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Active Coil Cancellation on a LCLS-II CM

Saravan K. Chandrasekaran, on behalf of the LCLS-II team

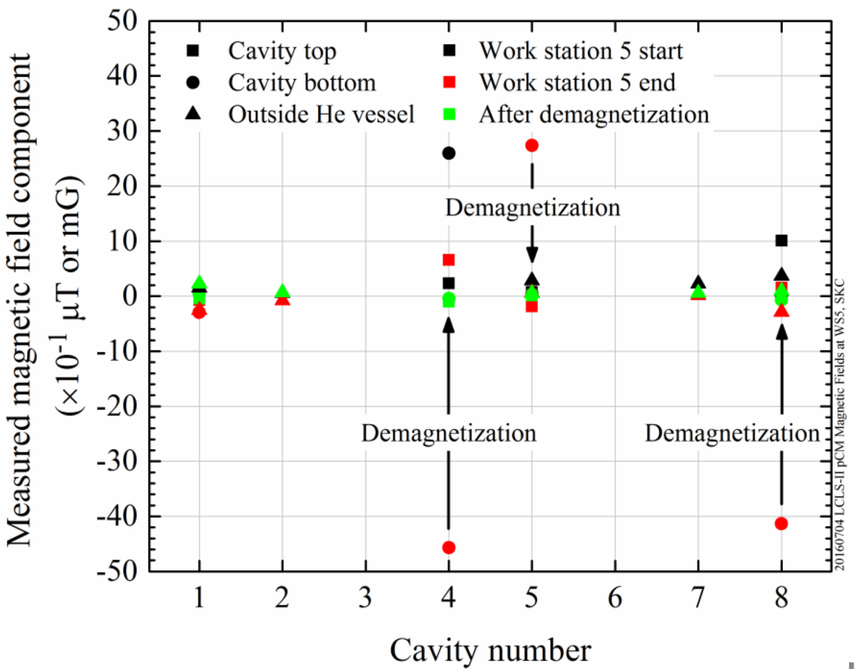
TESLA Technology Collaboration (TTC) Meeting, INFN, Italy

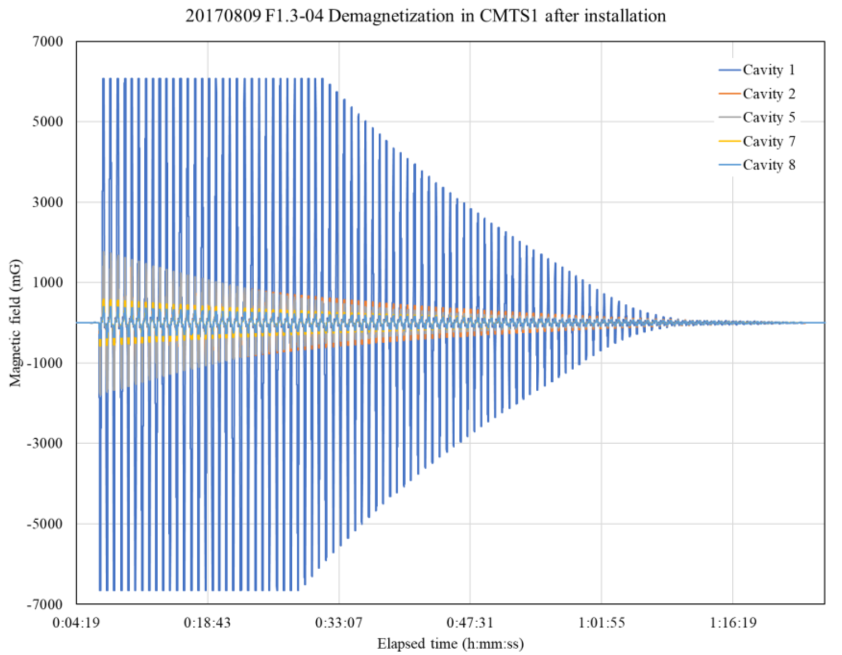
6 February 2018

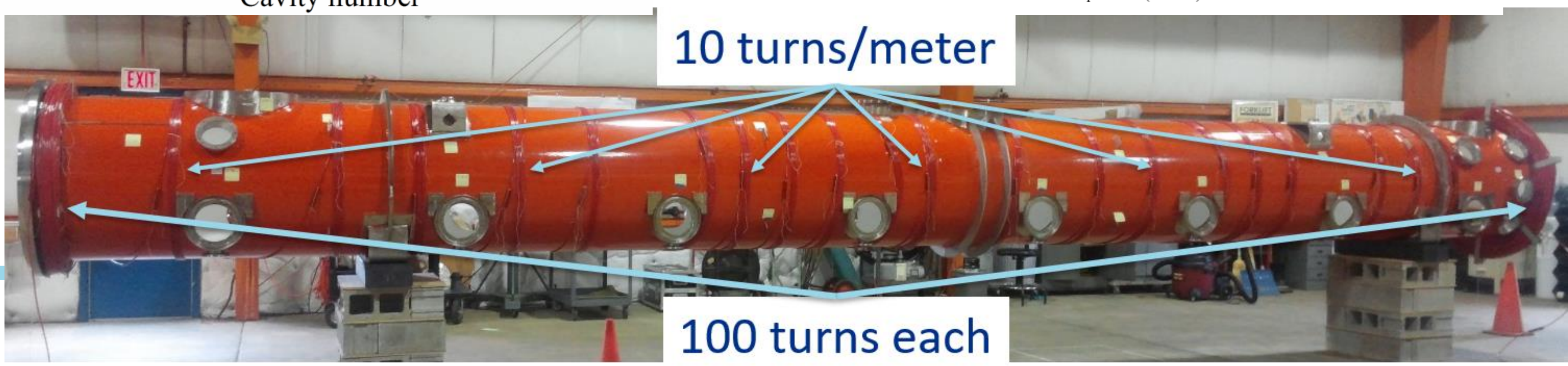
Motivation

TUPLR027 - LINAC 2016, TTC – CEA 2016, TTC – MSU 2017, IEEE T Appl Supercond 2017, arXiv:1507.06582

1. Cryomodules magnetize during assembly & shipping
   – In-situ demagnetization an effective method to mitigate this



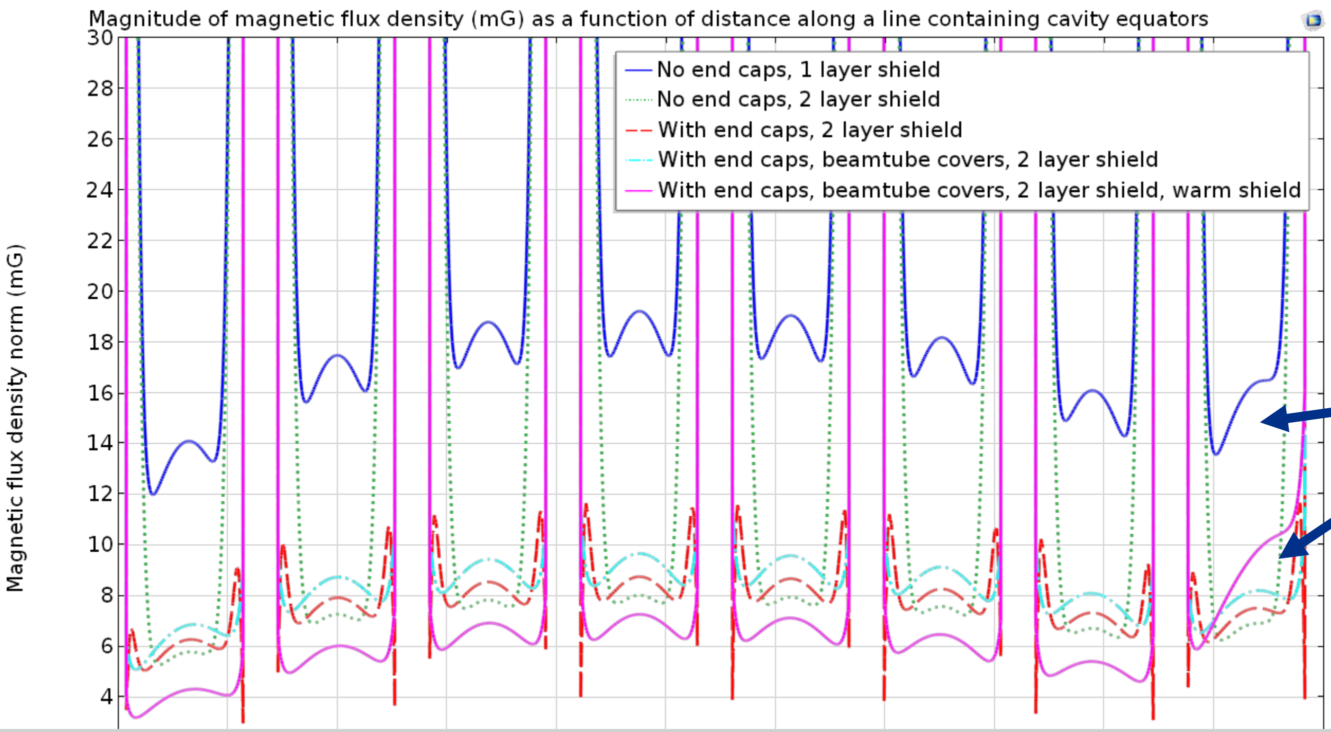


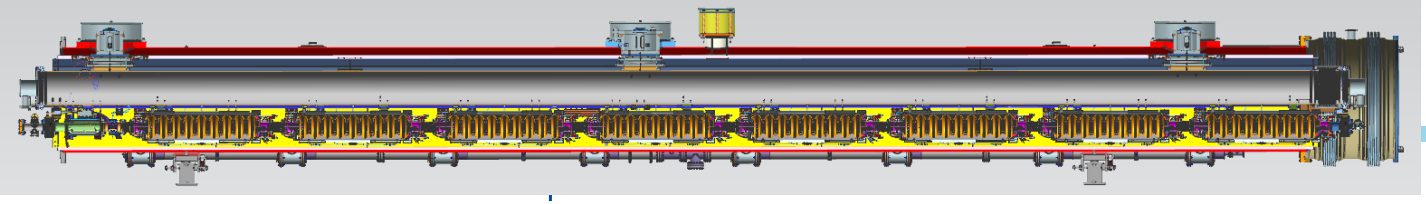


Motivation

arXiv:1507.06582, TTC – SLAC 2015

2. Longitudinal magnetic shielding of TESLA type CMs not as efficient as transverse shielding
   - Simulation: 150 mG longitudinal ambient field





Field plotted of line containing top equators

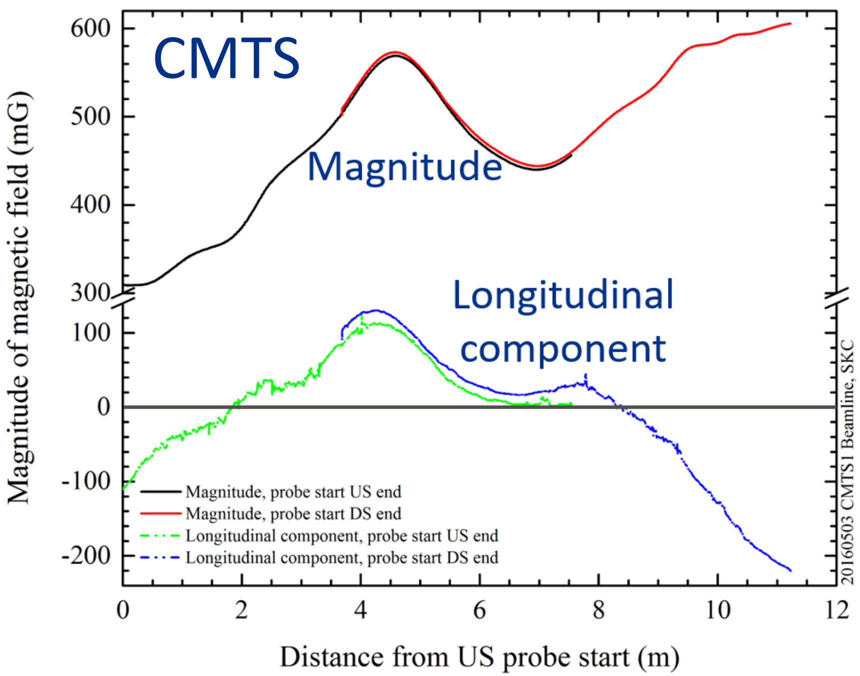
Enhancement due to end effects of vacuum vessel & warm shield (when present)

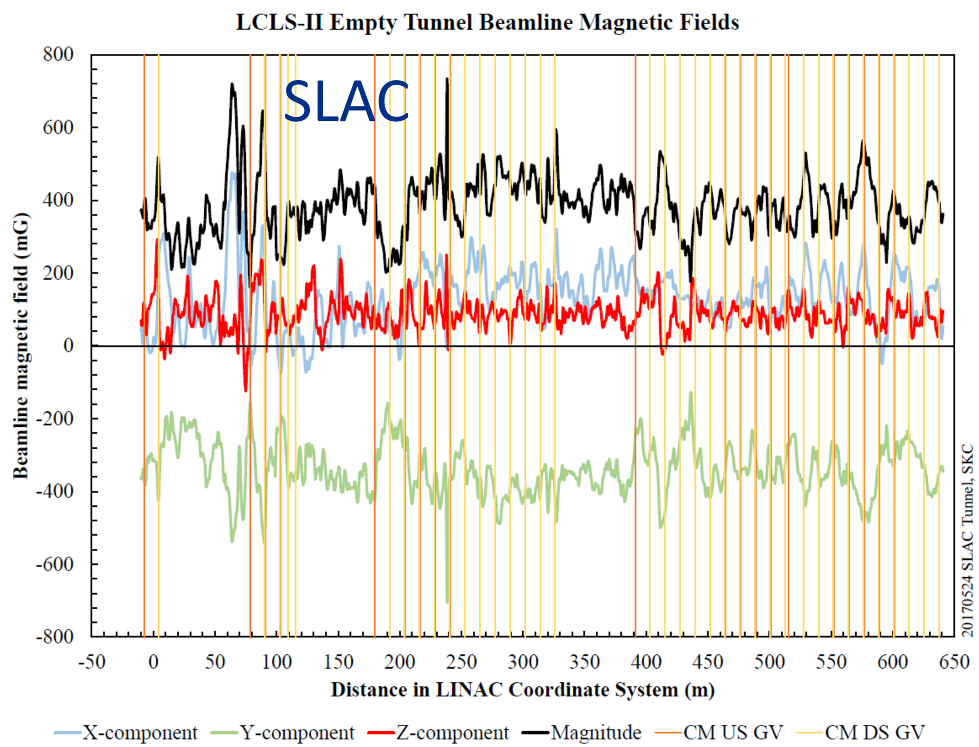
Shield μ = 10k; an exaggeration

Motivation

FNAL/SLAC internal docs, IPAC 2016

3. Magnetic fields at accelerator tunnels typically different from assembly & test locations
   - Very true for LCLS-II (FNAL & JLab assembly; SLAC tunnel)
   - True for ILC as well

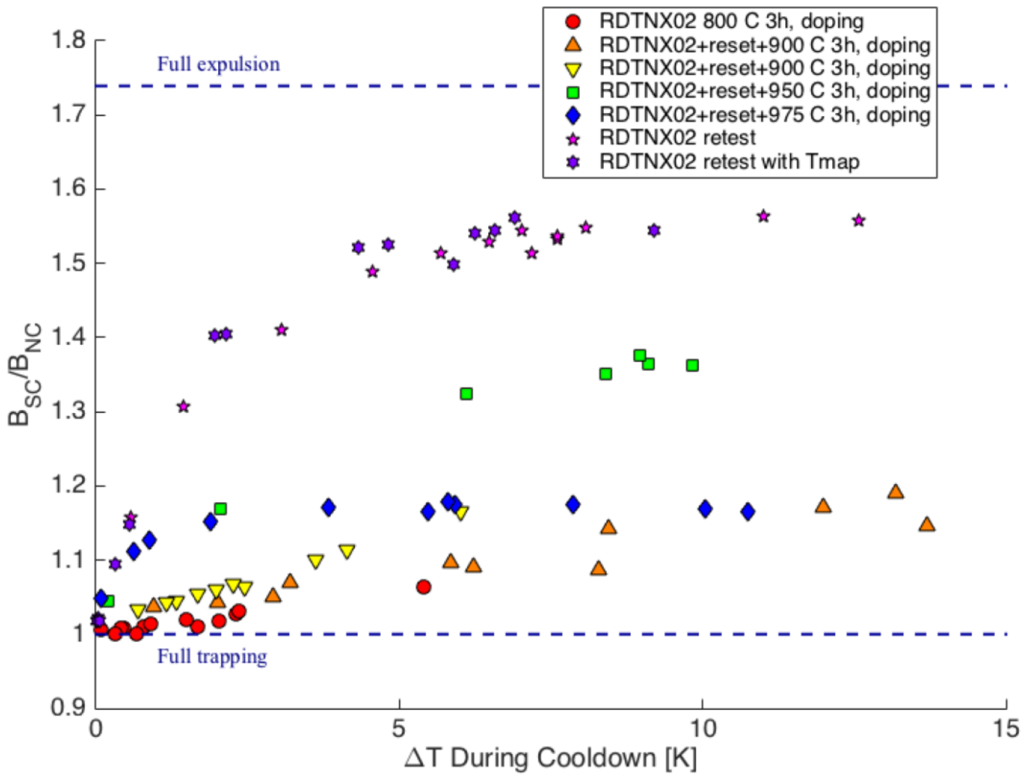




   - Empty SLAC tunnel fields – may get worse with installation

Motivation

4. Cavities may not expel magnetic flux due to material
   – Fast cool down not a solution for all



Sam Posen's talk – TTC – INFN 2018

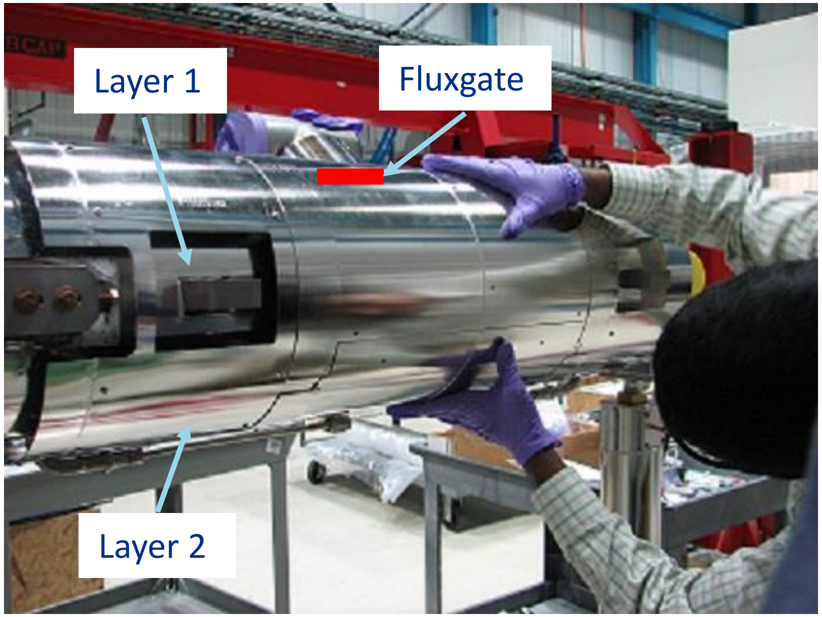
CM# F1.3-02

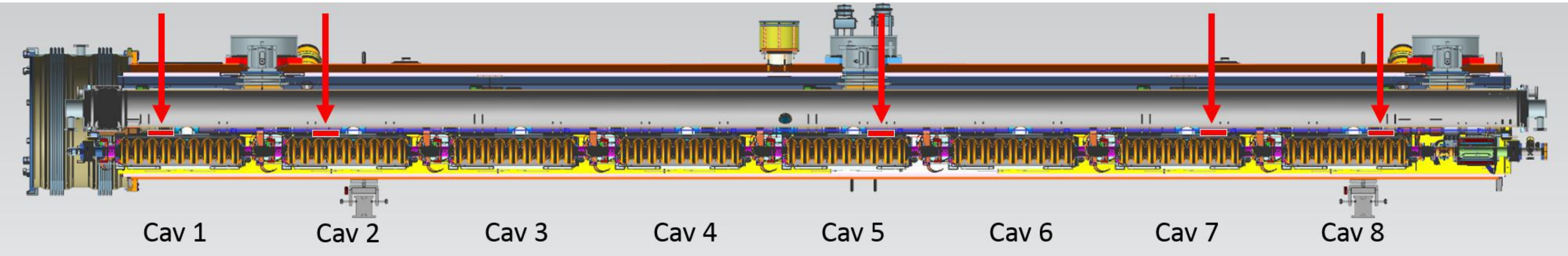
Cavity	Q0 at 16 MV/m & 2 K	
	VTS	CMTS
CAV0008	2.46E+10	2.0E+10
CAV0003	2.22E+10	2.5E+10
CAV0006	2.38E+10	2.0E+10
CAV0007	2.40E+10	2.2E+10
CAV0016	2.41E+10	1.8E+10
CAV0013	2.40E+10	2.0E+10
CAV0011	2.33E+10	2.3E+10
CAV0015	2.82E+10	2.3E+10
Average	**2.43E+10**	**2.1E+10**

FNAL/SLAC internal

Location of fluxgates in production CMs

- 5 fluxgates
  - Cavities 1, 2, 5, 7, 8
  - Mounted between the two layers of magnetic shields
  - Parallel to cavity axis

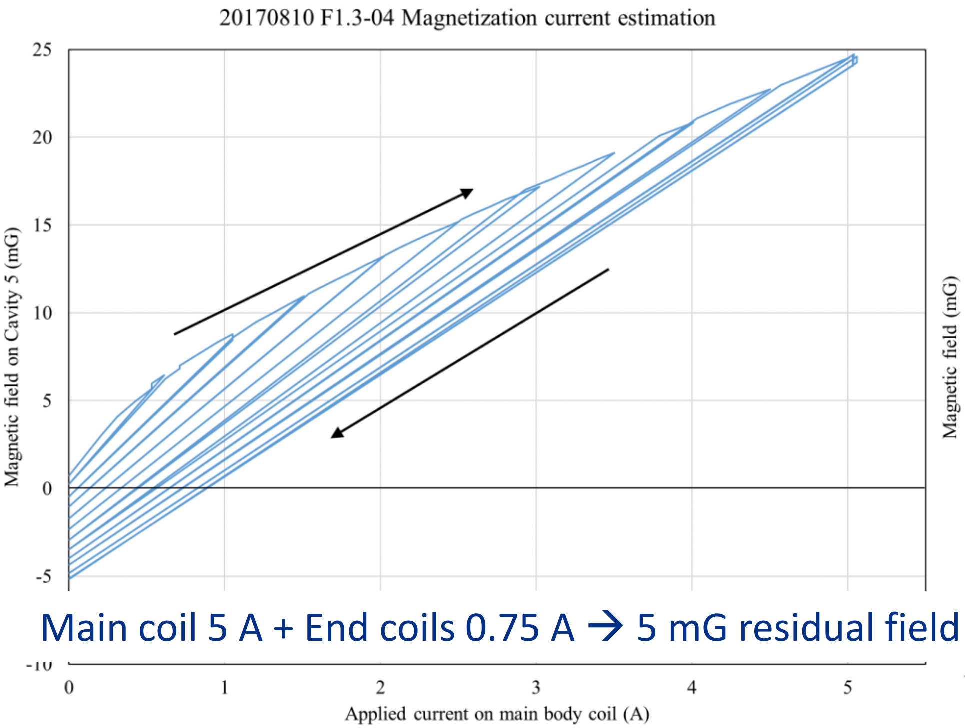


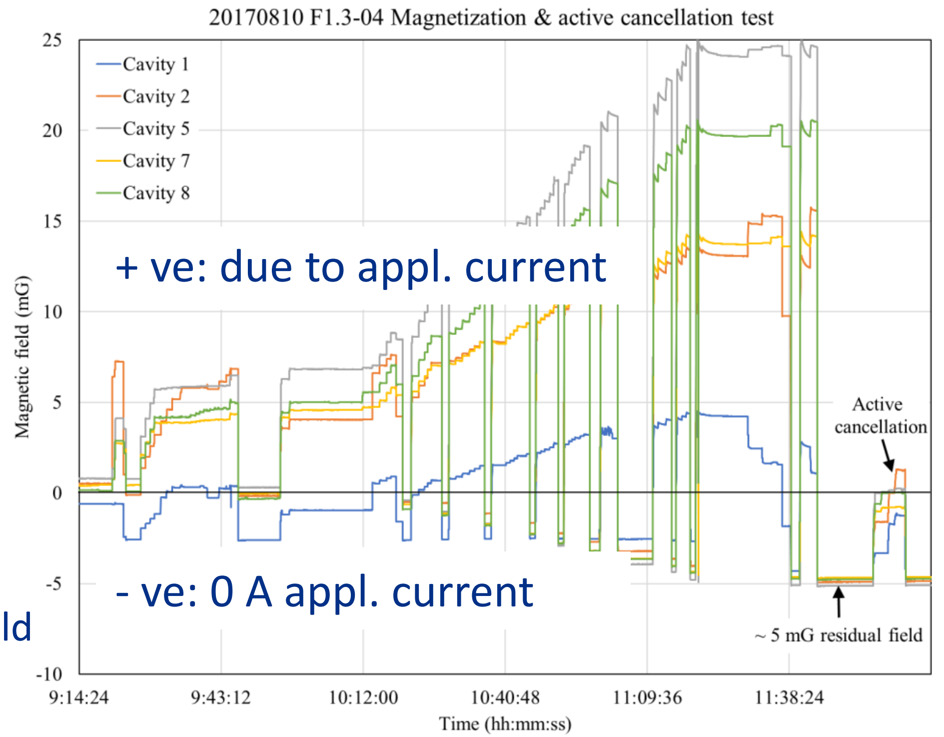


Sequence of tests

1. Demagnetize F1.3-04 at 300 K after installation at CMTS
2. Determine currents needed to *magnetize* CM to ~5 mG (avg) level
3. Repeat step 1
4. Slow (3 g/s) cooldown CM & measure baseline Q0 at 2 K
5. Re-magnetize CM at 25 K to ~5 mG level
6. Slow (3 g/s) cool down CM from 25 K & measure Q_0 at 2 K
7. Use active cancellation to negate magnetic field at 45 K
    - Tune the three sets of coils independently to reduce fields to zero
8. Slow (3 g/s) re-cool CM from 45 K & re-measure Q_0
9. Fast (32 g/s) re-cool CM from 25 K & re-measure Q_0
10. Warm up CM
11. Demagnetize CM at 300 K

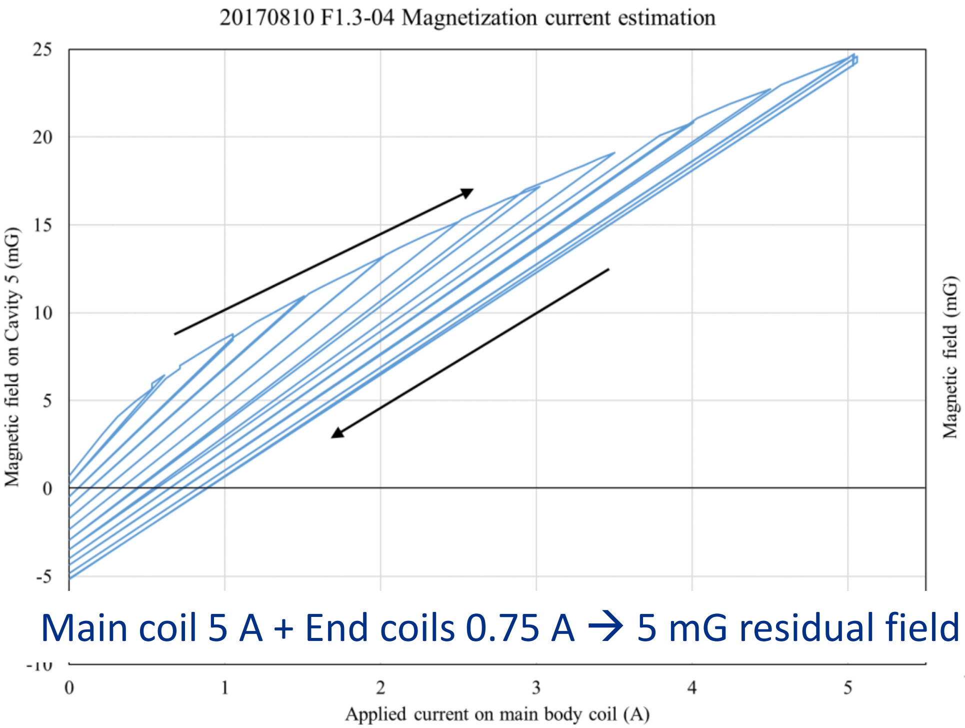
Determining 5 mG magnetization at 300 K

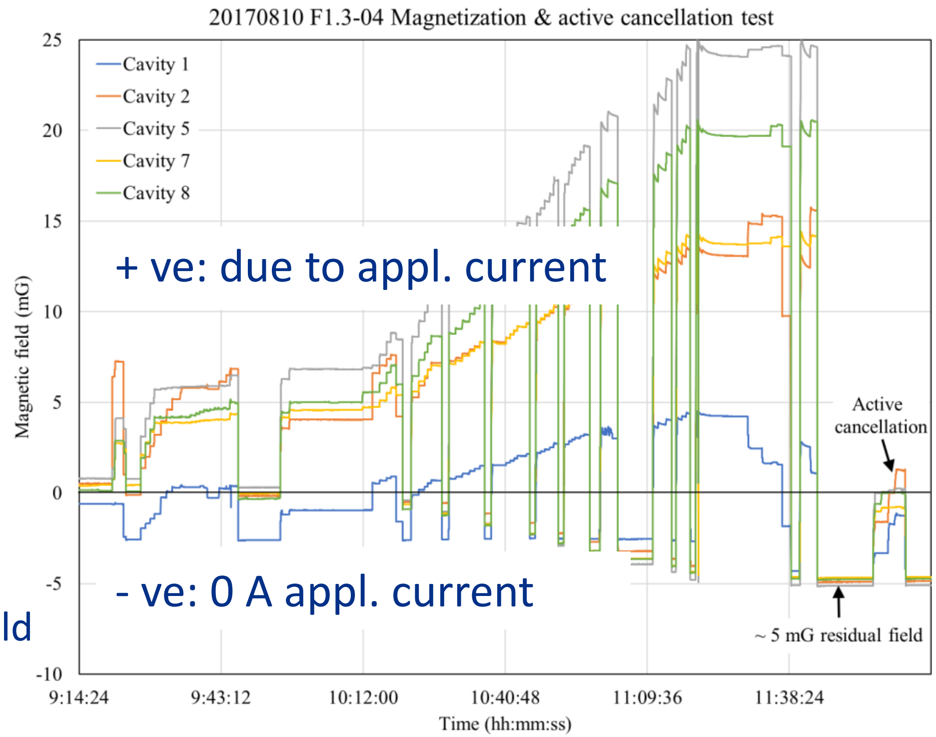




- Hysteresis observed
  - magnetic shielding & carbon steel “magnetized”
- CM then *re-demagnetized*, slow cooled, Q measured

Determining 5 mG magnetization at 300 K





- Hysteresis observed
  - magnetic shielding & carbon steel "magnetized"
- CM then *re-demagnetized*, slow cooled, Q measured
- Avg $Q_0 = 2.9\times10^{10}$ → baseline SCD Q

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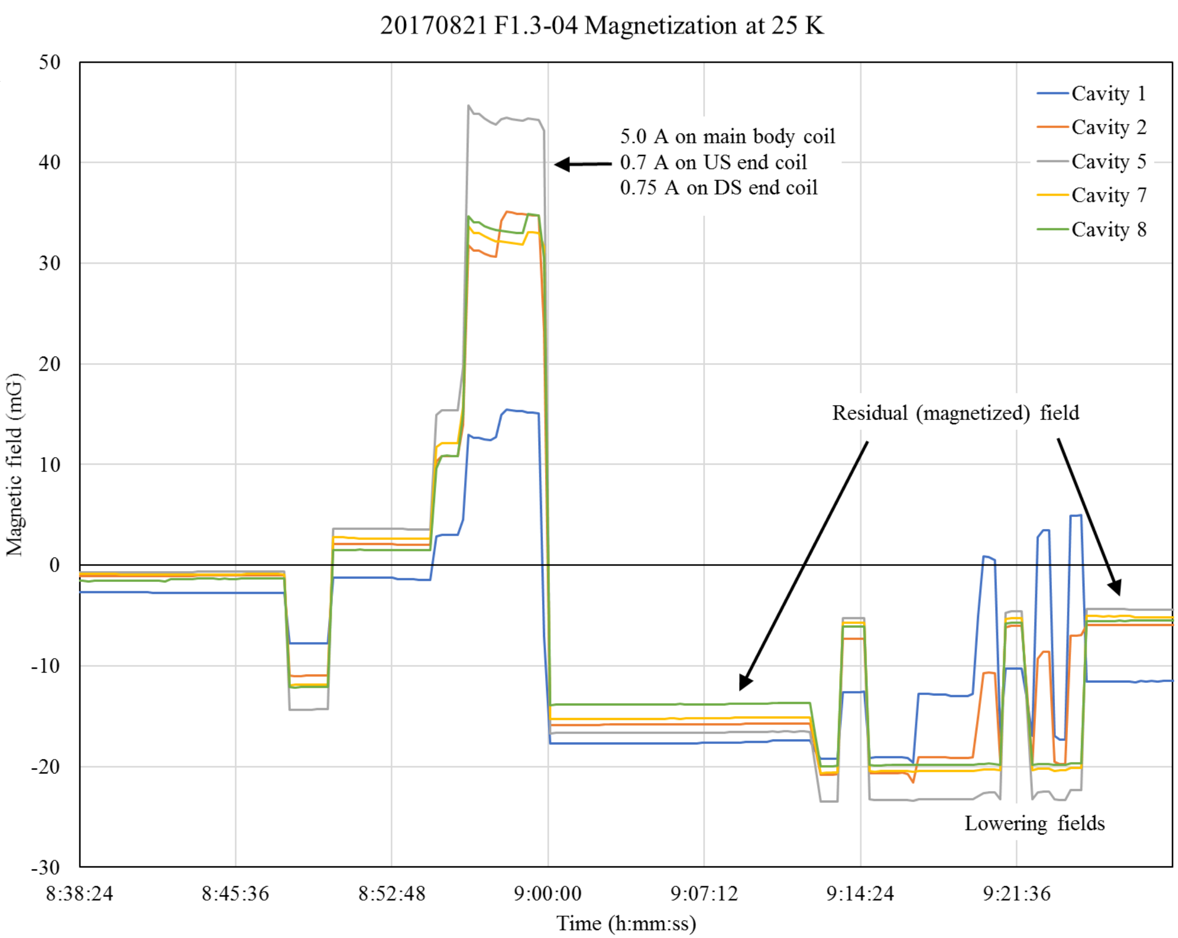
10. Warm up CM
11. Demagnetize CM at 300 K

Magnetizing F1.3-04 at 25 K

- Used currents determined at 300 K as guideline
  - Magnetic shield μ varies with *T*



- Magnetized to
  - Cav1 = -11.59 mG
  - Cav2 = -5.97 mG
  - Cav5 = -4.40 mG
  - Cav7 = -5.05 mG
  - Cav8 = -5.57 mG

- CM then slow cooled, Q measured

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- Used currents determined at 300 K as guideline
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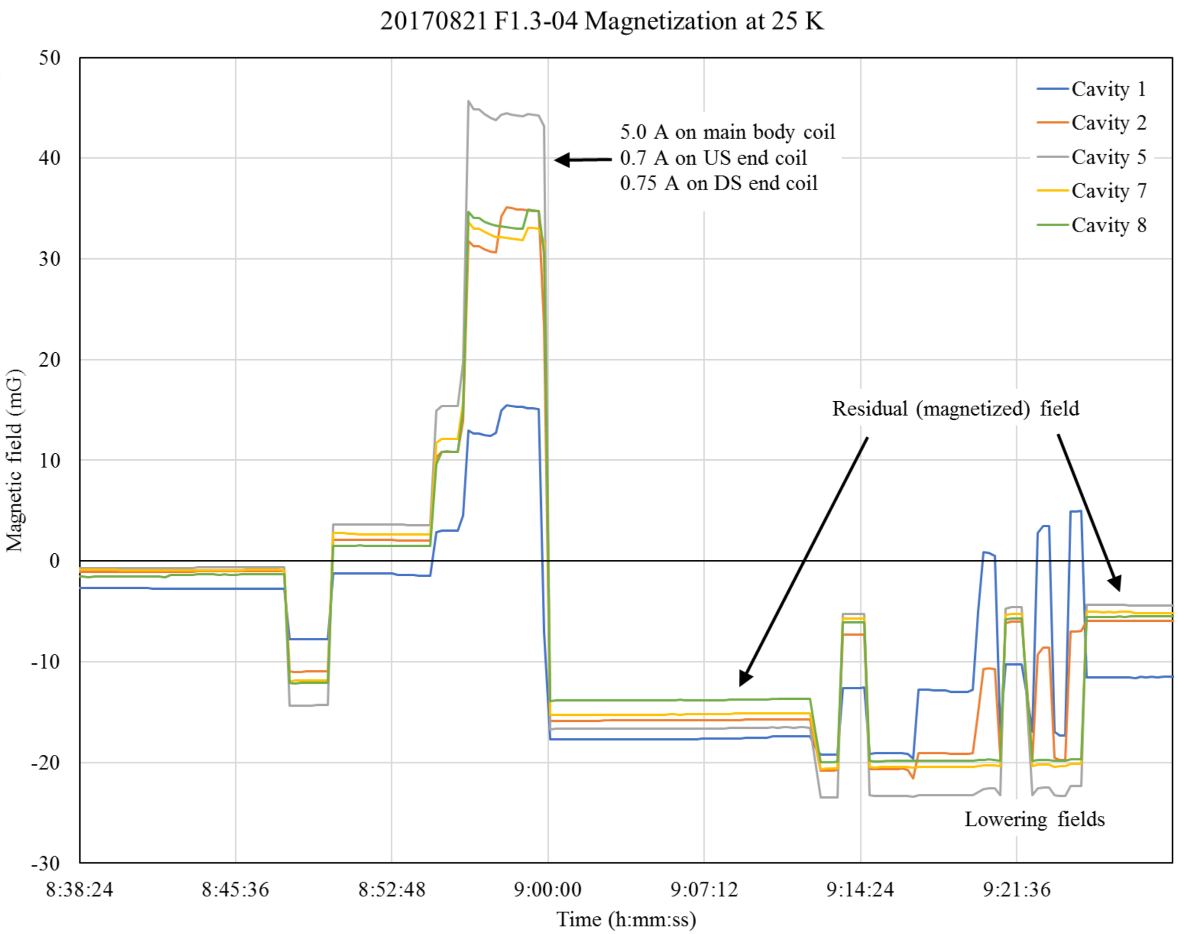

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  - Cav2 = -5.97 mG
  - Cav5 = -4.40 mG
  - Cav7 = -5.05 mG
  - Cav8 = -5.57 mG

- CM then slow cooled, Q measured: Avg $Q_0 = 1.74\times10^{10}$

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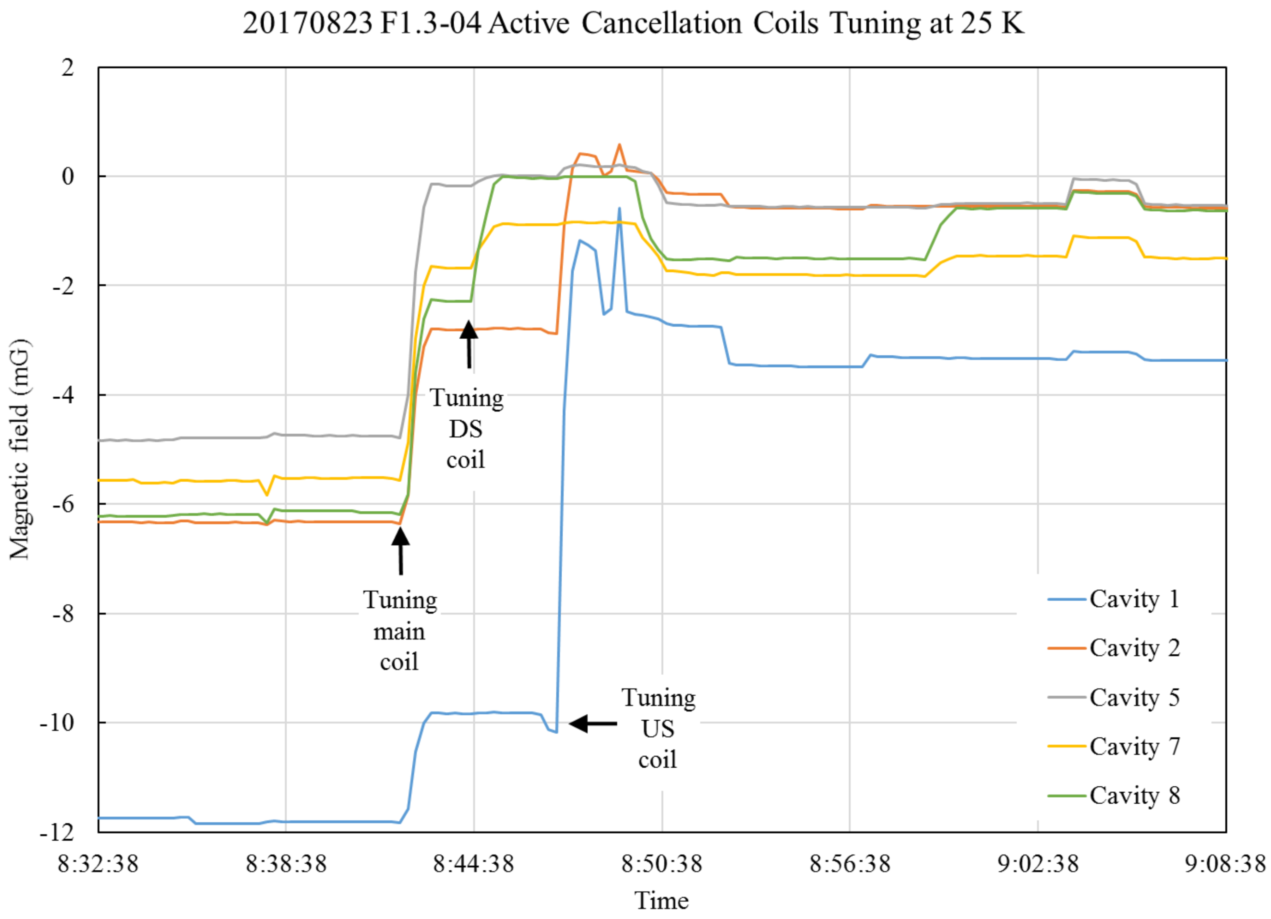
10. Warm up CM
11. Demagnetize CM at 300 K

Active cancellation at 25 K



- Goal: lower fields to ‘before magnetization’ level
- 3 independent coils to tune

Sequence of tests

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11. Demagnetize CM at 300 K

Q_0 after each test step

Cavity	Q0 at 16 MV/m & 2 K				
	VTS	CMTS			
		3 g/s SCD	Magnetized SCD	Active cancel SCD	Active cancel & 32 g/s FCD
CAV0052	3.70E+10	2.74E+10	1.38E+10	1.68E+10	2.74E+10
CAV0036	2.73E+10	2.52E+10	1.54E+10	2.28E+10	2.78E+10
CAV0019	3.71E+10	2.95E+10	1.65E+10	2.69E+10	3.52E+10
CAV0041	3.53E+10	2.91E+10	1.75E+10	2.97E+10	3.74E+10
CAV0030	3.62E+10	3.28E+10	2.10E+10	2.97E+10	3.64E+10
CAV0020	3.50E+10	2.92E+10	1.80E+10	2.77E+10	3.12E+10
CAV0051	3.36E+10	2.91E+10	1.75E+10	2.75E+10	3.12E+10
CAV0221	2.93E+10	2.99E+10	1.97E+10	2.28E+10	2.62E+10
Average	**3.39E+10**	**2.90E+10**	**1.74E+10**	**2.55E+10**	**3.16E+10**

Q_0 after each test step

Cavity	Q0 at 16 MV/m & 2 K				
	VTS	CMTS			
		3 g/s SCD	Magnetized SCD	Active cancel SCD	Active cancel & 32 g/s FCD
CAV0052	3.70E+10	2.74E+10	1.38E+10	1.68E+10	2.74E+10
CAV0036	2.73E+10	2.52E+10	1.54E+10	2.28E+10	2.78E+10
CAV0019	3.71E+10	2.95E+10	1.65E+10	2.69E+10	3.52E+10
CAV0041	3.53E+10	2.91E+10	1.75E+10	2.97E+10	3.74E+10
CAV0030	3.62E+10	3.28E+10	2.10E+10	2.97E+10	3.64E+10
CAV0020	3.50E+10	2.92E+10	1.80E+10	2.77E+10	3.12E+10
CAV0051	3.36E+10	2.91E+10	1.75E+10	2.75E+10	3.12E+10
CAV0221	2.93E+10	2.99E+10	1.97E+10	2.28E+10	2.62E+10
Average	**3.39E+10**	**2.90E+10**	**1.74E+10**	**2.55E+10**	**3.16E+10**

≈2×

- Active cancellation + 32 g/s → **greatest Q_0 at CMTS**

Active cancellation & poor expelling CMs

Magnetized SCD	Active cancel SCD
1.38E+10	1.68E+10
1.54E+10	2.28E+10
1.65E+10	2.69E+10
1.75E+10	2.97E+10
2.10E+10	2.97E+10
1.80E+10	2.77E+10
1.75E+10	2.75E+10
1.97E+10	2.28E+10
1.74E+10	**2.55E+10**

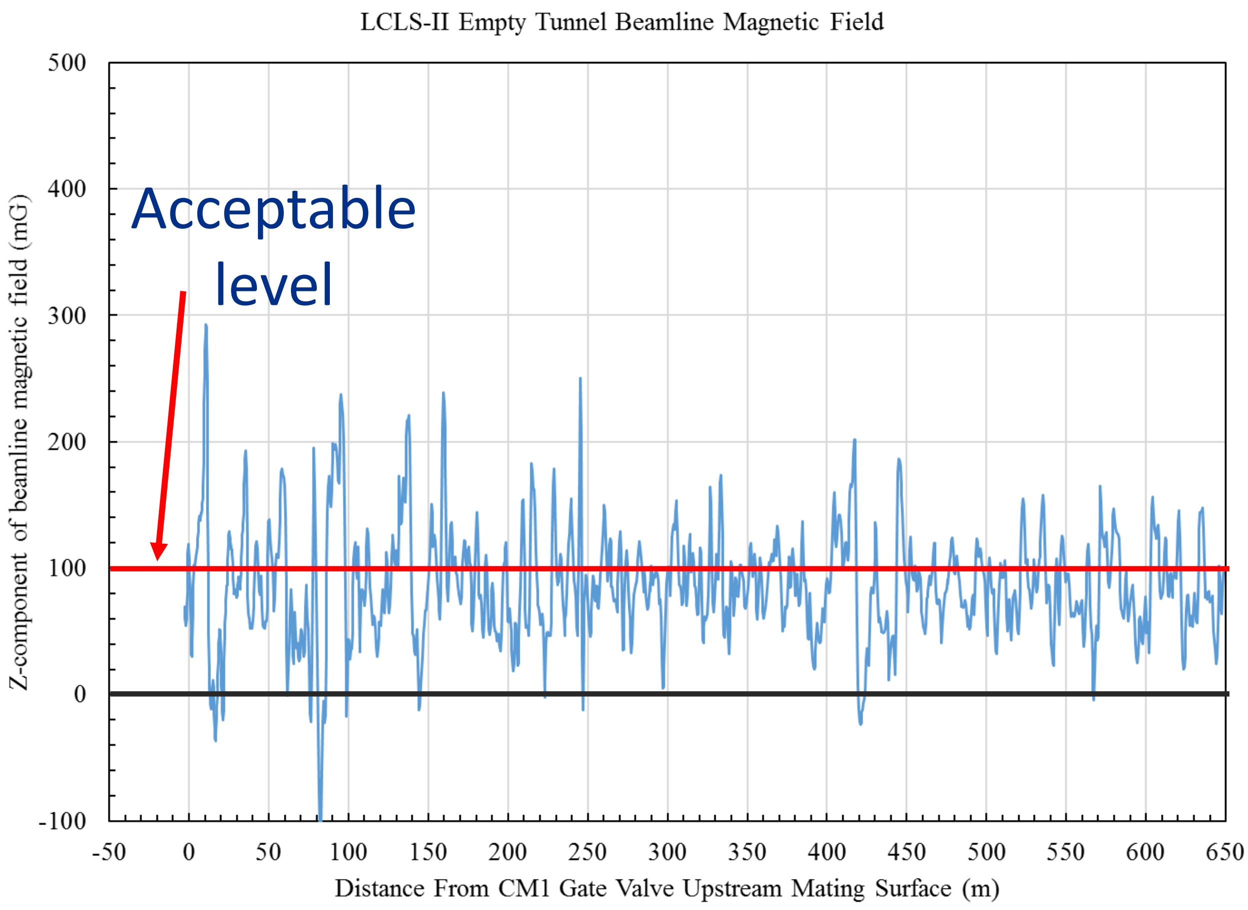
- Active cancellation lowers available field → increasing Q_0

Summary & conclusions

- **Active cancellation a tool to in-situ lower magnetic fields at the cavity**
  - Demonstrated by increased Q_0 after cancellation with slow cooldown
  - Best Q_0 for was with active cancellation & 32 g/s FCD
  - **Insurance technique for better performing CMs**
    - Especially for accelerator tunnels with greater longitudinal fields
    - For CMs with poor flux expelling cavities
    - In the event fast cooldown does not provide sufficient ΔT for all cryomodules
- *Fluxgates critical! Must be integrated in all CMs*
  - Would not be able to observe fields without them

SLAC tunnel Z-component magnetic fields

- Measured in ***empty*** tunnel
  - Max = 293 mG
  - Avg ≈ 100 mG
- Fields during installation may be worse due to new components in tunnel



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