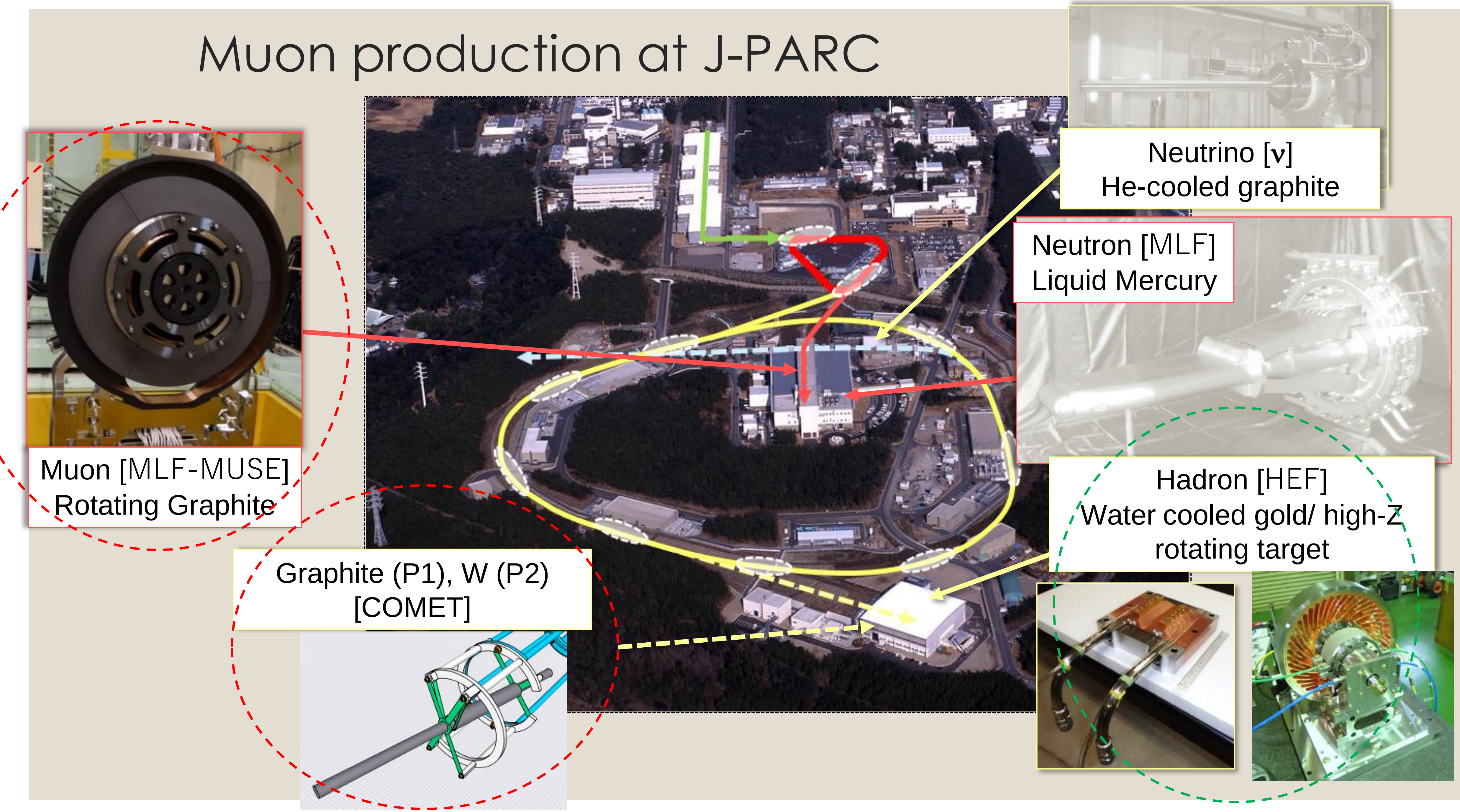
BRIDGING RESEARCH INNOVATIONS
IN DIVERSE MUON AND NEUTRON SCIENCE
BY GENERAL COLLABORATION
BETWEEN JAPAN AND SWITZERLAND @ PSI

18th, Oct. 2023

STRUGGLE TO PRODUCE MUONS WITH TEACHERS AND FRIENDS

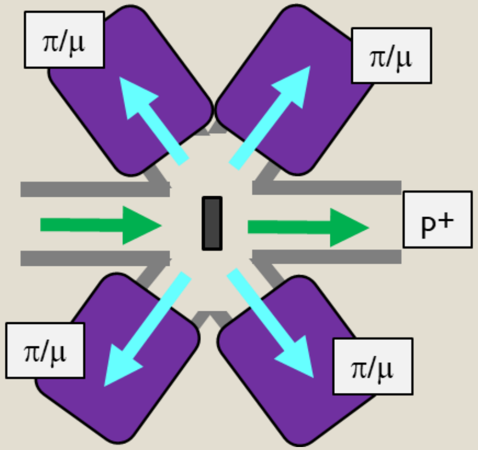
J-PARC, KEK
Shunsuke Makimura

Muon production at J-PARC

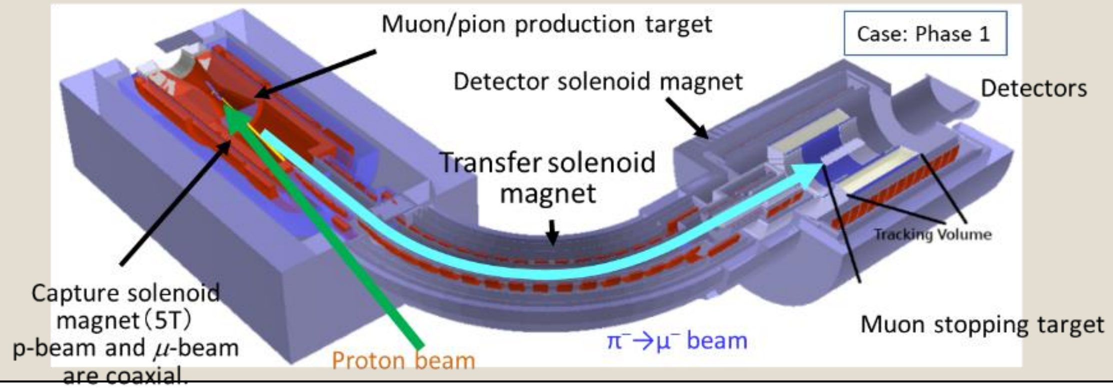


MLF muon target & COMET target
(MLF: Materials and Life Science experimental Facility)

	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.

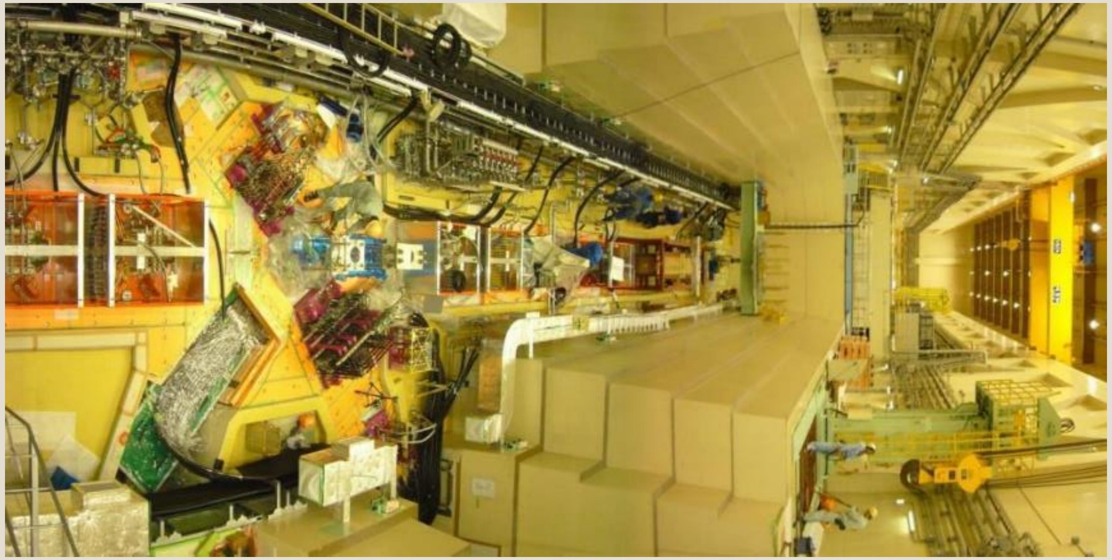


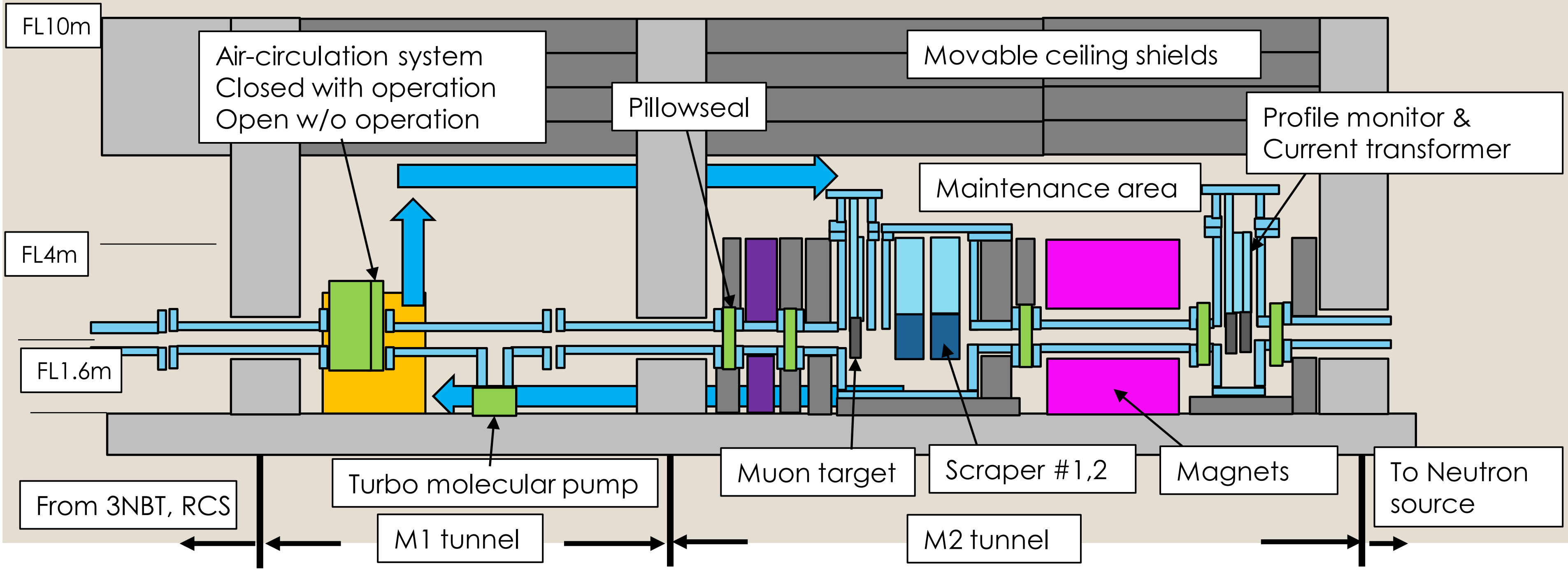
COMET target: Search for mu-e conversion
Located in high magnetic field to transport as large number of pions/muons as possible. Large B.G.
Difficult to disperse the beam loss.

1. MUON TARGET AT MLF

Position of target chamber in September 2005

Muon target is located at M1/M2 tunnel





M2 tunnel

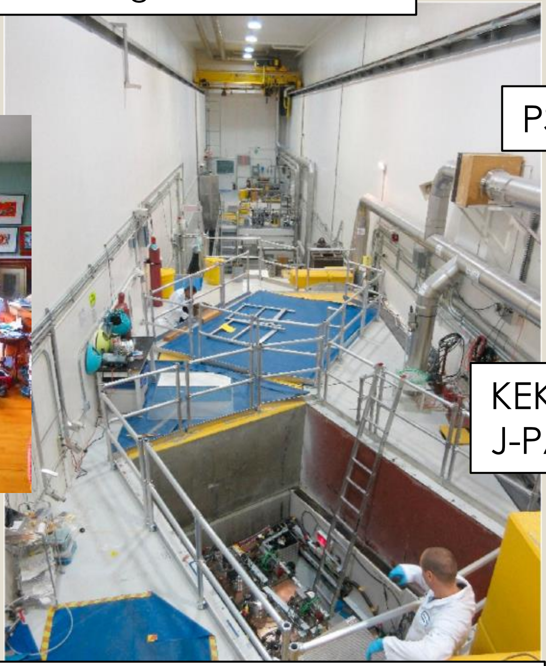
- Muon target
- Scrapers (collimator)
- Magnets
- Monitors
- Pillowseals
- Shields

Instruction from PSI & TRIUMF

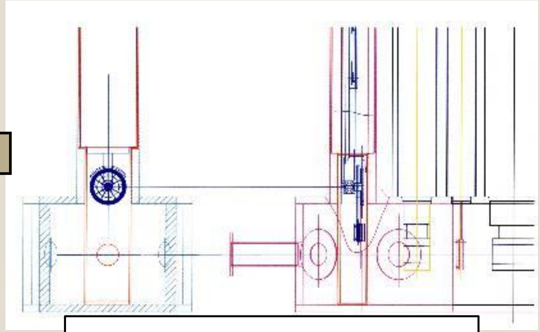
Since Muon Technical Advisory Committee, 2004
(Teacher: Dr. Gerd Heidenreich)

G. Minor et al., ISAC target hall @TRIUMF

2019@Victoria



Teacher, Dr. Jack Beveridge stayed KEK to support the design of J-PARC.



Conceptual design of rotating target in 2003.

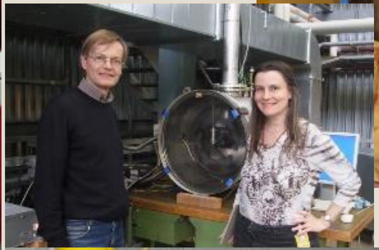
PSI

Rotating Target

Exchange flask (Cask)

Pillowseal

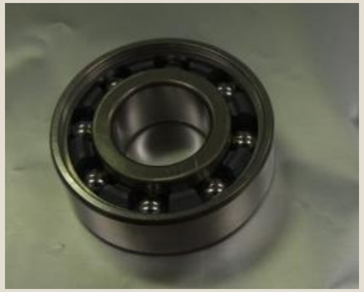
KEK, J-PARC



Visit to PSI in 2005, 2013 & 2014
Friends: Daniela, Auka, Daniel, Pedro,,,

Facility construction of MLF is based on the technologies originated in PSI.

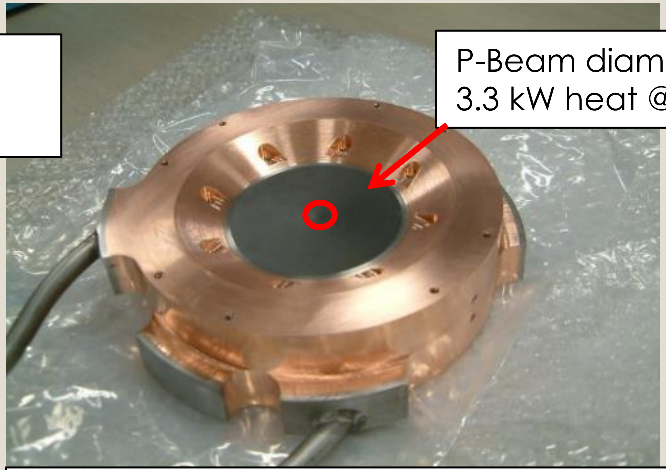
Recent collaboration (J-PARC, KEK to PSI)
Technology of long-life bearings were transferred from J-PARC to PSI.
(Press release at KEK, Scientific Highlight at PSI website)



MLF muon target: Fixed target & Rotating target

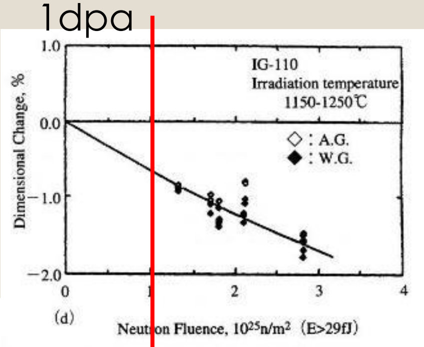
- Target material is polycrystalline graphite, IG-430U. (Thickness: 20 mm)
- To extend lifetime, the fixed target was replaced with rotating target that disperse the radiation damage of graphite.

Water-edge-cooled target

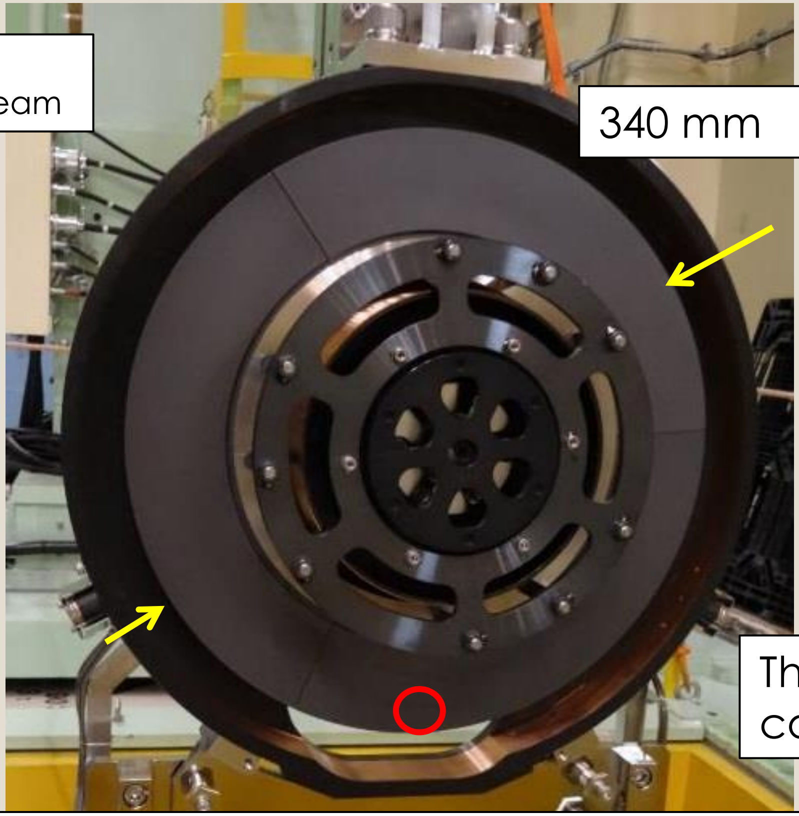


P-Beam diameter; 14 mm (2s)
3.3 kW heat @ 1MW proton beam

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



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



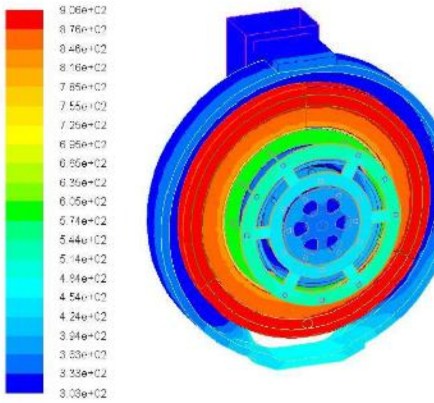
340 mm

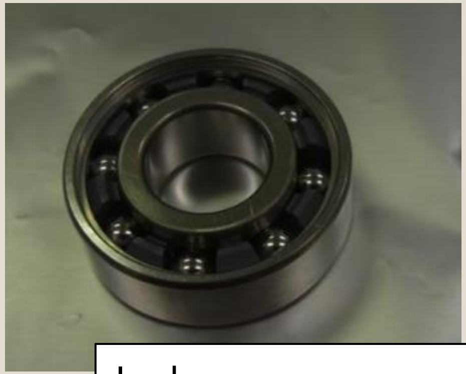
Thermal radiation cooling

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

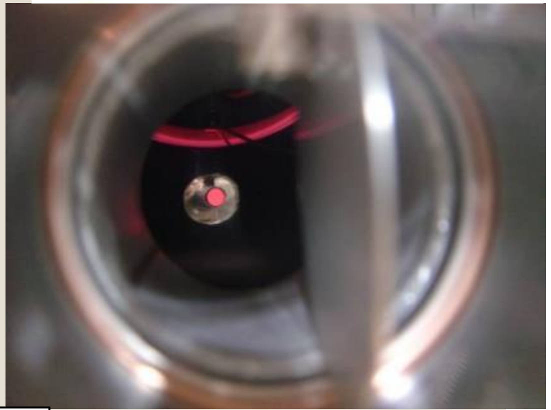
Bearing of Rotating target

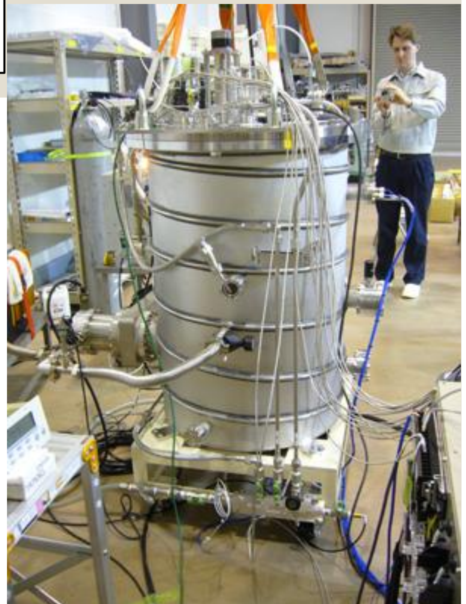
Solid lubricant in high temperature, high vacuum, and high radiation dose
Previously, the solid lubricant (Silver + MoS_2 at PSI) coating on the ball, rings, and separator. When peeling off, performance is lost.
In J-PARC, bulk lubricant WS_2 has been applied. Large amount of lubricant.





WS_2 lubricants

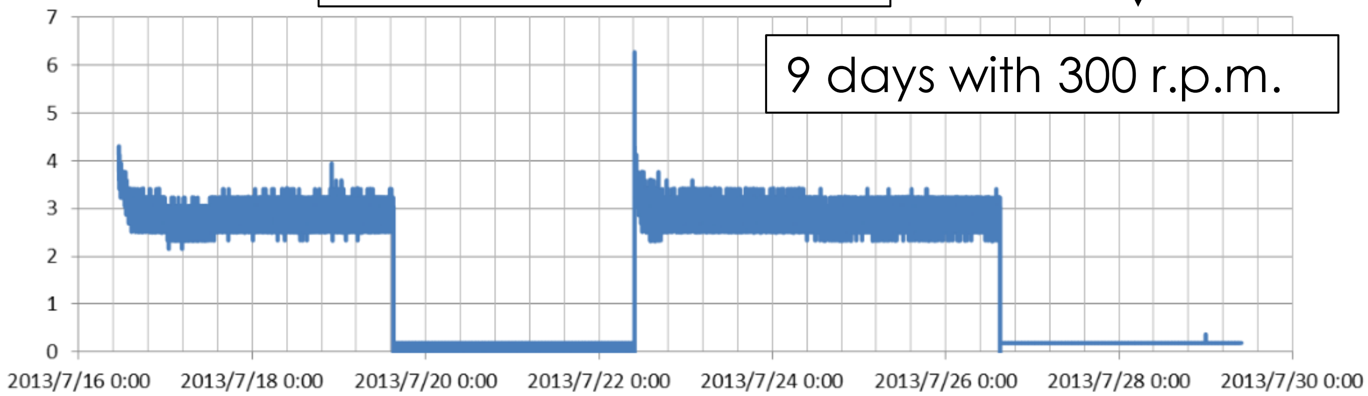




After test by mock-up

- In vacuum
- Heating
- Rotation

Design of the target is determined.



Other technologies implemented in Muon facility

High vacuum target chamber

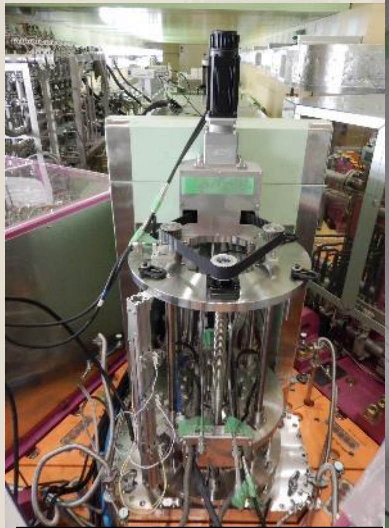
Scraper:
Water pipe is embedded in Cu

Transport of target by cask

30-m travel to U.G.

Remote-controlled gripper

Remote-controlled replacement

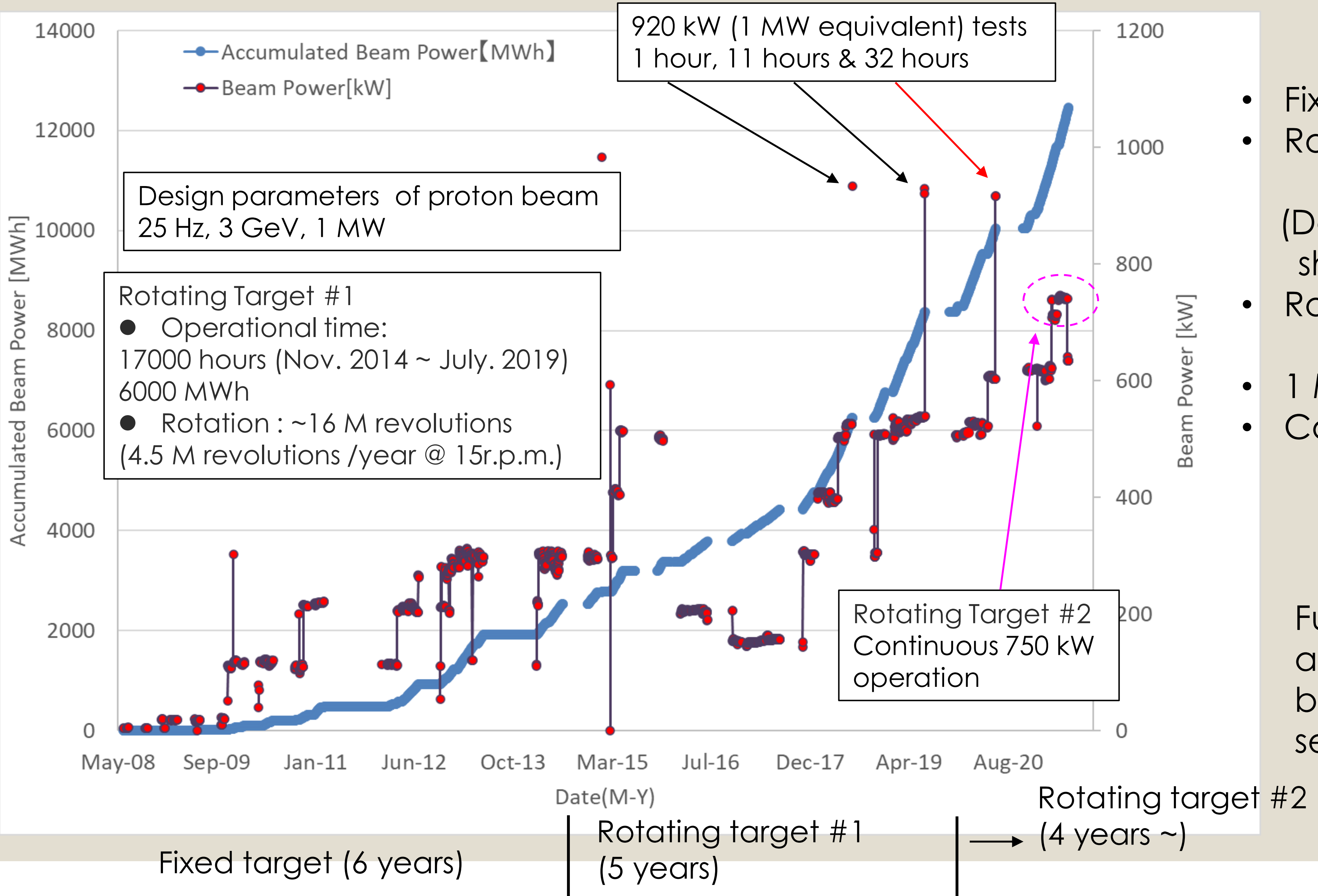


Up-down & rotation drive

Spline shaft

Absorbance of thermal expansion

History of Muon Target at MLF



- Fixed target: 6 years
- Rotating target #1: 5 years (Design mistake of shaft coupling)
- Rotating target #2: > 4 years
- 1 MW tests: Achieved
- Continuous 750 kW

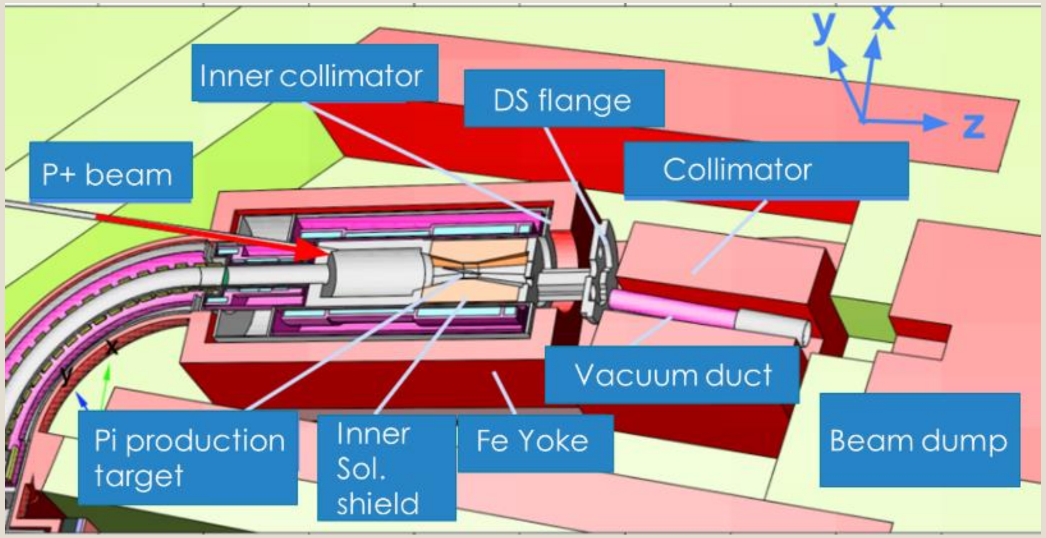
Further information and the update will be reported in poster session by Shiro.

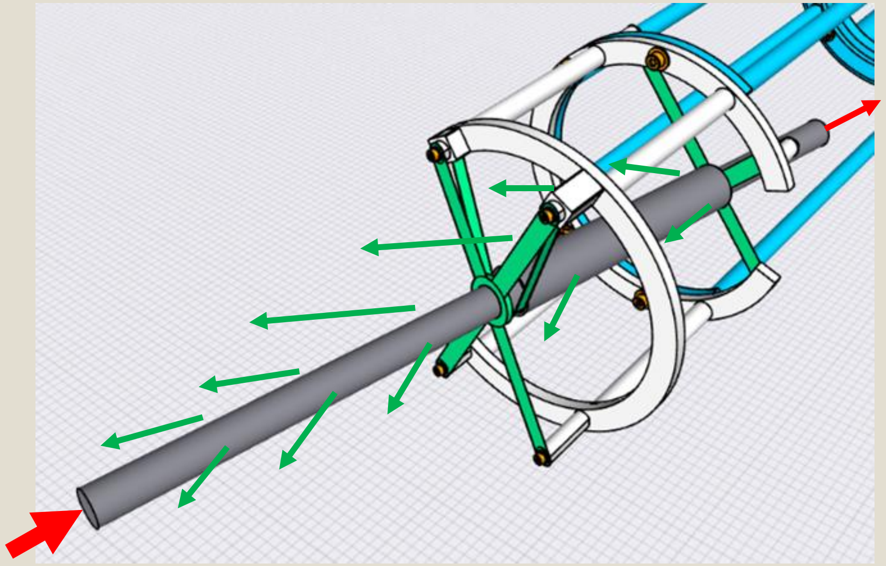
History of struggle with friends

2. COMET TARGET

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.

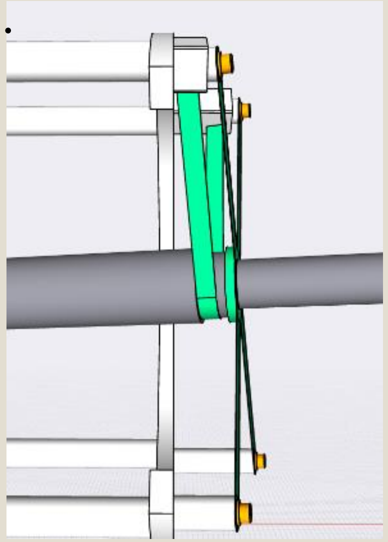
<u>Target support</u>

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

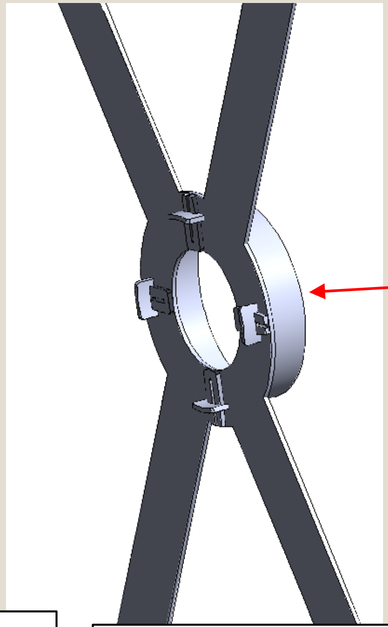
<u>Material & Structure</u>

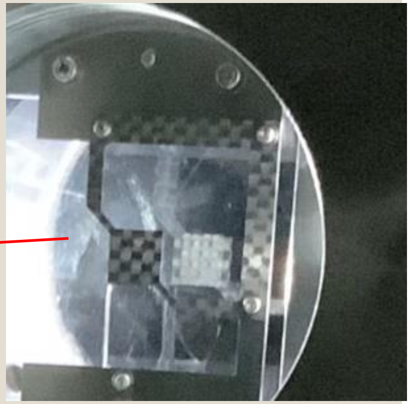
- Refractory material
- Not-bulk material
- Low-density is preferable

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



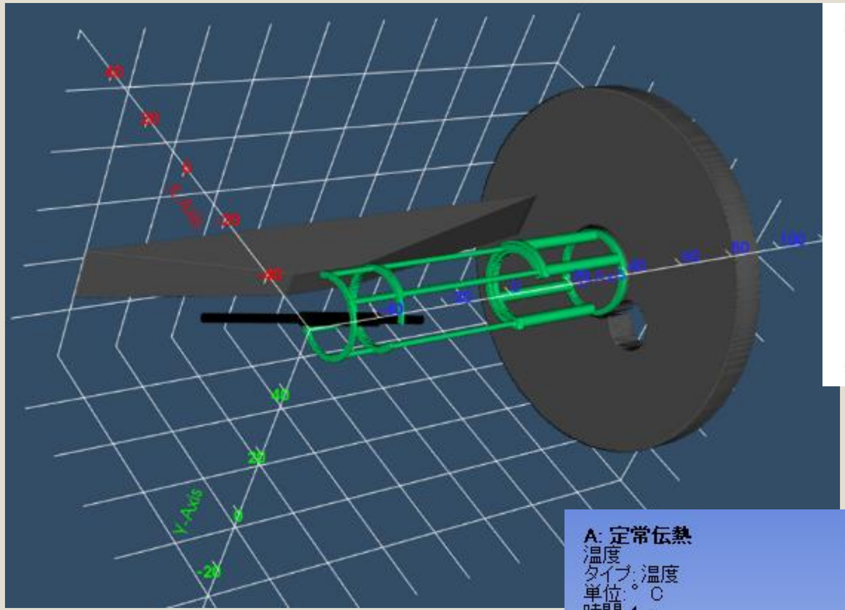
Reinforcement of target support for the axial direction

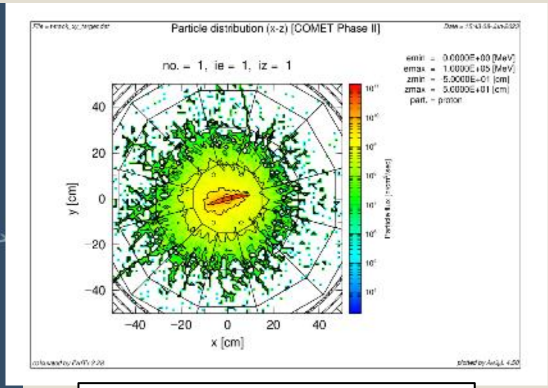




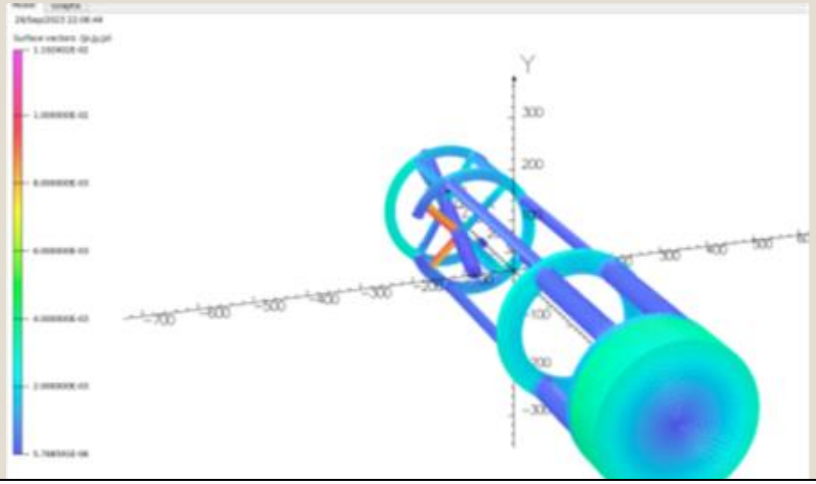
Manufacturing of target support by C/C composite

Dose analysis, Thermal analysis & Eddy current analysis

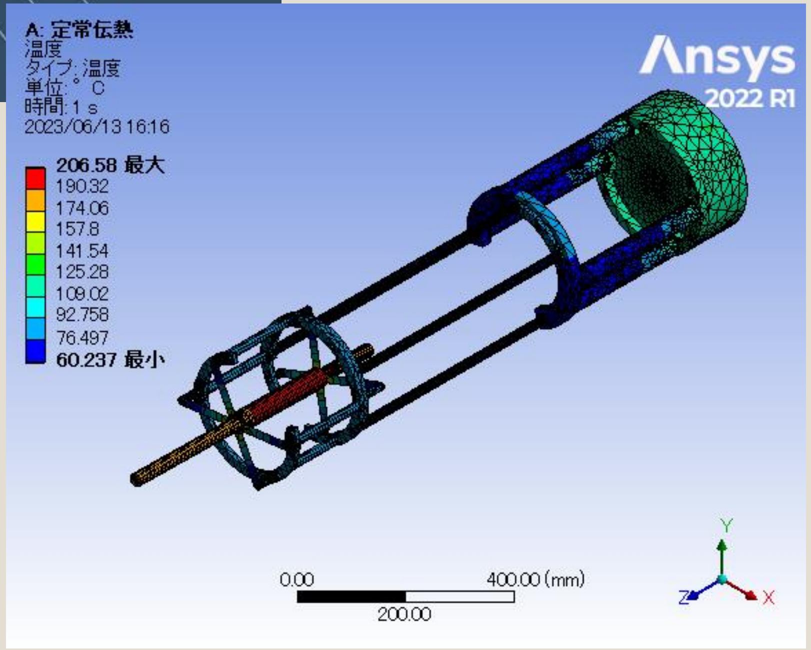




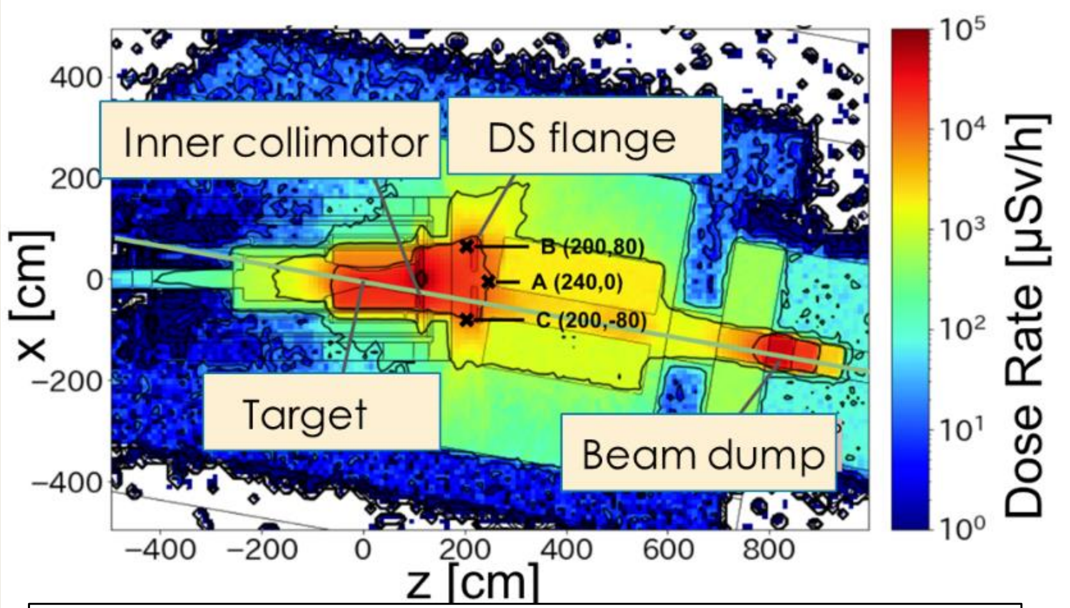
Proton distribution
on upstream view



Eddy current analysis when the quench occurs by
Sumi in Cryogenic section

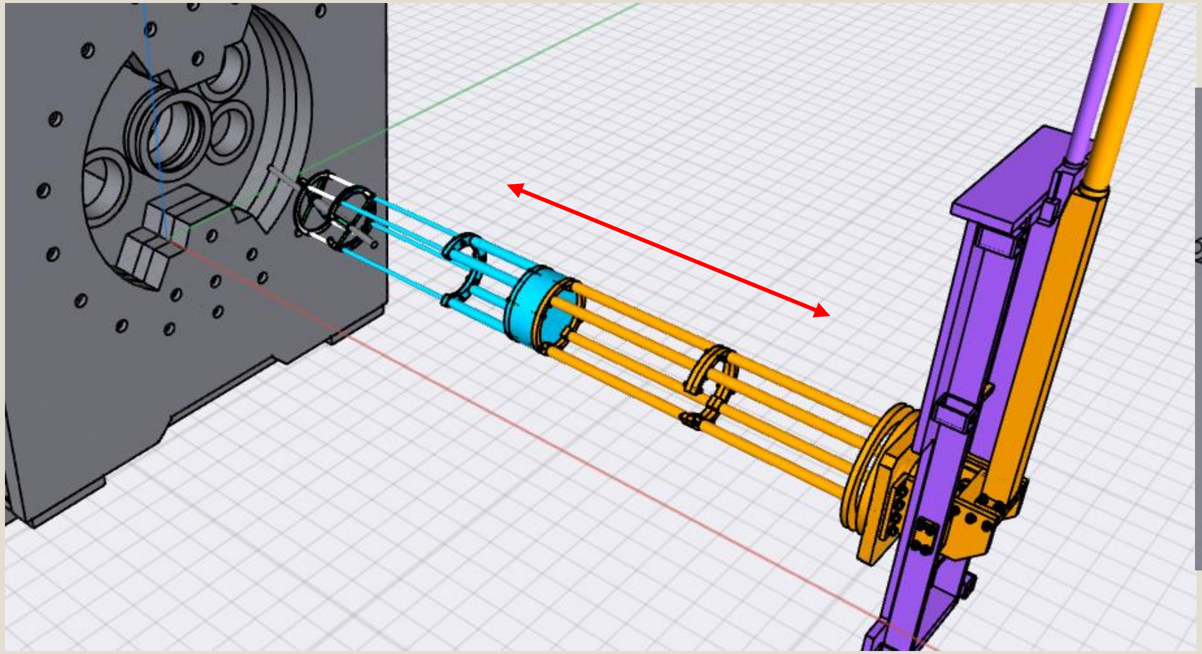


Max. temperature: 200 °C
PHITS & ANSYS simulation by
Metal technology Co., LTD.

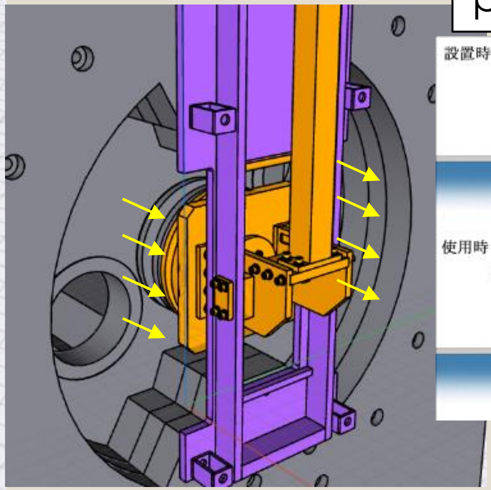


Residual radiation dose analysis by Kyusyu University

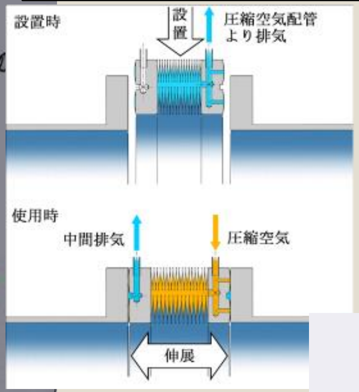
Target assembly in phase 1

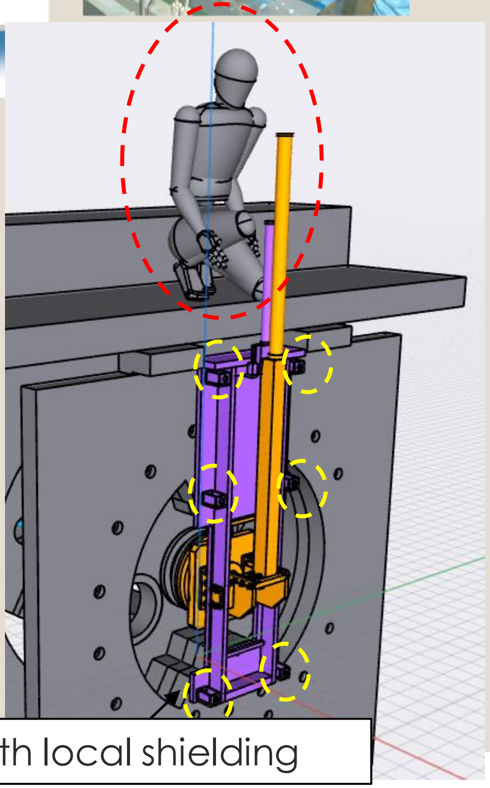


The target assembly is inserted into the solenoid shield by semi-remote-handling.



3000 kgf of load by the air-pressure of pillowseal must be considered.



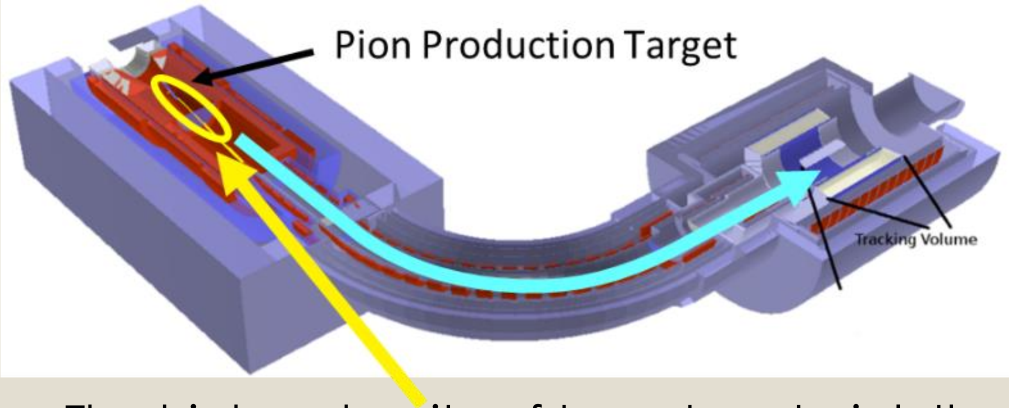


Maintenance with local shielding

We must consider

- How the structural strength is guaranteed.
- How the accuracy is guaranteed.
- How it is maintained in the high radiation area.

COMET Phase 2 target

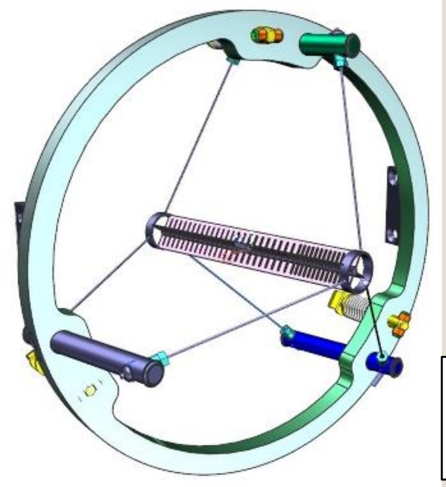


	graphite	tungsten
Density (g/cc)	1.82	19.2
Transport efficiency	1	3

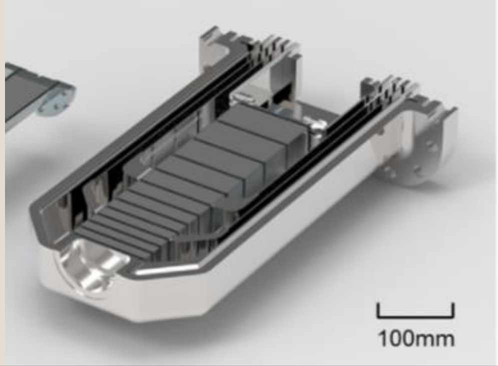
- The higher density of target material, the lower spatial volume of muon source
- The lower spatial volume, the higher capture and transport efficiency of muon

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

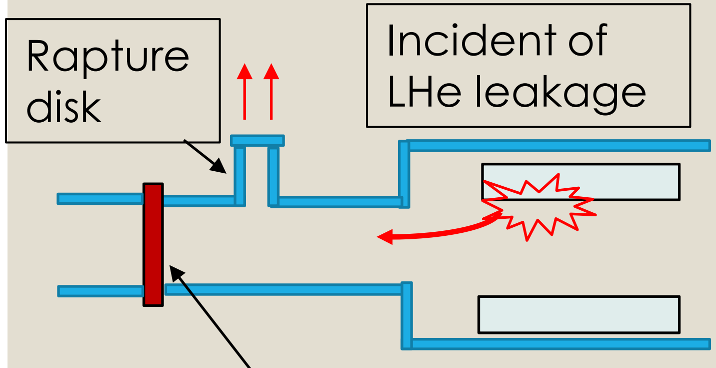


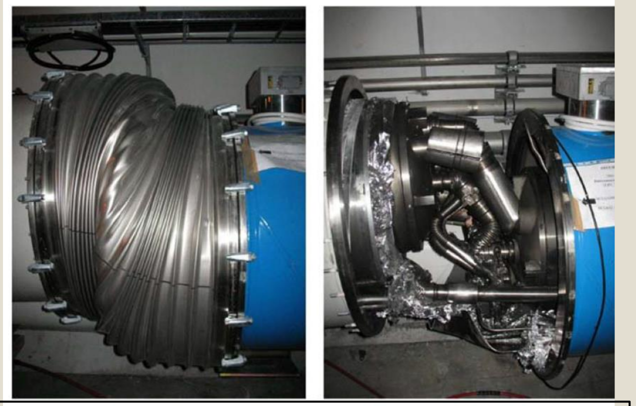
Water cooling Ta-cladding tungsten target at RAL

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

3. OTHER TECHNOLOGIES FOR FURTHER COLLABORATION

3D-printed beam windows

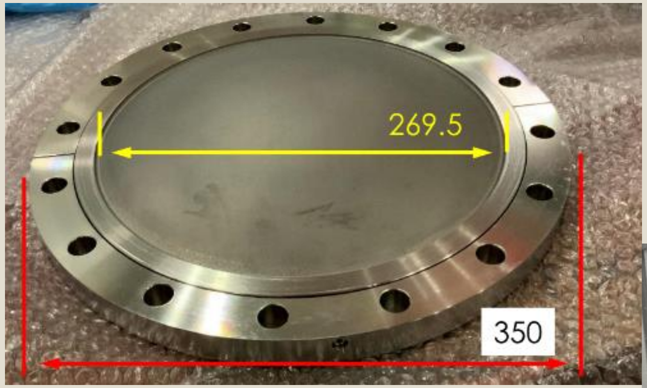




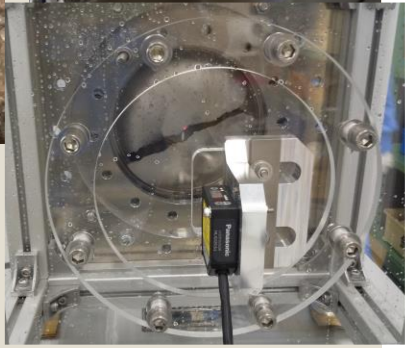
Requirement of Beam window with high proof pressure

e.g. The incident of 2008 at CERN, Pressure increases to 0.8 MPa

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



Installed in beamline



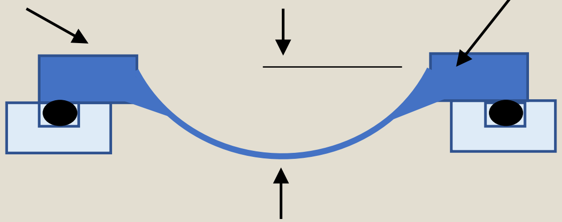
Destructive test

Pressure 4 MPa in DN200, t=0.5 mm

Monolithic structure

Large depression

Stress relief on the edge



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

Beam window out of Aluminum alloy, AlSi10Mg

- Low temperature (200 K)
- Flangeless window
- Directly-welded to AL duct

Succeeded in manufacturing

Next plan

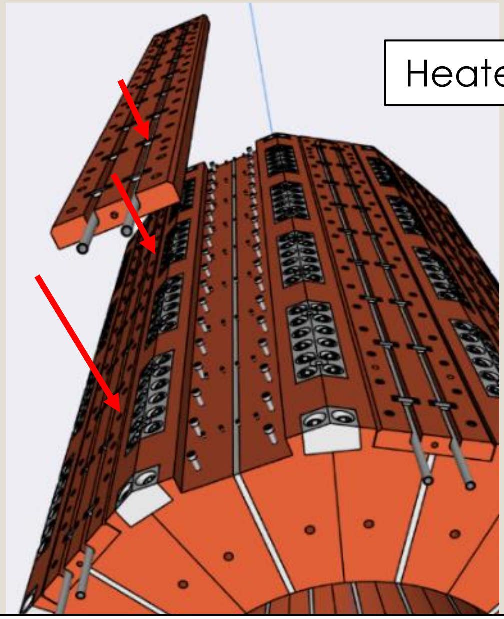
- ☐ Welding & polishing
- ☐ Checking of mechanical properties

Shield to protect super conducting magnet

DEVELOPMENT OF NEW MANUFACTURING PROCESS TO SAVE COST

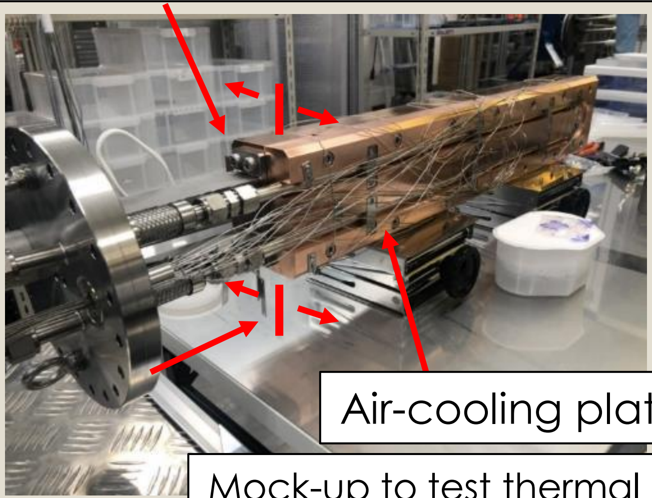
- Hot Isostatic Pressing process for larger collimator is too expensive.
- Based on thermal contact by mechanical connection
- How to keep a good thermal contact,,,
- Available to manufacture tungsten shield

Requirement for shielding of high dense material, tungsten.
COMET P2, MLF TS2, Muon collider



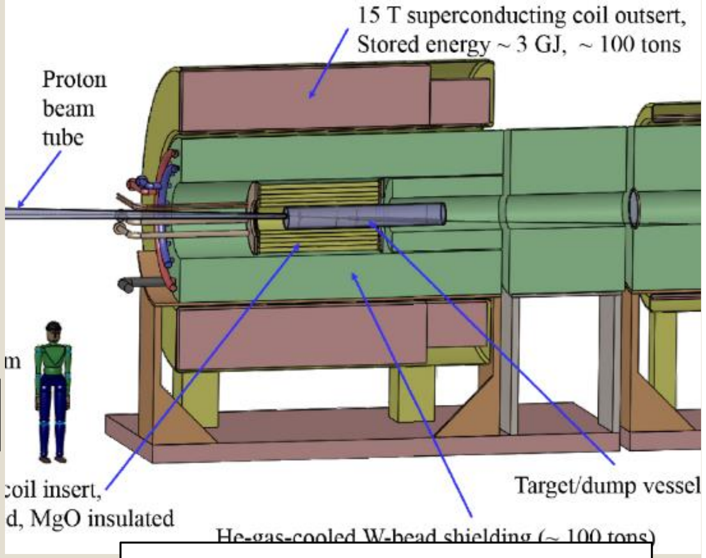
Mechanical connection by screws

Heater plate, heated by SHEATHED HEATER



Air-cooling plate

Mock-up to test thermal contact performance

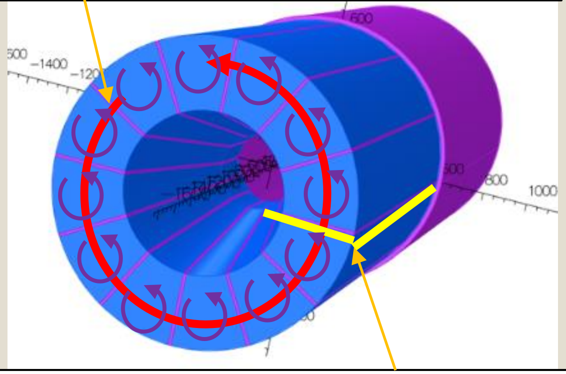


Conceptual design of muon collider

Effect of high magnetic field

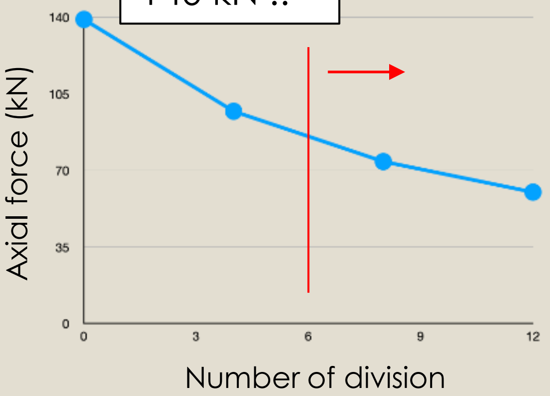
□ Effect of high magnetic field by superconducting magnet is not negligibly small.

Eddy current: Hoop direction



SS304 plates in each gaps, t=10 mm

140 kN !!



Cu shield should be divided to more than 6 pieces.

<u>Lorentz force occurs by a sudden drop of the magnetic field.</u>

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

OPERA simulation by Sumi in cryogenic group

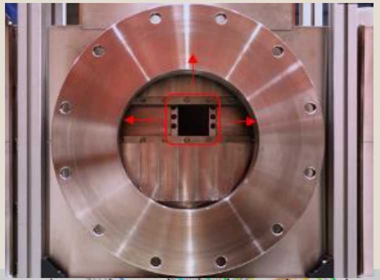
□ Mask system in COMET Phase α

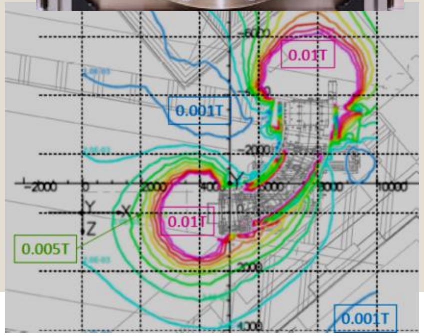
Developed in Imperial college

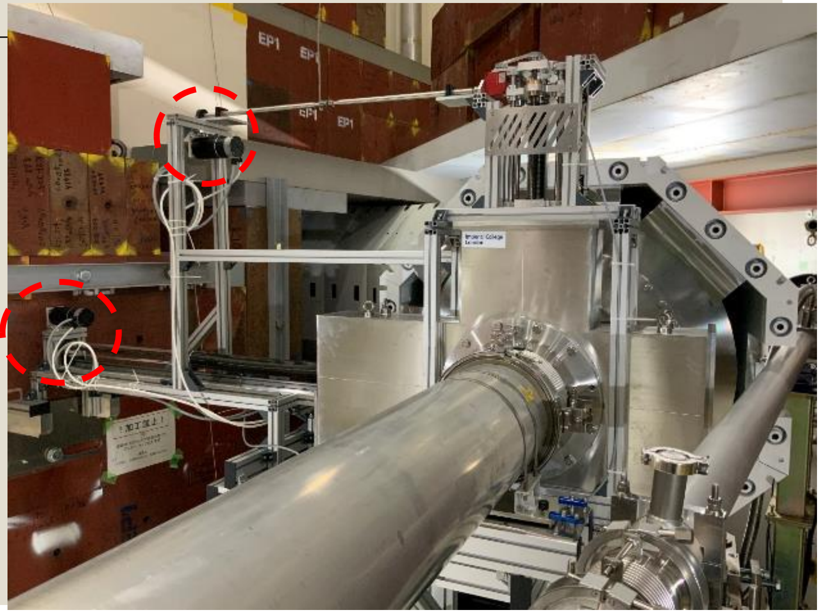
- Combination of 2-axis linear drive in front of superconducting magnet.
- Motor is located outside of high magnetic field.

In general,

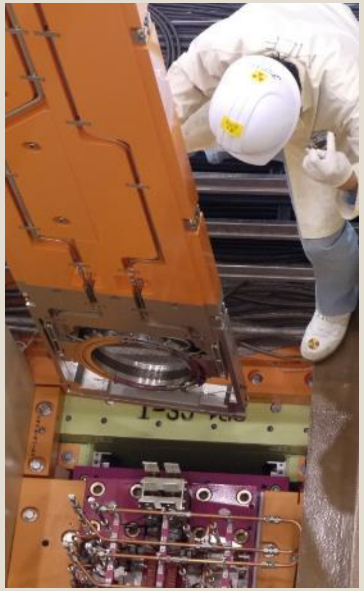
- How about rotating target or monitors besides superconducting magnet?



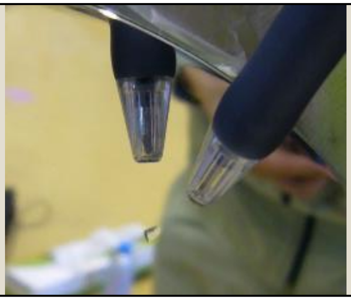




Repair device for pillowseal-mating-flange



Roughness < 0.2 um

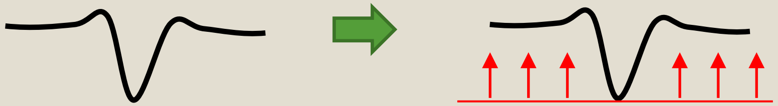


5-um depth of damage causes the leakage.

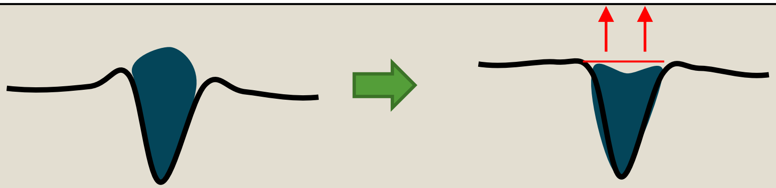
Pillowseal is remote-controlled gasket-less vacuum connection. When the mating flange of pillowseal is damaged, the huge activated components must be replaced.

Flange repair device will save the activated waste.

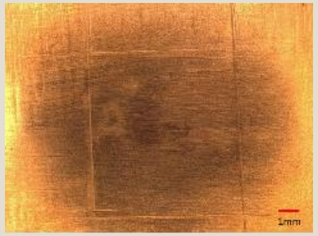
Concept of repair device

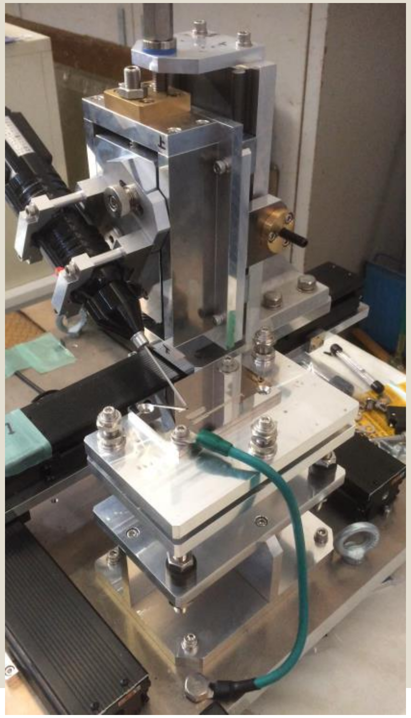


Polishing makes large amounts of activated dust.



Burying the scratch, then polishing to save the contaminated dust.



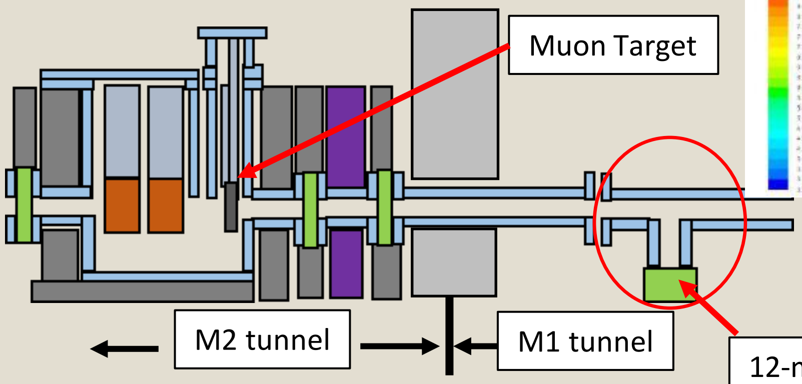


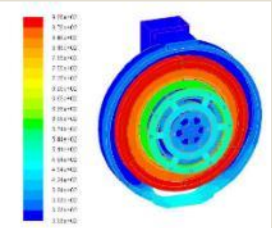
Electro Spark Deposition device succeeded in burying the scratch, then polishing.

In-situ measurement of target

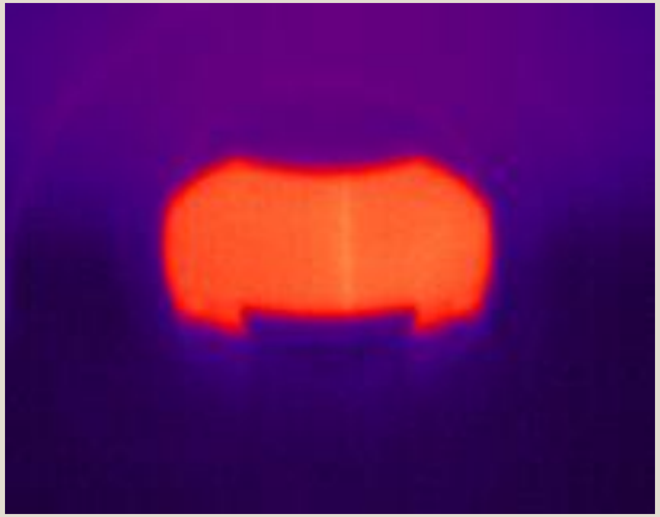
- Vibration analysis of rotation with deep learning by Sunagawa-san in muon group
- Rotation monitor by Muto-san in Hadron beam (Poster)

Temperature measurement of rotating target at MLF



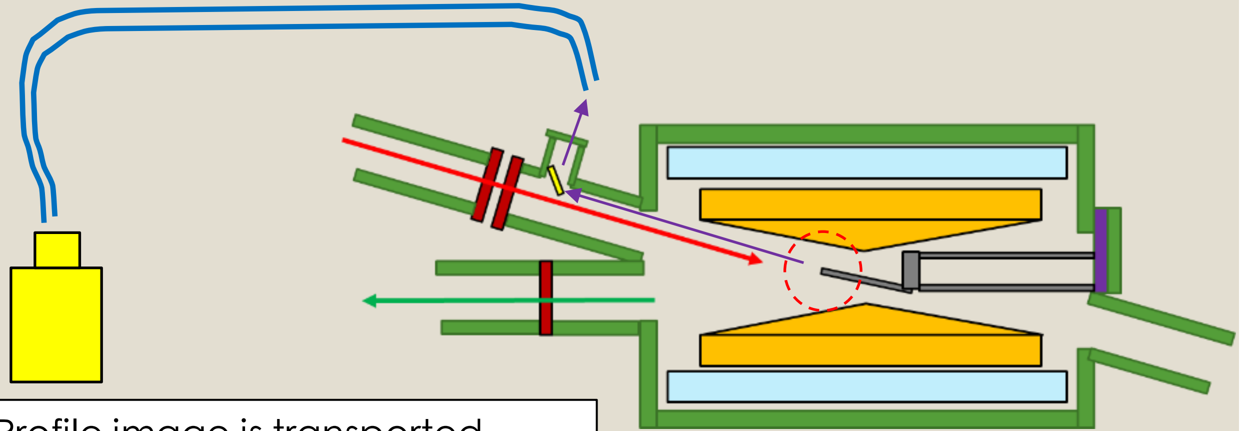


Infrared camera image at 1 MW

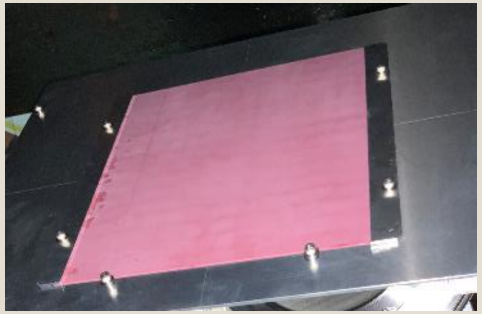


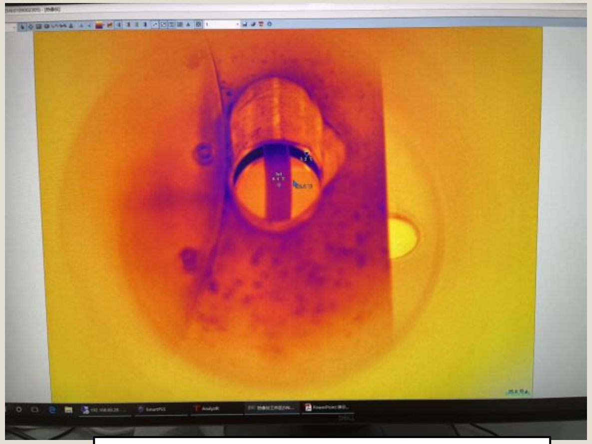
Reported in poster session by Shiro.

Beam profile measurement on COMET target



Profile image is transported through mirror and optical fiber.





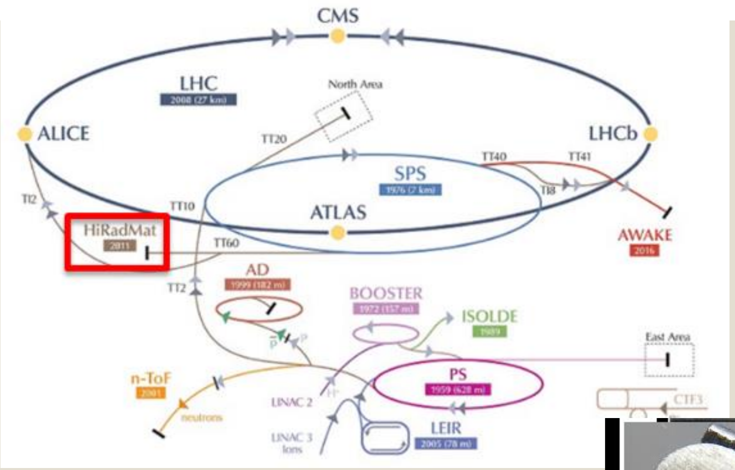
Profile measurement @CAFÉ Linac, IMP

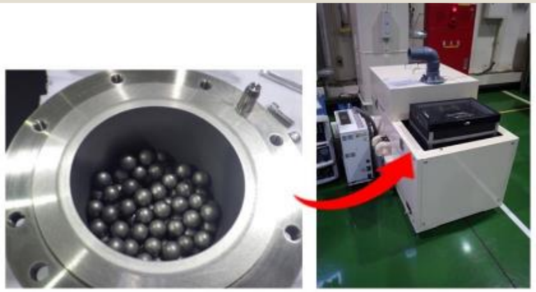
Collaboration with Institute of Modern Physics in China

Tungsten development

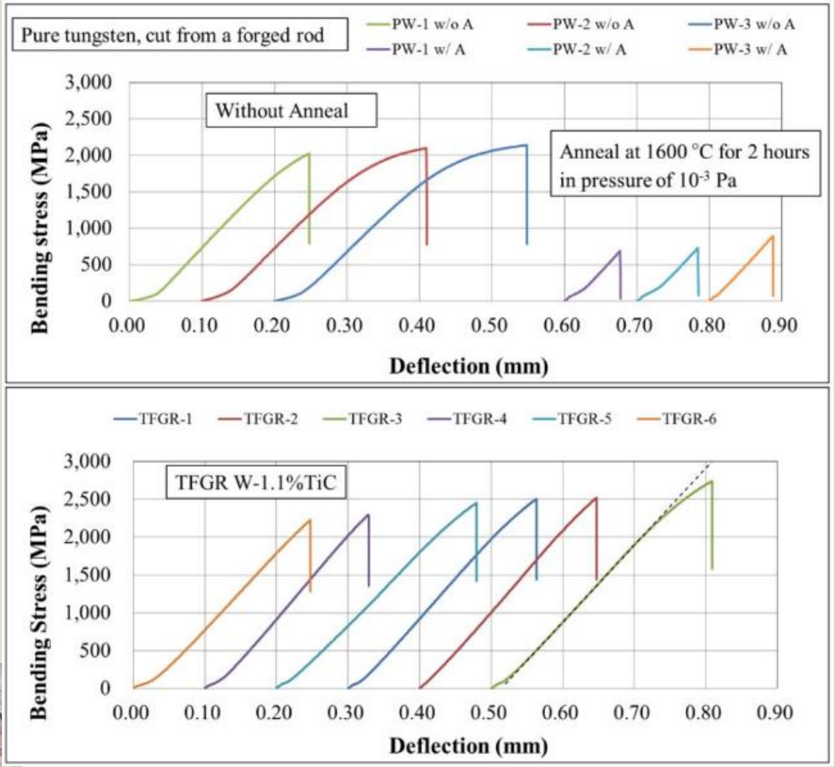
- Construction of manufacturing environment
- Overcome of recrystallization embrittlement of tungsten
- No damage on CERN HiRadMat irradiation test

Thermal shock by 700 °C temperature rise, 1 GPa tensile stress





S. Makimura et al., Materials Science Forum, Spallation Materials Technology, Vol. 1024, pp 103-109



Development of tungsten and the irradiation studies are supported by RaDIATE collaboration (The Radiation Damage In Accelerator Target Environments)

Collaboration with SINQ is welcome.

4. SUMMARY

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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.
- Collaboration with KEK and PSI has a long history.
- We are ready for further collaboration.
- MLF 2nd Target station, Muon Collider,,,

Danke schön!!