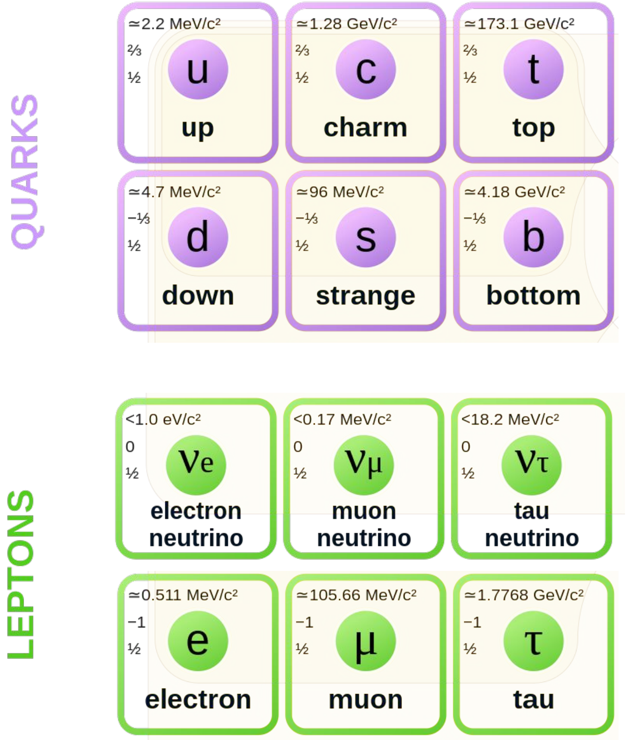
Search for cLFV with COMET experiment

Brief status report

The 18th International Workshop on Tau Lepton Physics (TAU2025)
20 - 24 October 2025, Marseille (France)

Thomas Clouvel, LPCA - UCA
23.10.2025, on behalf of COMET collaboration

Standard model and flavor violation



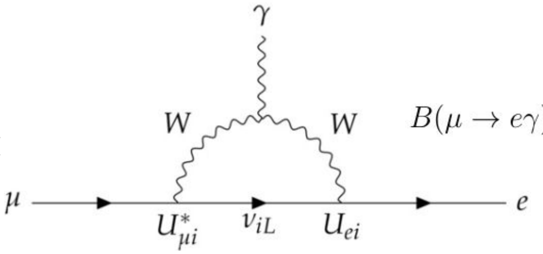
Quark mixing (CKM) -> established ✅

Neutrino oscillation -> established ✅

cLFV -> not observed yet ❌

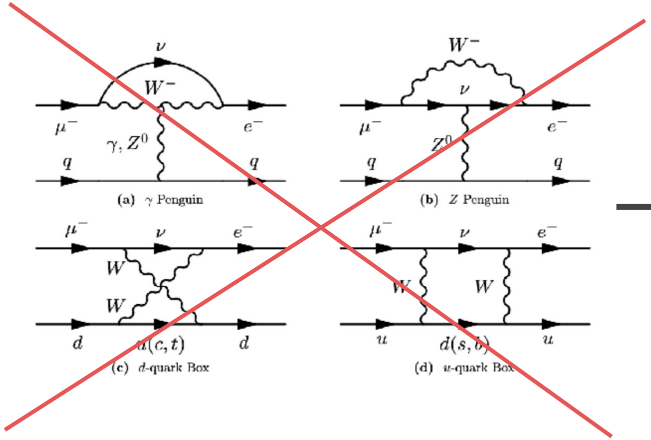
Charged lepton flavor violation (cLFV)

By including **neutrino oscillation** in the SM:



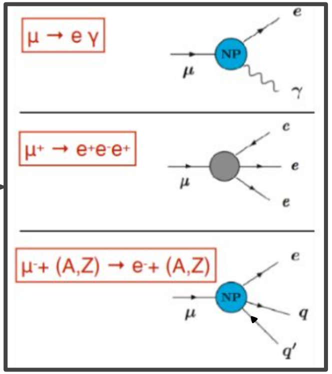
$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{j=1}^{3} U_{ej}U^*_{\mu j}\frac{m^2_{\nu j}}{M^2_W}\right|^2 \sim O(10^{-54})$$

→ theoretically possible, but **impossible to observe**…



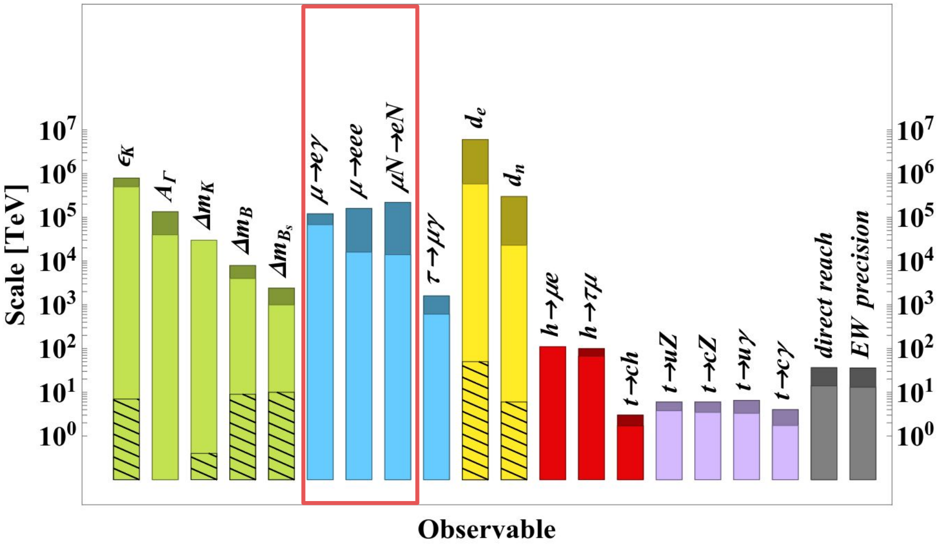
Any observation of cLFV cannot be explained only by neutrino oscillation.

It would be a **clear sign** of **BSM** physics!



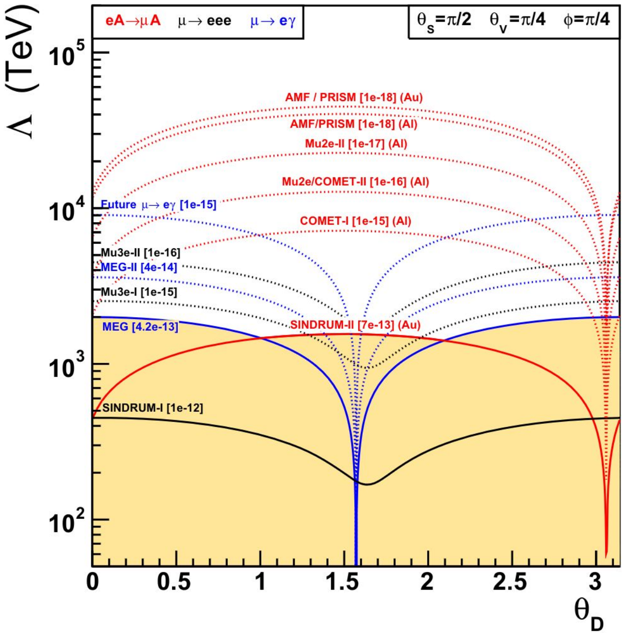
Muon LFV experiments sensitivity to BSM physics

Muon LFV experiments are sensitive to **high scale new physics**



European Particle Physics Strategy Update (1910.11775)

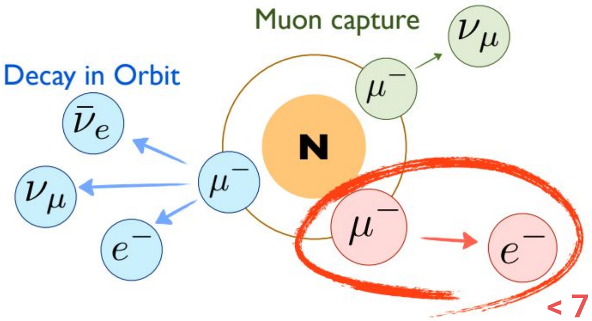
They are also **complementary**



S. Davidson, B.Echenard, Eur. Phys. J. C 82 (2022) no.9, 836

Muon-to-electron conversion

Muonic atom decays:

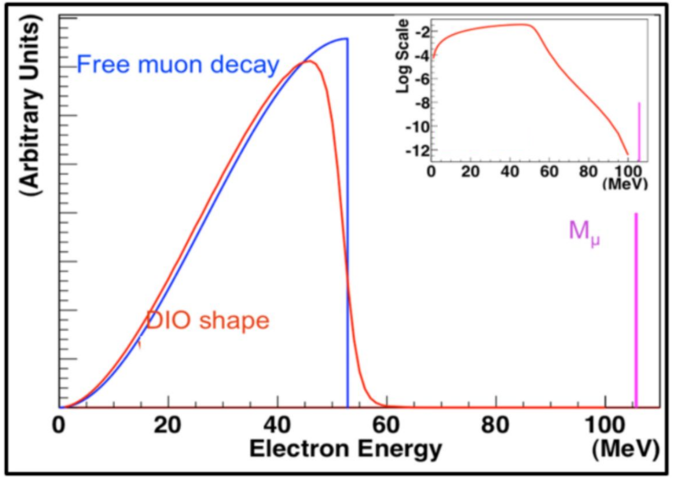


mono-energetic electron

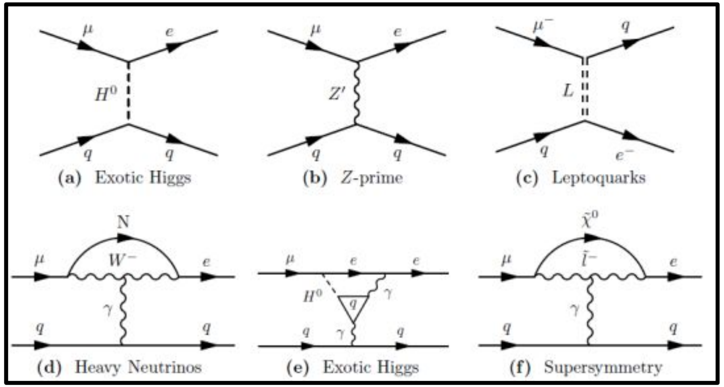
$$E_{\mu e} = m_\mu - B_\mu - E_{recoil}.$$

(104.97 MeV for Al)

< 7 x 10^{-13}
(SINDRUM-II)



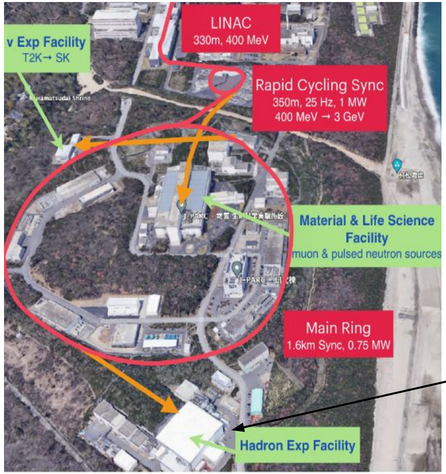
Examples of BSM models:

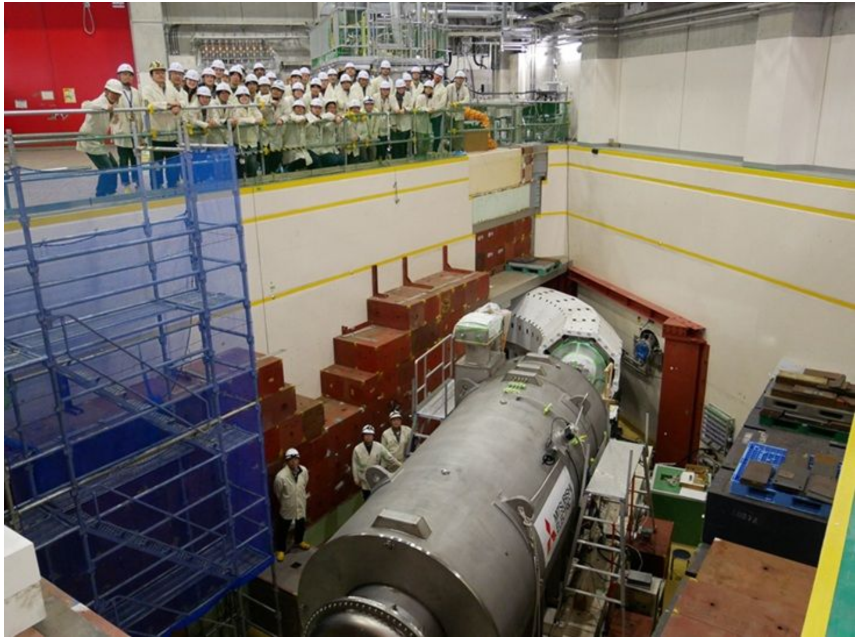


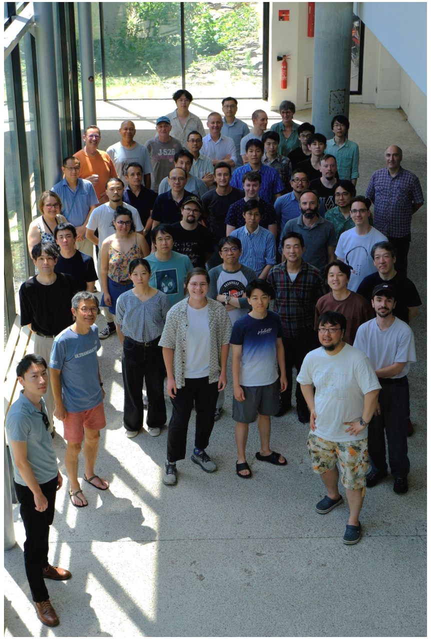
with different predicted conversion rate. Some of them are expected to be reachable by ongoing experiments: **~O(10^{-15}-10^{-17})**

This could significantly help to **constrain theoretical models**.

COMET experiment at J-PARC





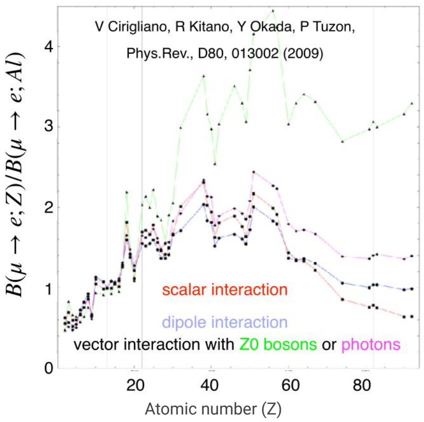


大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex

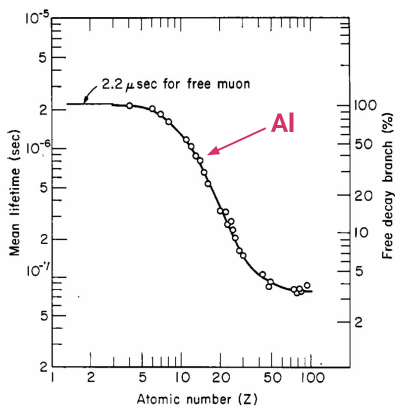
> 200 collaborators from 17 countries

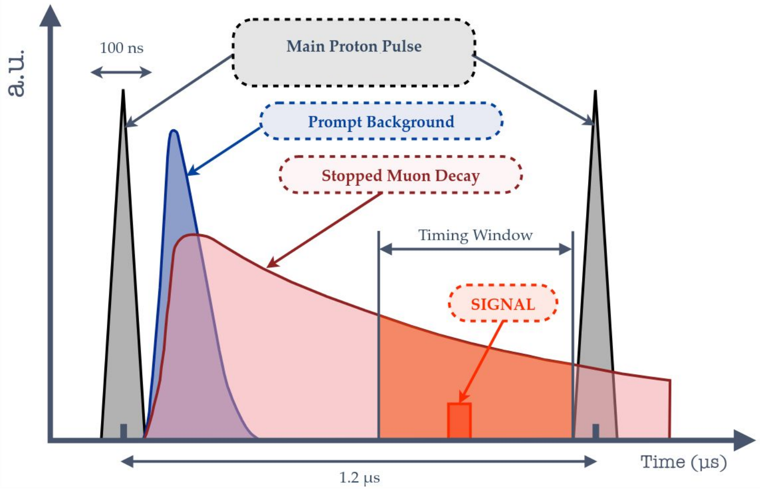
COMET measurement strategy

Muonic atom choice:
Aluminum



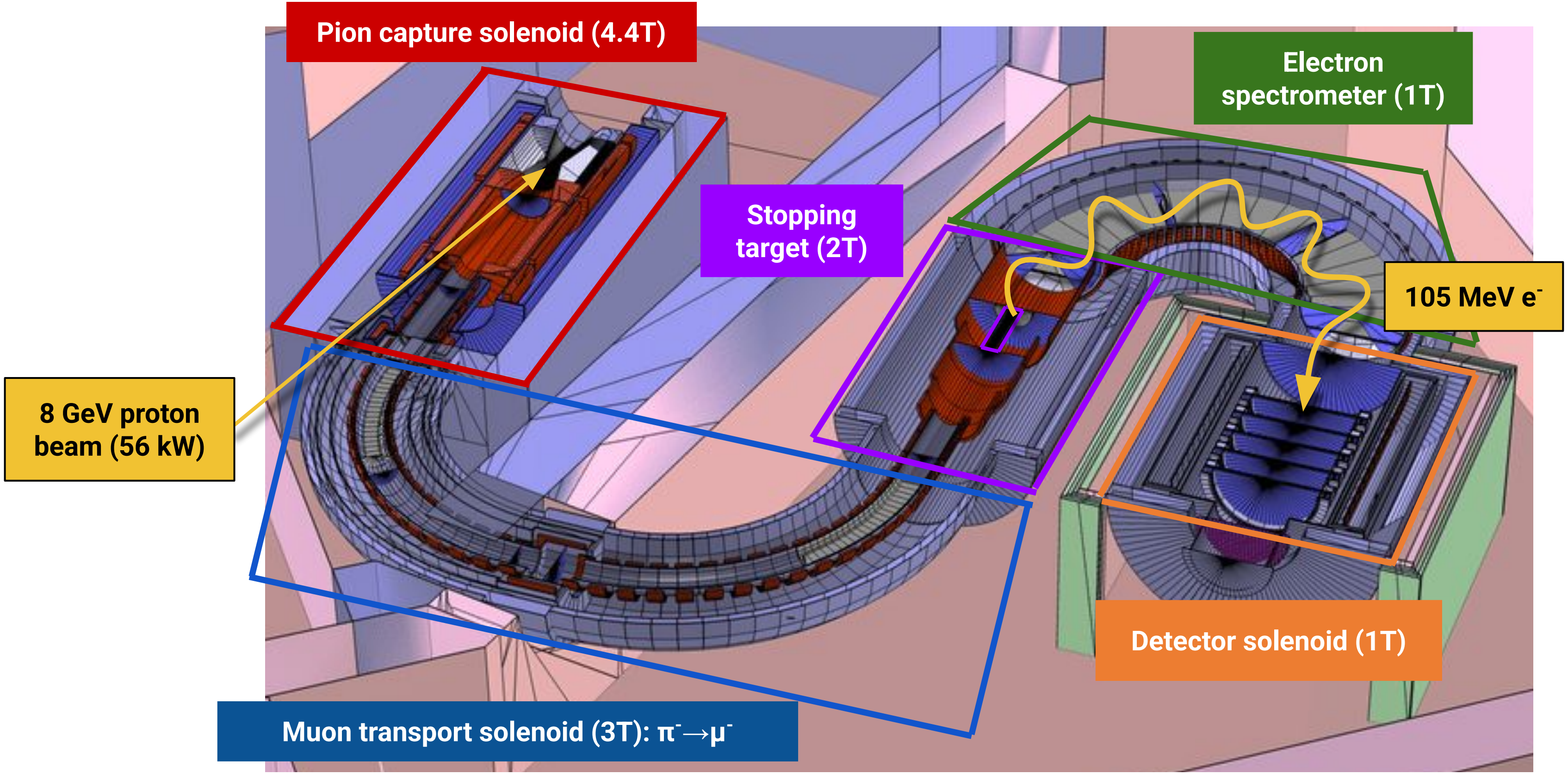
Material target	Atomic number (Z)	Muonium lifetime (ns)
Aluminum	13	864
Titanium	22	330
Lead	82	74



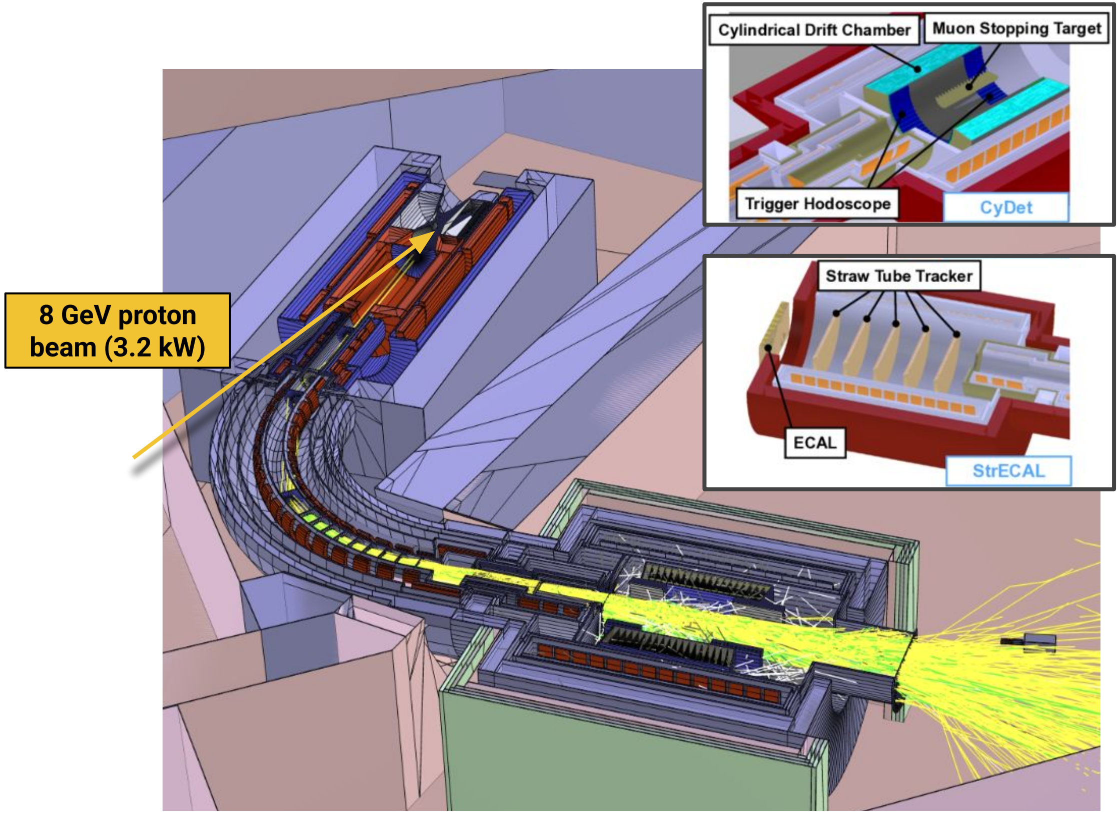


- Use a **pulsed** proton beam → narrow pulses (100 ns).
- Define a **delayed measurement** window (700 ns - 1117 ns) around the muonic atom lifetime.
- Aluminum muonic atom is a good compromise regarding its conversion rate and lifetime.

COMET design



COMET Phase-I



COMET Phase-I

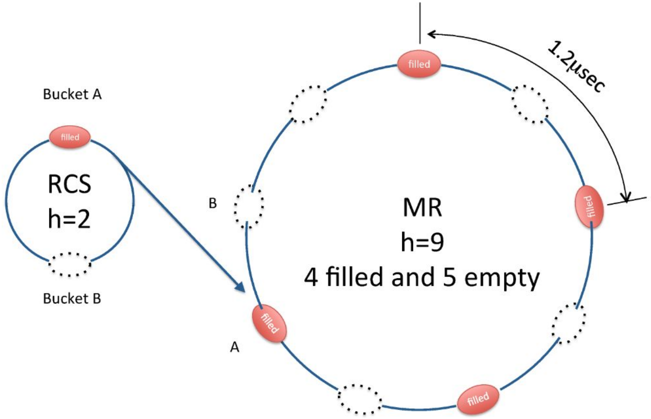
- Physics run:
  - Detector: CyDet
  - Target sensitivity $O(10^{-15})$
  - (x100 current limit)
- Beam measurement:
  - Detector: StrECAL
  - And R&D for Phase-II

COMET Phase-II

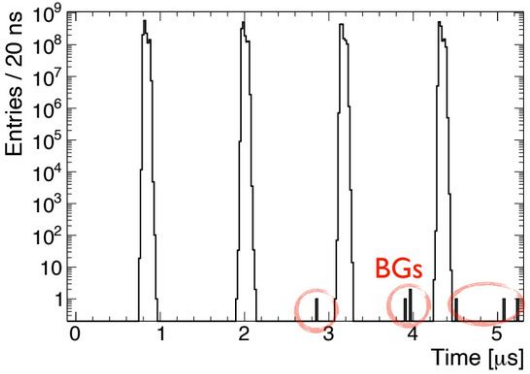
- Intensity increase to 56 kW
- Detector: StrECAL
- Full design (previous slide)
- Target sensitivity $O(10^{-17})$
- (x10,000 current limit)

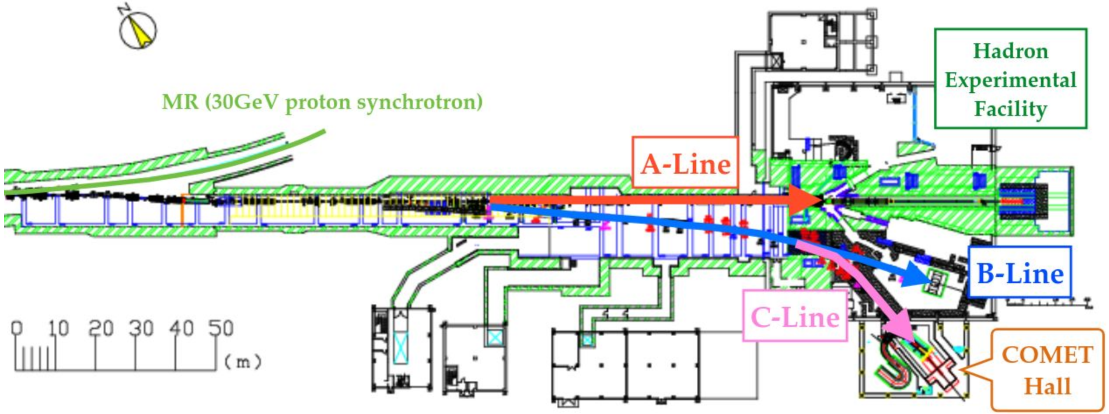
Proton beam line

- **J-PARC proton beam:**
  - Slow extraction of the bunches
    ↳4 out of 9 buckets



- **Beam "Extinction"** (fraction of residual protons between bunches):





  - Measured **< 1.0×10^{-10}**
    @K1.8BR of HD(T78 in 2021).

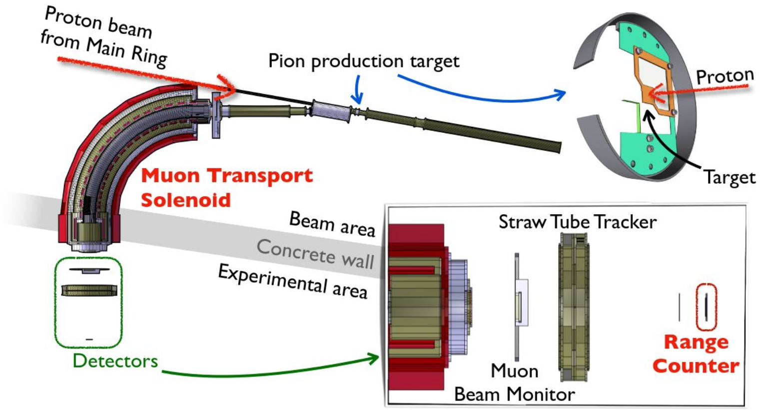
COMET Phase-α (2023)

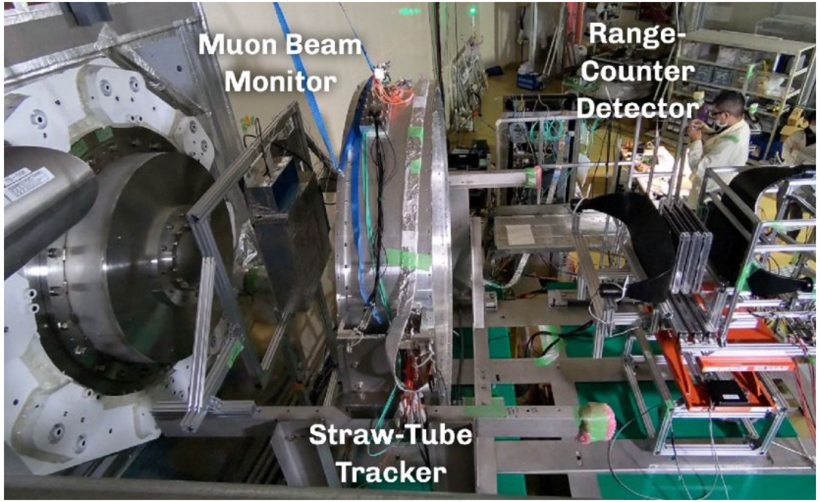
The 1st commissioning of the COMET facility

- **Proton beam:**
  - Slowly-extracted pulsed 8 GeV proton beam at 260 W (~1/10 of Phase-I).
  - Thin graphite pion-production target (1mm).
  - Beam tuning and beam profile measurement were performed.

- **Muon beam:**
  - The muon beam was successfully transported to detector area.
  - **First muon momentum spectrum measurement for COMET!**

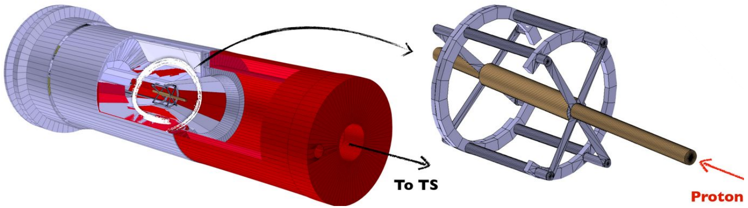
K. Oishi, et al., Nucl.Instrum.Meth.A 1082 (2026) 170904

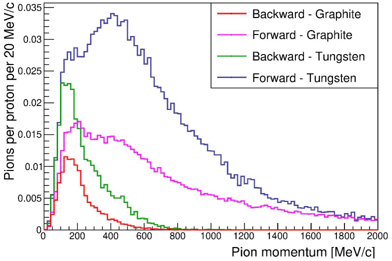


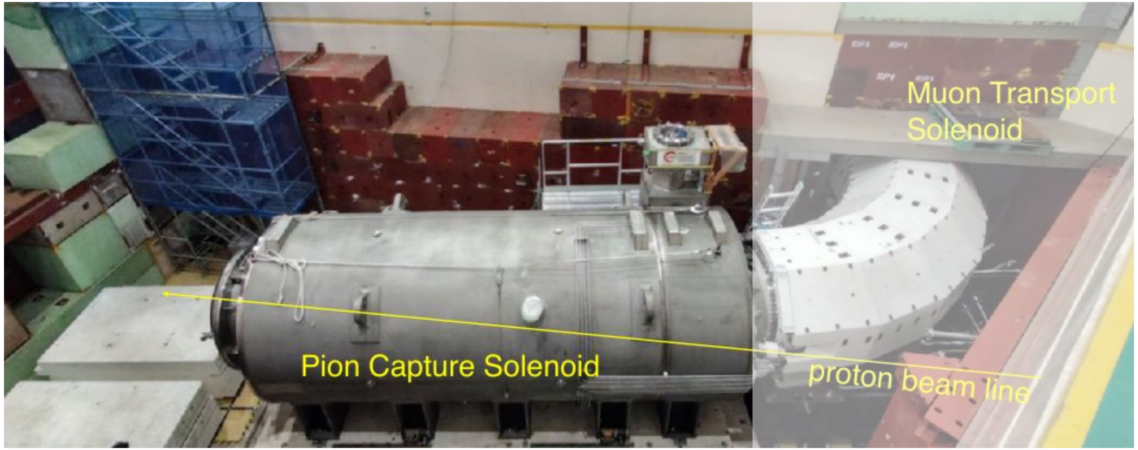


Proton target and Pion capture solenoid (PCS)

- **Proton target:**
  - **Graphite** target used for Phase-I.
  - Tungsten target used for Phase-II.
- **Pion capture solenoid:**
  - 4.4T magnetic field to extract pions in the **backward direction.**
  - Installed in November 2024.

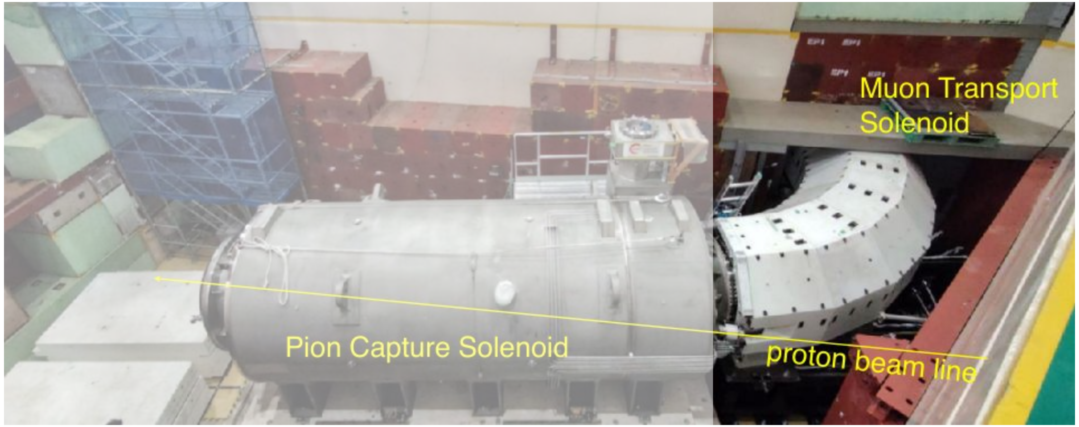


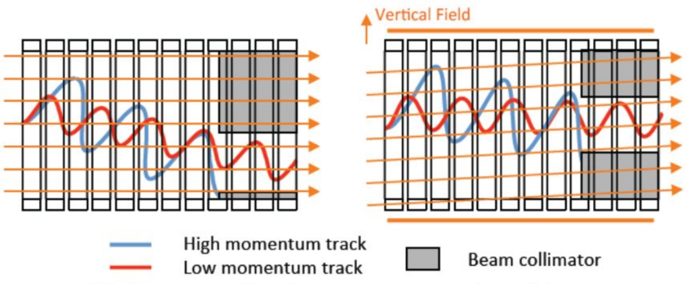




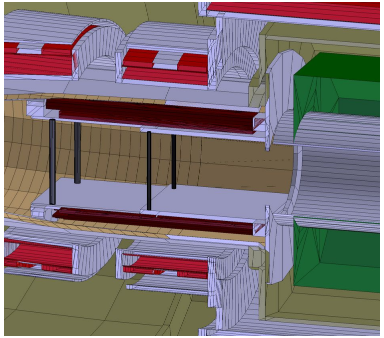
Muon transport solenoid (MTS) and beam collimator

- 90 deg. curved muon transport solenoid (3T).
- MTS operation was successfully confirmed in Phase-α
- Low momentum particles are selected and high momentum particles are rejected with an additional **dipole field** (~0.04T).
- Beam **collimator** designed for charge and momentum selection.





Trajectories in the transport solenoid



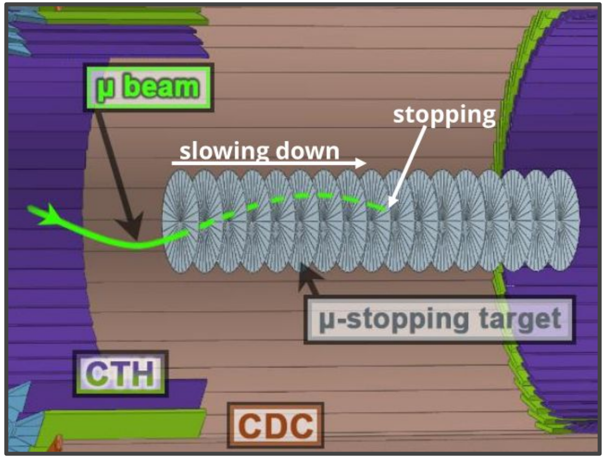
Bridge and detector solenoids

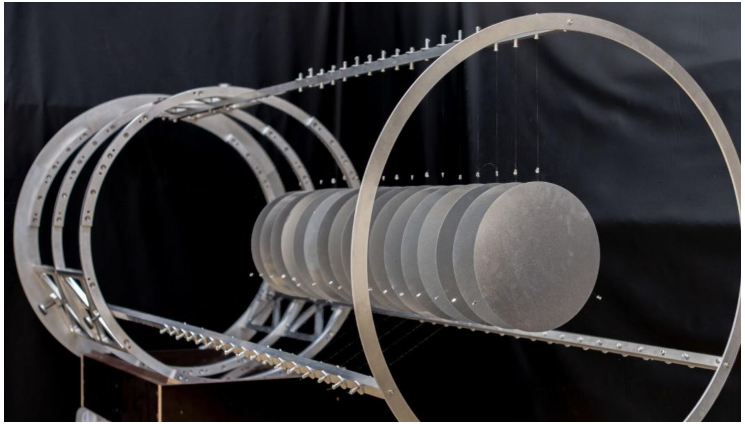
- BS magnet was **delivered** to J-PARC in 2022.
- DS magnet **tested successfully** in 2024 in Tsukuba. It arrived at the COMET hall few weeks ago. The initial check was carried out without any problem. **Important milestone!**
- Field measurement will follow.

Muon stopping target

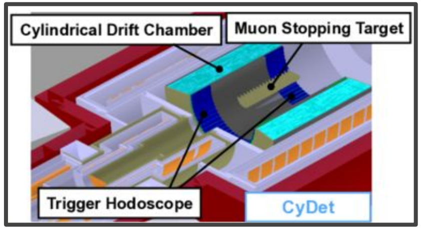
- ❖ **Aluminium target:**
  - ➢ 17 discs.
  - ➢ 10cm radius, 200µm thickness and 50mm spacing.
  - ➢ Stability & performance tests of Al. alloys concluded.

- ❖ **Germanium detector:**
  - ➢ To be place further downstream to measure muonic X-rays for **normalisation**.

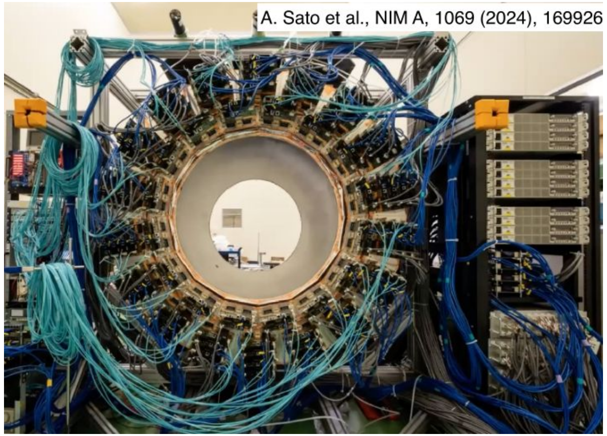


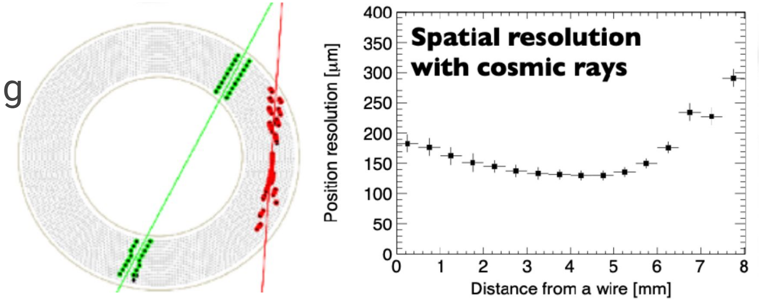


Cylindrical Drift Chamber (CDC)



- Signal electron tracking → **momentum** measurement.
- Momentum resolution requirement:
  - below **200 keV/c** @ 105 MeV/c
- Helium based gas (**He: iso-C_4H_{10}= 90:10**) to minimise multiple scattering.
- ~5000 (gold plated) sense wires in 20 layers
  - **Stereo** wire → **3D position measurement**
- Basic performance test with cosmic rays done.
- Full readout test, construction of gas system are ongoing
- Studies of the track reconstruction with a high hit occupancy are also ongoing





A. Sato, et al., Nucl.Instrum.Meth.A 1069 (2024) 169926

Cylindrical Trigger Hodoscope (CTH)

❖ For trigger and **timing** measurement, but also showed great performance in **e/μ separation**.

❖ Timing resolution requirement:
  ➢ below **1 ns**.

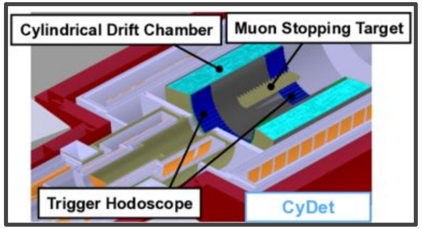
❖ 2 wheels of 2×64 plastic scintillators + fibre + MPPCs
  ➢ >40 p.e. for a detection efficiency > 99%

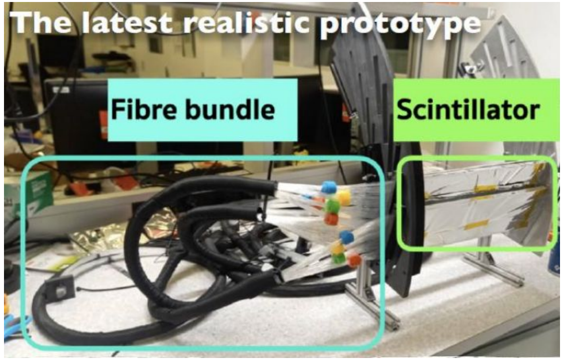
❖ **4-fold coincidences** for trigger
  ➢ Trigger rate < 100 kHz.

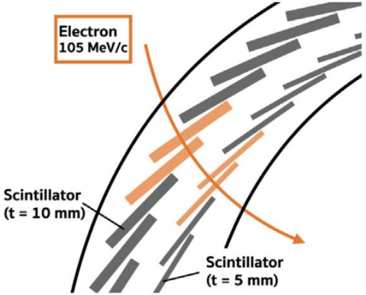
❖ MPPCs are cooled to -36°C
  ➢ radiation damage,
  ➢ placed outside of DS.

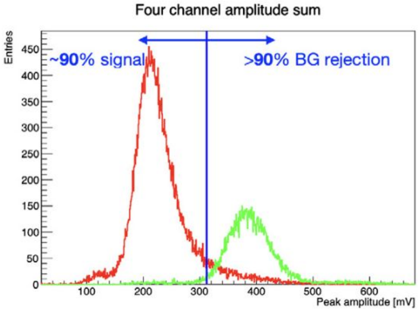
❖ Front-end electronics is being **commissioned**.

❖ Mass production will start soon.









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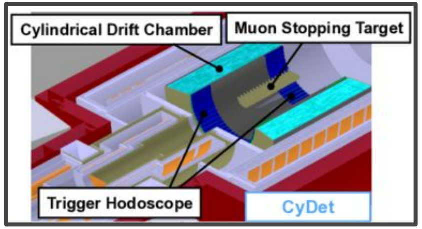
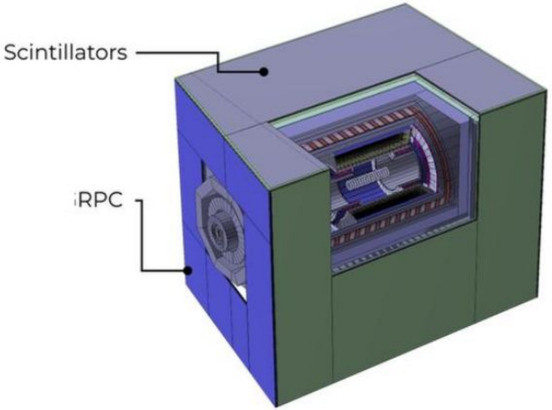
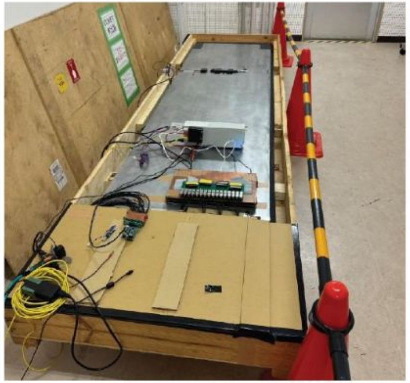
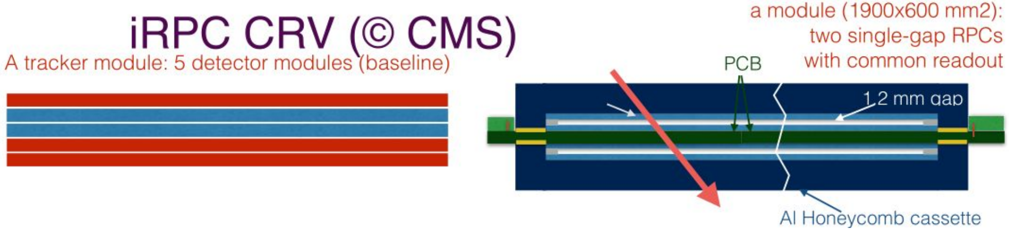
Cosmic Ray Veto (CRV)



- **Cosmic rays** is one of the most crucial background source.
  - Estimation using backward Monte-Carlo simulations.
- Hybrid design for CRV:
  - **Scintillators** (top)
    - 4 layers
    - readout by MPPCs through wavelength-shifting fibres
  - **Resistive plate chambers**
    - existing RPCs
      - CMS iRPC (front & back)
      - Argo RPC (sides)
    - 5 layer as baseline
- First scintillator module was constructed and currently being **commissioned** with cosmic rays.

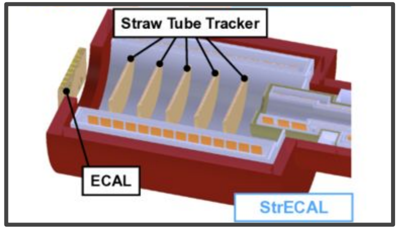


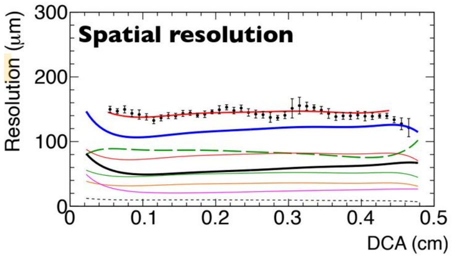




Straw Tube Tracker

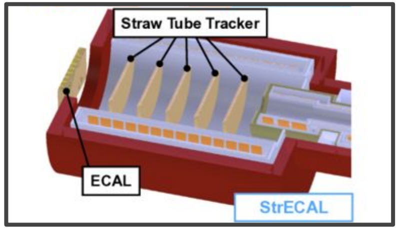
- ❖ Signal electron tracking → **momentum** measurement.
- ❖ Momentum resolution requirement:
  - ➢ below **200 keV/c** @ 105 MeV/c
- ❖ Thin-wall straw tube gas detector
  - ➢ 9.75 mmΦ straw with 20 μm thickness
- ❖ Prototype showed great results:
  - ➢ spatial res. ~110 μm.
  - ➢ mom res < 200 keV/c is achievable.
  - ➢ operated in vacuum of < 0.1 Pa.
- ❖ The 1st station was **commissioned** in Phase-α.
  - ➢ Others are being **constructed**.



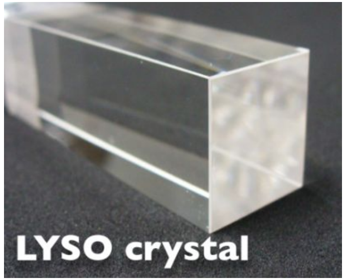


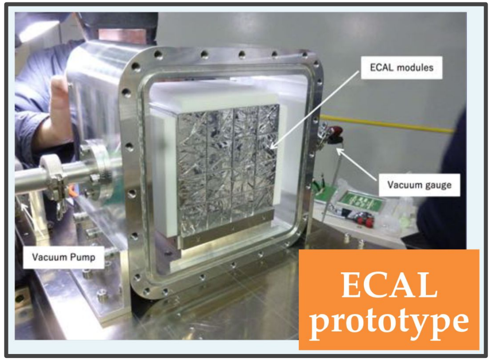
H. Nishiguchi, et al., Nucl.Instrum.Meth.A 958 (2020) 162800

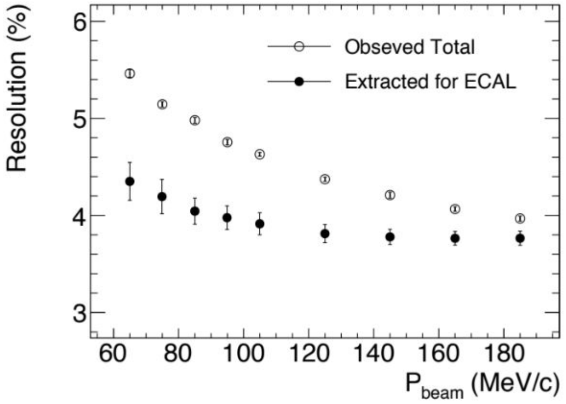
Electromagnetic Calorimeter (ECAL)



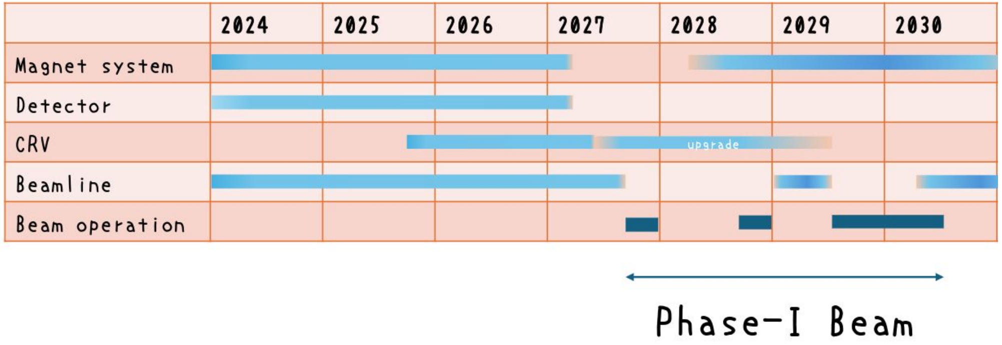
- ❖ Measurement of **energy, position, timing**.
  - ➢ Provides trigger and PID for Phase-I beam measurement program, and for Phase-II physics measurement.
- ❖ Energy resolution requirements:
  - ➢ below **5% energy** resolution @ 105 MeV.
- ❖ LYSO crystal scintillators
  - ➢ High density (7.1 g/cm^3), high light yield (70% NaI), and fast time response (40 ns).
  - ➢ Dimension of 2×2×12 cm^3.
  - ➢ ~2000 crystals.
- ❖ Prototype 8x8 crystals performance (@ 105 MeV/c):
  - ➢ Energy res. 3.9%,
  - ➢ Position res. 0.77 cm,
  - ➢ Timing res. 0.5 ns.
- ❖ Detector construction is **ongoing**.







Summary & schedule



- COMET Phase-I will search for **neutrinoless muon to electron conversion** with a target sensitivity which is a factor of 100 better than the current limit.

- The **Phase-I** is expected to start with low intensity (~10% power) **runs in 2027** for commissioning the detector and the muon beam line before reaching the nominal beam intensity.

- In addition to the physics measurement, COMET Phase-I will fully **characterise the muon beam and the backgrounds** with prototypes of COMET Phase-II detectors.

- A sensitivity of $O(10^{-17})$ is expected to be reachable by COMET Phase-II thanks to improved muon beam intensity and backgrounds and systematics under control.