Magnets and Conductor – Highlights and Summary

Daniel Schoerling
with the conveners of the magnet sessions

28th of June 2019

The sessions

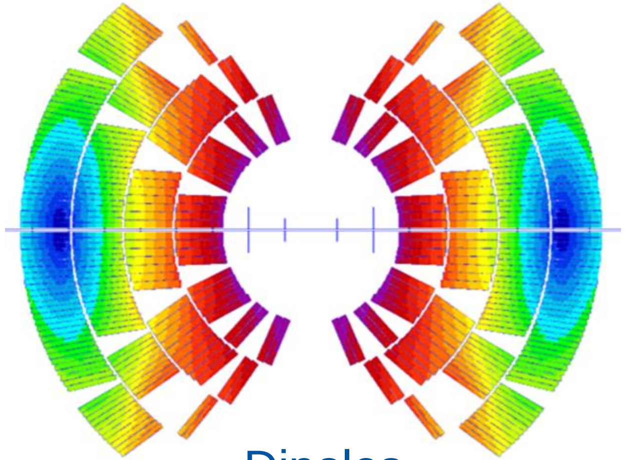
EuroCirCol WP5 16 T Magnets (2 sessions, 8 talks)

Conductor Nb_3Sn wire (and other conductor) development (2 sessions, 14 talks)

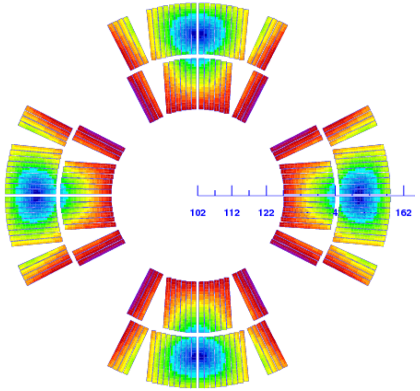
High Field Magnet R&D (1 session, 5 talks)

Magnets in the CDR (baseline)

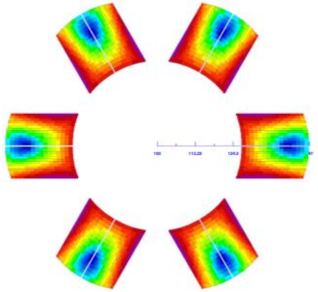
Arcs



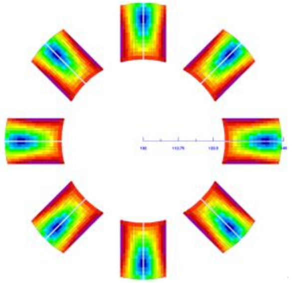
Dipoles



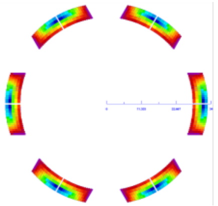
Quadrupoles



Sextupoles

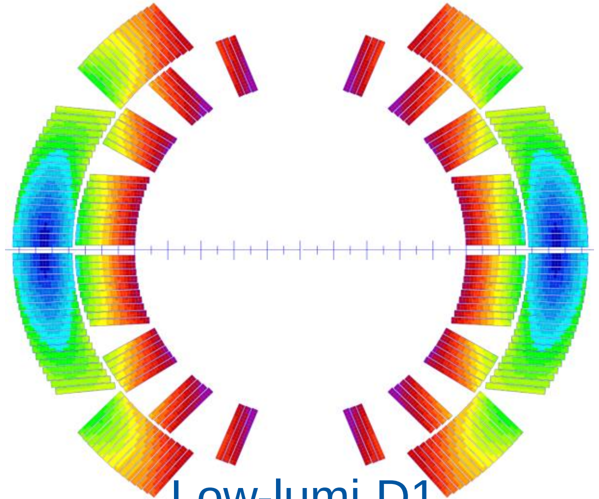


Octupoles

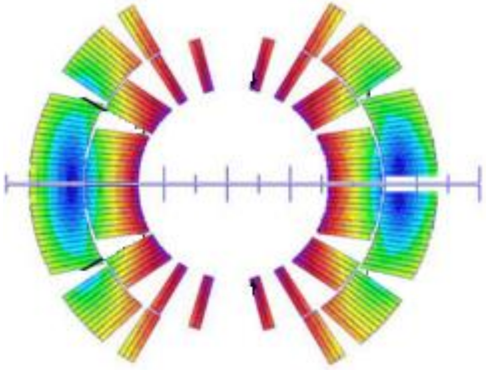


Sextupole spool pieces

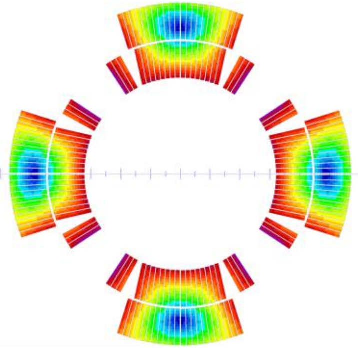
Interaction Regions



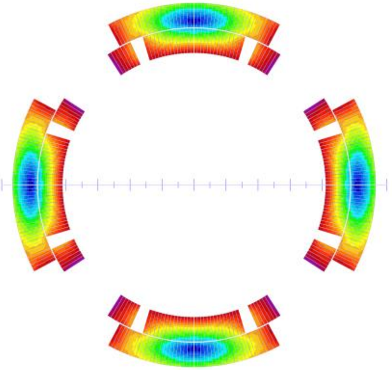
Low-lumi D1



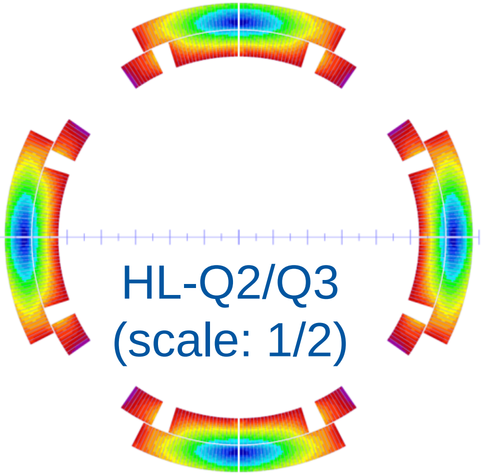
Low-lumi D2



LL-Q1/Q2/Q3

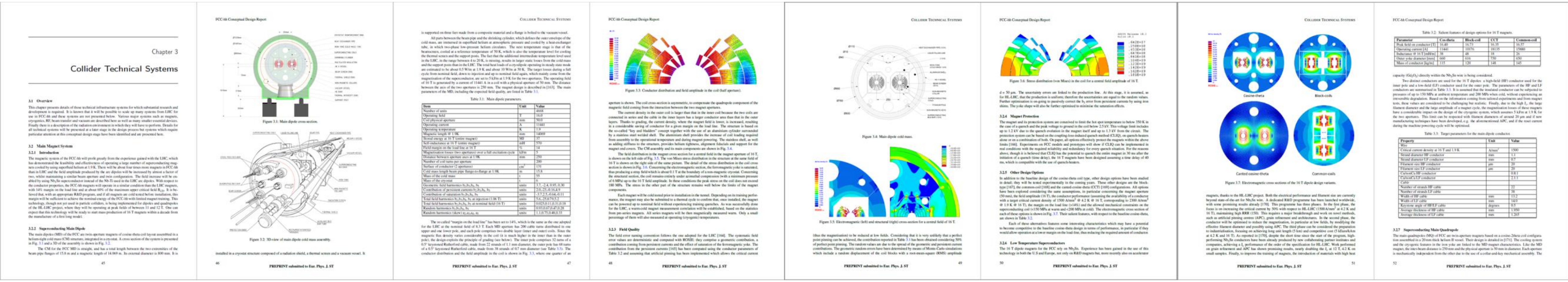


HL-Q1 (scale: 1/2)

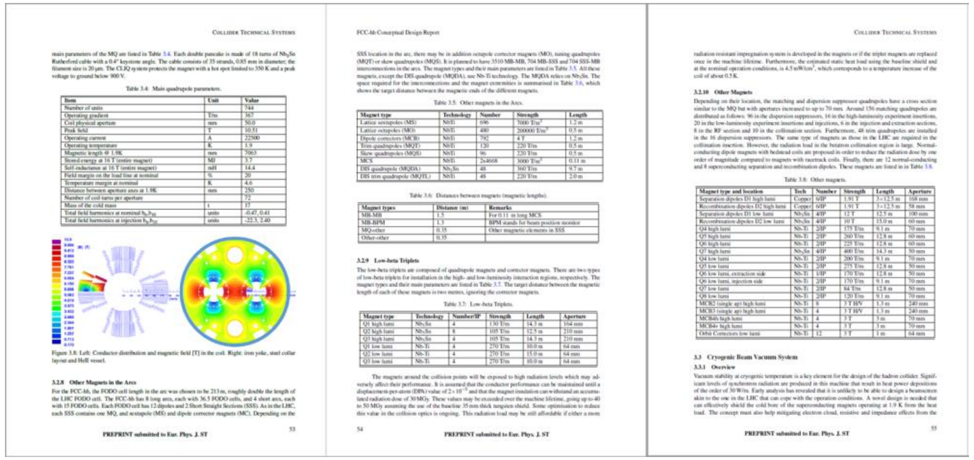


HL-Q2/Q3 (scale: 1/2)

All deliverables of EuroCirCol are submitted


Chapter 3

Collider Technical Systems



16 T dipole design options for the CDR

Main evolution in the EuroCirCol parameters:

- Coil optimization and margin 18% → 14%
- Inter-beam distance: 250 mm
- Stray-field <0.1 T at cryostat

Status:

- All designs have been documented in scientific publications
- Addenda for building prototypes have been signed

ADDENDUM FCC-GOV-CC-0121 / KE3782/TE

The European Organization for Nuclear Research ("CERN"), an Intergovernmental Organization having its seat at Geneva, Switzerland, and the Commissariat à l'énergie atomique et aux énergies alternatives ("CEA"),

This Addendum defines a contribution by a Participant under Article 6 of the Memorandum of Understanding for the FCC Study (FCC-GOV-CC-0004, EDMS 1390795).

Address: Centre CEA Paris-Saclay, Gif-sur-Yvette, 91191 Cedex, France

Supplier's code: CEA-01, Address code: SC02 Budget code: 10832

SCOPE OF WORK

The development of magnets for the FCC requires the demonstration of Nb_3Sn accelerator magnets with performances far beyond the HiLumi targets with 50 mm coil aperture. This work follows-up on the Nb_3Sn high-field development program started at CEA with the participation in the design and construction of FRESCA2 dipole magnet. It covers the realization of a FCC-hh short dipole model magnet designed within the H2020 EuroCirCol design study and the conceptual design of the FCC-hh arc quadrupole magnet.

CEA

Thursday 15:30-17:00
High-field magnet R&D
The CEA dipole model for the FCC (Etienne Rochepault)

ADDENDUM FCC-GOV-CC-0130 / KE3920/TE

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (hereinafter referred to as "CERN"), an Intergovernmental Organization having its seat at Meyrin, CH-1211, Geneva 23, Switzerland, represented by Frédérick Bordry, Director for Accelerators and Technology,

THE CENTER FOR THE DEVELOPMENT OF INDUSTRIAL TECHNOLOGY, E.P.E. (hereinafter referred to as "CDTI"), a Spanish public entity, created by R.D.-Ley 8/1983, of 30th November, established in C/ Cid n. 4, 28001 Madrid, Spain, duly represented by Javier Ponce Martínez, Director-General, and

THE CENTER FOR RESEARCH ON ENERGY, ENVIRONMENT AND TECHNOLOGY, O.A, M.P. (hereinafter referred to as "CIEMAT"), a Spanish public entity with registered office at Avenida Complutense, 40, 28040 Madrid, duly represented by Rafael Rodrigo Montero, President, as stipulated in Article 8, R.D. 1952/2000, 1 of December, which approved the Statutes of CIEMAT,

(hereafter individually referred to as the "Contributor" and jointly as the "Contributors"),

CIEMAT

Just signed

ADDENDUM No. KE4102/FCC

to

FCC Memorandum of Understanding (FCC-GOV-CC-0004/17.10.2014)

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

and

THE ISTITUTO NAZIONALE DI FISICA NUCLEARE ("INFN")

concerning

Collaboration on 16 T - Nb_3Sn Short Model Magnet Production in the framework of the FCC Study hosted by CERN

INFN

Thursday 15:30-17:00
High-field magnet R&D
The INFN dipole model for the FCC (Riccardo Valente)

Cosine-theta (baseline)

INFN Istituto Nazionale di Fisica Nucleare

Block-type coils

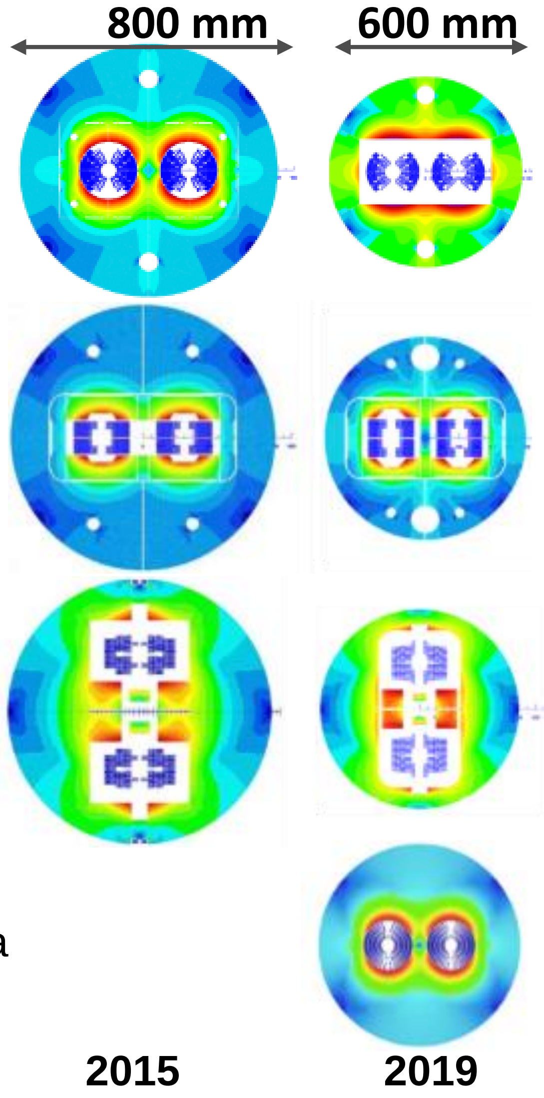
cea

Common-coils

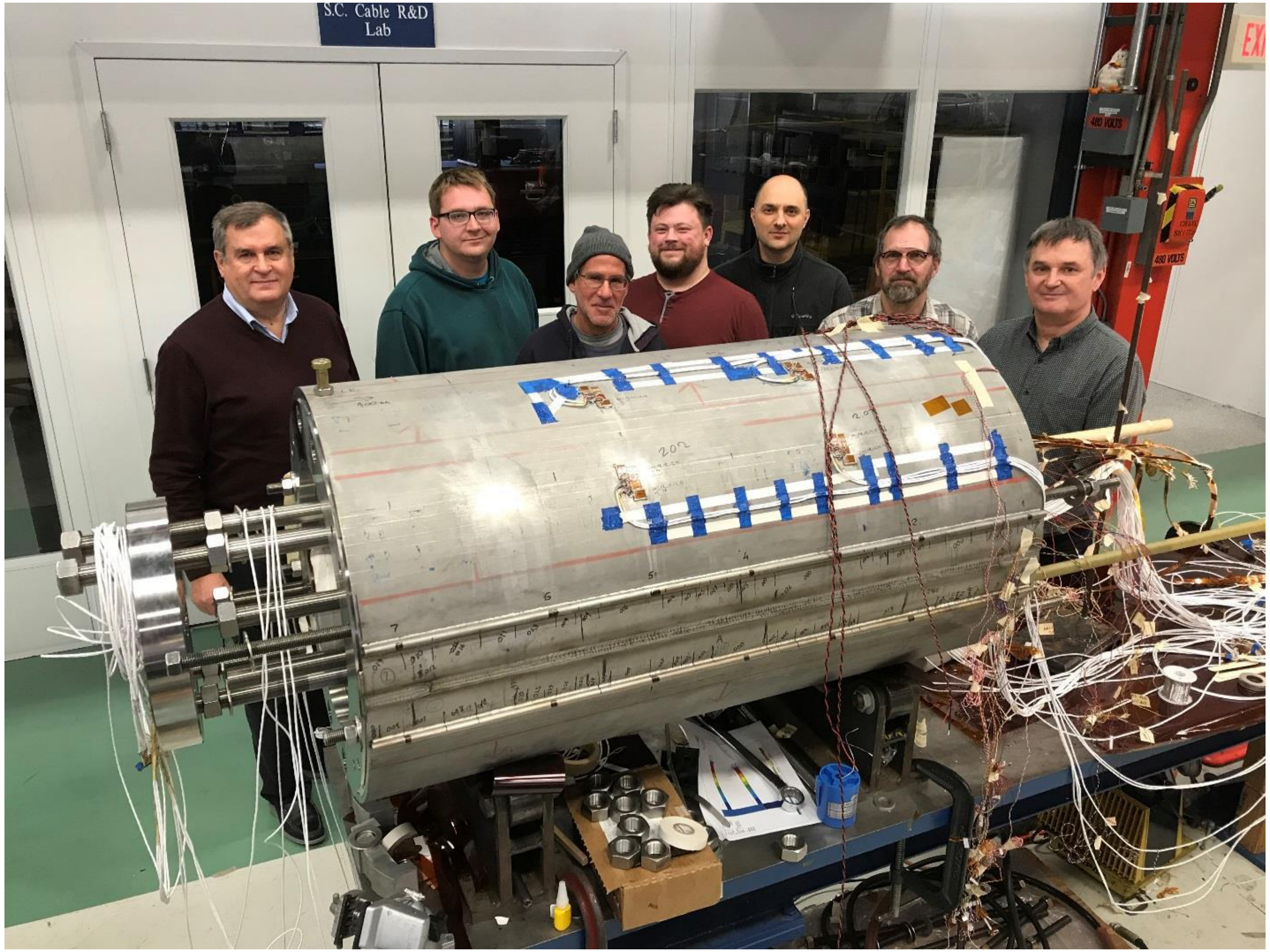
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

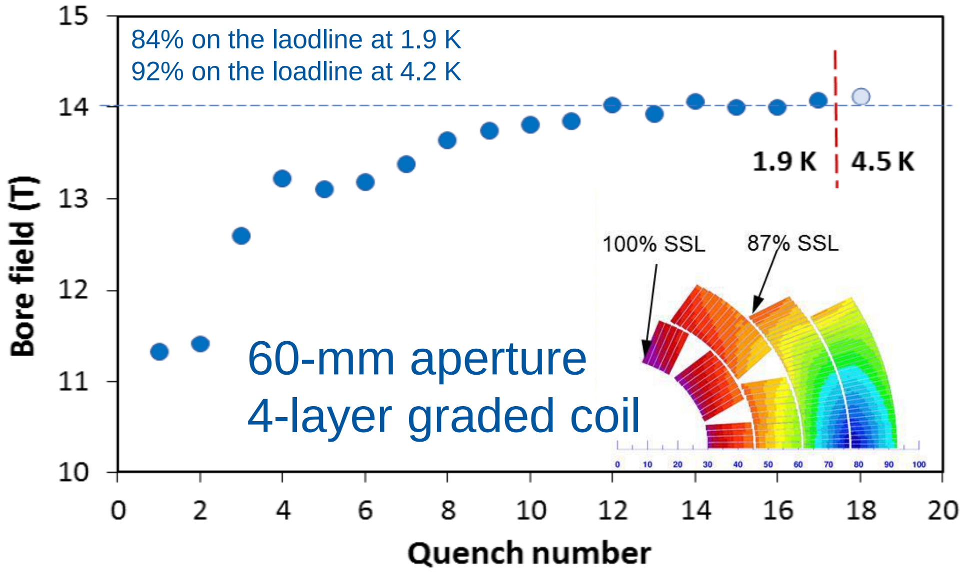
Canted cos-theta

PAUL SCHERRER INSTITUT PSI



14 T magnet tested at FNAL!



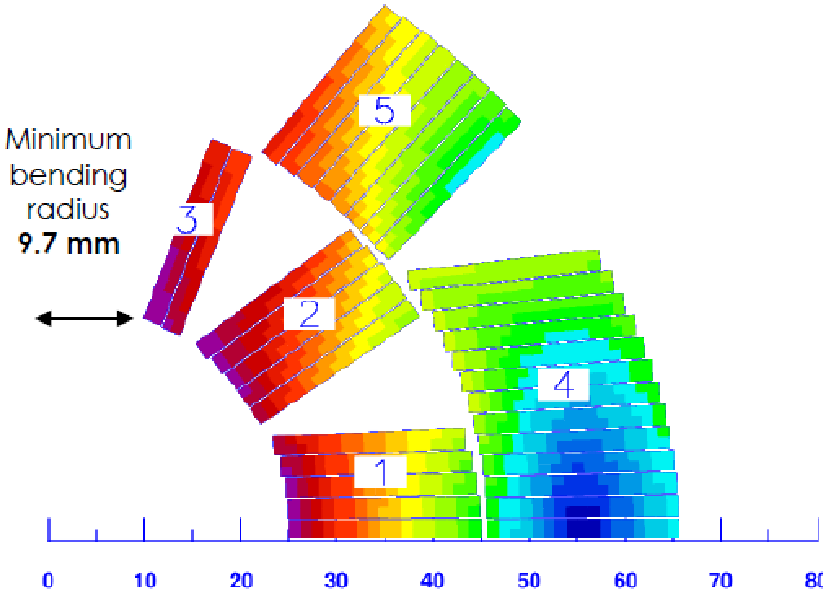


- 15 T dipole demonstrator
- Staged approach: In first step pre-stressed for 14 T
- Second test foreseen in fall 2019 with additional pre-stress for 15 T

Magnet development: Magnet models

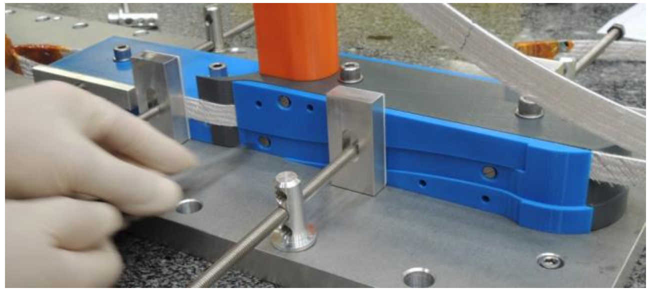
FALCON DIPOLE

INFN: 14 T magnet with 14 % margin (FCC spec), 9.5% with current wire spec



F2D2 or

CEA: 15.5 T magnet with 14% load line with current wire spec



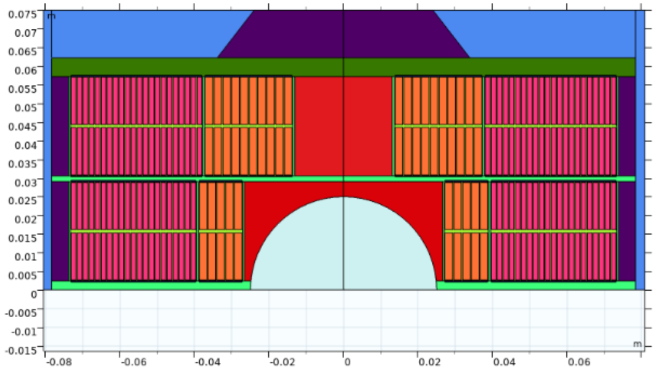
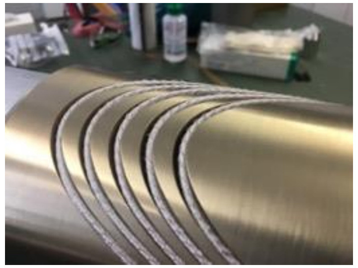
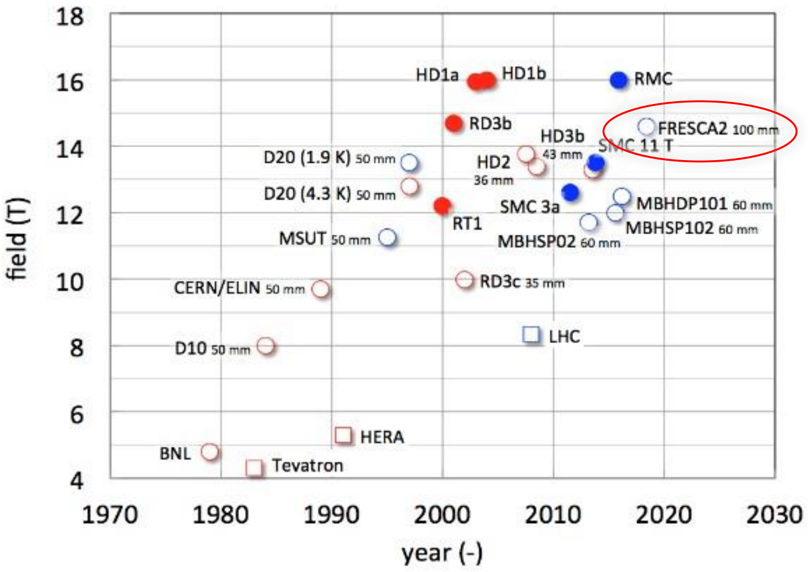


CHART2 – Swiss Accelerator Research and Technology

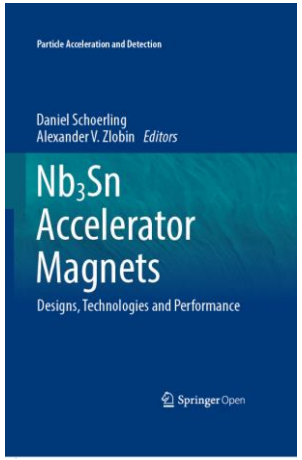


What about the field level?

- Past experience with Nb_3Sn high field magnets (13 programs), and the very recent success of FNAL shows the great potential of Nb_3Sn high-field magnet technology for a next collider in the ~14 T range
- With the aim to reduce the cost and complexity, a ~40 TeV FCC-hh with 6 T may be considered (see M. Benedikt’s talk)
- What about 12 T to 14 T which would also considerably reduce the magnet cost and complexity for a collider in the next decades?



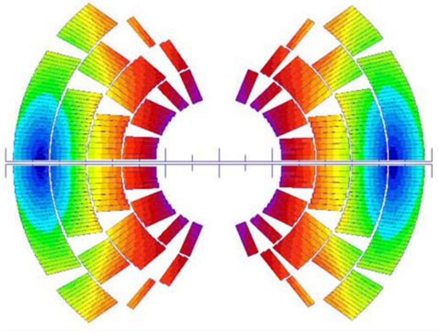
Fresca2: 14.6 T at 1.9 K



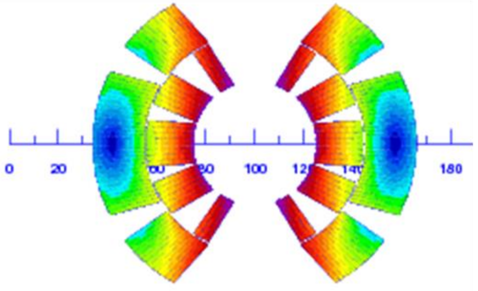
ESG request for parameters of a lower-energy hadron collider

parameter	FCC-hh		FCC-hh-6T	HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		37.5	27	14	14
dipole field [T]	16		6	16	8.33	8.33
beam current [A]	0.5		0.6	1.1	1.1	0.58
synchr. rad. power/ring [kW]	2400		57	101	7.3	3.6
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	10 (lev.)	16	5 (lev.)	1
events/bunch crossing	170	1000	~300	460	132	27
stored energy/beam [GJ]	8.4		3.75	1.4	0.7	0.36

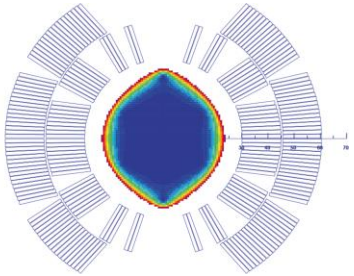
- NbTi technology from LHC, magnet with single-layer coil providing 6 T at 1.9 K:
  - → Corresponding beam energy 18.75 TeV or 37.5 TeV c.m.
  - → Significant reduction of synchrotron radiation wrt FCC-hh (factor 50) and corresponding cryogenic system requirements.
- Luminosity goal 10 ab^{-1} over 20 years or 0.5 ab^{-1} annual luminosity:
  - → Beam current 0.6 A or 20% higher than for FCC-hh, 1.2E11 ppb (FCC-hh: 1.0 ppb).
  - → Stored beam energy 3.75 GJ vs 8.4 GJ for FCC-hh.
- Analysis of physics potential, technology requirements and cost ongoing.



16 T (FCC spec)



14 T (FCC spec)

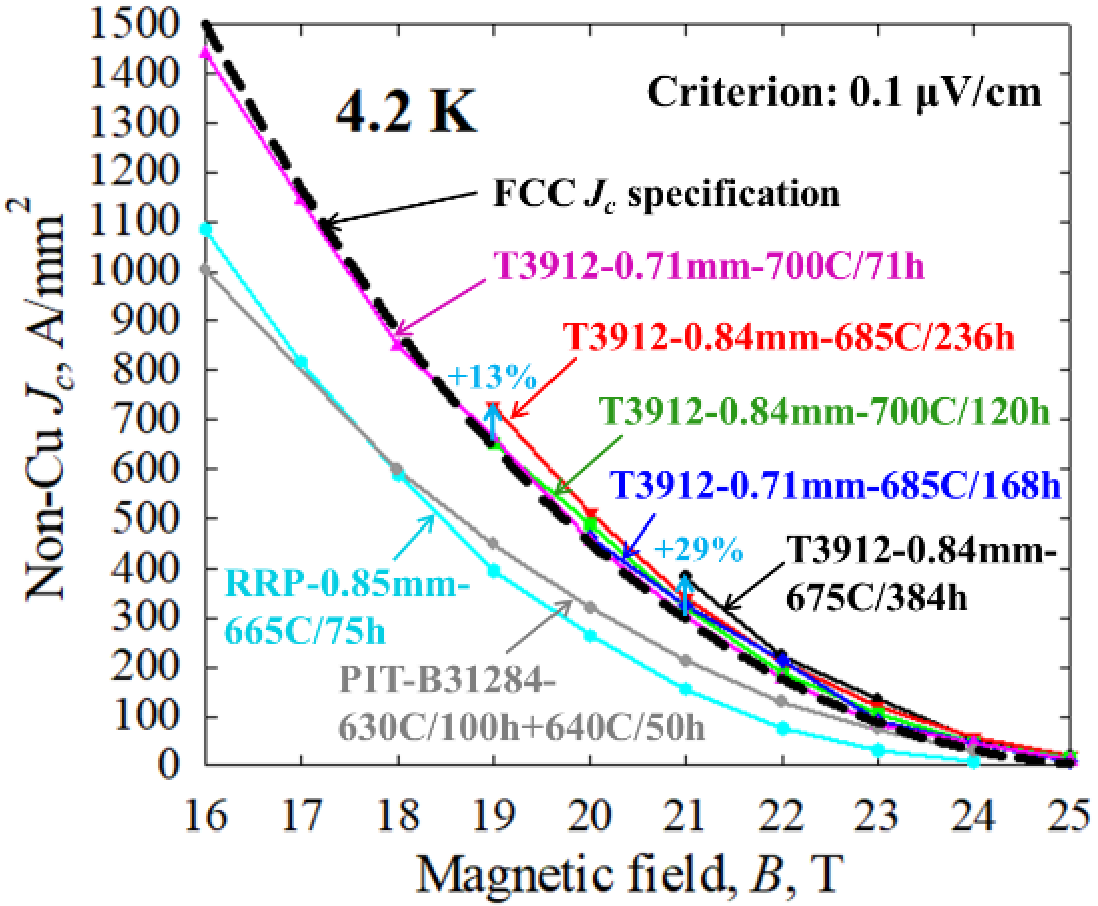


11 T (HL-LHC spec)

Conductor: Large international collaboration

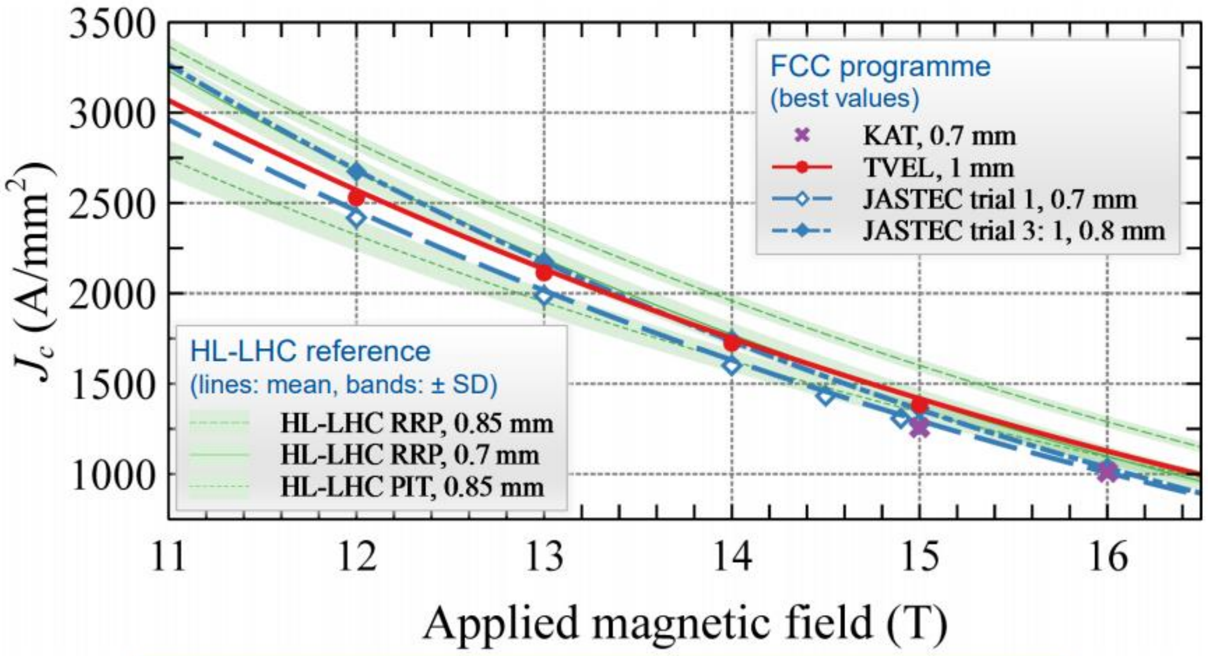
>15 partners,
And growing participation

Conductor: Fantastic results



Courtesy X. Xu etal. 1. https://arxiv.org/abs/1903.08121

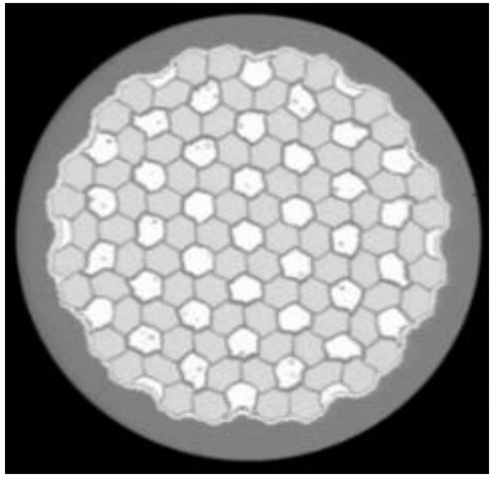
- Wire with APC has reached FCC target J_c
- Other suppliers reach now the HL-LHC specification (broadening of supplier base)
- High B_{c2} (28.8 T at 4.2 K) has been reached

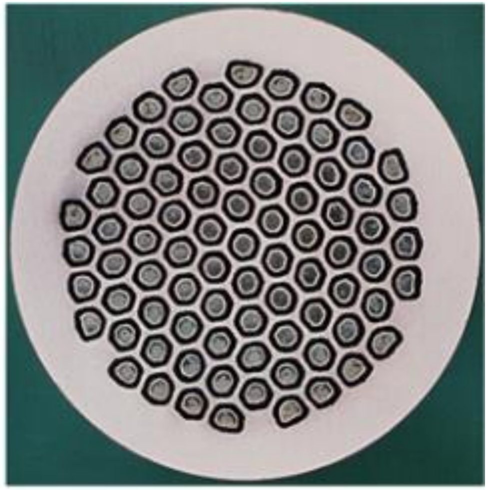


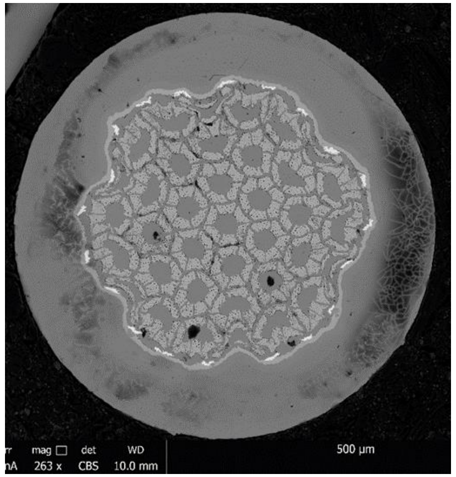
Summary of non-Cu $J_c(B)$ achieved so far, with HL-LHC wires for comparison
Points: measurements at 4.2–4.3 K Lines: fits scaled to 4.22 K

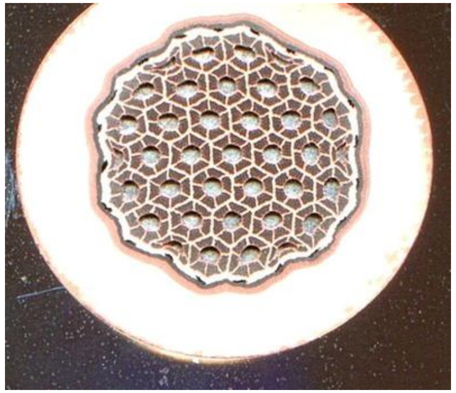
Conductor: Exciting activities

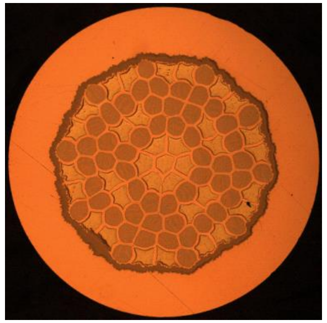
KOBELCO KOBE STEEL GROUP · JASTEC SUPERCONDUCTOR · FURUKAWA ELECTRIC · ROSATOM · TVEL · BOCHVAR INSTITUTE OF INORGANIC MATERIALS JSC VNIINM · NATIONAL NUCLEAR CORPORATION "ROSATOM" · Kiswire

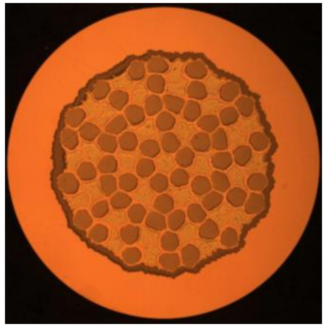


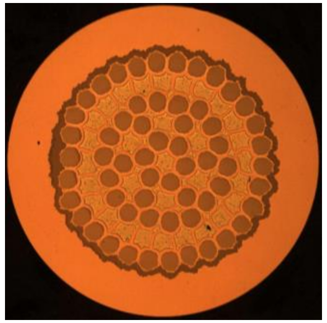






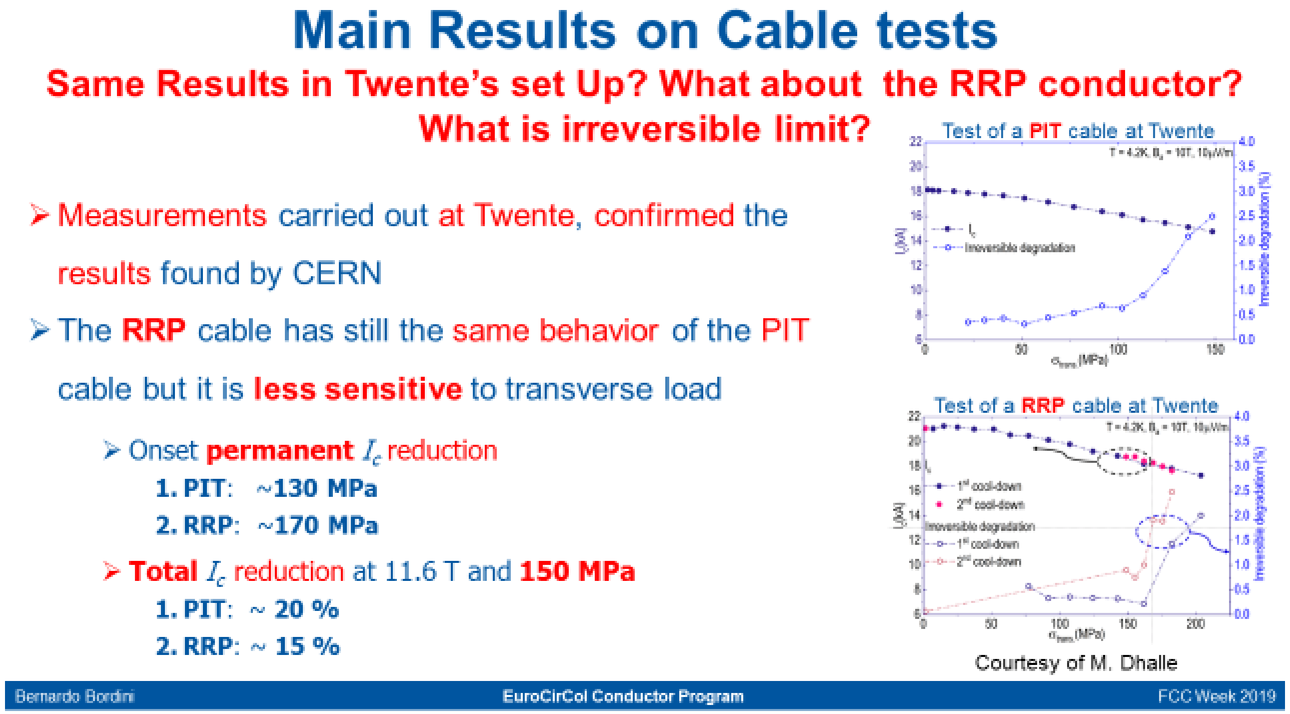






Conductor: Electro-mechanical characterization

- ***Irreversible*** degradation: EuroCirCol assumption (peak stress: 150 MPa at warm and 200 MPa at cold)
- ***Reversible*** degradation: Strong influence of conductor technology, sample preparation and operation field: $\rightarrow$ Important input for magnet design: disentangle high-field and high-stress areas!
- The present designs attempt to place high-stress in the low-field regions
- As done for the HL-LHC magnets, to further reduce the peak stress, the pre-load can be set to a lower value than the one required for nominal field for having no pole detachment.
- The same approach was also used for the LHC magnets, which unload below ~7 T

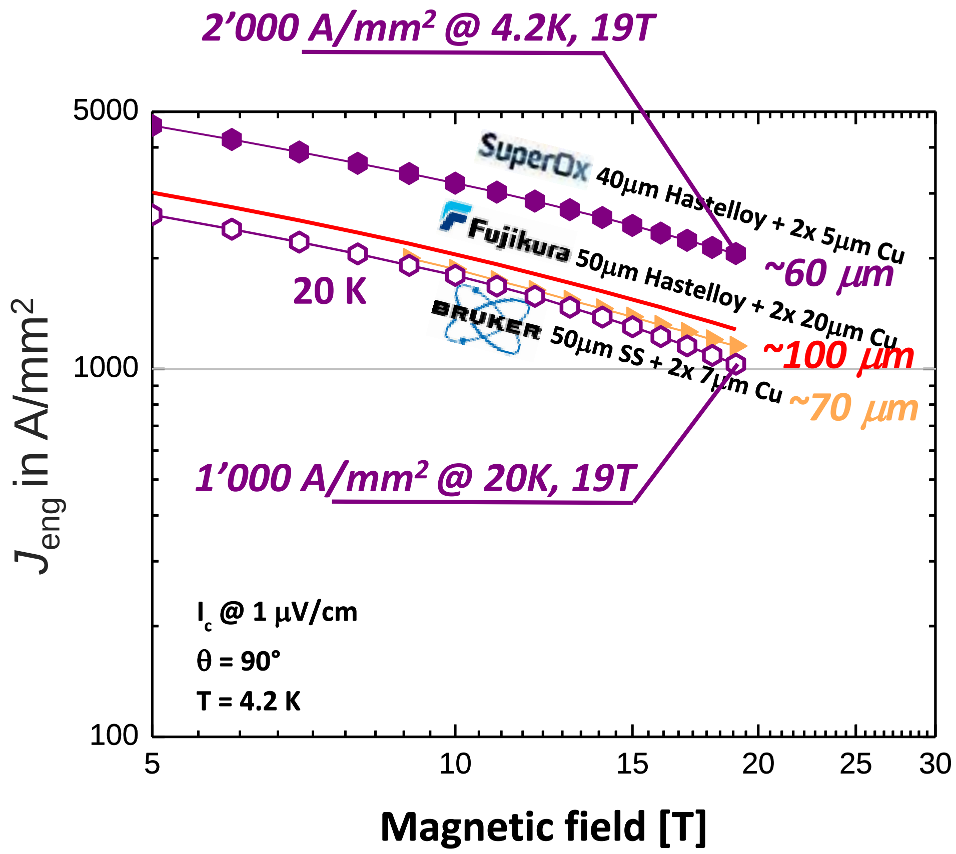


Options towards ~20+T dipoles

Bi-2212

- Promising performance parameters: J_c far exceeds the FCC specification, but stress sensitive
- Expensive production process (silver & over-pressure reaction) → 7-15 times the Nb_3Sn (volumetric) cost

REBCO



- Industrialization and cost reduction yet to come (~10 times more expensive than Nb_3Sn)
- Possibility to operate in the ~10 K range
- Magnet design and operation is challenging
- 3 T insert was tested and 5 T insert will be tested soon

Conclusion

- Past experience with Nb_3Sn high field magnets (13 programs), and in particular the very recent success of FNAL shows the great potential of Nb_3Sn high-field magnet technology for a next collider. A model magnet (15 T) has been tested (staged process) and smoothly reached 14 T (as planned for the first stage)
- The difference between a 14 T and a 16 T magnet is very large, in terms of quantity of conductor needed, number of coils, and complexity of the construction. Though, on paper, a 16 T magnet is possible and is costing about twice the cost of a LHC magnet for twice the field. Achieving such a construction on a large series may be extremely difficult. A two layer design with a target field in the range of 12 T to 14 T is considered by the magnet community present during the FCC week as ‘consensus’ for a collider in the next decades
- The design work has shown that all the considered options have a potential for FCC. This has motivated the decision of exploring experimentally all options to answer the outstanding questions of which design meets best the requirements, which margin field level (~12-14 T) should be selected
- In the last three years, the FCC Conductor Development Program coordinated by CERN has succeeded in engaging the Japanese (Jastec and Furukawa via the KEK coordination), the Russian (TVEL) and the Korean (KAT) companies in developing for the first time very high-performance Nb_3Sn wire. Critical current densities of up to about 1250 A/mm^2 at 16 T have been achieved, and kilometers length of wire have been produced in industry and delivered to CERN for first cabling trials
- In the US, the FCC current density target (1500 A/mm^2 at 16 T) has been achieved! Industrialization and cost reduction has yet to come