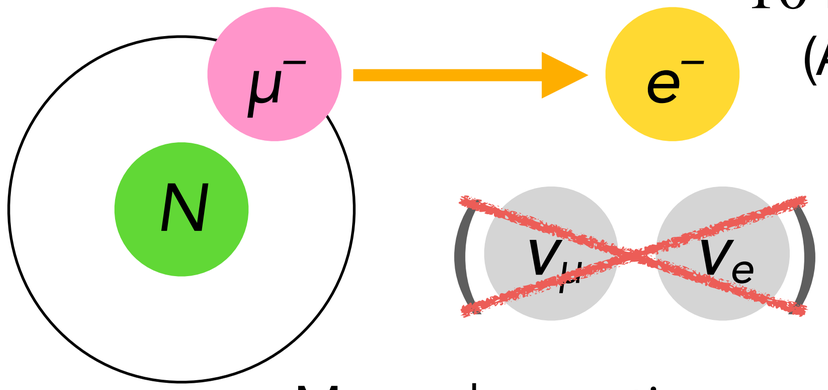
Status of the COMET Experiment

Ryo Nagai

The University of Osaka

On behalf of the COMET Collaboration

Muon-to-Electron Conversion ($\mu^- N \to e^- N$)

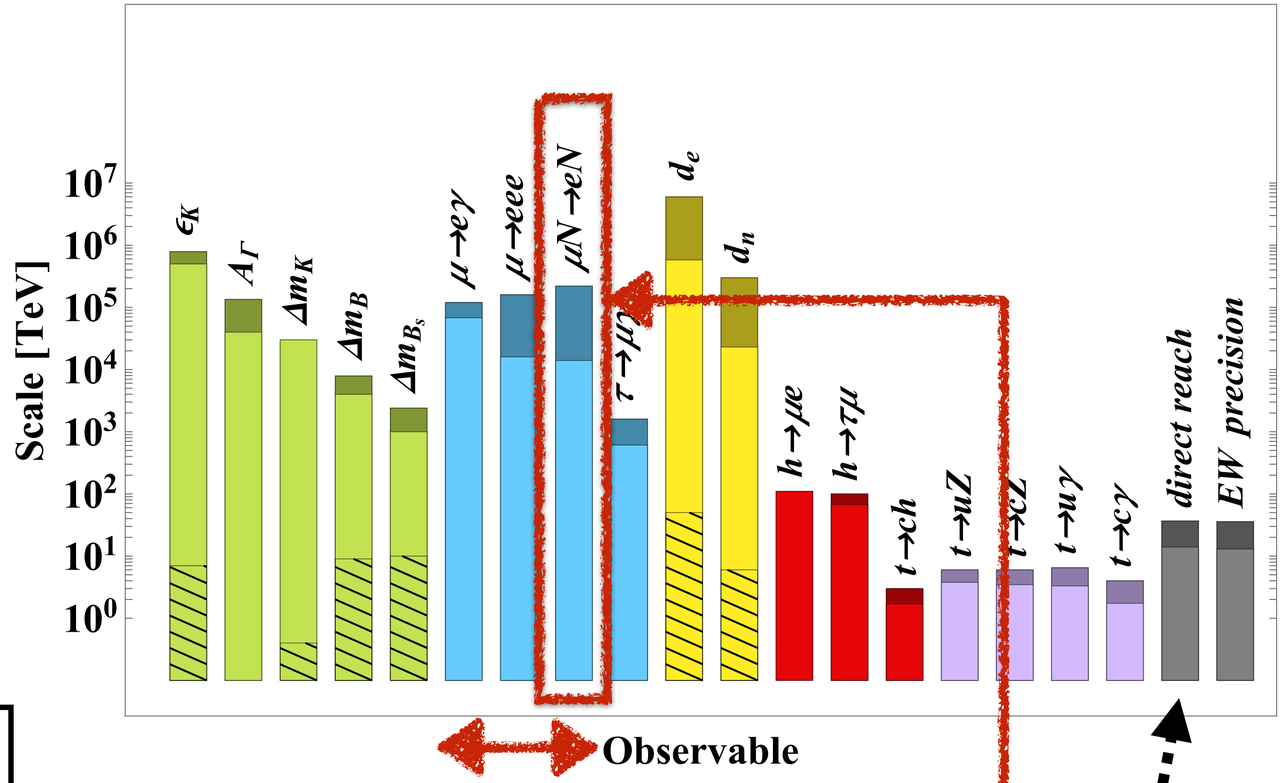


$104.9\,\mathrm{MeV}/c$
(Al target)

Monochromatic momentum electron w/o neutrinos

→ ***Peaked, low-BG signals***

Physics Briefing Book : Input for the ESPPU 2020 (CERN-ESU-004)



Complementary to $\mu \to e\gamma$, $\mu \to 3e$

New Physics scale up to $\sim 10^5\,\mathrm{TeV}$

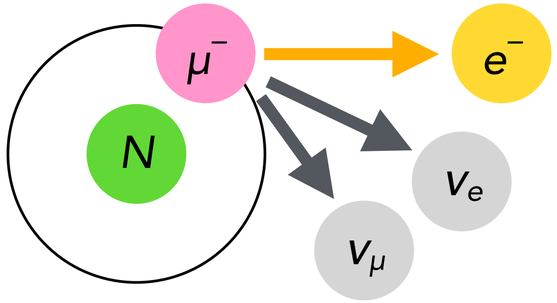
✔***~1000 times higher than direct searches***

However, $\boldsymbol{\mu N \to eN}$ is not so easy…

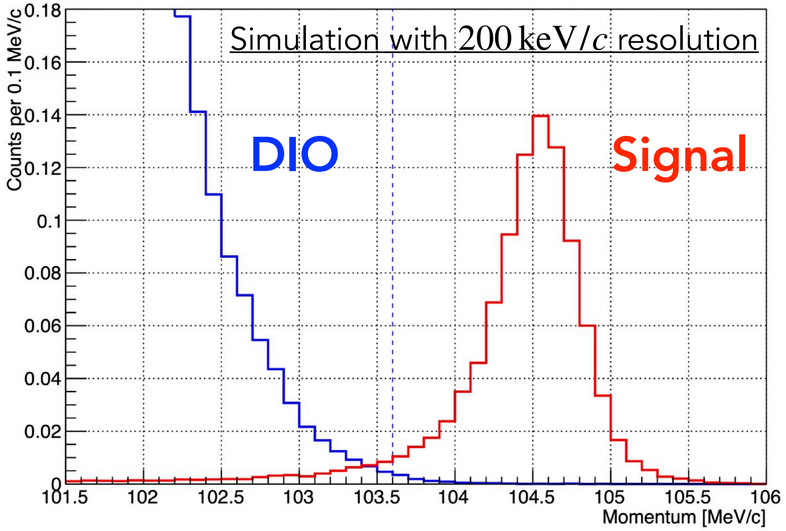
Sensitivity is built by beam control,
not only by detectors

Search for μ-e conversion in an atom

- **Decay-in-Orbit (DIO)**
  — ***main background, irreducible***



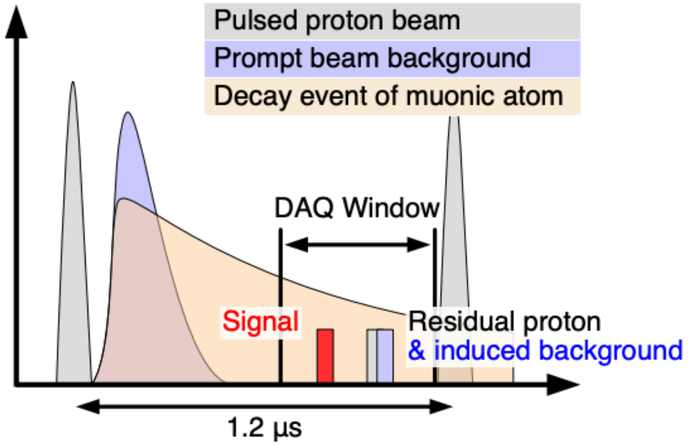
Continuous spectrum
$105\,\mathrm{MeV}/c$ endpoint



Excellent momentum resolution is a key

- **Beam-Related Backgrounds**
  - Using pulsed beam
  - Delaying signal using the muonic-atom lifetime in Al

  → **Reduce beam BG**



- **Cosmic-ray Backgrounds**
  - Due to the rare event search, cosmic ray contribution is **not negligible**
  - high-energy electrons & muons from CRs mimicking the signal
    → vetoed by surrounding CRVs

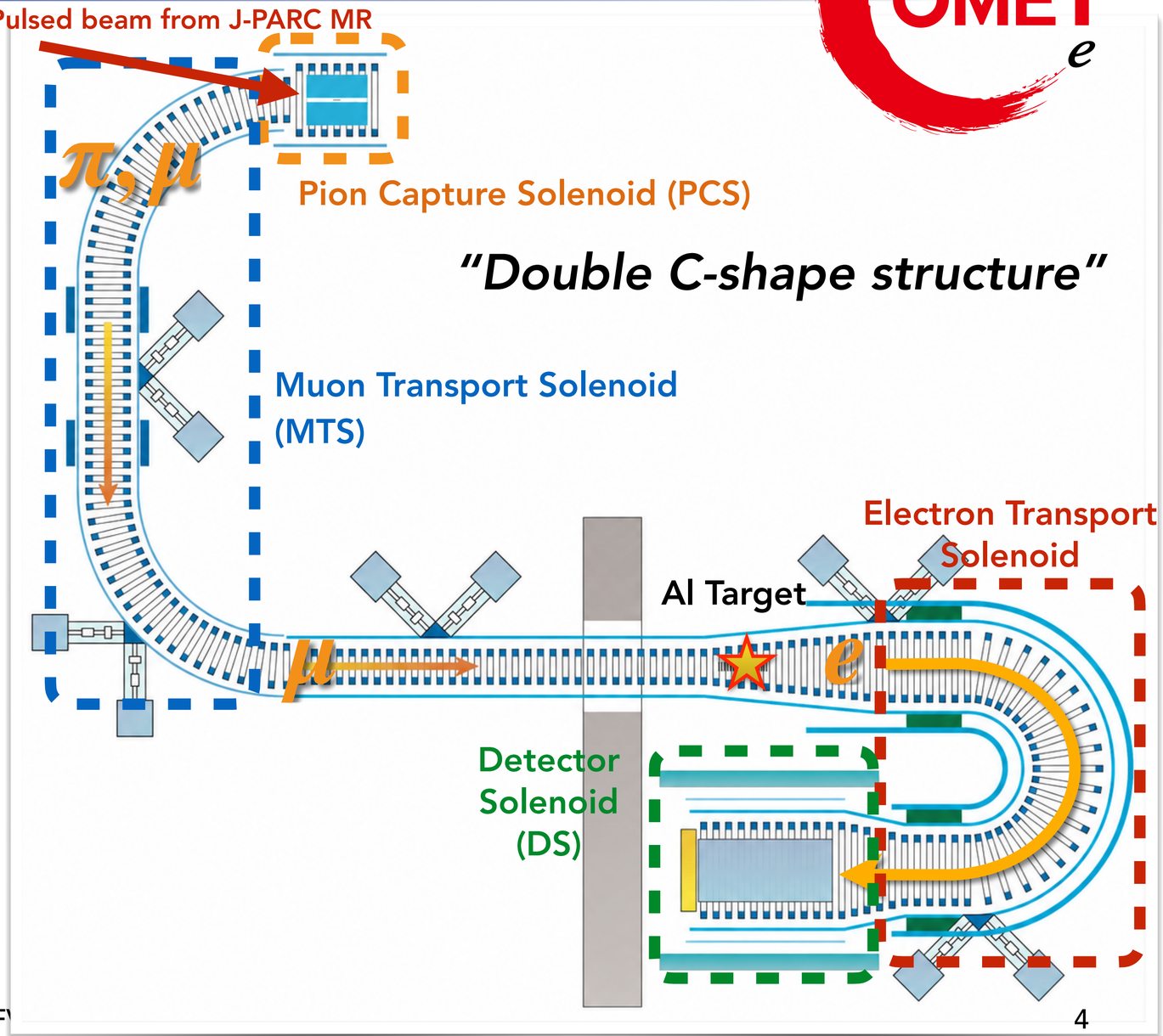
COMET Experiment Concept

Search for $\mu^- \to e^-$ conversion with sensitivity of $O(10^{-17})$

Current limit: $< 7 \times 10^{-13}$ (Au target)

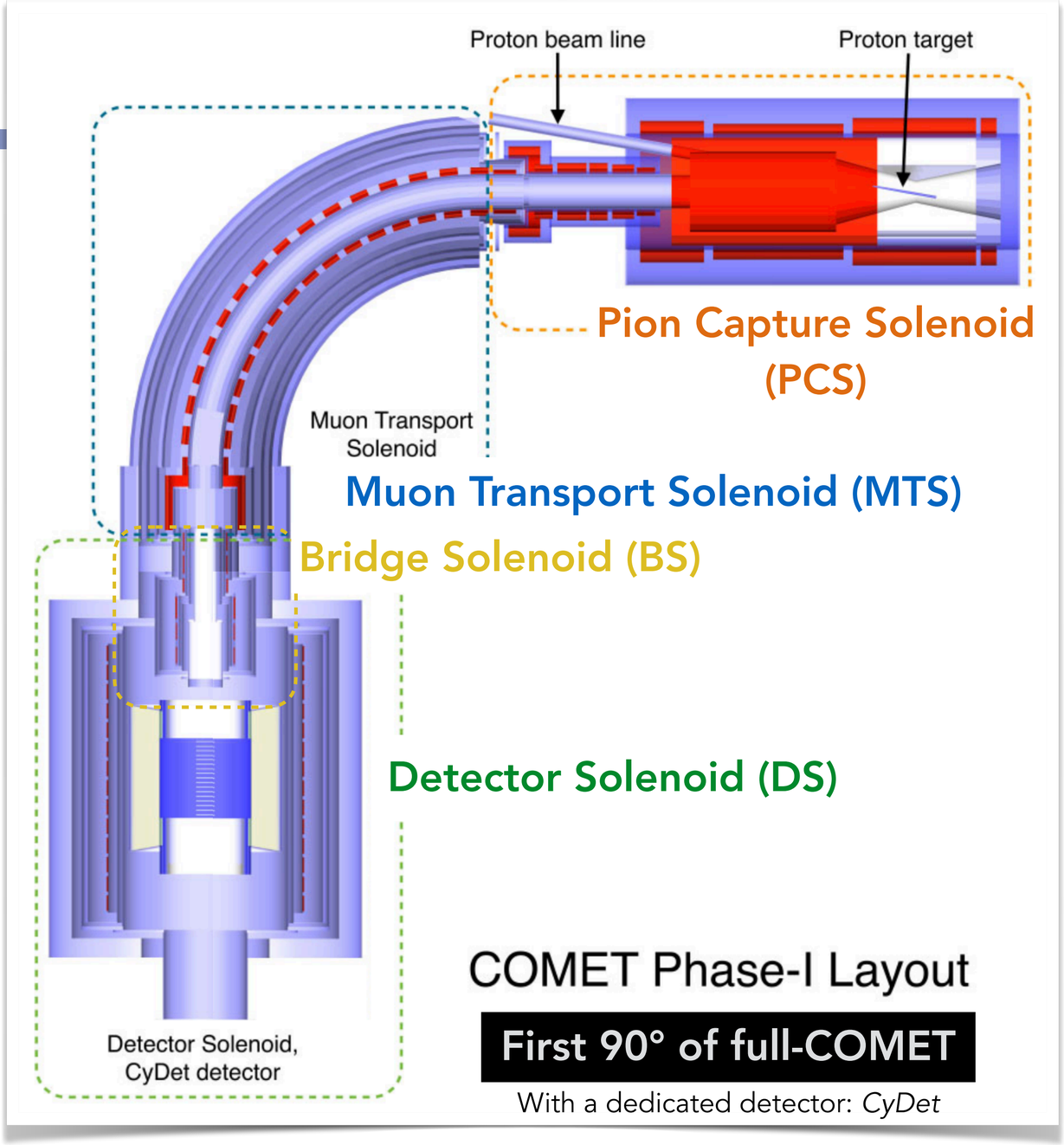
SINDRUM II, Eur. Phys. J. C 47, 337–346 (2006)

- Utilizing the **pulsed proton beam** from J-PARC Main Ring
- **4 superconducting solenoids** for efficient capture and curved transport
  - ***C-shape Transfer Solenoids***… diff from Mu2e
- **Al** stopping target to form muonic atoms
- Detector system optimized for $105\,\mathrm{MeV}/c$ electrons



COMET Phase-I

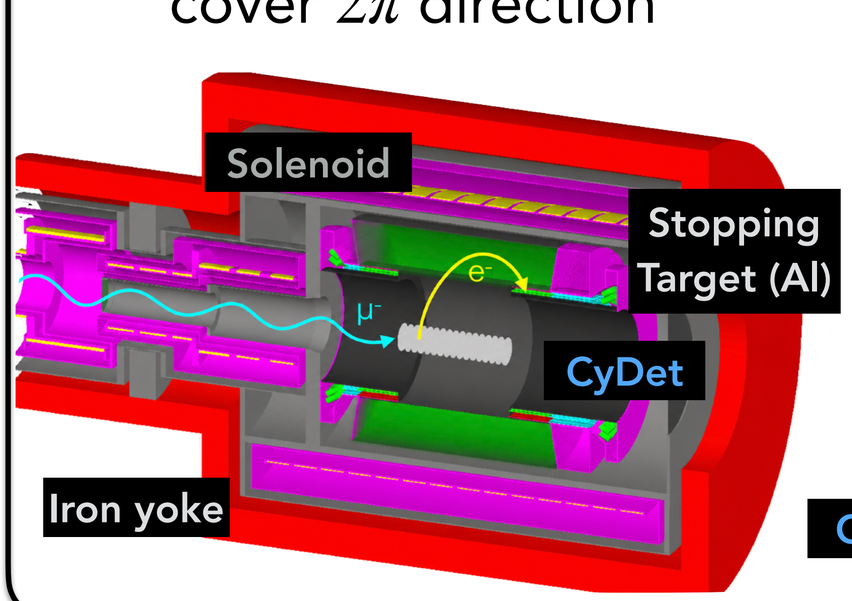
- Physics search with SES $\sim 10^{-15}$ with a ***dedicated*** detector
- Furthermore,
  - Measure muon beam characteristics to reduce beam-related syst. uncertainties
  - Validate detector performances for Phase-II
- B-fields from the solenoids are partially overlapped
  → integrated field control is one of the keys

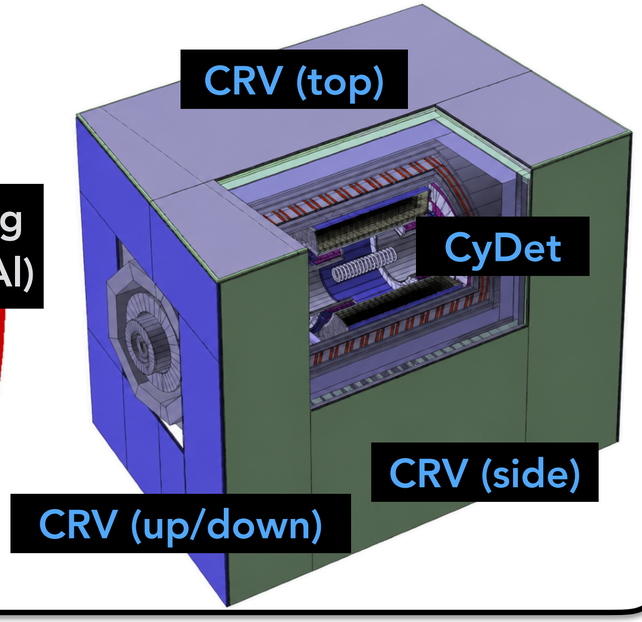


Phase-I Detectors

Physics Run

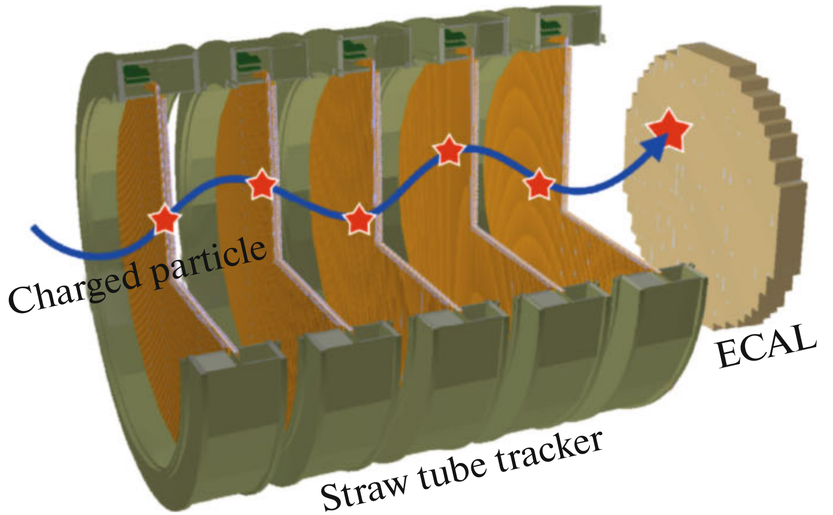
- **CyDet** (drift chamber + trigger hodoscope)
  - $105\,\mathrm{MeV}/c$ electron spectrum
- **CRV** (cosmic ray veto)
  - Surrounding whole detector + solenoid to cover 2π direction



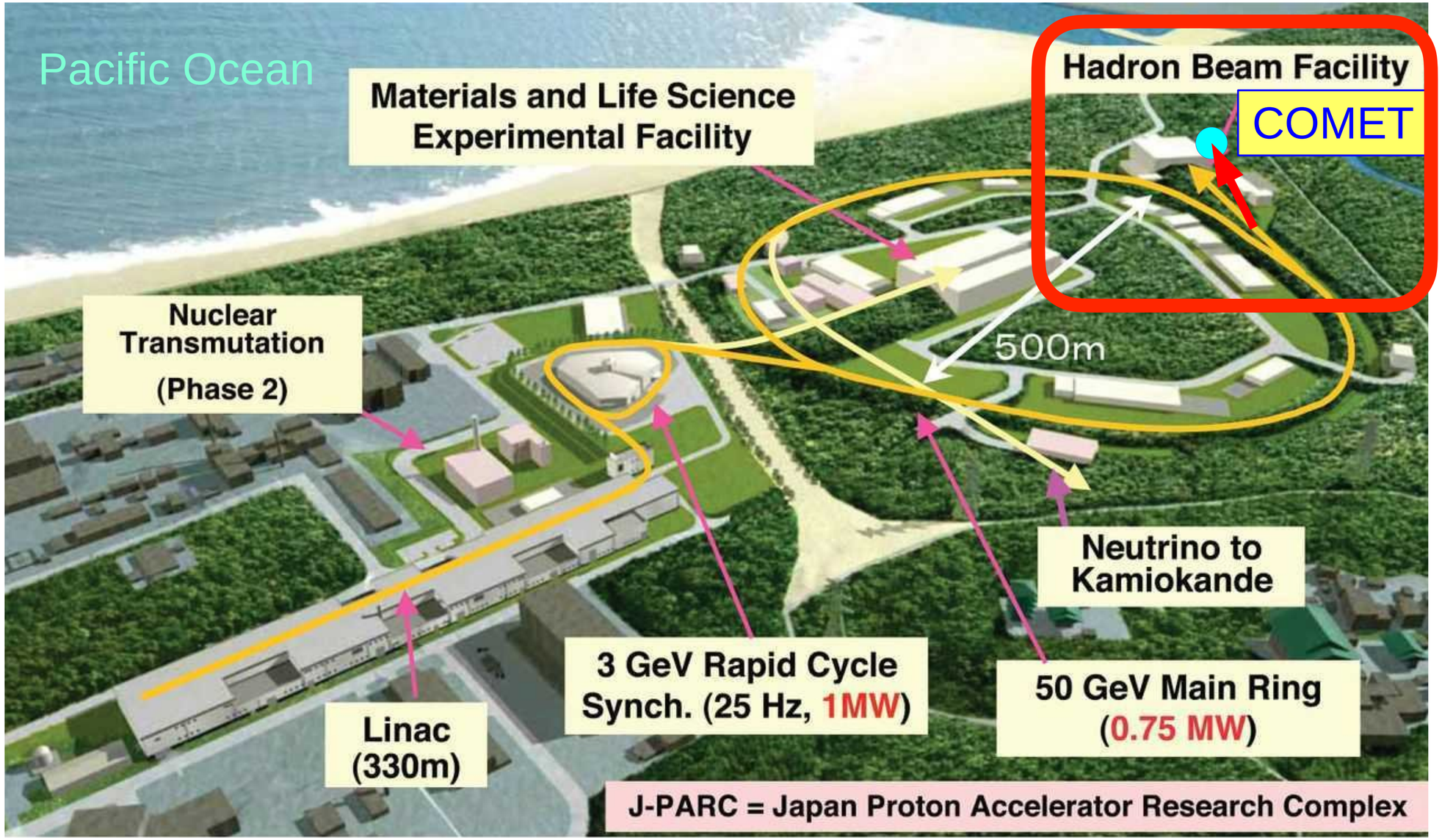


Beam Measurement

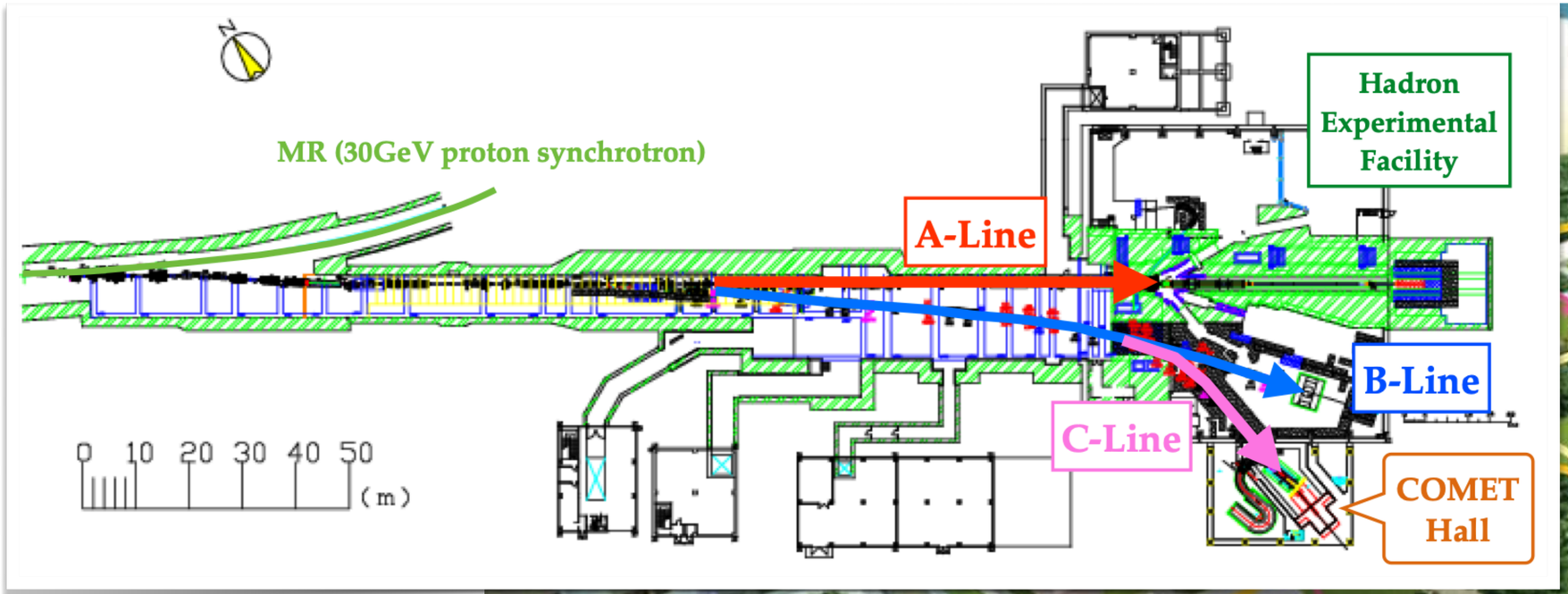
- **StrECAL** (straw-tube tracker + LYSO calorimeter)
  - Reduce systematics, *optimize Phase-II design*



Proton Beam from J-PARC



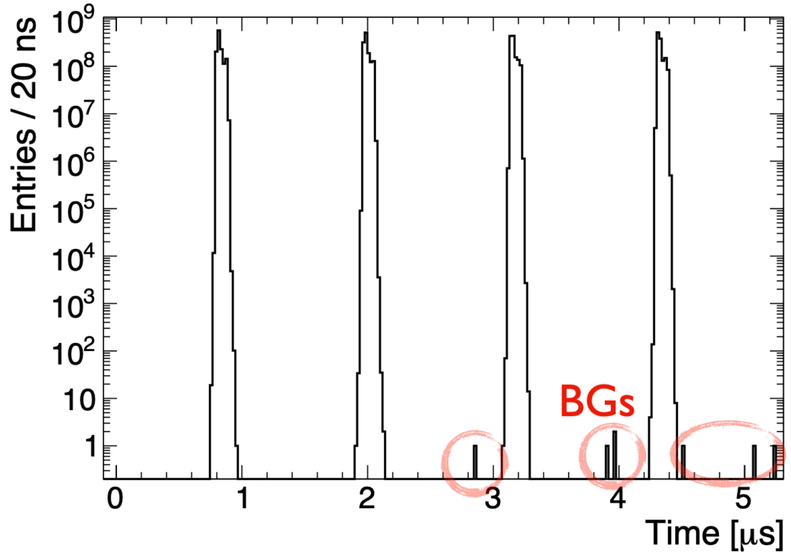
Proton Beam from J-PARC

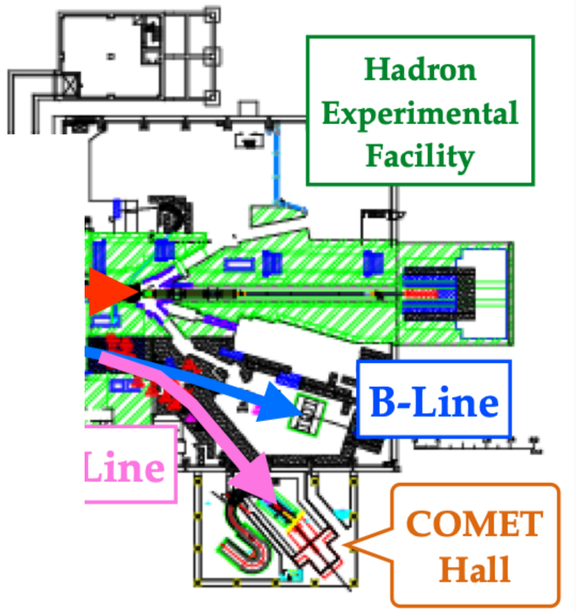


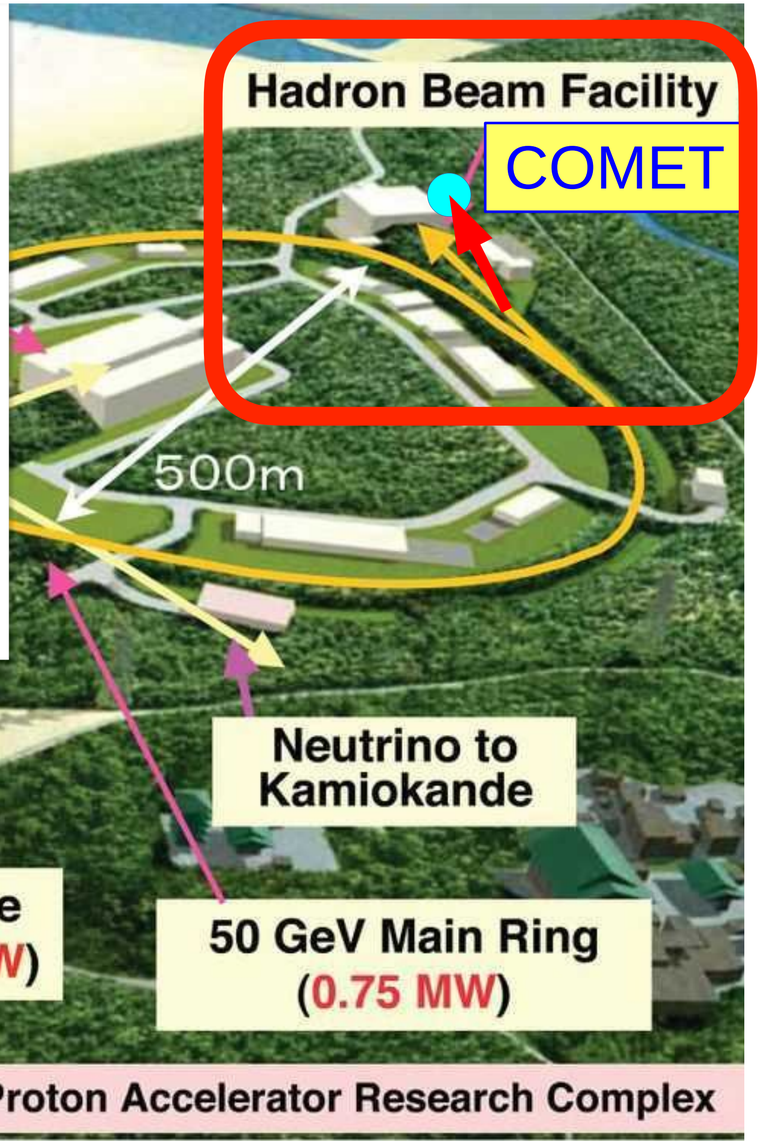
Proton Beam from J-PARC

J-PARC beam specification for COMET

- **Bunched slow extraction**
- Energy: $8\,\mathrm{GeV}$ (maximize backward emission)
- Extinction $\leq 1.02 \times 10^{-10}$ (90% C.L.)
  - Measured at K1.8BR of the Hadron Facility (T78)

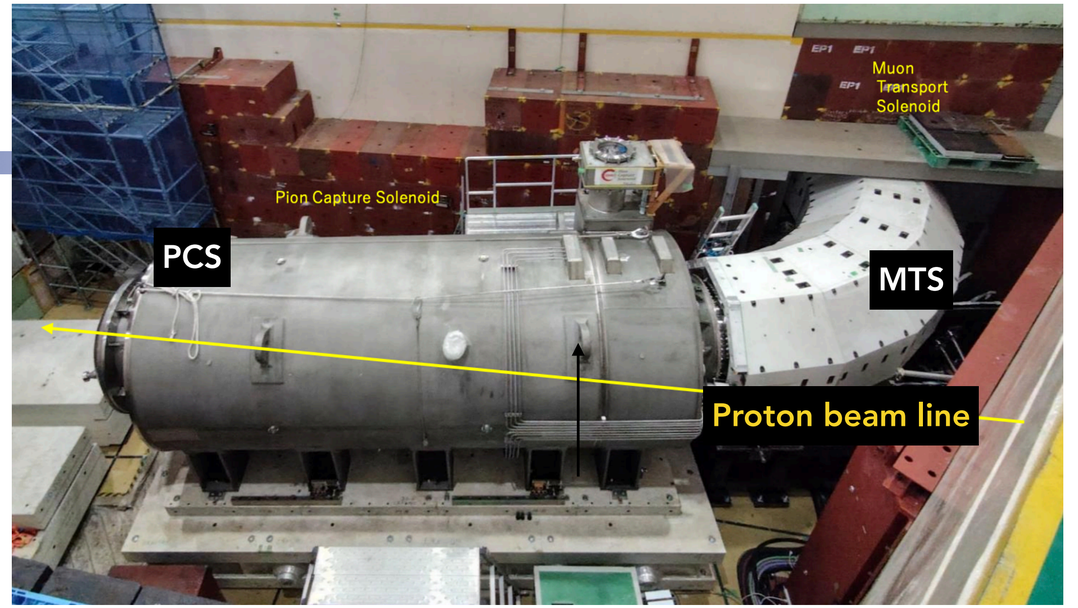


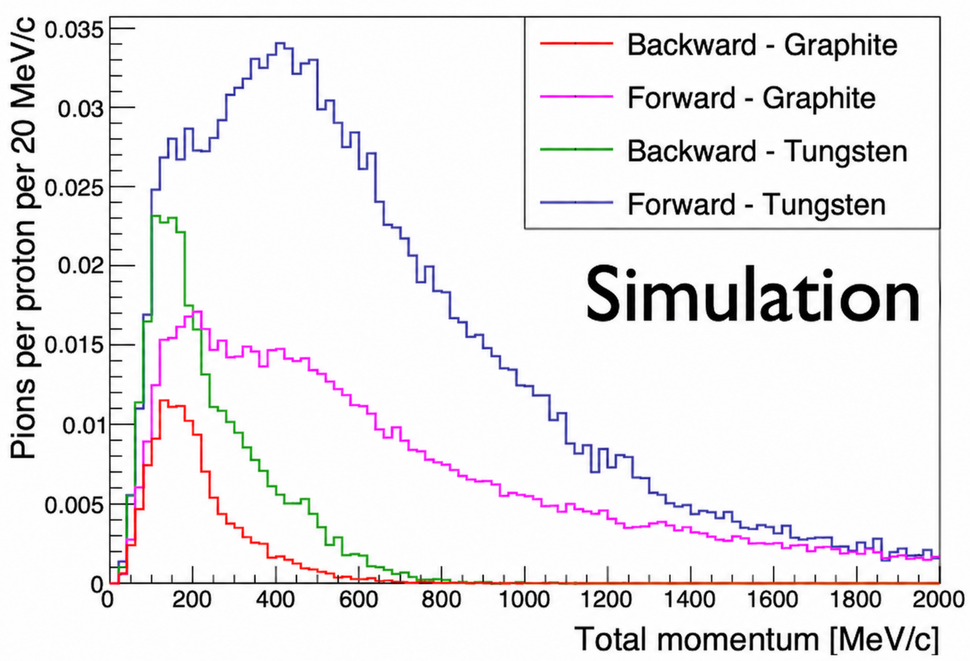




Pion Capture Solenoid (PCS)

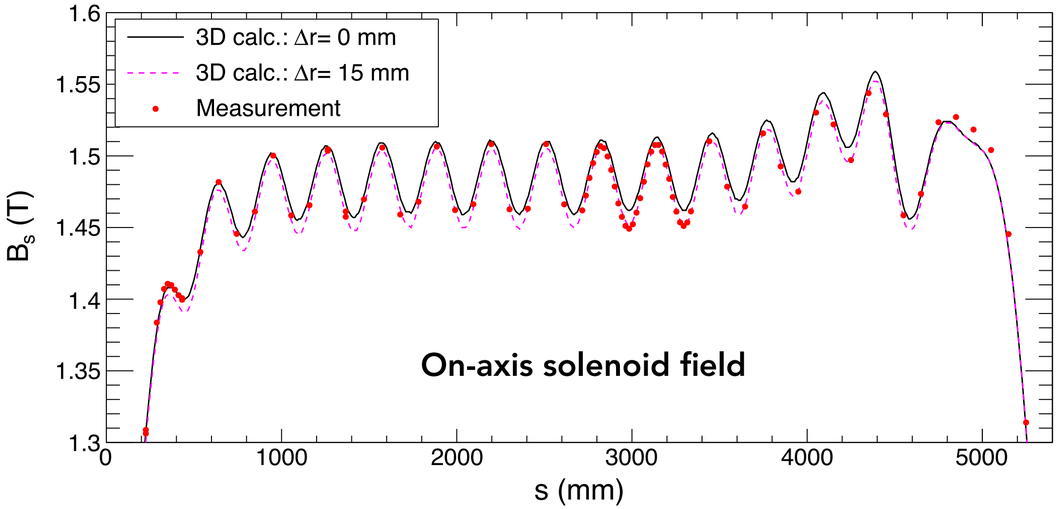
- Capture pions **backward-emitted from Graphite** target with $< 5\,\mathrm{T}$ field, guide muons/pions into MTS
- **Installed and connected with MTS in Dec. 2024**
  - Vacuum vessel deformation during evacuation: $1.2\,\mathrm{mm}$ at proton duct flange
  - Coil resistance & voltage withstand up to $500\,\mathrm{V}$
  - Leak tests of LHe- & water-cooling pipes successful
- **Radiation tolerance** is needed ($3.2\,\mathrm{kW}$, $8\,\mathrm{GeV}$ beam)
  - Thick stainless shielding ($\sim 40\,\mathrm{cm}$) protects coil
- **Excitation test after installation of return yokes and transfer tubes**



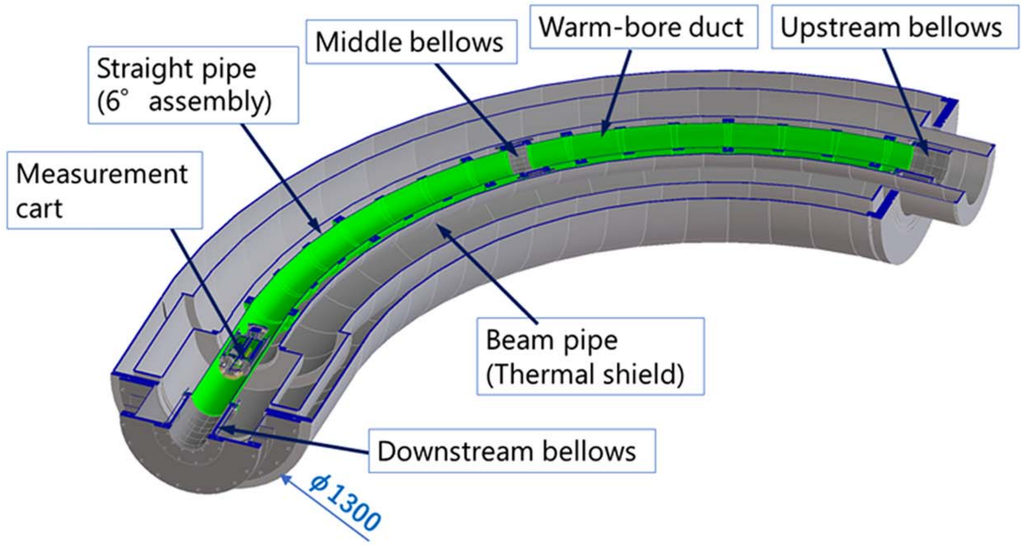


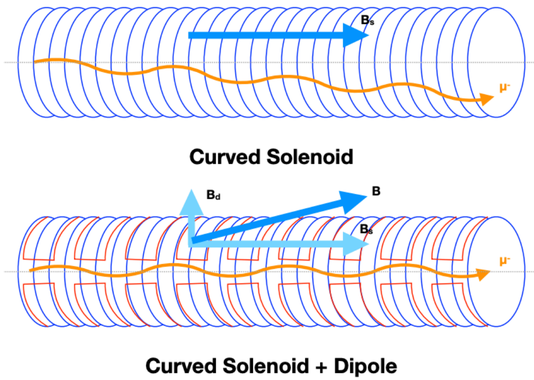
Muon Transport Solenoid (MTS)

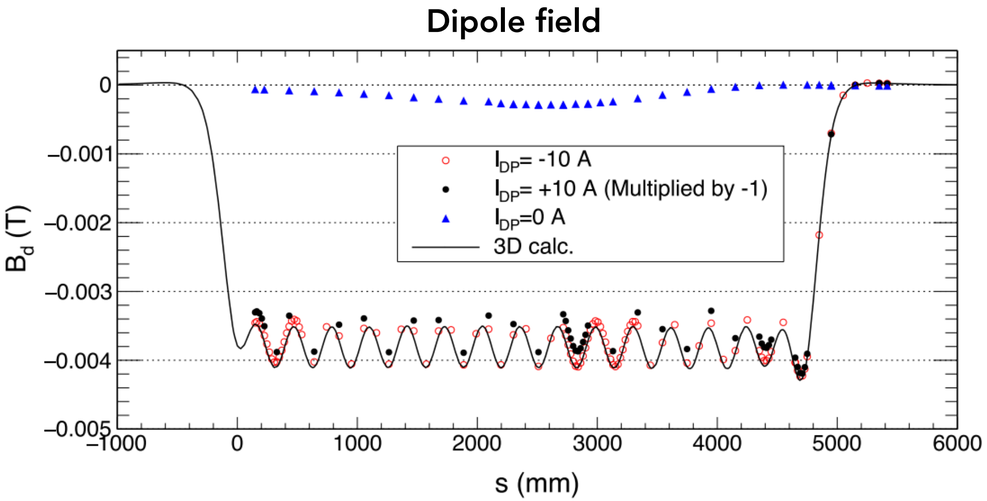
- Select low-momentum muons ($\sim 40\,\mathrm{MeV}/c$)
- Suppress background by curved transport
- Drift compensation with **dipole field** ($\sim 50\,\mathrm{mT}$) — a difference from Mu2e
- Performance is **verified** by measurement and simulation
  - On-axis solenoid field measured with **0.4% accuracy**



IEEE Trans.Appl.Supercond. 34 (2024) 5, 9000205

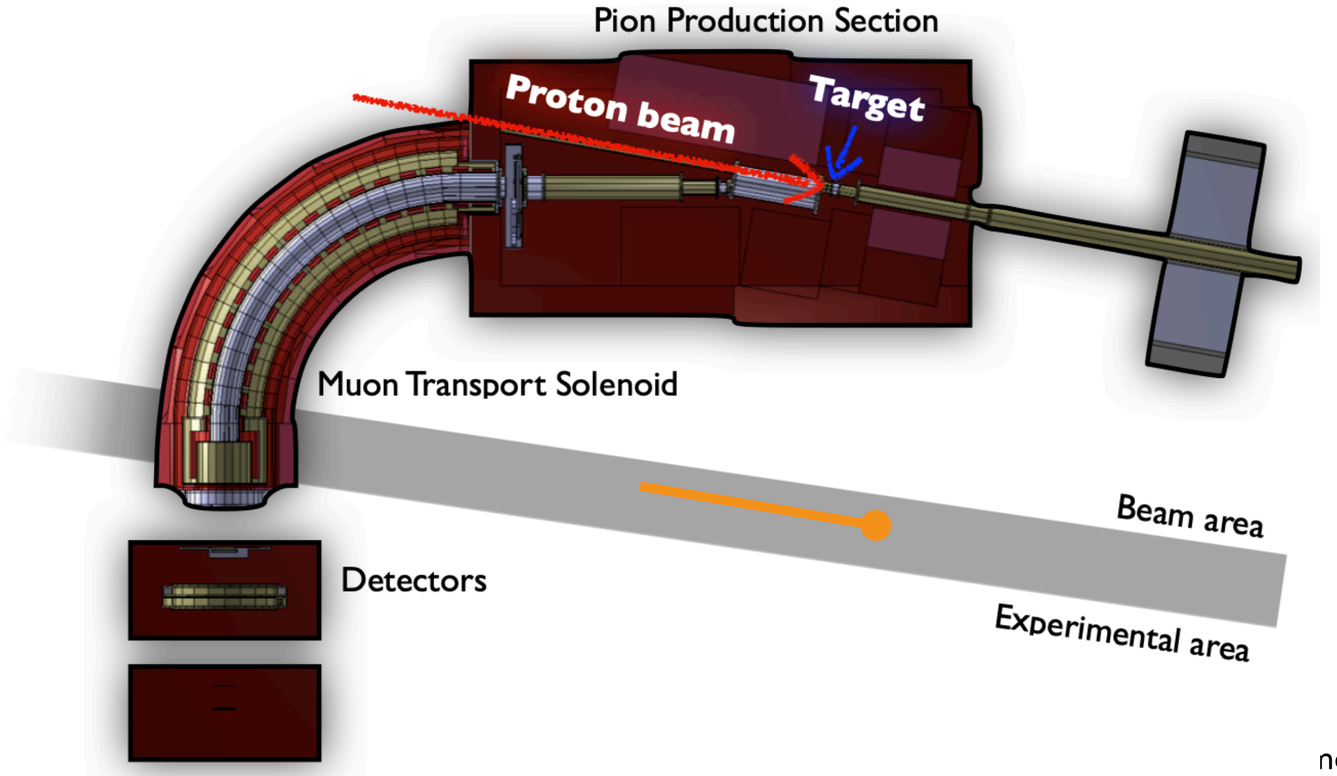


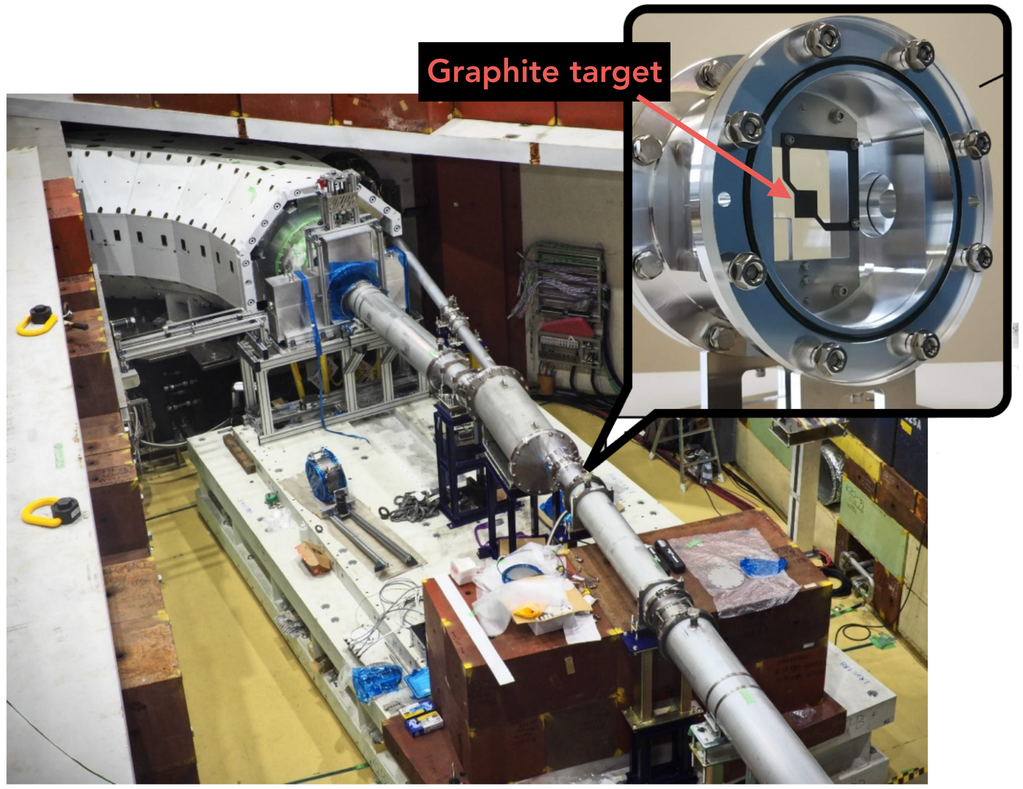




Phase-α: 1st beam commissioning

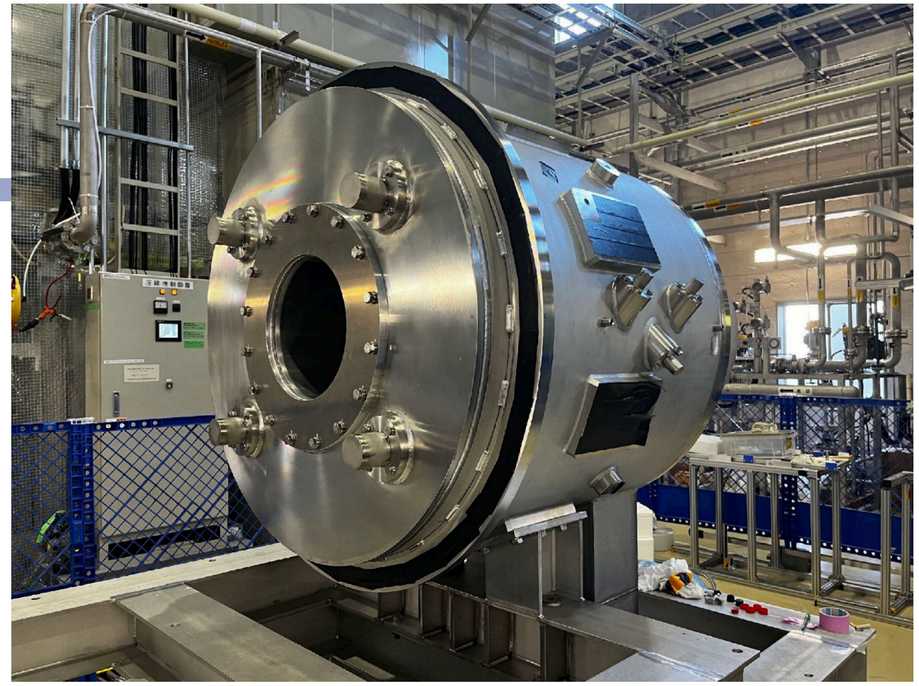
- Performed in 2023
- Measure the *proton beam profile* & *muon beam profile* after passing through the transport solenoid
- **Publication in prep.**

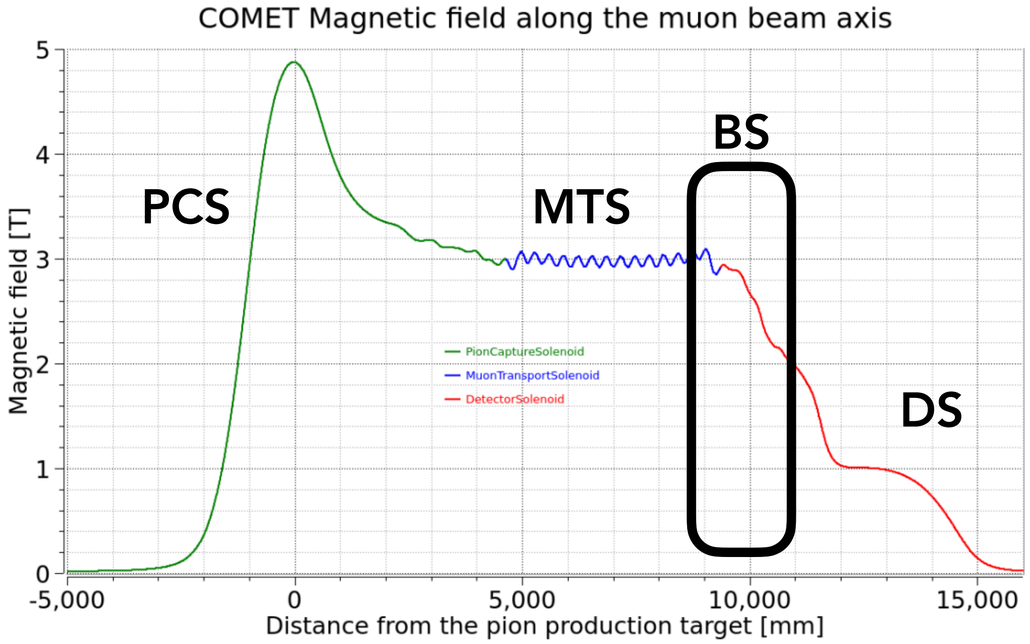




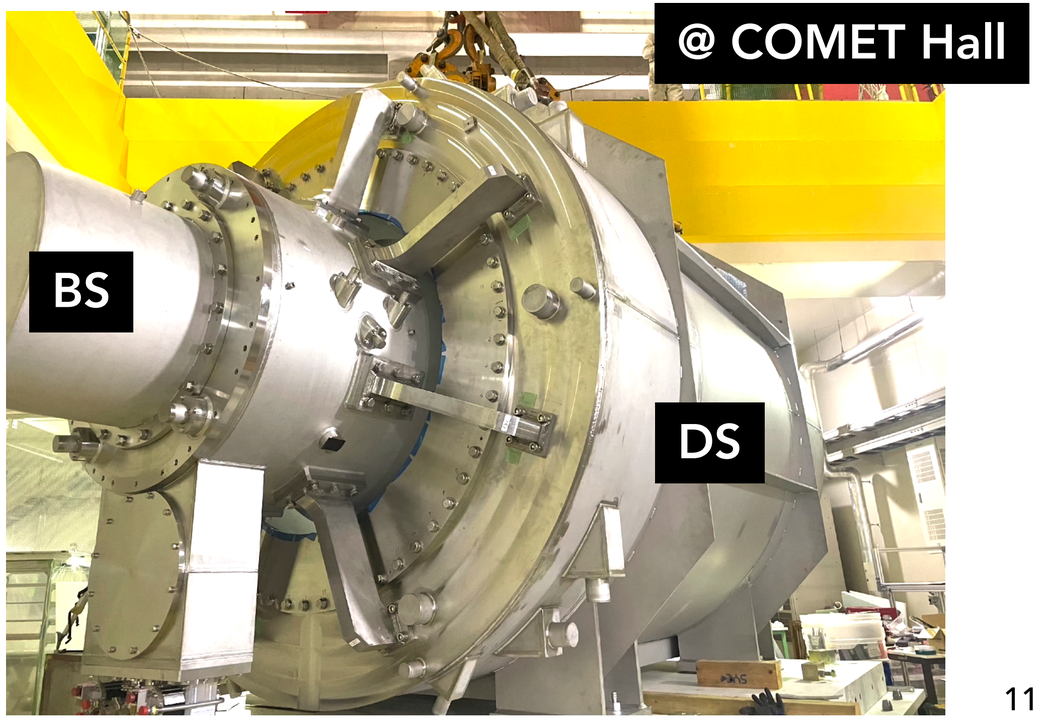
Bridge Solenoid (BS)

- Connects magnetic fields between MTS & DS
- Construction & excitation tests were completed without any problems
- Already connected with DS





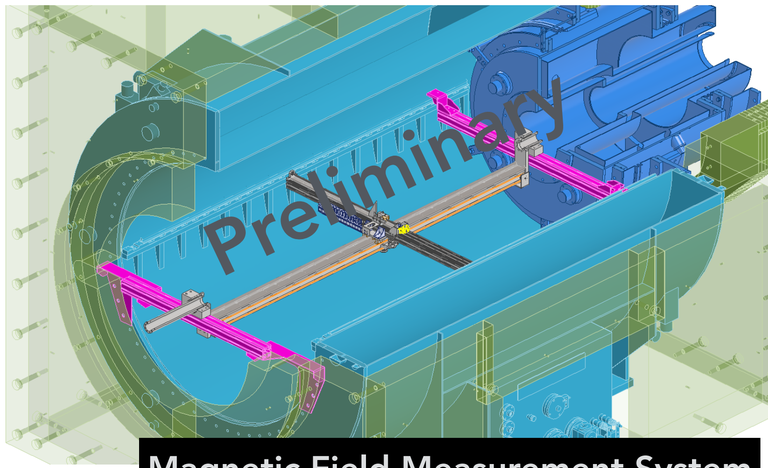
MTS



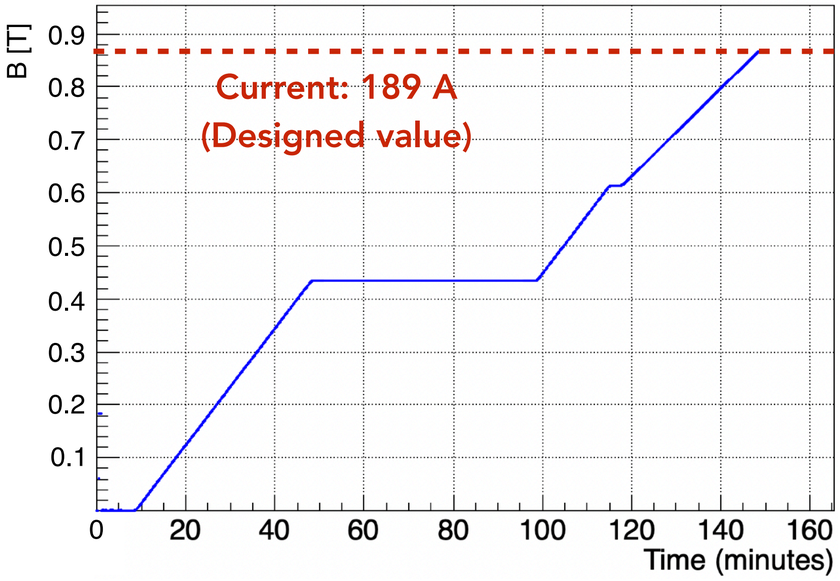
Detector Solenoid (DS)

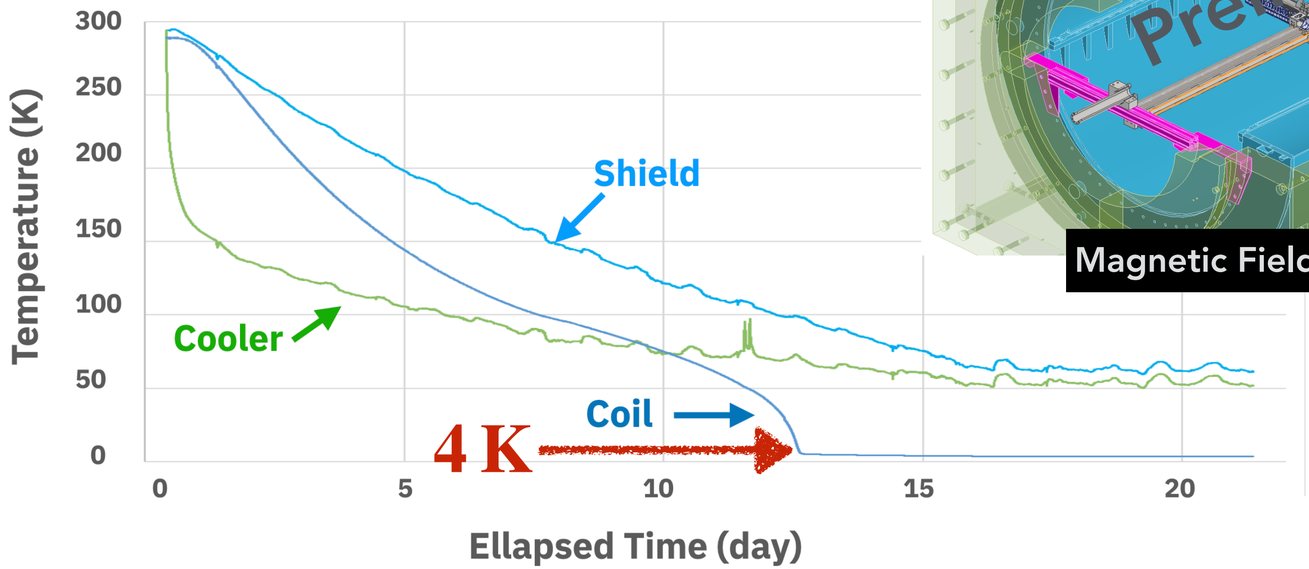
- Provide $1\,\mathrm{T}$ magnetic field to the detector
- Basic performance was successfully tested in 2024
  — published: *IEEE TASC 36(3), 4500404 (2026)*.
  - Cooled to **$4.2\,\mathrm{K}$ within 14 days** (with N_2 cooling)
  - Ramped up to the rated current **without any training quenches**
- B-field mapping (10^{-4} acc.) will be measured in 2026
  (now scheduling — *detail in a following slide*)

Delivered in KEK-Tsukuba in Sept. 2024



Magnetic Field Measurement System

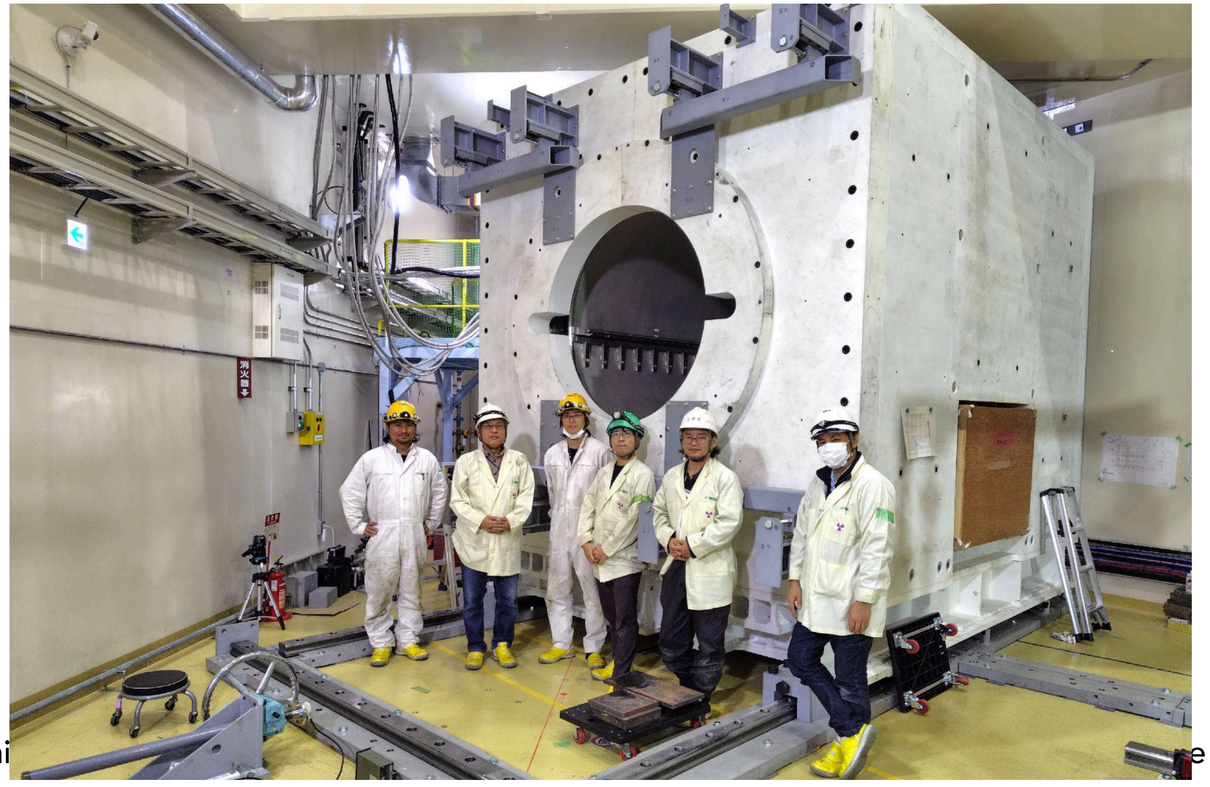




Installation of DS

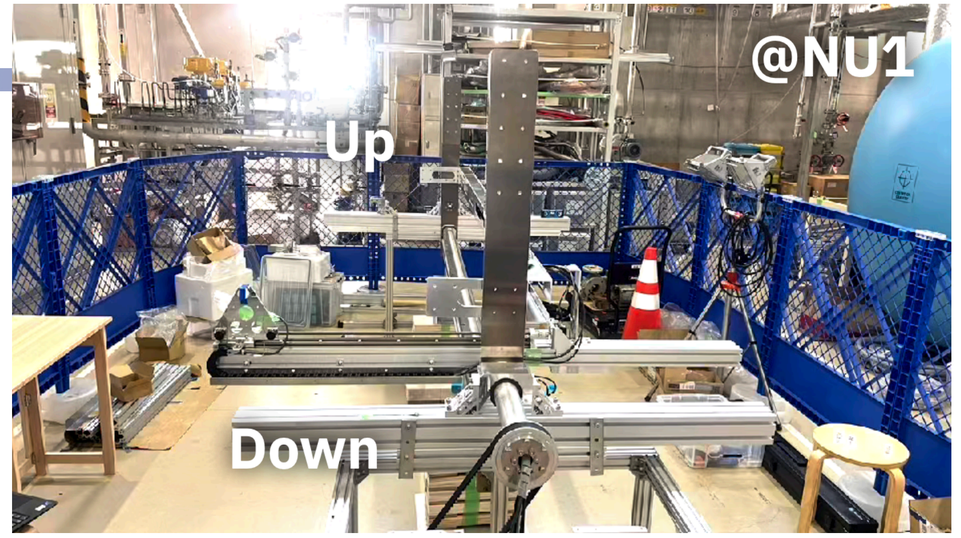
- Installation in the COMET Hall was completed in Nov. 2025
- Ready for the (integrated) B-field measurement and the detector installation!

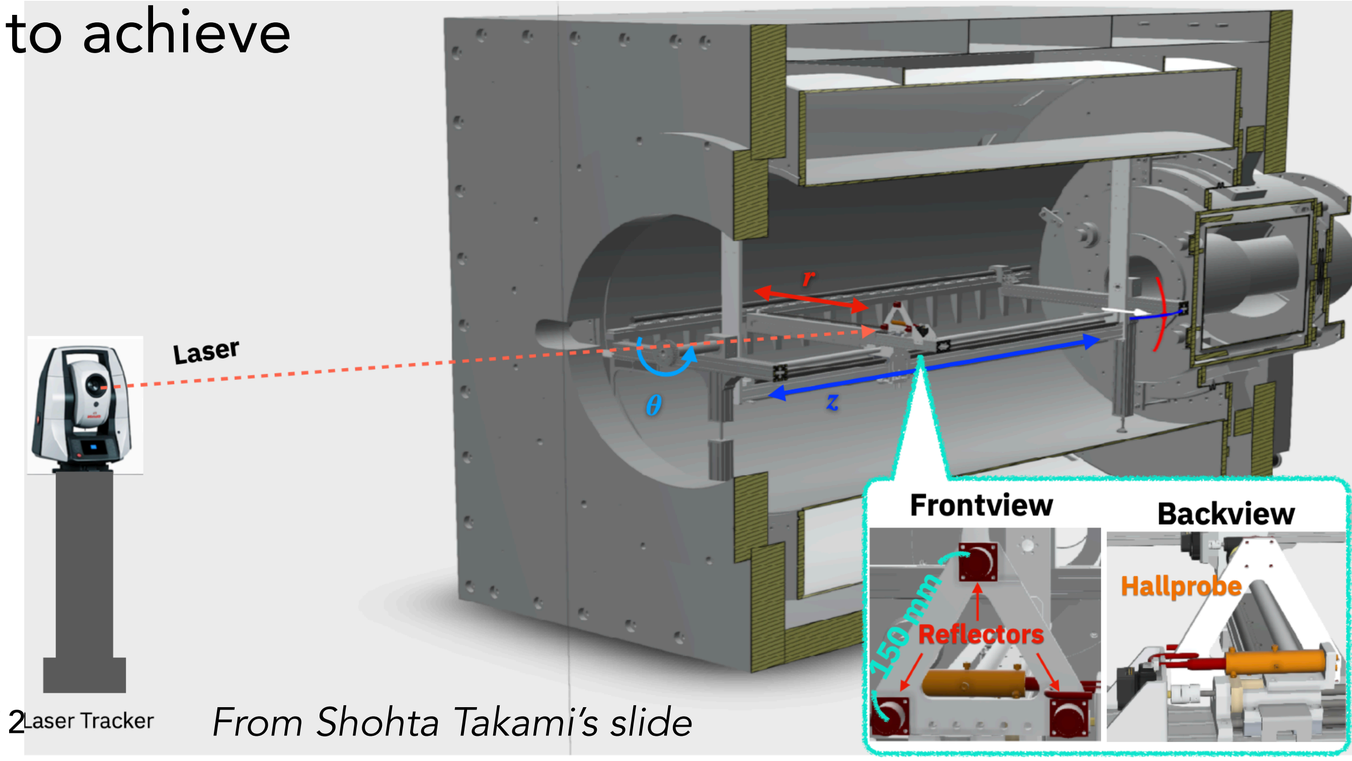
https://youtu.be/y7w5exfLMx4?si=9qHu7cPR23ywz6BK



B-Field Measurement

- Although a standalone field measurement was performed in 2024, **a precise and integrated measurement in the final experimental configuration is required**.
- Constructed a new *field mapper system* controlling rotation and keeping position tracking to achieve $O(10^{-4})\,\mathrm{T}$ accuracy,
  and performance tests are ongoing
- **Installation to the DS will start soon**

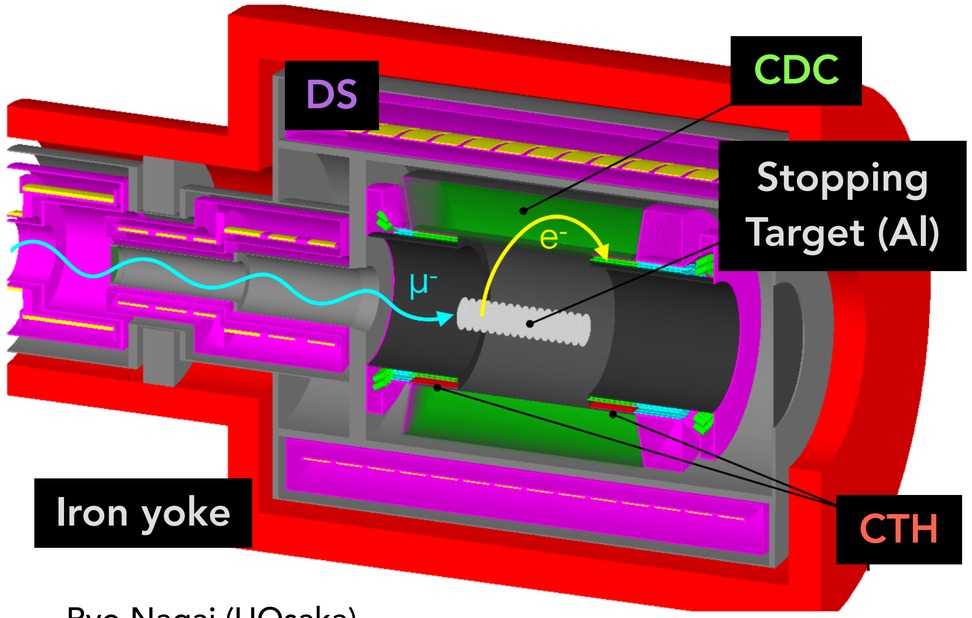


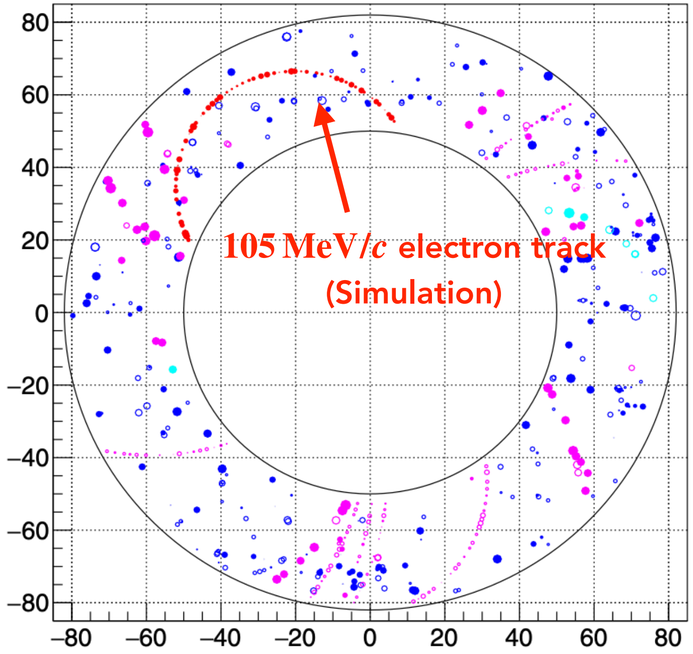


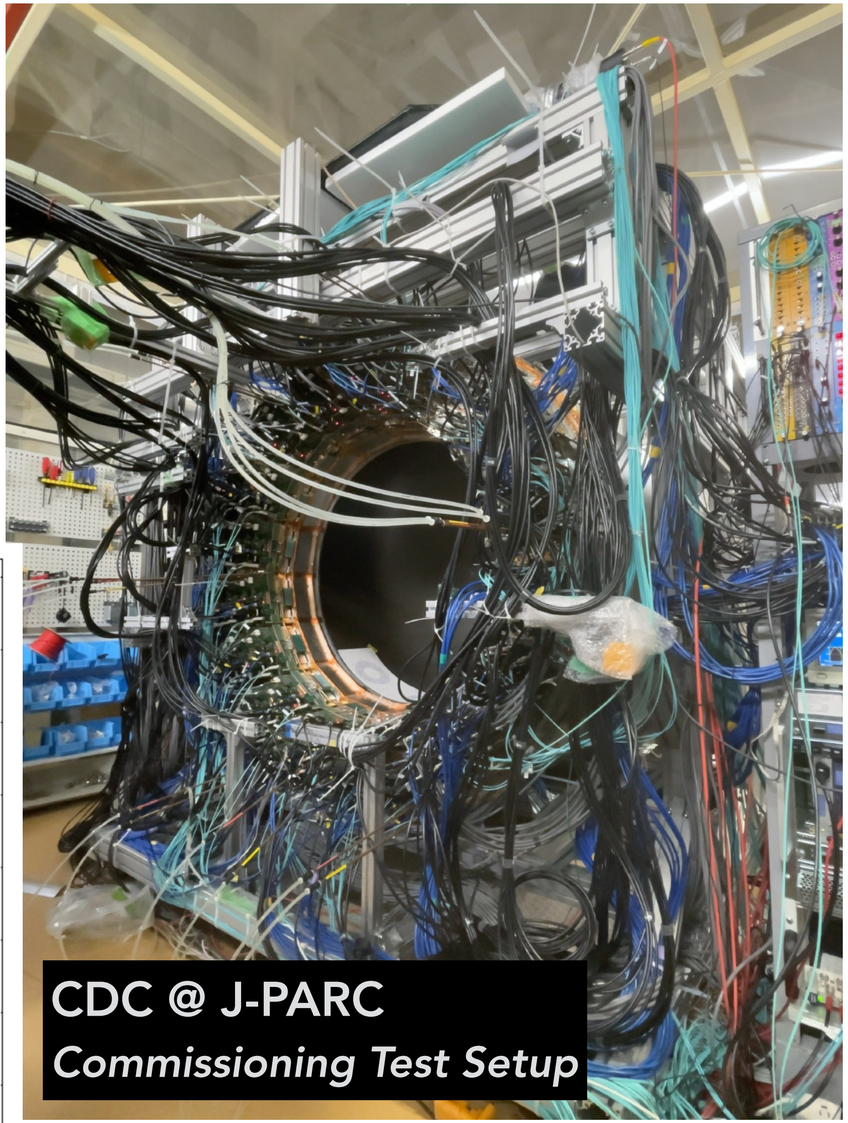
From Shohta Takami's slide

CyDet — Physics Detector

- Consists of **Cylindrical Drift Chamber** (CDC) and **Cylindrical Trigger Hodoscope** (CTH)
- **CDC**: Momentum resolution $\mathbf{200\,keV/}c$ (curvature)
  - *B-field measurement of DS is essential*
- **CTH**: 4-fold coincidences (as the first hardware trigger)

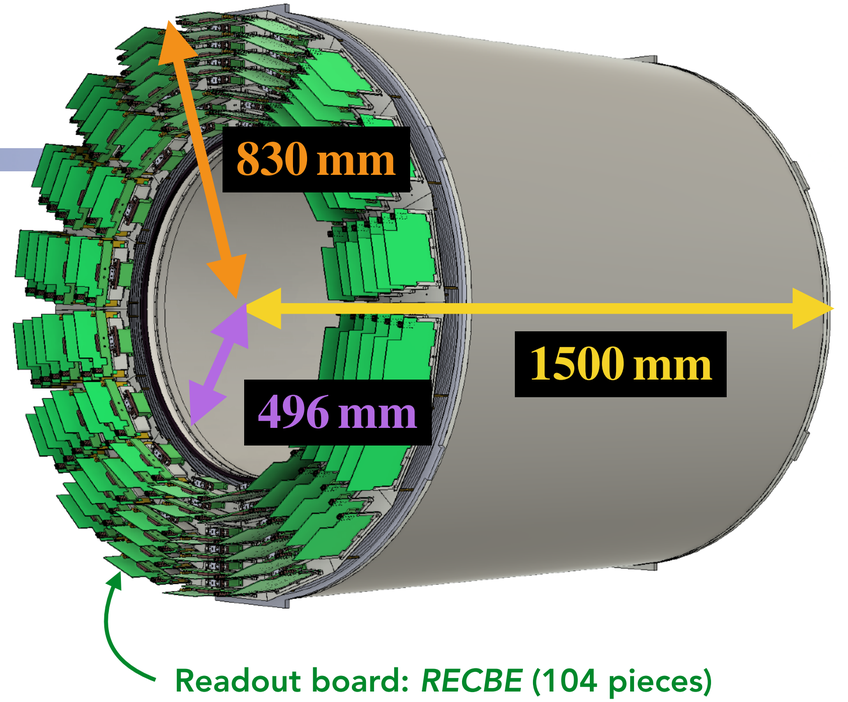




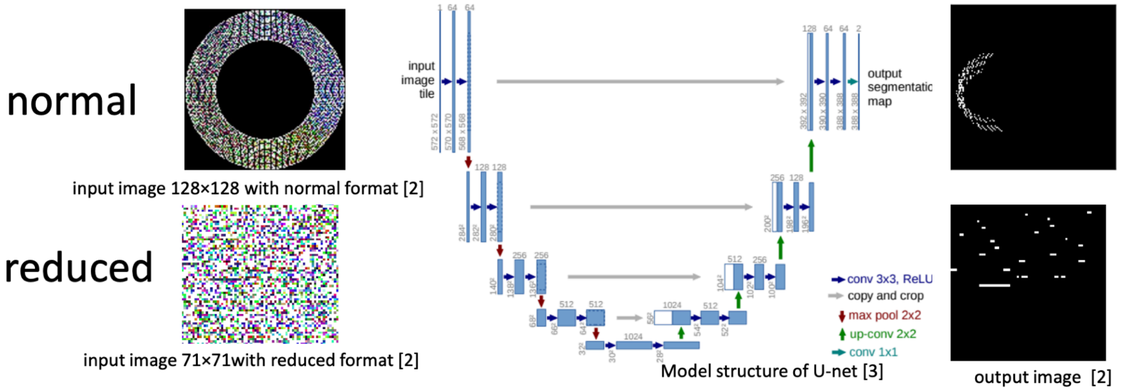


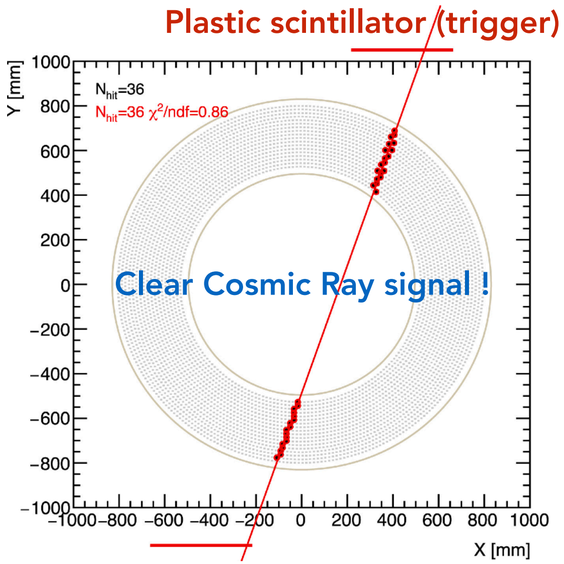
Cylindrical Drift Chamber (CDC)

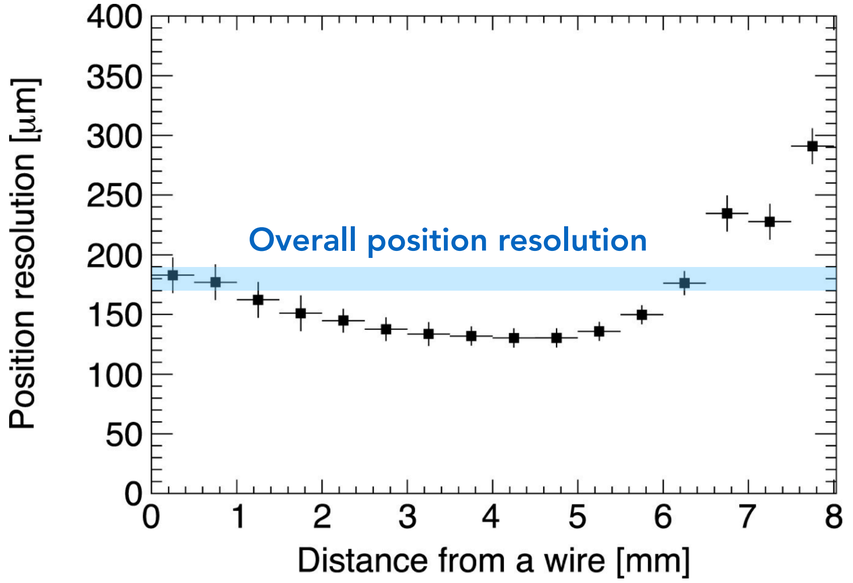
- 20 concentric layers with 4,986 sense & 14,562 field wires
- $2084\,\mathrm{L}$ volume filled with He/iC_4H_{10} (90:10)
- Basic performance test using CRs has been completed
  - (Overall) position resolution $\sim 200\,\mu\mathrm{m}$ — expected level
  - Further analysis is ongoing (gas flow dependence, …)
- Track Reco. studies with a high hit occupancy are ongoing



U-net deep-learning reconstruction scheme



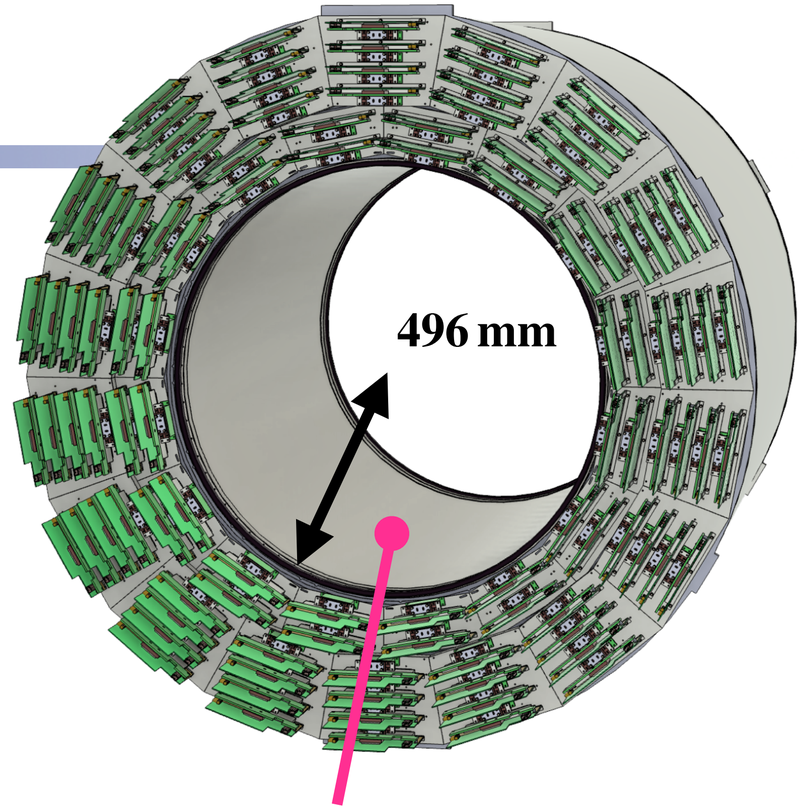




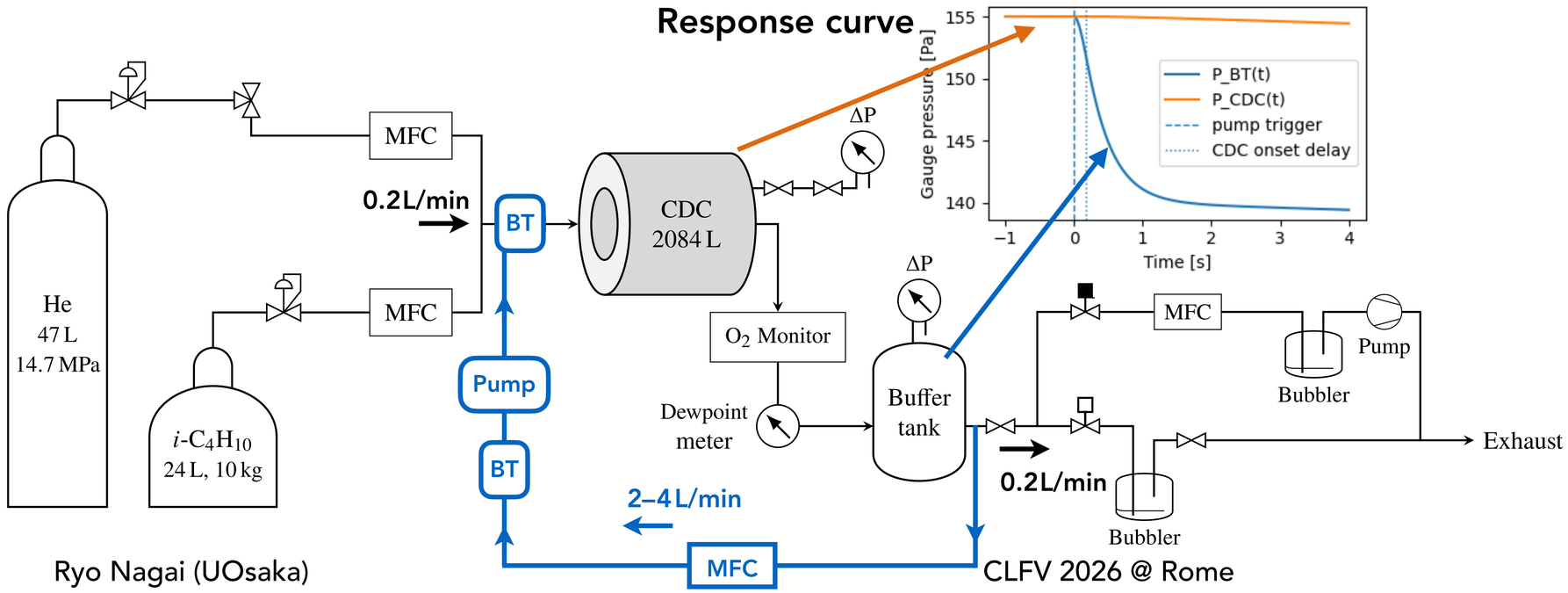
Gas Circulation System for CDC

Stable/safe CDC operation → ***precise gas/pressure control***

- To reduce contribution from low-p particles, CDC inner wall is made of thin CFRP with a large radius → easy to buckle
- To keep proper performance + safety, careful design is needed
  — transient pressure-response analysis for each component is ongoing

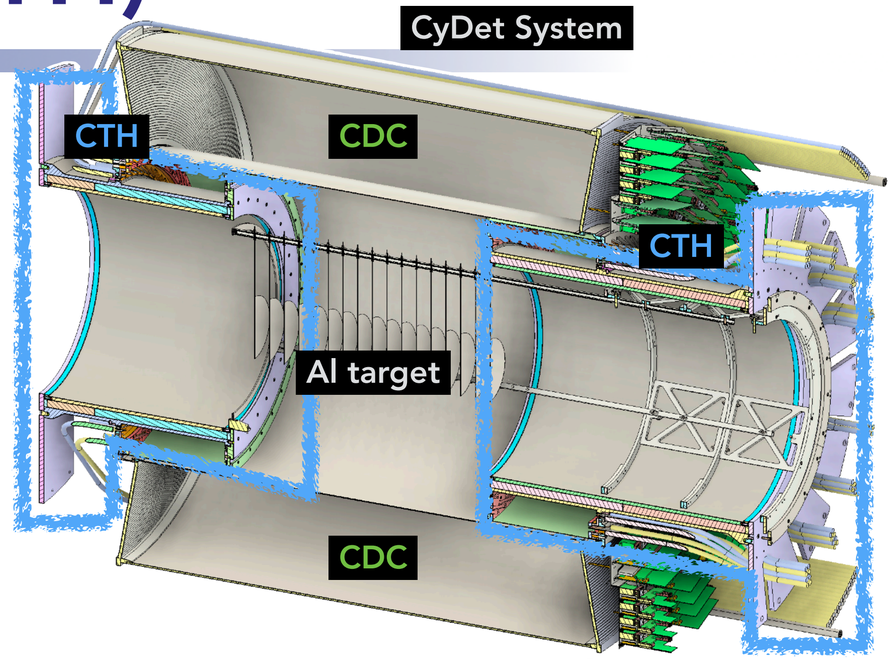


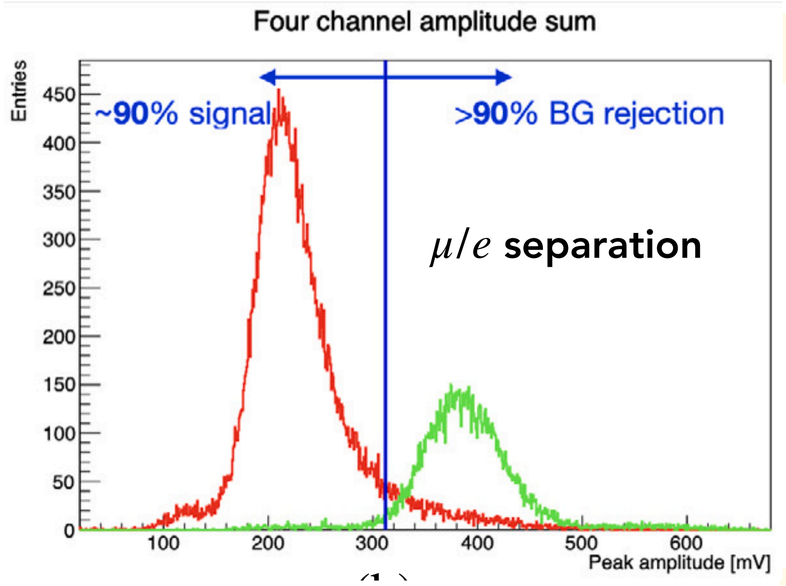
Buckling risk > 350 Pa

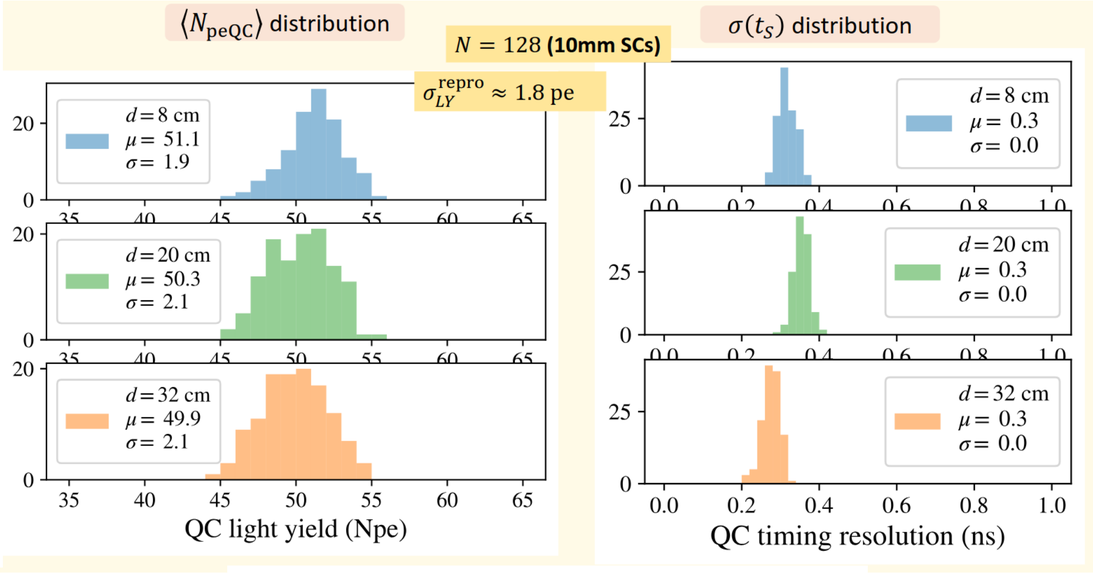


Cylindrical Trigger Hodoscope (CTH)

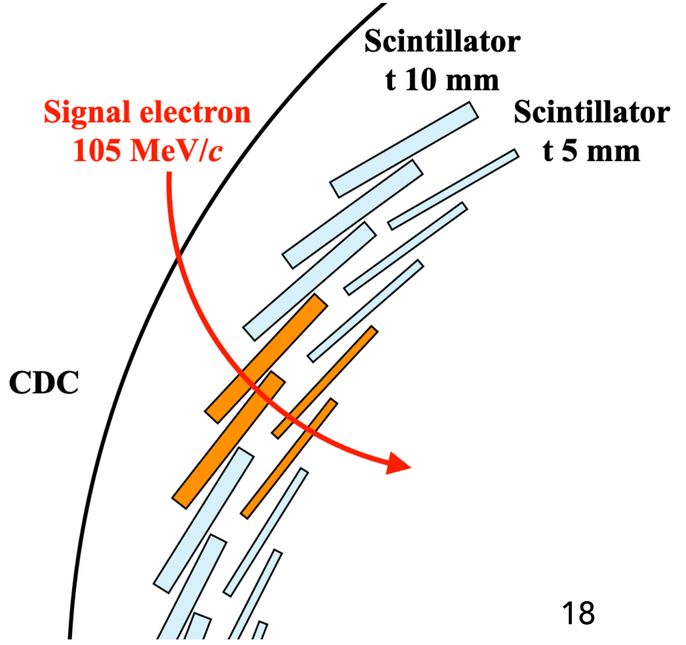
- $10\,\mathrm{mm^t}/5\,\mathrm{mm^t}$ plastic scintillators (in total 256) located at the both ends of the CDC with a MPPC readout system
  - Trigger signals generated by 4 scintillators' coincidence
  - Tilt is tuned for the signal ($105\,\mathrm{MeV}/c$ electrons)
- **μ/e separation was measured in beam test with the prototype**
- MPPC and Scintillator QC are ongoing
  - Completed: **300** for MPPCs ; **128**(all of $10\,\mathrm{mm^t}$)/256 for Scintillators







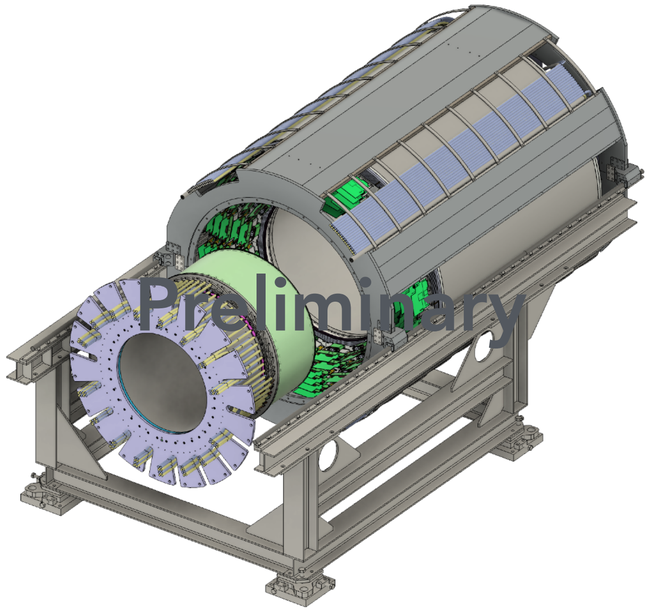
10 mm Scintillators' QC summary



NIM A 1067 (2024)169665

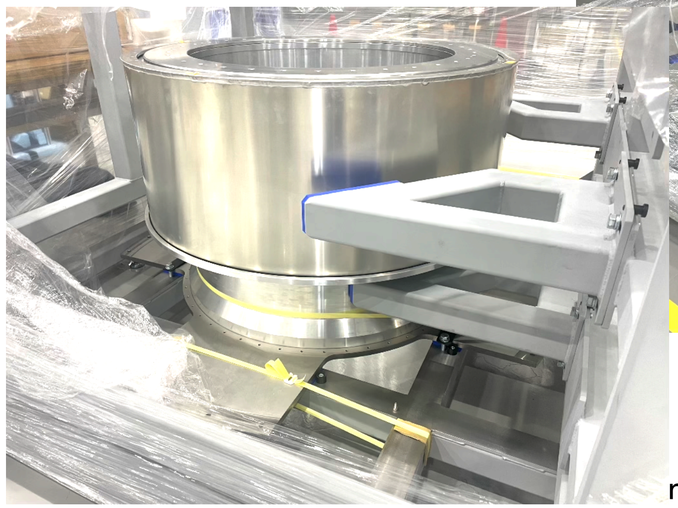
Integration

- CTH frame was already manufactured
- CDC+CTH will be installed in a stainless-steel support structure
- This structure was constructed and now testing a scheme of the integration of CDC+CTH
- **The system is getting ready for installation!**

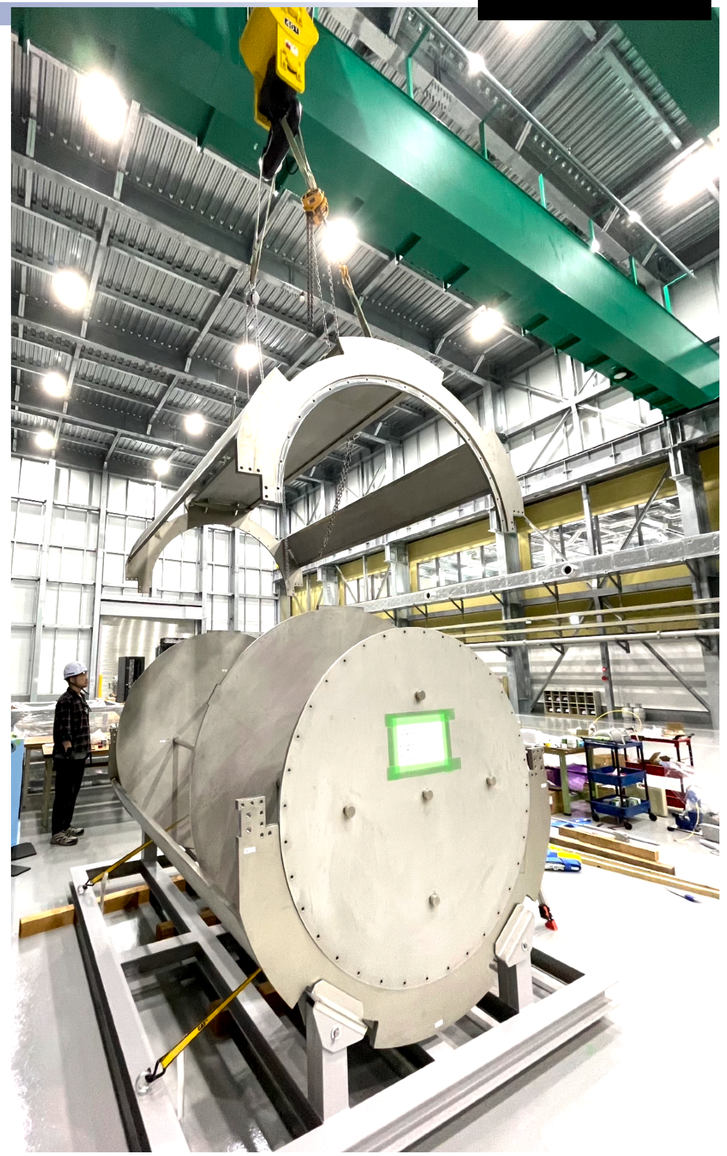


Cydet mount draft

CTH frame ▶

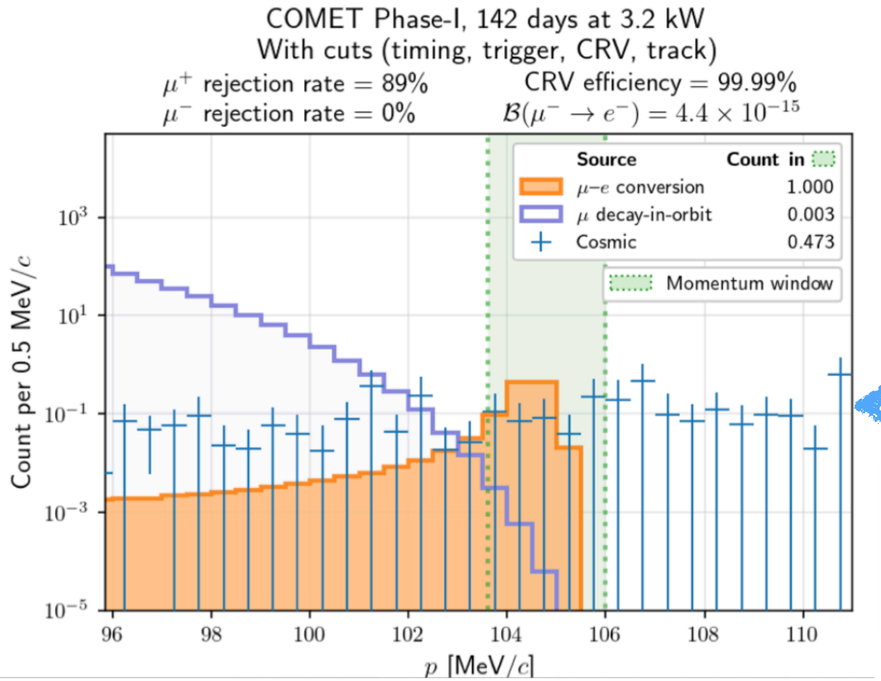


@ J-PARC

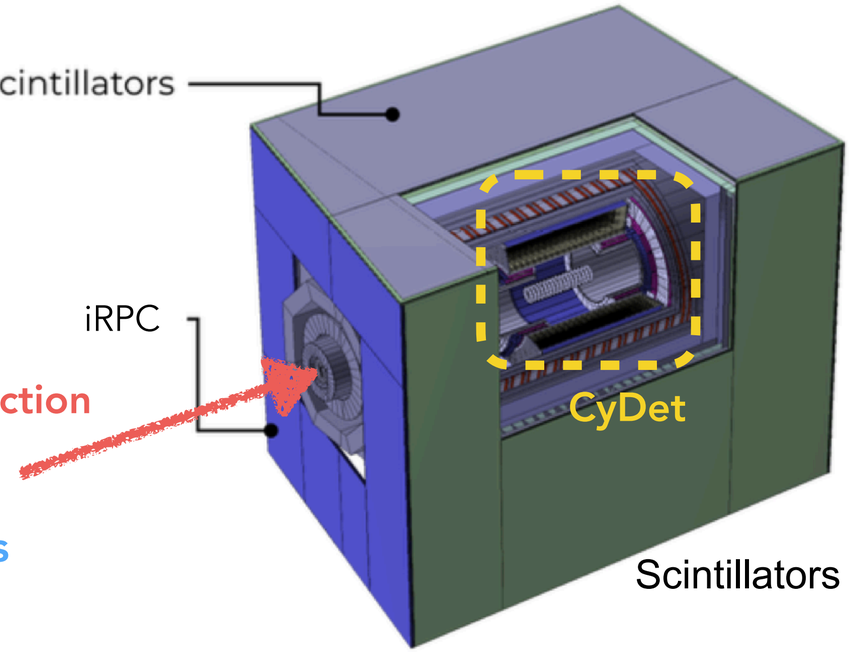


Support structure ▲

Cosmic Ray Veto Detectors

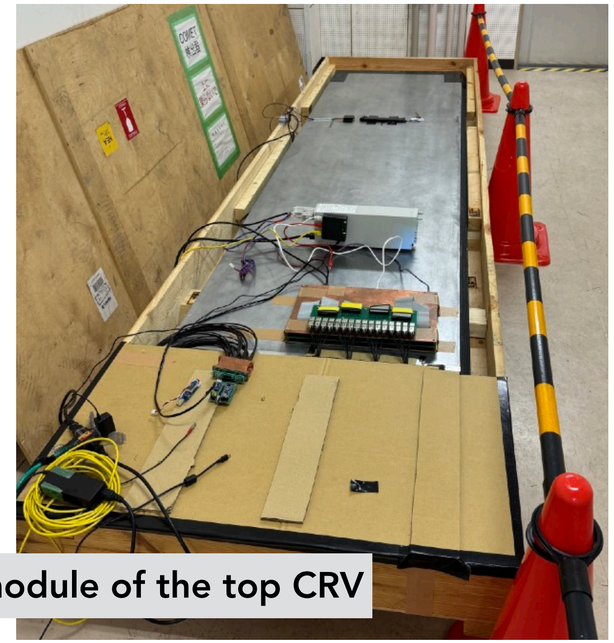


Large contribution from Cosmic Rays



CRV ensures >99.99% cosmic rejection — indispensable for COMET sensitivity.

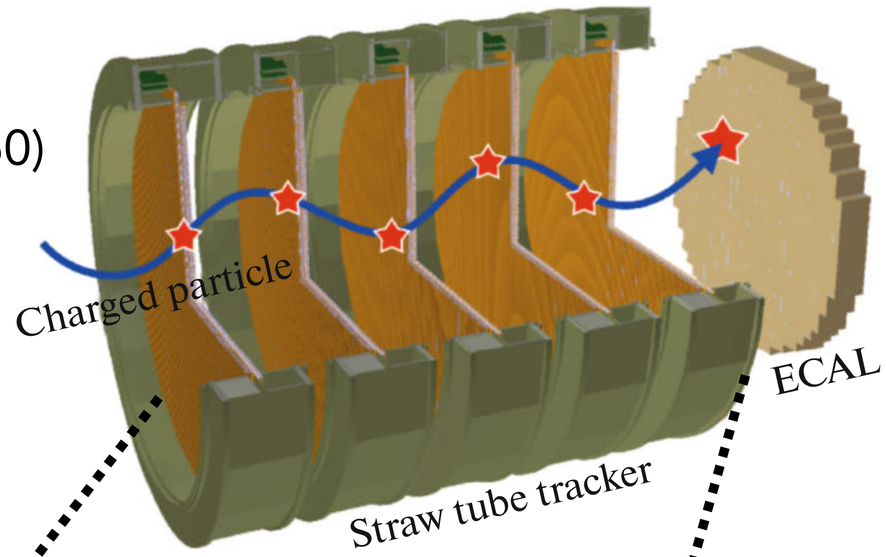
- Nearly full coverage except the beam holes, using different technologies
  - Top/Side CRV: plastic scintillator layers (considering ARGO-RPC also)
  - Up/Downstream CRV: improved RPCs
- Scintillator CRV is **under construction**, and RPC-based CRVs are under development.

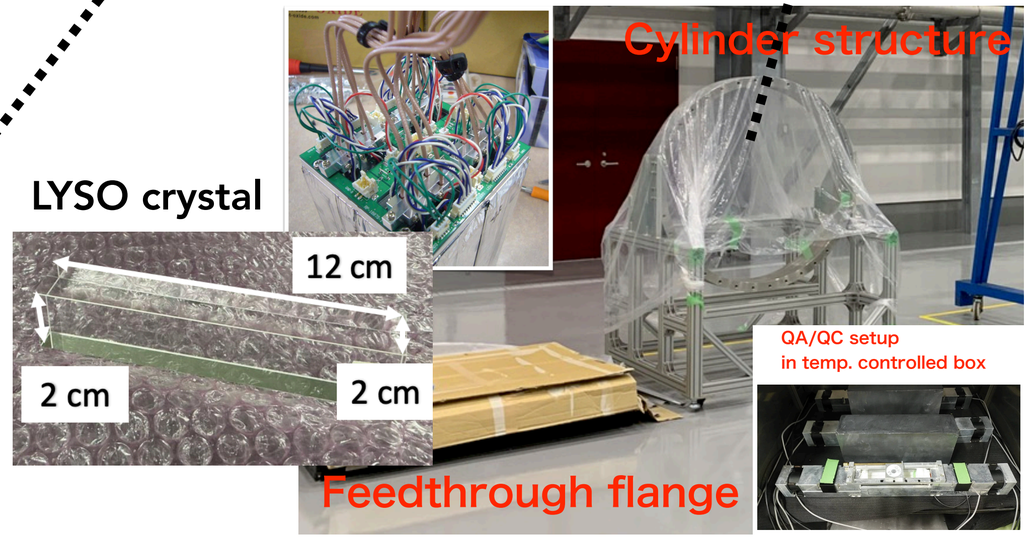


First module of the top CRV

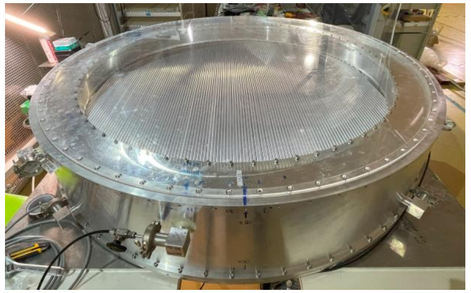
StrECAL — Beam Measurement & Phase-II Prototype

- **Straw tracker**:
  - 2,400 straws ($\phi 10\,\mathrm{mm}$, $20\,\mu\mathrm{m}$ aluminized Mylar), gas: Ar/C_2H_6 (50:50)
  - **(3/5) station completed**, 4th/5th under construction
  - Spatial resolution achieved $\sim 110\,\mu\mathrm{m}$ (prototype; req: $< 200\,\mu\mathrm{m}$)
- **Calorimeter**:
  - Structure has been built: ready
  - LYSO crystal (**485**/512) QC/QA ongoing (light yield, irradiation)
  - APDs: **all delivered**; QA in progress
  - Electronics: final version under refinement and validation

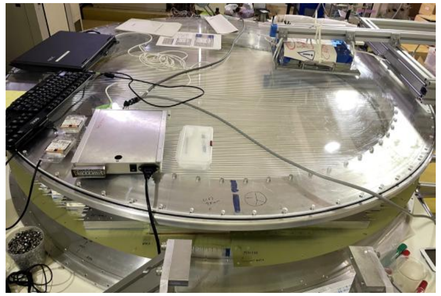




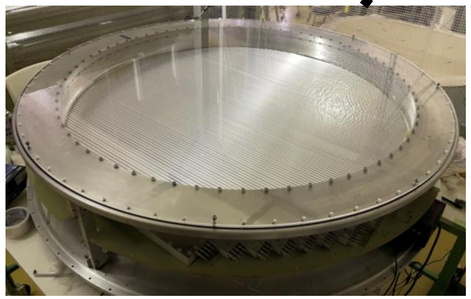
1st station



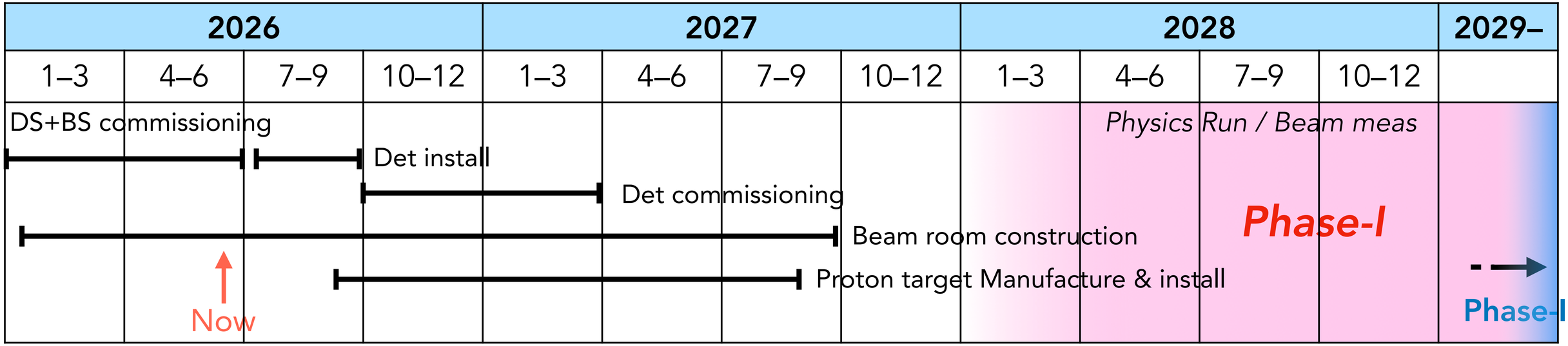
2nd station



3rd station



Phase-I Timeline



- Precise B-field meas will be performed soon
- Detector install planned this year
  - Components ready for install

Phase-II Outlook

- Target SES $\sim 10^{-17}$ (**×10,000** beyond previous limits)
- Key Upgrades:
  - Introduce the **Electron Transport Solenoid**
    — complete “double c-shape” curved geometry
  - Improve background suppression (cosmic ray veto, shielding)
  - Improve the detector and DAQ performance based on the Phase-I results

Summary

- COMET searches for $\mu^- \to e^-$ conversion using muonic atoms
- **Phase-I**: construction will be completed in ~1.5 years
  → **Physics run is planned to start in 2028** (target SES $\sim 10^{-15}$)
- **Phase-II**: target SES $\sim 10^{-17}$ with full transport solenoid system and better background suppression based on Phase-I results
- COMET can provide a leading probe of CLFV and New Physics scale up to $\sim 10^5\,\mathrm{TeV}$