COMET-Mu2e Collaboration

Feb. 19, 2024

KEK IPNS
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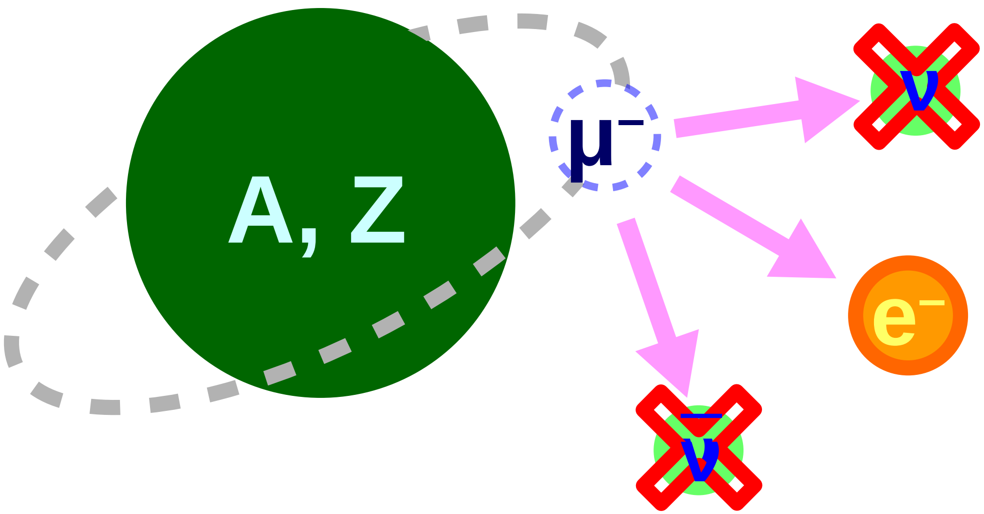
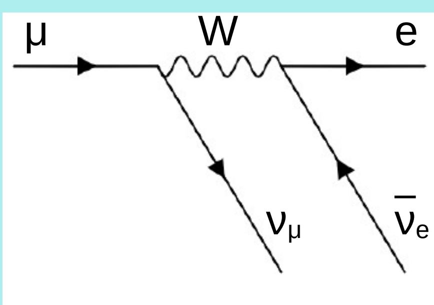
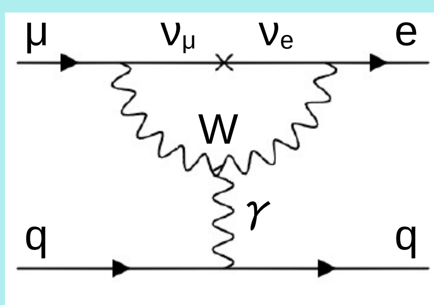
The μ-e Conversion



- Conversion of a muon to an electron is "Charged Lepton Flavor Violation" process and strongly prohibited in the Standard Model.
- Its discovery is an evidence of the new physics.

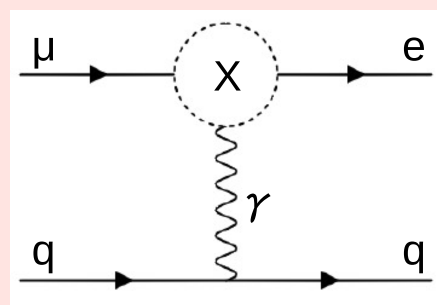
Standard Model

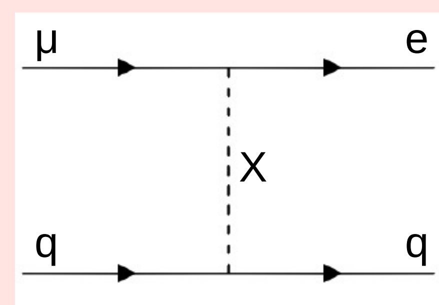




- ✓ Muon can decay to electron with neutrinos.
- ✓ μ-e conversion via neutrino oscillation is <O(10^{-54}).

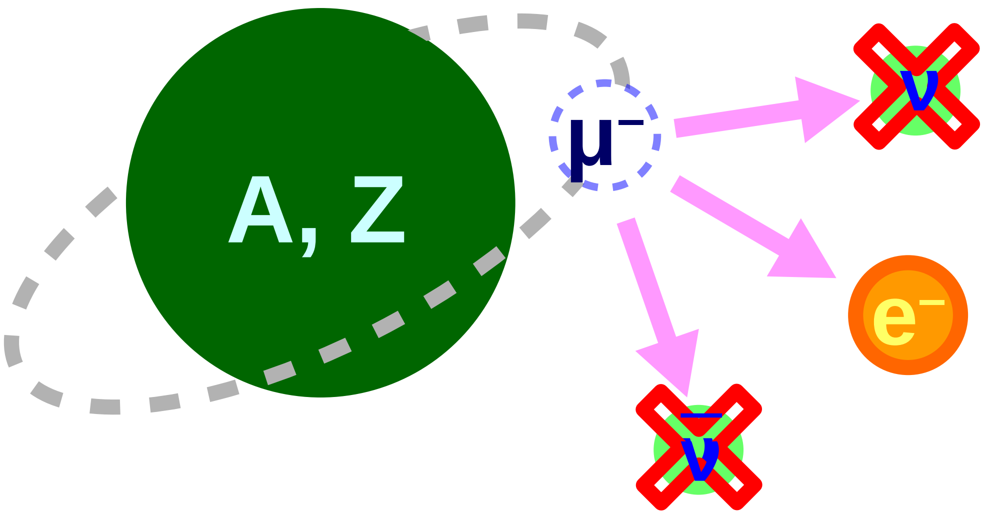
New Physics



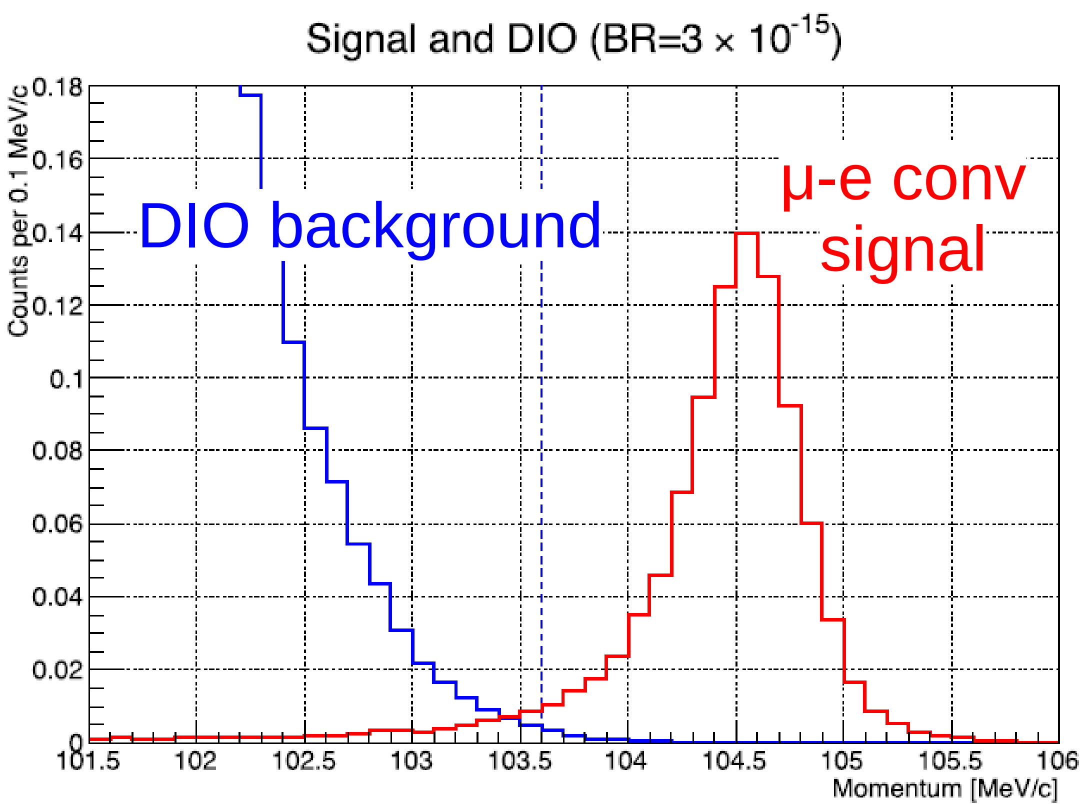


- ✓ Sensitivity for the new physics scale is >1000TeV.
- ✓ μ-e conversion has sensitivity to both photonic and non-photonic interaction.

The μ-e Conversion

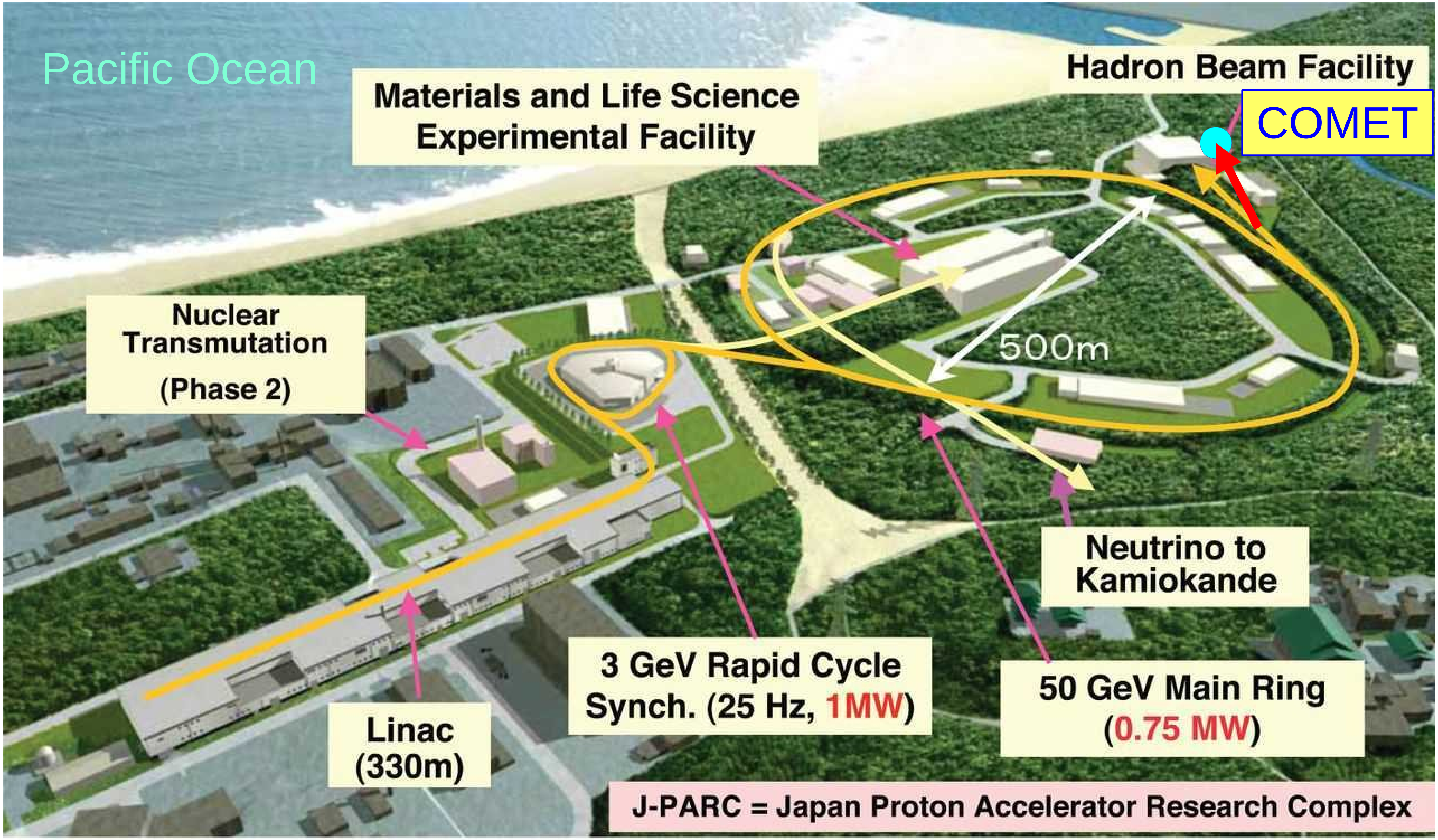


- Current world record of the μ-e conversion is 7×10^{-13} by SINDRUM-II experiment. The COMET experiment aim to reach $O(10^{-17})$ at Phase-II.

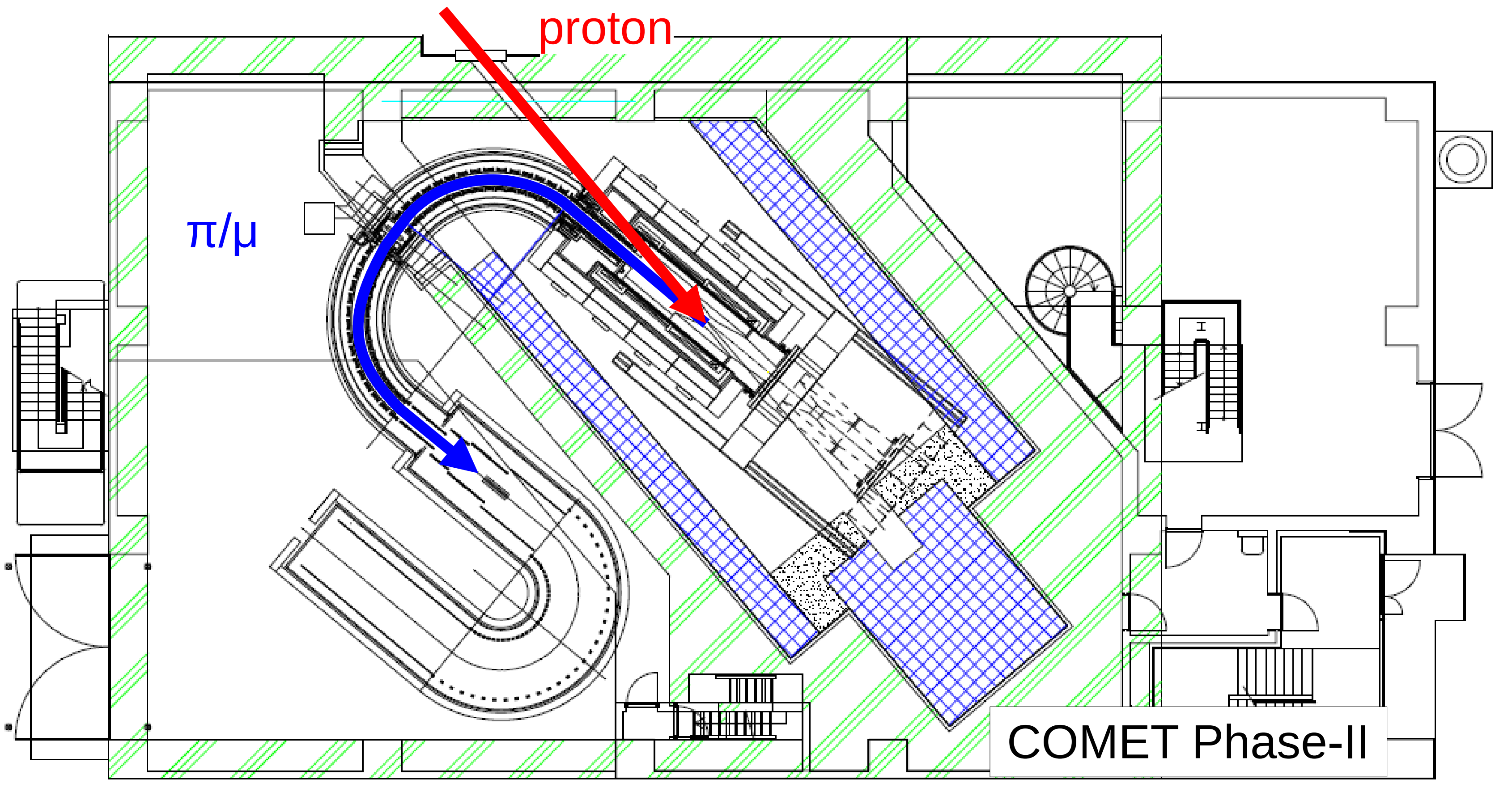


- The signal of μ-e conversion is single electron with energy of about muon mass.
- Electrons from muon decay-in-orbit (DIO) is a major background. It emits a high-energy electron due to recoil of a nucleus.

COMET in J-PARC



COMET in Hadron Facility

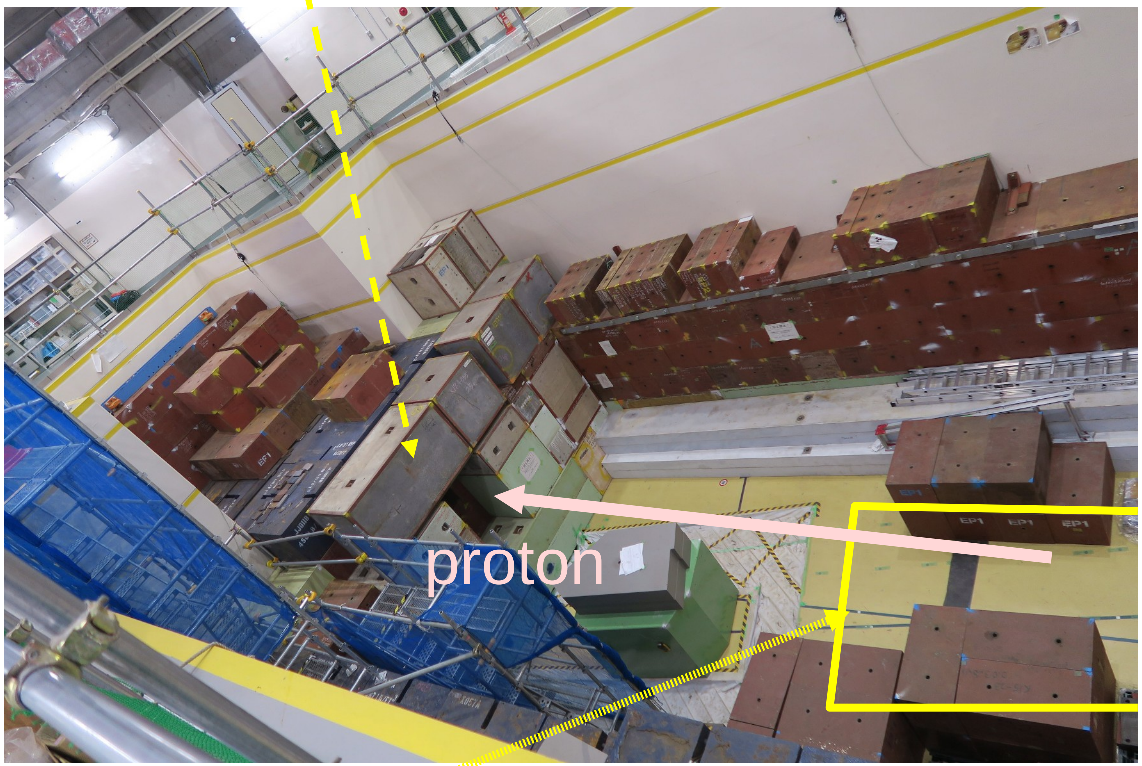


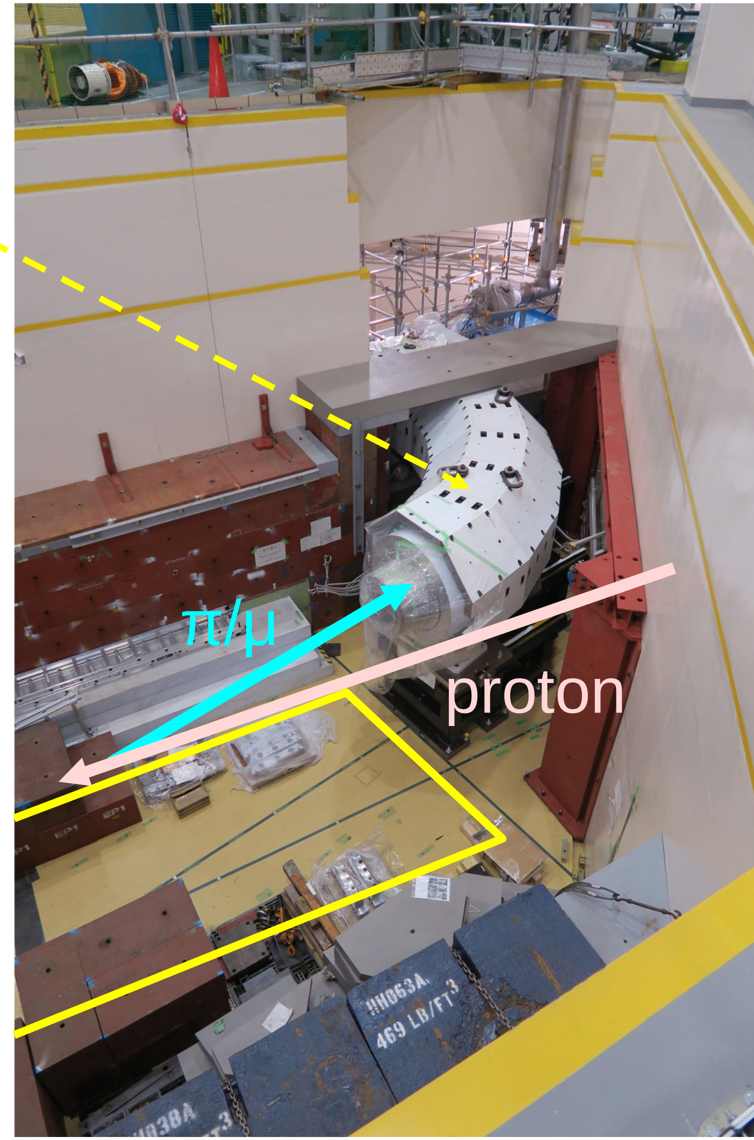
1. J-PARC 8GeV proton beam (56kW max) is injected to the pion production target to generate high-intensity muon beam.
2. Muon beam is stopped at Al target to form muonic atom.
3. Search for high-momentum electrons of the μ-e conversion signal.

COMET Beam Room (old)

Beam Dump

Transport Solenoid



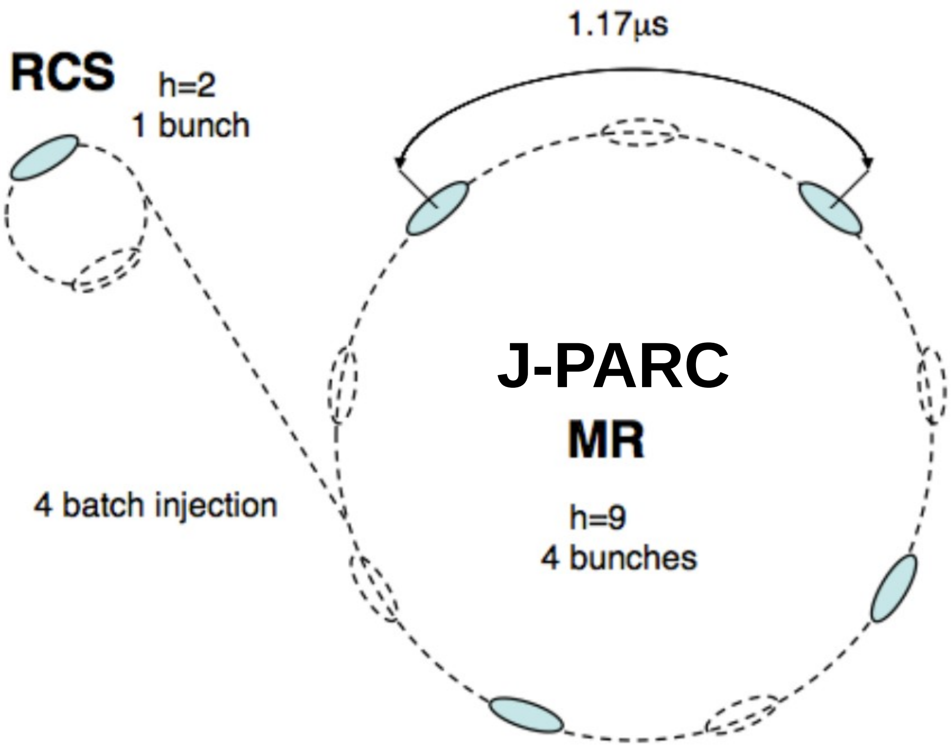


Bottom part of Iron Yoke for Capture Solenoid will be installed in this JFY.

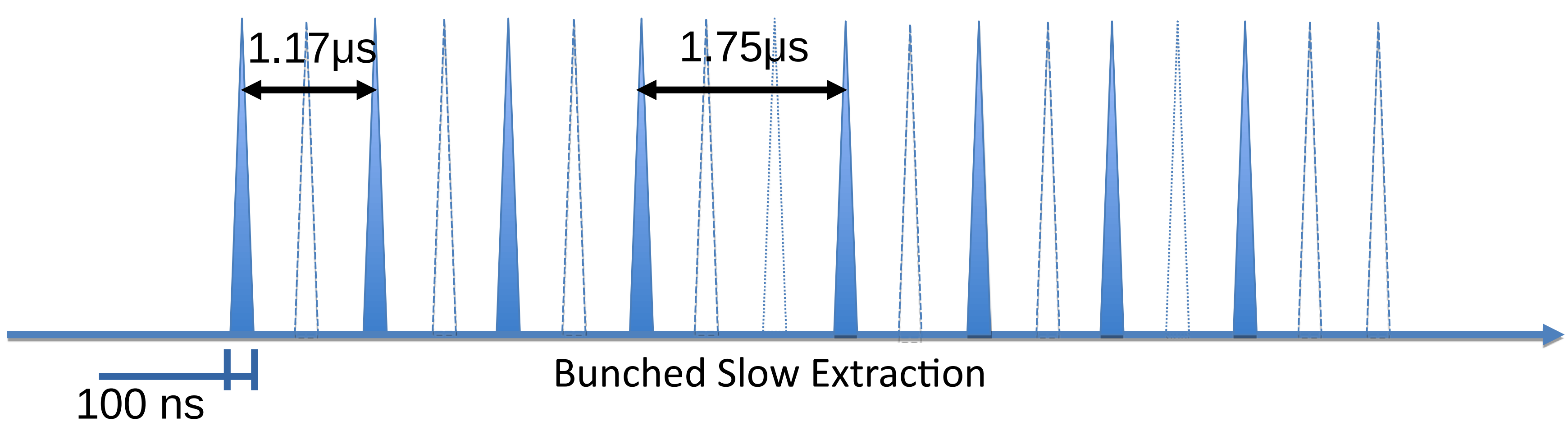
COMET Beam Room

We performed beam commissioning : Phase-alpha

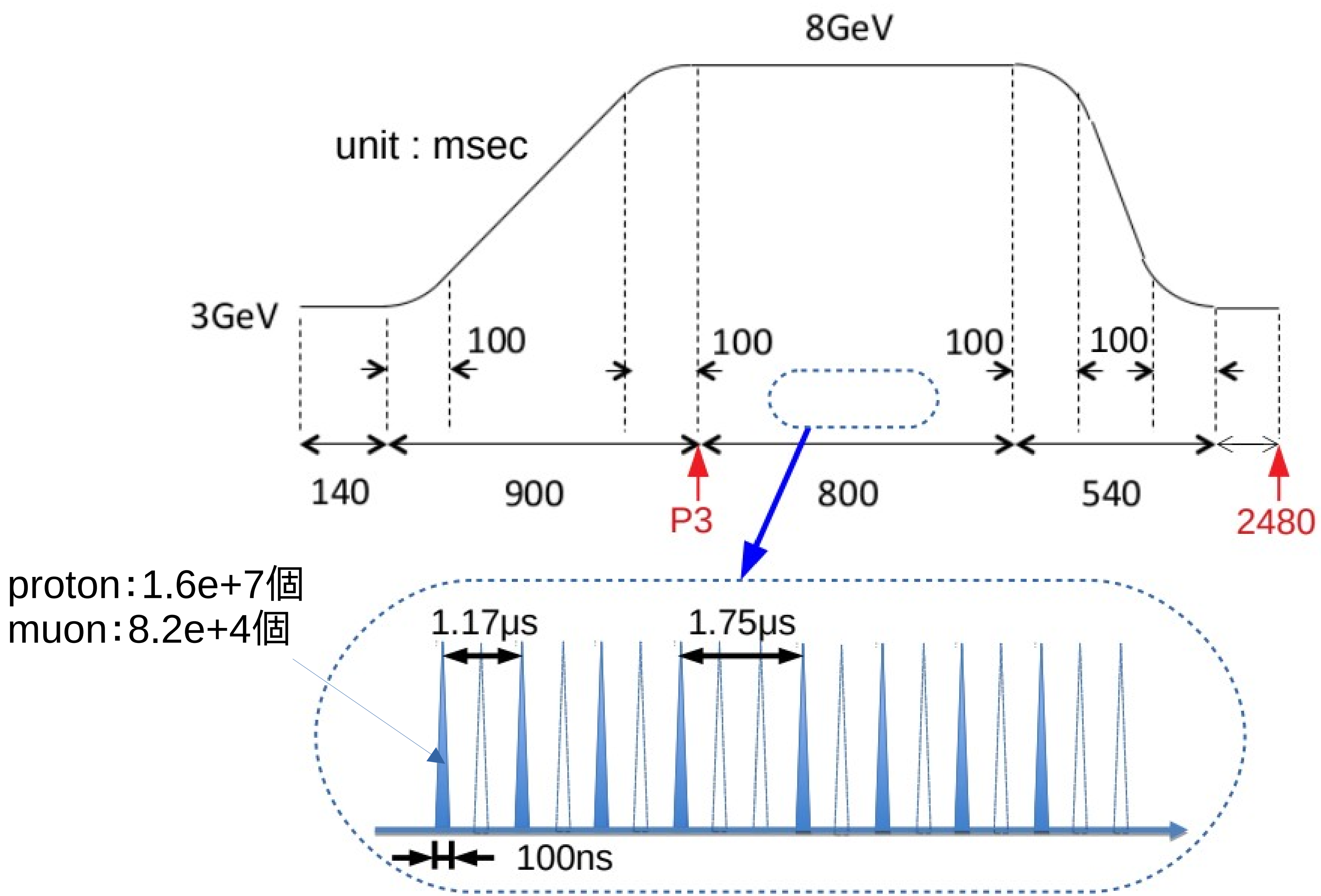
Proton Beam Time Structure



	Phase-1	Phase-2
Energy	8GeV	
Power	3.2 kW	56kW
shot cycle	2.48 sec	(2.48 sec)
proton/bunch proton/shot	1.6×10^{7} 6.2×10^{12}	(2.8×10^{8}) (1.1×10^{14})
muon/bunch	8.2×10^{4}	1.4×10^{6}

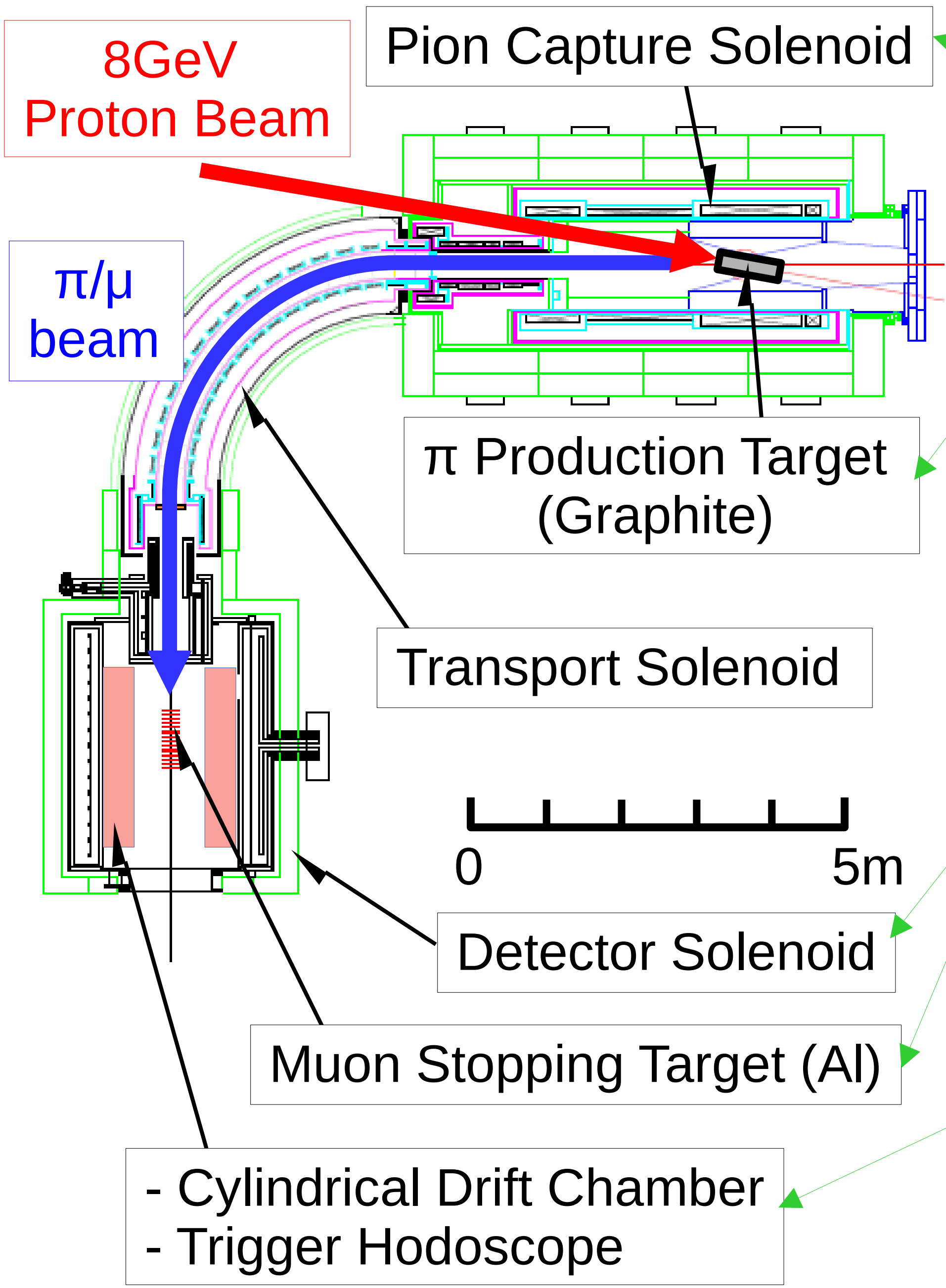


Proton Beam Time Structure



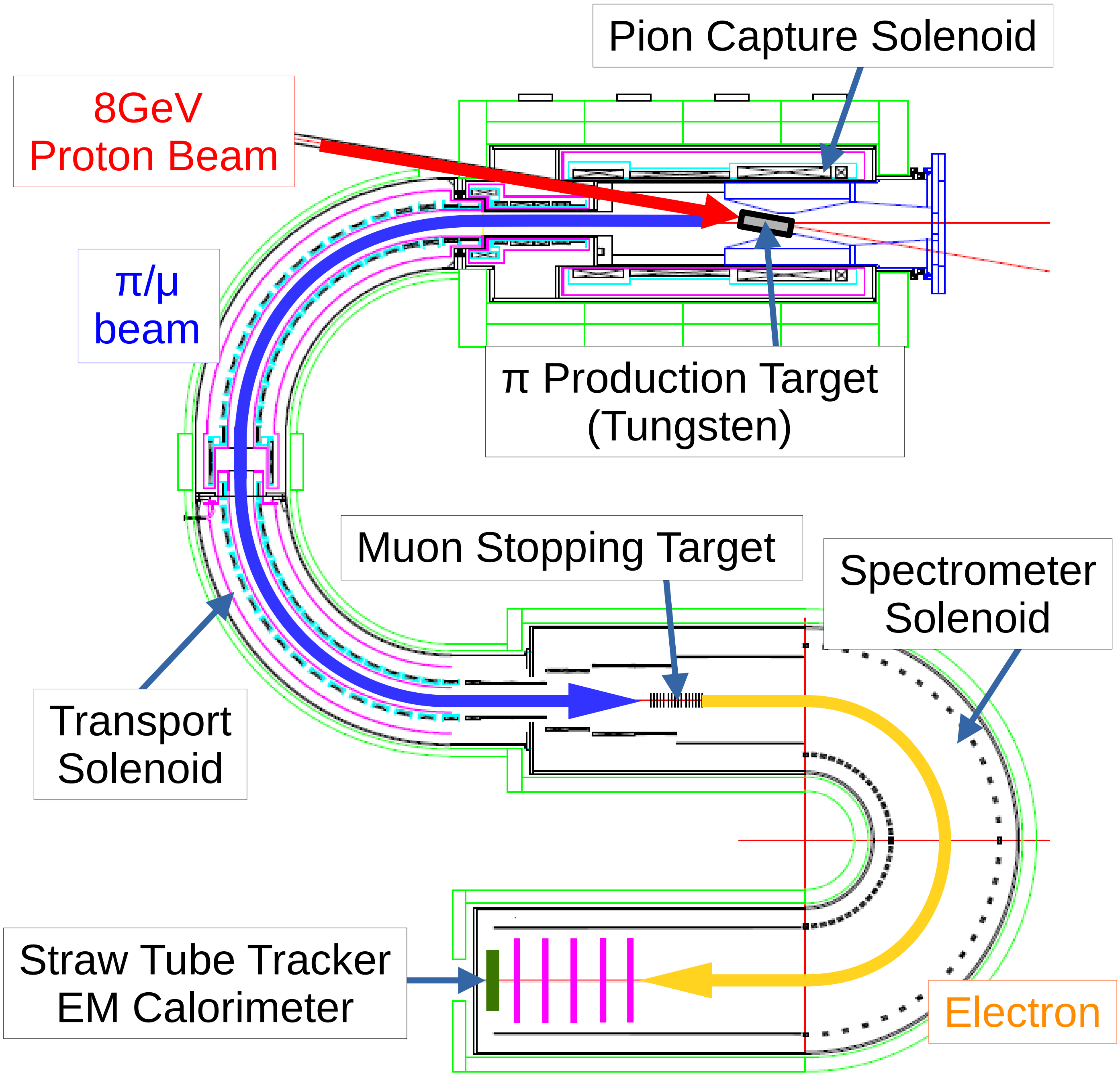
Beam extraction during 0.5 sec

COMET Phase-I



- Pion Capture Solenoid will be installed. It will enhance muon yield by an order of 1000.
- Pion production target will become 700mm long to increase muon yield.
- Expected sensitivity at COMET Phase-I is 7×10^{-15}.
- Detector Solenoid and aluminum muon stopping target will be installed to measure momentum of decay electrons.
- Main detector at Phase-I is Cylindrical Drift Chamber.

COMET Phase-II : Final Setup



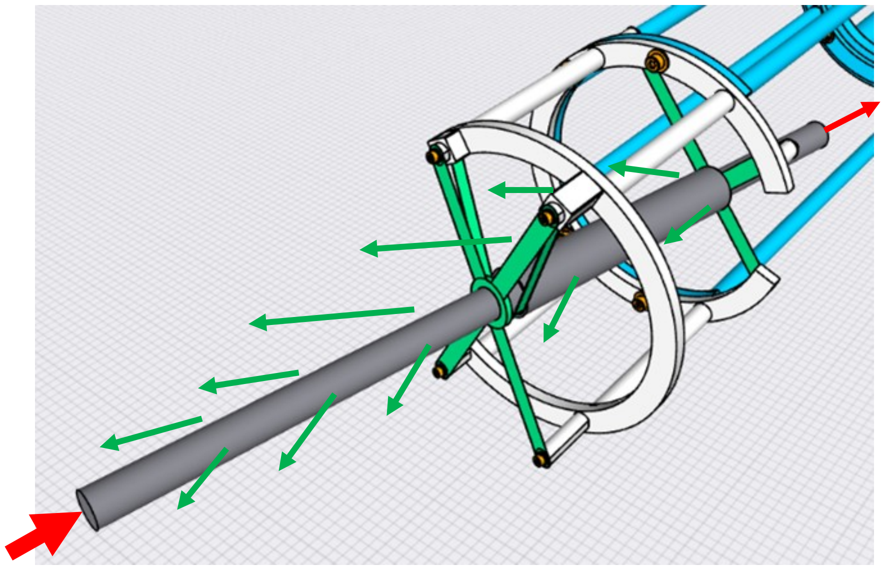
After Phase-I completed, significant upgrade is planned to achieve further sensitivity of a factor of 100.

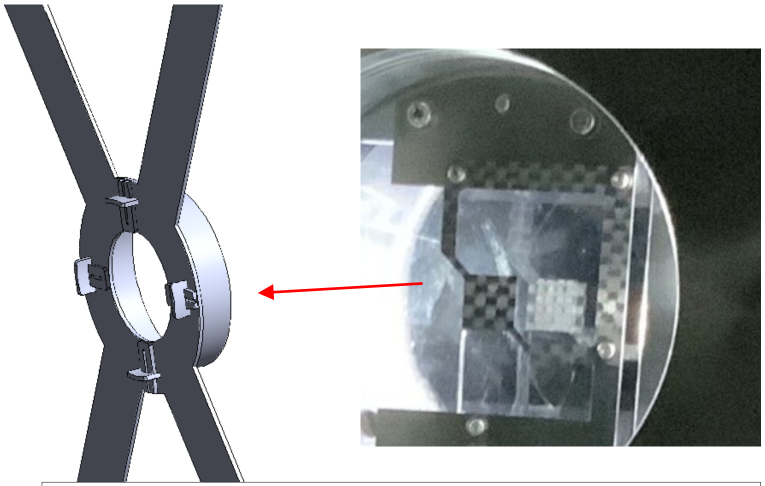
1. Proton beam intensity will become 20 times higher.
2. Production target will be replaced to tungsten.
3. Transport Solenoid will be extended twice longer.
4. Electron spectrometer will be installed.
5. Straw tube tracker with EM calorimeter will be installed.

Pion Production Target

	COMET Phase-1	COMET Phase-2
Proton beam	8 GeV, 3.2 kW	8 GeV, 56 kW
Beam sigma	H: 2.3 mm, V: 2.3 mm	(H: 2.3 mm, V: 2.3 mm)
Target material	graphite	Tungsten
Target thickness	700 mm	160 mm
Beam loss on target	110 W	7 kW
Time structure	0.5 s. extraction in 2.5 s.	-

Graphite Target @ Phase-1





Manufacturing of target support by C/C composite

The objective is to collect as many muons as possible.

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

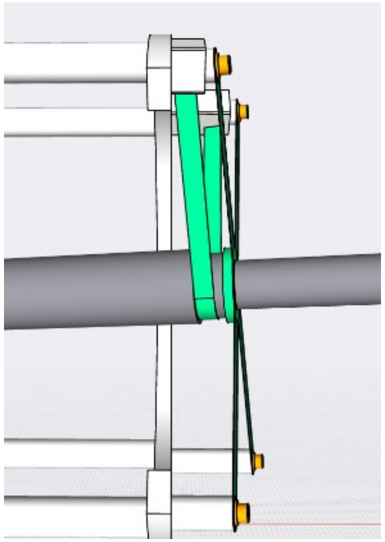
<u>Target support</u>

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

<u>Material & Structure</u>

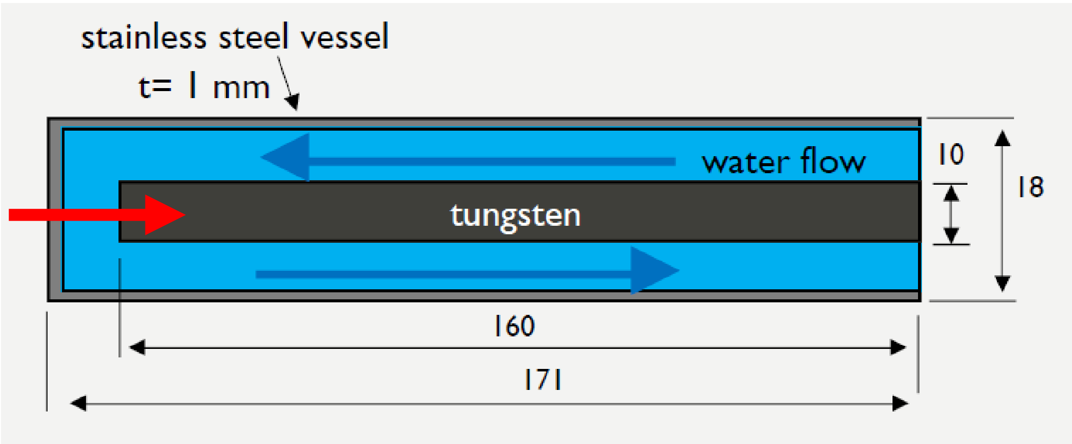
- Refractory material
- Not-bulk material
- Low-density is preferable

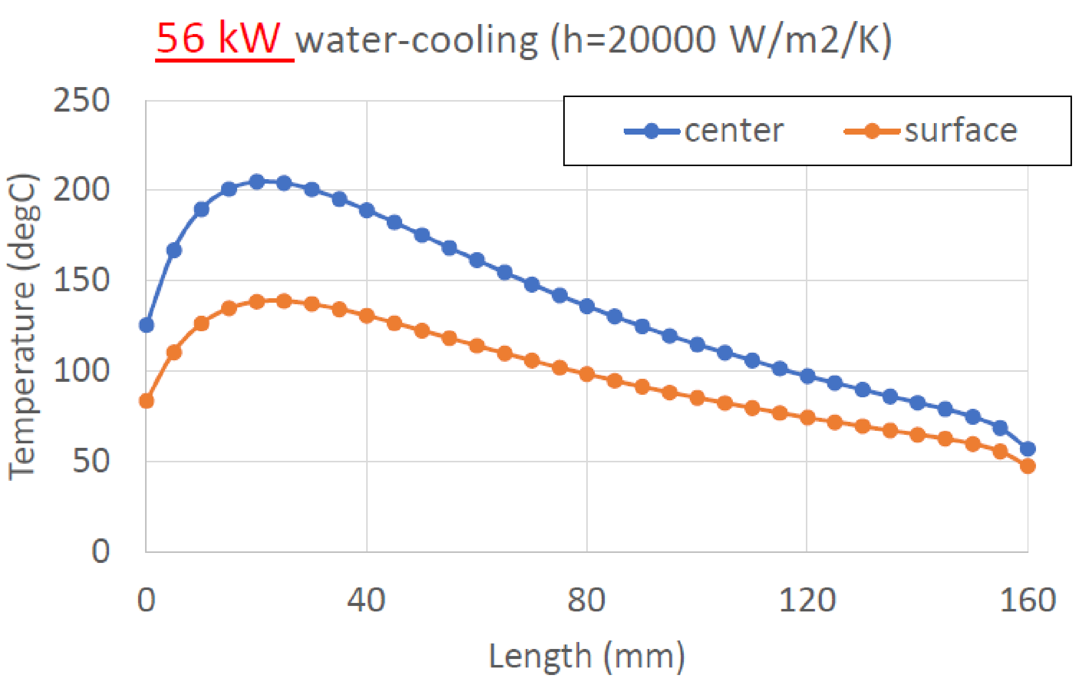
- C/C composite
- SS304, 64Ti, Inconel



Reinforcement of target support for the axial direction

Tungsten Target @ Phase-2





To yield more muons, upgrade of the target material from graphite to tungsten is needed.

Radiation cooling is not enough with tungsten target and 56kW beam power. Water cooling is needed.

Simple model shows realistic results. But further optimization is needed.

- Tungsten material itself
- Water flow
- Corrosion
- Target dimension
- Remote handling

Higher performance by New TUNGSTEN and Technology

1. Developments of TFGR tungsten to improve recrystallization embrittlement

   Maximum available temperature

   ITER grade tungsten: 1200 °C

   TFGR tungsten: 1700 °C

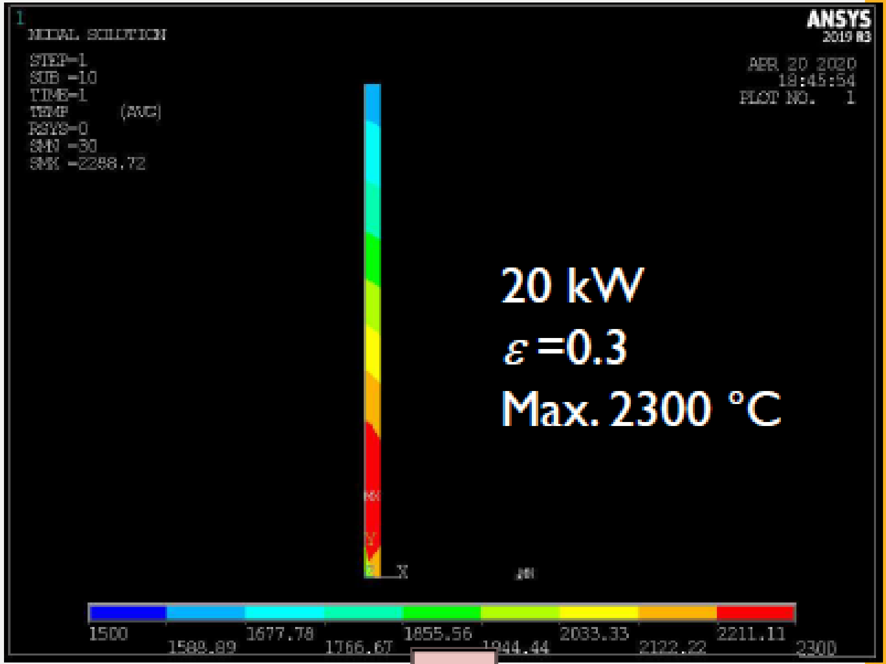
KEK-MTC collaboration, S. Makimura et al., Scientific Net, in press

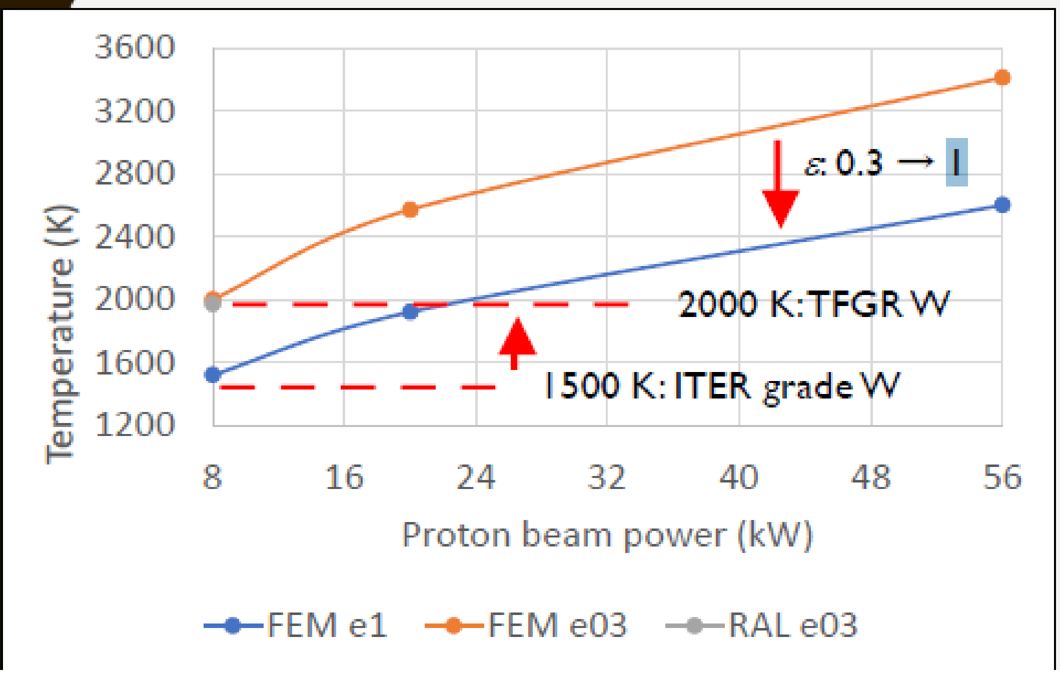
2. Increment of emissivity

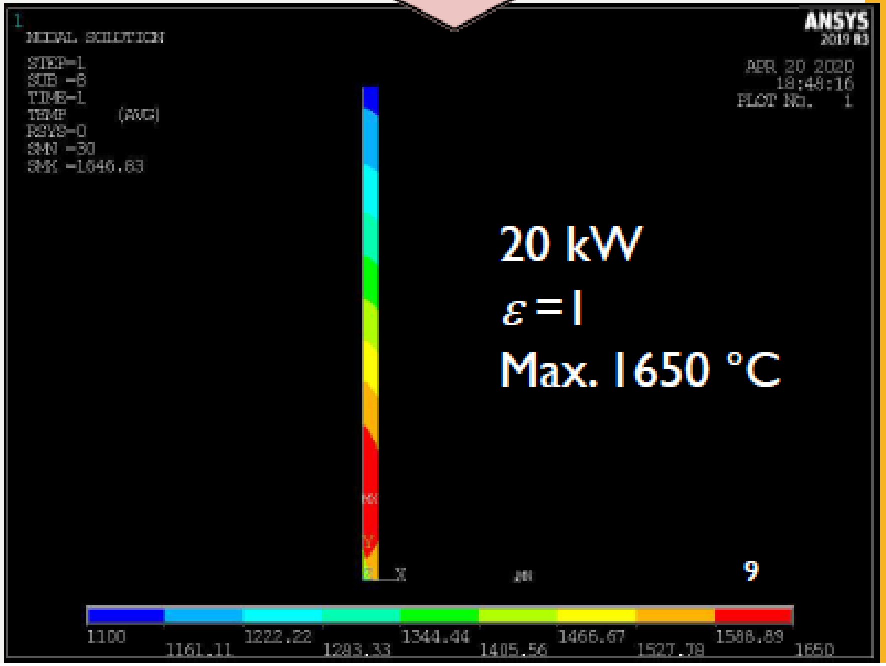
   Surface treatment: 0.3 → 1

   Collaboration with STFC/RAL is under discussion.

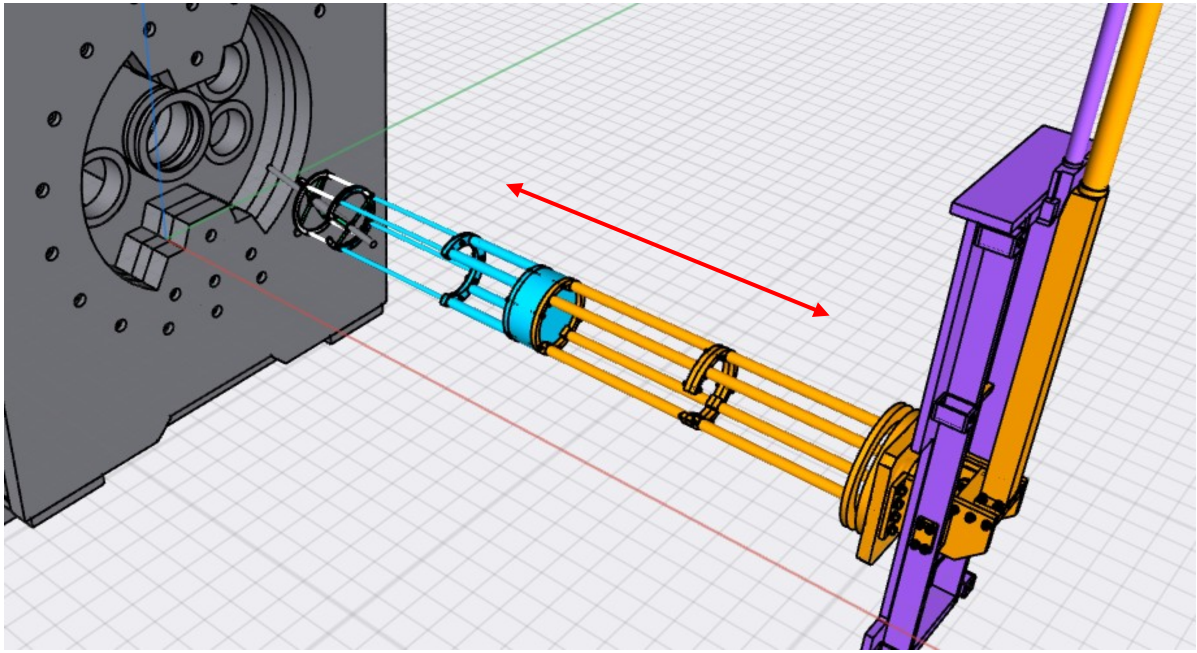
Aiming beam intensity: 20 kW



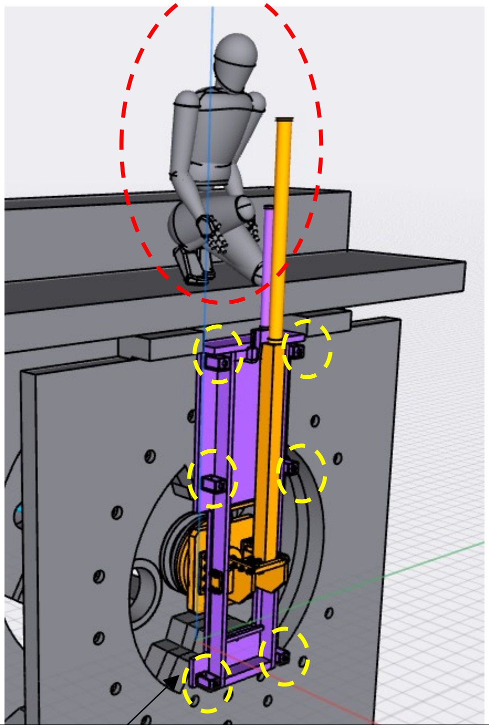




Target Assembly



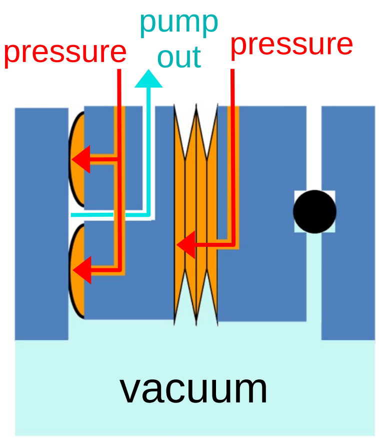
The target assembly is inserted into the solenoid shield by semi-remote-handling.

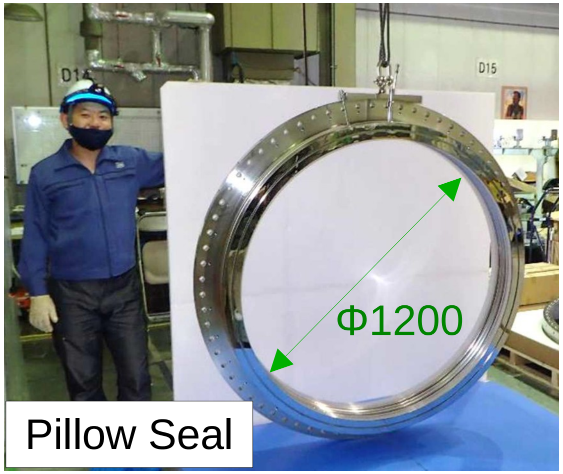


- Maintenance with local shielding
- 3000 kgf of load by the air-pressure of pillowseal must be considered.

We must consider

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





New US-JP Proposal

As a first step, we focus on the tungsten target development.

- COMET : Water Cooled Tungsten (56kW)
- Mu2e : Radiation Cooled Tungsten (8kW)

Study Items

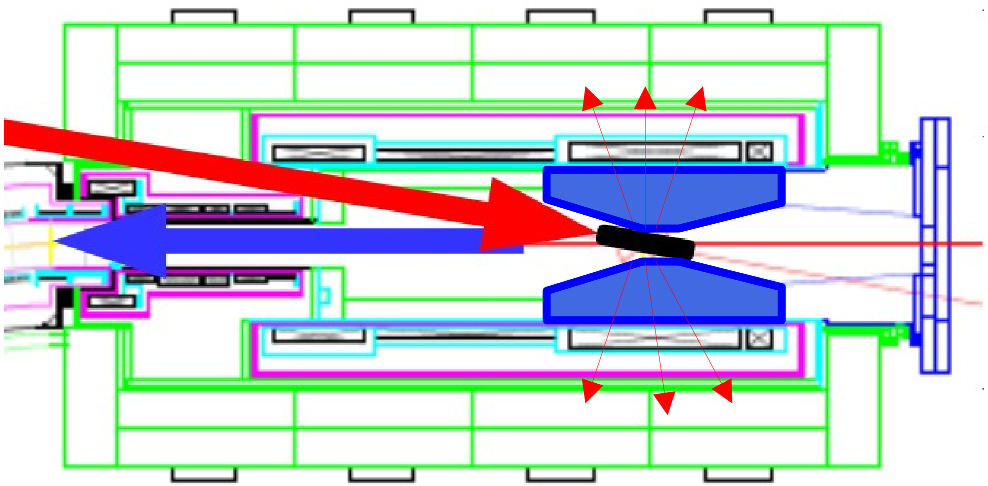
- Fatigue property
- Creep property
- Alternative W-alloy search
- Emissivity improvement
- Coating/Cladding technology against corrosion

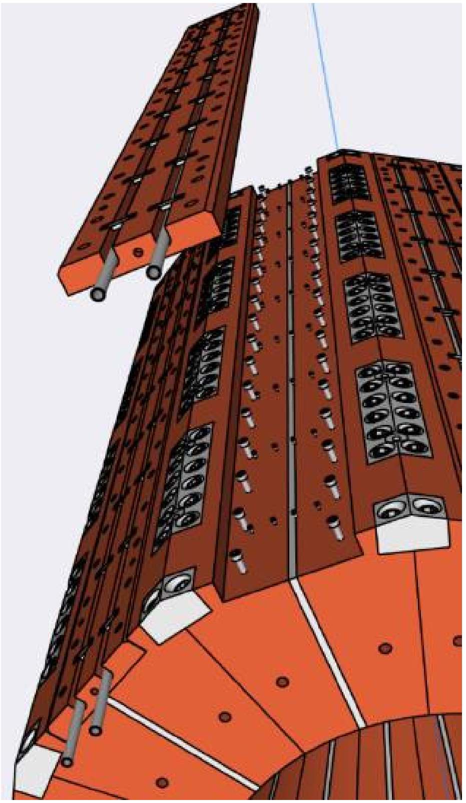
In the future, we would like to include other items.

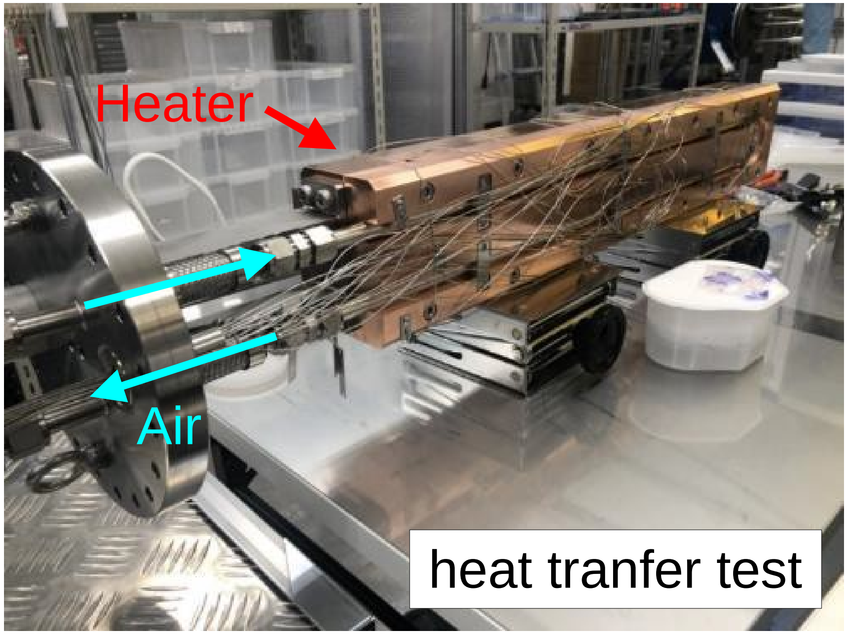
Radiation Shield in Capture Solenoid

Massive shield is needed between the target and the superconducting coil to prevent quench.

Yuske U will present the current situation.



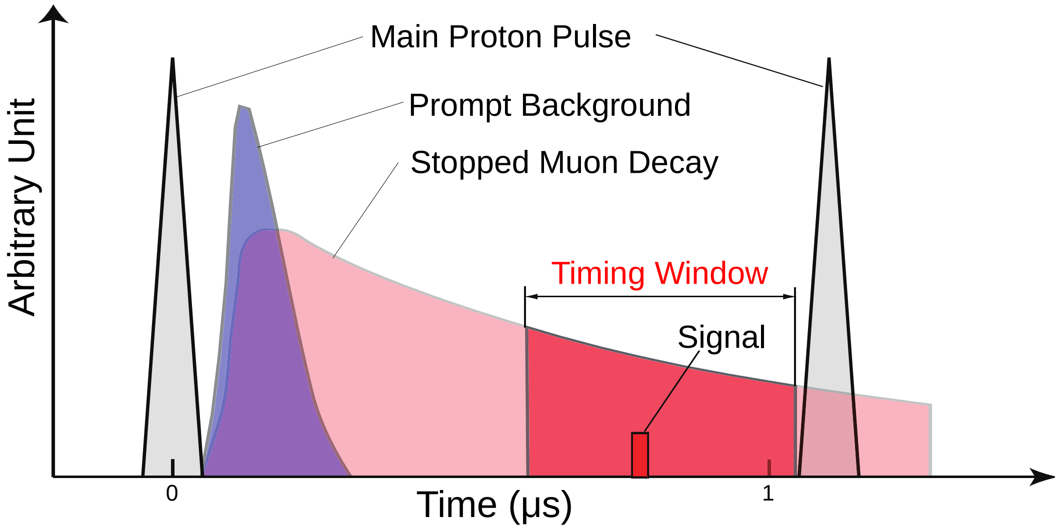




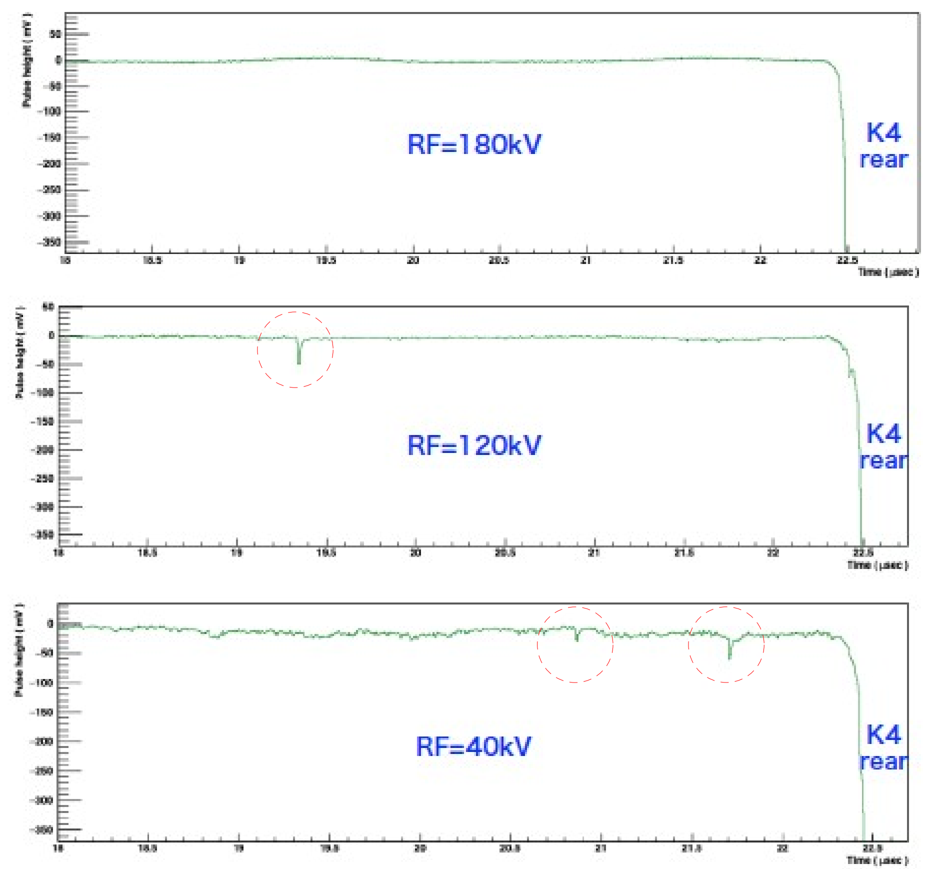
Copper / Stainless Steel will be used at Phase-I.

Further R&D is needed towards Phase-II where heavier material will be favored (tungsten, Pb).

Extinction Monitor



Measurement time window will be set ~700ns after proton pulse to avoid prompt background.
→ Remaining protons between bunches can generate background in the window.

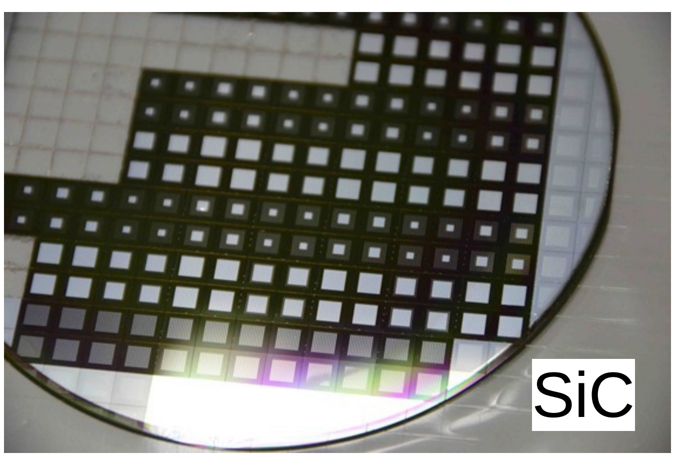


Extinction (=remaining proton between beam bunches) was measured at the MR Abort Line during the COMET Phase-alpha.

Increasing voltage of RF cavity will reduce the extinction to be sufficient level for the COMET experiment.

Beam Extinction Monitor

Protons remaining between bunches (Beam Extinction) can generate background in mu-e conversion measurements.
We are trying direct detection of the Extinction.
- The detector must detect single proton.
- The detector should have sufficient radiation tolerance.



Wide Band-gap Semiconductor Detector

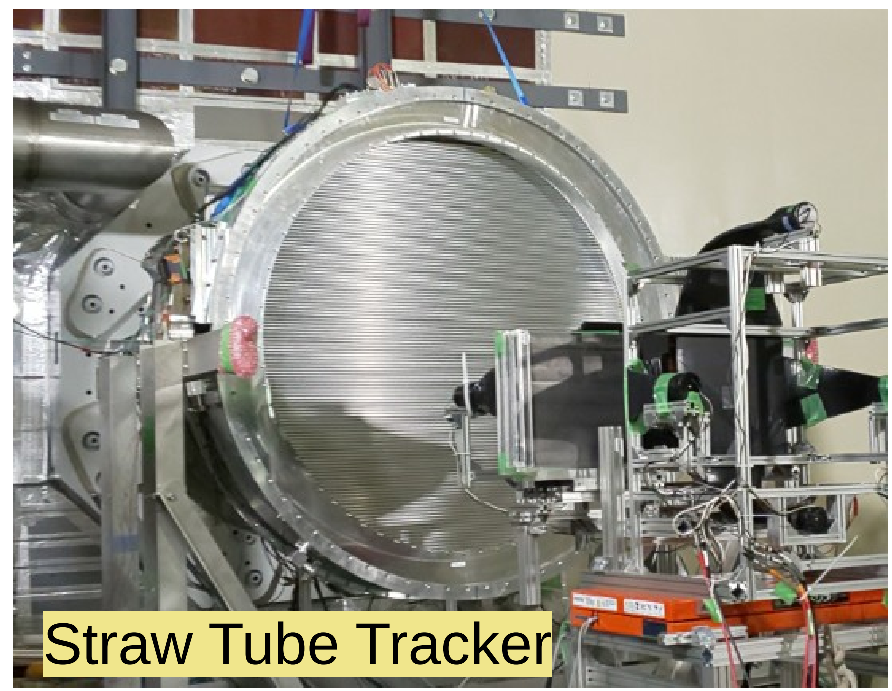
- **Diamond**
  - High radiation tolerance
  - Expensive
- **TiO_2**
  - New technology
  - Cheap
- **SiC**
  - Better radiation tolerance than Si
  - Cheap
  - We are developing muon monitor.

Other Items


Cold Mass of Pion Capture Solenoid

Cryogenic system must be upgrade towards Phase-2.


Cylindrical Drift Chamber


Straw Tube Tracker

Radiation Hardness Study

Experimental equipment must be designed / selected to satisfy requirements of radiation hardness.
- Non-ionizing damage > 1e+12 n/cm2
- Ionizing damage : 1 kGy ~ 1 MGy

- Target, Radiation Shield

- Superconducting Coil
  - Degradation causes quench

- Beam Monitor
  - High intensity charged particles hit Sensor

- Readout Electronics
  - Frontend electronics must be installed near the sensors
  - Various kinds of ICs were tested with neutron/gamma beam.

Summary

- Construction of the COMET experiment is ongoing in the J-PARC Hadron Facility. COMET aims to search for the μ-e conversion that is an evidence of the new physics.

- We proposed new US-JP collaboration (Mu2e-COMET). The first step is the tungsten target development.

- Further development for the Phase-I and -II are necessary and ongoing.

  - Target, Radiation Shield, Beam Extinction Monitor