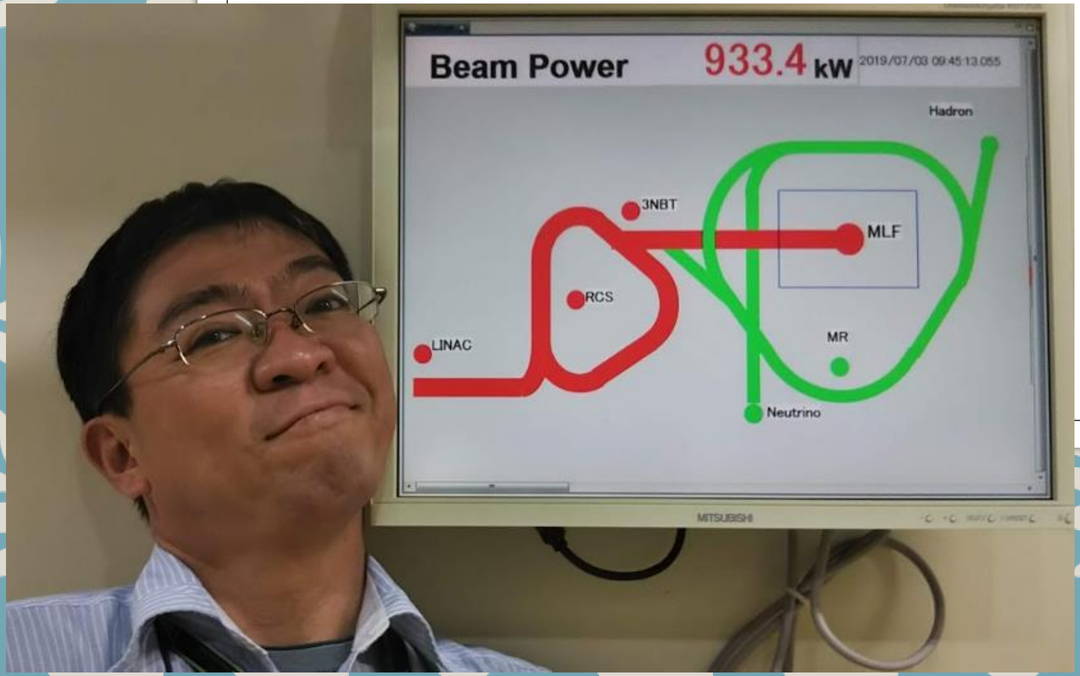
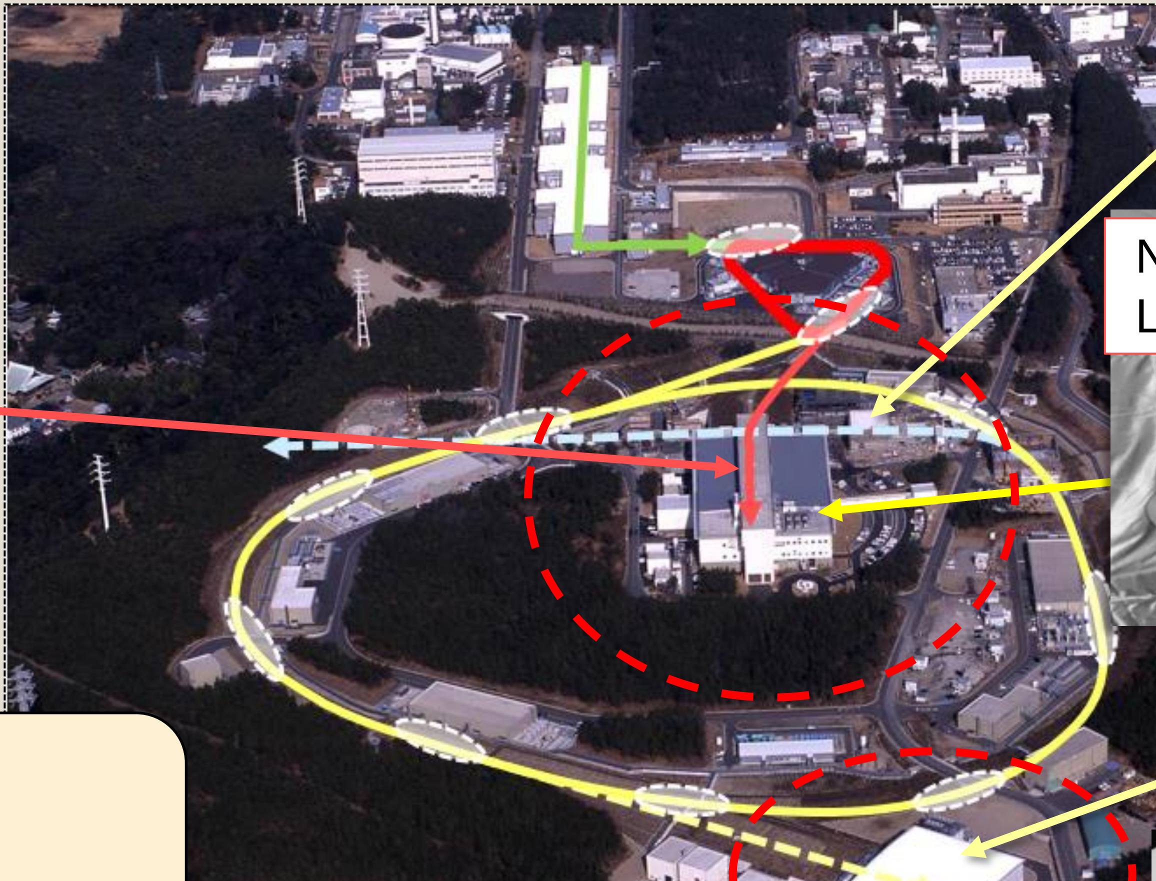
Muon production program at KEK

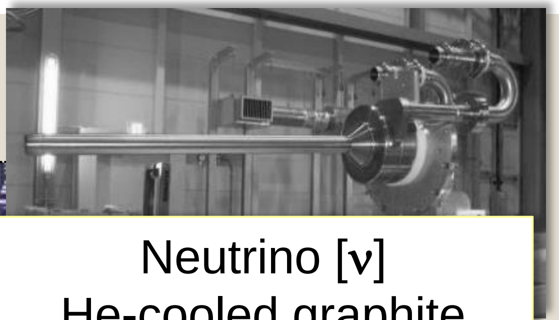
J-PARC, KEK
Shunsuke Makimura

FNAL collaboration meeting
19th, Feb. 2024

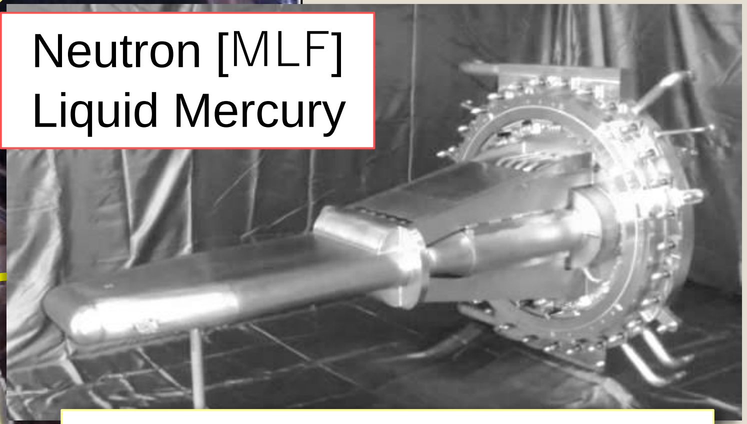


Muon production at J-PARC

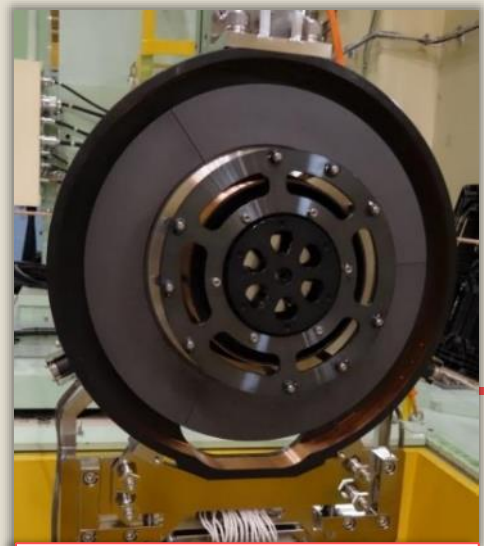




Neutrino [ν]
He-cooled graphite

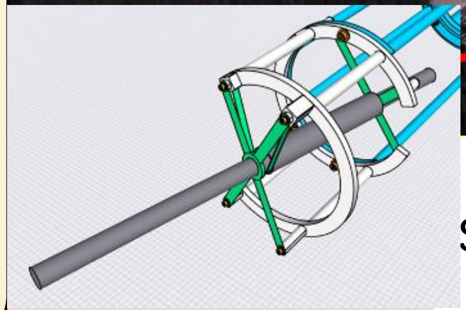


Neutron [MLF]
Liquid Mercury



Muon [MLF-MUSE]
Rotating Graphite

Hadron [HEF]
Water cooled gold/ high-Z rotating target



Graphite (P1),
SiC/SiC(P1.5), W (P2)
[COMET]

Materials & Life science experimental Facility

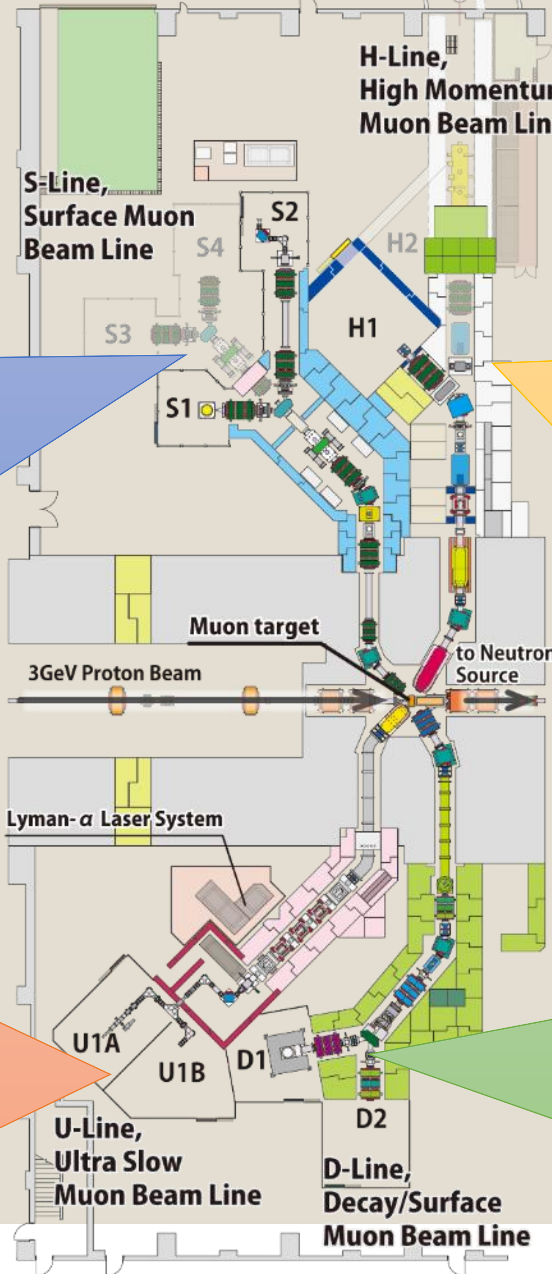
- μSR for mater. & Life science
- Non-destructive analysis by μ^-
- Fundamental physics, G-2/EDM

Hadron experimental facility

- COMET experiment

1. MUON SCIENCE AT MLF

Muon Science at Materials and Life Science experimental Facility, MLF



S-line μ^+

Surface muon (4 MeV) dedicated to bulk μSR in 4 experimental areas w/ various sample env.:

ultra-low temperature
high magnetic field
pulsed excitations *etc.*

4 areas Simultaneous use

H-line μ^+/μ^-

High-intensity surface ... muon (<4 - 50 MeV) ... "fundamental physics" requiring high precision, high sensitivity

High Intensity General Use

U-line μ^+

Ultra slow muon ... surface/sub-surface ...

Test-bench for TμM (U1B)

Ultra Slow Muon Surface/Interface

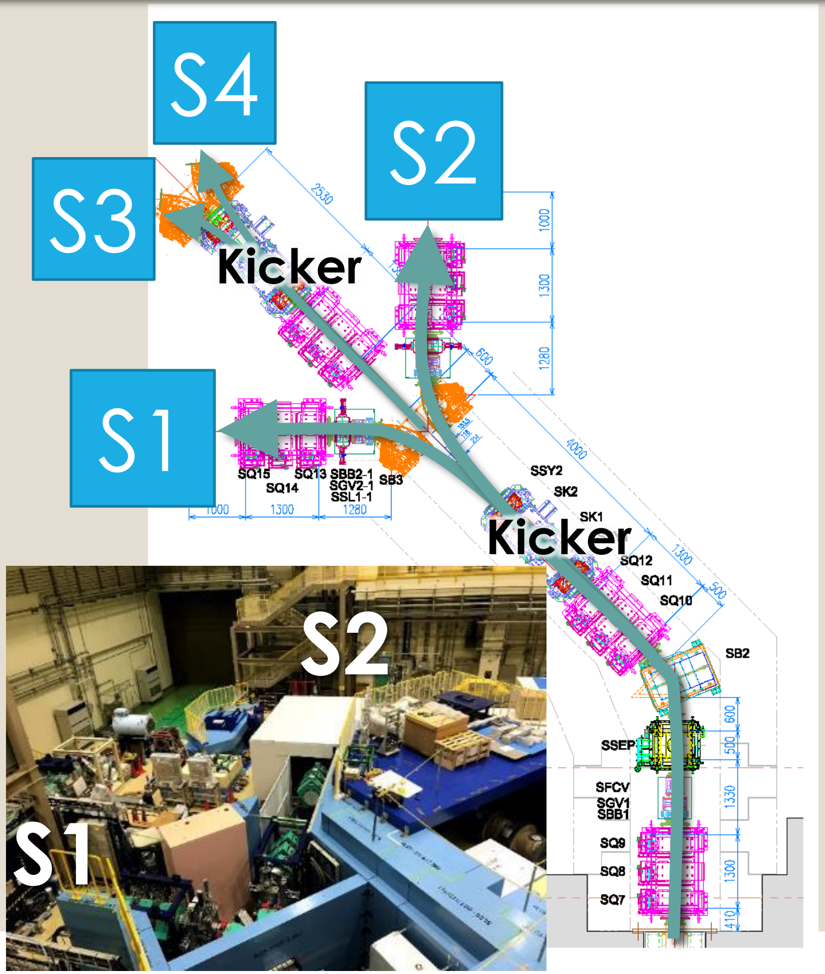
D-line μ^+/μ^-

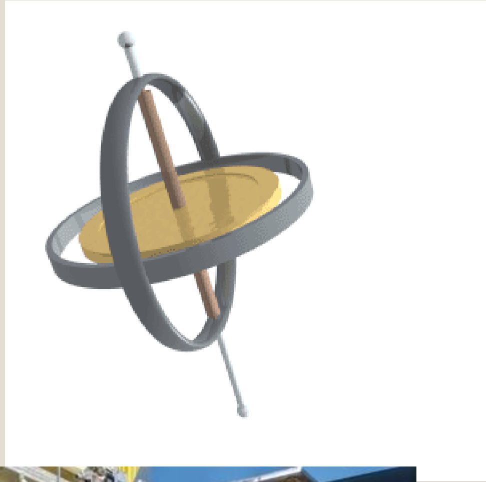
Decay and surface muon (... 50 MeV) to answer a variety of users' demands with μSR spectrometer (D1) general purpose (D2)

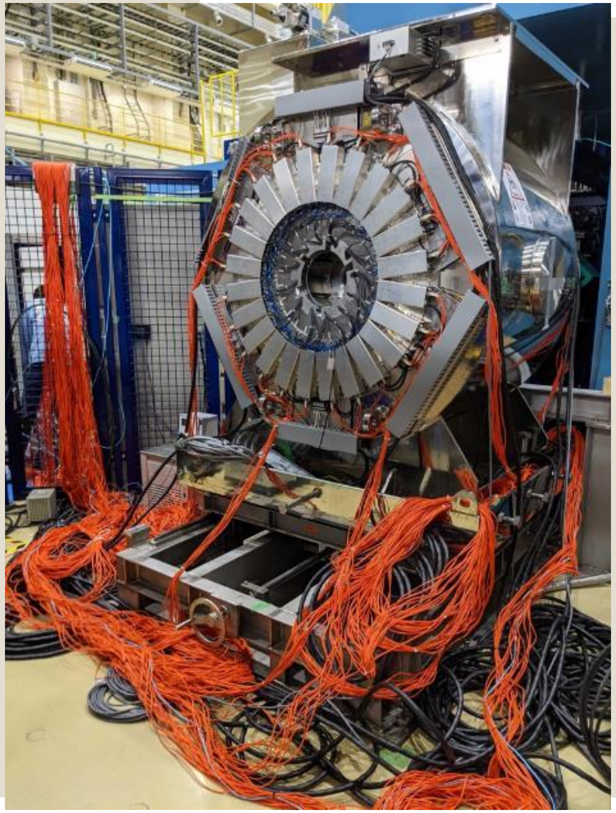
General Use

Highlight of S-line: A surface muon beamline for muSR

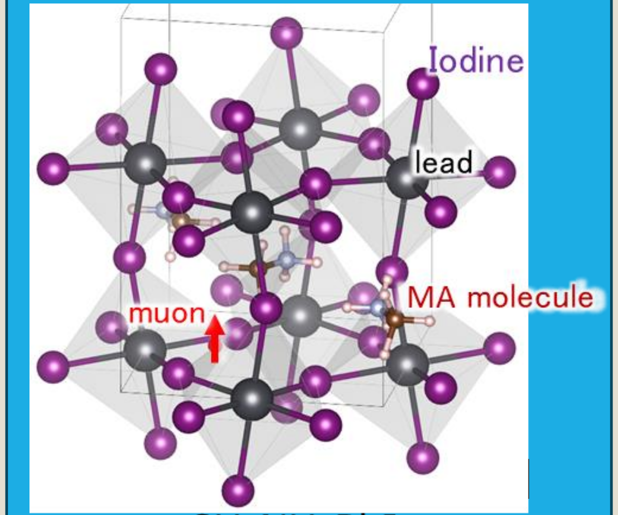
S line is dedicated to transport surface muon beam. By using two kicker system, S line provides muon beams to all 4 areas simultaneously. At present two experimental areas, S1 and S2, were completed.







Study on a next-generation solar cell

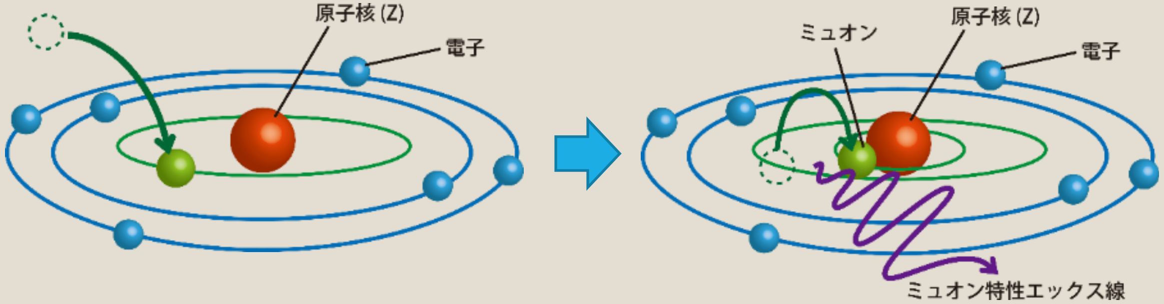


$CH_3NH_3PbI_3$

Next generation solar cell material, organic-inorganic hybrid perovskite $CH_3NH_3PbI_3$ ($MAPbI_3$) was studied by muSR, and it was revealed that the lifetime of charge carriers correlates with the rotational motion of organic MA molecules.

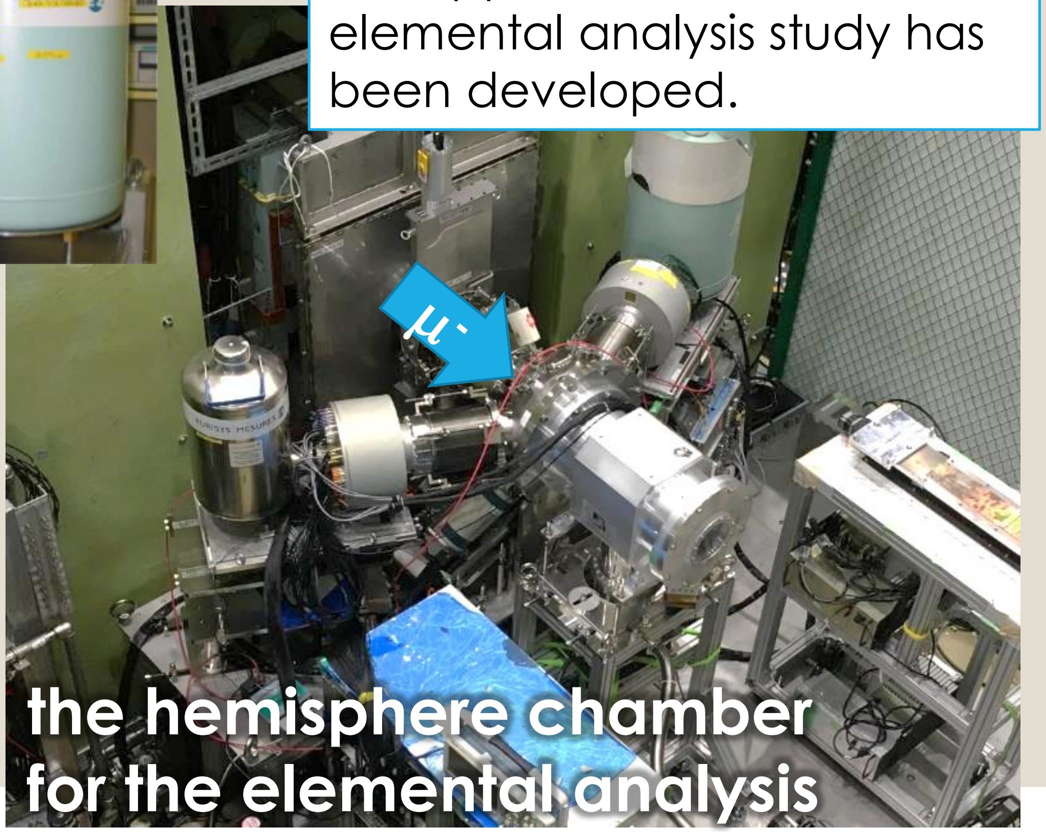
A. Koda *et al.*, DOI:10.1073/pnas.2115812119

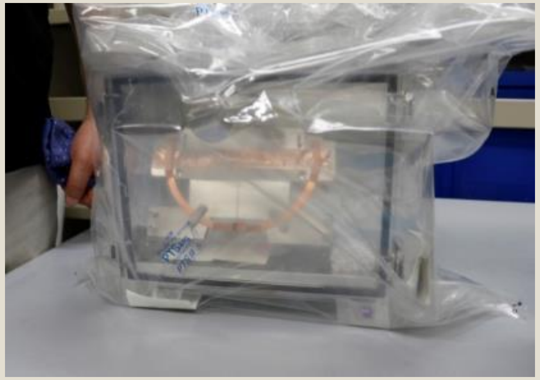
Highlight of D-line: Non-destructive inspection by negative muon



In recent years, applying to archeological artifacts, *etc*, the fraction of the elemental analysis studies by μ^- has been getting increased in the D2 area.

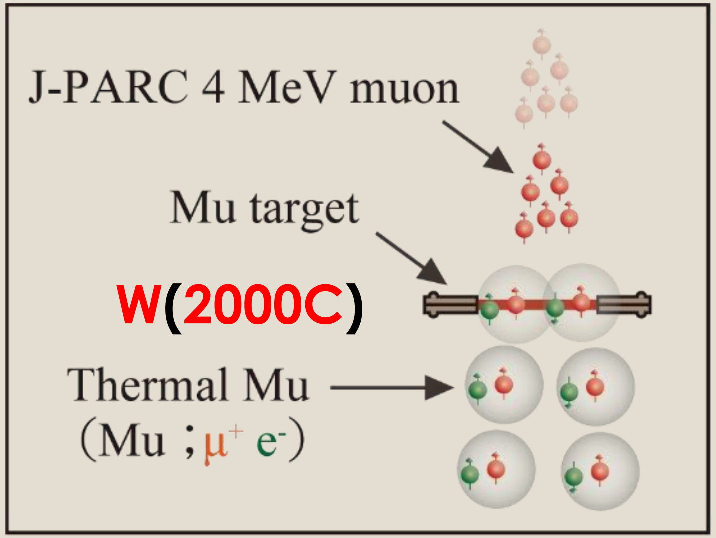
To answer such demands, the apparatus for the elemental analysis study has been developed.



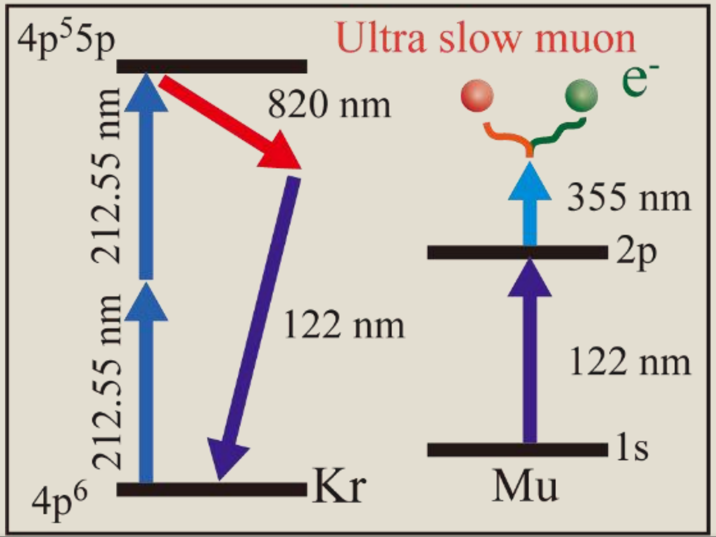


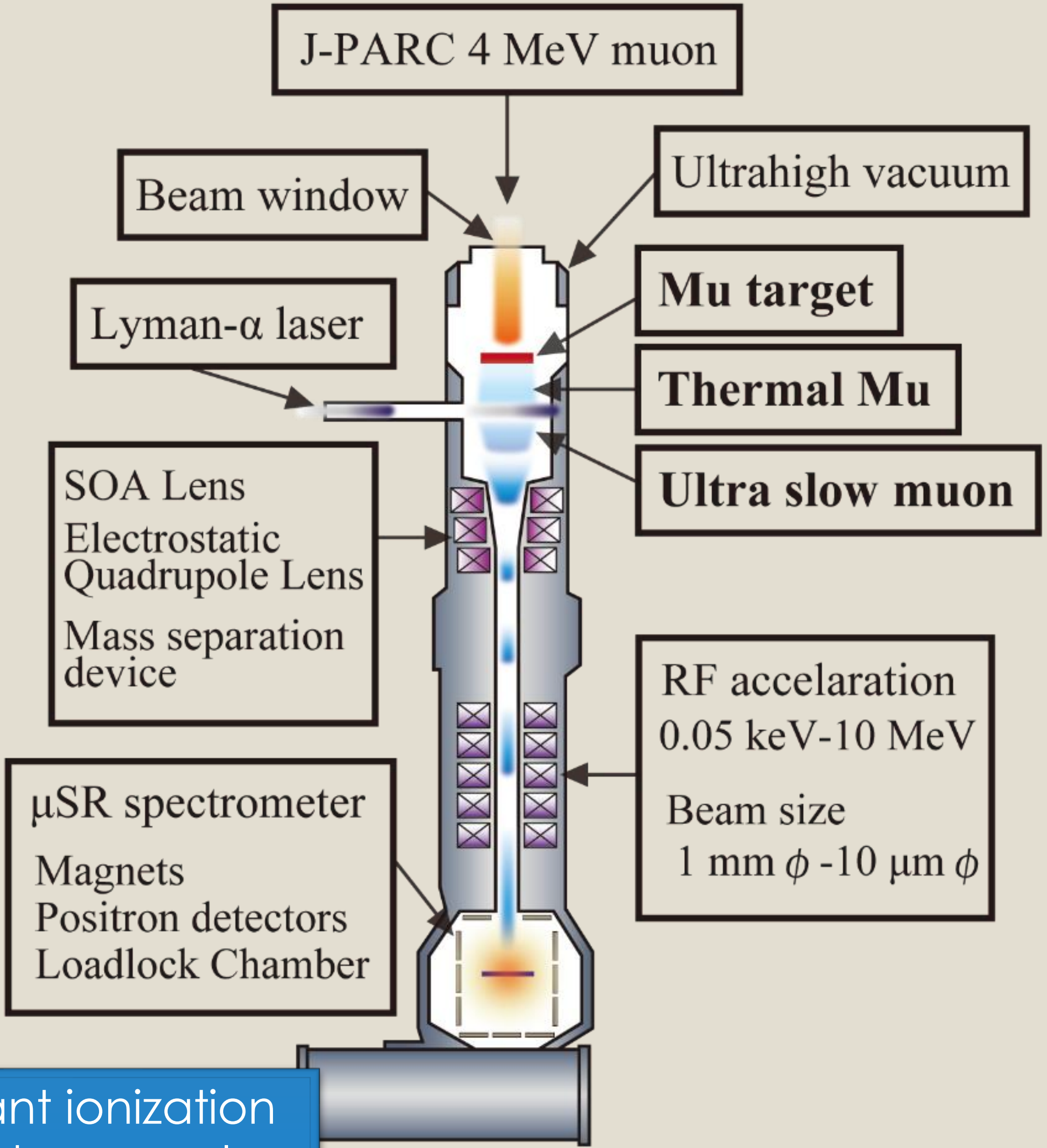
HAYABUSA2 return sample, rocks of the asteroid RYUGU was analyzed in 2021.

U-line: Generation of Ultra slow muon (USM)



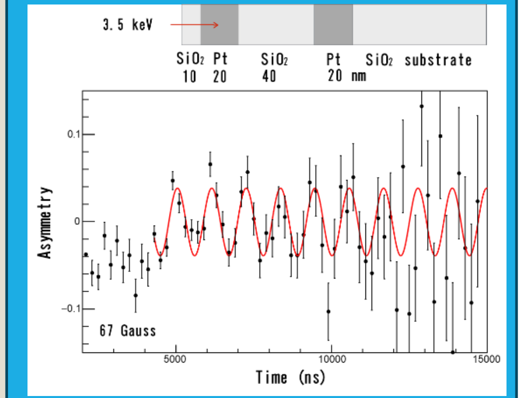
Mu generator





USM is generated by the laser resonant ionization method synchronized with the muon beam pulse.

USM can be stopped at the surface and the interface of materials to study a novel function appeared on them.

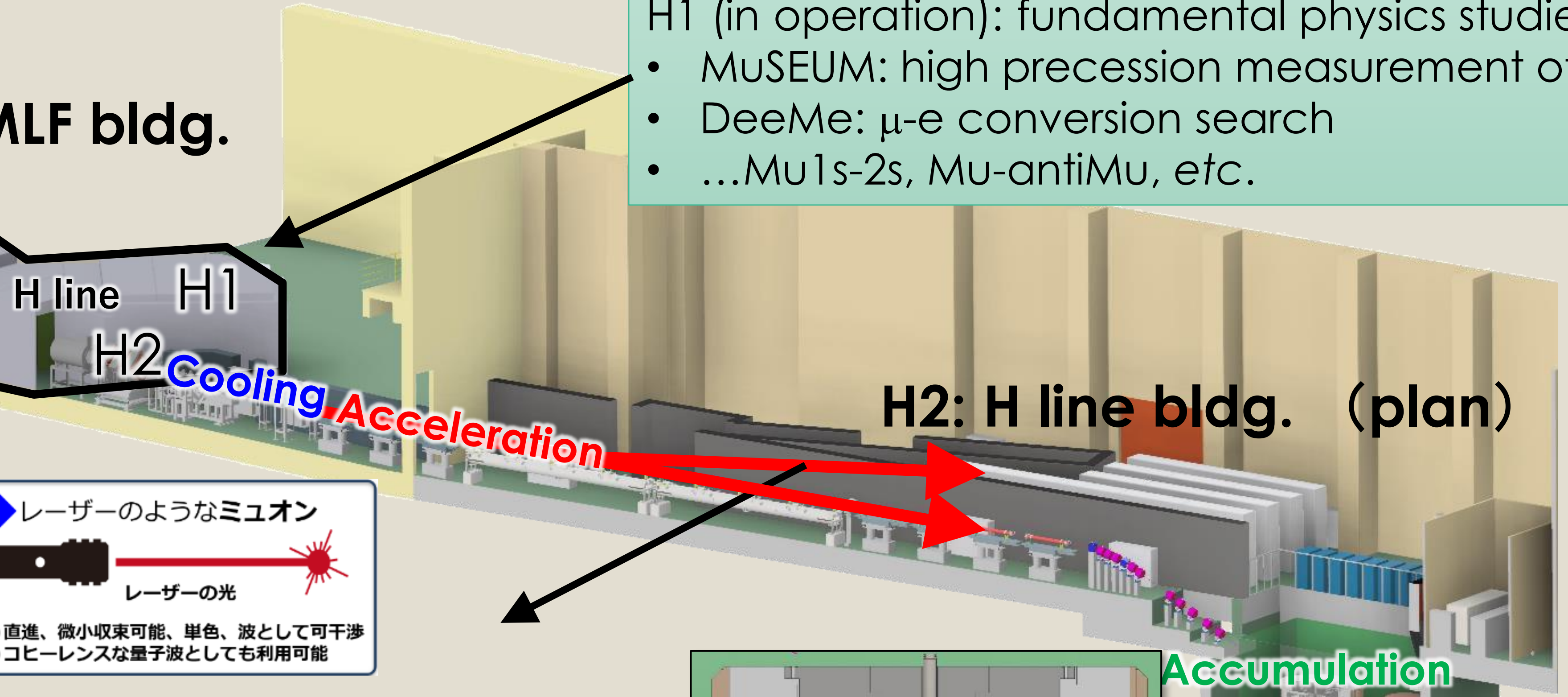


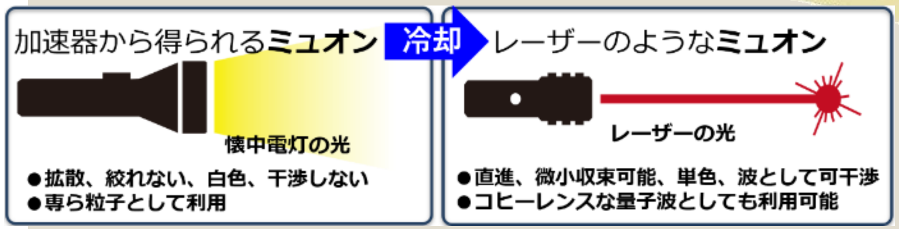
A thin film sample of (Ca,Sr)CuO2, the parent material of infinite-layer cuprate superconductors will be studied.

Highlight of H-line: MuSEUM, DeeMe, TMM, G-2/EDM,,,

H1 (in operation): fundamental physics studies
- MuSEUM: high precession measurement of Mu HFS
- DeeMe: μ-e conversion search
- …Mu1s-2s, Mu-antiMu, *etc*.

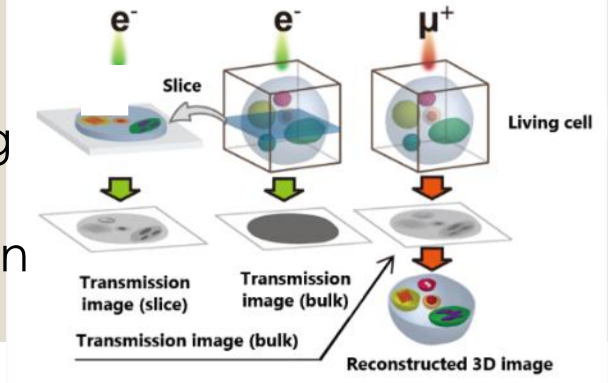
MLF bldg.

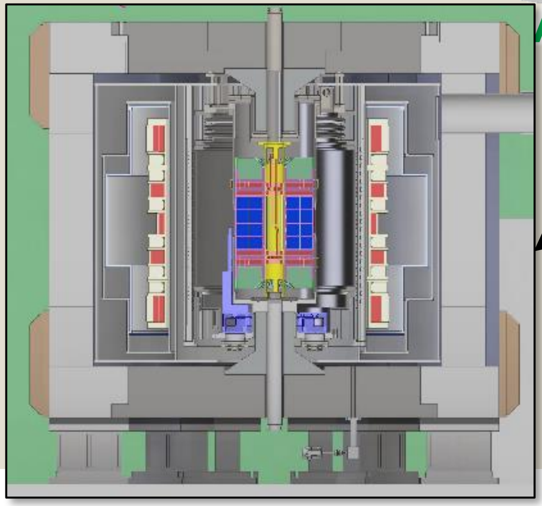




Transmission Muon Microscope

Observation of whole living cell owing to high penetration power of muon





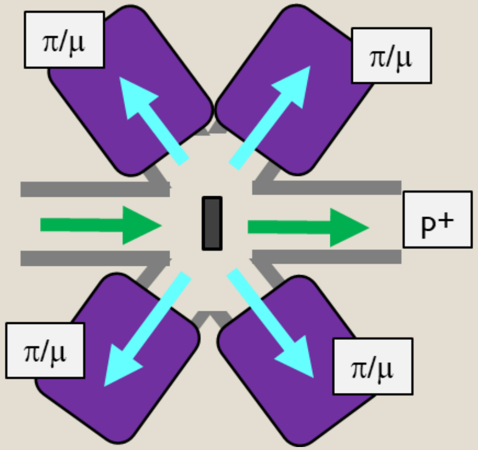
g-2/EDM exp.
Searching for BSM.

2. MUON TARGET AT MLF

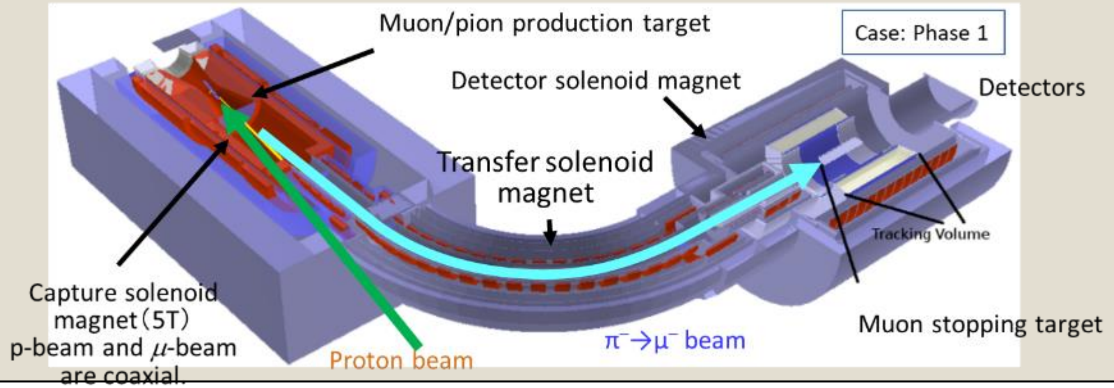
Position of target chamber in September 2005

MLF muon target & COMET target

	MLF target	COMET P1	COMET P2
Proton beam	3 GeV, 1 MW	8 GeV, 3.2 kW	8 GeV, 56 kW
Beam sigma	3.5 mm	H: 2.3 mm, V: 2.3 mm	(H: 2.3 mm, V: 2.3 mm)
Target material	graphite	graphite	Tungsten
Target thickness	20 mm	700 mm	160 mm
Beam loss on target	3.3 kW	110 W	7 kW
Time structure	25 Hz, Double Pulsed, 110 ns	0.5 s. extraction in 2.5 s.	-

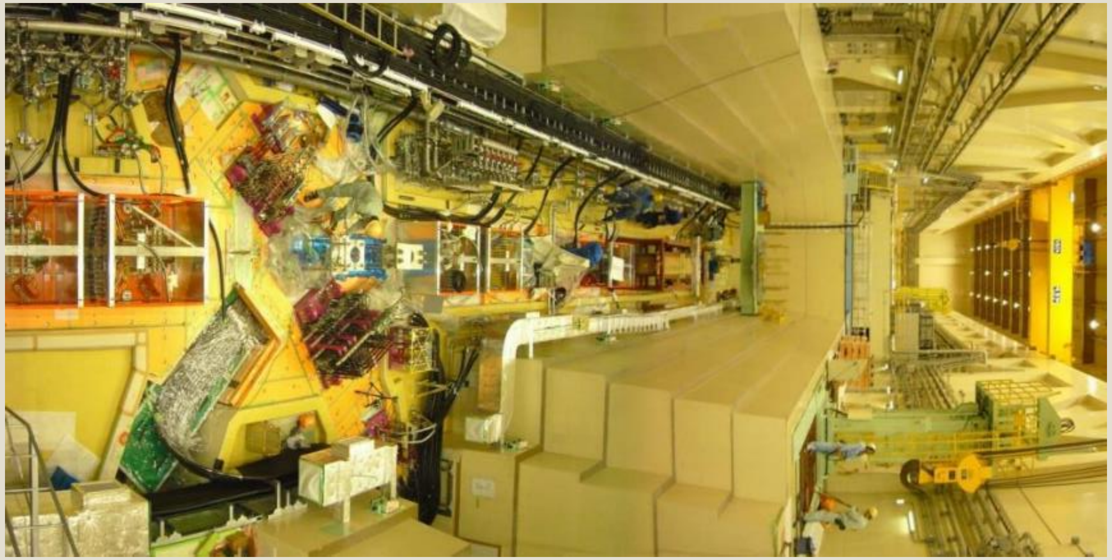


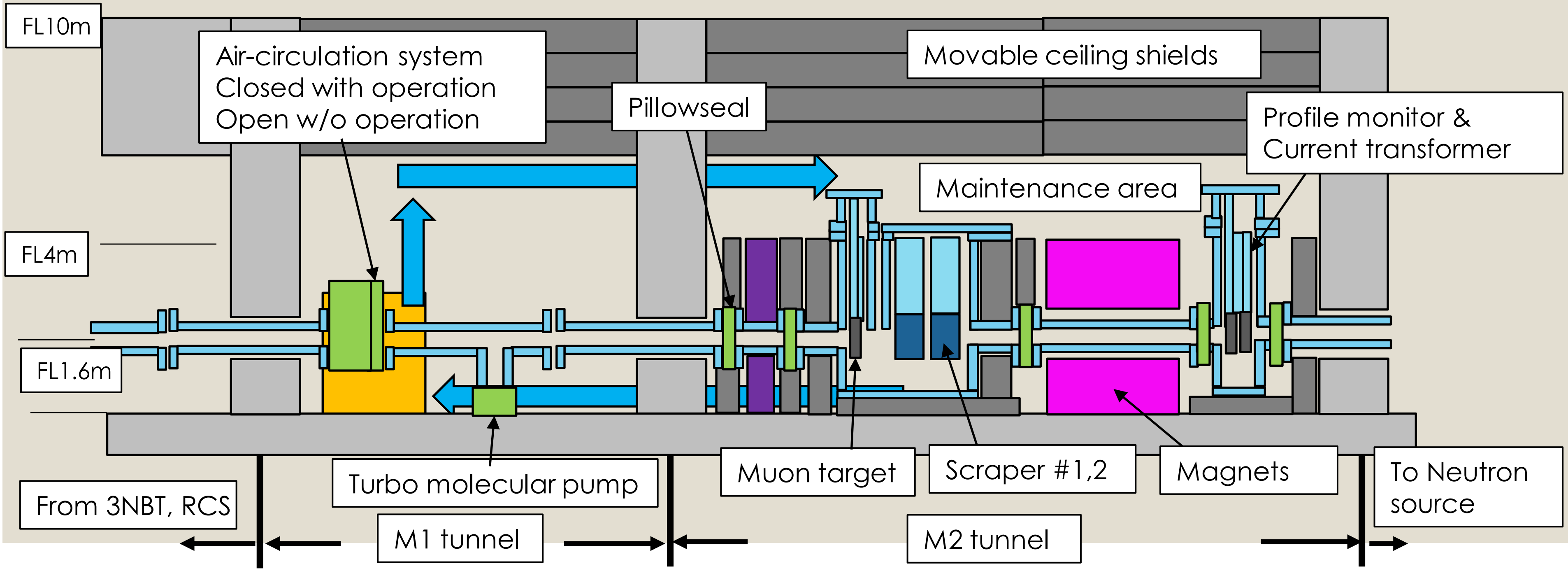
MLF muon target:
Multipurpose use, low B.G.



COMET target: Search for mu-e conversion
Located in high magnetic field to transport as large number of pions/muons as possible. Large B.G.
Difficult to disperse the beam loss.

Muon target is located at M1/M2 tunnel





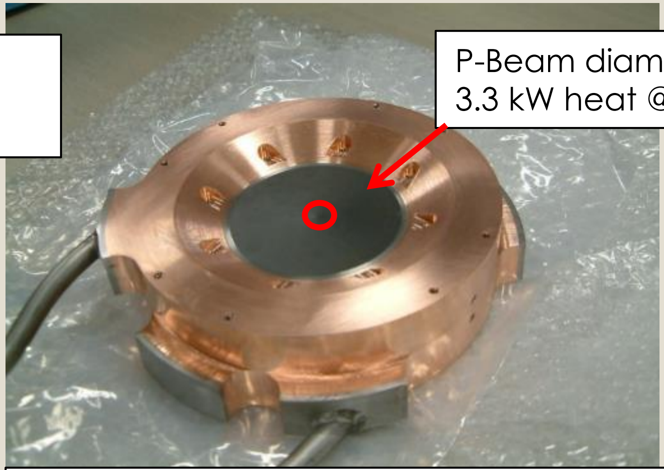
M2 tunnel

- Muon target
- Scrapers (collimator)
- Magnets
- Monitors
- Pillowseals
- Shields

MLF muon target: Fixed target & Rotating target

- Target material is polycrystalline graphite, IG-430U. (Thickness: 20 mm)
- To extend lifetime, the fixed target was replaced with rotating target that disperse the radiation damage of graphite.

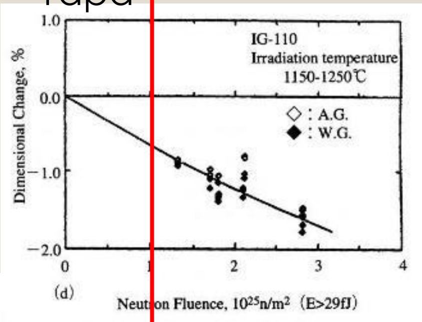
Water-edge-cooled target



P-Beam diameter; 14 mm (2s)
3.3 kW heat @ 1MW proton beam

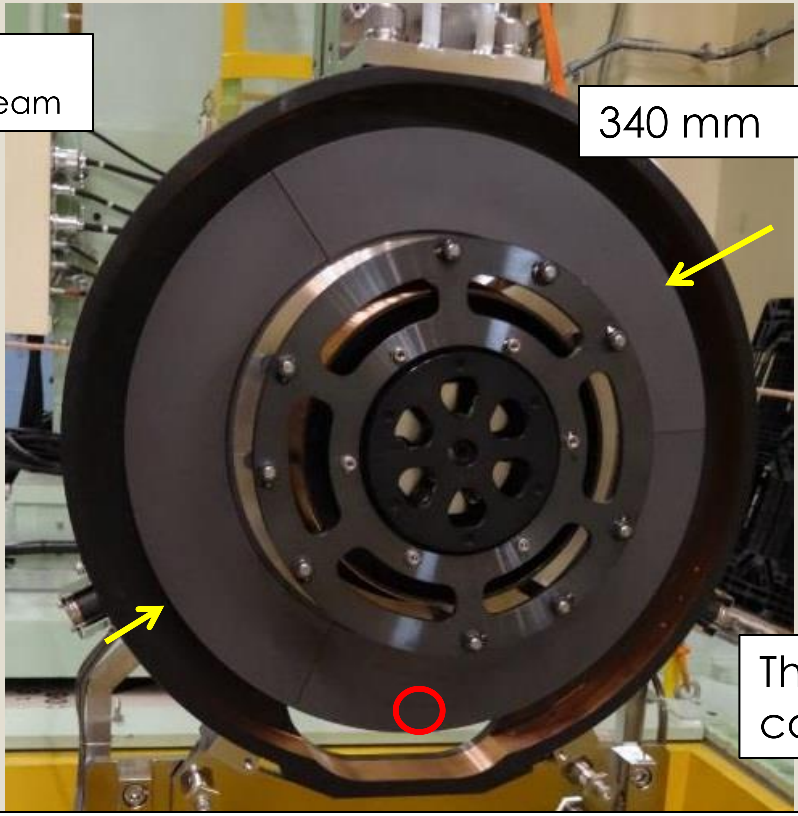
Fixed target, from 2008 to 2014
Lifetime: Irradiation damage of graphite
1 year at 1 MW operation

1dpa



H. Matsuo, graphite1991 [No.150] 290-302

340 mm

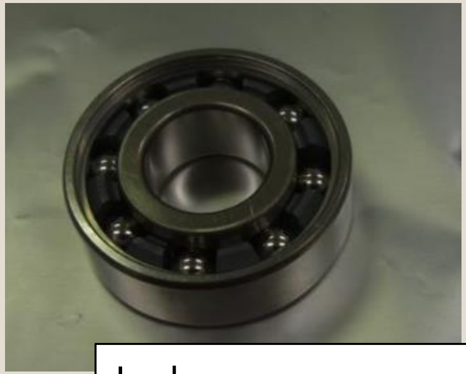


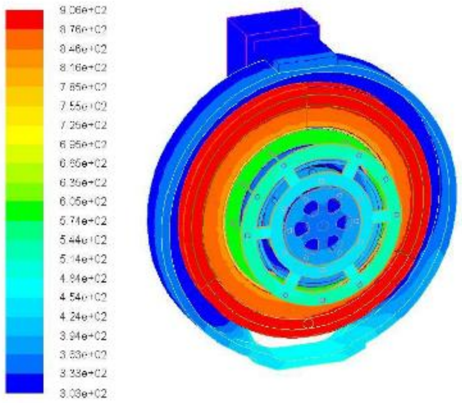
Thermal radiation cooling

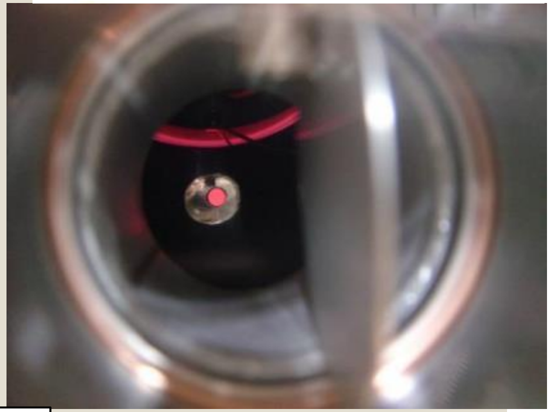
Rotating target, installed in 2014
Lifetime: Bearings
Aiming Lifetime: 10 years at 1 MW operation

Bearing of Rotating target

Solid lubricant in high temperature, high vacuum, and high radiation dose
Previously, the solid lubricant (Silver + MoS_2 at PSI) coating on the ball, rings, and separator. When peeling off, performance is lost.
In J-PARC, bulk lubricant WS_2 has been applied. Large amount of lubricant.





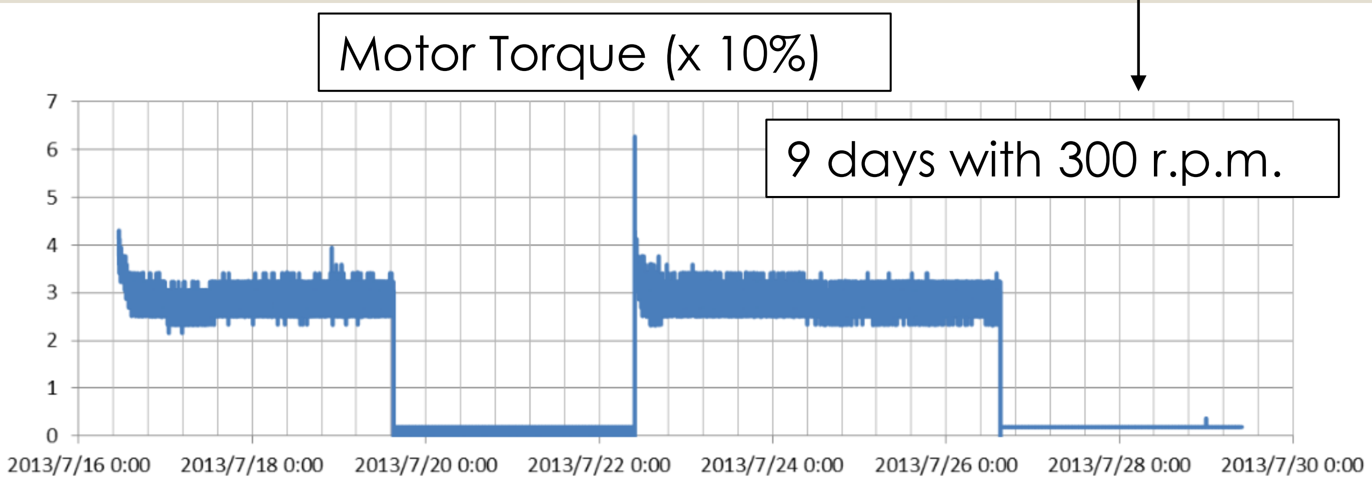


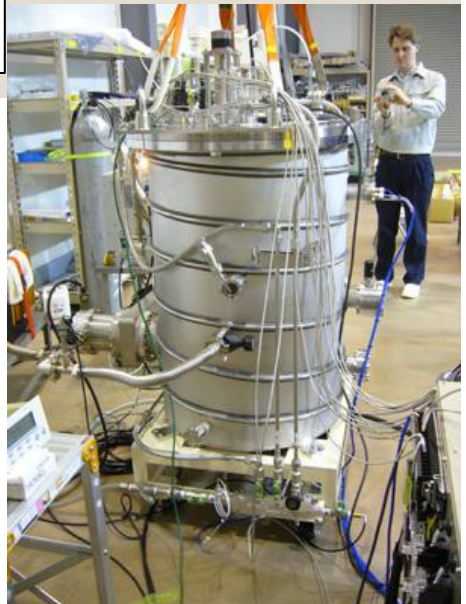
WS_2 lubricants

In beam operation, 15 r.p.m. in one year

After test by mock-up
- In vacuum
- Heating
- Rotation

Design of the target is determined.





Other technologies implemented in Muon facility

High vacuum target chamber

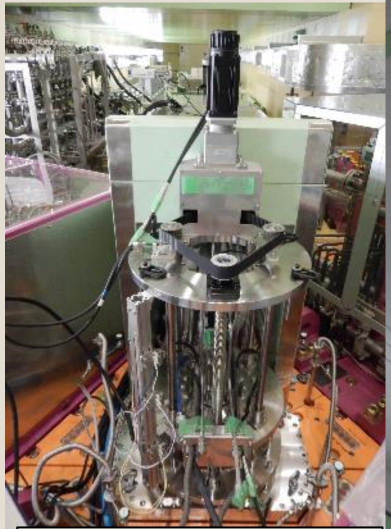
Scraper:
Water pipe is embedded in Cu

Transport of target by cask

Remote-controlled gripper

30-m travel to U.G.

Remote-controlled replacement

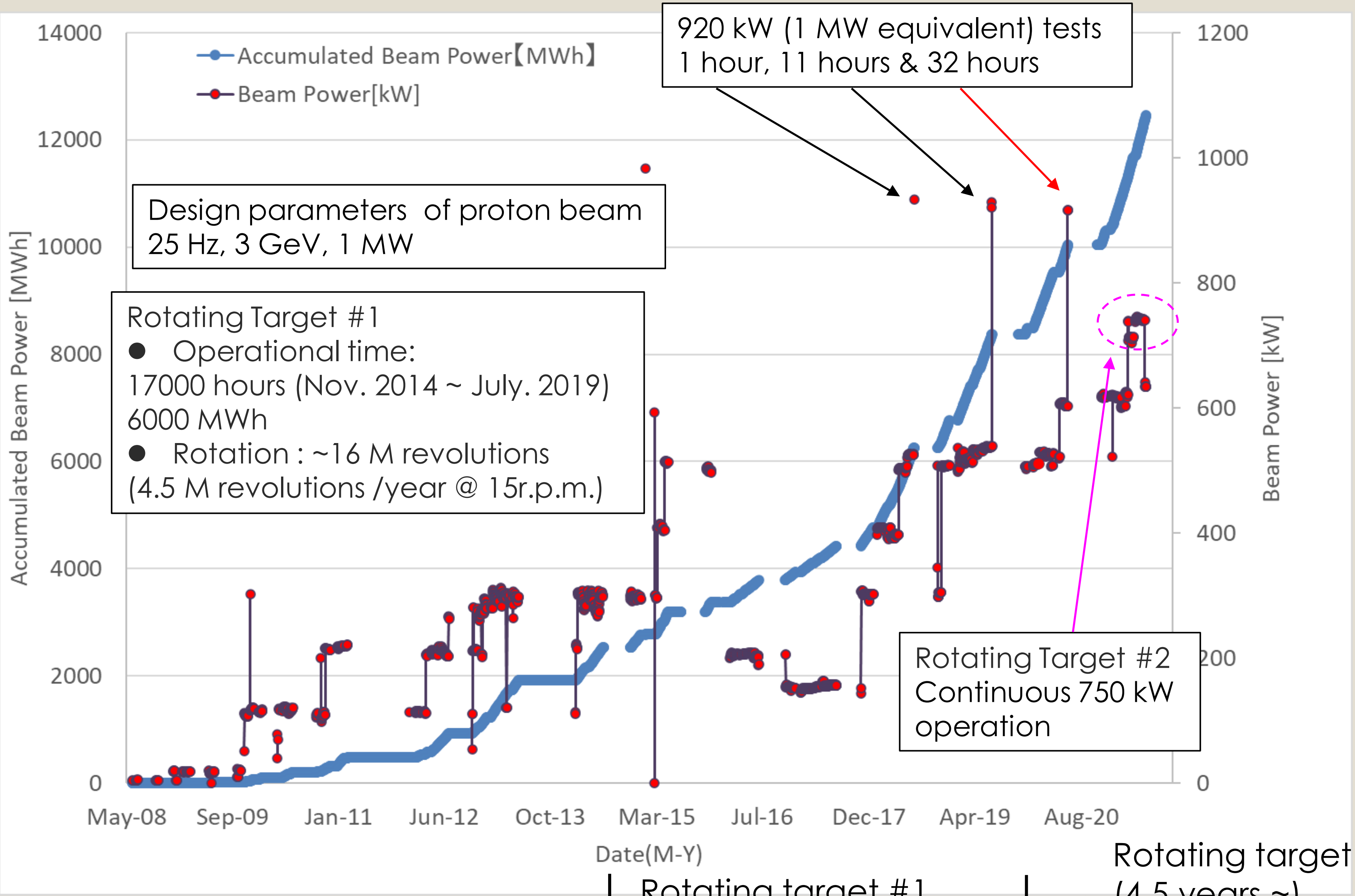


Up-down & rotation drive

Spline shaft

Absorbance of thermal expansion

History of Muon Target at MLF



- <u>Fixed target: </u>6 years
- <u>Rotating target #1</u>:
  5 years
  (Design mistake of shaft coupling)
- <u>Rotating target #2</u>:
  > 4.5 years
- 1 MW tests: Achieved
- Continuous 750 kW

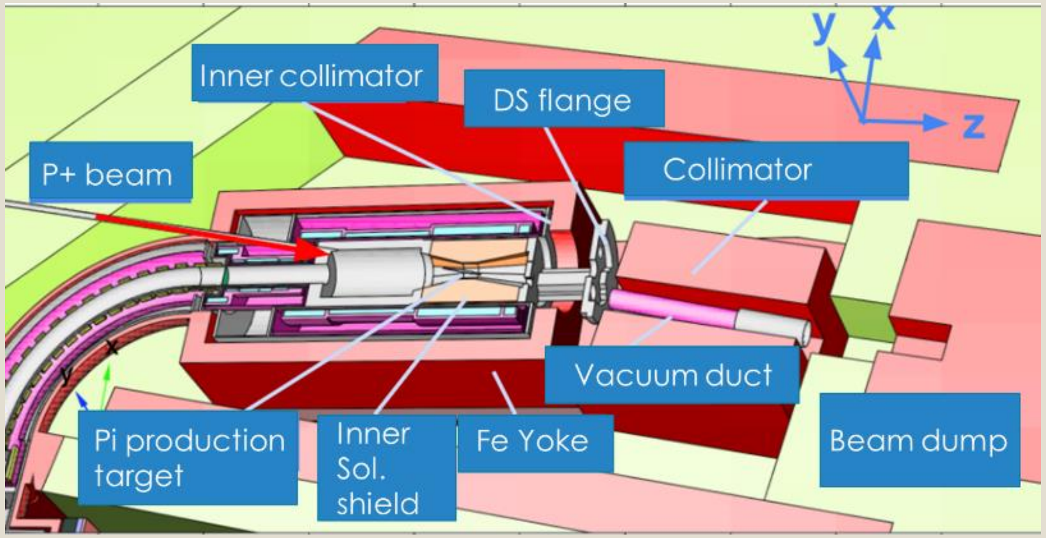
Fixed target (6 years) | Rotating target #1 (5 years) | → Rotating target #2 (4.5 years ~)

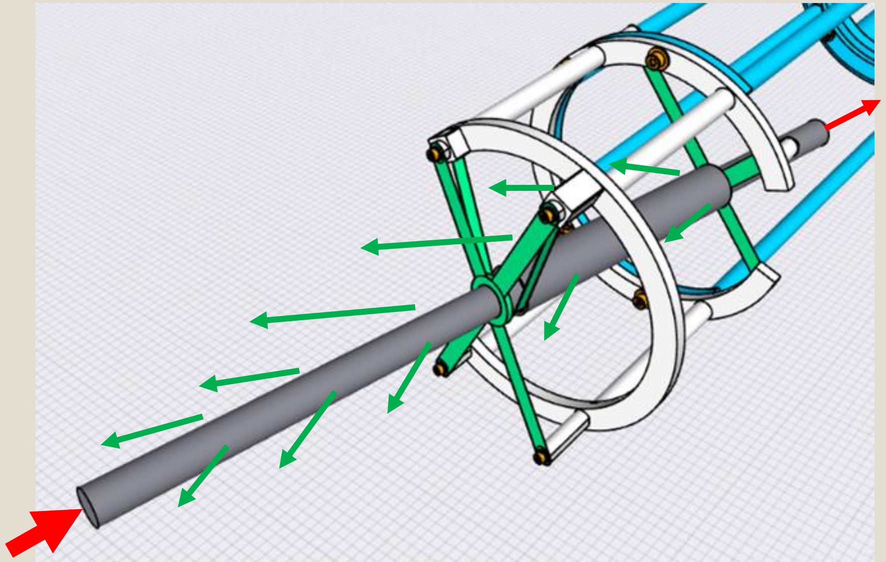
3. COMET TARGET

The detailed will be presented by Yoshi Fukao.

A picture of COMET Phase alpha target out of C/C composite taken from pion beamline.
COMET Phase alpha in Feb. 2023.

Pion production target for phase 1





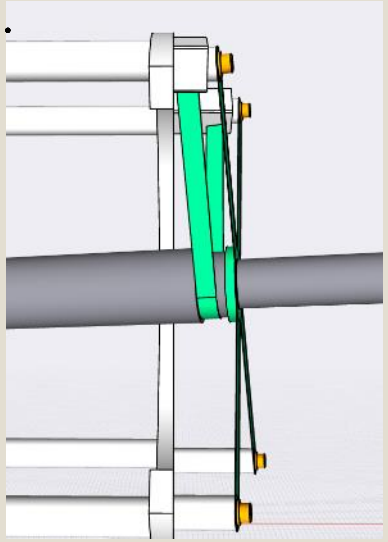
The objective is to collect as many muons as possible.

Graphite rod, L=700 mm, is floating on the center of superconducting solenoid magnet.

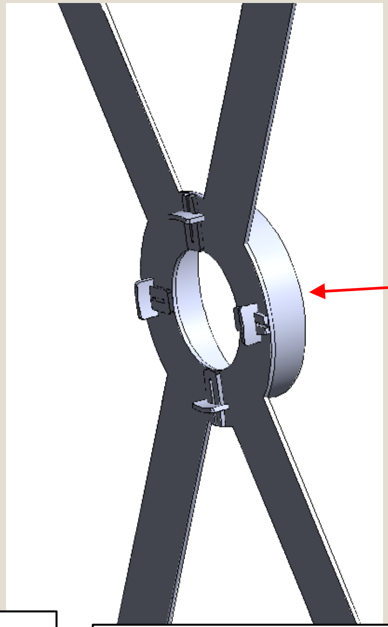
Target support
- Should not disturb the pion transport
- Will be irradiated by proton beam

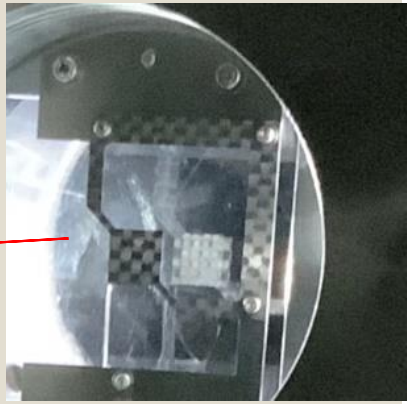
Material & Structure
- Refractory material
- Not-bulk material
- Low-density is preferable

- C/C composite
- SS304, 64Ti, Inconel



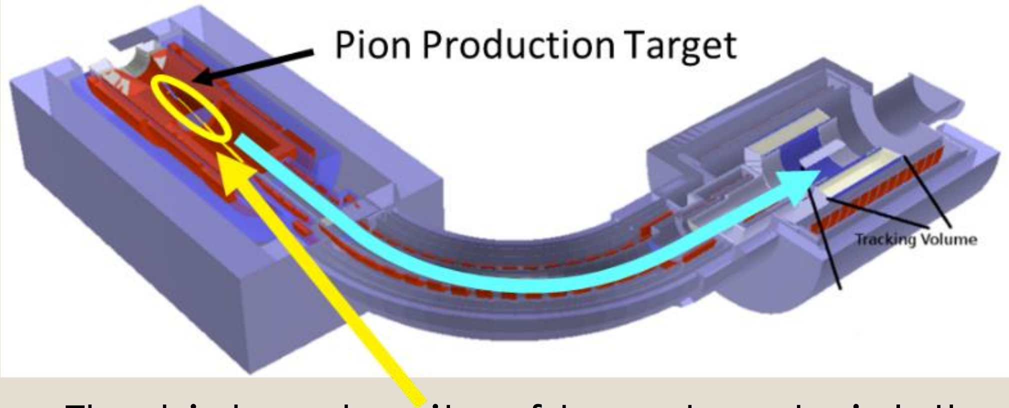
Reinforcement of target support for the axial direction





Manufacturing of target support by C/C composite

COMET Phase 2 target

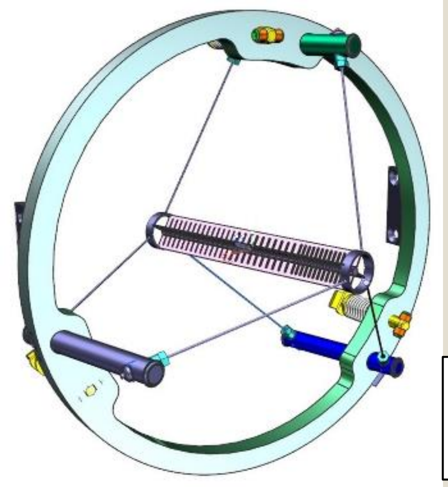


	graphite	tungsten
Density (g/cc)	1.82	19.2
Transport efficiency	1	3

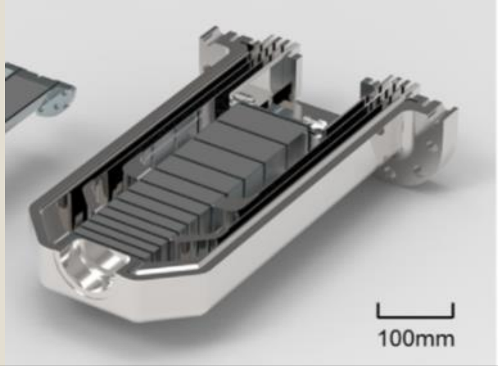
- The higher density of target material, the lower spatial volume of muon source
- The lower spatial volume, the higher capture and transport efficiency of muon

COMET	Proton beam power	Target material	Cooling
Phase 1	3.2 kW	Graphite	Thermal radiation
Phase 2	56 kW	Ta-clad Tungsten	Water cooling

Mu2e@ Fermi	Proton beam power	Target material	Cooling
Phase 1	8 kW	Tungsten	Thermal radiation



Thermal radiation cooling tungsten target at Mu2e

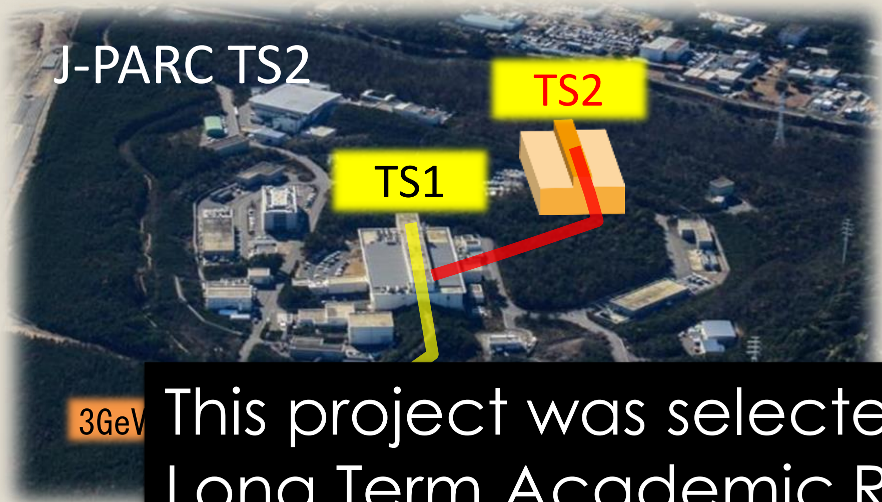


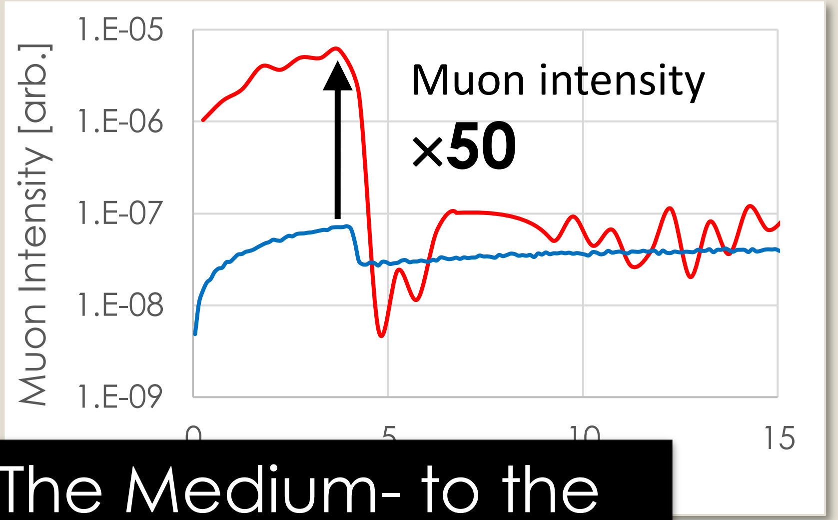
Water cooling Ta-cladding tungsten target at RAL

Design & Fundamental Research: US-JP collaboration with Fermi-lab is under discussion.

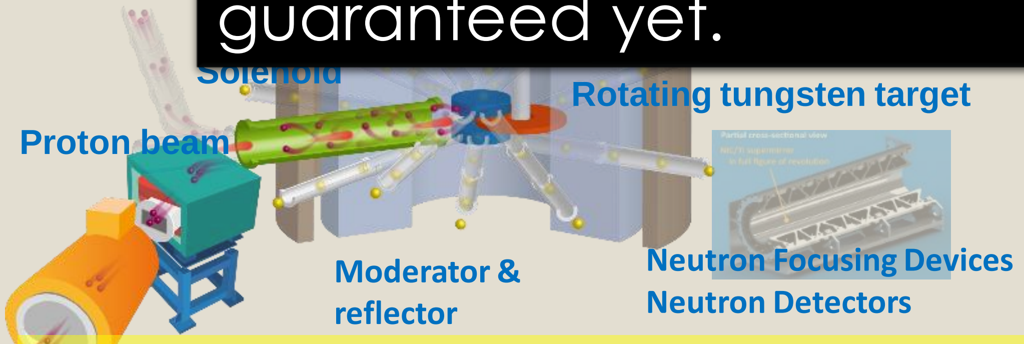
3. MLF SECOND TARGET STATION

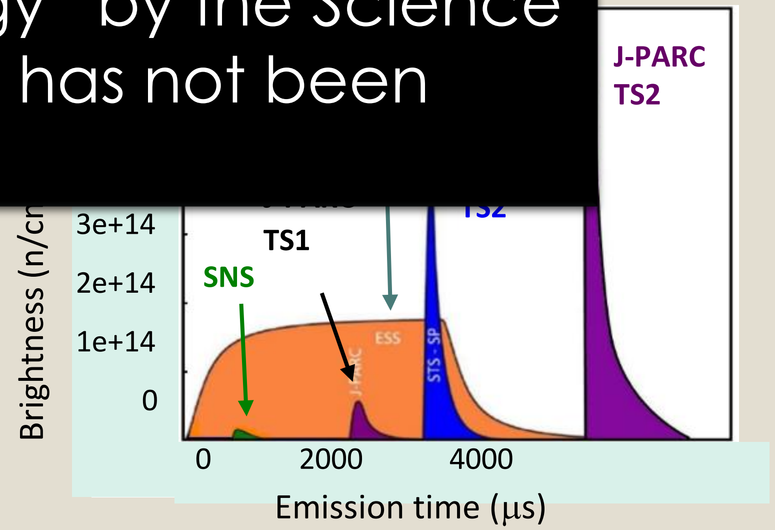
MLF Second Target Station





This project was selected as one of "The Medium- to the Long Term Academic Research Strategy" by the Science Council of Japan although the budget has not been guaranteed yet.



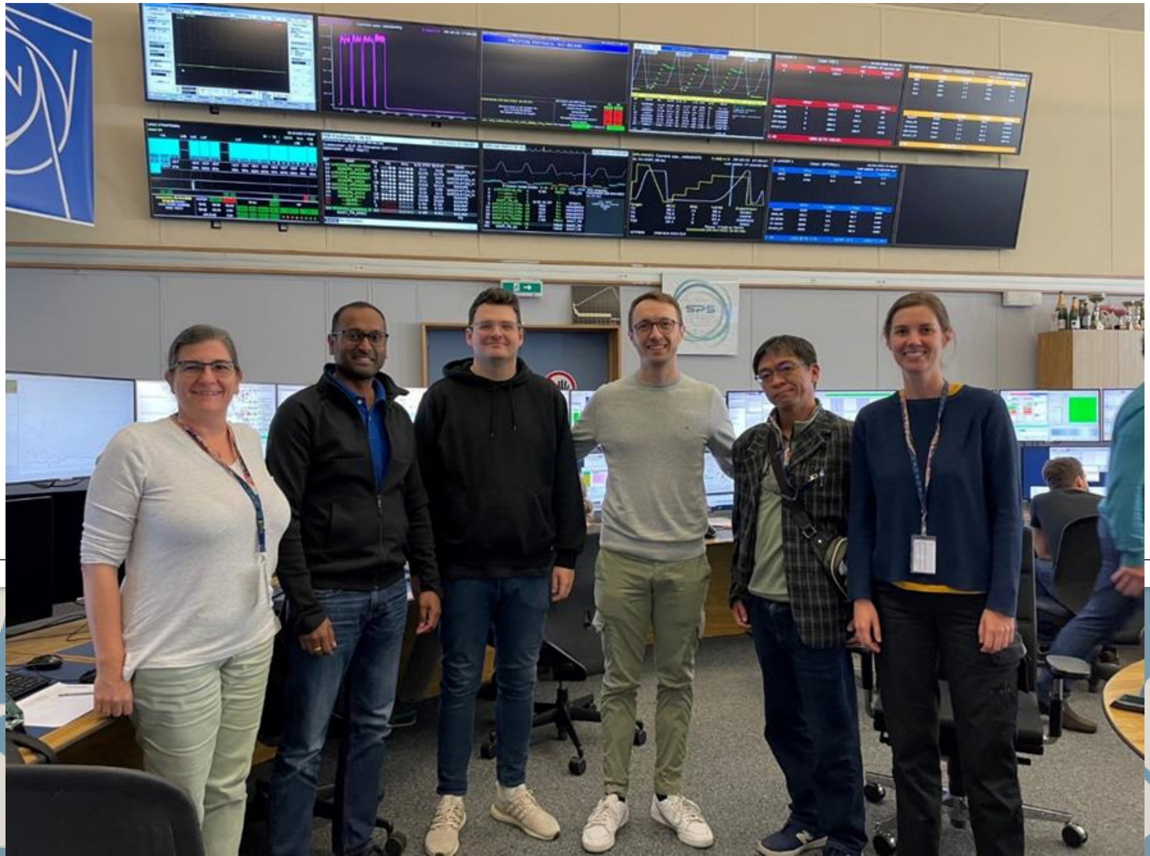


Neutron:
10 (target) x 2 (device) → 20 times gain of brightness

Muon: :
10 (target) x 5~10 (Muon capture solenoid) → 50 ~100 times gain of flux

Brightness of MLF TS2 will be the world's highest compared to the next plan of overseas facilities

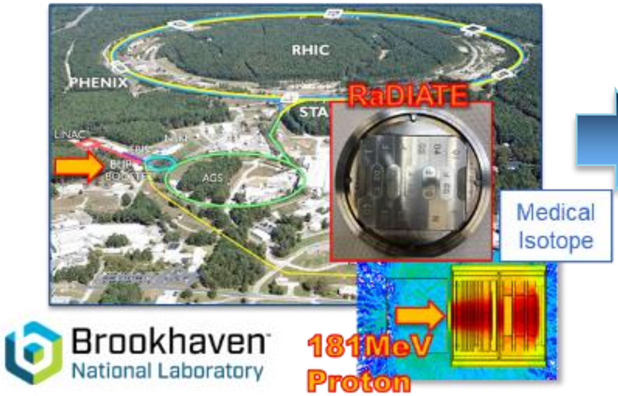
4. RaDIATE collaboration



RaDIATE
Radiation Damage In Accelerator Target Environments

US-JP collaboration

Brookhaven Linac Isotope Producer



High-energy proton irradiation at BNL-BLIP facility in 2017/2018 in partnership with the RaDIATE collaboration

Post-Irradiation Examination (PIE) at PNNL: Mech. property, Microstructure, Gas analysis,,,

Thermal shock experiment at CERN's HiRadMat facility

Radiation damage + Thermal shock

Ion irradiation at HIT, Tokyo University

- Screening test
- High fluence & no activation, but local damage, a few μm.
- Nano-hardness, Microstructure analysis

RaDIATE collaboration:

Mutual utilization of accelerator and post-irradiation examination facilities to promote research on the radiation damage and thermal shock.

13 institutions (~Dec. 2022) + 6 new institutions.

- Beam window for next J-PARC/FNAL neutrino projects (1.2 - 2.4 MW)
  Titanium alloys (Ti): (T2HK/LBNF-DUNE) & Beryllium (Be): (LBNF)
- Development of novel materials for neutrino, muon, neutron targets
  - ✓ SiC coated graphite, SiC-SiC composite: n, μ target
  - ✓ TFGR-W-TiC: m-e conversion, neutron, anti-proton target,,,
- Other researches
  - ✓ DPA cross section measurements
  - ✓ Fatigue testing machine, Radiation Damage Modeling, etc.

5. SUMMARY

Summary

- Proton beam operation by the muon target at MLF has been successfully conducted.
- The construction of the COMET facility is on going, and the P1 experiment will start very soon.
Summary
- MLF 2nd Target station will be a next muon production program
- RaDIATE collaboration is on going.
- We are ready for further collaboration.

Thanks !!