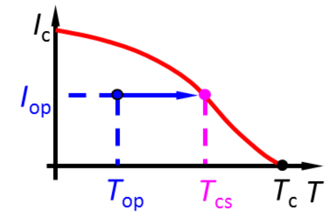
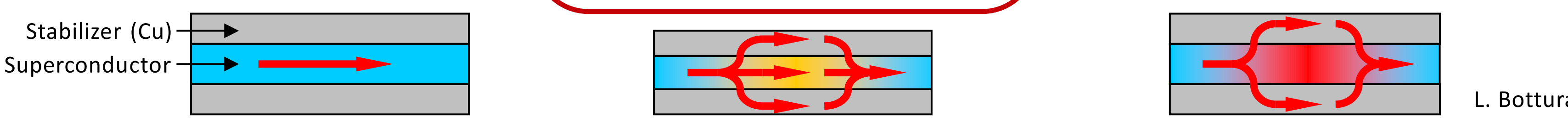
Magnet Quench

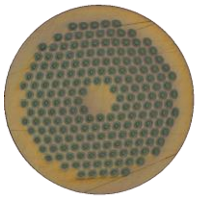


- Quench: transition from the superconducting to the normal-conducting state
  – Once quench occurs, if heating > cooling → propagation of normal zone

$T < T_{cs}$	$T_{cs} < T < T_{c0}$	$T > T_{c0}$
Superconductivity	Current-sharing regime	Normal conductivity
Current in SC	Partial current in SC + Partial current in stabilizer	Current in stabilizer
No heating	Joule heating + Quench	Joule heating + Quench



- SC: high normal-state resistivity → reach a very high *T* in few ms in a quench
- Cu: low resistivity → current redistributes in Cu matrix → a lower *T*
  – Provide time to act on power circuit
  – Stabilize the conductor against flux jumps



Quench Protection

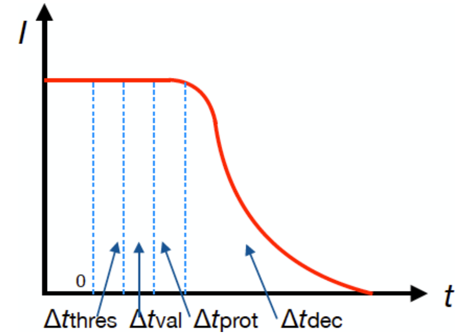
- Detection: R_{quench} ↗ Joule heating in the copper, causing T ↗ in the normal-conductivity zone

- Protection: After detection (power switched off), the magnet can be seen as an *LR* circuit $I(t) = I_0 e^{-t\frac{R(t)}{L}}$
  - Dissipate the magnetic energy as heat
  - Quench the entire coil by increasing the normal zone (maximize *R* to decrease *I*)
  - Goal: limit peak temperature and voltage to ground to avoid damage in the coil

- Different phases in a quench:
  - *I* constant, heat propagation:

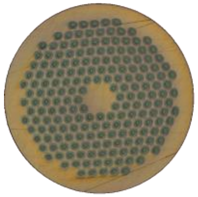
    1a. Detection $\Delta t_{\mathrm{thres}}$ 1b. Validation Δt_{val}
  - *I* decreases, energy dissipation by Joule heating:

    2a. Protection Δt_{prot} 2b. Discharge Δt_{dec}



Quench Protection

- Typical values for a quench protection system:
  - Detection time: 5-20 ms for a voltage threshold ~100 mV
  - Validation time: 5-20 ms to avoid false triggers
  - Switch opening for discharge: 5 ms
  - Switch opening for quench heaters: 2 ms
  - Heater delay time (10-40 ms) from strip to cable, then propagate, additional time in the low field area, between different layers…



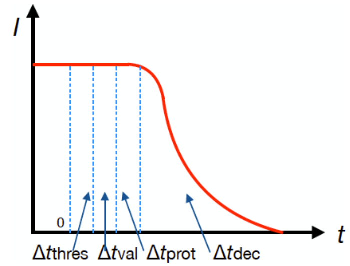
- Magnet design efficiency: less time – less Cu fraction – smaller coil

My Tasks

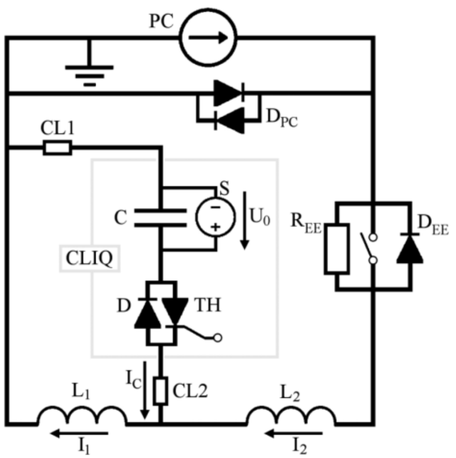
- Simulations:
  - Study quench propagation and different protection methods in 2D/3D models for two-/four-layer CCT magnet CCT to improve the protection delay time.

- Experiments:
  - Get necessary components in advance and install them properly;
  - Study LBNL's instrumentation and interface to solve the compatibility and connection issues;
  - Interpret test results and compare with simulations.

Protection Concepts for CD1



- Detection:
  - Co-wound Cu wire (*d* = 0.1 mm): voltage measurements affected by flux jumps and electromagnetic fluctuations → Δt_{val} obligatory
  - Co-wound optical fiber: temperature and strain data from analysis of spectral shift; high risk but we expect to eliminate Δt_{val} for a shorter delay time; collaboration with North Carolina State University (NCSU)



Possible circuit setup
Courtesy of E. Ravaioli

- Protection:
  - Energy extraction (R_{dump} = 0.04 ohm): suitable for a single-magnet system; basic method for R&D magnets
  - Coupling-Loss Induced Quench (CLIQ): *I* oscillations → coupling losses (heat) → quench; most promising method
- Diagnostics:
  - Spot heater: produce heat to trigger a quench
  - Acoustic emission sensor: sound like resin cracks can be heard

Instrumentation Plan for CD1