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Transverse stress limits of Bi-2212 Rutherford cables at 11 T, 4.2 K

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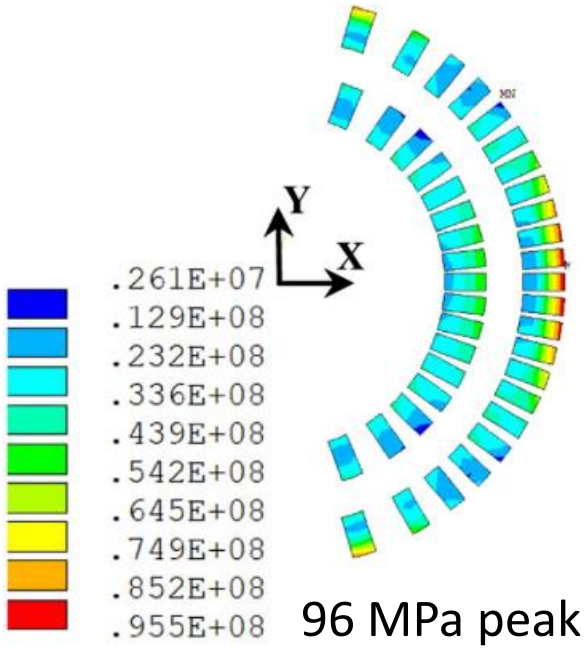
24th of July 2024

Motivation: stress in Bi-2212 dipole magnets

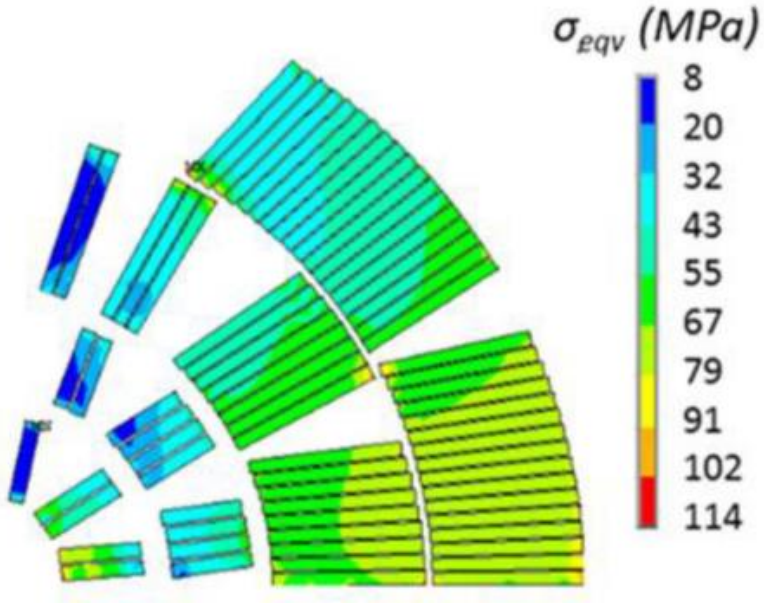
- 80 to 105 MPa stress (von Mises) expected in Bi-2212 dipoles
- Experimental data of Bi-2212 cables under transverse load is needed

Garcia Fajardo et al. (2022)
https://doi.org/10.1109/TASC.2023.3264788



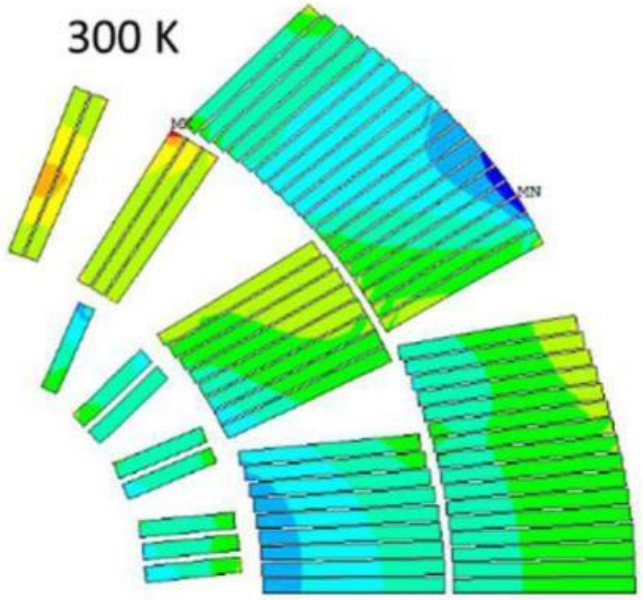
96 MPa peak stress

Zlobin et al. (2022)
https://doi.org/10.1109/TASC.2022.3158635



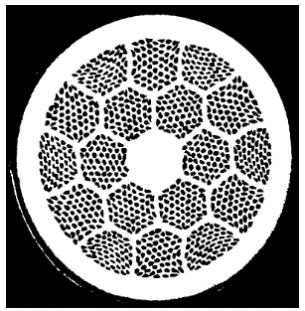
104 MPa peak stress

Zlobin et al. (2023)
https://doi.org/10.1109/TASC.2023.3264165



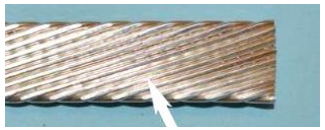
80 MPa peak stress

Collaboration for Bi-2212 transverse stress test

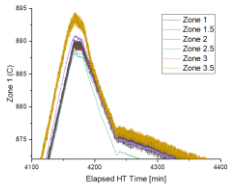


Bi-2212 powder from Engi-mat (commercial)

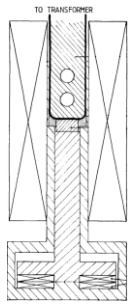
Wire preparation by Bruker OST (commercial)



Rutherford cabling at LBNL



Over-pressure heat treatment (OPHT) by NHMFL



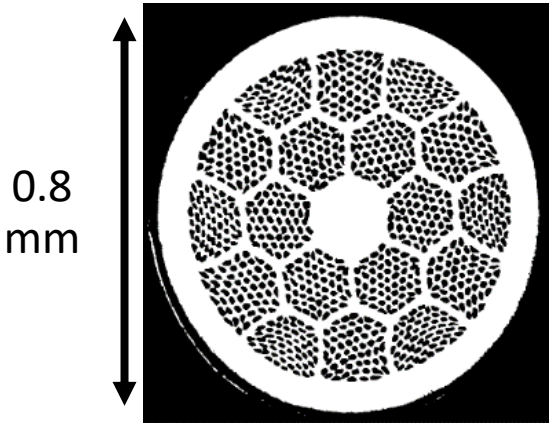
Transverse stress test at Twente University

four cables tested in two years time (2022-2024)

Wire and cable properties

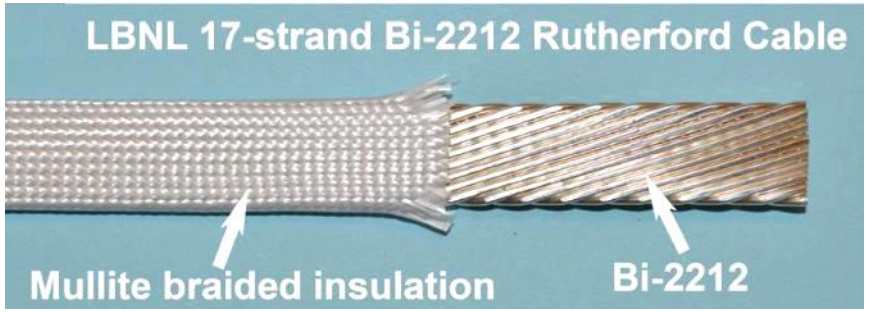
Wire layout

- Bi-2212 in Ag matrix
- 0.8 mm diameter
- 55x18 filaments



Rutherford cable

- 17 strands
- 58 mm twist pitch
- 7.8 mm x 1.4 mm
- Insulated by mullite or alumina sleeve



Samples

- Same parameters but from different cable and wire batches
- Changed to alumina insulation for sample 5 and 6

	Cable	Insulation	Measurement
Sample 3	LBNL1109	Mullite	Dec. 2022
Sample 4	LBNL2002	Mullite	June 2023
Sample 5	LBNL1109	Alumina	April 2024
Sample 6	LBNL1109	Alumina	July 2024

Images by Zhang et al. (2018) https://doi.org/10.1088/1361-6668/aada2f

Sample preparation

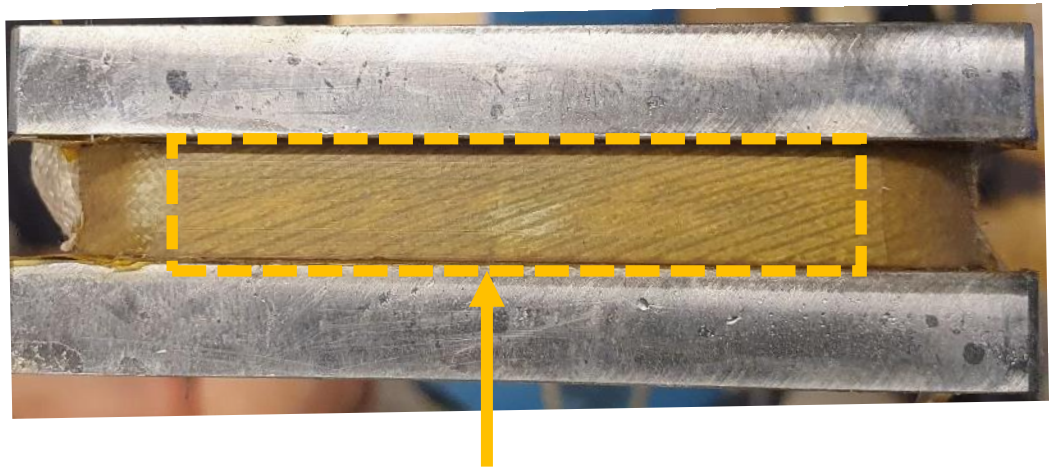
Heat treatment

- OPHT at 50 Bar with 1 Bar oxygen
- U-shape for press experiment

30 cm

Vacuum impregnation

- CTD-101k epoxy resin
- Done on U-shaped sample holder for press



45 mm section for applying transverse stress

Transverse stress setup

- 50 kA superconducting transformer
- 11 T solenoid magnet
- 250 kN press
- 4.2 K helium bath

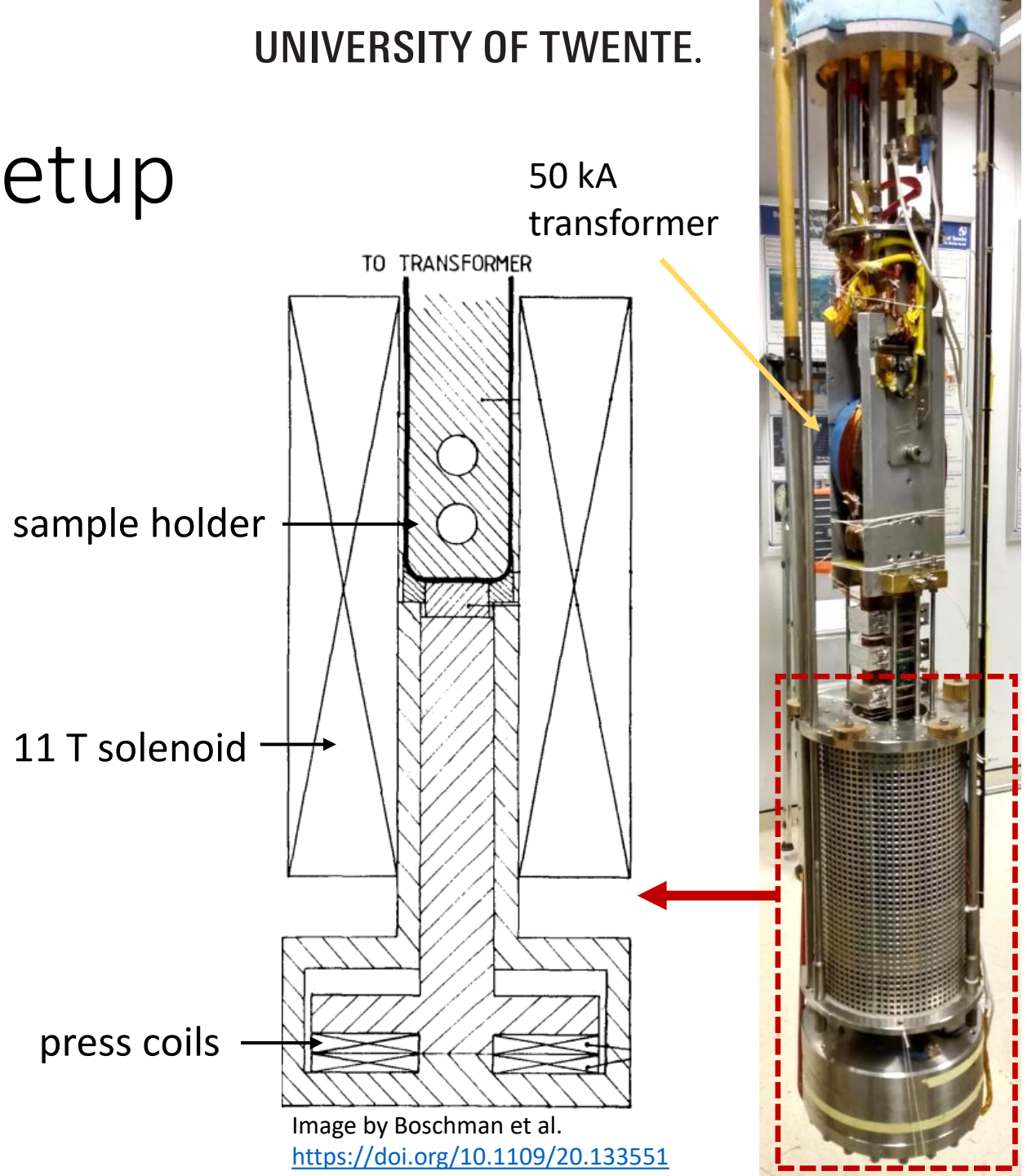
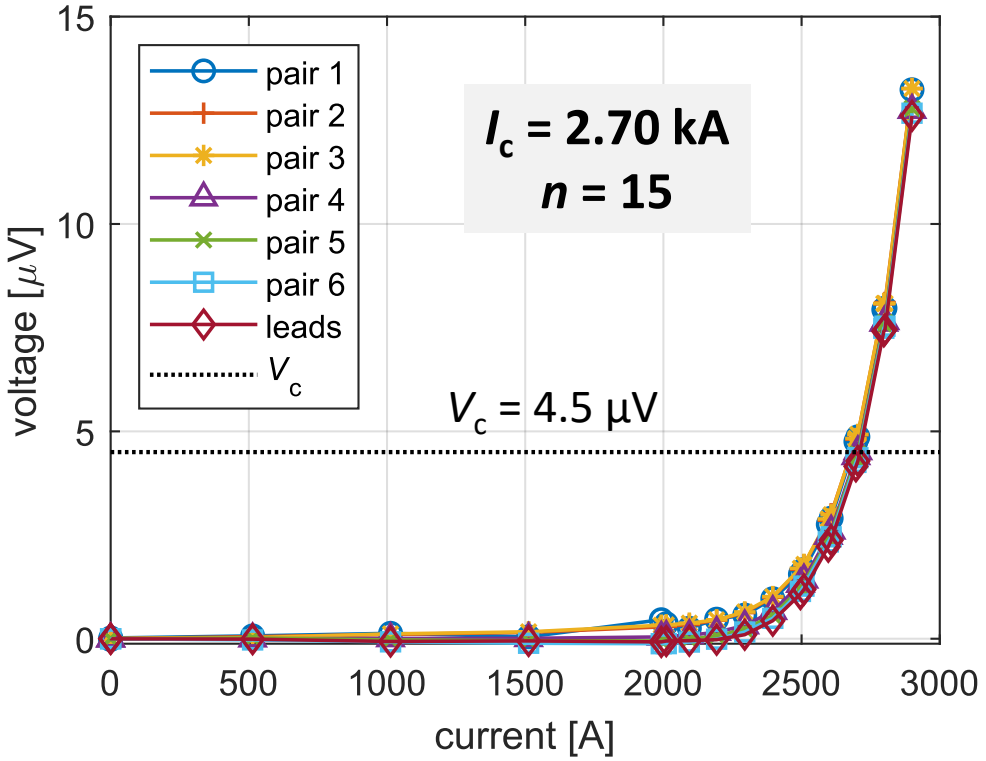


Image by Boschman et al.
https://doi.org/10.1109/20.133551

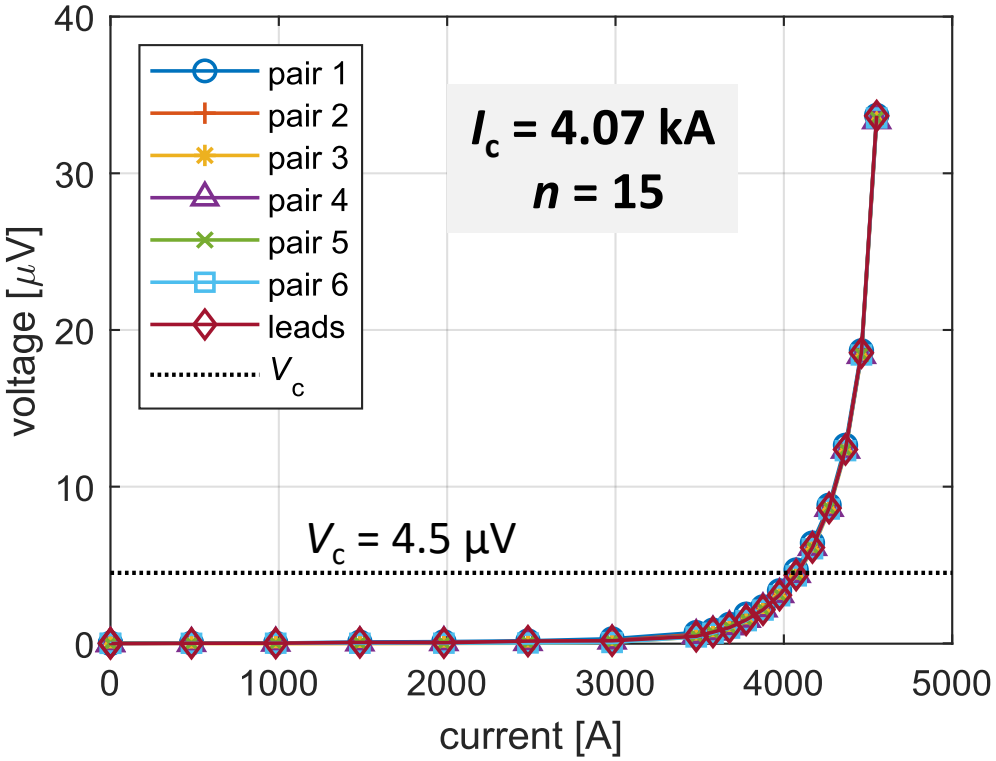
Initial current-voltage curves

- Measured at T = 4.2 K, B_a = 11 T and 10 MPa of transverse stress
- All cables are stable up to E > 100 µV/m without training
- $V(I)$ curves measured on six strands yield consistent I_c and n values

Sample 3: LBNL1109 (Dec 2022)

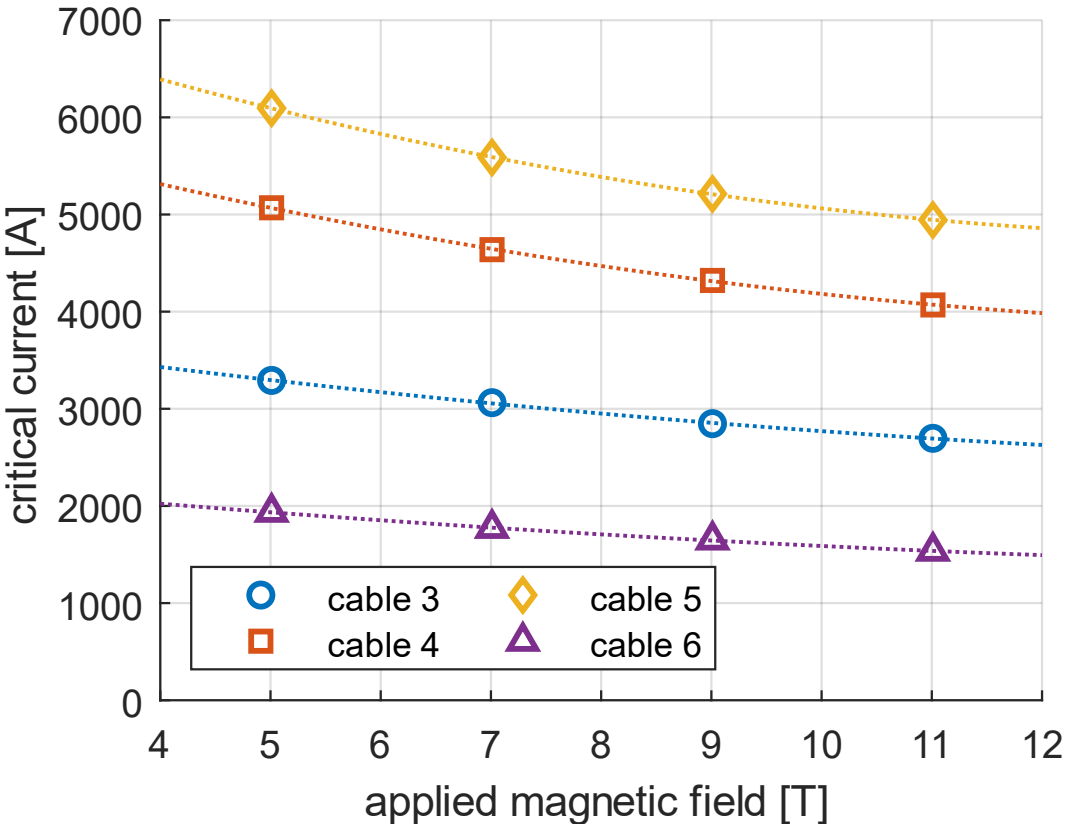


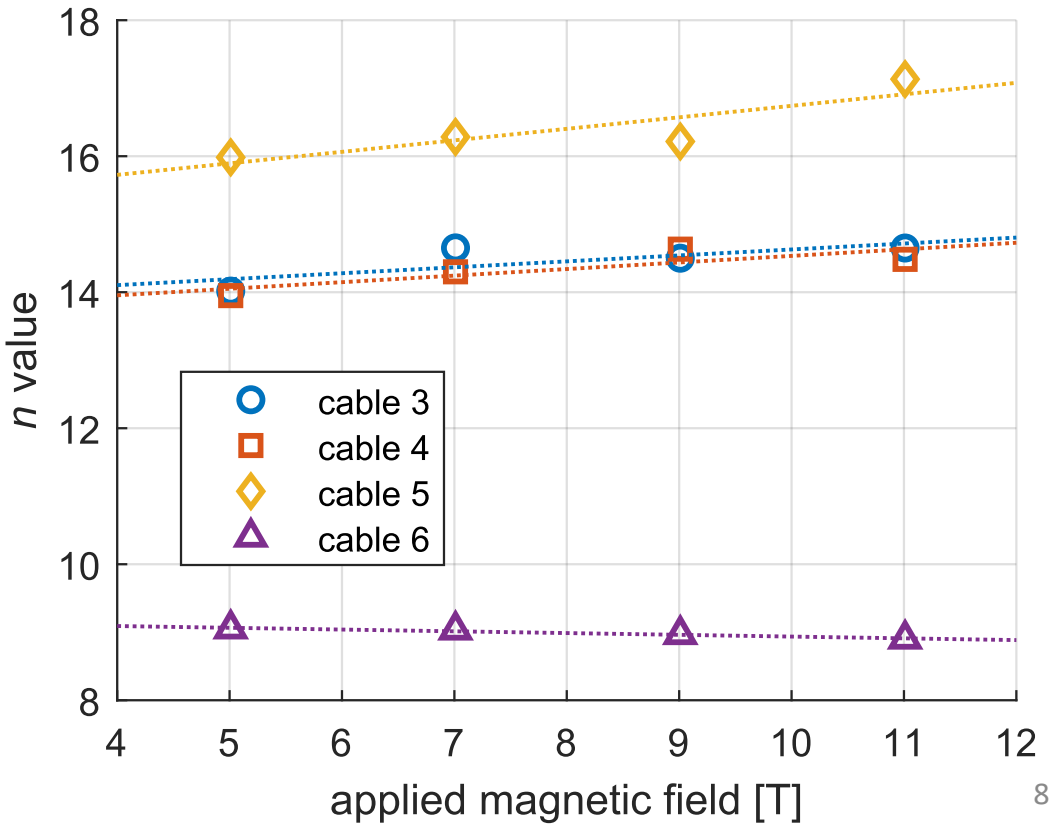
Sample 4: LBNL2002 (June 2023)



Initial $I_c(B_a)$ curves

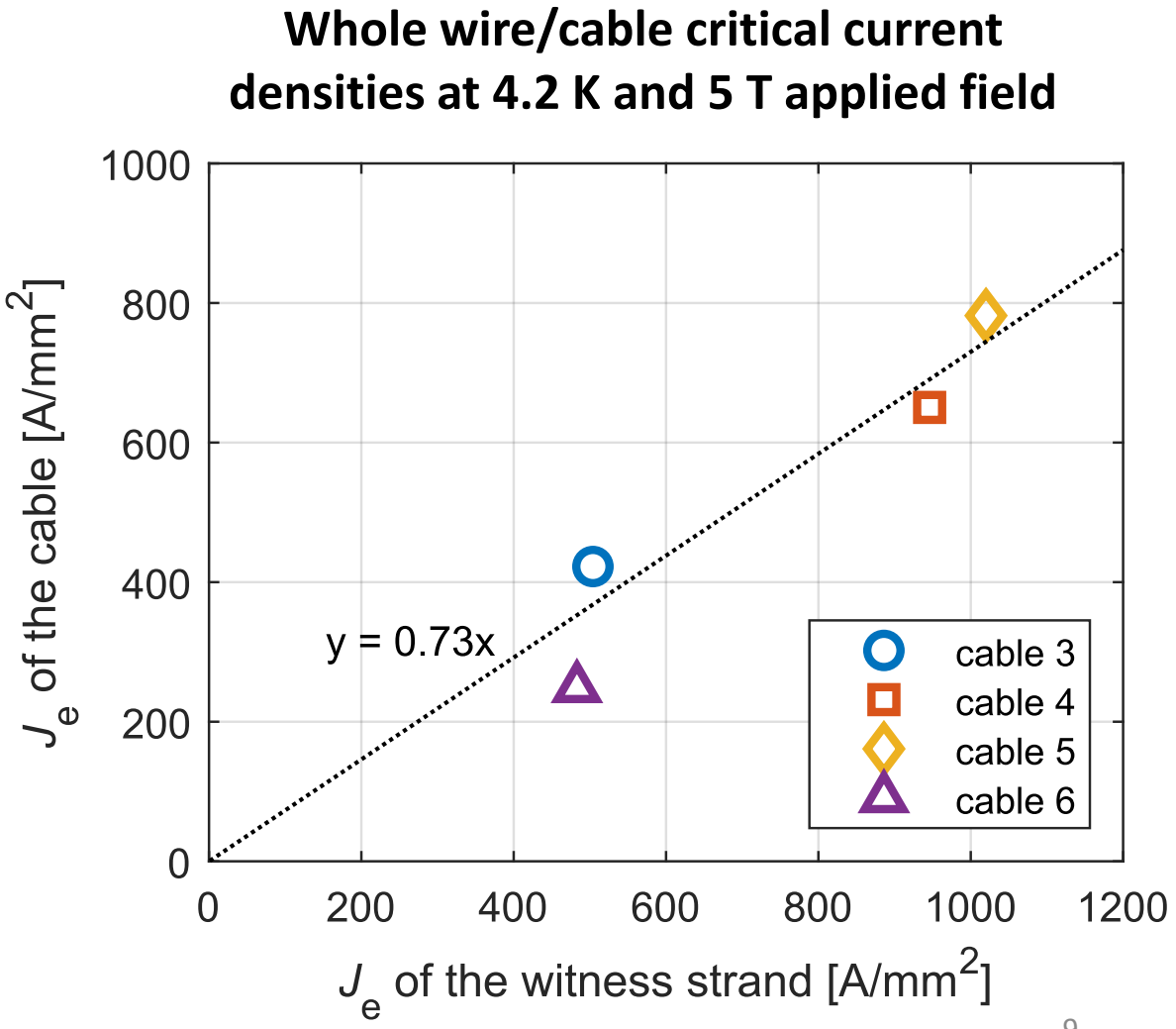
- Measured at T = 4.2 K and 10 MPa transverse stress
- There is a significant difference between the samples in both I_c and n





Comparison with witness strands

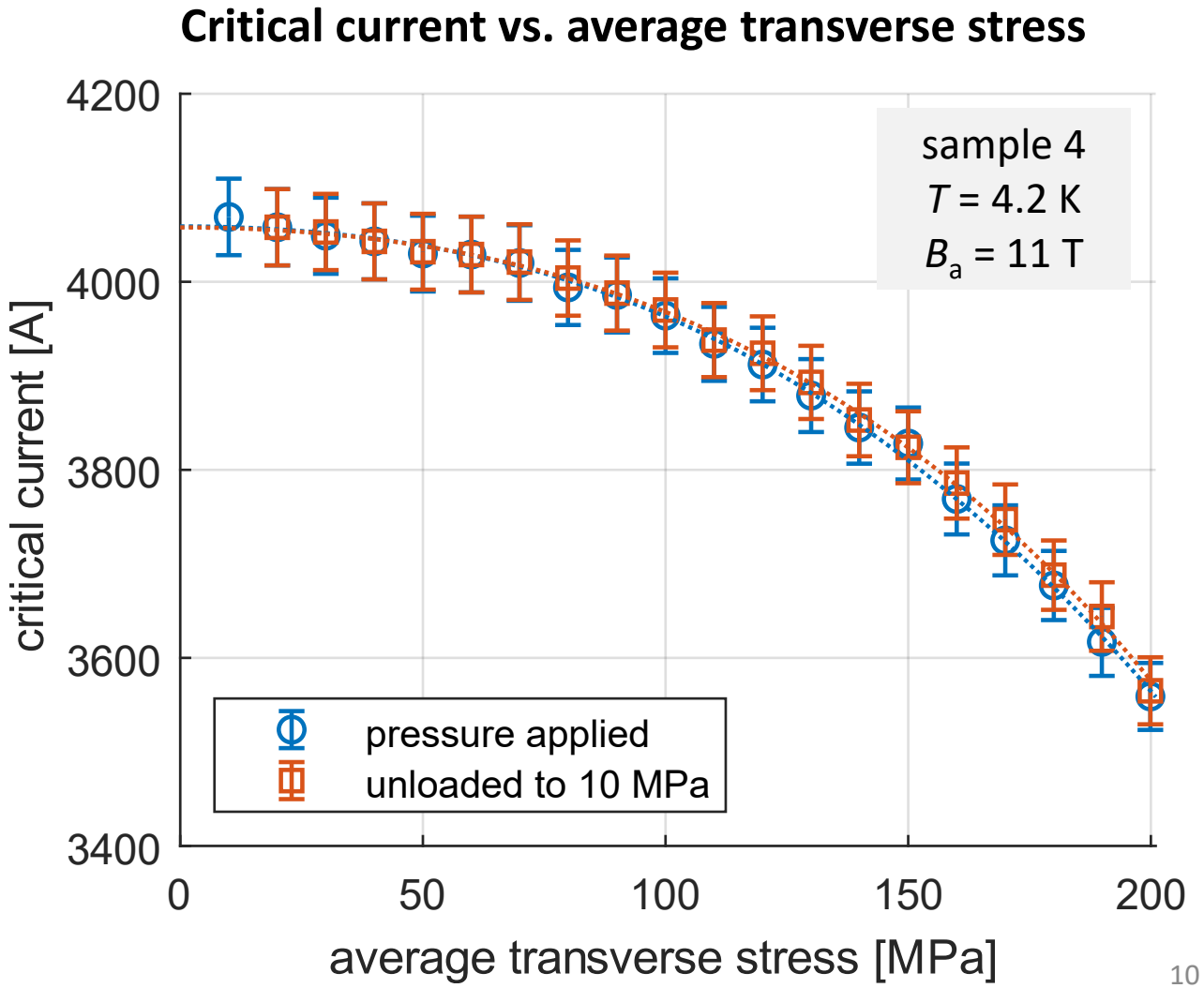
- Witness strands of cable 4 and 5 reached nominal performance (900-1000 A/mm^2)
- Witness strands of cable 3 and 6 had below nominal performance
- Note: witness strand and cable are not from the same wire batch



Transverse stress test: measurement sequence

- Measurement sequence:
  - **10 MPa**
  - **20 MPa**
  - **10 MPa**
  - **30 MPa**
  - **10 MPa**
  - **40 MPa**
  - etc.

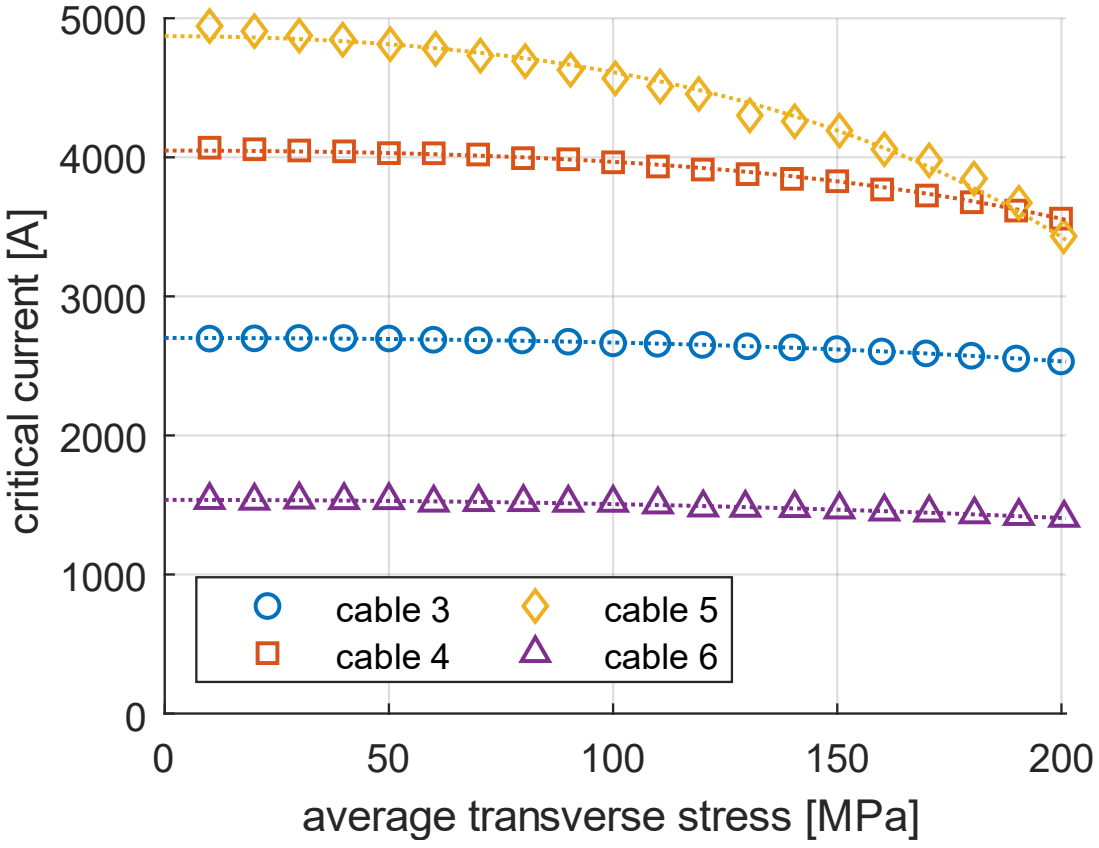
- No reversible effect observed in any sample



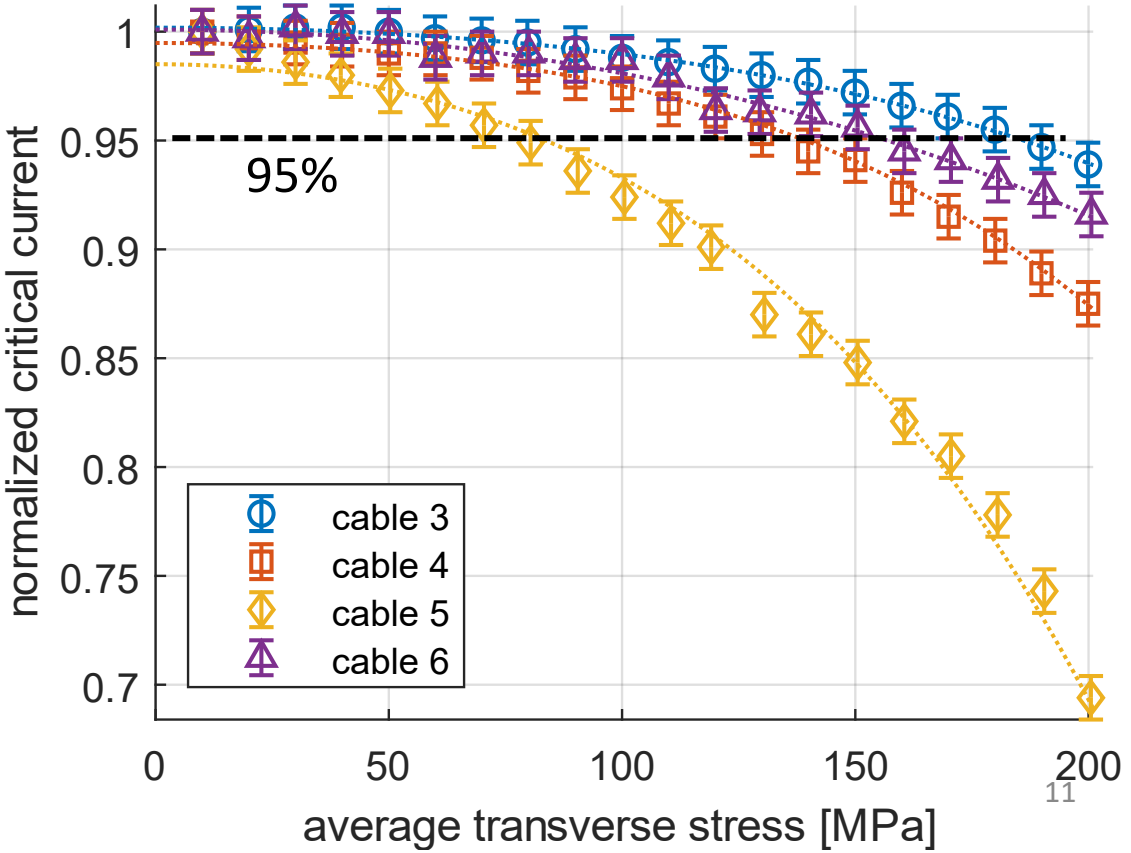
Transverse stress test: sample comparison

- Samples 3, 4, and 6 reach 5% degradation above 120 MPa
- Sample 5 outlier: high I_c, but more sensitive to transverse stress

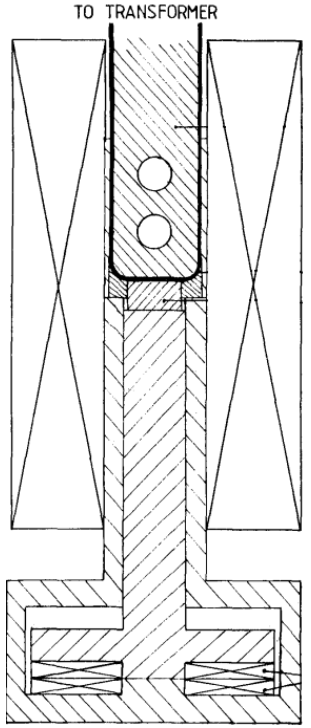
Critical current vs. transverse stress



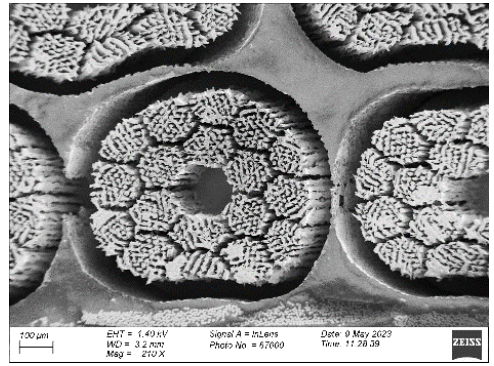
Normalized critical currents



Conclusion



- Four Bi-2212 Rutherford cables tested in a transverse stress set-up at Twente University.
- Initial current densities in range 250-780 A/mm^2, and correlate well with witness strand values (4.2 K, 5 T).
- Three out of four cables had less than 5% degradation at 120 MPa average transverse stress.
- All changes in critical current were irreversible.



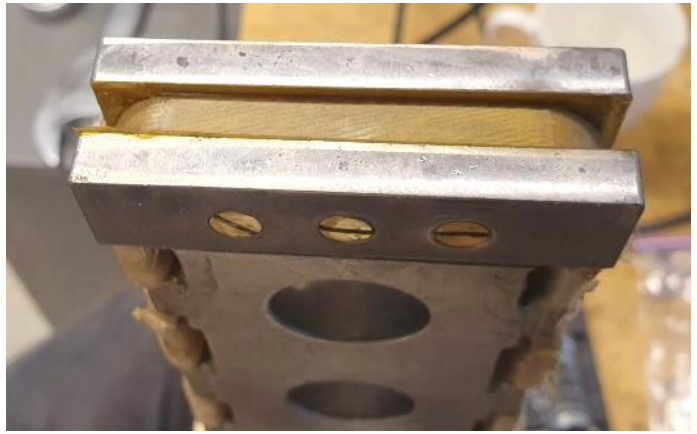
Discussion slide: the sample holder

- Innovative sample holder by PSI may more closely reproduce CCT magnet conditions.

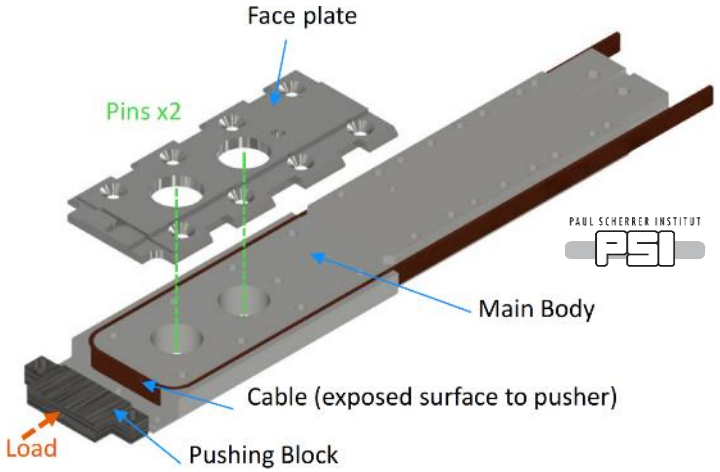
- Other benefits
  - Reaction and stress test on the same holder
  - Impregnation with pushing block in place, **aligned to the sample holder**

- We may consider this design for future tests.

Current open sample holder



PSI "Compression BOX" (M. Daly et al.)



Pictures of the samples after OPHT

Sample 3: mullite insulation

Sample 4: mullite insulation, some stains visible (possible leakage)

Sample 5: alumina insulation

Sample 6: alumina insulation