



# MQXFAP2 TEST STATUS UPDATE

Joseph Muratore, M. Anerella, P. Joshi, A. Marone  
16-Oct-2018

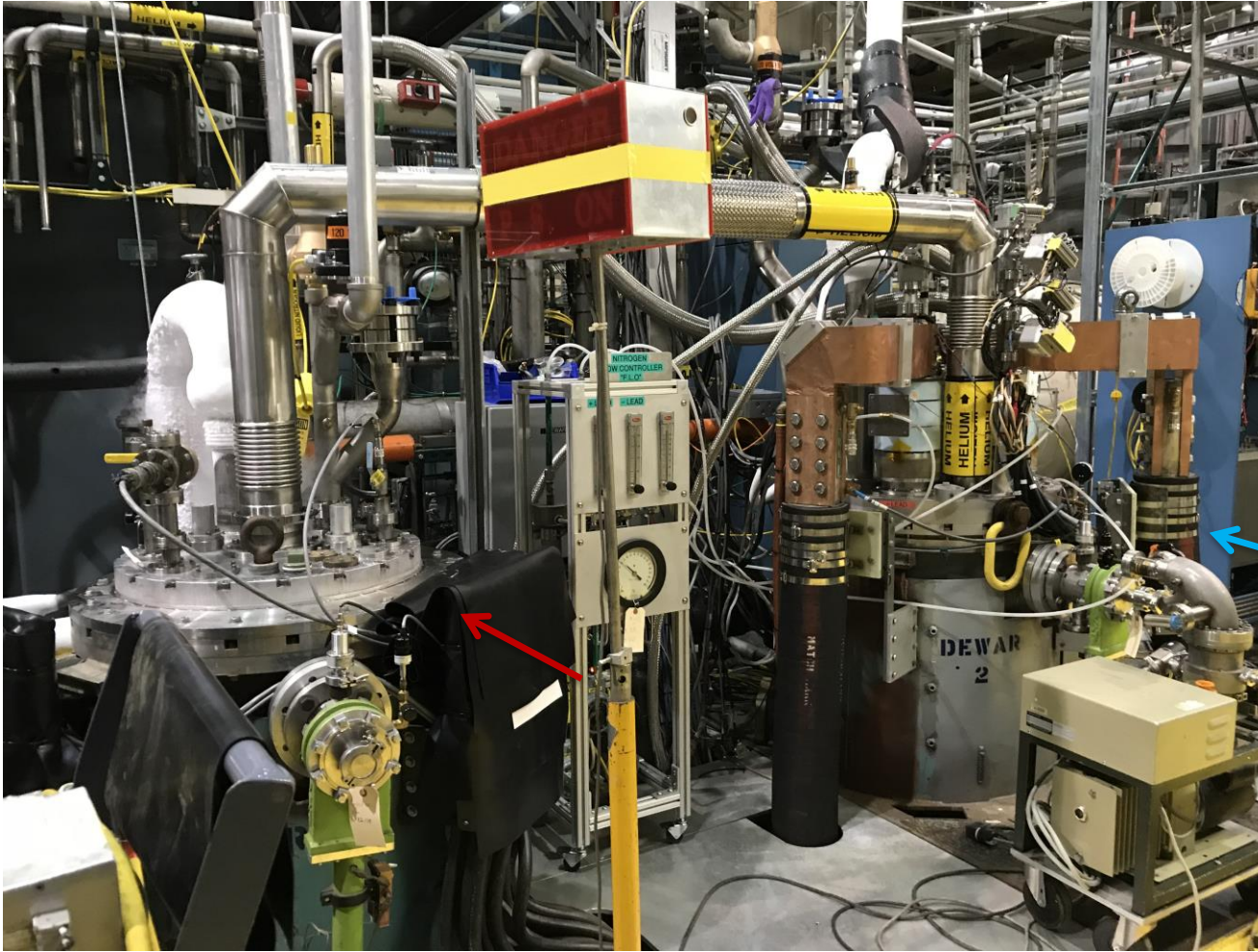


8<sup>th</sup> HL-LHC Collaboration Meeting CERN Oct 2018

# OUTLINE

1. Present status of MQXFAP2 test at 1.9 K.
2. MQXFAP2 quench performance so far.
3. Quench precursor spikes.
4. Flux jump spikes.
5. Test facility modifications implemented to mitigate He losses due to high fast pressure increases.

# STATUS



Vertical Test Facility at BNL. The picture shows the test stand with MQXFPM2 being tested. Long arrow points to **Vertical Test Cryostat 2 (1.9K and 24kA)**. Short arrow points to **Test Cryostat 3**, which is being used as cold buffer tank for the He return during quench tests.

# STATUS

1. Room temperature and cold electrical checkouts were good.
2. High voltage withstand tests (hipots) at room temperature – 1.66 kV magnet coils and heaters to ground.
3. High voltage withstand tests (hipots) at cold - coils to ground 1.1 kV, heaters to coil and to ground 2.3kV.
4. MQXFAP2 is cold and testing is underway – presently at 4.5K and is being cooled to 1.9 for test this afternoon.
5. As of Mon 15-Oct, 10 quench tests have been done.
6. Quenches have occurred in all four coils, all in inner layer pole turns.

# STATUS

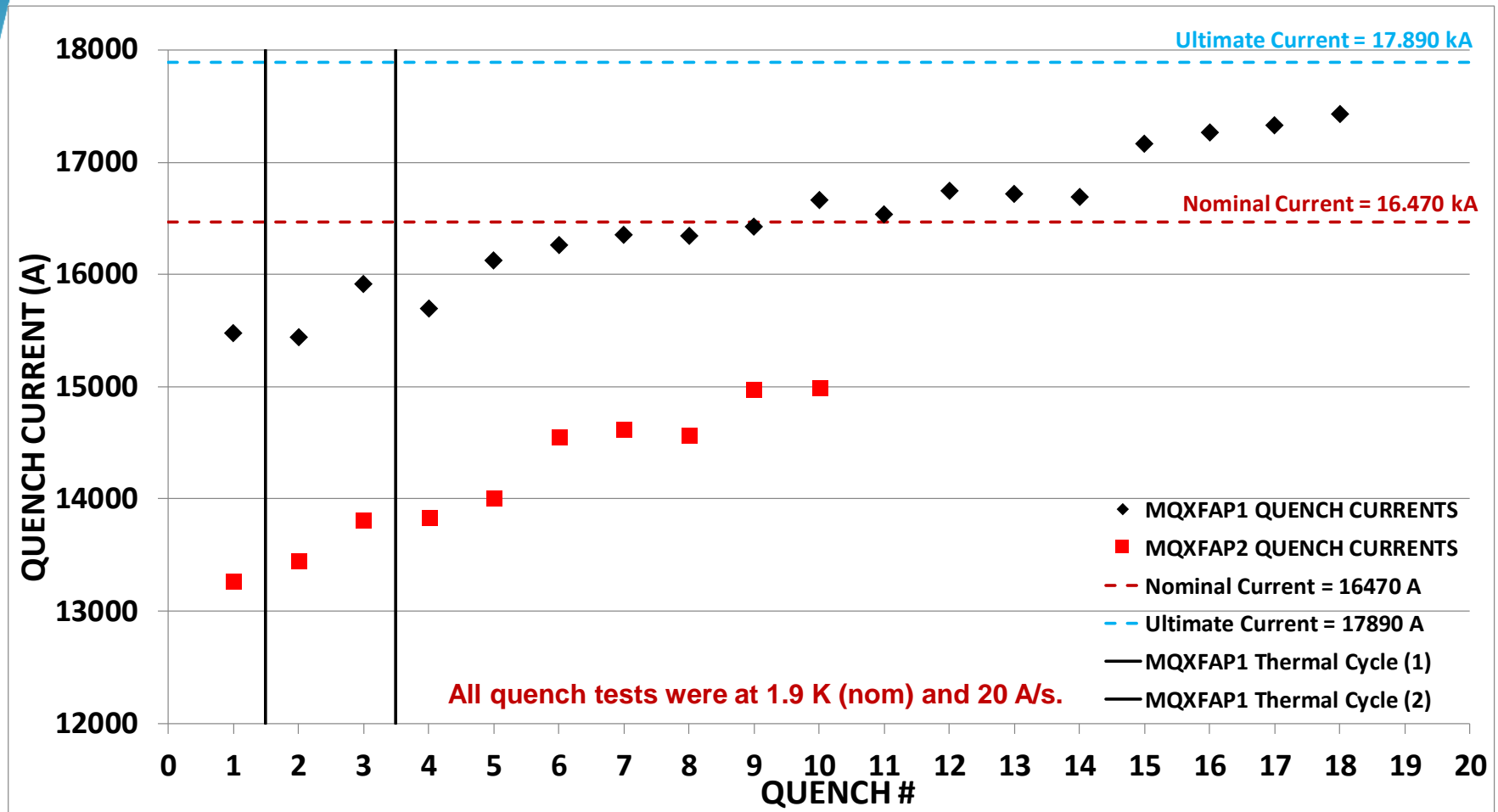
7. Numerous pole turn taps have opened, so determining locations on the pole turn with voltage taps is problematic.
8. However, quench antenna analysis (by M. Marchevsky) has shown that most quenches have originated in or near the nonlead end section.
9. The new magnetic field measurement system has been commissioned successfully. Measurements have been performed at room temperature and at various temperatures during cooldown and the results are being analyzed.
10. Spike detection measurements are being done.
11. Strain gauge (shell, coil, rods) are running continuously

# TEST PARAMETERS

For all quench tests so far:

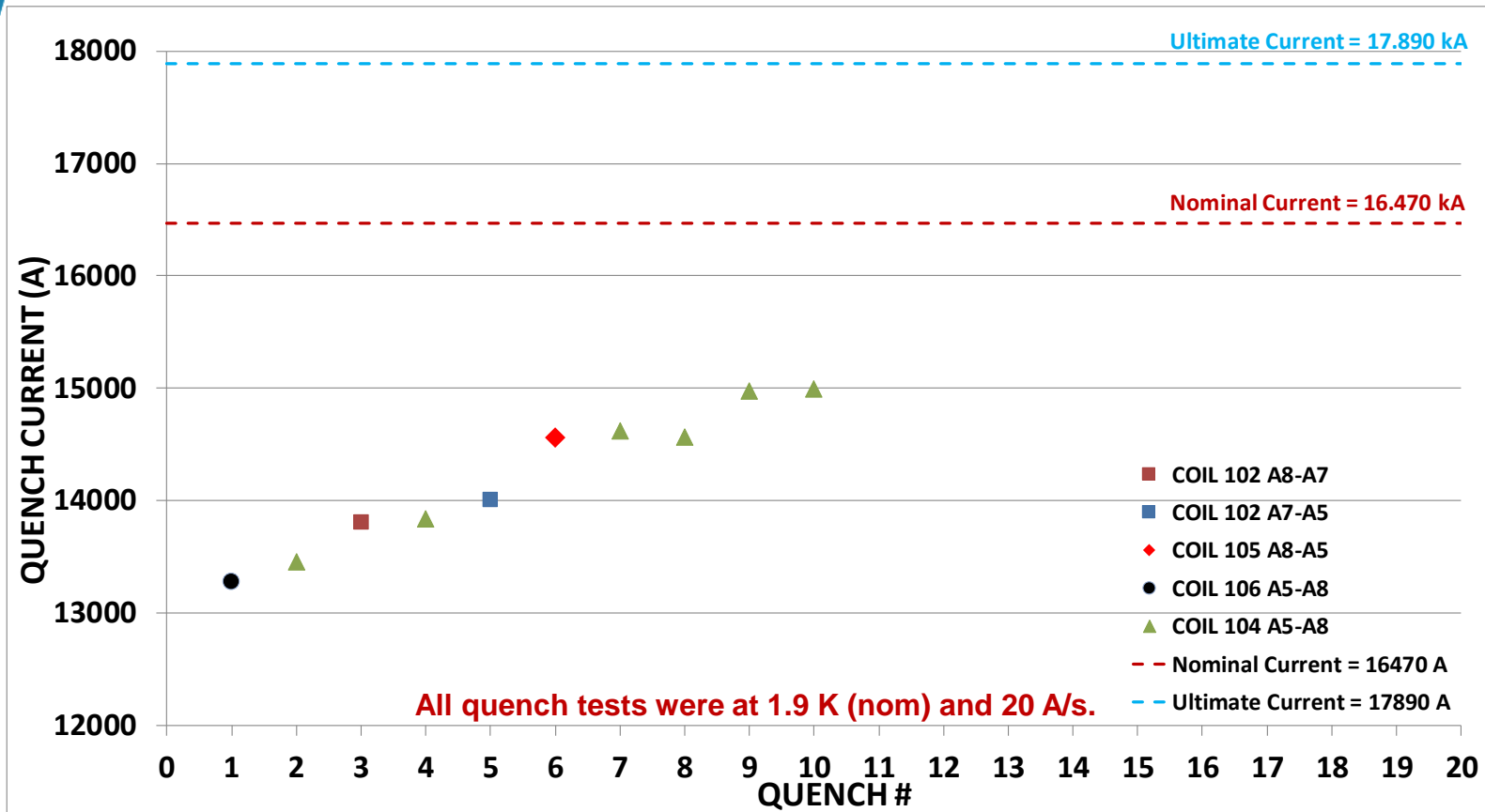
1. Magnet half difference voltage threshold = 150 mV ( $>8000$  A).
2. Validation time = 4 ms ( $>8000$  A).
3. Outer layer protection heaters only; 465 V (nom), 12.4 mF.
4. CLIQ at 500 V and 40 mF.
5. Energy extraction at 37.5 m $\Omega$  with 10 ms delay.

# Test Results – MQXFAP1 / MQXFAP2

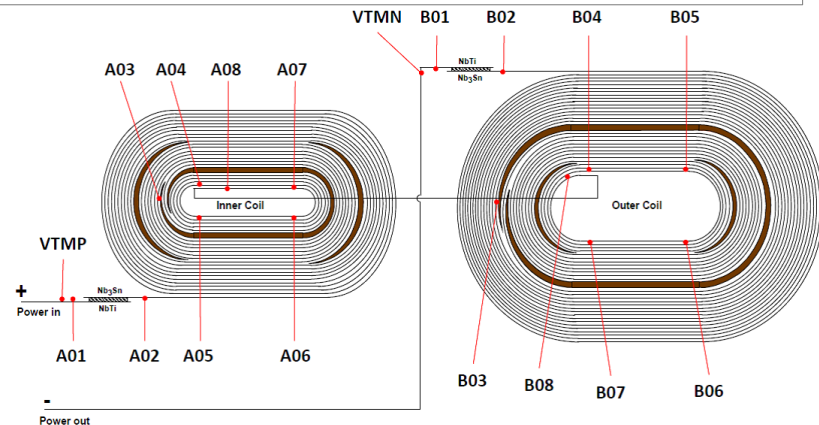




# Test Results – MQXFAP2

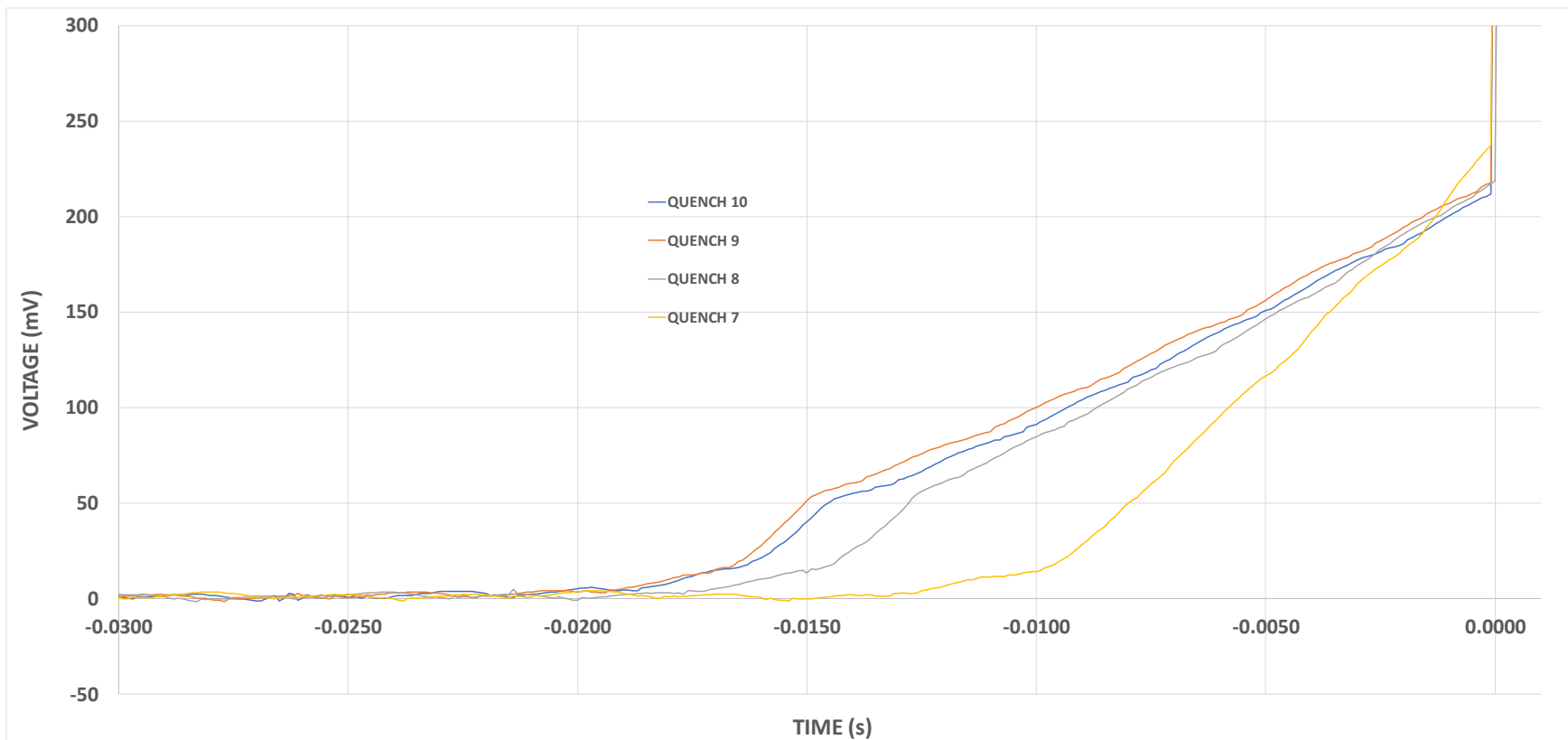


Quench integral values range from 25 – 28 MLts (~170 – ~200 K).  
Threshold for training is 250 K.

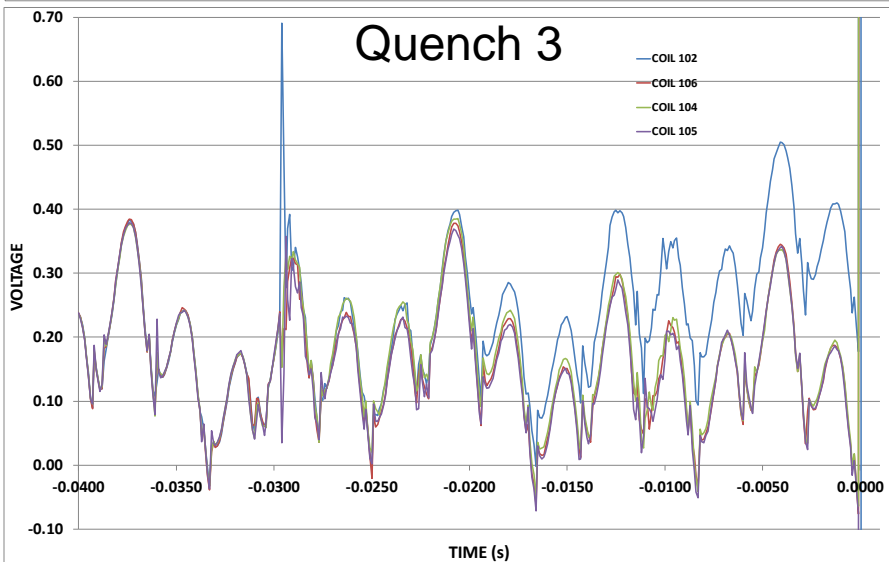
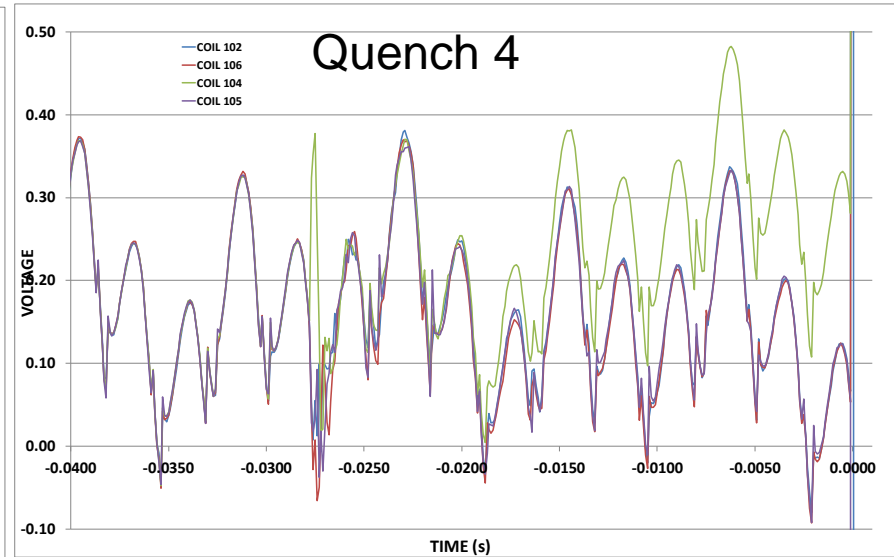
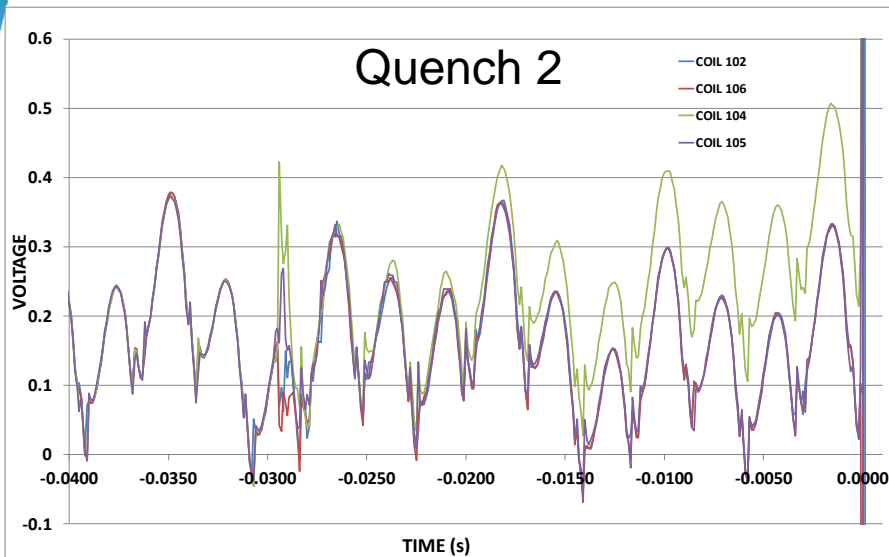




# Quenches 9-10 A5-A8 Voltages



# Test Results – Precursor Spikes



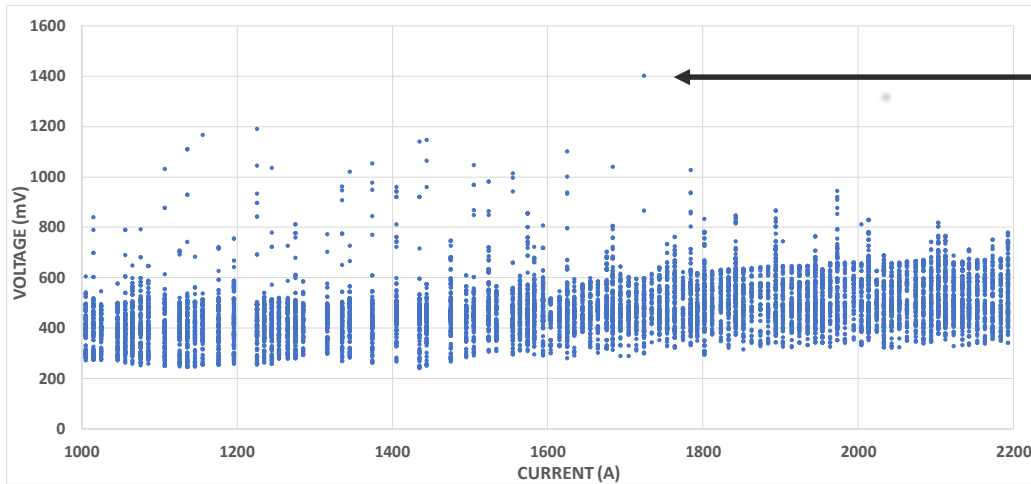
Precursor spikes were observed in Quenches 1-7 and 9, and occur typically 0 – 8 ms before quench start.

# Test Results

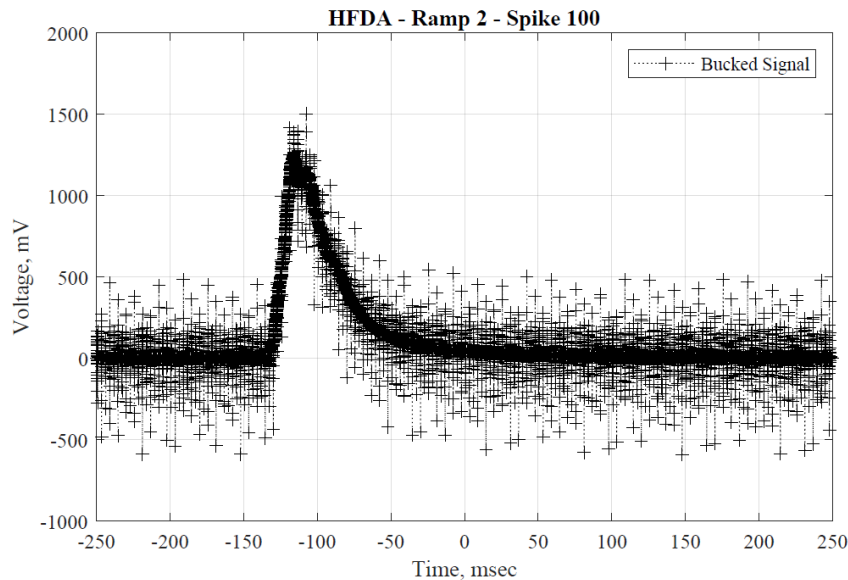
Up to now the following observations can be made:

1. All quenches originated in the inner layer pole turn, as determined by the voltage taps, and in or near the nonlead end section, as determined by the quench antenna (except not known for Quenches 1 and 2, for which the quench antenna had not yet been installed).
2. For all coils, the taps A6 and A7, which bracket the nonlead end section in the inner layer pole turn, have opened up.
3. For all quenches except #8 and #10, a precursor spike is observed 0-8 ms prior to the quench start.

# Test Results - Flux Jump Spikes



1400 mV spike at 1724 A  
during a 6000 A ramp



Plot by M. Baldini

# Test Results - Flux Jump Spikes

**Pulse Delays 1-8 (ms)**

10.0

**WARNING CHECK THRESHOLDS!!**

DCCT Cal Const 3000.0

Coil Thresholds at current levels

Mag Cur Range 1

-20 Coil Diff Threshold 1 600 Valid time 1 (ms) 4.0

Mag Cur Range 2

400 Coil Diff Threshold 2 1500 Valid time 2 (ms) 4.0

Mag Cur Range 3

1500 Coil Diff Threshold 3 1800 Valid time 3 (ms) 8.0

Mag Cur Range 4

3000 Coil Diff Threshold 4 1500 Valid time 4 (ms) 4.0

Mag Cur Range 5

4000 Coil Diff Threshold 5 1500 Valid time 5 (ms) 4.0

Mag Cur Range 6

5000 Coil Diff Threshold 6 800 Valid time 6 (ms) 4.0

CLIQ Delay (ms)

0.0

Solenoid Delays (ms)

0.0

Mag Cur Range 7

6000 Coil Diff Threshold 7 500 Valid time 7 (ms) 6.0

Mag Cur Range 8

8000 Coil Diff Threshold 8 150 Valid time 8 (ms) 4.0

Mag Cur Range 9

22000

Q Dect Enable Disable

Q Info Lock Enable Disable

Coil Half Threshold (mV) 600

Total Coil Threshold (mV) 1900

Noise Pk Count Successive 0

Noise Pk Count Isolated 0

Q Info Lock Action

Coil half diff -0.300598

Tot coil V-Ldi/dt -798.808

Sup Cond Section Threshold(mV) 50

Validation time (ms) 4.0

1 Half Coil Inductance 0.0200005

2 Half Coil Inductance 0.0200005

1 Half Coil di/dt -0.025177

2 Half Coil di/dt 0.043869

Mag Current

0.000745773

0.00323105

0.00363922

SC1-C02 B01

C04-A01 SC4

1/2(+)-1/2(-)

Quench-Man Trig

Reset Trig

**QUENCH**

Latched L7

Latched L8

L 3 SC1-Q1 B01

L 14 1/2(+)-1/2(-)

L 7 Coil Half Diff

L 8 Total Coil

L 11 Q3-A01 SC4

Sec1 V @ Q 165.035

Sec2 V @ Q 380.456

Tot Coil - Ldi/dtV @ Q 12.9745

Mag Current @ Q 14973.3

Coil Half Threshold @ 150

Noise Pk Count Successive @ 0

Validation time @ Q (ms) 4.0

Inner and outer Coil Inductance for various current ranges

Mag Cur Range 10

-20 Inner Coil Inductance 2 0.02 Outer Coil Inductance 2 0.02

Mag Cur Range 11

2000 Inner Coil Inductance 3 0.019 Outer Coil Inductance 3 0.019

Mag Cur Range 12

6000 Inner Coil Inductance 4 0.0165 Outer Coil Inductance 4 0.0165

Mag Cur Range 13

22000

CLIQ

OFF

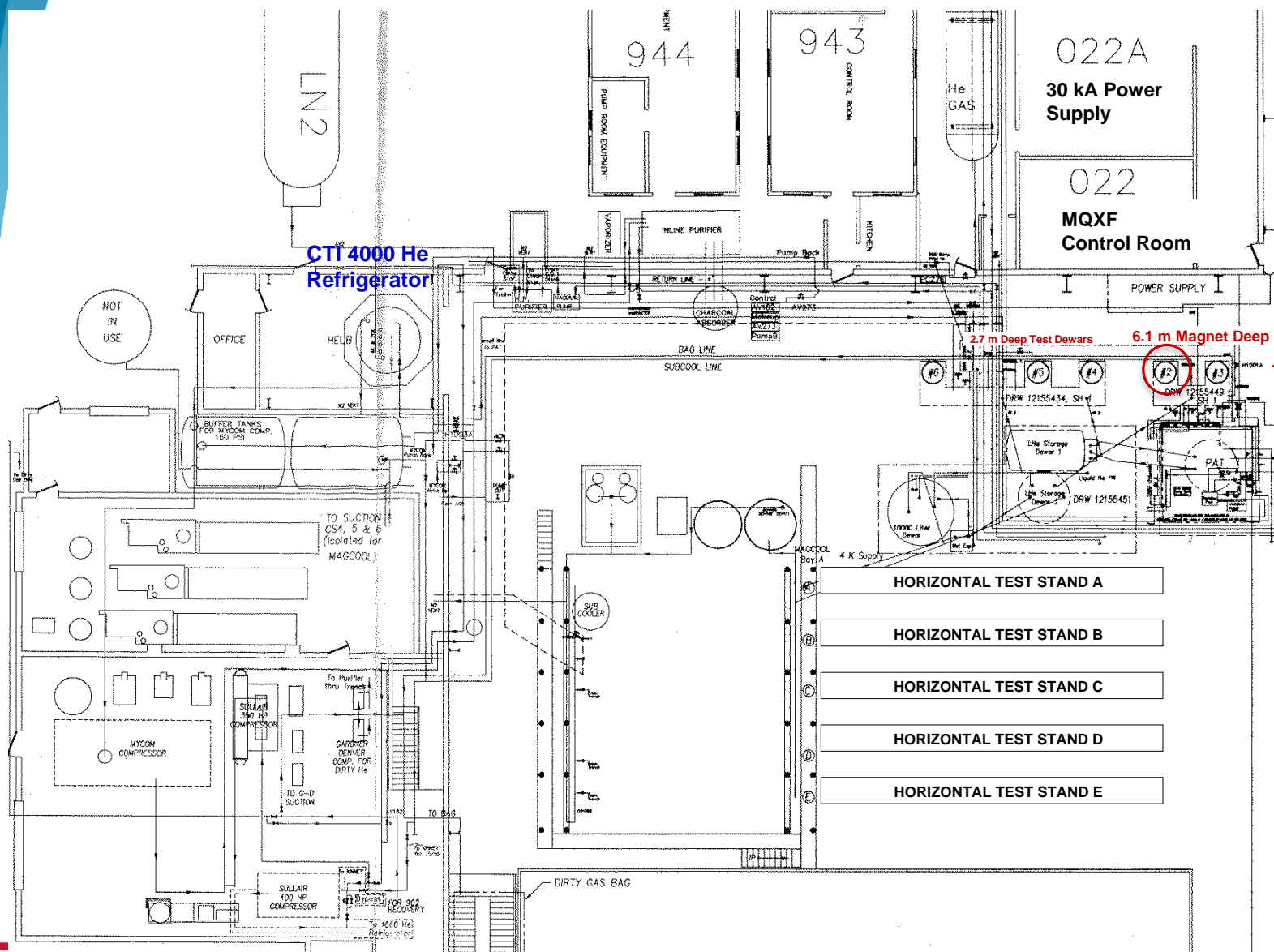
stop

Voltage thresholds during ramps have been lowered as a result of the spike data. Also validation times have been varied as well.

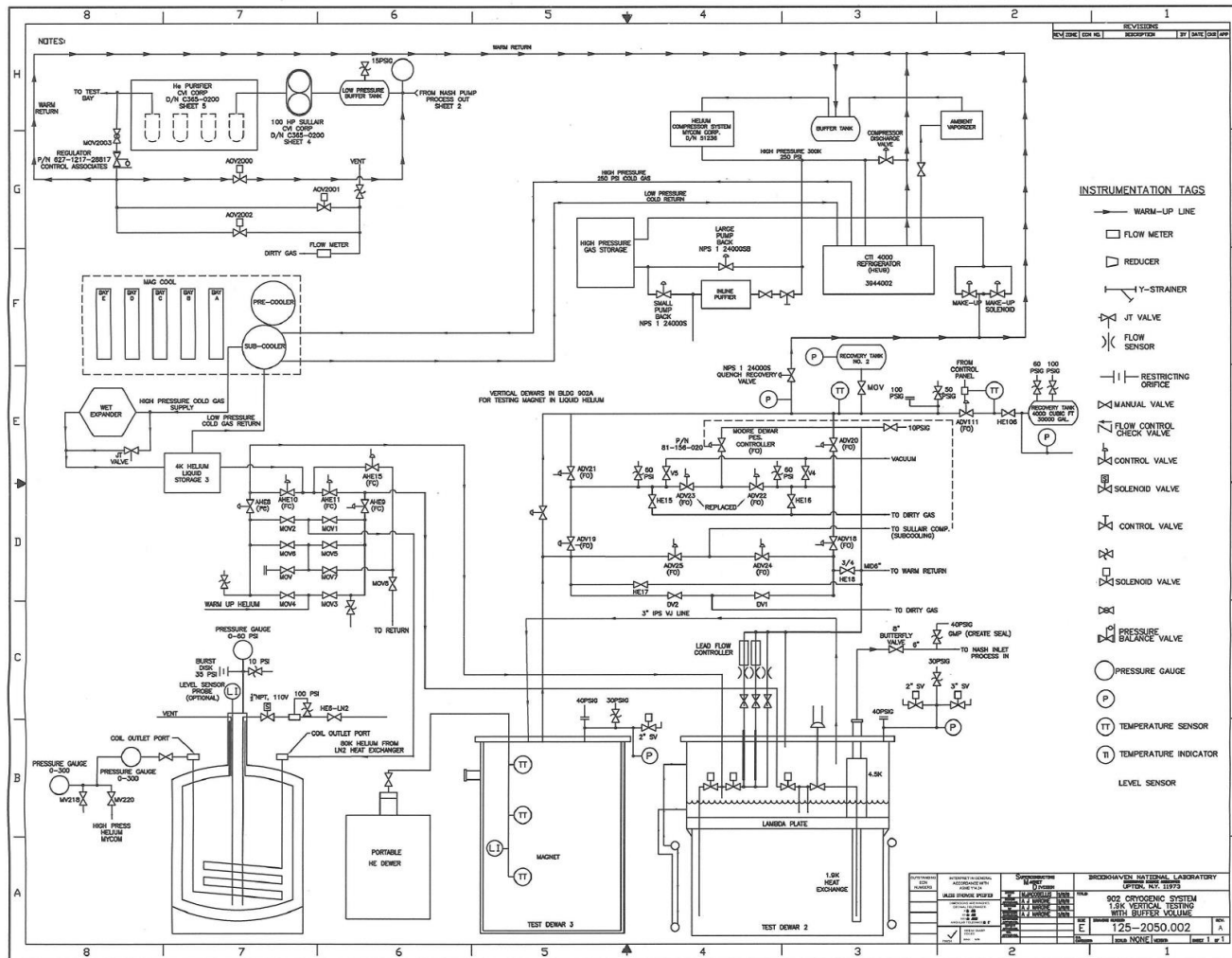
# Test Facility Infrastructure

Nash "high capacity" vacuum Pump (1.9K)

**Building 902  
Test Facility  
Floor Plan  
and  
Overview**



# Cryogenic System Upgrades

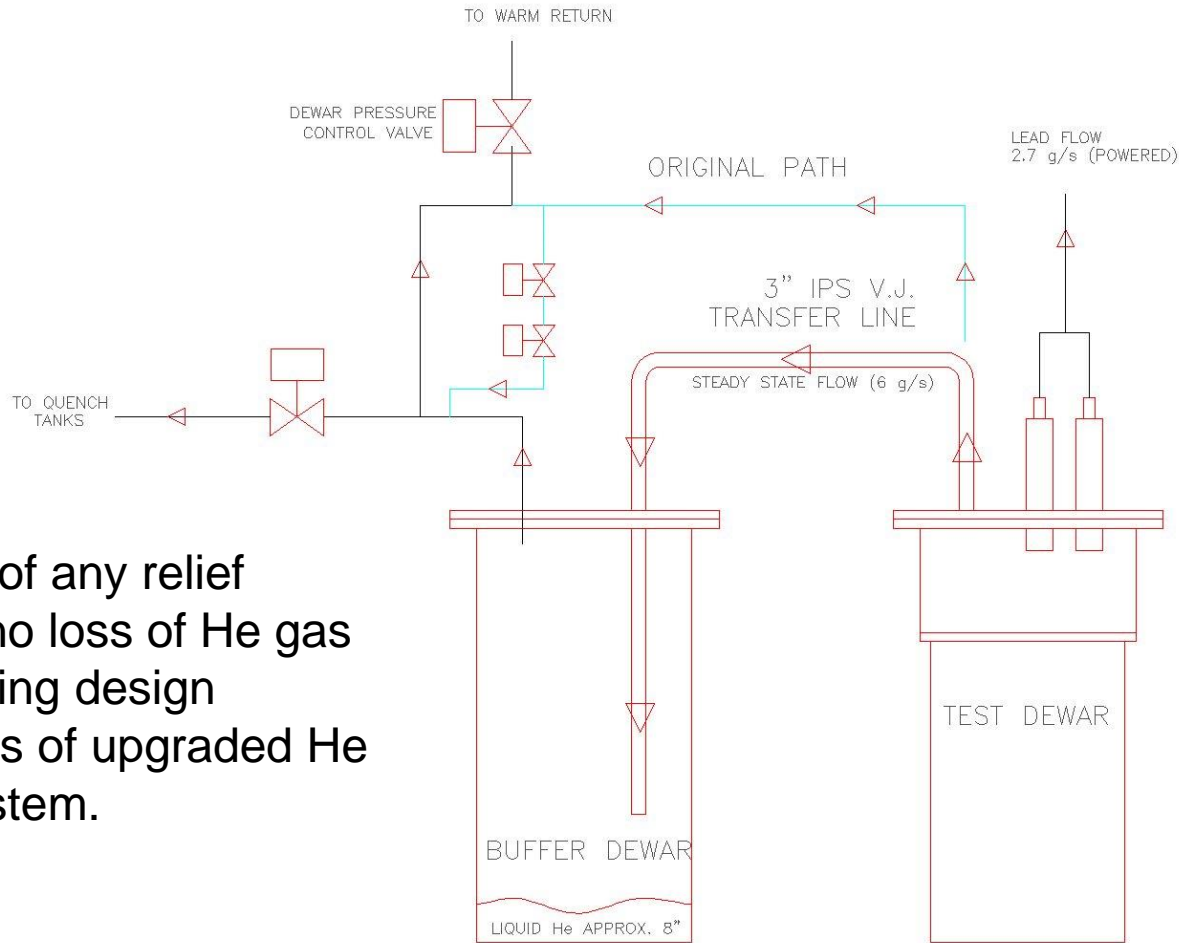


Upgrades to the He gas recovery system after quench were made to minimize or prevent the loss of He gas after a quench at the high energies of the MQXFA magnets and resulting rapid and high gas pressure increase.



# Cryogenic System Upgrades

## Helium Flow Schematic Using 2<sup>nd</sup> Test Cryostat as Cold Buffer



No opening of any relief valves and no loss of He gas so far, verifying design computations of upgraded He recovery system.

This slide courtesy of A. Marone

# SUMMARY

1. So far, 10 training quenches 1500 – 2000 A lower than MQXFAP1.
2. All four coils have quenched, with Coil 104 being the most frequent and in the last 4.
3. Quench antenna and voltage taps show that all quenches are located in the inner layer pole turn and most probably near or in the nonlead end section.
4. MLTs values have been within safe threshold.
5. Power supply ground currents have been nominal with no anomalies.
6. So far, relief valves have not opened after quench, resulting in no loss of He gas, verifying the design of the upgraded He recovery system.
7. Measurement of flux jump spikes have been successful and have allowed the lowering of voltage thresholds during ramps.
8. Magnetic field measurement system has been commissioned and operated successfully.
9. MQXFAP2 cold testing is still underway at present.

# THANK YOU FOR YOUR ATTENTION



# EXTRA SLIDES

# Scope and Deliverables

## MQXFA NOMINAL PARAMETERS AND DESIGN

Coil inner aperture :

Coil magnetic length:

Coil actual length:

Yoke length

Total length with end plates

**Operational temperature**

**LHC nominal operating current (1.9 K)**

**LHC ultimate operating current (1.9 K)**

Maximum current (300 K)

Conductor limit at 1.9 K:

Conductor limit at 4.5 K:

Peak field in the coil at  $I_{nom}$  (1.9 K):

Peak field in the coil at  $I_{ult}$  (1.9 K):

Field Gradient at  $I_{nom}$  (1.9 K):

Field Gradient at  $I_{ult}$  (1.9 K):

Magnet resistance at room temperature:

Magnet inductance (at 1.9 and 1 kA) :

Magnet inductance (at 1.9 and  $I_{nom}=16.5$  kA) :

Operating stored energy (at  $B_{nom}$ ,  $I_{nom}$ ):

**Ultimate stored energy (at  $B_{ult}$ ,  $I_{ult}$ )**

Maximum allowed temperature at quench:

Maximum allowed voltage across magnet

Dump resistor (energy extraction) options

$D = 150$  mm

$L = 4.2$  m

$L = 4.523$  m

$L = 4.5629$  m

$L = 5$  m (nom)

**$T = 1.9$  K**

**$I_{nom} = 16.470$  kA**

**$I_{ult} = 17.890$  kA**

$I_{300} = 15$  A

$I_{ss} = 21.000$  kA

$I_{ss} = 19.017$  kA

$B_{nom} = 11.4$  T

$B_{ult} = 12.3$  T

$G_{nom} = 132.6$  T/m

$G_{ult} = 143.2$  T/m

$R = 2.37$   $\Omega$

$L = 43.0$  mH

$L = 34.4$  mH

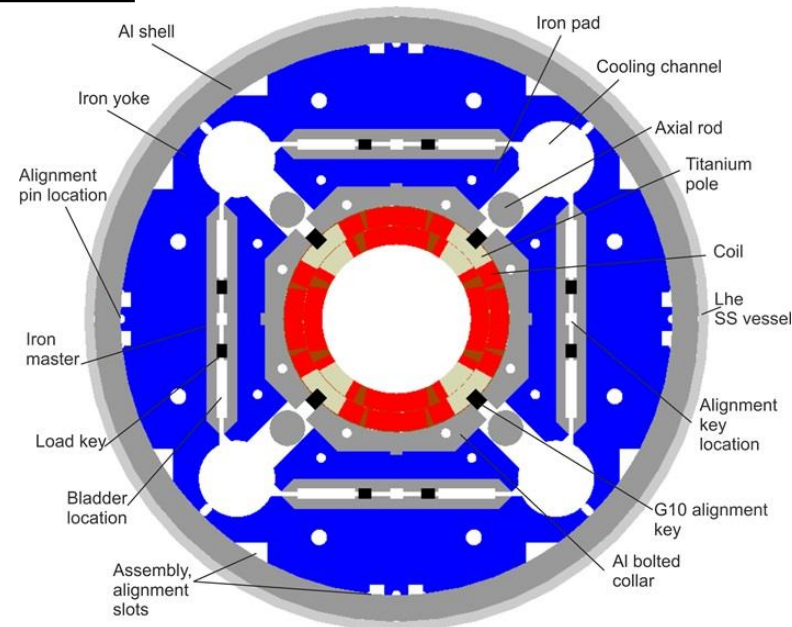
$E_{max} = 4.67$  MJ assuming  $L=34.4$  mH

**$E_{max2} = 5.50$  MJ assuming  $L=34.4$  mH and  $I_{ult}=18$  kA**

$T_{max} = 250$ K (training); 350K (protection studies)

$V_{max} = 1000$  V (500 V to ground) with 50 m $\Omega$  EE

$R_D = 30, 37.5, 50, 75, 150$  m $\Omega$



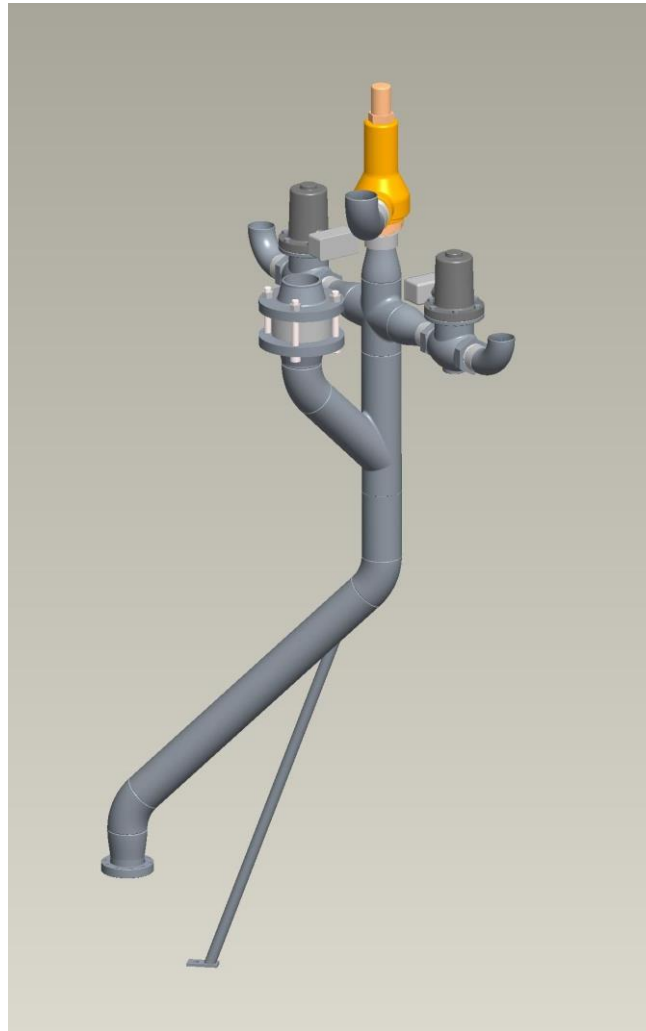
The four coils are connected in the following order from the positive lead (Tap WC+) to the negative lead (Tap WC-): 102  $\rightarrow$  106  $\rightarrow$  104  $\rightarrow$  105.

# Cryogenic System Upgrades

## Dewar Relief Systems

### Test Dewar Relief Stack (Unchanged)

- Cash Relief Valve (1380g/s @ 30 PSIG)
- 3" Burst Disk (40 PSIG)
- 2" Solenoid Valve (1400 g/s @ 30 PSIG)
- 3" Solenoid Valve (2700 g/s @ 30 PSIG)

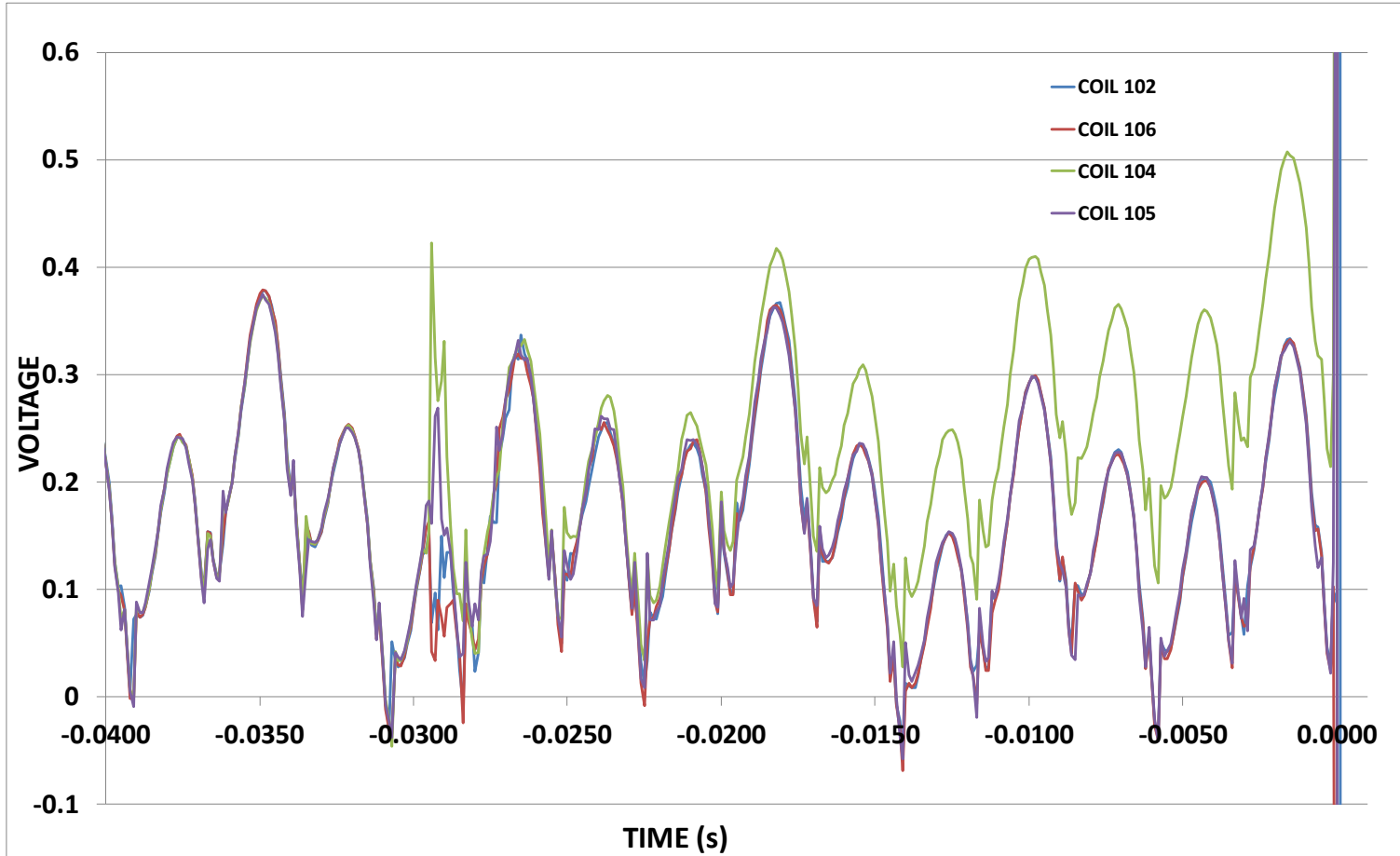


Buffer Dewar relief stack is identical except that it does not have the 3" solenoid valve.

- Solenoid valve activation time is approx. 1 s after signal.
- Cash relief valve full open @ 33 PSIG.

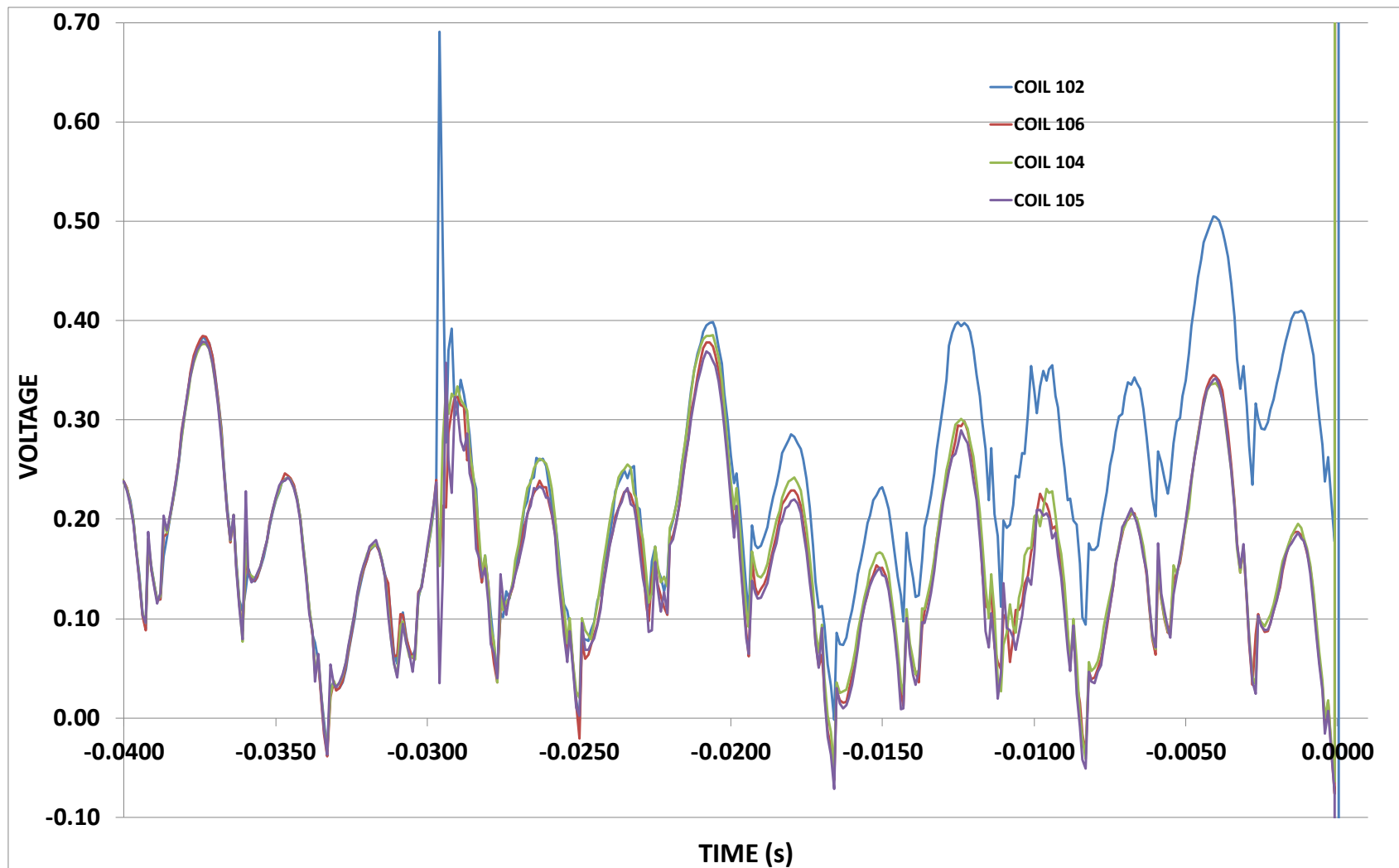
This slide courtesy of A. Marone

# Test Results – Precursor Spikes





# Test Results – Precursor Spikes



# Test Results – Precursor Spikes

