Cryomodule Results for LCLS-II

Genfa Wu

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ACLW2018, Fukuoka, Japan

Outline

- Introduction
- Thermal Management and Challenges
- Reducing Field Trapping during Superconducting Transitions.
  - Fast Cool Down to Expel any Remaining Magnetic Field
    - Thermal Currents
    - Cool Down Rate
  - Reduce thermoelectric currents
- Field Emission is still an issue

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LCLS-II Q0 Specification

Cryomodule Q0 ≥ 2.7e10 @ 16 MV/m

Average Magnetic Field < 2.5 mG (Amplitude)

Magnetic Field Sources:

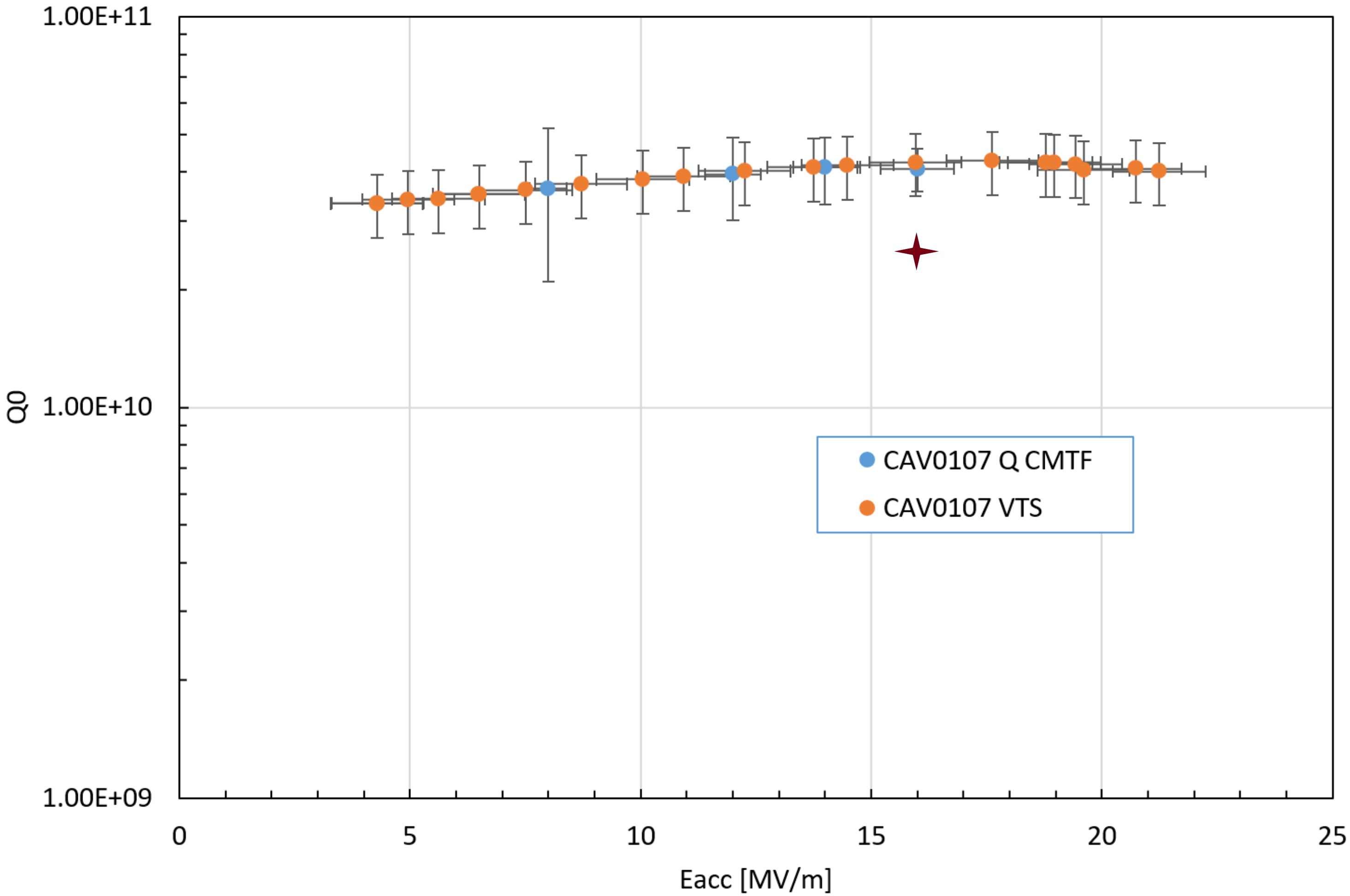
- Ambient field
- Thermoelectric current
  - Dynamic thermoelectric current during fast cool down
  - Static thermoelectric current regardless of cool down rate

Q0 Measurement of LCLS-II Cryomodules at FNAL

Cryomodule	Q0 with Slow Cool Down (<5g/s))	Q0 with Fast Cool Down (30-80g/s)	Material
F1.3-01	2.1E+10	3.0E+10	WC 800C
F1.3-02	2.1E+10		TD 800C
F1.3-03	2.6E+10	3.5E+10	TD 900C
F1.3-04	2.9E+10	3.2E+10	TD 900C
F1.3-05	2.5E+10	3.1E+10	TD 900C
F1.3-06		2.3E+10	Mostly NX 900C
F1.3-07	2.4E+10	2.7E+10	Mostly NX 900C
F1.3-09	2.9E+10	3.4e10	Mostly TD 900C
J1.3-01	2.5E+10	2.9E+10	WC 800C
Average	2.5E+10	3.0E+10	

New Record Q0 for 1.3GHz CW Cryomodule is now 3.5e10 (±11%)

Q0 Measurement of LCLS-II Cryomodules at FNAL



Single cavity Q0 in a cryomodule has achieved 4.1e10 (±11%)

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Magnetic Field Management

Good Flux Expellable Material

- Ambient Field →
  - Magnetic Shield Design
  - Magnetic Hygiene
  - Active Coil Field Cancellation
- Thermoelectric Currents → Improve thermal profiles

→ Flux Expulsion by Fast Cool Down

Poor Flux Expellable Material

- Ambient Field →
  - Magnetic Shield Design
  - Magnetic Hygiene
  - Active Coil Field Cancellation
- Thermoelectric Currents → Must improve thermal profiles

→ Flux Expulsion by Fast Cool Down

Challenges

- Poor flux expulsion material in some cryomodules
- Poor thermal profile induced ambient thermoelectric current (static thermoelectric current)
- No instrumentation to troubleshoot issues

- Q0 measurement to calculate trapped field

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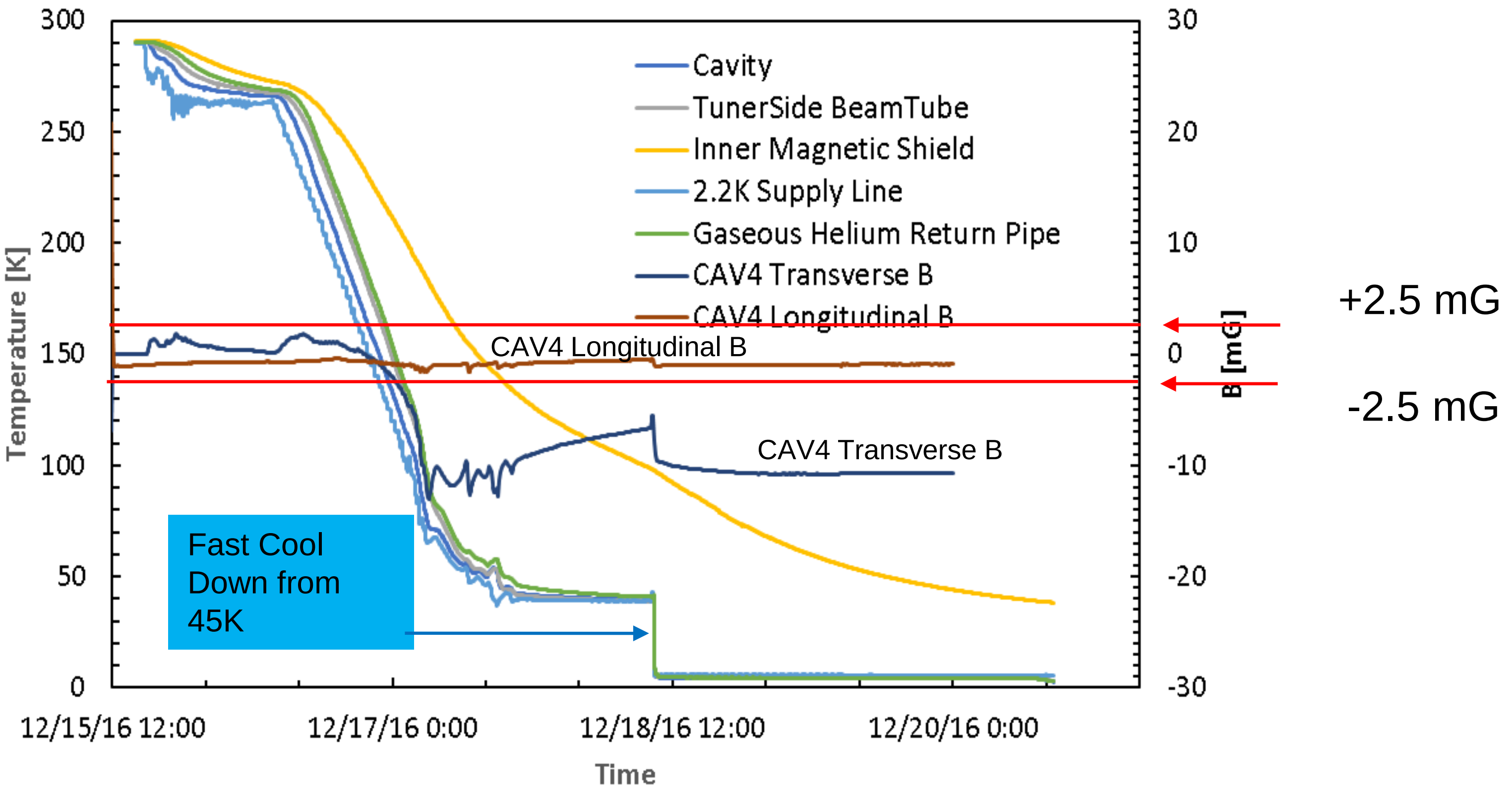
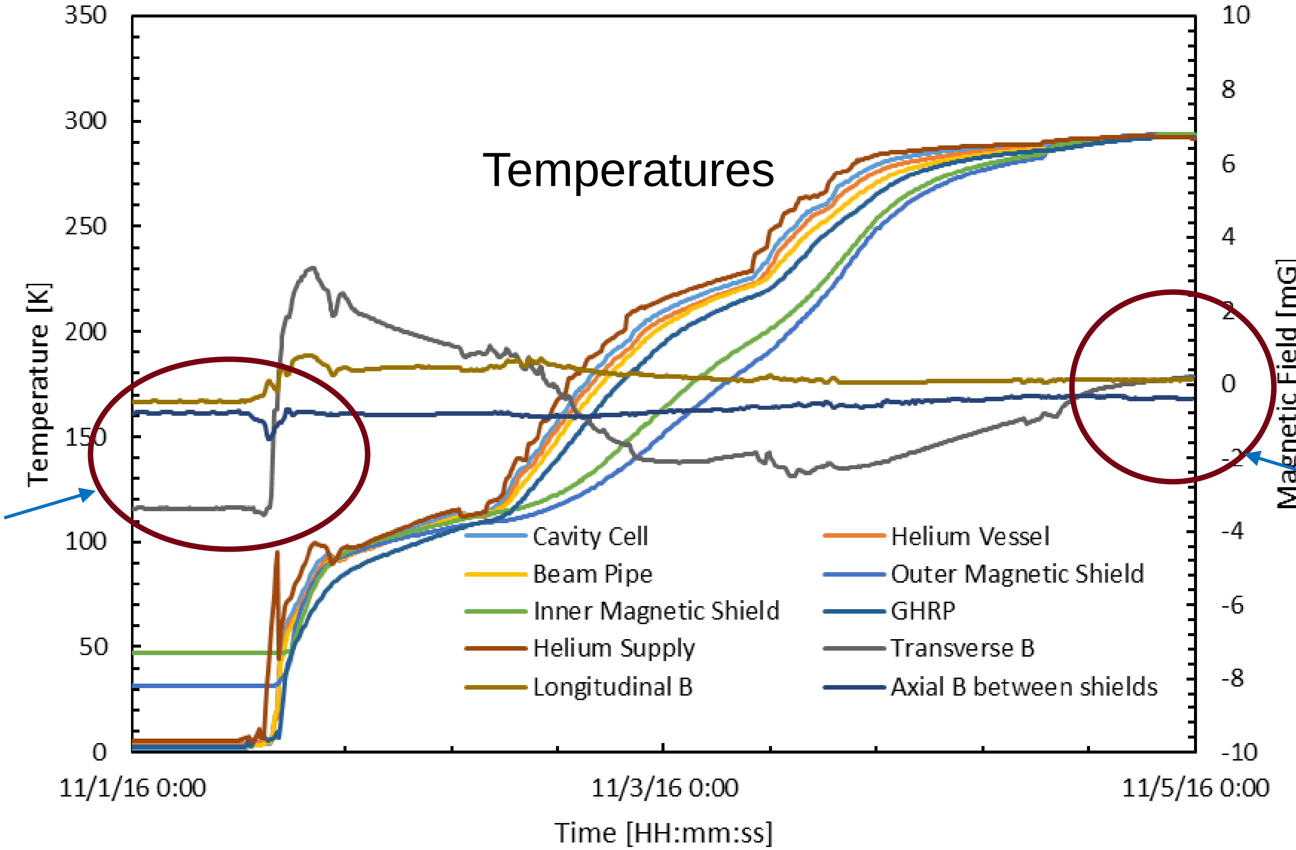
Cryomodule Cool Down – Magnetic Field



Static thermoelectric magnetic field is primarily caused by cryomodule's intrinsic thermal gradients.

Static Magnetic Field Resets at Room Temperature

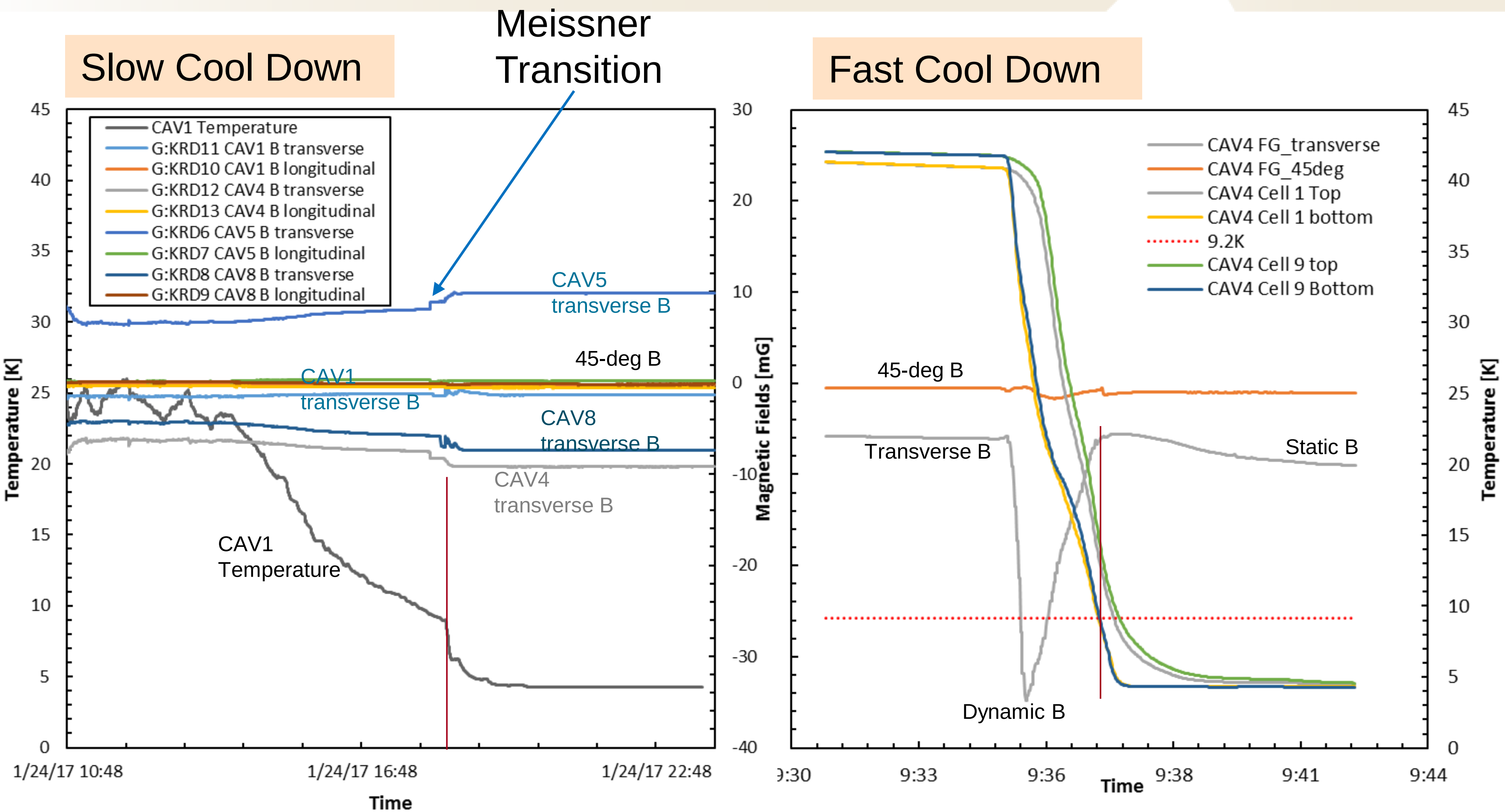
Fluxgate Readings at 2 K



Fluxgate Readings at 300 K

Static thermoelectric magnetic fields were restored to near zero as cryomodule warmed up

Dynamic Thermoelectric Current vs. Static Thermoelectric Current



Dynamic thermoelectric magnetic fields disappear before superconducting transition

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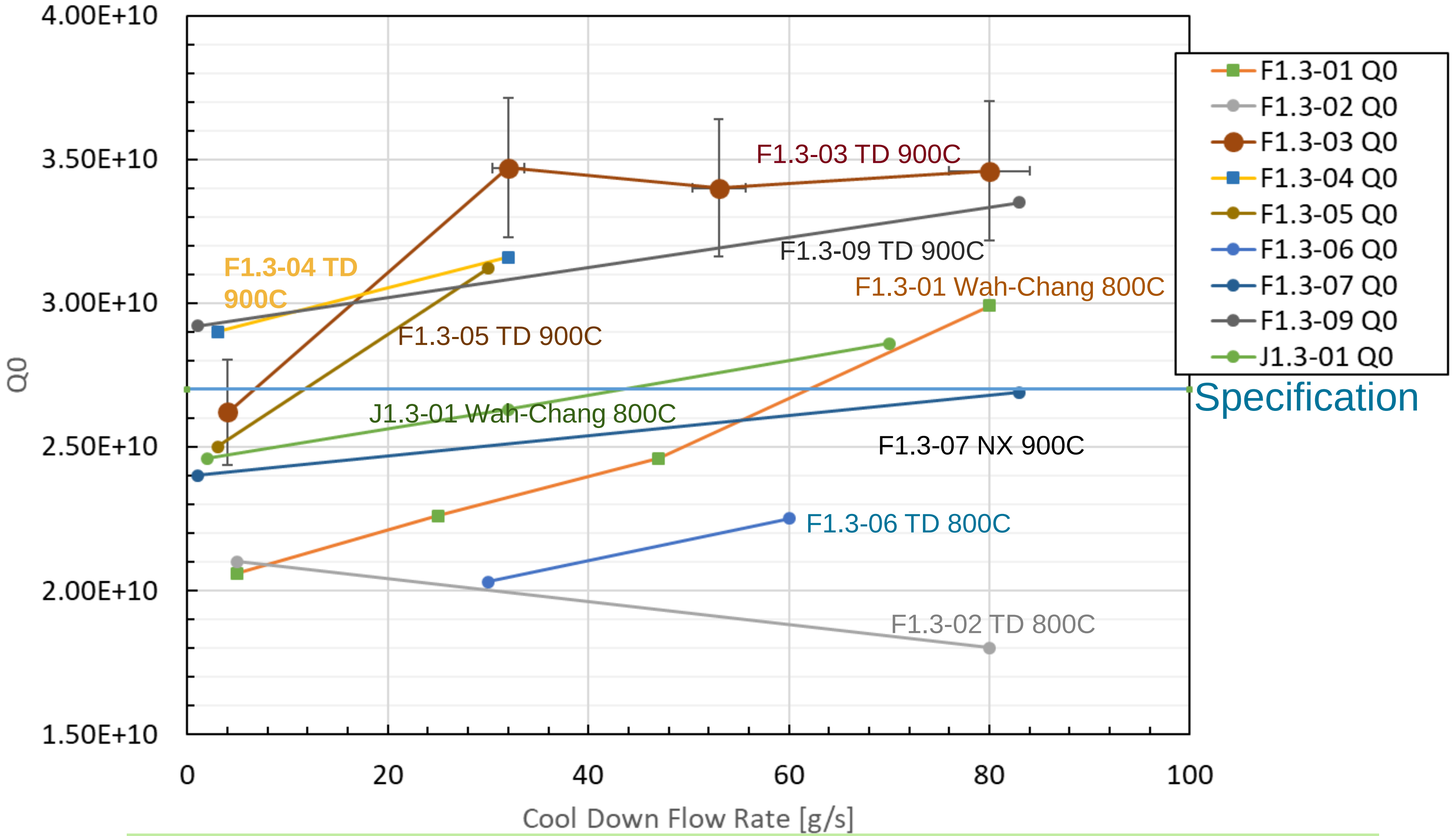
Q0 under Different Cooldown Mass Flow

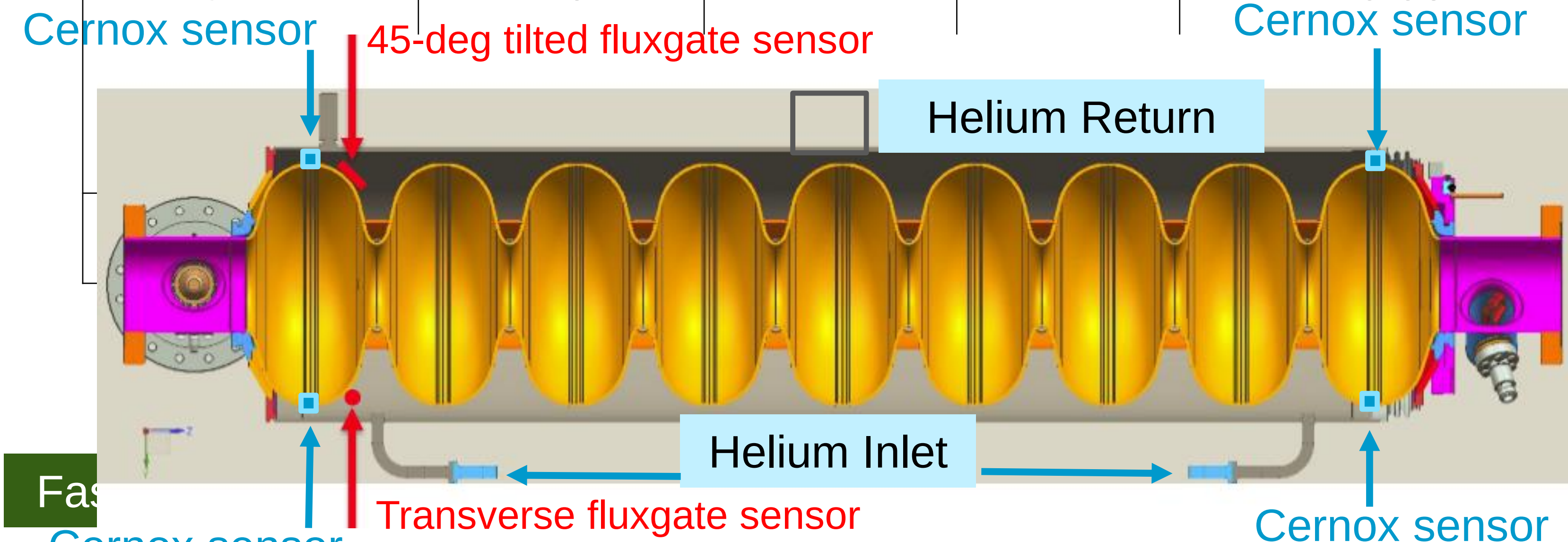


Fast Cool Down is beneficial for expelling magnetic field

Q_0 under Different Cool Down Mass Flow

Temperature difference from top of the cavities and bottom of cavities in pCM

Mass Flow	80 g/s	47 g/s	25 g/s	Slow Cool Down
Cavity	Δ T(K)	Δ T(K)	Δ T(K)	Δ T(K)
CAV1	4.1	3.3	2.6	≤0.08
CAV4	4.9	4.7	4.4	≤0.08



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Fas

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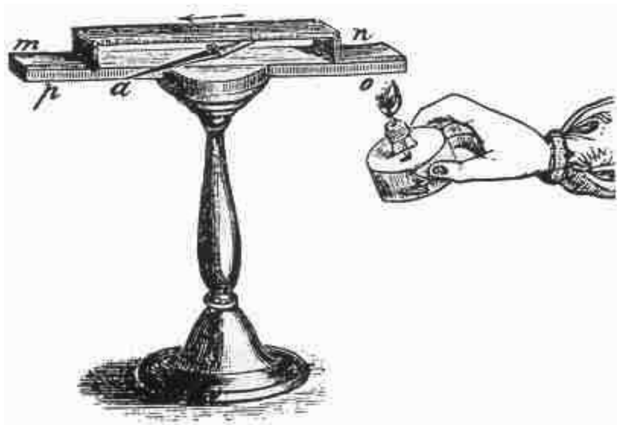
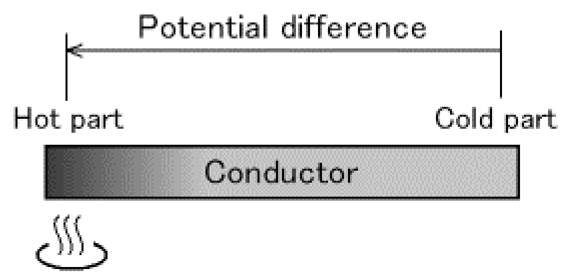
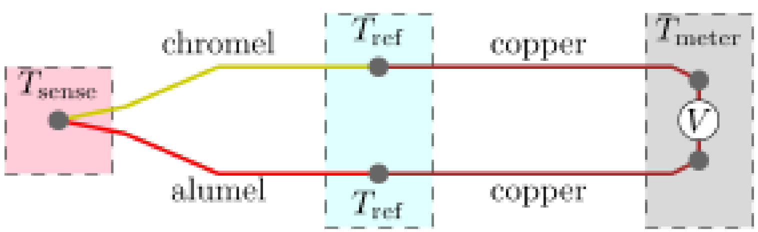
Thermoelectric Currents



Thomas Seebeck 1821

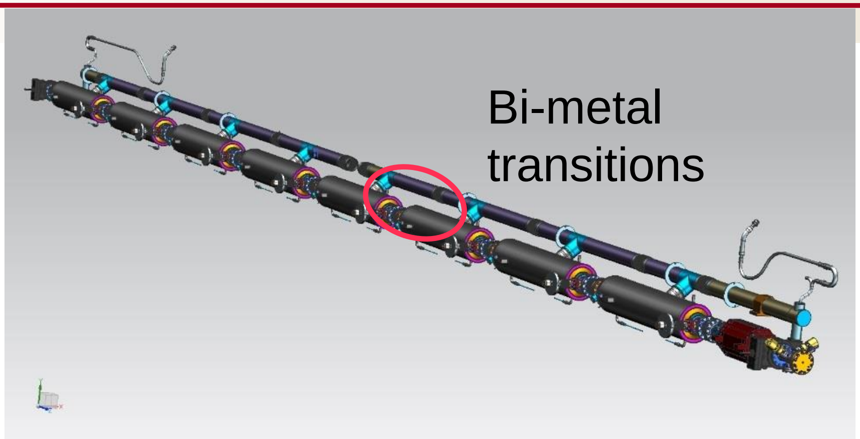


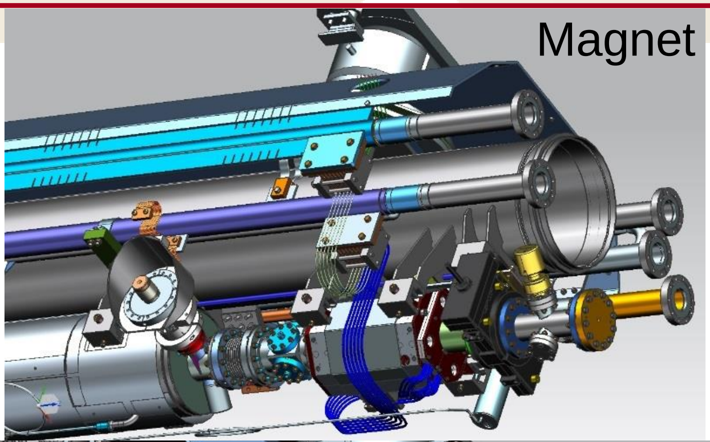
Seebeck coefficient varies from metal to metal

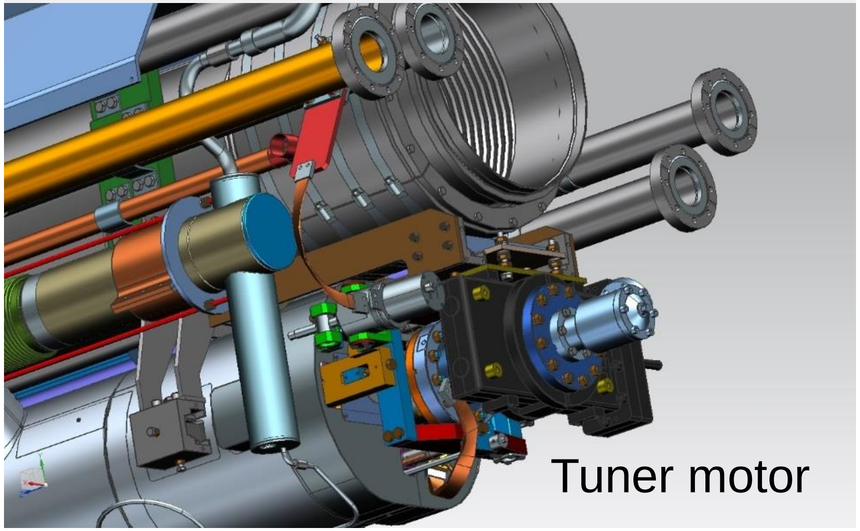


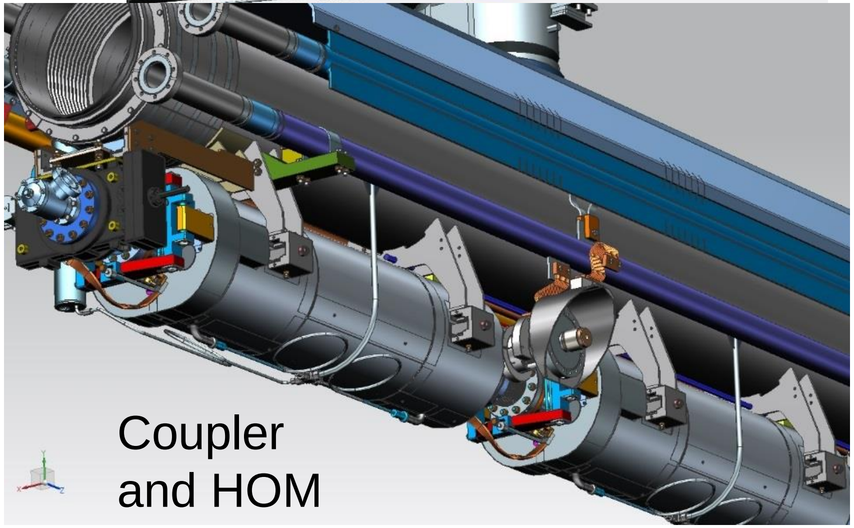
Thermocouple Temperature Measurement

Potential Sources of Thermal Electric Current

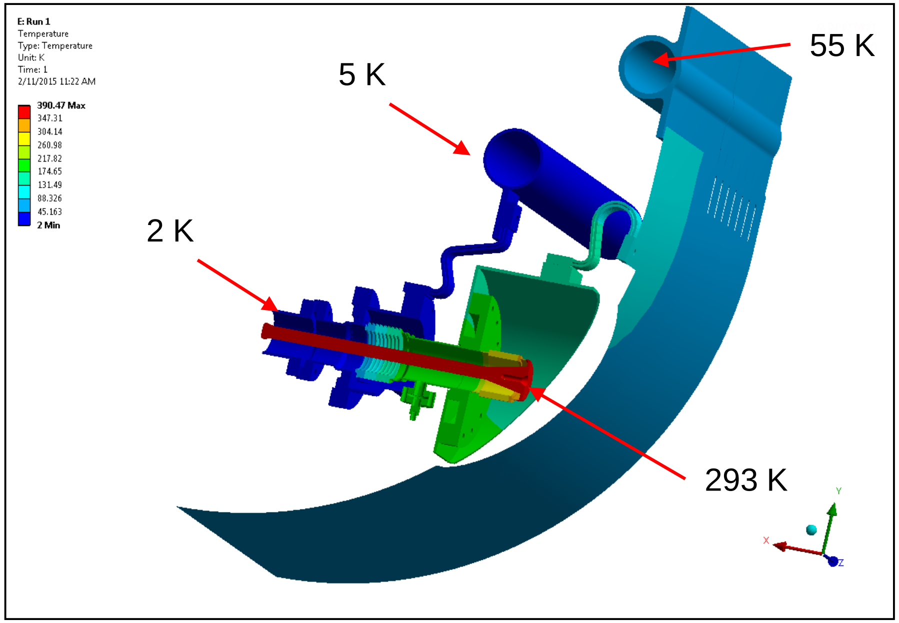


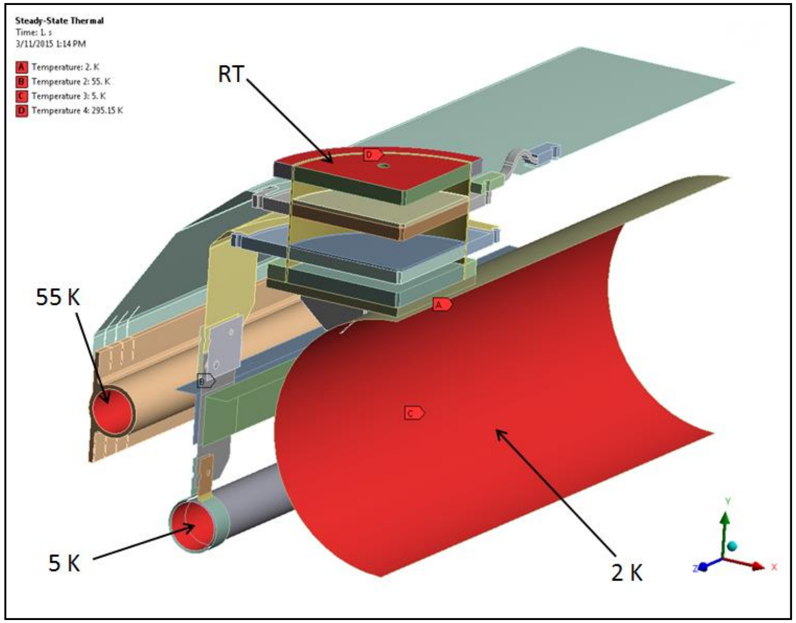




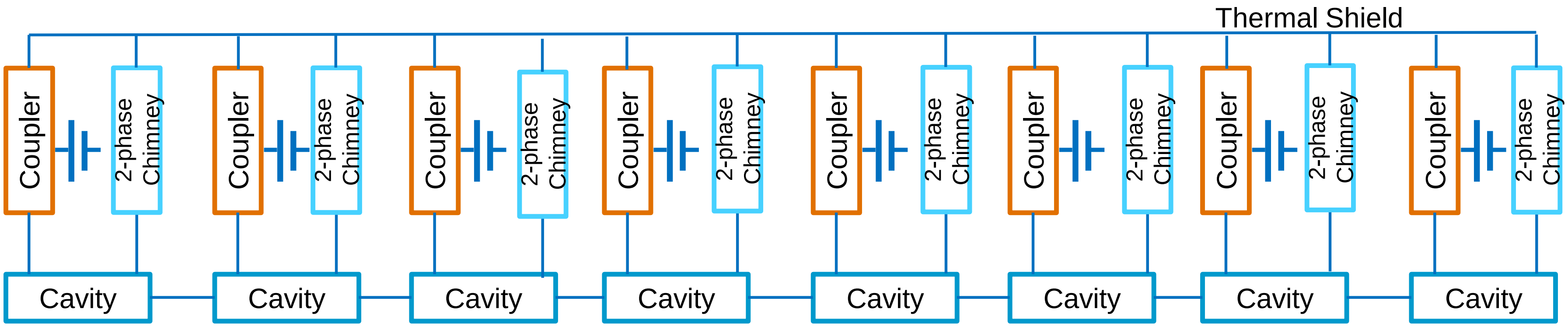


Coupler Maybe the Primary Source



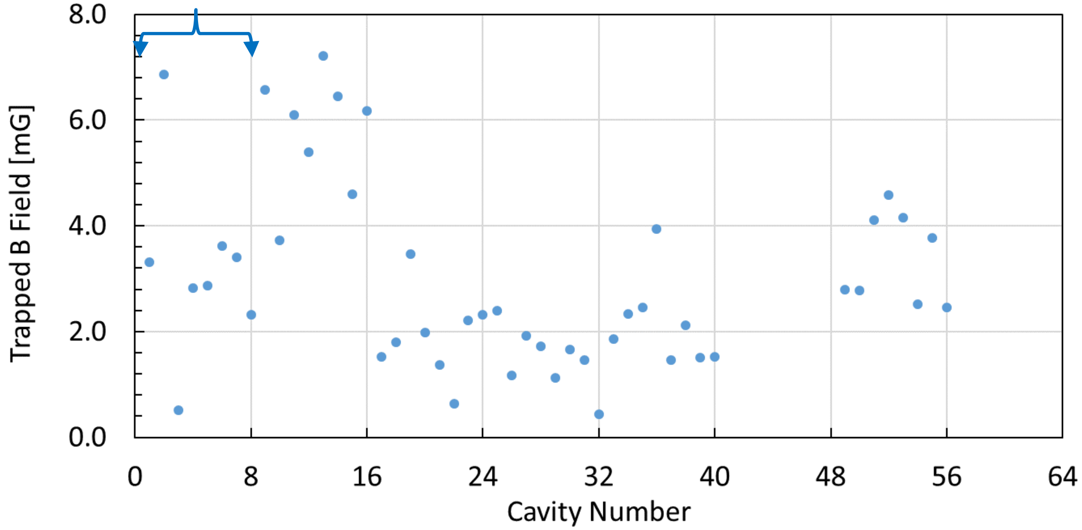


Courtesy of R. Fischer, J. Kaluzny, T. Peterson.

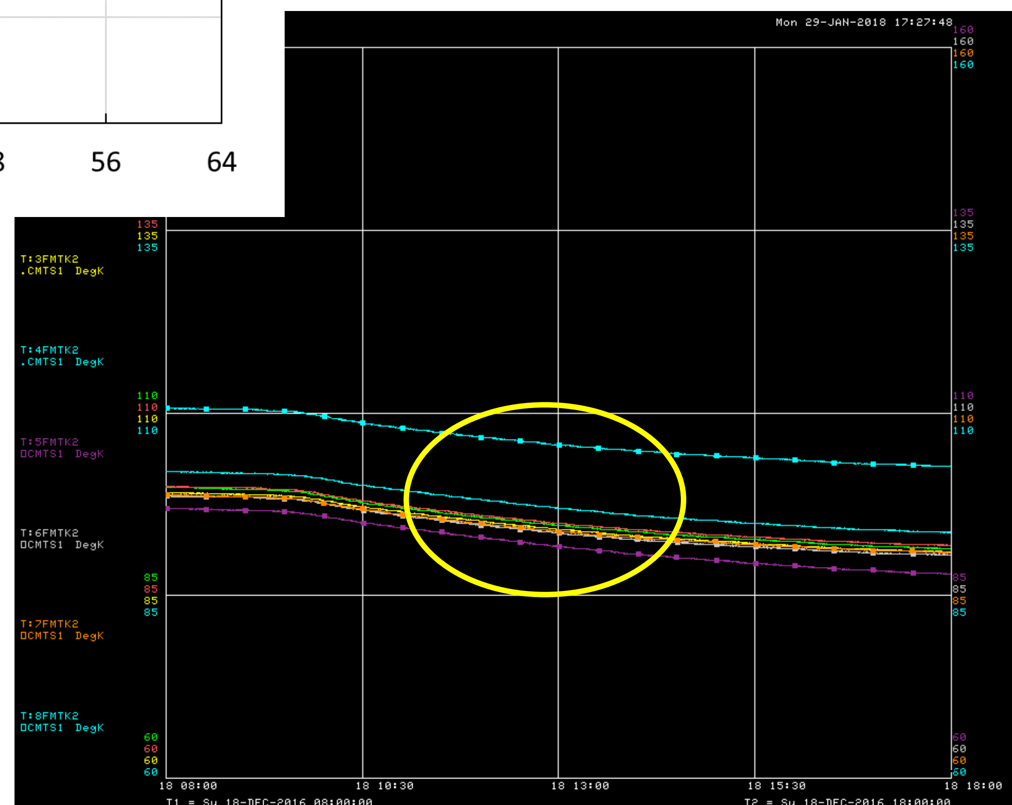


Coupler Temperatures

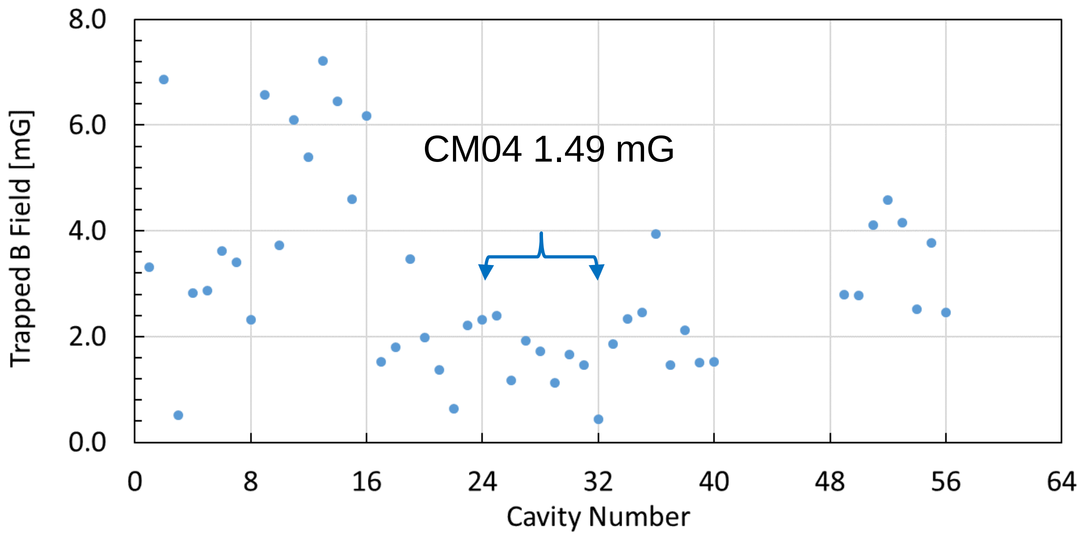
CM01 3.21 mG



Coupler T (K)	Coupler ΔT (K)	Trapped Field (mG)
95	7	3.2
81	8	3.4
68	3	1.5



Coupler Temperatures



Slow Cool Down Q0 ~ 2.9e10
Fast Cool Down Q0 ~ 3.2e10

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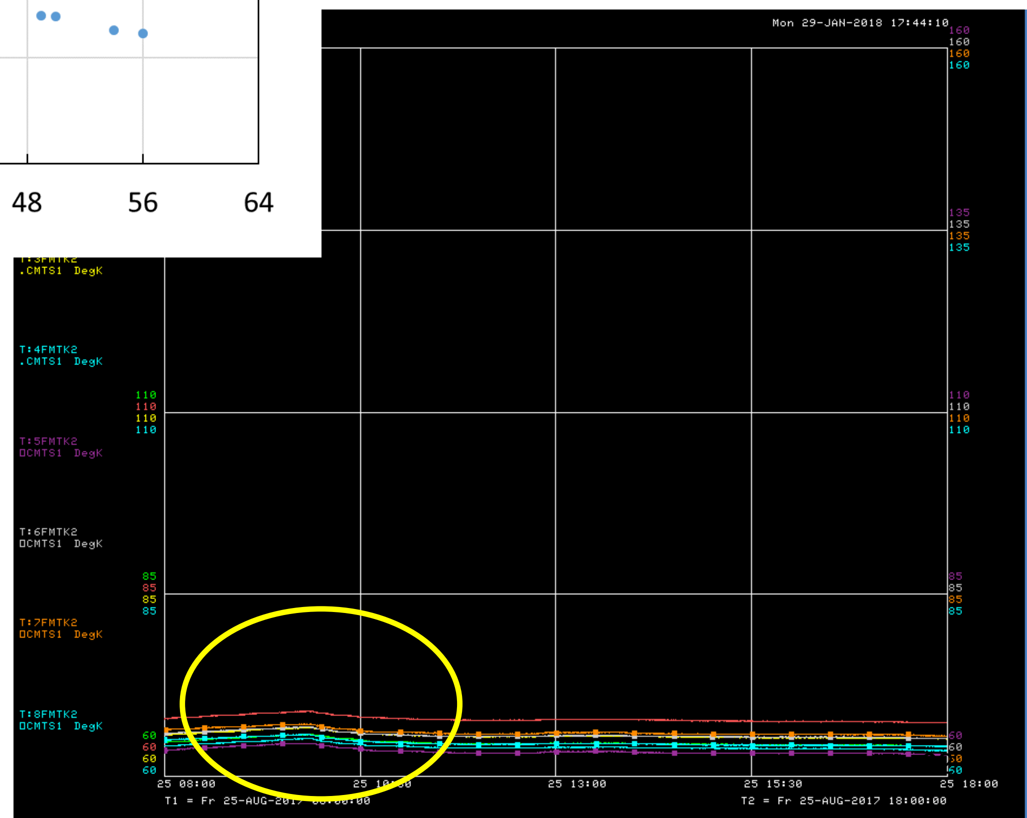

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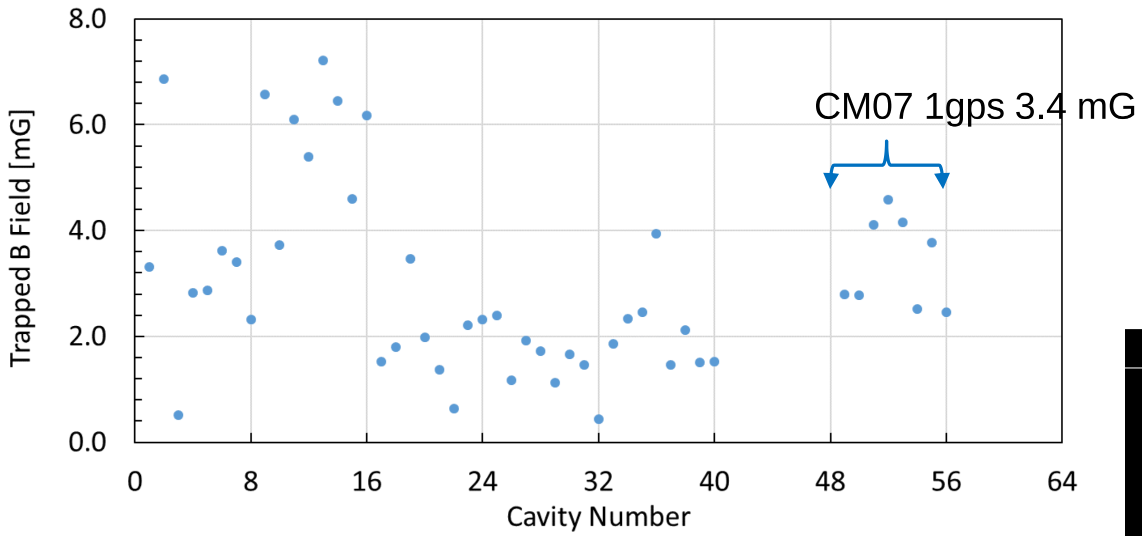

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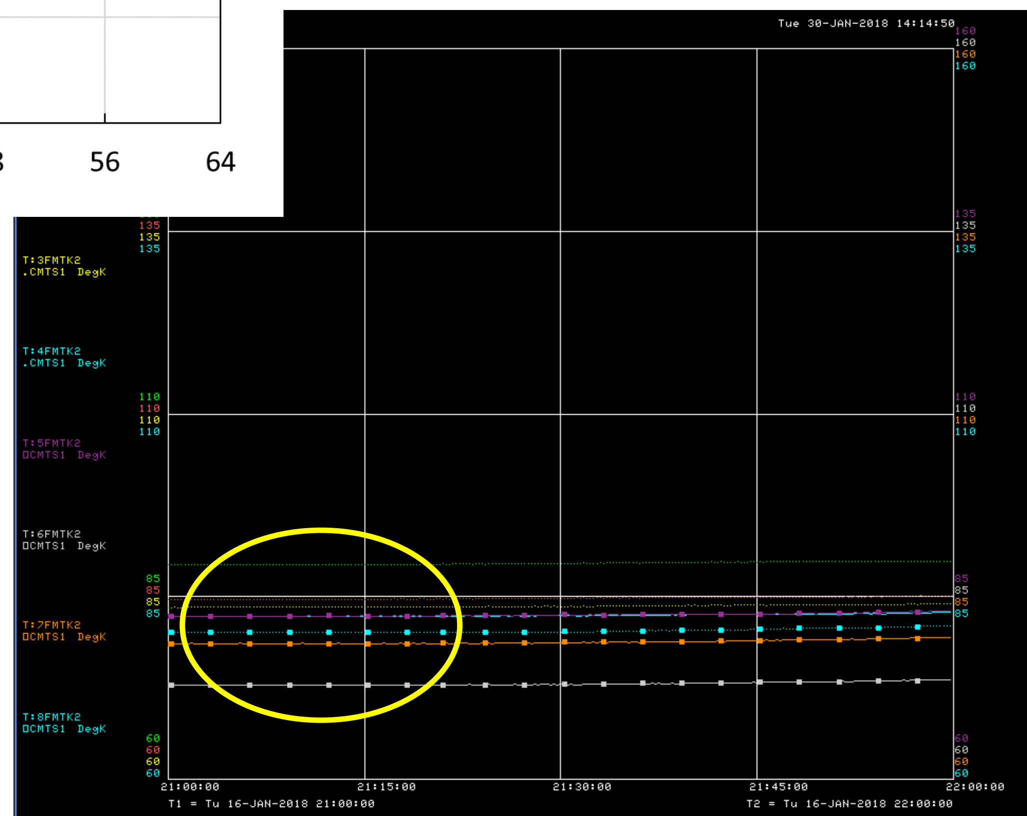
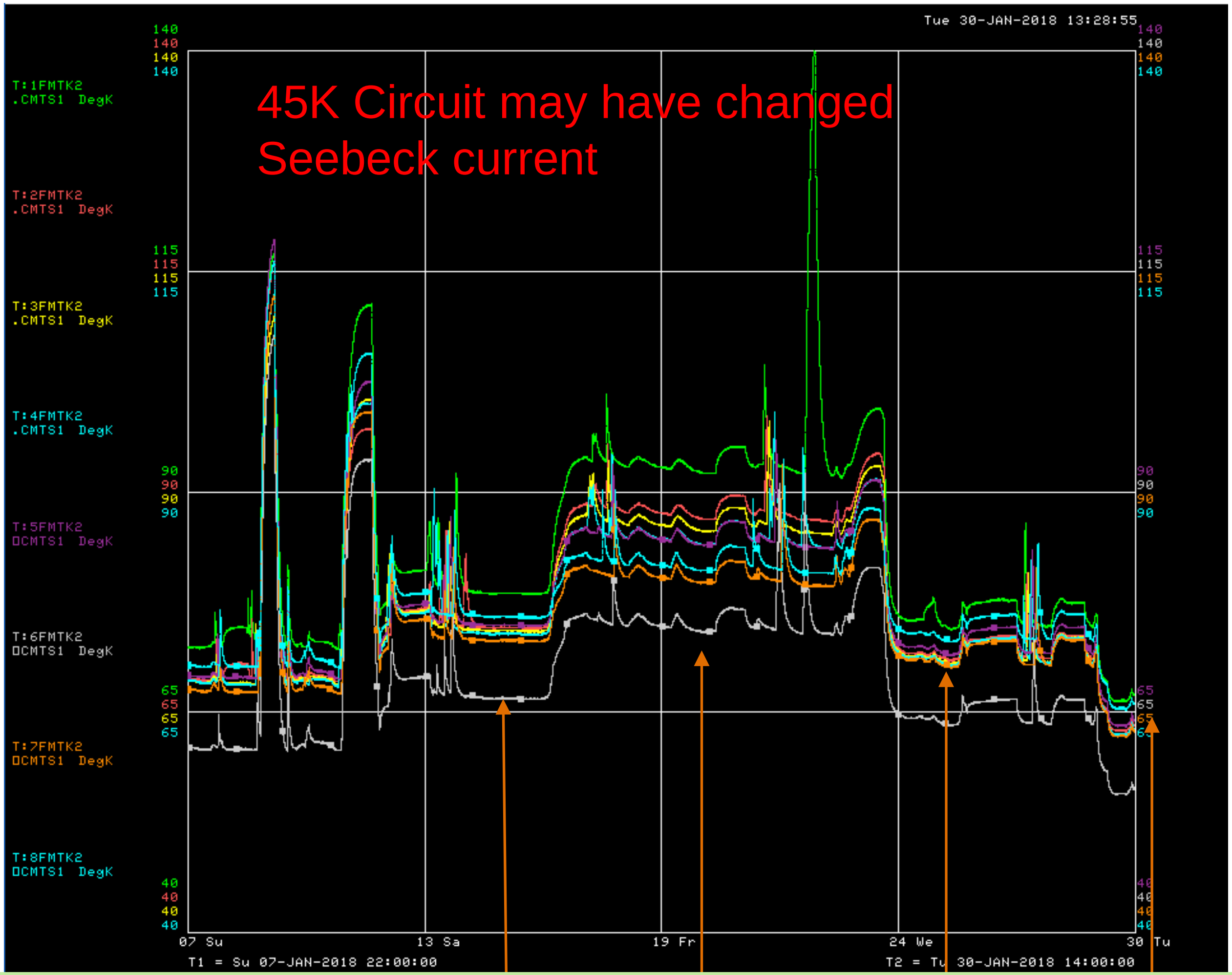
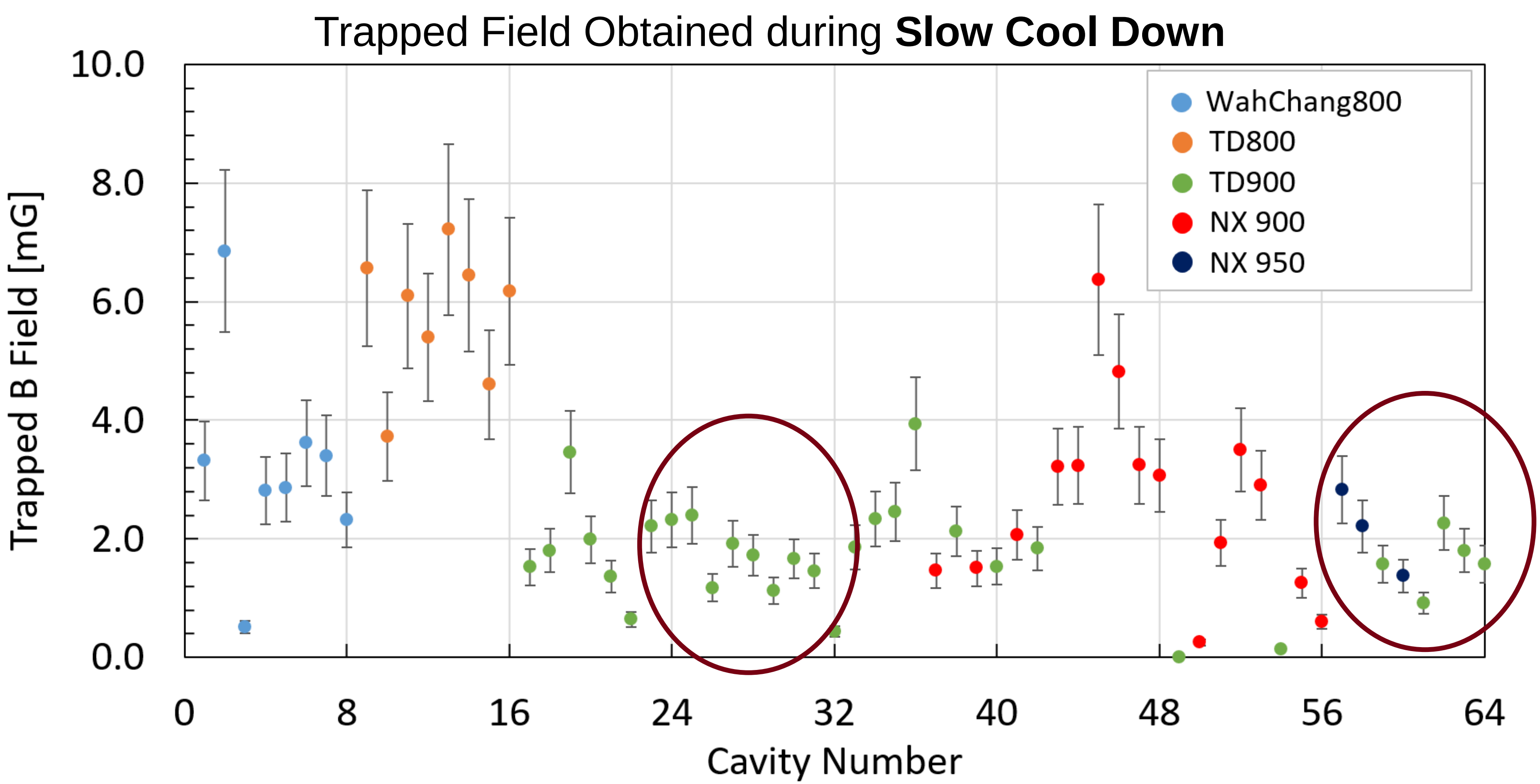


Coupler Flange Temperature Affected by 45K Circuit



It may be possible to reduce thermoelectric current by optimizing a cool down procedure

Trapped Field in LCLS-II Cryomodules



Even a slow cool down achieves Q0 > 2.7e10 when thermoelectric current is low

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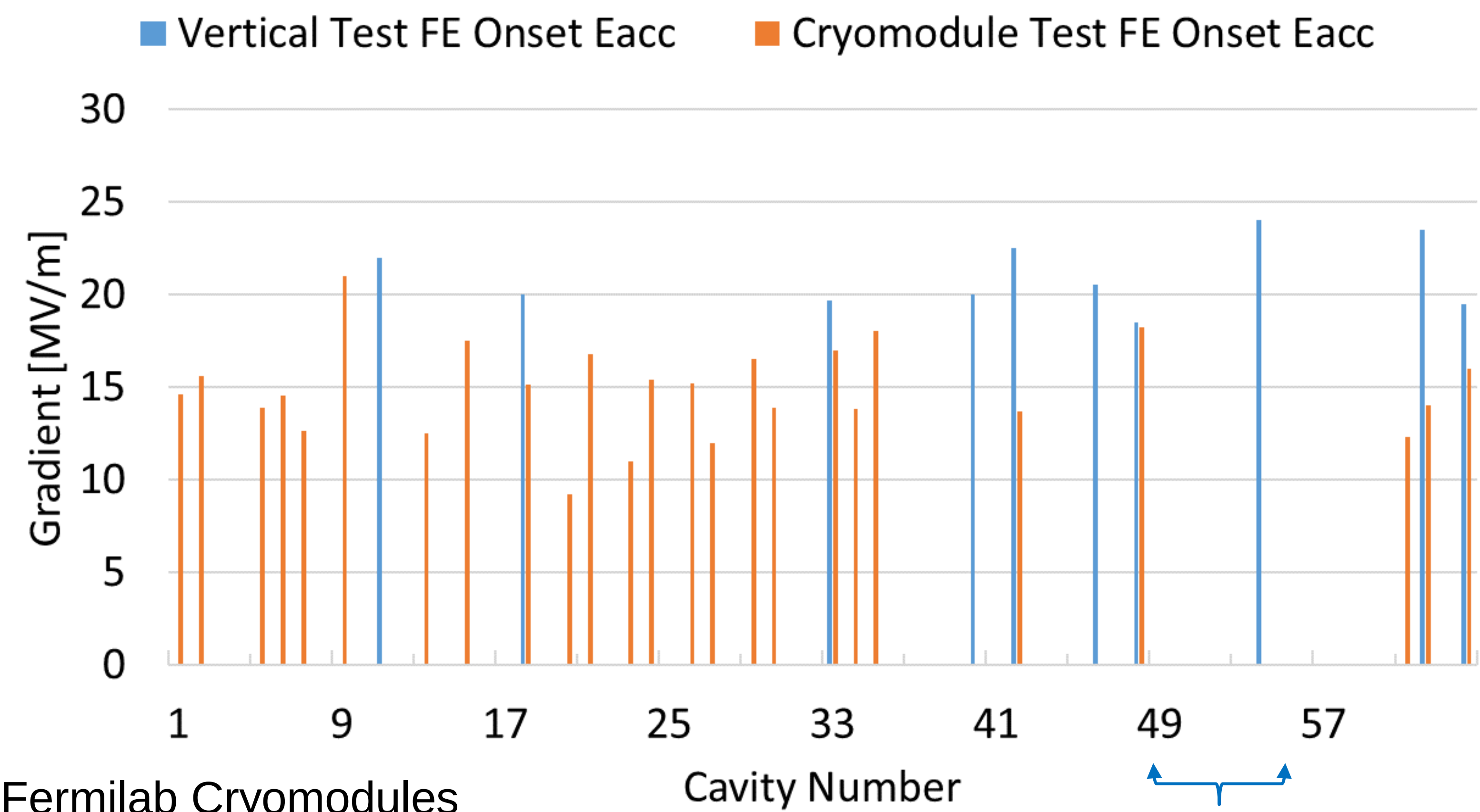
Field Emission Still an Issue



- Fermilab Cryomodules
- CW measurement
- X-ray detector all around

CM07 No Field Emission up to 21 MV/m

Summary relevant to ILC Cryomodules

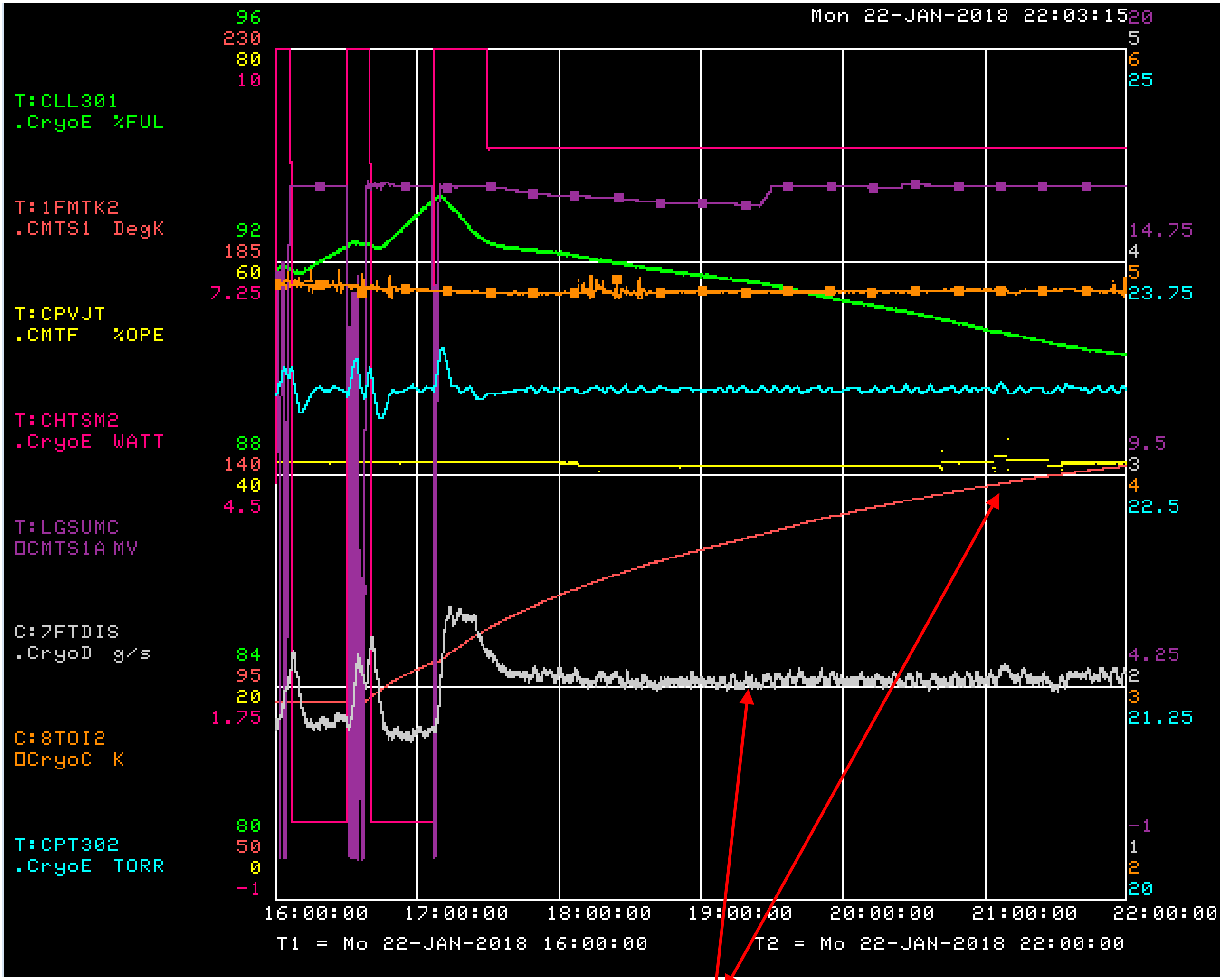
- Reduce thermoelectric current
  - Study the thermoelectric current mechanism
  - Improve thermal design of cryomodules
  - Optimize cool down procedures
- Use niobium material that expels remnant magnetic field
- Fast cool down to expel remnant magnetic field
- Don’t forget the field emission

Extra slides

Summary

- Thermoelectric currents are better characterized, but not well controlled.
  - Dynamic thermal currents during fast cool down were not harmful.
  - Static thermal currents are not understood yet.
- Higher cool down rate improves the field expulsion
- If material does not expel flux well
  - Fast cool down becomes less effective, but still beneficial if material can expel some flux.
  - Thermal profile must be improved (test is in progress)
    - Improve coupler thermal strapping
    - Lower coupler thermal intercept temperature
    - Use coupler power to equalize the coupler temperature
- Field Emission is still an issue

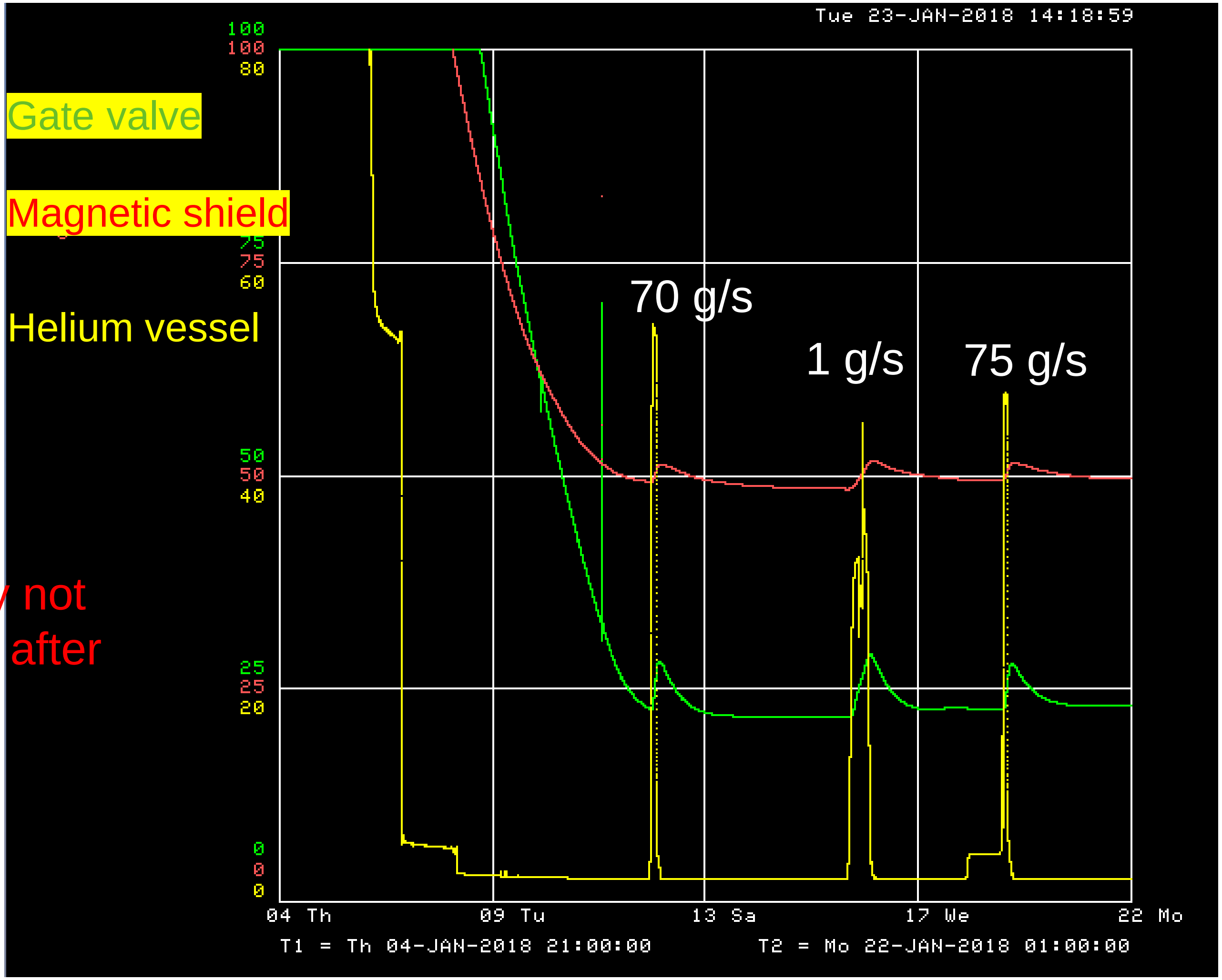
Coupler Heating is Negligible to Q0 Performance Change



N. Solyak and G. Wu

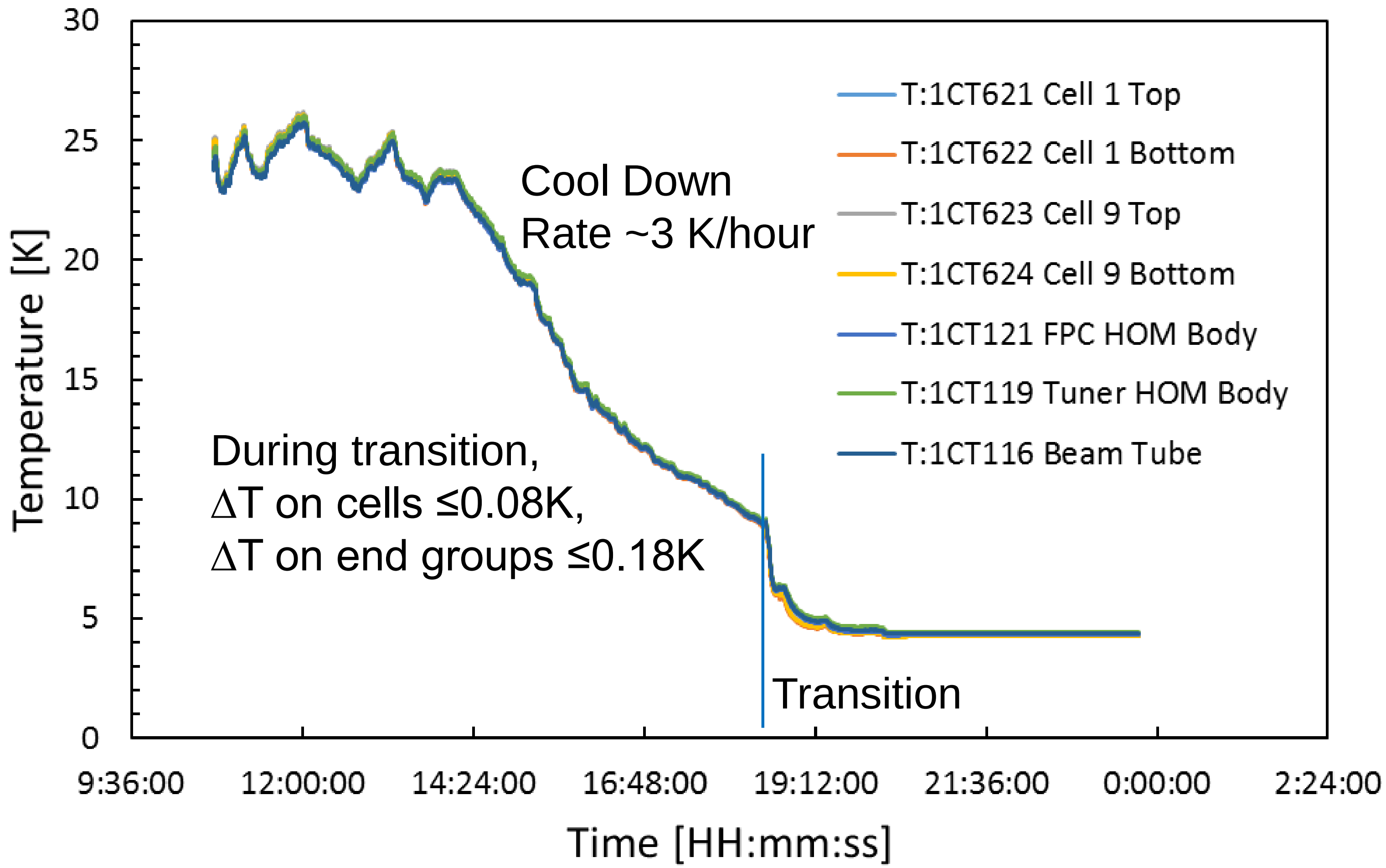
Mass flow remained constant despite coupler heats up to 140K at its 50K flange

Temperature Profile of F1.3-07



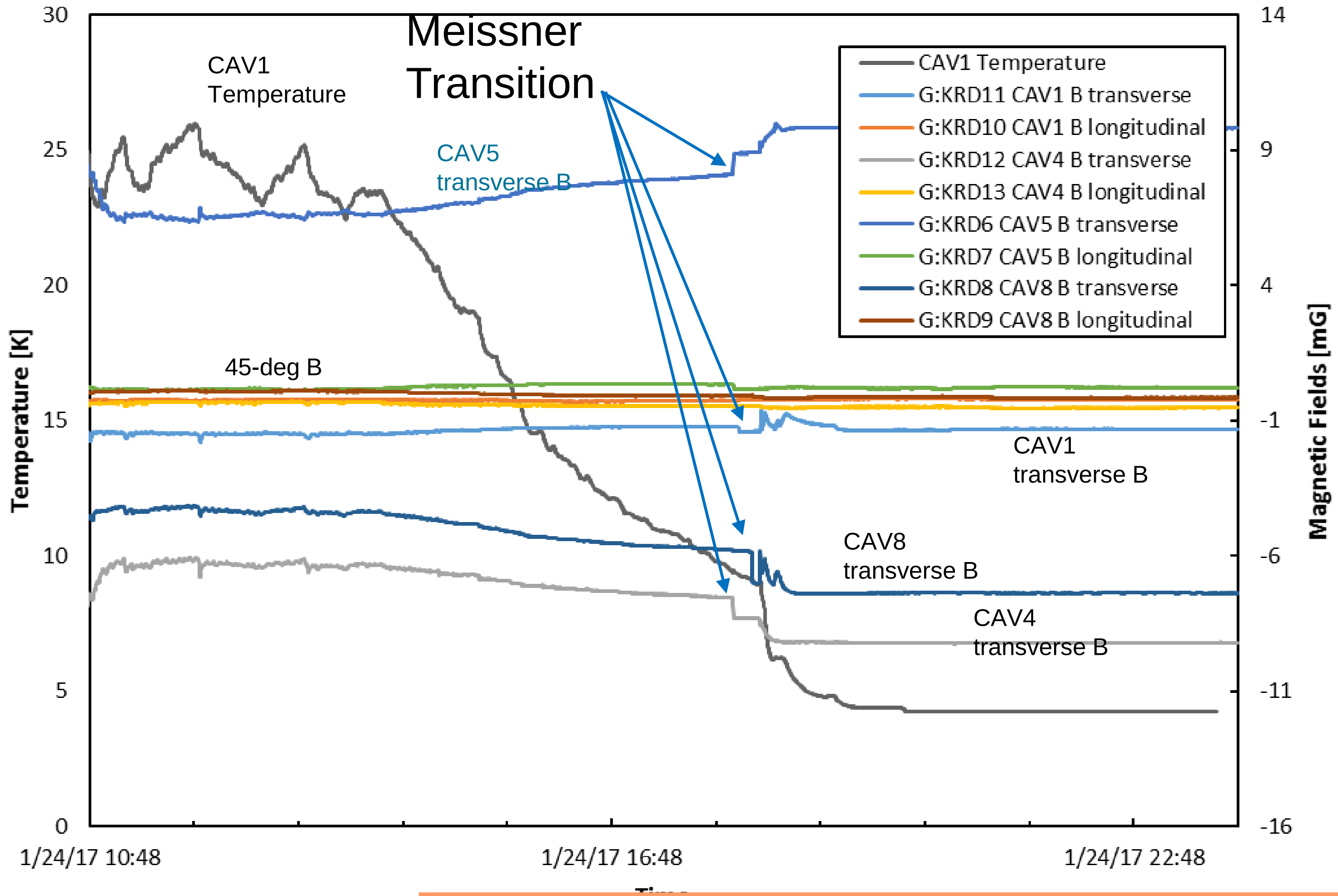
Soaking may not bring benefit after 11-days

Slow Cool Down



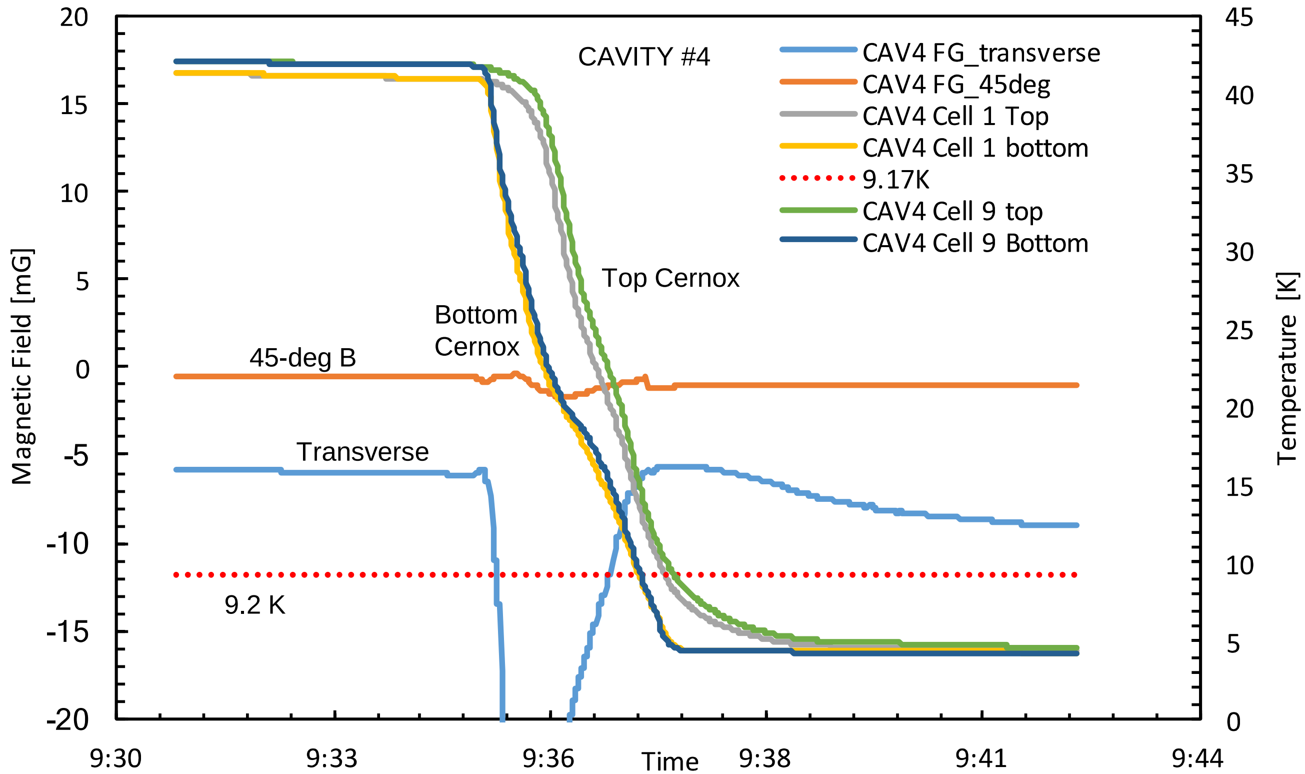
Slow cool down created a uniform temperature on cavity

Static Thermal B Field



Static thermal magnetic field is trapped during superconducting transition (Slow cool down)

Temperatures and Magnetic Fields During Fast Cool Down



During a fast cool down under 80 g/s mass flow:

1. Bottom of cavity sees faster drop of the temperature.
2. A temperature gradient persists during transition.
3. Large temperature difference induces strong transverse magnetic field in addition to existing fields also caused by cryomodule thermal currents.
4. 45-degree sensor sees relatively small to negligible field.
5. Cool down lasts about three minutes