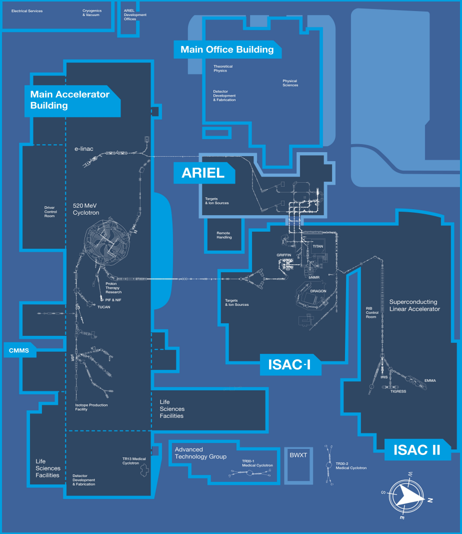
High-Temperature Superconducting Accelerator Magnets in Canada

2026 TRIUMF-KEK Symposium

Thomas Planche

TRIUMF

Conventional DC magnets at TRIUMF



At TRIUMF:

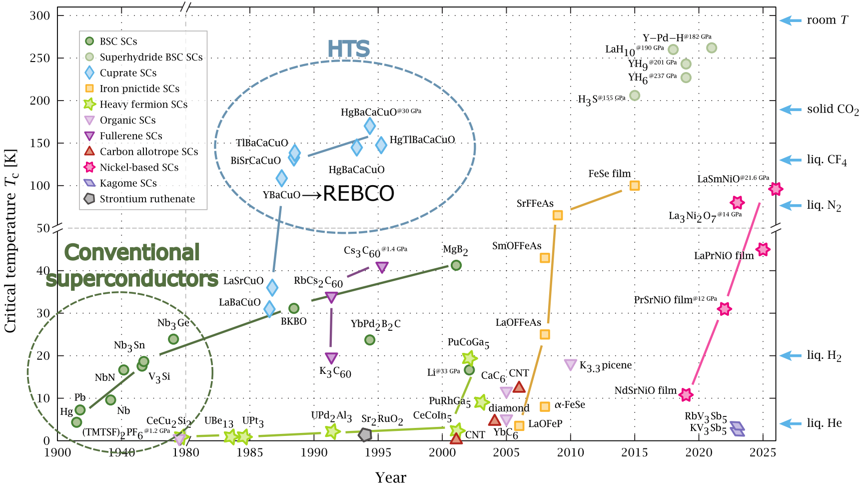
∼30 magnets consuming >20 kW each; several reaching ∼100 kW. Cyclotron main magnet uses 1.4 MW.

DC fields only; no energy transfer to the beam.

Superconducting (superferric) dipoles initially (2016) considered for ARIEL Beamline 4N: perceived technical/ operational risks led us to use conventional magnets instead.

Objective: build in-house superferric magnet expertise and reduce barriers and perception of risks.

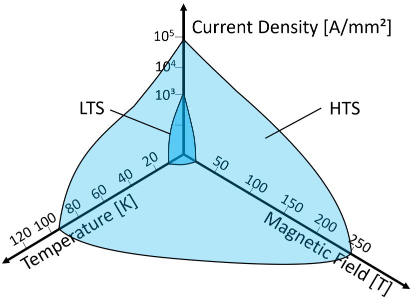
Families of superconductors



Source: Wikimedia Commons, file `Timeline_of_Superconductivity_from_1900_to_2015.svg`.

Critical Surface

A superconductor can carry more current density (J) and sustain higher field (B) at lower temperatures (T). It remains superconducting within the **critical surface** in (J, B, T) space. Outside: quench. The critical current density $J_c = f(T, B)$.



Schematic. Haubner *et al.*, Appl. Sci. **13**, 2765 (2023), Fig. 1(a), CC BY 4.0 [Haubner et al., 2023].

With REBCO tapes the angle between $\vec{B}$ and $\vec{J}$ matters.

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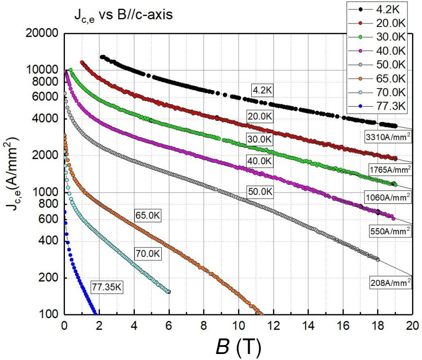

Measured REBCO tape critical curves at various temperatures (Faraday Factory Japan) [Lee, 2023].

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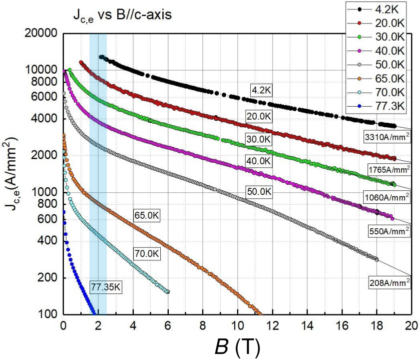

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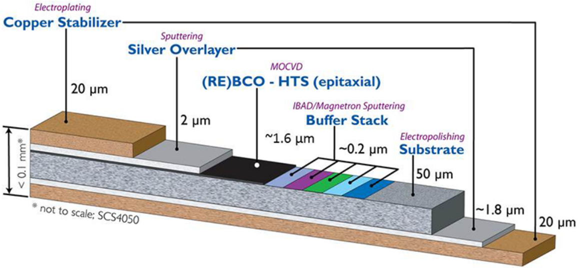
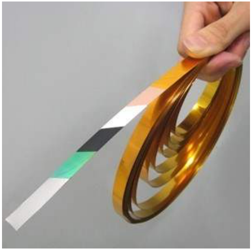
REBCO tape: what does it look like?



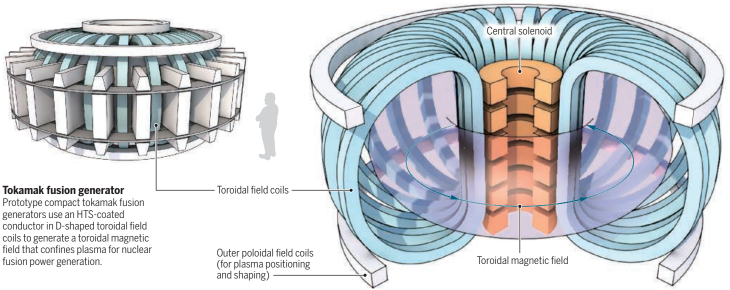


Left: SuperPower SCS4050 coated conductor. Right: © Fujikura.

REBCO tapes are flexible but anisotropic, manufactured using sophisticated thin-film deposition techniques.

In contracts: conventional NbTi wires are produced by conventional drawing of the superconductor in a normal conducting matrix.

Why REBCO production is booming: fusion

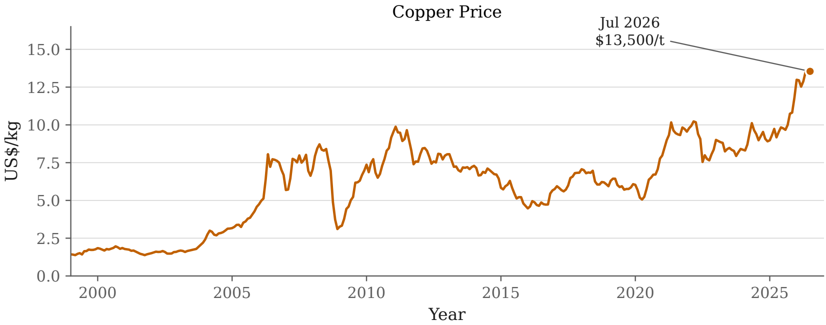


Prototype compact tokamak that uses HTS for the D-shaped toroidal coils [Molodyk and Larbalestier, 2023].

Fusion reactor require huge magnets, and very high fields (up to 20 T in the coil).

Around 12 companies now build on REBCO tape, and fusion takes >**90%** of world production [Sirois, 2026], driving the cost down per kA·m.

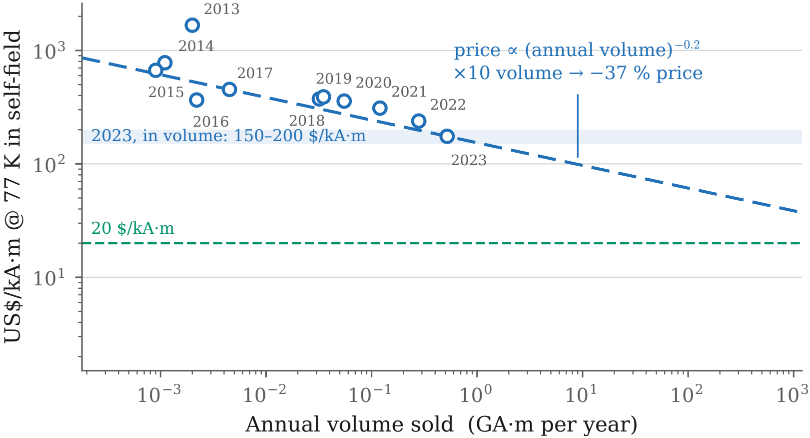
Copper is getting expensive



Copper price nearly tripled last decade [International Monetary Fund, 2026].

1 m of DC copper cable carrying 1 kA at @ 5 A/mm^2 is 200 mm^2, or 1.8 kg. This leads to $\sim$**$20/kA.m** of raw copper.

REBCO tape is getting cheaper



Points and fit [Molodyk, 2024]; scale anchored to 175 $/kA·m [Molodyk and Larbalestier, 2023]. J_c is increased by ∼3× at 65 K, and ∼15× at 50 K from [Wimbush and Strickland, 2026].

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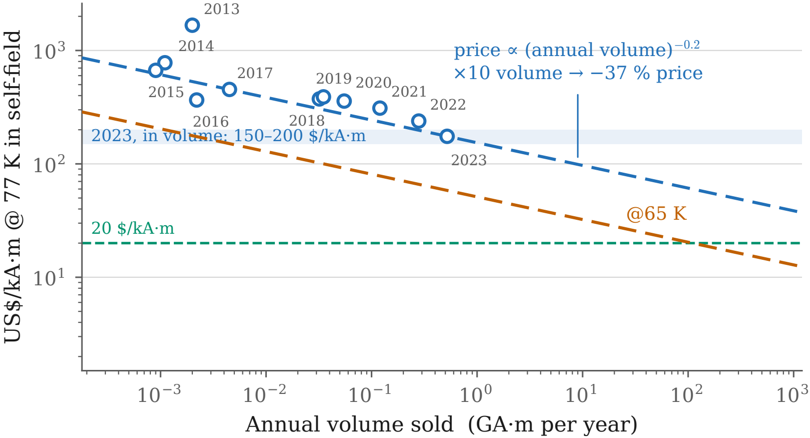

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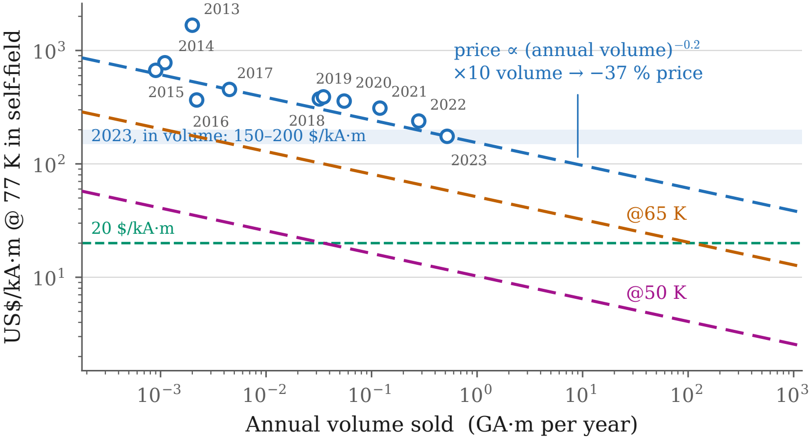

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Application to superferric magnets at TRIUMF

Superferric electromagnet: superconducting coils driving an iron yoke with shaped pole pieces. An advantageous configuration around 2–4 T:

- simpler coil geometry: the field shape is set by the steel, not by the winding;
- less field in the coil: a large part of the flux is carried by the steel;
- fewer amp-turns needed than with no steel.

2026: HTS Magnet Grant

NSERC awarded Polytechnique Montréal + U. of Victoria + TRIUMF a 2-year project grant to “design an energy-efficient cryocooled HTS dipole magnet for TRIUMF beamlines”, with 4 main objectives:

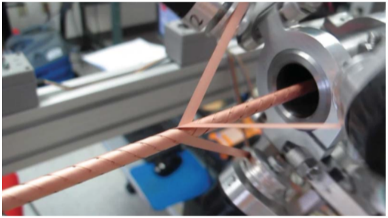
1. Determine suitable dipole magnet geometry & HTS wire/cable/coil configuration.
2. Devise and demonstrate the quench detection/protection strategy.
3. Design and quantify the economics of the magnet cryocooling system.
4. Quantify the impact of radiation on REBCO degradation at TRIUMF.

This is a **design study**, not a magnet build. Building it is the job of a follow-up equipment proposal, with the goal of a first HTS magnet on a TRIUMF beamline within five years.

Magnet design

Target: a ∼3 T superferric dipole bending 500 MeV protons by 45°, 60 mm pole gap, drawing ∼**2 kW at 50 K** in place of the 30-100 kW of the copper magnet it replaces.

Design tools: COMSOL/OPERA for the first sizing, then BELFEM [Messe et al., 2023], the LBNL-Polytech REBCO code, for screening currents, losses and quench dynamics.



Winding a CORC cable. Advanced Conductor Technologies [Sirois, 2026].

One of the expertise at Polytechnique is with **cables**: a round cable is isotropic and easier to wind, at the cost of manufacturing complexity [Wang et al., 2021].

PhD student **Simon-Mathieu Bergeron Hartman** has been hired at Polytechnique to work on the magnet design.

Quench protection

A hot spot can destroy a magnet in seconds. In REBCO it propagates up to **two orders of magnitude slower** than in LTS: the voltage signal stays small while the temperature runs away [Marchevsky, 2021].

It is the primary concern of the HTS magnet community today, and the specialty of Polytechnique Montréal:

- Current Flow Diverter tape architecture, which raises the normal zone propagation velocity [Lacroix et al., 2022];
- optical fiber detection embedded in the cable itself;
- modelling of intra- and inter-tape current transfer, to settle whether a 3 T magnet can be left self-protected or needs a dump resistor.

Prof. Frédéric Sirois

Polytechnique Montréal

At LBNL a single quench destroyed a subscale REBCO accelerator dipole [Sirois, 2026]: detection has to fire in milliseconds.

Cryogenic system

Choosing the operating temperature is the main economic lever. Relative to the critical current at 77 K and 3 T, a tape carries roughly $\times 100$ at 20 K, $\times 15$ at 50 K, $\times 3$ at 65 K [Wimbush and Strickland, 2026].

Choosing the operating temperature and the cooling concept is a main economic lever. So the colder the magnet, the less tape it needs, but the heavier and the hungrier the cryogenics:

- **20 K**: two-stage cryocooler and a radiation shield — a larger, costlier cryostat, eating the gain from the smaller coil. Still $\sim 10\times$ less power than copper.
- **50 K**: $\sim 7\times$ more tape, but single-stage cryocooler, no shield, $4\times$ less electricity than 20 K.
- **65 K**: subcooled LN_2, helium-free. At 77 K J_c is too low to pay; at 65 K, worth quantifying.

Prof. Tobias Junginger

UVic & TRIUMF

Cryocooler expertise at **UVic**: T. Junginger's group built a vibrating sample magnetometer on a two-stage cryocooler, and brings the thermal design and simulation tools.

Impact of radiation

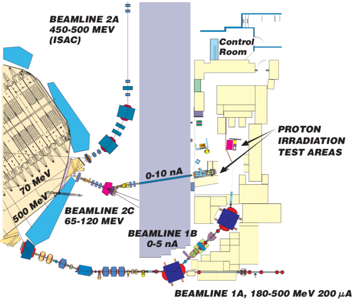
500 MeV protons at up to ∼100 μA on BL1A: the magnets sit in a field of protons, fast neutrons and gammas, both of which degrade the critical current of REBCO tape, the electrical insulators and epoxy impregnation [Jirsa et al., 2018].

A similar issue is met by the fusion community.

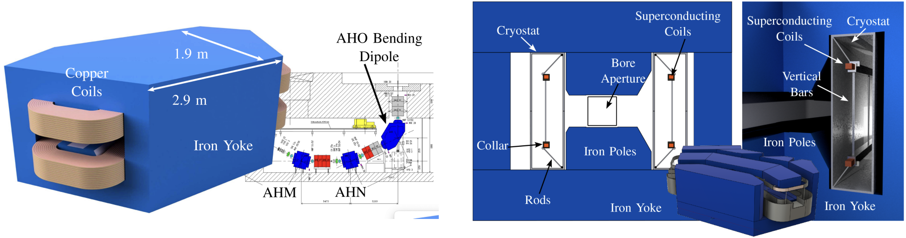
Plan: expose REBCO samples in a representative accelerator environement near an operating beamline, and under controlled conditions at **PIF & NIF**, then measure the critical current degradation at Polytechnique. Ideally in cryo-vacuum, to emulate the operating point.

Dr. Camille Bélanger-Champagne

PIF & NIF Facilities Coordinator



It has been done on paper: the PSI retrofit



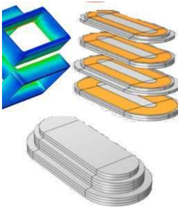
Left: the normal-conducting AHO dipole (1.45 T). Right: mechanical assembly of the HTS version [Mariotto et al., 2025].

Keep the iron, replace the copper coils by a REBCO winding at 50 K inside a cryostat: warm enough that no thermal shield is needed.

The copper coils draw **190 kW** (715 MWh/year). Two single-stage cryocoolers would draw **3.4 kW or 5.8 kW** depending on the cold head: an energy saving factor of 33 to 58, paying back the cost of the superconducting coil in ∼**3 years** [Mariotto et al., 2025].

HTS4SRI: a Horizon Europe project led by PSI

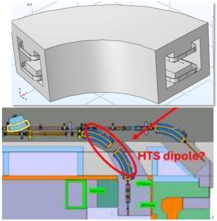
3 flagship demonstrators



GSI / SIS18

Two conduction-cooled quads, $\sim$4 T peak.

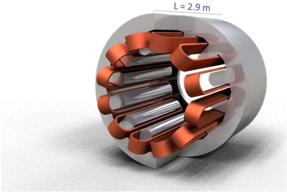
Replaces a $\sim$60 kW normal-conducting system.



PSI / TATTOOS

A compact 4 T bending dipole for HIPA.

Expected saving 0.3 GWh/year.



CERN / FCC-ee

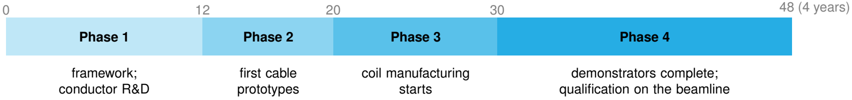
A superferric combined quadrupole–sextupole:

2 T peak, 50–65 K.

All three panels from [Sanfilippo, 2026].

HTS4SRI: a Horizon Europe project led by PSI

Scope: Realize prototypes and testing (TRL 6): magnet, cryogenics, powering.



Months from the 1 September 2026 start [Sanfilippo, 2026].

Started 1 September 2026. Demonstrators are due 2030.

7.57 M€ in total, 5.0 M€ of it from the EU. 8 partners: PSI with Bruker, CEA, CERN, CIEMAT, GSI, INFN and UMIL.

A life-cycle analysis is also part of the study for the 3 demonstrators.

The same questions, at a different scale

What HTS4SRI is working on is also very similar to what we are working on:

- **Low-ish fields**: Peak field levels in the 2-4 T range;
- **radiation hardness of REBCO**: irradiation campaigns at PSI and GANIL/SPIRAL-2 feeding back into the coil design;
- **quench detection**: combining electrical, magnetic, acoustic and optical signals;
- **conduction cooling at 20–77 K**.

But they have a head-start.

Conclusion

REBCO magnet technology is still in its infancy: but it is here to stay. Fusion is paying for the tape, the tape is getting cheaper, and copper is getting more expensive.

Todo: Something about the convergence of ideas PSI, TRIUMF, others. . . **Canada missed the LTS magnet train**: no NbTi or Nb_3Sn magnet industry, and not one REBCO tape manufacturer on this side of the border.

There is still time to catch the HTS one. That is what the NSERC-funded Polytechnique × UVic × TRIUMF collaboration is for.

Thank you for you attention

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