Flavour changing and conserving processes (FCCP2019)
Anacapri, 29-31 Aug 2019

Status of the g-2 and EDM experiment at J-PARC

K. Ishida (RIKEN)

on behalf muon g-2/EDM (E34) collaboration at J-PARC

muon g-2 and EDM

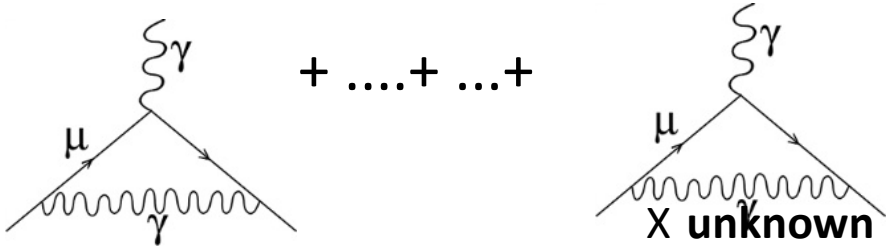
$\boldsymbol{\mu} = g_\mu (e/2m_\mu)\, \boldsymbol{s}$

$a_\mu = (g_\mu - 2)/2$: anomalous magnetic moment

Dirac equation predicts g=2.

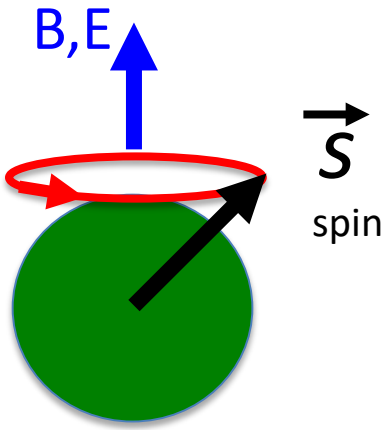
Radiative corrections deviates g from 2.

a = a(QED) + a(Hadronic) +a(Weak) + ...



Contributions from all particles/interactions, even undiscovered

=> 3.5 σ discrepancy (BNL E821 vs THEO) not solved



BNL E821

$\boldsymbol{d} = \eta\, (e/2mc)\, \boldsymbol{s}$

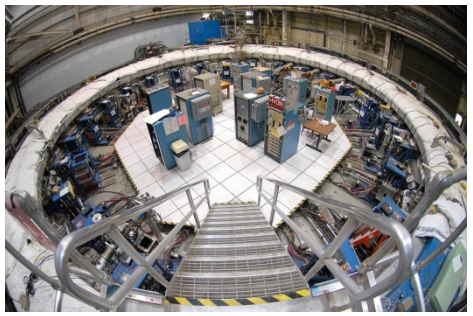
If EDM is nonzero -> T reversal is violated.

=> Indication of CP violation in the lepton sector.

=> Only upper limit is known so far

=> Measurements at FNAL and J-PARC

FNAL E989



What's new? Muon g-2/EDM@J-PARC

Independent measurement at J-PARC

Reaccelerated low-emittance muon beam and MRI-type storage ring

different scheme -> different systematic errors.

BNL/FNAL method

E≠ 0, magic γ (p=3 GeV) makes (...)=0

g-2 measurement EDM

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

Out-of plane oscillation is an indication of EDM.

J-PARC method

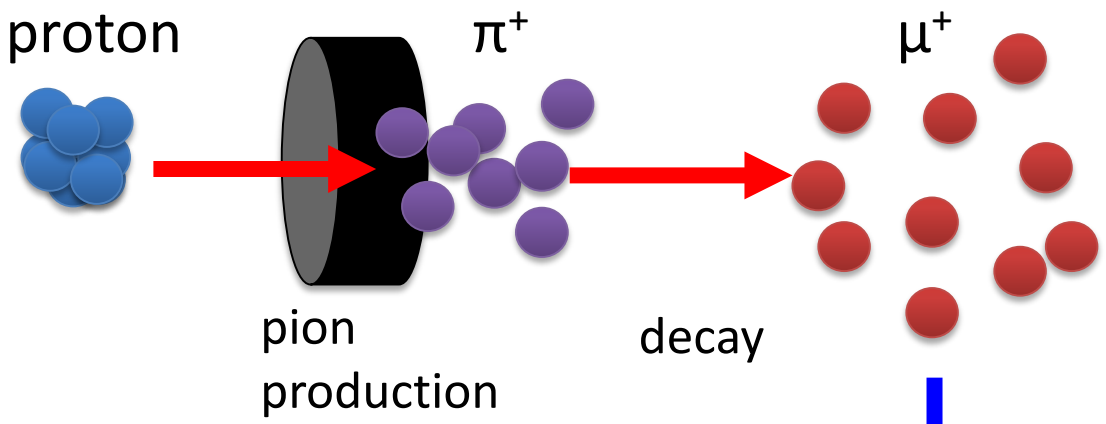
Make E=0 by removing strong focus requirement

- not restricted to high "magic" momentum

Need of well controlled muon beam

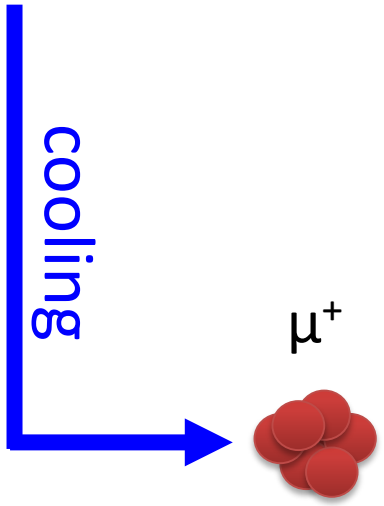
- start with ultra cold muon beam

Key technique: Reaccelerated muon beam with thermal energy emittance



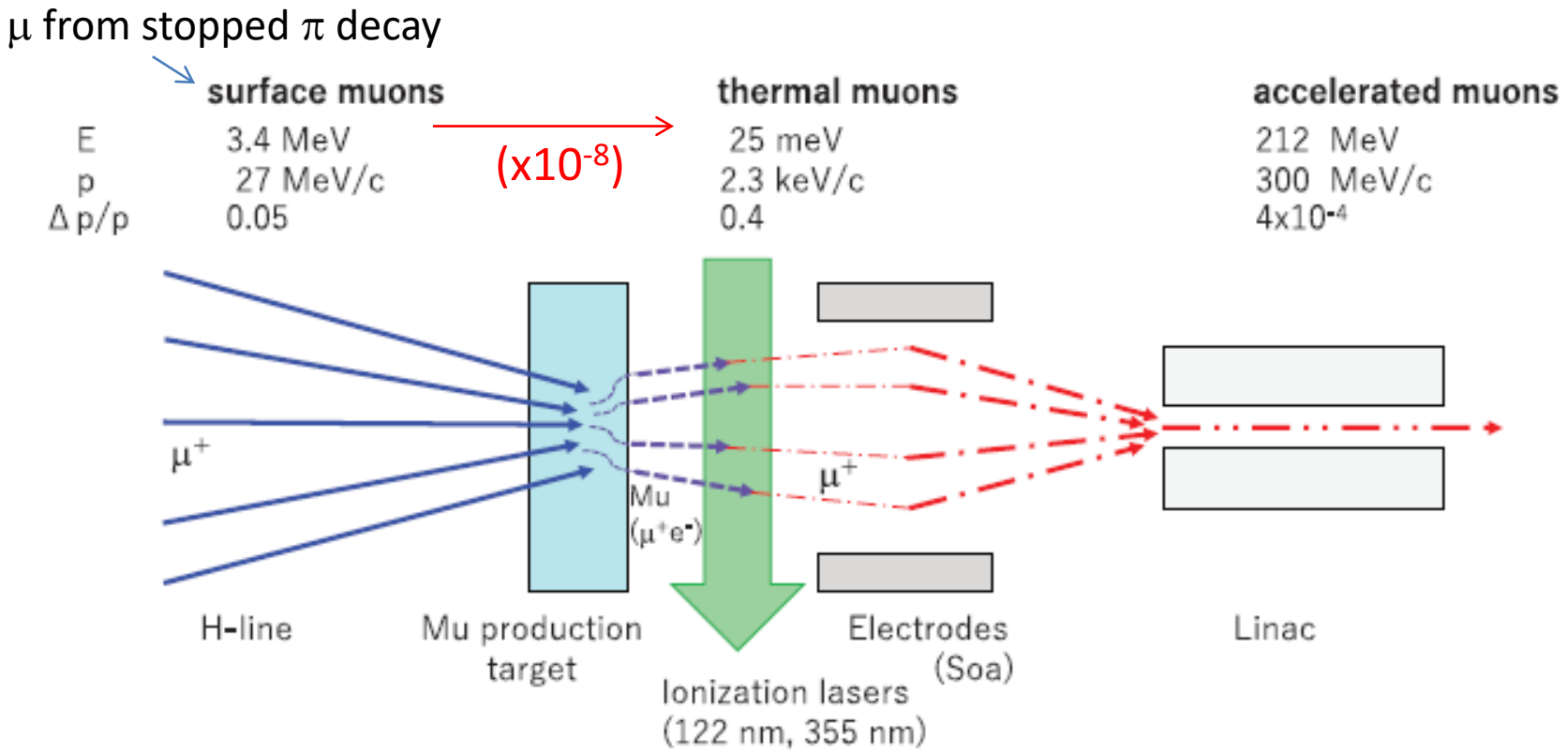
emittance
~1000π mm･mrad

Strong focusing
Muon loss
BG π contamination



emittance
1π mm･mrad

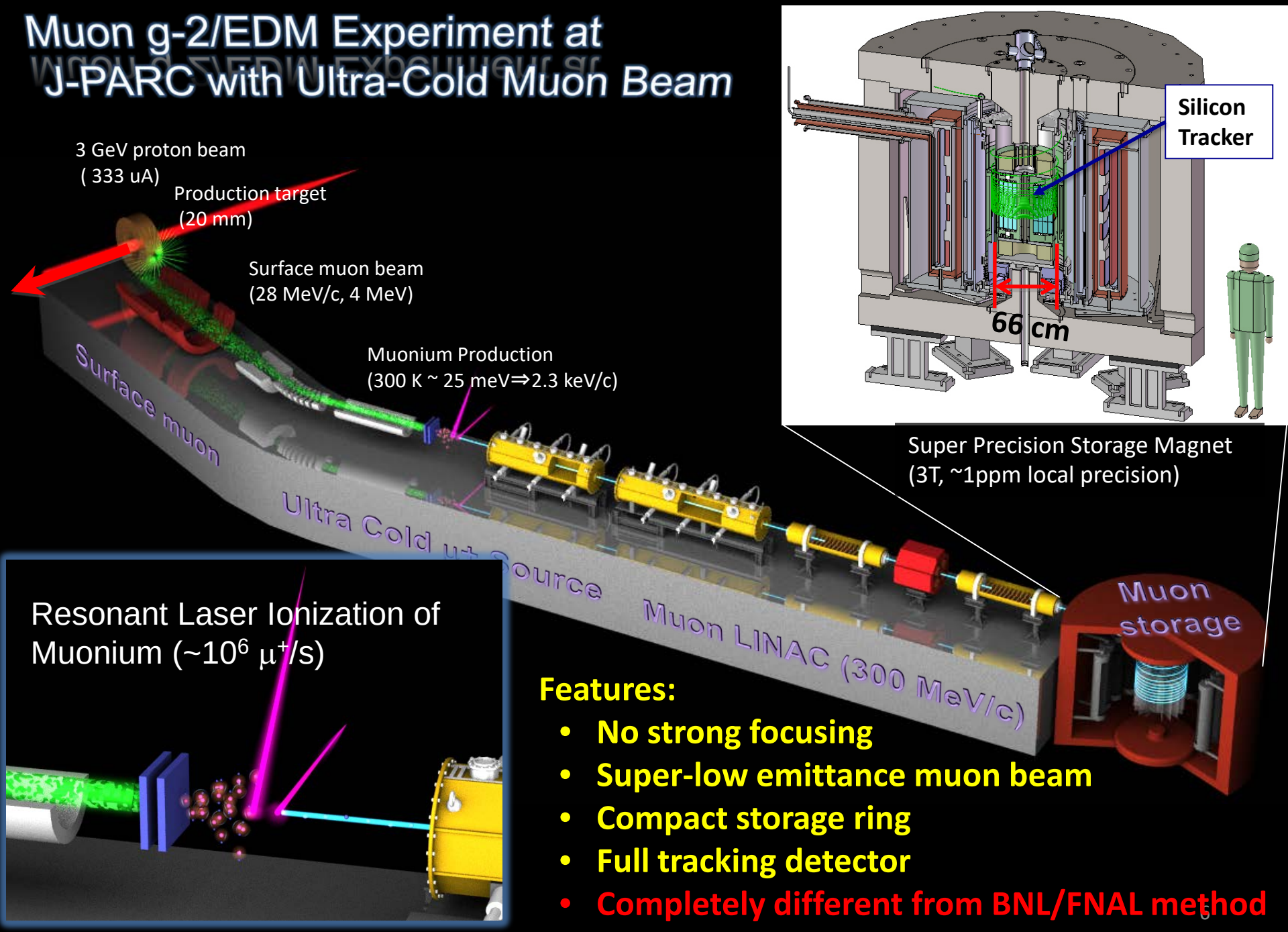
How to make it?



Requirements

1) Intense primary muon beam
2) Efficient muon cooling
3) Acceleration

Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam



Features:

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

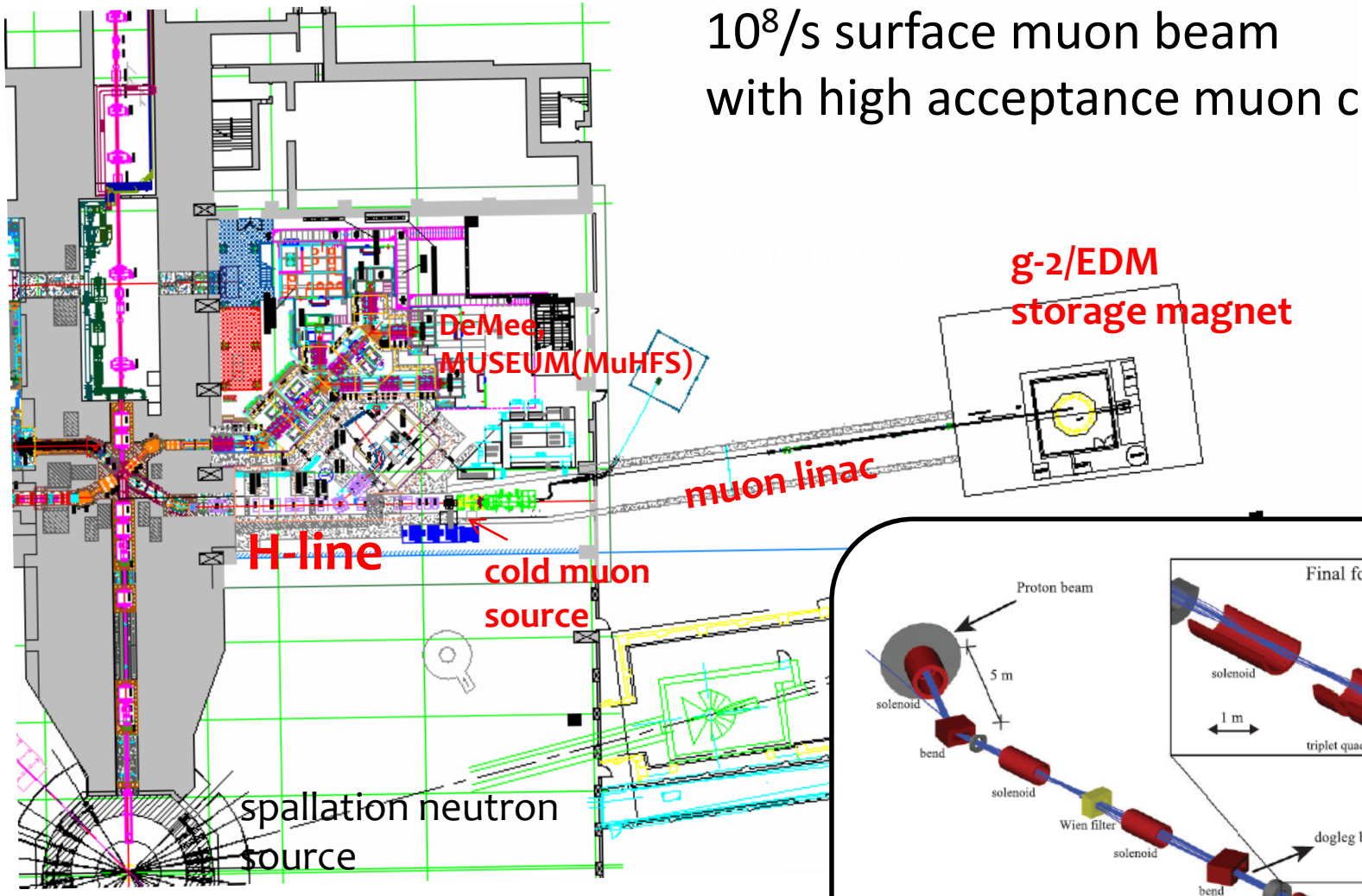
J-PARC and Muon source

1 MW 3 GeV proton beam

to in Feb. 2008

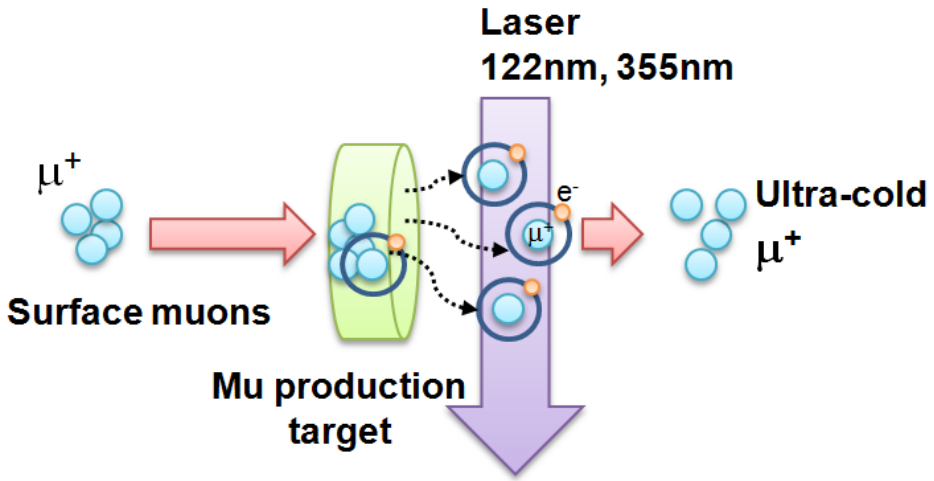
High-intensity muon beam @MLF H-line

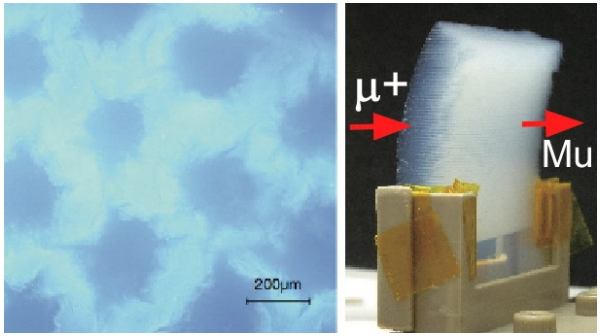
10^8/s surface muon beam
with high acceptance muon channel

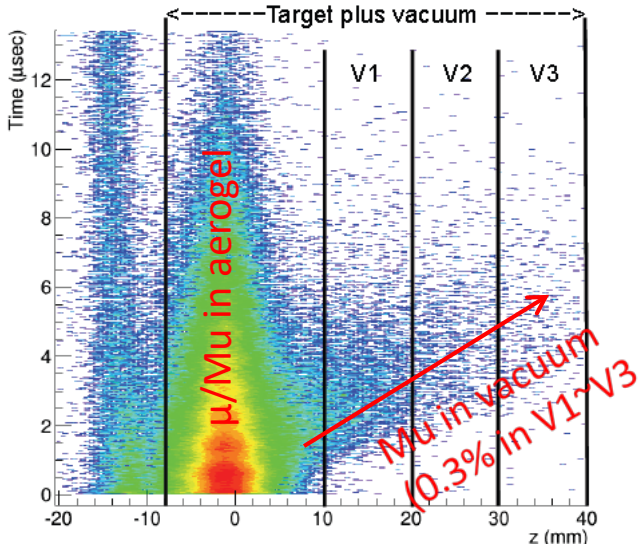


Muon Cooling-1: Thermal muonium

4 MeV muon -> 0.03 eV Muonium

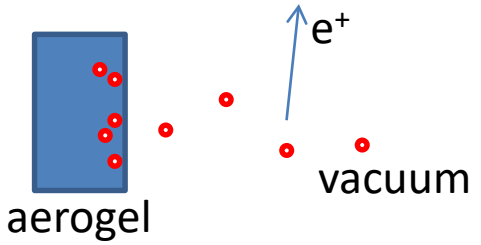






We developed silica aerogel!

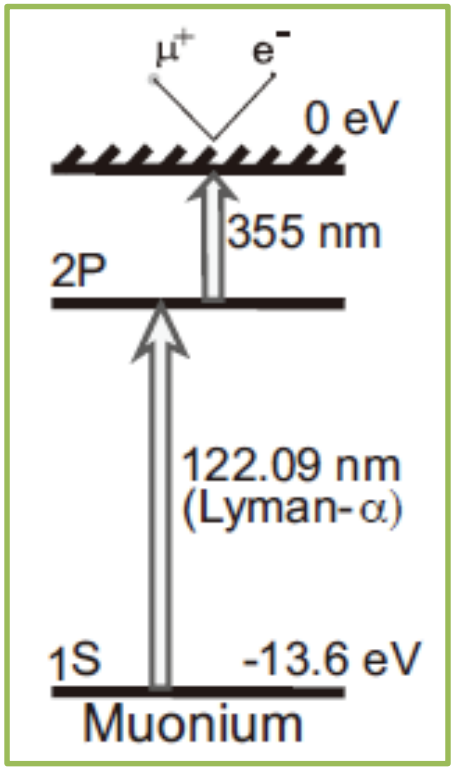
Fast Mu diffusion through voids in aerogel
+ increased surface area with laser ablation
(TRIUMF S1249)



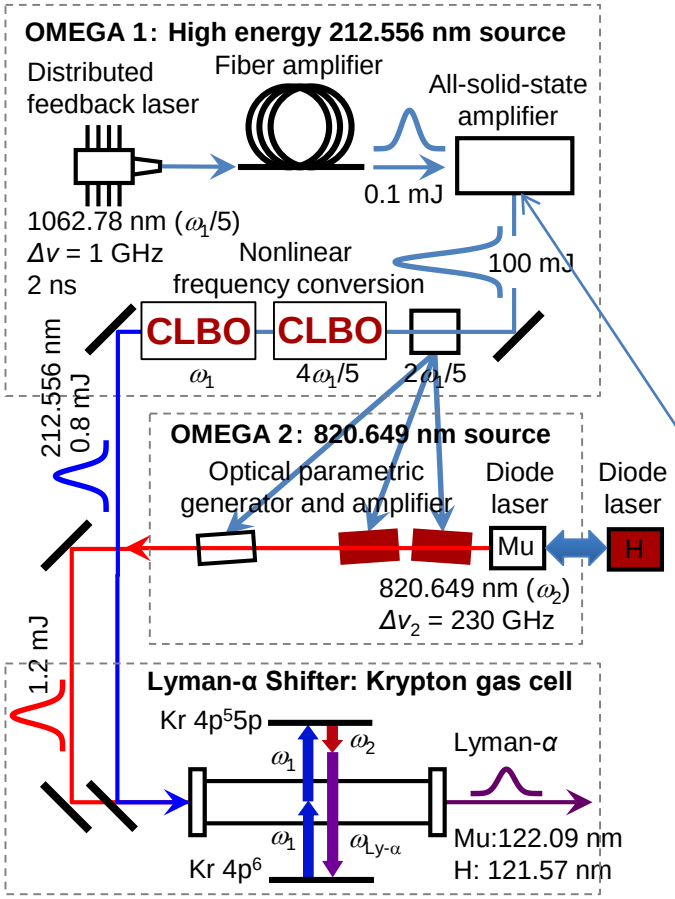
P. Bakule et al., Prog. Theor. Exp. Phys. 103C01 (2013)
G.A. Beer et al., Prog. Theor. Exp. Phys. 091C01 (2014)

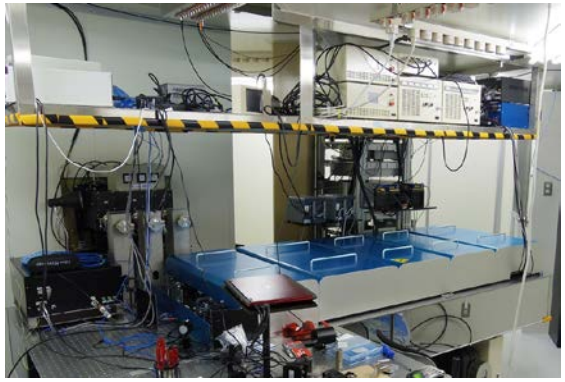
Muon cooling-2: Mu ionization with Lyman-alpha Laser

Remove e^- with lasers for acceleration



Improved Coherent Lyman-α System Configuration

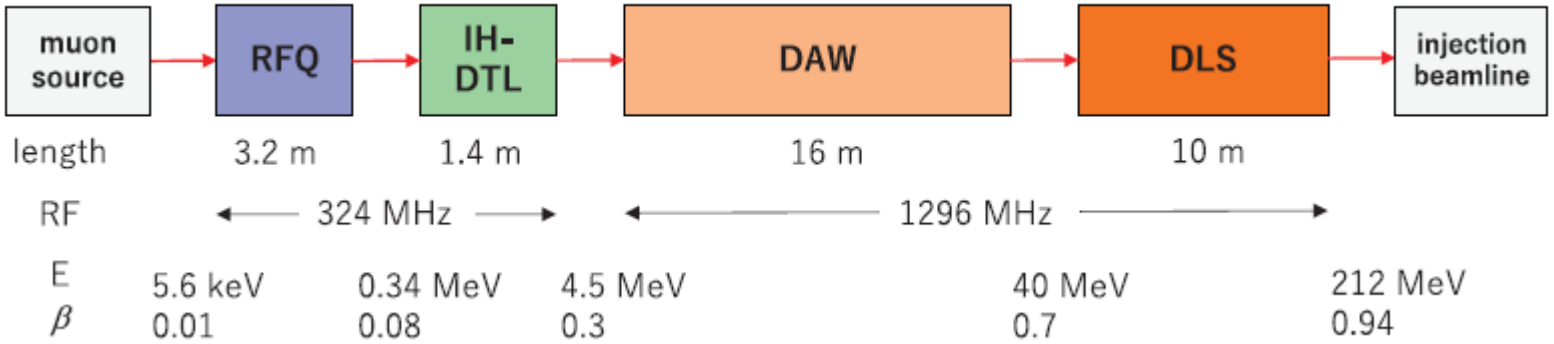




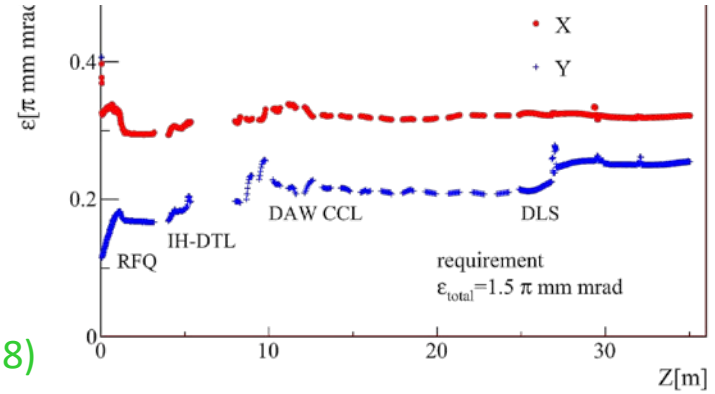
100 μJ pulsed Lyman-alpha laser + 400 mJ 355nm laser will ionize ~75% Mu

10 μJ Ly-α achieved, synthesizing larger YGAG crystal to increase $\omega_1/5$ power

Muon acceleration

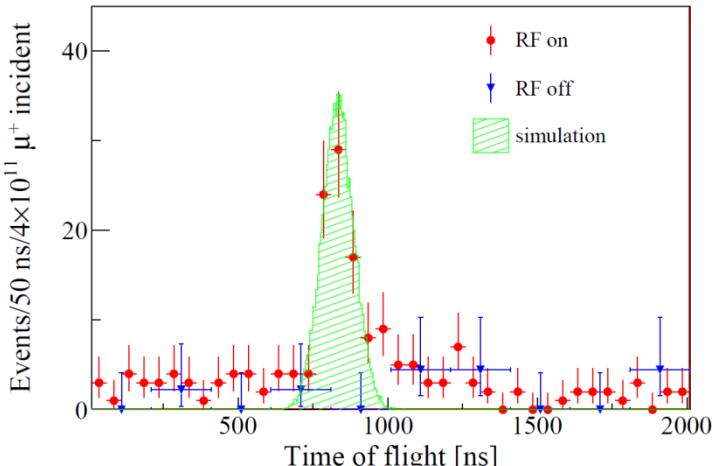


End to end simulation
- transmission loss ~7% + decay loss
- emittance growth is small

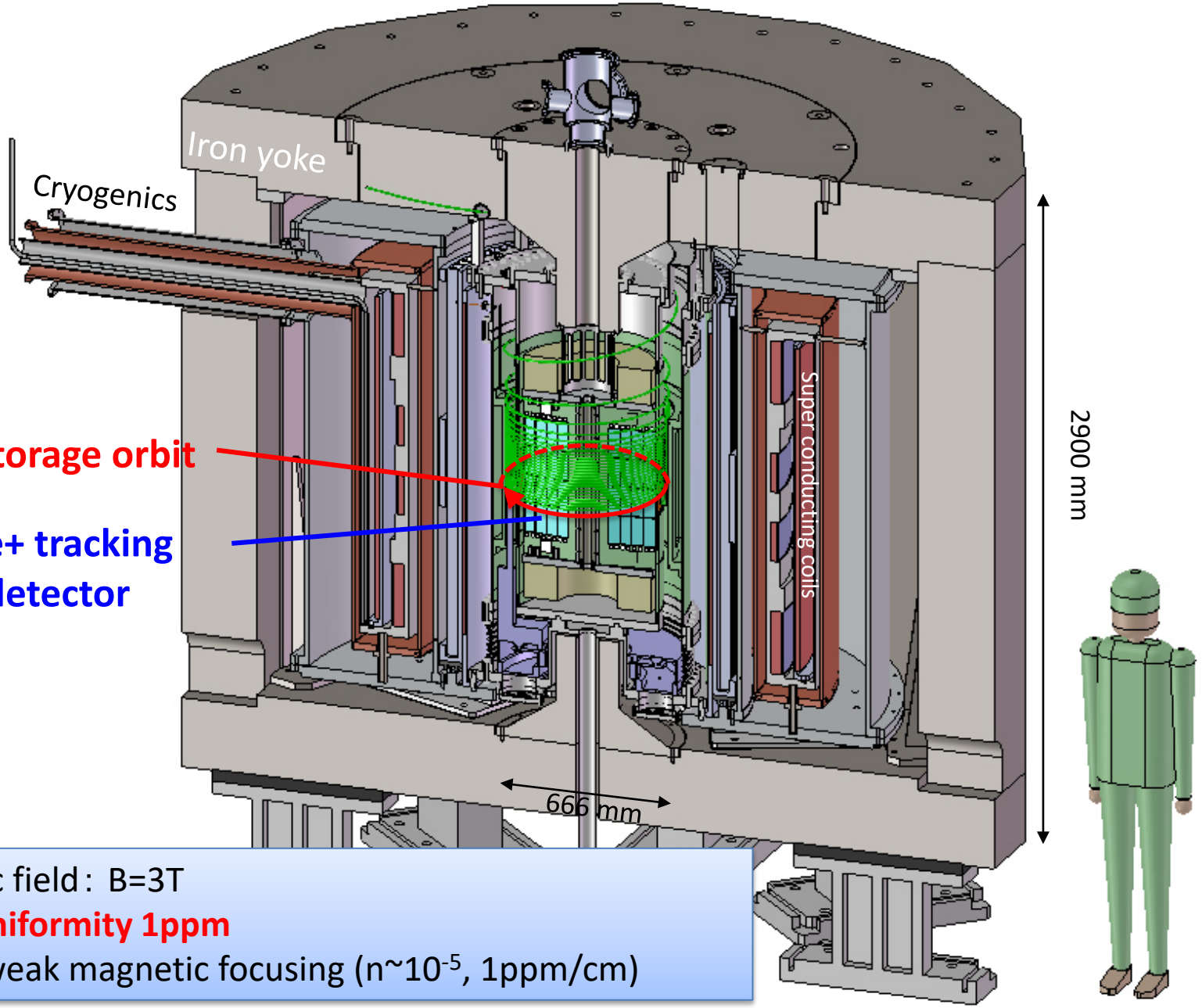


First muon acceleration with RFQ!

S. Bae et al., Phys. Rev. Accel. Beams 21, 050101 (2018)



Muon storage magnet and detector



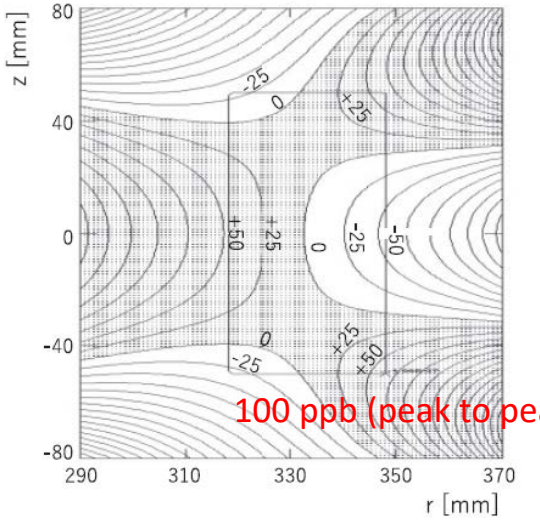
Magnetic field : B=3T

local uniformity 1ppm

+very weak magnetic focusing (n~10^{-5}, 1ppm/cm)

Magnetic field

design field (in ppb)



100 ppb (peak to peak)

Detailed Magnet Design in progress

fabrication 2 years, commissioning 1 year

M. Abe et al., Nucl. Instrum. Meth. A 890, 51 (2018)

$$B_r = -n\frac{B_{0z}}{R}z,$$

$$B_z = B_{0z} - n\frac{B_{0z}}{R}(r-R) + n\frac{B_{0z}}{2R^2}z^2,$$

n~1.5 x 10^{-4}

Shimming study with Mu HFS Coil (1.7 T)

With shim plate, achieved local homogeneity

5.31 ppm -> 0.45 ppm in 30cm DSS

+ correction coils

Field monitor

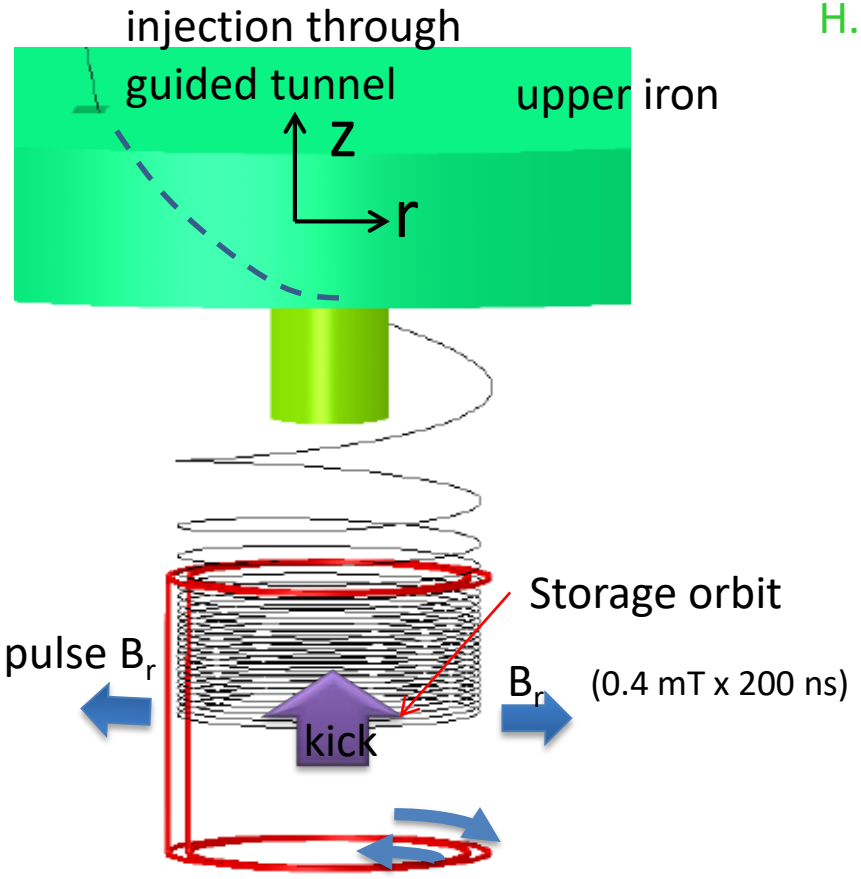
Cross calibration of J-PARC and FNAL NMR probes in progress at ANL

Study of material effect

$$B_{\mathrm{Measure}} = B_0 + \delta_s$$

Spiral beam Injection

Spiral injection + weak magnetic kick (8 mr) to storage-orbit



H. Iinuma et al., NIM A 832, 51 (2016)

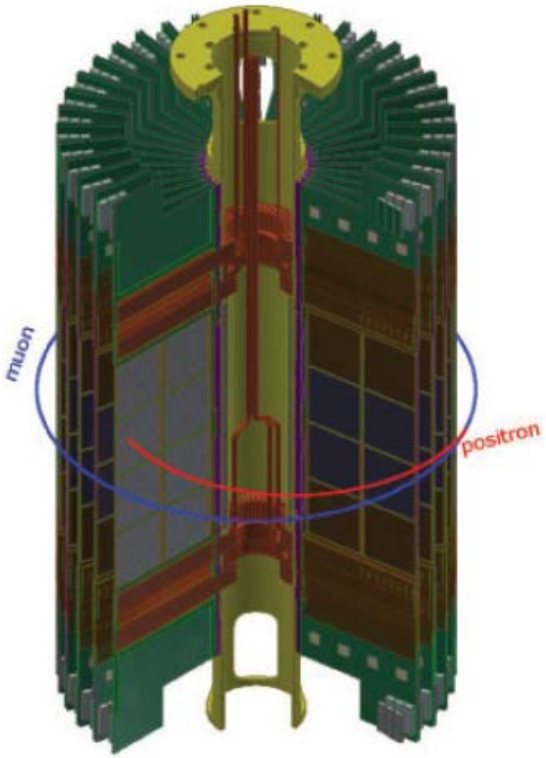
Detailed trajectory design with OPERA field
~80% injection efficiency

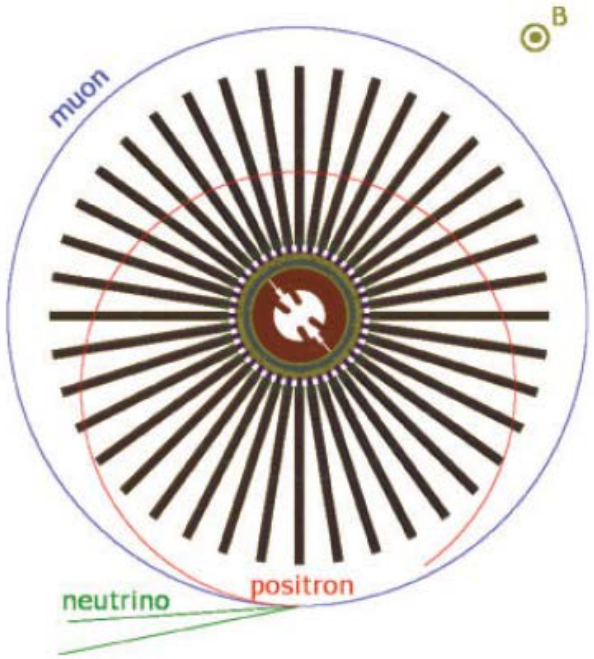
Kicker coil and power supply design

Spiral injection test with mini-solenoid and electron gun

Positron Detector

Measure muon decay positron tracks with Silicon-strip detectors
Forward/backward decay gives different positron momentum





Test boards have been studied
at J-PARC and electron at Tohoku-U

40 vanes
each 200 mm(R) x 400 mm(Z)
Single-sided Silicon strip sensor

Detectors and track reconstruction

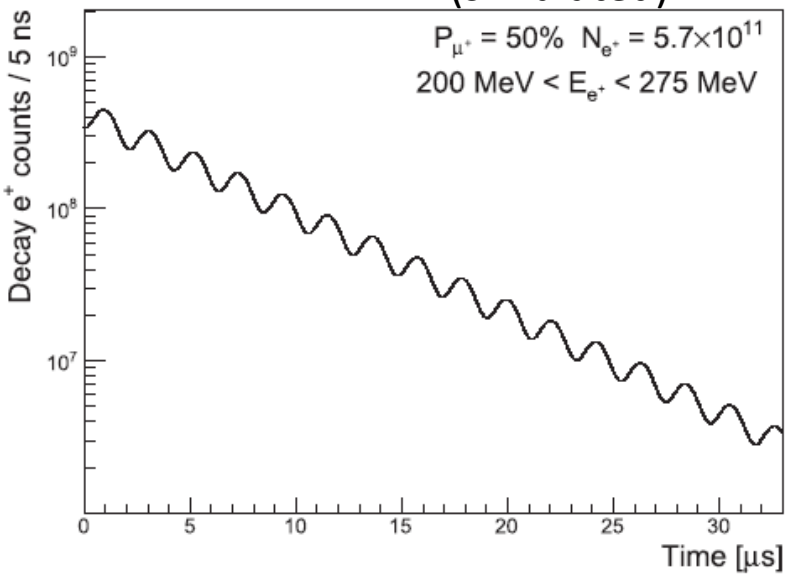
Decay of 300 MeV/c muons

Spin direction - positron energy range (sensitivity optimization)

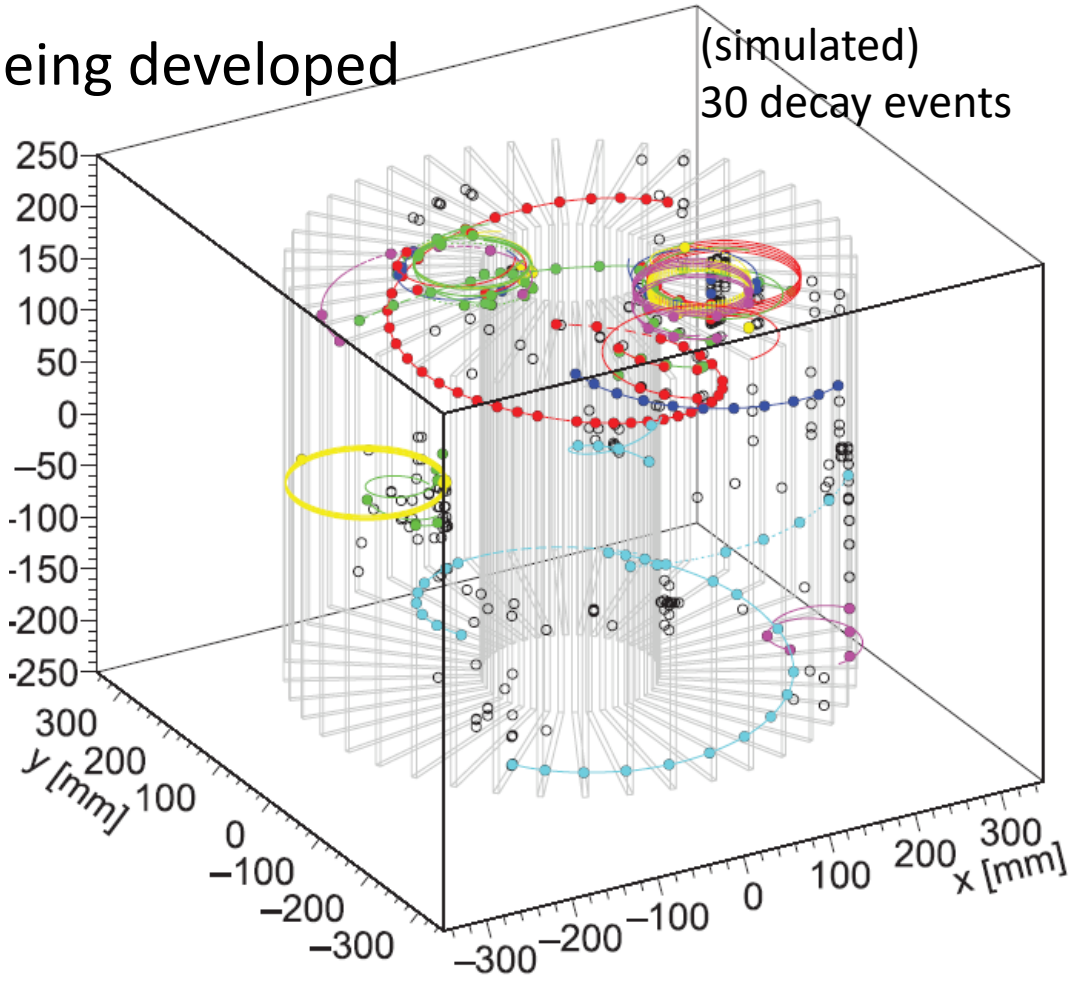
E = 200~275 MeV

Reconstruction software is being developed

(simulated)



(simulated)
30 decay events



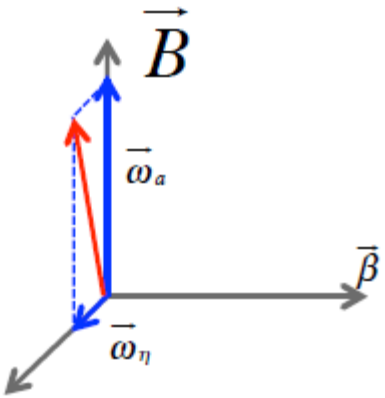
Muon EDM

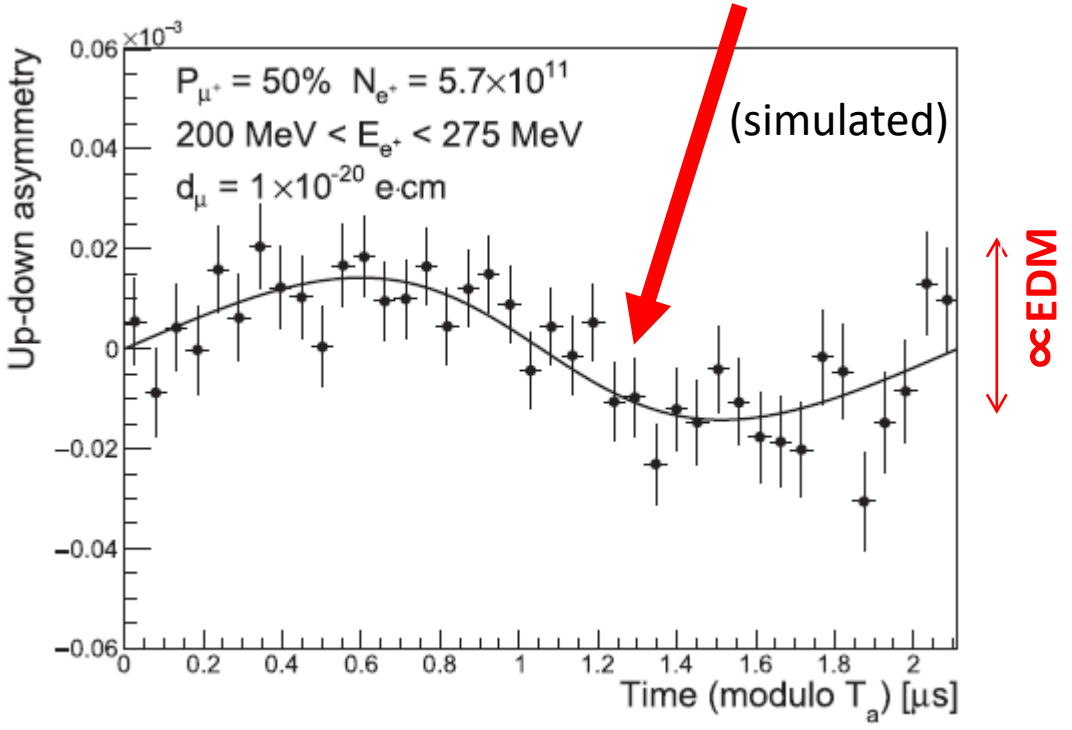
no E-field

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

Observation

Out-of-plane (up-down) oscillation with g-2 frequency





Key

Precise detector alignment and monitor system

Expected beam intensity and statistical error

Table 13.1: *Efficiency and beam intensity*

Quantity	Reference	Efficiency	Cumulative	Intensity (Hz)
Muon intensity at production target	[2]			1.99E+09
H-line transmission	[2]	1.62E-01	1.62E-01	3.22E+08
Mu emission	[3]	3.82E-03	6.17E-04	1.23E+06
Laser ionization	[4]	7.30E-01	4.50E-04	8.97E+05
Metal mesh	[5]	7.76E-01	3.49E-04	6.96E+05
Init.Acc.trans.+decay	[5]	7.18E-01	2.51E-04	5.00E+05
RFQ transmission	[6]	9.45E-01	2.37E-04	4.72E+05
RFQ decay	[6]	8.13E-01	1.93E-04	3.84E+05
IH transmission	design goal	1.00E+00	1.93E-04	3.84E+05
IH decay	[7]	9.84E-01	1.90E-04	3.78E+05
DAW transmission	design goal	1.00E+00	1.90E-04	3.78E+05
DAW decay	[8]	9.94E-01	1.88E-04	3.76E+05
High beta transmission	design goal	9.80E-01	1.85E-04	3.68E+05
High beta decay	[9]	9.88E-01	1.83E-04	3.64E+05
Injection transmission	design goal	1.00E+00	1.83E-04	3.64E+05
Injection decay	[10]	9.90E-01	1.81E-04	3.60E+05
Detector start time	[10]	9.27E-01	1.67E-04	3.34E+05
Muon at storage				3.34E+05

(from TDR)

Statistical error in 2 years run - 450 ppb

(and $\Delta d_\mu < 10^{-21}$ e cm)

Needs further improvement towards <200 ppb

Muon polarization recovery (0.5->0.9), improving Mu emission, ...

Our systematic error goals

in ω_a (Precession measurement)

in ω_p (B-field)

Anomalous spin precession (ω_a)		Magnetic field (ω_p)	
Source	Estimation (ppb)	Source	Estimation (ppb)
Timing shift	< 36	Absolute calibration	25
Pitch effect	13	Calibration of mapping probe	20
Electric field	10	Position of mapping probe	45
Delayed positrons	0.8	Field decay	< 10
Diffential decay	1.5	Eddy current from kicker	0.1
Quadratic sum	< 40	Quadratic sum	56

aim at systematic error better than 100 ppb

Muon g-2/EDM@J-PARC : Status

J-PARC PAC

Letter of Intent submitted (July 2009) - 45 authors
Conceptual Design Report (Jan 2012)
Stage 1 approval as E34 (Sep 2012)
Technical Design Report (TDR) (May 2015) - 144 authors
Focused Review on TDR (Nov 15-16, 2016)
Stage 2 approval (Nov 2018)

R&D (including partial construction)

-using several competitive grants
Detector, ...
- in collaboration with other experiments
Lyman-alpha laser (muon microscope)
Magnet (Mu HFS)

Construction funding request has been submitted

from R&D to construction phase!
- We look for new collaborators

Status (collaboration)

Structure

~100 members

Spokes person : Tsutomu Mibe, KEK

Collaboration board chairman: Seonho Choi, Seoul Univ.

Collaboration meetings (every half year)

To share/discuss global matters and progress from each subgroup

18th Meeting, Seoul, Jun 2019

PTEP Prog. Theor. Exp. Phys. 2019, 053C02 (22 pages)
DOI: 10.1093/ptep/ptz030

A new approach for measuring the muon anomalous magnetic moment and electric dipole moment

M. Abe[1], S. Bae[2,3], G. Beer[4], G. Bunce[5], H. Choi[2,3], S. Choi[2,3], M. Chung[6], W. da Silva[7], S. Eidelman[8,9,10], M. Finger[11], Y. Fukao[1], T. Fukuyama[12], S. Haciomeroglu[13], K. Hasegawa[14], K. Hayasaka[15], N. Hayashizaki[16], H. Hisamatsu[1], T. Iijima[17], H. Iinuma[18], H. Ikeda[19], M. Ikeno[1], K. Inami[17], K. Ishida[20], T. Itahashi[21], M. Iwasaki[20], Y. Iwashita[22], Y. Iwata[23], R. Kadono[1], S. Kamal[24], T. Kamitani[1], S. Kanda[20], F. Kapusta[7], K. Kawagoe[25], N. Kawamura[1], B. Kim[2,3], Y. Kim[26], T. Kishishita[1], R. Kitamura[14], H. Ko[2,3], T. Kohriki[1], Y. Kondo[14], T. Kume[1], M. J. Lee[13], S. Lee[13], W. Lee[27], G. M. Marshall[28], Y. Matsuda[29], T. Mibe[1,30], Y. Miyake[1], T. Murakami[1], K. Nagamine[1], H. Nakayama[1], S. Nishimura[1], D. Nomura[1], T. Ogitsu[1], S. Ohsawa[1], K. Oide[1], Y. Oishi[1], S. Okada[20], A. Olin[4,28], Z. Omarov[26], M. Otani[1], G. Razuvaev[8,9], A. Rehman[30], N. Saito[1,31], N. F. Saito[20], K. Sasaki[1], O. Sasaki[1], N. Sato[1], Y. Sato[1], Y. K. Semertzidis[26], H. Sendai[1], Y. Shatunov[22], K. Shimomura[1], M. Shoji[1], B. Shwartz[9,32], P. Strasser[1], Y. Sue[17], T. Suehara[25], C. Sung[6], K. Suzuki[17], T. Takatomi[1], M. Tanaka[1], J. Tojo[25], Y. Tsutsumi[25], T. Uchida[1], K. Ueno[1], S. Wada[20], E. Won[27], H. Yamaguchi[1], T. Yamanaka[25], A. Yamamoto[1], T. Yamazaki[1], H. Yasuda[33], M. Yoshida[1], and T. Yoshioka[25,*]

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First Collaboration Paper!

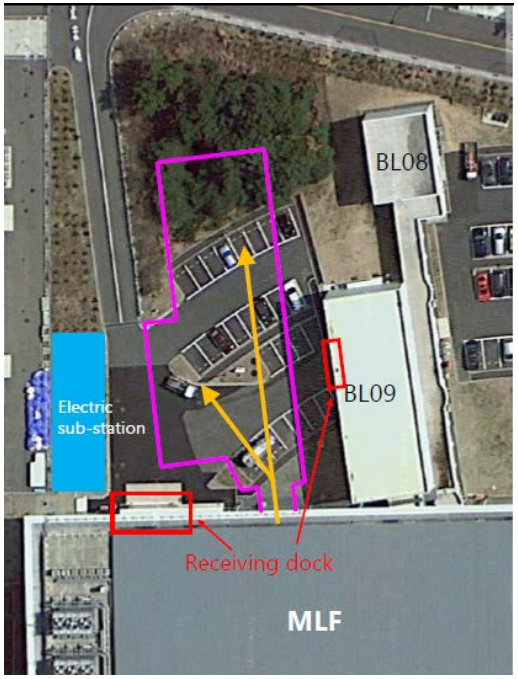
M. Abe et al., PTEP 2019,053C02 (May 2019) - 96 authors

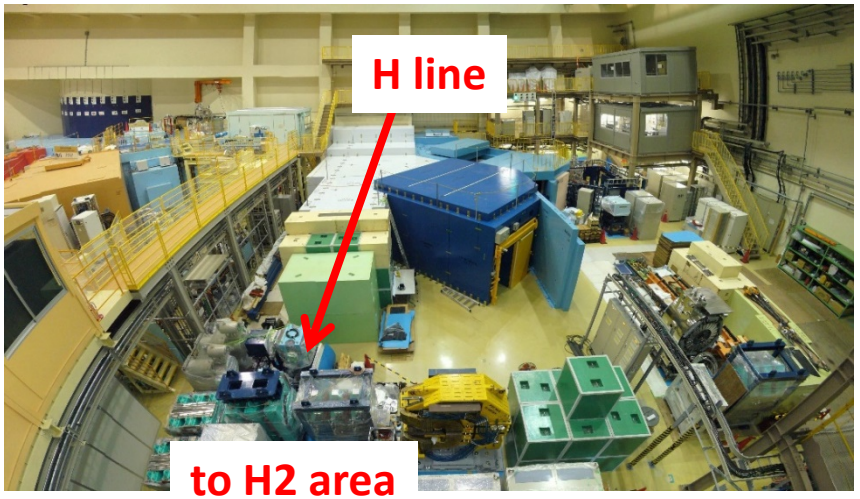
"A New approach for Measuring the Muon Anomalous Magnetic Moment and Electron Dipole Moment"

Status (Construction/Run Schedule)

H-line first muon beam expected next year.
Electric power station under construction.
Building extension is being designed.

Intended schedule
2019 Funding request from KEK to MEXT
2020-2023 Construction
2023 Commissioning
2024-2026 Data Run





Summary

We aim to measure muon g-2 and EDM
with accelerated low emittance muon beam at J-PARC.

An independent measurement to BNL/FNAL

R&D phase is ending.
Construction phase is starting.

Further information

http://g-2.kek.jp