Muon g-2/EDM Measurement at J-PARC

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on behalf of the J-PARC E34 Collaboration

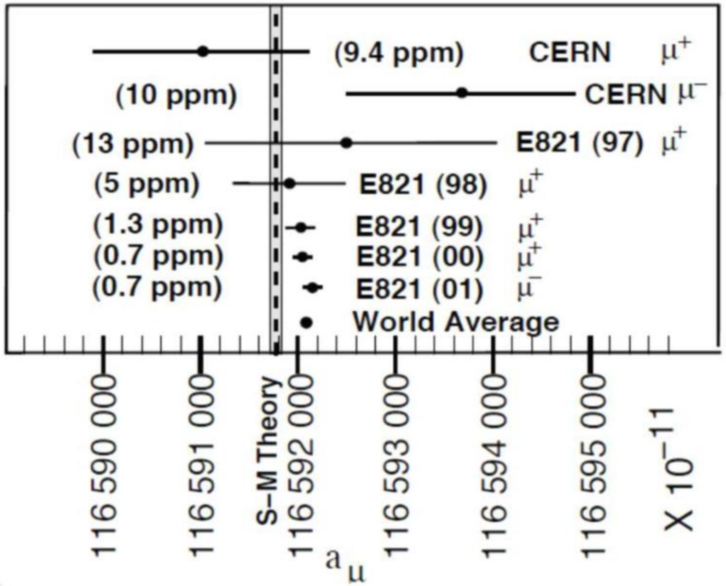
10th International Workshop on Fundamental Physics Using Atoms
January 8, 2018

Muon g-2 and EDM

- Anomalous magnetic moment

  $$a_\mu = \frac{g-2}{2}$$

  - Calculated at the order of 0.4 ppm precision in the SM for muon
  - The best experimental uncertainty is 0.54 ppm by BNL E821.
  - There is ~3 σ deviation between the theory and the experiment.



  - New physics (e.g. SUSY) can explain this discrepancy.

- Electric dipole moment (EDM)
  - If non-zero EDM exists, it indicates CP violation.
  - Current experimental limit is at $<10^{-19}$ e・cm by BNL E821.
  - The SM expectation of muon EDM is ~2×10^{-38} e・cm.
  - New physics (e.g. SUSY) predict much larger EDM.

Muon Spin Precession Vector

- The g-2 and EDM are obtained by measuring spin precession vector

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

- In the previous experiments by CERN and BNL and ongoing experiment by FNAL → magic momentum: p=3.094 GeV/c

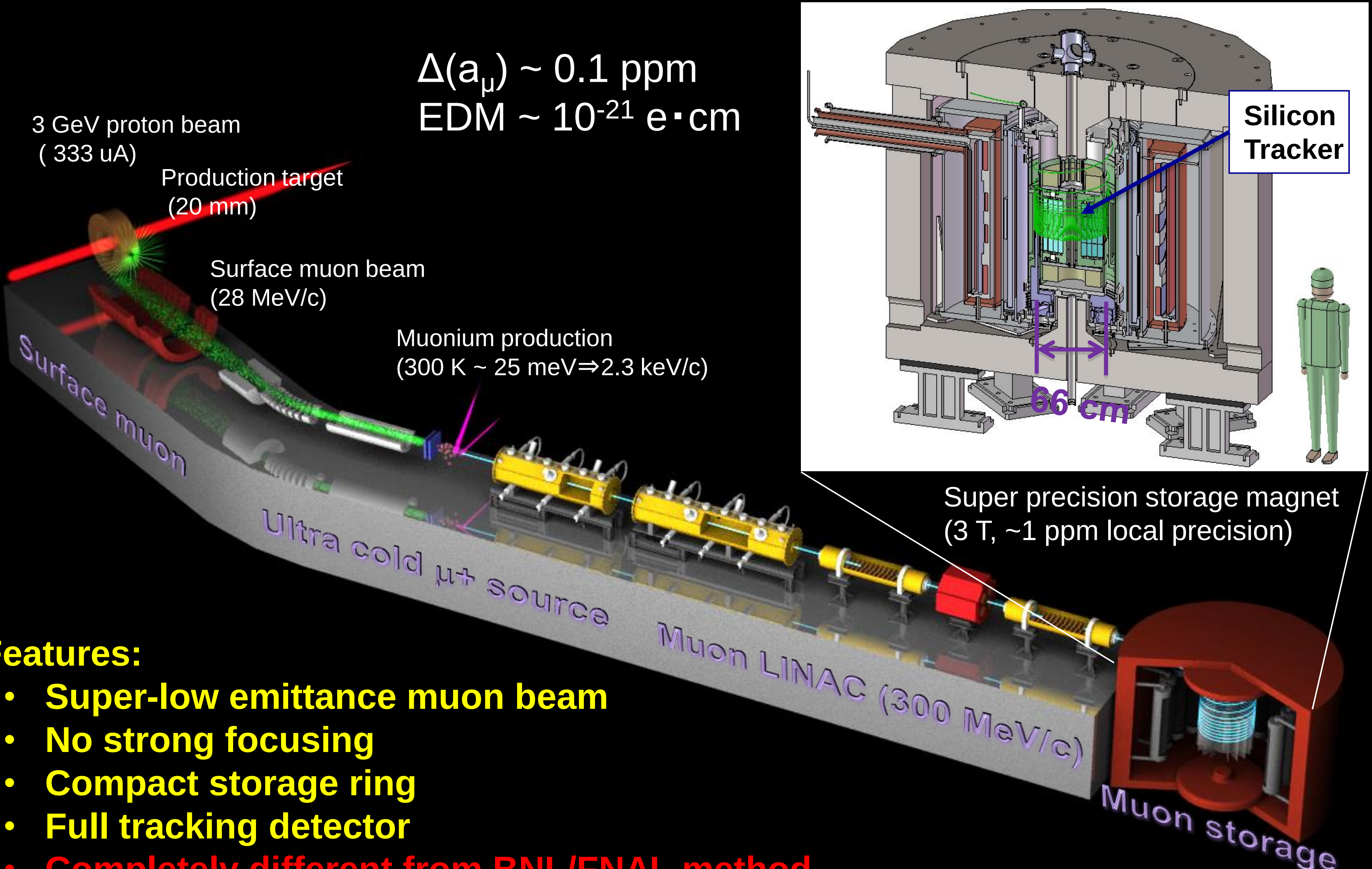
$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

- In J-PARC E34 experiment → E=0

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

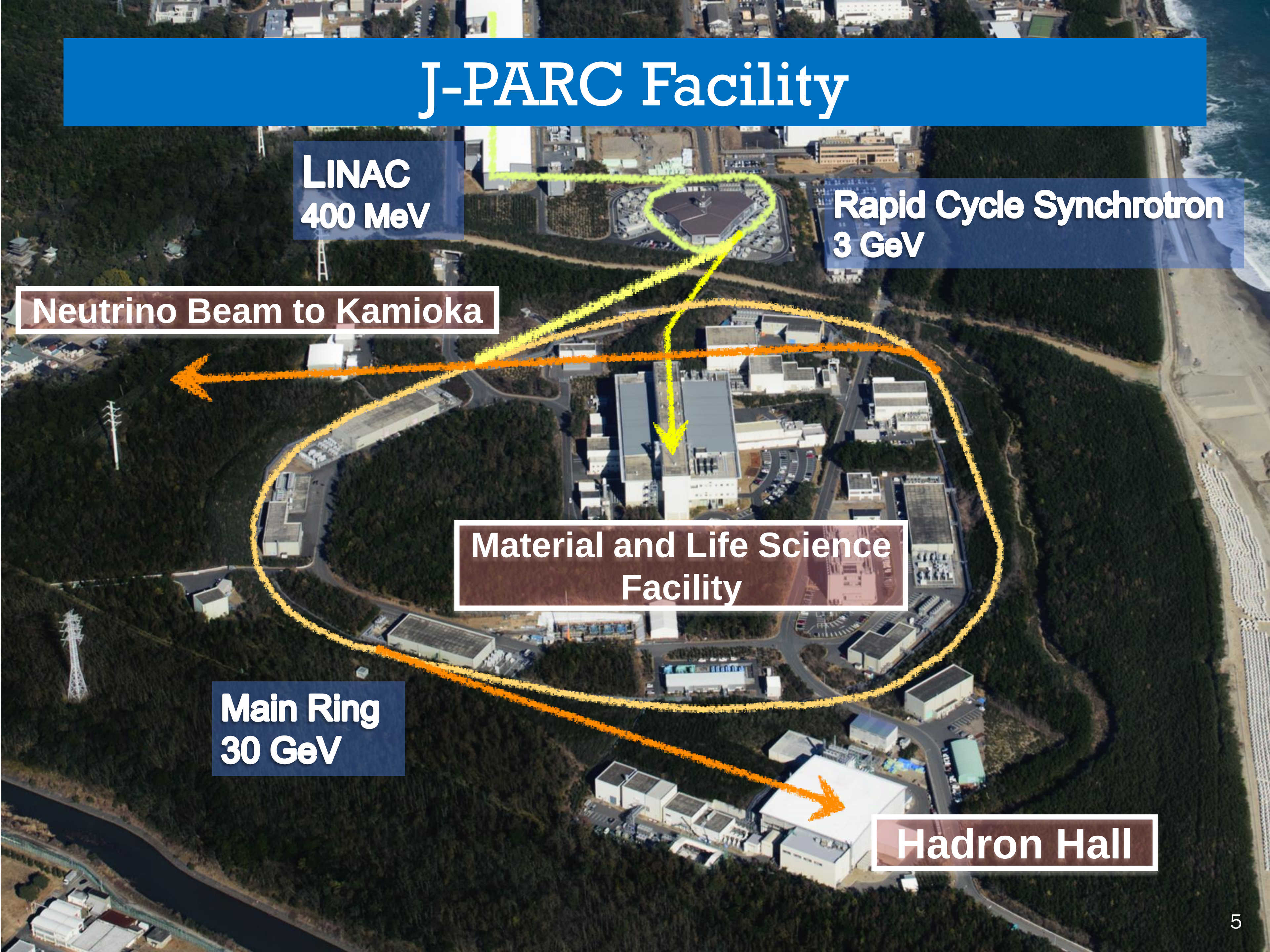
J-PARC Experiment Overview

$\Delta(a_\mu) \sim 0.1$ ppm
EDM $\sim 10^{-21}$ e·cm



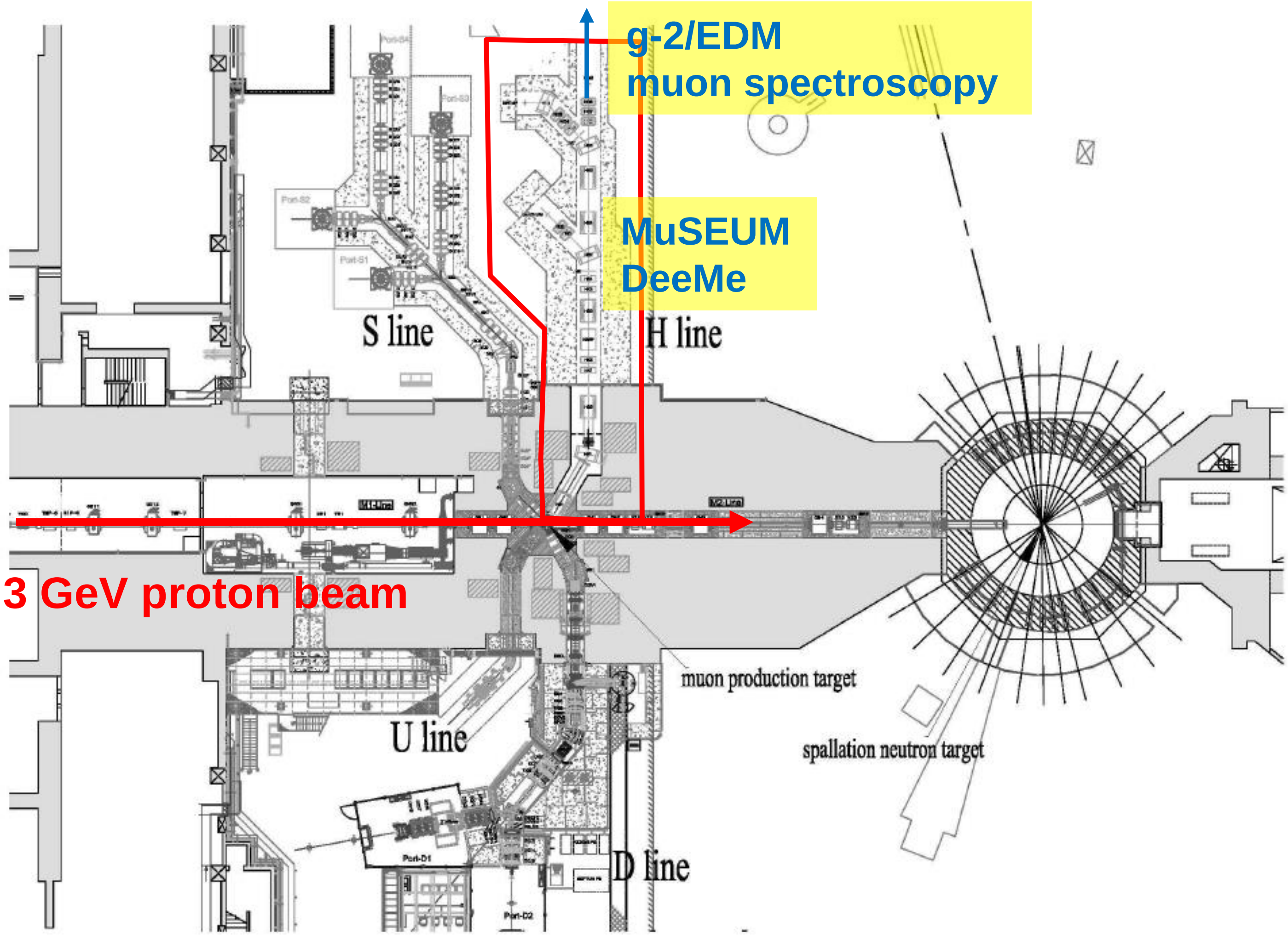
Features:
- **Super-low emittance muon beam**
- **No strong focusing**
- **Compact storage ring**
- **Full tracking detector**
- **Completely different from BNL/FNAL method**

J-PARC Facility



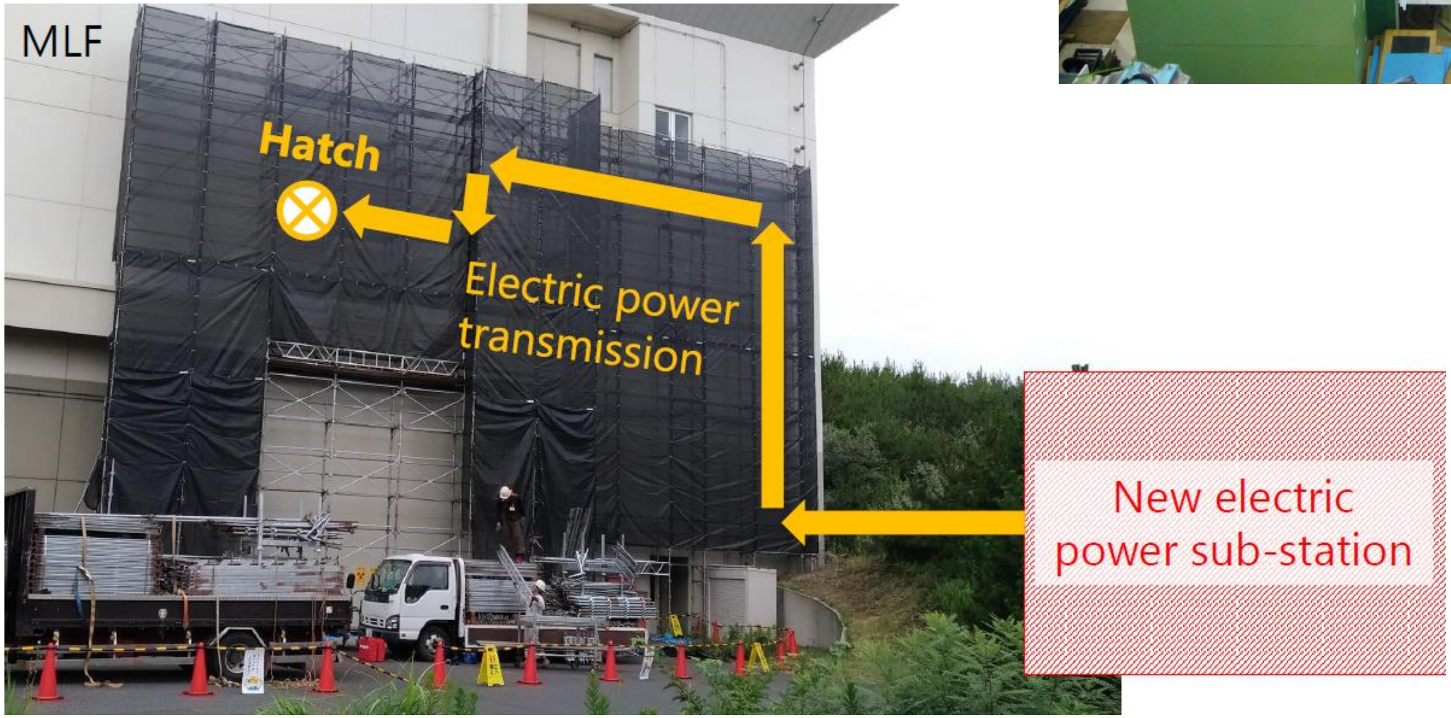
H-line

- For high intensity beam and long beam time, a dedicated beam line will be constructed.

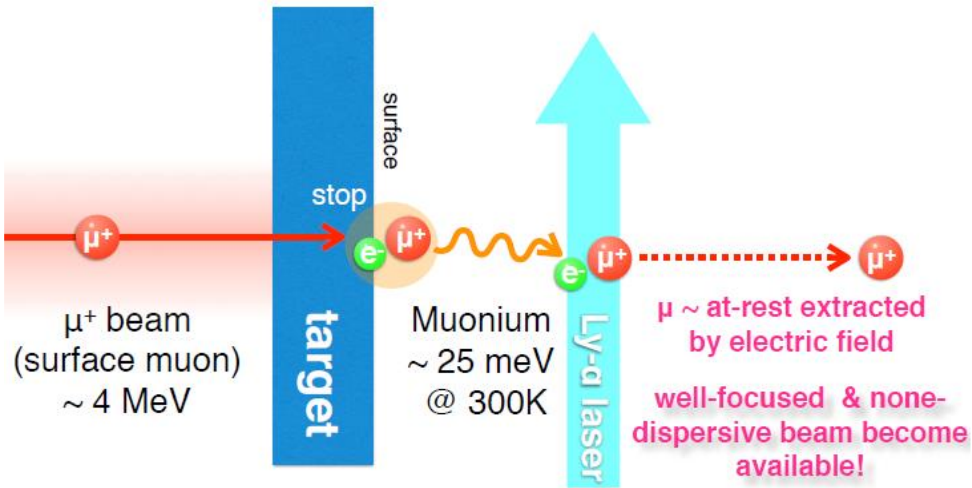


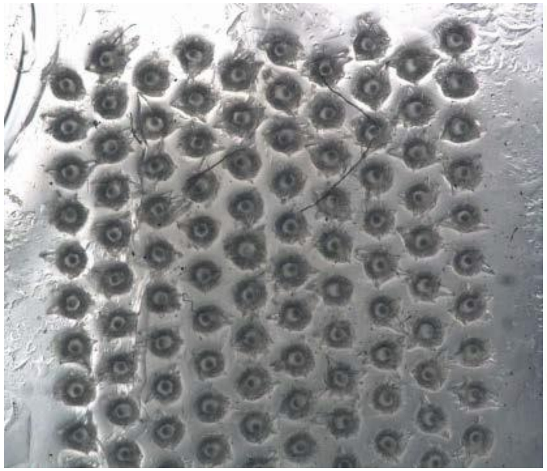
H-line Construction Status

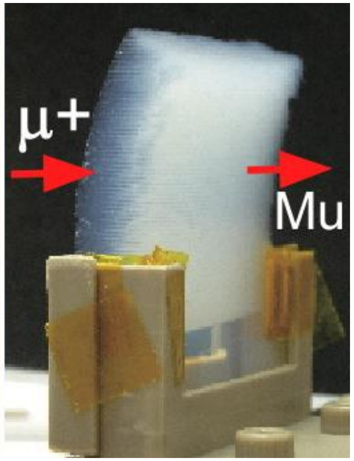
- Frontend devices and radiation shield were already installed by JFY2016.
- Construction of the new power sub-station for H-line has been started.
  - Bedding of the station and renovation of MLF wall were done.



Muon Source





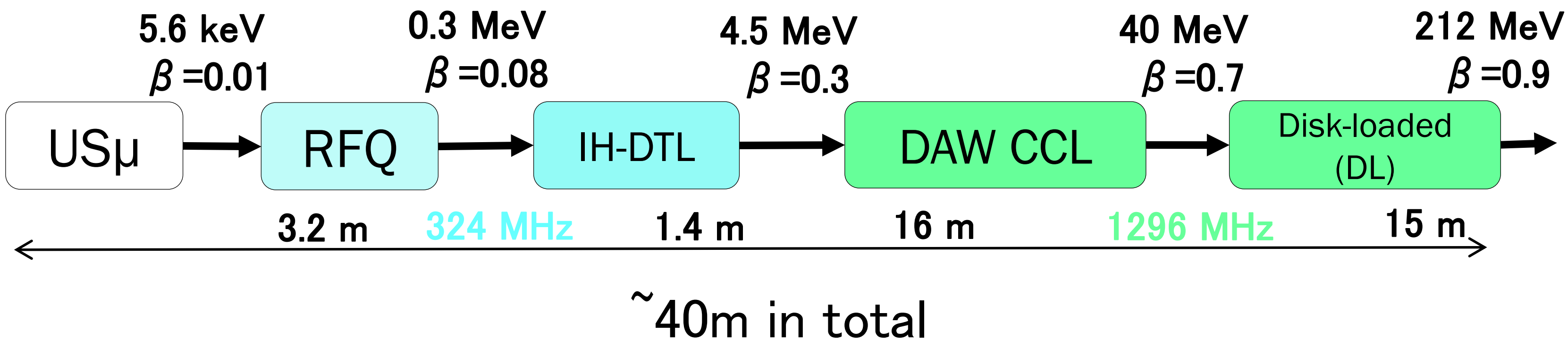


Mon source: laser ablated silica aerogel

- Muonium yield was measured for various aerogel samples and long term stability was tested in beam test at TRIUMF in 2017.
- Laser system is constructed in U-line and achieved 10 μJ.
  - Development for >100 μJ is ongoing.

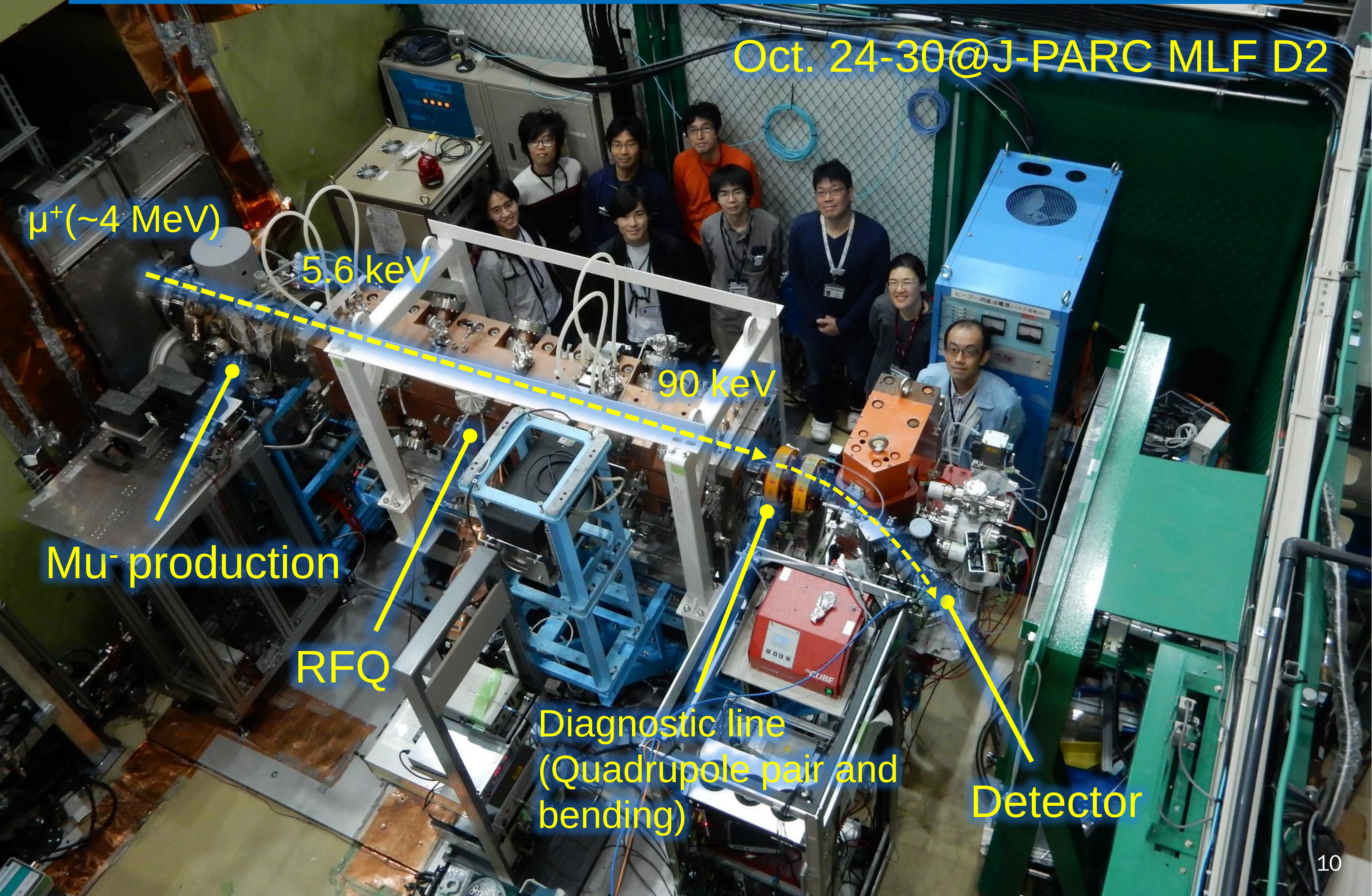
Laser system at U-line

Muon Acceleration



- Basic design for all structures was finished.
  - M. Otani et al., Phys. Rev. AB, 19, 040101, 2016.
  - Y. Kondo et al., J. Phys.: Conf. Ser. 874 012054 (2017) [link]
- Next goal was demonstration of muon acceleration.
  - Electro-static acceleration was already demonstrated.
  - Test of muon acceleration using RFQ has been performed.

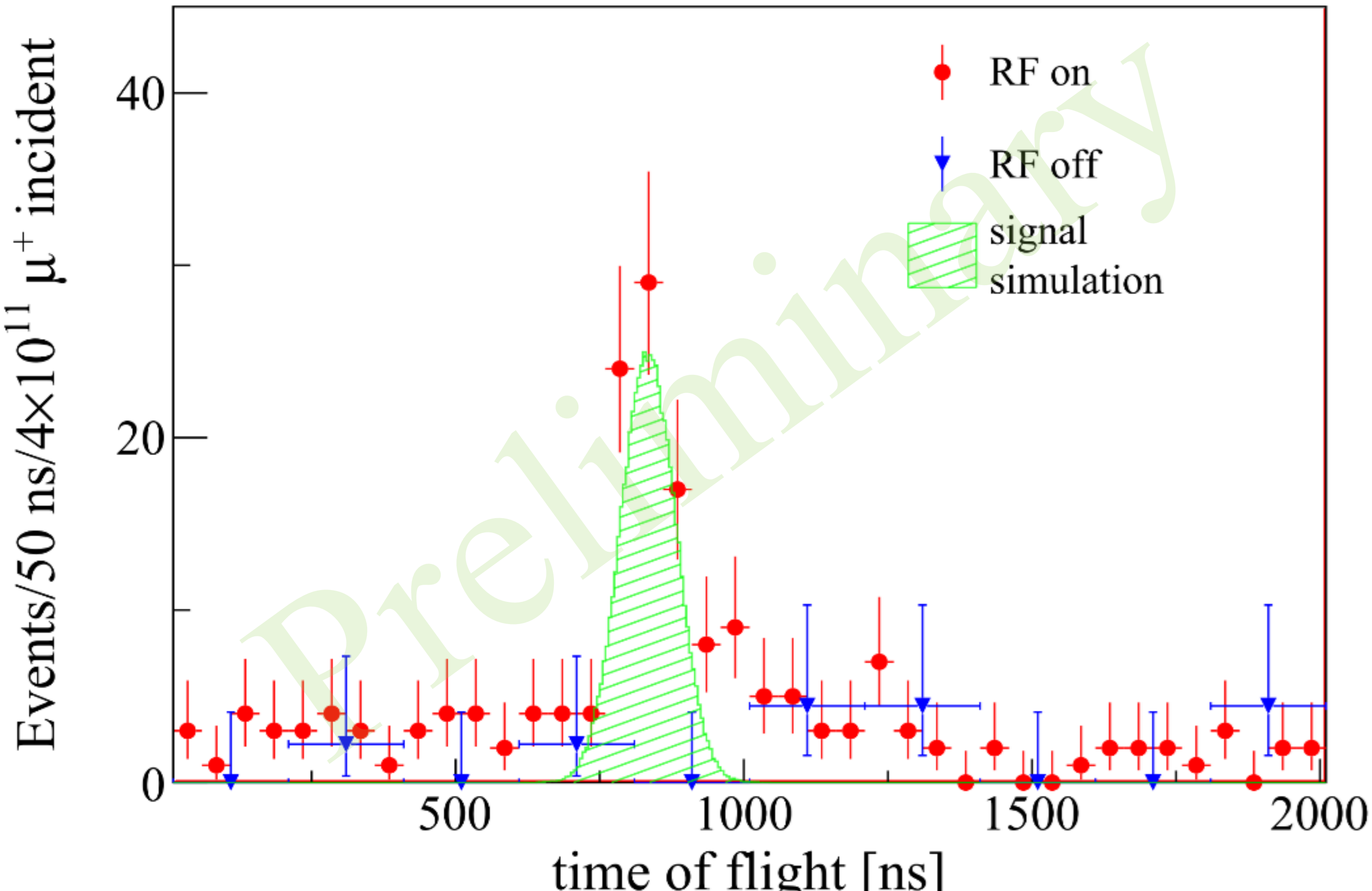
Muon Acceleration Beam Test



Acceleration Result

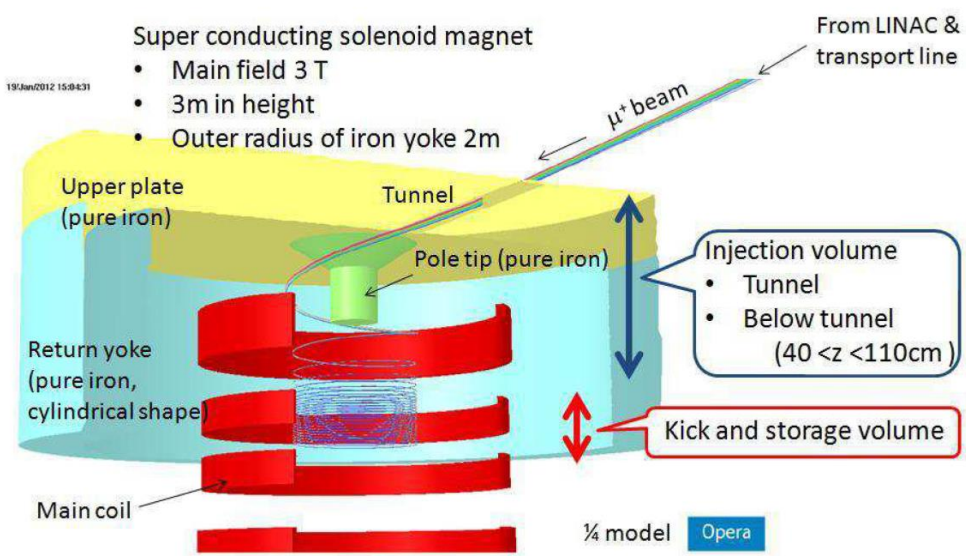
The first muon (Mu⁻) RF linear acceleration in the world!

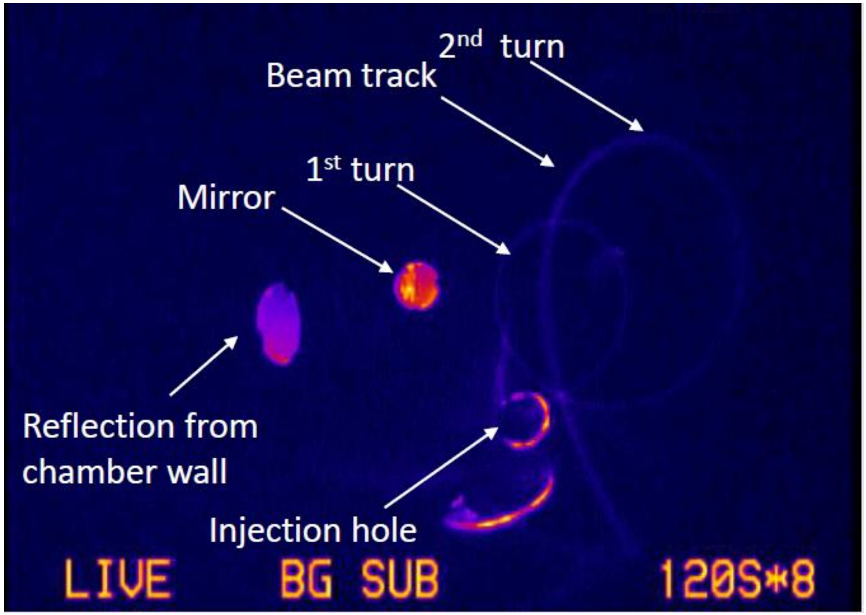
- Paper draft is in preparation.



Spiral Injection

- Accelerated muon beam is injected to storage region vertically using spiral injection.
  - H. Iinuma et.al., Nucl. Instrum. Meth. A 832 51-62 (2016)
  - High injection efficiency>80%
- Spiral injection is being tested using electron beam.

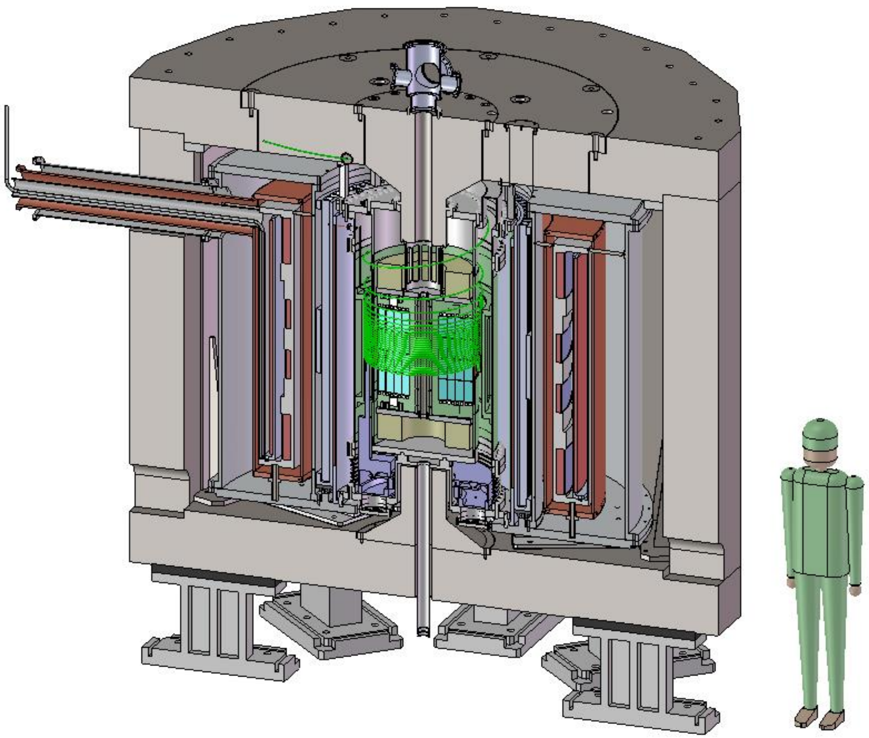




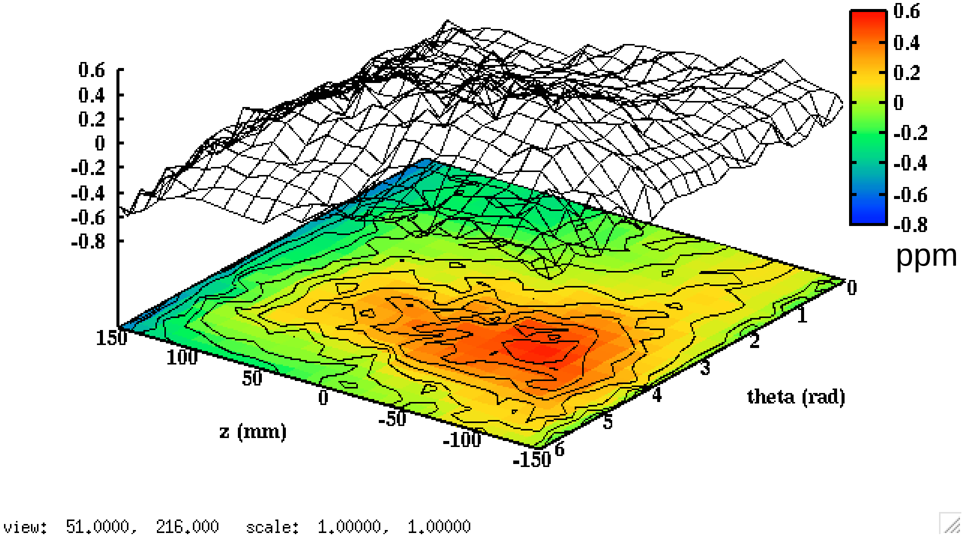
CCD image of electron beam trajectory

Storage Magnet

- 3 T MRI-type solenoid magnet will be used.
  - Weak focusing magnetic field is also applied to keep beam size.
  - Several designs are made and their performances are being evaluated in simulation.
- Field uniformity is achieved by shimming.
  - Local uniformity of 1 ppm is confirmed with the magnet used in MuSEUM experiment.
  - NMR probe will be used for field measured. The probe was cross-calibrated at ANL.

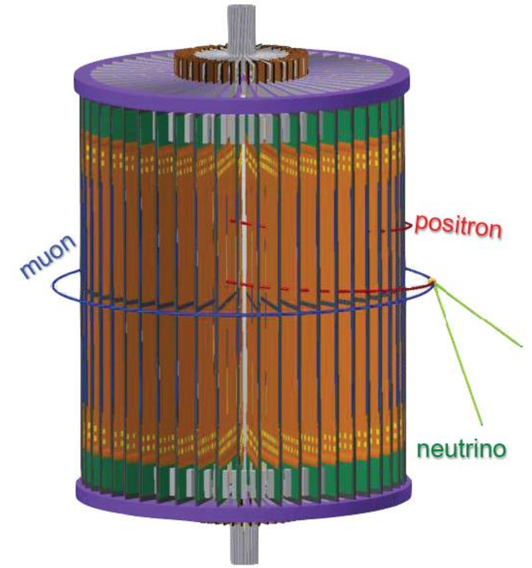


Magnetic field after shimming

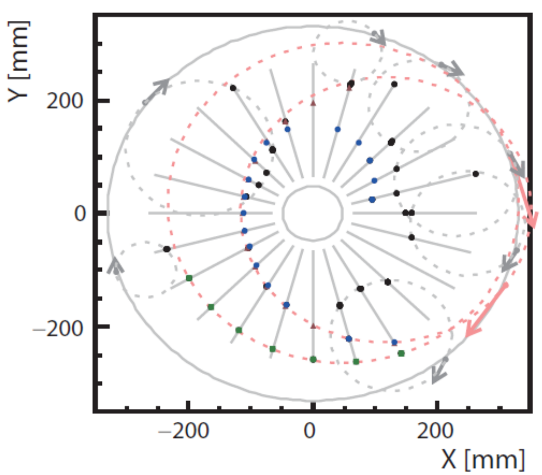


Positron Tracking Detector

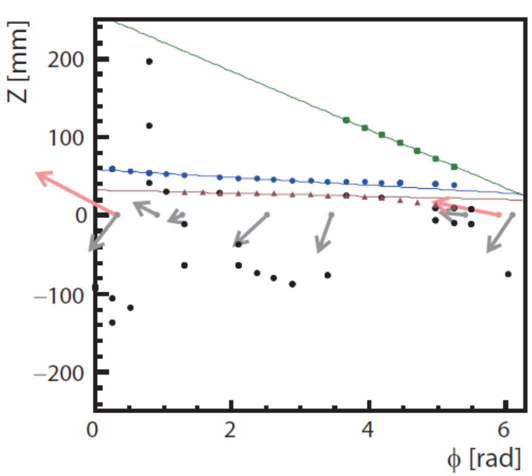
- Tracking detector consists of 48 vanes and each vane has 8+8 silicon strip sensors.
  - Detail of structure design is on-going as well as construction procedures.
- Track reconstruction algorithm is being developed.
  - With the current version of algorithm, more than 90% efficiency is expected even in the highest pileup condition.

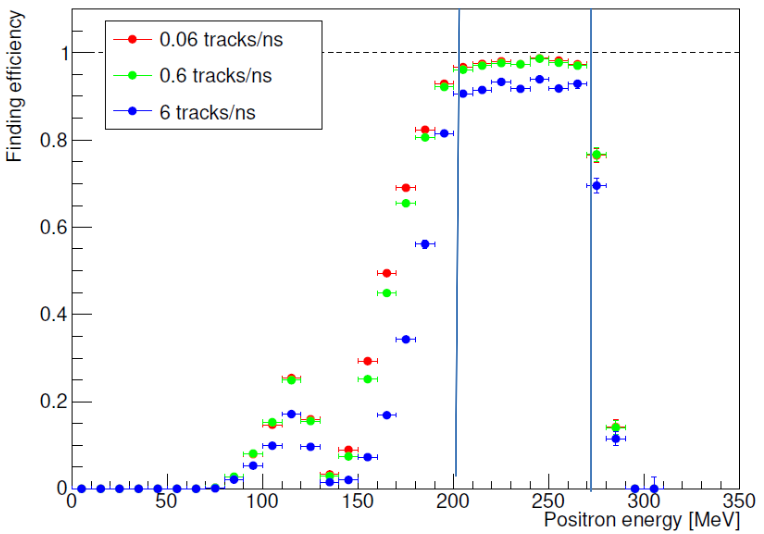


event display (x-y plane)



event display (ϕ-z plane)





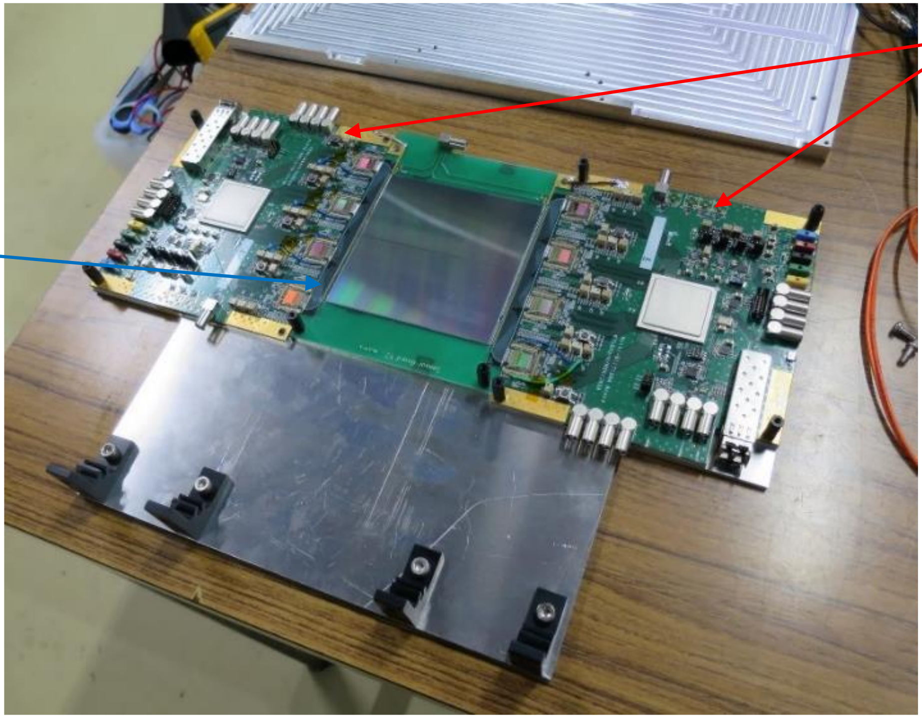
Simulated track finding efficiency

Detector Module

- The detector module consisting of one silicon strip sensor and prototype of readout ASIC was already put into MuSEUM experiment and recorded physics data.
  - The next version of detector module will be more close to the final version and will be put into the beam time of MuSEUM experiment in autumn of this year.

Silicon strip sensor
- Mass production has been started.

Specification
98.77 × 98.77 mm
190 μm pitch
512ch × 2 block



Readout boards
- Final prototype readout-ASIC is being fabricated.

Specification
4 MIP range
839 e^- ENC
128 ch/chip
8096 buffer
5 ns sampling

Measurement of a_μ

- a_μ is calculated from $$a_\mu = \frac{R}{\lambda - R}$$

$\lambda = \mu_\mu / \mu_p$ Muon/proton magnetic moment ratio
- will be measured in MuSEUM experiment in 0.01 ppm

$R = \omega_a / \omega_p$ Muon anomalous spin precession frequency/Larmor frequency of proton
- will be measured in this experiment

– Several error sources are not yet fully evaluated but they are expected to be constrained less than 0.1 ppm on a_μ.

Systematic uncertainties on ω_a

Source of errors	Error on ω_a [ppb]
Timing shift due to pileup	< 36
Pitch correction	13
E-field	10
High energy positron	TBD

Systematic uncertainties on ω_p

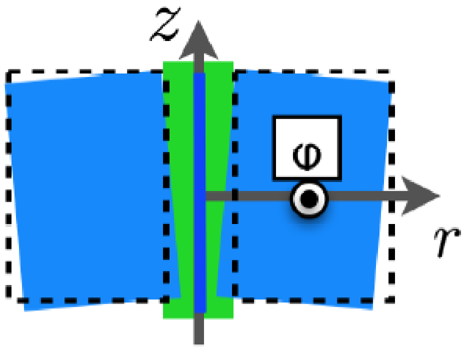
Source of errors	Estimation
Absolute calibration standard probe	25 ppb
Calibration of trolley probe	20 ppb
Total magnetic field $B_{tot} = B_{main} + B_{weak}$	45 ppb +TBD
Uncertainty from the muon distribution	TBD
Field decay	< 10 ppb
Eddy current from kicker	0.1 ppb
Others	—

Measurement of EDM

- EDM is obtained by fitting up-down asymmetry of the number of positrons.

$$A_{\mathrm{UD}} = \frac{N_{\mathrm{up}} - N_{\mathrm{down}}}{N_{\mathrm{up}} + N_{\mathrm{down}}} = \frac{A_{\mathrm{EDM}} \sin(\omega t + \phi)}{1 + A\cos(\omega t + \phi)}$$

- Dominant systematic uncertainty comes from detector misalignment.
  - Skew is the most demanding alignment and <10 μrad is required for EDM<10^{-21} e·cm.
  - Detector alignment will be performed with laser interferometer system and positron tracks.

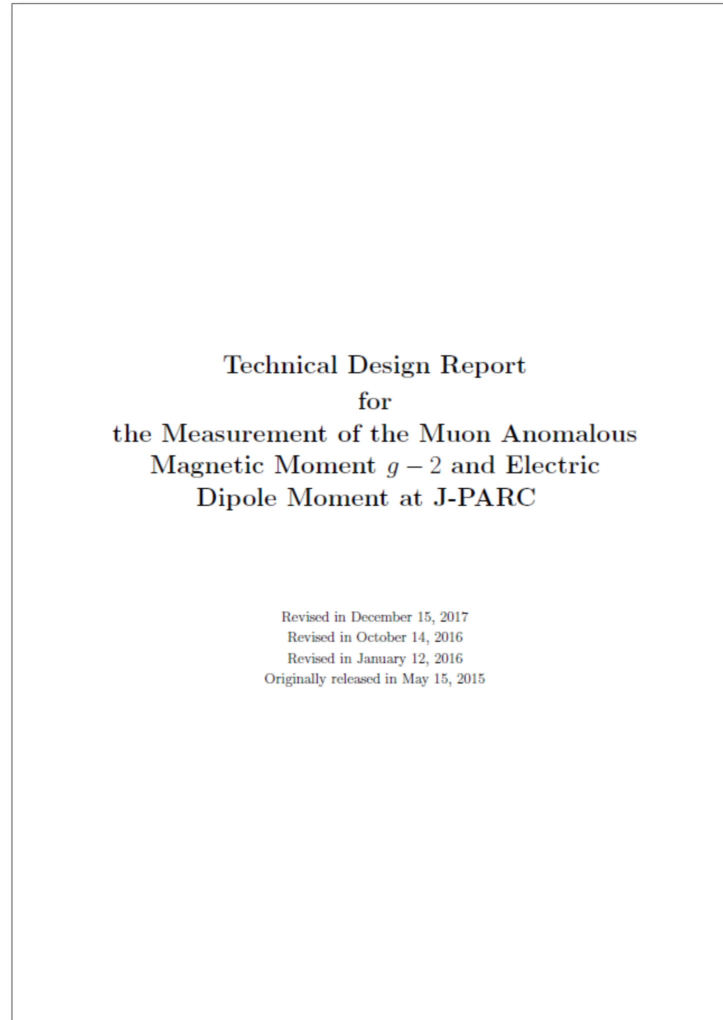


Systematic uncertainties on EDM

Uncertainty source	EDM 10^{-21} [e·cm]
Detector misalignment	0.36
Axial E field	0.001
Radial B field	0.00001
Total	0.36

Technical Design Report

- Revised version of technical design report has been submitted to review committee on December 15, 2017.
  - Updated to reply Focused Review Committee's recommendations
- J-PARC PAC meeting will be held on January 15-17, 2018 and E34 experiment will receive the review.



Technical Design Report
for
the Measurement of the Muon Anomalous Magnetic Moment $g - 2$ and Electric Dipole Moment at J-PARC

Revised in December 15, 2017
Revised in October 14, 2016
Revised in January 12, 2016
Originally released in May 15, 2015

E34 Collaboration

J-PARC muon g-2/EDM organization

20170823

- Authors has been increased from 144 to 158 in the last year.
- Group structure is organized.

Collaboration board (CB)
Chair: Seonho Choi
members: IG representitives

Executive board (EB)
Tsutomu Mibe (spokesperson)
Hiromi Iinuma
Ken'ichi Sasaki
Naritoshi Kawamura
Seonho Choi (ex-officio)
Naohito Saito (ex-officio)
Yasuhiro Miyake (ex-officio)

Subgroups

- **Surface muon beam** — leader: Takayuki Yamazaki, Naritoshi Kawamura
- **Ultra-slow muon** — leader: Katsu Ishida, Glen Marshall
- **LINAC** — leader: Yasuhiro Kondo, Masashi Otani
- **Injection and storage** — leader: Hiromi Iinuma
- **Storage magnet, field measurements** — leader: Ken'ichi Sasaki
- **Detector** — leader: Tamaki Yoshioka
- **DAQ and computing** — leader: Yutaro Sato, Soohyung Lee
- **Analysis** — leader: Takashi Yamanaka

Interface coordinators

- Katsu Ishida
- Masashi Otani
- Yasuhiro Kondo
- Hiromi Iinuma
- Tatsuya Kume
- Yutaro Sato
- Taikan Suehara
- Takashi Yamanaka

Working groups

- **WG : fast-track plan** — Leader: Tsutomu Mibe
- **WG : systematic uncertainties** — Leader: Tsutomu Mibe
  Yutaro Sato (omega_a)
  Hiromi Iinuma (Magnetic field)
  Tamaki Yoshioka (EDM)

Committees

- **Speakers committee** — chair: Katsuhiko Ishida
- **Publication committee** — chair: Glen Marshall

15th Collaboration Meeting@Kyushu University on Dec. 11-14, 2017

Summary

- In J-PARC E34 experiment, measurement of muon g-2 and EDM are planned with a different method from the previous experiments.
- Developments of each component of the experiment are ongoing and there are several achievements in the last year.
- To proceed to the next approval stage, the collaboration will receive the review soon.