大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex

J-PARC MLF

MSL
Muon Science Laboratory
Institute of Materials Structure Science
High Energy Accelerator Research Organization,KEK

Muon beamlines at J-PARC MLF

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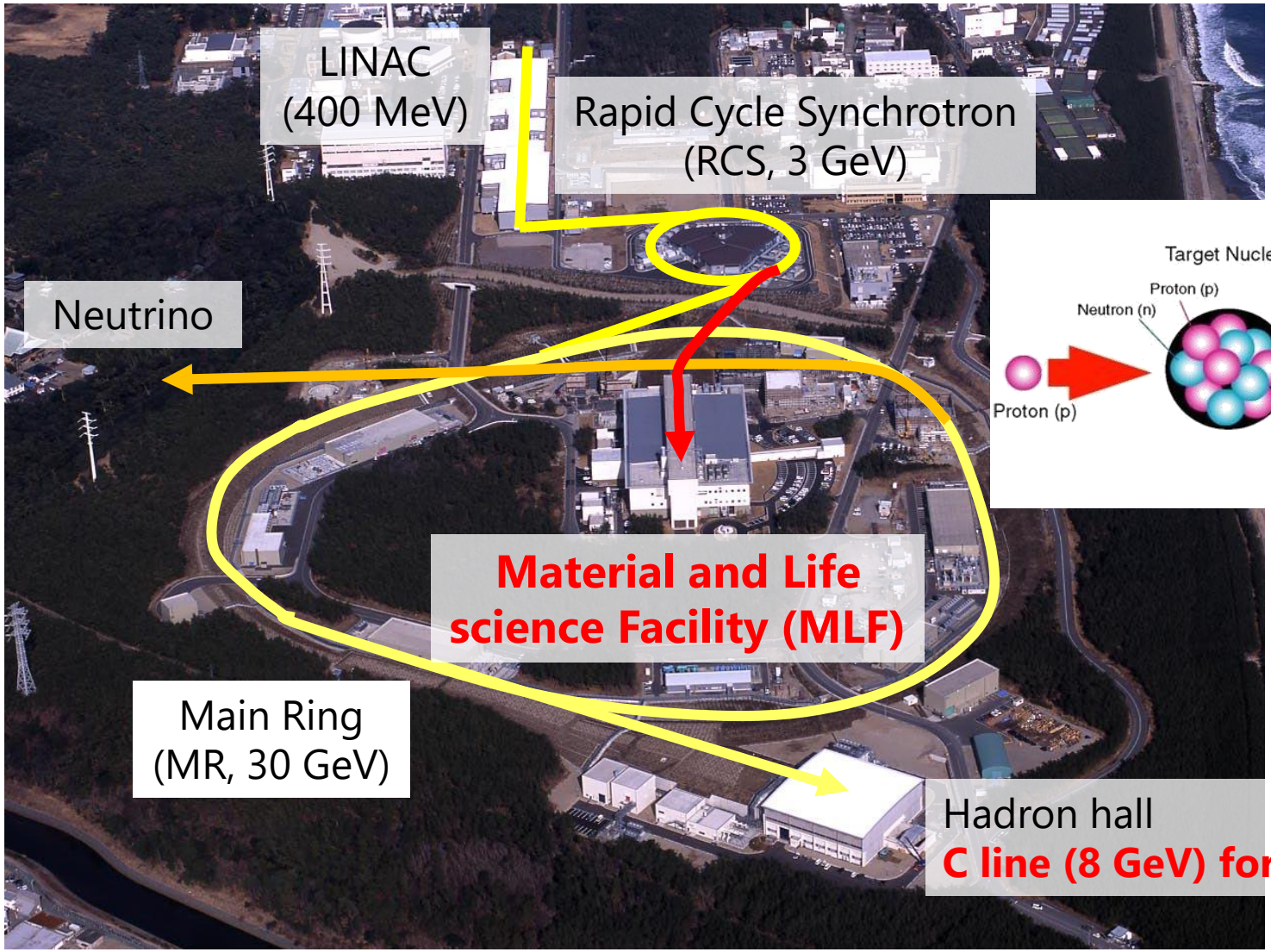
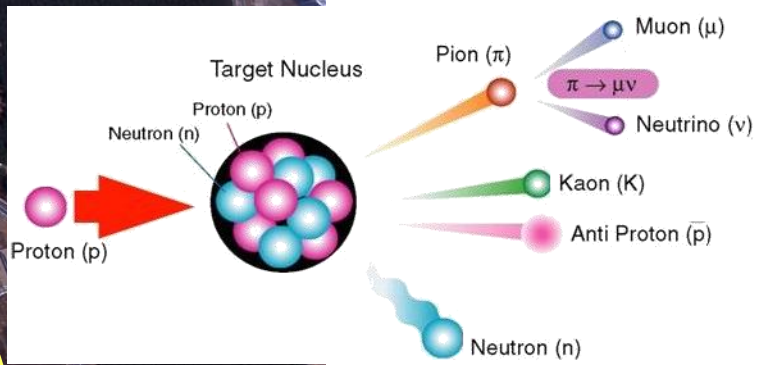
BDX&Beyond, JLab, 5 Sep 2025

J-PARC

J-PARC (Japan Proton Accelerator Research Complex)

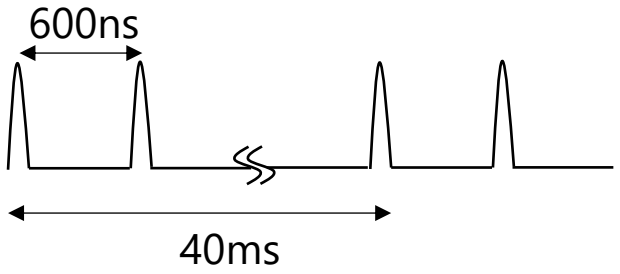


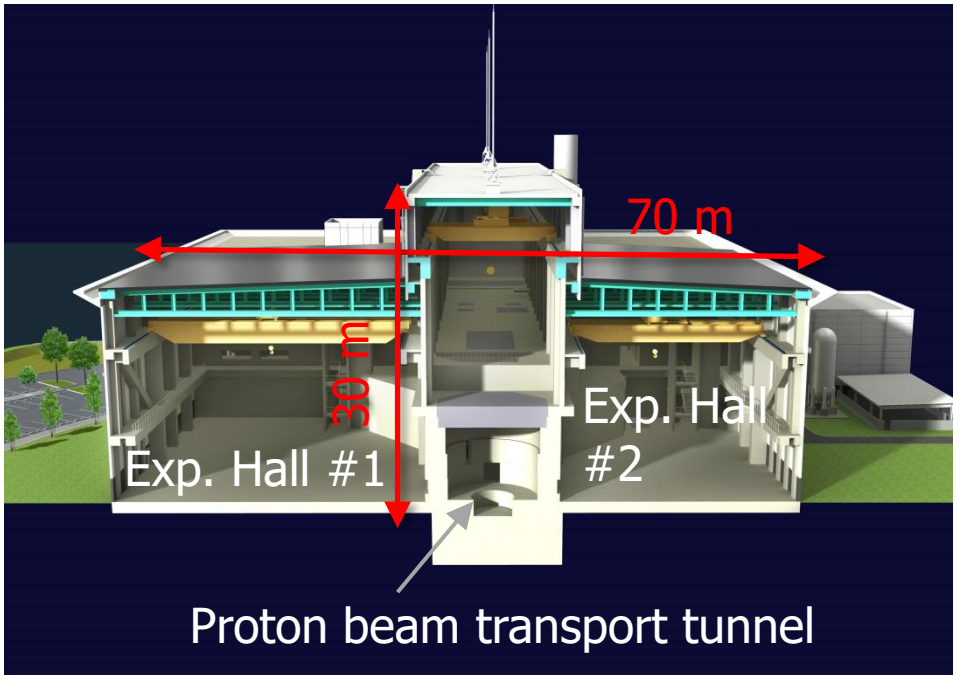


MLF

MLF (Material and Life science Facility)

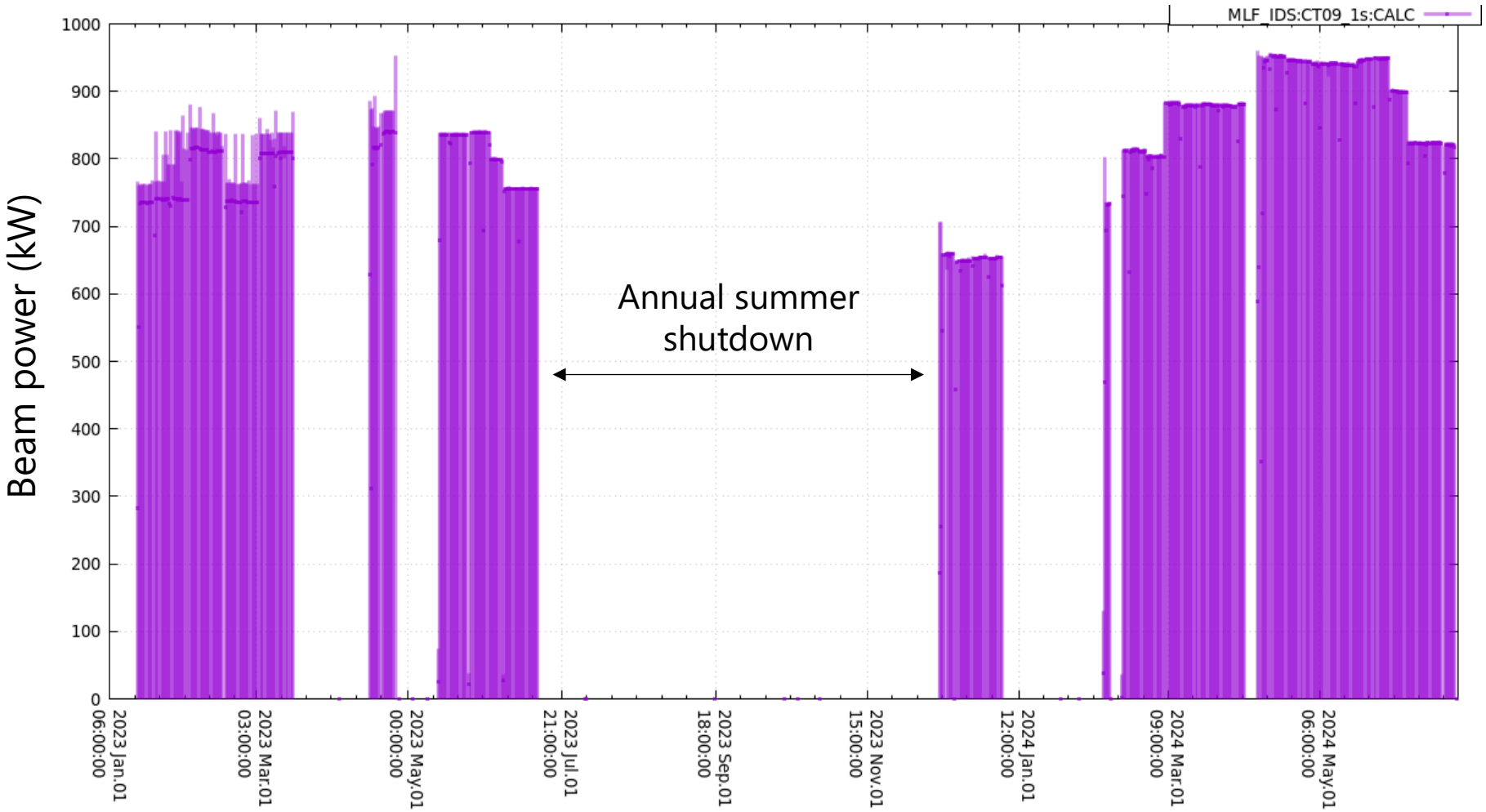
- Beam power 1 MW (~840 kW stable operation at present)
- Repetition rate 25 Hz, double bunches
- Tandem target: 5% for μ, 95% for n





Experimental hall #1

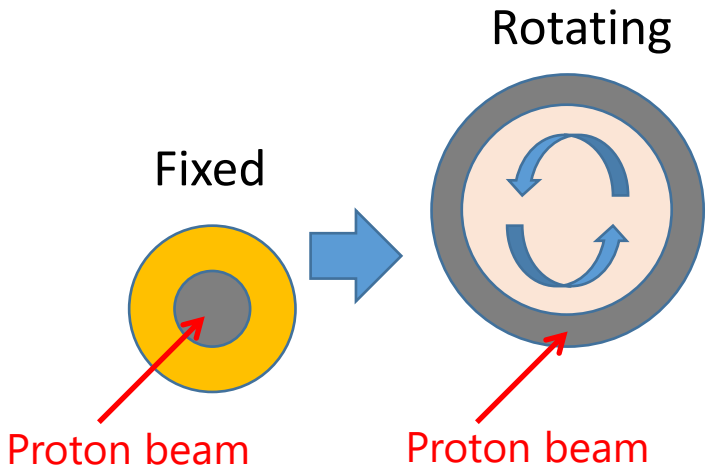
Recent beam power

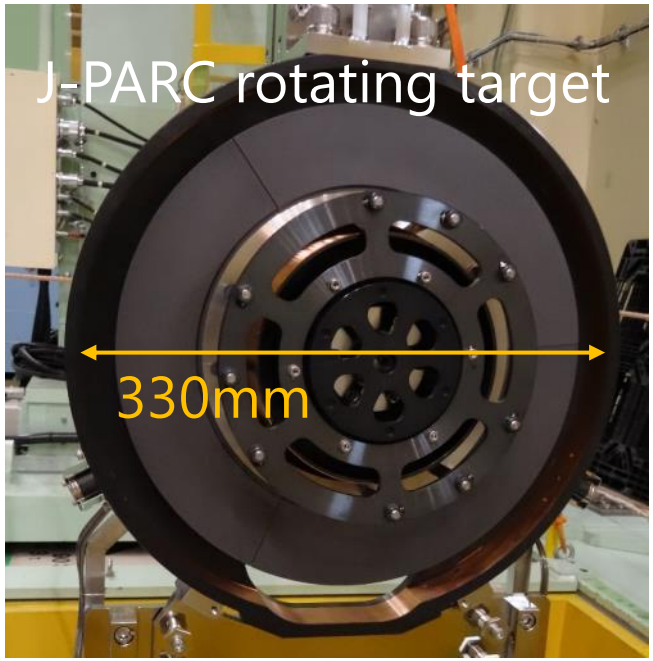


940 kW stable operation at present

Muon production target

- Rotating target
  - Like a muon target @PSI
  - Disperse heat and radiation damage
  - Prolong target's lifetime
    - ✓ Lifetime of graphite = 30 years
    - ✓ Target lifetime is determined by the lifetime of the bearing (~10 years)
  - Graphite (IG-430U)
  - Thickness = 20mm
  - Rotating speed = 15rpm



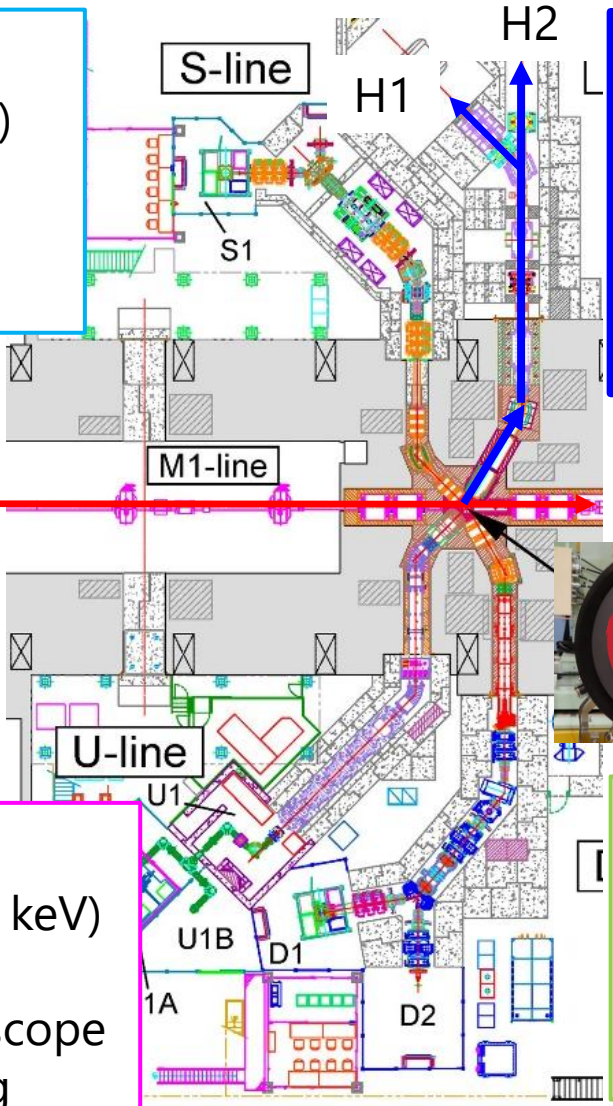


J-PARC muon facility

- MUSE (MUon Science Establishment). 4 BLs and 8 exp. areas

S-line μ^+
- surface μ^+ (30 MeV/c)
- S1 for bulk μSR
- S2 for Mu 1S-2S
- S3/S4 are planned

H-line μ^+/μ^-
- surface μ^+ (30 MeV/c, 10^8 μ^+/s), cloud μ^+/μ^- (up to 120MeV/c)
- H1 for fundamental physics
- H2 for g-2/EDM & TμM



3GeV proton from RCS

2e15 /s @1MW

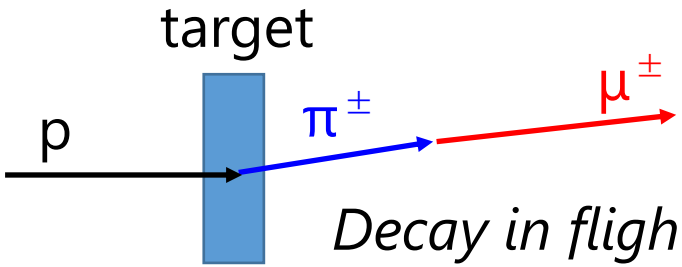
Muon target
(graphite, t20mm)
Rotating target

U-line μ^+
- Ultra slow μ^+ (0.1~30 keV)
- U1A for surface μSR
- U1B for muon microscope
- under commissioning

D-line μ^+/μ^-
- Decay μ^+/μ^-, surface μ^+
- D1 area for μSR
- D2 for μ^-X and various sciences

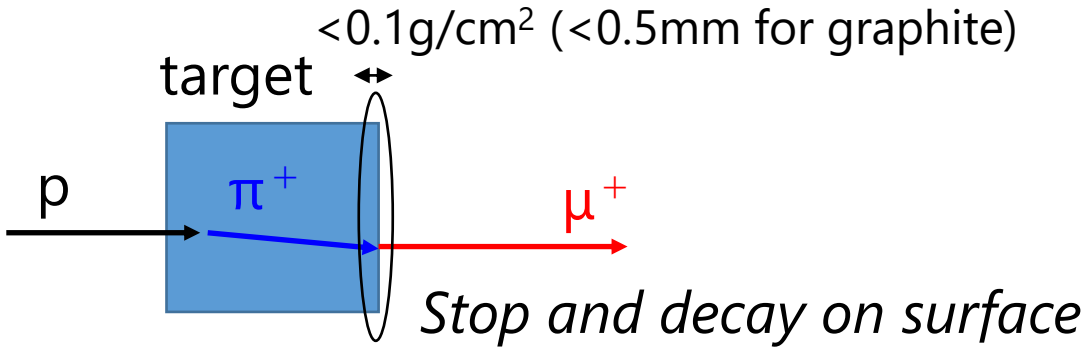
Decay / surface μ

- ***Decay μ^+/μ^-***

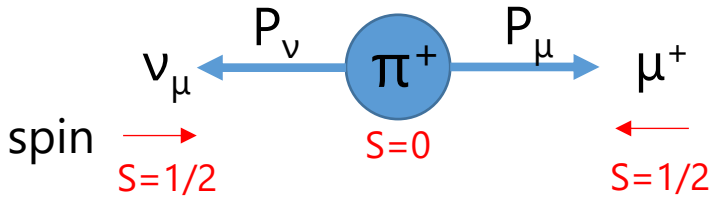


  - ✓ Mean flight length of 150MeV/c $\pi^\pm$ is $L = c\beta\gamma\tau = 8.4$ m
  - ✓ Both μ^+ and μ^-, and momentum is tunable

- ***Surface μ^+***



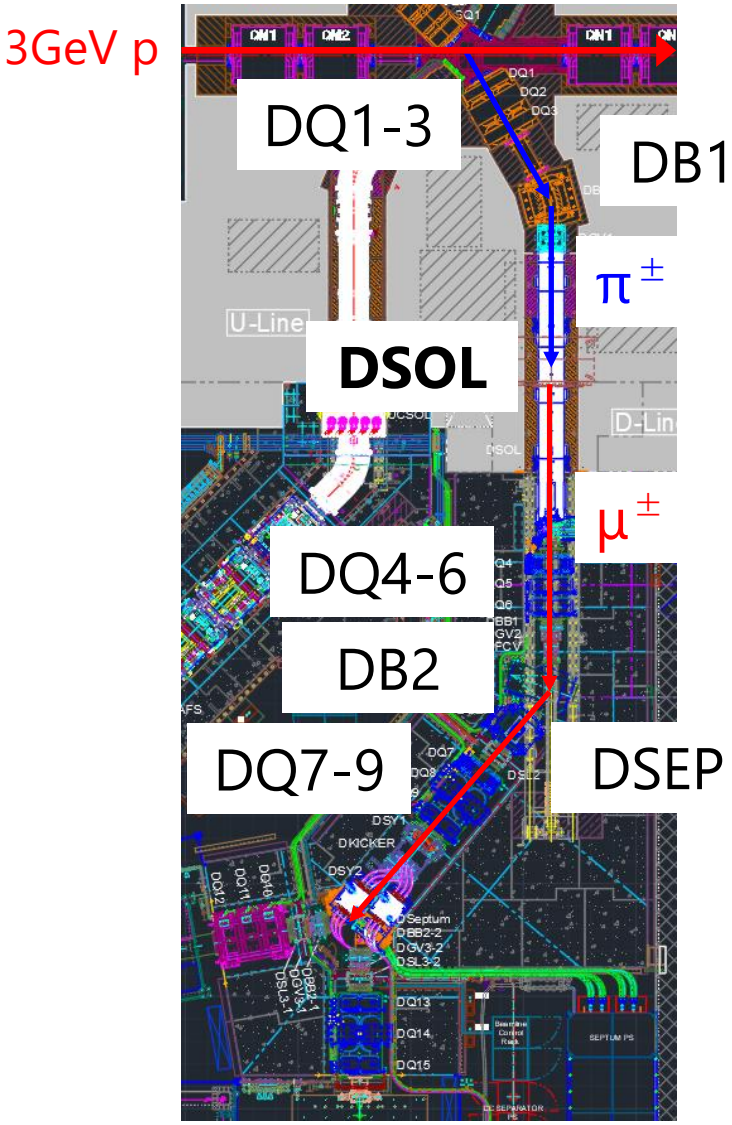
  - ✓ High intensity but μ^+ only (π^- is captured by target nucleus)
  - ✓ Monochromatic (T=4 MeV, P=28 MeV/c)
  - ✓ 100% polarization (spin is anti-parallel to momentum)



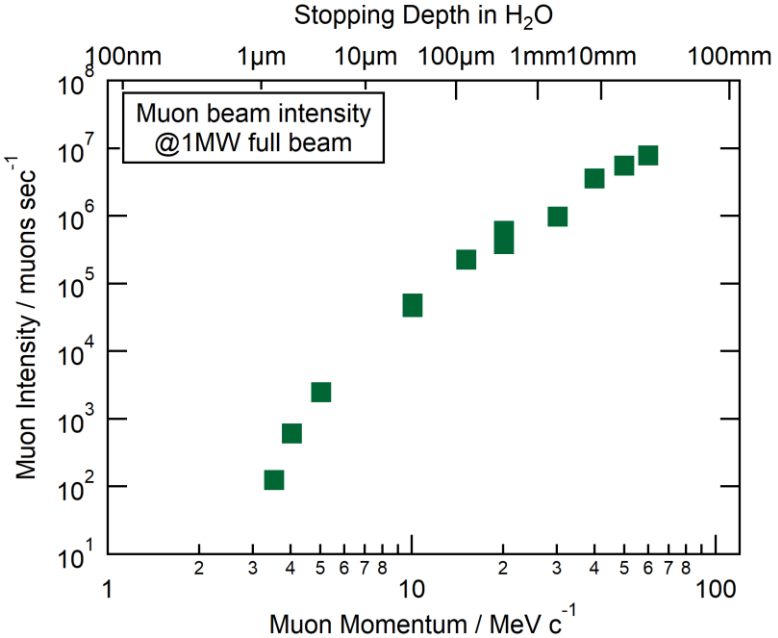
Neutrino is (nearly) massless and left-handed.

D-line: Decay muon beamline

* Surface muon beam is also available

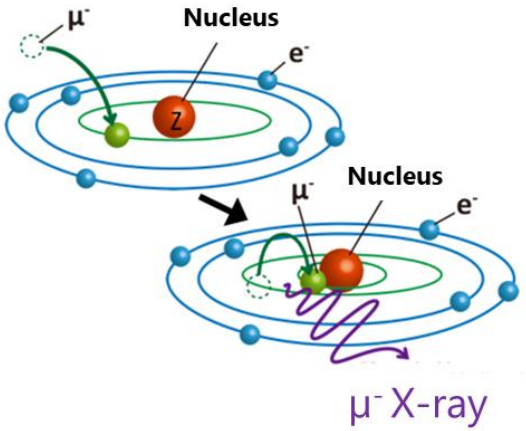


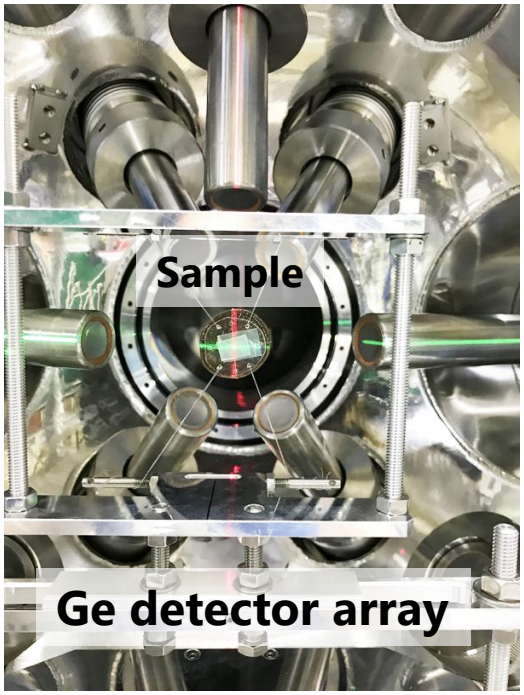
- First muon beamline of our facility
- DQ1-3: Q-triplet to capture $\pi^{\pm}$
- DB1 : Bending magnet to select $\pi^{\pm}$ momentum
- **DSOL** : Long (~6m) superconducting solenoid. $\pi^{\pm} \rightarrow \mu^{\pm}$ decay volume
- DB2 : select $\mu^{\pm}$ momentum



Elemental analysis using Muonic X ray

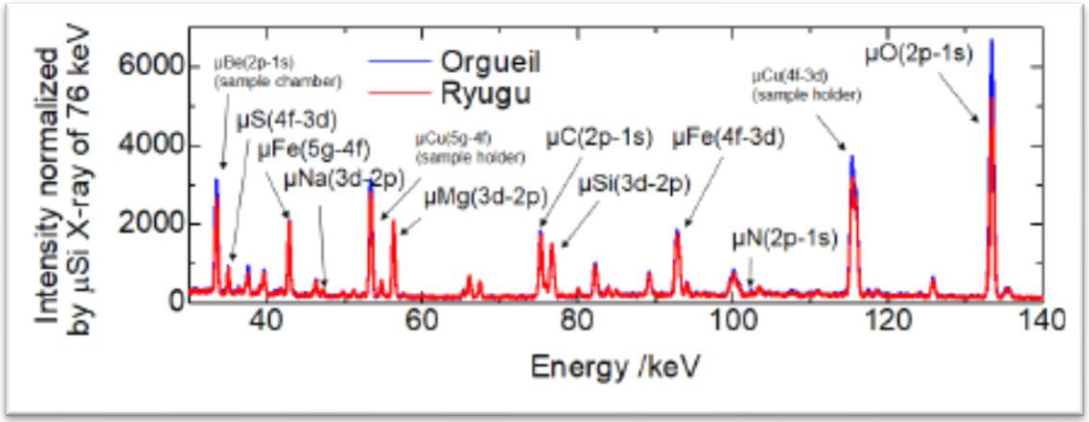
Muonic X-ray energies are unique to each element and 200 times higher than electron's characteristic X rays.



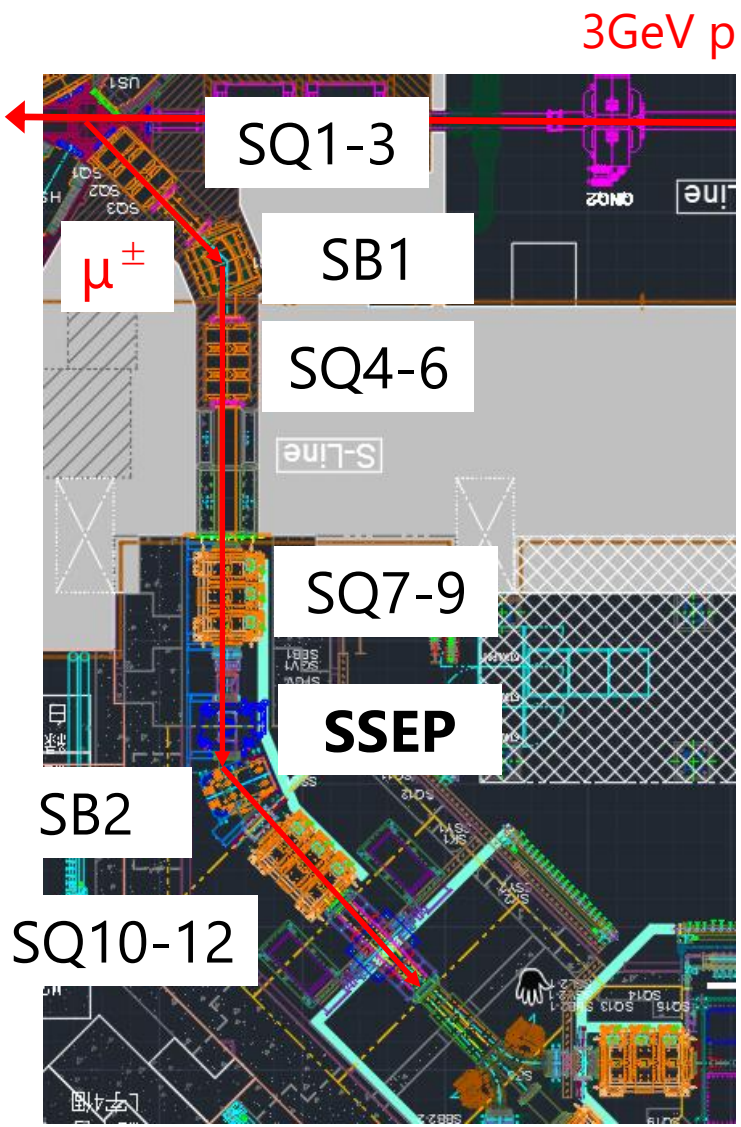


Cultural heritage

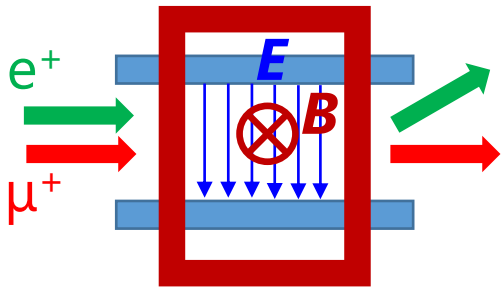
Sample from asteroid Ryugu



S-line: Slow (surface) muon beamline



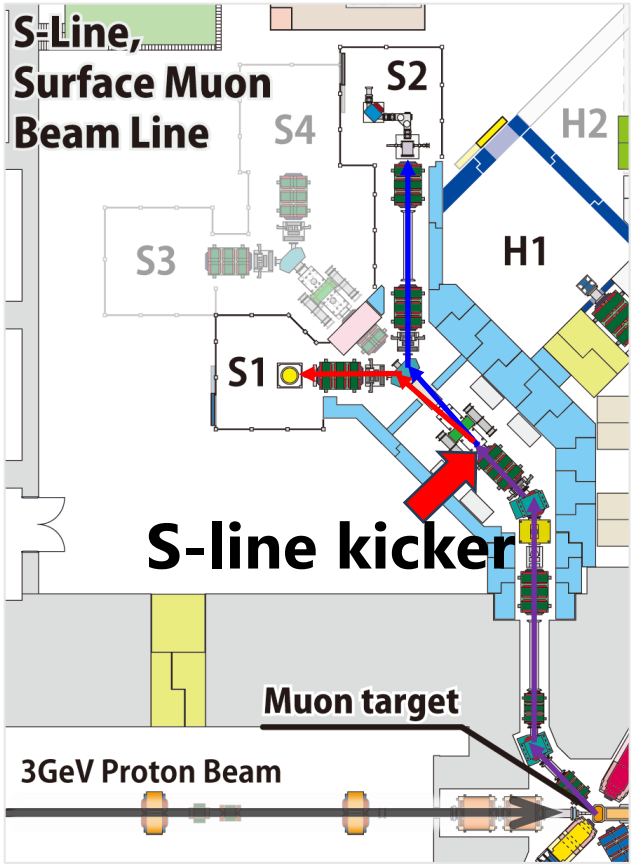
- Capture and transport surface μ^+ (30 MeV/c, 4 MeV) generated on the muon production target using Q-triplets and bending magnets.
- **SSEP** is a DC-separator (Wien filter).
  - ✓ Surface muon beamline has a lot of e^+ contamination of the same momentum
    - Prompt $\pi^0 \rightarrow 2\gamma$
    - Delayed $\pi^+ \rightarrow \mu^+ \rightarrow e^+$

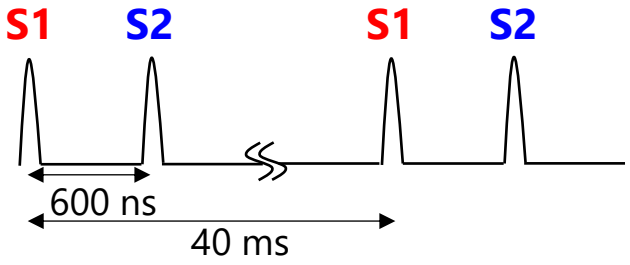


$\boldsymbol{F}=q(\boldsymbol{E}+\boldsymbol{v}\times\boldsymbol{B})$

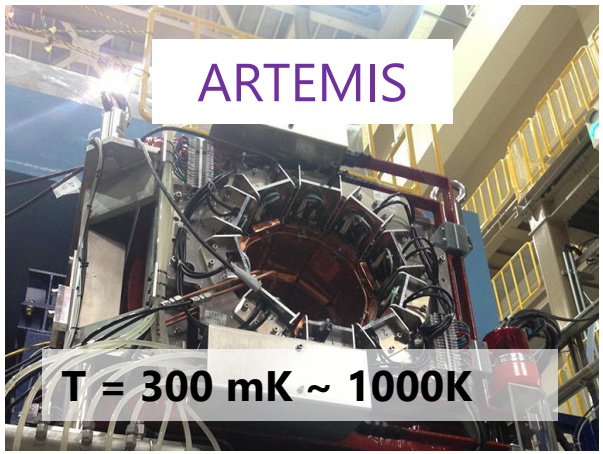
Velocity selector

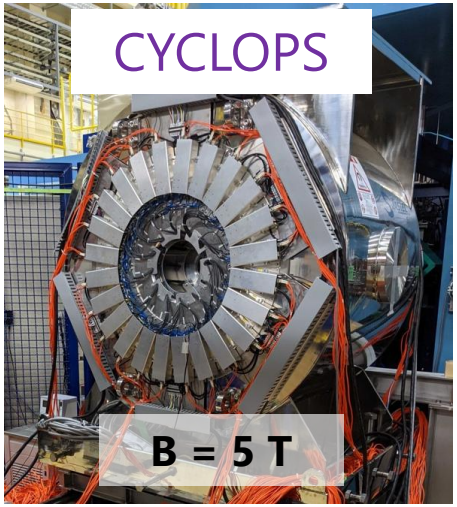
S-line: Kicker and spectrometer



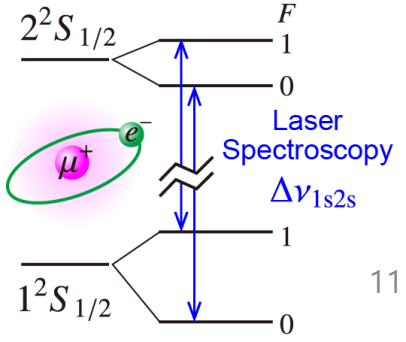


- The S-line electric kicker is a key device that provides single-pulsed beams to the S1 and S2 areas simultaneously.
- S1 area: μSR. Highly segmented and large (21.2%) acceptance μSR spectrometers

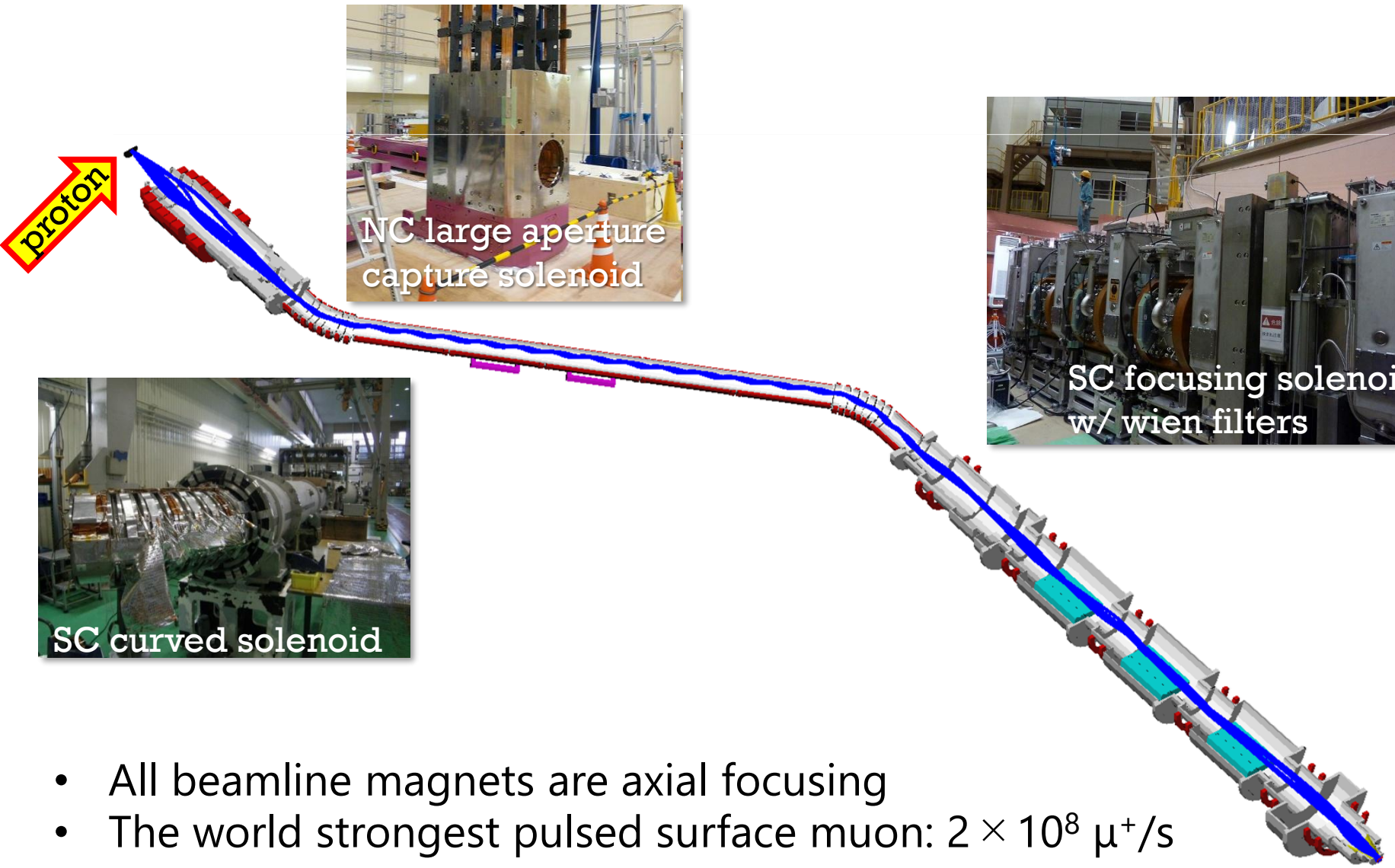




- S2 area: Muonium 1S-2S spectroscopy to measure m_μ
- S3 area will be constructed next year.

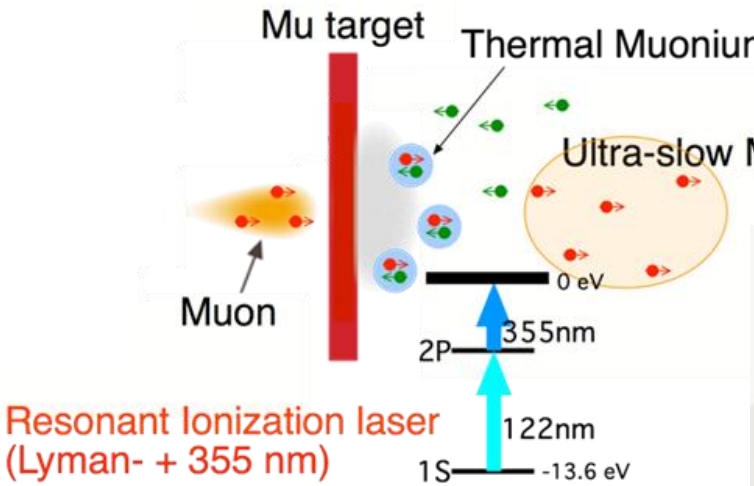


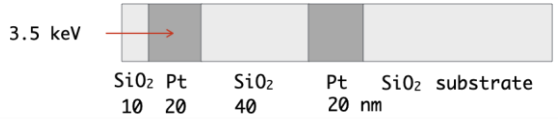
U-line: Ultra-slow muon beamline

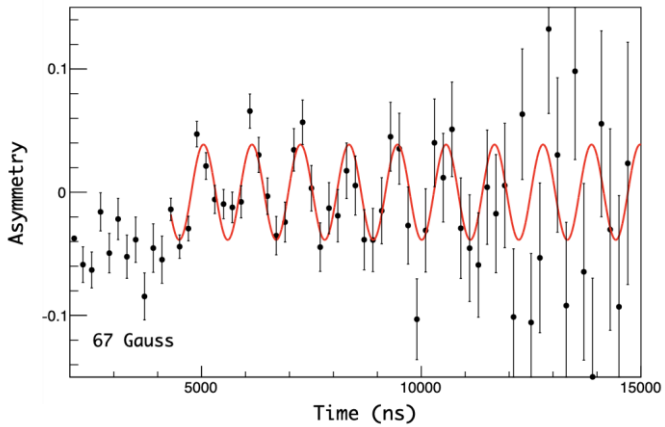


- All beamline magnets are axial focusing
- The world strongest pulsed surface muon: 2×10^8 μ^+/s

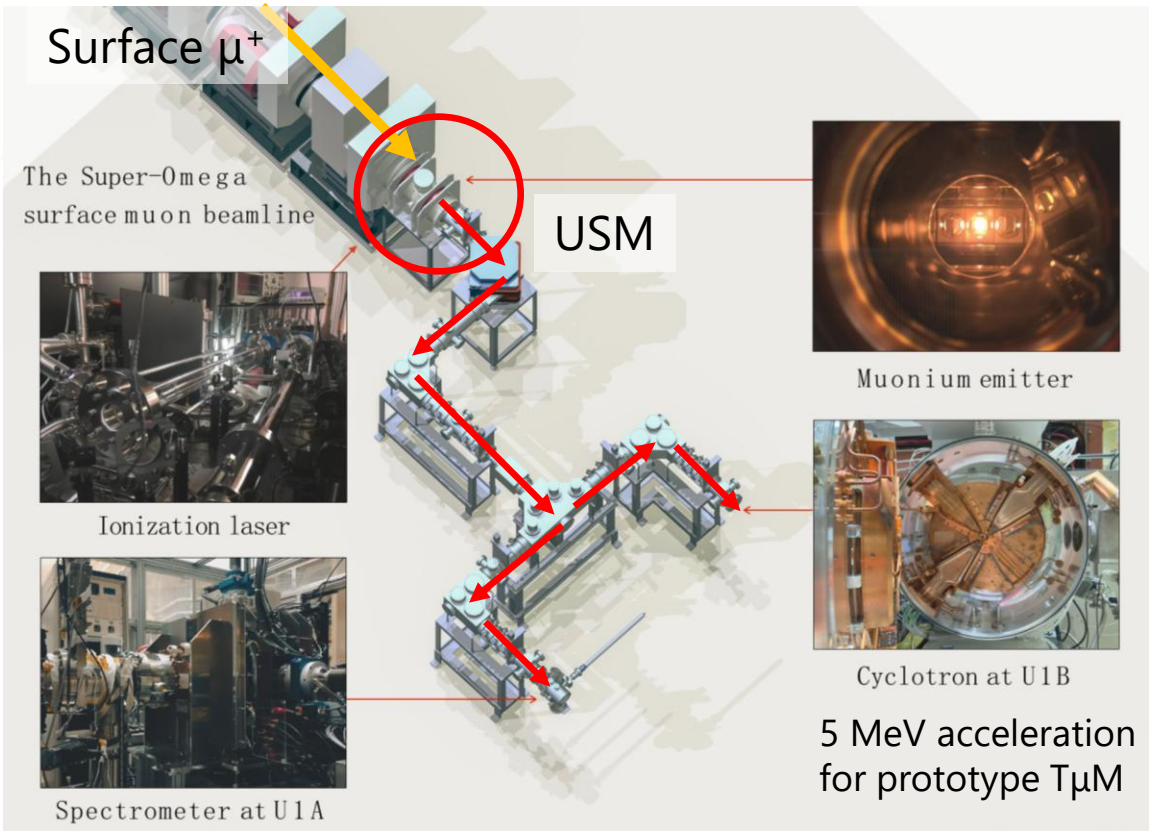
Ultra-slow muon (USM) generation



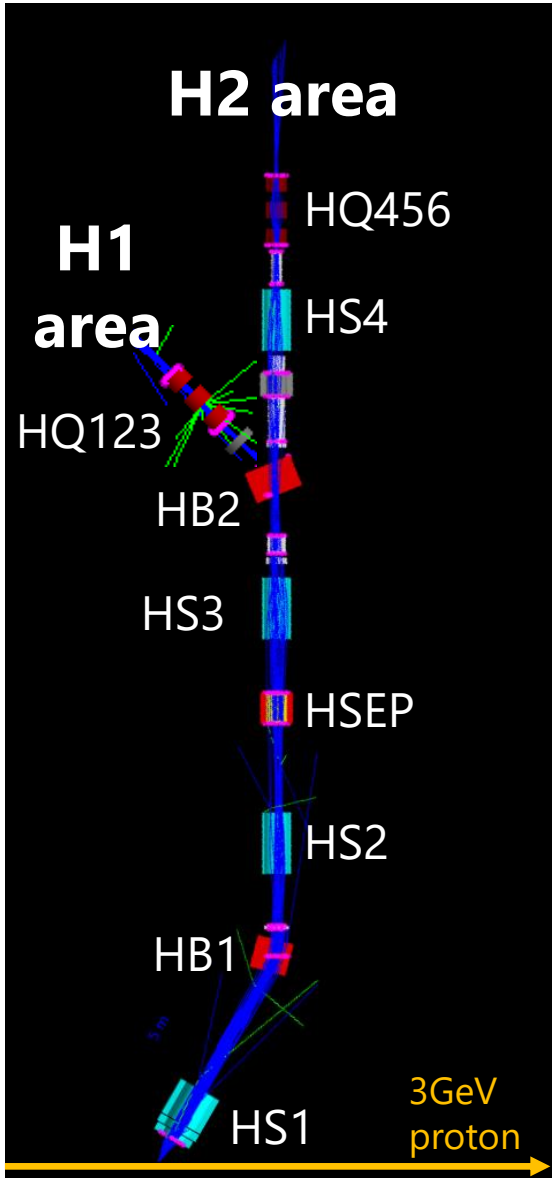




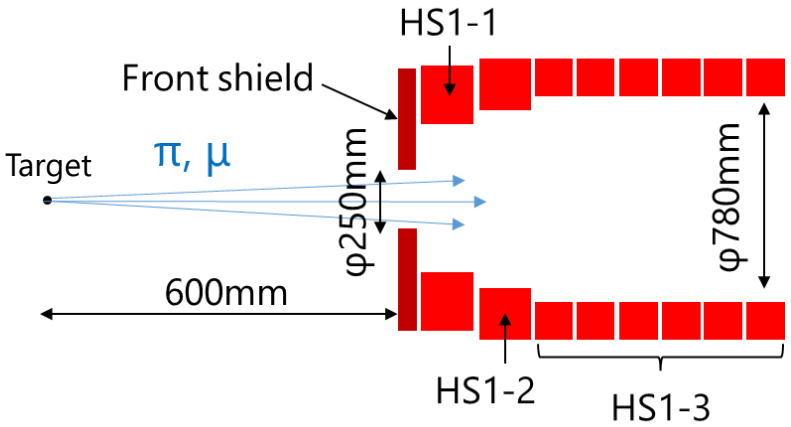
USM-μSR result obtained by the U1A spectrometer.



H-line: high-intensity muon beamline



- H line is a high intensity muon beamline which can deliver both of surface μ^+ and cloud μ^+/μ^- up to 120 MeV/c.
- Beamline optics
  - HS1 : large acceptance capture solenoid

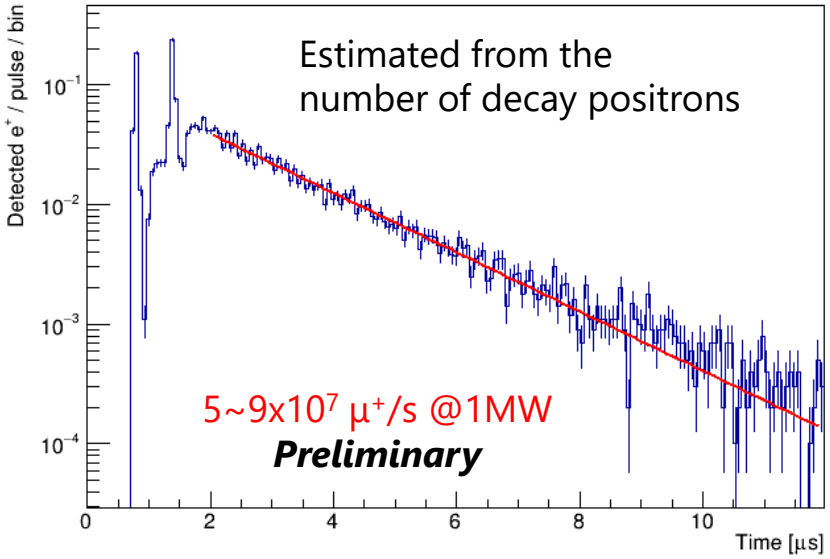


Spec.
HS1-1 : 0.36T
HS1-2 : 0.31T
HS1-3 : 0.58T
*Normal conducting
*Good radiation resistance (MIC)

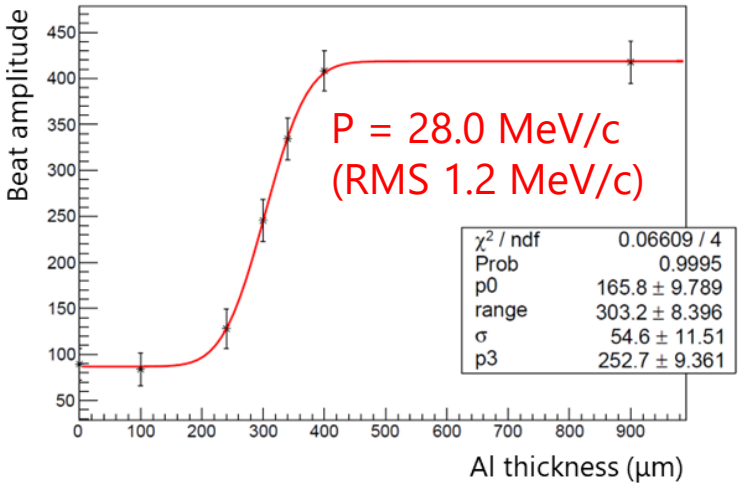
  - HS2,3 : Two superconducting solenoid with opposite polarities
  - HSEP : Wien filter to reduce e^+/e^- background
  - HQ123: Q-triplet for H1 area
  - HS4 and HQ456: Solenoid and Q-triplet for H2 area

Muon beam @H1 area

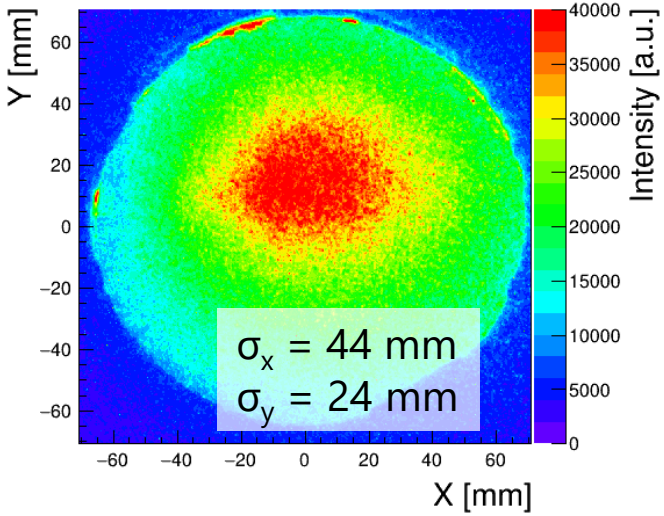
Surface muon intensity



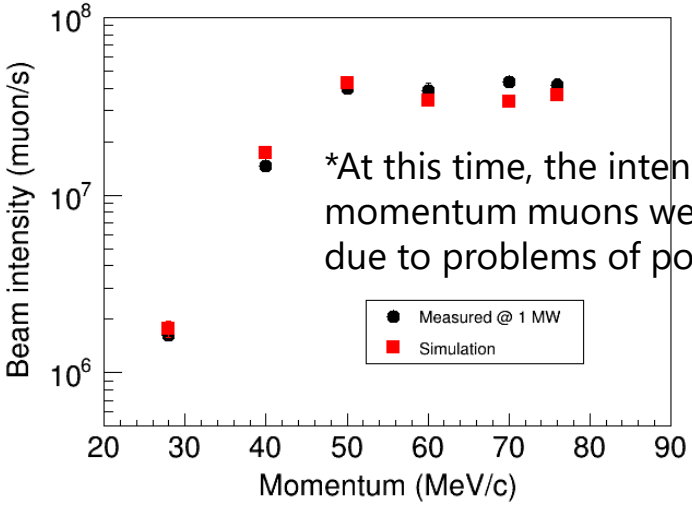
Momentum of surface muons
estimated from μ^+ range in Al target



A typical profile of surface μ^+



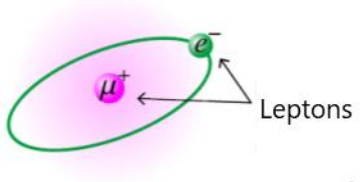
Negative (cloud) muon intensity



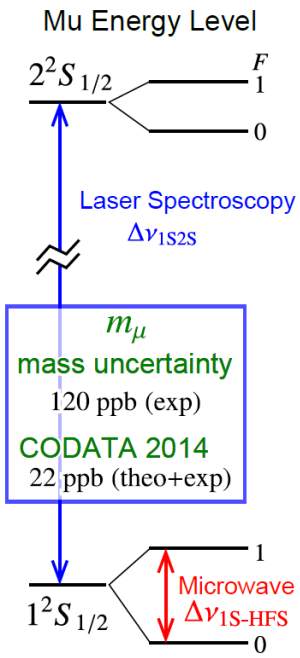
*At this time, the intensity of high momentum muons were limited due to problems of power supplies.

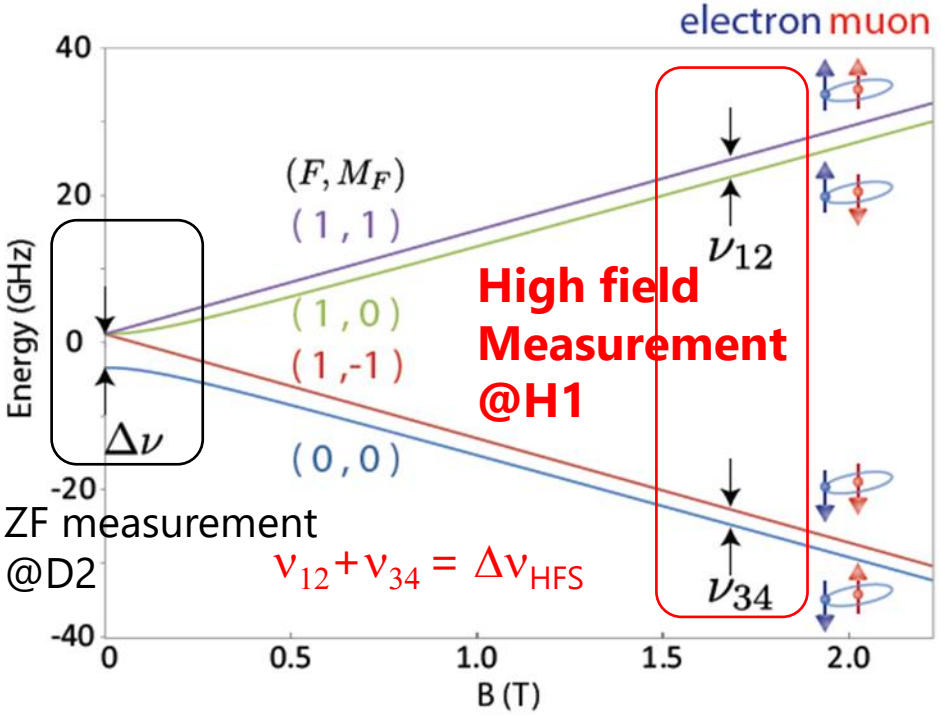
MuSEUM @H1 area

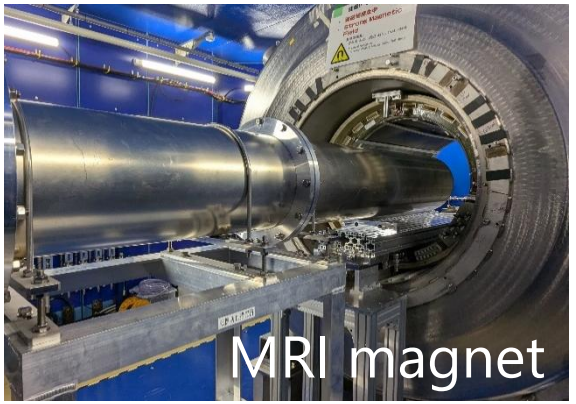
Muonium (Mu)



Precise measurement of the hyperfine structure of muonium





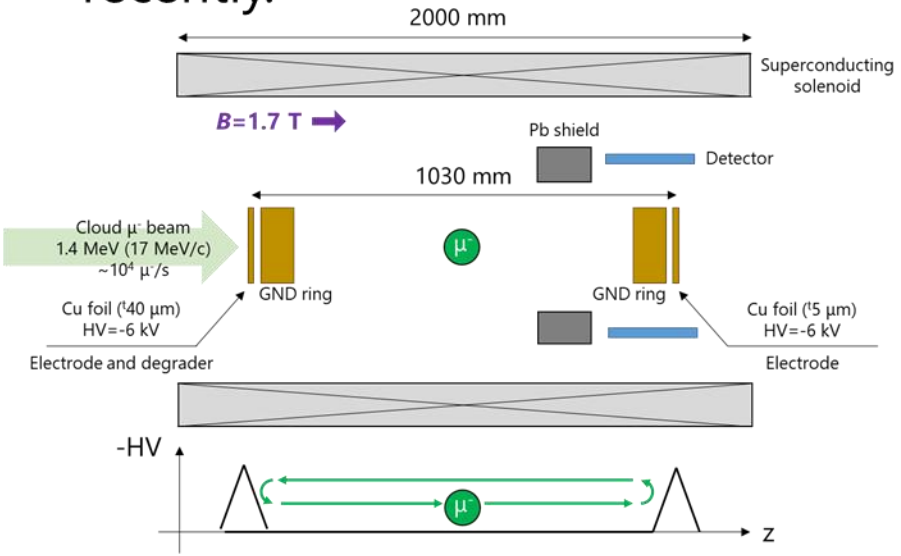


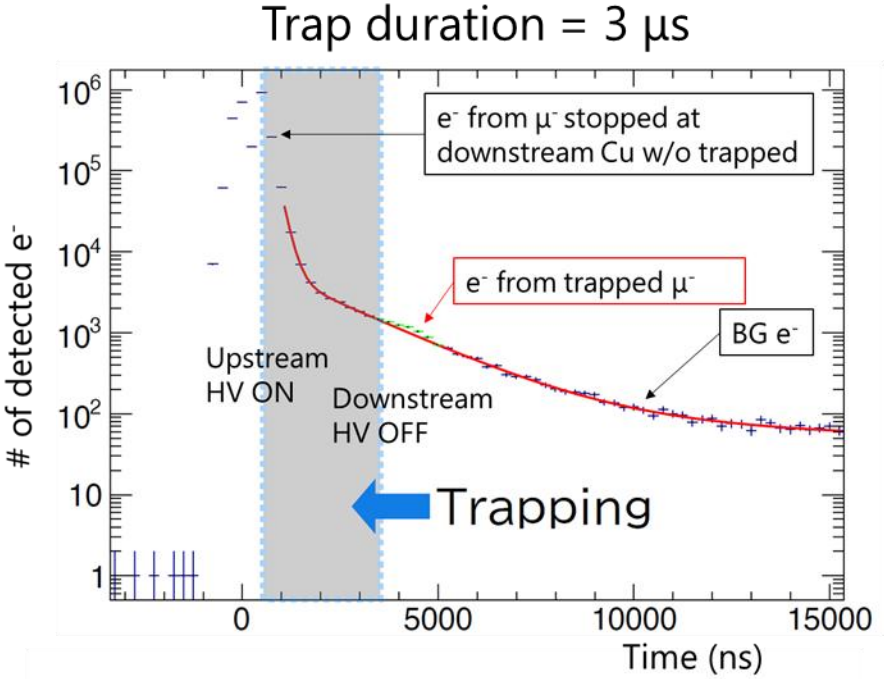
Previous experiment: 4 463.302 765 (53) MHz (LAMPF1999)

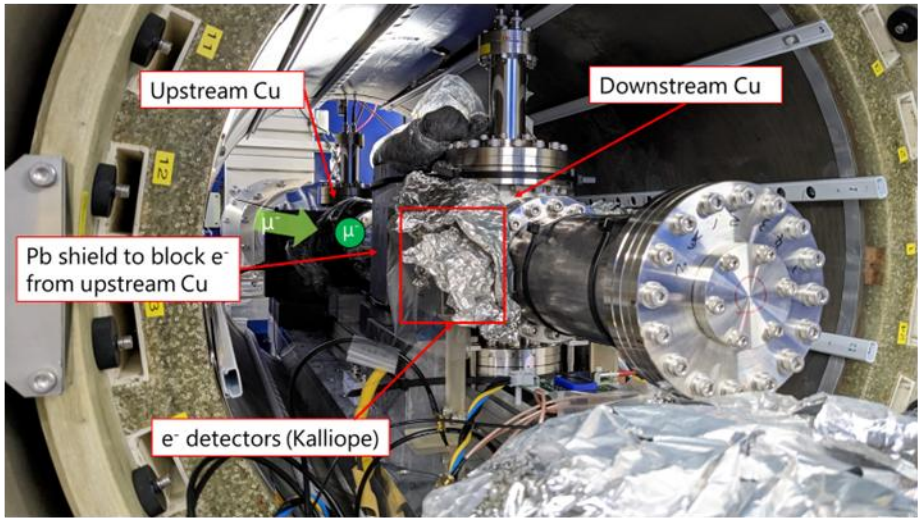
Precision of 8 Hz will be reached by a high field measurement at the H-line.

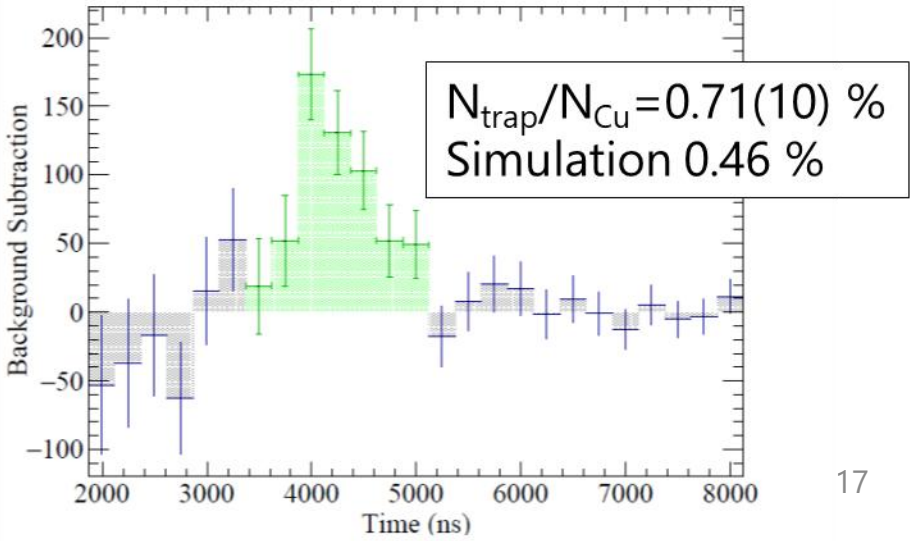
Muon Trap @H1 area

- Negative muon trap was achieved recently.



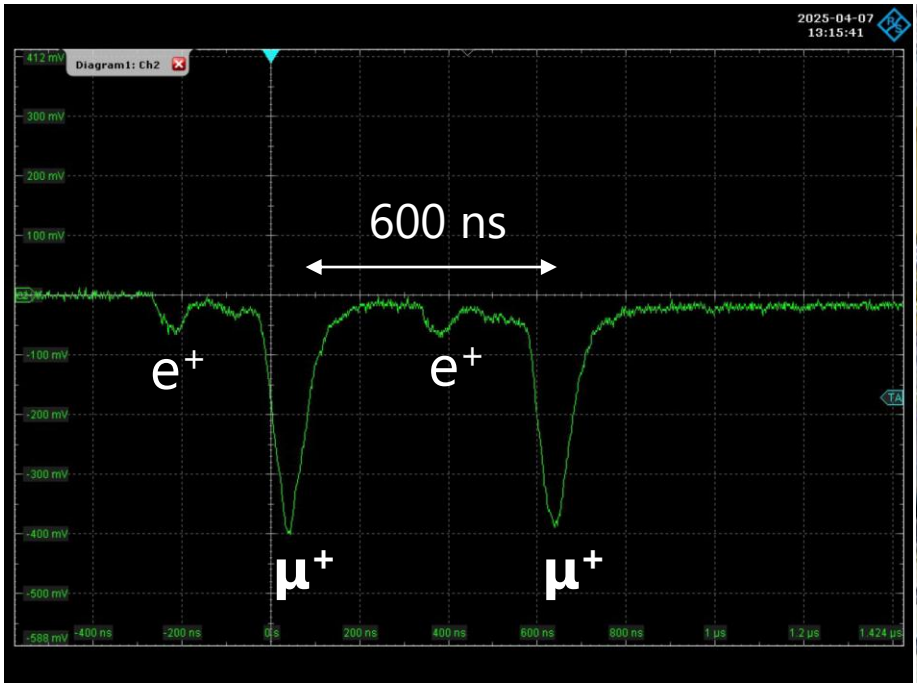






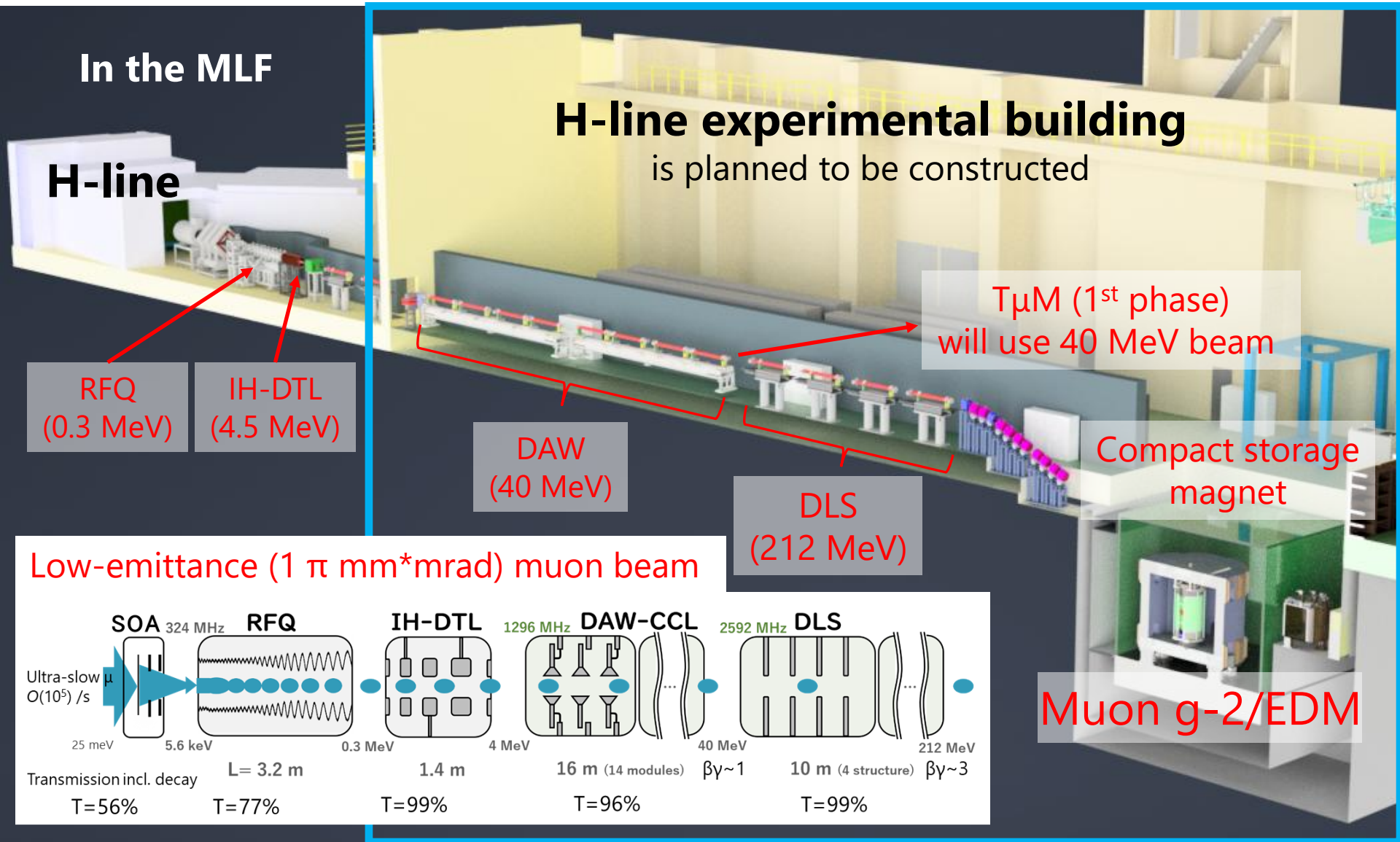
First beam @H2 area

- The second branch (H2 area) was completed in April 2025.



- First beam was observed on April 7.
- We passed facility inspection by Nuclear Regulation Authority in Japan on May 13.

H-line extension



Low-emittance (1 π mm*mrad) muon beam

Transmission Muon Microscope

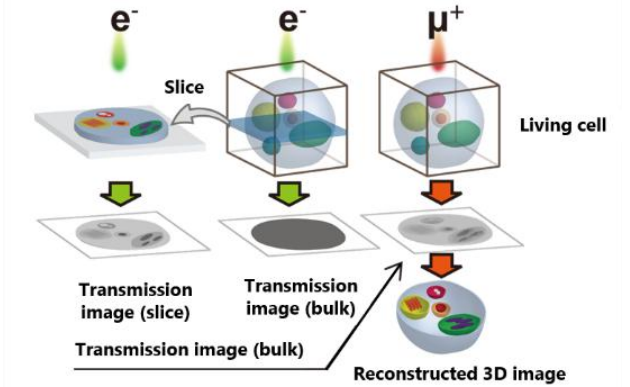
= Accelerated Muon : Strong Penetration + Ultraslow Muon : High Luminance / Resolution

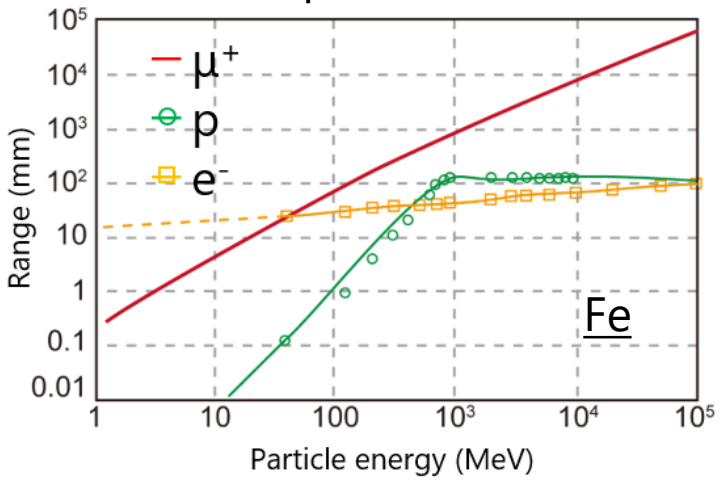
Collaboration with muon g-2/EDM exp.

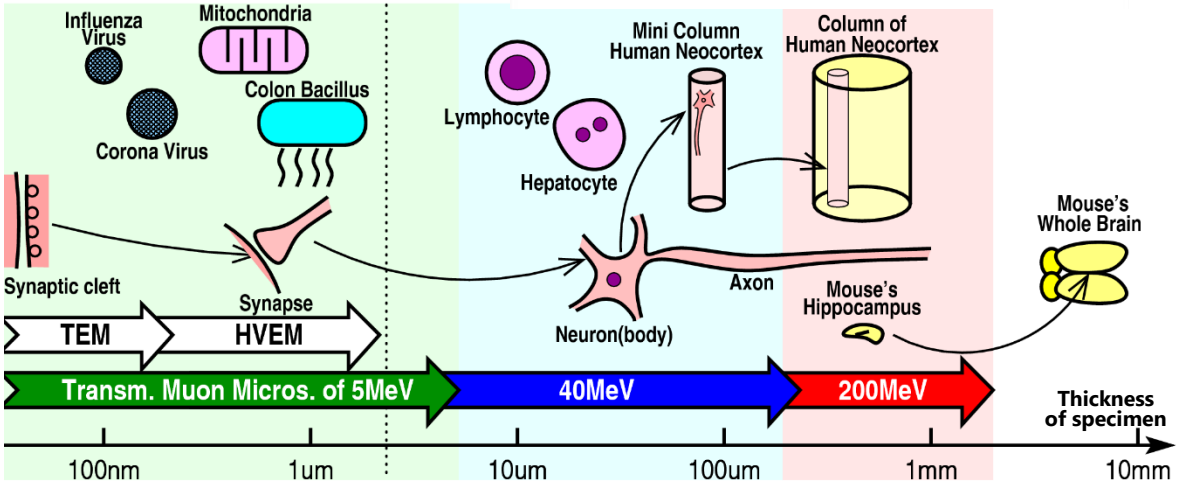
Microscopy optics

Observe bulk samples utilizing the strong penetrative power of re-accelerated muons

- Any methods for TEMs are applicable
- Functional imaging of living/cryo-tissues
- It can see EM fields in packaged IC/LSI, Li ion battery, solar cell, piezo, etc.







Summary

- J-PARC muon facility can provide high-intensity pulsed muons
  - Surface muon (μ^+, 30 MeV/c): 10^7~10^8 μ/s
  - Decay muon (μ^+ 3-120 MeV/c, μ^- 3-60 MeV/c): O(10^7) μ/s
- 4 muon beamlines and 8 experimental areas.
  - D-line (Decay muon beamline): nondestructive elemental anslysis using μ^- X ray, and μSR
  - S-line (Surface muon beamline): μSR, and muonium 1S-2S
  - U-line (Ultra-slow muon beamline): nm-μSR, and TμM. Under commissioning
  - H-line: (High-intensity muon beamline): Fundamental physics using muon and muonium
- Plan in near future: H-line extension
  - Low-emittance (1 π mm*mrad) muon beam by accelerating USM up to 212 MeV
  - Muon g-2/EDM and TμM