

The Muon $g - 2$ in the Post-Fermilab Era: Status and Experimental Outlook

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RAL seminar
March 2026



The Muon $g - 2$ in the Post-Fermilab Era: Status and Experimental Outlook

- Why muon $g-2$?
- (Some) Lessons learned from Fermilab
- Next-generation experimental ideas?

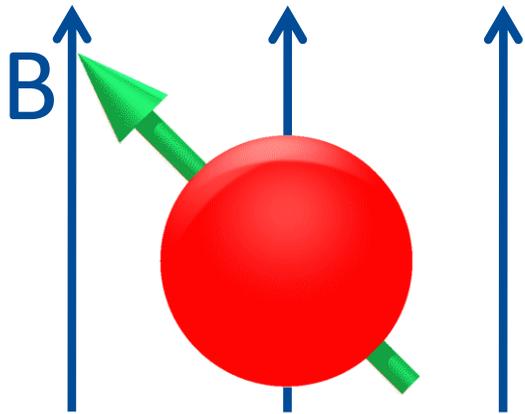
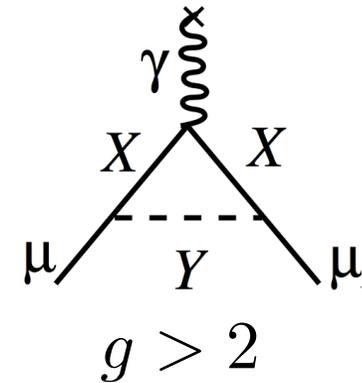
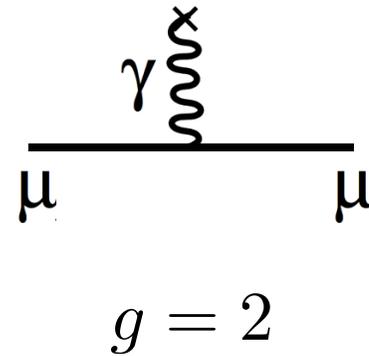
g The gyromagnetic ratio relates a particle's magnetic moment to its spin, and determines its precession in a magnetic field.

Torque in B-field

$$\vec{\mu} \times \vec{B}$$

Magnetic Moment

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



- For a pure Dirac spin- $1/2$ charged fermion, g is exactly 2
- Interactions between the lepton and **virtual particles** drive $g > 2$. X & Y particles could be SM or new physics

The Magnetic Moment of the Electron†

P. KUSCH AND H. M. FOLEY

Department of Physics, Columbia University, New York, New York

(Received April 19, 1948)

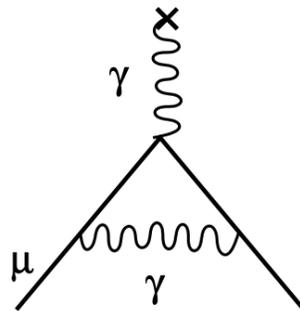
A comparison of the g_J values of Ga in the $^2P_{3/2}$ and $^2P_{1/2}$ states, In in the $^2P_{1/2}$ state, and Na in the $^2S_{1/2}$ state has been made by a measurement of the frequencies of lines in the hfs spectra in a constant magnetic field. The ratios of the g_J values depart from the values obtained on the basis of the assumption that the electron spin gyromagnetic ratio is 2 and that the orbital electron gyromagnetic ratio is 1. Except for small residual effects, the results can be described by the statement that $g_L = 1$ and $g_S = 2(1.00119 \pm 0.00005)$. The possibility that the observed effects may be explained by perturbations is precluded by the consistency of the result as obtained by various comparisons and also on the basis of theoretical considerations.

$g-2$

1948: Schwinger calculated higher order QED, giving $g > 2$ for electron



$$a = \frac{(g-2)}{2} = \frac{\alpha}{2\pi} = 0.001161$$

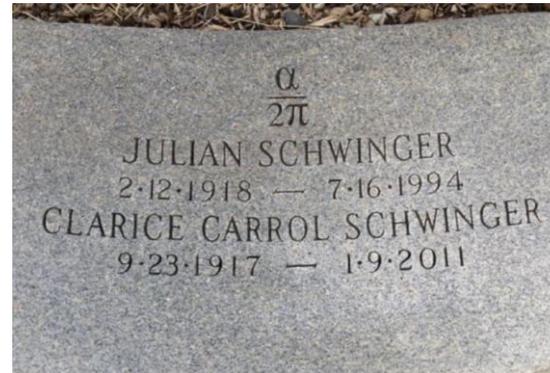
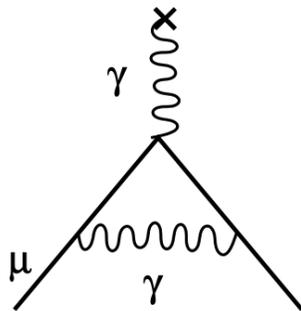


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$\alpha/2\pi$ is universal for all spin $\frac{1}{2}$ fermions (electron, muon).

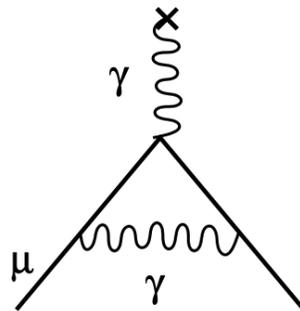
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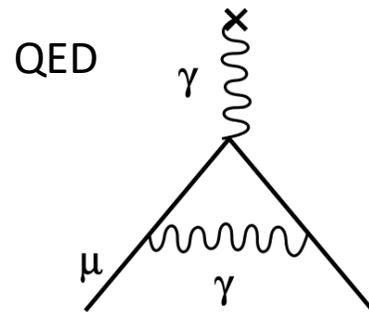
Magnetic anomaly



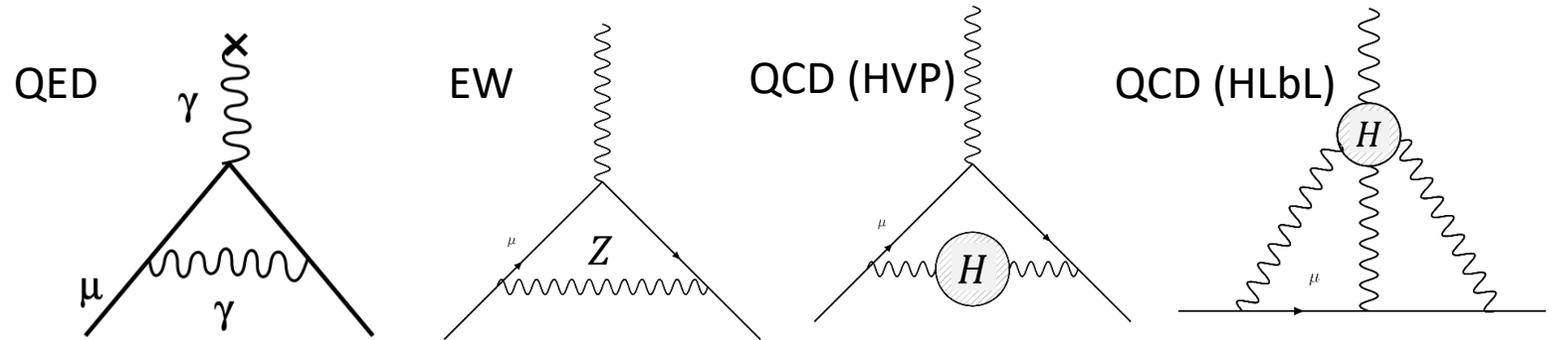
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g_{-2}



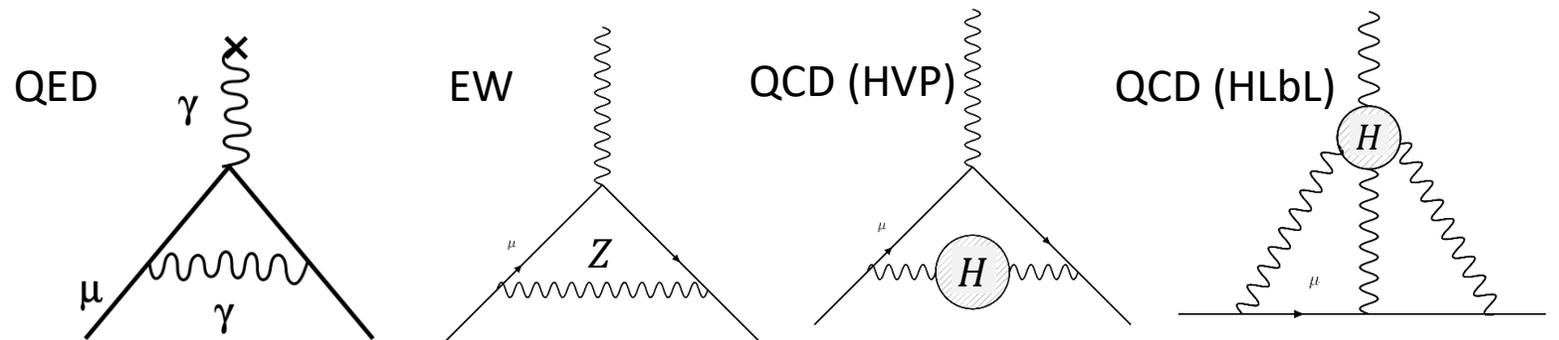
g_{-2}



g-2

- Within the Standard Model, a^{SM} receives contributions from QED, electroweak interactions, and hadronic effects:

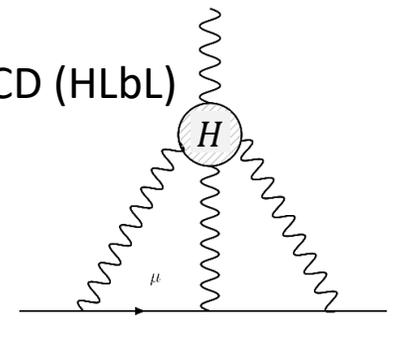
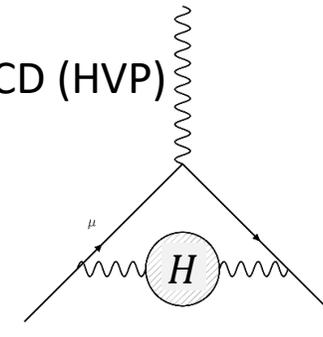
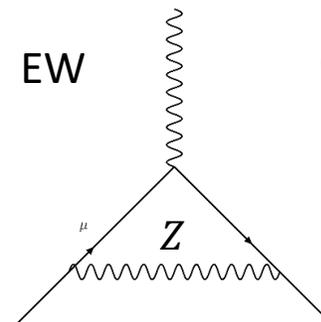
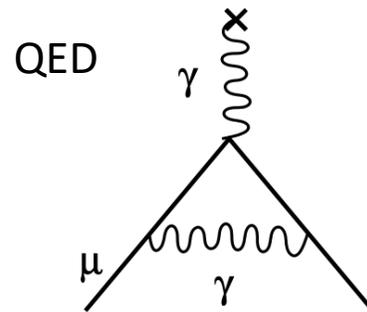
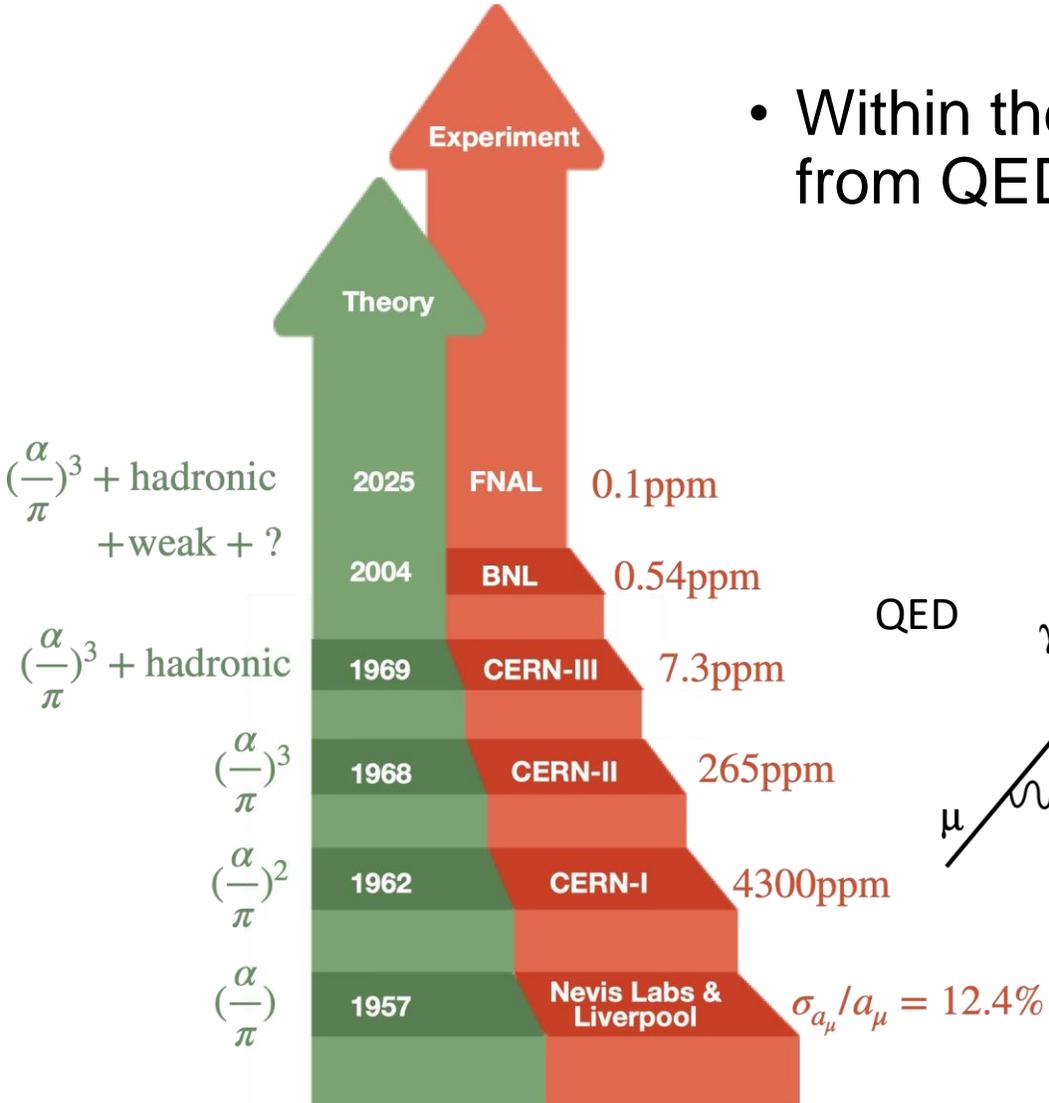
$$a^{\text{SM}} = a^{\text{QED}} + a^{\text{EW}} + a^{\text{QCD}}$$



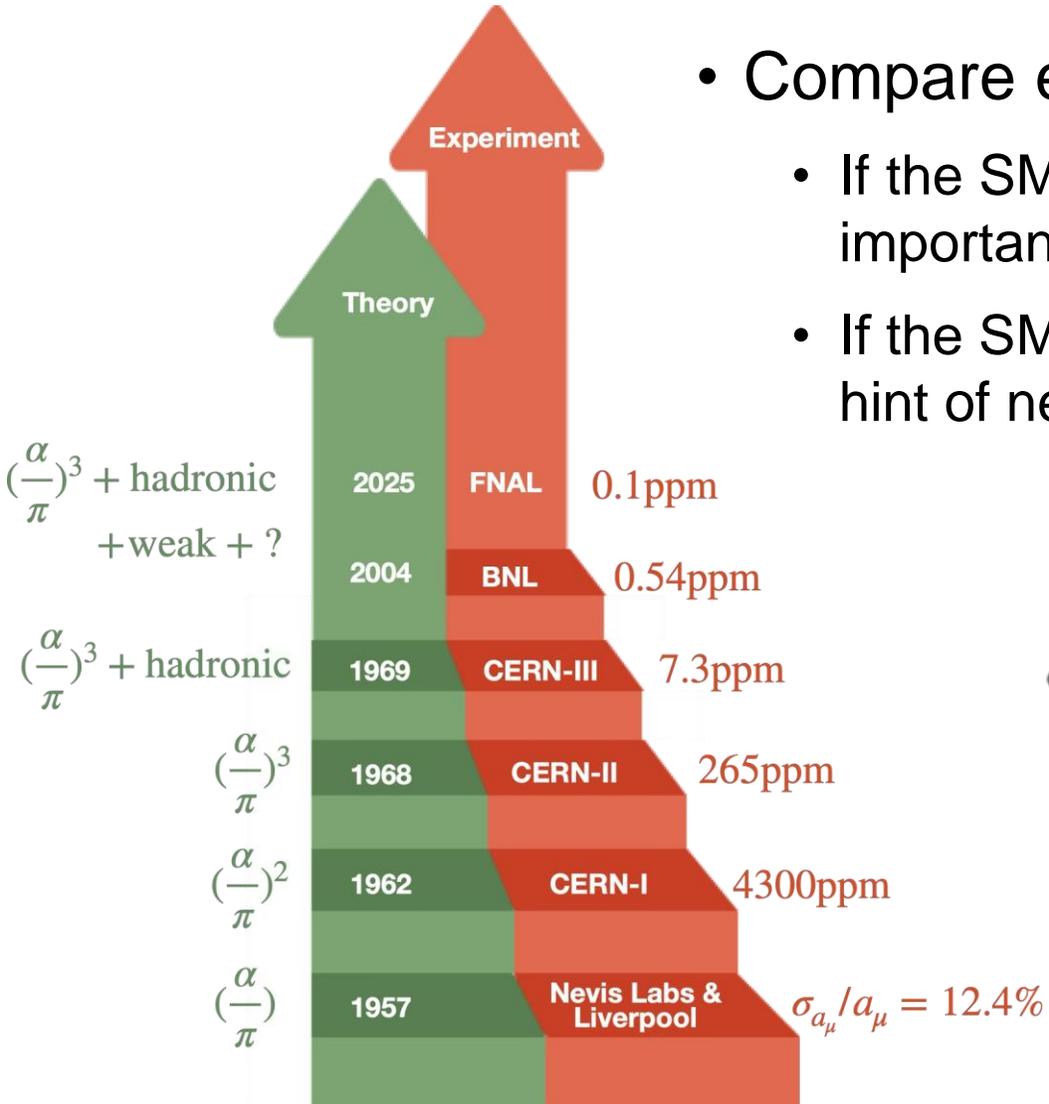
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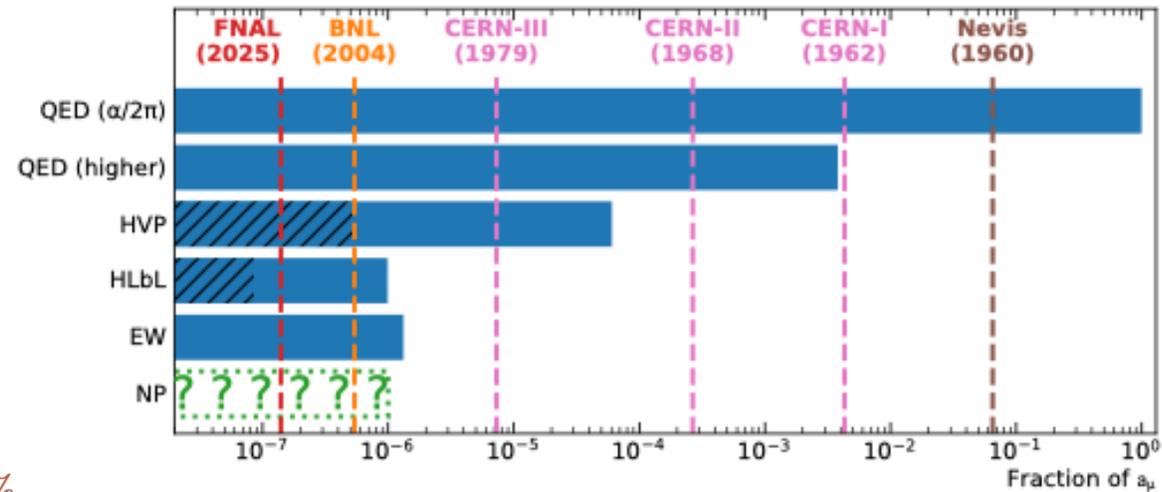


g_{-2}



- Compare experimental & predicted values:

- If the SM is correctly predicted, and we match their value \rightarrow important confirmation; rules out a lot
- If the SM is correctly predicted, and we don't agree with it \rightarrow hint of new physics; opens up a lot



$g-2$ of the muon

- Both electron and muon magnetic moments can be measured and calculated to extraordinary precision
- But, sensitivity to New Physics scales (Λ) as mass ratio squared:

$$\Delta a_\mu \sim g^2 \frac{m_\mu^2}{\Lambda^2} \Rightarrow \Lambda \sim g \frac{m_\mu}{\sqrt{\Delta a_\mu}} \quad , \quad \Delta a_\mu \sim 2.5 \times 10^{-9} \rightarrow \text{O}(10\text{--}100 \text{ TeV})$$

- Muon with $(m_\mu/m_e)^2 \sim 43000$ enhanced sensitivity to new physics particles. Precision becomes a high-energy probe, reaching energy scales beyond current collider limits (e.g. \sim TeV for LHC).

$$a_e = 1\,159\,652\,180.73(0.28) \cdot 10^{-12} \text{ [0.24ppb]} \quad \Leftrightarrow \quad a_\mu \sim 0.13 \text{ ppm}$$

Hanneke et al., *PRL* 100(2008)120801 @ Harvard

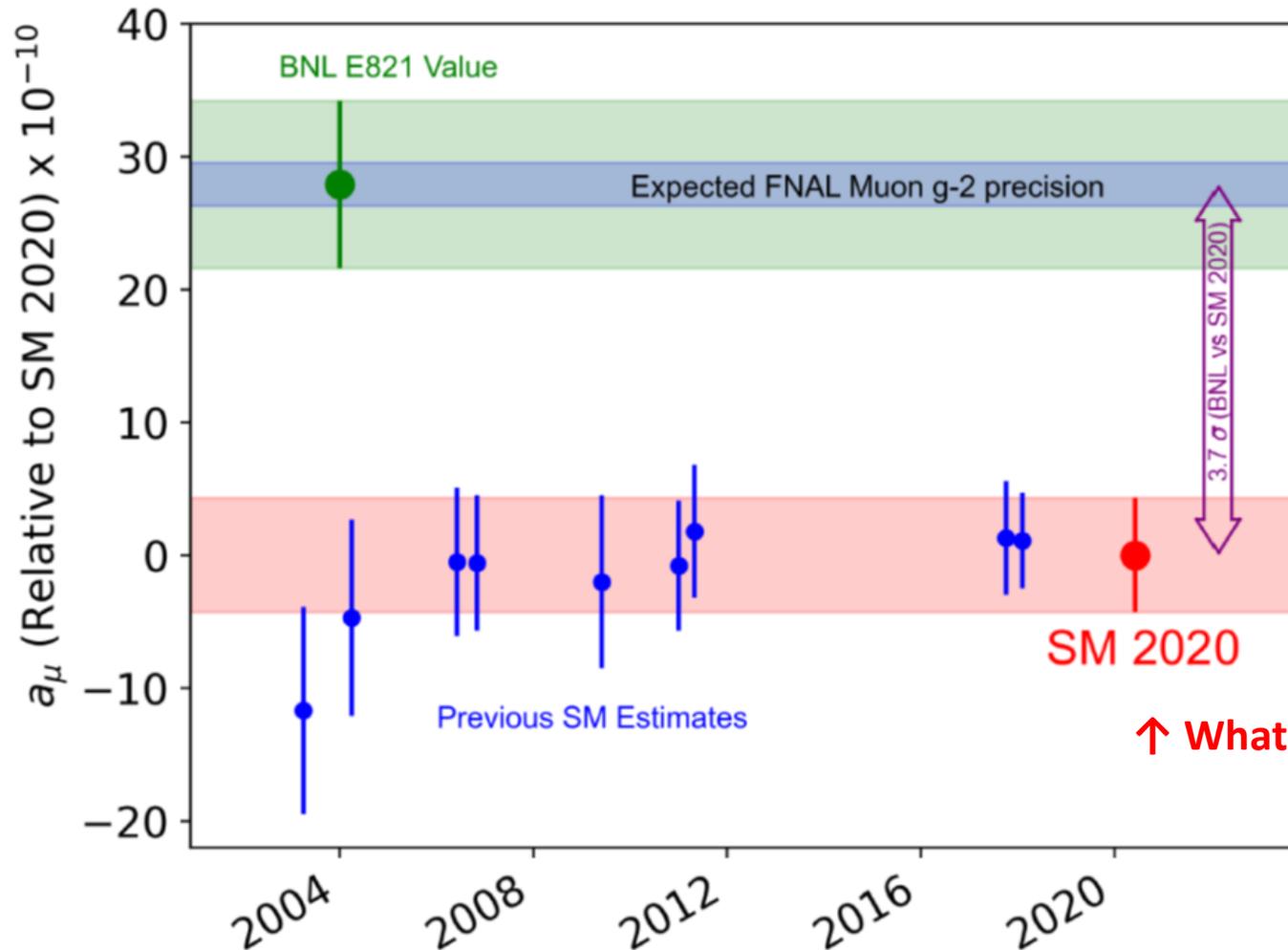
(currently the most precisely measured particle physics observable)

New physics interpretations

[Refs: Athron et al, 2104.03691; Buen-Abad et al, 2104.03267; Krnjaic et al, 1902.07715; Dermisek et al, 2103.05645]

NP type	diagrams	mass range	probe
Supersymmetry		200~500 GeV	$\tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow (h \tilde{\chi}_1^0) (W^\pm \tilde{\chi}_1^0)$ $pp \rightarrow \gamma\gamma \rightarrow \tilde{\ell}\tilde{\ell}^*$
Scalar extensions		20~100 GeV, 150~250 GeV	$Z \rightarrow \tau^+ \tau^-$ $h \rightarrow AA$
Axion-like particle		40 MeV~6 GeV	$e^+ e^- \rightarrow \gamma a, a \rightarrow \gamma\gamma$
$U(1)_{L\mu-L\tau}$		10~200 MeV	$e^+ e^- \rightarrow \mu^+ \mu^- Z'$ $K^- \rightarrow \mu^- \bar{\nu} Z'$
Leptoquark		1.5~2 TeV	$pp \rightarrow LQ\bar{L}\bar{Q}$ $Z \rightarrow \mu^+ \mu^-$
Vector-like lepton		< 7 TeV	$h, Z \rightarrow \mu^+ \mu^-$

After BNL (2001), the theory evolved and sharpened such that in 2020 when the first Muon g-2 Theory Initiative published, the deviation was $3.7 \sigma \rightarrow$ Tempting!

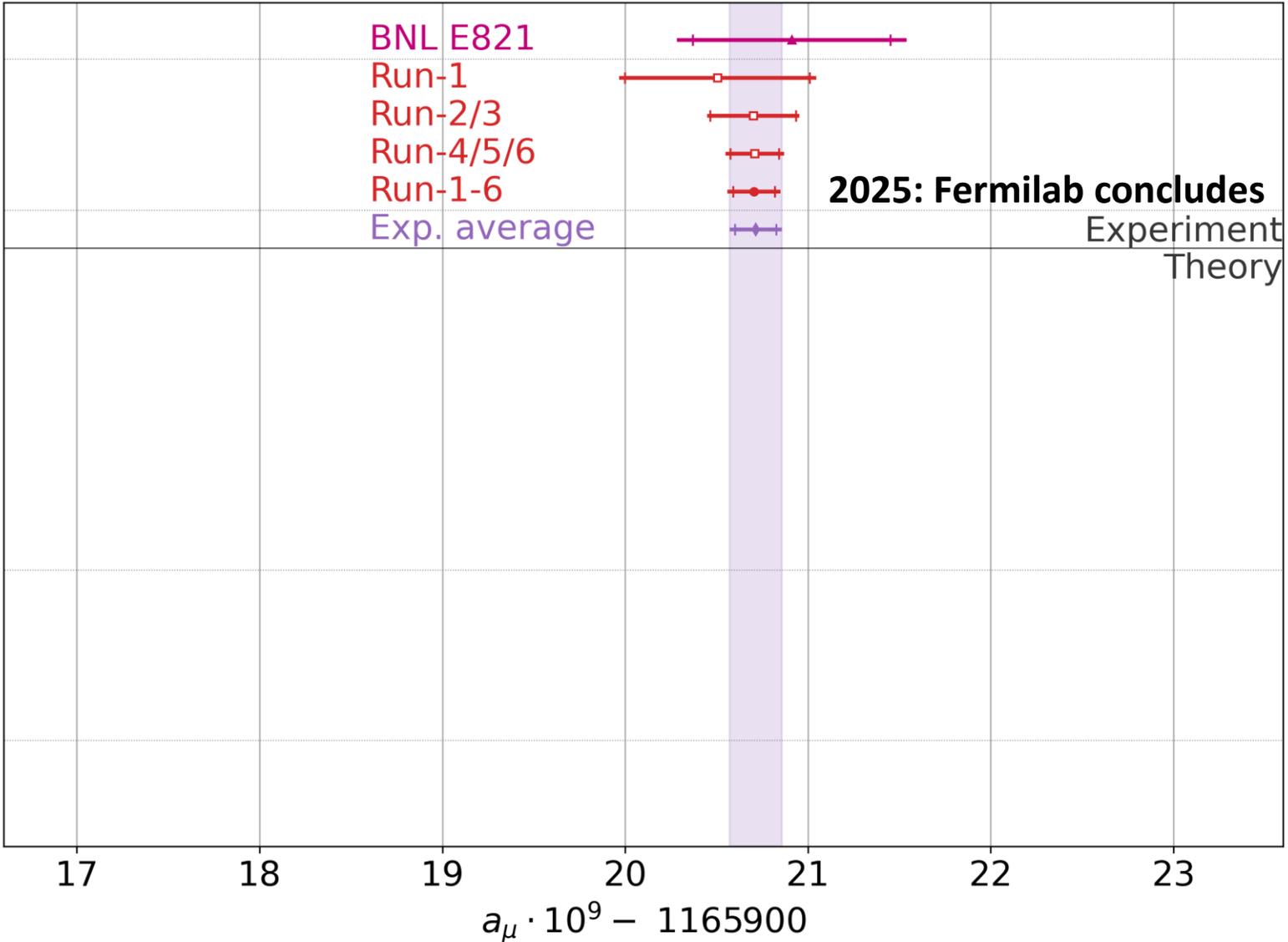


BNL was the only precision measurement
Was it correct?

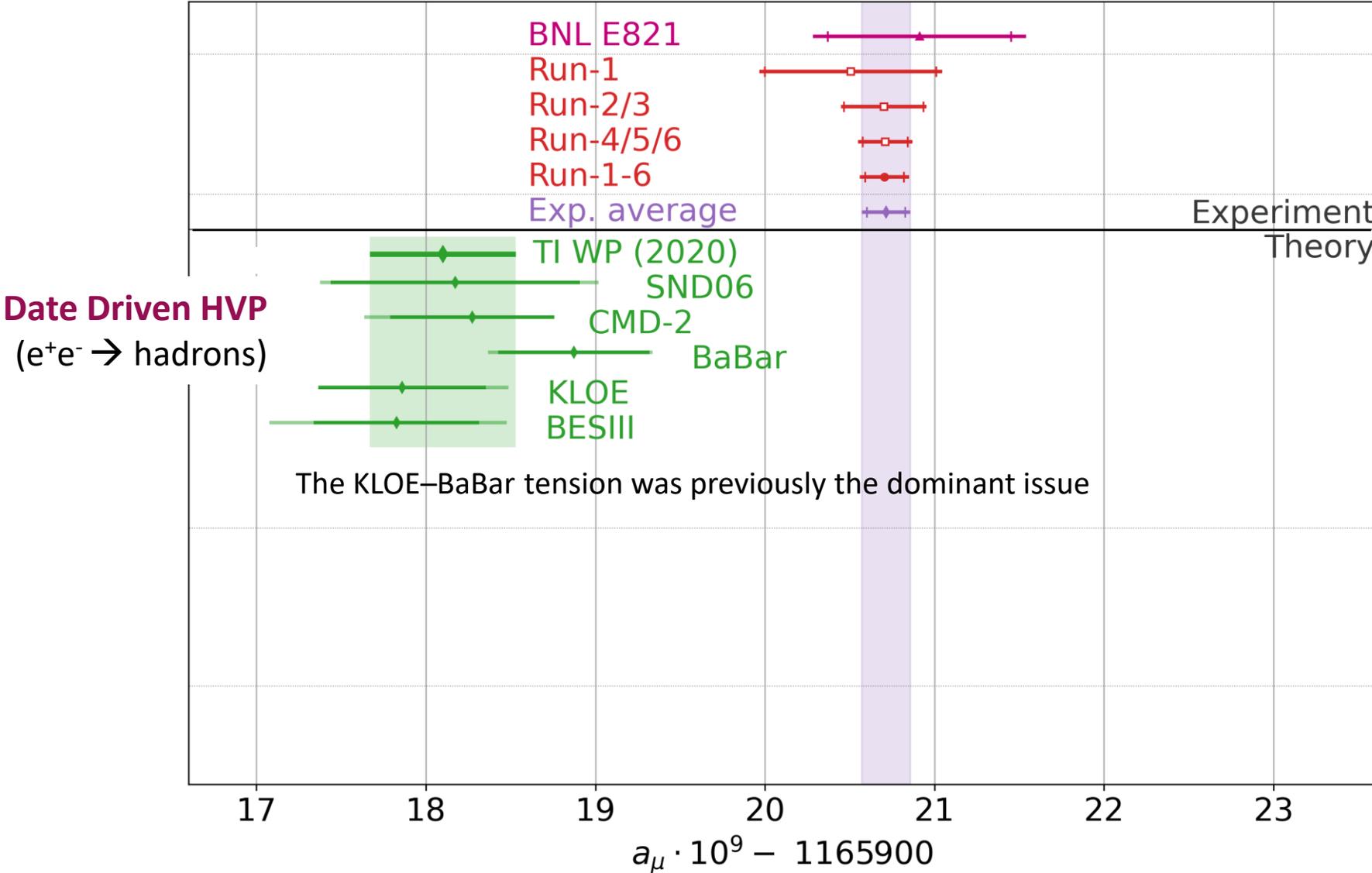
At this time, the theory had
been nicely converging

\uparrow What ~ 160 Theorists recommended in 2020

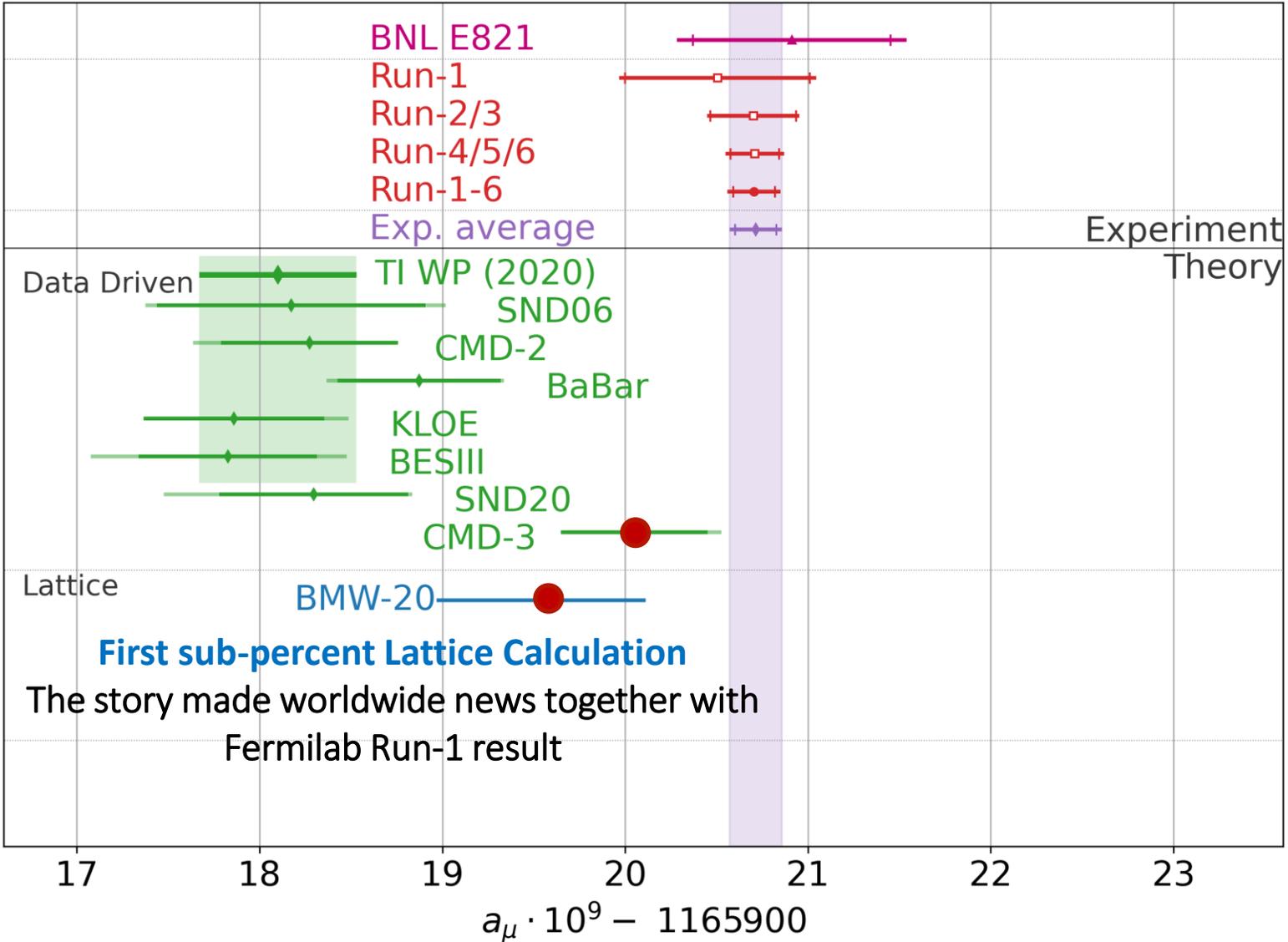
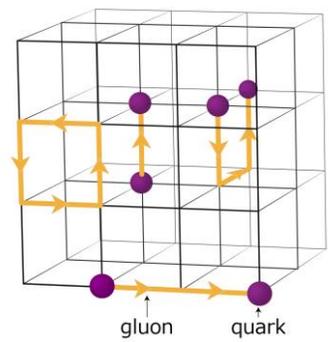
Progression of a_μ Since the 2021 Fermilab Result



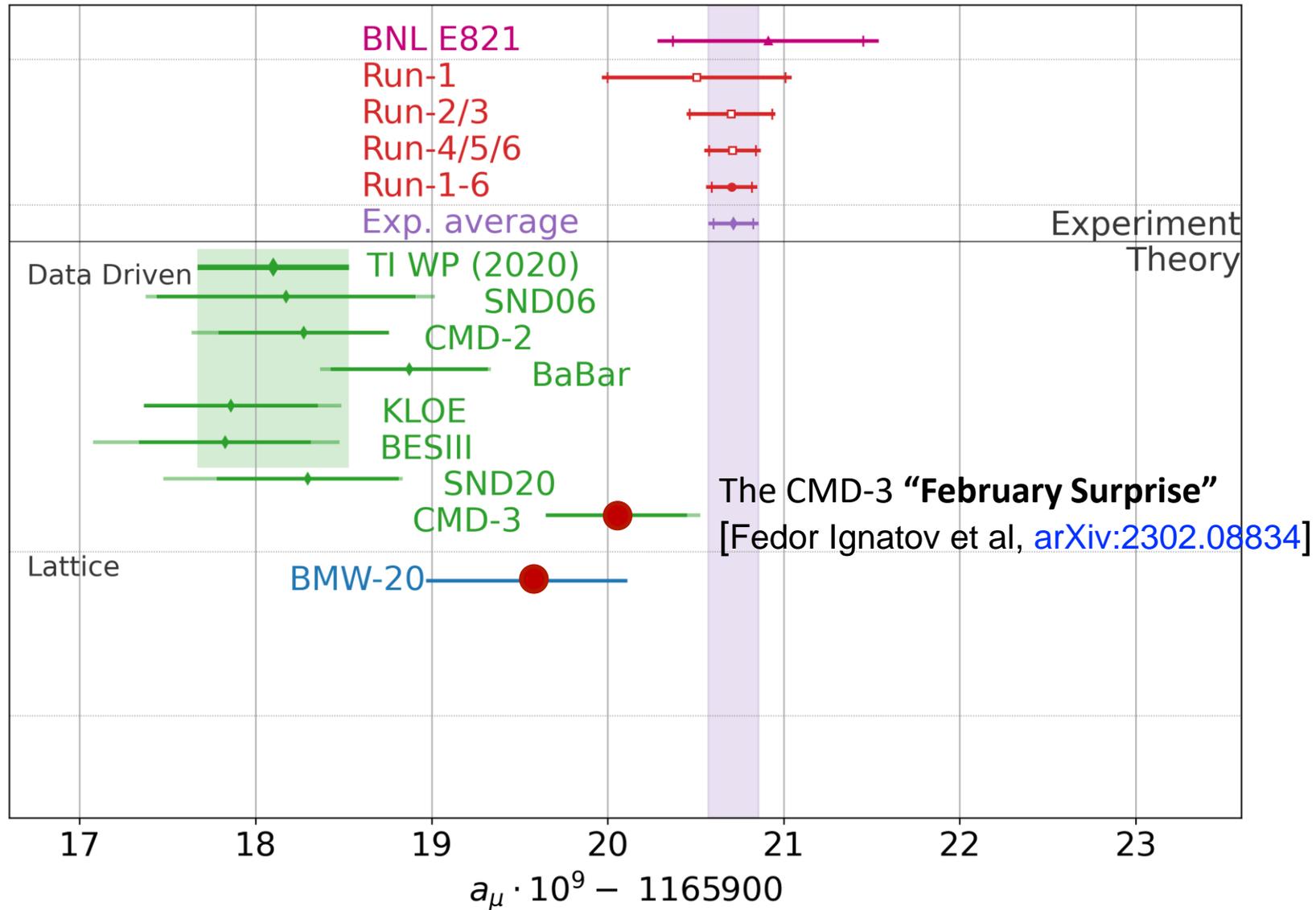
The 2020 Theory Initiative value relies on **Data-Driven HVP**



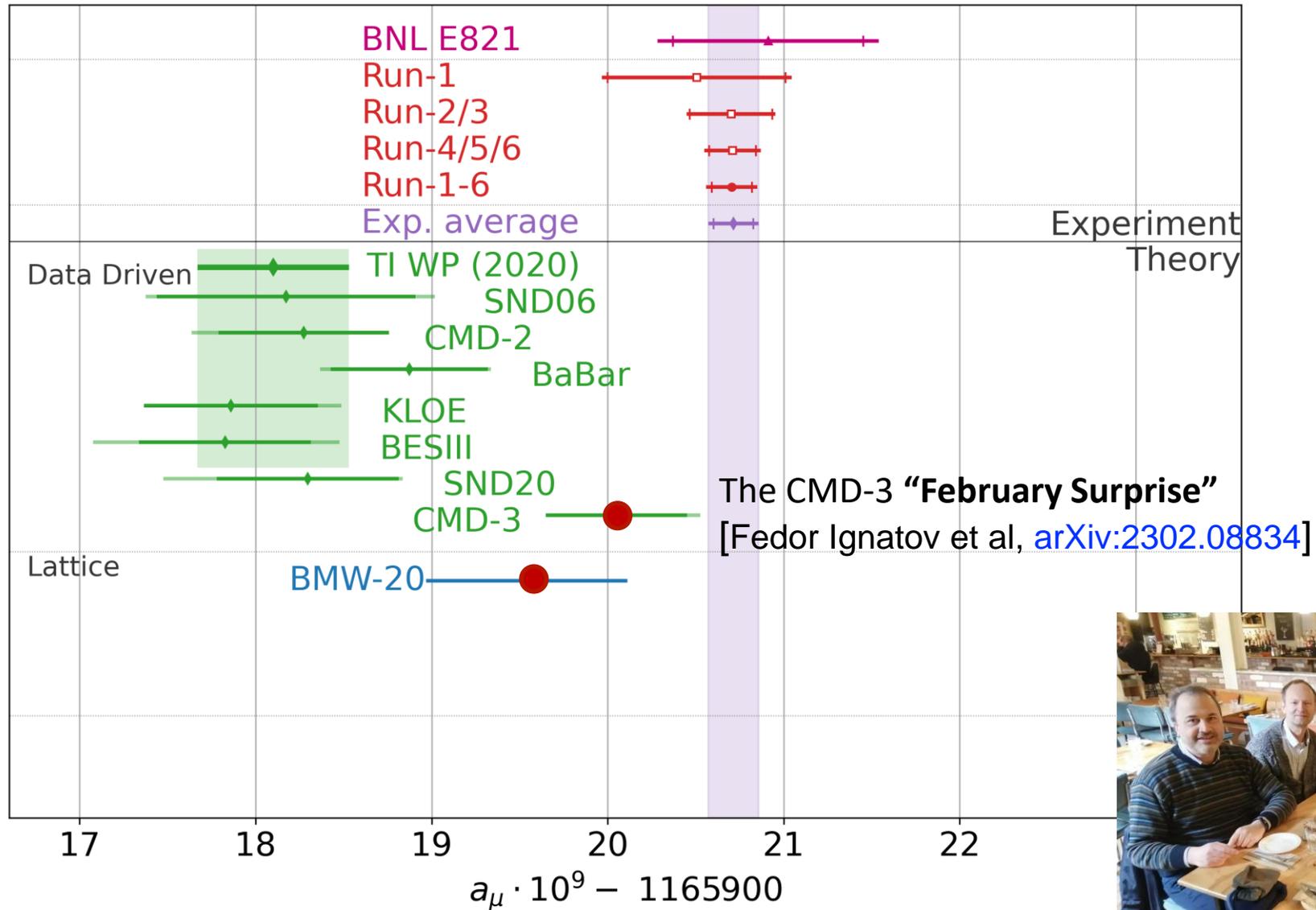
Progression of a_μ In 2021, two things shake the confidence



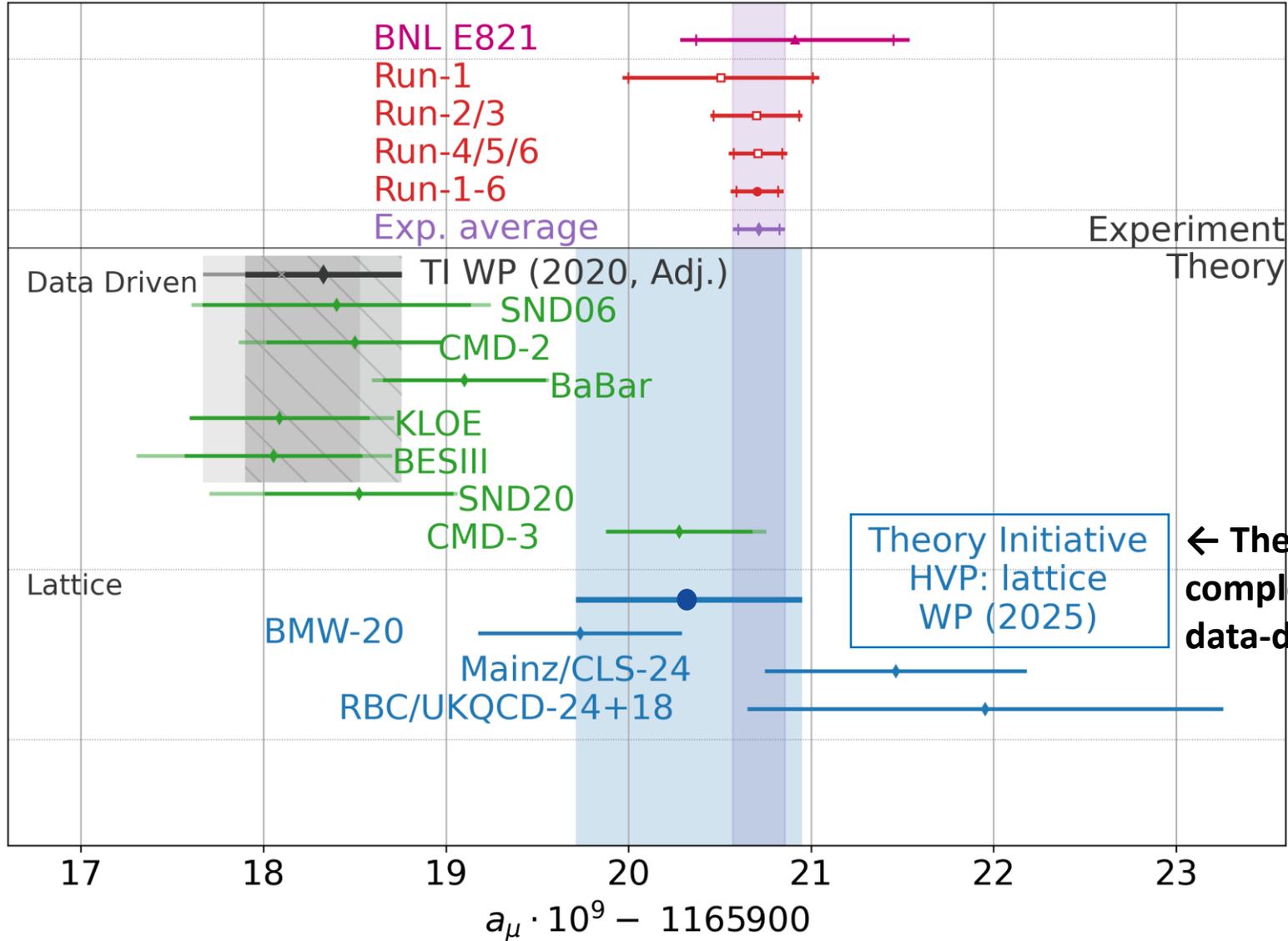
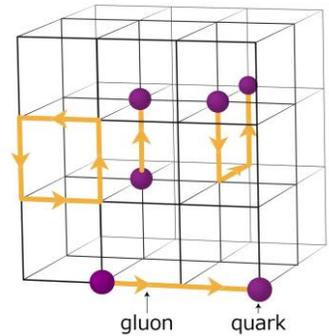
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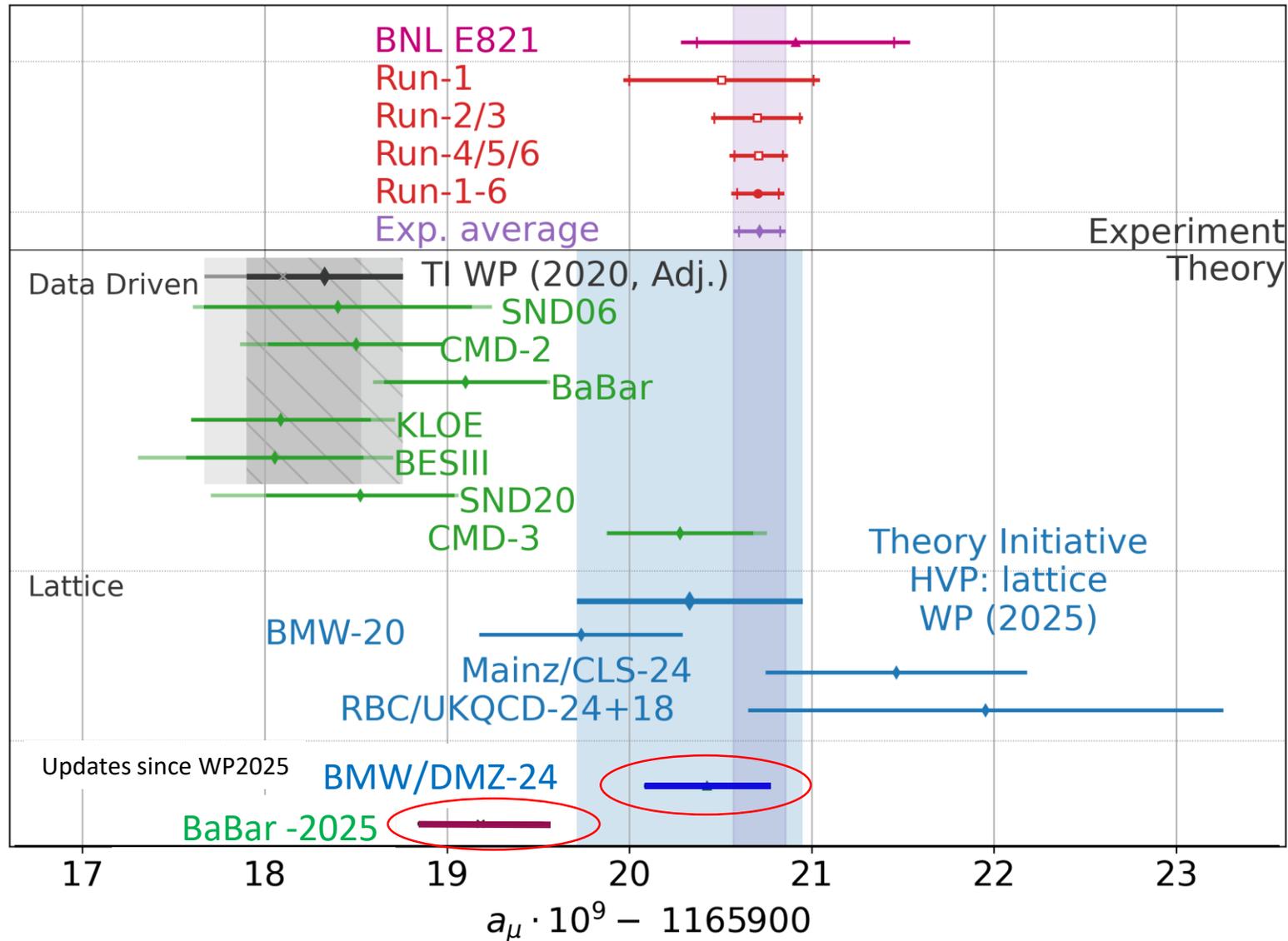


The SM recommendation 2025: pure Lattice approach

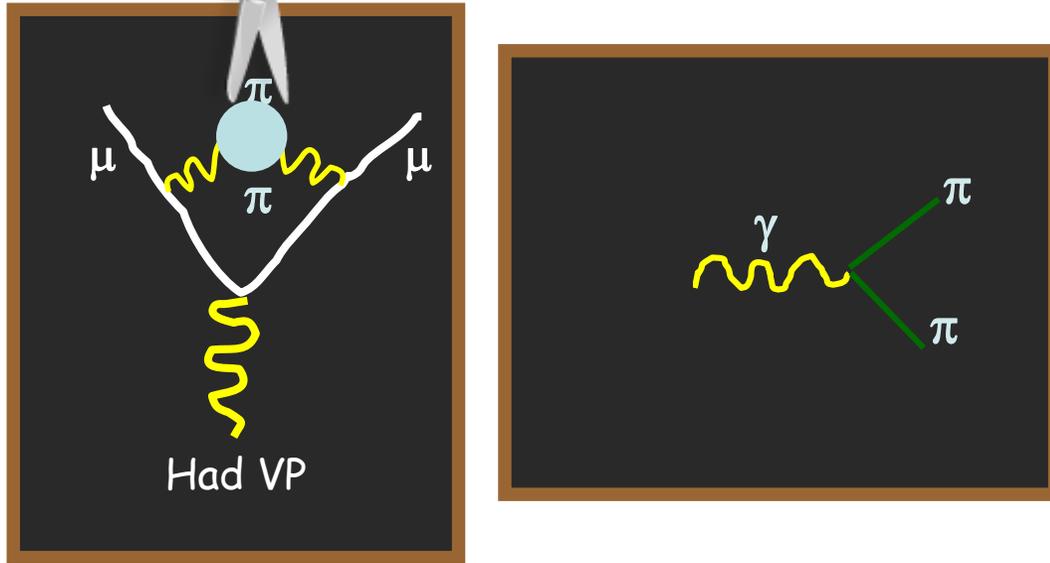


← The SM recommendation 2025 completely *ignores* the green data-driven results

Recently, new Hybrid Lattice and BaBar data

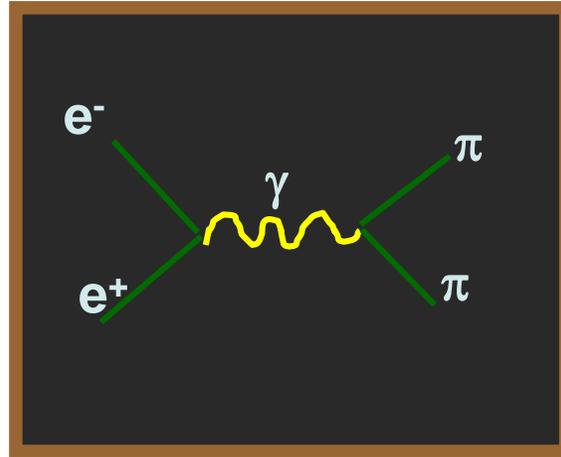
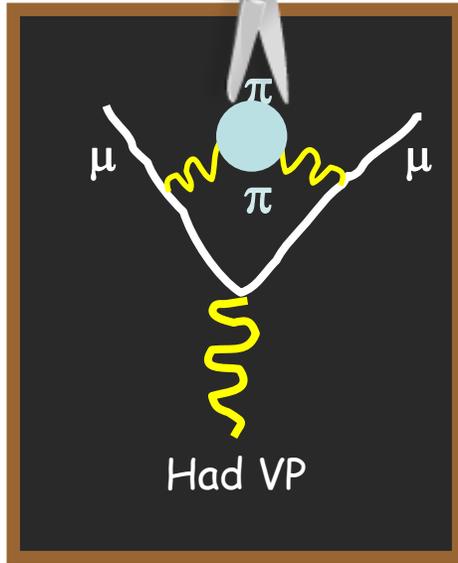


The long-standing recipe: data-driven approach



1. Cut diagram down middle
2. It now looks like $\gamma \rightarrow \pi\pi$ (and all allowed intermediate states)

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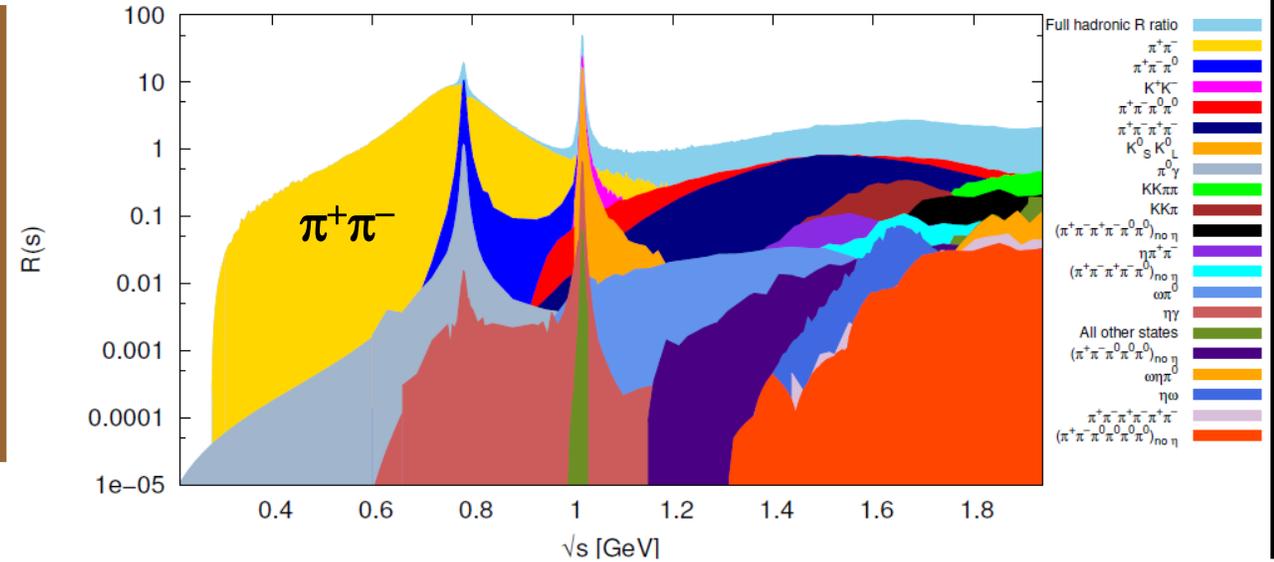
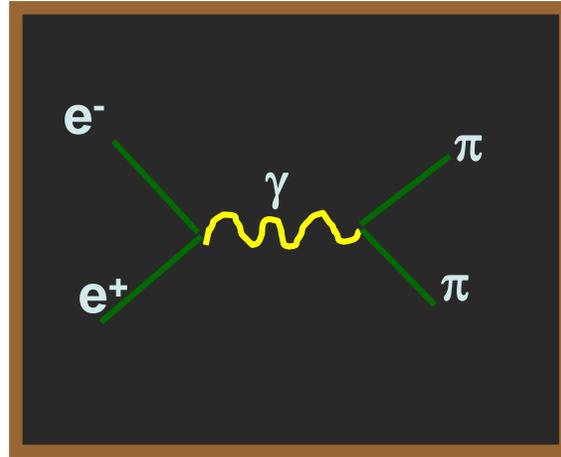
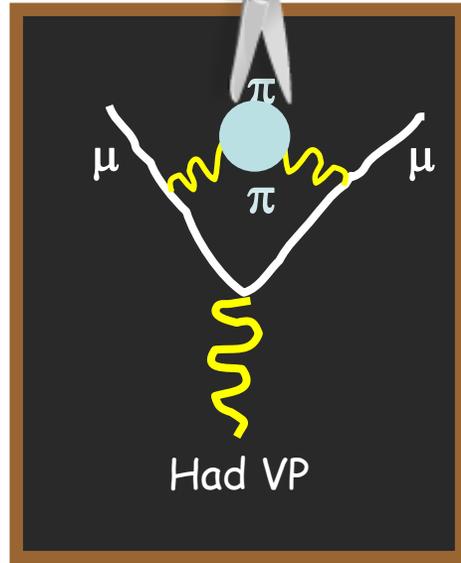


1. Cut diagram down middle
2. It now looks like $\gamma \rightarrow \pi\pi$ (and all allowed intermediate states)
3. Dispersion relation connects $e^+e^- \rightarrow \pi\pi$ cross section measurement to anomaly contribution of 1st-order Hadronic Vacuum Polarization (HVP)

$$a_{\mu}^{\text{had,LO}} = \frac{\alpha^2(0)}{3\pi^2} \int_{4m_{\pi}^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

$$R(s) = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \text{muons})}$$

The long-standing recipe: data-driven approach



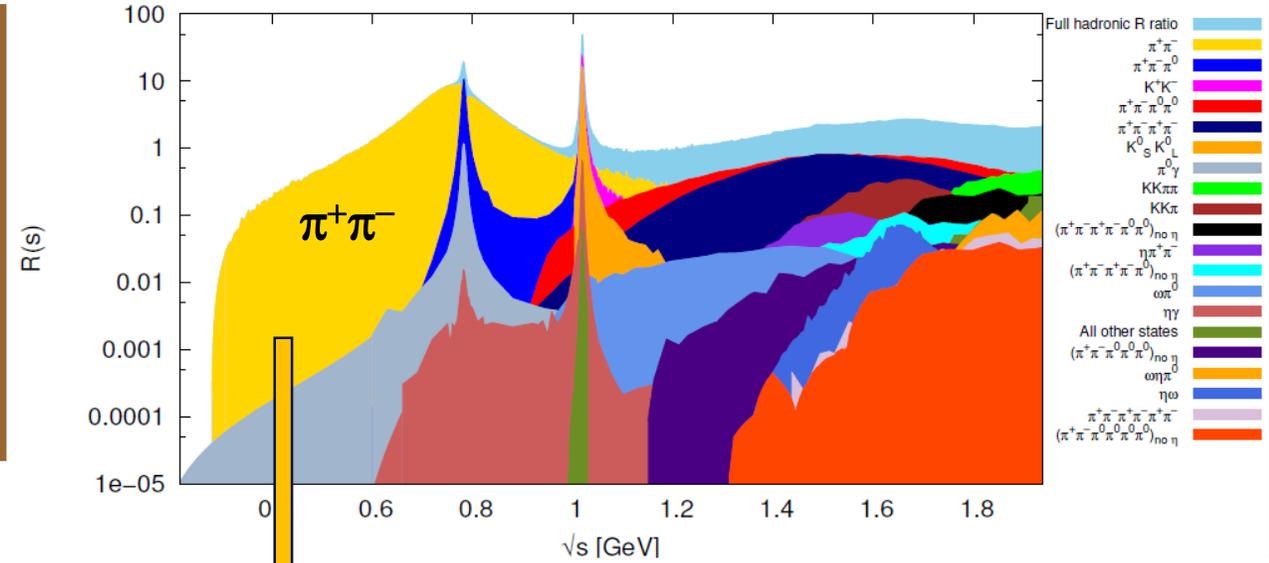
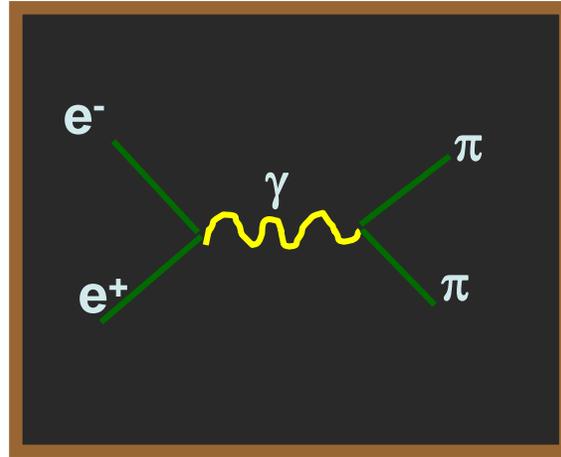
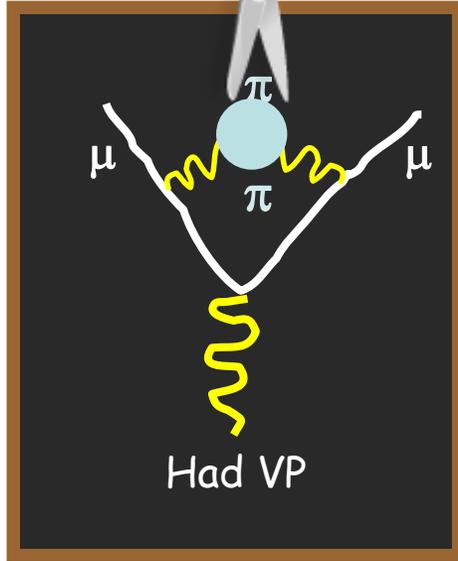
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~ 250 measurements in > 50 hadronic channels
 Uncertainties are “all” experimental

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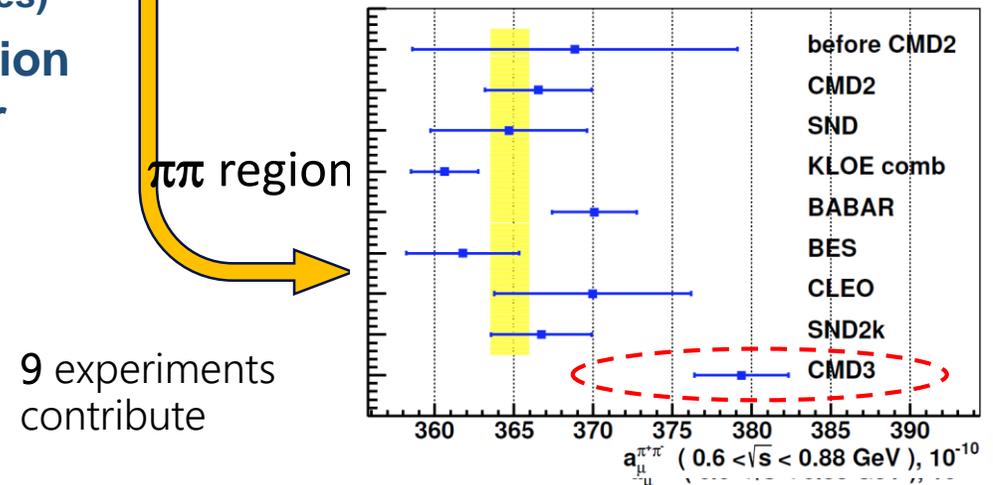
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9 experiments contribute

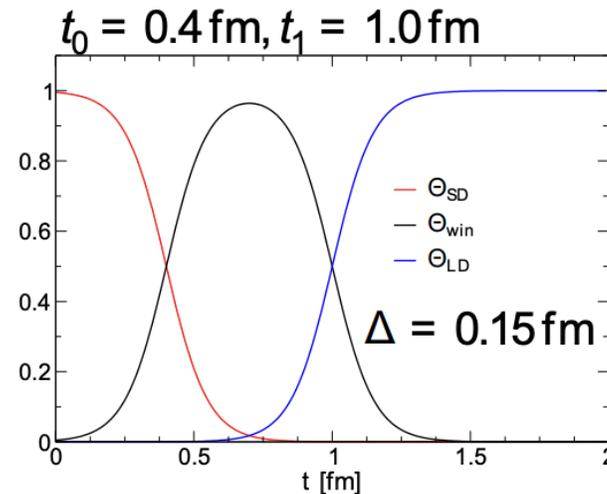
The lattice ... eventually the most precise HVP method?

The 2021 BMW HVP publication: First full lattice prediction with errors matching the datadriven approach.

Since then, more lattice groups have improved their precision and are also exploring alternative approaches to understand the tension:

- Use windows in Euclidean time to consider the different time regions separately.

Short Distance (SD) $t : 0 \rightarrow t_0$
Intermediate (W) $t : t_0 \rightarrow t_1$
Long Distance (LD) $t : t_1 \rightarrow \infty$



... and, then?

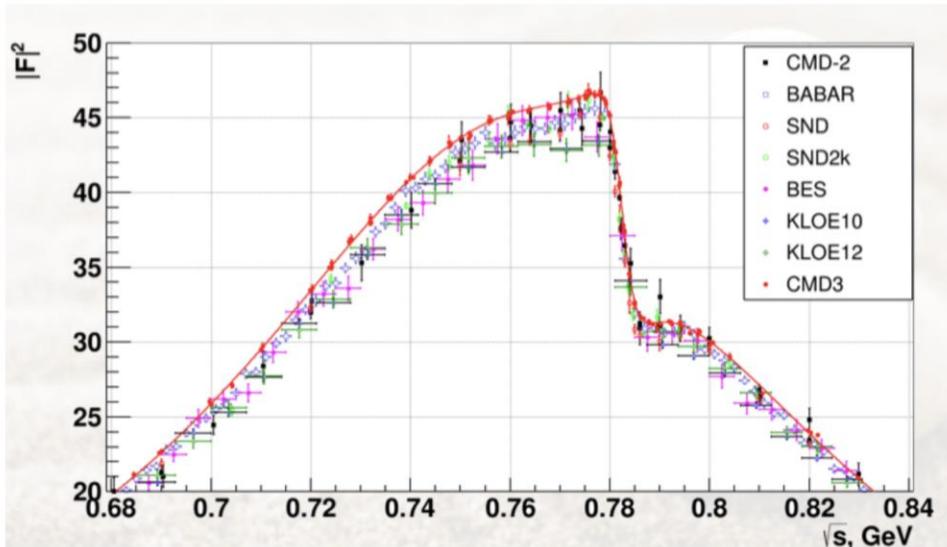
1) Data-driven approach needs clarification

- Ongoing work in experimental inputs: Babar, KLOE, SND
- MC Generators...

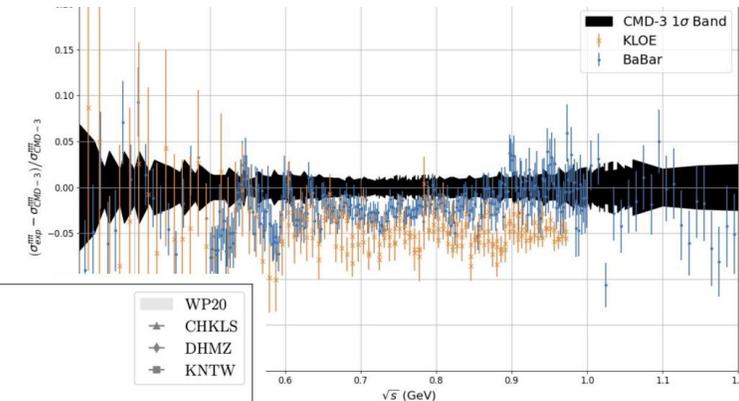
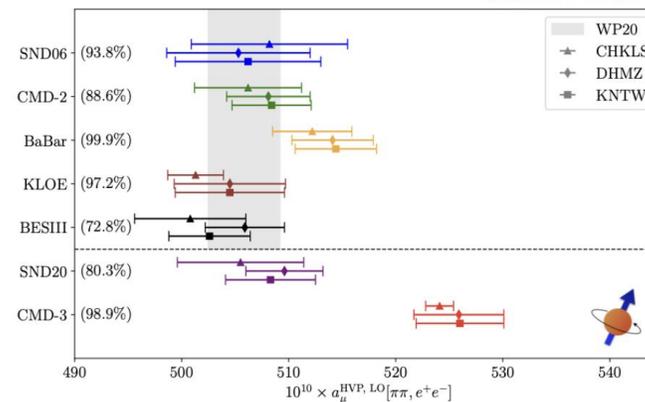
2) The Lattice approach could take the HVP uncertainty down to the 0.1% → push for next-generation measurements

Figure from Fedor Ignatov's TI talk 27.3.2023

PRD 109(2024)11,112002 PRL 132(2024)23,231903



- CMD-3 spectrum much higher than all other previous data
- tensions with BaBar ($\sim 2.5\sigma$) and KLOE ($\sim 5\sigma$)
- no errors found despite significant efforts



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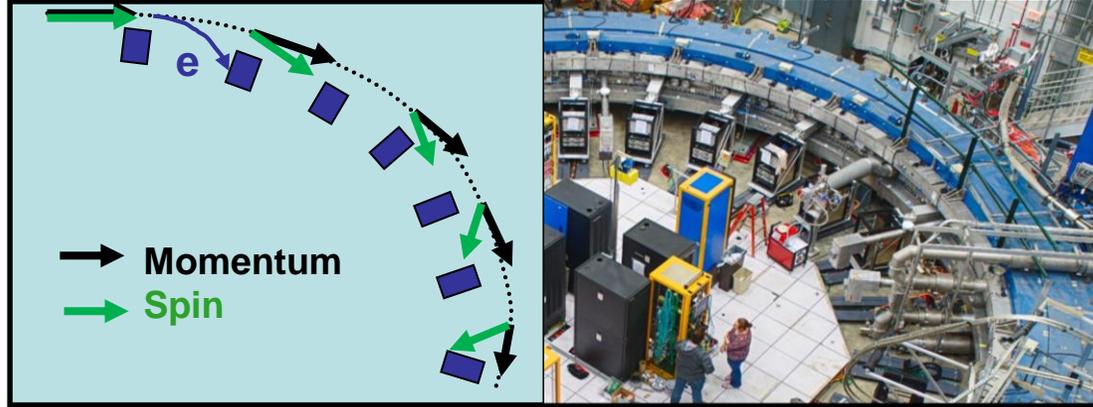
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Theory is advancing, but no experiment approved today can surpass the Fermilab record - a next-generation g-2 experiment?

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- Next-generation experimental ideas?

The Basic Principle is Simple



Determine difference between

- **spin precession frequency ω_S** and
- **cyclotron frequency ω_C**

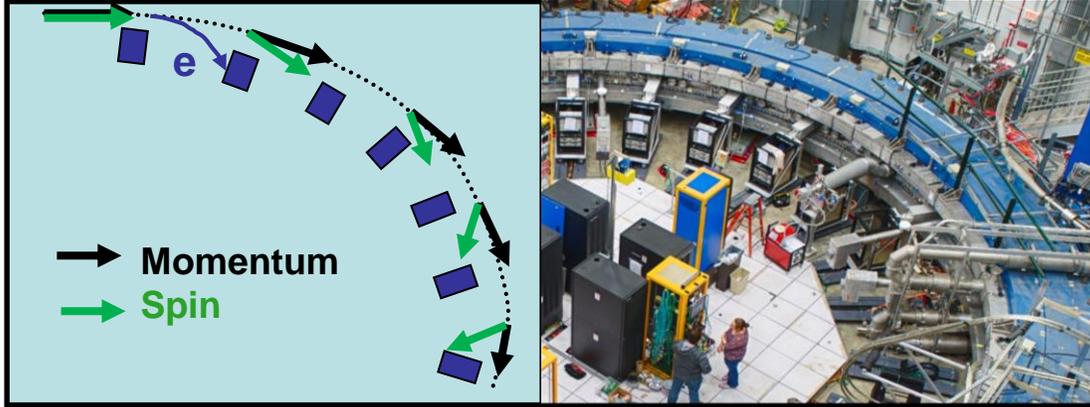
for a (polarized) muon moving in a B field

Remember: $a_\mu \equiv \frac{g_\mu - 2}{2}$

$$\omega_S = \frac{qB}{m} \left[\frac{g}{2} - \frac{\gamma - 1}{\gamma} \right] = -\frac{q}{m} \left(a_\mu + \frac{1}{\gamma} \right) \mathbf{B}, \quad \omega_C = \frac{qB}{\gamma m}$$

- **Spin rotates ahead of momentum** as muon orbits the ring
- if pure spin precession (ω_S) \rightarrow **muSR** (Lamor precession, 'g' rather than 'g-2')
- Muons have intrinsic properties enabling a spin measurement:
 - They are born polarized
 - Their decay is self analyzing to the spin direction

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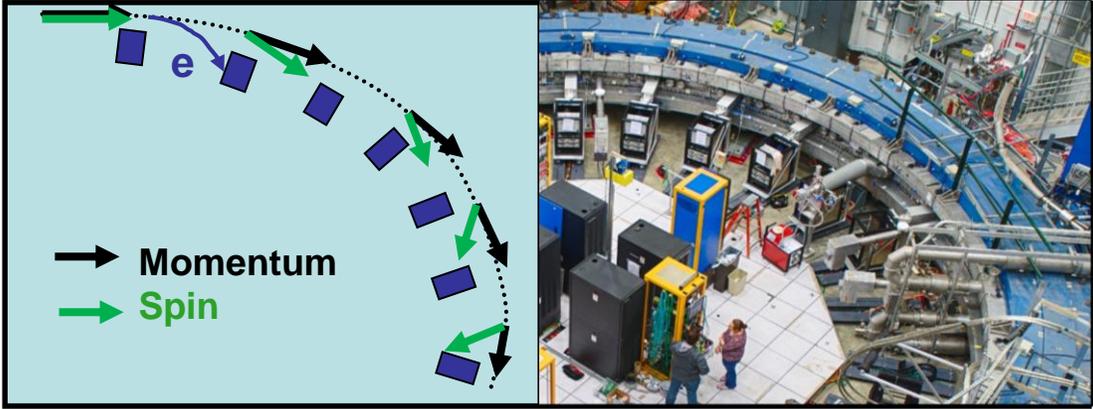
- **spin precession frequency** ω_S and
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$$\omega_S - \omega_c \equiv \omega_a = \frac{qB}{m} a_\mu$$

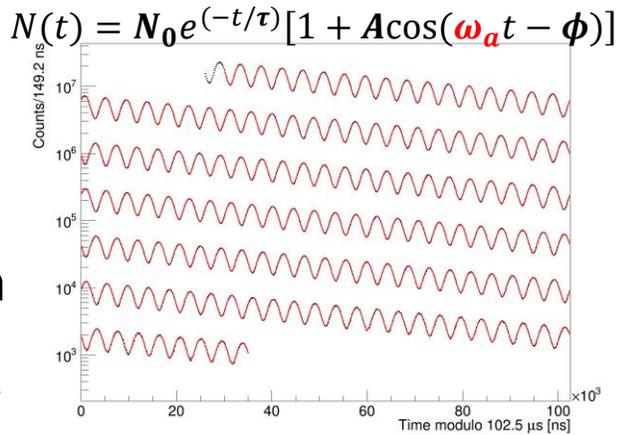
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Determine difference between

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for a (polarized) muon moving in a B field



1. Measure ω_a : modulation of decay positron time spectrum
2. Measure B : proton nuclear magnetic resonance (NMR)

$$\rightarrow 2\mu'_p(\text{H}_2\text{O}, T_r)B = \hbar\omega'_p(\text{H}_2\text{O}, T_r)$$

3. Extract a_μ

Measure these



$$\omega_S - \omega_C \equiv \omega_a = \frac{qB}{m} a_\mu$$

↑
Extract

The Full Recipe

The motion is very *nearly* planar and the momentum is very *nearly* the ideal one, but both effects are not perfect and require corrections

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

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0 if “in plane”

We have electric quadrupoles!

→ Term cancels at 3.094 GeV/c, the “Magic γ ”

The Full Recipe

The motion is very *nearly* planar and the momentum is very *nearly* the ideal one, but both effects are not perfect and require corrections

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

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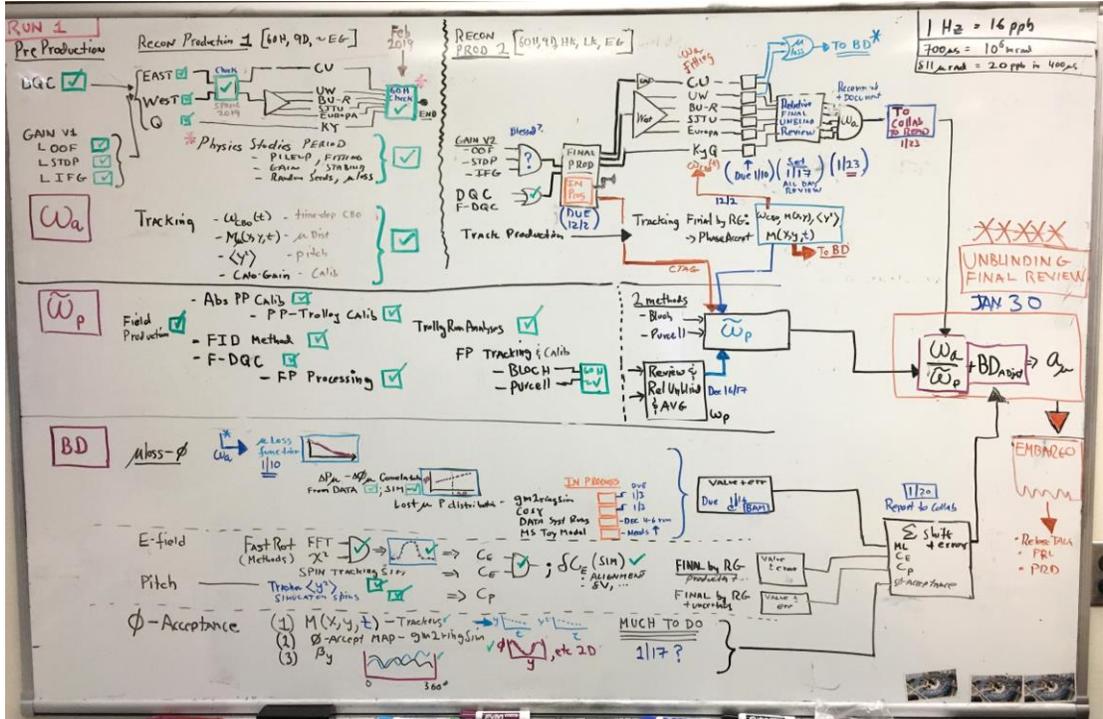
The CERN III Miracle in the 1970's
Precision: 7000 ppb

The Full Recipe - a real-world equation

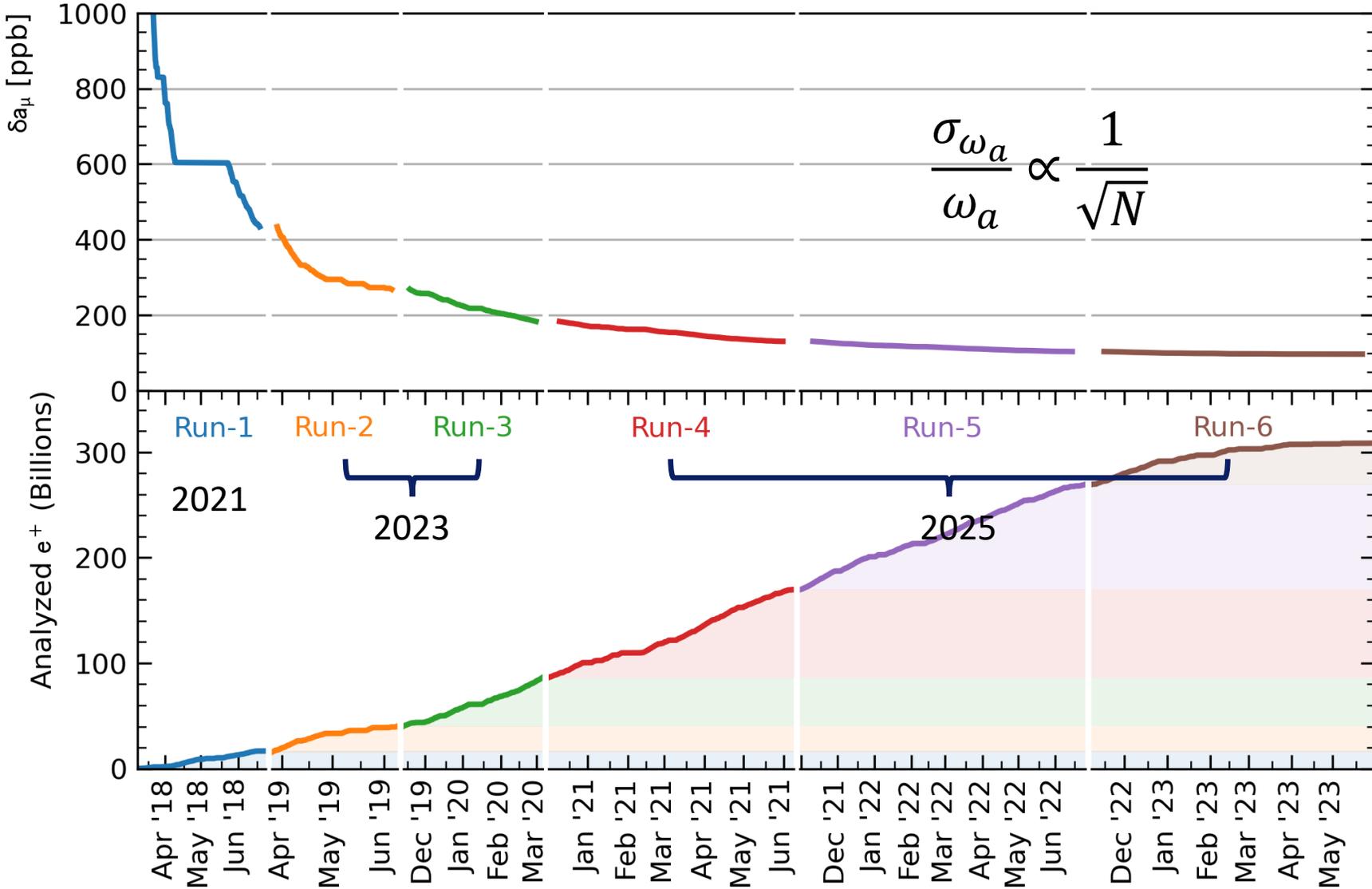
Corrections from Beam Dynamics

$$a_{\mu} = \frac{\omega_a}{\omega_p} \times \frac{(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{(1 + B_k + B_q)} \times \left[\frac{\mu'_p(T_r)}{\mu_e(H)} \frac{\mu_e(H)}{\mu_e} \frac{m_{\mu}}{m_e} \frac{g_e}{2} \right]$$

Corrections from Magnetic Field Transient



Statistics: After 6 years of running

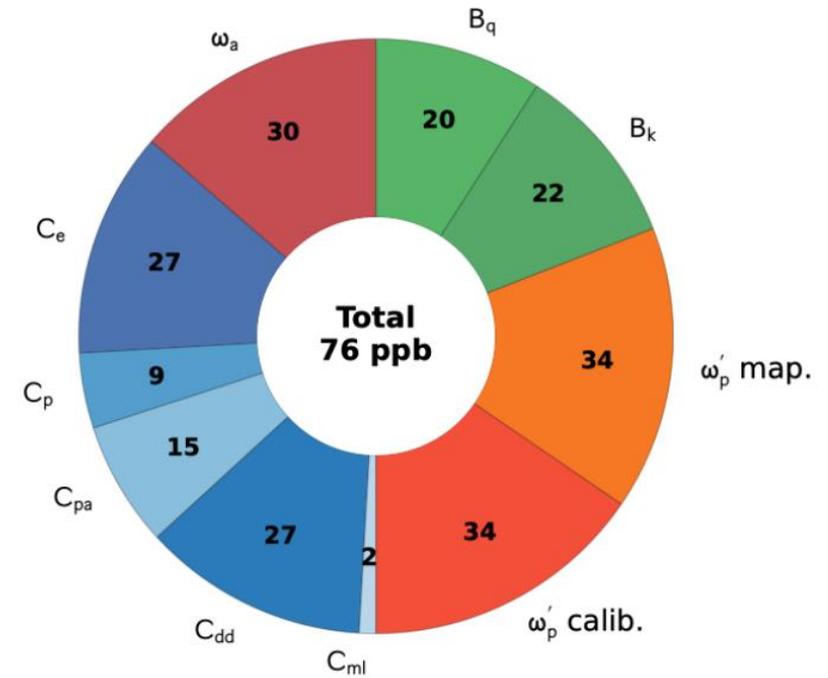


Final uncertainty budget

$$\frac{f_{clock} \omega_a^{meas} (1 + C_e + C_p + C_{ml} + C_{pa} + C_{dd})}{f_{calib} \langle \vec{x}(x, y, \phi) \times \omega_p(x, y, \phi) \rangle (1 + B_k + B_q)}$$

Run-4/5/6

Quantity	Correction (ppb)	Uncertainty (ppb)
ω_a^m (statistical)	...	114
ω_a^m (systematic)	...	30
C_e Electric Field	347	27
C_p Pitch	175	9
C_{pa} Phase Acceptance	-33	15
C_{dd} Differential Decay	26	27
C_{ml} Muon Loss	0	2
$\langle \omega_p' \times M \rangle$ (mapping, tracking)	...	34
$\langle \omega_p' \times M \rangle$ (calibration)	...	34
B_k Transient Kicker	-37	22
B_q Transient ESQ	-21	20
μ_p' / μ_B	...	4
m_μ / m_e	...	22
Total systematic for \mathcal{R}'_μ	...	76
Total for a_μ	572	139

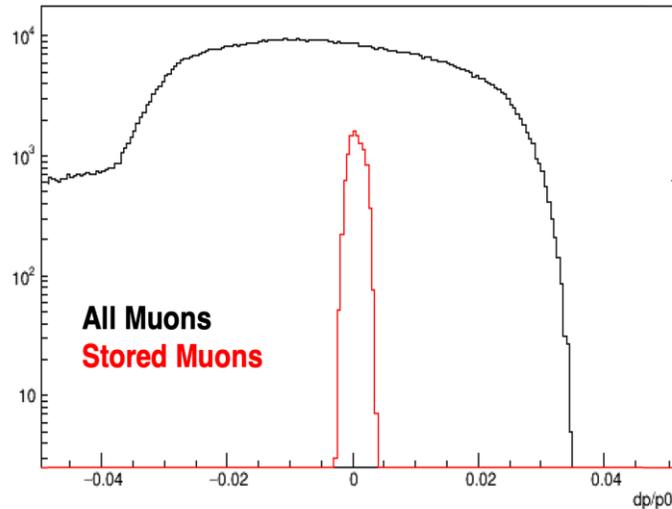


- TDR goal: 100 ppb ✓
- Systematics are “evenly” distributed:
 - No dominant source
 - Further improving would require to reduce in many categories
- **How?**

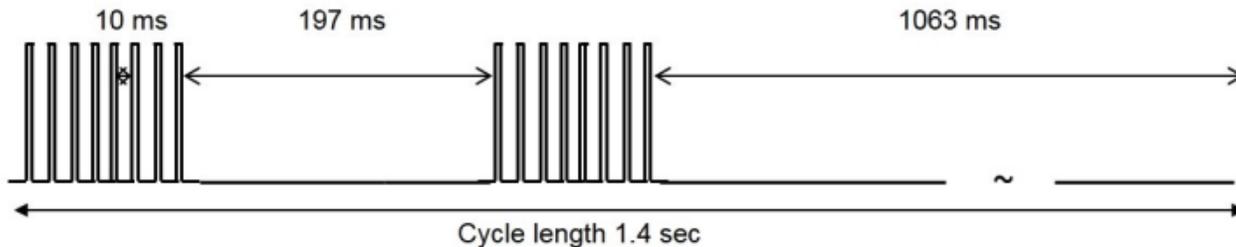
How might we do better: more muons

$$\frac{\Delta\omega_a}{\omega_a} \propto \frac{1}{\gamma BP \sqrt{N}}$$

Momentum at Ring Entrance



- Fermilab g-2 only stores **2% of incoming muons**
- A very tight momentum acceptance and time spread \rightarrow required by the **magic momentum condition**.
- A better muon beam (e.g. lower emittance muon beam) would release the current acceptance requirement and also give smaller beam oscillations (smaller C_e & C_p)



- Current bunch structure:
11 Hz operation with 1 ms data-taking
- Limited room for further improvement, given the accelerator constraints

How might we do better: linear improvement with γ & B

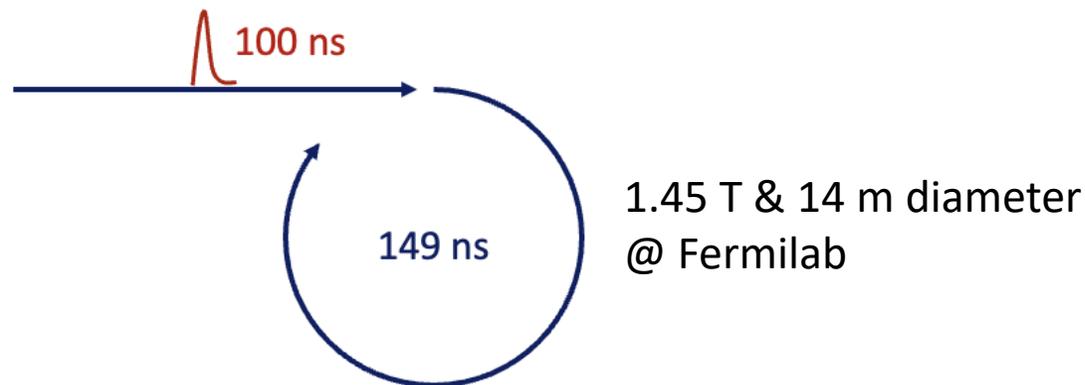
$$\frac{\Delta\omega_a}{\omega_a} \propto \frac{1}{\gamma BP\sqrt{N}}$$

- A higher γ factor \rightarrow also require relaxing the **magic momentum condition**, it could be very effective

How might we do better: linear improvement with γ & B

$$\frac{\Delta\omega_a}{\omega_a} \propto \frac{1}{\gamma B P \sqrt{N}}$$

- A higher γ factor \rightarrow also require relaxing the **magic momentum condition**, it could be very effective
- A higher **B-field** \rightarrow compact solenoid;
 - e.g. x10 improvement \rightarrow 15 T field & 1.4 m diameter for p_{magic}
 - but many challenges: bunch width < cyclotron period; hard injection, ...



Lessons learned 1) the magic momentum constraint

$$\frac{\Delta\omega_a}{\omega_a} \propto \frac{1}{\gamma B P \sqrt{N}}$$

- Therefore, it all comes down to the magic momentum:
 - It used to be a miracle, but now a limiting factor for boosting muon numbers (N) and operating at higher energy γ
 - Even for a higher \mathbf{B} -field, a higher energy γ is needed to keep the cyclotron period T_c and storage radius within a reasonable range

Lessons learned 2) systematics improvement



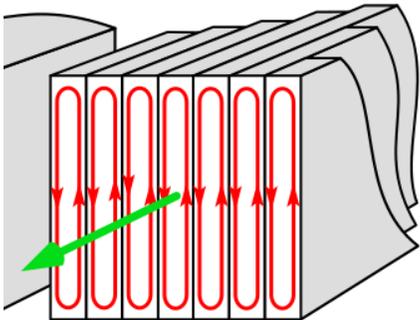
Replace calorimeters with in-vacuo silicon trackers

- Removes/reduces **gain & pile-up** issues
- Azimuthal coverage reduces beam systematics



Improve field extraction

- Better calibration chain, mapping & use of ^3He
- $\delta(m_\mu/m_e)$ of 22 ppb will decrease with MuSEUM experiment



Design out transient fields

- Remove pulsed electrostatic quadrupoles
- Redesign vacuum chambers to control kicker eddy currents

Lessons learned 2) systematics improvement

<https://arxiv.org/abs/2512.16980>

The anomalous magnetic moment of the muon: status and perspectives

David W. Hertzog¹ and Martin Hoferichter²

¹University of Washington, Department of Physics, Box 351560, Seattle, WA 98195, USA

²Albert Einstein Center for Fundamental Physics, Institute for Theoretical Physics, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland

5.2. Can an experiment go beyond 124 ppb?

5.2.2. At FNAL. Inevitably, the question arises: *Can one do better at FNAL?* Despite the present limitations of the SM prediction, we describe a thought exercise that illustrates a potential path toward an improved experimental precision by roughly a factor of three—to the level of $\simeq 40$ ppb—should future developments warrant it.¹¹ The concept envisions a ten-fold increase in statistics (30 ppb) combined with a three-fold reduction in systematics (25 ppb). The external constant uncertainties should decrease to about 10 ppb because of anticipated future muonium experiments (200).

In this discussion, the existing FNAL SR, beamlines, and supporting infrastructure are largely retained. The PIP-II LINAC upgrade (201) is expected to deliver a 30% higher proton flux at a 33% faster repetition cycle. It will be necessary to upgrade the Recycler RF system to better rebunch the injected proton batches into shorter pulses. This will both improve the kicker efficiency and largely eliminate the systematic uncertainty from differential decay (see Fig. 2(C)). Current $g - 2$ simulations indicate that 25 ns-long bunches are stored 1.7 times more efficiently and another multiplicative factor of 1.3 can be realized by installing the built, but never used, open-ended inflector. Additional nearly two-fold storage efficiency is expected if the ESQ voltages can be raised to their design values, a challenge that remains owing to sparks that limited the maximum voltage in F089. These

arXiv:2512.16980v2 [hep-ph] 18 Feb 2026

Ann. Rev. Nucl. Part. Sci. 2026. 76:1–27

<https://doi.org/10.1146/annurev-nucl-102422-040841>

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Keywords

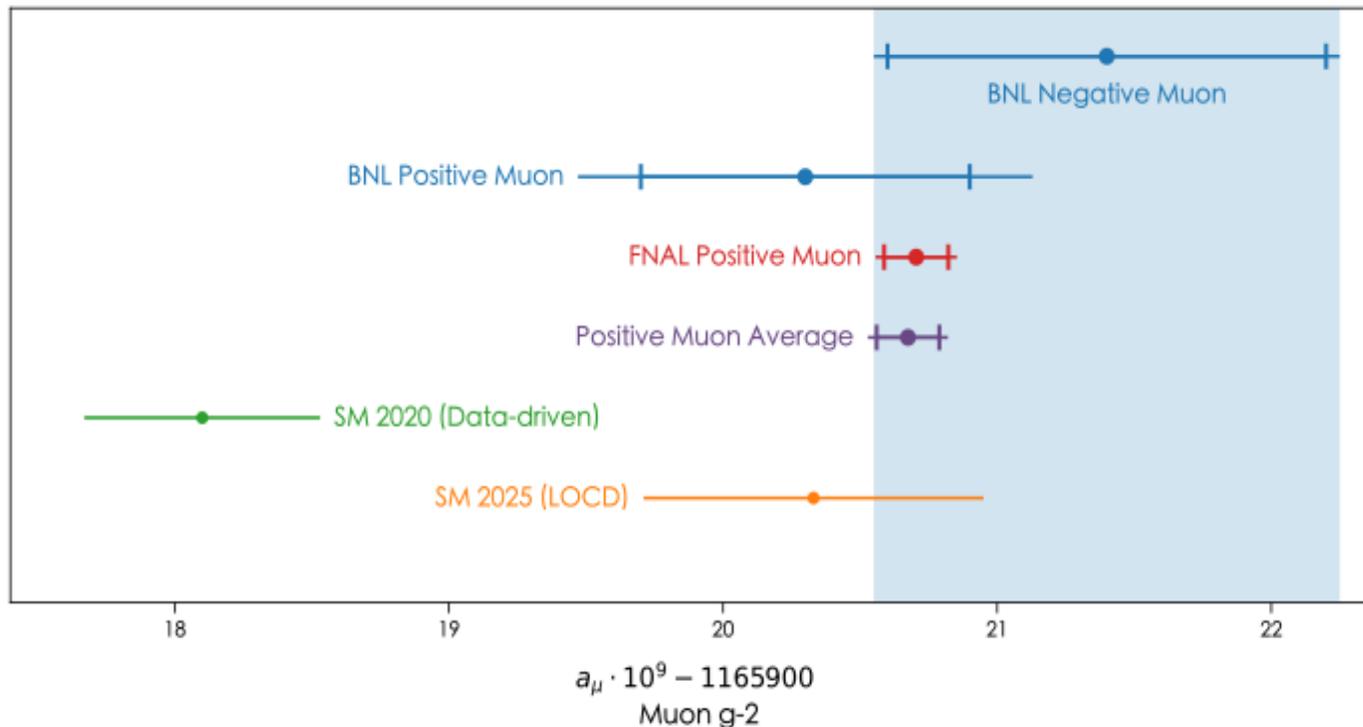
anomalous magnetic moment, muon

Abstract

We review the status of the anomalous magnetic moment of the muon as a precision probe of physics beyond the Standard Model (SM) after the release of the final results from the Fermi National Accelerator Laboratory (FNAL) Muon $g - 2$ experiment and the second White Paper of the Muon $g - 2$ Theory Initiative. While the SM prediction requires further improvements by a factor of four to fully leverage the sensitivity achieved in experiment, the FNAL measurement will set the standard for many years to come, and we discuss a variety of features of the experimental campaign that made this achievement possible. In going forward, we discuss current efforts to improve the SM prediction, and imagine how an experiment would have to be devised to surpass 124 ppb in precision.

Yet another limitation: only *positive* muons measured @ Fermilab

- Fermilab measured the *positive* muon (μ^+) with a precision of **0.14 ppm**;
- The most recent measurement of the *negative* muon (μ^-) still dates back to the BNL era, with a precision of **0.7 ppm** — about five times worse.



CPT and Lorentz-violation test with negative muon ($g - 2$)

- In the Standard Model, μ^+ and μ^- $g-2$ should be the same \rightarrow any difference would be direct evidence of CPT violation and new physics.
- A precise μ^- $g-2$ alongside μ^+ would greatly improve sensitivity to new physics in the muon sector and tightens constraints on many models.

PRL 100, 091602 (2008)

PHYSICAL REVIEW LETTERS

week ending
7 MARCH 2008

Search for Lorentz and CPT Violation Effects in Muon Spin Precession

G. W. Bennett,² B. Bousquet,¹⁰ H. N. Brown,² G. Bunce,² R. M. Carey,¹ P. Cushman,¹⁰ G. T. Danby,² P. T. Debevec,⁸ M. Deile,¹³ H. Deng,¹³ W. Deninger,⁸ S. K. Dhawan,¹³ V. P. Druzhinin,³ L. Duong,¹⁰ E. Efstathiadis,¹ F. J. M. Farley,¹³ G. V. Fedotovitch,³ S. Giron,¹⁰ F. E. Gray,⁸ D. Grigoriev,³ M. Grosse-Perdekamp,¹³ A. Grossmann,⁷ M. F. Hare,¹ D. W. Hertzog,⁸ X. Huang,¹ V. W. Hughes,^{13,*} M. Iwasaki,¹² K. Jungmann,^{6,7} D. Kawall,¹³ M. Kawamura,¹² B. I. Khazin,³ J. Kindem,¹⁰ F. Krienen,¹ I. Kronkvist,¹⁰ A. Lam,¹ R. Larsen,² Y. Y. Lee,² I. Logashenko,^{1,3} R. McNabb,^{8,10} W. Meng,² J. Mi,² J. P. Miller,¹ Y. Mizumachi,^{9,11} W. M. Morse,² D. Nikas,² C. J. G. Onderwater,^{6,8} Y. Orlov,⁴ C. S. Özben,^{2,8} J. M. Paley,¹ Q. Peng,¹ C. C. Polly,⁸ J. Pretz,¹³ R. Prigl,² G. zu Putlitz,⁷ T. Qian,¹⁰ S. I. Redin,^{3,13} O. Rind,¹ B. L. Roberts,¹ N. Ryskulov,³ S. Sedykh,⁸ Y. K. Semertzidis,² P. Shagin,¹⁰ Yu. M. Shatunov,³ E. P. Sichtermann,¹³ E. Solodov,³ M. Sossong,⁸ A. Steinmetz,¹³ L. R. Sulak,¹ C. Timmermans,¹⁰ A. Trofimov,¹ D. Urner,⁸ P. von Walter,⁷ D. Warburton,² D. Winn,⁵ A. Yamamoto,⁹ and D. Zimmerman¹⁰

(Muon $g - 2$ Collaboration)

In 2008, BNL set stringent limits on the parameters of CPT-violating Standard-Model Extension (SME):

$$\Delta\omega_a \equiv \langle \omega_a^{\mu^+} \rangle - \langle \omega_a^{\mu^-} \rangle = \frac{4b_Z}{\gamma} \cos \chi$$

$$b_Z = -(1.0 \pm 1.1) \times 10^{-23} \text{ GeV}$$

b_Z is a parameter characterizing the potential for CPT-odd (CPT-violating) effects.

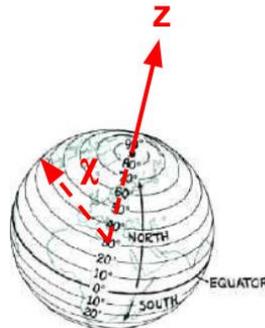
CPT and Lorentz-violation test with negative muon ($g - 2$)

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- A precise μ^- $g-2$ alongside μ^+ would greatly improve sensitivity to new physics in the muon sector and tightens constraints on many models.

• SME Lagrangian:

$$\mathcal{L}' = -a_\kappa \bar{\psi} \gamma^\kappa \psi - \underbrace{(b_\kappa)}_{\text{CPT-odd}} \bar{\psi} \gamma_5 \gamma^\kappa \psi - \frac{1}{2} H_{\kappa\lambda} \bar{\psi} \sigma^{\kappa\lambda} \psi + \frac{1}{2} i c_{\kappa\lambda} \bar{\psi} \gamma^\kappa \overleftrightarrow{D}^\lambda \psi + \frac{1}{2} i d_{\kappa\lambda} \bar{\psi} \gamma_5 \gamma^\kappa \overleftrightarrow{D}^\lambda \psi$$

- All terms violate Lorentz invariance
- a_κ, b_κ are CPT-odd; others are CPT-even

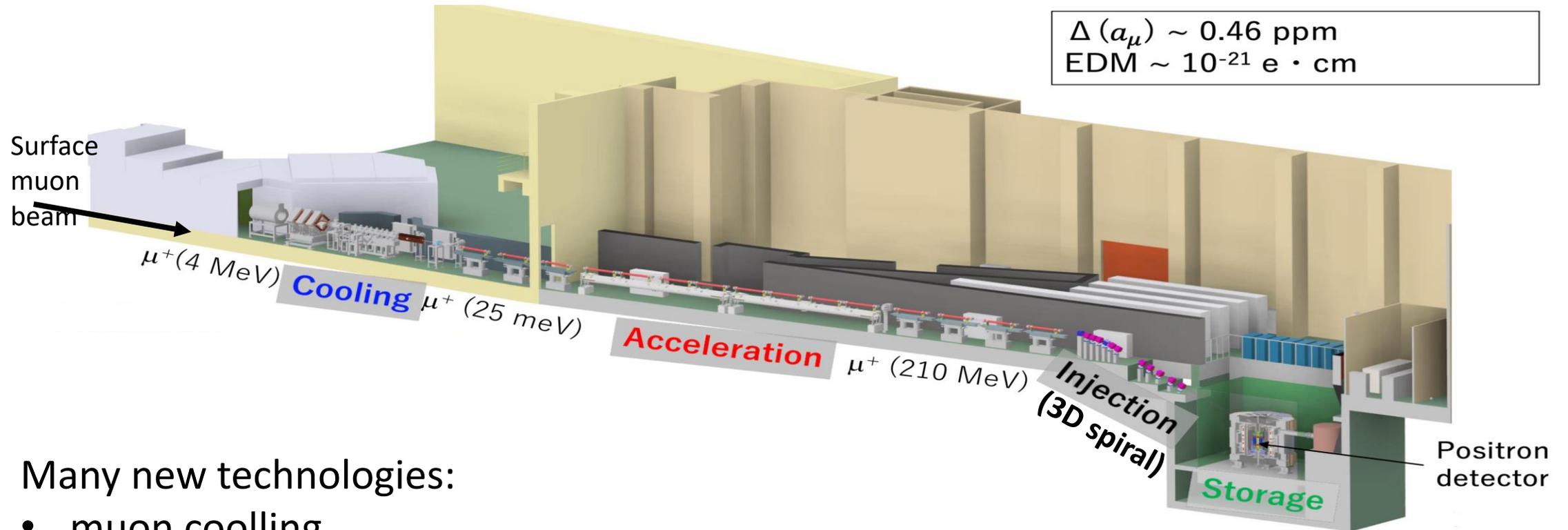


Courtesy: Breese Quinn

Table D21. Muon sector, $d = 3$

Combination	Result	System	Ref.
$ \text{Re } H_{011}^{\text{NR}(0B)} , \text{Im } H_{011}^{\text{NR}(0B)} , \text{Re } g_{011}^{\text{NR}(0B)} , \text{Im } g_{011}^{\text{NR}(0B)} $	$< 2 \times 10^{-22}$ GeV	Muonium spectroscopy	[20]*
$ \text{Re } H_{011}^{\text{NR}(1B)} , \text{Im } H_{011}^{\text{NR}(1B)} , \text{Re } g_{011}^{\text{NR}(1B)} , \text{Im } g_{011}^{\text{NR}(1B)} $	$< 7 \times 10^{-23}$ GeV	"	[20]*
b^T/m_μ	$(7.3 \pm 5.0) \times 10^{-7}$	Muon decay	[184]*
b_Z	$-(1.0 \pm 1.1) \times 10^{-23}$ GeV	BNL $g_\mu - 2$	[185]
$\sqrt{(\tilde{b}_X^+)^2 + (\tilde{b}_Y^+)^2}$	$< 1.4 \times 10^{-24}$ GeV	"	[185]
$\sqrt{(\tilde{b}_X^-)^2 + (\tilde{b}_Y^-)^2}$	$< 2.6 \times 10^{-24}$ GeV	"	[185]
$\sqrt{(\tilde{b}_X)^2 + (\tilde{b}_Y)^2}$	$< 2 \times 10^{-23}$ GeV	Muonium spectroscopy	[186]
$b_Z - 1.19(m_\mu d_{Z0} + H_{XY})$	$(-1.4 \pm 1.0) \times 10^{-22}$ GeV	BNL, CERN $g_\mu - 2$ data	[187]
b_Z	$(-2.3 \pm 1.4) \times 10^{-22}$ GeV	CERN $g_\mu - 2$ data	[187], [188]*
$ \text{Re } H_{011}^{(3)(0B)} , \text{Im } H_{011}^{(3)(0B)} $	$< 5 \times 10^{-23}$ GeV	"	[20]*
$\tilde{H}_{011}^{(3)}$	$(-1.6 \pm 1.7) \times 10^{-22}$ GeV	BNL, CERN $g_\mu - 2$ data	[20]*
$ \text{Re } \tilde{H}_{011}^{(3)} , \text{Im } \tilde{H}_{011}^{(3)} $	$< 2.0 \times 10^{-24}$ GeV	BNL $g_\mu - 2$	[20]*
$m_\mu d_{Z0} + H_{XY}$	$(1.8 \pm 6.0) \times 10^{-23}$ GeV	"	[185]

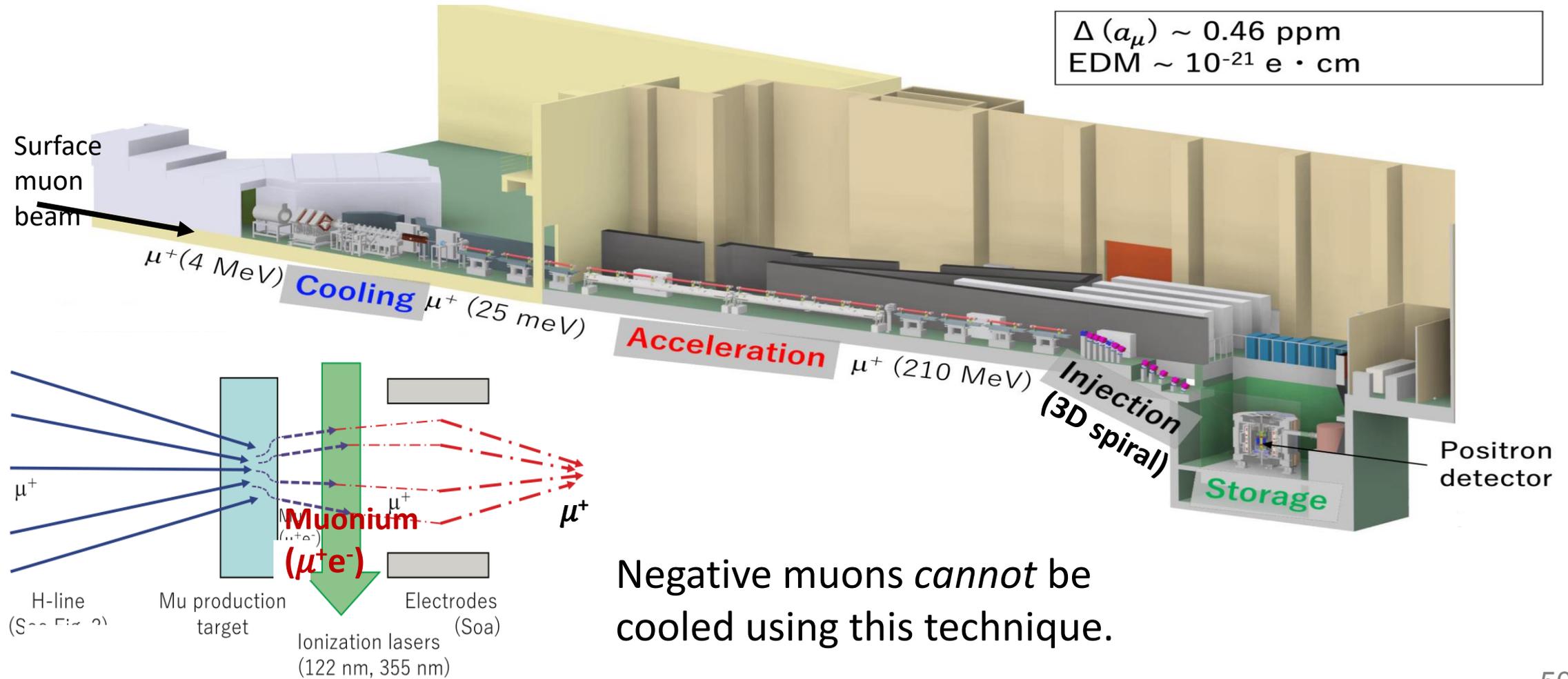
The g-2 experiment at J-PARC



Many new technologies:

- muon cooling
- low-emittance beam \rightarrow NO E-field and **NO magic momentum constraint!**
- but it only reaccelerates (positive) muon up to 210 MeV...

The g-2 experiment at J-PARC

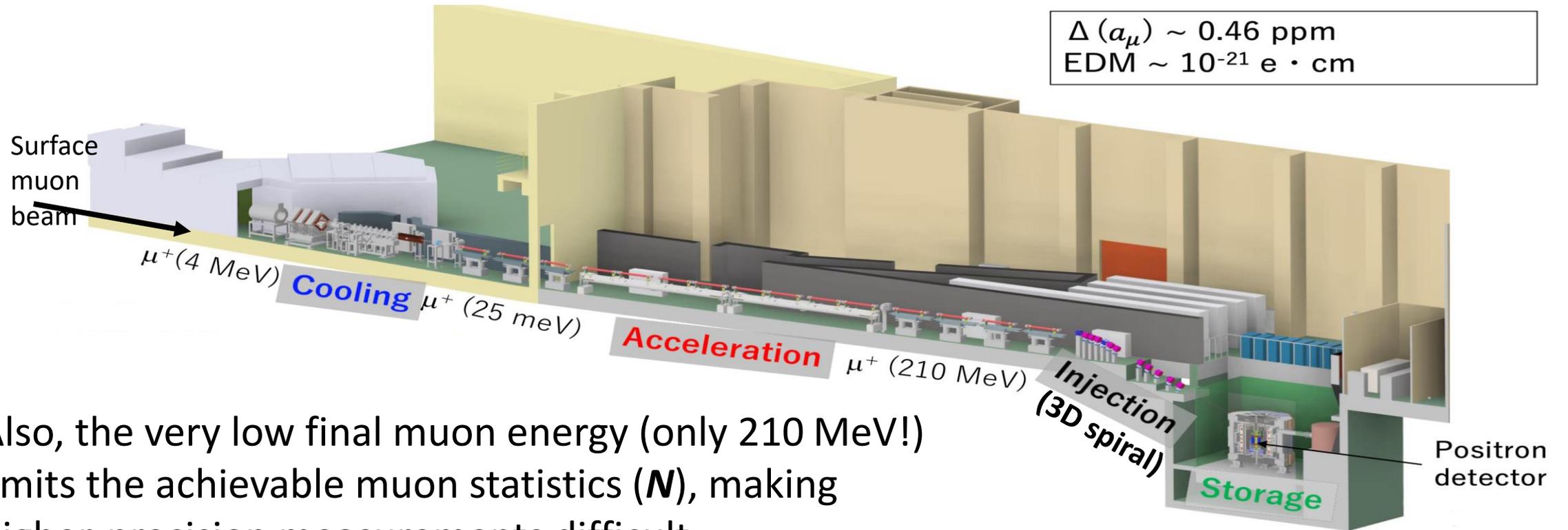


Negative muons *cannot* be cooled using this technique.

The g-2 experiment at J-PARC

Remember: Fermilab achieved 0.13 ppm

$$\Delta(a_\mu) \sim 0.46 \text{ ppm}$$
$$\text{EDM} \sim 10^{-21} \text{ e} \cdot \text{cm}$$



Also, the very low final muon energy (only 210 MeV!) limits the achievable muon statistics (N), making higher-precision measurements difficult.

In this sense, I would not call J-PARC g-2 a real 'next-generation experiment', but it is a good platform for technological development.

Probably another lesson learned: plan ahead and avoid rapid technology changes...

A Next-generation muon g-2?

- 1) Precision goals match or surpass FNAL precision (0.1 ppm)
- 2) A new approach as an independent cross-check of the Fermilab result
- 3) If feasible, prioritize negative μ^- for additional physics reach

A Next-generation muon g-2?

- 1) Precision goals match or surpass FNAL precision (0.1 ppm)
- 2) A new approach as an independent cross-check of the Fermilab result
- 3) If feasible, prioritize negative μ^- for additional physics reach

Lessons learned suggest considering relaxing the magic momentum constraint:

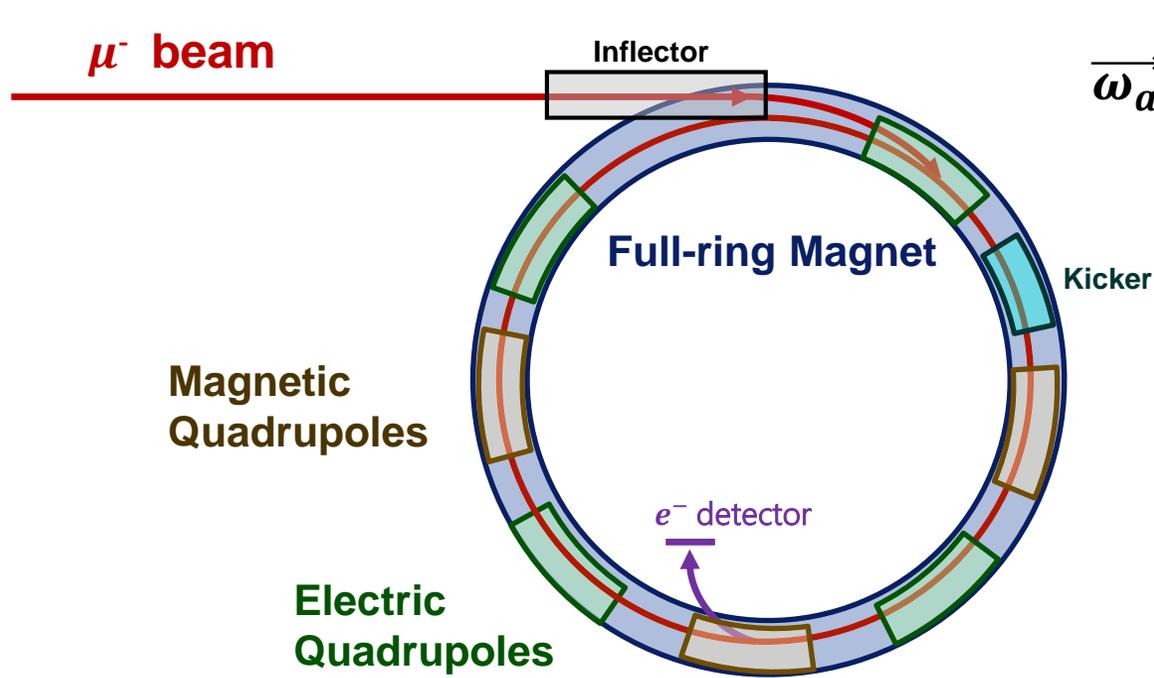
- Increase statistical precision (via higher γ , B , \sqrt{N} , ...)
- Reduce E-field-related systematics (C_e , B_k , ...)

This naturally points to **a novel focusing scheme**

*Prerequisite for sufficient statistics: a high-intensity GeV-scale muon source

Concept 1) Hybrid weak focusing

- A hybrid focusing system with E-quadrupoles and B-quadrupoles, using higher-order B fields to compensate for higher-order E-fields:



$$\vec{\omega}_a = -\mathbf{a}_\mu \frac{q}{m_\mu} (\vec{B}_0 + \dots) + \frac{q}{m_\mu} \left[\left(\mathbf{a}_\mu - \frac{1}{\gamma^2 - 1} \right) \frac{\vec{\beta} \times \vec{E}}{c} \right]$$

PHYSICAL REVIEW ACCELERATORS AND BEAMS 25, 024001 (2022)

Analytical estimations of the chromaticity and corrections to the spin precession frequency in weak focusing magnetic storage rings

On Kim^{1,*} and Yannis K. Semertzidis^{1,2}

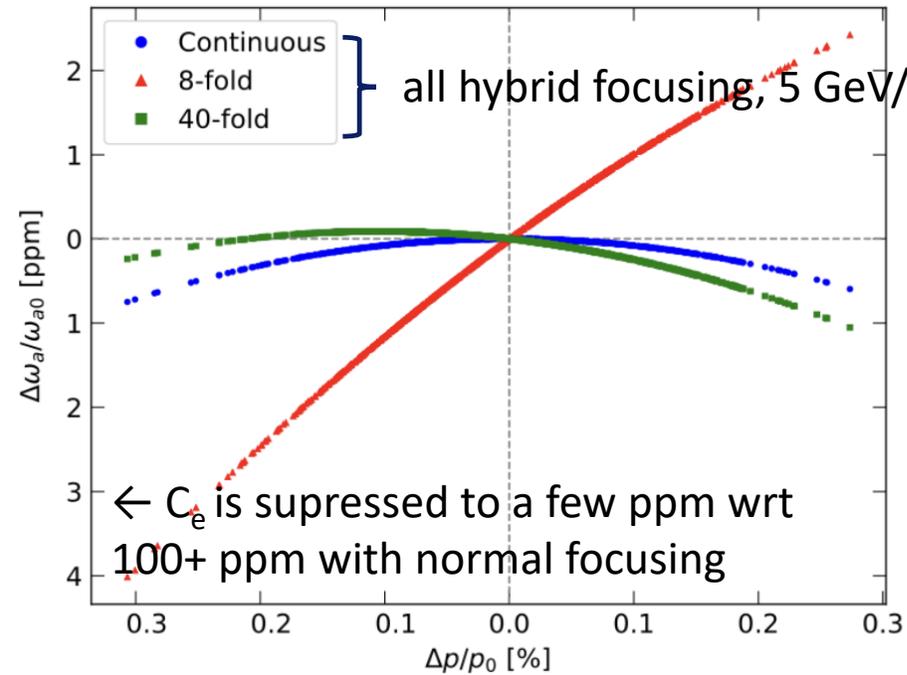
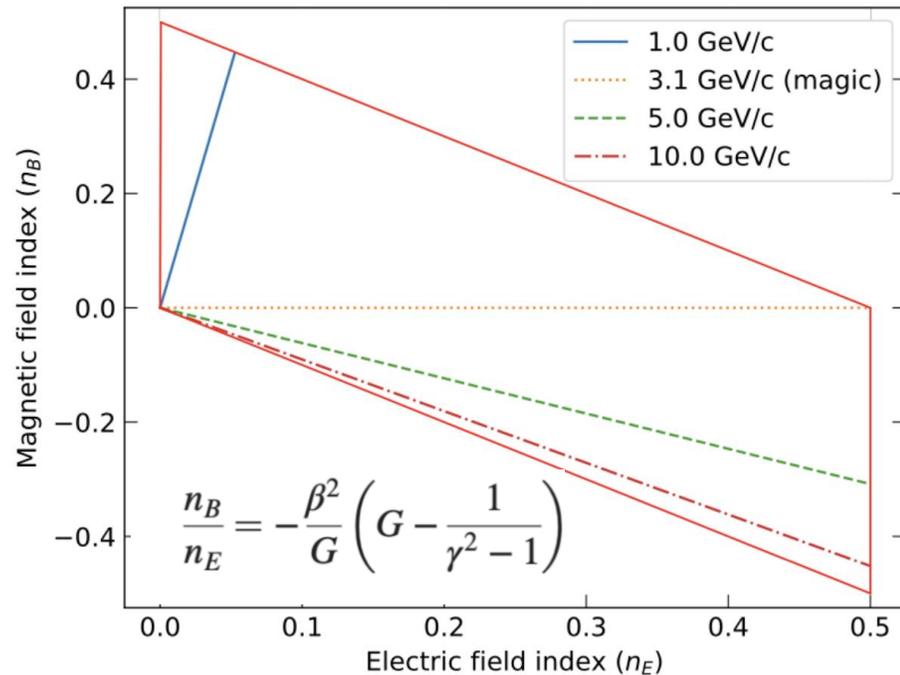
¹Center for Axion and Precision Physics Research, Institute for Basic Science, Daejeon 34051, Republic of Korea

²Department of Physics, Korea Advanced Institute for Science and Technology, Daejeon 34141, Republic of Korea

(Received 18 October 2021; accepted 8 February 2022; published 18 February 2022)

Concept 1) Hybrid weak focusing

Detailed configs for E and B field



Now all are analytic - will need to demonstrate it works with a more realistic beam dynamics

- In principle it's straightforward to recycle the magnet from FNAL
- If Concept A turns to be too challenging, one could start with a more traditional version here.

Concept 2) Proton beam comagnetometer

HFRS (HIRIBL)

μ^- bunch

Nuclear Instruments and Methods in Physics
 Research Section A: Accelerators, Spectrometers,
 Detectors and Associated Equipment
 Volume 523, Issue 3, 11 May 2004, Pages 251-255

A new ring structure for muon ($g-2$)
 measurements

F.J.M. Farley

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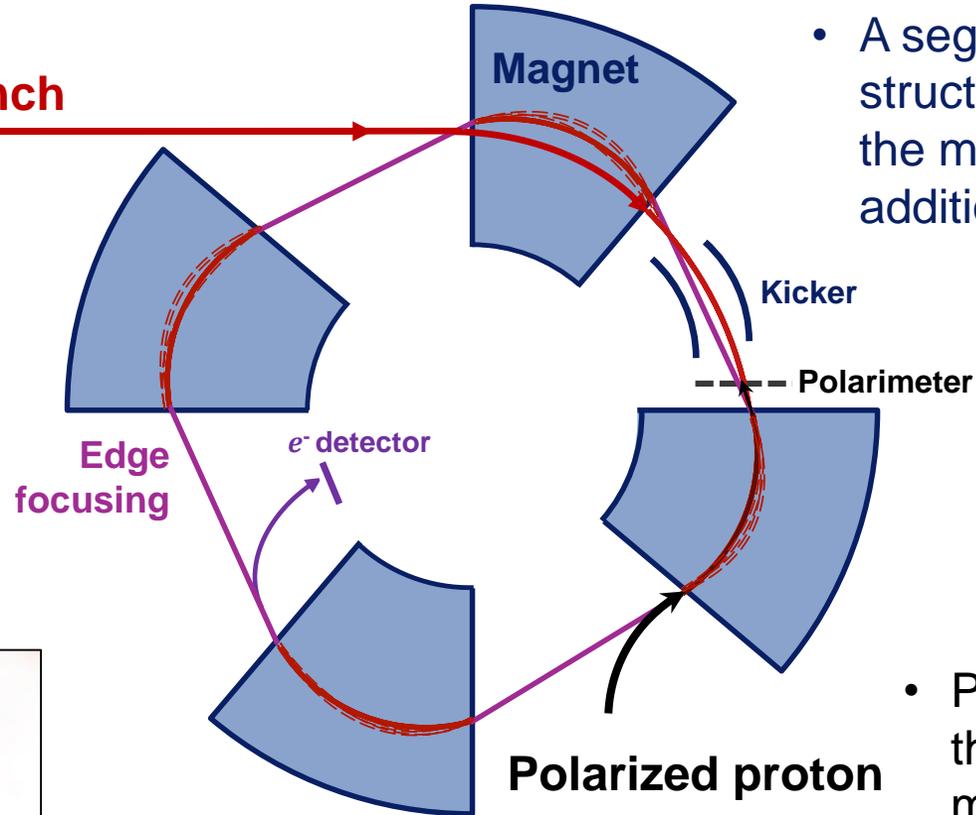
<https://doi.org/10.1016/j.nima.2003.12.016>

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UNIVERSITY OF LIVERPOOL

"Edge focusing"

courtesy: Chris Rogers



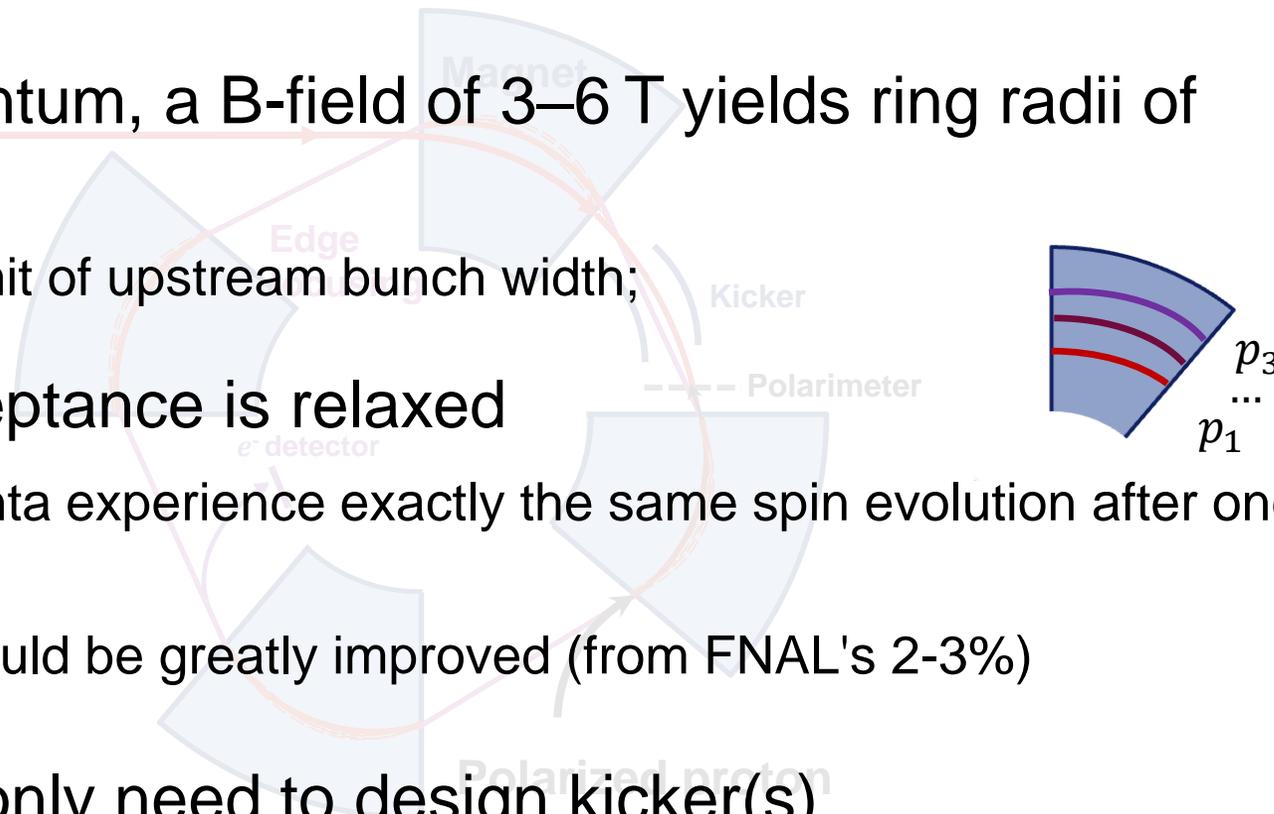
- A segmented sector magnet structure with fringe fields to focus the muons, removing the need for additional E field focusing.

- Polarized protons experience the same magnetic field as the muons for a direct calibration of the magnetic field.

Concept 2) Proton beam comagnetometer

A bit more ideas

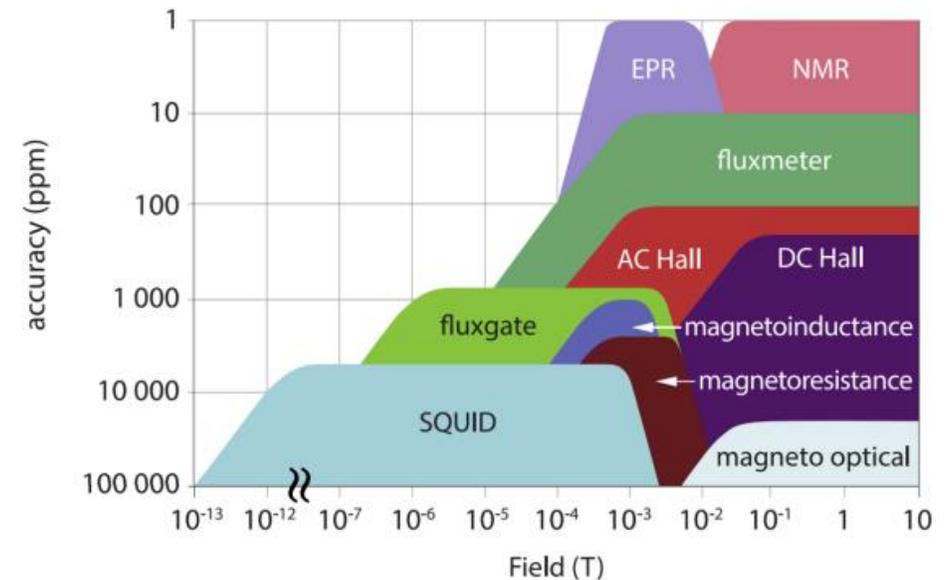
- Given the magic momentum, a B-field of 3–6 T yields ring radii of approximately 7–3 m
 - Challenging due to the limit of upstream bunch width;
- A strict momentum acceptance is relaxed
 - Muons of different momenta experience exactly the same spin evolution after one full turn in the magnetic field;
 - The injection efficiency could be greatly improved (from FNAL's 2-3%)
- No inflector needed → only need to design kicker(s)



Concept 2) Proton beam comagnetometer

B-field calibration systematics

- Forseeably, one big challenge is the segment magnets and the calibration of its edge field calibration
- **Polarized proton beam:** essentially a 'denser form' of the NMR probe.
 - Fringe fields with large gradients confined to limited regions where NMR fails;
 - The proton approach could be combined with conventional methods — EPR probes or machine-learning-based fitting — to further improve the precision.



Proposal at China's HIAF

arXiv > hep-ex > arXiv:2512.11486

Search

Help

High Energy Physics – Experiment

[Submitted on 12 Dec 2025]

CANTON- μ Proposal: A Next-Generation Muon $g-2$ Measurement at Sub-0.1 ppm Precision

Ce Zhang, Yu Xu, On Kim, Bingzhi Li, Guodong Shen, Liangwen Chen, Fedor Ignatov, Liang Li, Qiang Li, Xueheng Zhang, Zhiyu Sun

We propose a next-generation precision measurement of the muon anomalous magnetic moment ($g - 2$) at the High Intensity Heavy-Ion Accelerator Facility (HIAF) in Huizhou, China. The project, named CANTON- μ (Coherent Anomalous magNetic momenT ObservatioN with muon), describes novel experimental approaches based on HIAF's unique capability to produce intense pulsed muon beams at the GeV scale, particularly for negative-muon polarity. These approaches incorporate innovative focusing concepts such as the sector-magnet and weak-focusing ring designs, complemented by advanced magnetic-field calibration methods including a polarized-proton co-magnetometer. This independent measurement with distinct systematics is designed to achieve a precision of 0.1 ppm in Phase 1, matching the latest Fermilab result for μ^+ , and 0.05 ppm in Phase 2 with the HIAF upgrade. Such precision will provide an exceptionally sensitive test of the Standard Model and a powerful probe of New Physics and CPT symmetry.

Comments: 25 pages, 7 figures

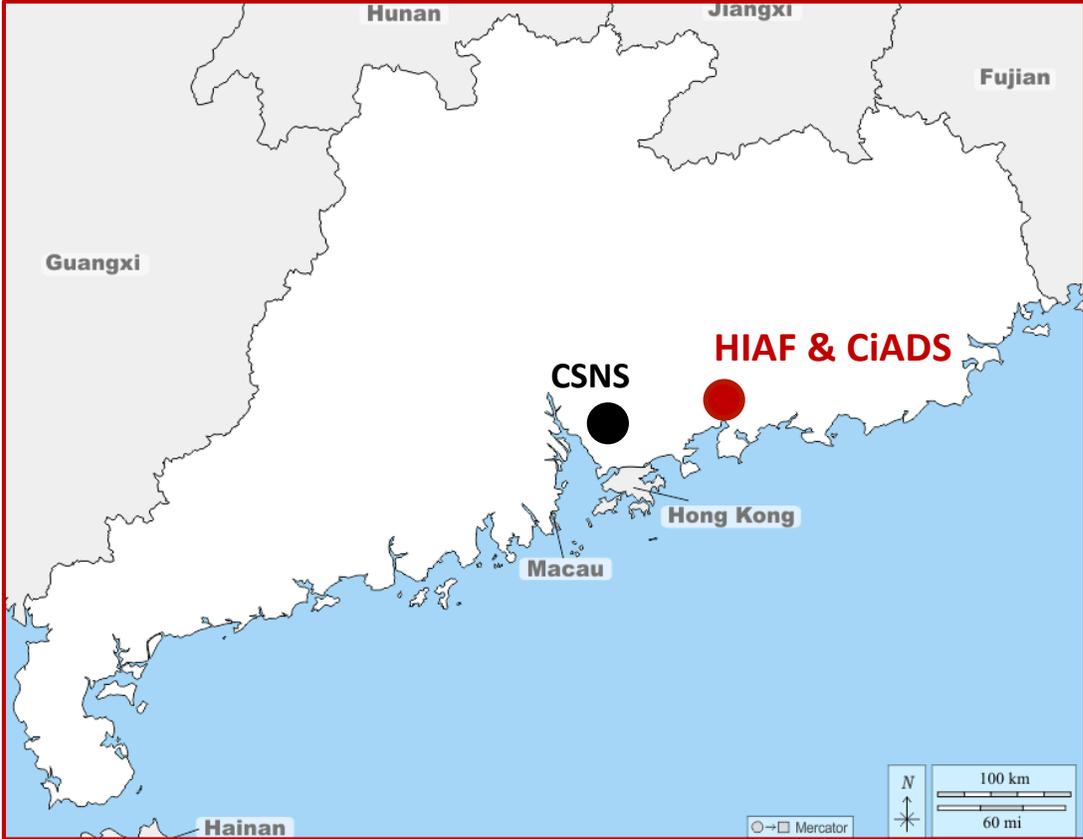
Subjects: **High Energy Physics – Experiment (hep-ex)**

Cite as: [arXiv:2512.11486](https://arxiv.org/abs/2512.11486) [hep-ex]

(or [arXiv:2512.11486v1](https://arxiv.org/abs/2512.11486v1) [hep-ex] for this version)

<https://doi.org/10.48550/arXiv.2512.11486> 

Proposal at China's HIAF

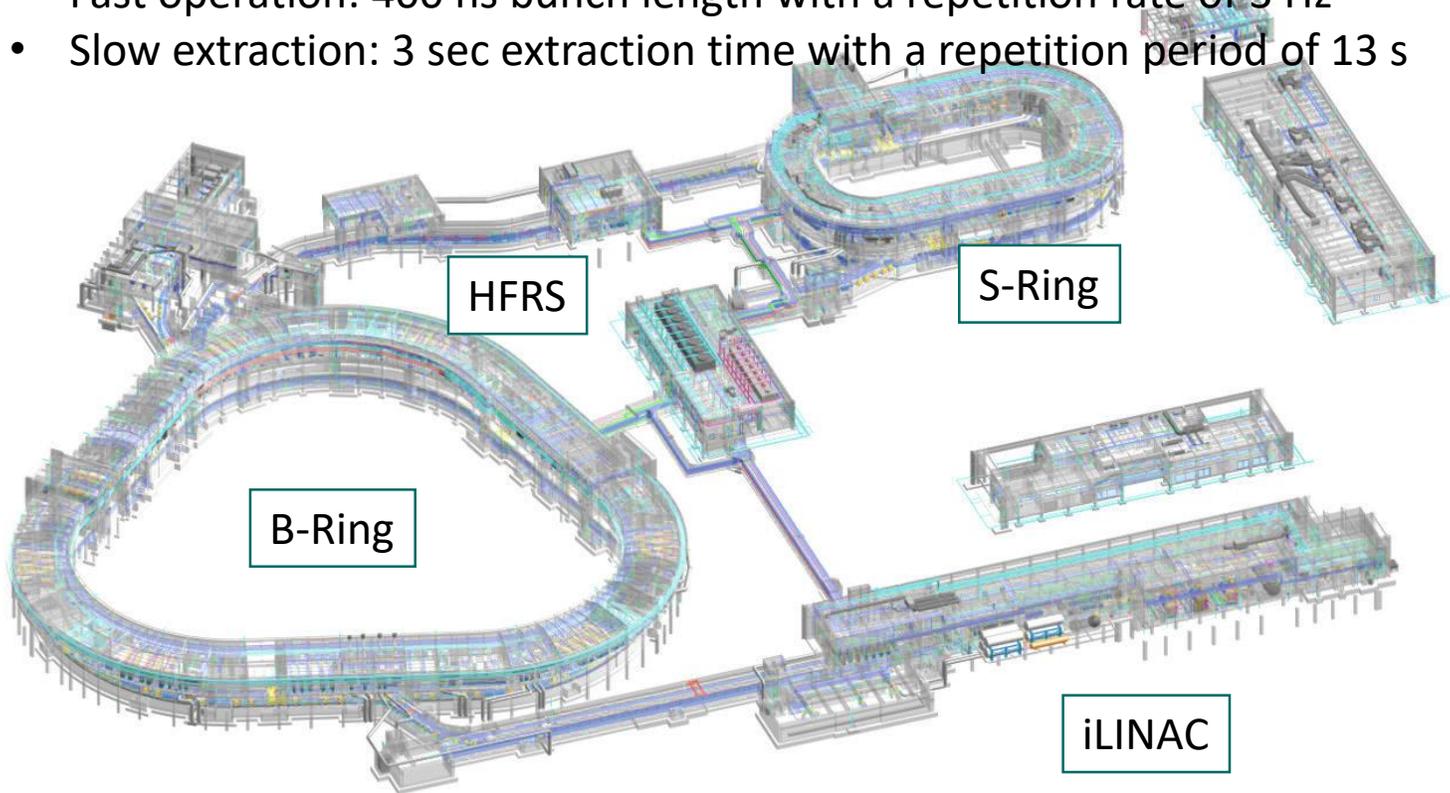


HIAF

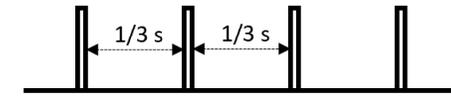
High Intensity heavy-ion Accelerator Facility

Two modes :

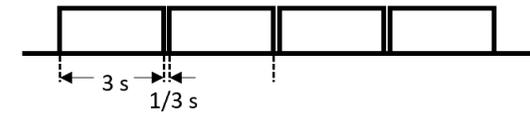
- Fast operation: 400 ns bunch length with a repetition rate of 3 Hz
- Slow extraction: 3 sec extraction time with a repetition period of 13 s



Fast extraction: High-intensity pulsed p/ion



Slow extraction: Quasi-continuous p/ion



	34Tm, 3Hz	
Ions	Particle per pulse (ppp)	Energy(Ge V/u)
$^{238}\text{U}^{35+}$	1.0×10^{11}	0.84
$^{209}\text{Bi}^{27+}$	1.2×10^{11}	0.85
$^{78}\text{Kr}^{19+}$	3.0×10^{11}	1.7
$^{18}\text{O}^{6+}$	6.0×10^{11}	2.6
Proton	2.0×10^{12}	9.3

HIAF

High Intensity heavy-ion Accelerator Facility

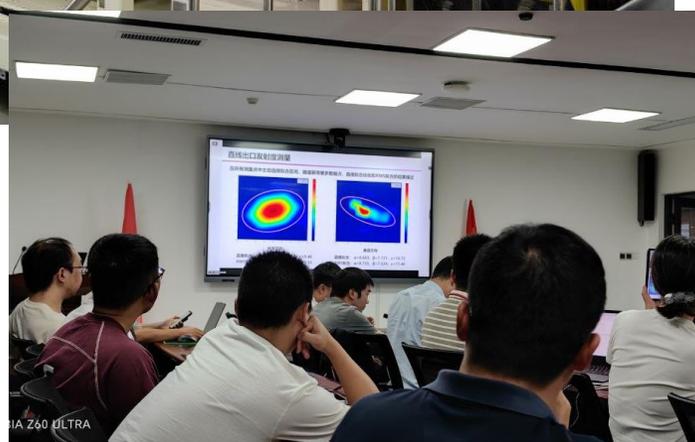
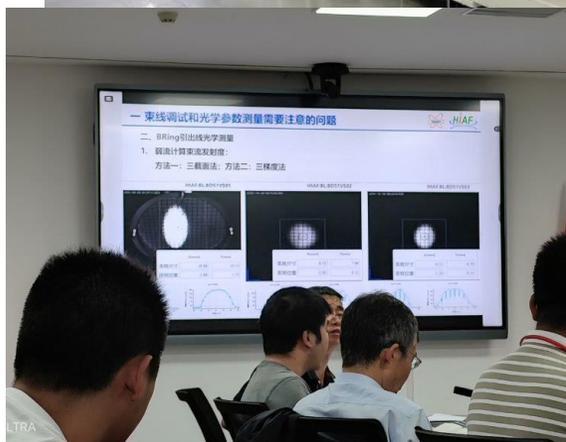


HIAF

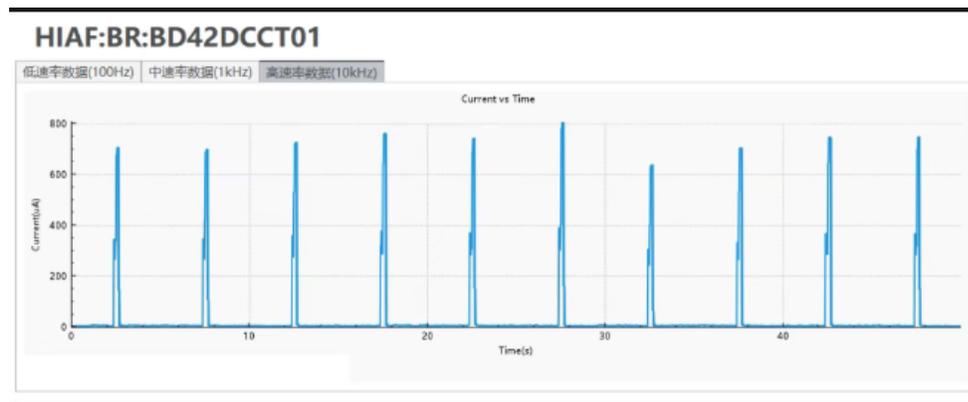
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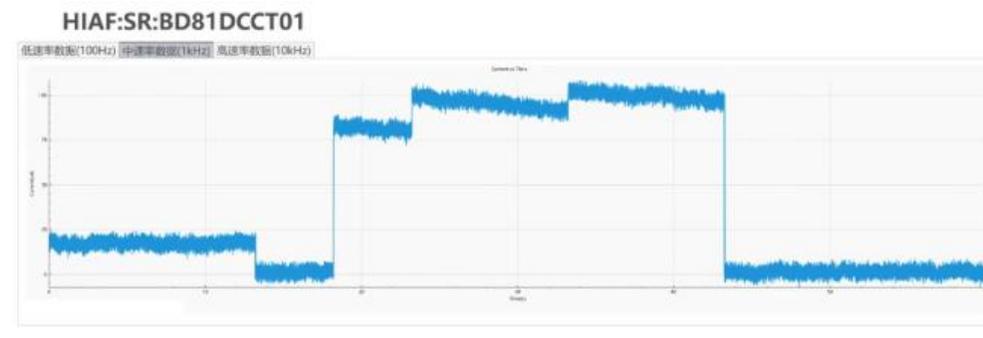
HIAF



First beam commissioning on 28th October 2025
First muon beam expected this year (2026)!



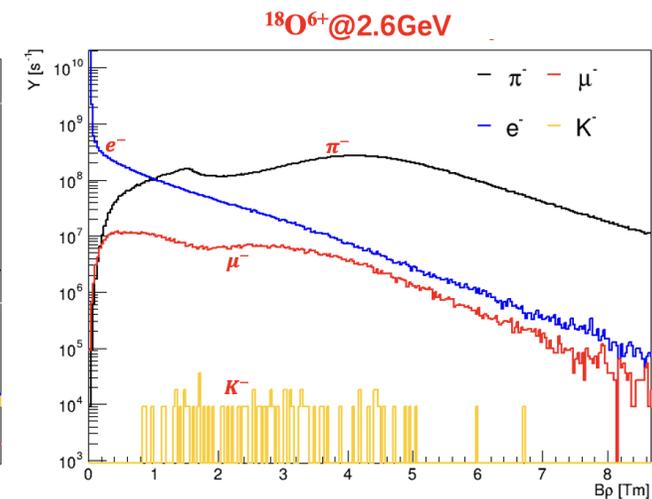
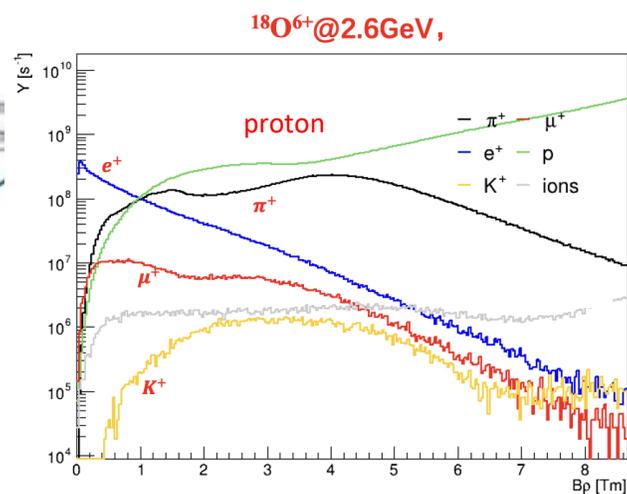
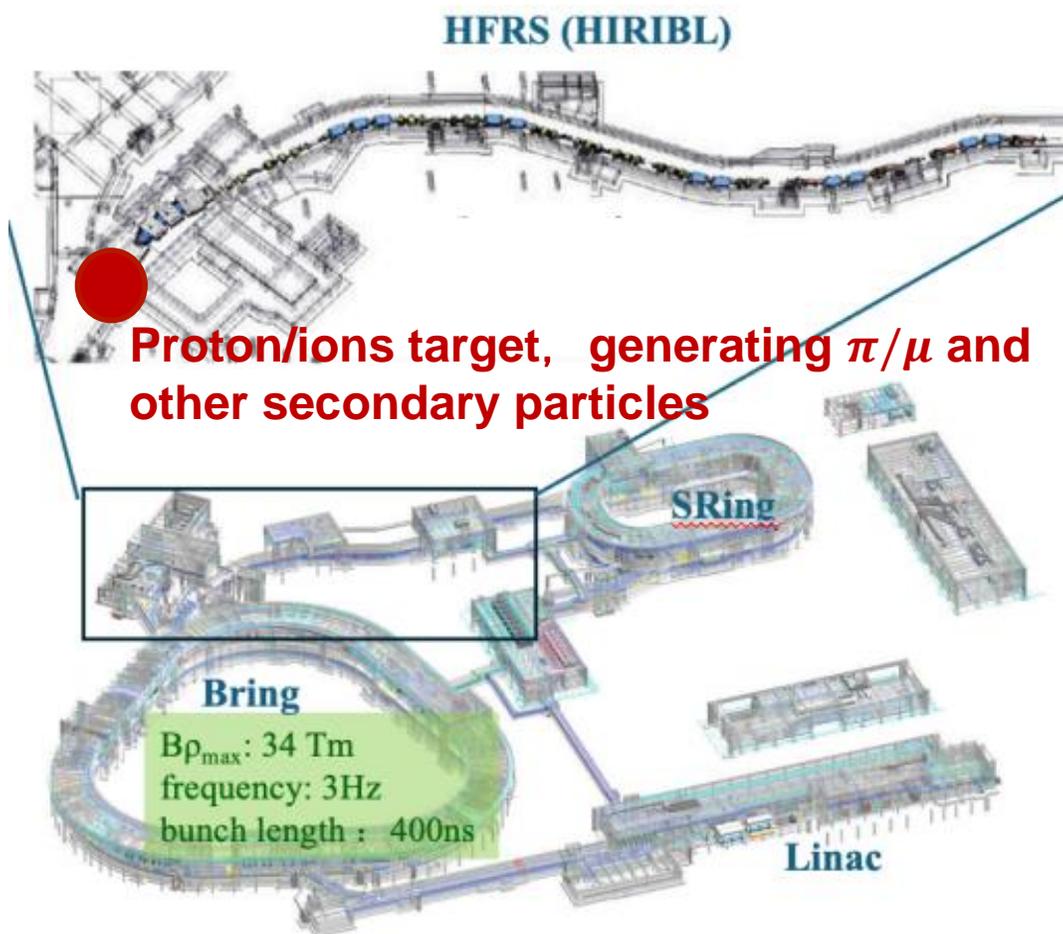
the first signal ^{18}O at B-ring



the first signal ^{18}O at S-ring

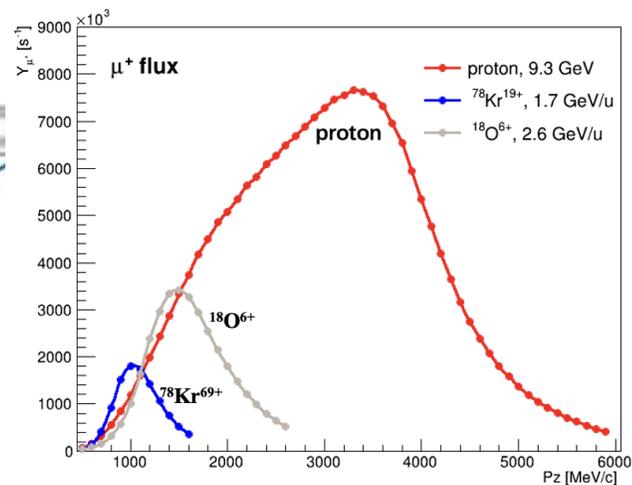
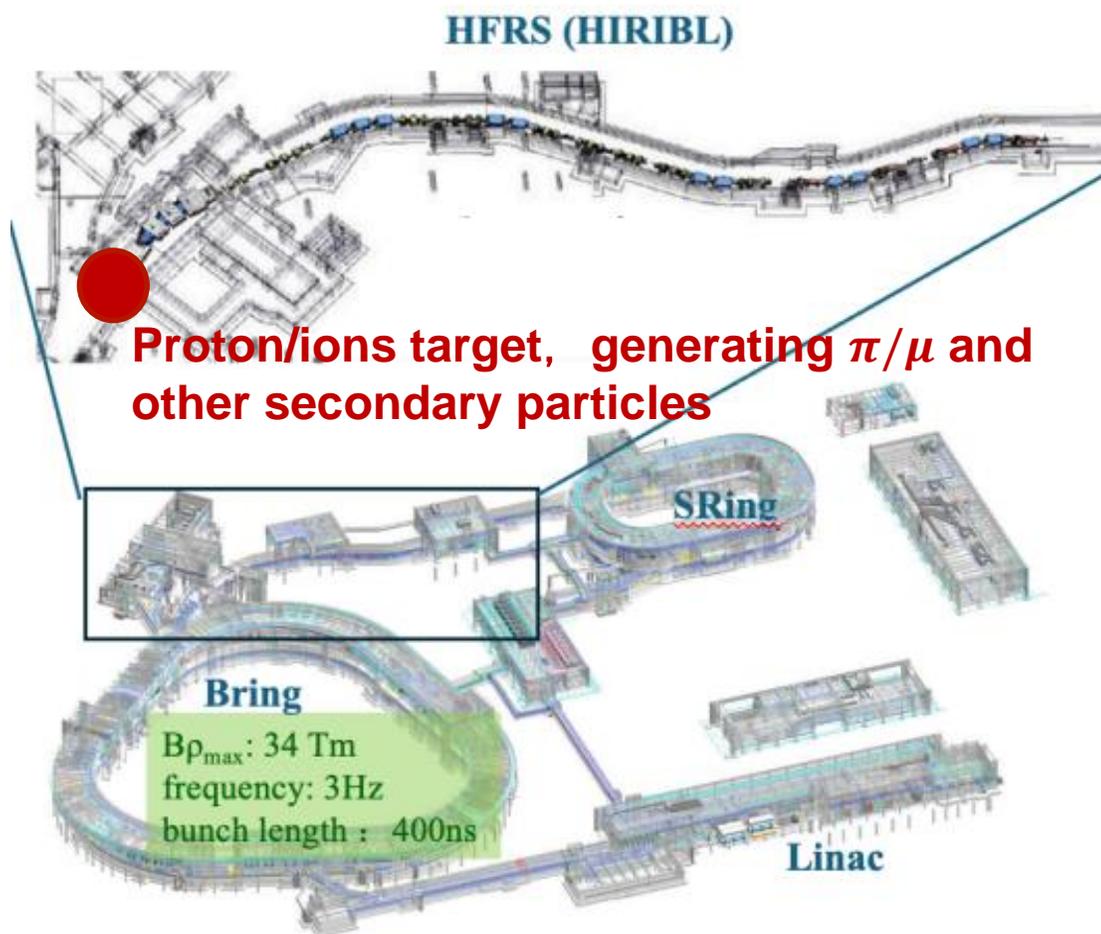
HFRS (HIRIBL)

For pion & muon production and extraction



HFRS (HIRIBL)

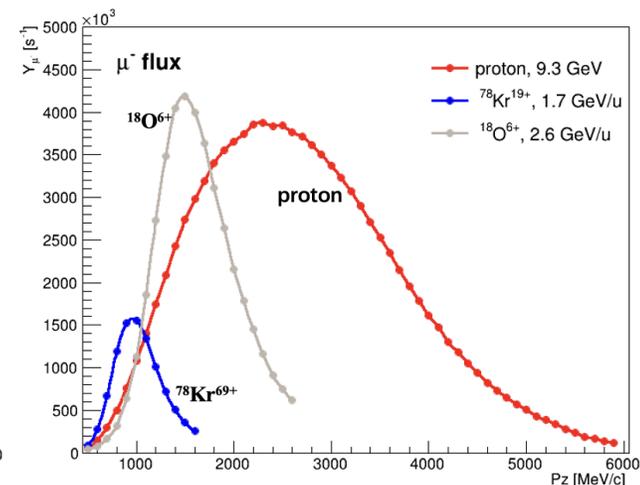
For pion & muon production and extraction



positive muon

- Maximum μ^+ flux: $8.2 \times 10^6/\text{s}$
 - projectile : proton
 - P_z : 3.5 GeV/c

w/ purification: $2.4 \times 10^5/\text{s}$



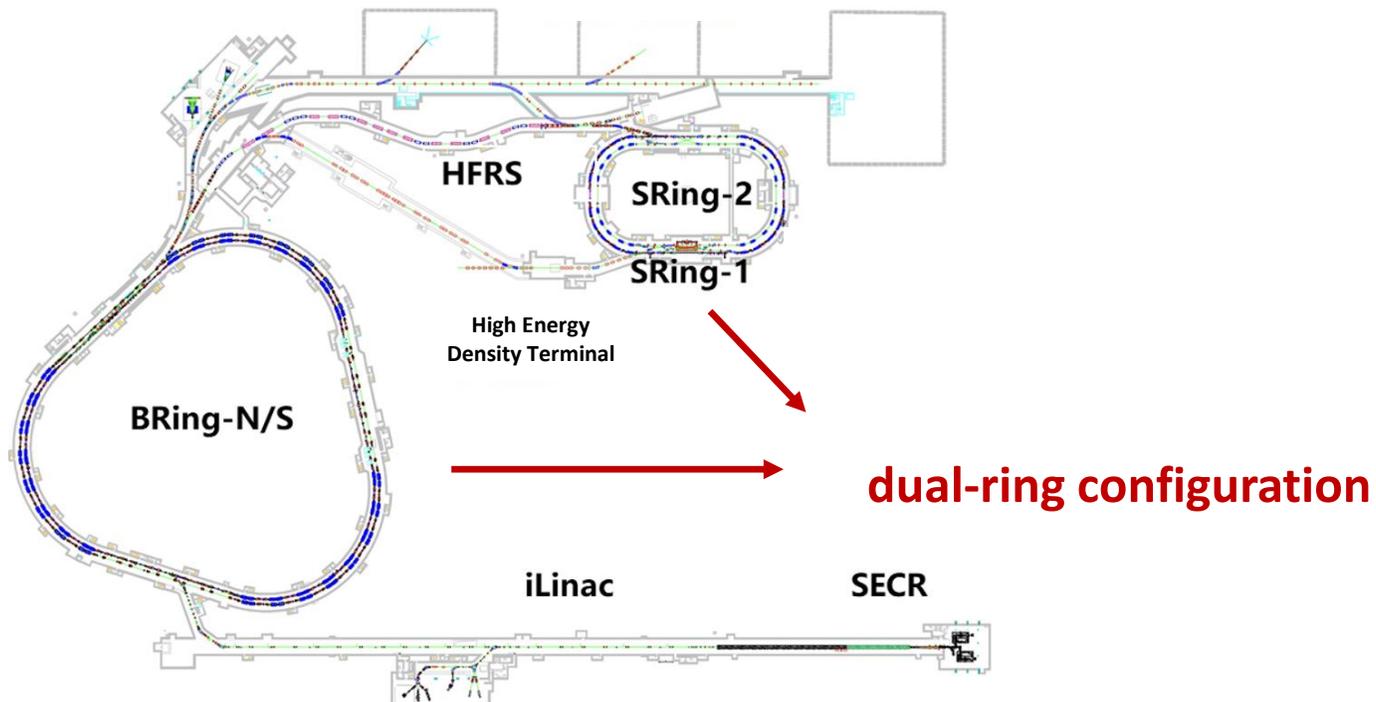
negative muon

- Maximum μ^- flux: $4.2 \times 10^6/\text{s}$
 - projectile: $^{18}\text{O}^{6+}$
 - P_z : 1.5 GeV/c

w/ purification: $3.7 \times 10^5/\text{s}$

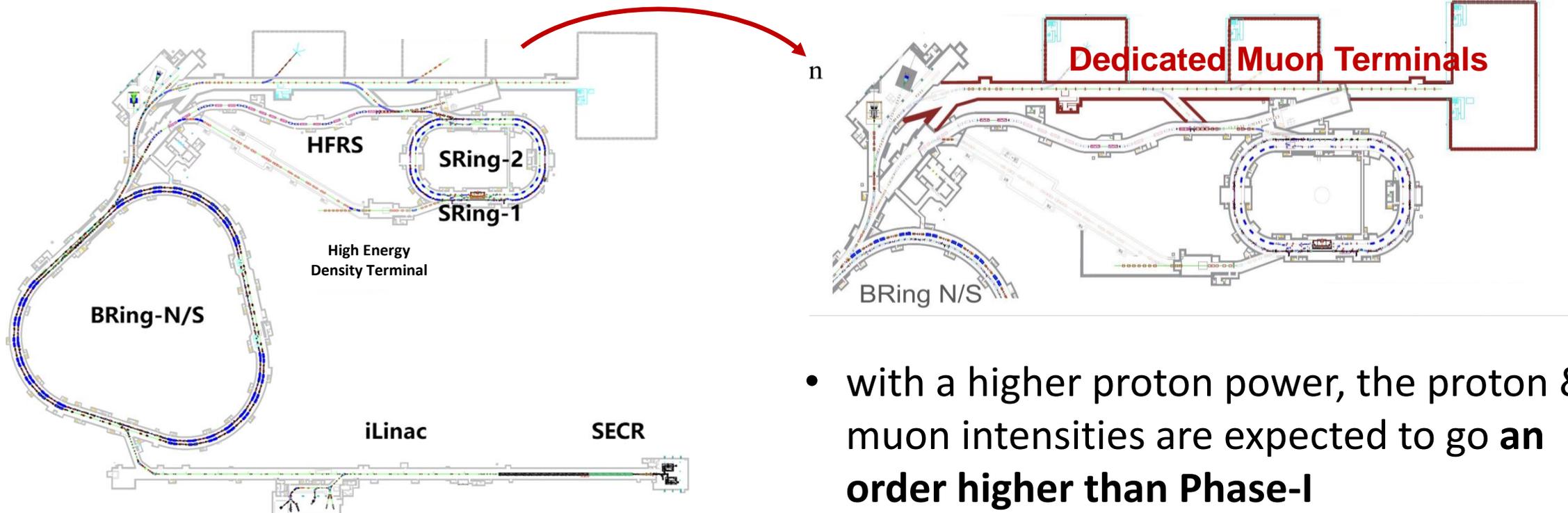
HIAF-U

- An upgrade planned for the second phase of HIAF, aims to increase the proton energy from 9 to **25 GeV**, with a dedicated muon beamline in the design.



HIAF-U

- An upgrade planned for the second phase of HIAF, aims to increase the proton energy from 9 to **25 GeV**, with a dedicated muon beamline in the design.



- with a higher proton power, the proton & muon intensities are expected to go **an order higher than Phase-I**

Muon beams comparison

a GeV-scale high-intensity pulsed μ^-

TABLE I. Comparison of muon beam parameters at Fermilab and HIAF

	Fermilab	HIAF	HIAF-U
Proton Intensity (/s)	6.8×10^{13}	5×10^{13}	4×10^{14}
Proton energy (GeV/u)	8.0	9.1	25
Repetition frequency (Hz)	15	3	10
Proton bunch time width (ns)	100	100-400 (TBD)	TBD
Muon intensity [/s]	5×10^6	$\approx 4 \times 10^6$	$\approx 4 \times 10^7$ (?)
Muon energy (for $g - 2$)	3.1 GeV/c	2 - 4 GeV/c	10 - 20 GeV/c
Muon momentum spread (%)	2%	2%-3%	TBD

→ Currently intensity at HIAF is comparable to FNAL, while HIAF-U would very likely surpass it.

Muon beam for $g - 2$

$$\frac{\Delta\omega_a}{\omega_a} \propto \frac{1}{\gamma B P \sqrt{N}}$$

	FNAL	J-PARC	HIAF	HIAF-U
γ	30	3	20 – 40 (2-4 GeV)	150 (15 GeV)
B	1.5 T	3 T	3 T or higher	6 – 15 T?
P	100%	50%	100%	100%
N required to achieve the same precision in $\Delta\omega_a/\omega_a$	N	100 N	$N/4$	$N/500$



In reality J-PARC is better than this due to high intensity of surface muons ($10^8/s$)



The statistical sensitivity won't be a problem at all. Purely systematics-limited;

HIAF-U with 10-20 GeV muon

- Being free from statistical limits opens a new window:
 - Both positive and negative muons
 - Low-emittance beam with a simple collimator: a better systematics related to beam dynamics – CBO, field mapping etc.
 - clock/counter-clock wise measurements
 - ...
- Others: a dedicated muon beam-line with a delivery ring (like Fermilab)?

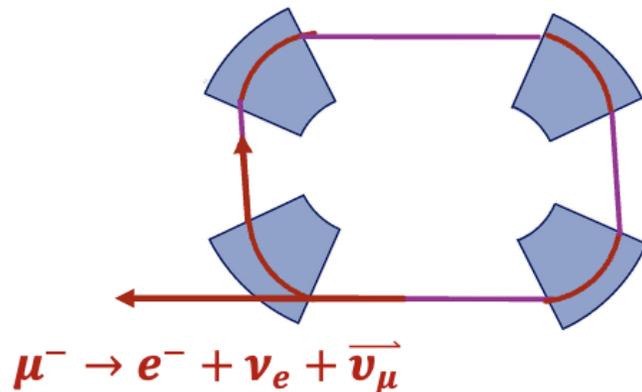


Precisions for $g - 2$

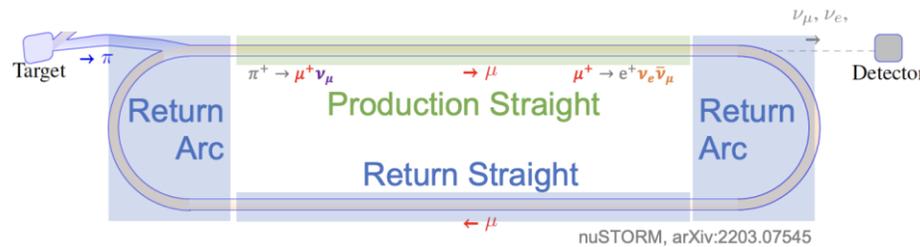
Facilities	CERN/BNL/FNAL	J-PARC	HIAF (HIAF-U)
Muon momentum	3.1 GeV/c	300 MeV/c	2-4 GeV (HIAF) 10-20 GeV (HIAF-U)
Magnet	Full-ring magnet	Full-ring magnet	Sector magnet
Storage	B-field & E-field	B-field	Edge B-field
Field calibration	NMR calibration	NMR calibration	Calibration via polarized proton and other methods
Precision	μ^+ : 0.14 ppm (FNAL) μ^- : 0.7 ppm (BNL)	μ^+ : 0.46 ppm \rightarrow 0.1ppm (?)	μ^-/μ^+ : 0.1 ppm \rightarrow 0.05 ppm

Physics and technical synergies

- Polarized protons: synergy with the Electron-ion collider project (EIC or EicC)
- Neutrino factory (NvStorm)
- Muon collider?



ν from *STORed* Muons (*nuSTORM*)



courtesy: Xianguo LU

➤ nuPIL: an improved version of nuSTORM production straight, a standalone beam line for DUNE

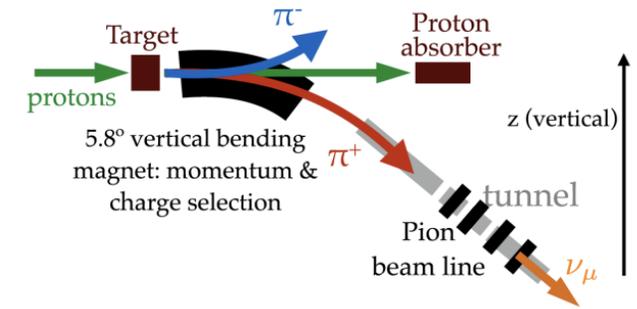
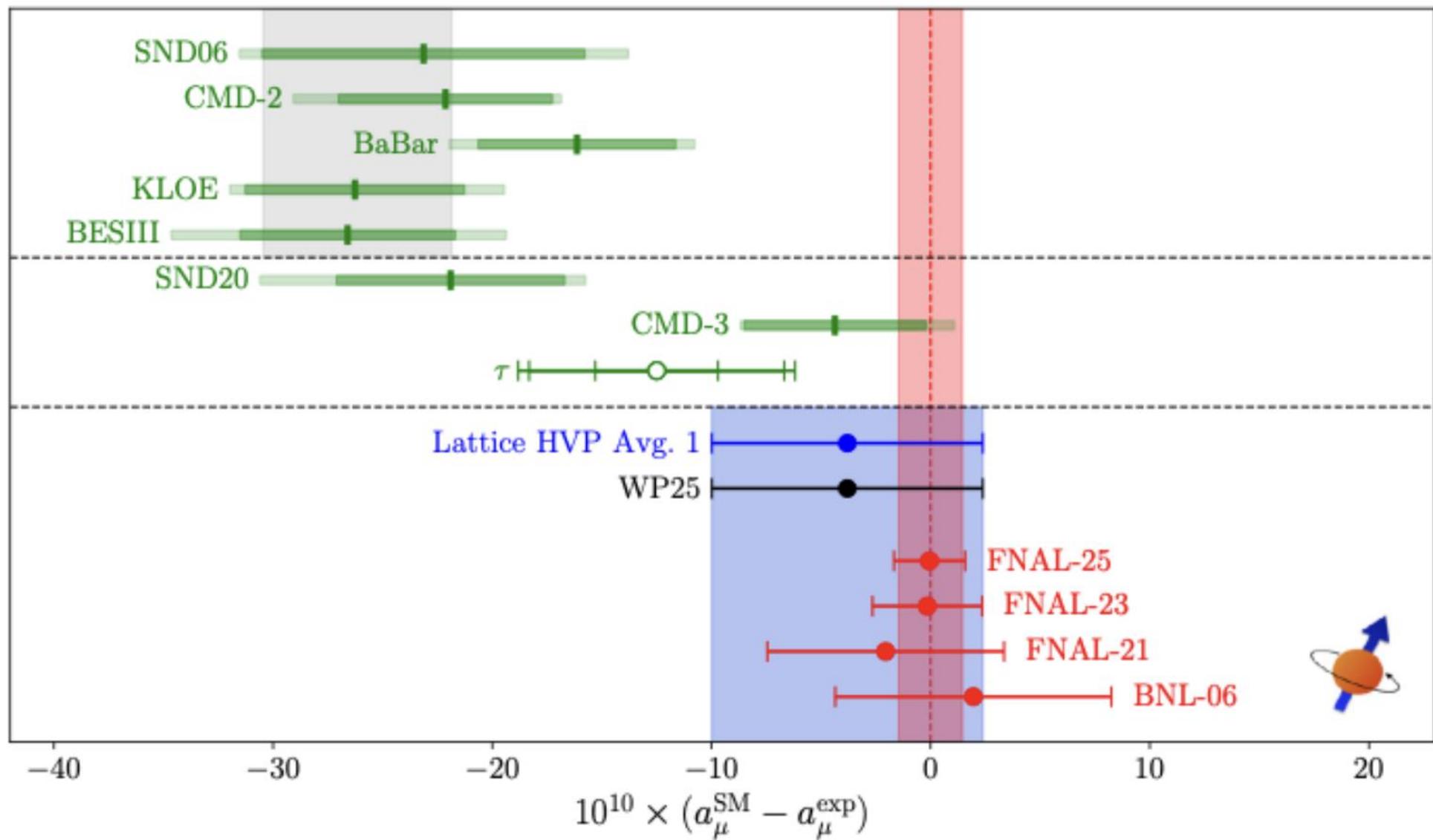


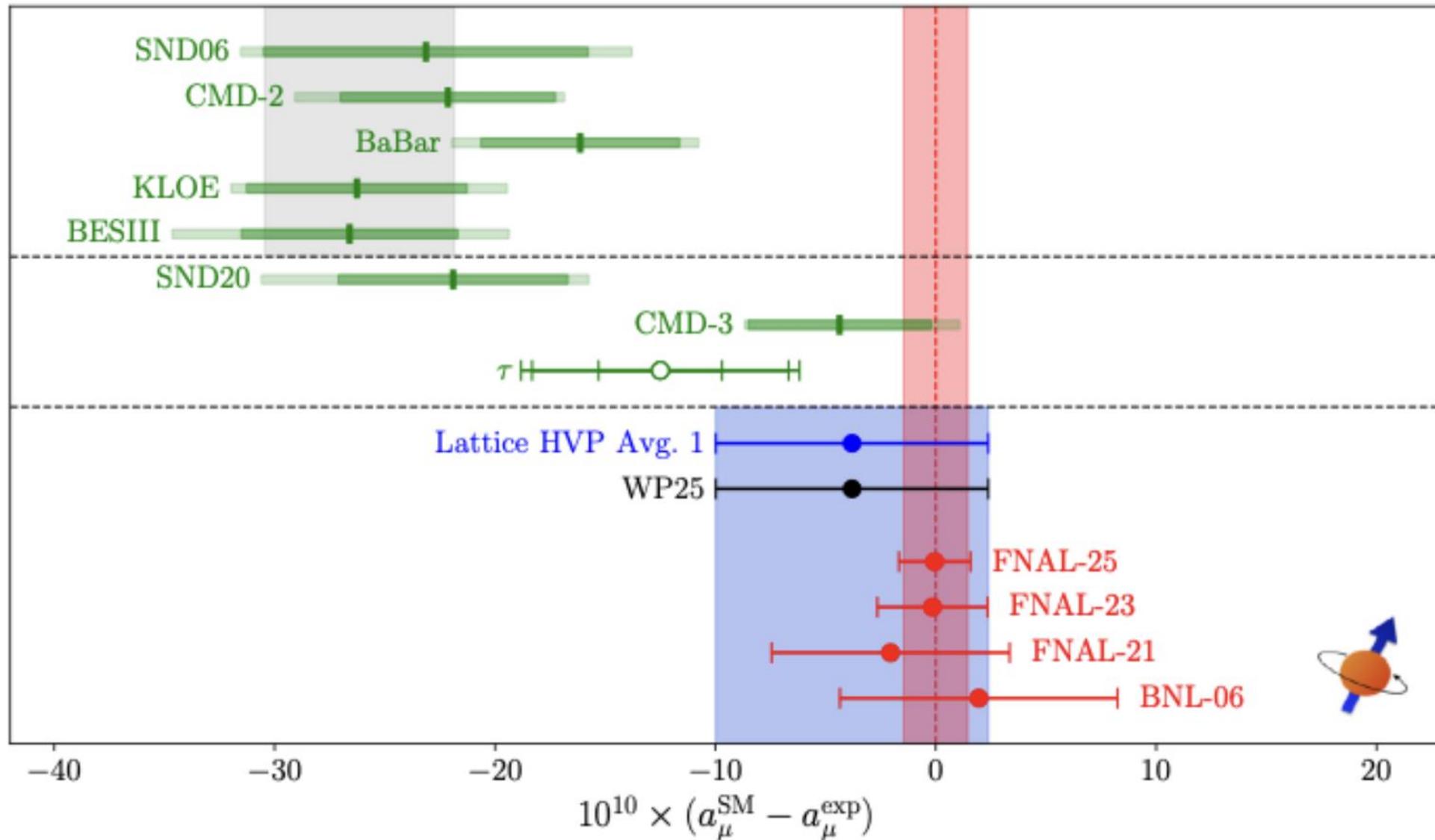
FIG. 1: Scheme of the nuPIL concept.

Summary

- The muon $g-2$ puzzles have triggered extensive experimental and theoretical activity over the past 60 years—and will continue to do so.
- **The current puzzles will eventually be clarified and resolved.** Theory precision will again match (and surpass) the Fermilab precision, as history has shown.
- The time will come for a **next-generation muon $g-2$ experiment.** Currently, none exists. In this talk, I have taken a step in that direction with a new proposal, featuring novel focusing schemes and targeting 0.05 ppm precision – x3 Fermilab.
- The concept is not limited to HIAF but adaptable to muon facilities worldwide, and also offers potential synergies with neutrino and muon collider programs.



'The closer you look the more there is to see' (Fred Jegerlehner)



Backup



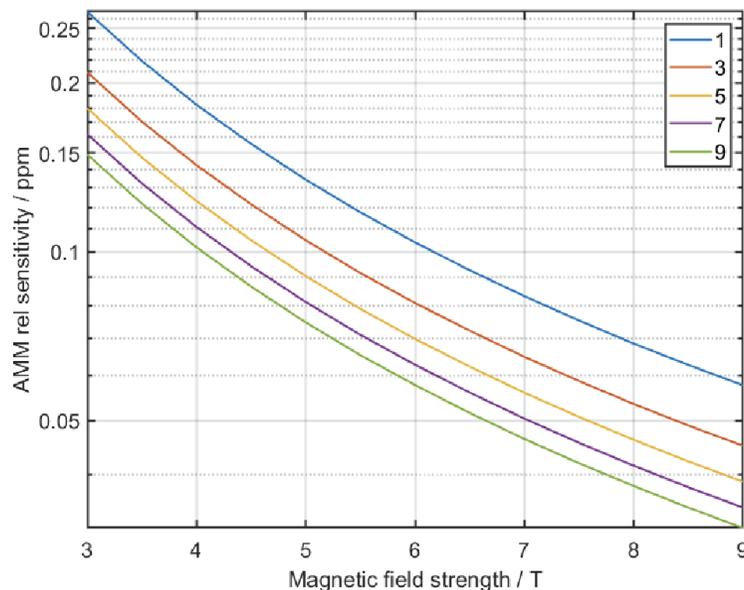
$(g - 2)_\mu$ Prospects at PSI



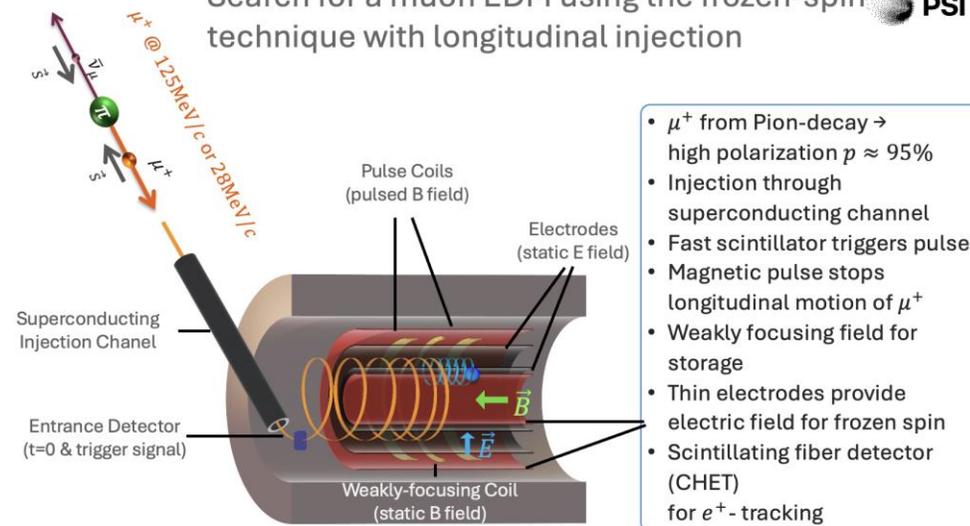
- Statistics as in muEDM phase 2 (one year data)
 - blue: single muon
 - red: 3 muons – how?
- Same magnet, same detector, no electric field
- Prospects with new beamline solenoid to go to $p = 140 \text{ MeV}/c$

Sensitivity: $\sim 0.1 \text{ ppm}$ statistically (4 years)

- Collaboration on magnet with JPARC and transport between institutes?



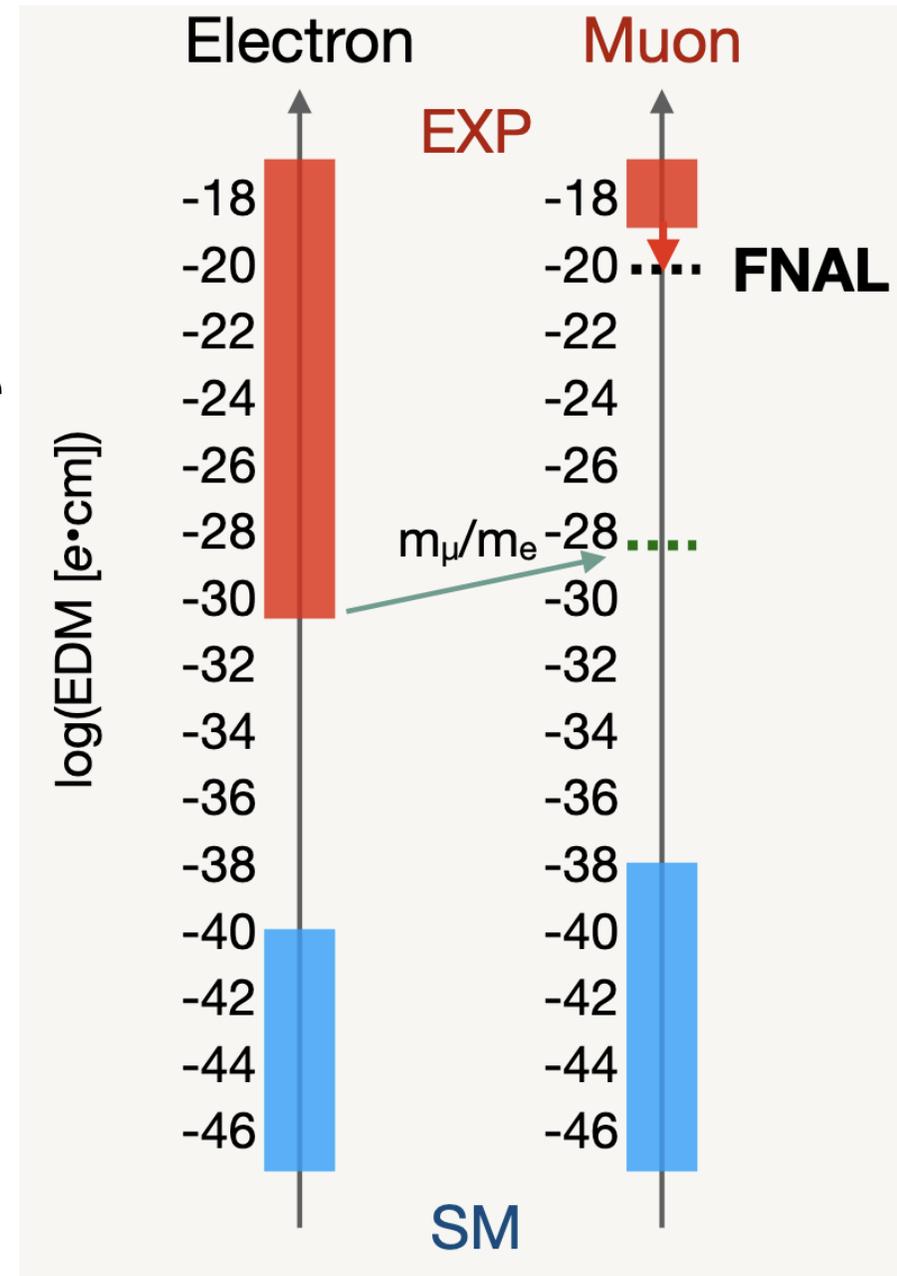
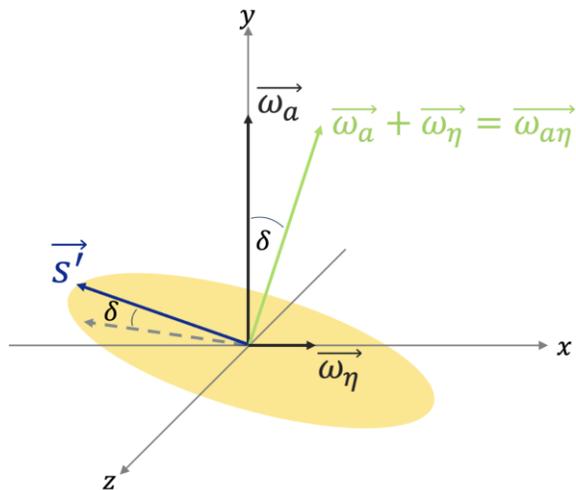
Search for a muon EDM using the frozen-spin technique with longitudinal injection



- μ^+ from Pion-decay \rightarrow high polarization $p \approx 95\%$
- Injection through superconducting channel
- Fast scintillator triggers pulse
- Magnetic pulse stops longitudinal motion of μ^+
- Weakly focusing field for storage
- Thin electrodes provide electric field for frozen spin
- Scintillating fiber detector (CHET) for e^+ -tracking

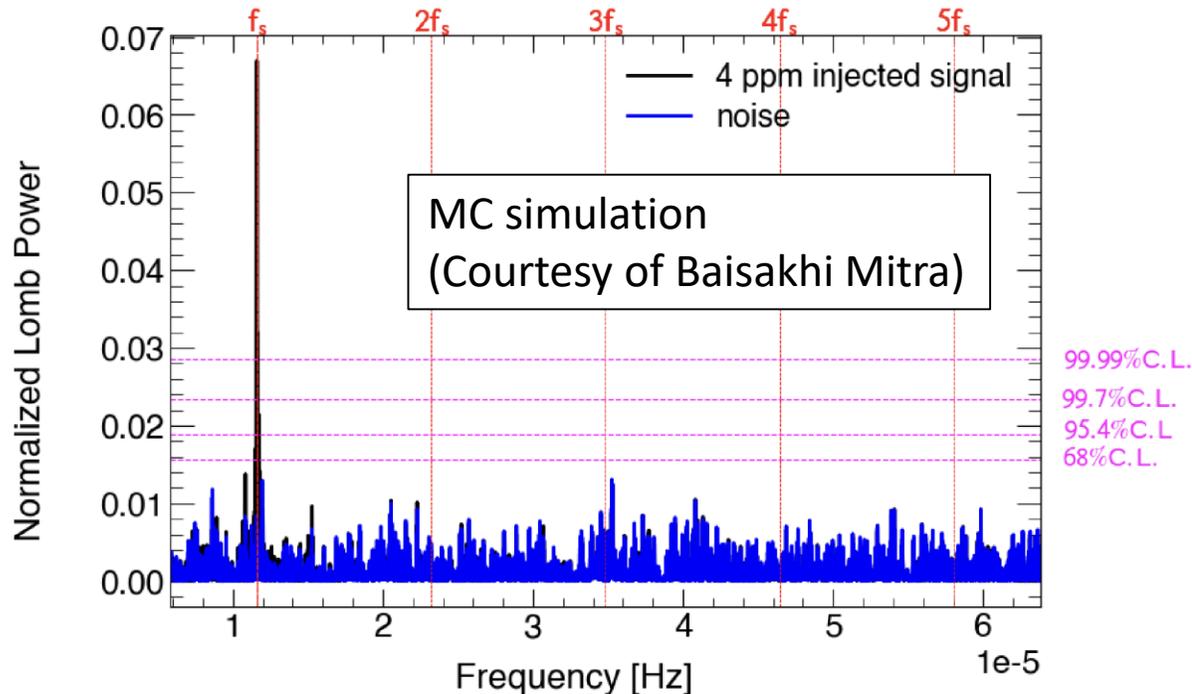
BSM Searches (Ongoing)

- Electric Dipole Moment (EDM)
 - The spin precession plane is tilted in the presence
 - Run-1/2/3 results are expected soon.
 - Current limit (BNL): $1.8 \times 10^{-19} \text{ e} \cdot \text{cm} \rightarrow$
Projected limit: $\lesssim 3 \times 10^{-20} \text{ e} \cdot \text{cm}$



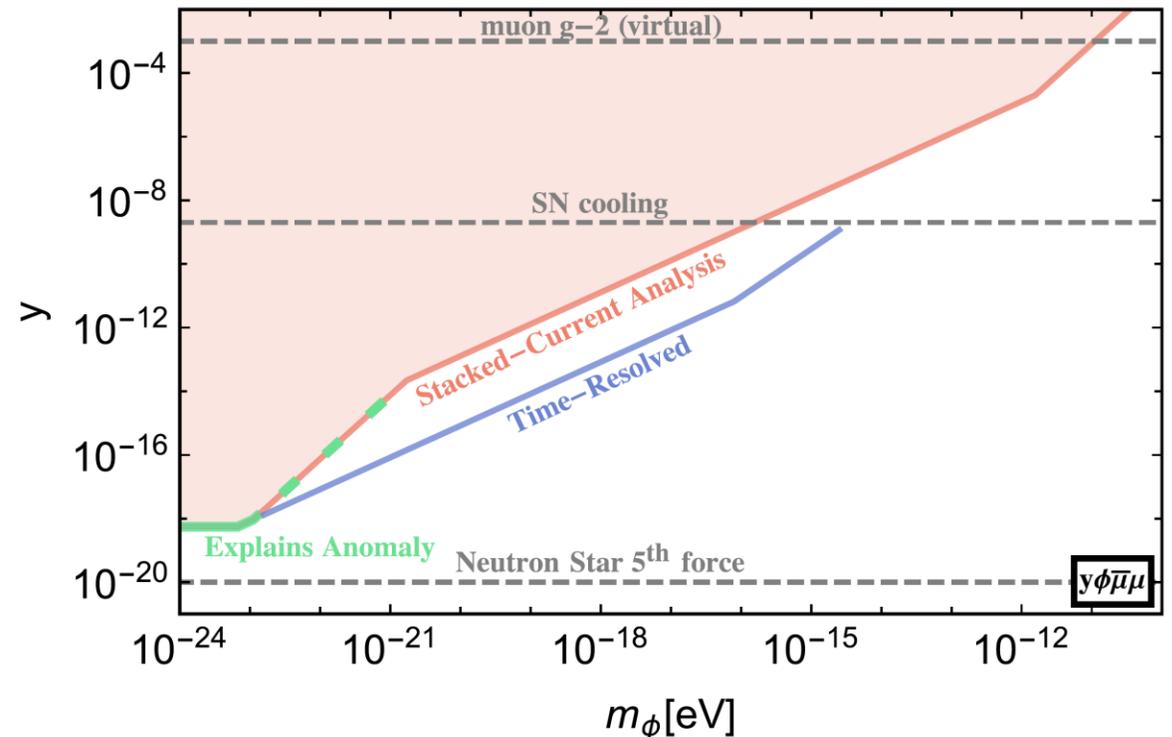
BSM Searches (Ongoing)

- *CPT* and Lorentz Invariance Violation
 - ω_a modulated at the sidereal motion.
 - Run-2/3 in review.
 - Current limit (BNL): 1.4×10^{-24} GeV \rightarrow
Projected limit (FNAL Run-2/3): $\mathcal{O}(10^{-25})$ GeV



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

Projected sensitivity PRD **102**, 115018 (2020)



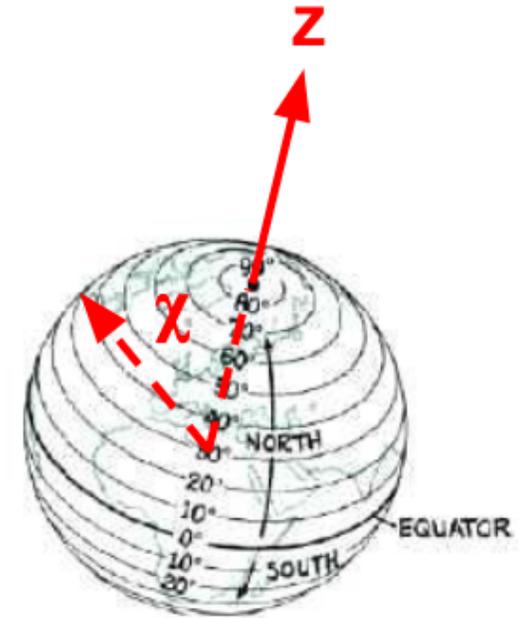
CPTLV: SME and Muon g-2



- SME Lagrangian:

$$\mathcal{L}' = -a_\kappa \bar{\psi} \gamma^\kappa \psi - \underbrace{(b_\kappa)}_{\text{circled}} \bar{\psi} \gamma_5 \gamma^\kappa \psi - \frac{1}{2} H_{\kappa\lambda} \bar{\psi} \sigma^{\kappa\lambda} \psi + \frac{1}{2} i c_{\kappa\lambda} \bar{\psi} \gamma^\kappa \overleftrightarrow{D}^\lambda \psi + \frac{1}{2} i d_{\kappa\lambda} \bar{\psi} \gamma_5 \gamma^\kappa \overleftrightarrow{D}^\lambda \psi$$

- All terms violate Lorentz invariance
- a_κ, b_κ are CPT-odd; others are CPT-even
- Predicts two CPT/Lorentz Violating signatures for muon g-2:
 - Gomes, Kostelecky, Vargas, Phys.Rev.D90:076009,2014
 - **Sidereal (or annual) variation in ω_a**
 - **Difference in ω_a between μ^+ / μ^-**
 - Use frame where Z is the orientation of the earth's axis relative to the fixed, distant stars, and χ is the colatitude (earth's precession negligible in our case)



SME Muon Sector Current Limits (Kostelecký et.al.)

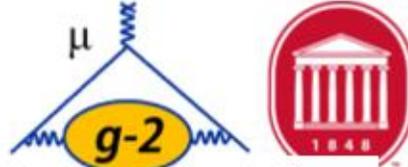


Table D21. Muon sector, $d = 3$

Combination	Result	System	Ref.
$ \text{Re } H_{011}^{\text{NR}(0B)} , \text{Im } H_{011}^{\text{NR}(0B)} , \text{Re } g_{011}^{\text{NR}(0B)} , \text{Im } g_{011}^{\text{NR}(0B)} $	$< 2 \times 10^{-22}$ GeV	Muonium spectroscopy	[20]*
$ \text{Re } H_{011}^{\text{NR}(1B)} , \text{Im } H_{011}^{\text{NR}(1B)} , \text{Re } g_{011}^{\text{NR}(1B)} , \text{Im } g_{011}^{\text{NR}(1B)} $	$< 7 \times 10^{-23}$ GeV	"	[20]*
b^T/m_μ	$(7.3 \pm 5.0) \times 10^{-7}$	Muon decay	[184]*
b_Z	$-(1.0 \pm 1.1) \times 10^{-23}$ GeV	BNL $g_\mu - 2$	[185]
$\sqrt{(\check{b}_X^{\mu+})^2 + (\check{b}_Y^{\mu+})^2}$	$< 1.4 \times 10^{-24}$ GeV	"	[185]
$\sqrt{(\check{b}_X^{\mu-})^2 + (\check{b}_Y^{\mu-})^2}$	$< 2.6 \times 10^{-24}$ GeV	"	[185]
$\sqrt{(\tilde{b}_X)^2 + (\tilde{b}_Y)^2}$	$< 2 \times 10^{-23}$ GeV	Muonium spectroscopy	[186]
$b_Z - 1.19(m_\mu d_{Z0} + H_{XY})$	$(-1.4 \pm 1.0) \times 10^{-22}$ GeV	BNL, CERN $g_\mu - 2$ data	[187]
b_Z	$(-2.3 \pm 1.4) \times 10^{-22}$ GeV	CERN $g_\mu - 2$ data	[187], [188]*
$ \text{Re } H_{011}^{(3)(0B)} , \text{Im } H_{011}^{(3)(0B)} $	$< 5 \times 10^{-23}$ GeV	"	[20]*
$\check{H}_{010}^{(3)}$	$(-1.6 \pm 1.7) \times 10^{-22}$ GeV	BNL, CERN $g_\mu - 2$ data	[20]*
$ \text{Re } \check{H}_{011}^{(3)} , \text{Im } \check{H}_{011}^{(3)} $	$< 2.0 \times 10^{-24}$ GeV	BNL $g_\mu - 2$	[20]*
$m_\mu d_{Z0} + H_{XY}$	$(1.8 \pm 6.0) \times 10^{-23}$ GeV	"	[185]

Concept 2) Proton beam comagnetometer

More general sytematics

Quantity	Correction (ppb)	Uncertainty (ppb)
ω_a^m (statistical)	...	114
ω_a^m (systematic)	...	30
C_e Electric Field	347	27
C_p Pitch	175	9
C_{pa} Phase Acceptance	-33	15
C_{dd} Differential Decay	26	27
C_{ml} Muon Loss	0	2
$\langle \omega_p' \times M \rangle$ (mapping, tracking)	...	34
$\langle \omega_p' \times M \rangle$ (calibration)	...	34
B_k Transient Kicker	-37	22
B_q Transient ESQ	-21	20
μ_p'/μ_B	...	4
m_μ/m_e	...	22
Total systematic for \mathcal{R}'_μ	...	76
Total for a_μ	572	139

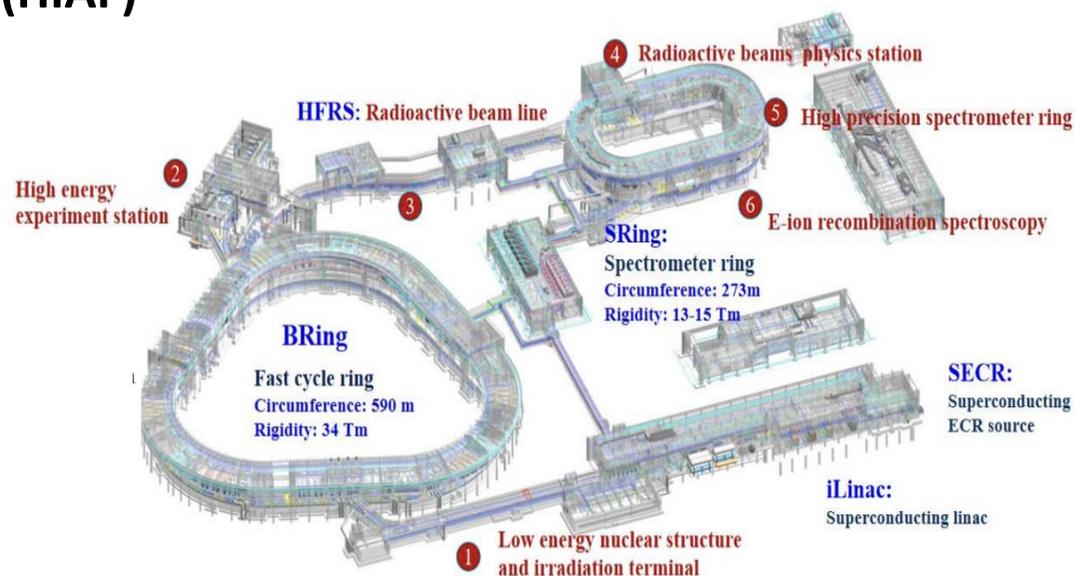
- Removing the E-field would improve the systematics for both ω_a and ω_p
 - For both it stands as one of the largest uncertainty sources
- New systematics at B-field (protons, calibration etc)
 - Remove the dominant part currently and distribute the new systematic effects to the magnetic field part, which has more 'buffer' in the systematics chart

Muon sources in China

HIAF and CiADS

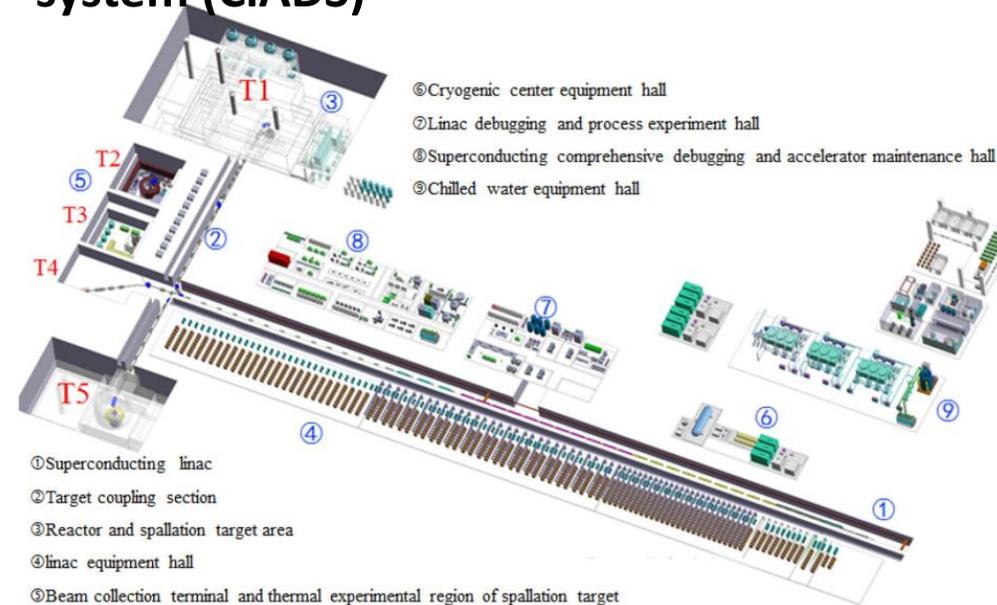
- Two neighbourhood facilities managed by **Institute of Modern Physics (IMP)**

High-Intensity heavy-ion Accelerator Facility (HIAF)



<https://english.imp.cas.cn/research/facilities/HIAF/>

China-initiative Accelerator-Driven Subcritical system (CiADS)



<https://english.imp.cas.cn/research/facilities/CIADS/>

Muon sources in China

HIAF and CiADS

- Two neighbourhood facilities managed by **Institute of Modern Physics (IMP)**

High-Intensity heavy-ion Accelerator Facility (HIAF)

- Heavy-ion acceleration and nuclear physics: nuclear structure, nuclear astrophysics, and high-energy-density matter;
- High-current ion sources, superconducting linacs, and large storage rings;
- Comparable to GSI/FAIR in capability;
- Planning a **high-energy muon (1-20 GeV)**.

China-initiative Accelerator-Driven Subcritical system (CiADS)

- Nuclear energy and waste transmutation;
- To demonstrate the Accelerator-Driven System (ADS) concept for sustainable nuclear energy and minimal radioactive waste;
- High-power proton linear accelerator coupled to a subcritical lead-bismuth reactor;
- Planning a **low-energy muon** (e.g. surface muon beam).

CiADS



HIAF and CiADS



HIAF and CiADS

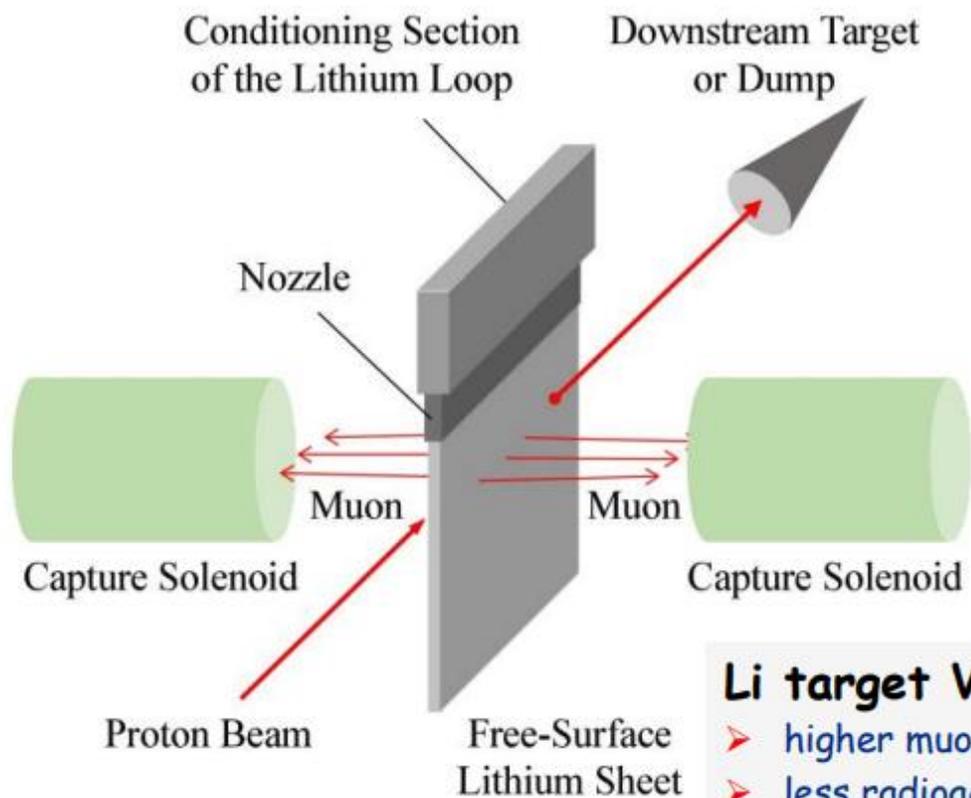
HIAF

CIADS

CiADS



Concept of lithium jet target



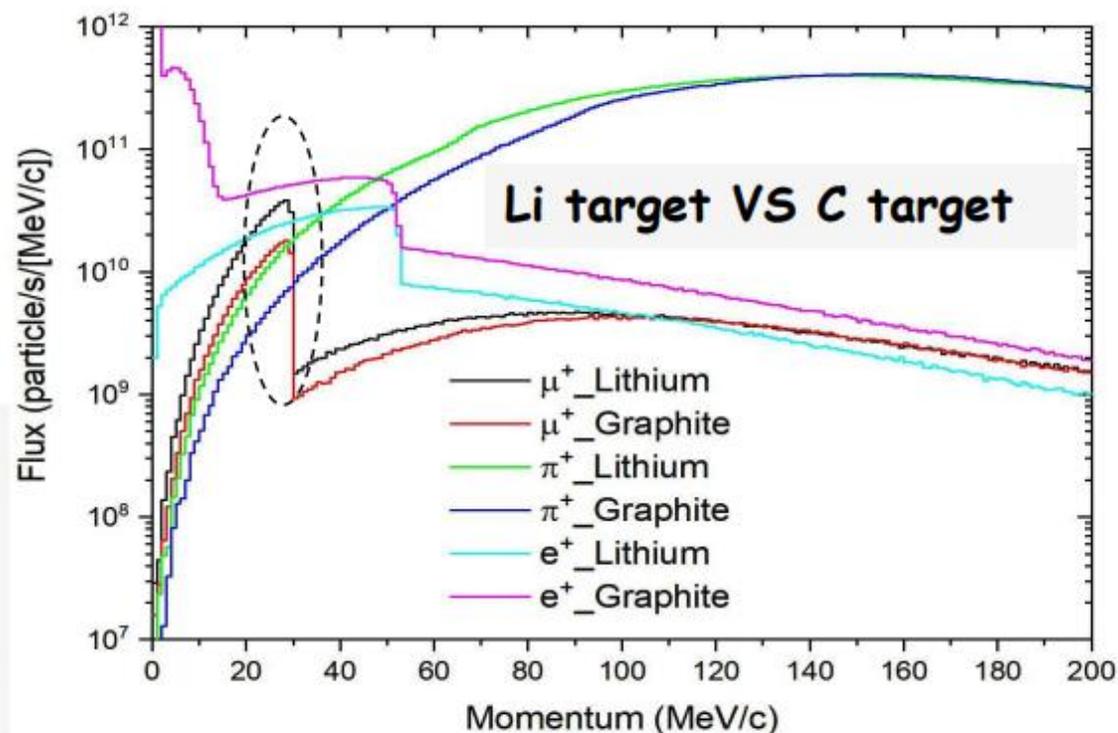
H.-J Cai et al, PRAB 27, 023703, 2024

Li target VS C target

- higher muon rate
- less radioactive nuclide and positrons background
- supporting higher beam power, free of irradiation damage

Design parameters:

- 3MW proton beam on target: 600MeV & 5mA
- Muon rate from target of $\sim 10^{11} \mu^+/s$

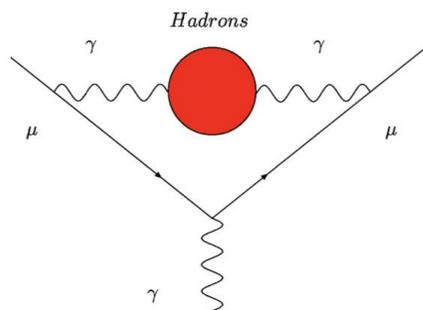


MUonE Experiment



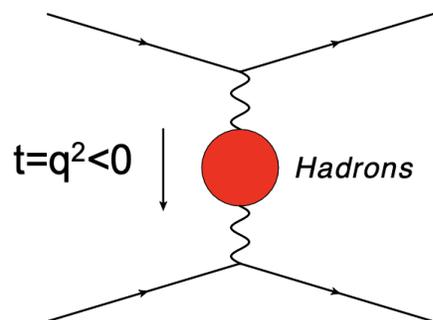
A New Approach towards a_{μ}^{HVP} with running of $\Delta\alpha_{\text{had}}$

- The dispersive approach to compute $a_{\mu}^{\text{HVP,LO}}$ is via the **time-like** formula:



$$a_{\mu}^{\text{HVP}} = \left(\frac{\alpha m_{\mu}}{3\pi}\right)^2 \int_{m_{\pi^0}^2}^{\infty} ds \frac{R_{\text{had}}(s) \mathbf{K}(s)}{s^2}, \quad \mathbf{K}(s) = \int_0^1 dx \frac{x^2(1-x)}{x^2 + (1-x)(s/m_{\mu}^2)}$$

- Alternatively, exchanging the x and s integrations \rightarrow **space-like** formula:



$$a_{\mu}^{\text{HVP}} = \frac{\alpha}{\pi} \int_0^1 dx (1-x) \Delta\alpha_{\text{had}}[t(x)], \quad t(x) = \frac{x^2 m_{\mu}^2}{x-1} < 0$$

- $\Delta\alpha_{\text{had}}$ is the hadronic contribution to the **running α** (electromagnetic coupling constant)

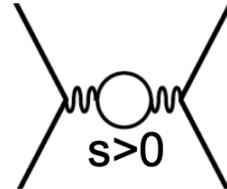
MUonE Experiment



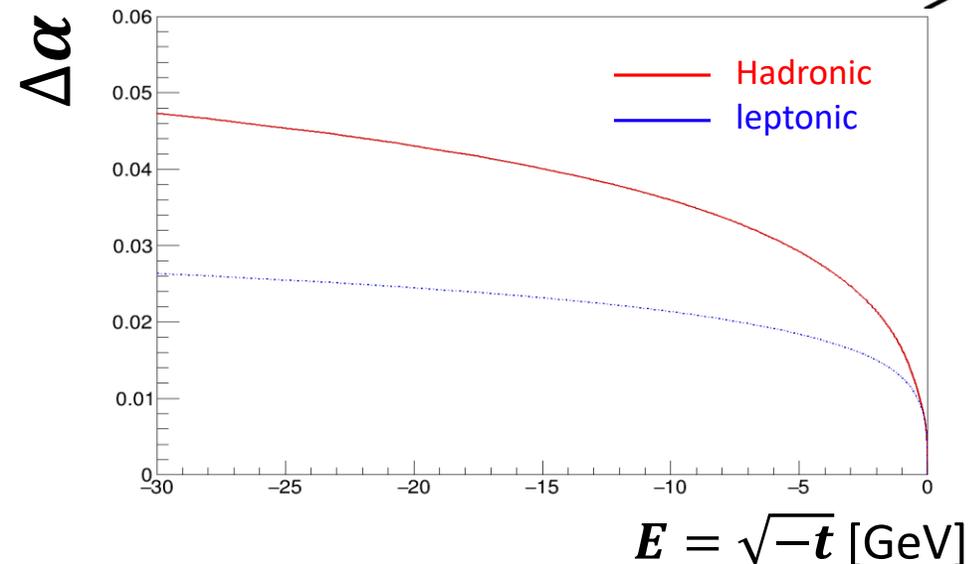
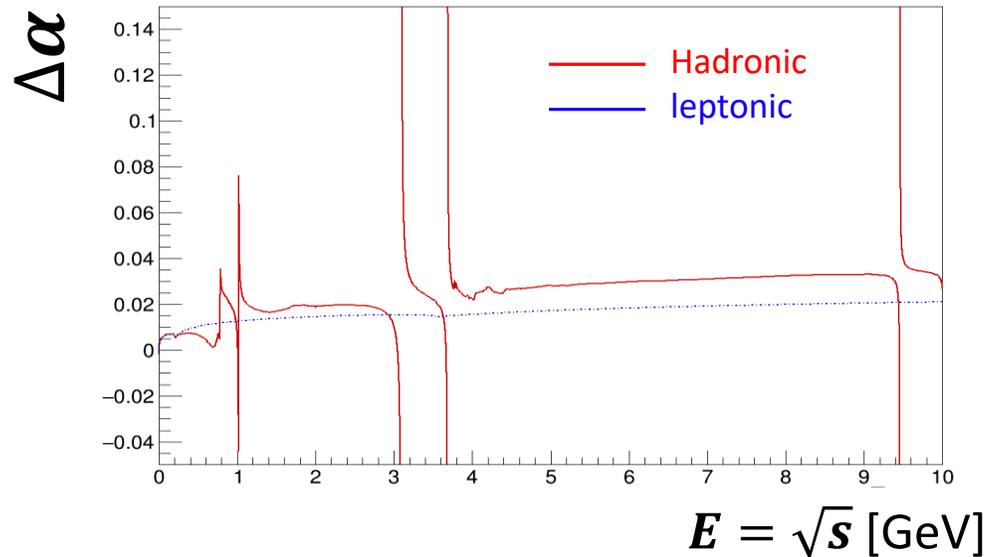
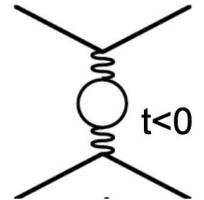
Running of $\Delta\alpha_{had}$: Time-like vs Space-like

$$\Delta\alpha_{had}^{(5)}(q^2) = -\frac{\alpha}{3\pi} q^2 \int_{m_{\pi^0}^2}^{\infty} ds' \frac{R(s')}{s'(s' - q^2)}$$

- **Time-like:** characterized by the opening of resonances



- **Space-like:** very smooth behaviour

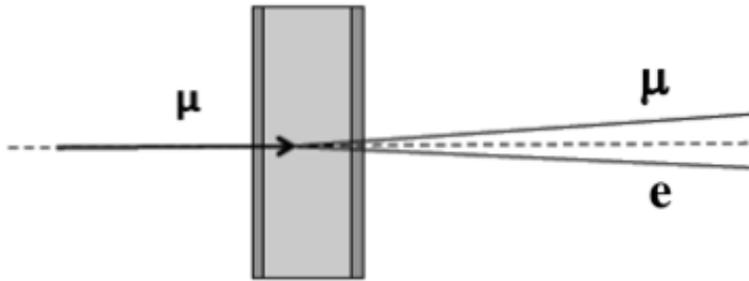


MUonE Experiment



$\Delta\alpha_{\text{had}}$ via Muon-electron Scattering

- $\Delta\alpha_{\text{had}}[t(x)]$ can be extracted from the shape of the differential cross-section of muon-electron scattering $\mu^+ e^- \rightarrow \mu^+ e^-$

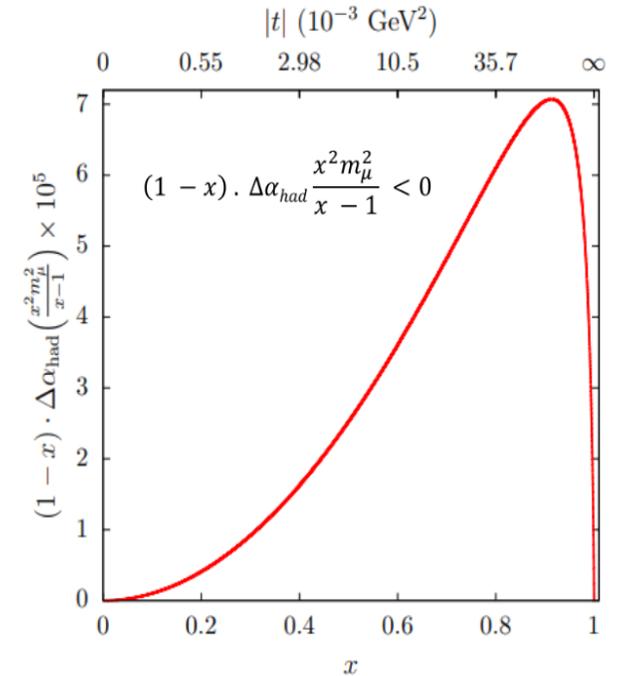
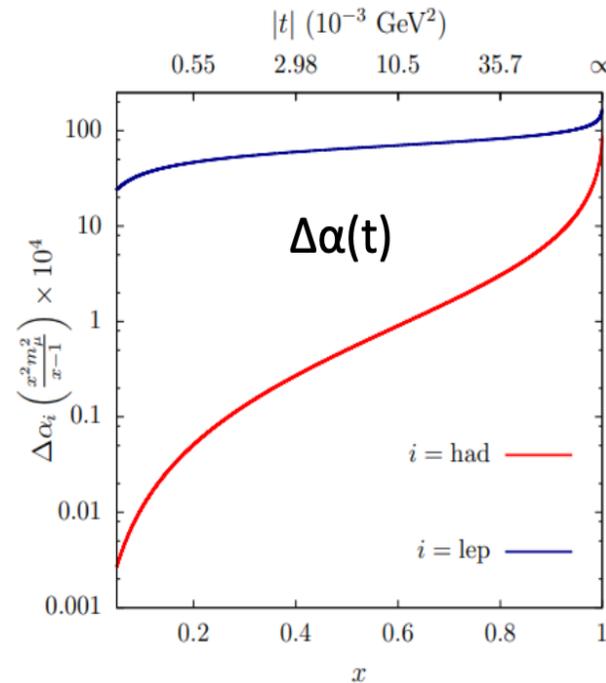


Shape of this is measured

$$R_{\text{had}} = \frac{d\sigma_{\text{data}}(\Delta\alpha_{\text{had}})}{d\sigma_{\text{MC}}(\Delta\alpha_{\text{had}} = 0)} \sim 1 + \underline{2\Delta\alpha_{\text{had}}(t)}$$

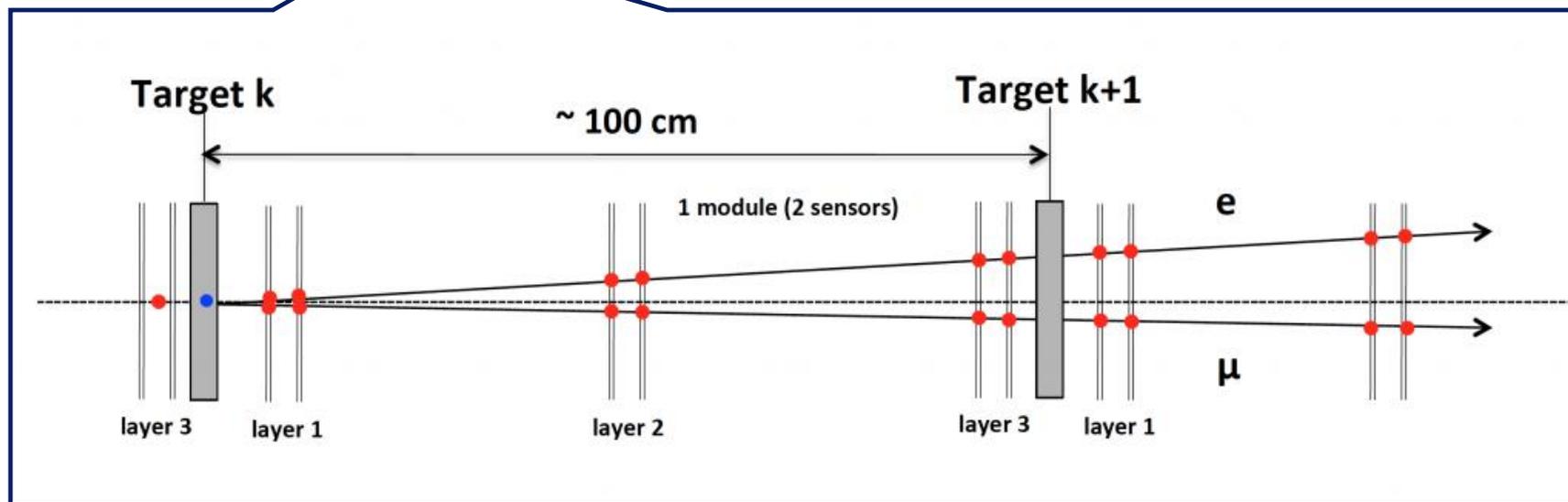
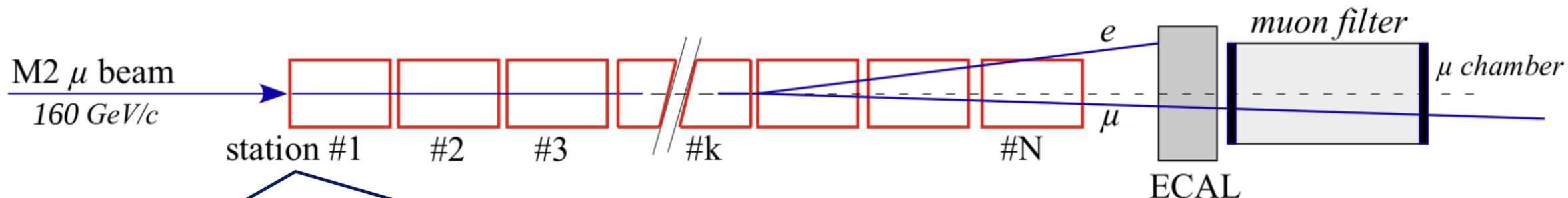
The NNLO differential cross section from **theoretical calculation**

To be determined in this experiment



MUonE Experiment

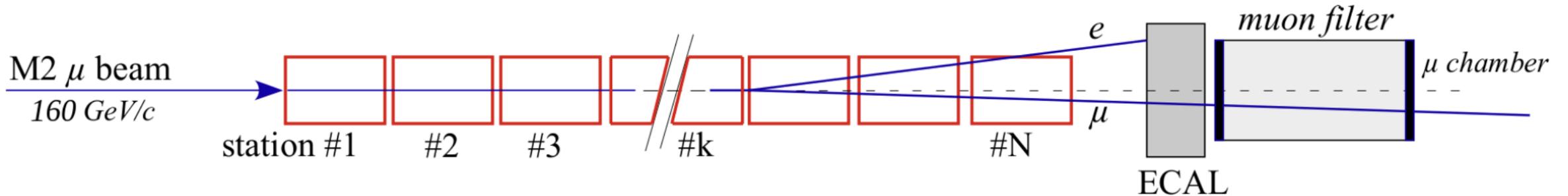
Setup Overview



- Be (or C) target divided into 40 slices with a few cm thickness
- Tracking system: 3 pairs of silicon strip detectors
- ECAL: energy and PID

MUonE Experiment

Setup Overview



- Correlation between muon and electron angles allows to select elastic events and reject background ($\mu N \rightarrow \mu N e^+e^-$).
- Boosted kinematics:
 - Single detector to cover full acceptance
 - $\theta_\mu < 5$ mrad, $\theta_e < 32$ mrad.

