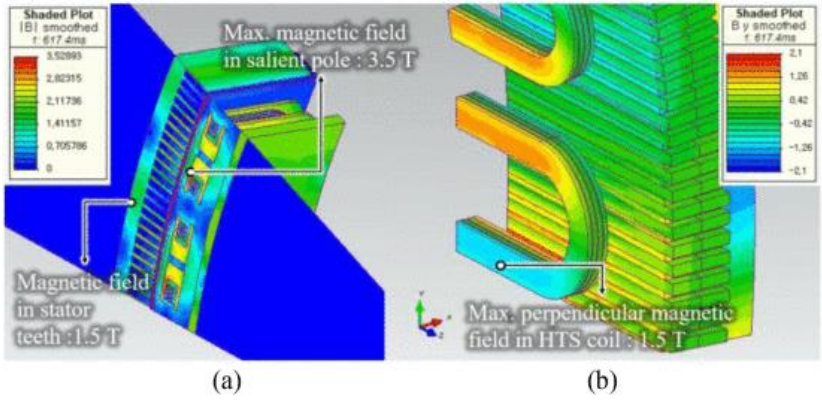




Small-size stator for PM generator

Saddle coils design for generator





Design of 10 MW HTS wind generator

Develop compact saddle HTS windings