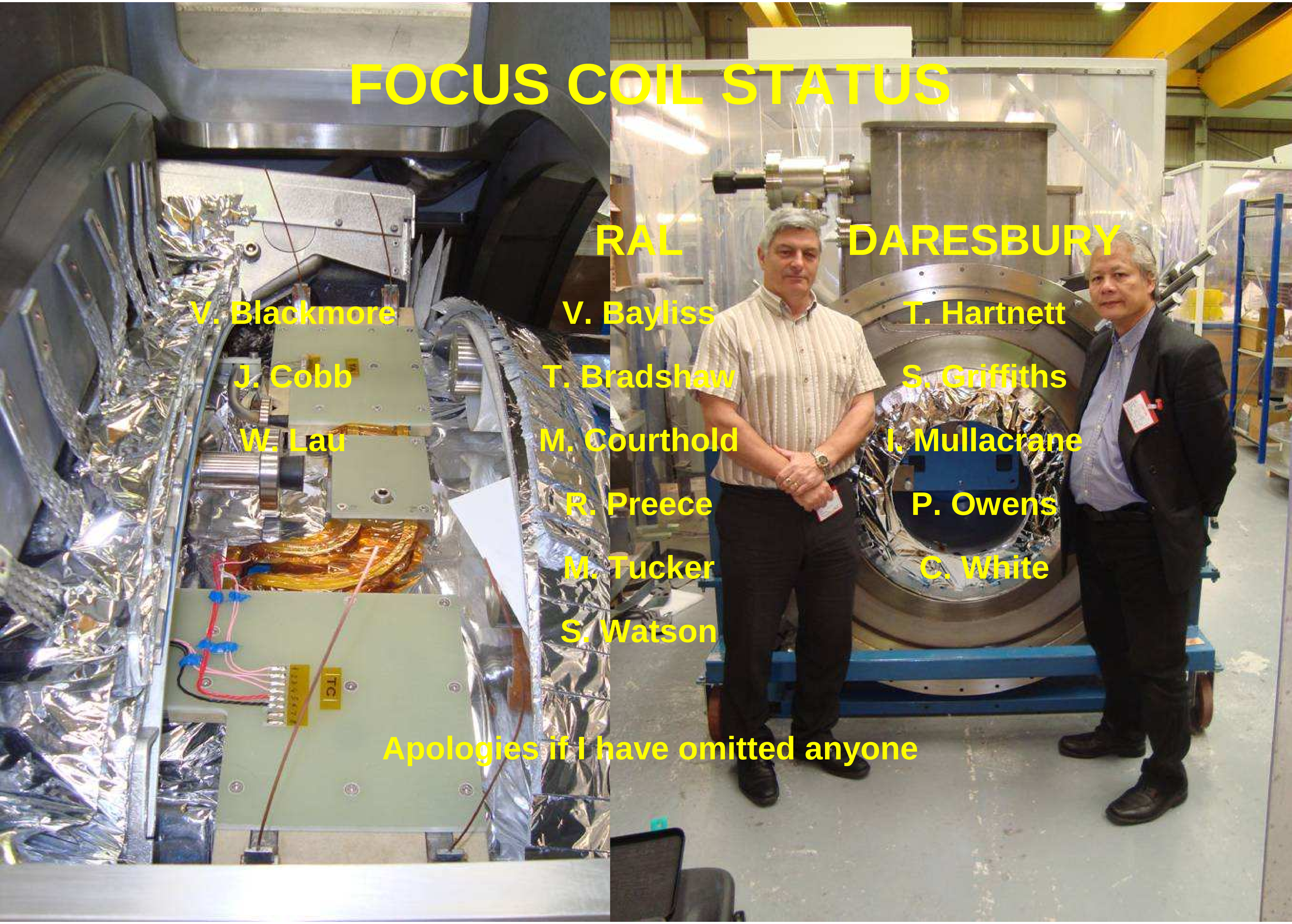
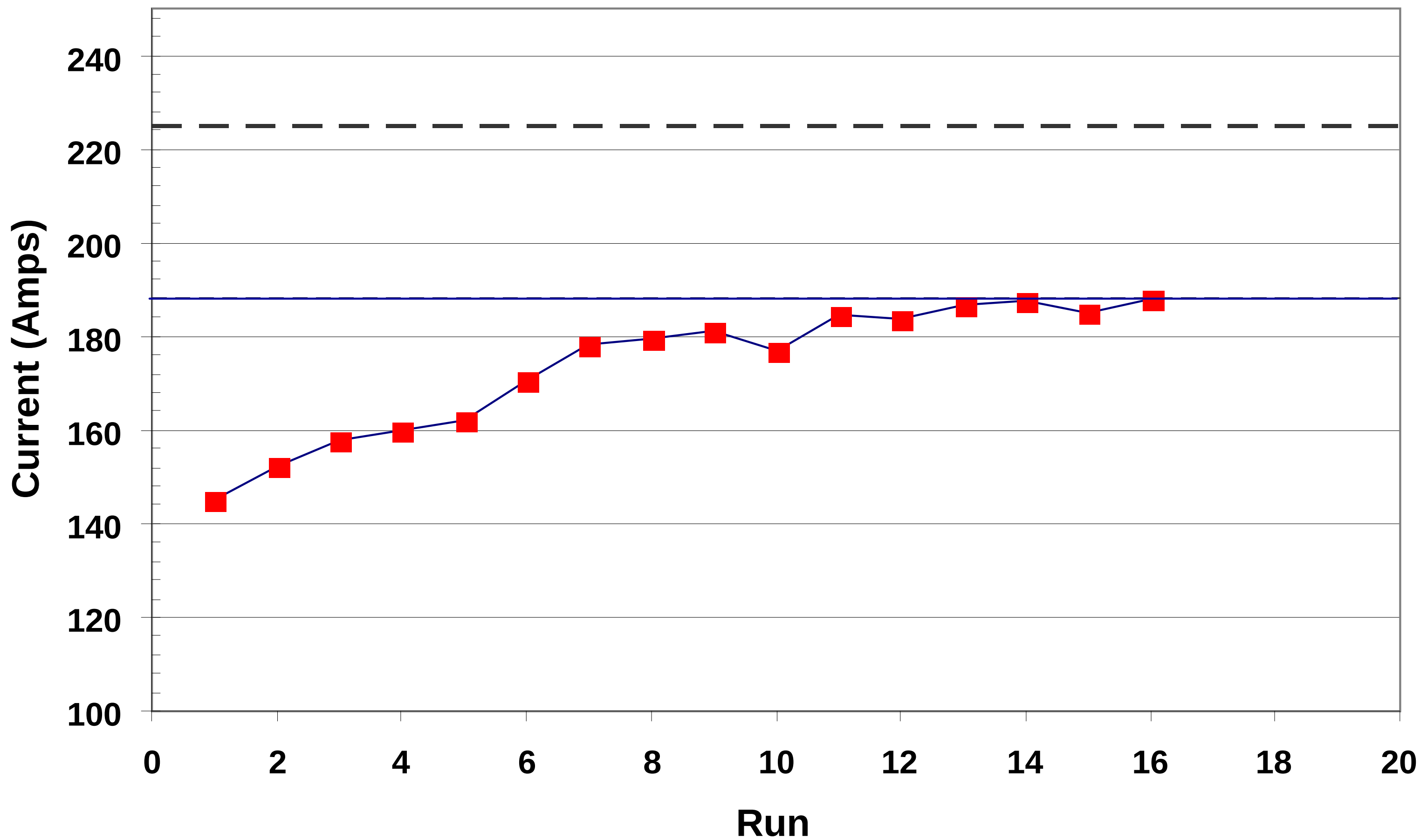

FOCUS COIL STATUS
RAL
DARESBURY
V. Blackmore
J. Cobb
W. Lau
V. Bayliss
T. Bradshaw
M. Courthold
R. Preece
M. Tucker
S. Watson
T. Hartnett
S. Griffiths
I. Mullacrane
P. Owens
C. White
Apologies if I have omitted anyone
TC

FC 1 TRAINING



Reached 188.05 Amps – gnat's whisker above 200 MeV/*c* operating current of 187.7 A

COMMENTS

- 16 training runs
  - stopped to disconnect two weeks before FC 2 due to arrive

- Seems to have reached its limit

- Baseline design in specification was for 200 MeV/*c*
  - All design calculations – forces &c – for 240 MeV/*c*
  - Barely reaching 188 A is not good enough
  - no overhead and not guaranteed
  - 170 A (+ a bit) might be safe

- Quenches do not originate in HTS leads or LTS tails

- 15/16 times Coil 1 quenched first

EXPECTED TEMPERATURE MARGINS

- **Recently re-calculated by Holger Witte in connection with PRY**

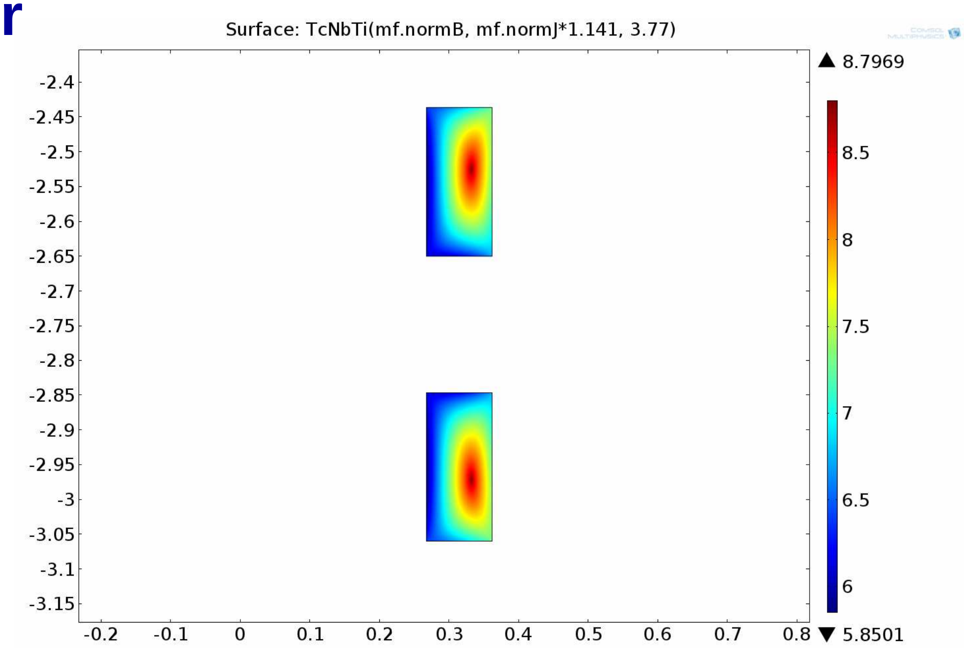
- **1.3K @ 200 MeV/*c***
- **0.5K @ 240 MeV/*c***

As expected

Coils should operate at 200 MeV/*c*

Hope (but not expectation) can get to 240 MeV/*c*

- ***It was always like this***

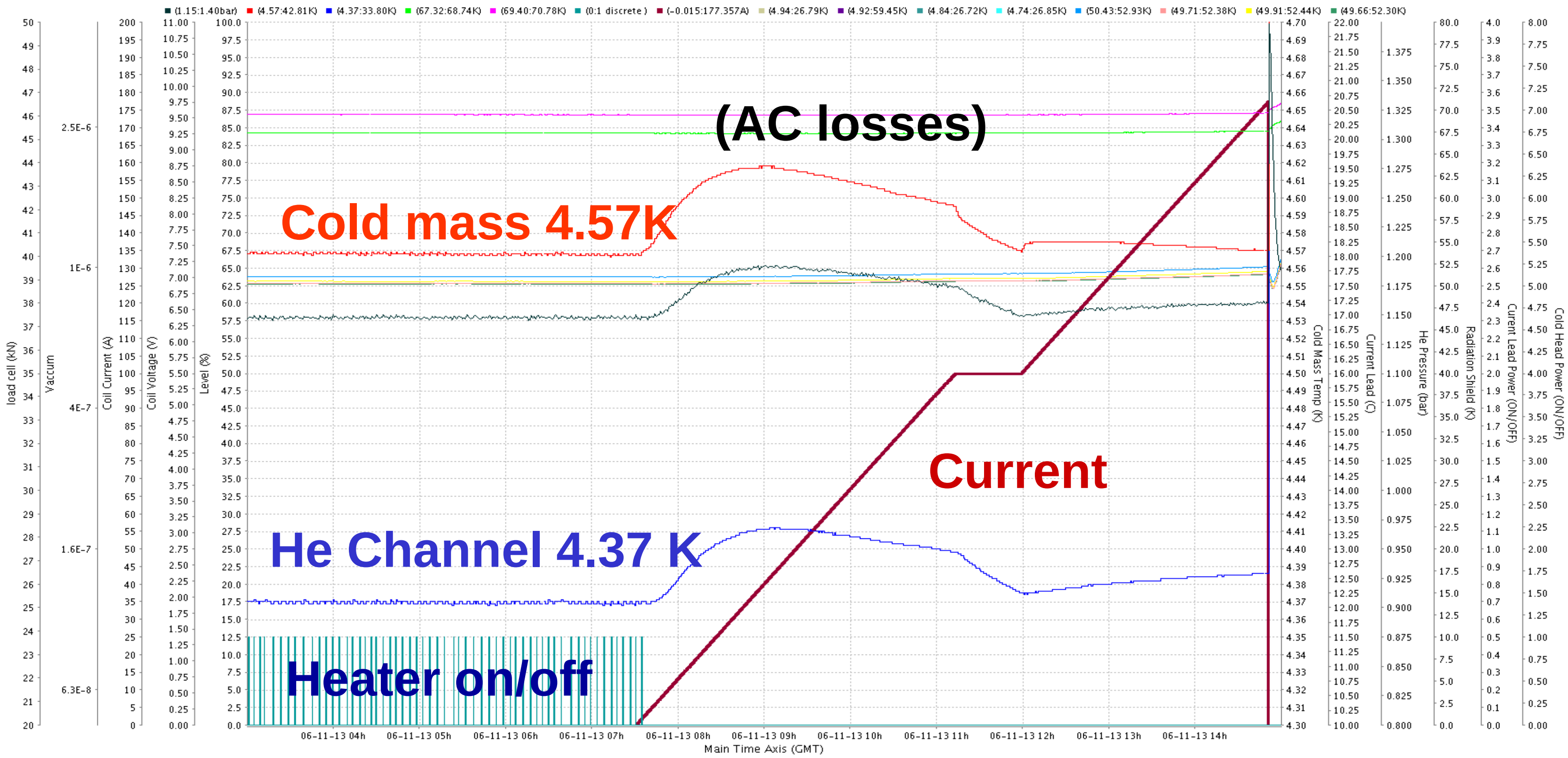


Tc maps of coils

Lowest Tc = 5.85 K @ 188 A

5.05 K @ 225 A

FC1 CRITICAL TEMPERATURES



Temperatures stable until quench

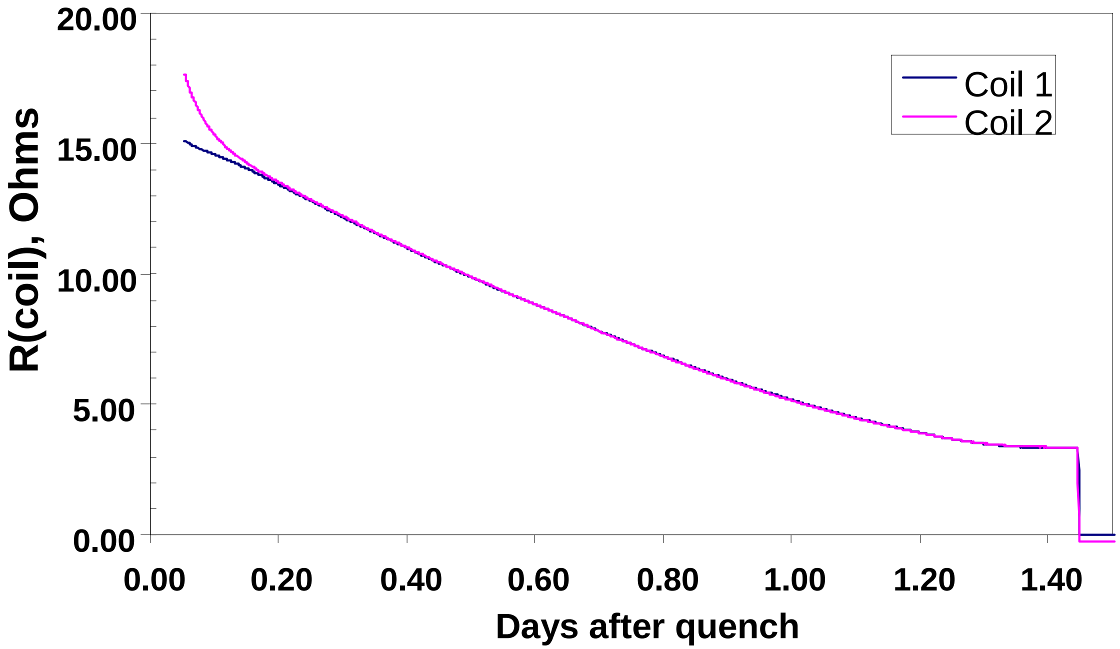
COIL 1 – COIL 2 DIFFERENCES ?

Coil 1 quenched first 15/16 times

Any evidence of difference?

e.g. thermal contact?

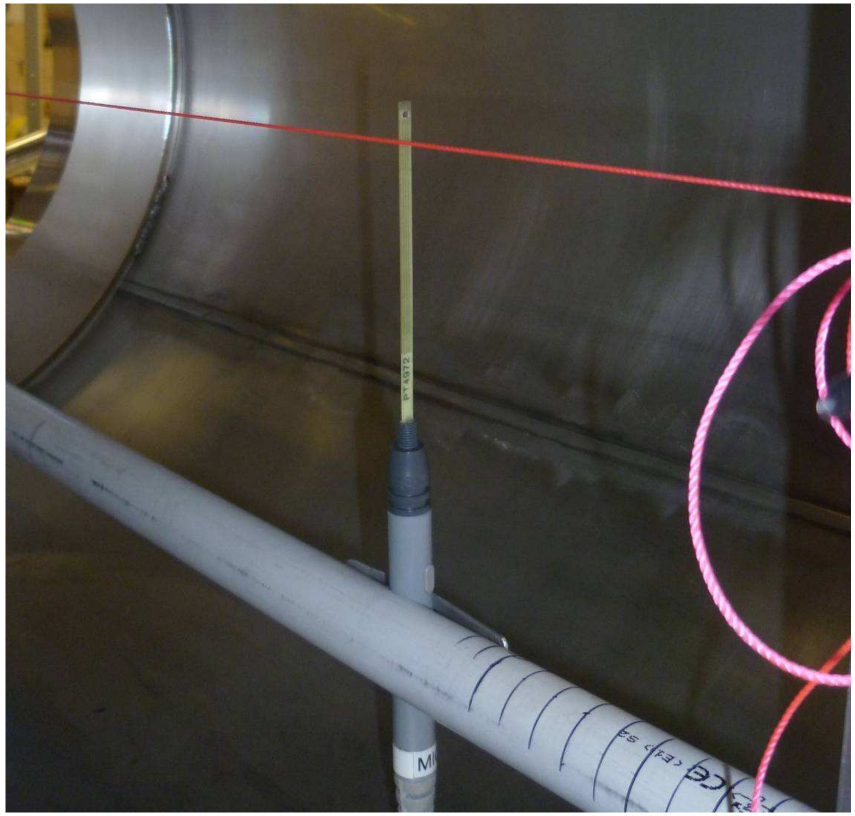
➔ Monitor S/C transition during cool down after quench



Both coils become superconducting within 1 minute ~1.5 days after quench

➔ No obvious evidence of bad thermal properties

FIELD MEASUREMENTS

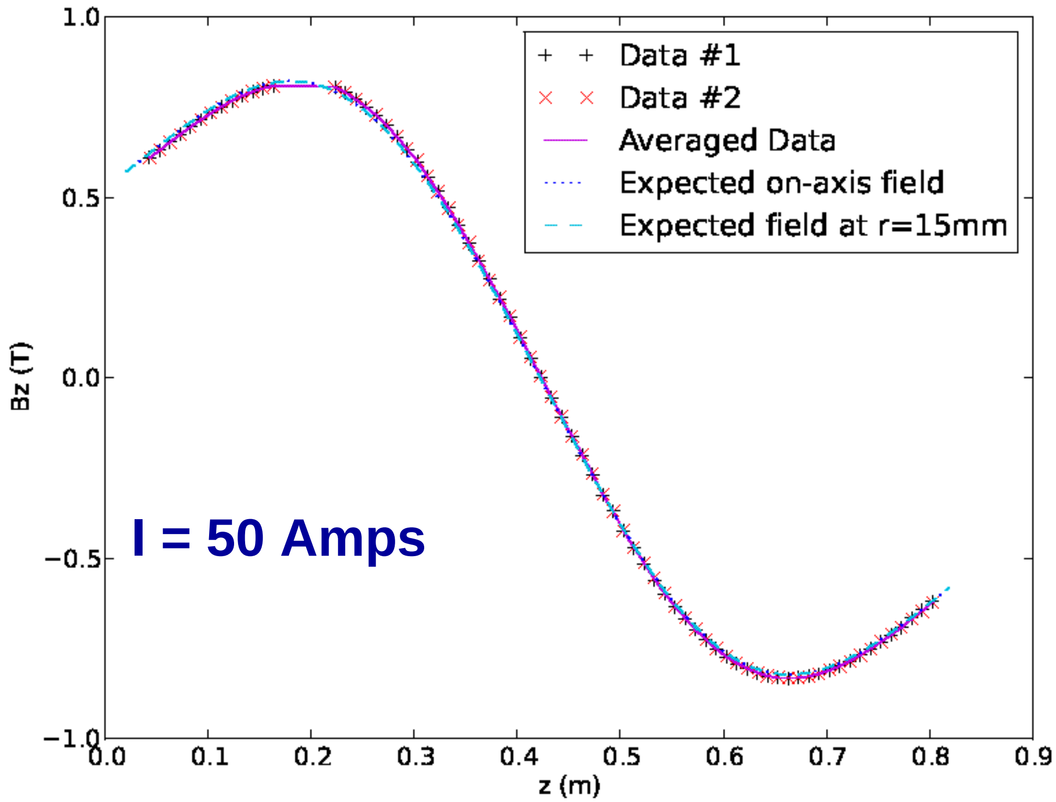


Basic (~ zero-cost) jig + Hall probe to measure field (almost) on axis

Tape measure survey – good to ~ 1mm wrt flanges

Hall probe agreed with TWB's calibration magnet to < 0.2% at 5.6kG

FIELD MEASUREMENTS



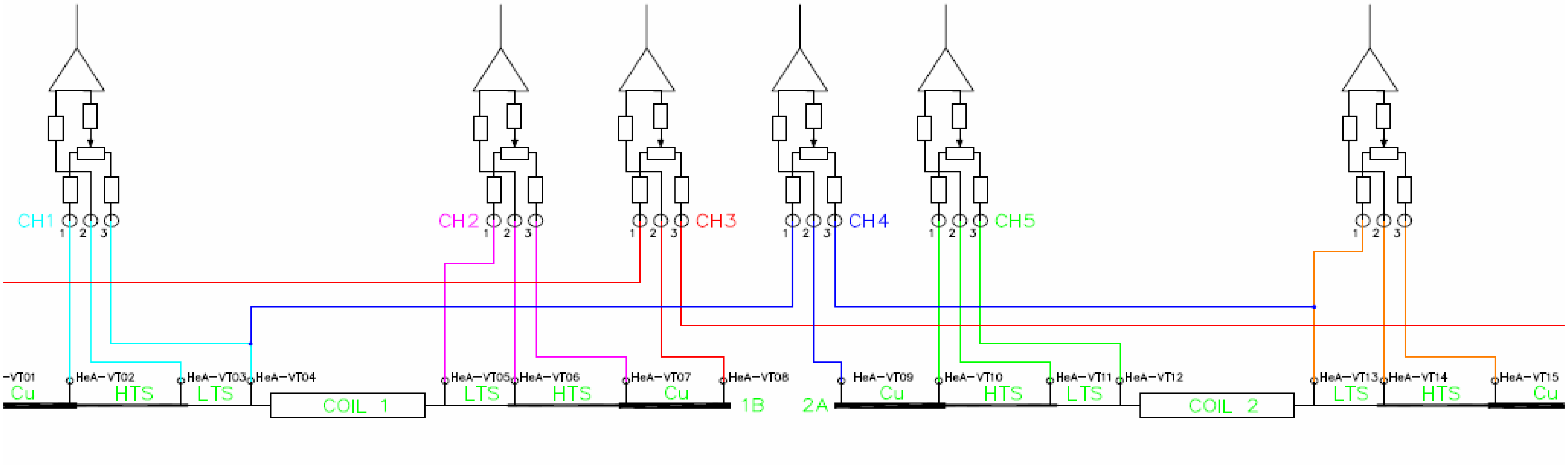
Measurements @ 50, 100, 150 Amps (some probe non-linearity above 50A)

Measured field ~1.5% greater than calculated field at 50 A

~0.5% agreement between coils at coil z-centres

➔ excludes short-circuited layers in one coil

VOLTAGE MONITORING

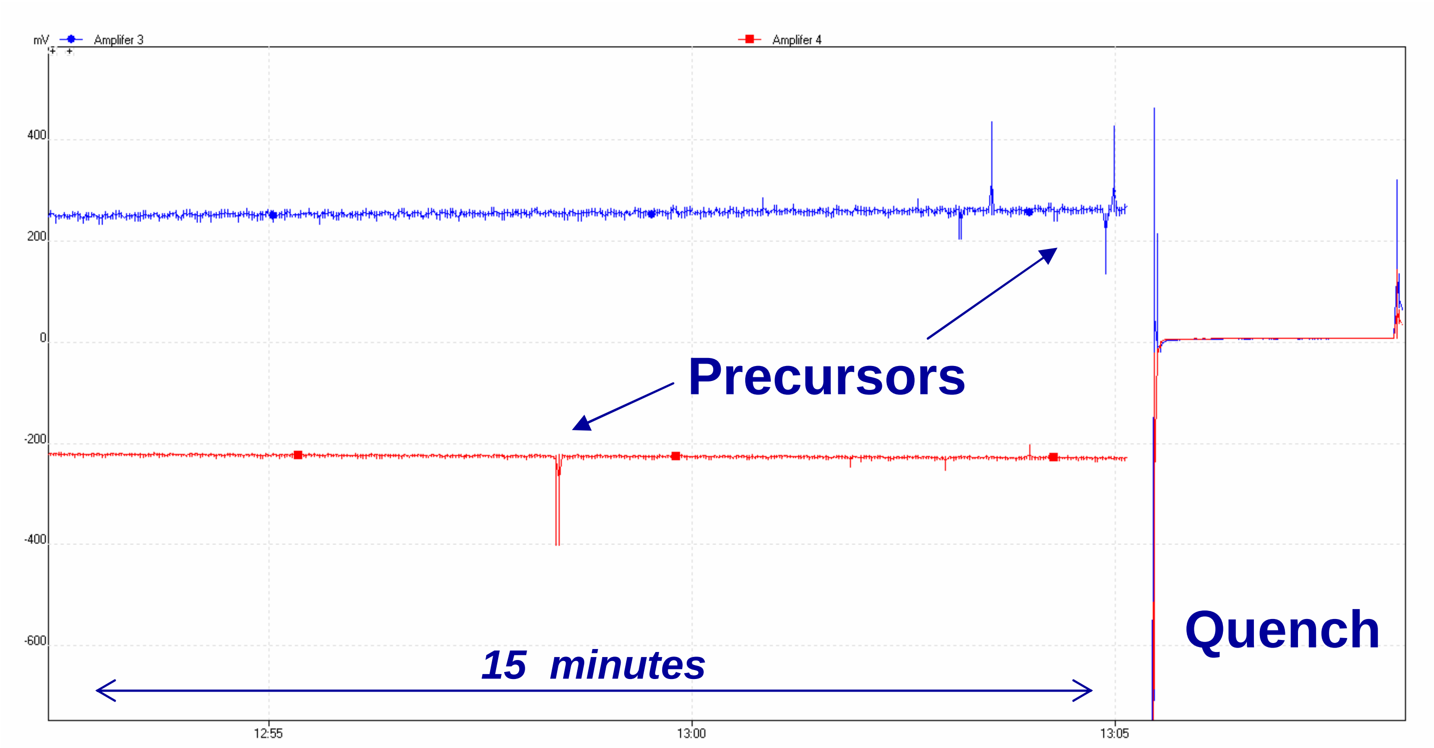


- **Q. P. system uses voltage *differences* to avoid noise triggers**

- **Voltage differences recorded with 16-channel 'Picologger'**
  - **Commercial slow ADC system**
  - **10 mSec samples**
  - **Channels sampled sequentially**

- **Voltage differences somewhat difficult to interpret… Nevertheless…**

PRECURSORS

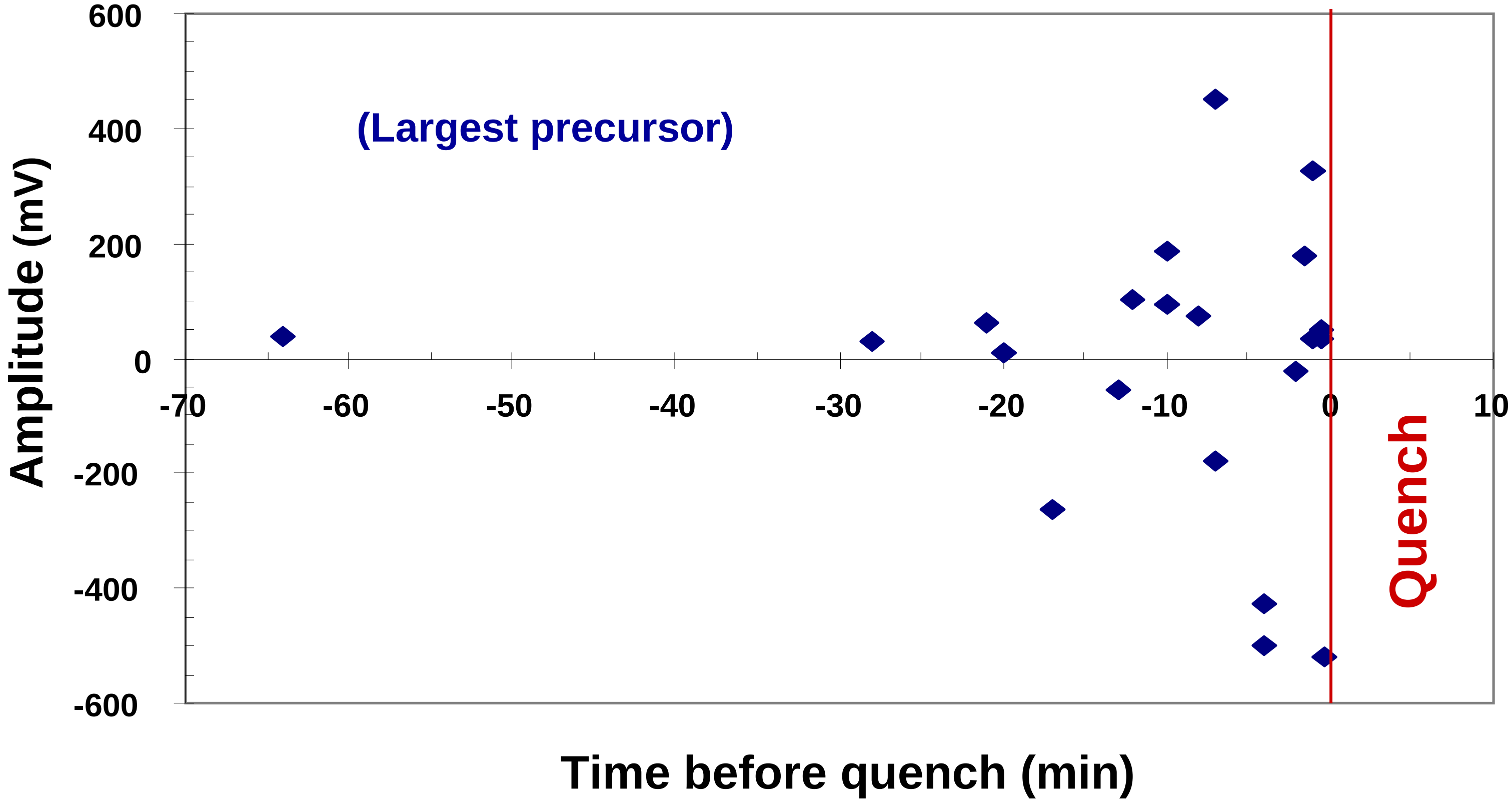


Difference voltages (after amplification of ~ 6) ➔ Precursors to quench

Picologger can't see coincidences of short transients
+ has dead time because of sequential sampling

Average of 7 precursors / quench – true rate a few times higher

PERCURSORS – 2

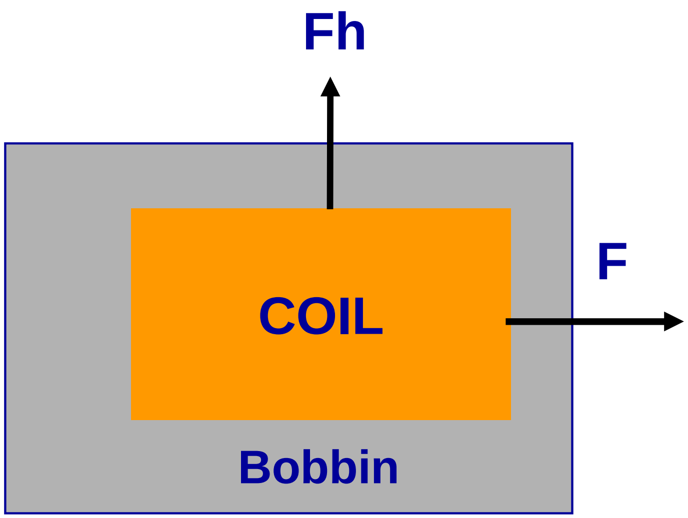


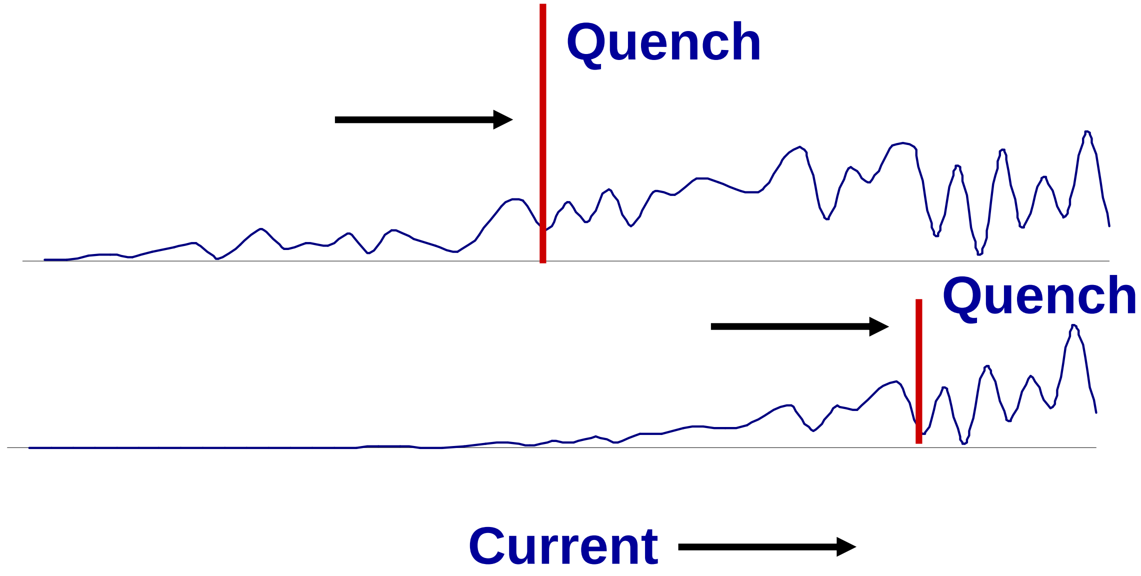
Frequency & amplitude of precursors increase towards time of quench
Last 10 minutes ~ last 5 Amps of current

May not cause quench but suggests ‘stick-slip’

Coil movement ➔ change of flux ➔ induced EMF in coils

STICK – SLIP





Coils move against small irregularities – stick then slip

Enough mechanical energy may be released in a slip to cause quench

Irregularities slowly ironed out

Hoop stresses also give radial motion

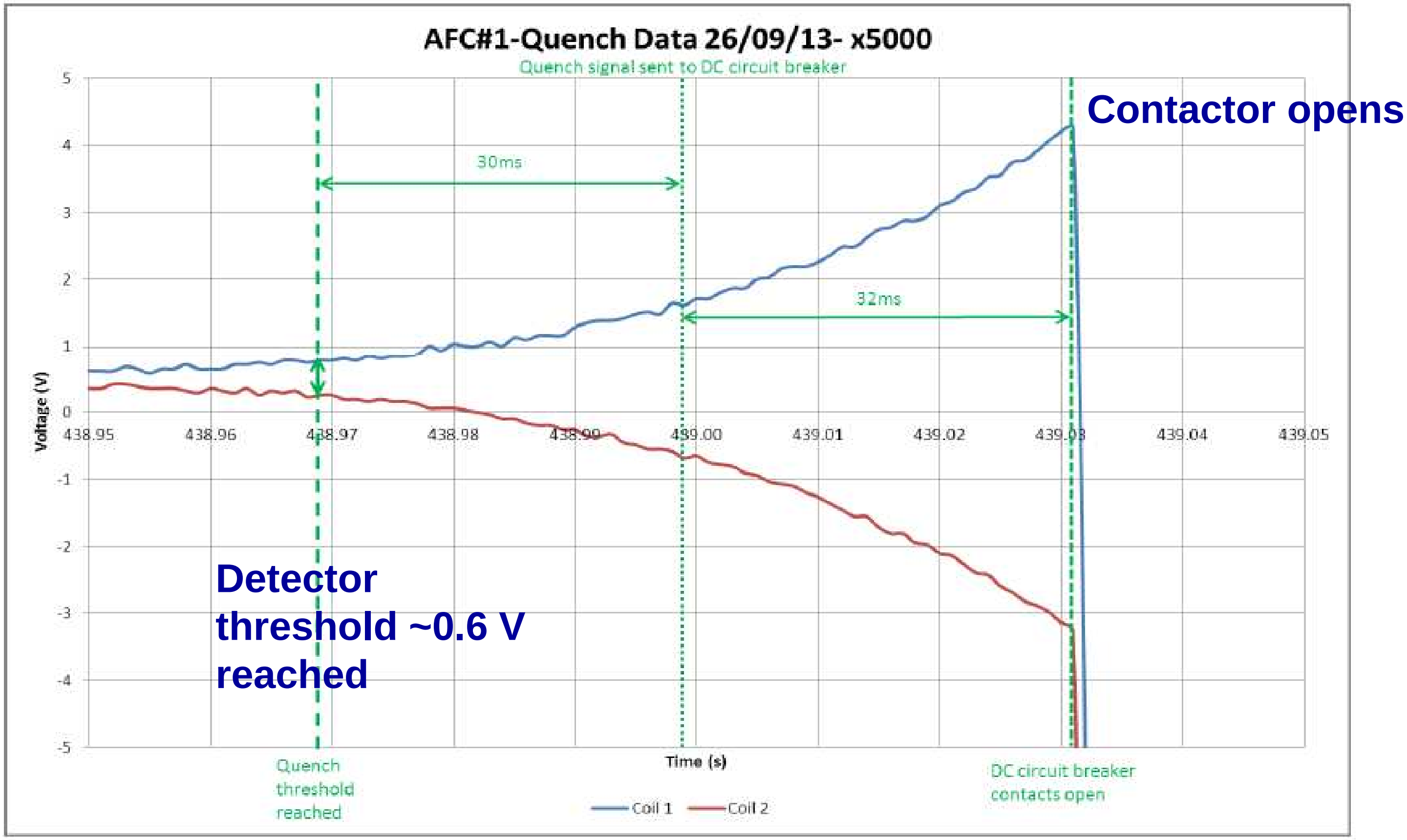
NEW VOLTAGE LOGGING

- **Picologger records show something interesting**
  - **But difficult to interpret & too slow**

- **New voltage logging system built by DL**
  - **16 channels of National Instruments ADCs**
  - **Records voltages between adjacent voltage taps**
  - **1 mSec sampling**
  - **Stores ~ 8 minute window of data around time of quench**

- **Operational for last run of FC #1**

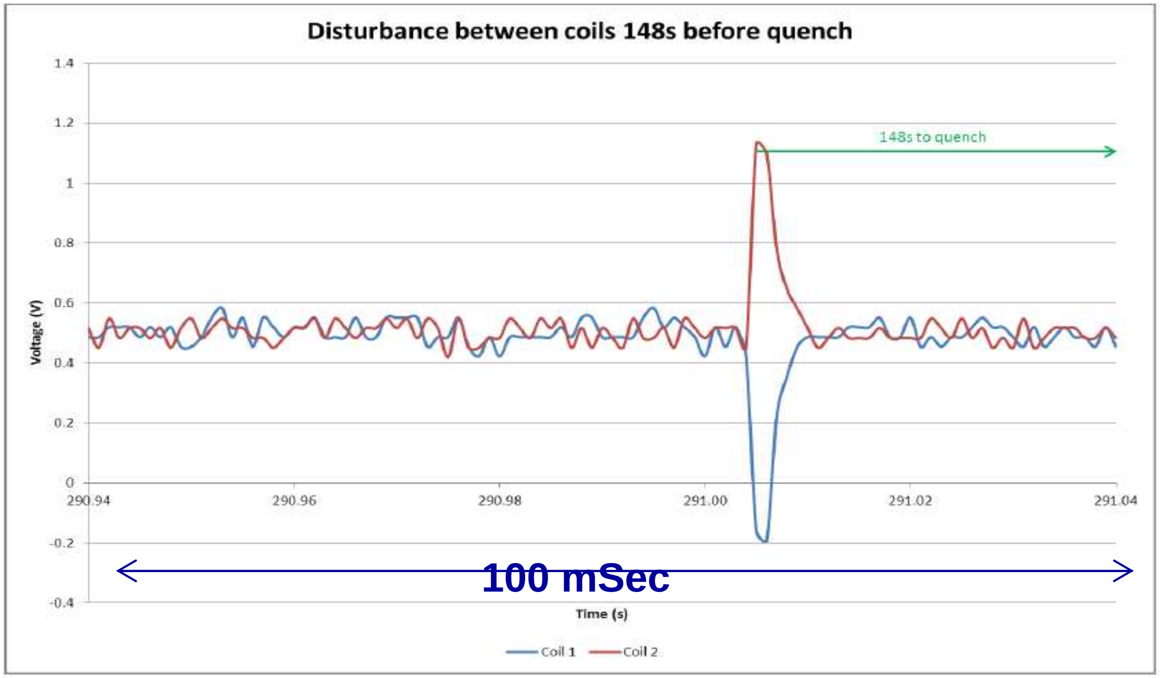
LAST QUENCH OF FC #1



Coil voltages run away over 10's of mSec

➔ Growth of normal (resistive) zone in coils – as expected

PRECURSOR



One precursor ~ 2.5 minutes before quench

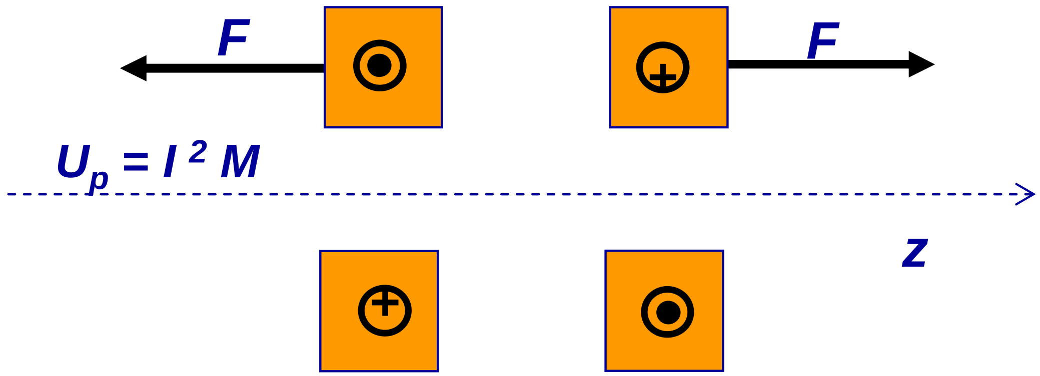
Voltage spike of ~650 mV for ~5 mSec on each coil; *I* = 188 Amps

Δ*U* = Energy = Integral [***I V dt***] = 2 * 0.65 * 0.005 * 188 / 2 **= 0.61 J**

>> Estimated MQE ~ 1 – 3 milliJoules

Didn't propagate as a quench → not resistive → movement of coils (?)

HOW LARGE IS MOVEMENT?



Coils move apart by Δ*z* and mutual inductance *M* changes ➔ Δ*V*

Δ*U* = 0.61 Joules = change in mutual potential energy of coils = *F* Δ*z*

***F* = 221 Tons = 2.17 MN (calculated)**

Δ*z* = Δ*U* / *F* = 0.61 J / 2.17 MN = 0.28 microns

Heat capacity 1 coil ~ 140 J/K so 0.61 J ➔ ΔT ~ 4.3 mK

Whether movement causes quench depends where / how mechanical energy converted to heat

IT LOOKS LIKE “TRAINING”…

- **American Magnetics (www.americanmagnetics.com/magnetp.php):**

“Premature quenching can also occur if the large forces between coil sections result in the motion of one coil with respect to another. This is most likely to occur in magnets having coils that are wound in opposition.”

- **Whole business is a Dark Art**

- **Obviously sensitive to things that are difficult to control**
  - **Surface properties**

- **Would have been interesting to instrument the cold masses with microphones to pick up movements – but too late**

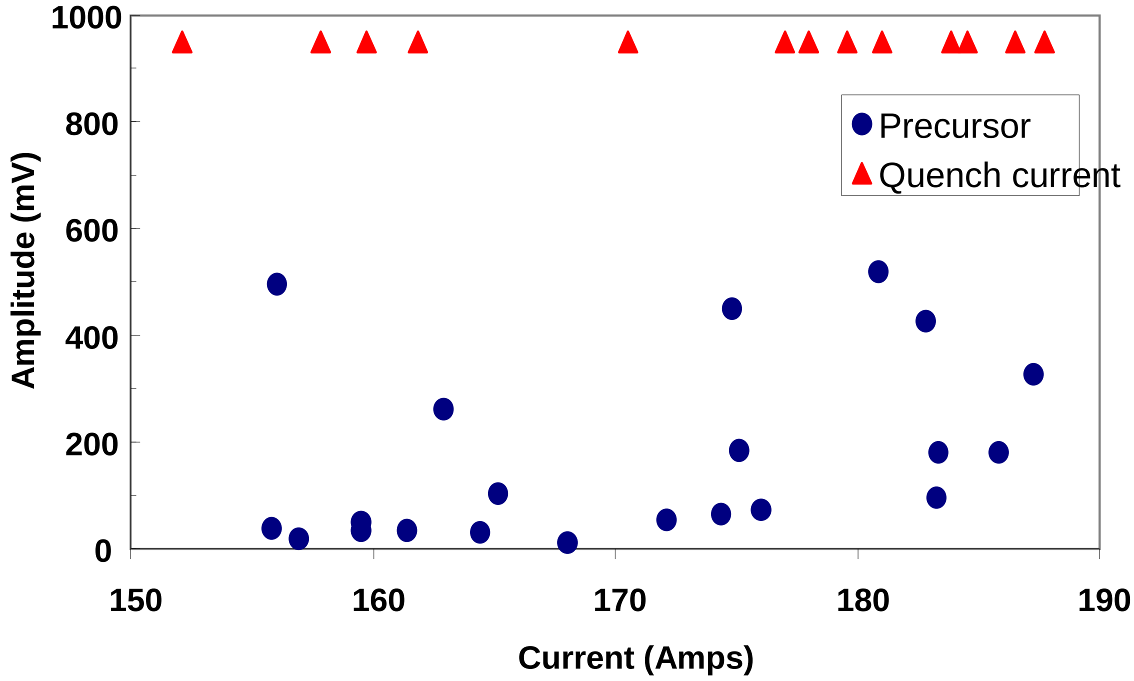
- **External coils may pick up coil movements**
  - **Being considered**

FC 2 STATUS

- **FC #2 delivered to R9 on 4 October**
- **Swapped with FC #1 and pumped down**
- **Started cooldown 4 November (i.e. two days ago)**
- **Anticipate starting to train at end of November**
  - **Initially solenoid mode**
- **Anticipate faster turnaround**
  - **Cryocoolers have proper insulation between Stages 1 & 2**
  - **But have to co-exist in R9 with SS #2 and Tracker**
- **The fate of FC #1 will depend on experience with FC #2**
  - ***Please don't advertise that it will be returned to manufacturer – it may not be – or company's name***
    - ***Commercial & legally sensitive issues***

THE END

No obvious correlation between positions of precursor and quench currents



Number of precursors may increase with quench current