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Properties of REBCO tape: what should be improved?

A user view

2nd High Temperature Superconductor Accelerator Technology Workshop

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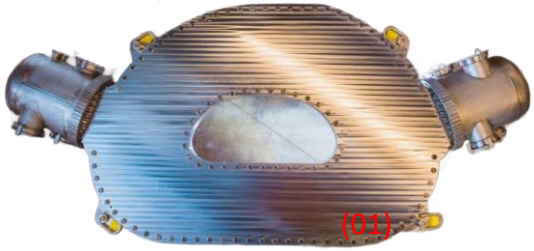
Acknowledgments:

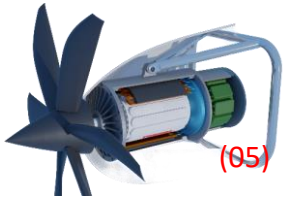
M.-P. Careil, J. Hurte, A. Saba, N. Gal, S. Morisi, T. Kramer, C. Vogl, C. Bonafous, the MSC-HSD & MSC-LSC sections

Applications of REBCO tapes

1) Fusion magnets
   - *High current, high field*
   - *Low field quality requirement*
   - *Soldered cables, drop-outs accepted*

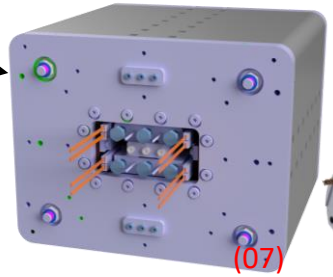


2) Solenoids, rotating machines
   - *Low current, mid-high field*
   - *Low field quality requirement*
   - *Single tapes, some / no drop-outs*

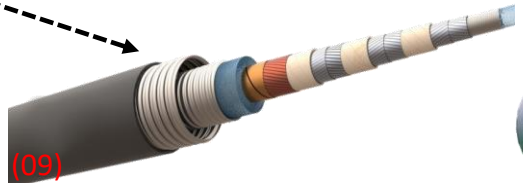


3) MRI & NMR magnets
   - *Low current, mid-high field*
   - *High field quality requirement*
   - *Single tapes, no drop-outs*

4) Accelerator magnets
   - *High current, mid-high field*
   - *High field quality requirement*
   - *Cables, no drop-outs*



5) Power transmission, FCL
   - *High current, low field*
   - *No field quality requirement*
   - *Cables, no drop-outs*



Applications of REBCO tapes

1) Fusion magnets

2) Solenoids, rotating machines

3) MRI & NMR magnets

4) Accelerator magnets

5) Power transmission, FCL

Cost

I_c at operating conditions

Long piece length

No I_c drop-outs

Electro-mechanically strong

Homogenous geometry

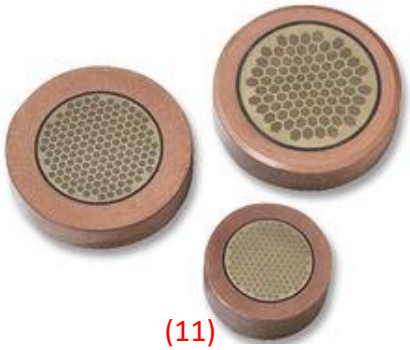
Homogenous $R_{interface}$

Homogenous I_c

- What is the state of these properties?
- If compared with LTS (Nb_3Sn wire)?

Outline

- Comparison with LTS (Nb_3Sn wire) using the HL-LHC procurement as an example
  - Unit Length & I_c dropouts in REBCO
  - Geometry
  - I_c homogeneity & lift factor variations in REBCO
- Properties of REBCO tapes for applications
  - $R_{internal}$ homogeneity
  - Electro-mechanical properties
- Summary & conclusions



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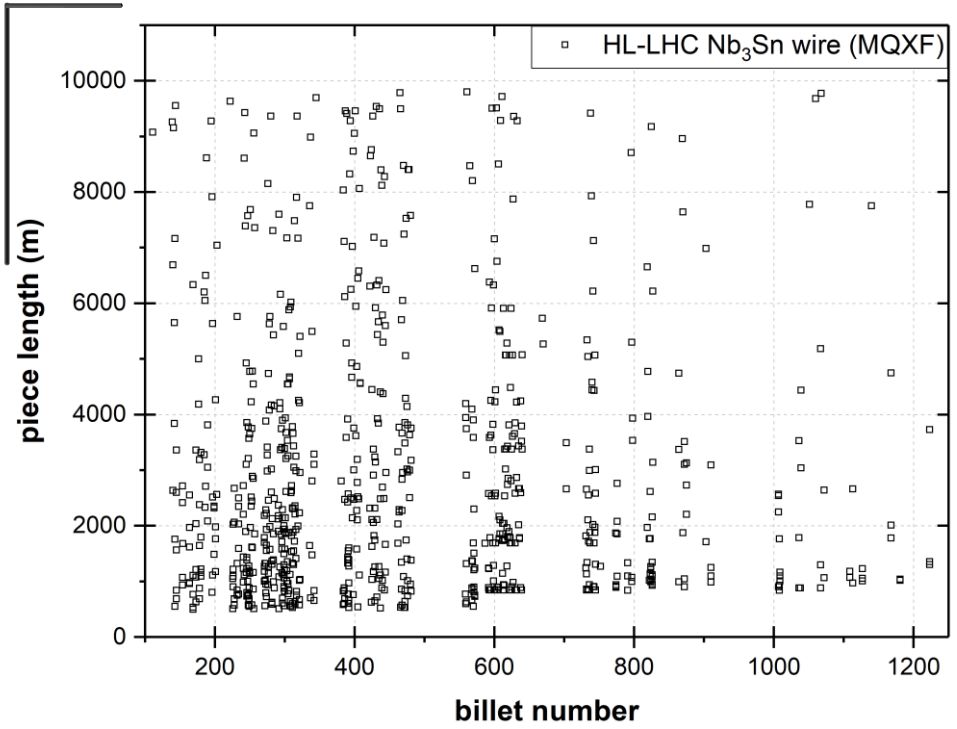
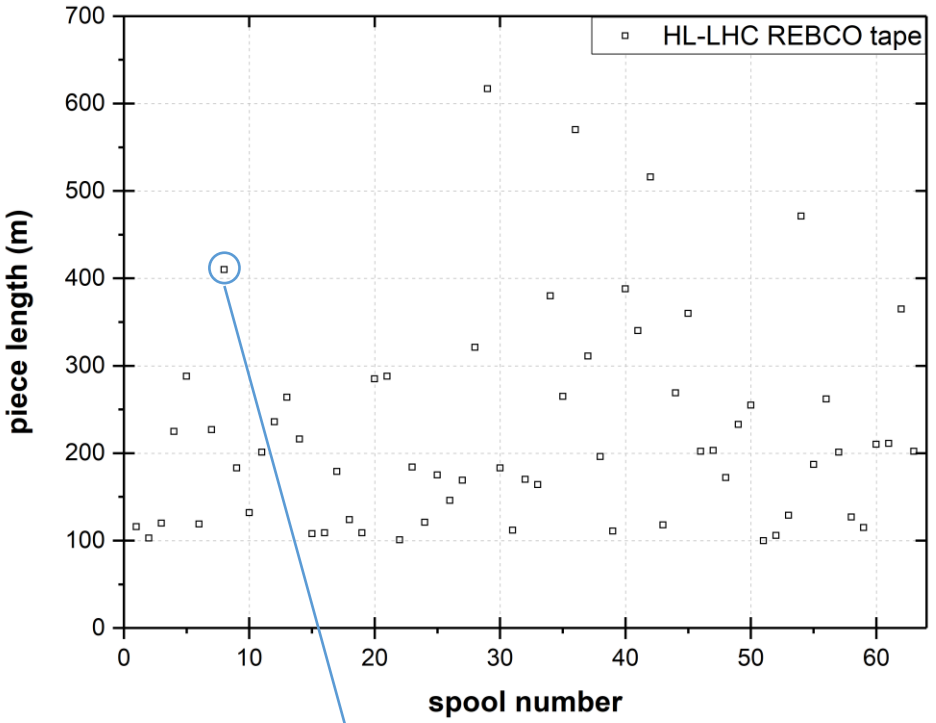
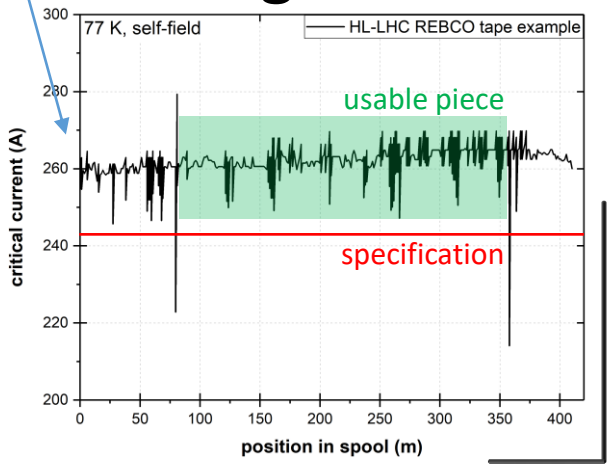
Nb_3Sn vs REBCO: Piece length

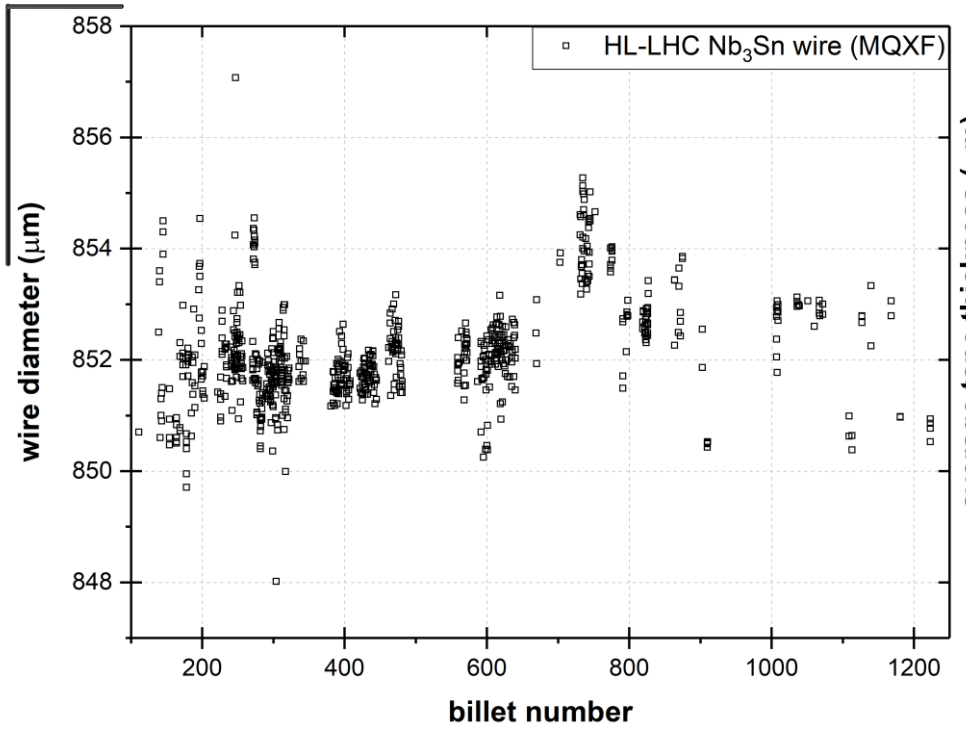


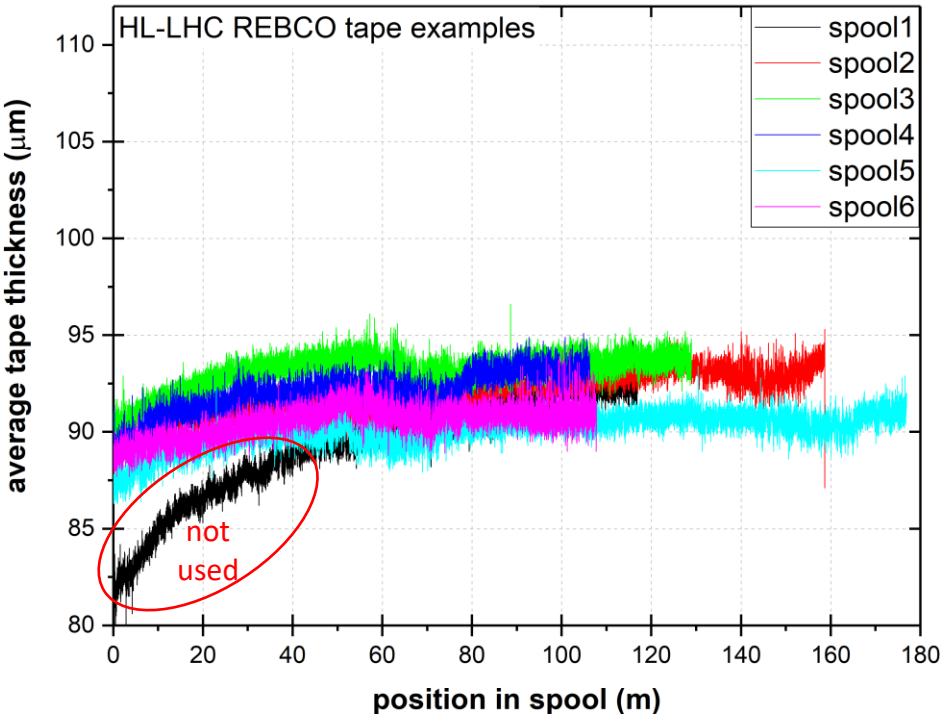


- REBCO piece lengths >10x below Nb_3Sn piece lengths
  - Lower fabrication length
  - Further reduced by I_c drop-outs that require cutting
- Longer piece lengths important for applications → enabling - reduce splices



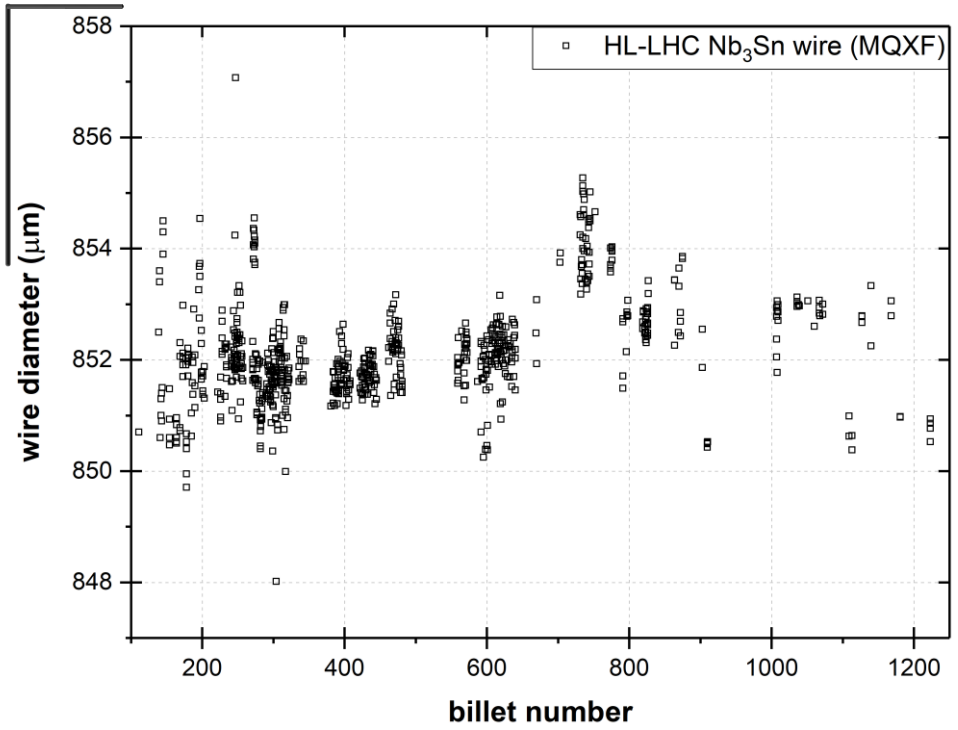
Nb_3Sn vs REBCO: Geometry homogeneity

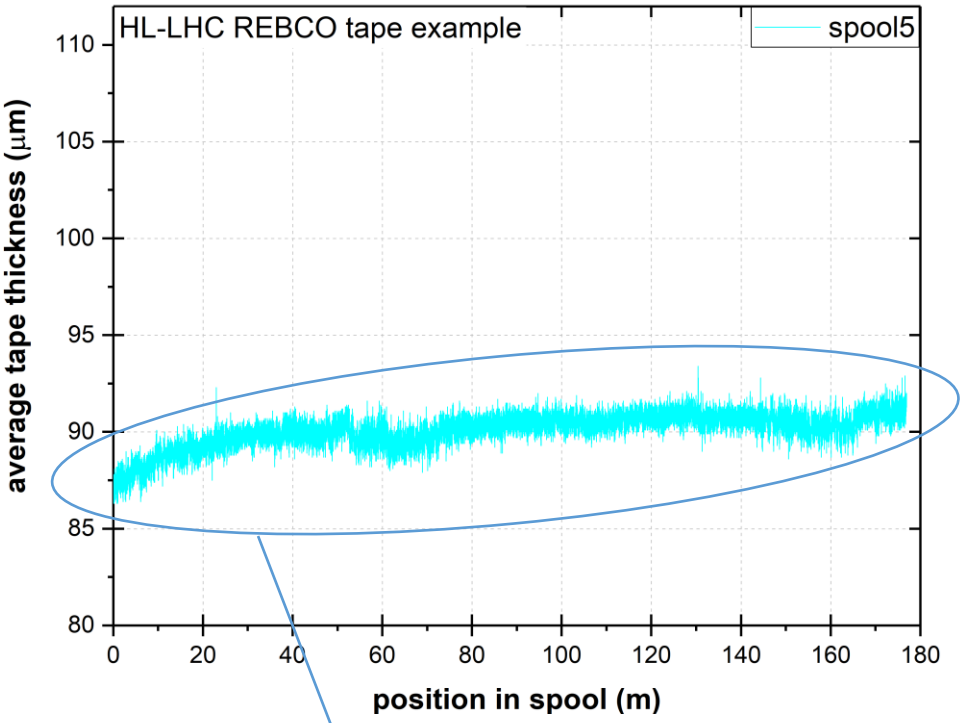




- REBCO rel. geometrical deviations >100x above Nb_3Sn
  - Possible source of rejection or cutting

Nb_3Sn vs REBCO: Geometry homogeneity

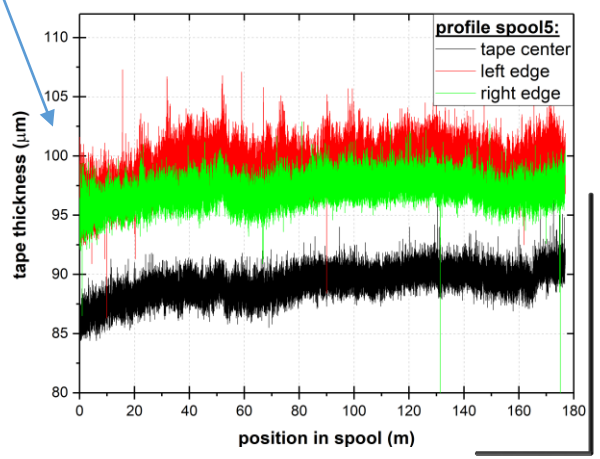




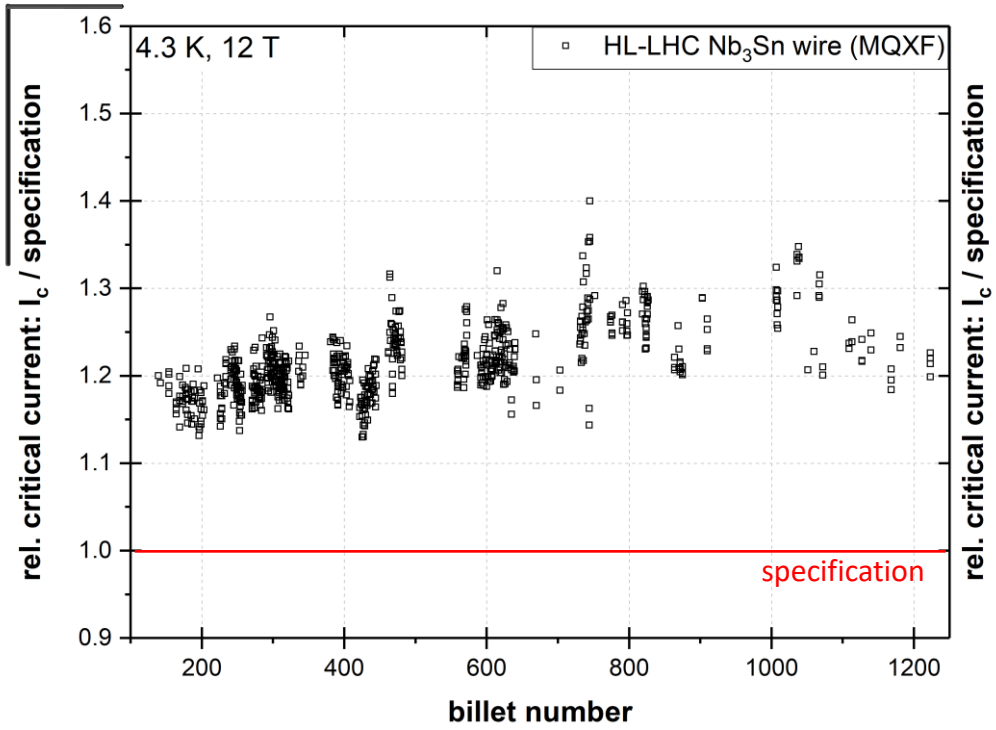
- REBCO rel. geometrical deviations >100x above Nb_3Sn
  - Possible source of rejection or cutting
  - 'Dog-bone' shape usually pronounced

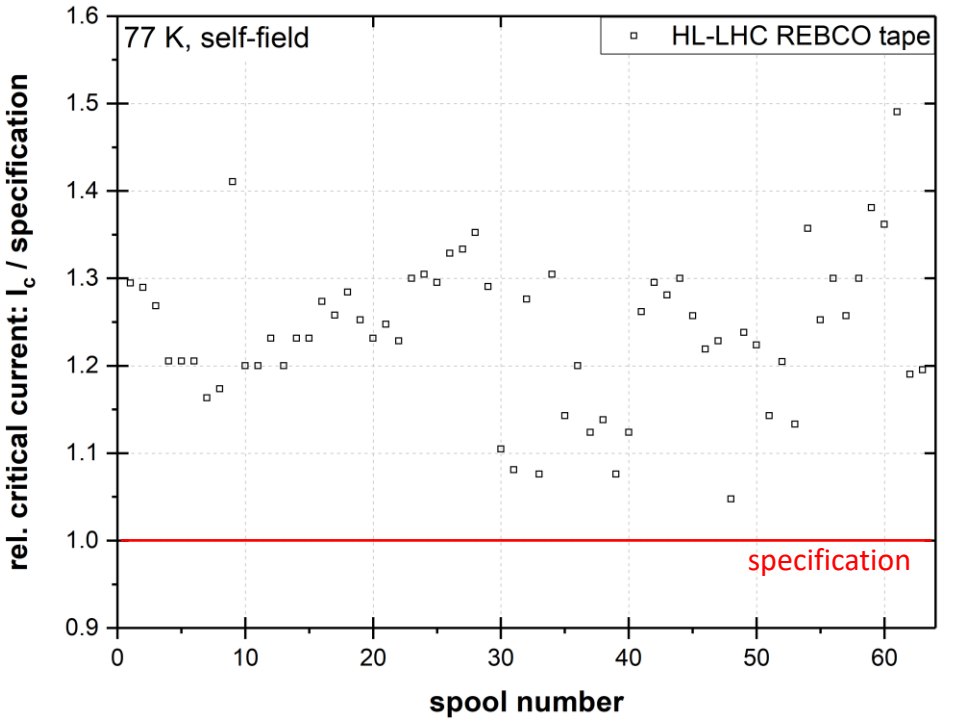
→ Challenging to achieve flat windings

- Better geometrical homogeneity highly beneficial for many applications



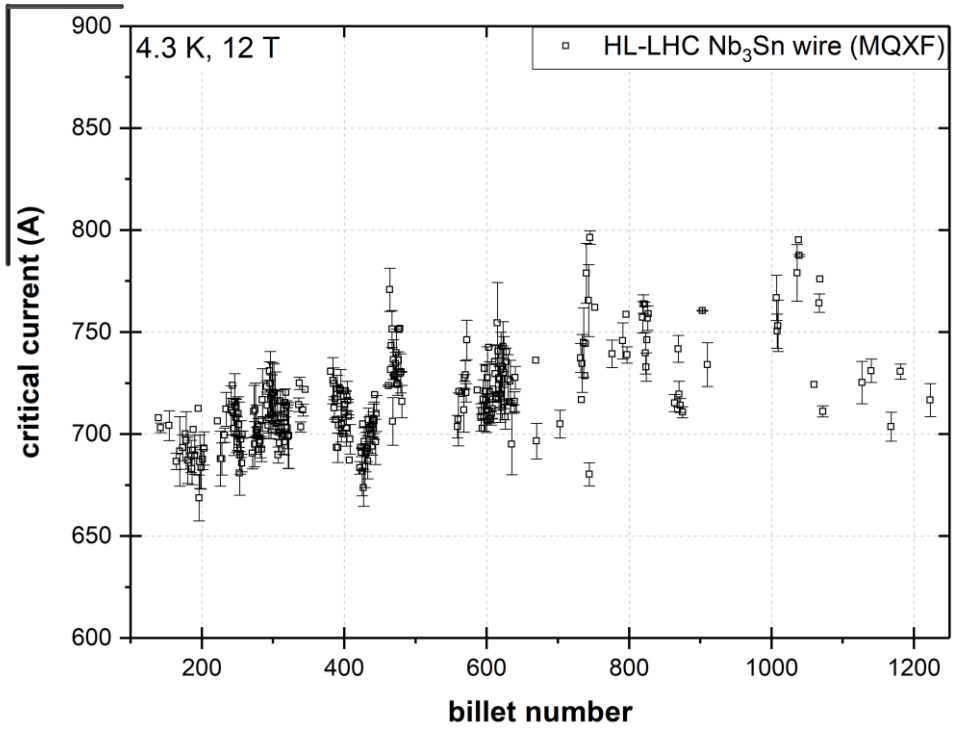
Nb_3Sn vs REBCO: I_c homogeneity

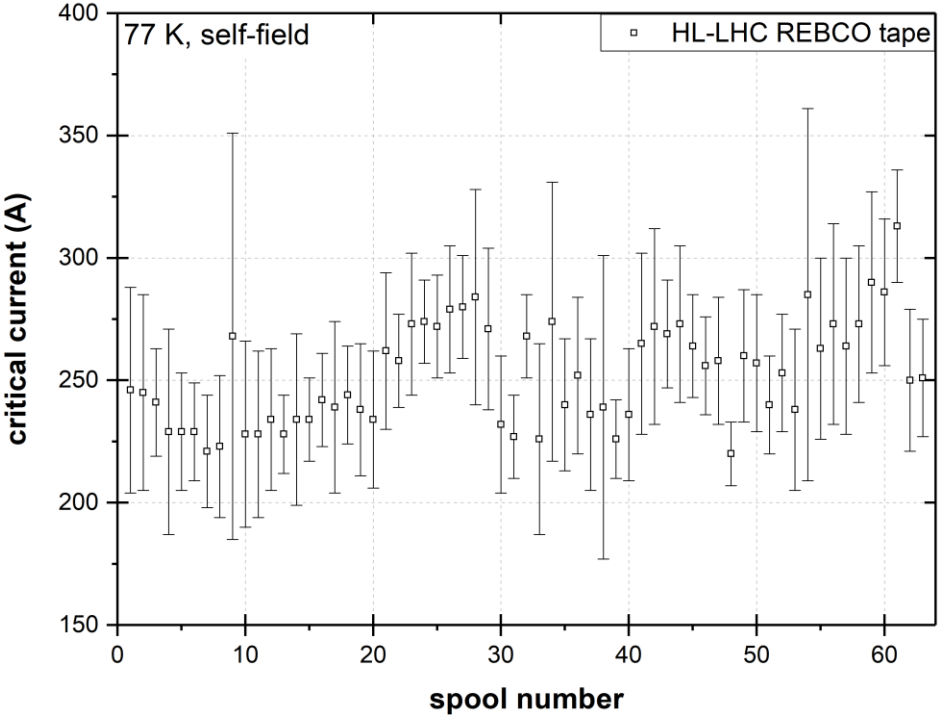




- Avg. I_c reliably above spec., margins similar to Nb_3Sn

Nb_3Sn vs REBCO: I_c homogeneity





- Avg. I_c reliably above spec., margins similar to Nb_3Sn
- >10x higher I_c spread
- Additional ≈ ±30 % lift factor spread
- Challenging to homogenously quench
- Additional screening currents possible

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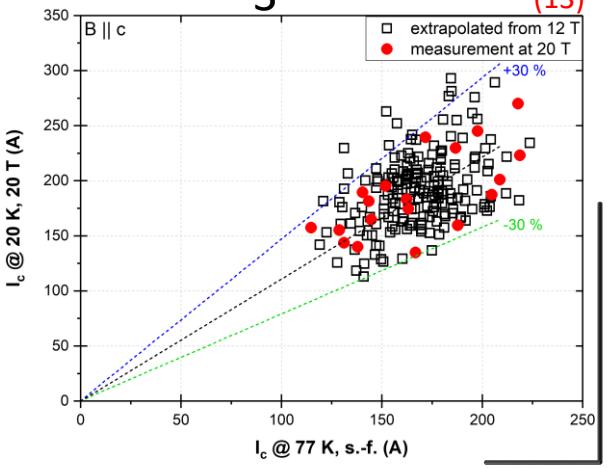

- Comparison with LTS (Nb_3Sn wire) using the HL-LHC procurement as an example
  - Unit Length & I_c dropouts in REBCO
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  - Electro-mechanical properties
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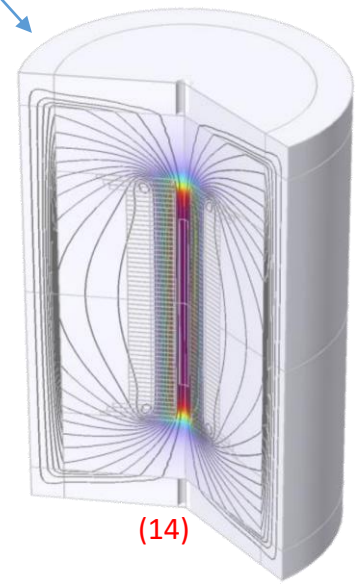

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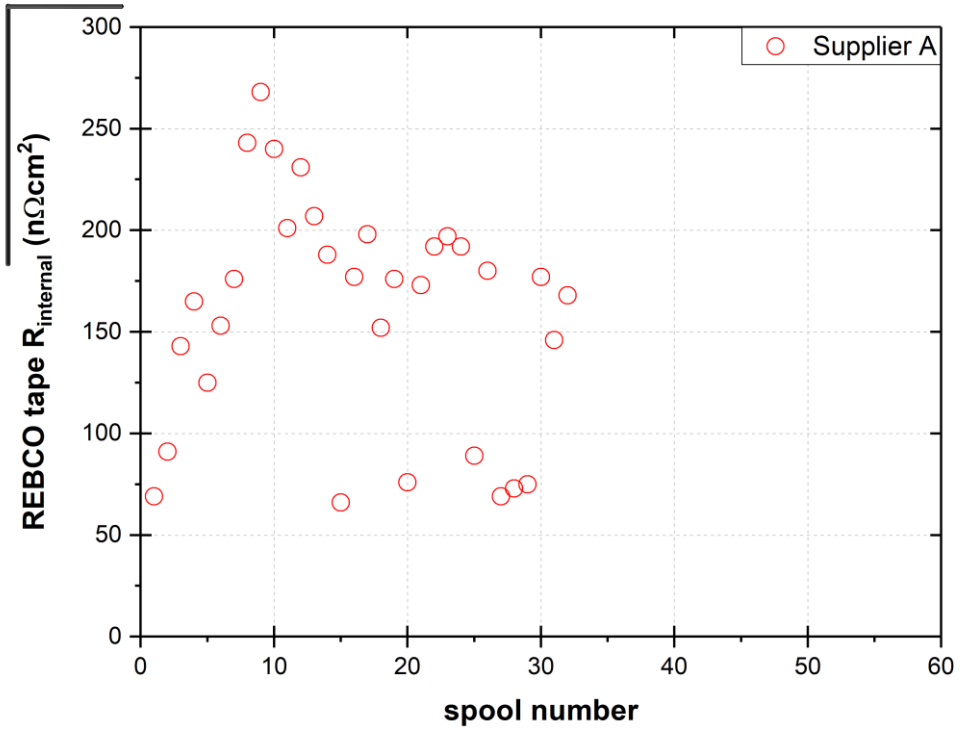
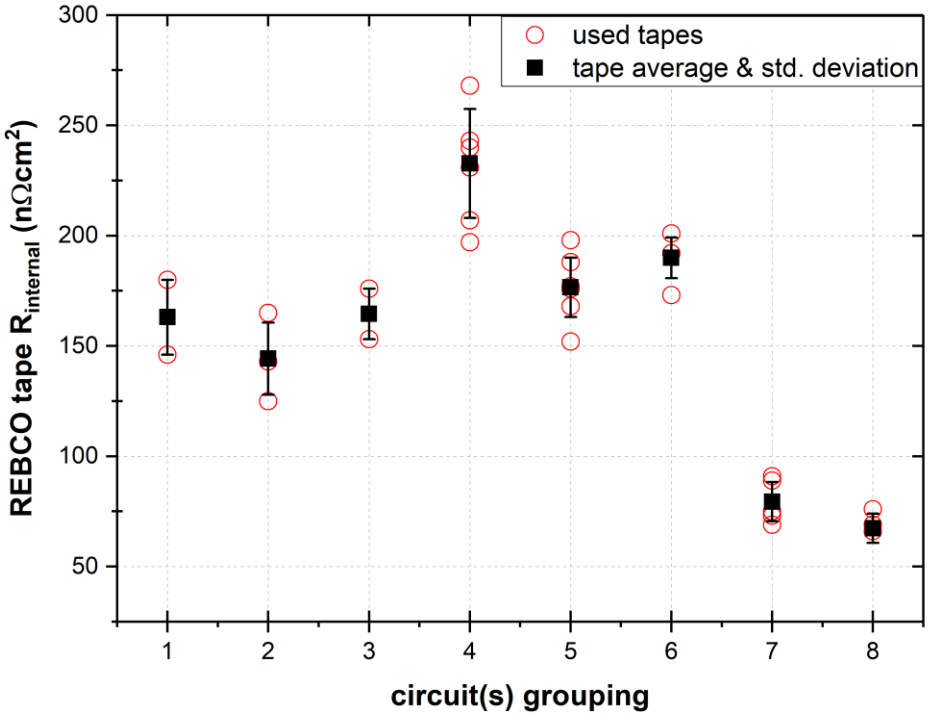
REBCO: $R_{internal}$ homogeneity

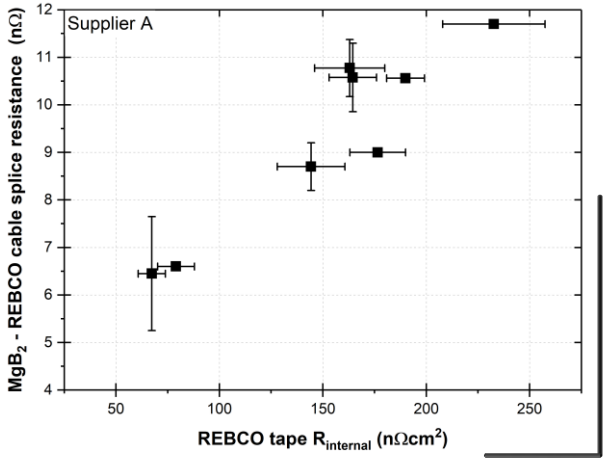




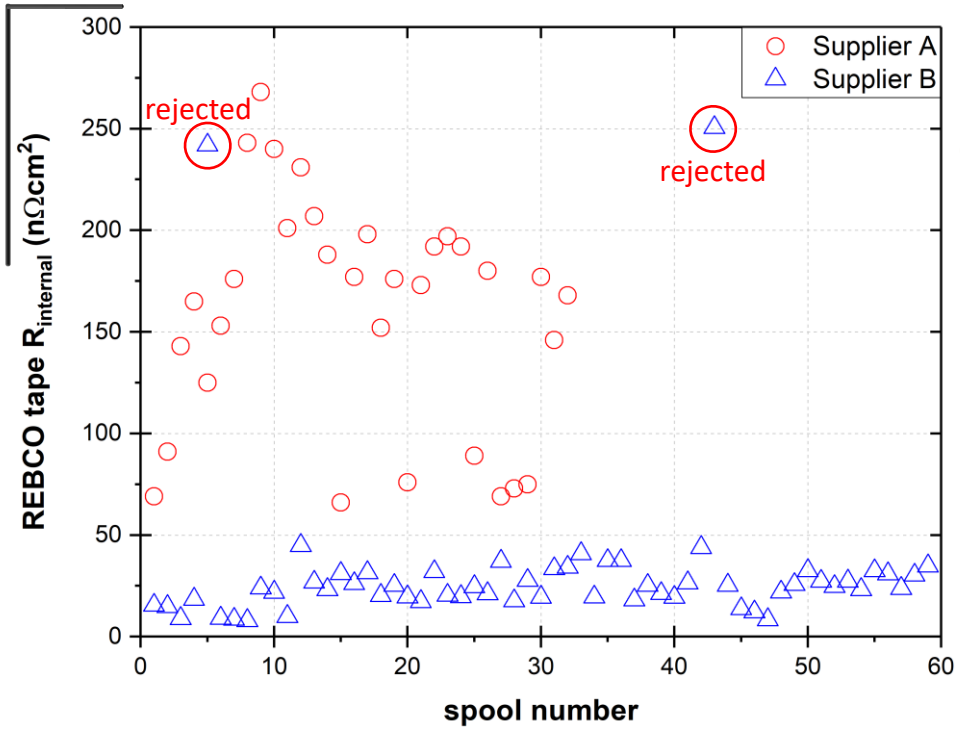
- Significant spread of $R_{internal}$ possible
- Homogenization in || tapes & cables

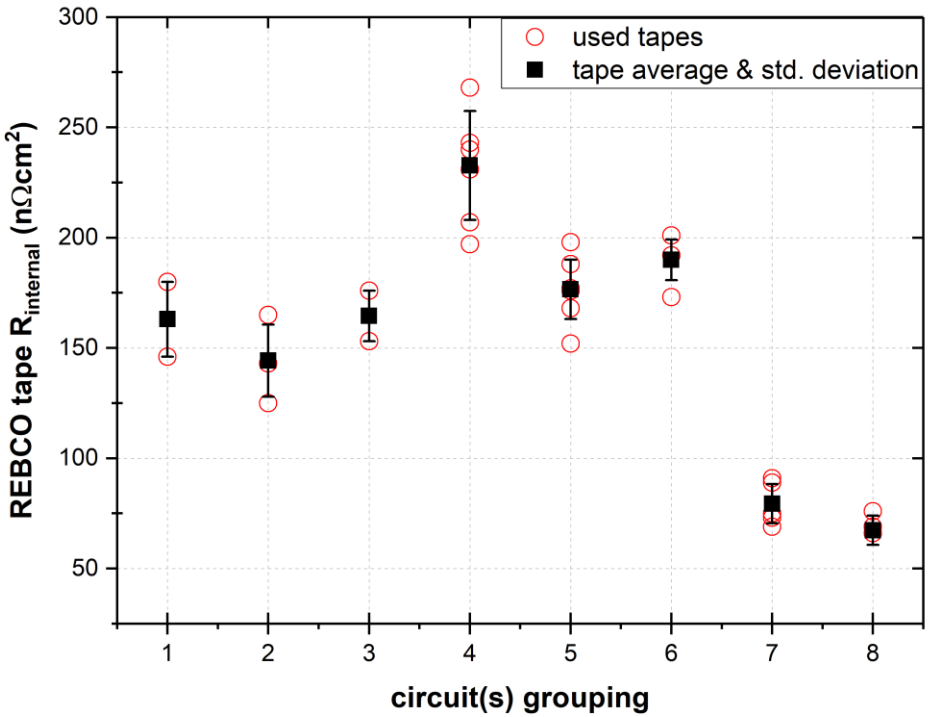
→ Equal current distribution

→ Correlation with splice resistance



REBCO: $R_{internal}$ homogeneity



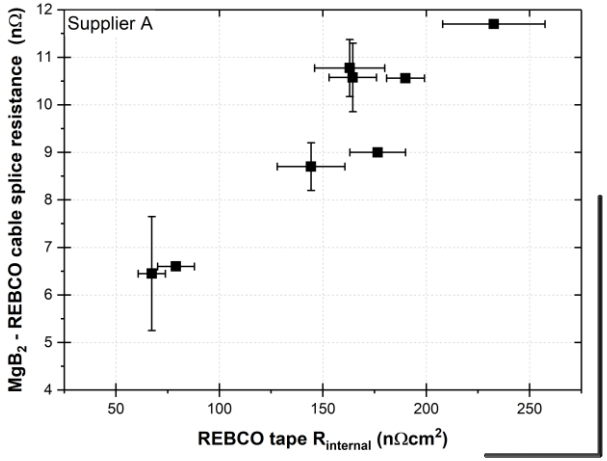


- Significant spread of $R_{internal}$ possible
- Homogenization in || tapes & cables

→ Equal current distribution

→ Correlation with splice resistance

- $R_{internal}$ spread only for some suppliers



REBCO: Electro-mechanical properties

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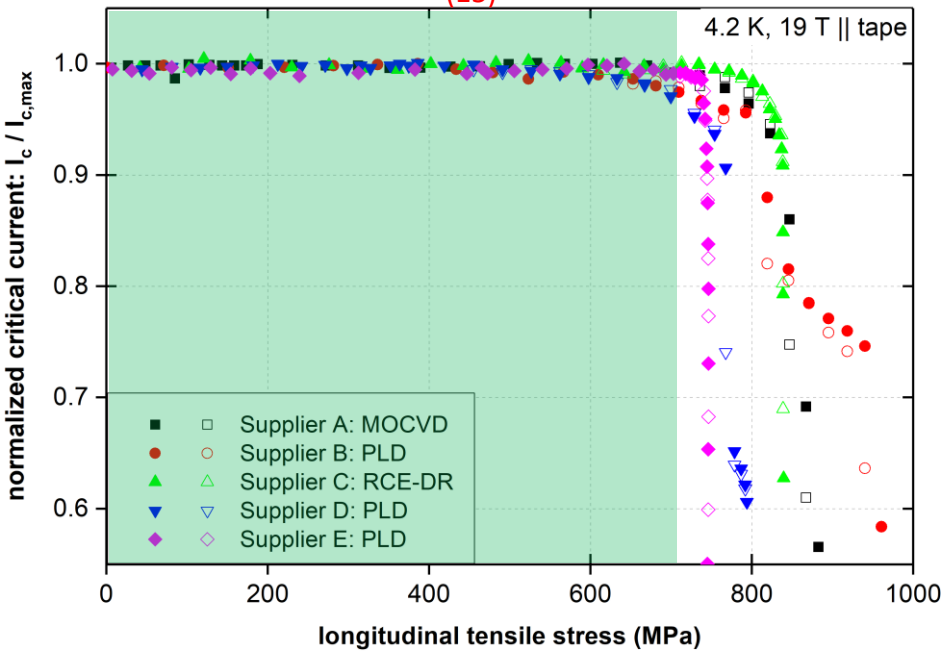

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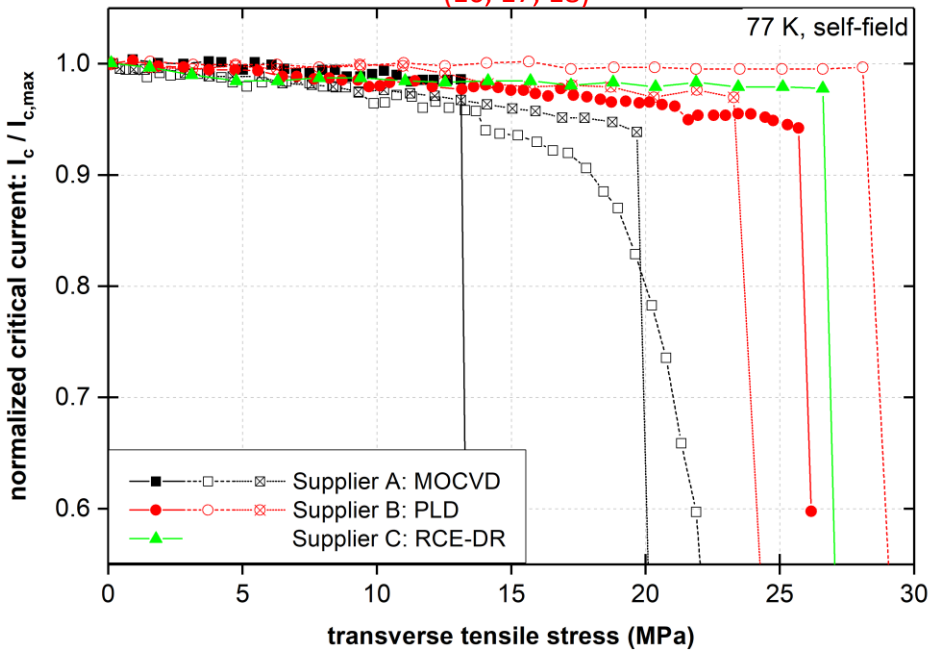
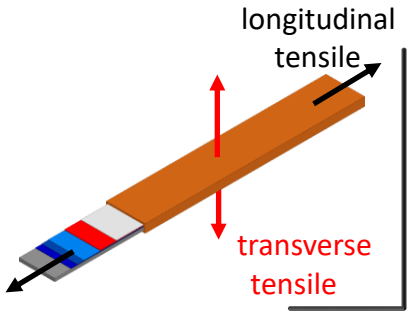


- Negligibly reversible strain / stress sensitivity of I_c ✓
- >700 MPa irreversible stress limit in longitudinal tension ✓
- Low delamination strength (transverse tensile)
  - → Limiting for many high field applications
  - → Delamination strength improvements beneficial for most application



Summary & conclusions

- Large variety of applications of REBCO tapes
  - In a large field range: from self-field to >40 T
  - In a large current range: from a few A to >100 kA
- Applications require properties beyond I_c & cost, currently:
  - Unit length, geometry & I_c homogeneity still >10x below Nb_3Sn
  - Good $R_{internal}$ homogeneity achieved by some suppliers
  - Good electro-mechanical properties in tape direction
  - Low delamination strength
- From a user view, which properties should be improved?
  - Almost all applications profit from cost reduction & I_c increase
  - Piece length & geometrical homogeneity beneficial for most applications
  - Delamination strength **limiting** for high force applications

→Delamination strength > cost > I_c > piece length > geometry

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- Thank you for your attention -

1. Commonwealth Fusion Systems: *https://cfs.energy/news-and-media/cfs-commercial-fusion-power-with-hts-magnet*
2. National High Magnetic Field Laboratory: *https://nationalmaglab.org/news-events/news/lbc-project-world-record-magnetic-field*
3. openPR: *https://www.openpr.com/news/2908100/superconducting-magnetic-energy-storage-smes-systems-market*
4. SciTechDaily: *https://scitechdaily.com/successful-test-for-superconducting-3-6mw-wind-turbine/*
5. Drives&Controls: *https://drivesncontrols.com/airbus-and-toshiba-join-forces-on-2mw-superconducting-motors/*
6. Bruker: *https://www.bruker.com/de/products-and-solutions/mr/nmr/ascend-ghz-class*
7. CERN
8. CERN
9. Nexans: *https://www.nexans.co.uk/en/business/power-transmission-distribution/superconductivity/high-temperature-superconductors*
10. SuperOx: *https://eng.superox.ru/projects/sfcl/*
11. Bruker: *https://www.bruker.com/en/products-and-solutions/superconductors/superconductors/niobium-tin-superconductor*
12. Marphil: *https://www.marphil.eu/en/products/hts-tapes/*
13. Scientific Reports (Molodyk, A. et al): *https://doi.org/10.1038/s41598-021-81559-z*
14. CCA 2025 (Caiffi, B. et al): *https://indico.cern.ch/event/1347361/contributions/6309790/attachments/3031335/5351574/MUCOL_CCA_2025_AP_LA.pdf*
15. SUST (Barth, C. et al): *https://doi.org/10.1088/0953-2048/28/4/045011*
16. Physica C (Gorospe, A. et al): *http://dx.doi.org/10.1016/j.physc.2013.04.062*
17. IEEE (Liu, W. et al): *http://dx.doi.org/10.1109/TASC.2015.2409197*
18. Review of Scientific Instruments (Zhang, X. et al): *https://doi.org/10.1063/1.4904736*