15th , Oct. 2024

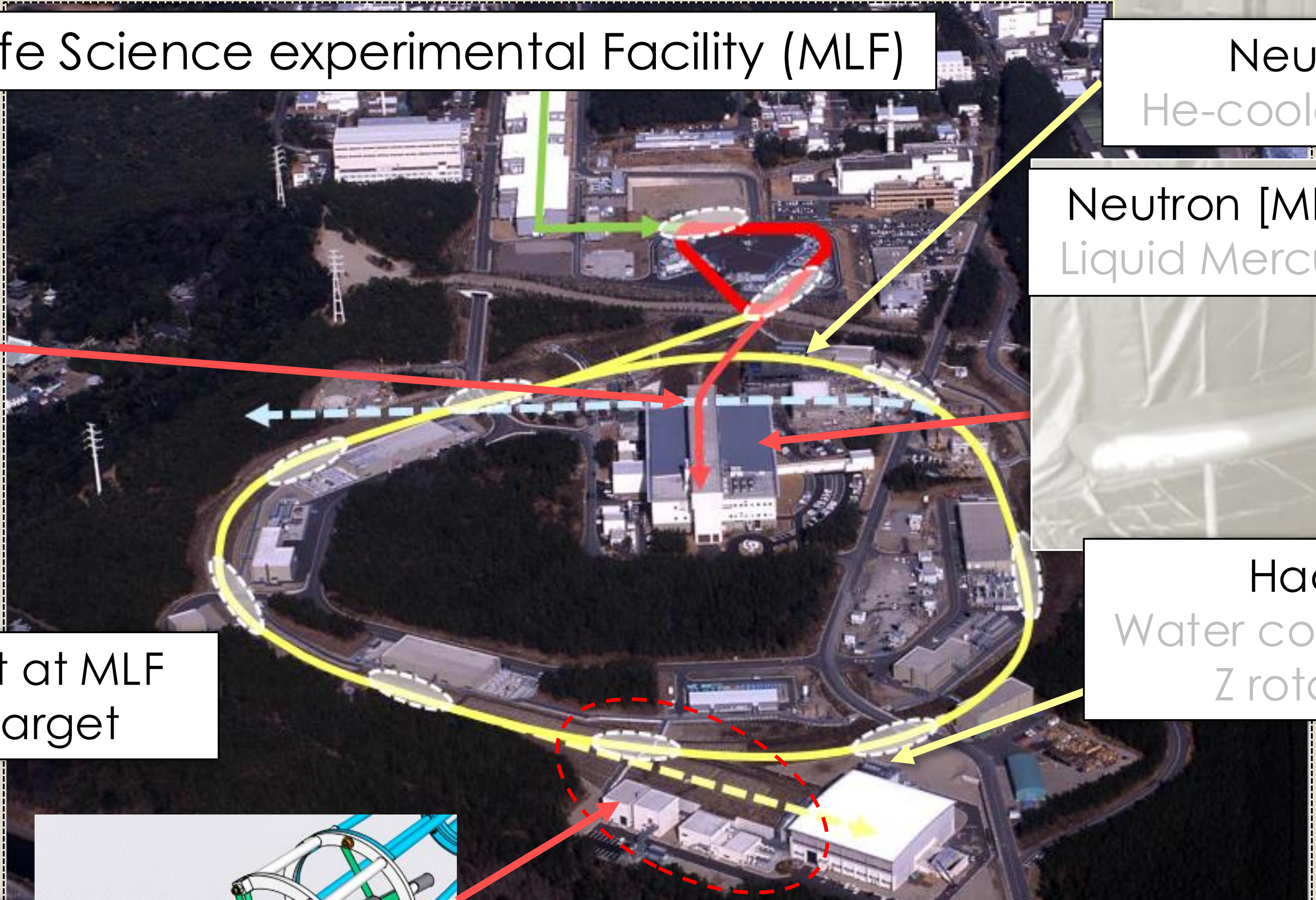
Recent upgrade on muon target at J-PARC

J-PARC, KEK
Shunsuke Makimura

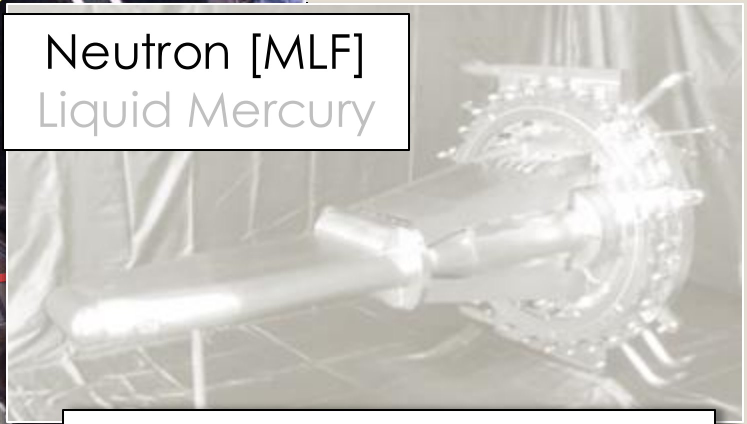
J-PARC SYMPOSIUM 2024 IN MITO

Muon production target at J-PARC

Materials and Life Science experimental Facility (MLF)



Neutrino [**n**]
He-cooled graphite

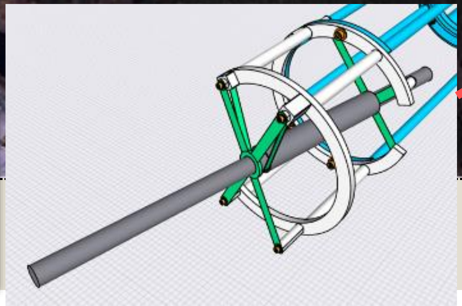


Neutron [MLF]
Liquid Mercury

Muon production target at MLF upstream of neutron target

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

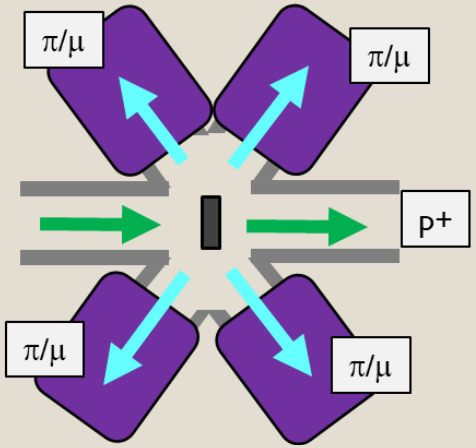
Muon production target
@COMET experiment
Graphite (P1), W (P2)



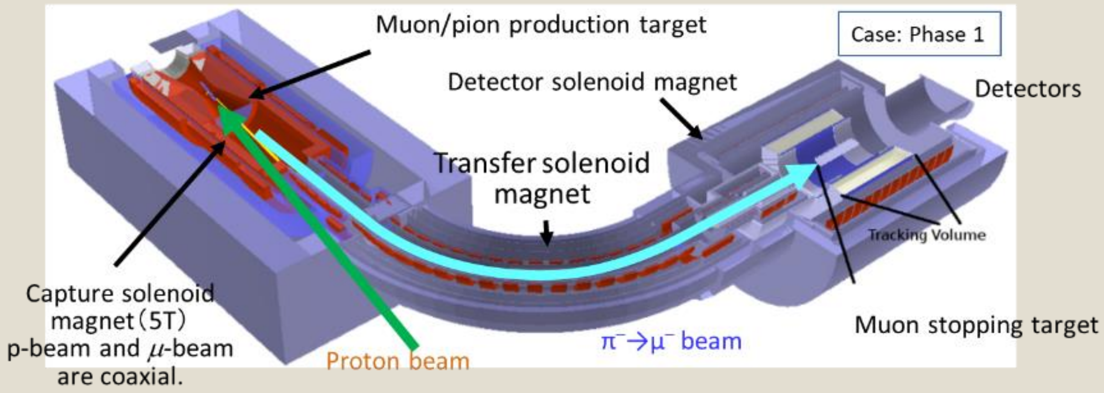
South building in Hadron facility

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.	-

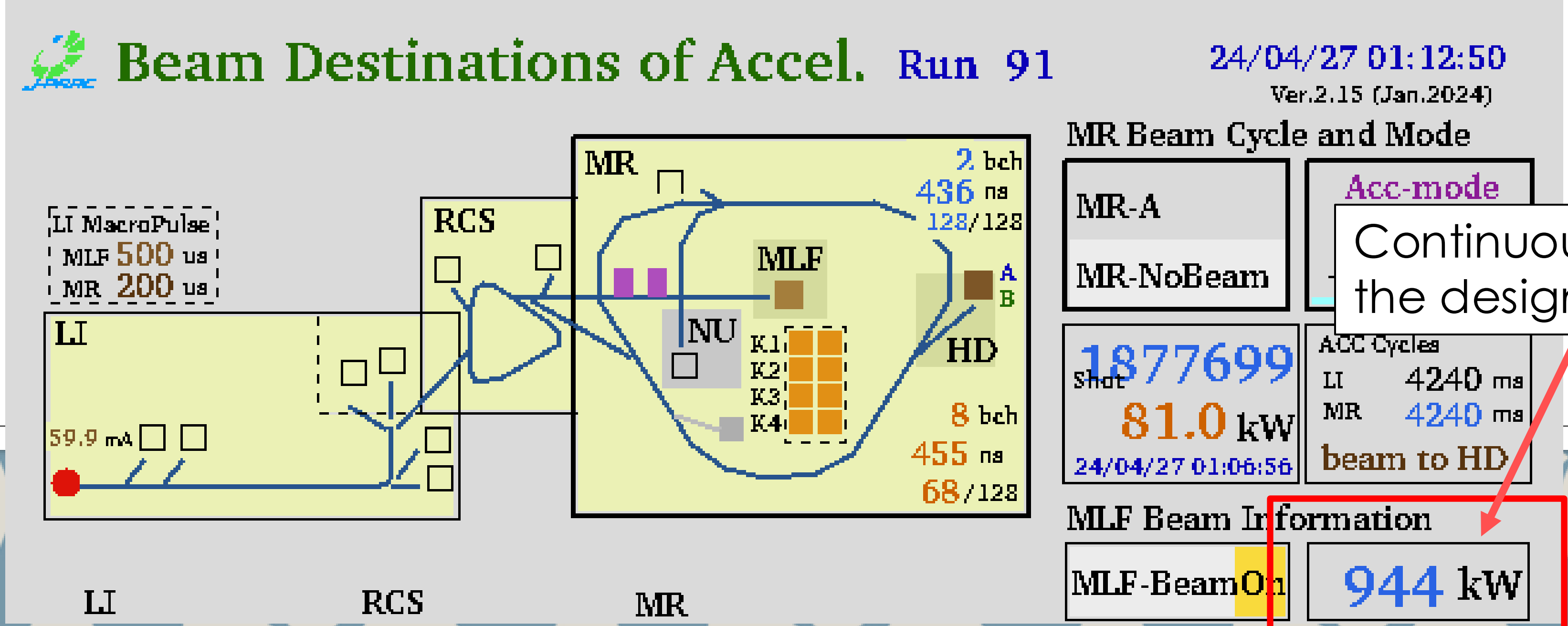


MLF muon target **<u>in 1 MW proton beam</u>**: Multipurpose use, low B.G.



COMET target: Search for mu-e conversion
<u>In high magnetic field by superconducting solenoid</u>
to transport pions/muons w/ large solid angle

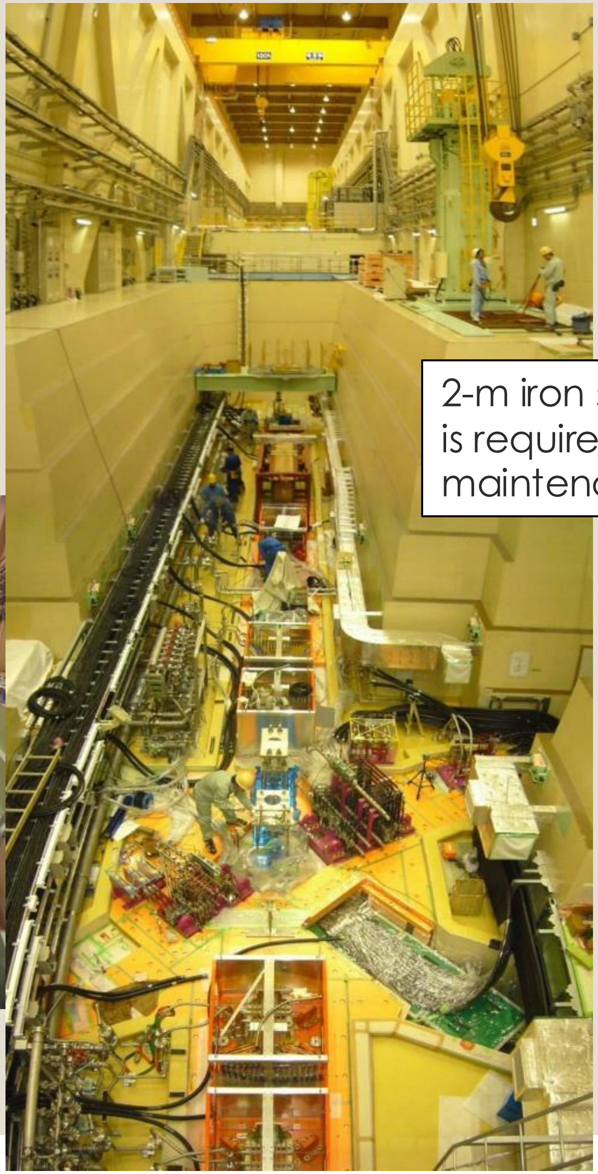
MUON PRODUCTION TARGET AT MLF

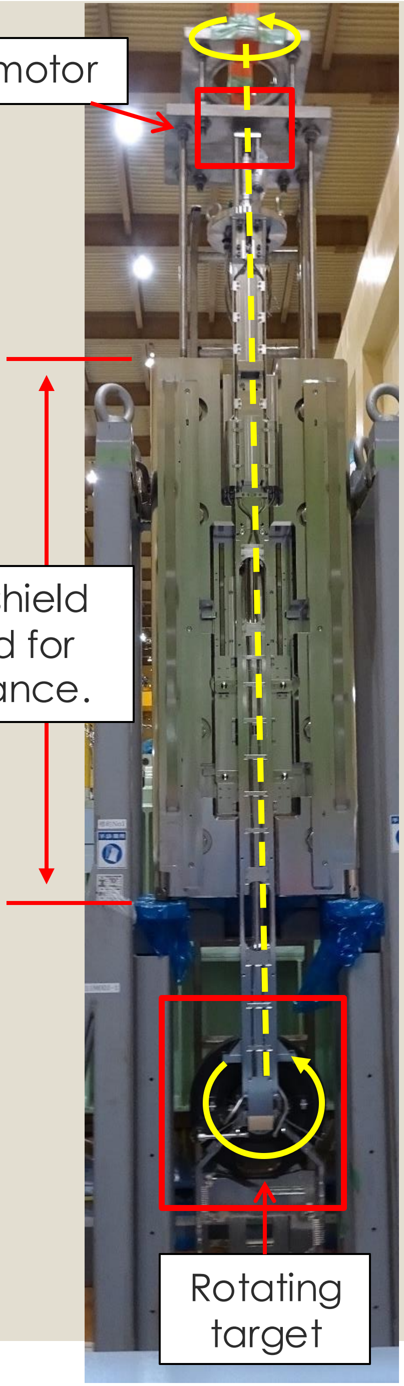


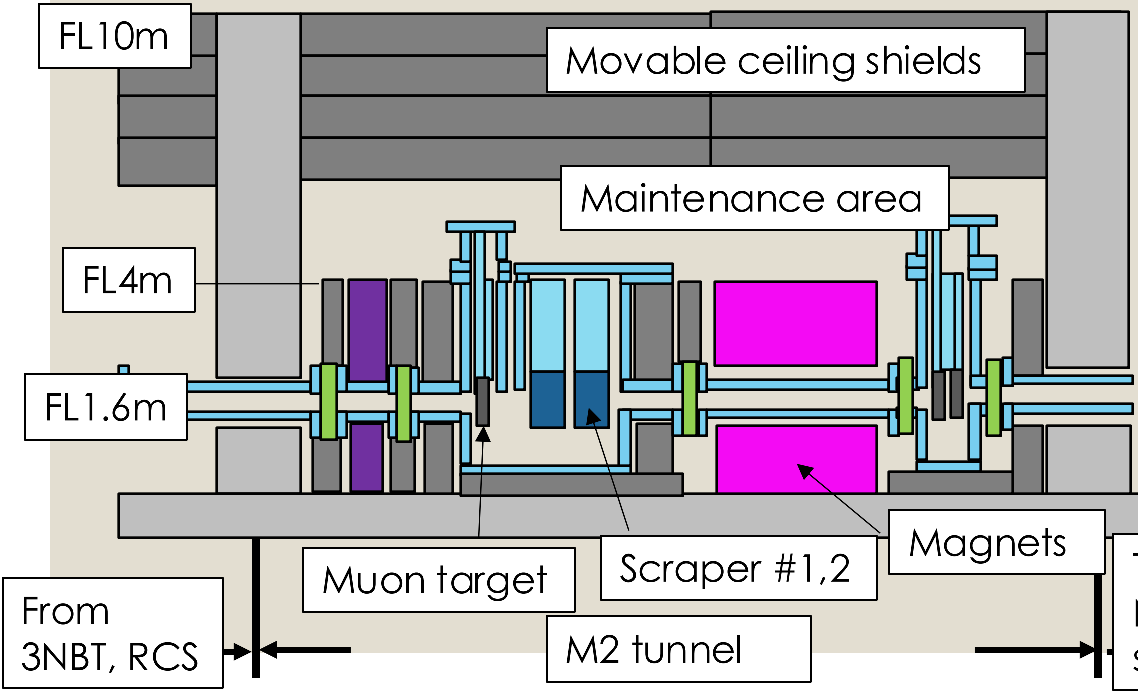
Continuous operation by the design beam power

Muon target is located at M1/M2 tunnel

- Muon target is highly activated.
- 2-m iron shield is required for maintenance.
- Target should be replaced by remote handling.





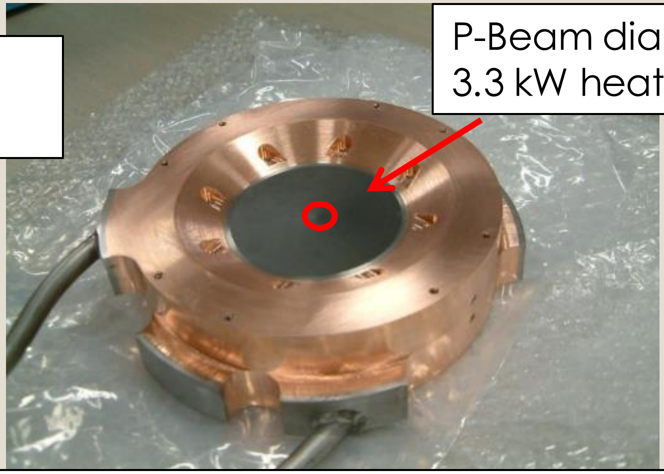


MLF muon target: Fixed target & Rotating target

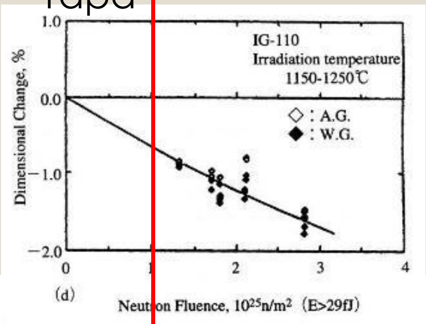
- Target material is polycrystalline graphite, IG-430U. (Thickness: 20 mm)
- To extend lifetime, the fixed target was replaced with rotating target that disperse the radiation damage of graphite.

Water-edge-cooled target

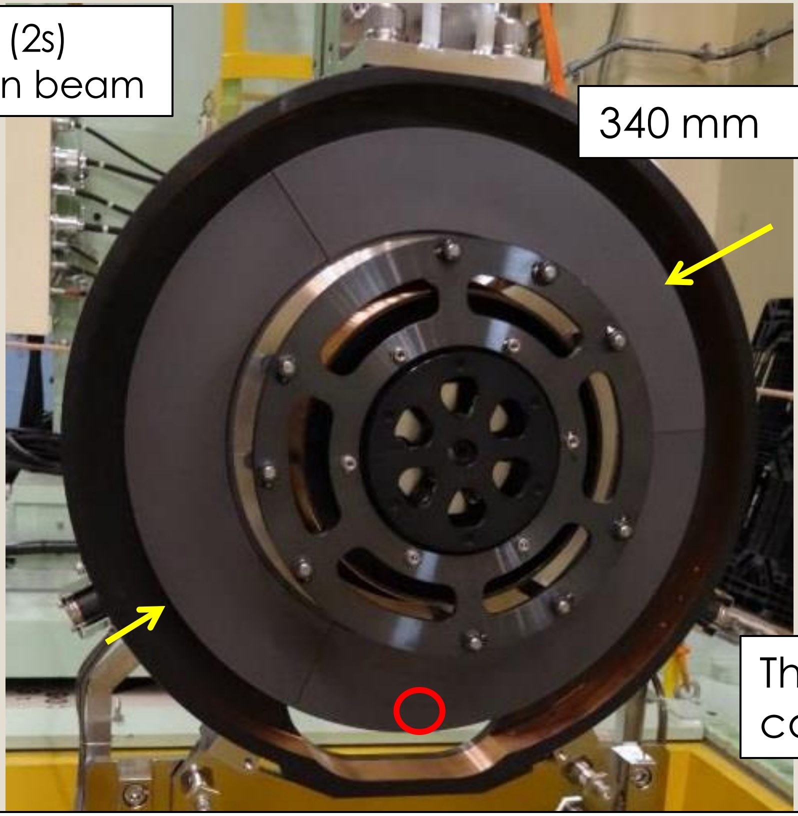
P-Beam diameter; 14 mm (2s)
3.3 kW heat @ 1MW proton beam



Fixed target, from 2008 to 2014 (< 300 kW)
Lifetime: <u>Irradiation damage of graphite</u>
<u>1 year</u> at 1 MW operation



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



Thermal radiation cooling

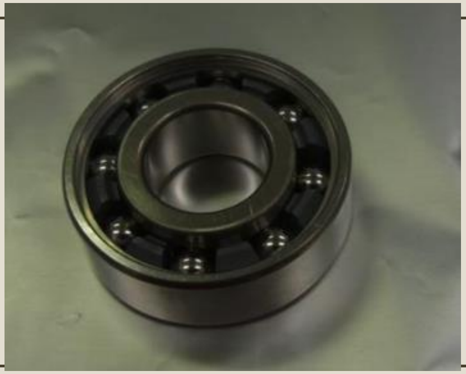
Rotating target, installed in 2014
Lifetime: Bearings
Aiming Lifetime: 10 years at 1 MW operation

Key technology: Lubricant in Bearing

Solid lubricant in
- high temperature
- high vacuum
- high radiation

Bearing in past targets:
Lubricant coating (e.g. Silver, MoS_2)
Small amount of lubricant
Lifetime: < 1 year

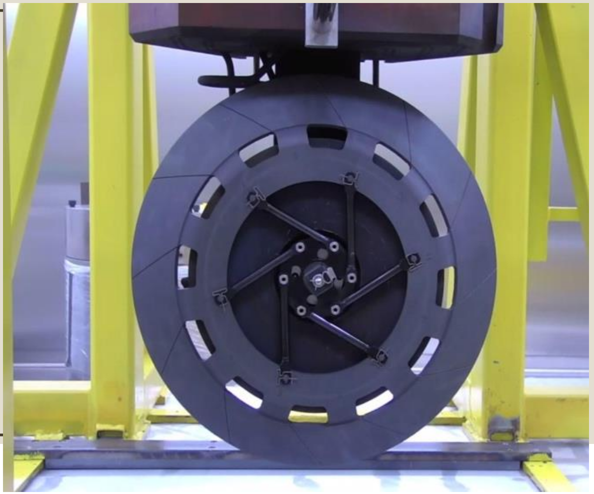
In J-PARC,
Bulk lubricant of WS_2
Large amount of lubricant
Lifetime: 10 years (aiming)
5 years (achieved)



WS_2 lubricants

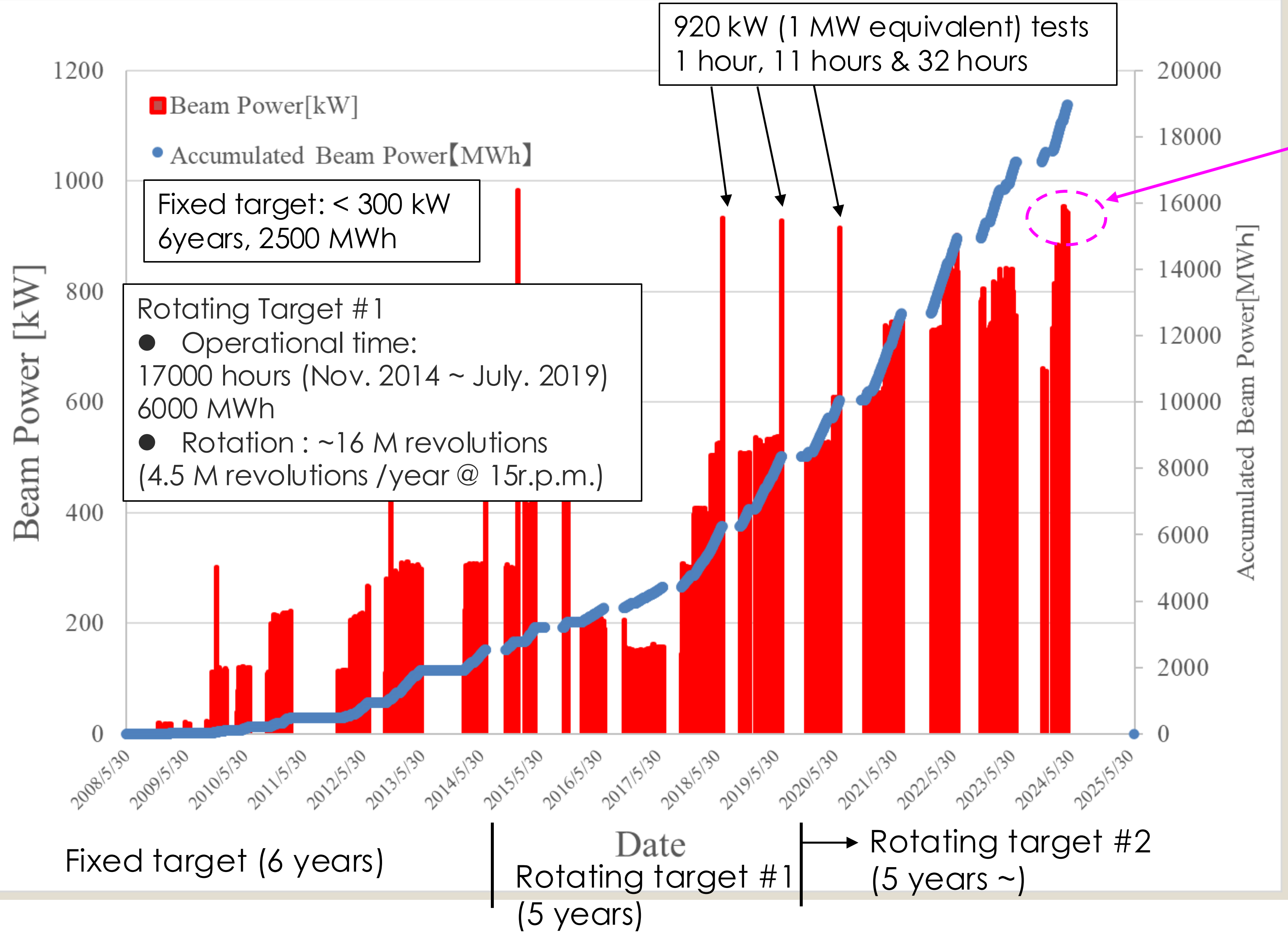
The technology has been transferred to Paul Scherrer Institutes and contributed to stable operation for 1 year.

Scientific Highlights at PSI
"Things run smoother without lubricants",
https://www.psi.ch/en/science/scientific-highlights/things-run-smoother-without-lubricants



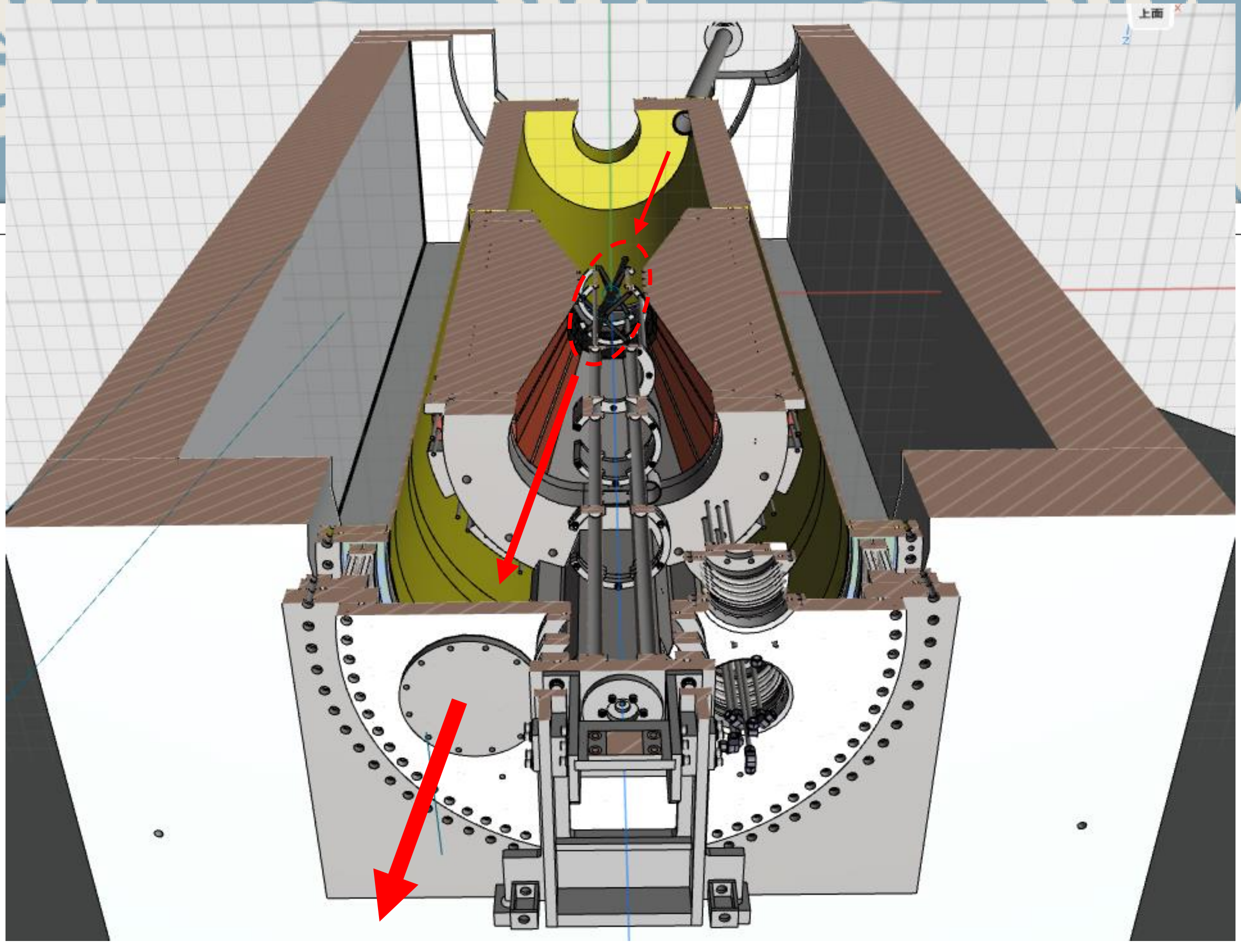
History of Muon Target at MLF

Reported in poster session by
P-283 Hikaru Sunagawa, P-285 Shiro Matoba



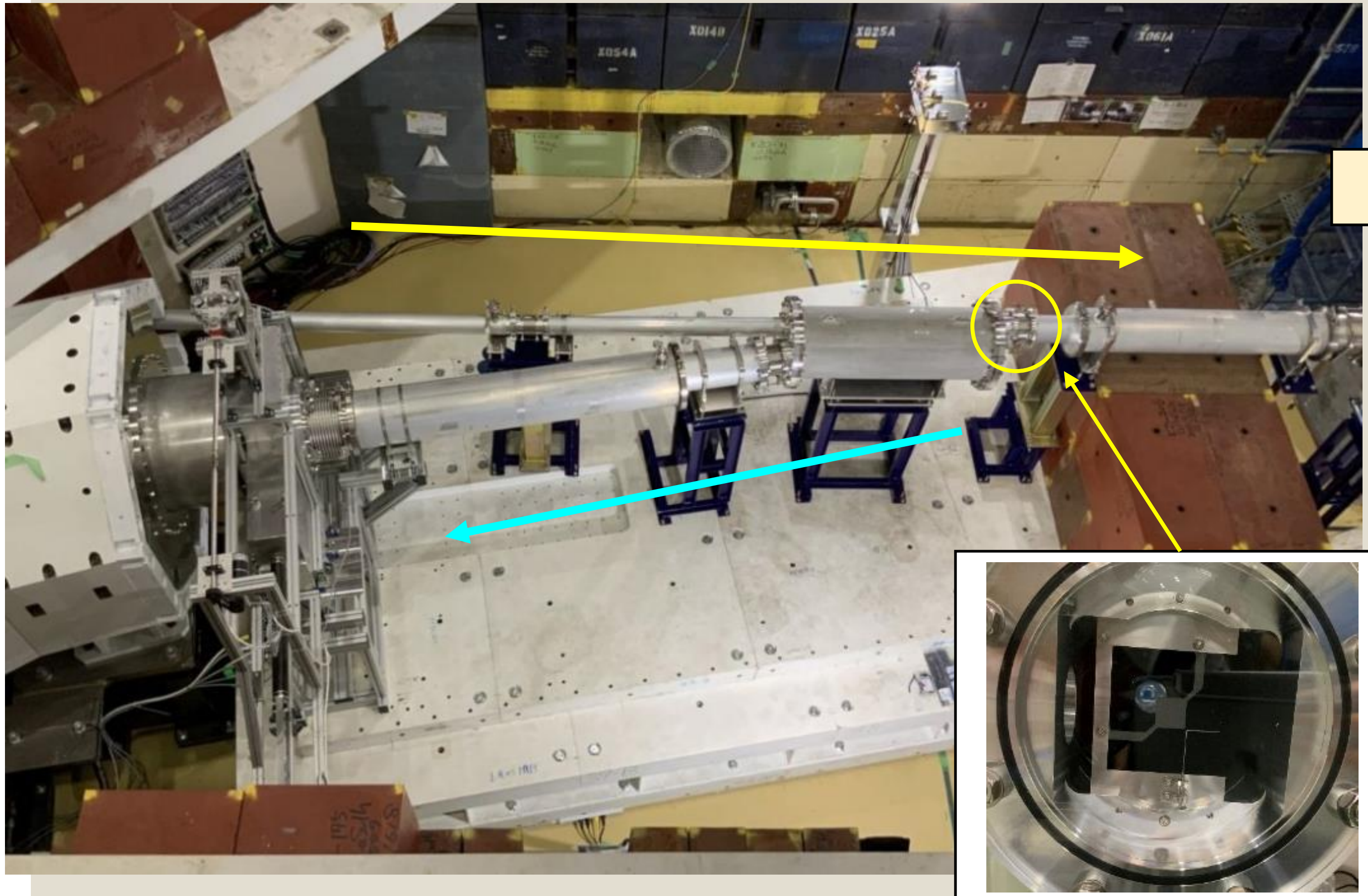
Rotating Target #2
> 5 years
12500 MWh
Continuous 1 MW operation

Rotating target #1 was replaced with #2 by design mistake of shaft coupling.



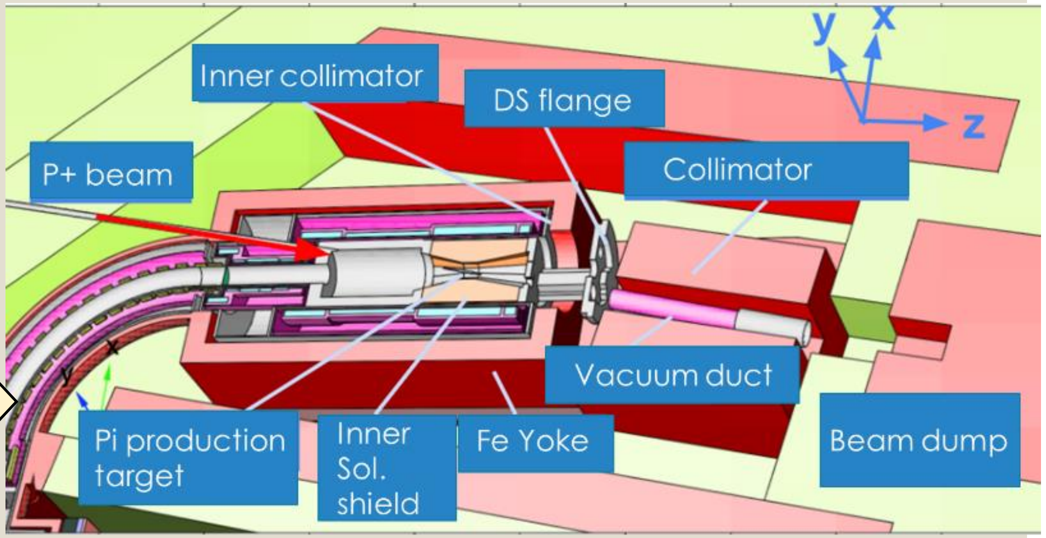
COMET TARGET

Status of COMET



Pi - production target
C/C composite, t=1.1 mm

Phase alpha: engineering run
Operation w/o capture solenoid magnet



<u>Phase alpha</u>

- Construction of the building was completed.
- Phase alpha was successfully completed in Feb, 2023.

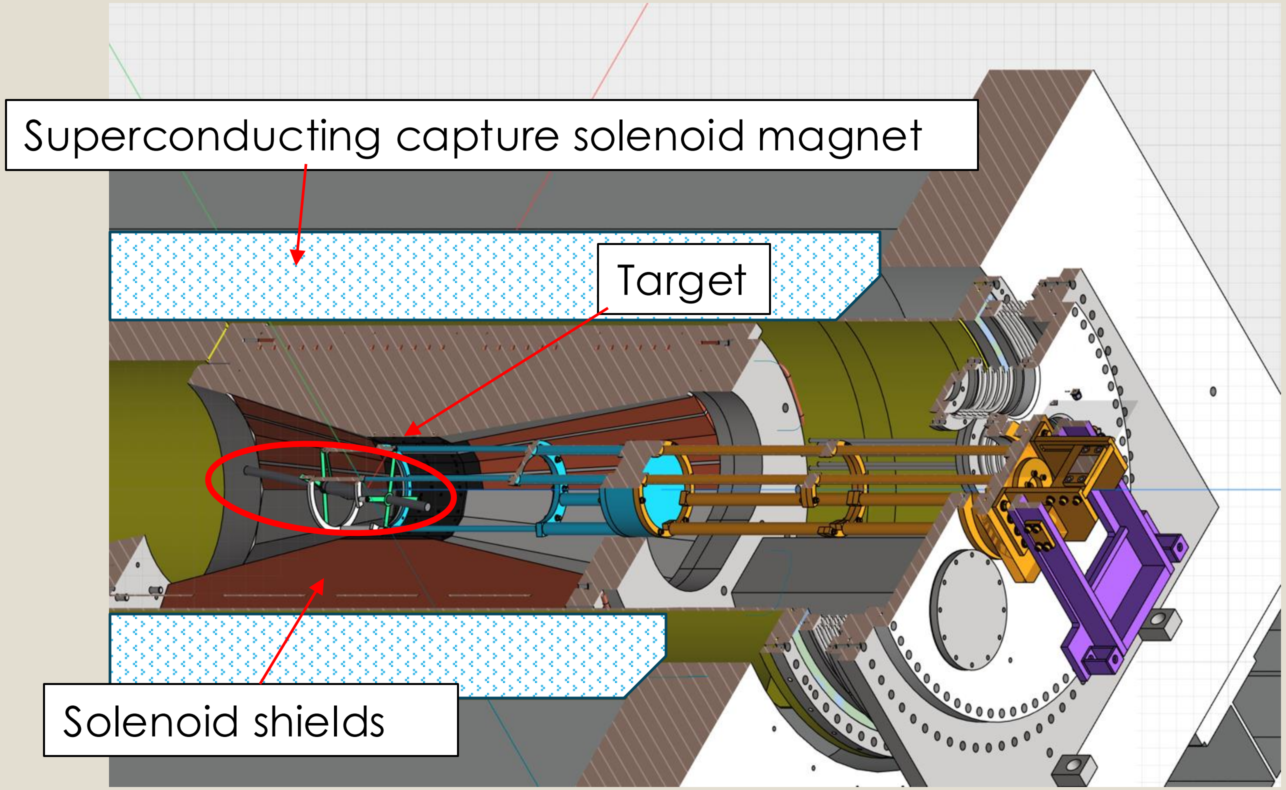
<u>Phase 1</u>

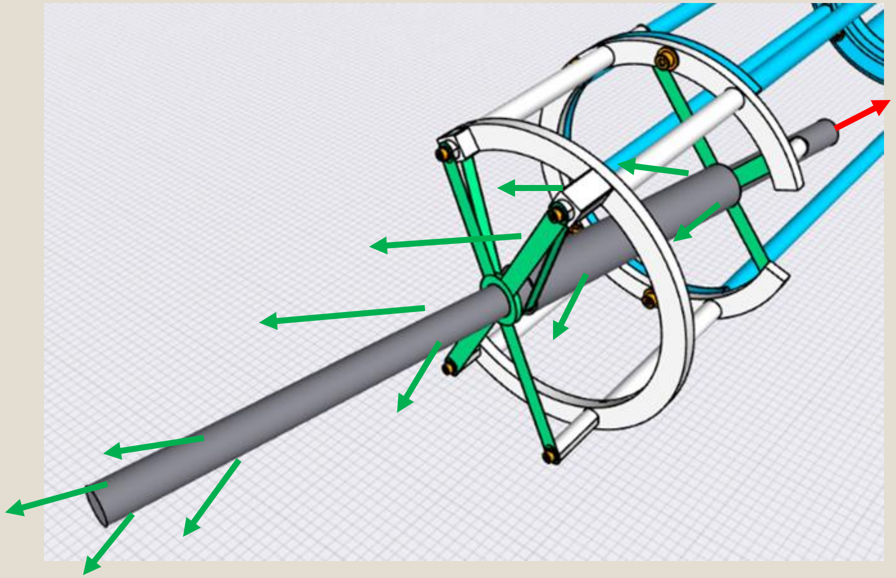
- Design of pion production target for Phase 1 is almost completed.

Then, we will start

- Manufacturing of Phase 1 target
- Feasibility study for Phase 2 target

Technical challenges in COMET target



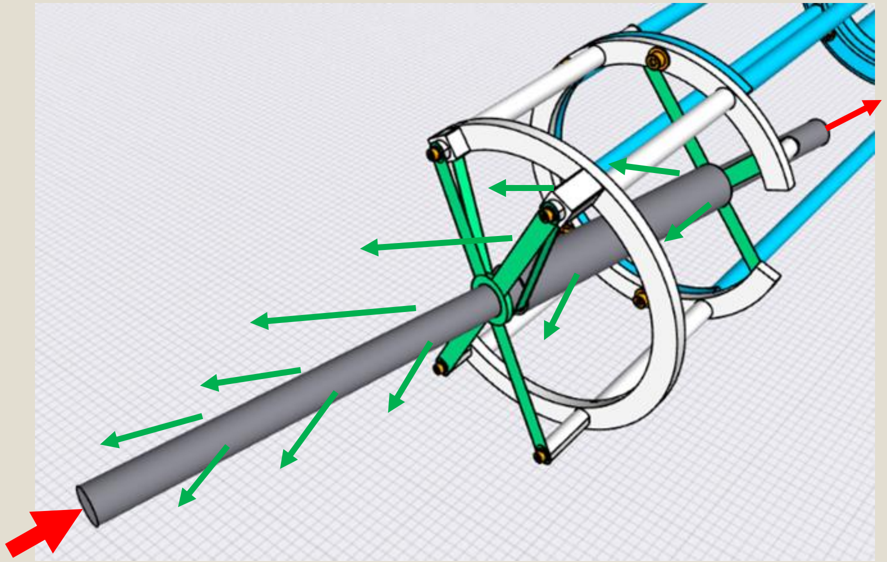


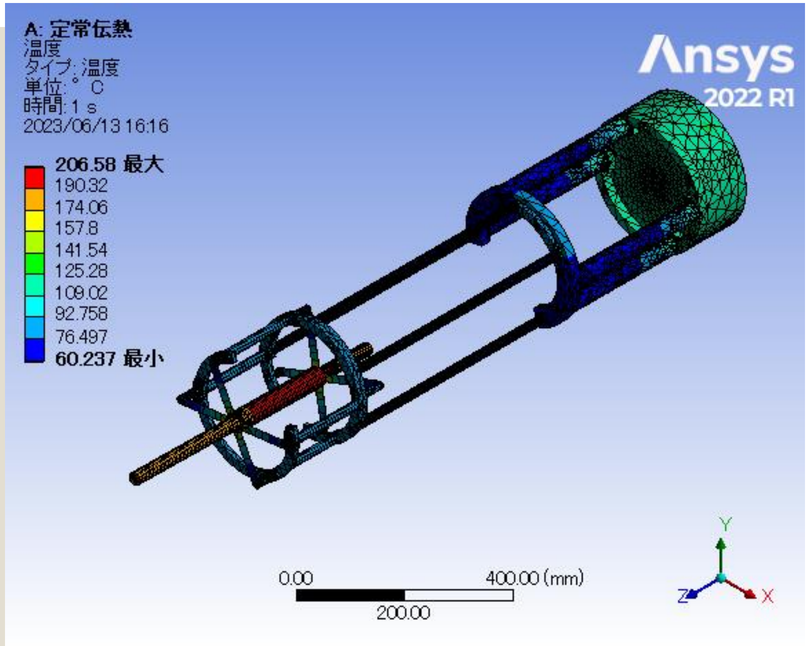
- Large solid angle by superconducting capture solenoid magnet
- Proton beam intensity is not so high, however,,,

<u>Technical challenges</u>

- Target is suspended on the center of high magnetic field.
- Solenoid shields to protect superconducting magnet
- Lorentz force on solenoid shield in quench incident
- Pressure rise in beamline when fatal leakage of LHe

Muon production target for phase 1





Max. temperature: 200 °C
PHITS & ANSYS simulation

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

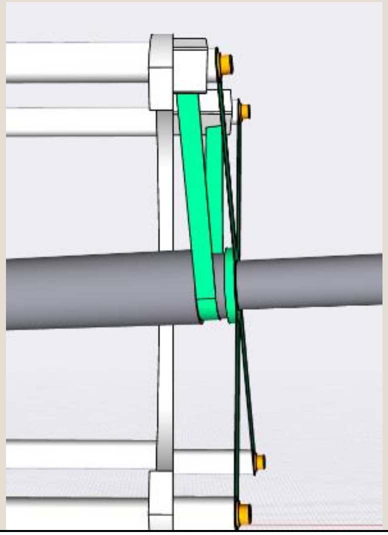
<u>Target support</u>

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

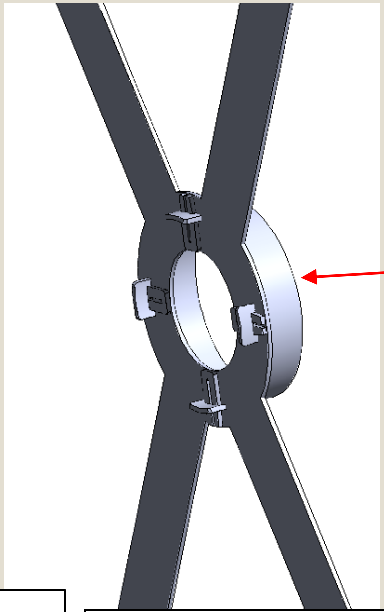
<u>Material & Structure</u>

- Refractory material
- thin material
- density

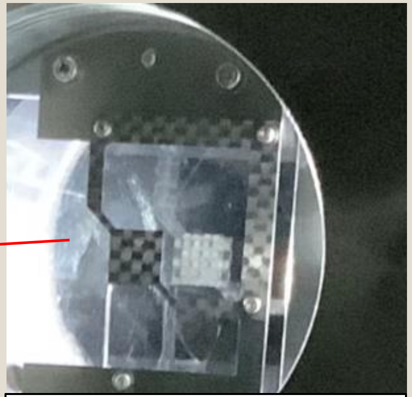
- Graphite
- <u>**C/C composite**</u>



Reinforcement of target support for the axial direction



Manufacturing of target support by C/C composite



Tested as phase alpha target

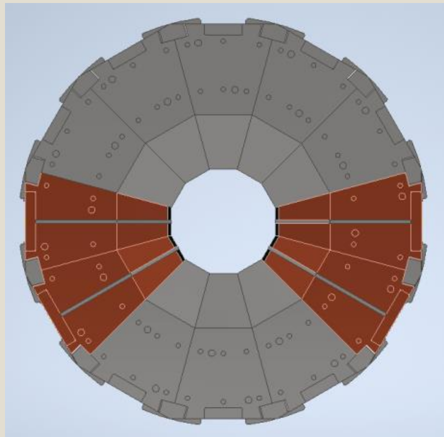
Reported by Yusuke Uchiyama in poster, P-287

Shields to protect S.C. magnet

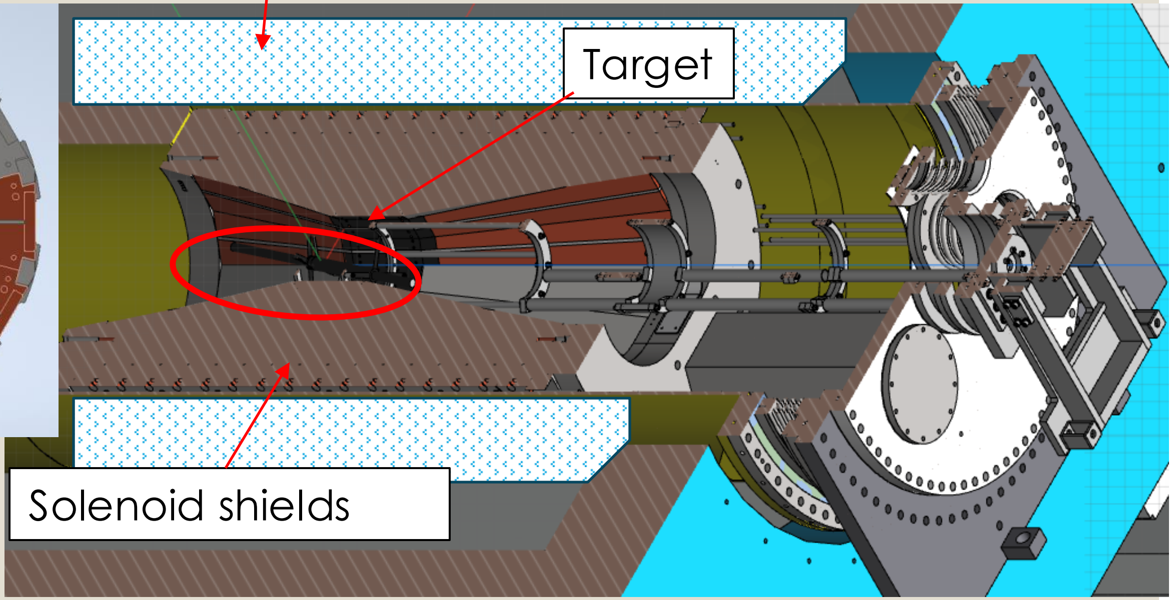
Material of the shielding determines the maximum available beam power.

- Tungsten: Great, but expensive
- Copper: Good, moderately expensive
- Stainless steel: Not good, but cheap

In Phase 1, Hybrid of Cu and SS:
Proton beam power, 2 kW
In Phase 2, upgrade to W shields



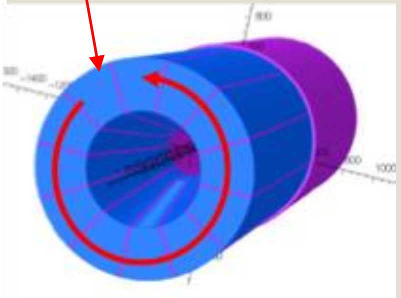
Superconducting capture solenoid magnet



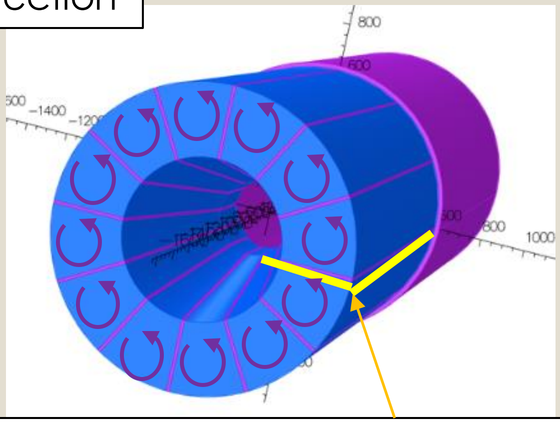
Effect of high magnetic field

- Effect of high magnetic field by superconducting magnet is not negligibly small.

Eddy current: Hoop direction

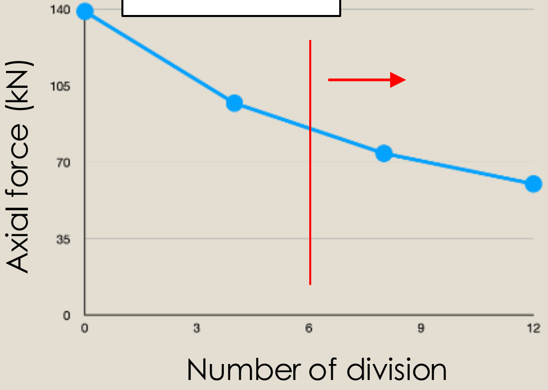


Monolithic Cu



SS304 plates in each gaps, t=10 mm

140 kN !!



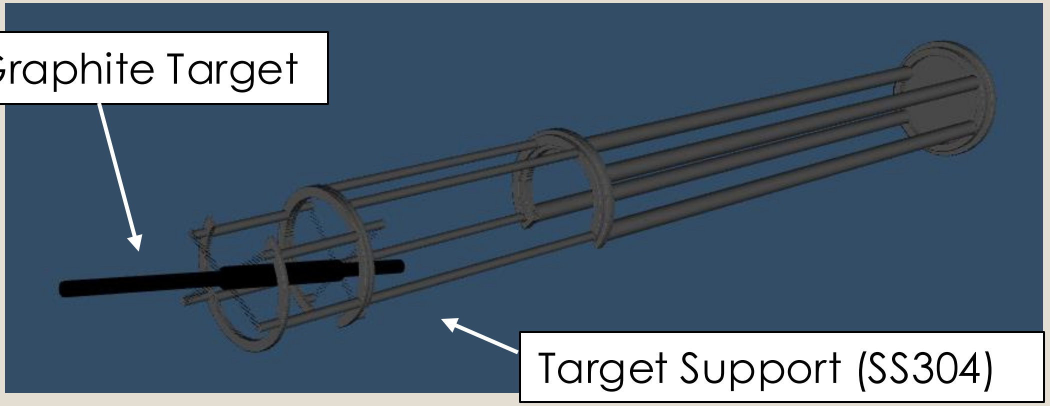
Cu shield should be divided to more than 6 pieces.

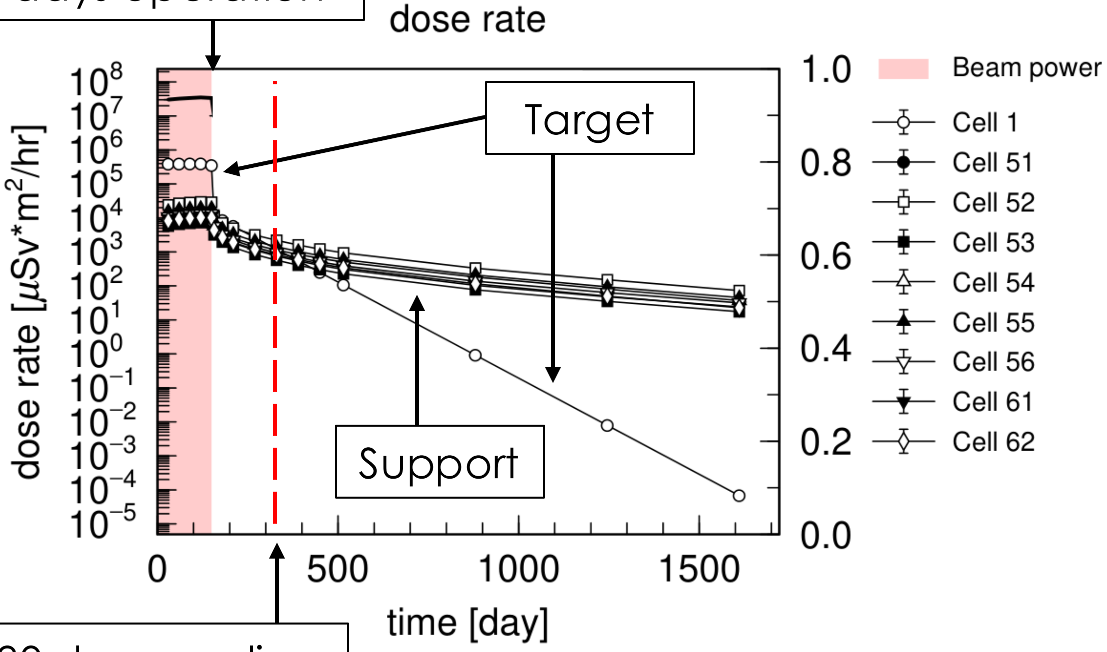
Lorentz force by a sudden drop of the magnetic field.

- High electric resistivity of the shield material decreases the force.
- Dividing the copper shield into several pieces by SS304 plates

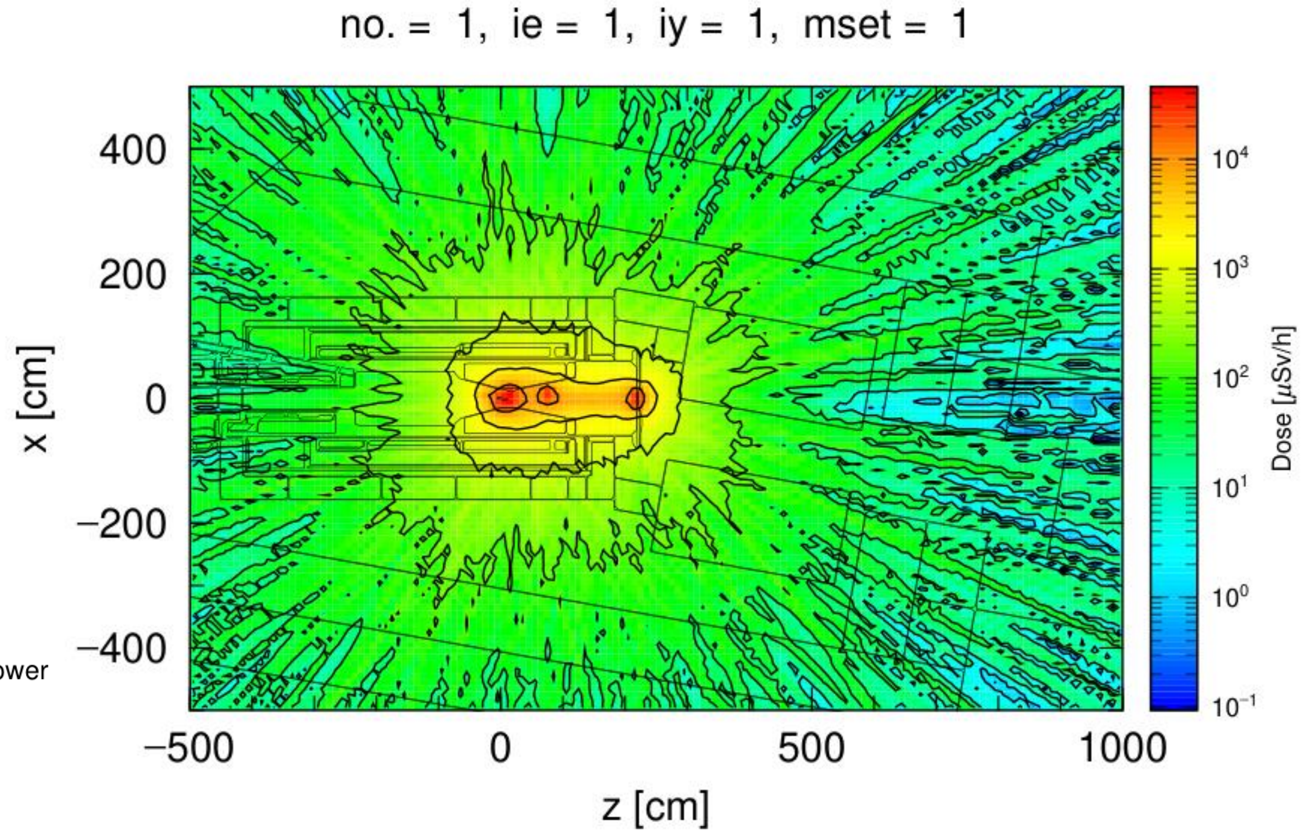
OPERA simulation by Sumi in cryogenic group

Activation of Target ASSY





Phase 1 (3.2 kW): 150 days operation, 180 days cooling

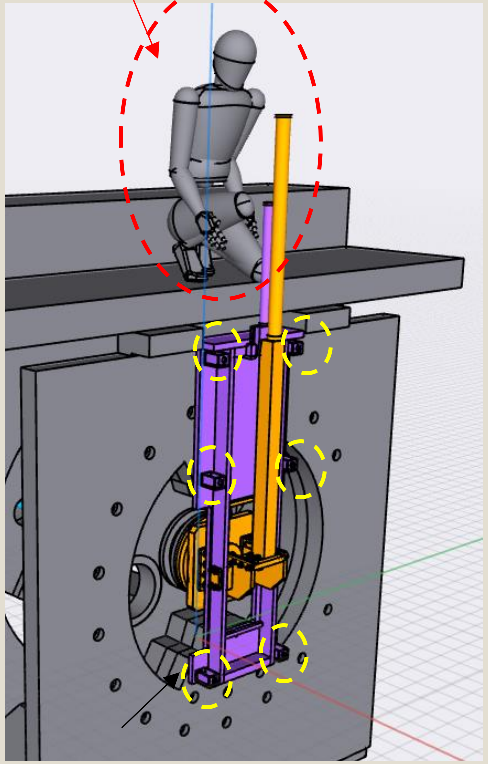


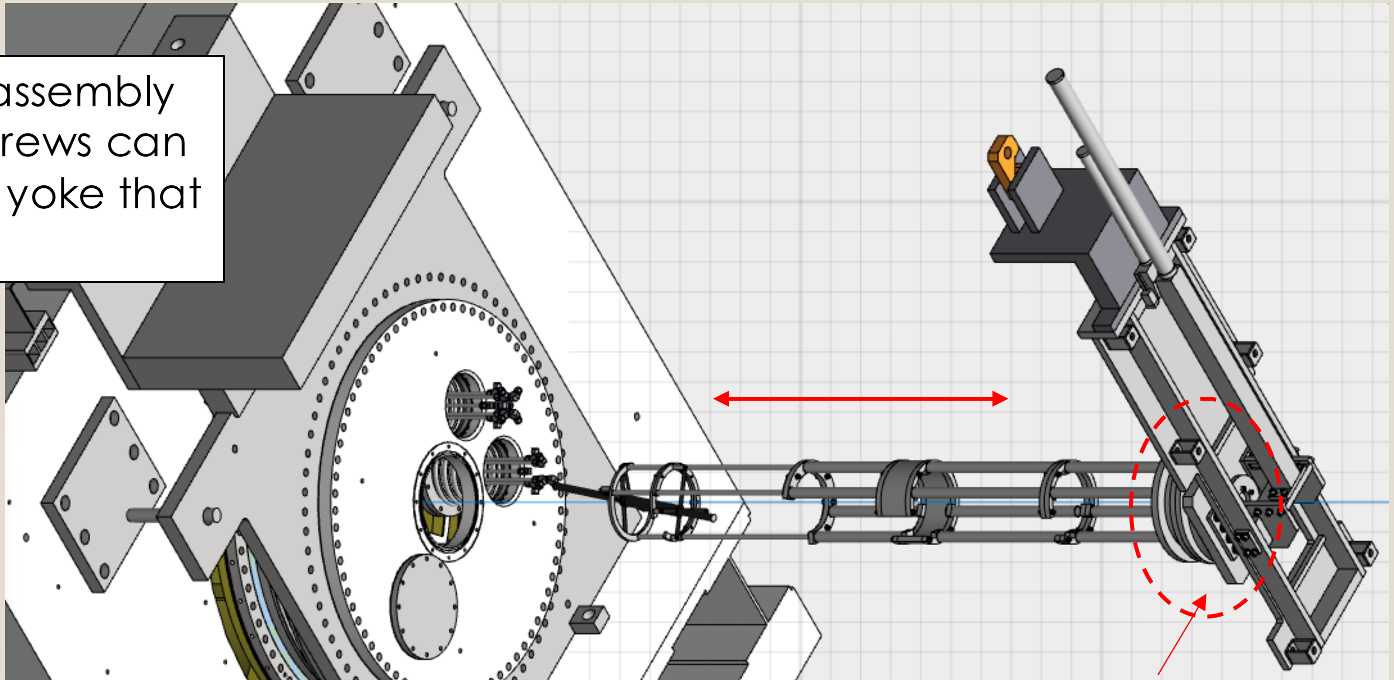
- Residual radiation dose of Target ASSY is a few tens of mSv/h. Not so high, not so low

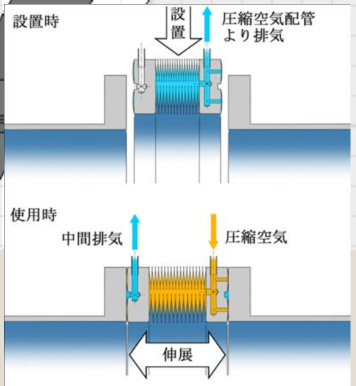
<u>Target ASSY is replaced by semi-remote handling.</u>

Semi-remote handling scenario of Target ASSY

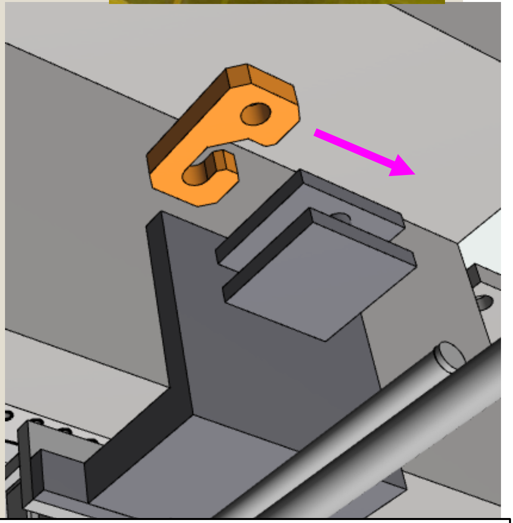
The position of the target assembly can be adjusted, and 6 screws can be fixed on the top of iron yoke that is low radiation area.







Pillowseal will be implemented for vacuum sealing.

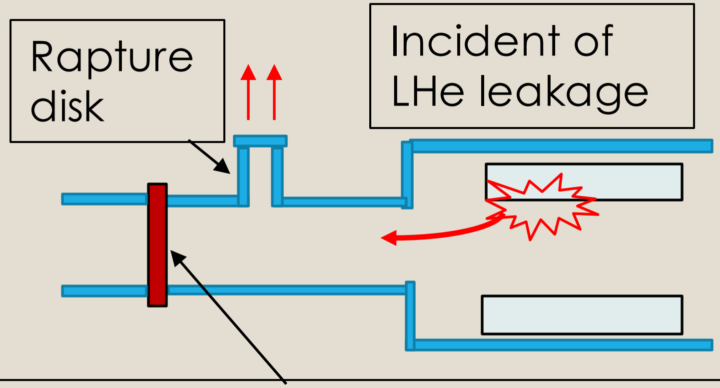


Semi-remote handling hook for Target ASSY

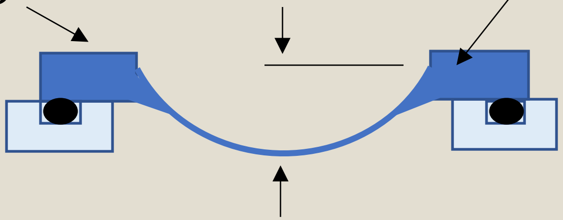
Beam window in superconducting-magnets beamline

Beam window in muon/pion transport by S.C. magnets:

- Low-density material & Thin
- Large diameter
- High proof pressure



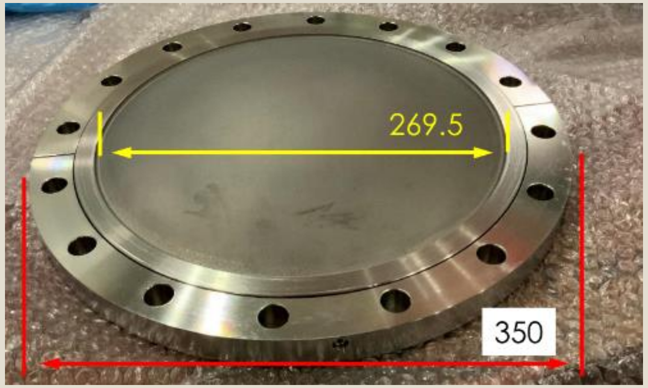
Requirement of Beam window with high proof pressure
(> proof pressure in rapture disk



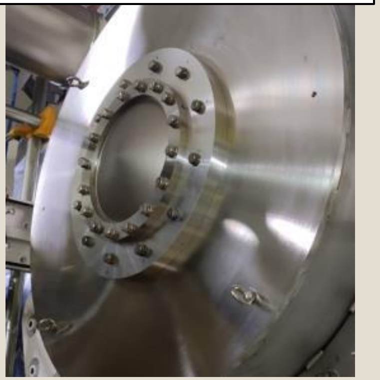
New technology to realize robust window by additive manufacturing (3-D printer)

Succeeded in manufacturing of D = 270 mm, t = 0.5 mm out of Ti-6Al-4V, Proof pressure is more than 1.0 MPa

Ti-6Al-4V beam window, t=0.5 mm



Installed in beamline

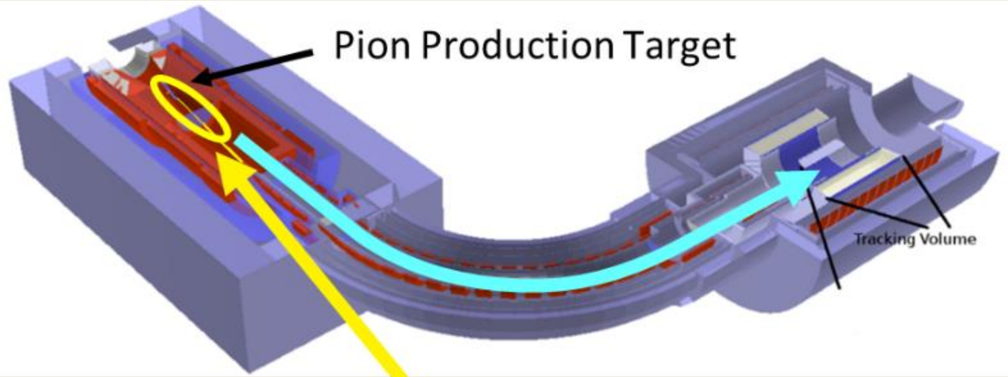


Next challenge: Beam window made of Al alloy

Reported by Hiroyuki Shidara in invited talk, (16th Wed, targetry session)
Displayed in Company exhibition booths, Metal Technology Co. Ltd.

MUON TARGET IN FUTURE

COMET Phase 2 target

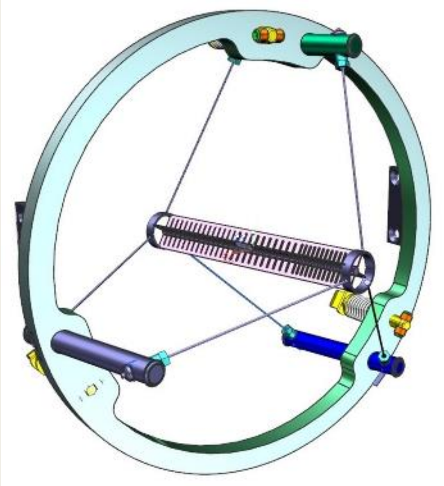


	graphite	tungsten
Density (g/cc)	1.82	19.2
Transport efficiency	1	3

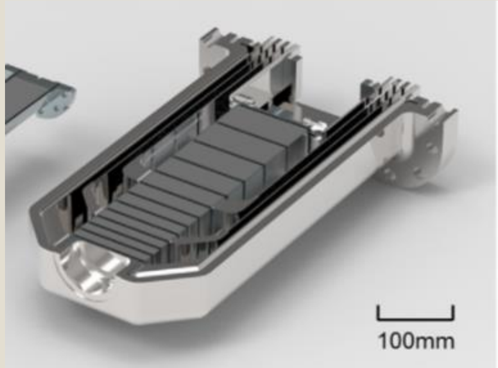
- The higher density of target material, the lower spatial volume of muon source
- The lower spatial volume, the higher capture and transport efficiency of muon

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



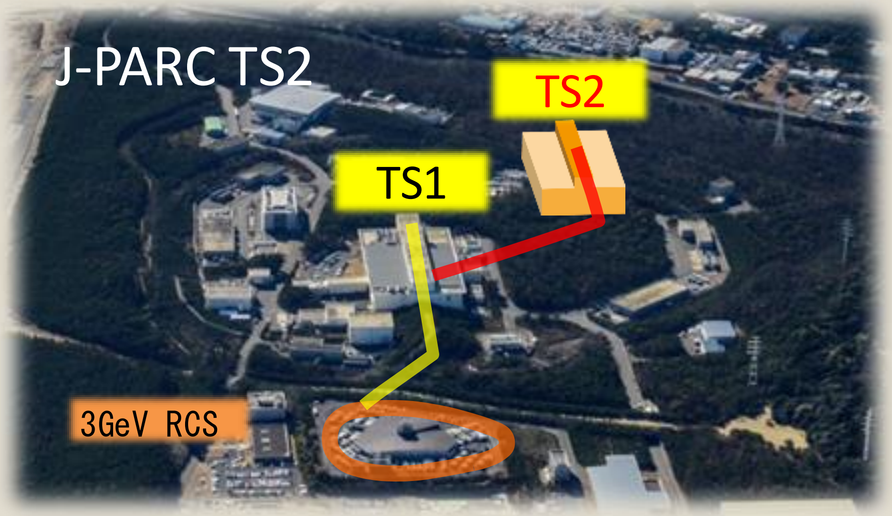
Thermal radiation cooling tungsten target at Mu2e



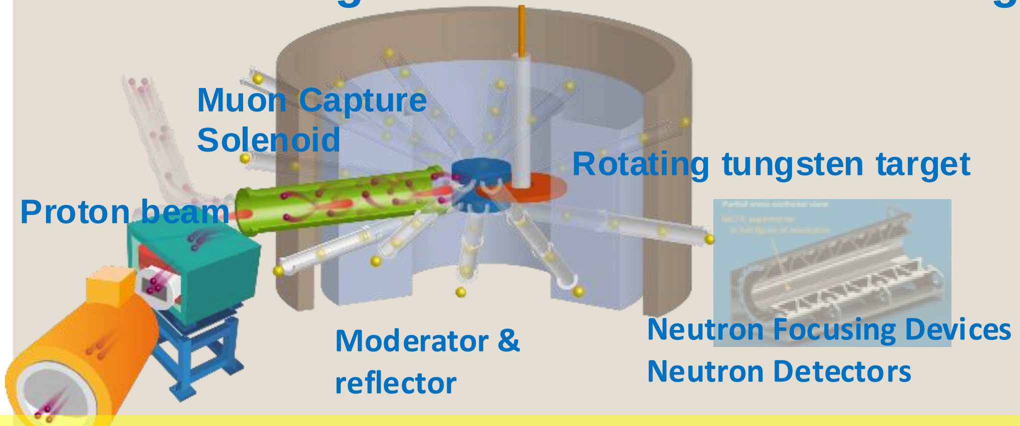
Water cooling Ta-cladding tungsten target at RAL

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

MLF Second Target Station



Integrated neutron and muon target

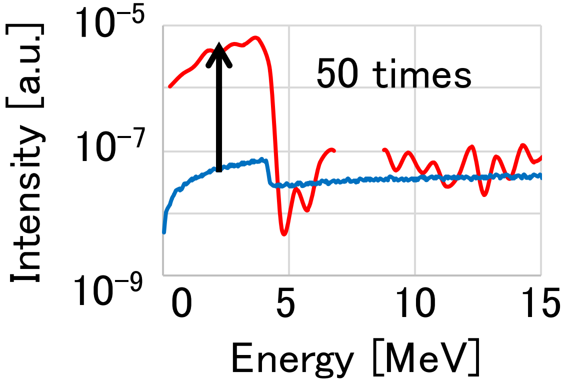


Neutron:
10 (target) x 2 (device) → 20 times gain of brightness

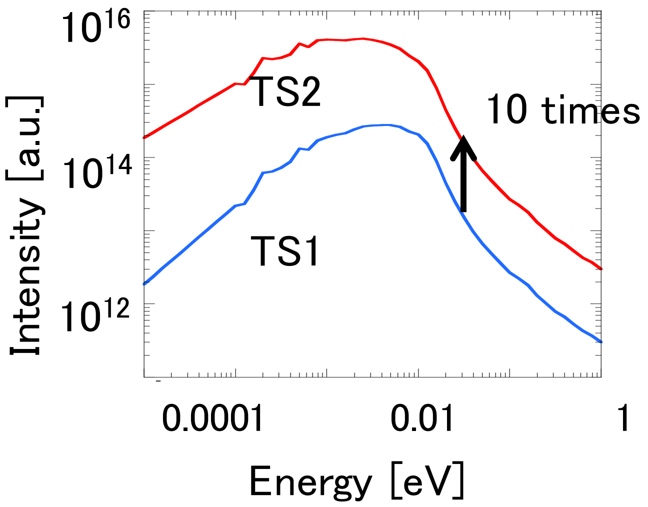
Muon: :
10 (target) x 5~10 (Muon capture solenoid) → 50 ~100 times gain of flux

Neutron・muon intensity

Muon beam



Neutron beam



Accelerator upgrade

Effective utilization of long wave neutron

Beam power 1 MW → 1.5 MW (TS1:1MW, TS2: 0.5MW)

Repetition 25 Hz → 25 HZ (TS1:17Hz, **TS2: 8Hz**)

		1 MW operation	1.5 MW operation
Ion source current	[mA]	50	62.5
Pulse width	[μs]	500	600
Repetition	[Hz]	25	25
Average current	[μA]	333.3	500
LINAC	[MeV]	400	400
RCS	[GeV]	3	3

SUMMARY

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Summary

- The muon target at MLF continues to successfully operate in 1 MW proton beam.
- The design of the COMET target in superconducting magnet is on going, and the P1 experiment will start soon.
- The tungsten targets are expected to be implemented in COMET Phase 2 and MLF 2nd Target station.