Muon g-2/EDM @J-PARC

K. Ishida (RIKEN)
for muon g-2/EDM at J-PARC group

Outline

muon g-2

Our proposed scheme
  ultra-cold muon beam

Progress since last year

Summary

muon g-2 and EDM

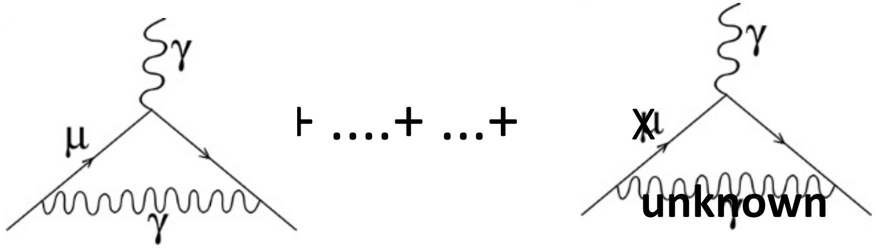
$\boldsymbol{\mu} = g_\mu (e/2m_\mu)\, \boldsymbol{s}$

$a_\mu = (g_\mu - 2)/2$: 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, even undiscovered

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

If EDM is nonzero -> T reversal is violated.

=> Indication of CP violation in the lepton sector.

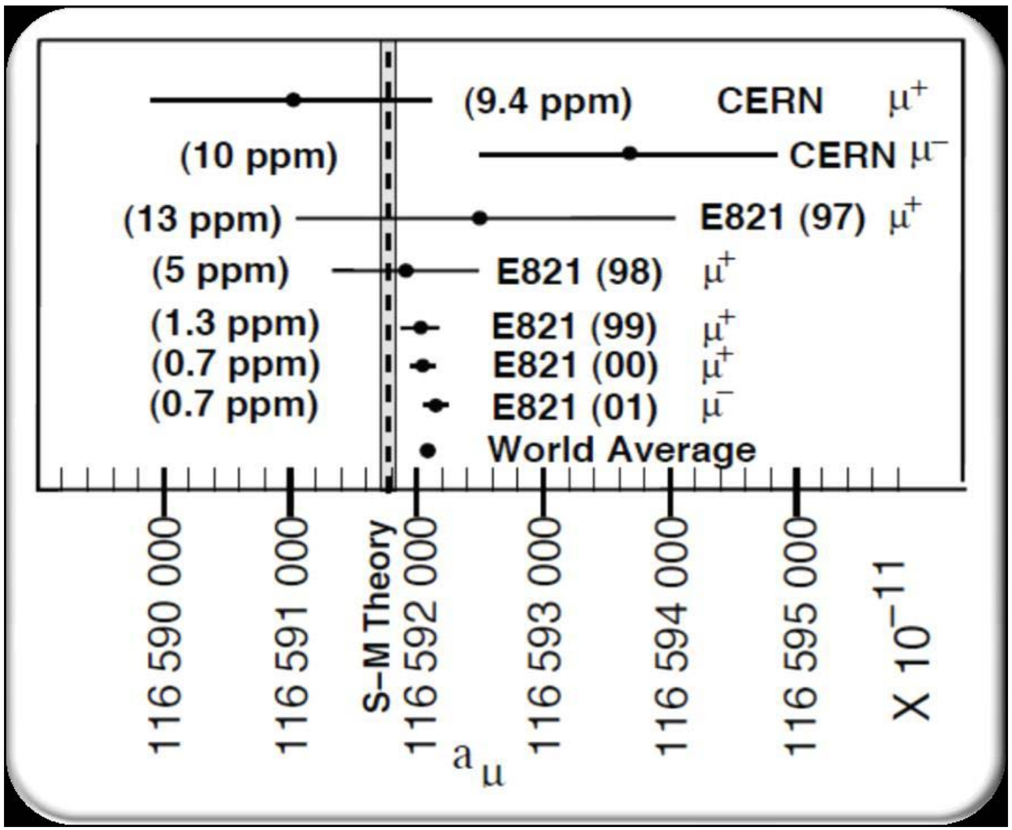
muon g-2

BNL E821 measured a_μ to 0.7 ppm for μ^+ and μ^- (sum 0.5 ppm)
Deviation of experiment and theory by 3~3.5 σ was observed.

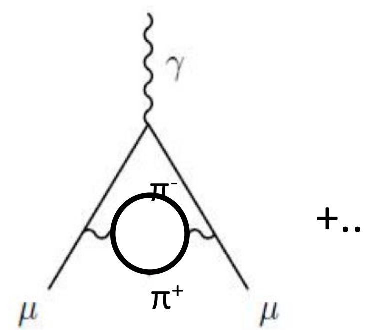
$$\Delta a_\mu = a_\mu(\text{Exp}) - a_\mu(\text{SM}) = (295{+-}88) \times 10^{-11}$$

New physics?
Experiment and theory to better precision is waited for.

M. Passera, WG1/WG
P. Paradisi, WG1/WG4



Hadronic contribution (experimental input) study by several groups and methods ("e+e- → γ^* → hadrons" and tau-decay).
=> Some variations but not large enough to explain the discrepancy.



muon g-2: method

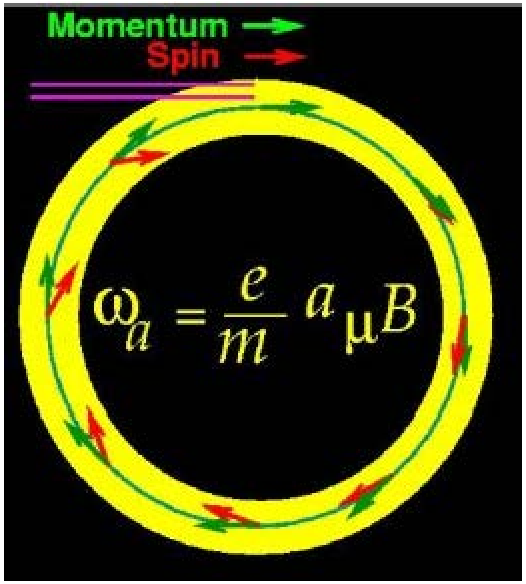
$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

make this zero

Measure ω_a and under well controlled B.

Previous measurement BNL E821

use of magic momentum (p=3.09 GeV/c)



14m

Muon g-2/EDM@J-PARC

We plan an independent measurement at J-PARC
based on ultra-cold muon beam and MRI-type storage ring.

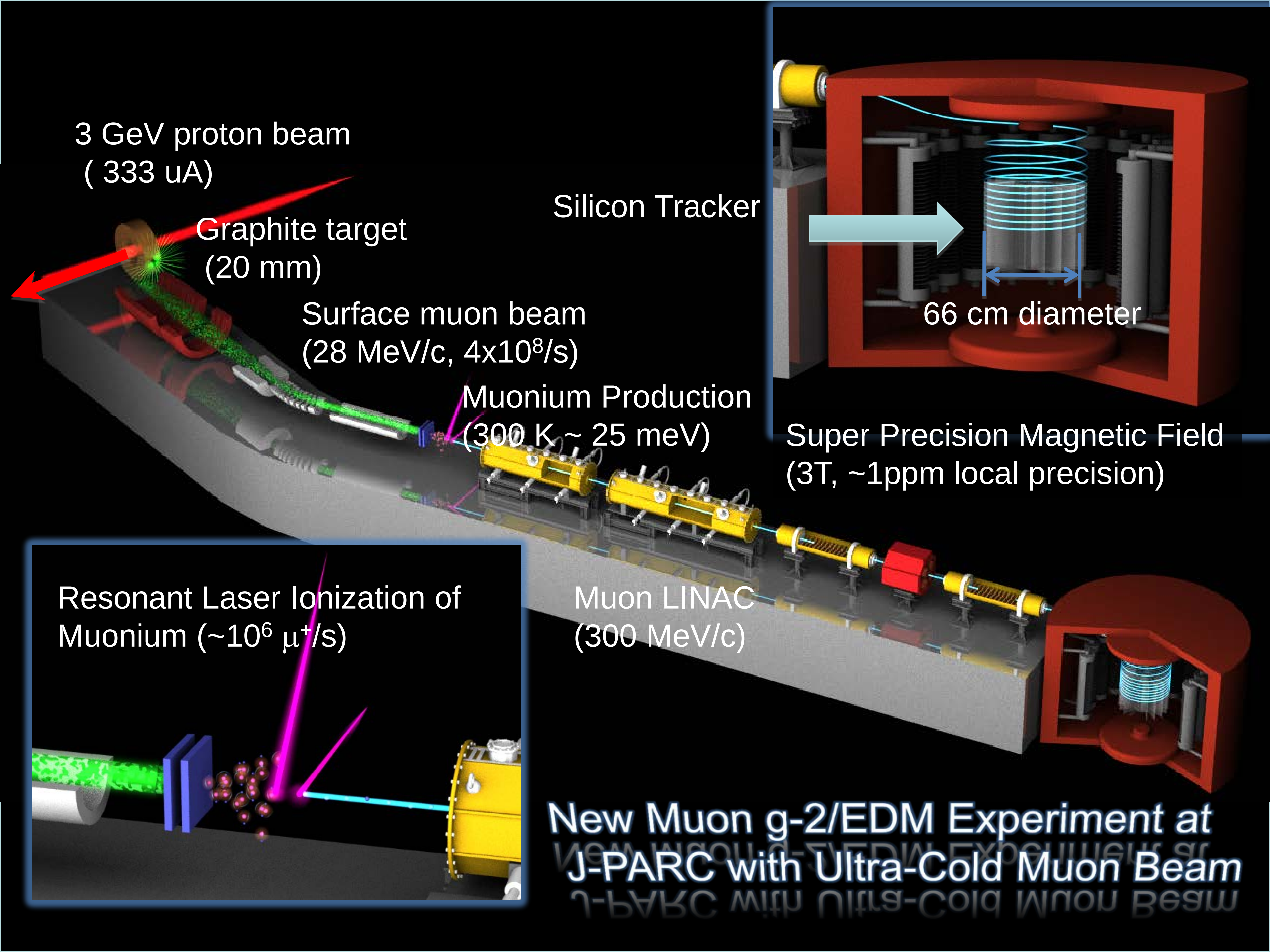
with different scheme - in systematic errors.

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.

Make E=0 by making focusing needs low.
- no high "magic" momentum requirement.
Need of well controlled muon beam
- start with ultra cold muon beam.


3 GeV proton beam
(333 uA)
Graphite target
(20 mm)
Surface muon beam
(28 MeV/c, 4x10^8/s)
Muonium Production
(300 K ~ 25 meV)
Silicon Tracker
66 cm diameter
Super Precision Magnetic Field
(3T, ~1ppm local precision)
Resonant Laser Ionization of
Muonium (~10^6 μ+/s)
Muon LINAC
(300 MeV/c)
New Muon g-2/EDM Experiment at
J-PARC with Ultra-Cold Muon Beam

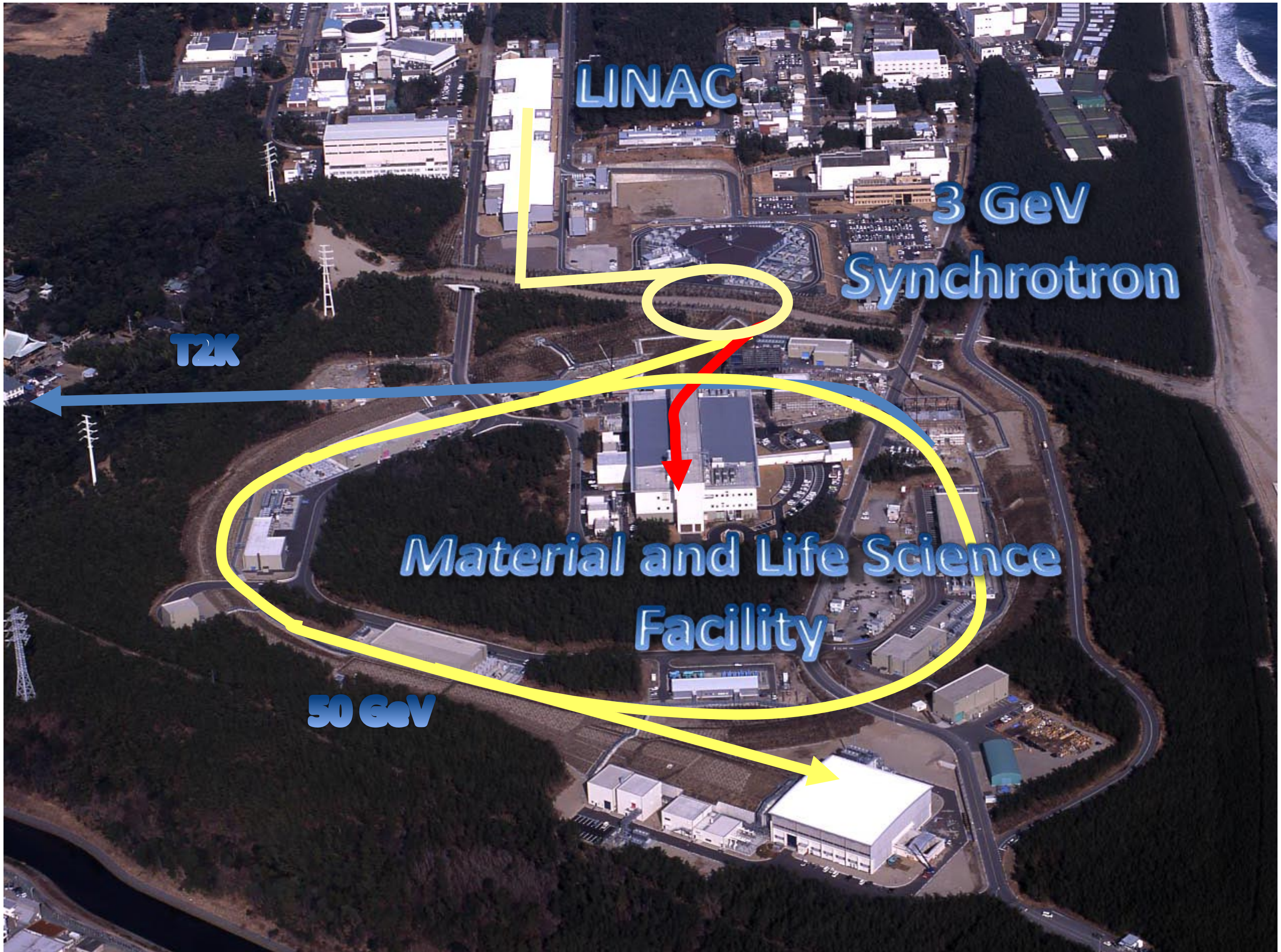
Our goal: comparison

	BNL-E821	Fermilab	J-PARC
Muon momentum	3.09 GeV/c		0.3 GeV/c
gamma	29.3		3
Storage field	B=1.45 T		3.0 T
Focusing field	Electric quad		Very weak magnetic
# of detected μ+ decays	5.0E9	1.8E11	1.5E12
# of detected μ- decays	3.6E9	-	-
Precision (stat)	0.46 ppm	0.1 ppm	0.1 ppm*

* Based on 1 x 10^6/s stored muons x 1 year data taking (10^7 s).

Muon g-2/EDM@J-PARC

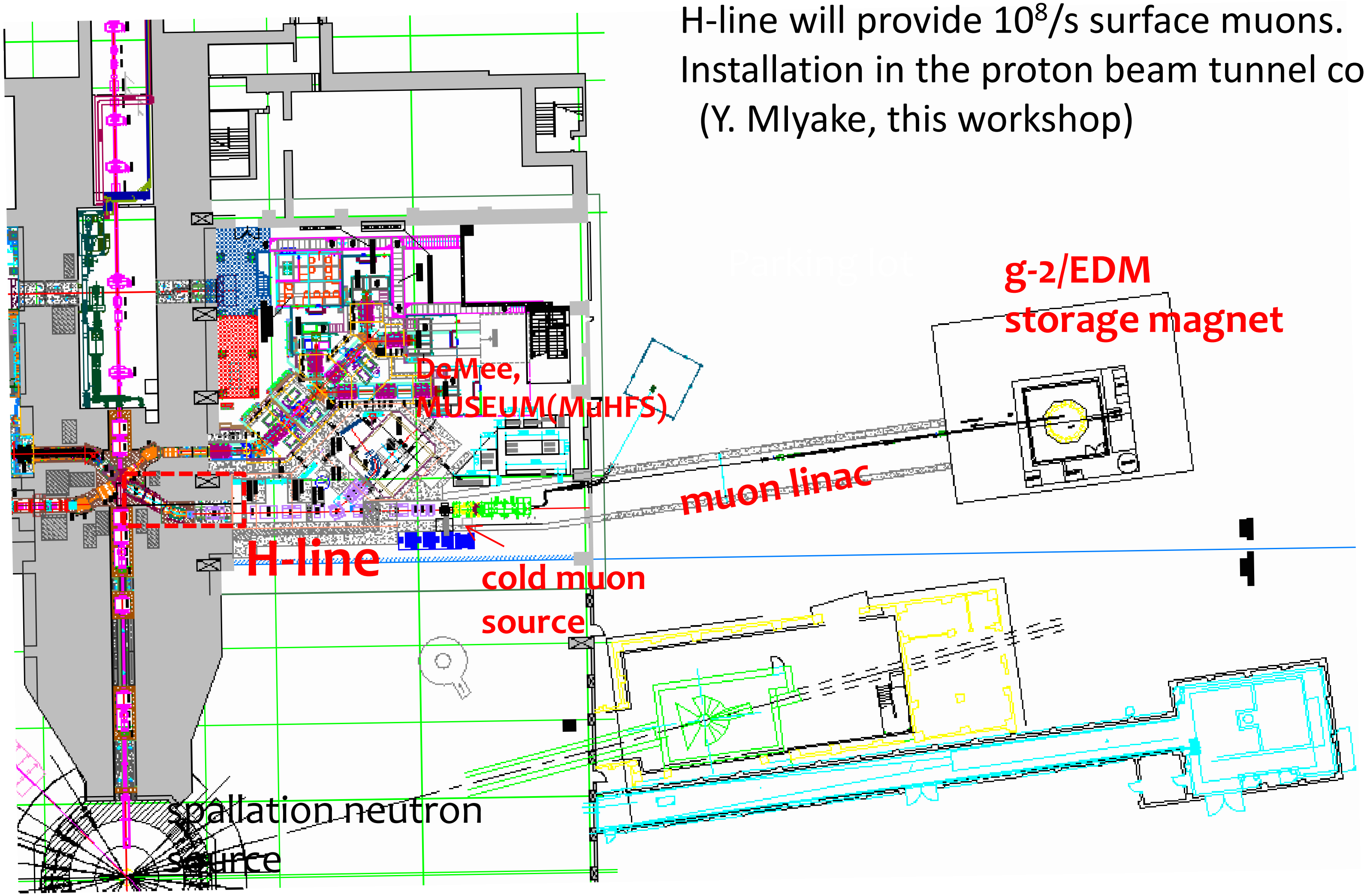
High intensity Japan Proton Accelerator Research Complex
1 MW at 3 GeV (0.3 MW at present), 0.75 MW at 30 GeV



proposed experimental site

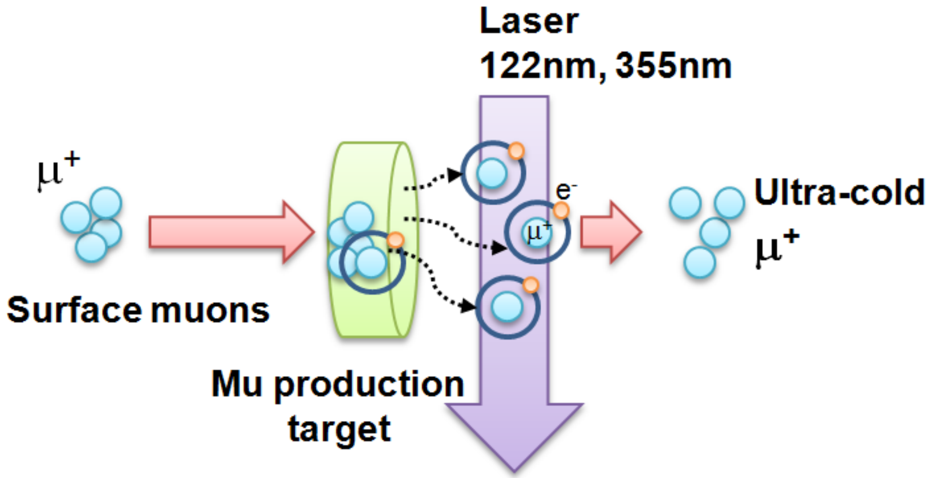
J-PARC MLF (Materials and Life Science Facility)

H-line will provide 10^8/s surface muons.
Installation in the proton beam tunnel completed
(Y. MIyake, this workshop)



Ultra-slow muon from Thermal Muonium

Starting from surface muon beam (4 MeV, Δp~2%, 4cmϕ, 50 mr)

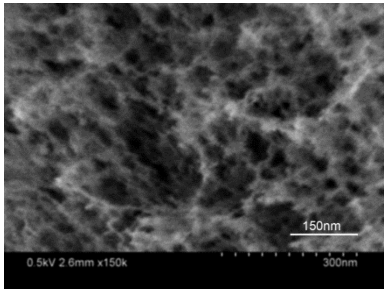


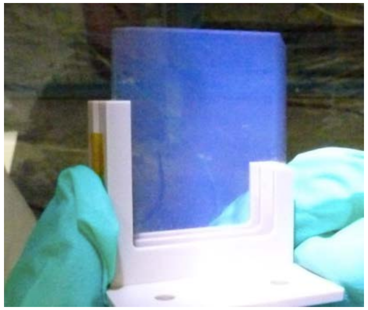
Stop muons in a material,
some diffuse out at thermal energy.
Good muonium emitter and
an intense laser to remove the electron
are essential.

(efficiency>1% required)

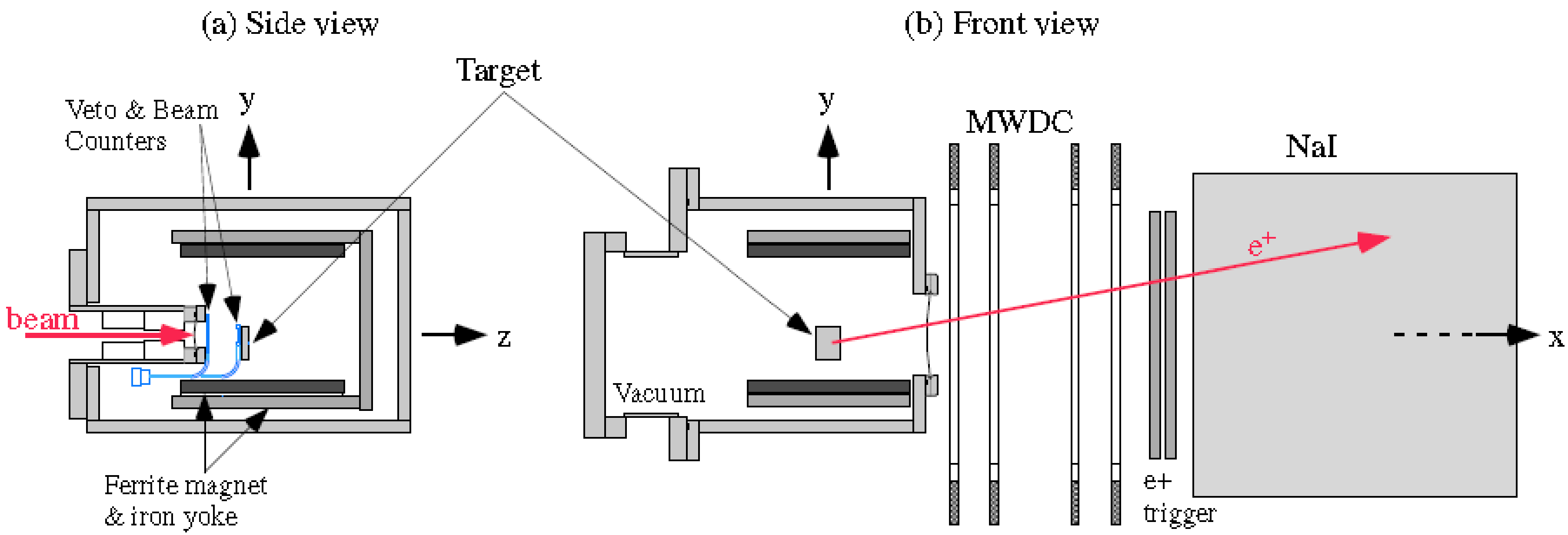
Silica powder has been known to be a good
Mu emitter at room temperature
Mu diffuse out through network of SiO_2 grains
(large surface area)

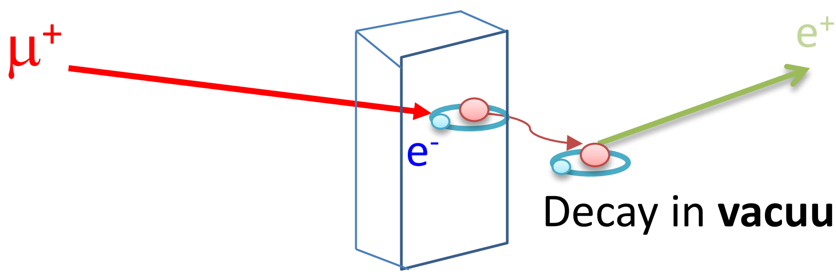
Silica aerogels with similar network structure
can be more easily handled and may fit better
our system





Measurement S1249@TRIUMF





Decay in **vacuum**

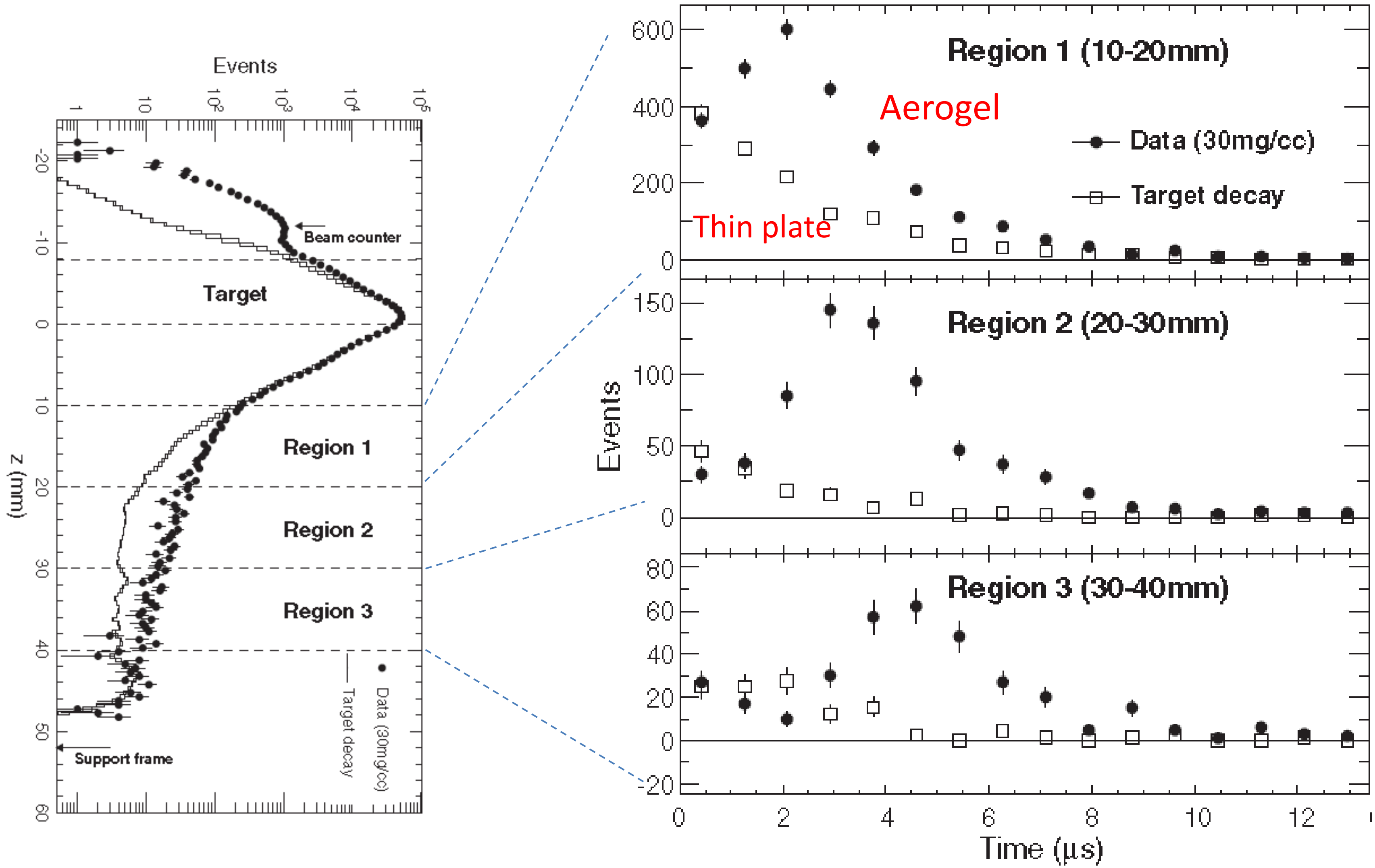
Muonium
Target

Mu velocity in vacuum ~5 mm/μs
MWDC intrinsic resolution ~0.1 mm
Track back resolution ~2mm
(from 0.1mm silica-plate data)

First results S1249@TRIUMF 2010-2011

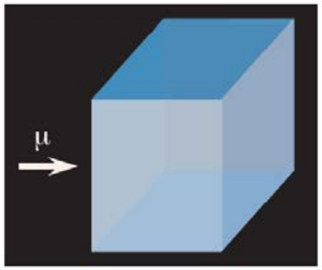
Mu excess over reference target was observed

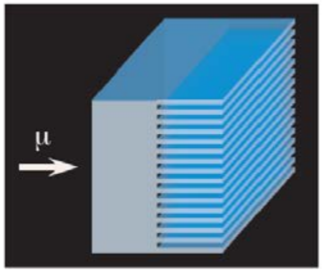
Yield was "not" satisfactory (~1% emission per stopped μ)

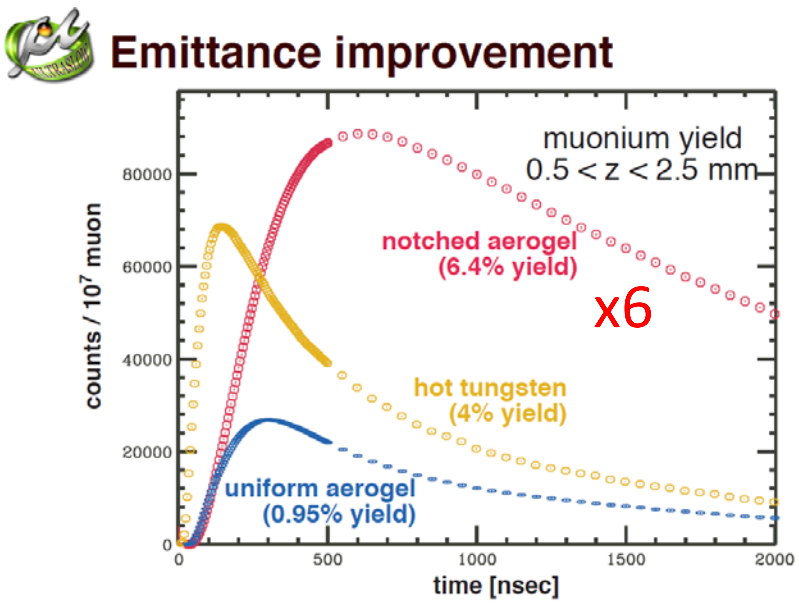


More muoniums wanted

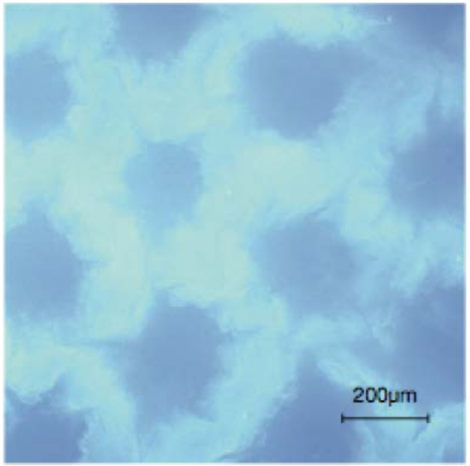
Muon should stop near surface (<0.1mm)
to come out!
Simulation with structured surface by M. Iwasaki
(Ultra Slow Muon Microscope Meeting, Sapporo, 2012)

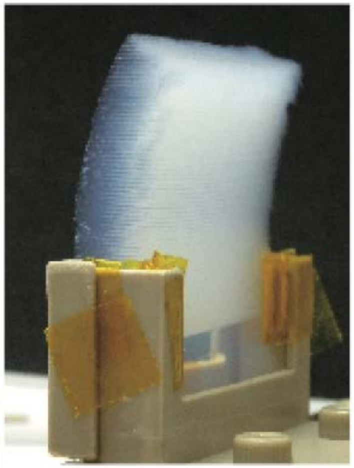




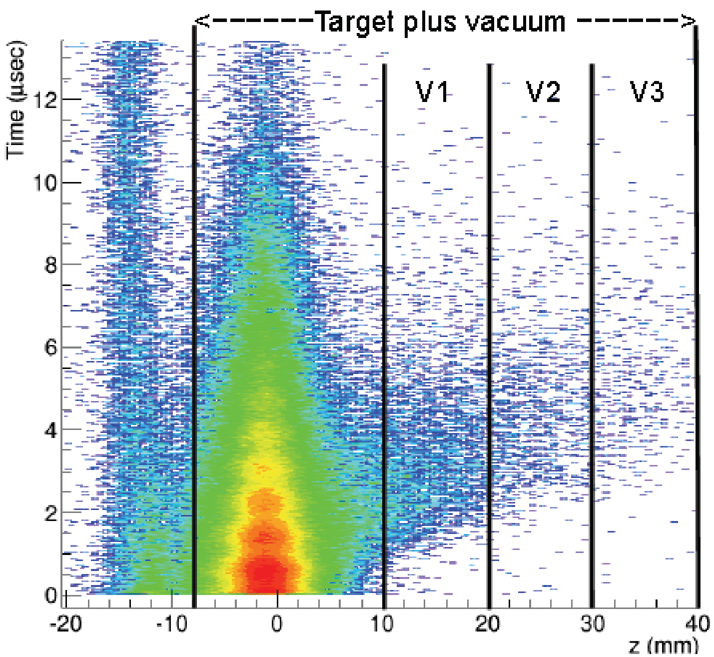


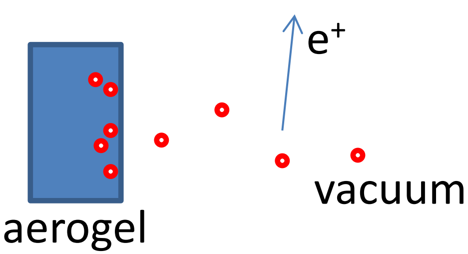
How to make it?
- Ion beam, dust-gun, mold, push-pin, ...
- Laser ablation was successfully applied.

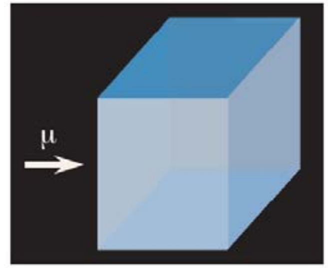


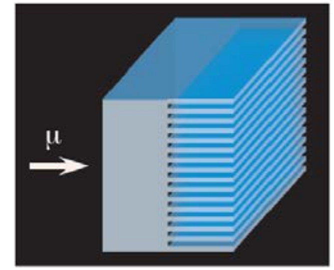


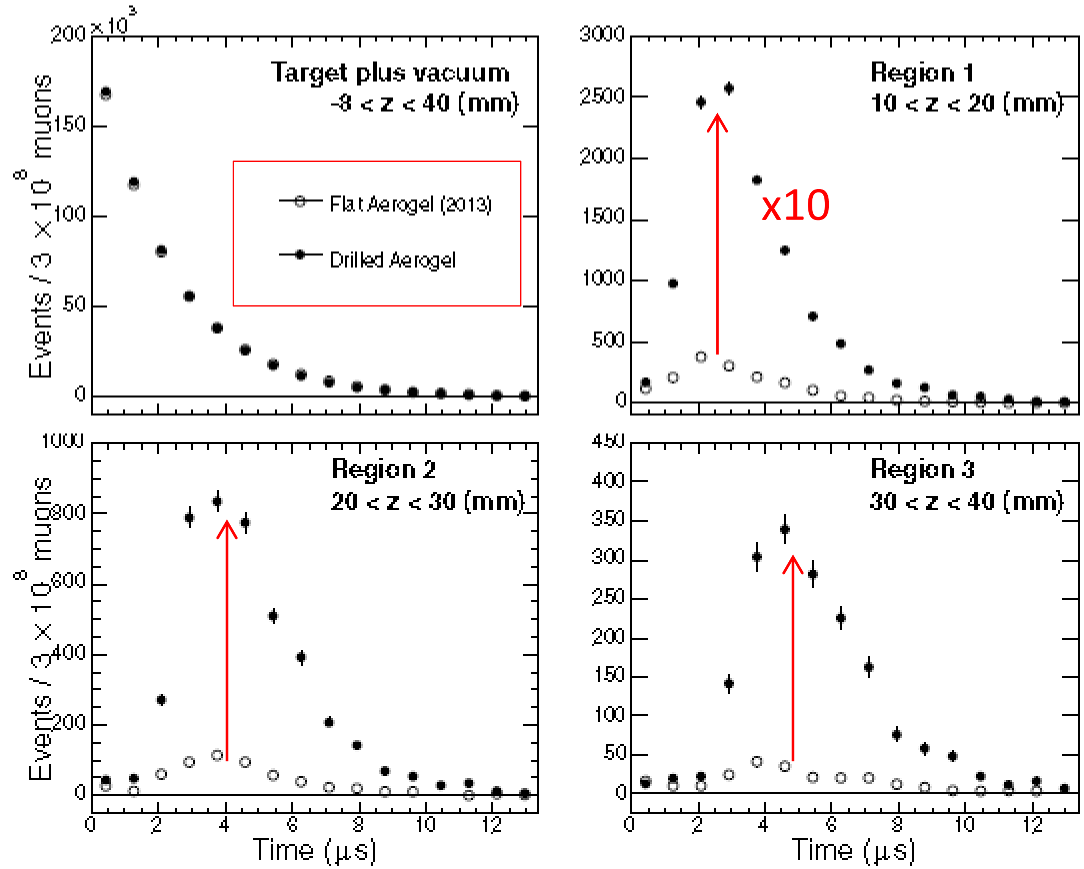
New measurement (S1249@TRIUMF 2013)











(to be published in PETP soon!)

Muon source

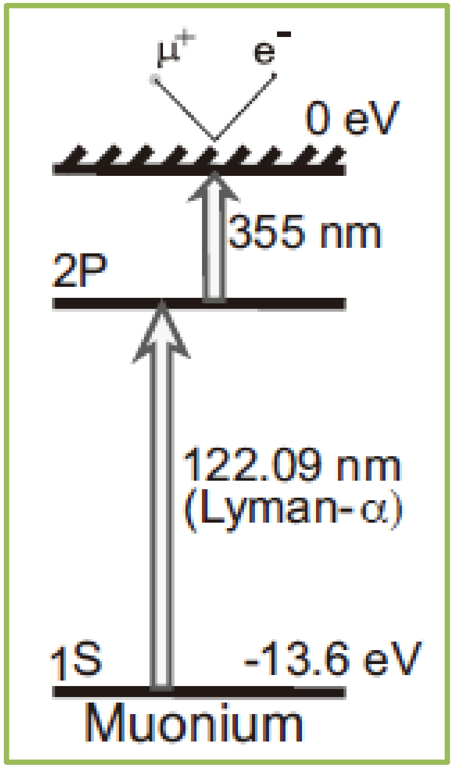
Huge increase (x10) of Mu yield in measurement last October.
We now have about 10% of muons coming out in vacuum.
(from 23 MeV/c, σ_p=2% beam)
Expected ultra-cold muon yield is only factors away from requirement.
(present estimate is 0.2 x 10^5/s assuming other conditions are fulfilled)

=> Further optimization of target condition (density, hole size/pitch, ...)
(we initially tested only four samples)
is now ongoing at J-PARC

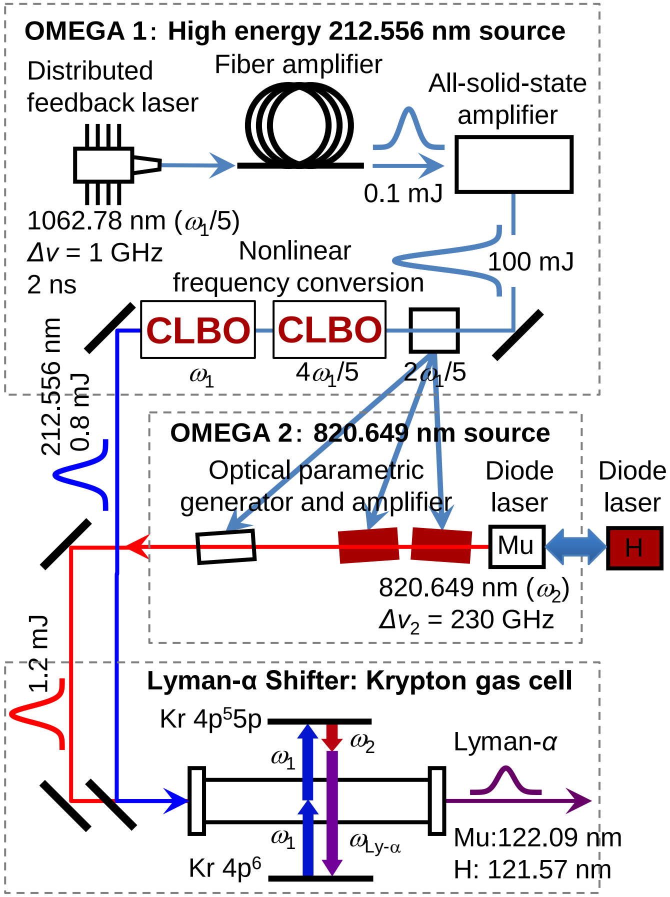
=> Demonstration of ionization from silica aerogel
is planned at RIKEN-RAL.

Mu Ionization Laser

Remove e^- for g-2 measurement (and acceleration) with lasers



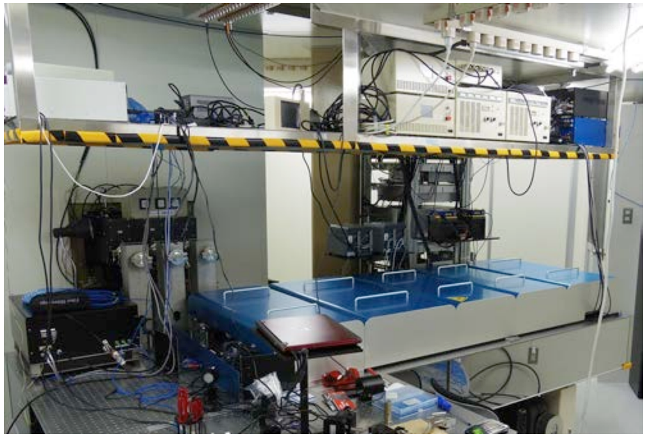
Improved Coherent Lyman-α System Configuration



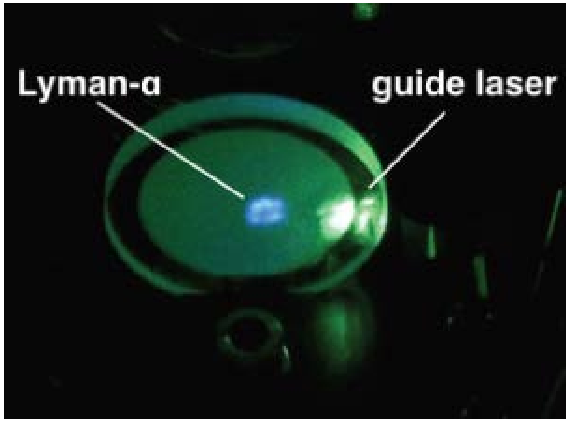
Lyman-α laser progress

New Lyman-α laser developed by RIKEN laser group
for ultra-slow-muon-microscope project (USMM by Grant-in-Aid)
aimed for use of ultra-cold-muons for materials study
=> Laser intensity goal is 100 μJ (x100 improvement over record)

Lyman-α was introduced to the USMM beamline this year.
Laser tuning and calibration progressing
=> Good R&D for muon g-2/EDM laser
Ionization test (with Mu source from hot-W) this autumn



laser system installed in J-PARC (for USMM)



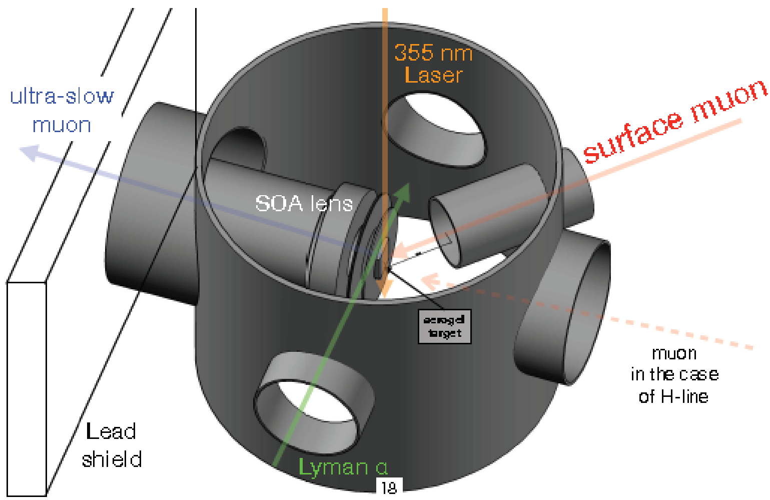
laser fluorescence in the source chamber

Ultra-cold muon from silica aerogel

Muonium to ultra-cold muon beam by ionization and acceleration
So far all the ultra-cold muon beam at KEK and RIKEN-RAL Muon Facility was based on Mu from hot-W (~2000K) and with static field (~10 keV).

Ultra-cold muon beam from silica-aerogel source need to be demonstrated.

Silica aerogel will be evaluated for
1) long term stability of Mu yield
2) brittleness and vacuum
3) electrical field stability
(use of meshed metal container)
and also we try good things
1) colder beam spread
2) multiple-pass laser mirror
3) other functions (spin control, ...)

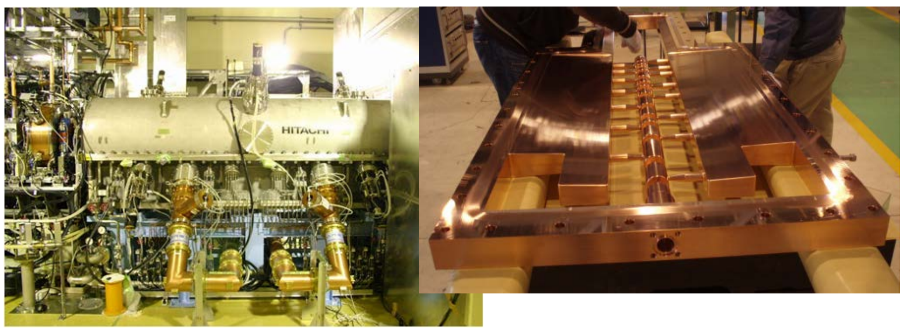


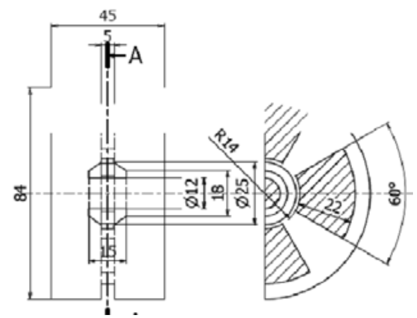
A new Muon Source chamber will be constructed for evaluation study.

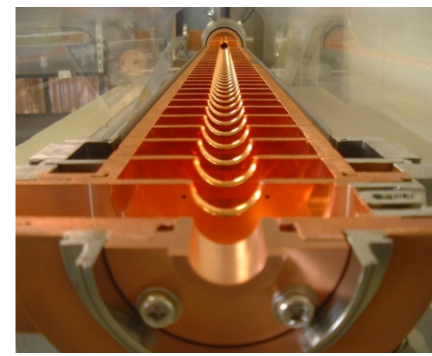
Baseline for muon g-2 accelerator

5.6 keV	0.34 MeV	5.1 MeV	42.3 MeV	200 MeV
β≈0.01	β≈0.08	β≈0.3	β≈0.7	β≈0.94

	Bunching Section	Low-β	Middle-β	High-β
μe^-	RFQ (324 MHz)	Interdigita-H (324 MHz)	CDS or DAW (1300MHz)	Disk loaded structure (1300MHz)

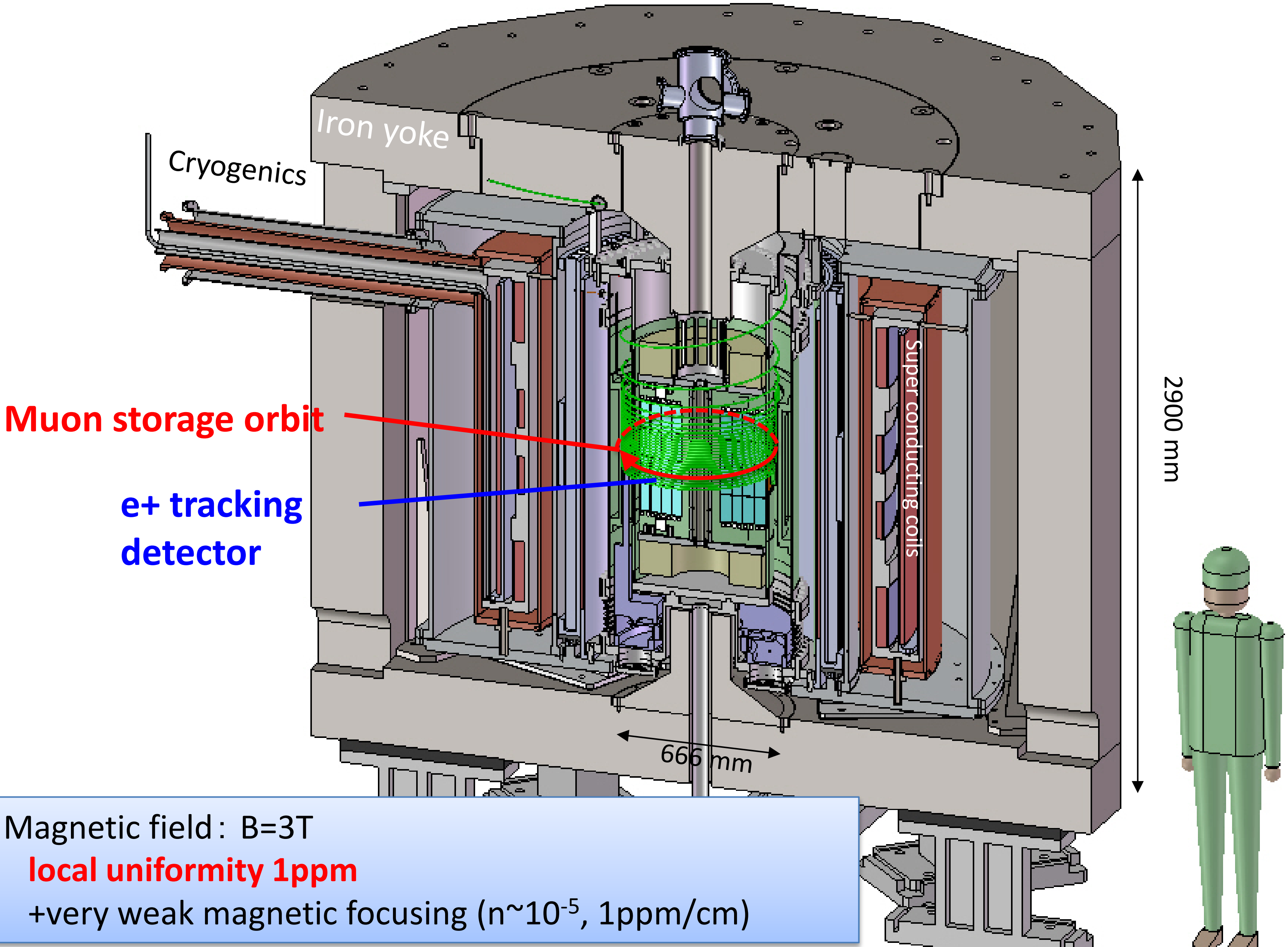






Initial acceleration simulation
for ex. RFQ capture loss~30%, muon decay x 0.7

Muon storage magnet and detector

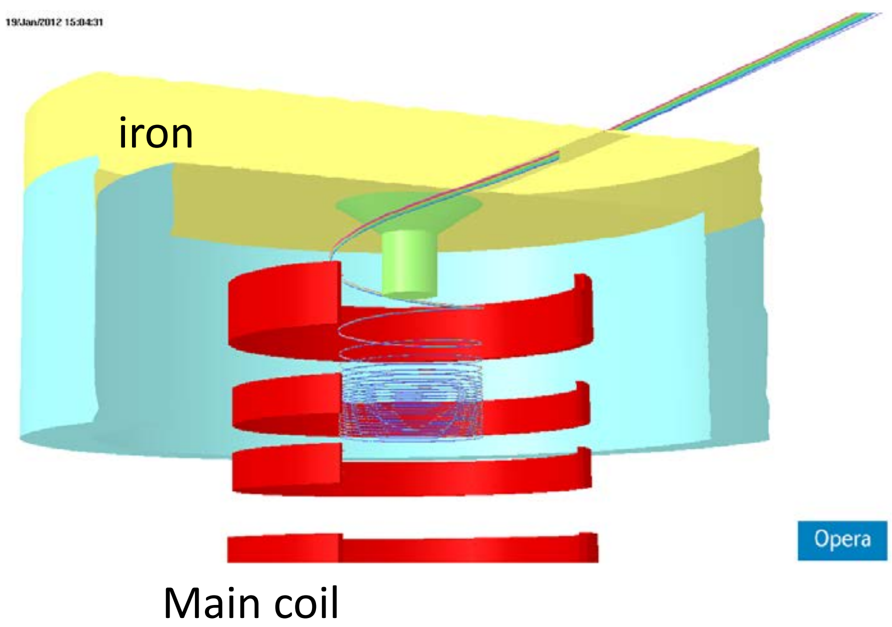


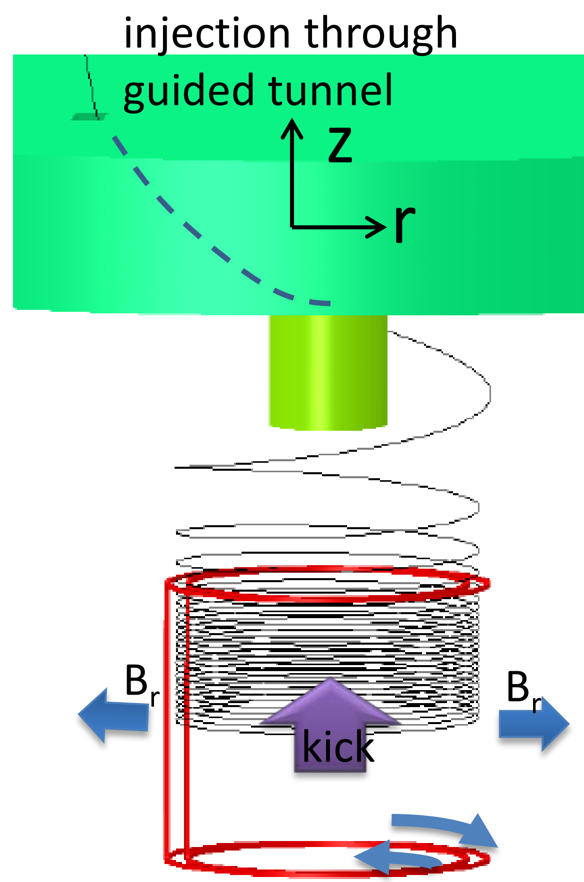
Magnetic field： B=3T
local uniformity 1ppm
+very weak magnetic focusing (n~10^{-5}, 1ppm/cm)

Beam Injection

Injection scheme

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





Design of injection-matching transport beamline.

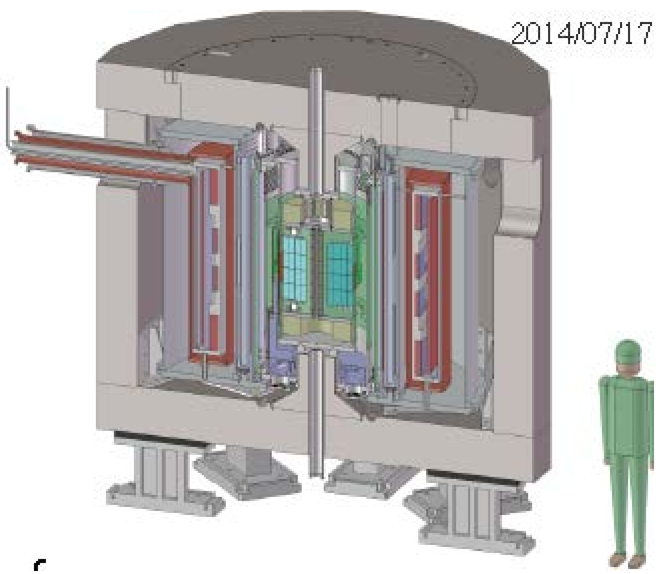
Spiral injection test with mini-solenoid and electron gun soon

Muon storage magnet and field monitor

Good synergy with MUSEUM (P. Strasser, MuHFS talk)

in physics ($\lambda=\mu_\mu/\mu_p$ needed for g-2)

ultra-precision magnet (3T vs 1.7 T)
 shimming method of MuHFS magnet

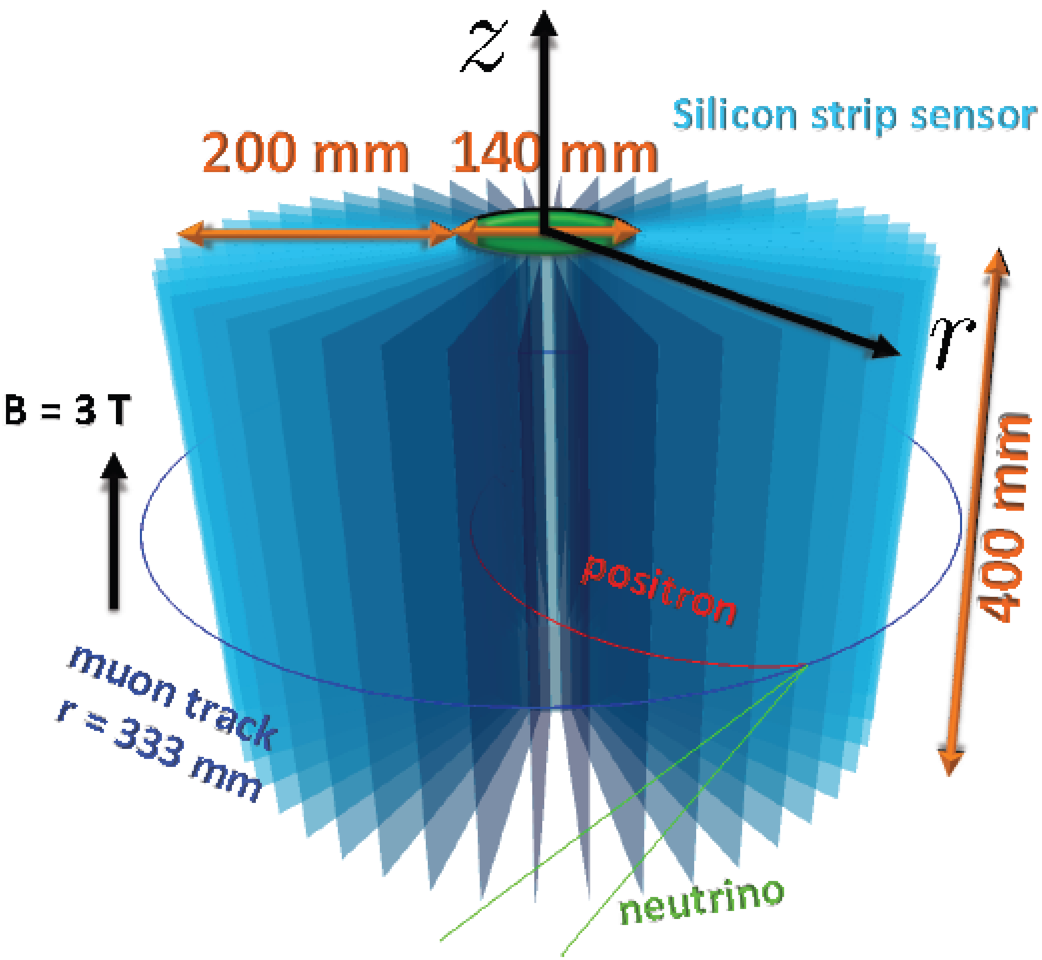


MuHFS magnet 1.7T

and field measurement
 monitoring system, NMR probe

Detector

measure muon decay positron tracks with Silicon-strip detectors
forward/backward decay gives different positron momentum



beam test with test sensor
muon beam at J-PARC
and electron at Tohoku-U
in progress

Collaboration

- > 98 members (…still evolving)
- > 21 Institutions
- Academy of Science, BNL, BINP, CRNS-APC, UC Riverside, Charles U., KEK, Korea U, NIRS, UNM, Osaka U., PMCU, RCNP, STFC RAL, RIKEN, Rikkyo U., SUNYSB, CRC Tohoku, U. Tokyo, TITech, TRIUMF, U. Victoria
- 9 countries
- Canada, China, Czech, France, Japan, Korea, Russia, UK, USA (alphabetic order)

Masaharu Aoki[8], Pavel Bakule[20], Bernd Bassalleck[24], George Beer[26], Gerry Bunce[27], Abhay Deshpande[19], Simon Eidelman[4], Douglas E. Fields[24], Miloslav Finger[6], Michael Finger Jr.[6], Yuya Fujiwara[17,14], Yoshinori Fukao[10], Noriyosu Hayashizaki[16], Seiko Hirota[10,14], Hiromi Iinuma[10], Masanori Ikegami[10], Masahiro Ikeno[10], Katsuhiko Ishida[17], Masa Iwasaki[17], Ryosuke Kadono[10], Takuya Kakurai[12], Takuya Kamitani[10], Yukihide Kamiya[10], Sohtaro Kanda[12], Frédéric Kapusta[5], Naritoshi Kawamura[12], Takashi Kohriki[10], Sachio Komamiya[14], Kunio Koseki[10], Yoshitaka Kuno[8], Alfredo Luccio[12], Oleg Luchev[2], Muneyoshi Maki[12], Glen Marshall[22], Mika Masuzawa[10], Yasuyuki Matsuda[9], Teijiro Matsuzaki[17], Tsutomu Mibe[10], Katsumi Midorikawa[2], Satoshi Mihara[10], Yasuhiro Miyake[10], William M. Morse[2], Jiro Murata[17,13], Ryotaro Muto[10], Kanetada Nagamine[23,10,18], Takashi Naito[10], Hisayoshi Nakayama[10], Megumi Naruki[10], Makiko Nio[21], Hajime Nishiguchi[10], Daisuke Nomura[10], Hiroyuki Noumi[15], Tomoko Ogawa[2], Toru Ogitsu[10], Kazuki. Ohishi[17], Katsunobu Oide[10], Masahiro Okamura[2], Art Olin[22,26], Norihito F. Saito[2], Naohito Saito[10,14], Yasuhiro Sakemi[7], Ken-ichi Sasaki[10], Osamu Sasaki[10], Akira Sato[12], Aurore Savoy-Navaro[5], Yannis K. Semertzidis[2], Yuri Shatunov[12], Koichiro Shimomura[10], Boris Shwartz[4], Wilfrid da Silva[25], Patrick Strasser[10], Ryuhei Sugahara[10], Michinaka Sugano[10], Ken-ichi Tanaka[10], Manobu Tanaka[10], Nobuhiro Terunuma[10], Nobukazu Toge[10], Dai Tomono[17], Eiko Torikai[12], Toshiyuki Toshito[11], Akihisa Toyoda[10], Kyo Tsukada[12], Tomohisa Uchida[10], Kazuki Ueno[17], Vlasov Vrba[1], Satoshi Wada[2], Akira Yamamoto[10], Kaoru Yokoya[10], Koji Yokoyama[17], Makoto Yoshida[10], Mitsuhiro Yoshida[10], Koji Yoshimura[10]

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

J-PARC PAC
Conceptual Design Report at J-PARC PAC (13 Jan 2012)
Stage 1 approval as E34 (21 Sep 2012)
Most recent PAC report highly recognized
our progress in muon source.

Collaboration Meeting held every half year.
9th C.M. will be in 6-8 Nov at KAIST in Daejon, Korea

Technical Design Report to be made this year
Expect to start running in 3~4 years (dep. on budget)

Several small grants obtained for development.
Overall budget is still a issue.

Summary

New muon g-2/EDM measurement is under preparation at J-PARC.
Since last year, there has been significant progresses.

Muon Source (x 10 Mu emission)
Practical Mu ionization study will follow

New Lyman-α Laser progressing in collaboration with USMM group

Also progress in accelerator, storage magnet, injection, detection.