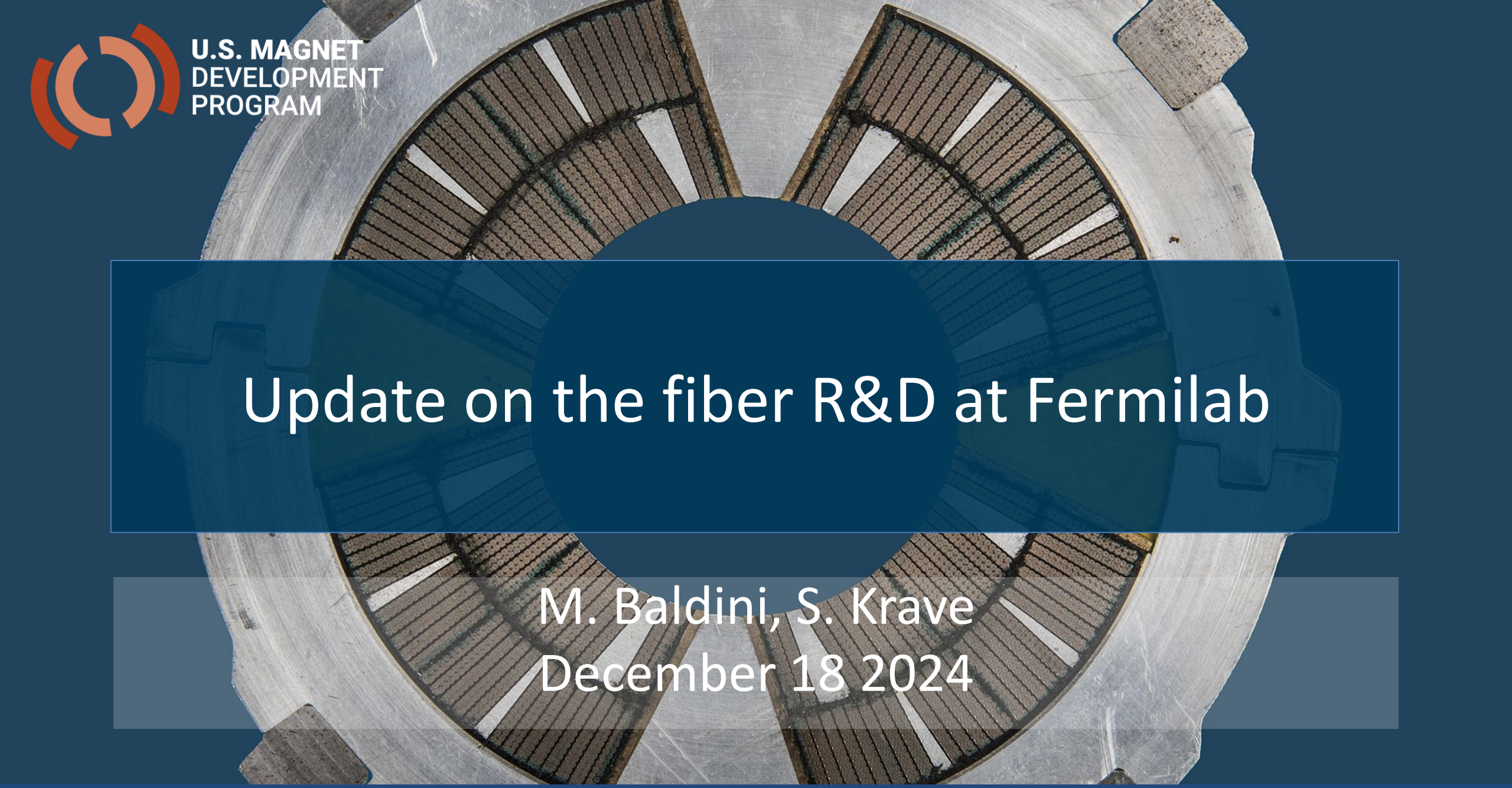

U.S. MAGNET DEVELOPMENT PROGRAM

Update on the fiber R&D at Fermilab

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December 18 2024

U.S. DEPARTMENT OF ENERGY | Office of Science

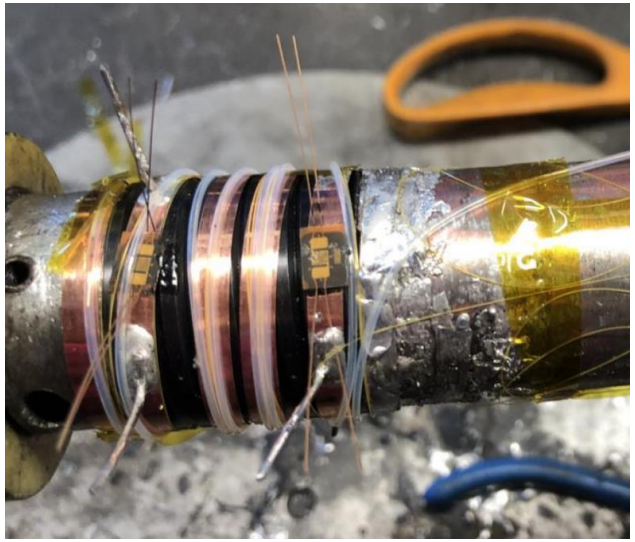
Outline

- **Quench propagation study using temperature fiber sensor**
  - Barrel Samples: Nb3Sn and REBCO
  - Test with a REBCO STAR cable
  - Short term plan

Quench propagation on REBCO tape

MDP collaboration meeting: results from a test performed at 4.5 K inducing a quench on Nb3Sn wire with a spot heater
Promising results but we did not have good electrical contact. Quench was a violent event

- REBCO superconducting tape from Faraday Factory was wrapped around a barrel
- Voltage taps and strain gages were soldered onto the tape
  - Strain gage = spot heater
  - Voltage tap
- Temperature sensor wrapped on top of the tape
  - Maximum contact
  - Gage locations were recorded
  - Staycast was applied afterward



REBCO tape by FF
Copper thickness: 20 um
Substrate thickness: 40 um
YBCO= 2.5 um
Width= 4 mm

REBCO test with fibers

TEST plan overview

Temperature: 4.5 K, test different magnetic Field: 12T, 15T

Determine critical current

Minimum quench power at several current levels: (80%, 60%, and 40% of IC)

Work performed by Emily Spreitzer undergraduate student at NIU

TEST 1

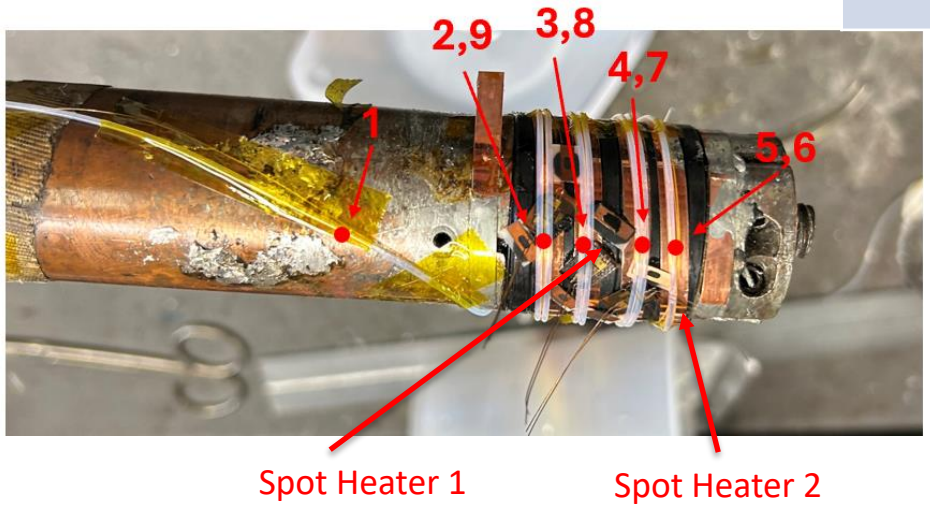
- Critical Current = 340A. The tape quenched at a lower current than expected and then it was degraded
- Numerous current tests were attempted
- The experiment was unsuccessful: we did not observe any temperature variation on the fiber

REBCO test #2

Test Run	Current (A)	Magnetic Field (T)	Gage Pitch (mm)	Sample Rate (Hz)	Spot Heater (Y or N)	Spot Heater Pulse (ms)
1	650 (IC)	12	2.6	160	N	-
2	160	12	2.6	160	Y	30
3	100	12	2.6	160	Y	30, 40
4	100	12	2.6	160	Y	30, 40
5	100	12	2.6	160	Y	40
6	100	12	2.6	160	Y	40
7	120	12	2.6	160	Y	40

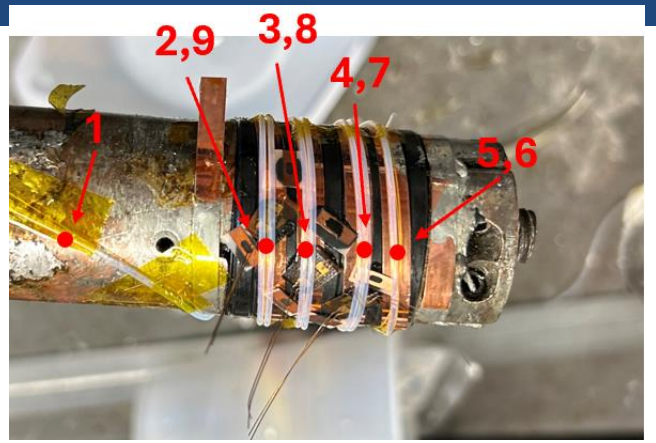
Gage #	Location(m)	
1	4.461	
2	4.603	
3	4.699	SH: 1
4	4.811	SH: 2
5	4.916	
6	5.020	SH: 1
7	5.125	
8	5.229	SH: 2
9	5.334	

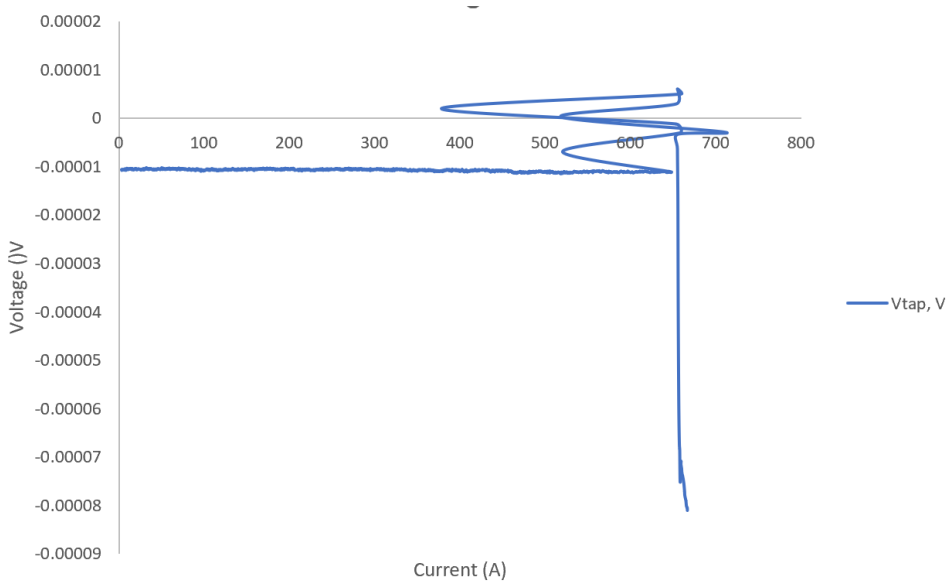
- The red dots indicate the spot on the fiber where the gage positions were recorded

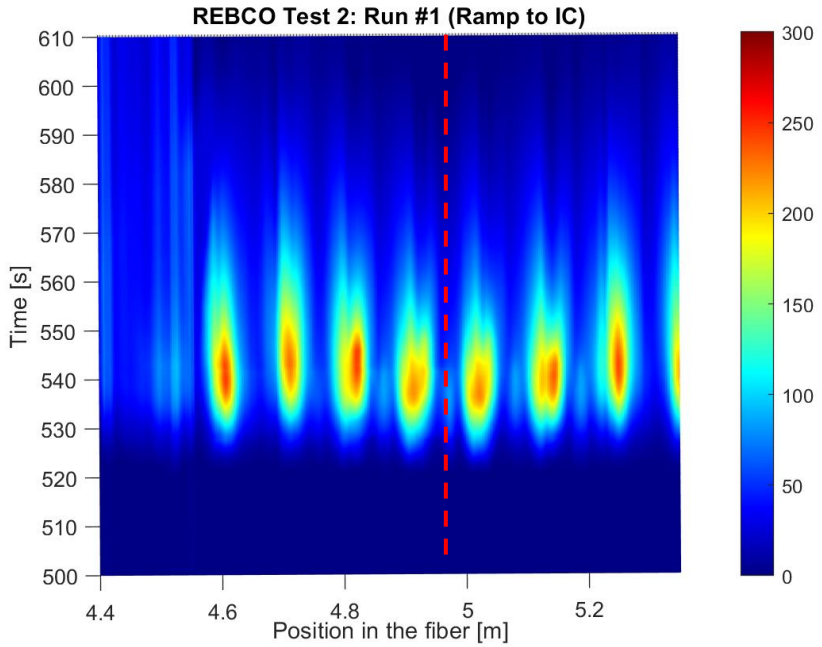


REBCO Test: critical current measurements

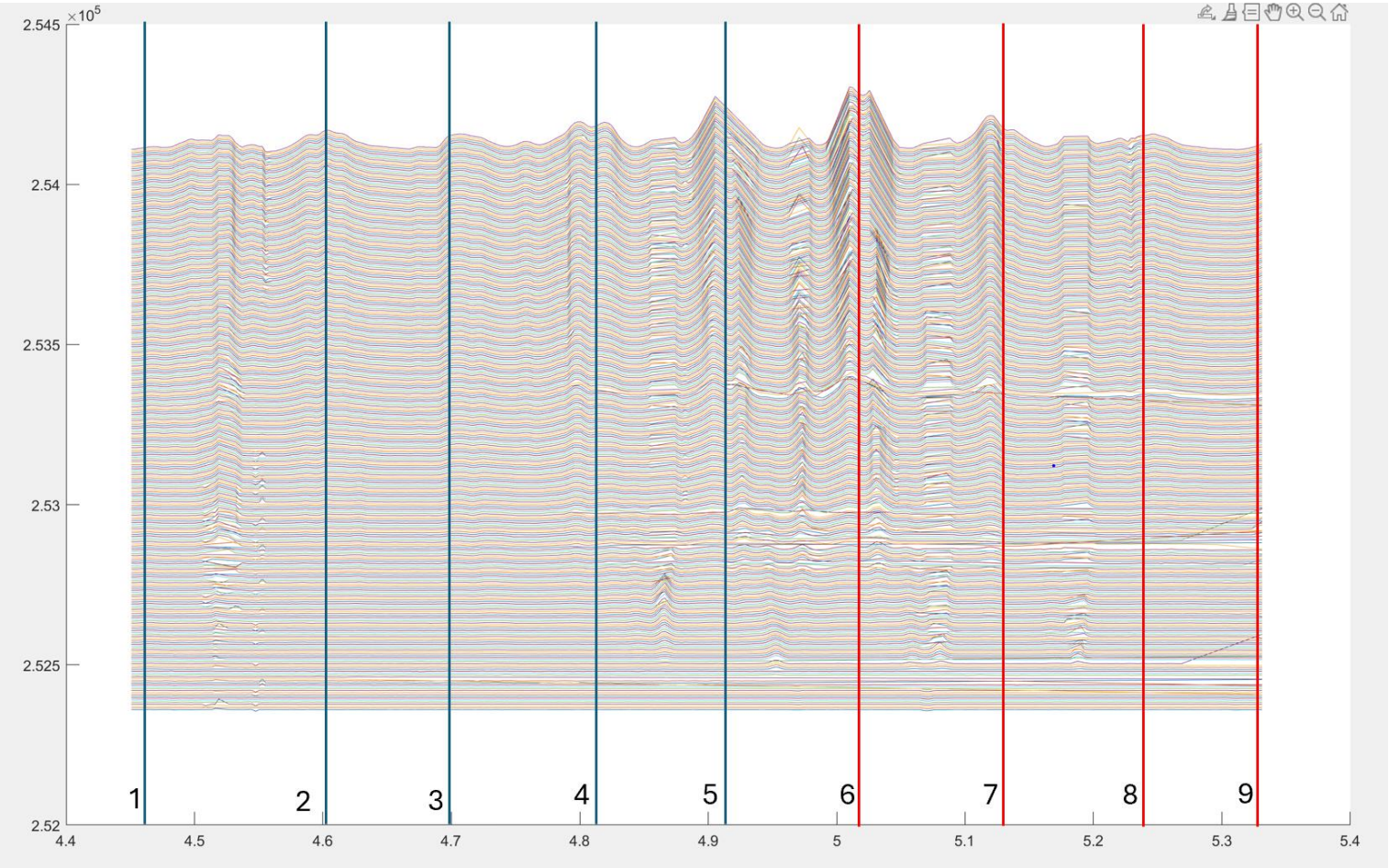
- Ramp to IC = 650A
- No clear voltage rise in the data
- The quench start propagated at the end of the barrel







REBCO Test: critical current measurements

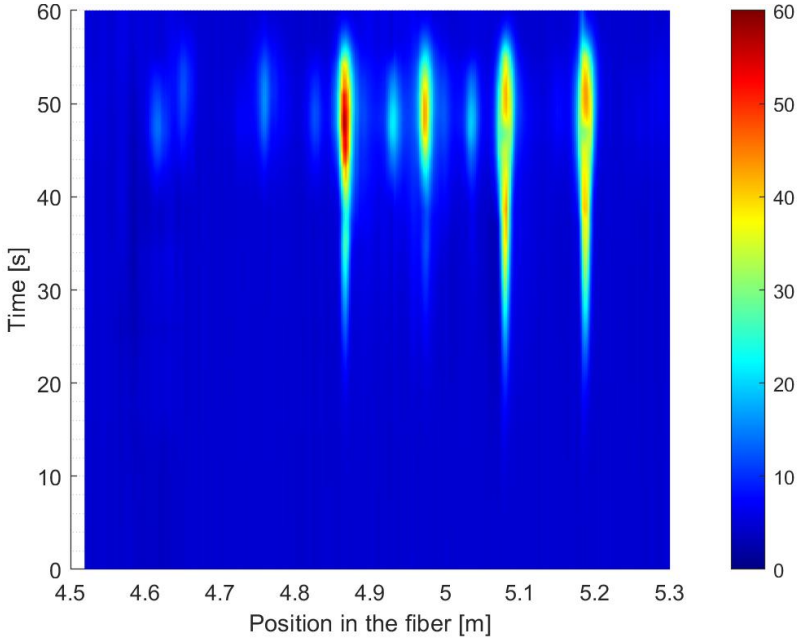


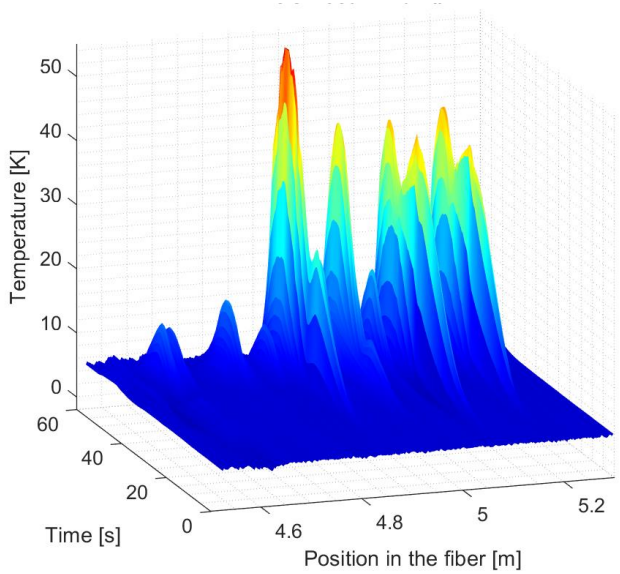
Fiber length (m)

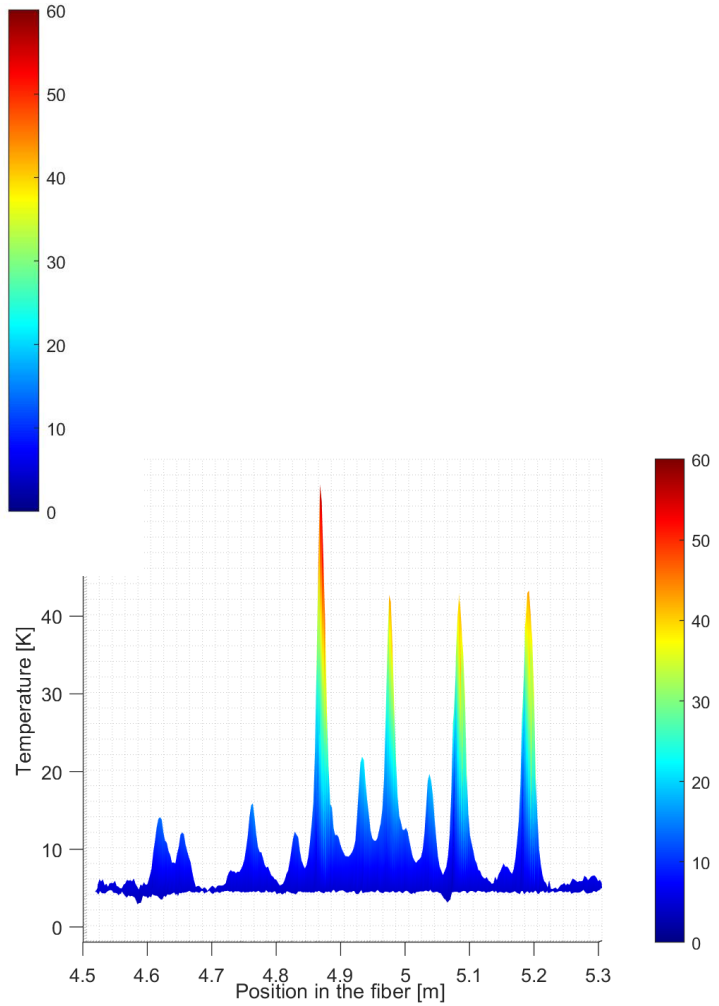
3 seconds of data during quench at IC
Data collected every 12 ms
Heat propagation began at the end of the barrel
T variation is large~ 242 K

REBCO TEST with spot heater

- Ramp to 80% of IC (I = 580 A) found in first test
- Quenched at ~ 160 A: sample was degraded after the first quench
- Similar to run #1, quench propagated from the end of the barrel







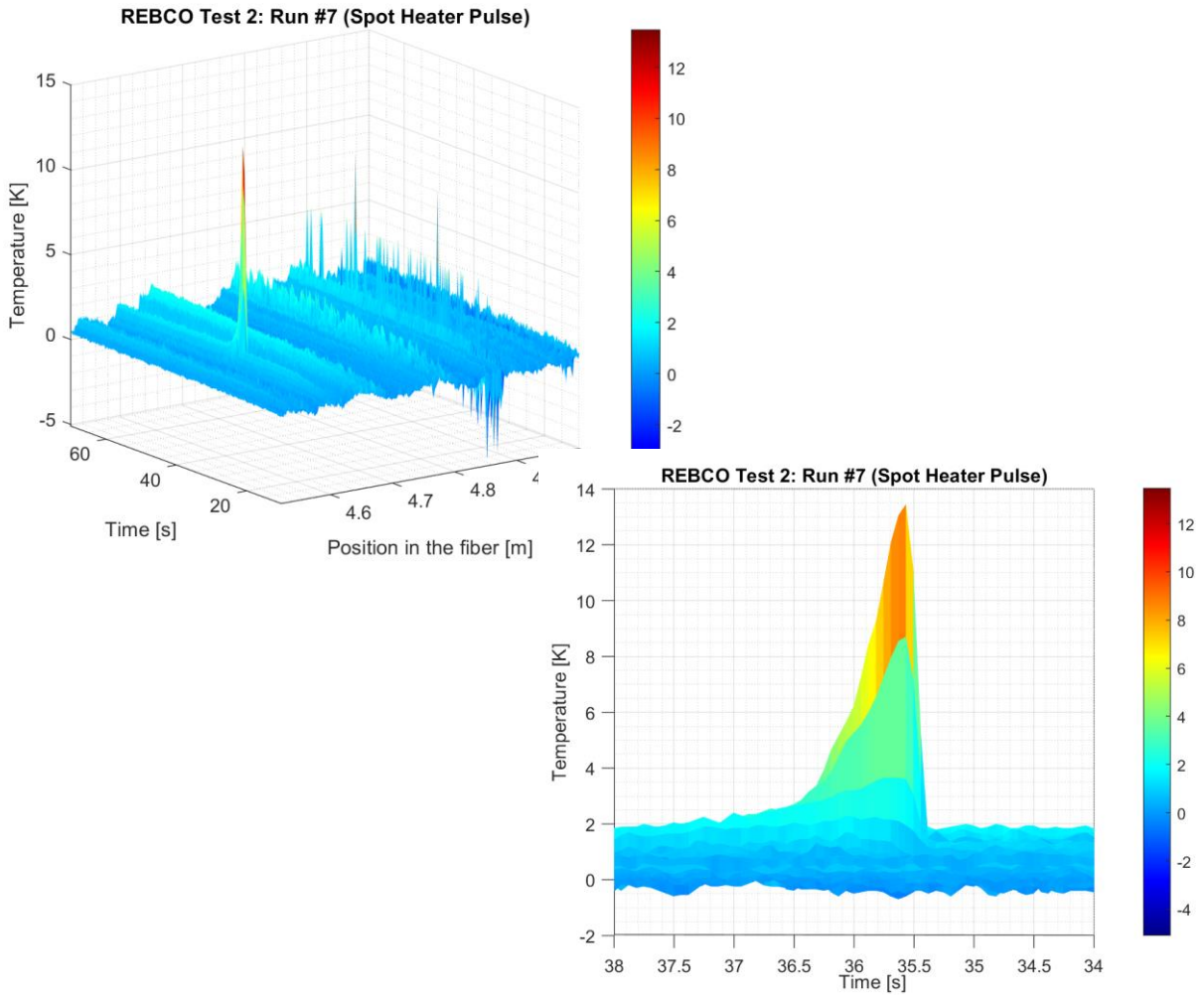
REBCO TEST with spot heater

- By this point, the tape was degraded from the previous runs
  - Current = 120A

- Spot Heater (strain gage)
  - Location – 4.58m on the fiber
  - Current = 0.1A
  - Voltage = 35V
  - Resistance = 350Ω
  - Pulse = 40ms

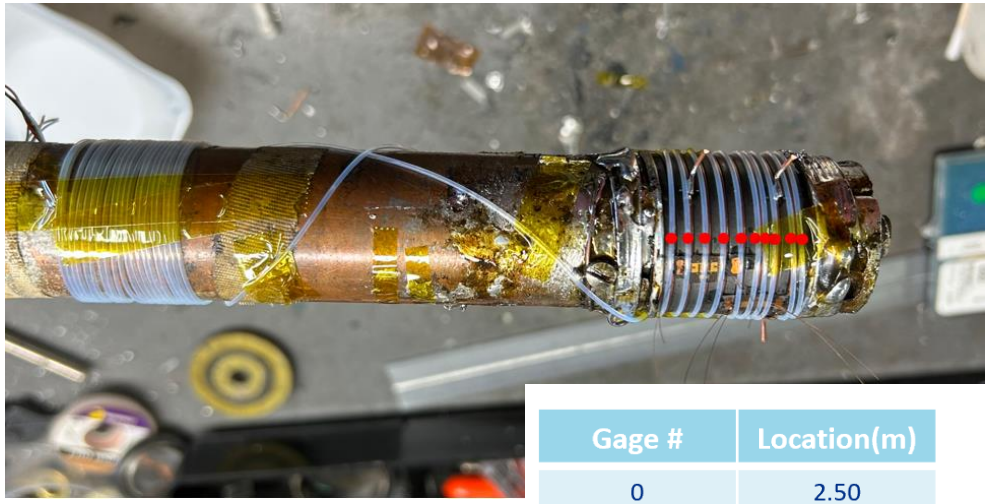
- Temperature pulse ΔT = 13.7 K
  - Did not induce a quench, but the pulse can clearly be seen with the temperature fiber

- Power = 3.5W



Nb_3Sn test

- Two spot heaters 1 and 2 were attached, each with the same resistance:
  - R = 350Ω
- 10 fiber positions onto each turn of the fiber.
- Magnetic Field: 15T, 12T
- To begin this test, current was increased at a rate:1A/s to reach the critical current of this conductor sample
  - IC: 360A
- 40 runs, run 1 and run 24 are the ramp to IC at different magnetic fields (12T and 15T)
  - Data is still under review
- Minimum quench power tests done at different magnetic field and current levels



Gage #	Location(m)
0	2.50
1	2.214
2	2.241
3	2.335
4	2.442
5	2.557
6	2.664
7	2.763
8	2.870
9	2.977
10	3.085

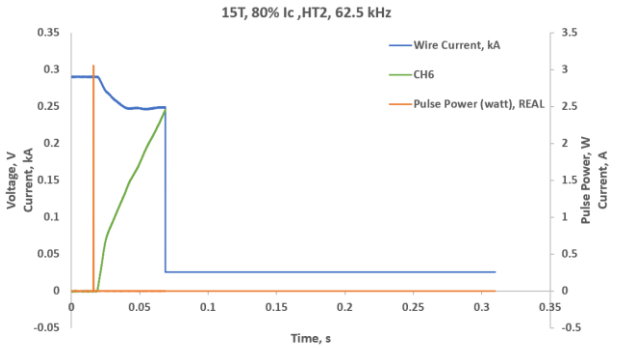
Location of spot heater: 1

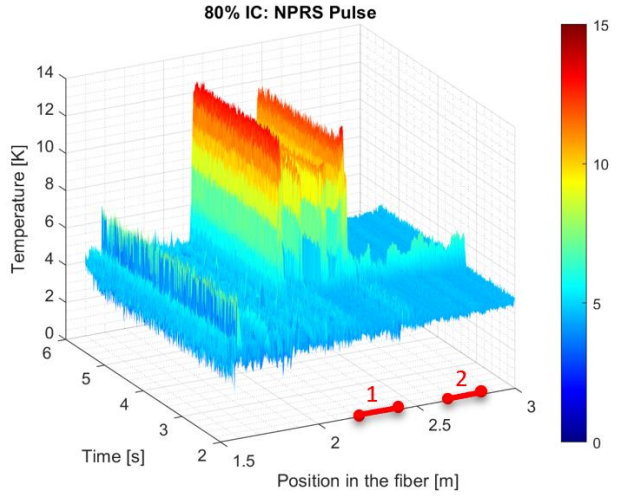
Location of spot heater: 2

Nb3Sn test: 15T, 80% Ic

- Current ~ 290A
- Spot heater pulse length remained constant
- Spot heater 1 requires larger power to quench the sample
- Temperature increase is better seen on the one half of the barrel.

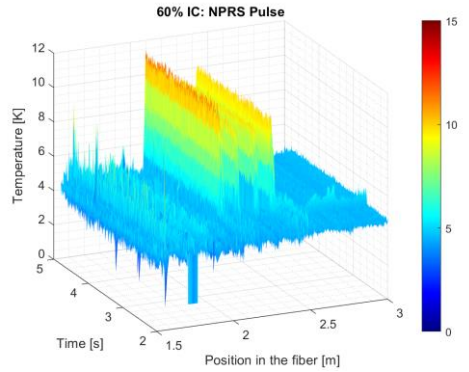
Spot Heater	Pulse (µs)	Current (A)	Power (W)	Quench Y/N	ΔT? (K)
1	200	0.06	1.26	N	-
1	200	0.07	1.72	N	-
1	200	0.08	2.24	N	-
1	200	0.09	2.85	N	-
1	200	0.12	5.04	N	-
1	200	0.15	7.875	N	-
1	200	0.20	14	Y	~
2	200	0.06	1.26	N	-
2	200	0.07	1.715	N	-
2	200	0.08	2.24	N	-
2	200	0.09	2.84	N	-
2	200	0.095	3.16	Y	8.85





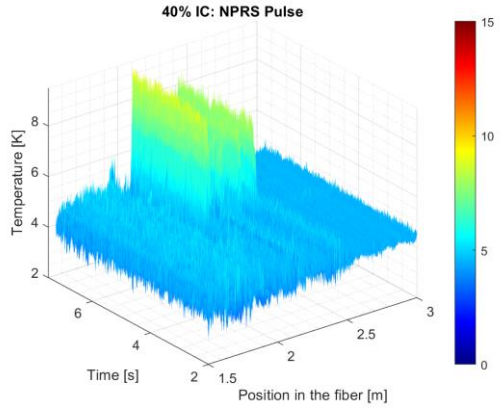
Nb3Sn test: 15T, 60% and 40% Ic

60% IC ~ 216A



Spot Heater	Pulse (µs)	Current (A)	Power (W)	Quench (Y/N)	ΔT? (K)
2	200	0.12	5.04	N	-
2	200	0.13	5.92	N	-
2	200	0.14	6.86	N	-
2	200	0.15	7.875	Y	6.5

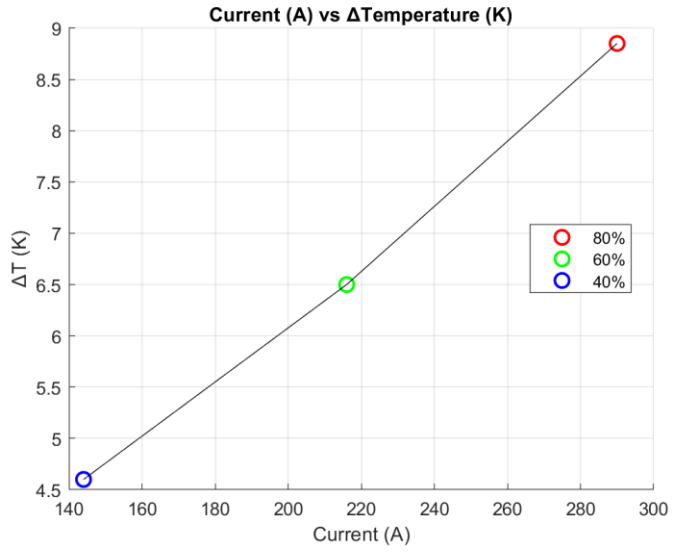
40% IC ~ 144A

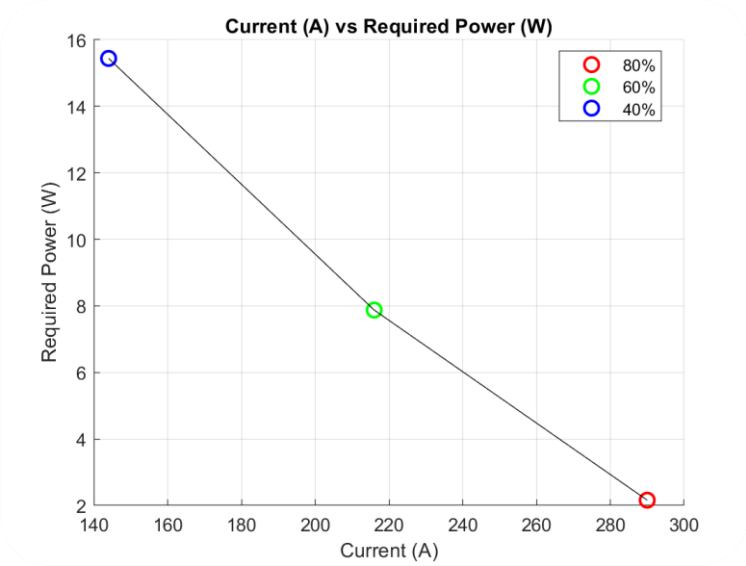


Spot Heater	Pulse (µs)	Current (A)	Power (W)	Quench (Y/N)	ΔT? (K)
2	200	0.20	14	N	-
2	200	0.21	15.44	Y	4.6
2	200	0.22	16.94	Y	4.45

Minimum quench power

- Current vs Power
- Current vs DT
  - Higher current will produce a greater change in temperature from quench
  - Can detect small temperature changes





REBCO STAR wire in liquid N (October 24)

Fiber without Kapton

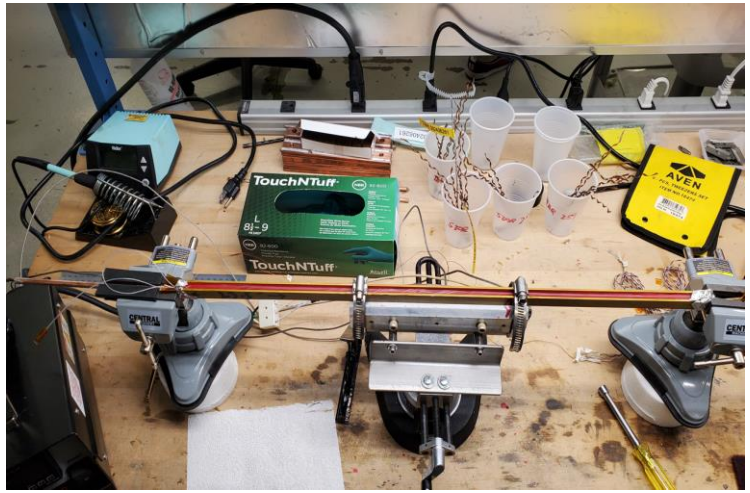
- RUN 1: up to 700A
- RUN 2: Up to 500 A
- RUN 3: Up to 600 A
- RUN 4: Up to 750 A

Fiber with Kapton

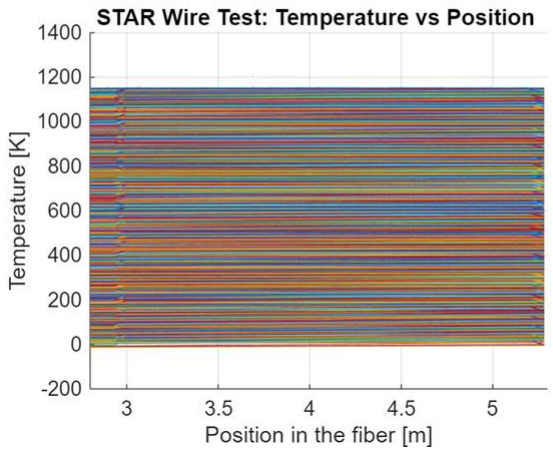
- The cable and the fiber were wrapped in a kapton layer with sticky kapton holding it in place.
- RUN 1: up to 500 A,
- RUN 2: Up to 600 A
- RUN 3: Up to 750 A
- RUN 4: up to 650 A holding the current at 650 A for two minutes.

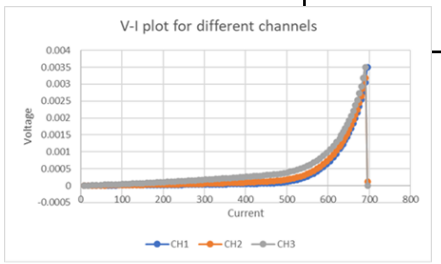
No signal observed with the fibers

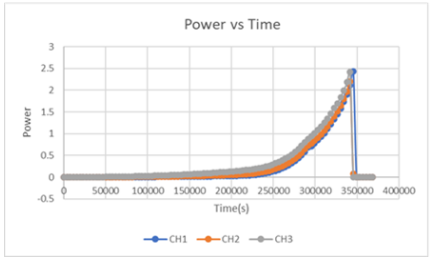
Experiment with STAR wire in liquid N



Test no.	Fixed Voltage Threshold	Current reached
1	1mV	600A
2	5mV (stayed for a while at 646 A)	695A
3	10mV	695A
4	20mV	695A
5	50mV	700A







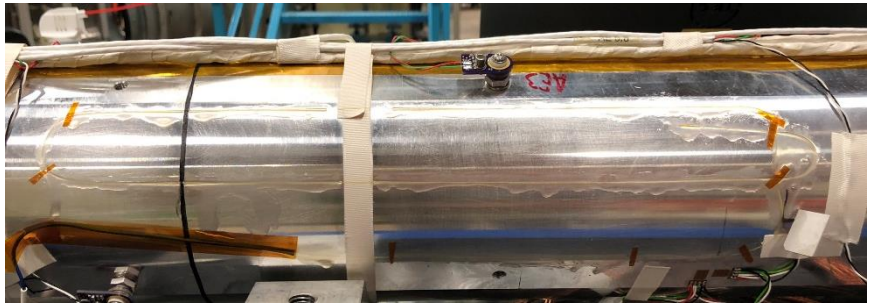
Work performed by Sai Srinivas Ganesh Panda

Conclusion

- Three tests were performed using fiber optics:
- Two tests in liquid He with fibers installed on REBCO tape and Nb3Sn strands.
- Test on wax impregnated REBCO STAR wire in liquid N
- **REBCO tape results**
  - Quench at IC was clearly observed
  - Tape was degraded from IC run
  - Tests with a spot heater were inconclusive because samples were degreaded
- **Nb3Sn sample**
  - Minimum quench power and change in temperature could be estimated with the fiber data
  - Repeat test with synchronization. How fast
- **STAR wire in liquid N**
  - No Temperature variations observed. Power is probably to low

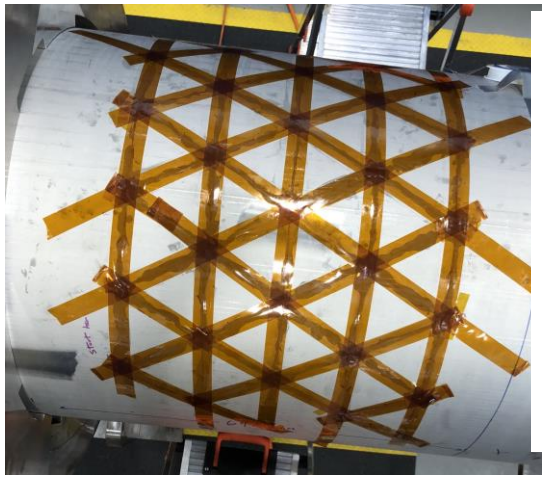
Fiber optics: to do list

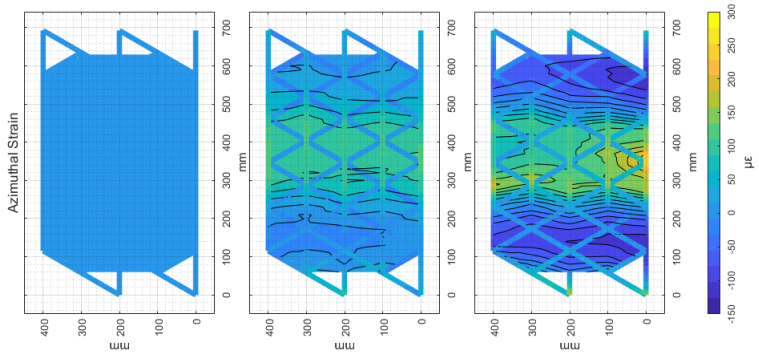
Strain map during test of Nb3Sn CCT magnets



Plenty of data to analyze

Strain map during welding of AUP coldmass 2 to 4





SHORT TERM PLAN

- Tests in liquid N with STAR wire in heat shrink
- Install a spot heater and see if we can observe the heat pulse in liquid nitrogen
- STAR wire installed on a barrel in liquid He
- Use non performing COMB STAR coil as a test bed

- Perform quench propagation study on 1 m long REBCO tape and compare with simulation with QLASA