Ultra-slow Muon Source for New g-2

K. Ishida (RIKEN)

Ultra-slow Muon Beam as muon source of new g-2 experiment

- Brief introduction (see Saito's presentation WG4)

Progress of slow muon development

- see Last talk by Y. Matsuda (NuFact05)

What's next?

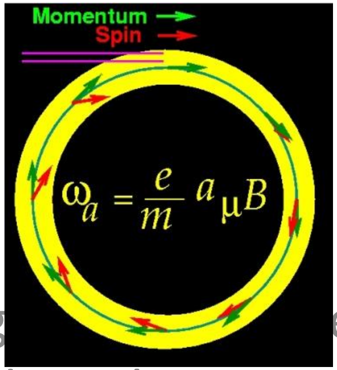
- Improvements

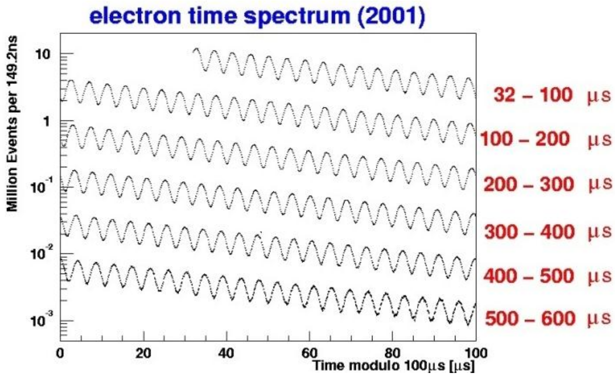
Muon g-2 experiment

Muon g-2 (anomalous magnetic moment) sum rule
sensitive to all the new physics beyond the standard model
BNL g-2 experiment result

$$\Delta a_\mu^{(\mathrm{EdR08})} = (29.7 \pm 7.9) \times 10^{-10}$$

shows 3.7 σ deviation from standard model prediction
(talks by L. Roberts
last Nufact08)





BNL g-2 was based on
Muon storage ring with homog etic fiel
Muon focusing by electric quadrupoles
Magic momentum (3.1 GeV/c) cancels E contribution to ω
Typical storage ring diameter 14m
The result was statistically limited but systematic error will also contribute

New muon g-2 proposal using ultra-cold muon beam

New g-2 experiment based on ultra-cold muon beam

see N. Saito's talk -> WG4, this afternoon

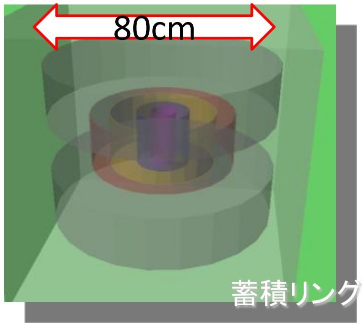
Muons with very small transverse momentum can stay in storage ring orbit until they decay even without focusing electric field.

Thus, no need of magic momentum (3.1 GeV/c) though acceleration to reasonably high γ (300 MeV/c) should help statistics (longer dilated lifetime)

Benefits: Compact muon ring, compact detection

Clean muon beam- no pion flash

Essential requirement is high-intensity well-aligned muon beam



Requirement on ultra-cold muon beam

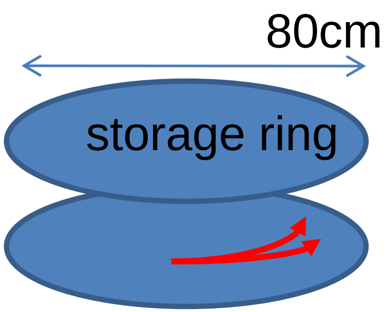
Small beam divergence

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

will limit vertical spread in storage ring

to 80 mm after 4000 turns (~5 $\gamma\tau_\mu$)

For p_L=300 MeV/c, p_T should be < 3 keV/c (T ~ 0.045 eV = 500K)



Muons originating from decay of pions produced by high energy protons have too high energies 100 MeV – 4 MeV

Very efficient cooling is required.

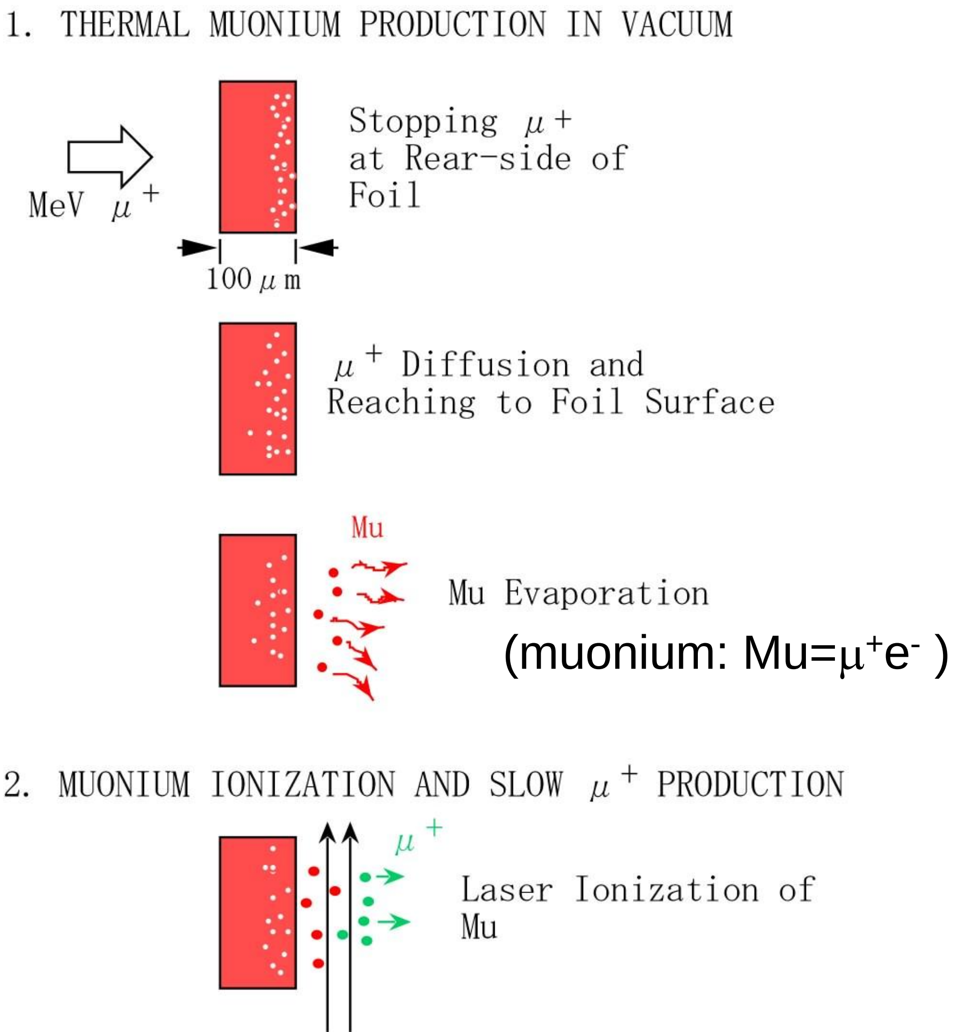
We should convert to ultra-cold muons and re-accelerate to achieve above criteria.

Development of cold muon beam at RIKEN-RAL

We have been developing cold muon beam at RIKEN-RAL.

(Initial stage was done by KEK muon group)

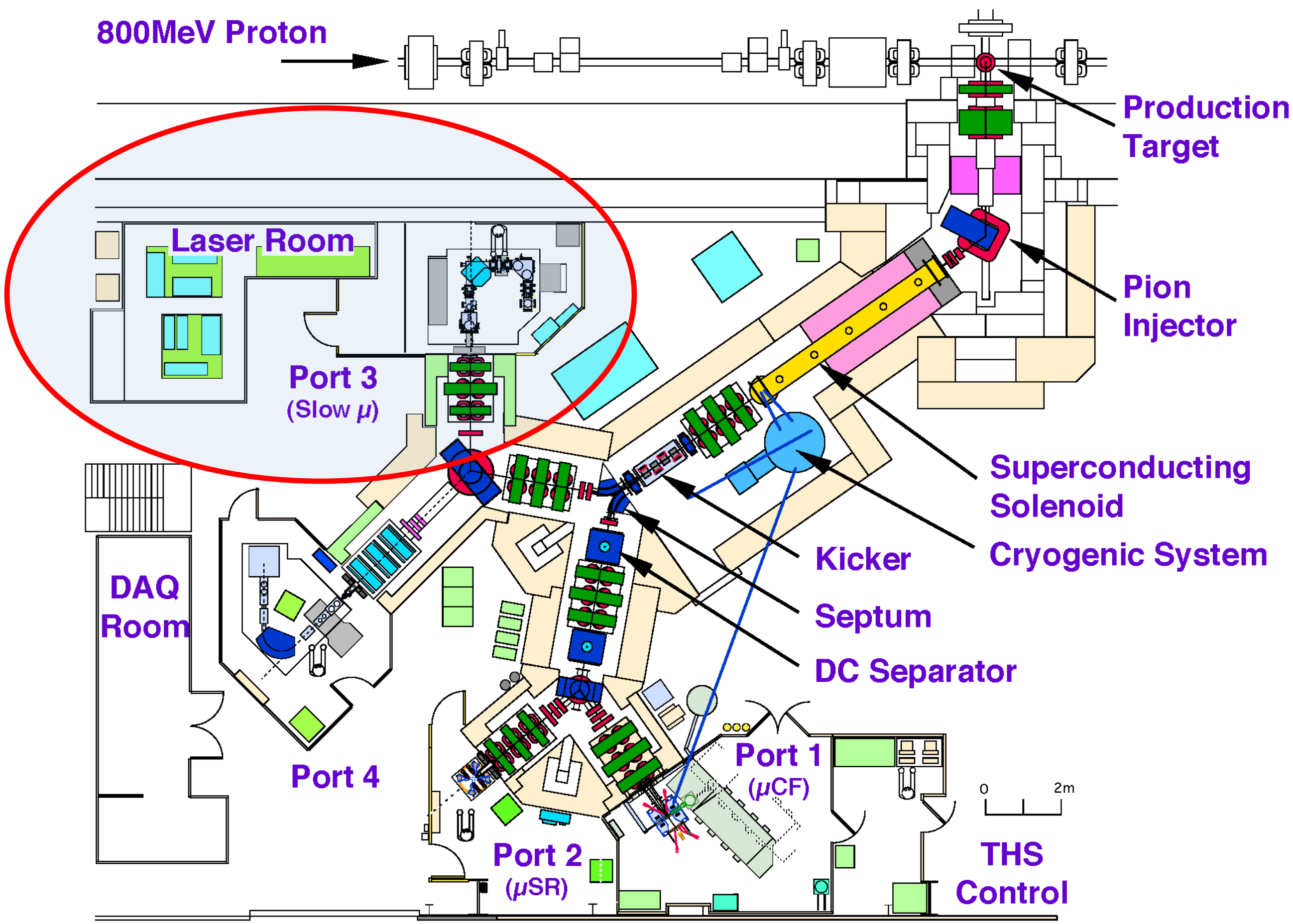
Original motivation was application to materials surface/sub-surface study by muon spin relaxation(μSR) method



RIKEN-RAL Muon Facility

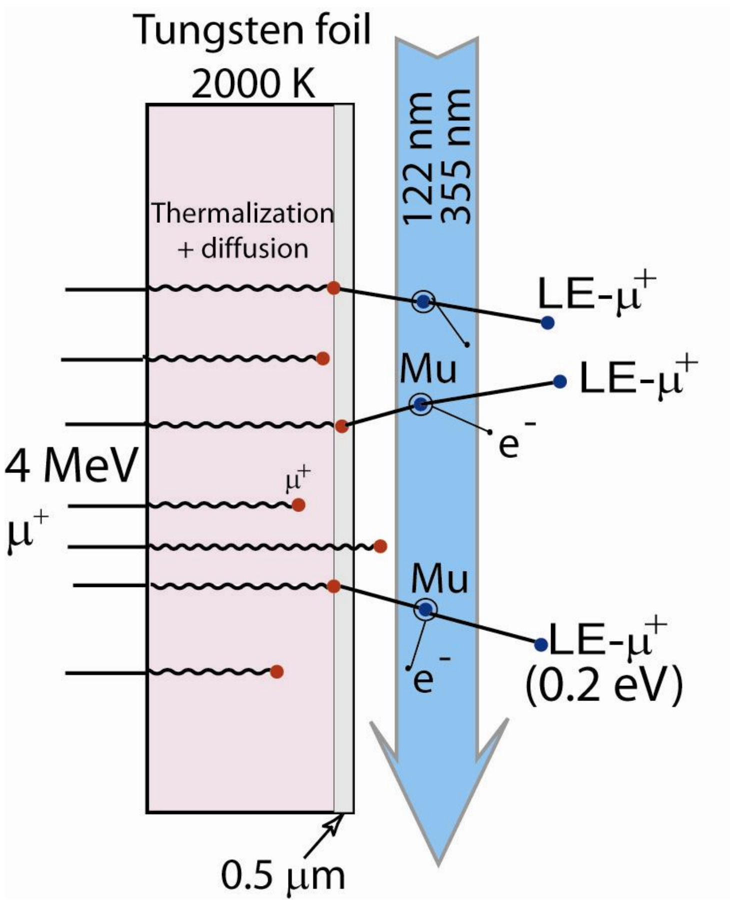
Rutherford Appleton Laboratory 200 kW proton source

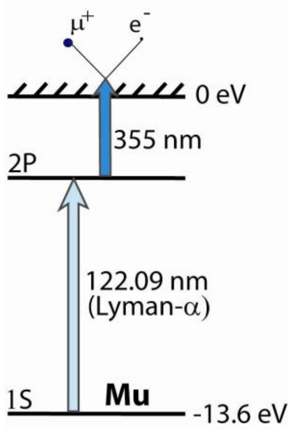
typical muon intensity : 10^6/s, pulsed beam @50 Hz



Laser ionization of muonium

4 MeV muons ⇒ (2%) 0.2 eV thermal Mu ⇒ 0.2 eV μ^+





122.09 nm (Mu)
121.57 nm (H)
121.53 nm (D)

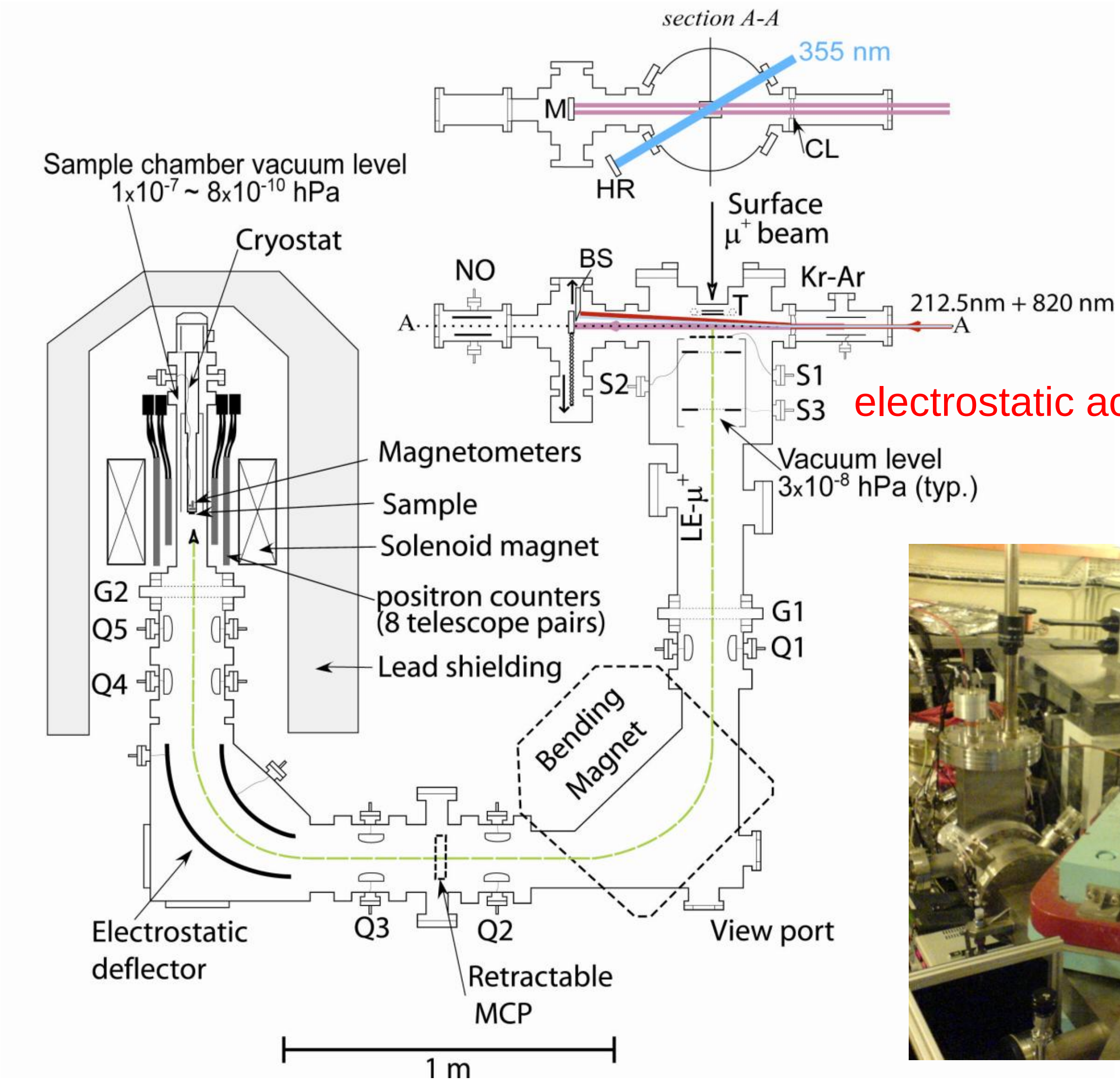
- **two** laser beams necessary for resonant ionization
- required very broad laser bandwidth due to thermal movement of atoms

1S-2P saturation intensity

I_{sat}=2.3 W/cm^2 monochromatic<100MHz ⇒ I_{sat}=4.6 kW/cm^2 (Doppler 200GHz)

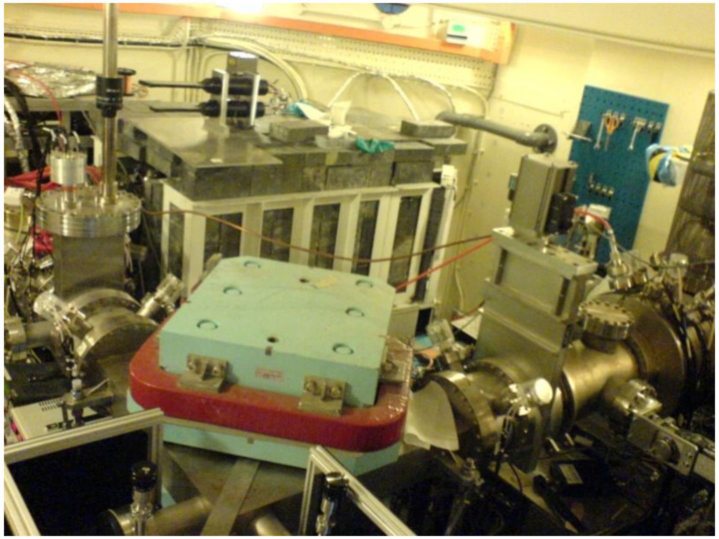
Main challenge: to generate VUV @ 122 nm and with 200 GHz (+ 1 ns jitter rel. to ext. trig.)

Transport beamline for slow μ⁺

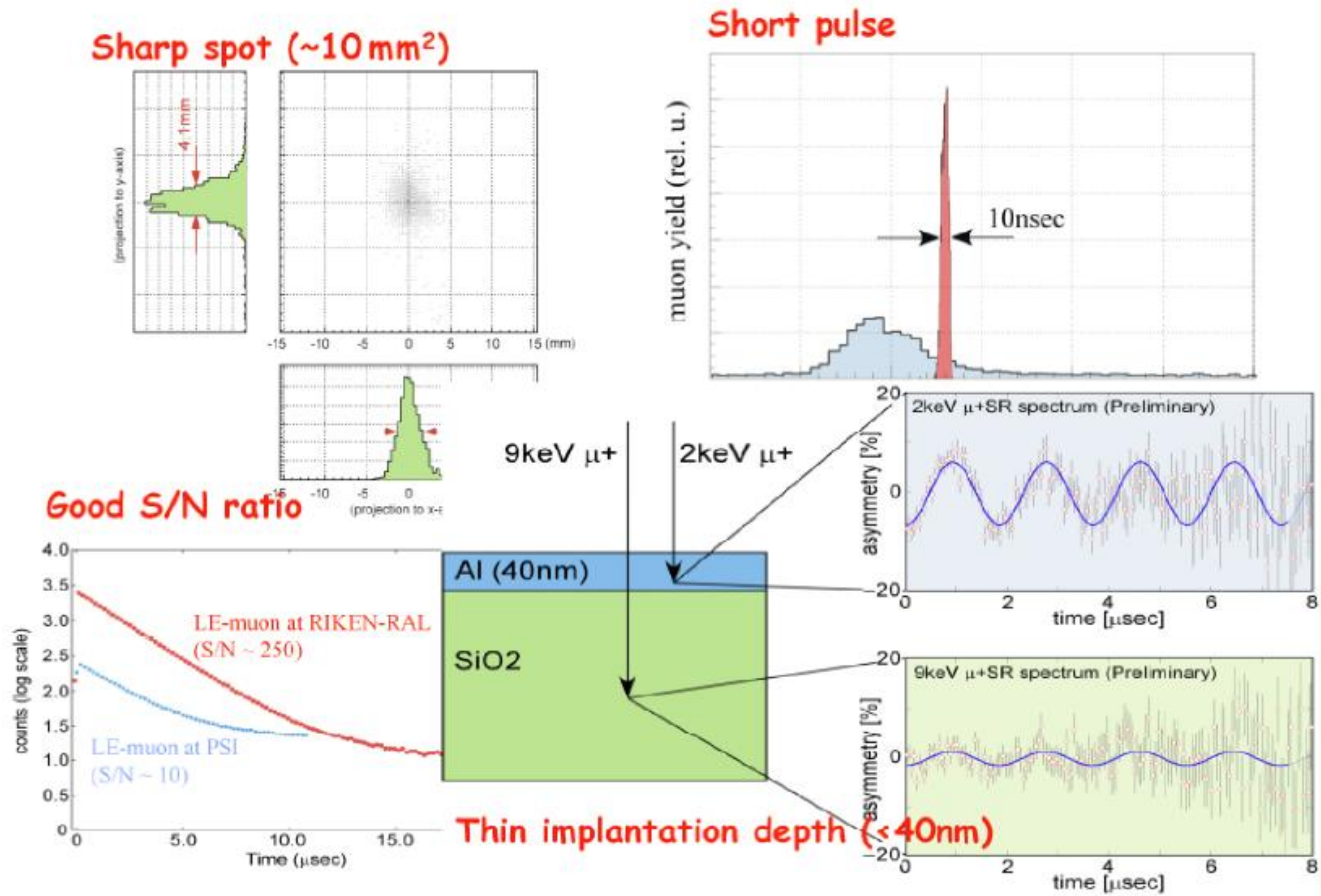


laser

electrostatic acceleration to 10 keV



beam properties measurement



present characteristics

Low energy μ^+ beam
Intensity at sample **~ 15-20 μ^+/s (starting from 10^6 muons)** Beam diameter (FWHM): **4 mm** Energy at target region **0.2 eV** Energy after re-acceleration **0.1-18 keV** Energy uncertainty after re-acceleration ~14 eV Pulse repetition rate **25 Hz** Single pulse structure 7.5 **ns** (FWHM) at 9.0 keV Spin polarisation ~**50%** Long time background < 1/250

Overall efficiency was 10^{-5}
Based on hot tungsten (2100 K)
We need lots of improvement in intensity and properties

Improving the ultra-cold muon source at RIKEN-RAL

1. Stopped muon intensity (density) in muonium emission target

2. Muonium emission efficiency and temperature

3. Laser ionization

4. Ultra-cold muon extraction optics

Source muon intensity

1. Stopping more muons

We will eventually need J-PARC

(x5 proton beam) (x2 production target) straightforward comparison

(x~10 curved solenoid beamline) talk by K. Nakahara, WG4, Friday

while it will take several more years to develop

At RAL we can test,

Stronger muon focusing at stopping target

optics, additional device

Using muon guide (it will work!)

Muonium production Target

Muon should diffuse to the surface, emitted to vacuum,
and better avoid re-absorption
Diffusion rate, or large surface area, small work function …
We have used 2000K tungsten.
Cold (room temperature) muonium source is preferred for g-2
Room temperature target such as SiO2 powder
  is equally efficient (~2% emission)
  muonium spread less spatially in vacuum
  but enough away from the surface
 and also automatic ionization gain (x3) with less Doppler broadening
Handling of fine powder is a problem.
We will test several other candidates in more solid form:
  high-density silica aerogel, etc

Laser development in RIKEN

Collaboration with RIKEN Laser Group

S. Wada, N. Saito, T. Ogawa, O. Louchev and K. Midorikawa

1.Supreme expertise

Guide star for Subaru Observatory in Hawai, …

stable and maintenance free laser…

2. In house technique of special crystal growing

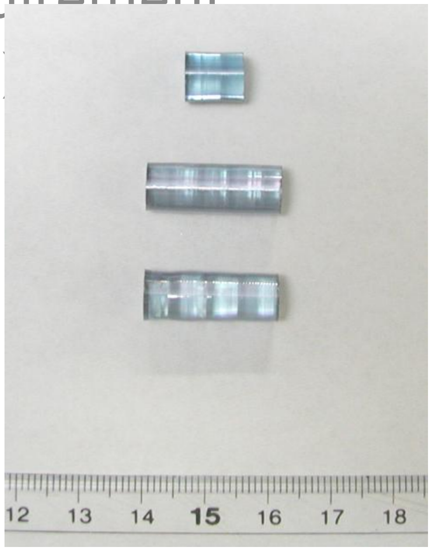
wave length matching our requirement

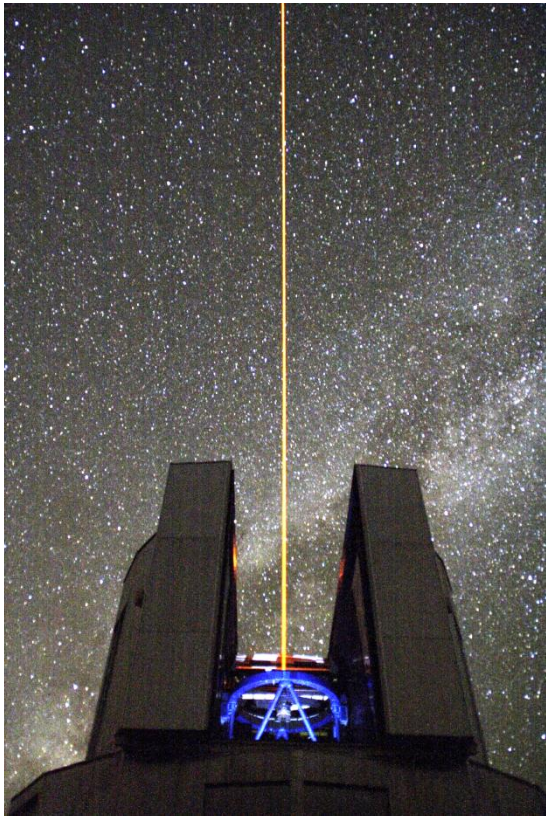
Nd:GdVO4 (1062.75 nm->212.55nm)

3. Compact laser system

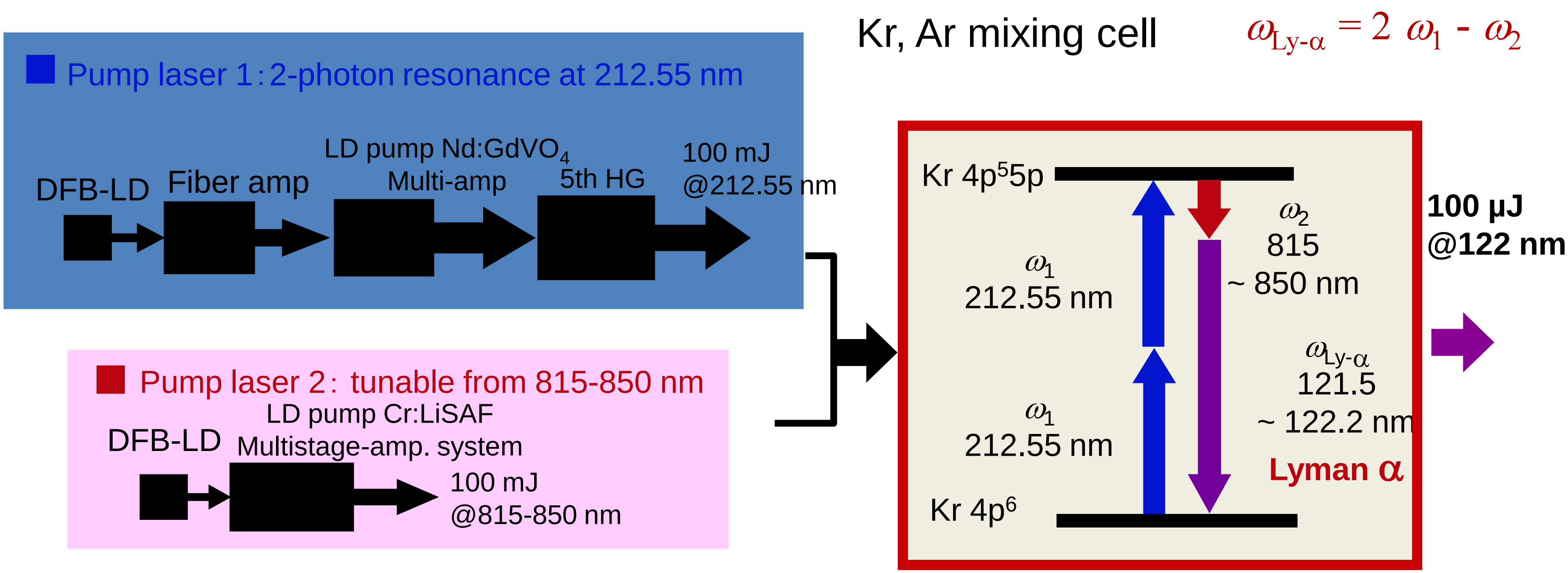
and energy efficient

4. Simulation of 4-wave mixing





Proposed laser system



We are confident we can improve pump laser powers by at least x10
(estimated intensity of present laser system ~1 μJ)
Lyman α intensity would bi-linearly or linearly increase with the pump laser intensity
However, saturation effect of 4-wave mixing by phase mismatch should be checked
if necessary, saturation could be avoided by multiple focusing optics

Ultra-cold muon extraction

Initial stage of muon acceleration

affects the size and pulse width of the re-accelerated muon beam

Einzel lens and electric muon channel (+mass analyzer)

We need improvement (stability, alignment,…)

to understand ultimate good quality of the ultra-cold muon

To be studied

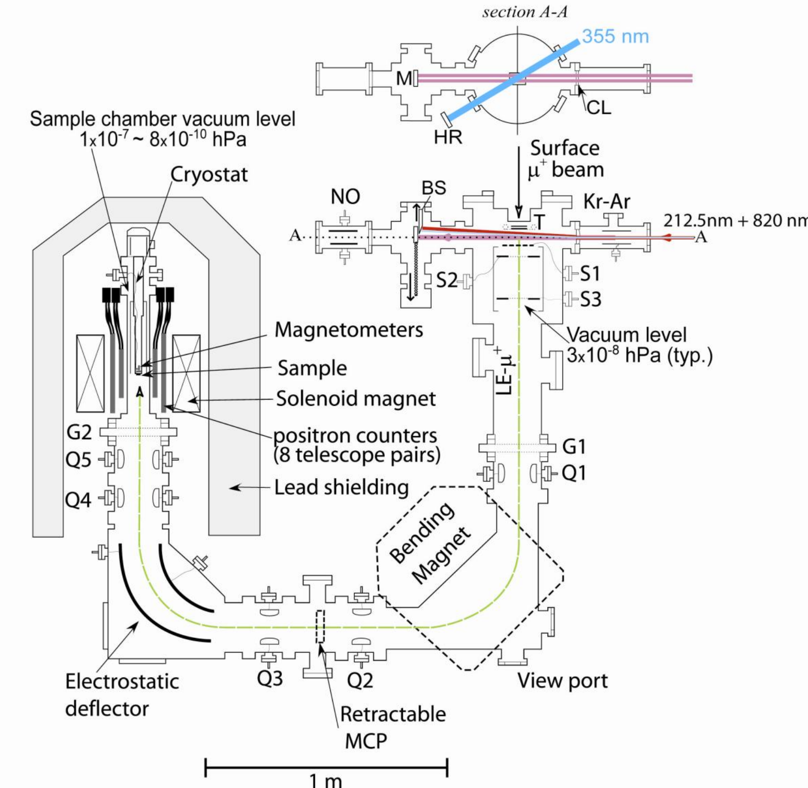
laser irradiation area and timing

(matching to muonium spread)

initial acceleration field gradient

Geant4 simulation has started

Completely new system may be designed



Expected cold muon yield (very preliminary)

At RIKEN-RAL

At present 20 /s

Laser x100

Cold muon source x3

Muon density x2

600 x 16 = 10000 mu+

At J-PARC

Proton beam and target x10

New muon channel x10

10^6 /s

Summary

A new g-2 experiment is proposed based on ultra-cold muon source

We have been developing a cold muon source at RIKEN-RAL

for materials application

A few more improvements are necessary for the beam properties to match the new g-2 requirement

We have plans for further study

- Room temperature target should be developed
- Intense laser is likely to promise x100 improvement
- To fully understand cold muon beam extraction

Collaborators on new g-2 source development

M. Iwasaki, K. Ishida, T. Matsuzaki, K. Ohishi, D. Tomono

T. Wada, N. Saito, T. Ogawa, O. Louchev, K. Midorikawa (RIKEN)

P. Bakule (RAL)

Y. Matsuda (Univ. Tokyo)

K. Nagamine, K. Yokoyama (UC Riverside)

N. Saito, T. Mibe, H. Iinuma,

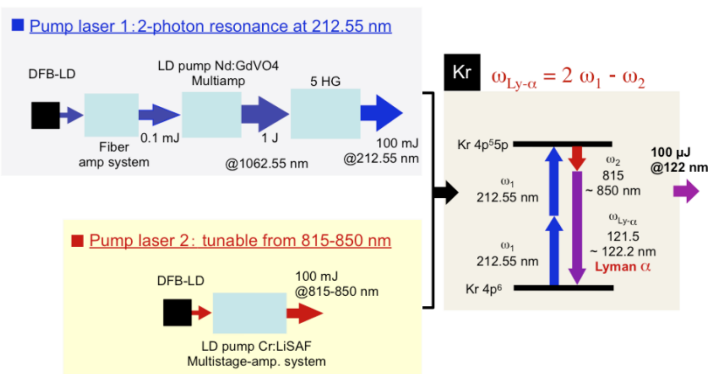
Y. Miyake, K. Shimomura, P. Strasser, N. Kawamura (KEK)

W. Higemoto (JAEA)

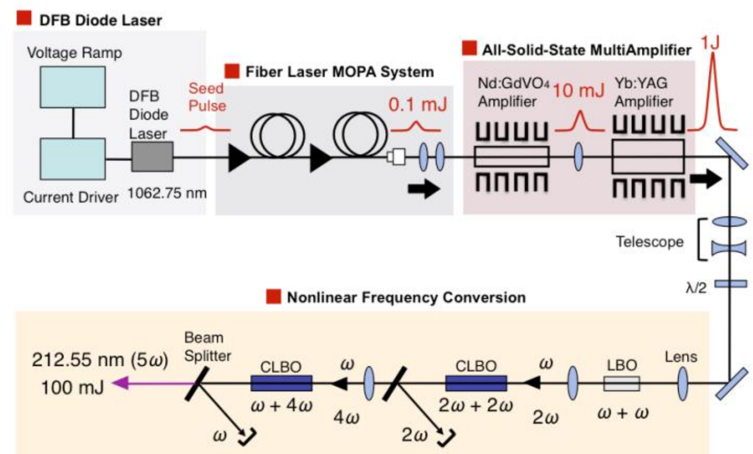
A. Olin, L. Lee (TRIUMF)

G. Beer (Univ. Victoria)

Schematic Diagram



Pump Laser 1



Pump Laser 2