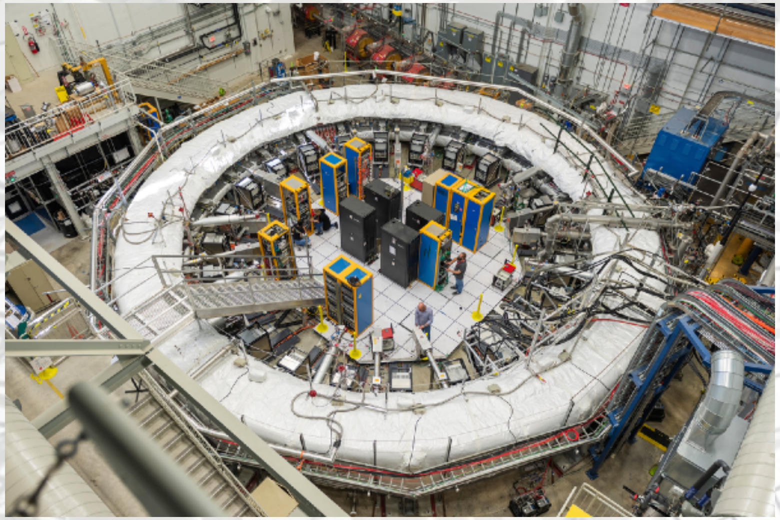
Final Result From The Fermilab Muon g-2 Experiment



Siew Yan Hoh (何守仁)

On behalf of the
Muon g-2 Collaboration

Vietnam Flavour Physics Conference 2025
ICISE, Quy Nhon, Vietnam

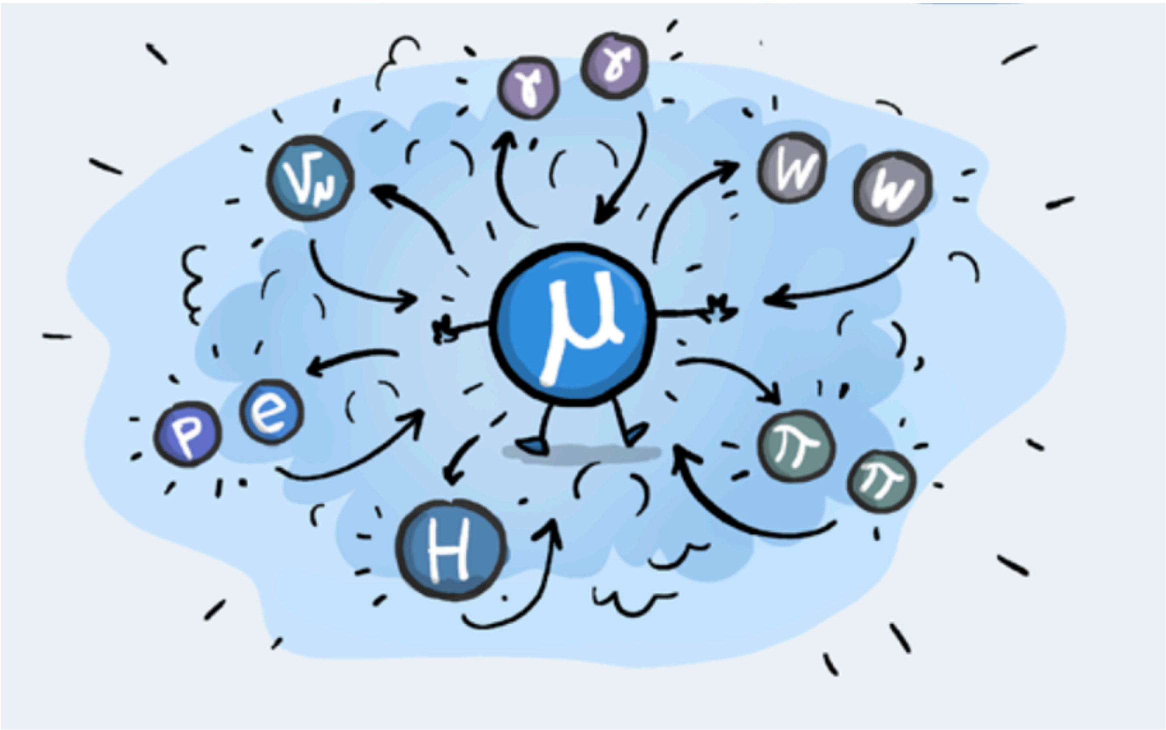
17th - 23rd August 2025

李政道研究所
TSUNG-DAO LEE INSTITUTE

Fermilab

Outline

- Magnetic Dipole Moment
- Muon as a probe
- Fermilab Muon g-2 Experiment
- Measurements:
  - Spin precession
  - Magnetic field
- Corrections and systematics
- Final results
- Conclusion and outlook



https://physics.aps.org/articles/v14/47

Magnetic Moment

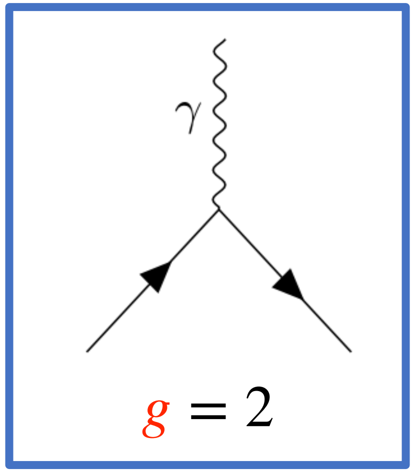
1. The magnetic moment of a lepton is connected to the spin via the **g-factor**.

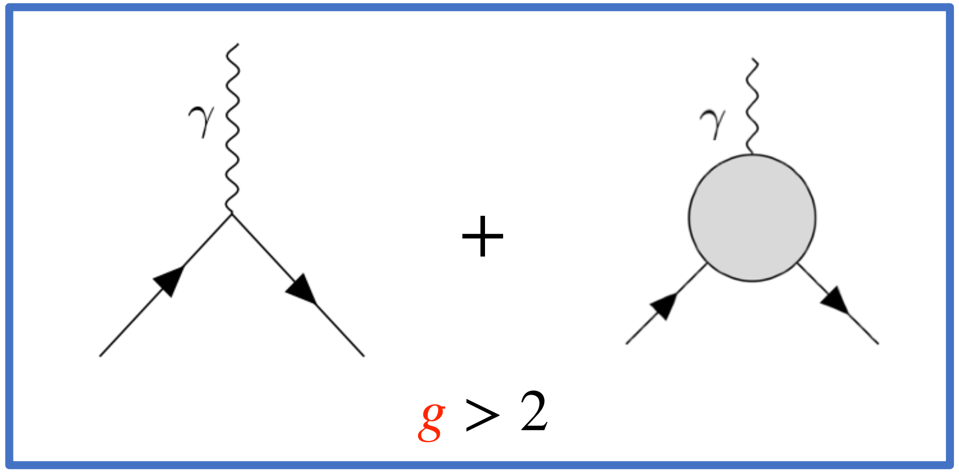
$$\vec{\mu} = g\frac{e}{2m}\vec{s}$$

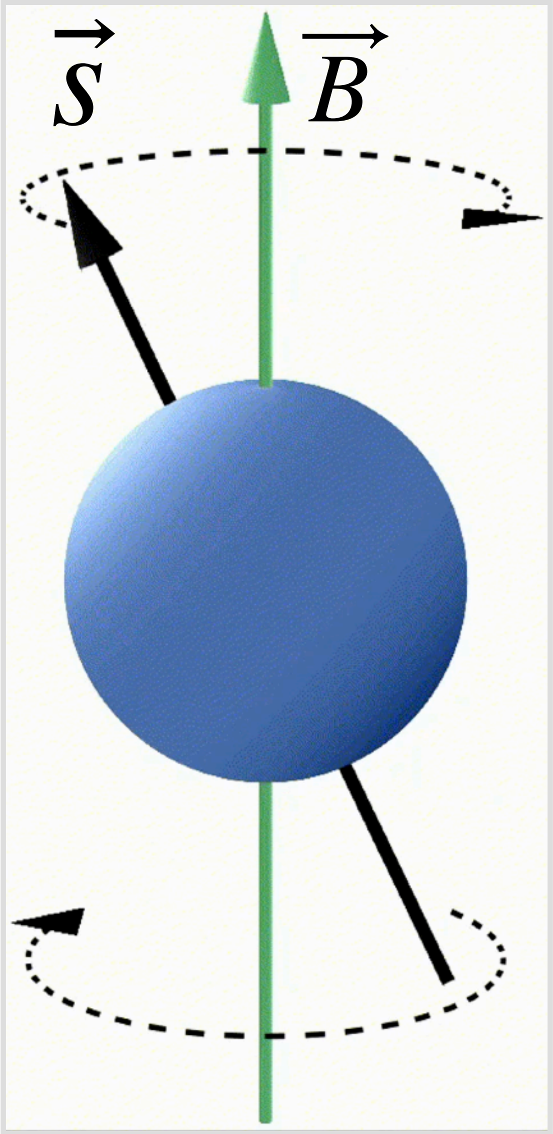
2. The value of **g-factor** can be measured from a lepton in the magnetic field, via the **spin precession frequency:**

$$\omega_s = \frac{g}{2}\frac{e}{m}B$$

3. Studying the **g-factor** helps us test the SM and understand the quantum effects (calculated up to 5-loops, with **precision up to 500 ppb**):

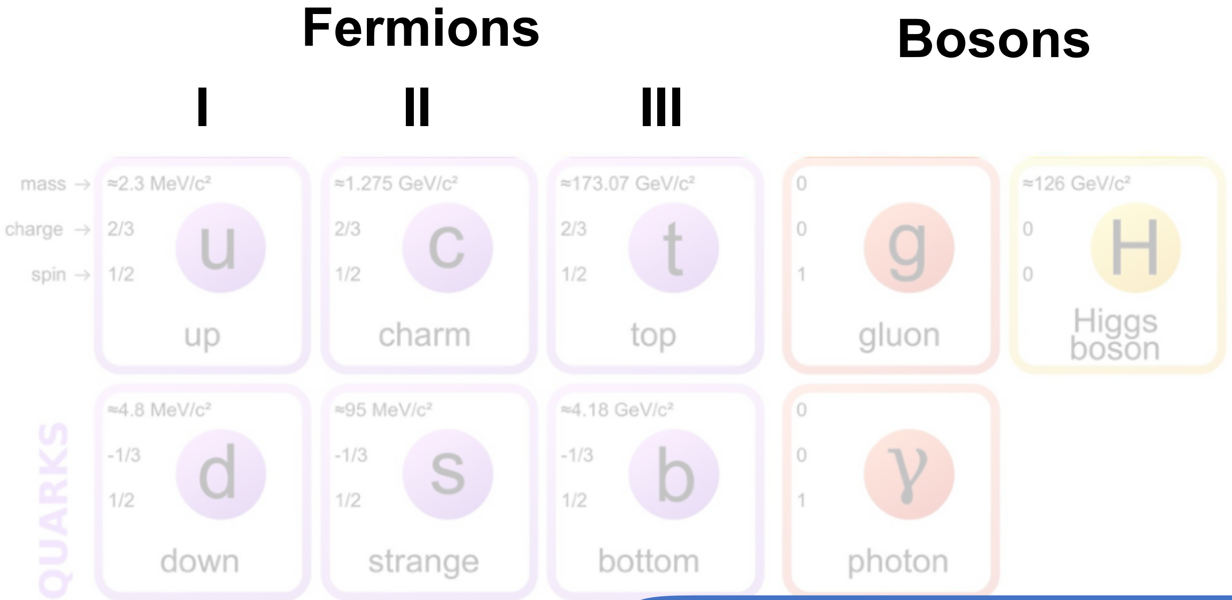




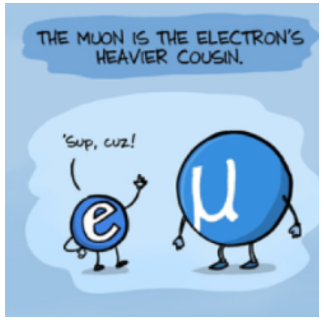


The Oddball of SM

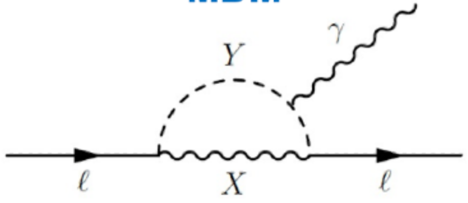
Tsung-Dao Lee Institute



Sensitivity to New Physics



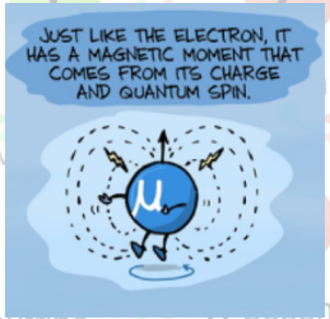
MDM

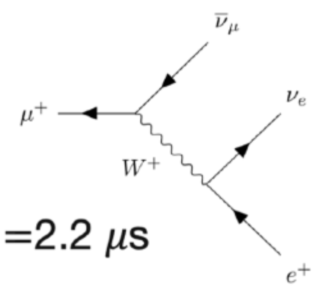


$$\mu_\ell^{\rm NP} \sim e\left(\frac{k_\mu^2}{4\pi}\right)^n \frac{m_\ell}{\Lambda_\mu^2}$$

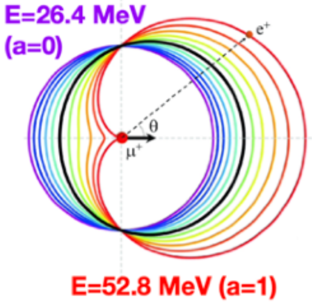
$$\frac{\mu_\mu^{NP}}{\mu_e^{NP}} \sim 207$$

Muon as a probe of the universe

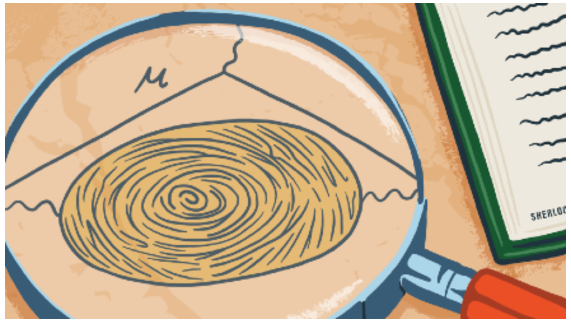




τ_μ =2.2 μs



Precision Measurement



arXiv:1801.05670

Precision measurement of muon's magnetic properties to validate SM and probe BSM

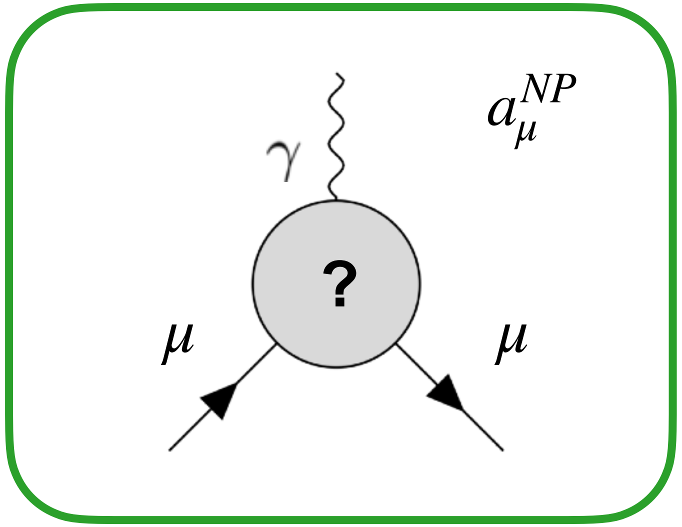
Testing SM with Muon g-2

李政道研究所 TSUNG-DAO LEE INSTITUTE

1. **Anomalous Magnetic Moment of muon**, a_μ is used to measure and predict g-factor:

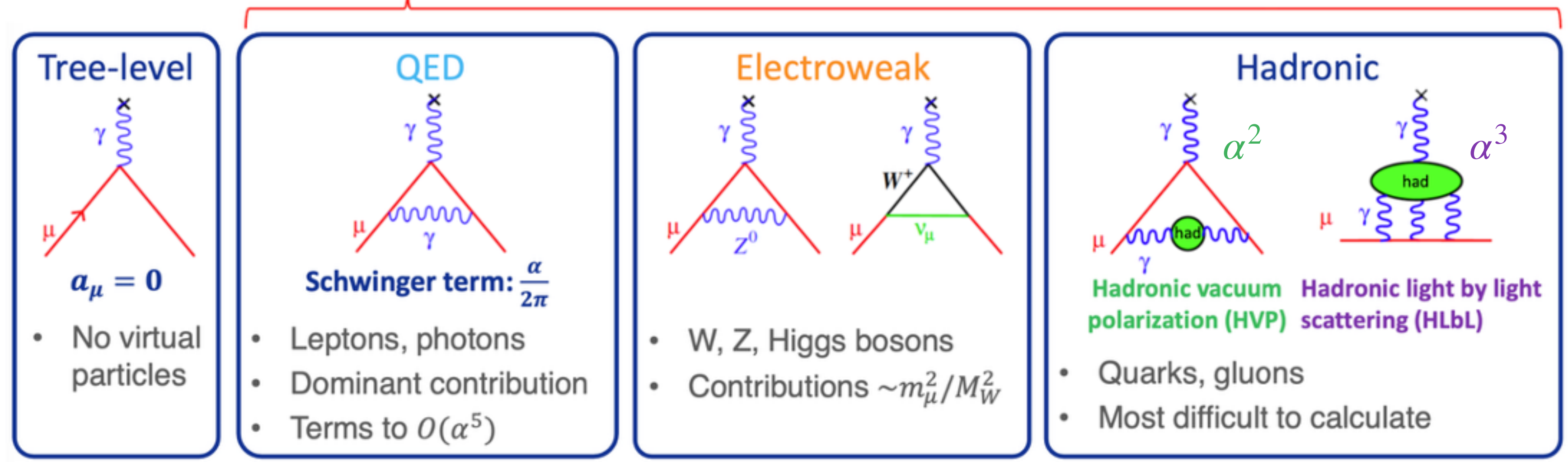
$$g_\mu = 2 + 2\underbrace{\left(\frac{\alpha}{2\pi} + \mathcal{O}(\alpha^2)\right)}_{a_\mu} \rightarrow \boxed{a_\mu = \frac{g_\mu - 2}{2} \neq 0}$$

Disagreement in SM prediction and measurement signals New Physics!!



2. The a_μ of SM is contributed by the following components:

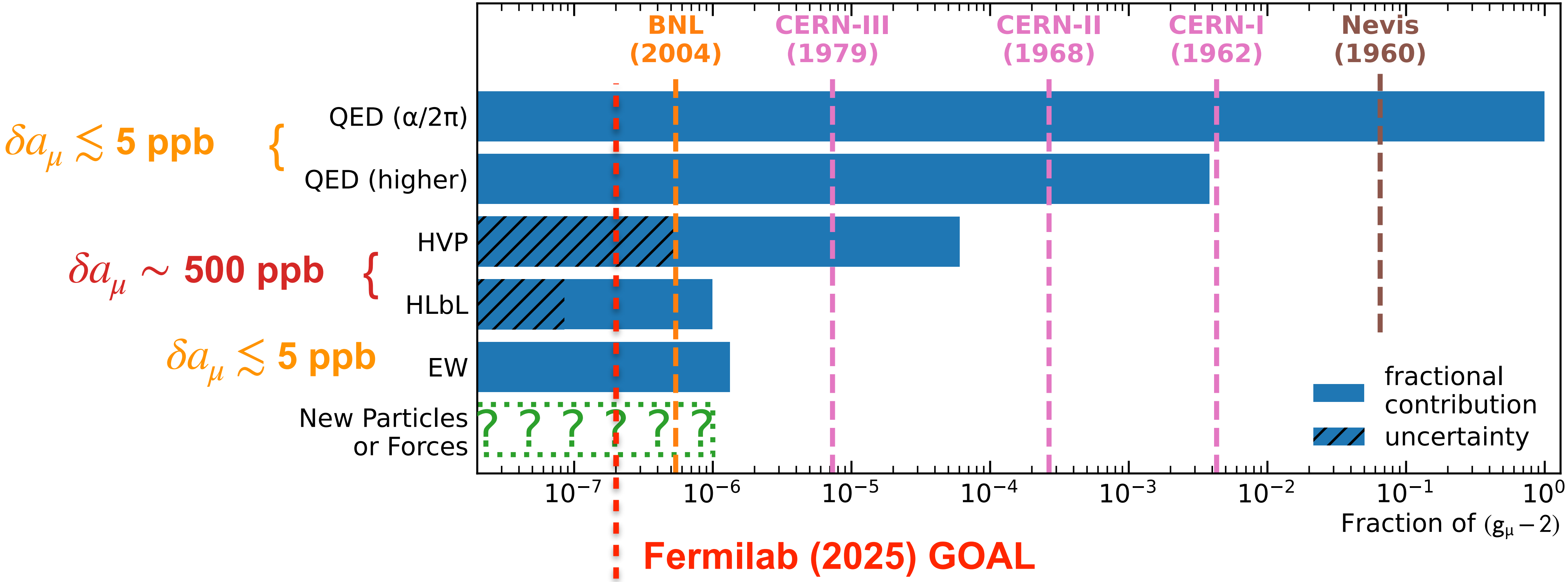
$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HVP} + a_\mu^{HLbL} \approx 0.0012$$



See Massimo's talk

SM Prediction of Anomaly

The **Muon g−2 Theory Initiative** provide a consensus SM prediction for a_μ , to be compared with experiment. https://muon-gm2-theory.illinois.edu/



- The hadronic effects are estimated from **Data-driven dispersive** and **Lattice QCD** **(major uncertainties)**
- The Fermilab experimental precision is improving over time, **goal is to achieve 140 ppb!**

Principle of g-2 Measurement

1. **Injects polarized muons** into a storage ring, circulated the ring at **cyclotron frequency** in a uniform magnetic field B:

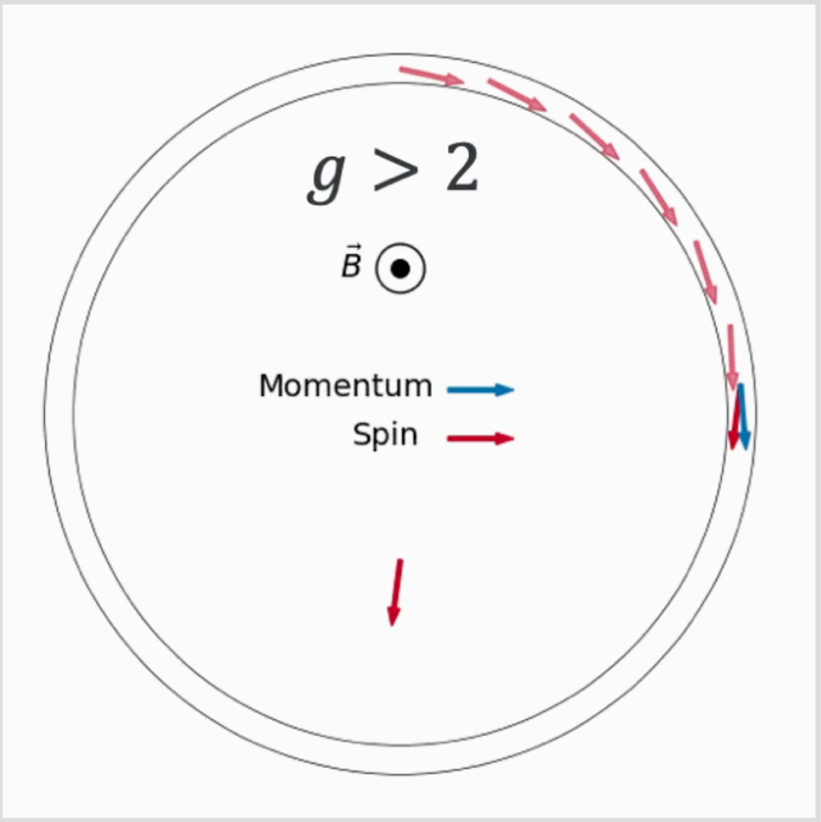
$$\omega_c = \frac{e}{m_\mu c} B$$

2. While muons are stored, its spin precesses slightly faster than its momentum, this precession rate, aka **anomalous precession frequency**:

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

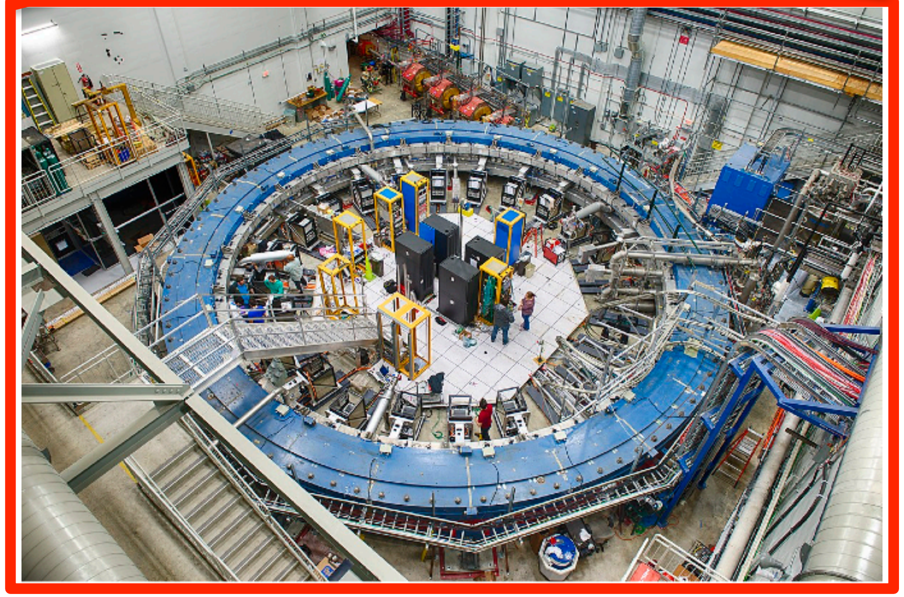
3. Muon anomaly can be extracted by measuring B, and ω_a from the decayed positrons:

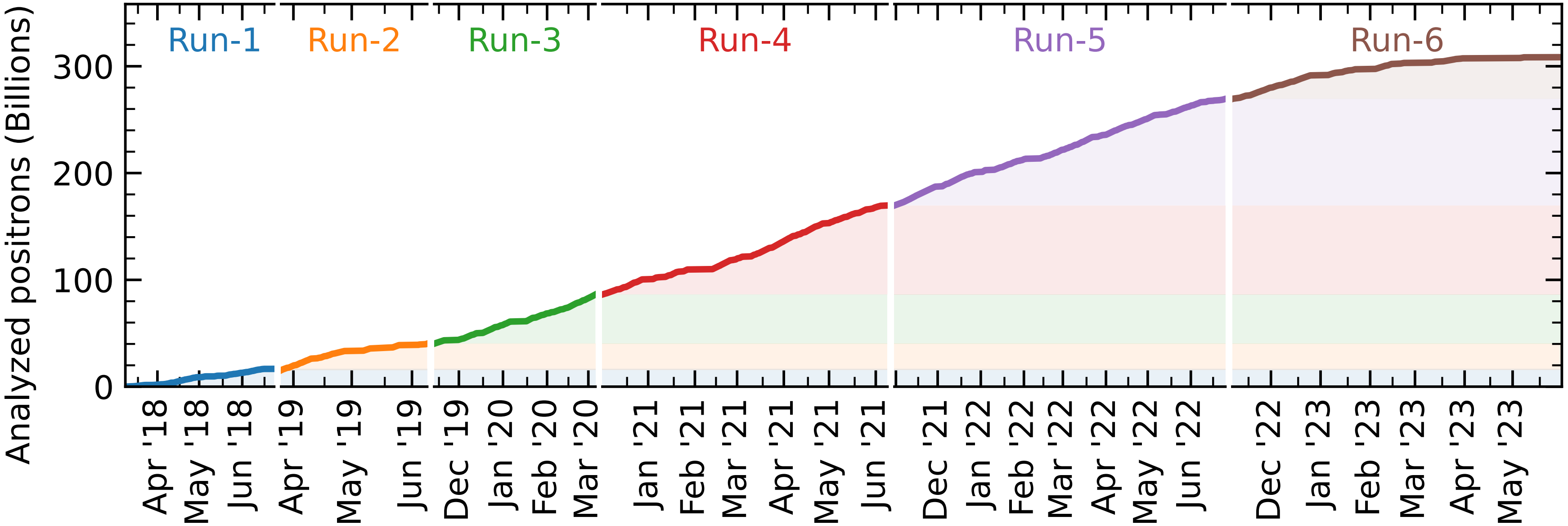
$$\omega_a = a_\mu \frac{e}{m_\mu c} B$$



The Goal: Measures ω_a and B as precise as possible!

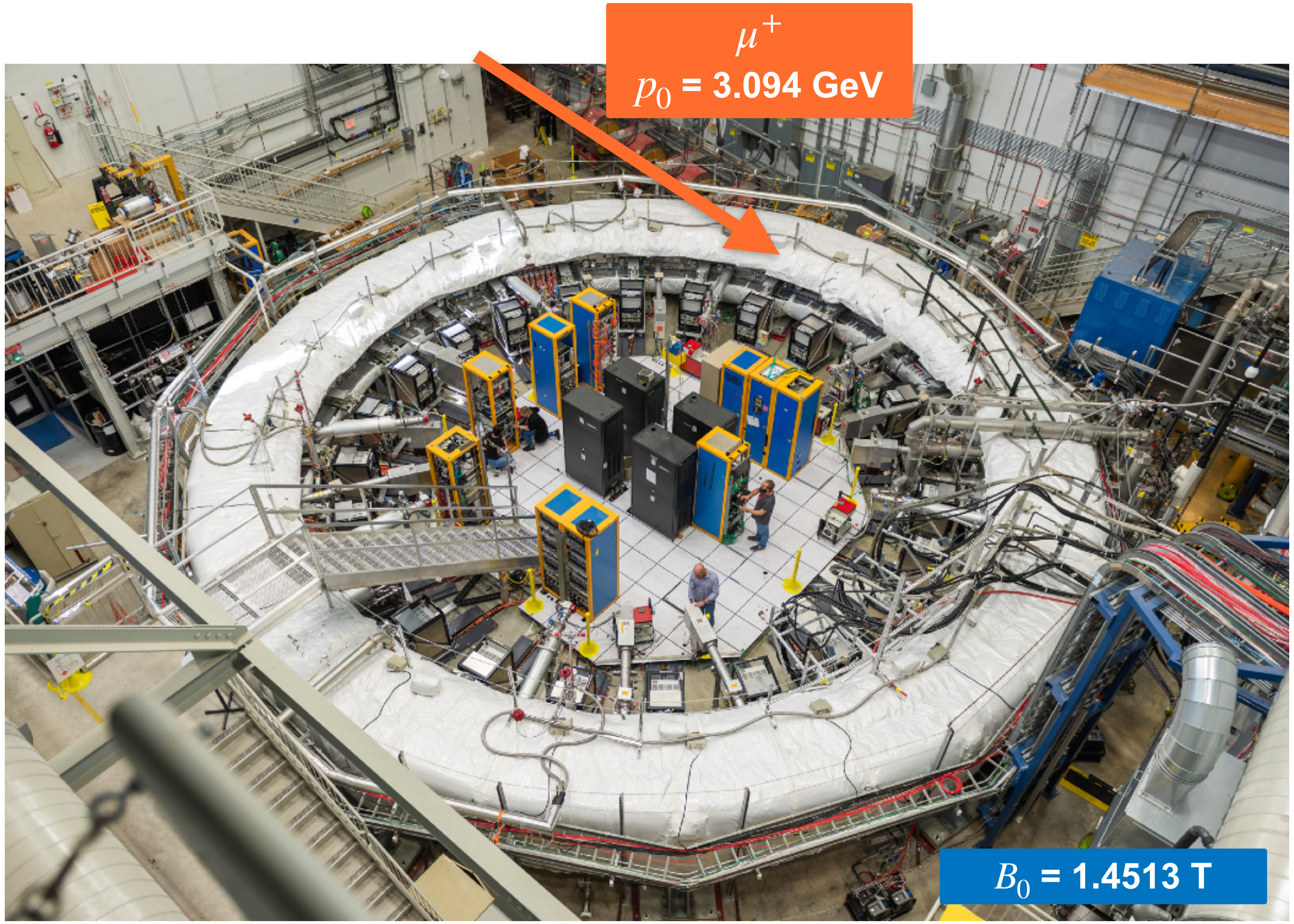
Fermilab Muon g-2 Experiment



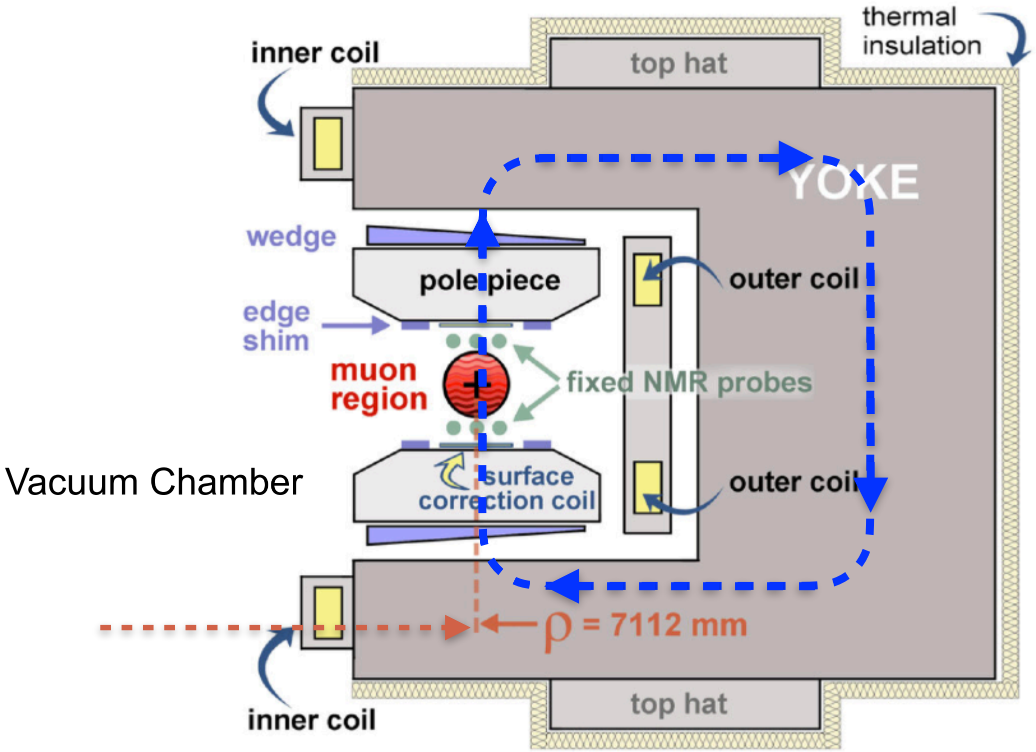


- Data collected over 6 years +, resulted in 6 Run
- Muon g-2 result was announced using
  - **April 2021** : Run-1 PRL 126, 141801 (2021)
  - **August 2023** : Run-2/3 PRL 131, 161802 (2023)
  - **June 2025** : Run-4/5/6 arXiv:2506.03069 PRL (2025) Accepted
- The final dataset has **2.6 times** more data than previous datasets.

Muon Storage: Dipole Magnet

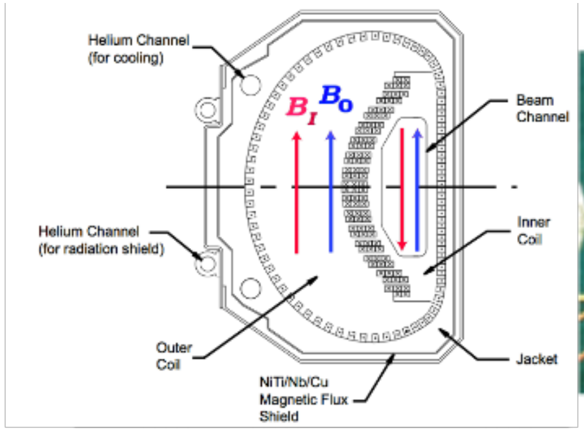


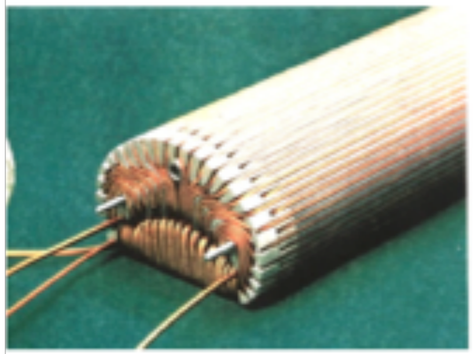
Field uniformity is important!



- **Dipole magnet** provides vertical and uniform magnetic field for radial confinement.
- C-shaped yoke to allow decay positrons inward towards the center of the ring.

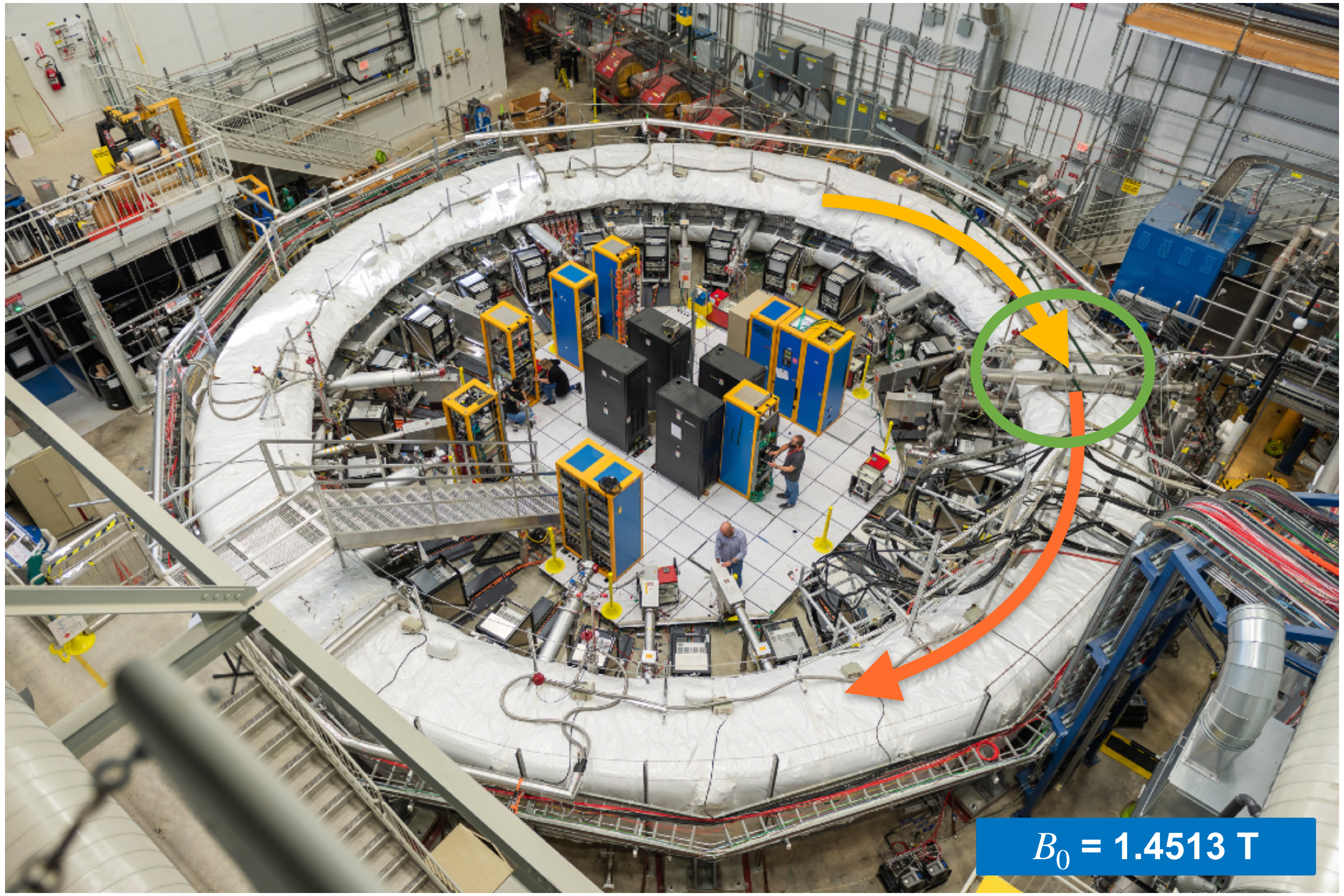
Muon Storage: Inflector

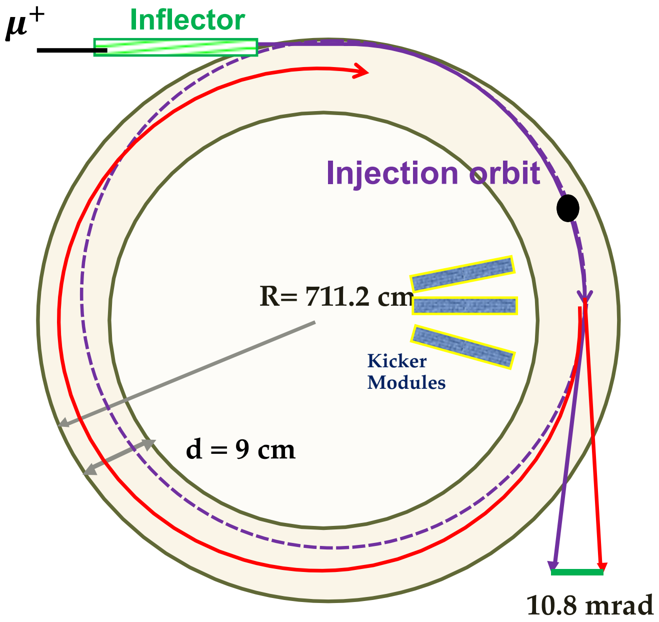


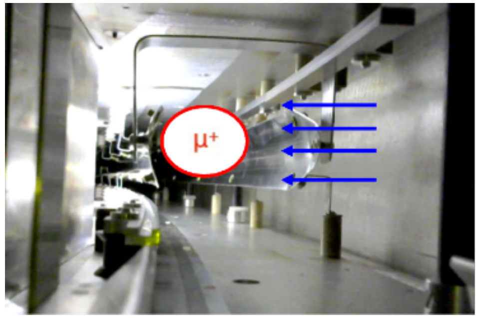


- **Inflector magnet** provide field free region (cancel B_0) in the magnet gap, for muon to enter the ring.
- The superconducting magnet is located at r = 77 mm outside of central closed orbit.

Muon Storage: Kicker

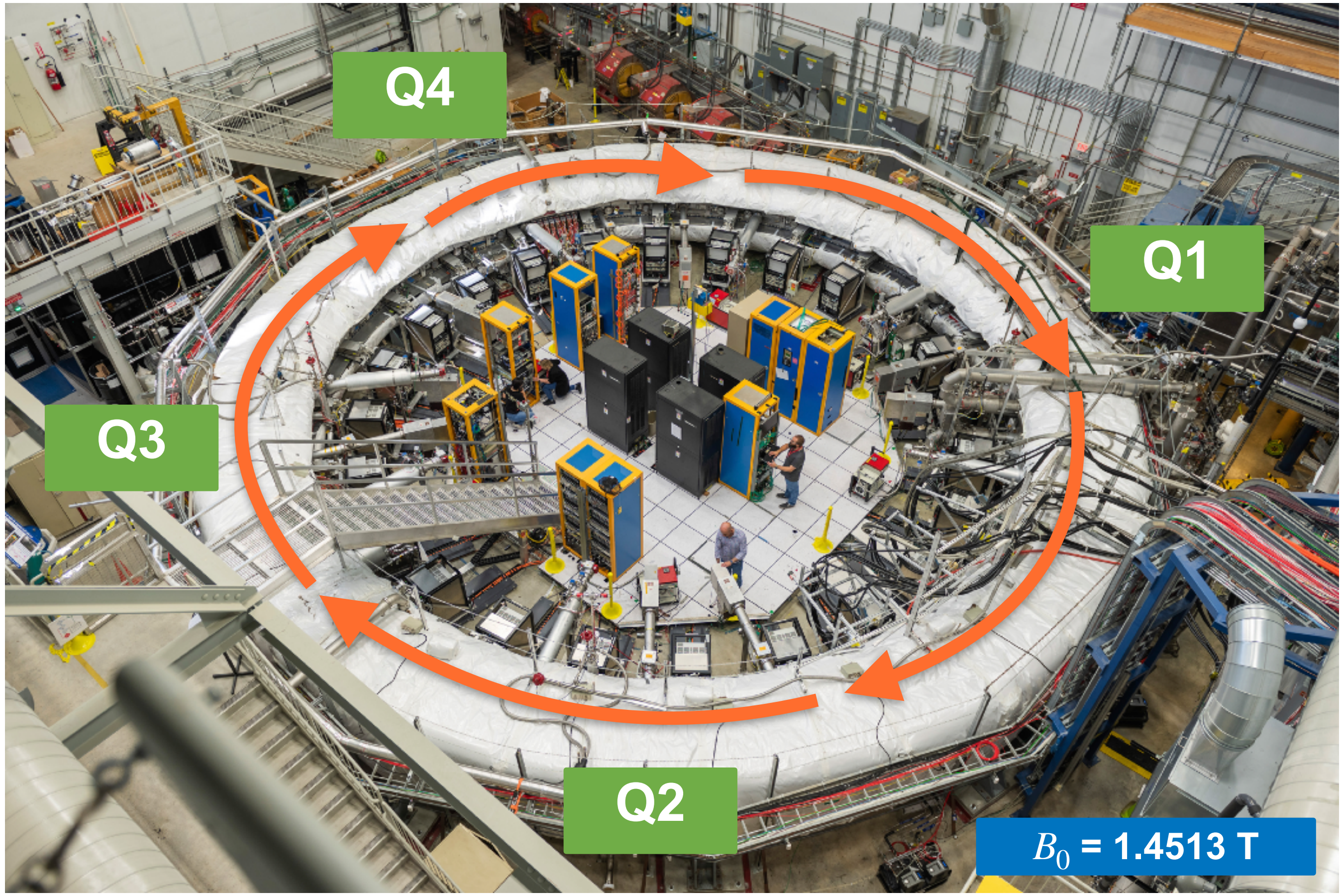


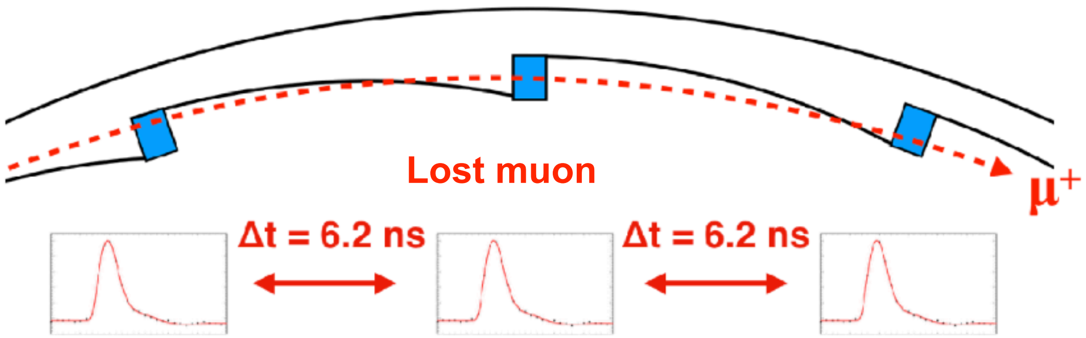


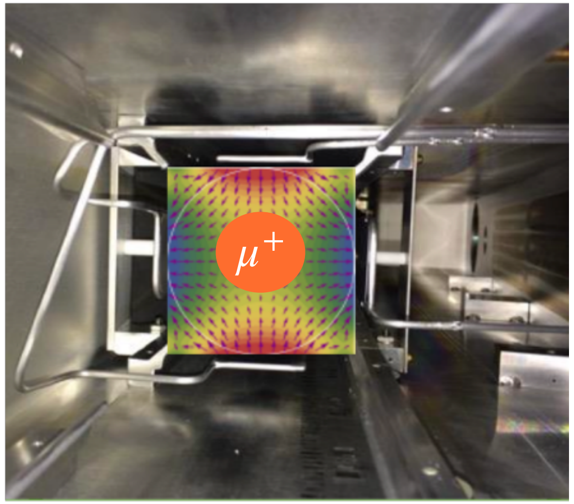


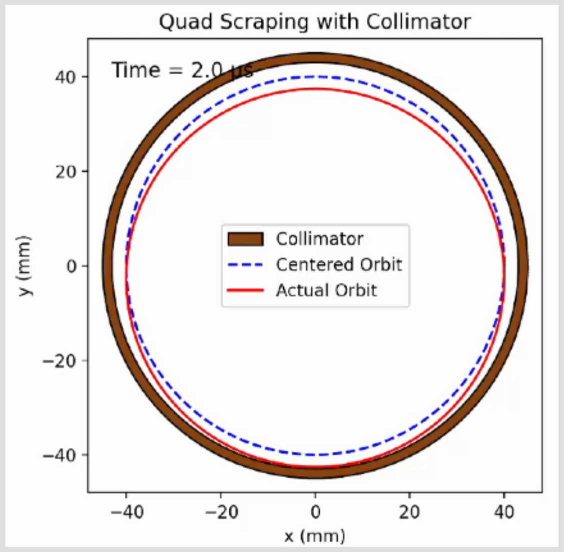
- **Kicker magnet** provides 10.8 mrad pulse kick (<149 ns), to offset the injected muons, centering the muons into ideal orbit.

Muon Storage: ESQ





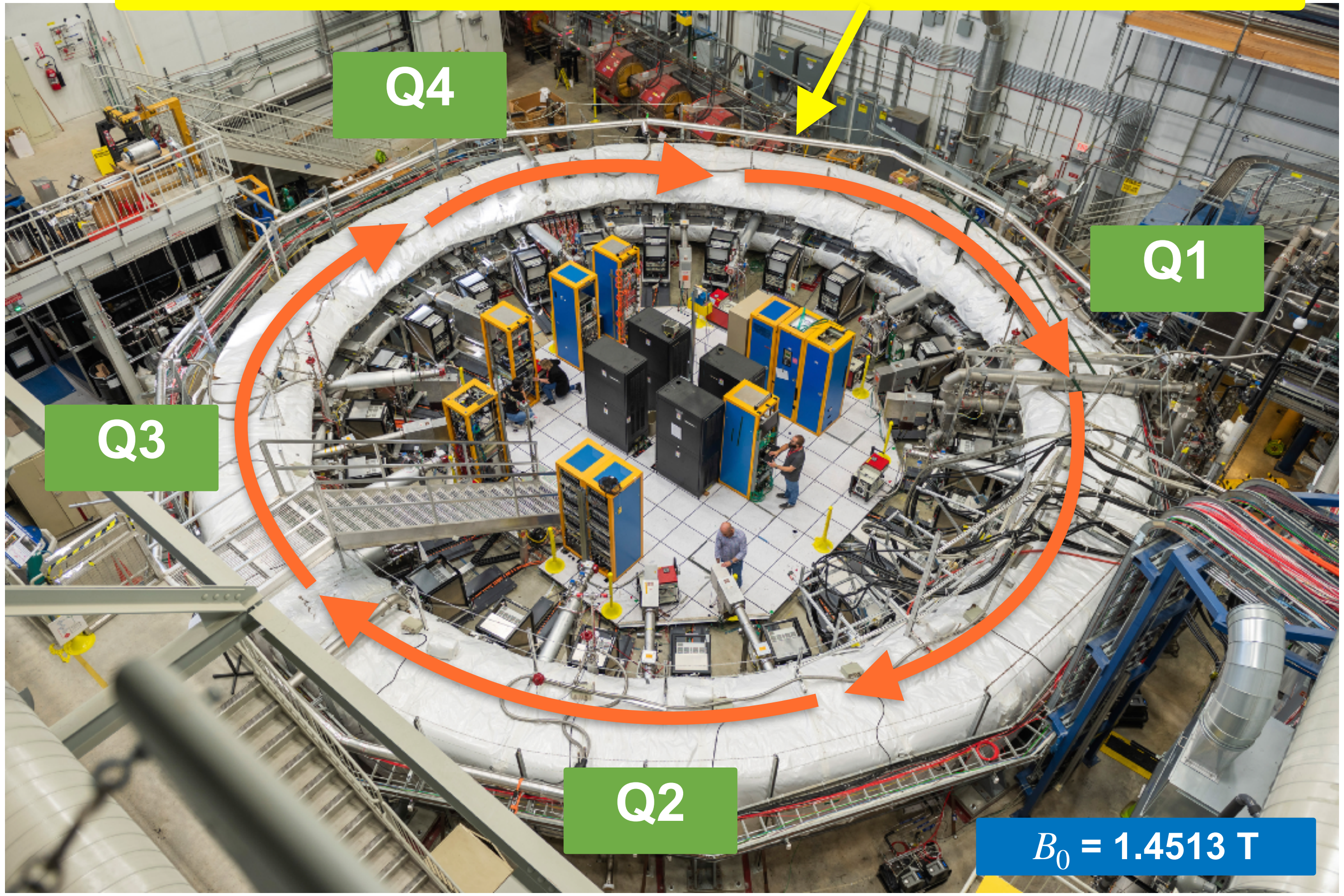


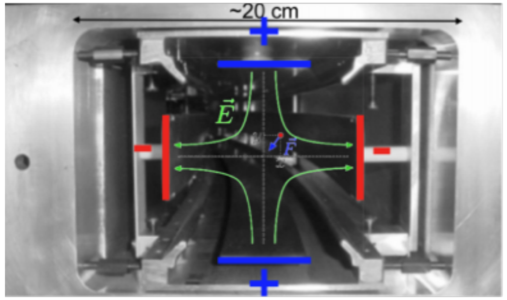


- Uses 4 **Electrostatic Quadrupoles** (quad) to provide vertical focusing.
- Scraping beam to reduce **muon lost rate (edge muon)**

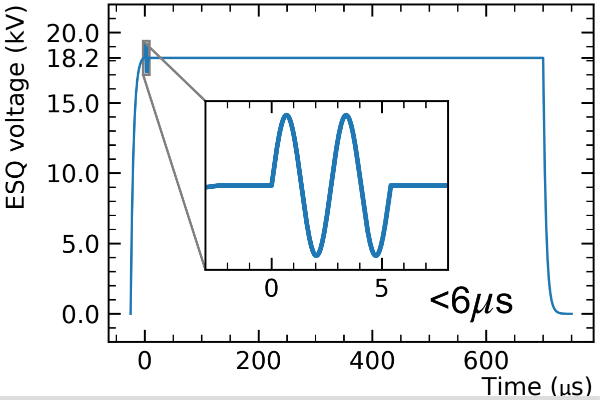
Muon Storage: RF-Matching

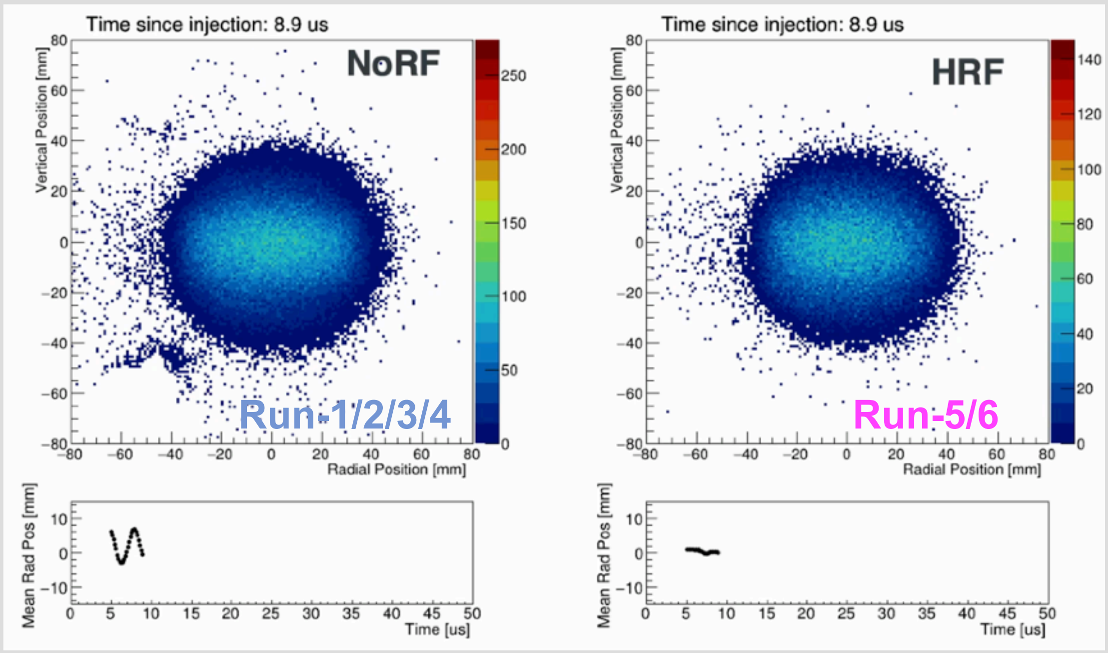
Mismatch between incoming beam phase space and storage acceptance, causes Coherent Betatron Oscillation (CBO)





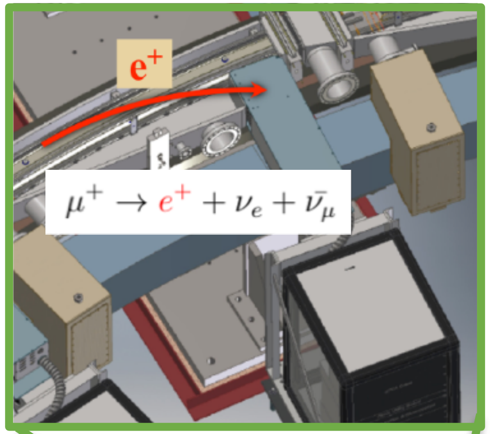
non−ferromagnetic materials

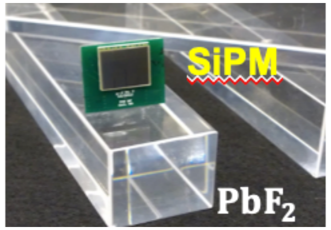




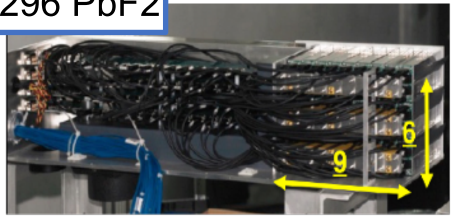
- The **RF voltage** was superimposed to the quad voltage (Run5/6).
- Introduce small modulation (~1kV) to ESQ voltage, to resonantly dampen CBO.

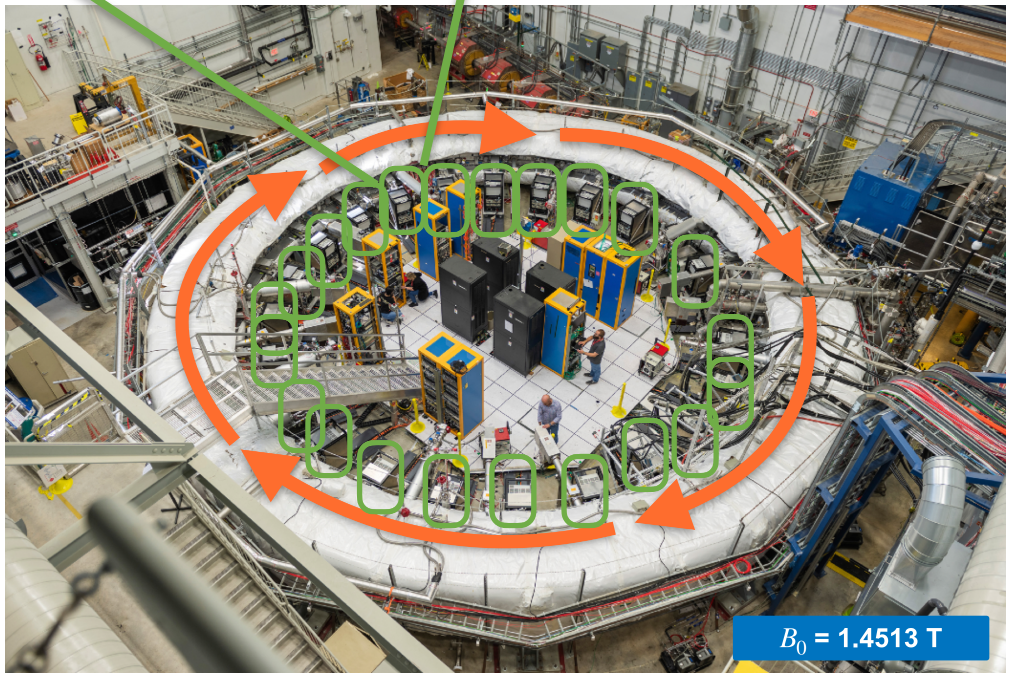
Muon Decay Measurement : Calorimeters





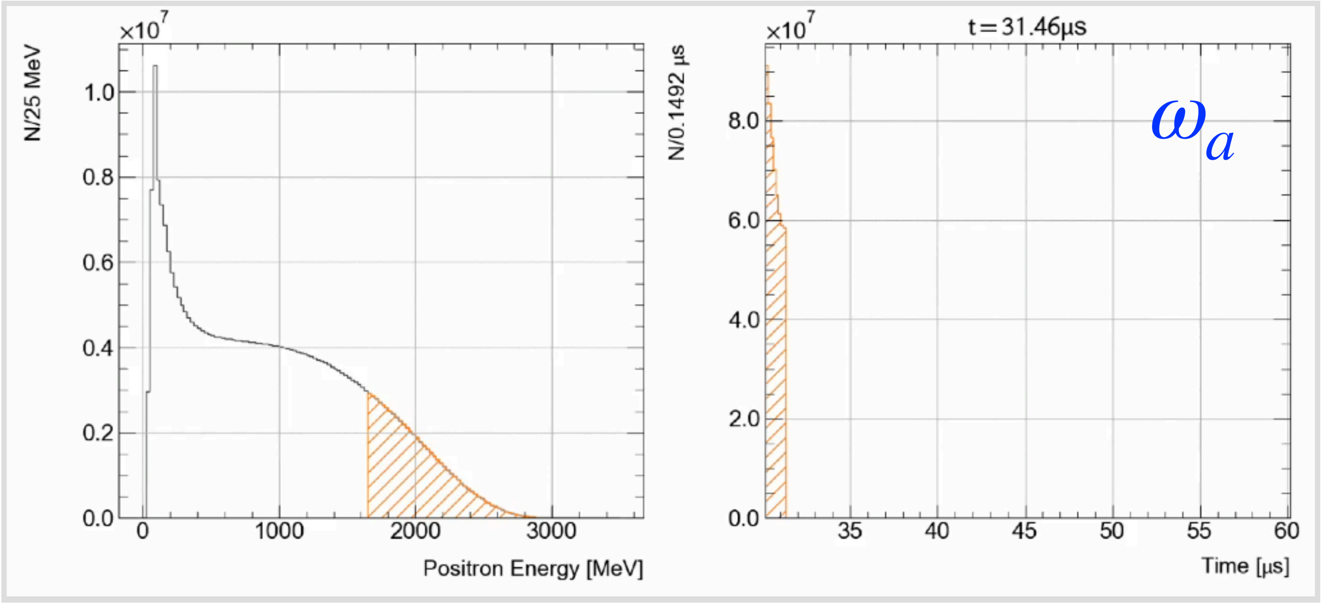
1296 PbF2



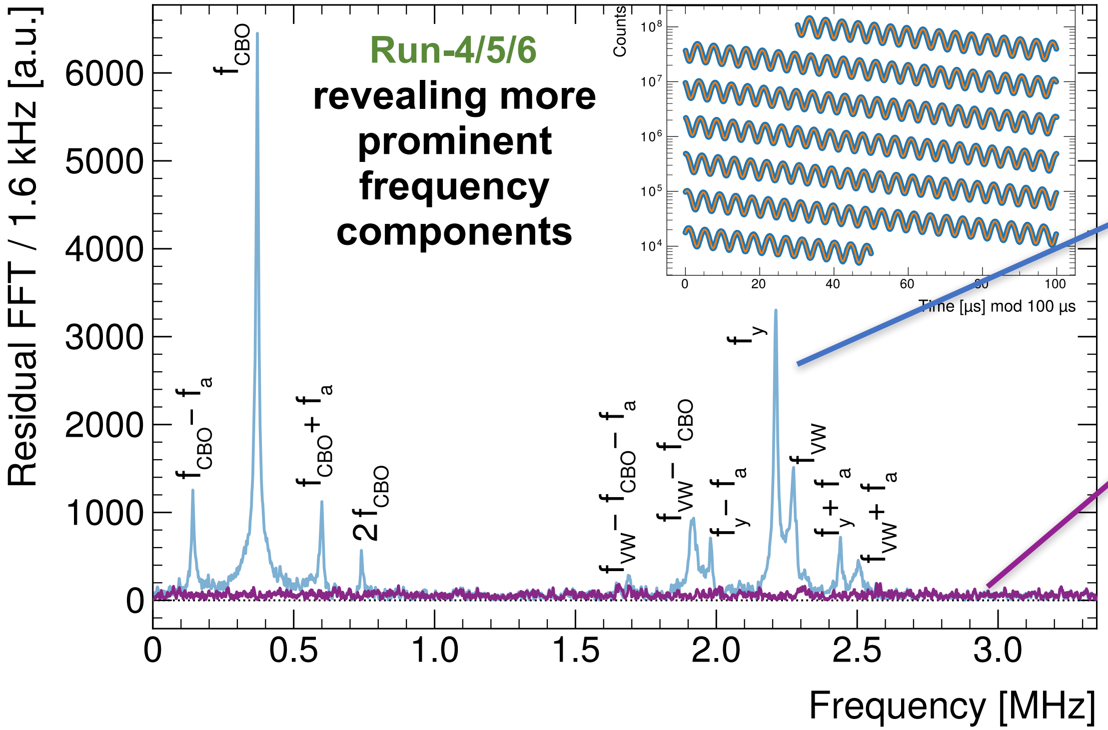


- **Calorimeters** (x24) around the ring measures the **energy** and the **arrival time** of the **positrons** decay from stored muons.
- Parity violation causes **high-energy** e^+ counts **oscillate** as spin point **towards** and **away** from the calorimeters.
- The ω_a can be readily extracted by fit to the high-energy e^+ arrival time:

$$N = N_0 e^{t/\tau_\mu} \left[1 + A\cos(\omega_a t + \phi)\right]$$



Spin Precession Frequency



Simplest form with only decay and g-2 oscillation

$$N = N_0 e^{t/\tau_\mu}\left[1 + A\cos(\omega_a t + \phi)\right]$$

Full form with beam (muon lost, CBO) and detector effects

$$N_0 e^{-\frac{t}{\gamma\tau}}\left(1 + A \cdot A_{BO}(t)\cos(\omega_a t + \phi \cdot \phi_{BO}(t))\right) \cdot N_{CBO}(t) \cdot N_{VW}(t) \cdot N_y(t) \cdot N_{2CBO}(t) \cdot J(t)$$

$$A_{BO}(t) = 1 + A_A\cos(\omega_{CBO}(t) + \phi_A)e^{-\frac{t}{\tau_{CBO}}}$$

$$\phi_{BO}(t) = 1 + A_\phi\cos(\omega_{CBO}(t) + \phi_\phi)e^{-\frac{t}{\tau_{CBO}}}$$

$$N_{CBO}(t) = 1 + A_{CBO}\cos(\omega_{CBO}(t) + \phi_{CBO})e^{-\frac{t}{\tau_{CBO}}}$$

$$N_{2CBO}(t) = 1 + A_{2CBO}\cos(2\omega_{CBO}(t) + \phi_{2CBO})e^{-\frac{t}{2\tau_{CBO}}}$$

$$N_{VW}(t) = 1 + A_{VW}\cos(\omega_{VW}(t)t + \phi_{VW})e^{-\frac{t}{\tau_{VW}}}$$

$$N_y(t) = 1 + A_y\cos(\omega_y(t)t + \phi_y)e^{-\frac{t}{\tau_y}}$$

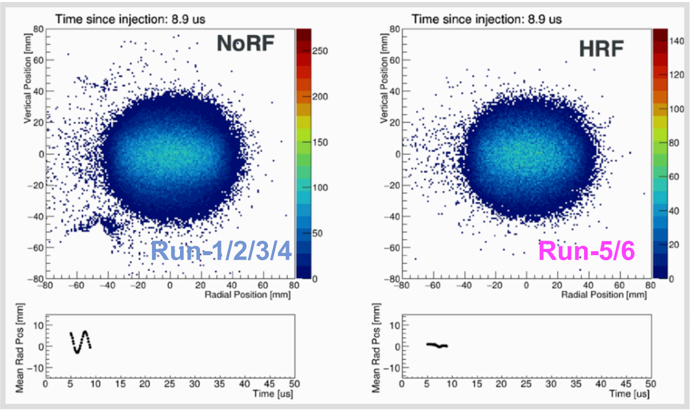
$$J(t) = 1 - k_{LM}\int_{t_0}^{t}\Lambda(t)dt$$

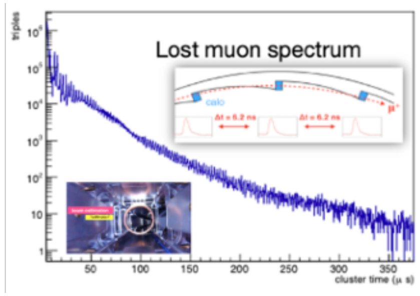
$$\omega_{CBO}(t) = \omega_0 t + Ae^{-\frac{t}{\tau_A}} + Be^{-\frac{t}{\tau_B}}$$

$$\omega_y(t) = F\omega_{CBO(t)}\sqrt{2\omega_c/F\omega_{CBO}(t) - 1}$$

$$\omega_{VW}(t) = \omega_c - 2\omega_y(t)$$

- The CBO effects account for:
  - **noRF: ~ 800 ppb!**
  - **With RF : ~ 90 ppb**

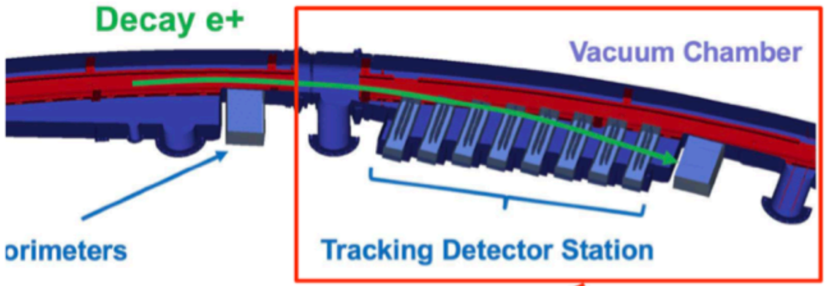


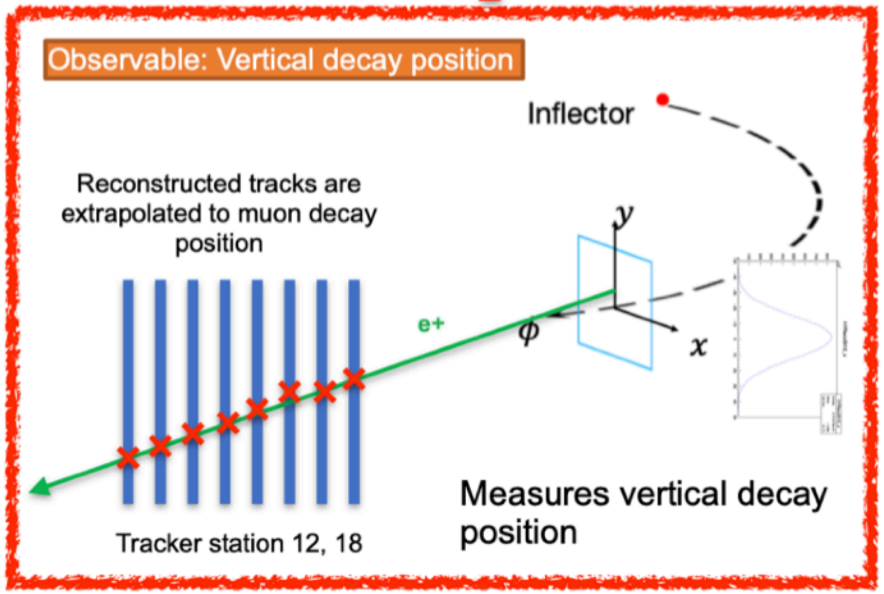


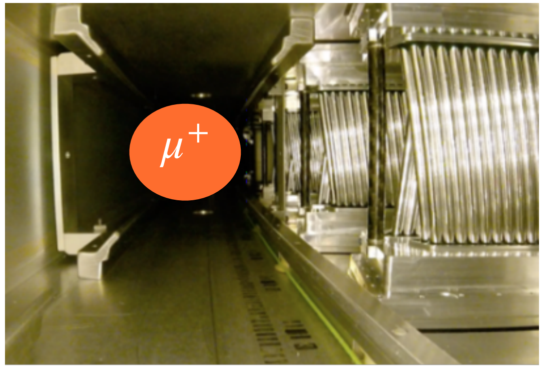
Effects were modeled with 40+ additional parameters in the final fit!

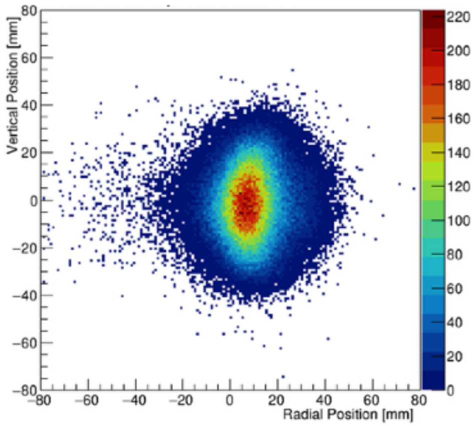
Red: free parameter
Blue: fixed parameter

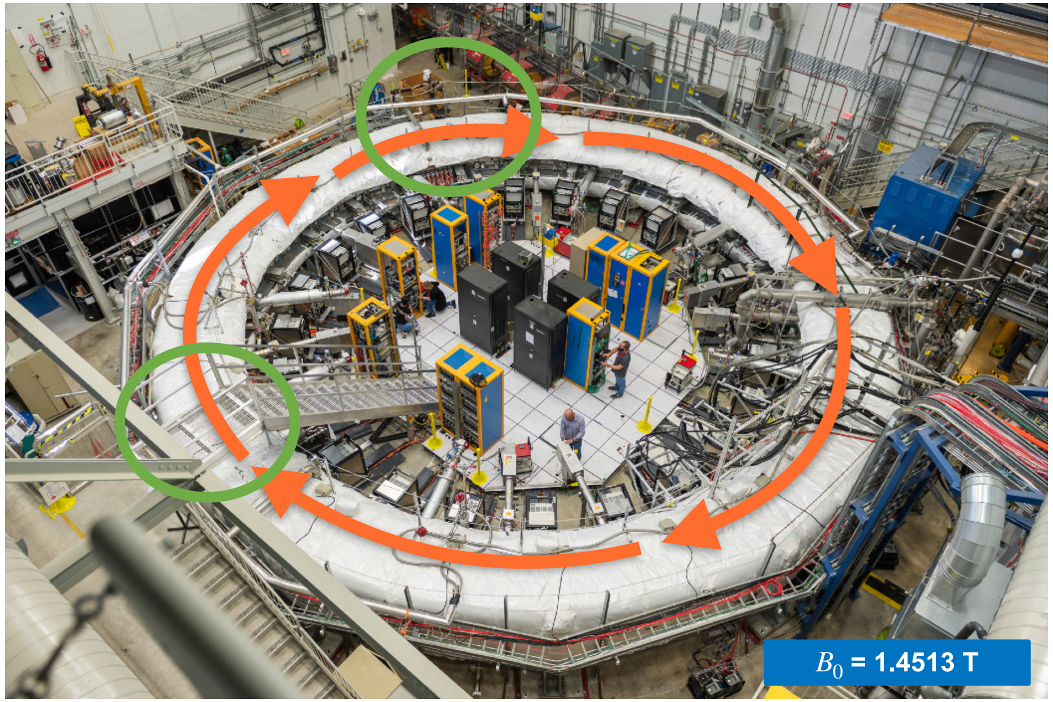
Muon Profile Reconstruction: Straw Trackers







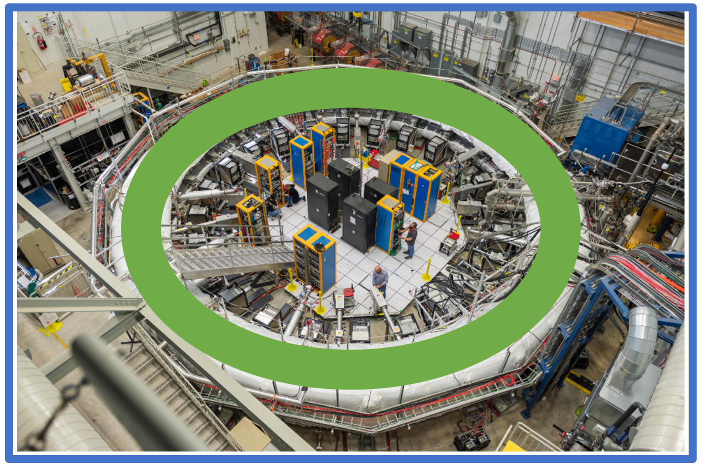




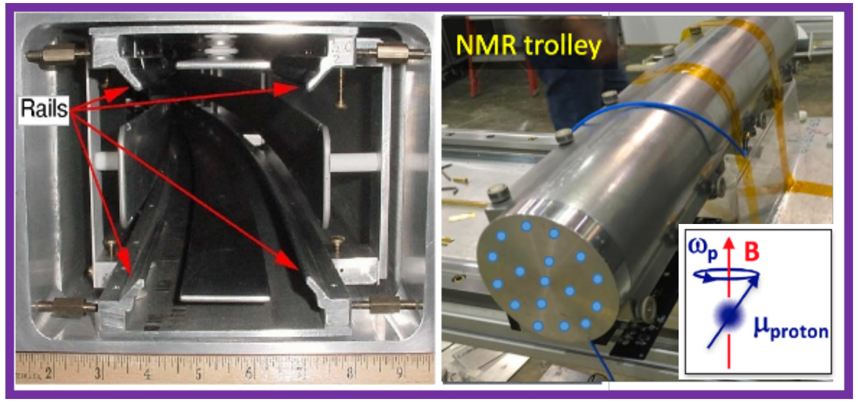
- Reconstructing muon beam profile from the **positron trajectories**:
  - Used for Beam Dynamics corrections.
  - Used to weight the measured magnetic field.

- **Tracker** station (x2) used, 8 modules per station (128 straws).

B Field Measurement : NMR Probe

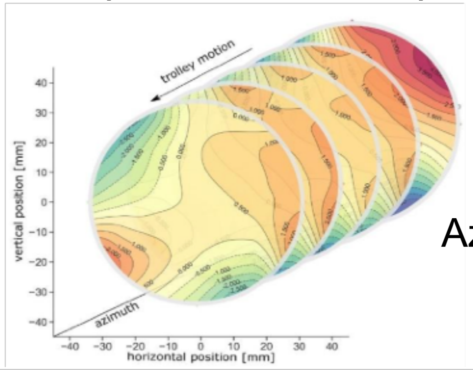


378 **Fixed Nuclear Magnetic Resonance (NMR) Probe** to monitor field. (w/o Beam time).

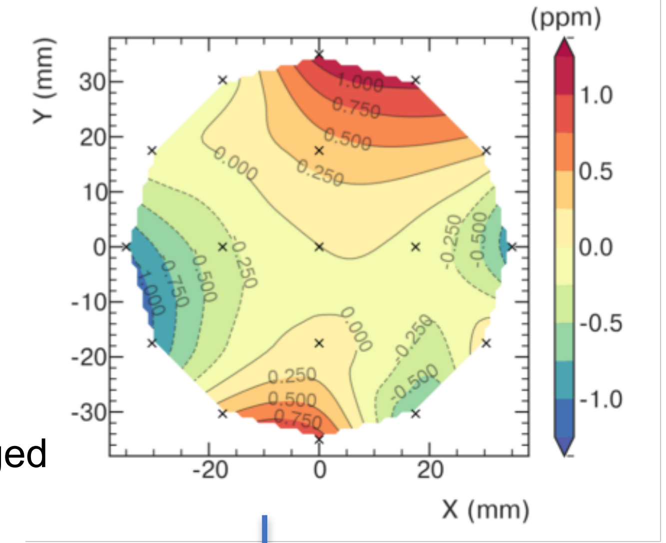


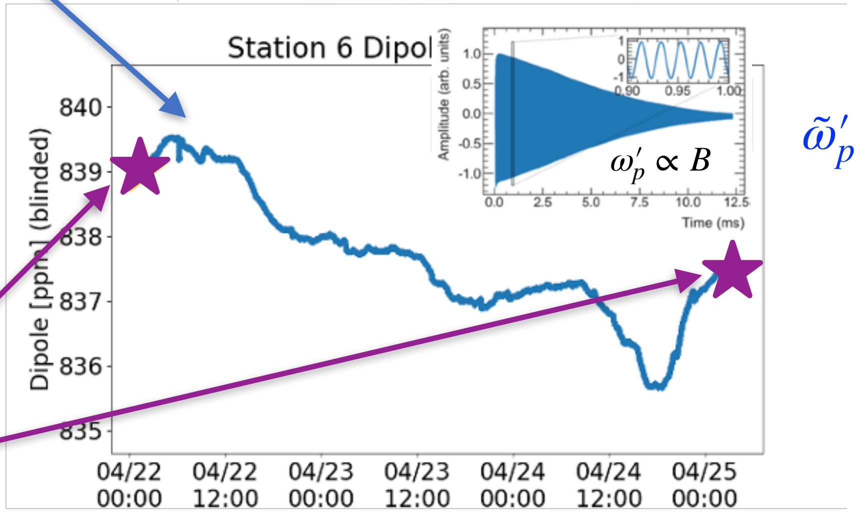
17 **Mobile NMR Probe** circles around the ring to map the field (no beam, every 3 days), totaling ~ 100km!

2D field map, ~ 9000 slides per scan



Azimuthally averaged

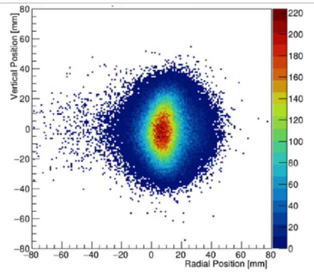


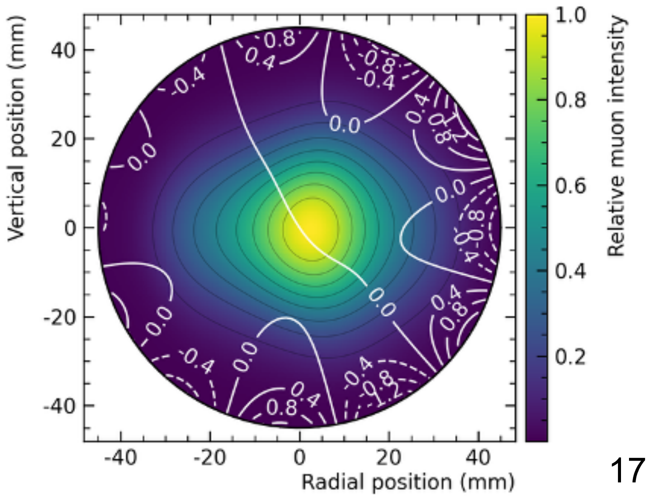


Fixed probe's field interpolates trolley's field

Weighted with muon distribution

$$\tilde{\omega}'_p = < \omega'_p \times M >$$



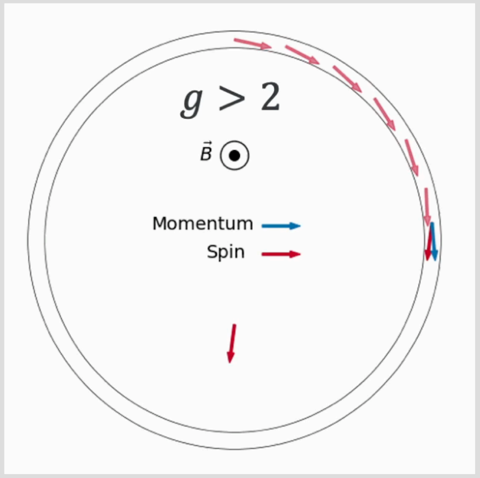


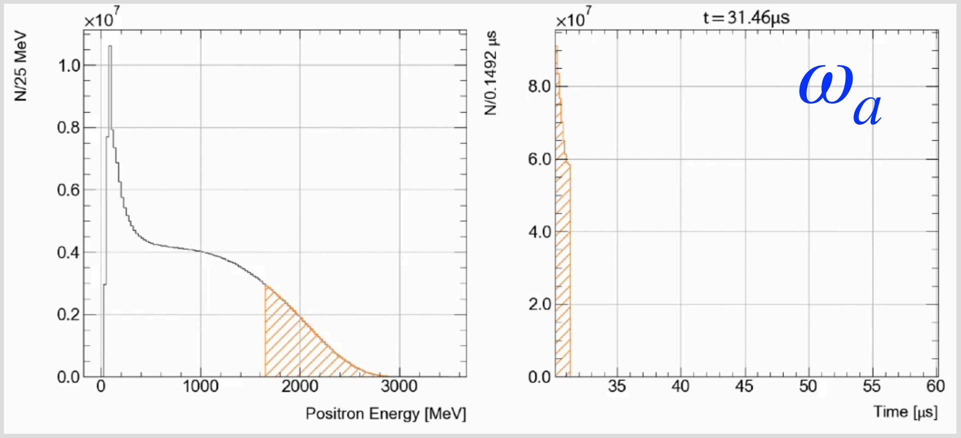
1 ppm field homogeneity !

Measuring the Anomaly

Tsung-Dao Lee Institute

Polarized muon injected with $p_\mu = 3.1$ GeV, $\tau_\mu = 64\mu s$
Storage time: $700\mu s$, expected 5000 muons stored in one fill.

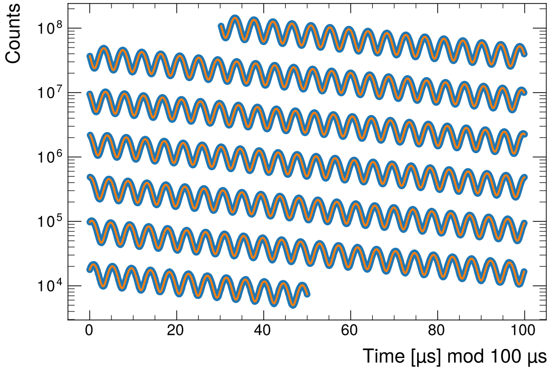


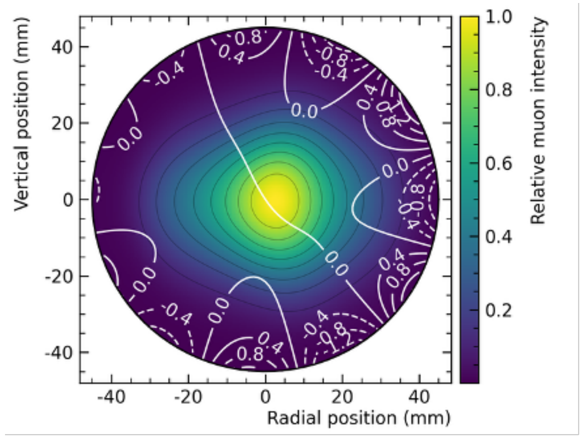


Cancel out contributions due to weakly focusing.(*)

Cancel out contributions due to electric field at magic momentum. (*)

$$\vec{\omega}_a = \frac{e}{m_\mu}\left[a_\mu \vec{B} - a_\mu\left(\frac{\gamma}{\gamma+1}\right)\left(\vec{\beta}\cdot\vec{B}\right)\vec{\beta} + \left(a_\mu - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right]$$





External factors known to be 22 ppb

$$a_\mu = \frac{\omega_a}{\tilde{\omega}'_p}\frac{\mu'_p}{\mu_B}\frac{m_\mu}{m_e}$$

However, one need to account for corrections due to systematic effects

Corrections and Systematics

TSUNG-DAO LEE INSTITUTE

Beam dynamics

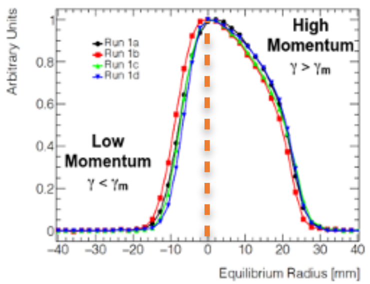
$$a_\mu \sim R'_\mu = \frac{\omega_a}{\tilde{\omega}_p{}'(T)} = \frac{\omega_a^m \cdot \left(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml}\right)}{< \omega'_p \cdot M > \cdot \left(1 + B_k + B_q\right)}$$

Transient field

Electric Field, C_e (*)

Due to finite Δp_μ around magic momentum.

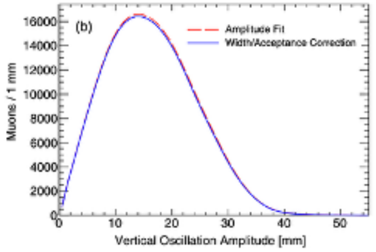
$$C_e \approx 2n(1-n)\beta_0^2 \frac{\langle x_e^2 \rangle}{R_0^2}$$



Pitch, C_p (*)

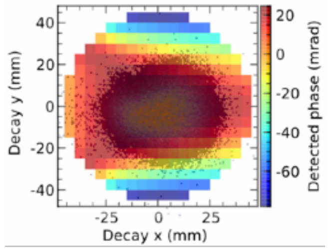
Non-zero vertical betatron oscillation

$$C_p \approx \frac{n}{2}\frac{\langle y^2 \rangle}{R_0^2} = \frac{n}{4}\frac{\langle A^2 \rangle}{R_0^2}$$



Phase Acceptance, C_{pa}

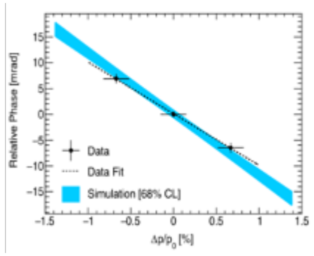
Non-zero correlation between decayed positrons and ϕ_0



Differential Decay, C_{dd}

Low/high p_μ causes short/longer lifetime, causes $\Delta\phi$ over time.

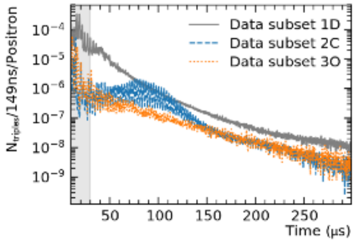
$$\frac{d\langle\phi\rangle}{dt} = \frac{d\langle\phi\rangle}{d\langle p\rangle}\left(\frac{d\langle p\rangle}{dt}\right)_{dd} \approx \frac{d\phi}{d\delta}\frac{1}{\gamma_0\tau_\mu}\sigma_\delta^2$$



Muon Lost, C_{ml}

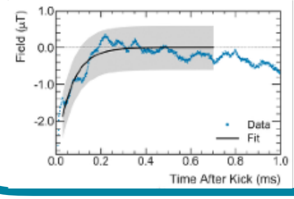
Low p_μ muon tend to be lost, Δp_μ causes $\Delta\phi$ over time.

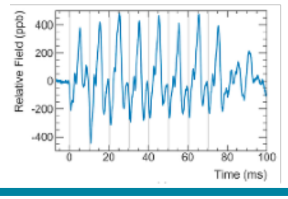
$$\frac{d\langle\phi\rangle}{dt} = \frac{d\langle\phi\rangle}{d\langle p\rangle}\left(\frac{d\langle p\rangle}{dt}\right)_{lm}$$



Transient Field, B_k, B_q

Kicker field causes eddy current; quad pulsing causes mechanical vibration.

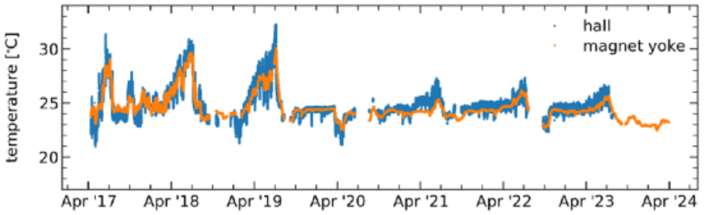


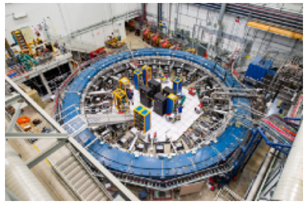


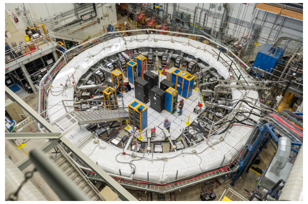
Overall Improvements (selected)

RUN-2/3 onwards
RUN-4/5/6 onwards
RUN-5/6 onwards

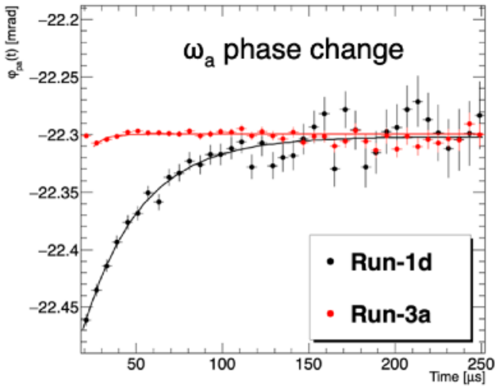
Hall/Ring temperature stabilized





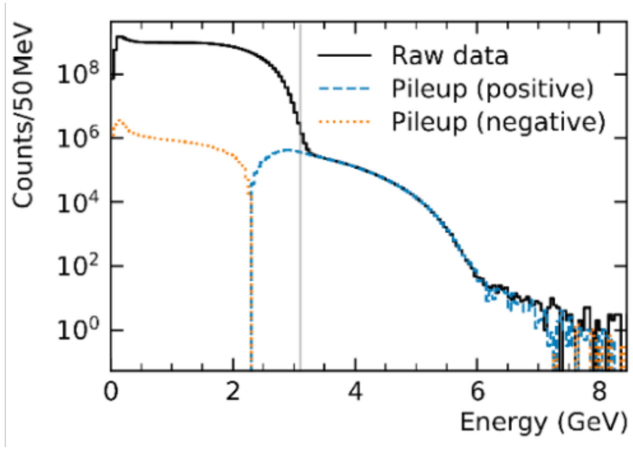


Fixed fail HV resistor in quad

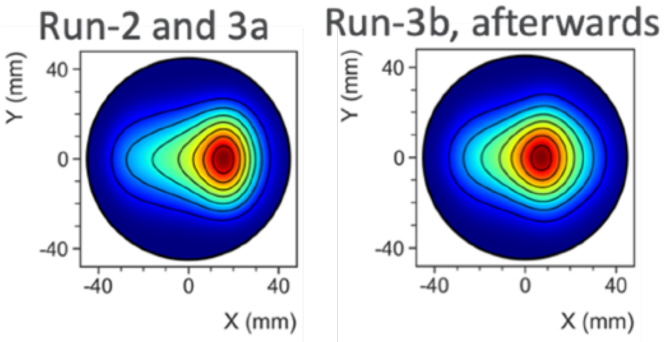


- Stable beam
- Smaller C_{pa}
- Smaller C_{ml}

Improved pileup reconstruction

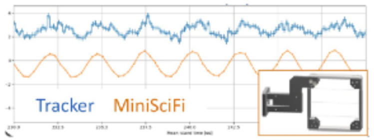


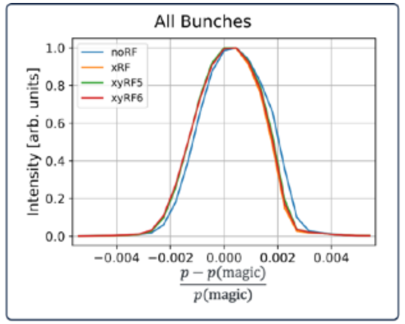
Stronger Kick



- More center beam
- Higher homogeneity
- Better measures C_e

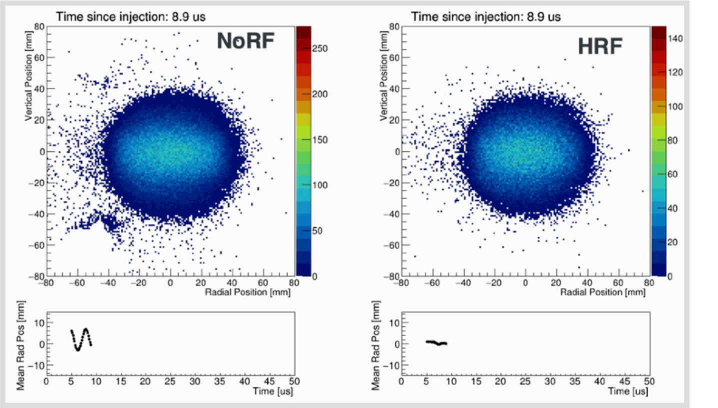
Additional Measurement





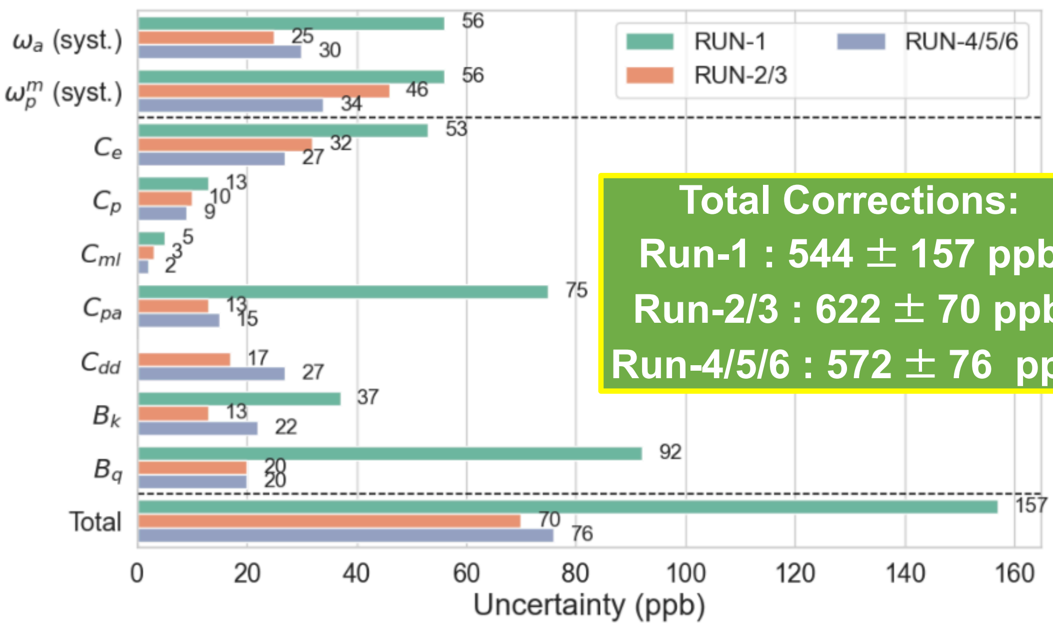
- MiniSciFi was used to cross-check tracker and calorimeter's momentum distribution measurements

RF matching



- Reduces ~ x9 times CBO

Corrections and Systematics



Total Corrections:
Run-1 : 544 ± 157 ppb
Run-2/3 : 622 ± 70 ppb
Run-4/5/6 : 572 ± 76 ppb

Beam dynamics

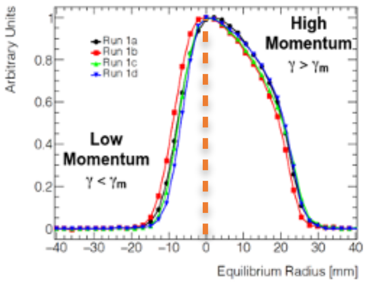
$$R'_\mu = \frac{\omega_a}{\tilde{\omega}_p{}'(T)} = \frac{\omega_a^m \cdot \left(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml}\right)}{< \omega'_p \cdot M > \cdot \left(1 + B_k + B_q\right)}$$

Transient field

Electric Field, C_e (*)

Due to finite Δp_μ around magic momentum.

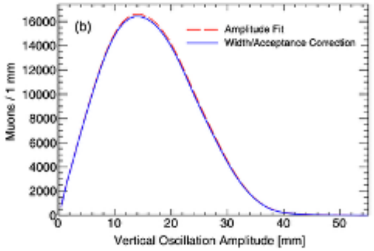
$$C_e \sim 350 \text{ ppb}$$



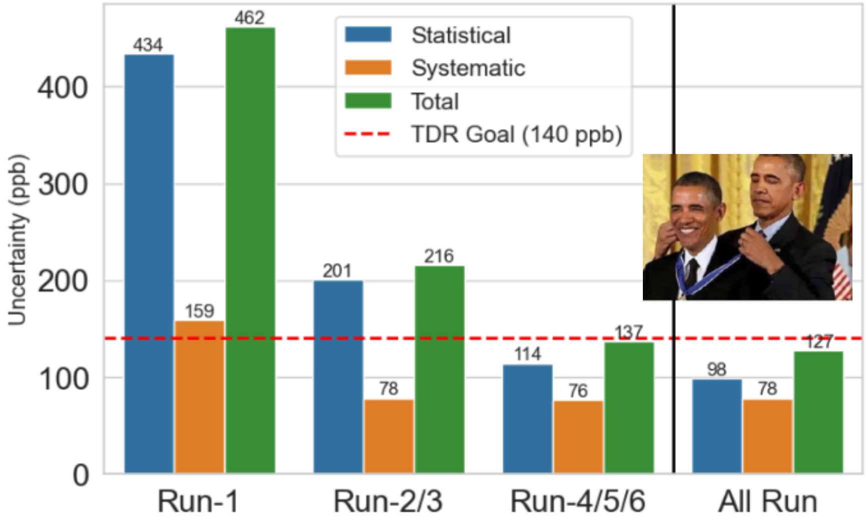
Pitch, C_p (*)

Non-zero vertical betatron oscillation

$$C_p \sim 170 \text{ ppb}$$



$$C_{pa} + C_{dd} + C_{ml} \sim 30 \text{ ppb}$$

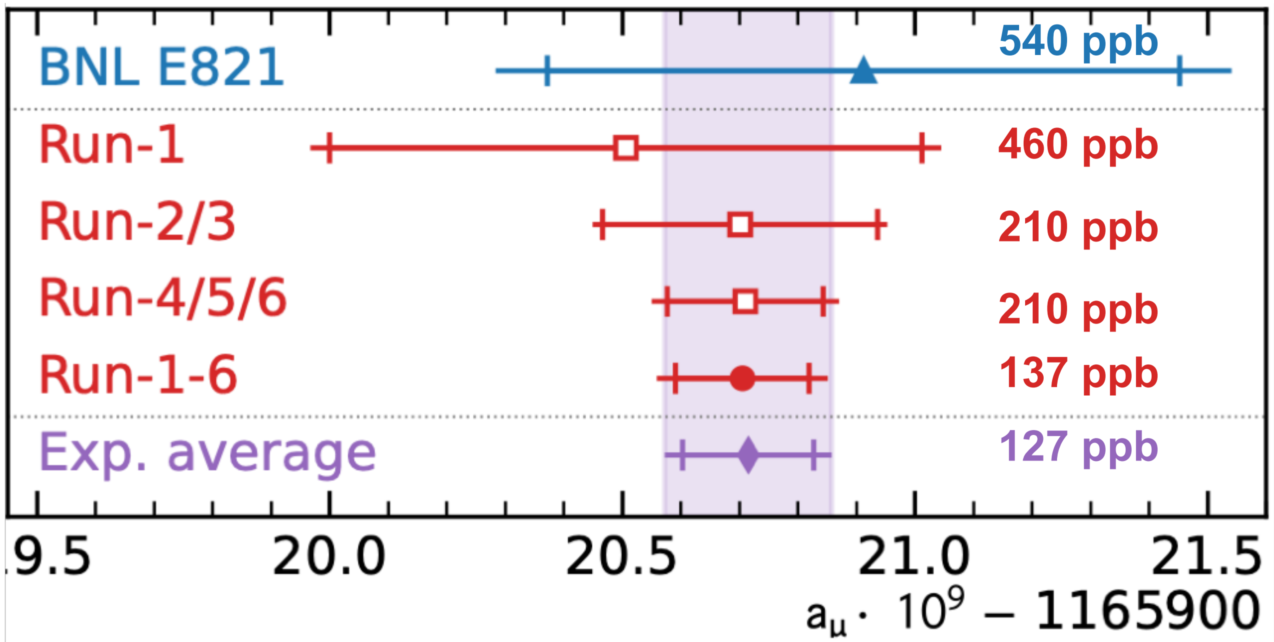


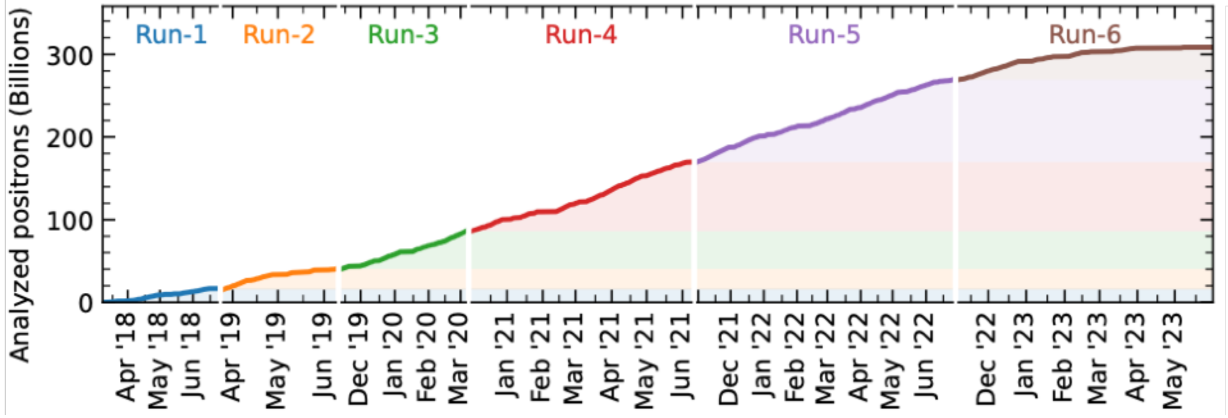
1. Largest corrections come from Electric field and pitch effects.
2. Uncertainties contribute equally to total error.
3. **Combined uncertainties surpassed total TDR precision goal of 140 ppb!**

Muon g-2 Final Results

Tsung-Dao Lee Institute

Phys. Rev. D 73, 072003 (2006)





- Fermilab results are in excellent agreement to the BNL E821.
- Run-2/3 result halved the uncertainty of Run-1.
- Run-4/5/6 reduced uncertainty by another x**1.8.**
- Combined average reduces the uncertainty by 4.3, compares to BNL E821.
- **The Fermilab result is the most precise measurement of a_μ.**

a_μ(**Run-4/5/6**) = **0.001165920710 (162)**

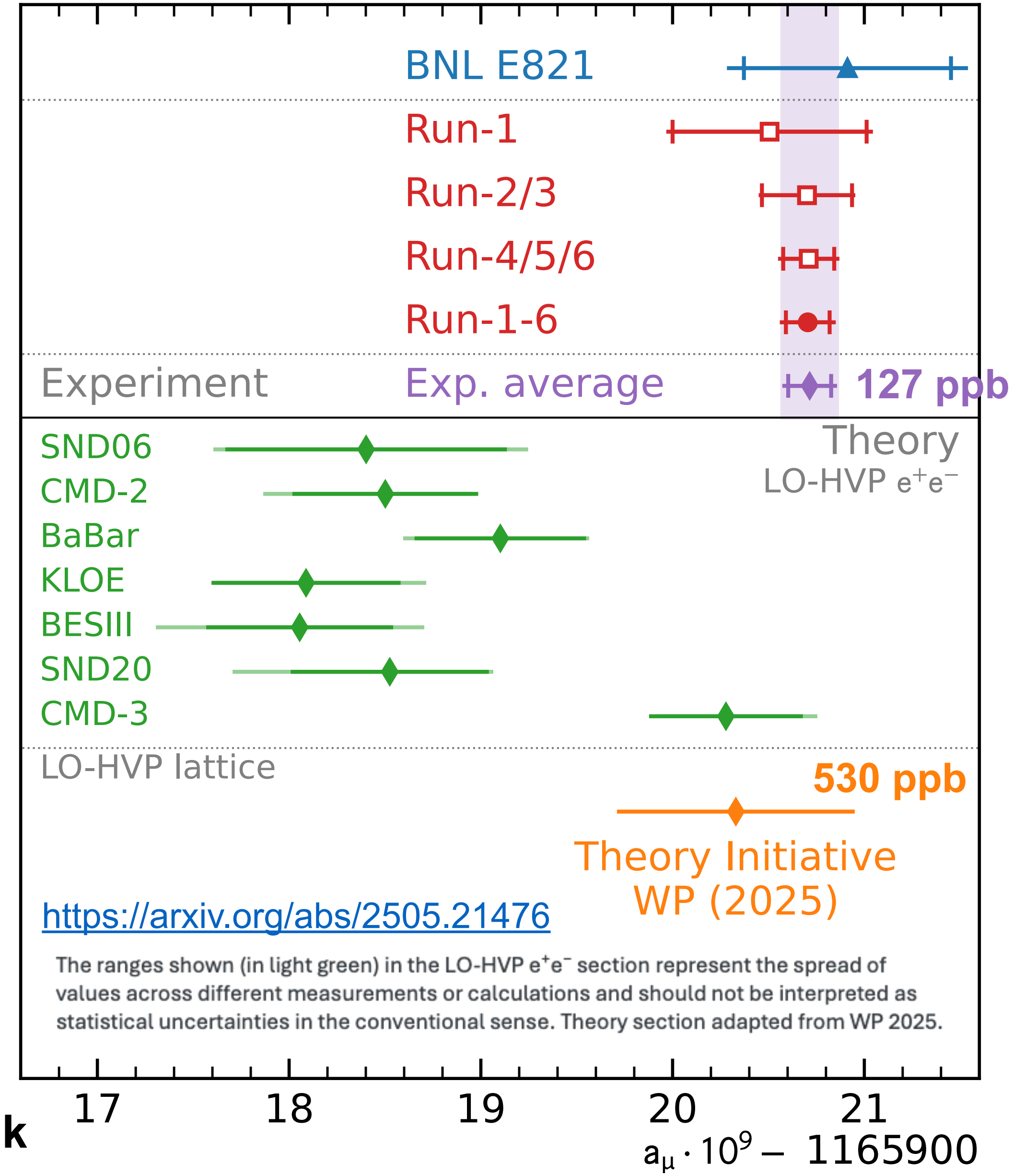
a_μ(**Run-1-6**) = **0.001165920705 (148)**

arXiv:2506.03069 PRL (2025) Accepted

Theory Initiative 2025 SM Prediction

Tsung-Dao Lee Institute

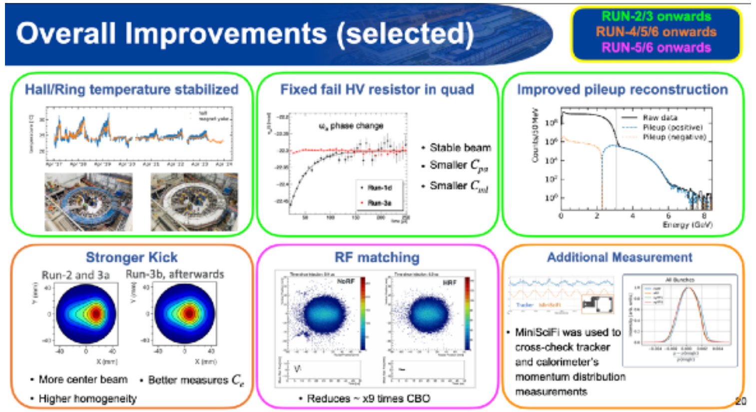
- **White Paper 2020 (WP2020)** : compilation of data-driven dispersive methods (20 years+): CMD-3 is in tension with previous evaluations.
- **WP2025** exclusively compiled Lattice-QCD results:
  - Hadronic effects:
    - **HVP (520 ppb)**
    - HLbL (85 ppb)
  - **No significant discrepancy with experiment at this precision.**
- **However, long standing tension between data-driven and Lattice-CQD exists.**

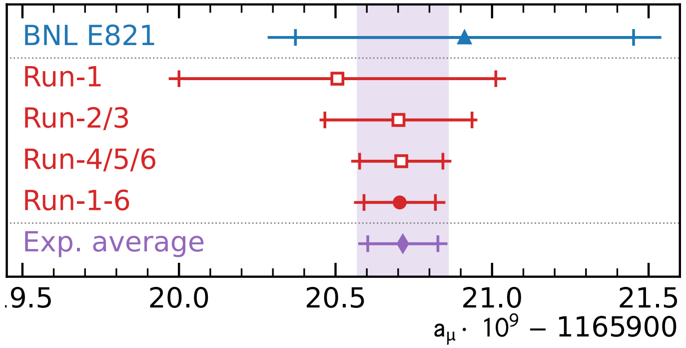


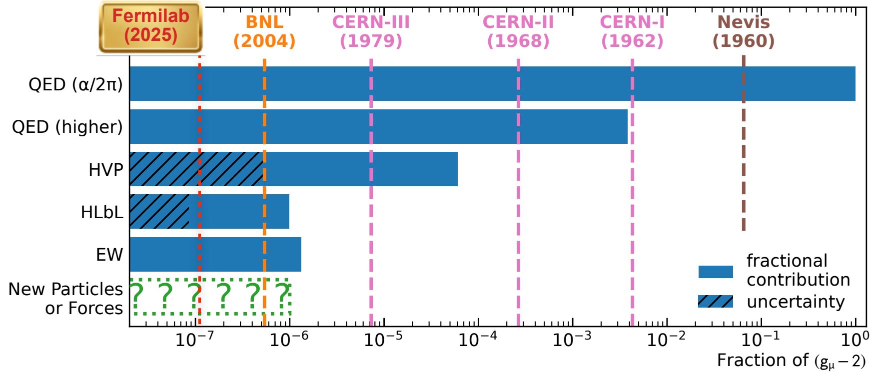
For more detail, see Massimo's talk

Conclusion and Outlook

Fermilab announced final result with record precision!!





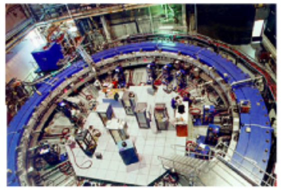


PRL (2025) Accepted   arXiv:2506.03069

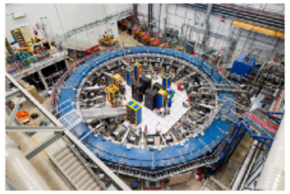
Benchmark for new models with new particles of forces (BSM)

J-PARC g-2 Experiment

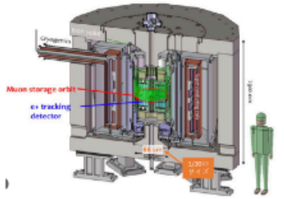
CERN
1960s - 1976
7.3 ppm
COMPLETED



BNL
1990s - 2001
0.54 ppm
COMPLETED



FNAL
2009 - 2023
0.14 ppm
COMPLETED

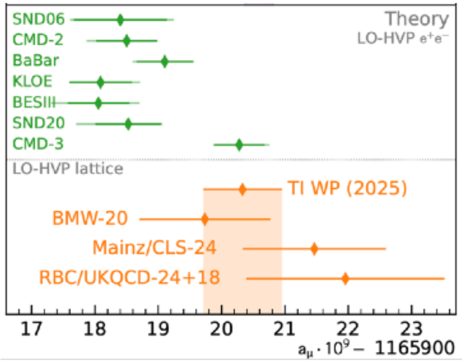


J-PARC
2009 - 2030s
0.45 ppm
UNDER CONSTRUCTION

See Gerco's talk

Theory initiative

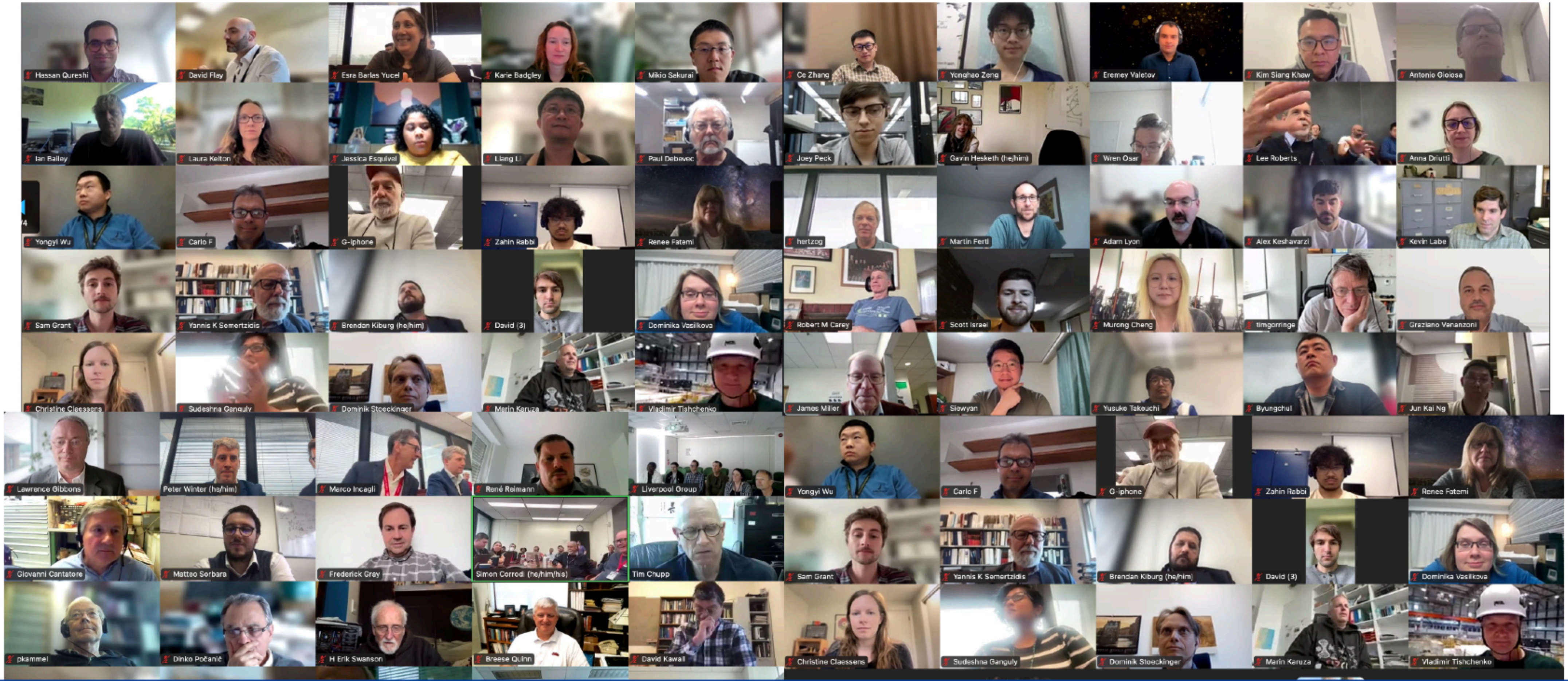
Improve HVP precision:
- long-distance, isospin.
- e^+e^- and τ new input.
- Space-like HVP (MUonE)



Aim to reduce theory uncertainty by x4 to test SM

Eur. Phys. J. C 77, 139 (2017)
https://arxiv.org/abs/2505.21476

Thanks For Your Attention!

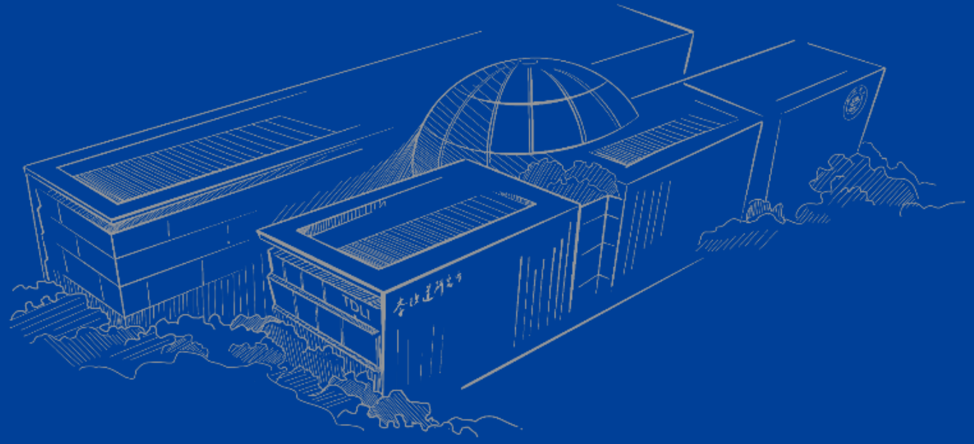


The Muon g-2 Collaboration:

176 collaborators, 34 institutes, 7 countries

Particle-, Nuclear-, Atomic-, Optical-, Accelerator-, and Theoretical-Physicists and Engineers

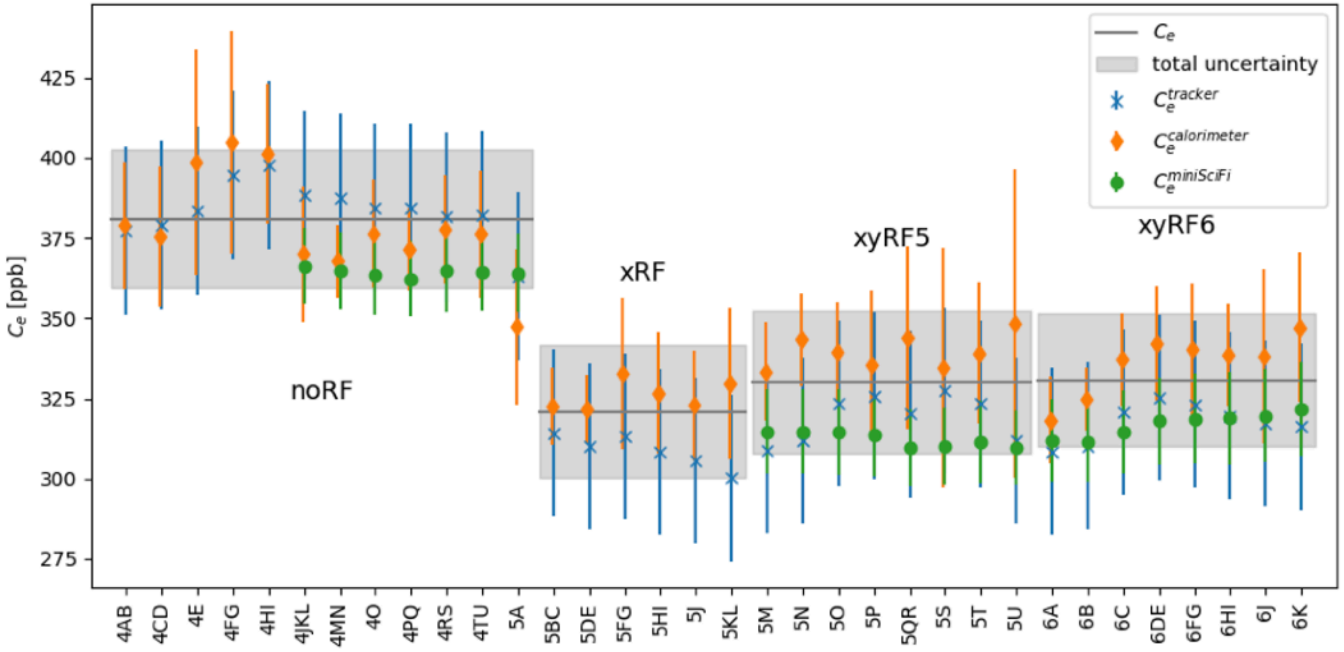
Backup

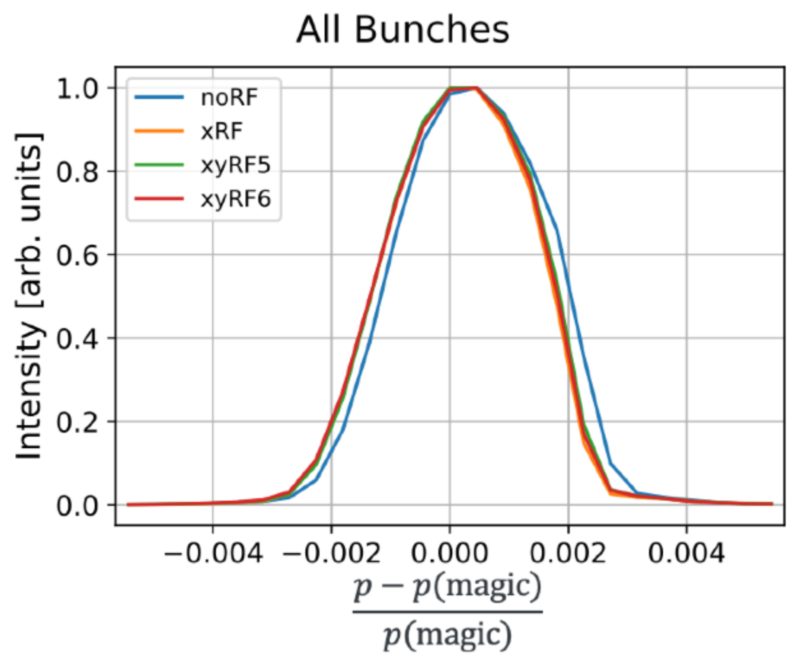


C_e Corrections

Electric-Field Correction: C_e

The **largest** correction





Increased confidence and small reduction of uncertainties to total of **27 ppb.**

Trackers

Parasitic: Dispersion & Beam Dynamics (Improved uncertainties from MiniSciFi)

Calorimeters

Parasitic: Muon Dephasing taking time-in-bunch into account (improved robustness of method)

NEW! Minimally Intrusive Scintillating Fiber Detector (MiniSciFi)

Vertical and Horizontal versions

Dedicated studies: Cross-checks and uncertainty determination (tracker)

RF-Matching

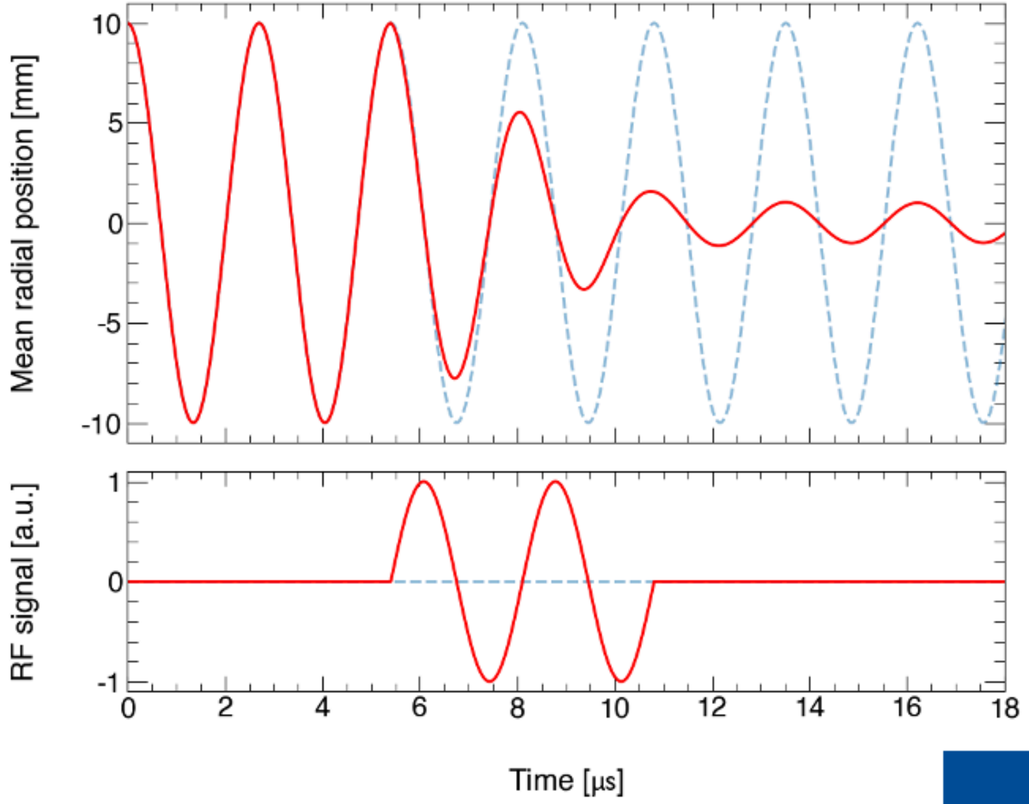


*illustration of the effect

- RF acts like a forced harmonic oscillator (for 6 μs)
- If tuned correctly to the CBO frequency:
  - Phase-shifts different muon distributions
  - Reduces the oscillation of the **mean** of the particle ensemble (reduces the coherence)

Split data into 4 datasets
noRF, xRF, xyRF5, xyRF6

Total Corrections

李政道研究所 TSUNG-DAO LEE INSTITUTE

Quantity	Correction terms (ppb)	Uncertainty (ppb)	
ω_a^m (statistical)	...	434	
ω_a^m (systematic)	...	56	
C_e	489	53	
C_p	180	13	
C_{ml}	−11	5	
C_{pa}	−158	75	
$f_{\text{calib}}\langle\omega_p(x,y,\phi)\times M(x,y,\phi)\rangle$	...	56	
B_k	−27	37	
B_q	−17	92	
$\mu'_p(34.7°)/\mu_e$	...	10	
m_μ/m_e	...	22	
$g_e/2$	...	0	
Total systematic	...	157	**159**
Total fundamental factors	...	25	
Totals	544	462	

[PRL 126, 141801 (2021)]

Quantity	Correction (ppb)	Uncertainty (ppb)	
ω_a^m (statistical)	...	201	
ω_a^m (systematic)	...	25	
C_e	451	32	
C_p	170	10	
C_{pa}	−27	13	
C_{dd}	−15	17	
C_{ml}	0	3	
$f_{\text{calib}}\cdot\langle\omega'_p(\vec{r})\times M(\vec{r})\rangle$	...	46	
B_k	−21	13	
B_q	−21	20	
$\mu'_p(34.7°)/\mu_e$	...	11	
m_μ/m_e	...	22	
$g_e/2$	...	0	
Total systematic for $\mathcal{R}'_\mu$	...	70	**78**
Total external parameters	...	25	
Total for a_μ	622	215	

[PRL 131, 161802 (2023)]

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

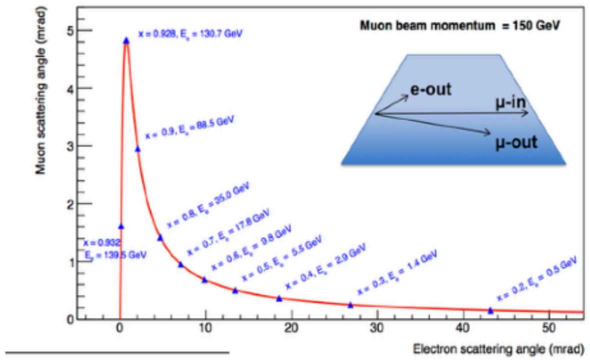
[arXiv:2506.03069]

[PRL (2025) Accepted]

MUonE

MUonE uses a new, independent evaluation of a^{HLO}

$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 dx(1-x)\Delta\alpha_{had}[t(x)]$$



$\Delta\alpha_{had}$: hadronic contribution to the running of α in the space-like region

$\Delta\alpha_{had}(t)$: can be extracted from the shape of $\mu e \to \mu e$ differential cross section

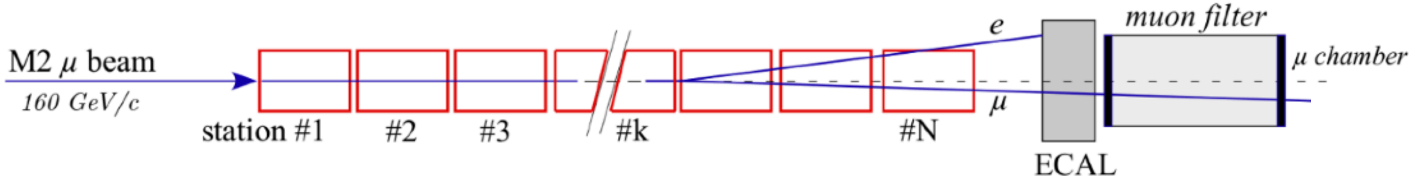


Figure 24: Schematic view of the MUonE experimental apparatus (not to scale).

Conclusions

- The MUonE Phase I is ongoing with reduced setup – MiniMUonE
- 3 more weeks of data taking as main users of the M2 beamline
- Next step:
  - Analysis of the data taken during 2025
  - R&D activities to improve the experimental apparatus
    - e.g. SciFi Muon Filter, IR HAM, mechanics of the tracking stations..
- Full Setup ready after the Long Shutdown 3 (~2029)
- More info about the MUonE experiment with some preliminary results will be given in Eugenia Spedicato's talk "*Tackling the muon g-2 anomaly with the MUonE experiment at CERN*"

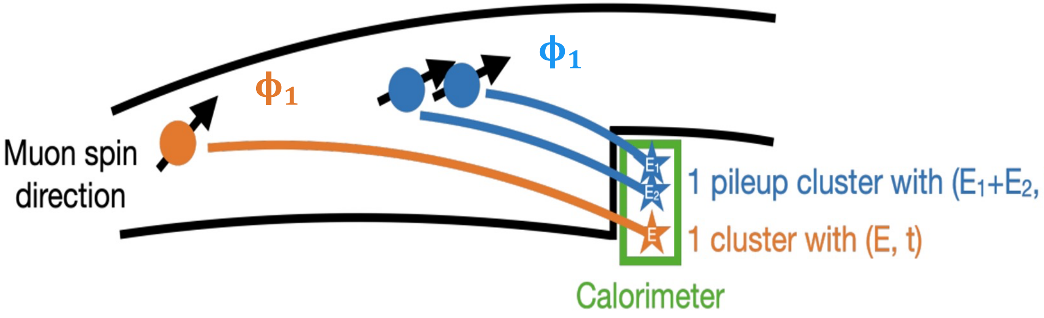
07/07/25 MUonE detector at CERN, EPS-HEP 2025 23

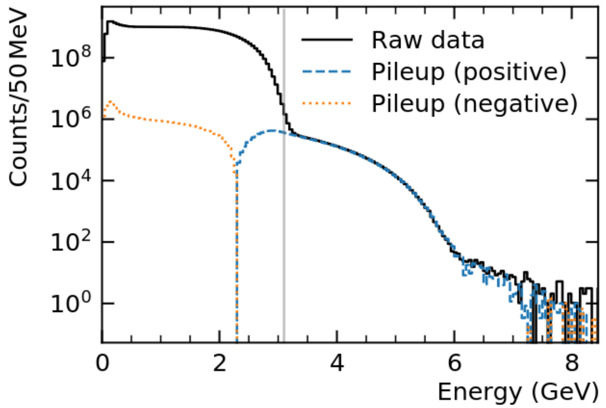
https://indico.in2p3.fr/event/33627/contributions/155307/attachments/93967/144046/AArena_EPS-HEP2025.pdf

Pile-up and Lost Muon

TSUNG-DAO LEE INSTITUTE

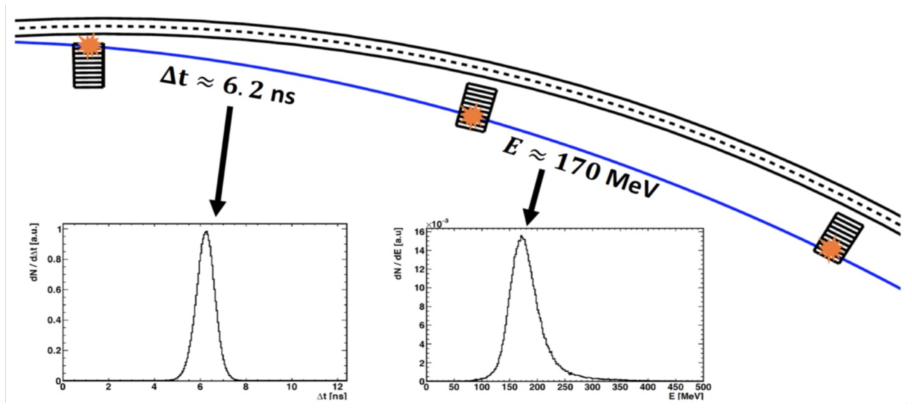
- Low energy positrons with different phase measured in calorimeter, contributing to pile-up event; compares to high energy positron, a single event.

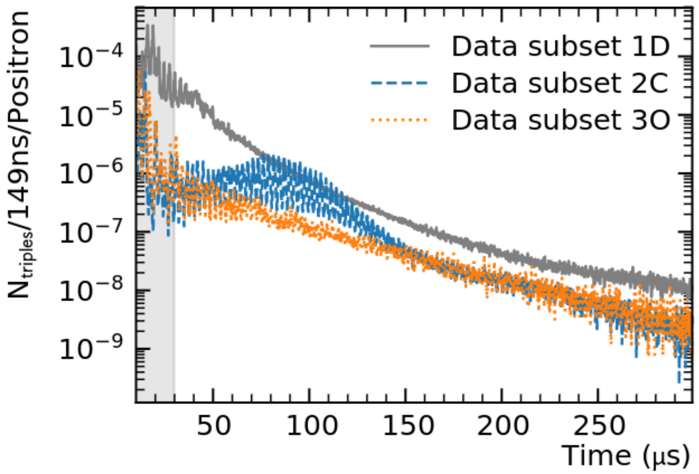




pileup model uncertainty, ~ 3 ppb

- Muons impact on vicinity of the SR, losses energy, exits the SR before decaying into positrons.
- Lost muons introduce time-dependent distortion of measured positrons.

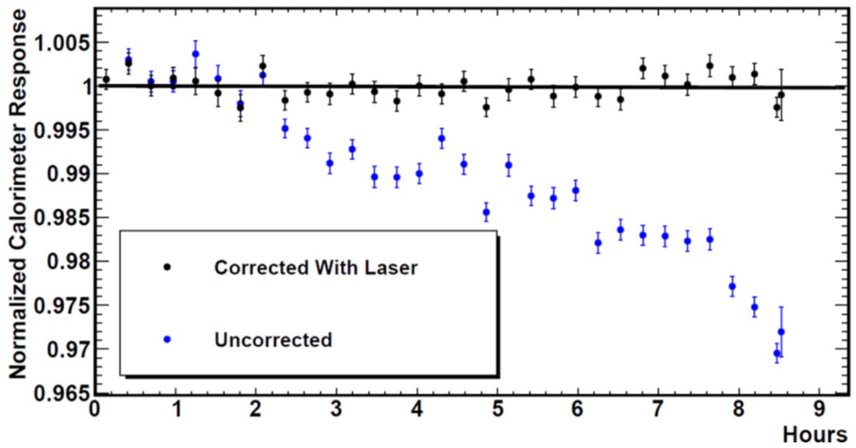




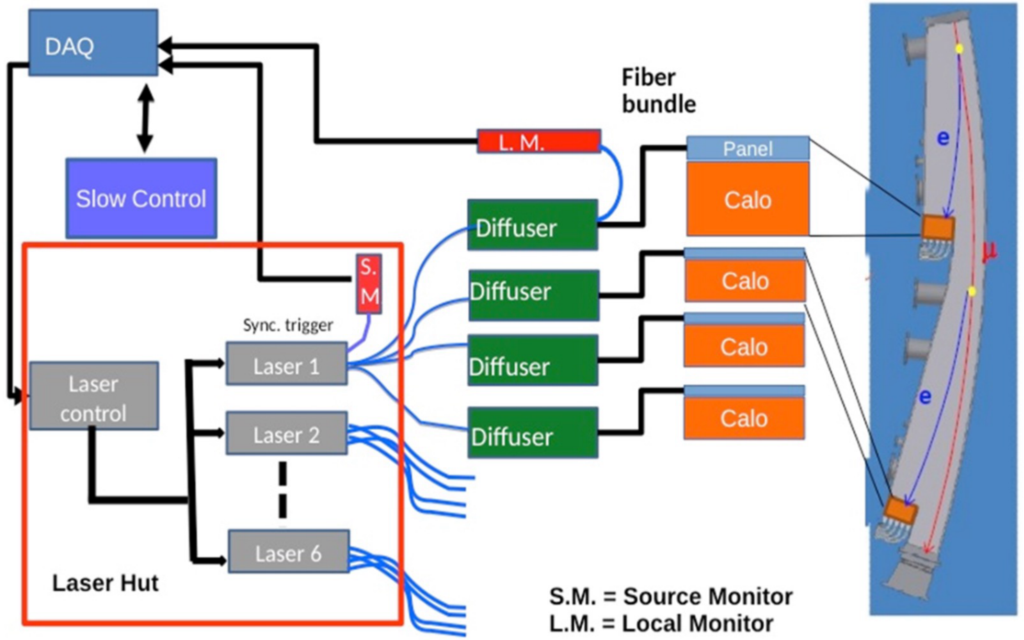
Muon lost time distribution for different sub-datasets.

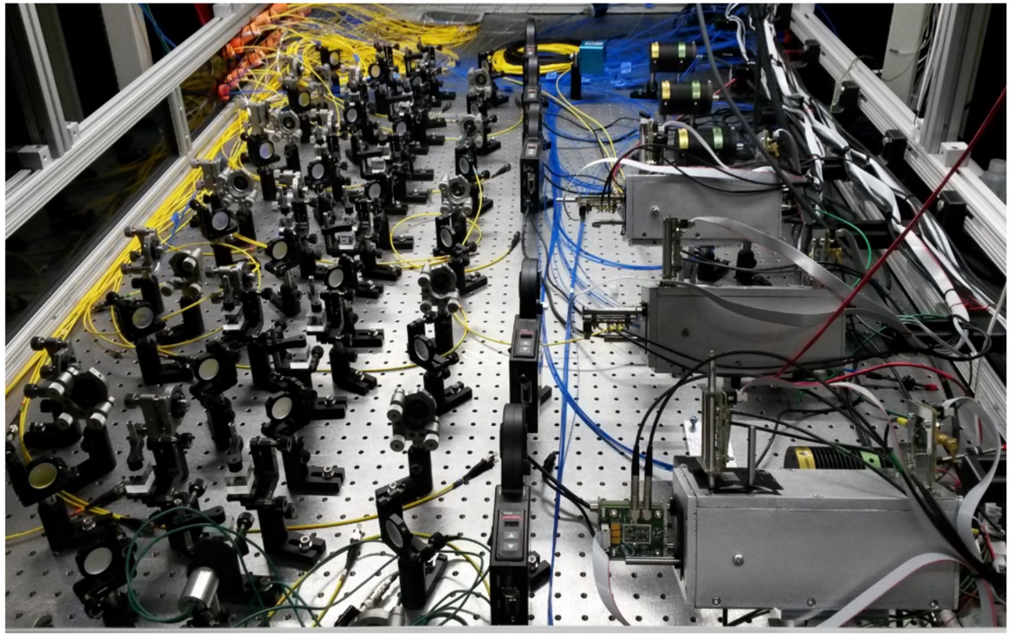
Laser Calibration

- Sends laser pulse synchronously on all calorimeter channels:
    - provide calibration for the SiPMs response,
    - short and long term calibration of the SiPM gain function,
    - troubleshoot calorimeter and DAQ systems,
    - additional synchronization signals.



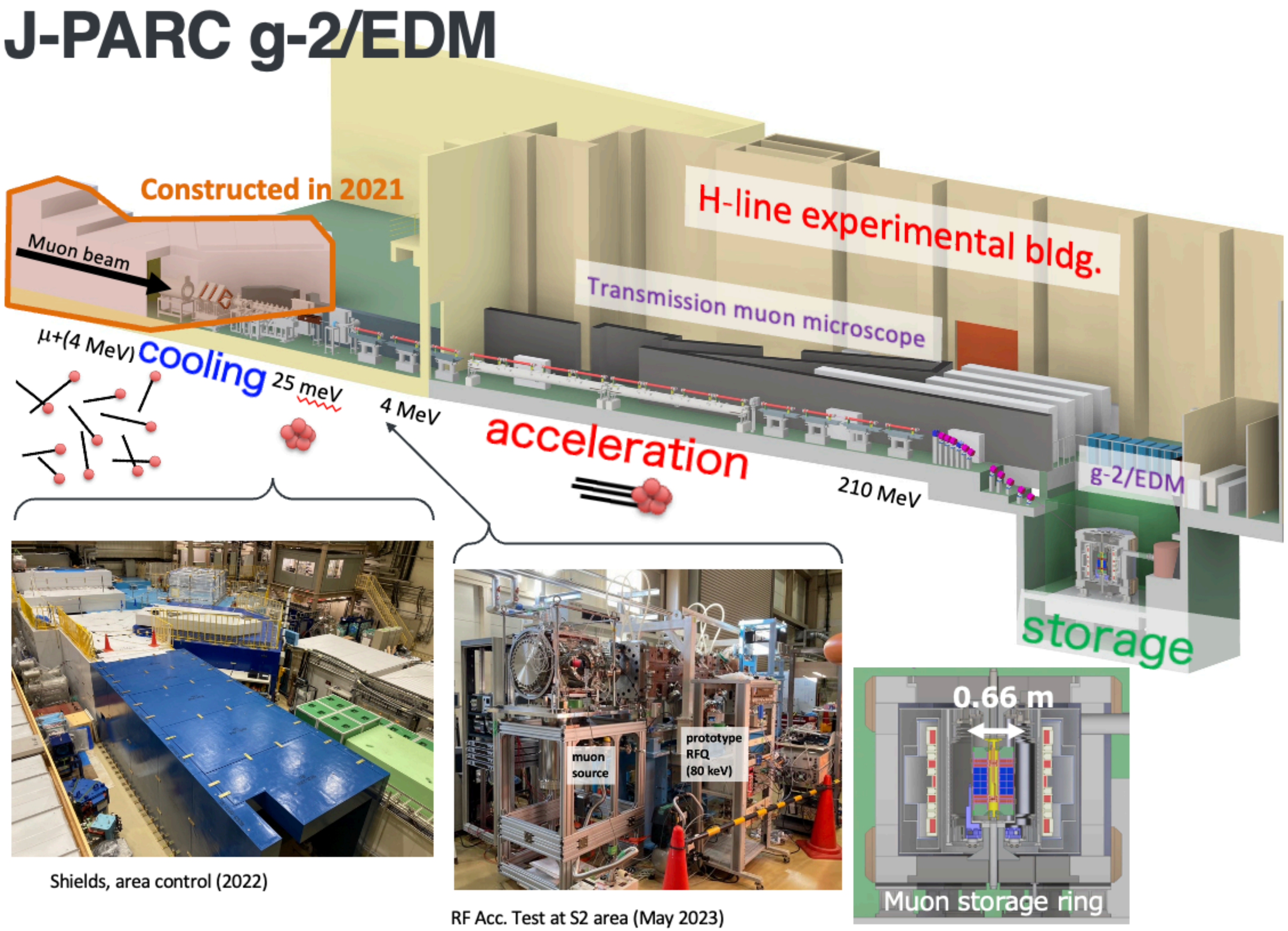
Stable gain 10^{-4} achieved





J-PARC g-2/EDM

Tsung-Dao Lee Institute



Shields, area control (2022)

RF Acc. Test at S2 area (May 2023)

More to come!

from **Muon g-2 at Fermilab**

- Muon EDM results
- More Beyond Standard Model Analysis:
  - CPT/Lorenz-violating
  - Dark Matter

from others

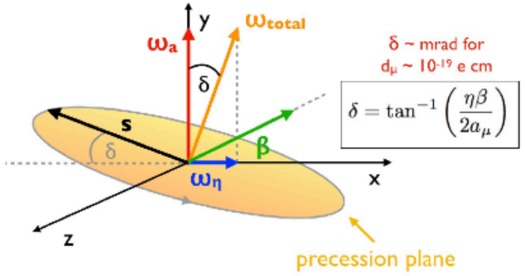
- J-PARC g-2/EDM experiment plans to take data in the next years
  - Complementary technique, no electric fields, not at the magic momentum
  - goal: a 450 ppb measurement
- Theory community including experimental input for data-driven HVP determination
  - including the MUonE experiment, complementary input data

BSM searches (EDM, CPT/LV, DM)

李政道研究所 TSUNG-DAO LEE INSTITUTE

Muon Electric Dipole Moment (EDM)

- The spin precession plane is tilted in the presence of the EDM.
- Run-2/3 analysis to be announced soon!
- Current limit (BNL): 1.8×10^{-19} e · cm
  → Projected limit: $\sim \mathcal{O}(10^{-20}$ e · cm)

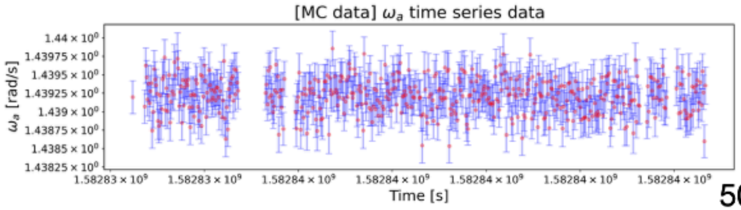


CPT and Lorentz Invariance Violation

- ω_a modulated at the sidereal motion freq.
- Run-2/3 analysis in review.
- Current limit (BNL): 1.4×10^{-24} GeV →
  Projected limit (FNAL Run-2/3): $\mathcal{O}(10^{-25})$ GeV

Ultralight Muonic Dark Matter (scalar)

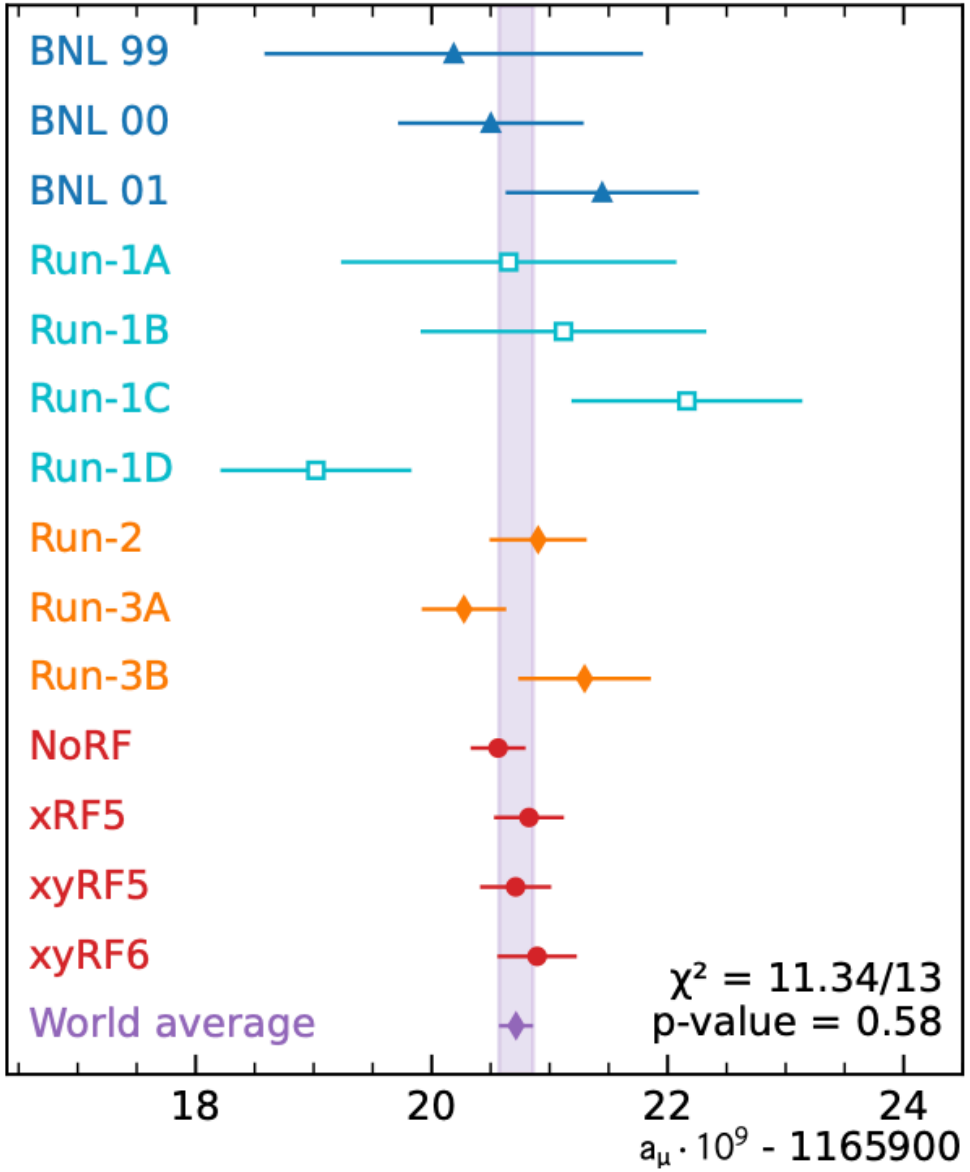
- ω_a modulated at the DM Compton frequency.
- Run-2/3 analysis in progress.



50

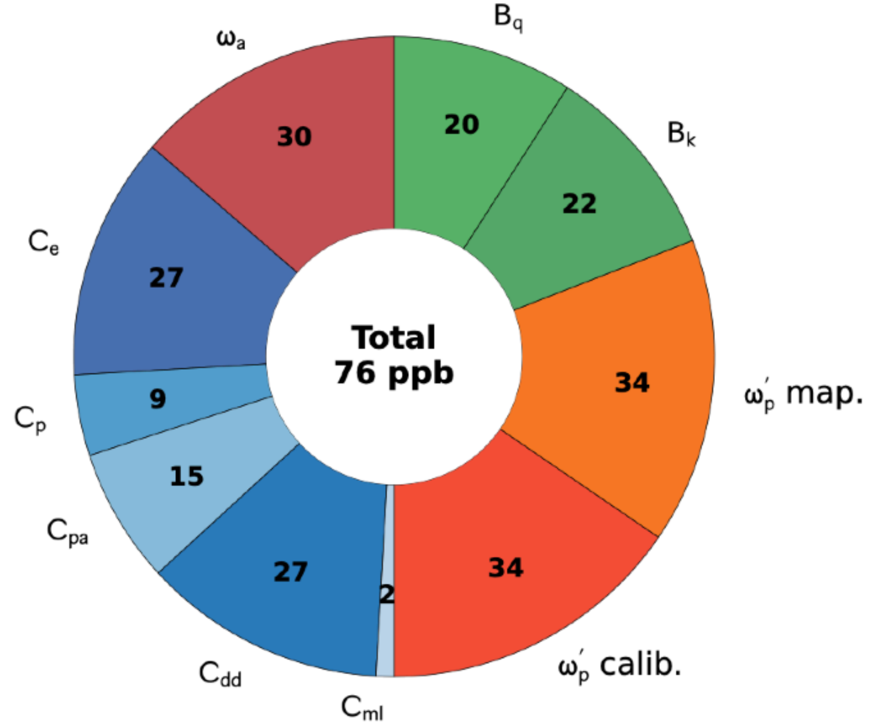
Large Dataset

allows to demonstrate consistency



Final Systematics

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
$\langle \omega_p' \times M \rangle$	⋯	48
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



TDR goal : 100 ppb ✓

- “Evenly” distributed
- No dominant source
- Further improving would require reducing in many categories