Visit of Tsutomu Mibe to Liverpool

G. Venanzoni – 7/10/24

- From 2/10 (arrival) to 5/10 (departure)
- Seminar on 3/10 “Acceleration of Positive Muon and PrecisionMeasurement of Muon Dipole Moments at J-PARC”
- Discussion on 4/10 on possible collaboration/common activities

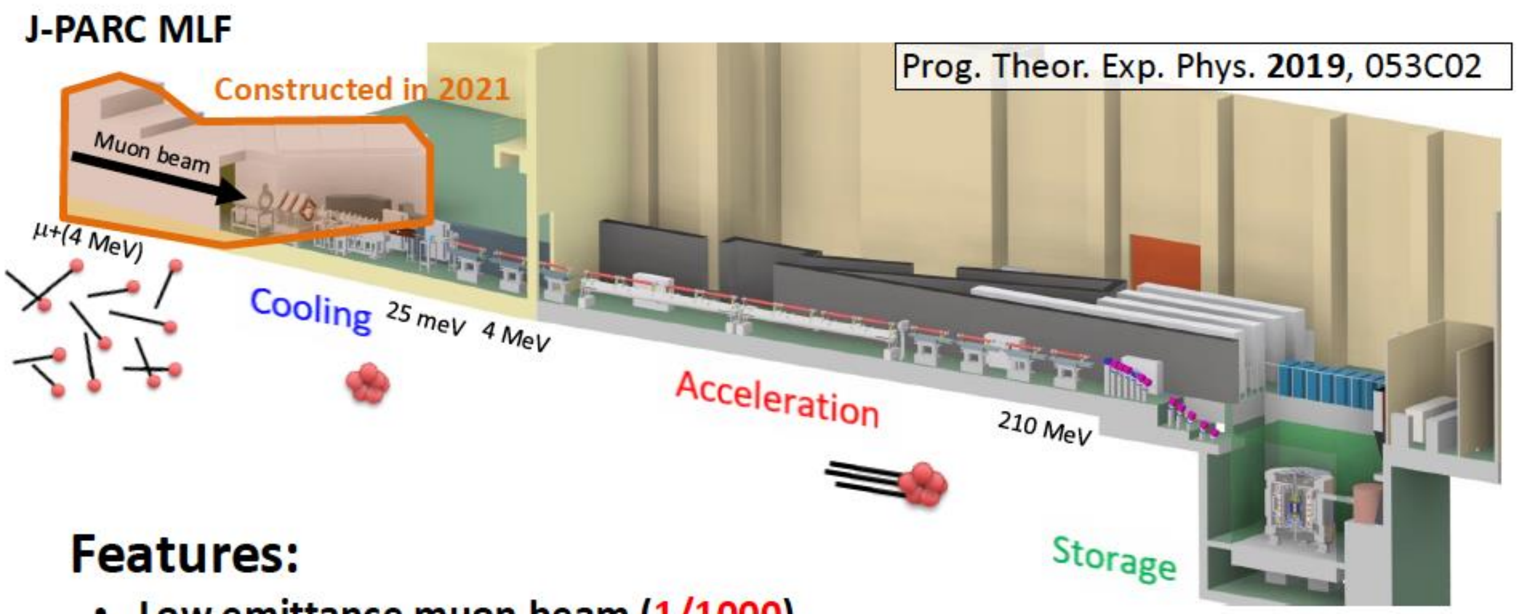
Acceleration of Positive Muon and Precision Measurement of Muon Dipole Moments at J-PARC

3

October ~~2~~, 2024

Tsutomu Mibe (KEK)

J-PARC muon *g*-2/EDM experiment



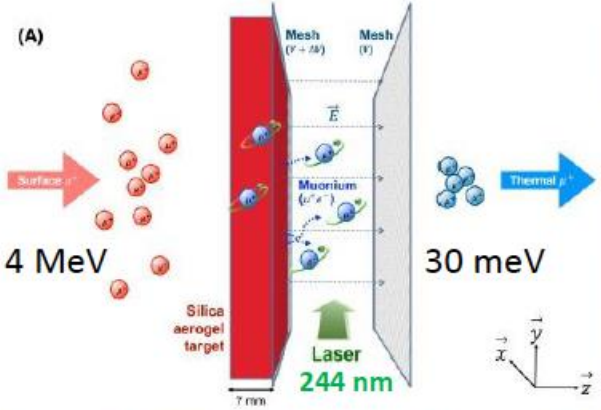
Features:

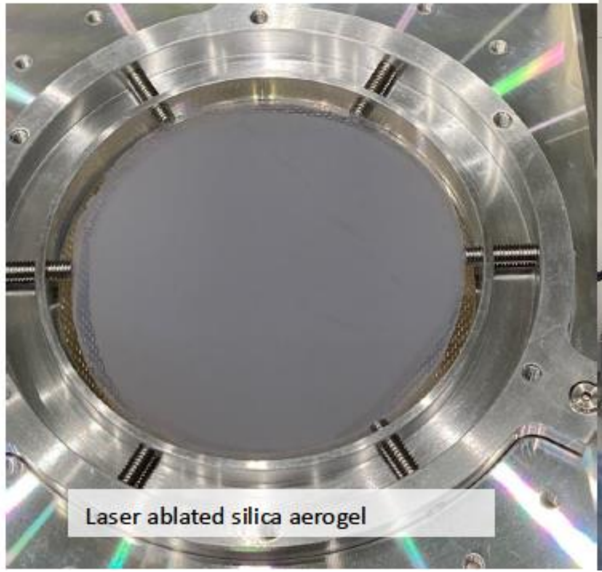
- **Low emittance muon beam (1/1000)**
- **No strong focusing (1/1000) & good injection eff. (x10)**
- **Compact storage ring (1/20)**

The only experiment to check FNAL/BNL *g*-2 results

Excellent sensitivity to muon EDM about 100 times better than the previous limit (sensitivity : 1.5 E-21 ecm)

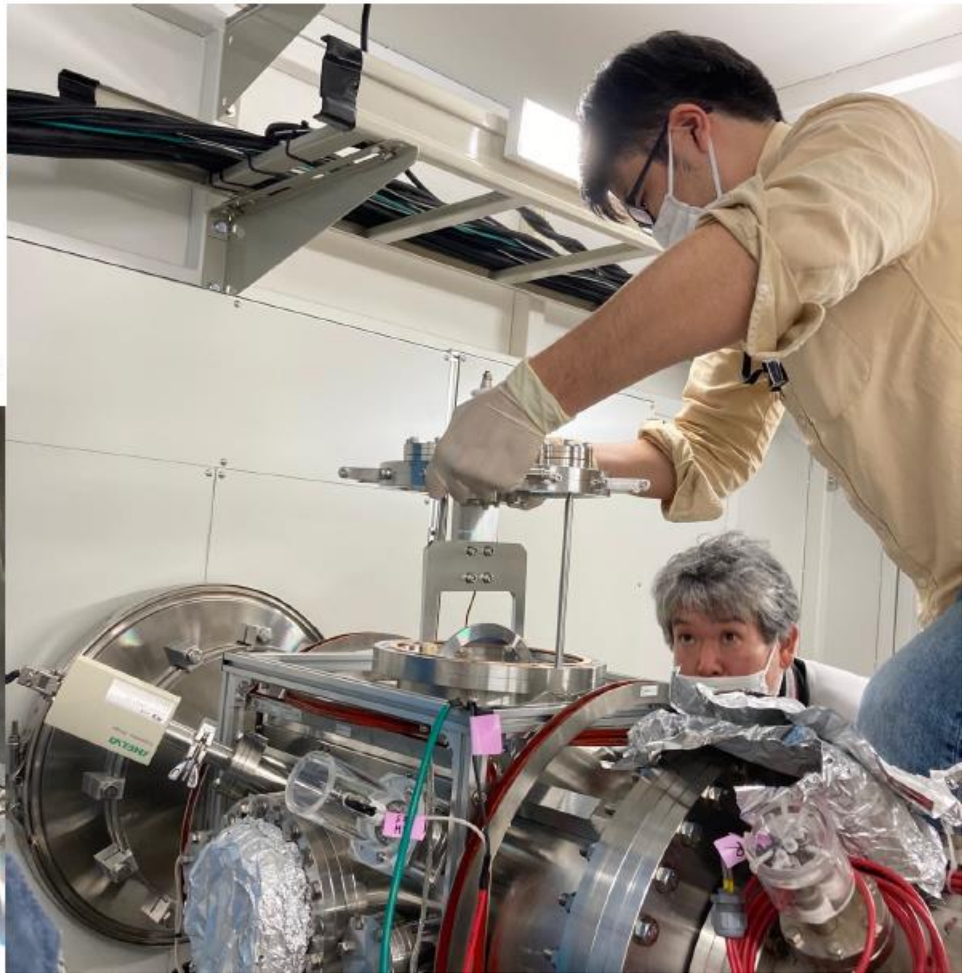
Muon cooling demonstration



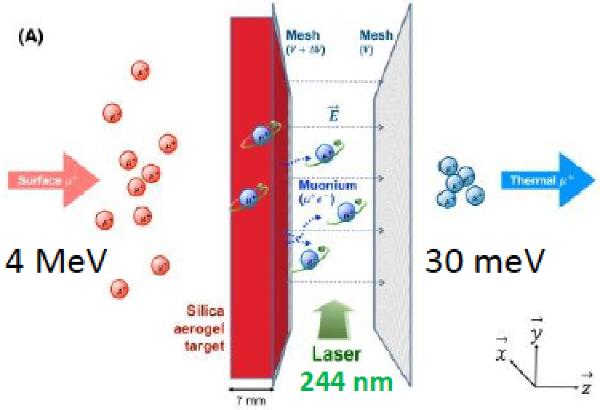


Laser ablated silica aerogel

J-PARC S2 area



Muon cooling demonstration



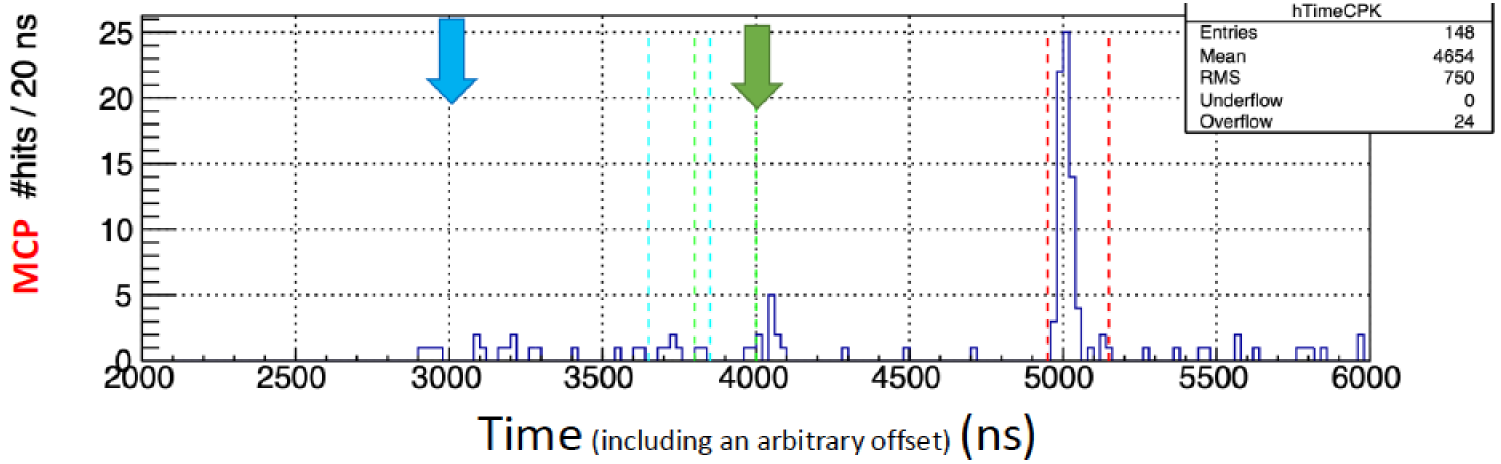
Electrostatic acceleration (10 kV) → Electric bend (energy filter) → Magnetic bend (momentum filter) → MCP

Surface muon arrival

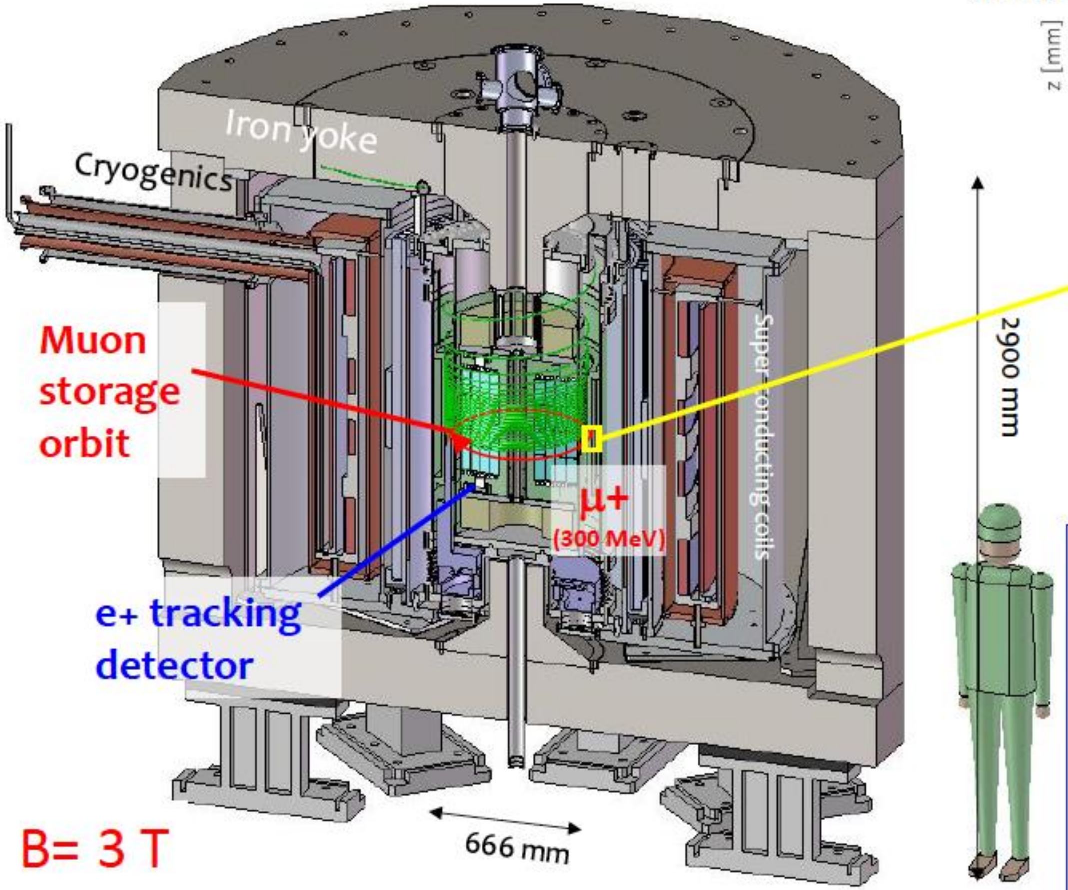
Laser injection time

Signal of Cold muon

4 x 10^{-3} / pulse

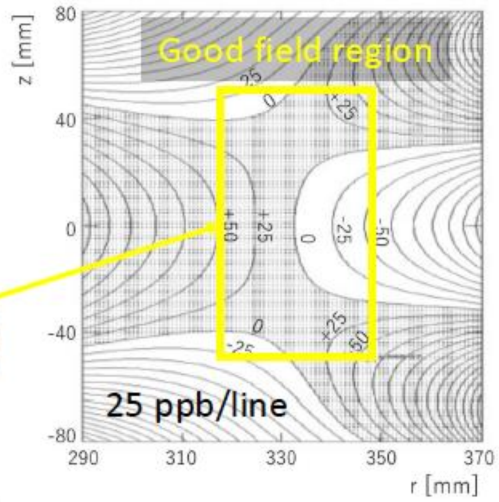


Muon storage magnet and detector

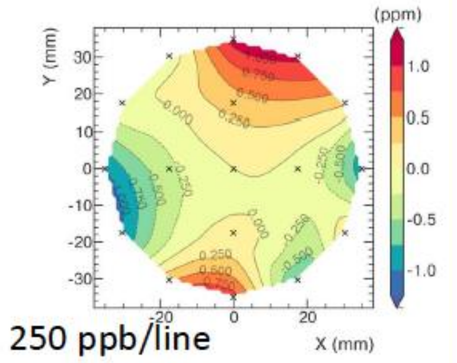


M. Abe et. al., NIM A 890, 51 (2018)

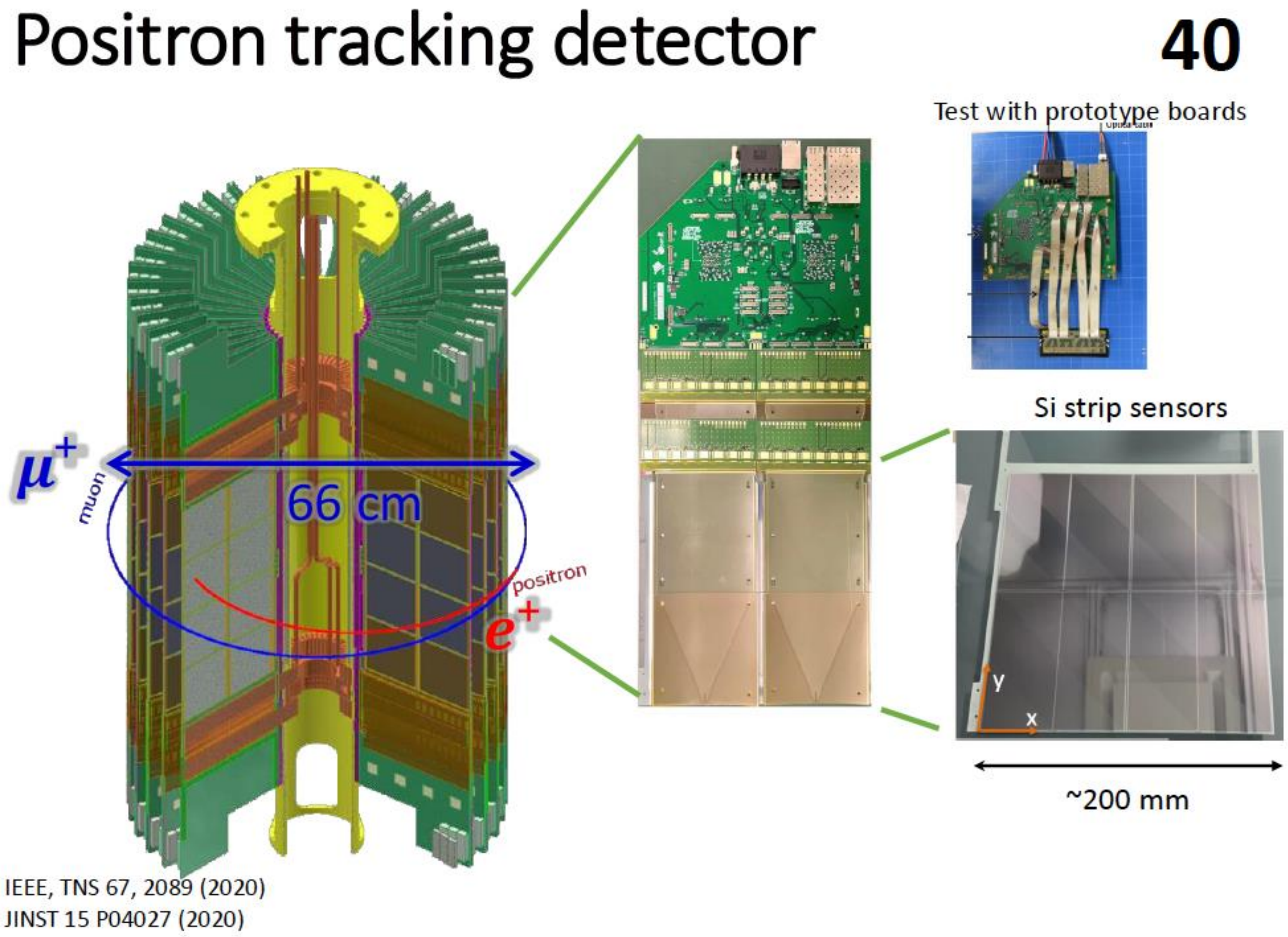
Calculated average field uniformity



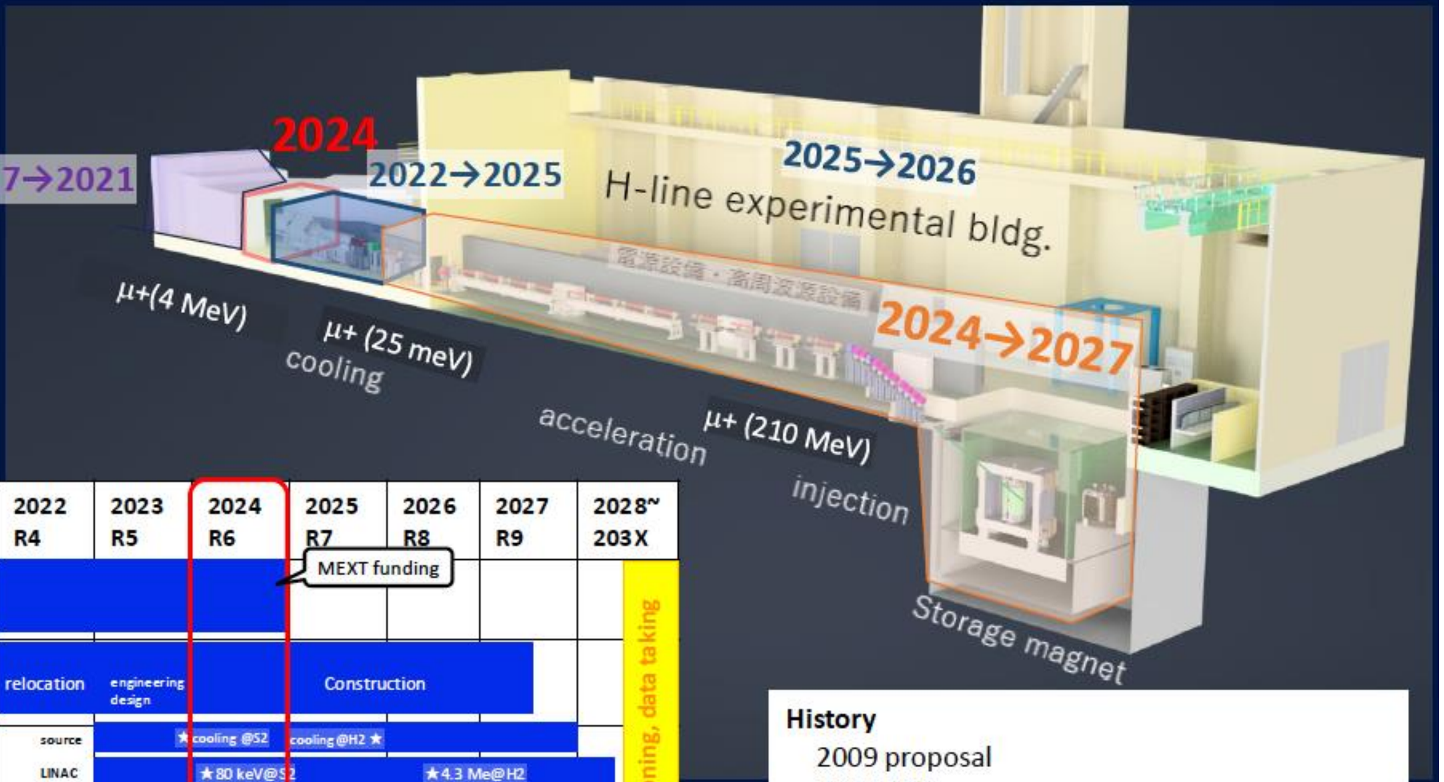
FNAL Run 1 PRA 103, 042208 (2021)



Possible common activity and interest



Intended schedule



	2022 R4	2023 R5	2024 R6	2025 R7	2026 R8	2027 R9	2028~ 203X
Beamline			MEXT funding				Commissioning, data taking
Bldg. & facility	relocation	engineering design		Construction			
Source, LINAC, storage — source			★cooling @S2	cooling@H2 ★			
LINAC			★80 keV@S2		★4.3 Me@H2		
Storage			procurement			Installation ★	
Detector	positron tracker magnetic field monitors						

History

- 2009 proposal
- 2015 TDR
- 2016 IPNS focused review
- 2016 SAC (priority #3)
- 2019 KEK-IPNS stage-2, KEK-IMSS stage-2
- 2024 MEXT funding (construction)

Comparison of g-2 experiments

Prog. Theor. Exp. Phys. **2019**, 053C02 (2019)

	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	<70 ppb
EDM precision (stat.)	$0.2\times10^{-19}\ e\cdot$cm	–	$1.5\times10^{-21}\ e\cdot$cm
(syst.)	$0.9\times10^{-19}\ e\cdot$cm	–	$0.36\times10^{-21}\ e\cdot$cm
	Completed	Running	In preparation

Expected uncertainties

	Estimation
Total number of muons in the storage magnet	5.2×10^{12}
Total number of positrons	0.57×10^{12}
Effective analyzing power	0.42
Statistical uncertainty on ω_a [ppb]	450
Statistical uncertainty on ω_p [ppb]	100
Uuncertainties on a_μ [ppb]	460 (stat.) < 70 (syst.)
Uncertainties on EDM [10^{-21} $e\cdot$cm]	1.4 (stat.) 0.36 (syst.)

Prog. Theor. Exp. Phys. **2019**, 053C02 (2019)

Topics for discussion

T. Mibe, Oct. 4, 2024 @Liverpool

- **muon g-2**
  - J-PARC muon g-2/EDM
    - silicon strip tracker (mechanical design of structure, assembly)
    - timing layer
    - timing calibration
    - options for higher energy (300 MeV/c → 600 MeV/c?), higher polarization (>50%?)
  - MUonE
    - precision alignment monitor, silicon strip tracker
- **muon EDM@PSI & J-PARC**
  - Injection
  - detector alignment
  - track reconstruction
- **Misc.**
  - KEK/J-PARC summer student program for undergraduate students
  - MPP2024, Shinji Ogawa (KEK, the leader of detector mechanics and assembly) will come to Liverpool in November.

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

$$\omega_a = a\frac{qB}{m}$$

If p (=300 MeV) → 2 p (=600 MeV):

- B → 2 B → ωa → 2 ωa
- γ → 1.9 γ

→ A factor 3.8 statistical gain:
450 ppb → **119 ppb** (=450/3.8)

If Polarization (50%) → 2 P (=100%):

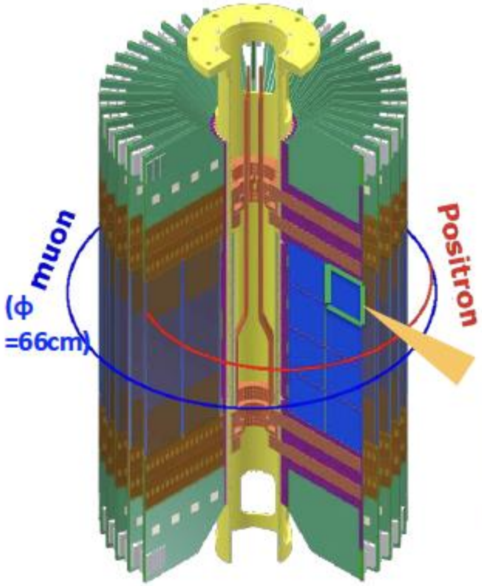
- additional factor 2:
- 119 ppb –> **60 ppb** (=230/2)

- TOT: possible factor 7.6 stat gain

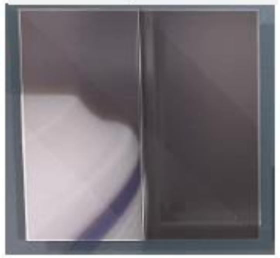
Positron detector

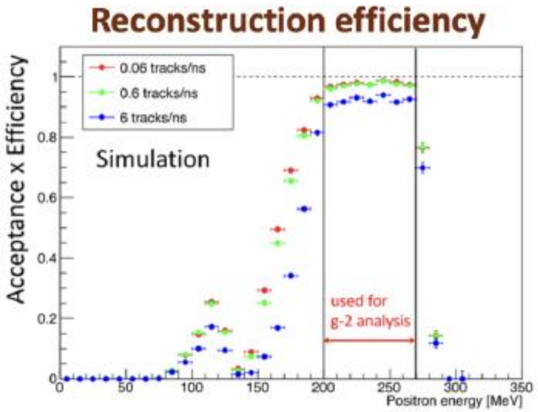
- Silicon detector for momentum measurement of decay positrons.
  - High hit rate capability (6 tracks/ns) and stability over rate changes (1.4 MHz❼10 kHz)
  - Silicon strip sensor: Hamamatsu S13804, 190um pitch.
  - High efficiency for positron in the analysis window (p=200-270 MeV/c).

Dr. Shinji Ogawa (KEK)



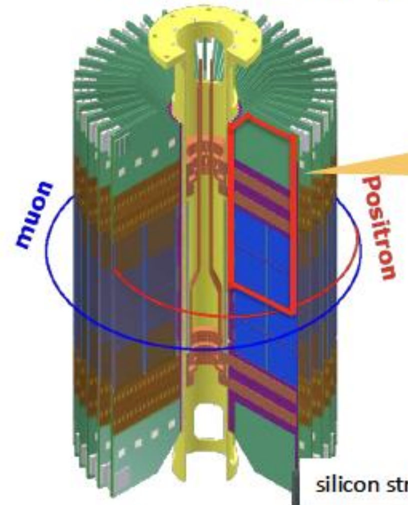
HPK S13804
- silicon strip detector
- size: 100 x 100mm^2, 190um strip



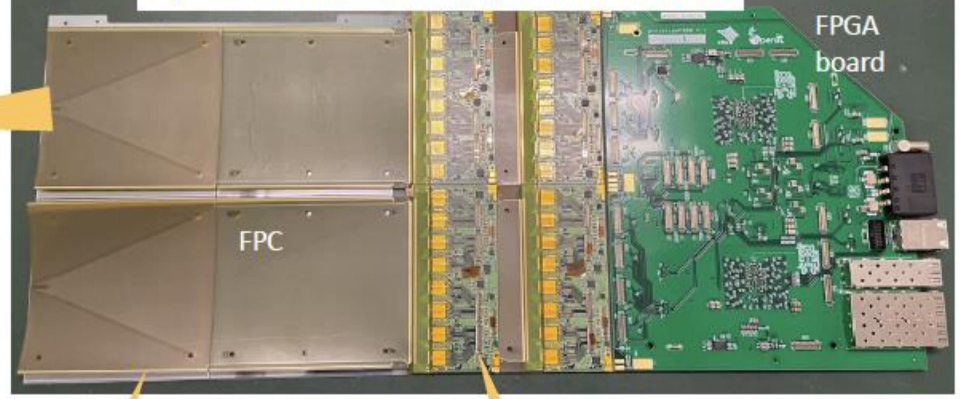


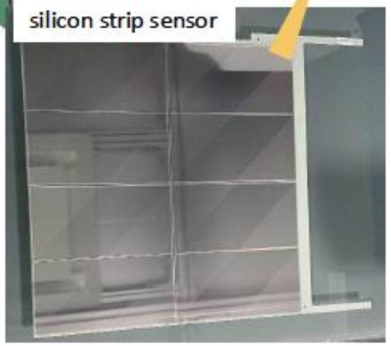
Positron detector

- Major components are in or completed the mass-productions.
- Assembly procedure is under R&D.
- A quarter-vane prototype is under readout electronics test.

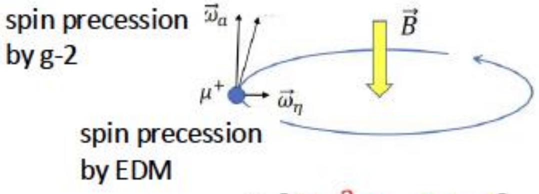


Quarter-vane: submodule of detector





Sensor alignment for EDM measurement



- Precise alignment between detector and B-field is essential for muon EDM measurement.
  - If rotated each other, "g-2 component" of spin precession comes into "EDM component".

$$\vec{\omega}_a + \vec{\omega}_\eta = -\frac{\mathrm{e}}{\mathrm{m}}\left[\frac{g-2}{2}\vec{B} + \frac{\eta}{2}\vec{\beta}\times\vec{B}\right]$$

g-2 EDM

- Goal of sensor alignment is 10 urad precision.
  -> Sensor position/rotation/deformation should be monitored during DAQ.
  - This will be achieved by a combination of several methods.

Track-based alignment

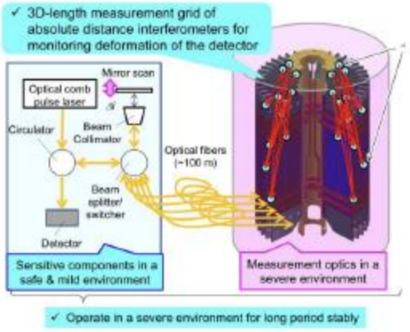
- Sensor position reconstructed by minimization of positron track fitting in physic data.

Minimize χ^2 in the positron track fitting.

$$\chi^2 = \sum_{track}\sum_{point}\frac{(x_{meas} - x_{fit})^2}{\sigma^2}$$

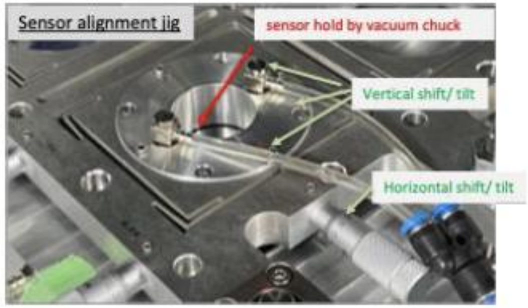
Laser-based alignment monitor

- Interferometer with optical comb laser.
- Monitor distance between fixed points.



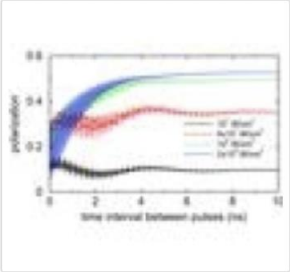
Precise detector assembly

- Sensor position measurement by CMM & laser tracker.
- Position alignment by dedicated jig.



Polarization scheme

Optics Express Vol. 18, Issue 26, pp. 27468-27480 (2010) • https://doi.org/10.1364/OE.18.027468



A scheme to polarize nuclear-spin of atoms by a sequence of short laser pulses: application to the muonium

Takashi Nakajima

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Abstract

We theoretically show that a sequence of short laser pulses can efficiently polarize nuclear-spin of atoms/ions. This is a variant of optical pumping with an important difference that a sequence of short laser pulses is used instead of a continuous-wave laser. Such a replacement is particularly useful if the pumping wavelength is in the ultraviolet or vacuum-ultraviolet region where obtaining a continuous-wave light source with a sufficient intensity is very difficult. Because of the use of short laser pulses neither hyperfine transitions nor fine structure transitions are spectrally resolved, which is quite in contrast to the standard optical pumping scheme by a continuous-wave laser. As an example we apply the scheme to polarize the muonium (μ^+e^-, lifetime 2.2 μs), for which the pumping wavelength is 122 nm. From numerical solutions of a set of density matrix equations, we find that the use of only a single, two, and five pulses with a ps duration at the peak intensity of 2×10^8 W/cm^2 and a 5 ns time interval results in the degrees of spin-polarization of 33, 50, and 80 %, respectively, within the time scale of a few tens of ns.

(Personal) comments:

- Visit of Mibe very useful
- Room for collaboration (detector/polarization/…)
- Room for improvement of the proposal (300 MeV → 600 MeV)
- Possible collaboration of Mibe's group with MUonE /EDM@PSI/…(although not formally easy as KEK requires employees to work on laboratory activities)

→ Certainly more iterations/discussions needed (and expected!)

MPP2024 Workshop 12-14 November 2024

- Agenda mostly finalized
- Few spekers missing or TBC