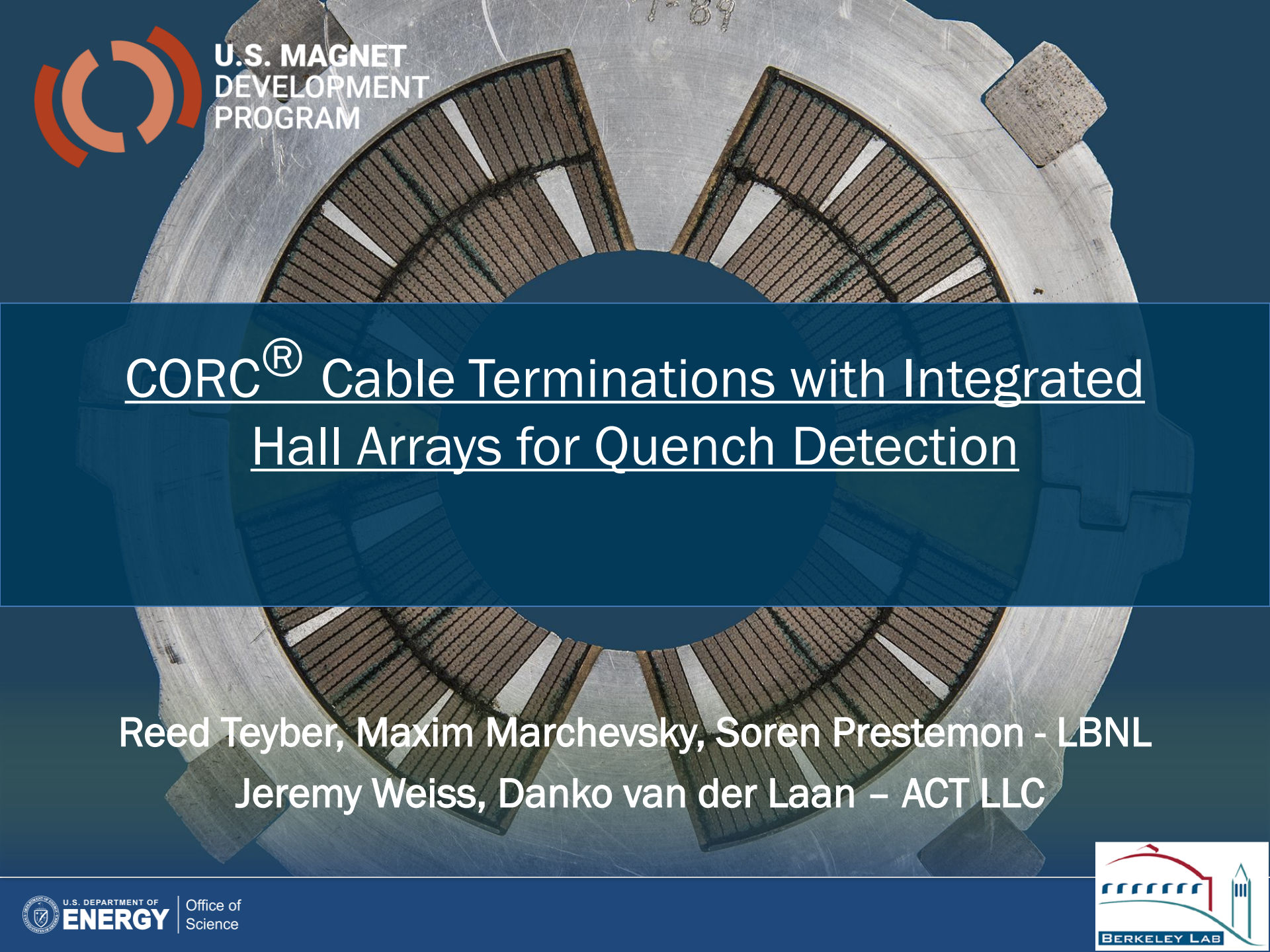

U.S. MAGNET DEVELOPMENT PROGRAM

CORC® Cable Terminations with Integrated Hall Arrays for Quench Detection

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U.S. DEPARTMENT OF ENERGY | Office of Science

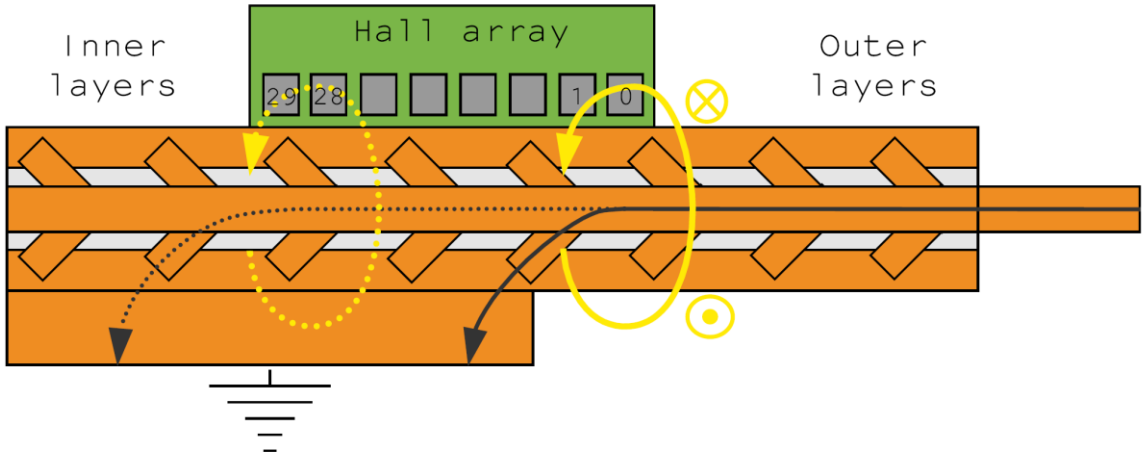
BERKELEY LAB

Motivation

- Normal zone detection in HTS cables remains an active area of R&D
- In Fusion reactors, coils can operate with fast ramp rates
  - Detection problems exacerbated
- Seek a non-invasive (outside of reactor), real-time quench detection system
  - Supplement voltage measurements

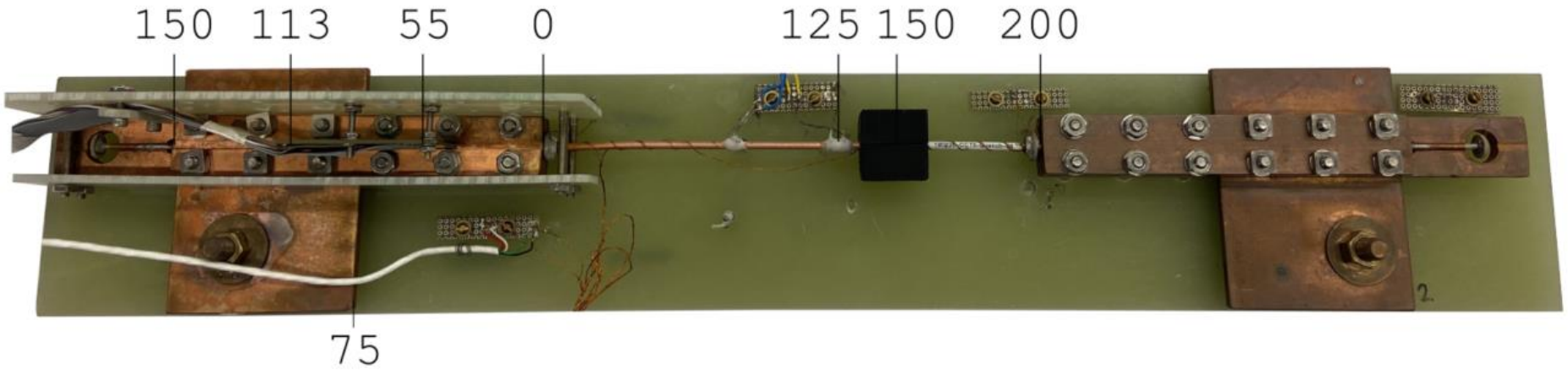
Motivation

- Previous paper by Maxim uses Hall sensors to detect quench in slit ReBCO tape
  - "Quench detection method for 2G HTS wire. SUST, 23(3):034016, March 2010"
- Monitor current redistribution in CORC® terminal using Hall sensor array as proxy for quench detection
  - Exploit low current sharing and layered terminal topology in CORC®
  - Layer quench manifests as axial shift in terminal current
  - *SBIR with Maxim/LBNL and ACT*



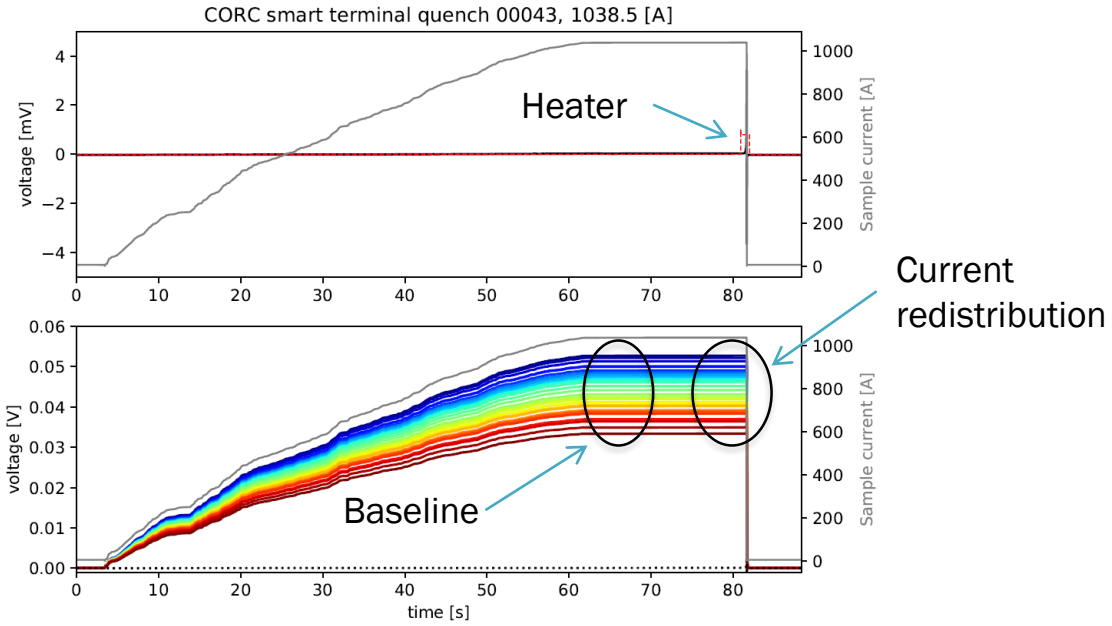
Methods

- Experimental setup
  - 8 layer CORC® (16 tapes), I_C ~ 1.2 kA @ 77 K
  - PCB with 29 GaAs Hall sensors
  - Heater and PM induced magnet quenches
- Static and fast-ramped current
  - Up to 10 kA/s



Methods

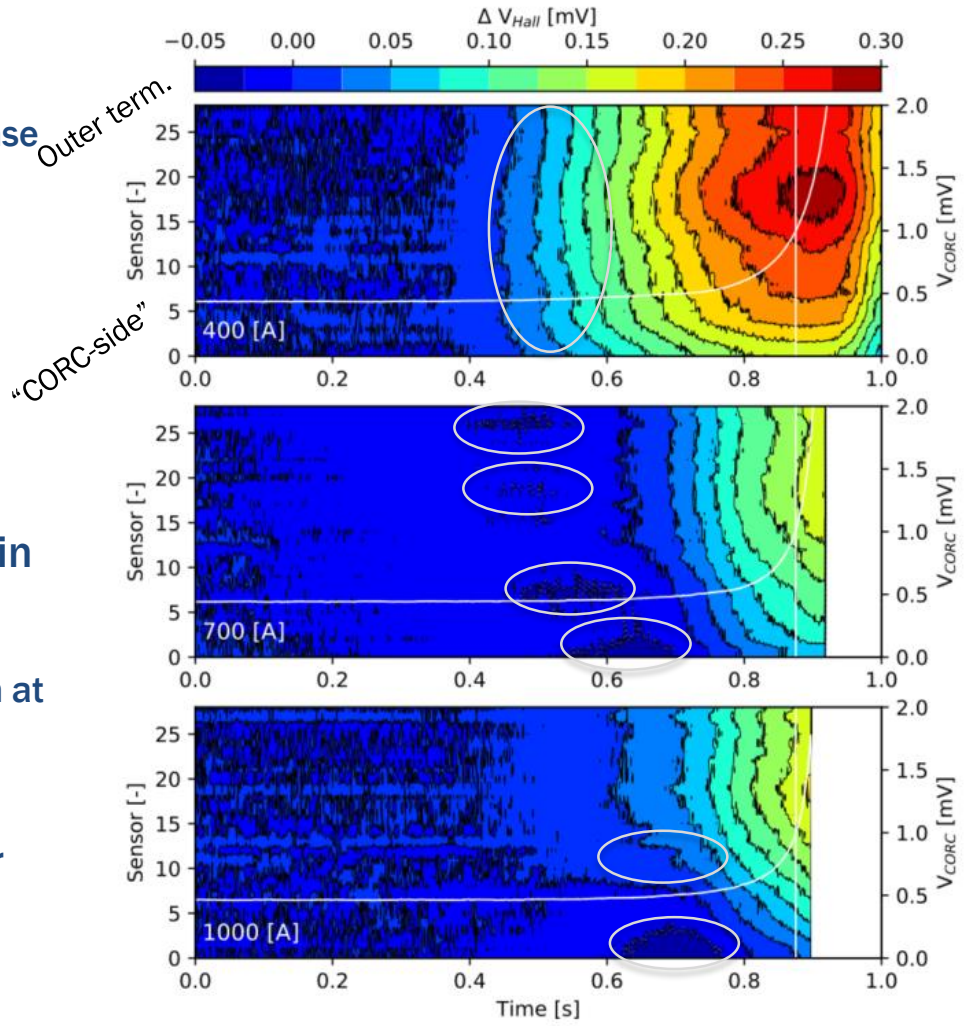
- **Experimental procedure**
  - Ramp current to desired value, turn on heater to induce quench
  - Plot *change* in sensor value (subtract baseline measurement)



Blue: sensor 0 (inner terminal)
Red: sensor 29 (outer terminal)

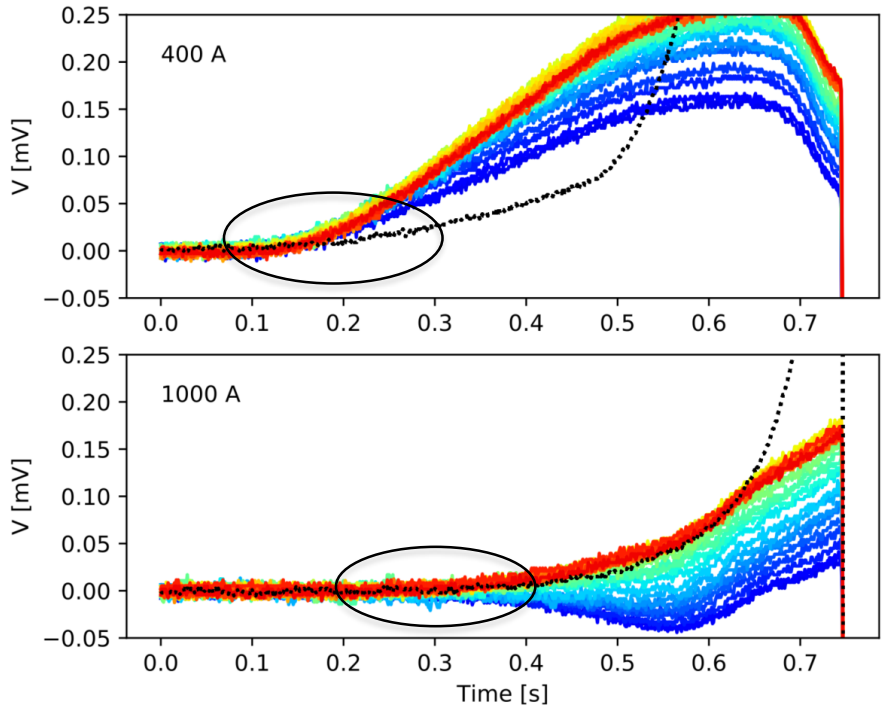
Static quenches

- Static current, heater induced quench
  - Contours show ***change*** in Hall sensor response
  - Right y-axis shows sample voltage
- Spatial frequencies to consider
  - Layer to layer: ~10 sensors
  - Twist-pitch: ~3 sensors
  - Tape-to-tape: ~1 sensor
- Response dominated by global increase in field
  - Fits simple model on previous slide
  - Periodic, wave-like normal zone propagation at 700 A
    - Originating at terminal *outside*
    - Not at helix twist-pitch length scales
  - Smaller variations observed on layer-to-layer scale (~10 sensors), as observed at 1000 A



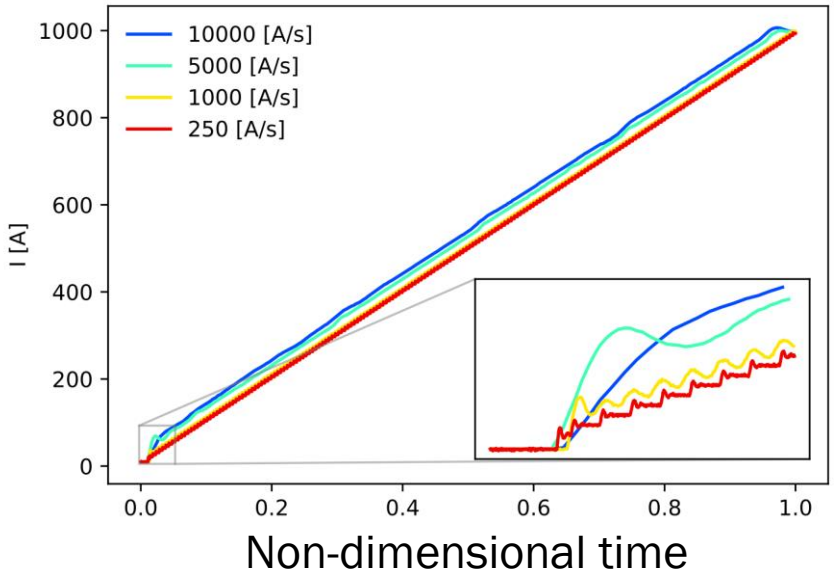
Static quenches

- Terminal Hall sensors can be used for real-time quench detection
  - Similar magnitude and temporal response as sample voltage



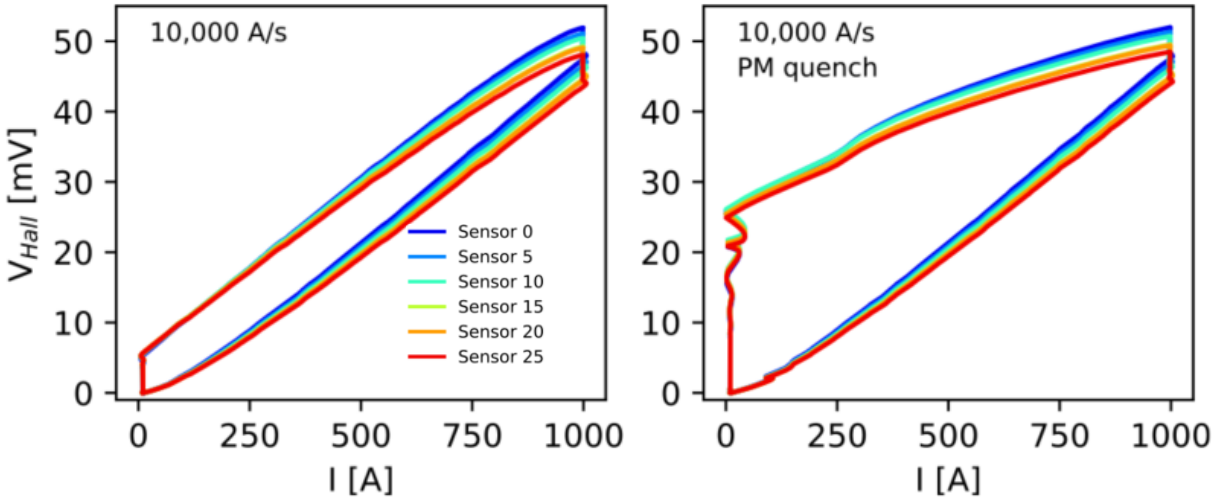
Dynamic quenches

- Explore feasibility of terminal Hall sensor for quench detection in ramped Fusion magnets
  - Ramp rates of 1 kA/s, 5 kA/s and 10 kA/s
  - Sorenson SGA 10/1200 PSU programmed with PyVISA
  - Magnet-induced (left) and heater-induced (right) results
- With fast ramps (1-10 kA/s), small variations in tape inductances yield inductive voltage distribution



Dynamic quenches

- Raw Hall sensor signals demonstrate hysteresis loop over current excursion
  - Shielding currents induced in copper terminals
- Contours show change in Hall sensor plot between no-quench experiment and quench experiment



Dynamic quenches

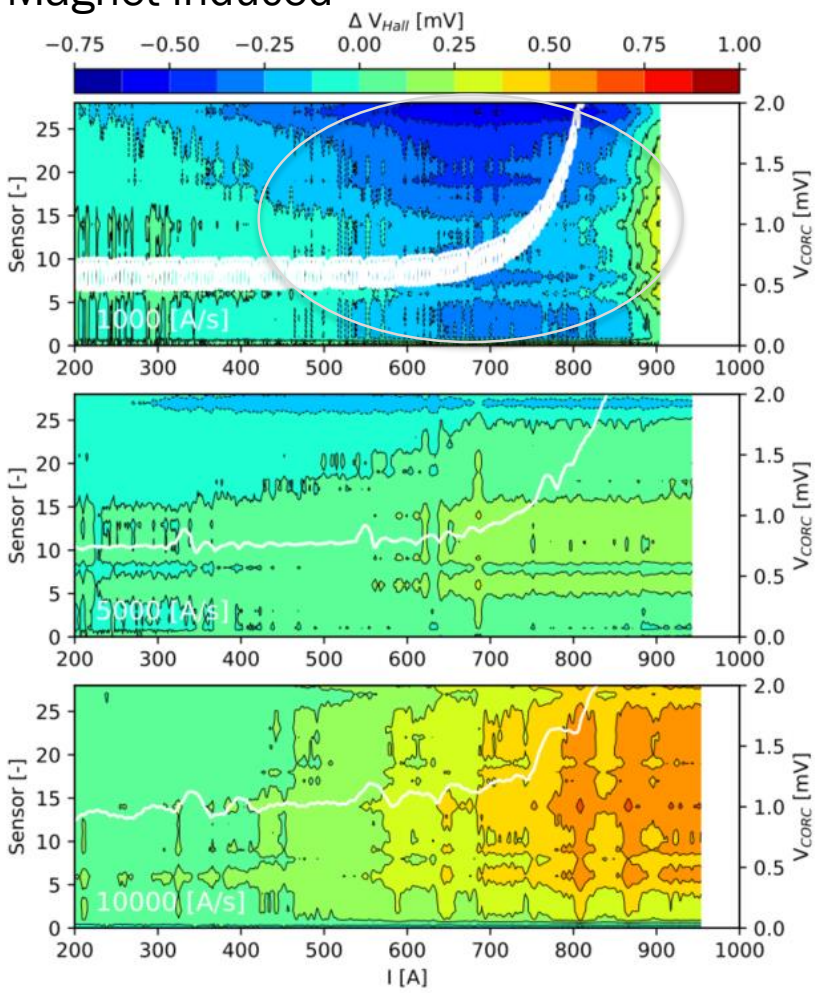
Magnet induced

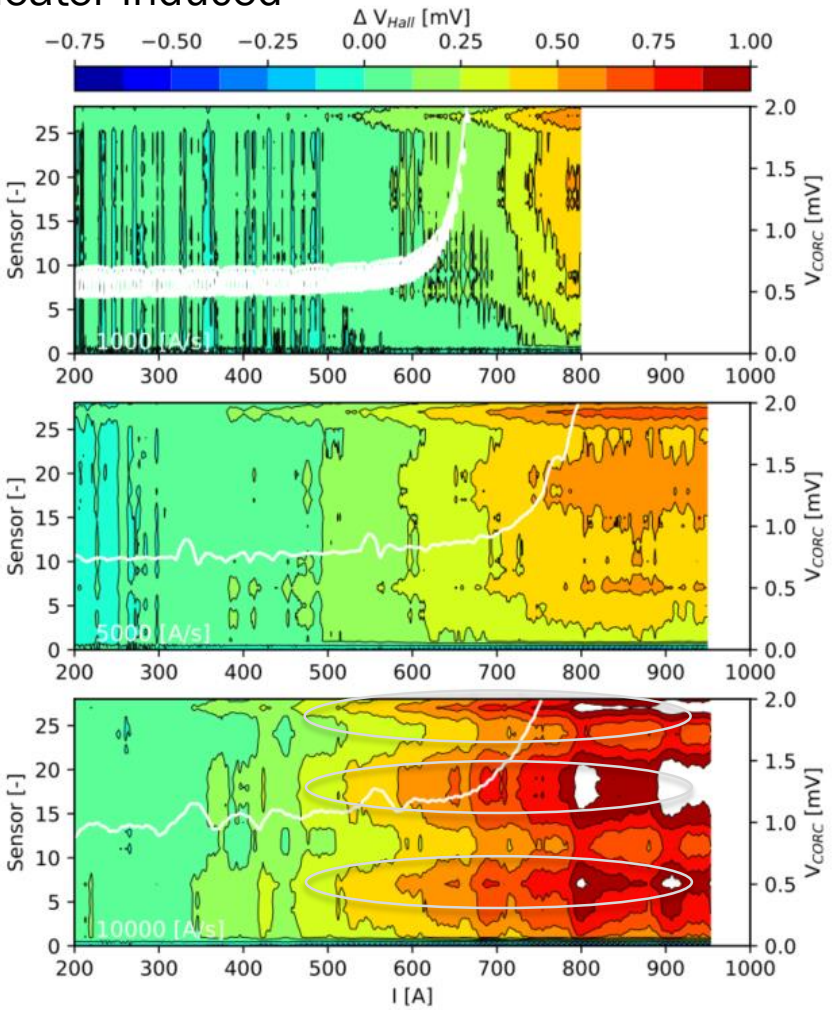
Heater induced

1 kA/s

5 kA/s

10 kA/s



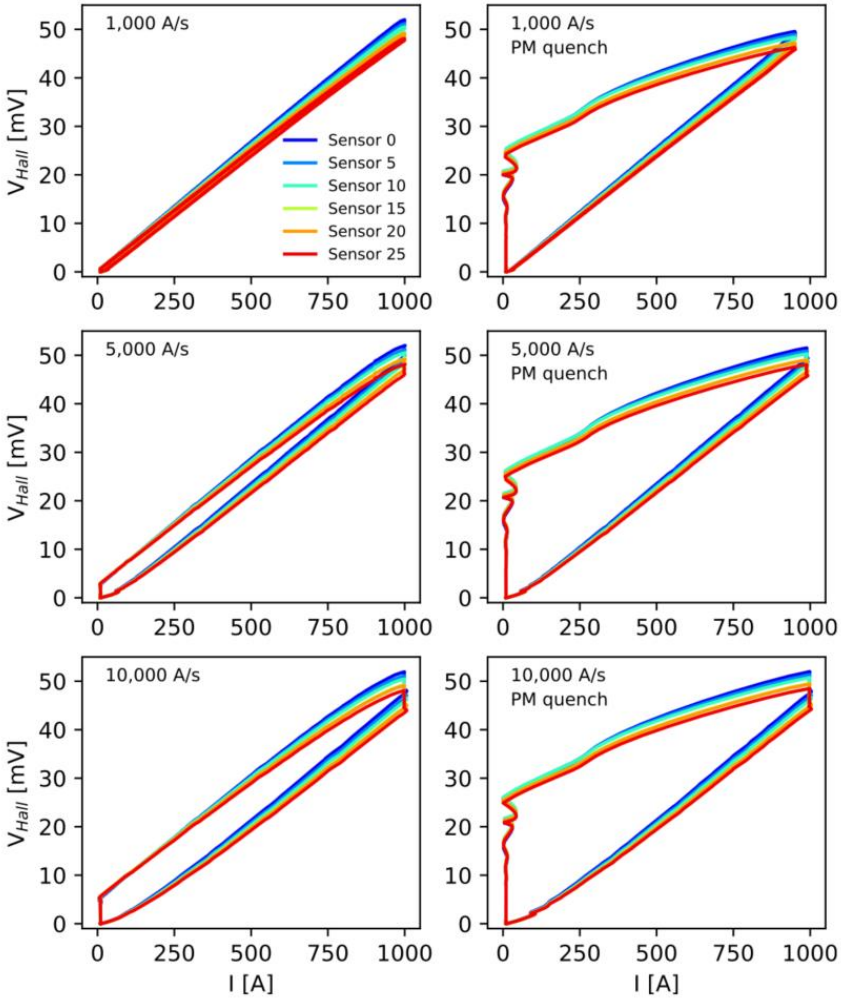


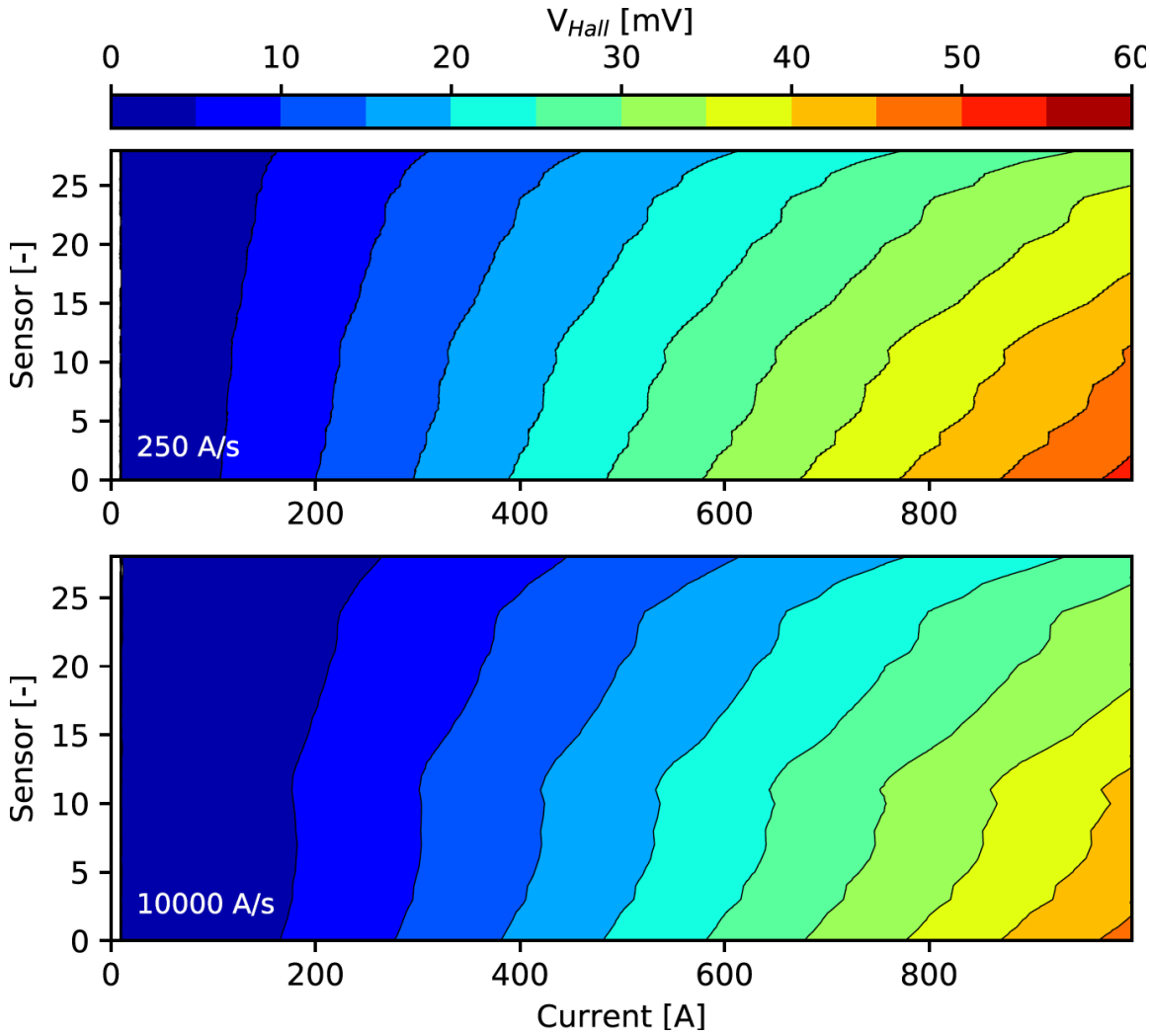
Discussion

- Implementation is ex-situ, and can be implemented with low-cost Hall sensors
- Promising quench detection method to supplement voltage measurements
  - Real-time quench detection is more challenging with fast ramps, ongoing work
- Promising tool to study CORC® dynamics
  - Small changes in experimental parameters yield large changes in measured results
  - Would be helpful to know tape structure in terminal (industrial CT (Xiaorong), inverse Biot-savart optimization from Hall scan)
  - Higher current quench experiments (i.e. 4K) would increase SNR, potentially helping resolve tape-level current redistribution

- Extra Slides

Ramped Quench detection




V_{Hall} [mV]
0
10
20
30
40
50
60
Sensor [-]
250 A/s
10000 A/s
0
5
10
15
20
25
0
200
400
600
800
Current [A]