JLAB 12GeV Upgrade Measurement Overview

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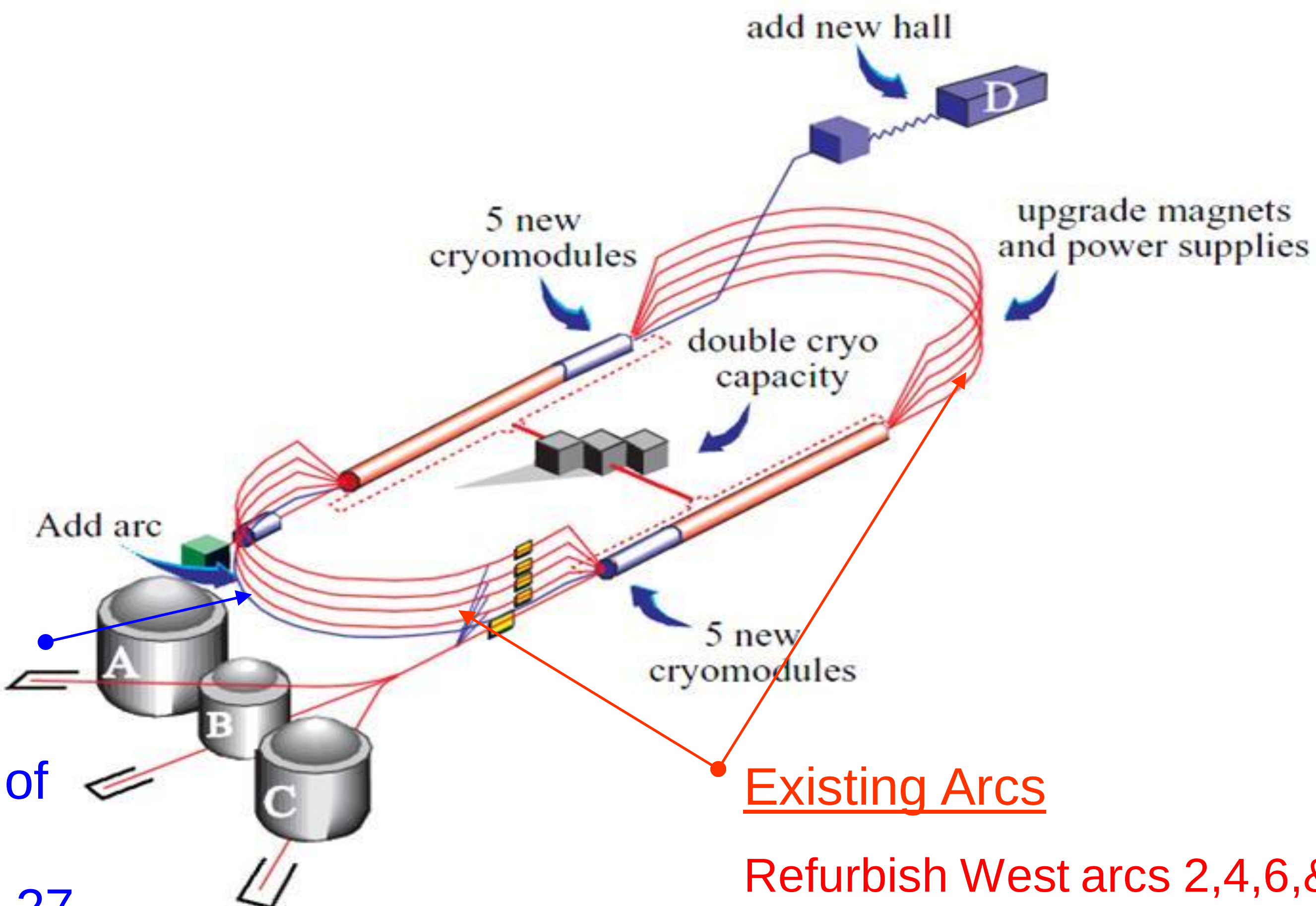
What's happening at JLAB

- **Jlab is in the midst of a major upgrade of the accelerator which will increase the energy from 6GeV to 12GeV to accommodate the experimental program in the new hall (Hall D).**

- **For magnet measurement this means:**
  - **Make the modifications to the magnets in the recirculation arcs and their power supplies to keep the higher energy beam confined to the existing beam path.**
  - **Measure the tenth arc-beamline to provide an extra pass through the North Linac.**
  - **QC and measure magnets for the new beamline connecting Hall D to the baseline accelerator**

- **Challenge for Magnet Measurement Group:**
  - <u>**Meet throughput requirements for the upgrade project and**</u>
  - <u>**Meet measurement specifications**</u>

Design overview: 6mo Down Scope



Arc 10

Install 27 of 32 Quad Girders & 27 of 32 4m Dipoles

Existing Arcs

Refurbish West arcs 2,4,6,&8

Stretch goal includes east arcs 7&9

Production Measurements over last year

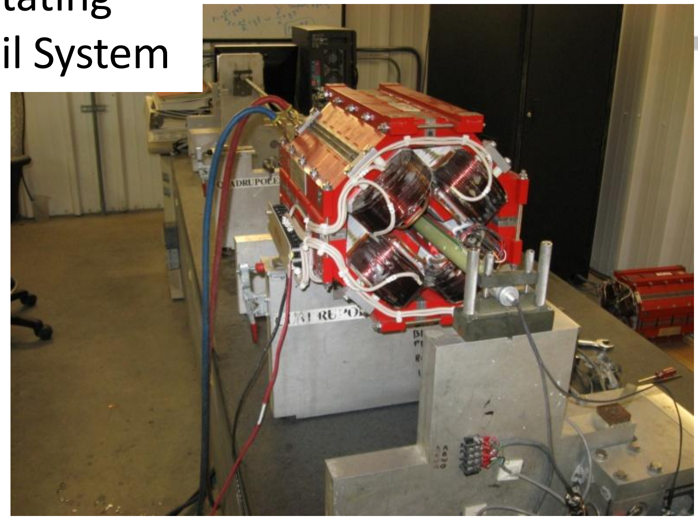
- **Pre-Down Goals**
  - Measure 37 4m Dipoles
  - Measure 130 correctors
  - Measure 117 Quadrupoles
- **6MSD Baseline Goals**
  - Remove, refurbish, measure and reinstall West Arc (112 dipoles in Arcs 2, 4, 6, & 8)
- ***Stretch Goals*: Baseline plus**
  - Remove, refurbish, measure and re-install an additional 64 dipoles (East: Arcs 7 and 9)
  - (Total 176 dipoles)

***6MSD Magnet work timeline ~2.5 months**

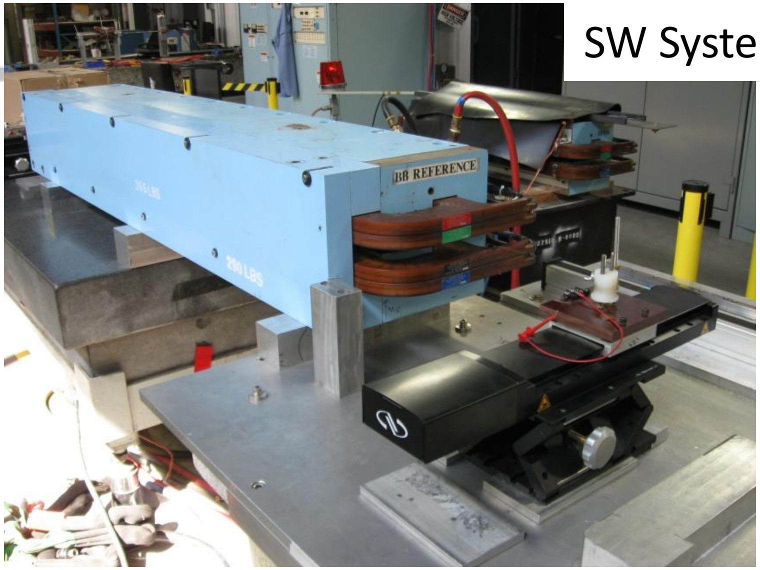

West Arc


East Arc

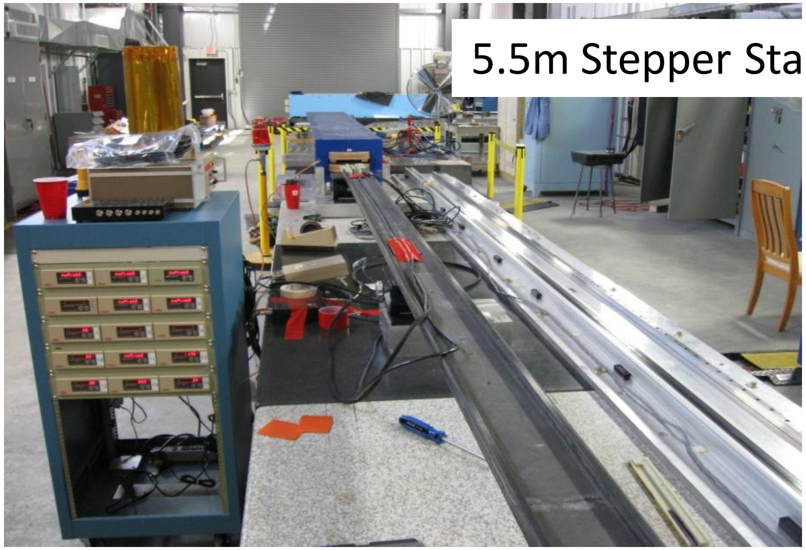
Rotating Coil System



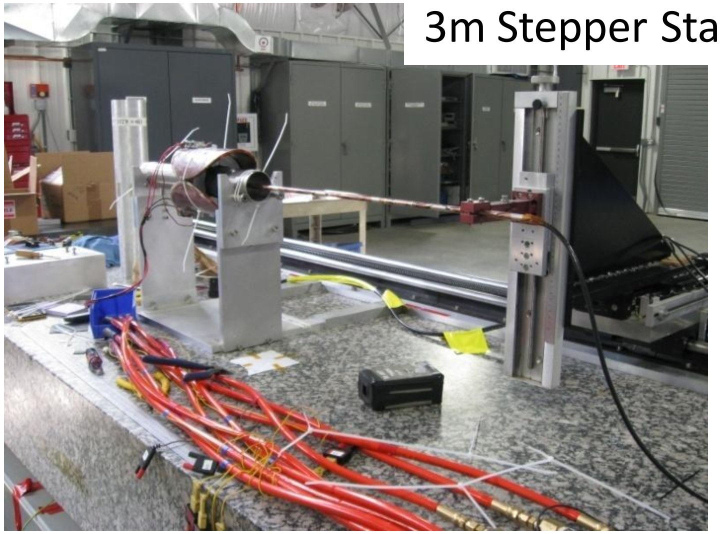
SW System



5.5m Stepper Stand



3m Stepper Stand



Dipole Mapping Specs

- Spec for accuracy of <u>absolute strength </u>(BL) along an arc was fairly loose (0.4%)
- Spec for <u>precision</u> of strength measurements for matching along an arc are pretty tough (0.03%).
- Need all magnets along an arc to match at 0.1%.
- Still need knowledge of field quality (gradient).
- After 12GeV refurbishment and measurement still need to re-establish maps for 6GeV operations.

- Approach used to meet specs and throughput:
  - Stretched wire used to get BL and B'L on all magnets
  - Detailed maps with Hall probes and NMRs used to build map along curved trajectory.
    - Done for 10% sampling of arc dipoles.
    - Transformation map between curved and straight calculated from the sampling and applied to all

Our Magnet "Challenge"

- Lots of dipoles to process
  - Need measurement throughput rate of 3/day

- Need to create easy setups that still give accurate positioning
  - Mechanical stops for both magnets and measurement stages

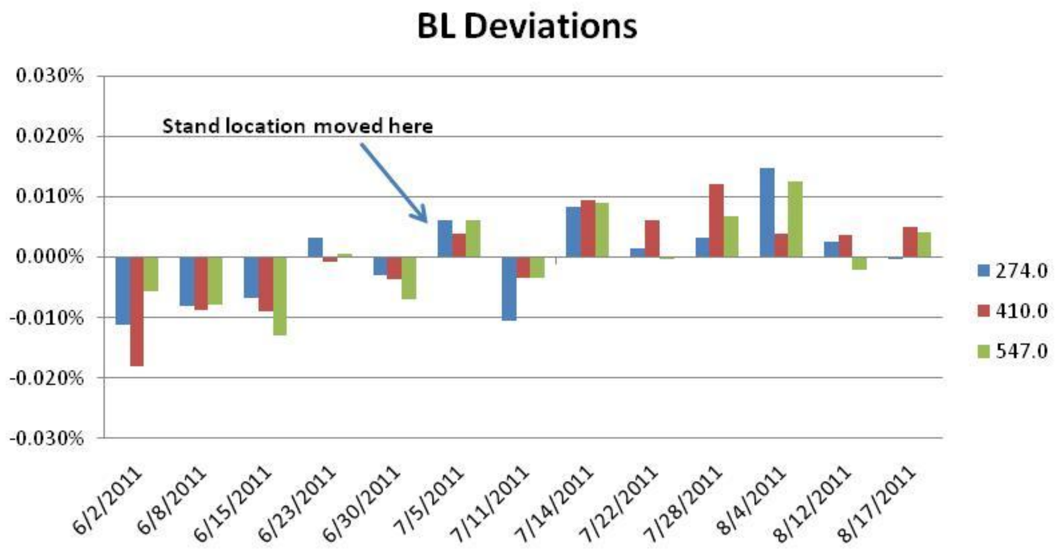
Arc Dipole Upgrade Process

- Remove Dipoles from Tunnel
- Separate Magnet Cores
- Remove Vacuum Chamber
- Replace Insulation (EPDM), Thermal Switches, Coil Spacers
- Add “H-Steel”
- Add synchrotron radiation coils (3m and 4m dipoles)
- Flow Check
- Hi-pot
- Magnetically Measure
- Remove cover plate and re-install chamber
- Final QC
- Re-install

- Lots of potential for magnets to change during process

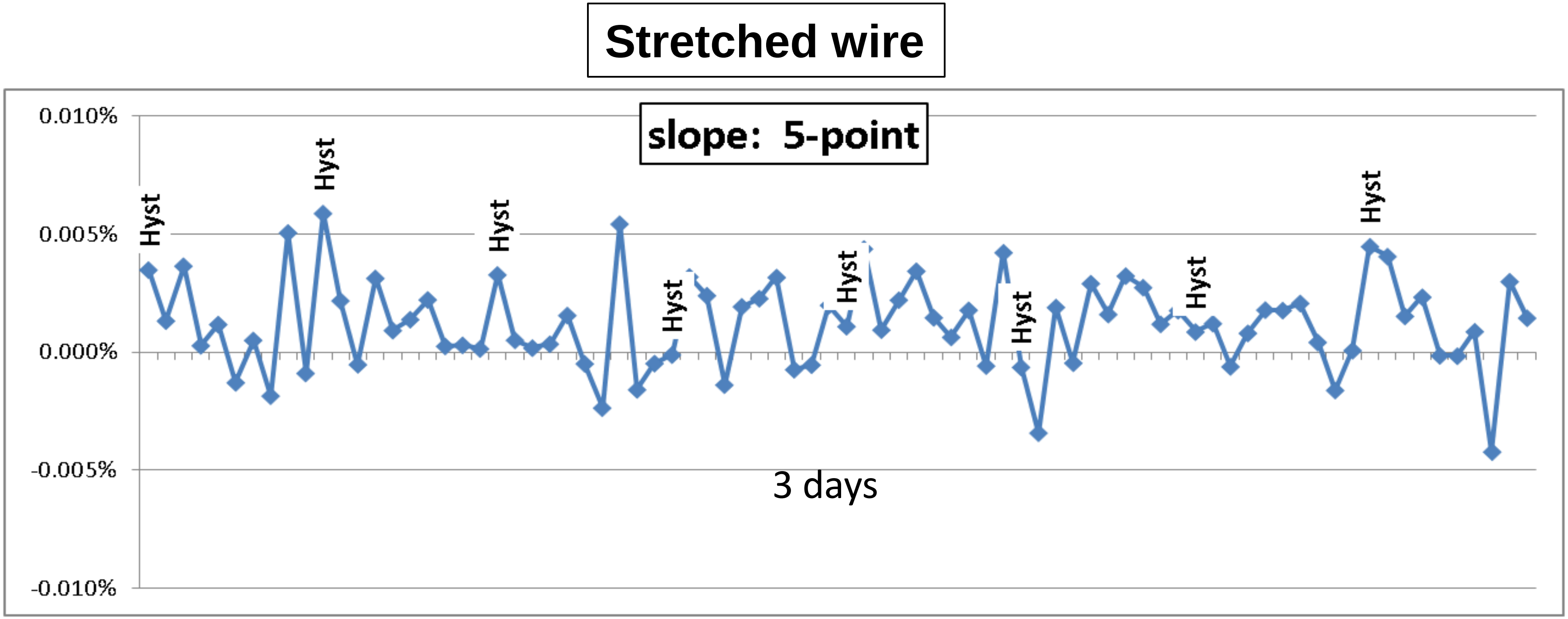
Stretched Wire measurements

- Stretched Wire was used for the majority of dipole mapping
  - System core: 4 µm Newport stages / HP3458A voltmeter
  - Need to verify measurement results match between the SW and Hall probe systems
- We measured consistency of the SW measurements over production period
  - Reference measurements (1 "check" / week)
  - Repeatability <0.026% throughout the 6MSD mapping.
  - Drift is still small
    - Could be result of moving to second stand.
    - Could be small changes in the gap between new "H-Steel" plates and older magnet steel



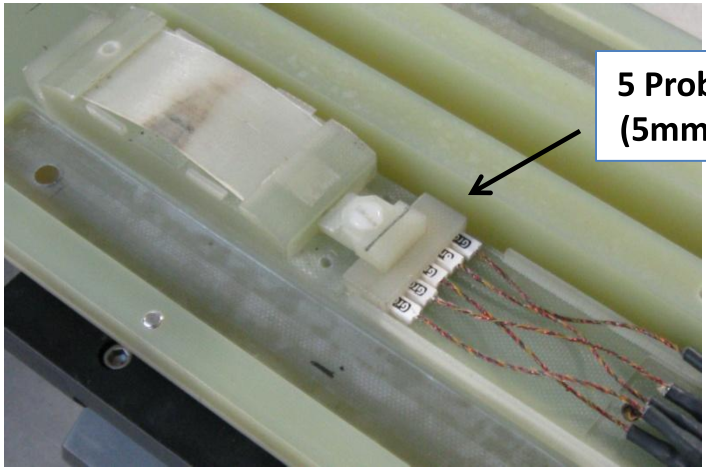
SW Repeatability: B'L/BL (4m dipoles)

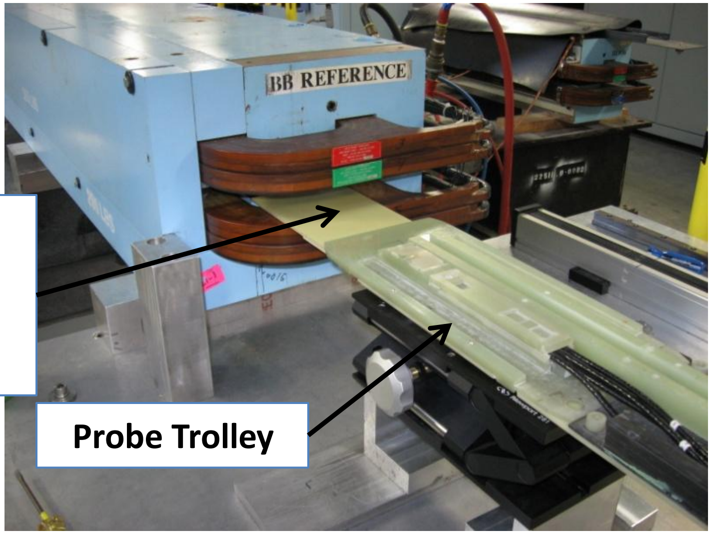
- **Testing was done to determine the repeatability of the stretched wire system of predicting the dipole body gradient**



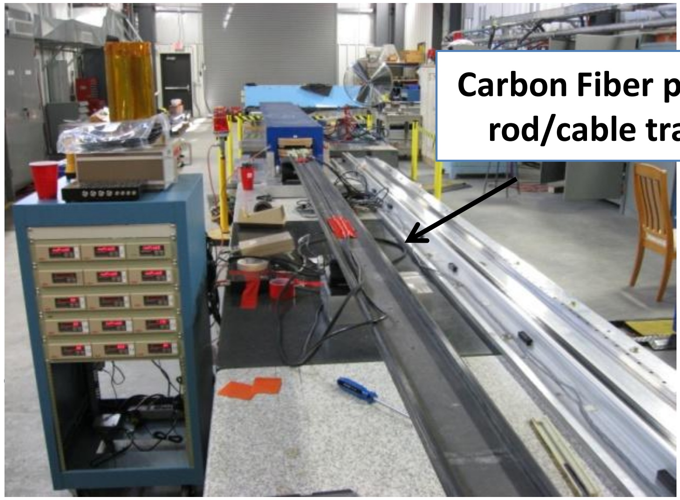
Stdev = 0.0019%

Dipole Grid Mapping



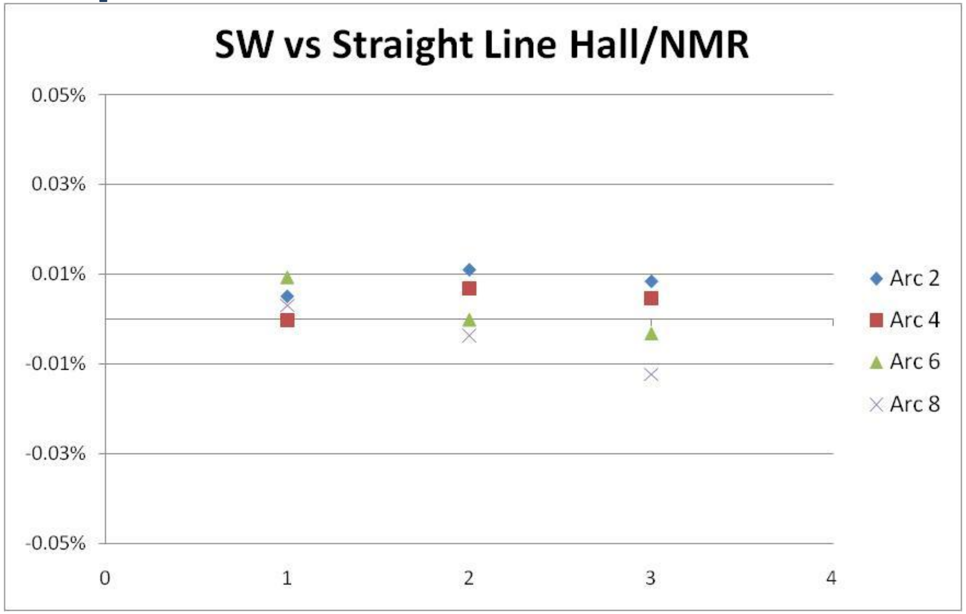


- Needed way to map 2m, 3m and 4m "H" dipoles
  - Probe on a stick would not work
- 3 Part Solution
  - 5m Carbon Fiber Push Tray
  - Hall probe holder for 5 probes
  - Probe Trolley
    - Springs lock to magnet pole tip (X and Y)
- Proper alignment of landing pad difficult
  - Need to check alignment in a high derivative field
- Probe calibration for cos errors necessary often
  - Probes could pull out of holder seating



Dipole Mapping (cont)

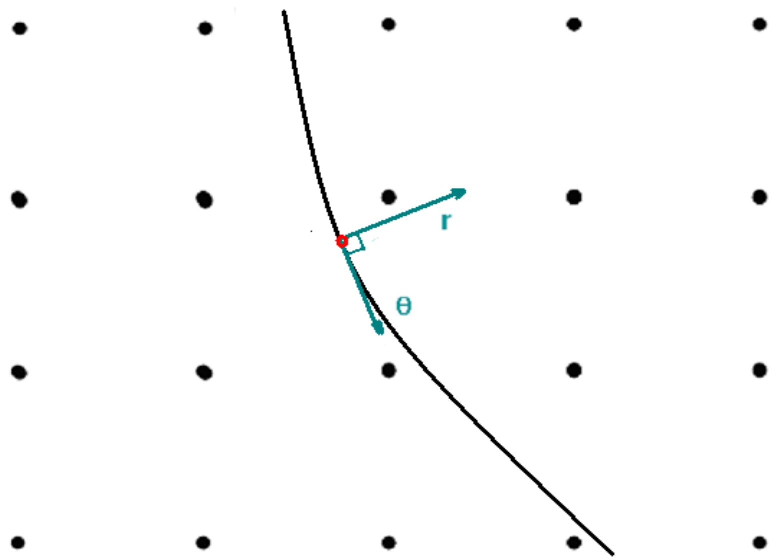
- **Field integral (BL) matching between measurement systems was acceptable**
  - **Hall probe grids and SW matched at the 0.01% level throughout production**



- **Spec for B'L was 0.08%, but wanted reporting much tighter**
  - **0.005% σ**

B’L from Detailed Grid Data

- **Software was written to calculate B’ normal to the trajectory using grid data by calculating x and z derivatives at each point and then applying a rotation matrix to the x and z derivatives.**



$$\frac{dB}{dr} = \frac{dB}{dx}\cos\emptyset + \frac{dB}{dz}\sin\emptyset$$

$\phi = 0°$
is at center
of magnet

- **B’L is computed by integrating dB/dr along trajectory**
  - **This accounts for end effects**

SW vs. Hall Grid Curved Integral: B'L/BL accuracy

- For each Arc:
  - Get wire-vs-curved offset for each current then average over 3 magnets

Arc 6 B'L/BL (Curved-straight)			
wire	274	410	547
6A03	-0.027%	-0.026%	-0.022%
6A29	-0.026%	-0.030%	-0.023%
6A30	-0.028%	-0.029%	-0.028%
Avg diff	-0.027%	-0.028%	-0.025%

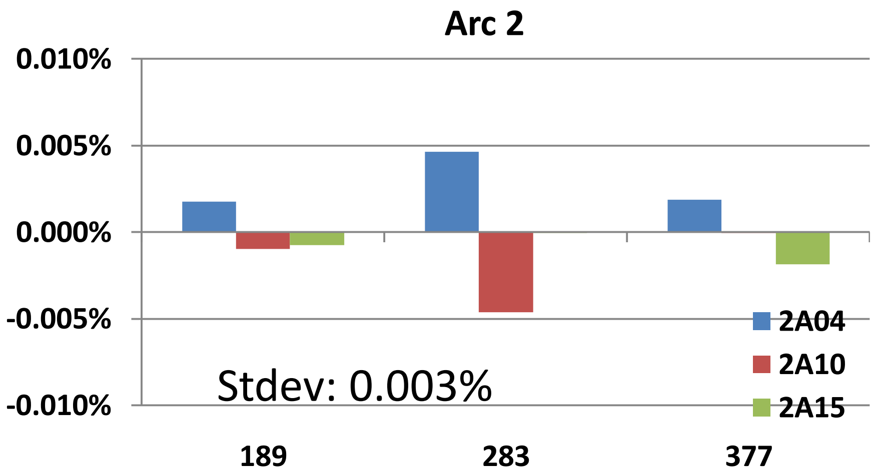
  - Use current-dependent offsets to "predict" curved-integral B'L/BL and compare to the actual B'L/BL from the curved-integrals

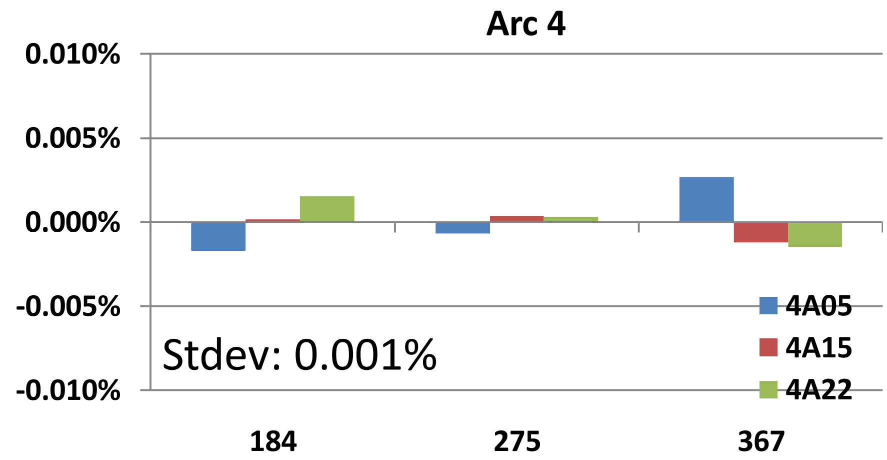
"Error" in calculated B'L/BL			
wire	274	410	547
6A03	0.000%	-0.002%	-0.002%
6A29	-0.001%	0.001%	-0.001%
6A30	0.001%	0.001%	0.003%

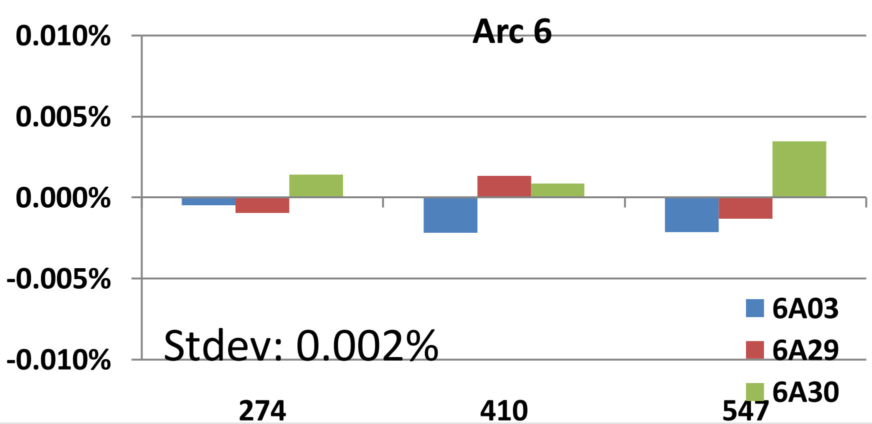
Overall stdev (9pts): 0.002%

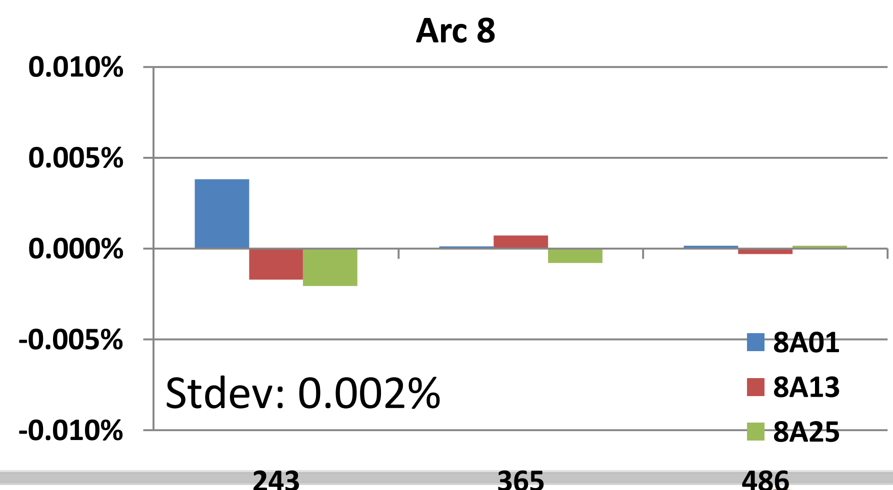
Consistency of B'L/BL: 2, 4, 6, & 8

- **Differences between curved data and stretched wire data fell within 0.005%/cm spec for reporting**
  - Still see noise at this level using 5 points for calculation



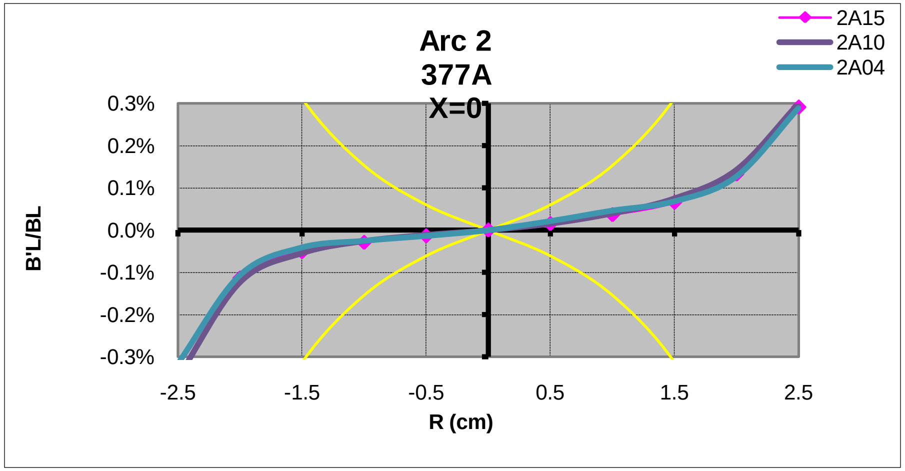


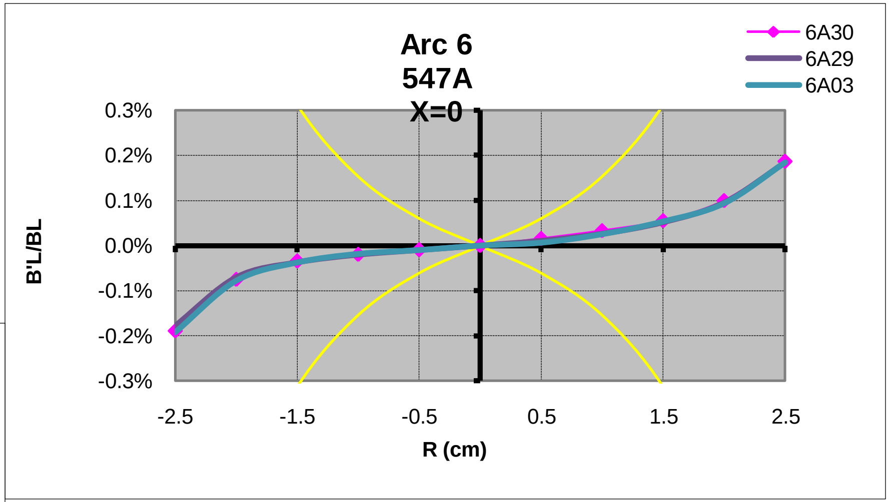


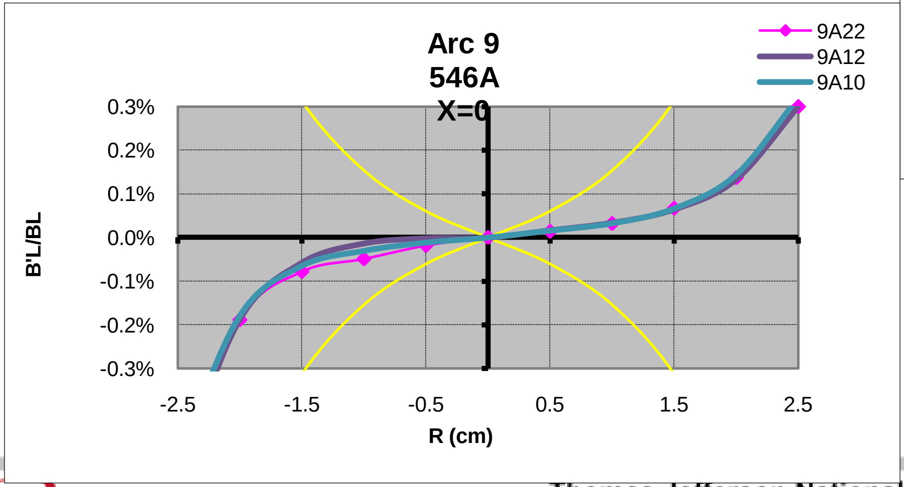


B'L/BL : Perpendicular to Curved Trajectory

- **B'L/BL calculated at different radius values**
  - Results for each arc found to be well within specified acceptability range

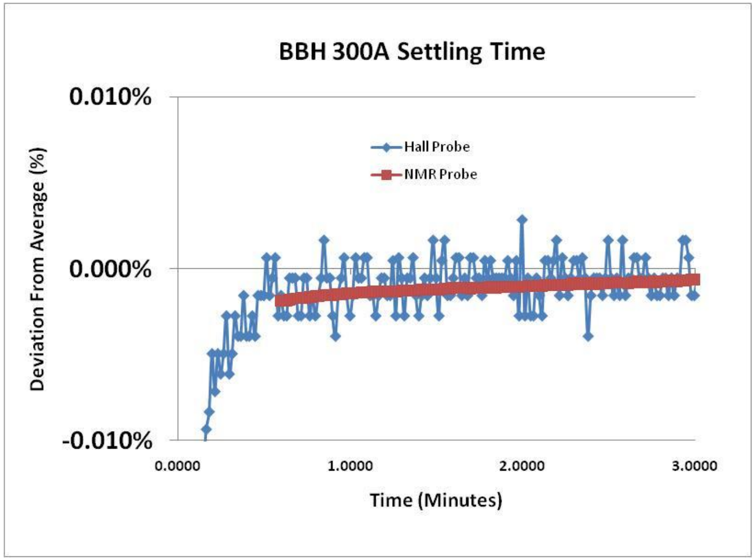


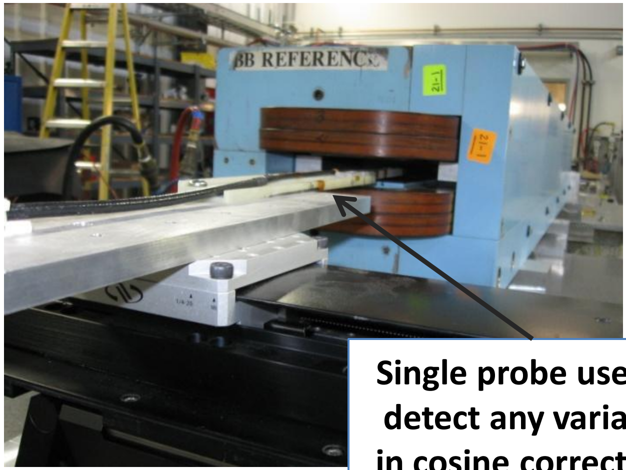




Other Measurement Considerations

- **Settling Time**
  - Hall probe is within 0.01% of final value within <15sec.
  - LCW connections done first (by procedure) and 5 minute warm up at maximum current prior to measurement
- **LCW Flow**
  - Magnets were in tunnel for ~20 years.
  - Evidence of “dead heading” and over heating
  - All but 1 set of coils passed flow tests at allowable levels.
    - Failed coil restored to passing by acid flushing coil
- **Probe Calibration**
  - NMR measurements taken with each detailed grid
  - Single probe on stick used as “cosine correction” check for each magnet pass
  - Each hall probe calibrated against NMRs
  - Probe positions checked by alignment group





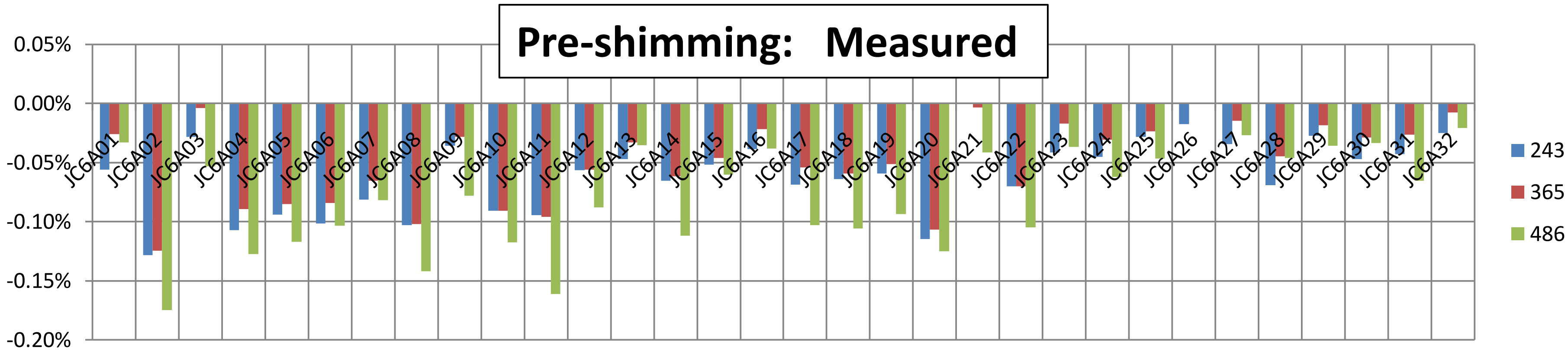
Single probe used to detect any variance in cosine corrections for trolley probes

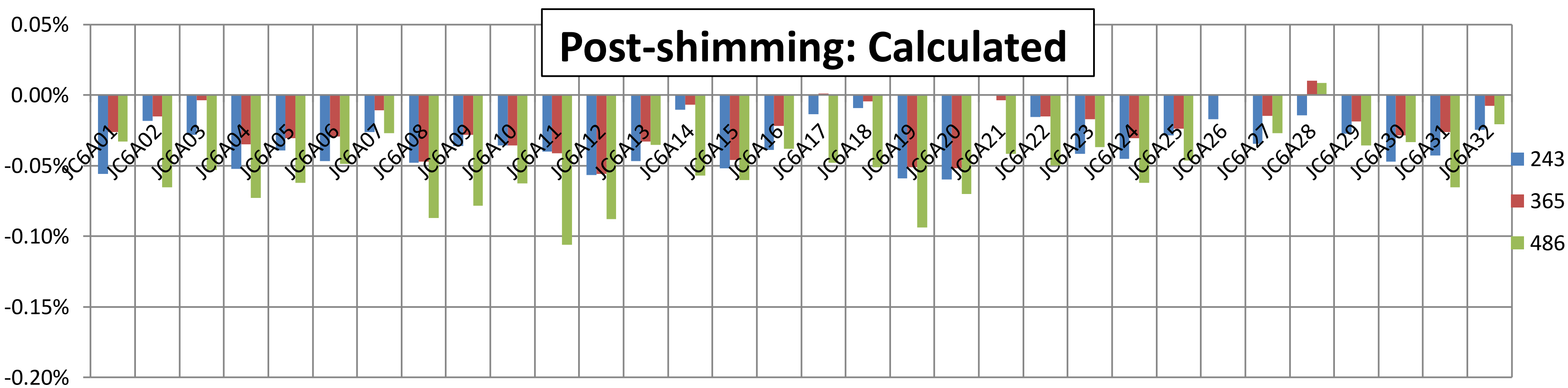
Matching Dipoles in the ARC

- **Shim sets were used to bring each arc within 0.1% spec**
  - **Shims are 0.054”-0.057”.**
    - **Assumed 0.054” for the calculations**
  - **Some excitation dependence seen in magnet-magnet differences**
    - **Gaps at interface points leading to varying saturation effects?**
  - **For final experiment, sets were optimized for 6 GeV ops.**
    - **Will re-optimize for 12 GeV next year.**

BL matching

Arc 6: Wire measurements on 2m dipoles





Production Quad Measurements

- Integrator:
  - MetroLab 5025
- Radial Probes:
  - Circuit Board Design
    - (Dimarco IMMW 15)
- Transducers:
  - Danfysik Ultrastab 866
- Power supply:
  - Danfysik 7000
- Motion Control:
  - NI FW-7602 Stepper Motor
  - 4000 count encoder
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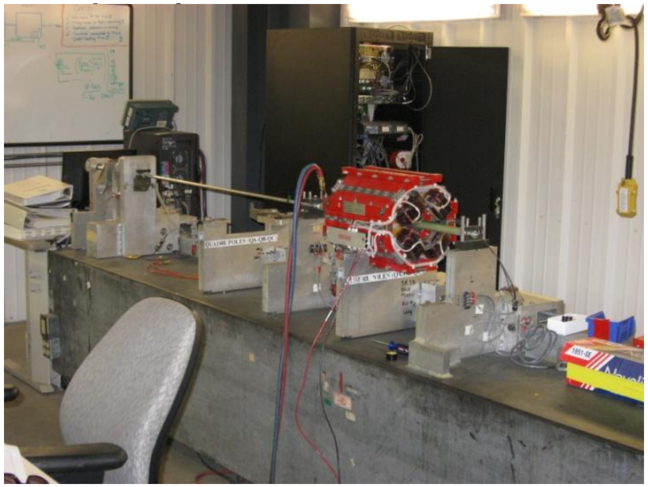
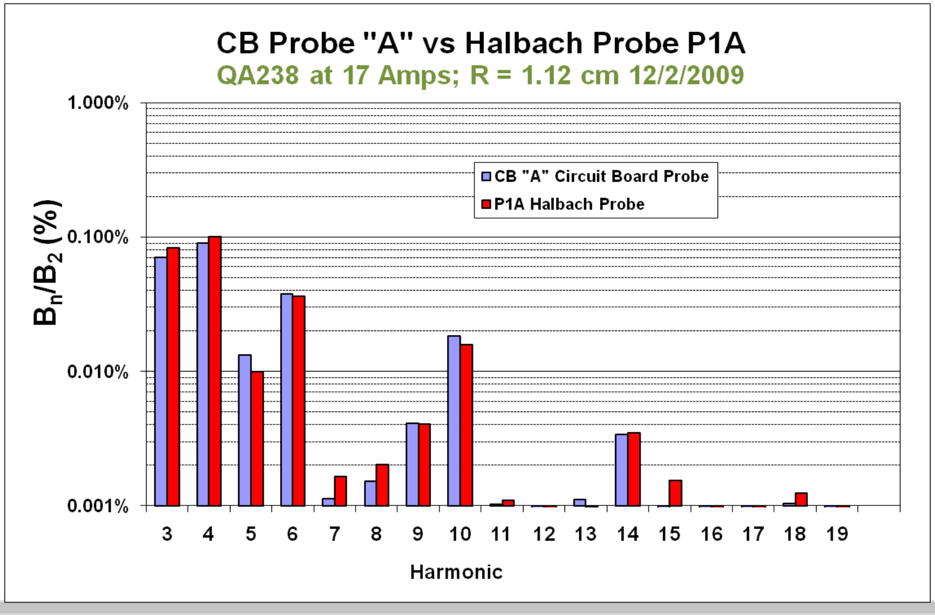


- 57 QR Quadrupole Magnets
  - I = +-18.5A (1A increments)
  - LCW = 0.3 gpm
  - Mag Length = 14"
  - Mag Width/Height = 12"
  - Bore = 1"
  - Approx Strength = 10000 G / Amp (Gradient Integral)
  - Weight ~435lbs
- 57 QP Quadrupole Magnets
  - I = +-19A
  - LCW = 0.3 gpm
  - Length = 12"
  - Mag Width/Height = 12"
  - Bore = 1.5"
  - Approx Strength = 4500 G / Amp (Gradient Integral)
  - Weight ~380lbs

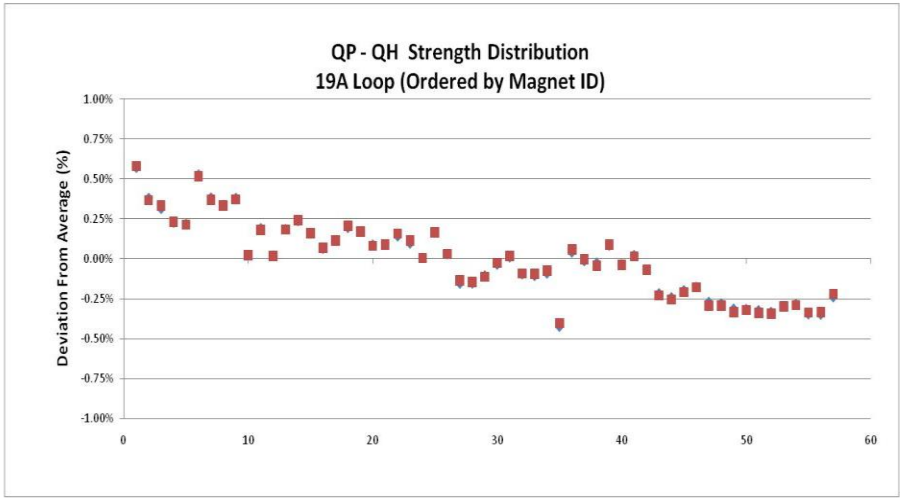
Rotating Coil Performance: Multipole tests

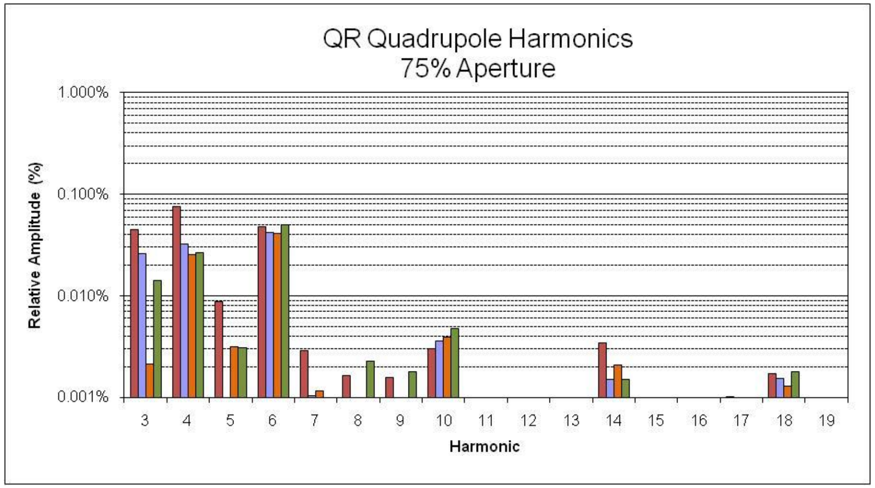
- QP aperture is 1.5”
  - No probe that size in the inventory
- Needed a new radial probe.
  - Circuit board probe?
- What we found:
- Pros
  - Fairly easy to draw up
  - Cheap to order
  - Quick delivery
  - Comparable performance to the traditional wound coils
  - Great signal to noise for multipoles
    - Compared well to existing wound probes
  - Calculated absolute strength compares at the 0.06% level (DBUCK coil compared to SW)
- Cons
  - Fewer turns so not as much signal
  - 2 Layers easy but had shorting issues with multiple layering.
    - Could overcome with manufacturing specs (but more tests add $)

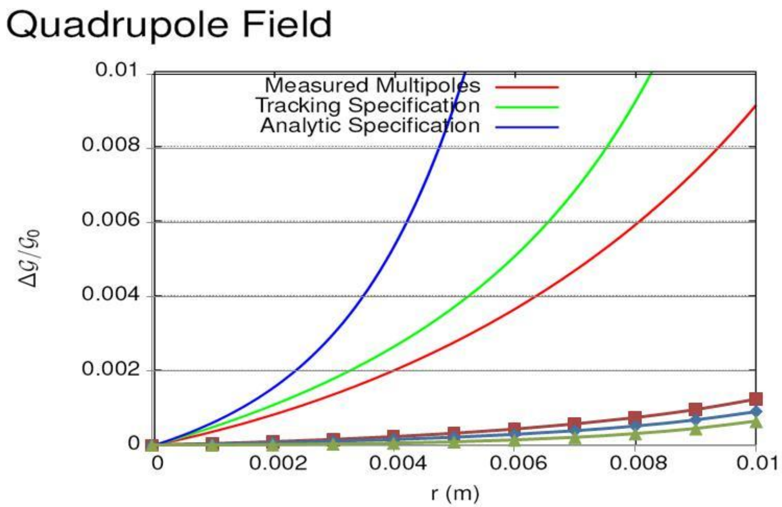


Production Quadrupole Measurements

- **All 117 quadrupoles have been measured.**
- **Results:**
  - **Non-linear terms net <1/5 of the specification.**
  - **Quite similar "allowed" multipole content (n=2, 6, 10, 14….)**
  - **Strength variation in the populations at the 1% level.**







Moving Forward

- Focus will be on meeting throughput requirements for remaining production measurements
  - Measurement of ~30 new dipoles
    - C, H, and curved configurations
  - Refurbishment and measurement of ~80 altered dipoles to complete the spreaders and re-combiners
  - Measurement of 48 1m dipole
- Continued development of the linear stages
- Refinement of multi-probe trolley
  - Automated calibration