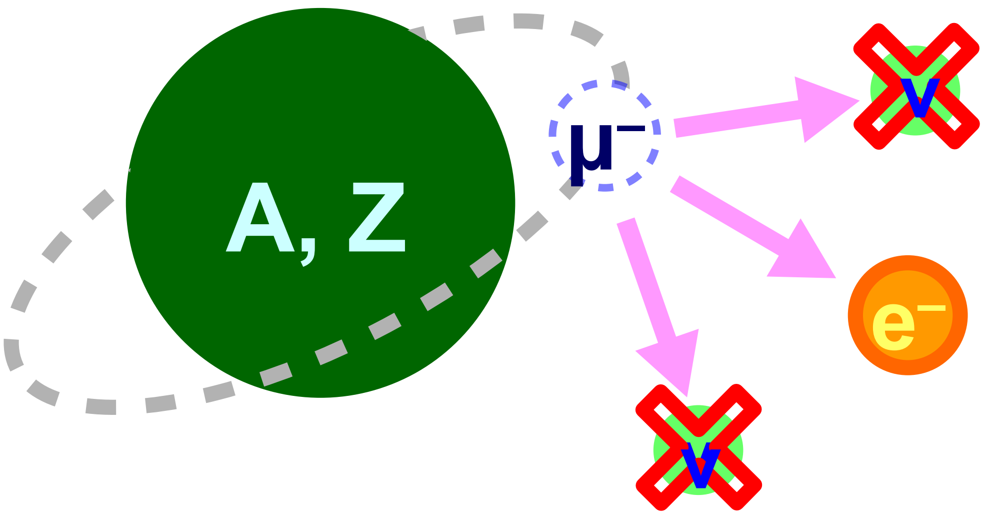
Facility Design of the COMET Experiment at J-PARC

6, Nov. 2023
High Power Target Workshop

Y. Fukao, S. Makimura, N. Kamei and S. Mihara (KEK IPNS)

COMET Experiment



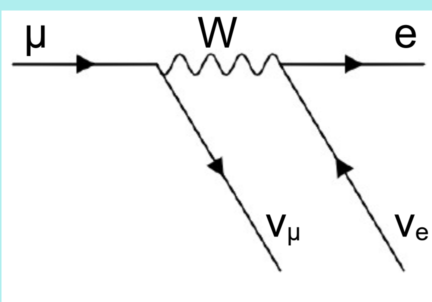
- Search for the new physics

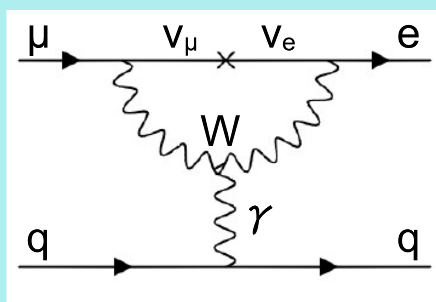
  μ-e conversion = rare event

  → High Intensity Muon Beam

  → High Power Target

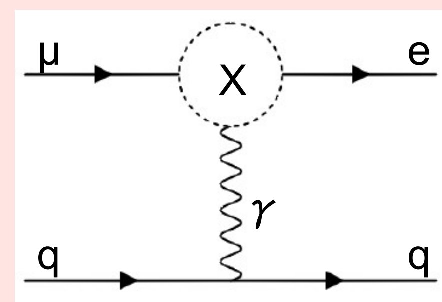
Standard Model

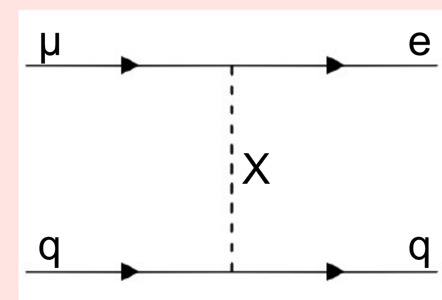




- ✓ Muons can decay to electrons with neutrinos.
- ✓ μ-e conversion via the neutrino oscillation is $<O(10^{-54})$.

New Physics

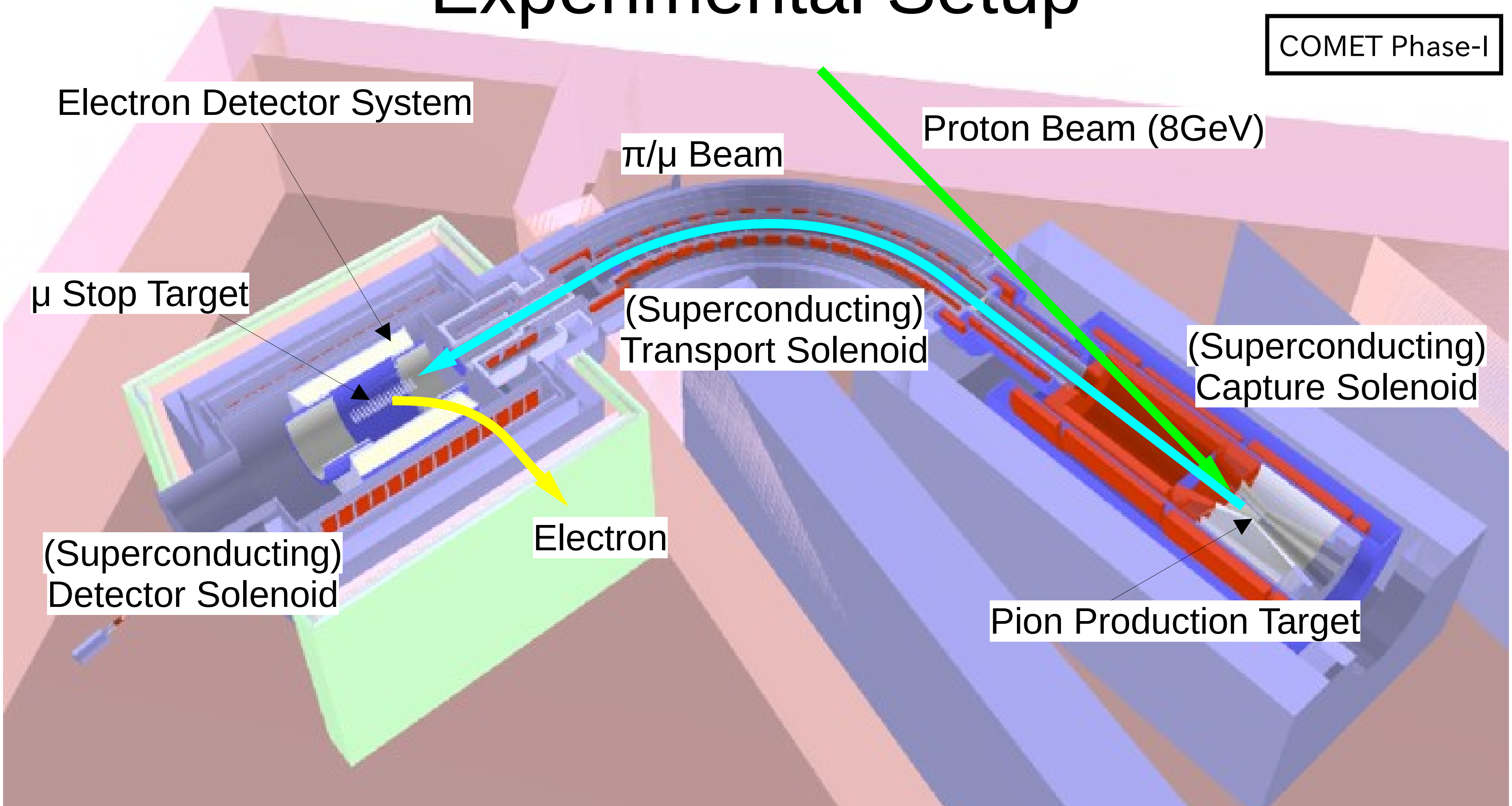




- ✓ Sensitivity for the new physics scale is >1000TeV.
- ✓ μ-e conversion has sensitivity to both photonic and non-photonic interaction.

Experimental Setup

COMET Phase-I

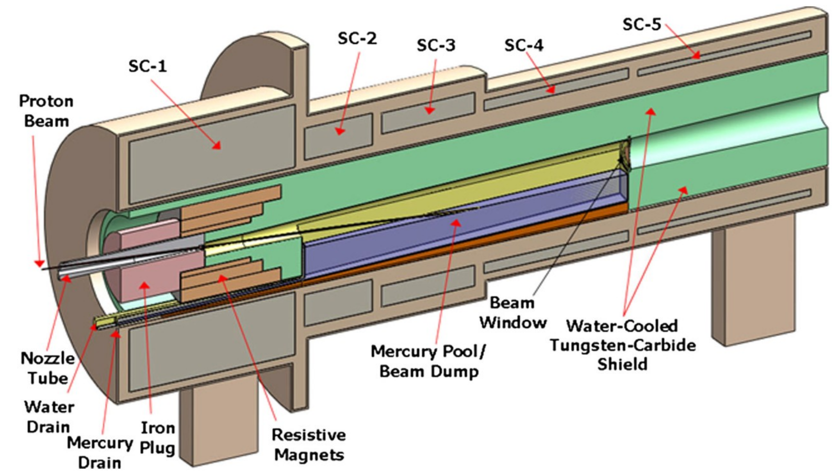


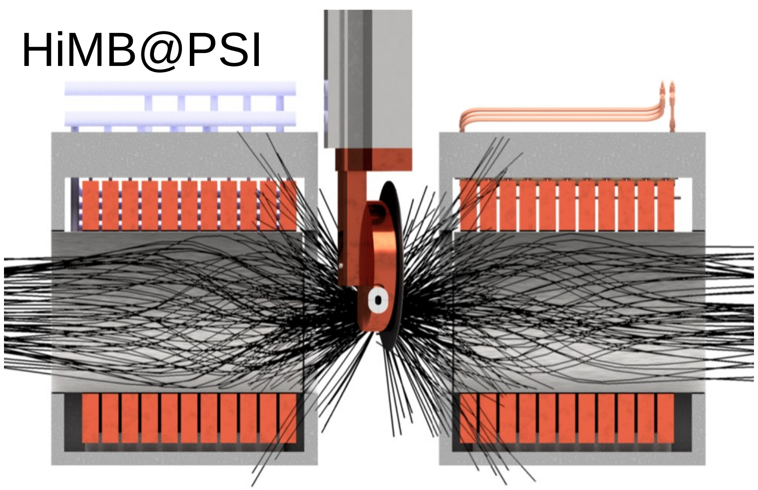
To generate high intensity muon beam

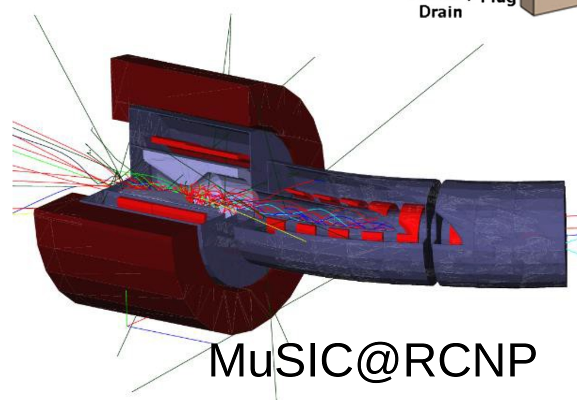
- ✔ High intensity proton beam
- ✔ (Superconducting) Capture Solenoid
- ✔ Thick pion production target inside Capture Solenoid
- ✔ Radiation shield between target and Superconducting coil

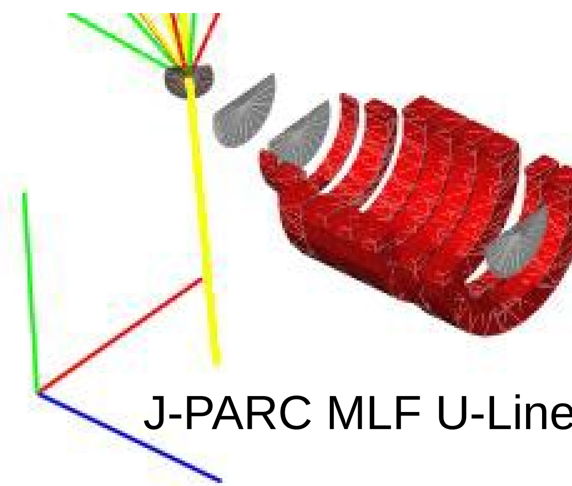
Various Pion Capture System

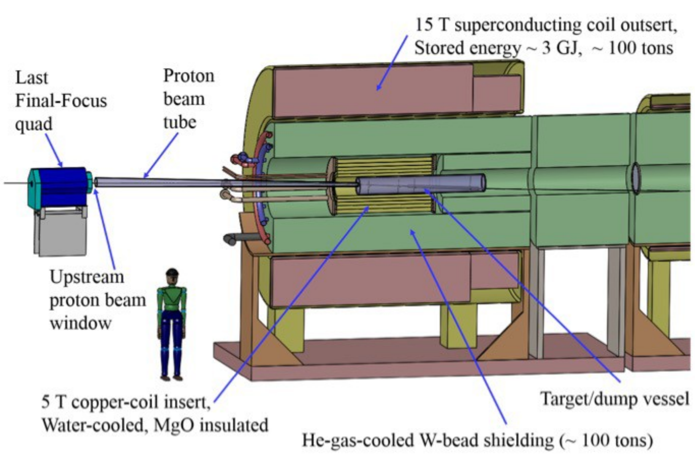
It’s becoming a common technique to generate a high intensity secondary beam using (super-/normal- conducting) solenoid with high power target.



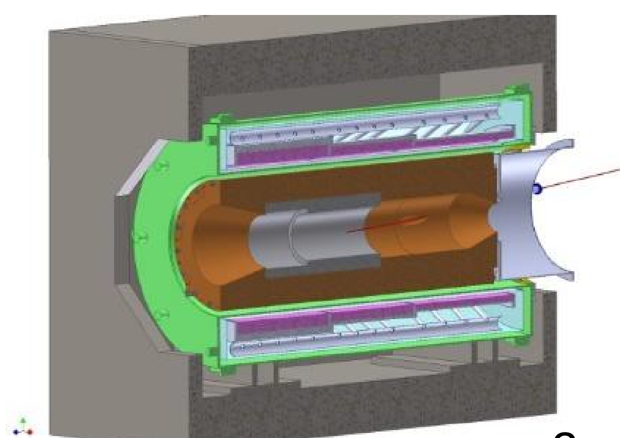

HiMB@PSI


MuSIC@RCNP


J-PARC MLF U-Line

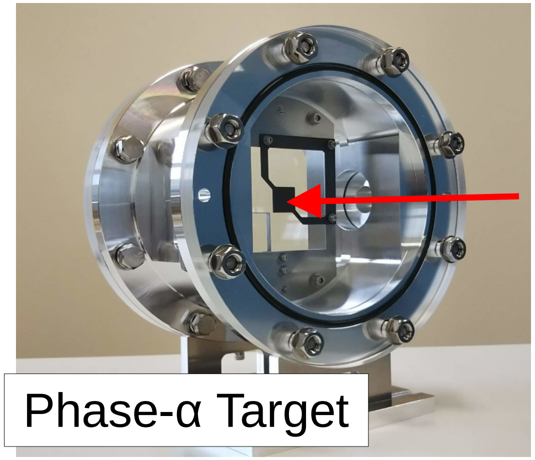


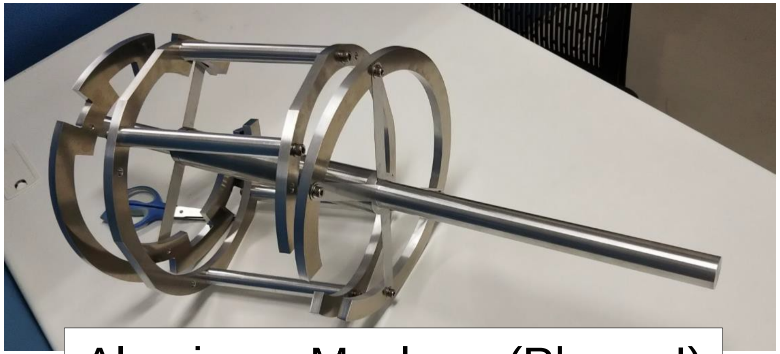
Muon Collider

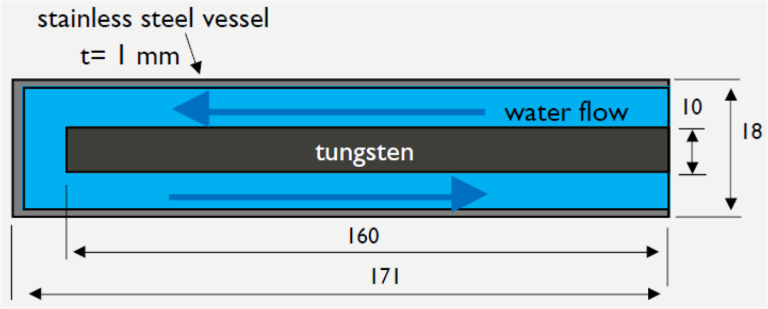

mu2e

Target

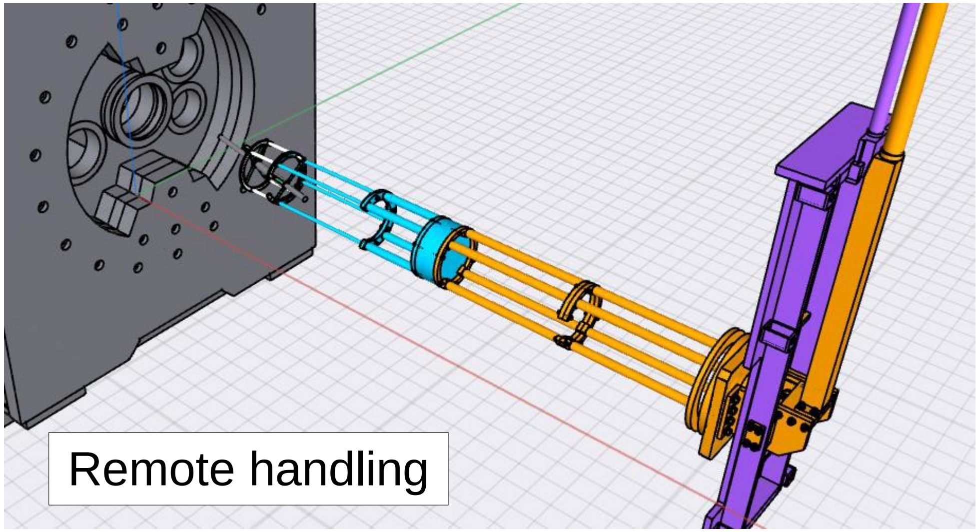
	Beam Power	Material	Thickness	Cooling
Phase-α	260W	C/C Composite	1.1mm	Thermal Radiation
Phase-I	3.2kW	Graphite	700mm	Thermal Radiation
Phase-II	56kW	Tungsten	160mm	Water


Phase-α Target


Aluminum Mock-up (Phase-I)

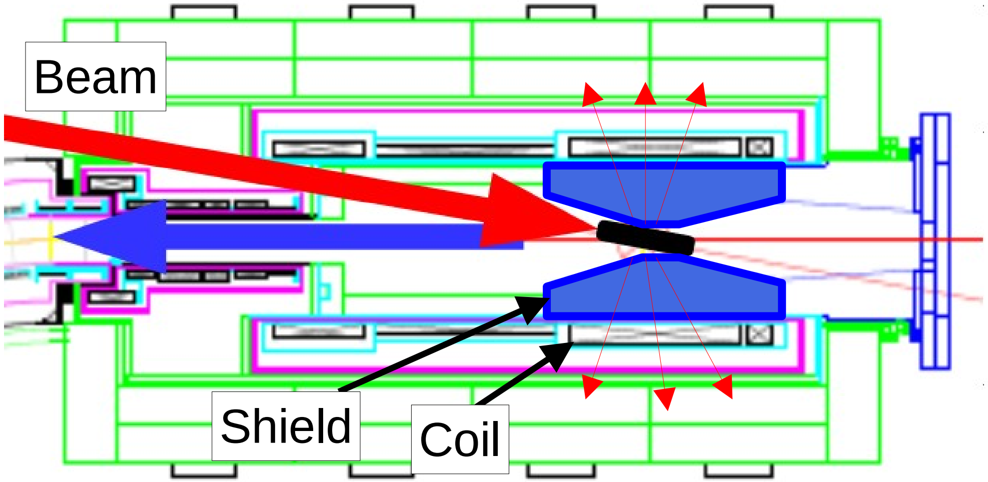


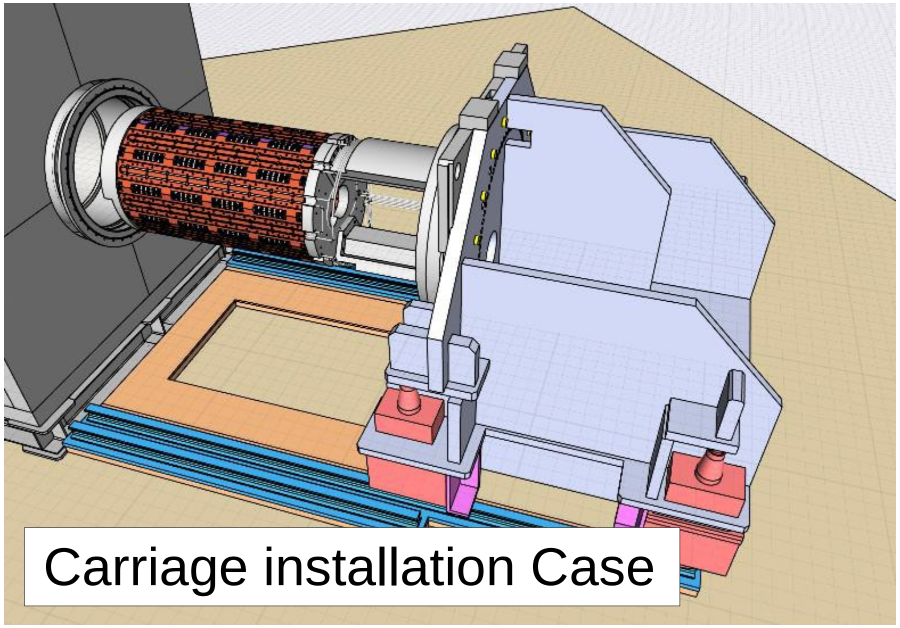
Tungsten (Phase-II)


Remote handling

Makimura-san will present details on
11/8(Wed) 11:00 (#4-2).

Inner Radiation Shield for Capture Solenoid





Beam interaction with a thick target will generate intense radiation which attack superconducting coil.

- Cryogenic quenching
- Degradation of coils

➔ Shield is needed.

Shield material

- Copper, SUS (~25t) @ Phase-I
- Tungsten (~40t) @ Phase-II

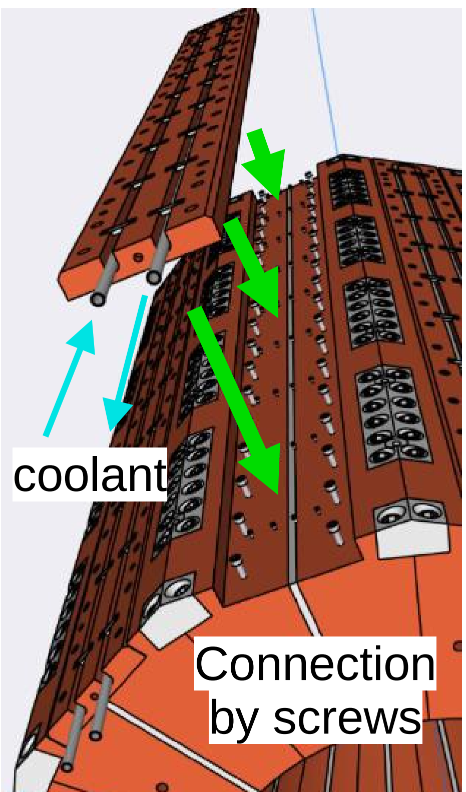
Side-Sliding Installation is needed.
We are considering two ways.

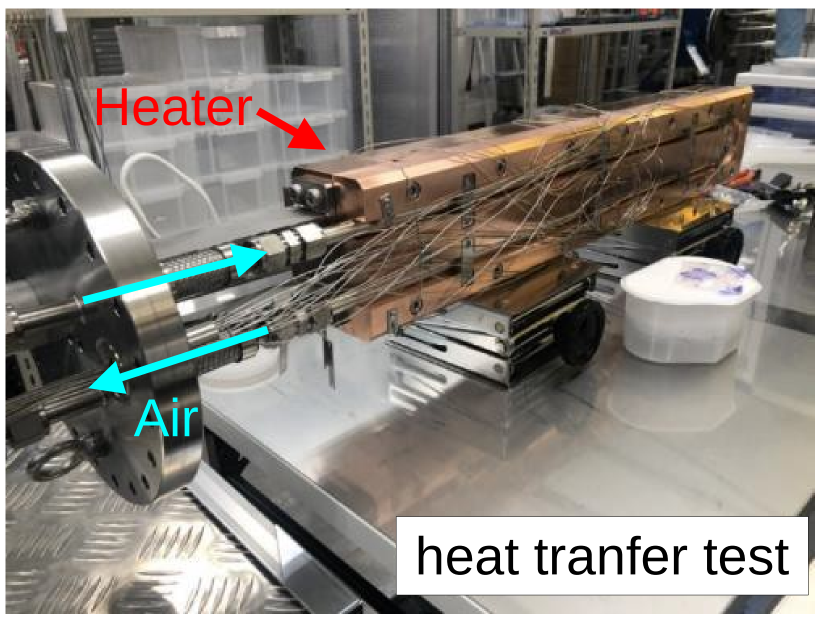
- Carriage Installation
  - ◊ Stable on the floor
  - ◊ Huge carriage is needed
- Crane Installation
  - ◊ Simple structure
  - ◊ Flexibility

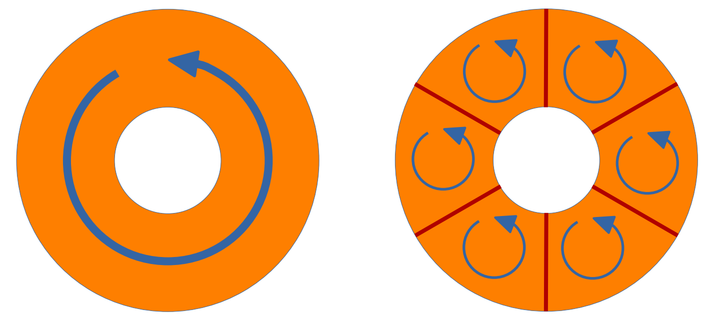
Inner Radiation Shield for Capture Solenoid

Manufacturing with small pieces

- Manufacturing with single large piece is too expensive.
- Hop Isostatic Pressing is applied for cooling pipe attachment
- Sufficient Heat conduction between cooling part and main body is needed.
- Large force by eddy current is induced by rapid magnetic field disappear by quench.

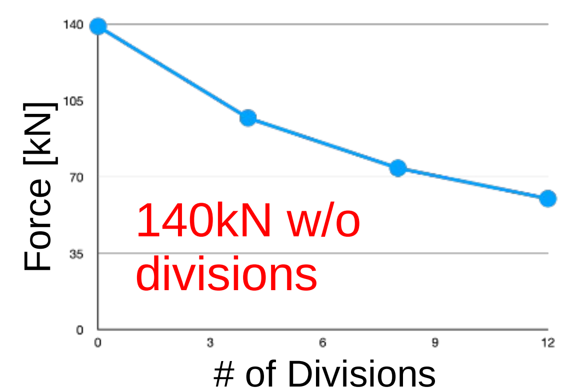






Large piece → Large force

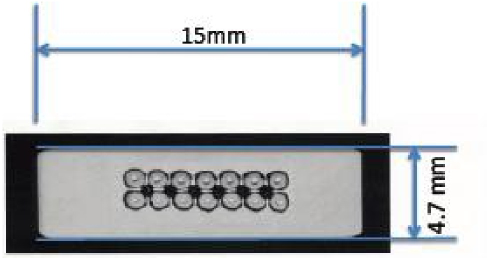
Small piece → Small force



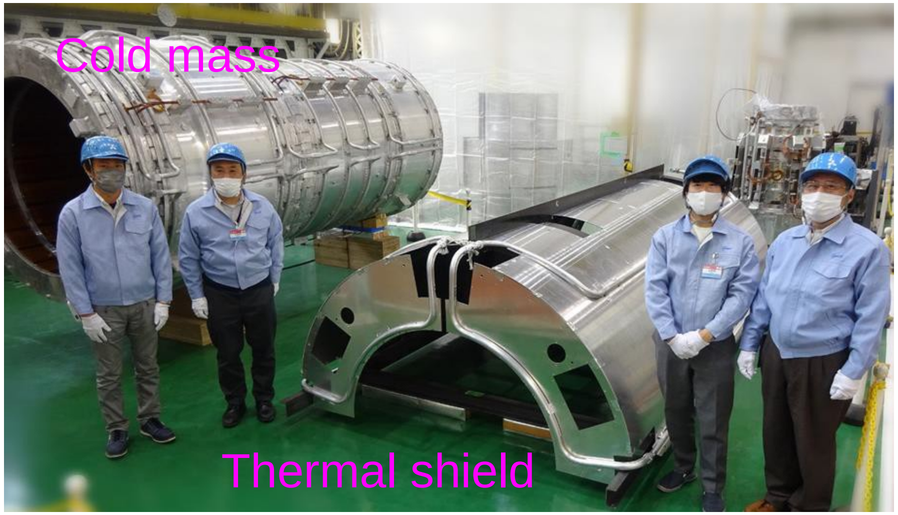
Pion Capture Solenoid

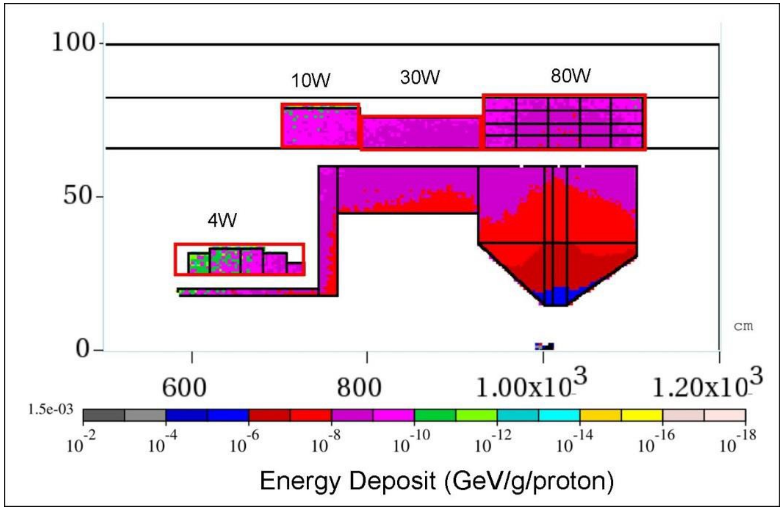
PCS should have sufficient radiation tolerance.

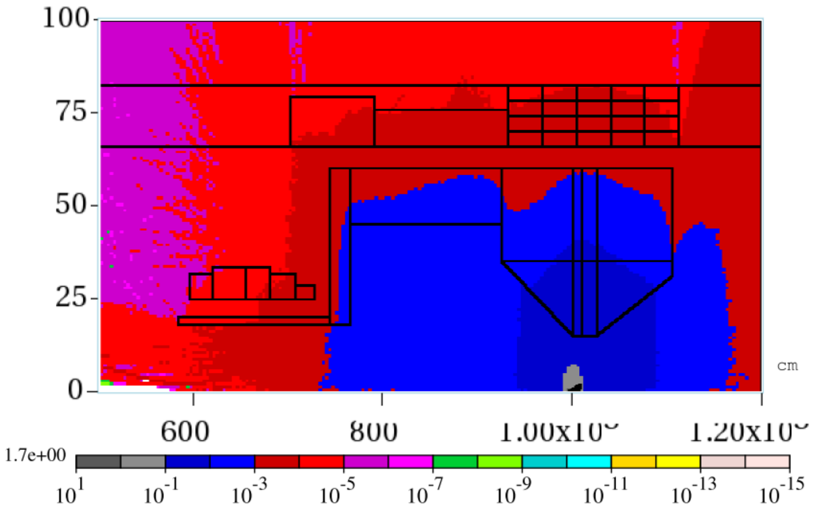
- Al-stabilized superconducting coil is adopted to reduce interaction of the scattered particle.
- Al-alloy shows full recovery of electrical resistivity after thermal cycle.
- NbTi shows no degradation up to 10^{22} n/m^2
- BT-based resin shows excellent radiation hardness >10MGy.



Al-stabilized SC



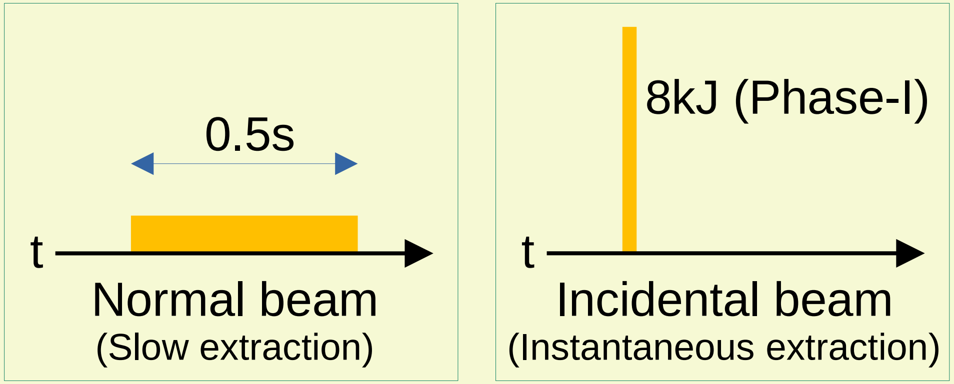




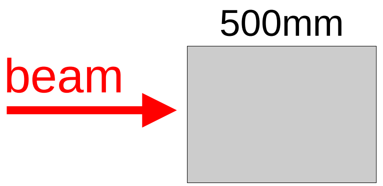
Nuclear Heating > 100W
Ionizing damage > 1MGy
Neutron fluence > 10^{21} n/m^2

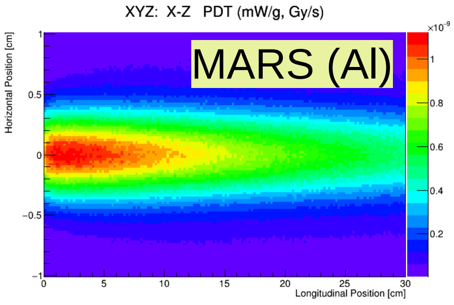
Incidental Beam Assumption

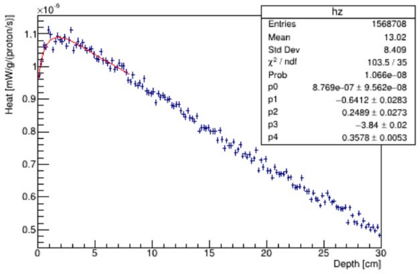
Usage of high power beam has risk of damaging experimental equipment when Incidental beam is delivered by accelerator failure. J-PARC Main Ring is designed to stop beam at least within one-shot beam injection.



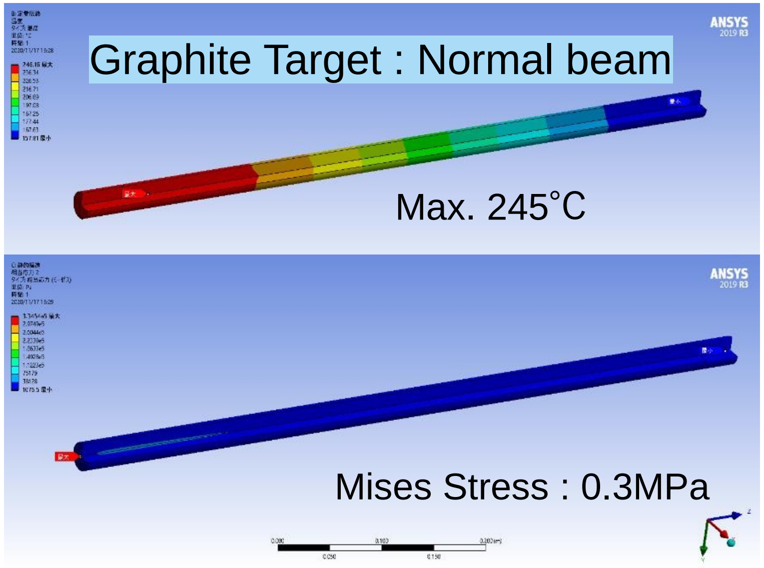
Failure of beam extraction magnet causes instantaneous beam injection.







Material	Temp. Rise [K]	Thermal Stress [MPa]
Al	7.2	12
Brass	24.8	49
Copper	23.3	51
Iron	19.8	35
Lead	78.1	37
SUS316	18.2	56
Tungsten	91.1	135
Ti-6Al-4V	12.5	12



Max. Heat density ~ 10J/g.

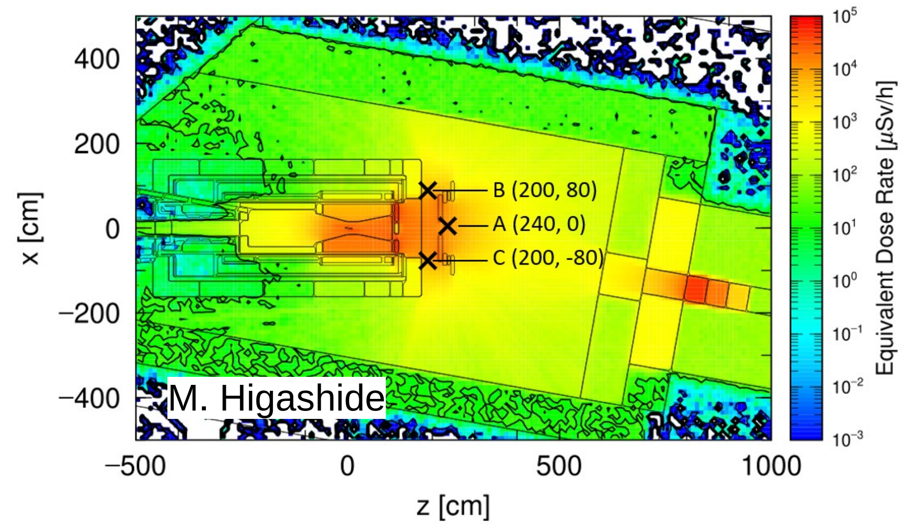
Temperature rise in adiabatic condition ~ 9.1K.

Upgrade to Phase-II

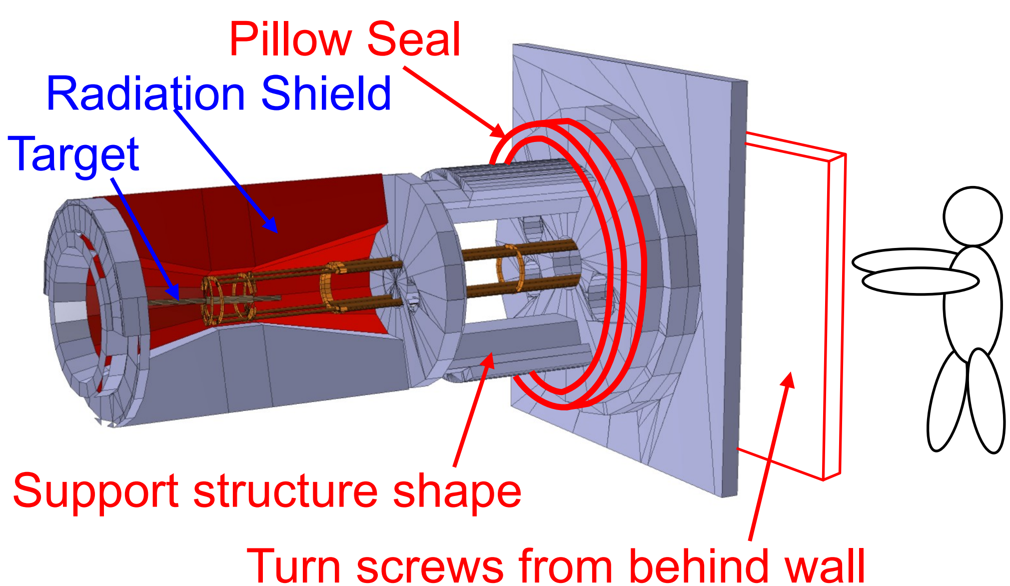
Upgrade is needed to achieve the final goal.

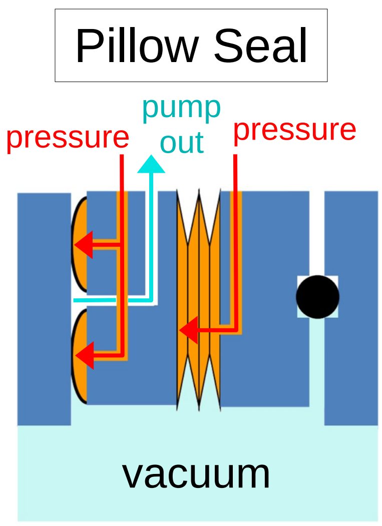
- Replace target
- Replace radiation shield in Capture Solenoid
- Upgrade beam dump

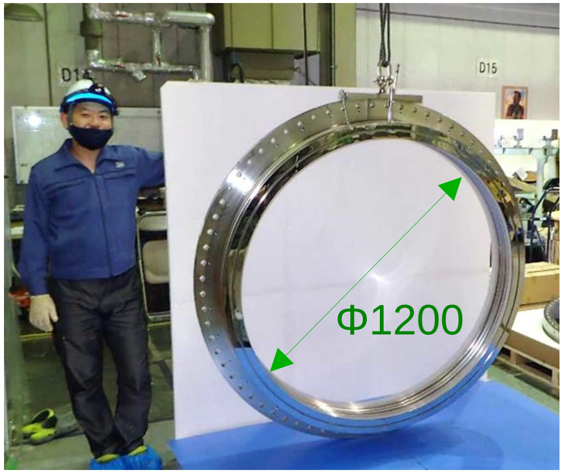
Work in high residual radiation circumstance will be needed.



After 180-days cooling		
A [μSv/h]	B [μSv/h]	C [μSv/h]
1.27×10^4	9.59×10^3	8.15×10^3

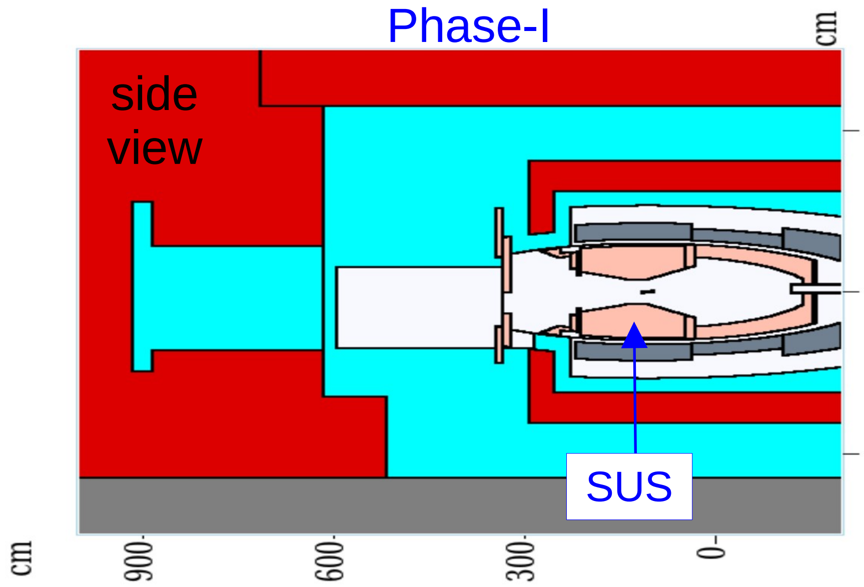


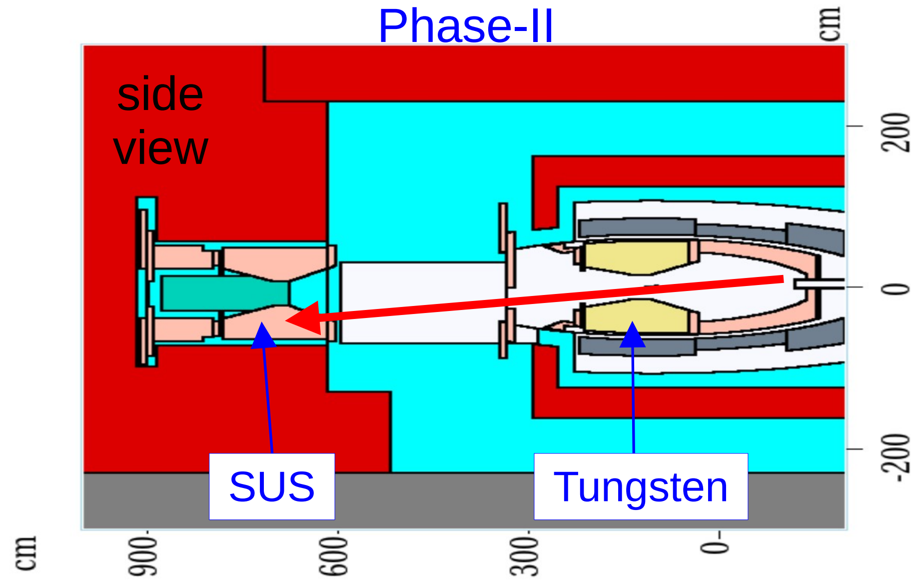




Reuse of Radiation Shield as Beam Dump

Reduce activated waste and enhance the beam dump performance



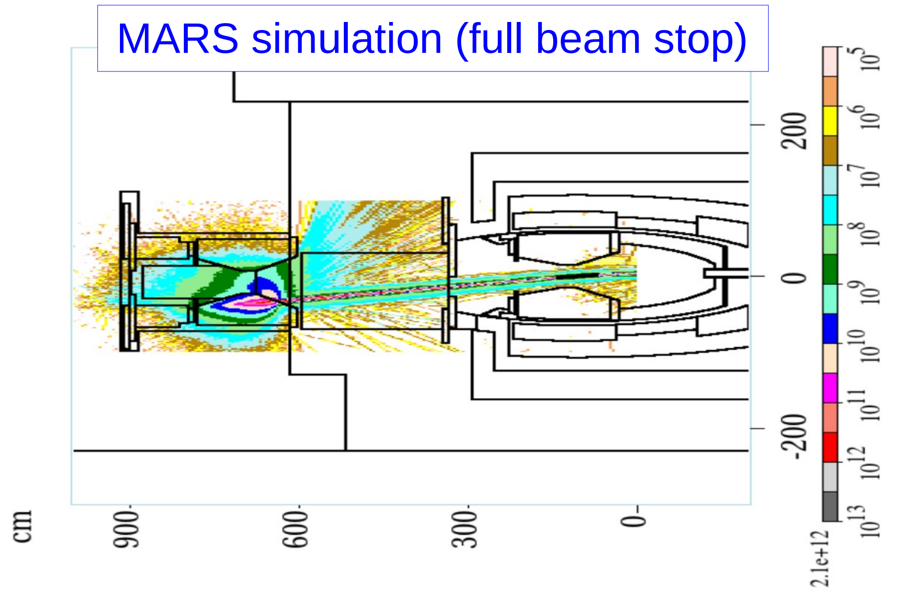


One of the issues in the facility design is the storage of the activated waste.

Phase-I : Low beam intensity
  Beam dump with iron blocks can stop the beam.

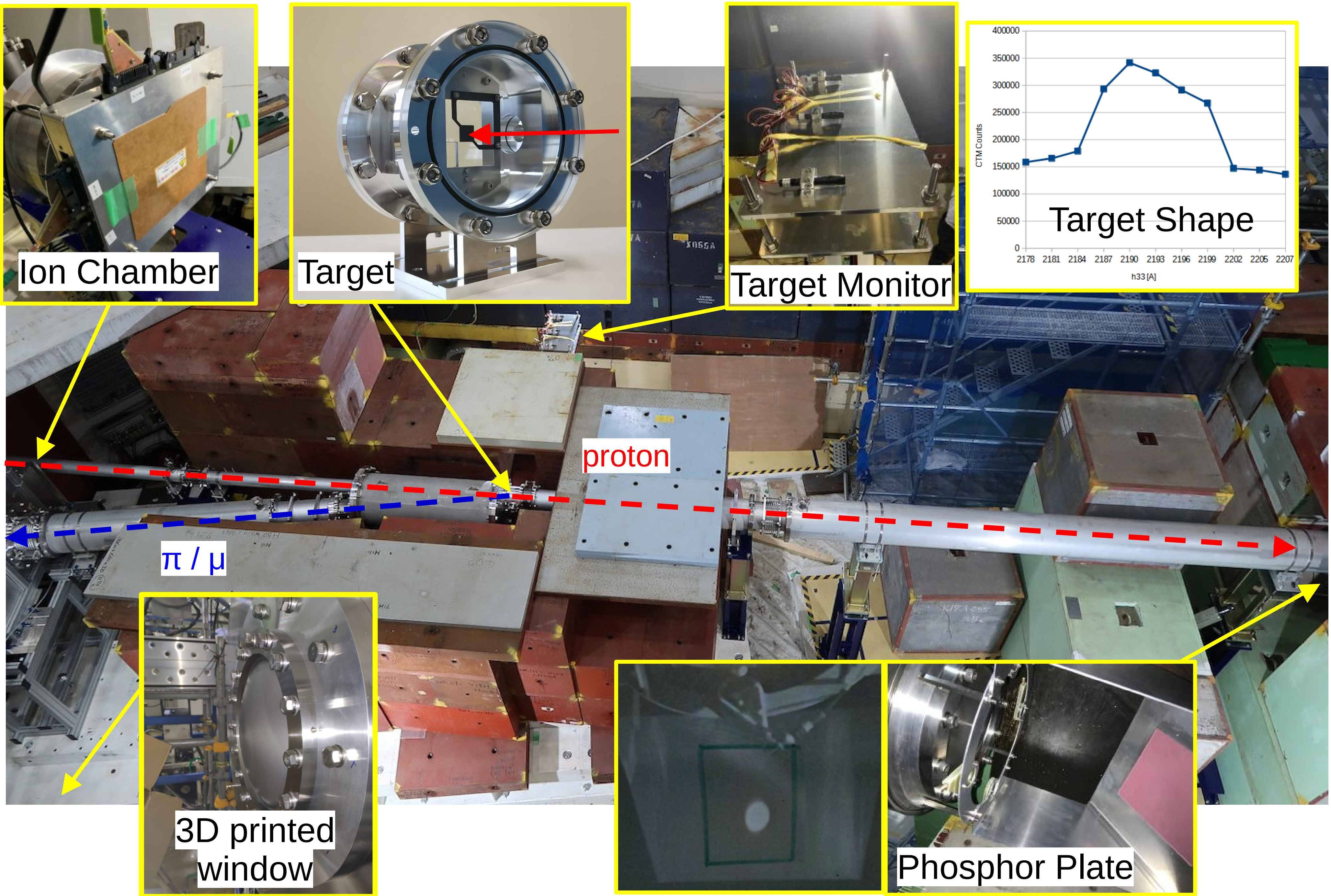
Phase-II : High beam intensity
  Replace radiation shield in the magnet.
  Locate the old shield at the beam dump core.

MARS simulation shows the reused shield looks well stop the beam.



Proton Beam Commissioning

Proton Beam Commissioning



Summary

The Construction of the COMET experiment is ongoing at J-PARC. The experiment utilizes high intensity proton beam to search for the rare event of the μ-e conversion.

One must consider various situation related to the high power beam use to design the experimental facility.

* Realization of the pion capture system with target in the superconducting solenoid
* Sufficient preparation for an Incidental beam injection
* Evaluate residual radiation and method to upgrade the experiment

The first beam commissioning was performed in the last February. Construction towards physics measurements is underway.