REBCO HTS Studies for Application in a Future Muon Collider

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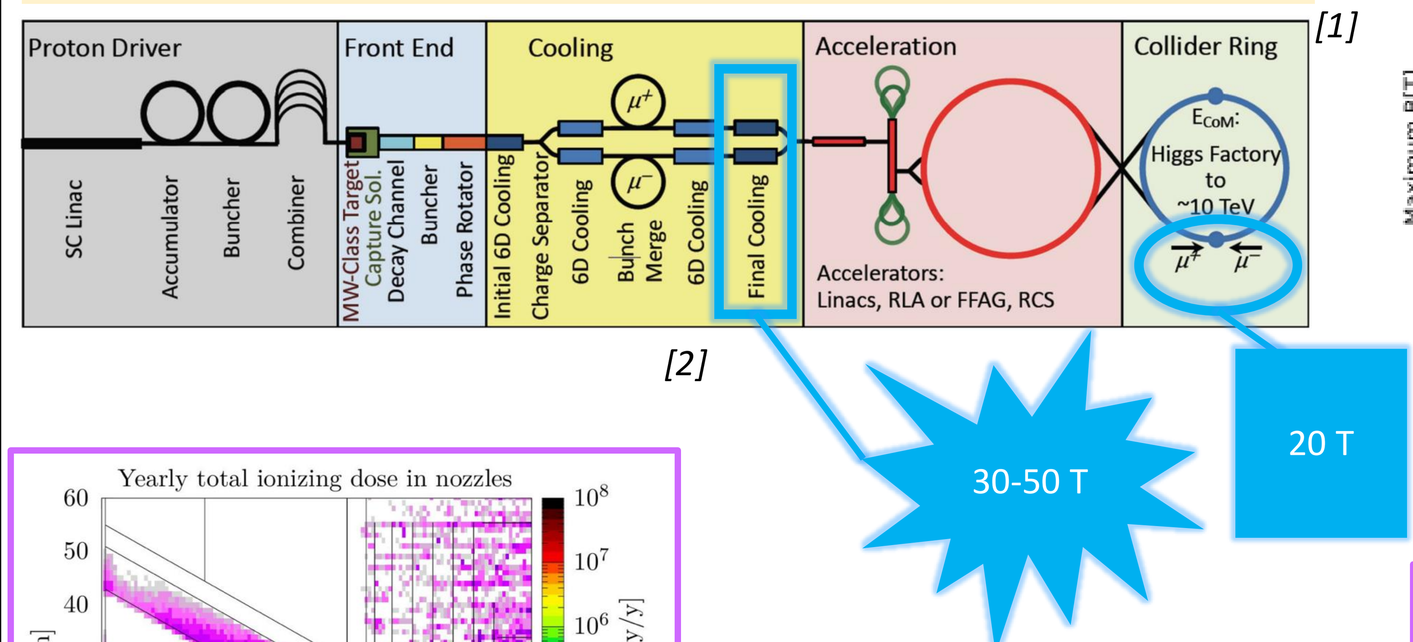
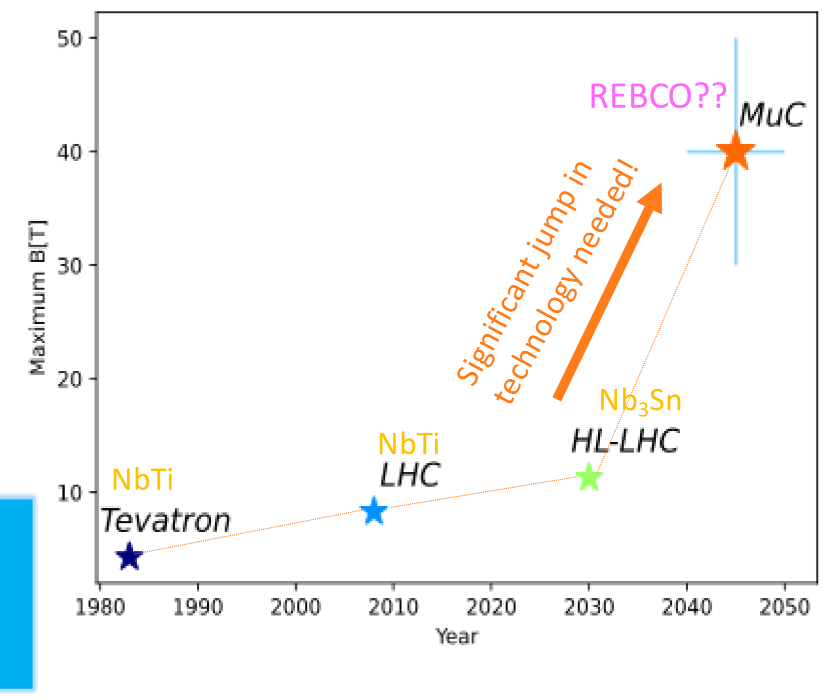
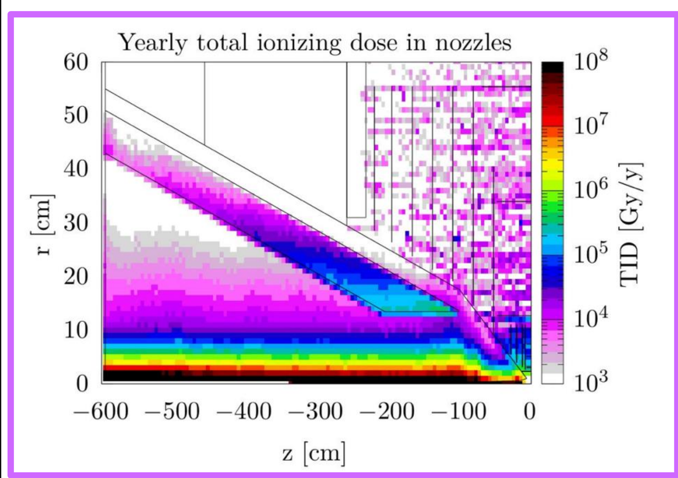
High-Temperature Superconductors: A MuC Necessity

From cooling to acceleration to final focusing, the Muon Collider design relies on high-field magnets!







*The Muon Collider is also a **high-radiation environment***

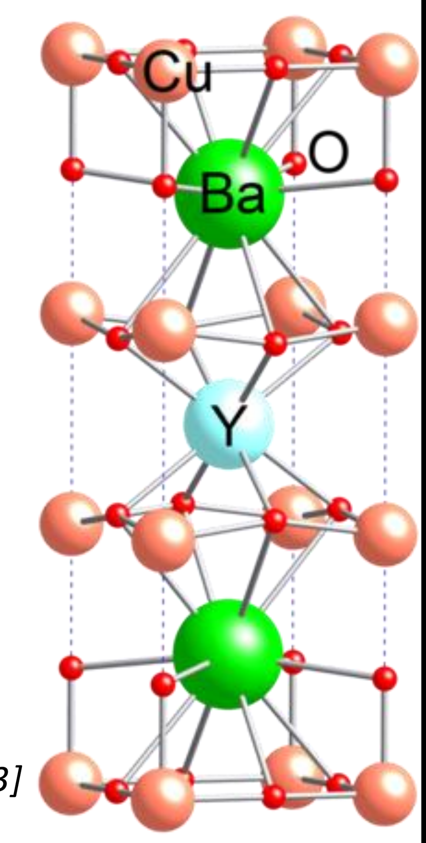
*Superconductors operating in the 20-50K temp range or above (HTS) **significantly improve energy efficiency** and may **reduce shielding thickness** by 10mm. [1]*

REBCO HTS

***R**are **E**arth **B**arium **C**opper **O**xide*

Cuprate superconducting material with:

- **Higher critical B field** than Nb_3Sn, NbTi
- Critical temperature in **liquid N regime (77K)**
- Manufactured in **tapes** instead of wires



[3]

Strain and Critical Current Retention

*REBCO is a **brittle, ceramic** material – under strain, can be **irreversibly damaged***

Sources of strain:

1. Thermal strain during tape production
2. Mechanical strain due to **winding tape** around wire/cable former
3. Mechanical strain due to **cable bending** during coil formation
4. EM strain due to **Lorentz forces** after magnet is energized and in-field

Currently under investigation at Fermilab for neutral-axis tape on flat rounded-edge Rutherford cable

Strain can't be directly measured, only modeled

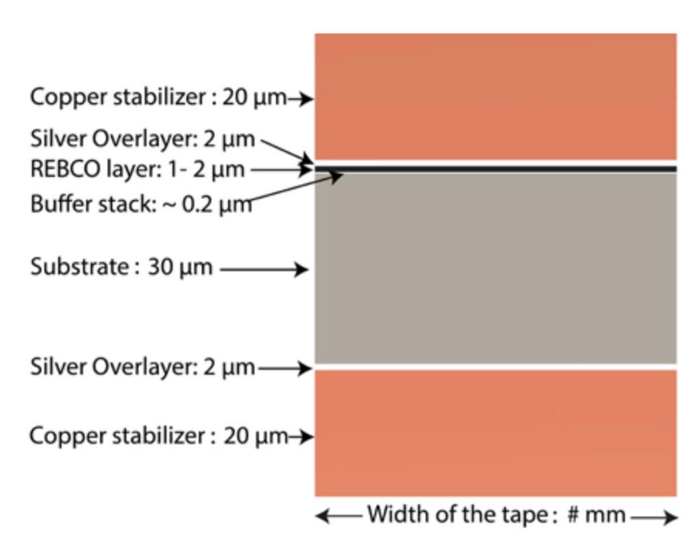
- Our real figure of merit is **critical current retention**
- Measured **before** and **after** strain is induced
- Correlated to **modeled critical strain**

Critical current retention goal: $I_c^f/I_c^0 > 0.9$

REBCO Tape Geometry

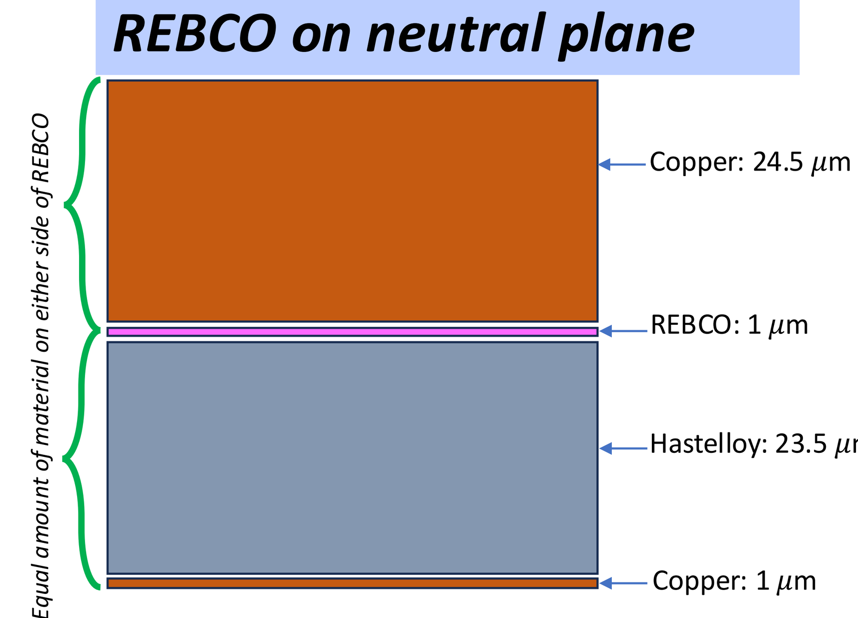
Tape Components:

- REBCO
- Hastelloy substrate
- Copper stabilizers



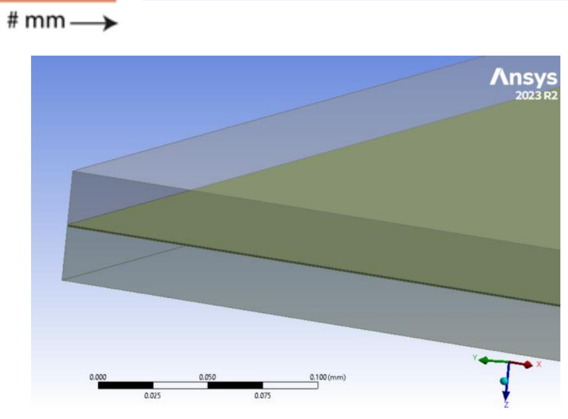
*Our **asymmetric** tape design*

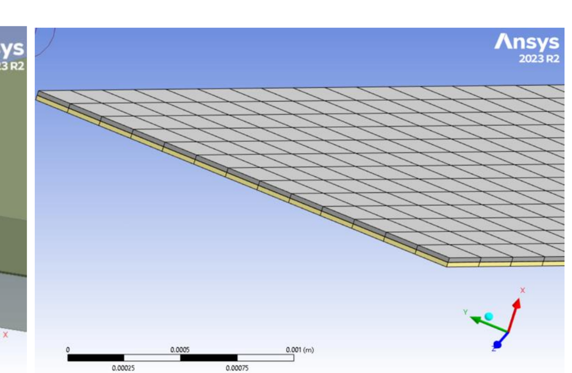
REBCO on neutral plane



*Left: example of a **symmetric** tape design, used in [4]*

In the FEA model, we neglect the thin layer of copper and instead set equal widths of upper copper and Hastelloy. Left: tape geometry model with REBCO layer selected. Right: tape model after finite element meshing.



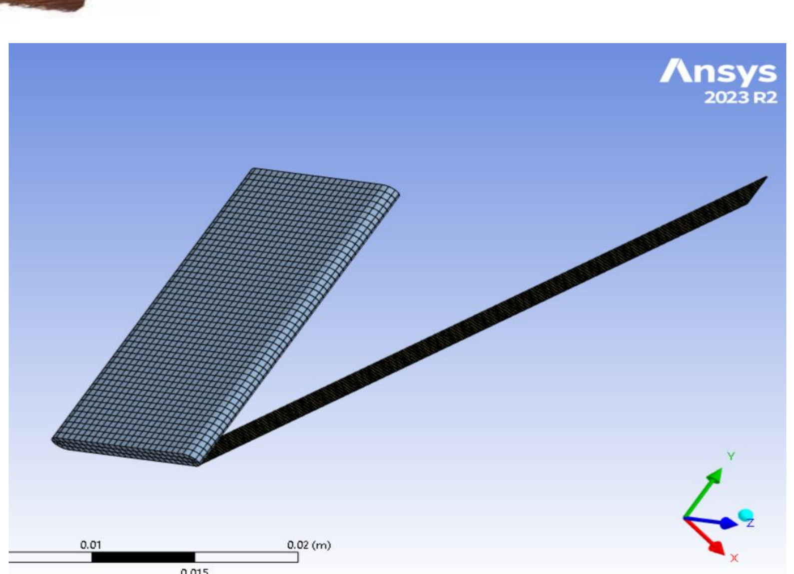


Rutherford Cable Geometry

Rutherford cable: multi-stranded cable used in most SC accelerator magnets

We will wind REBCO tapes around flat rounded-edge cable to minimize bent sections.

Aluminum tape wound around copper RC for illustrative purposes. Our REBCO tapes will be thinner (width ~ 2-4mm).

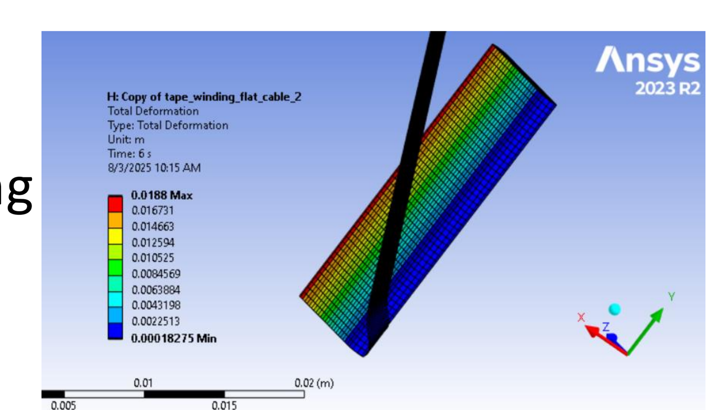


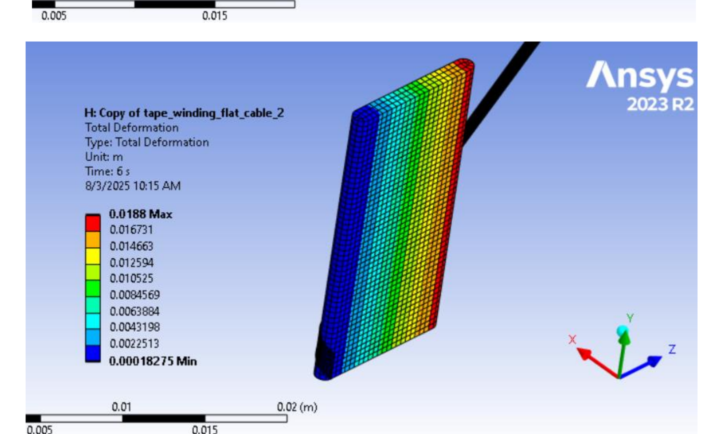
Segment of flat rounded-edge cable with tape contact, pre-winding simulation, after FE meshing.

Tape Winding Simulation

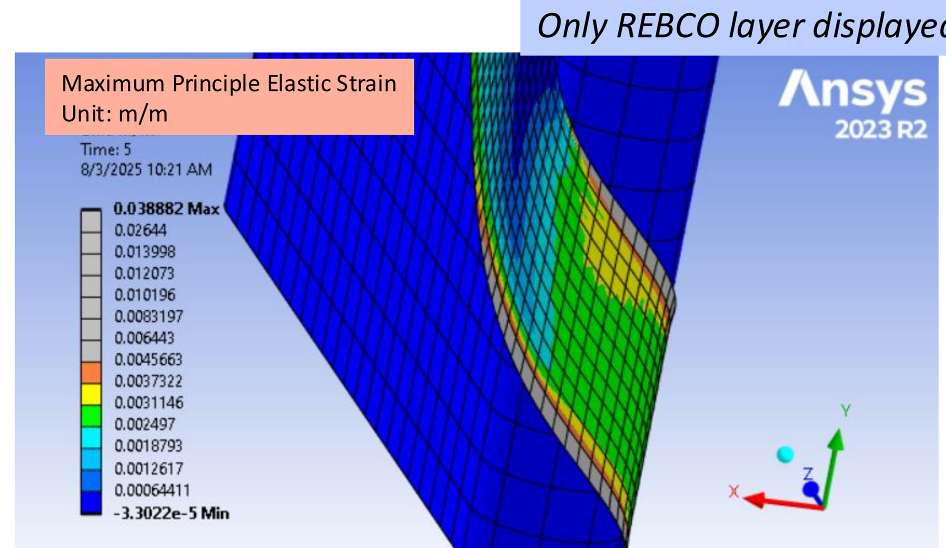
We use **Ansys Mechanical** to model winding

- Tape connected to cable at edge
- Tape then placed under **tension**
- **Cable rotated** through 180º or 360º to model a **half** or **full twist pitch**





Only REBCO layer displayed.



After one half-winding (180º rotation), ~1.67% of the tape nodes exceeded critical damaging strain.

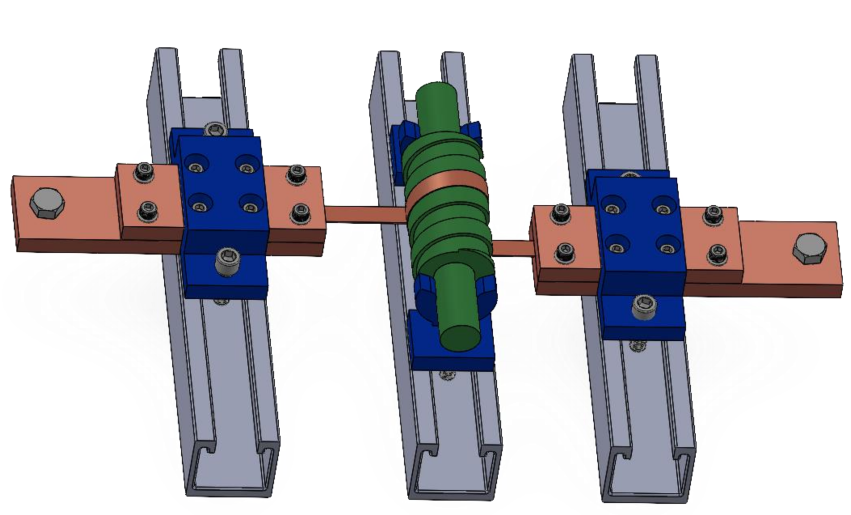
Cable Bending Simulation + Tests

Modeling

- Tape and cable model will be **pre-stressed** with stress-strain state from winding simulation
- Ansys will then model the **360º helical bending of the Rutherford cable around a steel core**

Testing

- Once neutral plane tapes are received at FNAL from AMPeers LLC, they will be wound around the Rutherford cable and testing will begin
- Critical current will be tested **prior to bending** and again **after bending** (right)



Testing will occur at 77K (cooled with liquid nitrogen)

Experimental setup designed and figure provided by Emily Romancew (FNAL, NIU)

Future Considerations: Coil Formation and Quench Testing

After bending tests, we will need to model and evaluate:

- Various **coil geometries**
- REBCO response to **quenching** (rapid and irreversible transition to normal-conducting regime)
- Quench prevention

References:
[1] L. Bottura *et al.*, "Magnets for a Muon Collider—Needs and Plans," in *IEEE Transactions on Applied Superconductivity*, vol. 34, no. 5, pp. 1-8, Aug. 2024, Art no. 4005708, doi: 10.1109/TASC.2024.3382069.
[2] D. Calzolari, "Muon Collider: MDI Update." (Internal Meeting Slides, 2025).
[3] "Rare Earth Barium Copper Oxide". *Wikimedia Foundation.* https://en.wikipedia.org/wiki/Rare-earth_barium_copper_oxide
[4] V. A. Anvar *et al.*, "Bending of CORC® Cables and wires: Finite element parametric study and experimental validation." 2018 *Supercond. Sci. Technol.* **31** 115006