Towards a Better Quench Instrumentation

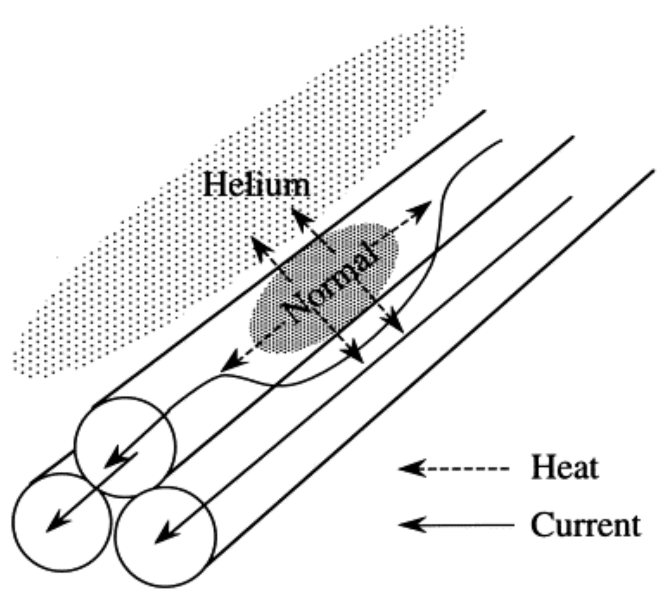
Atharva Kulkarni

Joseph Dimarco, Stoyan Stoynev, Magnet Systems Department, FNAL

FERMILAB-POSTER-22-147-STUDENT

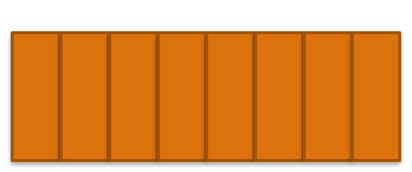
Introduction

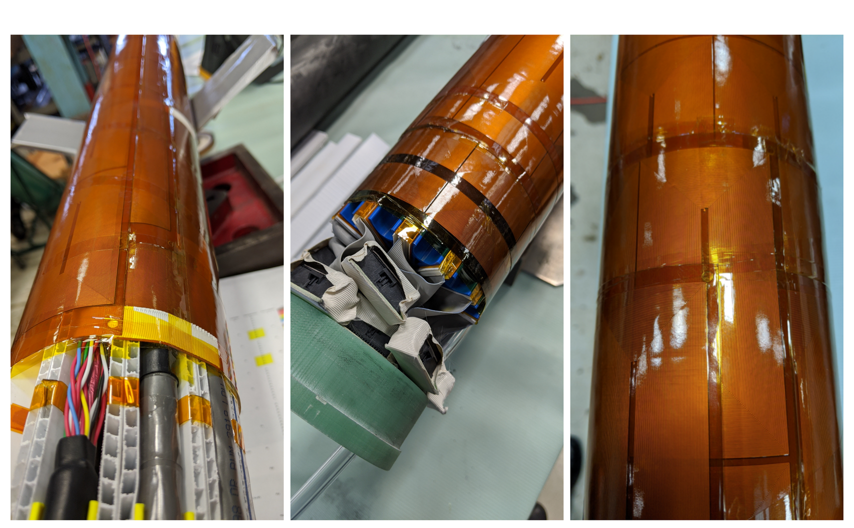
Superconducting magnets, which are an integral part of modern accelerators, suffer from quenches which occur when local environmental fluctuations cause a temporary loss in superconductivity.



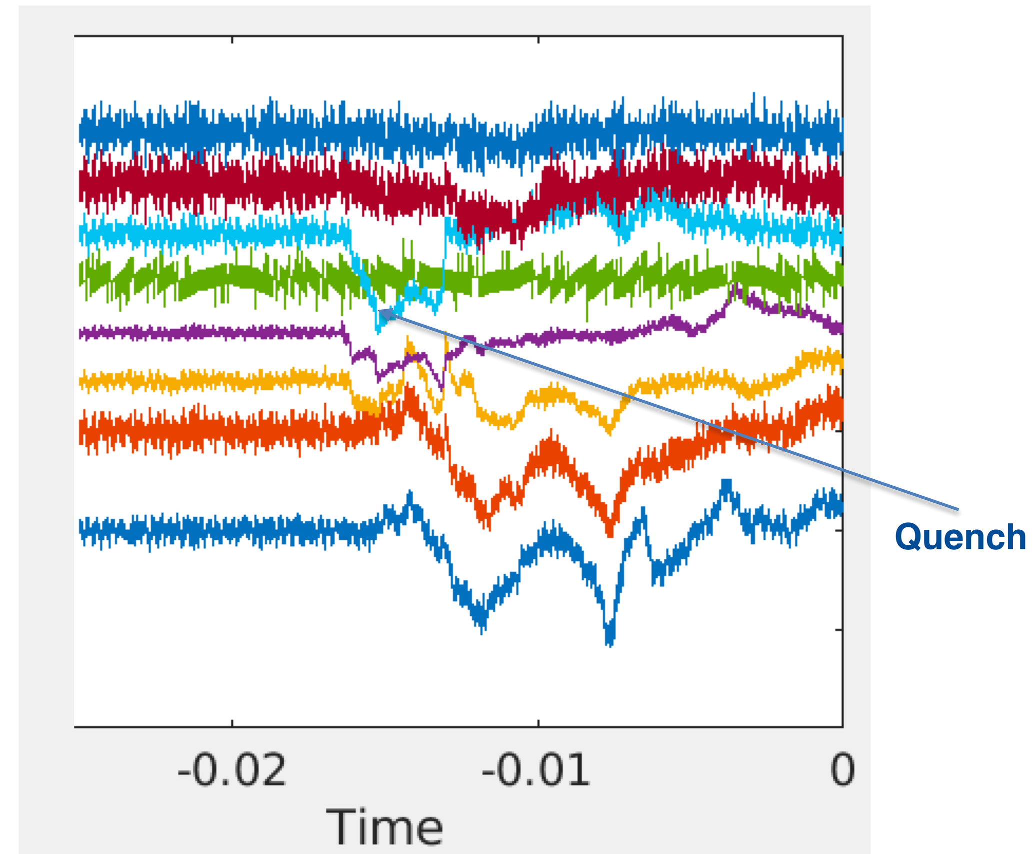
Cartoon schematic of a quench. Local temperature changes in the superconductor cause temporary losses of superconductivity

The increased resistance causes a change in the local current which we can detect using arrays of small windings, called quench antennas. They have voltages induced in them when the local magnetic flux changes. By knowing which antennas show voltage spikes, we can locate the start of the quench.





Quench antennas are stacked (top) and then wrapped around the inside of the super conducting magnet (bottom). The 8 quench antennas shown yield 8 data channels at various positions

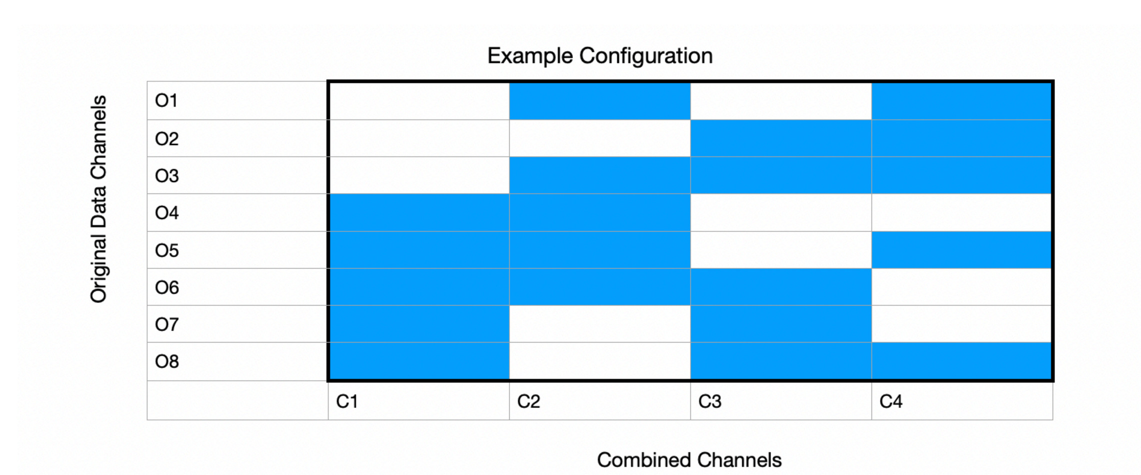


Voltage as a function of time for 8 different quench antennas (channels color-coded), during a quench.

If each antenna covers about 50mm, we would need almost 1000 to cover a 5m magnet. This project focused on understanding if we could achieve the normal quench antenna resolution while using less data channels.

Methodology

The key realization was that we could use less data channels if we had redundant quench antennas. By wiring particular ones in series, we could develop a kind of digital "encoding" for each original quench antenna channel.



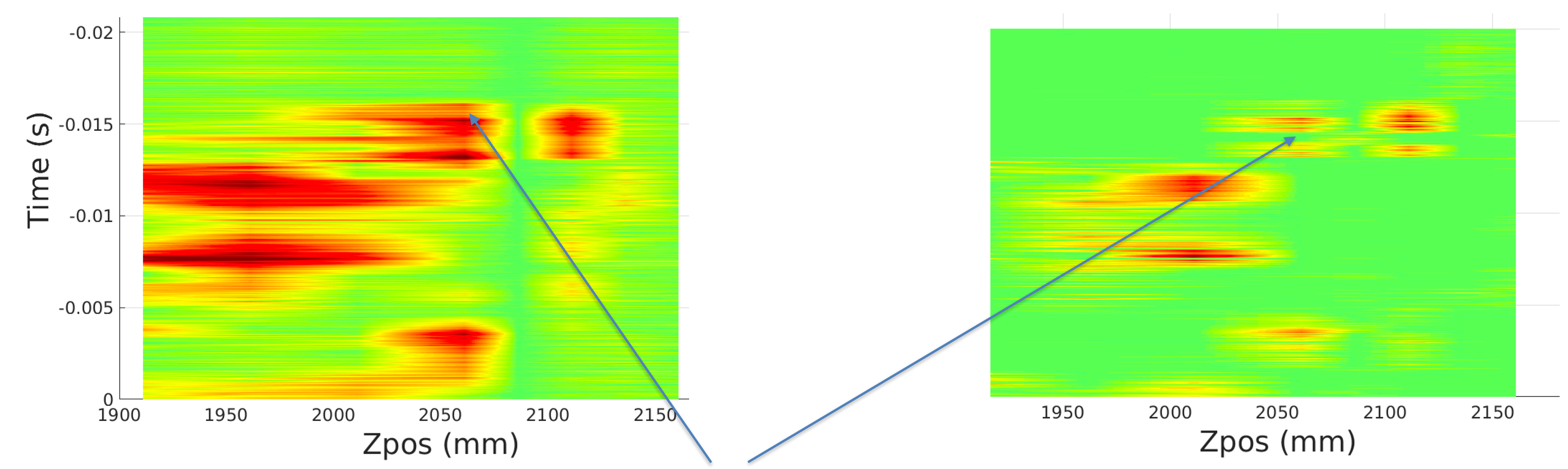
An encoding configuration where the highlighted areas show which original quench antennas (O1-O8) are wired in series for each redundantly combined data channel (C1-C4).

Thus, if C1 and C2 show a spike in voltage at some point, that must correspond to O4, since that is how the O4 location is 'encoded.'

By converting the data to a digital signal using a binary threshold and then applying the encoding configuration in reverse, we can recover the original locations that the combined channels represented. We can develop an analog representation by repeatedly applying multiple-different thresholds, essentially converting our data back into an analog form.

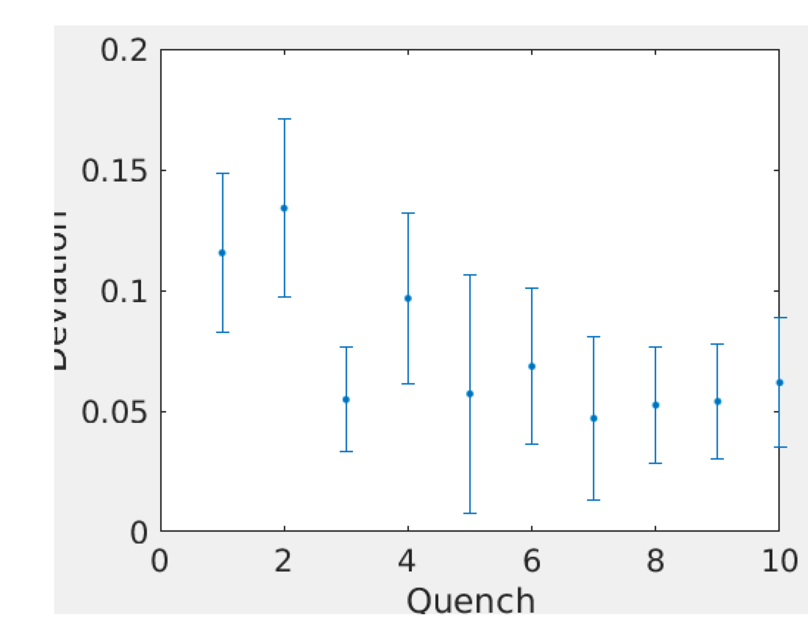
Analysis

Given the variety of ways in which quenches evolve, it is tricky to determine a numerical figure of merit for the start of the quench. Thus, as a proxy, we looked at the ability of our scheme to reconstruct the original quench antenna data. We normalized both the original and decoded data relative to it's highest peak and then compared them.



Left: Original 8 data channel plot showing quench start. Right: 4 combined channels decoded. Where Zpos refers to how far the original quench antennas are from the magnet's center The red points are peaks, interpolated over a surface.

To determine how good the scheme was at reconstruction, we looked at the average deviation between the original and reconstructed data points.



Right: Deviation for 10 different quenches. All showcase an accuracy of greater than 85%. Standard deviations show distance for average error.

Conclusion

By using redundant sets of quench antennas wired in series, we can use less data channels to achieve a similar resolution to a normal quench antenna arrangement that may require 4, or 5 times, less data ingestion channels.

Future research should focused on implementing this scheme practically and understanding its limitations. In particular, a better numerical figure of merit to understand the viability of various configurations is important to consider.

Acknowledgements

Thank you to the EDI and SULI internship team and my mentors at the Magnet System Department. This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.