Fermilab Muon g-2

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Reassembling the Wedge Shimming System of the Muon g-2 Ring

Kerbie Reader

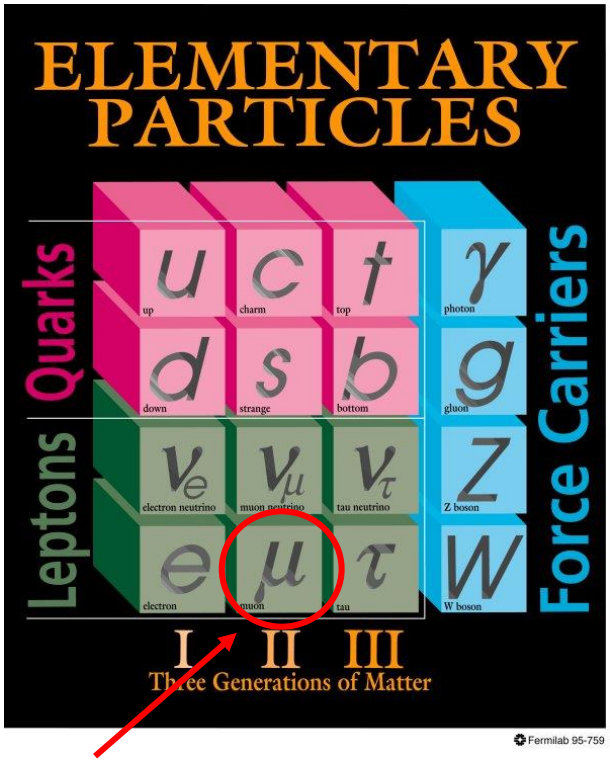
TRAC Presentation

July 30, 2015

Agenda

- Scientific motivation
- Experiment Engineering Design
- Wedge Shimming Process
- Lessons Learned

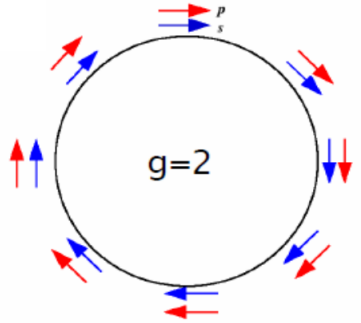
g-2: The Science

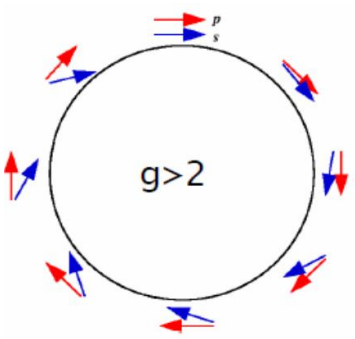


muon:
- charged lepton
- heavy
  - 207 x e-
  - “long” life
- SPIN

$$\overrightarrow{\omega_a} = \overrightarrow{\omega_s} - \overrightarrow{\omega_c} = -\left(\frac{g-2}{2}\right)\frac{q\vec{B}}{m} = -a_\mu \frac{q\vec{B}}{m}$$

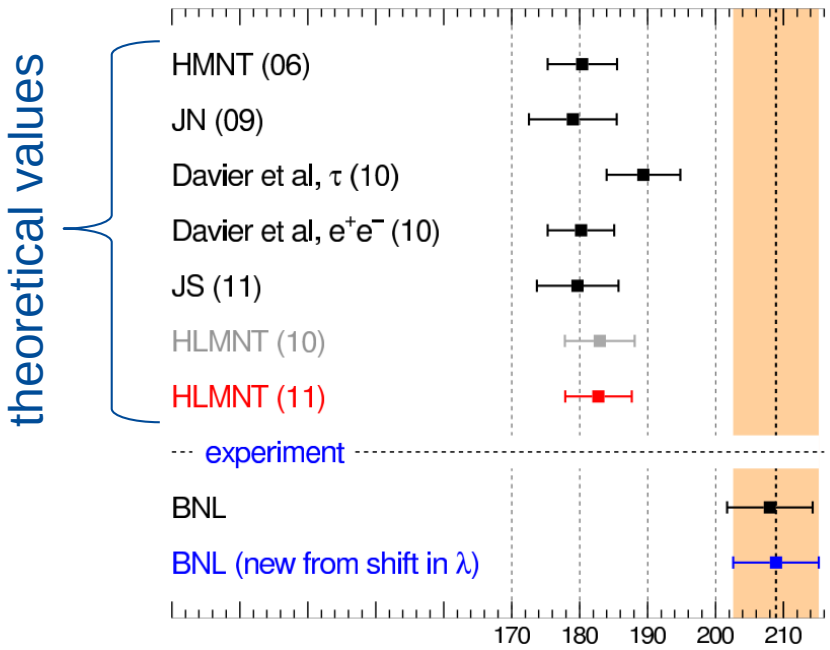
$\overrightarrow{\omega_a}$: anomalous precession frequency - MEASURE
$\overrightarrow{\omega_s}$: particle spin precession frequency
$\overrightarrow{\omega_c}$: cyclotron frequency
g: gyromagnetic ratio
q: particle charge - CONSTANT
$\vec{B}$: magnetic field vector - MEASURE
m: particle mass - CONSTANT
a_μ: anomalous magnetic moment $\approx 1.165918 \times 10^{-3}$





Fermilab

g-2: The Science



theoretical $a_\mu \approx 1.165918 \times 10^{-3}$

Goal: Improve precision on measurement of muon anomalous magnetic moment from 0.54 (3σ) to 0.14 ppm (5σ) in order to investigate discrepancy with standard model → then folks can look for new physics!

Figure 1: Comparison of theoretical and experimental a_μ values [1]

g-2: The Move

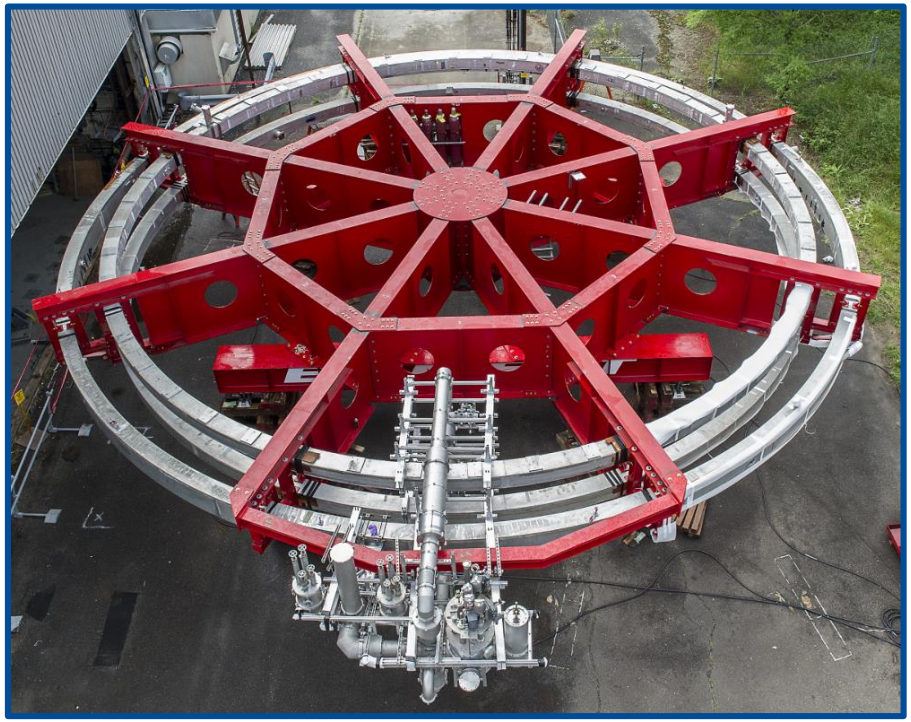


Figure 2: Superconducting coil assembly in transport support structure [7]

Figure 3: Map of travel path for g-2 ring [6]

g-2: The Engineering

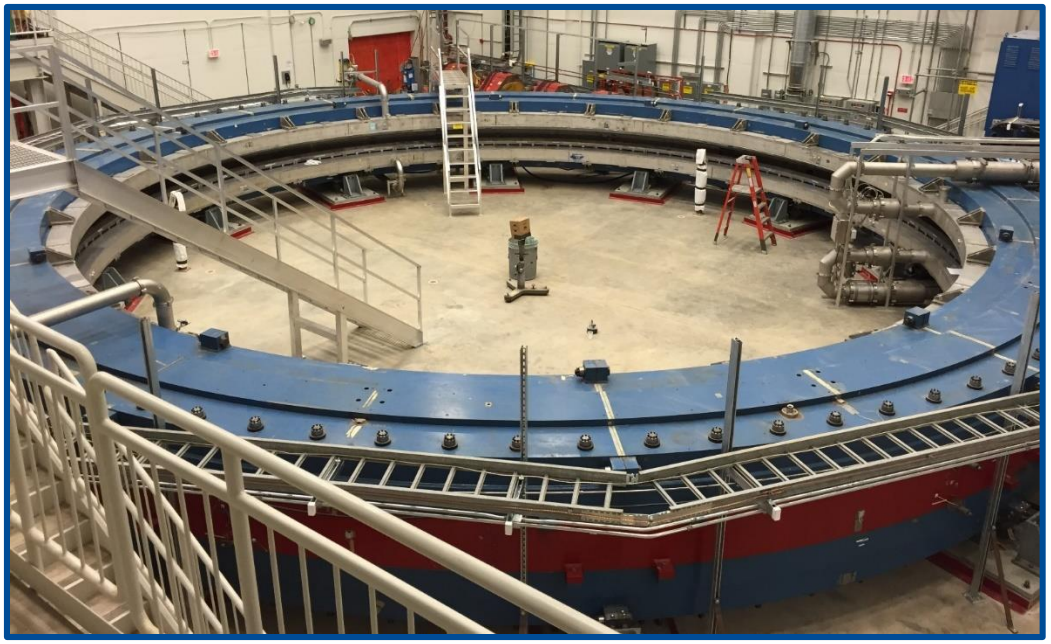
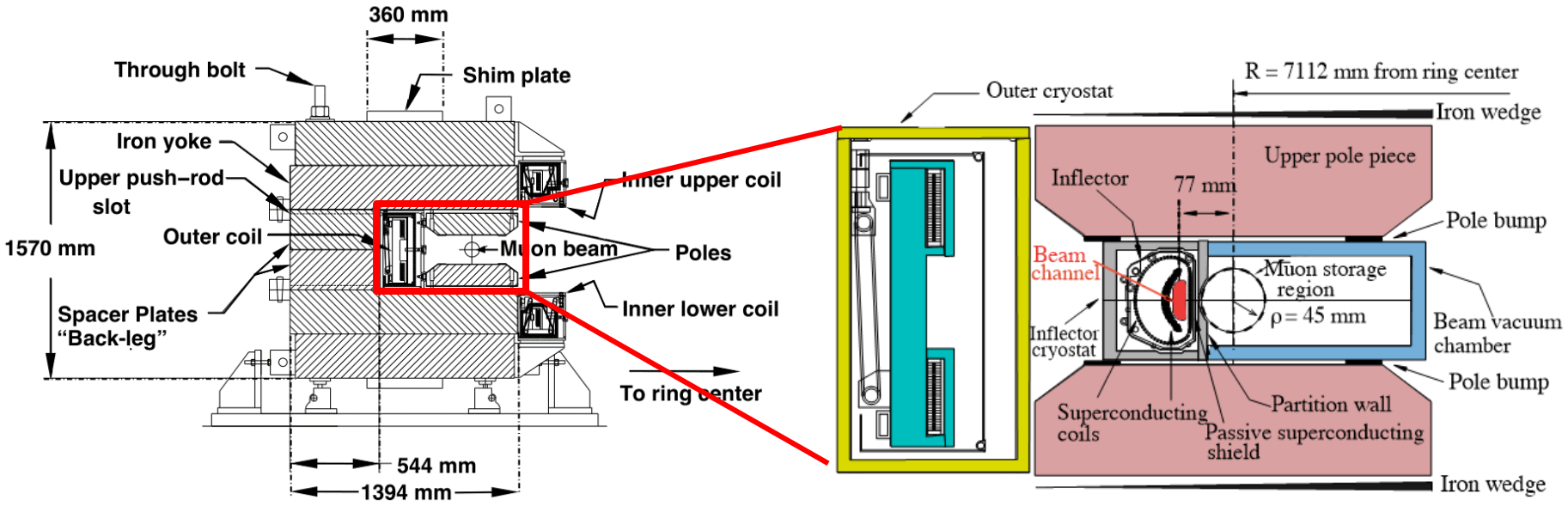


Figure 4: Ring reconstructed as of July, 2015

- Superconducting magnetic coils
- 1.45 T
- 4.7 K
- Moved 3200 miles from BNL
- Saved $20M and 2 years over new build

g-2: The Engineering

$$\overrightarrow{\omega_a} = -\left(\frac{g-2}{2}\right)\frac{q\vec{B}}{m} = -a_\mu \frac{q\vec{B}}{m}$$



(a) (b)

Figure 5: Elevation views of the storage-ring magnet cross section [3]

g-2: How to Create a Perfectly Uniform $\vec{B}$ Field

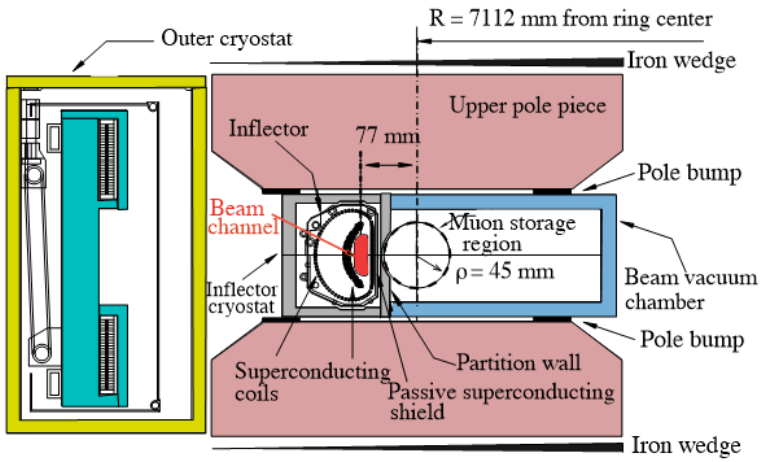
Step 1: Create an Ideal Design

- Highly flat gap width (180 mm)
- 72 x pole pieces steel (contribute to 1.45 T $\vec{B}$)
- Other metals are non-magnetic

Step 2: Correct for Reality

- Inner radius gap offset
- Holes from attaching screws (x 576)
- Pole Piece Gaps (x 72)
- Instrumentation holes
- Injection hole
- Tolerance non-uniformity

Figure 6: Photo of pole pieces and gap



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Perfect field only needed in a very small area!

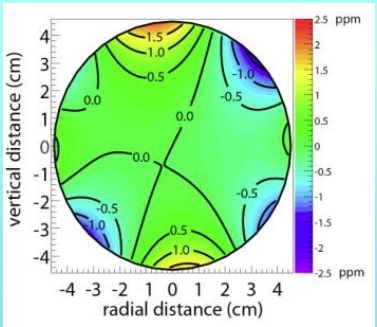
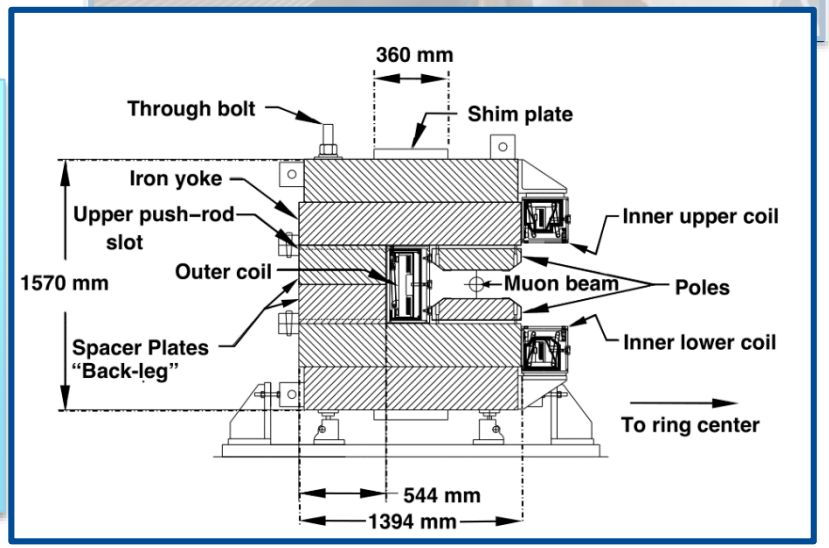


Figure 7: $\vec{B}$ field measurement cross-section [3]



g-2: Magnetic Field Issues

- Pole Piece Gaps (x 72)
- Instrumentation holes
- Injection hole
- Tolerance non-uniformity

432 wedge shims

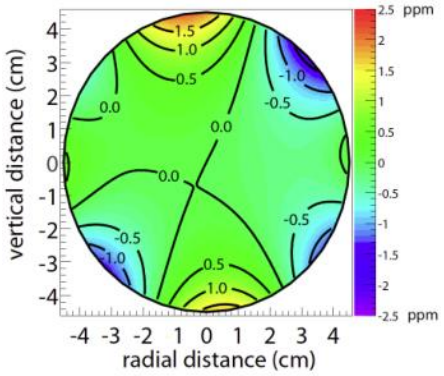


Figure 7: $\vec{B}$ field measurement cross-section [3]

g-2: Wedge Shimming Process

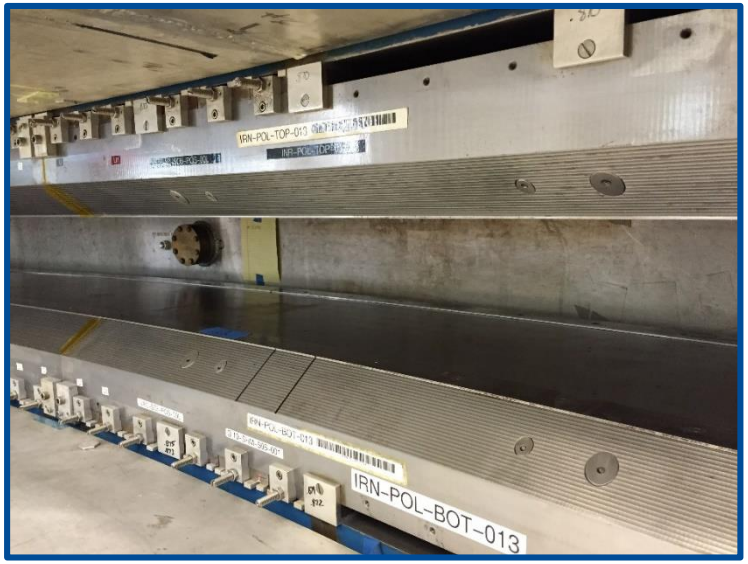
Step 1: Cleaning

- Remove all pieces; scrub with WD-40 and Scotch Brite

Step 2: Install

- Find a left, right, center
- Shim the “foot” to ~0.002 inches

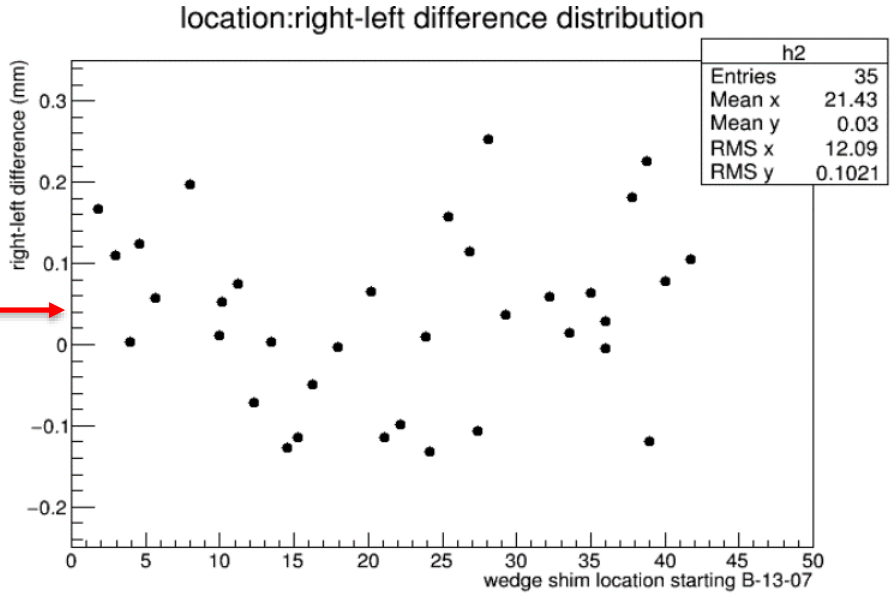
Step 3: Set radial locations



g-2: Radial Location Initial Setup

- Calibrated radial location/360° → 1.58 mm/screw turn
- Set 50 wedge shims to BNL locations, something was “off”
- Measurements on left vs right of bracket sometimes differed by as much as 0.25mm →0.5°
- Modeled simplified +0.5° change → not within tolerance
- Where to go from here?

No apparent correlation



g-2: Other Wedge Shimming Challenges

Also:

- Manpower
- Uniform installation practices
- Installation method development

Power On

Measure:

- B field (NMR probes)
- Gap distance (capacitec probes)
- Azimuthal location

Analyze:

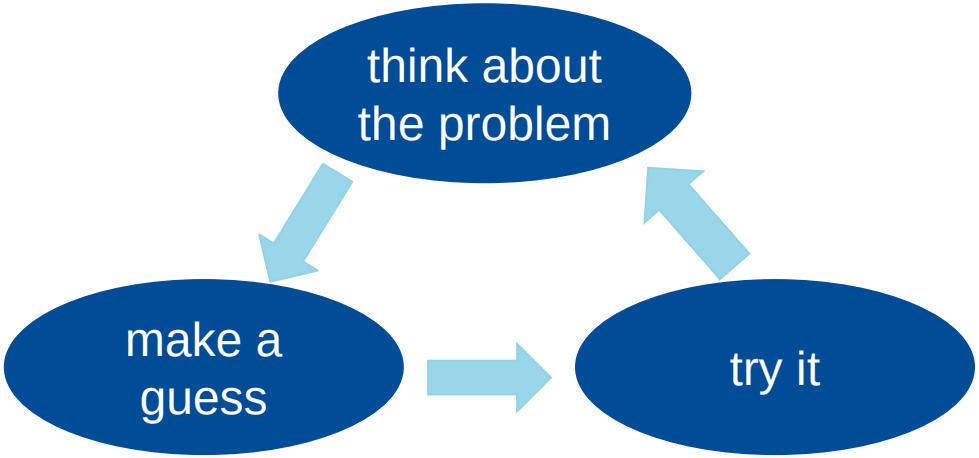
- Look for localized nonuniformity
- Look for periodicity

Adjust Wedge Shims

(a) (b)

Figure 8: (a) $\vec{B}$ field measurement cart
(b) Capacitec thin-gap probes

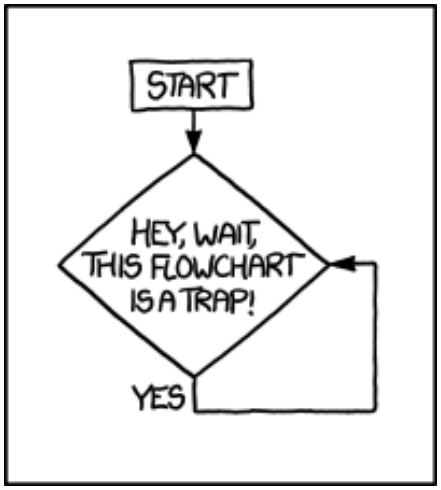
g-2: A Problem Solving Method - Iteration



- We inherited hardware that was not expected to be re-used
- We are trying achieve 4x higher precision with same hardware

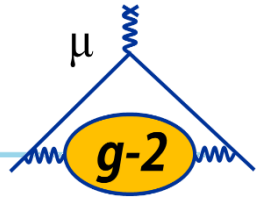
- SOME lessons are transferrable from past experience (develop a uniform procedure for repetitive tasks)

- Other lessons arise unexpectedly ($\pm 0.5°$ alignment of wedge shims may affect overall $\vec{B}$ field)



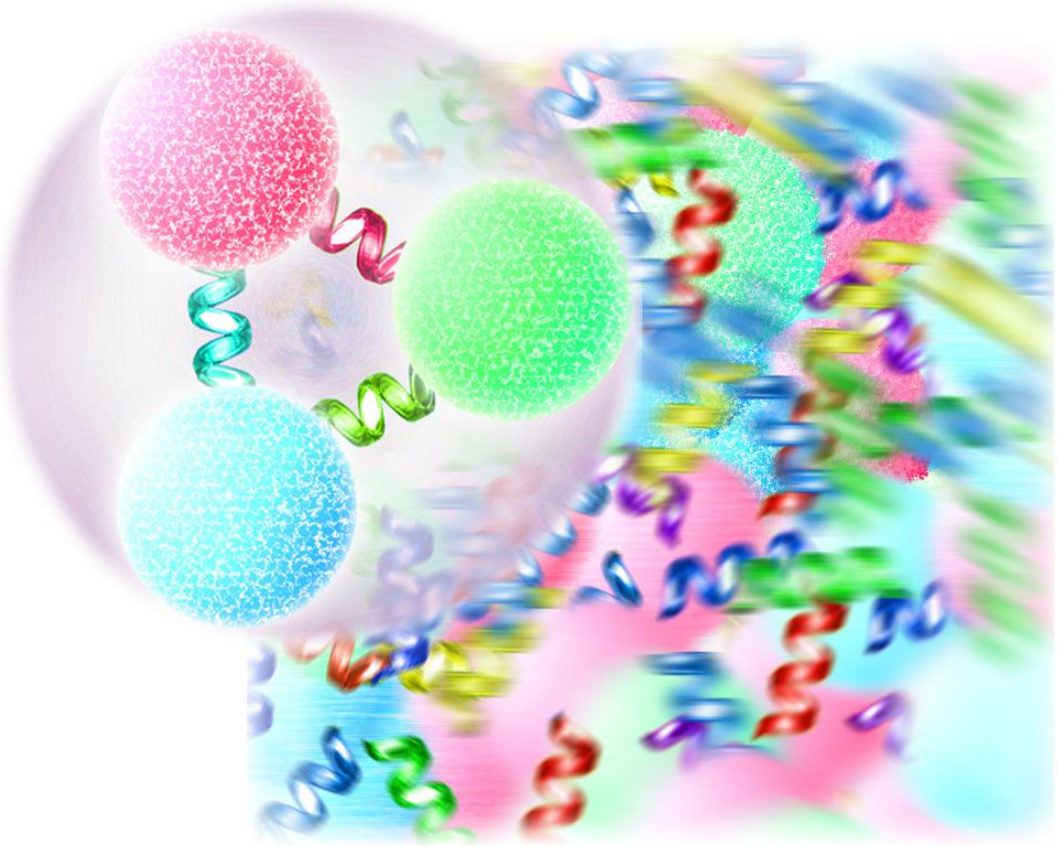
www.xkcd.com

g-2: What's Next?



- Finalize ring reassembly
- Instrument storage ring
- Measure magnetic field in vacuum storage ring with 2nd trolley
- Refine magnetic field with wedge shims to 1.4510000 $\pm$ 0.0000001 Tesla
- Muon injection
- Collect the anomalous precession frequency $\overrightarrow{\omega_a}$ data
- Find $\frac{g-2}{2}$ to < 0.14 ppm

g-2: What's Next?



… New Physics?

g-2: Lessons Learned Summer 2015

Mosquitos like Physics too!

- Technical/Industrial synergy
- Details, details, details for ppb scale

  "…*can't be paranoid enough*" – Mandy Rominsky
- Iteration
- Trigonometry is useful for more than shadows and tides

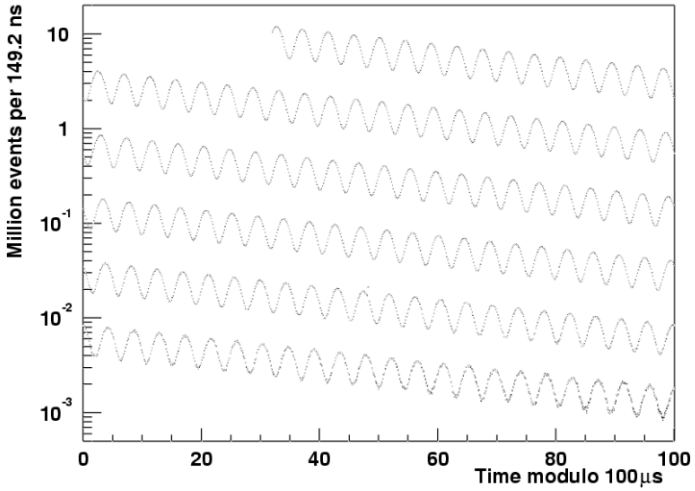
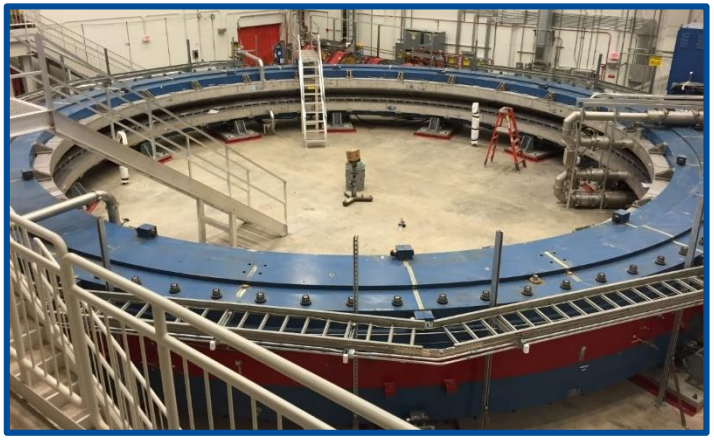
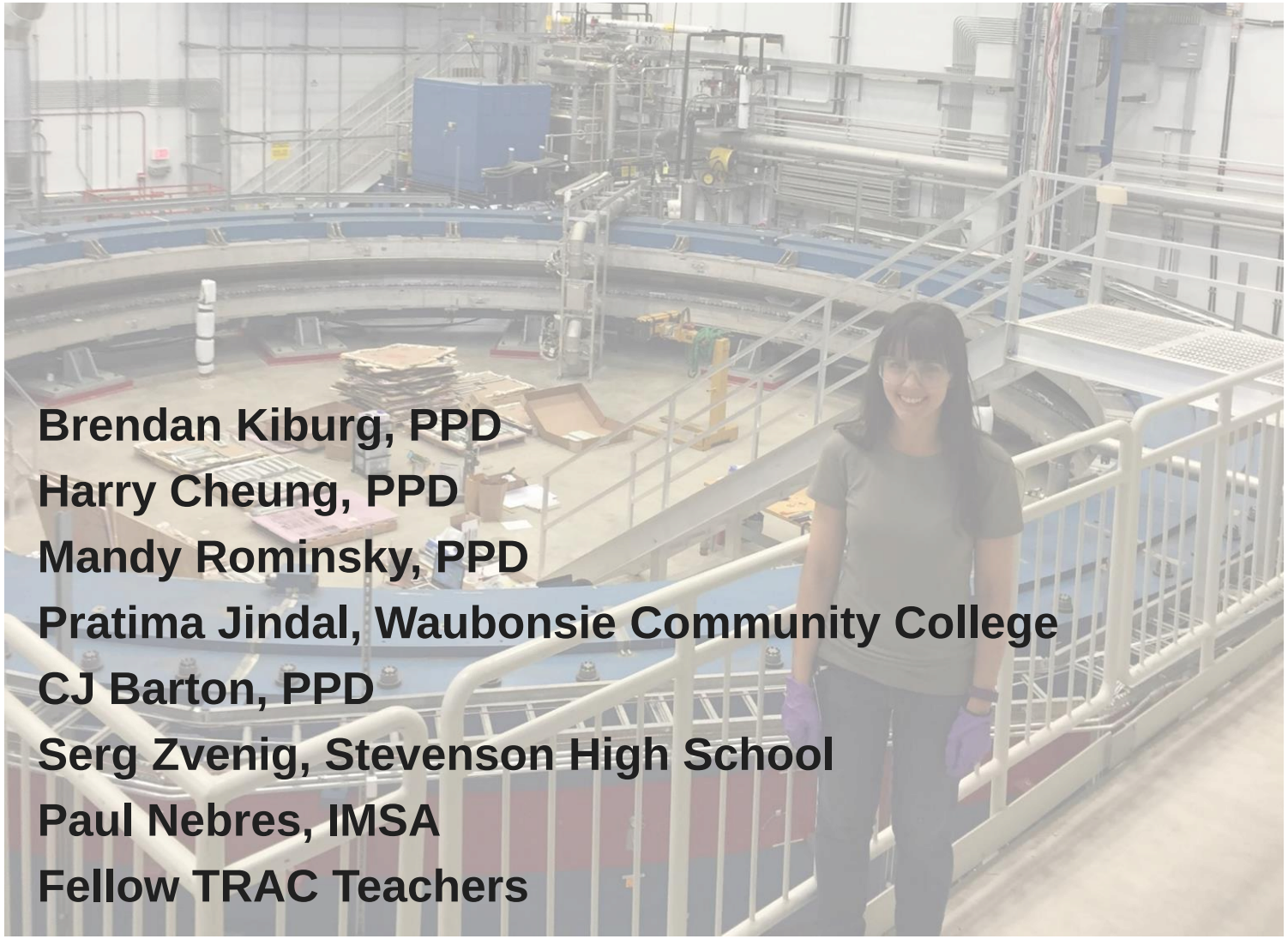


Figure 9: BNL results showing decaying sinusoidal relationship of muon decay to electron



It's a CIRCLE ☺

Many Thanks to:



Brendan Kiburg, PPD
Harry Cheung, PPD
Mandy Rominsky, PPD
Pratima Jindal, Waubonsie Community College
CJ Barton, PPD
Serg Zvenig, Stevenson High School
Paul Nebres, IMSA
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References

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[2] Bennett et al. [Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL] 2008.

[3] [Muon g-2 Technical Design Report] July, 2014

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[7] Kiburg [The Muon g-2 Experiment at Fermilab] Summer Student Tours. 2014.