Defect tolerant, low-AC loss YBCO cable for fast ramping magnets

Vyacheslav Solovyov, Hyunwoo Kim and Paul Farrell

[1]Brookhaven Technology Group Inc., Stony Brook, NY 11794

www.brookhaventech.com

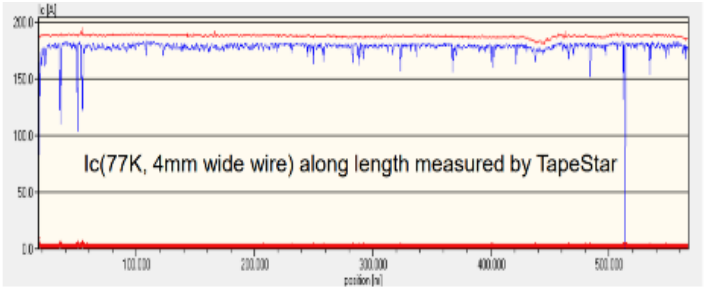
Supported by U.S. DOE Office of Science awards DE-SC0018737 and DE-SC0020832

Outline

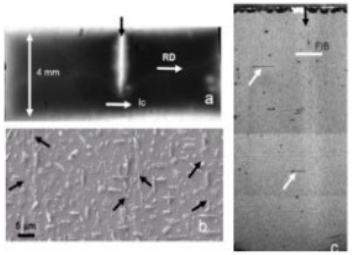
- Motivation: we need to overcome non-uniformity of 2G conductors
- Demonstration of defect tolerance
- Proposed defect –tolerance standard
- Narrow twisted stack manufacturing
- Conclusion and future work

Uniformity challenge of 2G technology

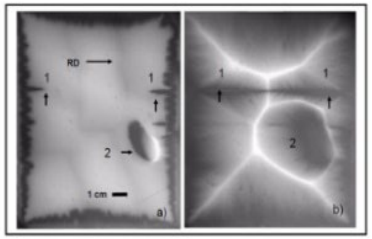
Defects reduce continuous coupon length



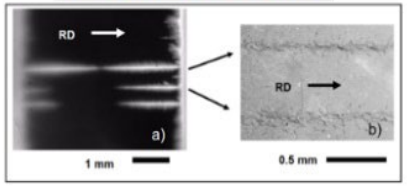
Across-tape defects



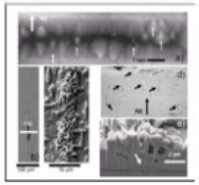
Deposition malfunction



Along-tape defects

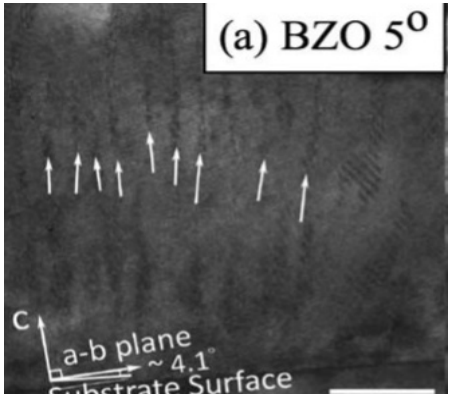


Epitaxy failure

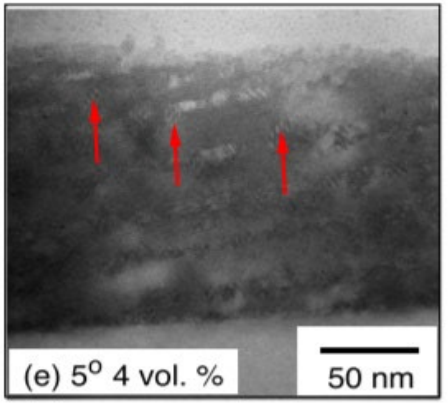


Non-uniform pinning properties, especially for correlated APC

Aligned nano-rods



Splayed-horizontal

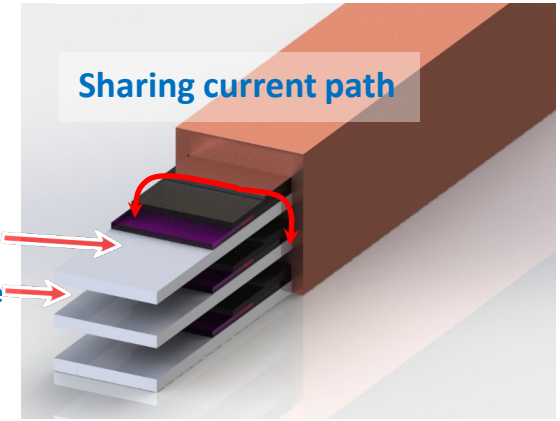


- ✓ Defects and non-uniformity
- ✓ High AC loss

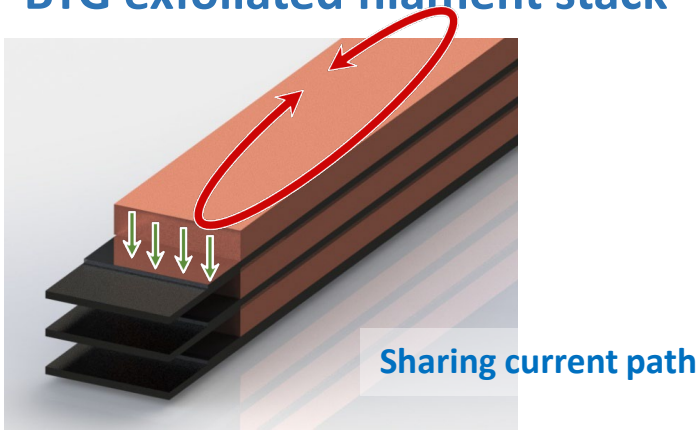
Defect—tolerant, low AC loss cable

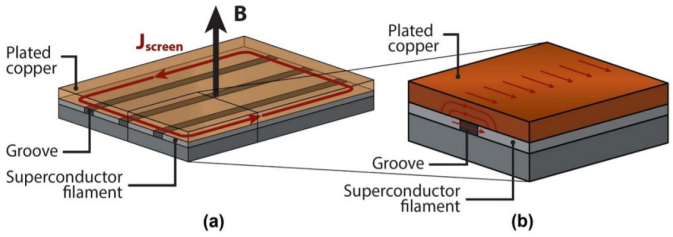
- Single-filament magnets proven difficult to protect against burnout
- Substrate prevents efficient current sharing, especially in narrow, low AC loss cables
- Multifilamentary cable is far more expensive than a single tape

2G wire stack

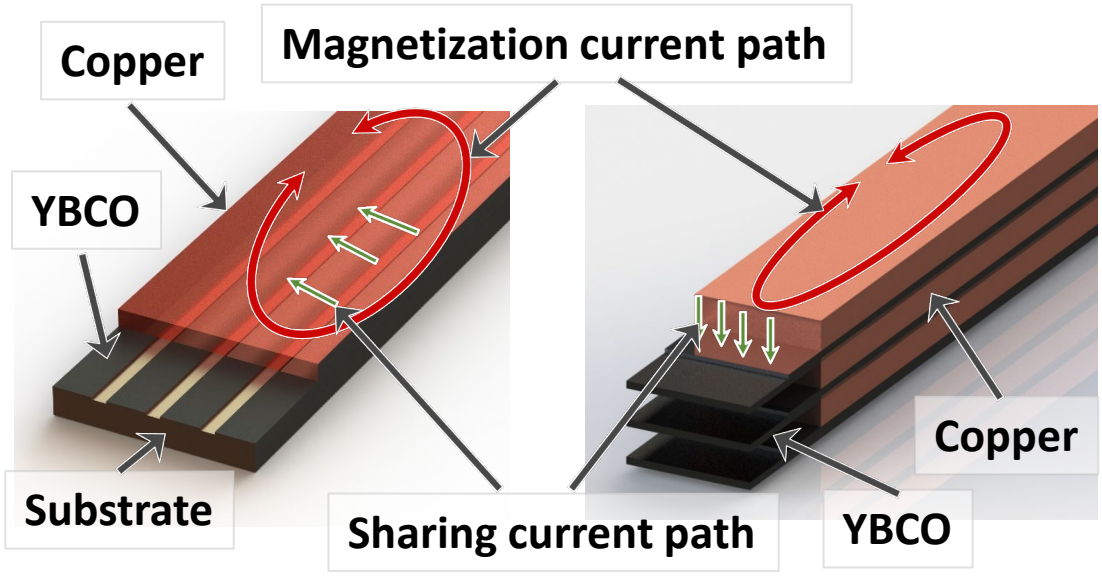


BTG exfoliated filament stack

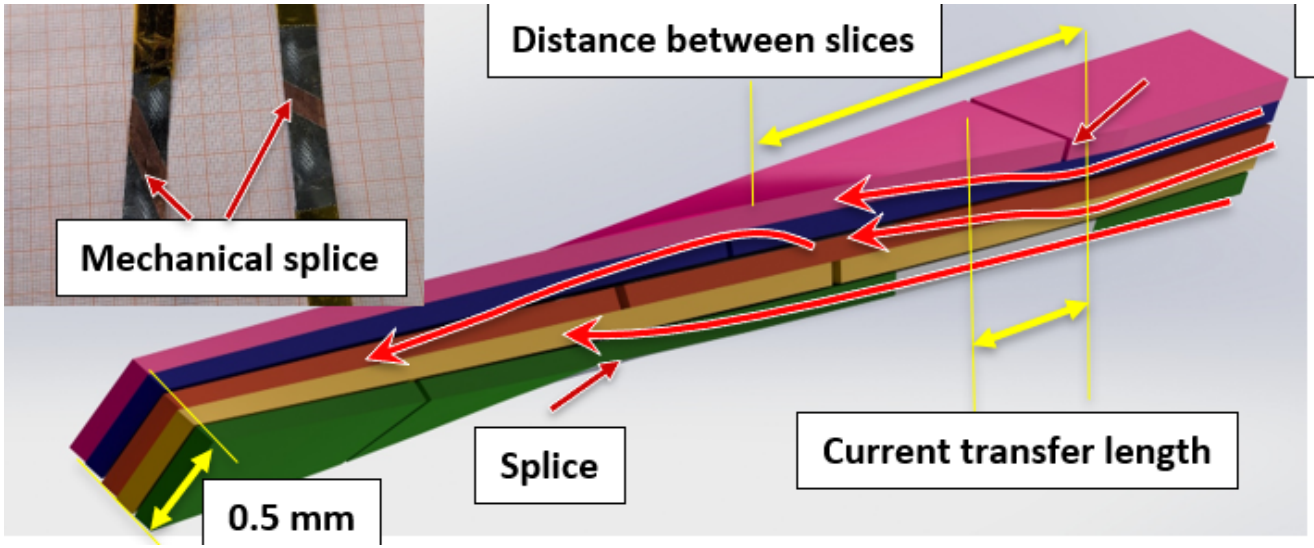


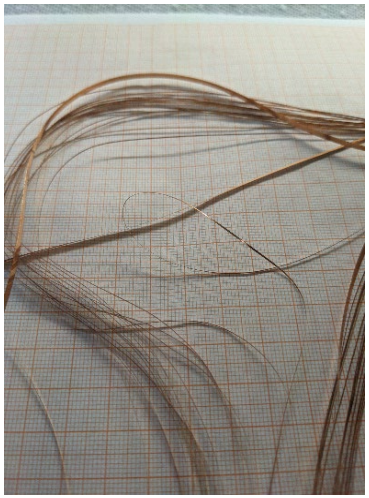


AC loss vs. defect tolerance



Infinite length, splice-free narrow cable

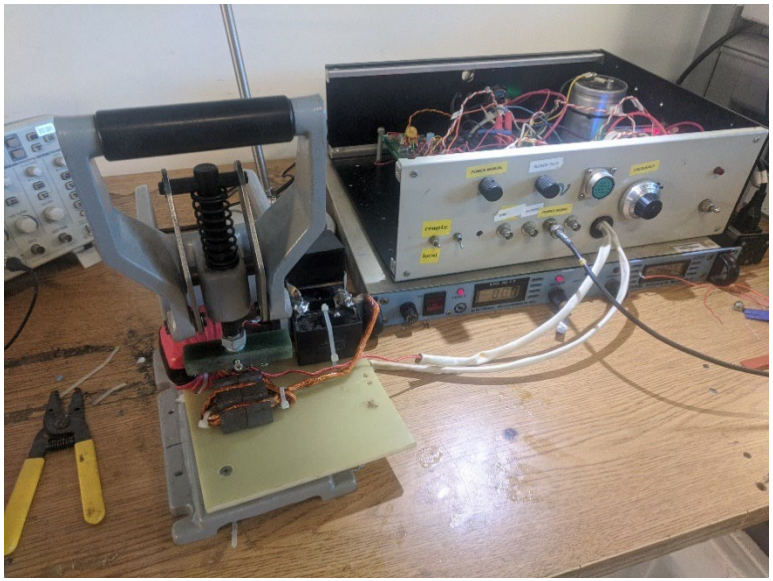


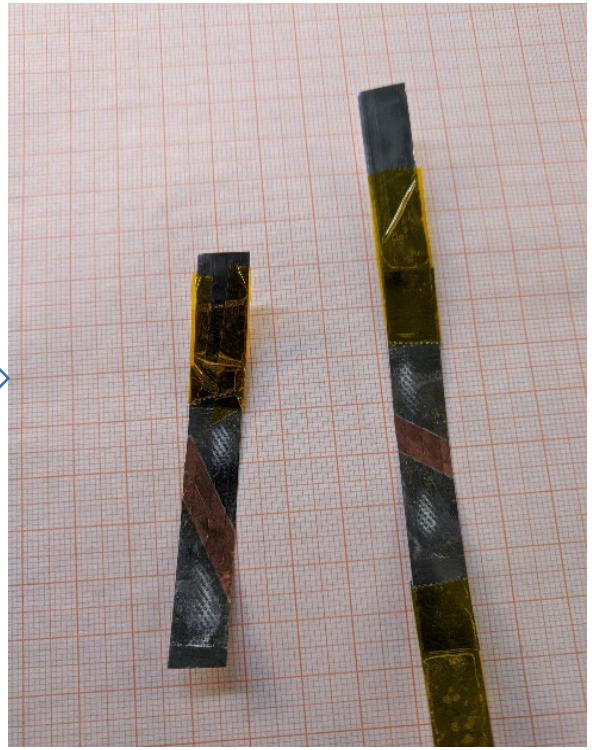


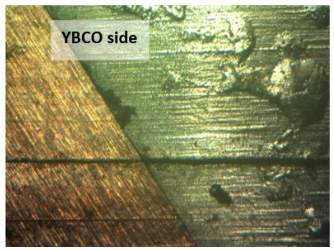
20 0.5 mm filaments

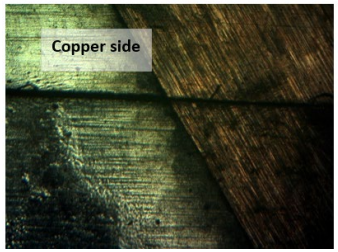
- **Human handling < 1 mm filaments is next to impossible**
- **Only wide, 10-12 mm tape is spliced and handled**

Low-profile mechanical bonding of filaments



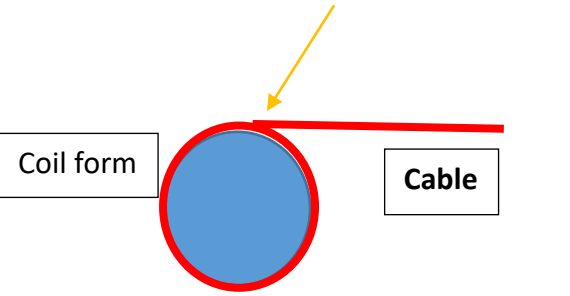




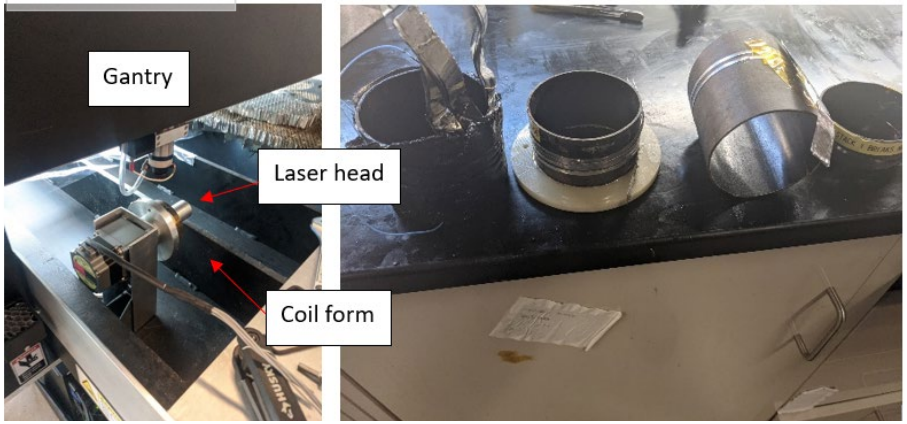


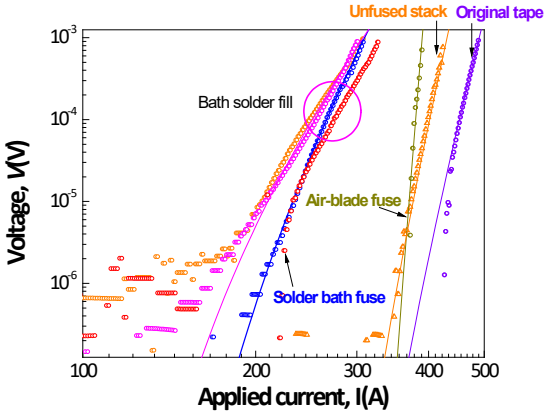
- ✓ **Low-profile mechanically strong bond: simulated “break”**

Fusing the filaments during the coil winding

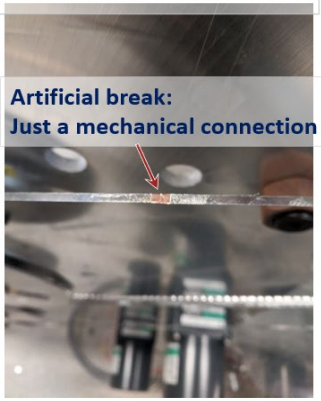


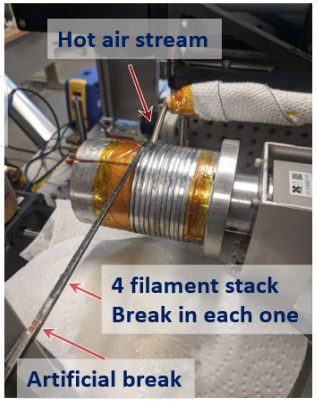
CO2 laser





Hot air stream

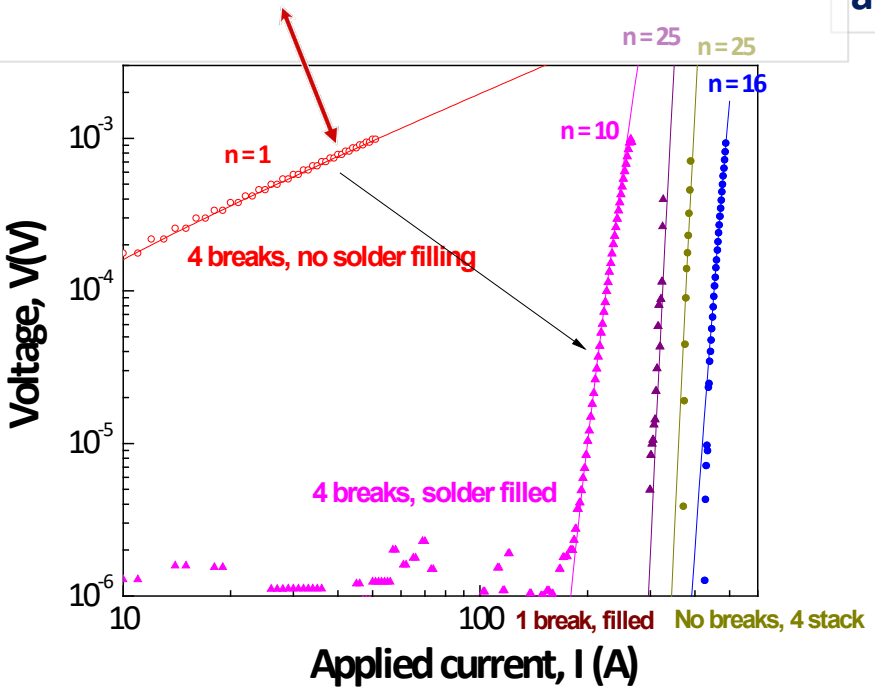




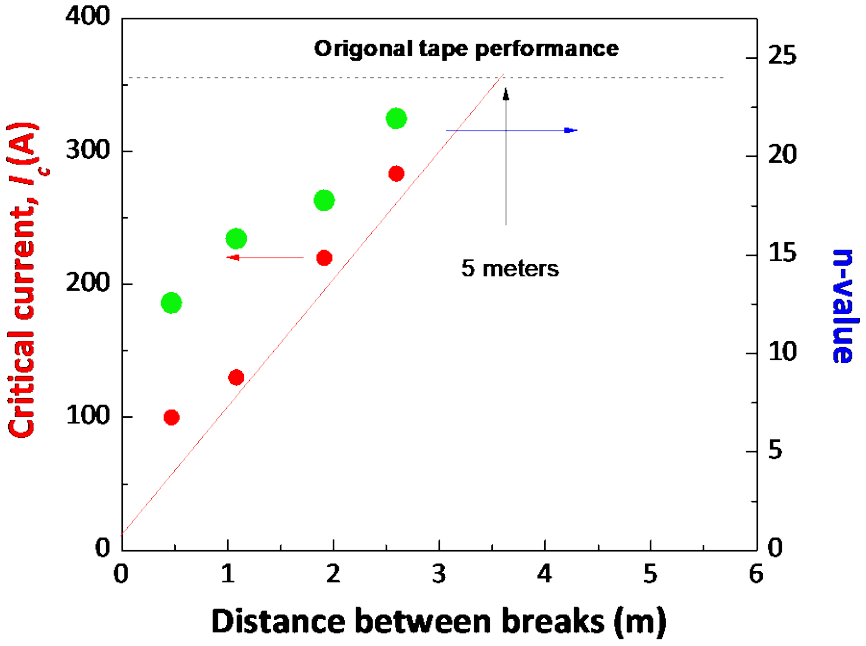
- ✓ Cable needs to be fused right before it is laid on the coilform
- ✓ Air blade method did not degrade I_c and provided the lowest contact resistance

Critical role of filament fusion

Without low-resistance filament soldering
We get a resistor



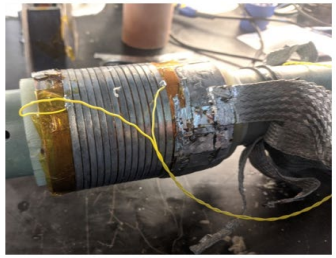
When breaks > 5 m apart, the coil would behave as if no breaks are present



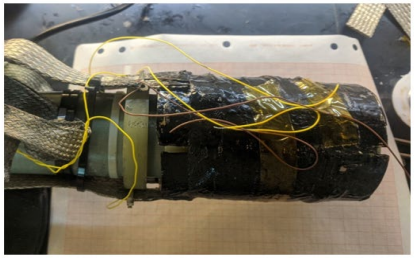
✓ Unfused filaments have negligible current sharing: just mechanical contact resistance is very high

Demonstration coil: 4 filaments, layer wound, break in each filament

As wound coil

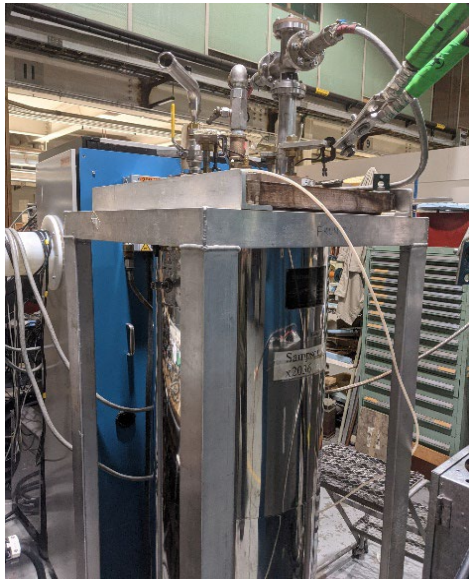


After impregnation



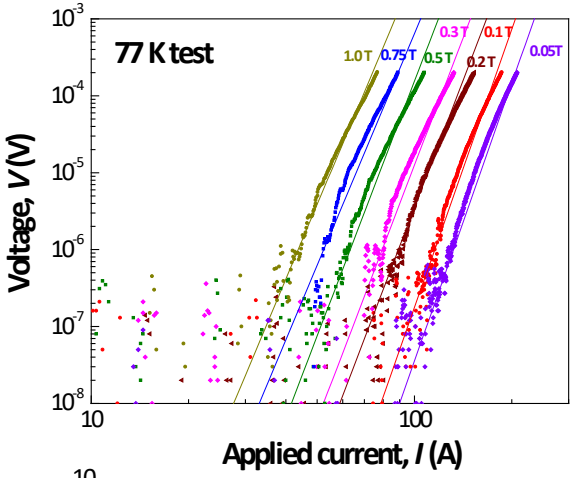
Demo coil:

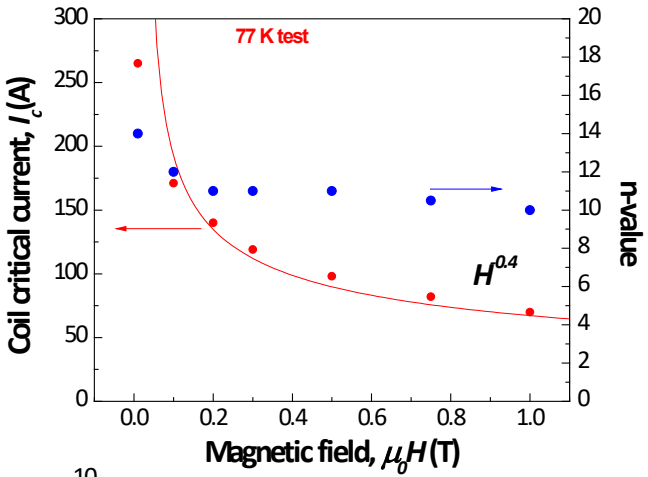
- **5 meters of 2 mm 4 filament cable**
- **Each filament has a break**
- **10 cm ID**



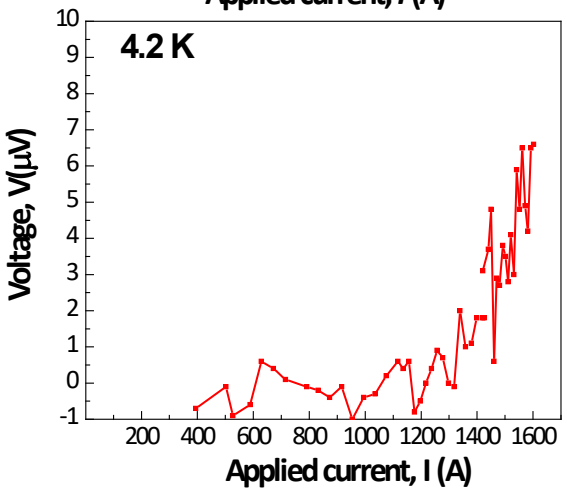
Demo coil test at 77 K and 4.2 K

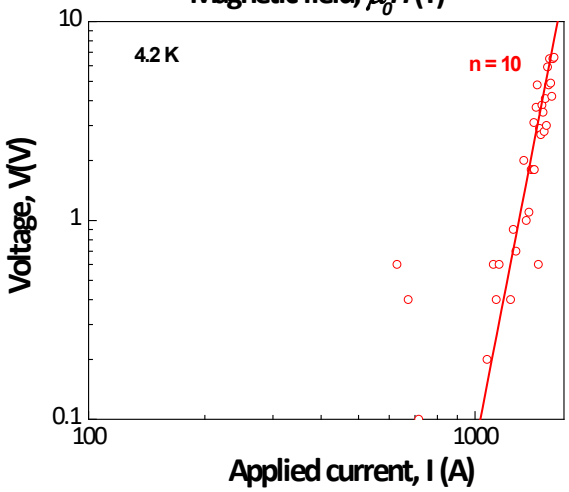
77 K





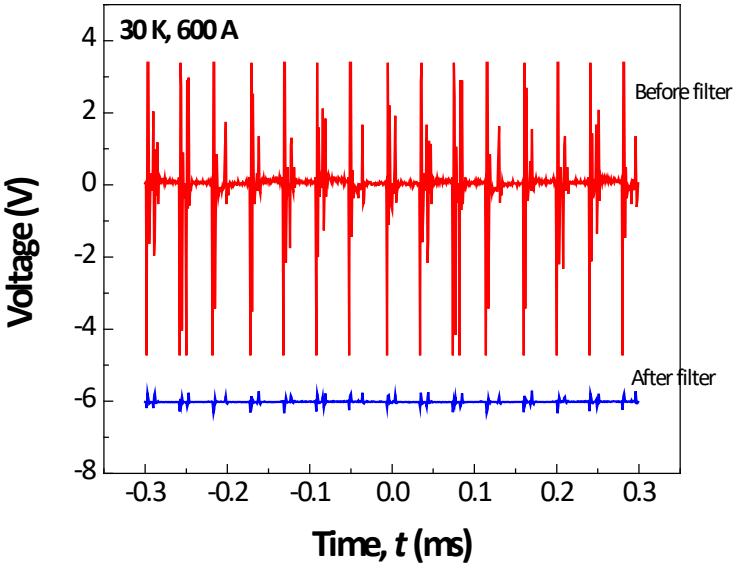
4.2 K

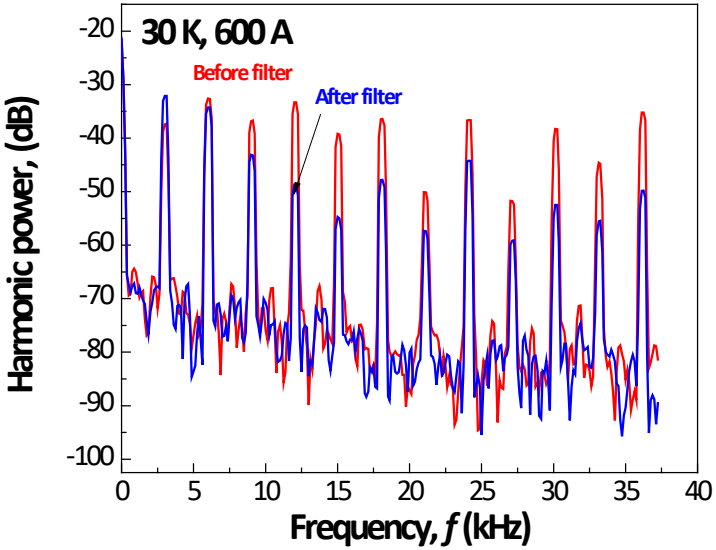


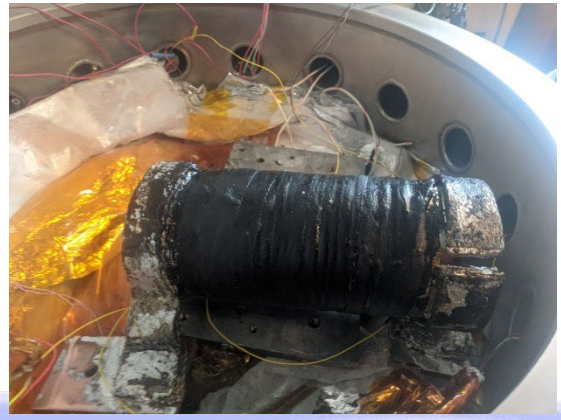


- ✓ The coil sustained 1,600 A at 4.2 K, $R < 1$ nΩ
- ✓ The n-value is limited by the discontinuities

Application: high current ripple filter for cryogenic power supply



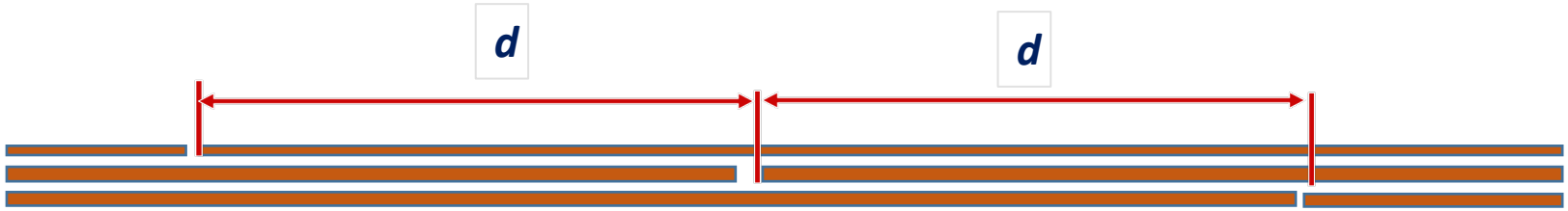




Superconducting ripple filter in the cryochamber

- ✓ Reliable operation in conduction-cooled mode under high AC ripple load because of narrow defect-tolerant cable

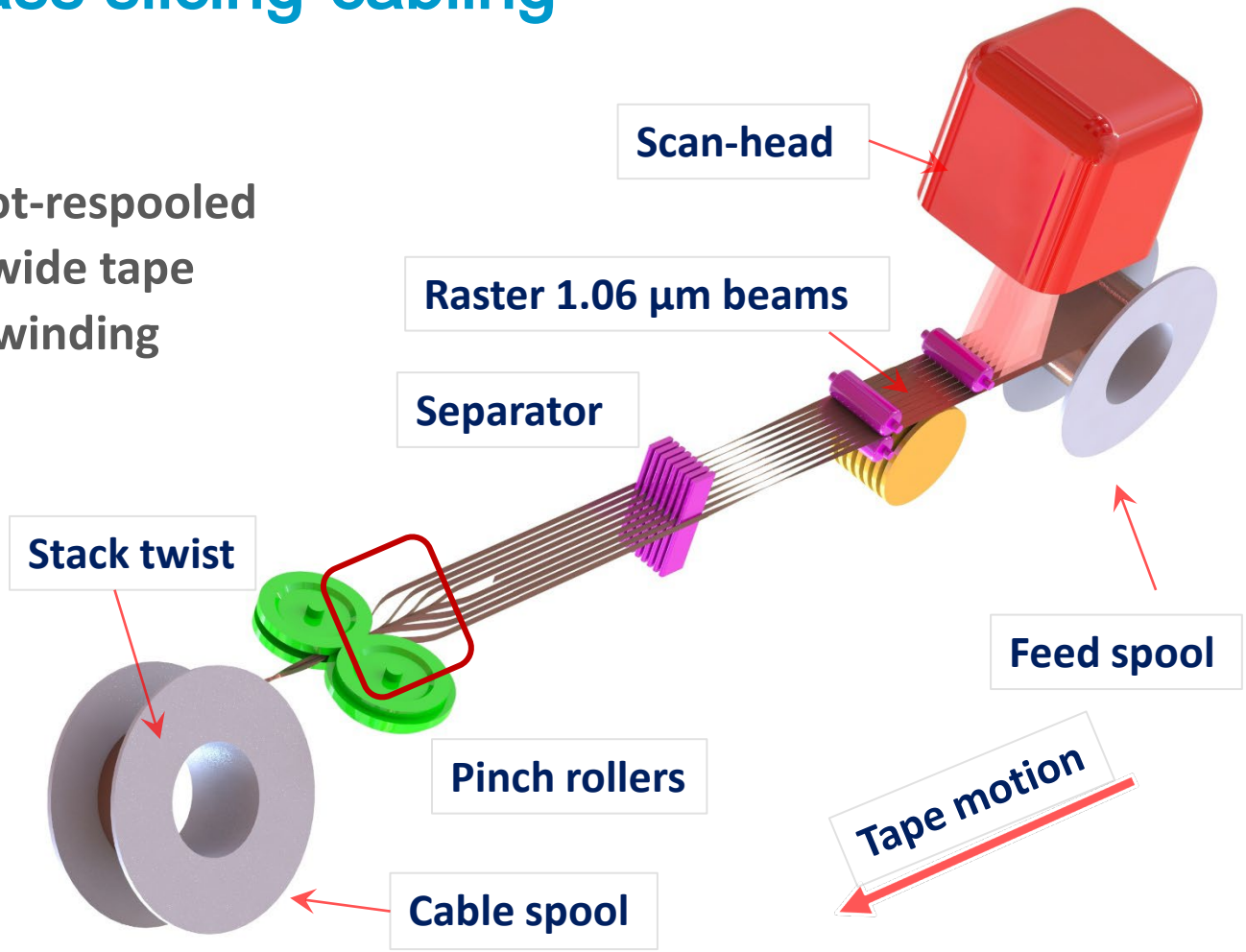
The proposed simple test/standard for HTS cable defect tolerance



- Cuts staggered at an average distance *d* from each other
- Both *n*-value and I_c are measured as a function of *d*
- The critical *d* value, $\boldsymbol{d_c}$, at which 90% of the cable performance, *n*-value and I_c, is restored
- For narrow 2G cable we estimate $d_c < 5$ m

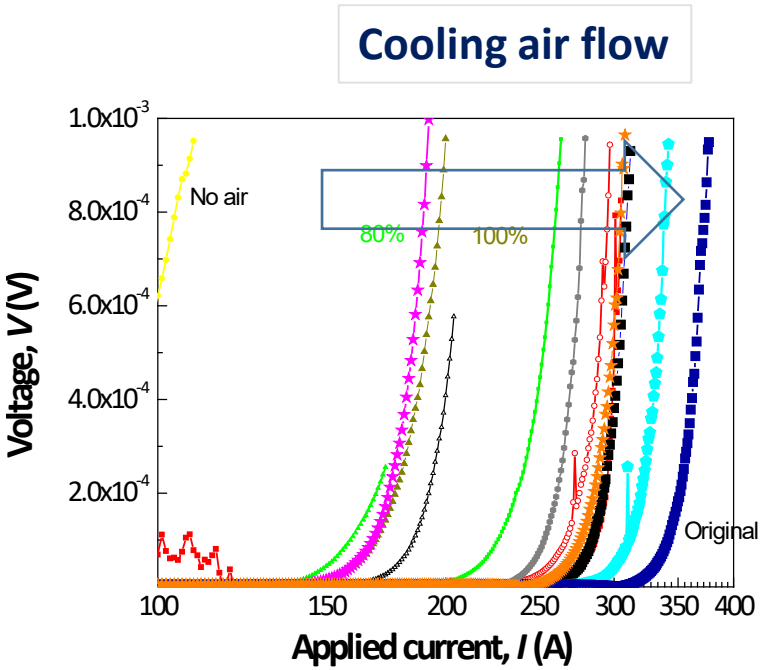
Approach: one pass slicing-cabling

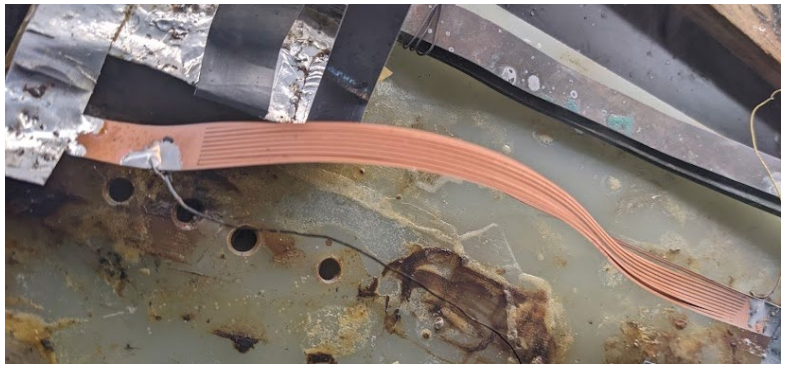
- Narrow filaments are not-respooled
- All processing done on wide tape
- The cable is fused post-winding

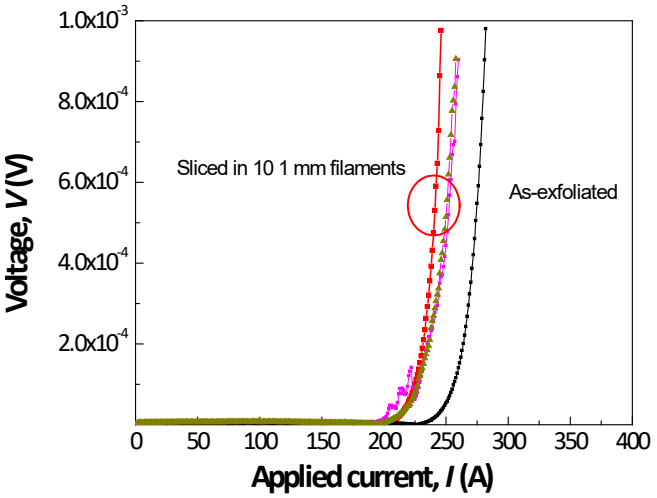


Human handling of only wide tape

Laser slicing optimization

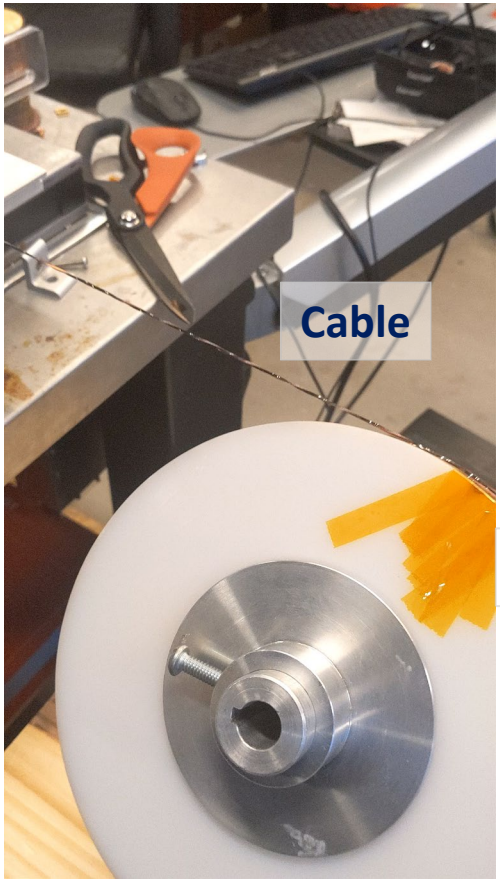






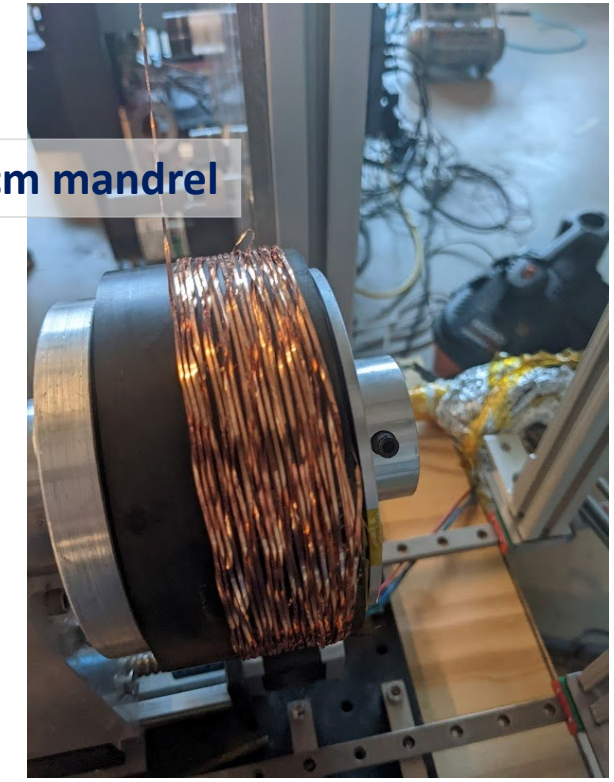
✓ **Optimized slicing retains up to 90% of the original Ic**

Cabling and twisting

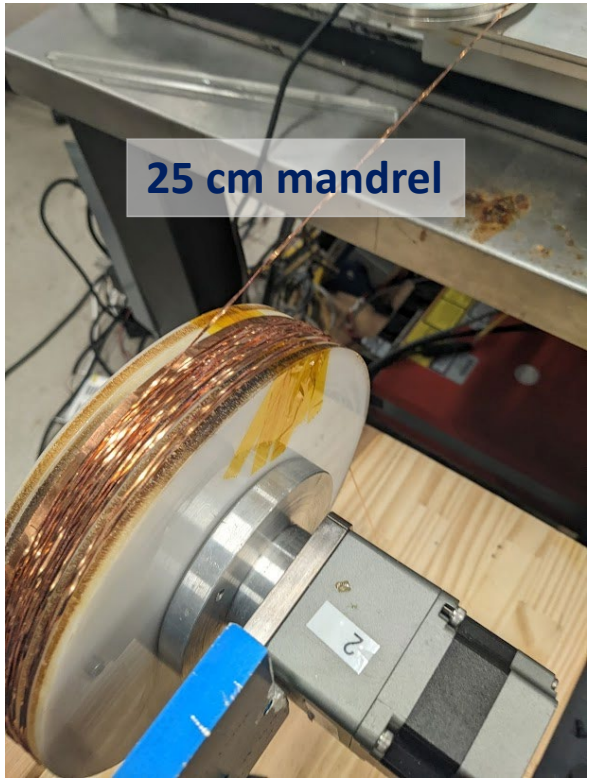


Copper filament tests

10 cm mandrel

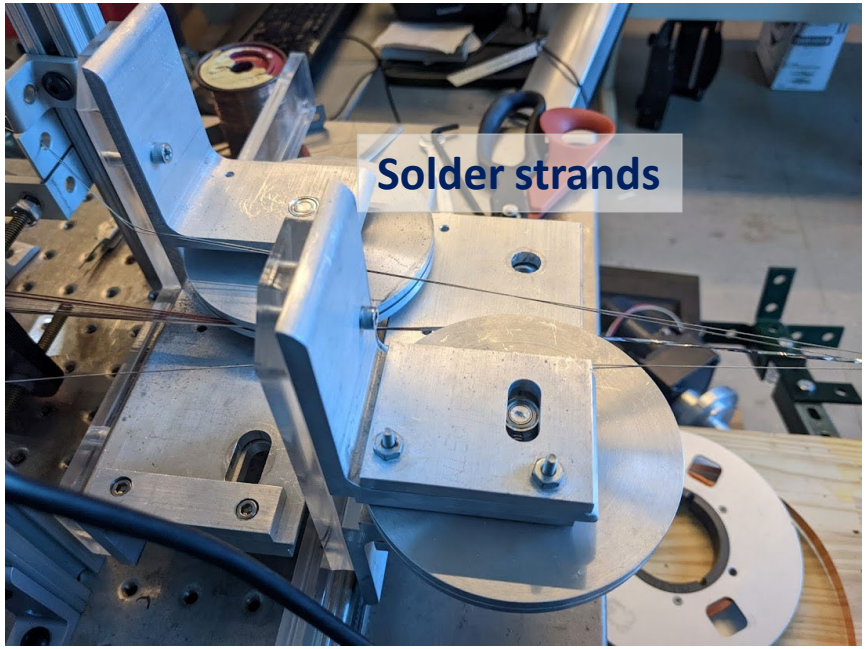


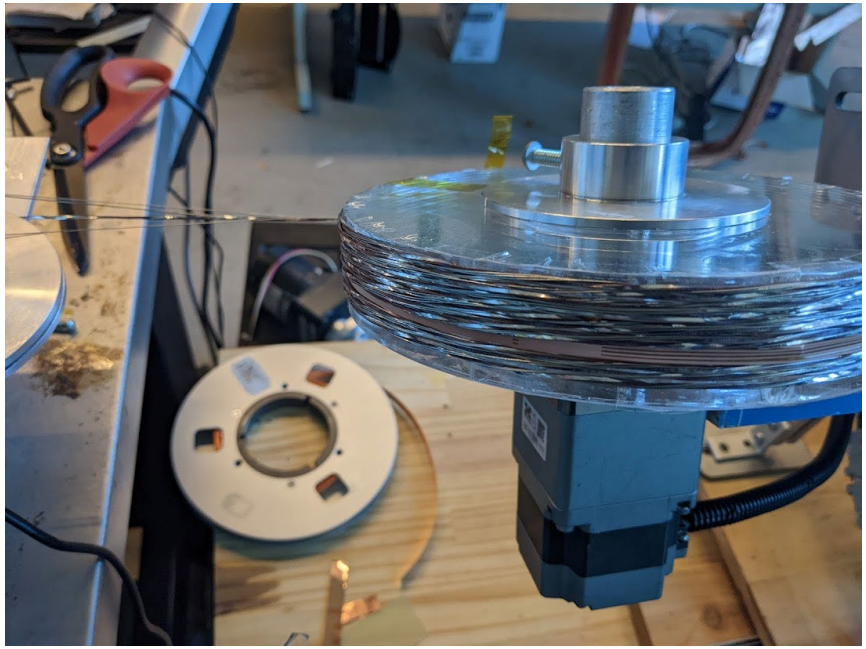
25 cm mandrel



✓ The setup was tested on 50 µm thick copper tape

YBCO cabling

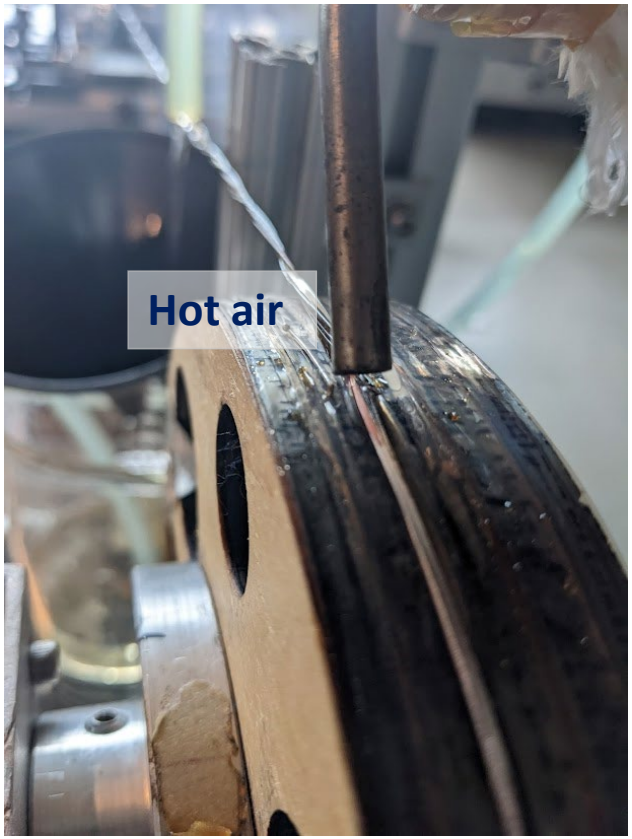


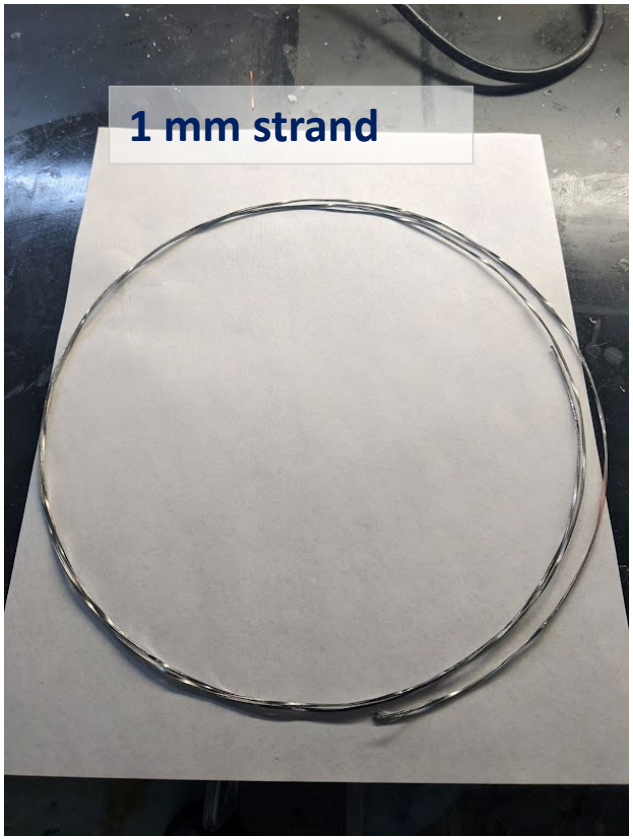


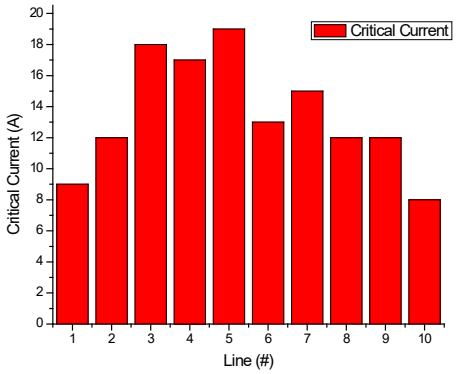
- ✓ **Solder is co-wound with the YBCO stack**

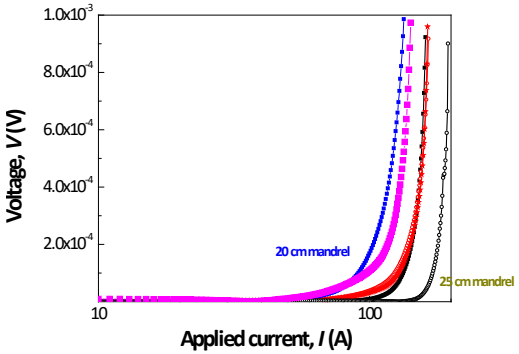
Coil winding-filament soldering

Outer filaments degrade more









- ✓ 150 A in a coil form
- ✓ Bending diameter 25 cm

Summary

- Defect tolerance can be achieved if resistivity between the filaments on the order of 100 $n\Omega\ cm^2$
- Mechanical contact unreliable, rapid solder fusion is critical
- We demonstrated defect tolerance by making a demo coil with each filament cut on purpose
- The coil operated up to 1,600 A (2,000 A/mm^2) at 4.2 K
- We propose a standard for defect-tolerance of 2G cables

Personal notes

- Buffer is a bad player: very brittle highly strained ceramic layer
- Filaments need to slide very freely during cabling
- Filaments cannot be pre-tinned
- Bend radius limit is real