High Field HTS SMES Potential Risks Conductor & Coil Performance

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High Risk, High Reward R&D

- HTS is a challenging conductor and is in R&D stage. The success of the program depends largely on developing a robust conductor.
- This is a challenging magnet, both in terms of design and in terms of protection with high stored energy.
- We are developing conductor and magnet technology together. This inherently poses a higher level of risk.
- This is truly a high risk, high reward program. If successful, it will have a significant impact on high energy density storage system. It also has a potential to have impact on other fields.

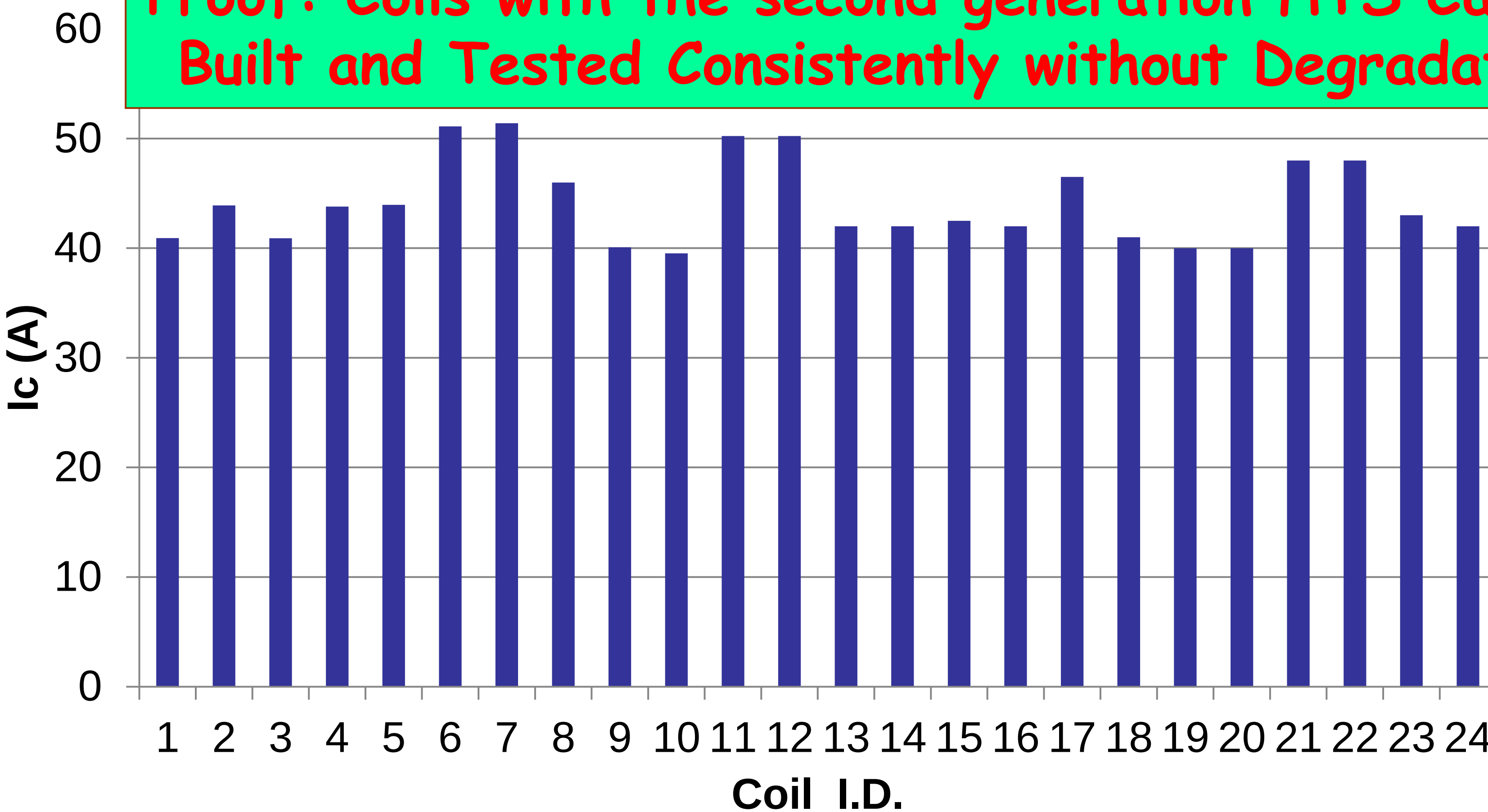
Conductor Coil Performance Relationship #1

HTS Coils for Muon Collider Solenoid

- **29 coils for 100 mm aperture solenoid have been wound with stainless steel insulation**
- **Each coil is made with 100 meters of ~4 mm wide 2G HTS from SuperPower**
- **This is a significant HTS R&D program with ~3 km of conductor already consumed**
- **All coils have been individually tested at 77 K (24 coils needed for the solenoid)**
- **24 coils have been selected after they passed all QA requirements, including 77 K test**

Test Results of 24 Coils at 77K

Proof: Coils with the second generation HTS Can be Built and Tested Consistently without Degradation



- **Coils have significant instrumentation for detailed analysis.**
  - **Five coils out of 29 had some performance issues…**

R&D Conductor

Recent 2G HTS Wires from SuperPower to BNL (does not include previous purchases used in making earlier RIA coils, etc.)										
Spool I.D.	Internal Tape I.D.	Length(m)	Width(mm)	Thickness(mm)	Ic average(A)	STDEV(%)	Ic Minimum	coil I.D.		purchase number
SCS4050 (High Current)										
20090910-1	M3-699-5 BS, 748.5-798.5m	50	4.01	0.094-0.102	170	1.5	165	1Aout		SP-PBL-20090910
20090910-2	M3-699-5 BS, 807.8-857.8m	50	4.03	0.096-0.102	164	2.3	158			
20090910-3	M3-699-5 BS, 862.8-912.8m	50	4.03	0.096-0.099	165	3.3	154	1Bin		
20090910-4	M3-699-5 BS, 987.8-1037.8m	50	4.08	0.093-0.099	178	2.2	171	1Ain		
20090910-5	M3-637-2 FS, 931.01-981.01m	50	4.01	0.098-0.106	156	5.4	137			
20090910-6	M3-637-2 BS, 931.01-981.01m	50	4.01	0.098-0.103	159	2.9	151			
20090910-7	M3-637-2 BS, 996.01-1046.01m	50	4.01	0.095-0.100	155	6.4	134	1Bout		
20090923-1a	M3-687-2 FS, 1522.1-1572.1m	50	4.16	0.098-0.105	88	1.84	85	2Aout		SP-PBL-20090923
20090923-1b	M3-687-2 BS, 1432.1-1482.1m	50	3.97	0.098-0.104	94	2.8	91	2Ain		
20090923-2a	M3-687-2 FS, 1452.1-1512.1m	60	4.12	0.096-0.106	85	4.4	80	2Bout		
20090923-2b	M3-687-FS, 1144.02-1184.02m	40	4.12	0.098-0.105	86	1.7	84	2Bin		
20090923-3a	M3-687-2 MS, 1282.02-1344.02m	62	4.09	0.099-0.105	90	2	87	4Aout		
20090923-3b	M3-687-2 MS, 1509.3-1547.3m	38	4.1	0.097-0.105	92	3.4	87	4Ain		
20090923-4a	M3-687-2 MS, 1344.02-1411.02m	67	4.12	0.098-0.104	91	1.2	88	3Aout		
20090923-4b	M3-687-2 MS, 1788.4-1821.4m	33	4.12	0.098-0.104	95	2.9	92	3Ain		
20090923-5a	M3-687-2 BS, 1509.4-1539.1m	29.7	4.12	0.095-0.105	96	2.6	92	3Bout		
20090923-5b	M3-687-2 FS, 1250.52-1320.82m	70.3	4.12	0.095-0.103	87	2.1	83	3Bin		
20090923-6a	M3-687-2 BS, 1672.3 -1752.1m	79.8	4.01	0.095-0.105	94	2.9	86	4Bout		

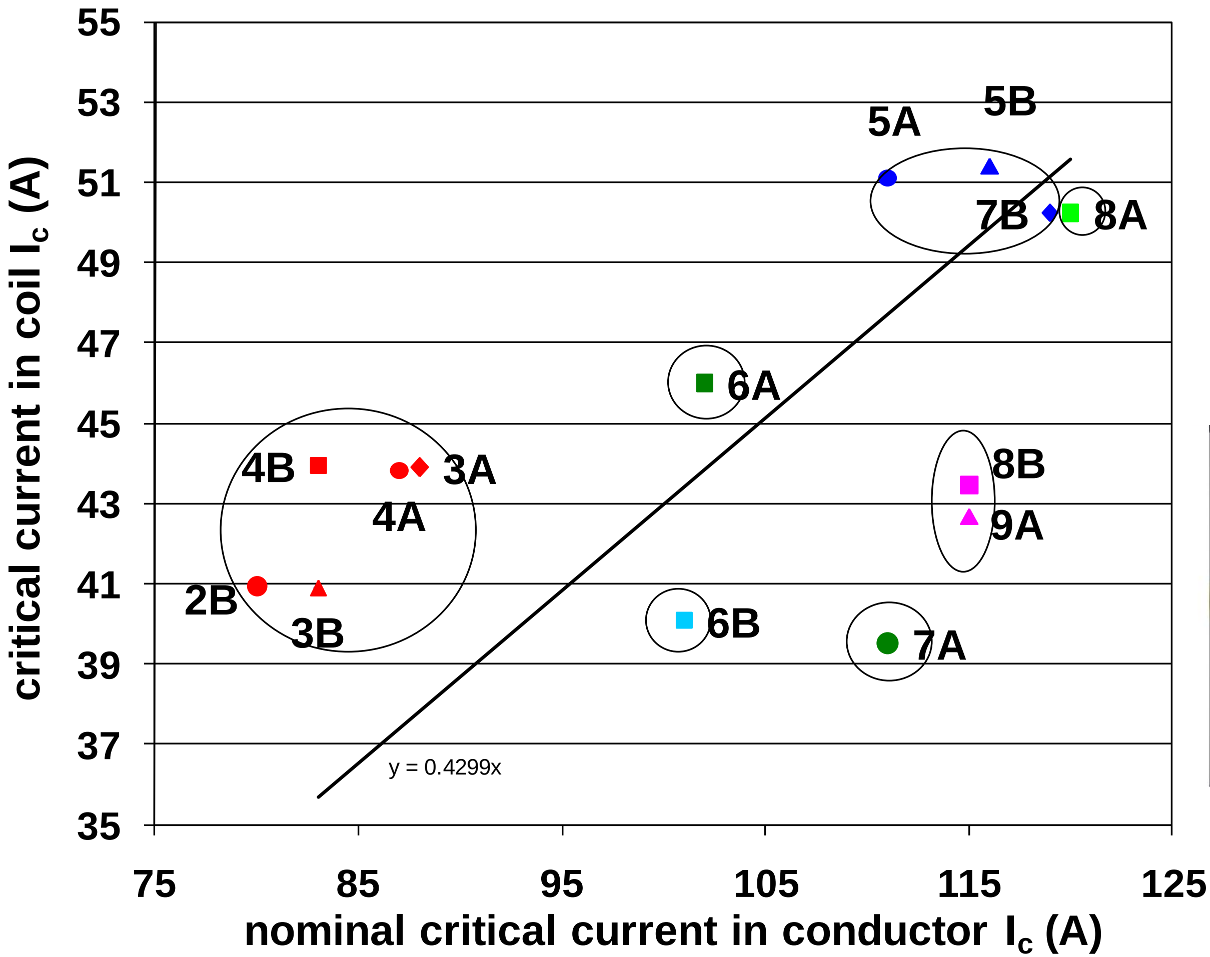
Higher Ic conductor with thicker coating appear to be too sensitive for magnet applications (???). We need to make sure that this is not the case for conductor being developed at Houston. Conductor must be usable for high field HTS SMES application.

20100630-7	M3-765-1 FS, 406-456m	50	4.02	0.097-0.103	103	1.9	100	
20100630-8	M3-745-2 FS, 1617.17-1667.17m	50	4.04	0.093-0.097	113	2.9	107	
20100630-9	M3-745-2 MS, 1617.17-1667.17m	50	4.04	0.090-0.094	115	3.7	104	
20100630-10	M3-742-2 MS, 507.83-557.83m	50	4.04	0.096-0.098	116	0.7	115	
20100805-1	M3-744-2 FS 875.3 -925.3m	50	4.04	0.095	112	1.5	110	KA03
20100805-2	M3-776-1 FS, 700-750m	50	4.05	0.096	104	2.1	100	
20100805-3	M3-767-1 BS, 986.25-1036.25m	50	3.95	0.094	110	4.6	101	
20100805-4	M3-744-2 MS, 631.8-681.8m	50	4.03	0.094	107	1.6	103	KA02
20100805-5	M3-744-2 MS, 481.8-531.8m	50	4.03	0.094	111	1	109	KA01
20100805-6	M3-781-4 MS, 913.7-963.7m	50	4.04	0.097	115	0.5	114	SS01
20100805-7	M3-781-4 MS, 863.7-913.7m	50	4.04	0.097	115	1.4	112	SS02
20100805-8	M3-776-1 MS, 560-610m	50	4.02	0.095	107	2.2	102	
20100805-9	M3-767-1 MS, 986.5-1036.5m	50	4.04	0.097	116	4.2	106	
20100805-10	M3-774-1 BS, 459-509m	50	4.04	0.095	104	0.4	103	
	total SP 4 mm conductor length (m)=	4500						

Build and test short coils with each batch of R&D conductor developed at Houston for SMES program

Conductor Coil Performance Relationship #2

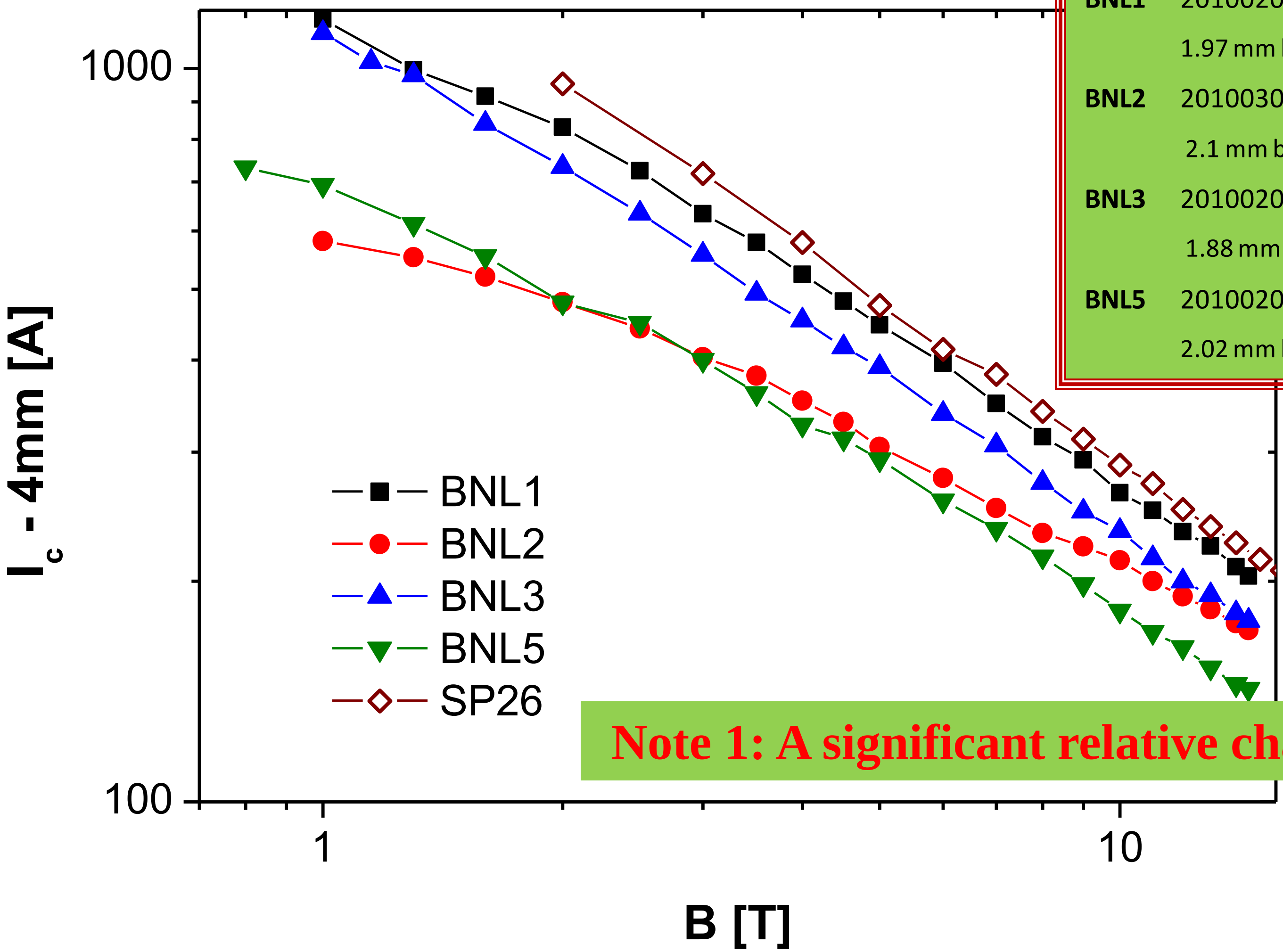
Correlation between Coil I_c and Wire I_c at 77 K



Conductor Coil Performance Relationship #3

NHMFL Tests of Production 12 mm Tapes (purchased by BNL from SuperPower)

BNL1	20100205-1	M3-735-2	285A @ 77K, s.f.
	1.97 mm bridge over 12 mm sample		
BNL2	20100301-2	M3-741-4	255A @ 77K, s.f.
	2.1 mm bridge over 12 mm sample		
BNL3	20100205-3	M3-730-2	240A @ 77K, s.f.
	1.88 mm bridge over 12 mm sample		
BNL5	20100205-5	M3-729-2	253A @ 77K, s.f.
	2.02 mm bridge over 12 mm sample		

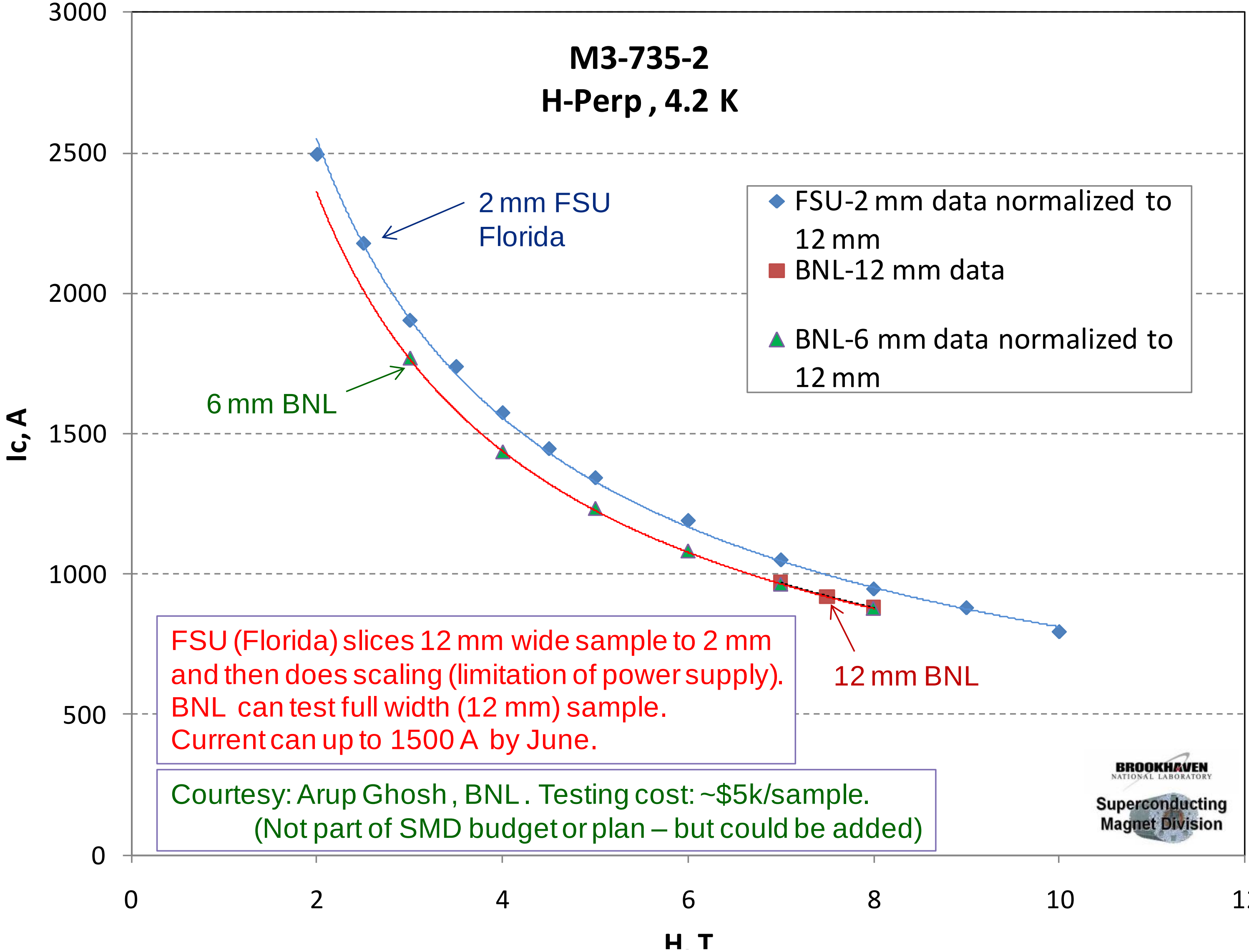


Note 1: A significant relative change in performance

Note 2: A factor of 2 or so difference in absolute performance

Brookhaven National Laboratory
Superconducting Magnet Division

Conductor Test Results at BNL & NHMFL of 12 mm Production Tape (being used at BNL in FRIB Magnets)



Summary

- **We must make sure that the high Ic conductor developed with thicker coating is a robust product.**
- **In past, in certain occasions there has been a significant variation in conductor performance from batch to batch and along the length.**
- **Remember: The overall coil performance will be limited by the weakest link in the conductor or coil.**
- **It is important that we study above in sufficient details and guide the conductor program at Houston so that the conductor developed is suitable for low temperature, high field SMES.**
- **HTS is a challenging conductor and is still in R&D stage. The success of the program depends largely on developing a robust conductor.**
- **This is a challenging magnet, both in terms of design and in terms of protection with high stored energy.**

Quench Protection in HTS Magnets

- Protection is one of the most challenging issues in HTS magnets, primarily because of slow quench velocities.

- We are developing an advanced quench protection system to detect small coil voltage rise in short time in presence of noise and large inductive voltage.

- In consultation with SuperPower, the amount of copper in HTS tape is being increased from 45 micron to 100 micron thickness. This will improve the protection of HTS in an event of a quench or thermal runaway. A safer SMES for field applications may require even higher amount of copper.

- We are performing a number of experiments and also exploring possibilities of collaborations with other institutions .