Muon beam density enhancement with tapered tubes

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Nufact 10

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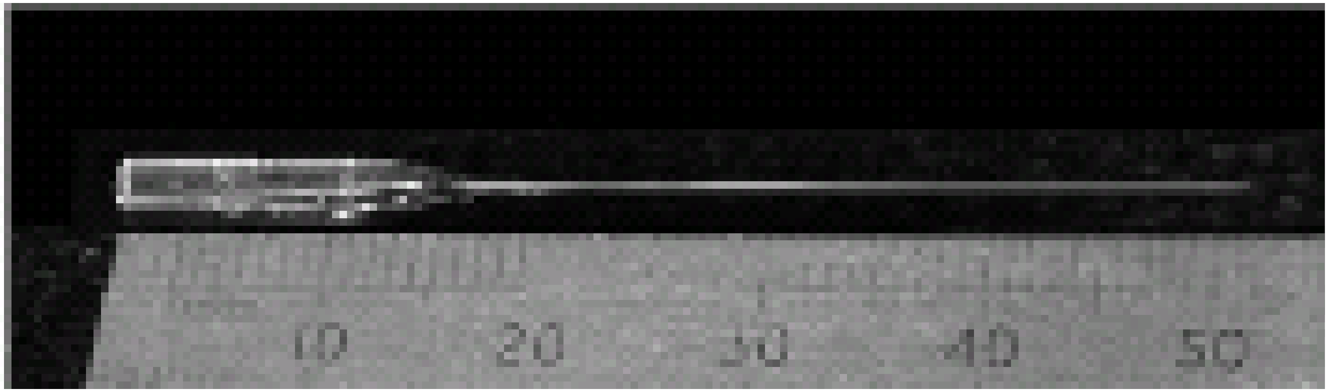
Capillary technique

Employ capillary technique: from ion beams to low energy muon beam

Capillary technique

Employ capillary technique: from ion beams to low energy muon beam



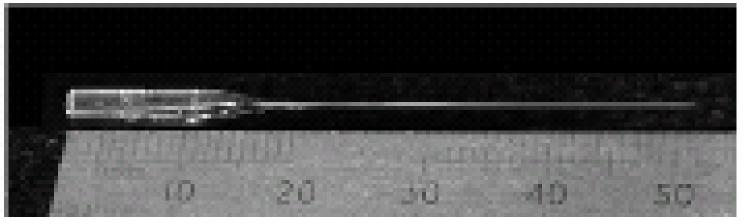
- Cheap, easy method
- Focus the ion beam

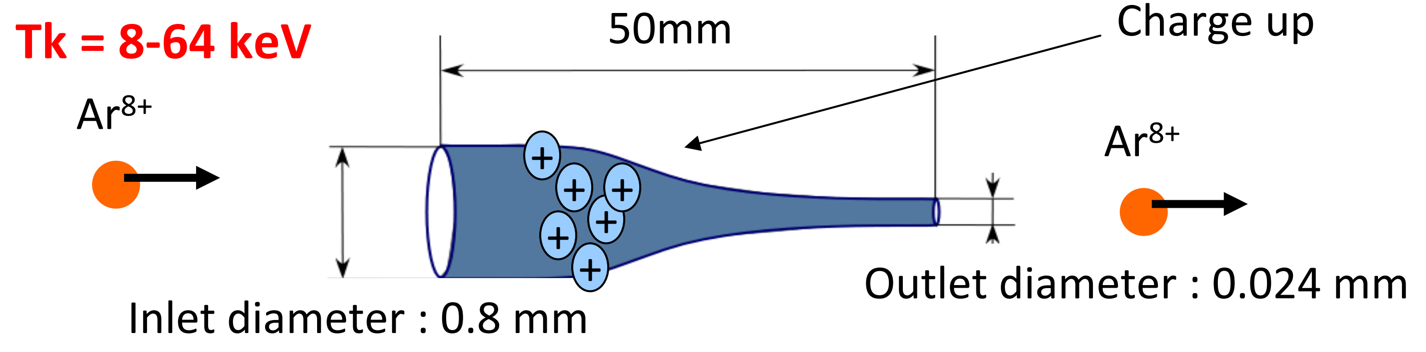
What is capillary ??

Employ capillary technique: from ion beams to low energy muon beam

Tapered capillary technique in ion beam

- guide the ion beam to the outlet
- focusing and guiding effect by charge-up





keep charge, focusing by charge-up on the inner surface

T. Ikeda et.al Applied. Phys. Lett. 89(2006)163502

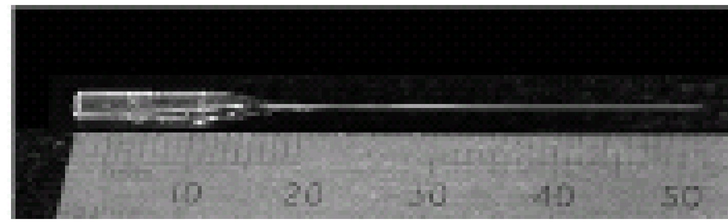
What is capillary ??

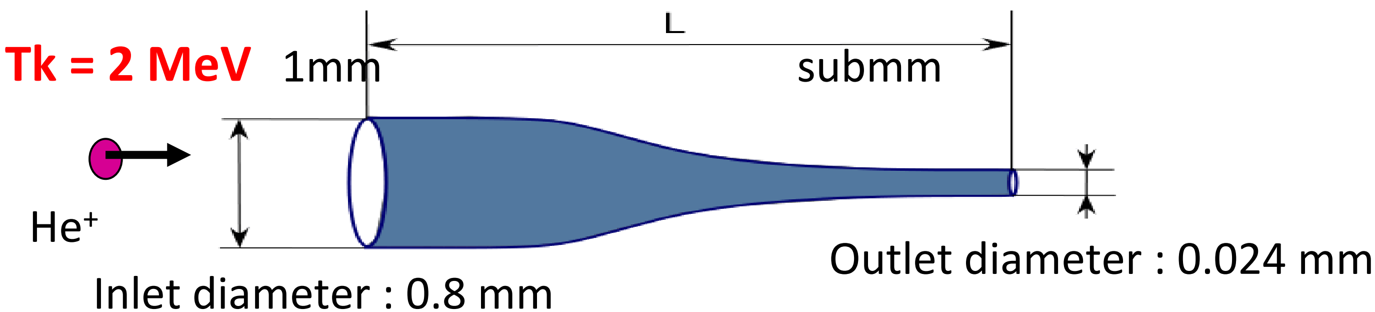
Employ capillary technique: from ion beams to low energy muon beam

Tapered capillary technique in ion beam

- guide the ion beam to the outlet
- focusing and guiding effect

by scattering





Focusing by scattering at inner surface, no guiding effect

T. Nebiki et.al. J. Vac. Sci. Technol. A 21 (2003)1671

Capillary technique

Employ capillary technique: from ion beams to low energy muon beam

Tapered capillary technique in ion beam

- guide the ion beam to the outlet
- focusing and guiding effect

Application to the muon beam

- low momentum muon (p=27 MeV/c) from pion decay at rest
- beam size is ~400mm, larger than stopping material
- possible to increaase muon beam ?

Capillary technique

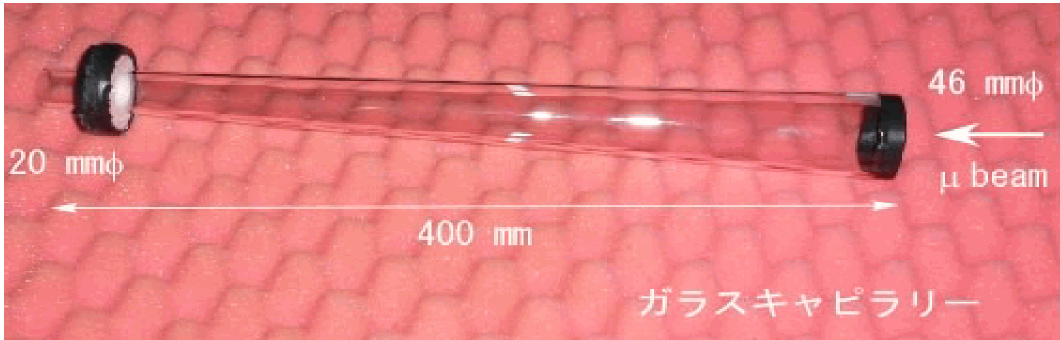
Employ capillary technique: from ion beams to low energy muon beam

Tapered capillary technique in ion beam

- guide the ion beam to the outlet
- focusing and guiding effect

Application to the muon beam

- low momentum muon (p=27 MeV/c) from pion decay at rest
- beam size is ~40mmϕ, larger than stopping material
- possible to increaase muon beam ?



Previous experiments with a capillary

	Low Energy beam (Tk = 1-100keV)	High Energy beam (Tk=1- 10 MeV)
Principle	Charge-up effect	Multiple scattering
Charged particle	Ar8+, etc	He+, He2+, etc
Effect	Guide and focus the beam	Focus the beam
Energy and Charge	Conserved (Energy and Charge)	Conserved ?
application	Nano dot production	Cell surgery
Density enhancement	- 10	100 - 1000 -

T. Ikeda et.al Applied. Phys. Lett. 89(2006)163502
T. Nebiki et.al. J. Vac. Sci. Technol. A 21 (2003)1671

- ✓ Which effect does muon beam have?
- ✓ How large density enhancement effect is observed?
- ✓ Is it possible to use the muon beam like the highly charged ion beam?

Capillary technique

Employ capillary technique: from ion beams to low energy muon beam

Tapered capiillary techmique in ion beam

- guide the ion beam to the outlet
- focusing and guiding effect

Application to the muon beam

- low momentum muon (p=27 MeV/c) from pion decay at rest
- beam size is ~40mmϕ, larger than stopping material
- possible to increaase muon beam ?

- When capillary method is applied to the muon beam, what happen will be occurred?
- Systematically investigate the low energy muon beam.

Application

Application to the muon experiment

μSR method

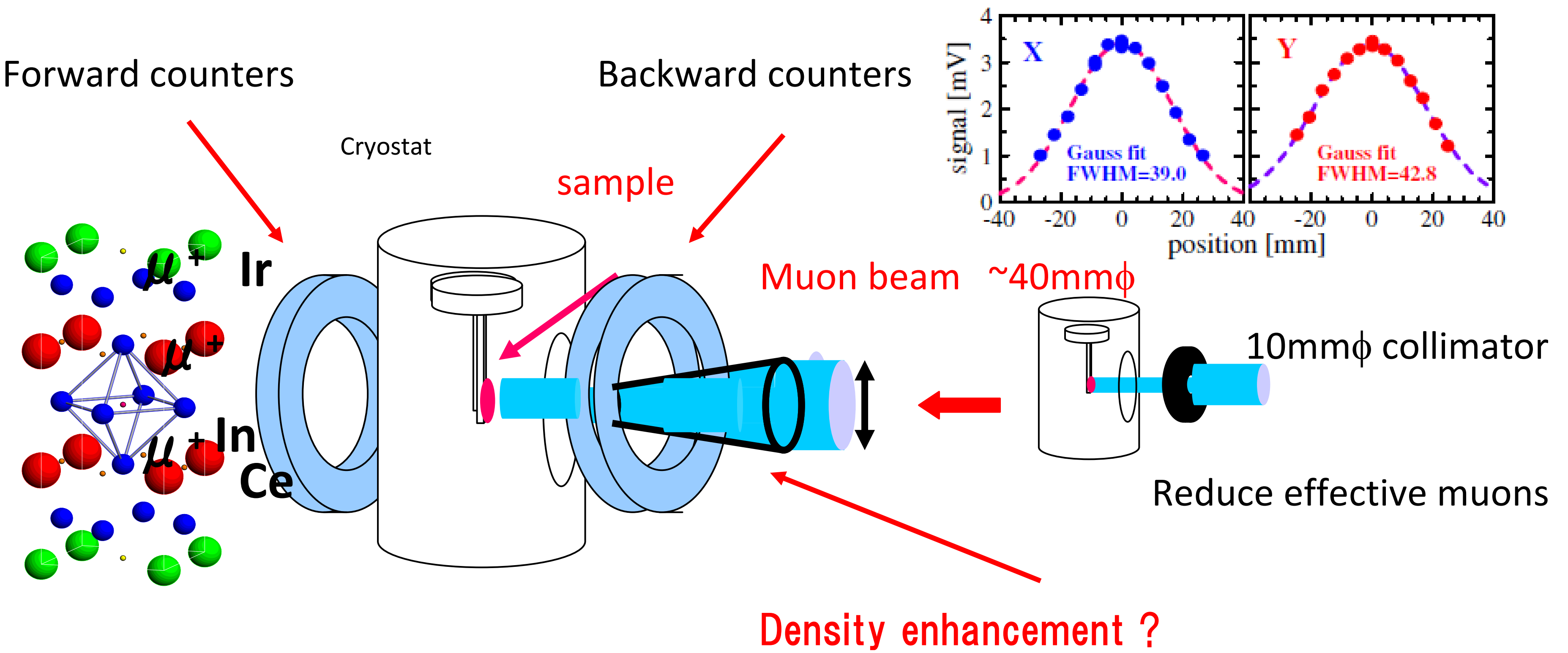
- Muon is used as a sensitive magnetic probe in the condensed matter physics
- increase muon beam density

g-2 precision measurement

- Precision measurement of the anomorous magnetic moment for the muon
  - Cooled muon (slow muon generation) by laser from ionizing muonium
    - high density muonium production

μSR Application

Beam is wider than sample size.



- The effective number of muon is reduced by collimator
- Increase the muon by capillary method
- Increase statistics within a short beam-time

Beam density, muon spin after passing through a capillary ?

Muon g-2 project

- Precision measurement of the muon g-2 at J-Parc
- Goal : within 0.1 ppm precision

$$g = \left(1 + \frac{g_\mu - 2}{2}\right)\left(\frac{e}{2m}\right)$$

Very strict beam requirement

.

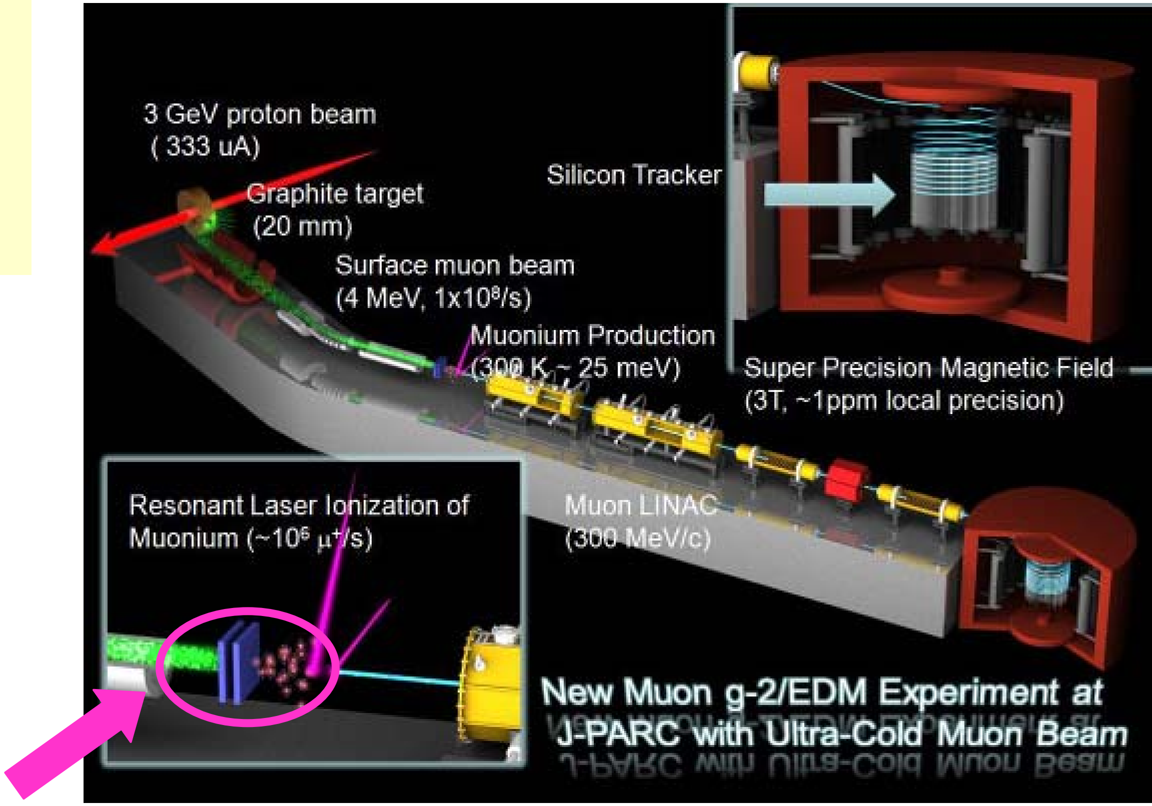
Very strict beam requirement

- Pt/P ~ 10-5 ~ 6,
- 4×10^{8} muons/sec

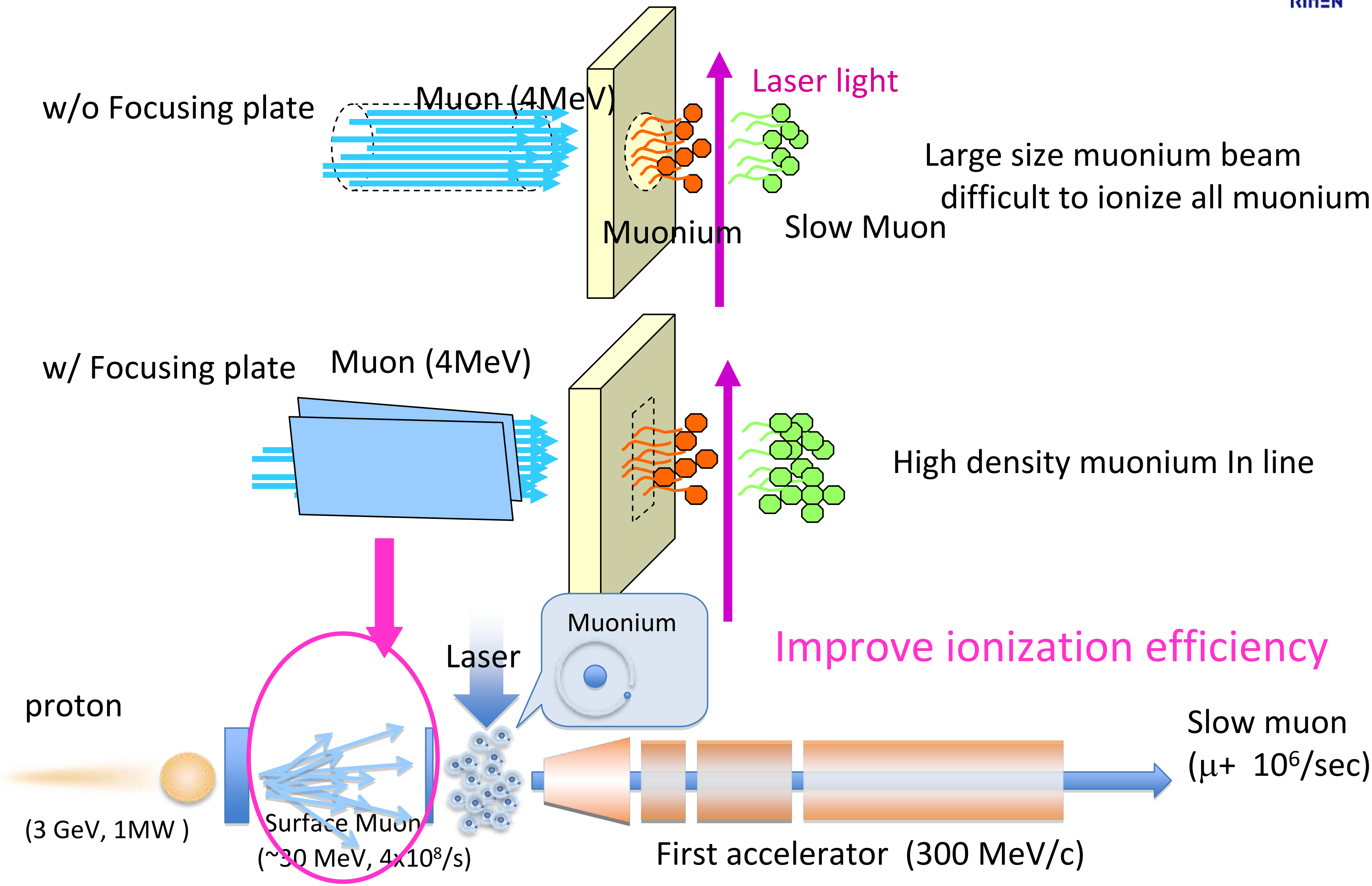
One order improvement

Employ ultra-slow muon

yesterday talk by K. Ishida



Muonium generation (~MeV muon)

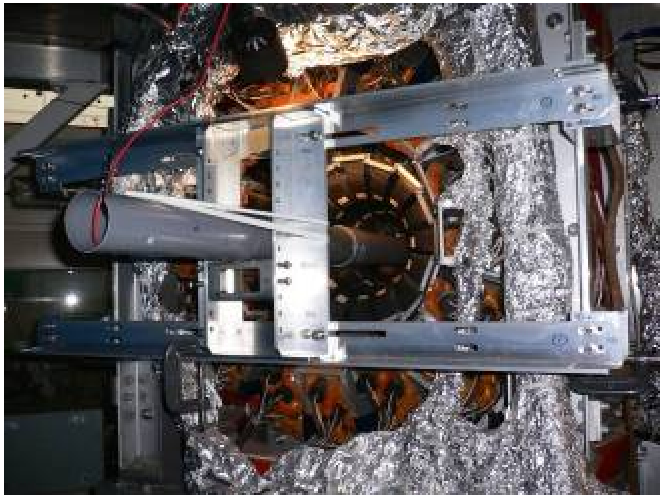


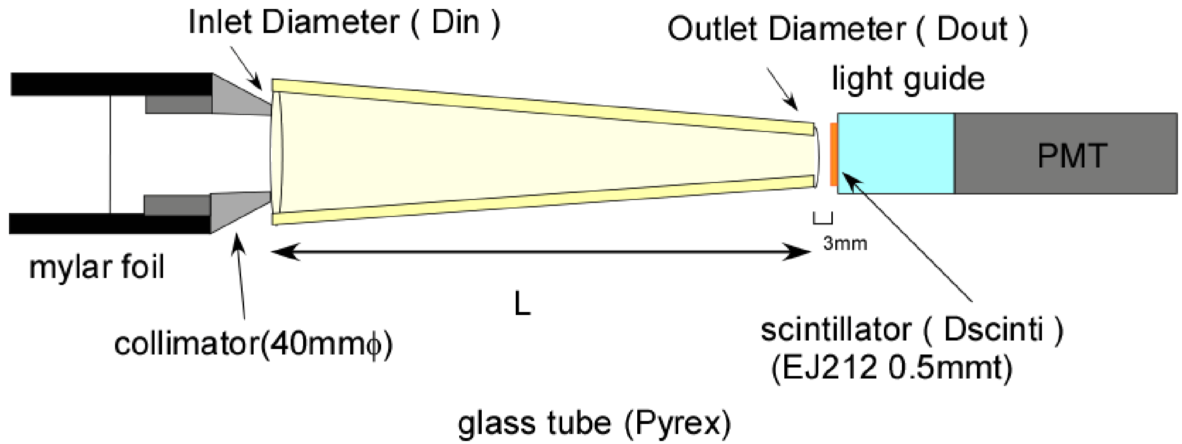
Muon energy distribution, Beam profile ?

Experiment

1. RIKEN-RAL (pulsed muon beam)
2. TRIUMF (TRIUMF)

Experimental : at the RIKEN-RAL



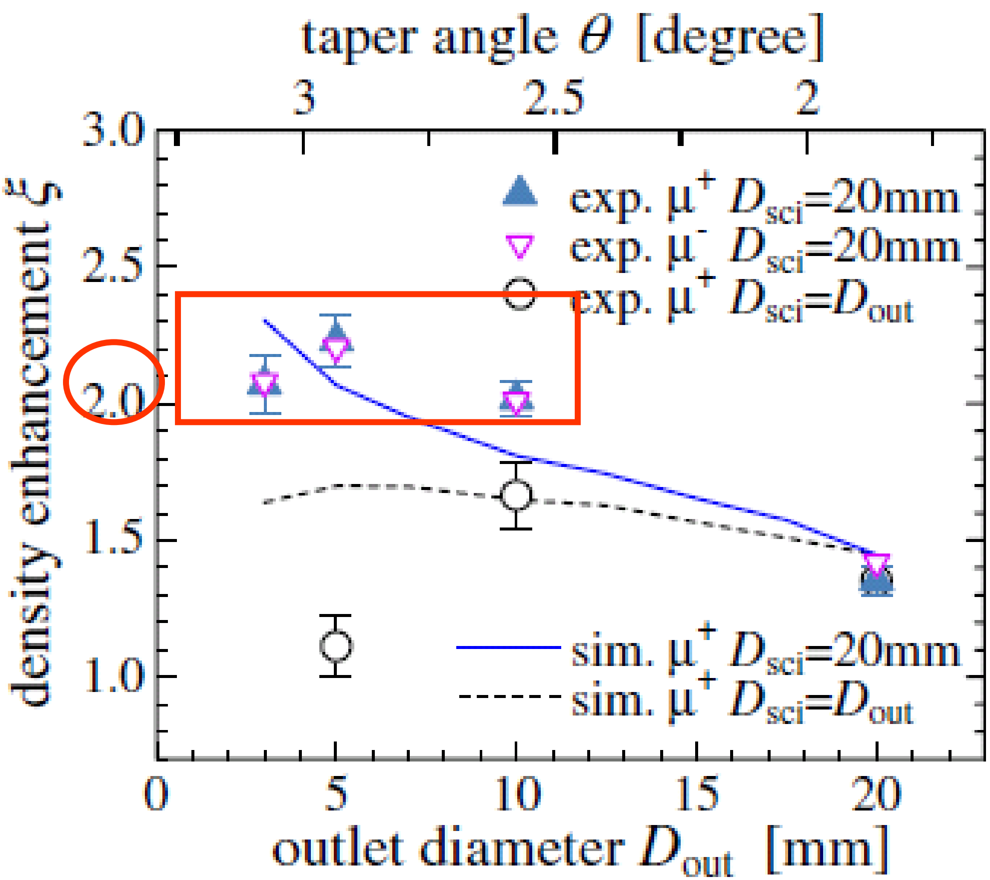


- Tube size
  - Dout = 3, 5, 10, 20 mm
  - Din = 40 mm
  - L= 100, 200, 300, 400 mm
  - Dscinti = 5, 10, 20 mm

- Beam momentum 54 MeV/*c* in-flight decay muon (～10^4 counts/spill)

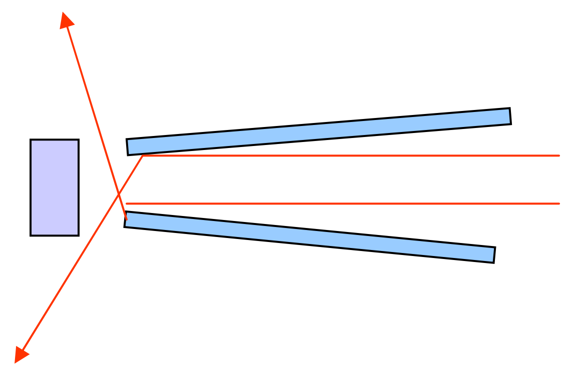
- Measurement in air
  - Measure an energy loss at the outlet with a thin scintillator + PMT
  - Calculate an enhancement factor comparing between w/ and w/o glass tubes
  - rough test experiment

Result ：tapered angle vs enhancement



- 54 MeV/c muon beam in the air

$$\xi = \frac{N_{capillary-in}}{N_{capillary-out}}$$



- Large angle scattering is observed when the scintillator is mounted close to the outlet
- Density enhancement factor of 2 is observed
- Same effect between positive and negative muons
- No charge-up. Scattering (reproduce the results from Scattering calculation)

Summary : RIKEN-RAL experiment

Results

- Density enhancement effect is observed (factor of ~ 2)
- Same tendency between positive and negative muon beam
- Explain the simulation including the multiple scattering effect
- Charge-up effect is not observed due to no guide effect
- Published in **<u>T.M. Kojima et.al. JPSJ let. 76 (2007) 093501</u>**

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LETTERS

Density Enhancement of Muon Beams with Tapered Glass Tubes

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We have demonstrated that the beam density of 54 MeV/c muons can be increased almost by a factor of two when a tapered glass tube is inserted coaxially along the muon beam. The observations are compared with a multiple Coulomb scattering calculation, which reproduces the observation reasonably. This technique opens a new and simple way to increase the muon intensity effectively.

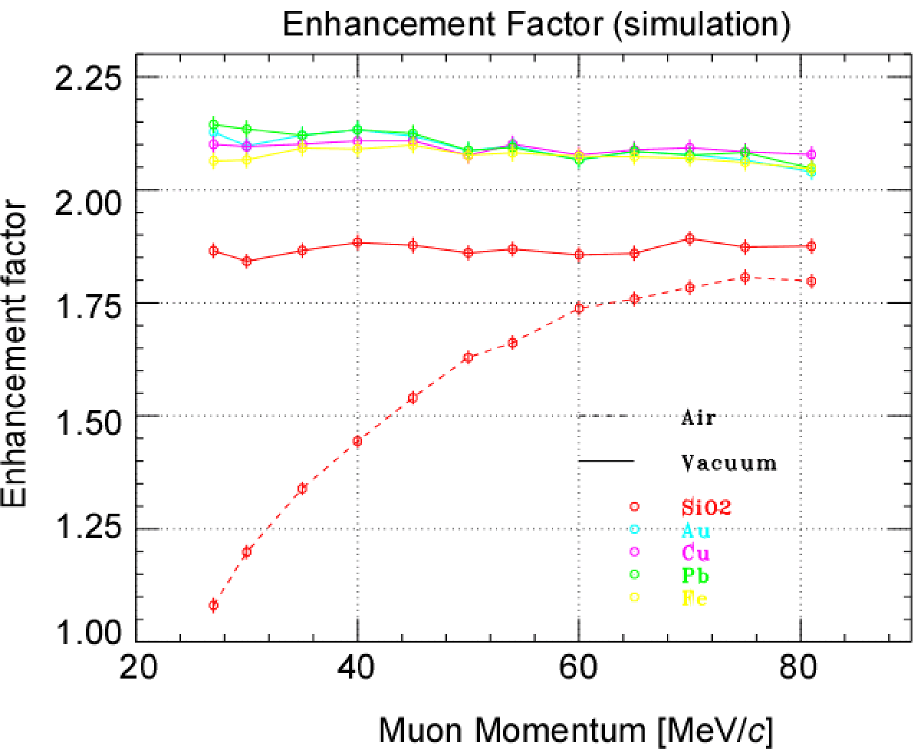
KEYWORDS: muon, beam density, glass capillary, enhancement, tapered glass tube
DOI: 10.1143/JPSJ.76.093501

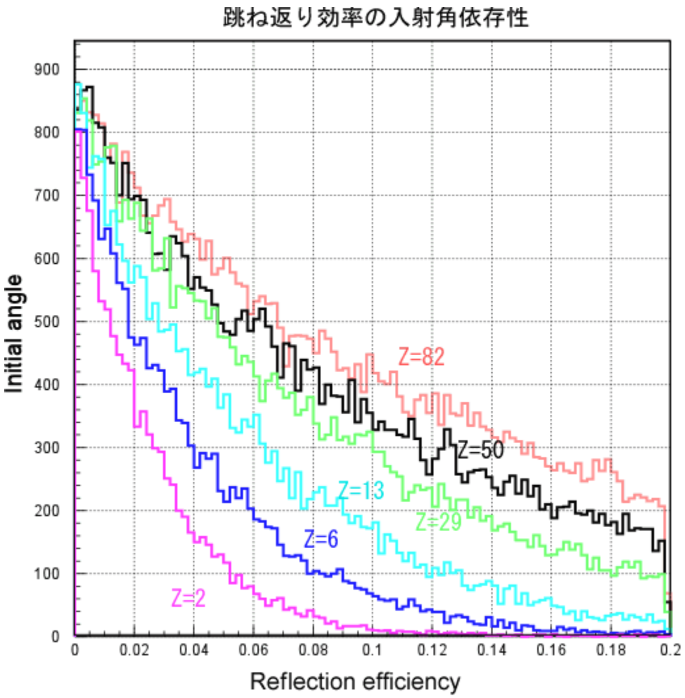
Problems -

- Quantitative enhancement factor ?
- Improvement of the glass tube ?
  - Heavy material (in the case of multiple scattering)
  - Energy distribution of outgoing muon
- Initial muon energy/outgoing muon energy? optimization of stopped muon ?
- Beam profile at the outlet ?

→ Using the DC beam @ TRIUMF

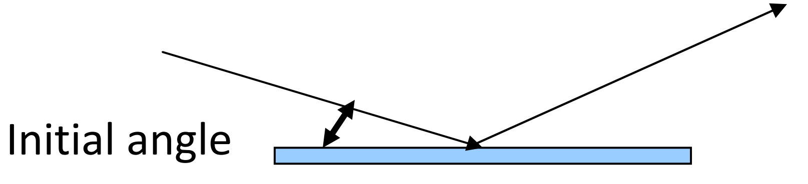
Change of the tube material





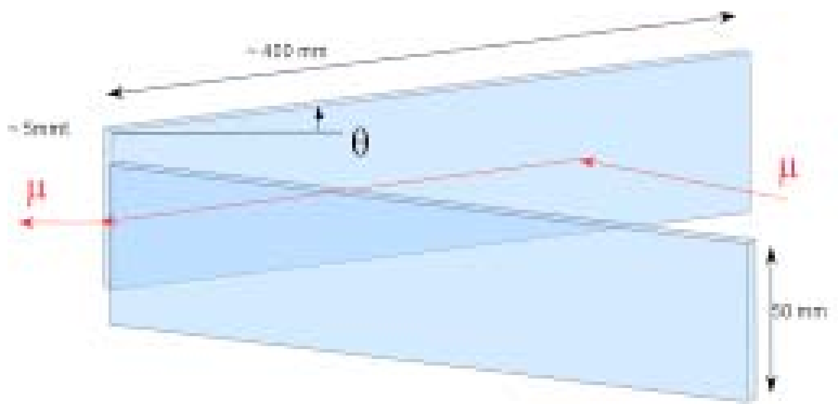
He, C, Al, Cu, Sn, Pb

- larger enhancement using heavier metal tubes
- p=27 MeV/c muon in vac
- For simplicity, use the narrowing plates, tube

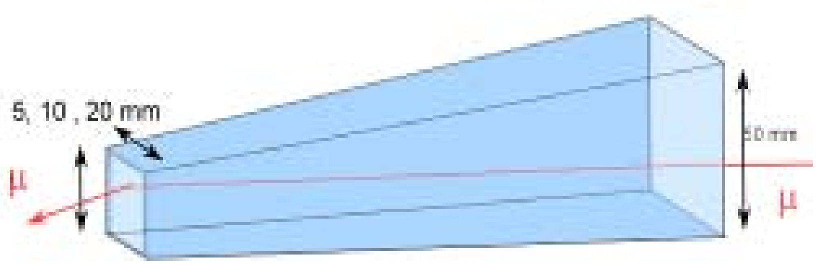


M1159 Experiment at TRIUMF

- Enhancement effect
- measure the enhancement factor
- Polarization of the muon at capillary outlet

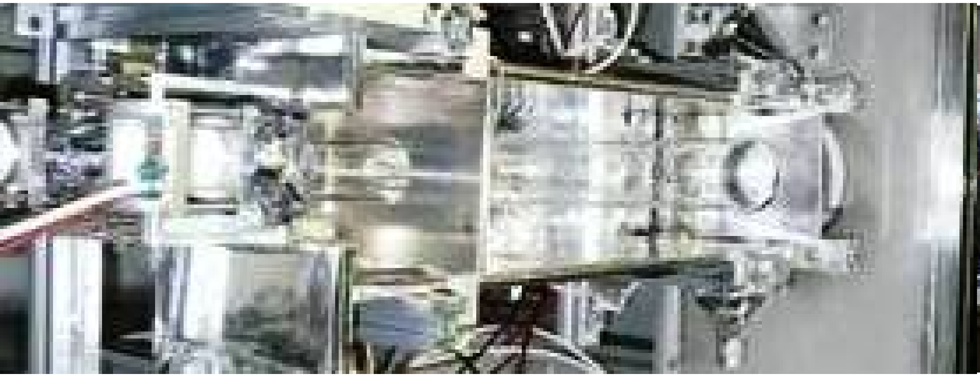


For simplicity, narrowing plates



Application to the experiment

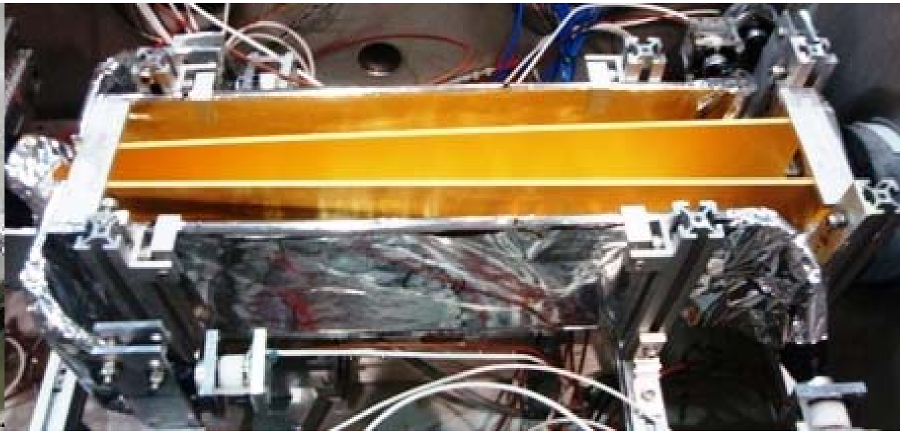
Various Material



Glass tube

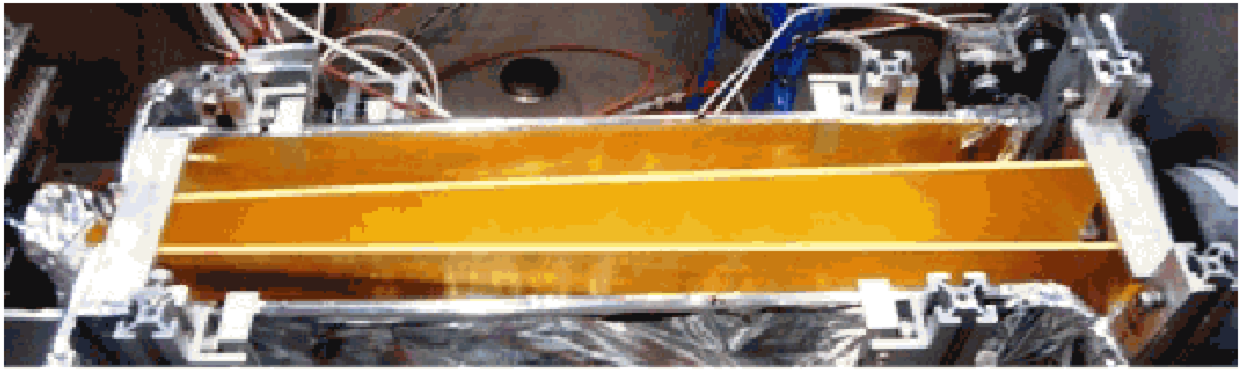
Glass plate

Copper (polished / rough)

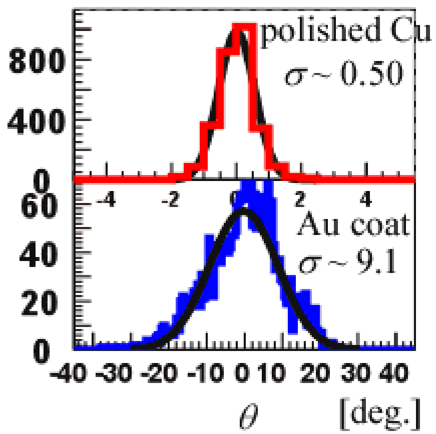


Gold coated copper

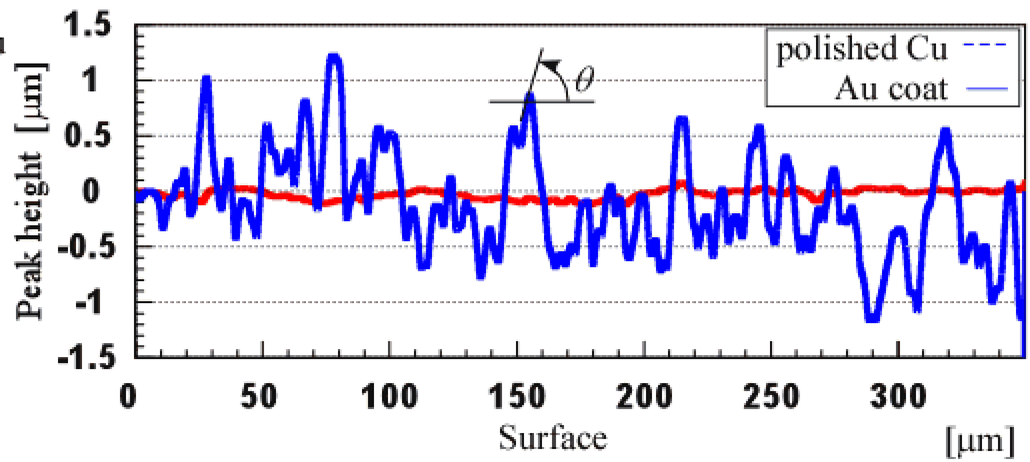
Surface condition



distribution

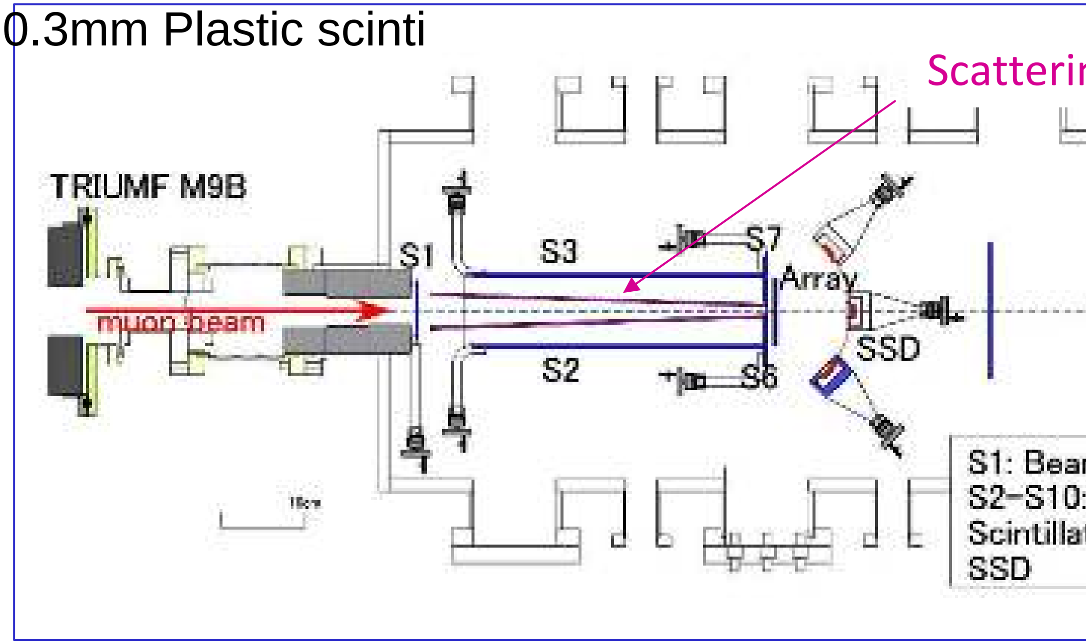


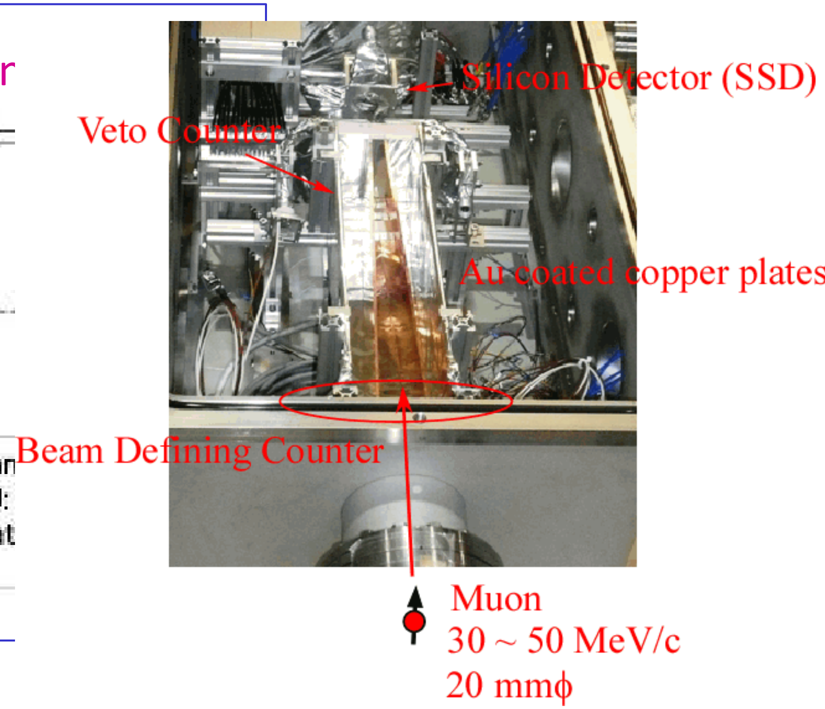
surface



Averaged gradient Au ~ 9.1 deg Cu~ 0.50 deg

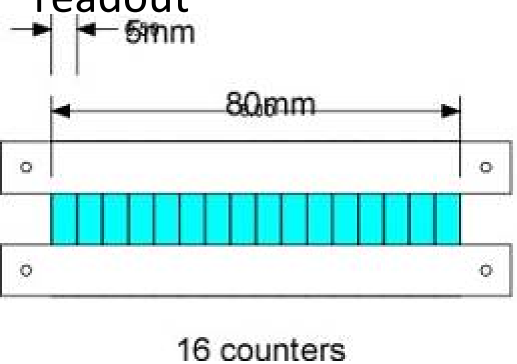
Setup in M9B beam-line





Array counter
 for angular dependence

Multianode PMT +WLS fiber
 readout

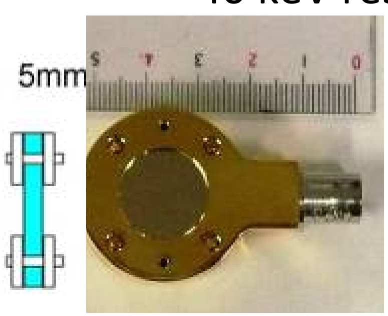


SSD for muon energy

Measure muon energy , ~ 8 MeV

ORTEC L-035-025-5 10 mmϕ

~ 40 keV resolution



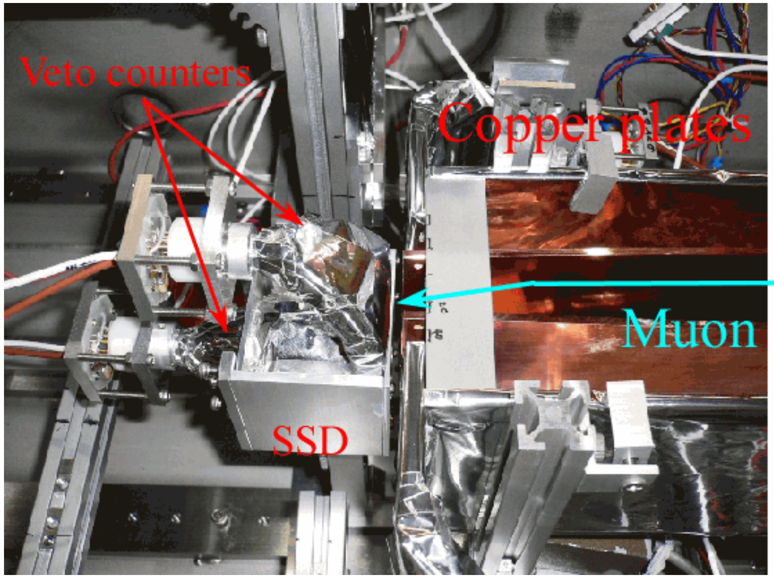
Scintillation counter
(PMT E5780mod)

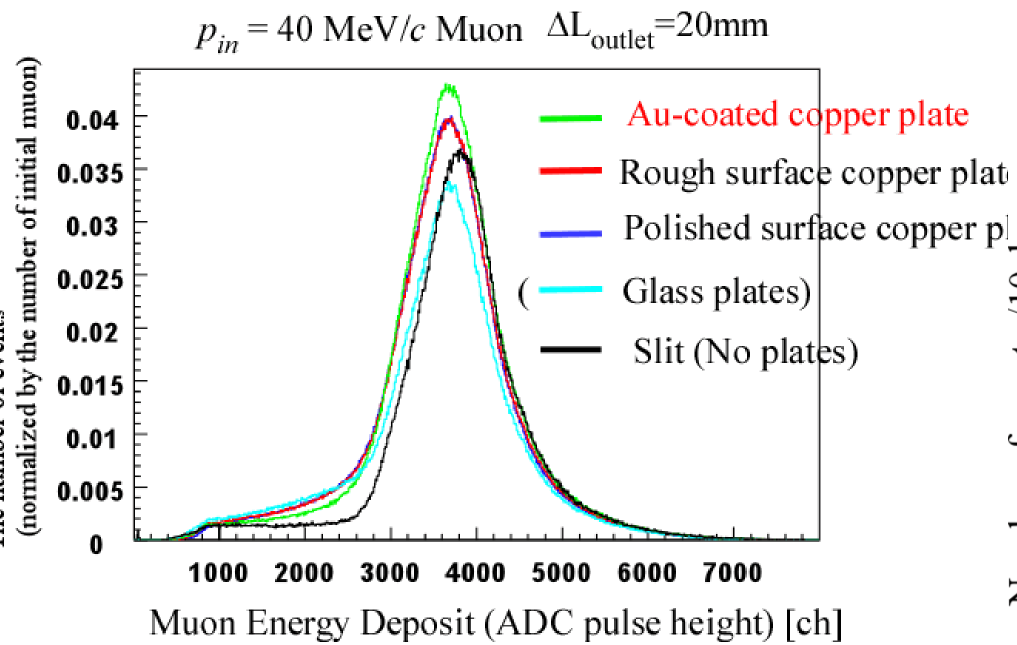
Muon beam

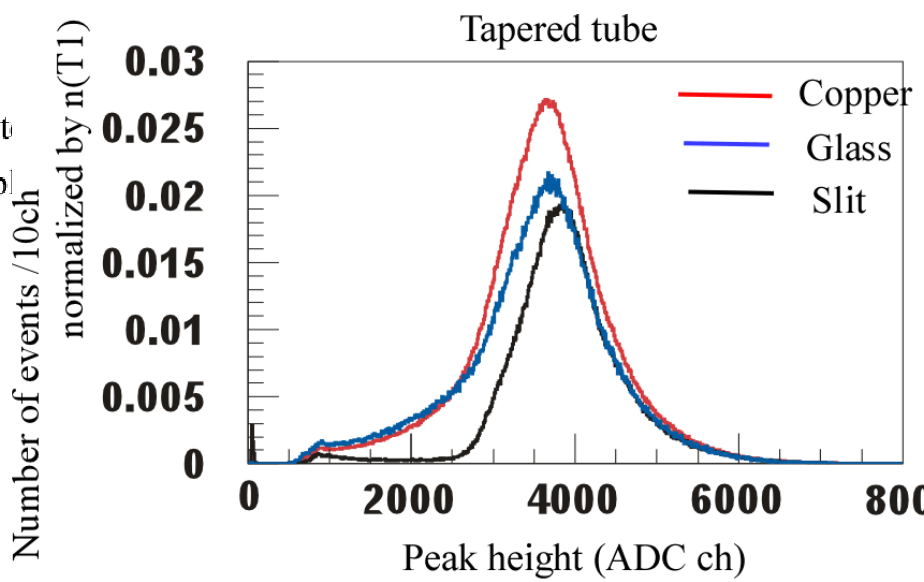
- 30, 40 and 50 MeV/c
- in Vacuum

Energy distribution

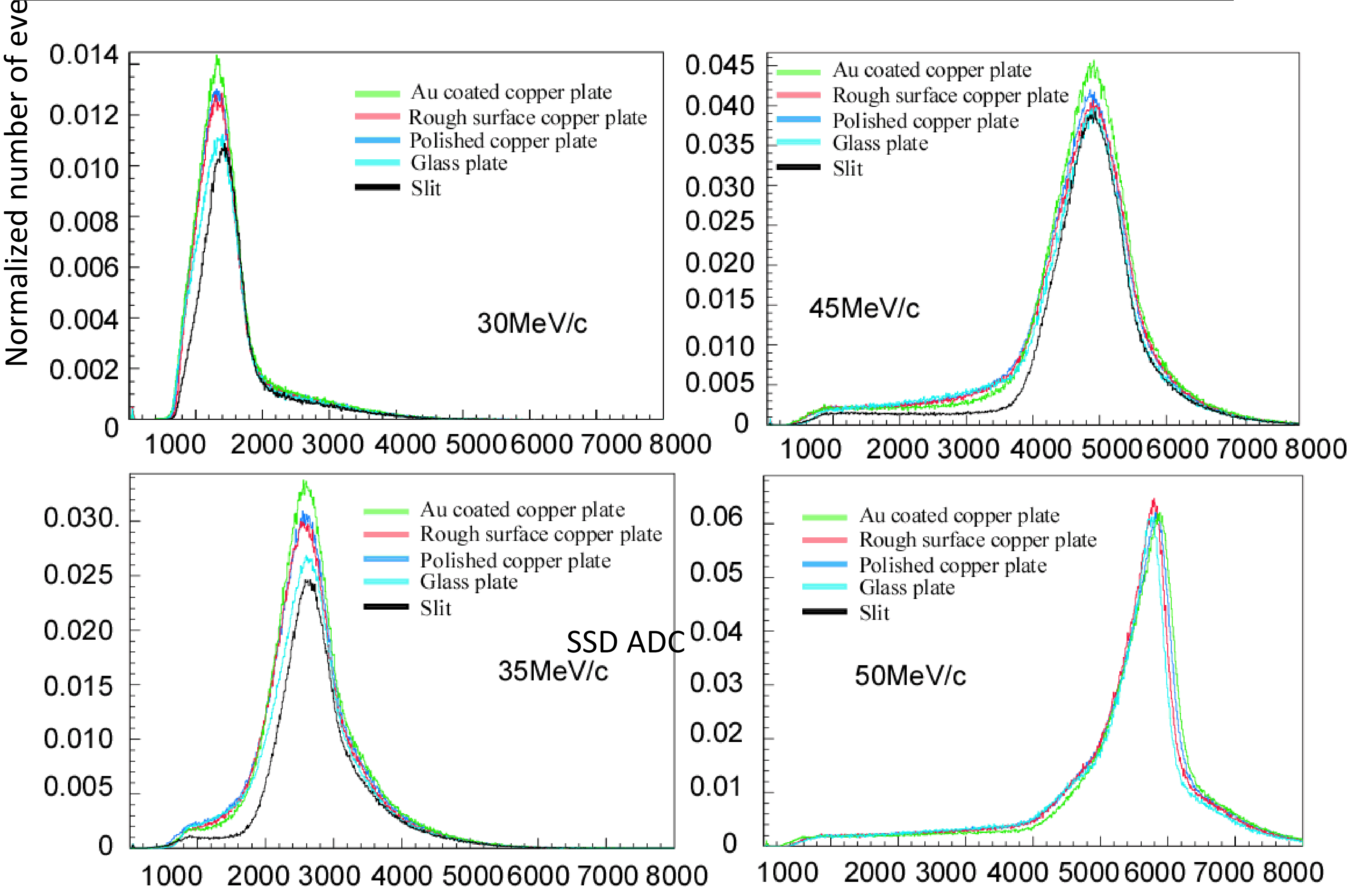
- 5mm thick SSD
- Mount downstream of 10 mm from the outlet



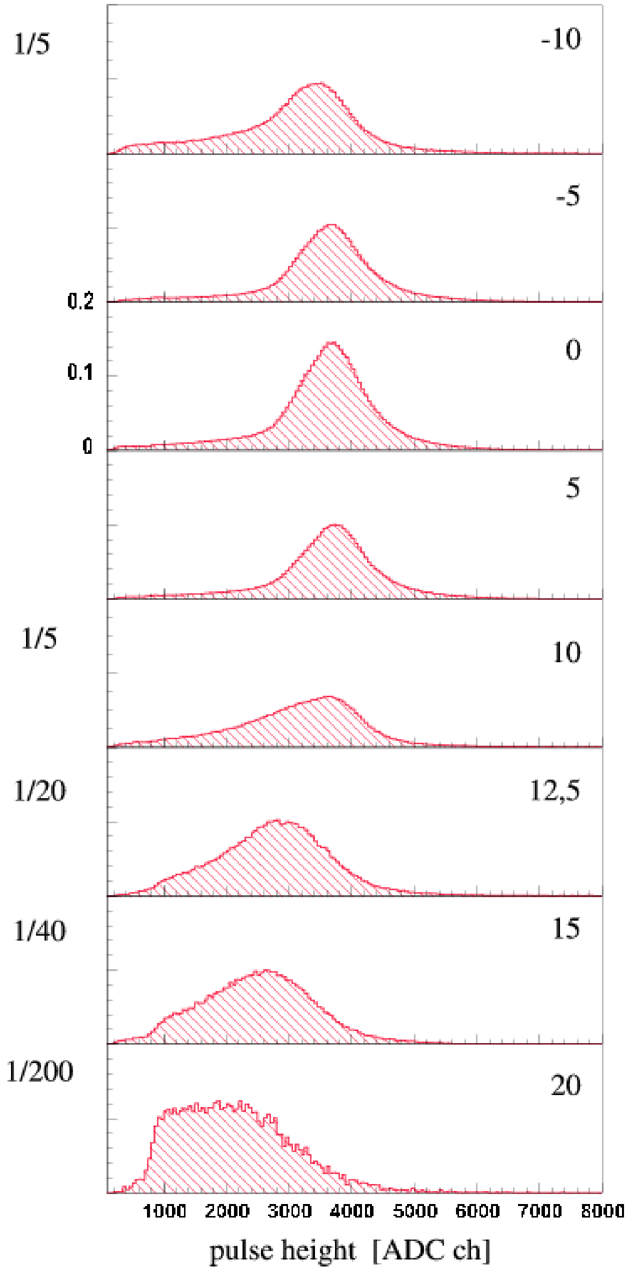


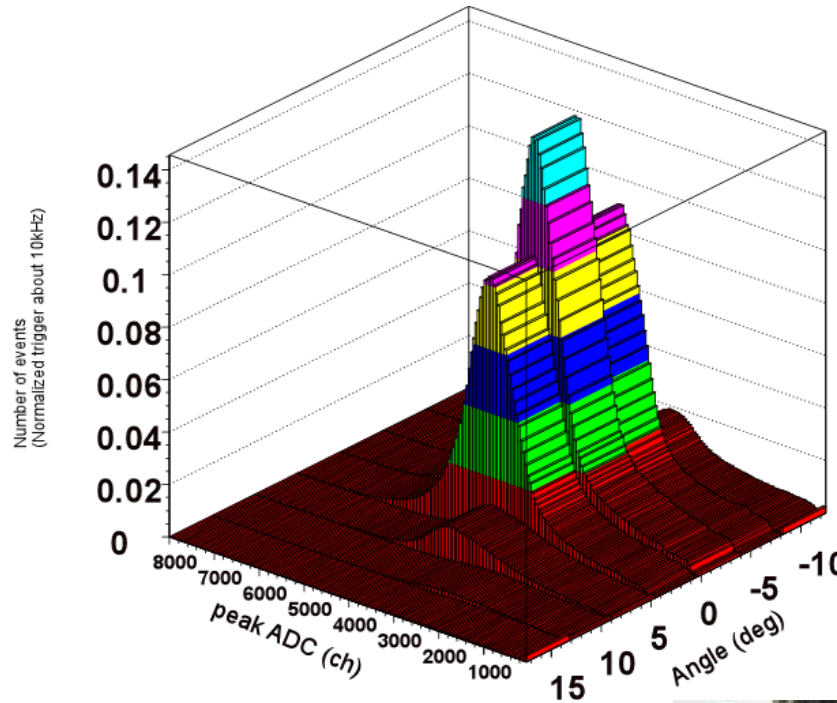


Energy distribution

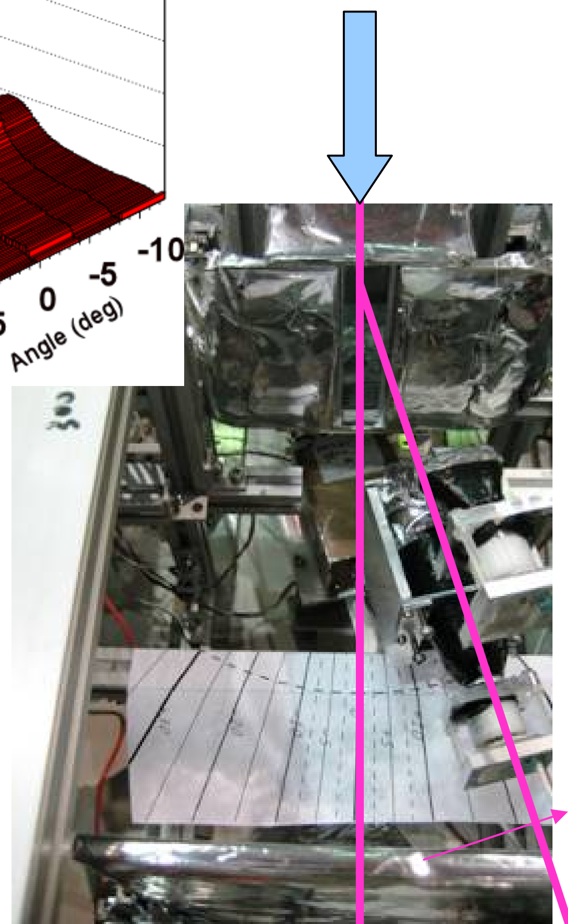


Angular distribution

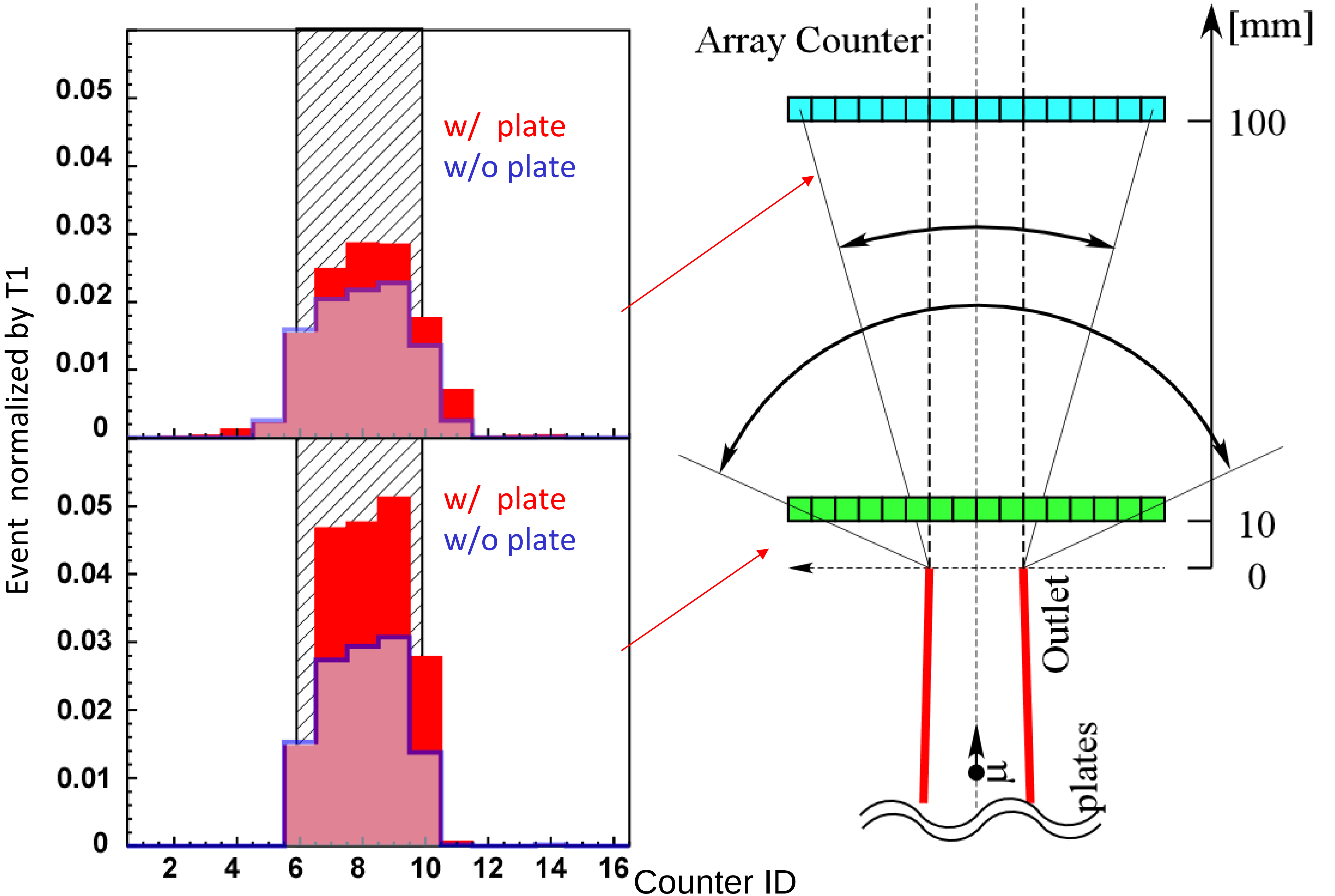




muon



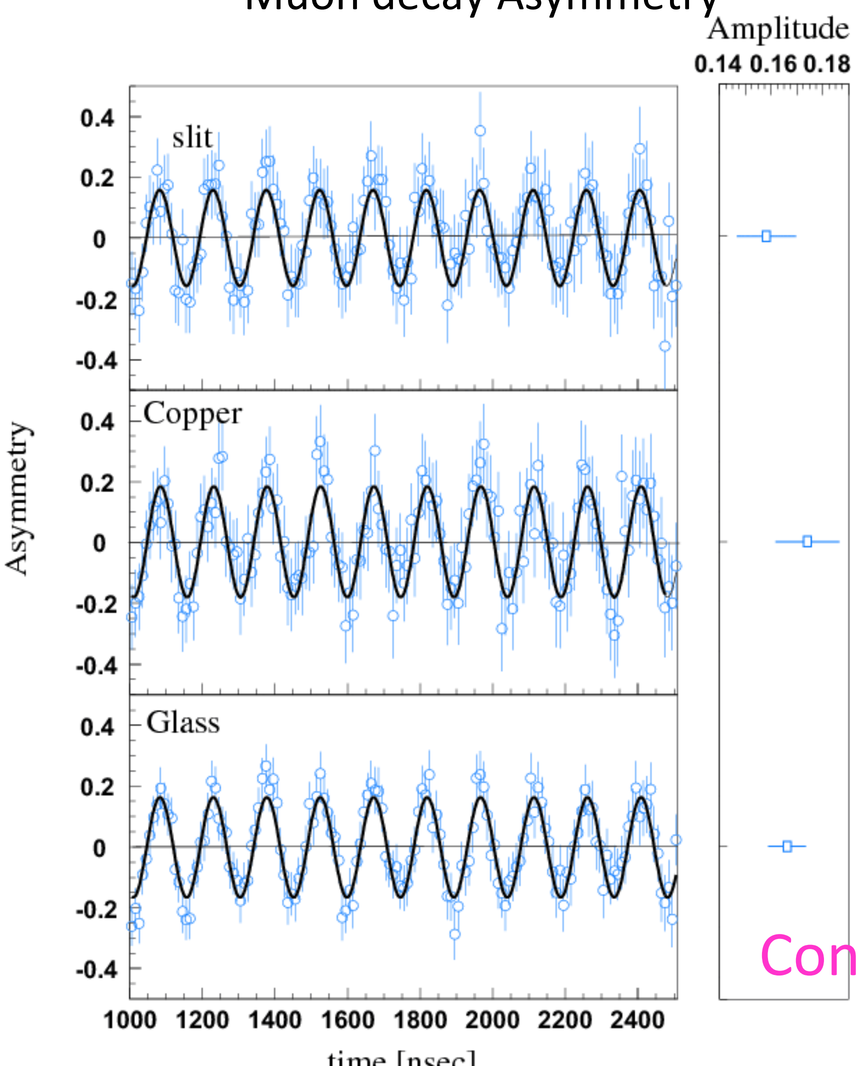
Beam distribution



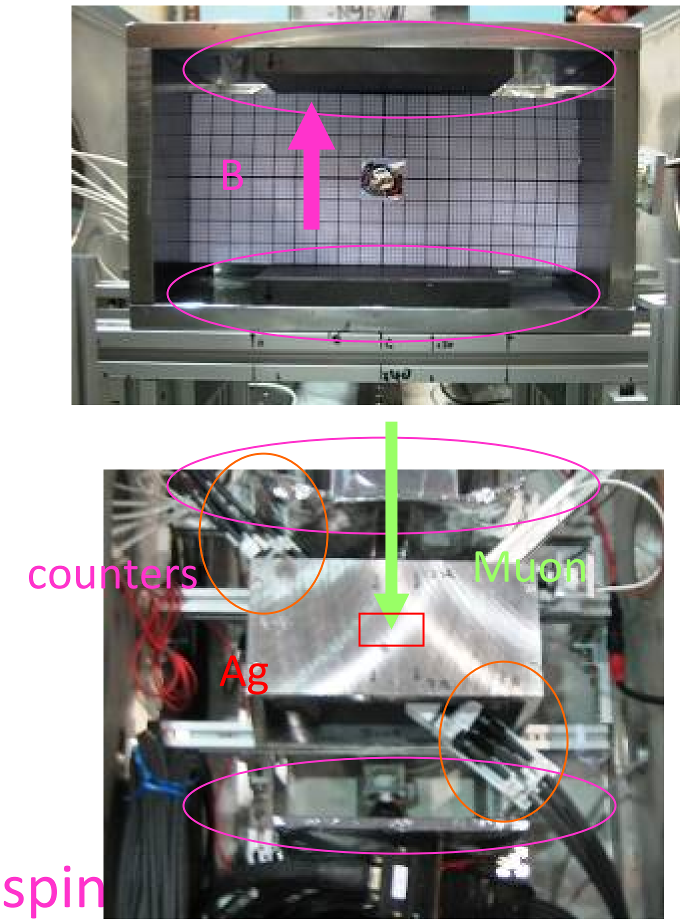
μSR at silver target

- Muon stopped at Ag in the transverse field of ~ 50 mT
- Is muon spin polarization conserved through the tube?

Muon decay Asymmetry



40 MeV/c muon beam



Conserve muon spin

Summary

- Muon beam density enhancement is observed with the glass capillary by a factor of 1.7 but smaller than our previous experiment about 2
- MeV energy muons (Tk ~ MeV) are scattered at inner wall surface and contribute to the density enhancement, independent of inner surface condition.
- A heavy material causes larger enhancement; largest muon density enhancement is observed by gold-coated copper plates of our candidates.

Further study is required

- Muon capillary is expected to increase not only muon but also muonium yield by focusing the initial muon beam.
- We are optimizing the capillary innter surface and muonium production target shape to maximize the muonium yield

  (slow muon, g-2, muonium spectroscopy)
- We are optimizing the capillary and initial muon beam to maximize the yield of stopped muon at a sample in condensed matter physics (muSR)
- Further development and installation should be proceeded in RIKEN-RAL muon facility.