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REBCO tapes with high normal zone propagation velocity: an avenue for faster quench detection/protection systems in REBCO magnets?

Christian Lacroix and Frédéric Sirois
Laboratory of Superconductivity and Magnetism (LSM)
Polytechnique Montréal, Canada

US MDP REBCO WG Meeting, OCTOBER 7TH 2021

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Polytechnique Montréal, Canada

Leading Canadian engineering institution in education and research

-French-speaking, nearly 150 years old!

-Active in all areas of engineering + many fields in pure and applied sciences

Over 9,000 **STUDENTS**

278 **PROFESSORS**

59,600 **GRADUATES SINCE 1873**

1,706 **DEGREES AWARDED IN 2018-2019**

$260 M **ANNUAL BUDGET**

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Laboratory of Superconductivity and Magnetism (LSM)

- Founded in 2020 to synergize these two activities through
  - shared personnel
  - common projects
  - common equipment and computer infrastructure
    - magnets, test benches, instruments, computation servers, etc.

- Associated with the microfabrication lab, which includes
  - thin film deposition facilities (sputtering, electrodeposition, etc.)
  - characterization facilities for properties of material
    - electric & magnetic, tribo-mechanical, chemical, structural, etc.
  - all types of microscopy (SEM, TEM, XPS, …)

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Current focus in applied superconductivity

- Development of advanced numerical modeling tool for HTS tapes
  - Electromagnetic + thermal problems = quench simulation

- Advanced characterization of HTS tape properties
  - Electric properties + quench behavior

- **Innovative HTS tape architectures and impact on NZPV → *<u>Today's topic</u>***
  - Past focus → fault current limiters
  - New focus → magnets

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Acknowledgements for today's presentation

Polytechnique Montréal (LSM)

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- Jaël Giguère (Master's student)
- Yannick Lapierre (intern)

Institute of Ciencia de Materiales de Barcelona (ICMAB, Barcelona, Spain)

- Pedro Barusco (PhD student)
- Prof. Xavier Obradors
- Prof. Xavier Granados

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Increasing quench velocity in 2G HTS CC

From Iwasa's book: Studies in superconducting magnets

$$NZPV = J\sqrt{\frac{\rho_n k_n}{C_n C_s (T_t - T_{op})}}$$

Changing materials properties…
…NOT SO EASY

E.g. Sapphire substrate
→ High thermal diffusivity
BUT
→ Not flexible
→ Costly
→ Only short lengths available

Another degree of freedom

IOP PUBLISHING SUPERCONDUCTOR SCIENCE AND TECHNOLOGY
Supercond. Sci. Technol. **23** (2010) 014021 (8pp) doi:10.1088/0953-2048/23/1/014021

The effects of superconductor–stabilizer interfacial resistance on the quench of a current-carrying coated conductor

G A Levin[1], K A Novak[2] and P N Barnes[1]

[1] Air Force Research Laboratory, Propulsion Directorate, Wright-Patterson Air Force Base, OH 45433, USA
[2] Department of Mathematics, Air Force Institute of Technology, Wright-Patterson Air Force Base, OH 45433, USA

Increase of the REBCO/Ag interfacial resistance (R_i or R_i^*)
→ ALLOWS INCREASING THE QUENCH VELOCITY

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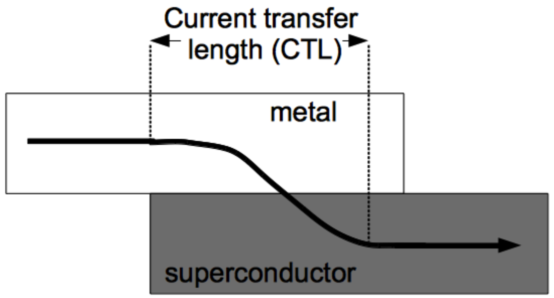
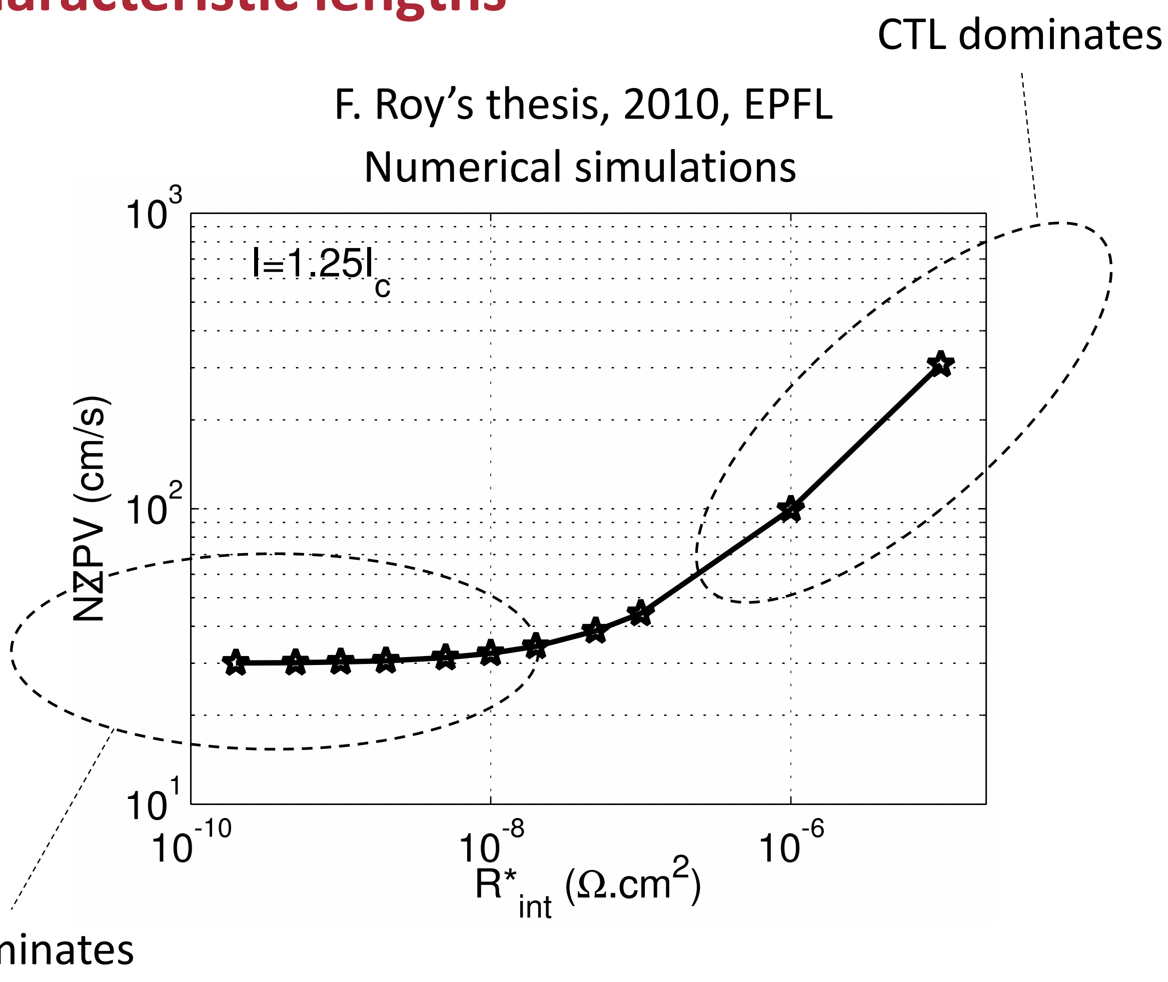
Characteristic lengths

What else did we learned from Levin's paper?

Quench velocity is driven either by
- the thermal diffusion length (L_d) OR
- the current transfer length (CTL)



F. Roy's thesis, 2010, EPFL
Numerical simulations



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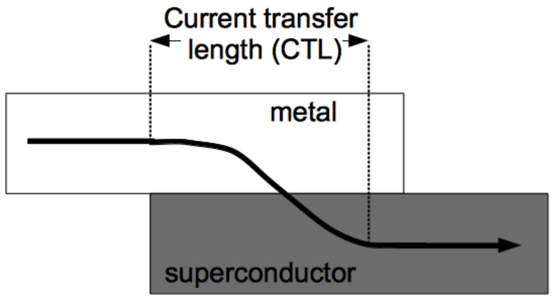
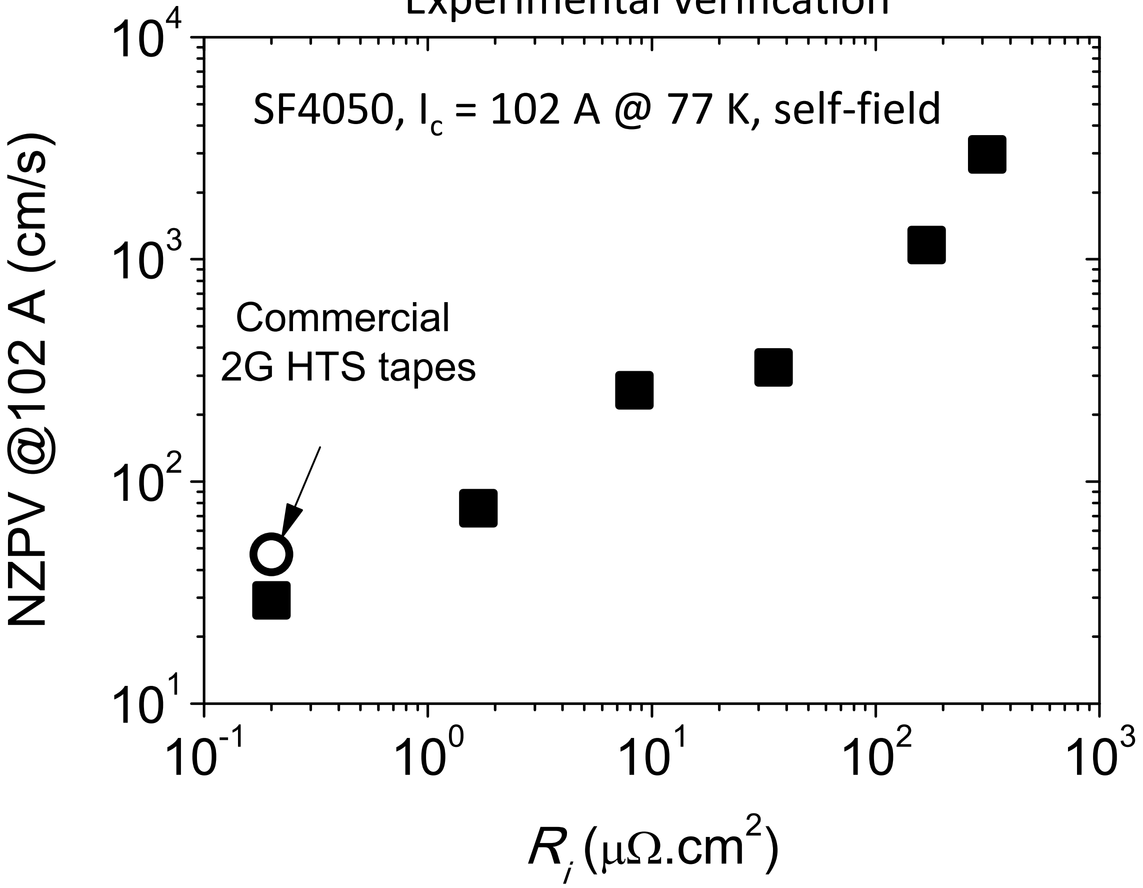


Experimental verification



Lacroix *et al. IEEE Trans. Appl. Supercond.* 23, 4701605 (2013)

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Current flow diverter (CFD) concept

From a practical point of view
…increasing the REBCO/Ag interfacial resistance may lead to premature quench at current lead contacts, which is **highly undesirable**

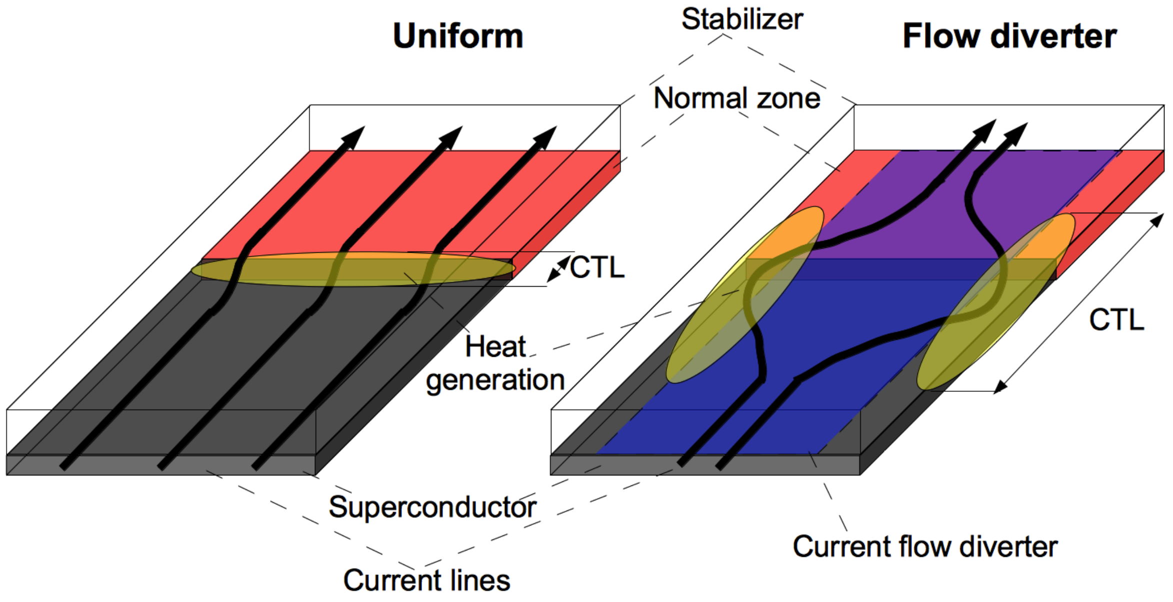
Can we increase the CTL without increasing R_i too much?

YES, with the Current Flow Diverter (CFD) concept

Goal: force the current to pass through a specific path
(leads to current crowding)

How?

By using a resistive layer that **partially** covers the Ag/HTS interface



Lacroix *et al. SUST* 27, 035003 (2014)
US Patent: Lacroix *et al.* US9029296B2

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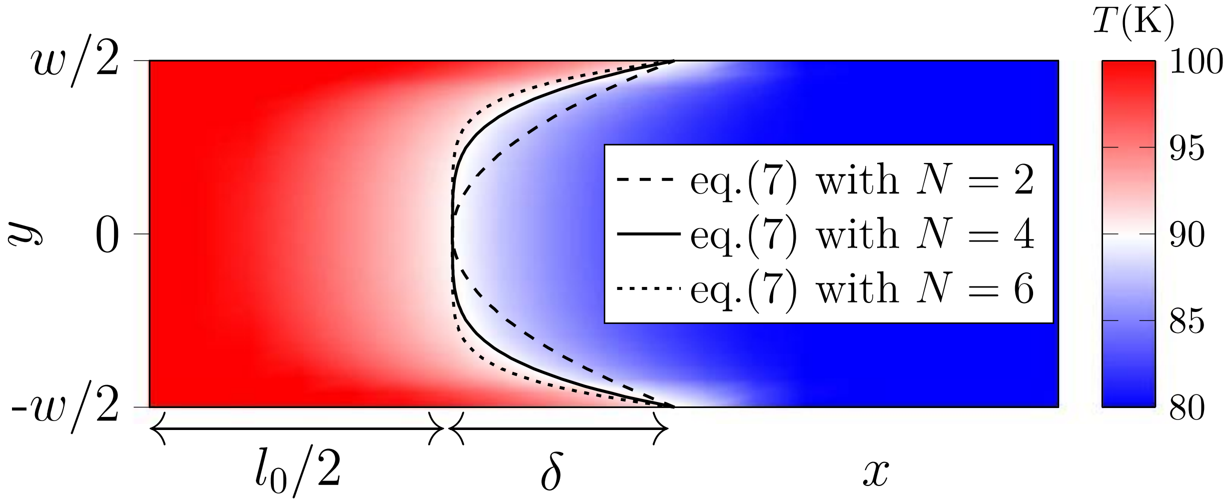
How?

Current crowding induces a **normal zone with a U-shape** that **further** increases the CTL (dynamic CTL vs static CTL)

static CTL = f(R_i)

dynamic CTL = f(R_i,$T_{profile}$) > static CTL



Fournier-Lupien *et al. SUST 34*, 085001 (2021)

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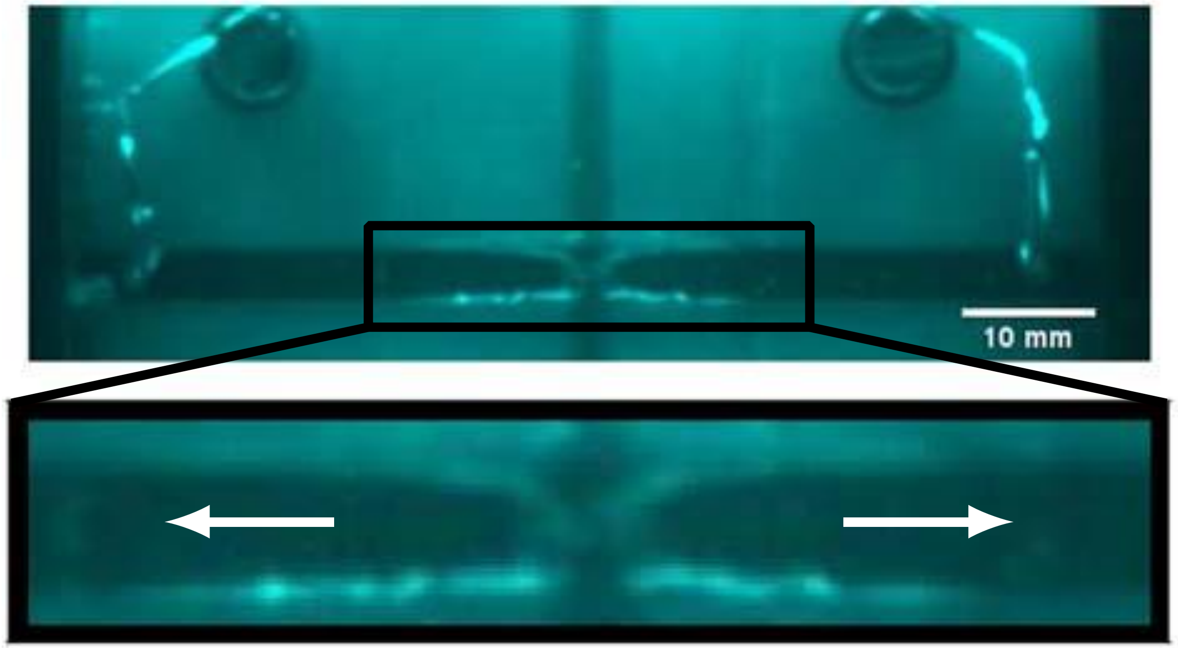

Fournier-Lupien *et al. SUST 31*, 125019 (2018)

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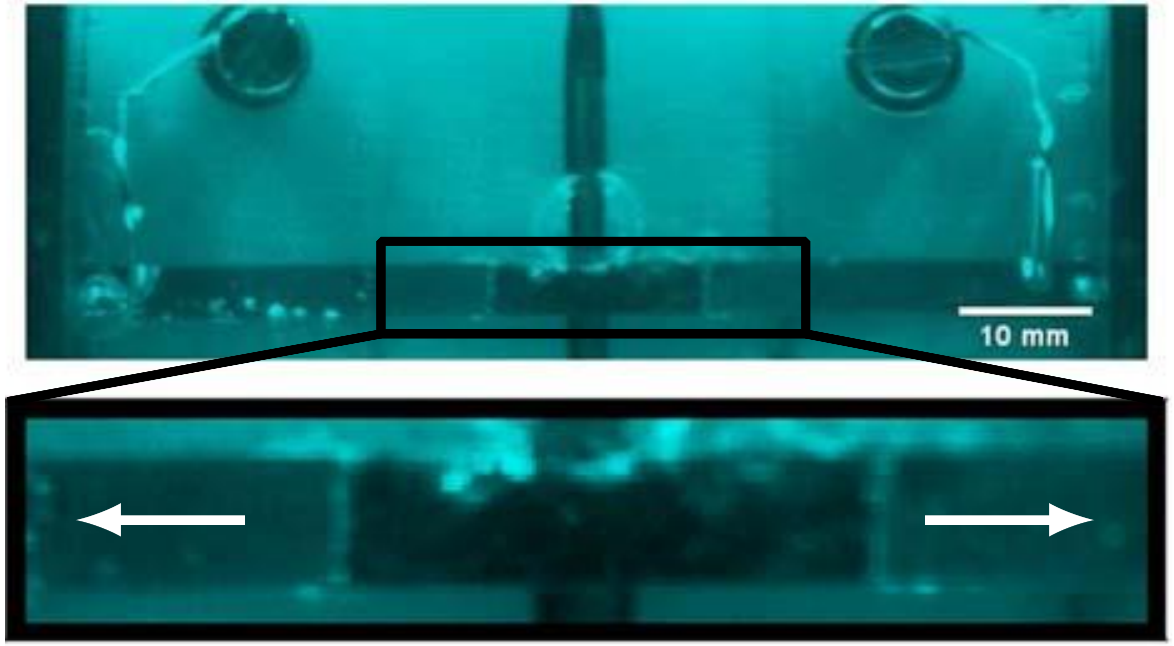
How?

For comparison, here is a quench in a commercial REBCO tape: the normal zone has a rectangular shape



Fournier-Lupien *et al. SUST 31*, 125019 (2018)

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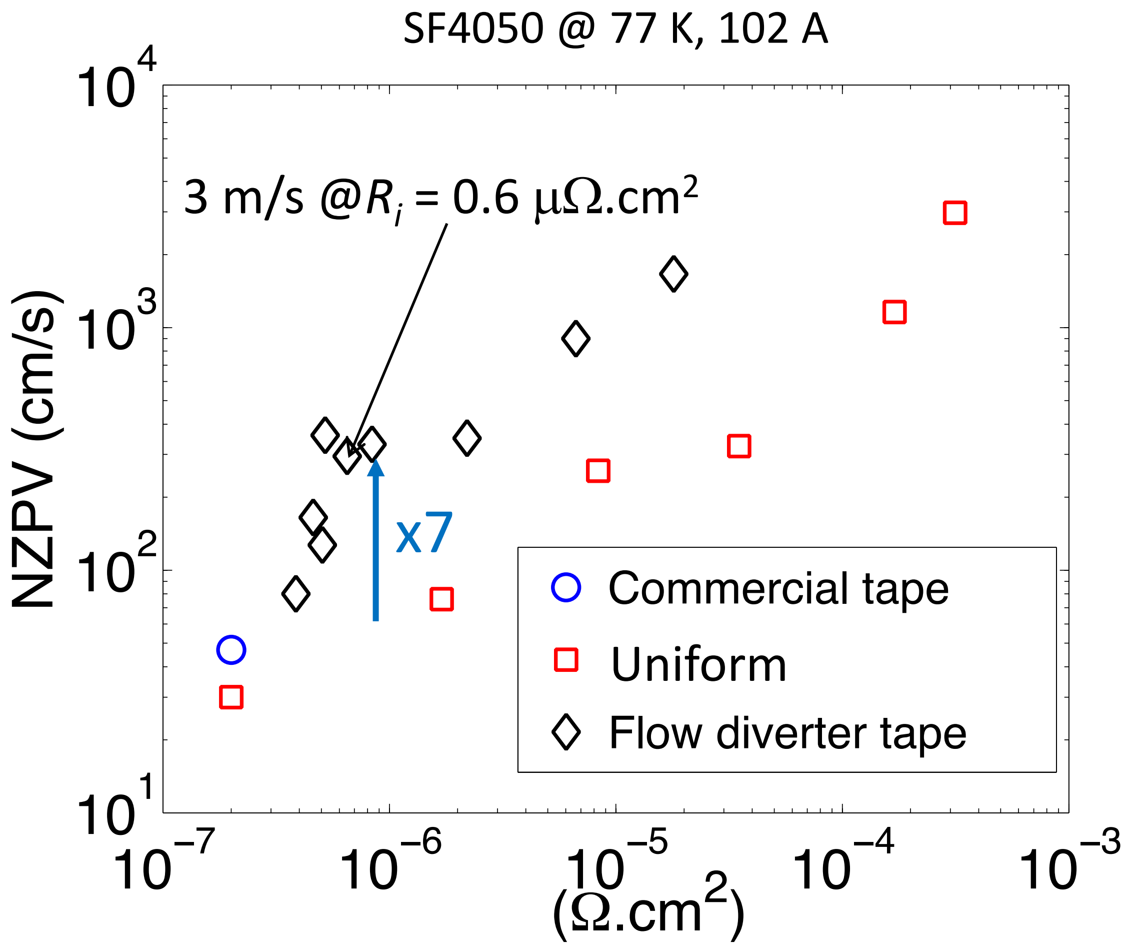

Lacroix *et al. SUST* 27, 055013 (2014)

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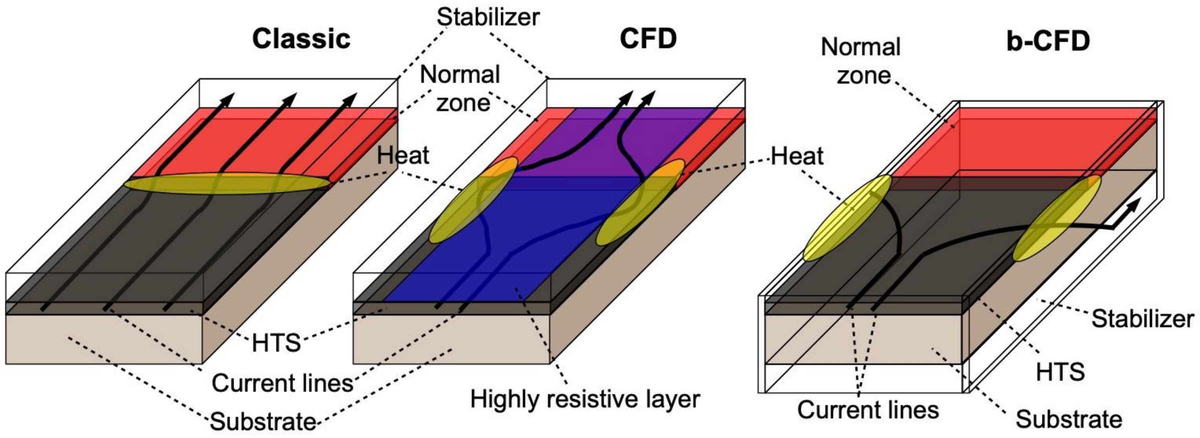
Alternative CFD architectures

IOP Publishing
Superconductor Science and Technology
Supercond. Sci. Technol. **31** (2018) 125019 (8pp)
https://doi.org/10.1088/1361-6668/aae2cd

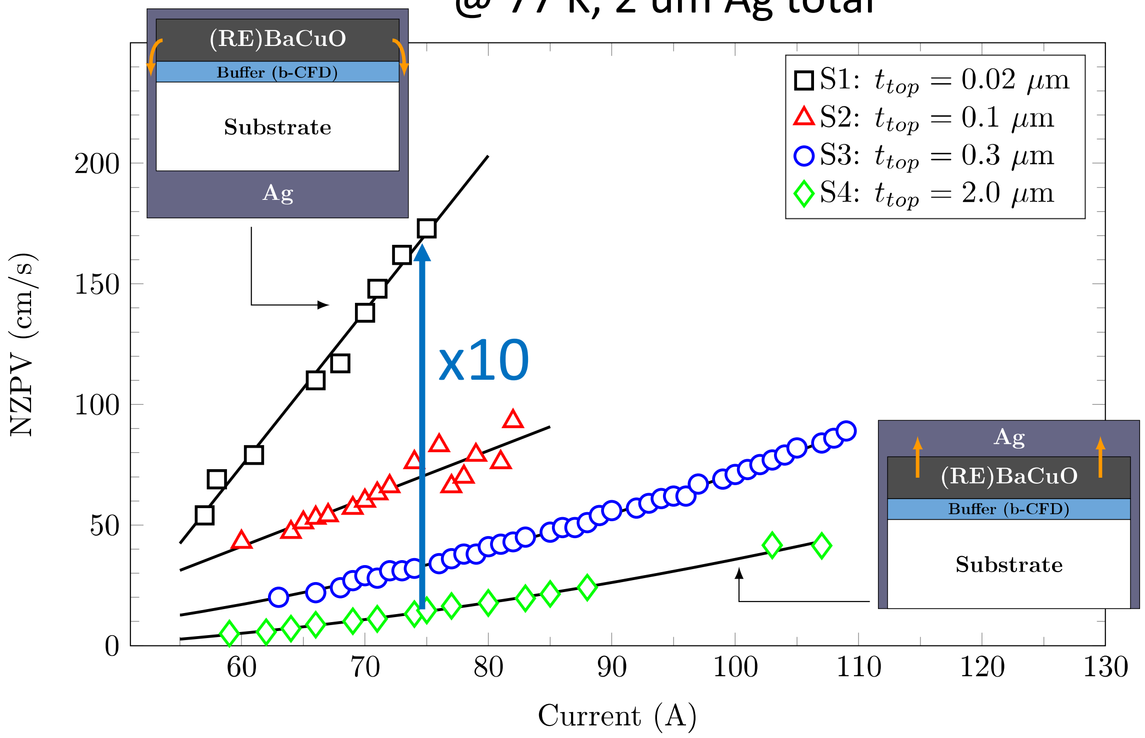
Use of the buffer layers as a current flow diverter in 2G HTS coated conductors

J-H Fournier-Lupien[1,2], **C Lacroix**[1], **S Hellmann**[2], **J Huh**[3], **K Pfeiffer**[3] and **F Sirois**[1,2]

[1] Polytechnique Montréal, Montréal, QC H3C 3A7, Canada
[2] Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, D-76344, Germany
[3] Superconductor Technologies Inc. (STI), 9101 Wall Street, Suite 1300, Austin, TX 78754, United States of America



Custom made 4 mm wide STI tapes
@ 77 K, 2 um Ag total

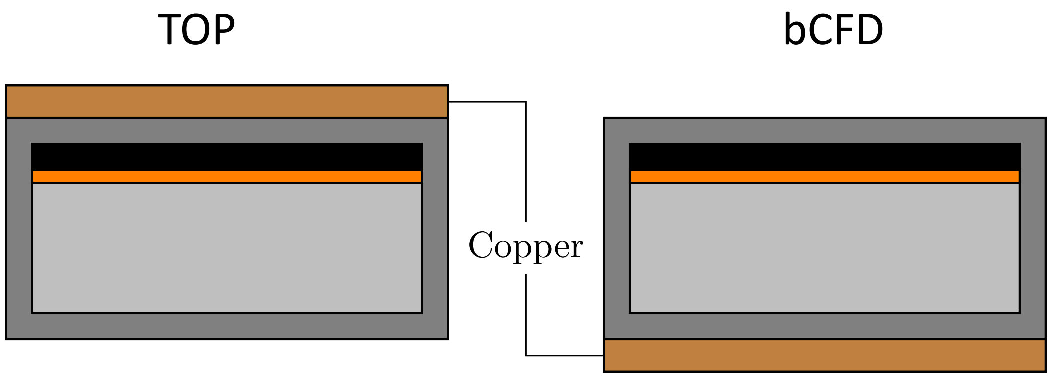


Agrees well with numerical simulations
(black lines in figure)

Alternative CFD architectures

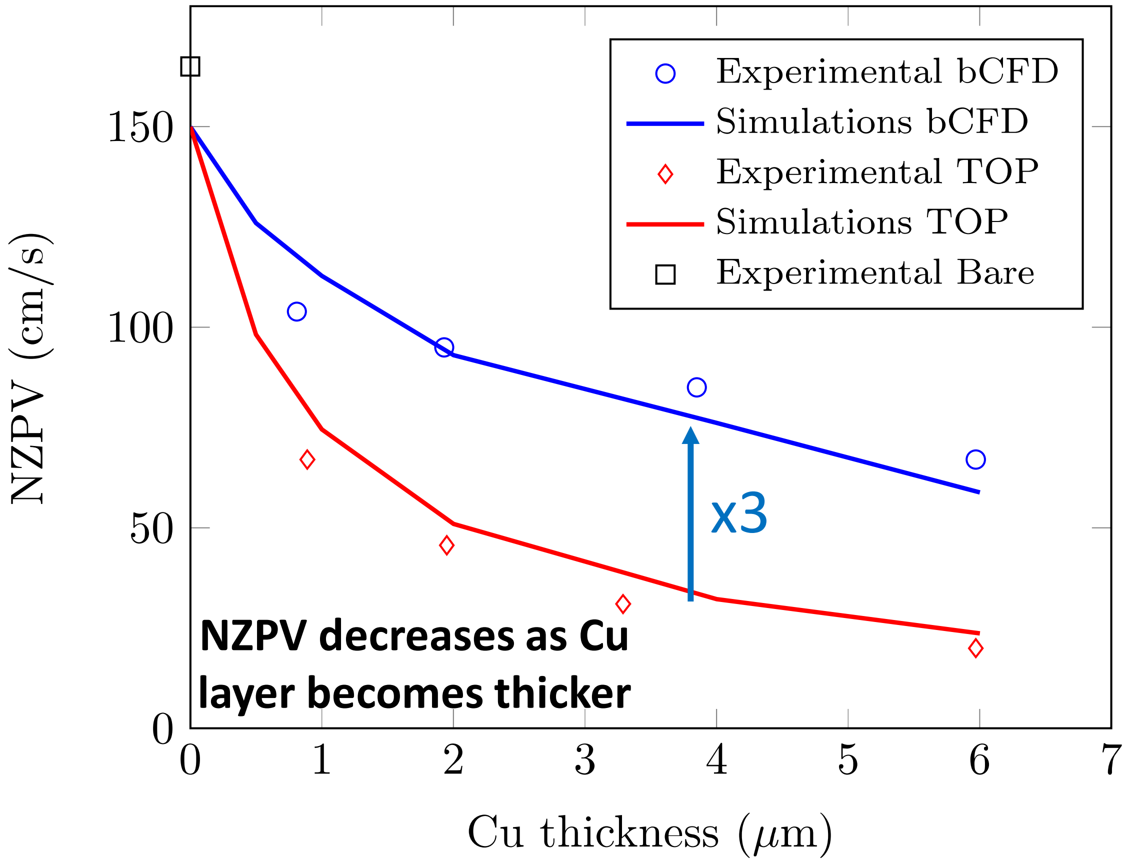
bCFD EFFECT OBSERVED WITH THICKER SHUNT

-> Cu electroplated on SuperPower samples



Giguère *et al. SUST 34*, 045010 (2021)

SF4050 @ 77 K, 160 A



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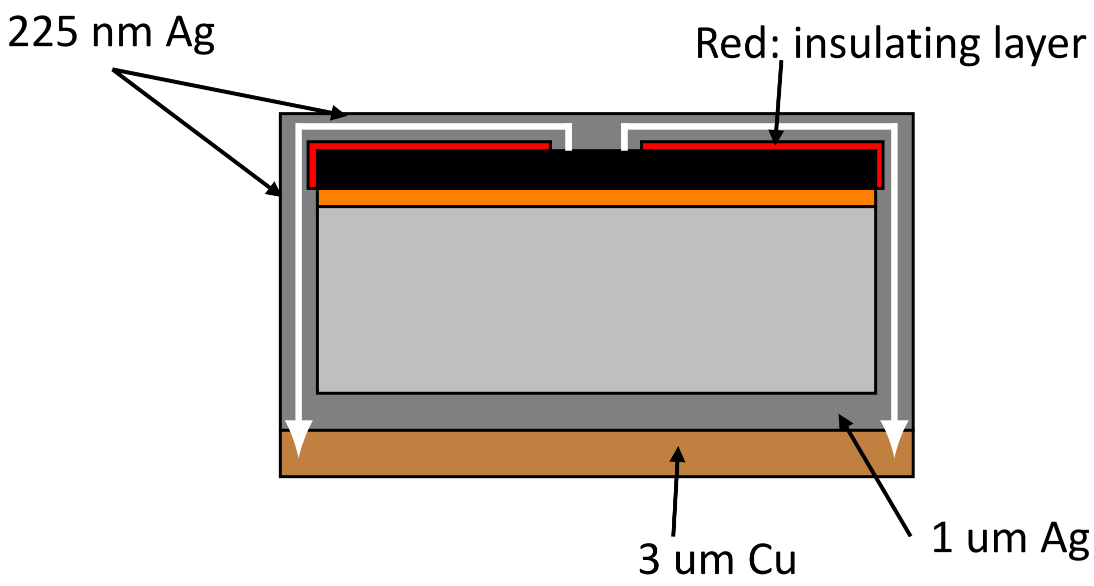
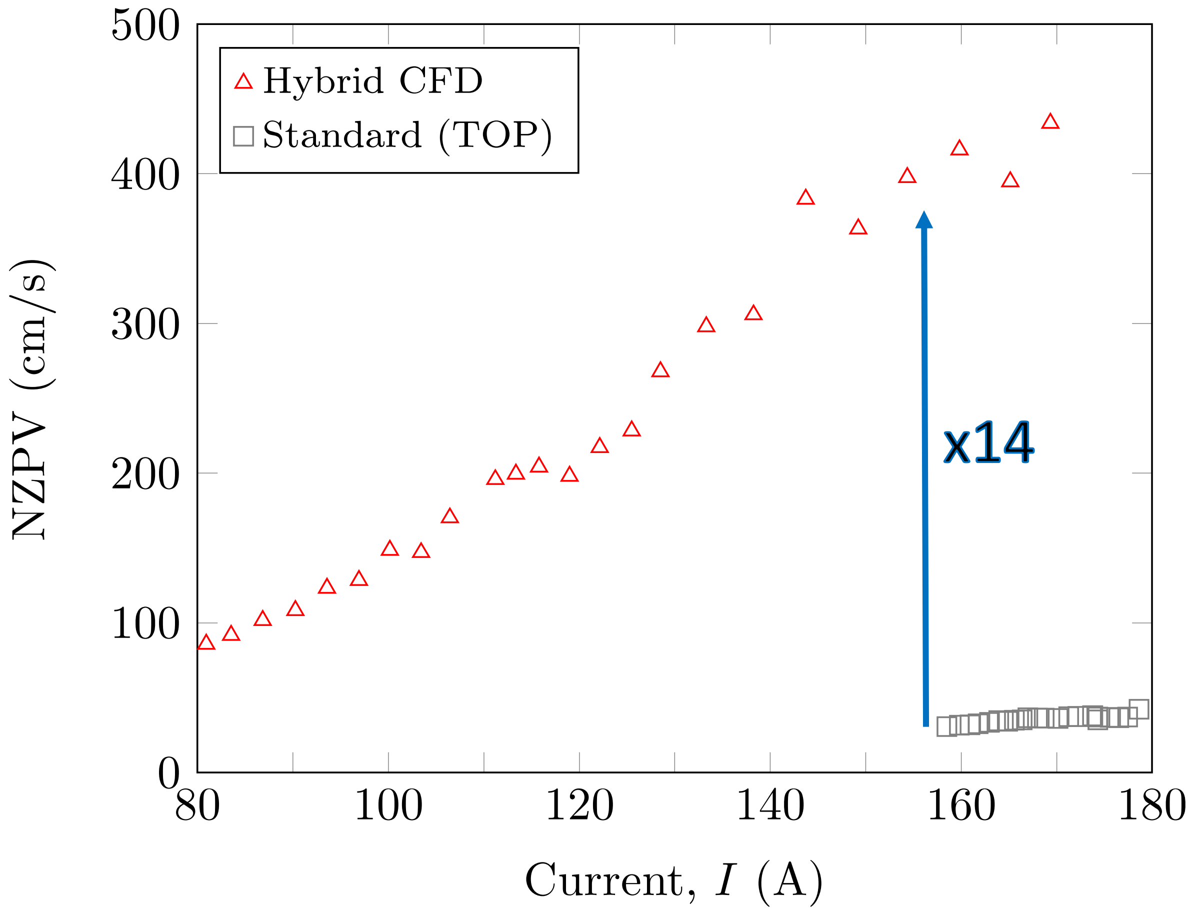
Alternative CFD architectures

Hybrid-CFD: combination of the traditional CFD and the bCFD



Giguère *et al. SUST 34*, 045010 (2021)

Modified SF4050 @ 77 K
with 3um Cu shunt



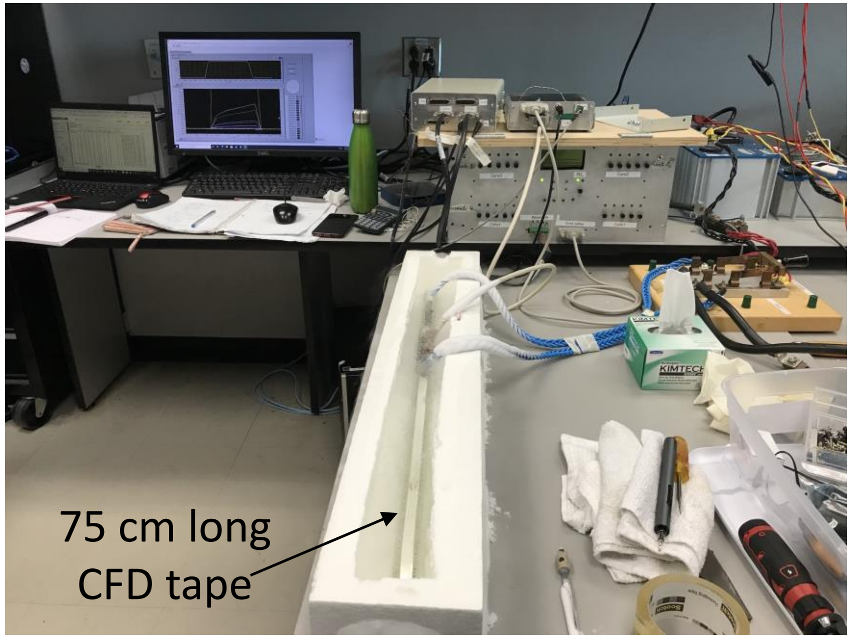
Manufacturing of long CFD REBCO tapes

What manufacturing process is acceptable (technical, cost, yield) ?

"Standard process"

1. Masking 2. Ag etching 3. Mask removal 4. Ag deposition

CFD tape (12mm wide THEVA tape)



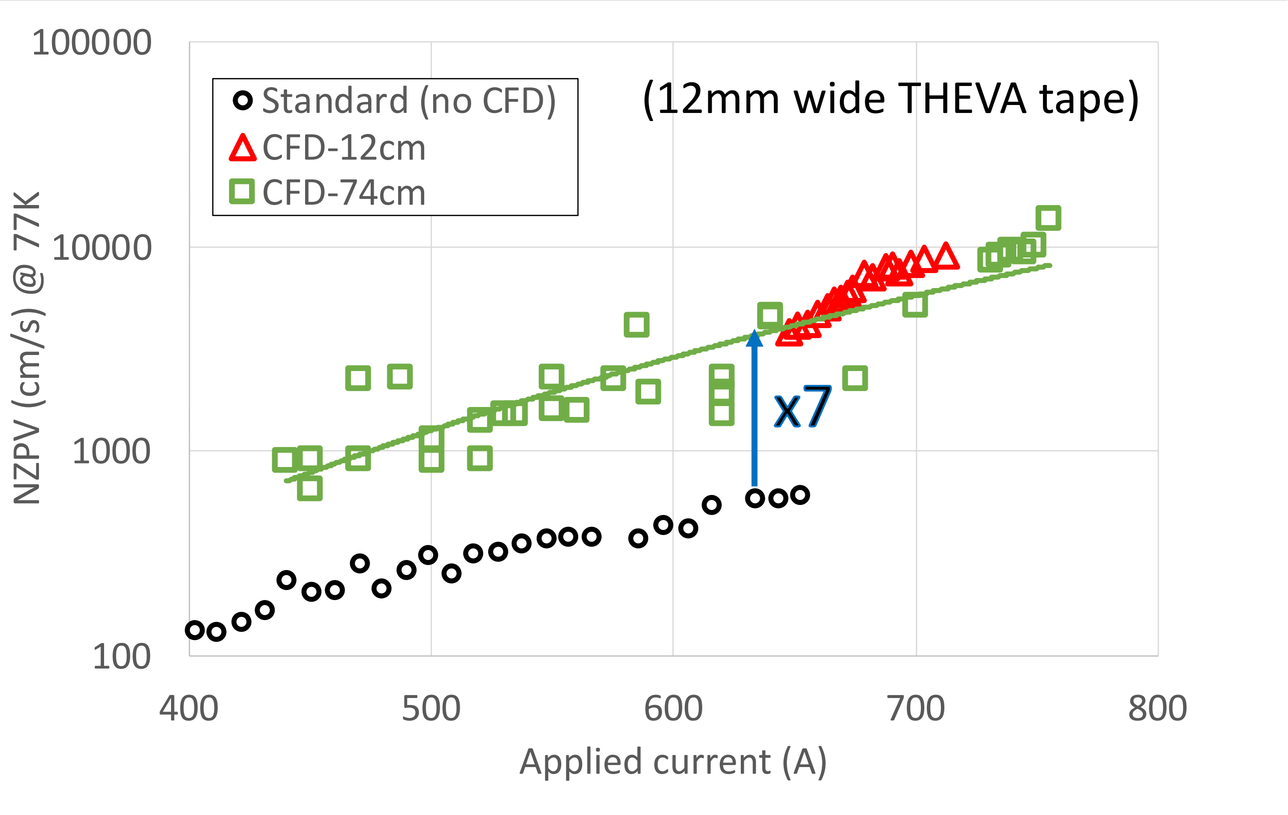
Facilities at Polytechnique:

Fabrication of 5 meters long CFD tapes (4 mm wide)

Ben Saâd *et al., manuscript in preparation.*

Manufacturing of long CFD REBCO tapes

What manufacturing process is acceptable (technical, cost, yield) ?



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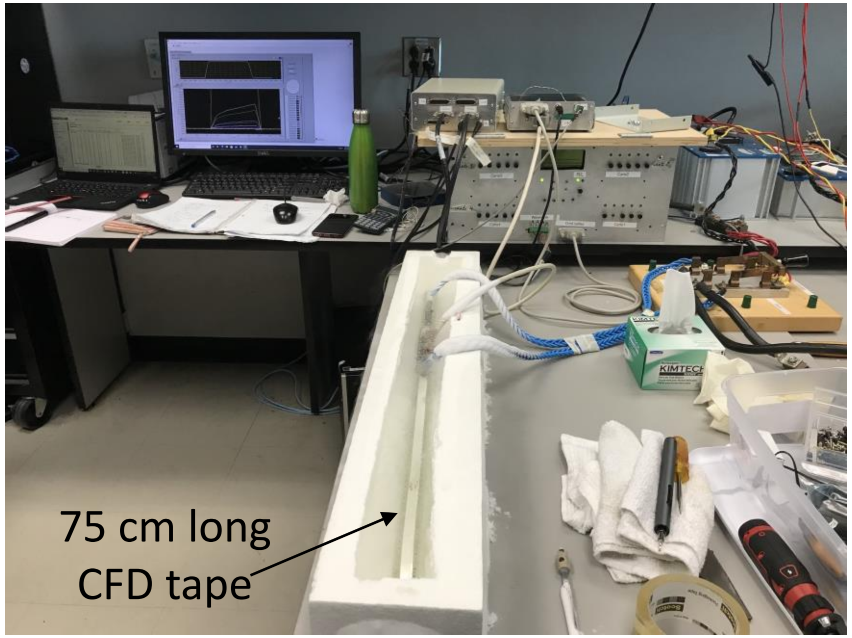

Ben Saâd *et al., manuscript in preparation.*

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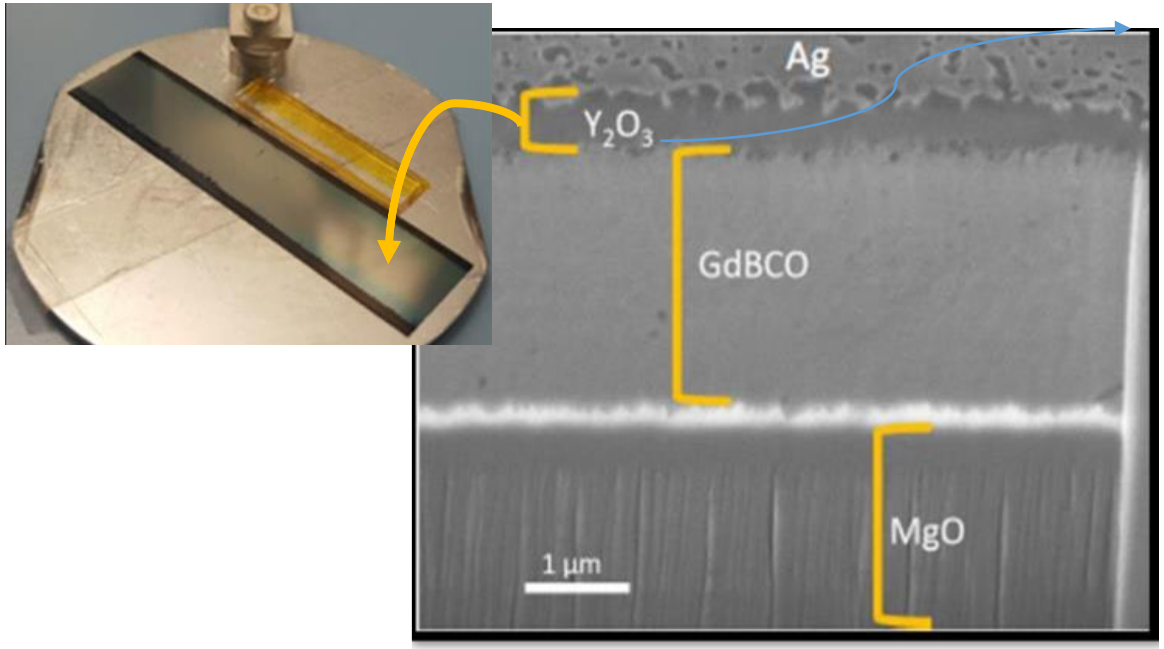
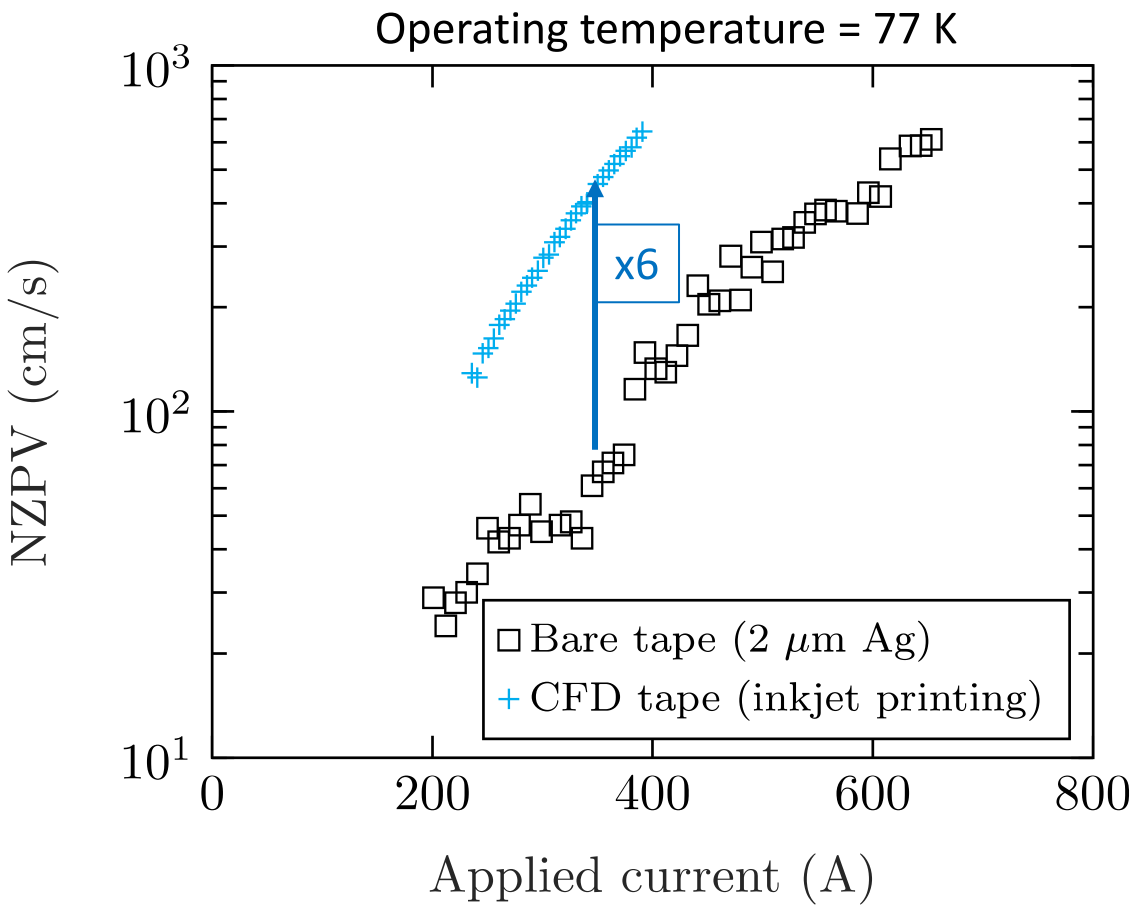
Manufacturing of long CFD REBCO tapes

H2020 European FASTGRID project

- Alternative manufacturing routes explored: use of inkjet printing for the CFD layer (Y_2O_3) on THEVA tape



Barusco *et al., submitted to ACS Omega.*



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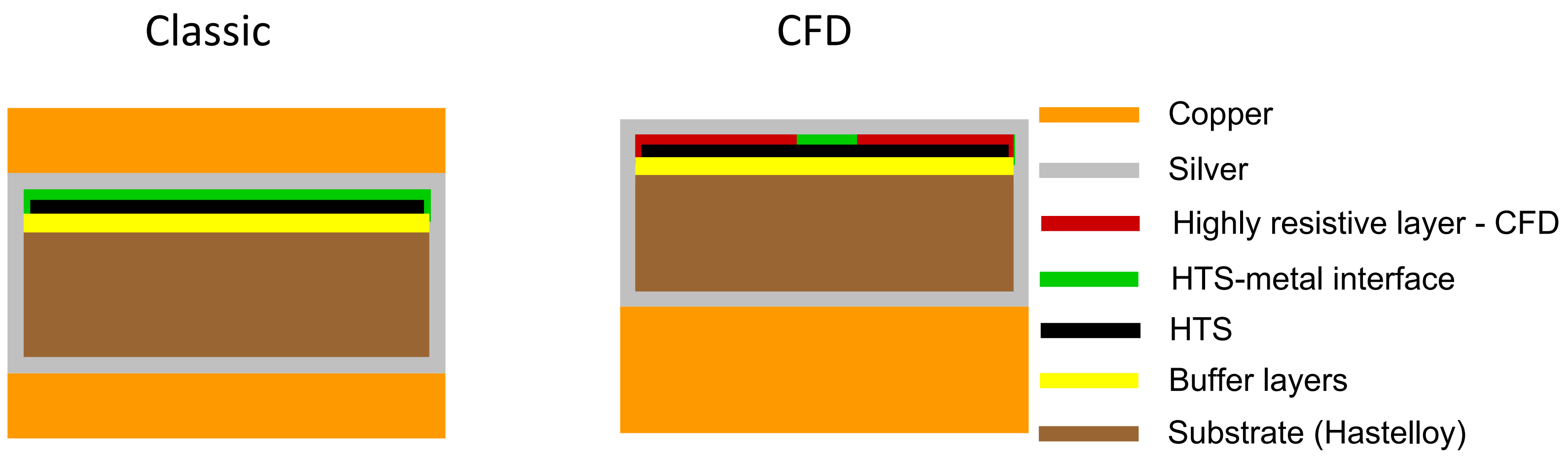
Application: high NZPV tapes for magnets

Is this CFD architecture useful for low temperatures applications ?

Helpful for quench detection ?

Case study: REBCO tape with a 10 um Cu shunt

T_{op} = 4.2 K
I_c = 1620 A
I_{op} = 1296 A ($0.8I_c$)
12 wide tape
1 um Ag surround
10 um Cu shunt (total)
50 um Hastelloy substrate
$I_{c,defect}$ = 810 A ($0.5I_c$)
Defect width = 1 mm

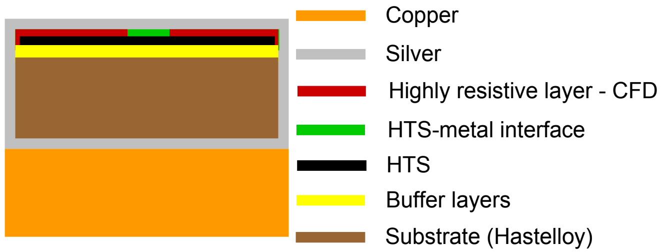


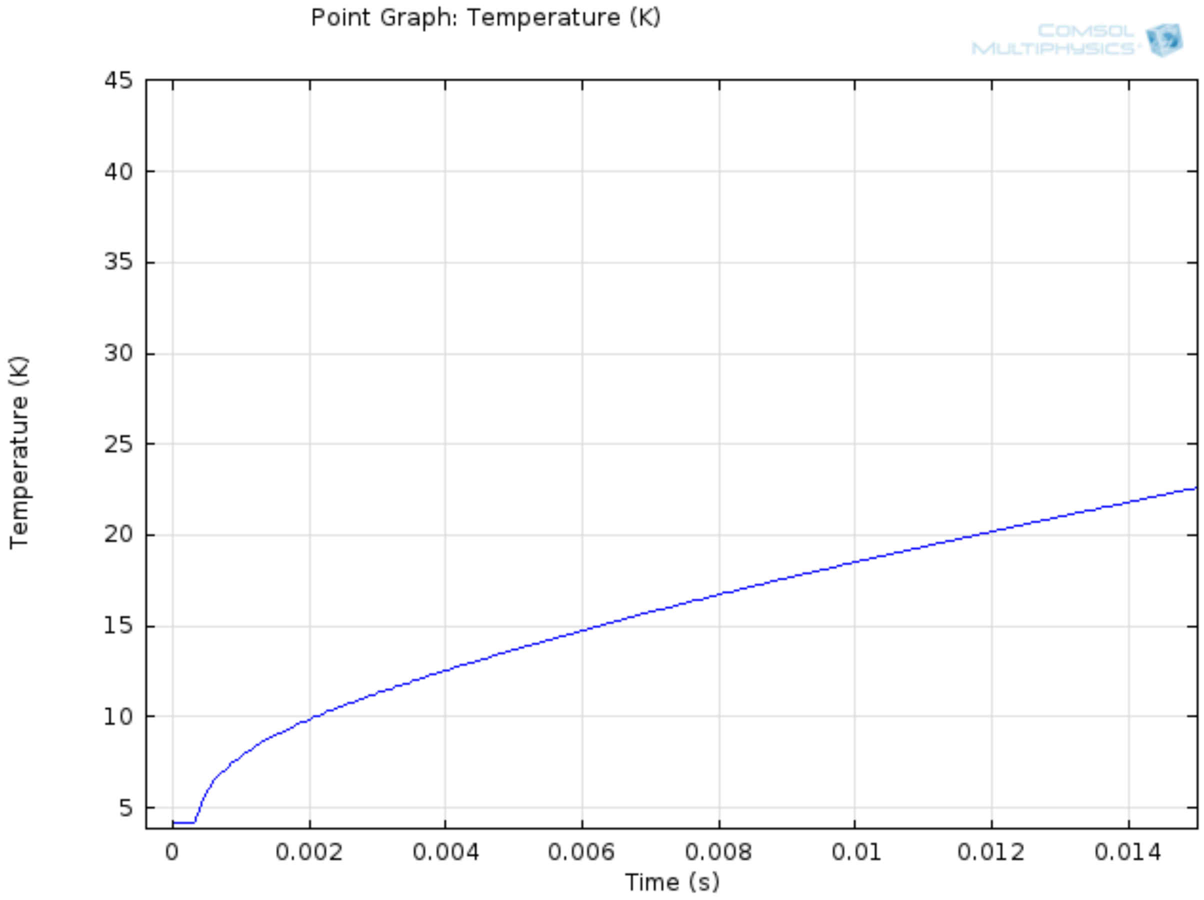
Limited length of tape in the 3D FEM software (COMSOL) → limits time range of simulations

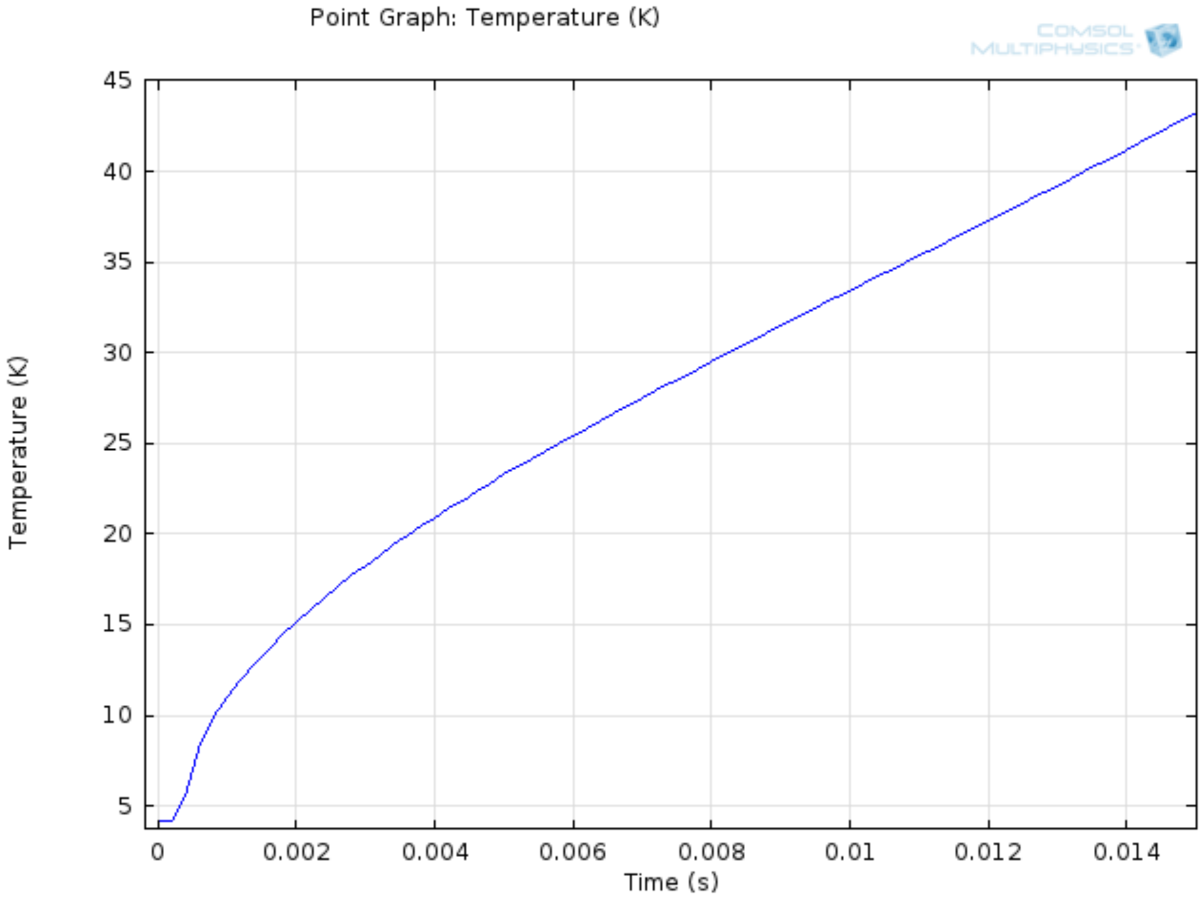
Homemade 2D FEM code with adaptive meshing currently in development

Example of adaptive meshing with the finite-difference method : Sosa-Rey *et al.*, *SUST 32*, 105005

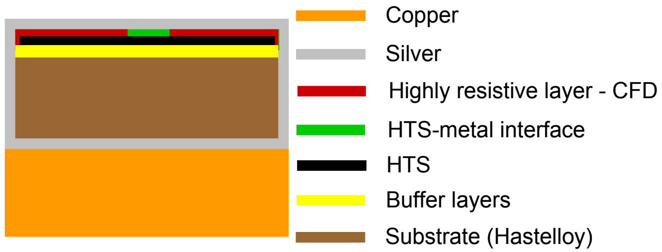
High NZPV tapes for magnets

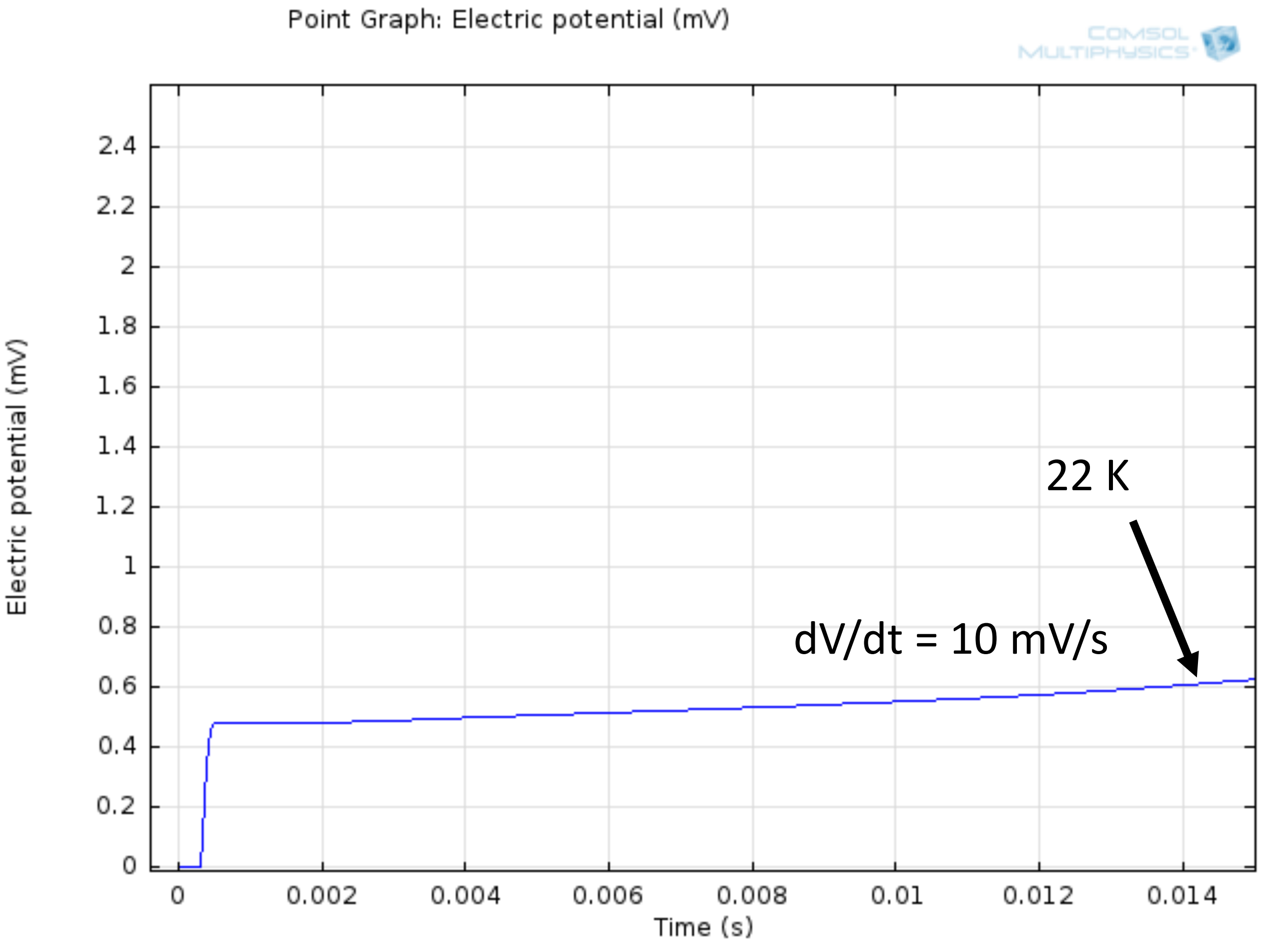


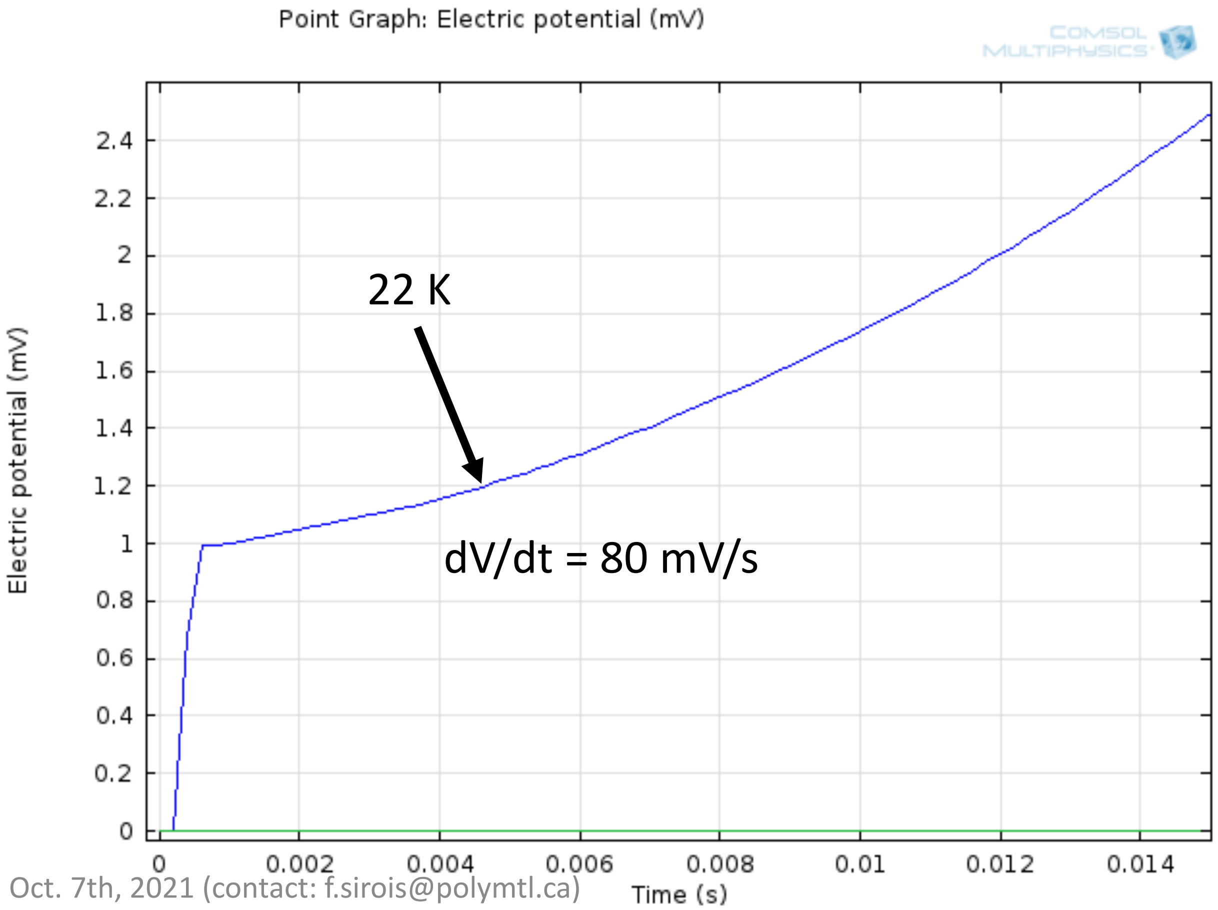




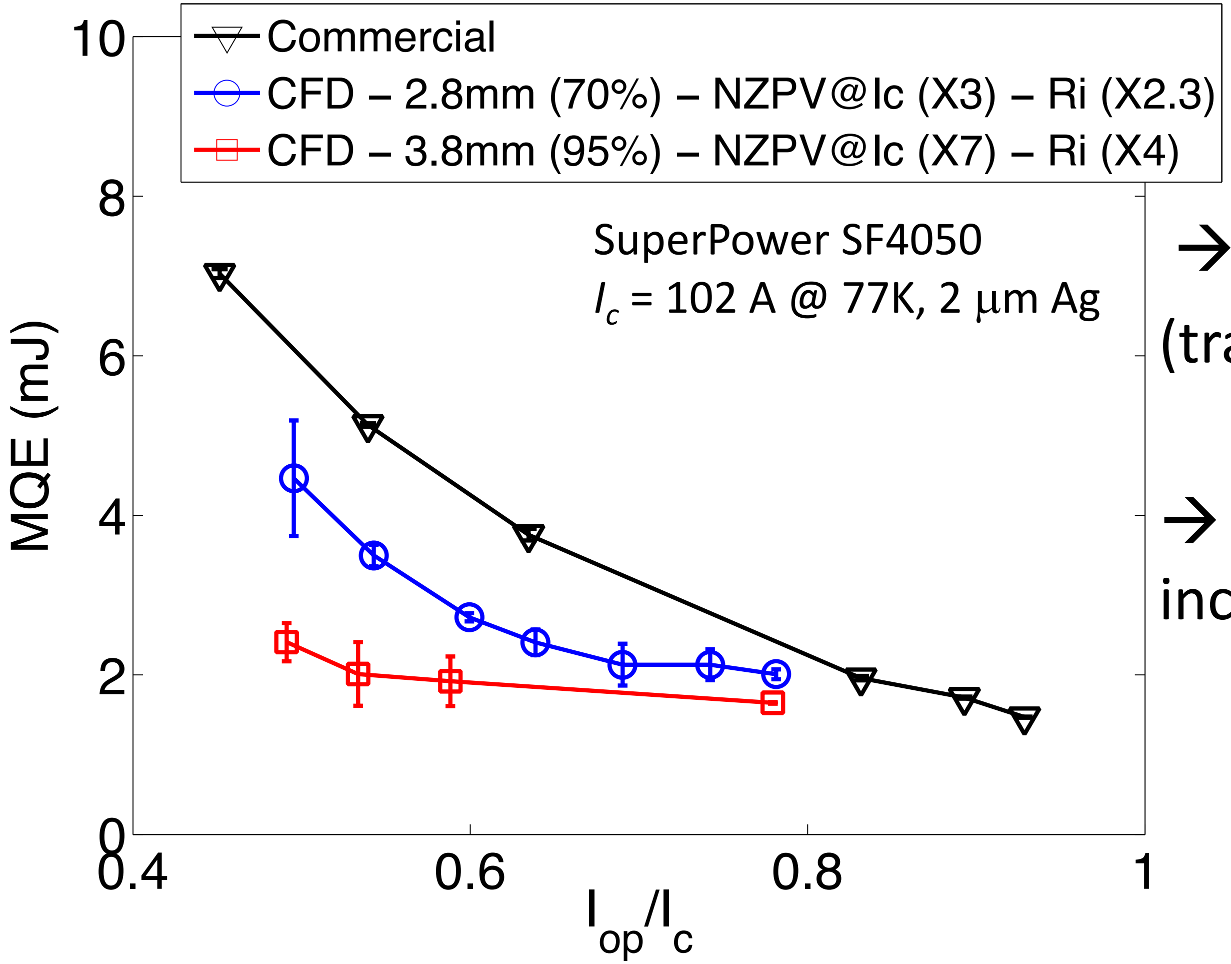
High NZPV tapes for magnets







Minimum Quench Energy (MQE) vs I_{op} (operating current): measurements



→ Reduced MQE in CFD tapes (tradeoff between NZPV and MQE)

→ Reduction less pronounced as we increase I_{op}

Lacroix *et al., ASC2014.*

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Future work

What else now?

- Pursue work on long-length CFD tapes

- New focus on high field magnets
  - Canadian proposals currently in elaboration
  - Targeted timeline: April 2022-March 2027

- In parallel, we try to
  - Learn more from literature and experts in the field
  - Identify lacks in knowledge and numerical tools impeding the R&D

Questions of importance already identified

- What is the quench behavior of REBCO cables using CFD tapes? How does it compare to the REBCO cables with nominal REBCO tapes?
- How does current sharing depend on
  i) local I_c drops in REBCO tapes?
  ii) contact resistances between multiple tapes and/or cable metallic sheath?
  iii) termination resistances?
- Would CFD tapes work well with current HTS magnet quench detection systems? (if such a system even exists!)
- What kind of experiment would allow confirming these questions?
- etc.

THANK YOU!

f.sirois@polymtl.ca

514 340-4711 ext. 3607

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