Current Status and Prospects of the COMET Experiment at J-PARC

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On behalf of the COMET Collaboration

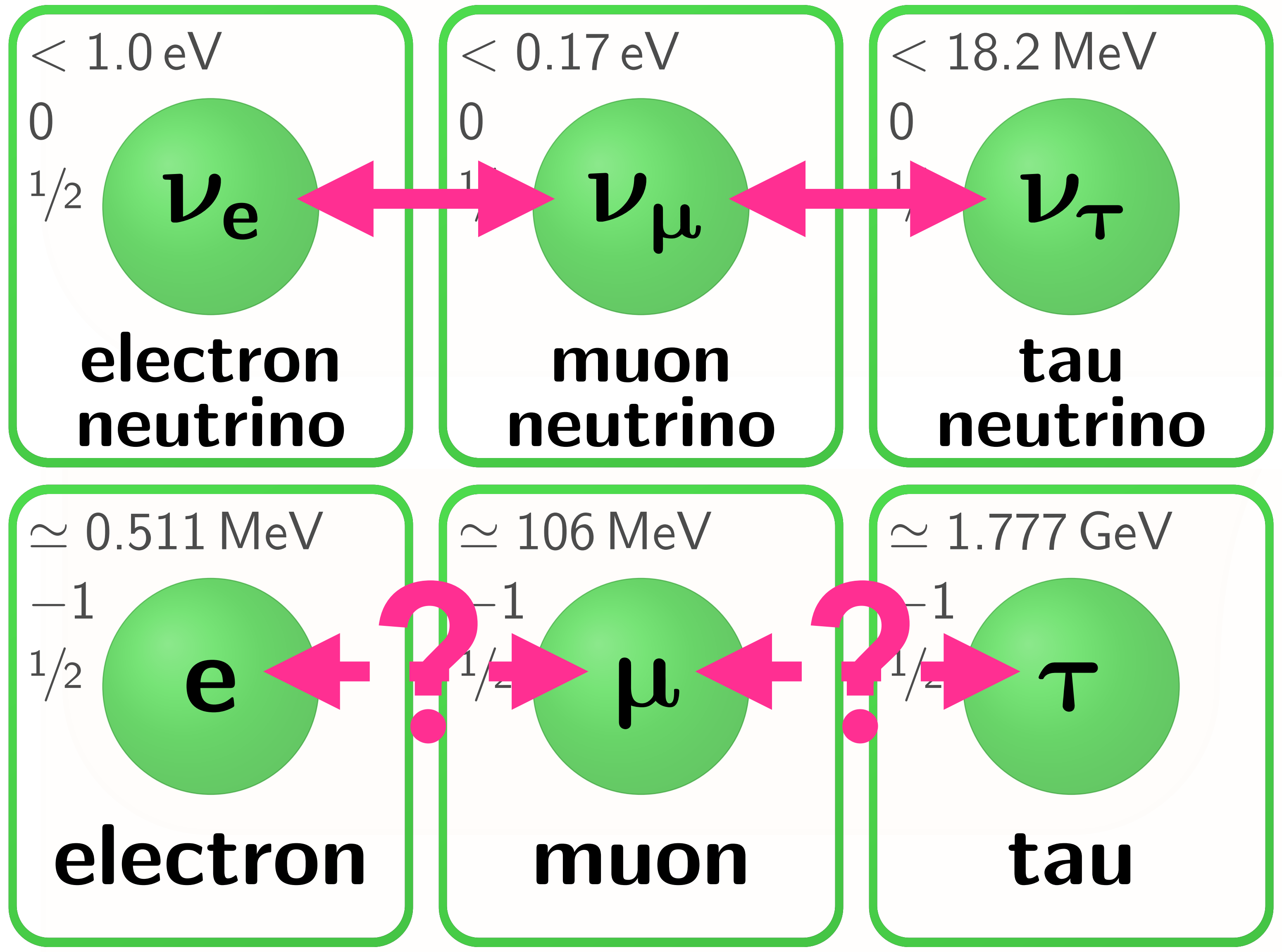
Why CLFV?

- Quark sector → CKM flavor mixing
- Lepton sector → Neutrino oscillations (PMNS)
- But: ***No evidence of charged lepton mixing***
- In the SM with neutrino oscillations:

$$\mathrm{BR}(\mu \to e\gamma) \propto \left| \sum U^*_{\mu i} U_{ei} \frac{m^2_{\nu_i}}{M^2_W} \right|^2 \sim 10^{-54}$$

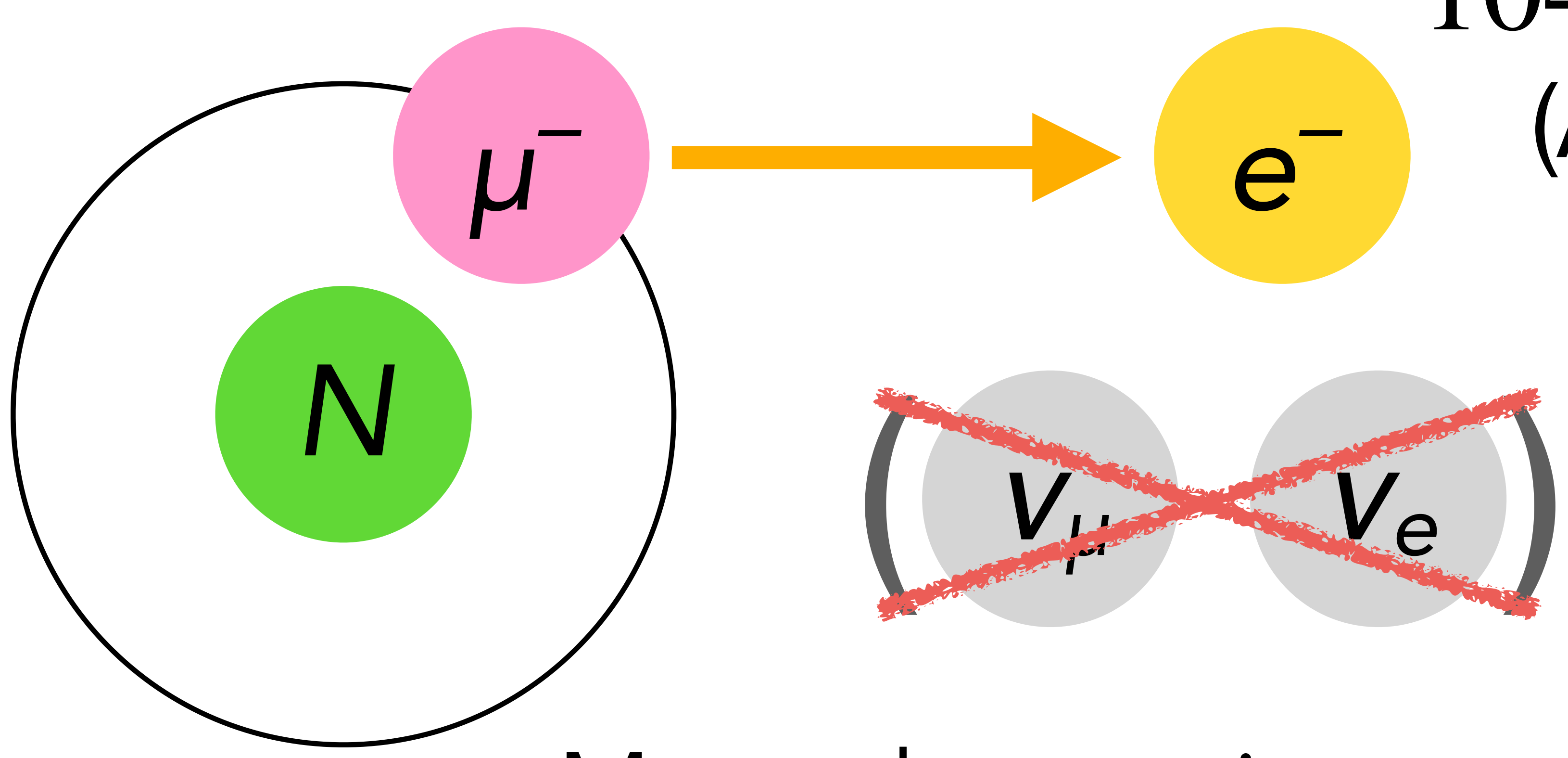
(essentially forbidden)

- New Physics models: SUSY, GUT, Seesaw, etc. *predict enhanced rates (can be close to the current limits)*



Any experimental signal would be a clear evidence of New Physics

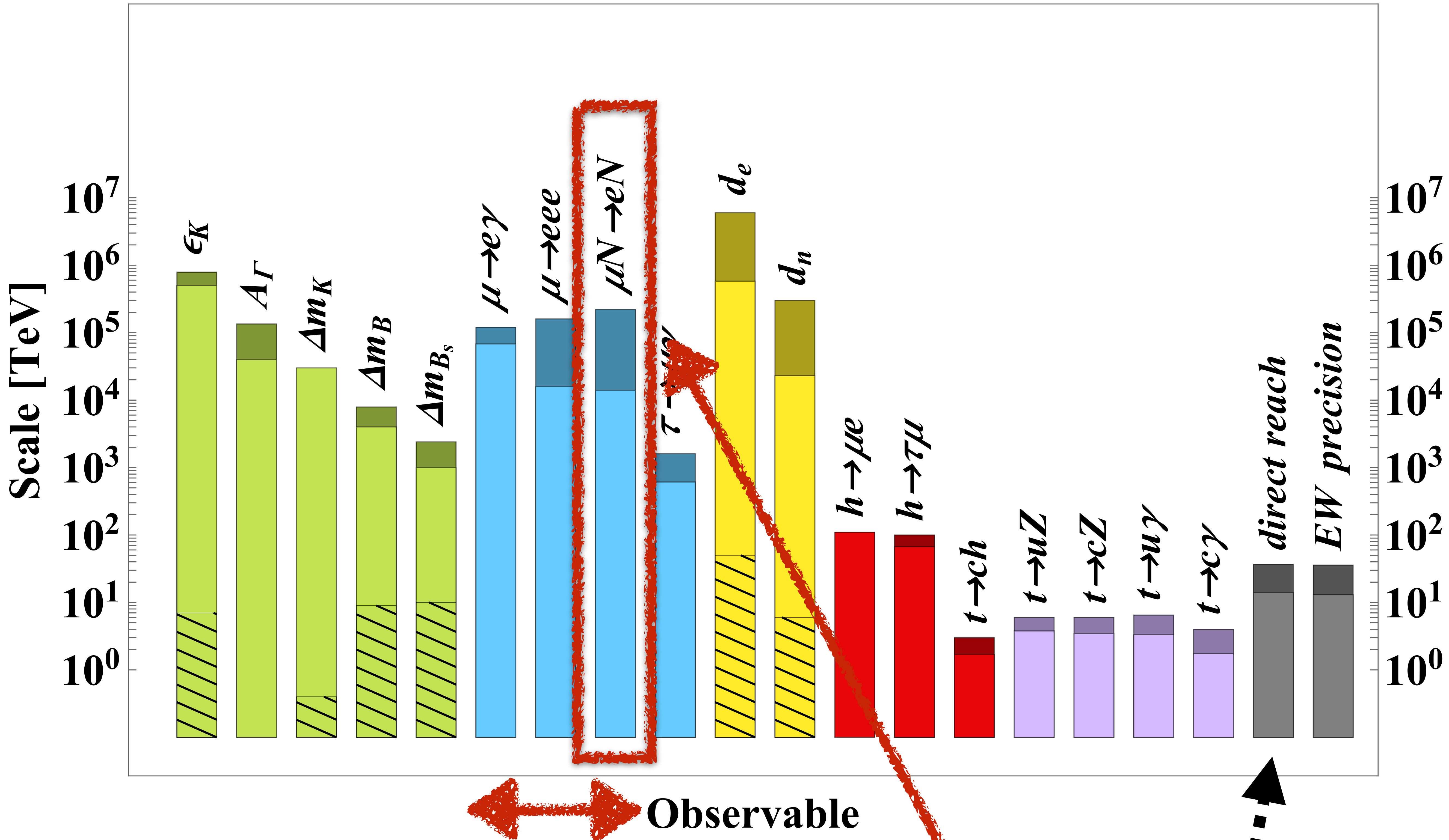
Muon-to-Electron Conversion ($\mu^- N \to e^- N$)



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

Monochromatic momentum
electron w/o neutrinos
→ ***clean signals***

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



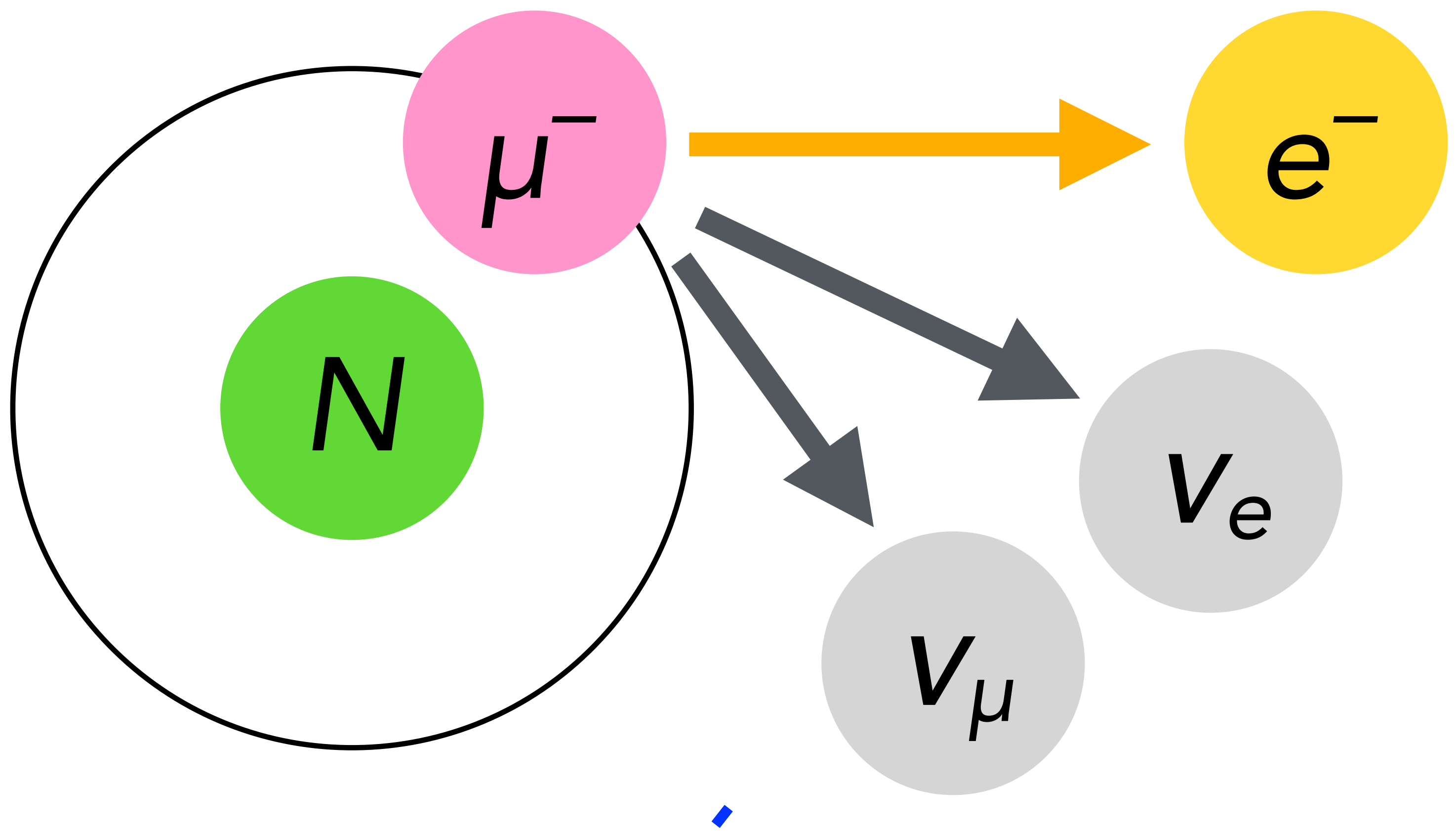
$\mu N \to eN$ is a frontier for fundamental discovery

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***

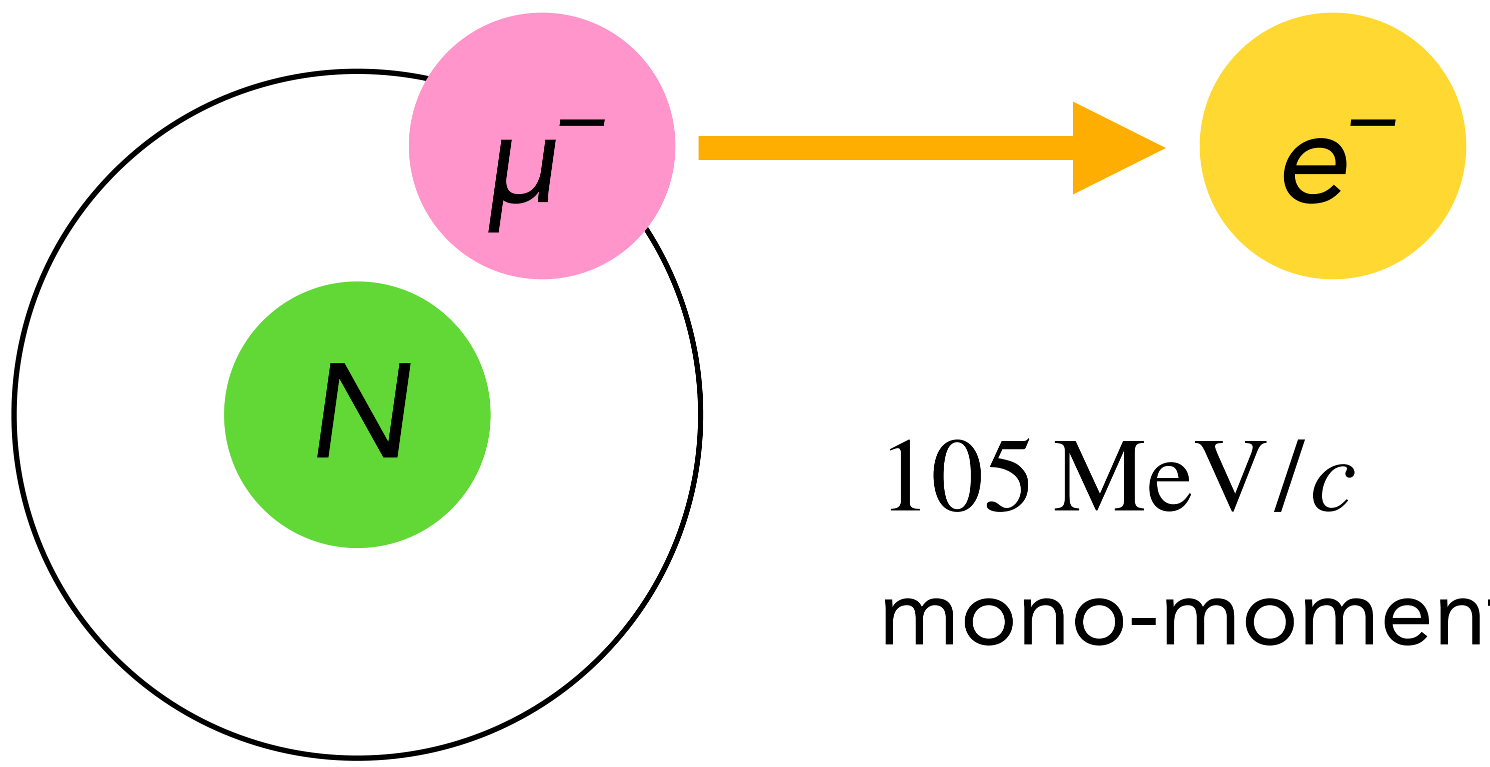
Search for μ-e conversion

Decay-in-Orbit (DIO) : background

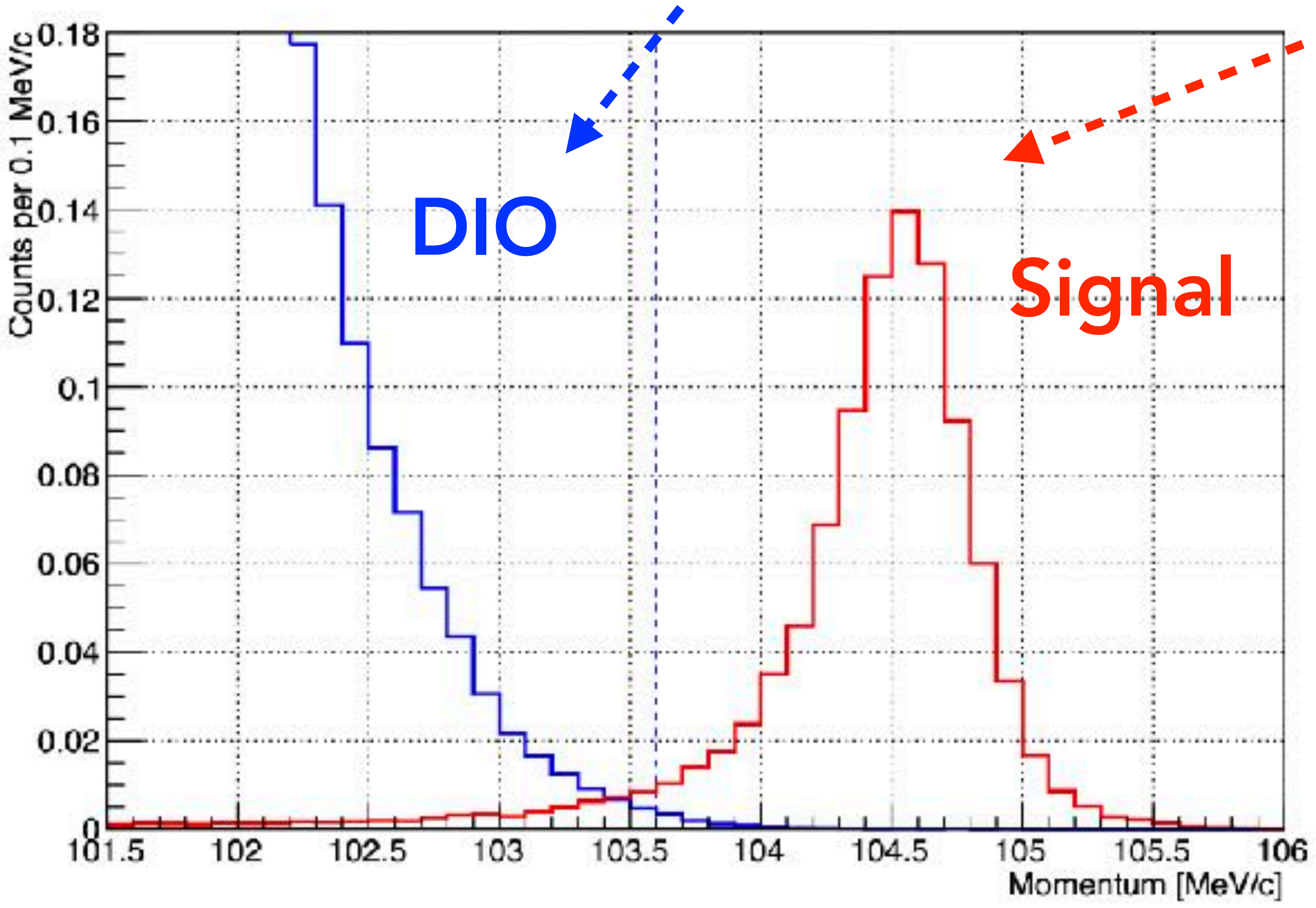


Continuous spectrum
$105\,\mathrm{MeV}/c$ endpoint

Signal



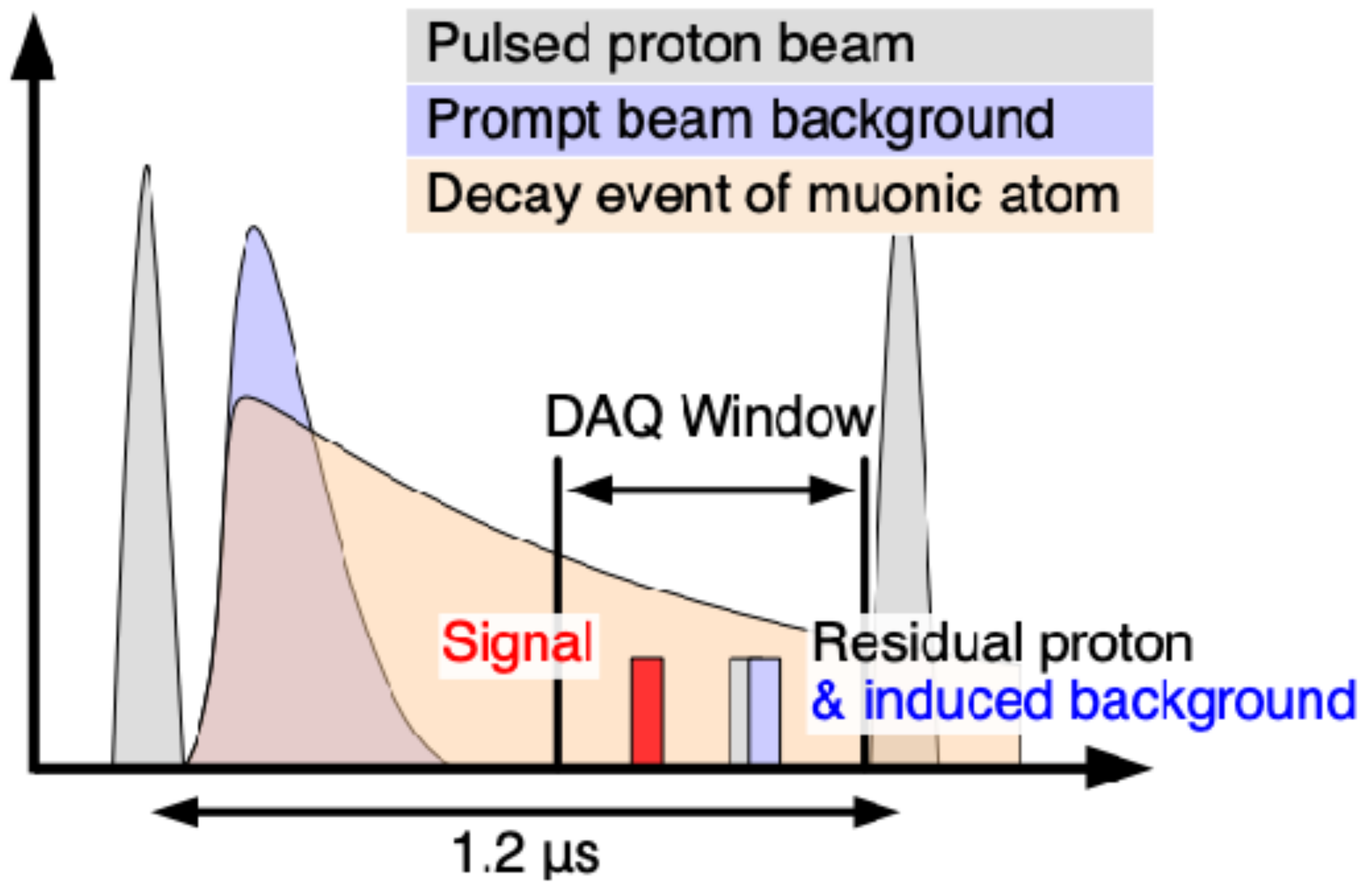
$105\,\mathrm{MeV}/c$
mono-momentum



Simulation with $200\,\mathrm{keV}/c$

- **Excellent momentum resolution** is a key to separate
- Other backgrounds:
  - ***Cosmic rays***: high-energy electrons & muons mimicking the signal → **Veto**
  - ***Beam-related***:
    - → **"C-shape" & delayed time window**
    - — Long μ lifetime needed… target material selection is a key (→ **Al** is adopted in COMET)

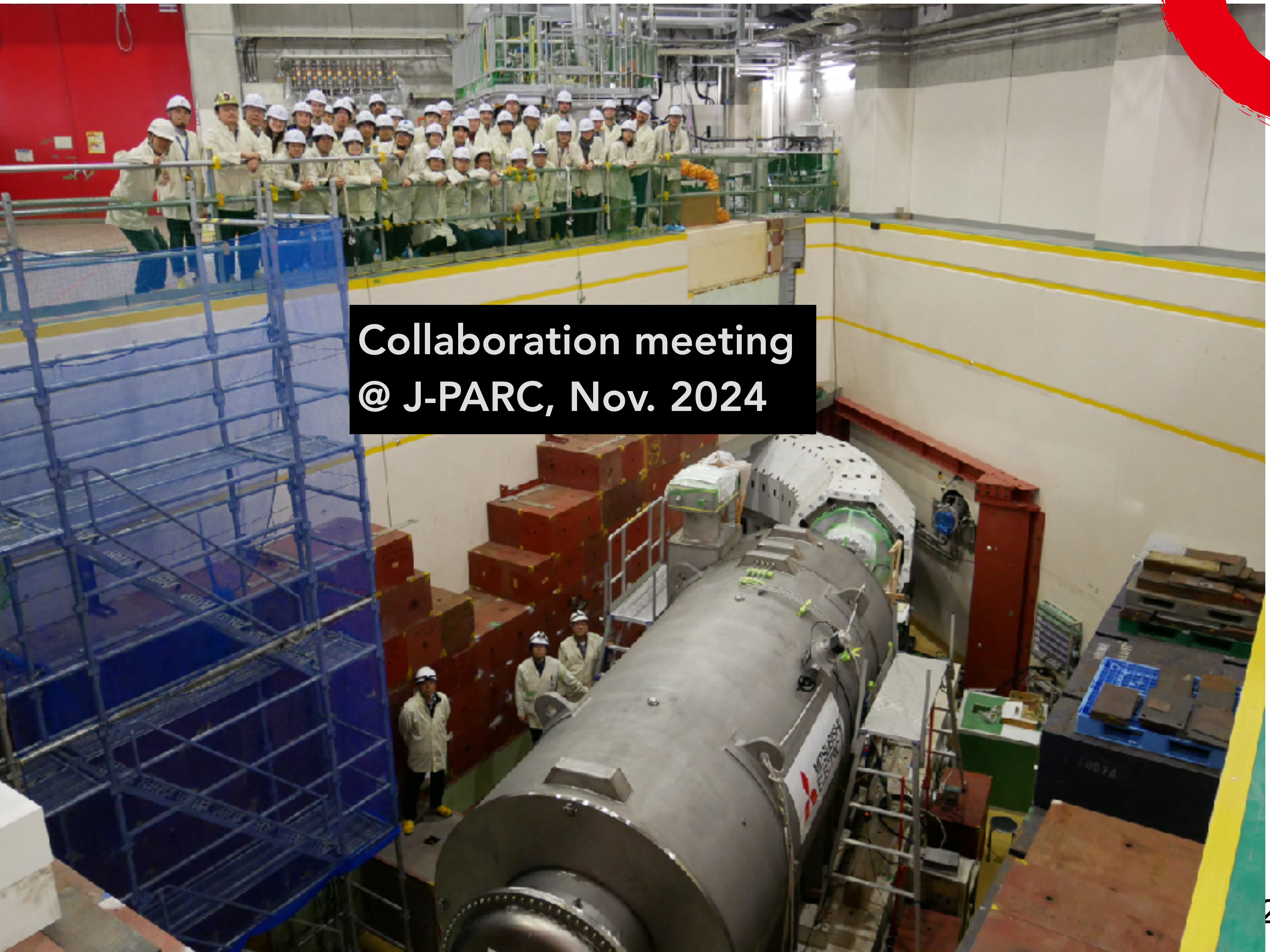
PoS(NuFact2021)104



COMET Collaboration

>10 countries / >50 institutes

>200 collaborators



Collaboration meeting
@ J-PARC, Nov. 2024

Collaboration meeting
@ LPCA, July 2025

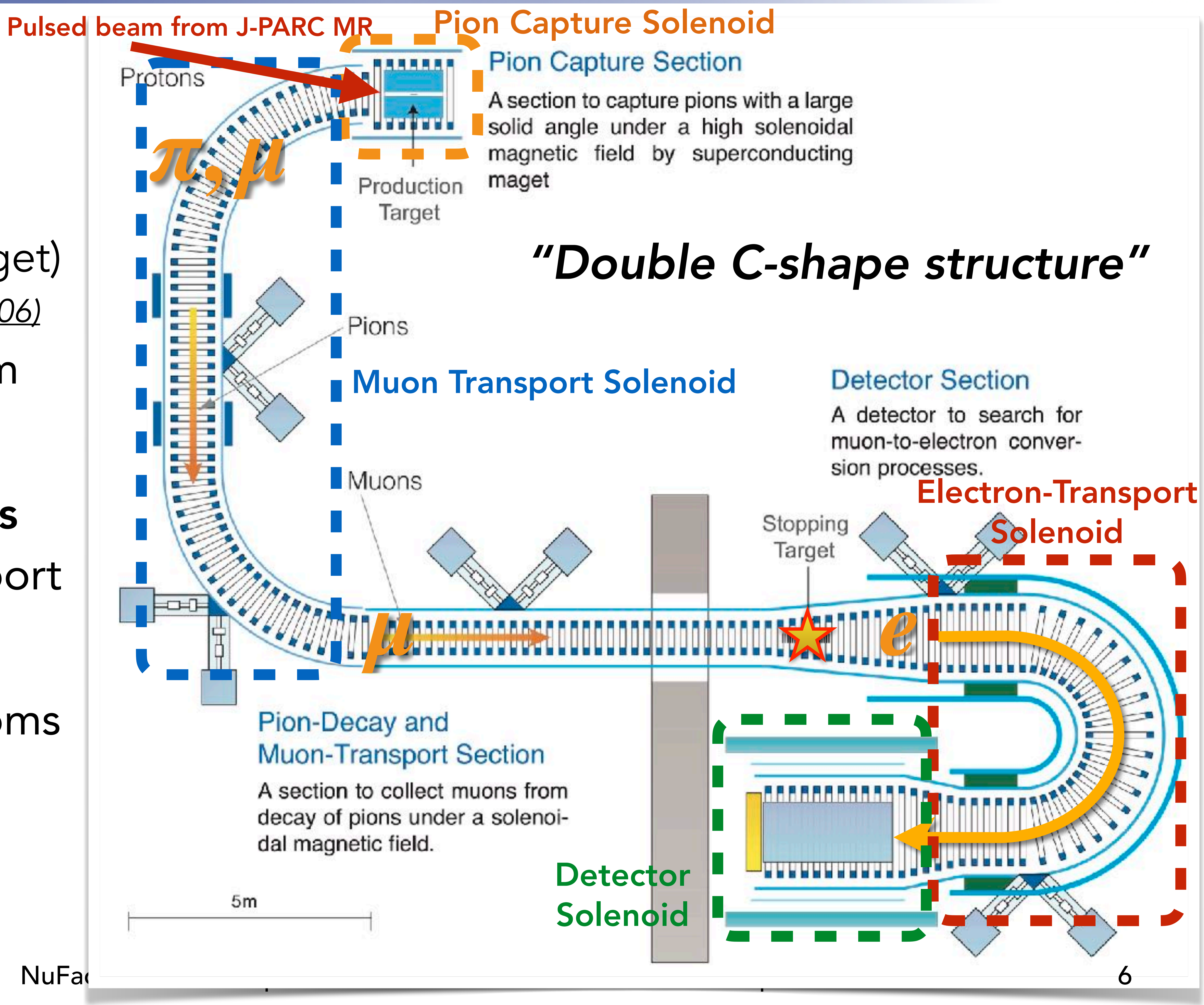
COMET Experiment

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 types of superconducting solenoids** for efficient capture and curved transport
  - ***C-shape***… different from Mu2e
- **Al** stopping target to form muonic atoms
- Detector system optimized for $105\,\mathrm{MeV}/c$ electrons



COMET Phase-I

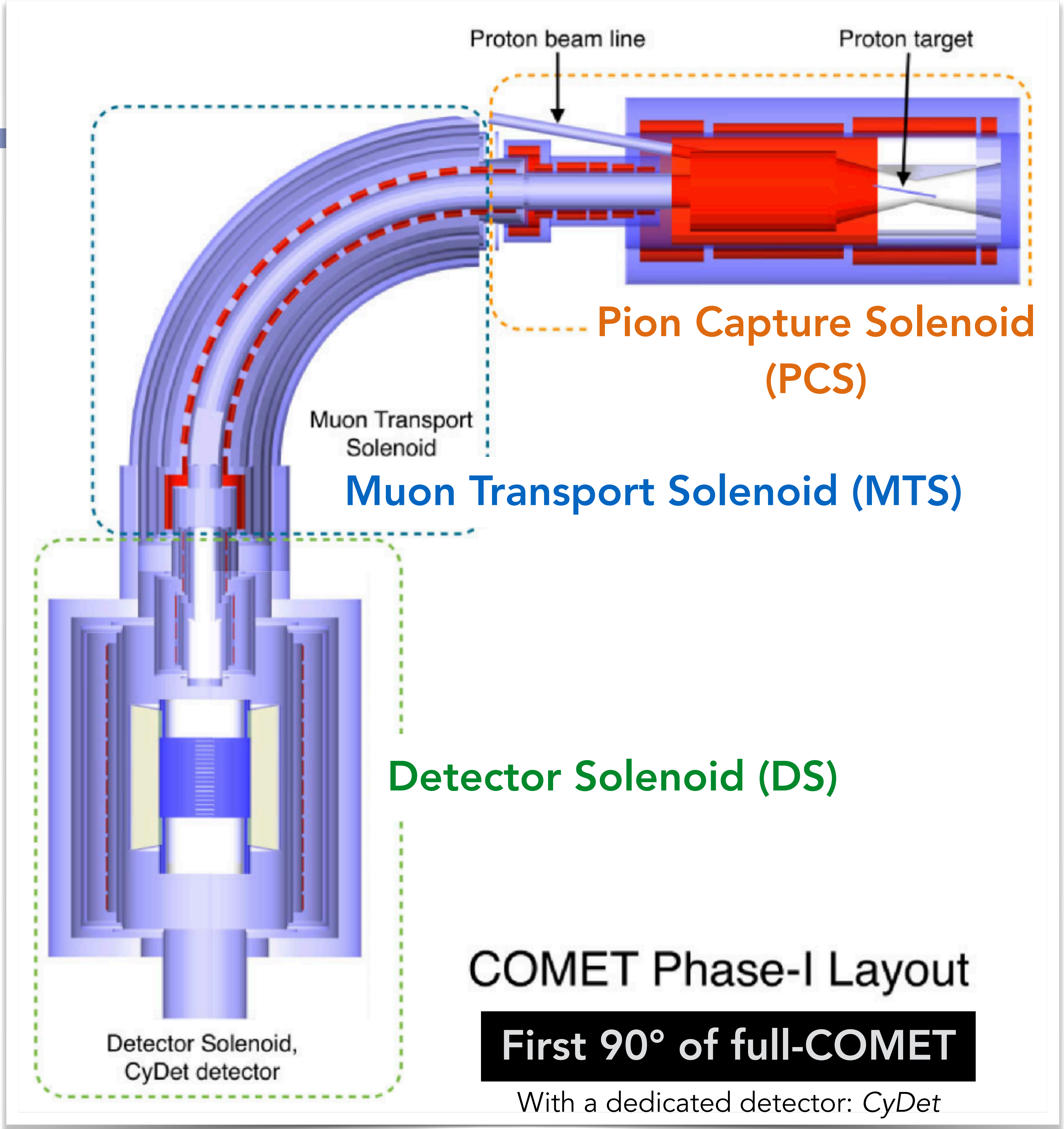
Why Phase-I?

- Beam characterization → **reduce uncertainties**
- Simple setup allows **fast physics measurement**

- Measure muon beam profile, intensity, extinction factor
- Validate detector performances for Phase-II
- First physics search with SES $\sim 10^{-15}$ with a dedicated detector

→ **×100 improvement** over current limit

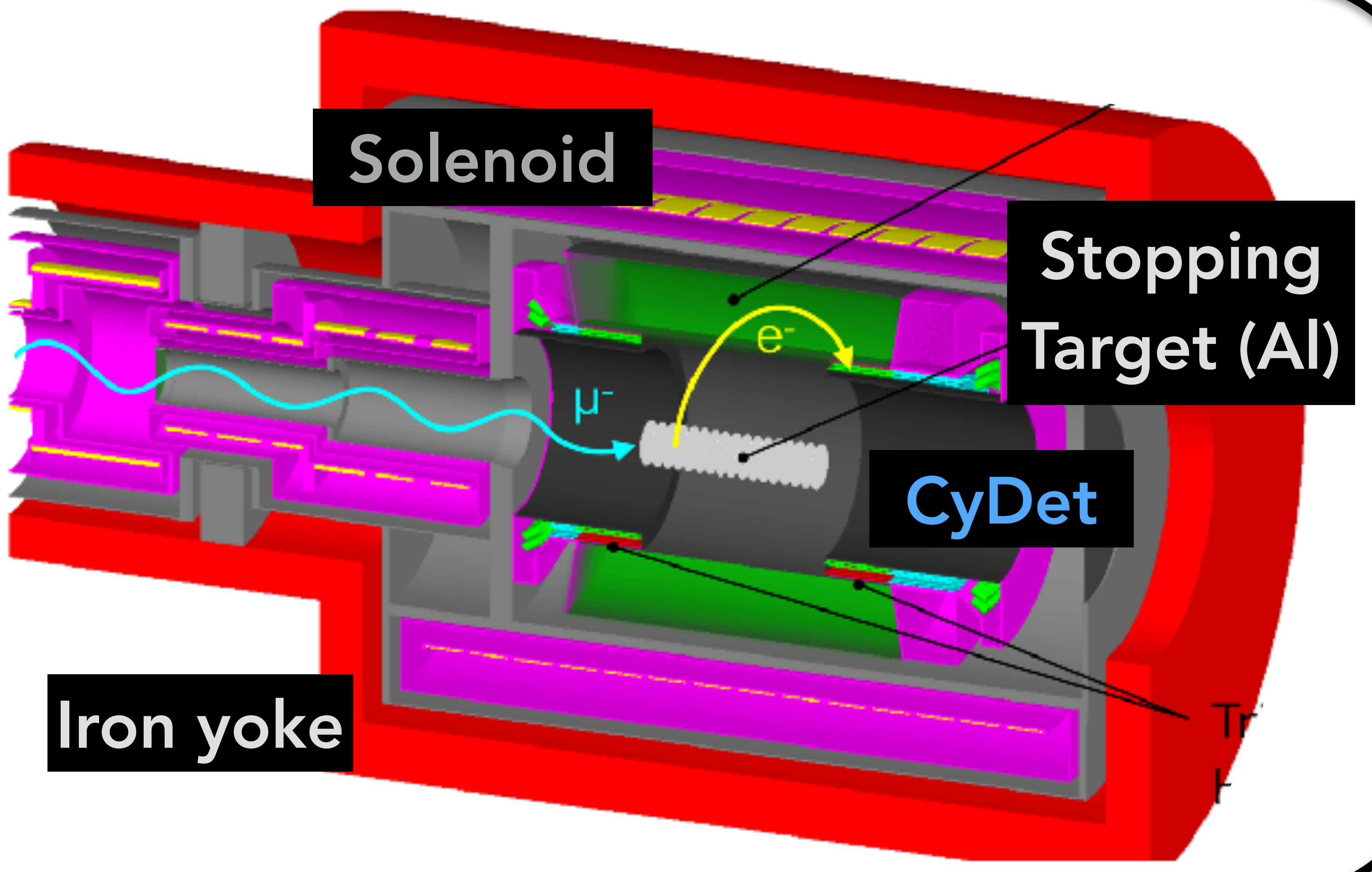
Essential beam characterization & first physics



Phase-I Programs

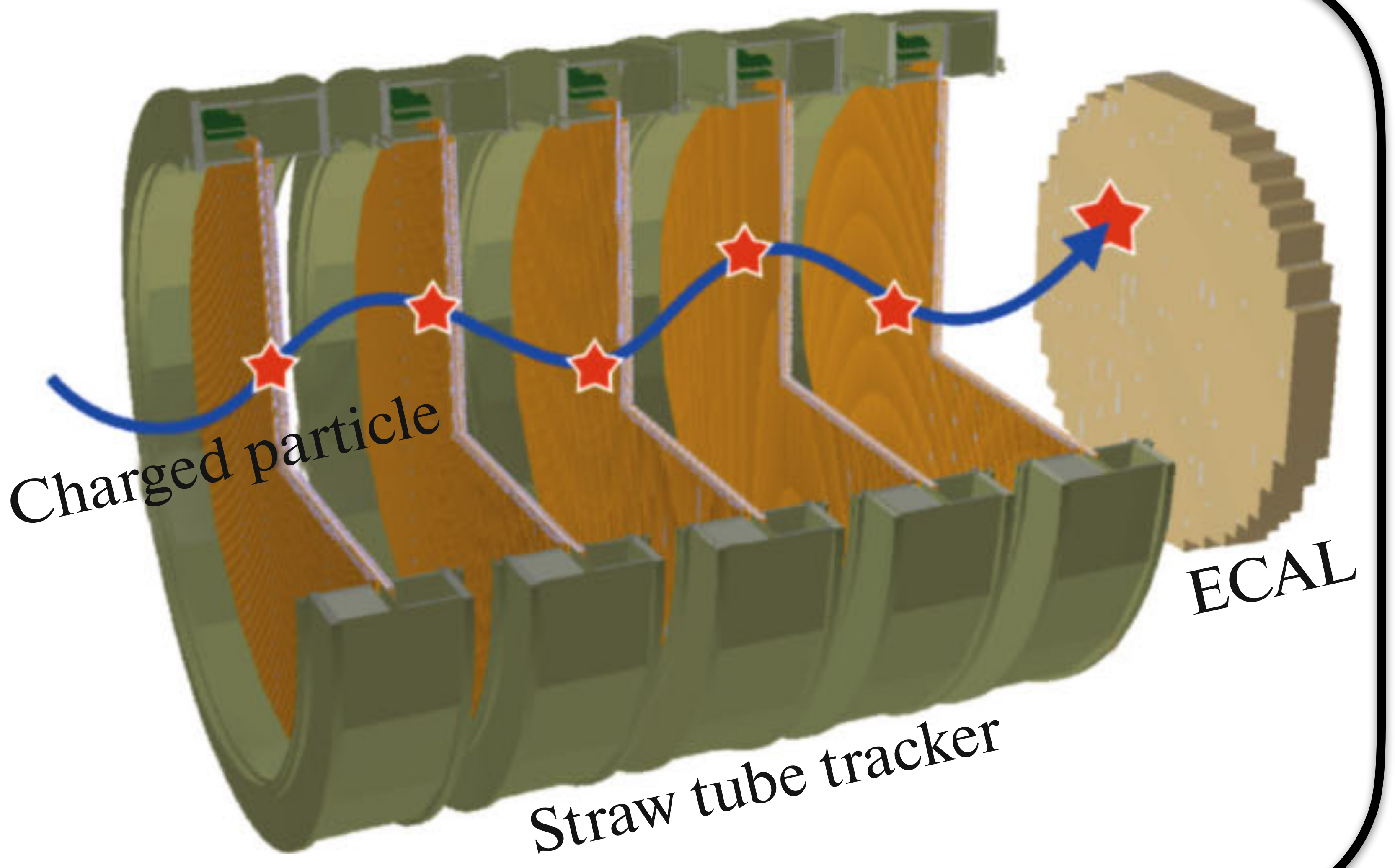
Physics Run

- Search for $\mu^- \to e^-$ at SES $\sim 10^{-15}$
  $\to \times 100$ better than current limit
- **CyDet** (drift chamber + trigger hodoscope)
  - $105\,\mathrm{MeV}/c$ electron spectrum

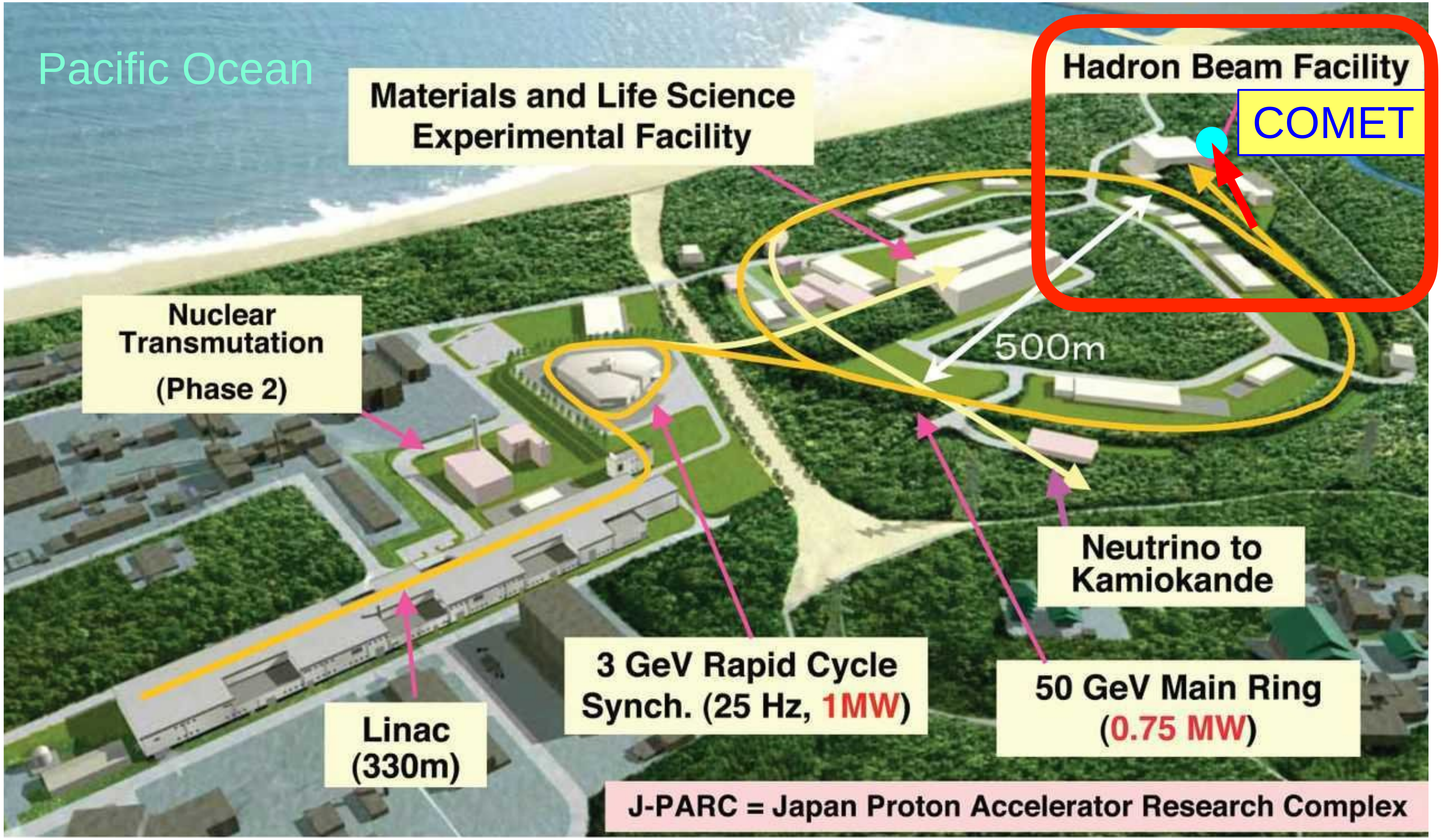


Beam Measurement

- Characterize the muon beam
  - Muon flux, profile
- **StrECAL** (straw-tube tracker + LYSO calorimeter)
  - Reduce systematics, optimize Phase-II design



Proton Beam from J-PARC



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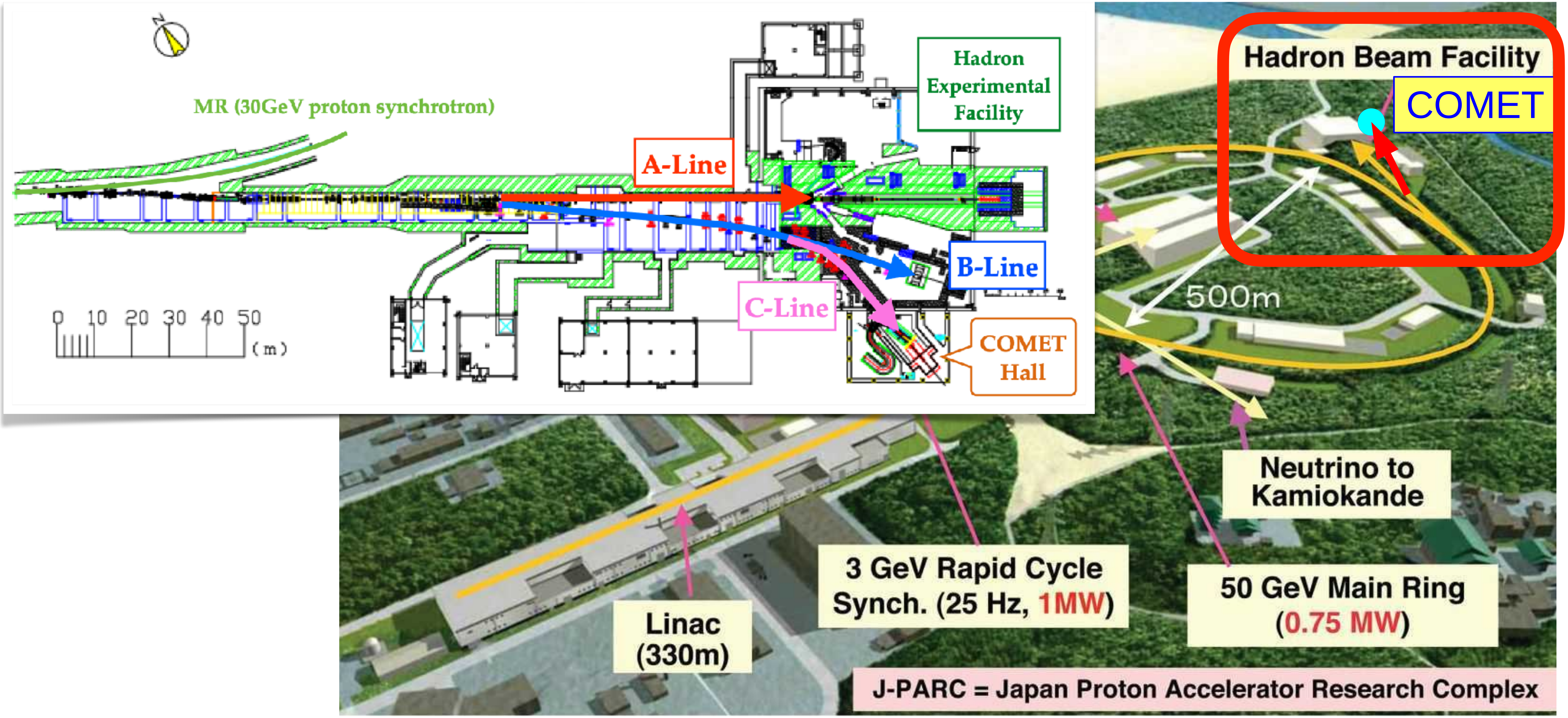
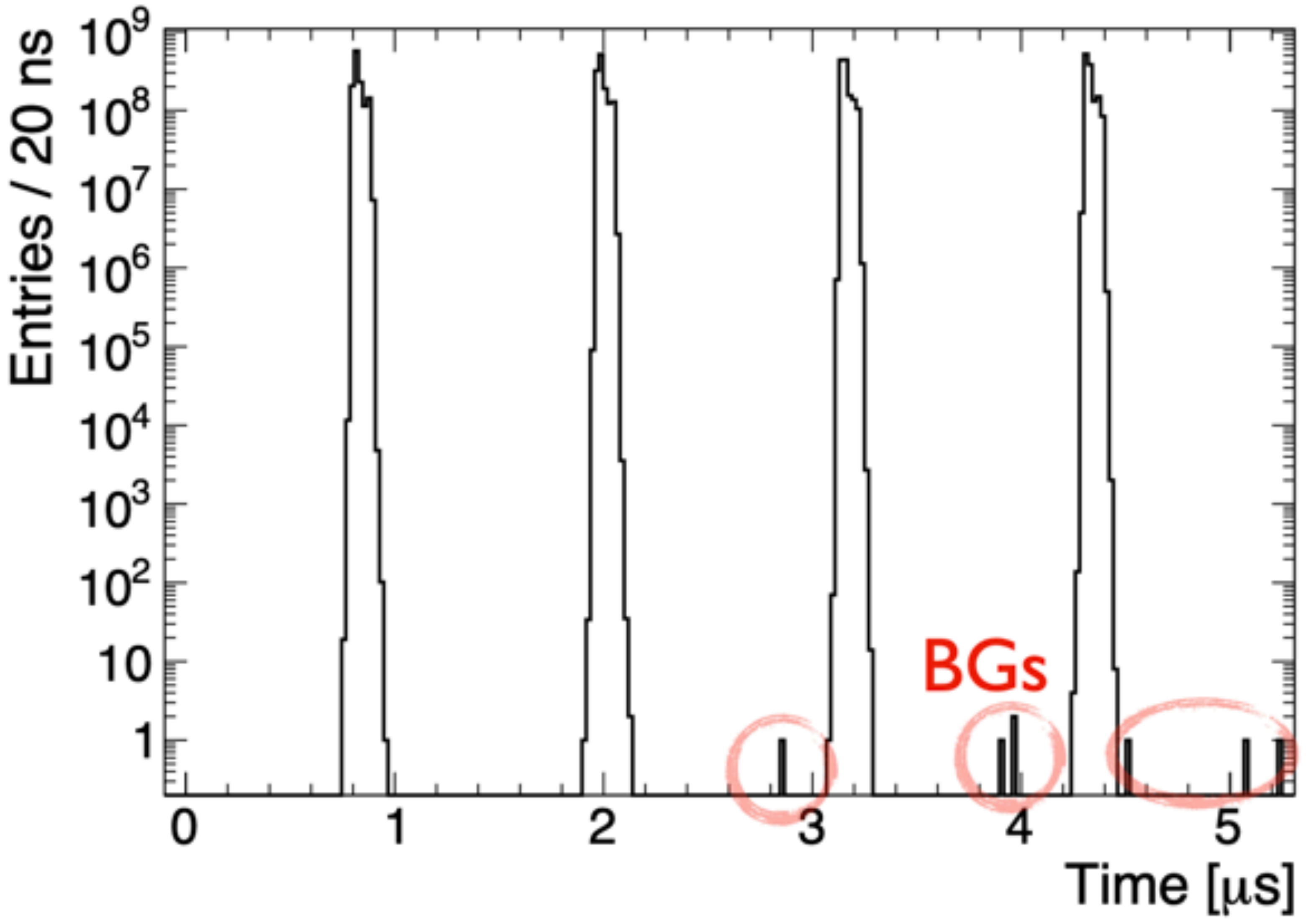
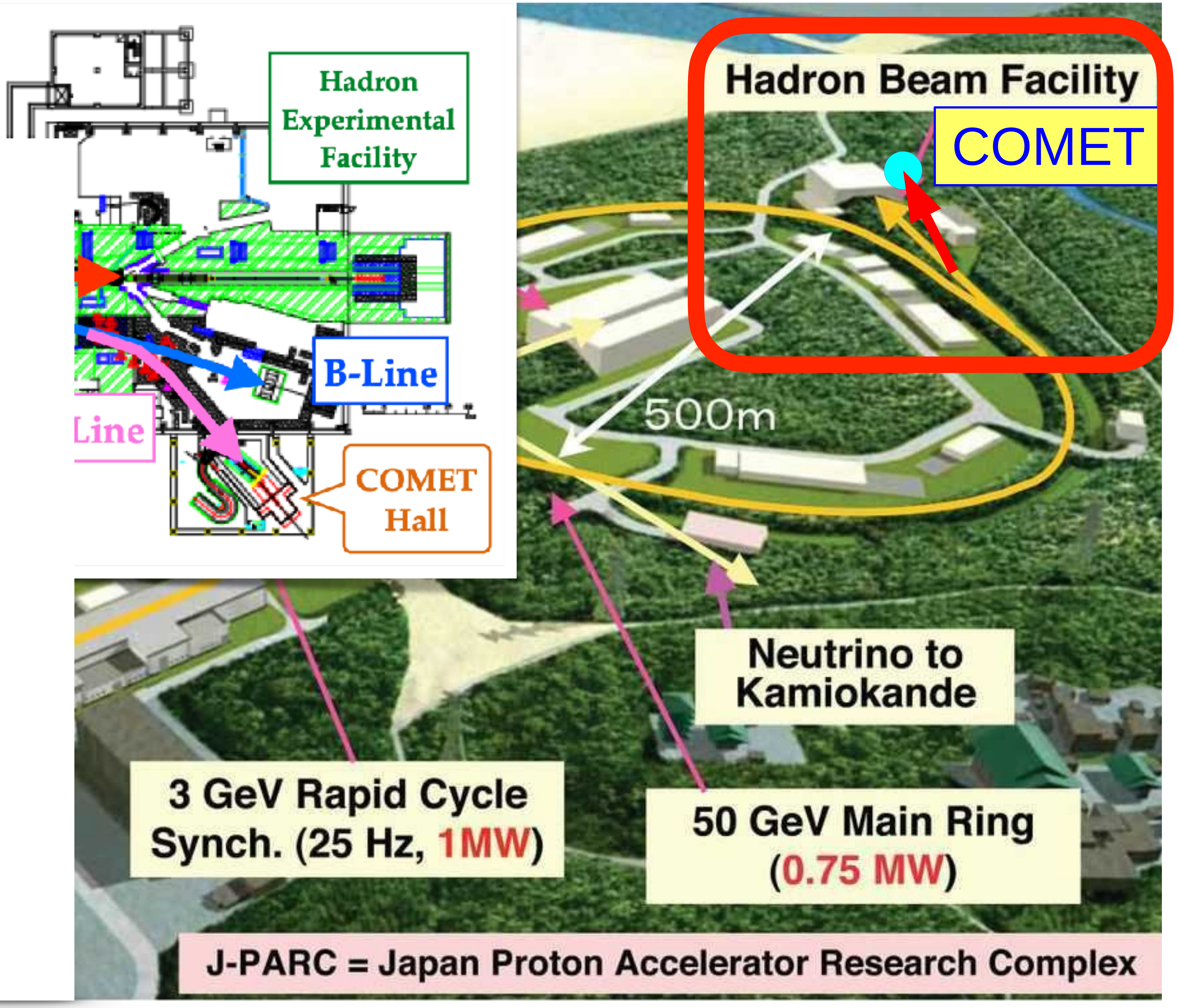


Proton Beam from J-PARC

J-PARC beam specification for COMET

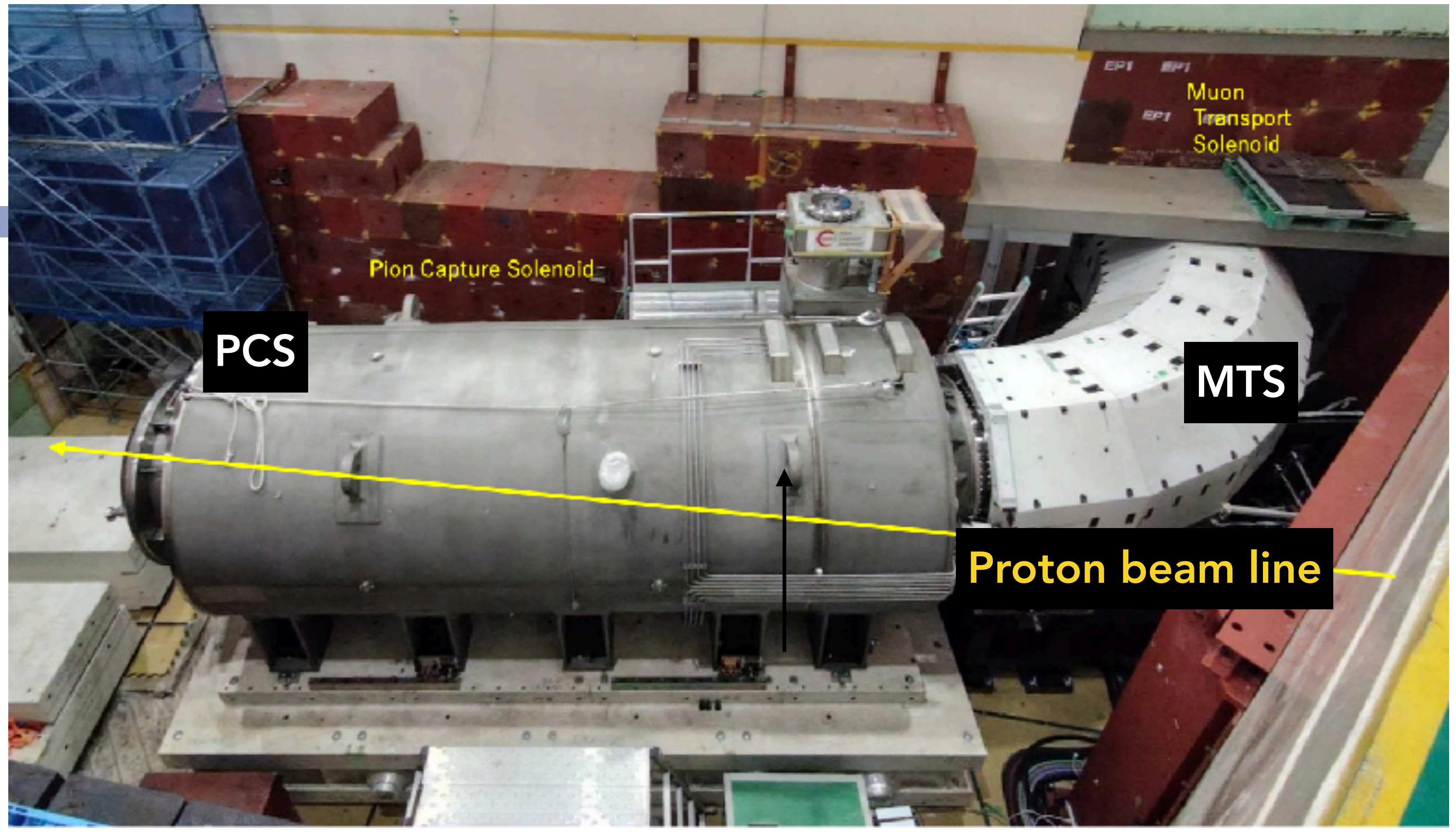
- Bunched slow extraction
- Energy: $8\,\mathrm{GeV}$
- Extinction $\leq 1.02 \times 10^{-10}$ (90% C.L.)
  - Measured at K1.8BR of the Hadron Facility (T78)

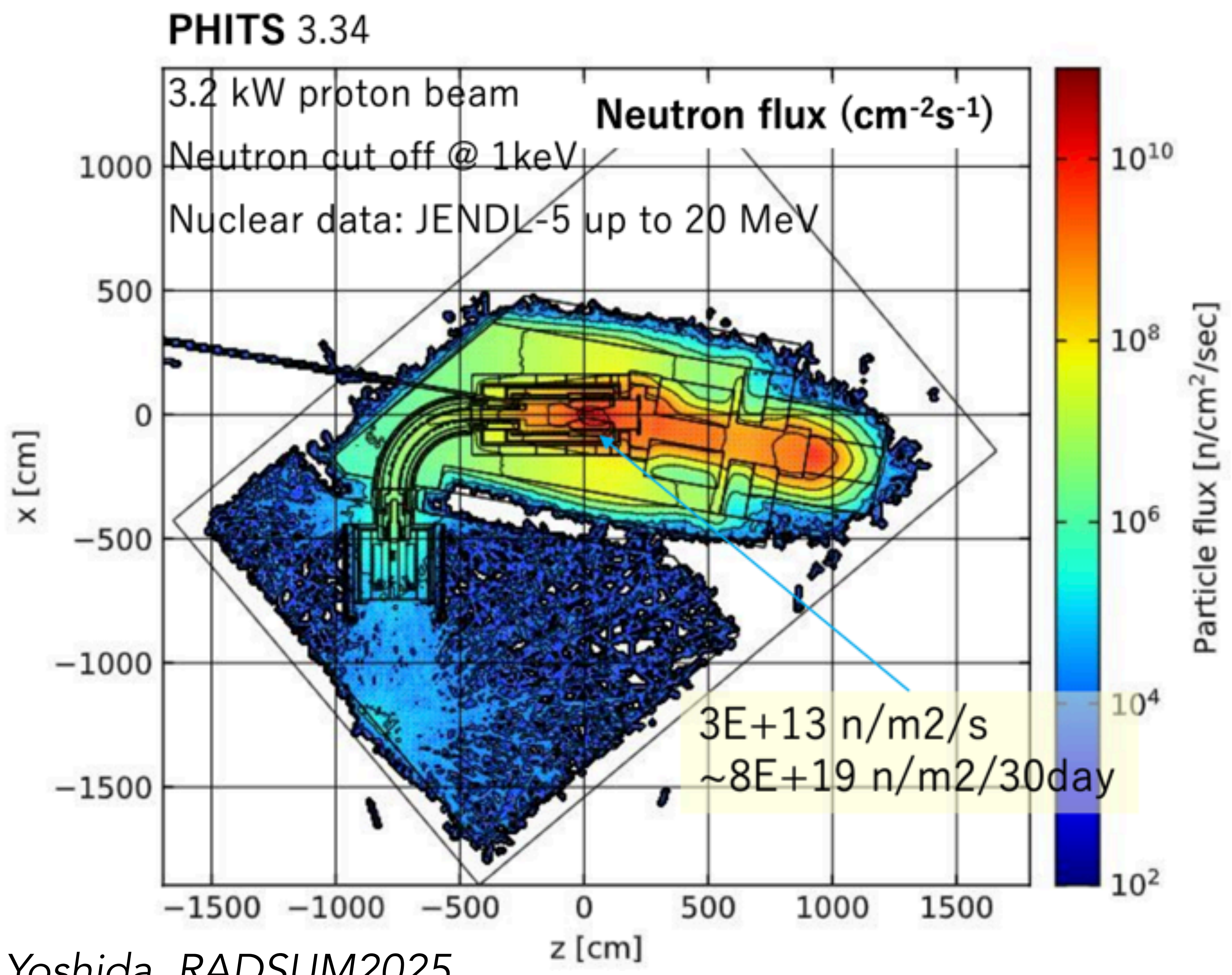




Pion Capture Solenoid (PCS)

- Capture pions backward-emitted from Graphite target with $< 5\,\mathrm{T}$ field, guide muons 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 hardness** is important ($3.2\,\mathrm{kW}$, $8\,\mathrm{GeV}$ beam)
  - Heat deposition: $\sim 2\,\mathrm{mW/kg}$ → $\sim 26\,\mathrm{kGy}$ / 150 days
  - Neutron flux: $3 \times 10^{13}\,\mathrm{n/m^2/s}$ → $4 \times 10^{20}\,\mathrm{n/m^2}$ / 150 days
  - Thick stainless shielding ($\sim 40\,\mathrm{cm}$) protects coil
- **Excitation test after installation of return yoke, transfer tube, and DAQ**





M. Yoshida, RADSUM2025

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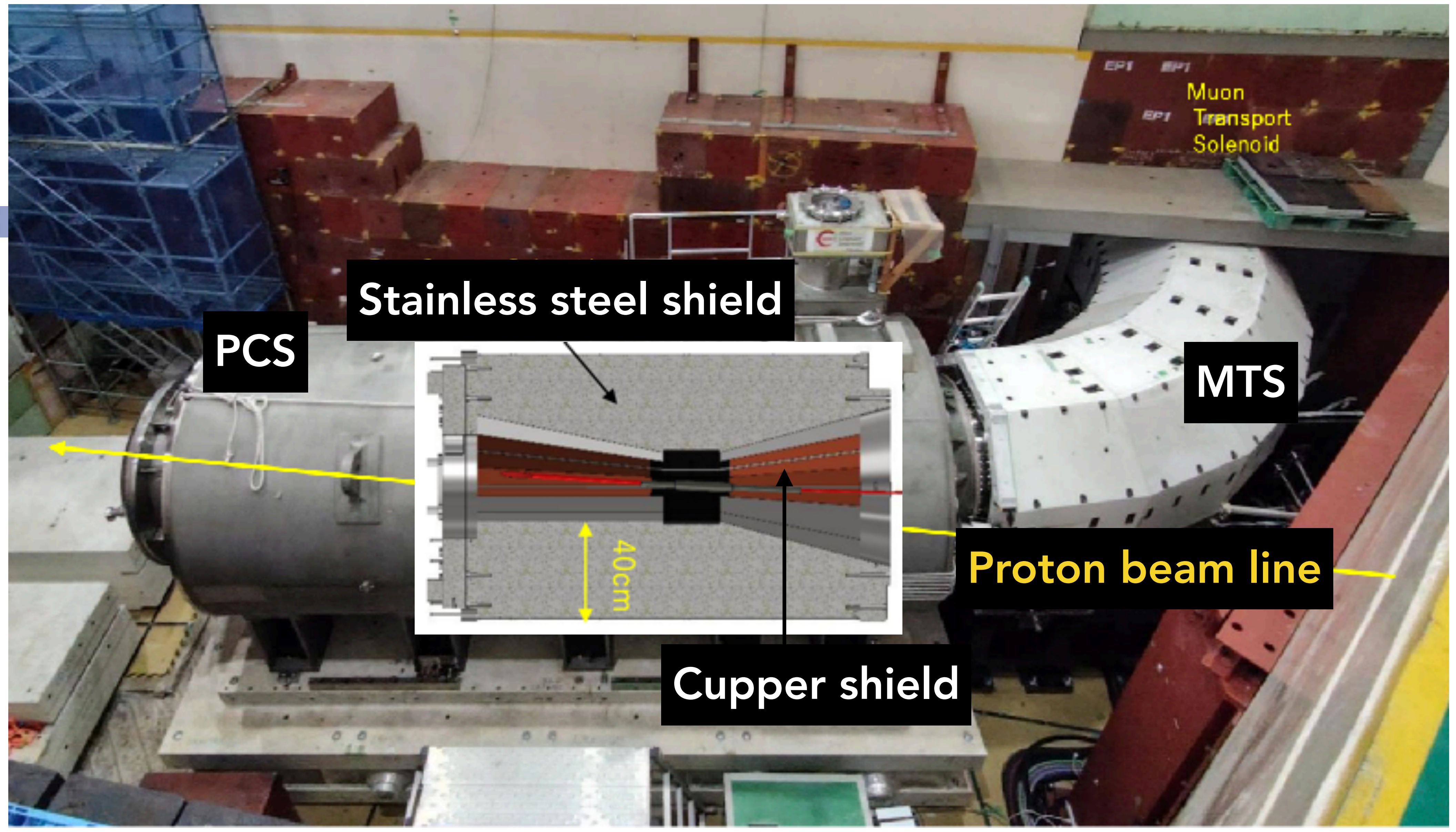
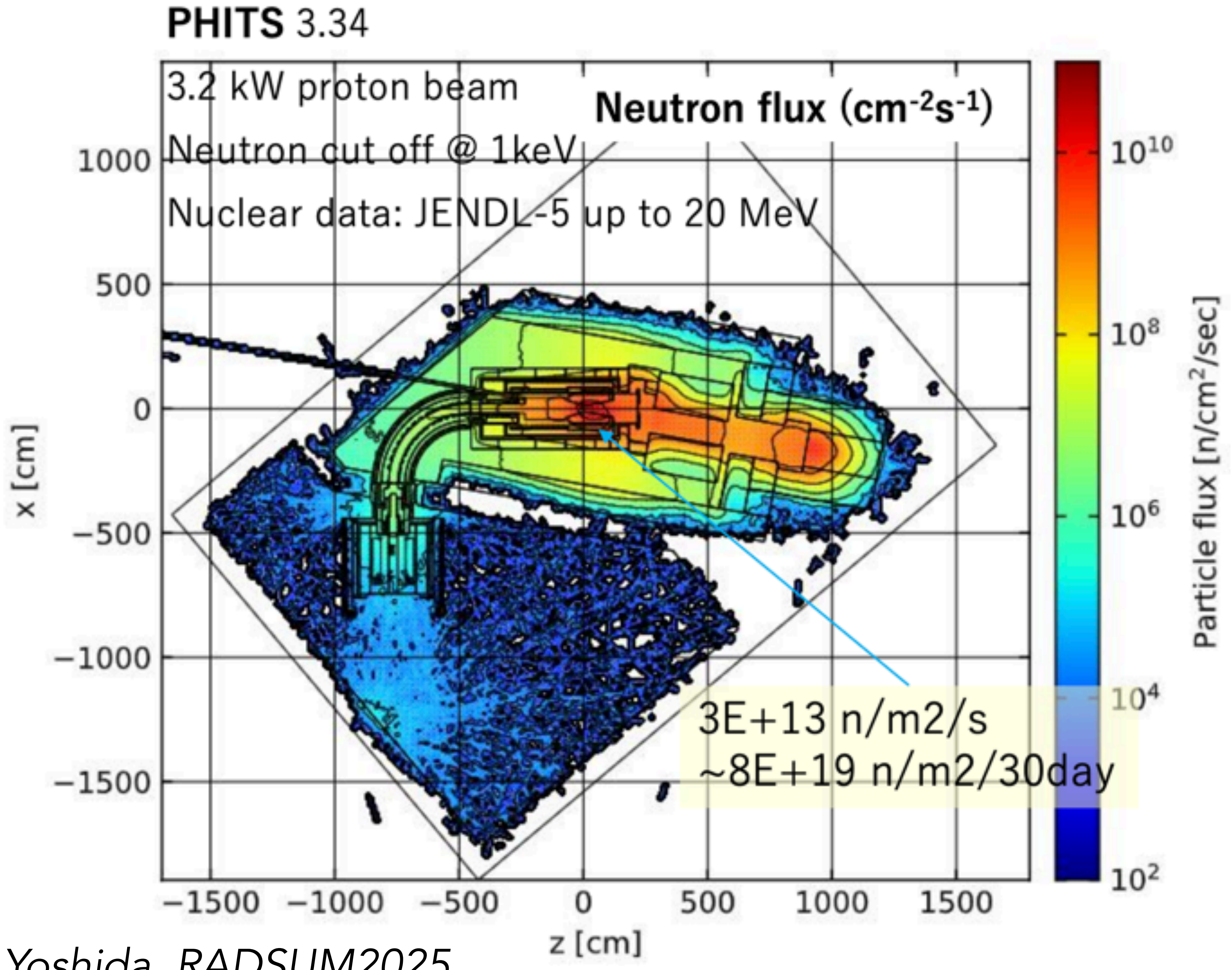
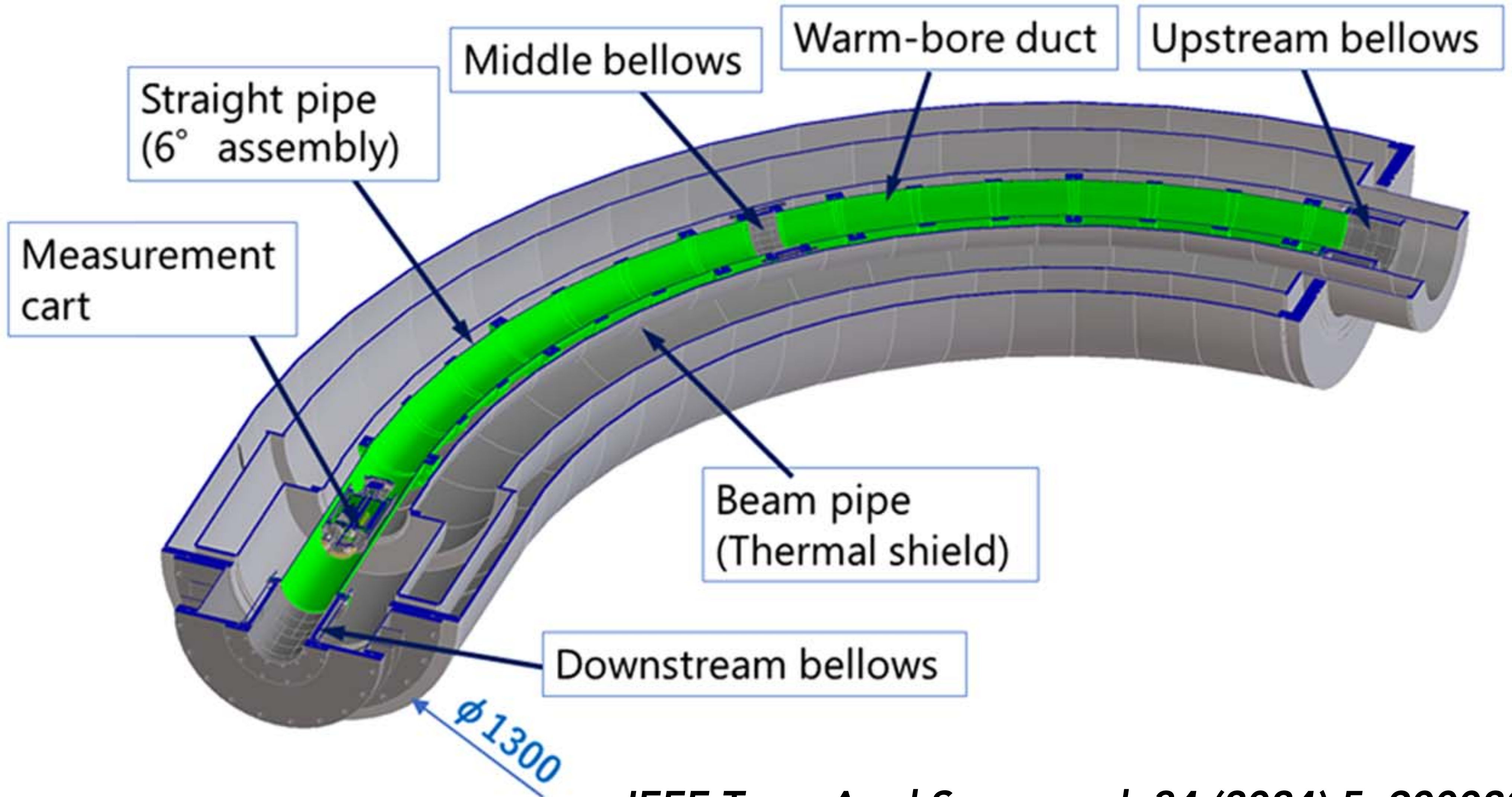




M. Yoshida, RADSUM2025

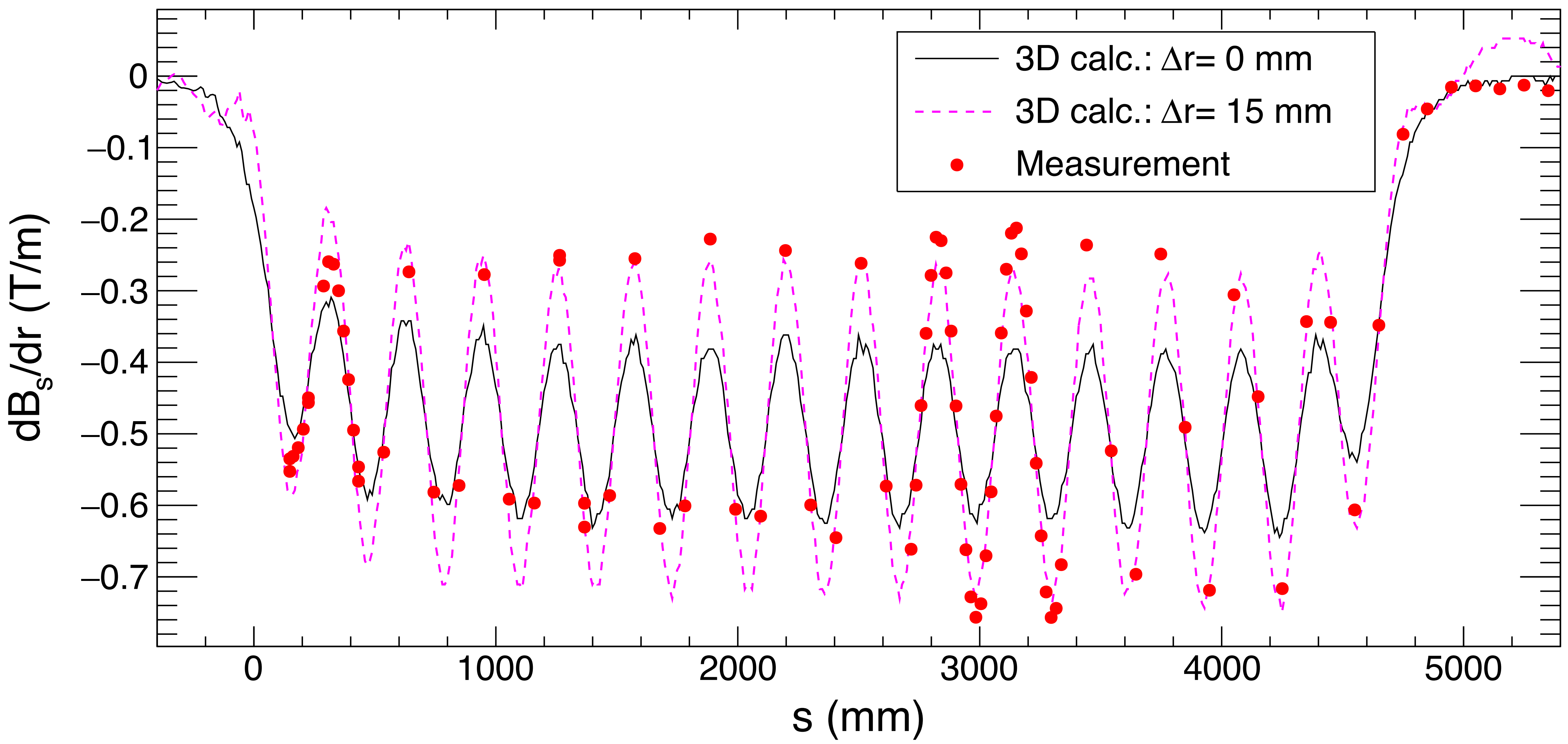
Muon Transport Solenoid (MTS)

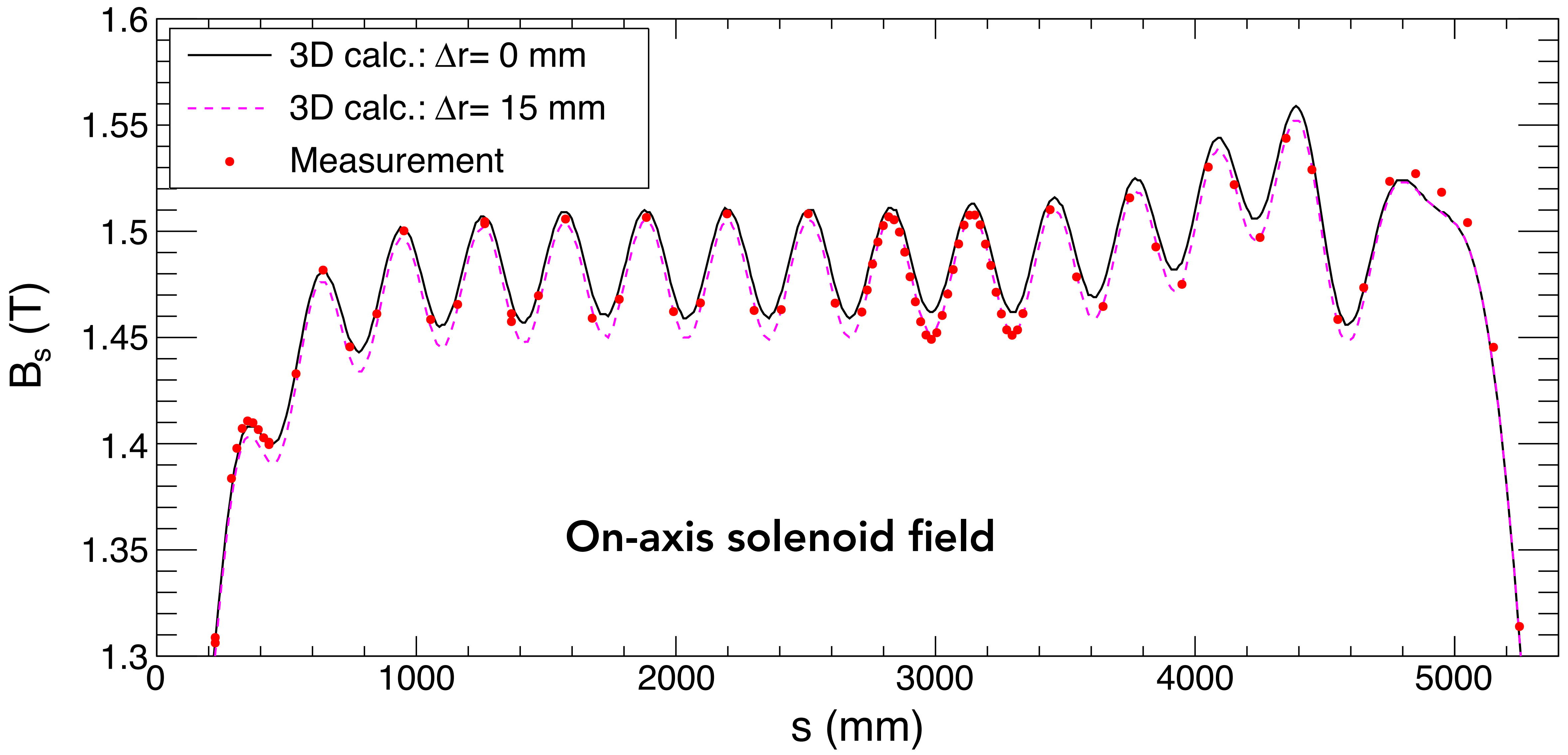
- Select low-momentum muons ($\sim 40\,\mathrm{MeV}/c$)
- Suppress background by curved transport
- Drift compensation with dipole field ($\sim 50\,\mathrm{mT}$)
  — difference from Mu2e
- Performance is verified by measurement and simulation
  - On-axis solenoid field measured with 0.4% accuracy



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

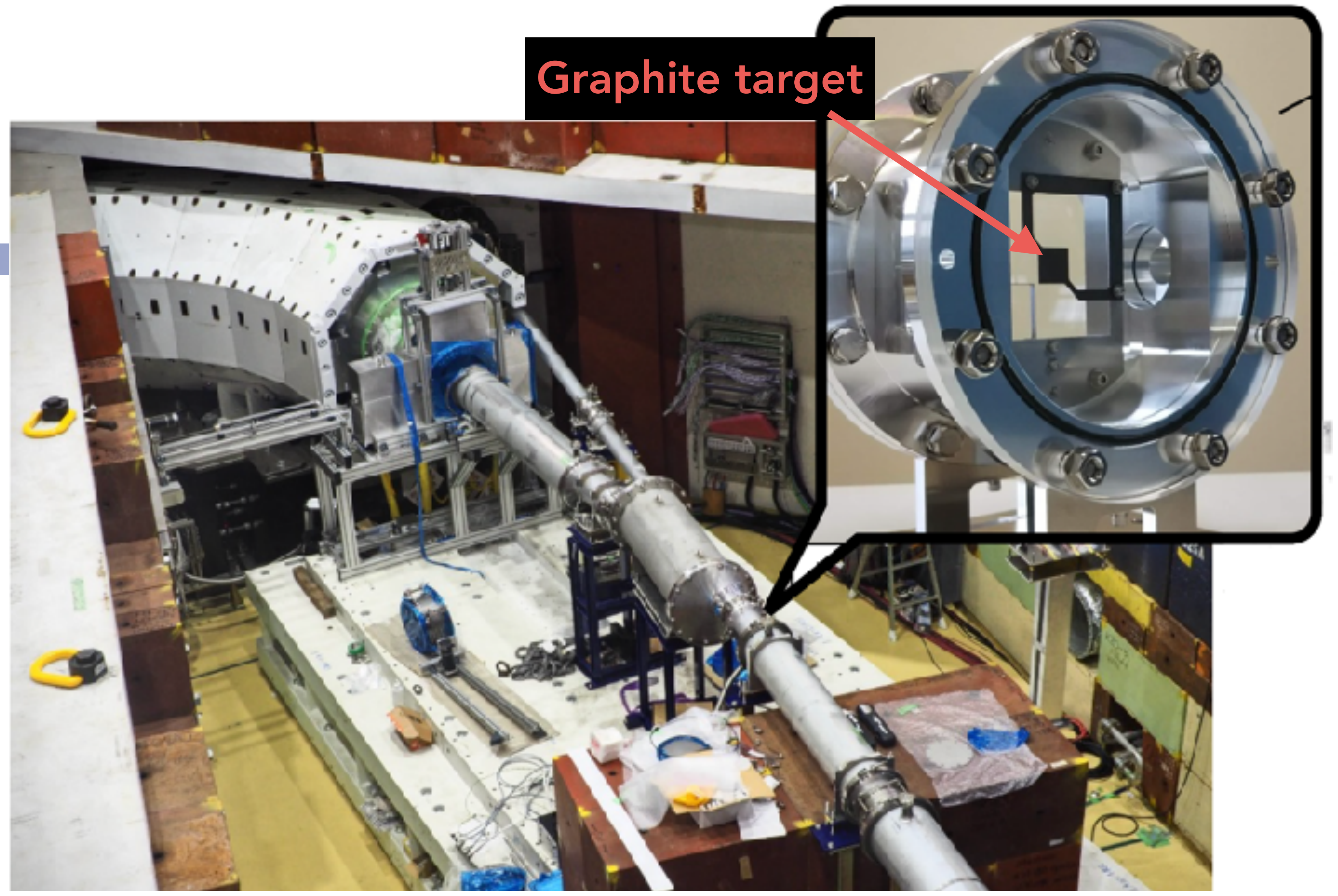
Field gradient
— leads drift and compensation by dipole



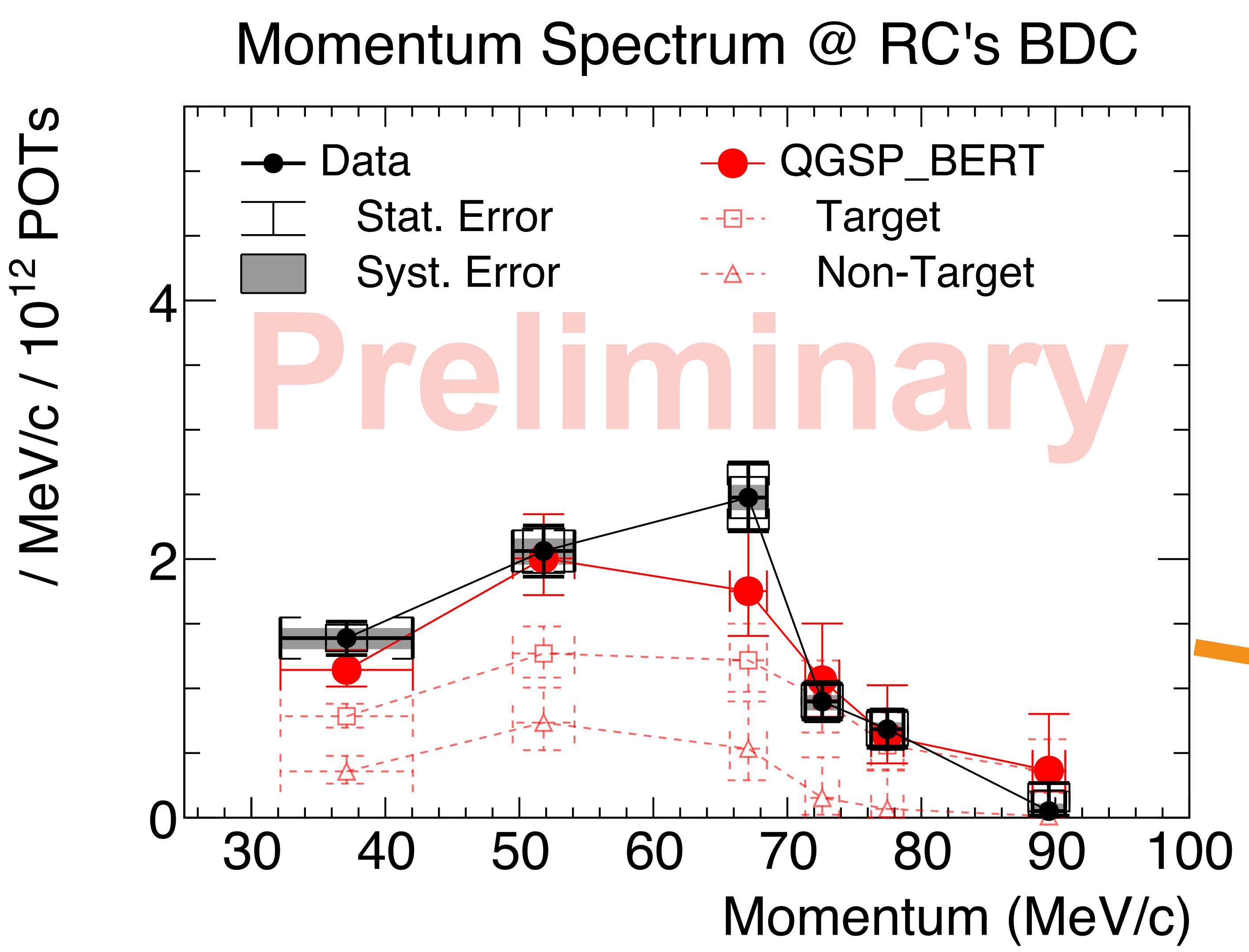


Phase-α: 1st commissioning

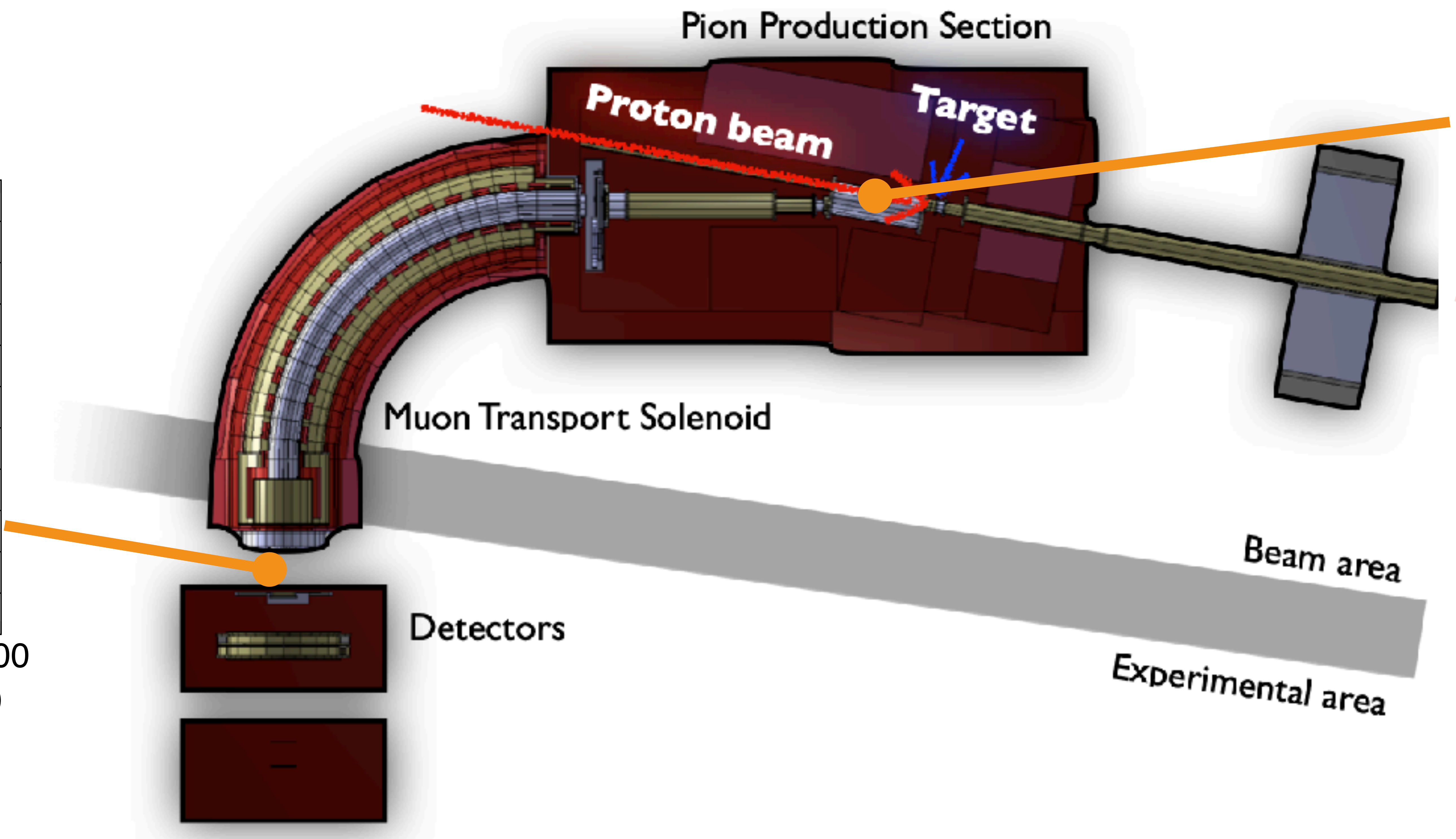
- Performed in 2023
- Measure the proton beam profile & muon beam profile after passing through the transport solenoid

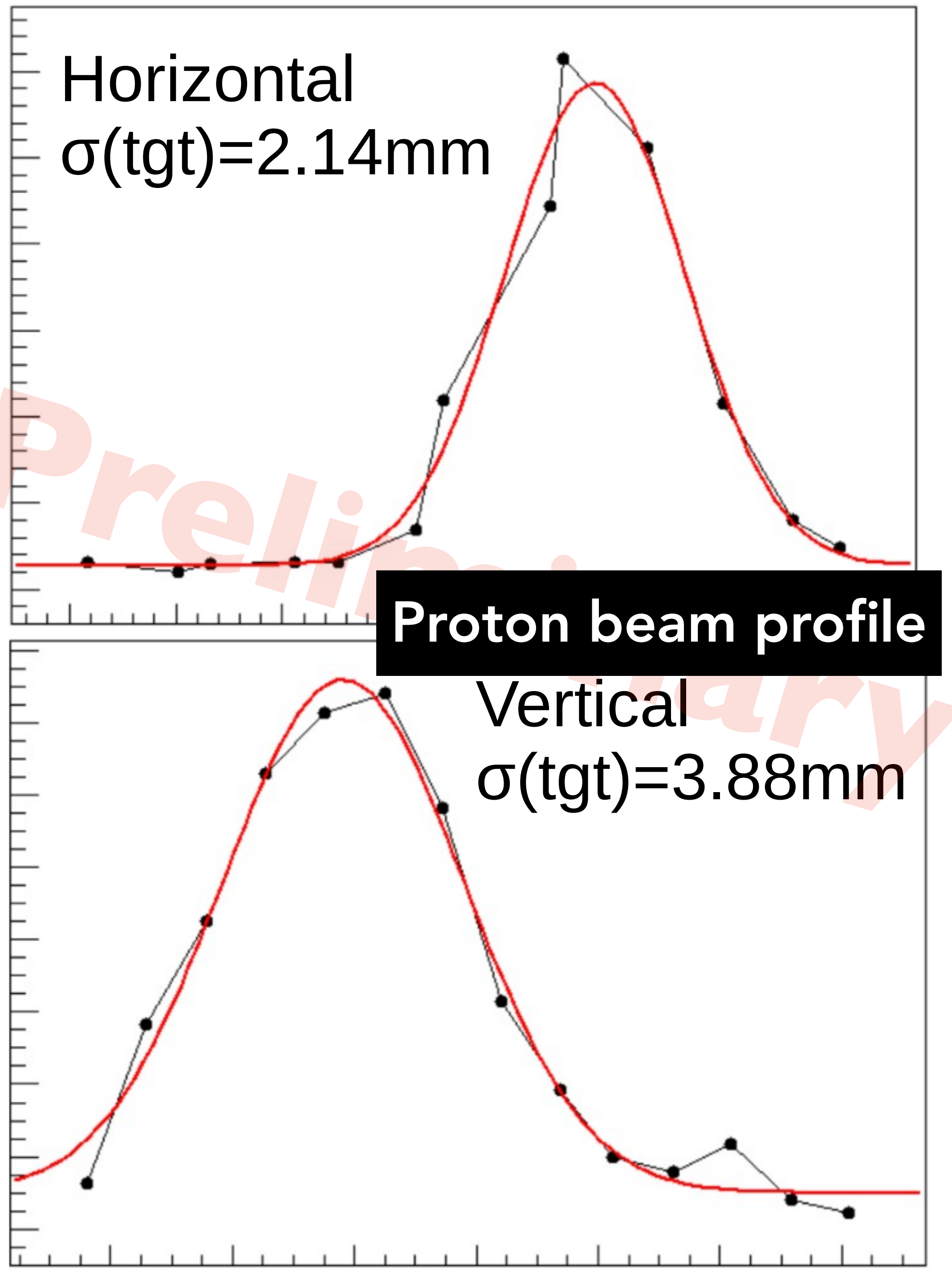


Muon beam spectrum



Consistent! *(Still under review)*



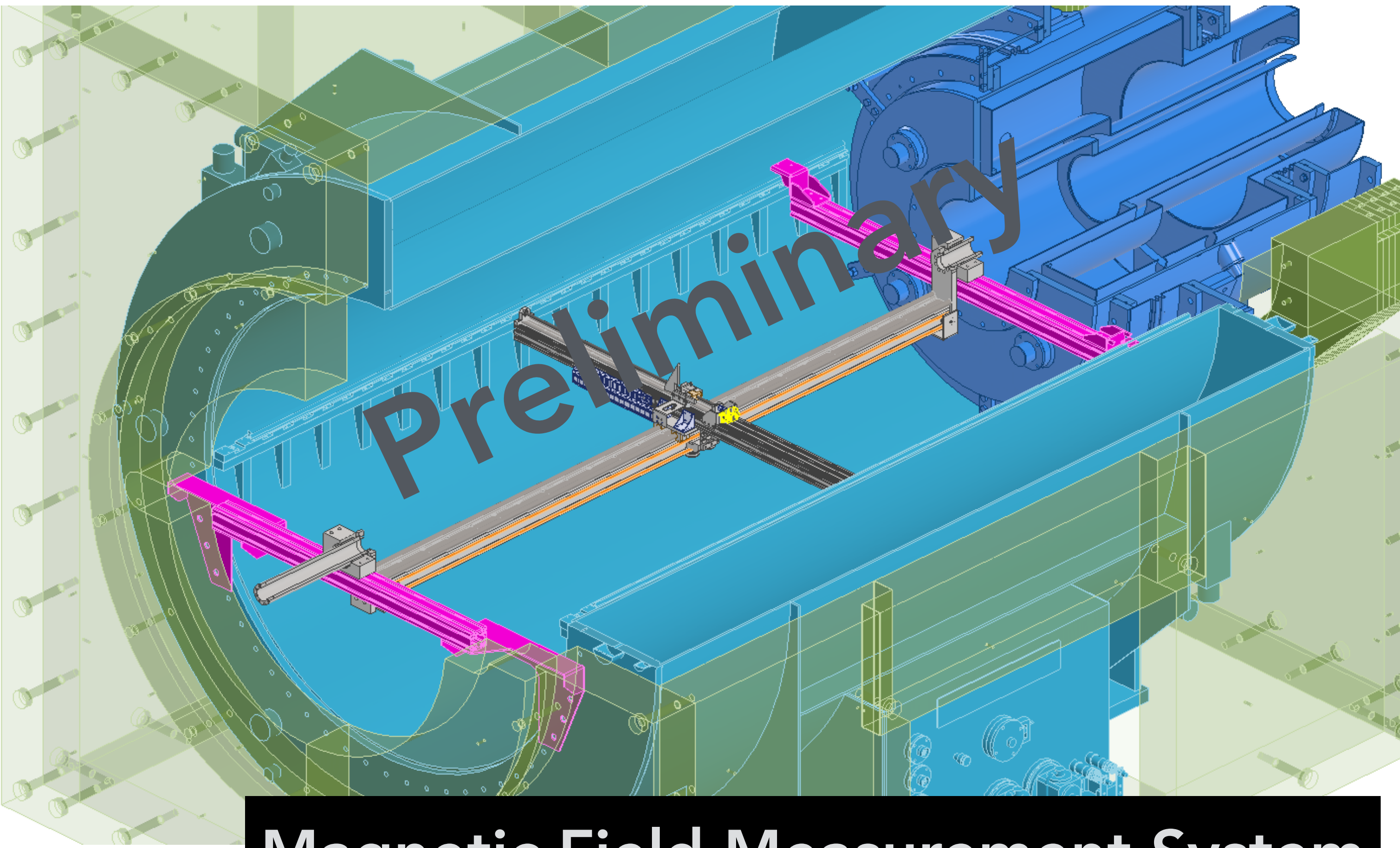


Measured beam dimensions

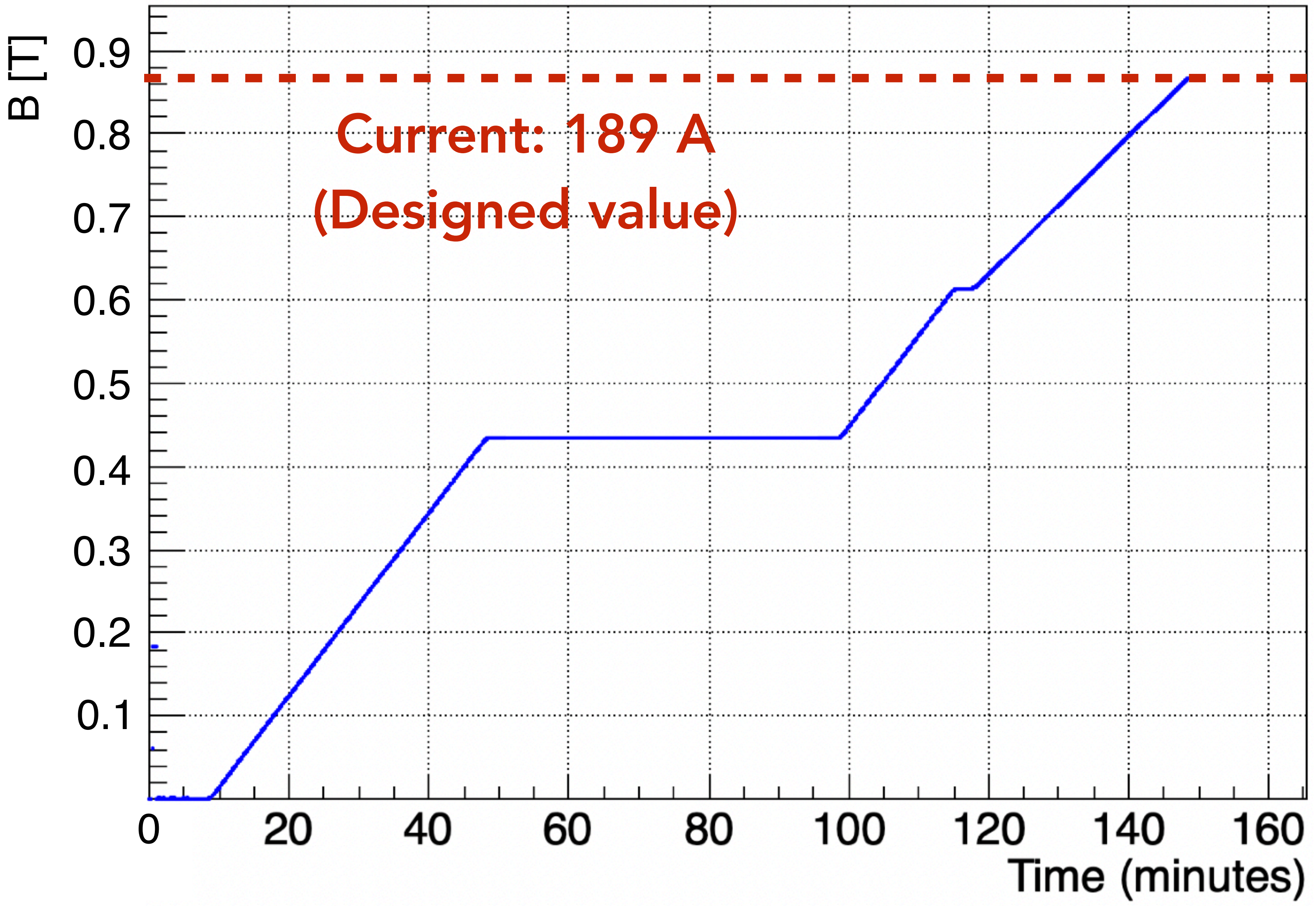
Detector Solenoid (DS)

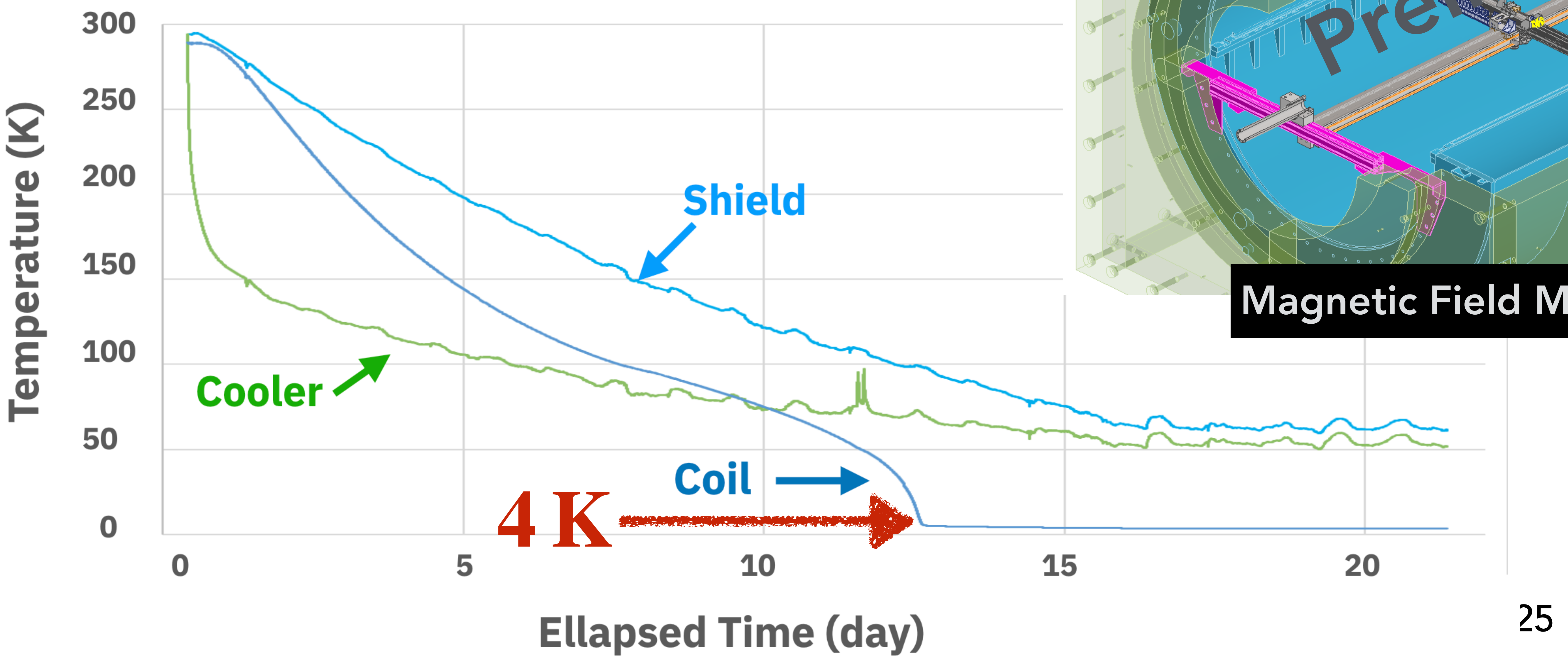
- Provide $1\,\mathrm{T}$ magnetic field to the detector
- Basic performance was tested in 2024 and successfully
  - Cooled to **$4.2\,\mathrm{K}$ within 14 days** (with N_2 cooling)
  - Ramped up to the rated current **without any training quenches**
- **Installation to the COMET hall is ongoing**
- Mag. field mapping (10^{-4} acc.) will be measured in Mar. 2026

Delivered in KEK-Tsukuba in Sept. 2024



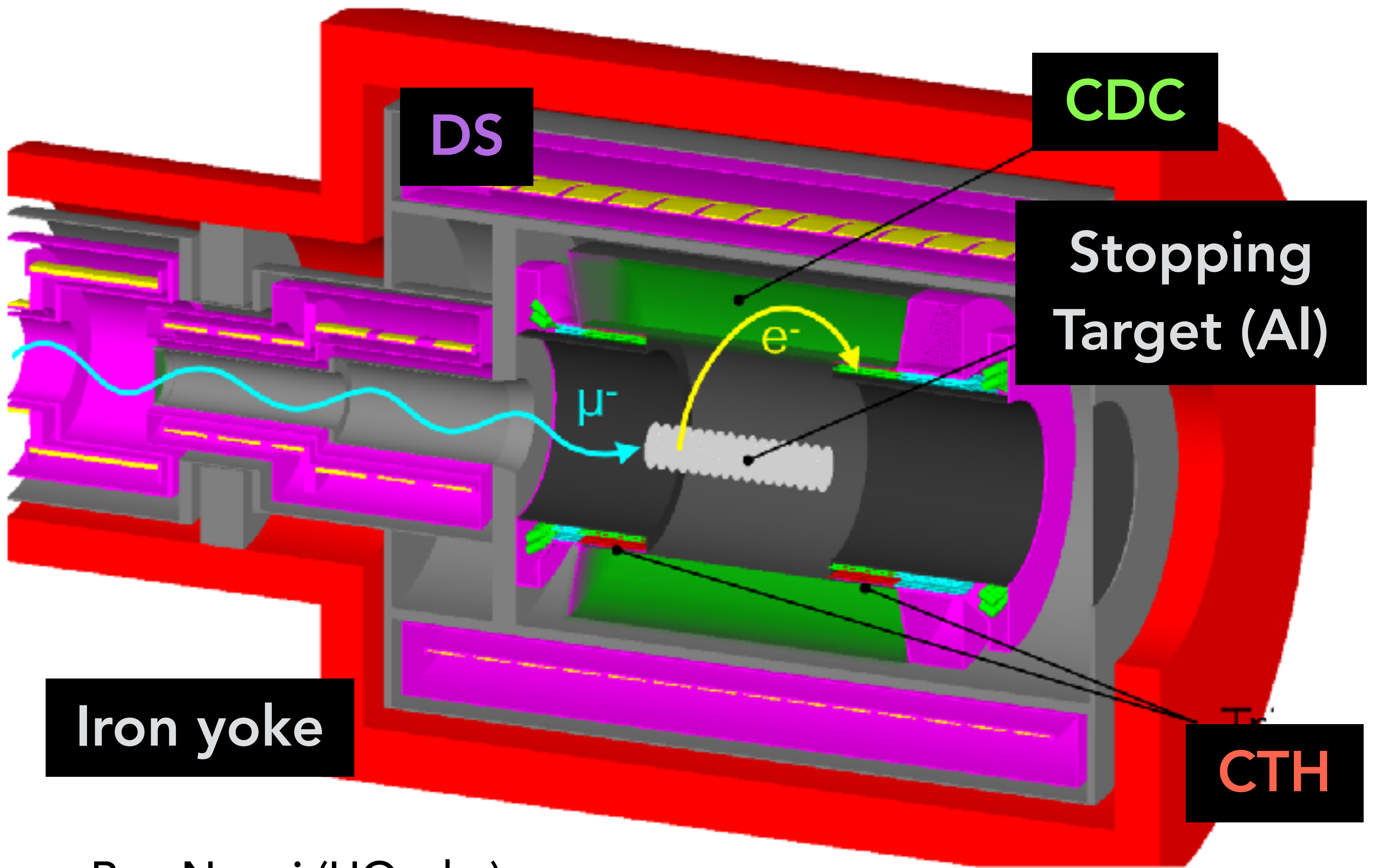
Magnetic Field Measurement System

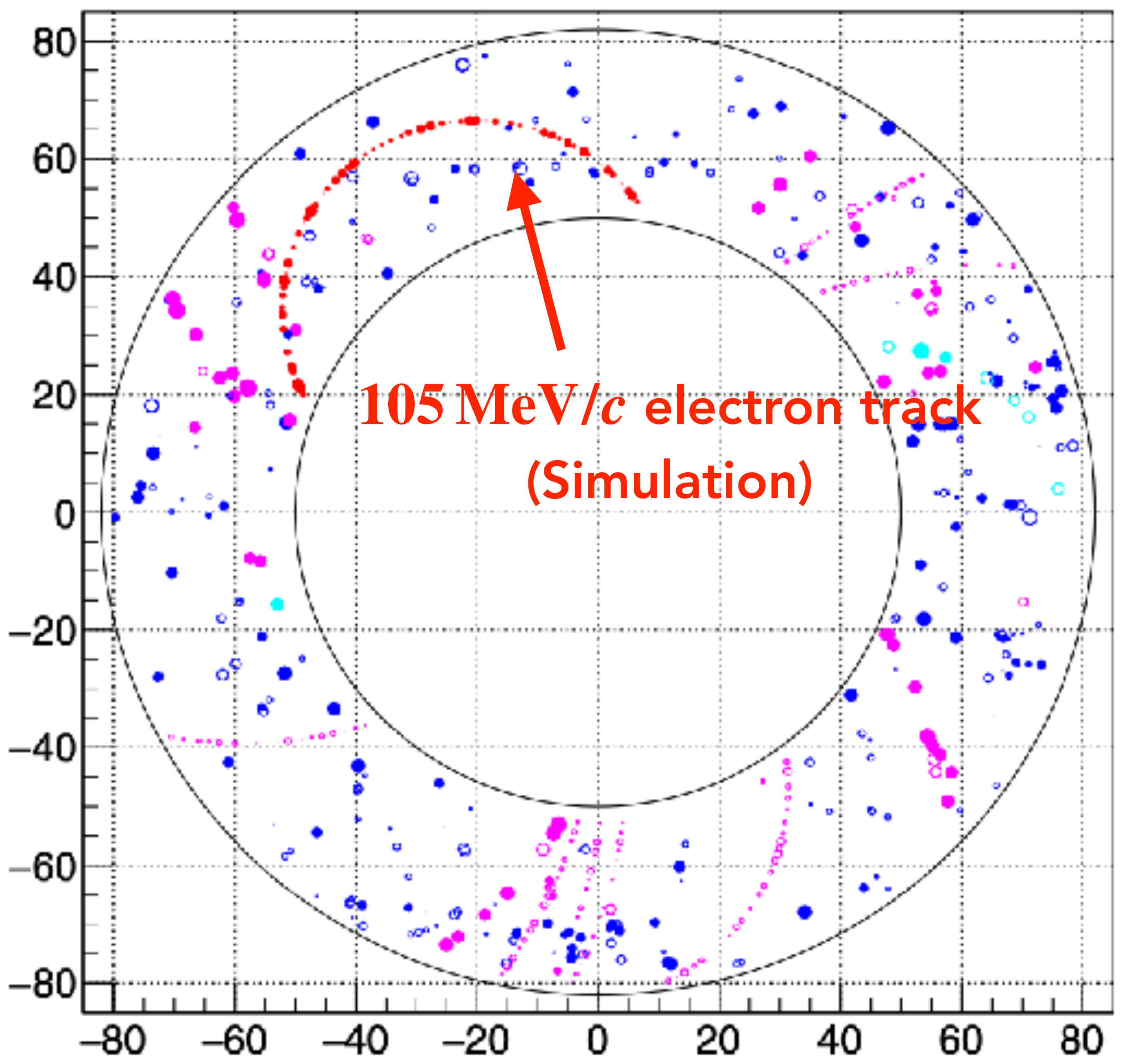


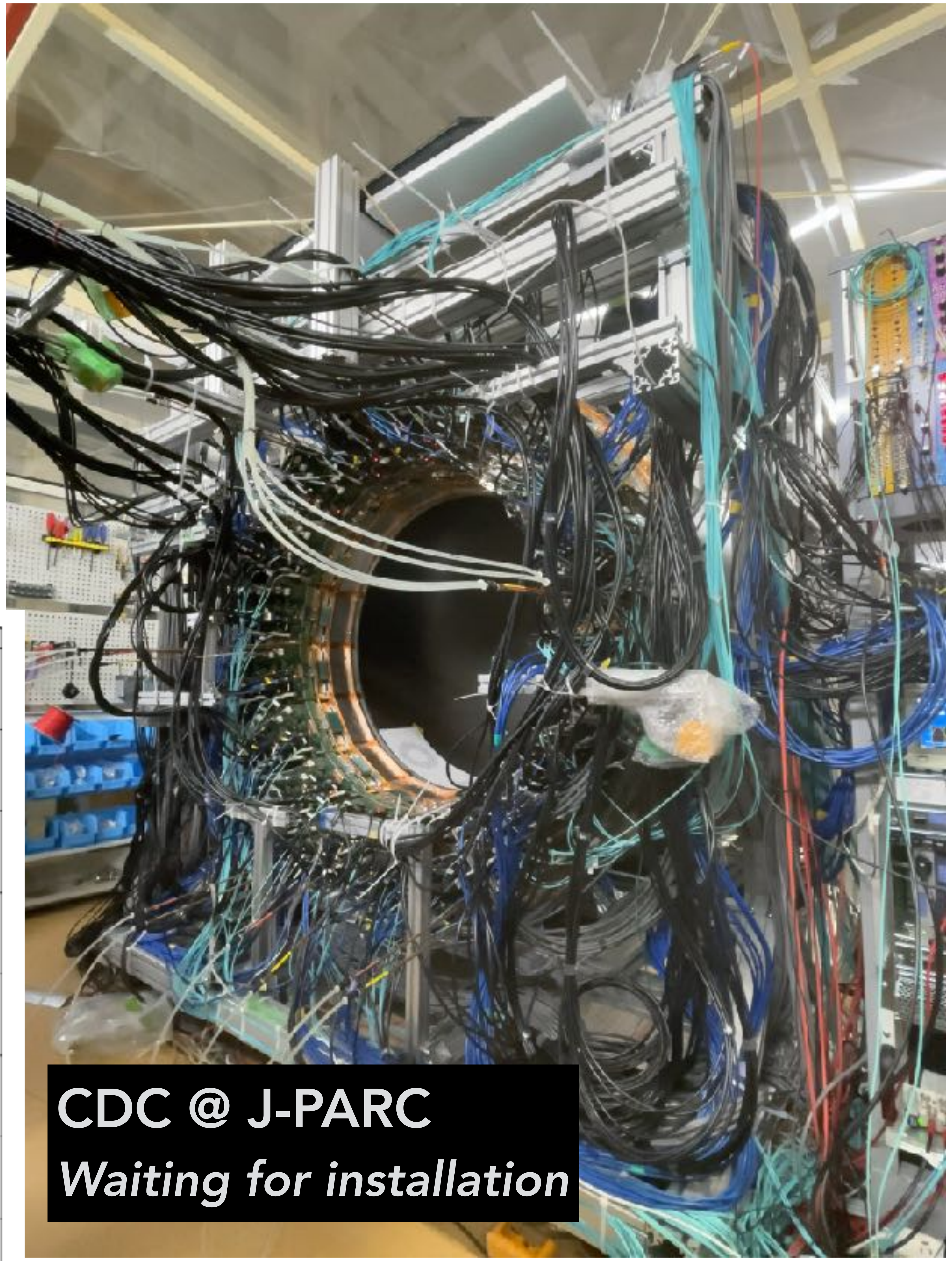


CyDet — Physics Detector

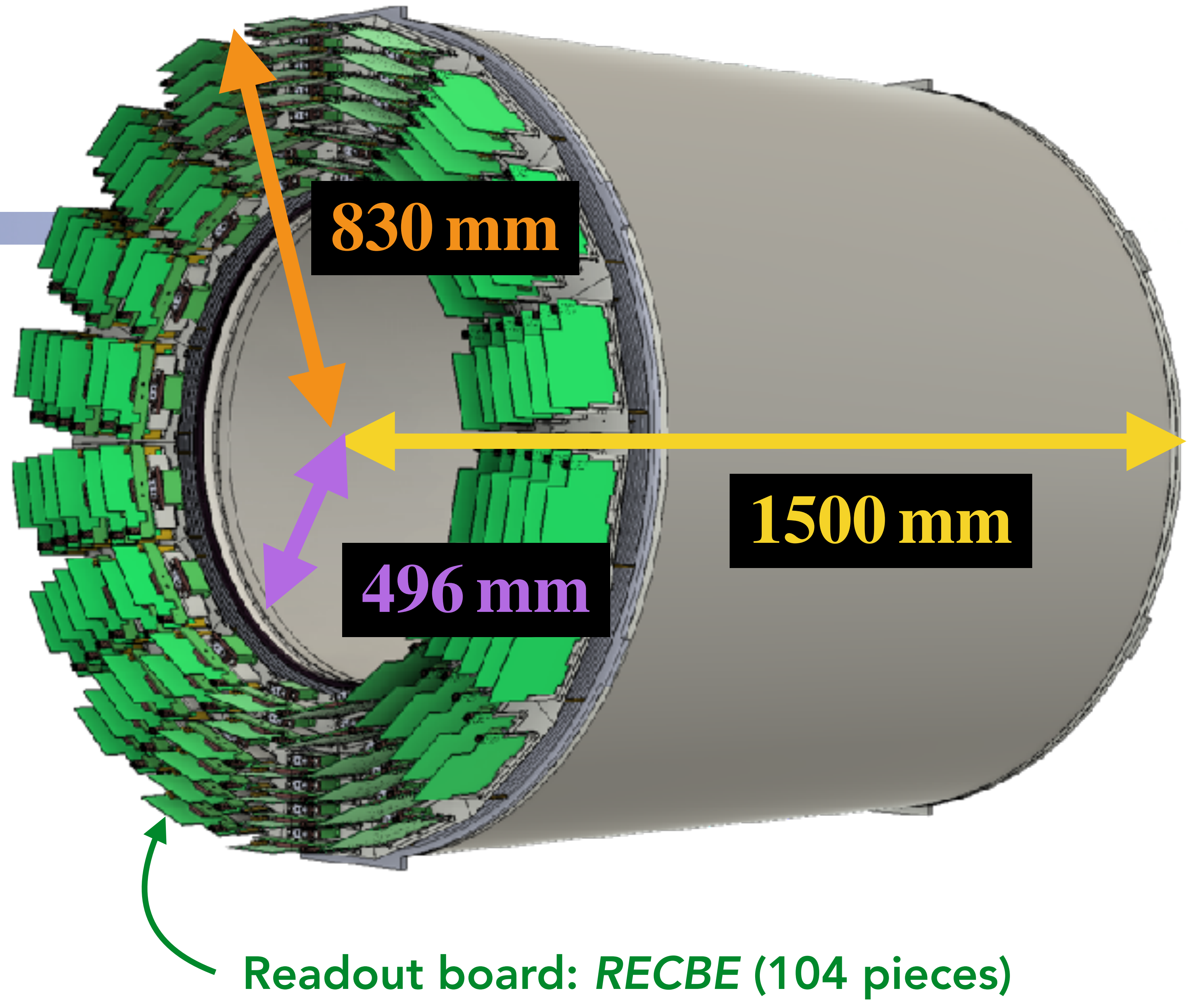
- Consists of **Cylindrical Drift Chamber** (CDC) and **Cylindrical Trigger Hodoscope** (CTH)
- **CDC**: Momentum resolution $200\,\mathrm{keV}/c$ (curvature)
  - Magnetic field measurement of DS is essential
  - Constructed at J-PARC, performance tests ongoing
- **CTH**: 4-fold coincidences (as the first hardware trigger)



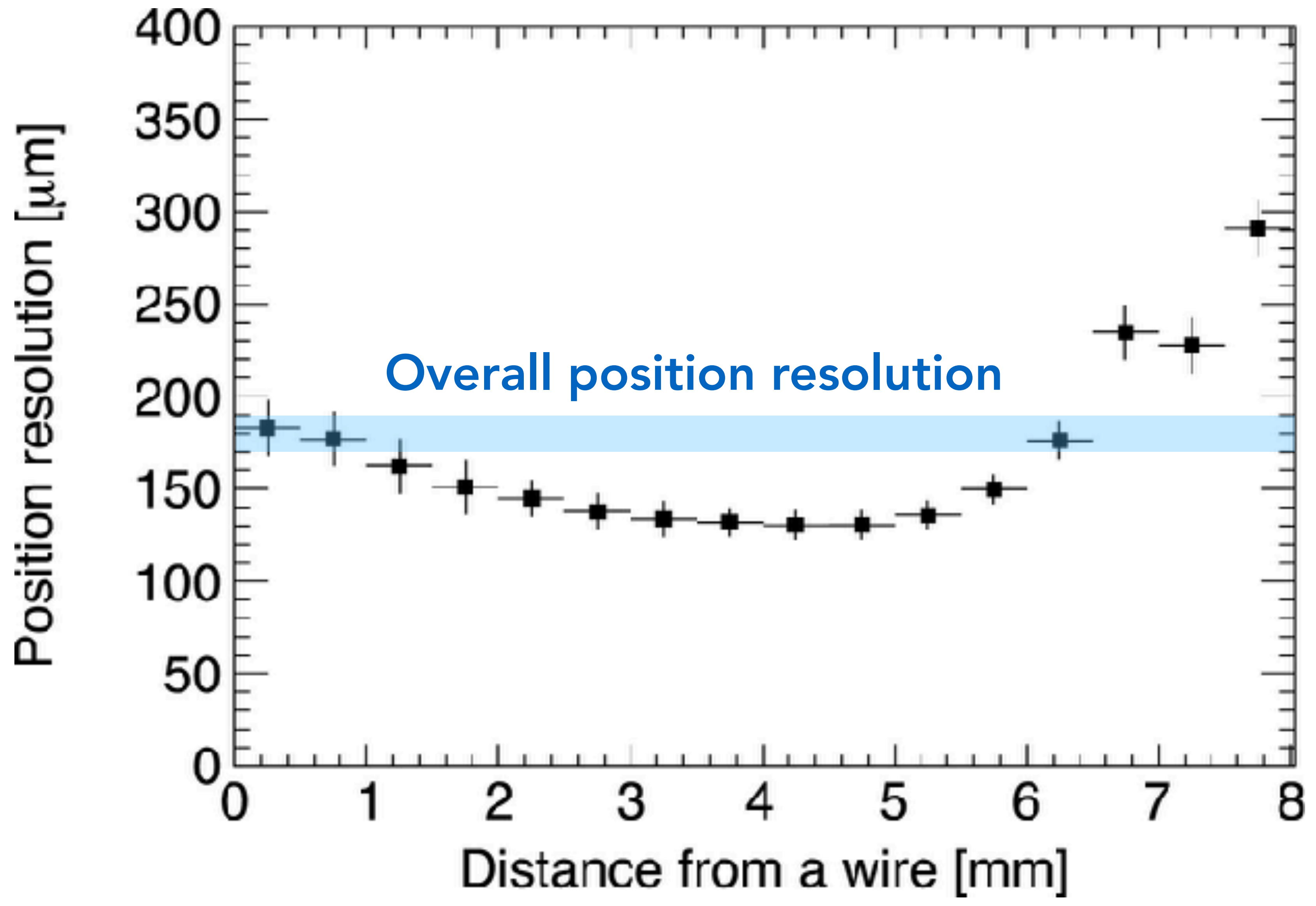




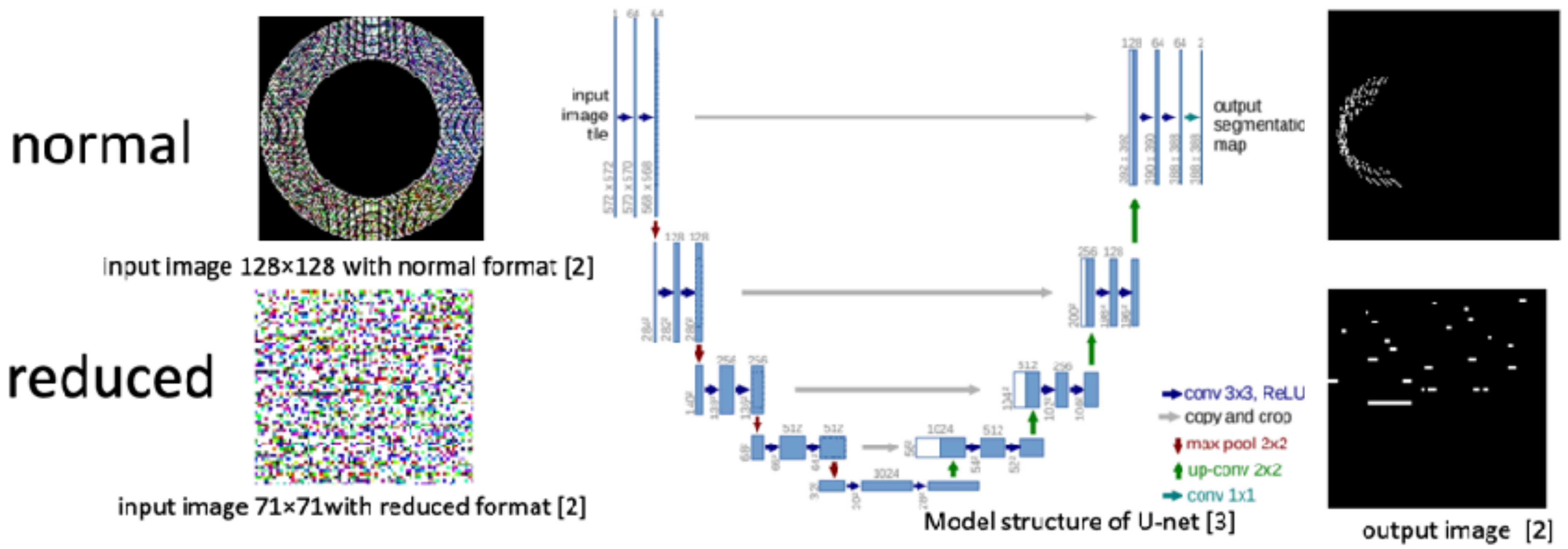
Cylindrical Drift Chamber (CDC)

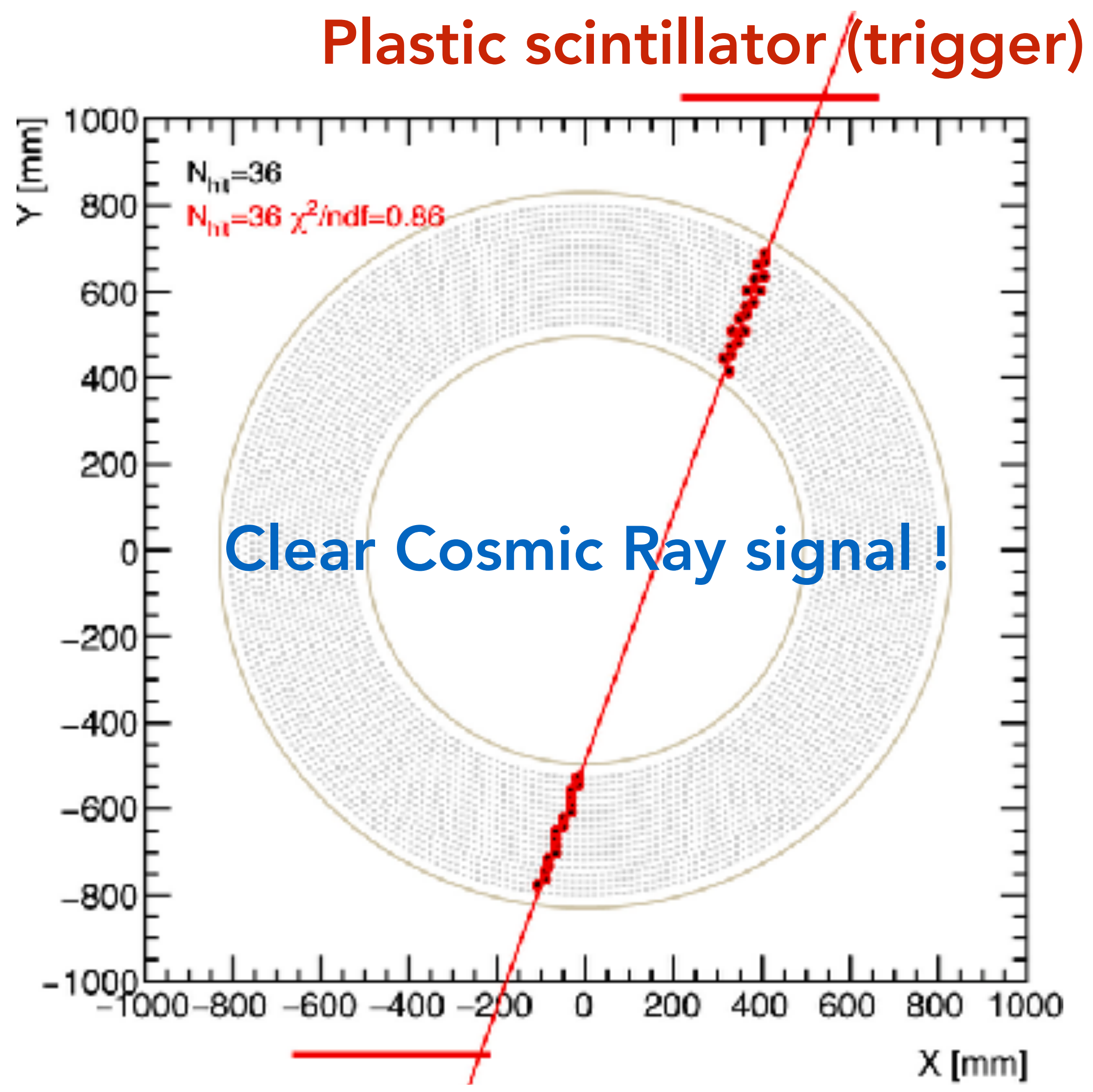


- Consists of 20 concentric layers with 4,986 sense wires & 14,562 field wires
- Chamber volume: 2084L filled with inner gas of He/iC_4H_{10} (9:1)
- Basic performance test using CRs has been completed
  - (Overall) position resolution $\sim 200\,\mu\mathrm{m}$ — expected level
  - Further analysis is ongoing (gas flow dependence, …)
- Studies of the track reco. with a high hit occupancy are ongoing

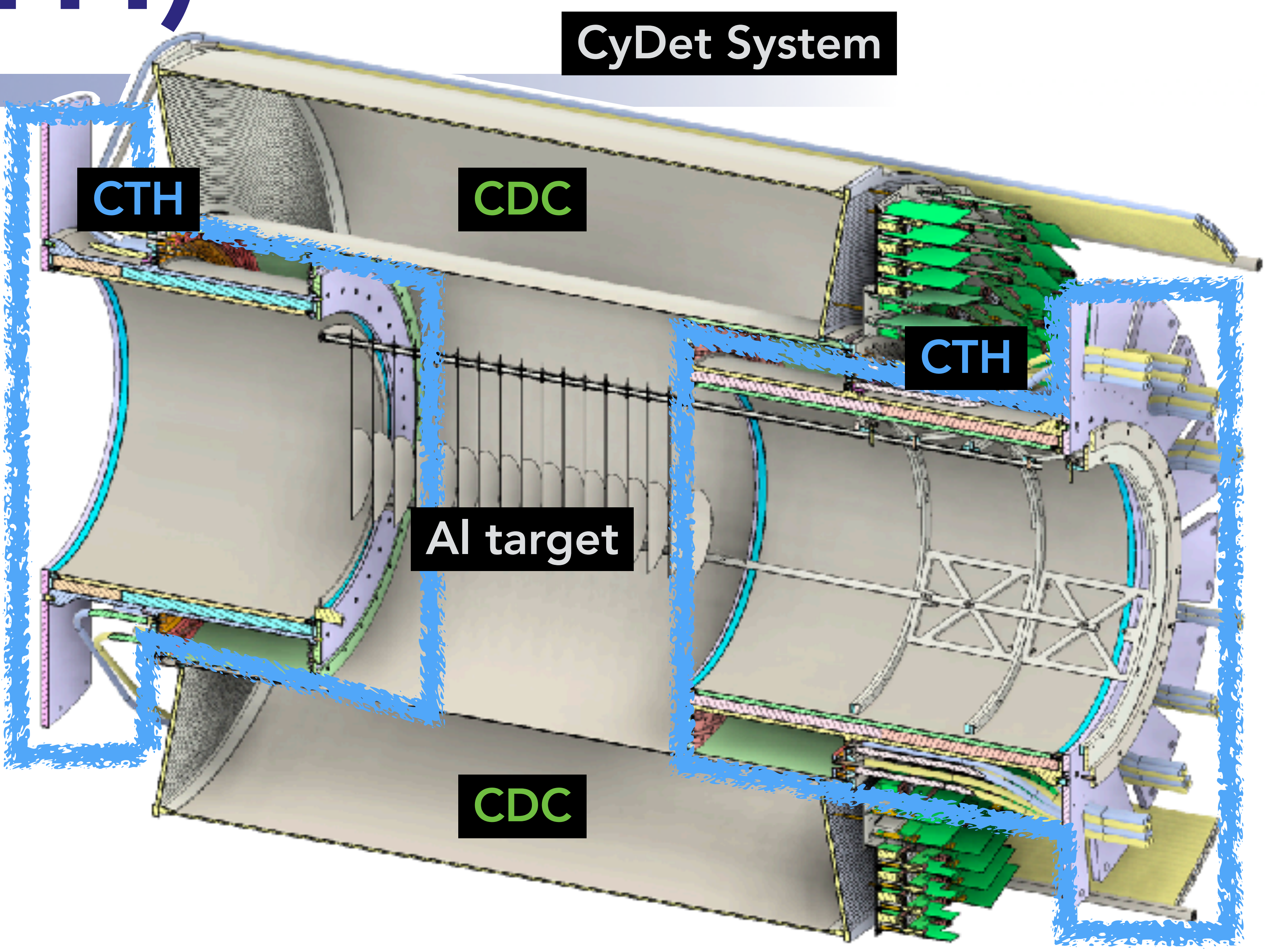


U-net deep-learning reconstruction scheme

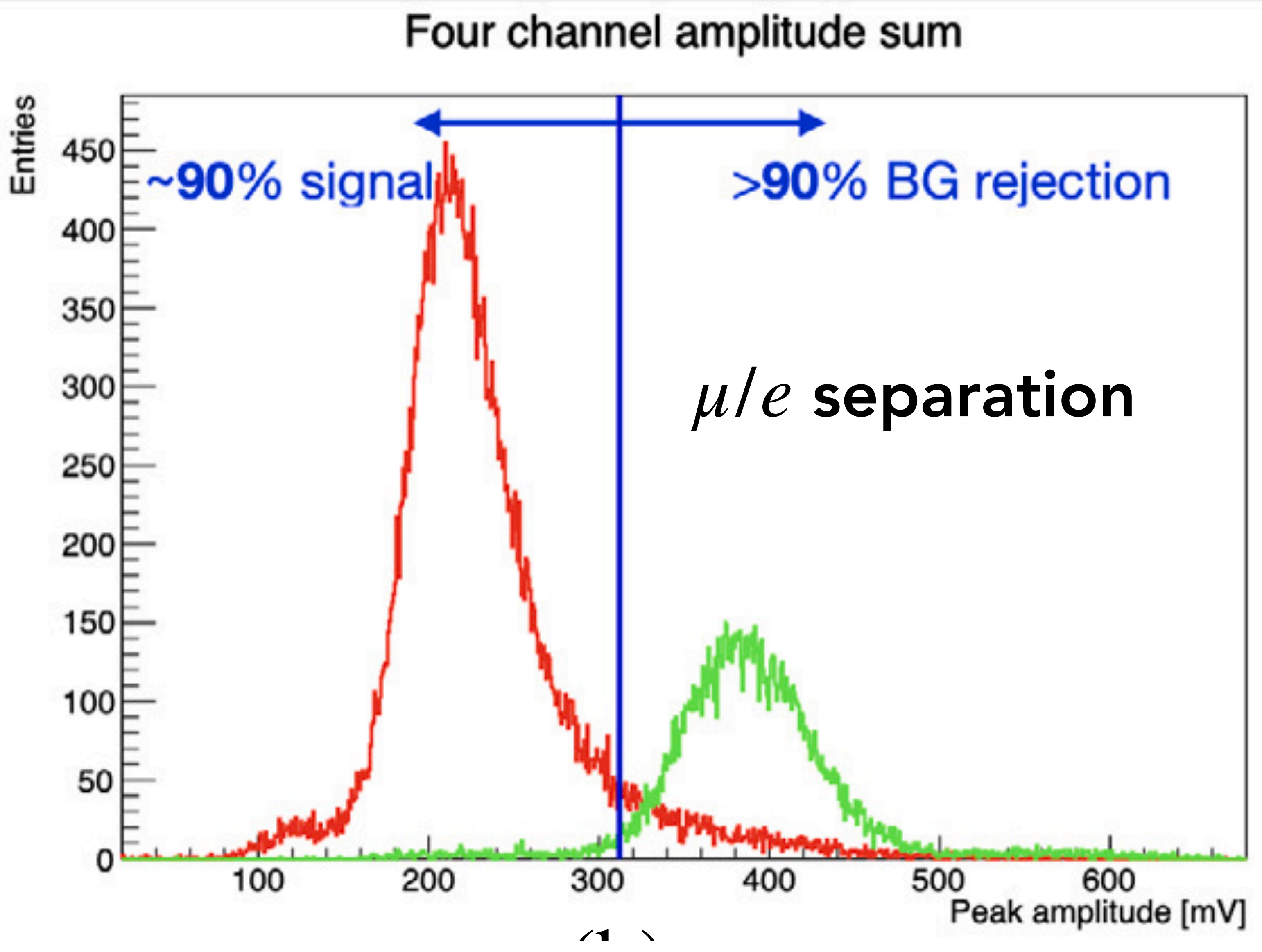


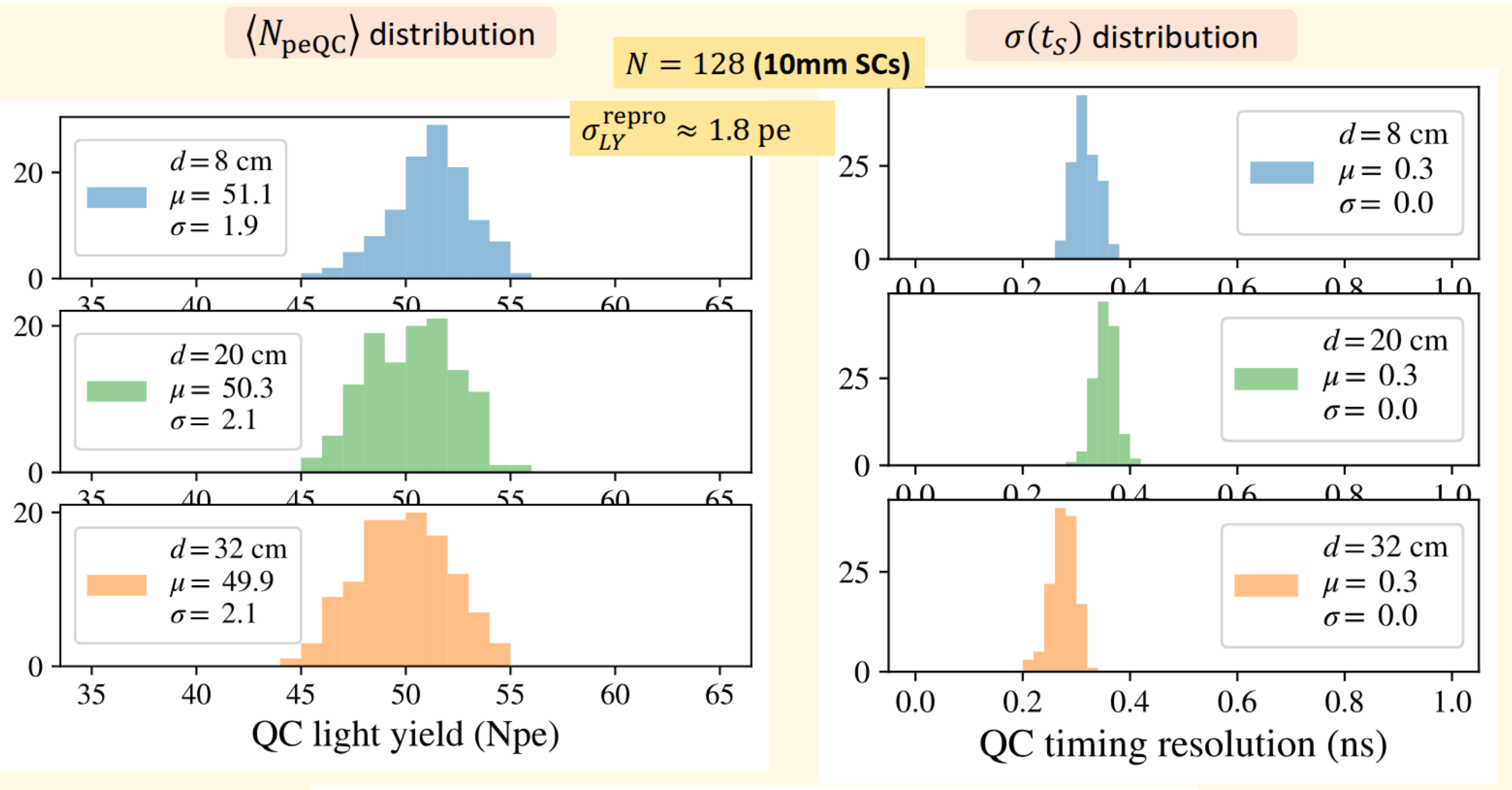


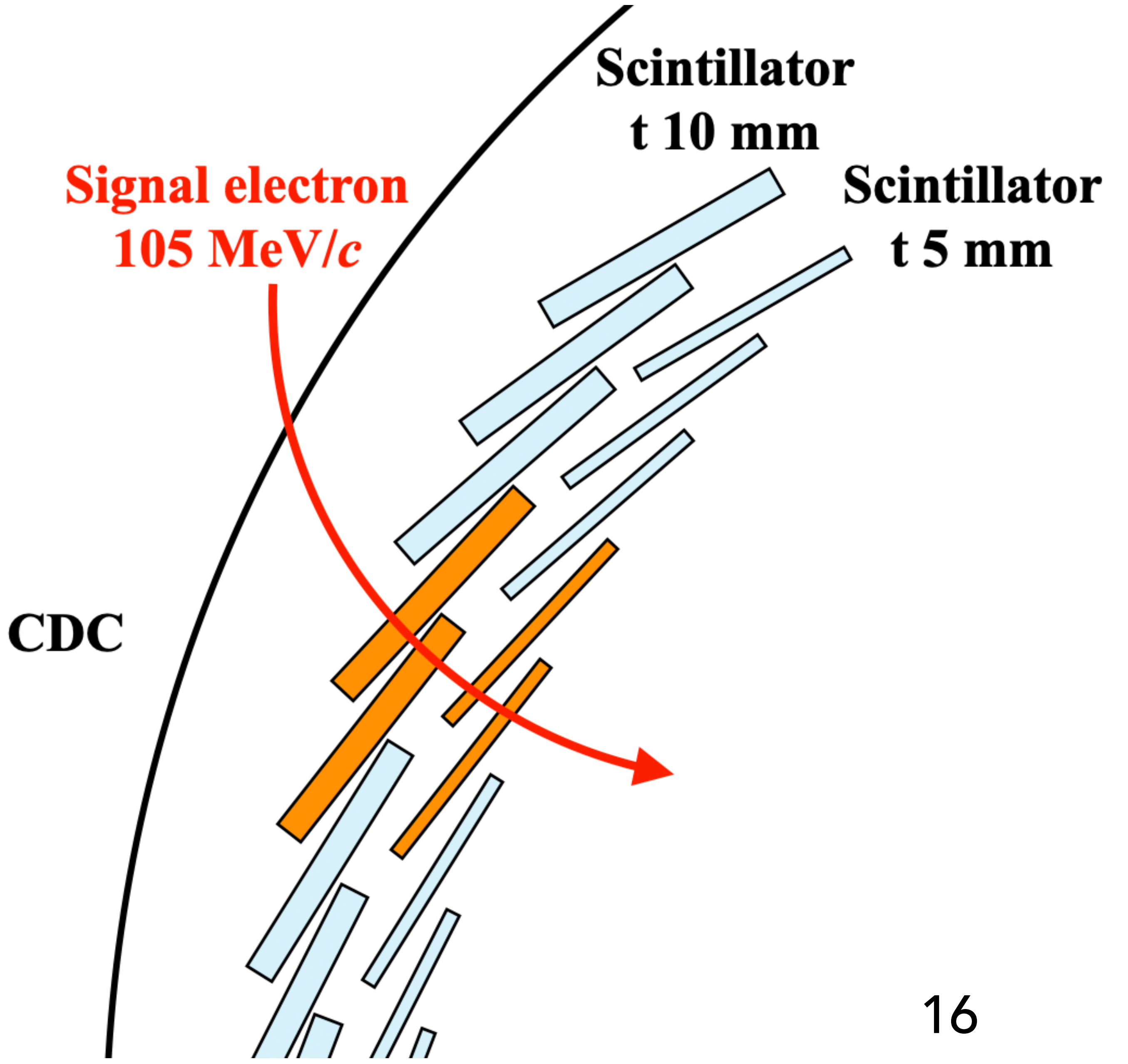
Cylindrical Trigger Hodoscope (CTH)



- $10\,\mathrm{mm^t}/5\,\mathrm{mm^t}$ plastic scintillators (in total 256) located at the both ends of the CDC + 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**/300 for MPPCs ; **128**(all of $10\,\mathrm{mm^t}$)/256 for Scintillators





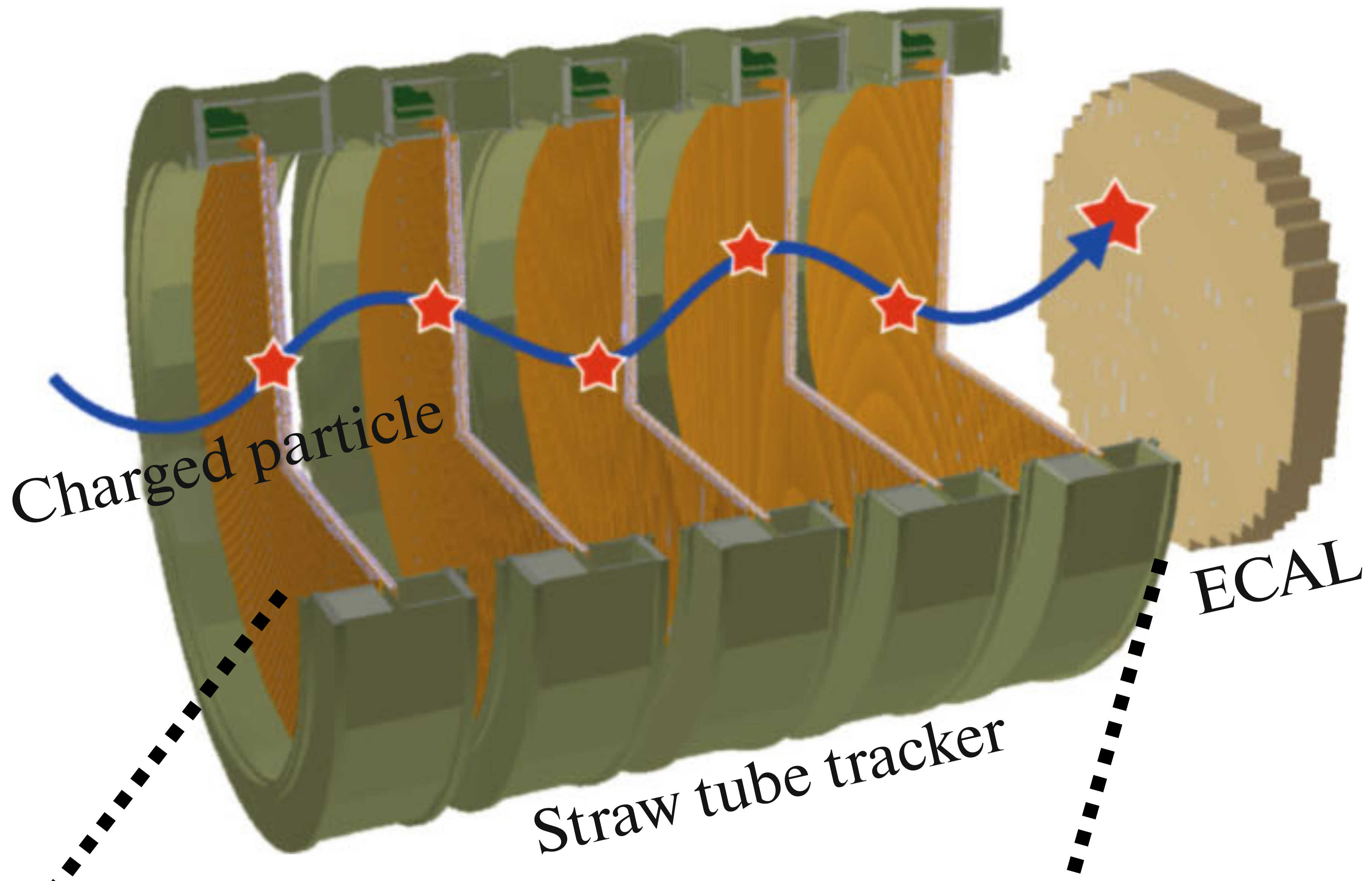


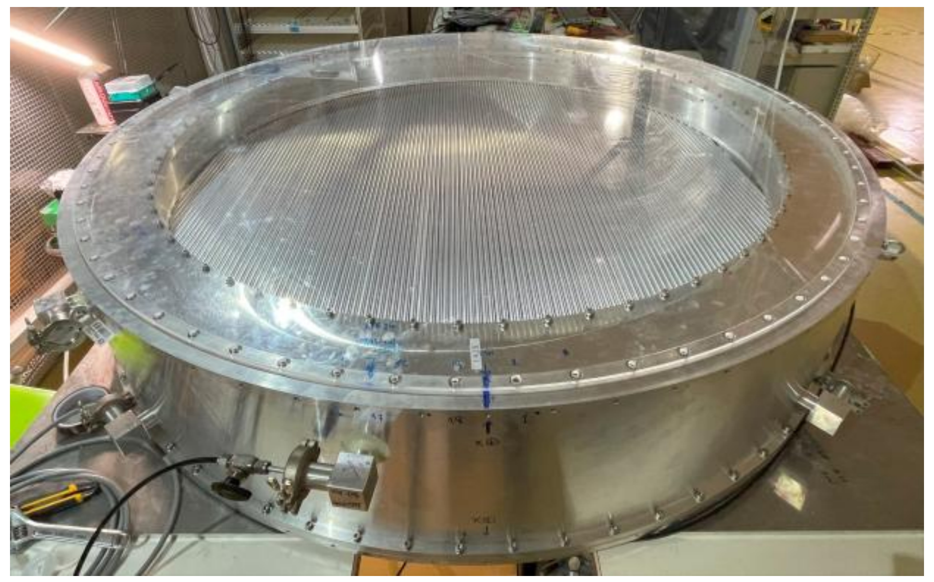
Ryo Nagai (UOsaka) *NIM A 1067 (2024)169665*

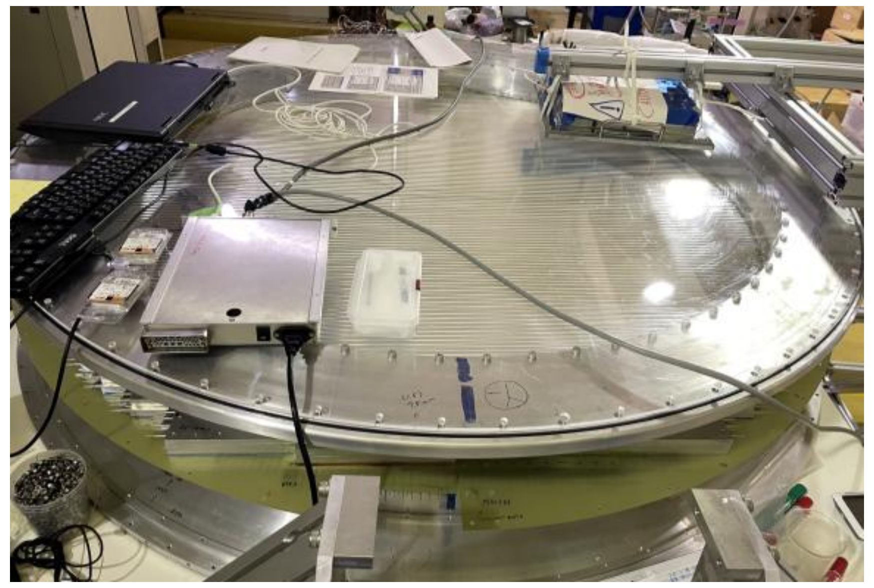
10 mm Scintillators' QC summary

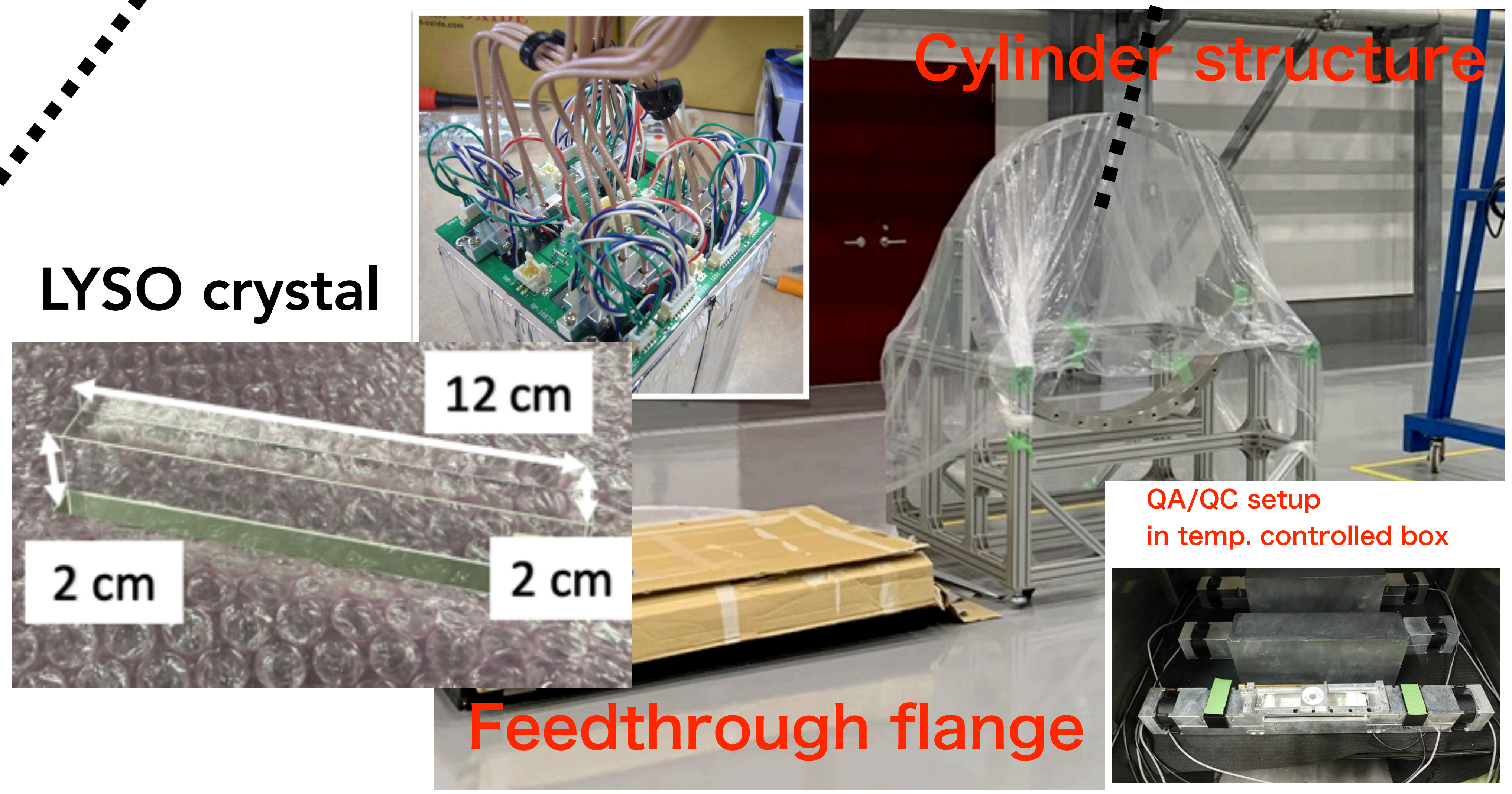
StrECAL — Beam Measurement & Phase-II Prototype

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

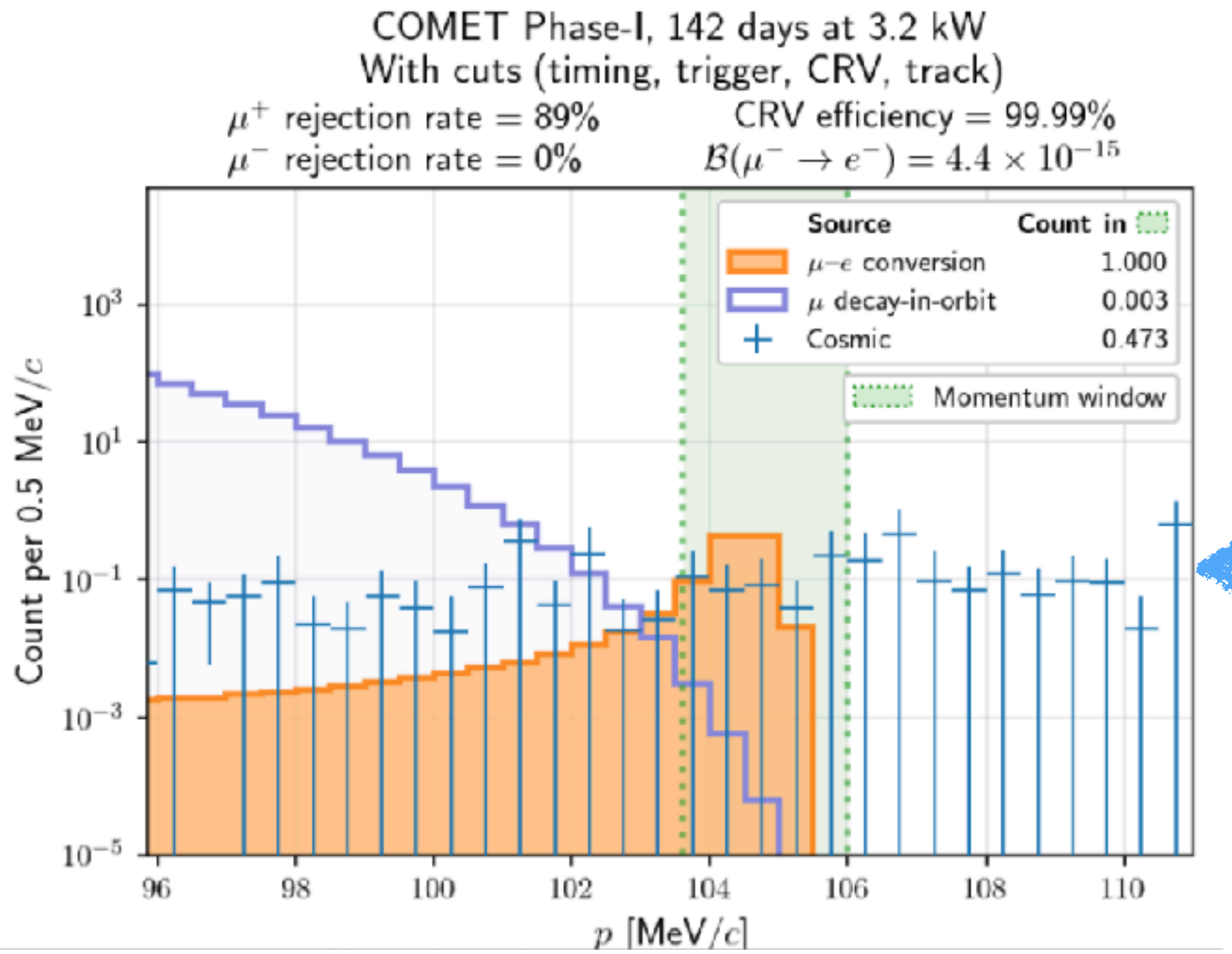




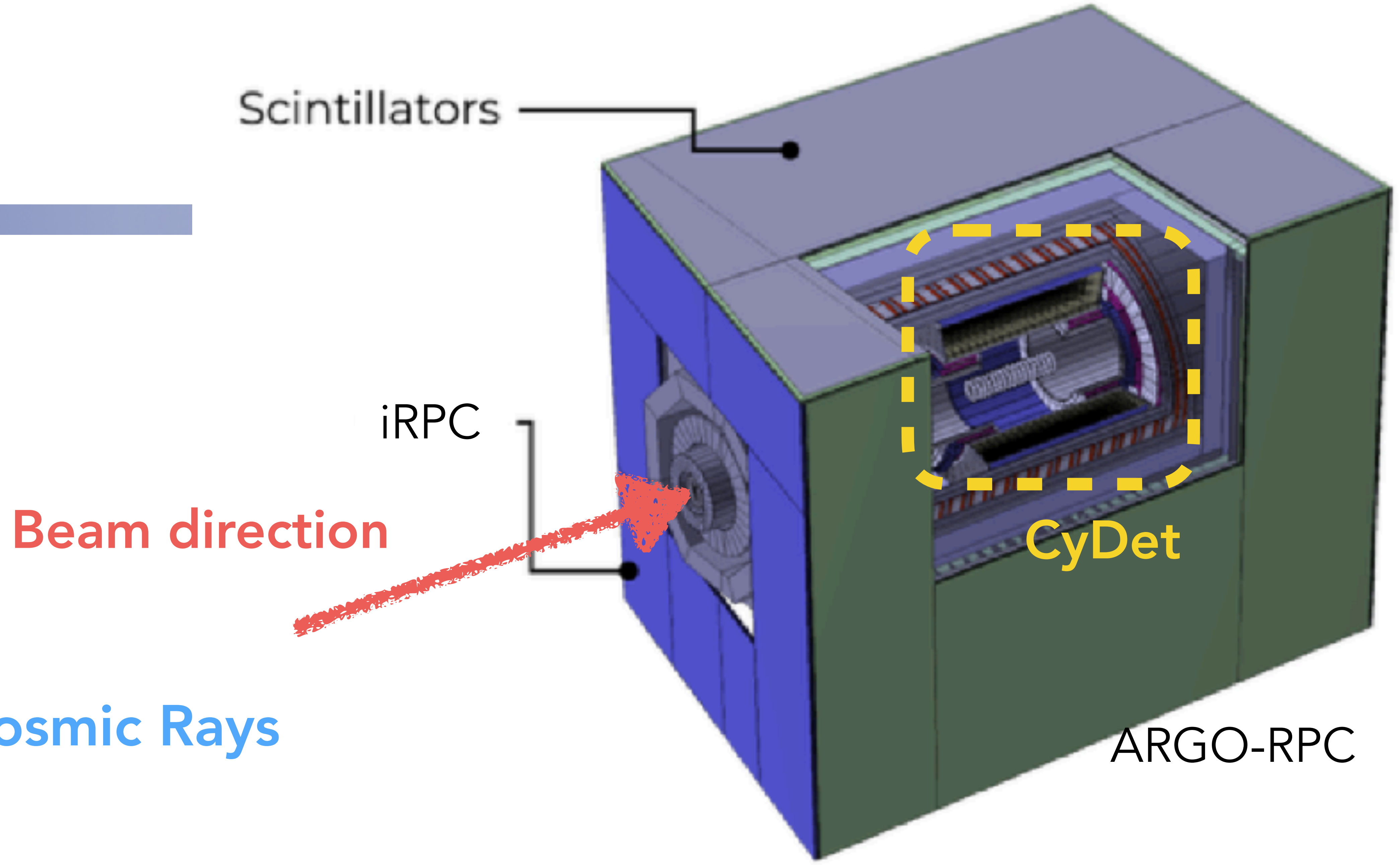




Cosmic Ray Veto Detectors

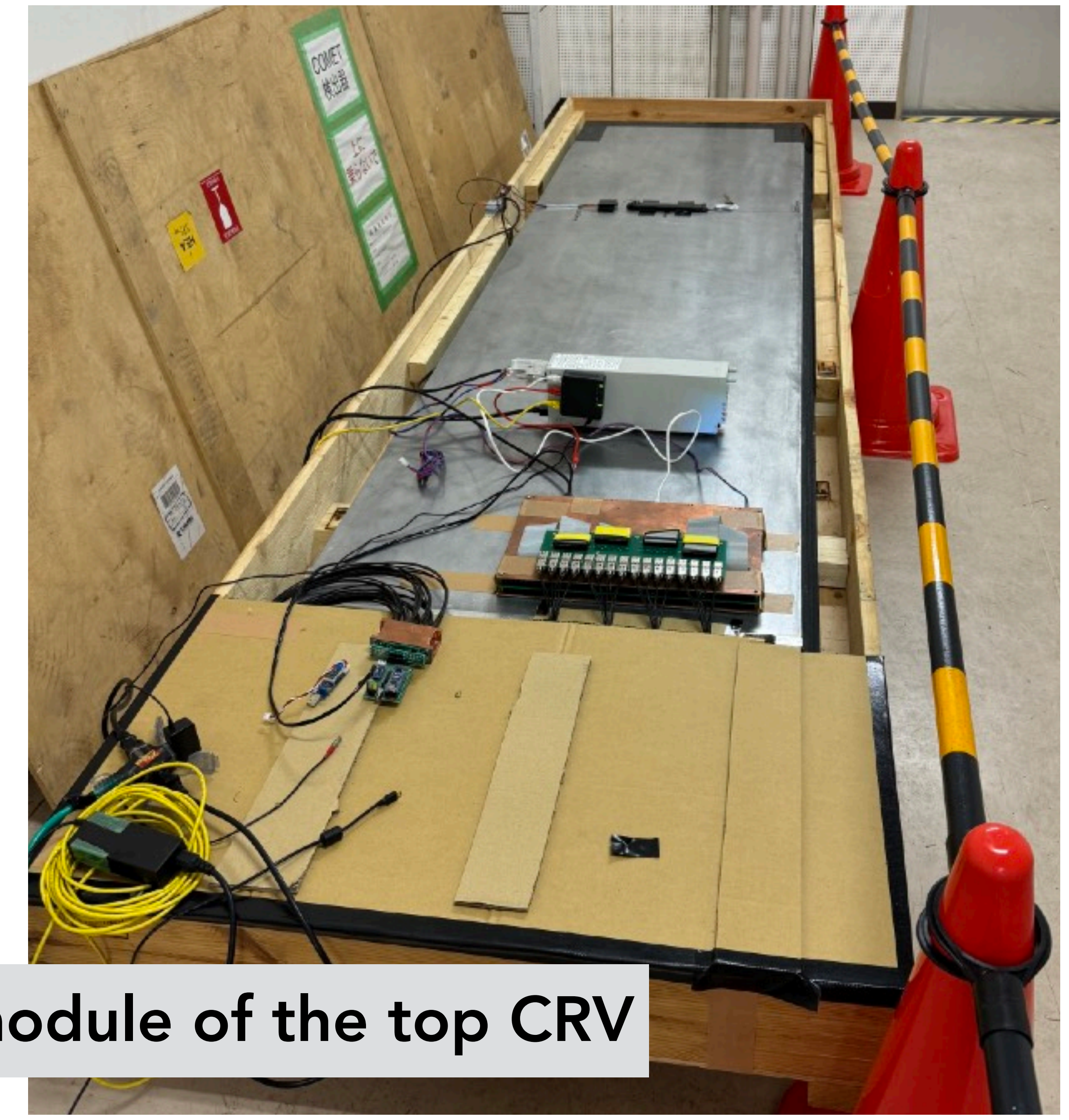


Large contribution from Cosmic Rays



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

- Full covering except the beam holes, using different technologies
  - Top CRV: plastic scintillator layers
  - Side CRV: ARGO-RPC modules
  - Upstream/Downstream CRV: improved RPCs
- Scintillator CRV is under construction, and RPC CRV are under developments.

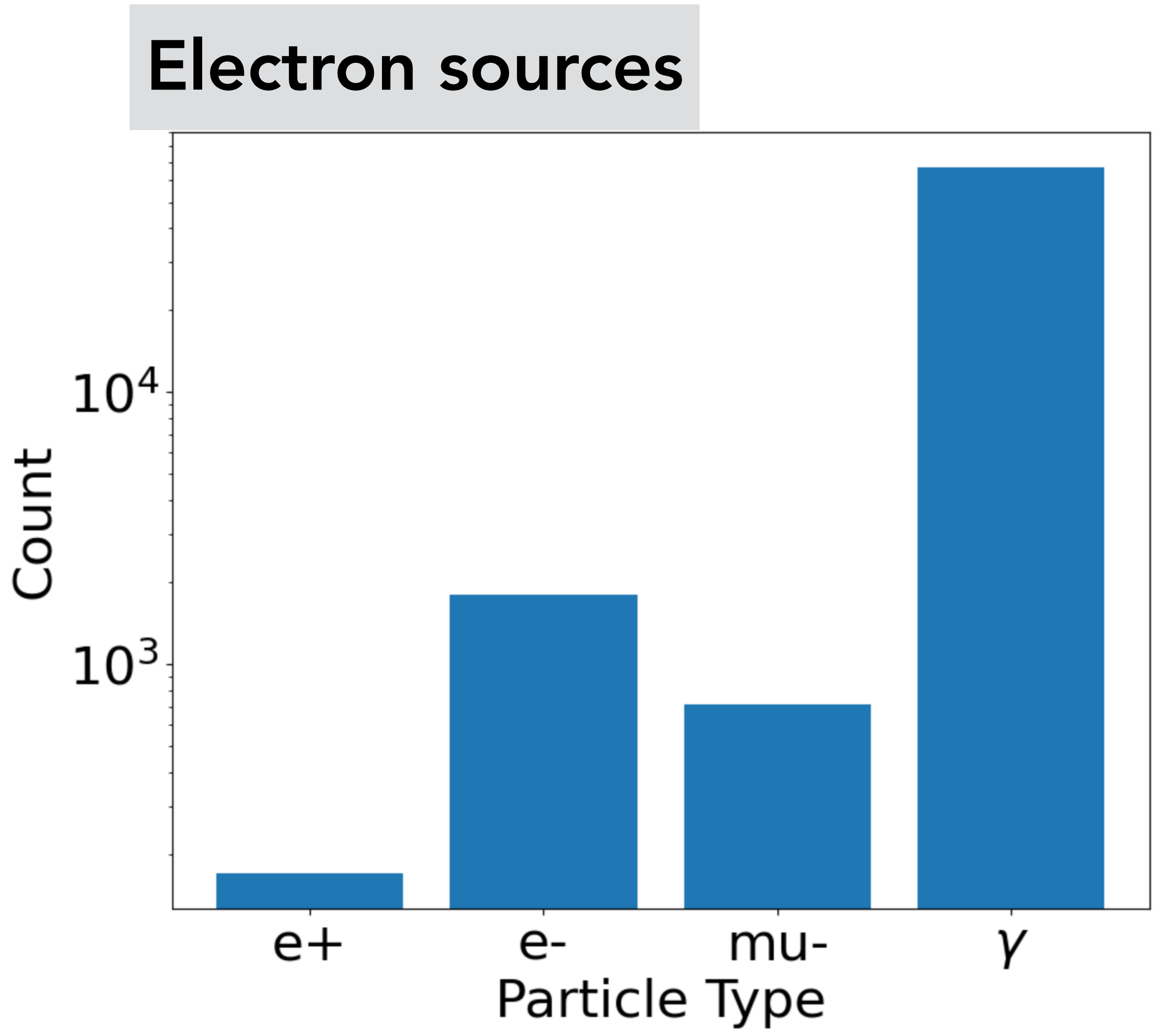


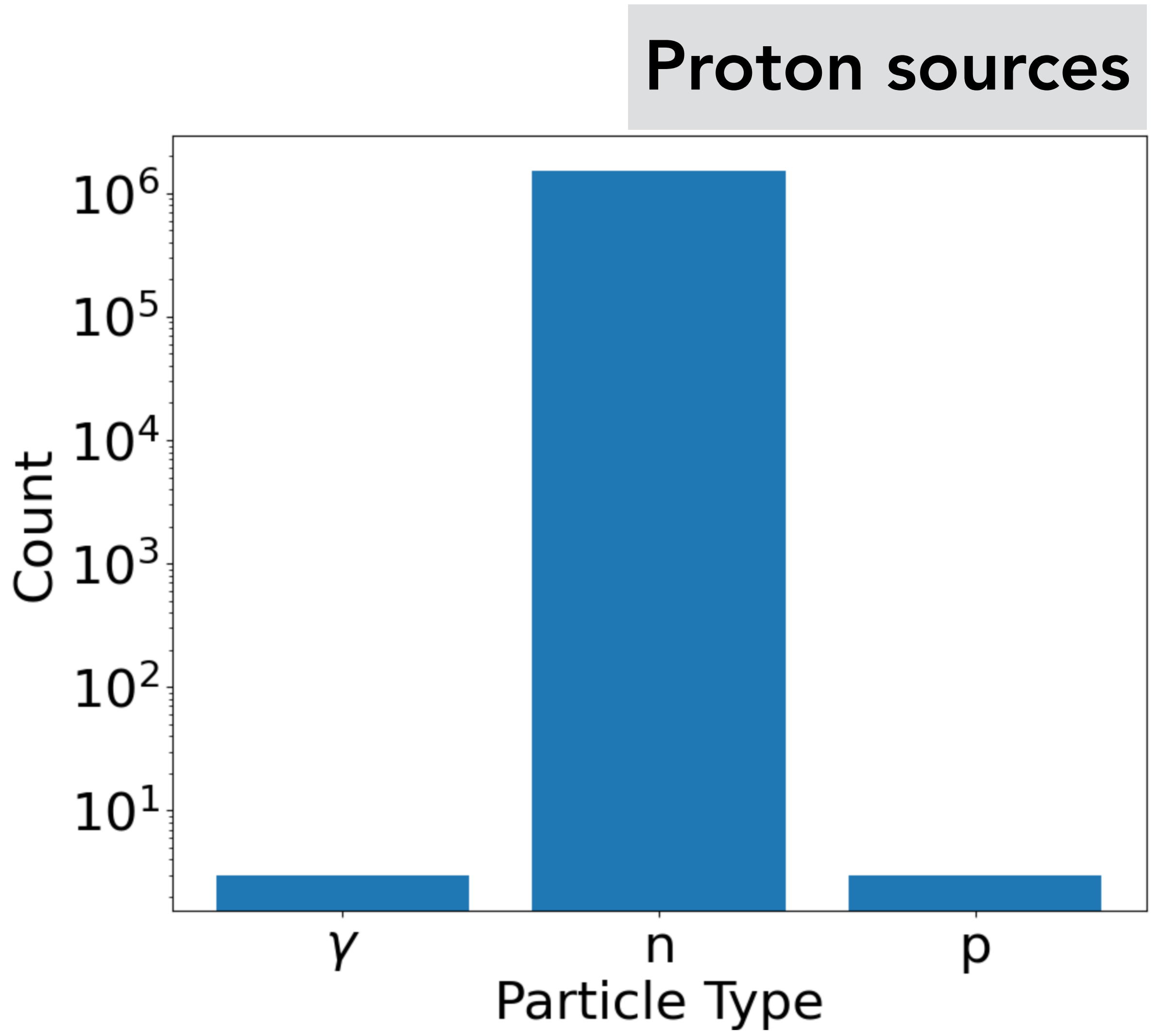
First module of the top CRV

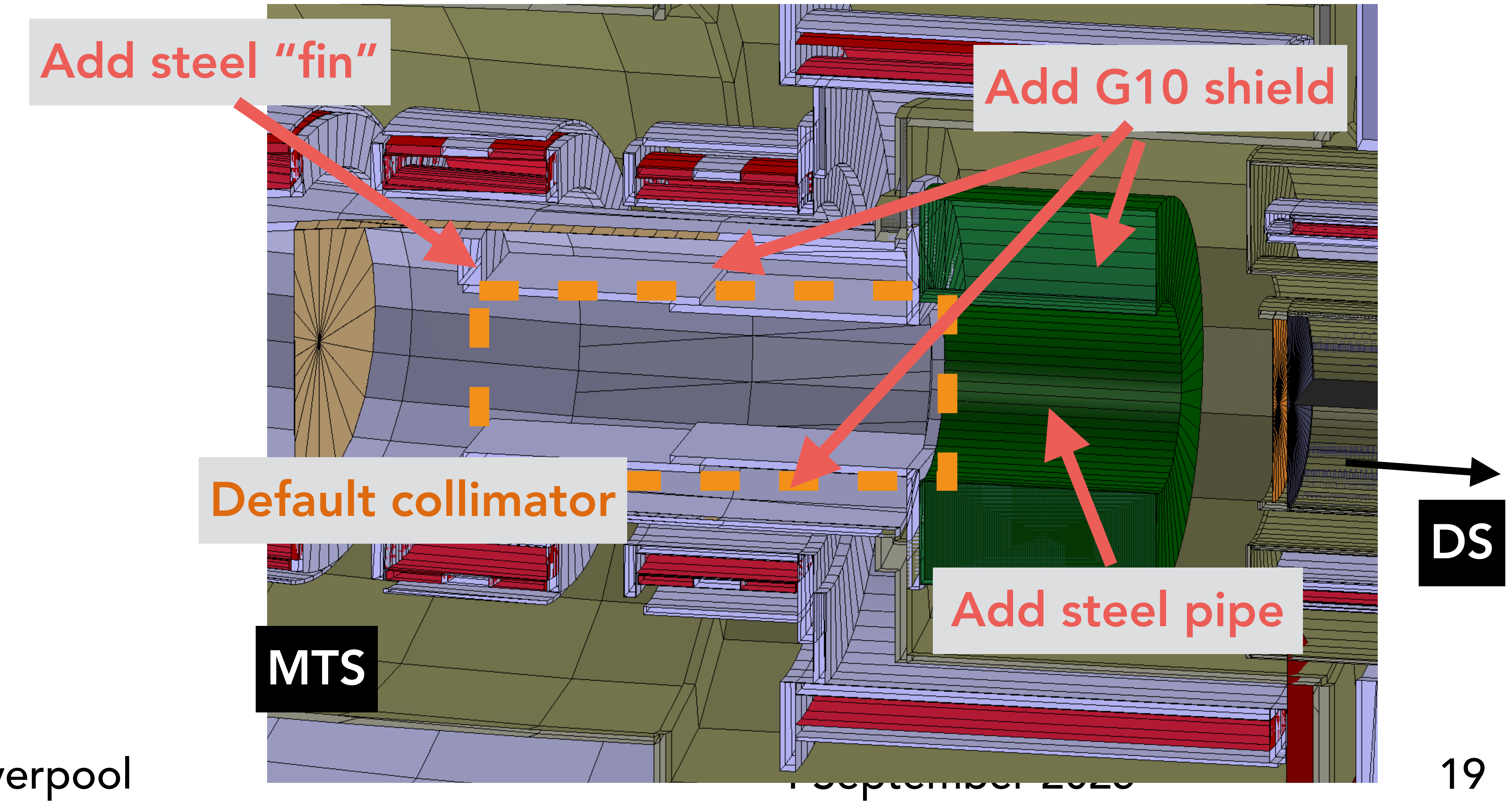
Re-adjustment of muon beam collimator

- **Confirmed** that the default collimator already achieves **70–80% background reduction** (from simulation studies)
- High CTH trigger rate observed in new MC samples → need further reduction
- Main background sources:
  - **Electrons from gammas**
  - **Protons from neutrons**

→ Now re-adjusted to fit into the **real MTS geometry**

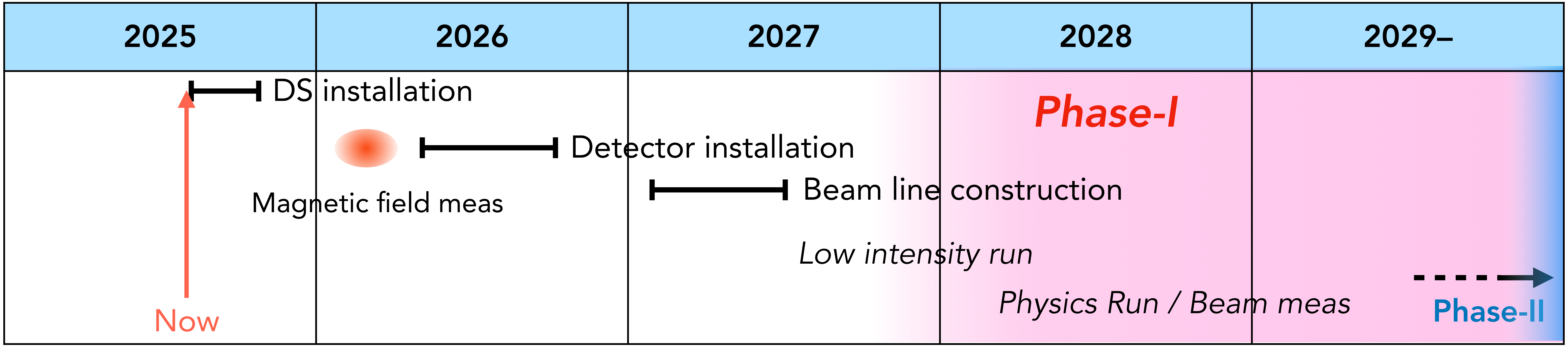






Final hardware optimization guided by simulation studies

Phase-I Timeline



- Now → 2026: Solenoid installation & magnetic field measurements
- 2026–27: Detector installation, beamline construction
  → **Phase-I physics run starts in 2027**
- 2028–: Toward full SES $\sim 10^{-15}$
  … and preparation for Phase-II (full double c-shape structure)

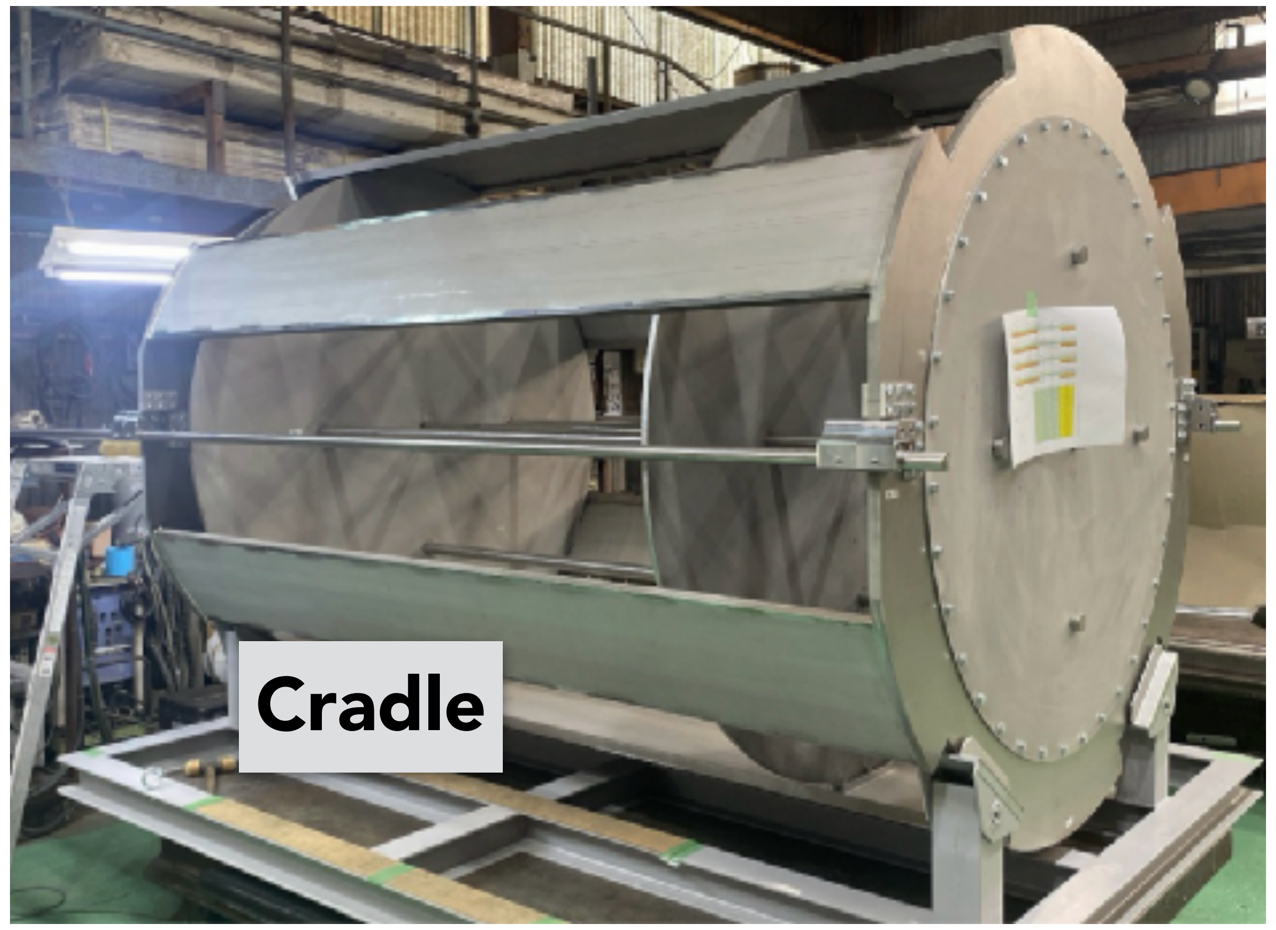
Summary

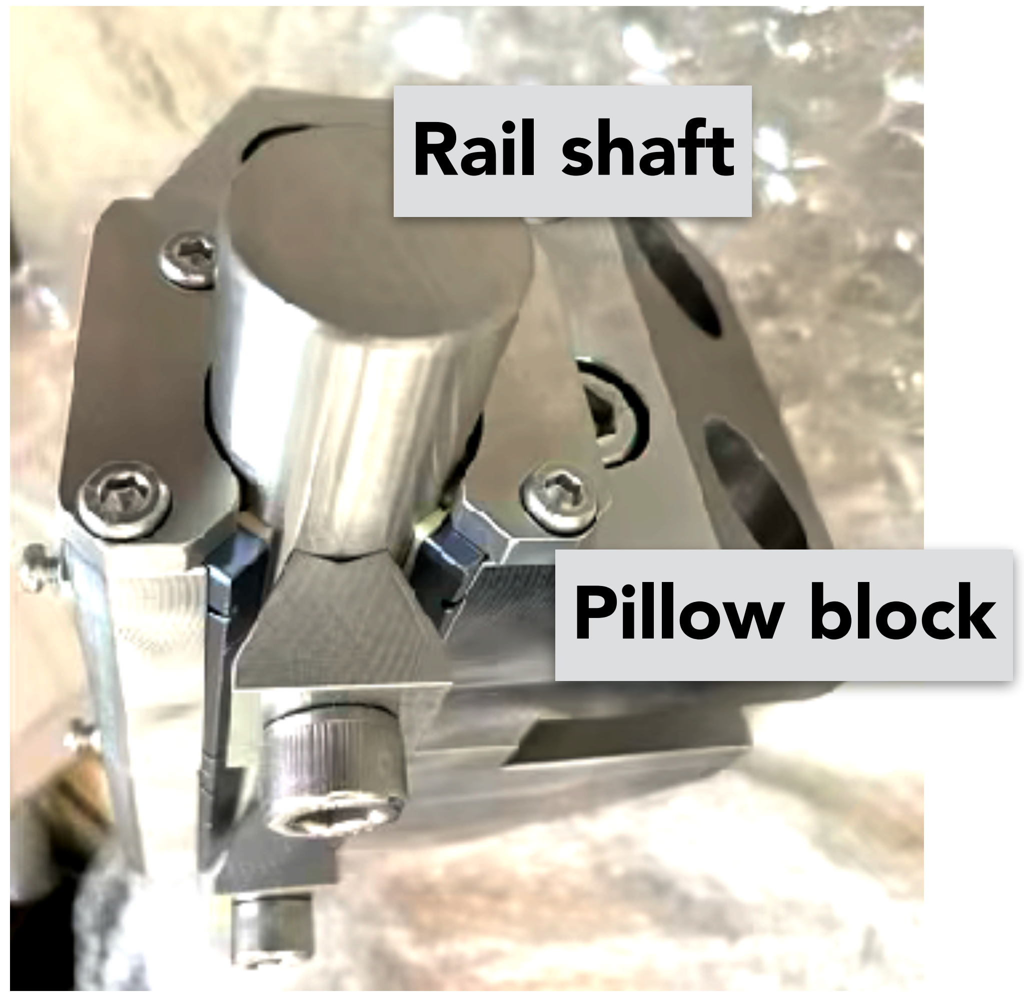
- COMET searches for $\mu^- \rightarrow e^-$ conversion
- **Phase-I**: construction will be completed in 2 years
  → **Physics run starts in 2027** (target SES $\sim 10^{-15}$)
- **Phase-II**: target SES $\sim 10^{-17}$ with full transport solenoid system and better background suppression
- COMET can provide a leading probe of CLFV and New Physics scale up to $\sim 10^5\,\mathrm{TeV}$

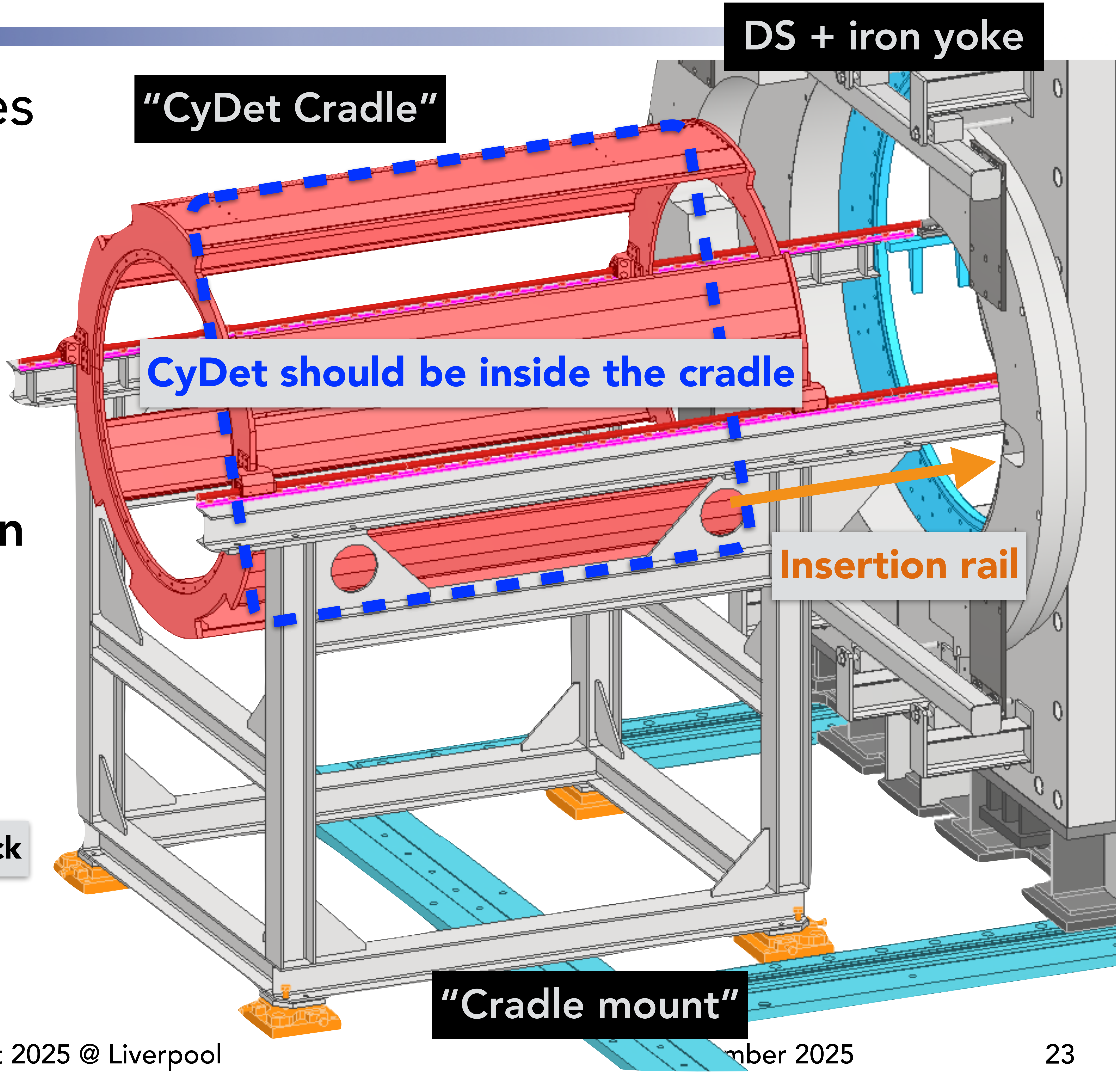
Backup

CyDet Installation Mechanism

- Limited DS entrance space requires **a dedicated rail system** for safe CyDet installation and removal
- 2 components:
  - CyDet Cradle — **manufactured**
  - Cradle mount with rail — **under design**







Phase-II Outlook

- Target SES $\sim 10^{-17}$ (**×10,000** beyond previous limits)
- Key Upgrades:
  - Introduce the Electron Transport Solenoid
    — complete "c-shape" curved geometry
  - Improve background suppression (cosmic ray veto, shielding)
  - Improve the detector and DAQ performance based on the Phase-I results
- **Comparable sensitivity to Mu2e** at Fermilab