

COMET Status

(COherent Muon-to-Electron Transition)



Yuki Fujii (Shiga University / TYL)

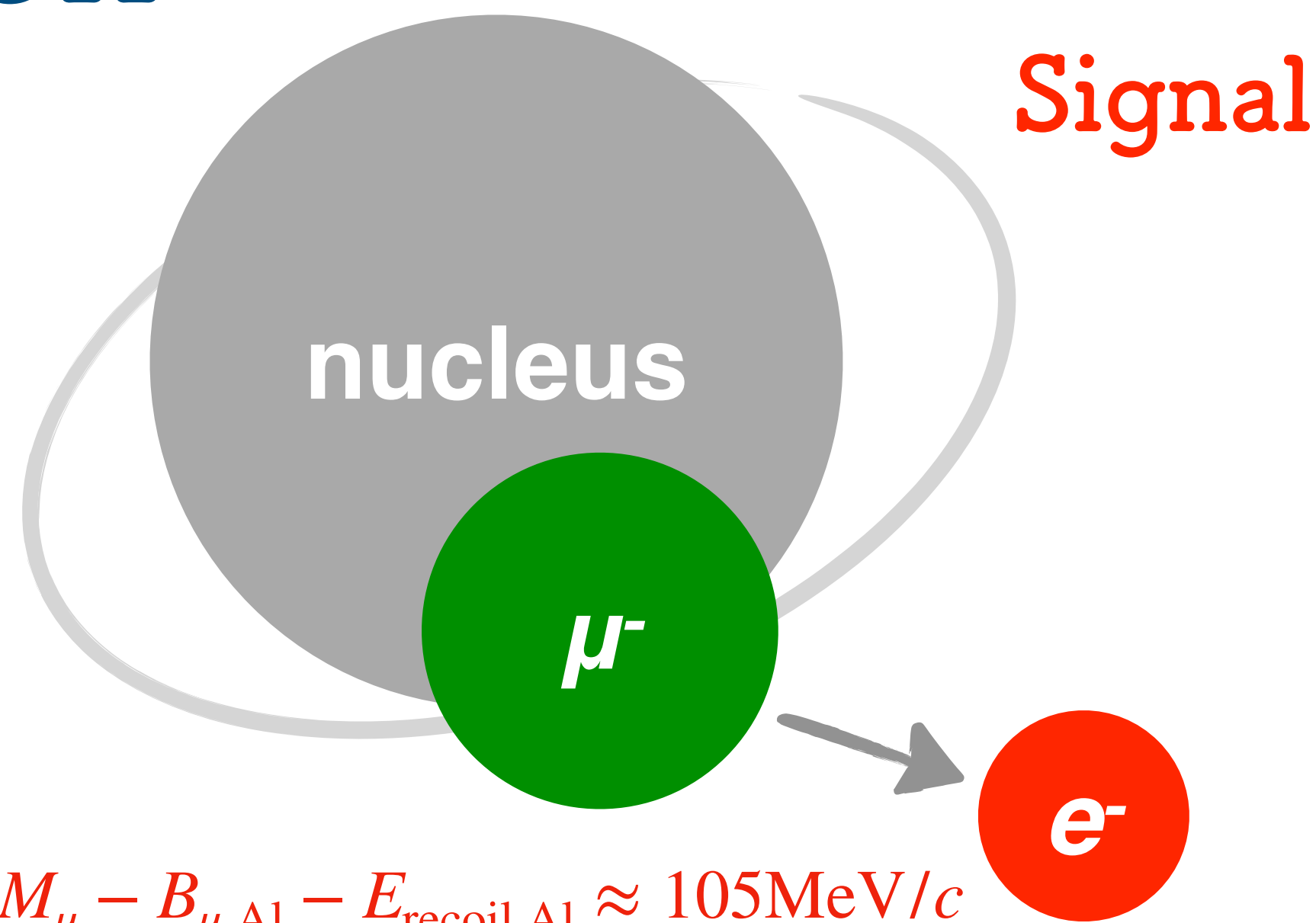
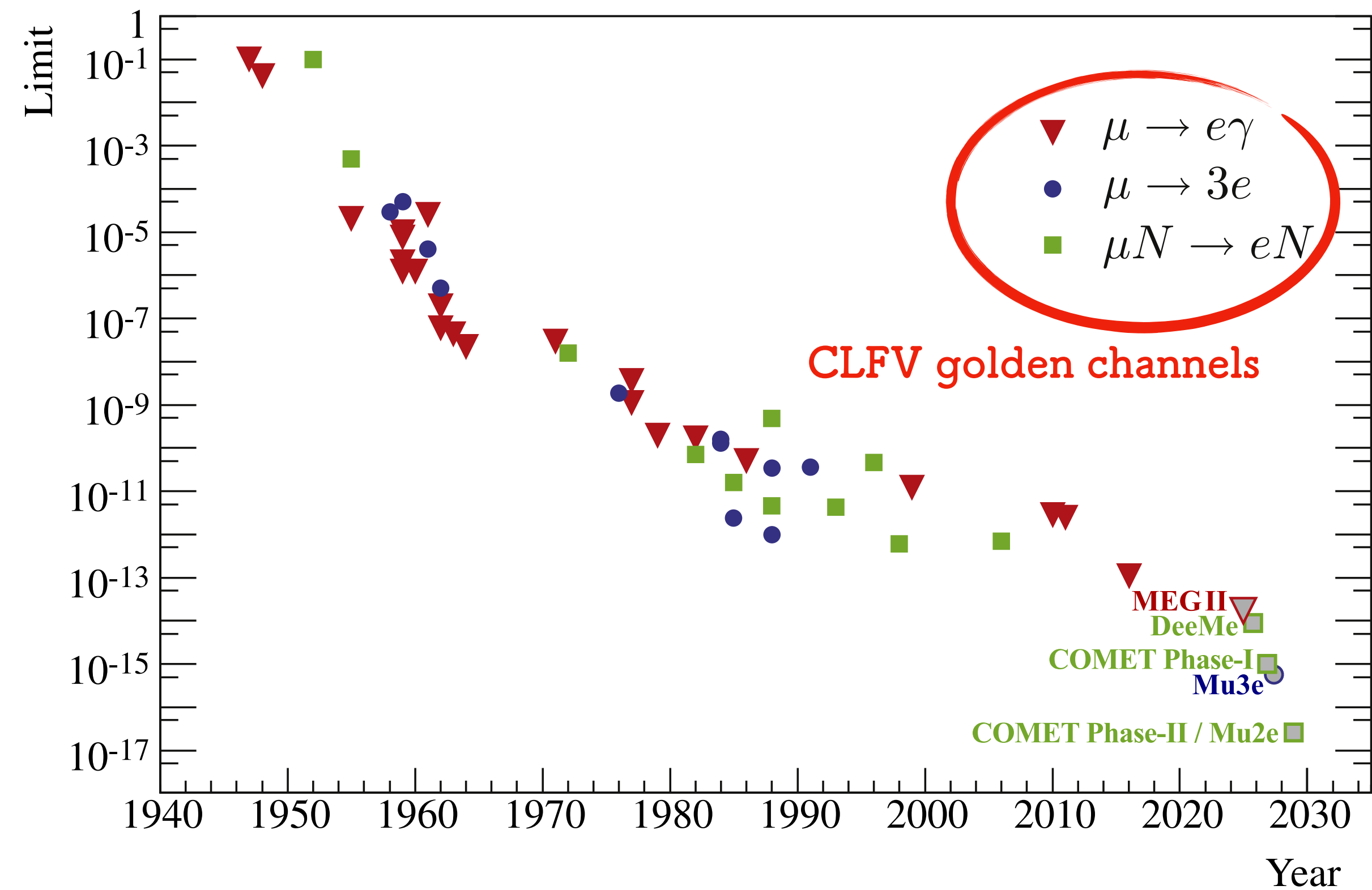
1st September 2026

NuFact2026 @ Shanghai



Muon-to-Electron Conversion

The History

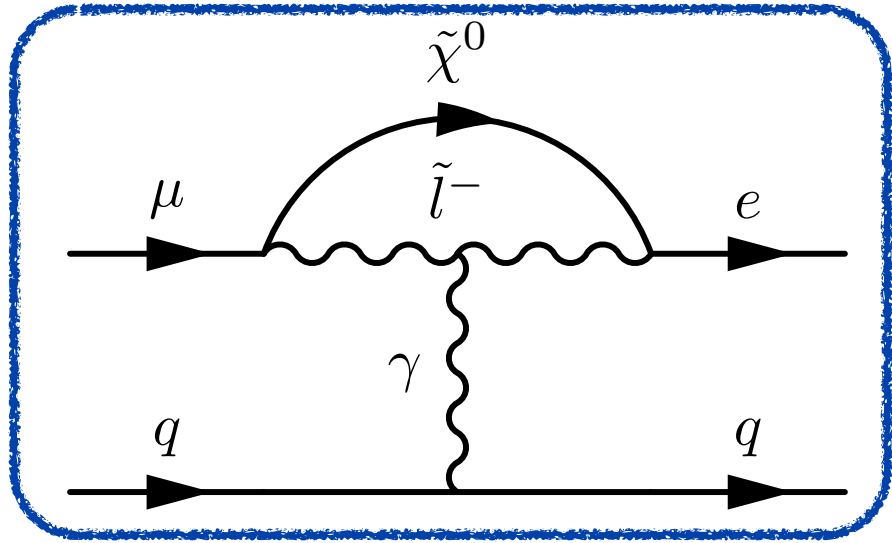


$E_e \approx M_\mu - B_{\mu,Al} - E_{\text{recoil},Al} \approx 105\text{MeV}/c$

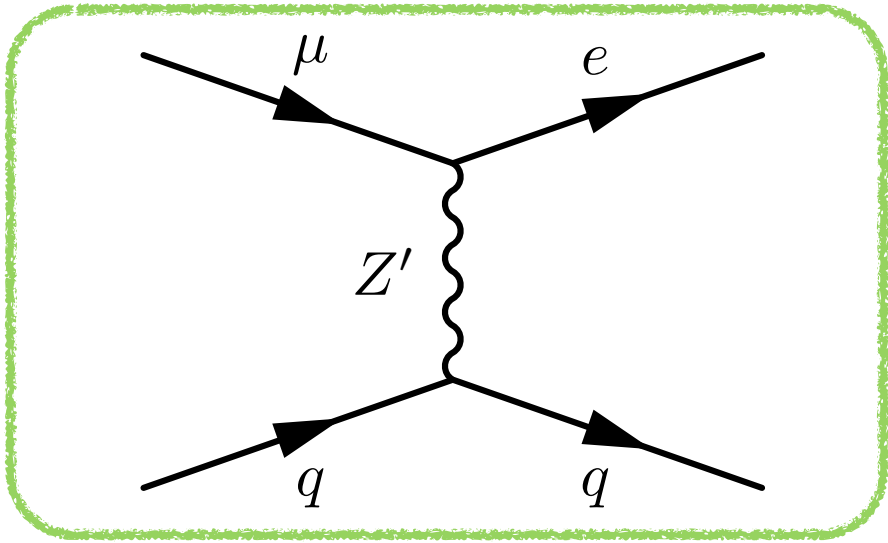
- One of the Charged Lepton Flavour Violation processes forbidden in the Standard Model
 - Clear sign of the new physics if discovered
- Extremely simple final state
- Current upper limit: 7×10^{-13} @90% C.L. by SINDRUM II with gold nuclei

Physics Motivations

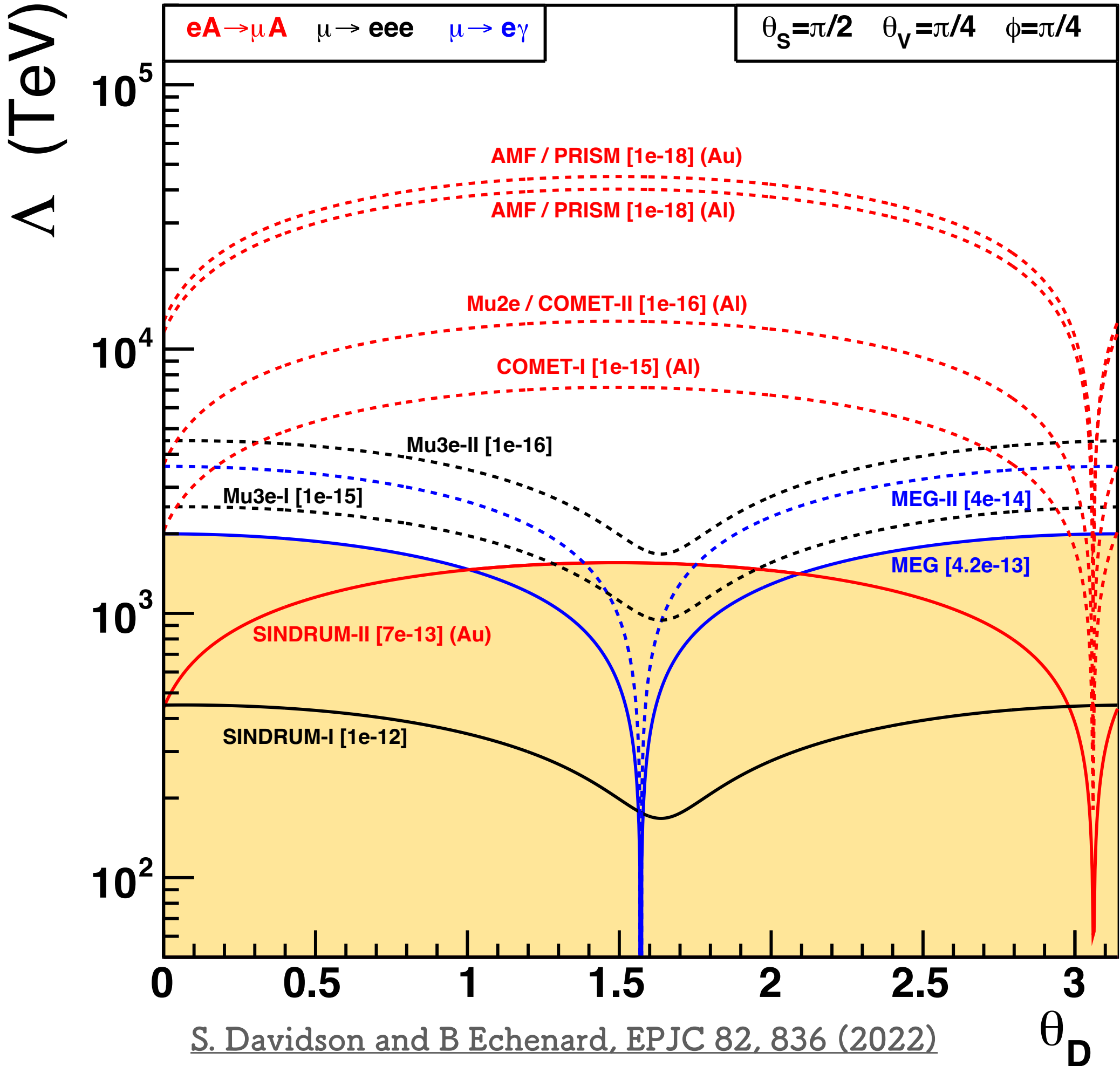
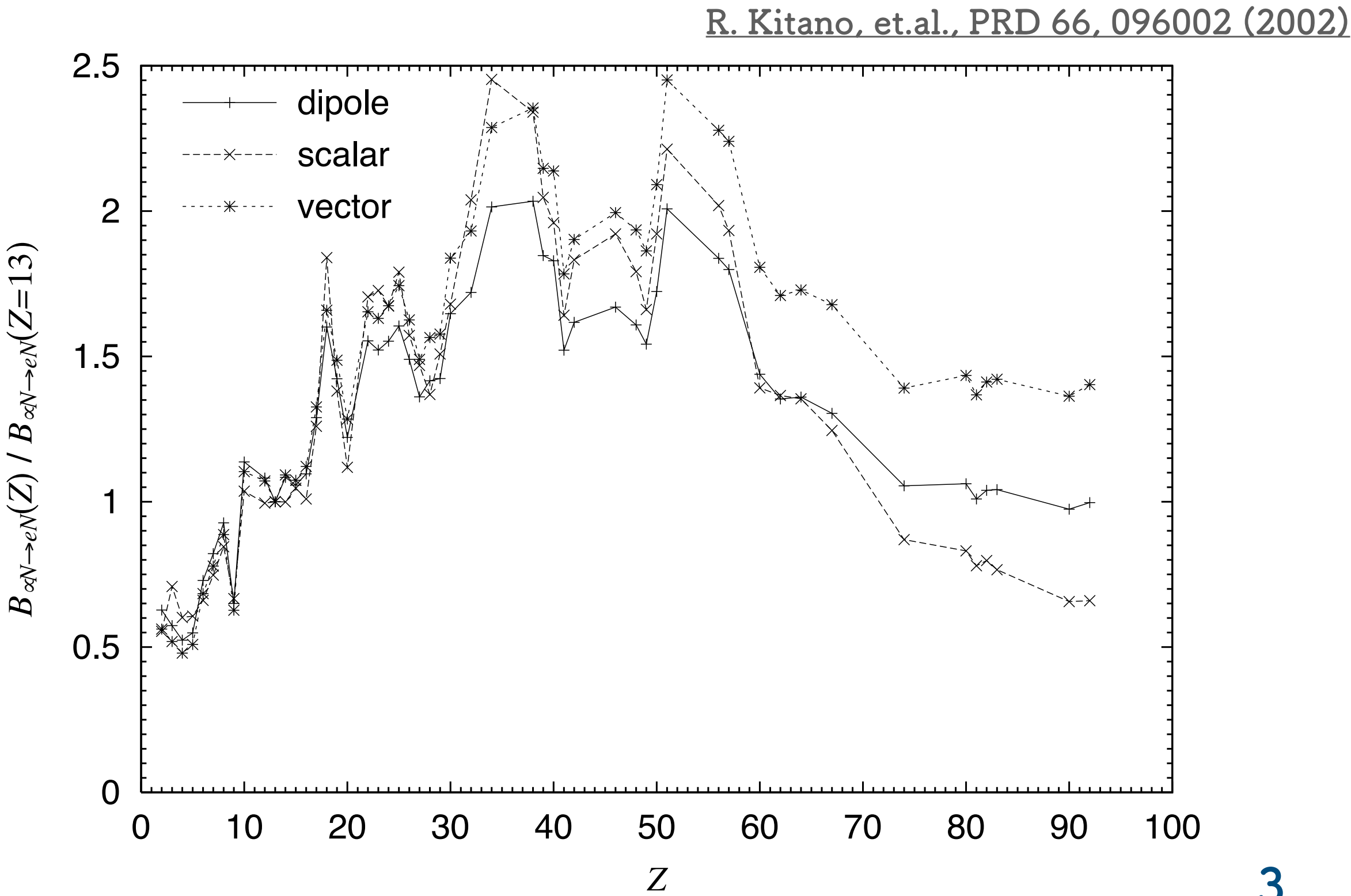
- New physics energy scale of $>10^3$ TeV achievable
- Complementary to other CLFV searches
- NP interaction models can be studied by comparing different nuclei when μ -e conversion is discovered



Photonic process



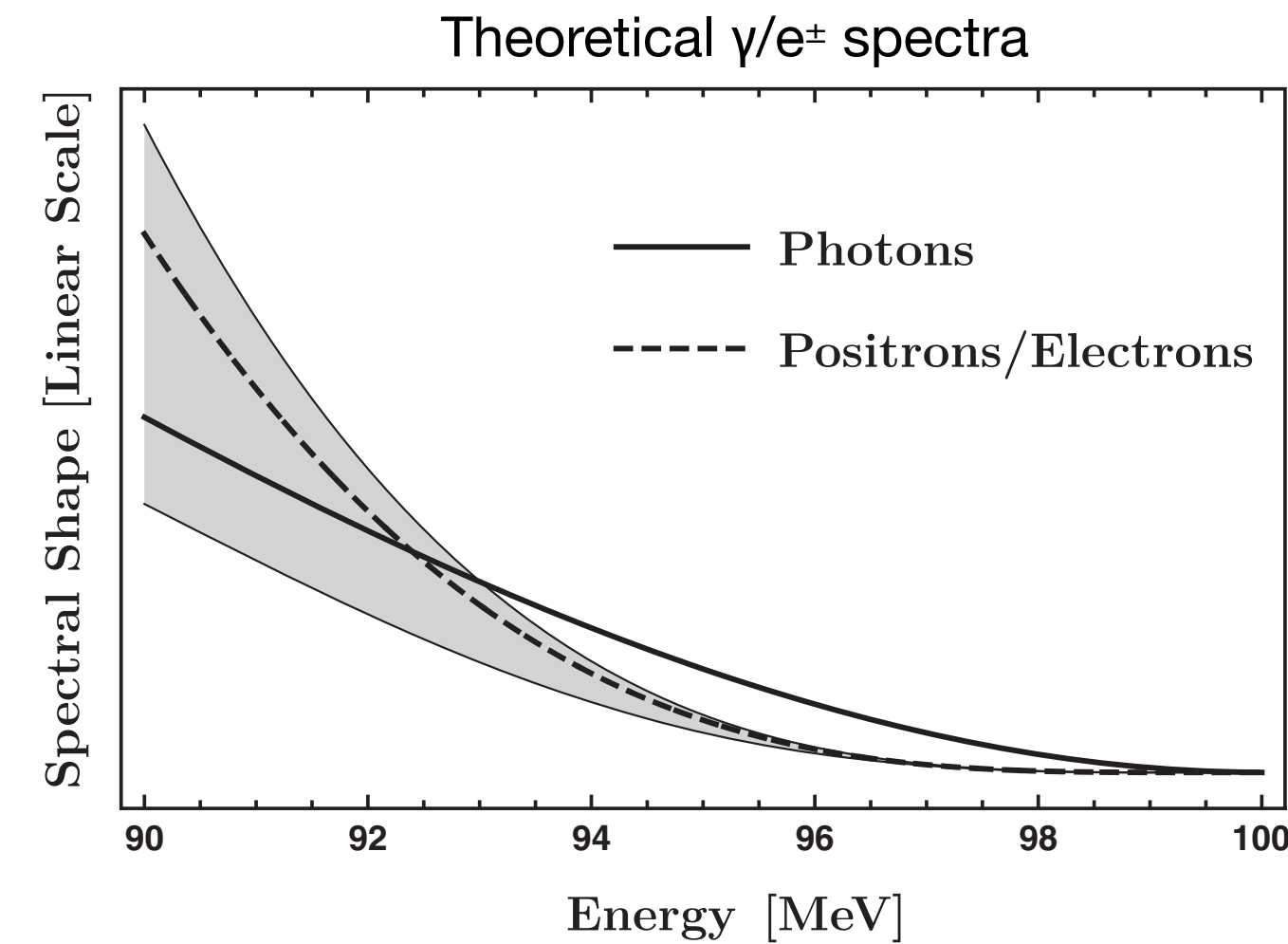
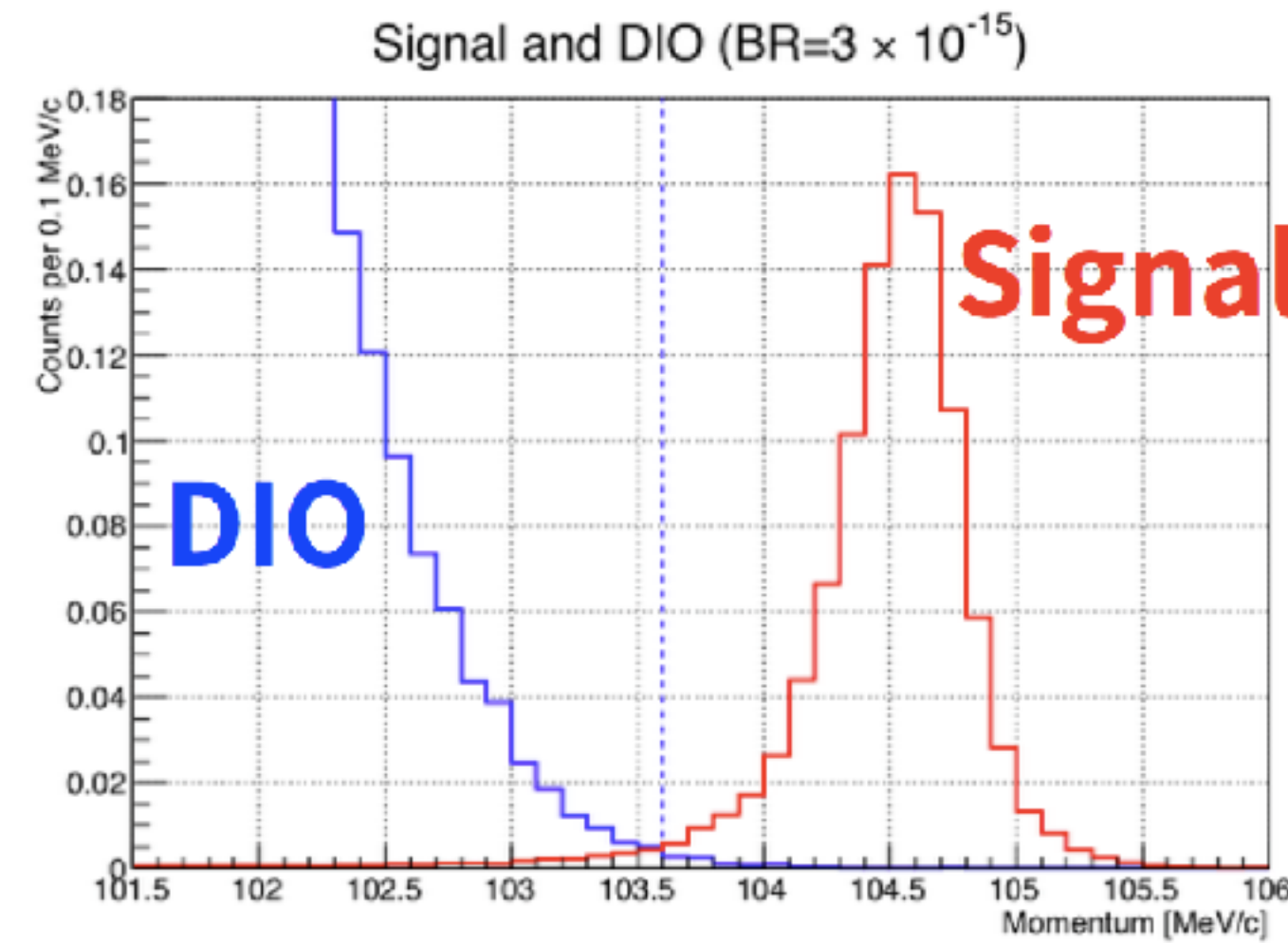
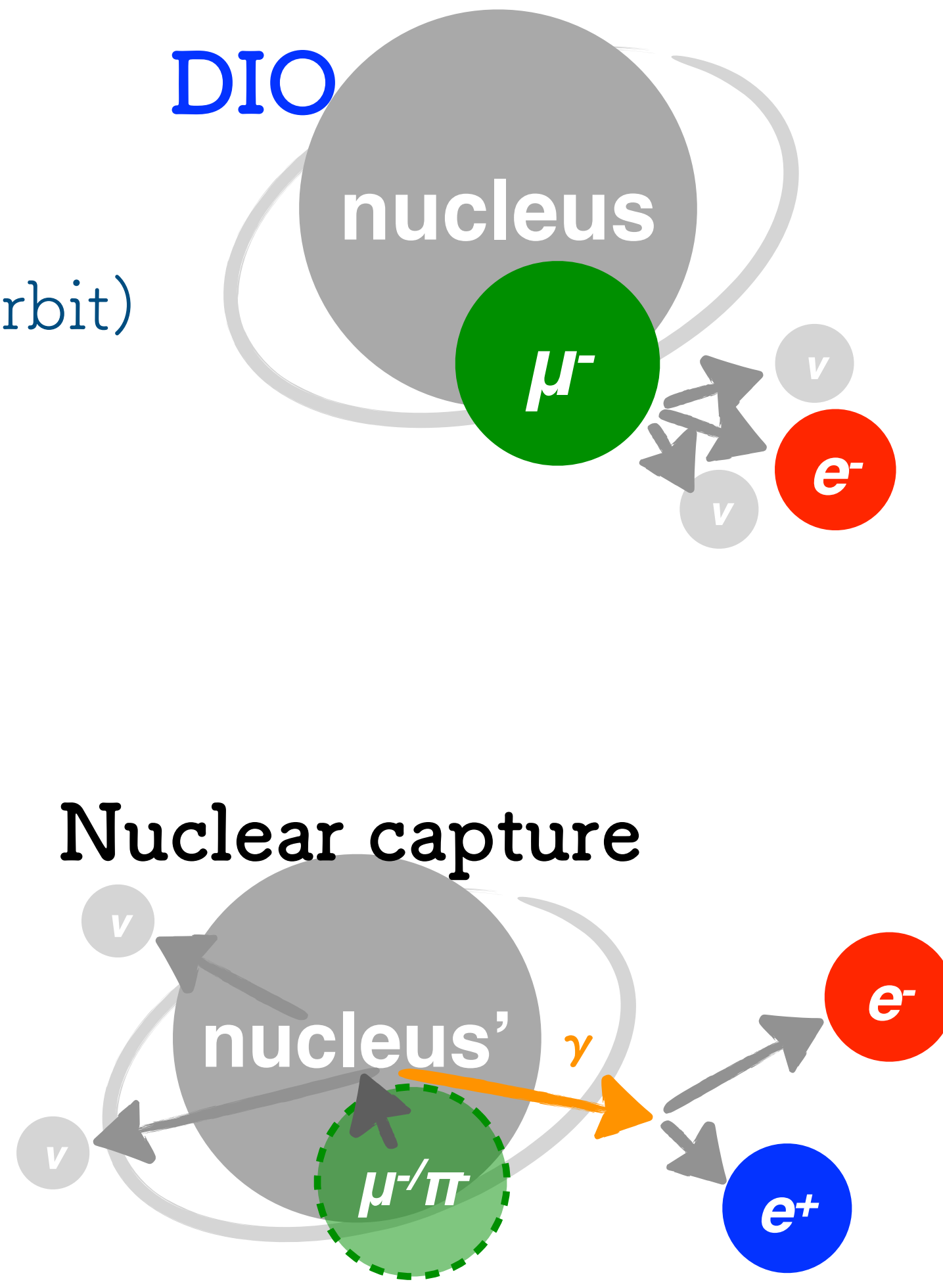
Four-fermion process



Backgrounds

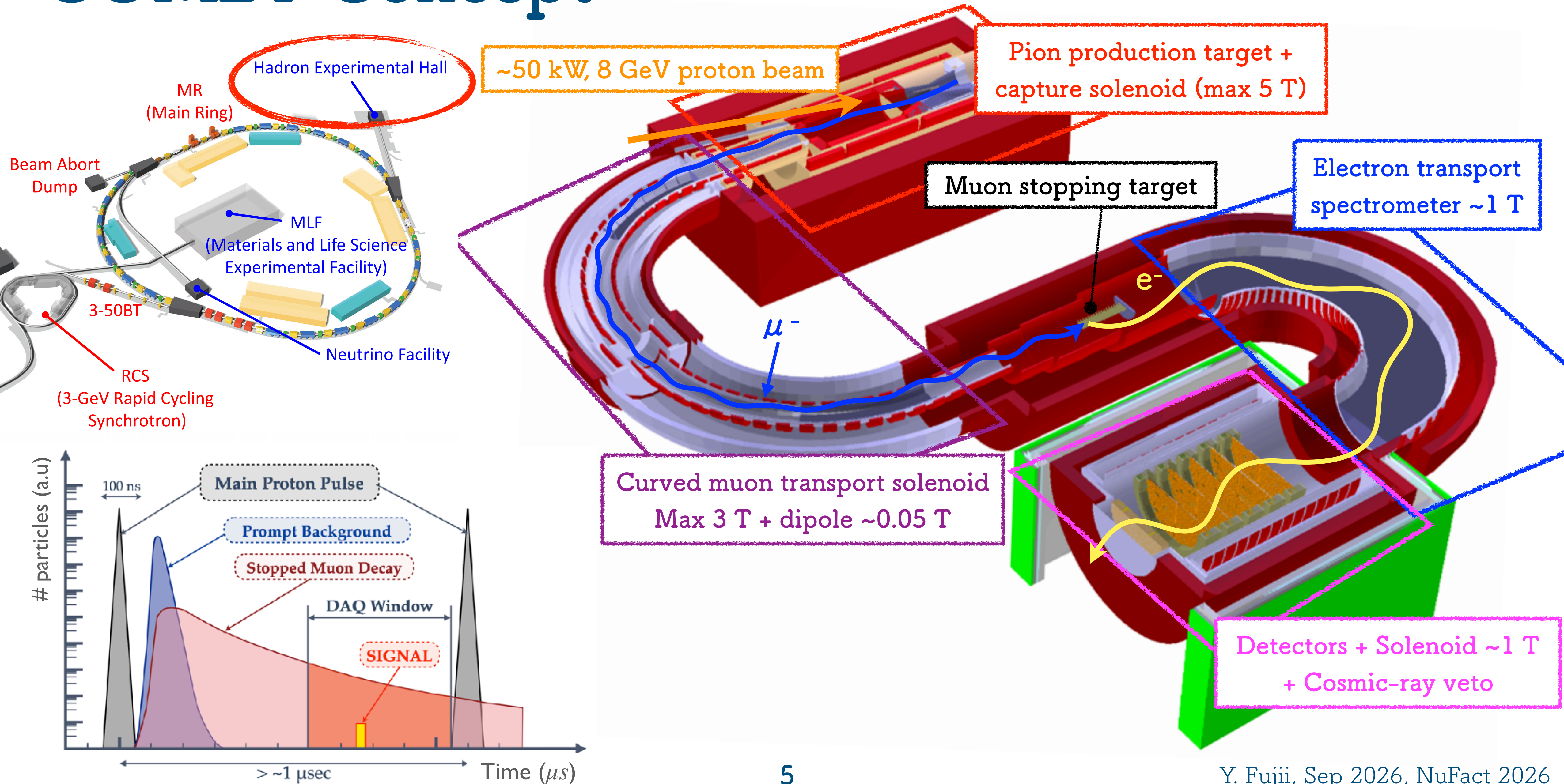
- Physics backgrounds
 - Standard Model BG (DIO: Decay-In-Orbit)
 - μ^-/π^- capture originated $\gamma/e^\pm$
- Beam-induced backgrounds
 - In-flight μ/π -originated $e^\pm$
 - Anti-proton induced $\pi \rightarrow (\gamma) e^\pm$
- Cosmic-ray induced backgrounds
 - Secondary $e^\pm$
 - Horizontally sneaking $\mu^\pm / e^\pm$

Delayed
Prompt
Uncorrelated

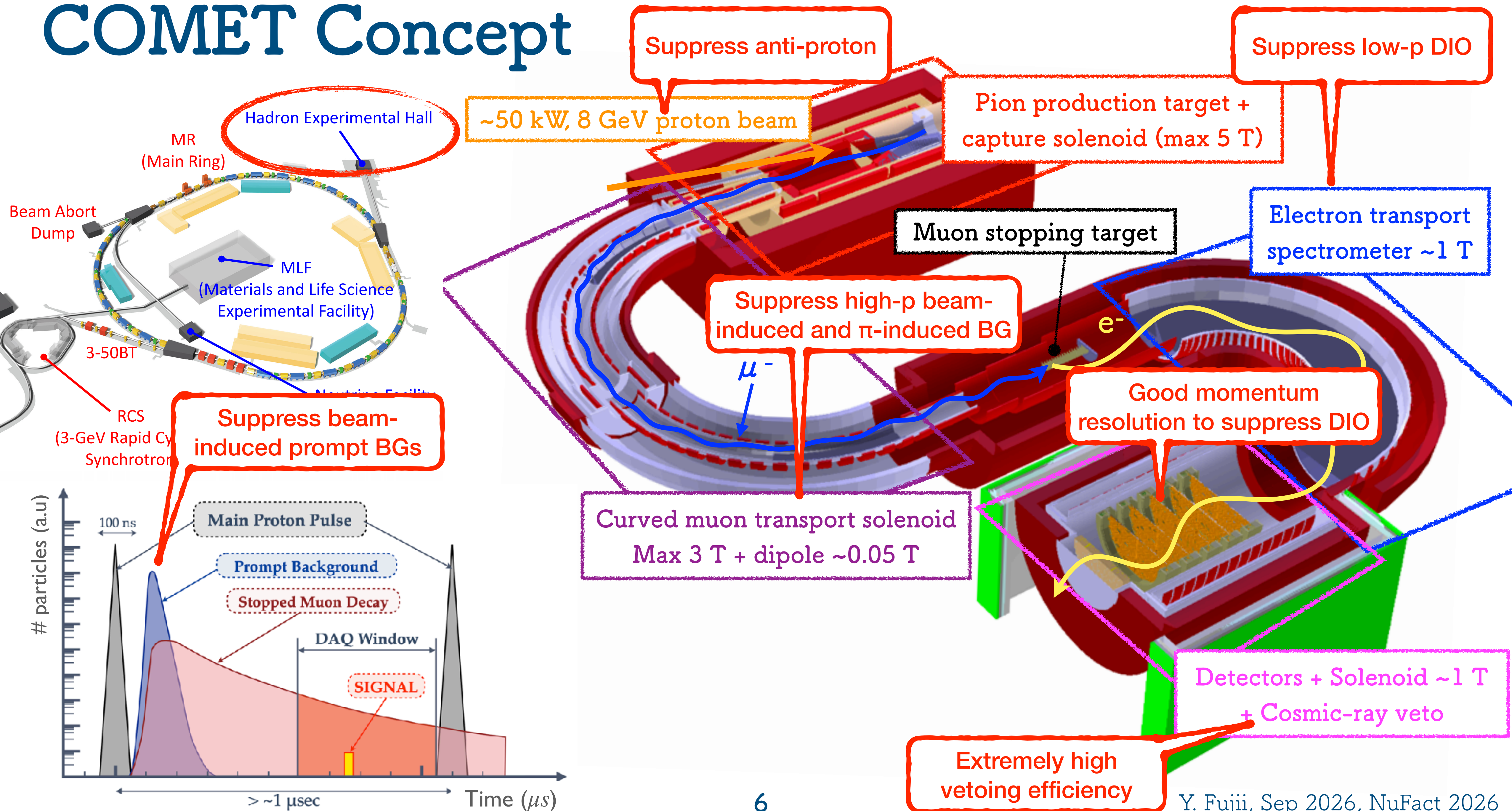


PRD **103**, 033002 (2021)

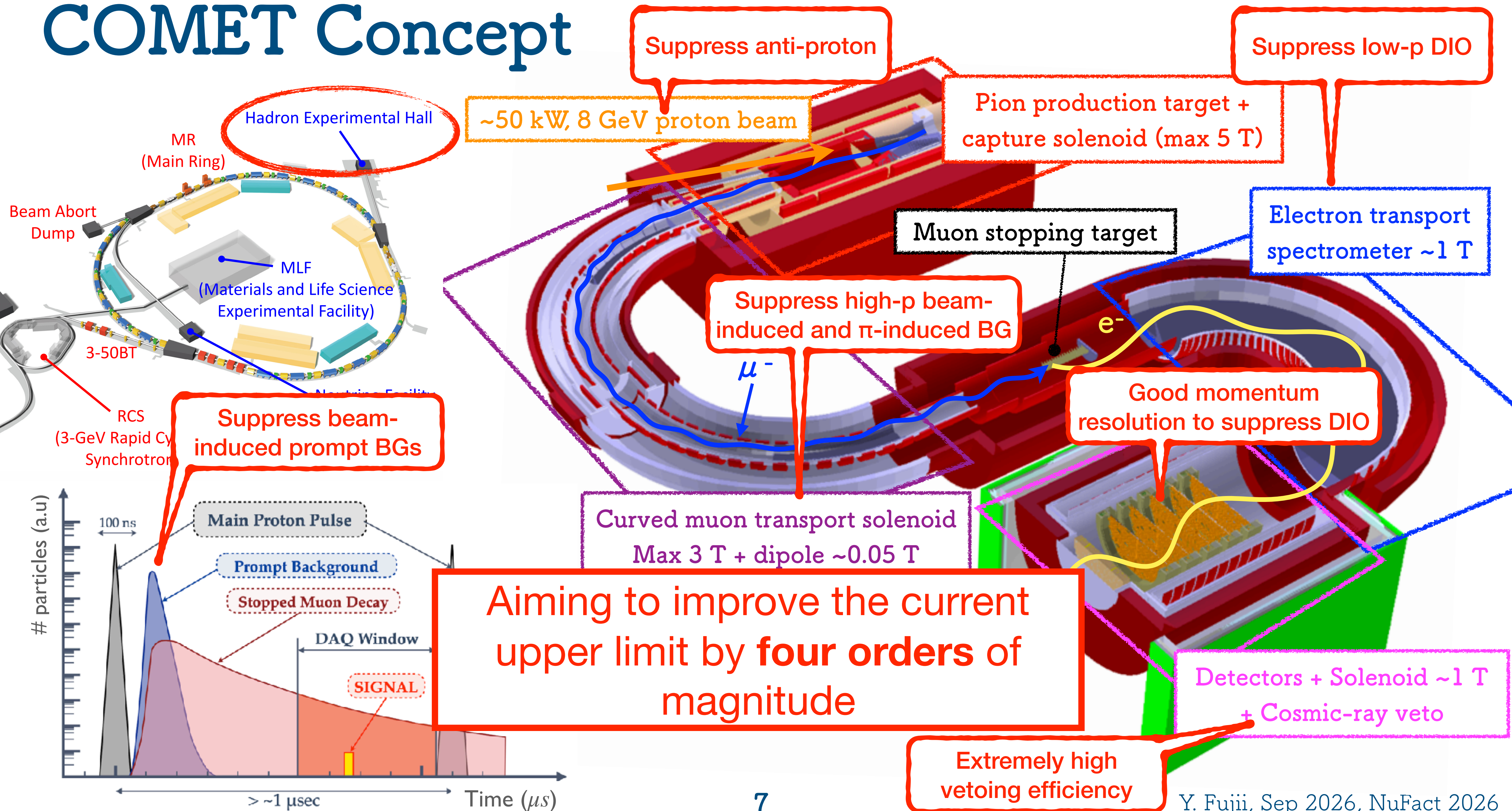
COMET Concept



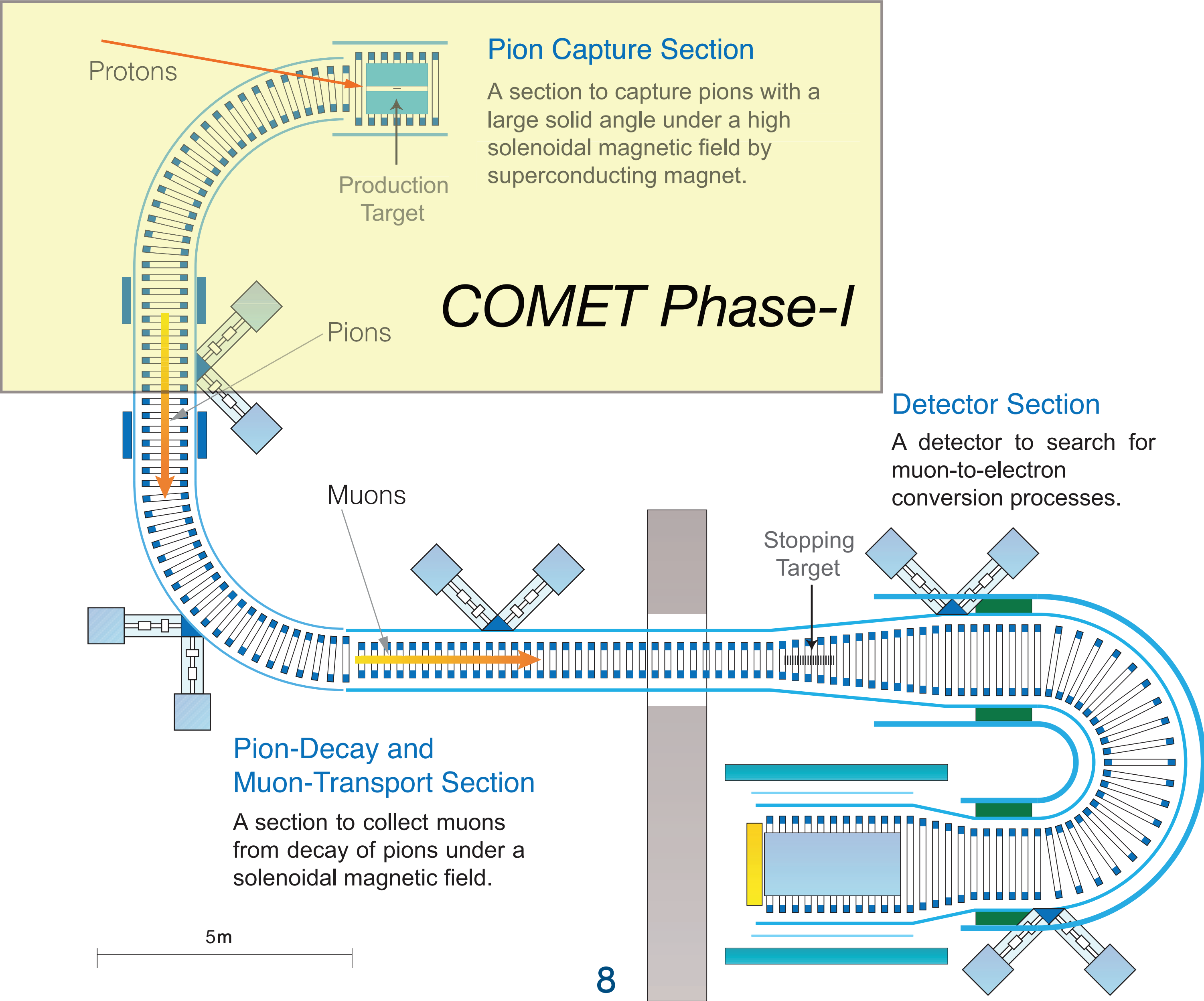
COMET Concept



COMET Concept

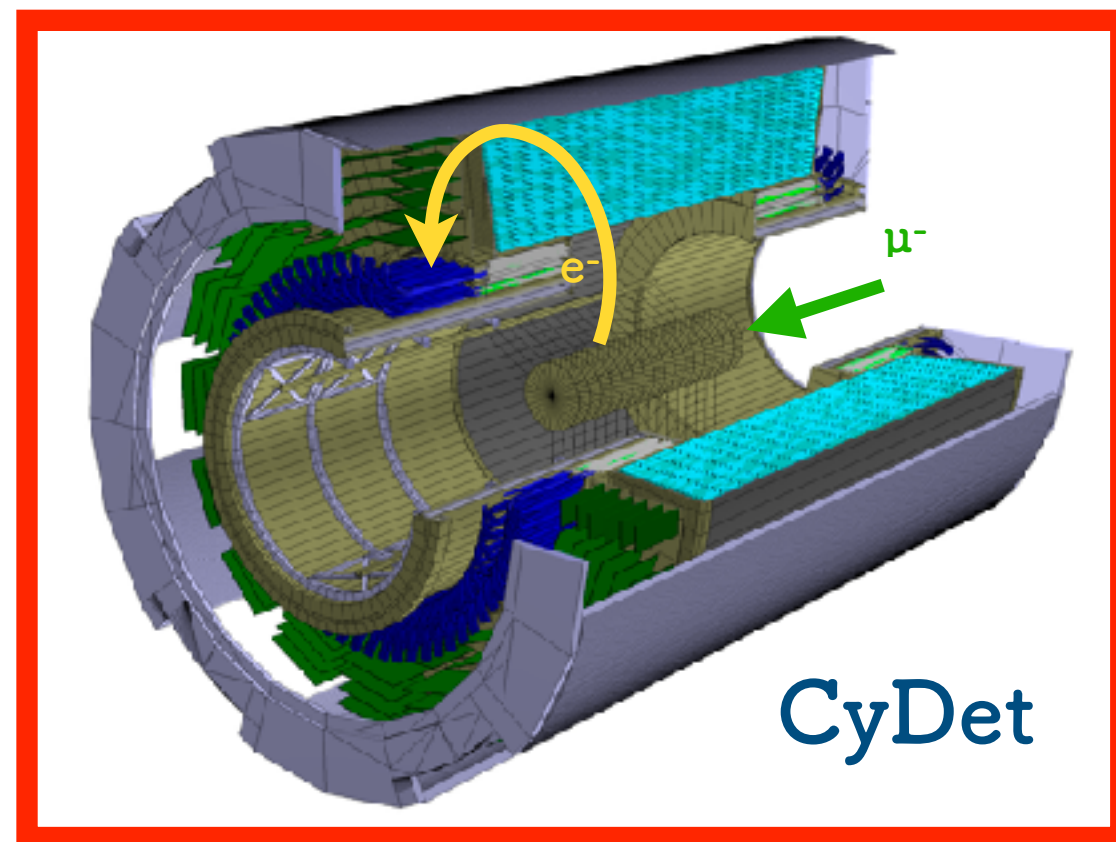


Staged Approach

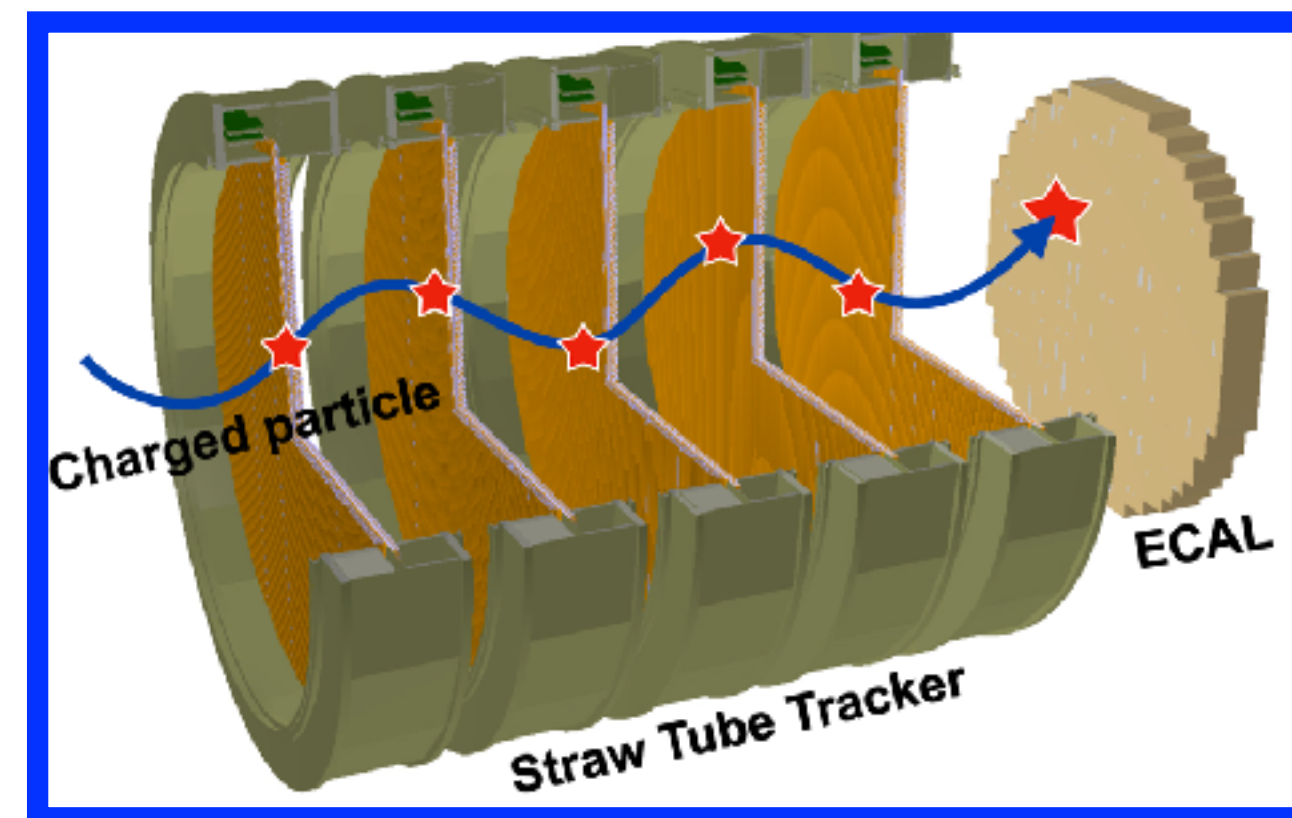
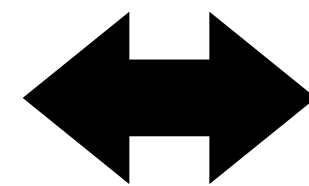


COMET Phase-I

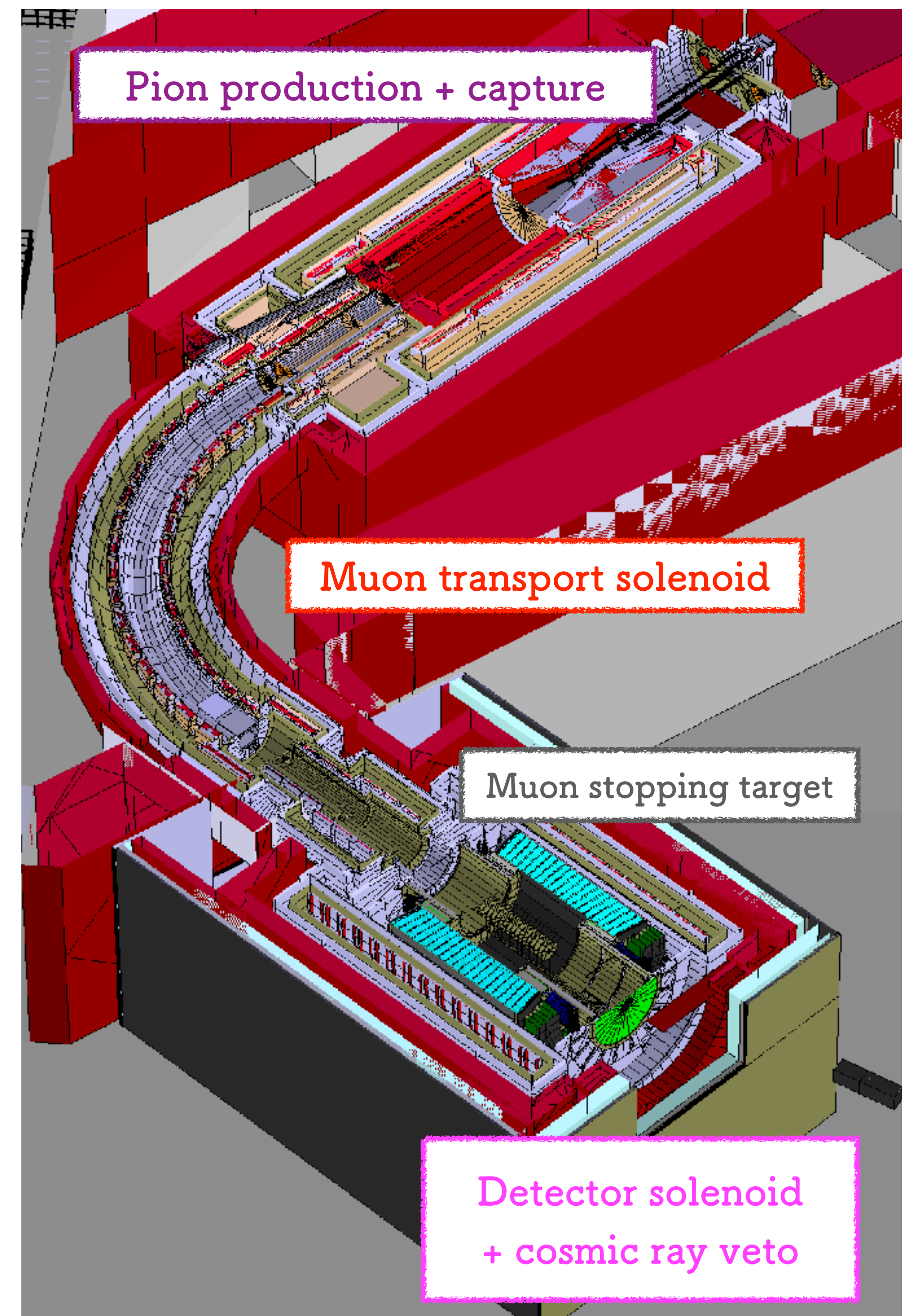
- 3.2 kW beam-power with a graphite proton target, 1/2 MTS without the curved electron spectrometer
- Cylindrical Detector (CyDet) to avoid the direct beam particles and DIO peak electrons
- Aiming $\times 100$ better sensitivity than the SINDRUM II's upper limit
- Beam measurement at the end of MTS for better understanding the beam properties



Physics detectors

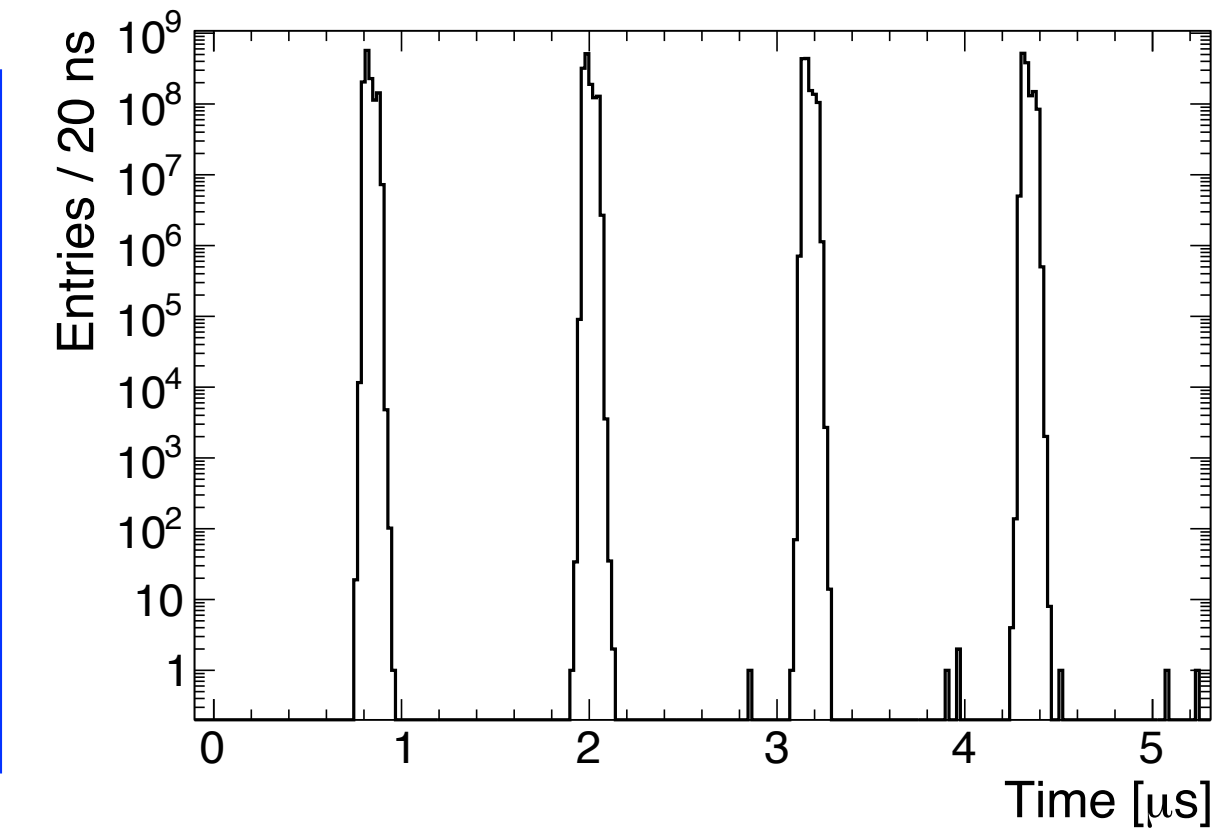
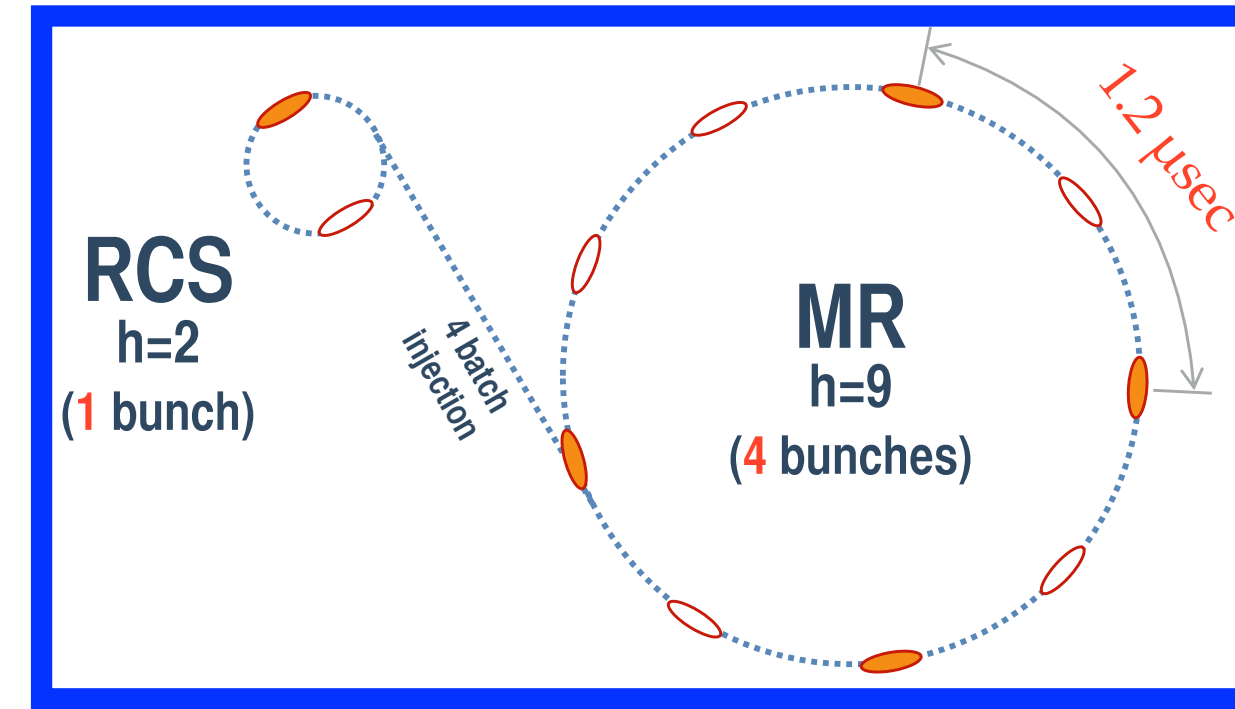


Beam measurement detectors

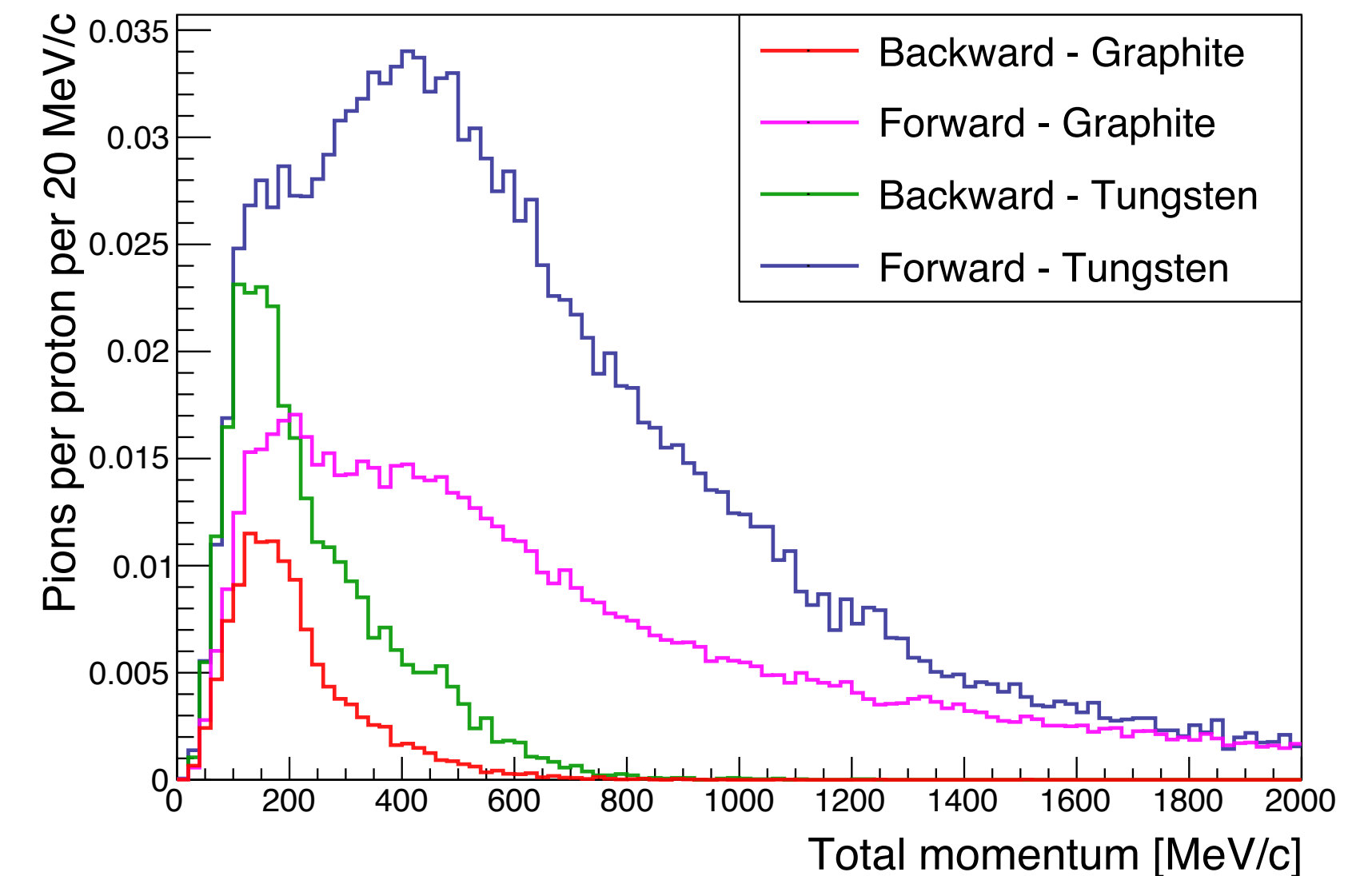
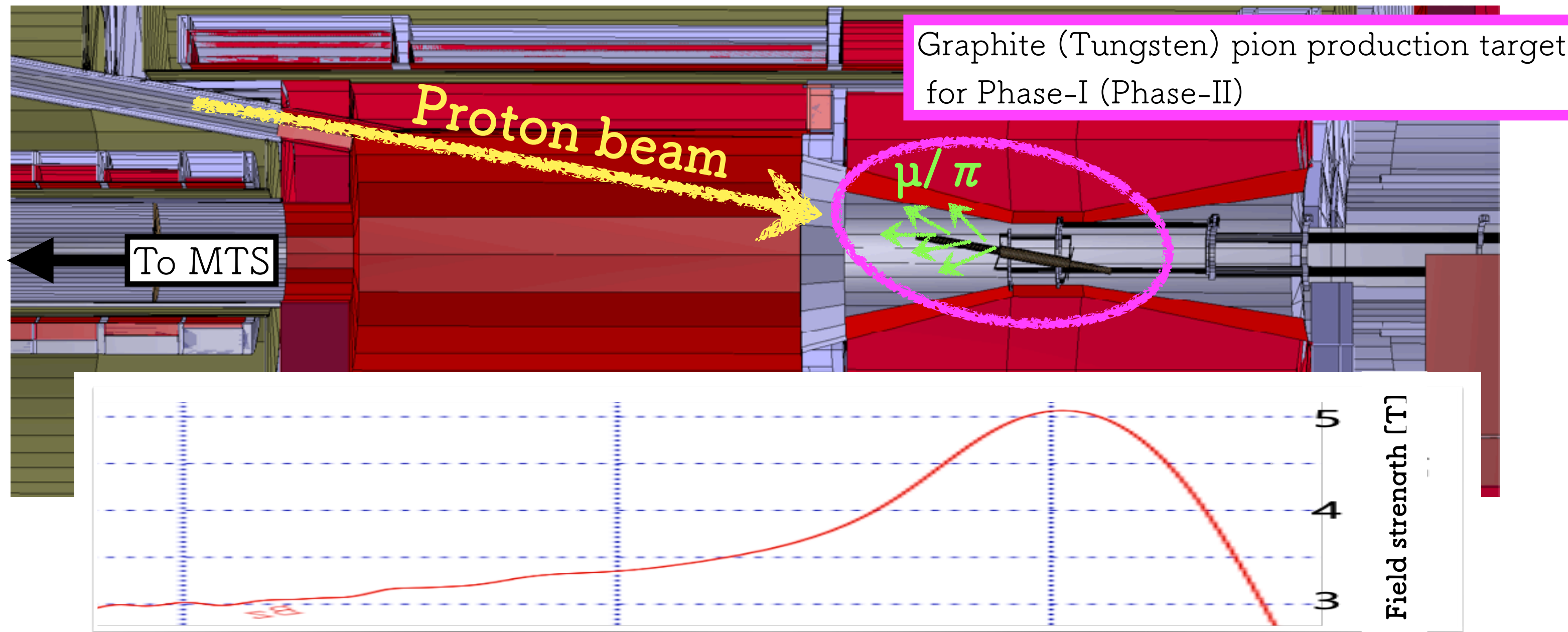


Proton beam & pion production

- Bunched proton beam slowly extracted from the J-PARC MR accelerator
- 1.17 (1.76) μsec bunch intervals $\leftrightarrow \tau_{\mu, \text{Al}} = 864 \text{ ns}$
- Extremely clean pulsed beam with an inter-bunch protons probability $< 10^{-10}$



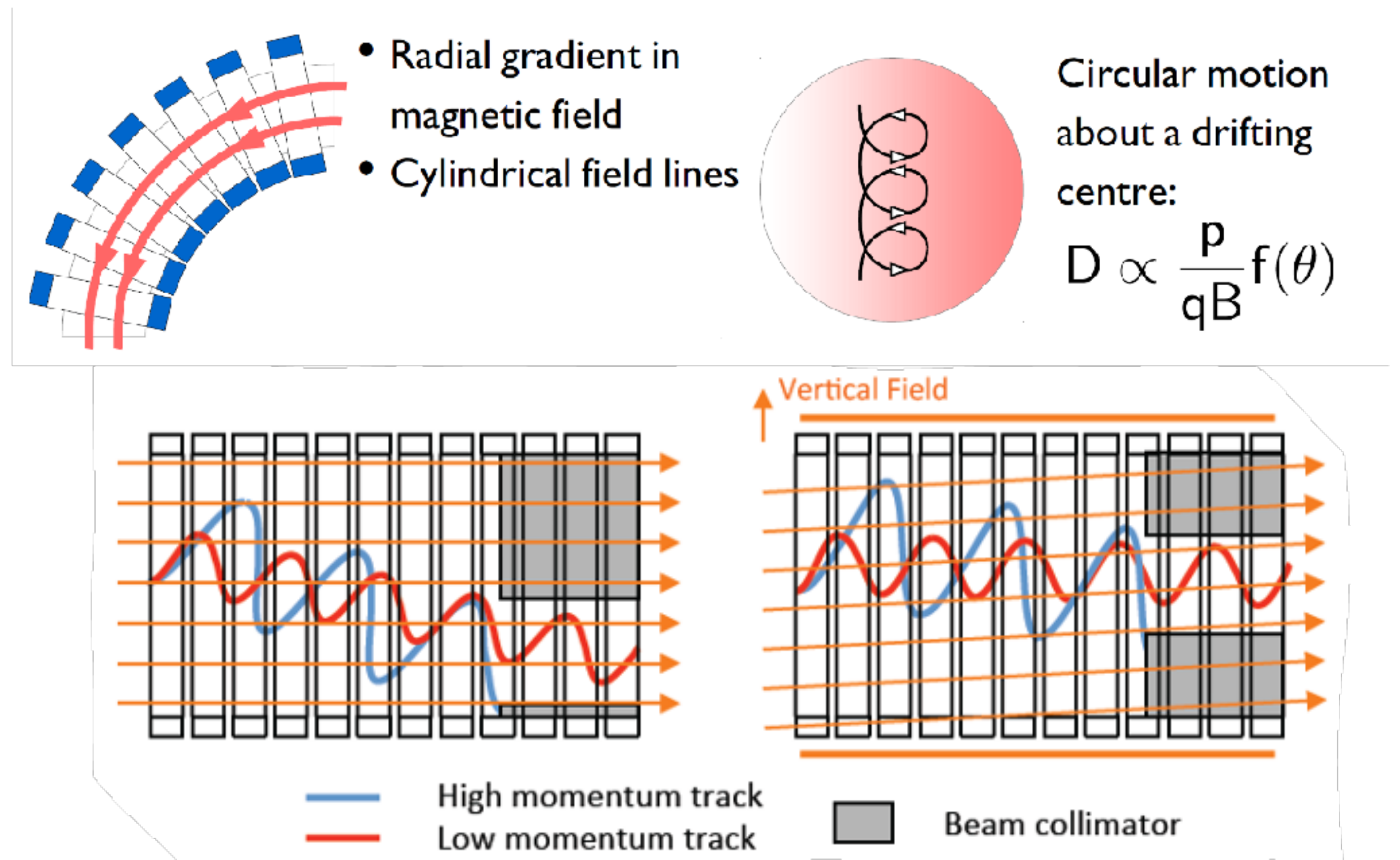
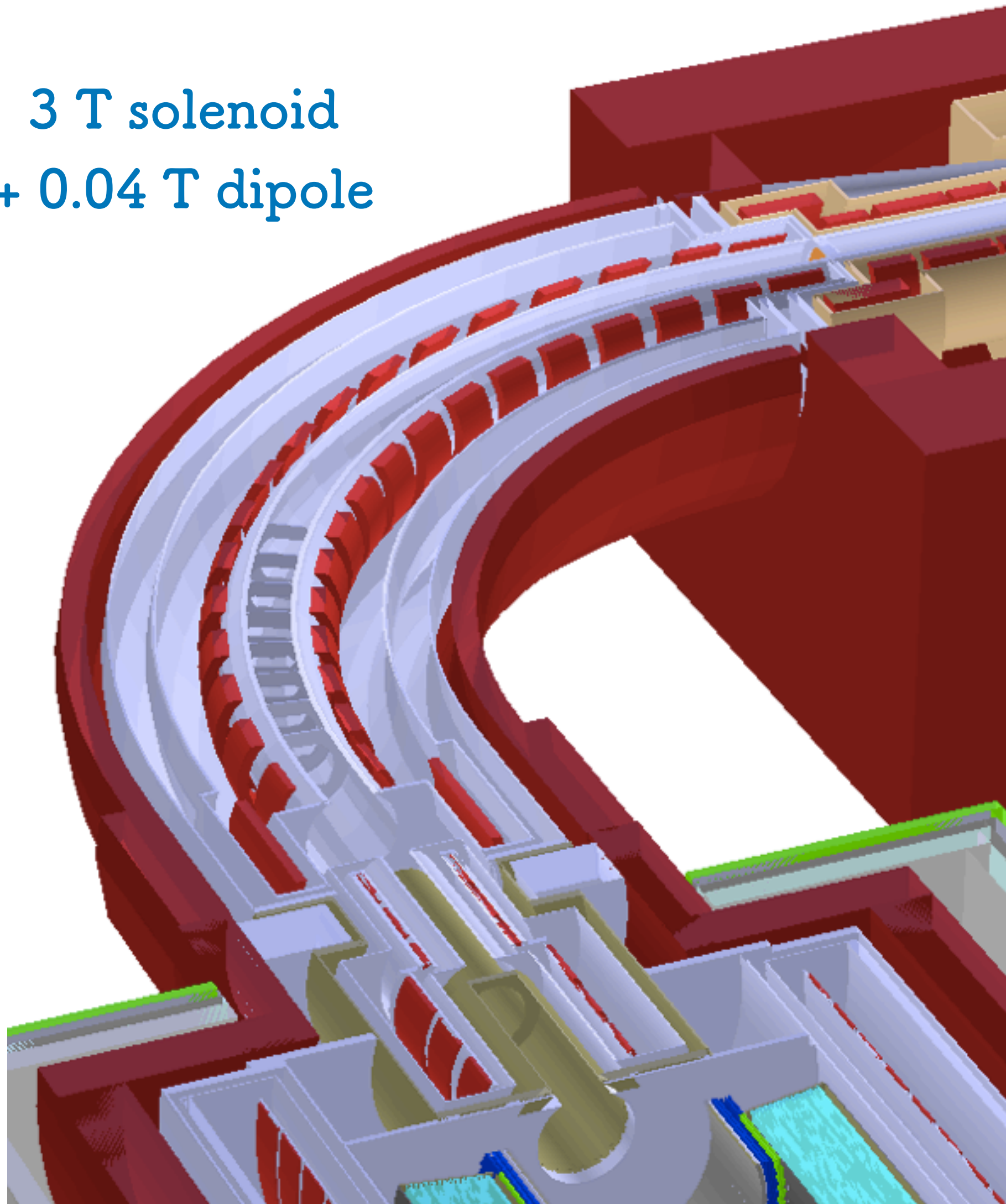
K. Noguchi, et al., Proc. of Sci., 402 (2022)



Select backward pions to highly suppress unwanted high-momentum pions/muons

Muon beam

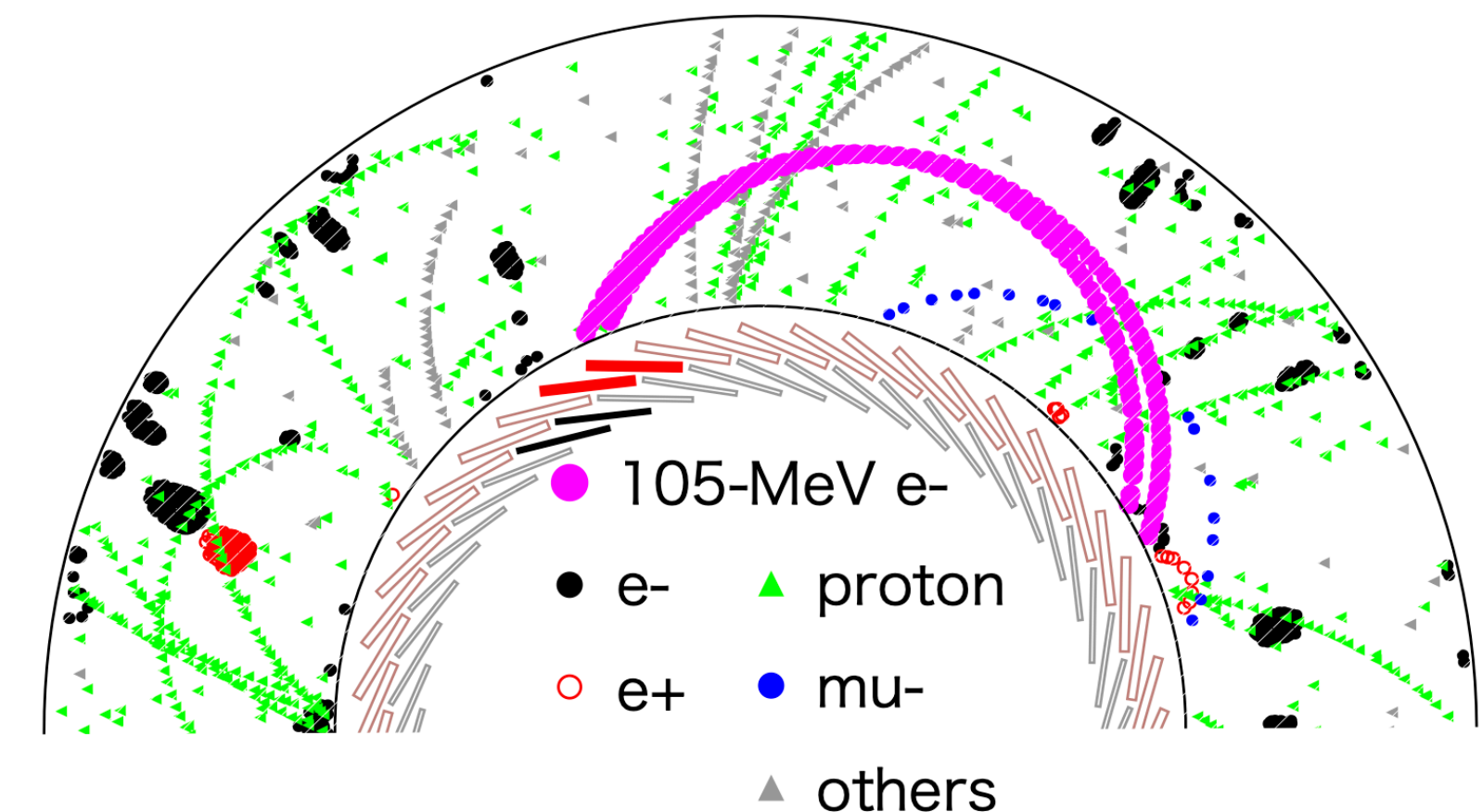
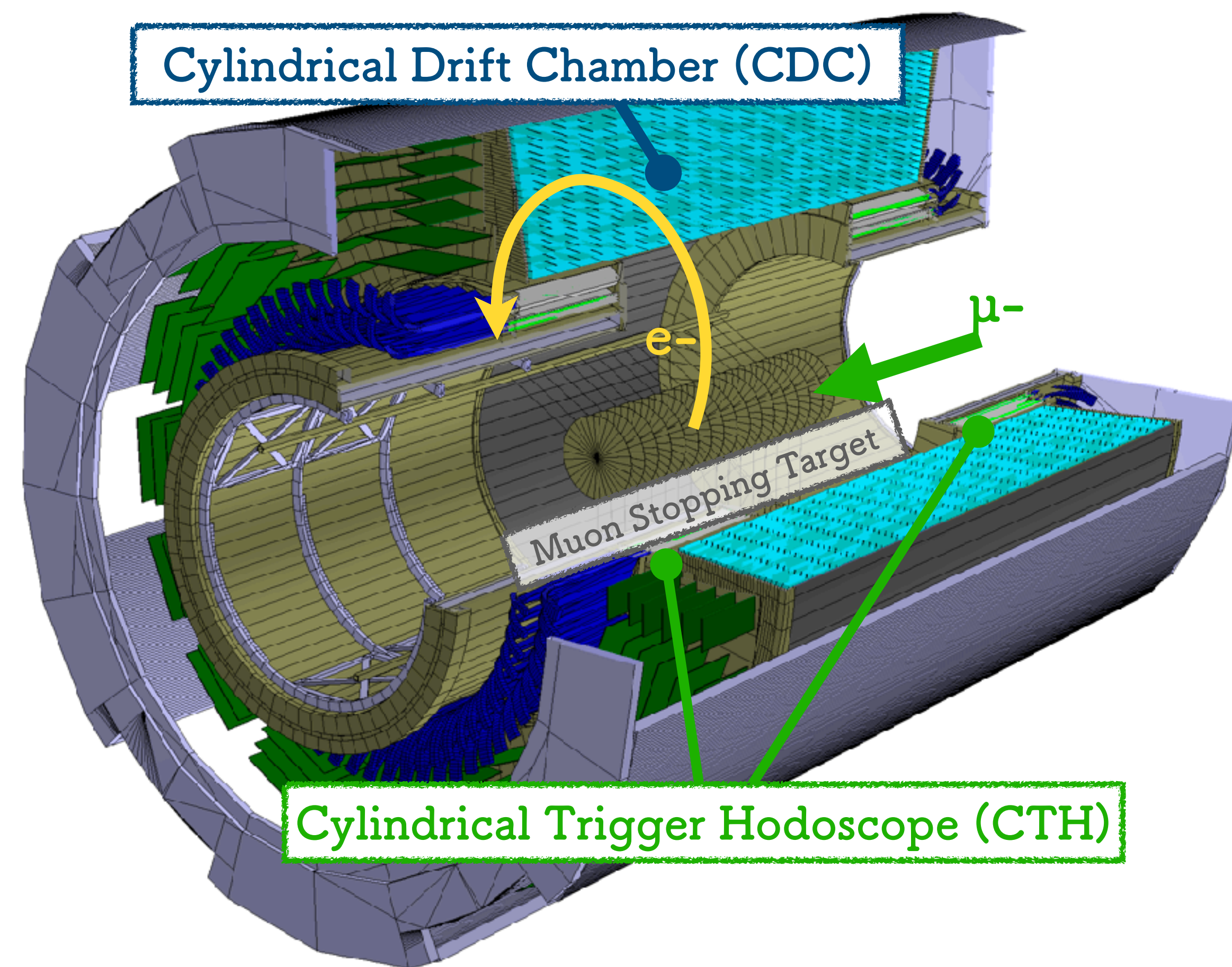
3 T solenoid
+ 0.04 T dipole



- Most pions decay before reaching the detector region
- Positive / high- p particles are filtered due to the vertical drifting while travelling inside the curved solenoid
- Additional dipole field for centring low- p muons < 50 MeV/c
- **MTS was demonstrated successfully in COMET Phase- α $\rightarrow$ K. Oishi's talk in this NuFact**

CyDet (1)

- Surrounding the muon stopping target discs to avoid high intensity beam and the majority of DIO electrons
 - Yet to be high hit rate + high radiation environment (1 kGy, 10^{12} n/cm²)
- Requirements
 - Momentum resolution: <200 keV/c in σ
 - High hit rate tolerance: O(1) MHz / channel
- Cylindrical Drift Chamber (CDC)
- Cylindrical Trigger Hodoscope (CTH)
 - Timing reconstruction, primary trigger generation



CyDet (2)

- Cylindrical Drift Chamber (CDC)

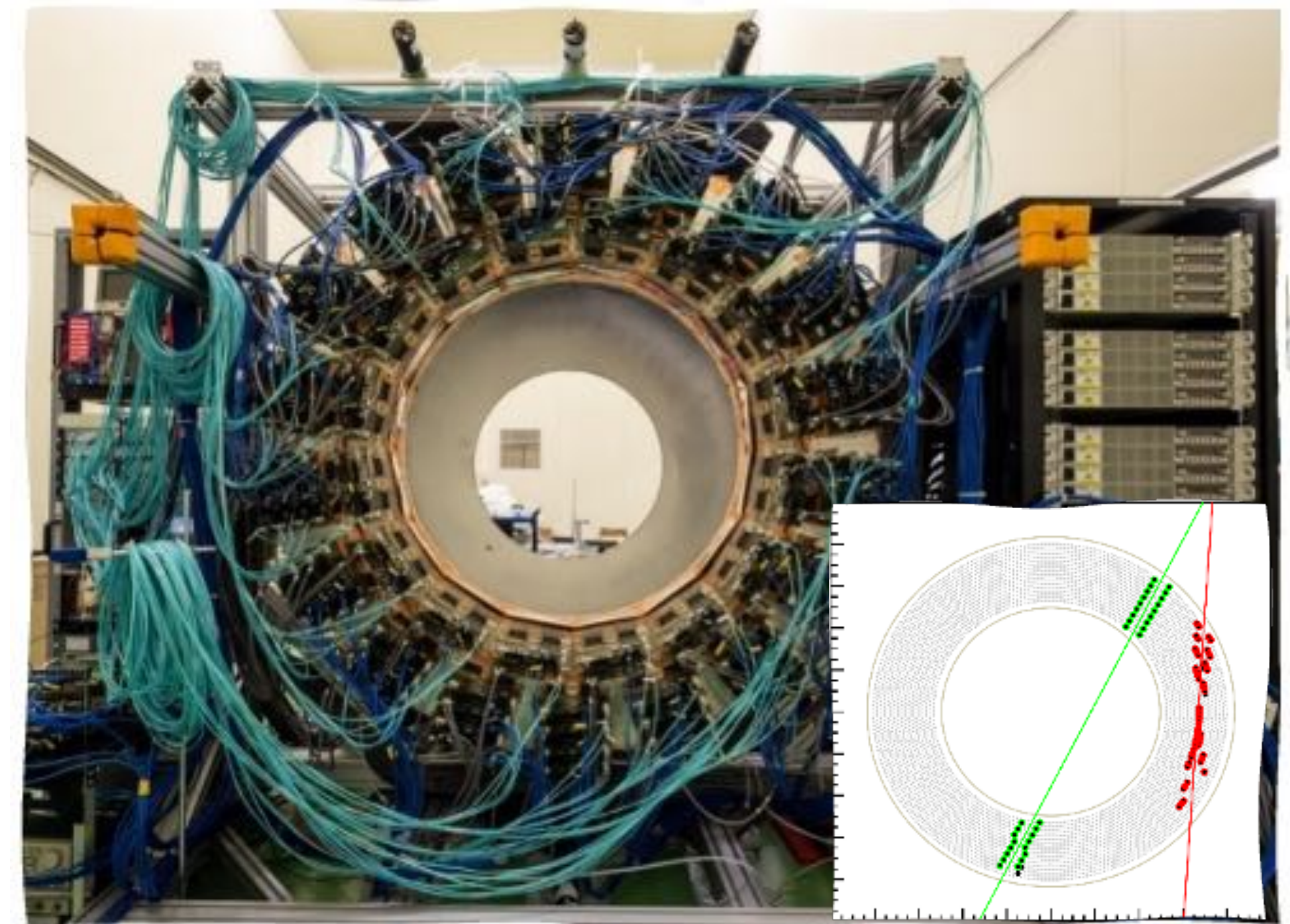
- Full stereo wire drift chamber, 20 layers, ~5k sense wires
- 0.5 mm^t CFRP inner wall + helium based gas mixture (He:iso-C₄H₁₀ = 9:1) to minimise the multiple scattering
- Average **spatial resolution of <200 μm achieved** → $\sigma_p \sim 200$ keV/c
- Full readout tests, gas system and DAQ tests are ongoing at J-PARC

A. Sato, et al., Nucl. Instrum. Methods Phys. Res. A, 1069 (2024), 169926

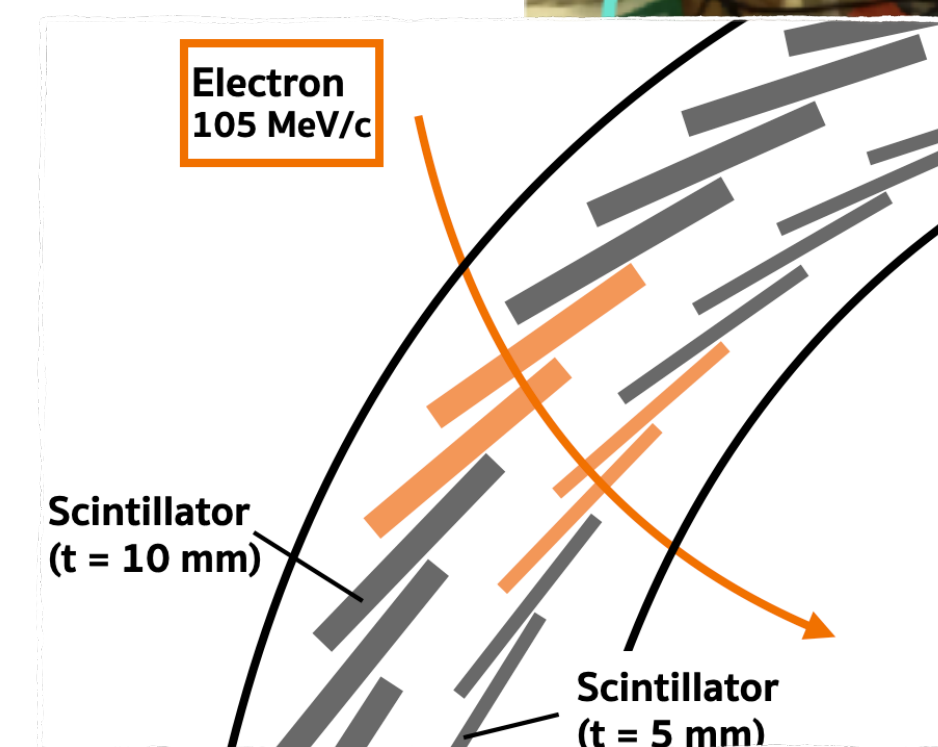
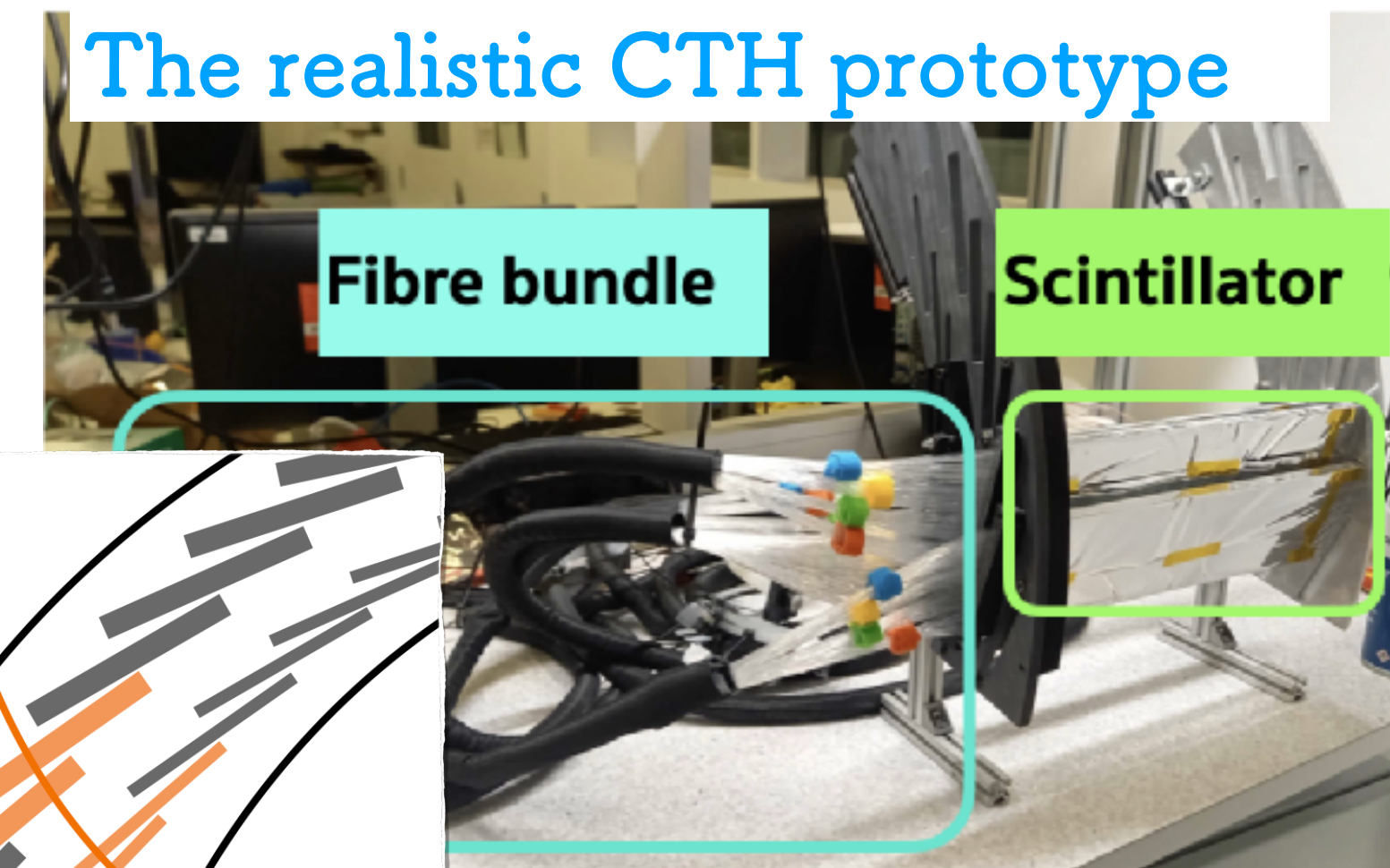
- Cylindrical Trigger Hodoscope (CTH)

- Timing measurement <1 ns & Four-fold coincidence to suppress accidental trigger rate <**100 kHz**
- Silicon photomultipliers will be installed outside of the detector solenoid to avoid the high radiation environment
- W/ the realistic prototype, <**1 ns time resolution was obtained** and the particle identification capability was tested

Y. Fujii, et al., Nucl. Instrum. Methods Phys. Res. A, 1067 (2024), 169665

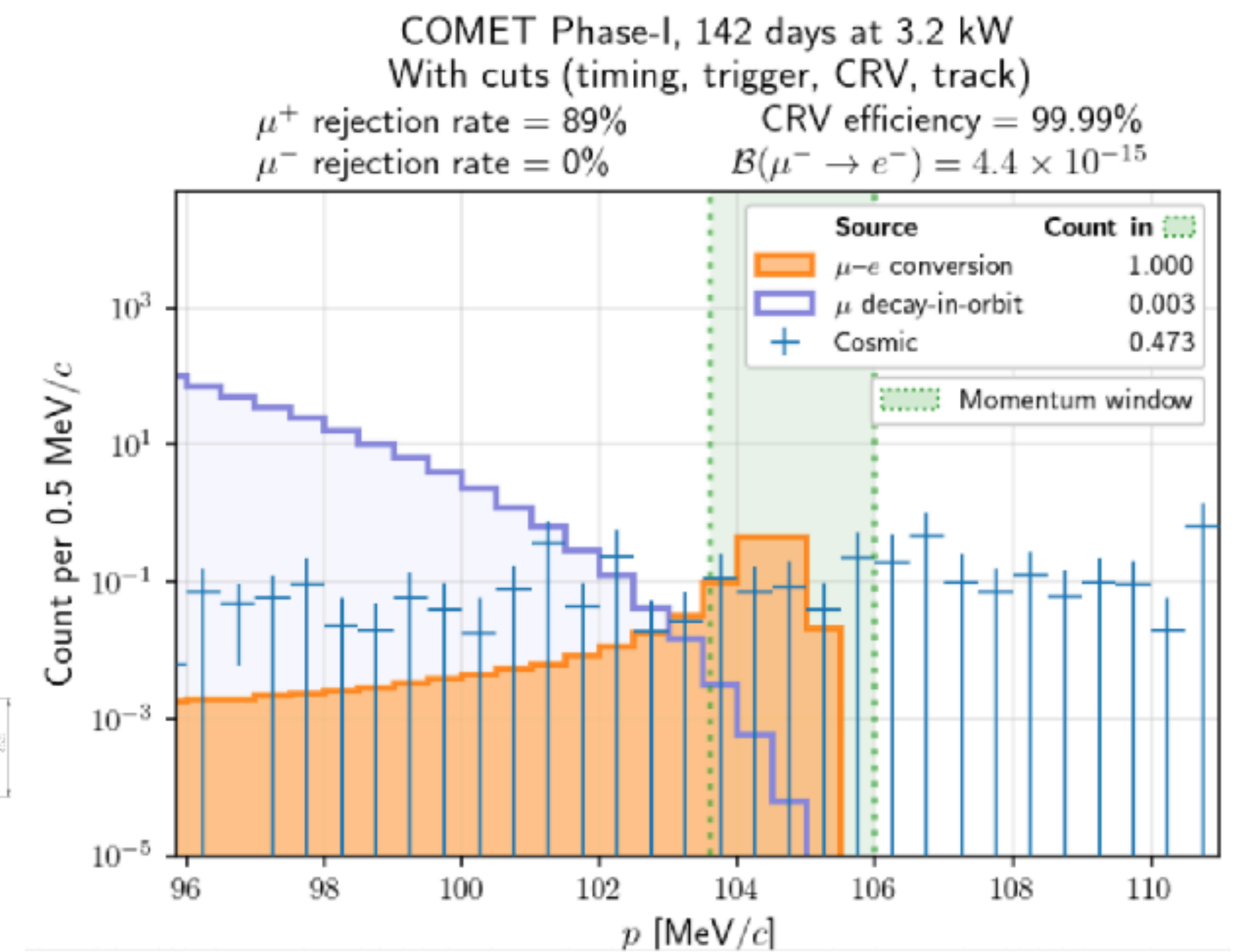
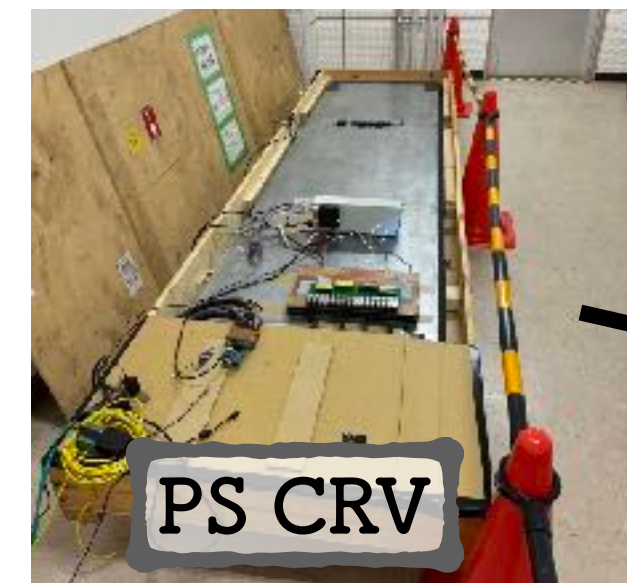
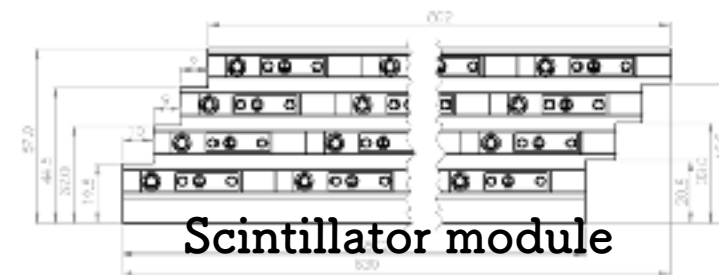


The realistic CTH prototype

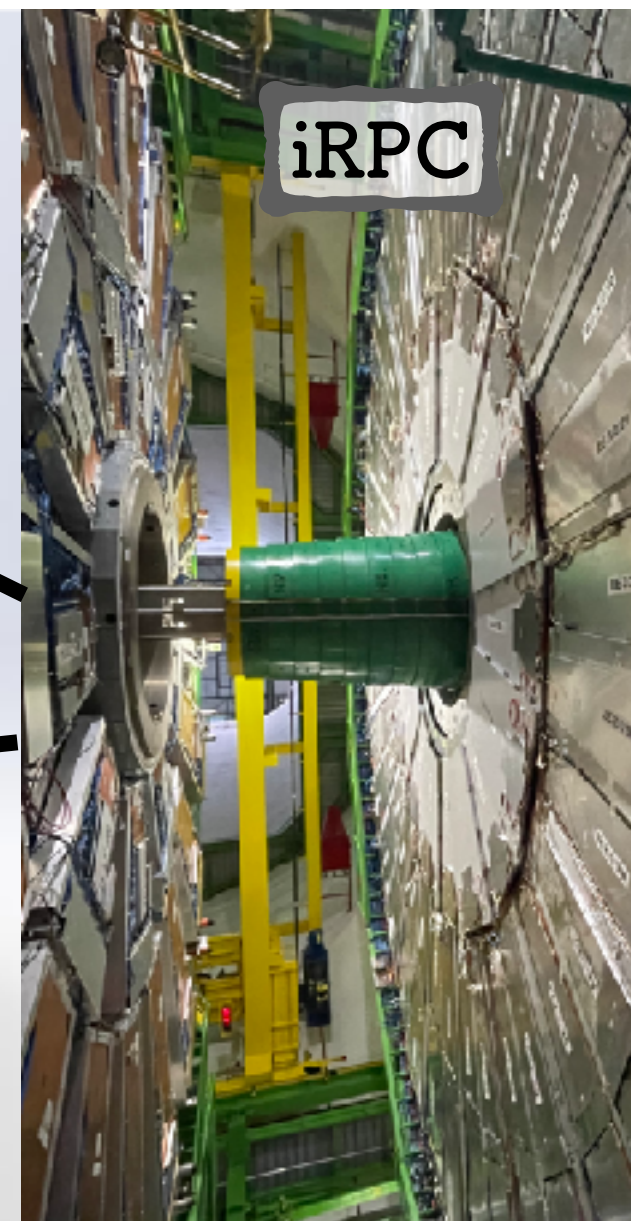
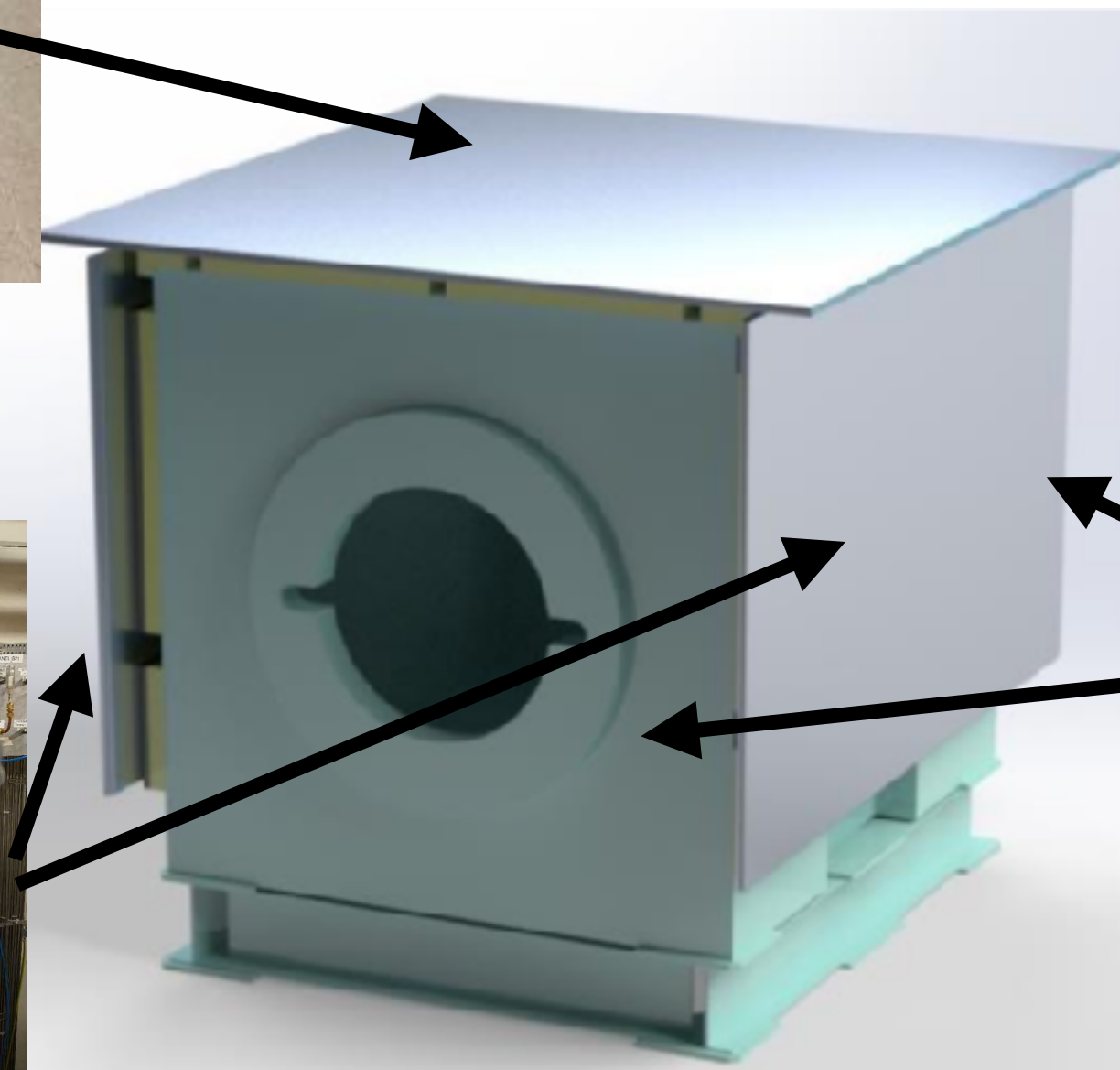


Cosmic-Ray Veto detectors

- Critical role to reduce the cosmic-ray induced background
 - >99.99% veto efficiency is required
 - High radiation / high hit rate tolerance is key to ensure sufficient veto-power in COMET
- Combination of different detector technologies
 - Top CRV: Plastic Scintillators from GTU/JINR
 - Side CRV: Same PS CRV or ARGO-RPC from ARGO-YBJ
 - Front / back CRV: iRPC from CMS



M. Dubouchet, PhD thesis



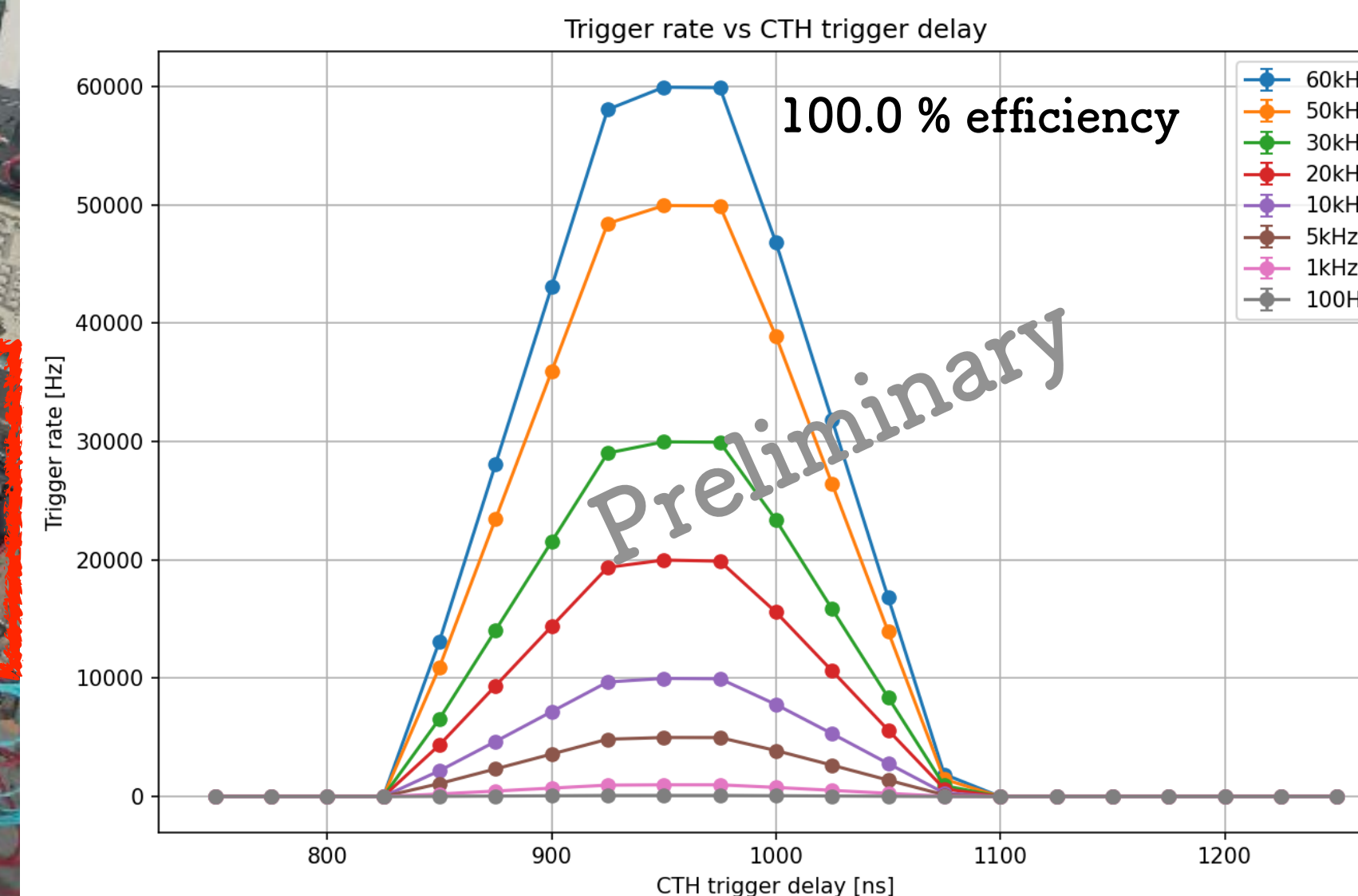
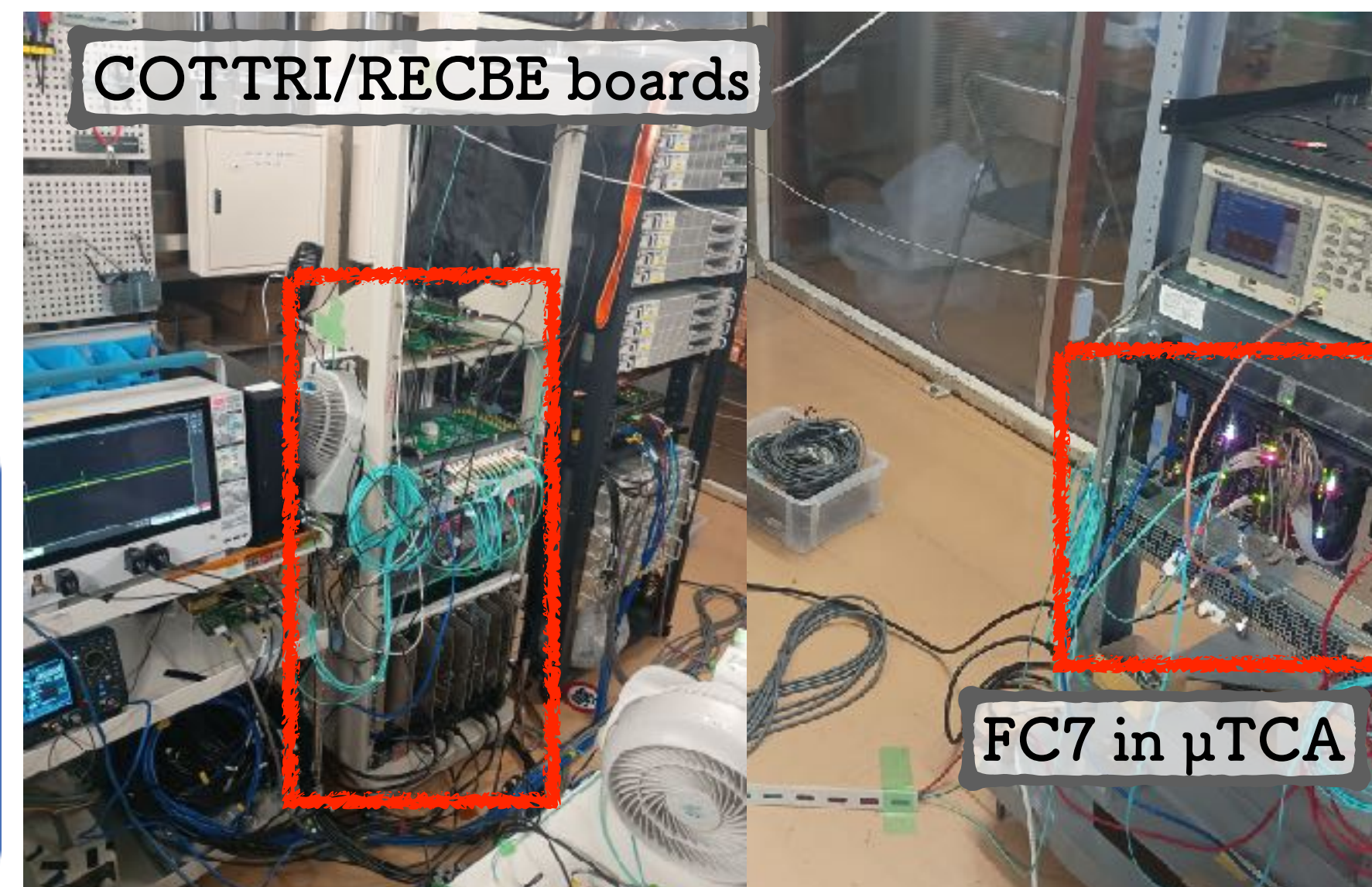
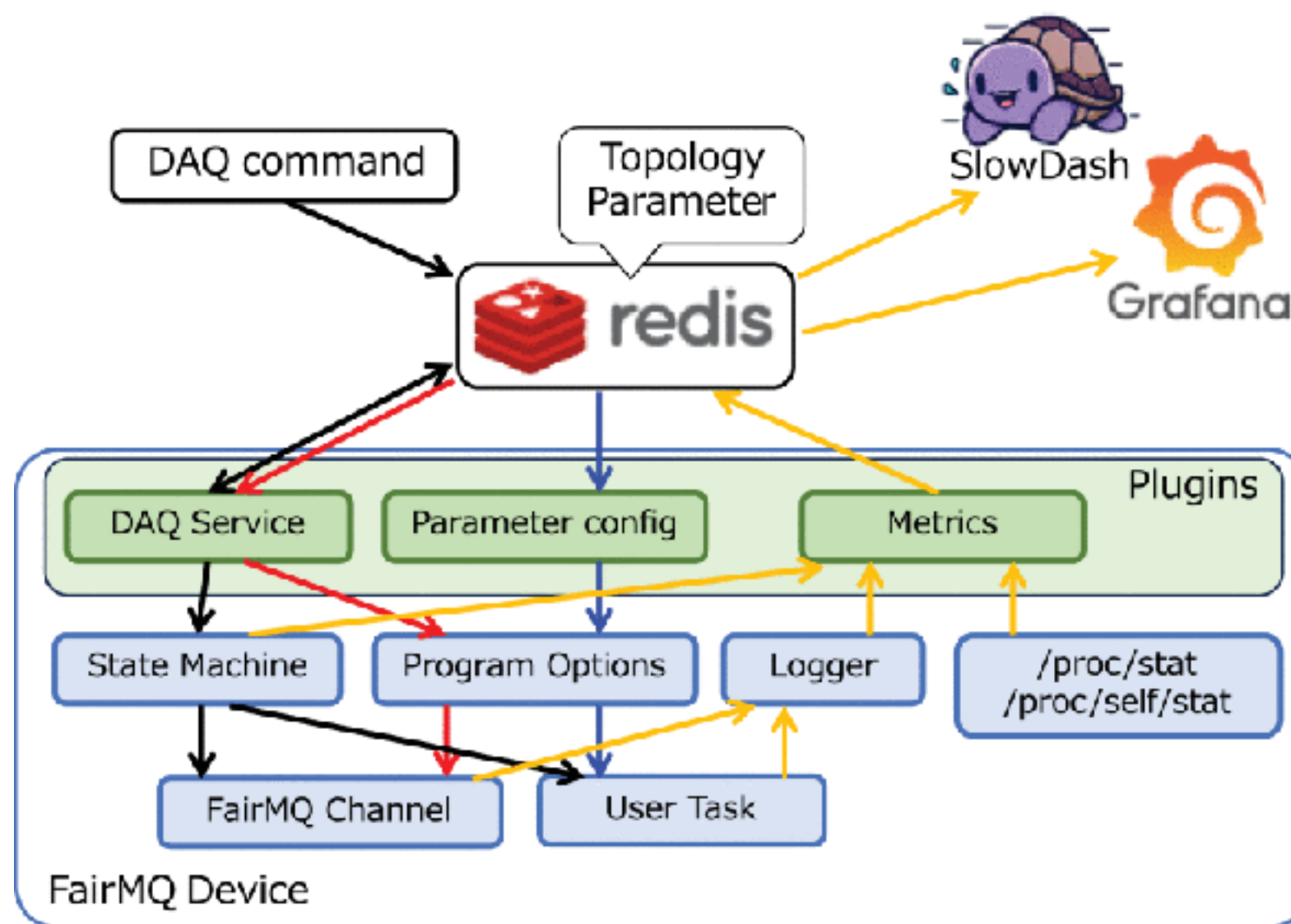
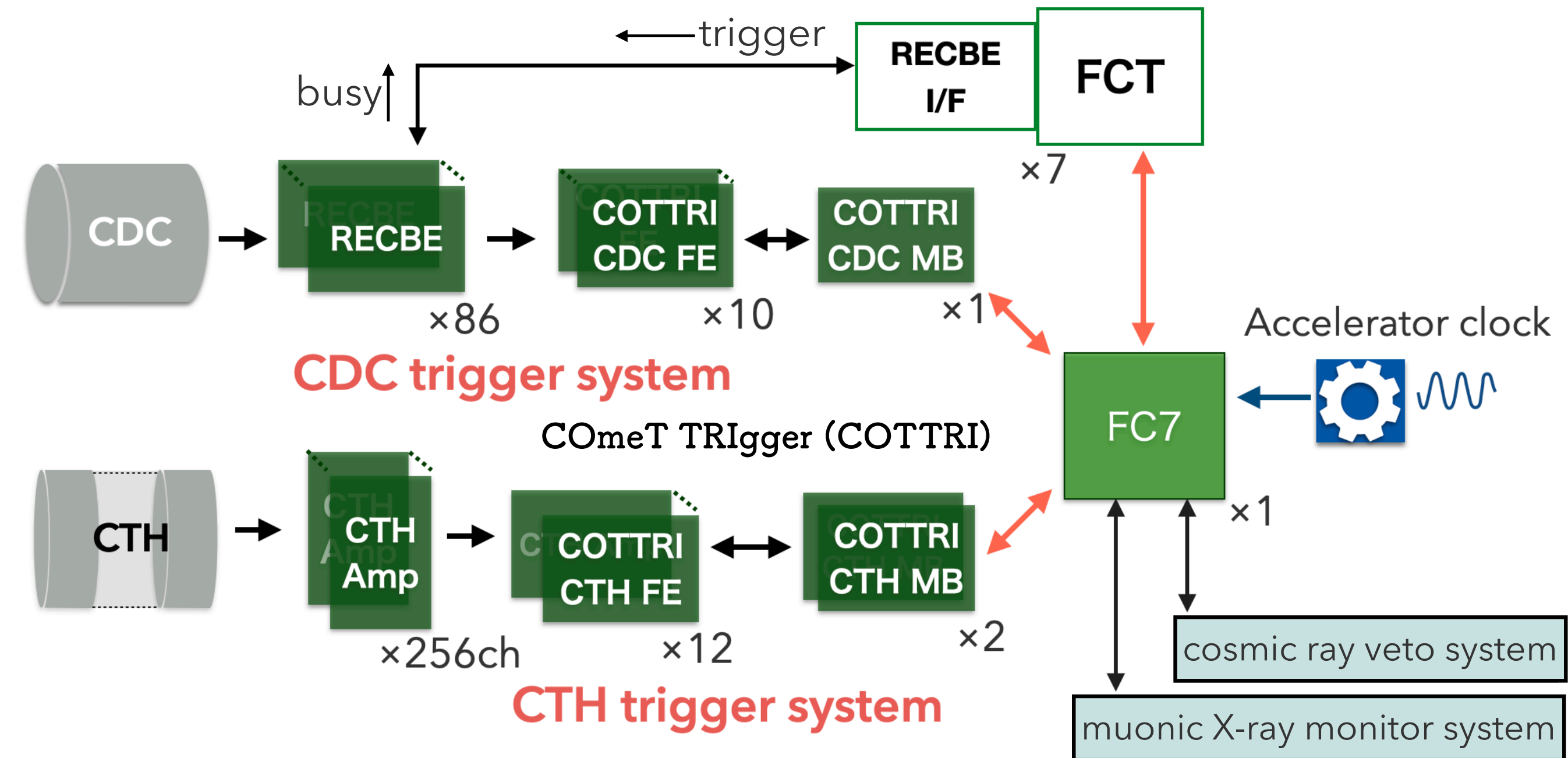
Trigger & DAQ

- Trigger:

- Hardware R&Ds completed
- Firmware almost ready
- CDC+CTH combined trigger + FC7 showed 100% trigger efficiency with the test pulse

- DAQ:

- Switching from MIDAS to NestDAQ



Phase-I expected sensitivity & BGs

$$\mathcal{B}(\mu^- N \rightarrow e^- N) |_{Al} = \frac{1}{N_\mu \cdot f_{cap} \cdot f_{gnd} \cdot A_\mu} \approx 3 \times 10^{-15}$$

N_μ : #of stopped μ^- , 1.5×10^{16} , exp. @ 150 days,

f_{cap} : fraction of stopped μ^- captured, 0.61, theory,

f_{gnd} : fraction of μ^- bound to ground state, 0.9 theory,

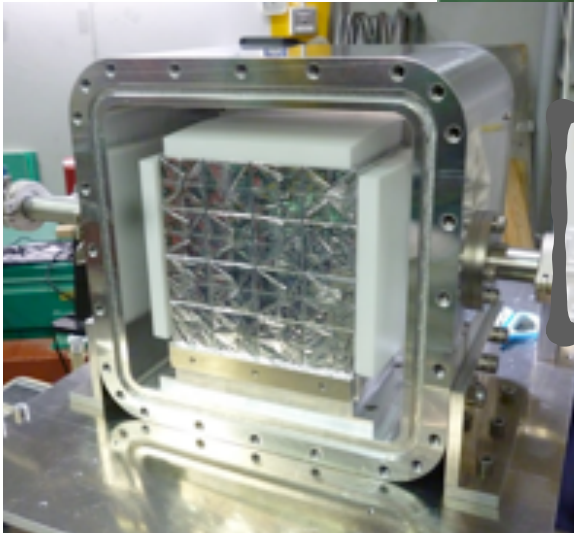
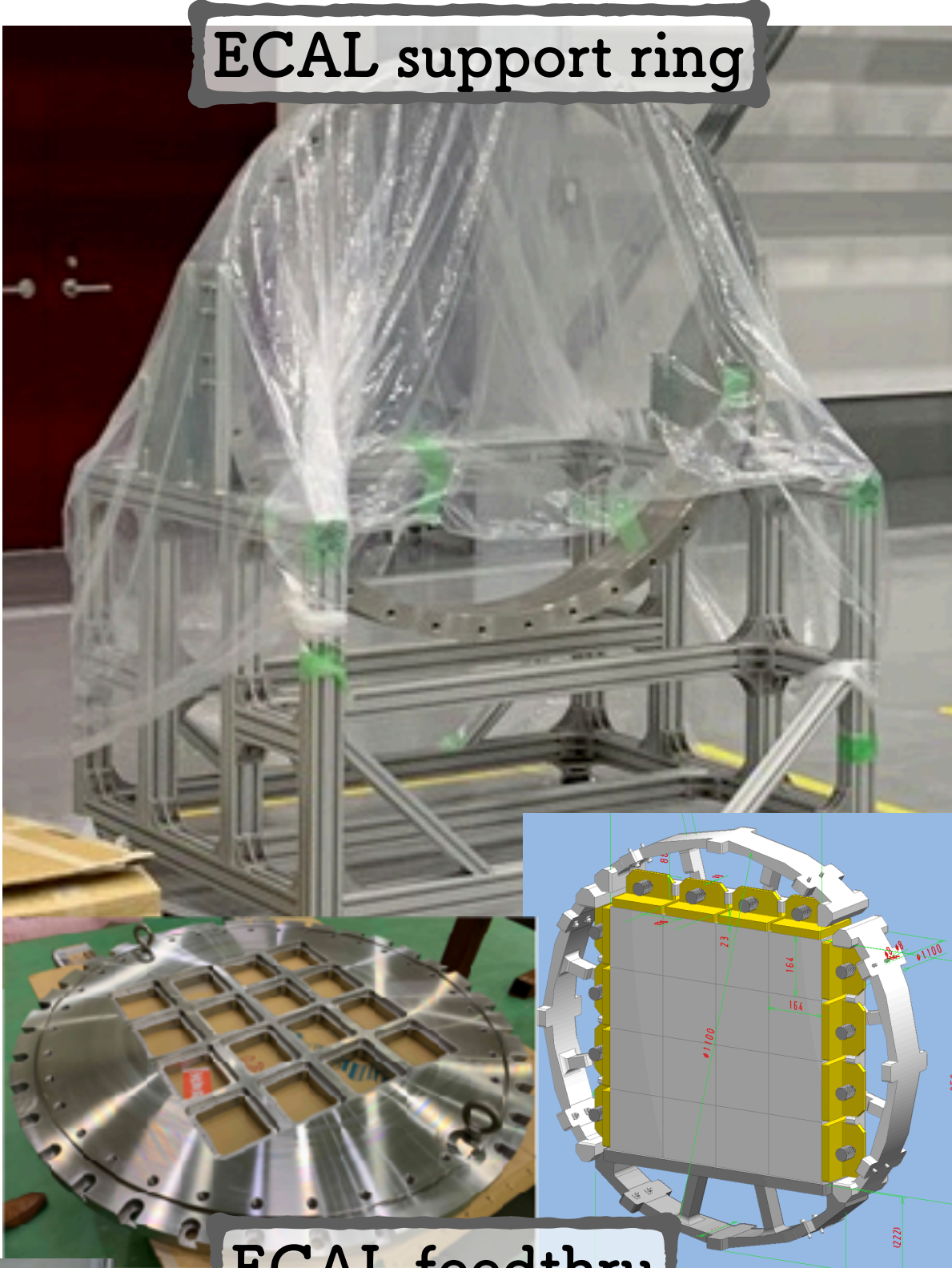
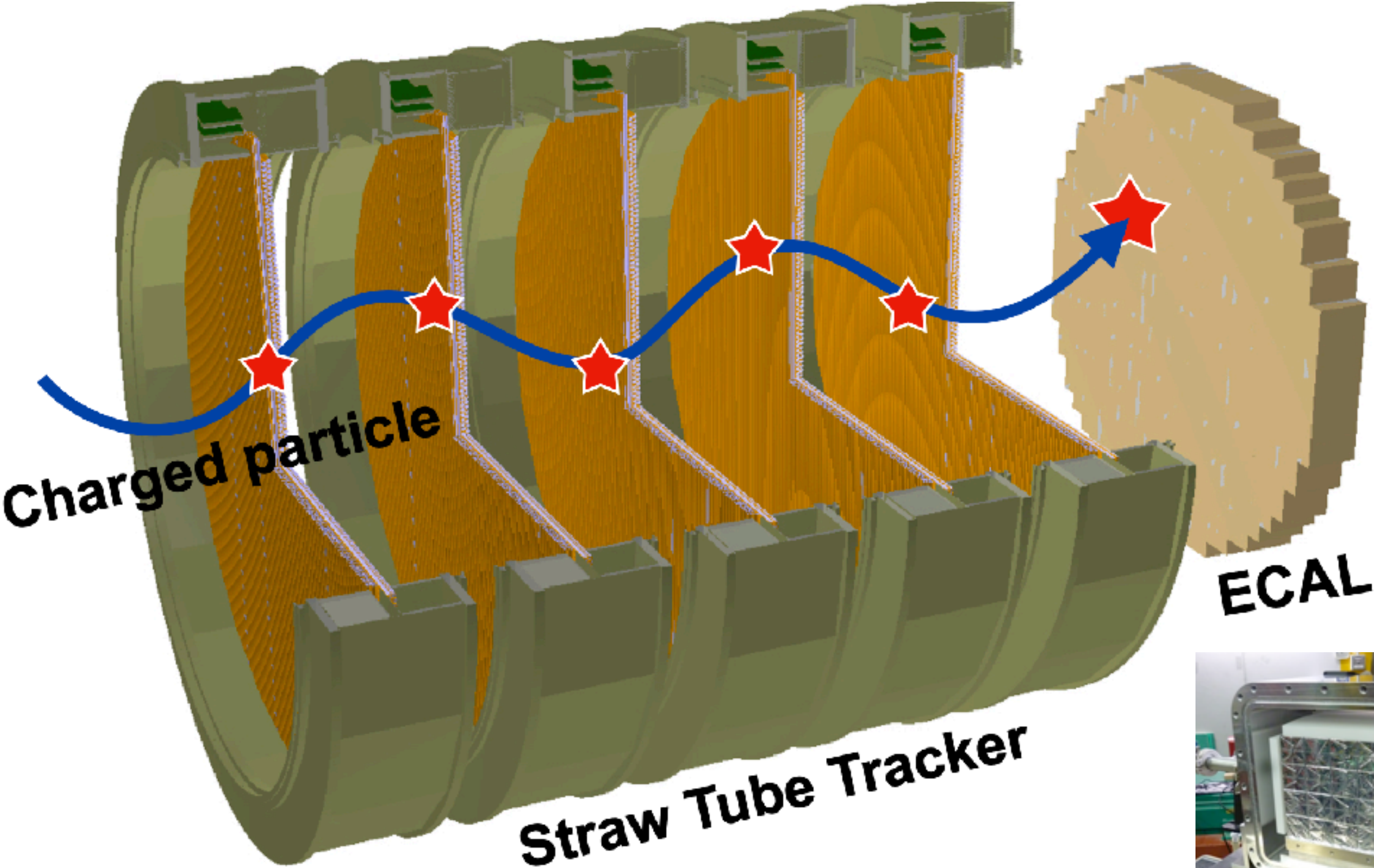
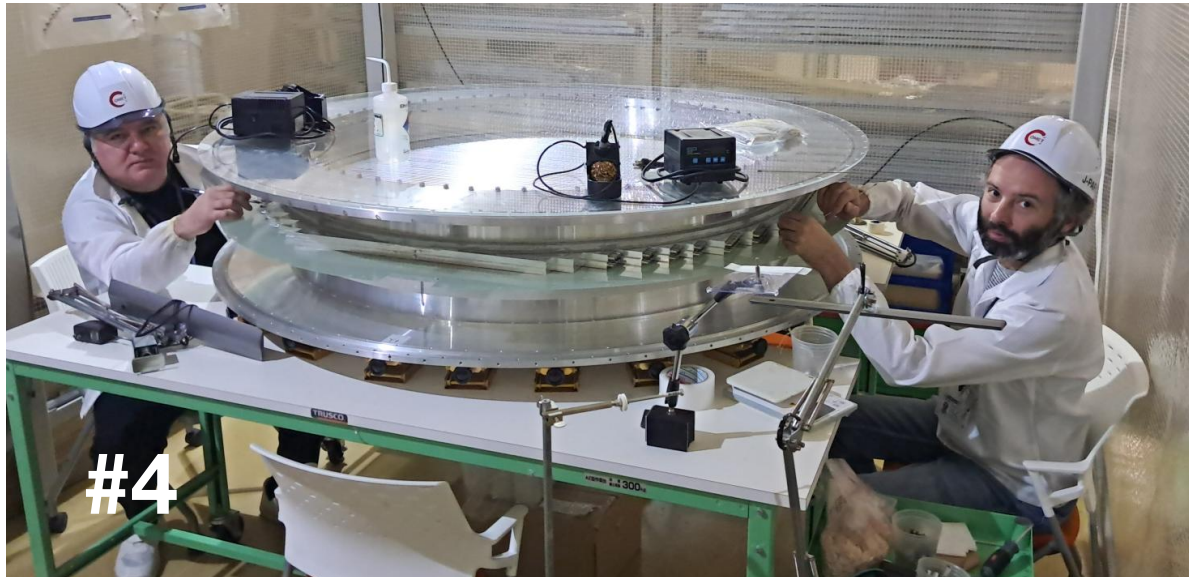
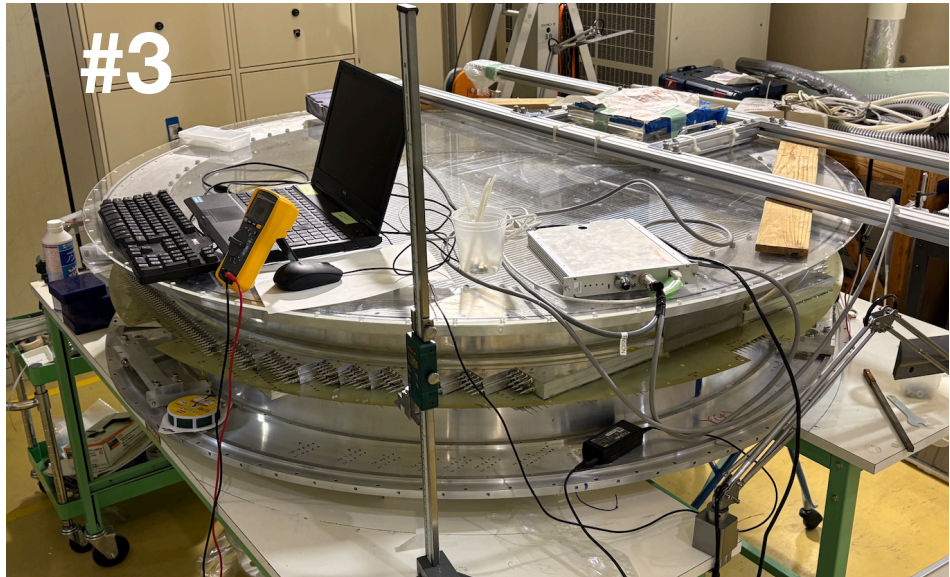
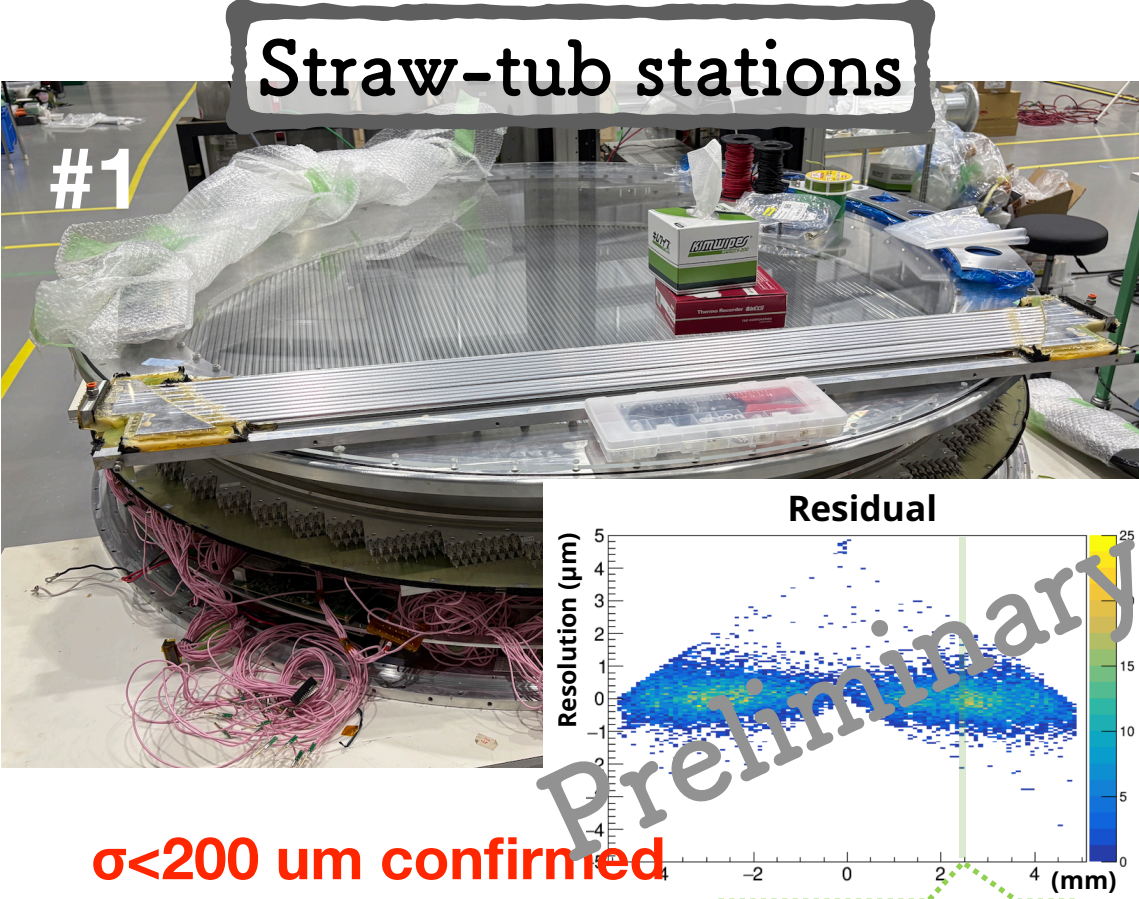
A_μ : acceptance of μ -e signal, 0.041, exp..

Event selection	Value
Online event selection efficiency	0.9
DAQ efficiency	0.9
Track finding efficiency	0.99
Geometrical acceptance + Track quality cuts	0.18
Momentum window (ε_{mom})	0.93
Timing window ($\varepsilon_{\text{time}}$)	0.3
Total	0.041

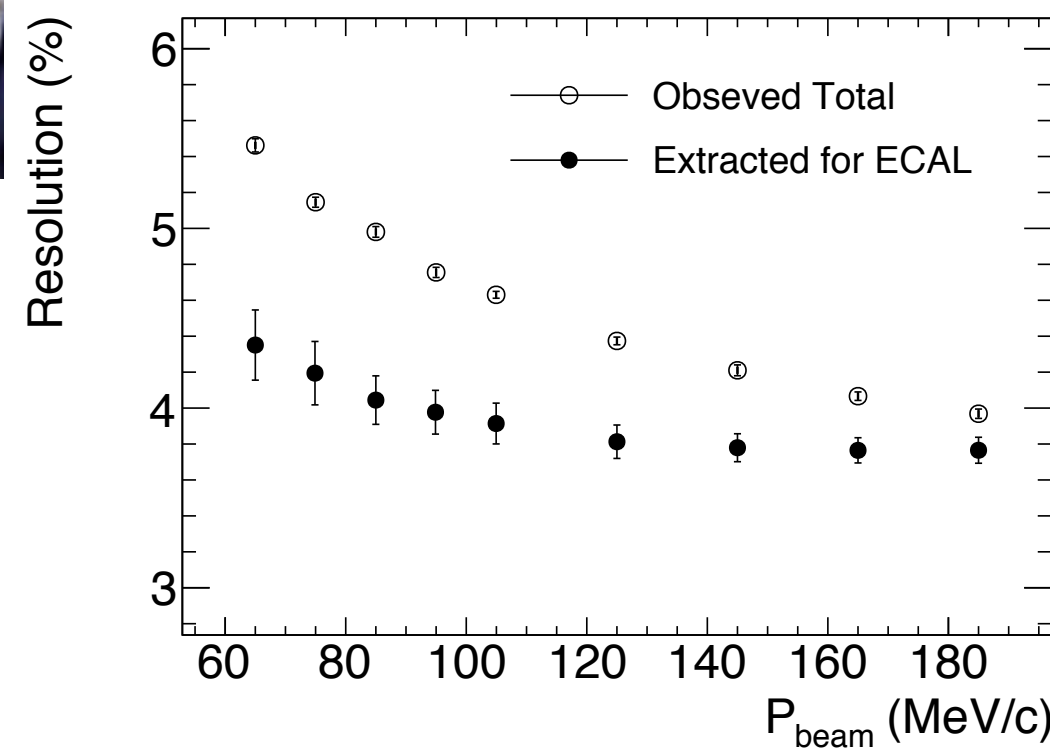
Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	
	All (*) Combined	≤ 0.0038
Delayed Beam	Radiative pion capture	0.0028 ~0.01
	Neutrons	$\sim 10^{-9}$
	Beam electrons	~ 0
	Muon decay in flight	~ 0
	Pion decay in flight	~ 0
Others	Radiative pion capture	~ 0
	Anti-proton induced backgrounds	0.0012
	Cosmic rays [†]	< 0.01 ~0.5
Total		0.032

[†] This estimate is currently limited by computing resources.

Beam Measurement Detectors

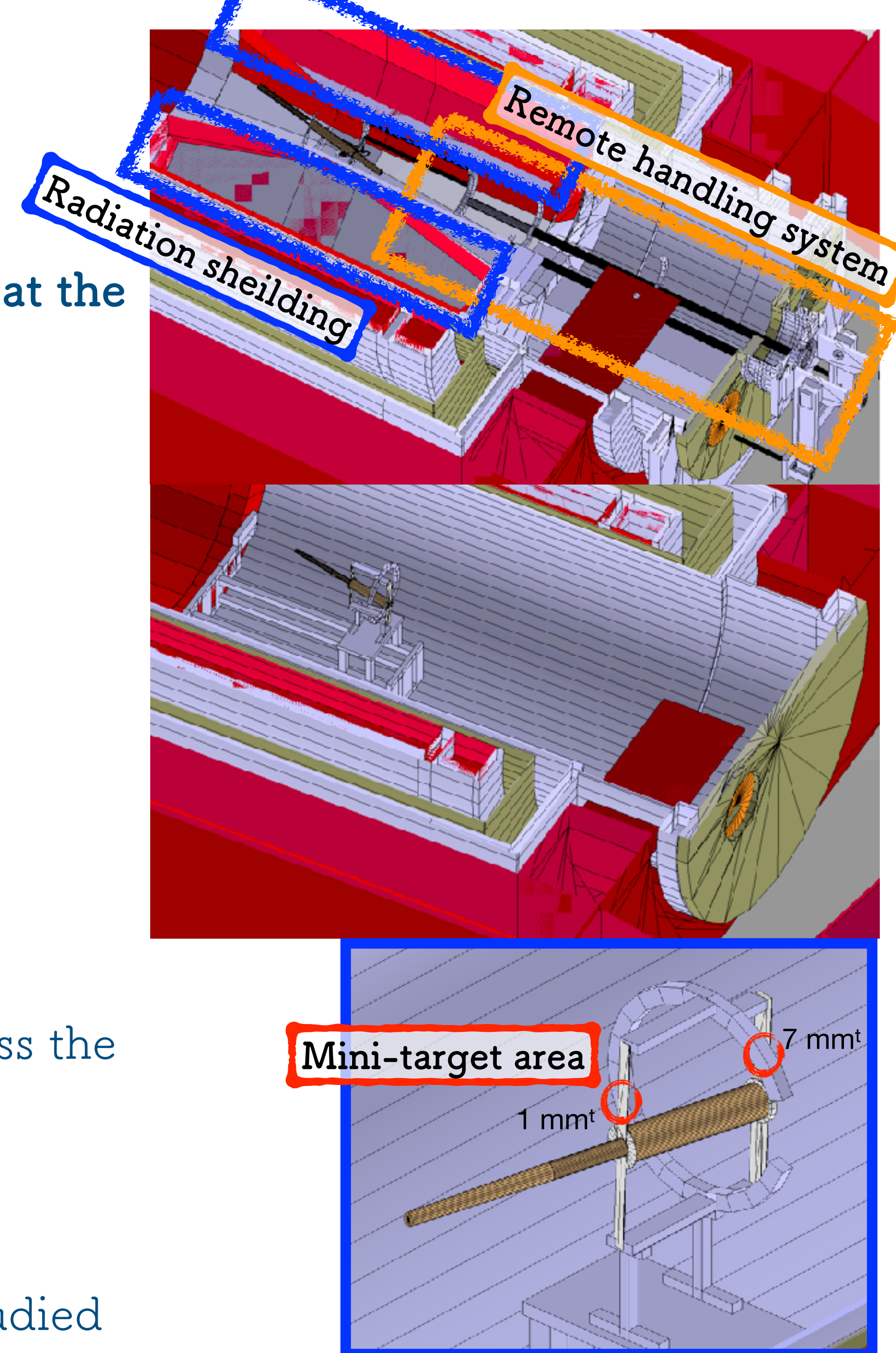


ECAL prototype and its energy resolution

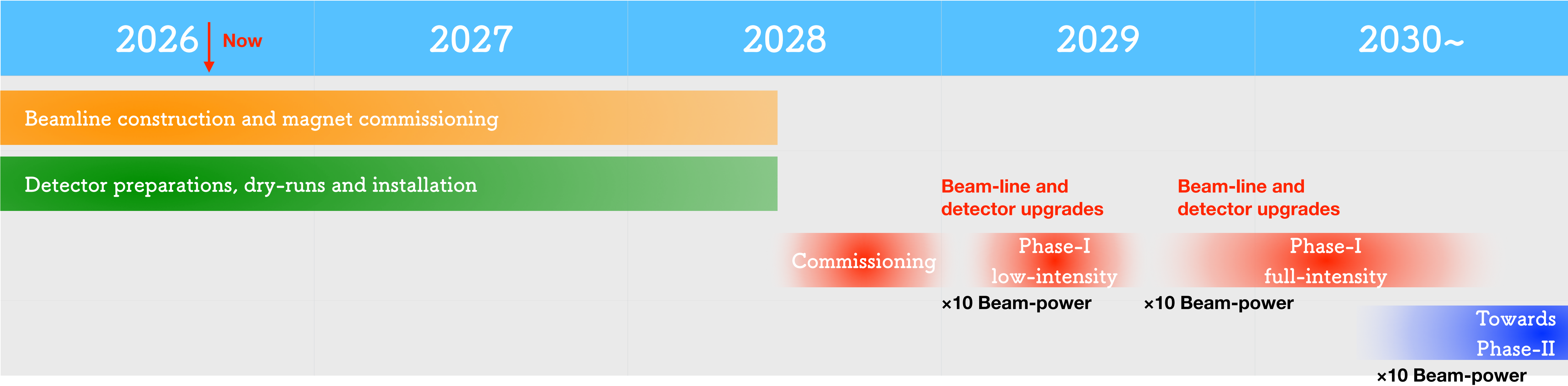


Phase-I Commissioning

- Minimum beamline / detector configurations to accept the muon beam **at the earliest**
 - Less shield materials w/ 1% beam power w.r.t. the Phase-I nominal
 - Simple proton target support structure
 - 1/3 CTH readout, partial CRV
- 1/2 strength BS/DS operation for the calibration study
 - Momentum calibrations with Michels e^+ edge / DIO peak e^- using positive / negative muon beam
 - Carbon target support bars as the “mini-target” to further suppress the rate
 - Only a day is required including the magnetic field switching
- Single shot operation with a Phase-I full intensity equivalent will be studied



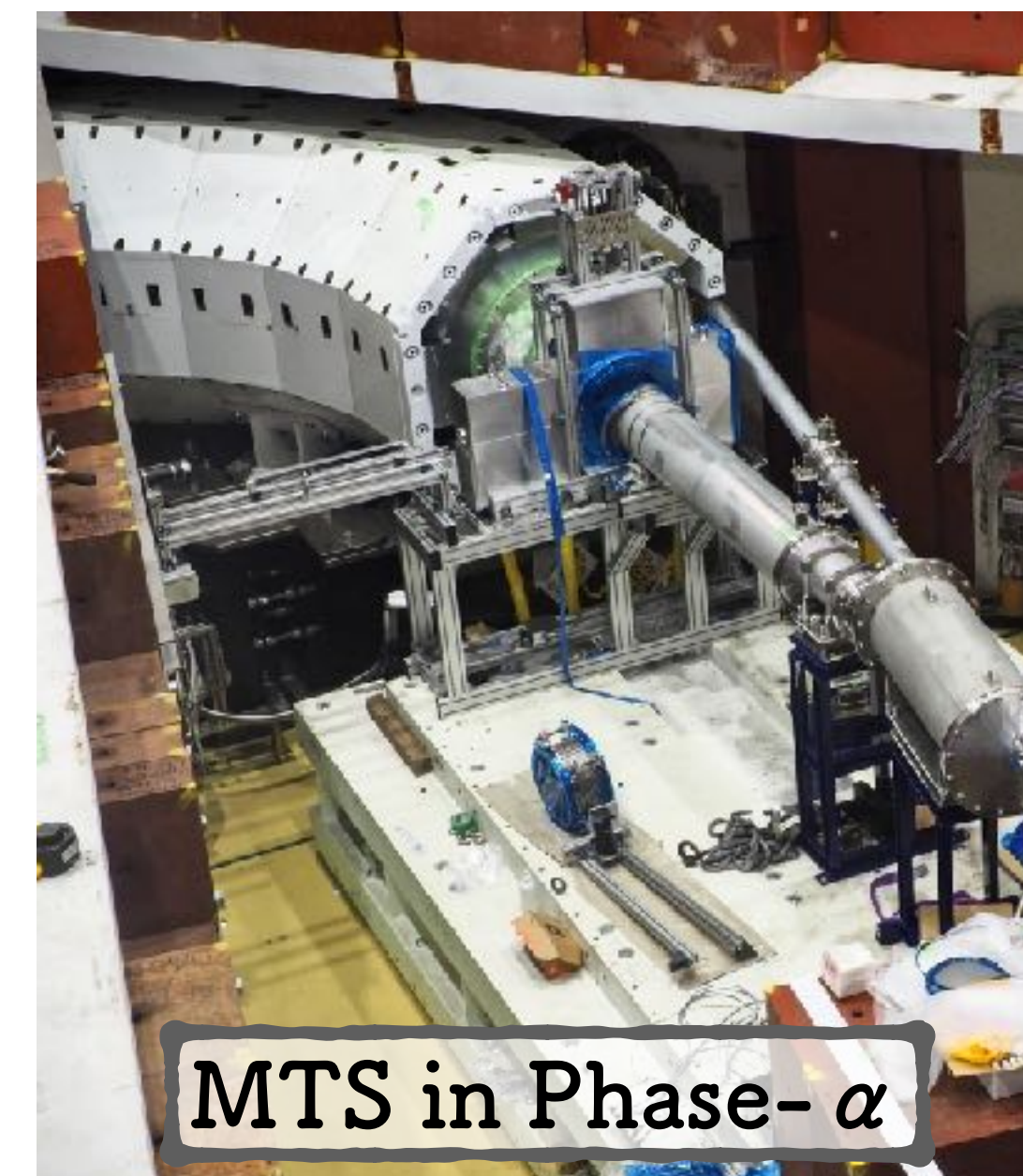
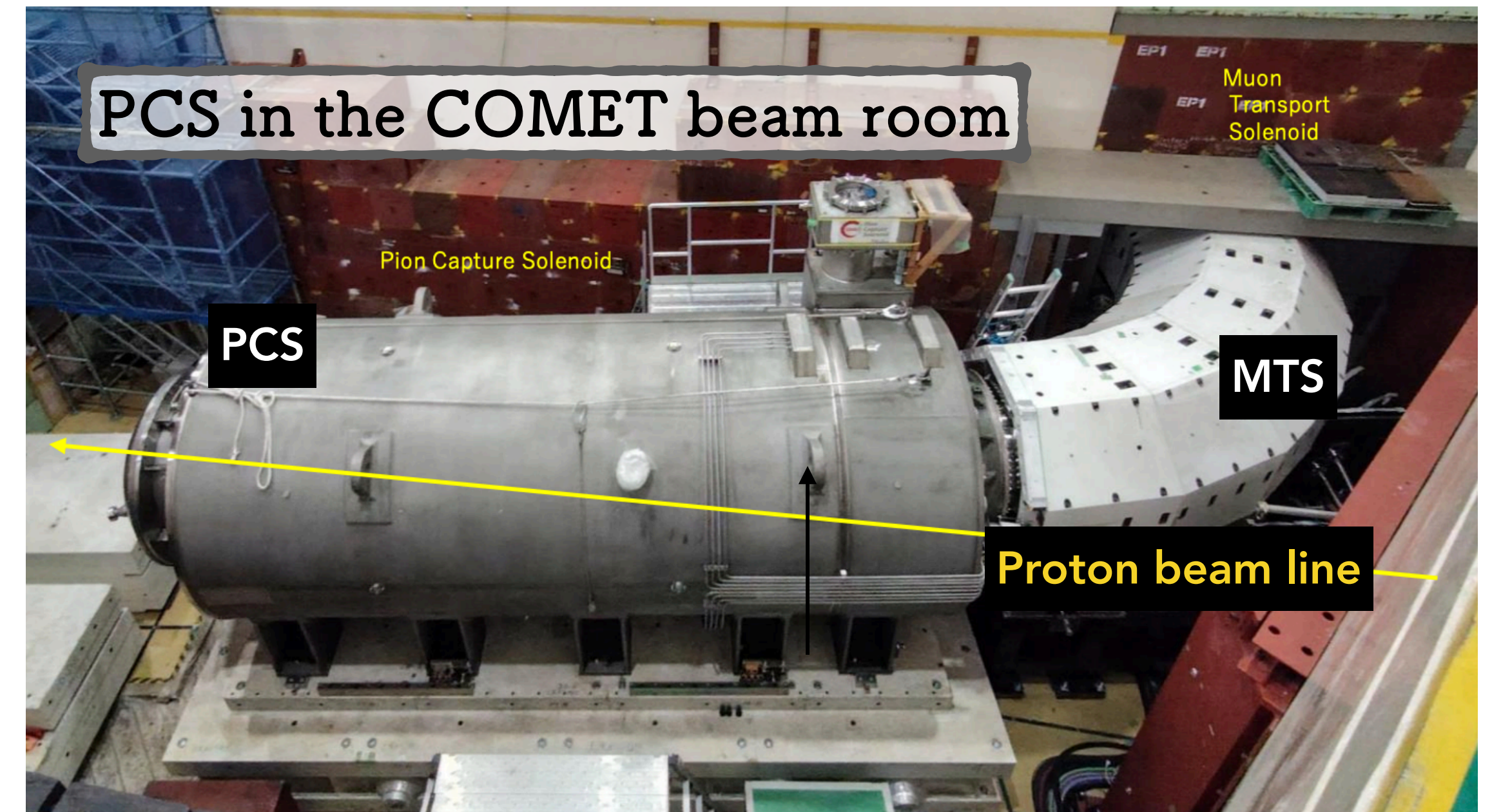
Schedule



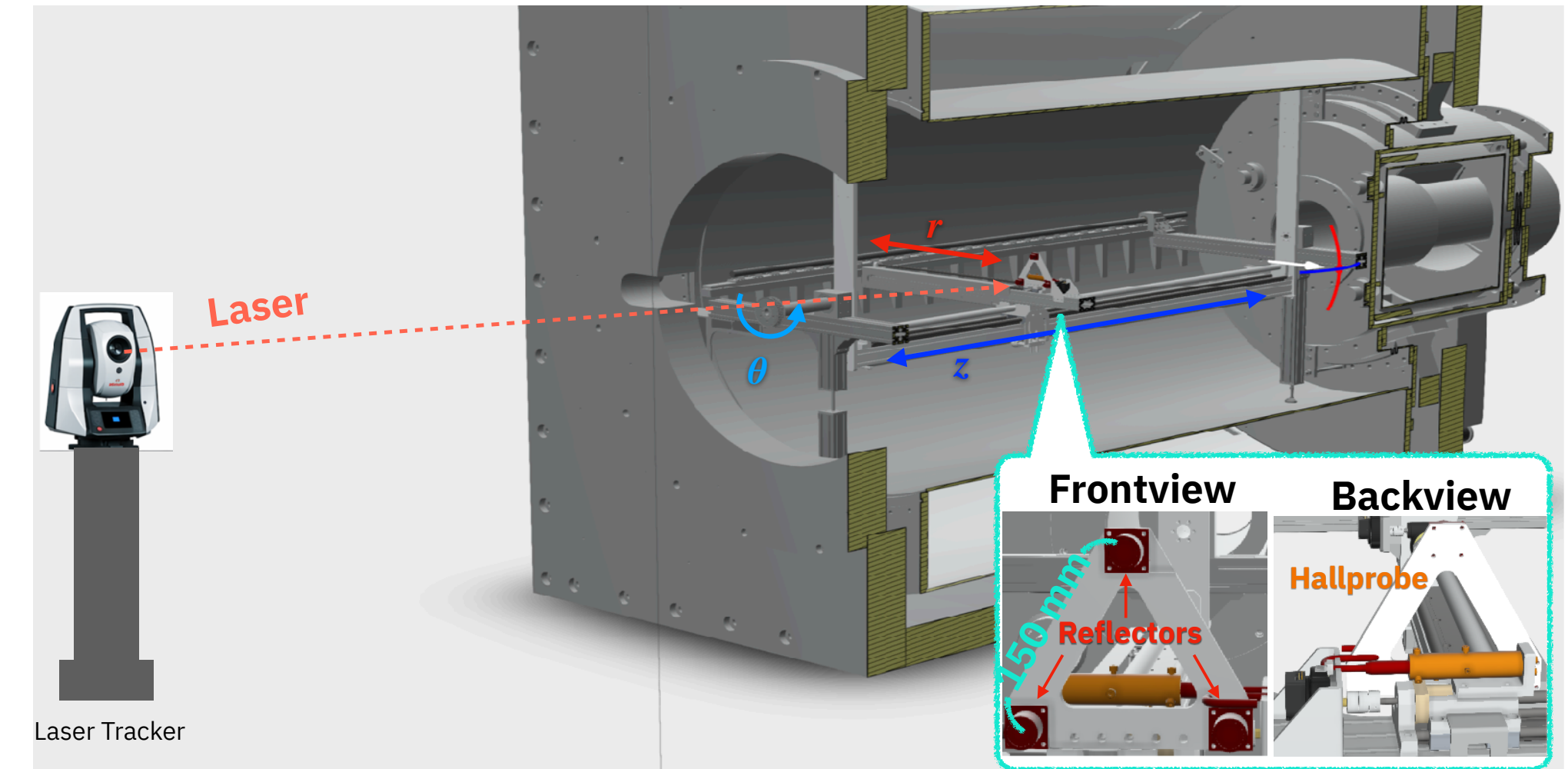
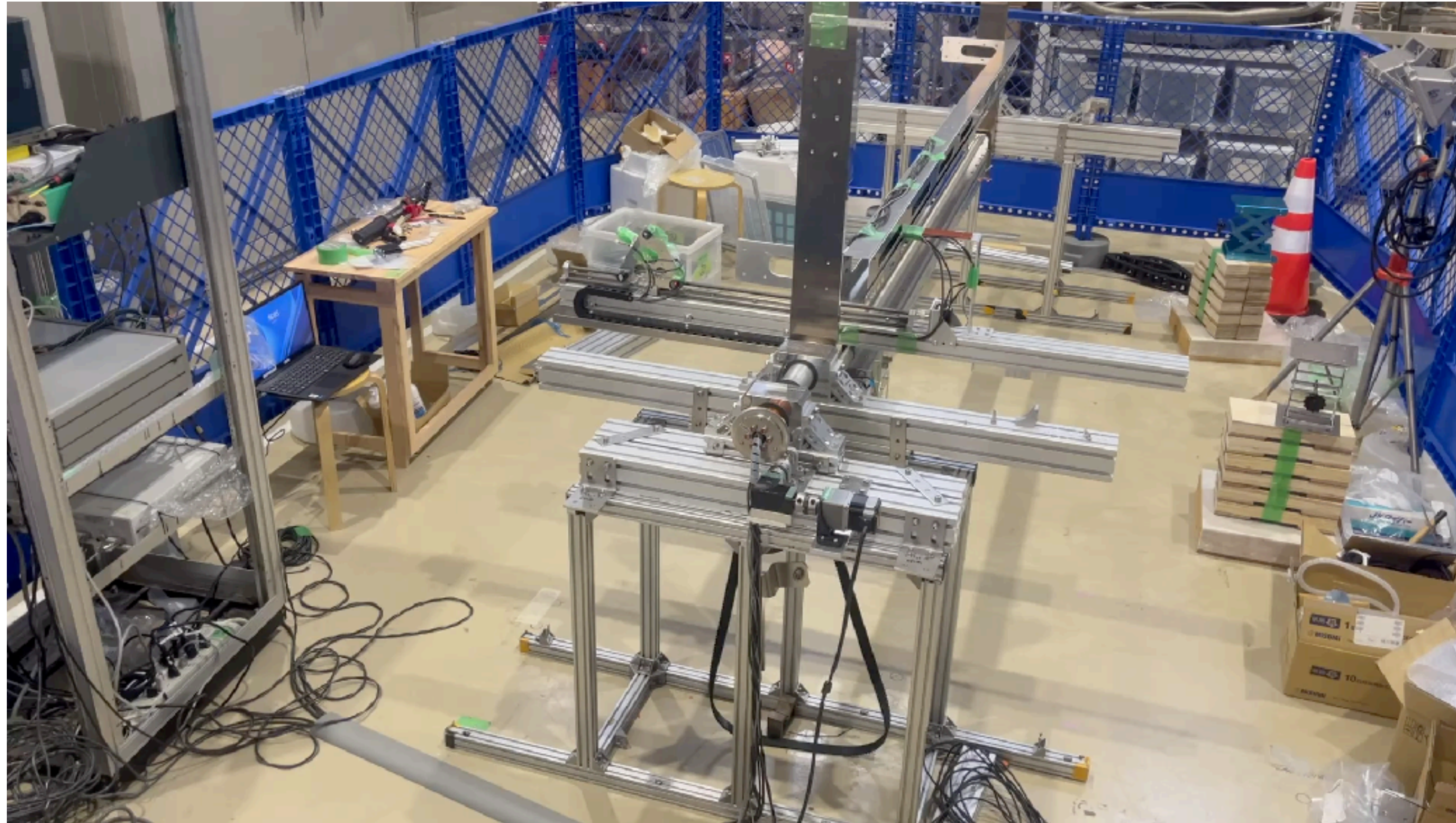
- We aim to start our first beam operation with detectors in 2028
- Gradually increasing the beam power while upgrading facility and detectors

Magnet status

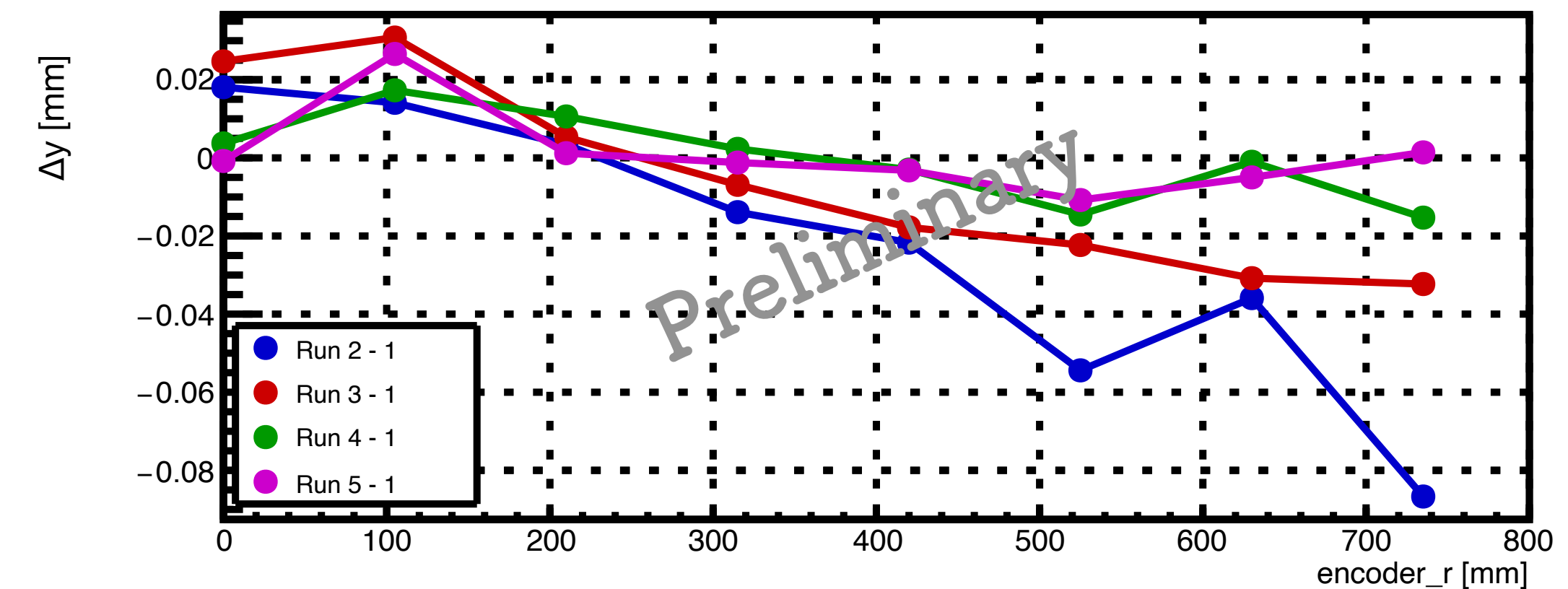
- All magnets have arrived at J-PARC in 2025
- PCS:
 - Iron yoke will be installed soon
 - Cooling system will be connected in this year / early next year
- MTS
 - Ready and tested in Phase- α
- BS/DS
 - All hardware is ready and excitation test was done
 - Field measurement will be performed in this month



Magnetic Field Measurement



Position variation from the linear interpolation



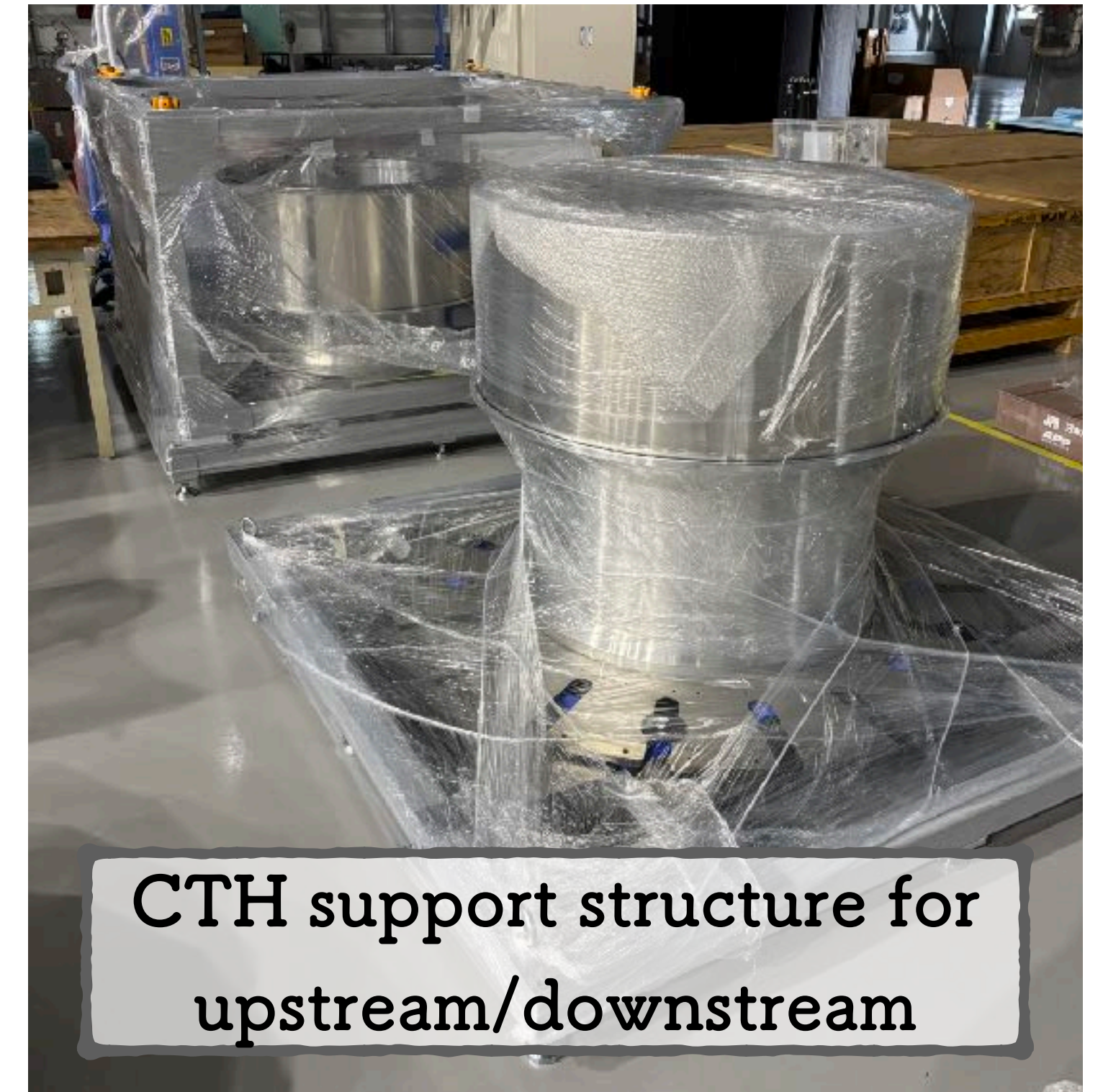
- DS magnetic field will be measured with the dedicated field mapping machine
- Measured probe positions were well reproduced

Physics Detectors' Dry-run

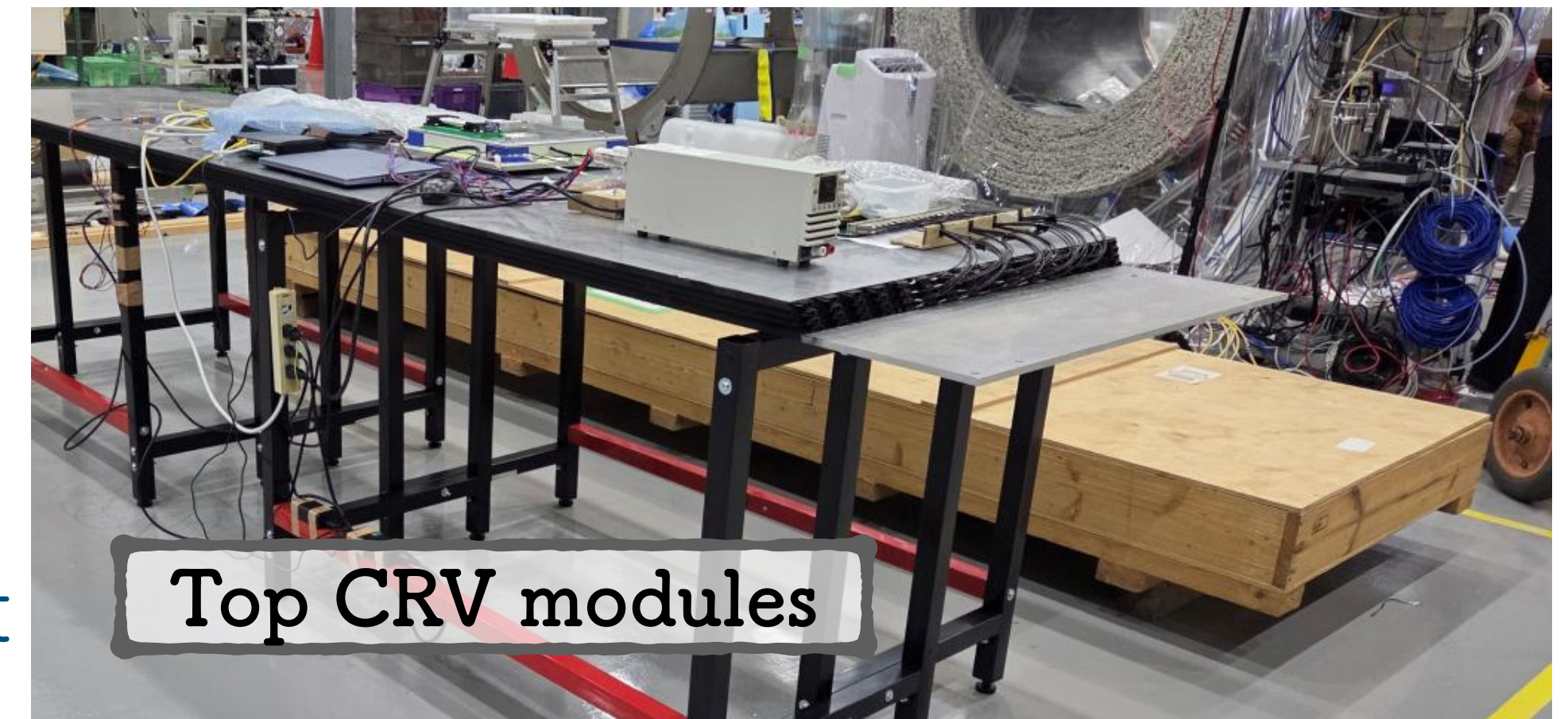


CDC installation cradle and CDC

- CDC, CTH and CRV are all gathered in the J-PARC R&D building
- Mechanical integration test will start soon followed by the cosmic-ray dry-run measurement



CTH support structure for upstream/downstream

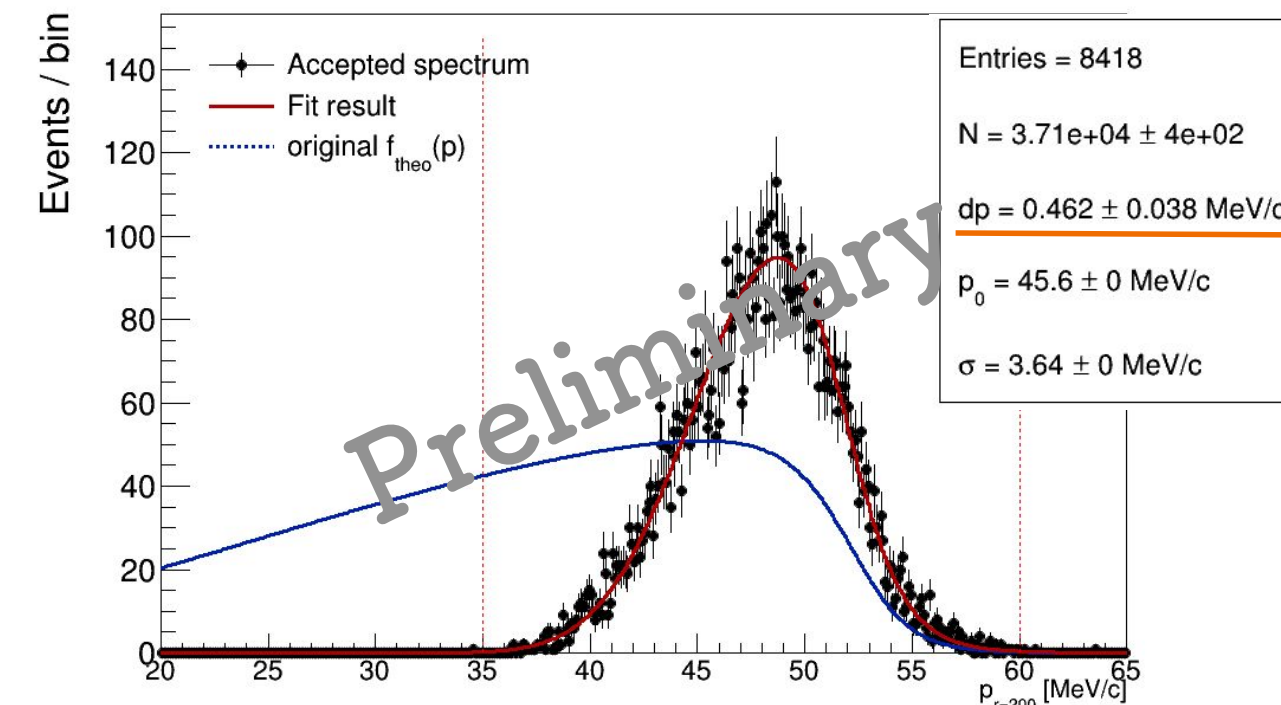


Top CRV modules

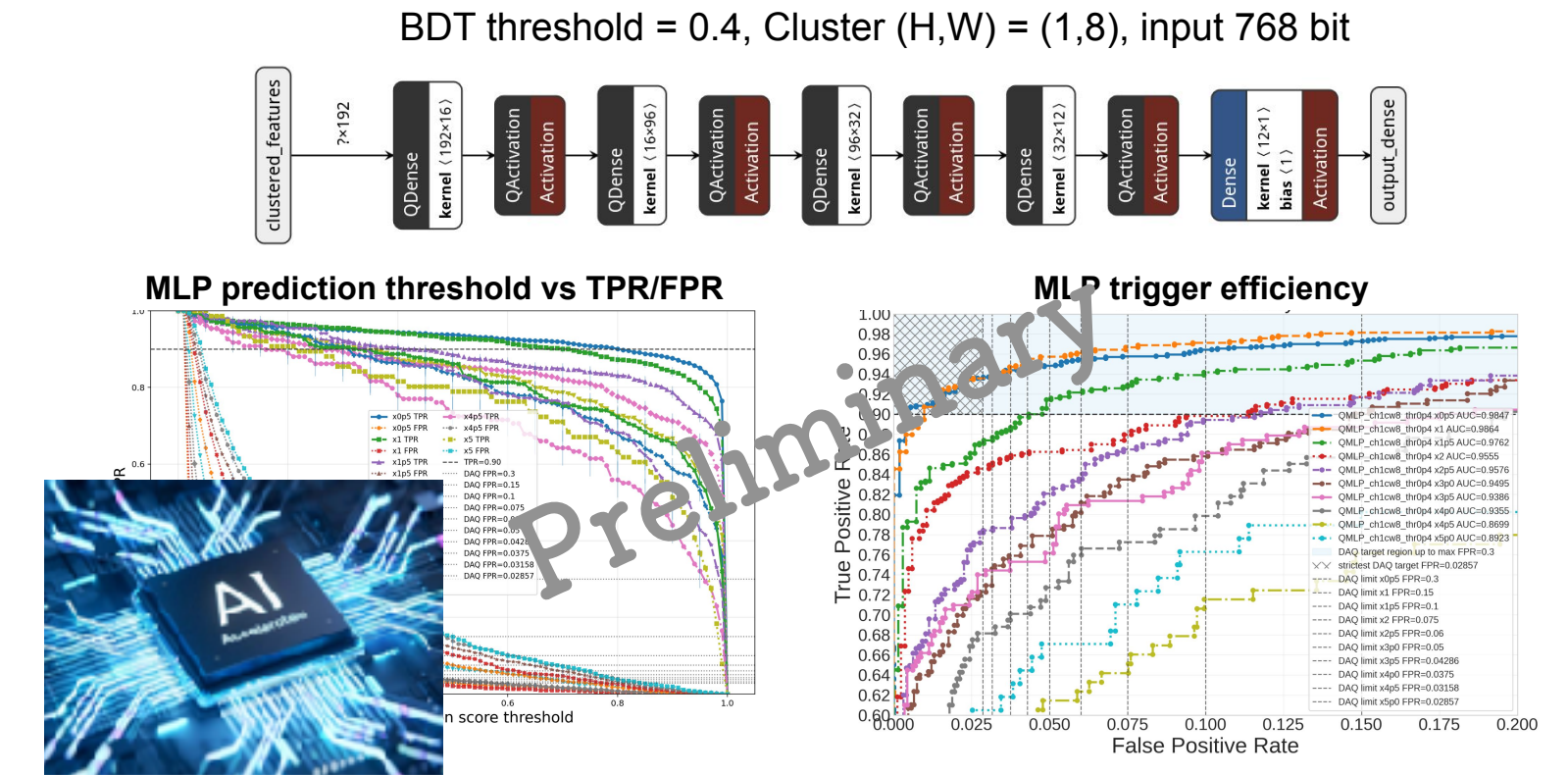
Other activities

- Momentum calibration studies
- ML-based studies
 - Hardware and software triggers
 - MC production enhancement
 - Enhance MC production from $\sim 10^{10}$ POTs to 10^{13} POTs by utilising ML methods, e.g. W-GAN, Copulas, etc
 - Track reconstruction
 - Using machine learning (U-net) not only for noise filtering, but also for extracting the track parameters

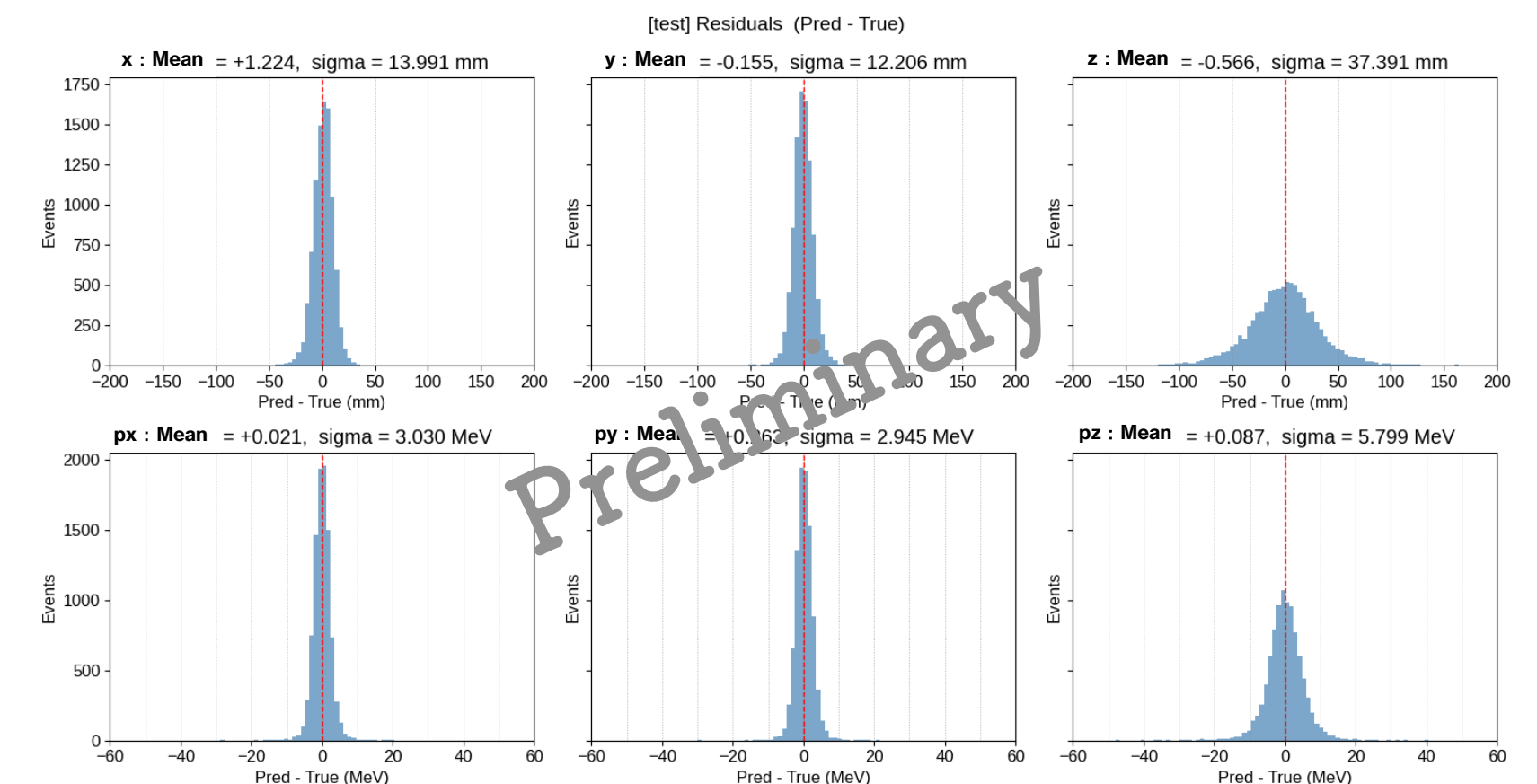
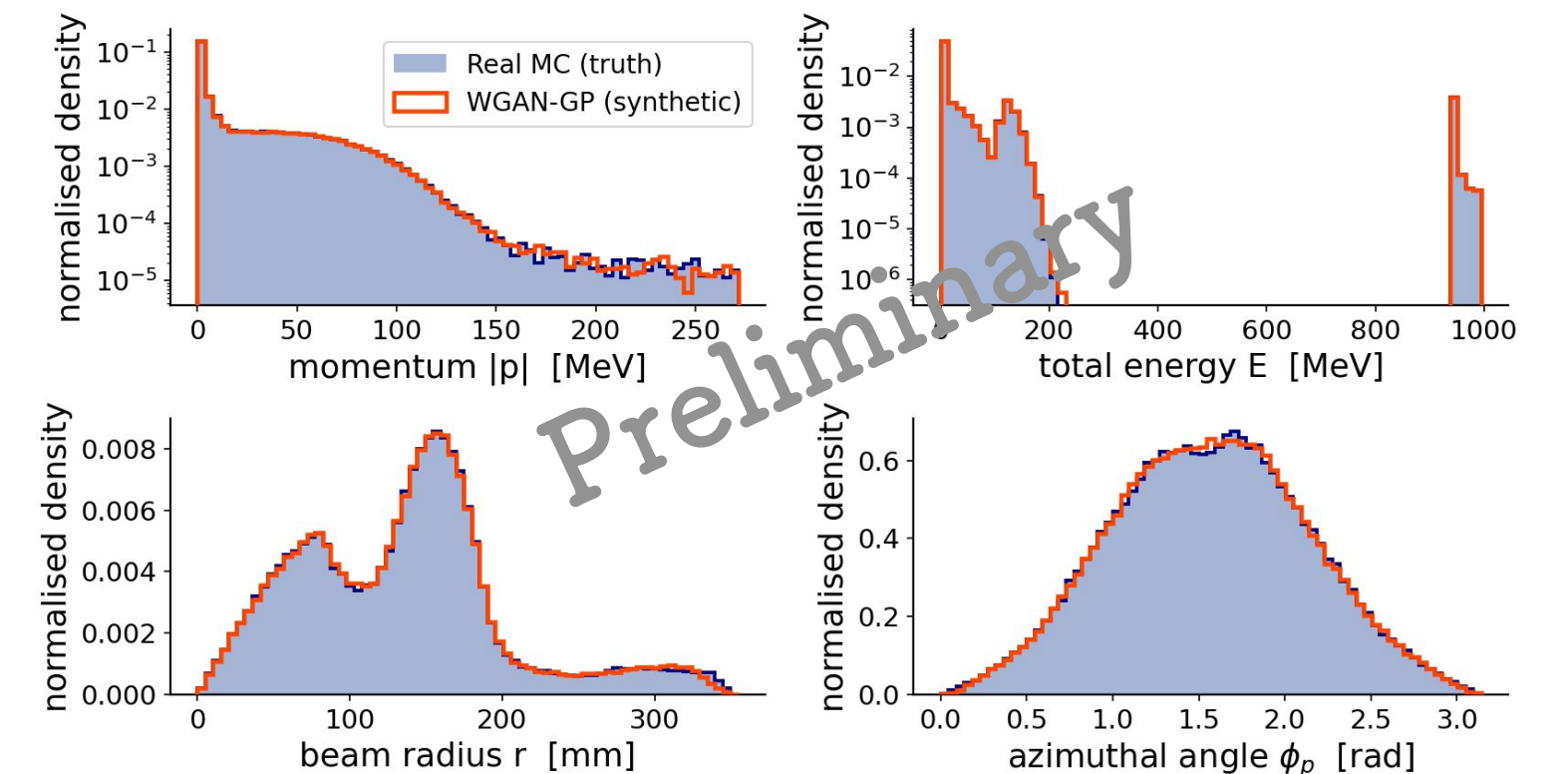
Momentum scale calibration tested with MC



MLP Optimization Result



Six-species mix at the true plane ratio: synthetic overlays real MC



Summary

- COMET aims to search for μ -e conversion with a single sensitivity below 10^{-16}
- Phase-I will start in a few years with a step-by-step approach
 - Many scientific outcomes are expected such as momentum calibrations, DIO measurement, positive-beam studies, direct beam measurement, etc
- Final target sensitivity $<10^{-14}$
- Almost all hardware components including all magnets have been delivered at J-PARC for the coming integration and dry-runs

Back up