ISBA – 24
Chiang Mai University

Student Session

Nguyen Huynh PHUC

PHUC - フック - FUKU

nhphuc@post.kek.jp

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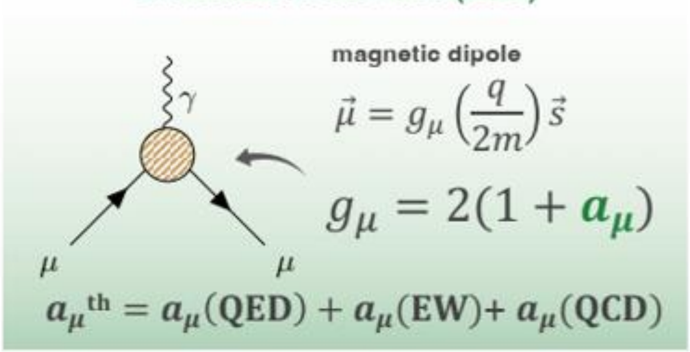
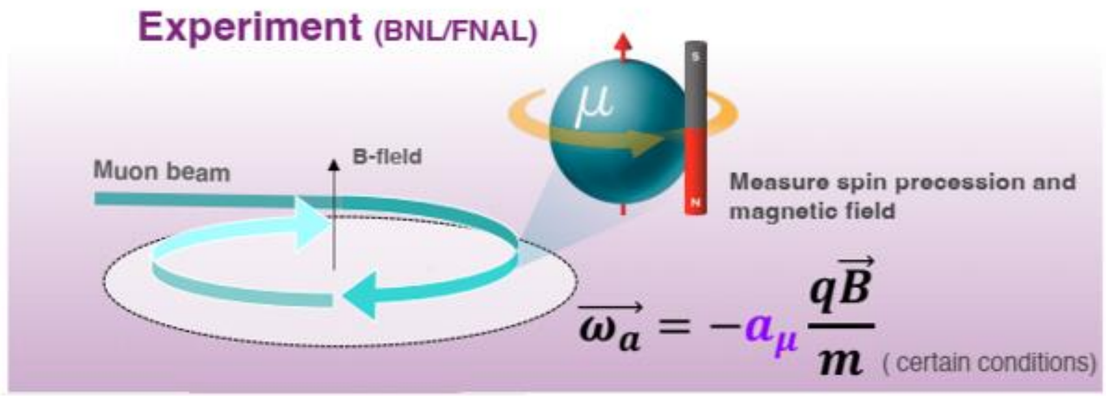
Outline

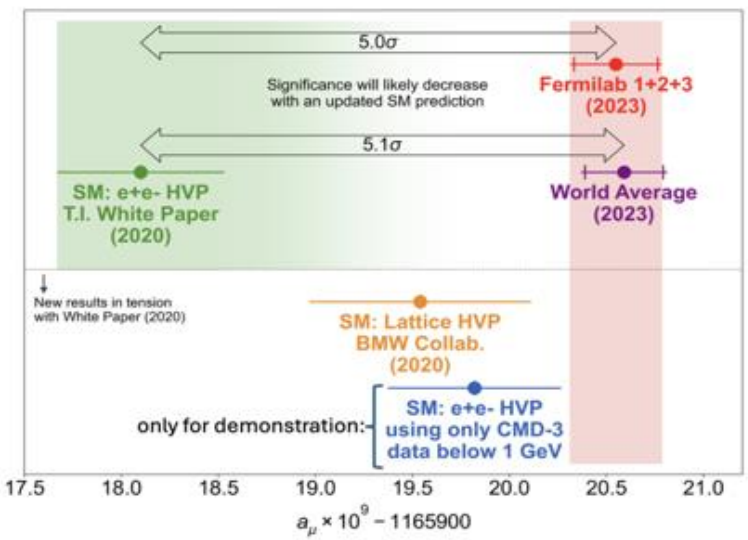
1. Muon g-2 experiment – Physics motivation
2. Muon g-2 experimental method
3. Differences of Muon g-2 Experiments at JPARC and BNL/FNAL
4. Muon g-2/EDM Experiment in JPARC
5. Design of Muon LINAC
6. Main study about APF beam dynamics design for DAW CCL.

Muon g-2 experiment - Physics motivation

Muon anomalous magnetic moment "g-2"







FNAL Run-1 + Run-2/3 Combination

a_μ(FNAL) = 0.00 116 592 055(24) [203 ppb]

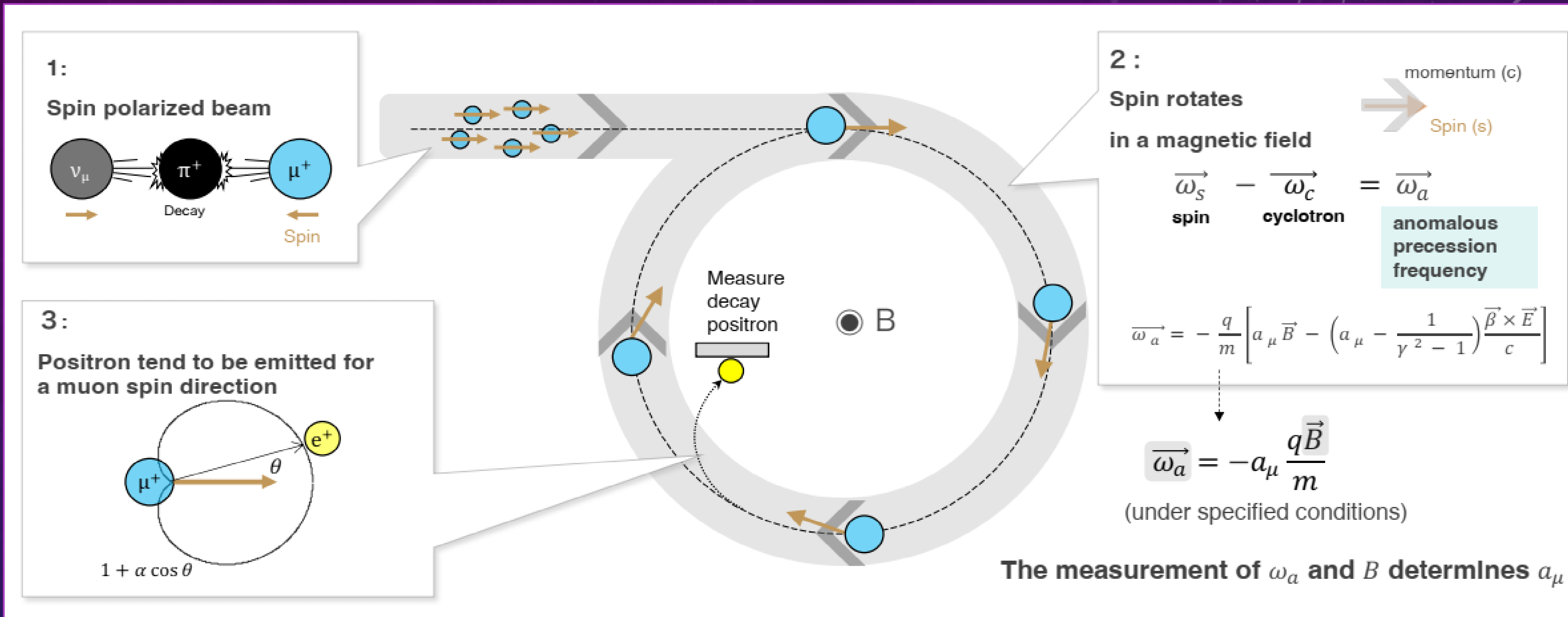
Mott, J., & Venanzoni, G. New Results from the Muon g-2 Experiment. FNAL (2023).
B.Abi etal., Phy. Rev. Lett., vol. 126, no. 14, p. 141801 (2021)
T.Aoyama etal, Physics Reports, vol. 887, pp. 1–166 (2020)

New physics beyond the Standard Model is expected.

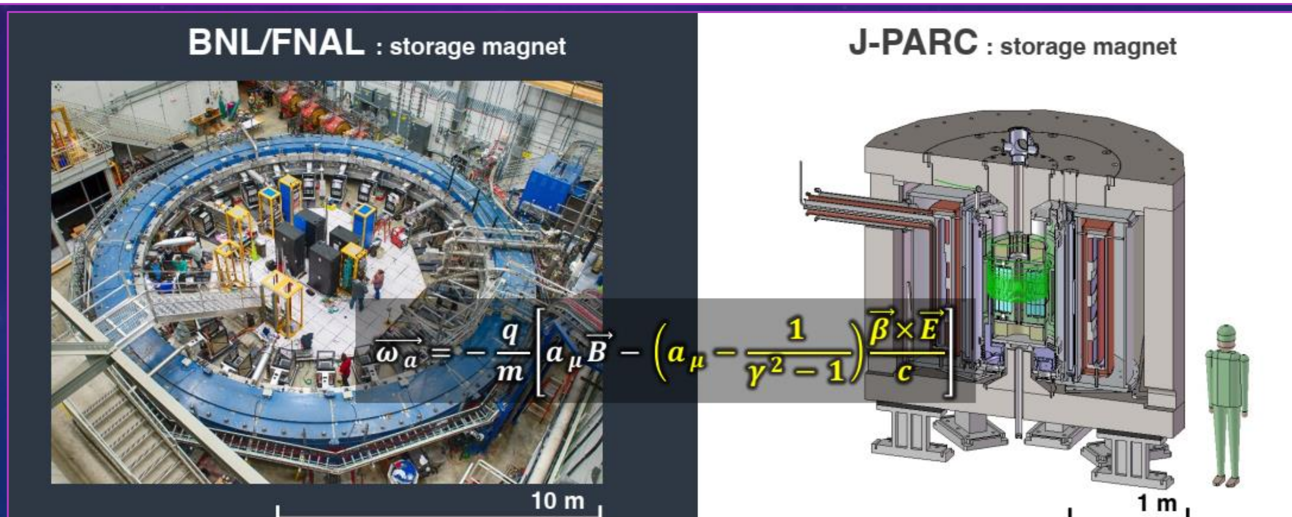
On the other hand, another method of verification is need.

→ J-PARC method.

Experimental method



$$a_\mu - \frac{1}{\gamma^2 - 1} = 0$$



No electric field
$\vec{E} = 0$

Differences of Muon g-2 Experiments at JPARC and BNL/FNAL

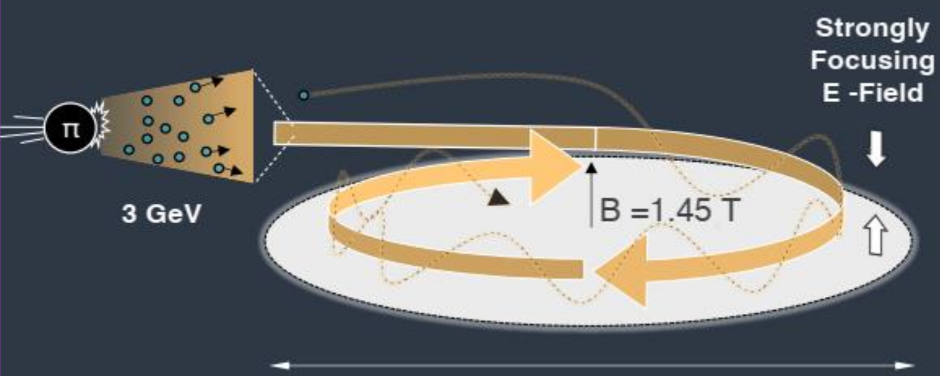
BNL/FNAL

Utilize muon beam decayed at a specific γ

→ **Large emittance**

→ **Strong focusing by E-field is essential**

Large magnetic field region is needed.

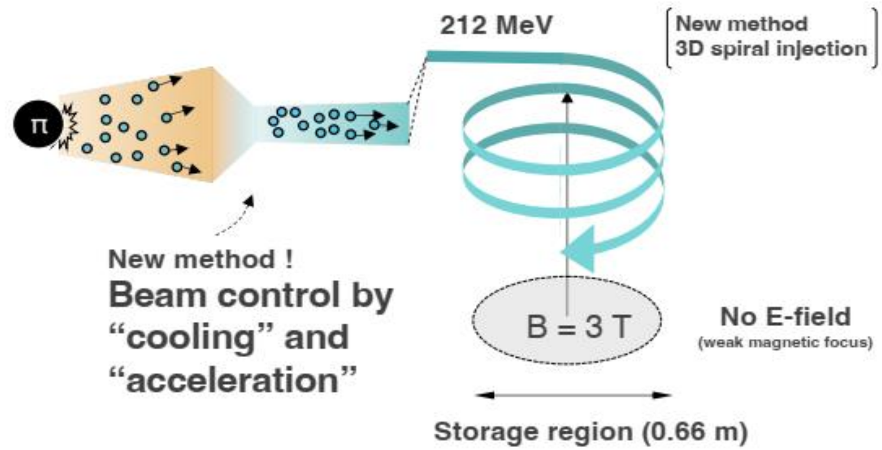


J-PARC

$g-2$ accuracy	0.46 → 0.1 ppm
EDM sensitivity	10^{-21} e·cm

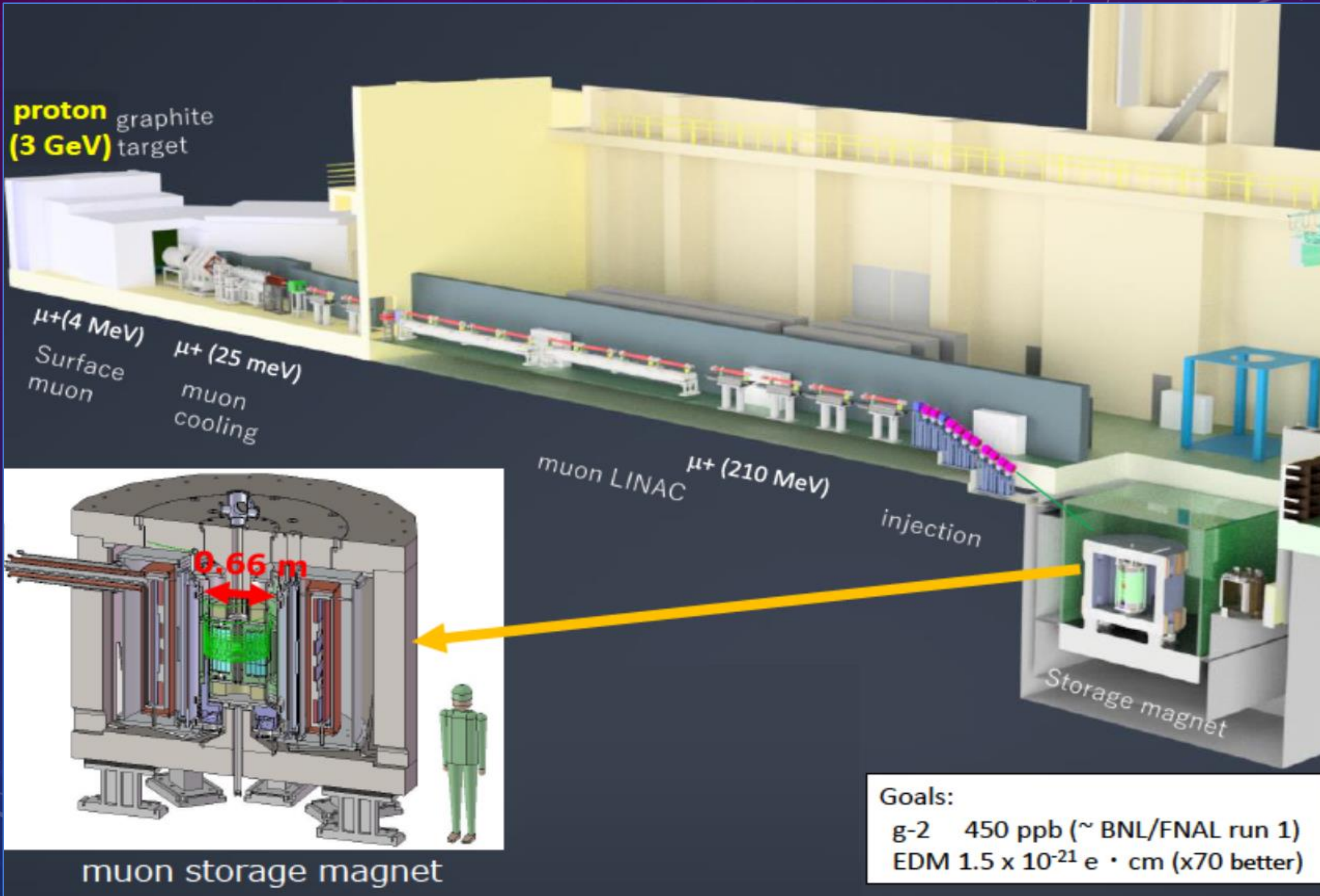
No E field focus + Compact magnetic field region

→ **Requires a low emittance beam of 1/1000 of conventional.**



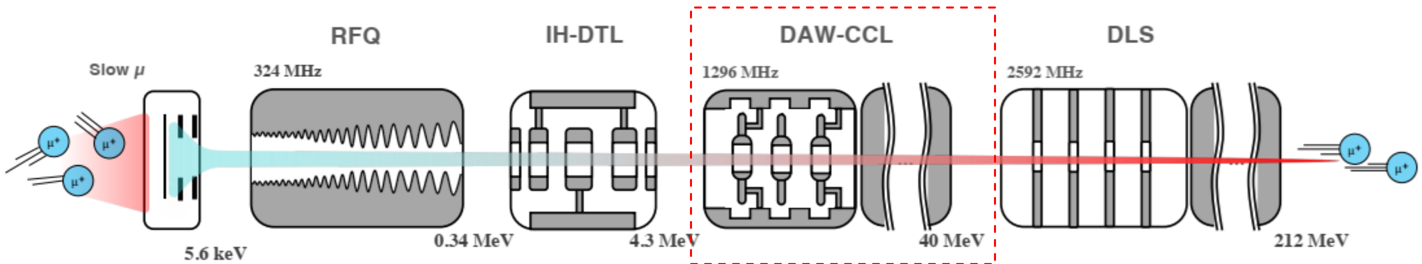
Reduction of beam-derived systematic error (ω_a) and high-precision magnetic field

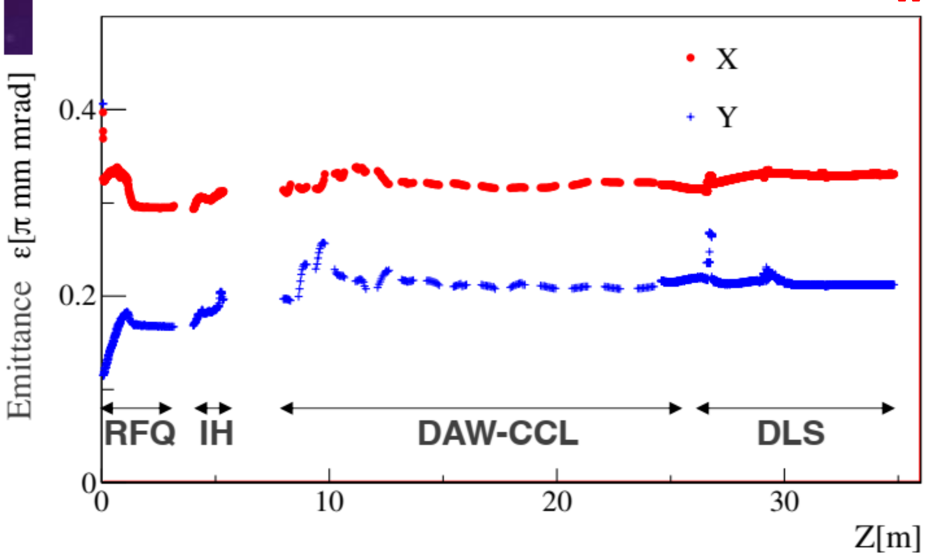
Muon g-2/EDM Experiment in JPARC



Goals:
g-2 450 ppb (~ BNL/FNAL run 1)
EDM 1.5 x 10^{-21} e · cm (x70 better)

Basic Design of Muon LINAC

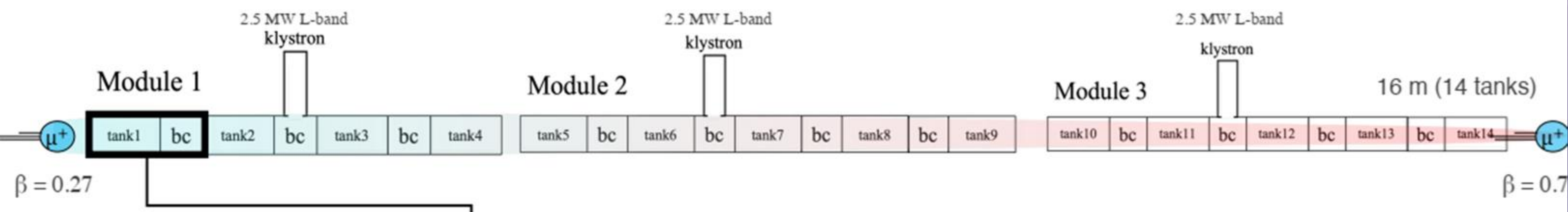




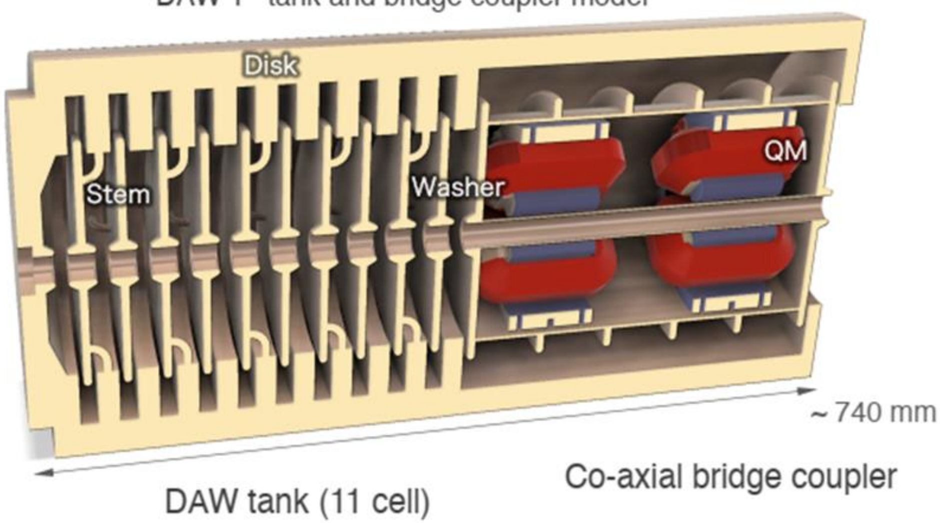
Frequency	324MHz, 1296MHz, 2592 MHz
Intensity	1×10^6 /s
Rep rate	25 Hz
Pulse width	10 ns
Norm. rms emittance	1.5 π mm mrad
Momentum spread	0.1 %

Designed muon LINAC performance satisfies experimental requirements.

DAW CCL - Disk and Washer Coupled Cavity Linac



DAW 1st tank and bridge coupler model



APF – (Alternating Phase Focusing)

- A negative synchronous phase (accelerating field increasing) results in longitudinal focusing and transverse defocusing, while a positive synchronous phase (field decreasing at gap center) causes longitudinal defocusing but transverse focusing.
- If the sign of the synchronous phase is periodically alternated, alternating-focusing forces are applied in all directions, leading to stable transverse and longitudinal motion.

⇒ No focusing magnets -> Simplified structure.

My main research will perform the beam dynamics design via APF (Alternating Phase Focusing) method for DAW CCL.

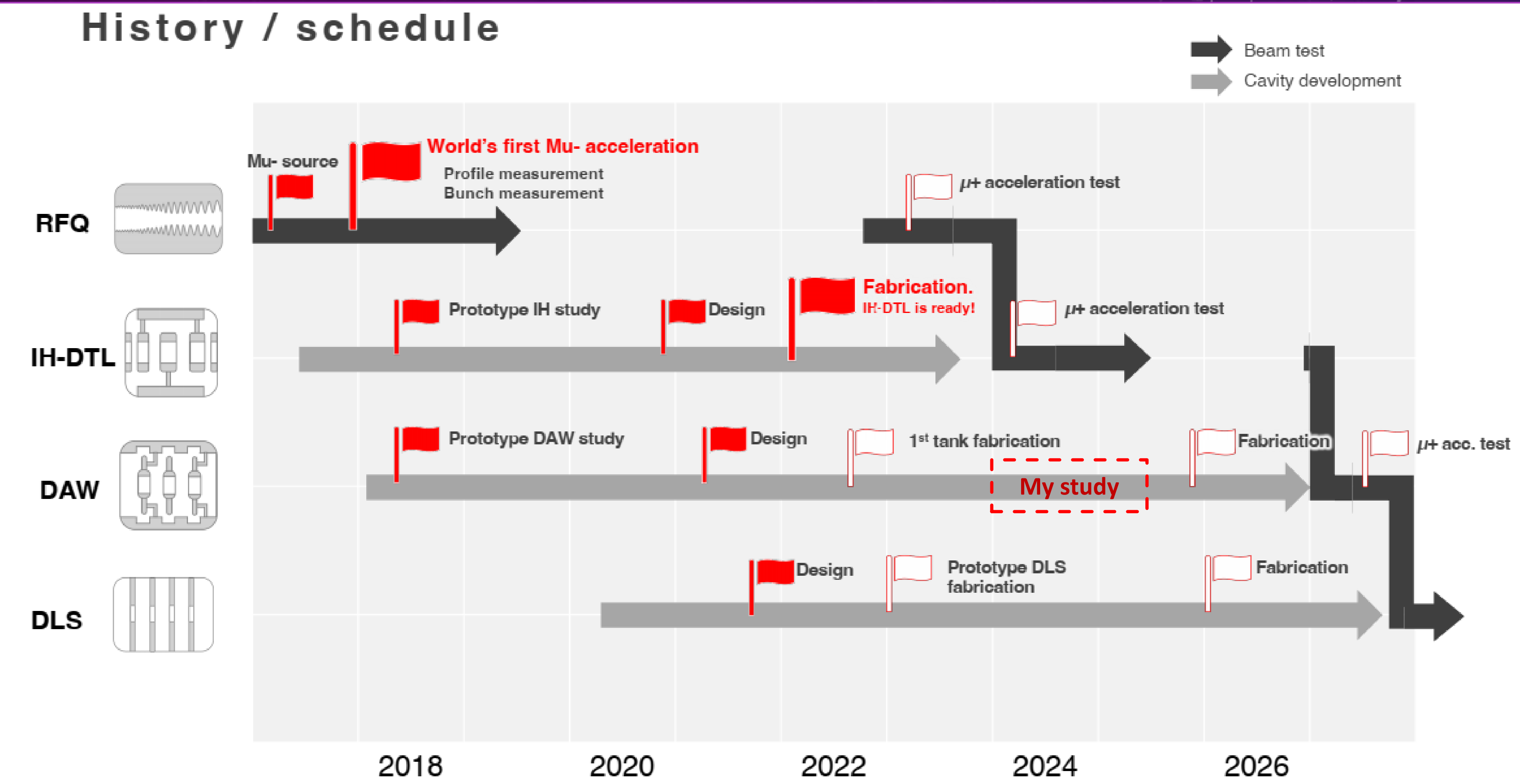
References

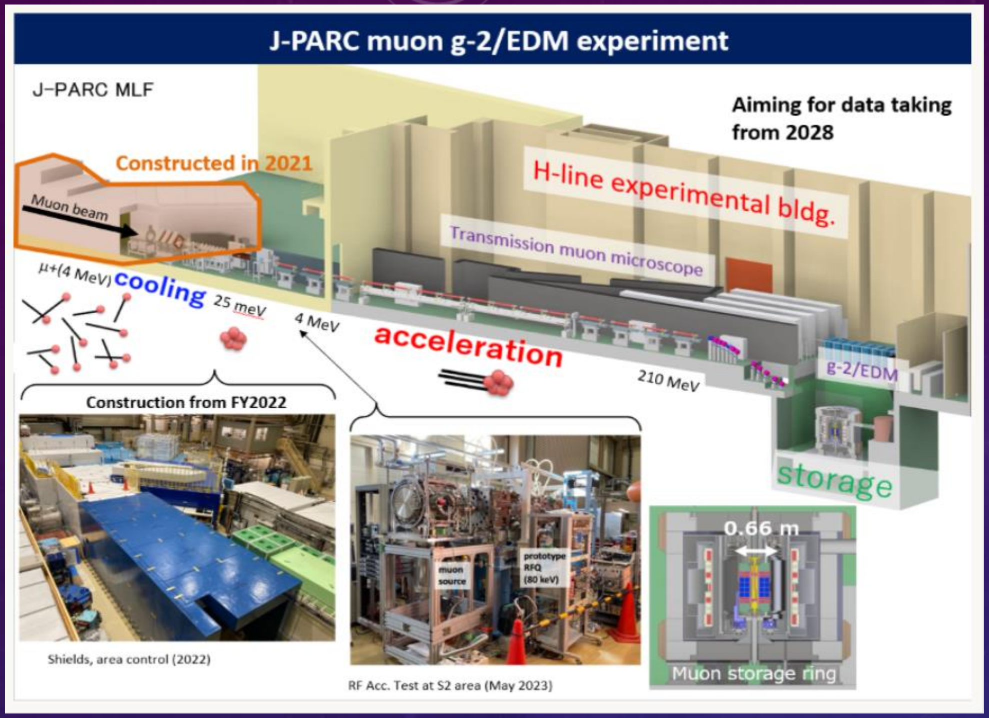
1. Otani, M., et al. (2019). *J. Phys.: Conf. Ser.*, *1350*, 012097.
2. Wangler, T. P. (2008). *RF Linear Accelerators* (2nd ed.). Wiley-VCH.
3. Nakazawa, Y. (2022). *Muon g-2: Disk and Washer Couple Cavity Linac Design and Cold-Model for Muon Linac*. NuFact 2022.
4. Venanzoni, G. (2023). *New results from the Muon g-2 Experiment*. (EPS-HEP2023), Hamburg, Germany.
5. Mott, J., & Venanzoni, G. (2023). *New Results from the Muon g-2 Experiment*. FNAL. Seminar presented at University of Liverpool.
6. Driutti, A. (2024). *Lecture 1: Muon Magnetic Moment Experiments*. University and INFN Pisa, Simon Eidelman School.
7. Swenson, D. A. (1976). *Alternating Phase Focused Linacs*. Particle Accelerators, 7, 61-67.

Thank you for the attention!

Back up

The timeline schedule





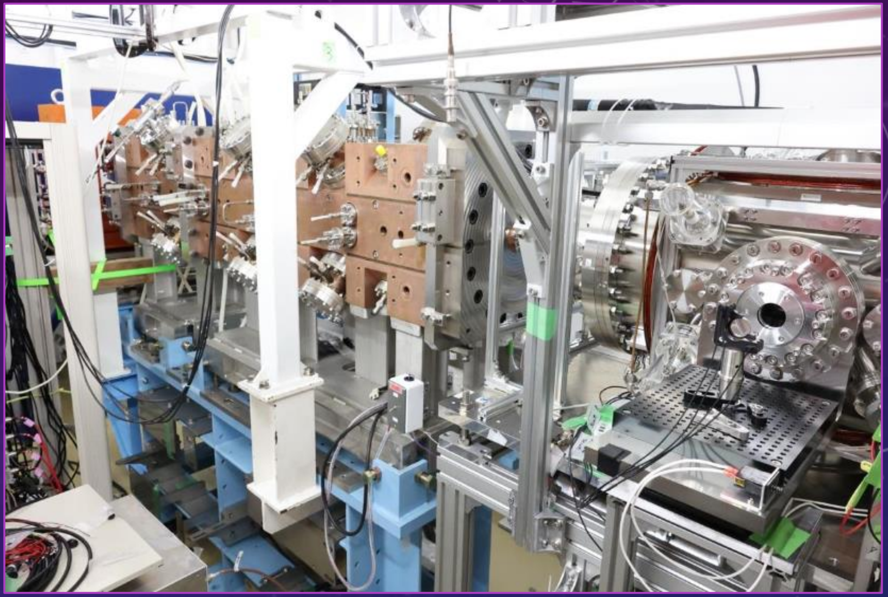


Figure 2. Experimental set up for muon cooling and acceleration at the J-PARC (MLF).

World's first cooling and acceleration of muon

Press Release (May 23, 2024)

A positive muon beam enters from the right side, is cooled in the muon cooling chamber on the right and is accelerated in the RF acceleration cavity on the left. The accelerated muon beam is measured by a diagnostics system at the exit of the acceleration cavity.

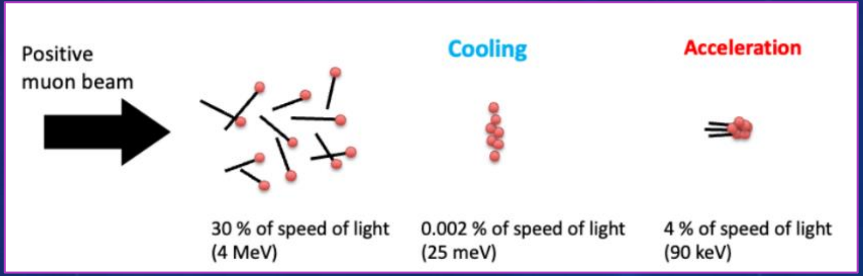
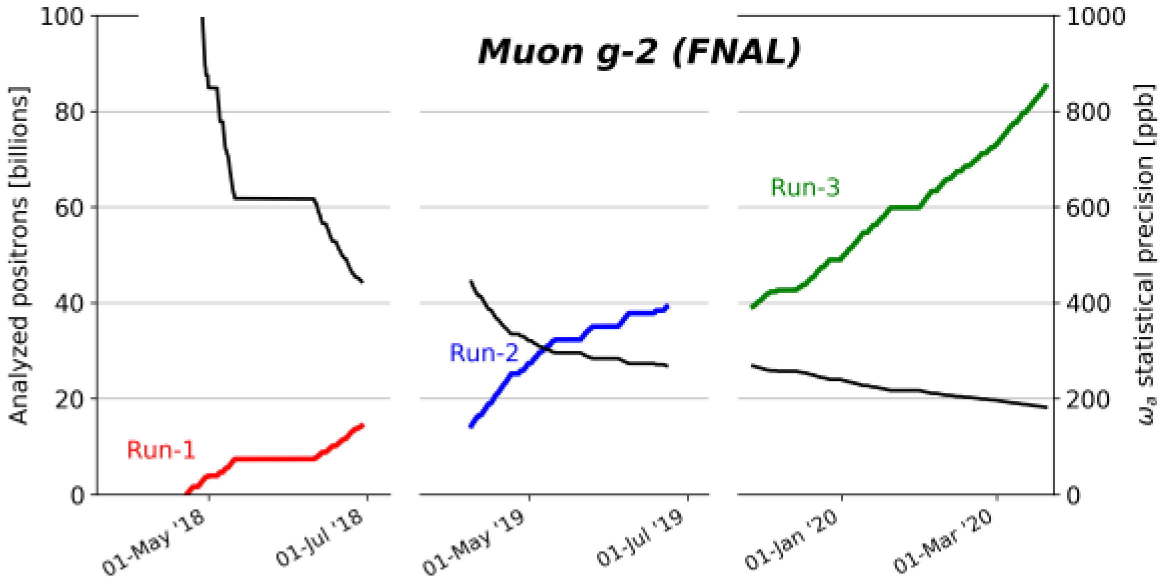


Figure 1. Cooling and accelerating a positive muon beam

Run-2/3 Improvement: Statistics

Weighted e⁺ in our final fit after quality control

E > 1 GeV
t > 30 us



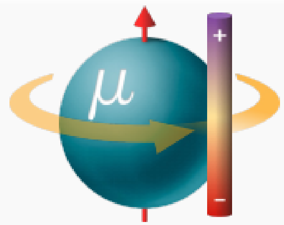
- Factor 4.7 more data in Run-2/3 than Run-1

Dataset	Statistical Error [ppb]
Run-1	434
Run-2/3	201
Run-1 + Run-2/3	185

Fermilab

Comparing between 2 experiments

EDM (Electric dipole moment)



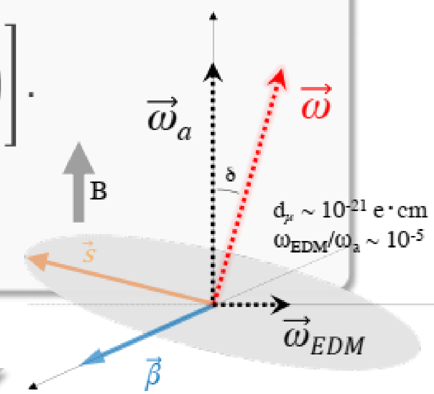
Time-reversal violation observation if we can see EDM ≠ 0.

$$\vec{d} = \eta\left(\frac{q}{2mc}\right)\vec{s}$$

A non-zero muon EDM, the spin precession is

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

g-2 precession — EDM precession — Orthogonal



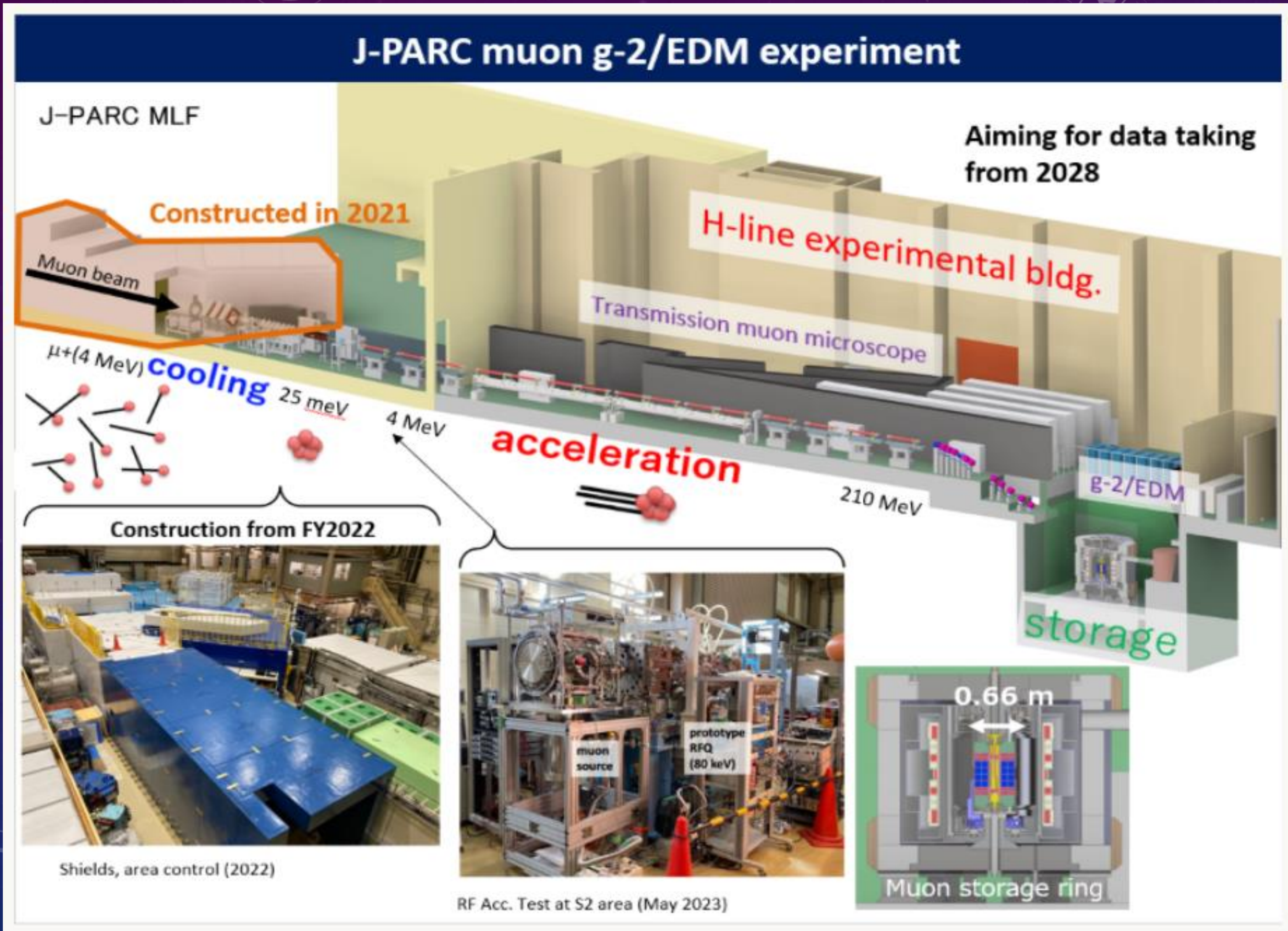
BNL/FNAL $a_\mu - \frac{1}{\gamma^2-1} = 0$

$$\vec{\omega} = -\frac{q}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right].$$

J-PARC $\vec{E} = 0$ at any γ

$$\vec{\omega} = -\frac{q}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right].$$

- **There is no contribution from $\vec{E}$ term.**
- **a_μ and EDM can be measured simultaneously.**


J-PARC muon g-2/EDM experiment
J-PARC MLF
Aiming for data taking from 2028
Constructed in 2021
Muon beam
H-line experimental bldg.
Transmission muon microscope
μ+(4 MeV) cooling 25 meV
4 MeV
acceleration
210 MeV
g-2/EDM
storage
Construction from FY2022
muon source
prototype RFQ (80 keV)
0.66 m
Muon storage ring
Shields, area control (2022)
RF Acc. Test at S2 area (May 2023)