Q-method Analysis for the Muon g-2 Experiment at Fermilab

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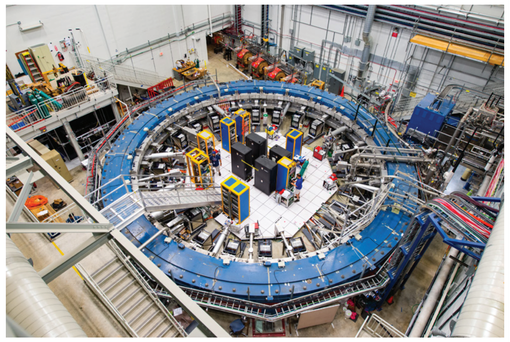
Introduction to the Muon g-2 Experiment

The Muon g-2 Experiment (E989) at Fermilab aims to measure the muon anomalous magnetic moment to a precision of 140 ppb, which will be a fourfold improvement over the previous BNL E821 experiment[1].



Physics Motivation

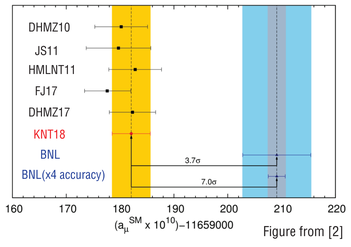


Figure from [2]

The precise measurement of the anomalous magnetic moment of the muon:

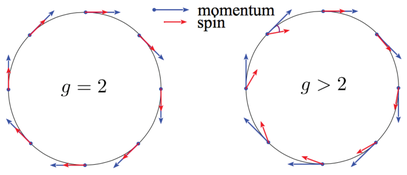
$$a_\mu = \frac{g_\mu - 2}{2}$$

can serve as a test for new theories. The muon has a relatively long lifetime of 2.2 μs and a mass 207 times electron mass The heavier mass increases the sensitivity of a_μ to new physics.

The previous experiment E821 at BNL shows a 3.7 sigma discrepancy between the measurement and the SM calculation.

With a higher precision, the muon g-2 experiment at Fermilab aims to resolve this discrepancy together with an improved calculation by theorists.

Explanation of the Measurement



After injection, muons revolve around the storage ring under the influence of the magnetic field. The muon spin also precesses in magnetic field.

The parity-violating muon decay process:

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

yeilds an anisotropic positron distribution, thereby modulating the time-energy distributions of decay positrons with the anomalous frequency:

$$\omega_a = \omega_c - \omega_s$$

ω_c is the cyclotron frequency

ω_s is the spin precession frequency

hence:

$$\omega_c = \frac{eB}{mc\gamma}$$

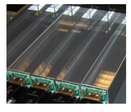
$$\omega_s = \frac{g_s eB}{2mc} + (1-\gamma)\frac{eB}{mc\gamma}$$

gives:

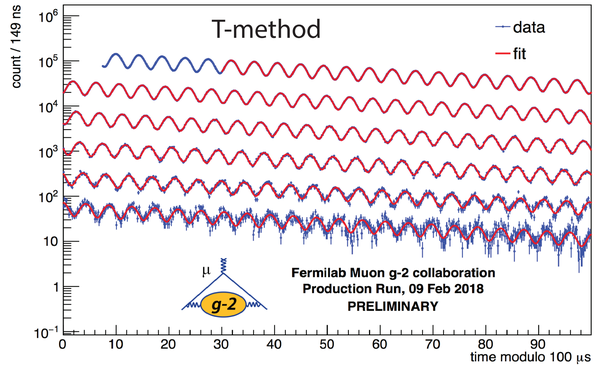
$$\omega_a = a_\mu \frac{eB}{mc}$$

Measurement of ω_a

- 24 calorimeter stations × 54 (PbF_2 crystals + SiPMs)

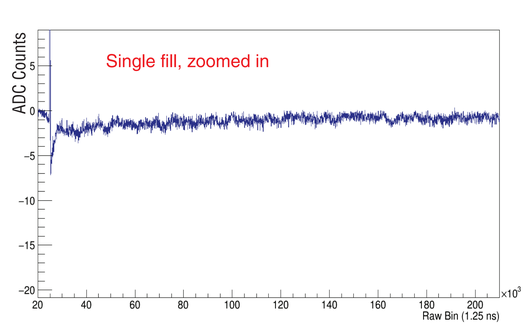


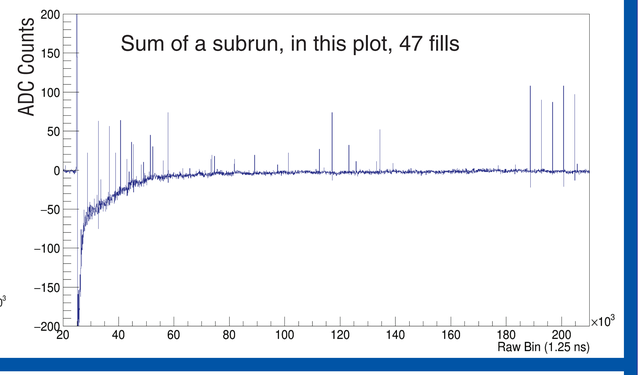
- 12 bits @ 800 MHz sampling rate × 700 μs per fill
- Auxilary detectors and laser calibration systems
- GPUs in DAQ for fast data processing



Introduction to Q-method

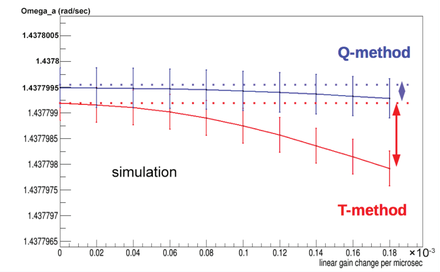
Q stands for charge. Instead of setting up a threshold and rejecting some events, all the hits in the calorimeters are stored in the Q-method traces. In this case, it is an analysis on the modulation of the deposited energy itself comparing to that of the counts of events above some set energy threshold

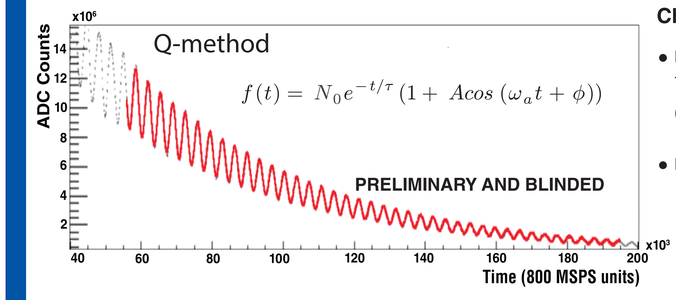




- Q-method is the most different analysis we have on ω_a in the same experiment
- Less sensitive to gain variation comparing to traditional analysis
- Less sensitive to pileup effect.

Advantages





Challenges

- Understanding the time-dependent pedestal.
  This issue rises from the summation of all the signals from the digitizers. It pollutes the time structure of the decay positron signals.
- Understanding uncertainties in the Q-method analysis
  - New method brings new uncertainties
  - Coherent Betatron Oscillation
  - Lost Muon
  - etc.

Current Development Status

- Using GPUs to simulate the process of building Q-method plots enables us to understand pileup, gain variation and pedestal efftect.
- We have just transitioned from engineering running to production running with a goal of collecting data for BNL level result by the summer of this year.

Reference

1. Grange, J. "Muon (g-2) Technical Design Report." 2015, DOI:10.2172/1251172.
2. A. Keshavarzi, D. Nomura and T. Teubner, arXiv:1802.02995 [hep-ph]
3. Gorringe, T.P. and D.W. Hertzog. "Precision Muon Physics." Progress in Particle and Nuclear Physics, vol. 84, 2015, pp. 73–123., doi:10.1016/j.ppnp.2015.06.001.

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Fermilab

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