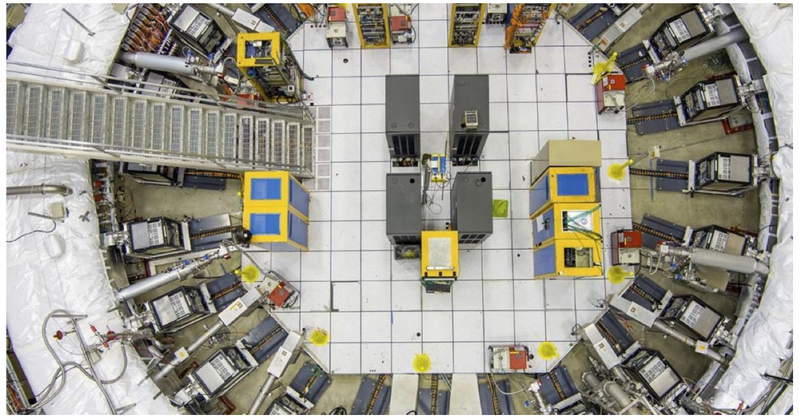
Final Result from the Muon g-2 Experiment at Fermilab



Sean Foster on behalf of The Muon g-2 Collaboration
Amherst College

Lake Louise Winter Institute

March 6, 2026

Muon g-2 Experiment at Fermilab

Muon g-2 Collaboration

US Universities
- Boston
- Cornell
- UIUC
- James Madison
- Kentucky
- Massachusetts
- Michigan
- Michigan State
- Mississippi
- North Central College
- Regis
- Trinity
- Virginia
- Washington
- York CUNY

US National Labs
- Argonne
- Brookhaven
- Fermilab

China
- Shanghai Jiao Tong

Germany
- Dresden
- Mainz

Italy
- Frascati
- Molise
- Naples
- Pisa
- Roma Tor Vergata
- Trieste
- Udine

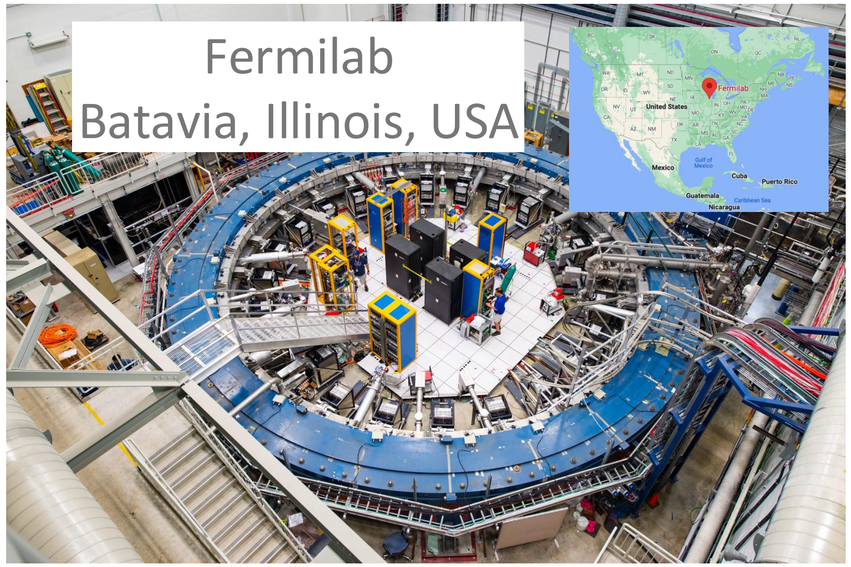
Korea
- IBS-CAPP
- KAIST

Russia
- Budker/Novosibirsk

United Kingdom
- Lancaster/Cockcroft
- Liverpool
- Manchester
- University College London

176 collaborators
34 Institutions
7 countries

Muon g-2 Collaboration Meeting @ Elba, Italy
May 2019

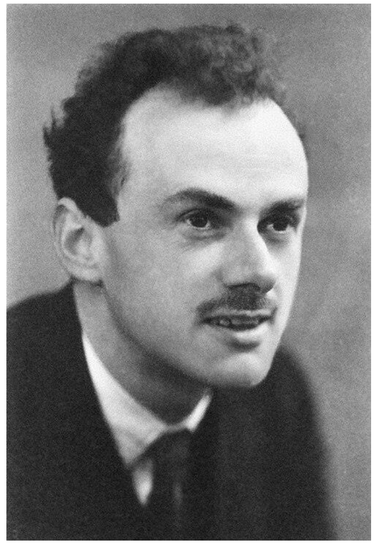


Goal: measure the **muon's anomalous magnetic moment** to 140 parts-per-billion

Six physics runs from 2018 to 2023

Final result released in June 2025

Magnetic Moments Drive Discovery



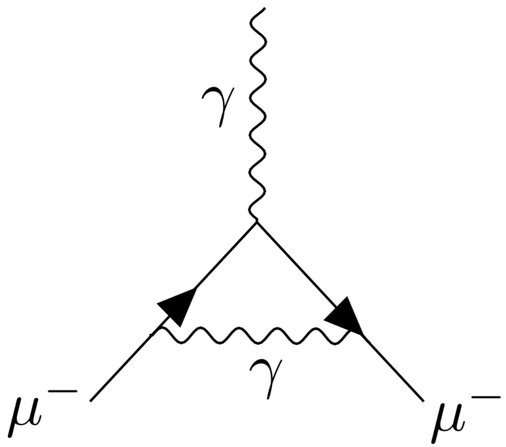
1928

Dirac

Predicts $g = 2$ for spin-1/2 fermions

$$\boldsymbol{\mu} = g\frac{e}{2m}\mathbf{s}$$

Proc. R. Soc. A 117, 610 (1928)



1947-1948

Kusch & Foley + Schwinger

Electron g deviates from 2 by 0.1%; explained by Schwinger term; early triumph of QED

Phys. Rev. 72, 1256 (1947)
Phys. Rev. 73, 416 (1948)

https://www.g-2.bnl.gov/

1997-2004

BNL E821

Muon magnetic anomaly tensions hint at new physics?

Magnetic anomaly $a = \frac{g-2}{2}$

Phys. Rev. Lett. 92, 161802 (2004)

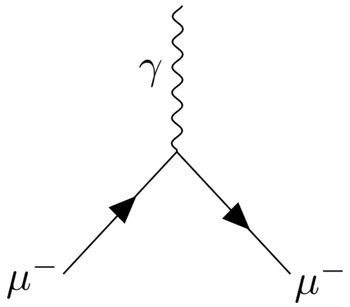
Why study muon $g-2$?

Deviations from $g=2$ probe interactions with all sectors of the SM (and possibly beyond)

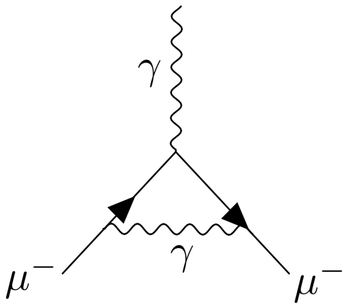
Dirac term (2)

Quantum Electrodynamics (QED)

$g =$

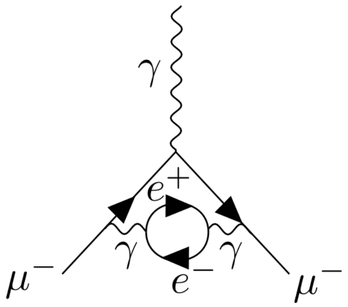


$+$



Schwinger term

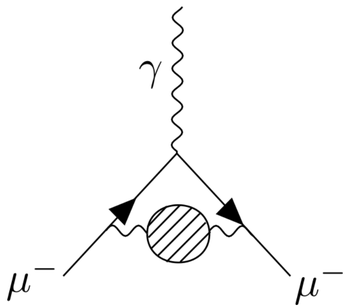
$+$



?

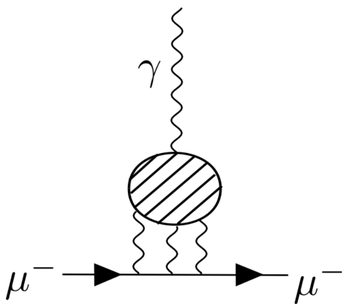
$=$

$+$



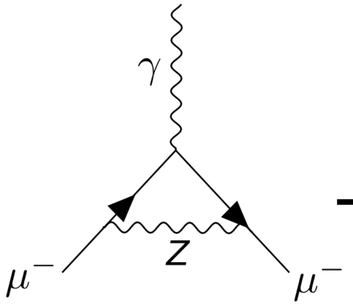
Hadronic Vacuum Polarization (QCD)

$+$



Hadronic Light-by-Light (QCD)

$+$



Electroweak (EW)

$+$?

New physics contributions to g scale with $(m_l/M)^2$

x40,000 sensitivity boost picking muon over electron

Muon g-2 Theory Initiative

held at the KEK Tsukuba campus (Tsukuba, Japan), 9-13 September 2024.

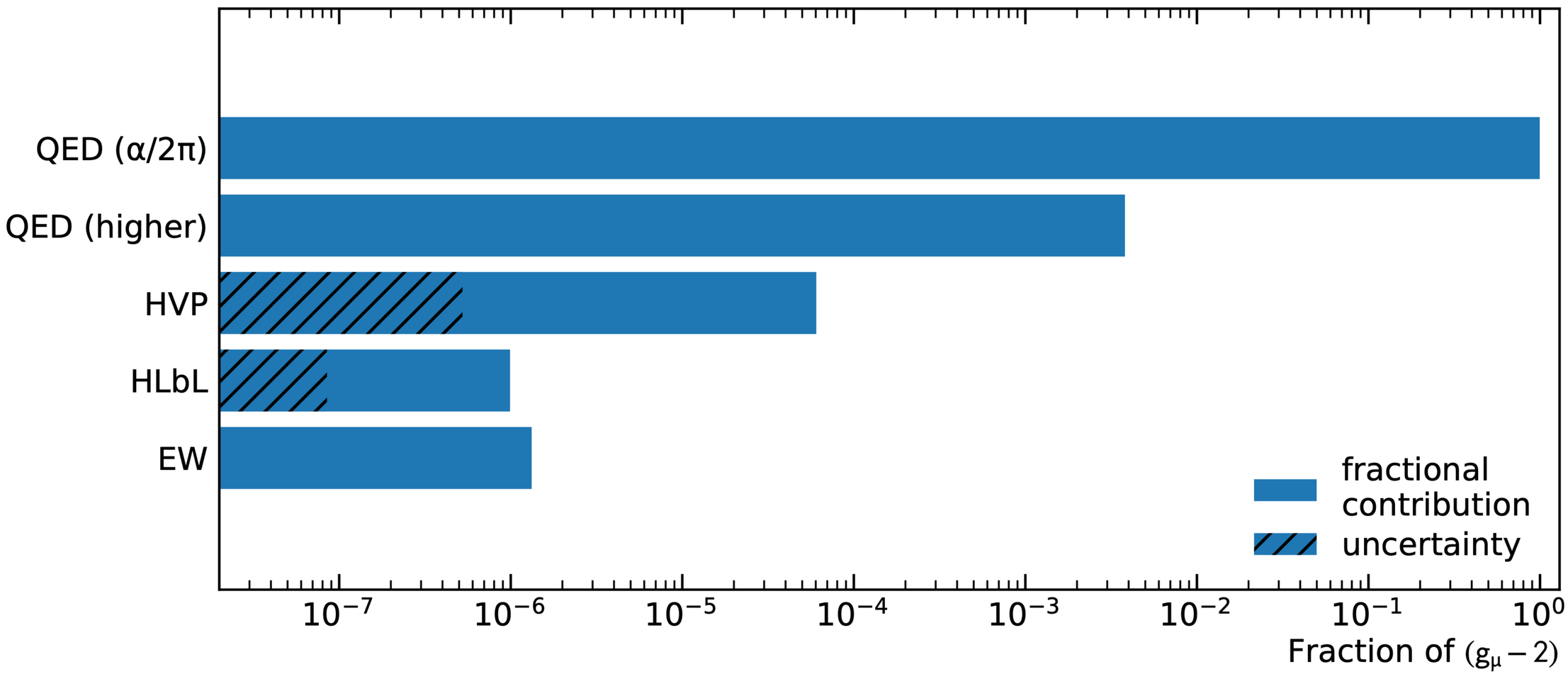
Group of scientists working to compile all inputs to Standard Model prediction of the muon magnetic anomaly

Published White Papers in 2020 and 2025

White Paper 2020: Phys. Rept. 887 (2020) 1-166

White Paper 2025: Phys. Rept. 1143 (2025) 1-158

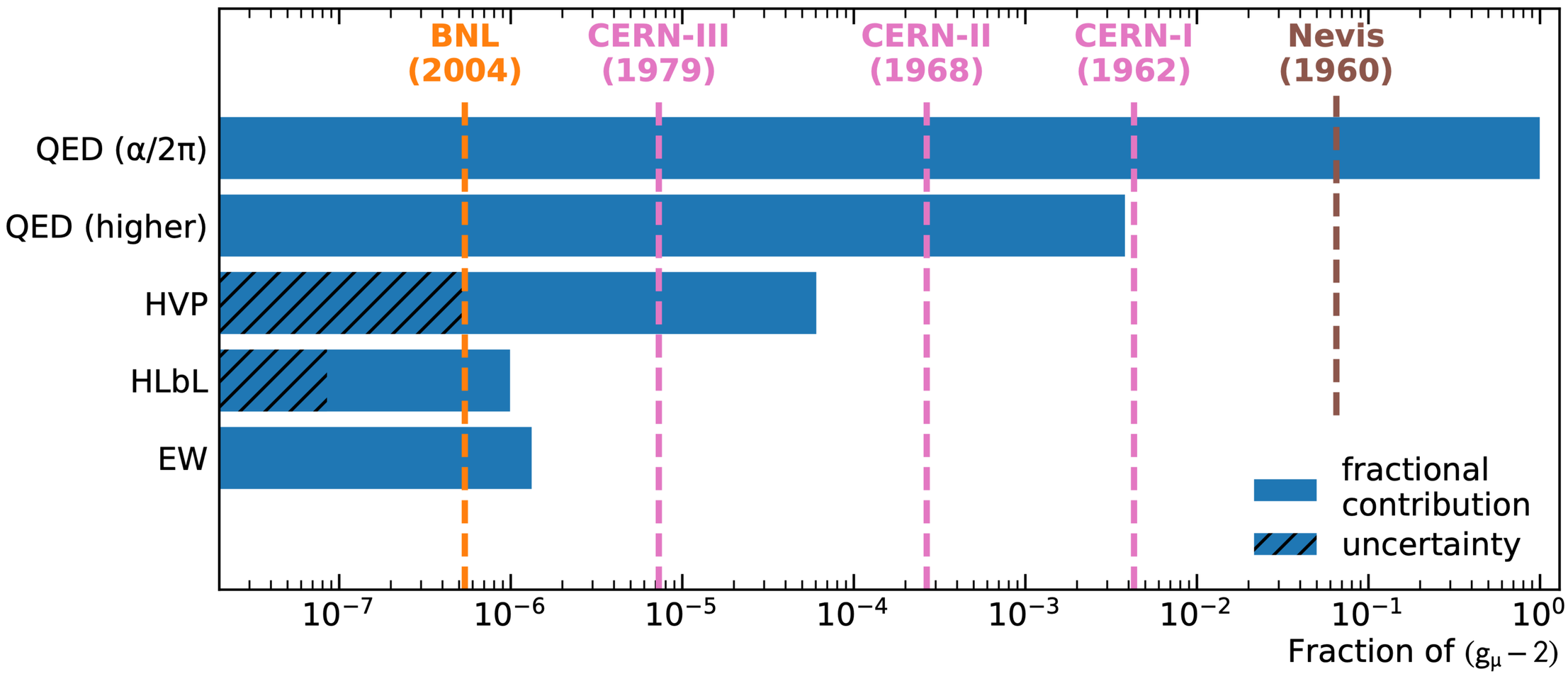
SM prediction: value & uncertainties



Value is dominated by QED

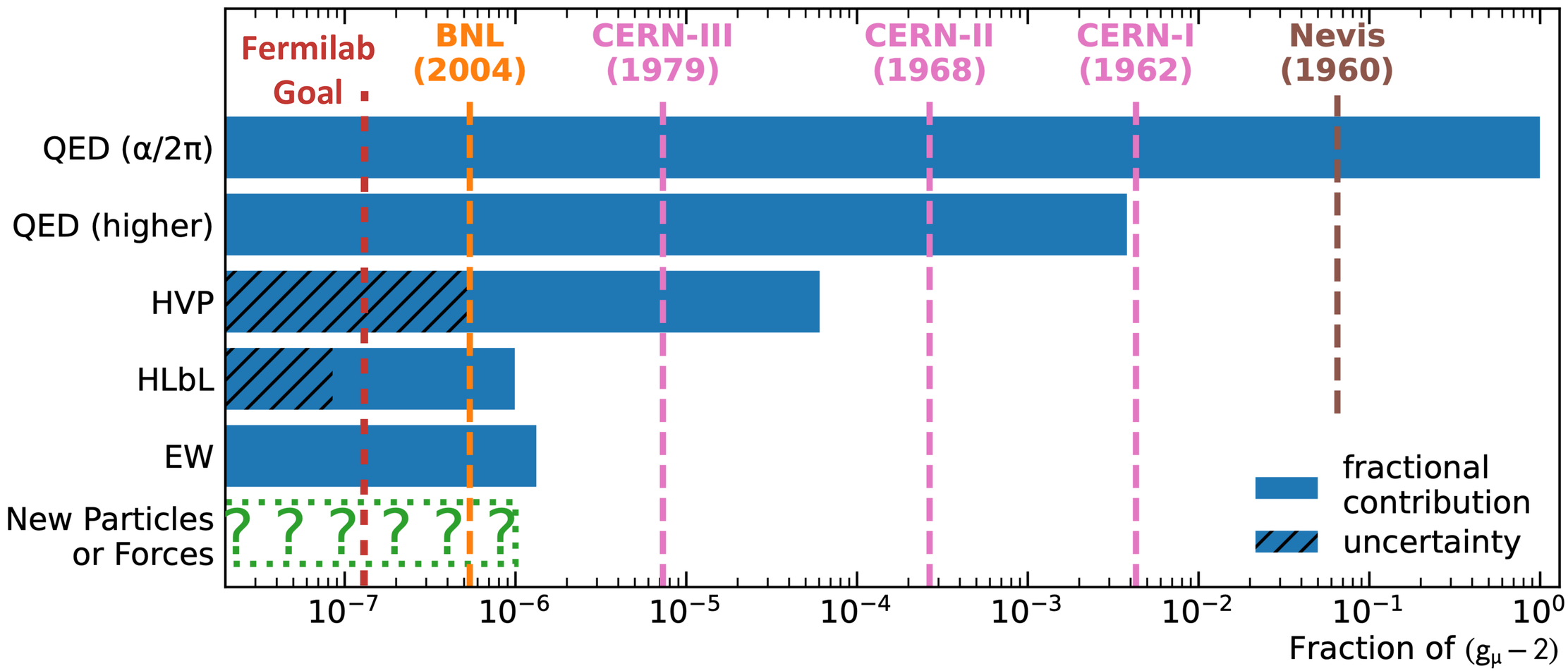
Uncertainty is dominated by HVP

History of Muon g-2 Measurements



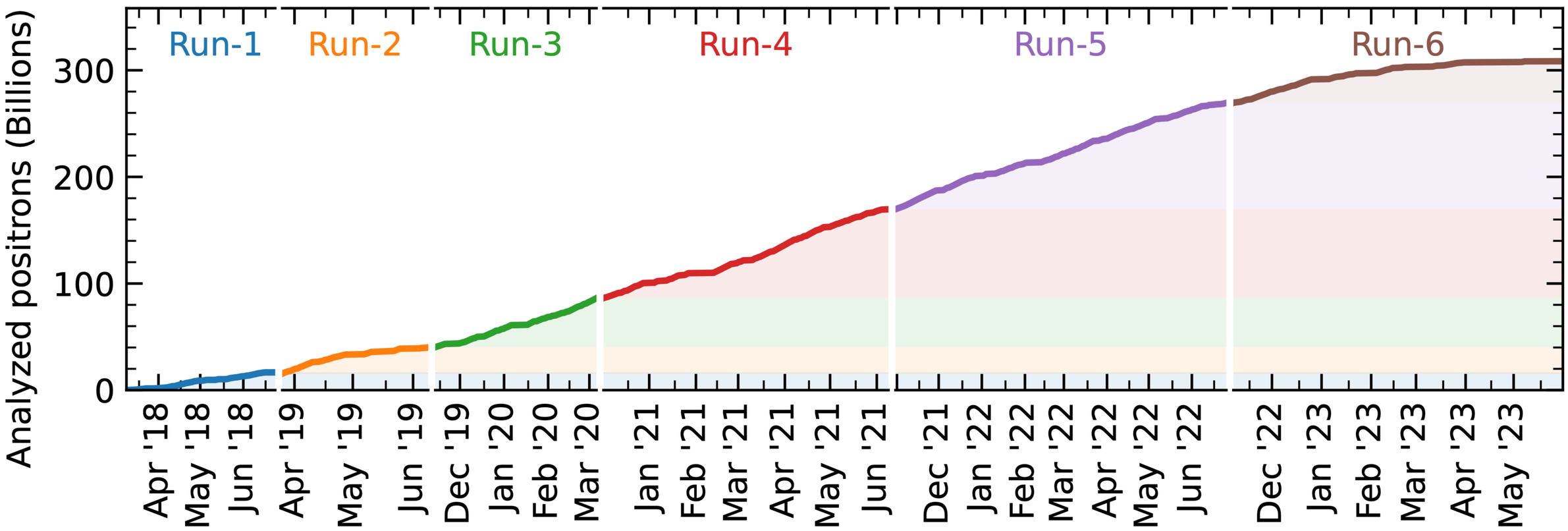
60+ year history of measuring a_μ

History of Muon g-2 Measurements



Fermilab goal: 140 parts-per-billion (ppb)

We exceeded our statistics goal!



Run-1 Result
April 2021
Similar statistics as BNL
Phys. Rev. Lett. 126, 141801 (2021)

Run-2/3 Result
August 2023
4.6 times more data than Run-1
Phys. Rev. Lett. 131, 161802 (2023)

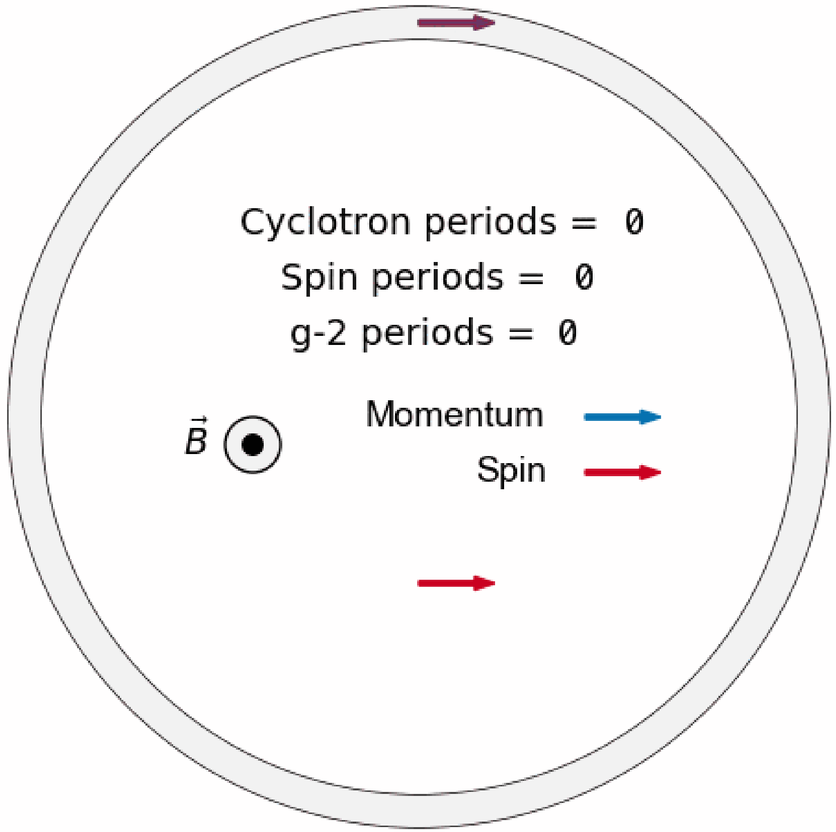
Run-4/5/6 Result
June 2025
2.6 times more data than Run-1/2/3
Phys. Rev. Lett. 135, 101802 (2025)

The Measurement Principle

Place muons in a **uniform** magnetic field

Measure the **difference** between spin and cyclotron frequencies

$$\omega_a = \omega_s - \omega_c = a_\mu \frac{e}{m} B$$



Measurement recipe:

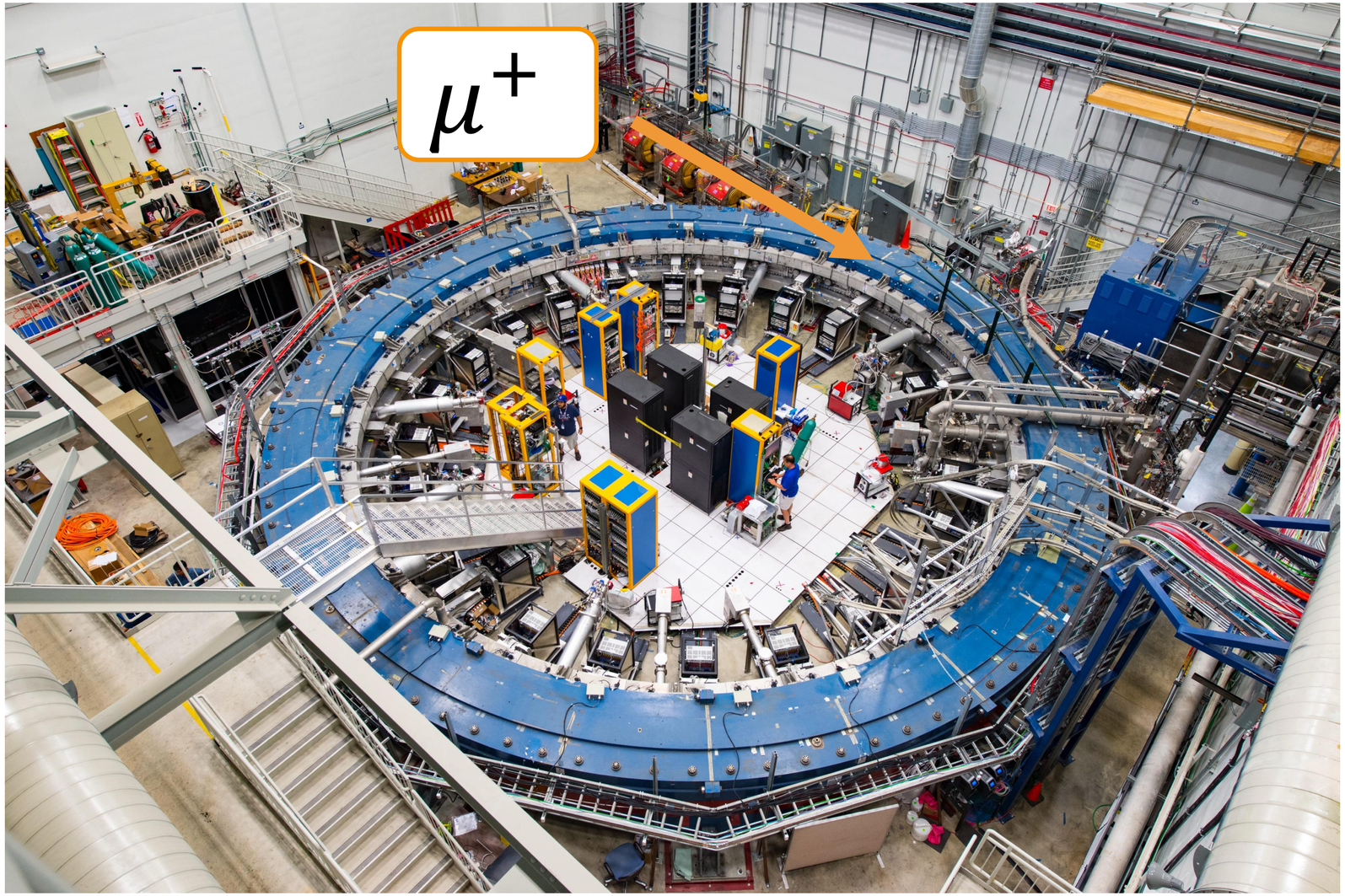
Measure ω_a and magnetic field B

Extract a_μ

Storage ring technique

Inject beam of **polarized** muons into superconducting storage ring magnet, 1.45 T field; 3.1 GeV/c momentum

Main magnet provides radial focusing



The Big Move in 2013 from BNL

Storage ring technique

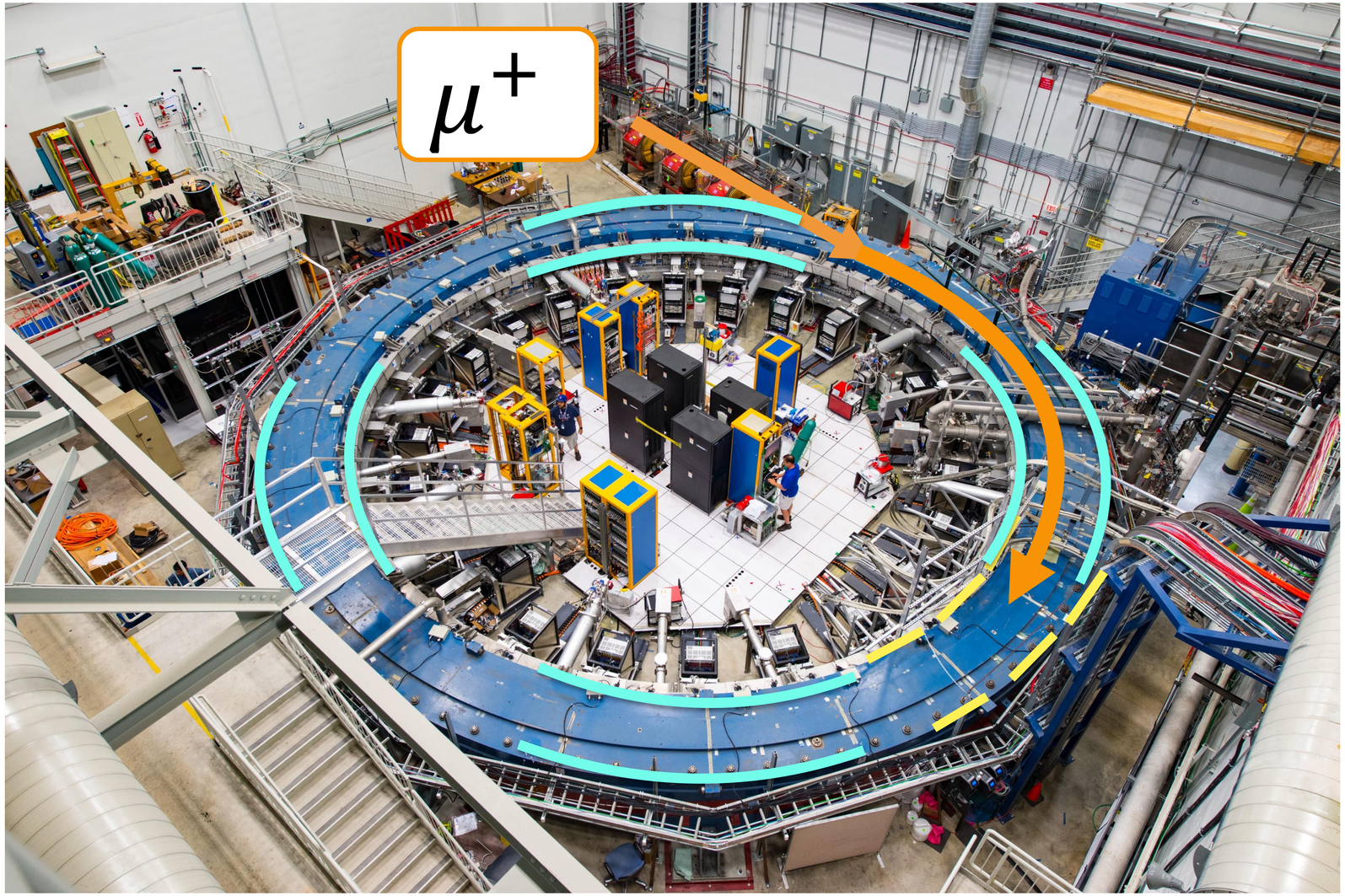
Inject beam of **polarized** muons into superconducting storage ring magnet, 1.45 T field; 3.1 GeV/c momentum

Main magnet provides radial focusing

Inflector magnet provides field-free region during injection

Fast **kicker magnets** move muons onto central orbit

Electrostatic quadruples provide **vertical focusing;** operate at “magic” momentum to mitigate electric-field effects

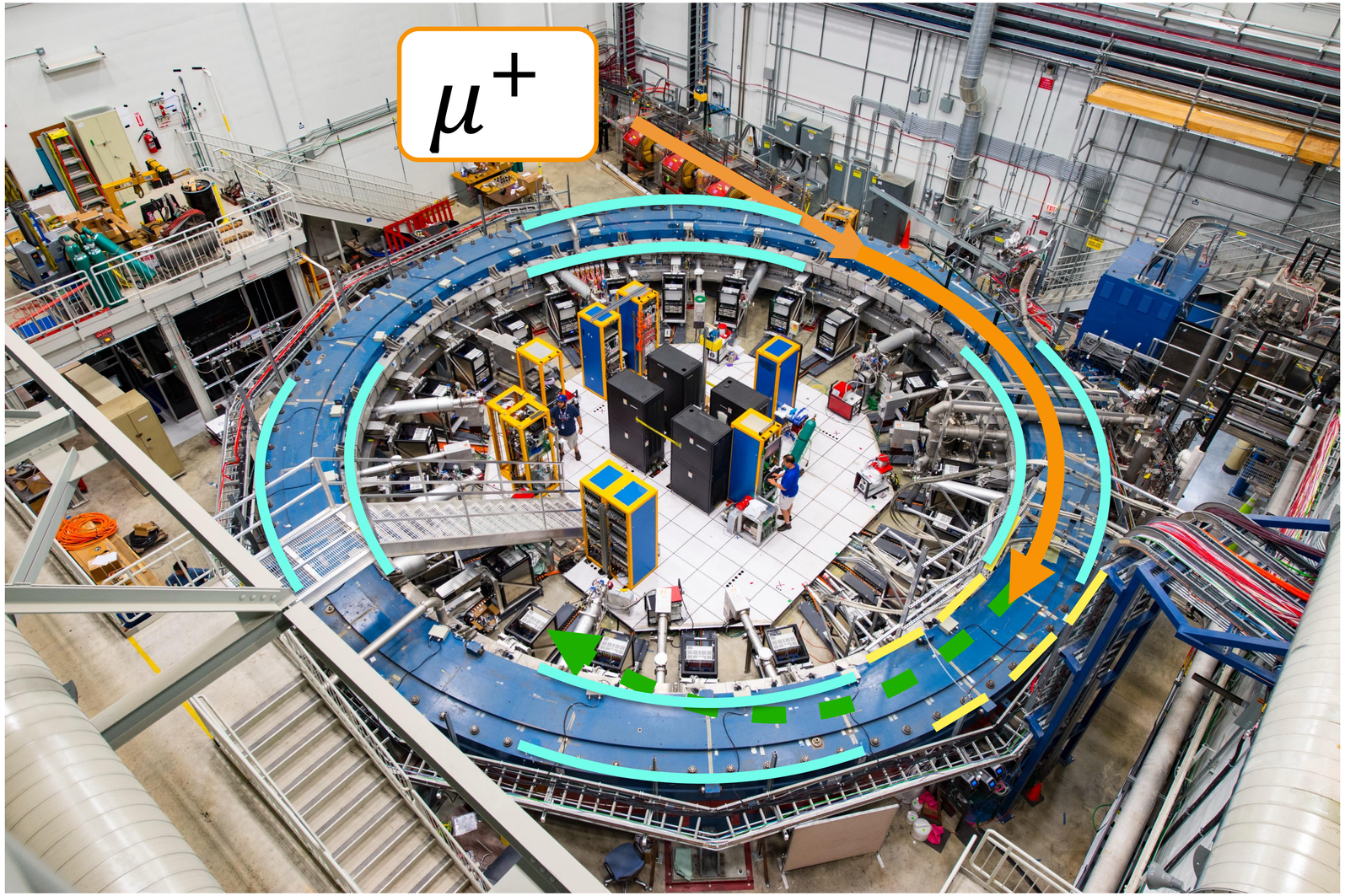


Muon decay

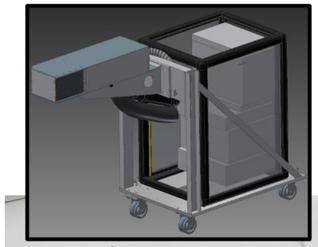
Muons decay via $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$

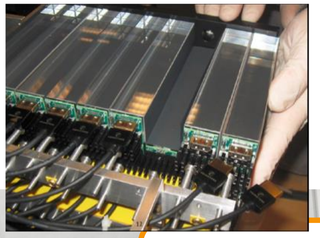
We detect the **inward spiraling decay positron**

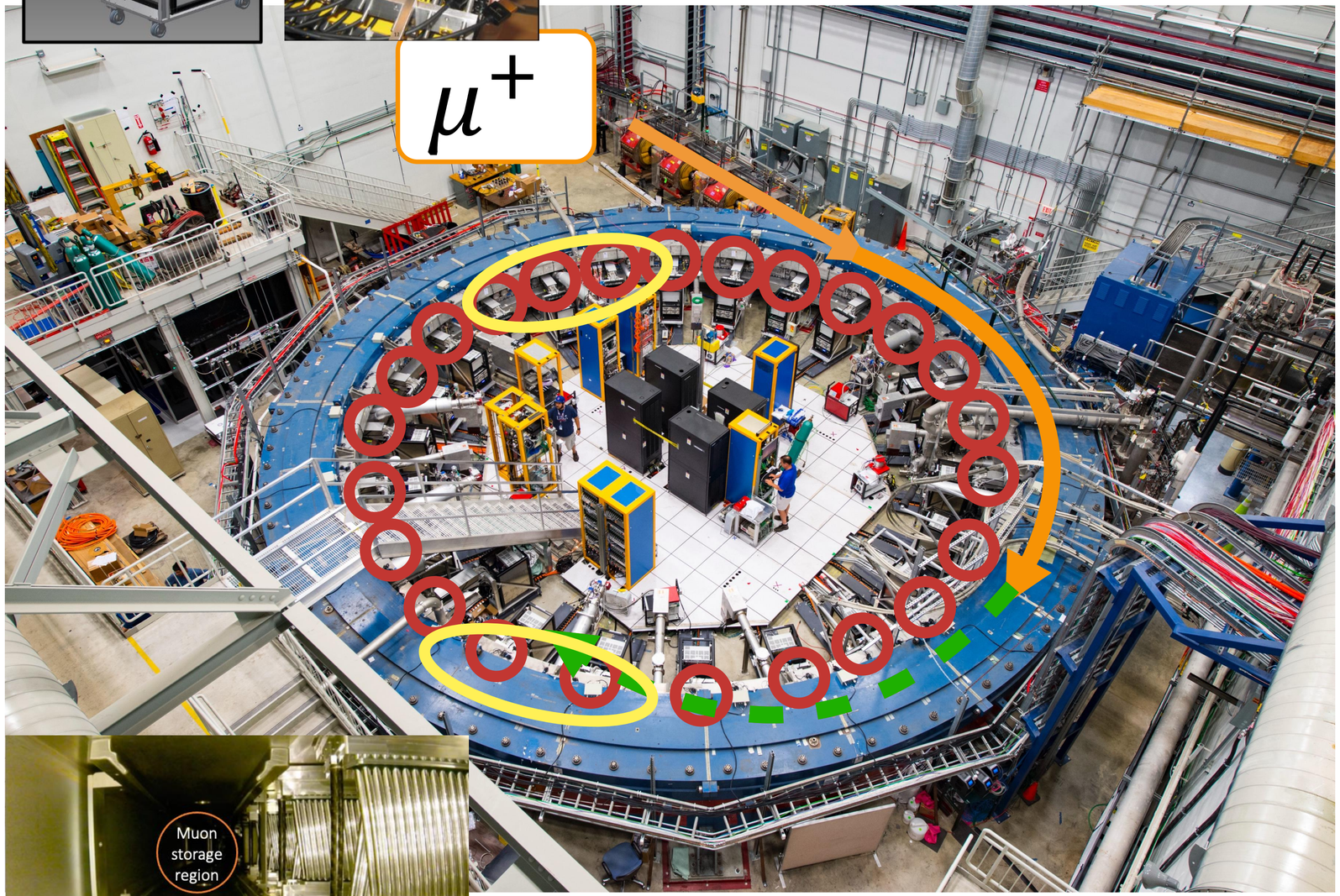
Muon spin information encoded in decay positron energy spectrum

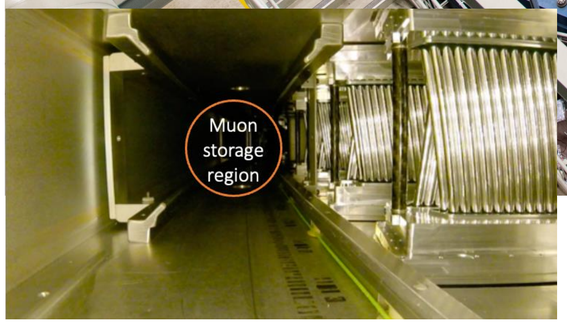


Detector systems









Electromagnetic calorimeters

Time and energy of decay positrons measured with 24 calorimeters

Each calo has 54 (9x6) Cherenkov PbF_2 crystals read out by SiPMs

Arrival time (~100ps), energy of e+ (~5% at 2GeV)

Laser calibration system for gain stability

Straw trackers

Two straw trackers used to measure positron tracks

Each contains 8 modules, 4 layers of 32 straws, 50:50 Ar:Ethane

Extrapolated tracks determine muon decay position; proxy for muon beam

The “master” formula

What we measure

$$\omega_a = a_\mu \frac{e}{m} B \quad \rightarrow \quad a_\mu = \frac{\omega_a}{\tilde{\omega}'_p(T_r)} \frac{\mu'_p(T_r)}{\mu_B} \frac{m_\mu}{m_e}$$

External inputs
(22 ppb uncertainty)

Precession frequency

Electric field + vertical beam motion

Phase changing effects

$$\frac{\omega_a}{\tilde{\omega}'_p(T_r)} = \frac{\omega_a^m (1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{\langle \omega'_p(T_r) \times M \rangle (1 + B_k + B_q)}$$

Weighted magnetic field

Transient magnetic fields

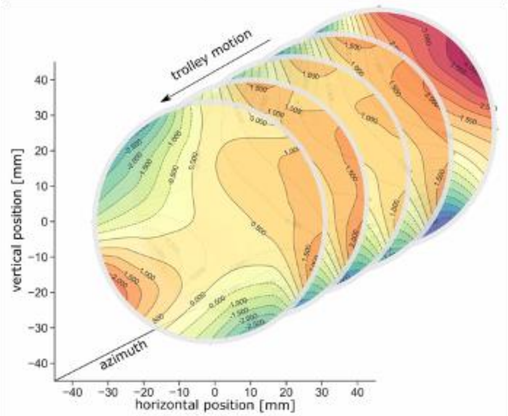
Magnetic field measurement

$$\frac{\omega_a}{\tilde{\omega}'_p(T_r)} = \frac{\omega_a^m(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{\langle \omega'_p(T_r) \times M \rangle (1 + B_k + B_q)}$$

Proton nuclear magnetic resonance (NMR) used to measure B-field

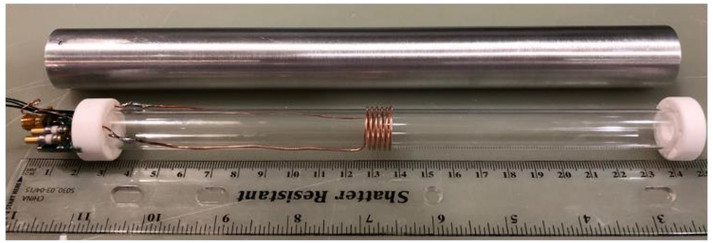
$$\omega_p \propto B$$

17 petroleum jelly NMR probes

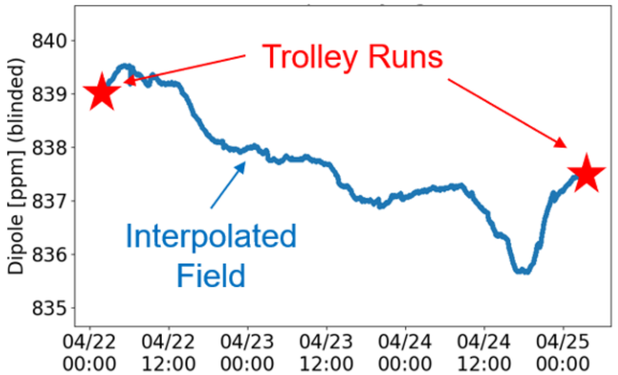


2D field maps (~8000 points)

In-situ NMR probes calibrated to a water-based cylindrical probe



water-based cylindrical **Calibration Probe**

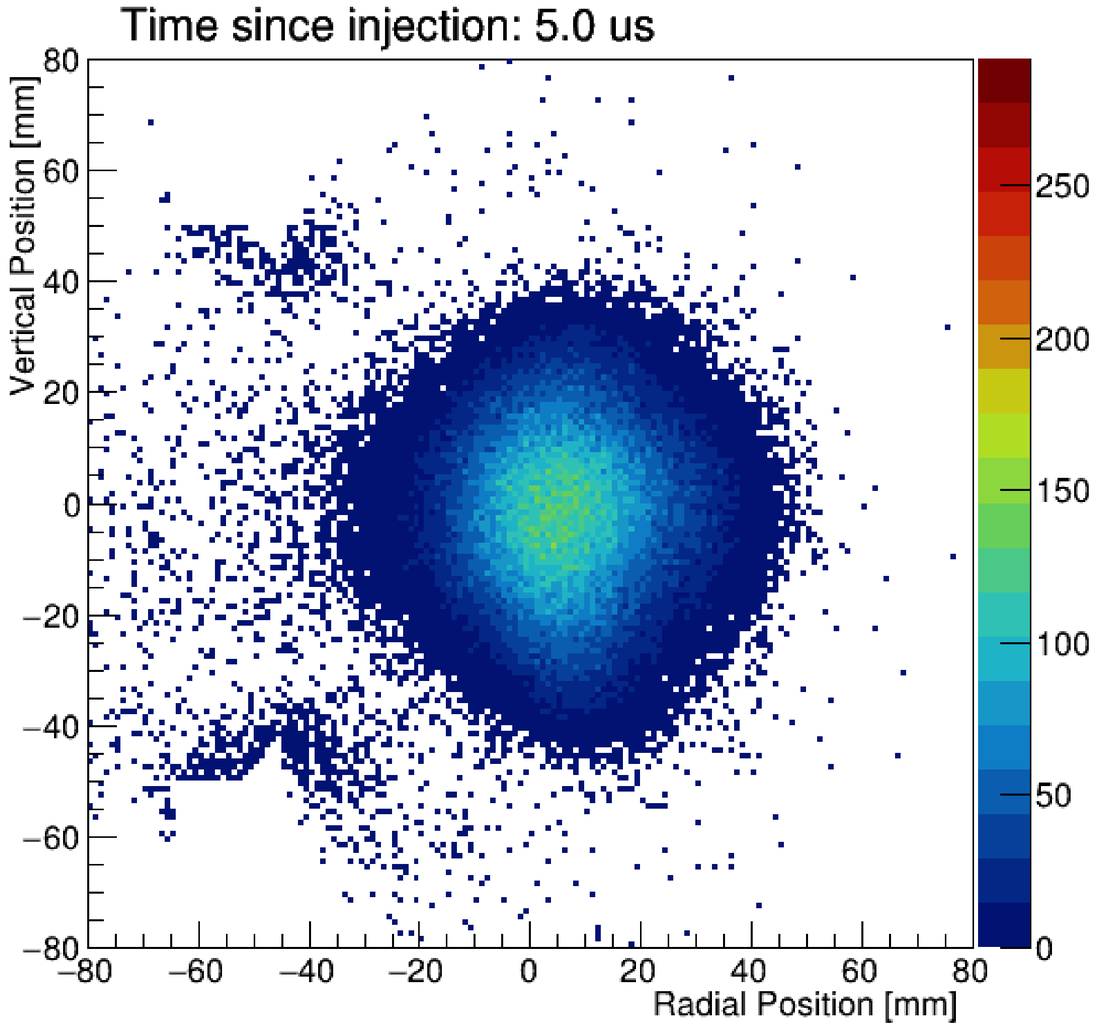


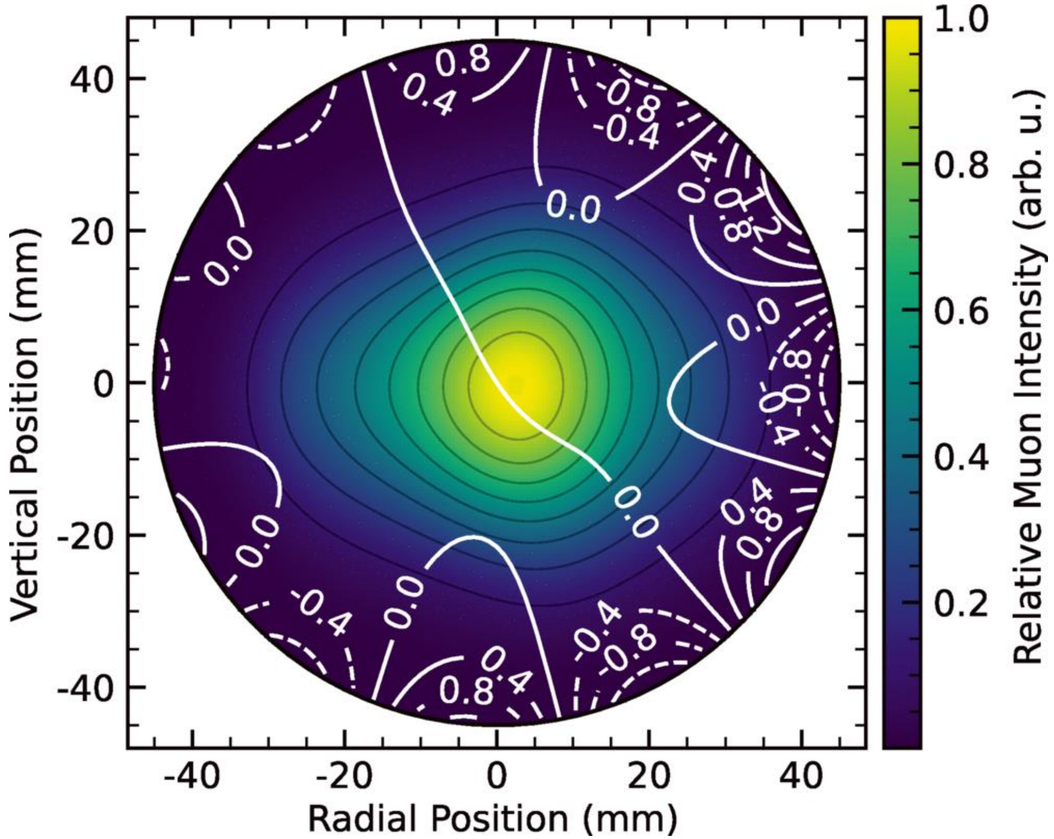
Absolute calibration to shielded protons in a spherical sample

Fixed probes above/below muon storage region

Muon distribution measured by trackers

$$\frac{\omega_a}{\tilde{\omega}'_p(T_r)} = \frac{\omega_a^m(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{\langle \omega'_p(T_r) \times M \rangle (1 + B_k + B_q)}$$

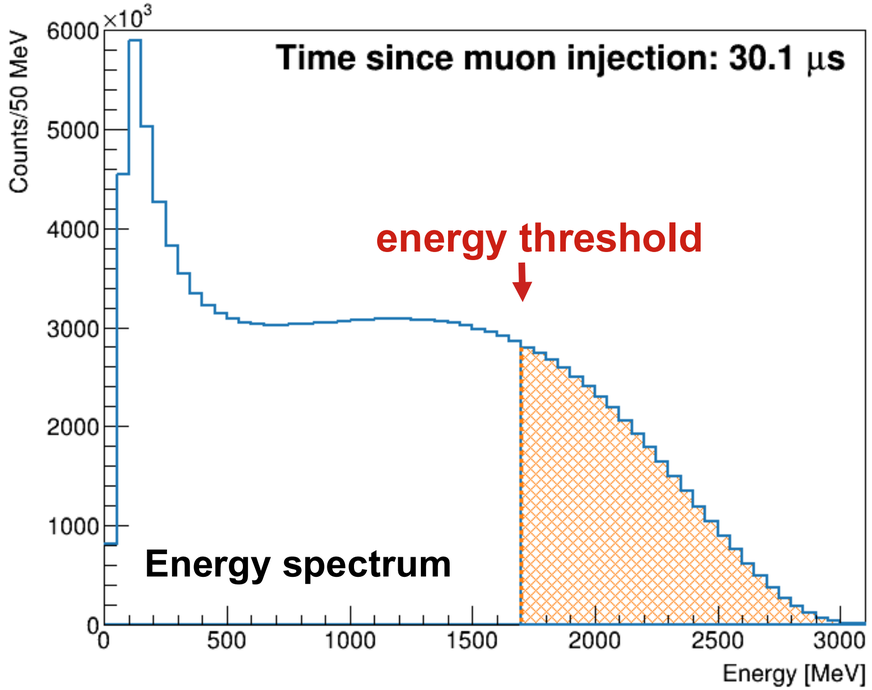


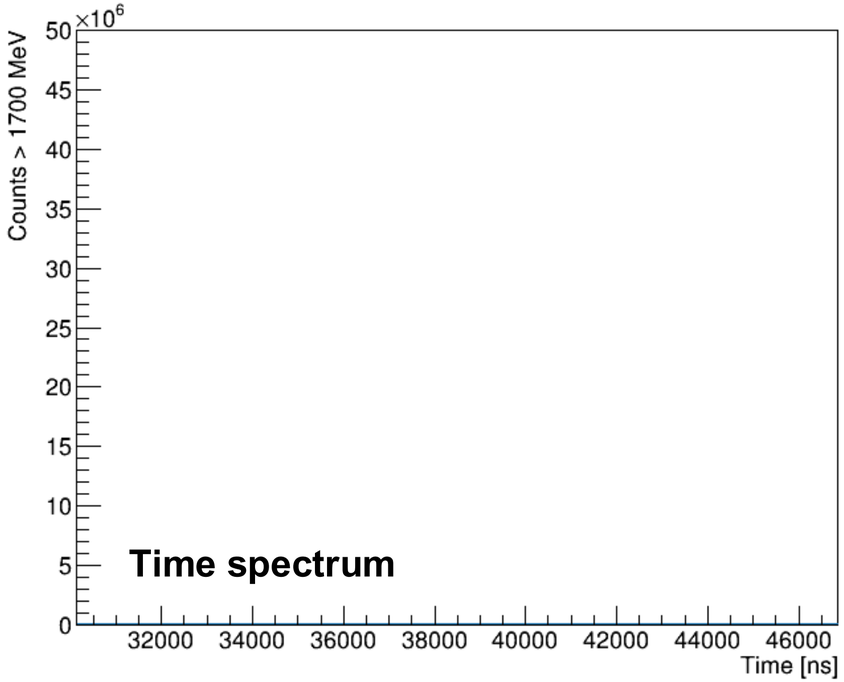


Precession frequency measurement

$$\frac{\omega_a}{\tilde{\omega}'_p(T_r)} = \frac{\omega_a^m(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{\langle \omega'_p(T_r) \times M \rangle (1 + B_k + B_q)}$$

Parity violation of muon decay causes shape of decay positron **energy spectra to oscillate** in time at ω_a





Count number of high energy positrons

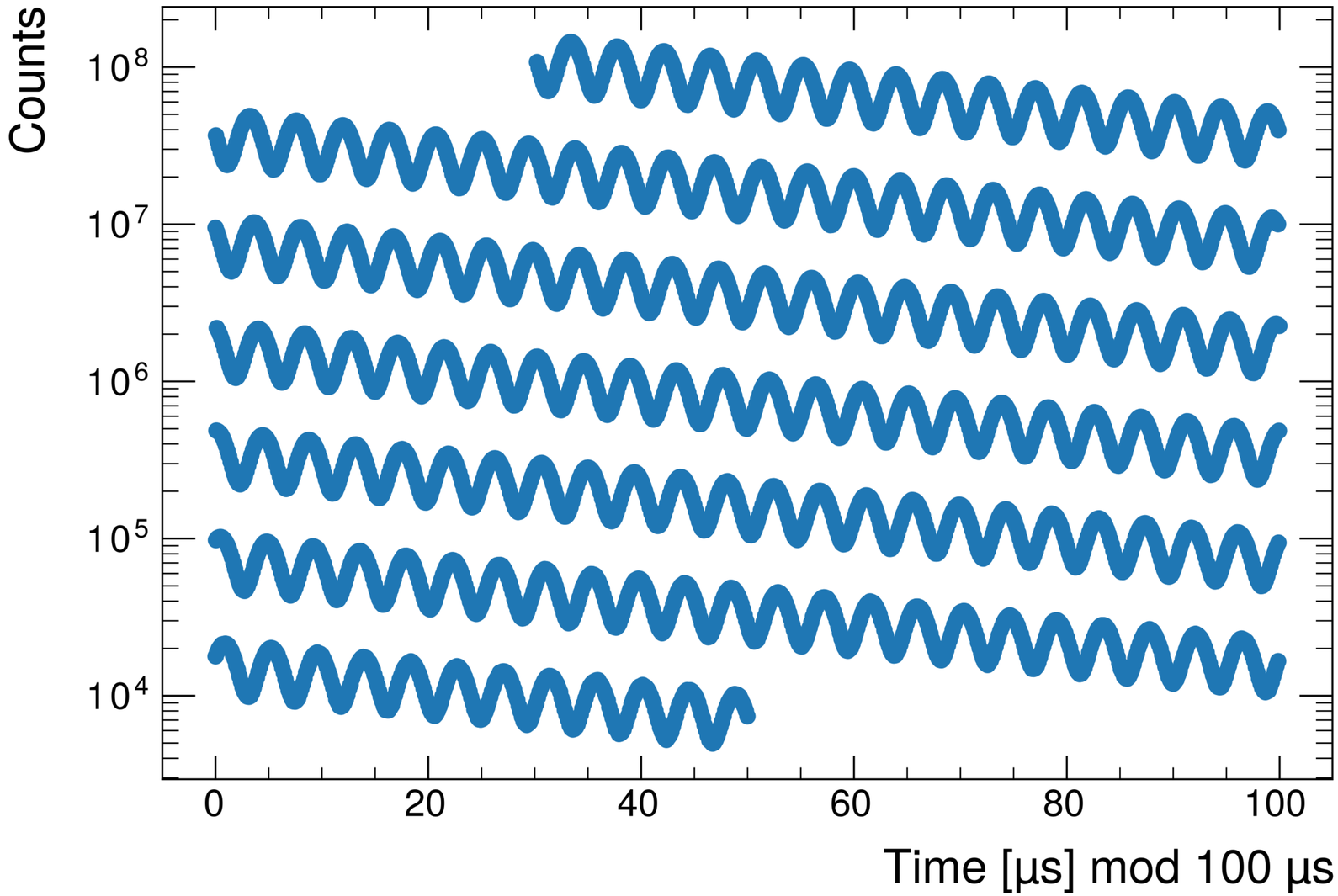
Oscillates in time at the difference frequency ω_a

$$\omega_a = a_\mu \frac{e}{m} B$$

Our data: the Wiggle Plot

$$\frac{\omega_a}{\tilde{\omega}'_p(T_r)} = \frac{\omega_a^m(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{\langle \omega'_p(T_r) \times M \rangle (1 + B_k + B_q)}$$

Run-4/5/6 data (~two thirds of Fermilab's data)



Signal is the prominent wiggle

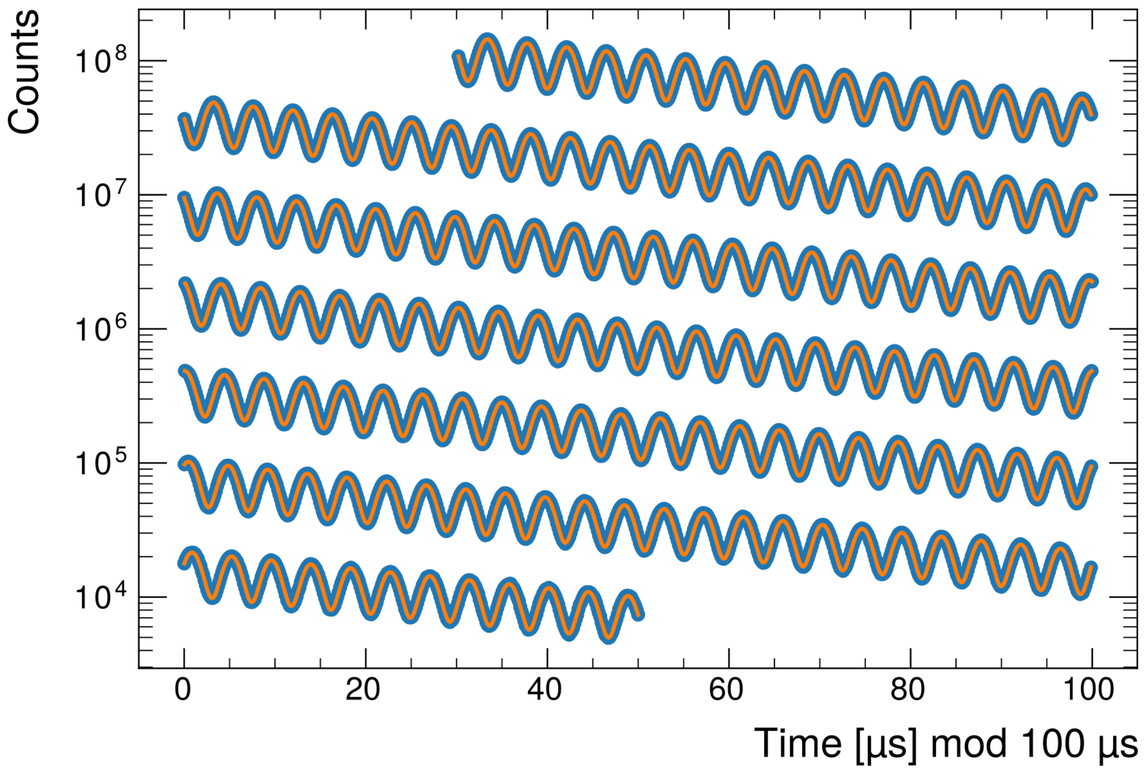
Exponential decay at boosted muon lifetime

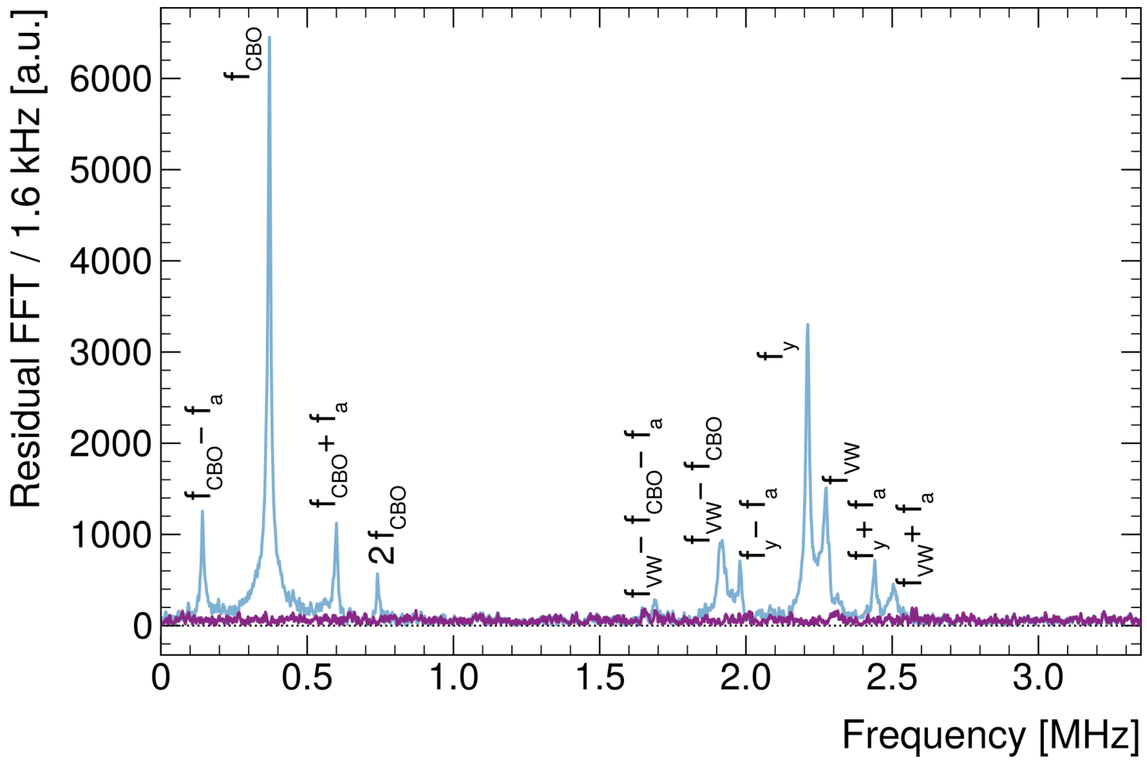
Size of the wiggle set by weak decay asymmetry and positron energy threshold

Frequency extracted from multi-parameter fit

$$\frac{\omega_a}{\tilde{\omega}'_p(T_r)} = \frac{\omega_a^m(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{\langle \omega'_p(T_r) \times M \rangle (1 + B_k + B_q)}$$

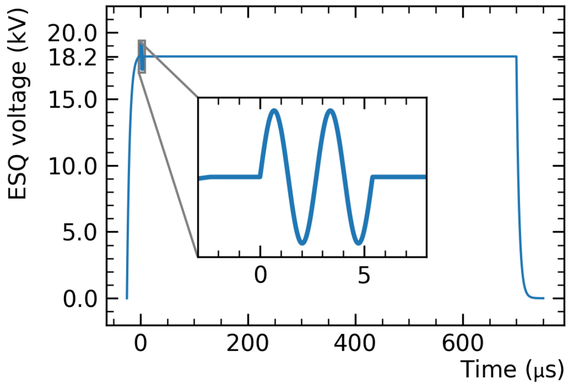
Simplest fit model captures $g - 2$ and exponential decay: $f(t) = \boldsymbol{N_0} e^{-t/\boldsymbol{\tau}}[1 + \boldsymbol{A}\cos(\boldsymbol{\omega_a} t - \boldsymbol{\phi})$



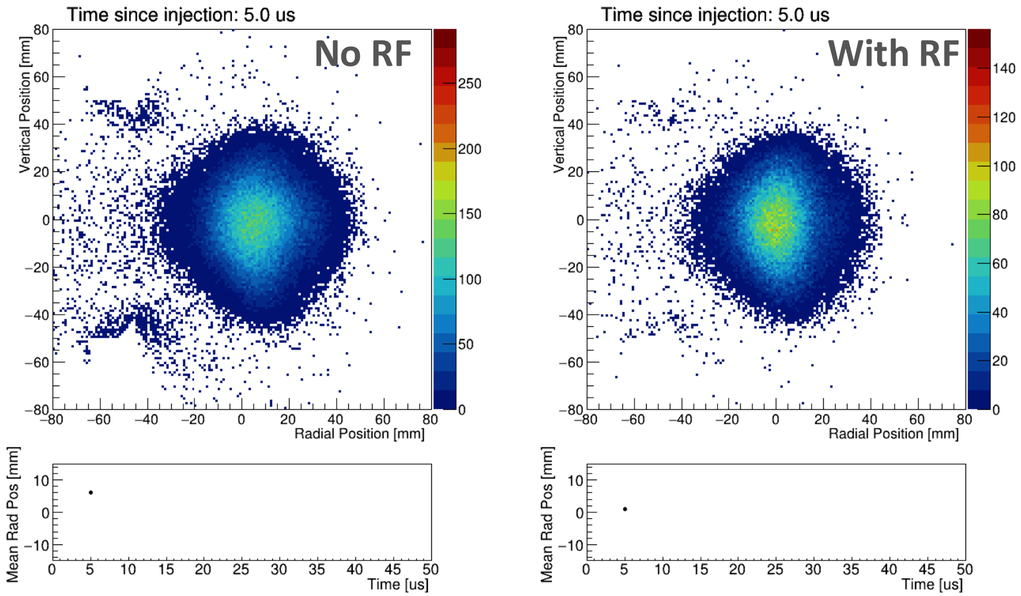


Full fit model accounts for **beam dynamics** and **muon losses** — require no structure in Fourier transform of fit residuals, good reduced χ^2, and pass consistency checks

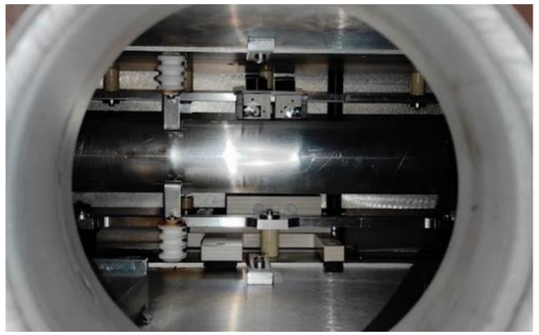
Highlighting Two Improvements



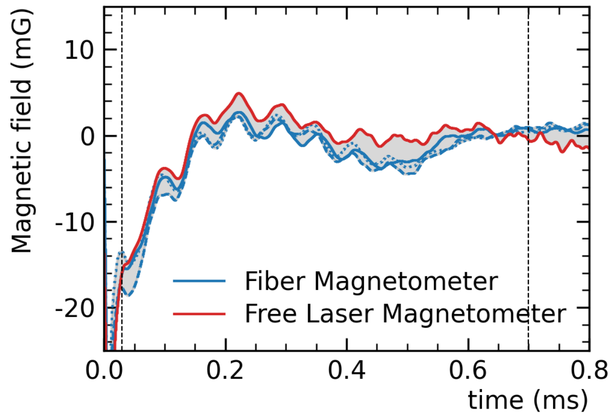
~1 kV voltage modulation in first 6 μs after injection



RF system installed to reduce beam oscillation effects



Two magnetometers used: fiber and free laser
Both use Faraday rotation in terbium gallium garnet crystals

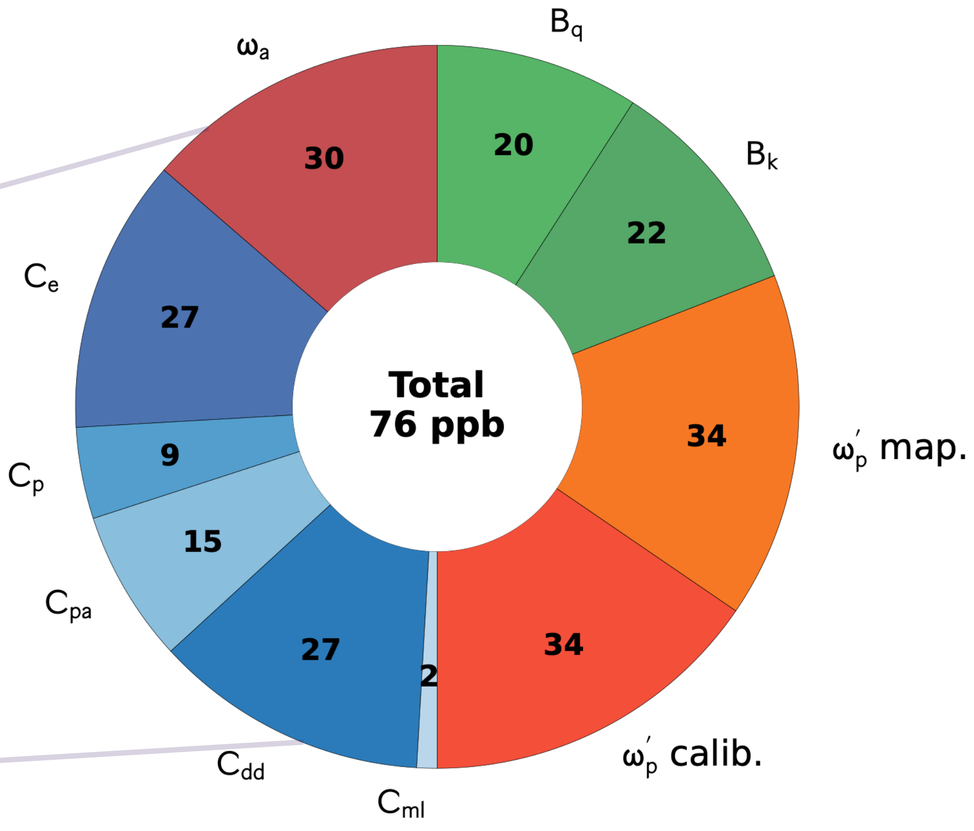


Kicker transient measurements enhanced understanding of the effect

We exceeded our systematic uncertainty goal

Runs 4/5/6

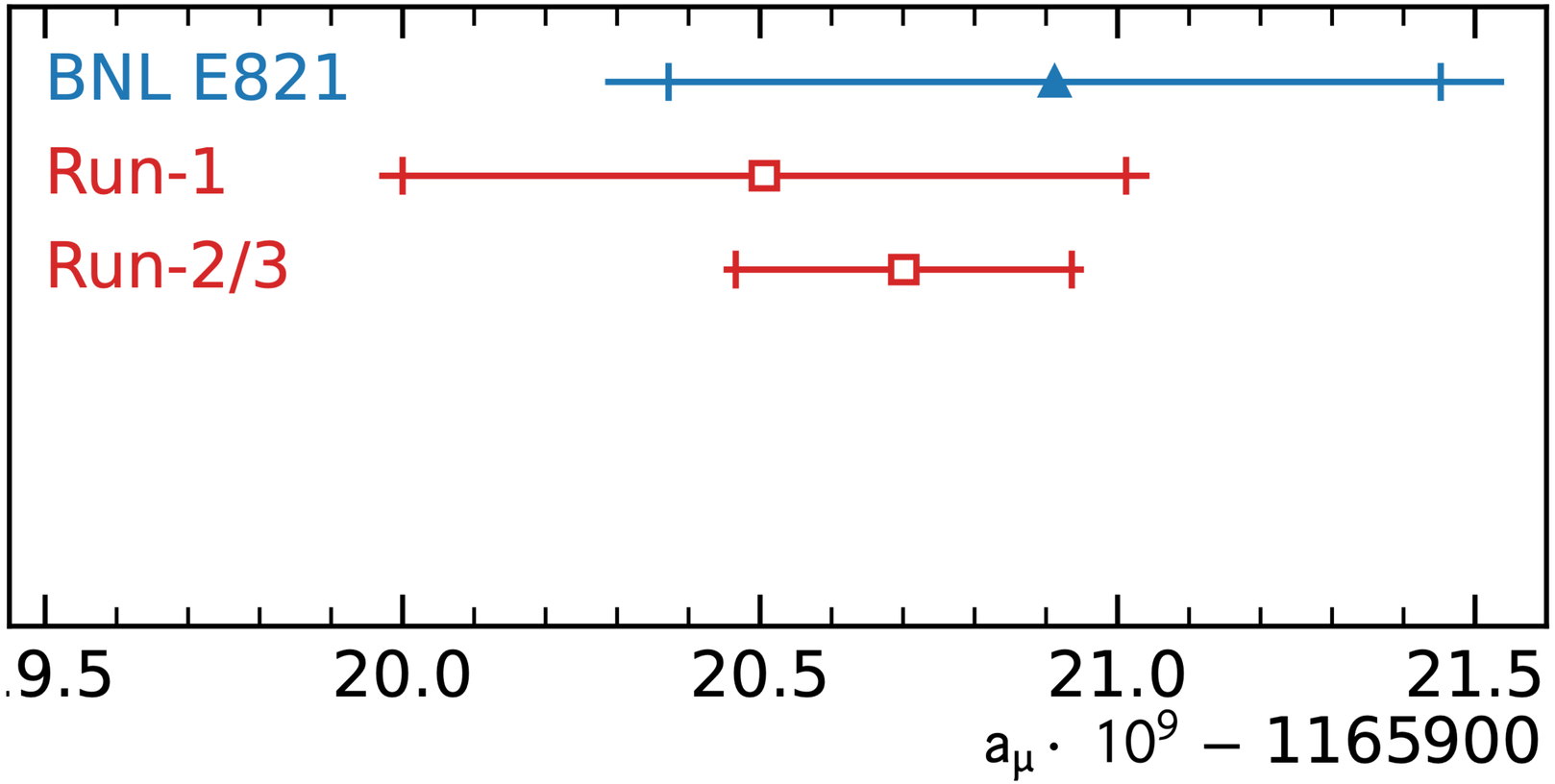
Quantity	Correction (ppb)	Uncertainty (ppb)
ω_a^m (statistical)	...	114
ω_a^m (systematic)	...	30
C_e	347	27
C_p	175	9
C_{pa}	-33	15
C_{dd}	26	27
C_{ml}	0	2
$\langle \omega'_p \times M \rangle$ (mapping, tracking)	...	34
$\langle \omega'_p \times M \rangle$ (calibration)	...	34
B_k	-37	22
B_q	-21	20
μ'_p/μ_B	...	4
m_μ/m_e	...	22
Total systematic for $\mathcal{R}'_\mu$	...	76
Total for a_μ	572	139



Below design goal of 100 ppb

No dominant source

Run-1 & Run-2/3 Results

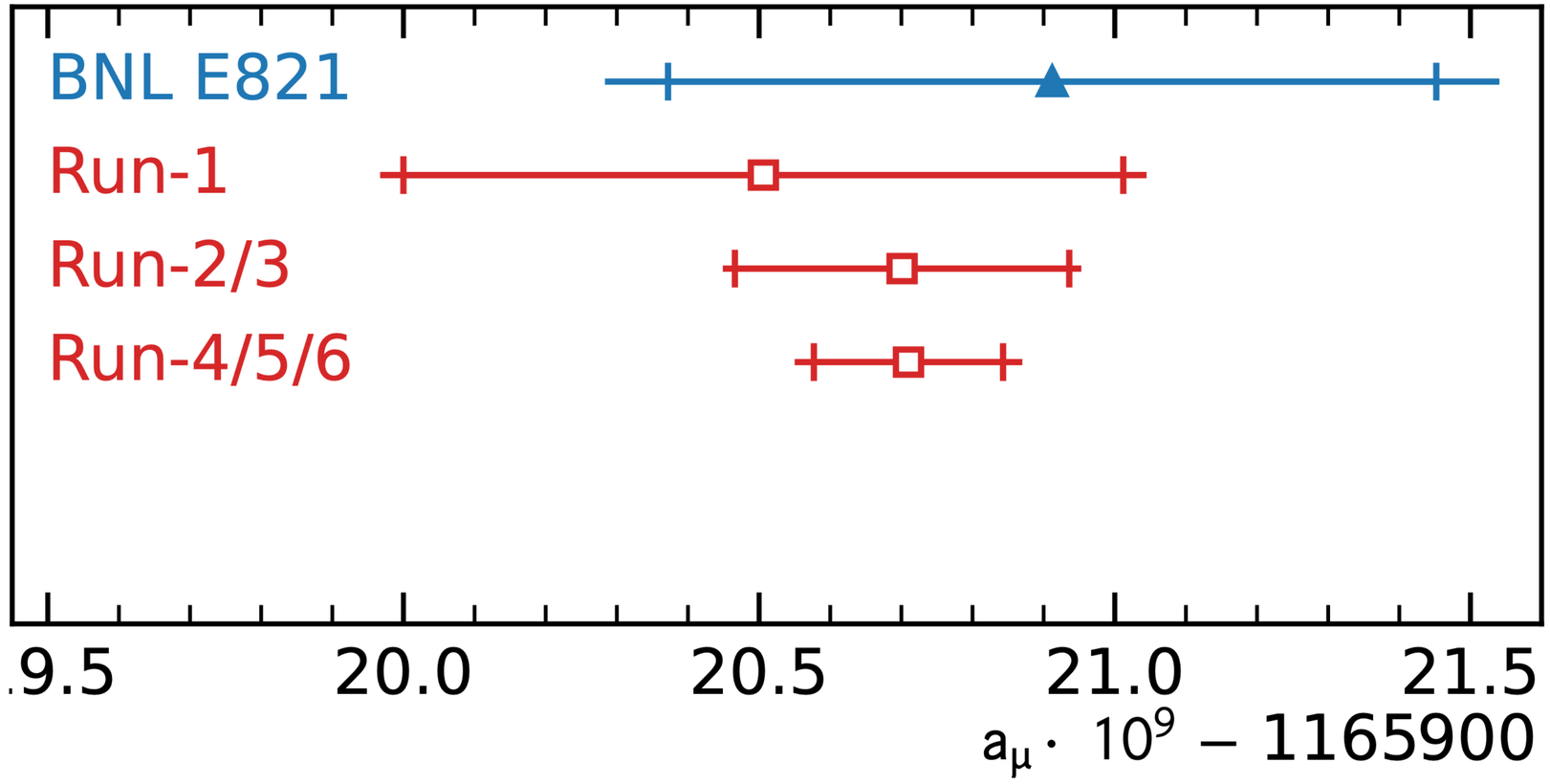


Our previous two results agree well with each other and the BNL measurement

Analyses are blinded and only unblinded after analysis is complete and collaboration agrees

The Run-4/5/6 Result (June 2025)

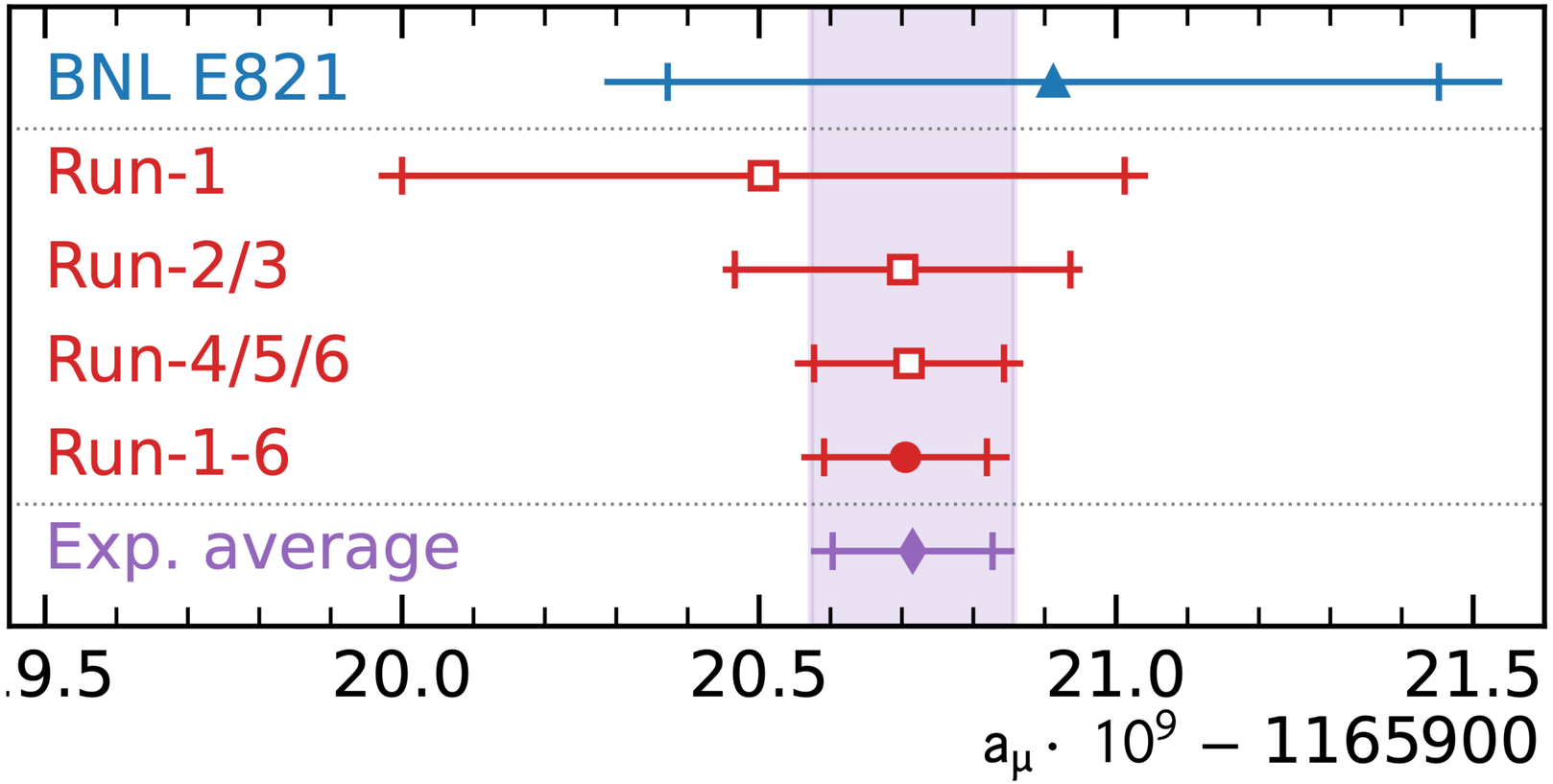
$$a_\mu(\text{Runs } 4/5/6) = 0.00116\ 592\ 0705(148)\ [127\,ppb]$$



Excellent agreement!!

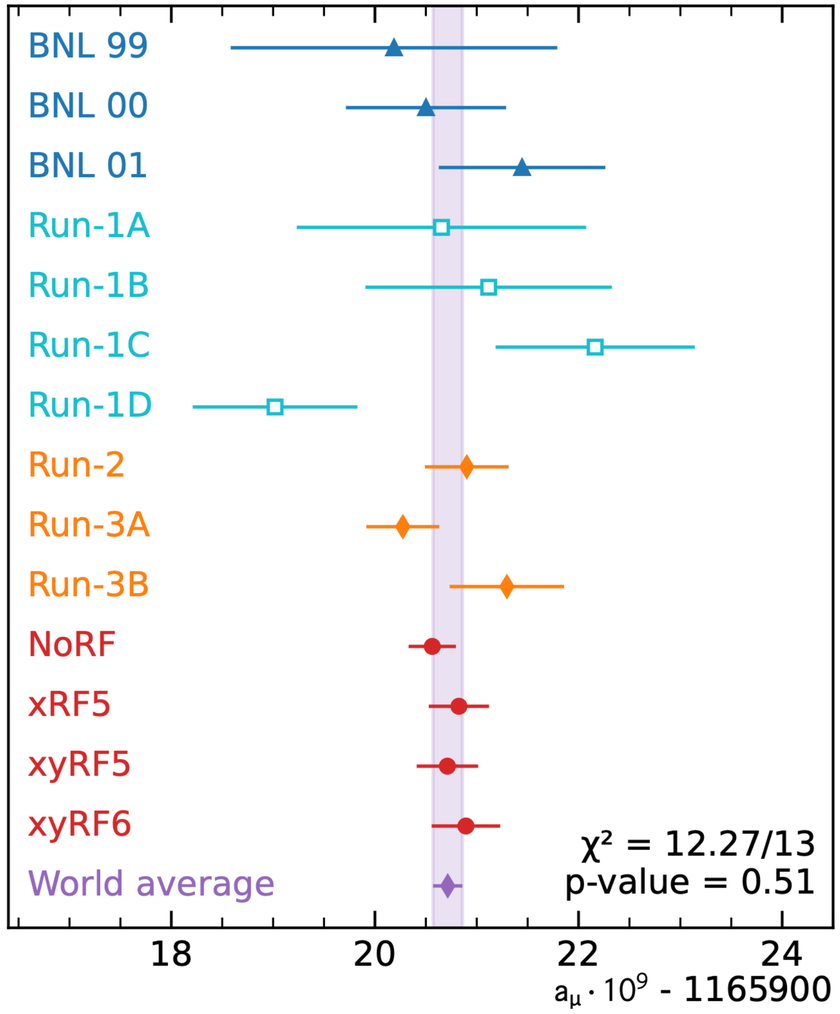
The Fermilab Result

$$a_\mu(\text{Runs } 1\text{–}6) = 0.00116\ 592\ 0715(145)\ [124ppb]$$

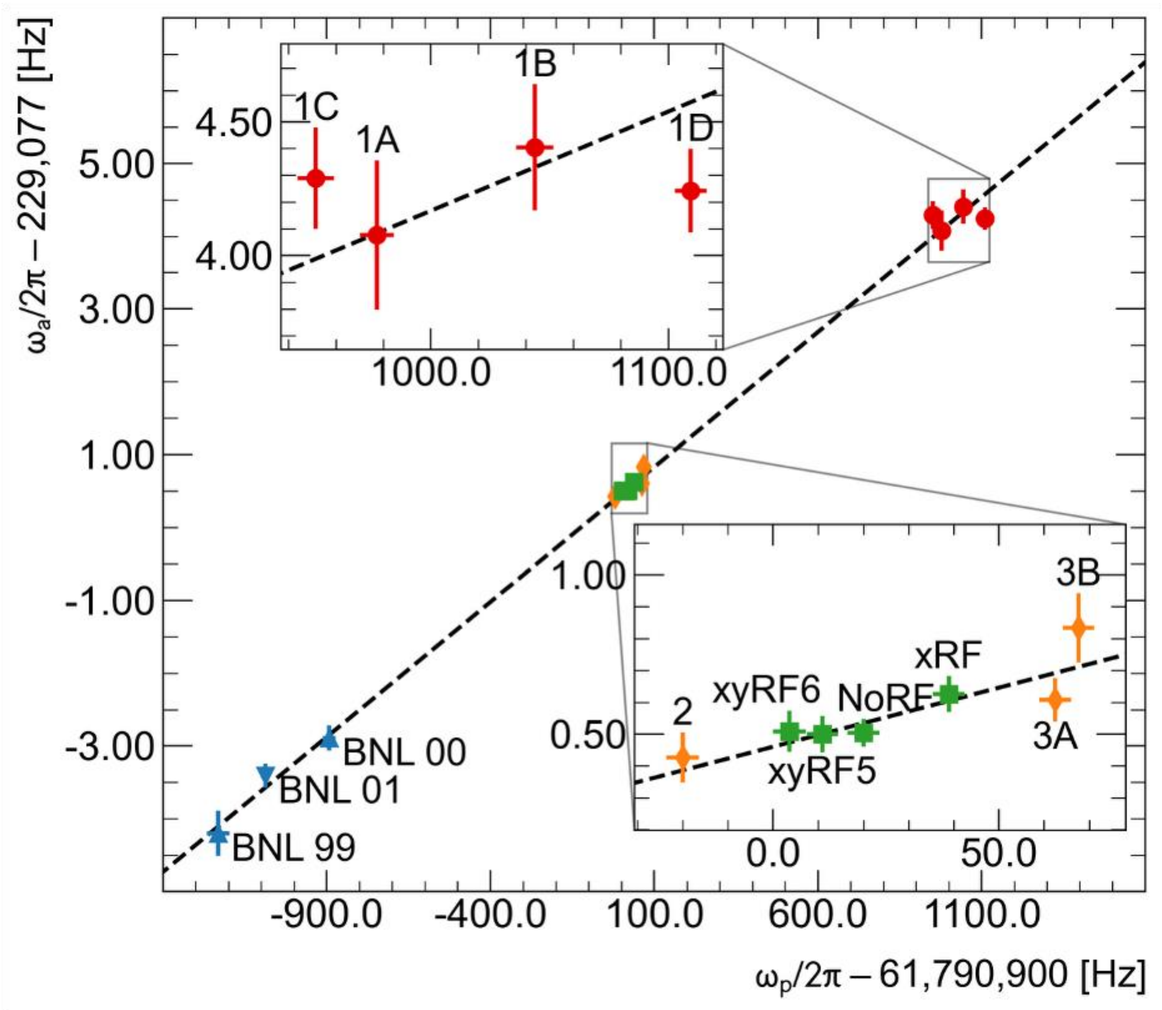


New experimental world average uncertainty is **4.4 times smaller** than BNL's uncertainty — exceeded our goal!

Data consistency



Datasets



Field set points

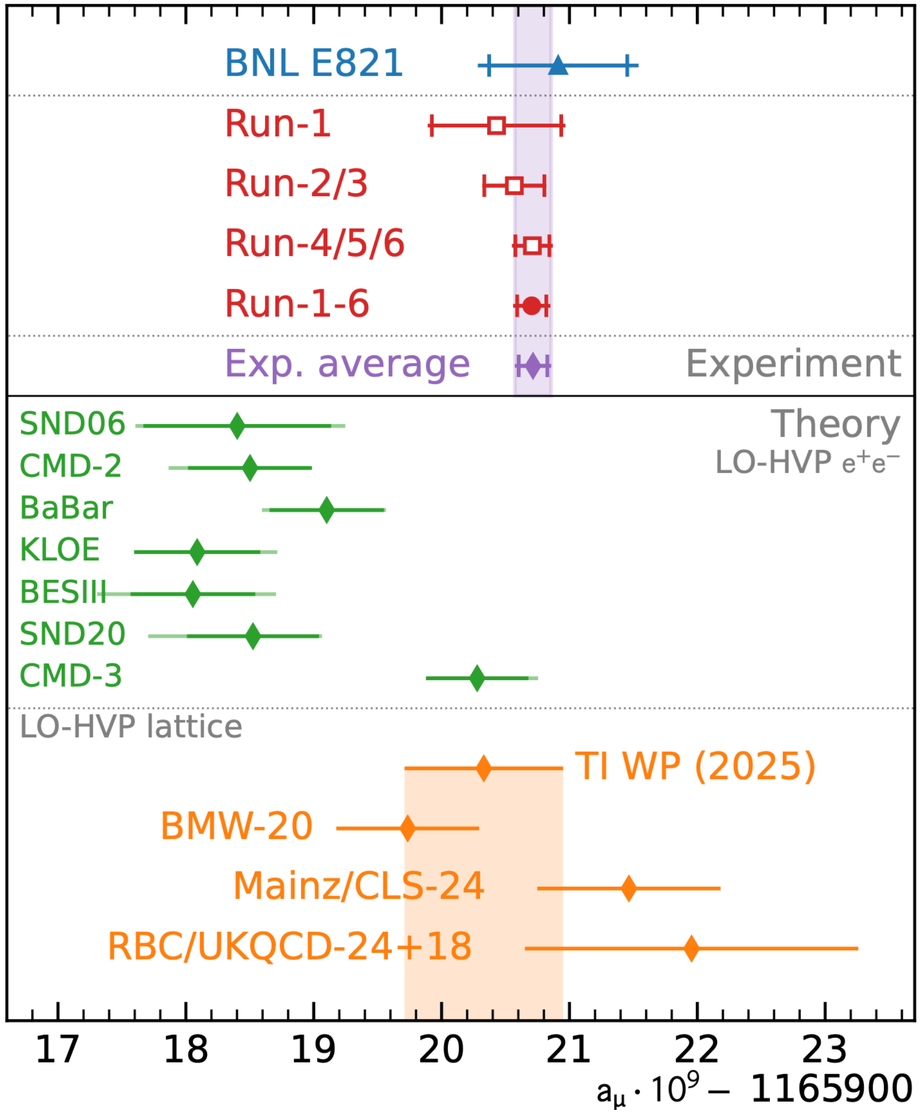
Comparison to Standard Model Prediction

Muon g- 2 Theory Initiative compiled prediction in latest White Paper 2025: Phys. Rept. 1143 (2025) 1-158

HVP determination based on lattice-QCD computations only; based on multiple groups

HVP e+e- data-driven approach not used, due to tensions

Consistent with experiment world average



Comparison to Standard Model Prediction

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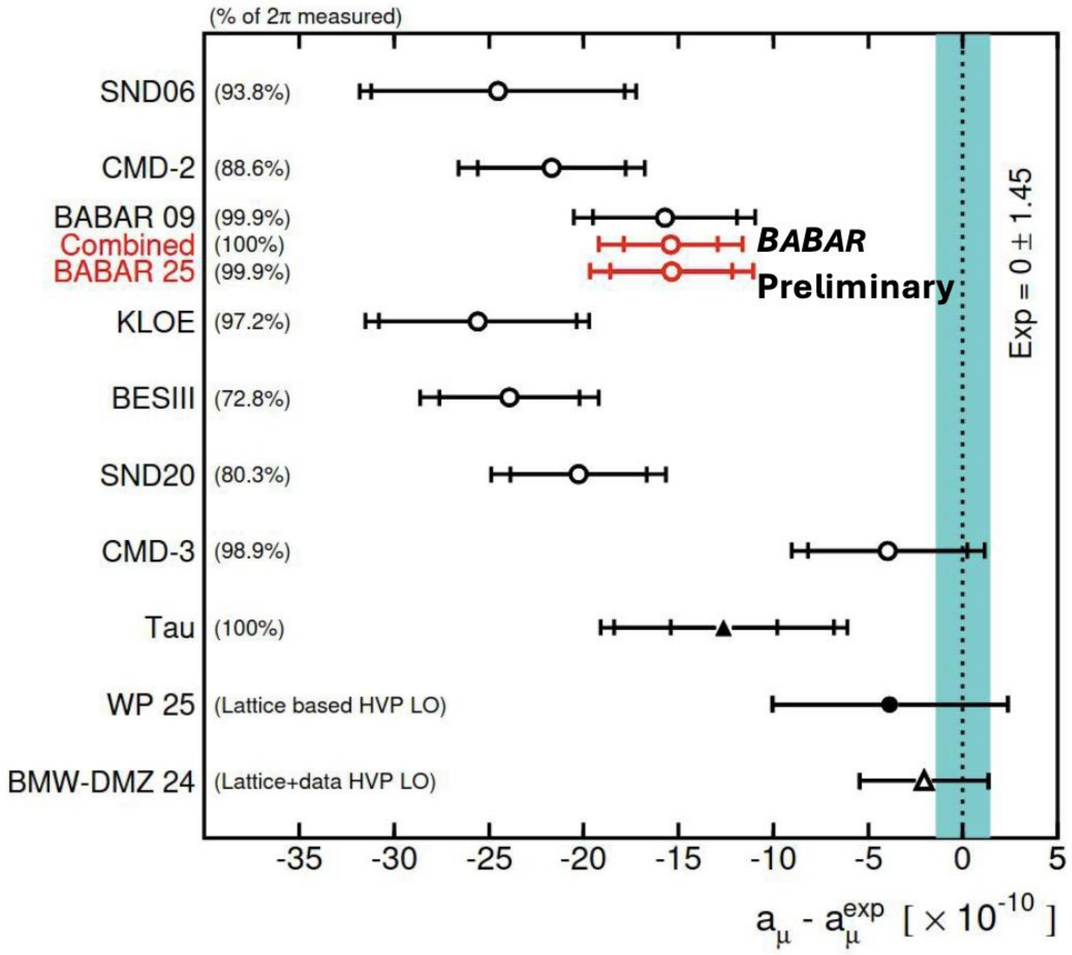
HVP determination based on lattice-QCD computations only; based on multiple groups

HVP e+e- data-driven approach not used, due to tensions

Consistent with experiment world average

New results from BaBar (2025) on $\pi^+\pi^-$ channel

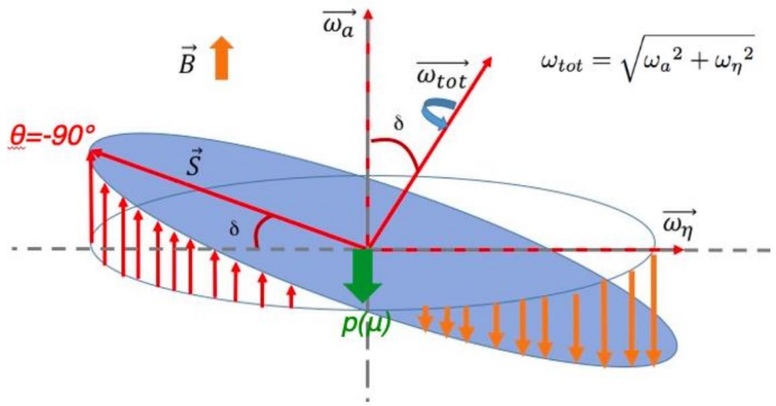
Result is consistent with their previous measurement: see Michael Roney's talk from Wednesday



Future Outlook

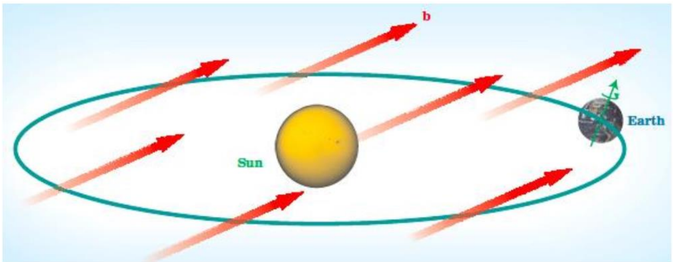
More from the Fermilab experiment:

Muon **EDM** search: EDM tilts the precession plane



Other searches for…

- **CPT/LV**
- Ultra light **Dark Matter**



Future for muon g-2:

New $e^+ e^-$ cross section measurements (e.g. BaBar result)

MUonE experiment: HVP from muon-electron scattering

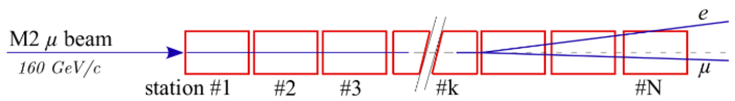
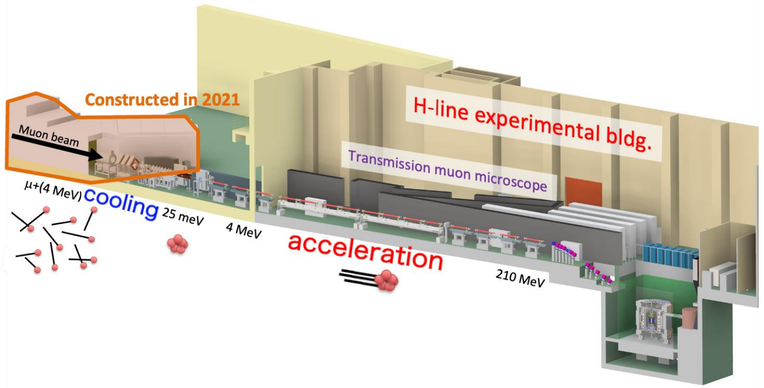


Figure 24: Schematic view of the MUonE experimental apparatus (not to

J-PARC Muon g-2/EDM experiment (independent and different approach)



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- Royal Society (UK)
- Leverhulme Trust (UK)
- European Union's Horizon 2020
- Strong 2020 (EU)
- German Research Foundation (DFG)
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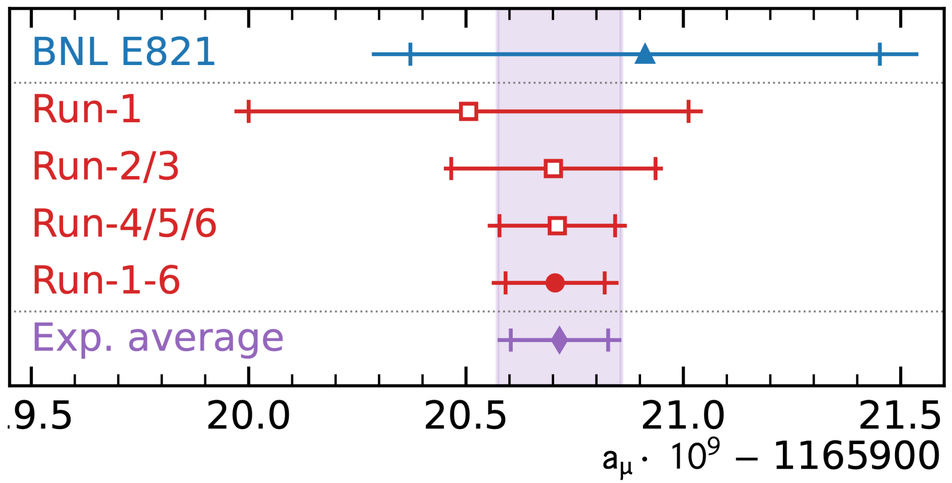
- MSIP, NRF, and IBS-R017-D1 (Republic of Korea)

Thank you for your attention



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