



# Magnetic Field Management for SRF

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TTC/ARIES topical workshop on flux trapping and magnetic shielding  
8 November 2018

# Motivation

- Nb used for SRF cavities susceptible to trapping external magnetic fields
- Trapped magnetic fields at RF surfaces a contributor to  $R_s$ 
  - $R_s \downarrow \rightarrow Q_0 \uparrow \rightarrow P_{\text{diss}} \downarrow \rightarrow \$\$_{\text{oper}} \downarrow$
- External magnetic field specifications at cavity RF surfaces constantly reduced for improved  $Q_0$
- LCLS-II specification:
  - $B_{\text{avg}} < 5$  mG to reach  $Q > 2.7 \times 10^{10}$  at 2 K, 16 MV/m
- Facilities specification:
  - As low as reasonably achievable

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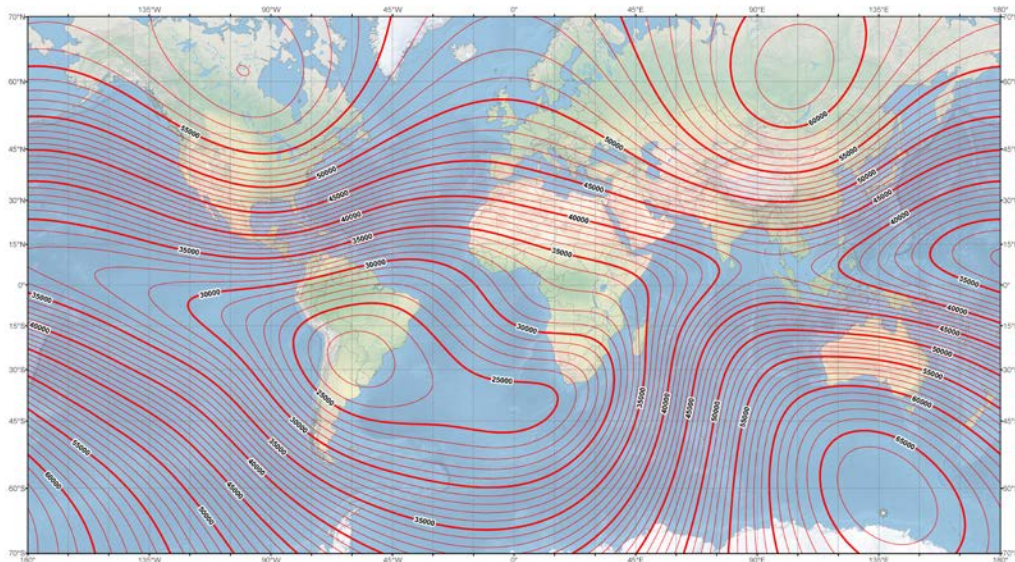
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# Sources of magnetic fields

Source	Magnetic field magnitude	Possible solutions
Earth	~0.5 G	High permeability passive magnetic shield
Components	>1 G	Passive shield + magnetic hygiene
Field enhancement due to shield proximity	>20 mG	Active cancellation
Solenoid / magnets	>1000 G	Degauss before warm-up

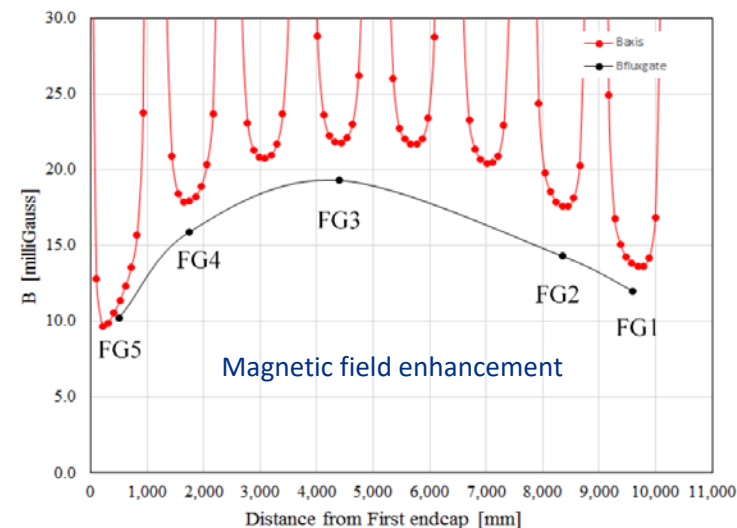
US/UK World Magnetic Model - Epoch 2015.0  
Main Field Total Intensity (F)



Main Field Total Intensity (F)  
Contour Interval: 1000 nT  
Magnetic Projection  
①: Position of dip poles

National Centers for Environmental Information,  
National Oceanic and Atmospheric Administration

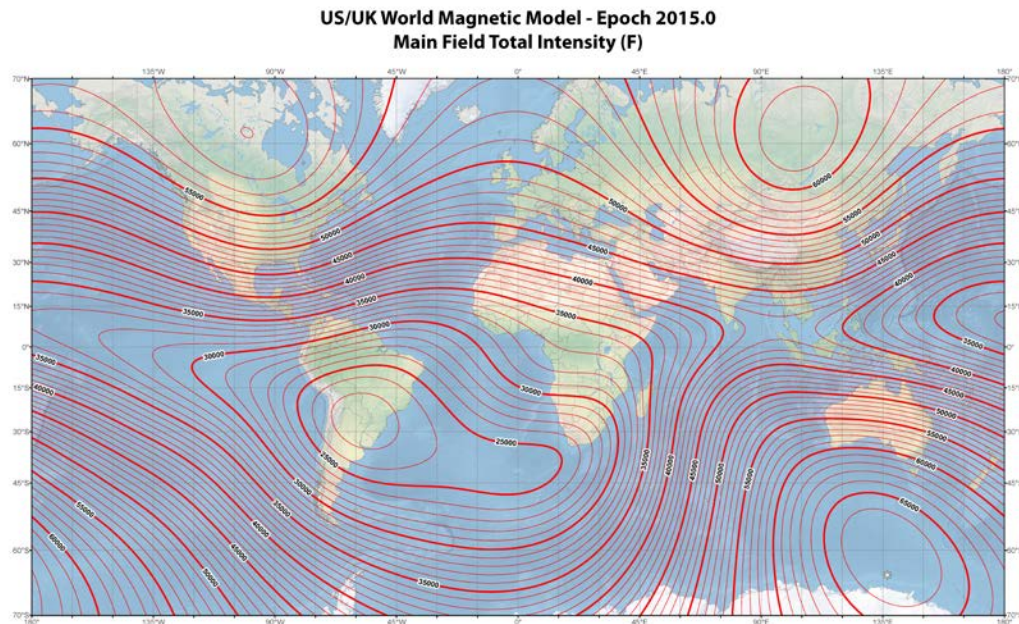
Map developed by NOAA/NGDC & CRES  
<http://ngdc.noaa.gov/geomag/WMM>  
Map reviewed by IAGA and IUGG  
Published December 2014



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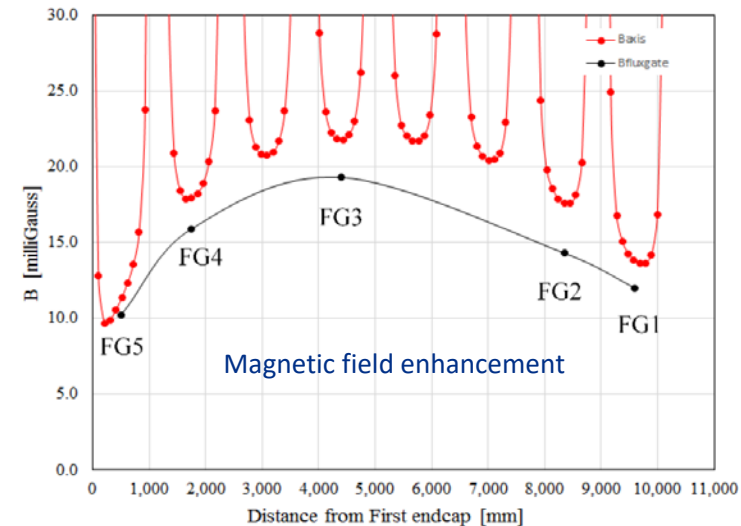
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# Passive magnetic shielding

- Global shields
  - Large volumes
  - For CMs:
    - Room temperature shields
    - Mu-Metal
  - For Test Dewars:
    - Room or cryo temperatures
    - Mu-Metal or Cryo versions
  - Smallest fields obtained  $\sim 10$  mG

Shield for Dewar

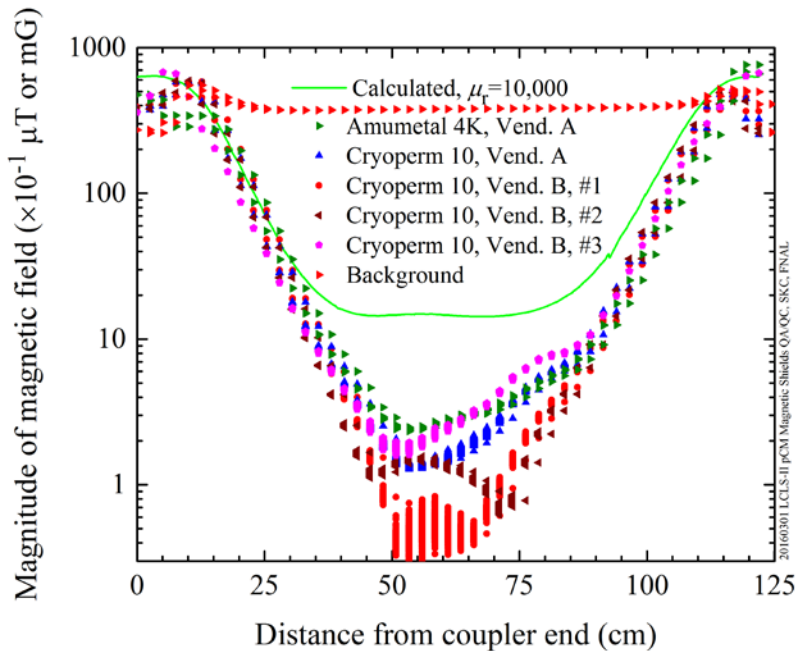


# Passive magnetic shielding

- Local shields outside cavity
  - Cryogenic temperature (4—25 K) & Cryo-compatible version of Ni-Fe alloys
  - LCLS-II shields & vendors qualified
    - Attenuation measurements



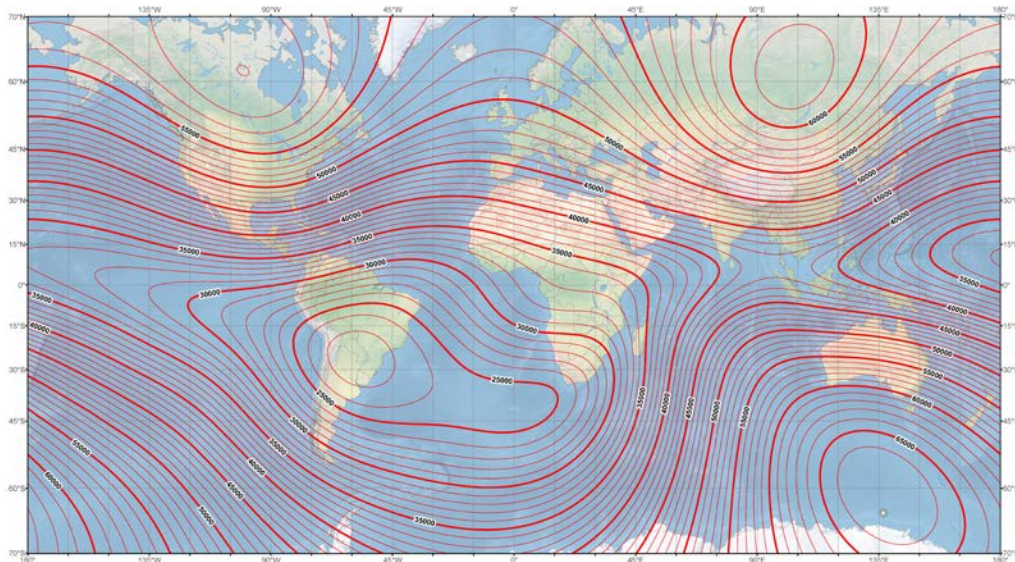
Local shield for LCLS-II



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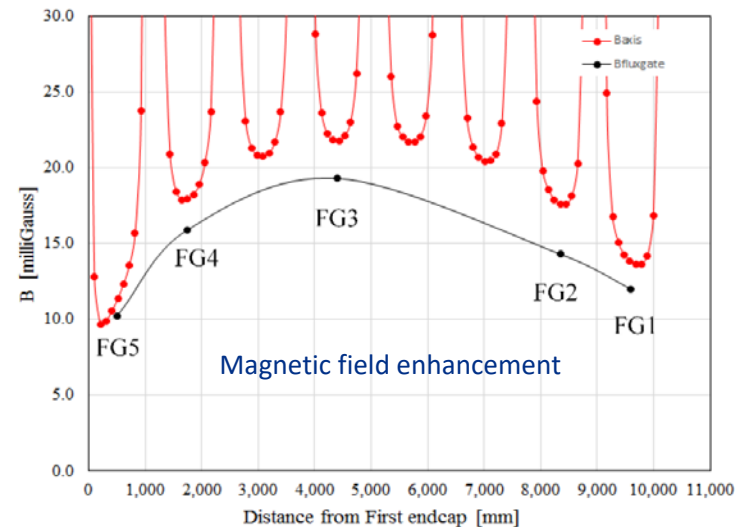
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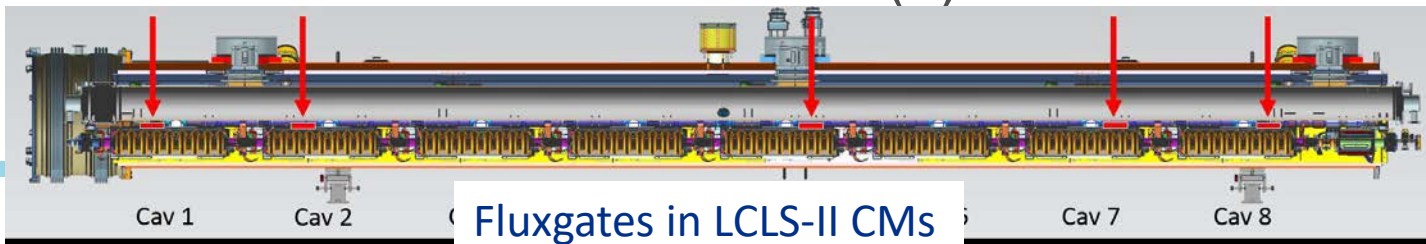
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# Magnetic hygiene

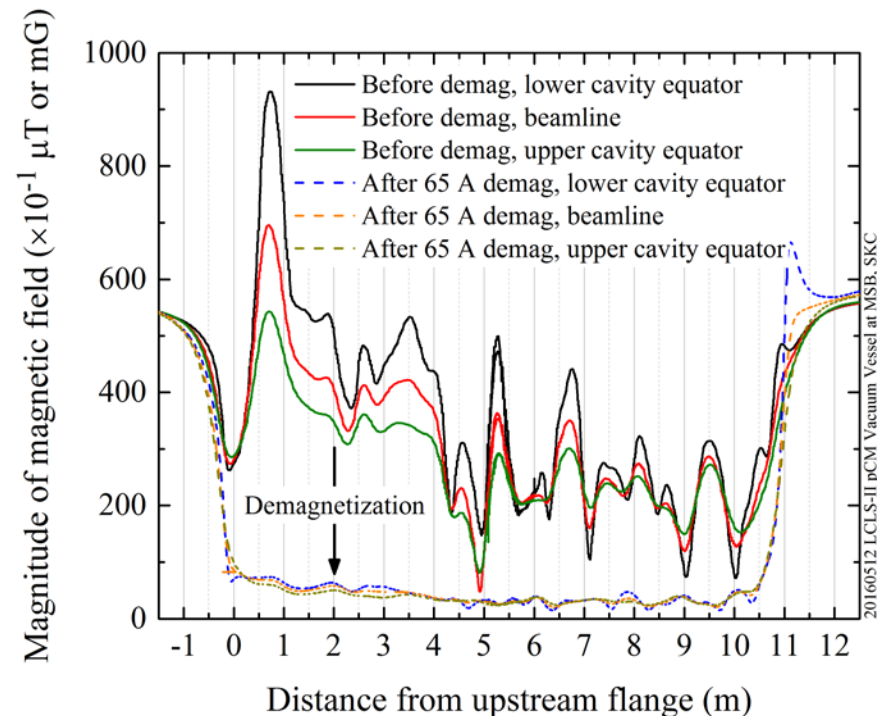
- Material choices
  - Non-magnetic materials
    - Brass, bronze, etc.
  - Low relative magnetic permeability
    - Stainless steels: 316LN, 316L, 316
    - DO NOT use: relative permeability probe – magnetizes component
    - Use direct residual magnetic field measurements to qualify
- Inspection & demagnetization of components near cavities
  - ALL low permeability material checked just prior to assembly
  - Table top demagnetizer proved sufficient to demagnetize
- Instrumentation to measure field(s) in-situ



# Magnetic hygiene – Vessel Demagnetization

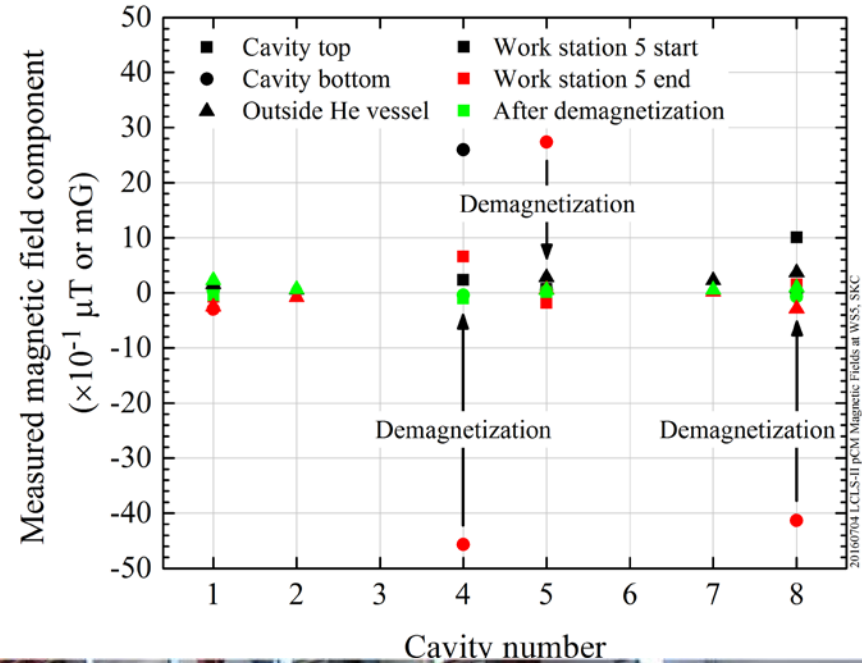


- Demagnetization of vacuum vessel
  - Carbon steel: easier to demagnetize & acts as passive shielding
  - Manufacturing operation results in  $>800$  mG

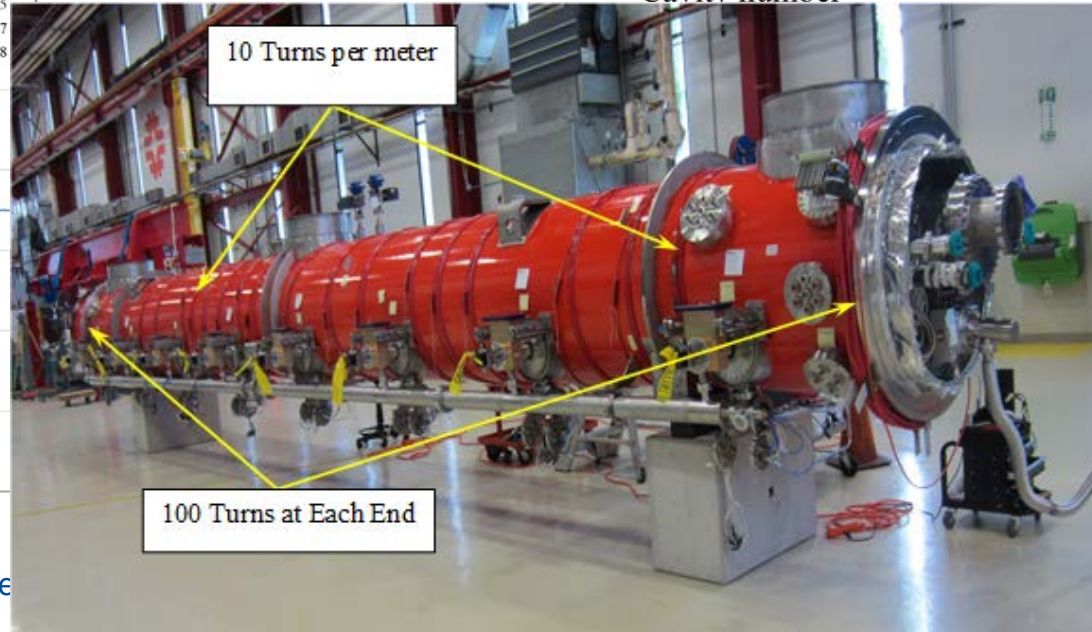
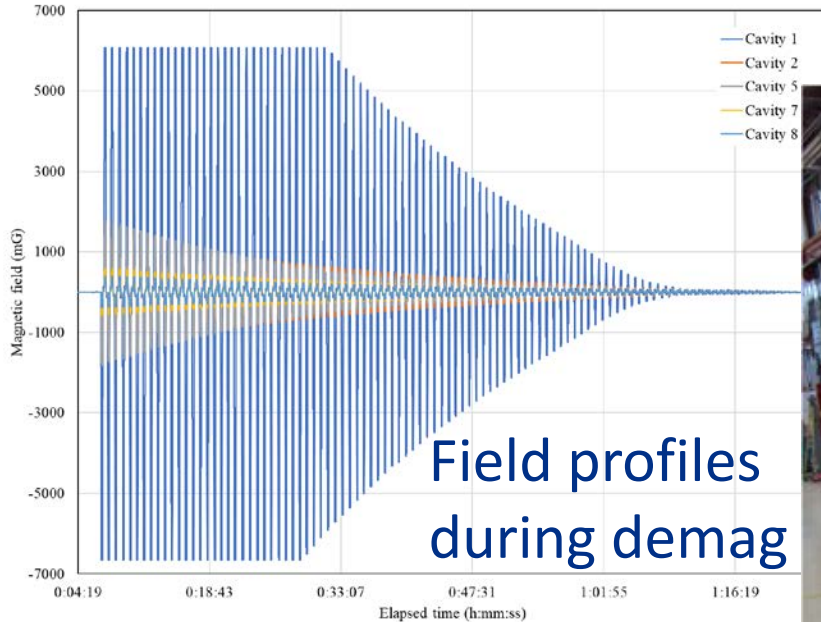


# Magnetic hygiene – Cryomodule Demagnetization

- Demagnetization of assembled cryomodule / vessel
  - Assembly processes magnetize high permeability components
    - Magnetic shields & carbon steel

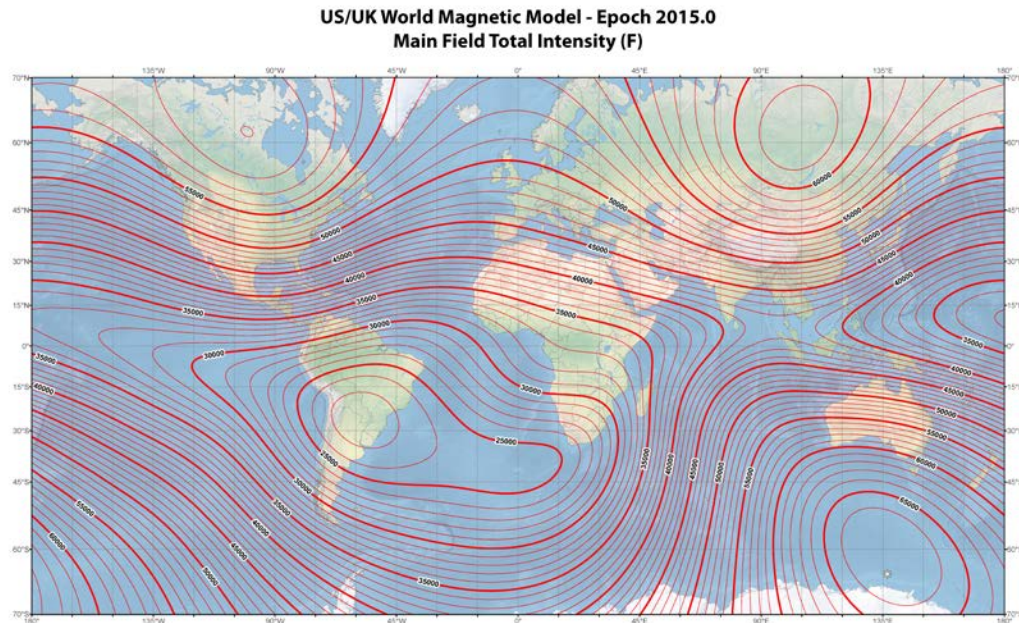


20170809 F1.3-04 Demagnetization in CMTS1 after installation



# Sources of magnetic fields

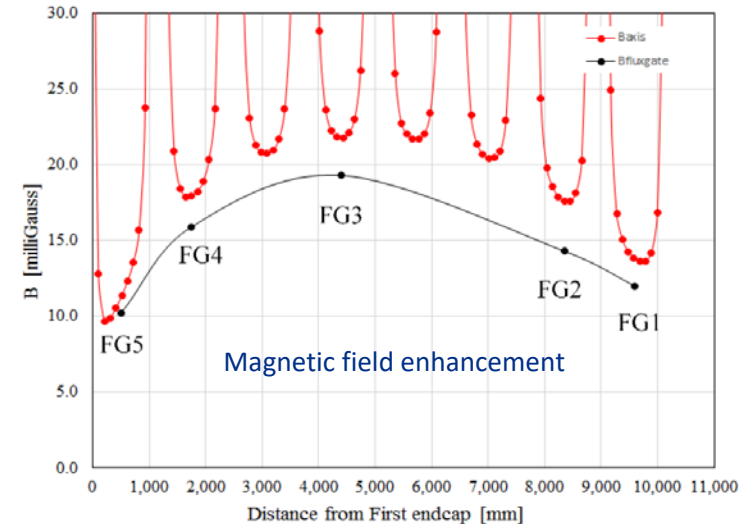
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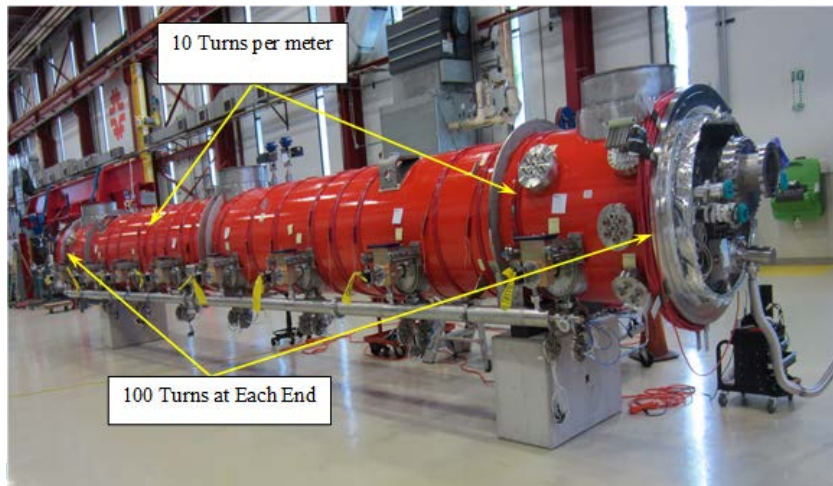
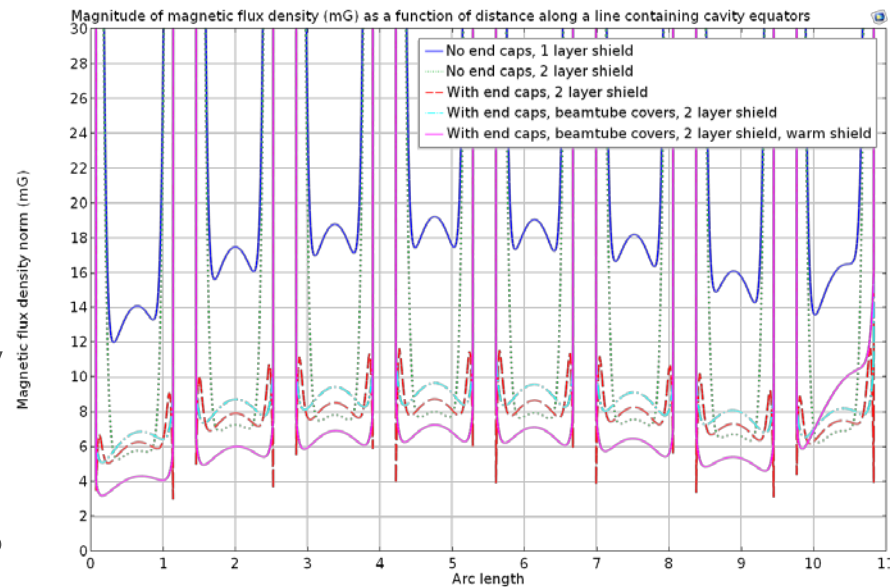
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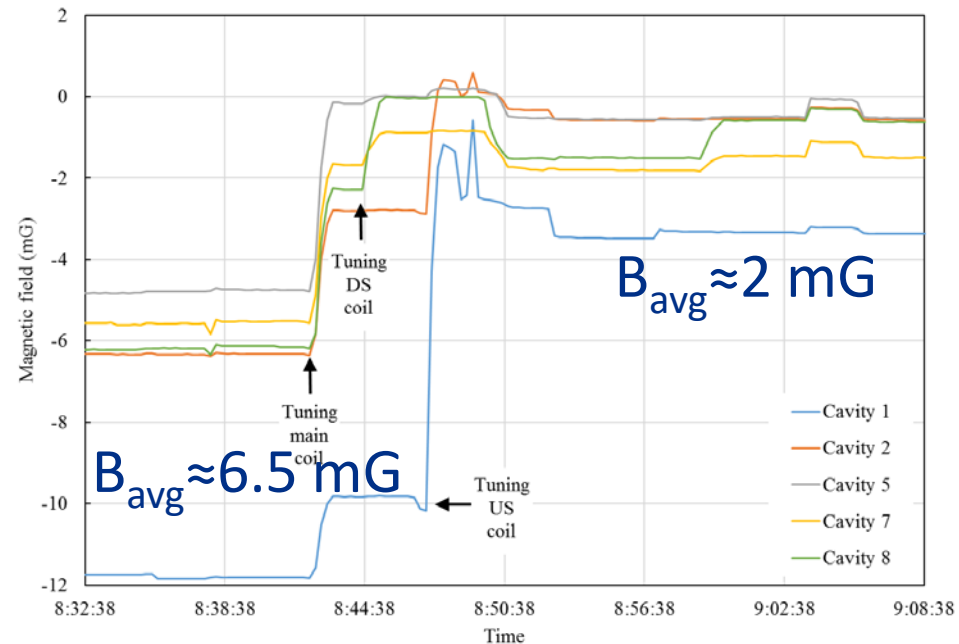
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# Active cancellation (AC)

- Cavities & CMs may couple with each other to decrease longitudinal shielding efficiency
- AC is insurance for lower fields



20170823 F1.3-04 Active Cancellation Coils Tuning at 25 K



# Active cancellation test

Cavity	Q <sub>0</sub> 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
<b>Average</b>	<b>3.39E+10</b>	<b>2.90E+10</b>	<b>1.74E+10</b>	<b>2.55E+10</b>	<b>3.16E+10</b>



- Active cancellation → improves Q<sub>0</sub>
- Active cancellation + 32 g/s → greatest Q<sub>0</sub> at CMTS

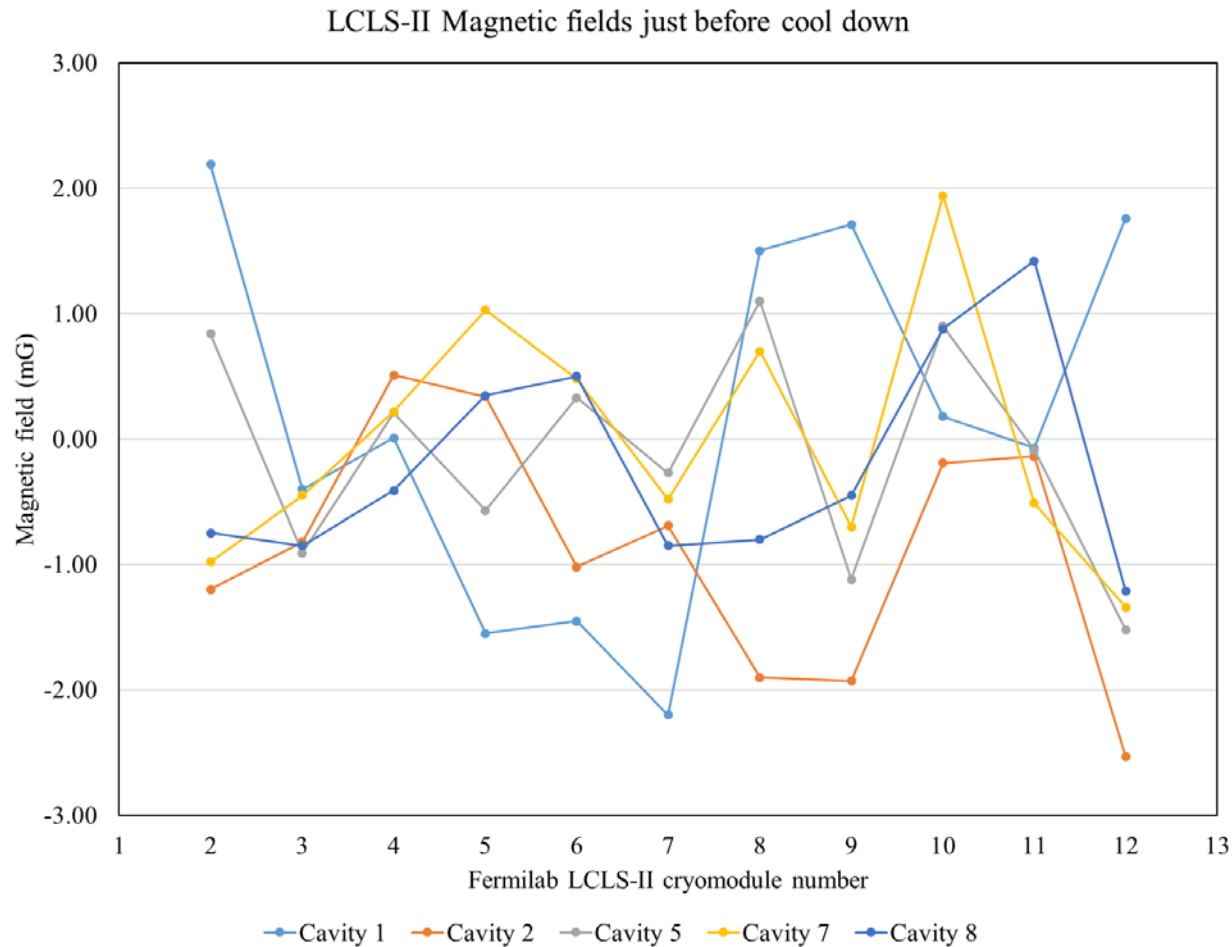
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CAV0019	3.71E+10	2.95E+10	1.65E+10	2.69E+10	3.52E+10
CAV0041	3.53E+10	2.91E+10	1.75E+10	2.97E+10	3.74E+10
CAV0030	3.62E+10	3.28E+10	2.10E+10	2.97E+10	3.64E+10
CAV0020	3.50E+10	2.92E+10	1.80E+10	2.77E+10	3.12E+10
CAV0051	3.36E+10	2.91E+10	1.75E+10	2.75E+10	3.12E+10
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# Production LCLS-II CMs: fields before cooldown



- All CM measured fields <2.5 mG
  - 1 axis (<2.88 mG assumed to meet 5 mG spec for magnitude)

# Summary

- Multiple techniques available to be used to manage magnetic fields in CMs and facilities
- LCLS-II CMs have successfully demonstrated low magnetic fields at cavity resulting in high Q
- For  $<5$  mG at cavities, requirement:
  - Passive & active magnetic shielding
  - Magnetic hygiene & demagnetization
- Active cancellation insurance to lower fields with unknowns in tunnel and installation
- Challenges exist even with all the techniques

# Challenges (1): passive magnetic shielding

- Shield design begins with computational magnetic model
- Typical shield thicknesses are 1—2 mm
- CM length may be as much as ~12500 mm
  - i.e., ~4 orders of magnitude difference
- Presents computational challenges, even when using clever techniques with meshing
- Cost: cryogenic shields typically higher in cost
  - Till date, no cheaper, high performing alternative

## Challenge (2): magnetic hygiene

- Possibility of magnetic hygiene checked parts getting re-magnetized exists
- CM demagnetization addresses higher permeability materials
  - i.e., carbon steel vessels & Ni-Fe alloy magnetic shields
- In-CM sensors may not detect all fields, due to smaller detection volume
  - Cost & reliability have been bottlenecks
  - Presence of greater fields may only be inferred from Q of CM, but typically too late to mitigate