ω_p Analysis in the Muon g-2 experiment at the Fermilab

Bingzhi Li[1], Liang Li[1], Dikai Li[1,2], Changbo Fu[1]

[1]Shanghai Jiao Tong University
[2]China University of Geosciences(Wuhan)
(Muon g-2 collaboration)

Outline

Scientific collaboration

US Universities
- Boston
- Cornell
- Illinois
- James Madison
- Kentucky
- Massachusetts
- Michigan
- Michigan State
- Mississippi
- Northern Illinois
- North Central
- Regis
- UT Austin
- Virginia
- Washington

National Labs
- Argonne
- Brookhaven
- Fermilab

Italy
- Frascati
- Molise
- Naples
- Pisa
- Roma 2
- Trieste
- Udine

China
- SJTU

Germany
- Dresden

Russia
- JINR/Dubna
- Novosibirsk

England
- Lancaster
- Liverpool
- University College London

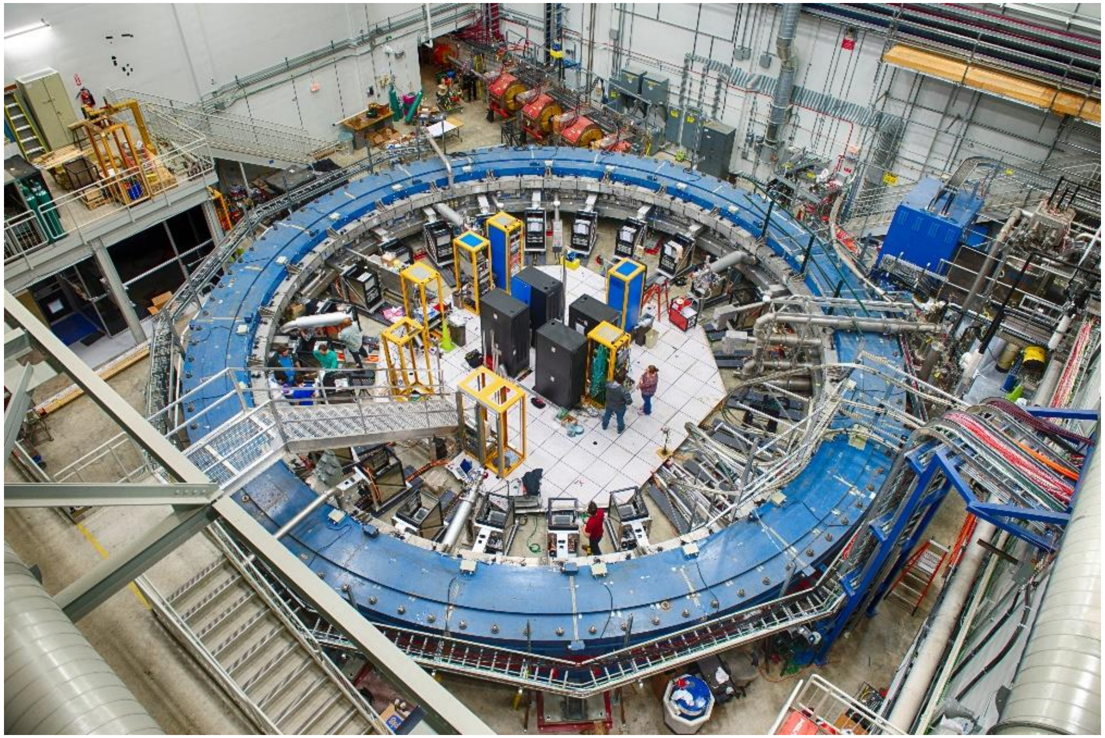
Korea
- CAPP/IBS
- KAIST

7 countries

34 institutions

1.Overview of Muon g-2 Experiment

Solving a Long Mystery



- $a_\mu \equiv \frac{g-2}{2}$
- A precision of ~10^{-7} (140 ppb)
- Probe Standard Model (SM) predictions for new physics effects

1.Overview of Muon g-2 Experiment

The Physics of g-2

$$\mu = g\frac{e}{2m}\vec{S}$$

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SJTU

The Physics of g-2

$$\mu = g\frac{e}{2m}\vec{S}$$

- Dirac: g = 2 for s = $\frac{1}{2}$ particles
- g found to differ from 2

$$a_\mu = \frac{g-2}{2} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{Had} + (a_\mu^{NP})$$

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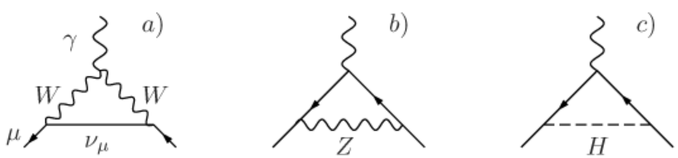

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The Physics of g-2

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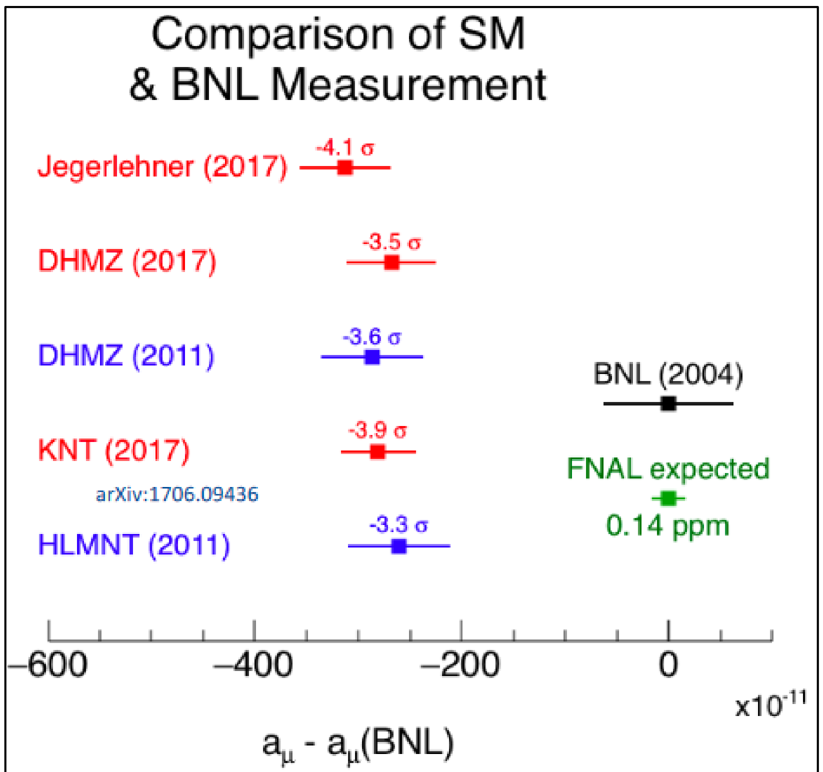

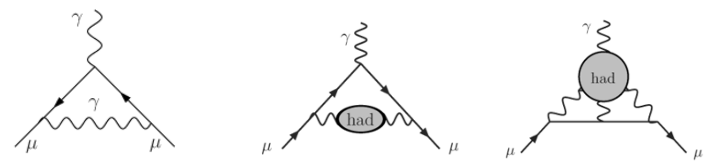

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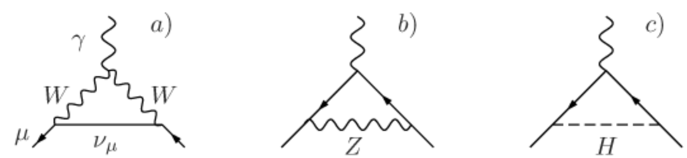
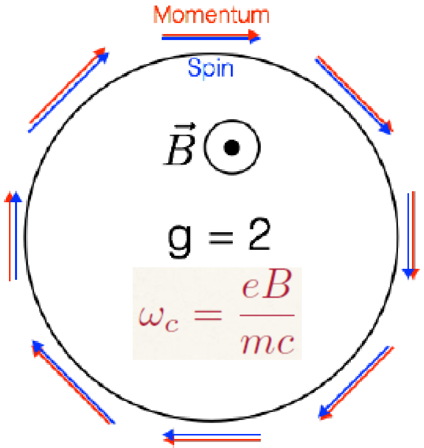
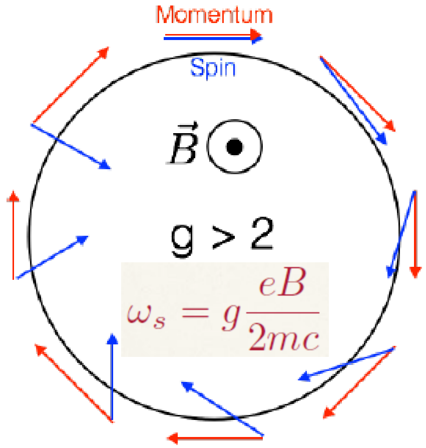


- The beyond standard model contribution may come from SUSY, dark photons and/or unknown new phenomena

1.Overview of Muon g-2 Experiment

Measure a_μ





$$\omega_a = \omega_s - \omega_c$$
$$= \frac{e}{m}[a_\mu B - (a_\mu - \frac{1}{\gamma^2-1})(\beta \times E)]$$

0 for γ=29.3

$$\omega_p = 2\mu_p B$$

$$a_\mu = \frac{\omega_a/\omega_p}{\mu_\mu/\mu_p - \omega_a/\omega_p}$$

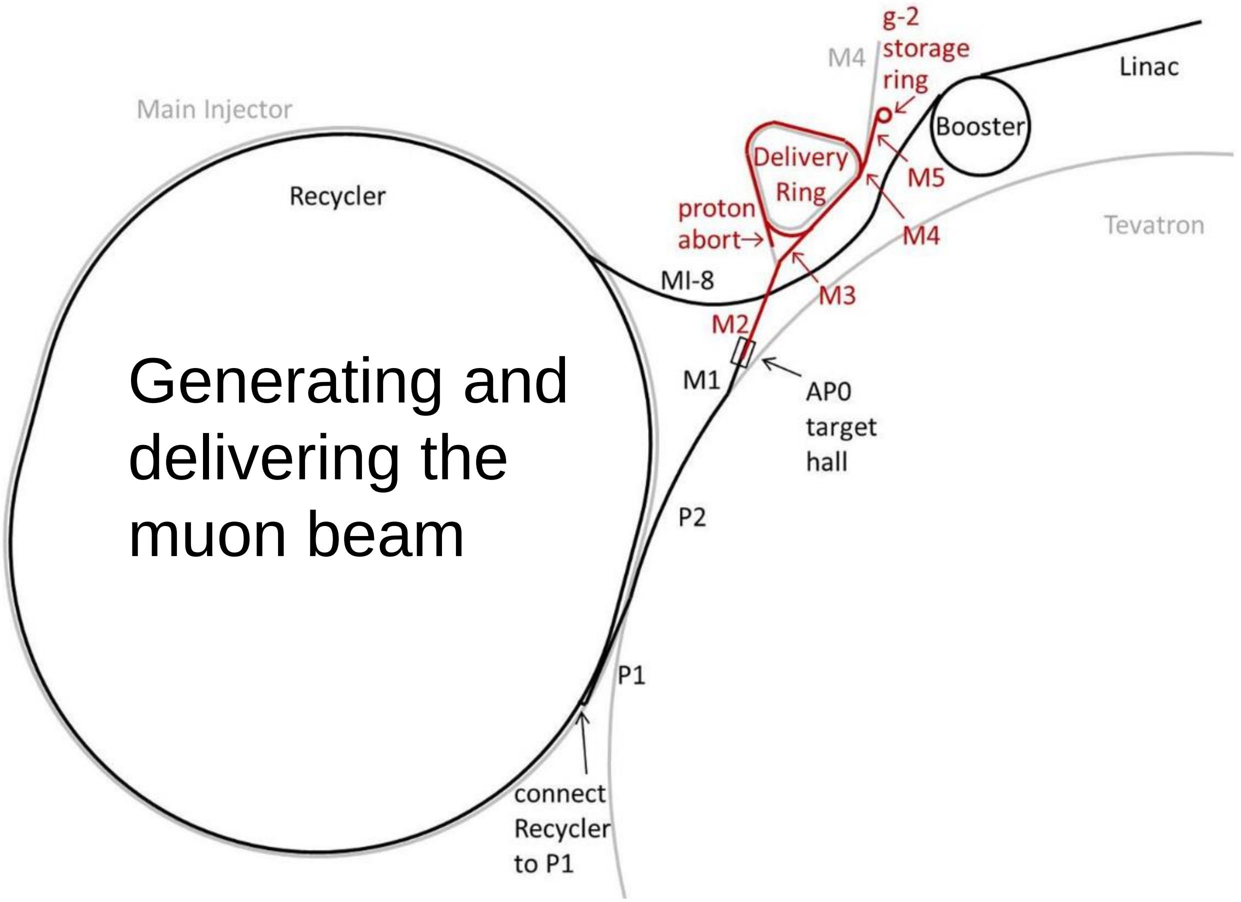
ω_a: Measure muon precession frequency
(next talk given by Dikai Li)

ω_p: Measure the magnetic field the muon experiences

μ_μ/μ_p: Hyperfine muonium structure experiment

1.Overview of Muon g-2 Experiment

How Does g-2 work



Generating and delivering the muon beam

1.Overview of Muon g-2 Experiment

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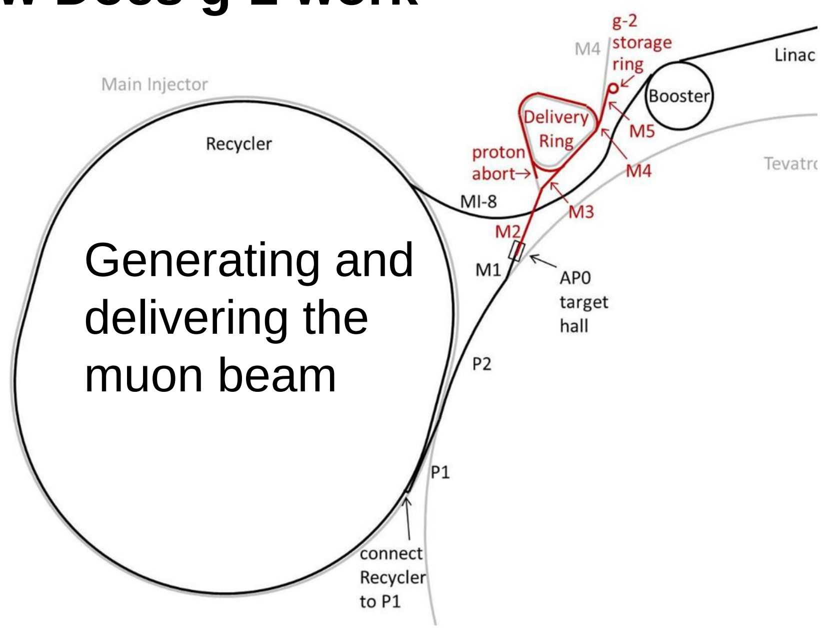

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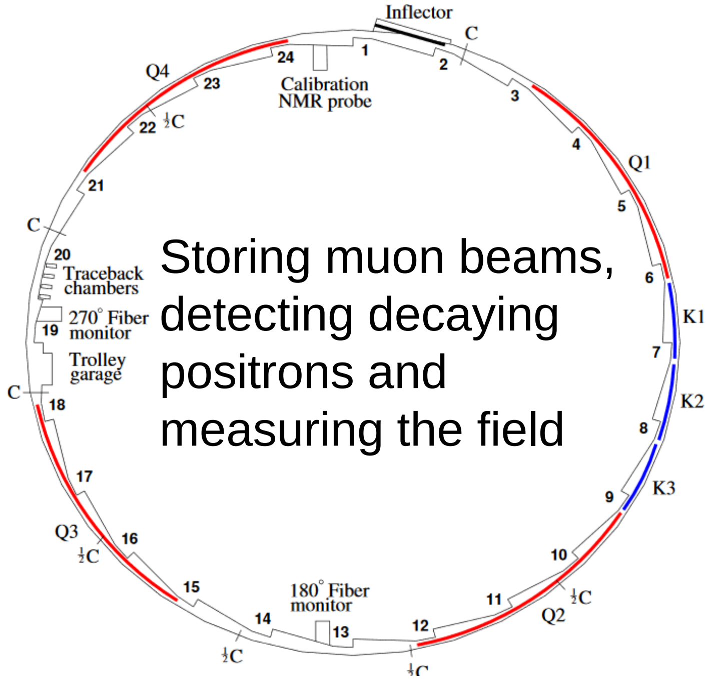
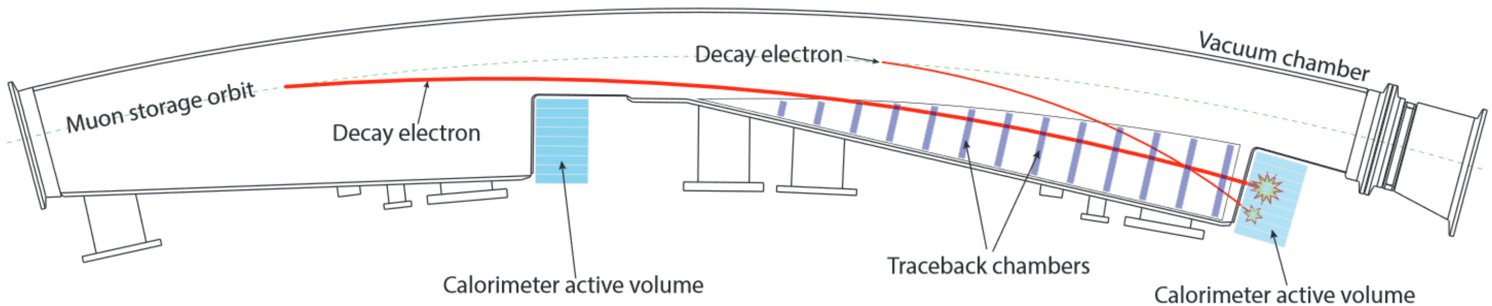


Storing muon beams, detecting decaying positrons and measuring the field



2.Magnetic Field Shimming

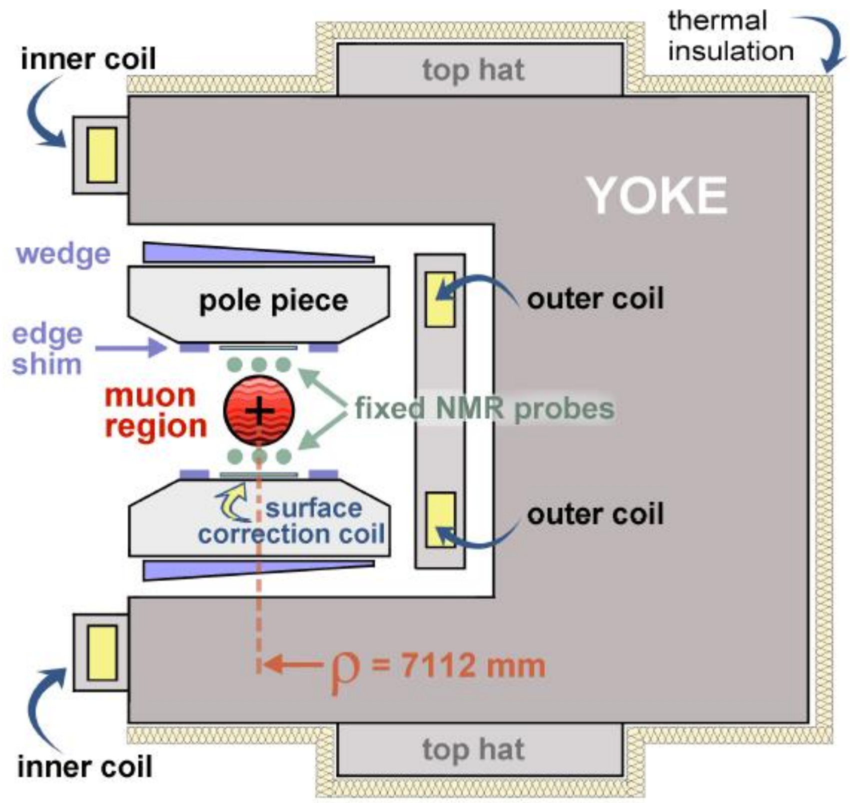
- Uncertainty Goal: $\delta a_\mu = 140ppb$ ($\delta\omega_a = 70ppb$, $\delta\omega_p = 70ppb$)
- The field (~1.45T) need to be uniform to ~1 ppm when averaged over azimuth

ω_p systematics

Category	E821 (ppb)	E989 (ppb)	Methods
Absolute probe calibration	50	35	More uniform field for calibration
Trolley probe calibration	90	30	Better alignment between trolley and the plunging probe
Trolley measurement	50	30	More uniform field, less position uncertainty
Fixed probe interpolation	70	30	More stable temperature
Muon distribution	30	10	More uniform field, better understanding of muon distribution
Time dependent external magnetic field	-	5	Direct measurement of external field, active feedback
Others*	100	30	More uniform field, trolley temperature monitor, etc
total	170	70	

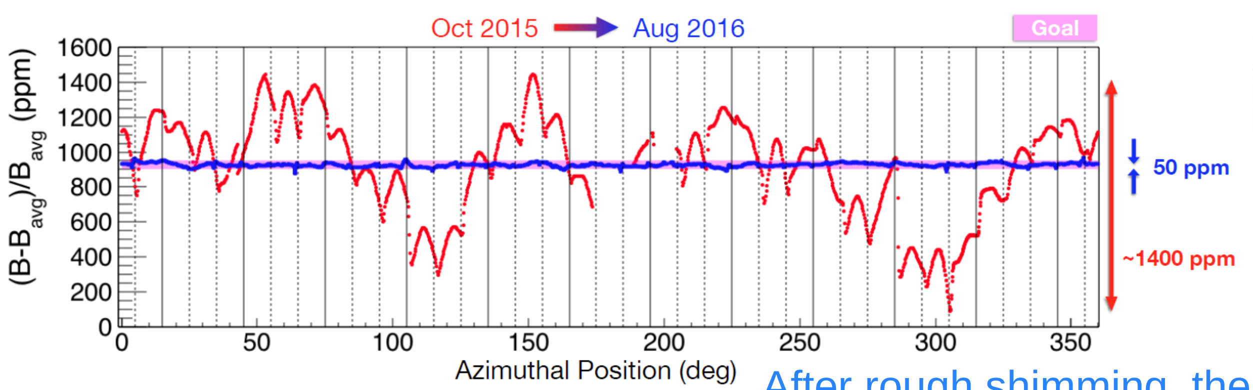
2.Magnetic Field Shimming

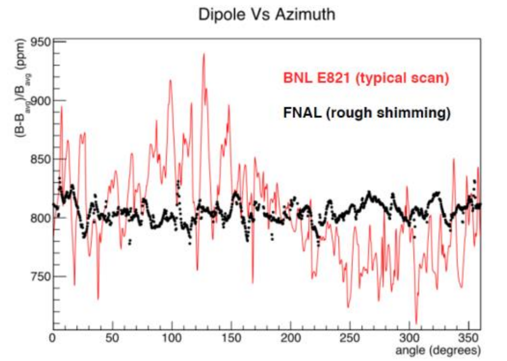
- Uncertainty Goal: $\delta a_\mu = 140ppb\ (\delta\omega_a = 70ppb\ , \delta\omega_p = 70ppb)$
- The field (~1.45T) need to be uniform to ~1 ppm when averaged over azimuth
- Field Shimming:
  - minimizing higher-order mutlipoles
  - dipole moment ~ 1.45T
- Passive shim method (geometry)
  - ✓ top hats, wedges, edge shim
    iron foil laminations
- Active shim method (current)
  - ✓ Surface correction coil
  - ✓ Power supply feedback



g-2 Magnet in Cross Section

2.Magnetic Field Shimming





After rough shimming, the field is uniform to ± 25 ppm

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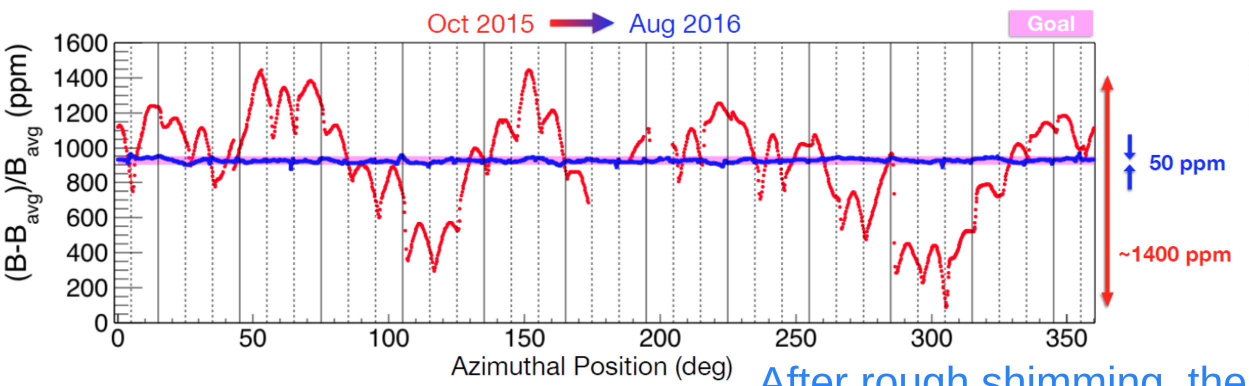

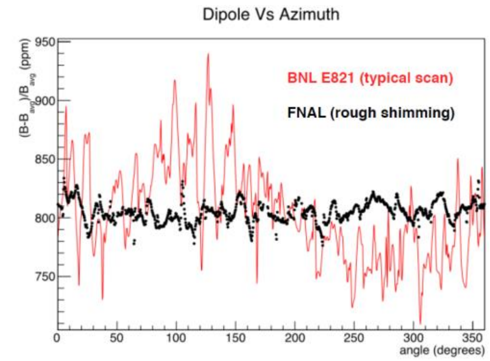

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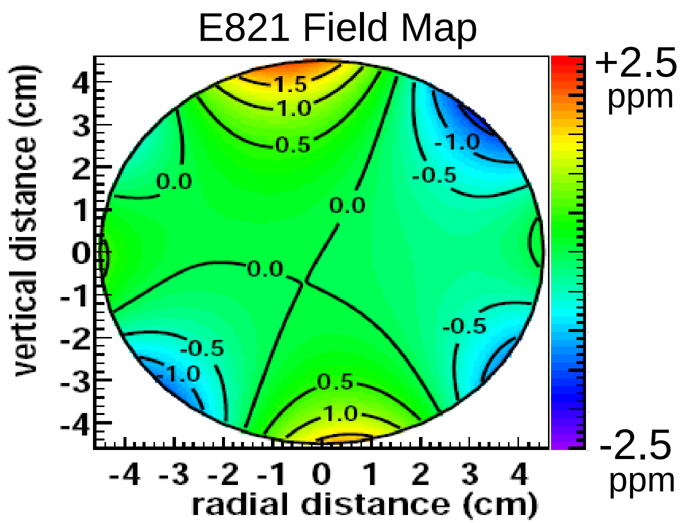
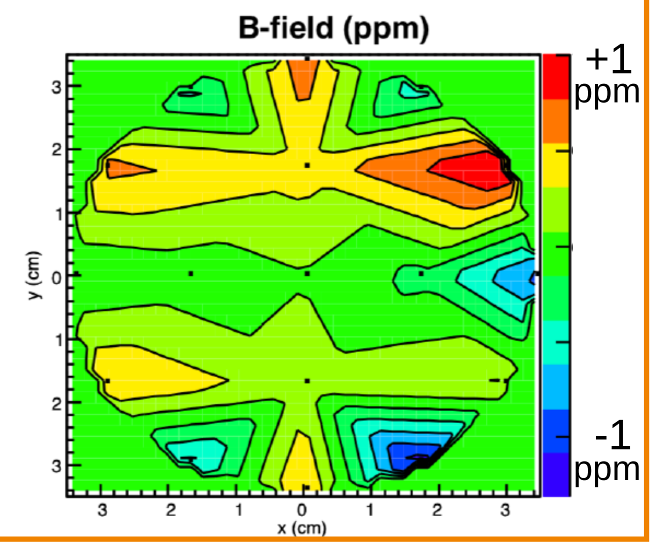


Field Map on 03/17/2018



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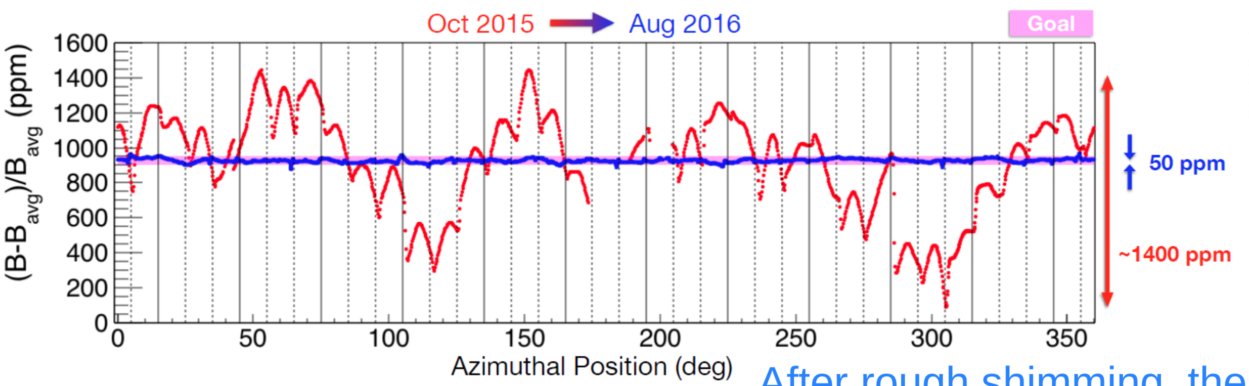
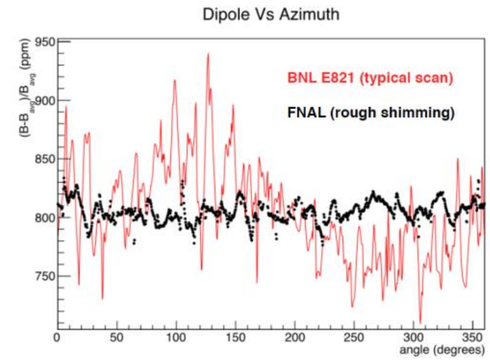
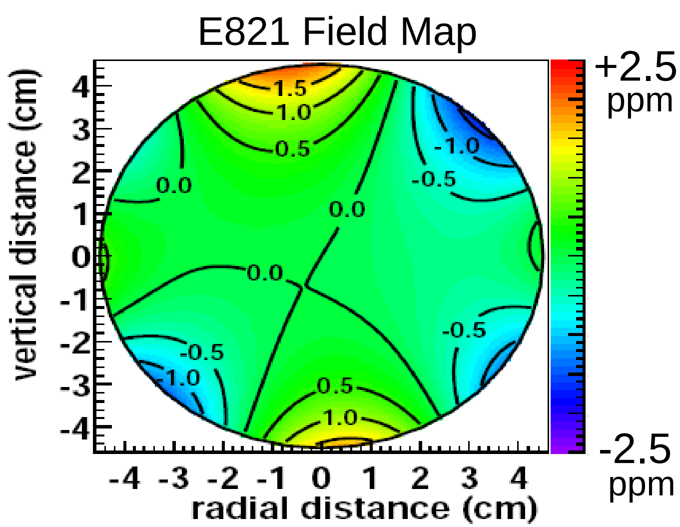


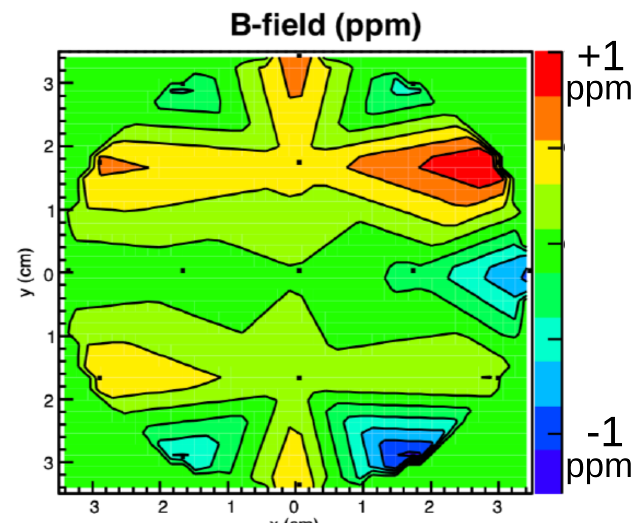


After rough shimming, the field is uniform to $\pm$25 ppm



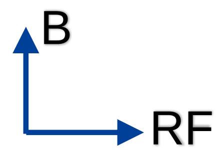
Field Map on 03/17/2018

Shimmed to $\pm$1 ppm level (averaged over azimuth)



3.Magnetic Field Measurement System

Method: Pulsed Nuclear Magnetic Resonance



- Apply RF pulse to the petroleum jelly sample at Larmor frequency
- The proton spins precess coherently in the external field
- The precess induces an EMF (Electromotive Force) in the pickup coil

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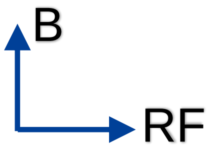
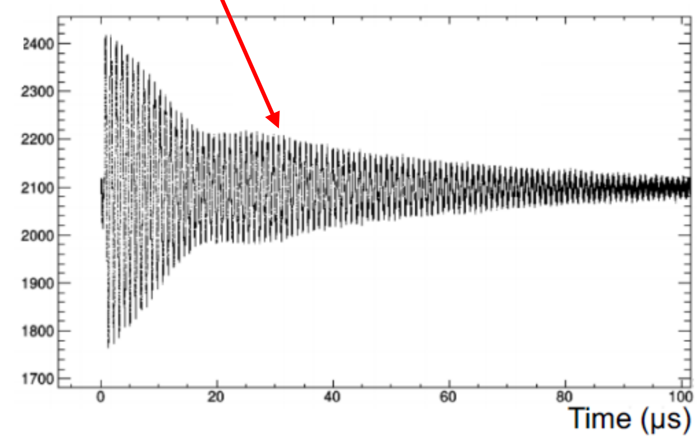


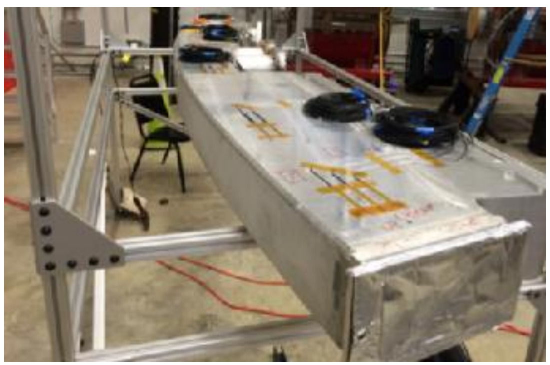
- Apply RF pulse to the petroleum jelly sample at Larmor frequency
- The proton spins precess coherently in the external field
- The precess induces an EMF (Electromotive Force) in the pickup coil
- After amplified and mixed down, the FID (Free Induction Decay) signal can be obtained
- Extracted frequency precision: 10 ppb/FID

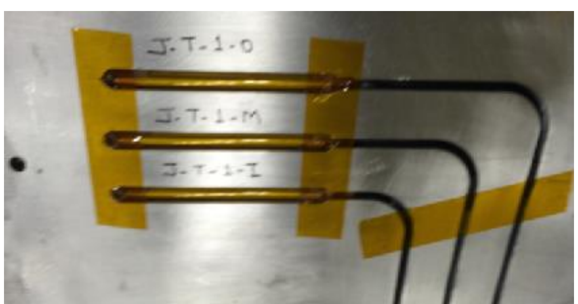
Monitor	Fixed Probe System
Scan	Trolley System
Correct	Calibration System

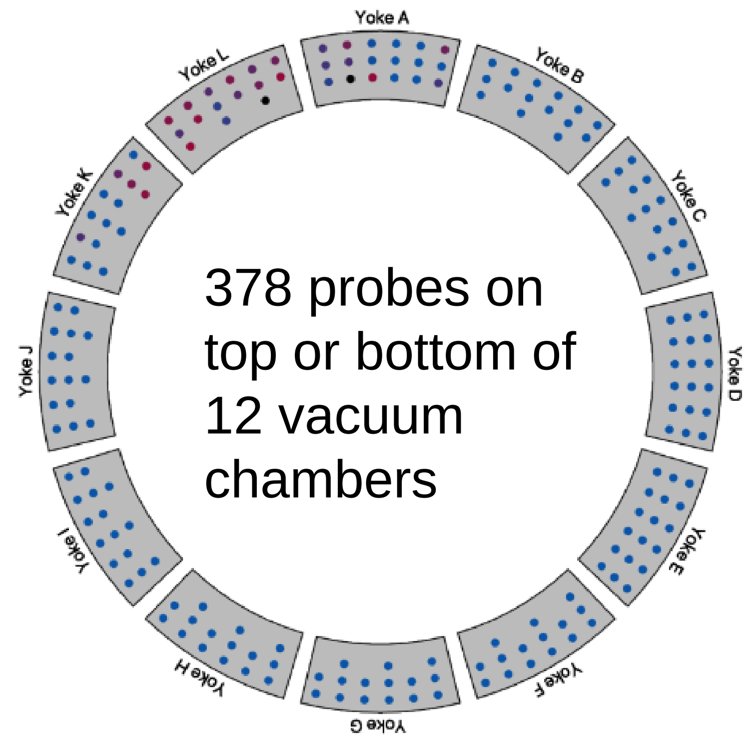


3.Magnetic Field Measurement System

- Fixed Probe System: Monitoring the field when muon data are being collected and supplying a feedback to shim the field

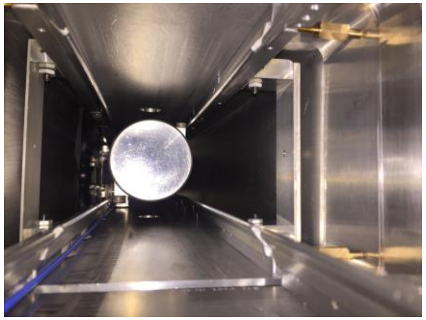


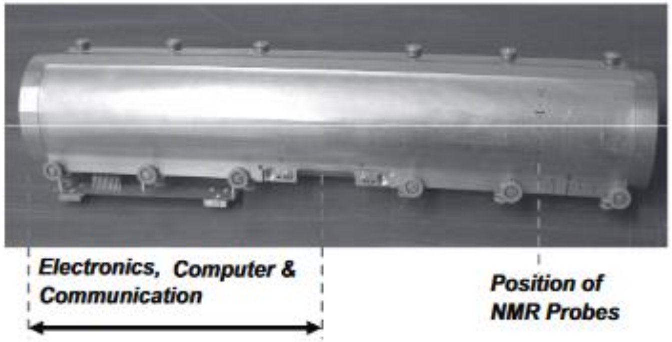


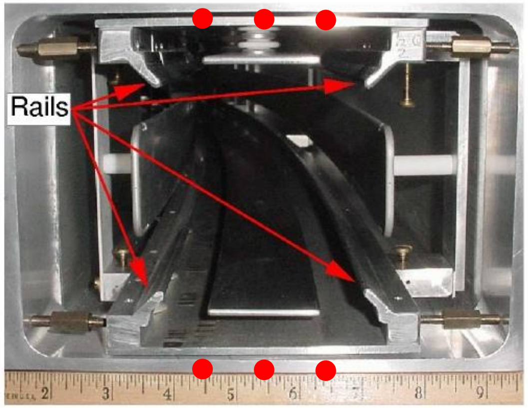


3.Magnetic Field Measurement System

- Trolley System: Mapping the storage ring field when the beam is off. When the beam is on, the trolley parks in the garage, out of the muon storage region

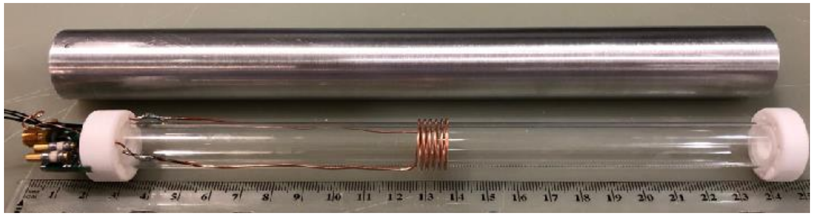






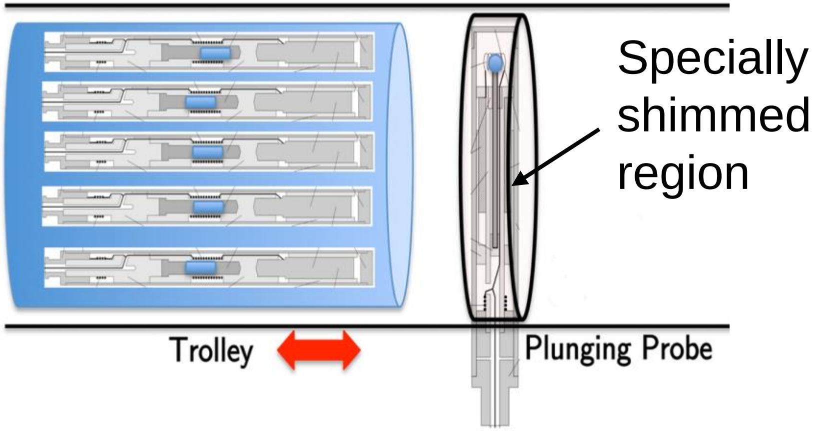
3.Magnetic Field Measurement System

- Calibration System: Providing an absolute calibration chain relating field measurements to the Larmor frequency of a free proton

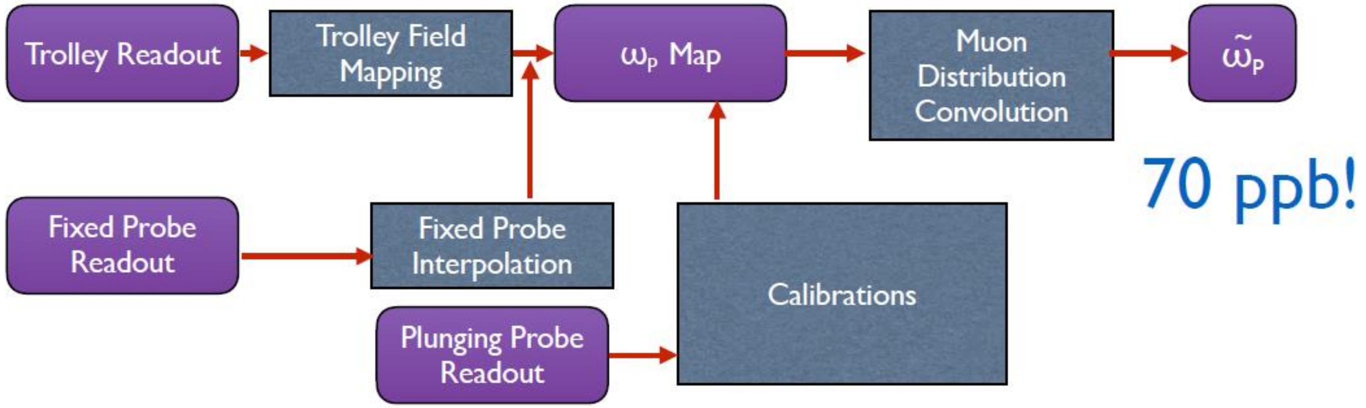


Plunging Prob: Used at FNAL to calibrate trolley probes

Absolute probe: Used at ANL for cross calibration



4.Summary and Recent Status



- The Muon g-2 Experiment at Fermilab is a sensitive way to explore physics that may beyond SM
- High Precision a_μ result relies on both muon precession frequency and the magnetic field measurement
- The experiment is taking data and the magnetic field measurement systems work stable
- Data analysis is going on (both ω_a and ω_p)
- The 1st Publication: ~early 2019

Thanks!