Status and prospects of Muon g-2 experiment at J-PARC

Katsu Ishida (RIKEN)
for muon g-2/EDM collaboration
E34 at J-PARC

PHIPSI13 (Rome)
9-12 Sep 2013

muon g-2

Discrepancy (~3.6σ) between theory and measurement (BNL E821) need to be solved.

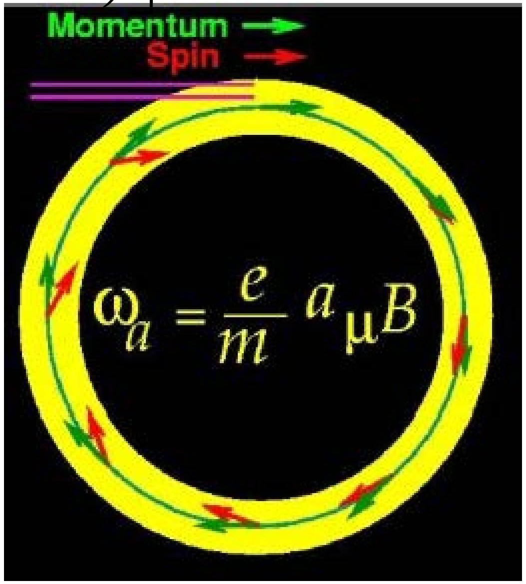
An improved measurement is planned at FNAL.

muon precession frequency in the uniform magnetic field

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \underbrace{\left(a_\mu - \frac{1}{\gamma^2 - 1} \right) \frac{\vec{\beta} \times \vec{E}}{c}}_{=0} + \frac{\eta}{2}\left(\vec{\beta} \times \vec{B} + \frac{\vec{E}}{c} \right) \right]$$

magic γ (p=3.09 GeV/c) is used for BNL/FNAL muon g-2

Storage ring size is 14m



New muon g-2 measurement at J-PARC
How is it different ?

Different approach was proposed at J-PARC (See N. Saito in PHIPSI11)

We do not use focusing electric field => E=0

g-2 measurement | EDM measurement

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

How is it possible?

Starting from thermal energy muon,

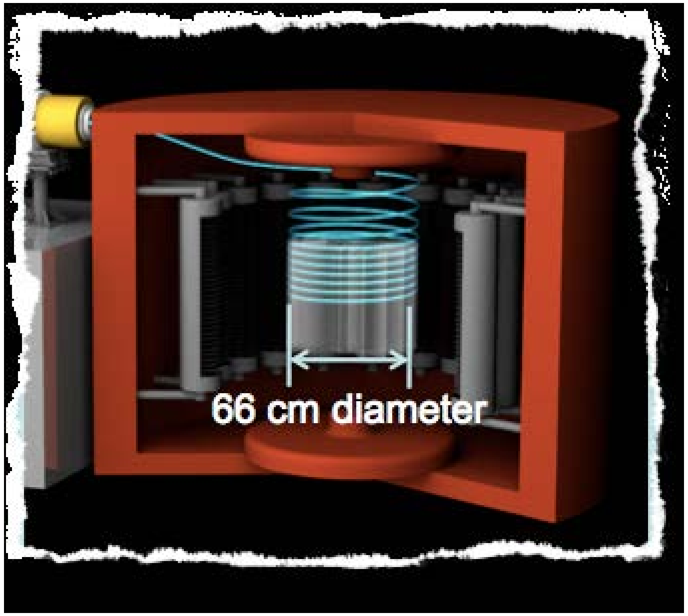
we make ultra-cold muon beam

so that beam focusing field is not needed

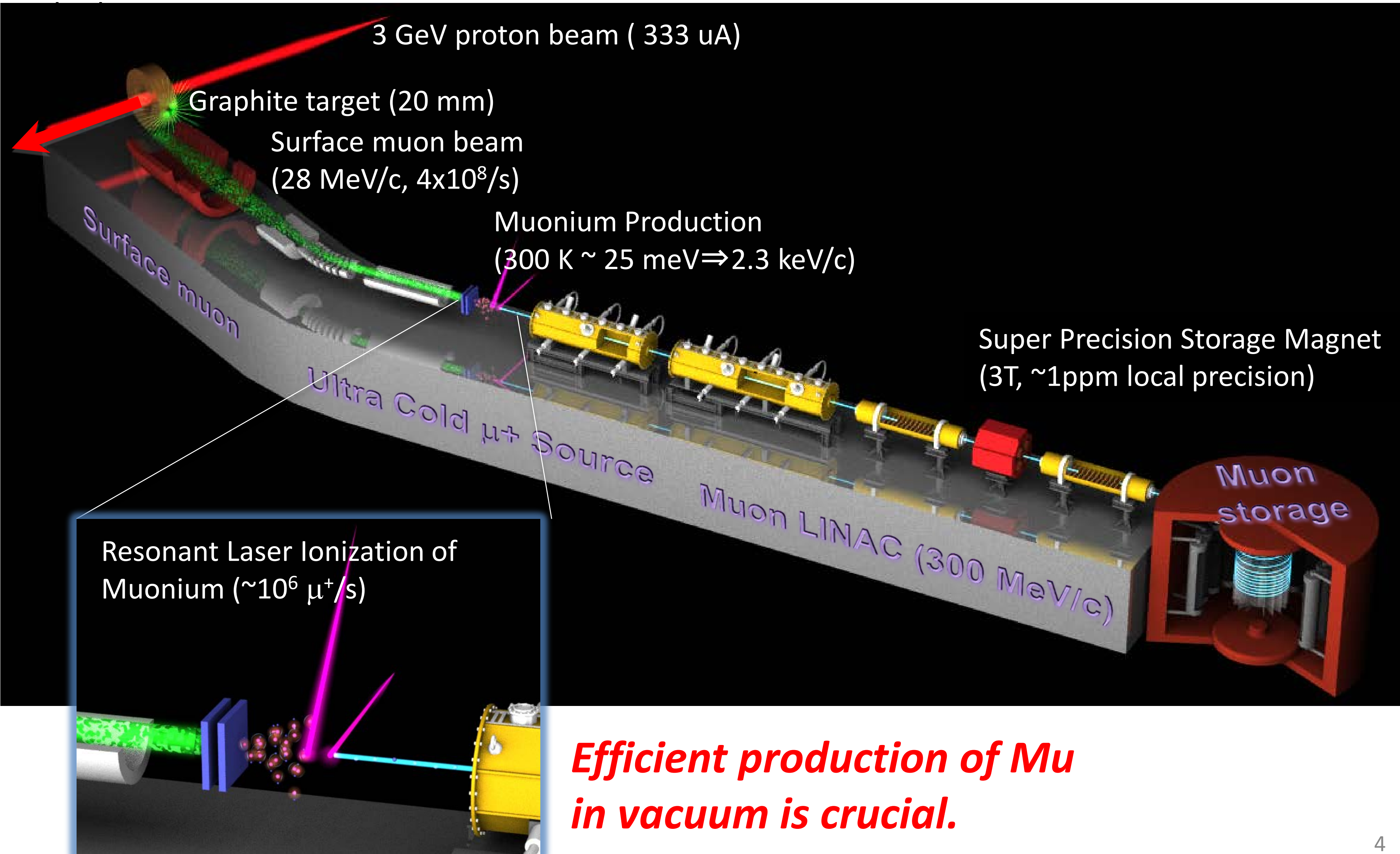
$$\sigma(p_T) / p_L \leq 10^{-5}$$

=> Free from 3 GeV/c magic momentum.

Use of MRI-type magnet as muon storage ring.



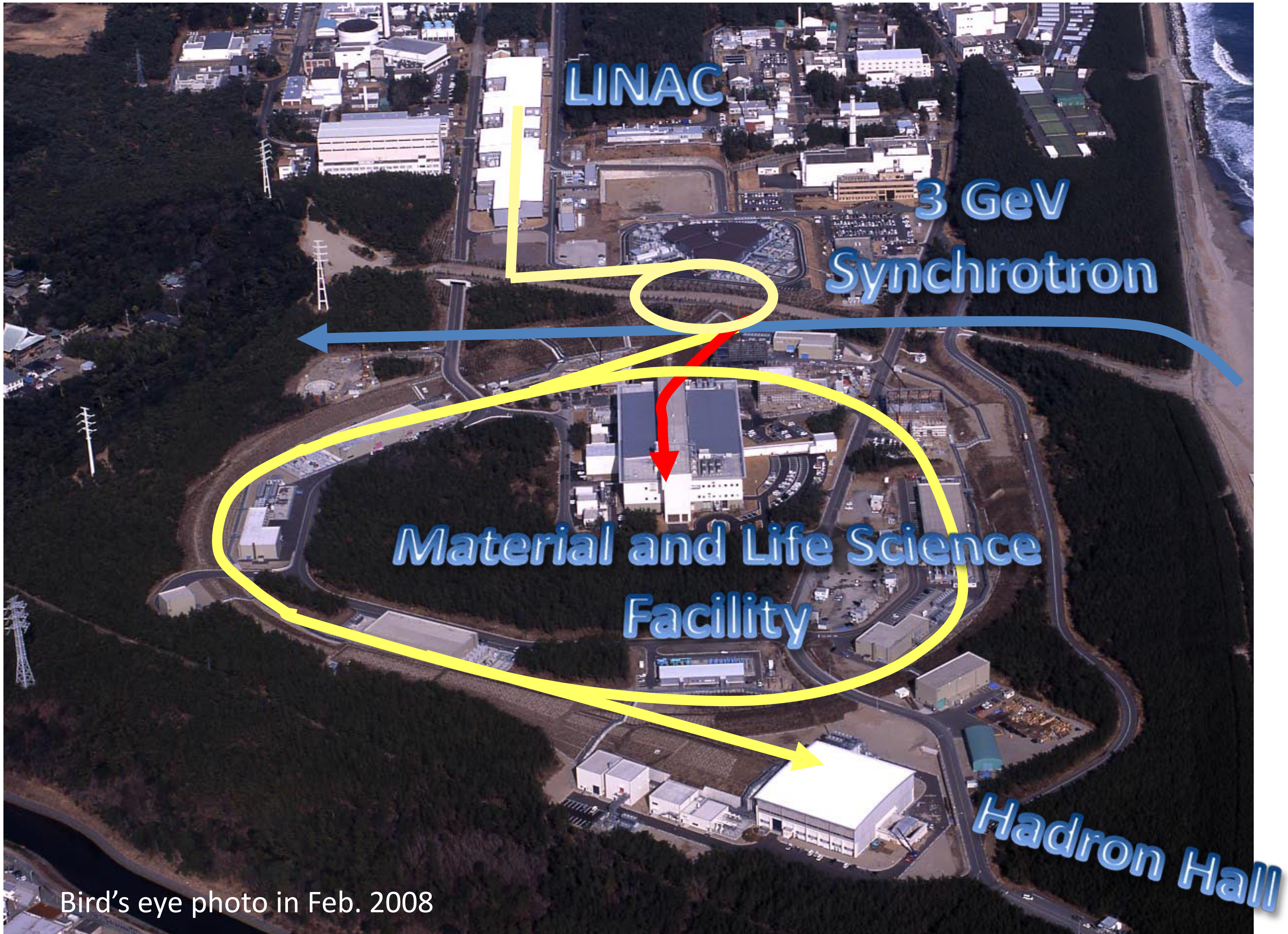
muon g-2 at J-PARC: Concept



Efficient production of Mu in vacuum is crucial.

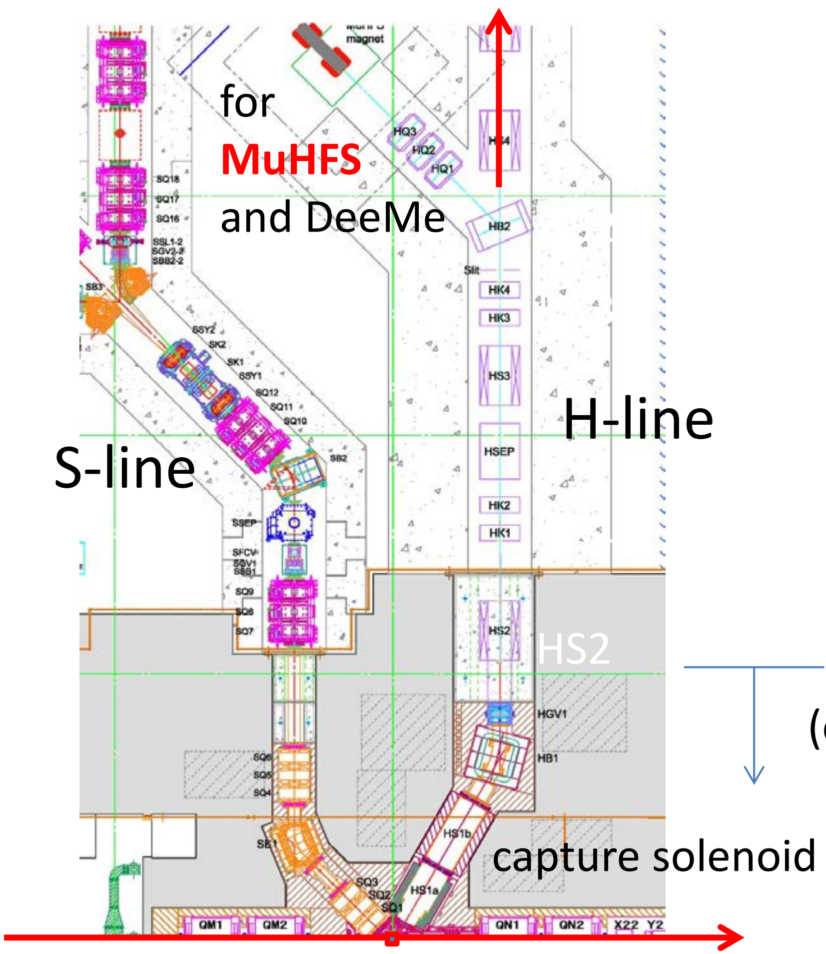
J-PARC

High intensity Japan Proton Accelerator Research Complex
1 MW at 3 GeV (0.3 MW at present), 1 MW at 50 GeV



H-line at J-PARC MLF

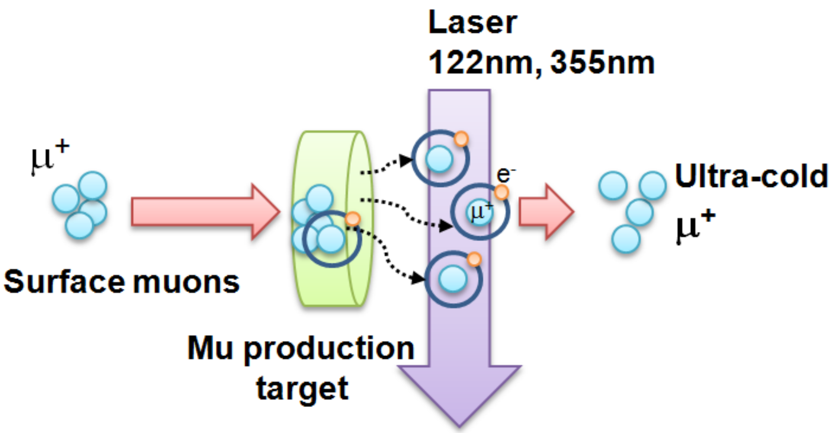
MLF (Materials and Life Science Facility) : intense pulsed neutron and muon beams



high intensity surface muon beam will be obtained (1~4 x 10^8 /s@4 MeV)

The beamline will be used also for MuHFS (-> H. Torii, 12 Sep)
-> Synergy in ultra precision magnet, field measurement, detector development etc
-> Also new improved muon mass for g-2

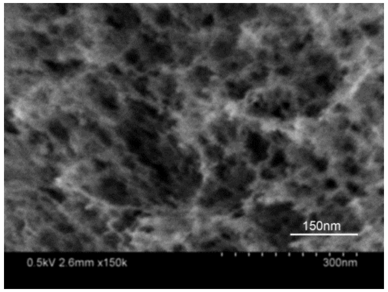
Ultra cold muon production:
Thermal muonium emission

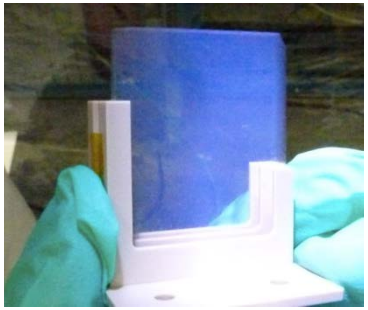


Stop muons in a material,
some diffuse out at thermal energy.
Good muonium emitter and
an intense laser to remove the electron
are essential.

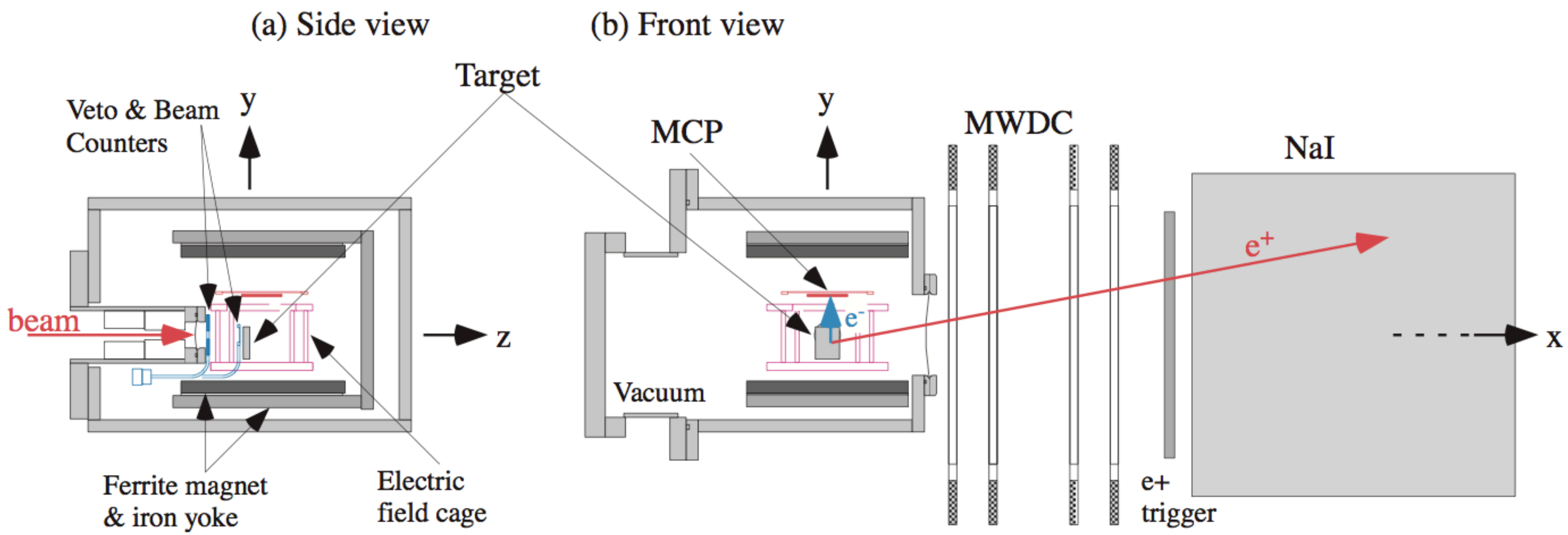
Silica powder has been known to be a good
Mu emitter at room temperature
Mu diffuse out through network of SiO_2 grains
(large surface area)

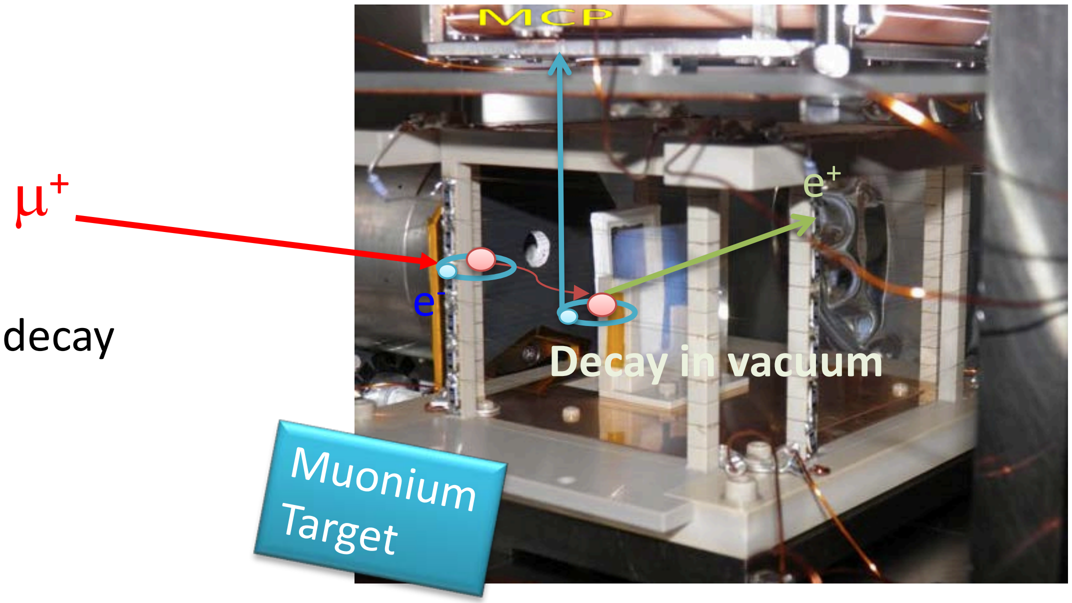
Silica aerogels with similar network structure
can be more easily handled and may fit better
our system





Ultra cold muon production materials study at TRIUMF



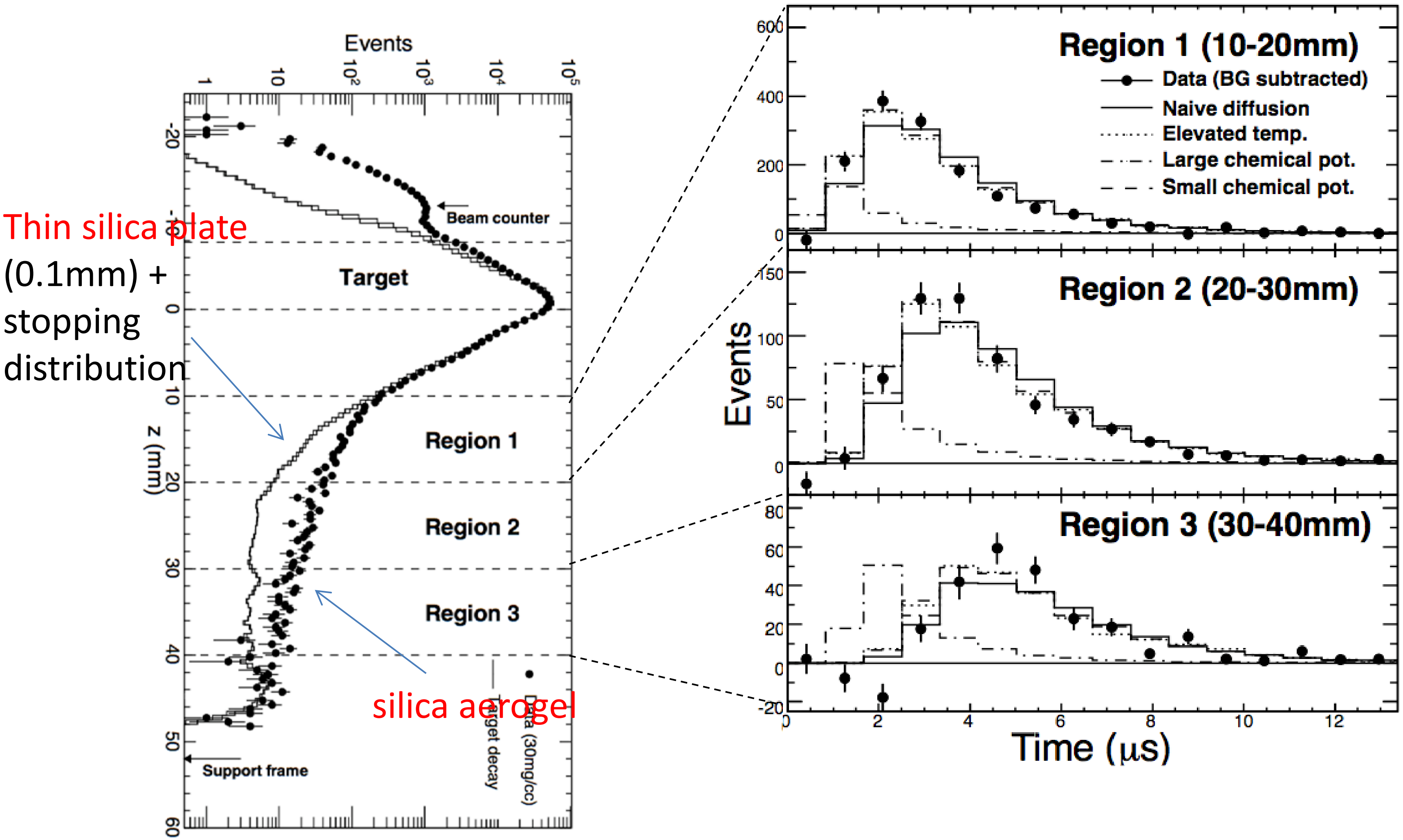


Tracking back of positrons from muon decay
=> muonium distribution in vacuum
=> emission efficiency
Nμ(in vacuum)/Nμ (in target)

Ultra cold muon production materials study at TRIUMF

Position of e+ trackback

Time spectrum after BG subtraction



to appear in PTEP, *arxiv:1306.3810*

Ultra cold muon production: materials study at TRIUMF

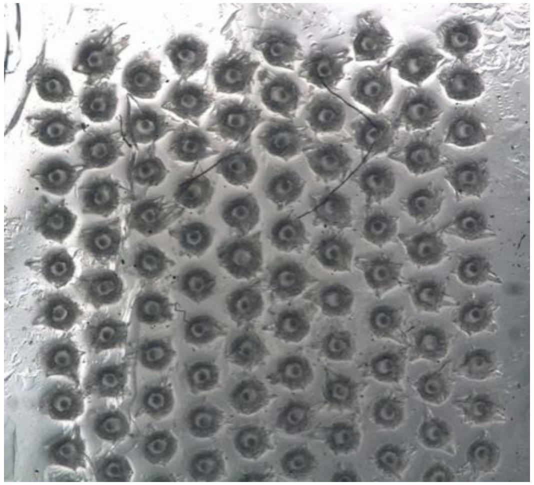
The first measurement showed the efficiency from silica aerogel was more than 5 times smaller than that for the silica powder.

We plan to carry out another measurement in October

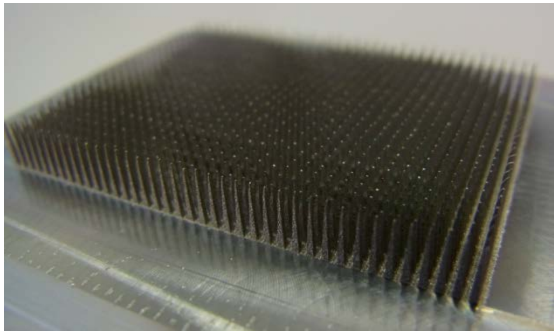
to test the aerogel samples with the sample surface area artificially increased.

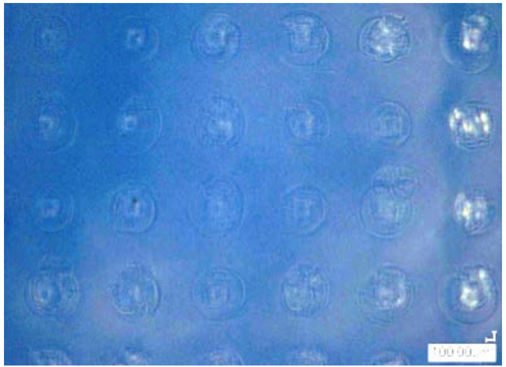
~5 times increase of emission is expected from simulation based on diffusion model

Laser drilling

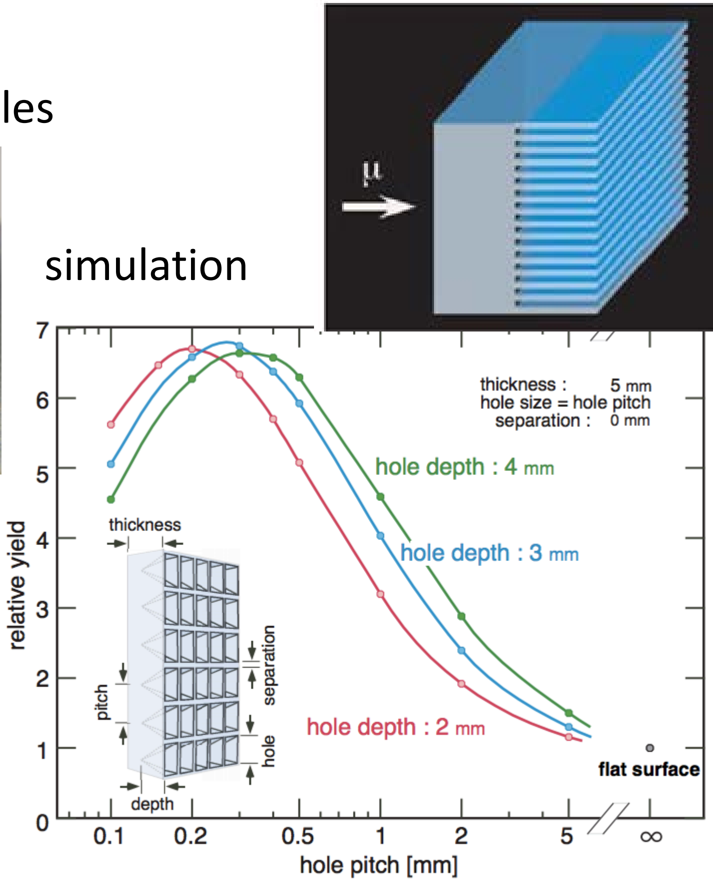


Push mold with multi needles





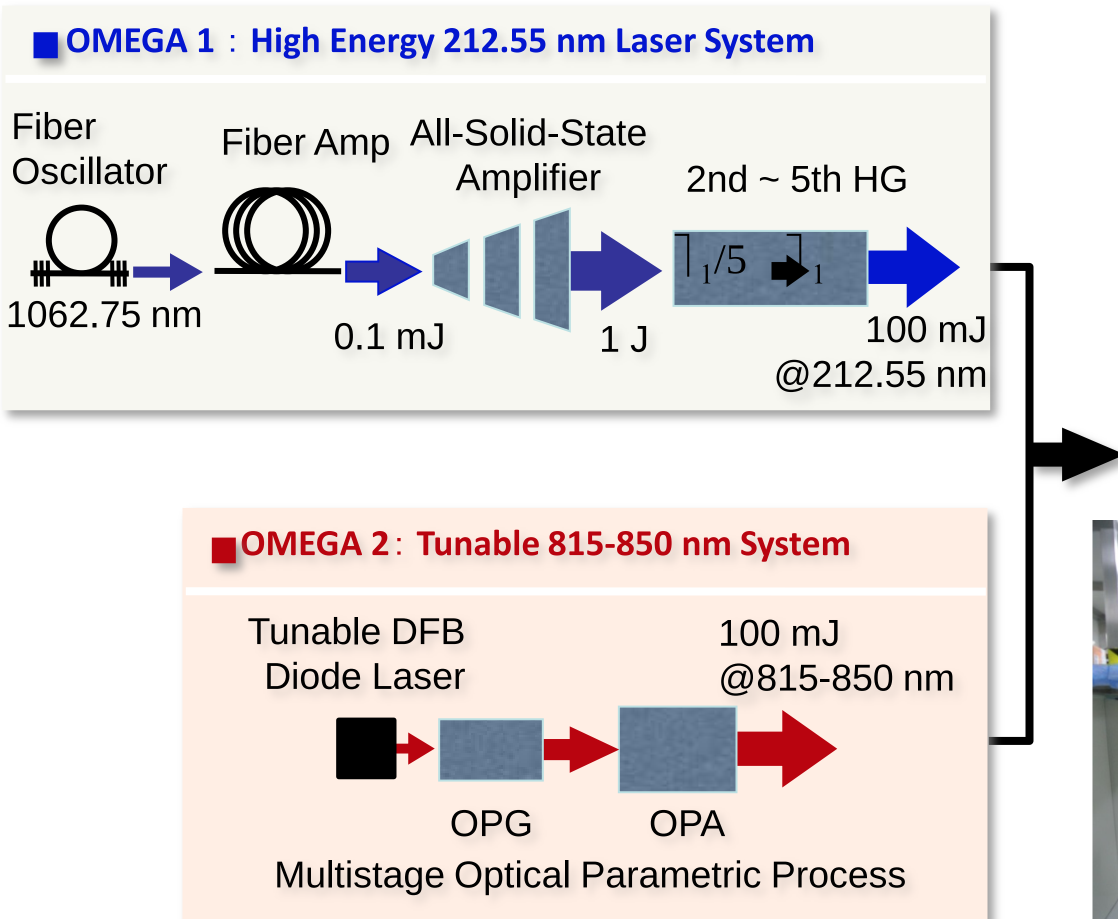
simulation

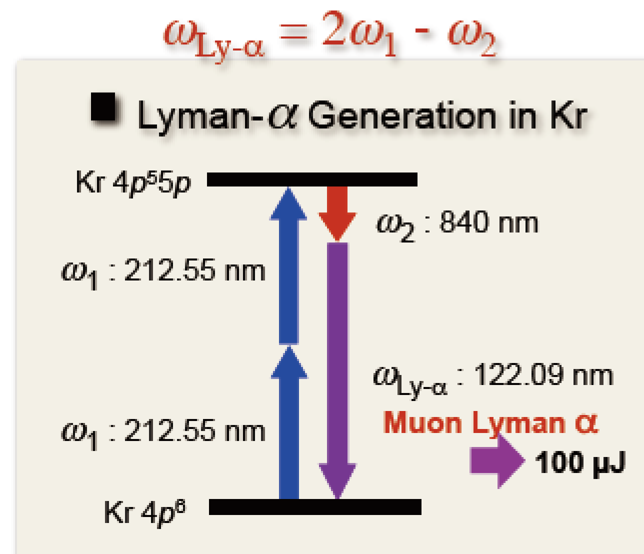


Ultra-cold muon production - ionizing Lyman-α laser

High power (x100) Lyman-α laser is under development at RIKEN.

To be completed soon, expect ionization efficiency >70%





Muon acceleration

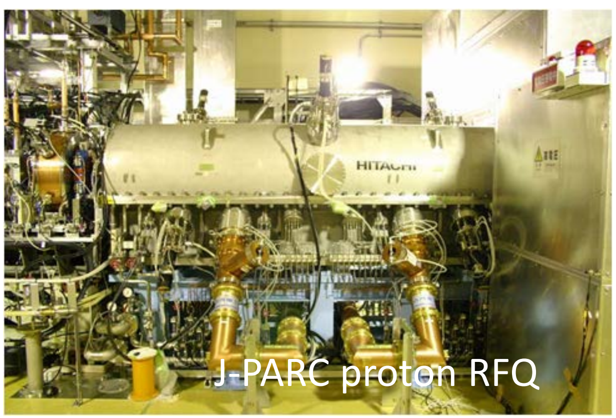
Acceleration from 0.03 eV to 0.3 GeV (x10^{10}) in the muon lifetime without heating

0.34 MeV	1.2	5.1	13.8	42.3 MeV	200 MeV
β≈0.08	β≈0.15	β≈0.3	β≈0.46	β≈0.7	β≈0.94

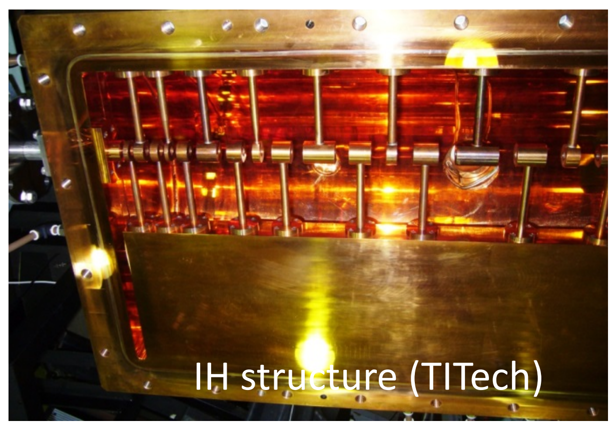
$\mu^+ \rightarrow$ [ ] [RFQ] [IH] [IH] [(IH, CDS, DAW … ?)] [Disk loaded structure]

Initial Acc. — Low-β — Middle-β — High-β

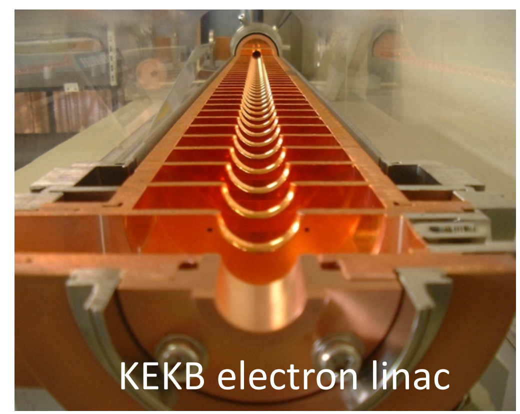
RFQ



IH linac



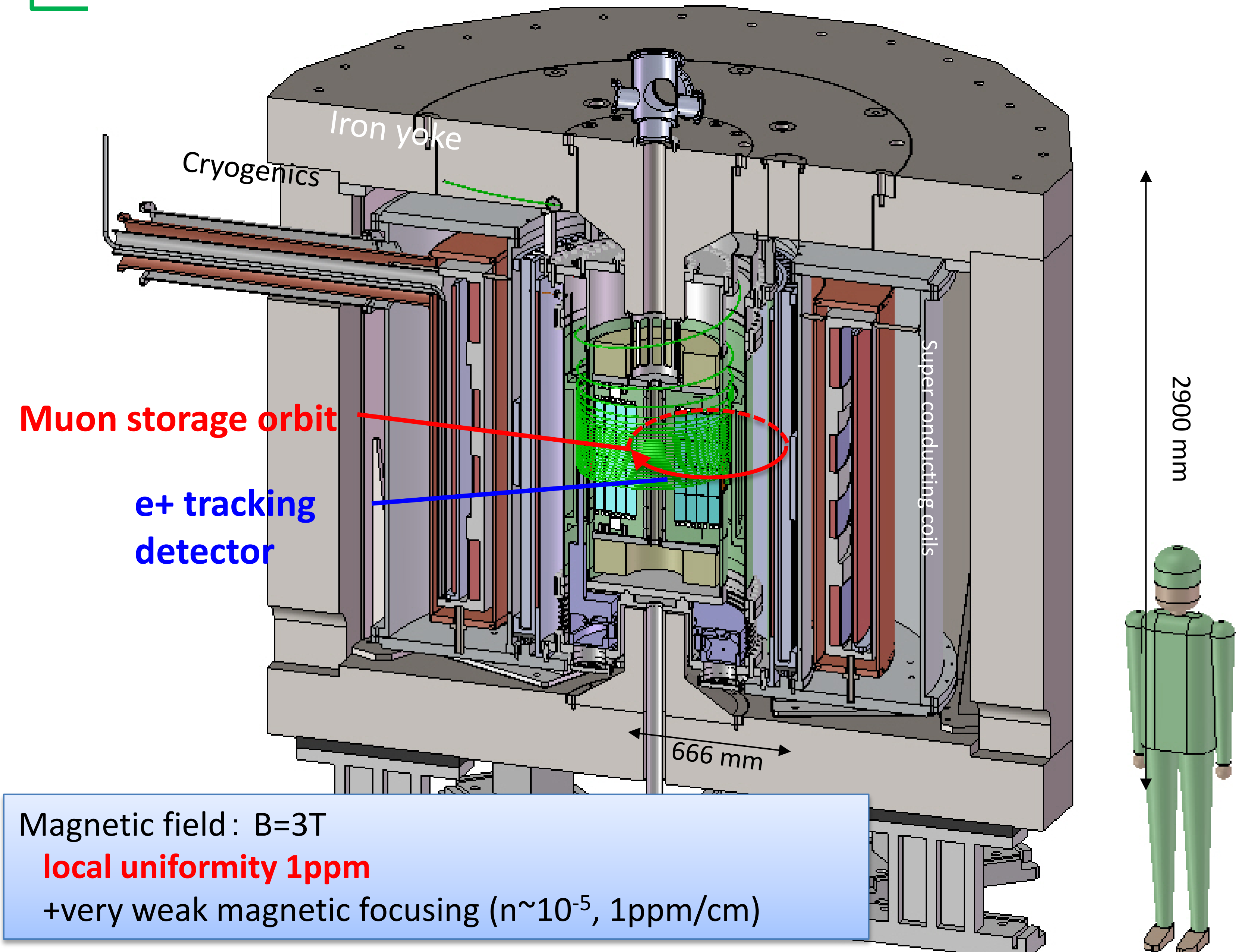
Disk loaded structure



KEKB/J-PARC accelerator group + TITech + Kyoto

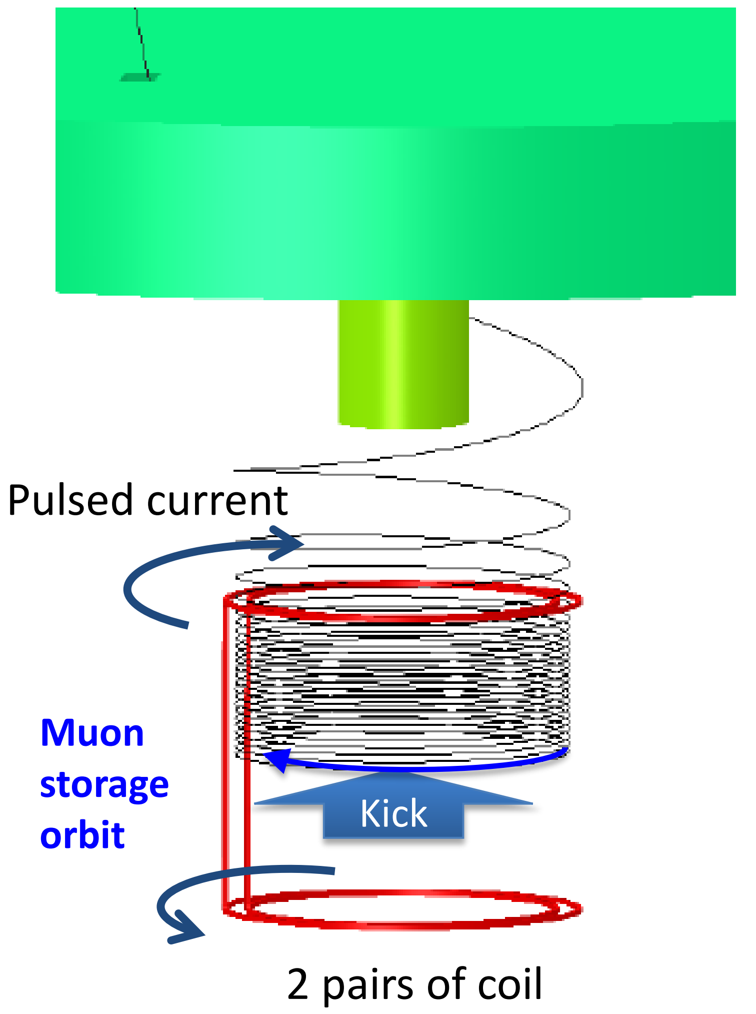
Beam simulations in progress. Muon acceleration test being planned at J-PARC

Storage ring



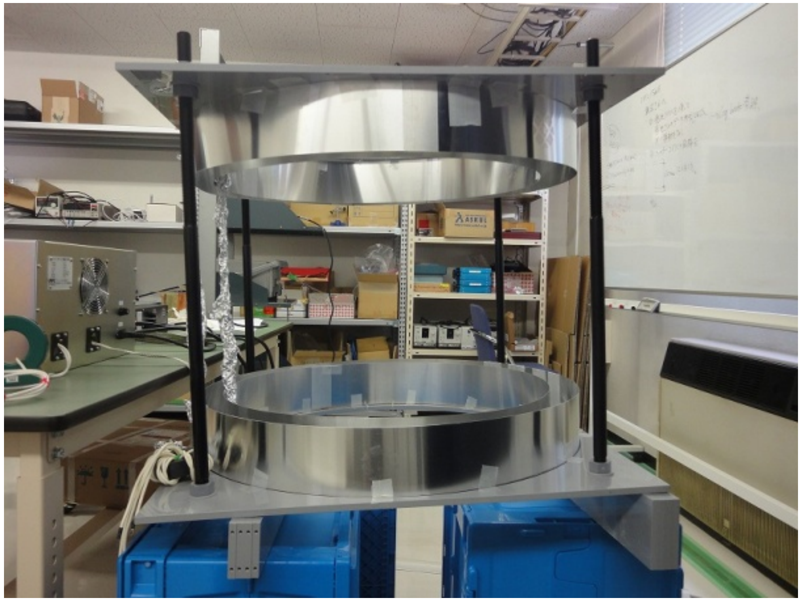
Magnetic field： B=3T
local uniformity 1ppm
+very weak magnetic focusing ($n \sim 10^{-5}$, 1ppm/cm)

Spiral muon injection



Kicker will stop vertical muon motion (7~9 mrad) in the muon storage area

Test kicker coil was produced
B~10G, ΔT~150ns(in 20 turns of muon)



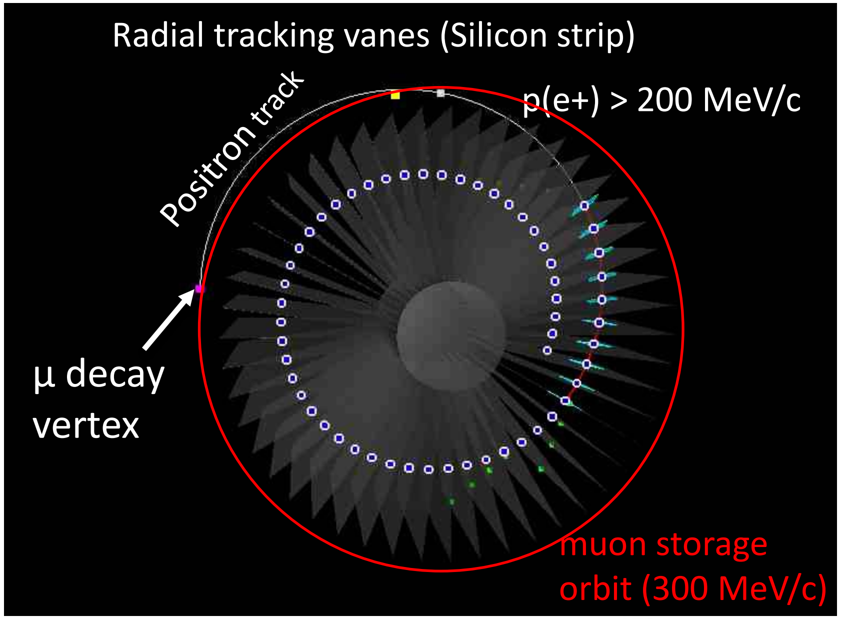
Detectors

Silicon strip tracker

240 mm (radial) x 400 mm (axial)

48 vanes

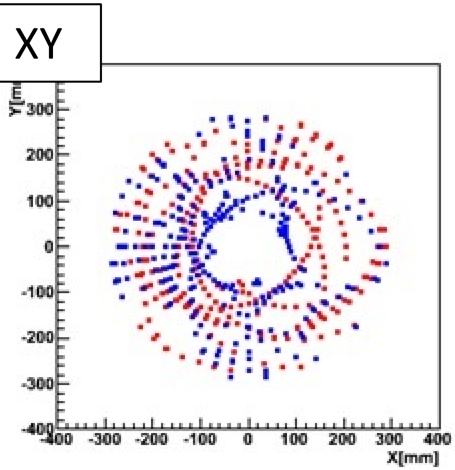
Trackback resolution d σ_r ~ 1mm

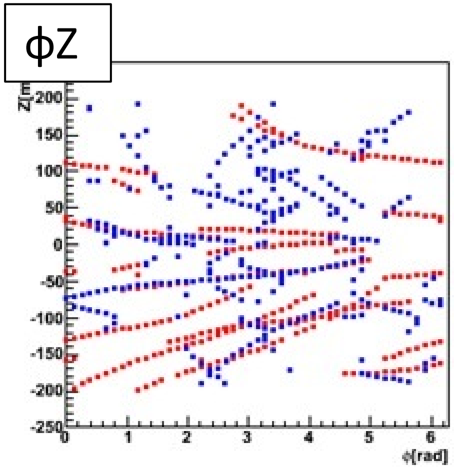


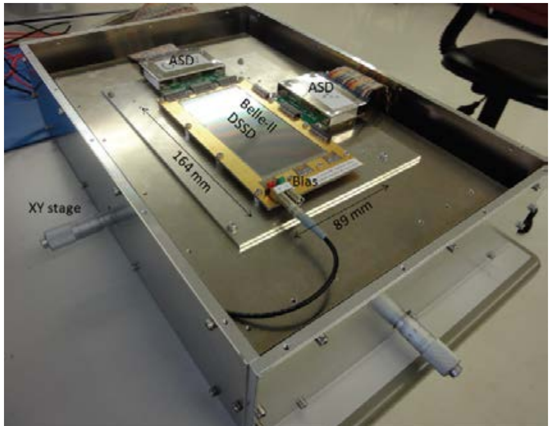
Track reconstruction study (KEK-RIKEN-LPNHE)

t=5-10ns, signal~14

effic. >97% for single track, ~80% for multi-track so far







Test detector module (KEK)

Studies on rate effects

Impact to precision B-field and E-field

Frontend ASICs under development (KEK)

Statistics 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

*J-PARC statistics based on 1 x 10^6/s ultra-cold muons and 1 year measurement

Status and milestones

Conceptual Design Report was presented at J-PARC PAC (13 Jan 2012)

The proposal was given stage 1 approval as E34 (21 Sep 2012)

Members are growing (more than 98 members)

Several milestones

M1) Demonstration of the ultra-cold muon production with the required conversion efficiency leading to an intensity of $1 \times 10^6 \mu^+/s$.

M2) Muon acceleration tests with the baseline configuration of low-β muon LINAC, i.e. RFQ, and IH LINAC.

M3) Tests of the spiral injection scheme.

M4) Production of a prototype magnet and development of the field monitor with the required precision.

M5) Demonstration of rate capability of the detector system for decay positron detection.

Summary

A new muon g-2 measurement was proposed at J-PARC and is under preparation.

The project use different approach from BNL/FNAL g-2 and involves several new interesting R&Ds.

We are working to achieve ultra-cold muon beam at the required intensity.

Key components will be tested soon.

Progress also in other several aspect of milestones