Development of Compact CORC Multi-Layer Racetrack and Solenoid Coils

Tim Mulder, Alexey Dudarev, Sander Wessel, Jeremy Weiss, Danko van der Laan and Herman H. J. ten Kate

CERN

Advanced Conductor Technologies LLC
www.advancedconductor.com

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*Re*BCO Multi-Tape Conductors

ReBCO Multi-Tape Cables:

- Large magnets require currents beyond the capacity of a single ReBCO tape.
- Multiple tapes combined to a high-current ReBCO cable.
- Increased stability, single tape defects are less pronounced.
- Reduction of inductive and coupling losses.
- Three main designs: Roebel, Twisted Stacked Tape Cable (TSTC) and Conductor on Round Core (CORC).

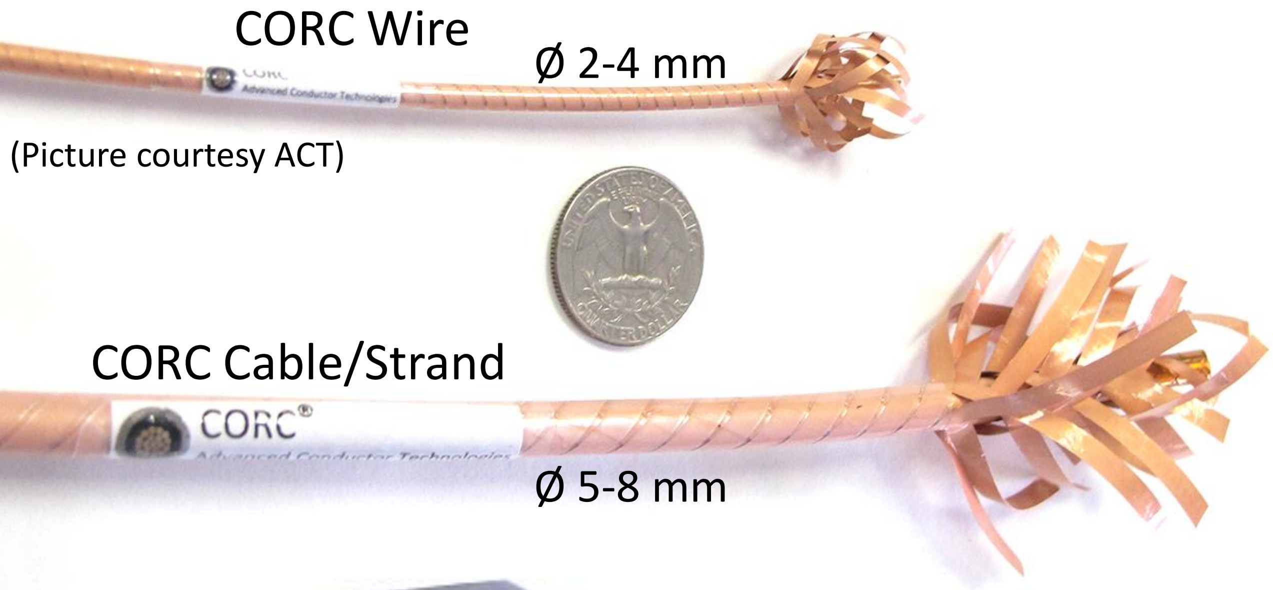
TSTC:

- Tape stack with high current density.
- Difficult to bend and long twist pitch.
- Copper shell for practical handling during magnet winding.
- Mainly designed for large-scale magnets for fusion reactors.

Roebel:

- High current density.
- Flexible in the 'out-of-plane' bending direction.
- Fully transposed.
- Designed for compact high-field magnets.

CORC Wires, Cables and Cable-In-Conduit Conductors



2014

1st CORC Al-jacketed Cable-In-Conduit Conductor.

CORC:

- High omni-directional flexibility.
- Round shape resilient towards transverse loads.
- Internal core stabilized.
- No tape lost during production.
- For compact high-field magnets and large magnets (detector and fusion) and bus bars.

CORC Wire: *accelerator magnets, high-field insert coils or standalone solenoids.*

CORC Cable: *general purpose, stable SC magnets and power transmission.*

CORC Cable-In-Conduit Conductor (CICC):
high current, high-field magnets and HTS bus bars.

Quest for CORC-wire optimized *Re*BCO tape

CORC Wires:

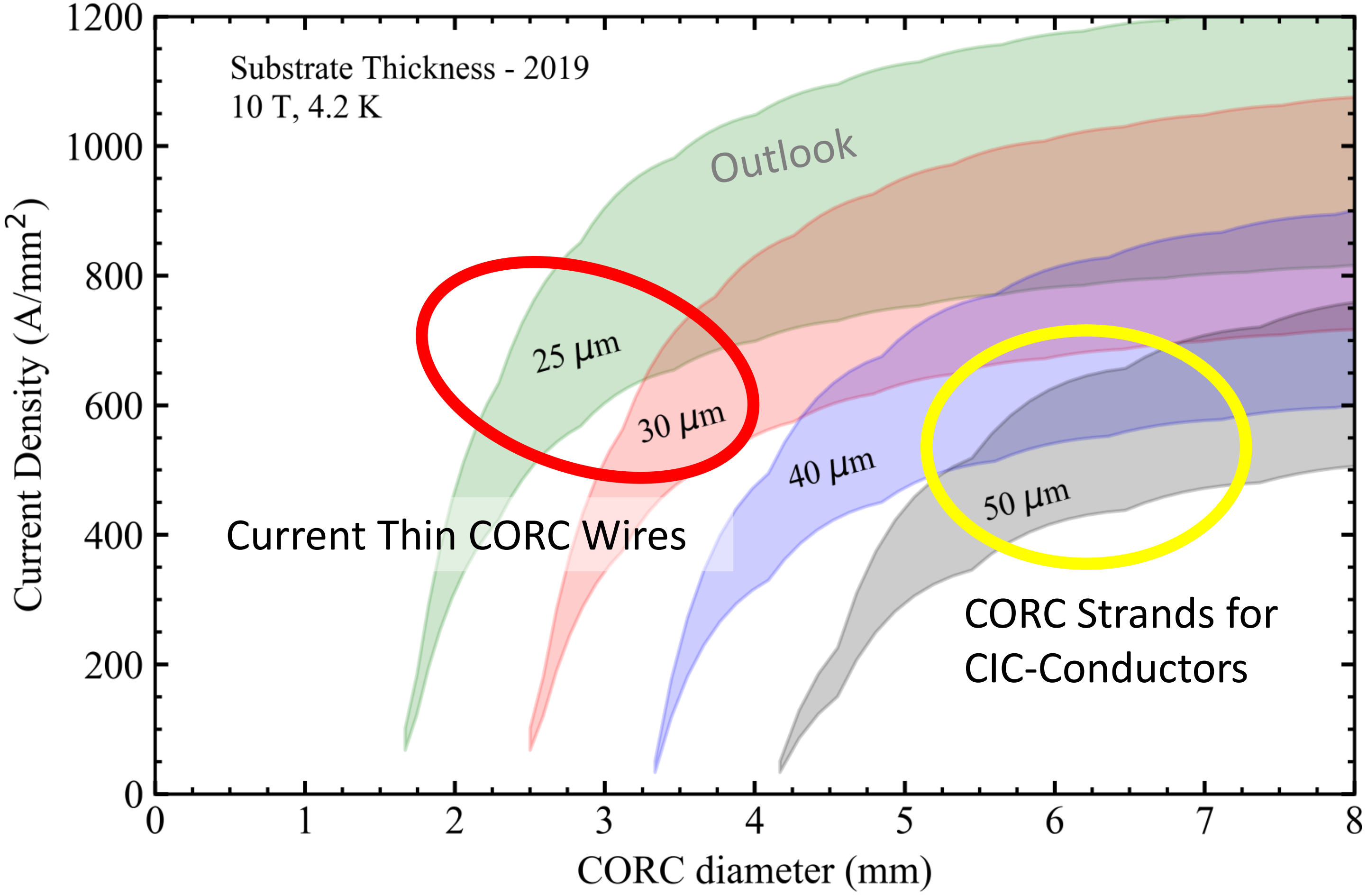
- Made possible by the reduction in substrate thickness from 50 to 30 µm.
- Narrower tapes of 2 mm wide.
- Designed for high-field magnets.

CORC Strands:

- Thicker medium-current cables.
- Designed for large high-field magnets, requiring high thermal/electrical stability.

Further Cable & Wire Optimization:

- Thinner substrate of 30 -> 25 -> 20 µm.
- Narrower tapes of 2.0 -> 1.5 -> 1.0 mm.
- Higher I_c by increasing *Re*BCO layer thickness to 2 or 3 µm (or even more!).



Thicker & Less flexible ------------>

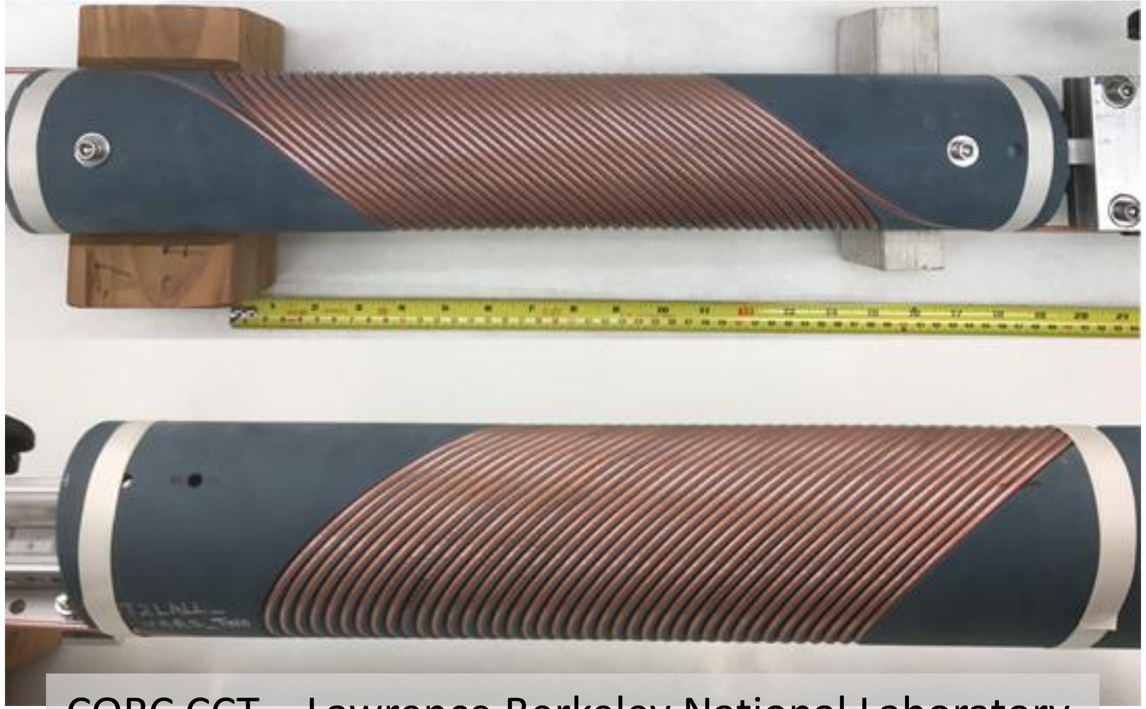
*Re*BCO High-Field Magnets - Examples

Benefits of *Re*BCO for High Field Magnets:

- *Re*BCO conductors by far surpass common LTS conductors in I_c and B_{c2} at 4.2 K.
- User magnetic field far beyond 20 T in 4 to 30 K range.
- Extreme thermal and electrical stability!
- Hybrid HTS/LTS solutions available.

✓ Several *Re*BCO Roebel and CORC demonstrator coils have been exercised in the last years.

✓ CORC's round shape allows multi-directional bending, thus practical coil winding, i.e. the CCT of LBNL.



CORC CCT – Lawrence Berkeley National Laboratory

Roebel cable based dipole magnet – CERN

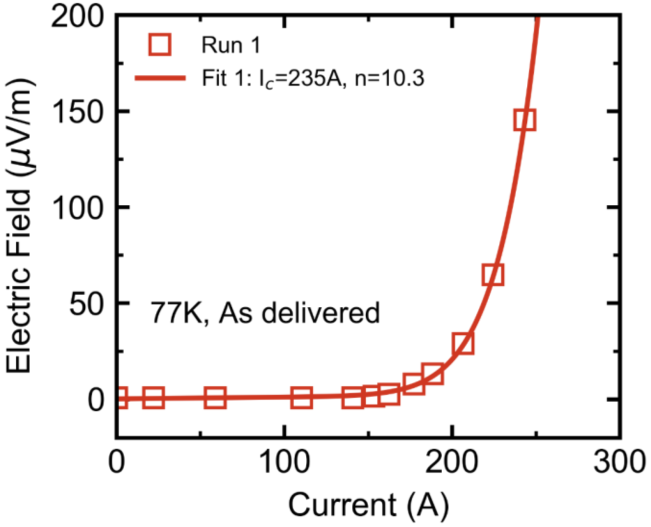
CORC Racetrack Coil Development at CERN

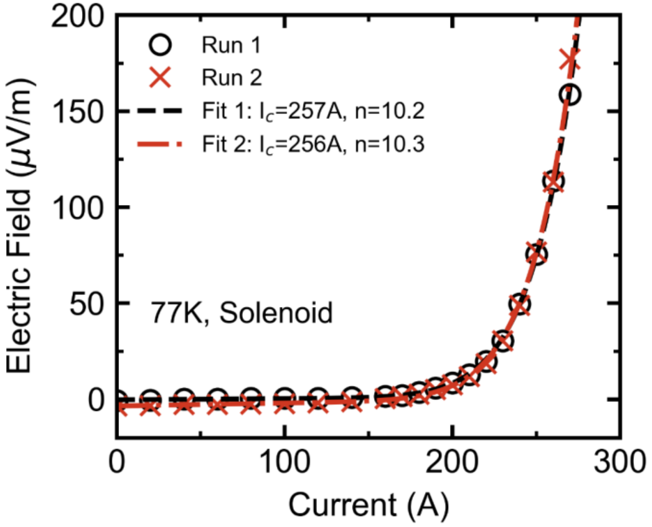
CERN CORC demonstrator racetrack coils:

- Layout: 2 layers with each 8 turns
- <u>Minimum bending diameter of 40 mm</u>
- Coil inductance ≈ 50 μH, 0.38 T per kA
- I_c of around 4.5 kA at 10 T and 4.2 K

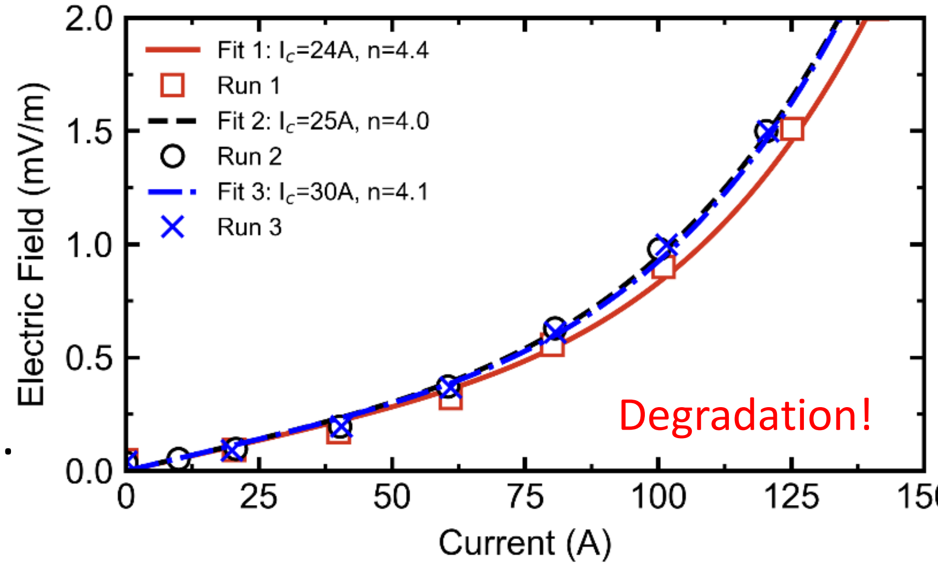
✓ First prototype using ⌀3.3 mm ‘dummy’ CORC wire comprising only a few ReBCO tapes.

✓ Tested in LN2 before and after winding.





CORC Racetrack Coil Development at CERN



Practice coil using dummy wire with 4 *Re*BCO tapes.

- Dummy wire: I_c = 250 A, n = 10 @ 77 K before winding

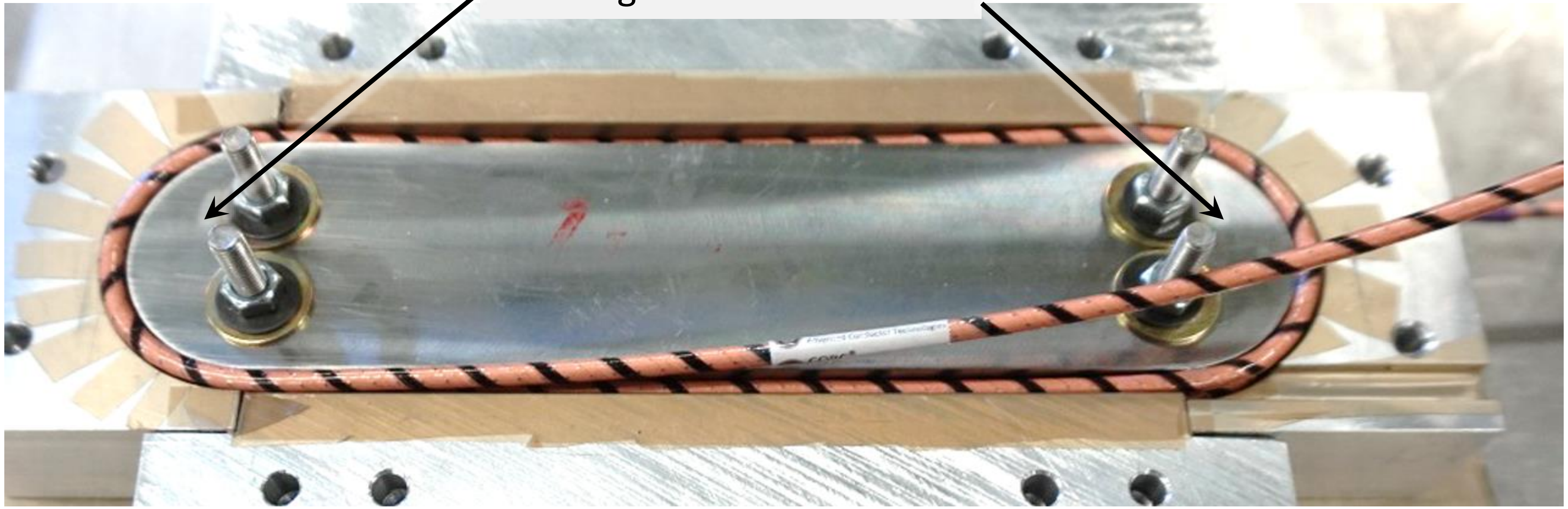
Racetrack wet wound with Stycast 2850FT epoxy resin.

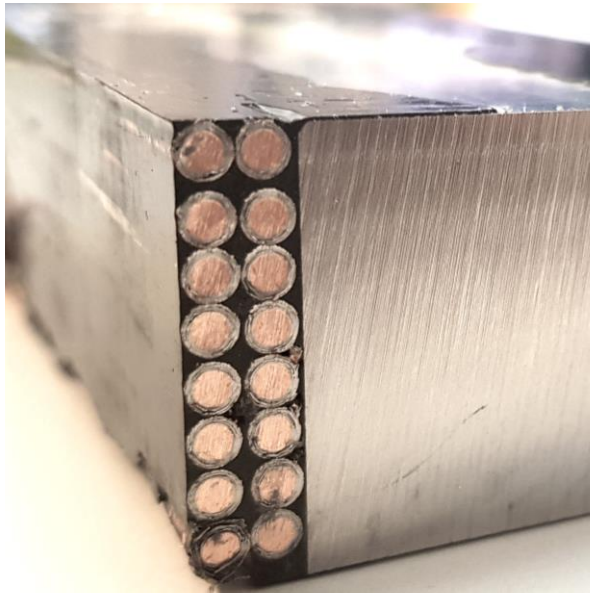
- Racetrack: I_c = 30 A, n = 4 @ 77 K

Bending diameter of 40 mm appeared to be too small for the tapes.

✓ **Narrower tapes with thinner substrate required!**

Winding Diameter = 40 mm





CORC Racetrack Coil Development at CERN

What is next?

Designs are in preparation for a new prototype CORC dipole.

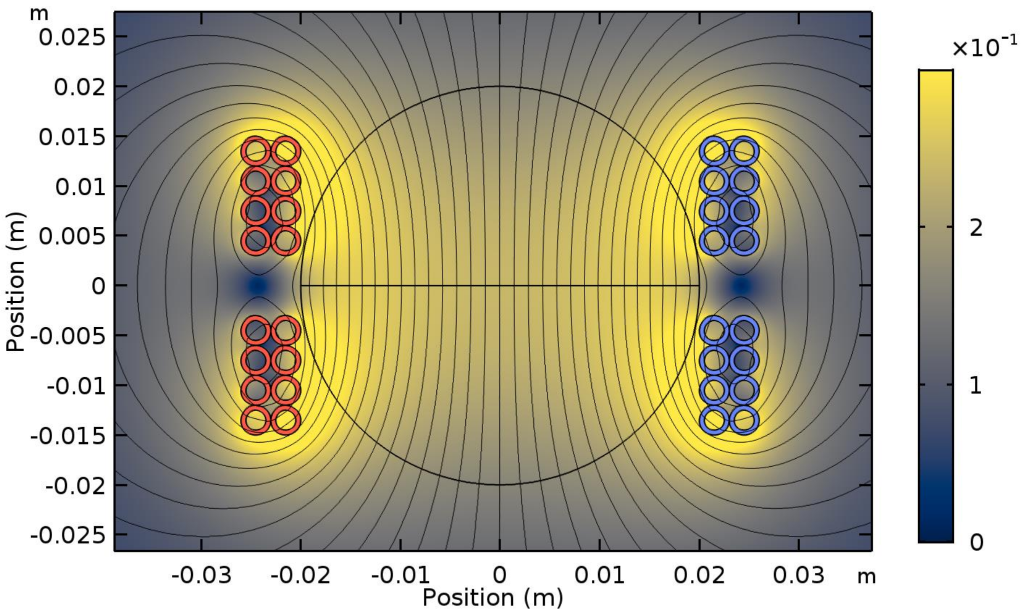
New CORC Racetrack

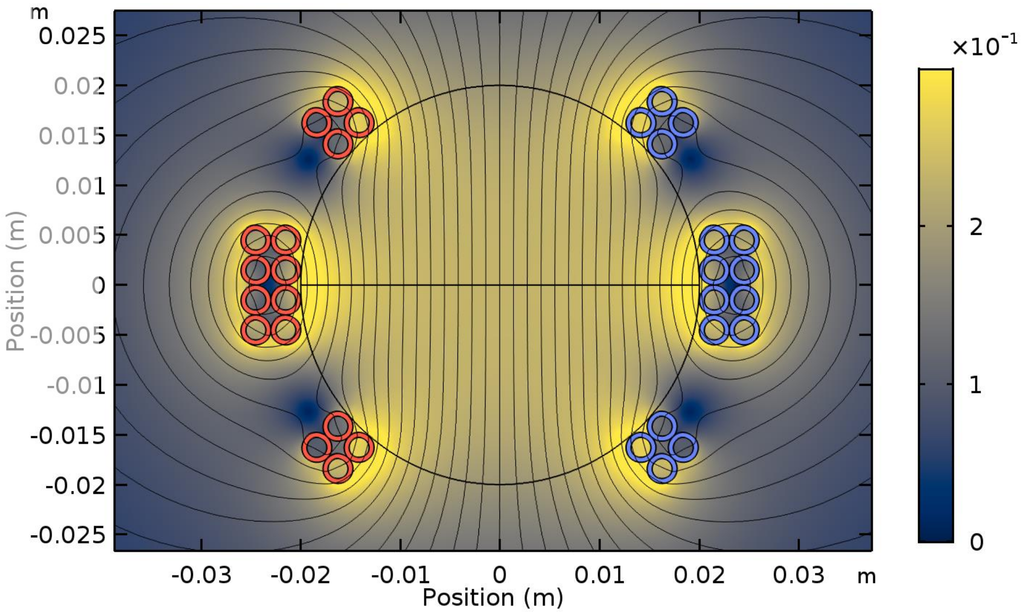
- Similar design as the first demonstrator
- Minimum bending radius of 20-25 mm (depends on wire)
- Two individual racetracks of 2 layers and 4 turns
- Intermediate connection between coils
- ~0.3 T/kA

A 1st CORC 'Block' Coil

- More complex design
- Minimum bending radius of 20-25 mm (depends on wire)
- Allows relatively homogenous magnetic field in the center over 20 mm and 0.3 T/kA

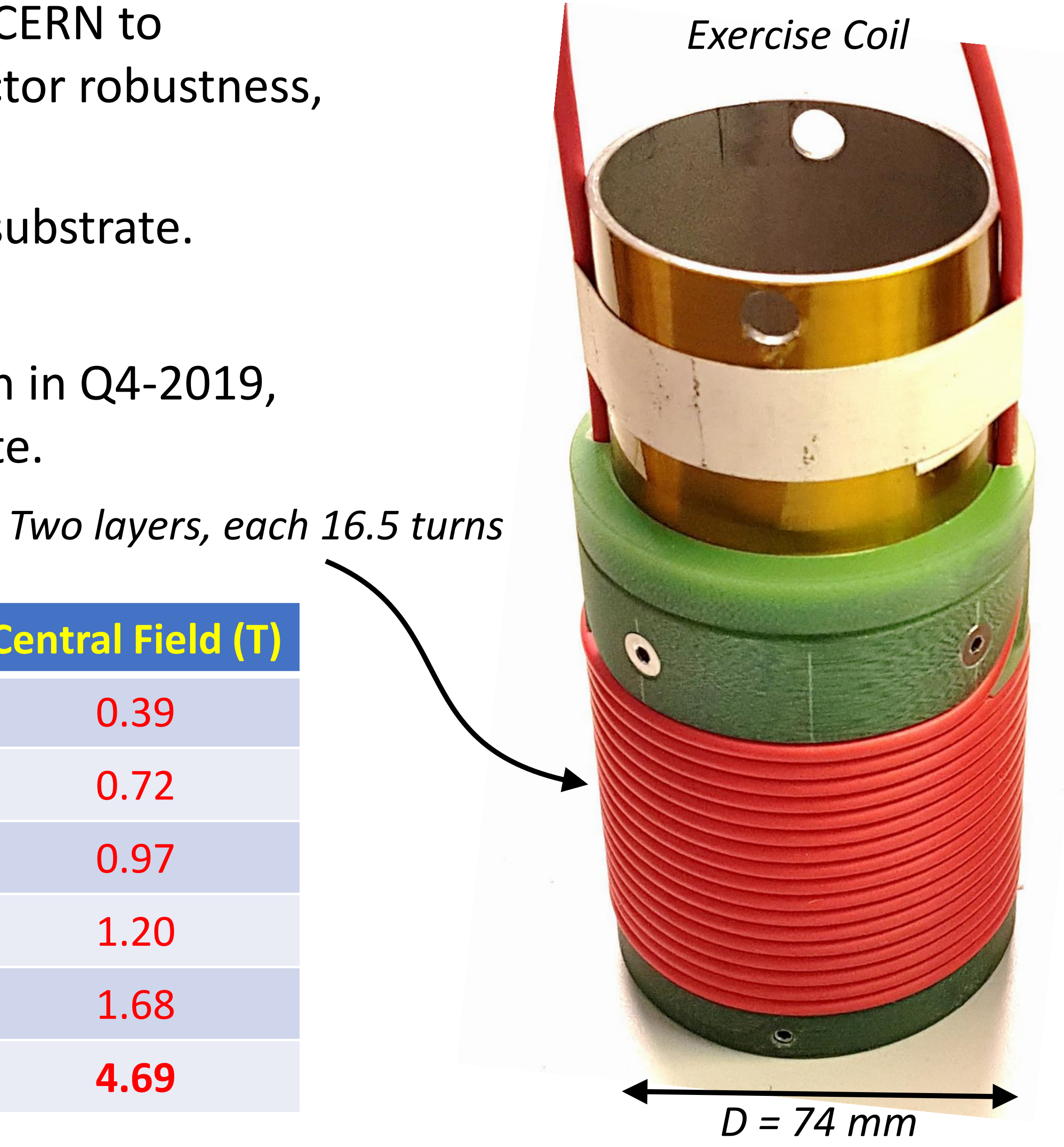
✓ **Thinner and narrower tape requires for small bore, d < 50mm, CORC based magnets.**





CORC Solenoid – Series of demonstrators

- A series of compact 2-layer CORC solenoids developed at CERN to demonstrate practical handling, materials choices, conductor robustness, and high performance of CORC wires for magnets.
- CORC wire: 27 *Re*BCO SCS2030 tapes, 2 mm wide, 30 µm substrate.
- Minimum bending radius of 30 mm.
- Magnet scheduled for testing in self-field in liquid nitrogen in Q4-2019, followed by a 4.2K test in background of 15 T at Uni Twente.



Design Self-Field Performance

T (K) *	High-Field I_c (A)	Overall I_c (A)
77	785	805
70	1467	1505
65	1968	2019
60	2438	2500
50	3405	3494
4.2	9517	9755

** 100 µV/m criterion*

T (K) **	Peak Field (T)	Central Field (T)
77	0.47	0.39
70	0.88	0.72
65	1.19	0.97
60	1.47	1.20
50	2.05	1.68
4.2	5.73	**4.69**

*** Using the Overall I_c*

CORC Solenoids – High-Field Test

- CORC coils are tested as insert in a 15T Nb_3Sn magnet at the University of Twente at 4.2 K.
- In 10 T background, the coil is expected to generate an additional 2.5 T.

Calculated in-field performance at 4.2K

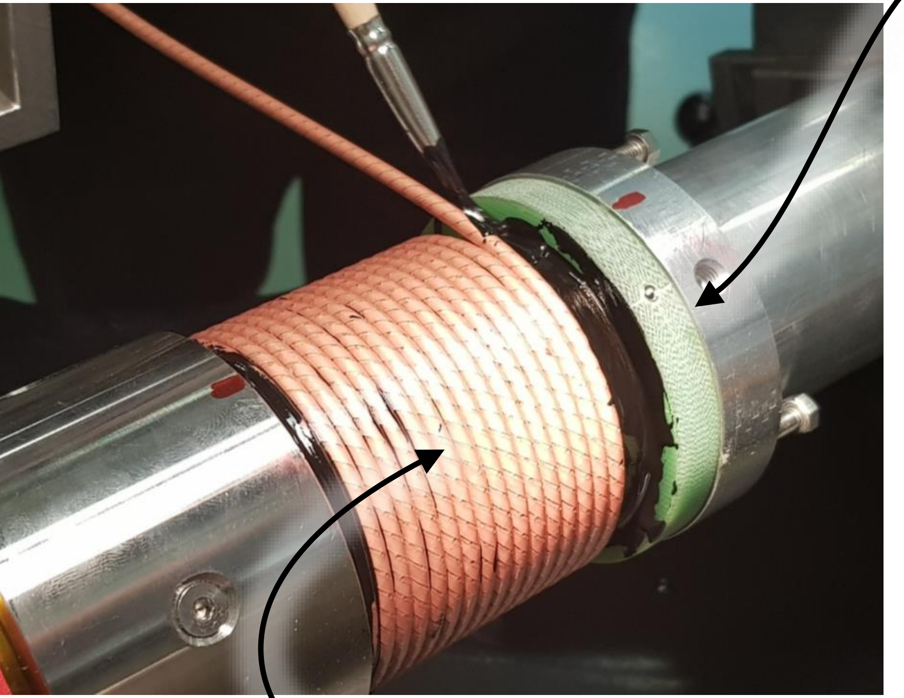
BG (T)	Ic (kA)	Peak field (T)	Central field (T)
0	9.76	5.73	4.69
2	8.56	7.02	6.12
4	7.39	8.34	7.55
6	6.50	9.81	9.13
8	5.83	11.4	10.8
10	5.20	13.0	12.5
12	4.74	14.5	14.3

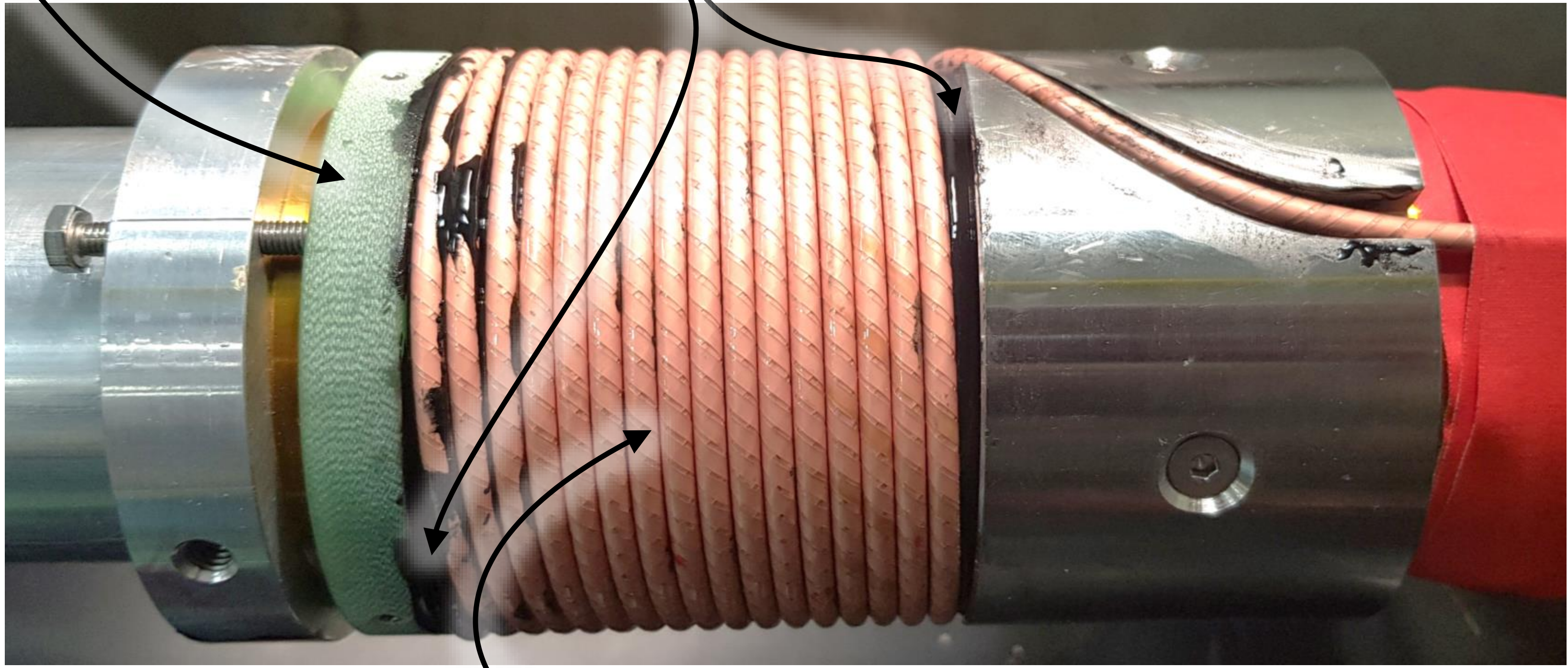
✓ This CORC solenoid is the first of several CORC demonstrator coils. It will be succeeded by <u>higher-performance CORC solenoid</u> with more layers and higher-I_c tapes and by a <u>CORC dipole magnet</u>.

Wet wound and reinforced with epoxy resin.

CORC Solenoid – Coil Preparation

- Two-layer CORC solenoid is prepared at CERN last week.
- The layers are wet-wound with Stycast 2850 FT epoxy.
- Insulation present around the CORC wire to prevent Stycast from leaking in.
- G10 spacers are placed on the coil extremities to fill the larger gaps.

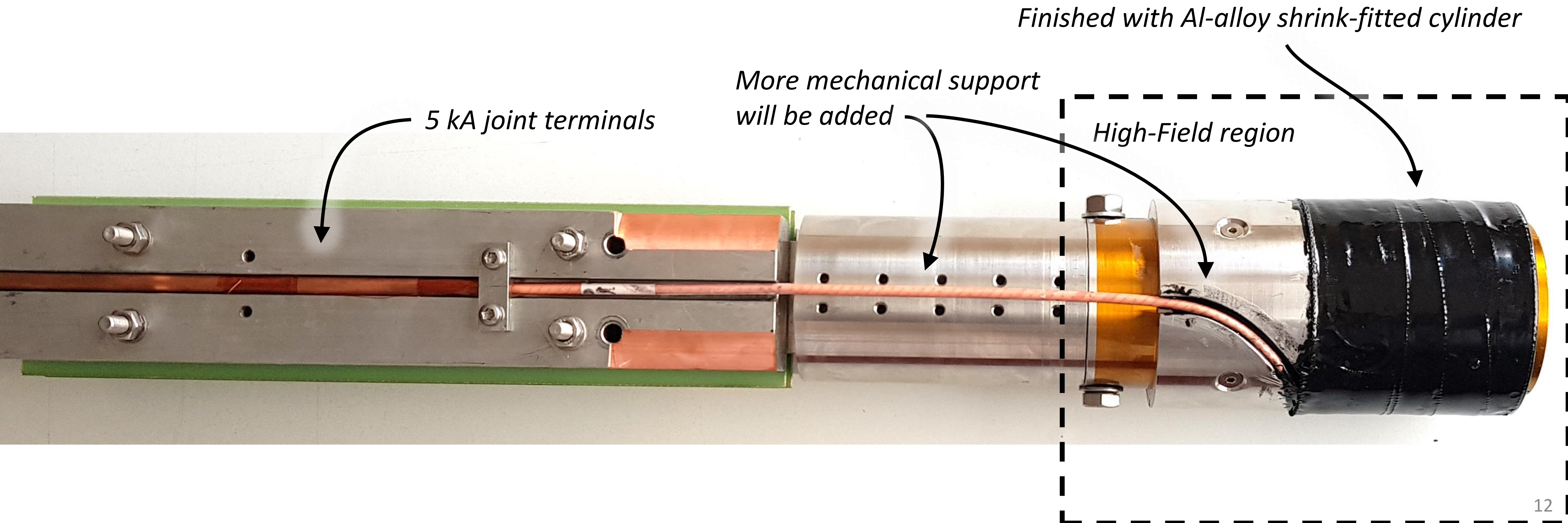




CORC Solenoid – Coil Preparation

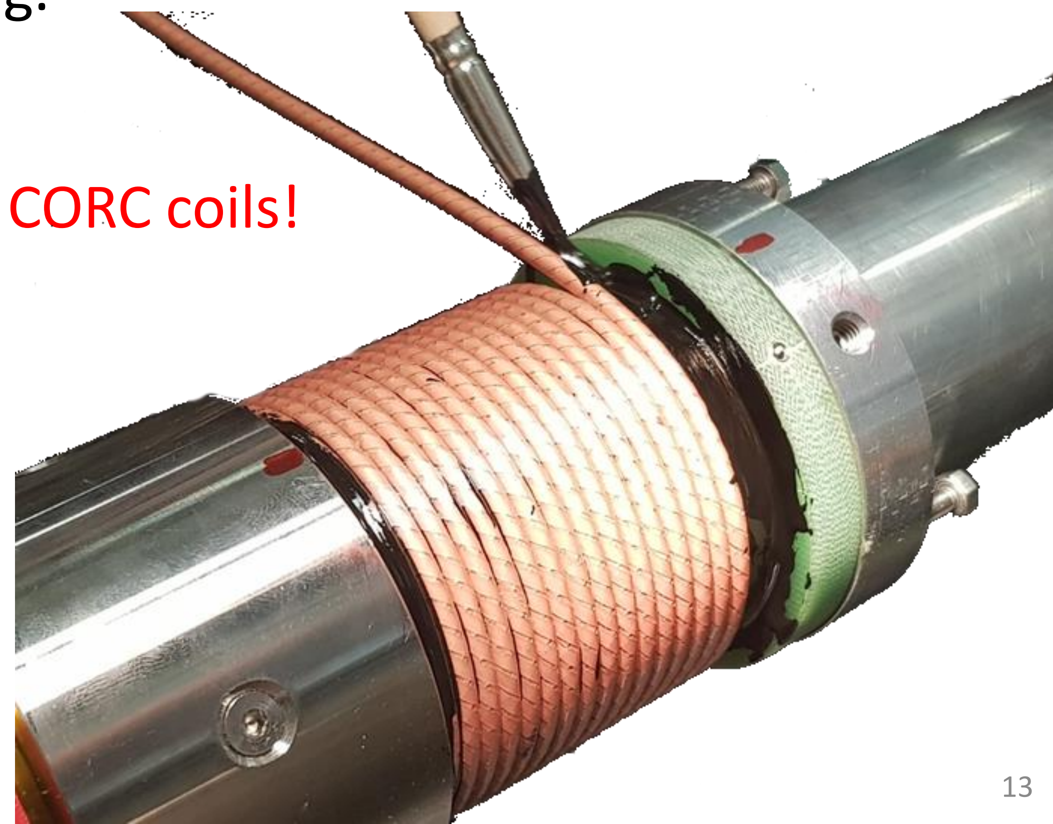
- Joint terminals are outside high-magnetic-field region.
- Two 5-kA vapor-cooled current leads are prepared for the test.
- Al-alloy cylinder is shrink-fitted around the solenoid for mechanical support.
- Test in LN2 is this month at CERN -> Test in high-field and 4.2 K at Uni. Twente afterwards.

✓ Test in LN2 this month



Conclusion

- ✓ Series of CORC wire based demonstrator magnets are under development at CERN.
- ✓ CORC wire in the first trial CORC Racetrack coil degraded due to small winding radius.
- ✓ New CORC Racetrack coils are in development.
- ✓ A 1st compact CORC Solenoid prepared now for testing.
- ✓ Research on CORC Coils is going forward!
- ✓ Narrower & Thinner tape required for more compact CORC coils!



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