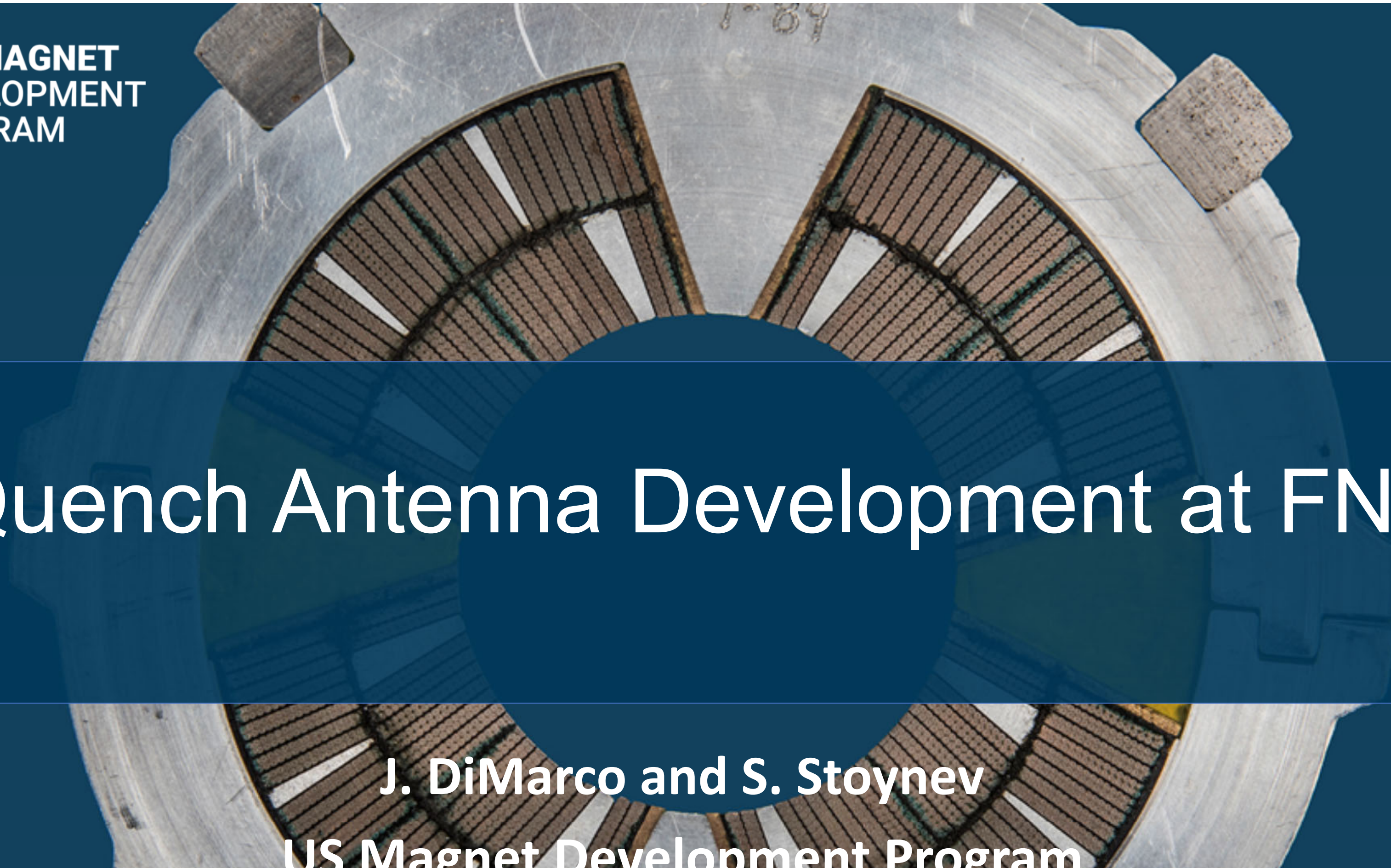


Quench Antenna Development at FNAL

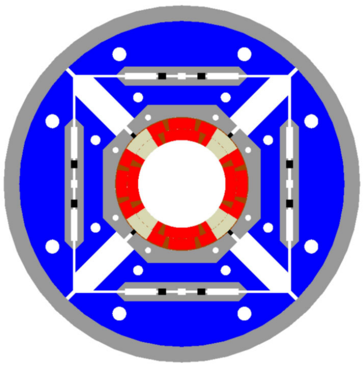
J. DiMarco and S. Stoynev

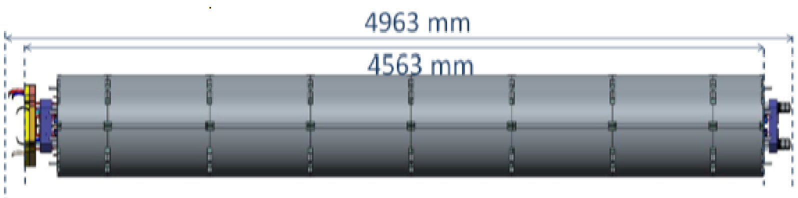
US Magnet Development Program

Fermilab

Main QA project in 2020

Quench antenna for MQXFA magnet vertical testing at BNL



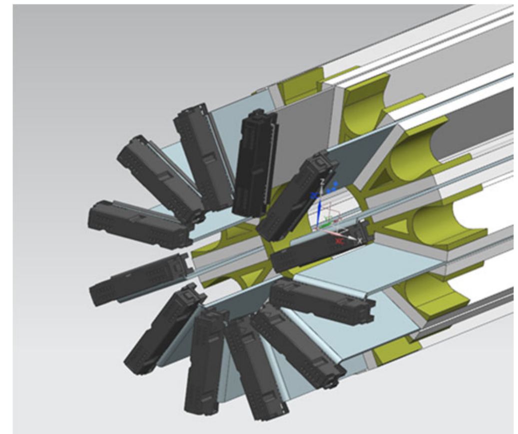


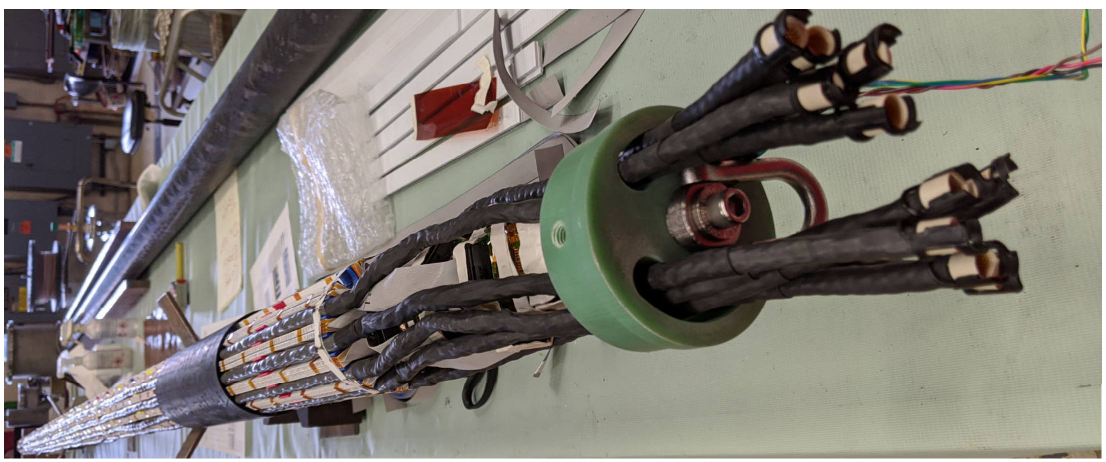
Cross section and total length of MQXFA magnet

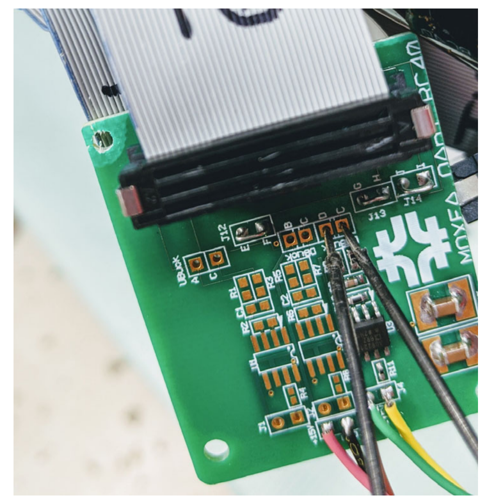
- MQXFA production series quadrupoles have very limited instrumentation. A full-length Quench Antenna Array (QAA) with axial resolution of 50mm was built by Fermilab and first used during testing of MQXFA04 in Fall 2020.
- The QAA has a 4.8 m active length and 5.2 m overall length, to provide full quench detection coverage for the 4.5 m long MQXFA04 magnet with ~4 m straight section.
- Two types of inductive pick-up QA are employed in the array: 111 antennas along the axis (referred to as Z-antennas, or **ZQA**), and 12 antennas distributed azimuthally (so-called theta-antennas or **TQA**).

TQA antennas

- The 12 TQA are distributed in theta every 30 degrees in the QA interior
- The TQA are made using ribbon cable with small printed circuit boards at each end to form the windings.
- The 25 mm-wide, 40 conductor cable becomes 4 separate loops with 10 wires (5 turns) each, connected so as to buck dipole and quad fields (DQ-bucked).
- To compensate for the weak sensitivity of these few turns, the TQA channels are outfitted with 1000x gain amplifiers on the lead end PCB which makes-up the circuit of each TQA (located inside the QA, upstream of the cables and datacq).







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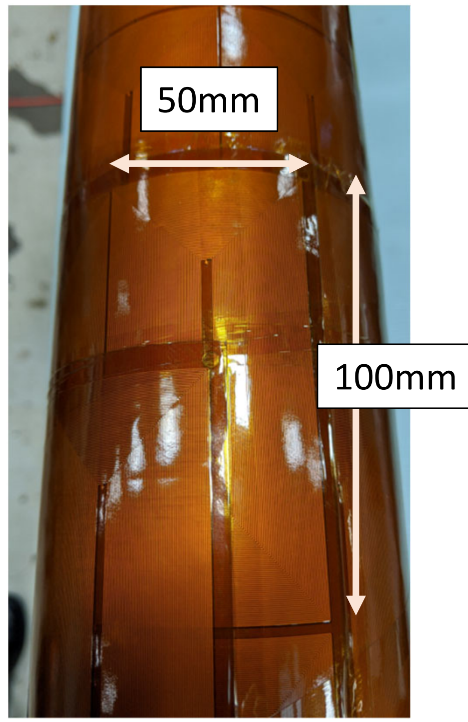
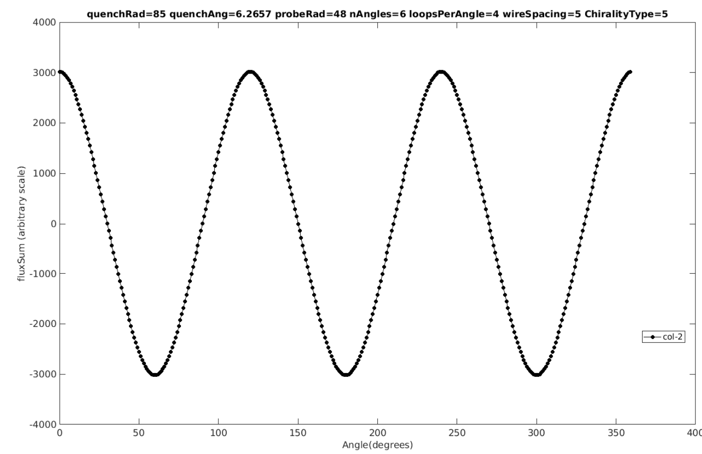
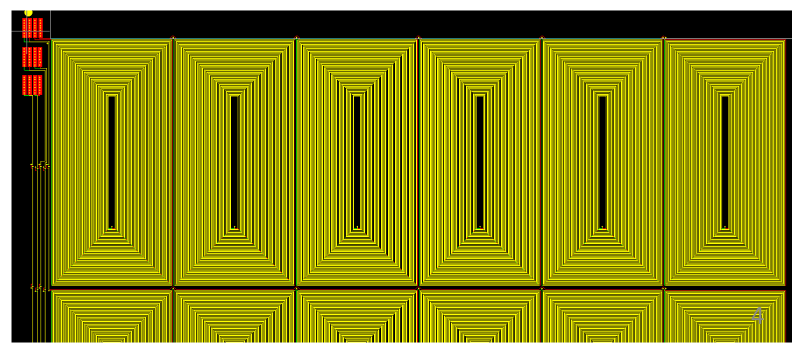
ZQA antennas

- 6-fold azimuthally-symmetric 'racetrack' windings with alternating chirality give a sextupole-sensitive configuration which bucks dipole and quadrupole fields.
- The ZQA are 100 mm long and are overlapped by half their length and the half the racetrack width to ensure sensitivity at all quench angles. Nominal resolution is 50mm.
- The racetracks of the ZQA are 6 x 50mm wide with 132 turns, wrapped around the TQA to form a ~300 mm circumference cylinder.
- A length of 0.5 m at each end of the QAA has higher density of ZQA with resolution 25 mm nominal.



Sensitivity of QA changes as function of quench angle because of symmetries





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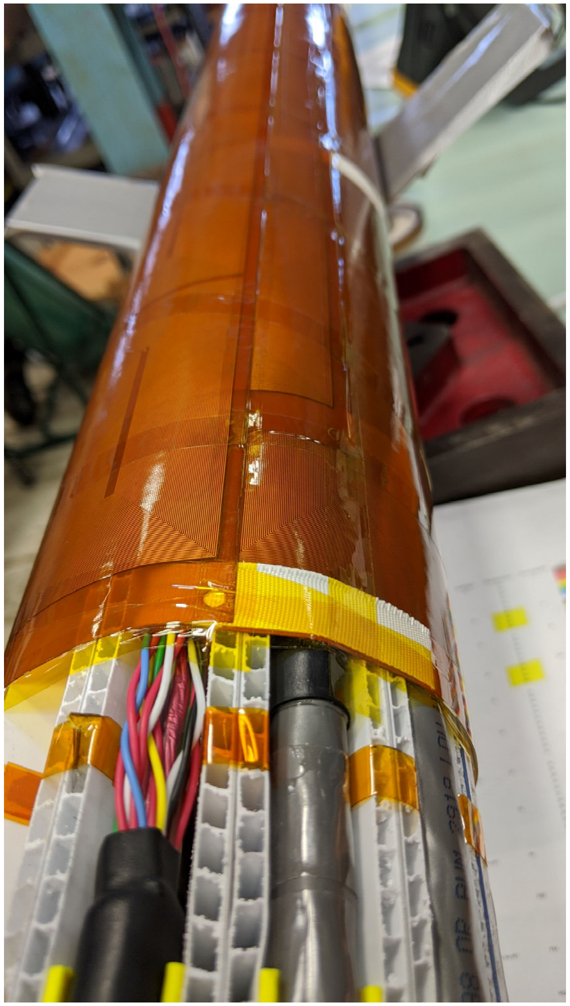
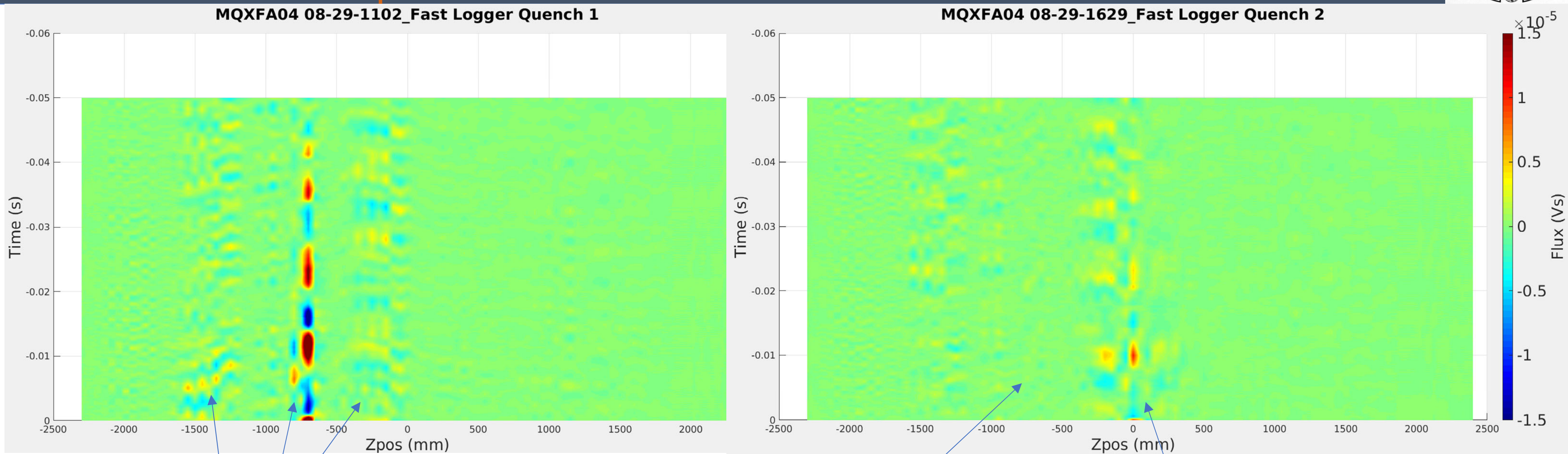
Assembly



QAA at BNL

- Our colleagues at Brookhaven, led by Piyush Joshi, Mike Anerella, and Joe Muratore, provided data acquisition hardware (128 channels, 16-bit resolution, 100 kHz sampling frequency), software, and interfacing to their vertical test facility.

Quench Data - ZQA



Regions of activity

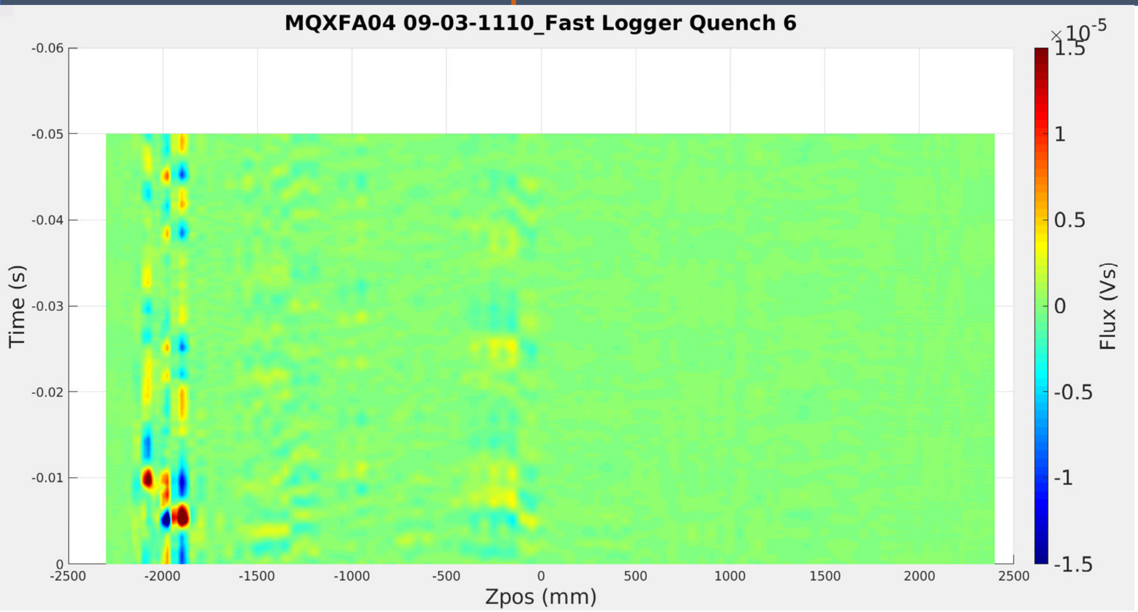
Region from first quench is now quiescent

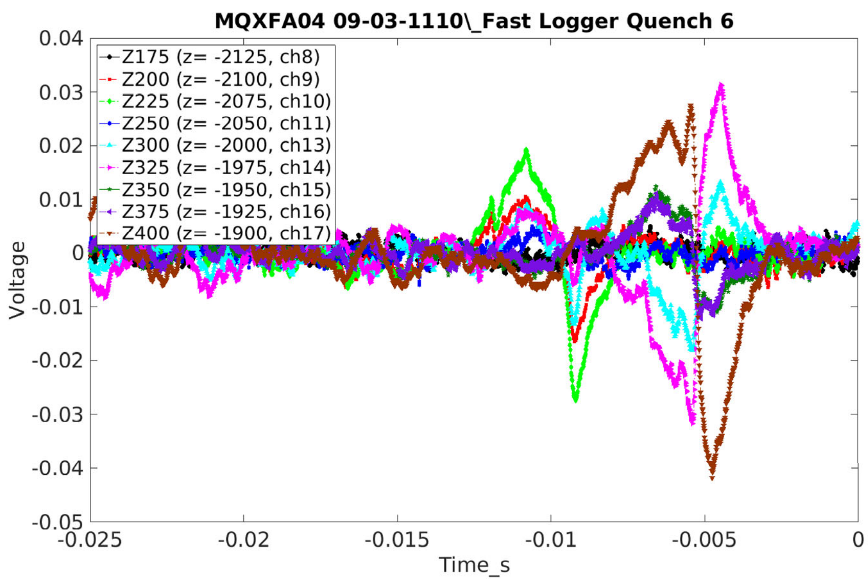
Second quench happens at one of the other active regions

Flux (shown by color intensity) vs. time and Z-position in magnet.
Quench #1 at Z= -700 mm, and Quench #2 at Z= 0

These are typical of all the quench localizations.

Quench Data - ZQA



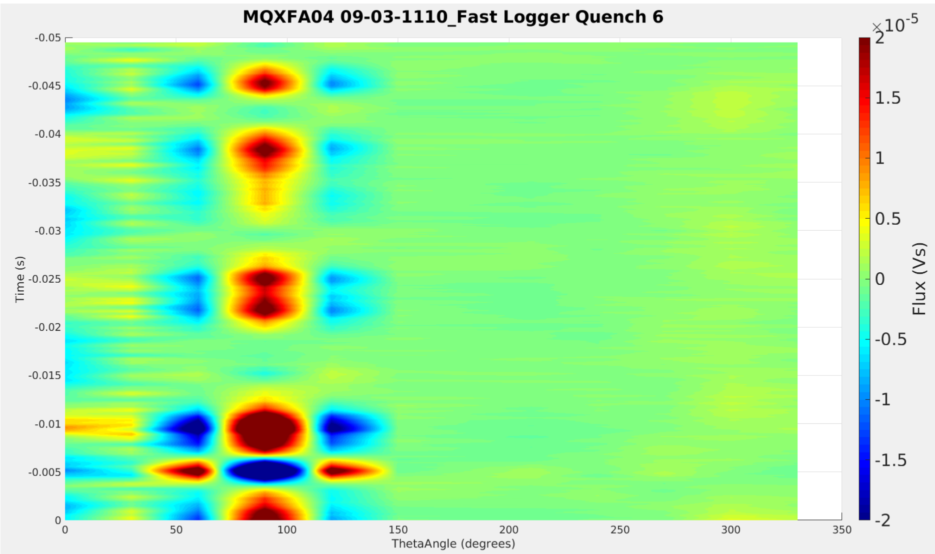


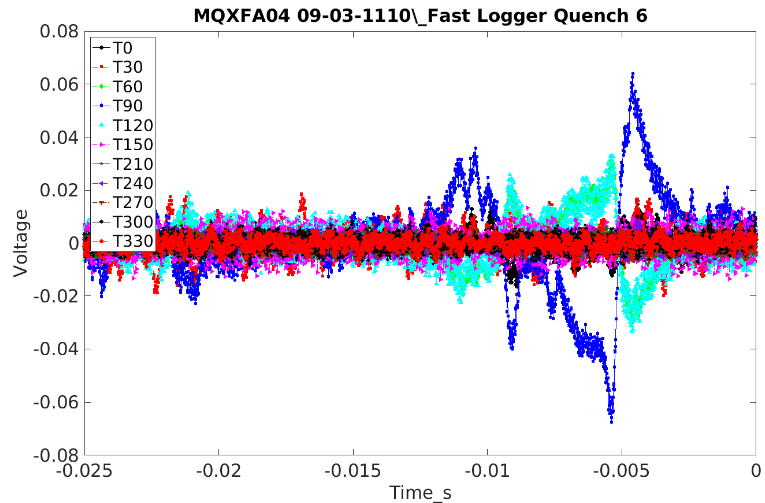
The QAA determined the Z-location of all recorded quenches to < 50mm.

In addition, flux activity was observed in some regions (likely having larger mechanical vibrations). Quenches tended to be observed in these areas – could potentially provide feedback for fabrication.

QAA could be run during ramps to further understand dynamic behavior (but so far has not been) .

Quench Data - TQA

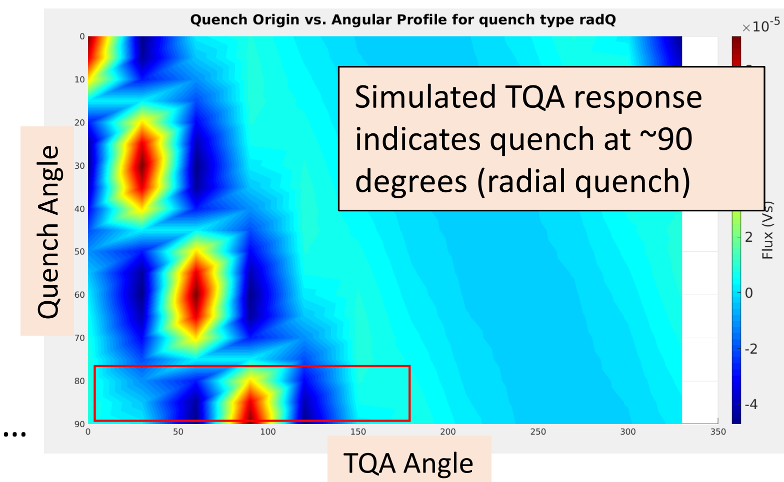




TQA quench activity was seen for all quenches and in the correct quadrant (and with relative intensity similar to that observed in ZQA).

However, angle did not obviously agree with voltage tap results (which had azimuthal localization for 3 of the quenches). The above quench was found by Vtaps to be at 'non transition side pole-turn', or about 33 degrees.

Hopefully additional data and further analysis will improve the theta localization…



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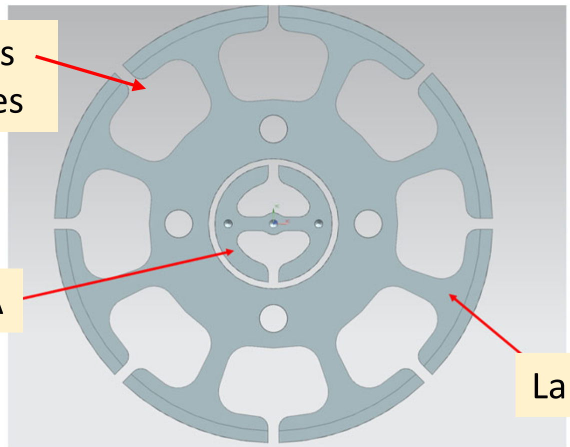
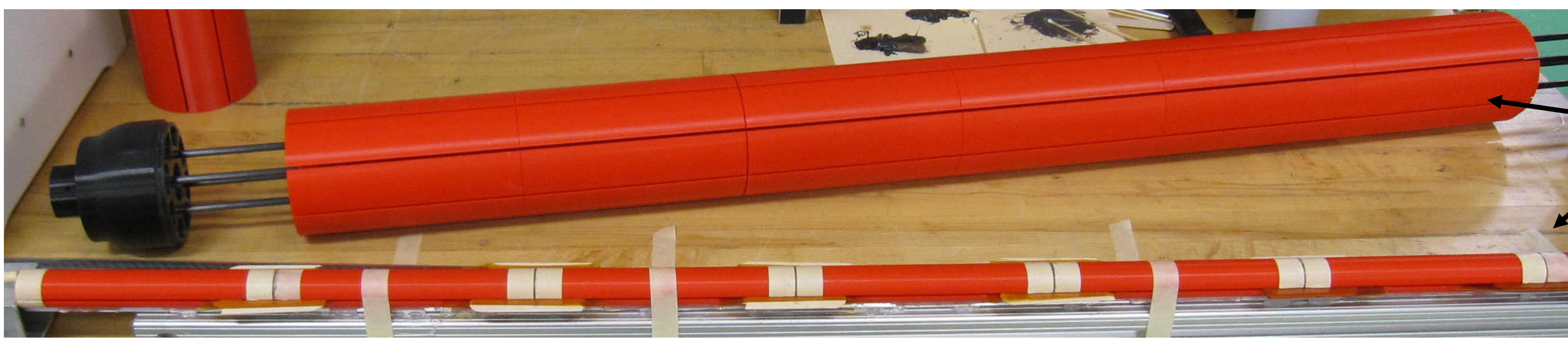
QA research projects

Warm-bore-tube-based QA test structure (matches 2 WBTs used for prototype magnets).



3d printed cross-section



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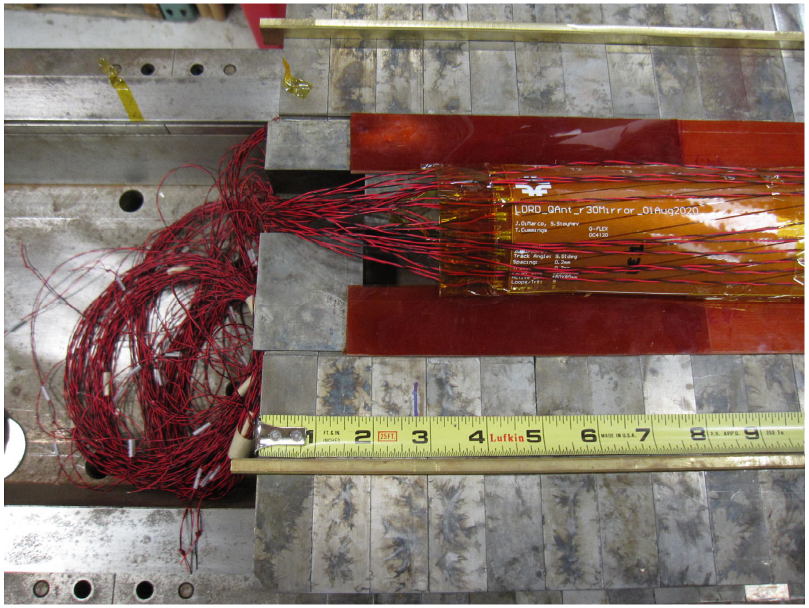
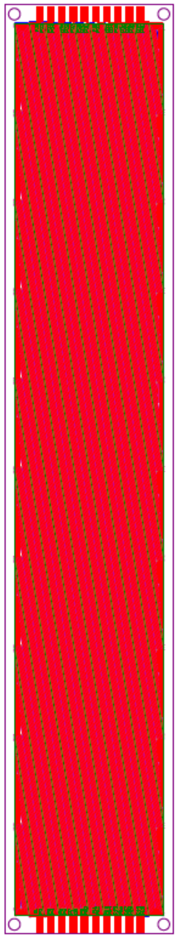
QA research projects

“Cold” Coil-based QA (fixed on or between coils used at cryogenic temperatures).



80 mm



480 mm

- First test panels are awaiting cold test in mirror magnet structure.
- These should have good sensitivity from close proximity to coils, and are designed to avoid the effects of ‘dead zones’.

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Summary

Quench Antenna development over the last year at Fermilab has included the fabrication of a 5m-long array (QAA) with high time and spatial resolution in Z, as well as angular sensitivity.

The QAA has been tested at BNL in MQXFA04 in Fall 2020 and achieved < 50mm Z-localization for all quenches. Theta antennas also saw activity during the quenches, but need further data and analysis.

New developments include structures for testing antennas in the anti-cryostats available at Fermilab and coil-mounted antennas that will be used in cryogenic conditions. Testing is scheduled for early April for new Qas with additional designs to follow.

Back-up slides

Theta Antennas

Quench Antenna T0 placed along Y-axis, s.t. Coil 113 lies between antenna signals T0 and T90