U.S. MAGNET DEVELOPMENT PROGRAM

REBCO technology – LBNL update

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MDP general meeting, 4 January 2023

U.S. DEPARTMENT OF ENERGY | Office of Science

What's new since July?

- Stay focused since March 2022 Collaboration Meeting
  - Make C3
  - Evaluate STAR® conductor

- Generated interesting results since last update in July 2022:
  - https://conferences.lbl.gov/event/1004/

C3 conductor order is not yet out of the woods, but hopefully soon

- As of November 2022, ACT received 87% of fully qualified HM tapes for the C3 order, up from 50% in June
  - *Thanks to ASC/FSU* for the I_c measurement that continues to provide critical and timely feedback on tape quality
  - 400 m long tape from M4-615 delivery will be returned as they do not meet the I_c spec
  - ACT received another 1 km long HM tape, acceptance pending qualification at ASC/FSU
- *Thanks to CPRD* for the C3 prototype wire to reduce the risks of wire production
  - We received 10 m long C3 prototype wire in November
  - Mandrels available in two weeks to wind and test the prototype wires
  - First opportunity to see the true wire performance
- We expect to start receiving the C3 order in March 2023
  - Delayed from December 2022

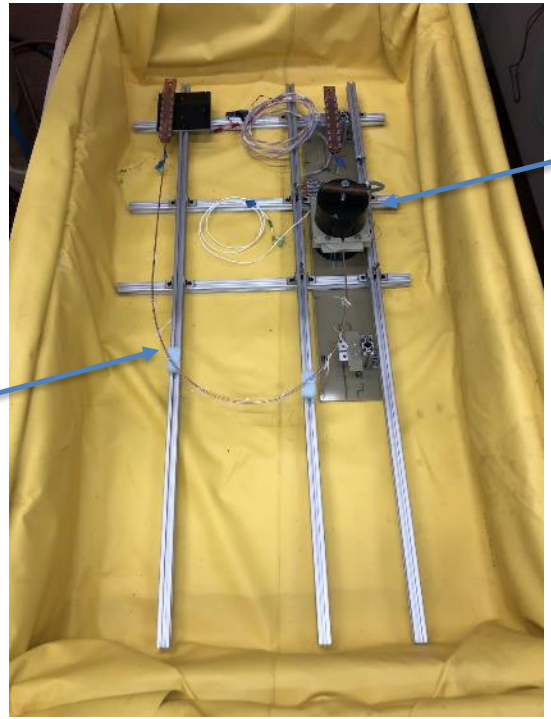
We made Layers 1, 2, and 3 for the 3-turn C3 using wires with standard SuperPower AP tapes

- Driving questions
  - What's the I_c evolution during each step of coil fabrication?
  - How much I_c decrease is due to magnetic field? How much is from winding?
  - What's the statistics?

- Approach
  - Measure the I_c at each step of the coil fabrication
    - Before winding
    - After winding
    - After Stycast
  - Scratch heads to (mis)understand the data

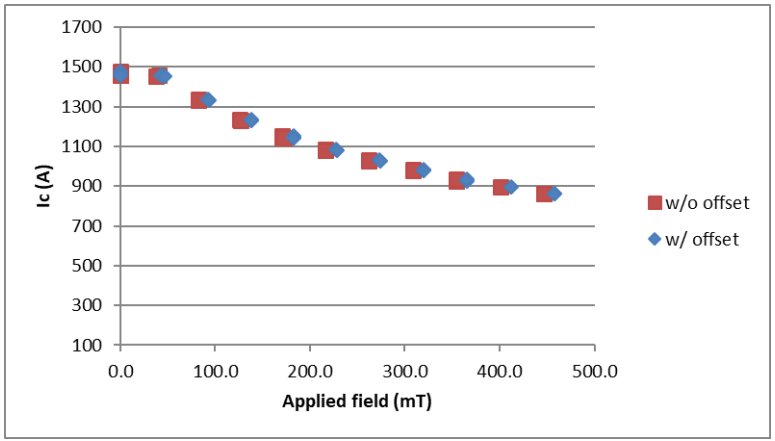
Measure the I_c before winding at 77 K

- Bend the wire to fit it inside a LN_2 box
  - Bend radius > 100 mm
- Measure the I_c in a background field up to 0.5 T

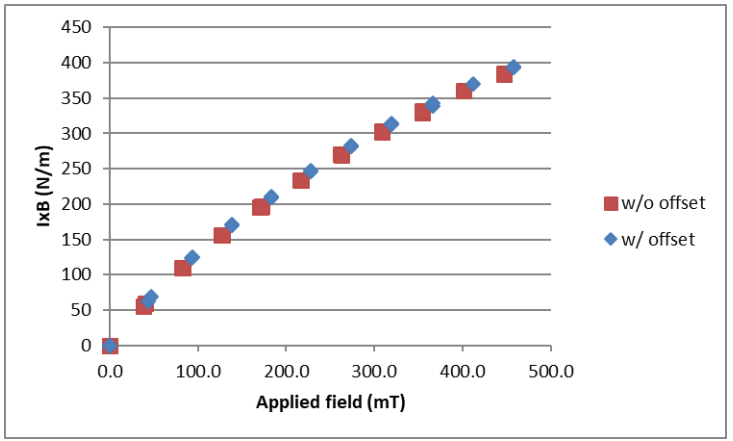


Layer 1, I_c(B, 77 K), before winding

- I_c(B, 77 K)

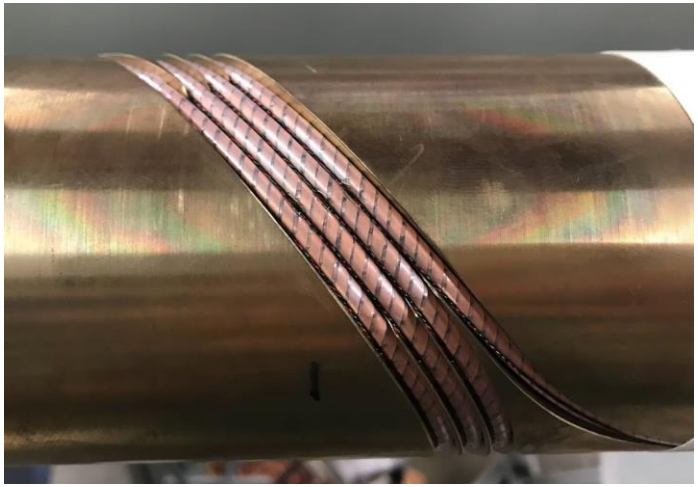


- Pinning force I_c x B



Winding with the winder Mark #2

Co-wound v-tap and fiber; Maxim's new sensor in Layer 2



Evolution of the transport performance for the first three layers

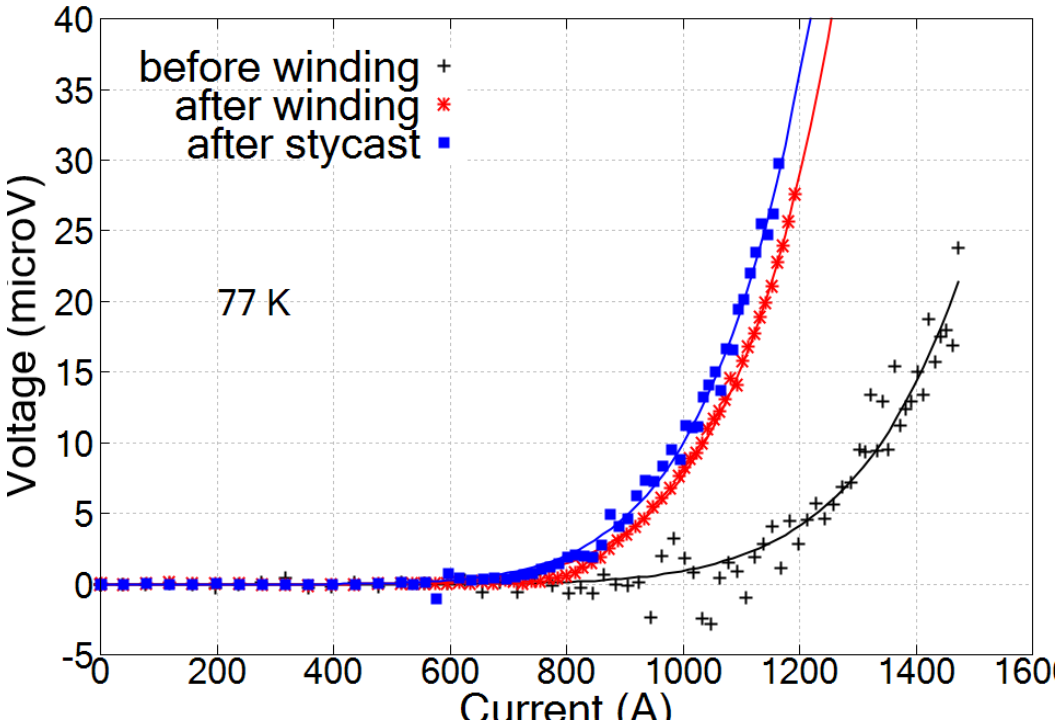
Measured I_c and n value

Layer	$R_{bend,\ min}$ (mm)	Before winding	After winding	After Stycast
3	30	1549 / 18.1	1265 / 26.0	1248 / 24.6
2	35	1588 / 19.1	1250 / 24.0	1035 / 17.8
1	30	1460 / 8.0	1145 / 7.7	1103 / 7.2

I_c normalized to before winding

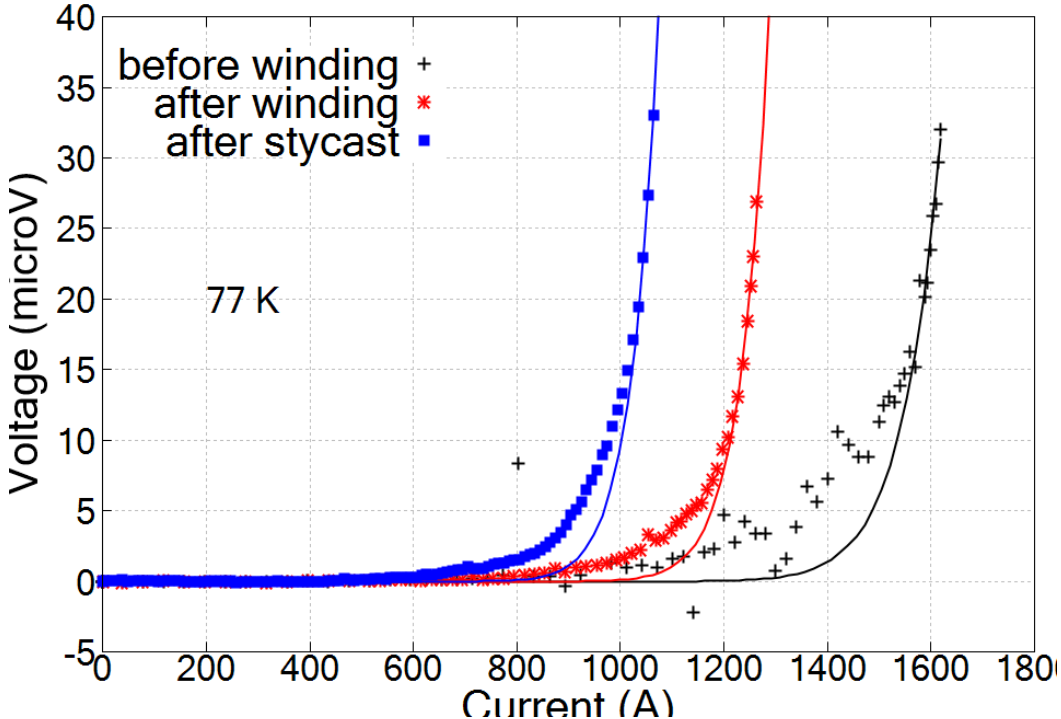
Layer	$R_{bend,\ min}$ (mm)	Before winding	After winding	After Stycast
3	30	100%	82%	81%
2	35	100%	79%	65%
1	30	100%	78%	76%

Layer 1 I_c evolution at 20 μV criterion: 78% retention after winding, 75% retention after stycast



- *n* value for all three cases: 7 – 8
- Short sample prediction after winding is 87% of before winding → 9% I_c reduction is due to bending

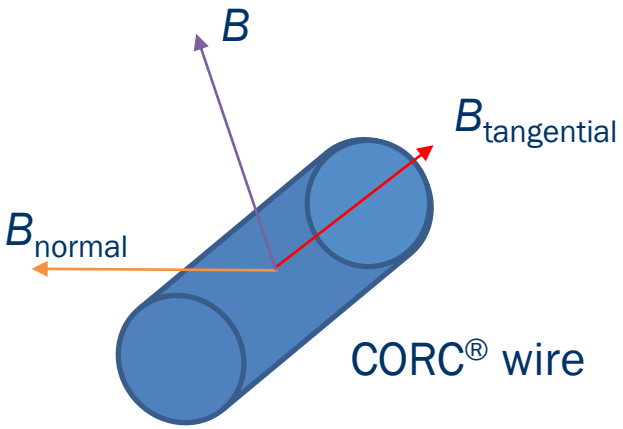
Layer 2 I_c evolution at 20 μV criterion: 79% retention after winding, 65% retention after stycast

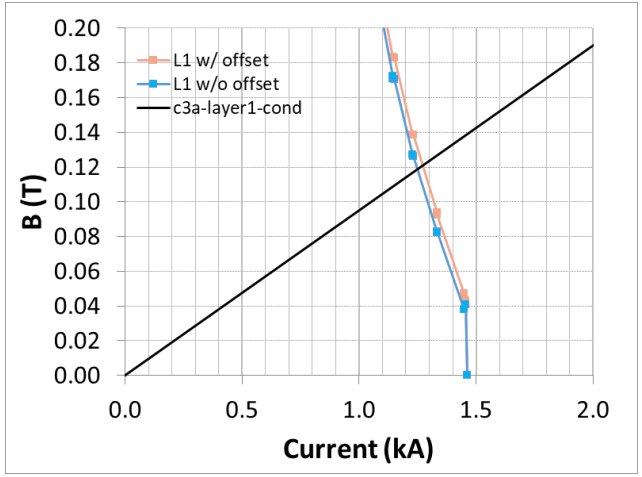


- Unclear why we have a large decrease in I_c
- Early voltage rise
- *n* value: 18 – 24
- Short sample prediction after winding is 86% of before winding → 7% reduction is due to bending

How much I_c decrease after winding is due to winding? First attempt…

- We use the component transverse to the wire axis to determine the expected coil I_c





- Expected I_c of Layer 1 is 87% of the I_c before winding. Magnetic field causes 13% decrease. Winding leads to the additional 9% decrease. What's the best way to verify this?

We started bending the 6/1 STAR® cable samples

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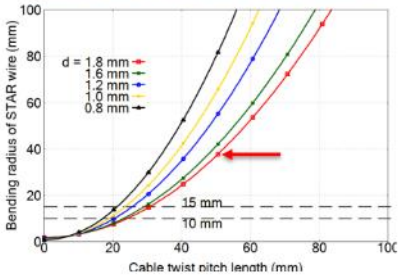
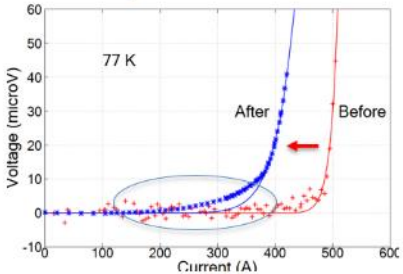
Prong 2: leveraging SBIR to investigate the feasibility of 6-around-1 STAR® cable for high-field dipole magnets

Analytically, it should be doable



The first test cable made by H. Higley including a single 1.8 mm diameter STAR® wire and five Cu wires. 50 mm twist pitch

First data point shows 20% reduction



- Early voltage rise is likely associated with current sharing between STAR® and Cu wires; severe degradation?
- Next steps
  - Repeat with another sample
  - Test the bending performance

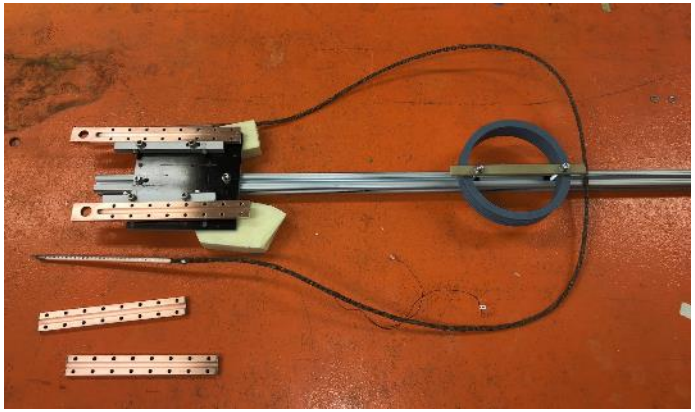
AMPeers

Results from a 6/1 STAR® cable

- Six STAR® wires cabled around a Cu core, ~ 50 mm twist pitch length, 1.5 m long between the terminations

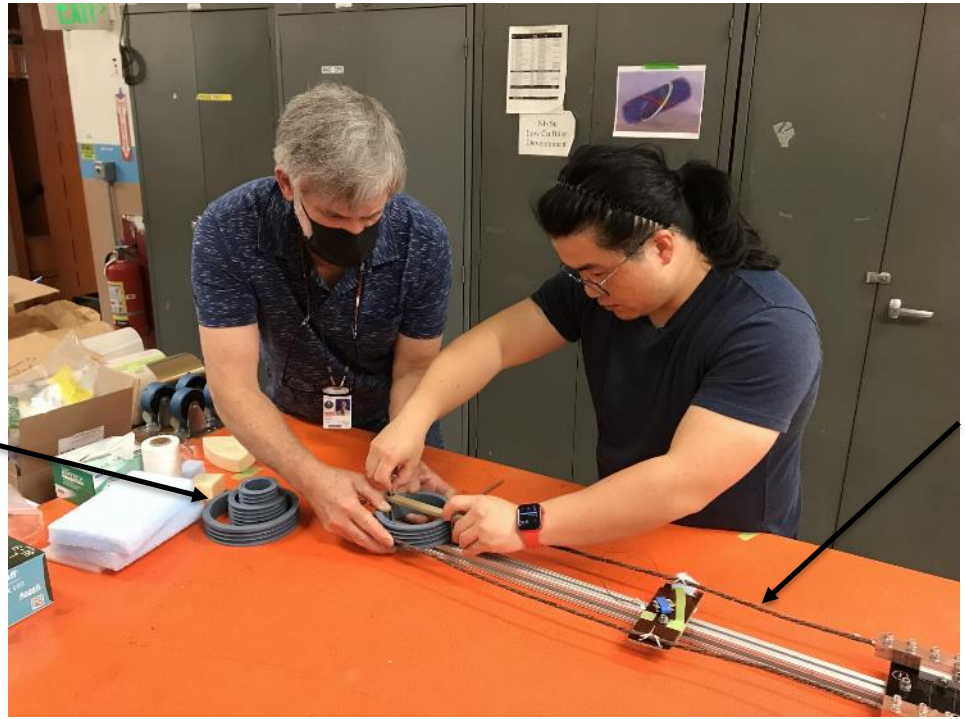
Previously it was wound into a CCT coil form with a minimum bend radius of 75 mm

Then we unwound and tested it at successively smaller bend radii



The same cable was bent to 75, 60, 45 and 30 mm radius

Printed holders with grooves



Cable under tension to stay bent at a specific radius

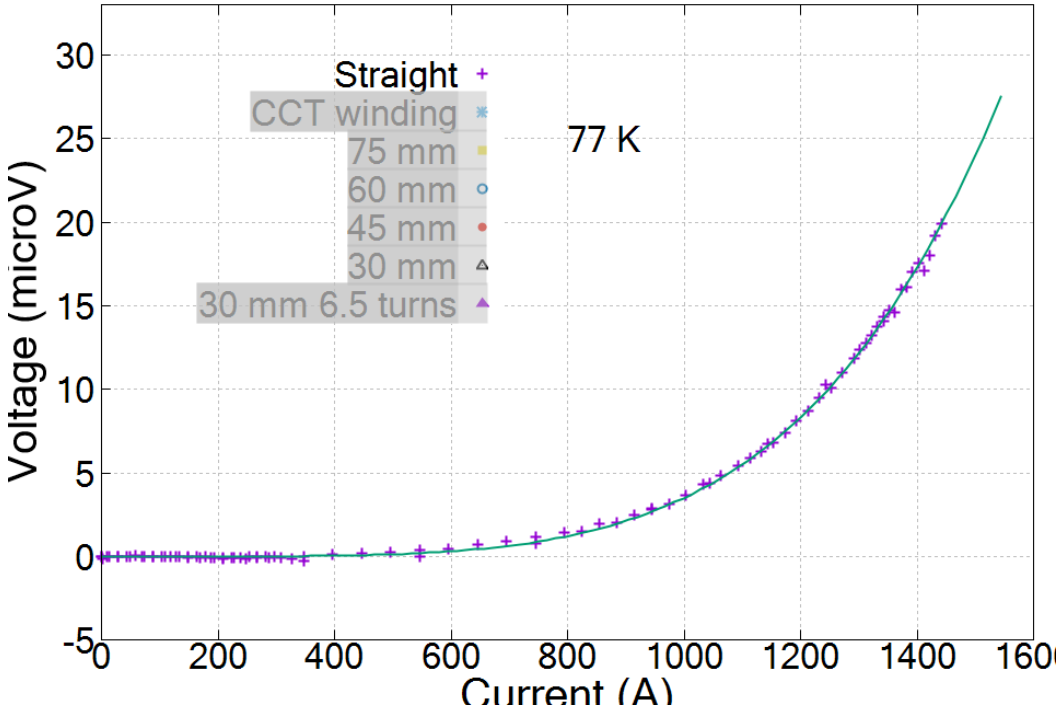
The cable is bent for about 0.5 turn; at least one twist pitch of the cable is bent

75 mm radius

30 mm radius

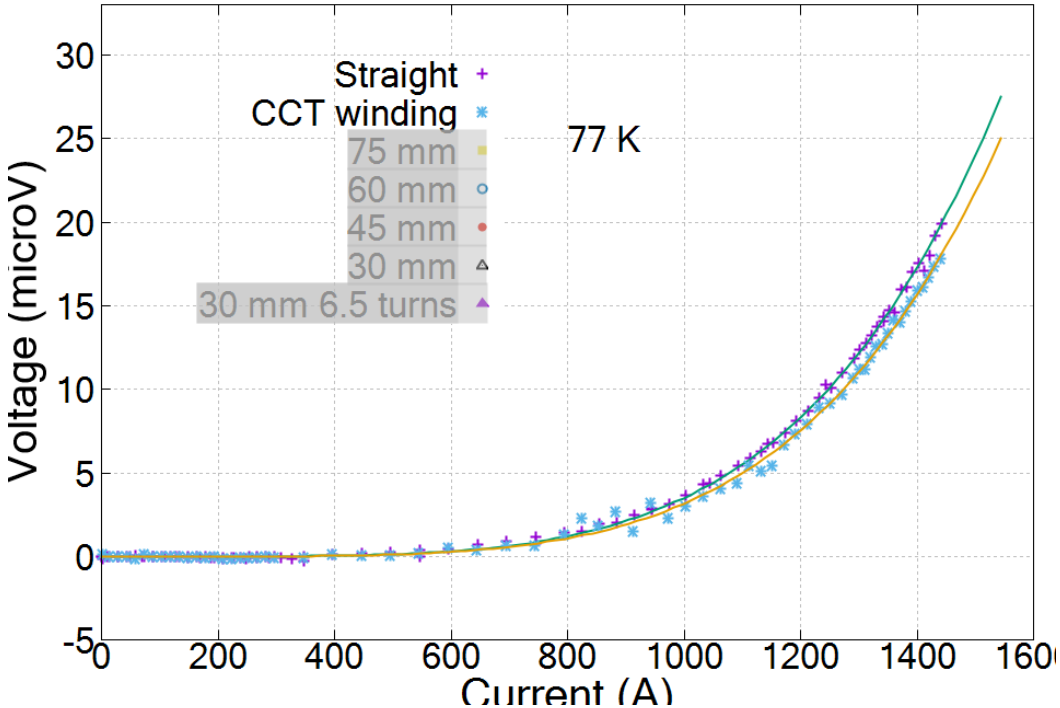
Cable bent along the groove

No obvious I_c degradation up to 30 mm radius



I_c ~ 1450 A,
n ~ 4.7 at 20 μV

No obvious I_c degradation up to 30 mm radius



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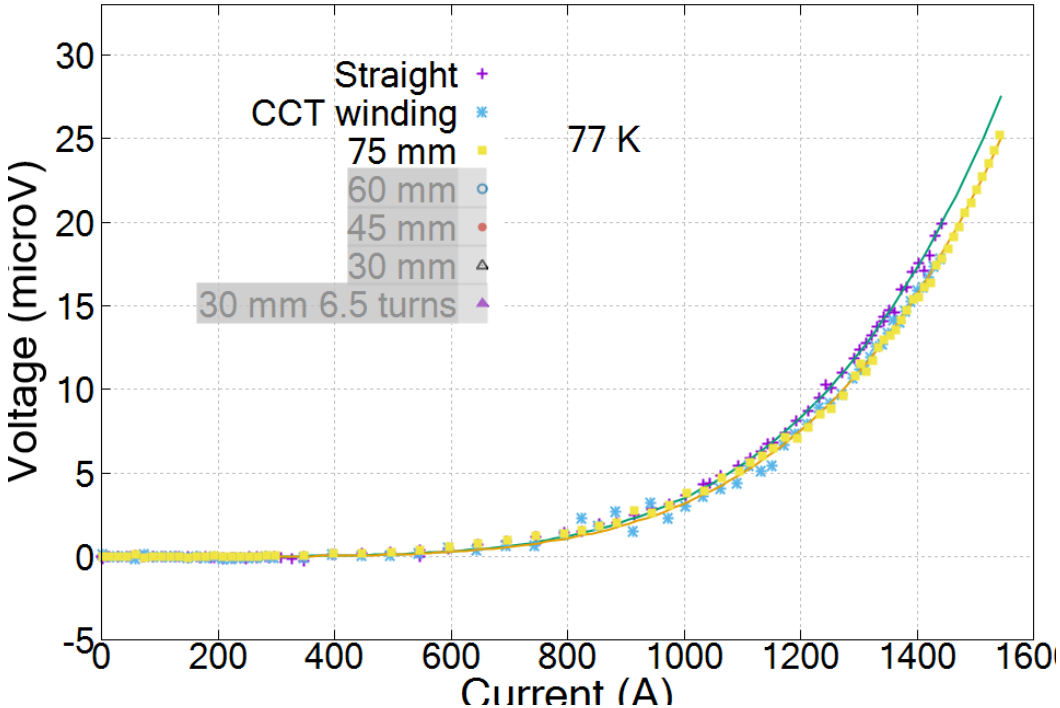

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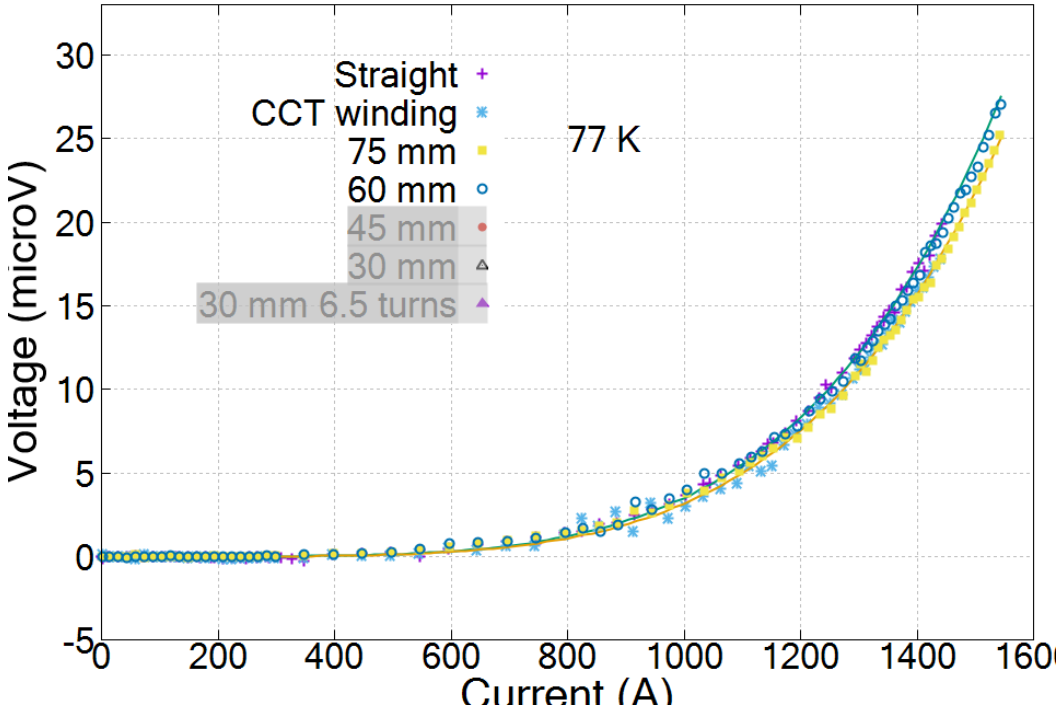

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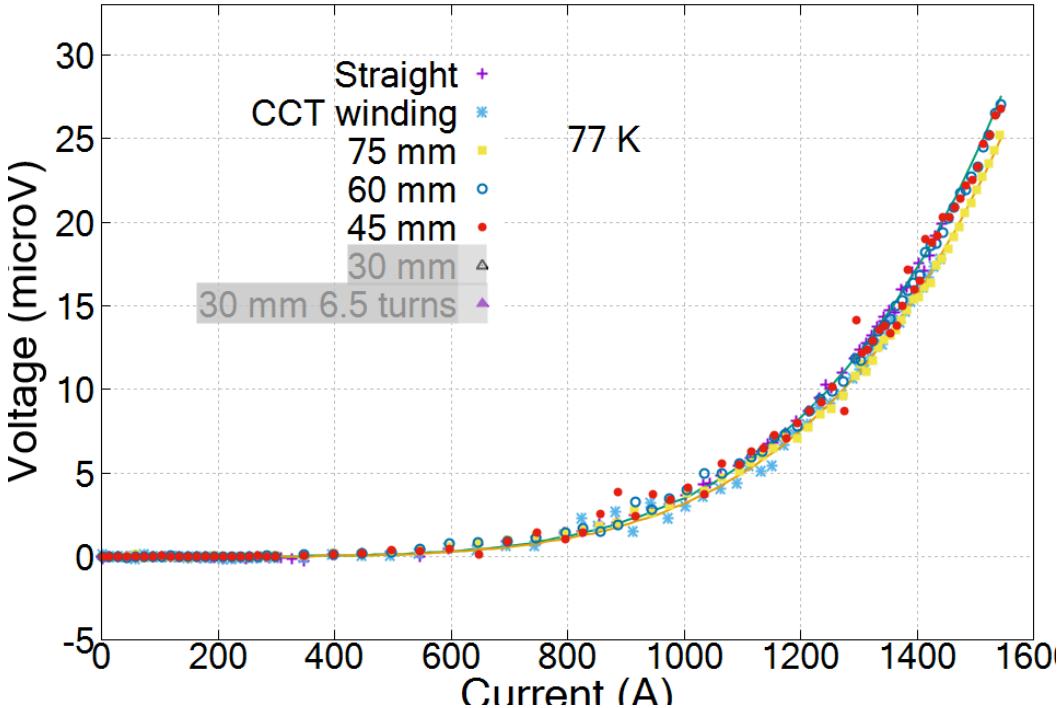

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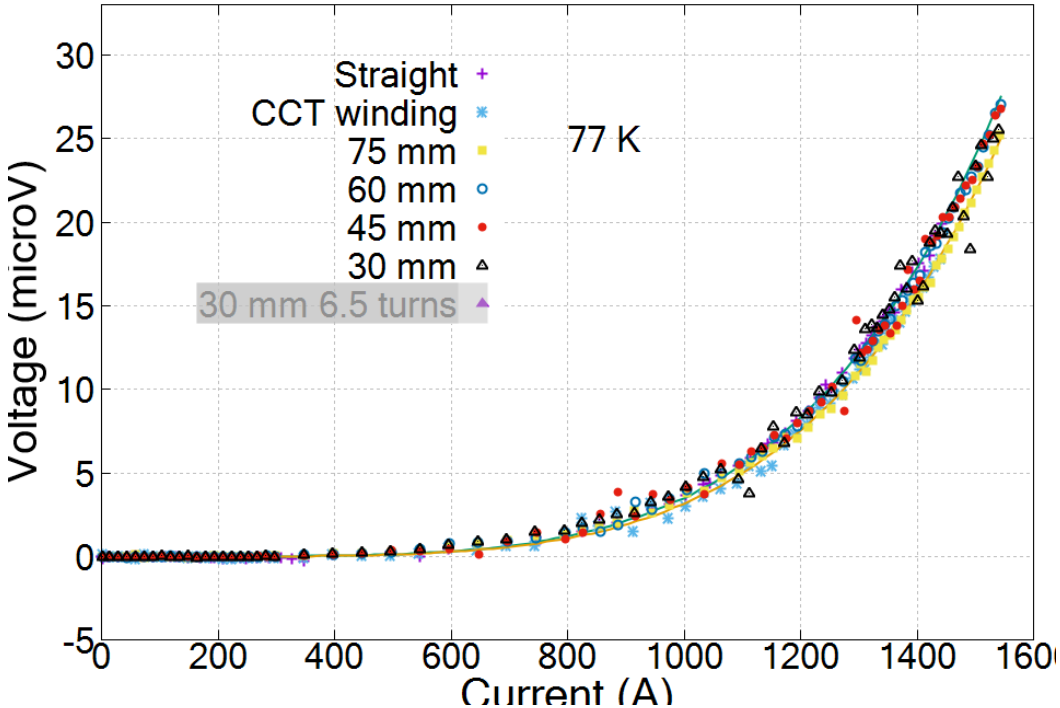
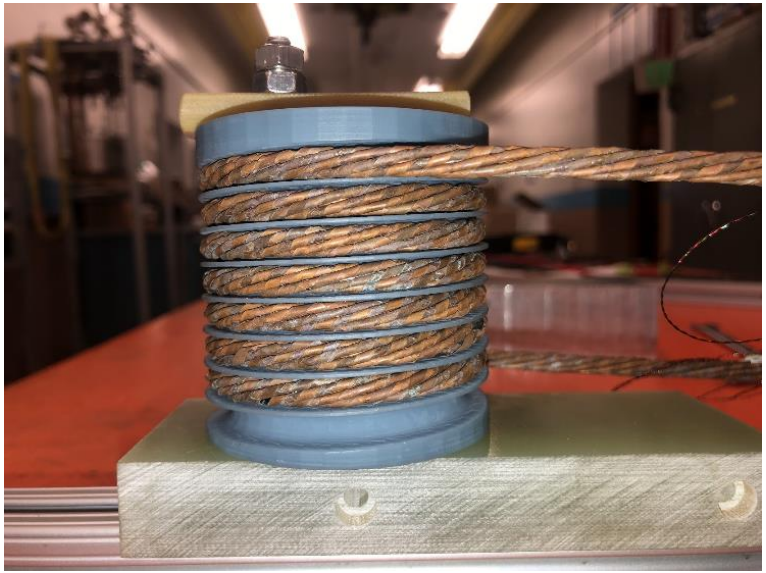
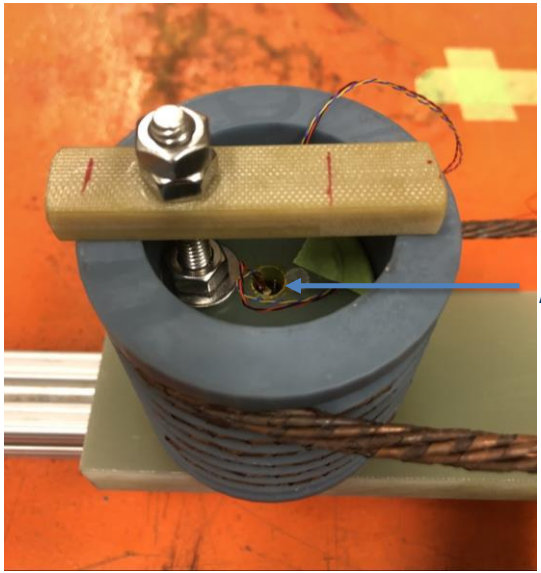
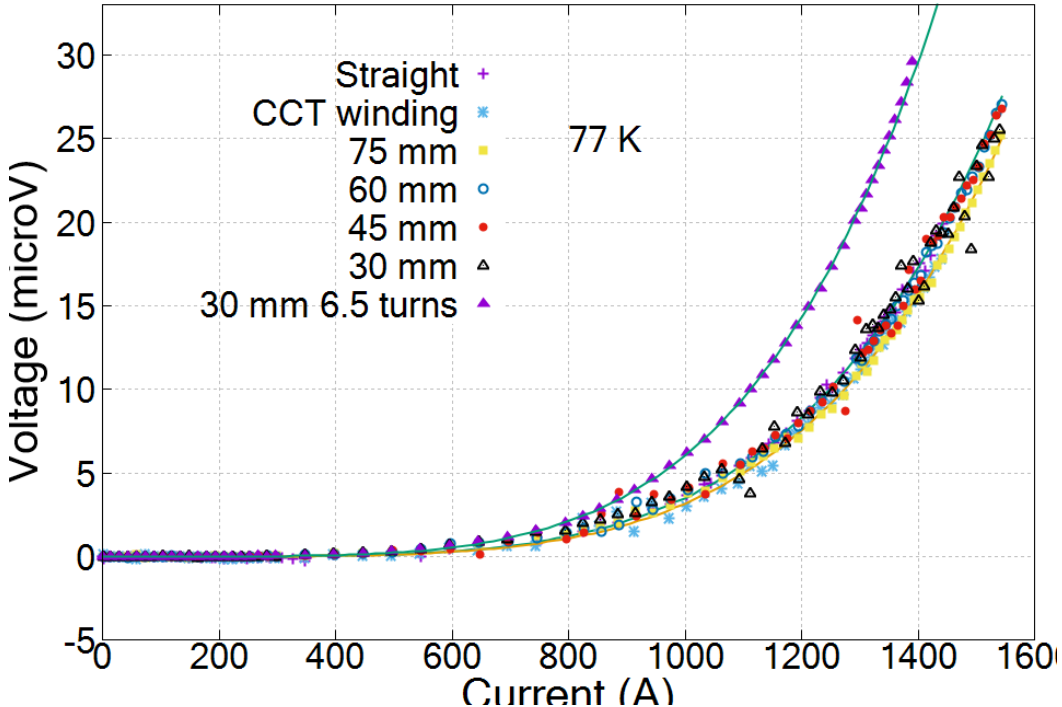


Then we wound the cable into a small solenoid with 6.5 turns at the same bend radius of 30 mm





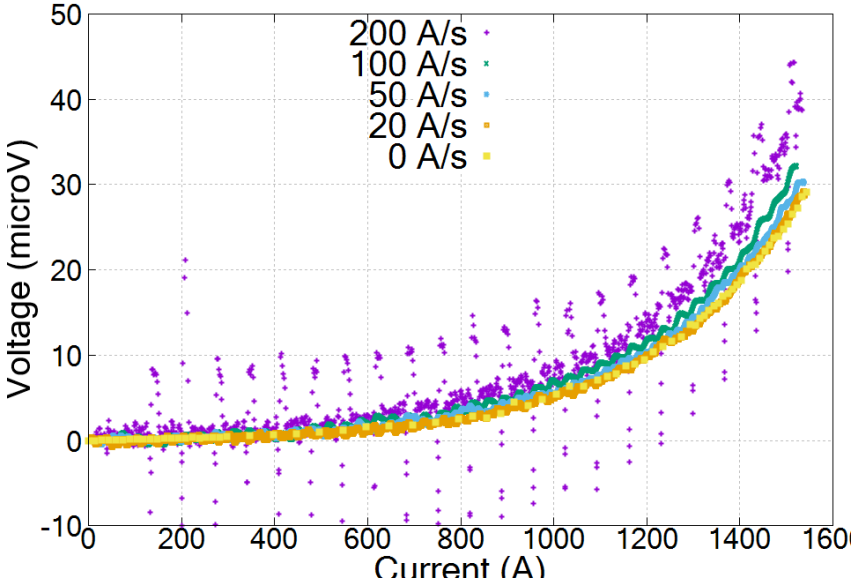
I_c reduced by about 12% in a solenoid form

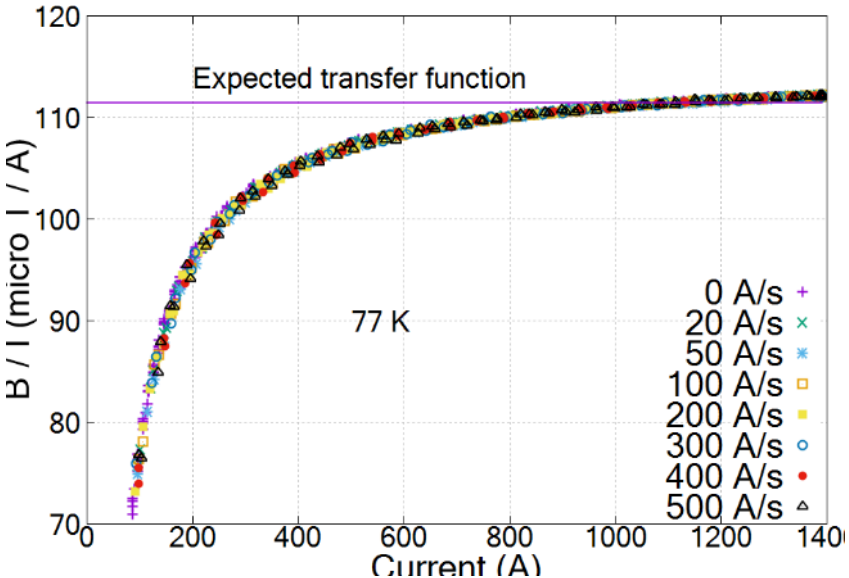


Analysis ongoing to determine the impact of increased self-field

The V(I) shows a ramp-rate dependence; less pronounced in the central solenoidal field – does the transposition work as expected?

Ramp-rate dependence of I_c: -0.45 A /(A/s)





What's next?

- Make C3
  - Continued tape qualification for C3 from ASC/FSU is critical and greatly appreciated
  - Assemble and test the 3-turn version in July 2023
  - Delivery of the C3 conductor now expected to start in March 2023
  - Make mandrels for the 40-turn and start winding in September 2023
- Evaluate STAR® wires
  - Continue the Phase II work on 6/1 cable
- Address the upcoming issue
  - Contract for the key worker expires in May 2023

“It’s lighter than you think” - picture of 2022

Master holding a 1.5 kA electric banjo, 9/29/2022