Recent Developments in High Temperature Superconductors (HTS) for Fusion Magnets

Joseph V. Minervini, Makoto Takayasu and Leslie Bromberg
MIT PSFC

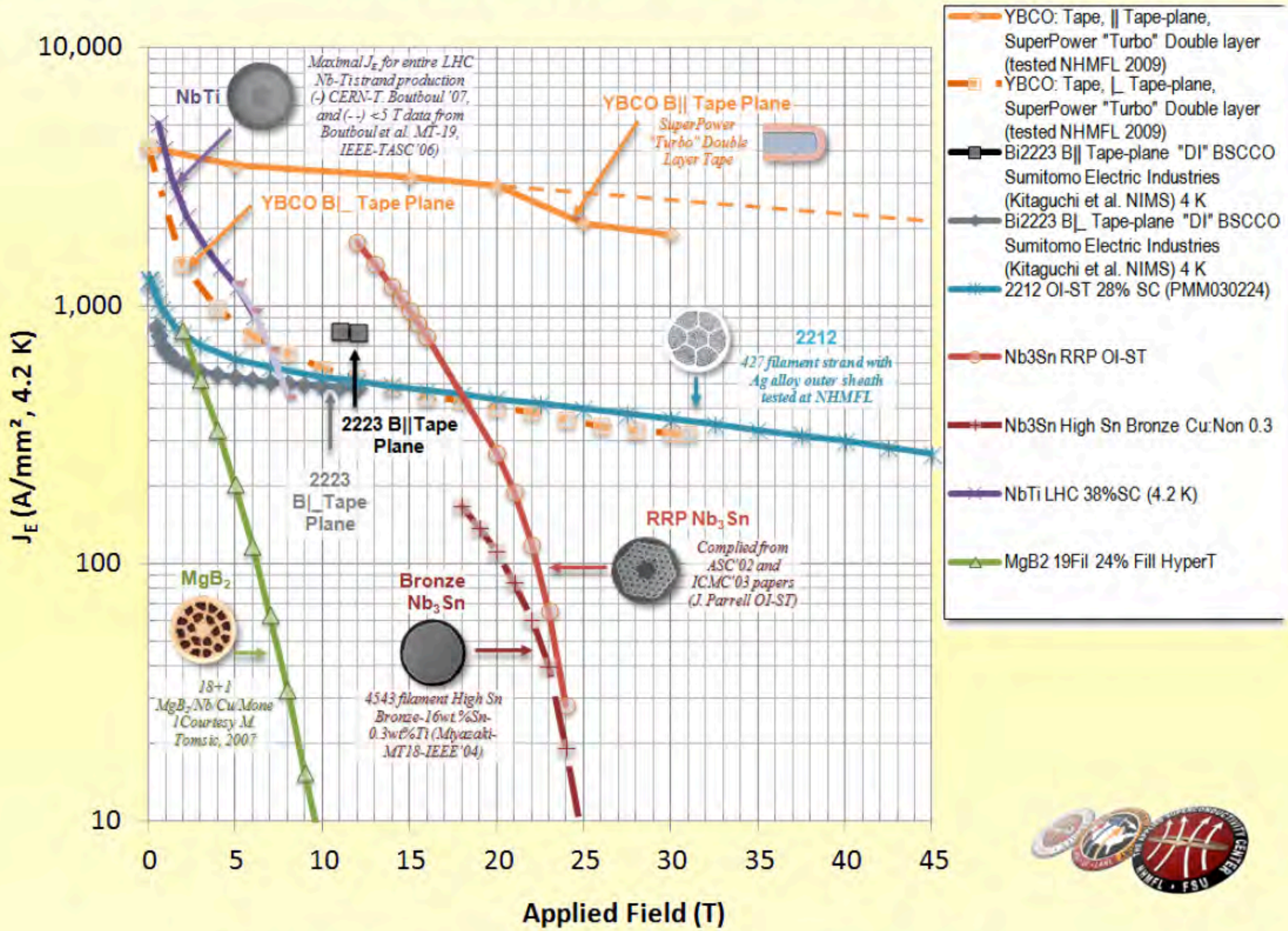
VLT Conference Call
June 16, 2010

ReNeW-Thrust 7 Elements

A structured R&D program consisting of the following elements:

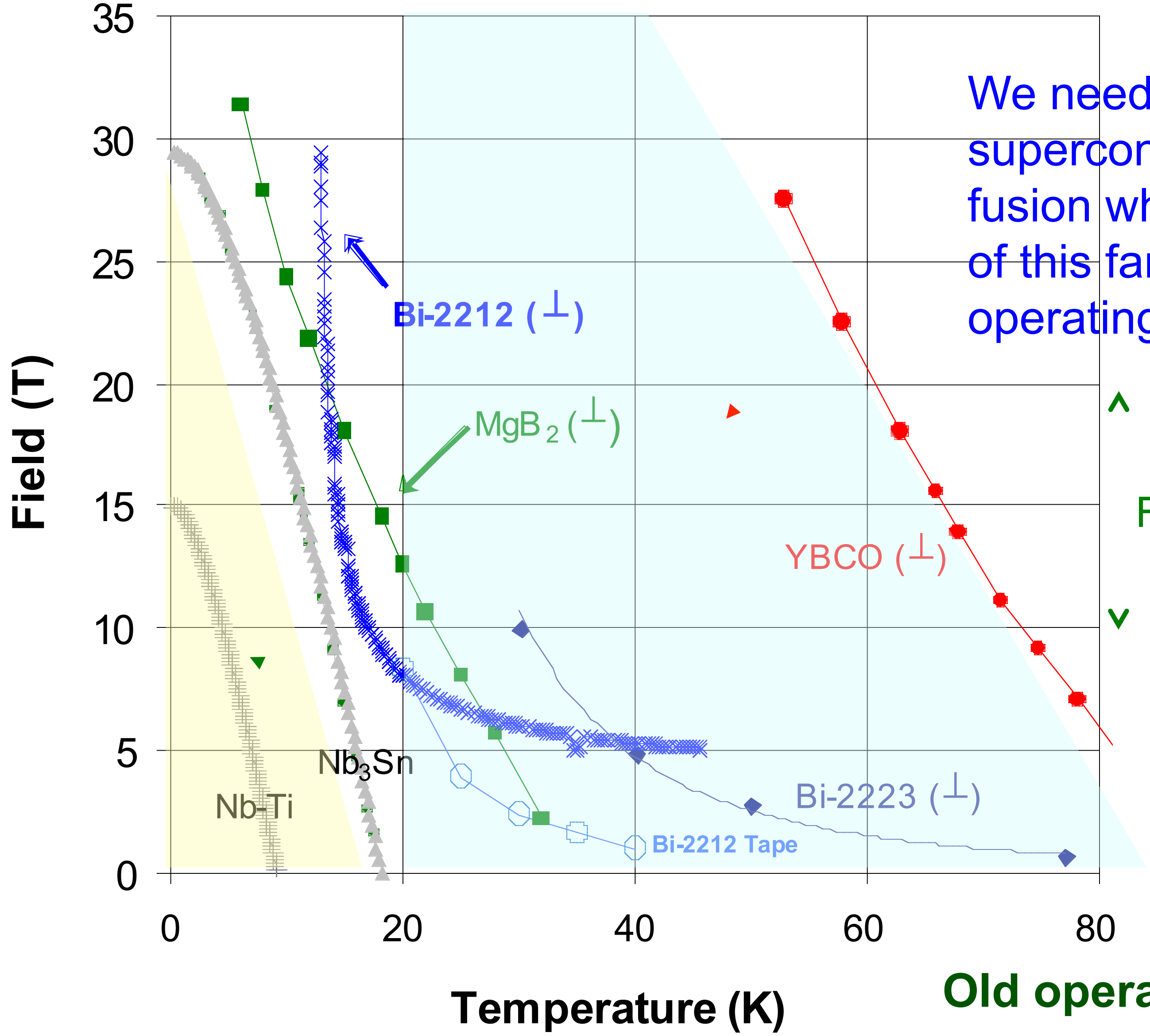
1. *HTS wire/tape*
2. High current conductors/cables
3. Advanced magnet structural materials/structural configurations
4. Cryogenic cooling methods for HTS magnets
5. Magnet quench detection/protection specific to HTS magnets
6. Advanced radiation tolerant insulating materials
7. Integration of conductor with structure, insulation, and cooling
8. Demountable joints for coils
9. Coil fabrication technology incorporating the unique features of elements 1-8

HTS greatly extends the capability at 4K



Courtesy Peter Lee www.asc.magnet.fsu.edu

HTS make much higher magnetic fields accessible………

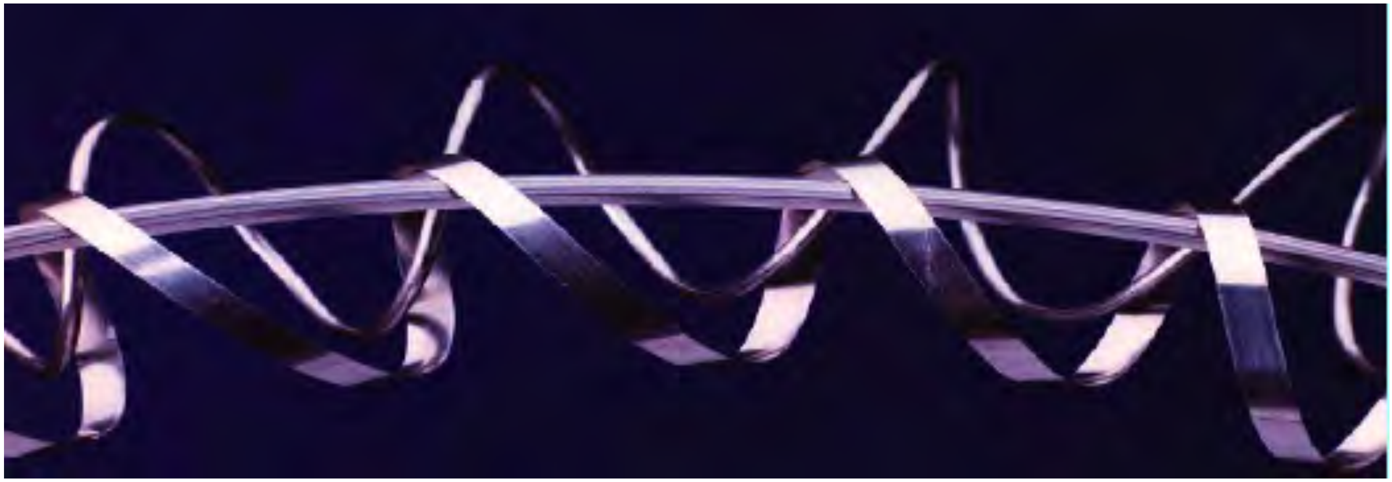


We need to develop superconducting magnets for fusion which take advantage of this fantastic new operating space

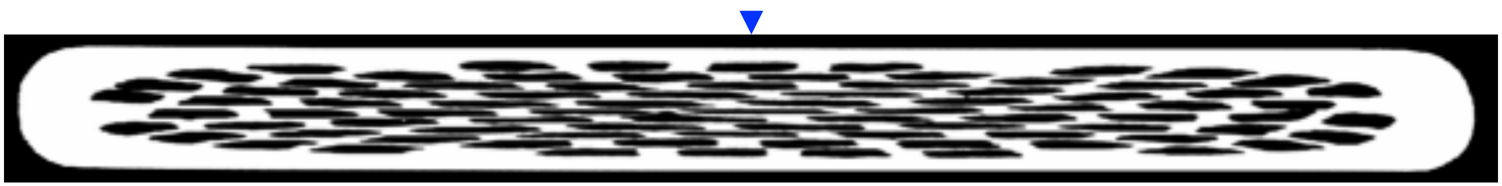
Fusion reactor range

Old operating space

BSCCO Wire (1st Gen) is Expensive

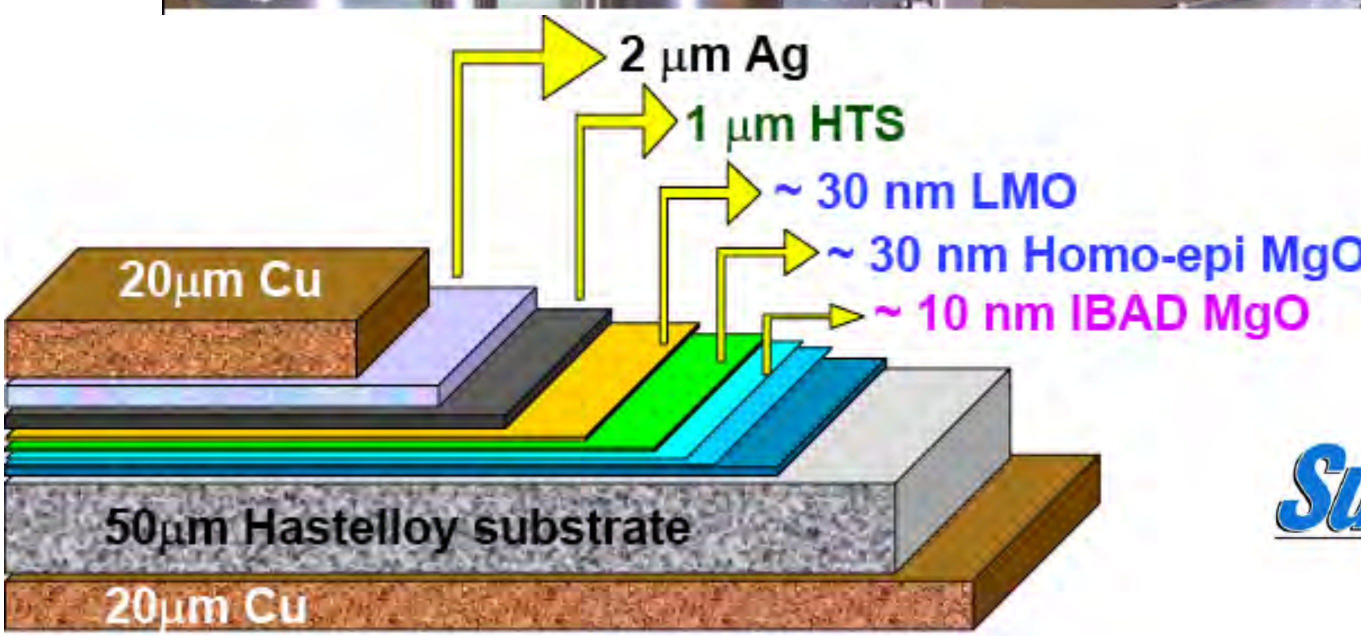


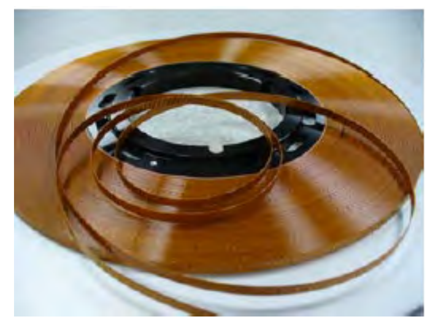
70% Silver!



YBCO Tape (2nd Generation-HTS)

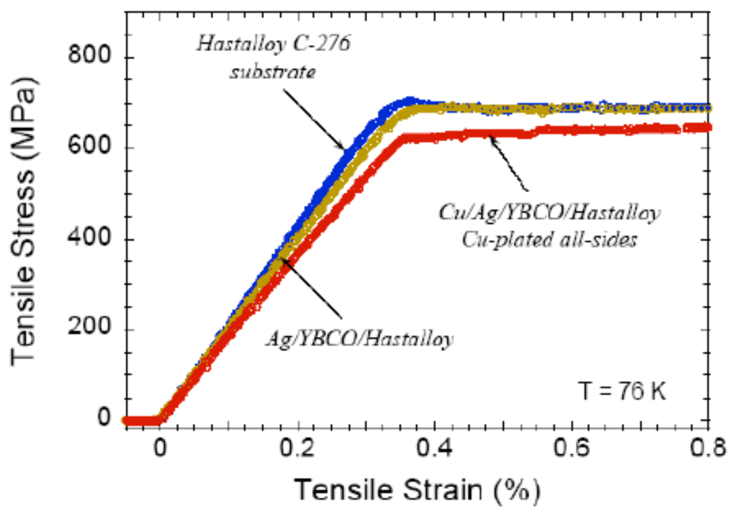
- SuperPower (Latham, NY) uses a reel-to-reel system for tape production

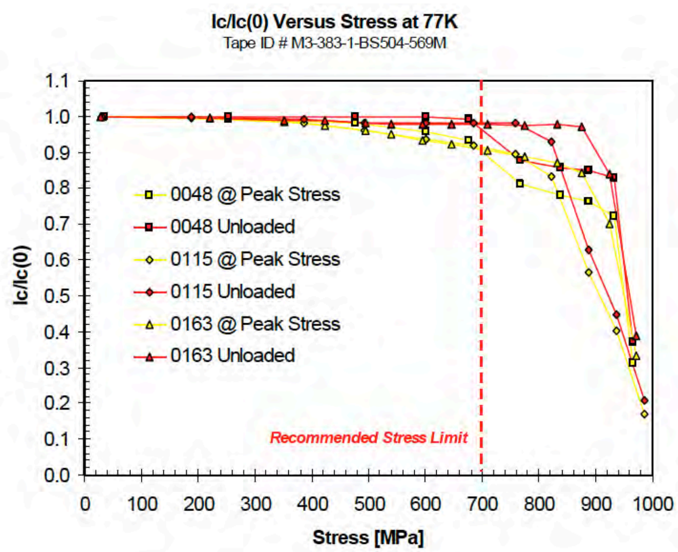




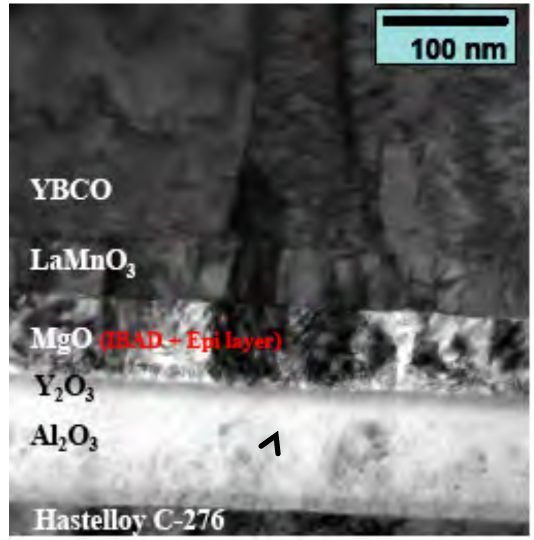
SuperPower Inc.
A Subsidiary of Intermagnetics General Corporation

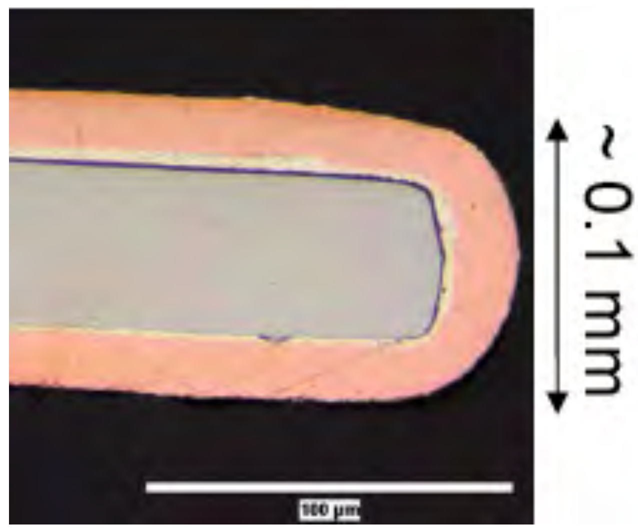
YBCO Tape (2nd Generation-HTS)





Data from R. Holtz, NRL





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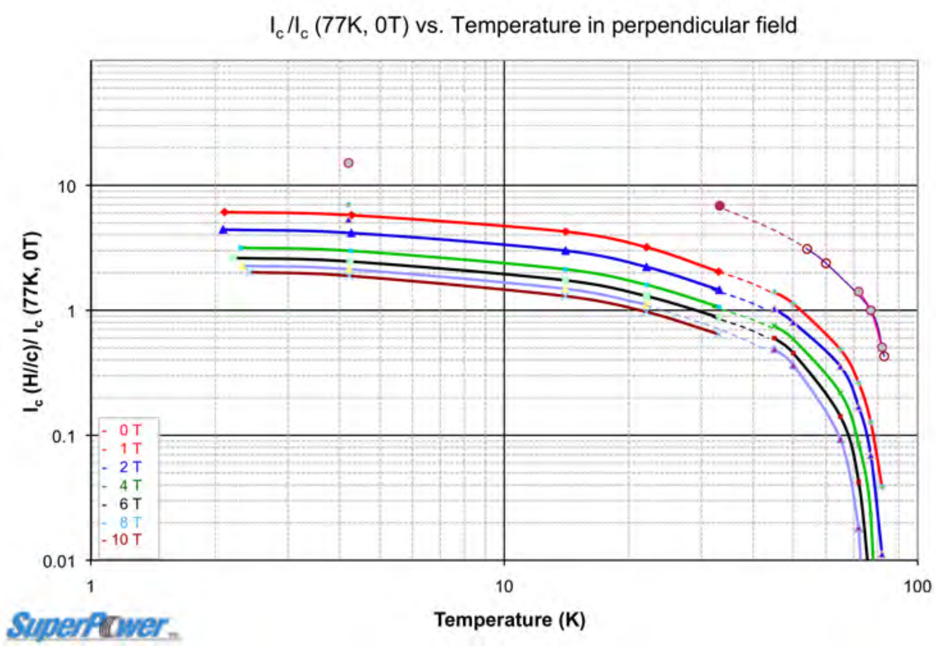
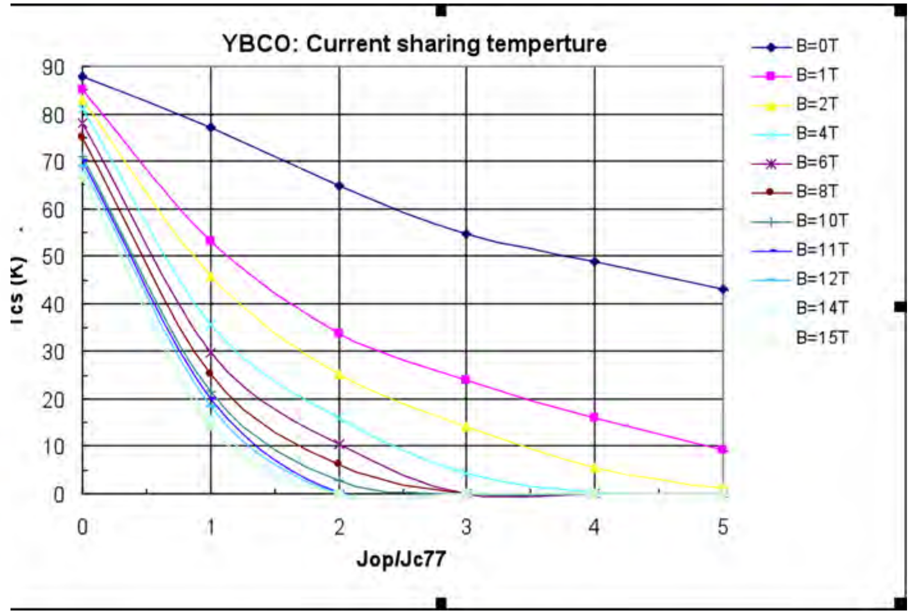
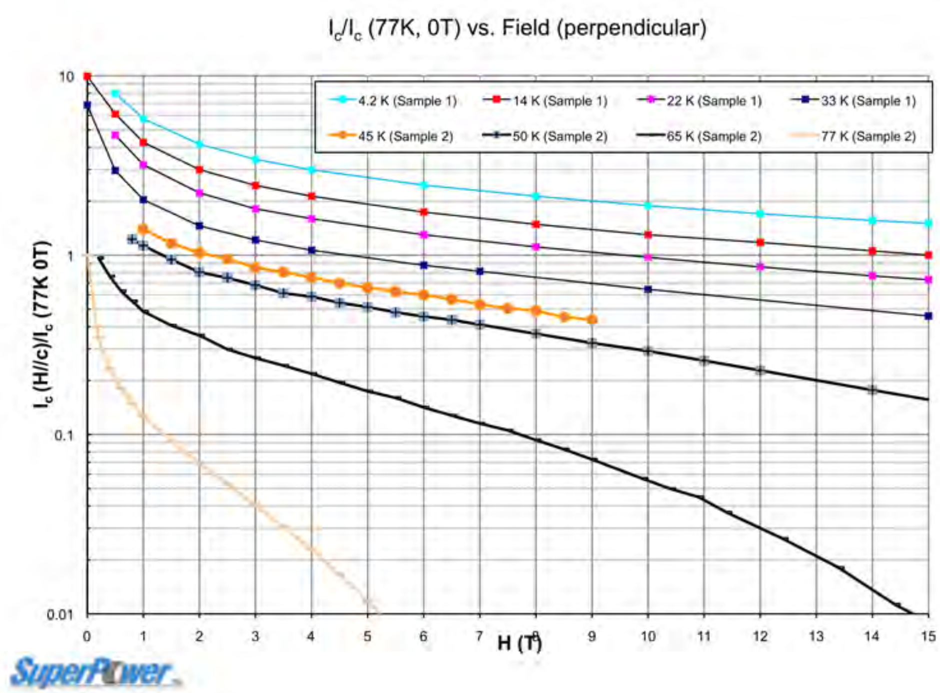
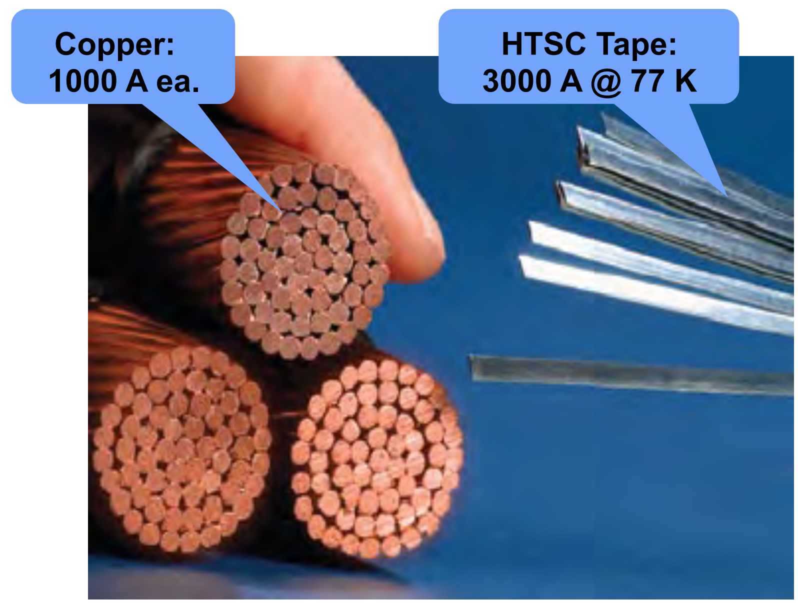

I_c/I_c (77K, 0T) vs. Temperature in perpendicular field
I_c (H//c)/ I_c (77K, 0T)
Temperature (K)
10
1
0.1
0.01
1
10
100
0 T
1 T
2 T
4 T
6 T
8 T
10 T
SuperPower


YBCO: Current sharing temperture
Ics (K)
Jop/Jc77
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
B=0T
B=1T
B=2T
B=4T
B=6T
B=8T
B=10T
B=11T
B=12T
B=14T
B=15T


I_c/I_c (77K, 0T) vs. Field (perpendicular)
I_c (H//c)/I_c (77K 0T)
H (T)
10
1
0.1
0.01
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
4.2 K (Sample 1)
14 K (Sample 1)
22 K (Sample 1)
33 K (Sample 1)
45 K (Sample 2)
50 K (Sample 2)
65 K (Sample 2)
77 K (Sample 2)
SuperPower


Copper:
1000 A ea.
HTSC Tape:
3000 A @ 77 K

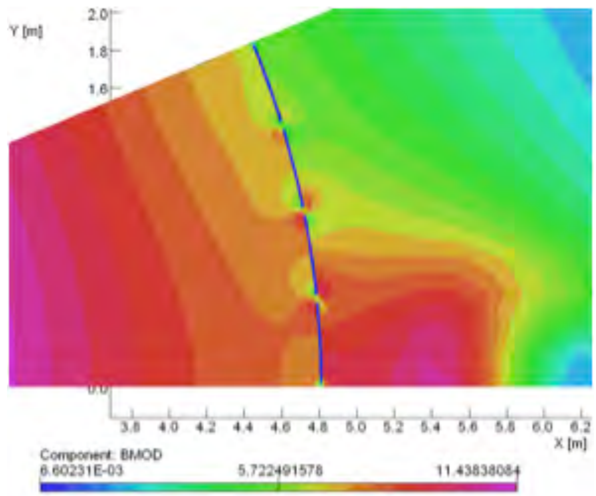
Stellarators using bulk HTS Tiles?

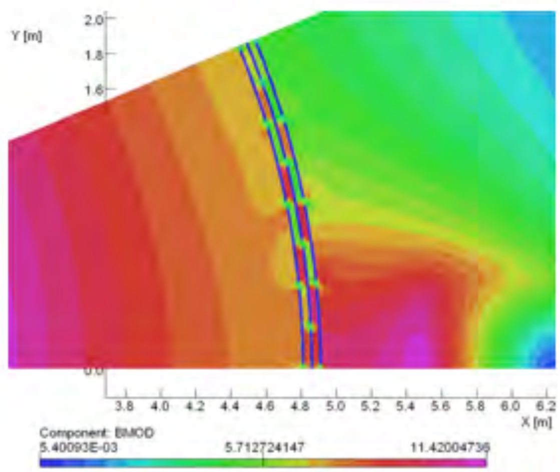
(PPPL and MIT)

Use diamagnetic properties of *Bulk Superconducting Tiles* to define flux surfaces?

Objectives of concept

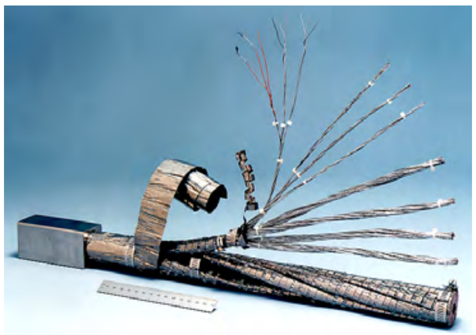
- Superconductor material can be used to shield magnetic field
- Use superconducting tiles to modify fields made from relatively simple coils
  - Reduced TF coils in tokamaks
  - Simplify coil geometries for stellarators



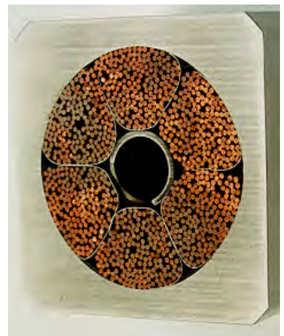


High Current Conductors Required for Fusion Magnets

Typical Large Scale Cable-in-Conduit Conductor (CICC)



40 kA at 13 T, 4.5 K

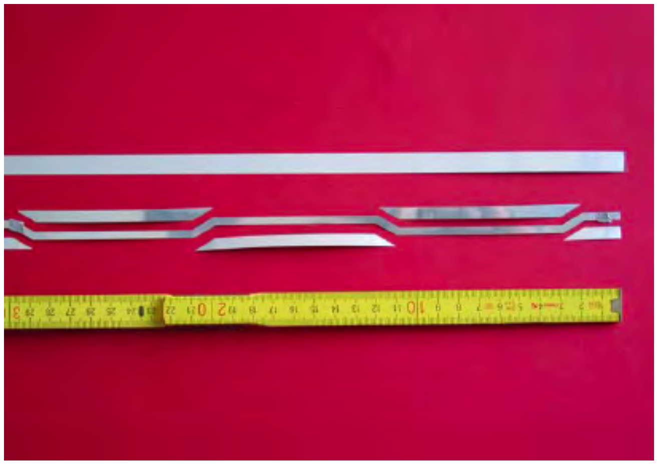


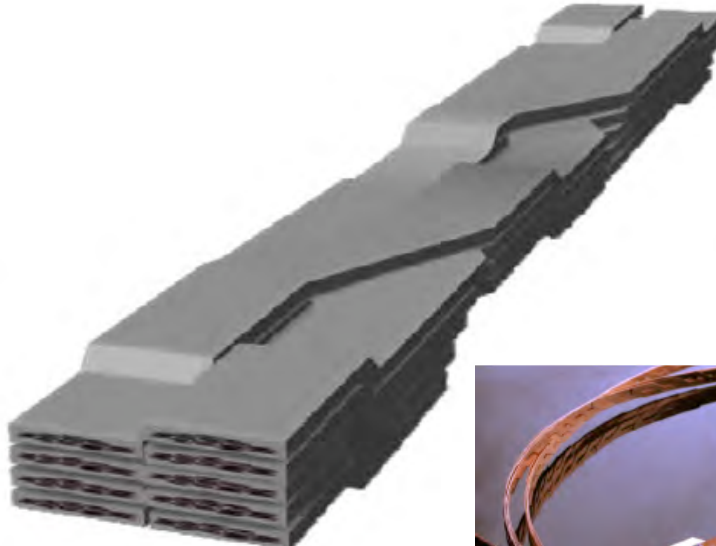
- High Currents Required to Limit Coil Inductance and Dump Voltage for Quench Protection

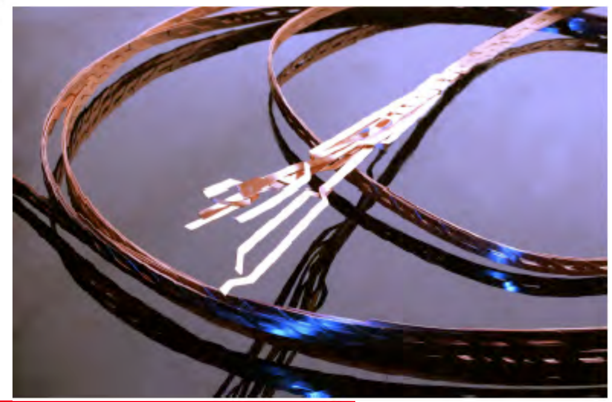
ITER TF coils (N*I = 9.1 MA, L = 0.349 H)

Conductor current	Number of turns	Inductance ratio L/L_{ITER}	Discharge voltage (τ_D = 12 s)	Discharge time constant (U_D = 10 kV)
68 kA	134	1	3.5 kV	4 s
30 kA	304	5	17.5 kV	21 s
10 kA	910	45	158 kV	190 s

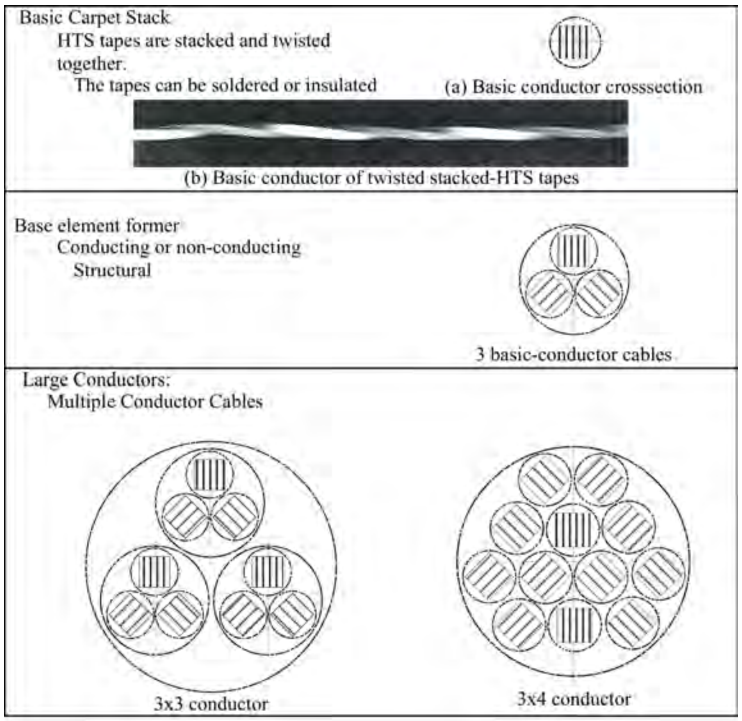
Roebeled HTS Tapes (YBCO)

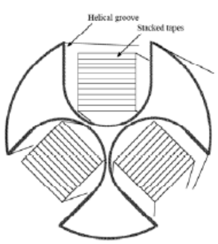




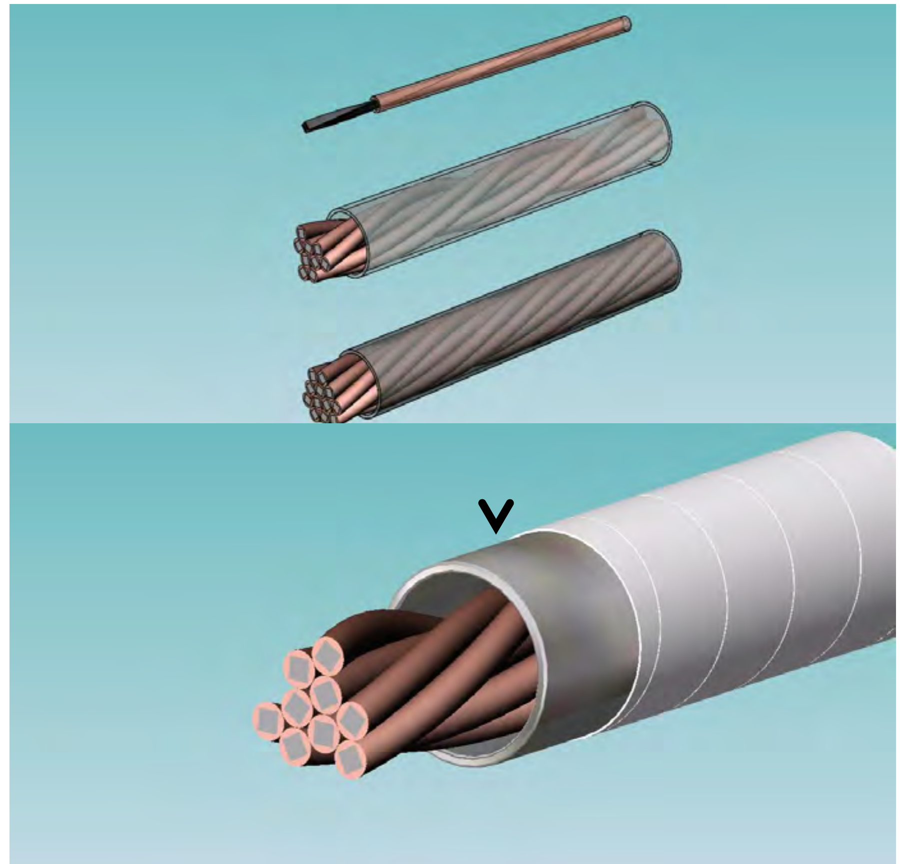


MIT proposed
Twisted Stacked Conductor Concept

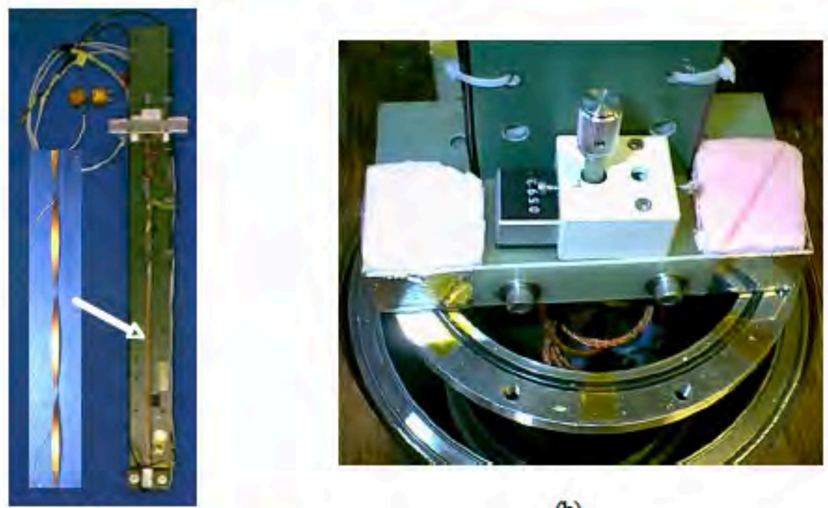




Supercon, Inc.
Phase I SBIR

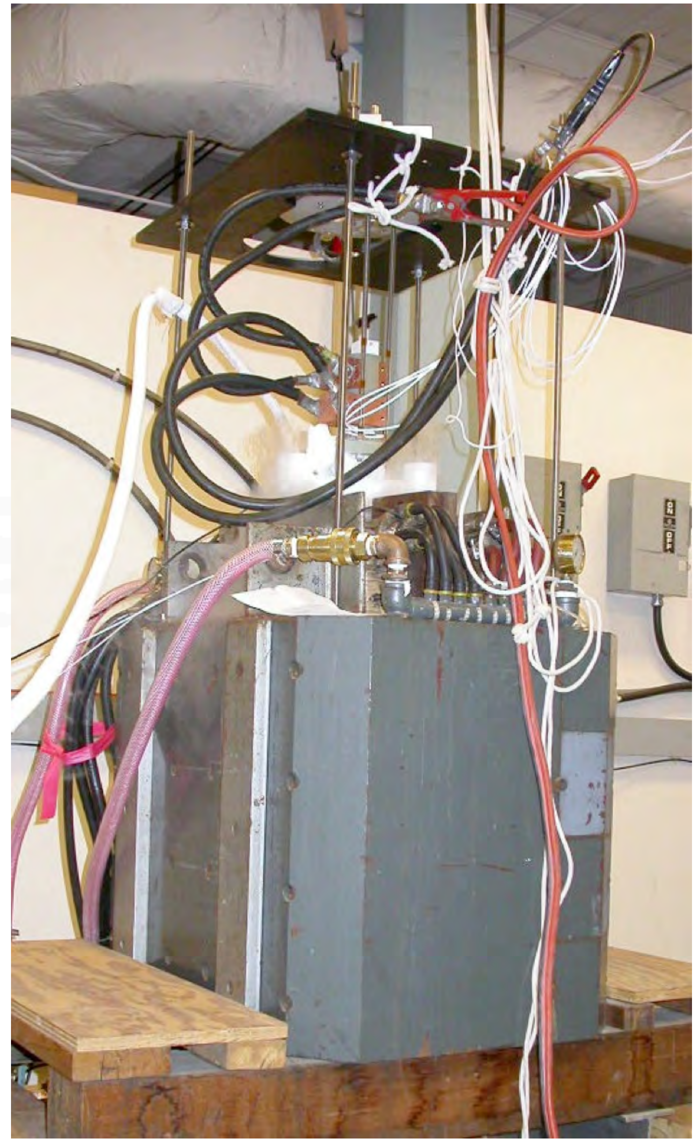


Small Conductor Test Rig



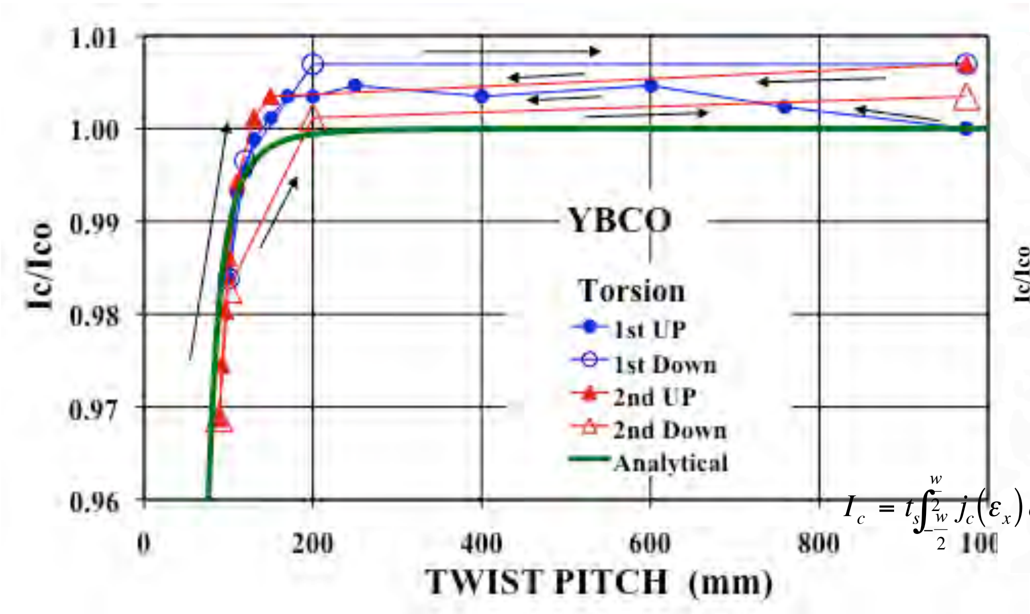
(a) (b)

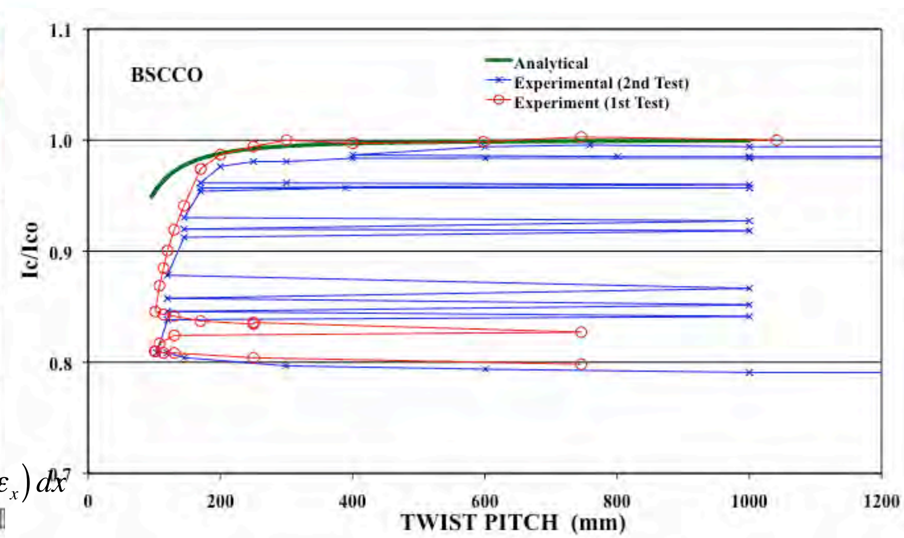
Fig. 2. (a) Overview of a torsion test probe on a G10 plate of 915 mm height, 76 mm width and 6 mm thick. Test tape of a 300 mm section is twisted by rotating the upper current lead. The insert shows an enlarged twisted tape. (b) The probe is in a Dewar. A counter on a top flange measures the twisting angle.



- Measure I_c as a function of tape orientation wrt magnetic field
- 2 T copper magnet with sample at 77 K
- New test rig to be developed in FY2011 to measure I_c (B,T) for:
  - $0 \leq B \leq 14$ T
  - $4.2 \text{ K} \leq T \leq 77$ K
  - $I_{max} = 1000$ A

Effect of twisting on critical current in YBCO and BSCCO tape

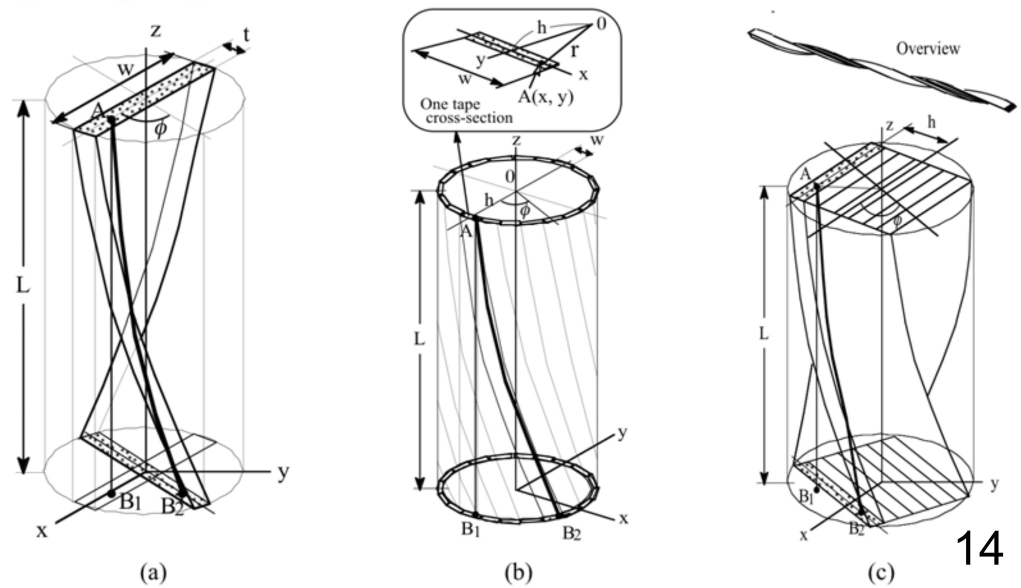




$$I_c = t_s \int_{-\frac{w}{2}}^{\frac{w}{2}} j_c(\varepsilon_x)\, dx$$

$$j_c(\varepsilon) = I_c(\varepsilon)/(t_s w)$$

$$\varepsilon_x = \frac{\theta^2}{2}\left(x^2 - \frac{w^2}{12}\right)$$



Lap-Joints Between HTS Tapes

- Joint fixture made at MIT, tests carried out at Creare

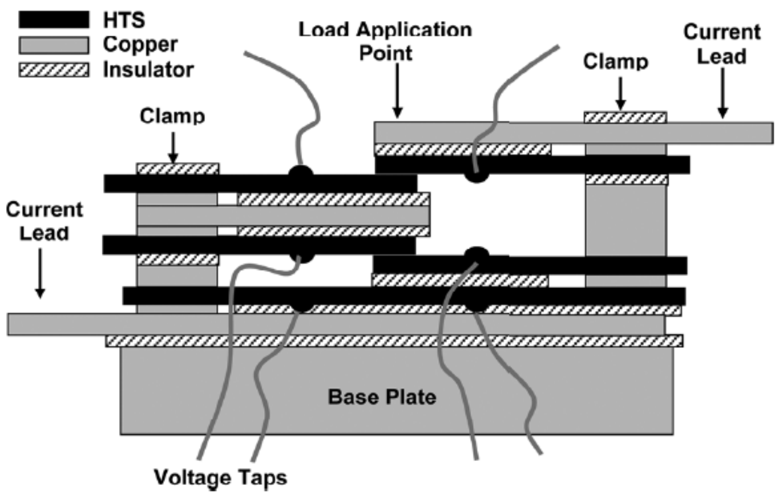
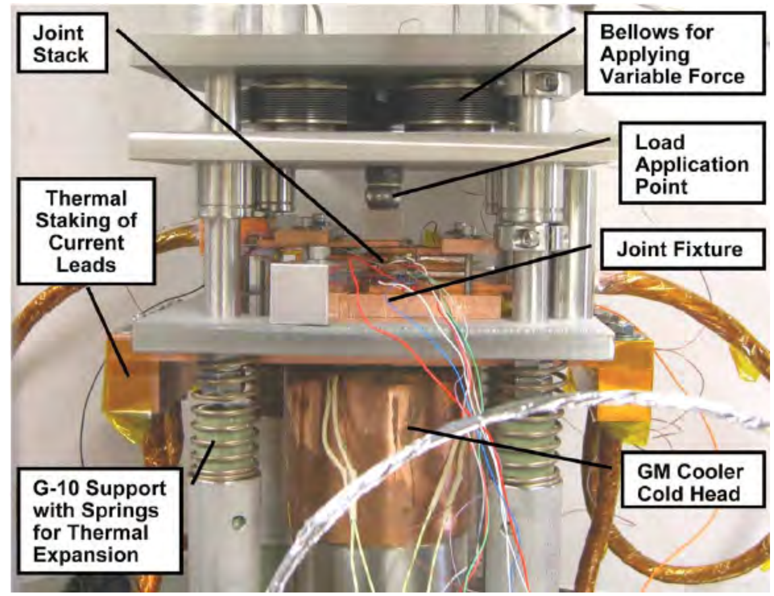


Fig. 3. Joint Fixture. Joints are connected and loaded in series. Voltage taps on either side of each joint are used to measure joint resistance.



Joint Loading Fixture.

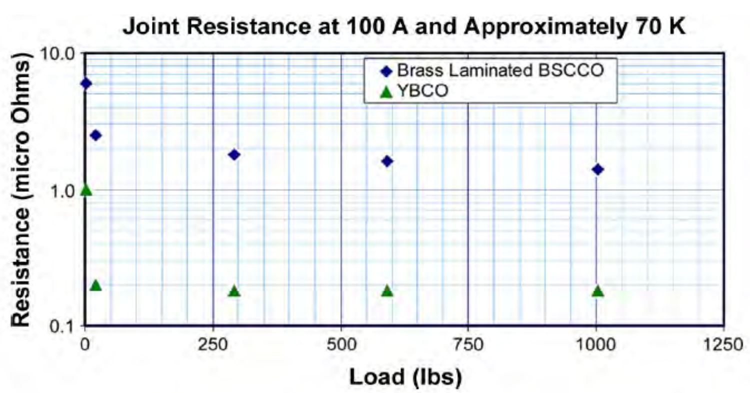
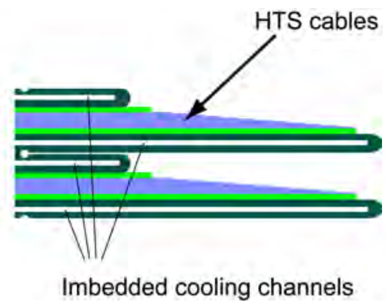


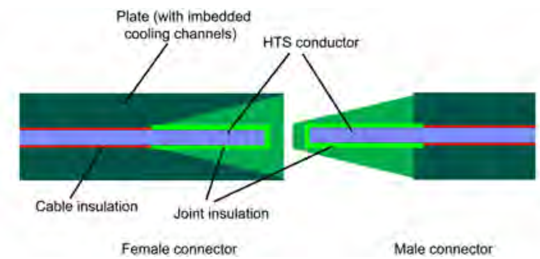
Fig. 6. Test Results. Measured resistance versus applied load for two lap joints: a dry joint between two unmodified *Hermetic* tapes (brass); and a shunt joint between two copper-laminated YBCO tapes soldered onto the *Hermetic* BSCCO tapes.

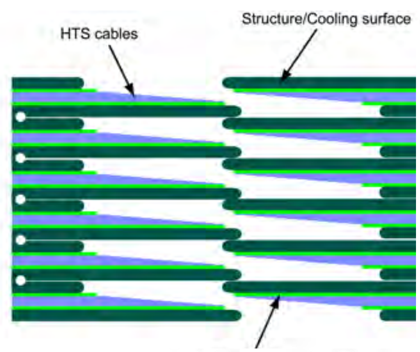
A.J. Dietz, W.E. Audette, L. Bromberg, J.V. Minervini, and B.K. Fitzpatrick, *Resistance of Demountable Mechanical Lap Joints for a High Temperature Superconducting Cable Connector, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY* **18** 1171 (2008)

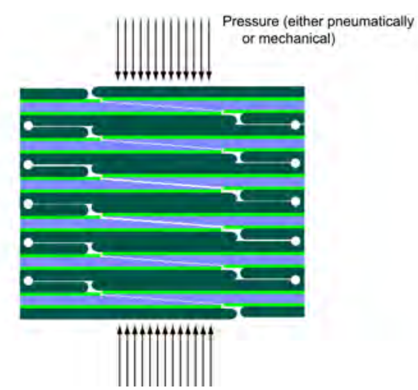
Geometry of Demountable Joints

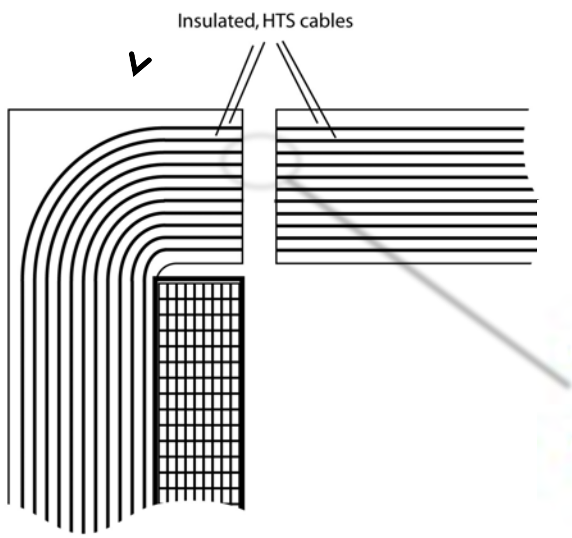
Case A Case B Case C

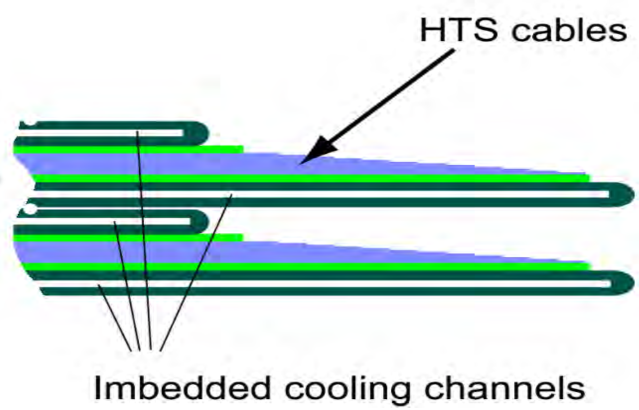












68 kA HTS current lead demo for ITER (BSCCO)

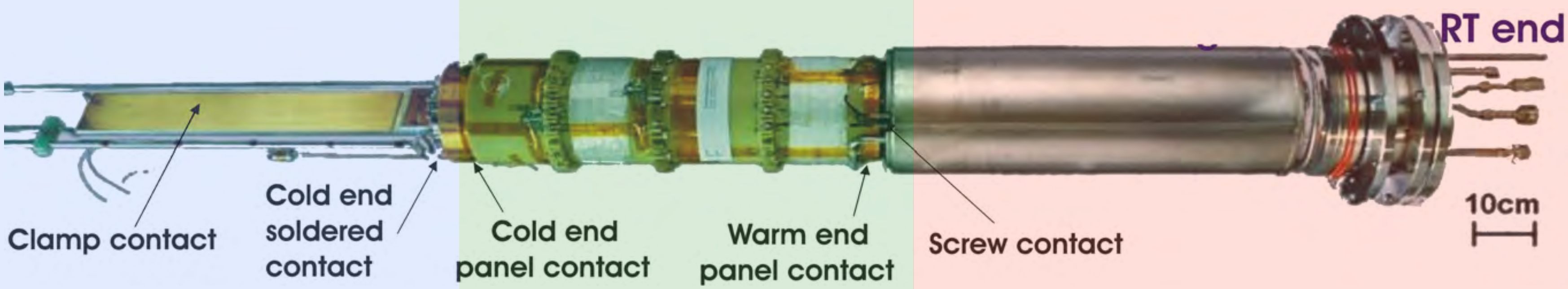
Developed and tested in FZK up to 80 kA

Current lead consists of three parts:

Connection to low T_c S.C.
4.5 K

HTS module (Bi - 2223/AgAu)
4.5 K - 65 K

Copper heat exchanger
65 K - 300 K



Conclusions

- HTS allows higher temperatures and fields compared to classical superconductors
- High current HTS conductors for operation with currents of tens of kA must be developed to address the following challenges:
  - Integration of large numbers of flat tapes into a conductor
  - Transposition of tapes to avoid circulating currents and to limit transient current and ac field losses
  - Hotspot temperature and quench requires:
    - Fast quench detection – need for new diagnostics based on optical fibers
  - Incorporation of copper stabilizer for quench protection
- Control of critical current anisotropy
- Development of low-loss joints
  - Demountable Coils