

Status of J-PARC muon g-2/EDM experiment

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(on behalf of J-PARC muon g-2/EDM (E34) Collaboration)

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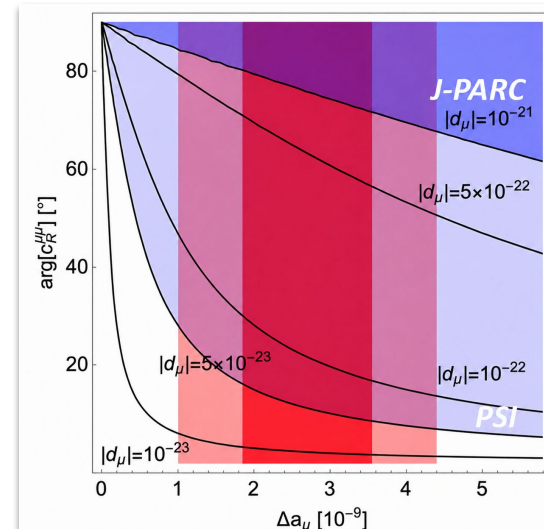
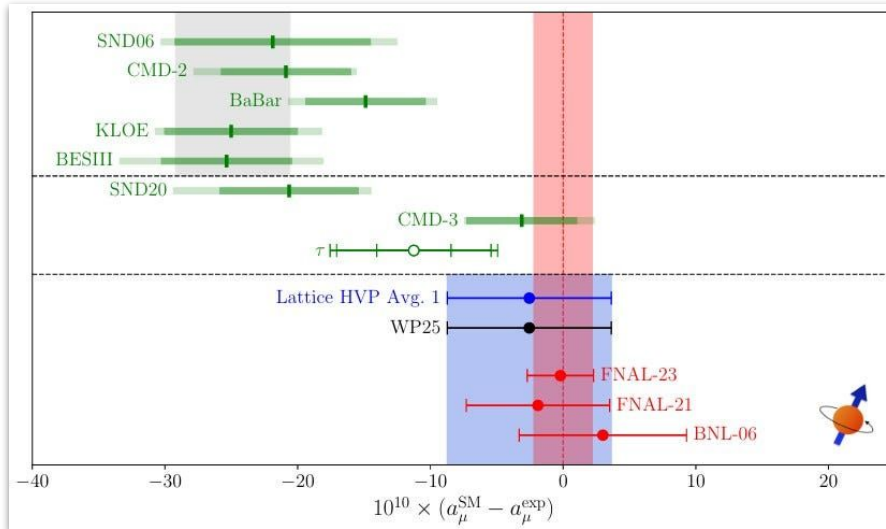
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- ❖ Muon $g-2$ /EDM
- ❖ Muon cooling and acceleration
- ❖ Injection and tracking
- ❖ Future prospect
- ❖ Recent commissioning study at J-PARC

Muon $g-2$ /EDM

- ❖ Fermilab's final result for muon $g-2$ has a precision of **127 ppb**, and with BNL the world average is **124 ppb**.
- ❖ Fermilab also gave the most stringent direct limit on the muon EDM: $|d_\mu| < 1.10 \times 10^{-19} \text{ e}\cdot\text{cm}$.
- ❖ The White Paper 2025 theory value is based on lattice calculations, and the data-driven e^+e^- evaluations are still ongoing in various groups.
- ❖ J-PARC uses a technique independent of BNL and Fermilab, which allows a cross-check of their result.
- ❖ J-PARC uses a small 3 T ring with a low-emittance muon beam and no electric focusing, so its systematic uncertainties are different.



Muon g-2/EDM measurement

Spin precession vector with respect to cyclotron motion in EM field

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

BNL/FNAL approach

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

J-PARC approach

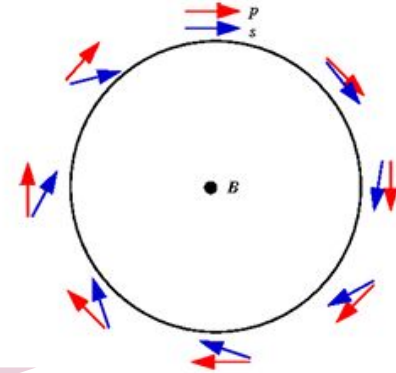
$$\vec{E} = 0$$

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

Magic momentum ($p = 3.094 \text{ GeV}/c$)

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

Re-accelerated thermal muon beam is used

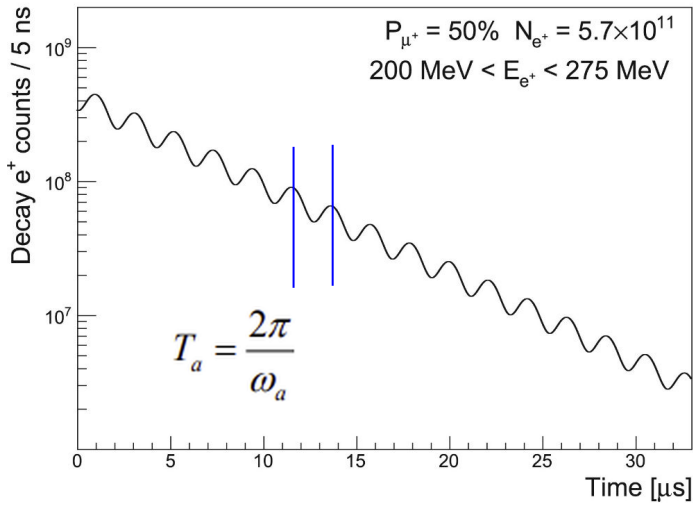
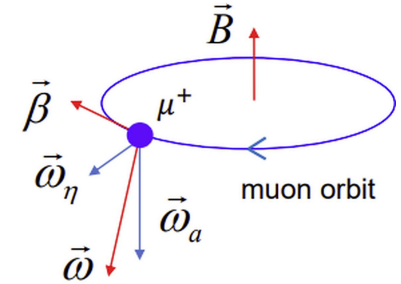


Spin precession in cyclotron motion

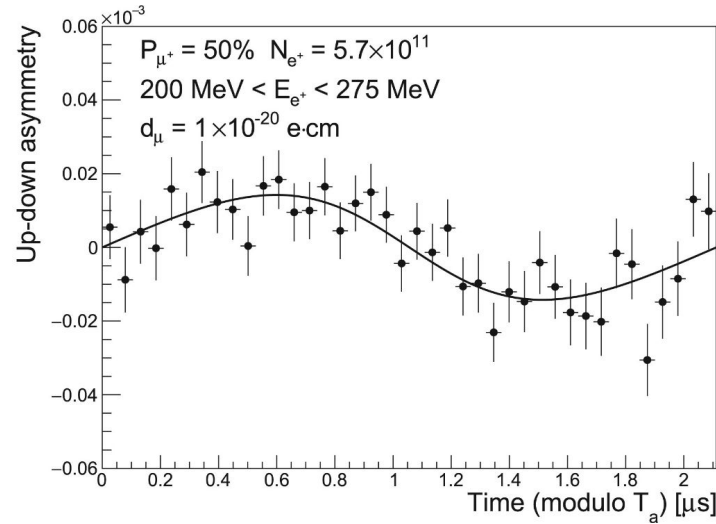
Muon g-2/EDM measurement

Once electric field contribution is eliminated, g-2 and EDM can be obtained from the time spectrum of the number positrons from muon decay.

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_\eta = -\frac{e}{m} \left[\underbrace{a_\mu \vec{B}}_{g-2} + \underbrace{\frac{\eta}{2} (\vec{\beta} \times \vec{B})}_{\text{EDM}} \right]$$

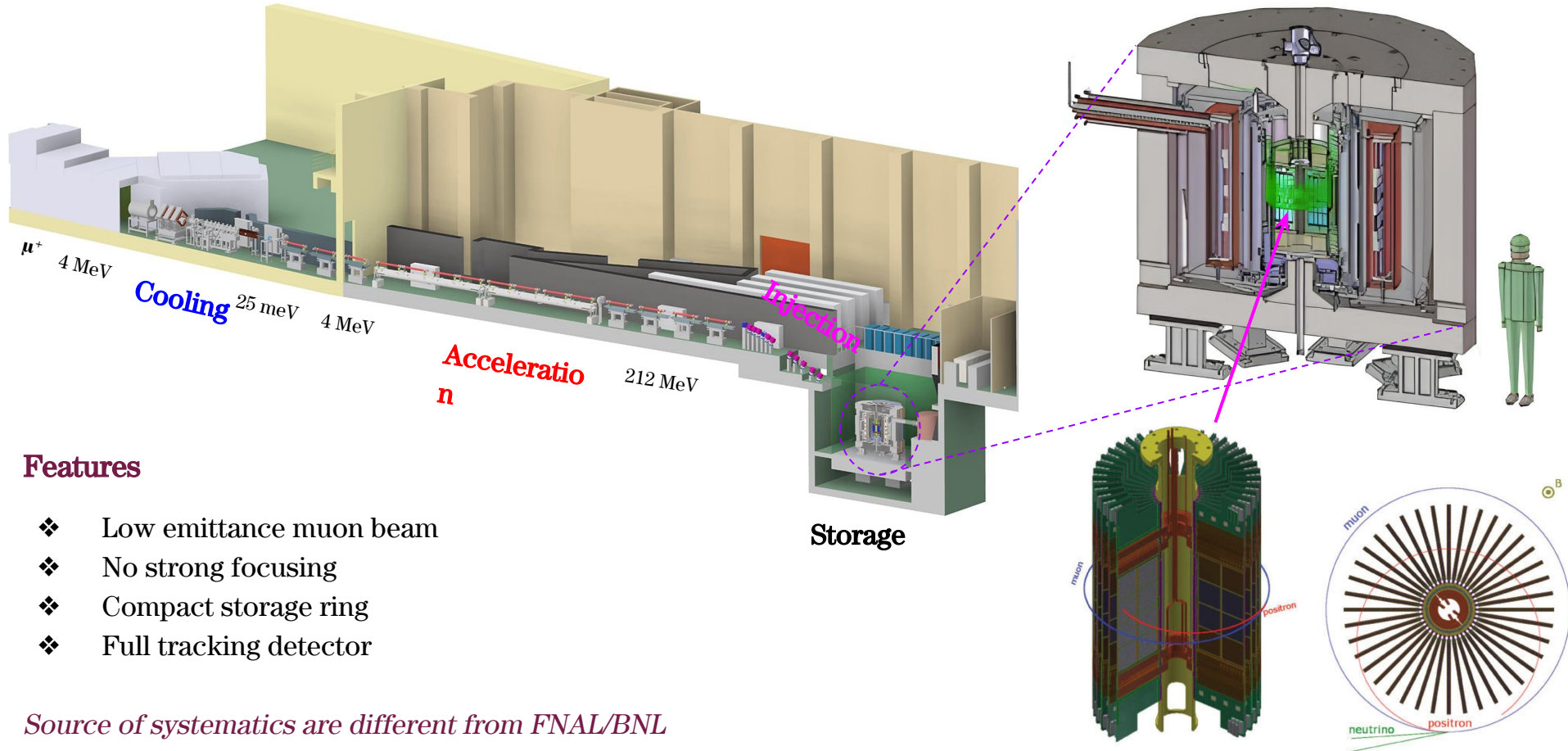


Time spectrum of the number of positrons from muon decay



Up-down asymmetry of positrons from muon decay

Muon $g-2$ /EDM measurement at J-PARC



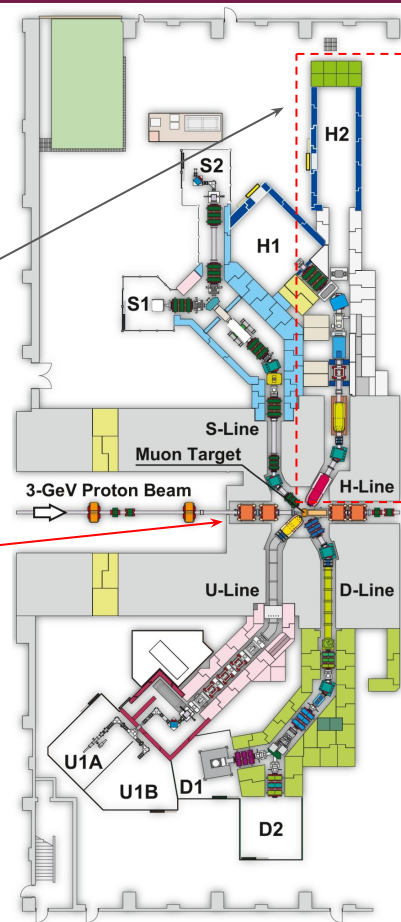
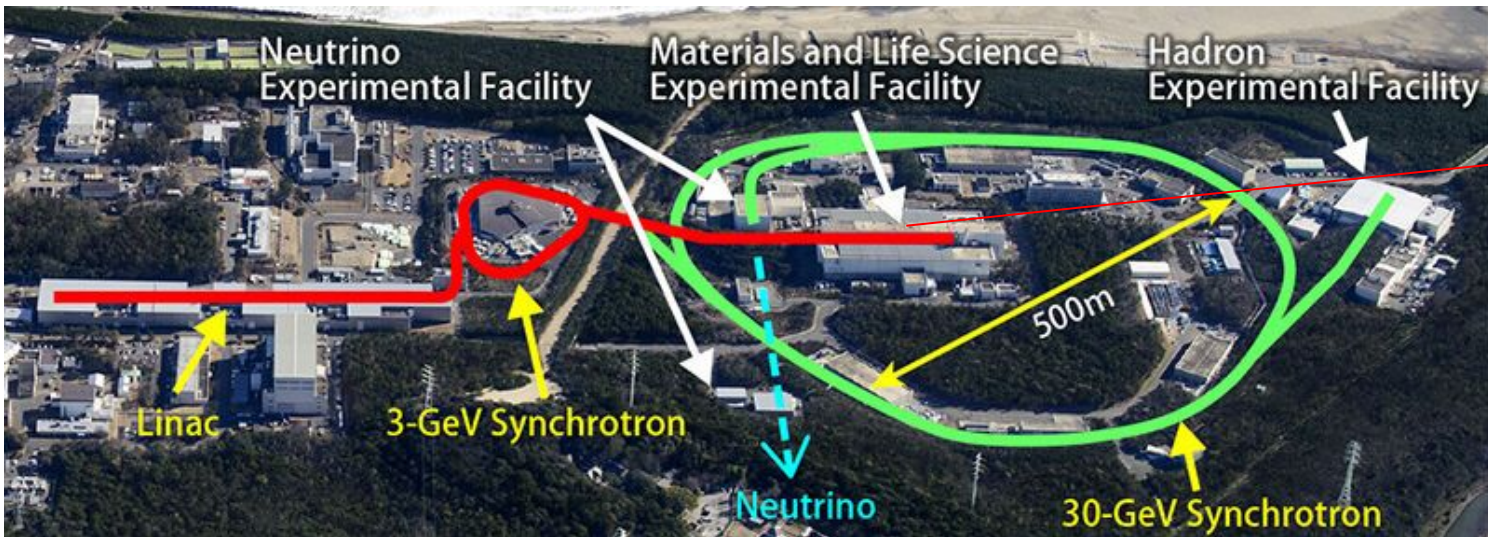
MLF H-Line at J-PARC

H beam line at J-PARC will be used for the muon $g-2$ /EDM experiment.

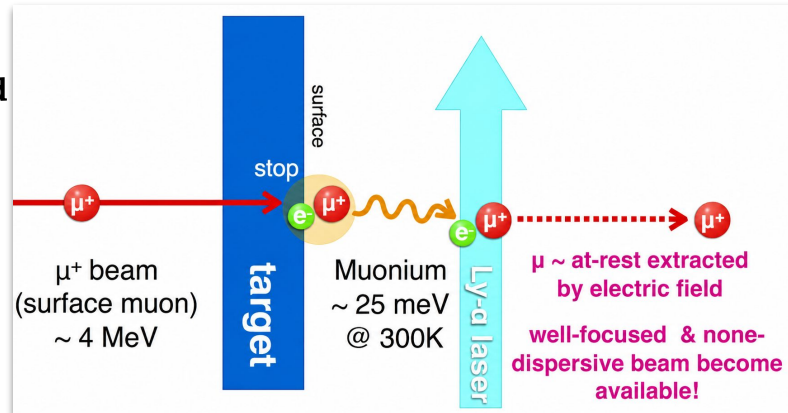
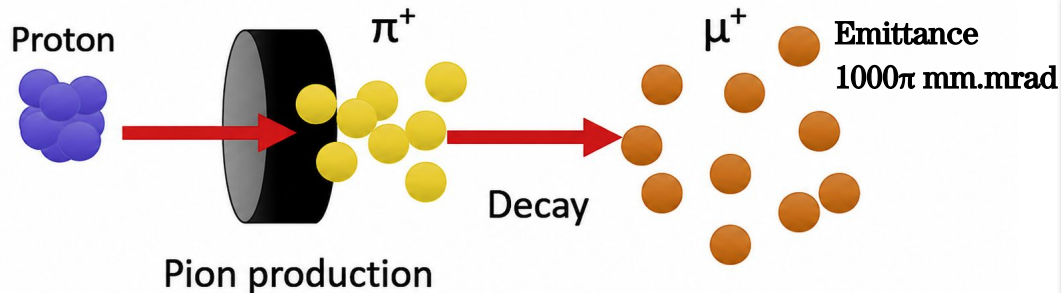
Current MLF building will not be able to accommodate the whole experimental setup

Extended building will be constructed towards the north side of the MLF building

New H2 beam line



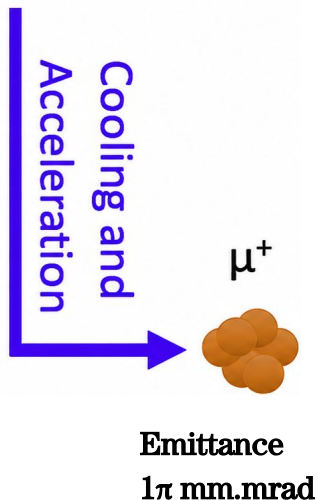
Muon beam at J-PARC



Re-accelerated thermal muon beam

Strong beam focusing by an electric field is not needed.

- Gradient magnetic field for beam focusing
- Free from magic momentum of 3.094 GeV/c
- Lower momentum beam of 300 MeV/c
- Compact storage region with highly uniform magnetic field
- Full tracking detector for decay positrons

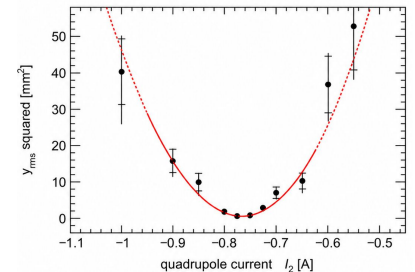
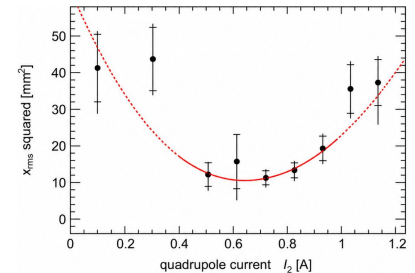
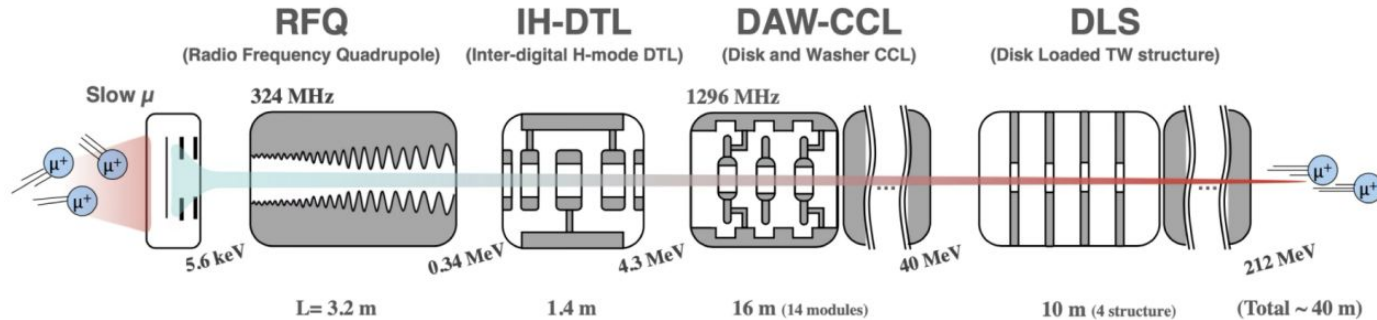
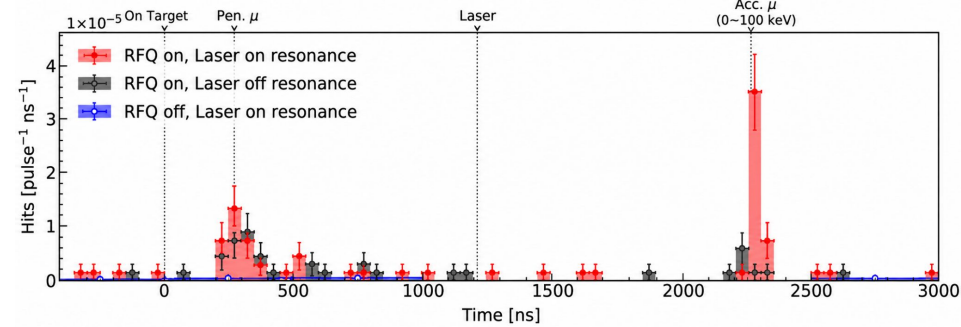


Thermal Muon Beam

- Surface muon beam from the H-line is stopped in a laser-ablated silica aerogel target to produce muonium (μ^+e^-).
- A laser strips the electron from the muonium, producing thermalized muons.
- The resulting thermal muon beam is used as the muon source.

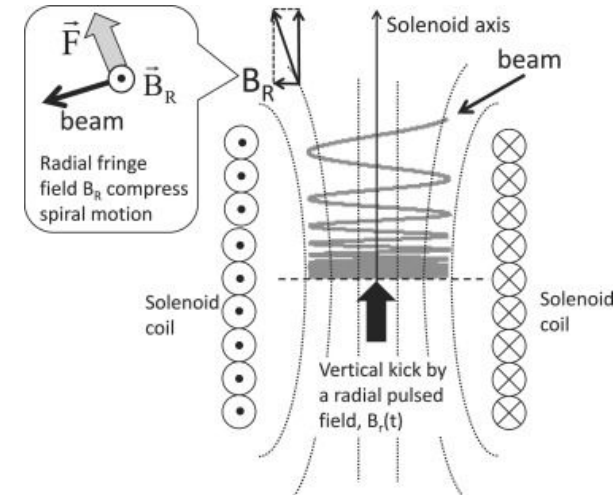
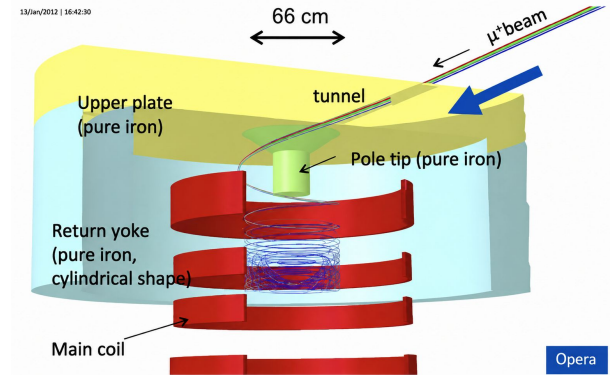
Muon acceleration

1. Thermal muon beam is to be accelerated to $p = 300$ MeV/c in LINAC
2. Different types of acceleration cavities are utilized to cover wide range of velocity
3. RFQ installation and test running is done and an acceleration of 100 keV is achieved.



3D spiral beam injection

1. A new 3D spiral injection scheme is developed due to the compact storage ring.
2. 3-D injection scheme recently demonstrated using low energy electron beam.
3. The 3D spiral injection scheme uses a multi-turn vertical kick to guide the beam into the storage region.
4. Beam storage was successfully observed for more than $1\ \mu\text{s}$, confirming stable beam storage using low energy electron beam.
5. The scheme provides a pathway toward ultra-compact storage rings for future muon $g-2/\text{EDM}$ experiments.



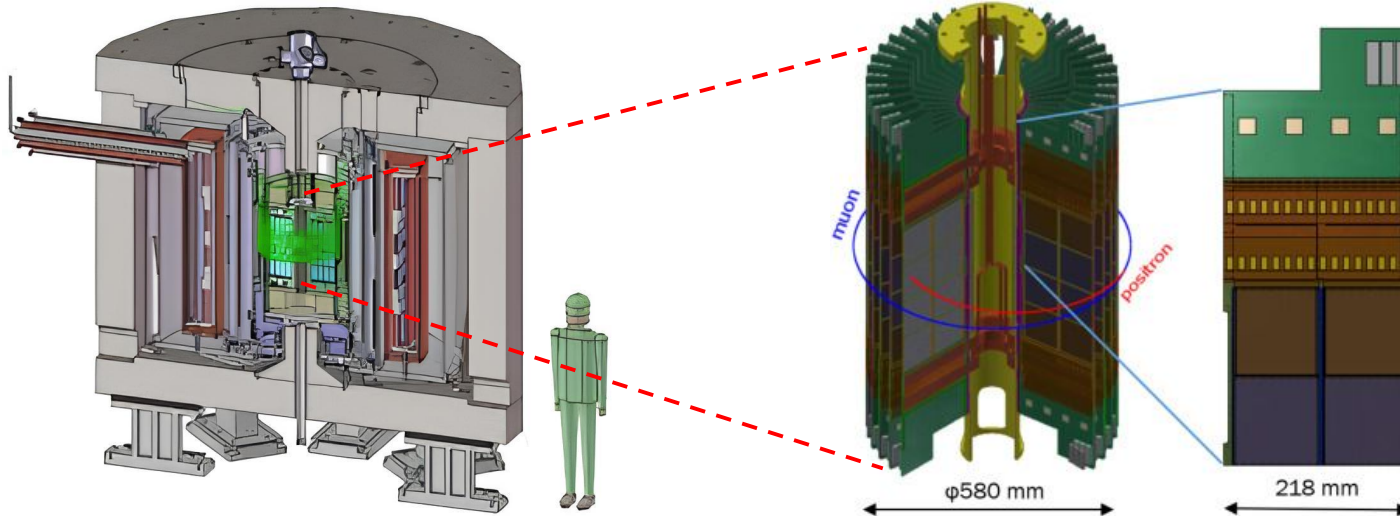
Storage Magnet and positron tracking detector

Storage magnet

- 3 Tesla MRI-type superconducting solenoid magnet is under design with the uniformity of 0.1 ppm
- Radius and height 333 +/- 15 mm and +/- 50 mm
- Injection field: $0.4 < z < 1.1$ m

Positron tracking detector

- 40 vanes each 200mm (radial) x 400mm (axial)
- Each vane consists of 16 Si sensors (10×10 cm², 320 μ m thickness)
- Detector is required to operate in the highest muon decay rate of 6 tracks/ns.

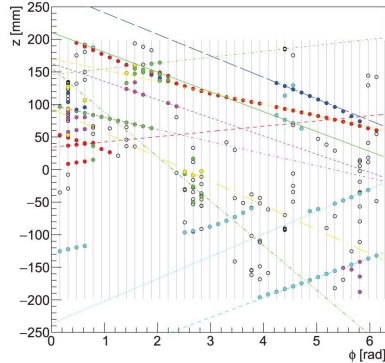
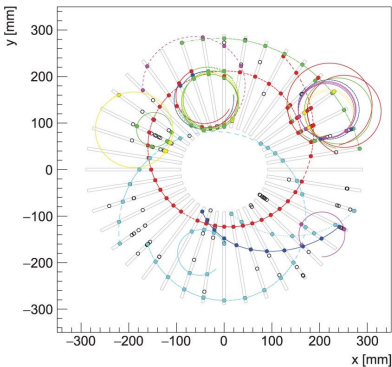
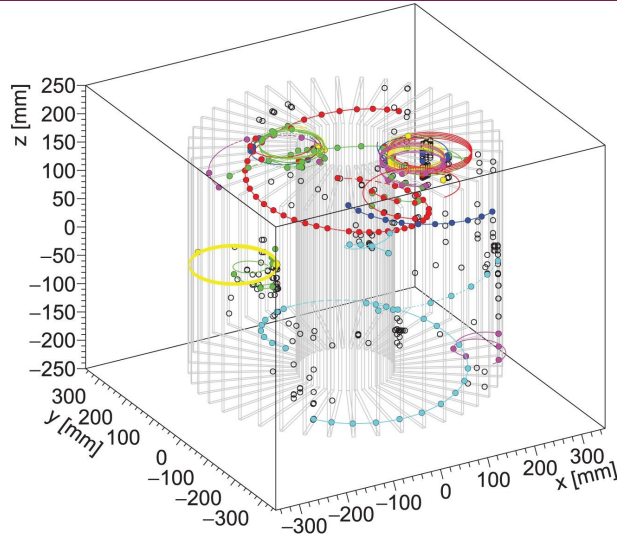


Software and Computing

- Software framework (g2esoft) was developed to manage detector simulation and track reconstruction.
- End-to-end simulation which starts from the muon beam from H-line to the detection in the storage magnet has been conducted.
- To support computing requirements at the actual experiment, Grid and CernVM File System (CVMFS) servers are set up at KEK Computing Center.



Track reconstruction

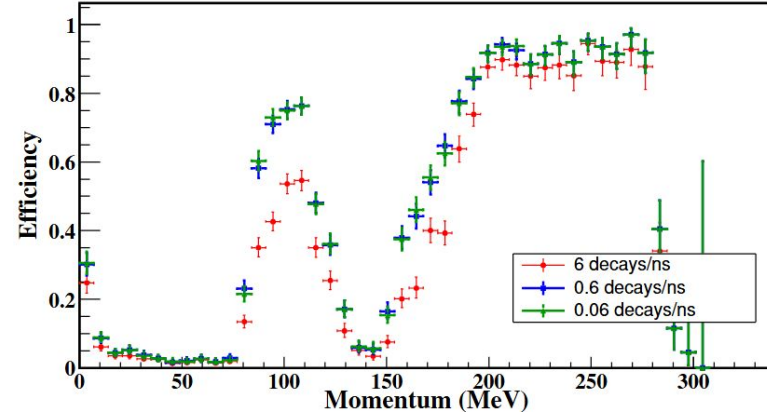


1. Challenge: Achieve high-speed track reconstruction for real-time data processing.
2. Expected rate: $\sim 3 \times 10^4$ signal tracks/s at the experiment.
3. Current approach: A high-speed Hough-transform-based algorithm in the z - ϕ plane has been developed.
4. Next step: Further optimization is needed to achieve the required processing speed using $\sim 1,000$ CPUs.
5. Alternative approaches have been studied like GPU based tracking finding and the GNN based tracking

Alternative approaches in Tracking

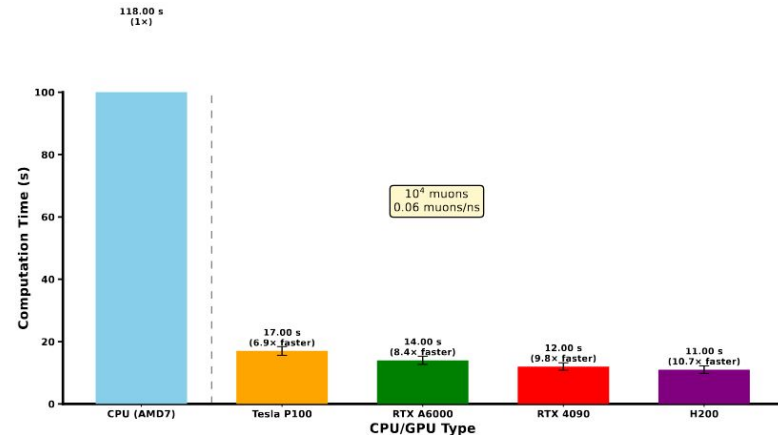
GPU based track finding

- We have seen a factor of 10 X improvement in the speed using the GPU H200 for 10^4 muons (0.06 muons decay/ ns)
- We have leverage the parallel processing capability of GPU
- Efficiency for signal region lies between 90 - 95 %



GNN based tracking

- We have developed GNN based pipeline for track finding and Neural Network for Track fitting completing the tracking with the ML
- The preliminary result has shown promising result in performance as well as in efficiency.
- The test is performed in H200 GPU with 256 GiB of memory



Expected $g-2$ /EDM sensitivity with current design

Comparison of the muon $g - 2$ and EDM experimental parameters for BNL E821, Fermilab E989, and J-PARC E34 (projected).

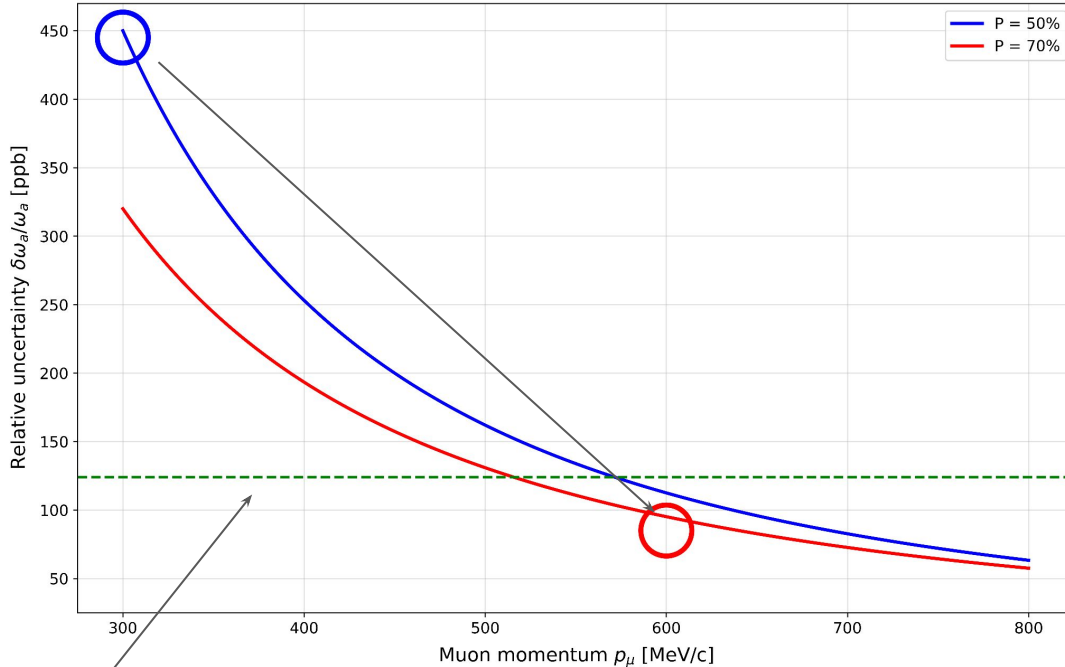
	BNL E821	Fermilab E989	J-PARC E34
Muon momentum	3.09 GeV/ c	3.09 GeV/ c	300 MeV/ c
Lorentz factor γ	29.3	29.3	~ 3
Muon lifetime in ring	64.4 μ s	64.4 μ s	6.6 μ s
Beam polarization P	$\sim 100\%$	97%	50%
Storage magnetic field B	1.45 T	1.45 T	3.0 T
Focusing method	Electrostatic	Electrostatic	Very weak magnetic
Ring diameter	14 m	14 m	0.67 m
Detected positrons e^+	8.5×10^9	1.43×10^{11}	5.7×10^{11} (proj.)
Statistical uncertainty	460 ppb	≈ 100 ppb	450 ppb
Systematic uncertainty	280 ppb	< 80 ppb	< 70 ppb
Total uncertainty	540 ppb	127 ppb	$\lesssim 455$ ppb
EDM sensitivity (stat.)	$0.2 \times 10^{-19} e \cdot \text{cm}$	—	$1.5 \times 10^{-21} e \cdot \text{cm}$
EDM sensitivity (syst.)	$0.9 \times 10^{-19} e \cdot \text{cm}$	—	$3.6 \times 10^{-22} e \cdot \text{cm}$
EDM limit (95% C.L.)	$1.8 \times 10^{-19} e \cdot \text{cm}$	$1.10 \times 10^{-19} e \cdot \text{cm}$	—

Higher sensitivity study

Current sensitivity
with 300 MeV/c and
3T

Statistical uncertainty only

Statistical uncertainty of ω_a vs muon momentum (J-PARC E34)



Current World
avg 124 ppb

Sensitivity with
600 MeV/c and 6T

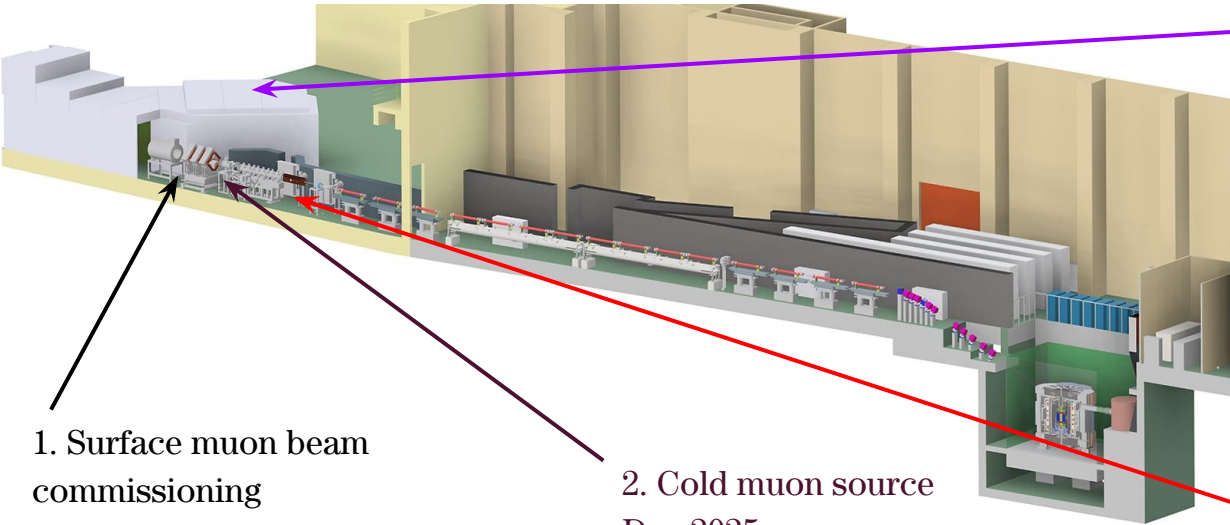
$$\frac{\Delta\omega_a}{\omega_a} = \frac{1}{\omega_a \gamma \tau P} \sqrt{\frac{2}{NA^2}}$$

- Higher polarization (P)
- Higher energy (γ)
- Stronger magnetic field (B)

Challenges:

- Designing LINAC to achieve the momentum of 600 MeV/c with low emittance
- Magnetic field strength with the desired precision
- Muon polarization

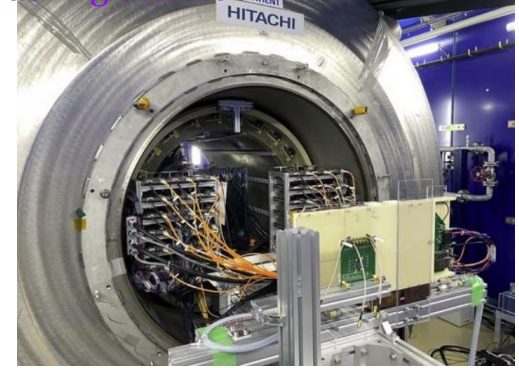
Recent commissioning studies at J-PARC



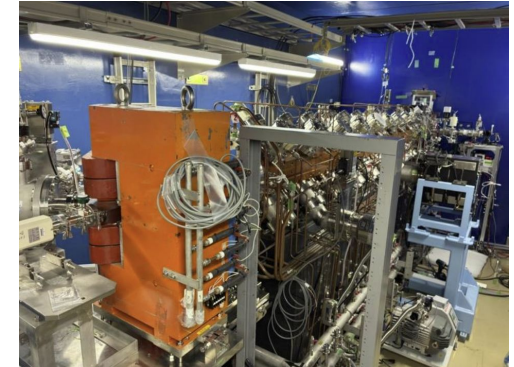
1. Surface muon beam
commissioning

2. Cold muon source
Dec 2025

3. MuSEUM (H1 area), positron
tracking detector



4. Cooling + Acceleration (June 2026)



Summary

1. In the J-PARC E34 experiment, measurement of muon $g-2$ and EDM is planned with a method different from BNL/FNAL experiments.
2. Initial precision is expected to be 450 ppb (stats) and 70 ppb (sys) with the 300 MeV muon beam and 3T Magnetic field
3. Upgrades are being studied to surpass Fermilab's precision, targeting less than 100 ppb (statistical uncertainty).
4. Recent progress:
 - a) demonstration of 3D spiral injection scheme
 - b) first cold muon beam acceleration
 - c) muon acceleration through RFQ to 100 keV
5. We have also achieved promising results in efficiency and in computation time tracking using GPU and GNN based approach

Thank You

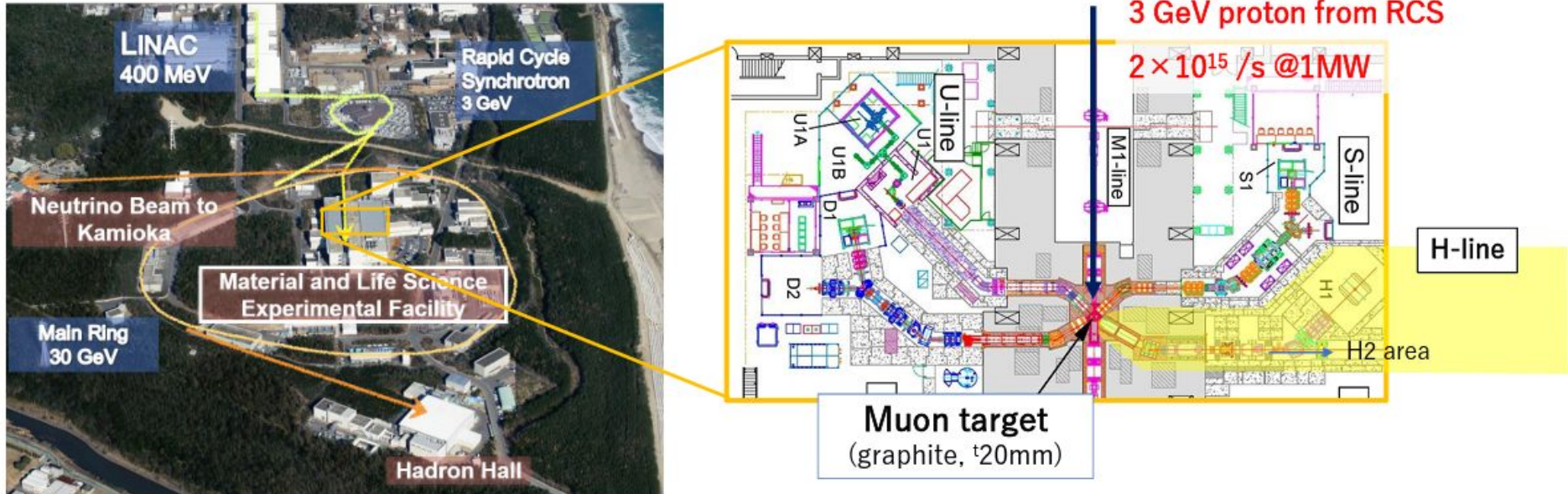
Thank you for listening

Reference

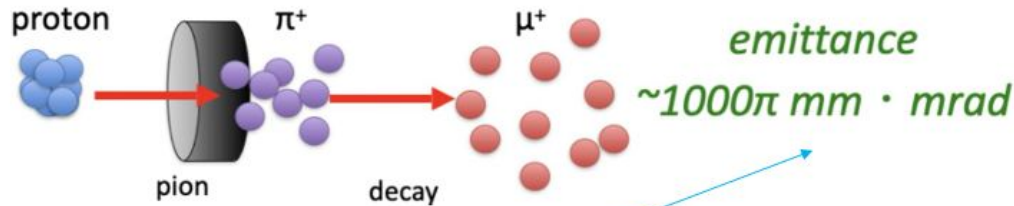
1. A. Driutti (for the Muon g-2 Collaboration), “Final measurement of the anomalous magnetic moment of the muon from the Muon g-2 experiment at Fermilab,” J. Subatomic Part. Cosmol., 100233 (2025).
<https://doi.org/10.1016/j.ispc.2025.100233>
2. R. Aliberti et al., “The anomalous magnetic moment of the muon in the Standard Model: an update,” Phys. Rep. 1143, 1–158 (2025). <https://doi.org/10.1016/j.physrep.2025.08.002>
3. Muon g-2 Collaboration, “An improved direct limit on the muon electric dipole moment,” arXiv:2608.11124 (2026). <https://doi.org/10.48550/arXiv.2608.11124>
4. S. Aritome et al., “Acceleration of positive muons by a radio-frequency cavity,” Phys. Rev. Lett. 134, 245001 (2025). <https://doi.org/10.1103/PhysRevLett.134.245001>
5. R. Matsushita et al., “First experimental demonstration of beam storage by three-dimensional spiral injection scheme for ultra-compact storage rings,” <https://doi.org/10.1103/8nxx-srgz> .
6. Hiromi Inuma et al., Three-dimensional spiral injection scheme for the g-2/EDM experiment at J-PARC <https://doi.org/10.1016/j.nima.2016.05.126>
7. H. Chetri, D. Samuel, S. Sandilya, T. Yamanaka, T. Mibe, and T. Suehara, “GPU-based track-finding for the J-PARC muon g-2/EDM experiment,” J. Instrum. 21, P01006 (2026).
<https://doi.org/10.1088/1748-0221/21/01/P01006>

J-PARC MLF H-line

- A new beam line (H-line) at J-PARC MLF will be used for the experiment.



First step: muon cooling

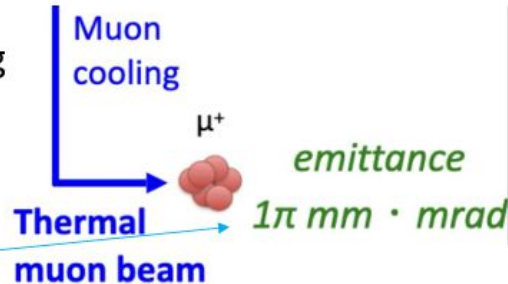


Conventional surface muon beam:

- High emittance $\rightarrow$ needs strong focusing and leads to muon losses
- Background from π contamination

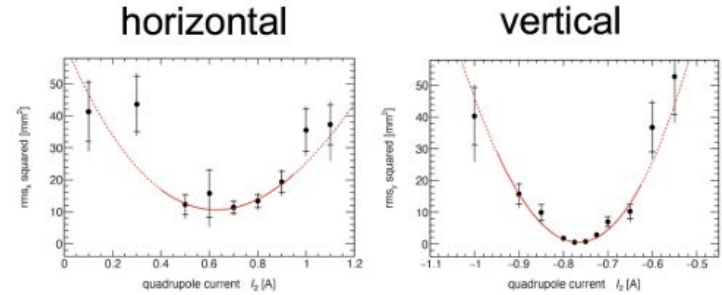
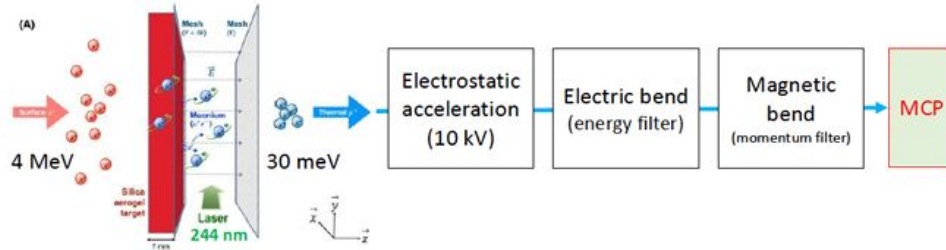
J-PARC muon beam by design:

- Low emittance (1000x improvement!)
- Disadvantage: not $\sim 100\%$ polarized



Second step: muon re-acceleration

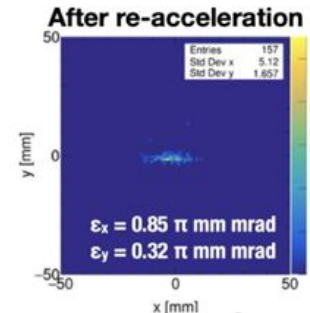
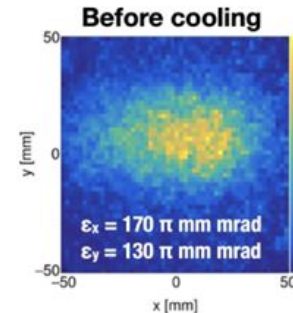
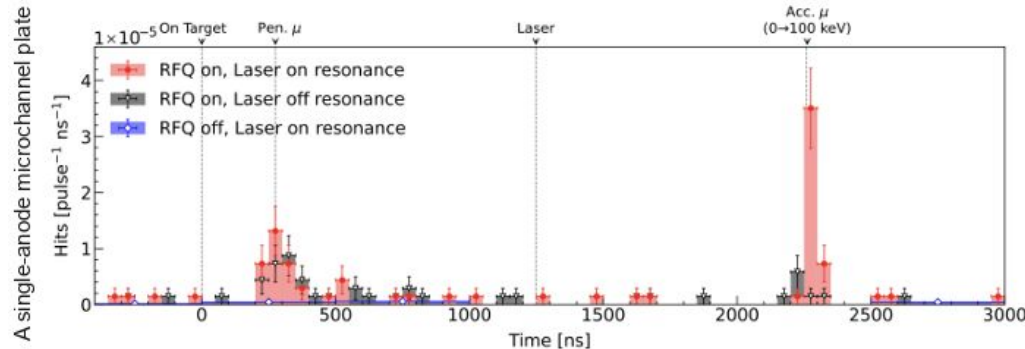
- Muon Cooling demonstration:
[Phys. Rev. Lett. 134, 245001](#)



$$\epsilon_x = 0.85 \pm 0.25(\text{stat})^{+0.22}_{-0.13}(\text{syst}) [\pi \text{ mm mrad}]$$

$$\epsilon_y = 0.32 \pm 0.03(\text{stat})^{+0.05}_{-0.02}(\text{syst}) [\pi \text{ mm mrad}]$$

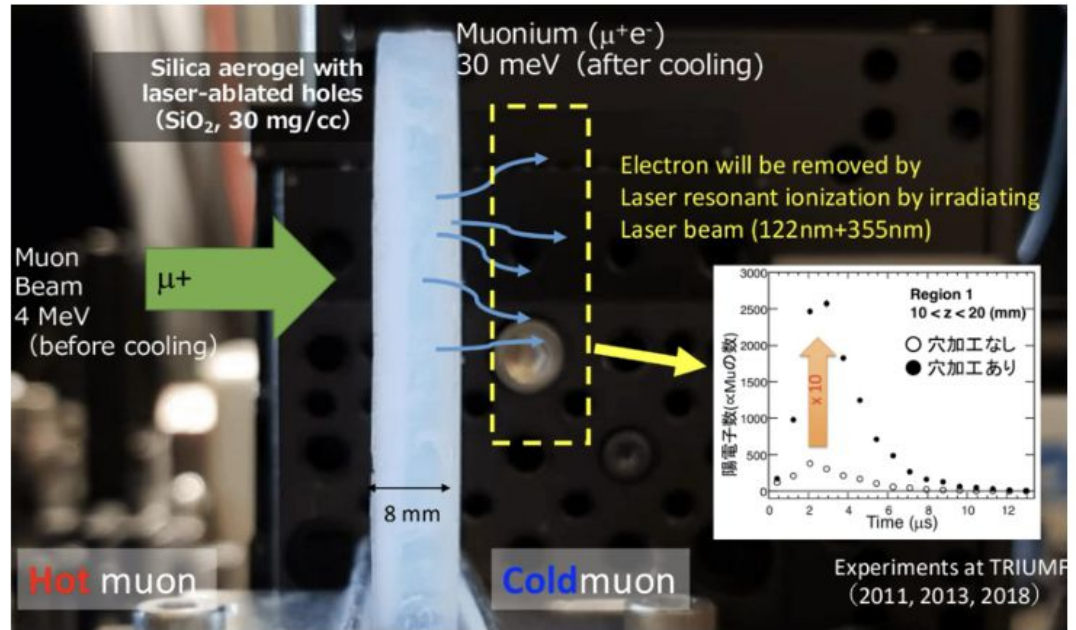
Emittance reduction by $\sim 10^{-3}$
The birth of low-emittance muon beam



Ultra-cold (thermal) muons

- Surface μ^+ stop in Aerogel and form Muonium (μ^+e^-) that diffuse into vacuum through laser ablated surface
Efficiency of $\sim 3 \cdot 10^{-3}$

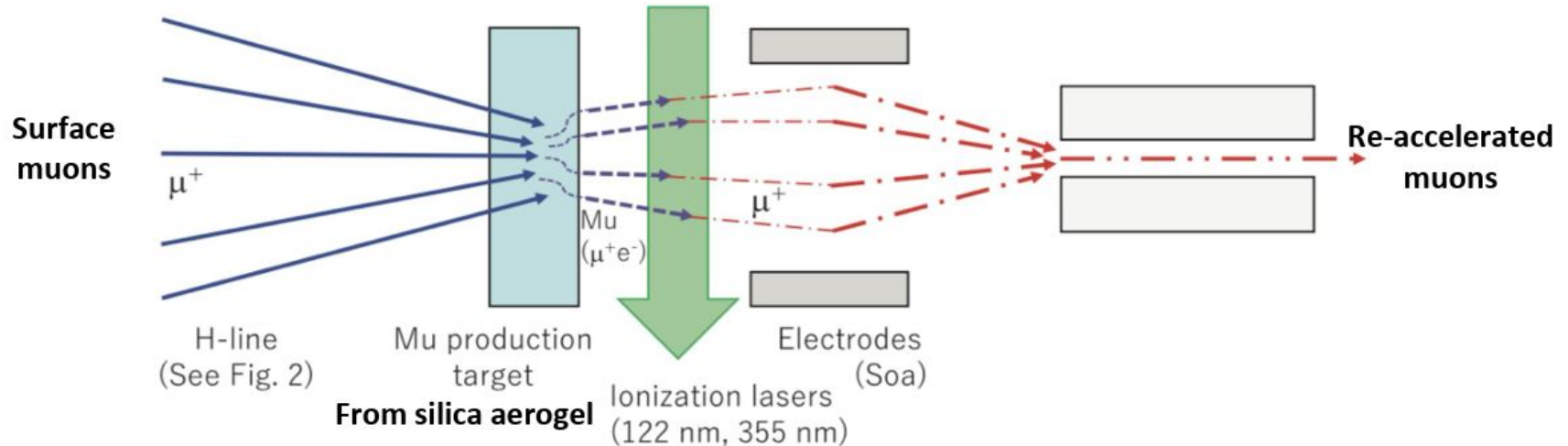
- Ionize e^- with two lasers:
 $1S \rightarrow 2P \rightarrow \text{unbound}$.
Maximum μ^+ polarization: 50%



- Thermal muons re-accelerated with E-field, RFQ, linear structures that inherit from proton and electron acceleration, up to $E=212$ MeV ($p=300$ MeV/c), retaining low transverse $\vec{p}$

Second step: muon re-acceleration

	Surface muon	Thermal muon	Accelerated Muon
E (kin.)	3.4 MeV	30 meV	212 MeV
p	27 MeV/c	2.3 keV/c	300 MeV/c
$\Delta p/p$	0.05	0.4	4×10^{-4}



Muon beam at J-PARC
