九州大学
KYUSHU UNIVERSITY

Status of J-PARC Muon g-2/EDM Experiment

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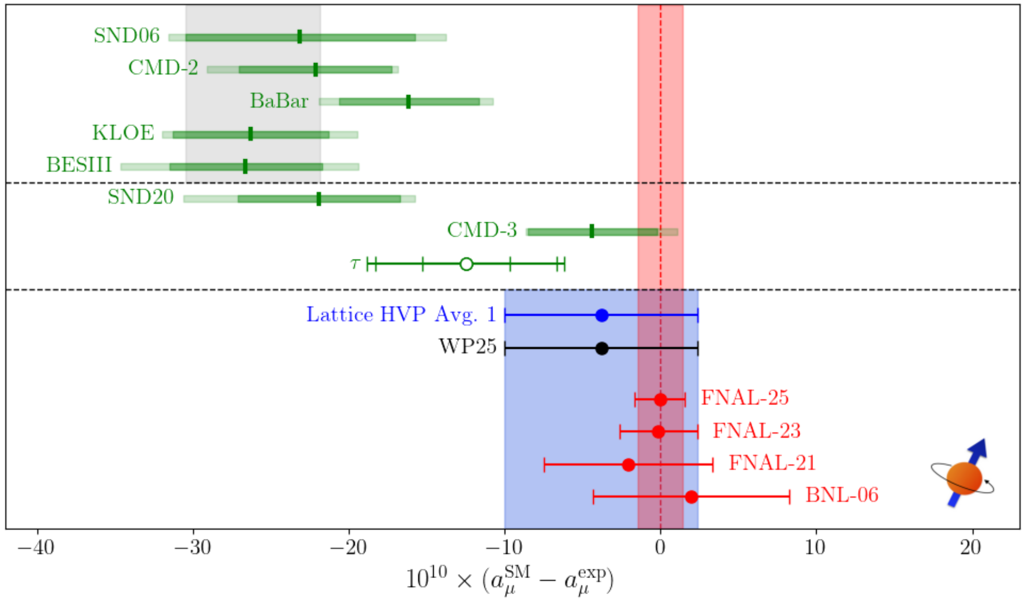
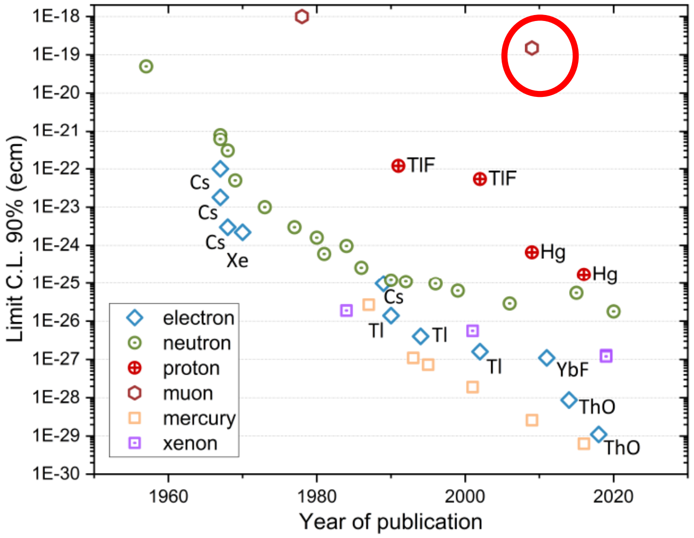
Muon g-2 and EDM

- Muon anomalous magnetic moment (g-2)
  - The SM prediction by the Muon g-2 theory initiative was updated in 2025.
    - Phys. Rep. 1143 (2025), 1-158
  - The final result of FNAL E989 was released in 2025.
    - Phys. Rev. Lett. 135 (2025), 101802
- Muon electric dipole moment (EDM)
  - Existence of EDM for elementary particles indicates CP violation.
  - The experimental bound: $|d_{\mu}| < 1.8 \times 10^{-19}$ e・cm
    - BNL E821：Phys. Rev. D 80 (2009), 052008



Phys. Rep. 1143 (2025), 1-158

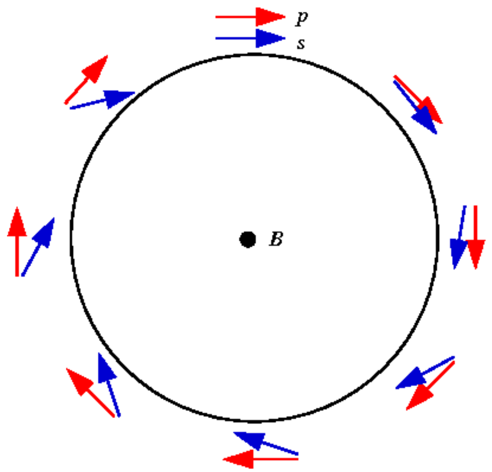


EDM limit history
arXiv:2102.08838

Experimental Approaches

Spin precession vector with respect to cyclotron motion in EM field

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



Spin precession in cyclotron motion

BNL/FNAL approach

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

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

Magic momentum of 3.094 GeV/c is used.

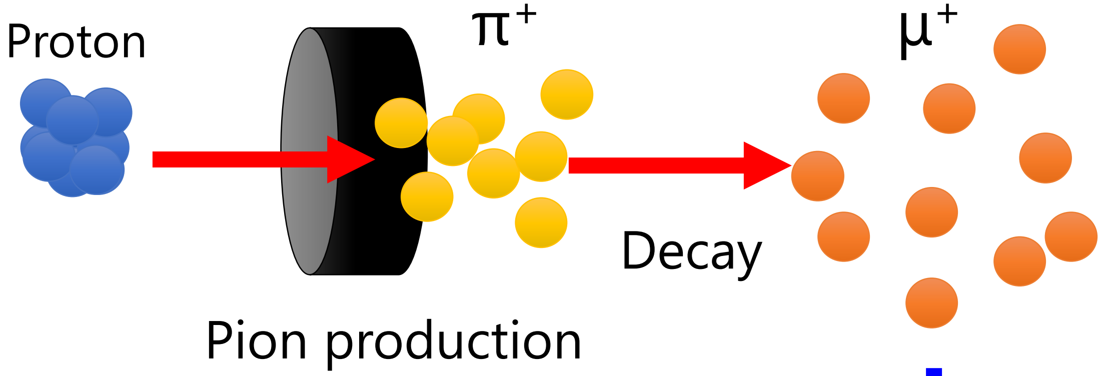
J-PARC approach

$$\vec{E} = 0$$

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

Reaccelerated thermal muon beam is a key of this method.

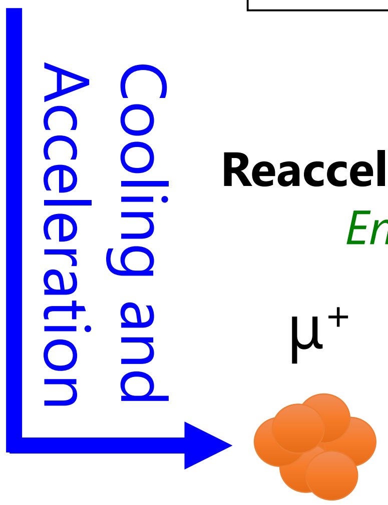
Reaccelerated Thermal Muon Beam



Conventional muon beam

Emittance ~1000π mm·mrad

Strong focusing with electric field
Muon loss
Pion background



Reaccelerated thermal muon beam

Emittance ~1π mm·mrad

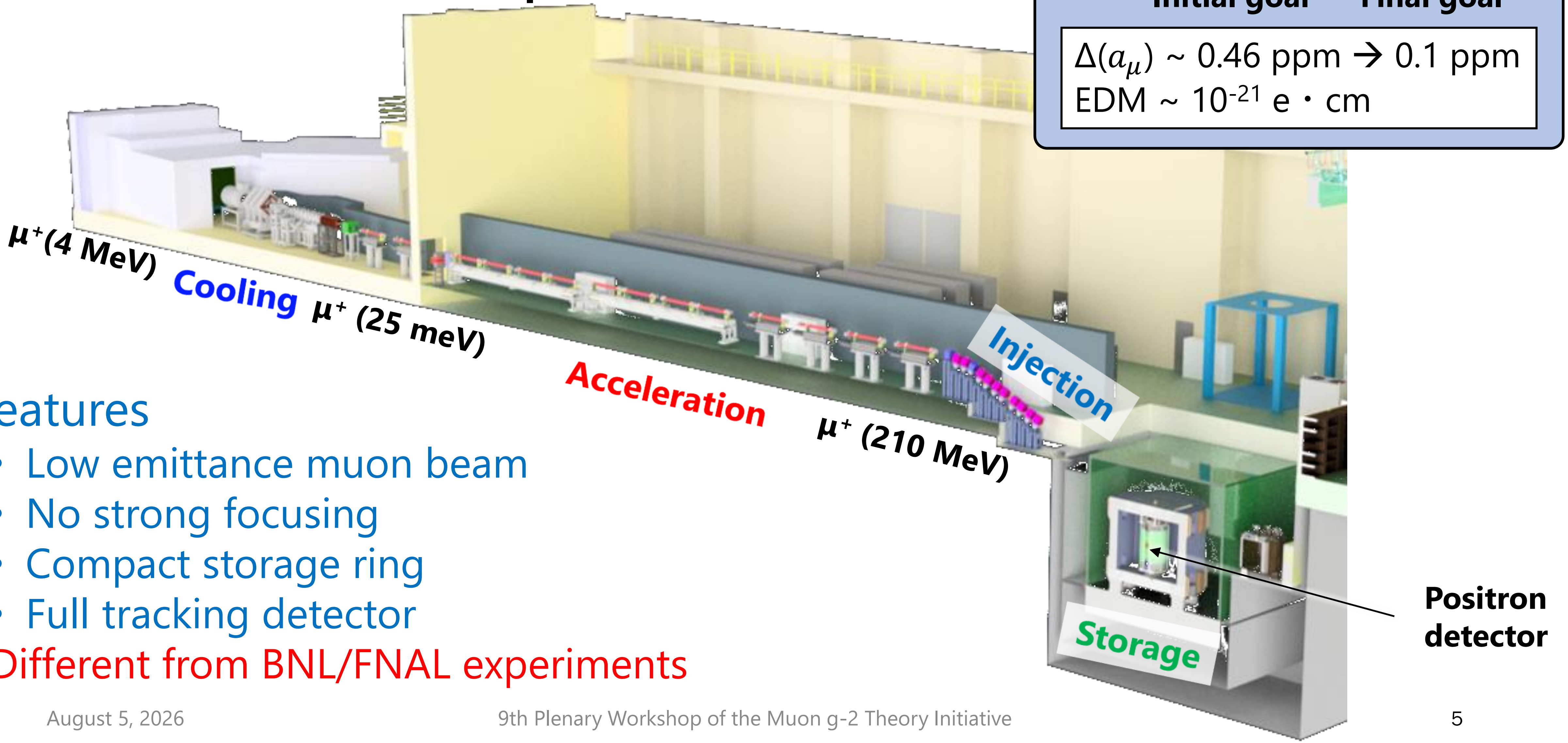
Free from any of the above

Reaccelerated 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**

J-PARC E34 Experiment

	Initial goal	Final goal
$\Delta(a_\mu)$ ~	0.46 ppm →	0.1 ppm
EDM ~ 10^{-21} e・cm		



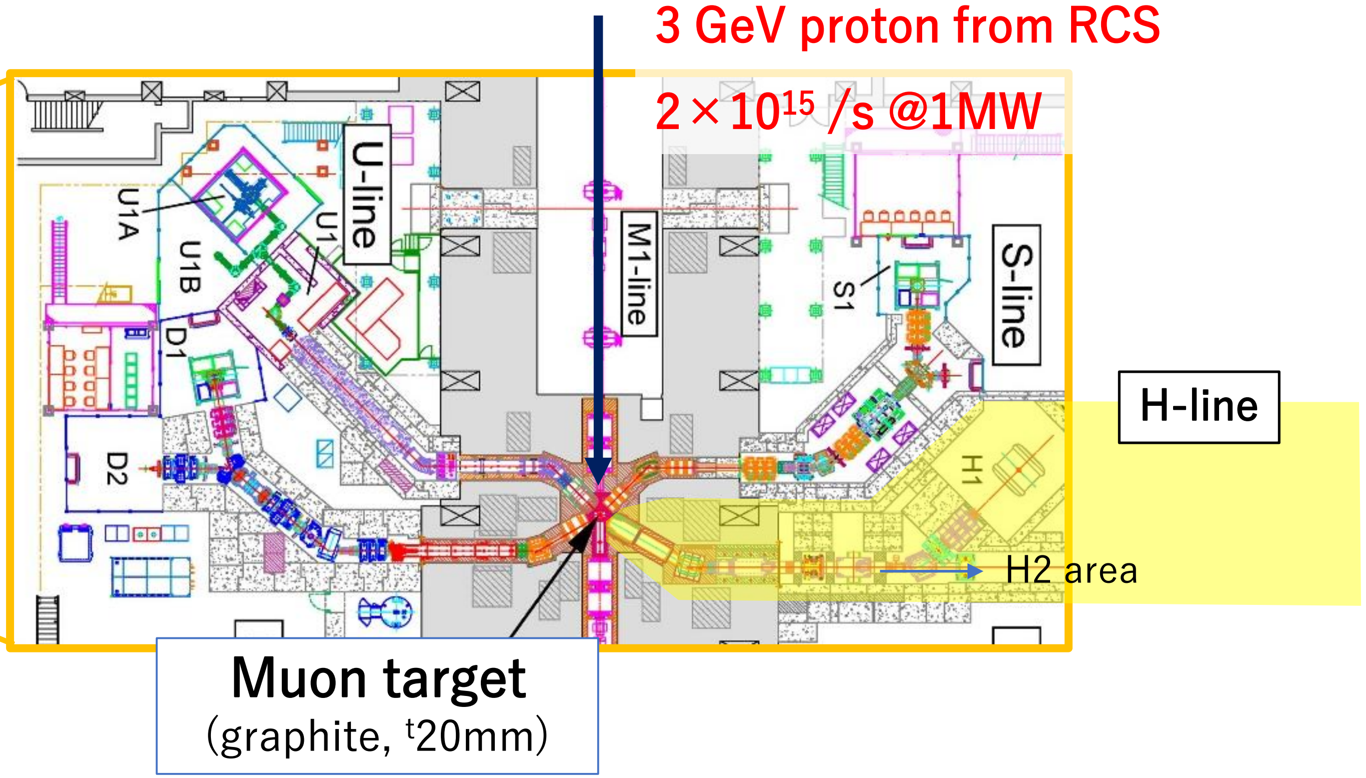
Features

- Low emittance muon beam
- No strong focusing
- Compact storage ring
- Full tracking detector

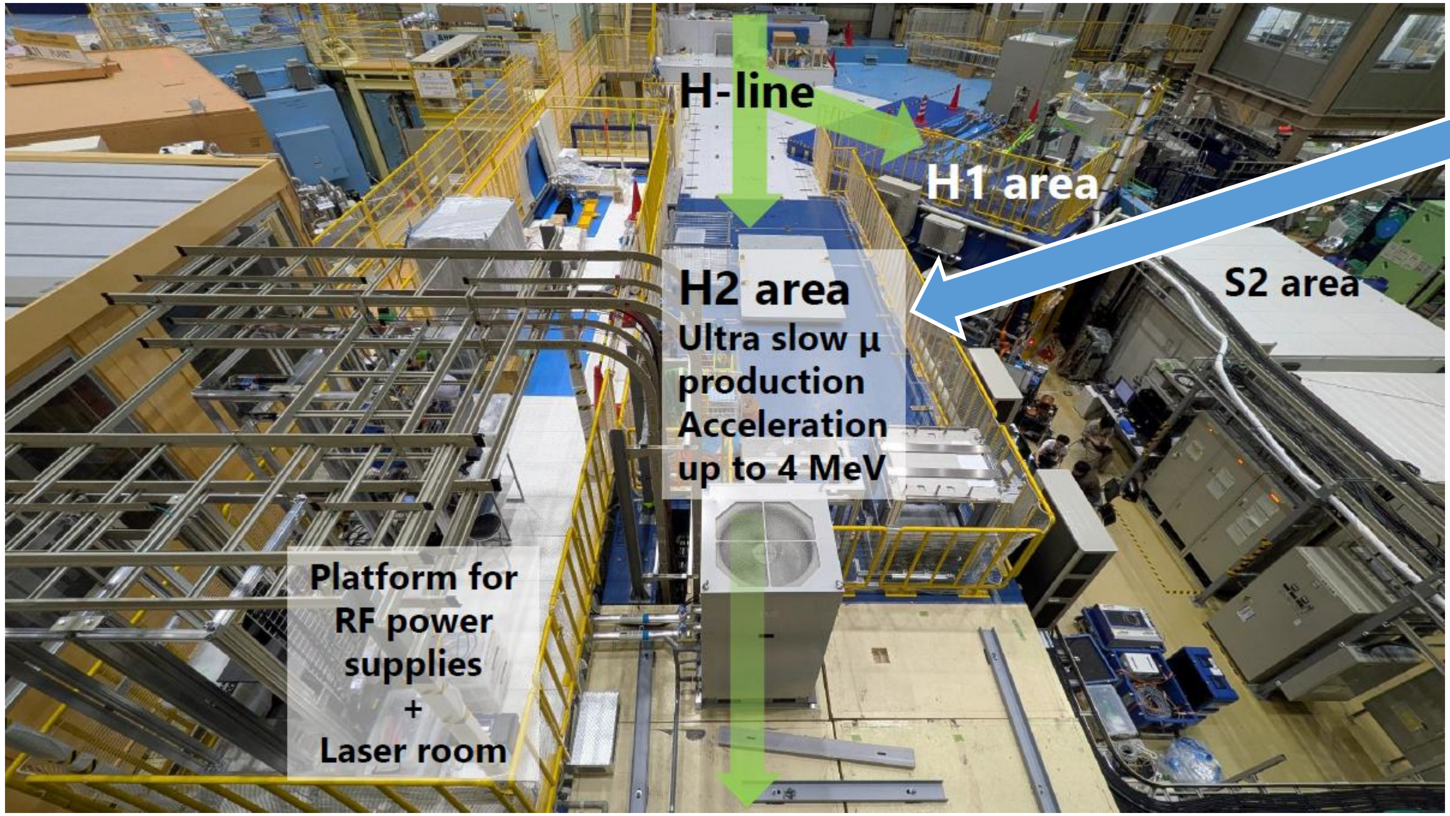
Different from BNL/FNAL experiments

J-PARC MLF H-line

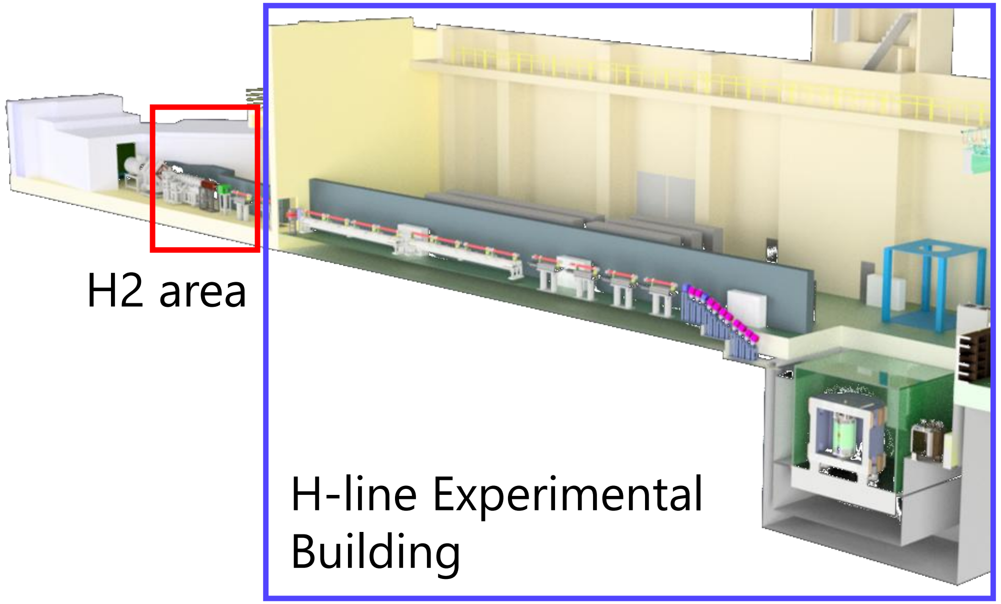
- A new beam line (H-line) at J-PARC MLF will be used for the experiment.



H-line Construction Status



Construction of H2 beamline

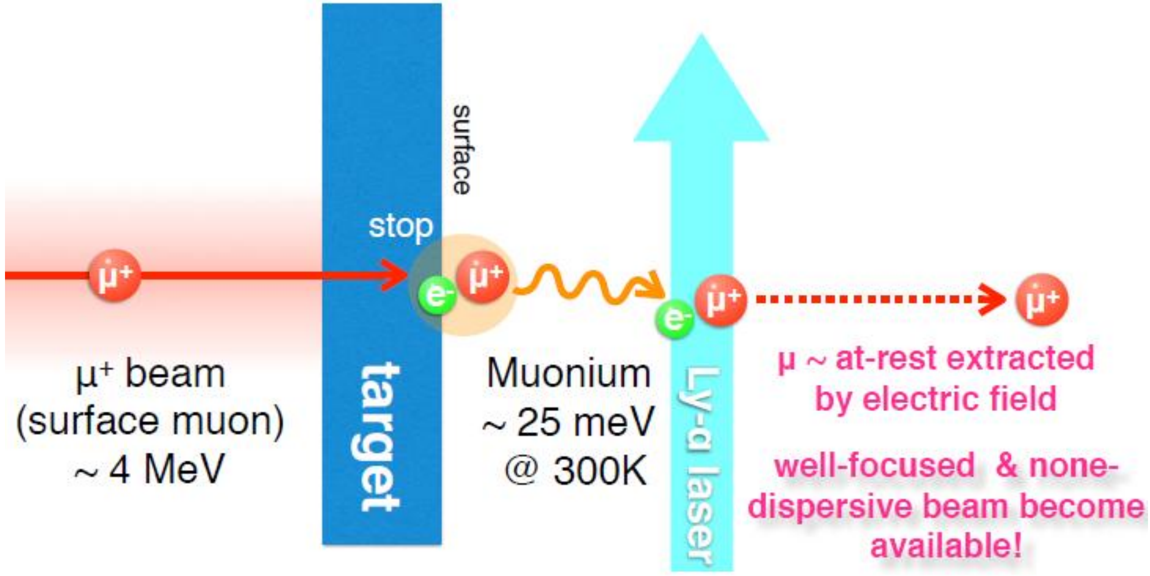


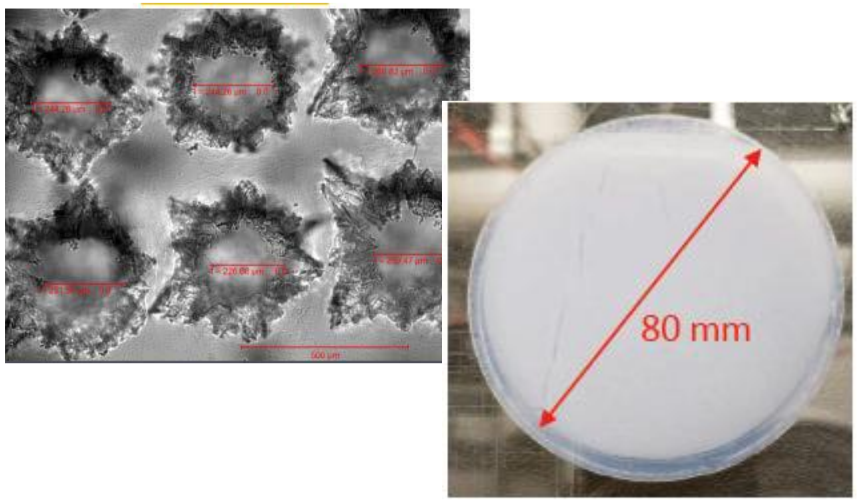
Construction of the extension building will be carried out in two steps: first (40~100 MeV) and second (212 MeV~).

- Construction of H2 area is being conducted for muon cooling and acceleration commissioning.

Thermal Muon Beam

- Surface muon beam from the H-line will be used as a source.
- Muon beam is stopped at an aerogel target, and muonium (bound state of e^- and μ^+) is produced.
  - Laser-ablated silica aerogel is used for muonium production target.
- An electron is stripped from a muonium by laser and thermal muon beam is produced.

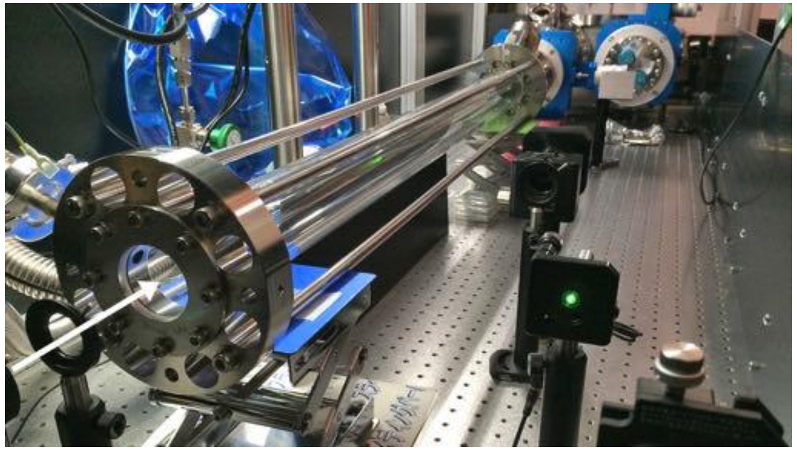




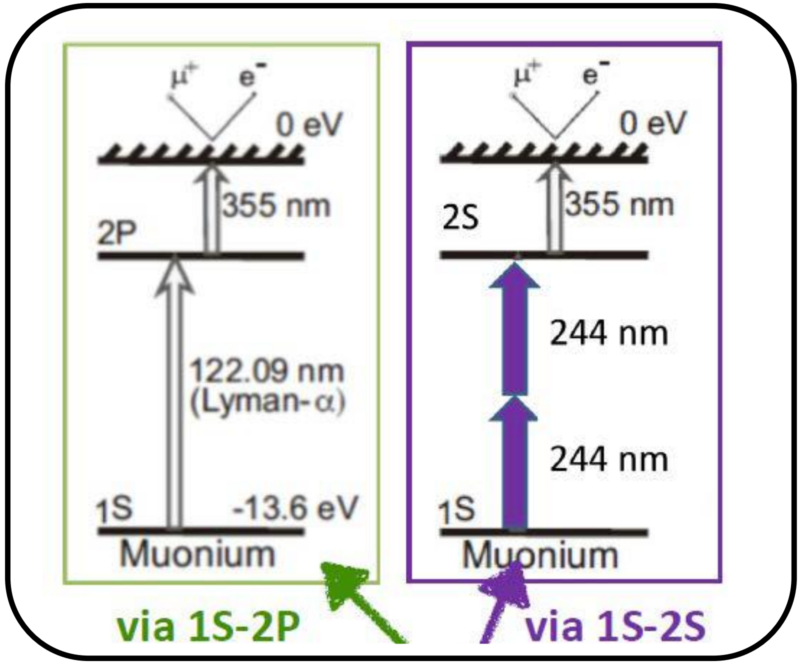
Silico aerogel target installed in S-line of J-PARC MLF

Muonium Ionization

- In the original design, an intense Lyman-α laser (122 nm) and 355 nm laser will be used to ionize muonium via 1S-2P transition.
  - Laser power of 100 μJ is needed for Lyman-α laser.
  - Improvement of laser power is expected by recent laser upgrade.
- As an alternative method, ionization scheme with 244 nm laser is being developed collaborating with the muonium 1S-2S spectroscopy measurement experiment.

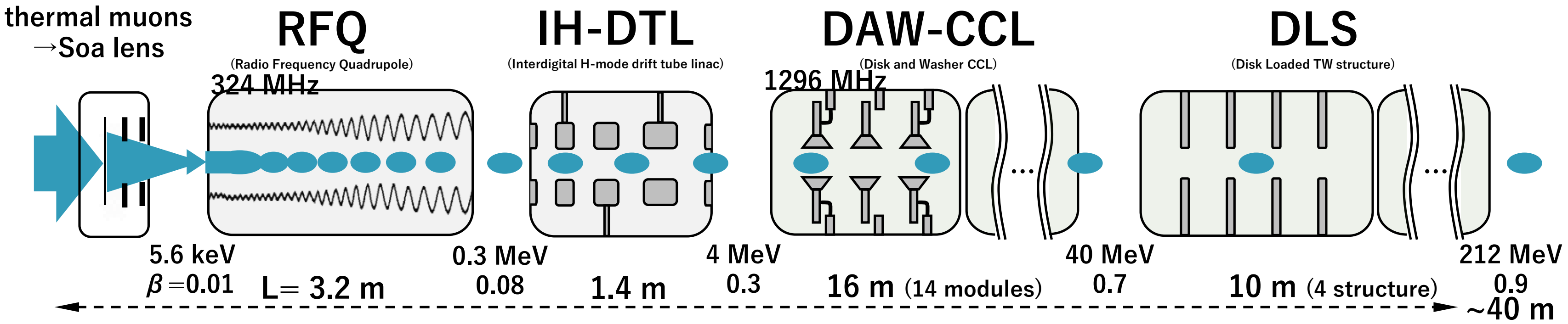


Lyman-α laser system



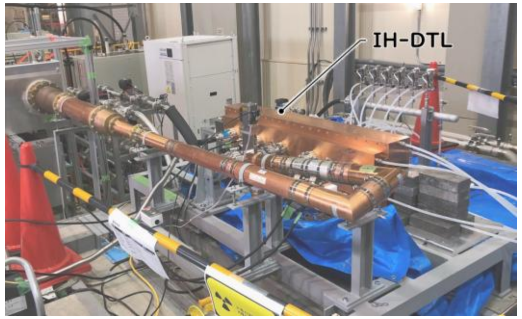
Muon Acceleration

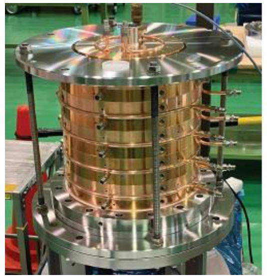
- Thermal muon beam is accelerated to p=300 MeV/c in LINAC.
- Different types of acceleration cavities are utilized to cover wide range of velocity.



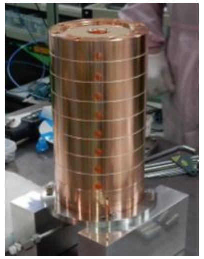
Ready

Fabrication was completed and high power test was successfully done.





Prototype tank

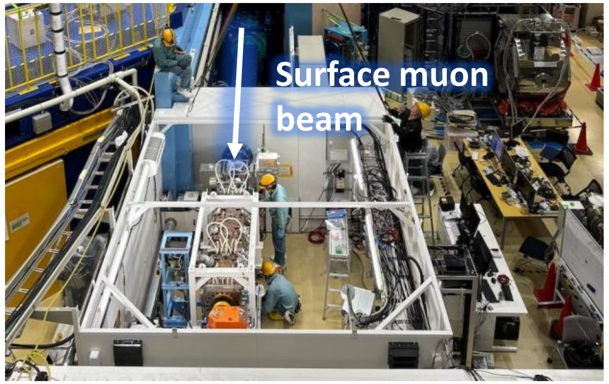


Prototype tank

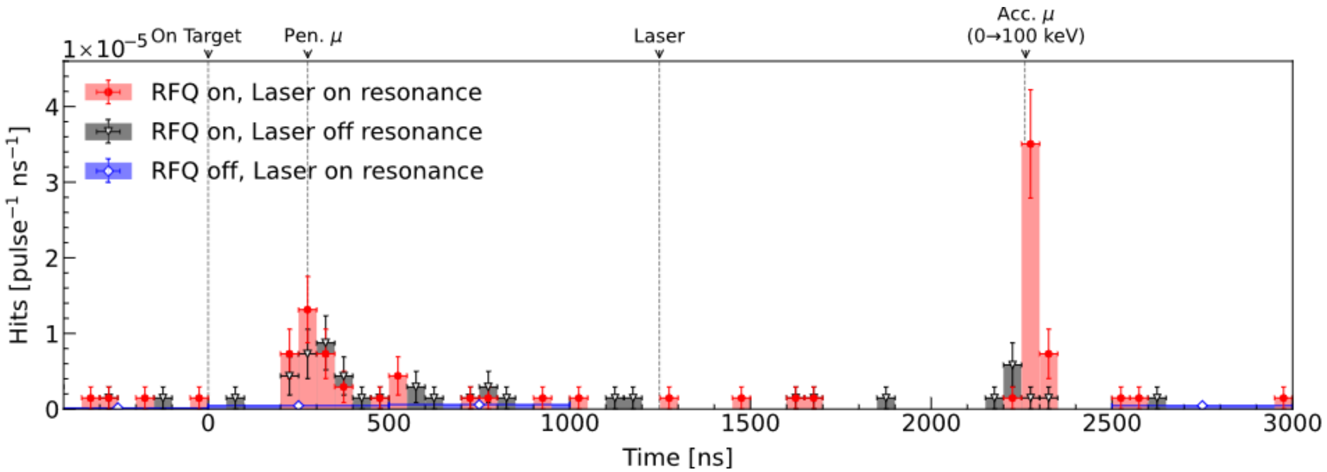
Demonstration of Muon Acceleration

- **The world's first cooling and acceleration of muon was achieved in 2025.**
  - Phys. Rev. Lett. **134**, 245001 (selected as PRL collection of the year 2025)

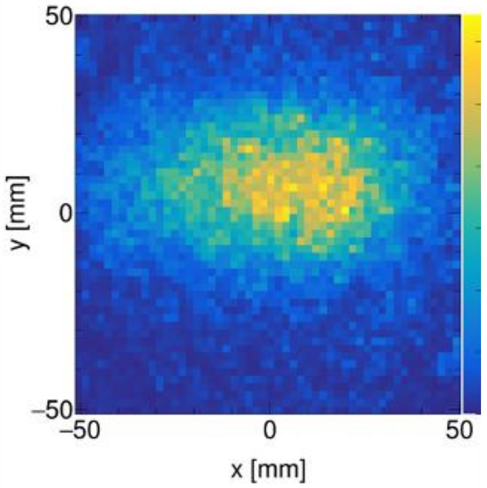
- S2 area instead of the H2 area
- 244 nm Ionization laser
- Prototype RFQ



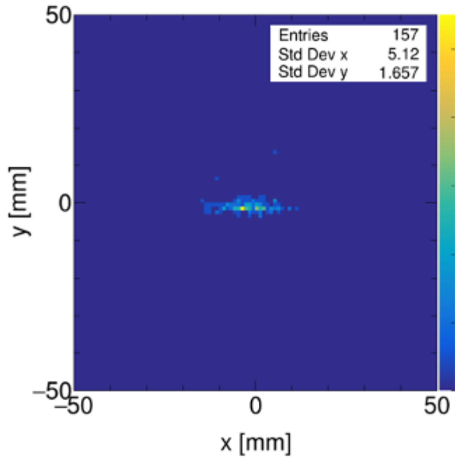
J-PARC MLF S2 area



Time of flight from muon on target



Beam profile before cooling

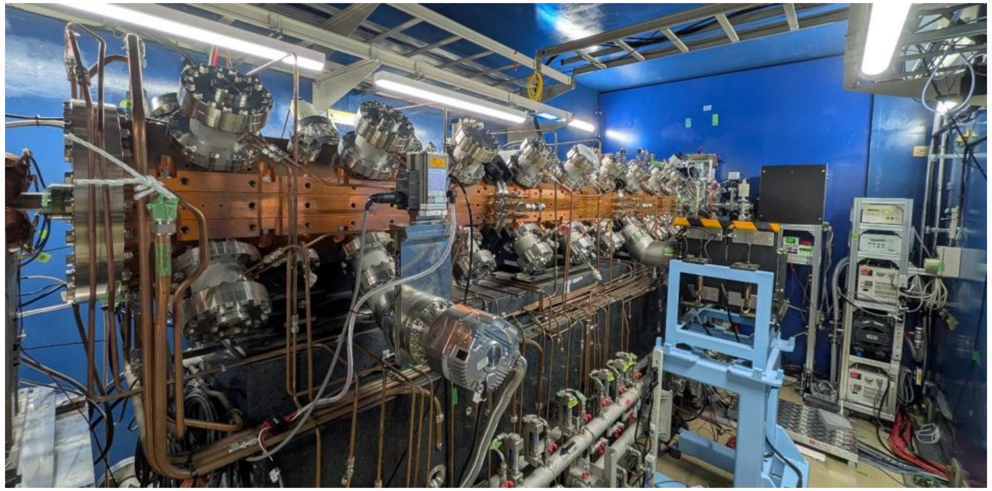


After reacceleration

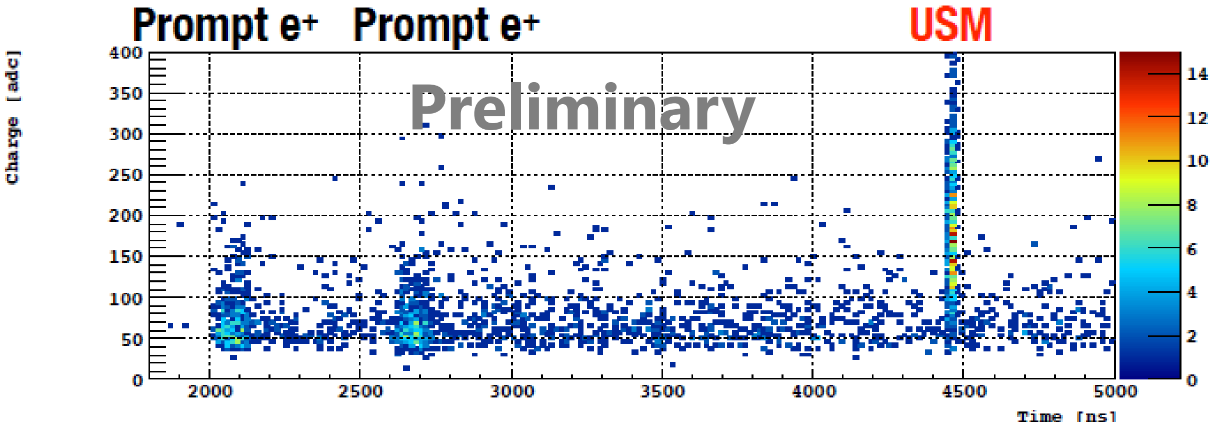
Emittance reduction by a factor ~200 (horizontal), ~410 (vertical)

Commissioning of Acceleration

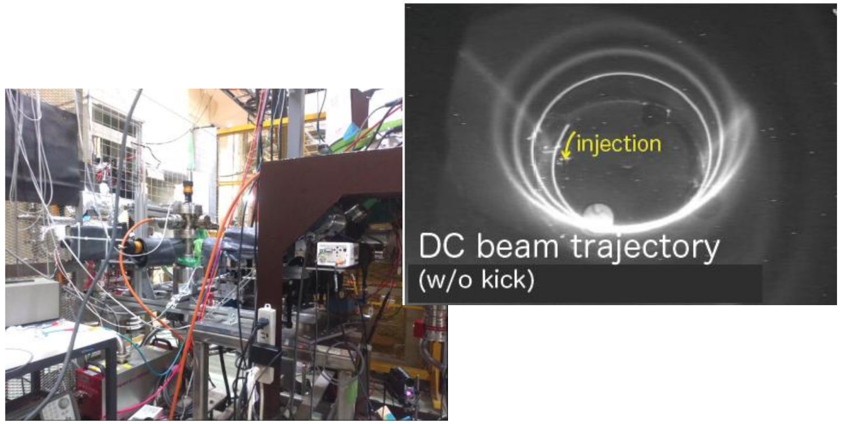
- After the successful acceleration of muon up to 100 keV, further acceleration tests are being performed.
  - Acceleration in H2 area
  - Use of 122 nm laser
  - Acceleration up to 340 keV
  - Much higher rate (~10 Hz) than before



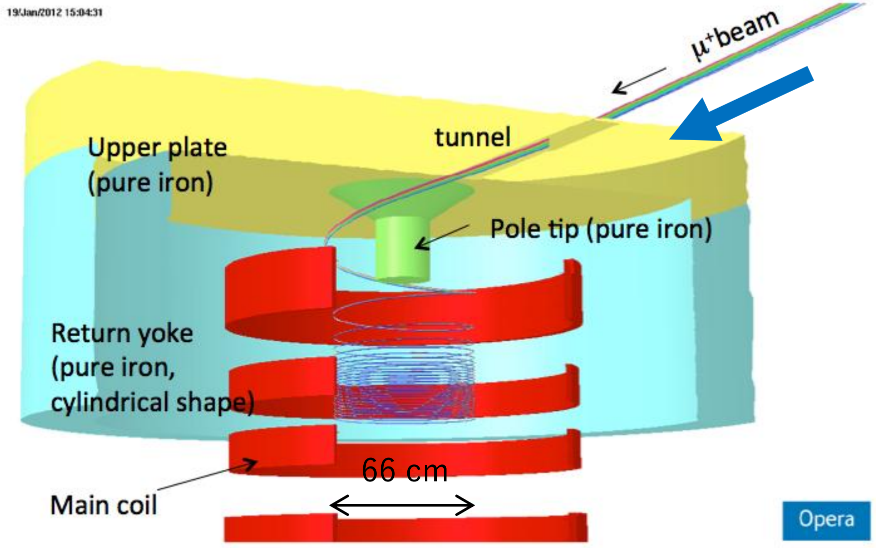
Current H2 beamline



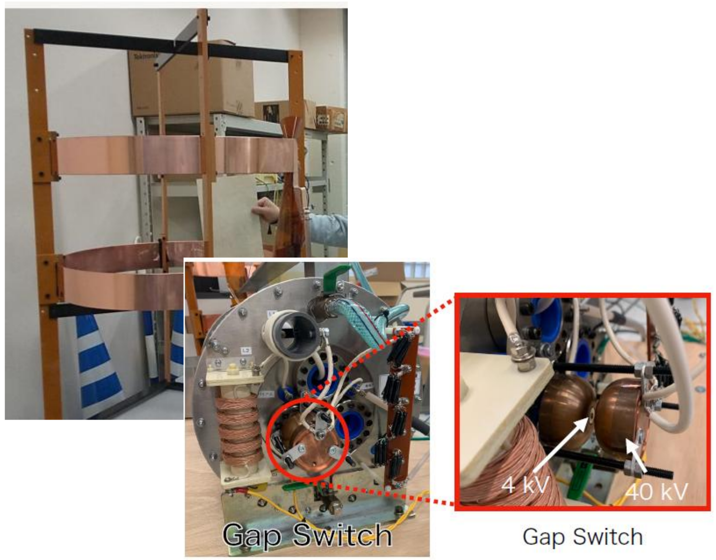
3D Spiral Injection



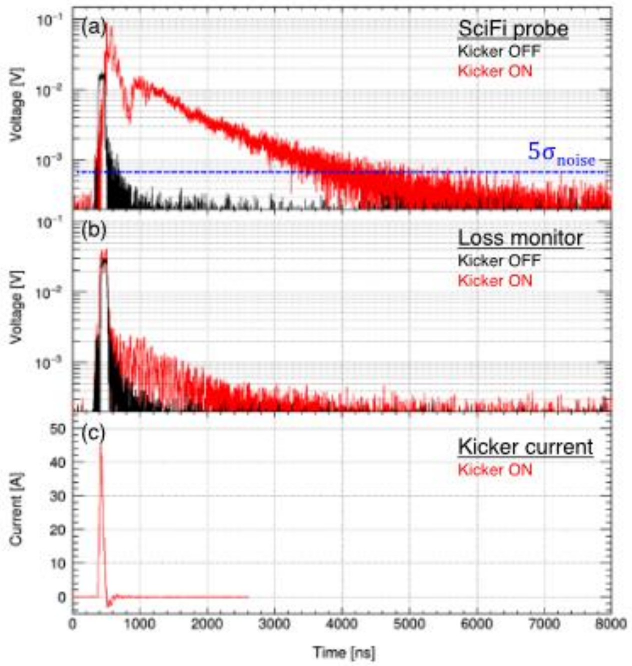
- To inject the 300 MeV/c muon beam into 66 cm-diameter storage ring, 3D spiral injection scheme is being developed.
- Prototypes of kicker were fabricated, and the injection scheme is validated using low momentum electron beam.
- Real scale prototype-kicker coil and power supply are fabricated and tested.



3D spiral Injection orbit



Real scale prototype of kicker coils and power supply

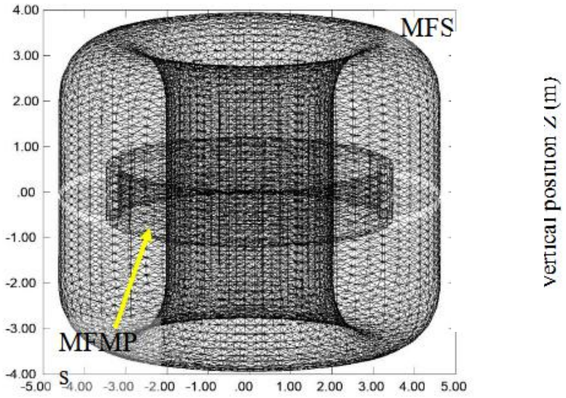


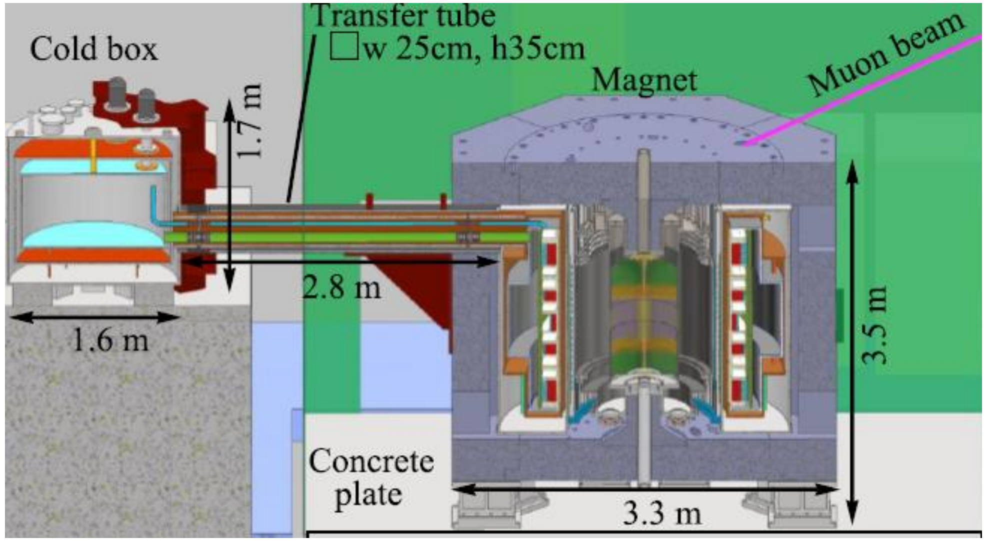
Demonstration of 3D injection with DC electron beam (Phys. Rev. Lett. 137 (2026), 025002)

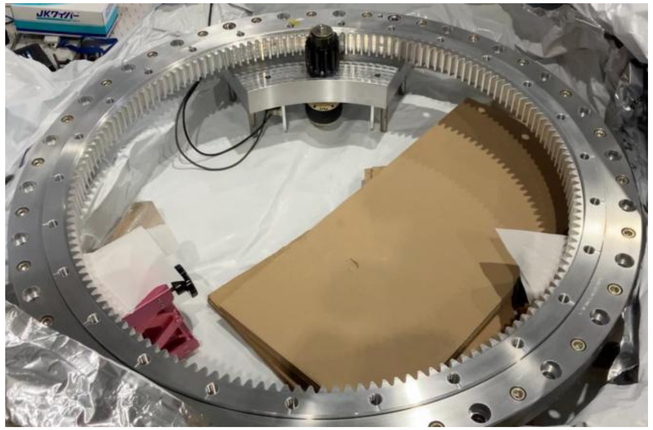
Storage Magnet

- 3 T MRI-type superconducting solenoid magnet is used to store a muon beam.
  - Engineering design of the magnet is ongoing.
- 0.1 ppm uniformity in Bz is required.
  - Field mapping system is being developed.
  - Design of shimming coils and shimming procedures are being developed.

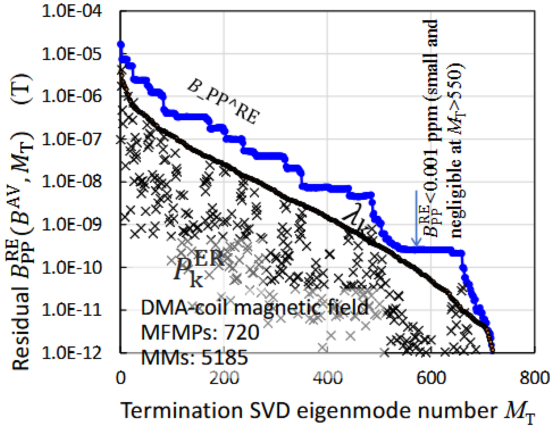
$$b_{ij} = \frac{\mu_0}{4\pi}\frac{3(m_j \cdot r_{ij})r_{ij} - r_{ij}^2 m_j}{r_{ij}^5}$$ (MM: Magnetic Moment)





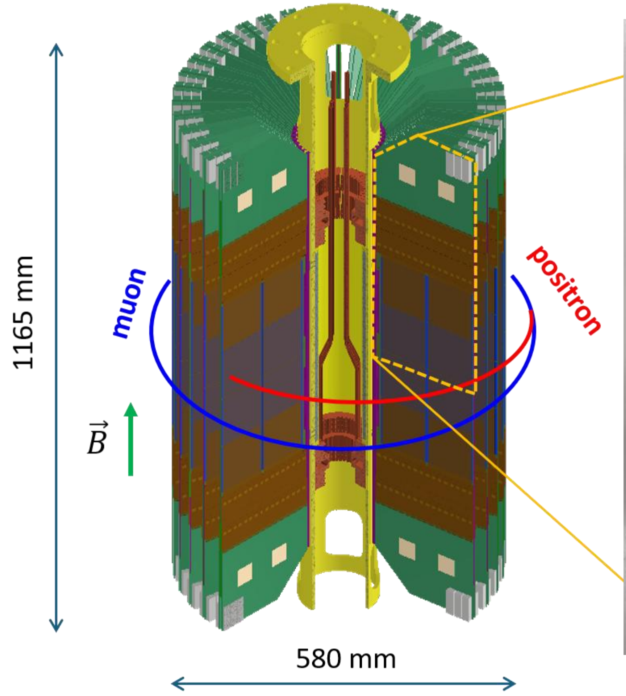


Moving stages for mapping probe

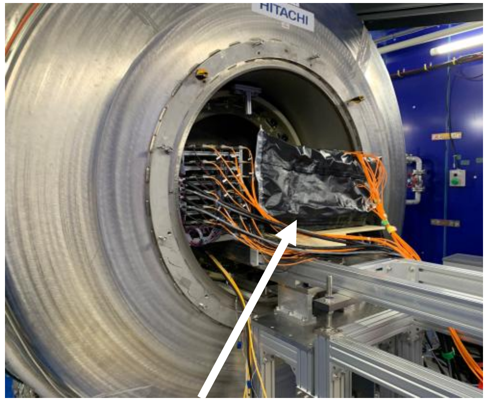


Positron Tracking Detector

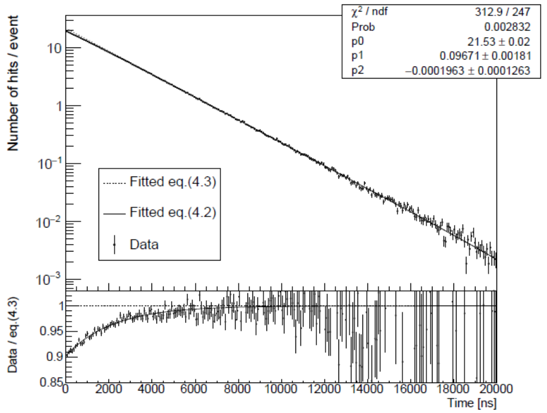
- Positrons from stored muon decays are detected by the detector consisting of silicon strip sensors.
  - The detector consists of 40-vane like modules.
- Requirements on the detector
  - Operate in 3 T magnetic field and ~0.1 atm vacuum
  - Tolerate 6 muon decays/ns for detection
  - 10 μrad accuracy (in r-z plane) for sensor alignment
- A 1/4 vane module was produced and its hit-rate capability was evaluated using J-PARC H1 area muon beam with the MuSEUM experiment setup.
  - Published in [JINST 21 (2026) P07039](#).



1/4 vane module



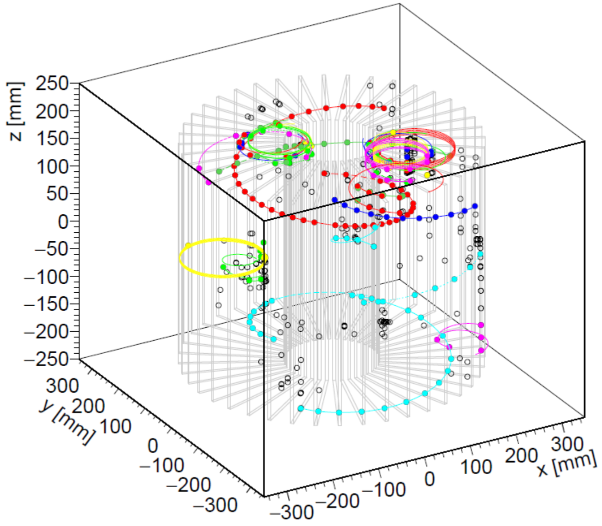
1/4 vane module installed in H1 area



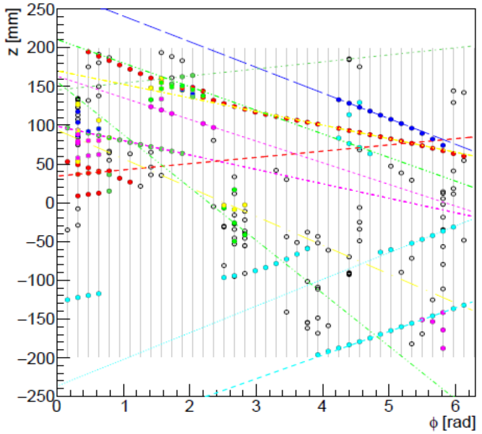
Time spectrum of decay positrons obtained by the 1/4 vane.

Track Reconstruction

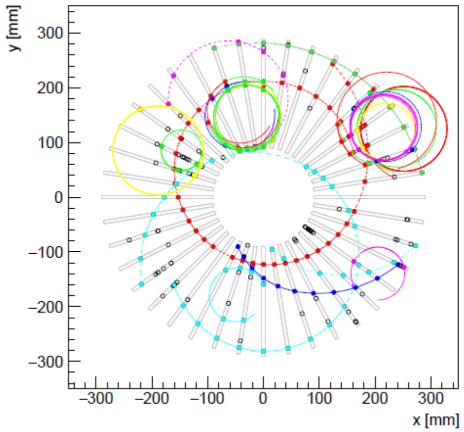
- One of the challenges in software is track reconstruction speed.
  - At the actual experiment, $\sim 3 \times 10^4$ signal tracks/s will be detected.
- High speed track reconstruction algorithm based on Hough transform in z-φ plane has been developed.
  - Possibility to accelerate processing speed by using GPU has been studied recently ([JINST 21 (2026) P01006]).
  - Introduction of new techniques such as Graph Neural Network (GNN) and LLM is also being studied.



Event display of detector (corresponding to ~one time window)



Projection to z-φ plane
- High momentum tracks leave hits on a straight line.



Top view of the detector

Experimental Parameters

	BNL-E821	Fermilab-E989		Our experiment
Muon momentum	3.09 GeV/c			300 MeV/c
Lorentz γ	29.3			3
Polarization	100%			50%
Storage field	$B = 1.45$ T			$B = 3.0$ T
Focusing field	Electric quadrupole			Very weak magnetic
Cyclotron period	149 ns			7.4 ns
Spin precession period	4.37 μs			2.11 μs
Number of detected e^+	5.0×10^9	1.6×10^{11}		5.7×10^{11}
Number of detected e^-	3.6×10^9	–		–
a_μ precision (stat.)	460 ppb	100 ppb		450 ppb
(syst.)	280 ppb	100 ppb	~78	<70 ppb
EDM precision (stat.)	$0.2 \times 10^{-19}\ e \cdot \mathrm{cm}$	–		$1.5 \times 10^{-21}\ e \cdot \mathrm{cm}$
(syst.)	$0.9 \times 10^{-19}\ e \cdot \mathrm{cm}$	–		$0.36 \times 10^{-21}\ e \cdot \mathrm{cm}$

$$\frac{\delta\omega_a}{\omega_a} = \frac{1}{\omega_a \gamma \tau_\mu P}\sqrt{\frac{2}{NA^2}}$$

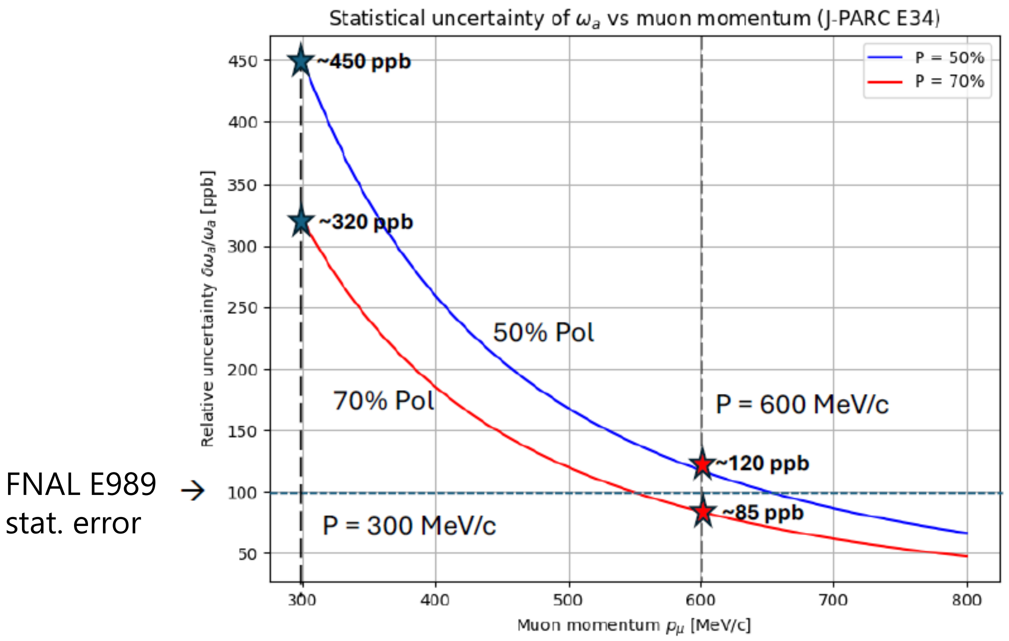
$$\omega_a = a_\mu \frac{eB}{m}$$

High Sensitivity Option

$$\frac{\delta\omega_a}{\omega_a} = \frac{1}{\omega_a \gamma \tau_\mu P}\sqrt{\frac{2}{NA^2}}$$

$$\omega_a = a_\mu \frac{eB}{m}$$

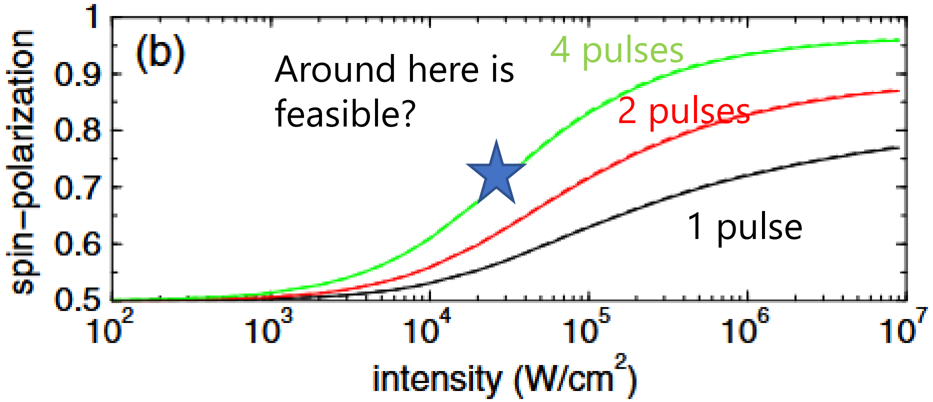
- In the original plan, the sensitivity to ω_a is statistically limited to 0.45 ppm even with two years operation (~250 days).
- Ways to higher sensitivity are;
  - higher polarization
  - higher momentum
  - higher magnetic field
- Studies have been started for high sensitivity option.



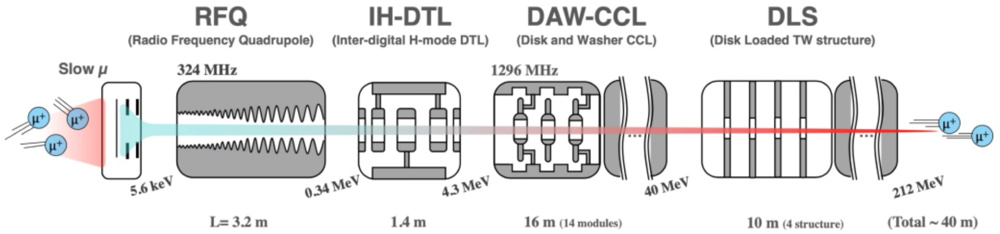
PoS EPS-HEP2025, 427 (2026)

Towards High Sensitivity (1)

- Higher polarization
  - The current muonium production method reduces polarization from 100% to 50%.
  - There is a possibility to improve this situation by optical pumping.
- Higher momentum
  - The final acceleration is based on S-band cavity (20 MV/m).
  - If it can be replaced with higher gradient cavity (~35 V/m, e.g. C-band), acceleration up to 600 MeV/c is feasible without extending the beam line.



Spin polarization by an optical pumping ([J. Opt. Soc. Am. B 29 (2012) 2420-2424]())

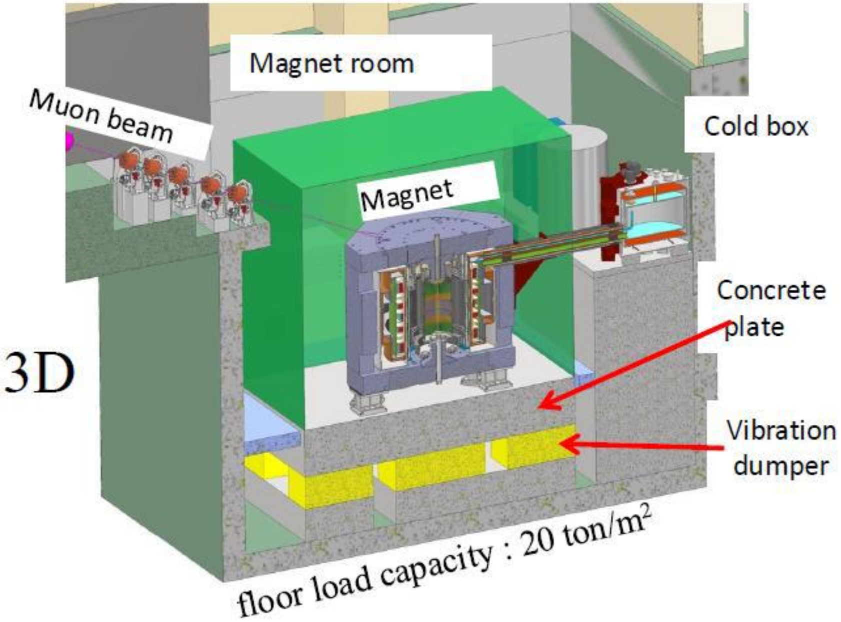


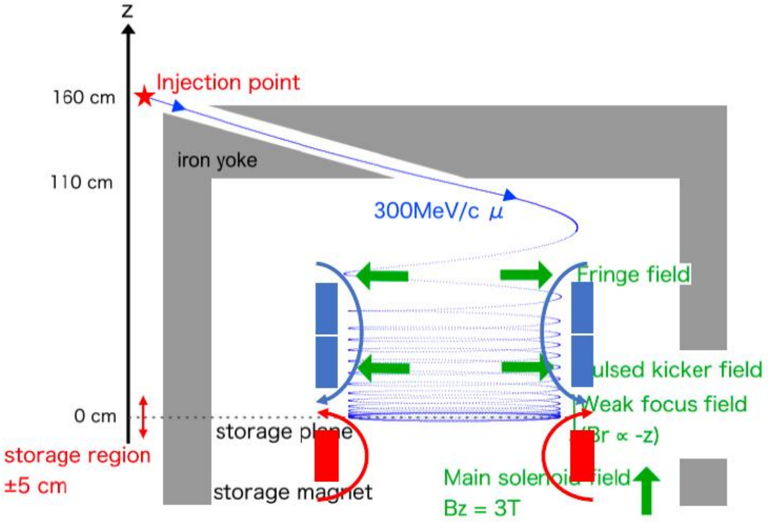
Current LINAC design

New S-band or C-band cavities

Towards High Sensitivity (2)

- Higher magnetic field
  - Feasibility study of a 6 T magnet design has been started with a private company focusing on uniformity of the magnetic field.
    - It is also required to fit in available space and can be fabricated with reasonable cost.
  - 3D spiral injection is also required to accommodate 6 T magnet design and no show stopper has been found.
    - Additional kicker coil founds to be promising to strengthen kicker field.

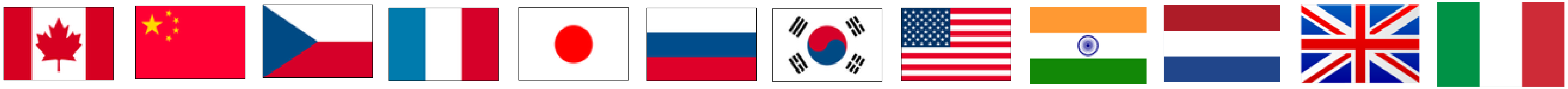




The Collaboration

- The Collaboration is expanding further.
  - More than 150 members

Liverpool (2025~) **INFN (2025~)**



Collaboration meeting in December 2025@Kyushu U.

Collaboration meeting in June 2026@J-PARC

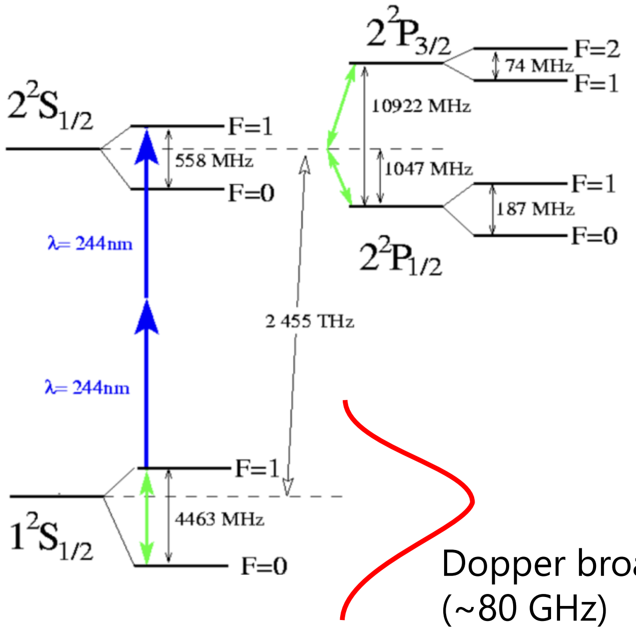
Summary

- In the J-PARC E34 experiment, measurements of muon g-2 and EDM is planned with a method different from BNL/FNAL experiments.
- Preparation and tests of experimental apparatus are ongoing in each sub-system.
  - Acceleration of thermal muon beam up to 100 keV was demonstrated in last year at J-PARC MLF and further commissioning are ongoing.
- Studies have been started to realize high sensitivity option.

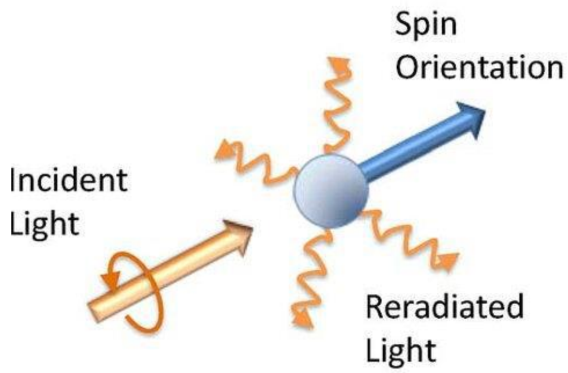
Backup

Muonium Polarization

- Polarization of muon is reduced to 50% when forming muonium.
- Selective excitation is impossible because;
  - 4 GHz hyperfine structure of muonium
  - huge Dopper broadening (~80 GHz)
- Shooting pulse train of circuital polarized VUV light to polarize muon inside muonium increase muon polarization.
  - A special version of well-known “optical pumping” of atomic system. ~ optical pumping of nuclear spin.
  - By absorbing circularly polarized photon, the angular momentum of photon is transferred to the nuclear (=muon) spin of an atom.



Dopper broadening (~80 GHz)



(a)