Electrical QA and quench antenna development

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Electrical QA

1. Coil on the table
   - Hi-pot (PHs, Endshoes, Island)
   - Impulse test
   - Sequential R
   - Inductance

2. Coil pack assembled
   - Basic R checks (PHs, coils-to-structure, coil-to-coil)

3. Magnet azimuthally loaded
   - Basic R checks (PHs, coils-to-structure, coil-to-coil)
   - *Hi-Pot (optional)*

4. Magnet fully loaded (before "pizza box")
   - Hi-pot (PHs, Endshoes, coil-to-coil, coil-to-structure)
   - Impulse tests (individual coils)

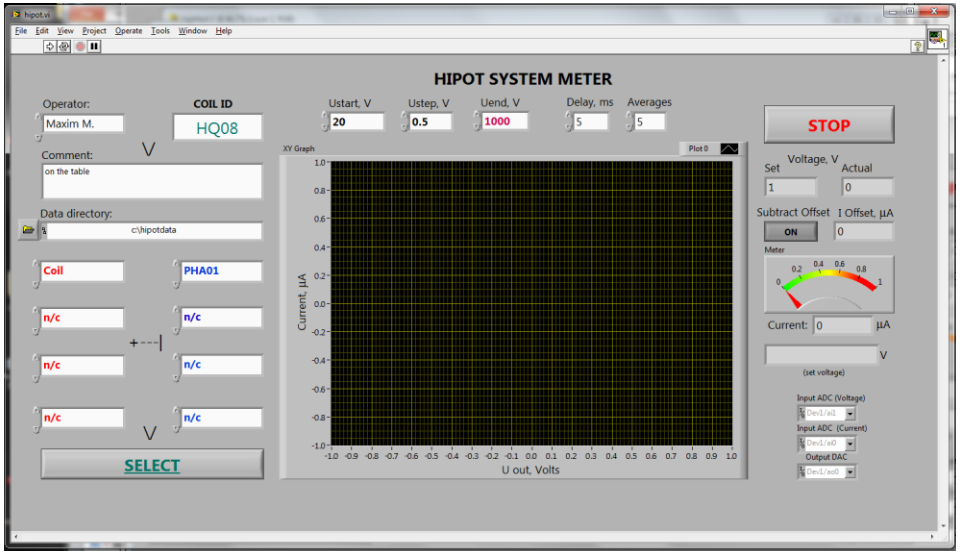
5. Magnet fully loaded (after "pizza box", before transport)
   - Sequential R
   - Impulse test (magnet)

6. Magnet at the test facility
   - Basic R checks (PHs, coils-to-shell, ground)
   - Sequential R (regular, with MVMS)

7. Magnet in the cryostat (warm)
   - Hi-pot (PHs, Coils-to-shell)
   - Impulse test

8. Magnet in the cryostat (4.2 K)
   - Hi-pot (PHs, Coils-to-shell)
   - Impulse test

Hi-Pot and Impulse test equipment



- Voltage step, ramp rate and averages control
- Ability to stop the test upon a non-linear current rise

- 100 MHz sampling
- 100-5000 V with 100 V increment
- Storage and comparative analysis of the waveforms
- Partial discharge detection

Hi-Pot test

HQ01d - Coil 9

Coil on the table /Full load/TARGET

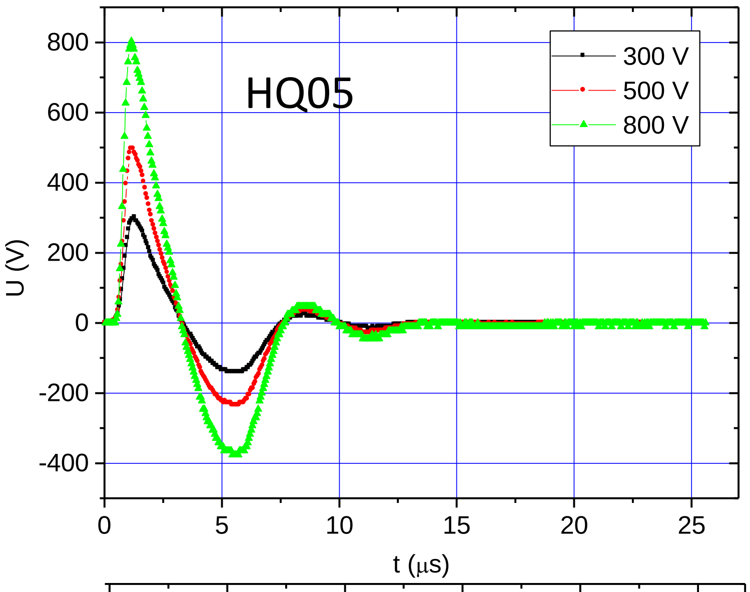
Current threshold 0.8 μA
Ramping at ~5-8 V/s

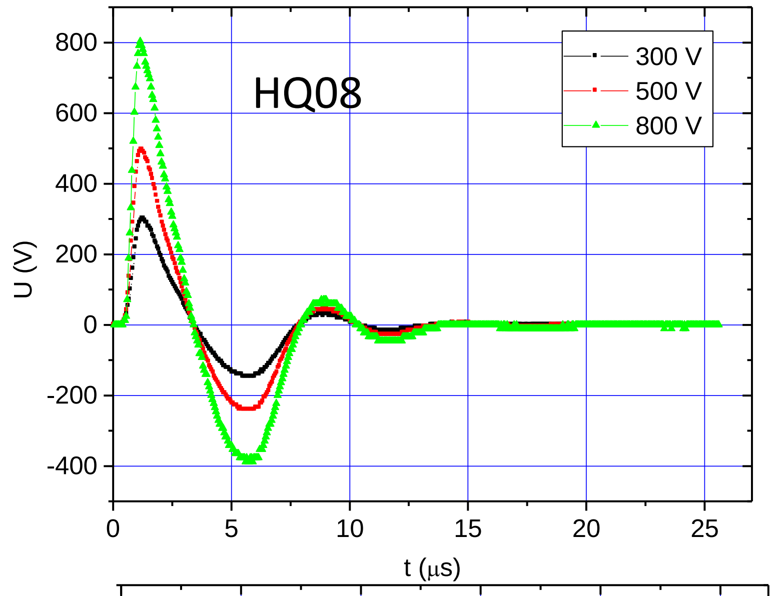
	Coil	PHA01	PHA02	PHB01	PHB02	LE IL Endshoe	RE IL Endshoe
Coil							
PHA01	1000/1000/1000						
PHA02	1000/1000/1000						
PHB01	1000/1000/1000						
PHB02	1000/1000/1000						
LE IL Endshoe	1000/1000/1000	500/500/500	500/500/500				
LE OL Endshoe	1000/1000/1000			500/500/500	500/500/500	500/500	
RE IL Endshoe	1000/1000/1000	500/500/500	500/500/500				
RE OL Endshoe	1000/1000/1000			500/500/500	500/500/500		**340**/**414**/500
Island	500/-/500						
Shell	1000/1000						

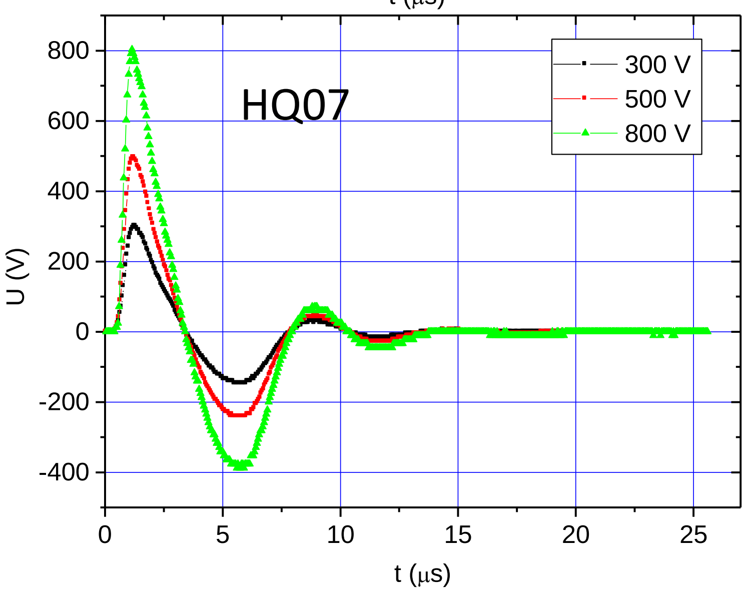
To Coil 8: -/1000/1000

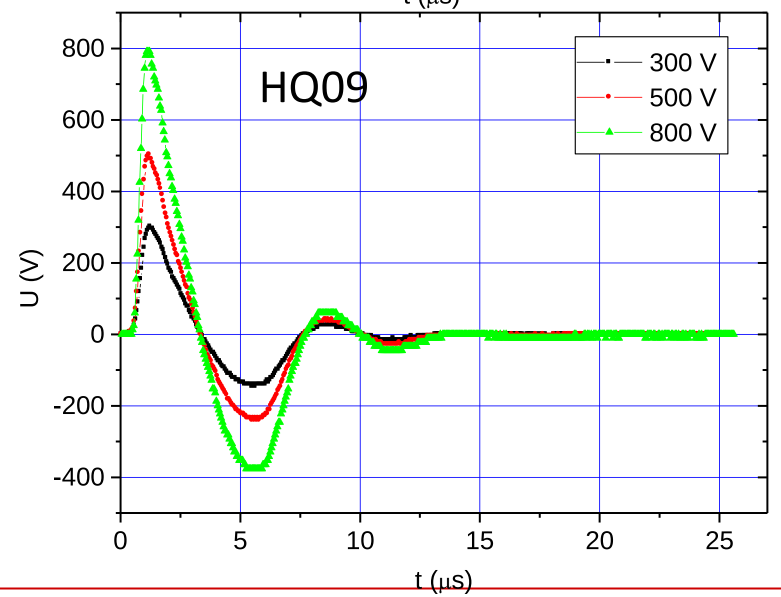
To Coil 5: -/1000/1000

Impulse test



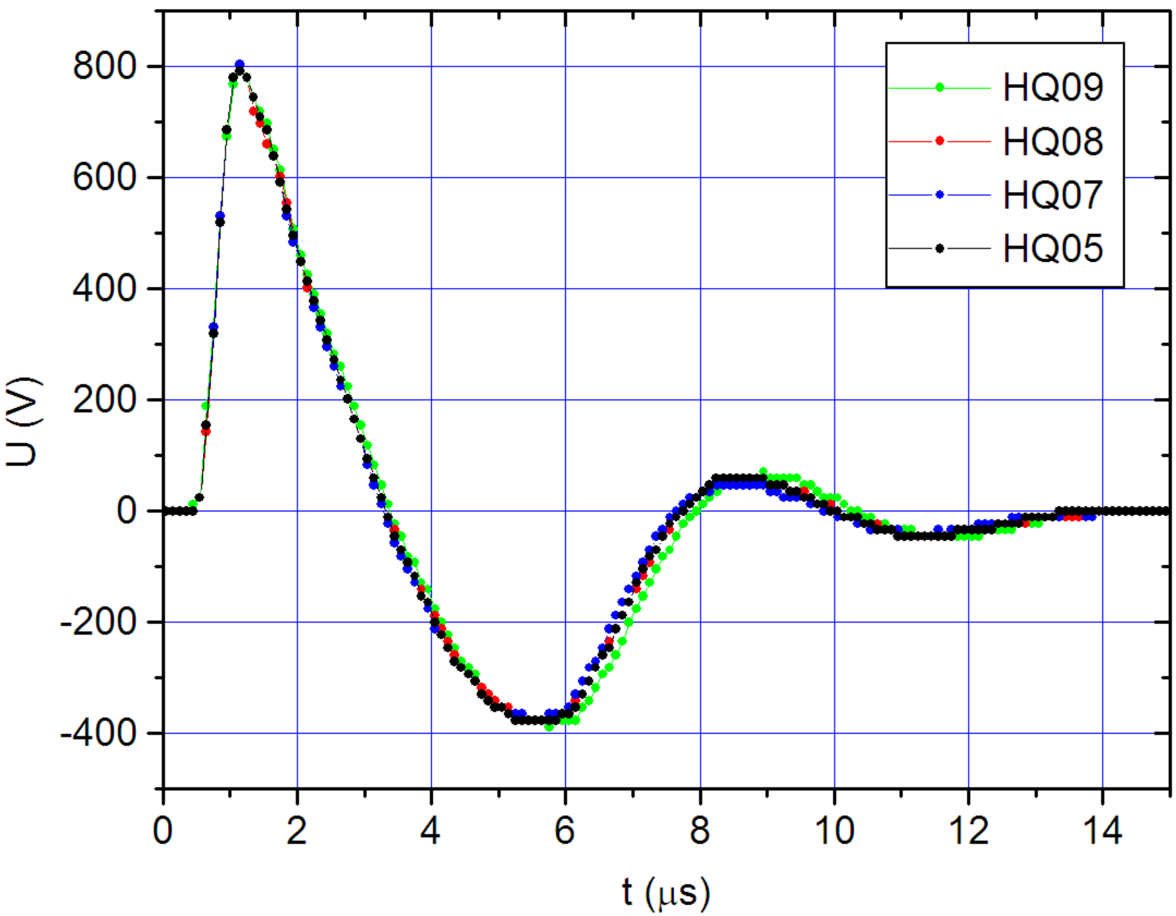




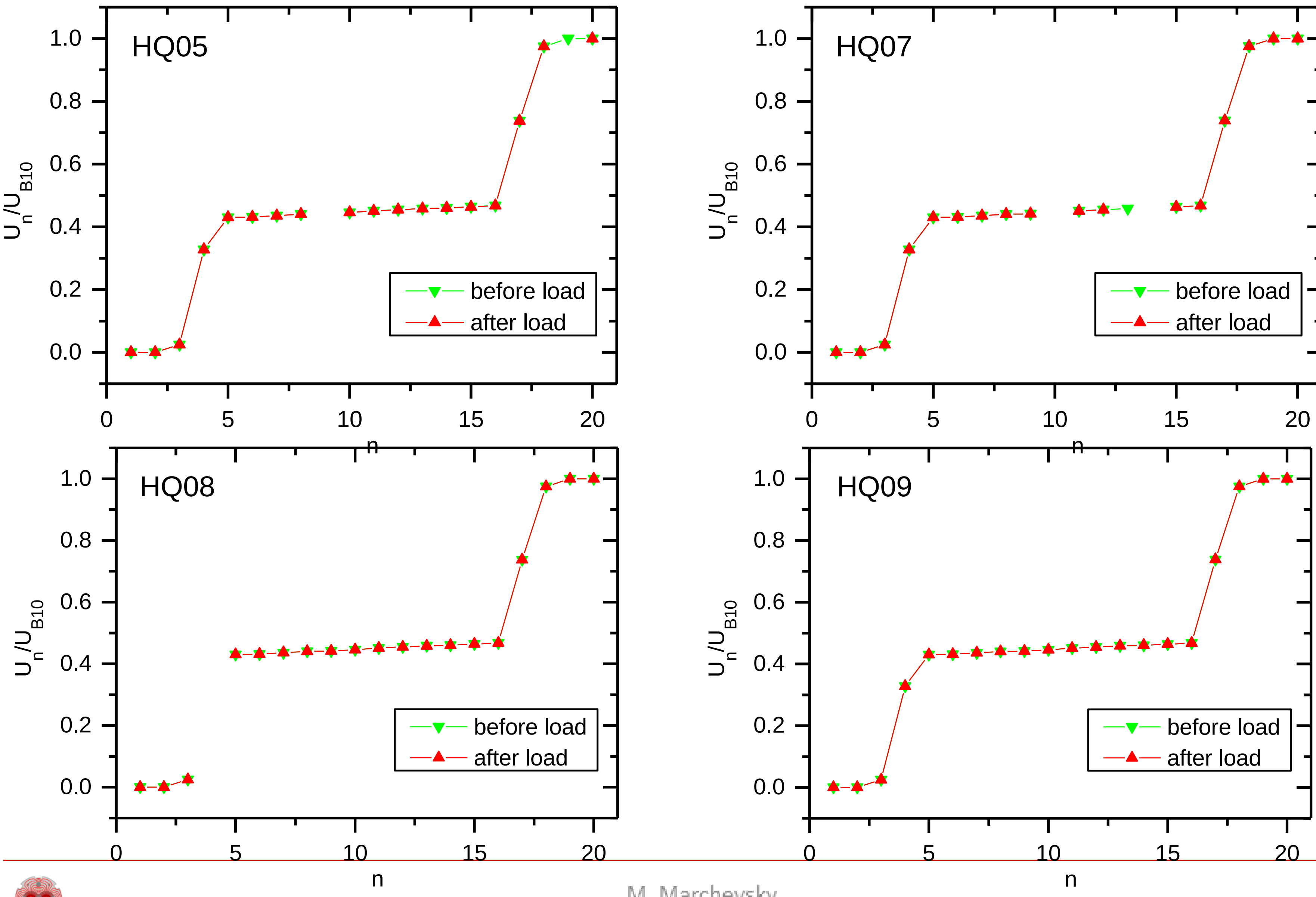


Impulse test

U=800 V



Sequential R



Further QA improvements

- Multi-channel hi-pot would be very useful to speed up the tests
- “Discharge protection” circuitry that would shorten the test pair in microseconds (nanoseconds?) time interval upon sudden current rise.
- Using quench antennas in combination with the impulse tester to detect any minor traces of partial discharge (HF noise) and localize its origin in the windings.

Comments? *Suggestions?*

Quench antenna development

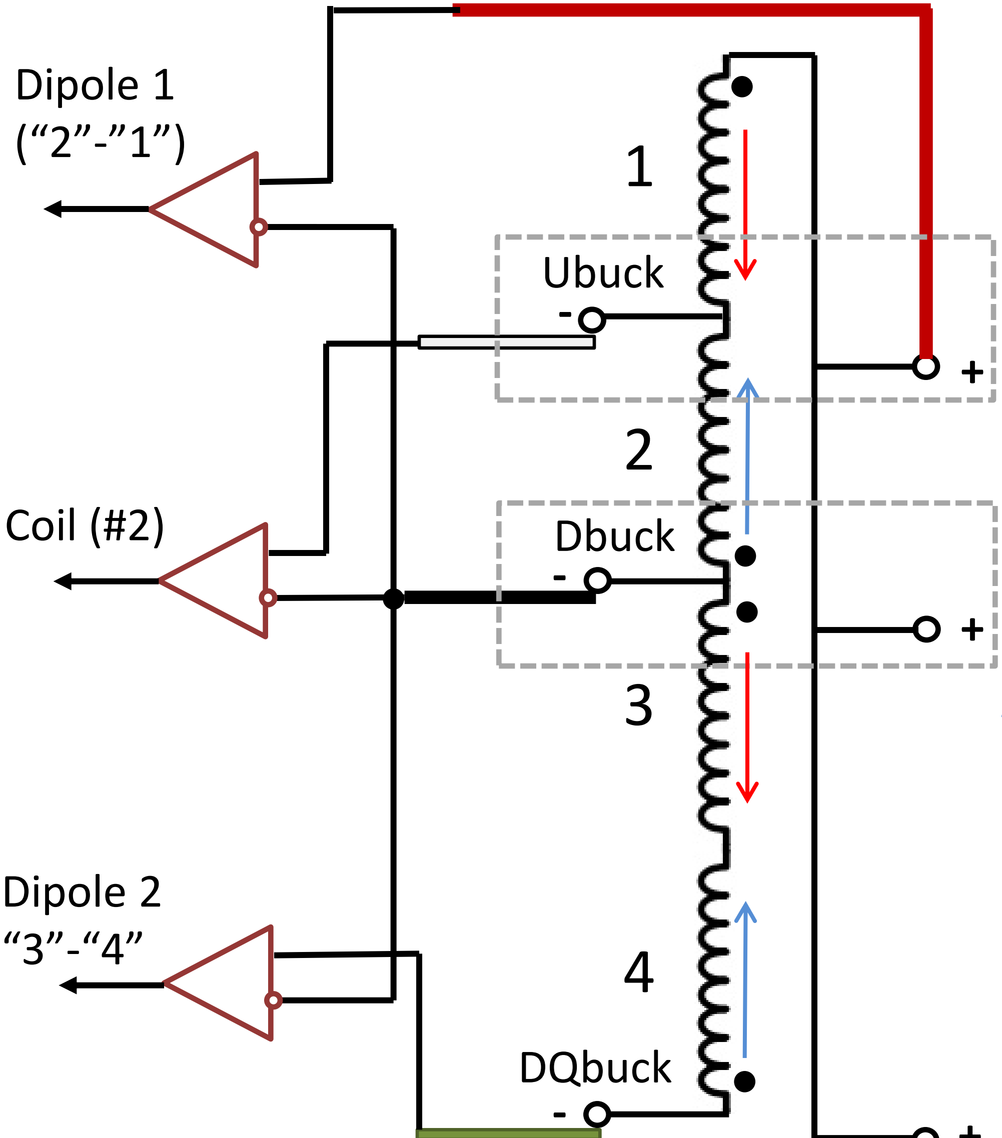
Motivation:

- Voltage taps are often insufficient for providing quench locations; quench origin localization based on entrance/exit timing requires too many Vtaps, and will be even more problematic for longer magnets like LHQ

- Inductive noise pickup in Vtap wiring longer magnets will further reduce sensitivity

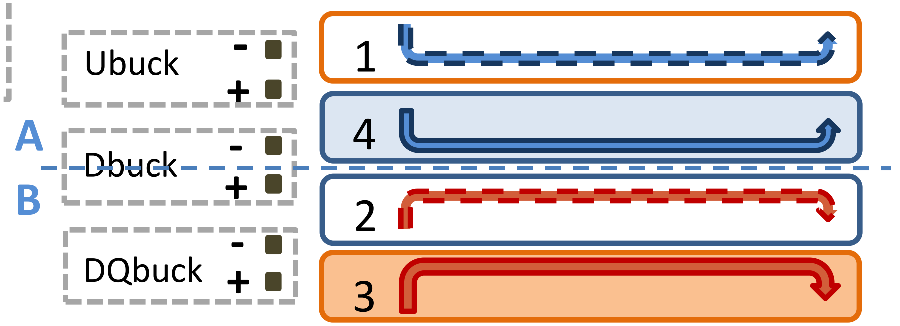
- Quench antenna senses current redistribution which in general precedes an onset of the resistive voltage. More accurate and earlier detection can be therefore expected

Quench antenna configuration



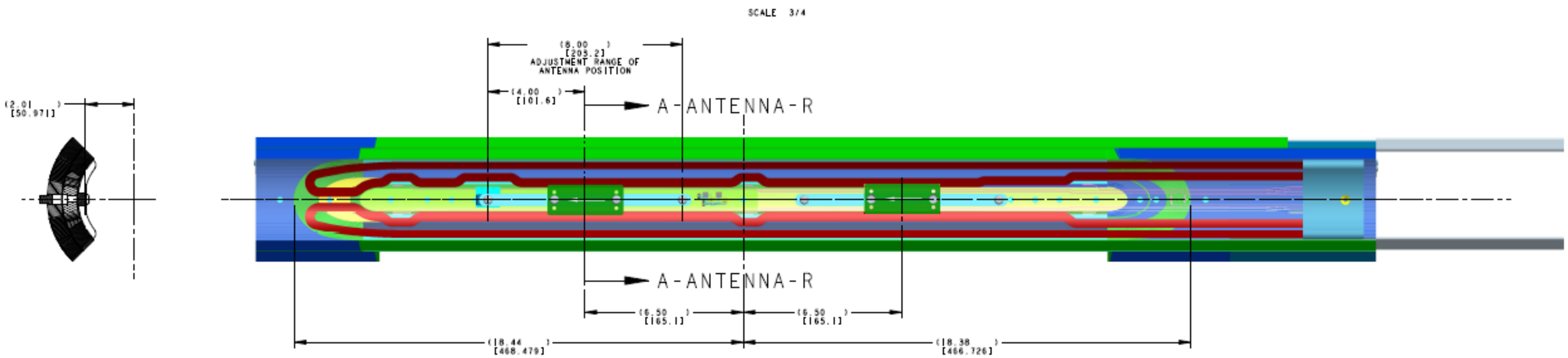
Shifting common "ground" from the "+" bus to "Dbuck –" makes signal acquisition scheme more flexible

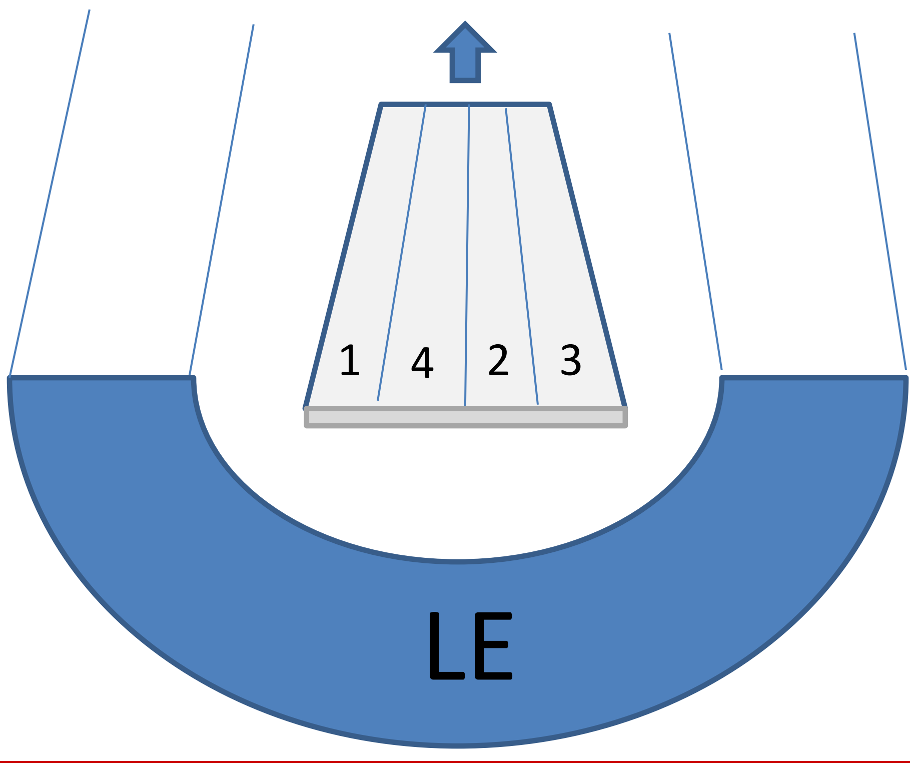
J. DiMarco, FNAL

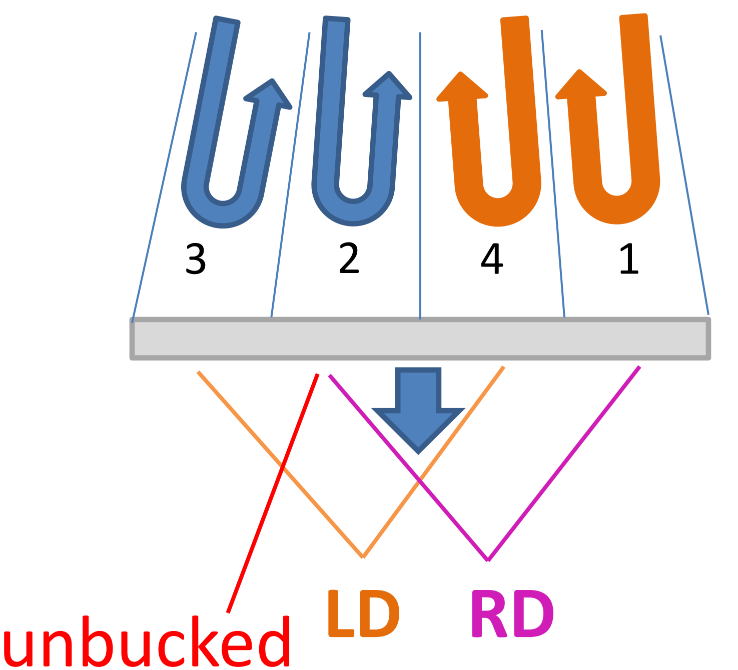


(Dipole 1 +Dipole 2) gives (1+4) – (2+3), that is side "A" of the PCB against side "B"
(Dipole 1 – Dipole 2) gives DQbuck signal

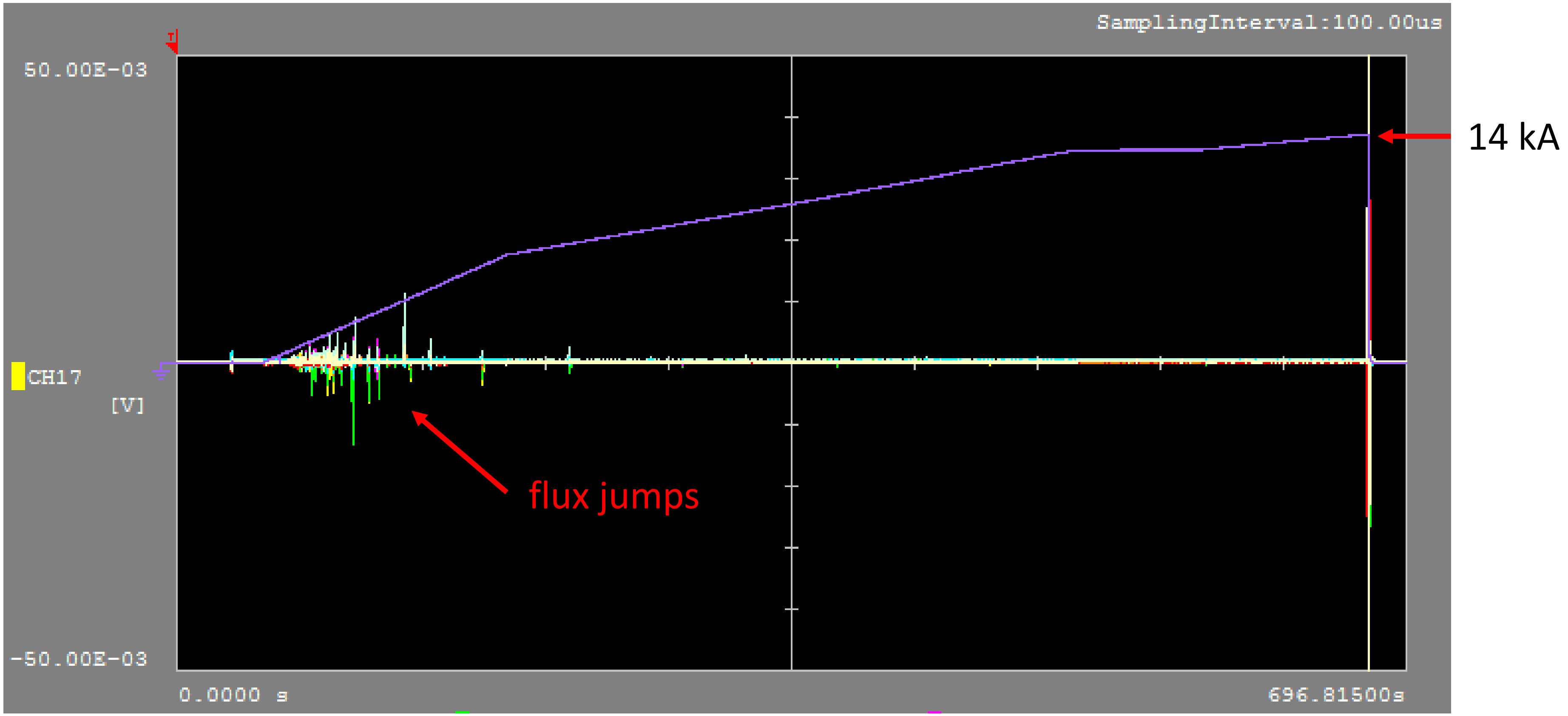
Quench antennas on the coil







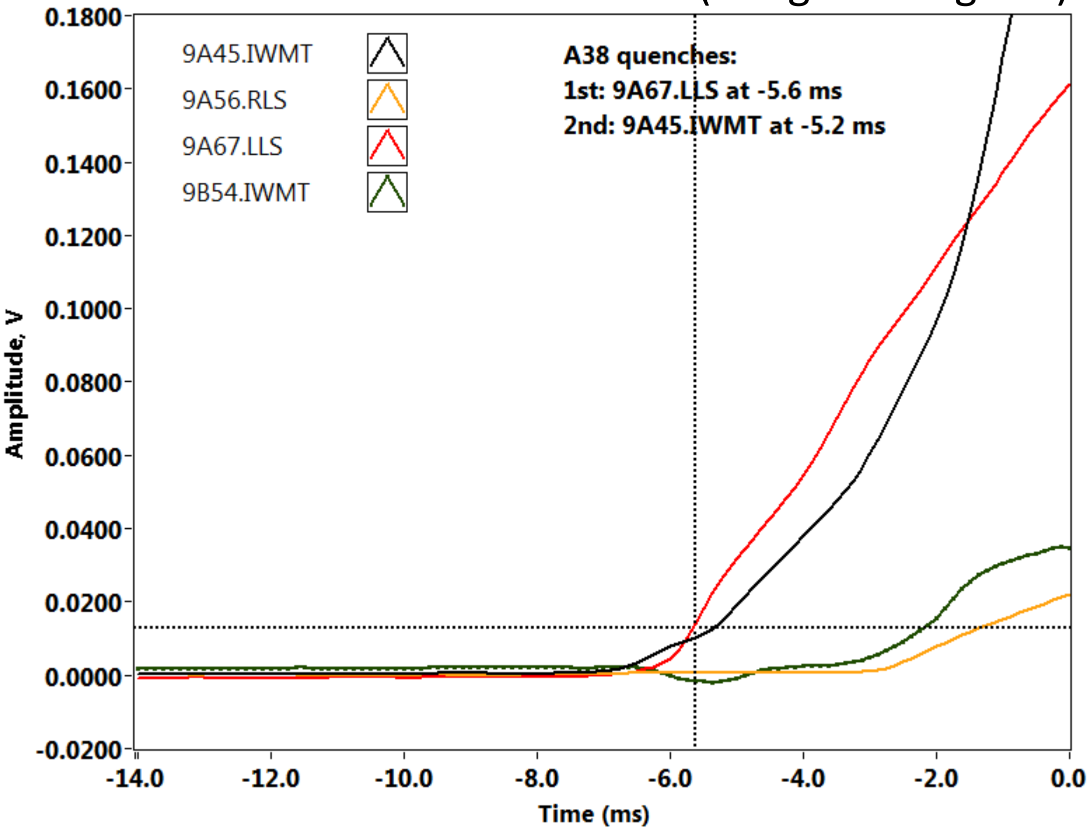
Quench antenna signal for the full ramp to quench

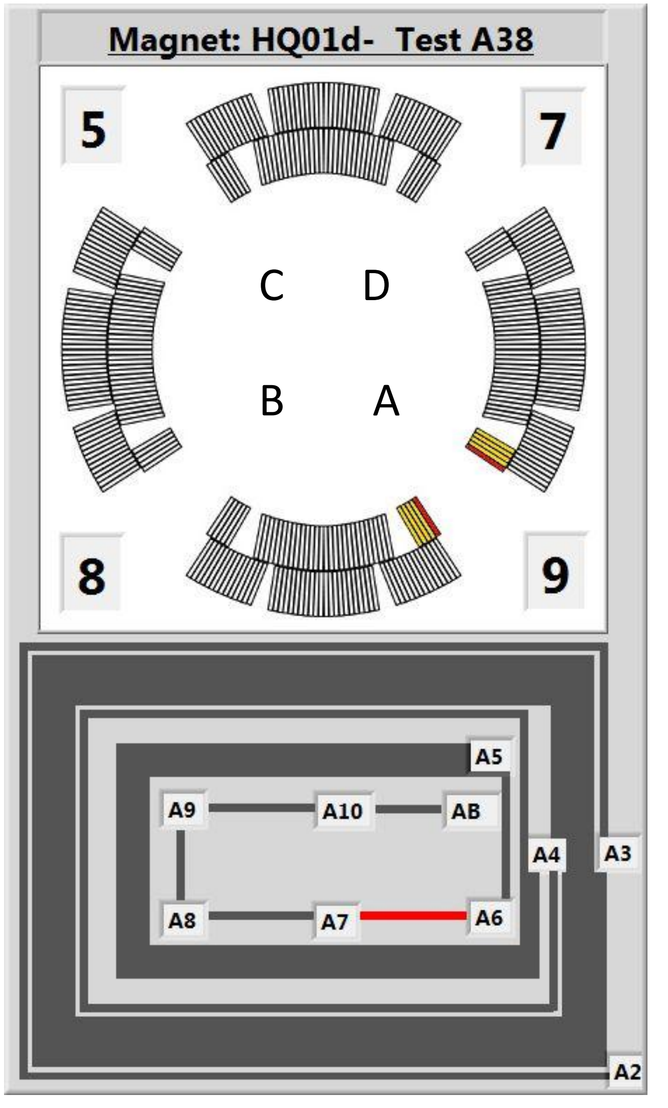


Continuous synchronous acquisition at 10^4 samples/s rate (up to 24 channels)

50 A/s to 7 kA, 20 A/s to 13.8 kA, hold (~1.5 min), then **10** A/s

(Integrated signals)





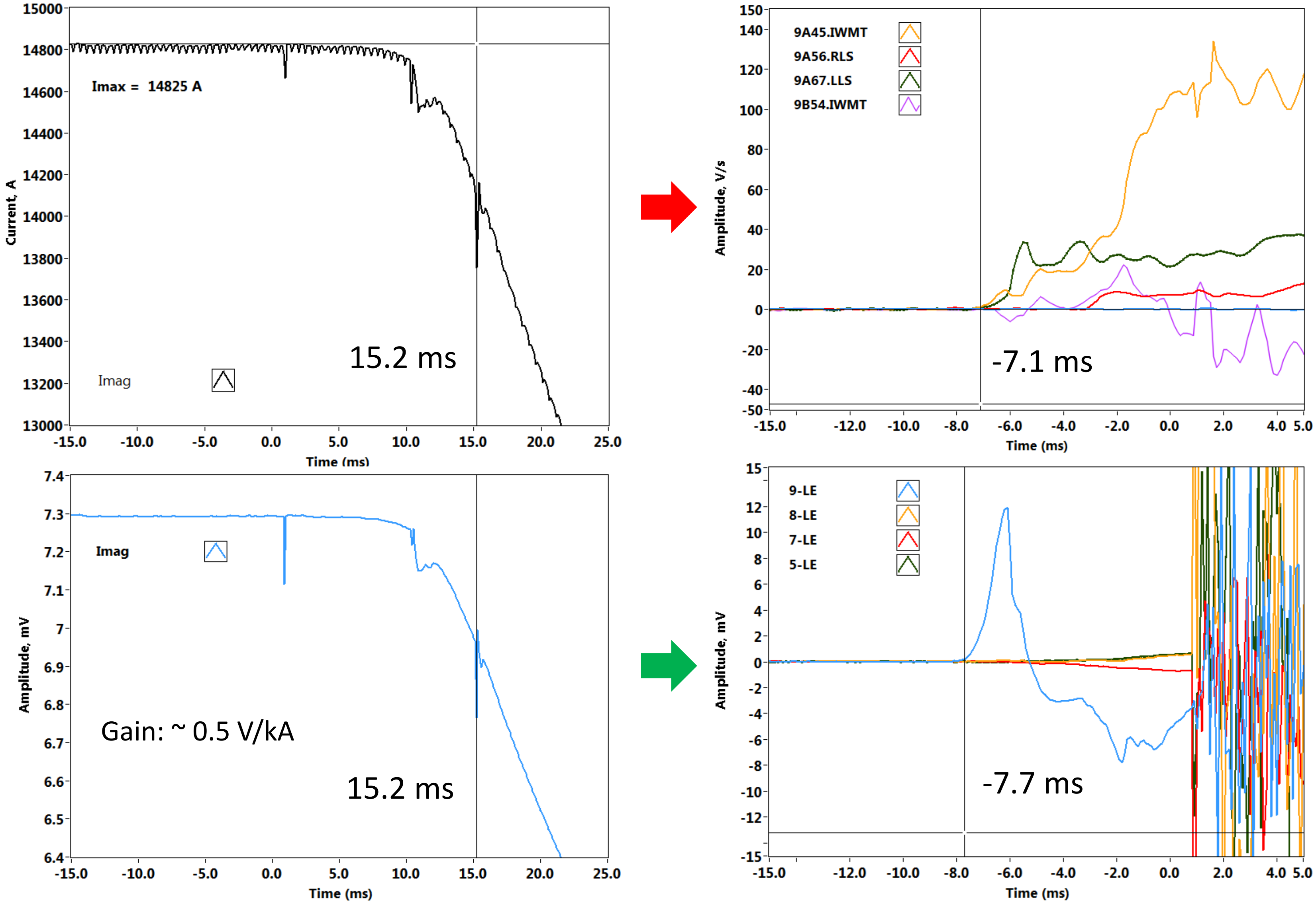
I= 14818 A

MIITS=10.54

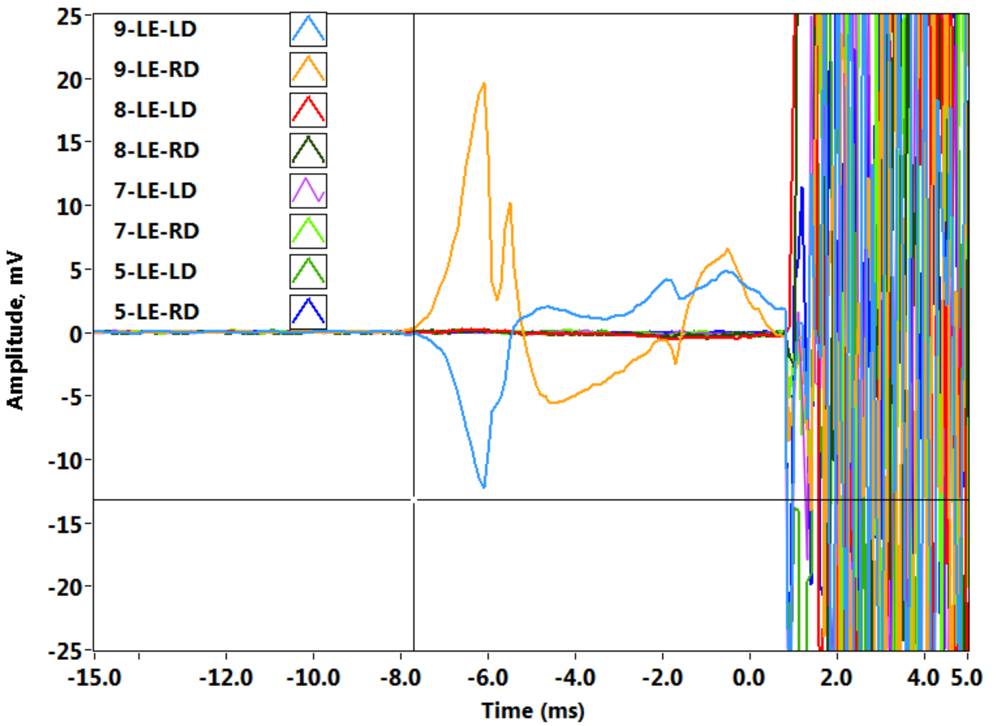
Synchronizing QA and voltage signals

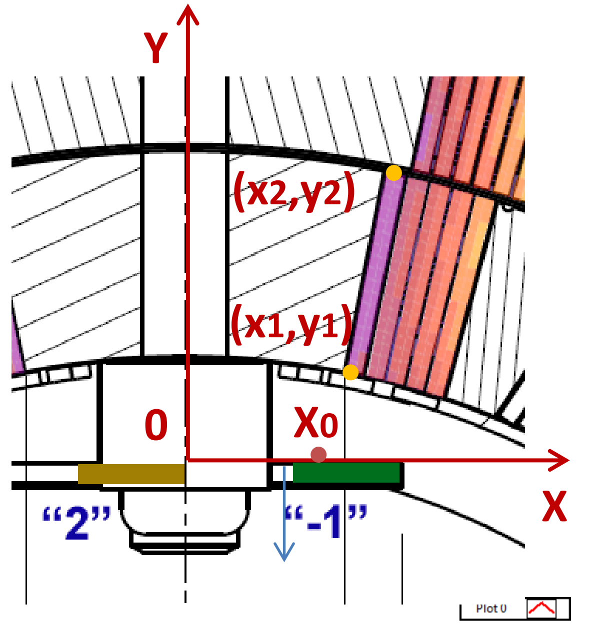
V o l t a g e

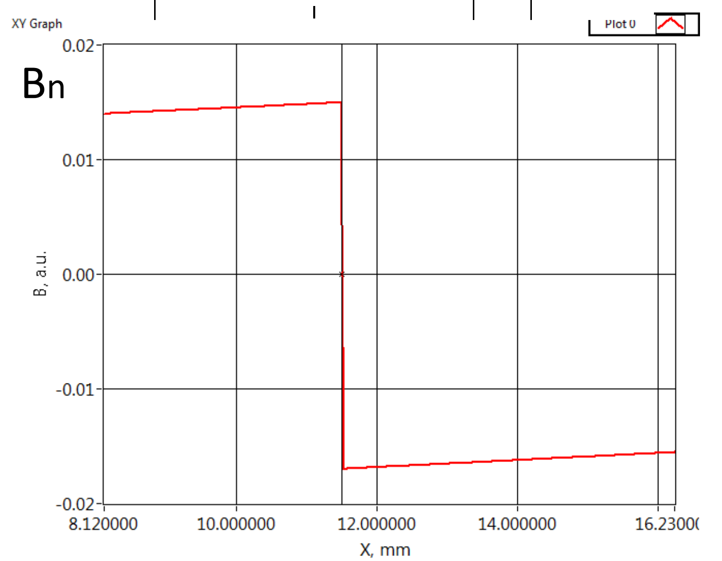
Q A



Flux reversals within the quench antenna





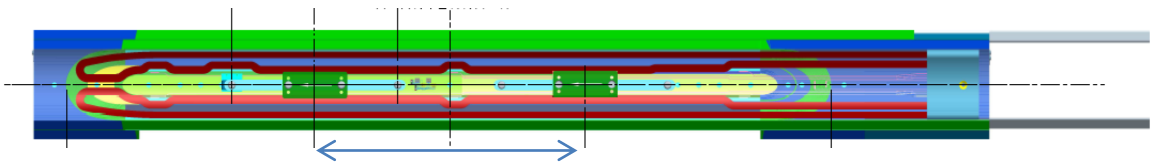


$$B_n(X_0) = \frac{\mu_0}{4\pi} \int_{x_1}^{x_2} \frac{Il(x - x_0)}{(x_2 - x_1)\left[(x - x_0)^2 + (\alpha x - y_0)^2\right]} dx$$

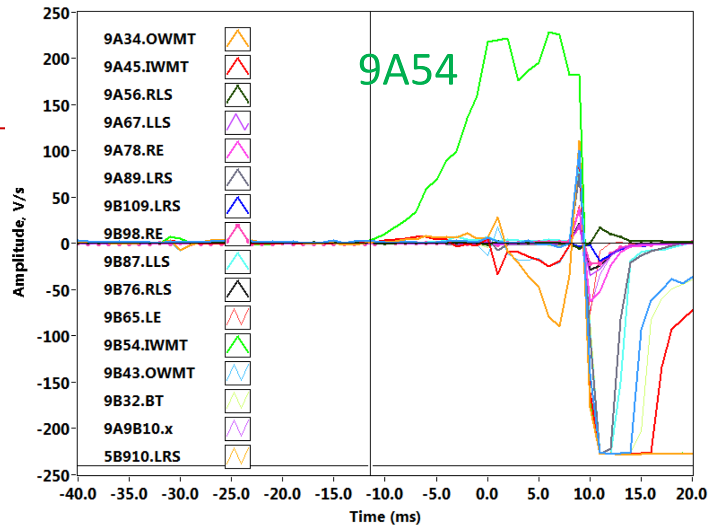
$$\alpha = \frac{y_2 - y_1}{x_2 - x_1}$$

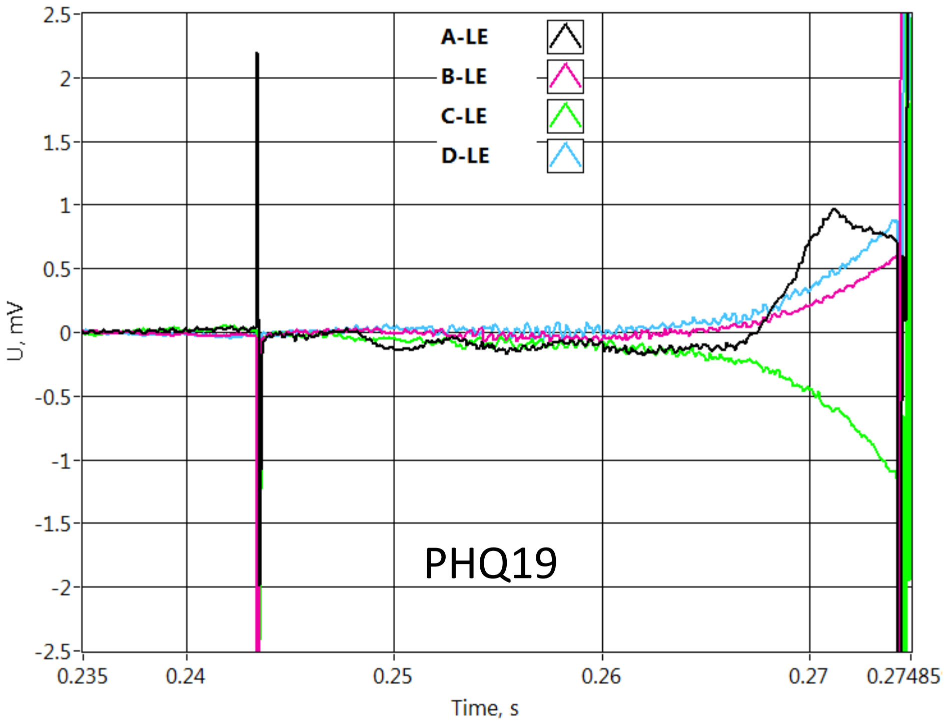
$$y_0 = y_1 - \alpha x_1$$

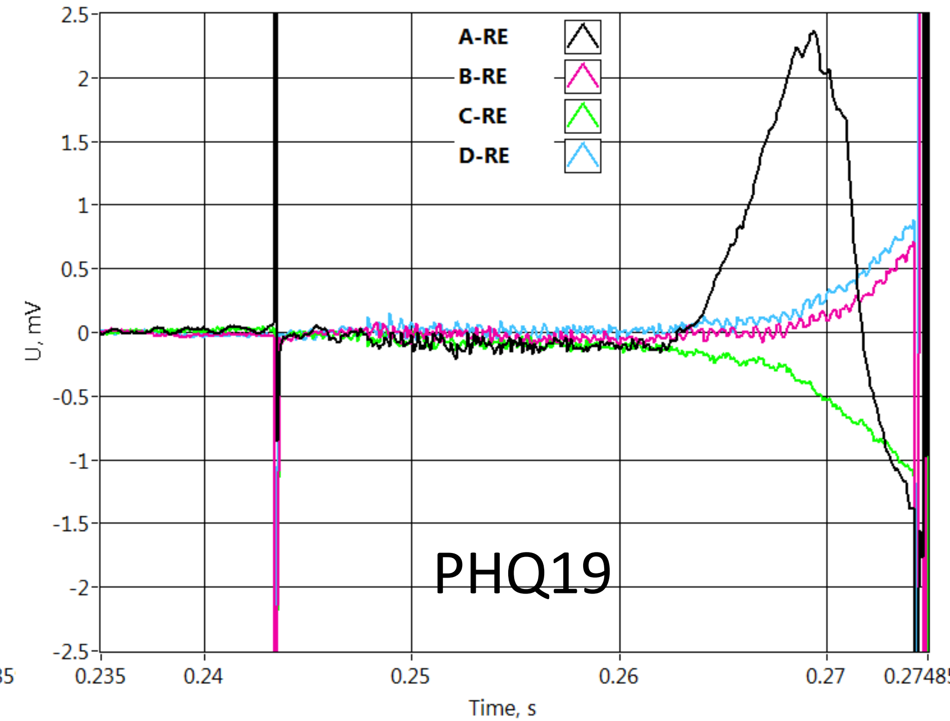
Heater-driven propagation



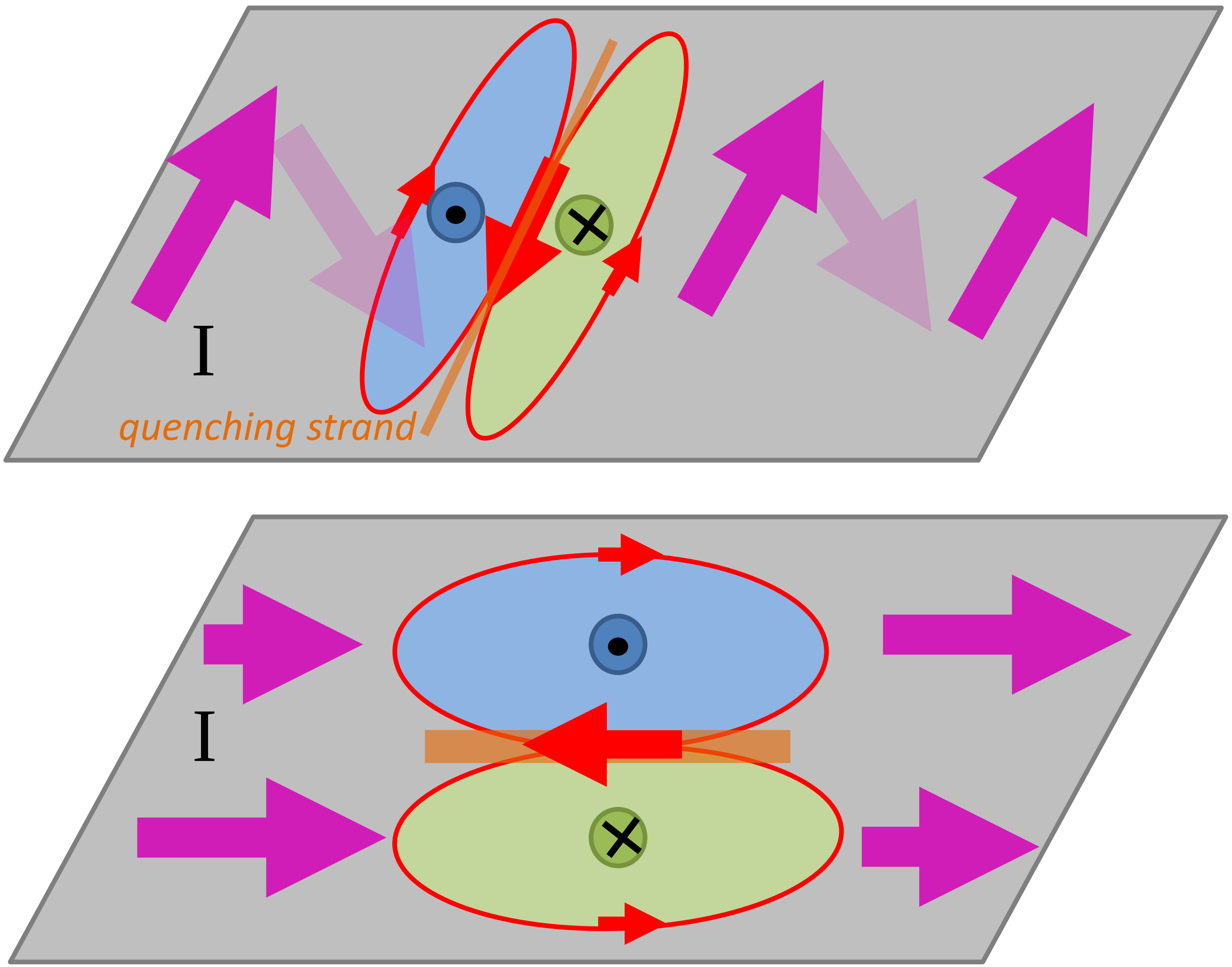
~4.5 ms signal delay between RE and LE quench antennas → **73 m/s**







Magnetic "signature" of the quench

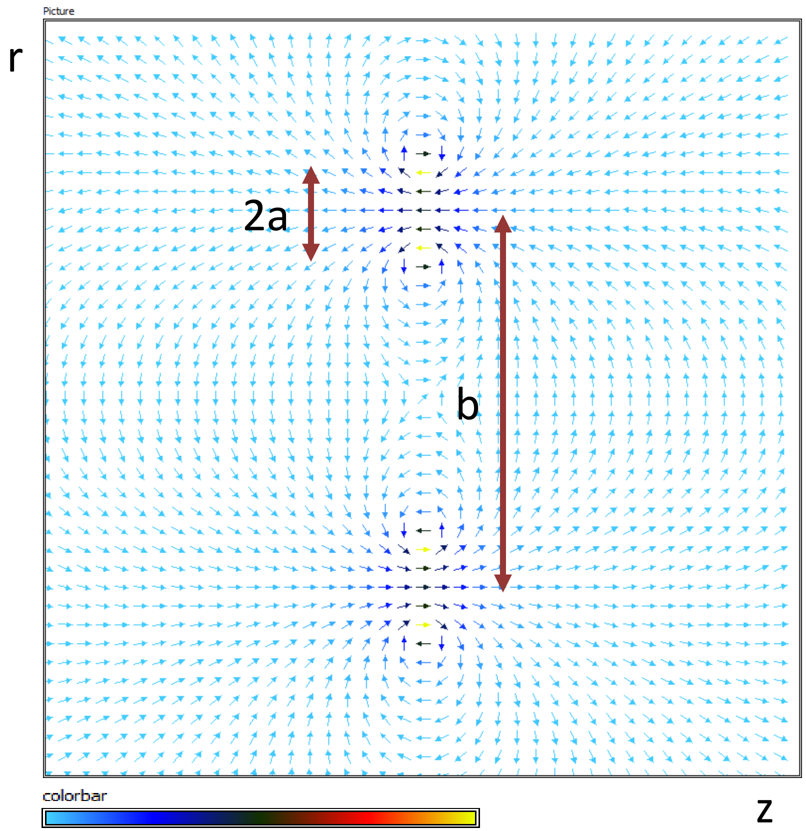


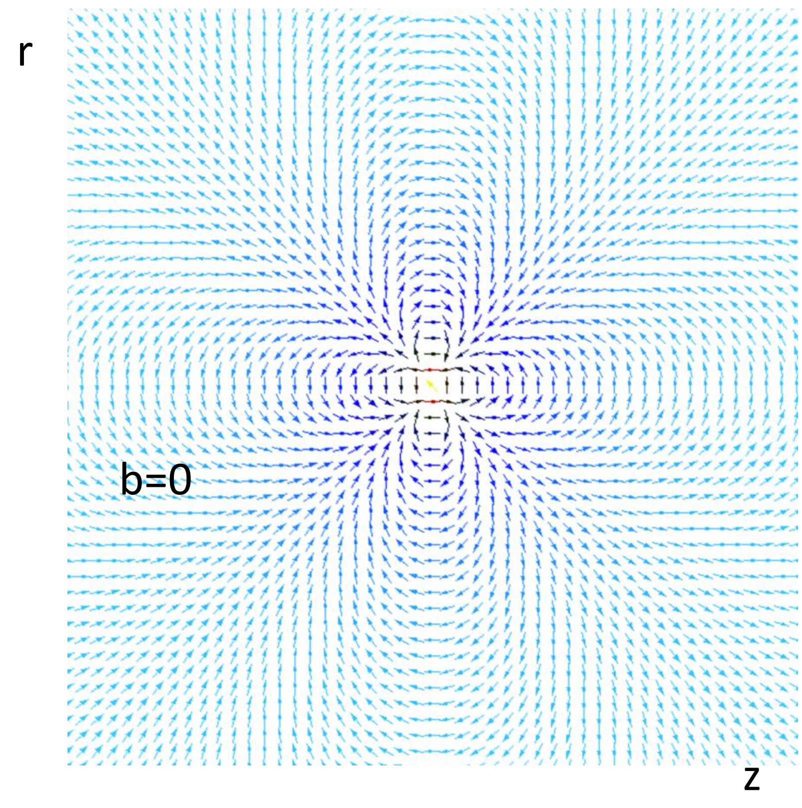
Redistribution of the superconducting current away from the quenching strand (region) will be equivalent to an introduction of two current loops with opposite orientation along the quench location

Field map of the double loop

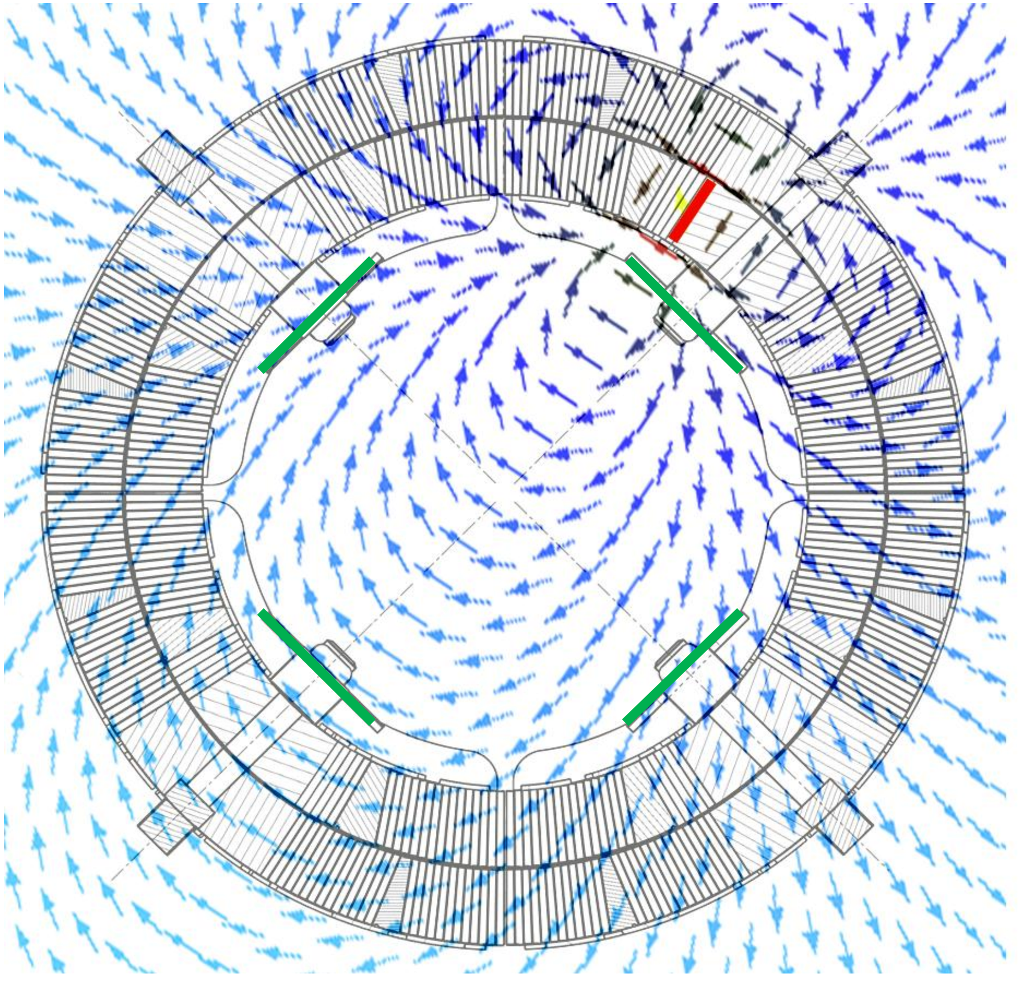
$$\mathbf{B}(r,z)=\frac{\mu_0 I k}{4\pi\sqrt{ar^3}}\left[-(z-h)\left(K-\frac{2-k^2}{2(1-k^2)}E\right)\hat{\mathbf{r}}+r\left(K+\frac{k^2(r+a)-2r}{2r(1-k^2)}E\right)\hat{\mathbf{z}}\right].$$

$$k=\sqrt{\frac{4ar}{(r+a)^2+(z-h)^2}}$$





Quench field in the magnet cross-section



QA array requirements

- Small QA coils, measuring all three components of the magnetic field at a given point seem more useful than the larger flat loop used presently
- Miniature gradient coil pairs?
- New approaches (RF resonators, probe coils embedded in the winding, fiber-optic, etc…?)

Comments? *Suggestions?*

Thank you!