C50-11 Q0 Analysis

Rongli Geng

CEBAF SRF Workshop

April 3, 2014
Jefferson Lab

Outline

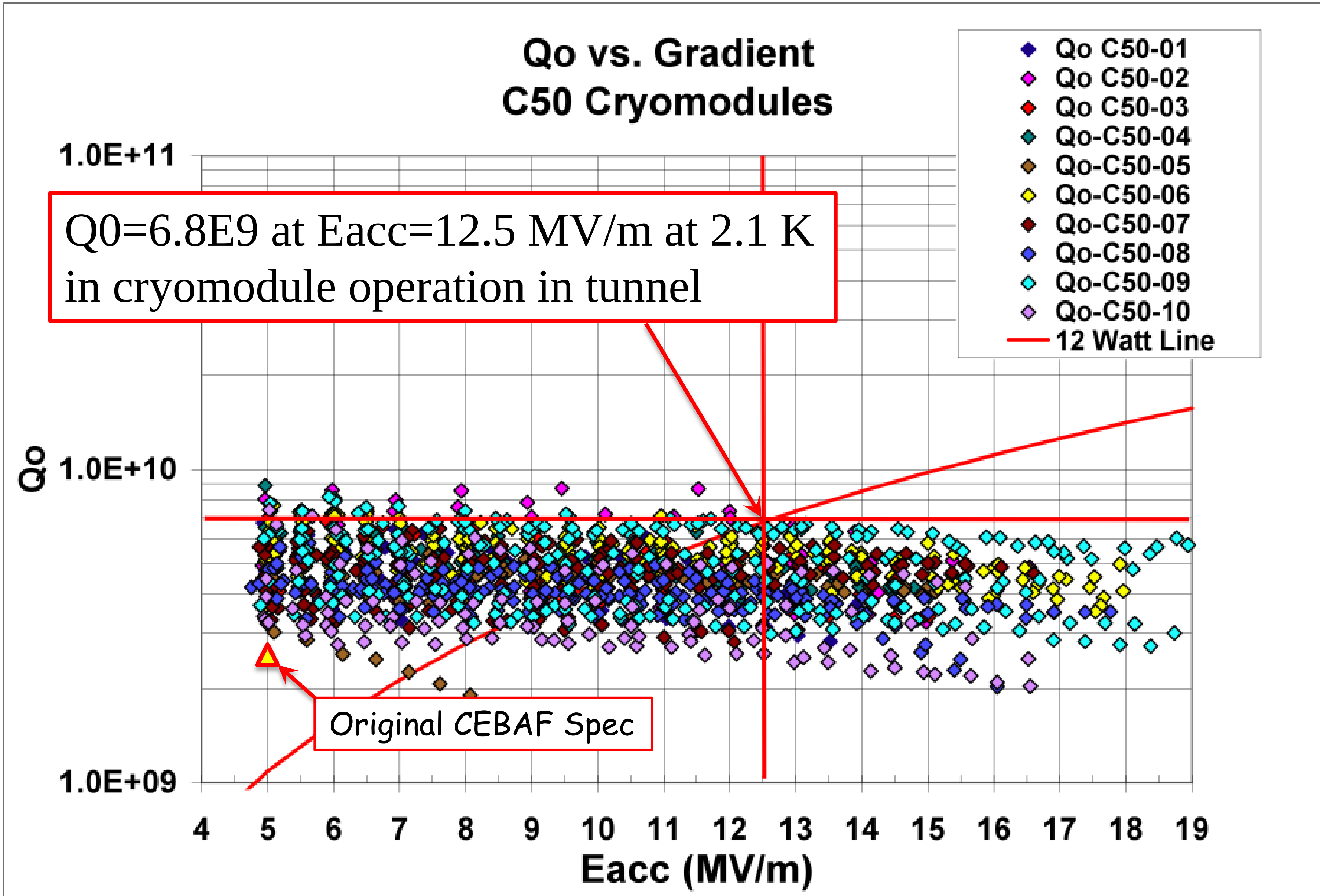
- C50 Q0 problem
- Motivation for understanding & solution
- C50-11 systematic components survey
- Major findings and recommendations
- Results and analysis
- What's next

C50 Top Level Parameters

- Raise gradient from 5 MV/m to 12.5 MV/m
- 100 W cryogenic load from RF dissipation at 2 K at 50 MV voltage (12.5 W per cavity at 12.5 MV/m)
  - Average static heat load at 2.1 K 13.2 W
- Q0 target 6.8E9 at 12.5 MV/m at 2.1K (M. Drury et al, PAC07, WEPMS059)
- Note original CEBAF design specification: cryomodule voltage 20 MV; cavity Q0 2.4E9 at 5 MV/m at 2 K. Q: is this spec the beam operation spec or the vertical cavity test spec?
- Original CEBAF cryomodules met 20 MV voltage spec at 45 W cryogenic load from RF dissipation

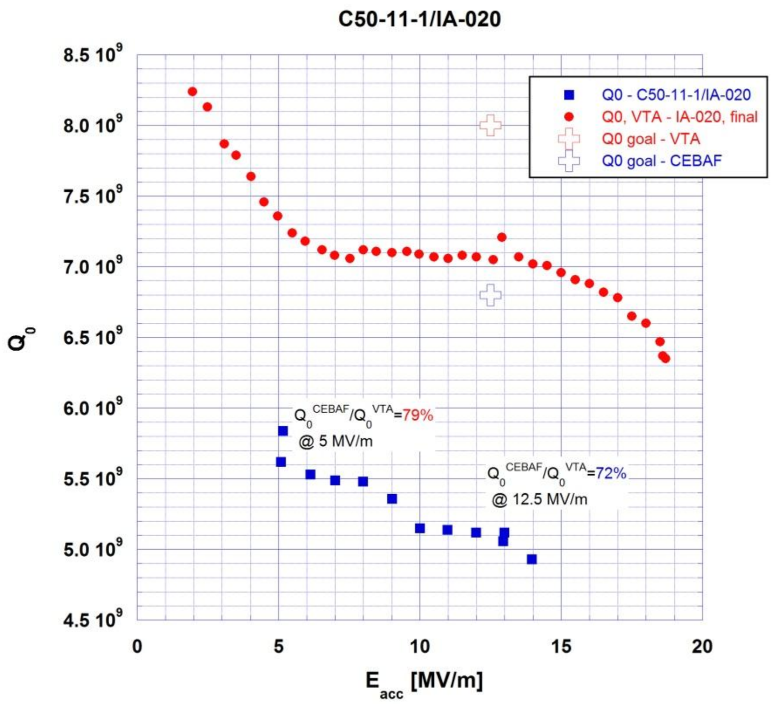
C50-01 Re-worked Cryomodule

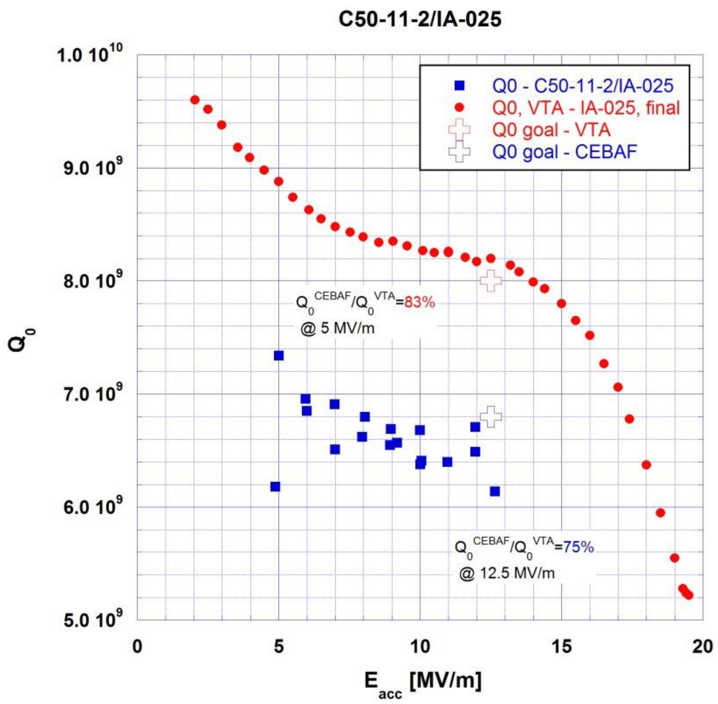
- Gradient reached target 12.5 MV/m on average
- No cavity reached target Q0 in commissioning test in CEBAF tunnel
- On average, Q0 in commissioning test is a factor of 2 lower than that in cavity vertical test
  - Q0 at vertical test > 1E10 at 12.5 MV/m
- At 6 MV/m, Q0 ~ 5E9 (observation by RG)
- In original 1992 commissioning test in CEBAF tunnel, Q0 ~ 5E9 at 6 MV/m (observation by RG from data provided by Drury; but there are exceptions when compared with Mammosser's paper published at SRF1993, more see later)
- Q0 at 6 MV/m is literally unchanged (Observation by RG: no improvement from re-work)



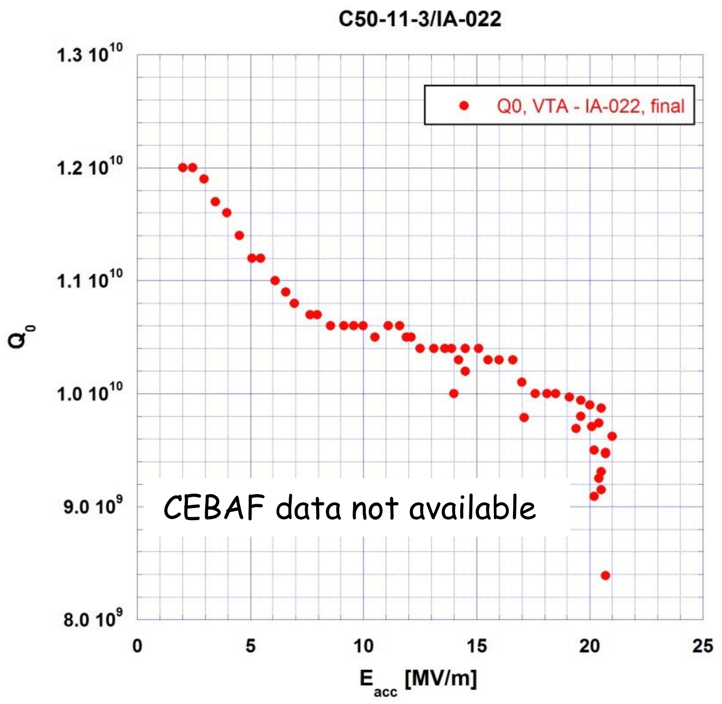
M. Drury et al., PAC2011, TUP108

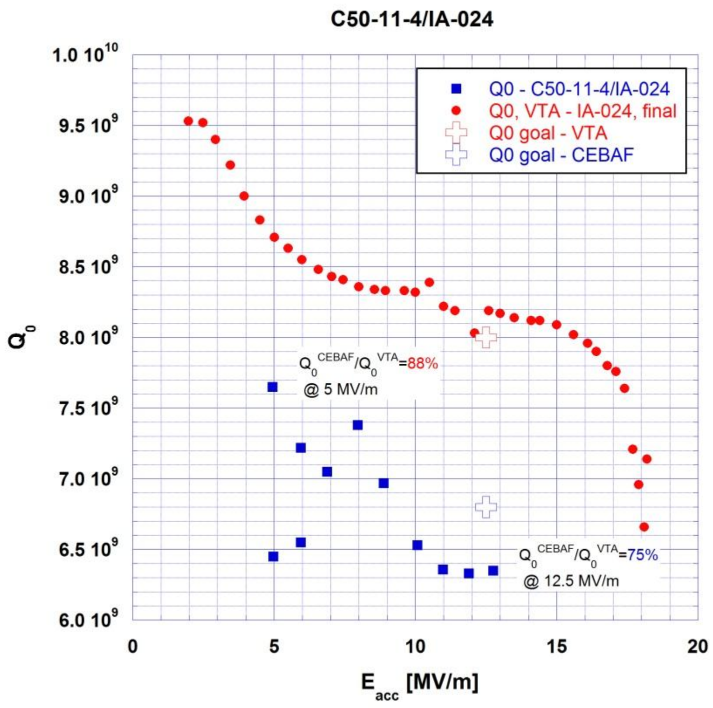
C50-11 Q(Eacc) CEBAF vs VTA



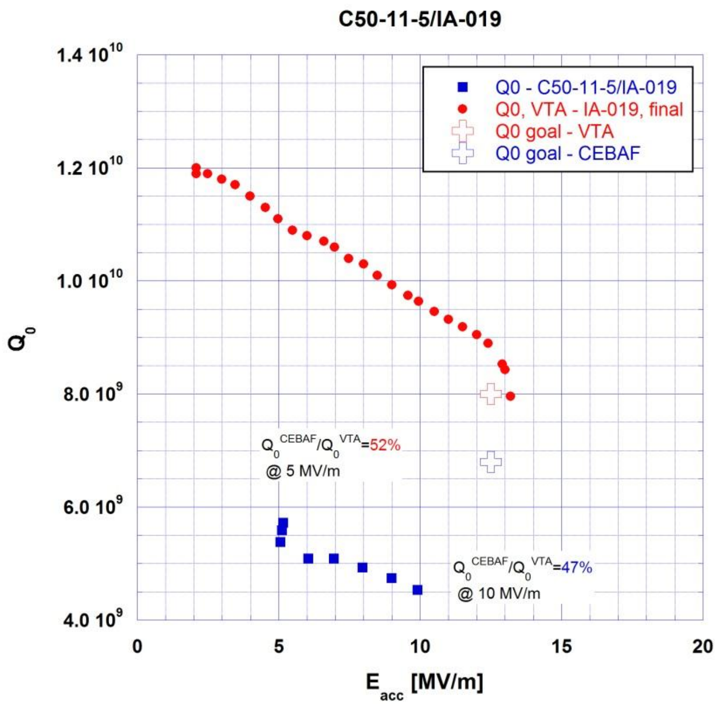


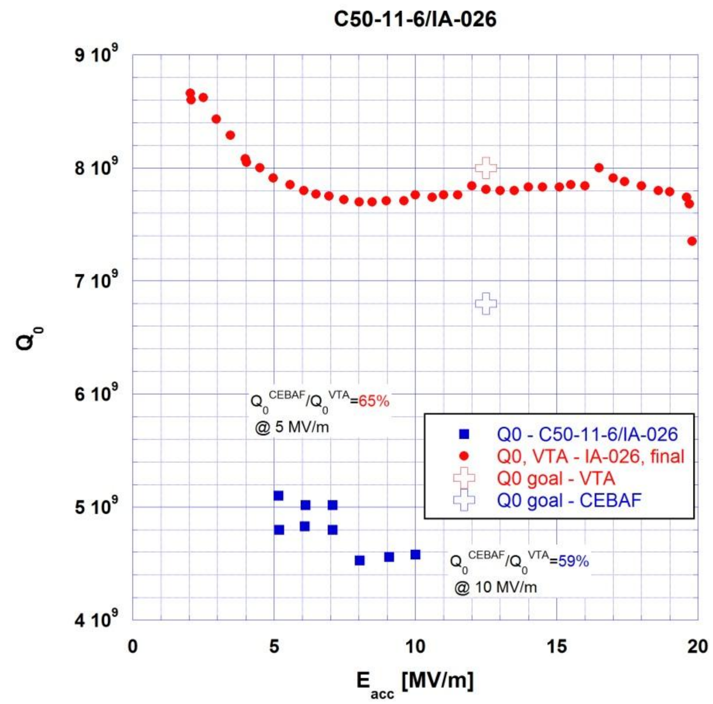
C50-11 Q(Eacc) CEBAF vs VTA



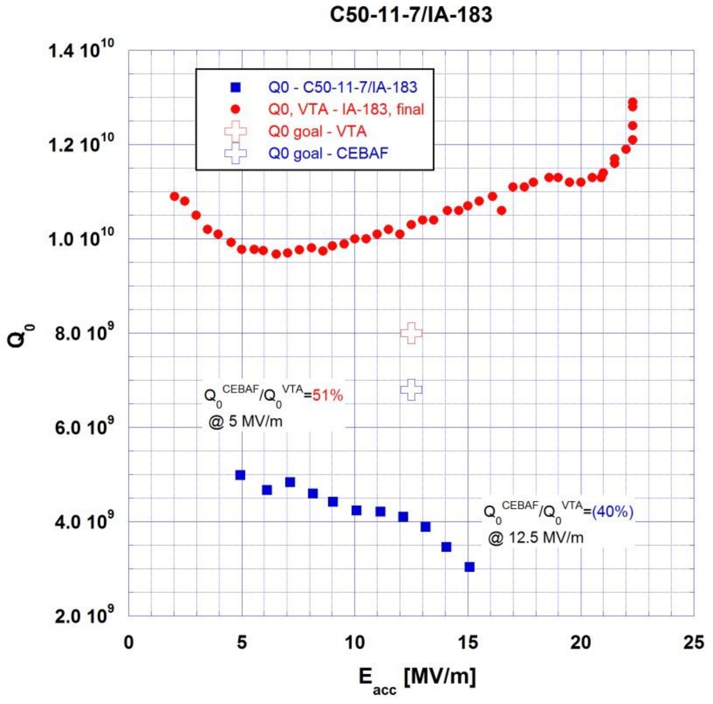


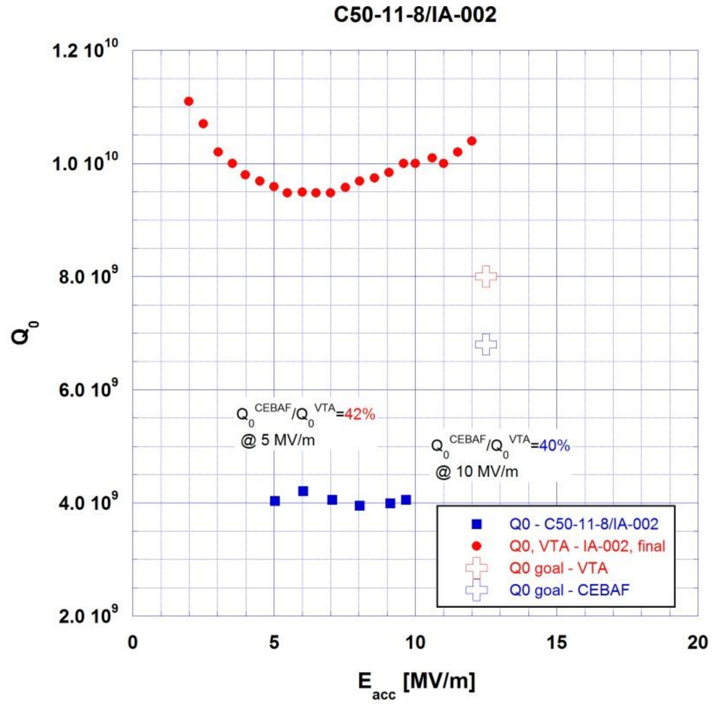
C50-11 Q(Eacc) CEBAF vs VTA



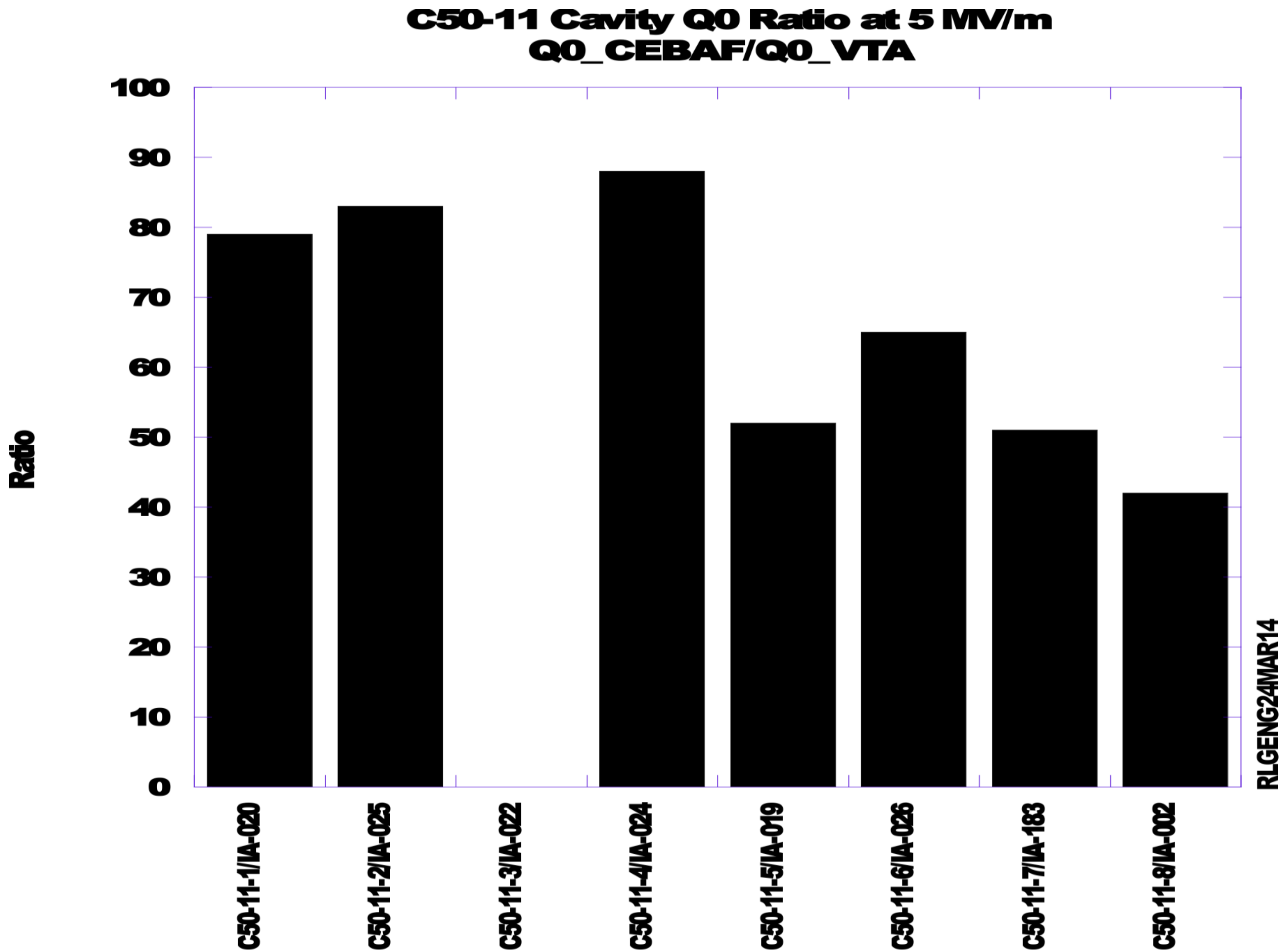


C50-11 Q(Eacc) CEBAF vs VTA





Q (at 5 MV/m) Reservation from VTA to CEBAF



Q0 Degradation in Original 1992-1993 Tests

(compiled by RG based on Mammosser's SRF93 paper)

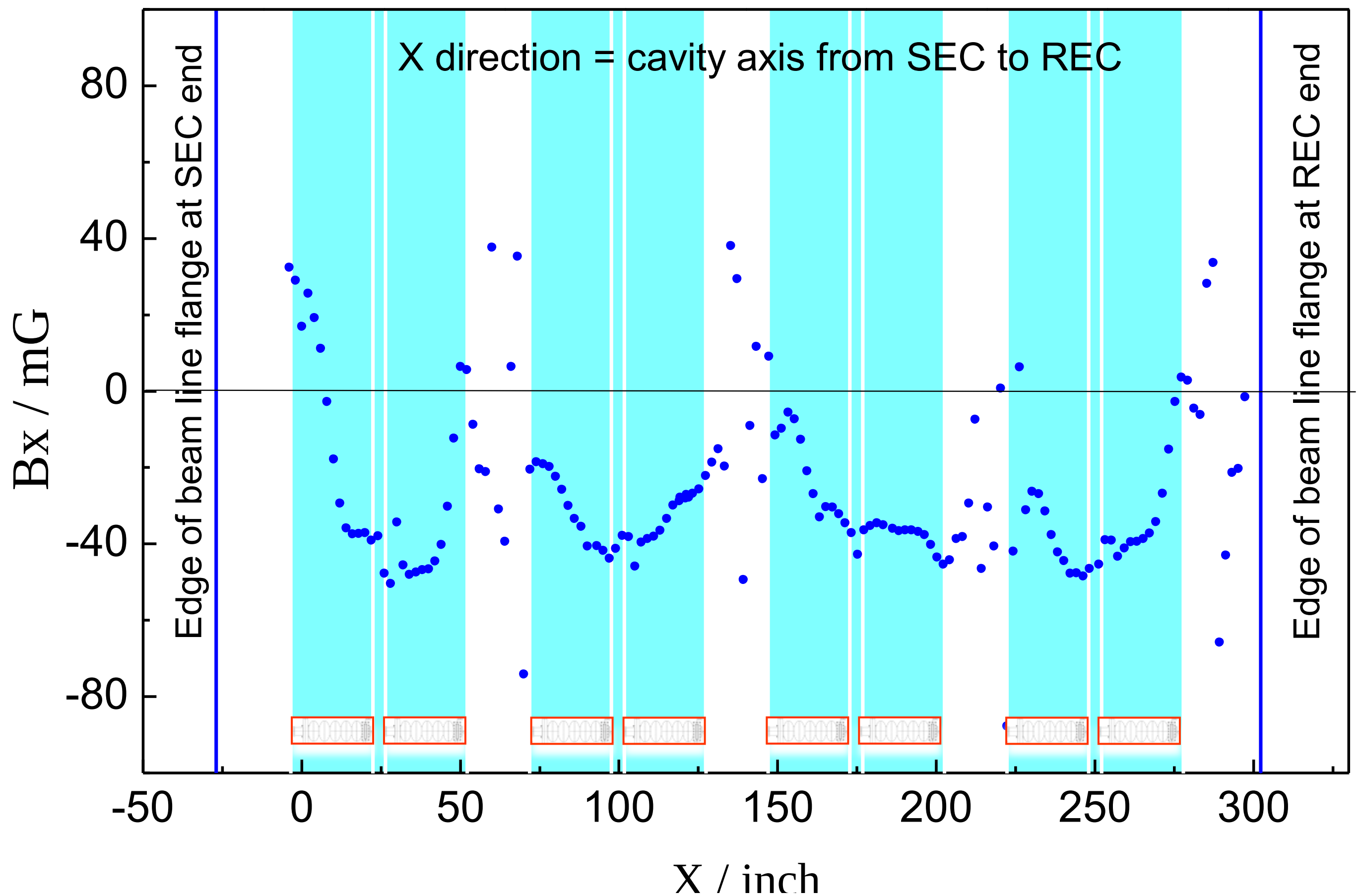
Cavity	Vertical test	Cryomodule test SL M8	Degradation/note
IA284	Q0=1E10 at 6.3 MV/m FE onset at 6.3 MV/m	Q0=8E9 at 6 MV/m; FE onset 6 MV.m	10E9 -> 8E9 at 6 MV/m (-20%)
IA50	Q0>=1E10 up to 10 MV/m; FE onset 10 MV/m	Q0=8E9 at 8 MV/m; FE onset 8 MV/m	10E9 -> 8E9 at 8 MV/m (-20%)
IA142	Q0=4E9 at 10 MV/m; FE onset 15.2 MV/m	Q0=5E9 at 10 MV/m; FE onset 10.8 MV/m	Q0 improved (+25%)
IA64	Q0=9E9 at 10 MV/m; FE onset 11.5 MV/m	Q0=2E9 at 2 MV/m	* Steep Q-slope at cryomodule test; ** ion pump tripped several times after vertical test
IA210	Q0=1E10 at 10 MV/m; No FE up to 11.6 MV/m	Q0=8E9 at 10 MV/; No FE up to 10.2 MV/m	10E9 -> 8E9 at 10 MV/m (-20%)
IA203	Q0=9E9 at 9 MV/m; No FE up to 10 MV/m	Q0=7.8E9 at 8.8 MV/m; FE onset 8.8 MV/m	9E9 -> 7.8E9 at 9 MV/m (-13%)
IA255	Q0=8E9 at 10 MV/m; No FE up to 18.2 MV/m	Q0=7E9 at 10 MV/m; No FE until 13.2 MV/m	8E9 -> 7E9 at 10 MV/m (-13%)
IA40	Q0=9E9 at 8 MV/m; FE onset 13.3 MV/m	Q0=6E9 at 8 MV/m; FE limit at >10 MV/m	9E9 -> 6E9 at 8 MV/m (-33%)

As-found SL10 (Victory) Magnetic Field Survey in TED High Bay

sensor penetration along central axis, longitudinal field only

As-Found On-Axis Magnetic Field in Complete Crymodule

Cavity location indicated by shaded area

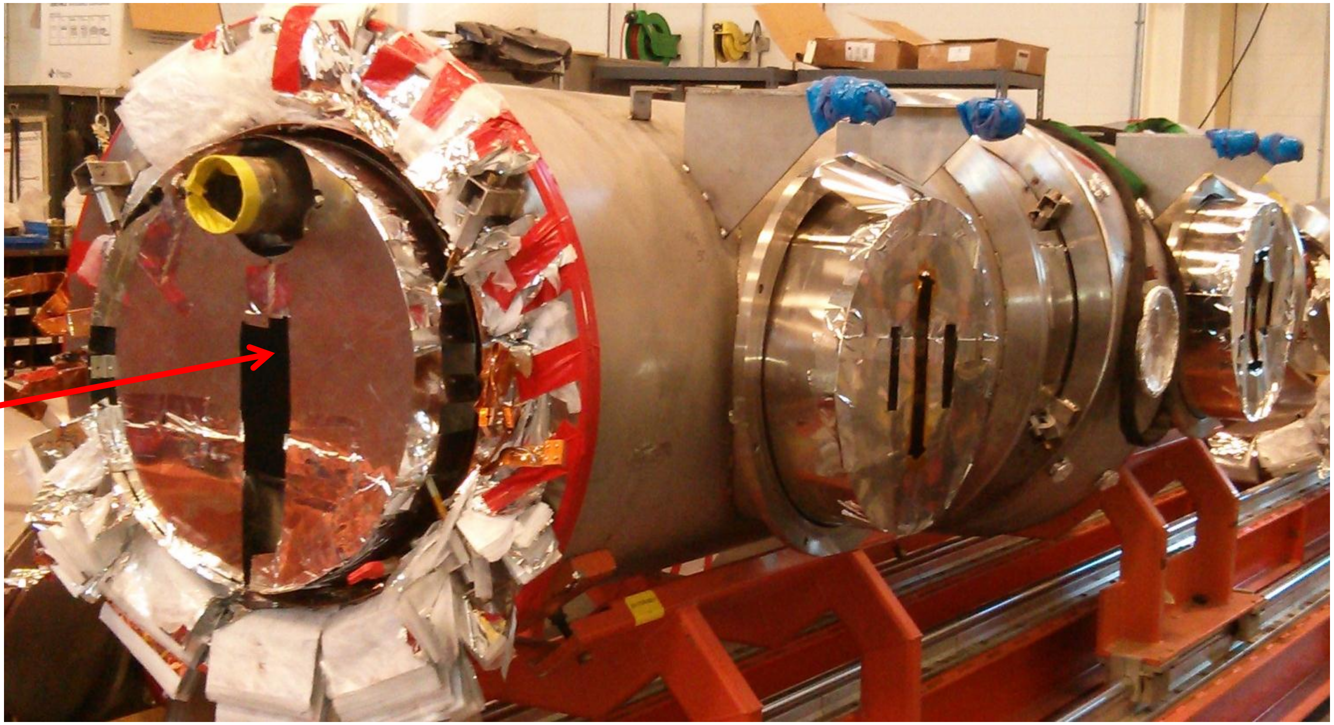


Survey of Mag. Field with Cavity and Tuuner Removed

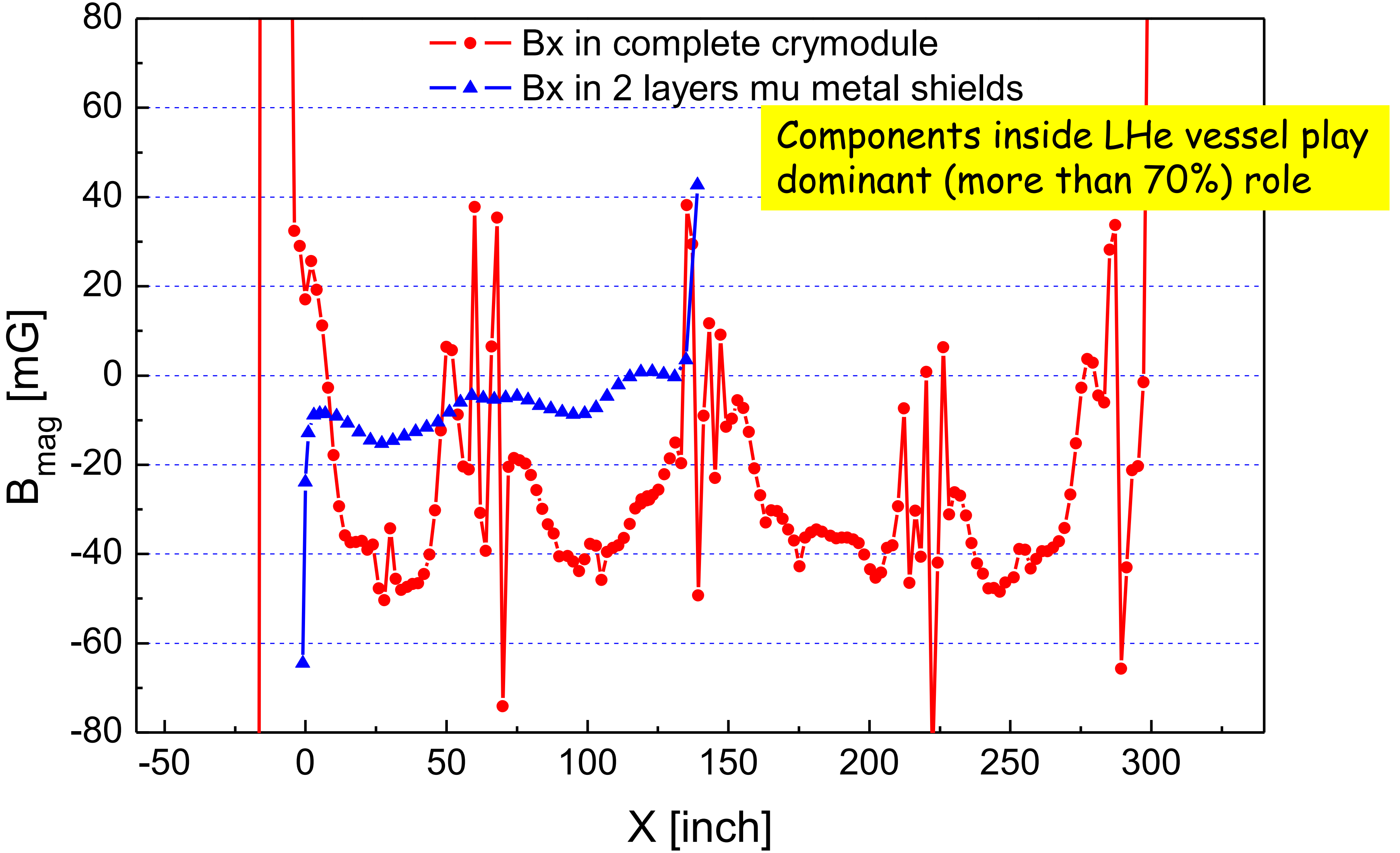
Two Cryounits with Original Magnetic Shields

On-Axis Longitudinal Field

Probe penetration

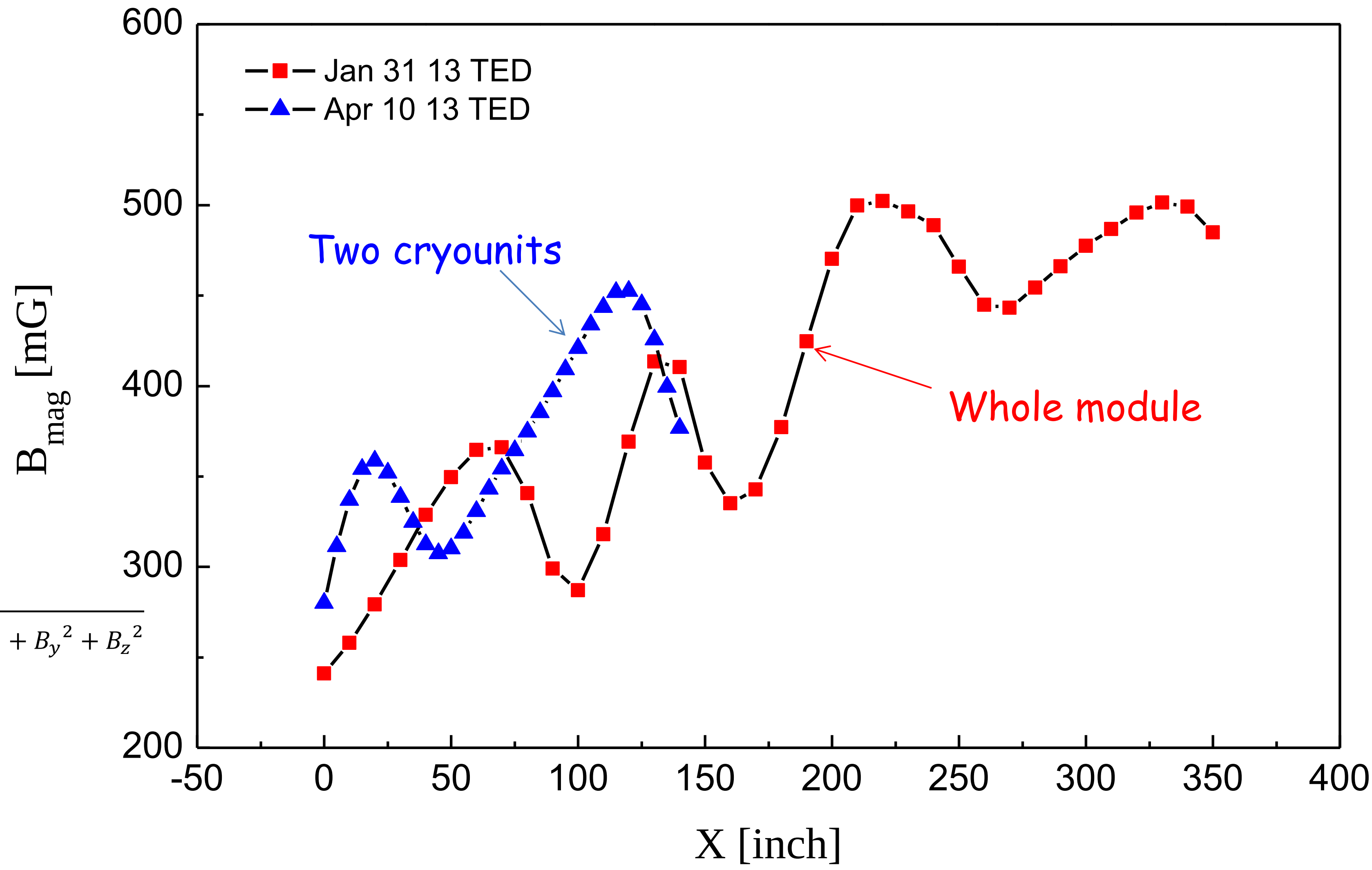


Comparison of Two Measurements



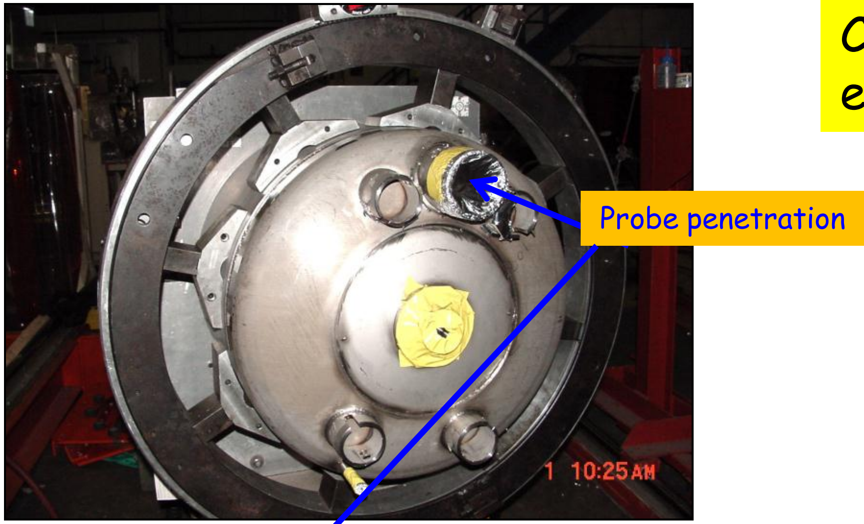
Ambient Magnetic Fields

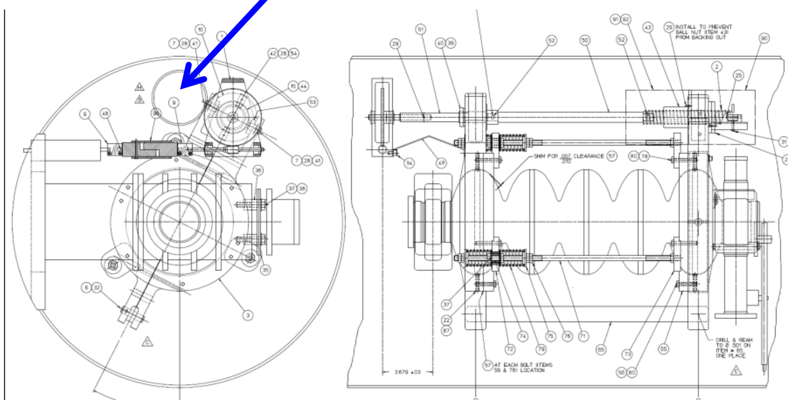
Field amplitude along same axis



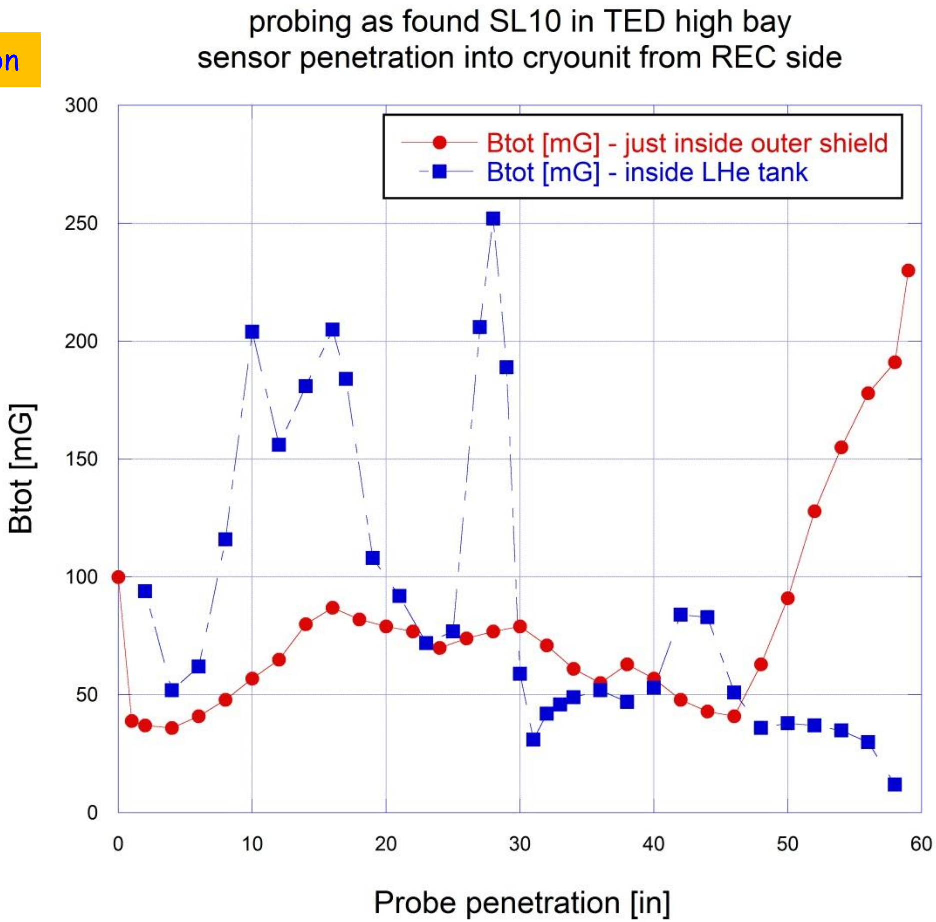
$$B_{mag} = \sqrt{{B_x}^2 + {B_y}^2 + {B_z}^2}$$

Additional Probing in As-Found Condition





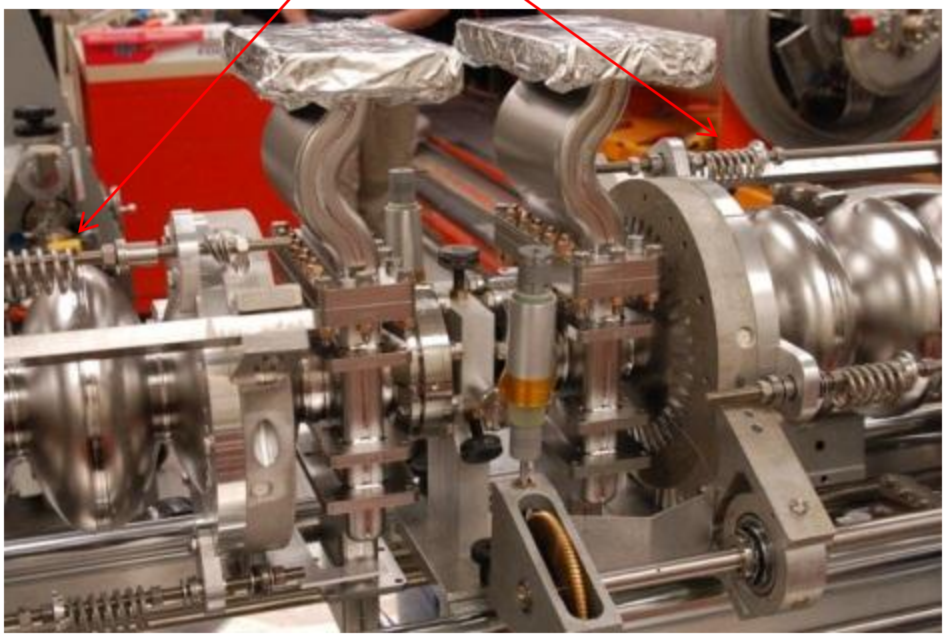
Components inside LHe tank generating excessive magnetic field further confirmed

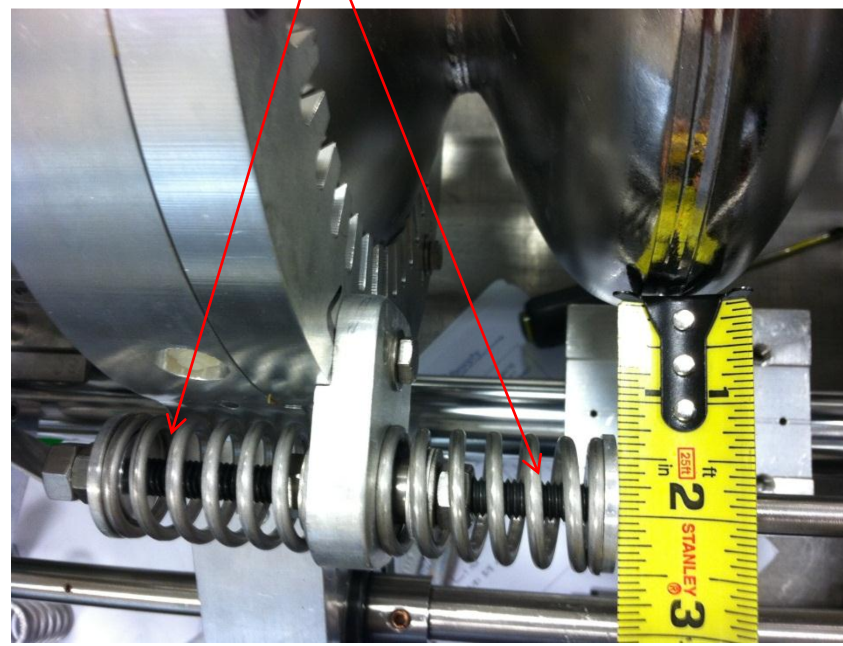


Discovery of Magnetized Strut Springs

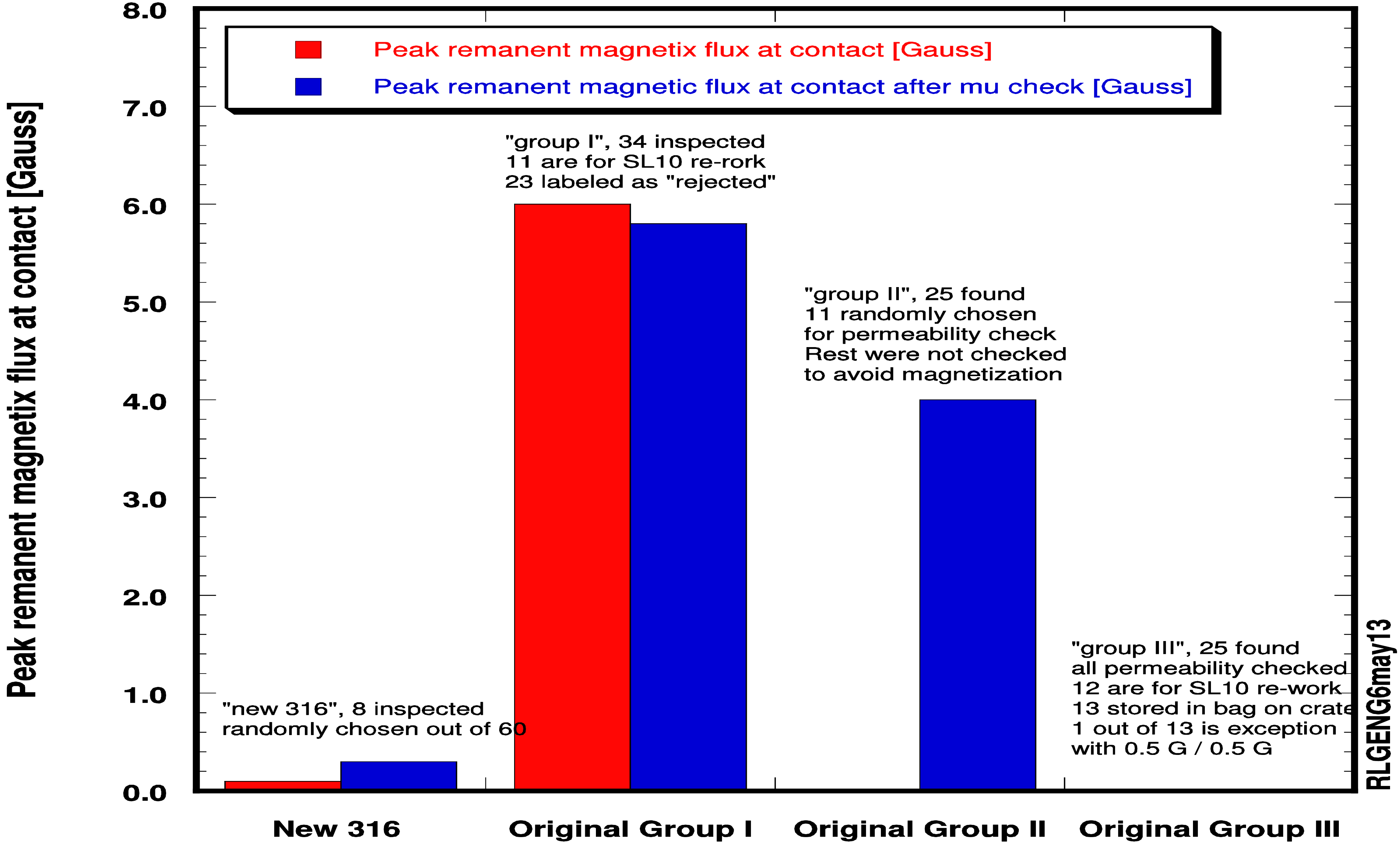
High-μ and high remanent field springs from original module

New low-μ and low remanent field Springs acquired and implemented

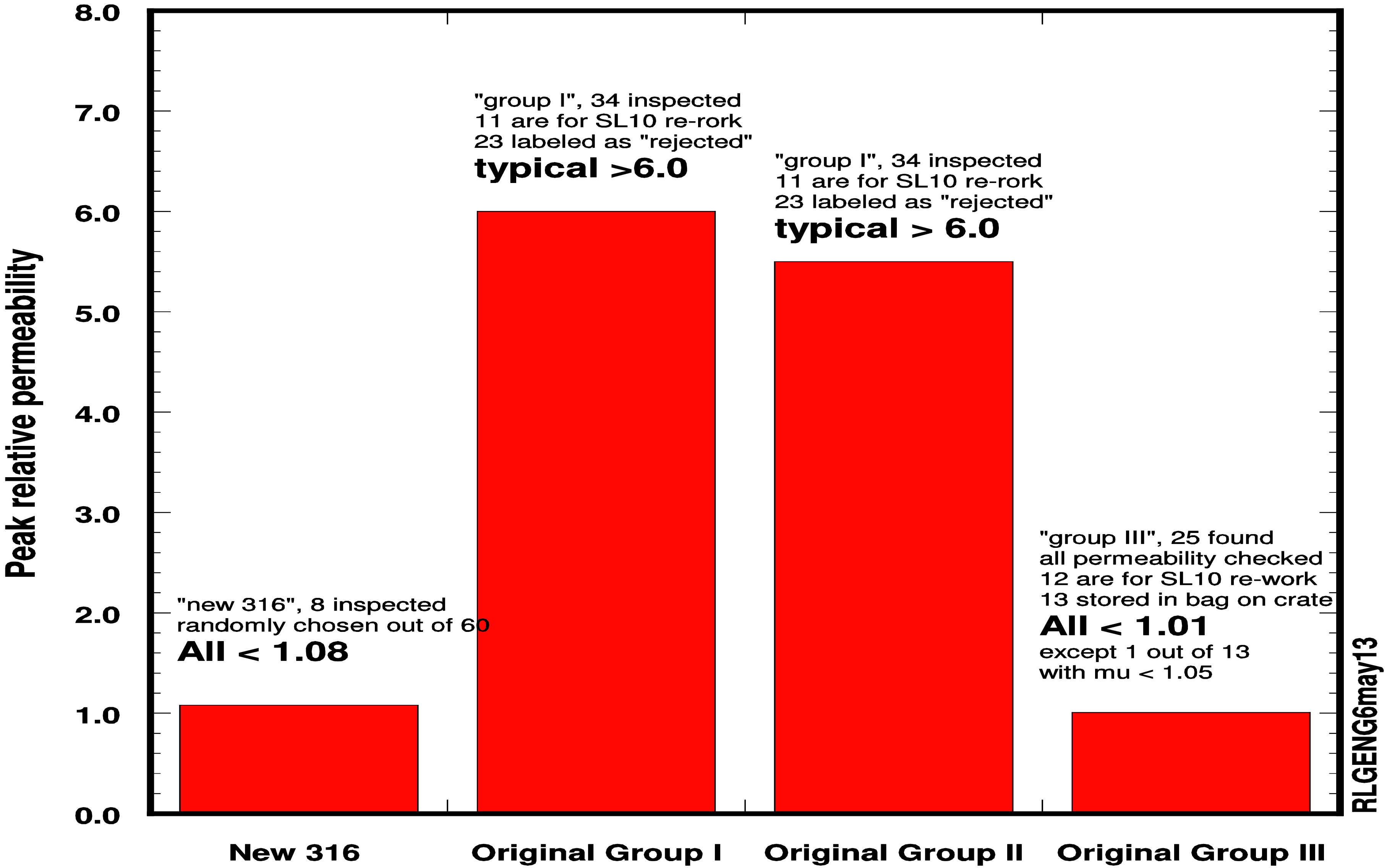




Remanent magnetic flux density of 4 groups of strut springs

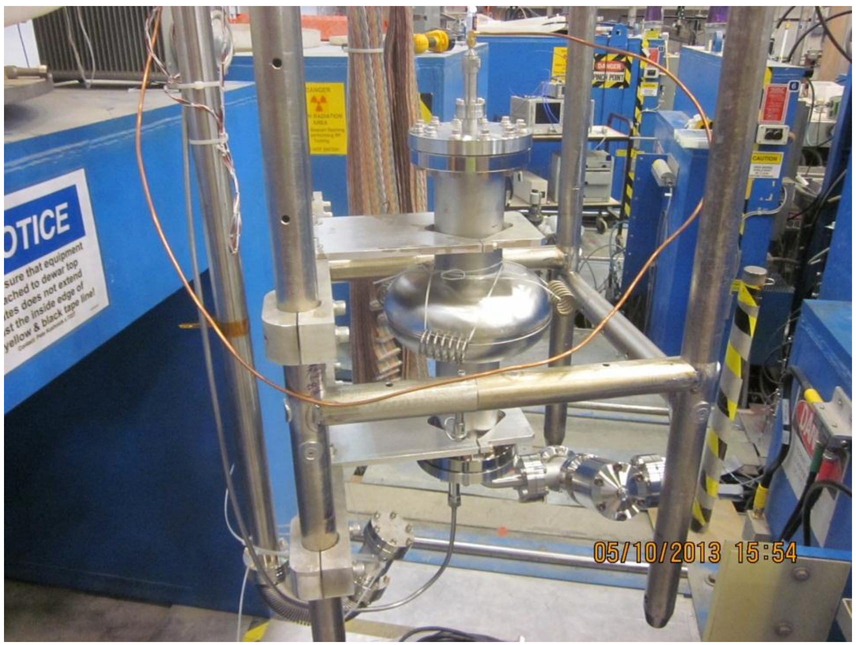


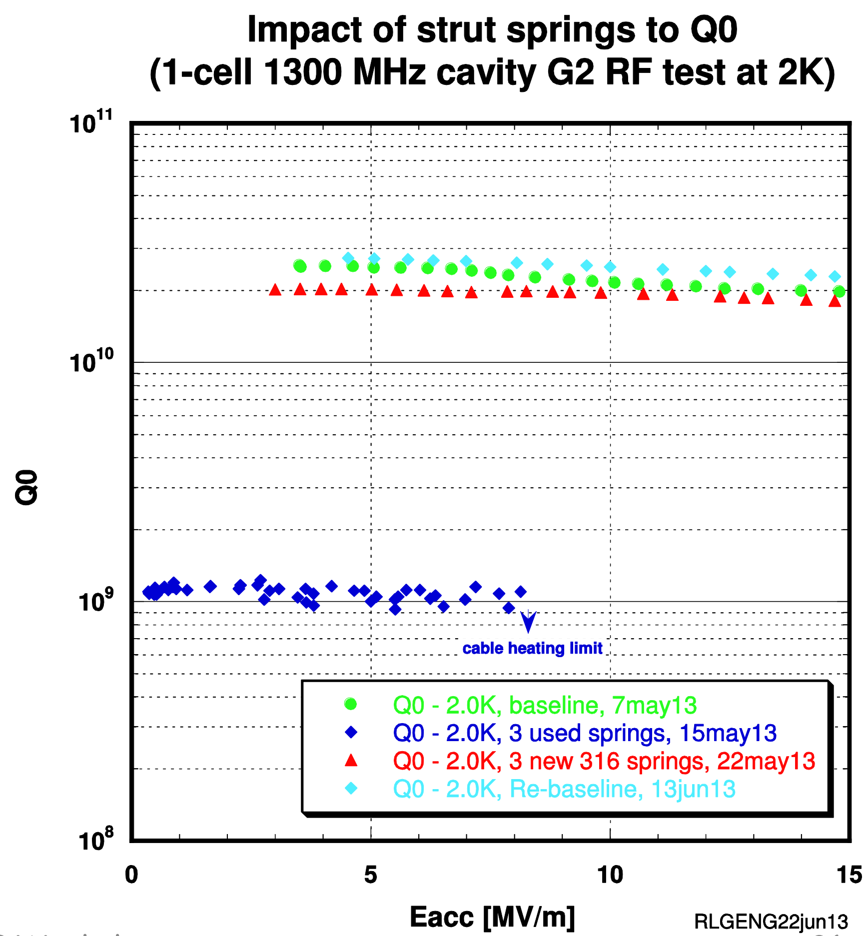
Peak magnetic permeability of 4 groups of strut springs



Assessment of Q0 Impact by Springs As-found vs New 316

New 316 springs far better !

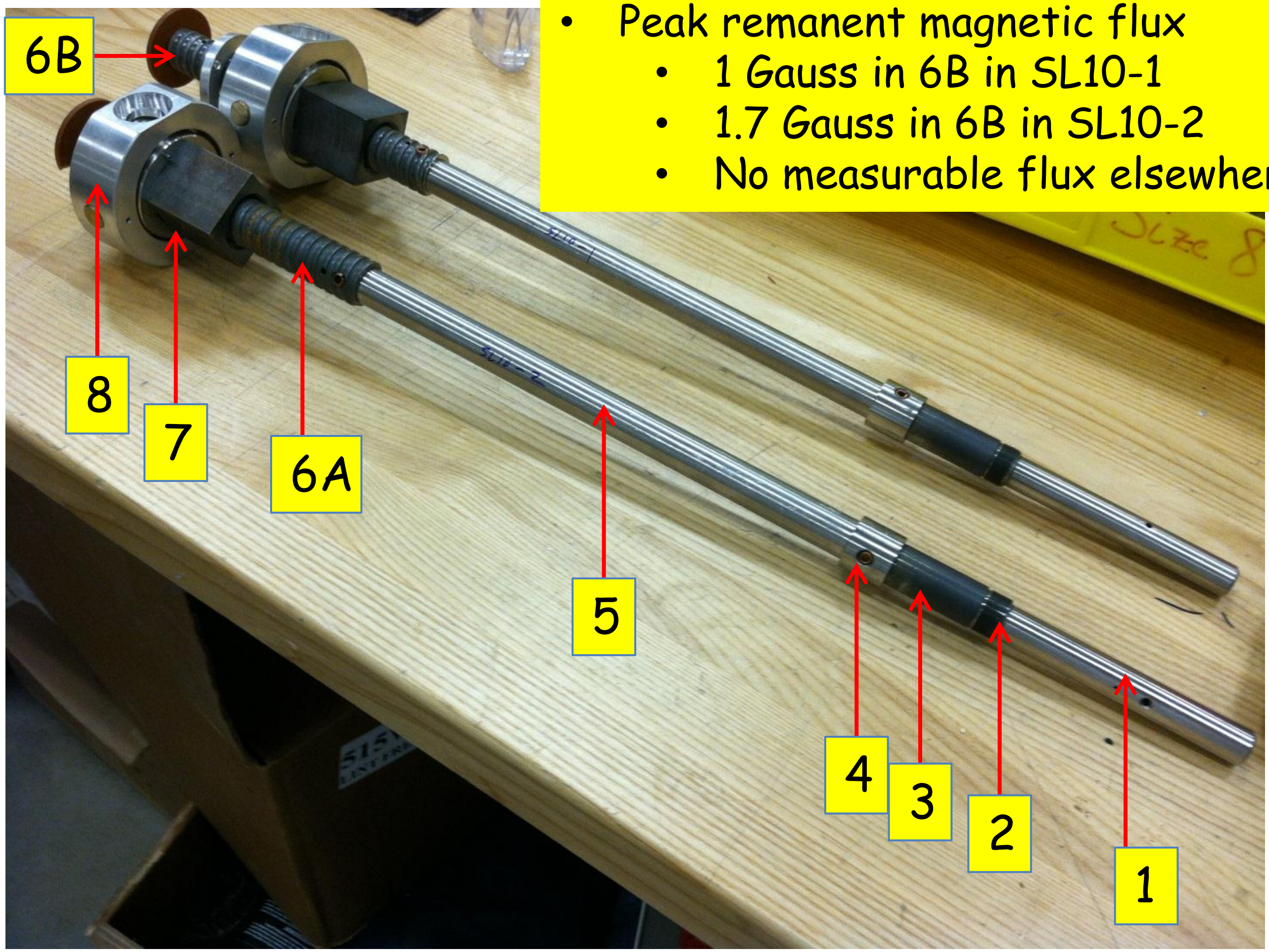




Tuner Assembly

SL10-1 and SL10-2

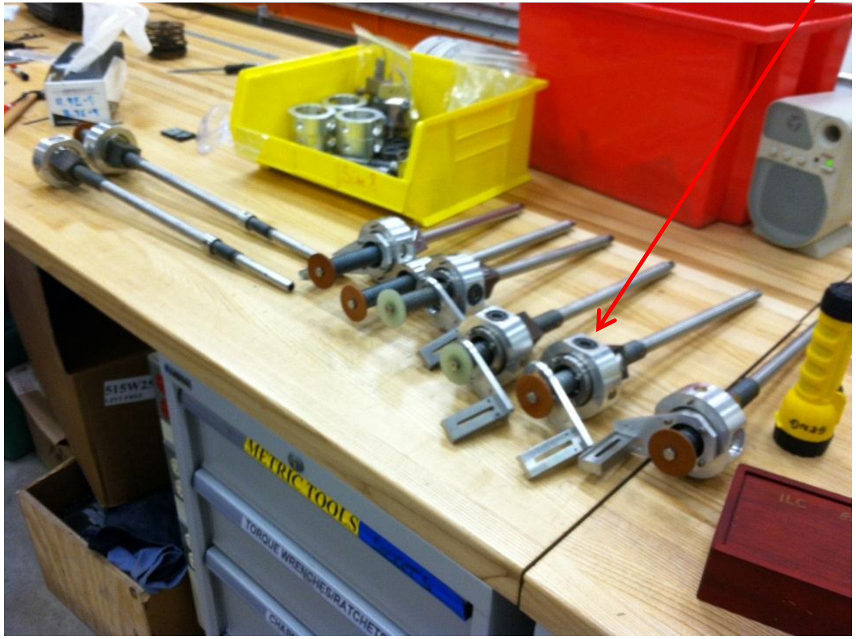
- Relative permeability < 1.08 in section 1,2,3,4,5,8 (no ball bearings in 8) – good news
- Relative permeability < 6.0 in section 6A, 6B, 7
- Peak remanent magnetic flux
    - 1 Gauss in 6B in SL10-1
    - 1.7 Gauss in 6B in SL10-2
    - No measurable flux elsewhere



SL10-3,4,5,6,7,8

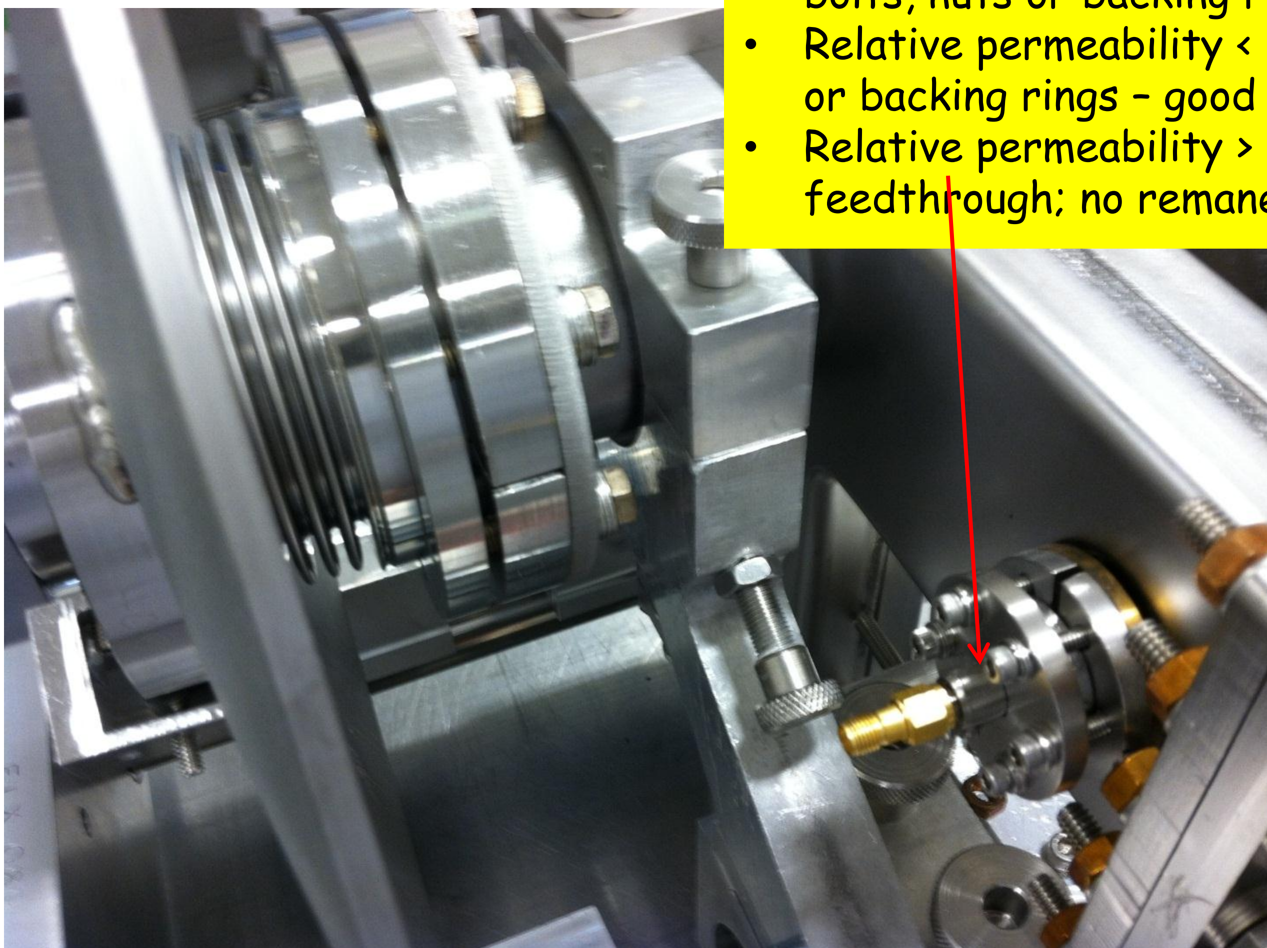
Similar behaviors as found in SL10-1 and SL10-2

- Remanent magnetic flux measured in section 6(A&B) w/ peak value in range of 1-2 Gauss
- Remanent flux also measured in section 5 of SL10-4 (0.5 Gauss);section 7 in SL10-5 (1 Gauss)
- Relative permeability < 1.08 in all sections except equivalent to section 6,7 in SL10-1 (threaded rod and the ball screw block) where the value is > 6.0
- Relative permeability > 6.0 in ball bearings of all sizes (including those in gear box)
- Remanent flux in ball bearings at most 0.5 Gauss, most has no measurable flux



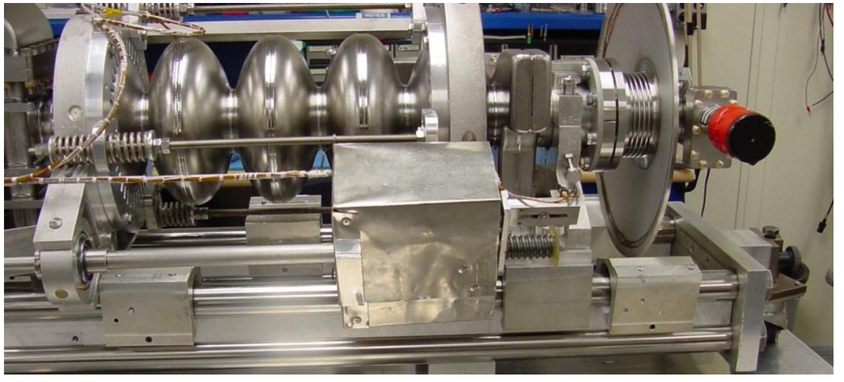
Other Components As Measured from First Cavity Pair

- No measurable remanent magnetic flux at washers, bolts, nuts or backing rings – good news
- Relative permeability < 1.08 at washers, bolts, nuts or backing rings – good news
- Relative permeability > 6.0 at waveguide RF feedthrough; no remanent flux through



Mitigation of Magnetic Tuner Components
Threaded Rod being a Major Contributor

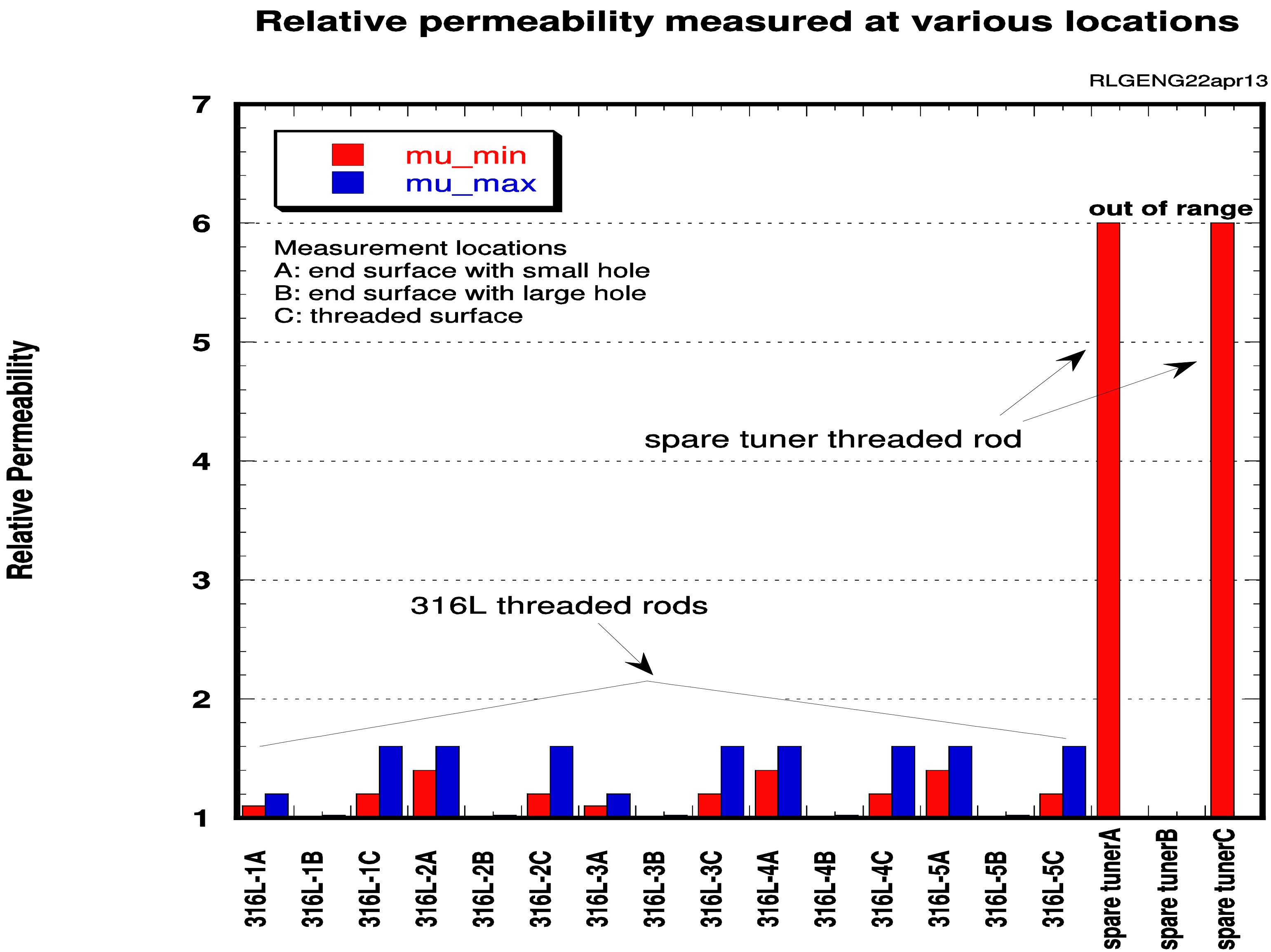
Shielding of ballscrew in earlier C50 modules
Result: visible but very small Q0 imporvement



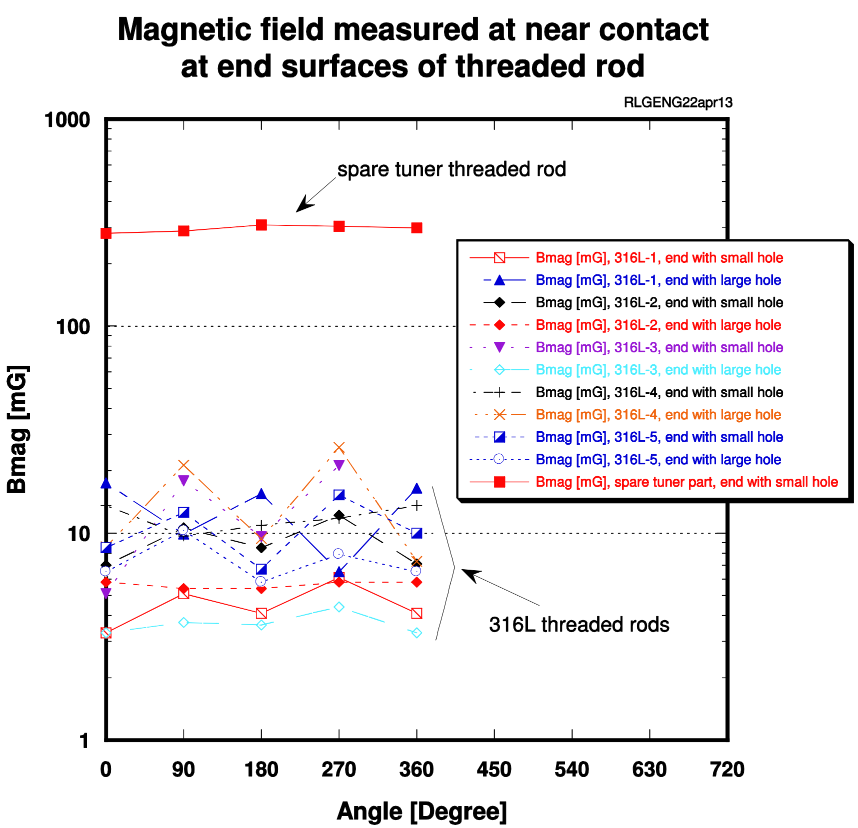
- Degauss the following tuner components
  - Threaded rod
  - Ball screw block
  - All ball bearing (including those in gear box)
- Practice "clean magnetic" handling practice after degaussing

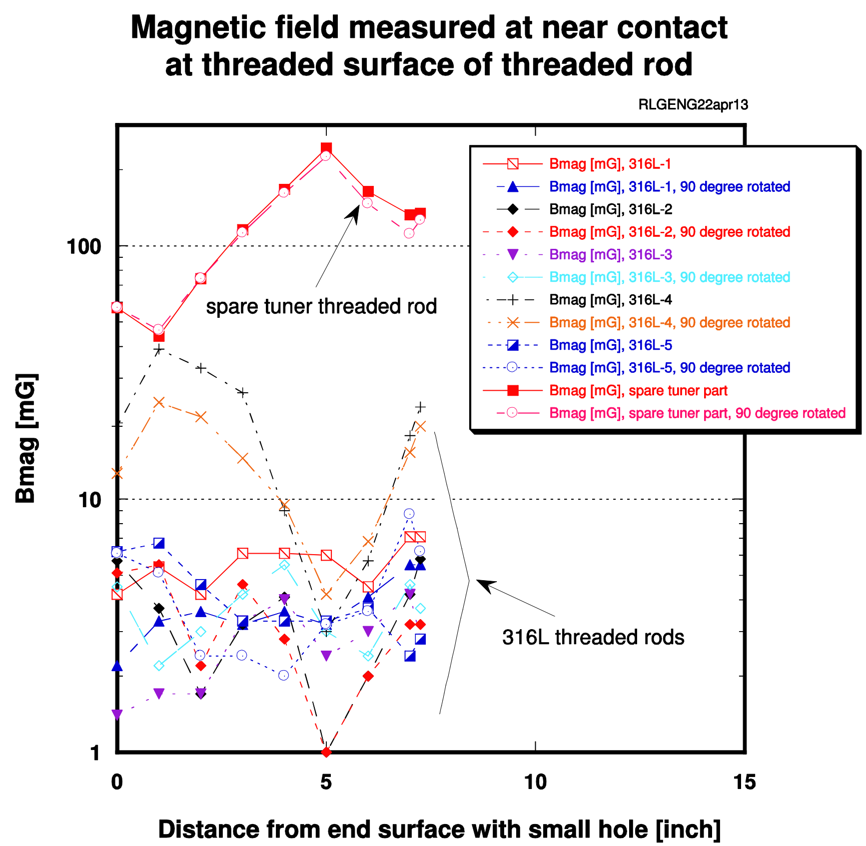
For future C50 re-work
Threaded rod should be replaced by new 316L threaded rod

New 316L Threaded Rod has Significantly Lower Permeability

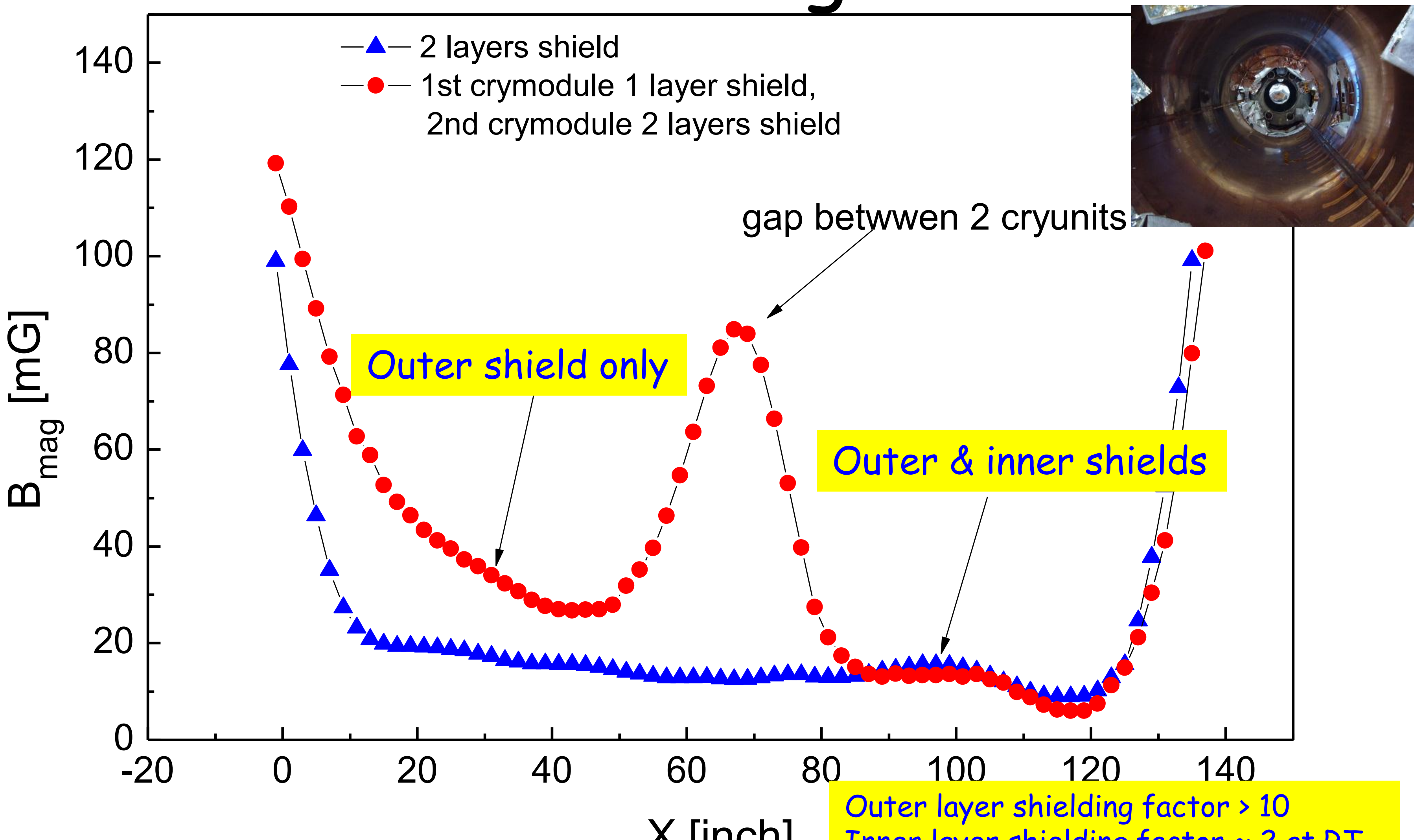


New 316L Threaded Rod has Significantly Lower Remanent Field

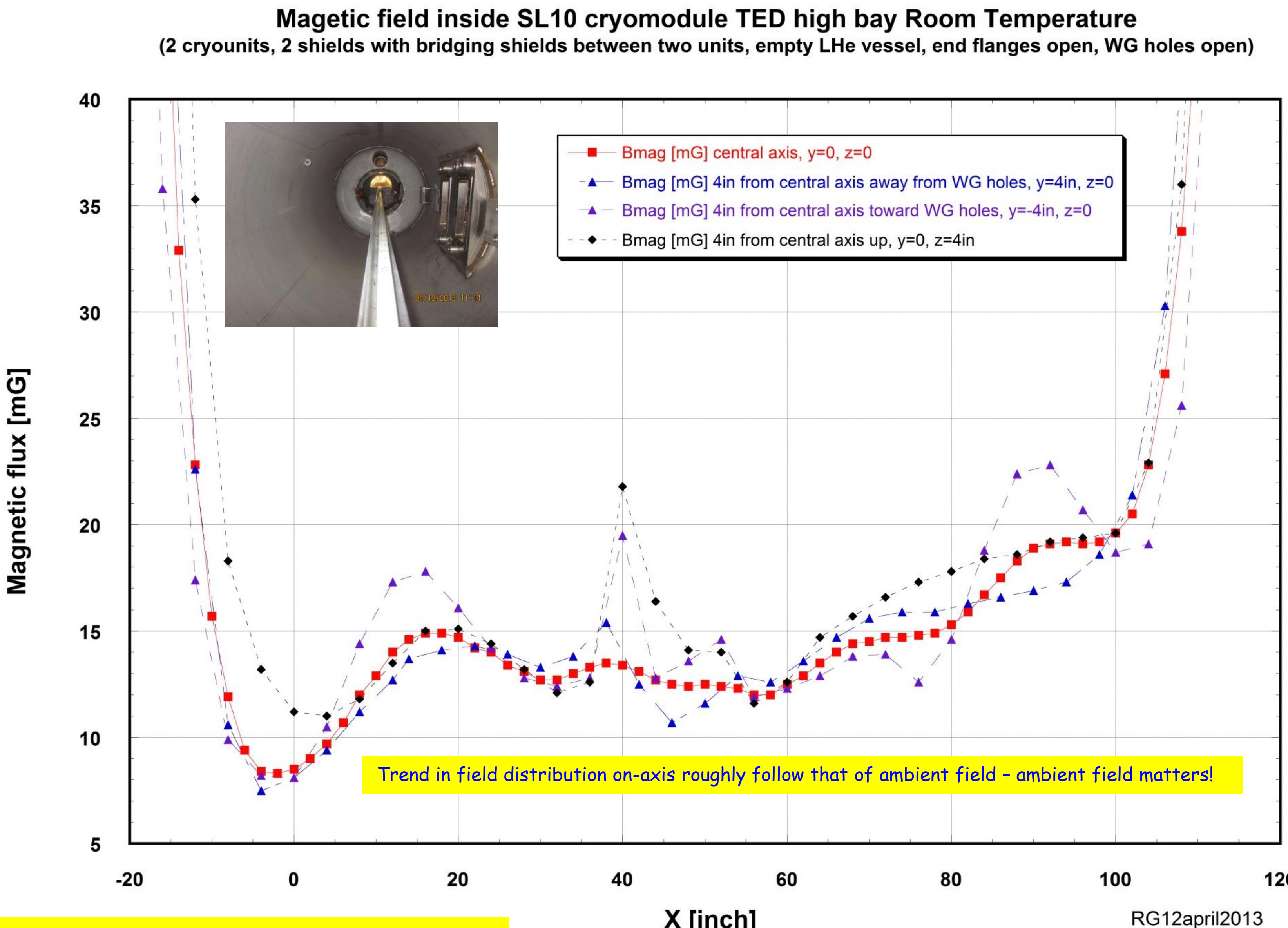




Preliminary Assessment of Outer and Inner Magnetic Shields



Outer layer shielding factor > 10
Inner layer shielding factor ~ 2 at RT



Outer layer shielding factor > 10
Inner layer shielding factor ~ 2 at RT

Achieved Magnetic Shielding in 1989

- "The magnetic shielding of the cryostat employs two layers of shielding, and achieves the design objective of ≤ 5 milligauss at the cavity location on cooldown. Previously, a 1-layer shield achieved only 50 milligauss." (Sundelin, SRF1989) Q: what was the ambient magnetic field for these measurements? What was the technique of the magnetic field measurement "at the cavity location on cooldown"?

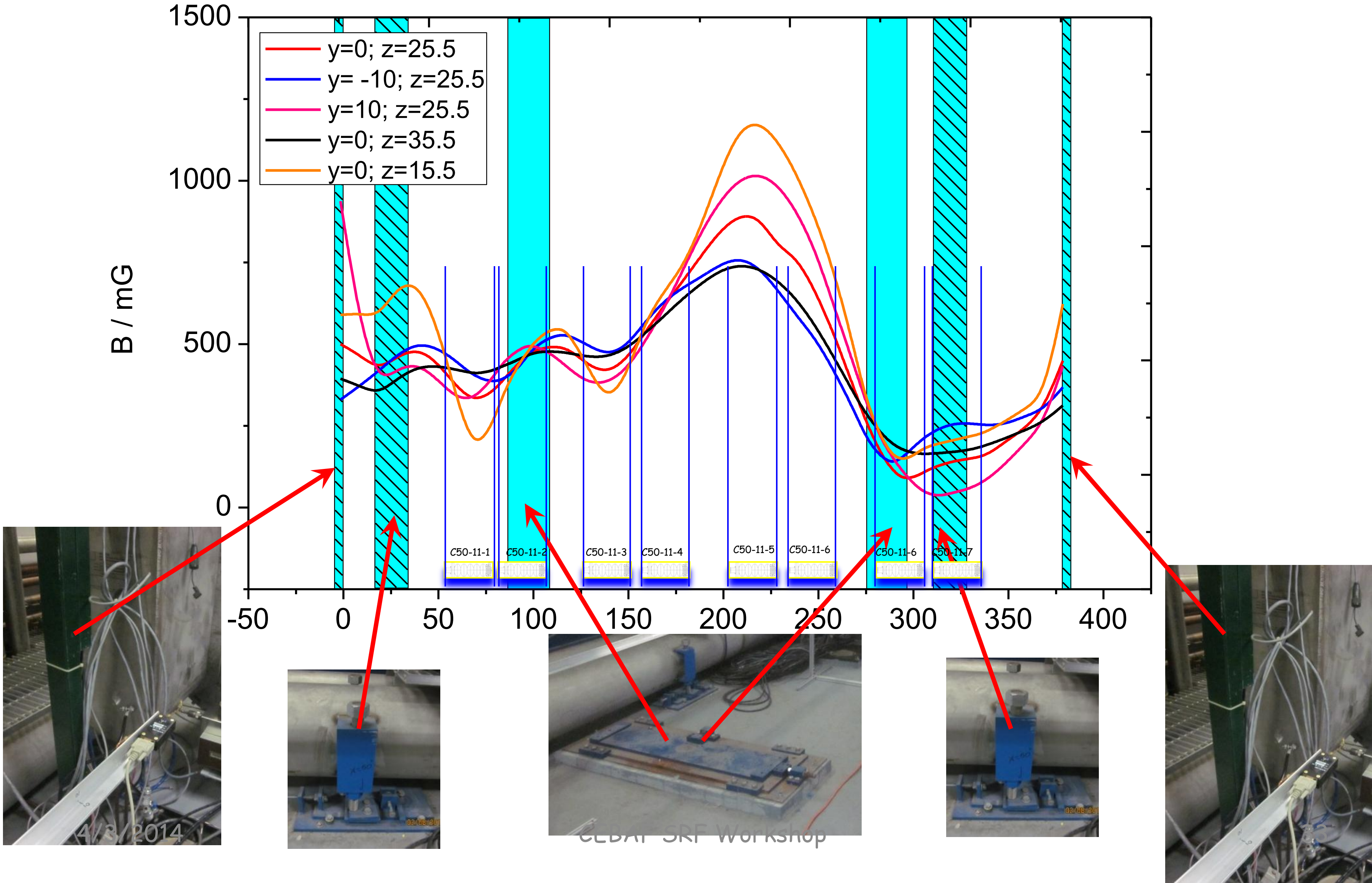
SL10 Ambient Magnetic Field Survey

February 7-8, 2012 in CEBAF Tunnel

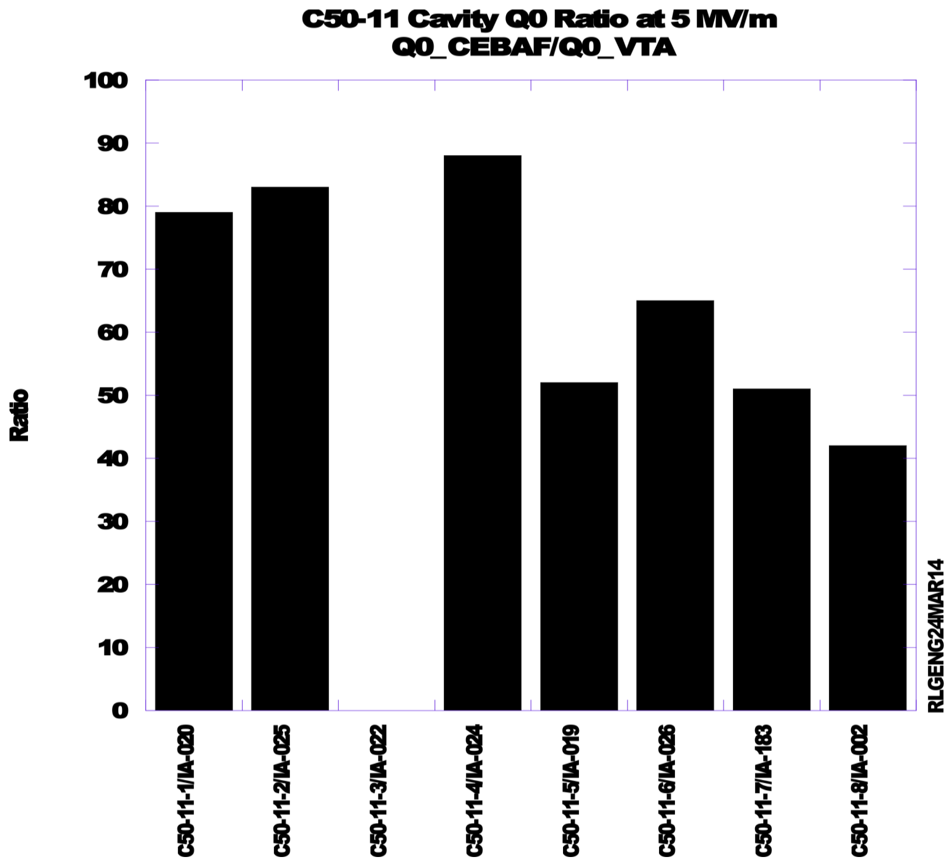
SL10 Ambient Field Survey Results

Coordinate adjusted , Mid-point between SL9 and SL10 at x=0

X direction point to West, Y direction point to South; Z direction point upward



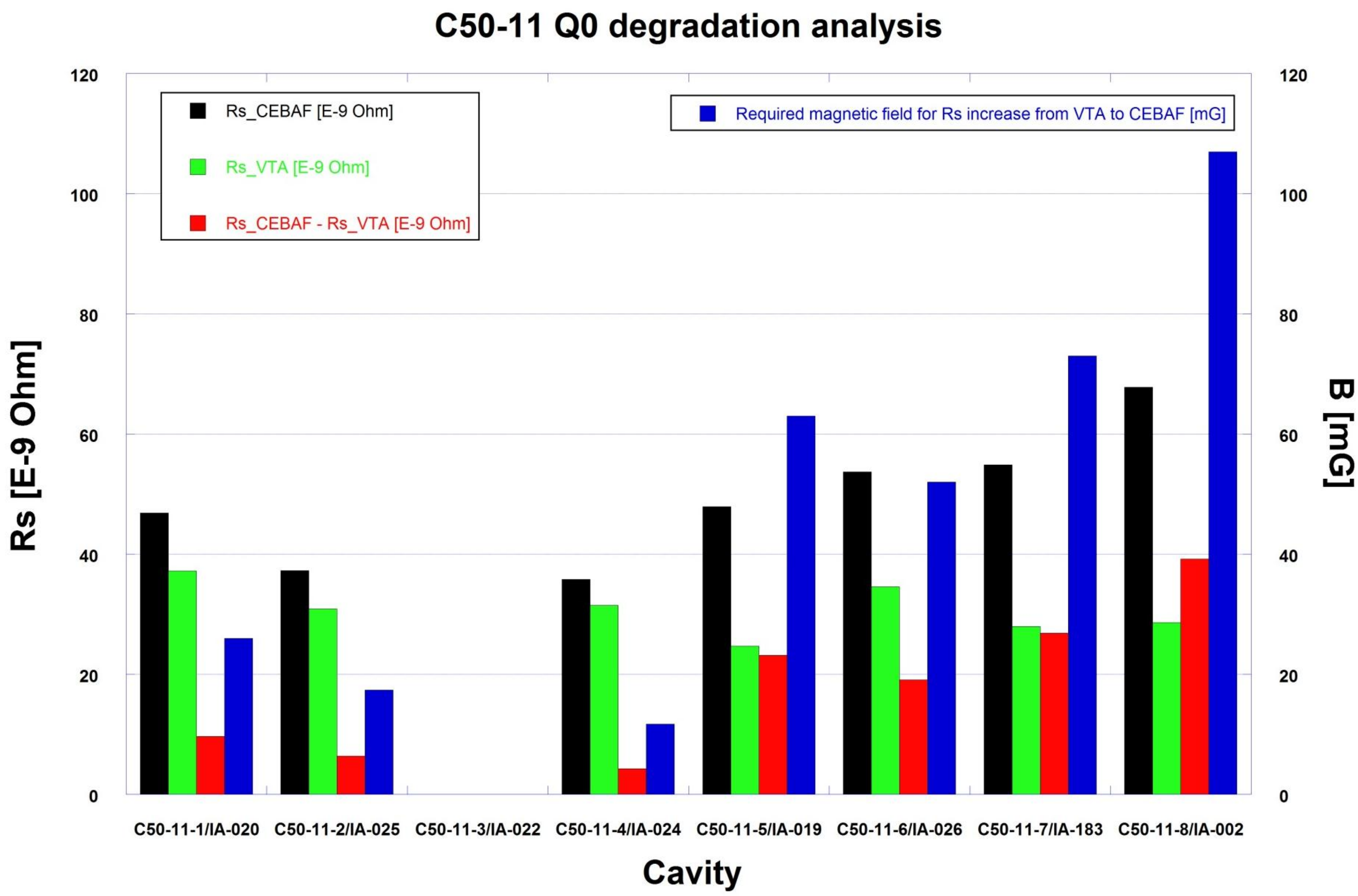
Preliminary Conclusion



- Clear demonstration of magnetized components inside inner shield.
- Discovery of magnetized strut springs. Worst offending!
- New 316 SS springs implemented. 3 of 8 cavities preserved VTA Q0 at ~ 80% level.
- 4 of 8 cavities preserved VTA Q0 at ~ 50% level.
  - 3 cavities could be further improved by reducing ambient field.

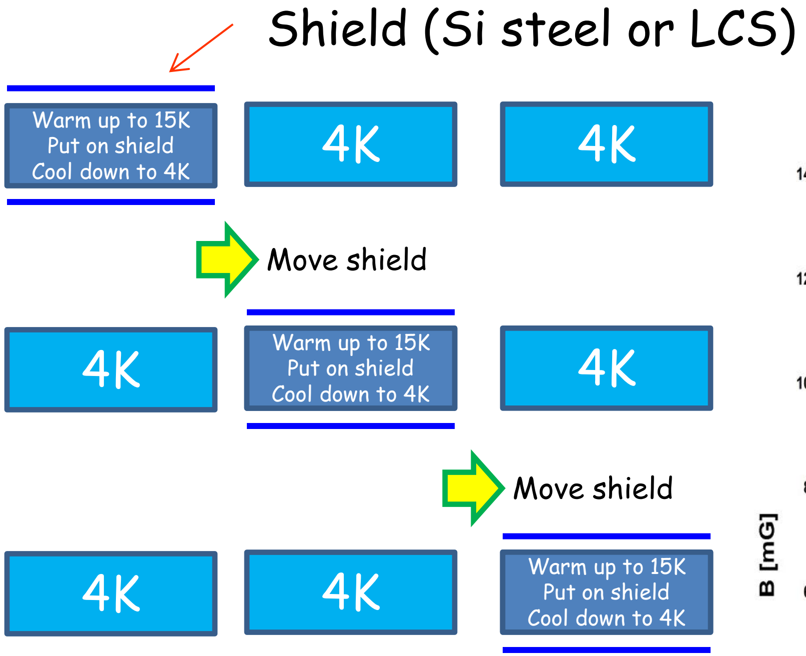
Recommendations and Proposed Future Studies

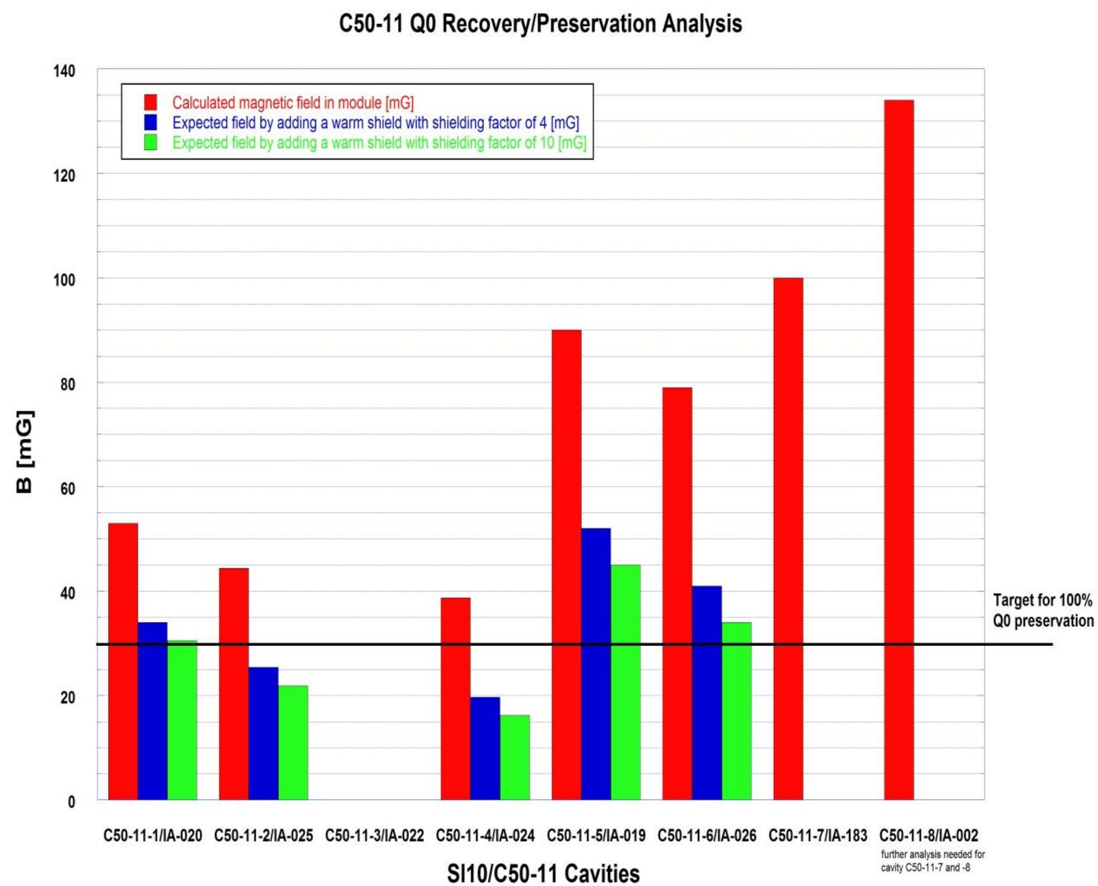
- For future C50 re-work cryomodules:
  - Continue implementation of good 316SS strut springs.
  - Replace threaded rods (2nd worst offending) with 316L rods.
  - Explore improved degassing procedure and apparatus for ball bearings (3rd offending), in particular integrated degassing of tuner assembly.
- For exisitng C20 and C50 moduels in CEBAF tunnel:
  - Explore methods of reducing trapped flux by added shielding around cryomodule during cool down crossing Tc ("mobile magnetic shield"). >20% reduction in cryo load can be expected without refurbishing modules.
    - Quarter module as testing vehicle
  - Explore methods of liberation of trapped flux by cryogenic thermal cyclsing ("thermal therapy"). Additional 30% reduction in cryo load might be expected without refurbishing or new hardware investment.
    - VTA integrated cavity/tuner assembly as testing vehicle



Note: C50-11-5,6,7,8 have ball-screw shielding box of one kind
C50-11-1,2,3,4 have another kind (note by RG on 4/14/14)

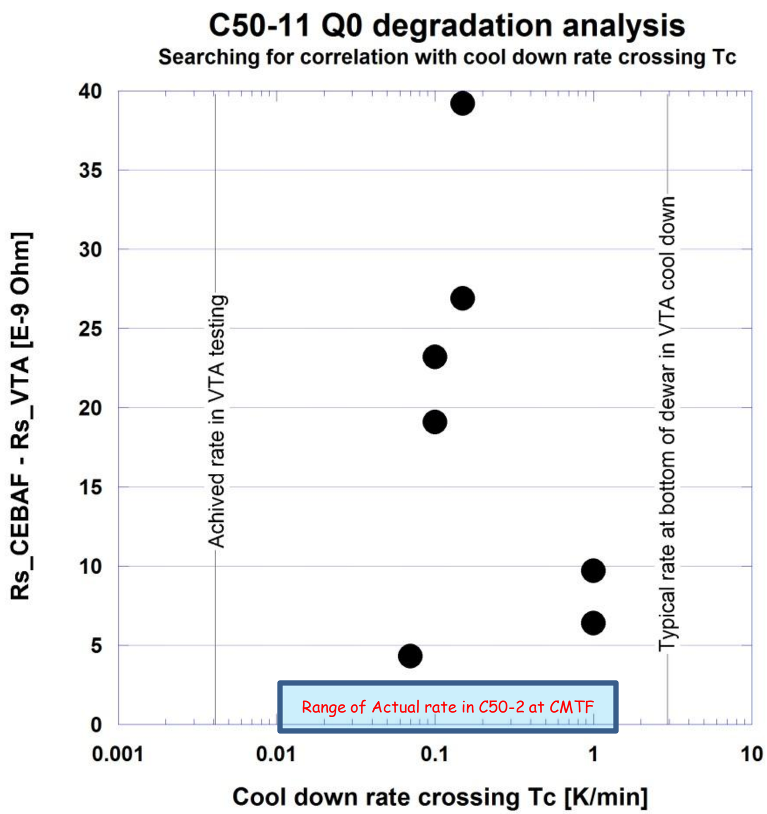
Possible Q0 Recovery by "Mobile Magnetic Shield"





- Possible scenario for application while CEBAF is at 4K for extended period
- A proof-of-principle test can be done with a quarter module in CMTF

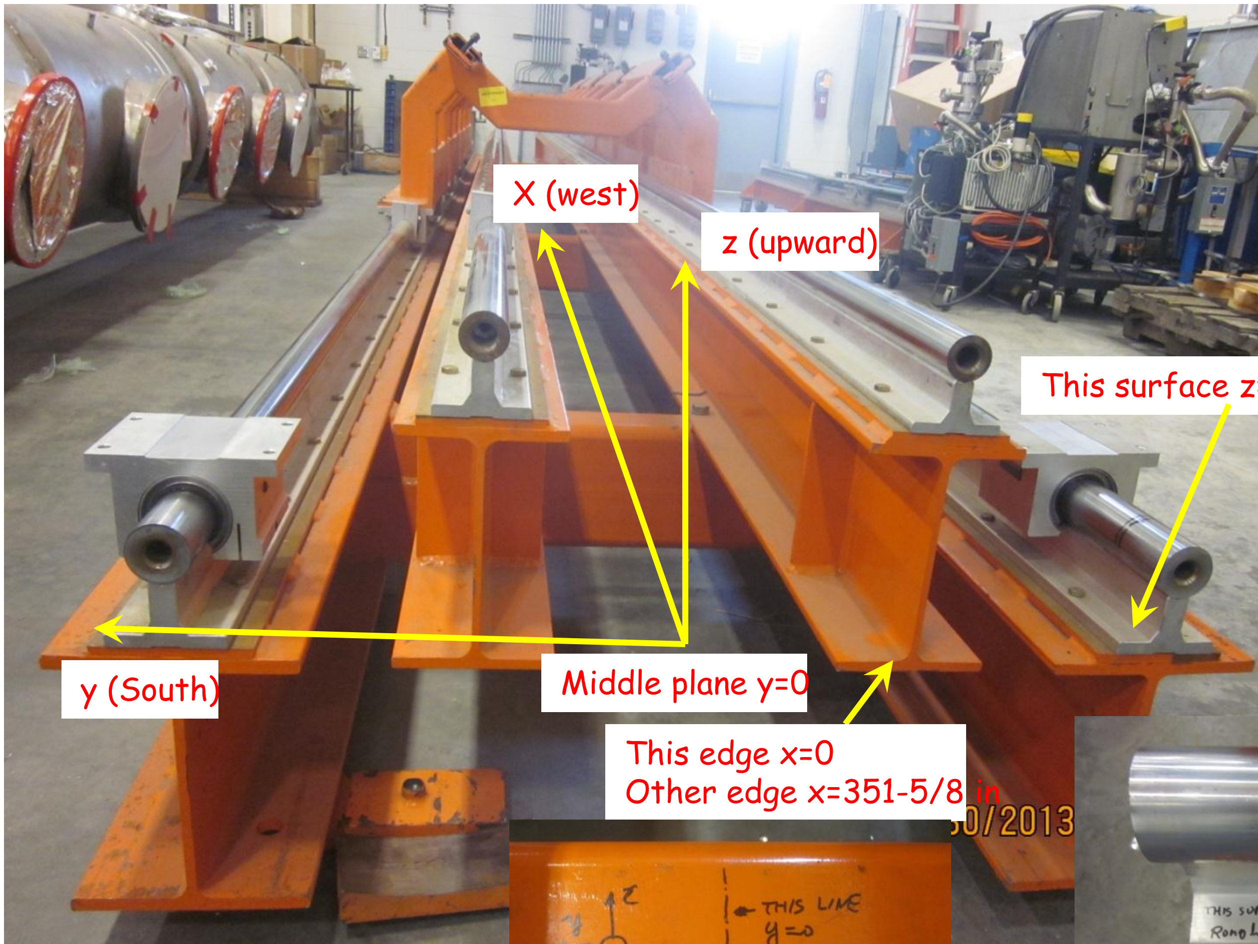
In Pursuit of Thermal Therapy for Improving CEBAF Cavity Q0

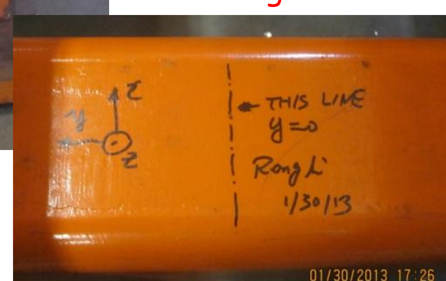


- Typical cool down rate crossing Tc at dewar bottom ~ 3K/min
- Lowest achieved 1-cell cavity cool down rate crossing Tc ~ 4mK/min
- Testing started in August 2013
  - 30% loss in Q0 from cryogenic thermal annealing below Tc
  - 30% loss in Q0 from slow crossing Tc
  - 30% gain by partial warm up followed by rapid cool down

Backup slides

Definition of Coordinate





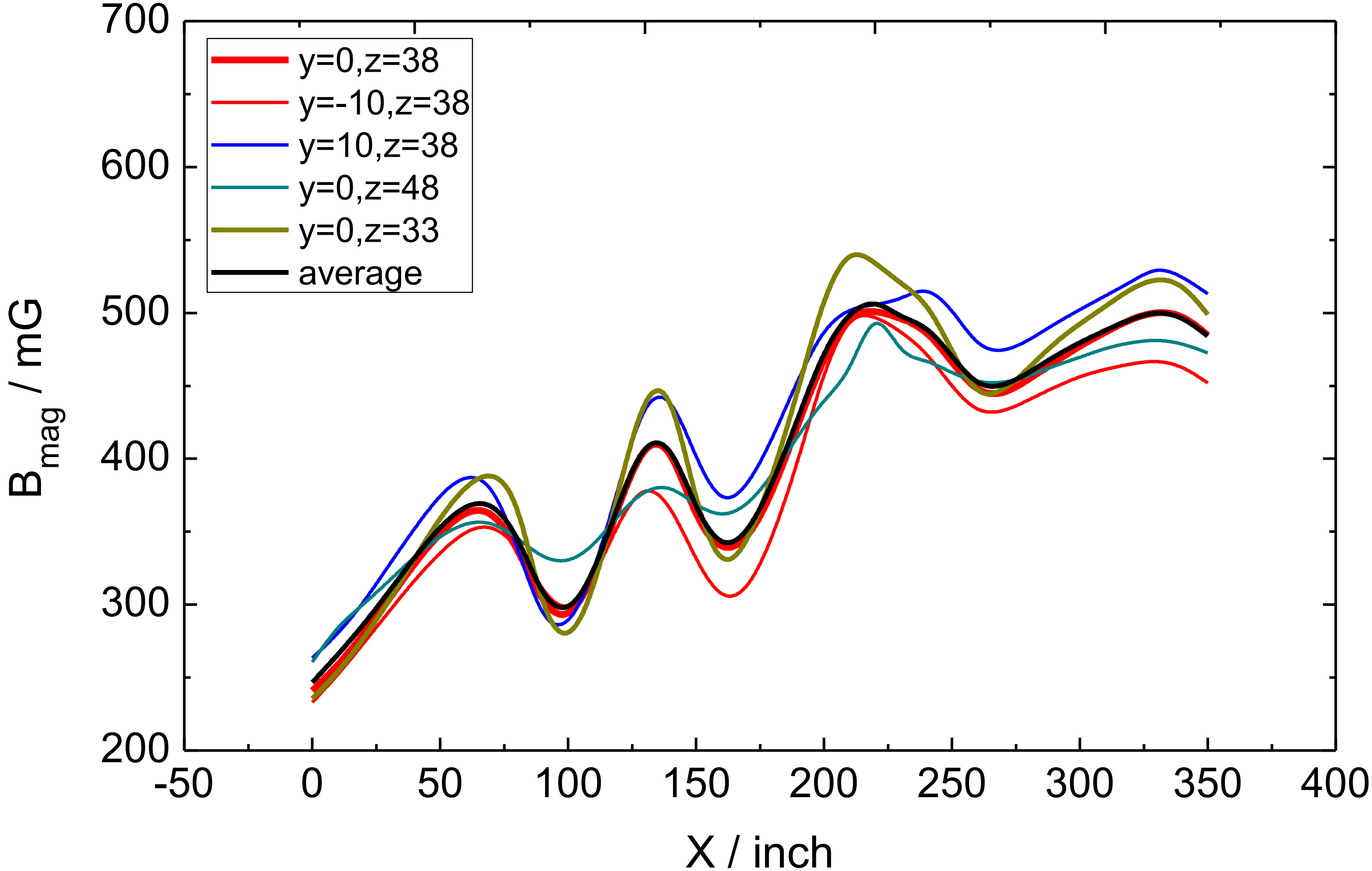
1. Ambient Field Measurement

Sensor: Honeywell HMR2300 three axis magnetometer

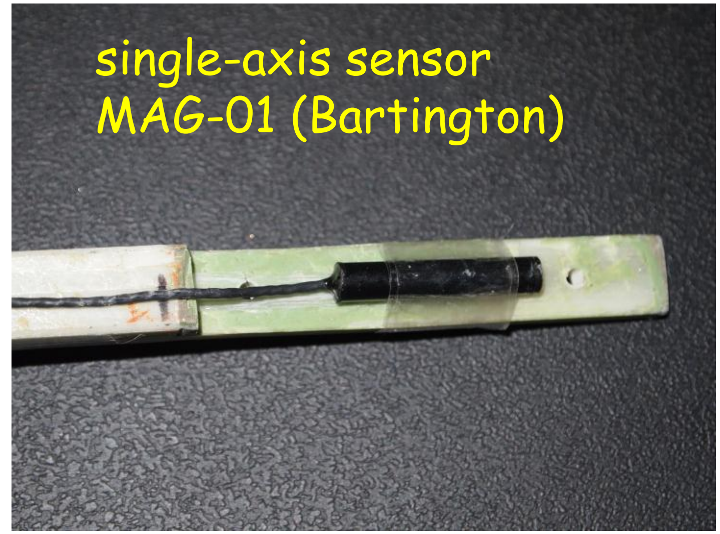
Measurements performed along 5 paths

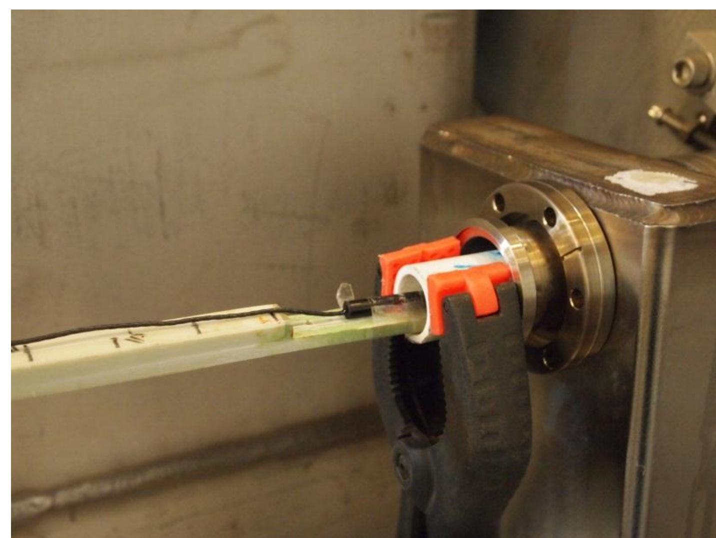
Path 1: y=0 in, z=38 in, x=[0,350] in, datum expected cavity axis location
Path 2: y=-10 in, z=38 in, x=[0,350] in, 10 in to the right from datum
Path 3: y=10 in, z=38 in, x=[0,350] in, 10 in to the left from datum
Path 4: y=0 in, z=48 in, x=[0,350] in, 10 in above from datum
Path 5: y=0 in, z=43 in, x=[0,350] in 5 in down from datum

C50-11 Survey in As-Found Condition Ambient Field in TED High Bay



Magnetic Field in complete crymodule

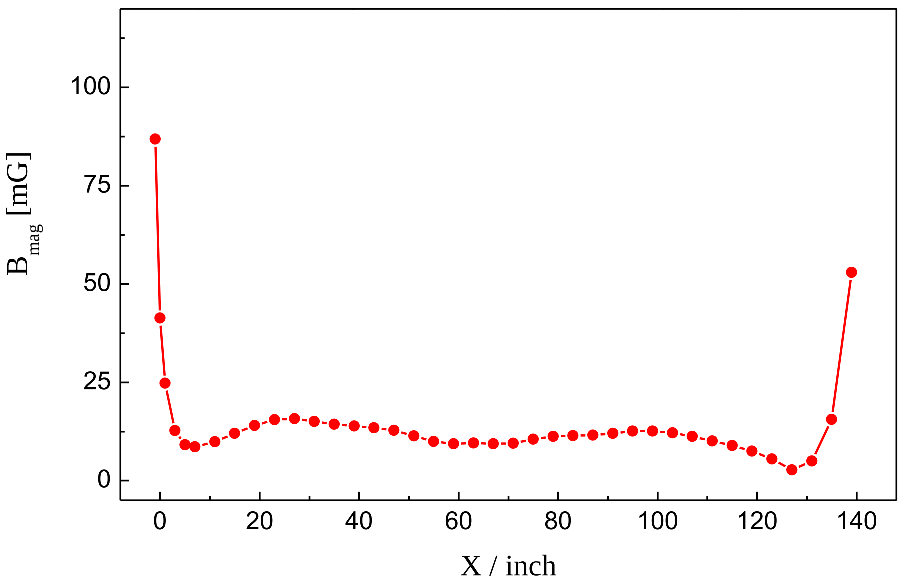




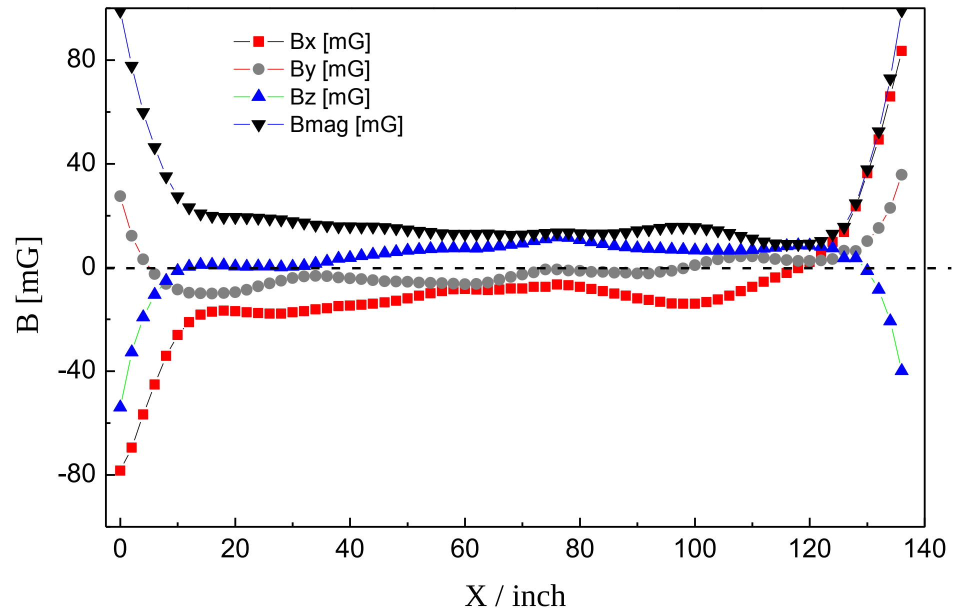
Assessment of Two Layers of Magnetic Shields

Two cryounits, both shields at RT, 3-axis sensor

Bmag field in two cryunits



B field in two cryunits



Tuner Component Survey Conclusion

- All threaded rods have > 6.0 permeability and have fairly high (1-2 Gauss) remanent magnetic flux density.
- All ball screw blocks have > 6.0 permeability and perhaps mild remanent flux.
- All ball bearings have > 6.0 permeability and mild remanent flux.
- Almost all components mounted in first cavity pair have acceptable magnetic properties
  - Except RF feedthrough on waveguide (kovar?)

Tuner Components Degaussing

- Degauss the following tuner components
  - Threaded rod
  - Ball screw block
  - All ball bearing (including those in gear box)
- Practice "clean magnetic" handling practice after degaussing
- **Ultimately replace all of the above components with "non-magnetic" substitute**
  - We already have superior threaded rods in hand (see previously C50 Q0 reports)

From Michael McCrea
Subject **magnetic measurements**
To Rongli Geng

Rongli, I have been out sick since we talked and I really hope this isnt too late. I did not have the info at home needed so I had to wait til I returned to email you.

All the large diameter bearings (16 of them) measured in range of 806 mil Gauss to 1.2 Gauss before Degaussing.
after Degaussing they went down to 32 to 41 mil Gauss .

All the small diameter bearings (48 of them) ranged from 430 -620 mil Gauss before Degaussing.
after Degaussing they dropped to 21 -30 mil Gauss.

These are the only 2 components consistently monitored. we also demagnetized all the tools used in the tuner assembly process but did not record any of those numbers.

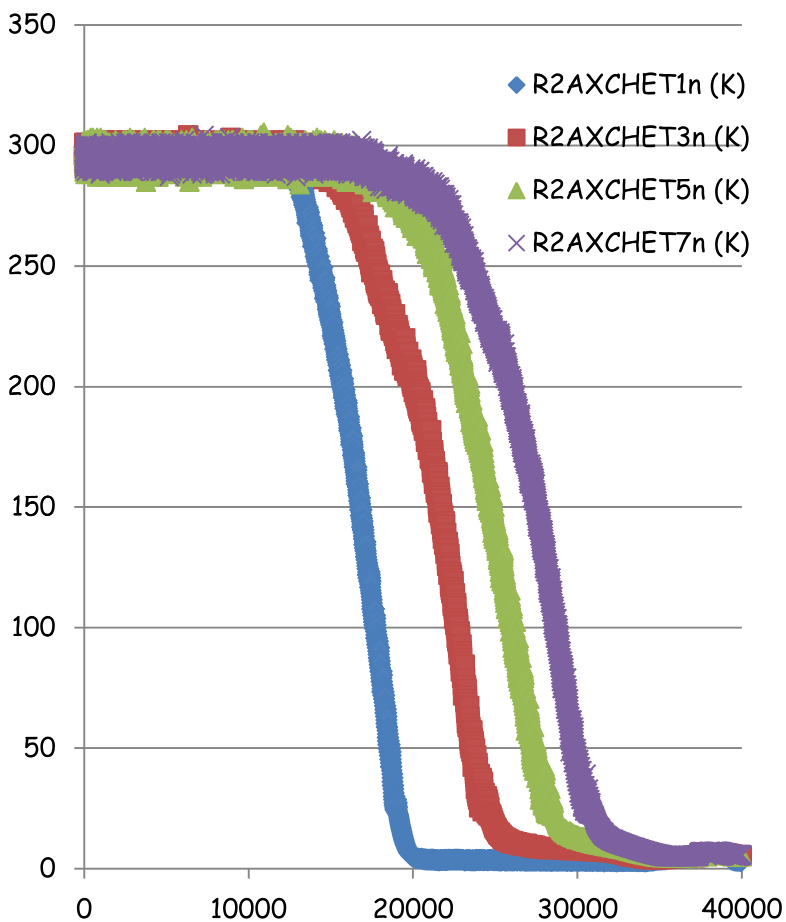
Sorry this is so late and I hope it helps. Mike

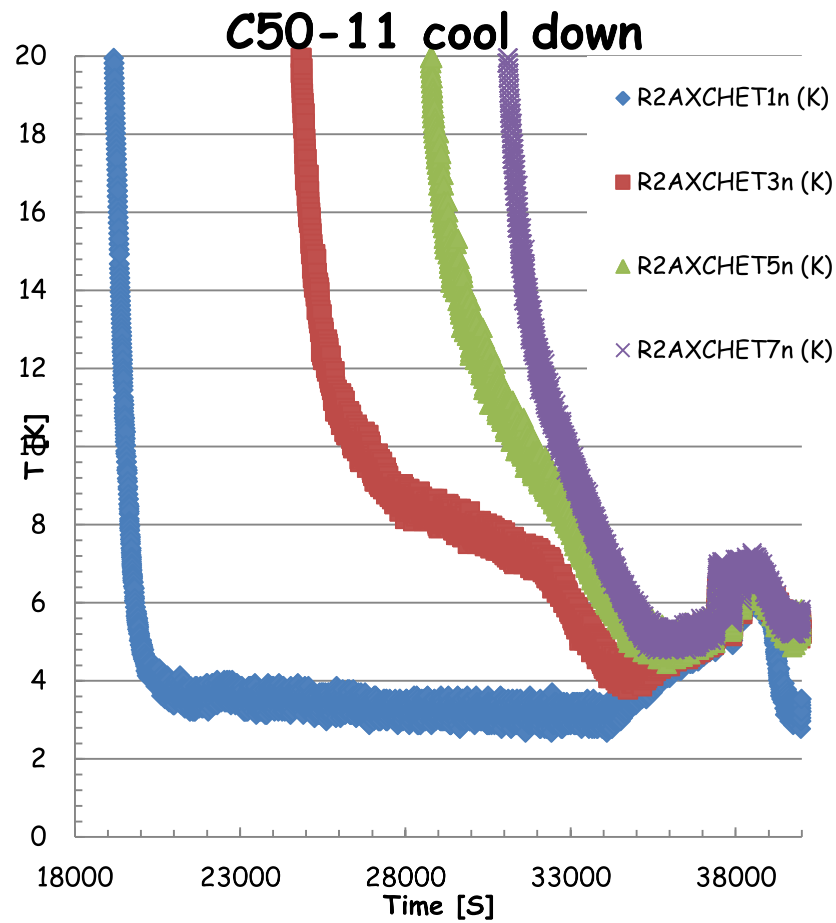
CEBAF Tunnel Field Survey

SL10

NL23

C50-11 Cool Down





Recent Module Cool-Down Profile in CMTF