CCT BIN5c1, the first Bi-2212 Rutherford cable based canted-cosine-theta dipole magnet

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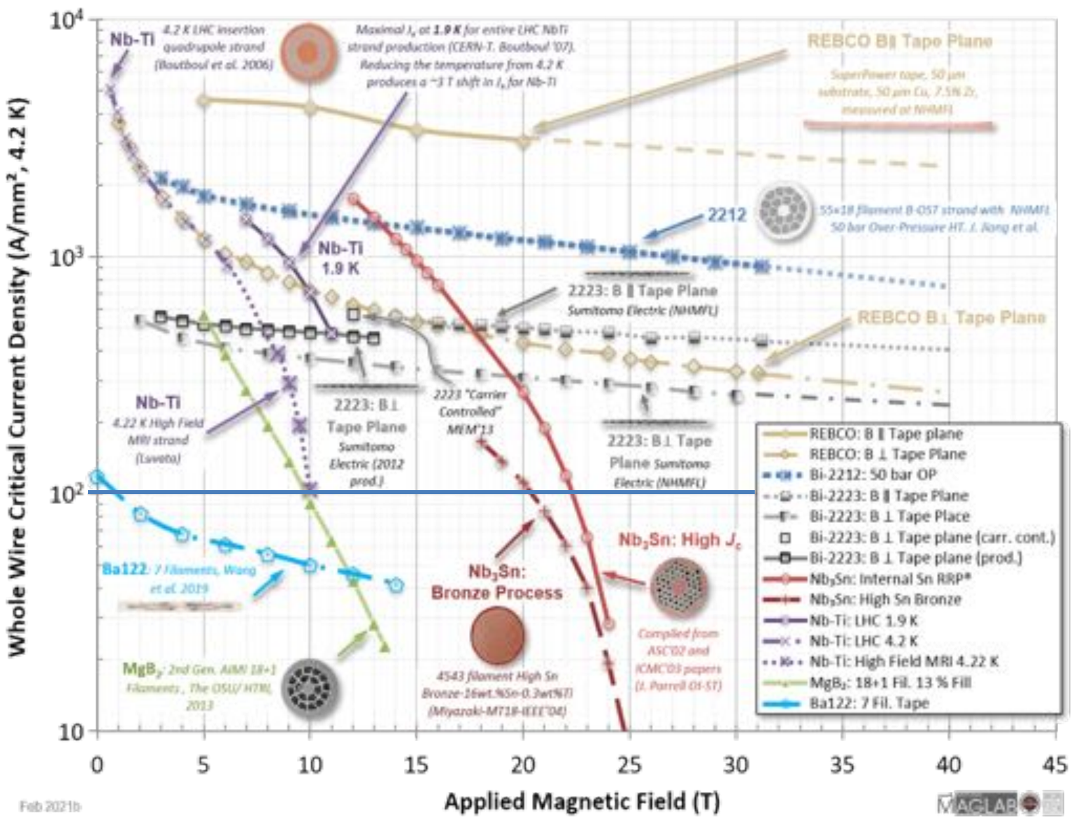
National High Magnetic Field Laboratory

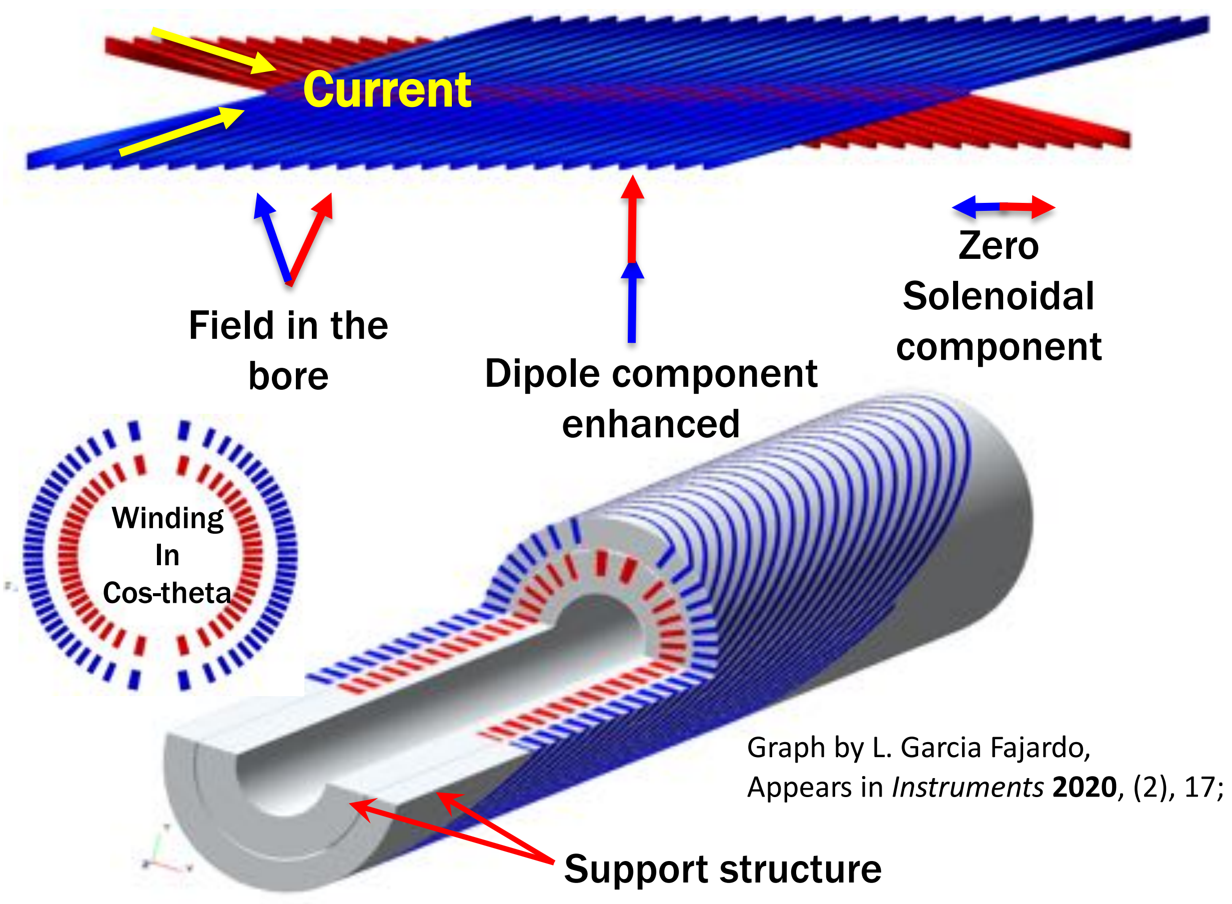
Work is supported by the US. Department of Energy, Office of Science, Office of High Energy Physics under the U.S. Magnet Development Program with contributions from Bruker OST LLC, and Engi-Mat Co. NHMFL is additionally supported by the State of Florida and the US National Science Foundation.

Bi-2212 is potentially a high-field superconductor and CCT design is unique



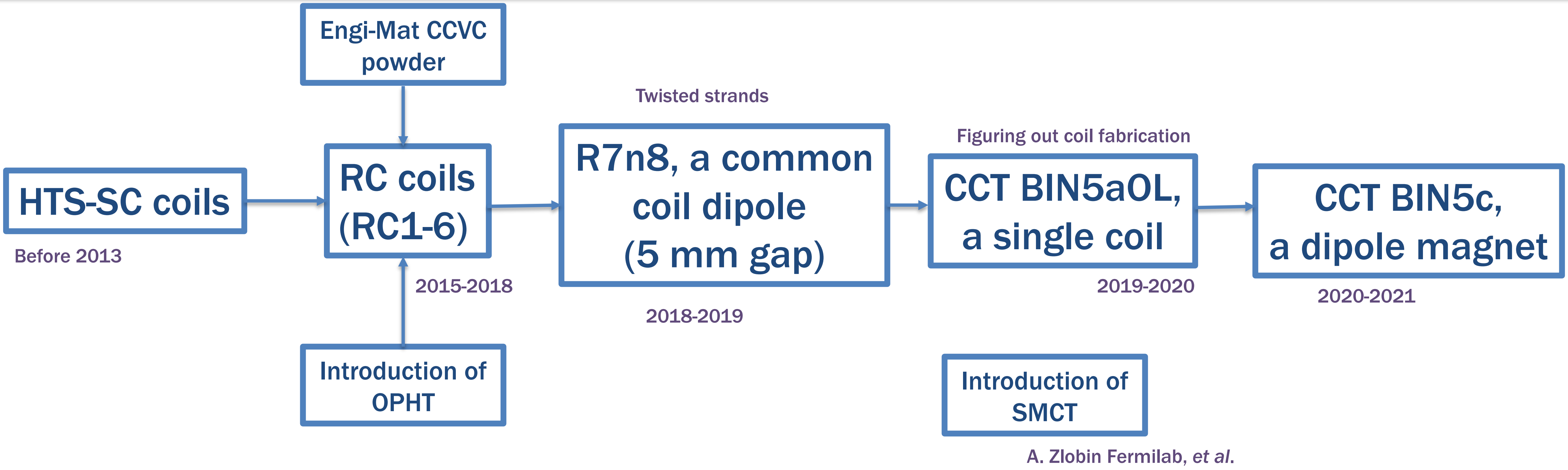
Peter J. Lee, NHMFL

The Canted-Cosine-Theta (CCT) concept



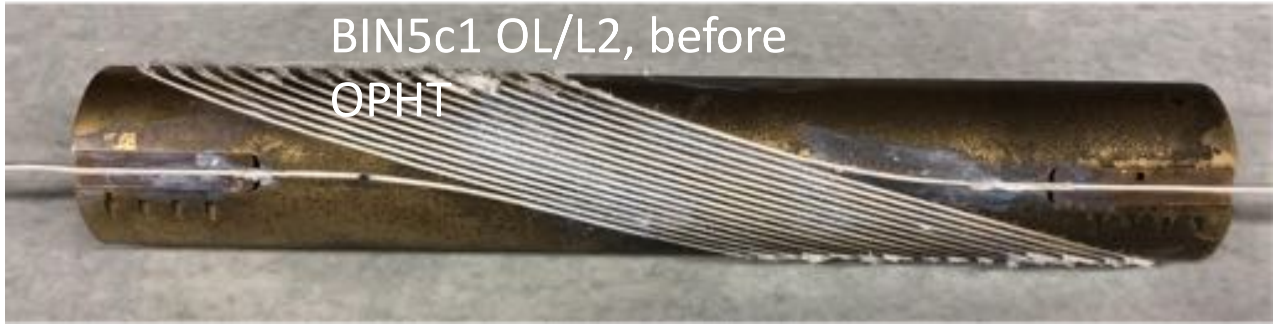
Graph by L. Garcia Fajardo, Appears in *Instruments* **2020**, (2), 17;

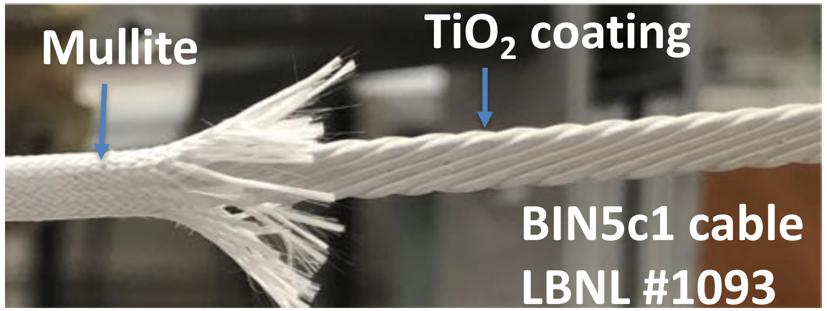
The path so far



Jiang et al., *IEEE TAS*, 29 (2019), 6400405
Shen et al., *Sci Rep* 9 (1) (2019), 10170
Zhang *et al*. *Supercond. Sci. Technol*. 31, 105009 (2018)
T. Shen, L. Garcia Fajardo,, *Instruments* **2020**, *4*(2), 17;
L. Garcia Fajardo 10.1109/TASC.2018.2818278
L Garcia Fajardo *et al,* 2021 /10.1088/1361-6668/abc73d

BIN5c, a subscale CCT magnet, used as a technology R&D vehicle for testing technology variants as well as magnet assembly



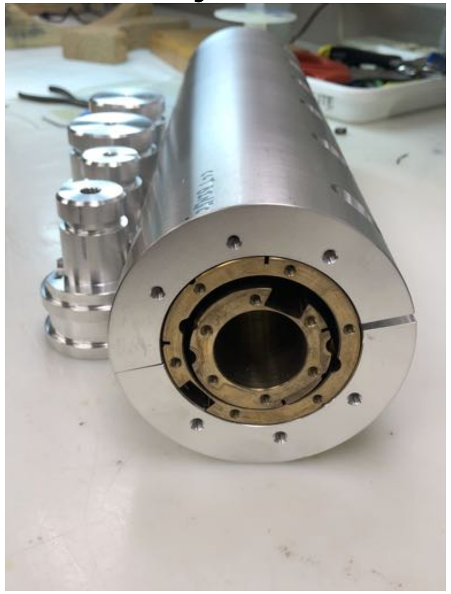


OPHT at NHMFL by E. Bosque and TiO_2 supplied by Jun Lu.

Layer 1 (inner layer)

Layer 2 (outer layer)

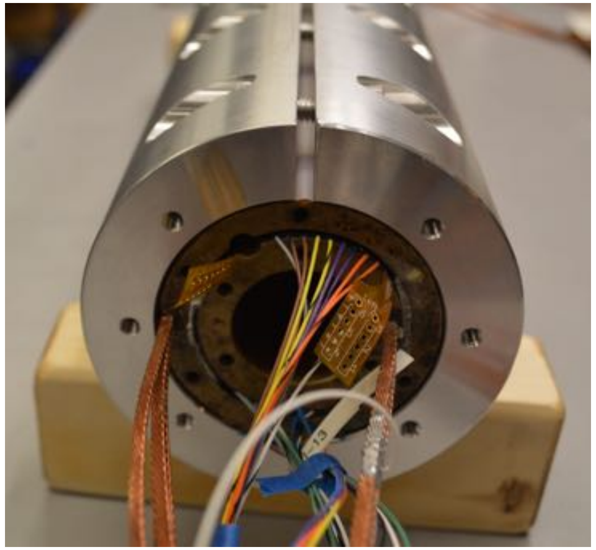
Kapton/epoxy bag for assembly



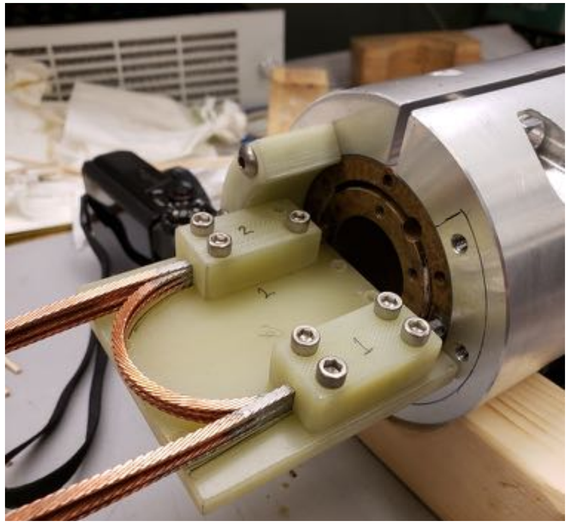
BIN5c1 magnet construction

Layer 1/2 being assembled (w 45-degree Kapton bag)

Magnet as assembled



Splice between two layers



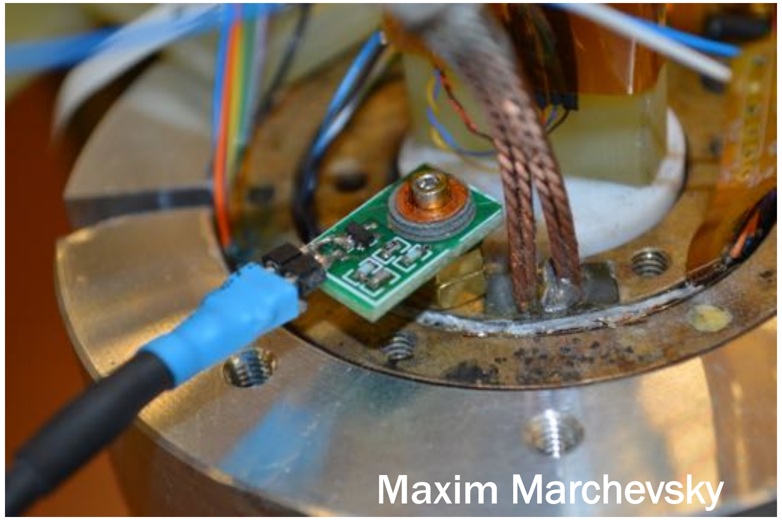
Magnet on header

Test history

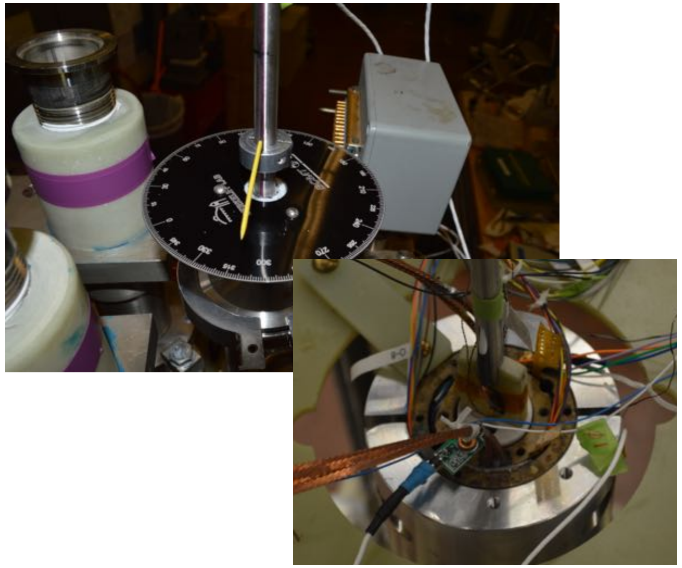
77 K individual coil test (after VPI) → 77 K assembled magnet test → 4 K assembled magnet test → 77 K assembled magnet test

4 K test Instrumentation

Acoustic sensors (active acoustic thermometry)



Hall probe

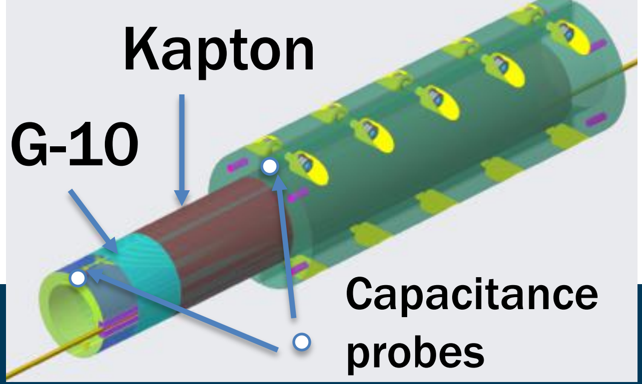


Lakeshore cryogenic hall sensor
2182 nanovoltmer

Interlayer flexible quench Antenna

Voltage taps (32-ch SCXI/PCI w 18 bit ADC, 300Vrms isolation, programable gain and filtering)

CAD by Ray Hafalia



Capacitance (LCR6020 at 20 kHz), between OL mandrel and split shell.

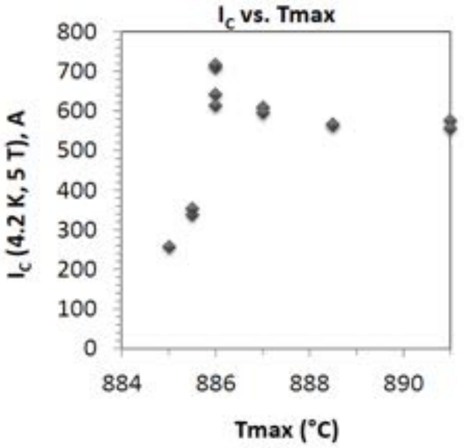
Davis et al., *IEEE TAS*, (2021) 10.1109/TASC.2021.3094769

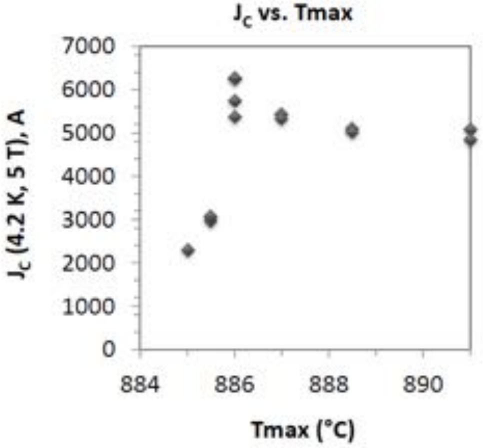
The magnetic design: (1) Conductor

Magnet I: BIN5c1

- *LBNL cable 1093, made from the nGimat SBIR wire PMM170725*

2. PMM170725, 0.8 mm, 55x18, untwisted, nGimat powder LXB-86).

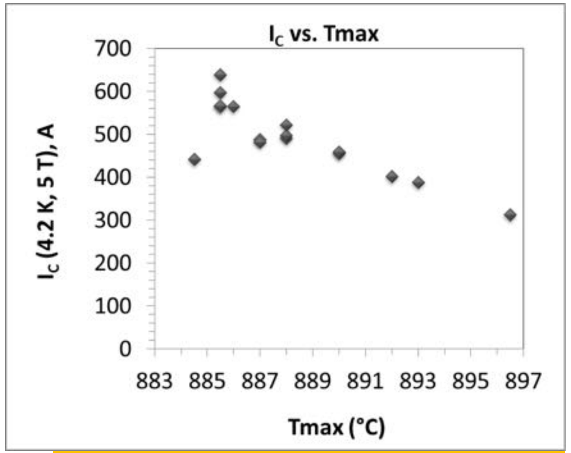




Strand I_c data by Jianyi Jiang of NHMFL

Magnet II: BIN5c2

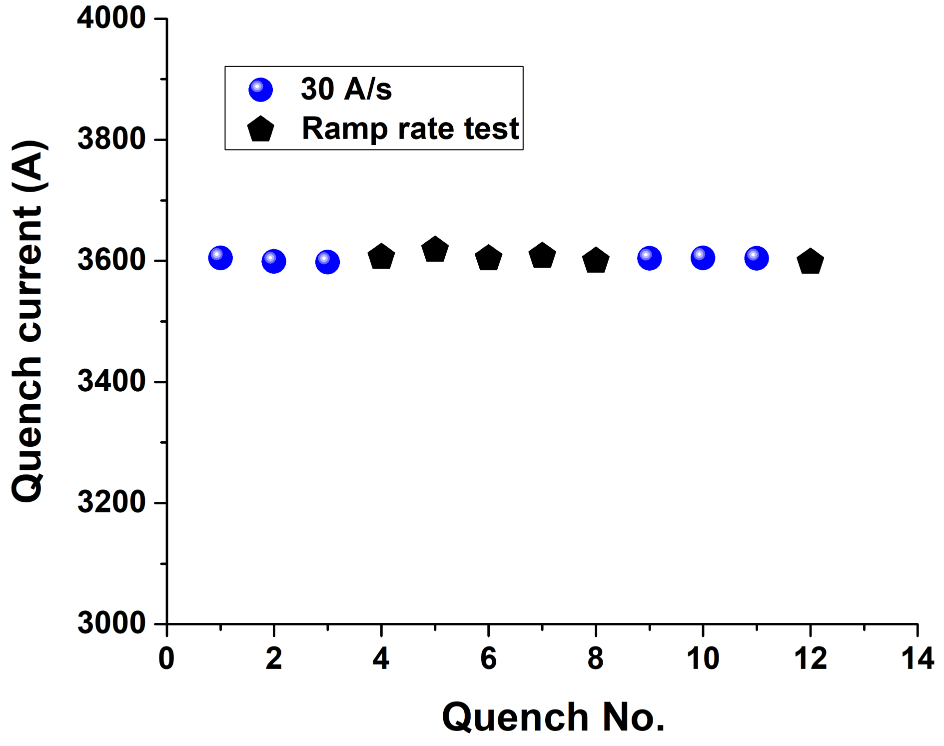
- *LBNL cable 2001, made from the MDP-CPRD strand PMM190118, 0.8 mm, 55x18, untwisted, Engi-Mat powder LXB-156*

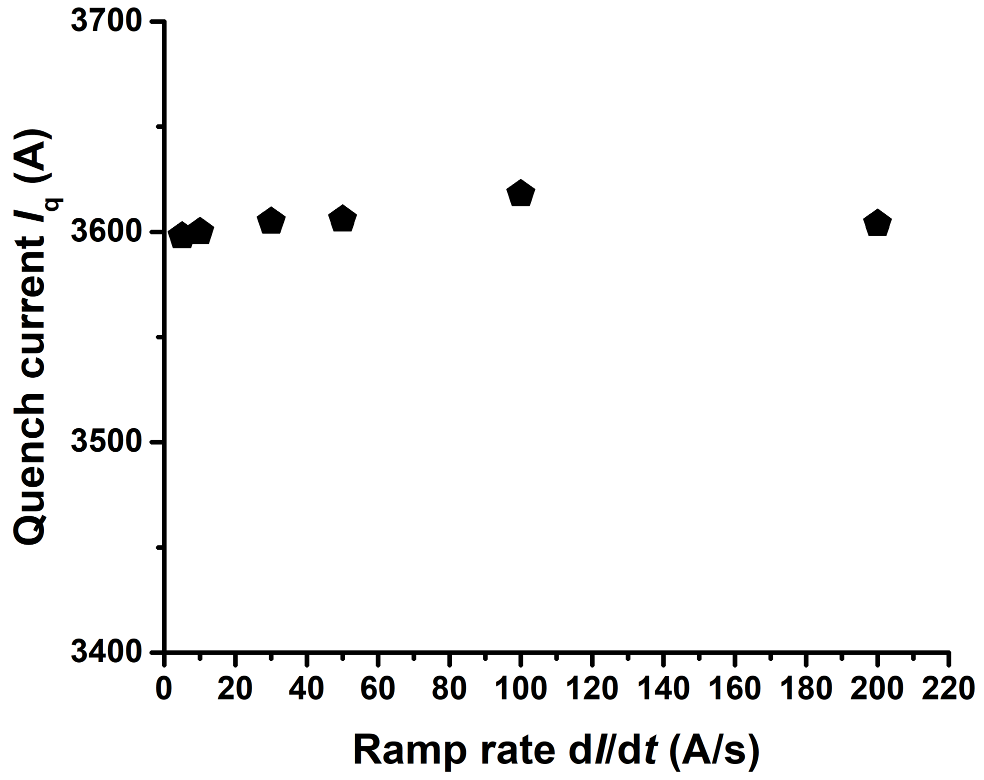


Strand I_c data by Jianyi Jiang of NHMFL

- The dimension specifications for both cables are::
  - Width: **4** mm under tension
  - Thickness: **1.44** mm under tension
  - Keystone angle: **0.0º**
  - Cable lay direction: **Left**
  - Cable lay pitch: **27.0** mm

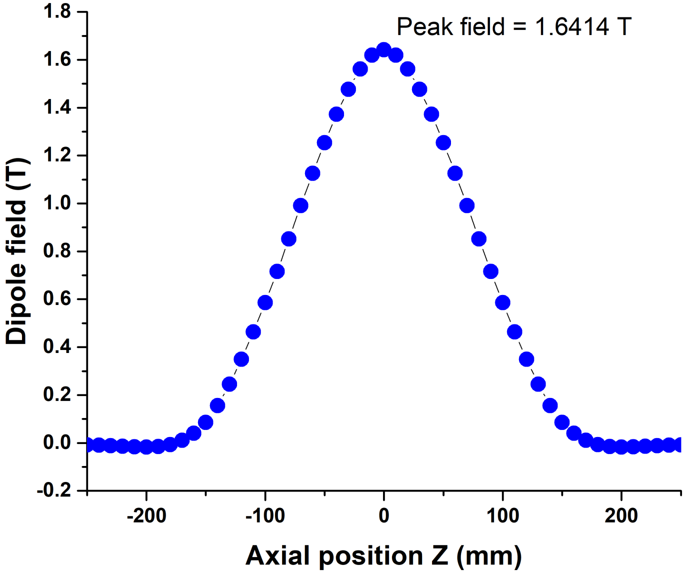
BIN5c1 4 K quench history

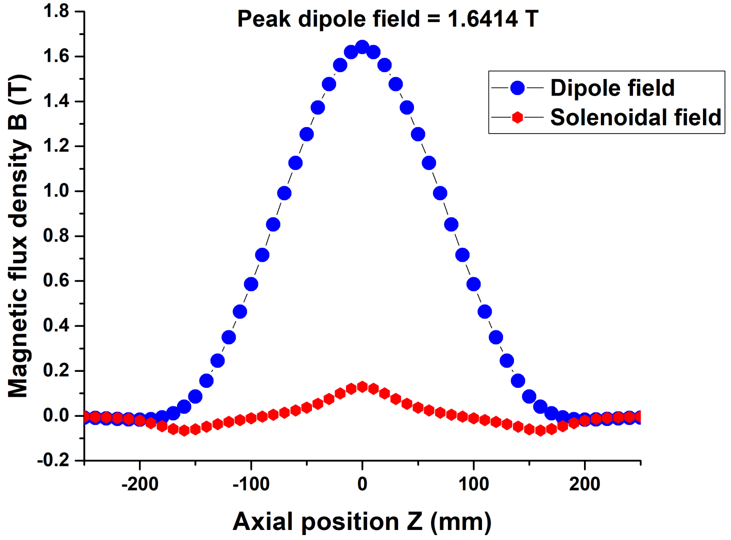




The magnetic design: (2) Magnetic field profile

Field constant = 1.6414 T/3.6 kA = 0.4559 T/kA.

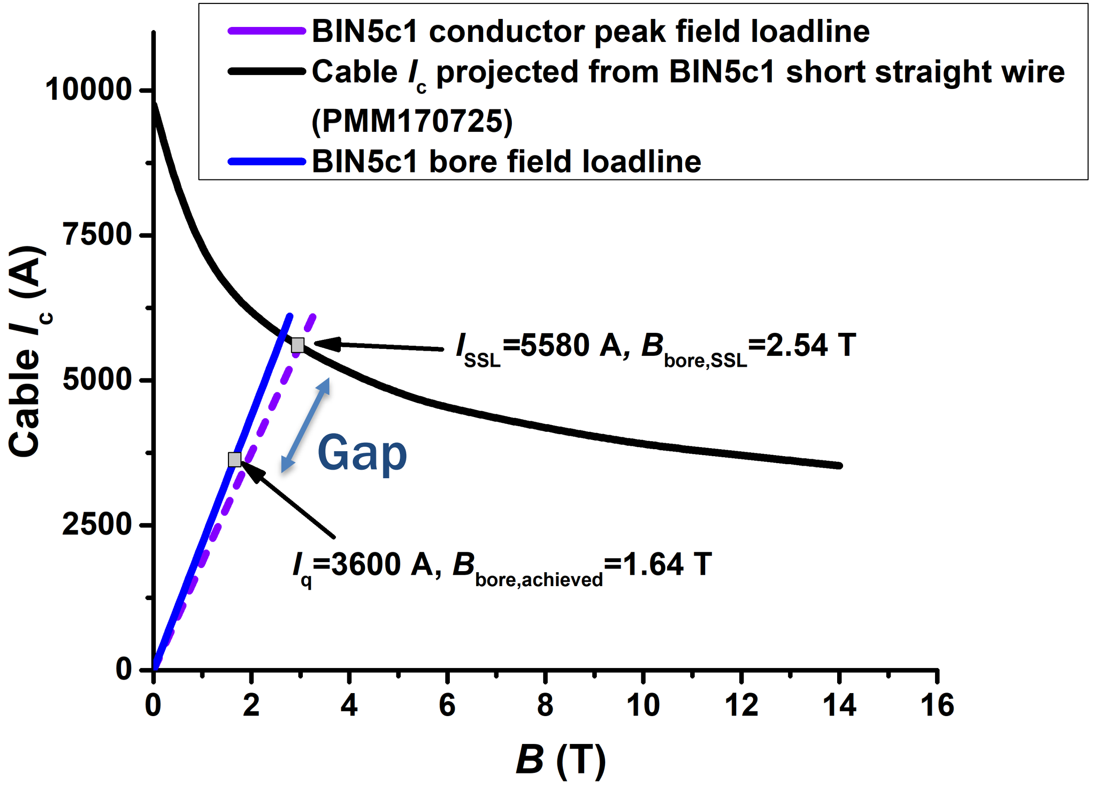


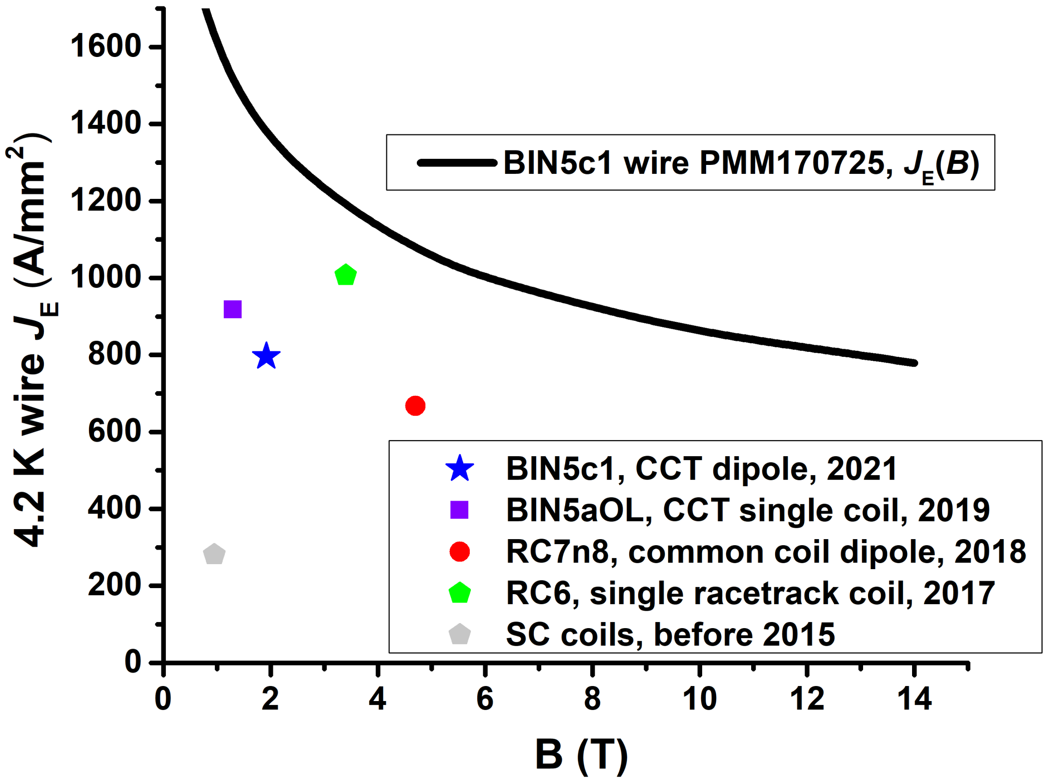


CCT BIN5c_1 and _2	Layer 1	Layer 2
Mandrel OD (mm)	47.3	64.7
Mandrel ID (mm)	30.8	51.3
Mandrel length (cm)	39	39
Turn No.	16	16
Cable length per coil (m)	5.7	8
Dipole field in the bore (T)	2.5 T@5580A	

- **Suitable as an insert in 90 mm bore Nb_3Sn CCT5.**

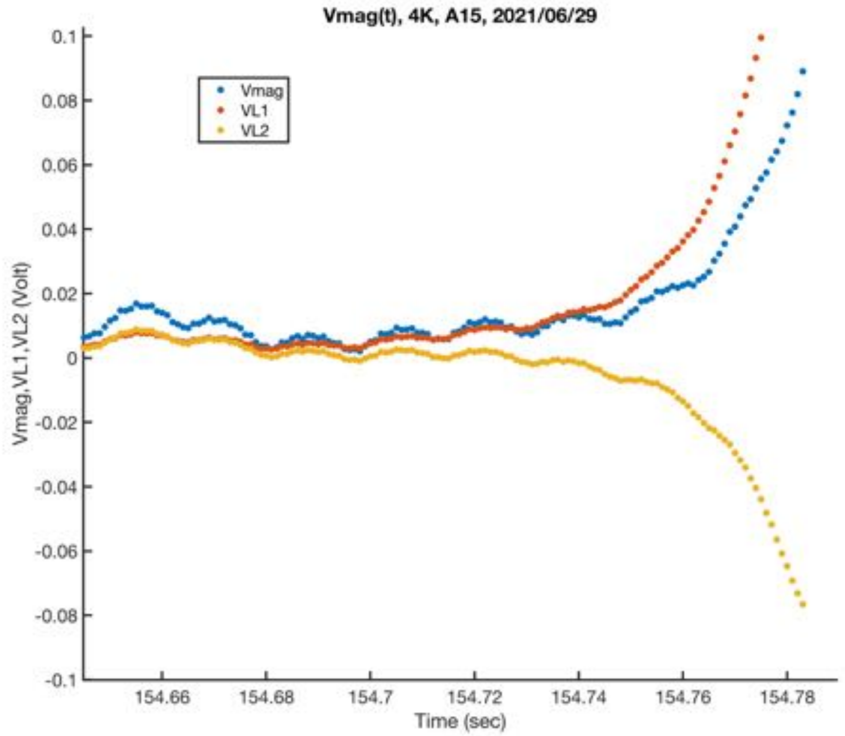
BIN5c1 performance compared to other coils – a gap exists between coil performance and short sample wire performance

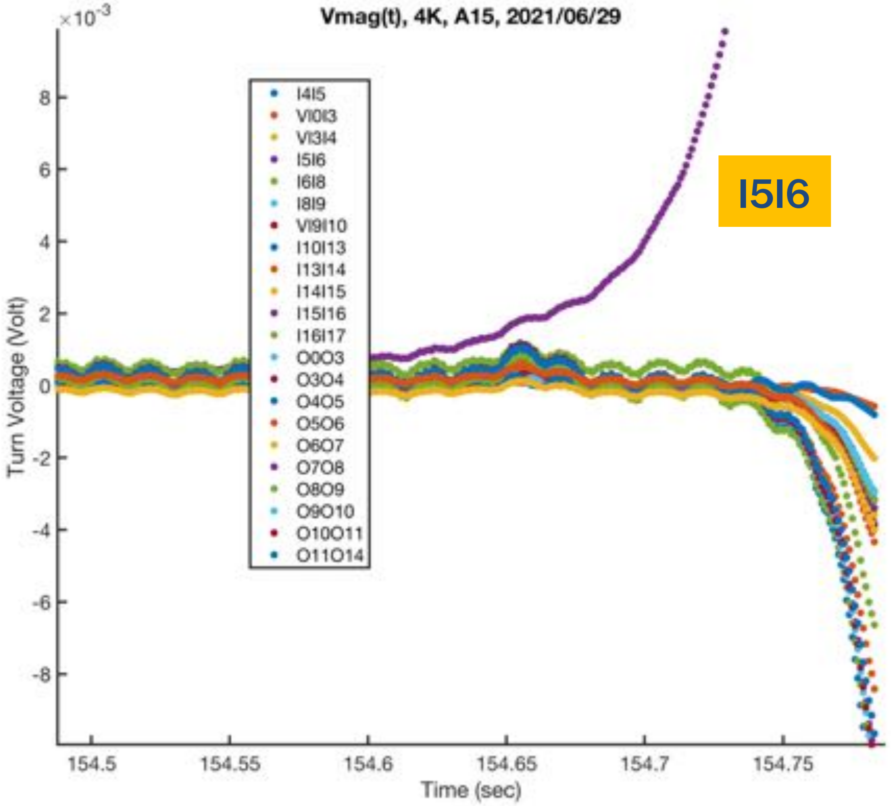


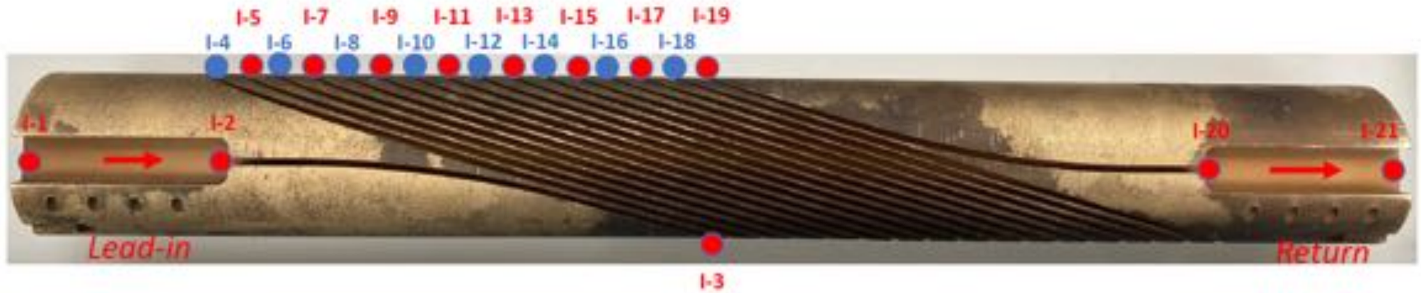


A typical quench – magnet terminal voltage and the quenching turn

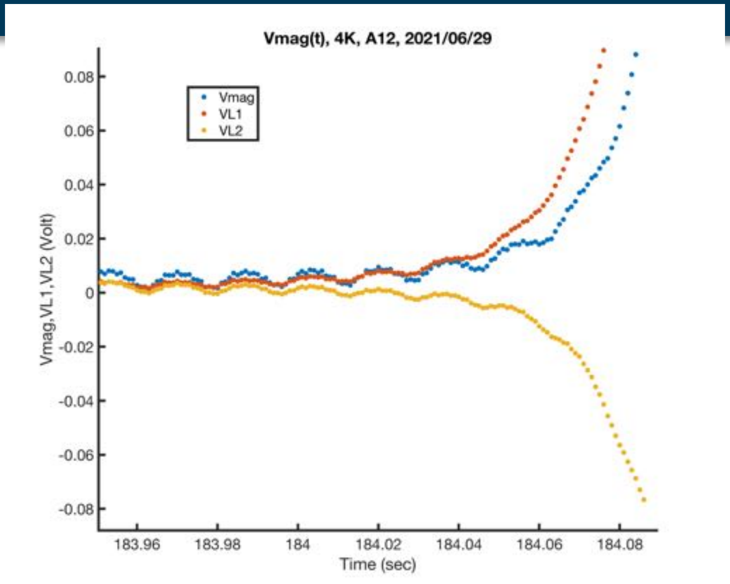
- Opportunity for modeling: Hot spot temperature as a function of the detection voltage.

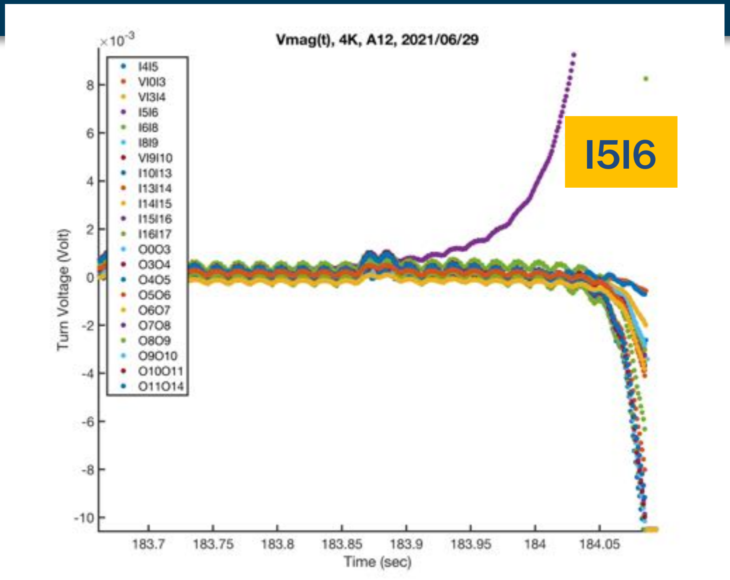


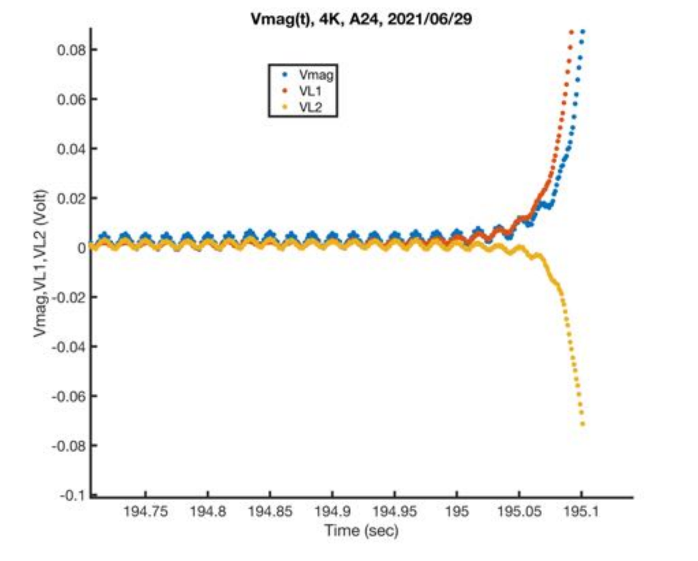


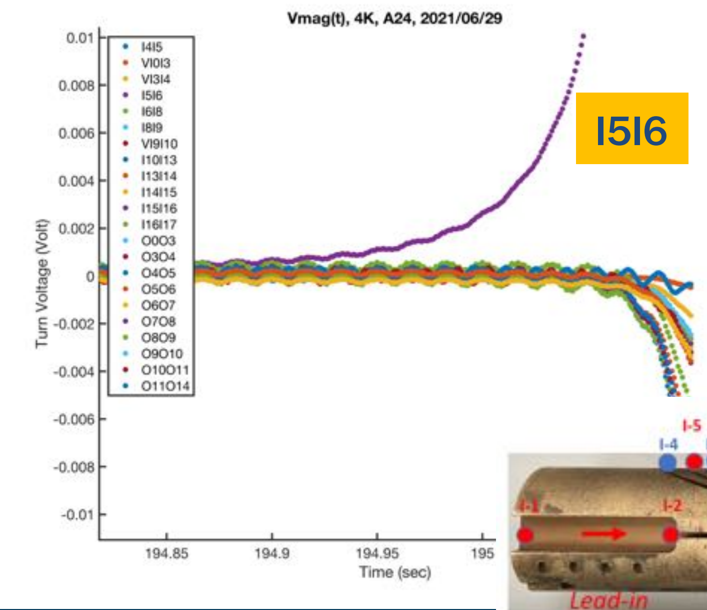


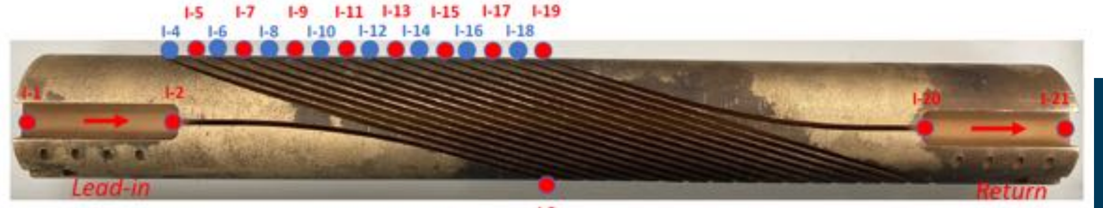
Consistency - The first and the last quench during the test



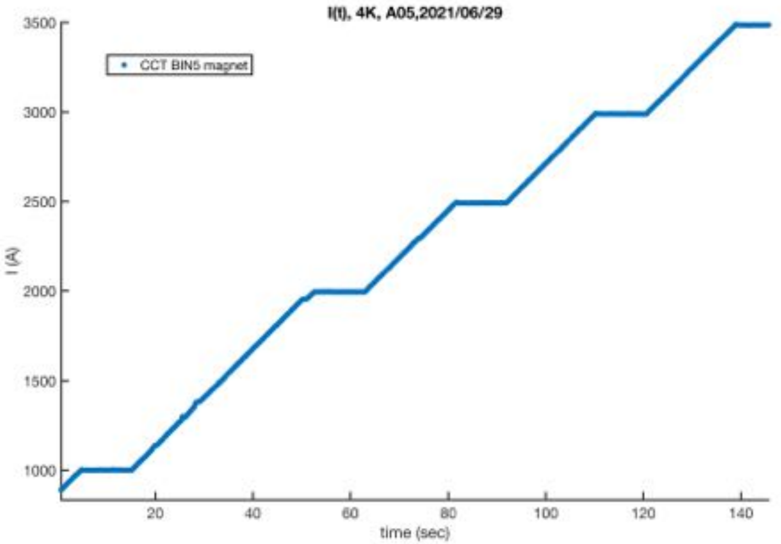




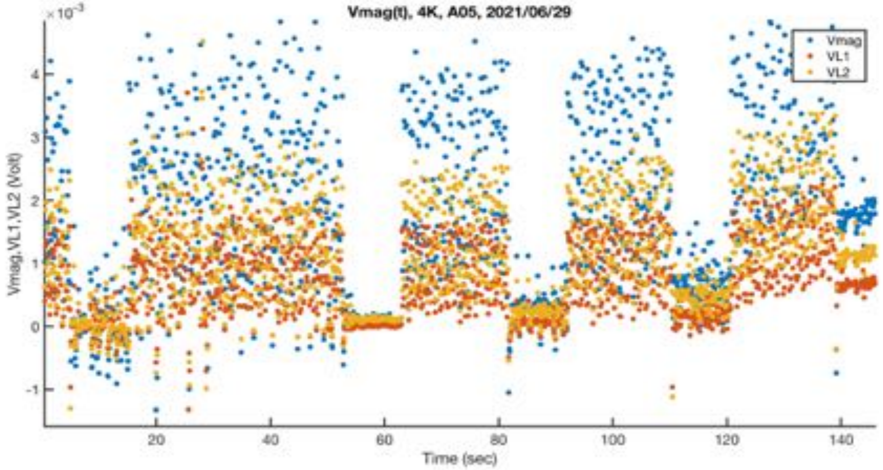




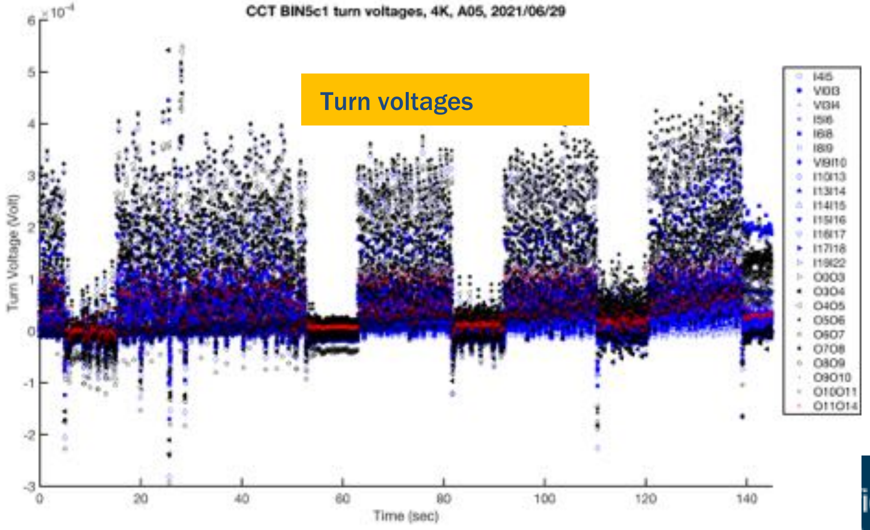
Predicting quench current before a thermal runaway quench through voltage measurement



Terminal voltages



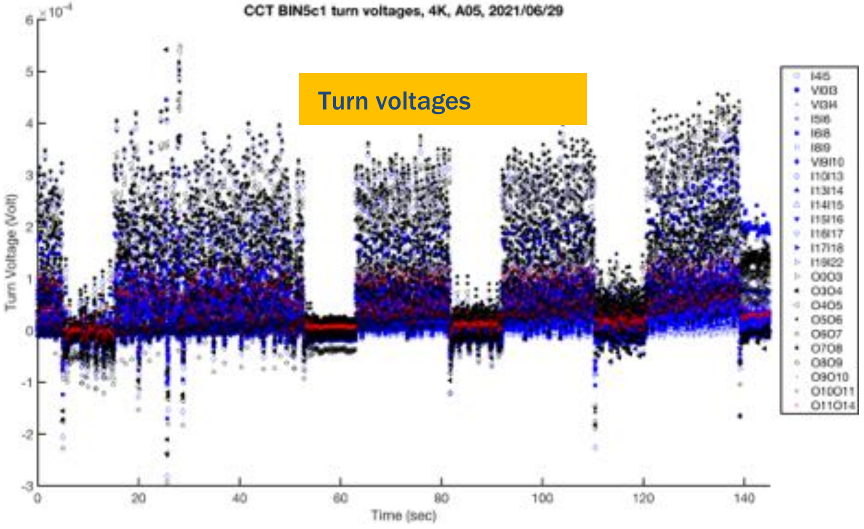
About 2 mV@3500A.

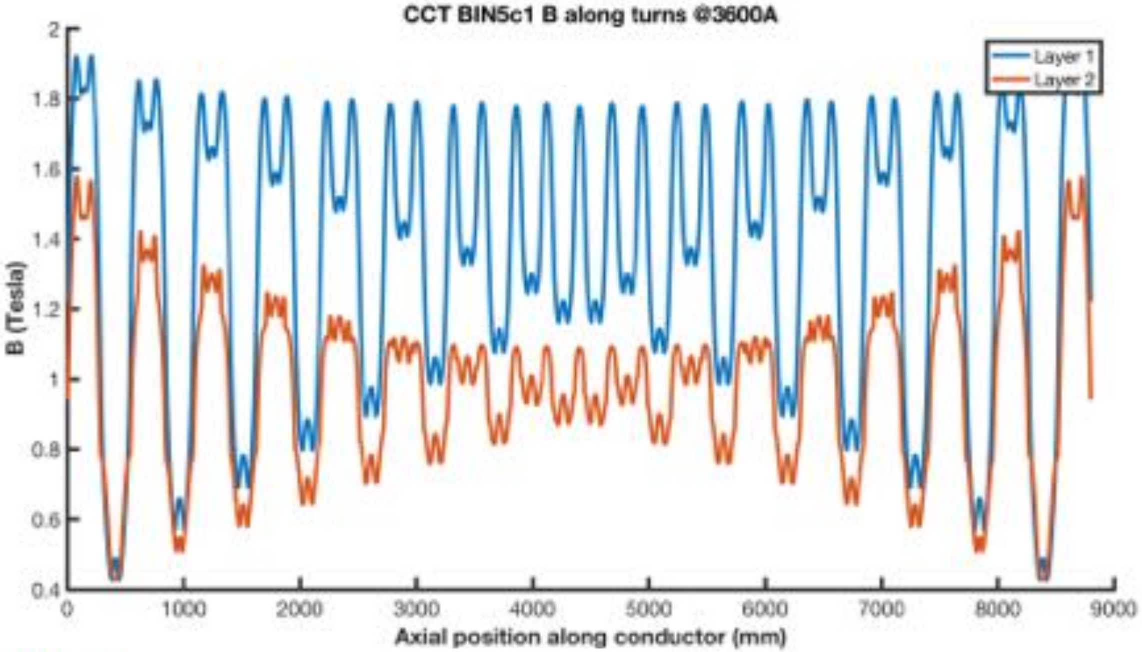


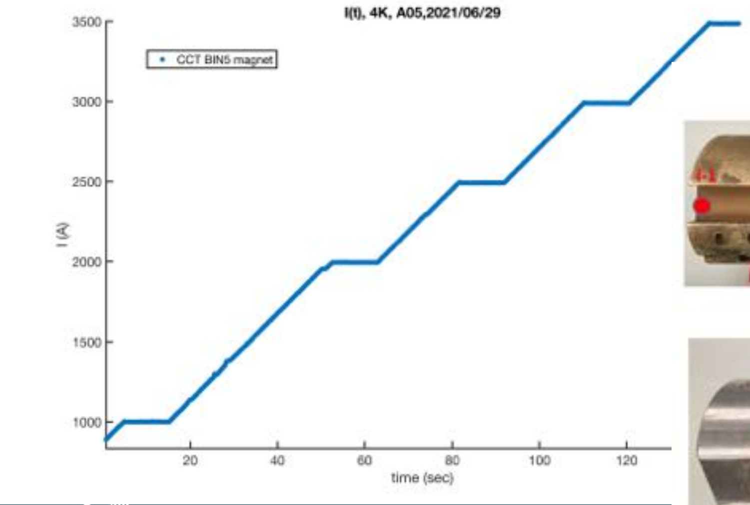
Turn voltages

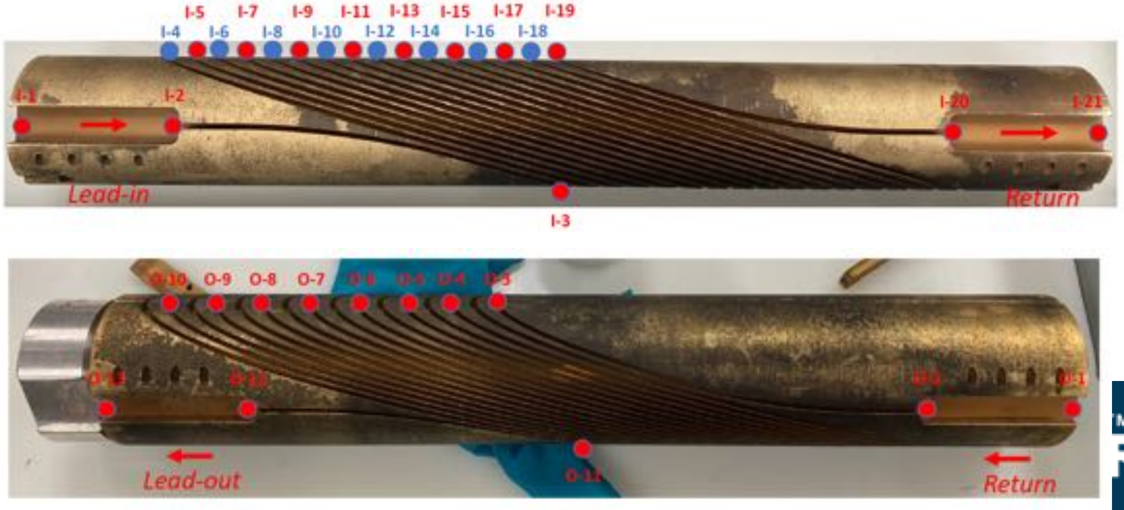
Highest at ~200 micro-V.

The nonuniformity and the quench turn

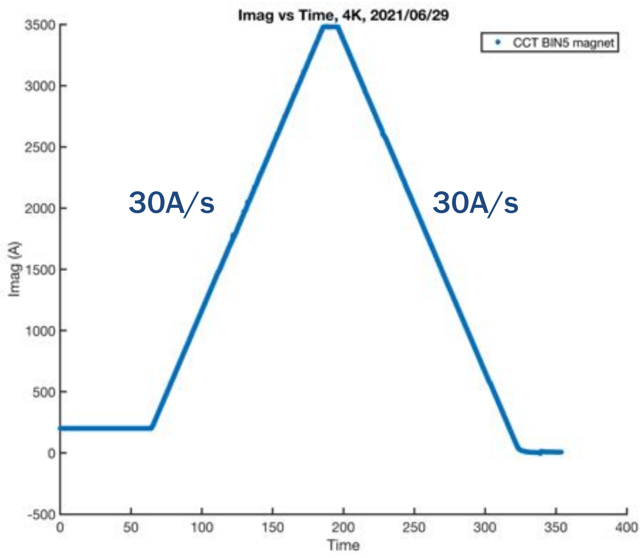


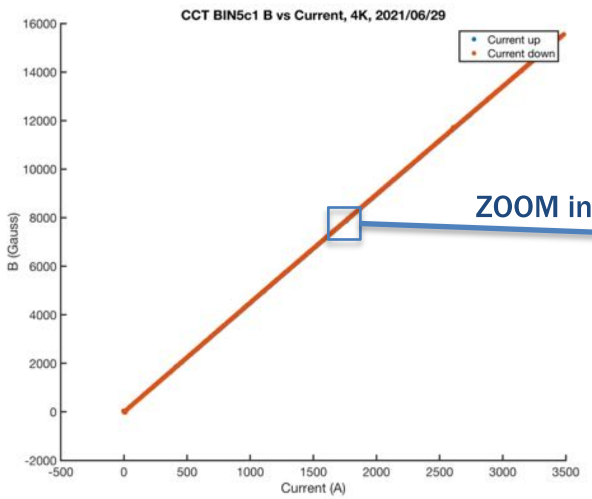




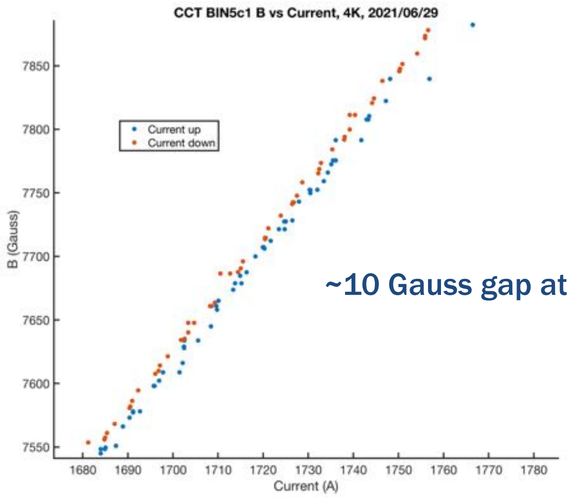


Field hysteresis is small

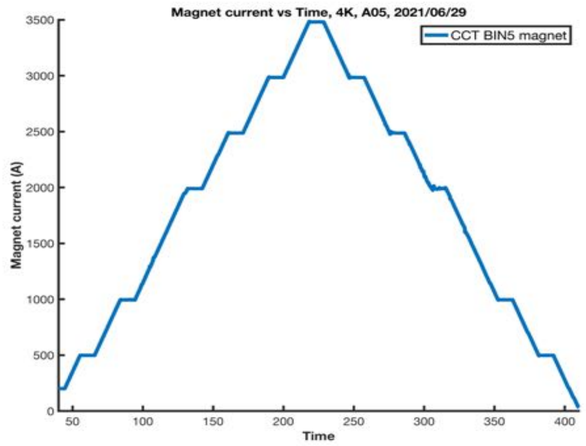


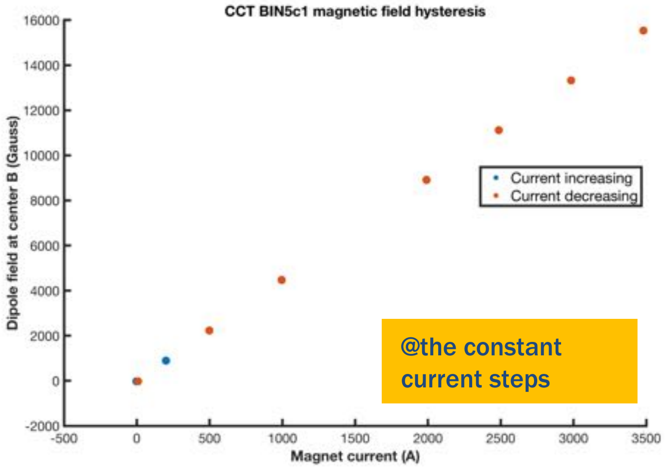


ZOOM in



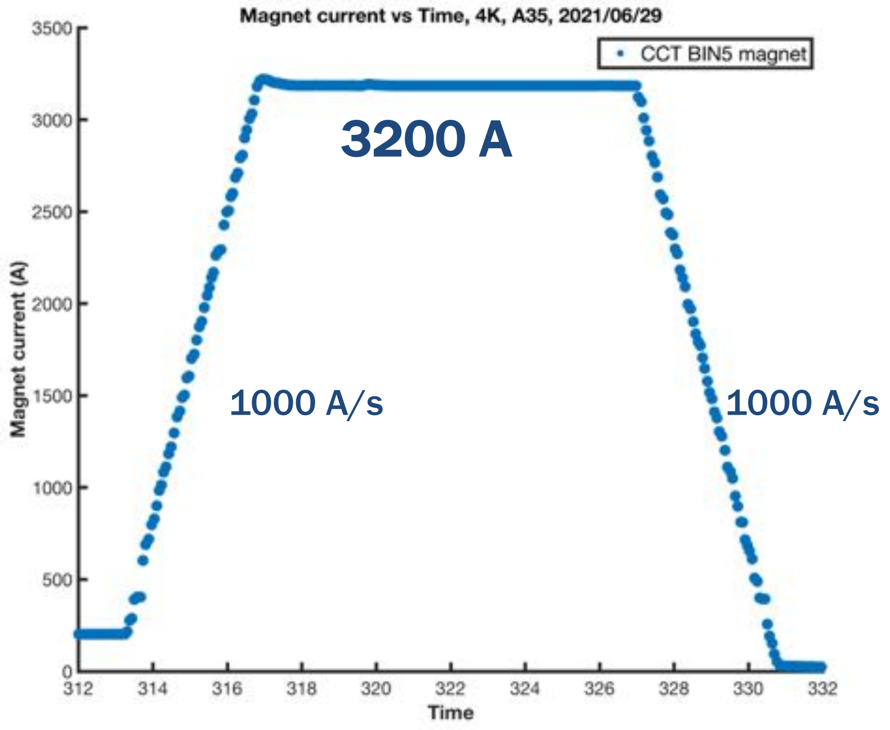
~10 Gauss gap at 8000 Gauss.

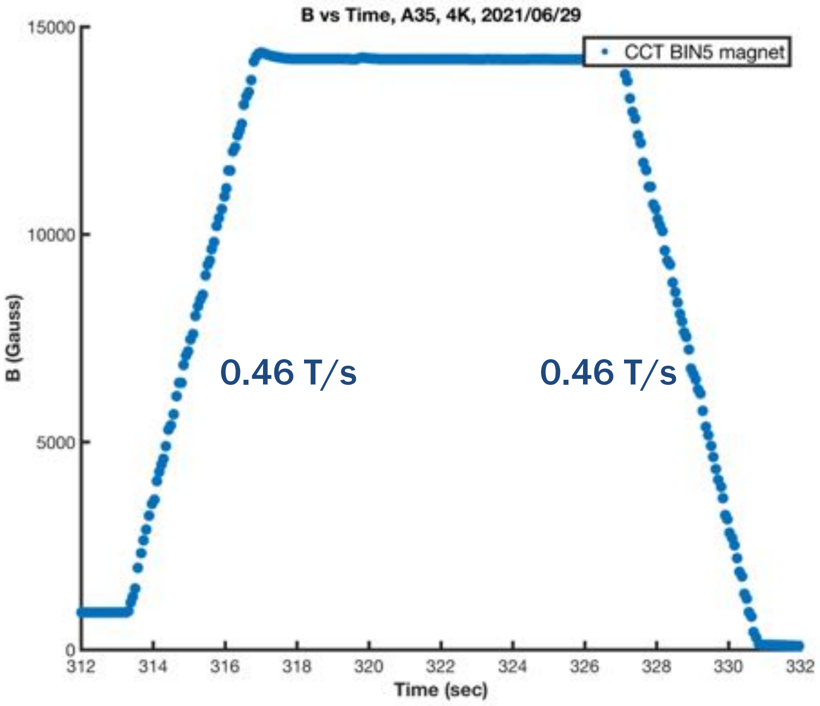




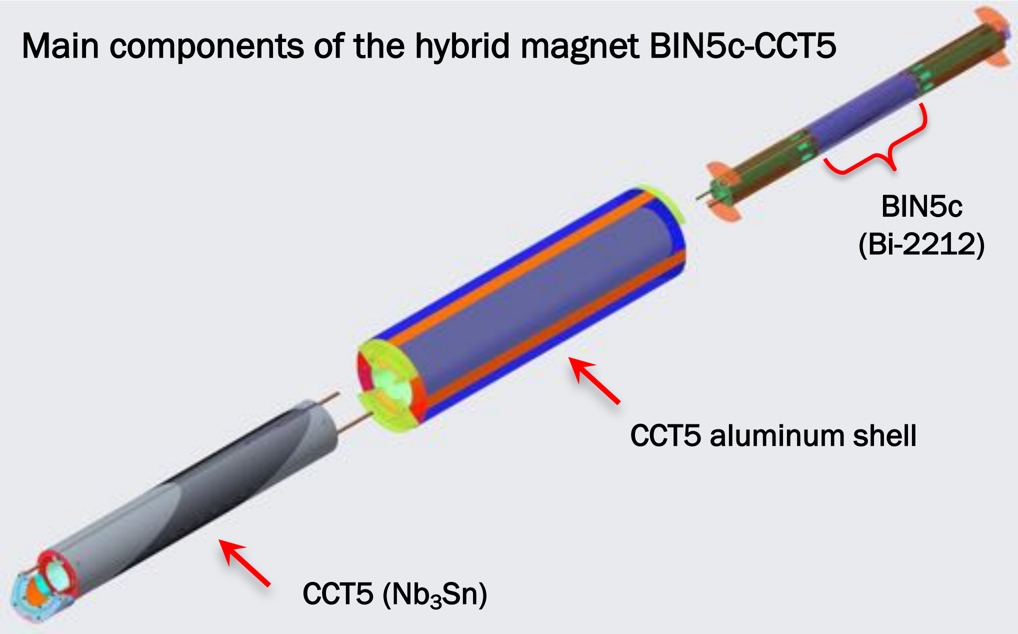
@the constant current steps

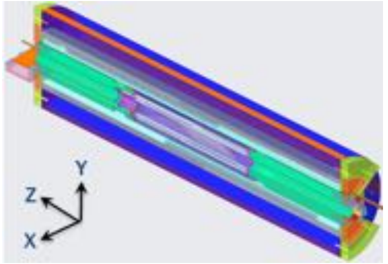
The fast ramping capability - 1000 A/s and 0.46 T/s

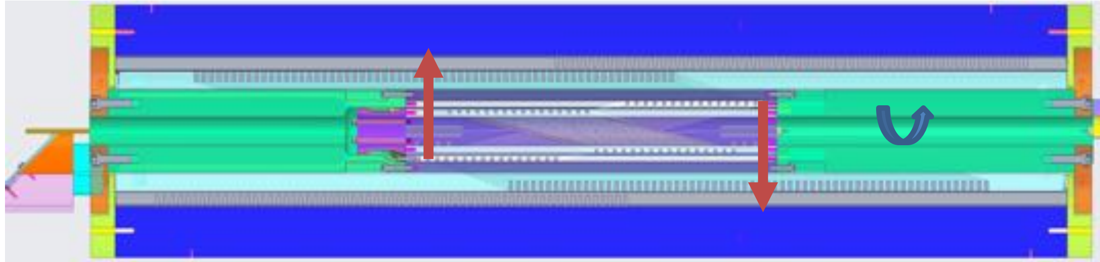


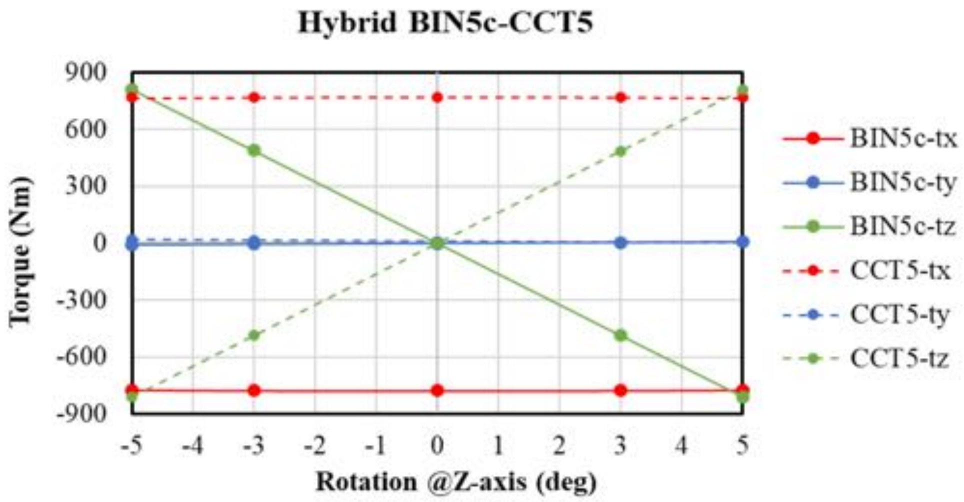


BIN5c1 sets up for Nb_3Sn/Bi-2212 CCT hybrid magnet tests









Coil size – growing in sizes - Bi-CCT1 and Bi-CCT2 – an overview

We are here.

2212 CCT

BIN5

0.4 m long
2.5 T dipole

Bi-CCT1/2

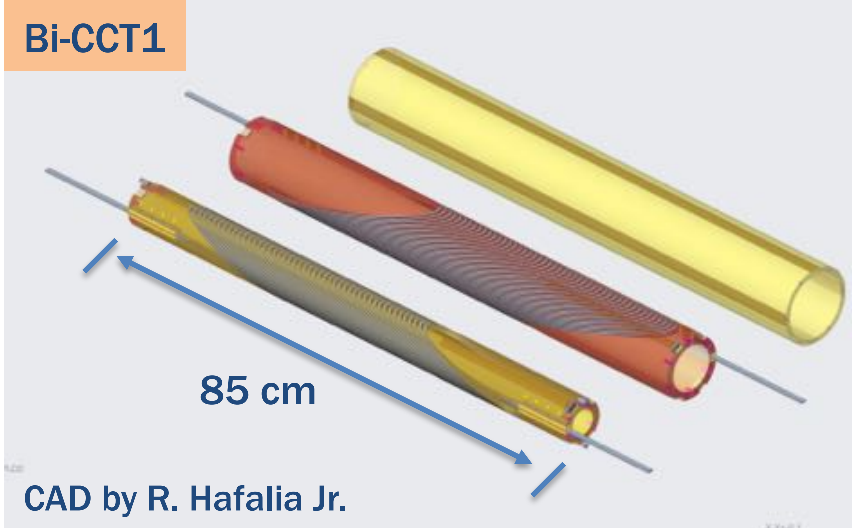
0.9 m long
5/7 T dipole

Bi-CCT1 + Nb_3Sn CCT6 or SMCT11T

11 T and above

RENEGADE, 1.2 m x 250 mm dia. homogeneity zone,
50 bar cold wall
Ulf Trociewitz on commissioning

BIN5 + CCT5



CAD by R. Hafalia Jr.

Wire needs and procurement status

CPRD lead: Lance Cooley

Magnet	Cable	Conductor mass (Extra 5 m + cable length needed)	Conductor status
Bi-CCT1	A - 17-strand, 7.8 mm wide, 0.8 mm strand	5.5 kg	LBNL1109 (from wire PMM180207) and LBNL2002 (PMM190118), cable insulated.
Bi-CCT2a	B - 19-strand, 10.1 mm wide, 1 mm strand	8.24 kg	PO submitted, 2 x 10 kg billets, one of which is a hexagonal bundle R&D billet
Bi-CCT2b	C - 23-strand, 10.1 mm wide, 0.8 mm strand	7.6 kg	
Bi-CCT2c	D - 28-strand, 12.3 mm wide, 0.8 mm strand	9.15 kg	

In Inventory

Wire	PO	Diameter	Architecture	Length received (m)	Length left (m)
PMM191004	7390861	0.8	55x18	2020	2000 m (in HTS cabinet) + 20 m in TS office

Concluding remarks

- BIN5c1– the first Bi-2212 CCT dipole magnet provides demonstration of a new, though not yet spectacular, superconducting dipole magnet technology
    - 1.64 T dipole field in 30.8 mm bore.
    - No quench training.
    - No thermal cycles or quench induced damages seen so far.
    - Low field hysteresis.
    - Fast cycling capability.
    - Gap in wire performance and coil performance.
    - Suitable as an insert for 90 mm bore CCT5.

Acknowledgement

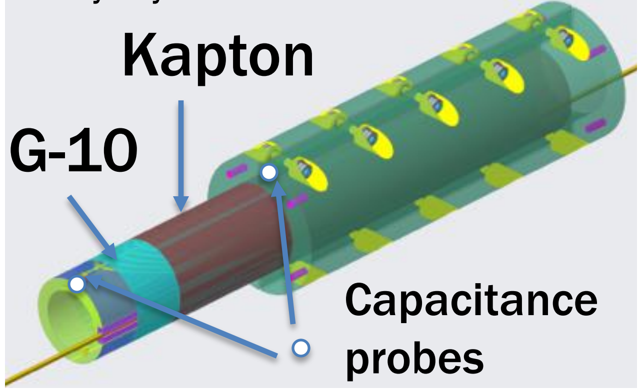
Work is supported by the US. Department of Energy, Office of Science, Office of High Energy Physics
under the U.S. Magnet Development Program with contributions from
Bruker OST LLC, and Engi-Mat Co. NHMFL is additionally supported by the State of Florida and the US National Science Foundation.

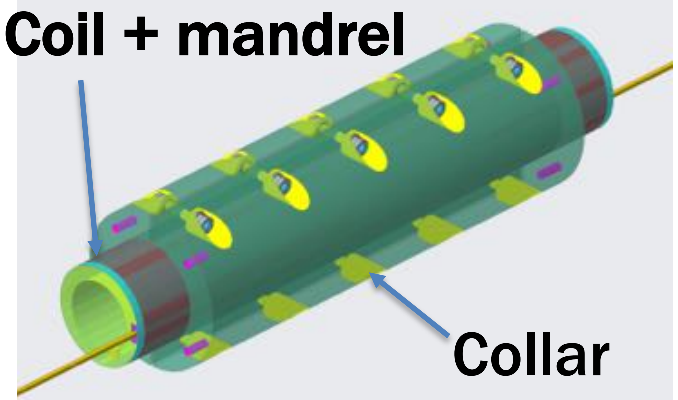
Many thanks to Engi-Mat Co. and Bruker OST LLC. for donating the SBIR wire PMM170725 to this work and for excellent powder and wires they have been fabricating.

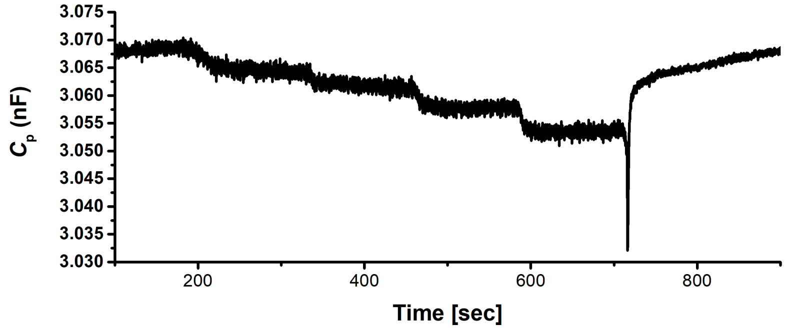
Thanks to generous support from US MDP CPRD (led by Lance Cooley).

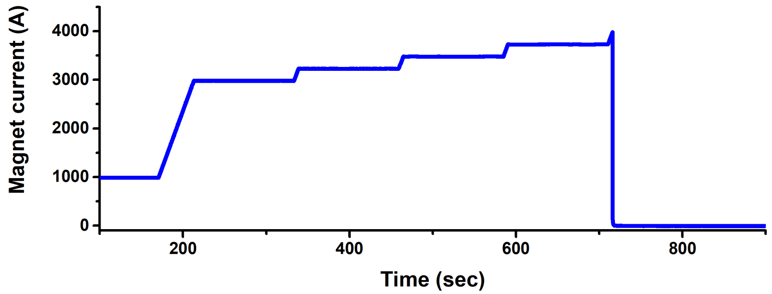
Stray capacitance monitoring as a tool applied to CCT BIN5aOL

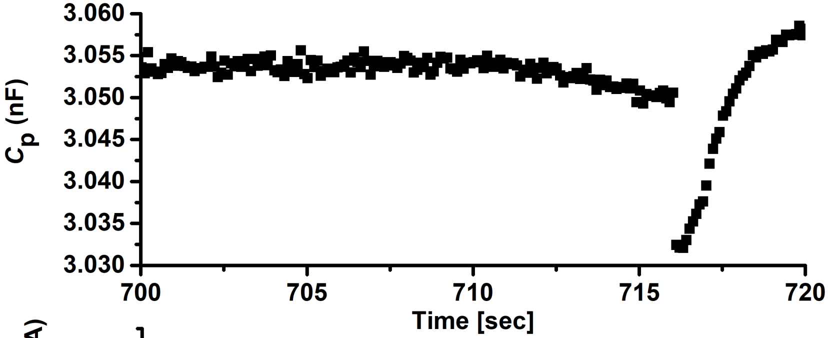
CAD by Ray Hafalia

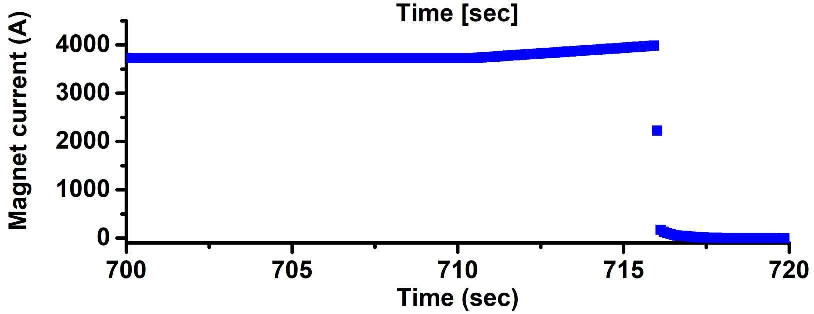












Local Heating → Cryogenic Fluid Boil-off → Permittivity Change → Capacitance Change → Quench Detection?

By Daniel Davis, MT26

[1] E. Ravaioli et al., "A new quench detection method for HTS magnets: stray-capacitance change monitoring," Physica Scripta, vol. Accepted September 2019.
[2] E. Ravaioli, M. Martchevskii, G. Sabbi, T. Shen, and K. Zhang, "Quench Detection Utilizing Stray Capacitances," IEEE Trans. Appl. Supercond., vol. 28, no. 4, pp. 1–5, Jun. 2018.