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
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

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

magic \( \gamma \) (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

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.
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 ⇒ 2.3 keV/c)

Super Precision Storage Magnet (3T, ~1ppm local precision)

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 \((1\sim4 \times 10^8 \text{ /s@4 MeV})\)

The beamline will be used also for MuHFS \(\rightarrow\) H. Torii, 12 Sep

\(-\rightarrow\) Synergy in ultra precision magnet, field measurement, detector development etc

\(-\rightarrow\) Also new improved muon mass for g-2

S-line

H-line

to muon g-2

for MuHFS and DeeMe

3 GeV proton beam and production target

S-line

H-line

capture solenoid

(complete in 2012)
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
\[ N_\mu(\text{in vacuum}) / N_\mu(\text{in target}) \]
Ultra cold muon production materials study at TRIUMF

Position of e+ trackback

Time spectrum after BG subtraction

Thin silica plate (0.1mm) + stopping distribution

silica aerogel

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%

**OMEGA 1: High Energy 212.55 nm Laser System**

Fiber Oscillator → Fiber Amp → All-Solid-State Amplifier

- 1062.75 nm → 0.1 mJ → 1 J
- 100 mJ @212.55 nm

**OMEGA 2: Tunable 815-850 nm System**

- Tunable DFB Diode Laser
- 100 mJ @815-850 nm

Multistage Optical Parametric Process (OPG → OPA)

Lyman-α Generation in Kr

\[ \omega_{\text{Ly-\alpha}} = 2\omega_1 - \omega_2 \]

- \( \omega_1 : 212.55 \text{ nm} \)
- \( \omega_2 : 840 \text{ nm} \)
- \( \omega_{\text{Ly-\alpha}} : 122.09 \text{ nm} \)

Muon Lyman-α

100 μJ

Muon acceleration

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

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Initial $\beta$</th>
<th>Low-$\beta$</th>
<th>Middle-$\beta$</th>
<th>High-$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.34</td>
<td>$\approx 0.08$</td>
<td>$\approx 0.15$</td>
<td>$\approx 0.3$</td>
<td>$\approx 0.46$</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Initial Acc. Low-$\beta$ Middle-$\beta$ High-$\beta$

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 \((n \sim 10^{-5}, 1\text{ppm/cm})\)
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 $d \sigma_r \sim 1$mm

Track reconstruction study (KEK-RIKEN-LPNHE)
- $t=5-10$ns, signal $\sim 14$
- effic. $>97\%$ for single track, $\sim 80\%$ 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

<table>
<thead>
<tr>
<th></th>
<th>BNL-E821</th>
<th>Fermilab</th>
<th>J-PARC*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muon momentum</td>
<td>3.09 GeV/c</td>
<td></td>
<td>0.3 GeV/c</td>
</tr>
<tr>
<td>gamma</td>
<td></td>
<td>29.3</td>
<td>3</td>
</tr>
<tr>
<td>Storage field</td>
<td>B=1.45 T</td>
<td></td>
<td>3.0 T</td>
</tr>
<tr>
<td>Focusing field</td>
<td>Electric quad</td>
<td></td>
<td>Very weak magnetic</td>
</tr>
<tr>
<td># of detected $\mu^+$ decays</td>
<td>5.0E9</td>
<td>1.8E11</td>
<td>1.5E12</td>
</tr>
<tr>
<td># of detected $\mu^-$ decays</td>
<td>3.6E9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Precision (stat)</td>
<td>0.46 ppm</td>
<td>0.1 ppm</td>
<td>0.1 ppm</td>
</tr>
</tbody>
</table>

*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.

6th collaborator meeting
KEK, Nov 2012
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