Muon g-2: An Overview

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On behalf of the Muon g-2 Collaboration

New Perspectives

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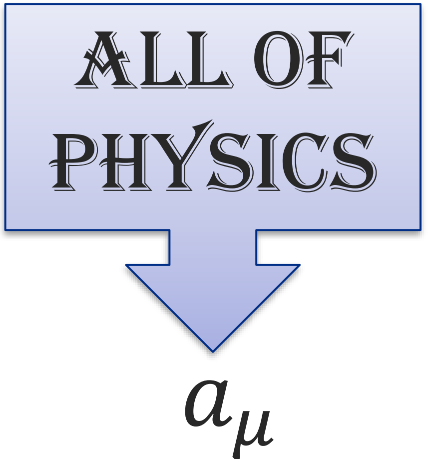
Background

- Muon g-2 is dedicated to measuring the **muon magnetic moment anomaly**.
- Muon magnetic moment: $\vec{\mu} = g \frac{q}{2m_\mu} \vec{s}$
- Magnetic moment anomaly: $a_\mu = \frac{g-2}{2}$



- With a muon beam in a magnet ring, we find the anomaly from **anomalous precession frequency $\overrightarrow{w_a}$** and **magnetic field $\vec{B}$**.

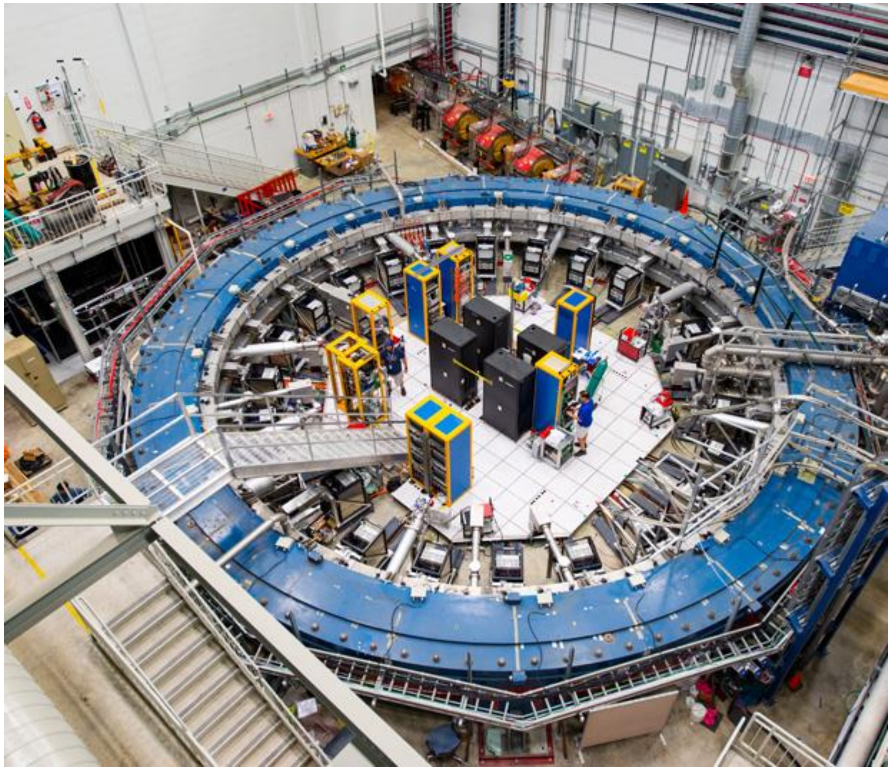
$$\overrightarrow{w_a} = \overrightarrow{w_s} - \overrightarrow{w_c} = a_\mu * \frac{-q}{m_\mu} * \vec{B}$$

Motivation

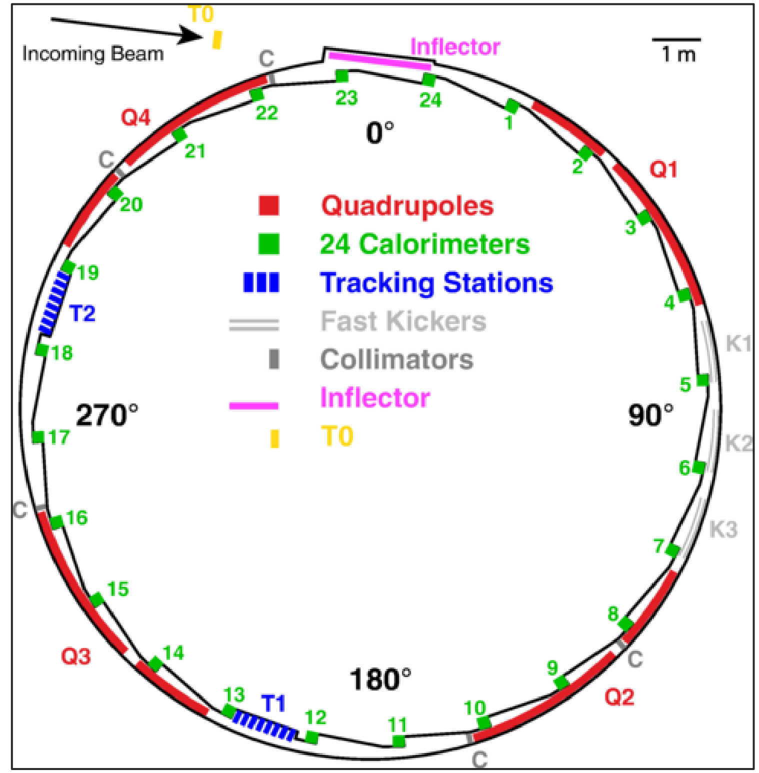
- In the early 2000s, a similar experiment at Brookhaven National Laboratory discovered a possible discrepancy with the Standard Model prediction for a_μ.
  - New physics could lead to such a discrepancy!
  - BNL experimental result ~3.5σ different than SM prediction.
  - Threshold for discovery is typically 5σ or greater difference.
- The goal of g-2 is to achieve an uncertainty of 140 ppb, four times smaller than BNL.
  - Run-1 results from g-2 show agreement with BNL, with uncertainty on track to reach the goal!

Overview

Figure 1, "Measurement of the anomalous precession frequency of the muon in the Fermilab Muon g−2 Experiment". Phys. Rev. D 103, 072002 – Published 7 April 2021.



The magnet ring contains the muon beam with a 1.45 T magnetic field.



Detector stations collect data while additional fields aim the muons and keep them on track.

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Precession Frequency

- **Anomalous precession frequency w_a** is connected to observables from muon decay.

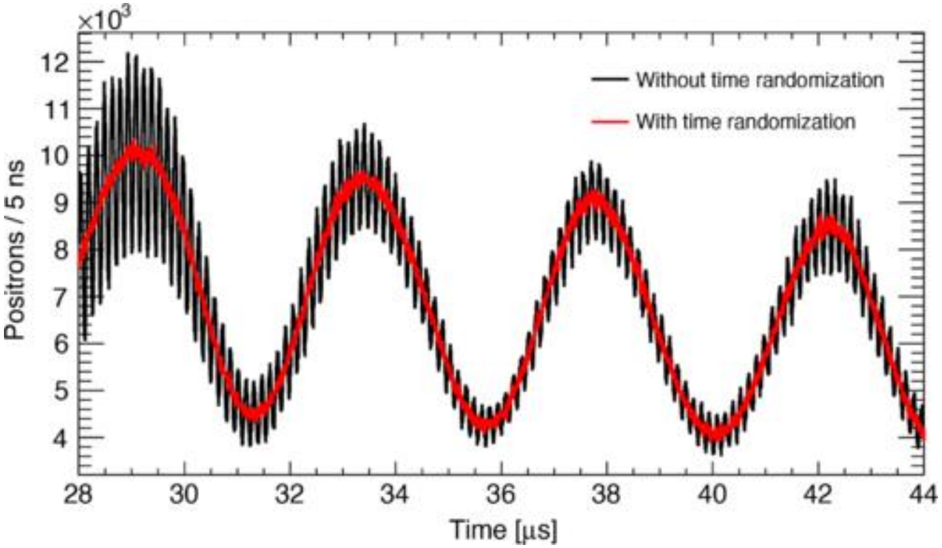
$$\mu^+ \rightarrow e^+ + \nu_\mu$$

- Energy distribution of decay e^+ depends on muon spin and momentum directions, and oscillates at w_a.

- Positron equation:

$$N(t,E) = N_0(E) * e^{\frac{-t}{\gamma\tau}} * \{1 + A(E)\cos[w_a t + \varphi_0(E)]\}$$

Figure 5, "Measurement of the anomalous precession frequency of the muon in the Fermilab Muon g−2 Experiment". Phys. Rev. D 103, 072002 – Published 7 April 2021.



Run-1 positron data from a single calorimeter shows modulation at w_a (red), as well as faster cyclotron oscillation (black) which vanishes when all calorimeters are combined.

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Beam Dynamics

- Because we are not in the ideal world of physics textbooks, many correction factors must be applied to the measured value of w_a (w_a^m).

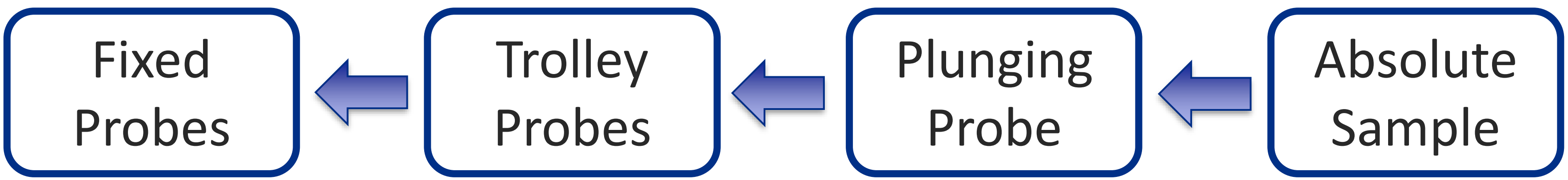
$$w_a^m * \left(1 + C_e + C_p + C_{ml} + C_{pa}\right) \rightarrow w_a$$

  – C_e: Correction from electric influence from ESQs.
  – C_p: Correction from small tilt of muon orbital plane.
  – C_{ml}: Correction for bias from lost muons.
  – C_{pa}: Correction for drift in beam profile.

- These steps provide w_a. Next, we need magnetic field B.

Magnetic Field

- Fixed NMR probes track the magnetic field while the muon beam is stored.
- Our “calibration chain” lets us use the field seen by the fixed probes to find the field seen by the muons.



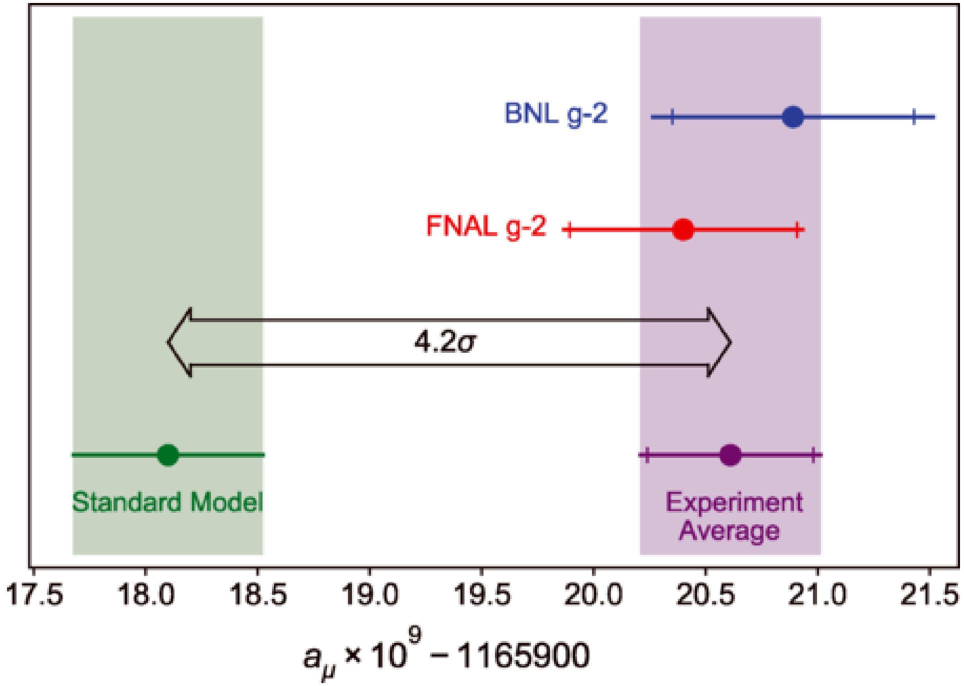
- Transient fields from kickers and quads are too small for the fixed probes, so they are measured separately.

Results (So Far)

- Run-1 result, unveiled in 2021:

$$a_\mu = 116592040(54) * 10^{-11}.$$

- This agrees with the BNL result, supporting the discrepancy with the Standard Model prediction.



The g-2 Run-1 result has comparable uncertainty to the BNL result.

Combining both into an average with a reduced final uncertainty expands the SM discrepancy to 4.2σ.

Figure 4, "Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm". Phys. Rev. Lett. 126, 141801 – Published 7 April 2021.

Next Steps

- Data from Runs 2 through 5 are being processed and analyzed. Aiming to publish next results in 2023.
- Run-1 uncertainty was dominated by statistics. Incorporating all of the data from later Runs will significantly reduce uncertainty.
- The g-2 Theory Initiative is making progress on the theory side, refining the SM prediction.
- Later Runs feature many improvements! Statistical and systematic uncertainties will be reduced.
  - More muons, better beam control, better field stability, better field calibration, and more!

Thank you!

- Thanks for listening! Any questions?

Appendix: Results and Uncertainty Breakdown

- g-2 Run-1 Result: $a_\mu = 116592040 * 10^{-11}$. Uncertainty: 460 ppb.
  - Uncertainty from w_a^m: 434 ppb statistical, 56 ppb systematic.
  - Uncertainty from beam dynamics: 90 ppb.
  - Uncertainty from B: 114 ppb.

- BNL Result (2006): $a_\mu = 116592080 * 10^{-11}$. Uncertainty: 540 ppb.

- Standard Model (2020): $a_\mu = 116591810 * 10^{-11}$. Uncertainty: 370 ppb.
  - New SM predictions from lattice QCD might reduce the discrepancy. Currently being investigated.