CANTON-μ Proposal:

A Next-Generation Muon $g-2$ Experiment at Sub-0.1 ppm

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LEVERHULME TRUST

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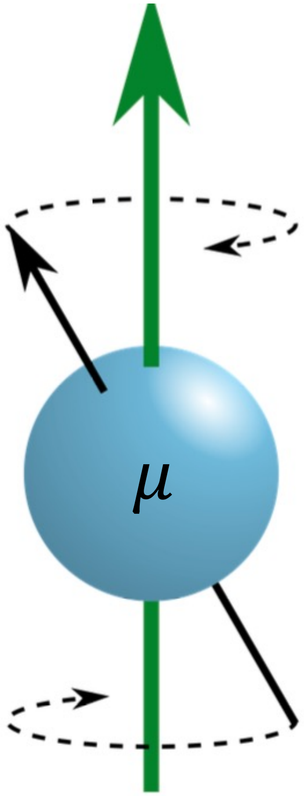
A Next-Generation Muon $g-2$ Experiment at Sub-0.1 ppm

- **Muon g-2 Theory**: where do we stand?
- **Lessons** learned from Fermilab g-2
- **A recipe** for next-generation muon g-2 experiment - CANTON-$\boldsymbol{\mu}$ @ HIAF
- **Physics reach** at sub-0.1 ppm precision

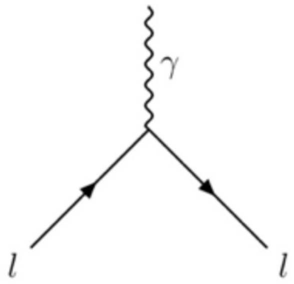
The Muon’s ‘g’ Factor

relates magnetic moment to its intrinsic spin



- Spin precession frequency is quantified in a magnetic field:

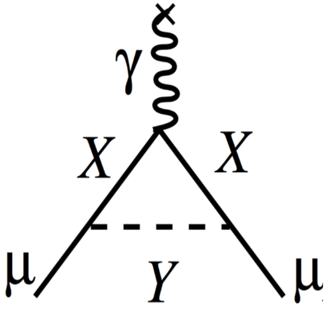
$$\vec{\mu} = g\frac{q}{2m}\vec{S}$$



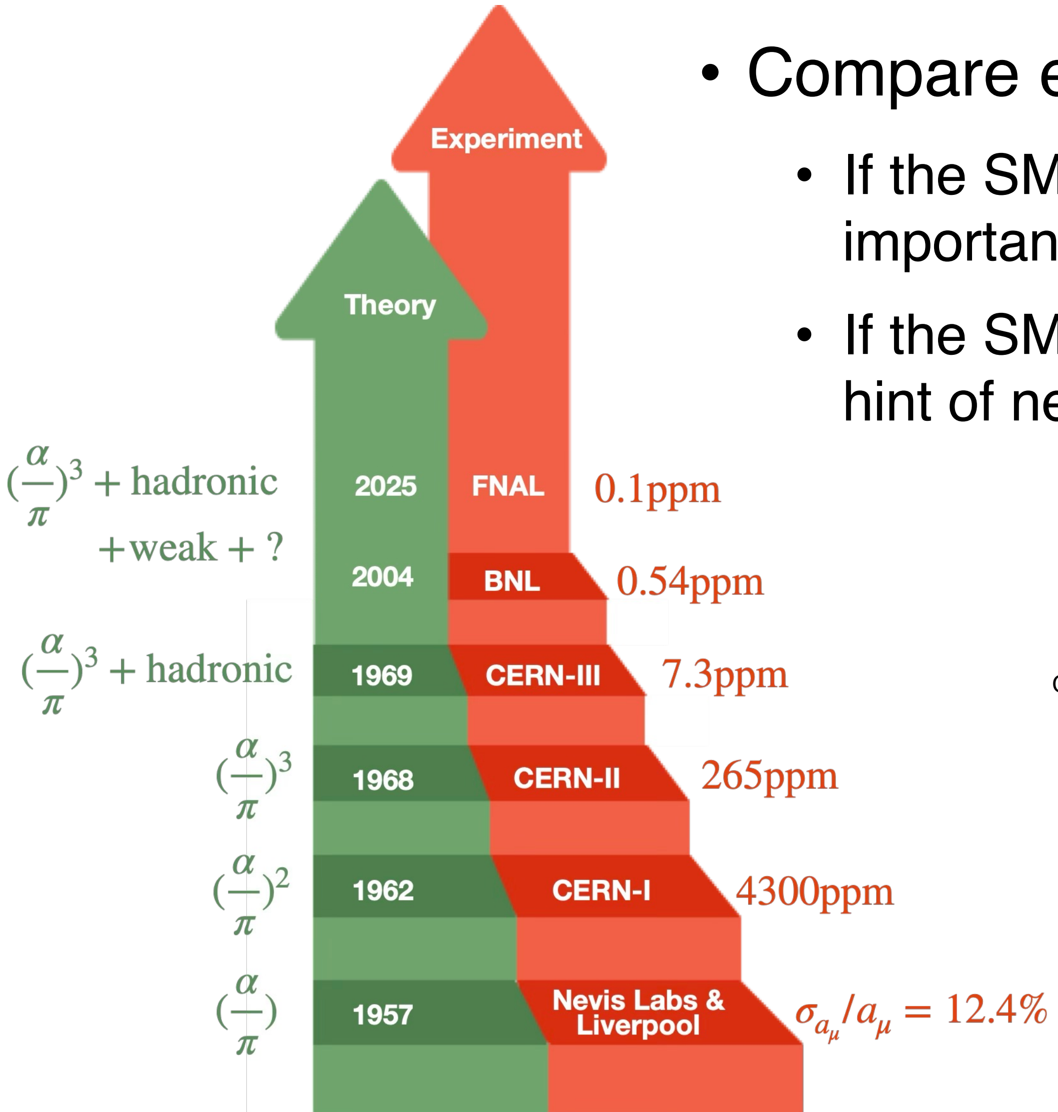
- For a pure Dirac spin-½ charged fermion, g is exactly 2.
- Interactions between the muon and virtual particles alter the value – we define muon magnetic anomaly to be

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

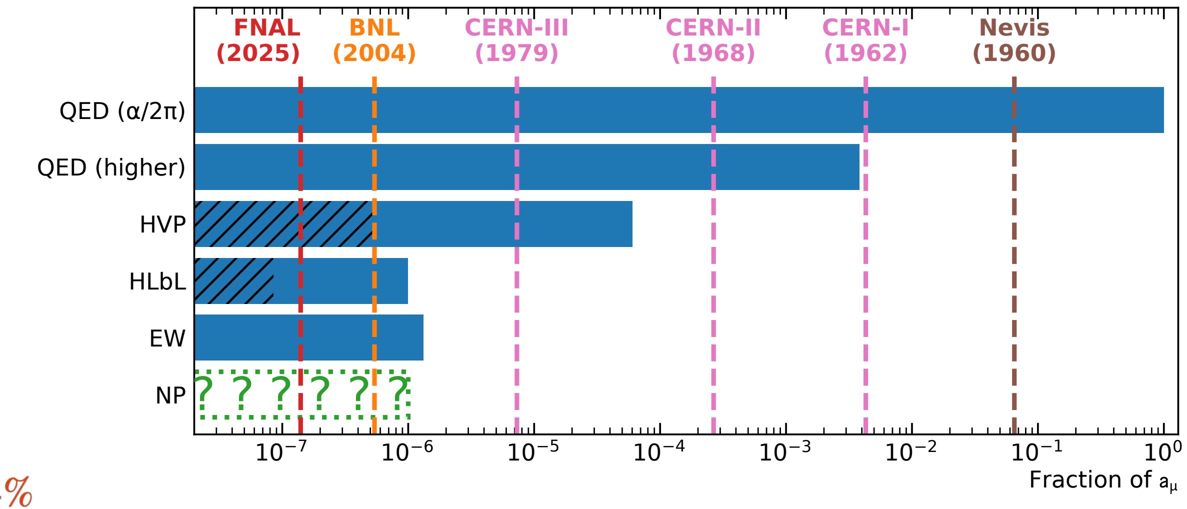
- Precisely measuring Muon $g-2$ **probes Standard Model** and is **a search for New Physics**.



A Window into the SM and Beyond



- Compare experimental & predicted muon g-2 values:
  - If the SM is correctly predicted, and **we match their value** → important confirmation; rules out a lot
  - If the SM is correctly predicted, and **we don't agree with it** → hint of new physics; opens up a lot



A Window into the SM and Beyond

- Sensitivity to New Physics scales (Λ) as mass ratio squared:

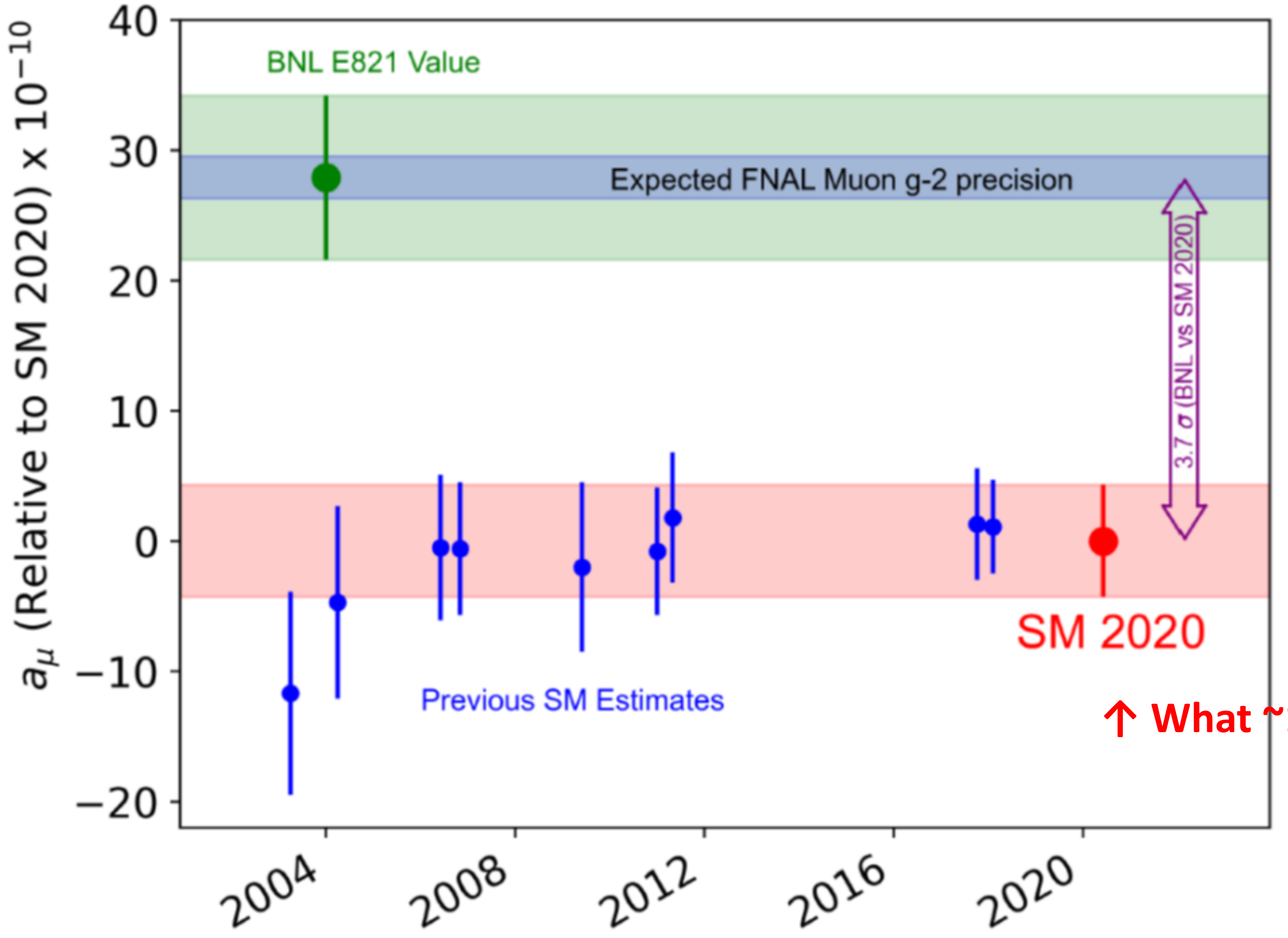
$$\Delta a_\mu \sim g^2 \frac{m_\mu^2}{\Lambda^2} \Rightarrow \Lambda \sim g \frac{m_\mu}{\sqrt{\Delta a_\mu}}$$, $\Delta a_\mu \sim 2.5\times10^{-9}$ → O(10–100 TeV)

- 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. ~TeV for LHC).

a_e= 1 159 652 180.73 (0.28) 10^{-12} [0.24ppb] ↔ a_μ~ 0.13 ppm
Hanneke et al., *PRL* 100(2008)120801 @ Harvard

(currently the most precisely measured particle physics observable)

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 σ → Tempting!



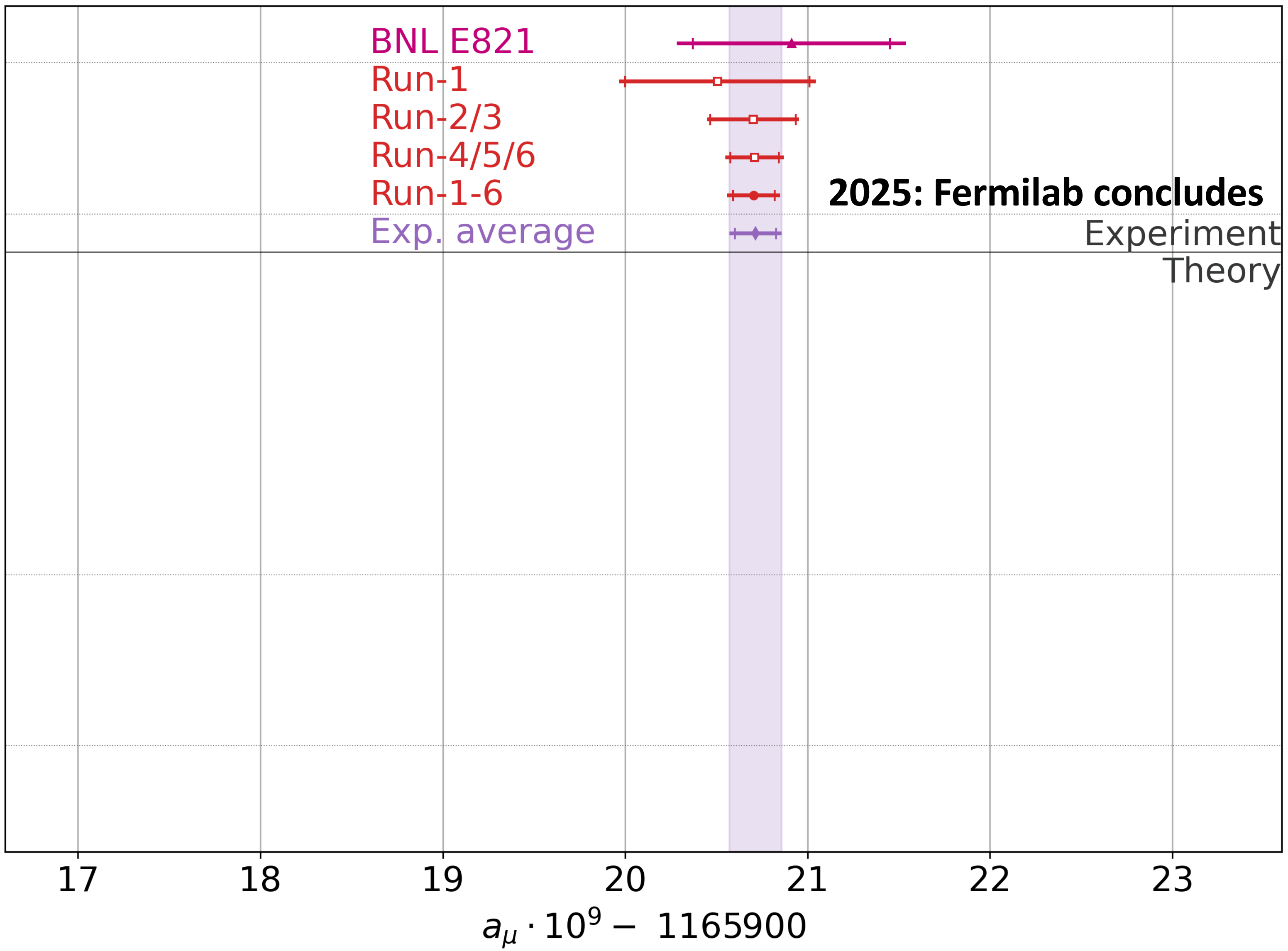
↑ What ~160 Theorists recommended in 2020

BNL was the only precision measurement

Was it correct?

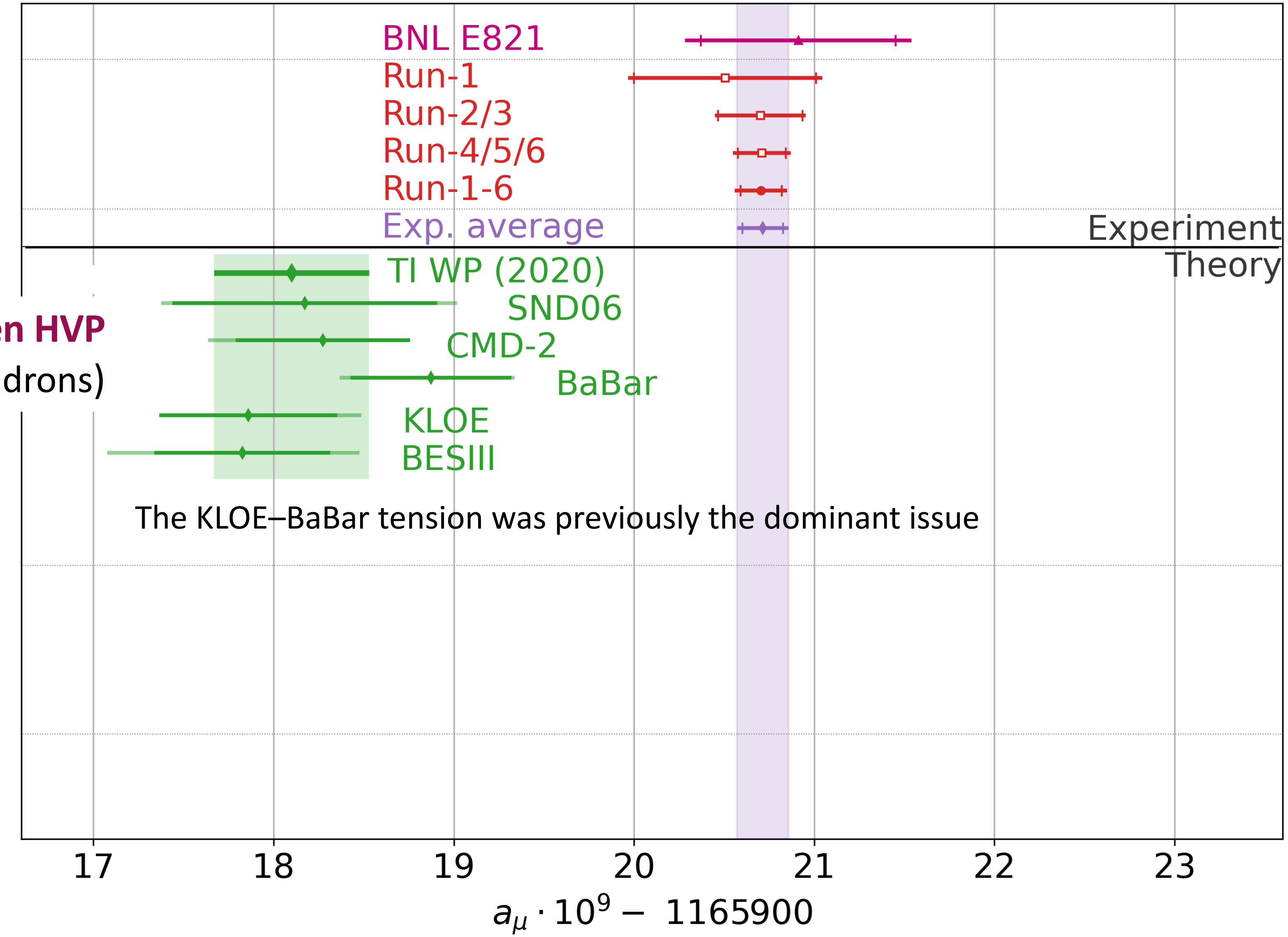
At this time, the theory had been nicely converging

Progression of a_μ Since the 2021 Fermilab Result



Plots courtesy Josh LaBounty

The 2020 Theory Initiative value relies on Data-Driven HVP

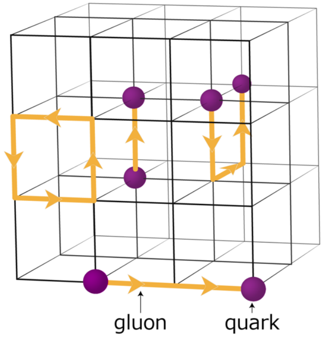


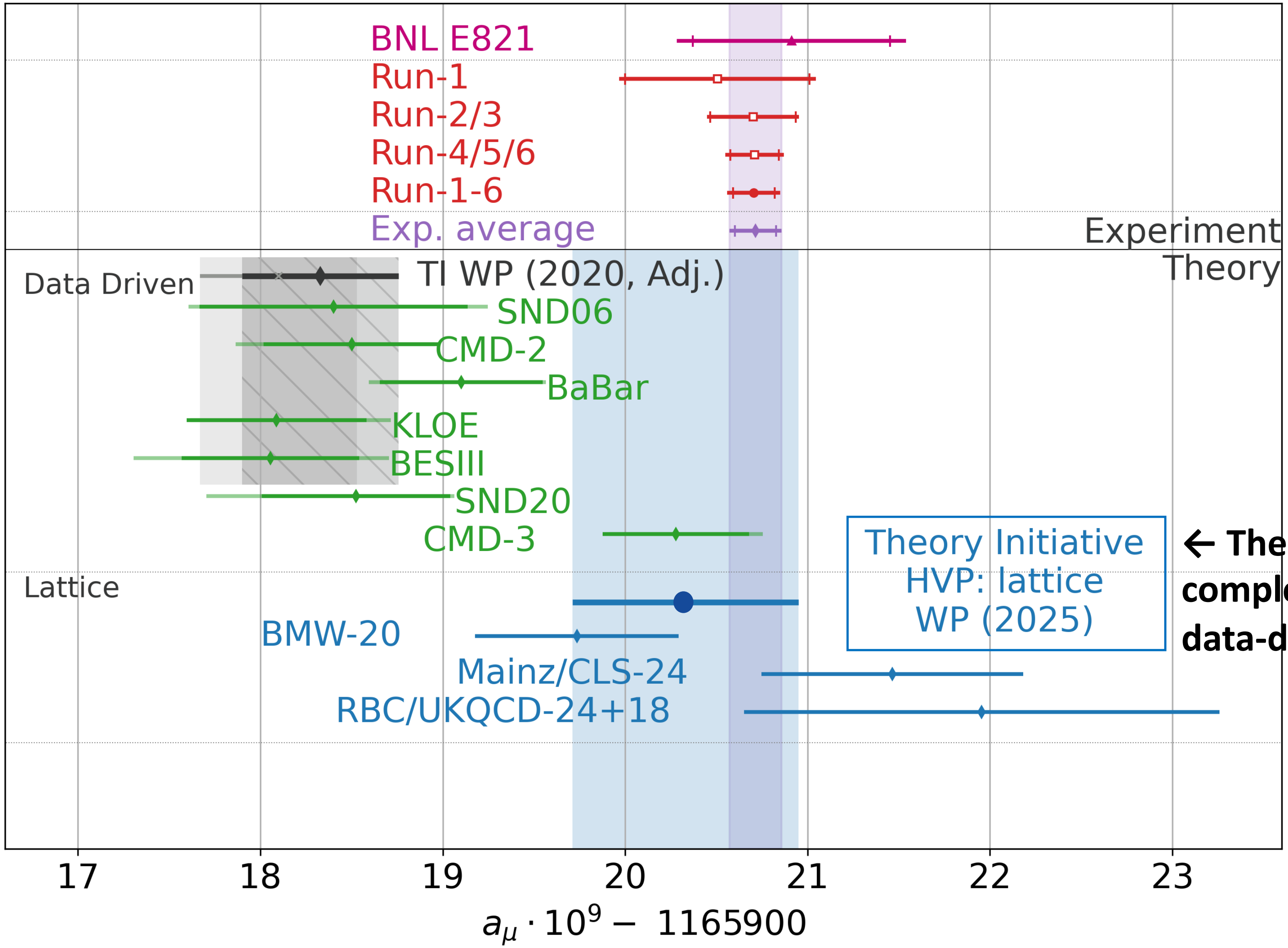
Date Driven HVP

($e^+e^- \rightarrow$ hadrons)

Plots courtesy Josh LaBounty

The SM recommendation 2025: pure Lattice approach

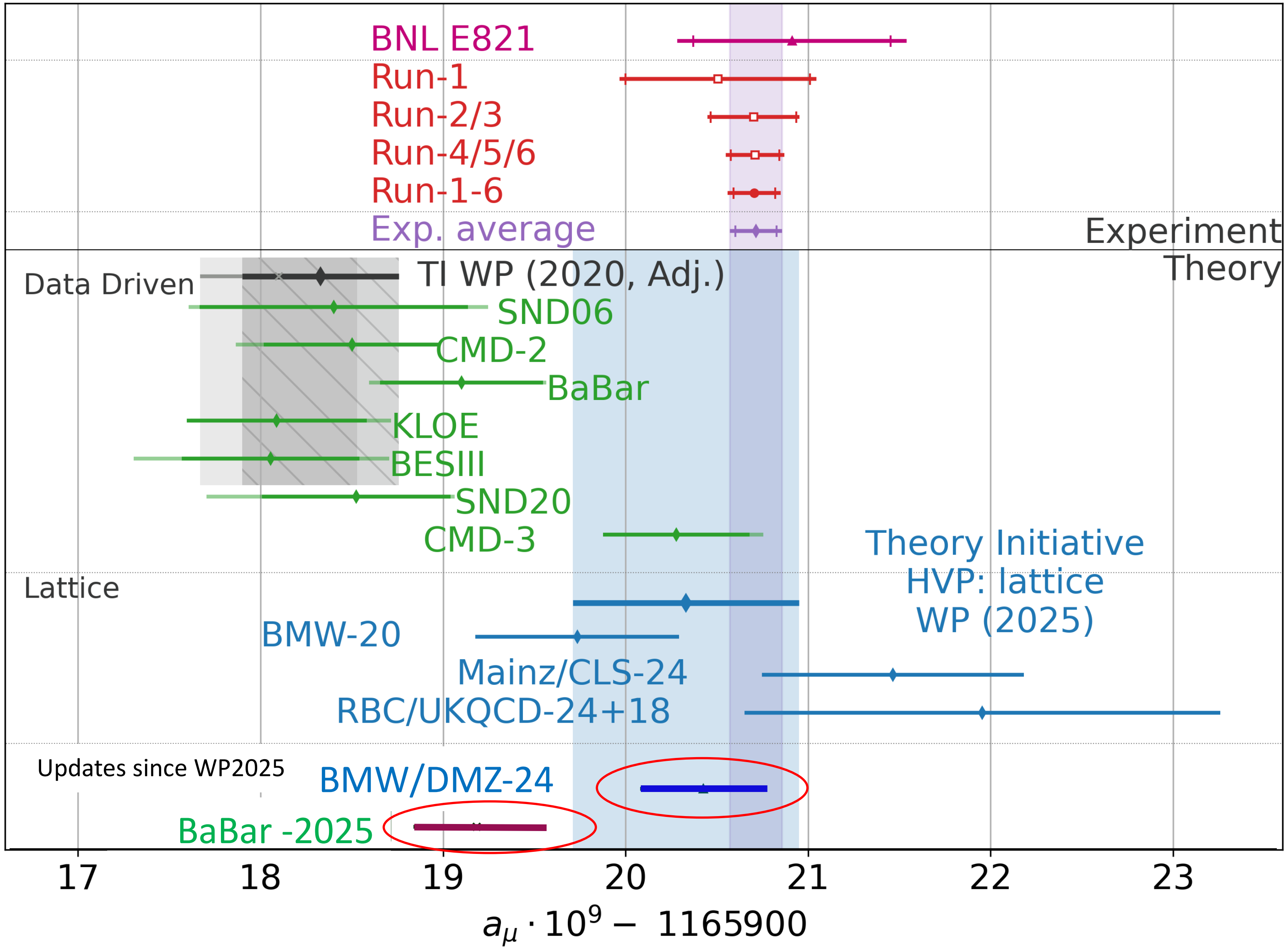




← **The SM recommendation 2025 completely *ignores* the green data-driven results**

Plots courtesy Josh LaBounty

Recently, new Hybrid Lattice and BaBar data



Plots courtesy Josh LaBounty

… and, then?

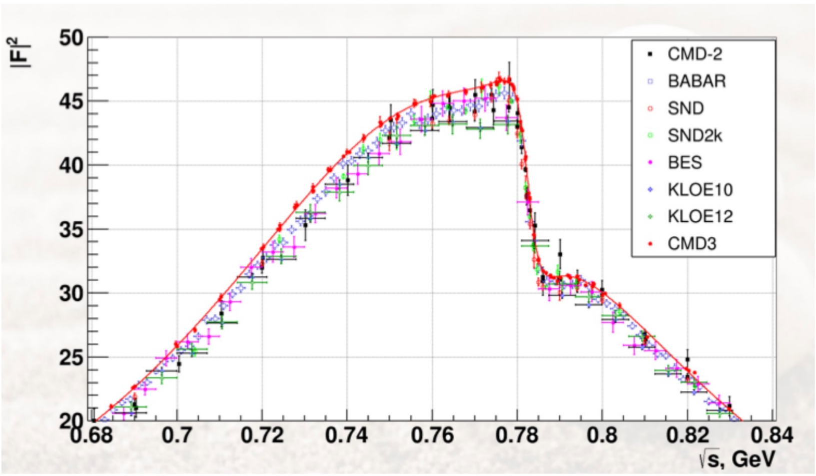
On one hand, theory is advancing -

1) Data-driven approach is under investigation
- Ongoing work in experimental inputs: Babar, KLOE, SND
- MC Generators...

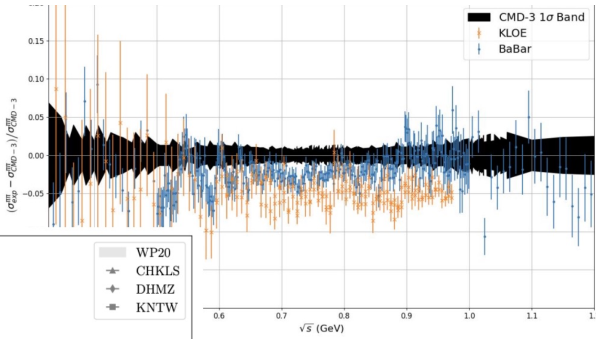
2) The Lattice approach could take the HVP uncertainty down to the 0.1% → push for next-generation measurements

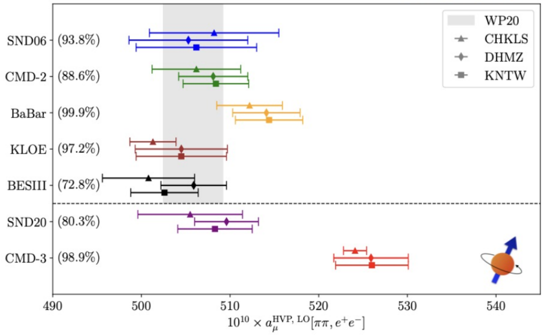
Figure from Fedor Ignatov's TI talk 27.3.2023

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



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





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On the other hand, currently -

No proposed experiment can surpass the Fermilab record of 0.13 ppm.

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- MC Generators...

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On the other hand, currently -

No proposed experiment can surpass the Fermilab record of 0.13 ppm.

Can we go beyond the Fermilab limit?

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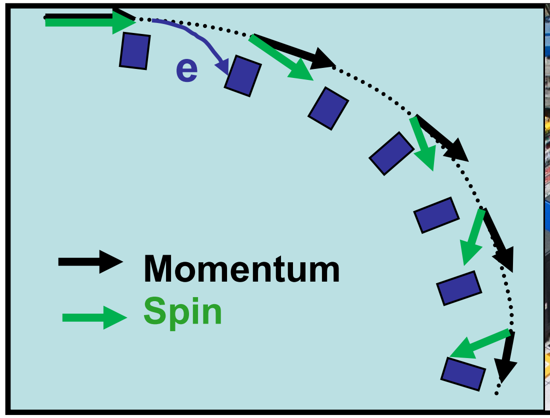
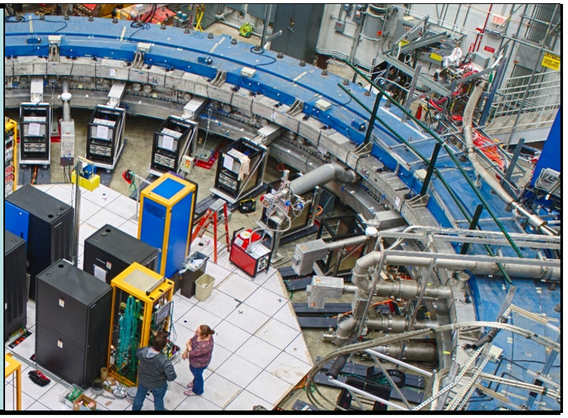
The Basic Principle is Simple





Determine difference between

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

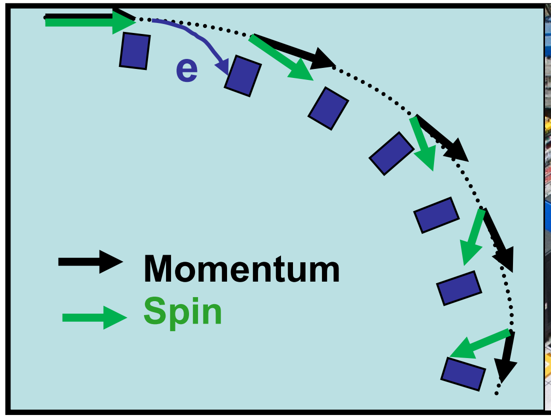
for a (polarized) muon moving in a B field

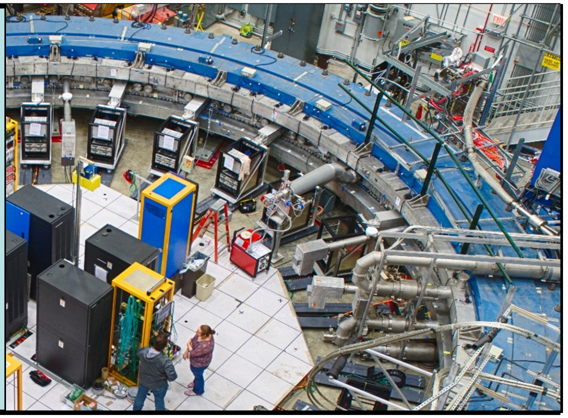
Remember: $a_\mu \equiv \frac{g_\mu - 2}{2}$

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

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

The Basic Principle is Simple



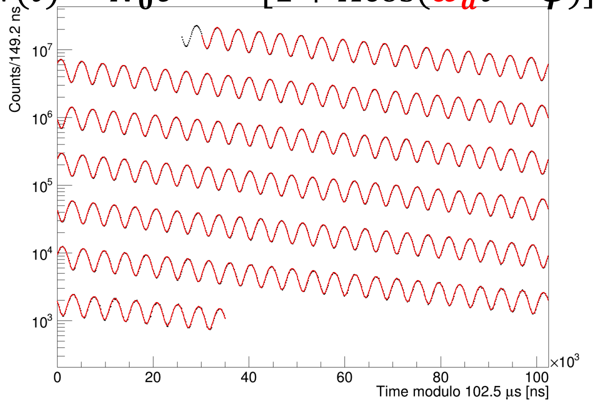


Determine difference between

- **spin precession frequency $\boldsymbol{\omega_S}$** and
- **cyclotron frequency $\boldsymbol{\omega_c}$**

for a (polarized) muon moving in a B field

$N(t) = \boldsymbol{N_0} e^{(-t/\tau)}[1 + \boldsymbol{A}\cos(\boldsymbol{\omega_a} t - \boldsymbol{\phi})]$



Measure these

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

Extract

1. Measure $\boldsymbol{\omega_a}$: modulation of decay positron time spectrum
2. Measure $\boldsymbol{B}$: proton nuclear magnetic resonance (NMR)

$\rightarrow 2\mu'_p(\mathrm{H_2O}, T_r)B = \hbar\omega'_p(\mathrm{H_2O}, \mathrm{T}_r)$

3. Extract a_μ

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

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

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0 if "in plane"

We have electric quadrupoles!

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

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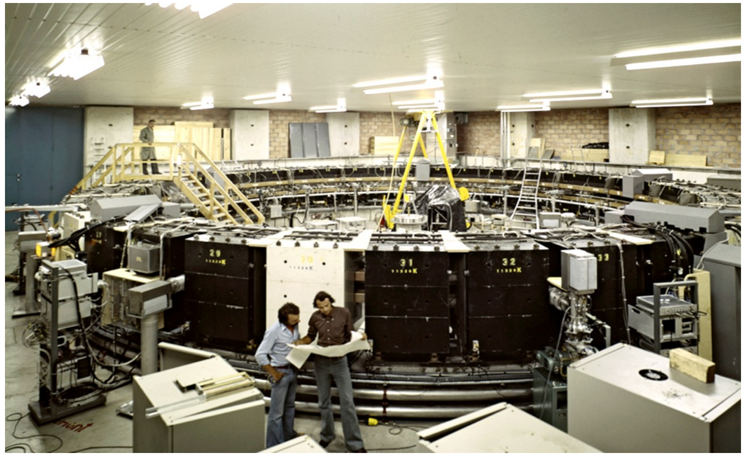

The CERN III Miracle in the 1970's
Precision: 7000 ppb

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0 if "in plane"

We have electric quadrupoles!

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

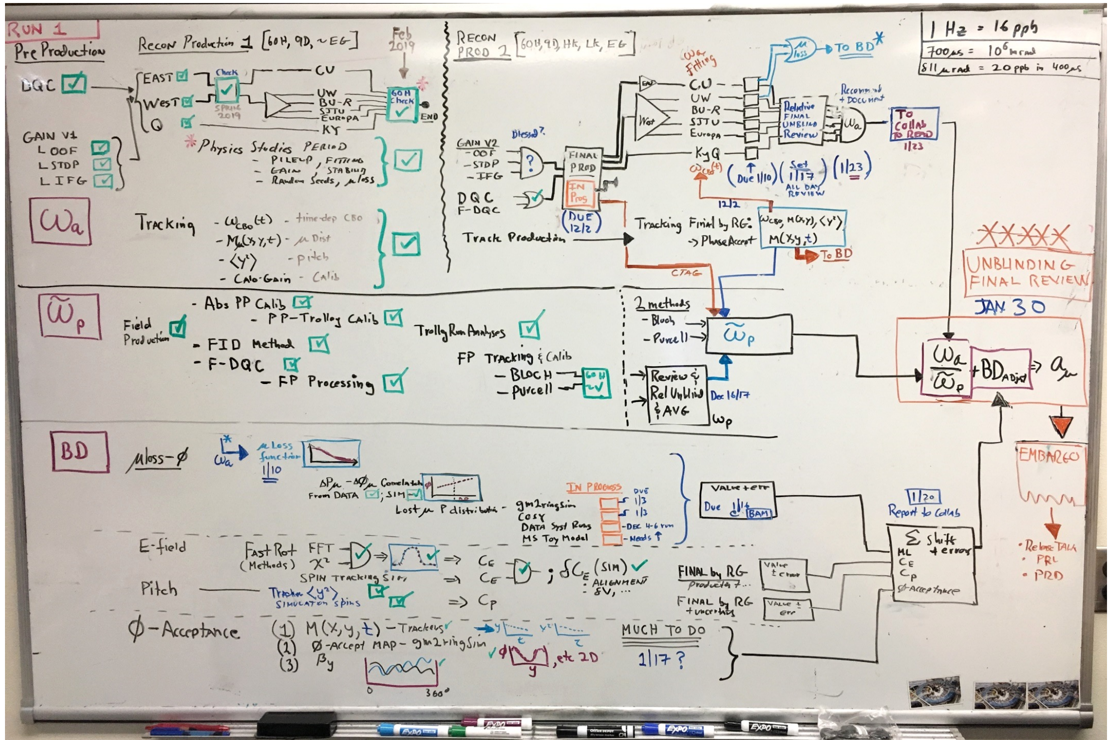
→ However, this magic γ also put a strict constraint to the experimental setup (energy, storage etc)

The Full Recipe - a real-world equation

Corrections from Beam Dynamics

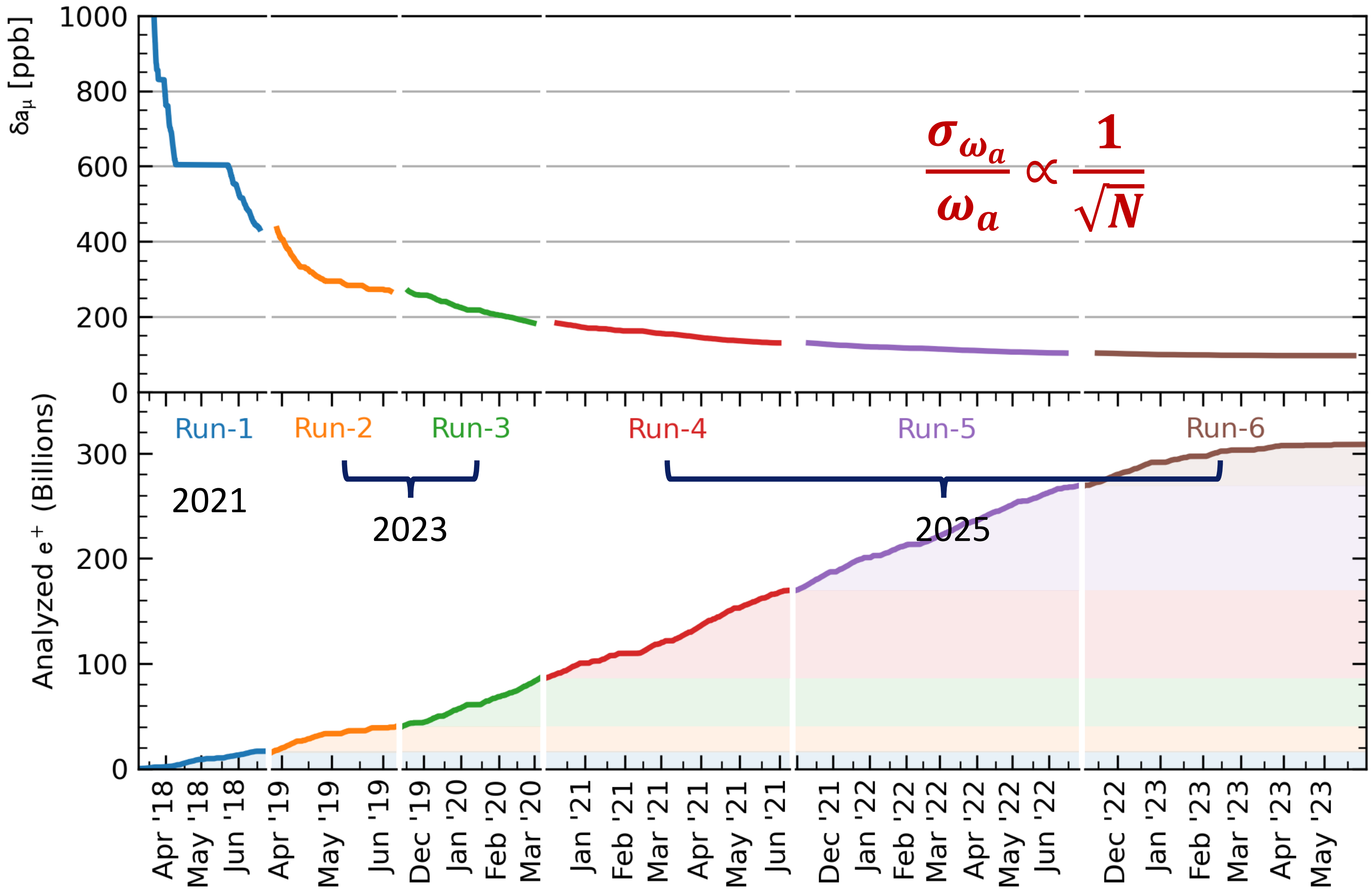
$$a_\mu = \frac{\omega_a}{\omega_p} \times \frac{(1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml})}{(1 + B_k + B_q)} \times \left[\frac{\mu_p'(T_r)}{\mu_e(H)} \frac{\mu_e(H)}{\mu_e} \frac{m_\mu}{m_e} \frac{g_e}{2} \right]$$

Corrections from Magnetic Field Transient



21

Statistics: After 6 years of running

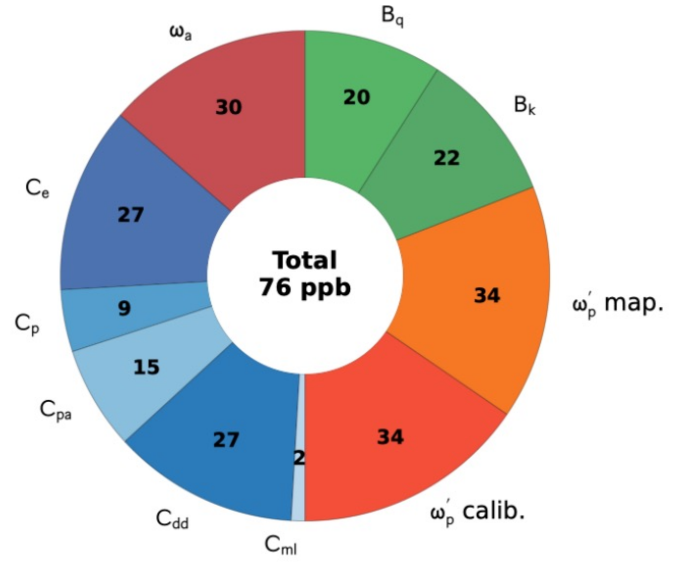


Final uncertainty budget

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

Run-4/5/6

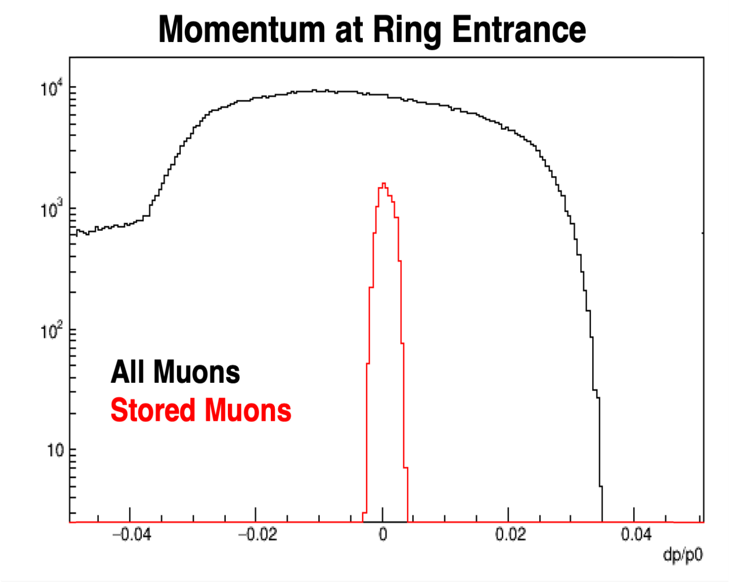
Quantity		Correction (ppb)	Uncertainty (ppb)
ω_a^m (statistical)		$\cdots$	114
ω_a^m (systematic)		$\cdots$	30
C_e	Electric Field	347	27
C_p	Pitch	175	9
C_{pa}	Phase Acceptance	-33	15
C_{dd}	Differential Decay	26	27
C_{ml}	Muon Loss	0	2
$\langle\omega_p' \times M\rangle$ (mapping, tracking)		$\cdots$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



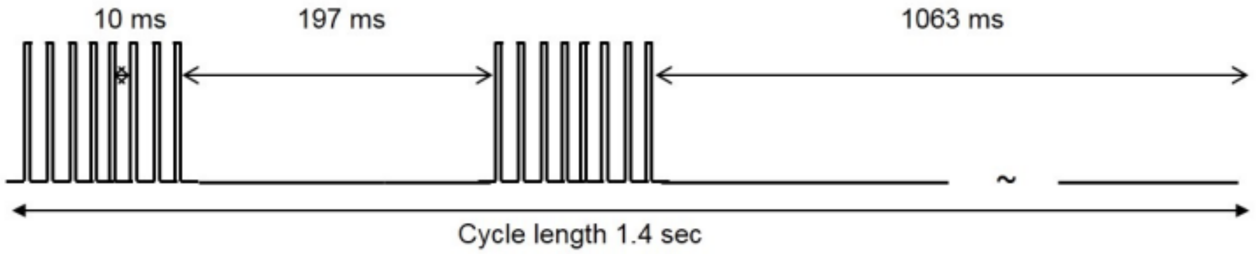
- TDR goal: 100 ppb ✓
- Systematics are “evenly” distributed:
  - No dominant source
  - Further improving would require to reduce in many categories **togerther!**
  - **How?**

How might we do better: more muons

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



- Fermilab g-2 only stores **2% of incoming muons**
- A very tight momentum acceptance and time spread → 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)



- Curent 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 $\boldsymbol{\gamma}$ & $\boldsymbol{B}$

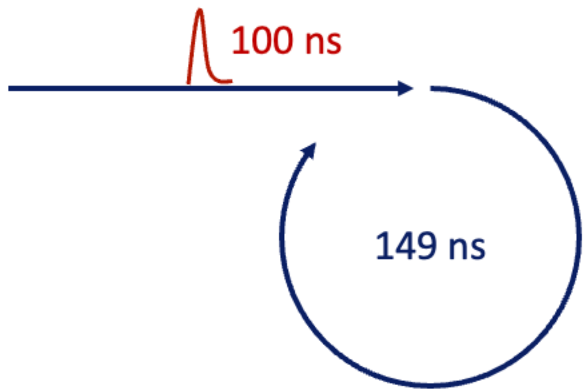
$$\frac{\Delta\omega_a}{\omega_a} \propto \frac{1}{\boldsymbol{\gamma B P}\sqrt{\boldsymbol{N}}}$$

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



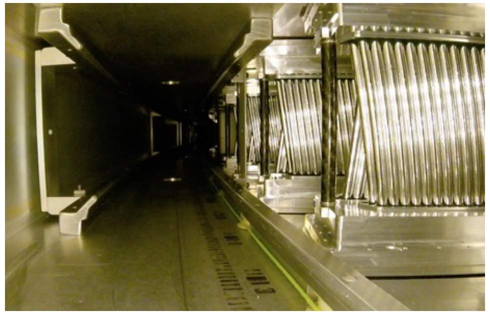
1.45 T & 14 m diameter
@ Fermilab

Lessons learned 1) the magic momentum constraint

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

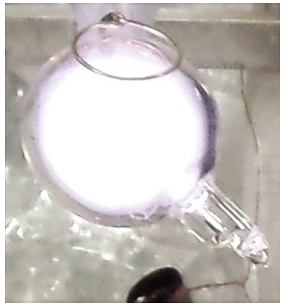
- Therefore, **it all comes down to the magic γ:**
  - It used to be a miracle, but now a limiting factor for boosting muon numbers ($\boldsymbol{N}$) and operating at higher energy $\boldsymbol{\gamma}$
  - Even for a higher **B**-field, a higher energy $\boldsymbol{\gamma}$ is needed to keep the cyclotron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

Lessons learned 2) systematics improvement



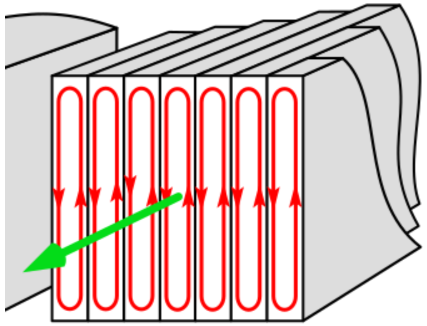
Replace calos with in-vacuo **silicon trackers**

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



Improve field extraction

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



Design out transient fields

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

slides courtesy: James Mott

Lessons learned 2) systematics improvement

https://arxiv.org/abs/2512.16980

The anomalous magnetic moment of the muon: status and perspectives

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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.

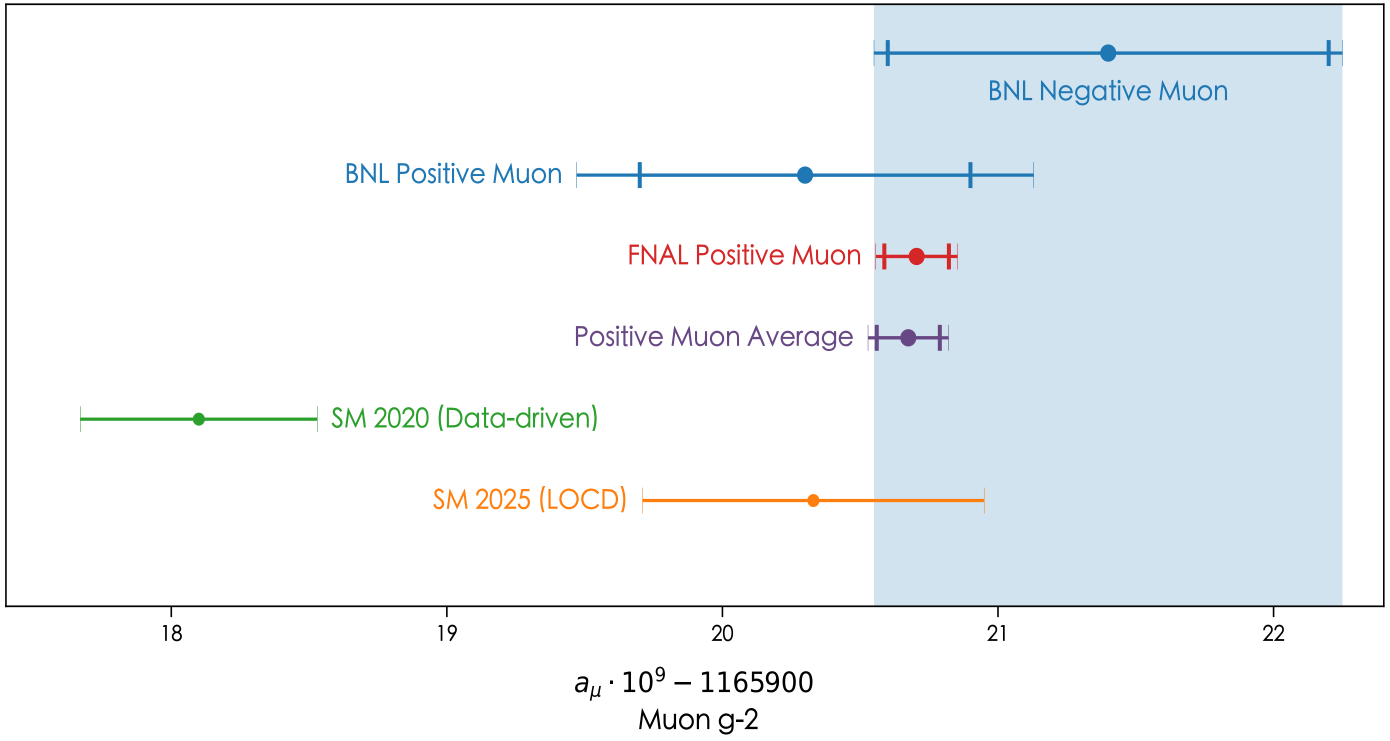
5.2. Can an experiment go beyond 124 ppb?

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 E989. These

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

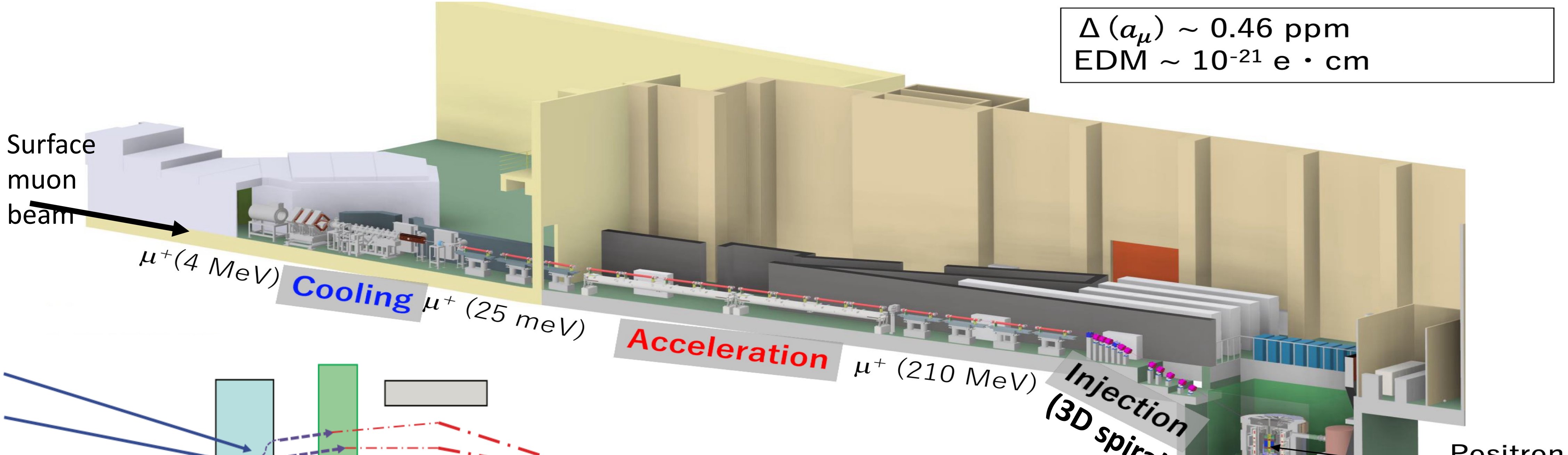
- Fermilab measured the *positive* muon (μ^+) with a precision of **0.14 ppm**;
- The most recent measurement of the *negative* muon (μ^-) still dates back to the BNL era, with a precision of **0.7 ppm** — about five times worse.

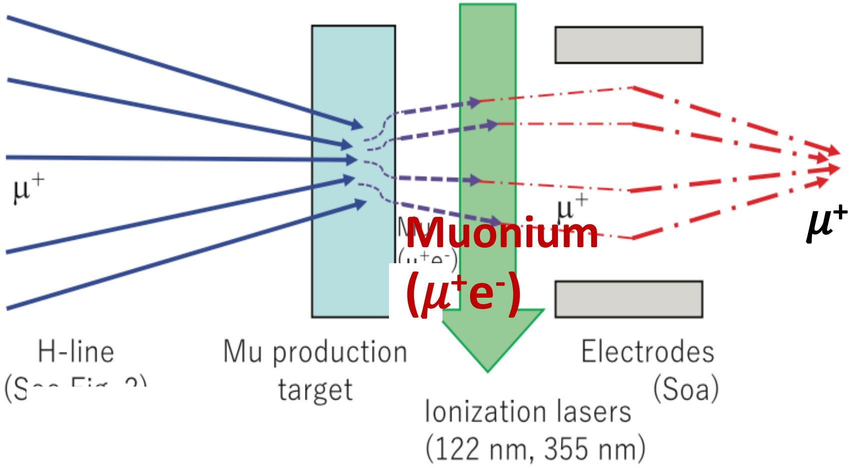


The g-2 experiment at J-PARC

Remember: Fermilab achieved 0.13 ppm

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





Negative muons ***cannot*** be cooled using this technique.

A Next-generation muon g-2 experiment?

Idealy, we would like to have:

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

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Lessons learned suggest considering relaxing the magic momentum constraint:

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

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

*and a prerequisite: a high-intensity GeV-scale muon beam

Proposal at China's HIAF

arXiv > hep-ex > arXiv:2512.11486

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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)**

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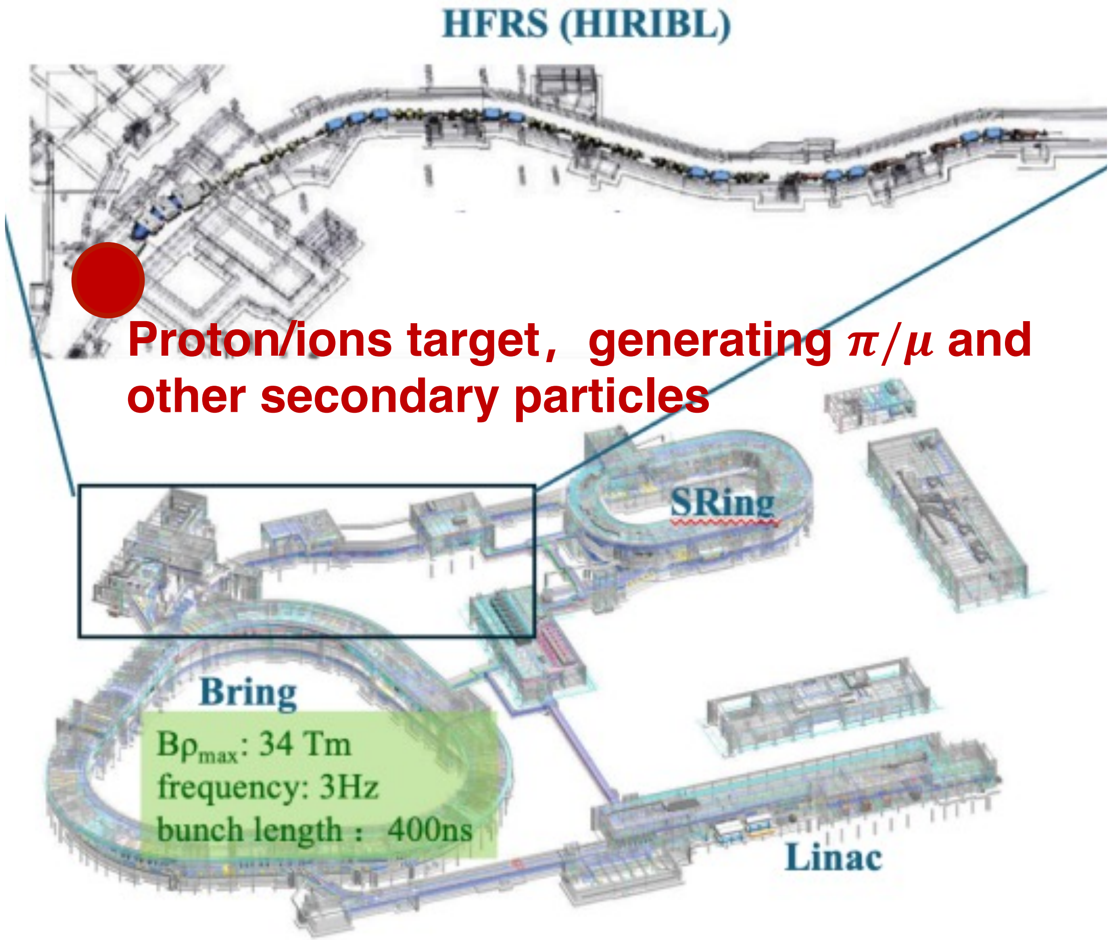
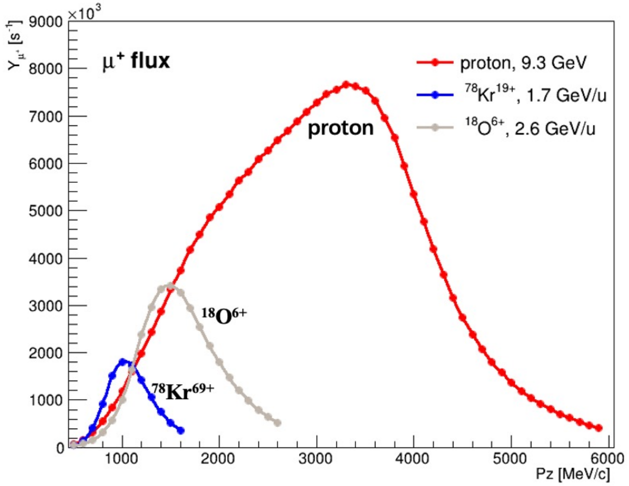
(or arXiv:2512.11486v1 **[hep-ex]** for this version)

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

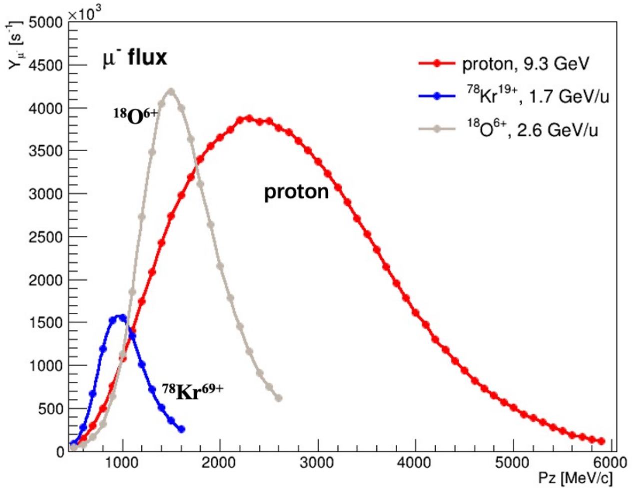
Muon beam at HIAF

Very high intensity *negative* muon beam!





positve muon



negative muon

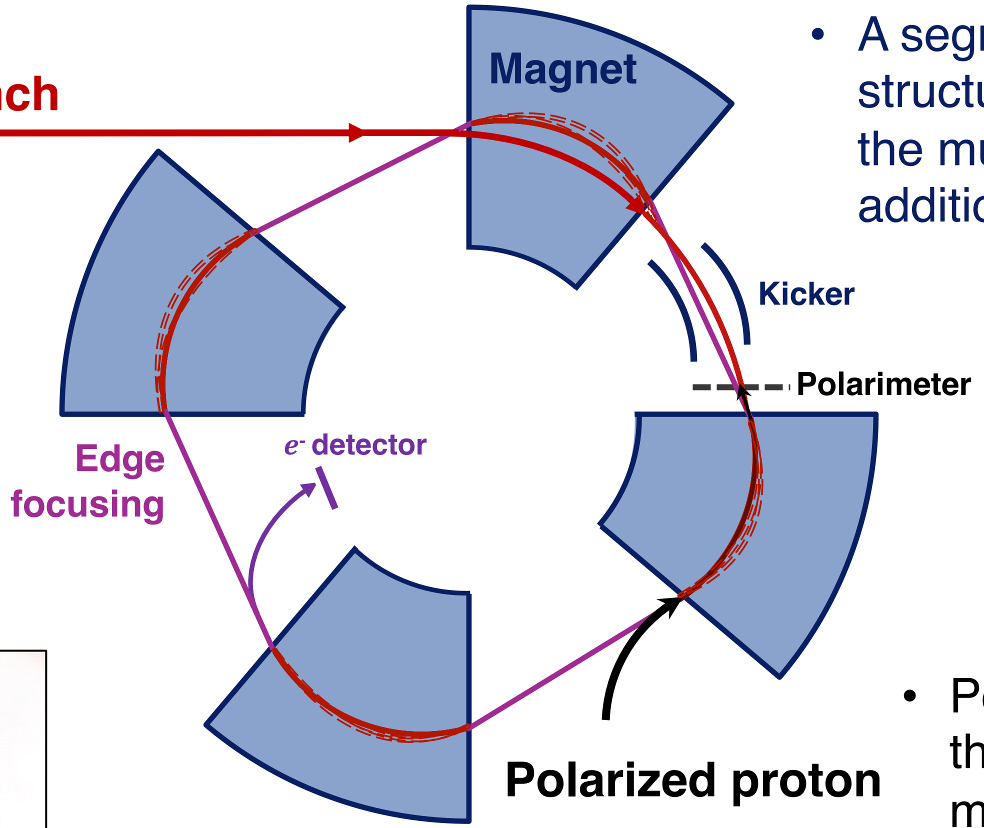
- Maximum μ^+ flux： $8.2\times10^6/s$
  - projectile： proton
  - Pz： 3.5 GeV/c

w/ purification: 2.4×10^5/s

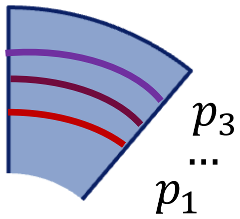
- Maximum μ^- flux： $4.2\times10^6/s$
  - projectile： $^{18}O^{6+}$
  - Pz： 1.5 GeV/c

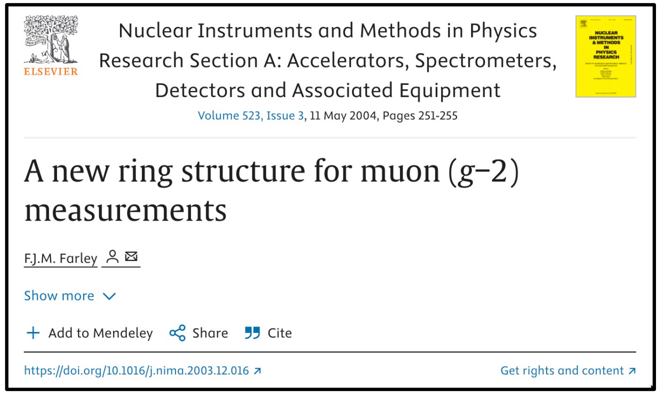
w/ purification: 3.7×10^5/s

Concept of proton-beam co-magnetometer



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





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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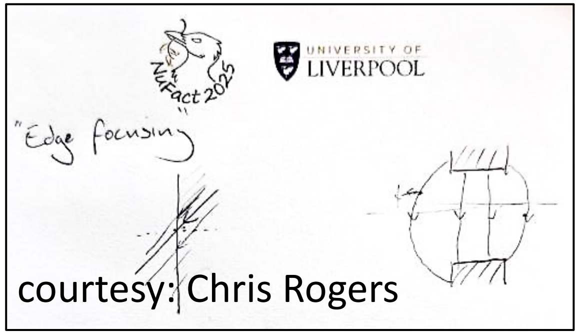
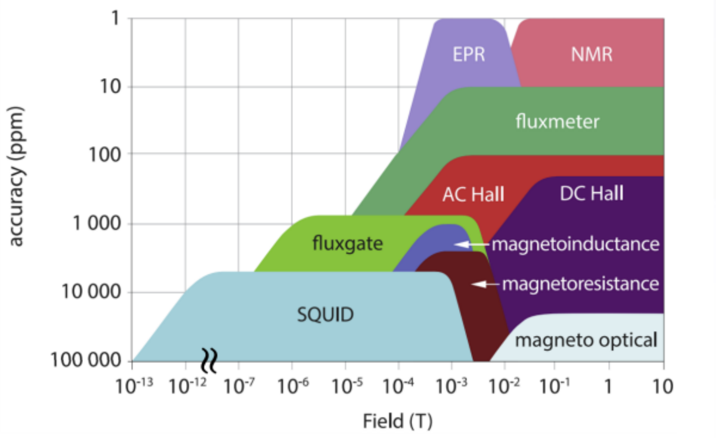


- Polarized protons experience the same magnetic field as the muons for a direct calibration of the magnetic field.

Concept of proton-beam co-magnetometer

- Given a few GeV muons, a B-field of 3–6 T gives radii of approximately 7–3 m
- A strict momentum acceptance is relaxed
- No inflector needed → only need to design kicker
- One big challenge is the calibration of its edge field calibration. **Polarized protons are** essentially a 'denser form' of the NMR probe.

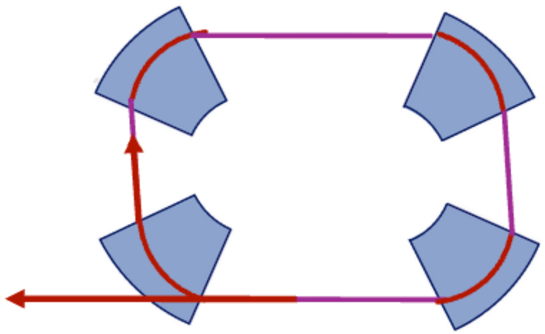


Model validation via CST constructed with ideal tracking simulation

We have started detailed magnet design (Liverpool, IMP), implementing field into the Geant 4 for muon tracking simulation (SJTU) and softwares (PKU)

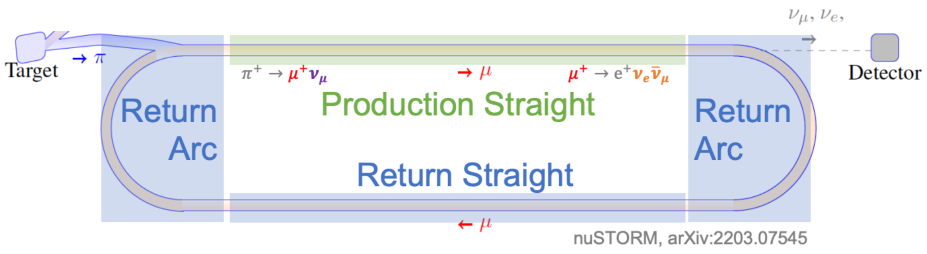
Technical synergies

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



$\mu^- \rightarrow e^- + \nu_e + \overrightarrow{\upsilon_\mu}$

ν from STORed Muons (nuSTORM)



courtesy: Xianguo LU

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

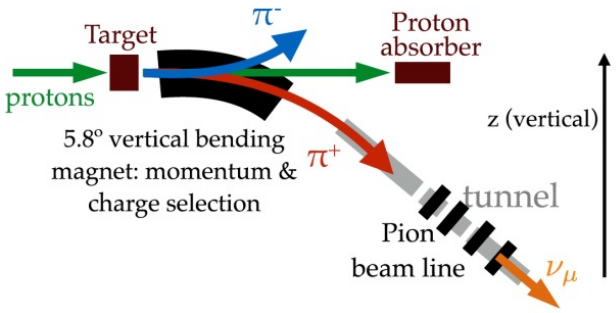


FIG. 1: Scheme of the nuPIL concept.

- The concept is not limited to HIAF but adaptable to muon facilities worldwide

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.

Precisions comparison - 1

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

	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 $\Delta\omega_a/\omega_a$	$\boldsymbol{N}$	100 $\boldsymbol{N}$	$\boldsymbol{N/4}$	$\boldsymbol{N/500}$

↑ 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;

Precisions comparison - 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 → 0.1ppm (?)	μ^-/μ^+: 0.1 ppm → **0.05 ppm**

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

- **Muon g-2 Theory**: where do we stand?
- **Lessons** learned from Fermilab g-2
- **A recipe** for next-generation muon g-2 experiment - CANTON-μ @ HIAF
- **Physics reach** at sub-0.1 ppm precision

What can we probe given a 0.05 ppm?

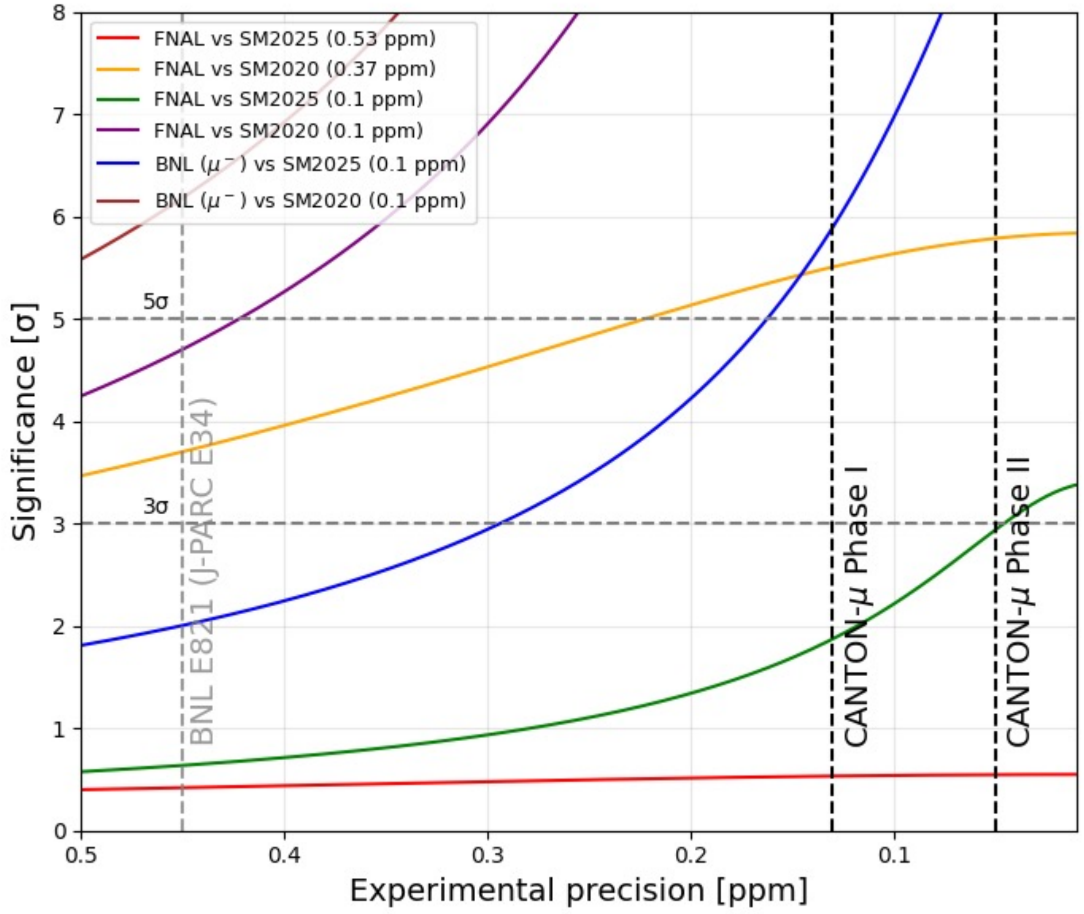
1) significance

New physics significance depends on the central values from both theory and experiment

$$\Delta a_\mu^{\mathrm{Exp-WP2020}} = 26.2(4.5) \times 10^{-10},$$

$$\Delta a_\mu^{\mathrm{Exp-WP2025}} = 3.8(6.3) \times 10^{-10}$$

- Phase-1 can reach 5σ for the exp central value centered on BNL (μ^-) vs. SM2025
- Phase-2 can reach $\sim 3\sigma$ for FNAL vs. SM2025 (assuming 0.1 ppm for theory)



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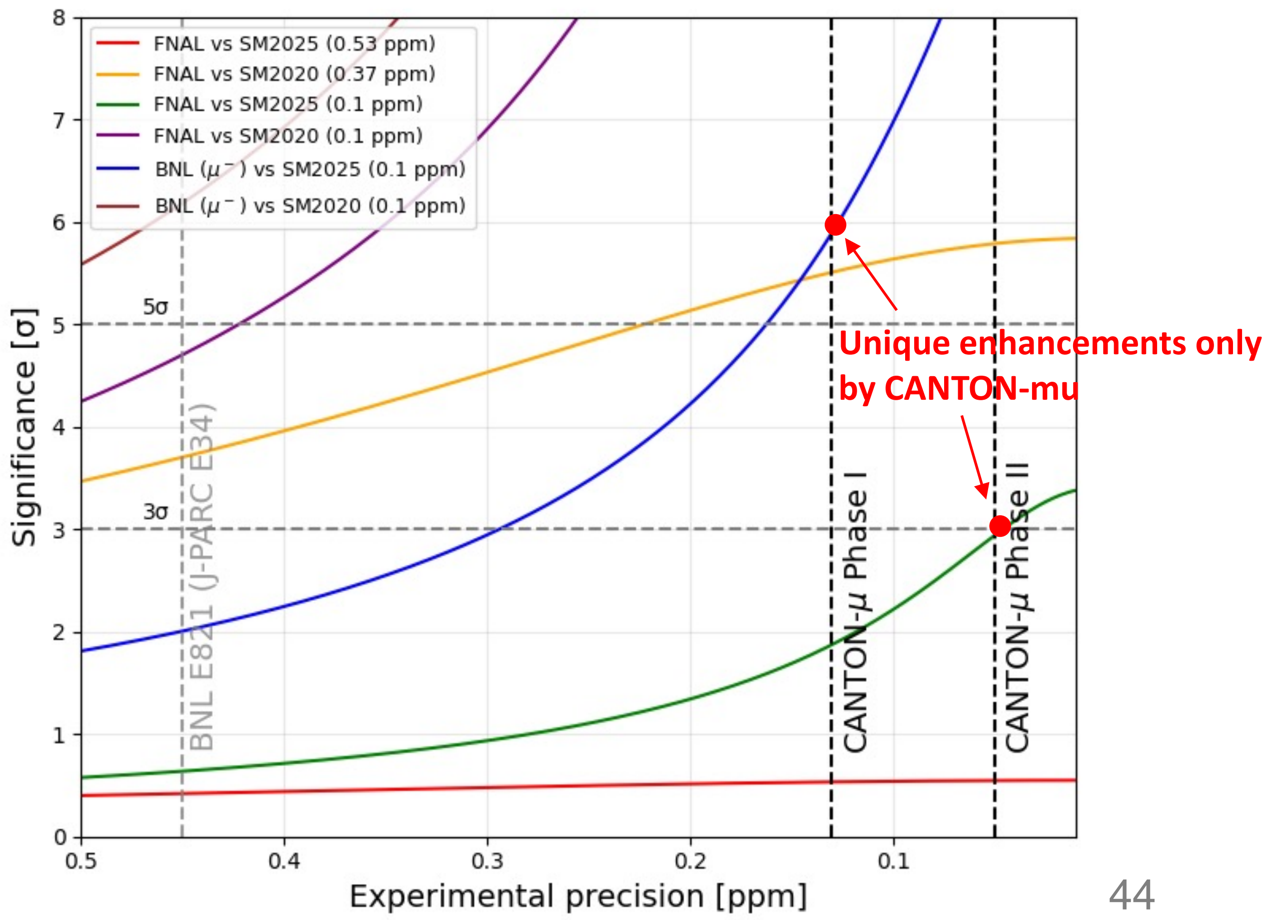
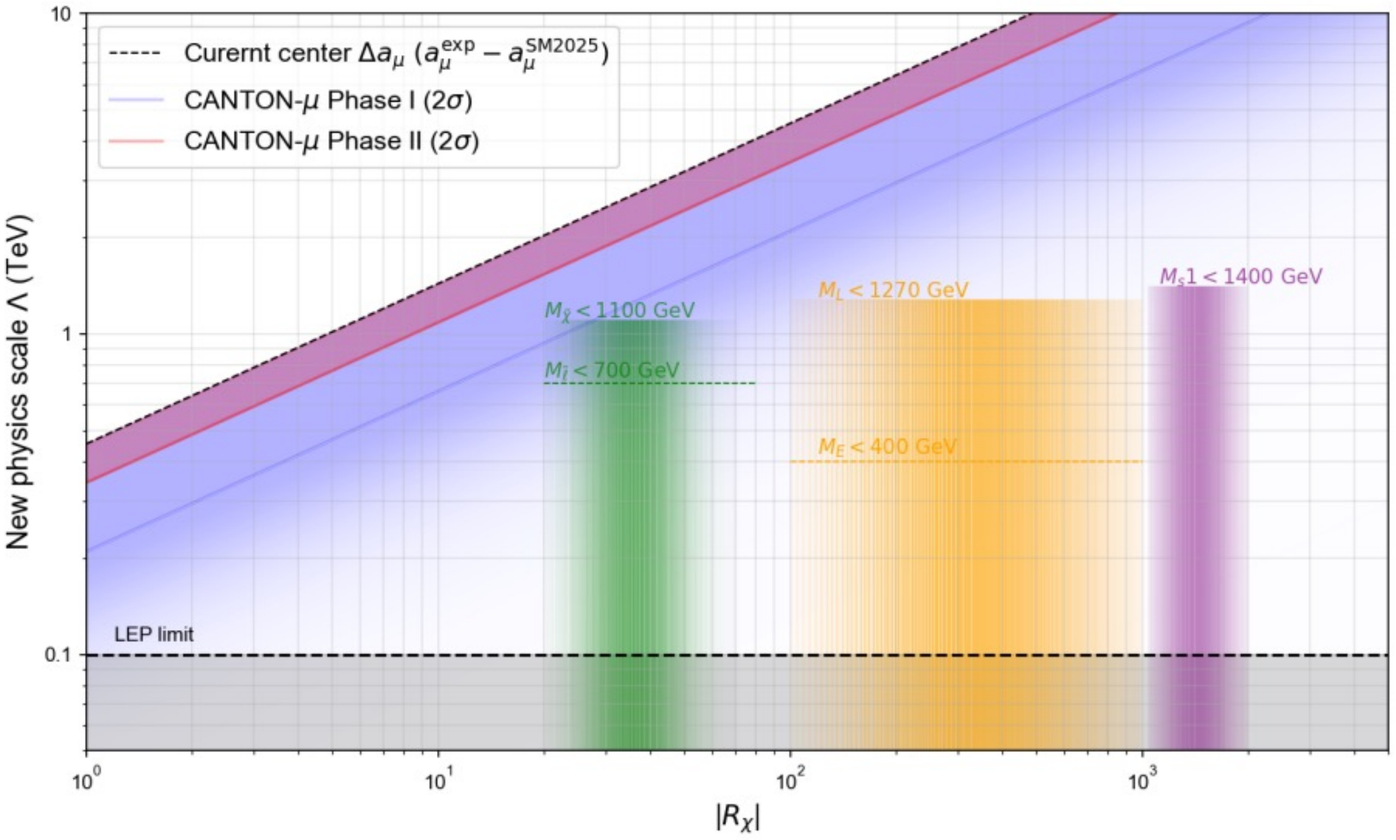


What can we probe given a 0.05 ppm?

2) New-Physics energy scale

- In the chiral enhancements, scaling behaviour for NP is parameteried as

$$\Delta a_\mu \sim R_\chi \times \frac{c_L c_R}{16\pi^2}, \frac{m_\mu^2}{\Lambda^2}$$

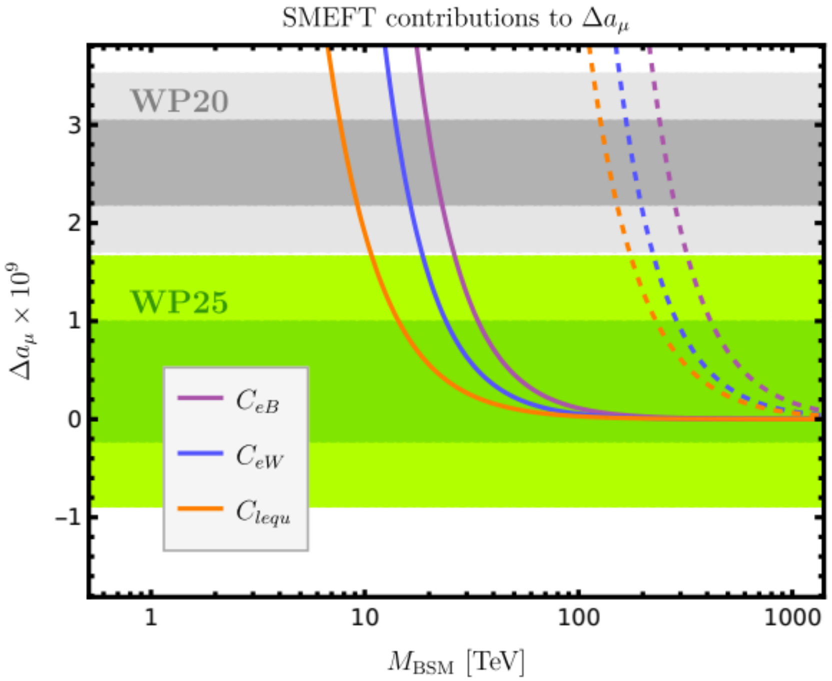


What can we probe given a 0.05 ppm?

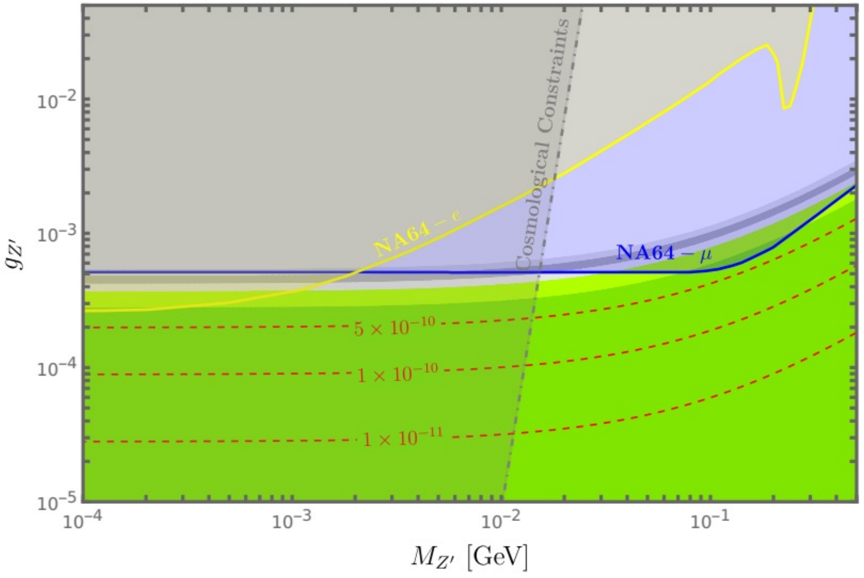
2) New-Physics energy scale

- An independent precise experimental result would decisively clarify the current WP20 vs WP25 puzzles over many NP models

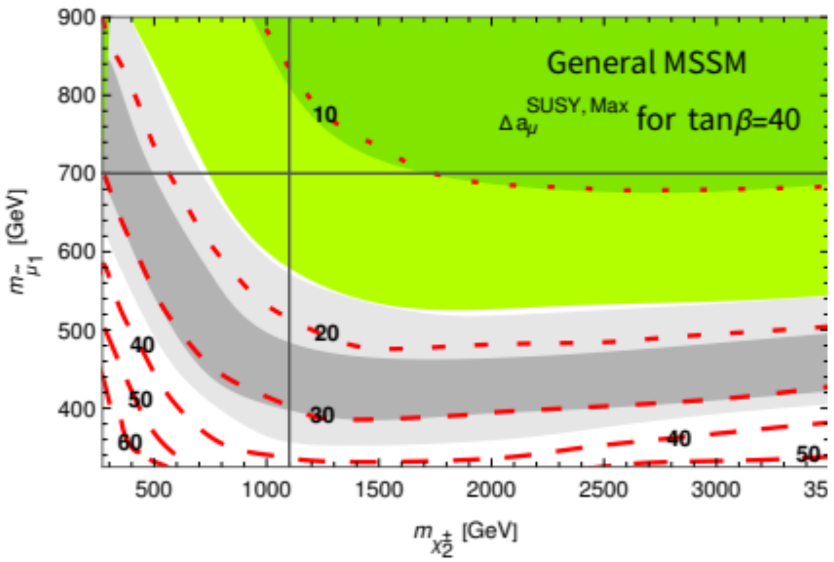
P. Athron et al., Prog.Part.Nucl.Phys. 148 (2026) 104225



SMEFT Wilson coefficients



Z prime constraint



SUSY MSSM contribution

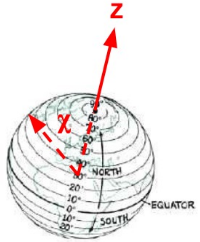
What can we probe given a 0.05 ppm?

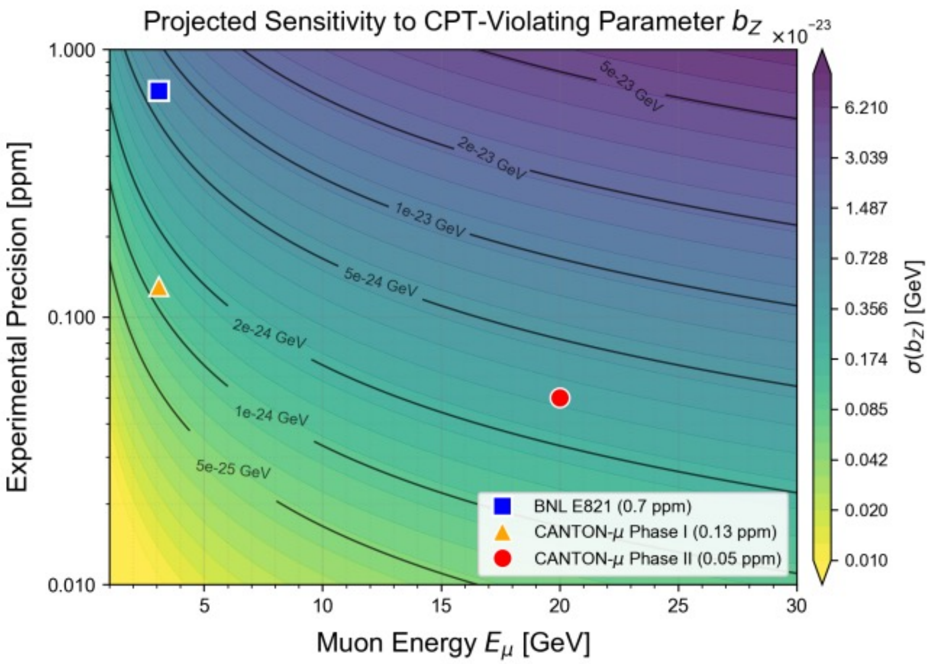
3) Unique CPT sensitivity

- SME Lagrangian:

$$\mathcal{L}' = -a_\kappa \bar{\psi}\gamma^\kappa\psi - b_\kappa \bar{\psi}\gamma_5\gamma^\kappa\psi - \frac{1}{2}H_{\kappa\lambda}\bar{\psi}\sigma^{\kappa\lambda}\psi + \frac{1}{2}ic_{\kappa\lambda}\bar{\psi}\gamma^\kappa \overleftrightarrow{D}^\lambda \psi + \frac{1}{2}id_{\kappa\lambda}\bar{\psi}\gamma_5\gamma^\kappa \overleftrightarrow{D}^\lambda \psi$$

  - 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)





Facility	Latitude ϕ	Colatitude $\chi = 90° - \phi$
BNL	40.9°N	49.1°
Fermilab	41.9°N	48.1°
CERN	46.2°N	43.8°
J-PARC	36.5°N	53.5°
HIAF	23.1°N	66.9°

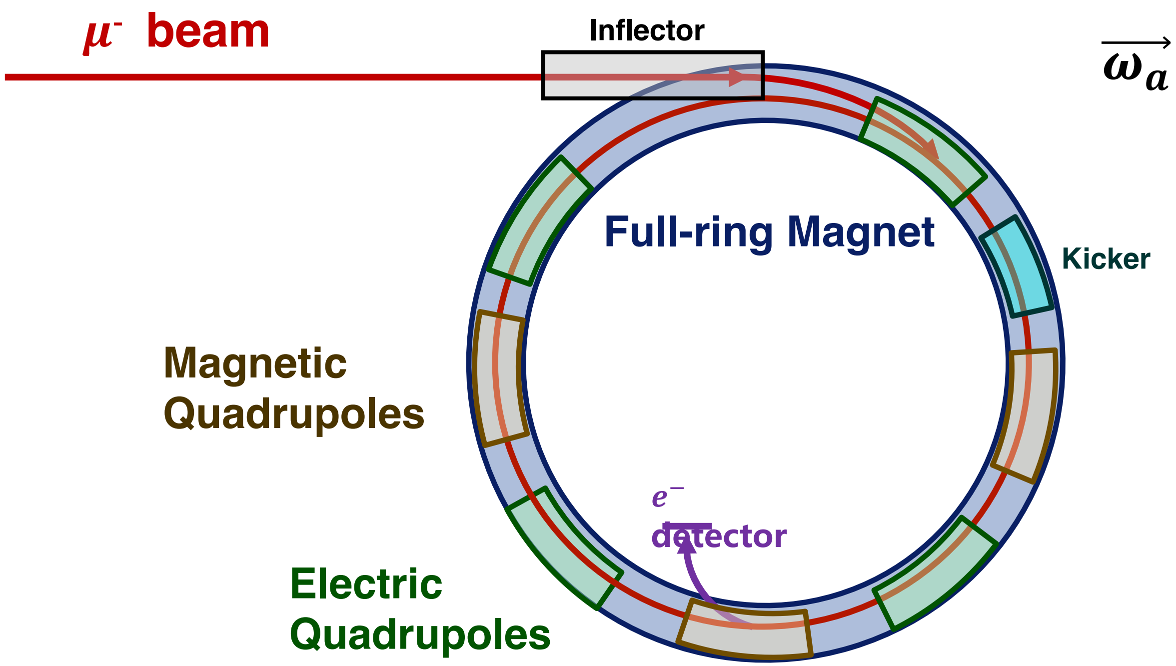
Closing remarks

- The muon g-2 have triggered extensive experiment and theory activities over the past 60 years—and will continue to do so.
- The current theory puzzles will be resolved and the precision will again match (and surpass) the Fermilab precision
- The time will come for a next-generation muon g-2 experiment. For now, none exists—except this proposal.
- For more details, see my recent seminar at Oxford, and more progress to come for workshops (Phipsi 2026 @ Pisa, Nufact 2026 @ Shanghai).
- Stay tuned!

backup

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:



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

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

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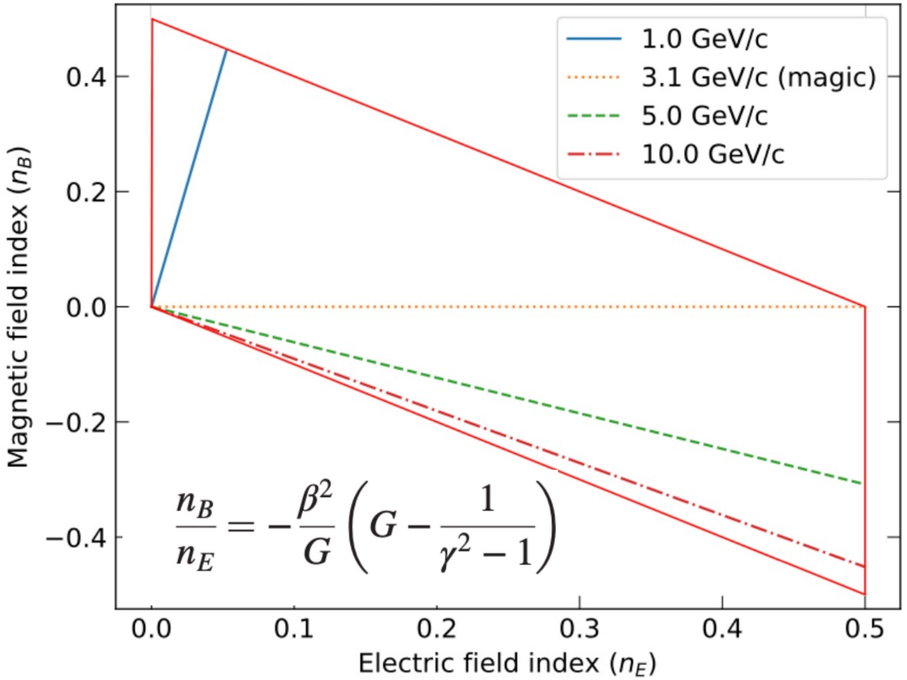
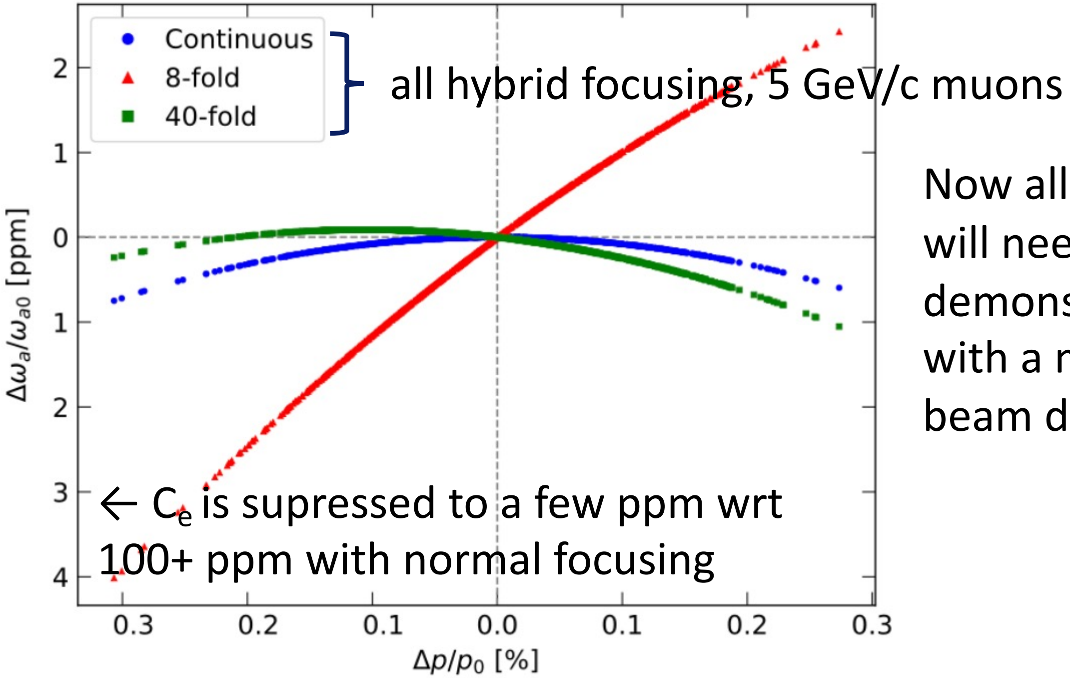
(Received 18 October 2021; accepted 8 February 2022; published 18 February 2022)

Concept 1) Hybrid weak focusing

Detailed configs for E and B field



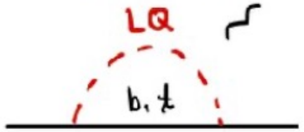


Now all are analytic - will need to demonstrate it works with a more realistic beam dynamics

- In principle it's straightforward to recycle the magnet from FNAL – an upgrade version (with potential of higher precision!)

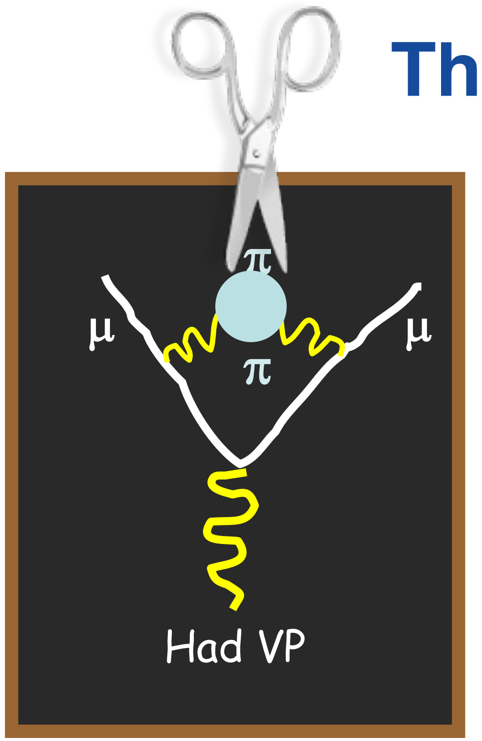
New physics interpretations

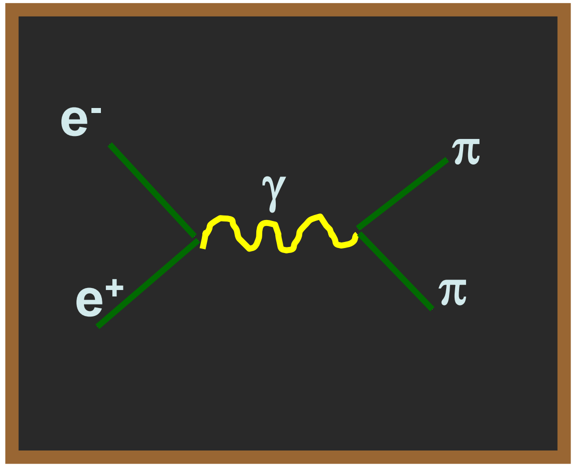
[Refs: Athron et al, 2104.03691; Buen-Abad et al, 2104.03267; Krnjaic et al, 1902.07715; Dermisek et al, 2103.05645]

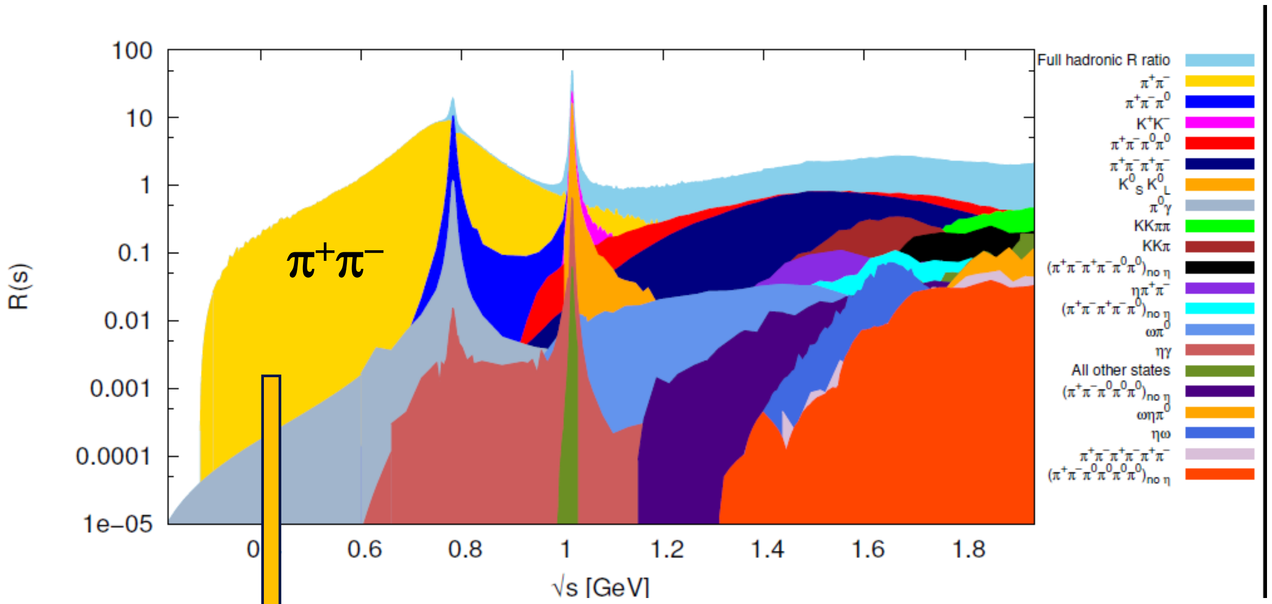
NP type	diagrams	mass range	probe
Supersymmetry		200～500 GeV	$\tilde{\chi}_2^0\tilde{\chi}_1^\pm \to (h\tilde{\chi}_1^0)\,(W^\pm\tilde{\chi}_1^0)$ $pp \to \gamma\gamma \to \widetilde{\ell\ell}^*$
Scalar extensions		20～100 GeV, 150～250 GeV	$Z \to \tau^+\tau^-$ $h \to AA$
Axion-like particle		40 MeV～6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

courtesy: slides from Teppei Kitahara

The long-standing recipe: data-driven approach





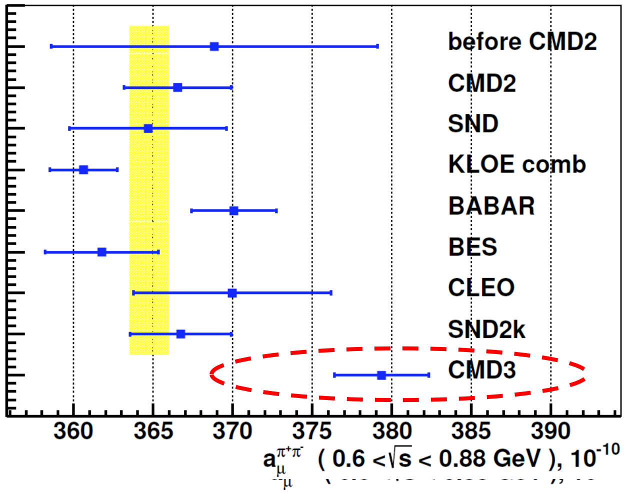


~ 250 measurements in > 50 hadronic channels

Uncertainties are "all" experimental

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)**

ππ region



9 experiments contribute

The lattice … eventually the most precise HVP method?

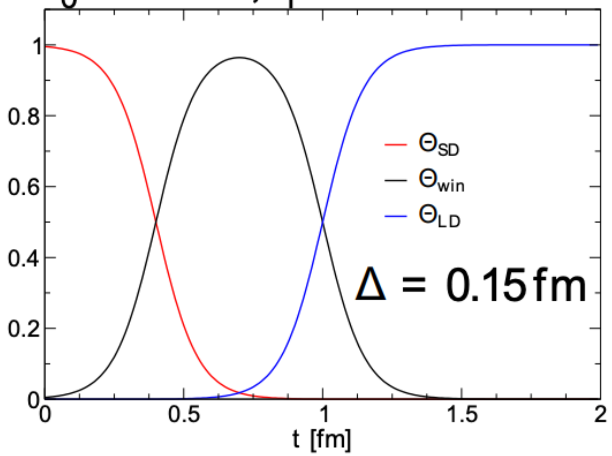
The 2021 BMW HVP publication: First full lattice prediction with errors matching the datadriven approach.

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)	$t : 0 \to t_0$
Intermediate (W)	$t : t_0 \to t_1$
Long Distance (LD)	$t : t_1 \to \infty$

$t_0 = 0.4\,\text{fm}, t_1 = 1.0\,\text{fm}$



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

- In the Standard Model, μ^+ and μ^- g–2 should be the same → any difference would be direct evidence of CPT violation and new physics.
- A precise μ^- g–2 alongside μ^+ would greatly improves 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. Fedotovich,[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. Zimmerman[10]

(Muon $g-2$ Collaboration)

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

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

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

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

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- SME Lagrangian:

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

- All terms violate Lorentz invariance
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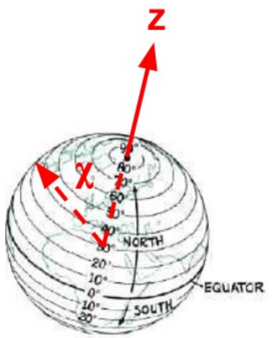


Table D21. Muon sector, $d = 3$

Combination	Result	System	Ref.
$\lvert\mathrm{Re}\, H_{011}^{\mathrm{NR}(0B)}\rvert$, $\lvert\mathrm{Im}\, H_{011}^{\mathrm{NR}(0B)}\rvert$, $\lvert\mathrm{Re}\, g_{011}^{\mathrm{NR}(0B)}\rvert$, $\lvert\mathrm{Im}\, g_{011}^{\mathrm{NR}(0B)}\rvert$	$< 2 \times 10^{-22}$ GeV	Muonium spectroscopy	[20]*
$\lvert\mathrm{Re}\, H_{011}^{\mathrm{NR}(1B)}\rvert$, $\lvert\mathrm{Im}\, H_{011}^{\mathrm{NR}(1B)}\rvert$, $\lvert\mathrm{Re}\, g_{011}^{\mathrm{NR}(1B)}\rvert$, $\lvert\mathrm{Im}\, g_{011}^{\mathrm{NR}(1B)}\rvert$	$< 7 \times 10^{-23}$ 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]*
$\lvert\mathrm{Re}\, H_{011}^{(3)(0B)}\rvert$, $\lvert\mathrm{Im}\, H_{011}^{(3)(0B)}\rvert$	$< 5 \times 10^{-23}$ GeV	"	[20]*
$\check H_{010}^{(3)}$	$(-1.6 \pm 1.7) \times 10^{-22}$ GeV	BNL, CERN $g_\mu - 2$ data	[20]*
$\lvert\mathrm{Re}\, \check H_{011}^{(3)}\rvert$, $\lvert\mathrm{Im}\, \check H_{011}^{(3)}\rvert$	$< 2.0 \times 10^{-24}$ GeV	BNL $g_\mu - 2$	[20]*
$m_\mu d_{Z0} + H_{XY}$	$(1.8 \pm 6.0) \times 10^{-23}$ GeV	"	[185]

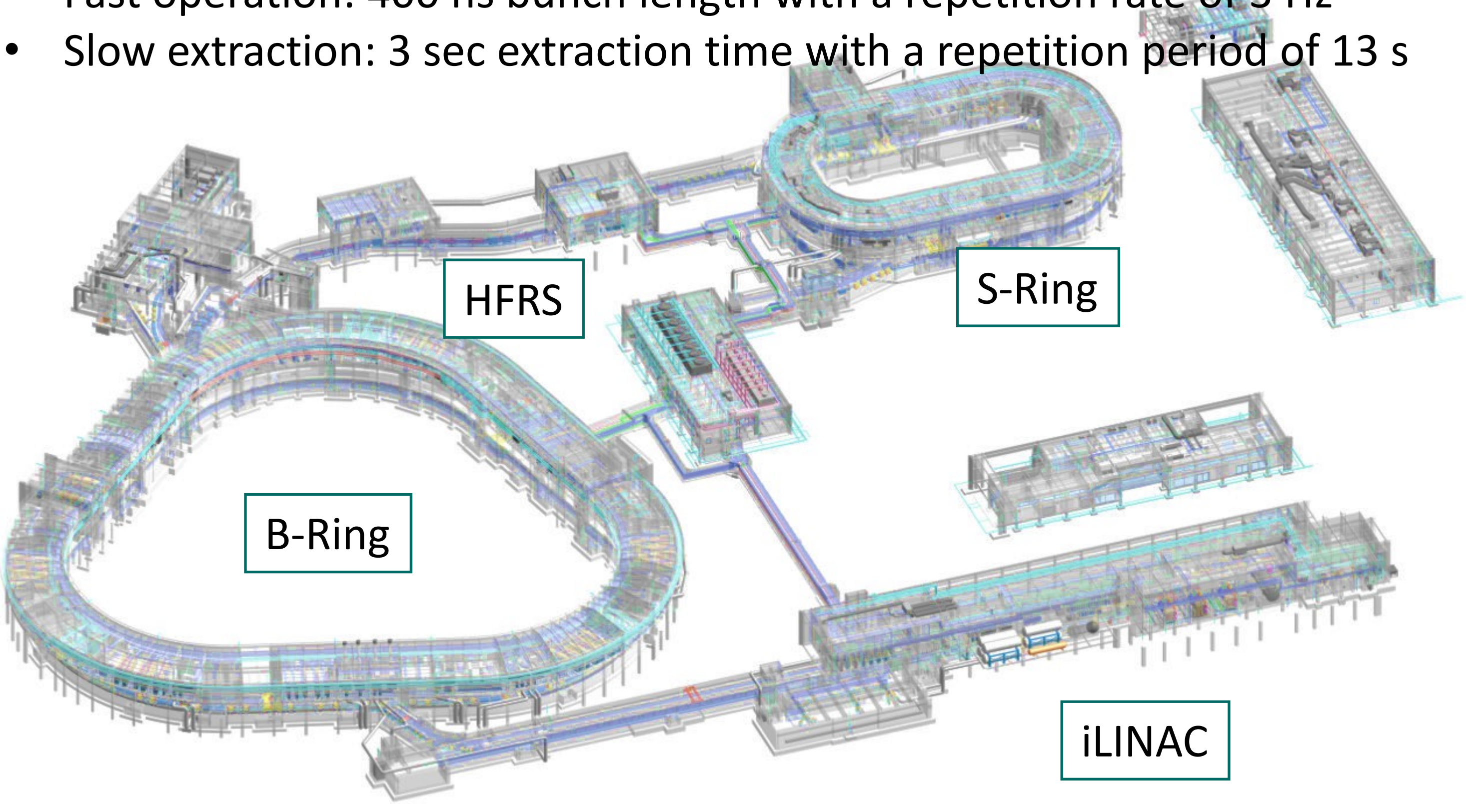
Courtesy: Breese Quinn

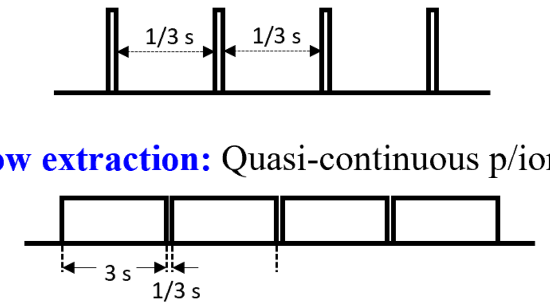
HIAF

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

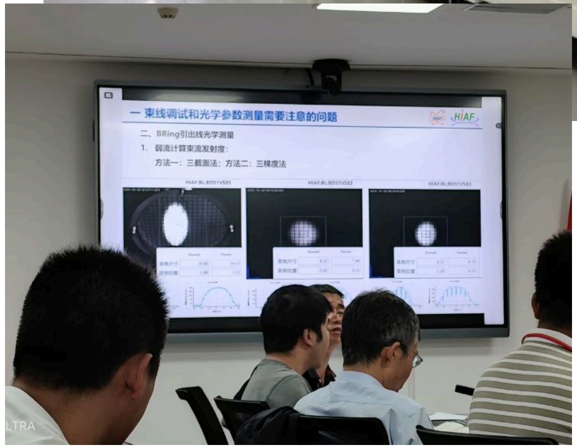
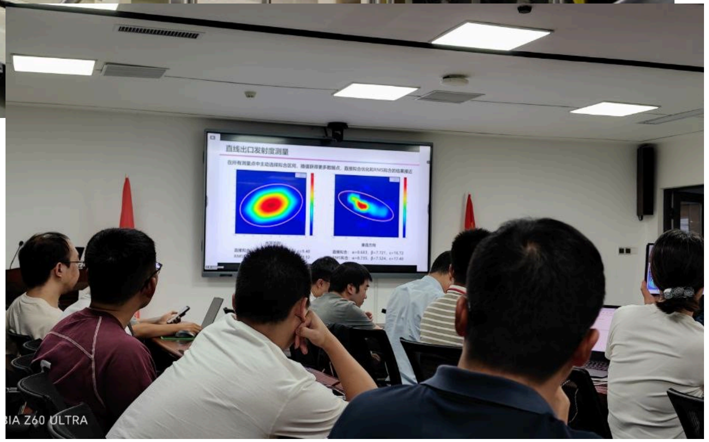


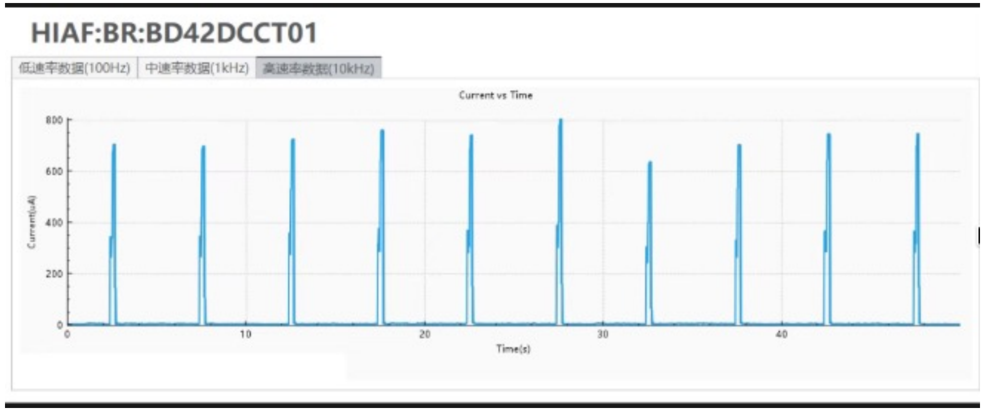


	34Tm，3Hz	
Ions	Particle per pulse (ppp)	Energy(GeV/u)
$^{238}U^{35+}$	1.0×10^{11}	0.84
$^{209}Bi^{27+}$	1.2×10^{11}	0.85
$^{78}Kr^{19+}$	3.0×10^{11}	1.7
$^{18}O^{6+}$	6.0×10^{11}	2.6
Proton	**2.0×10^{12}**	**9.3**

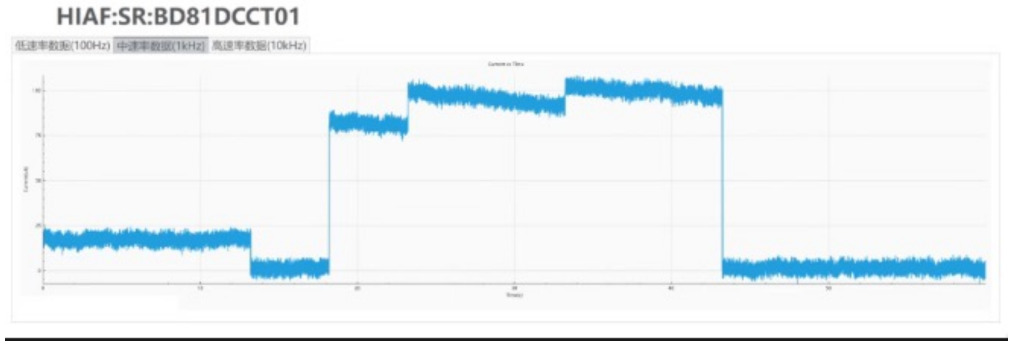
HIAF

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



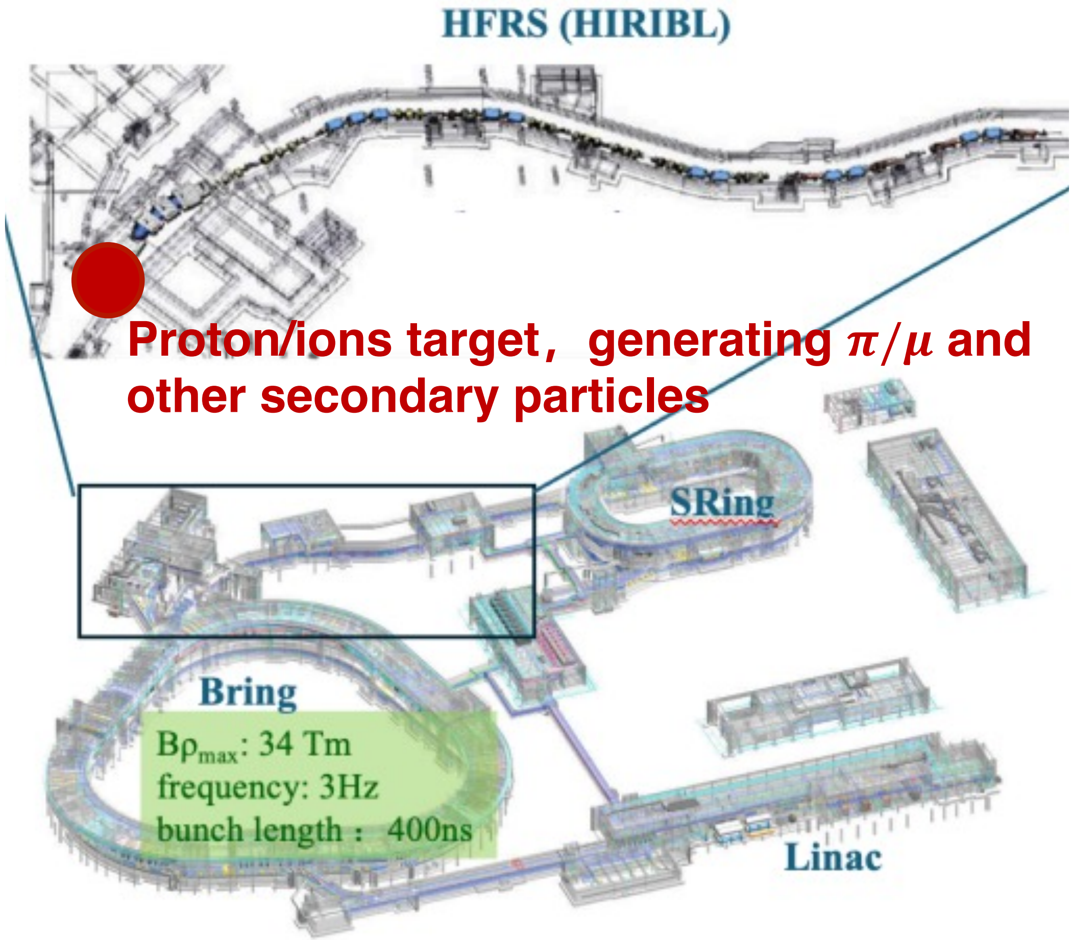
the first signal ^{18}O at B-ring

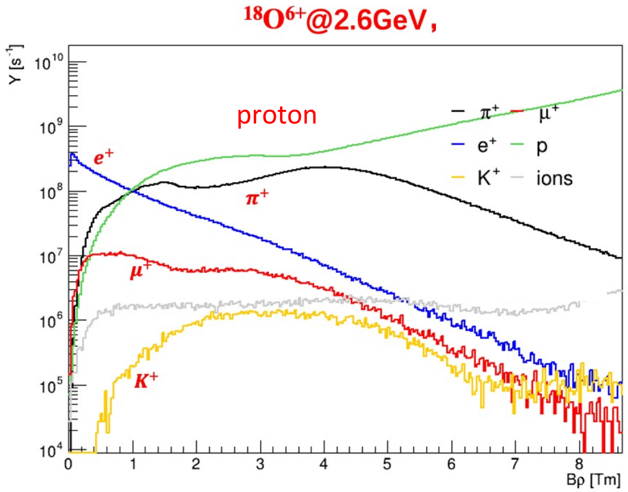


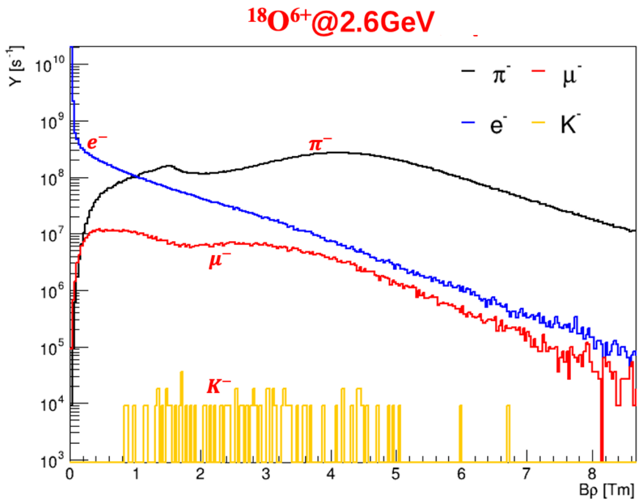
the first signal ^{18}O at S-ring

HFRS (HIRIBL)

For pion & muon production and extraction

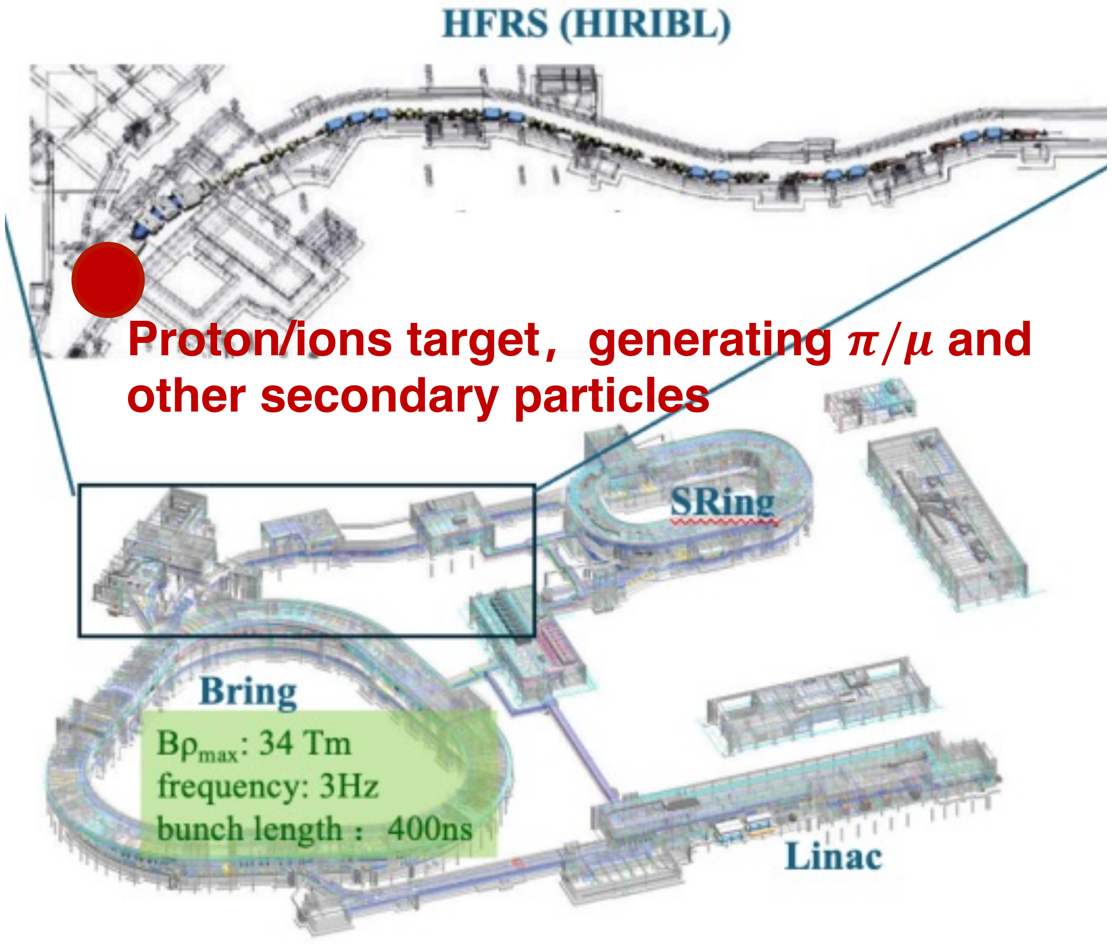


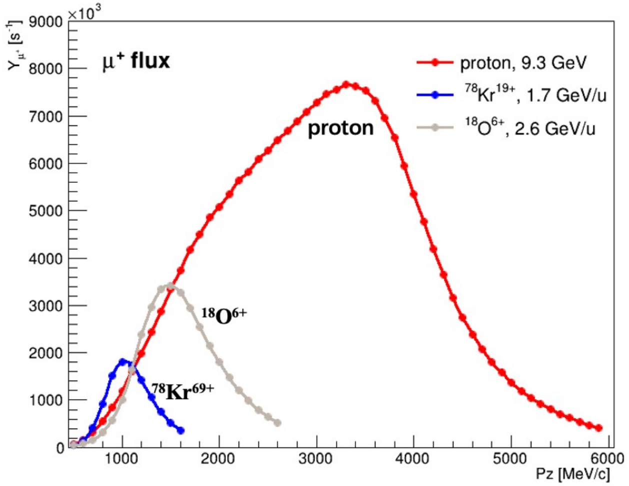




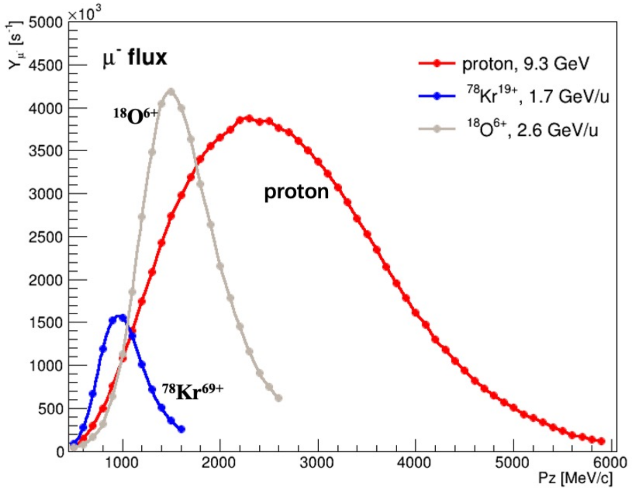
Muon beam at HIAF

Very high intensity *negative* muon beam!





positve muon



negative muon

- Maximum μ^+ flux： $8.2\times10^6/s$
  - projectile ： proton
  - Pz： 3.5 GeV/c

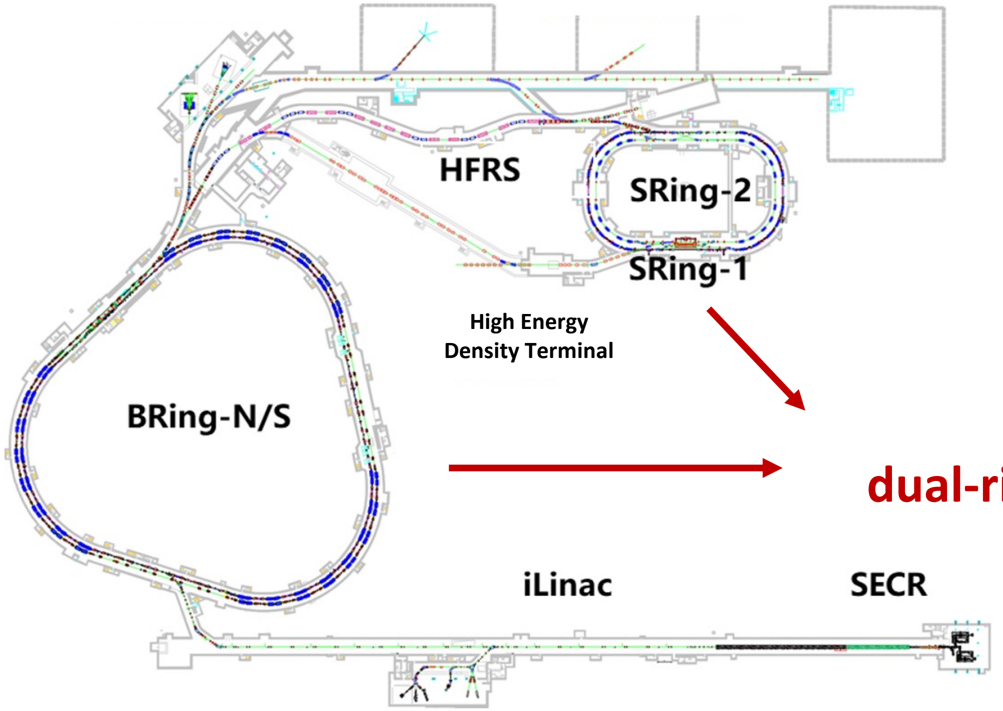
w/ purification: 2.4×10^5/s

- Maximum μ^- flux： $4.2\times10^6/s$
  - projectile： $^{18}O^{6+}$
  - Pz： 1.5 GeV/c

w/ purification: 3.7×10^5/s

HIAF-U

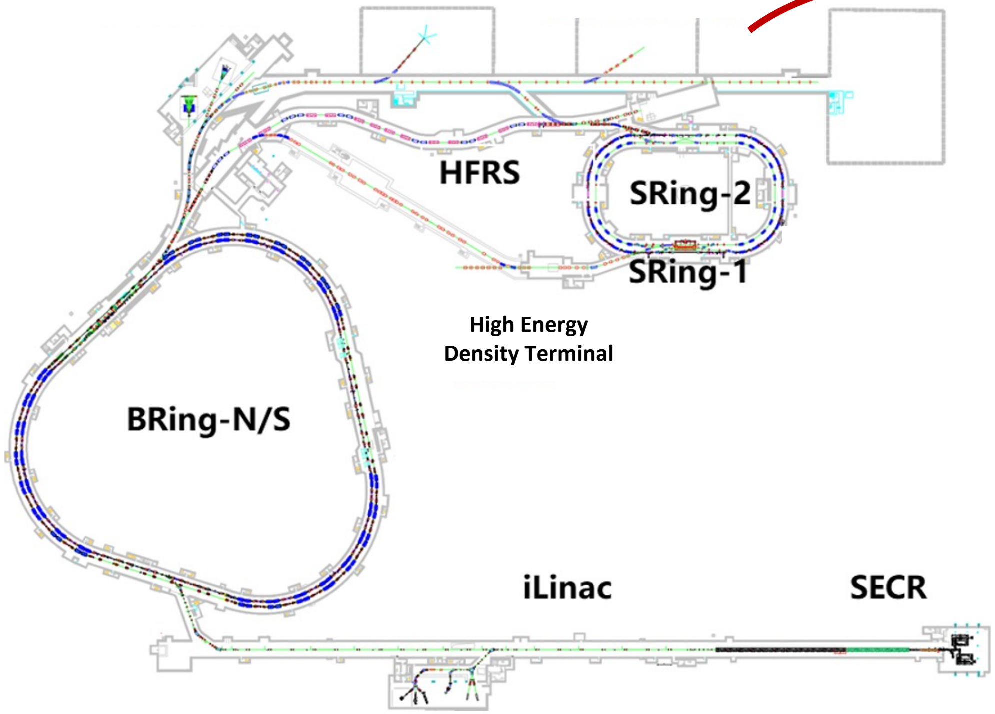
- An upgrade planned for the second phase of HIAF, aims to increase the proton energy from 9 to **25 GeV**, with a dedicated muon beamline in the design.

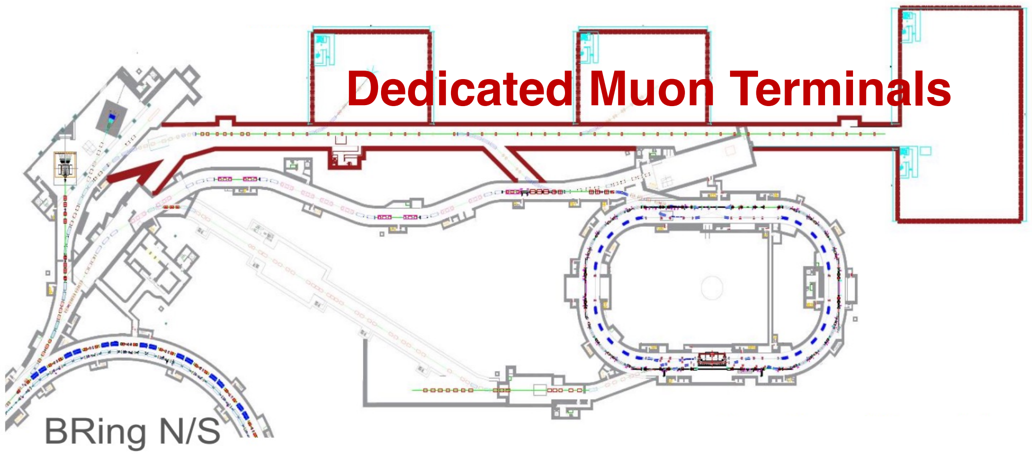


dual-ring configuration

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**