The Muon g-2 Experiment at Fermilab

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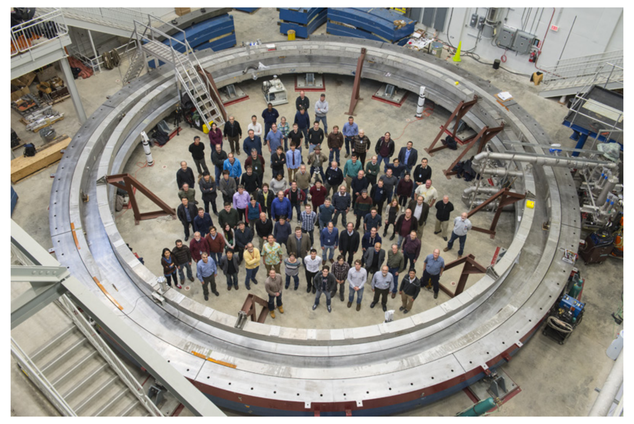
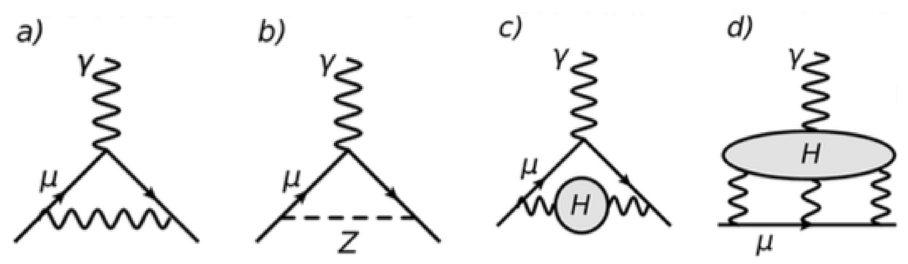
Goals



We will measure the anomalous magnetic moment of the muon, $a_\mu \equiv (g-2)/2$, to 140 ppb, a factor of 4 better than it has been measured previously.

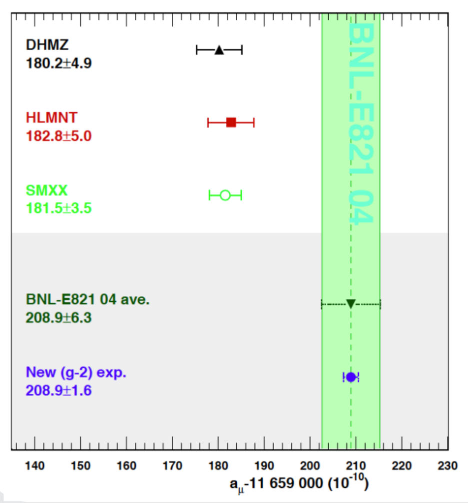
Physics of muon g-2

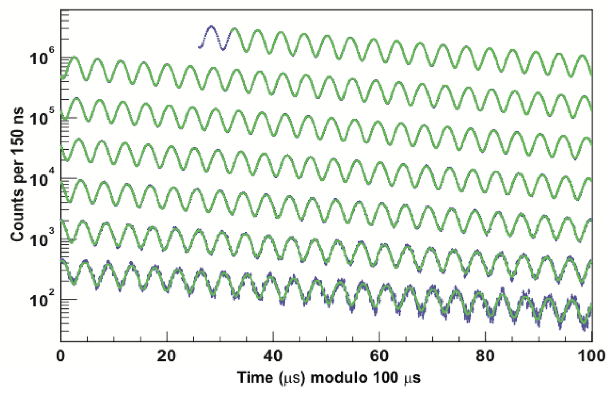
- In the standard model, the muon is a spin 1/2 pointlike particle [1].
- It has a magnetic dipole moment of $\vec{\mu} = g\frac{q}{2m}\vec{s}$, with $g = 2$ for a pointlike particle (Dirac)
- Additional effects from QED, electroweak theory, and hadronic factors move the standard model prediction of g away from 2. It has become customary to measure this discrepancy, g-2.
- If a discrepancy with the standard model value is found, beyond standard model contributions to g-2 could come from SUSY, dark photons, or other new physics (NP).



Measurements of g-2

- BNL E821 measured g-2 to have a 3.3σ discrepancy from the standard model (2006) [2].
- Fermilab E989 will measure 20 times the number of muons, reducing the uncertainty on this measurement by a factor of 4.
- Without theory improvements, discrepancy could reach $> 5\sigma$. With expected improvements on the theoretical value, the discrepancy could reach $> 7\sigma$.



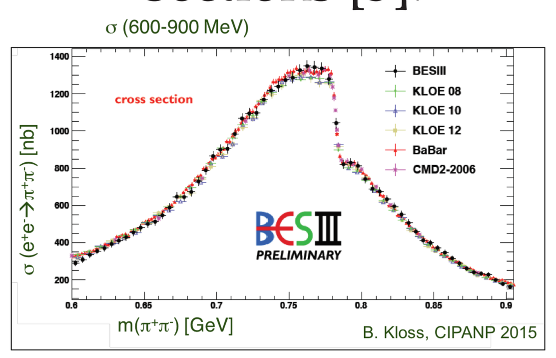


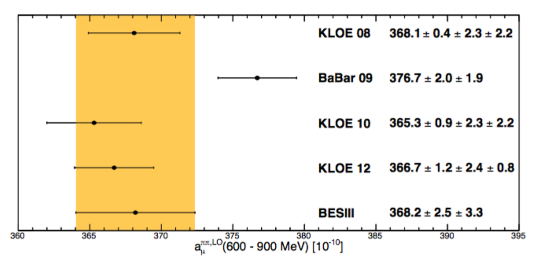
Project Status

- The ring was moved from BNL to FNAL in 2013.
- It has been installed in our new MC1 building and cooled to superconducting temperatures, and powered up to full field in October, 2015. Shimming of the magnet nearly complete.
- Plan for data taking to begin in 2017, and it will run for 3 years.

Theory Status

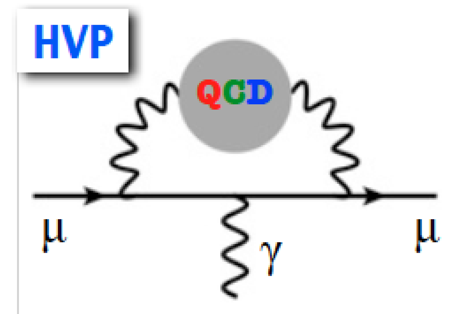
Hadronic Vacuum Polarization contribution determined from $e^+e^- \to hadrons$ cross sections [3].



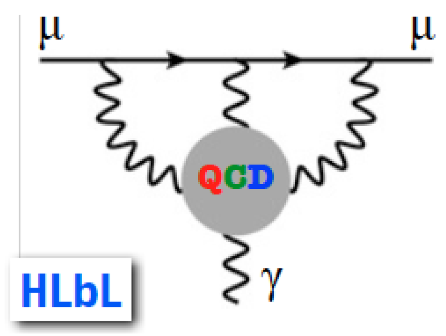


Lattice QCD is being used to compute contributions from HVP and hadronic light-by-light [4].

Target: $\delta(a_\mu^{HVP}) < 0.2\%$



Target: $\delta(a_\mu^{HLBL}) < 10\%$



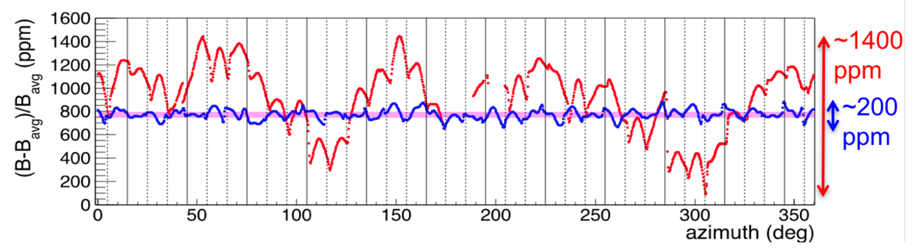
Statistics and Systematics

- We plan to collect 21 times the BNL statistics, which will reduce our statistical uncertainty by a factor of four.
- Uncertainties on ω_a will be decreased from 180 ppb in E821 to 70 ppb in E989 by using an improved laser calibration, a segmented calorimeter, better collimator in the ring, and improved tracker.
- Uncertainties on ω_p will be decreased from 170 ppb in E821 to 70 ppb in E989 by improving the stability and monitoring of the magnetic field, increasing accuracy of position determination of trolly, better temperature stability of the magnet, and providing active feedback to external fields.

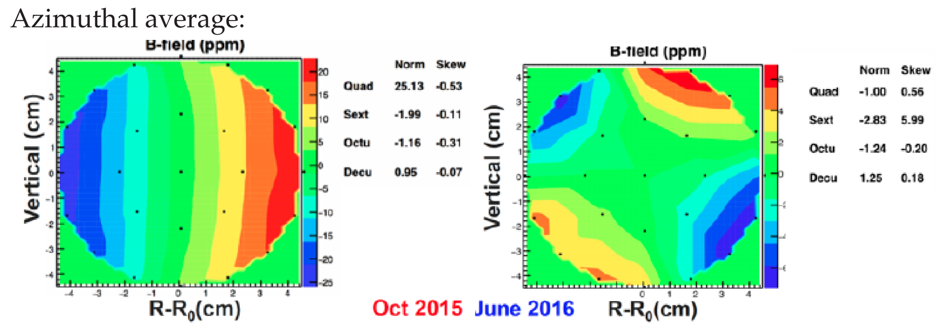
Magnetic Field

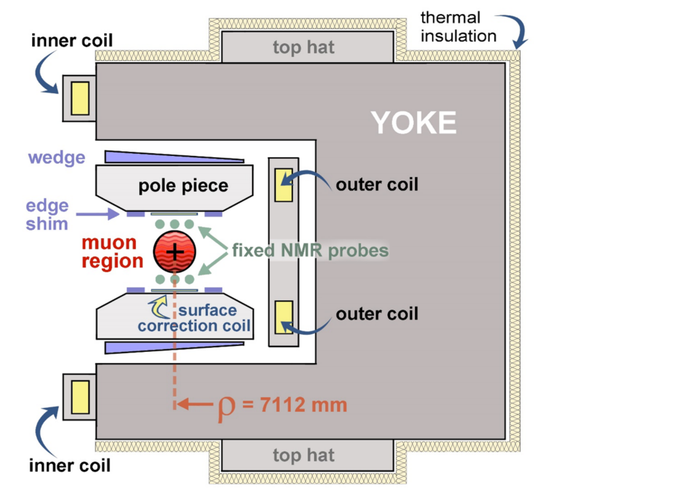
- The proton precession frequency ω_p is measured as a proxy for $\vec{B}$. Measure ω_p using NMR.
  $\omega_a = \frac{eB}{m} a_\mu \to a_\mu = \frac{\omega_a/\omega_p}{\mu_\mu/\mu_p - \omega_a/\omega_p}$
- Fixed NMR probes measure time variations of the field during data taking.
- A trolly with mounted NRM probes periodically circumnavigates the interior of the ring to perform precision measurements of the field in the muon storage region, performing 6000 magnetic field measurements per trolly run.

Azimuthal measurement:
(pink band signifies goal precision of 50 ppm)



Azimuthal average:



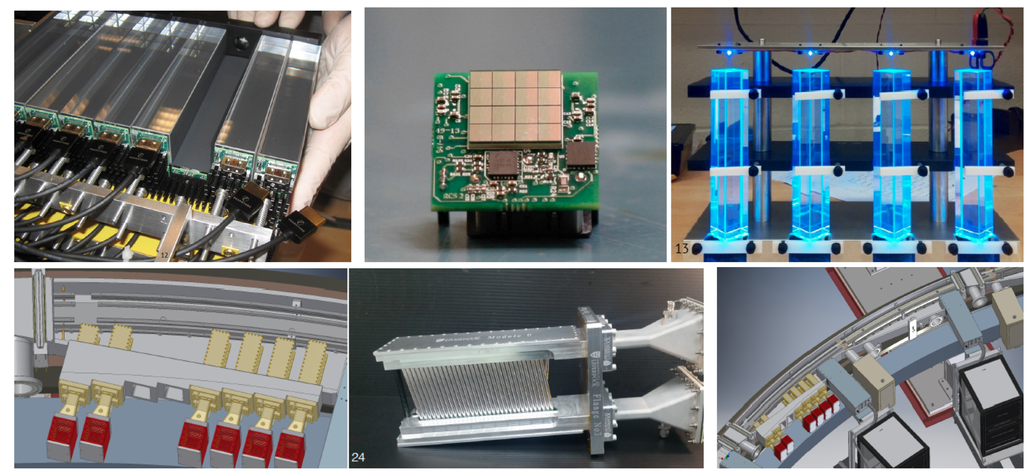


g-2 Magnet in Cross Section

- B field is 1.45 T, 5200 A.
- The magnetic field must be constant in the muon region to ±0.5 ppm.
- The field is homogenized by adding iron shims to remove quadrupole and sextapole asymmetries, adjusting the top hats, and using surface coils to add average field moments.

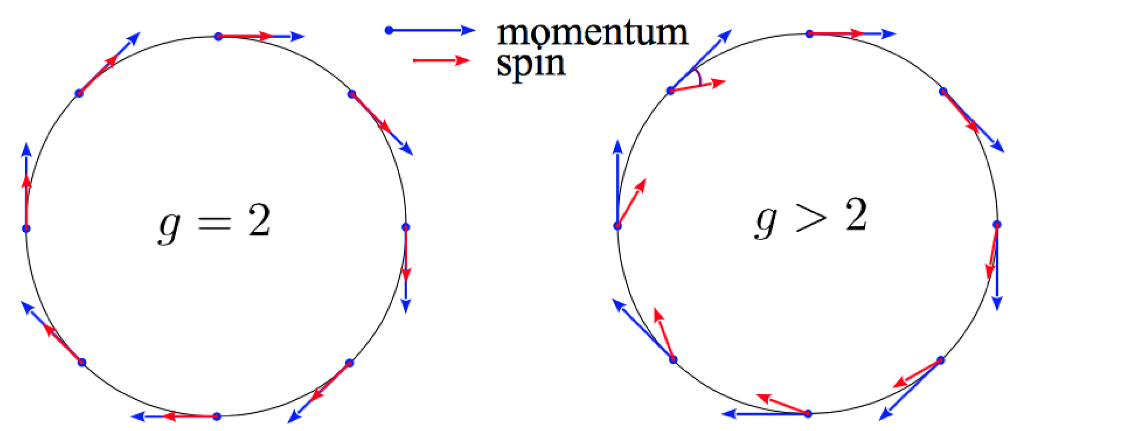
Detectors and DAQ

- The interior of the ring will be lined with 24 calorimeters, which perform the ω_a measurement. Each calorimeter is composed of 54 PbF_2 crystals with SiPMs and read out by custom 800 MSPS waveform digitizers.
- Three straw trackers positioned in the positron path will be used for determination of the track position.
- A fiber harp will be used during special calibration runs to measure beam dynamics.
- A laser calibration system is being constructed to actively provide calibration signals to the calorimeters in between muon fills.
- The data acquisition system is being constructed based on GPU technology to provide a deadtime free record of every muon fill.



Measurement of ω_a

- Polarized muons are produced naturally from pion decay and injected into a storage ring with a uniform magnetic field.
- Cyclotron frequency: $\omega_c = \frac{e}{m\gamma}B$
- Spin precession frequency: $\omega_s = \frac{e}{m\gamma}B(1 + \gamma a_\mu)$
- We measure $\omega_a = \omega_s - \omega_c = \frac{e}{m} a_\mu B$ via the timing of muon decays to positrons as measured in 24 calorimeters.
- Performing the measurement at the magic momentum where $\gamma = 27.3$, the electric field contribution is suppressed.
  $\vec{\omega}_a = -\frac{Qe}{m}[a_\mu \vec{B} - (a_\mu - (\frac{mc}{p})^2)\frac{\vec{\beta}\times\vec{E}}{c}]$
- Measurements of ω_a and B provide a_μ.



References

1. P.A. Dirac, Proc.Roy.Soc.Lond. A117, 610 (1928).
2. Muon g-2, G. Bennett *et al.*, Phys.Rev. D73, 072003 (2006).
3. BESIII, Phys.Lett B753 (2016) 629-638
4. Blum, PRL 91 (2003)

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