The COMET experiment

— Search for muon-to-electron conversion —

Activities in Kyushu University

Manabu MORITSU (Kyushu Univ.)

Mini-workshop on Hidden Symmetries of the Universe 2024
21st Feb., 2025, Kyushu University, Fukuoka, Japan

Memories in SNU

- I have visited SNU twice in 2010 & 2011,
- when I was a student in Kyoto University,
- for workshops on J-PARC Hadron experiments,
- organized by

Prof. Kiyoshi Tanida & Prof. HyoungChan Bhang.

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  Prof. Kiyoshi Tanida & Prof. HyoungChan Bhang.

- … by chance,
- Prof. Yoshi Kuno (former spokesperson of COMET) was there…
- after several years, I joined COMET.

Overview of COMET

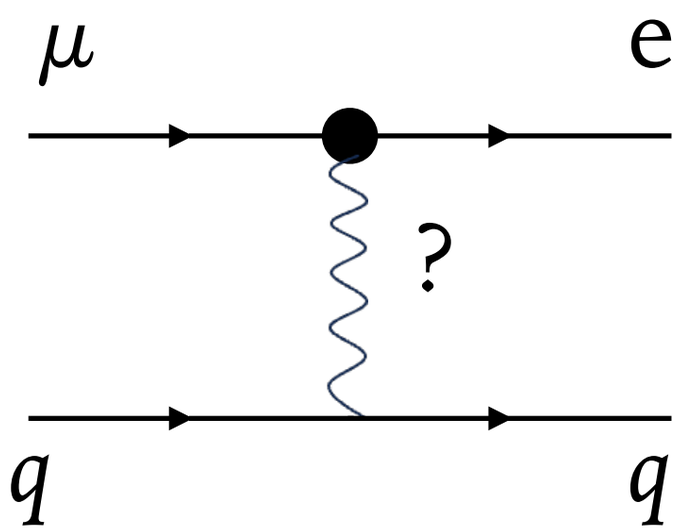
focusing on activities in Kyushu Univ.

Muon-to-electron conversion

- A new physics search using a muon rare process

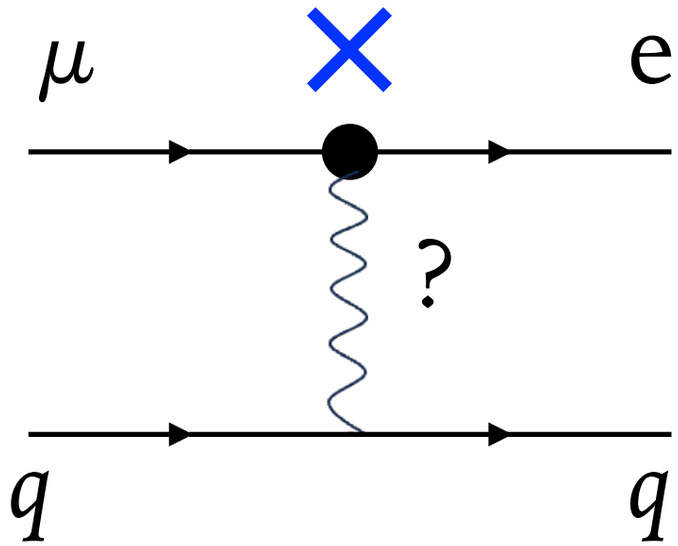
Muon-to-electron conversion

- A new physics search using a muon rare process
- μ^-N→ e$^-$N : neutrinoless conversion in a muonic atom (N=nucleus)



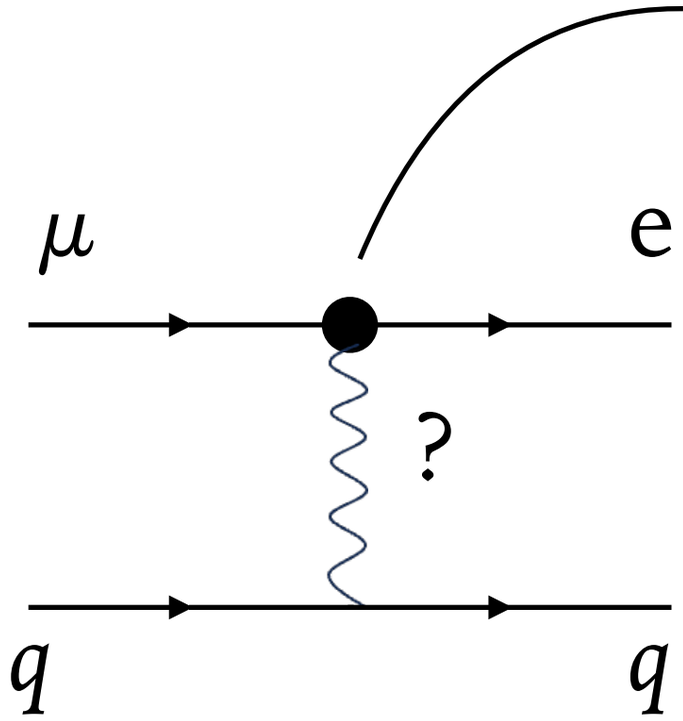
Muon-to-electron conversion

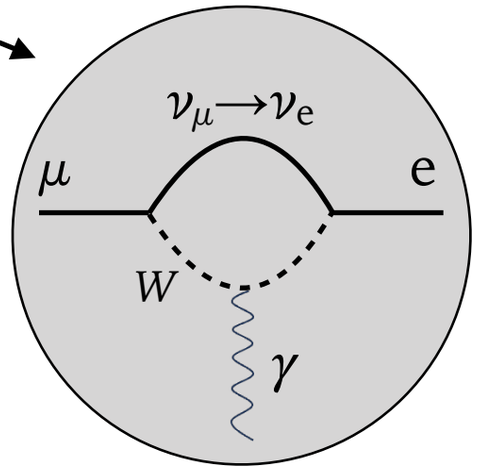
- A new physics search using a muon rare process
- μ^-N→ e$^-$N : neutrinoless conversion in a muonic atom (N=nucleus)
- Forbidden in **SM**: Lepton Flavor Violation (LFV)



Muon-to-electron conversion

- A new physics search using a muon rare process
- μ-N→ e-N : neutrinoless conversion in a muonic atom (N=nucleus)
- Forbidden in SM: Lepton Flavor Violation (LFV)
- contribution from **neutrino oscillation** is still too small → negligible

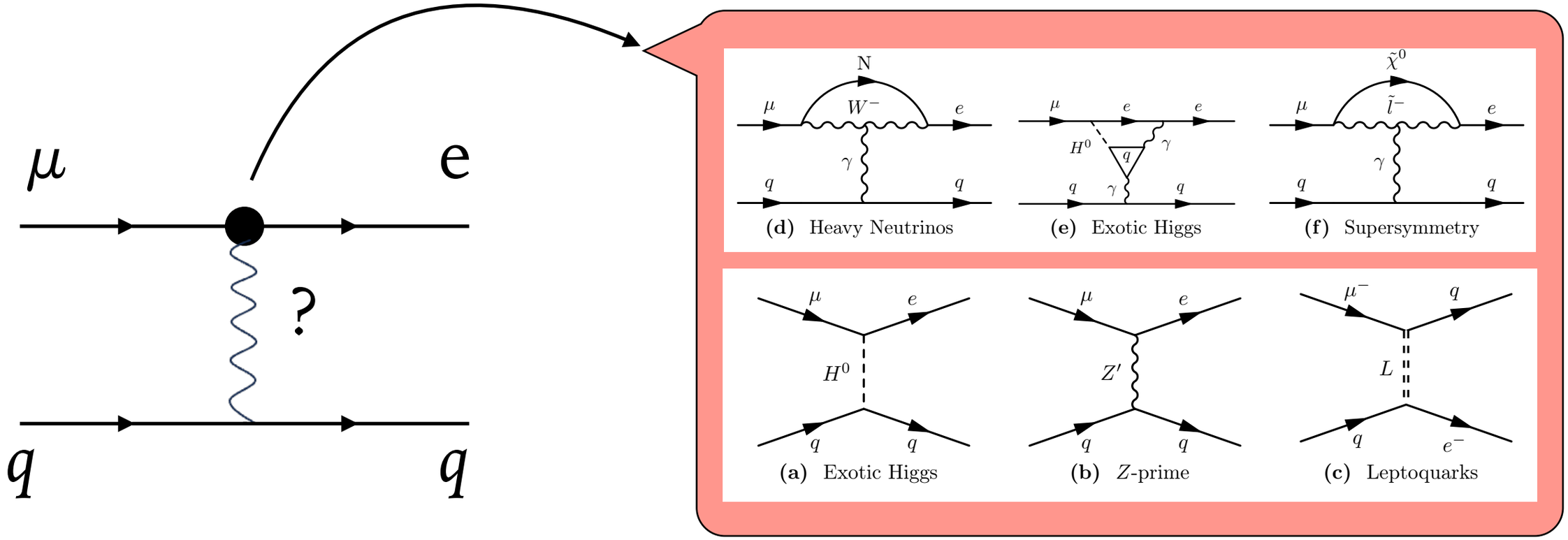




$BR \lesssim 10^{-54}$

Muon-to-electron conversion

- A new physics search using a muon rare process
- μ-N→ e-N : neutrinoless conversion in a muonic atom (N=nucleus)
- Forbidden in SM: Lepton Flavor Violation (LFV)
- contribution from neutrino oscillation is still too small → negligible
- contribution from **New Physics** may appear !

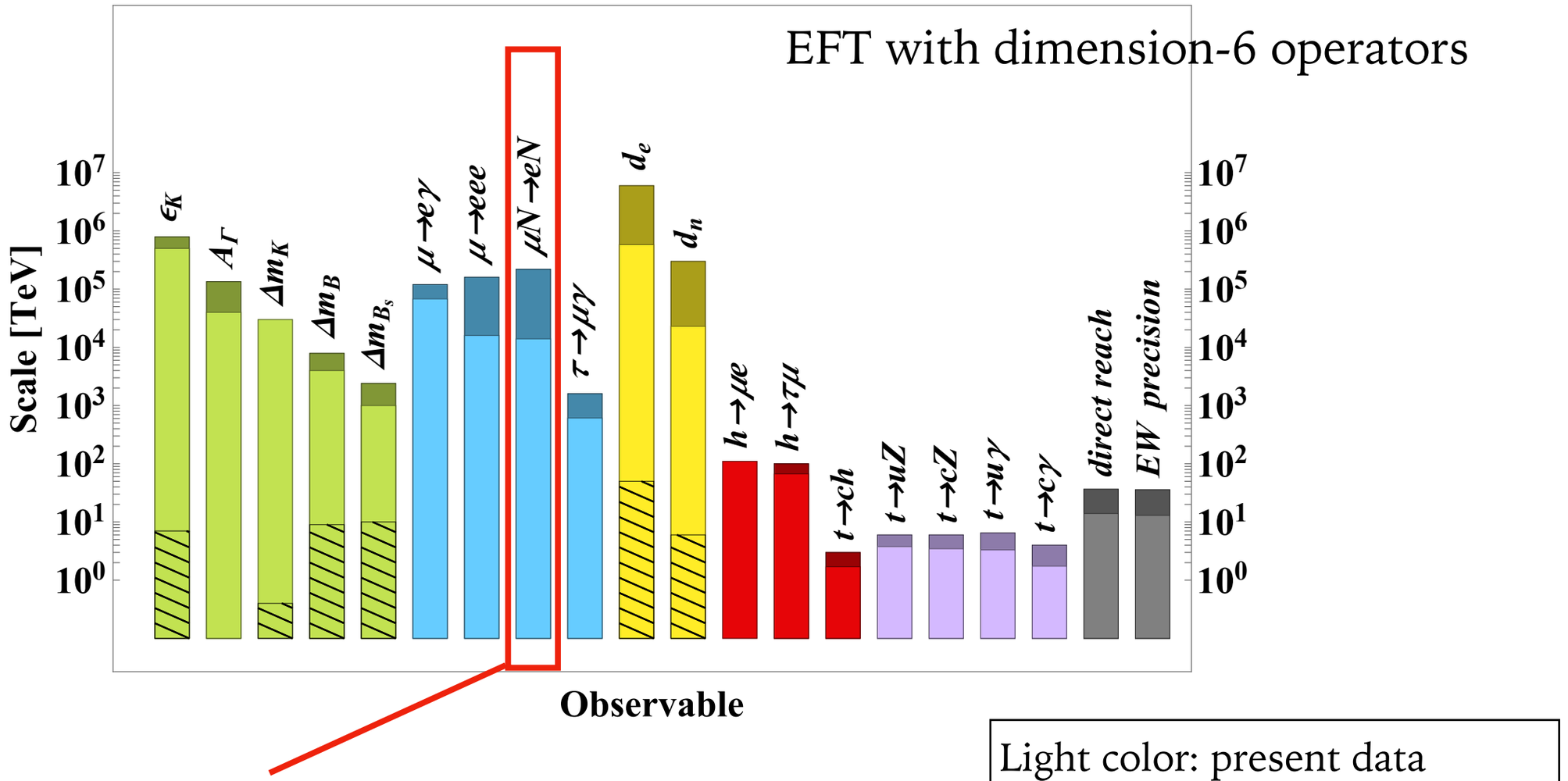


Predicted BR ~ 10^{-16}~10^{-12}

Cf.) Current experimental upper limit < 7 x 10^{-13} (90%CL)

Reach in new physics scale

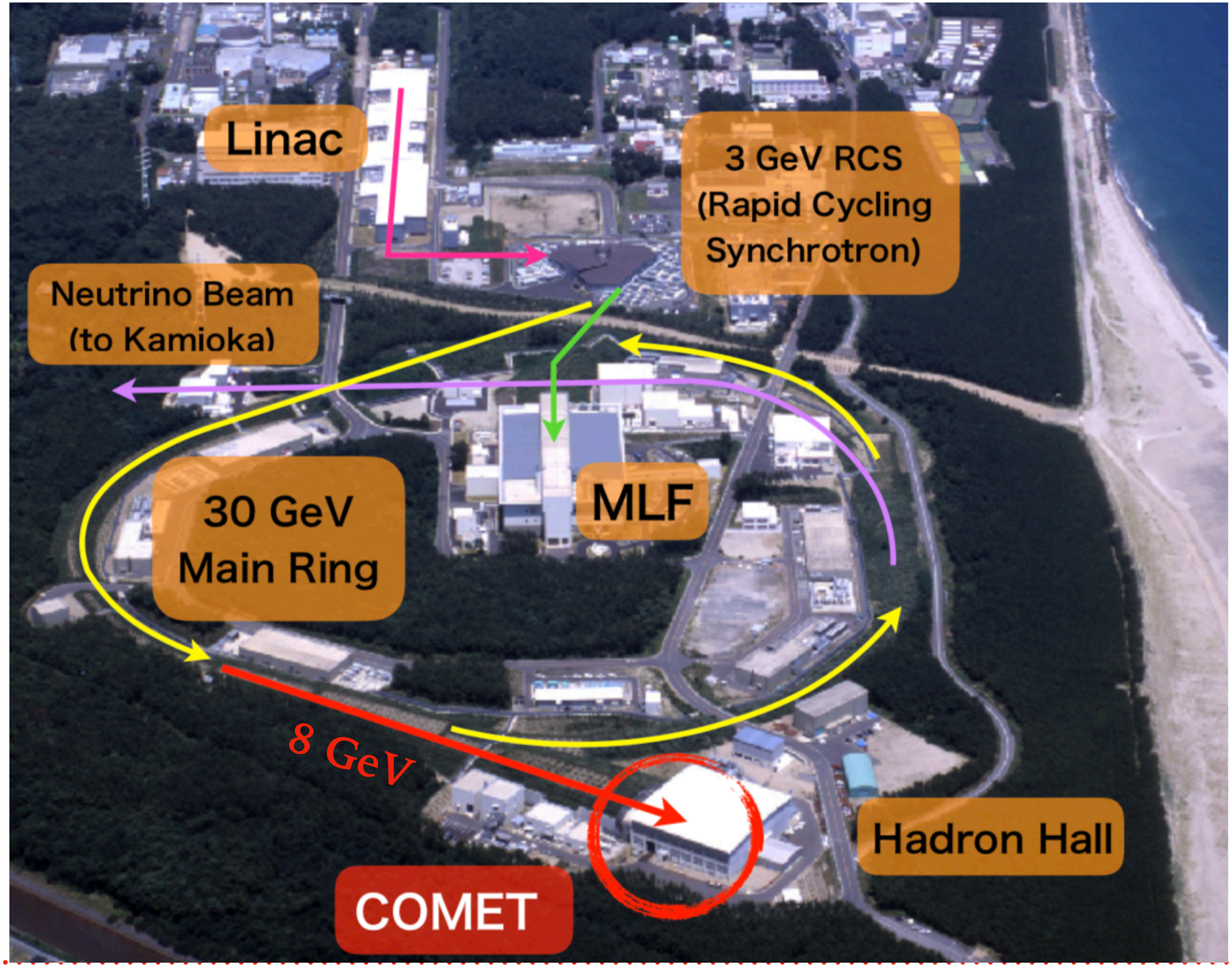
from European Strategy for Particle Physics Update 2020



Light color: present data
Dark color: mid-term prospects

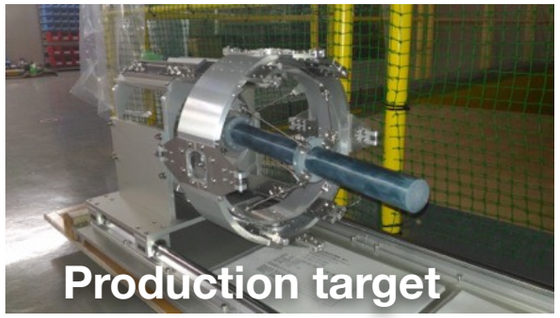
μ-e conversion has very high energy reach
among many flavor measurements,
also compared with direct searches.

J-PARC accelerator



Muon source

Powerful muon source is mandatory !!

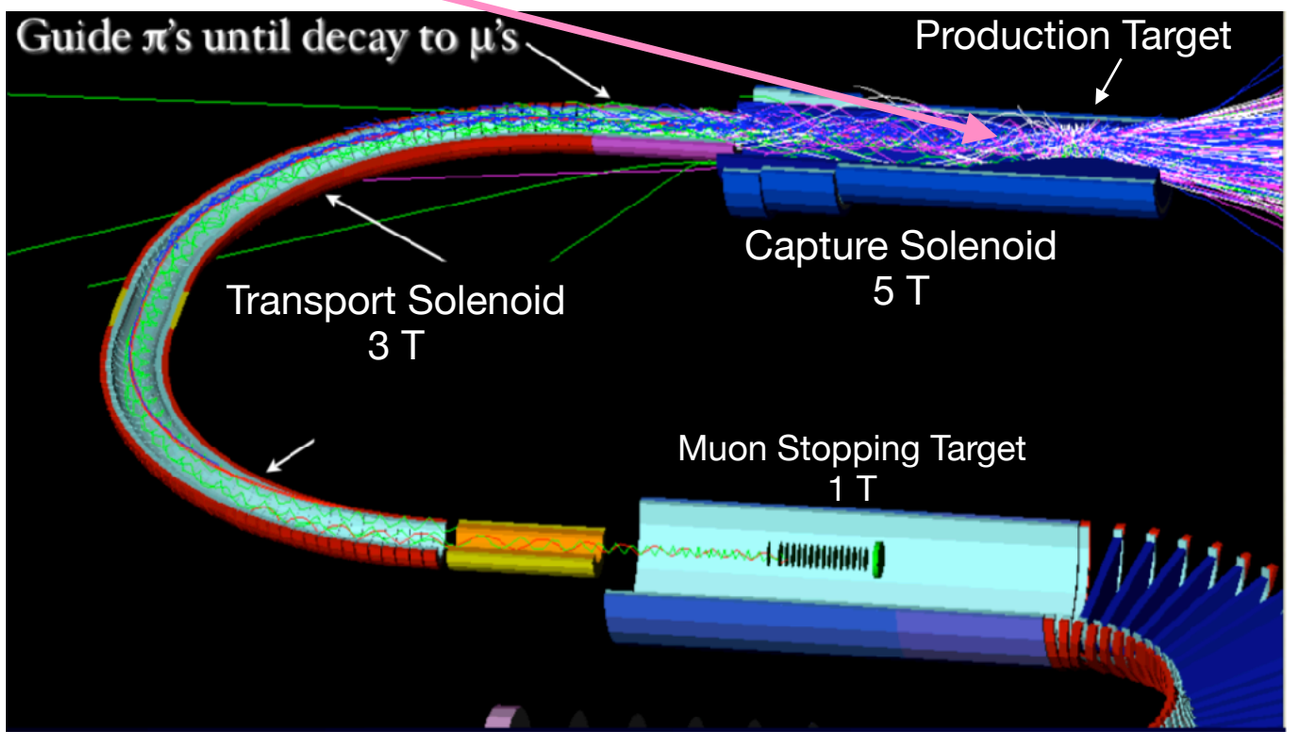


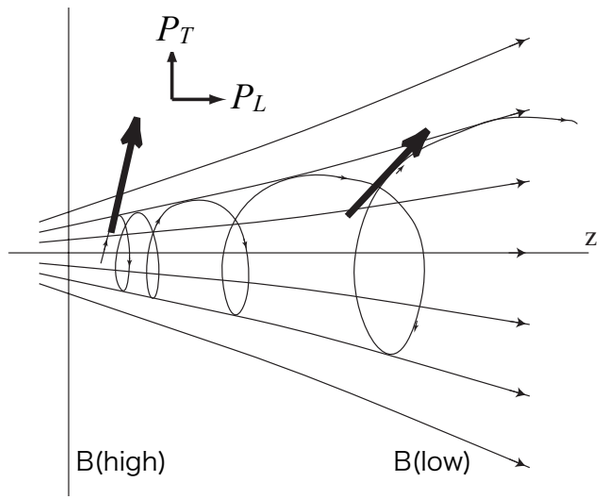
To achieve 10^{-17} sensitivity,

~10^{11} muons/sec

(with 10^7 sec running time.)

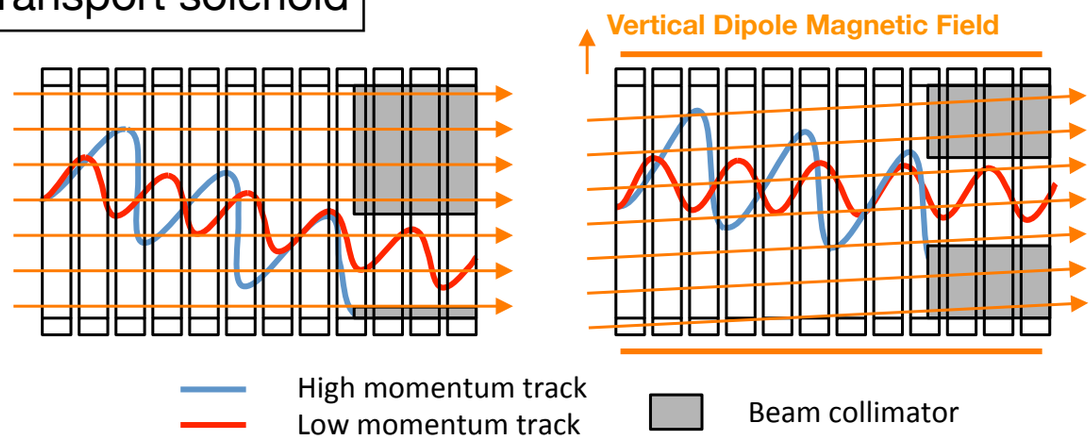
- We need low-energy muons, which stop at thin target disks.
- Pion Capture solenoid
  - Backward generated pion → muon
- Curved Transport solenoid
  - Vertical drift → Momentum & charge selection





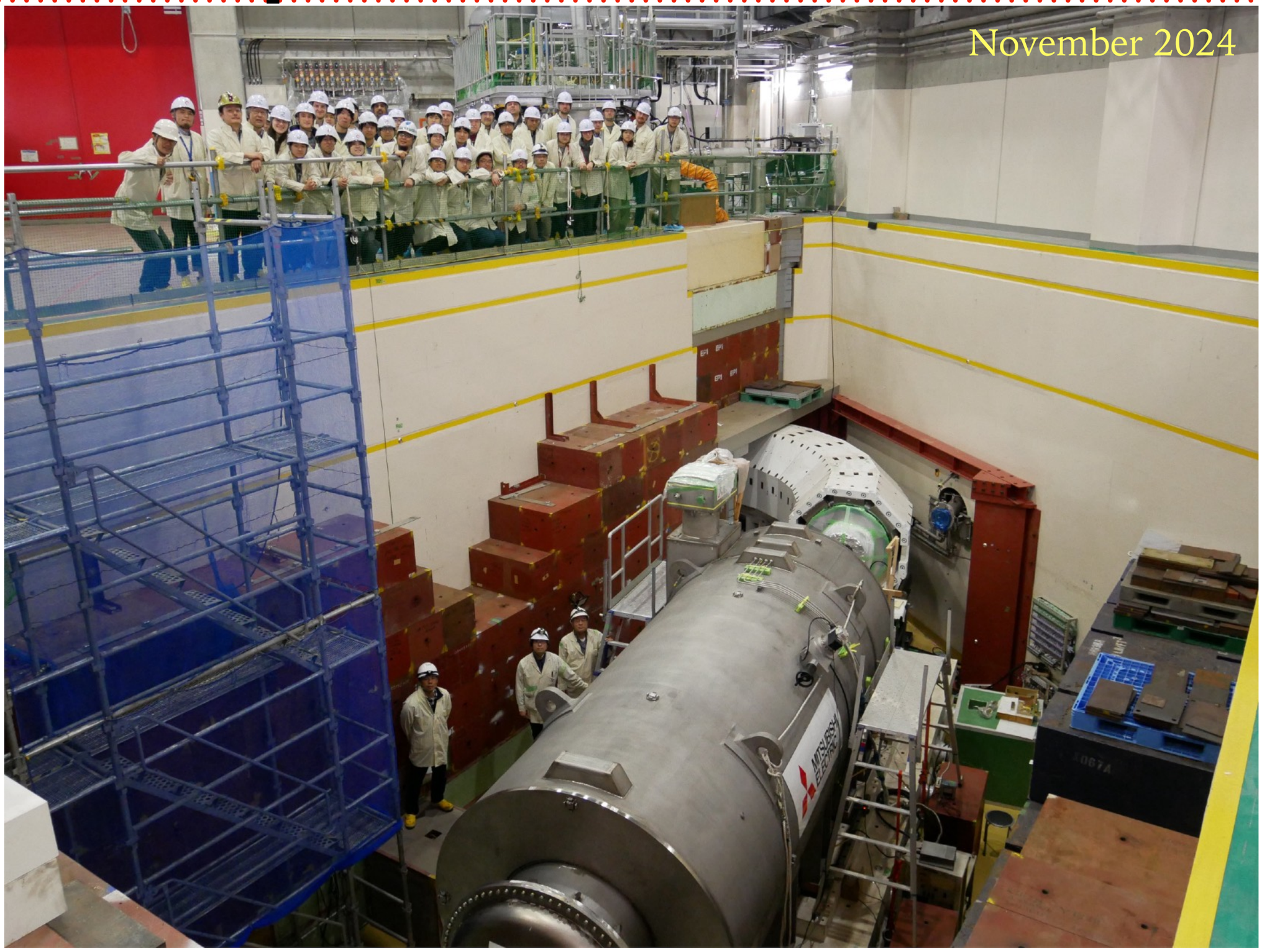
gradient magnetic field

Transport solenoid



$$D = \frac{1}{qB}\left(\frac{s}{R}\right)\frac{p_L^2 + \frac{1}{2}p_T^2}{p_L}, \qquad B_{\rm comp} = \frac{1}{qR}\frac{p_0}{2}\left(\cos\theta_0 + \frac{1}{\cos\theta_0}\right)$$

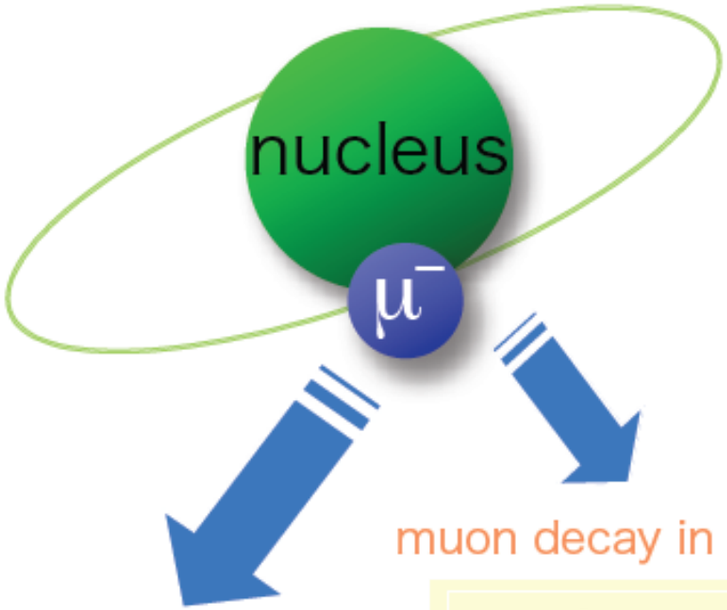
Pion Capture Solenoid



Signal and background

Fate of muonic atom

1s state in a muonic atom



muon decay in orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

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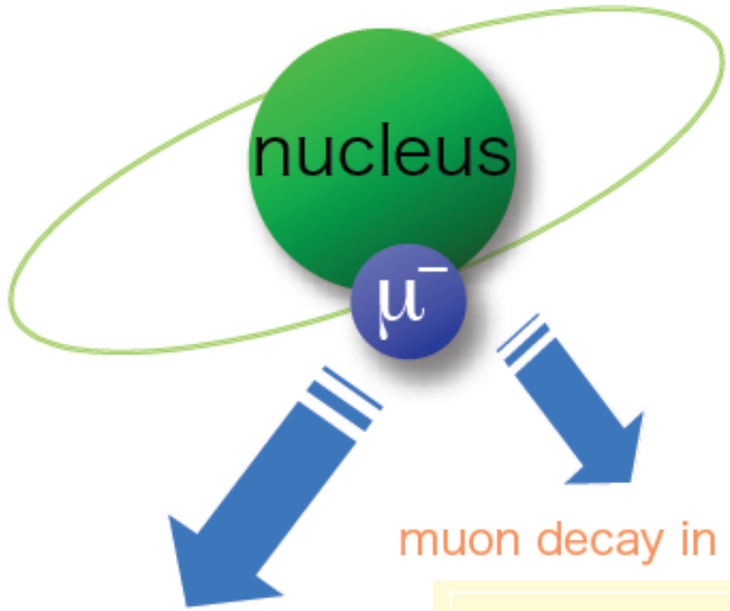

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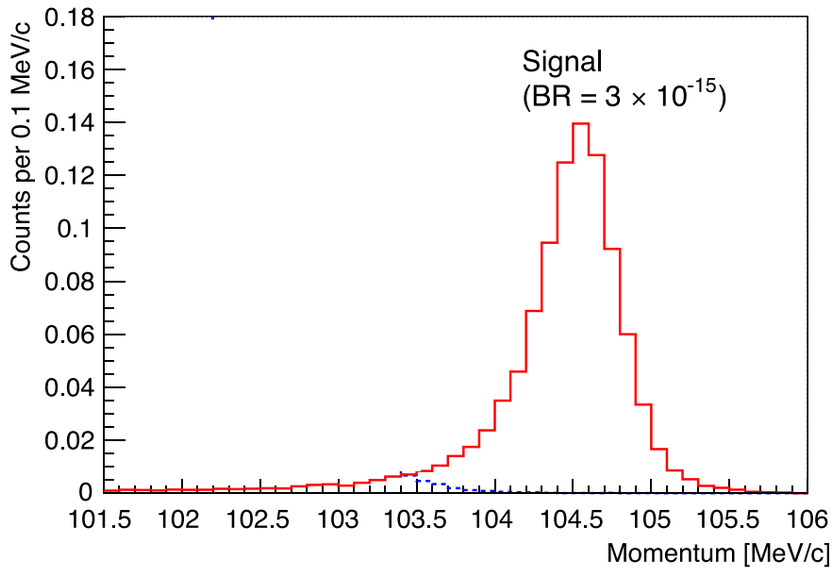
μ-e conversion signal

$$\mu^- + N \rightarrow e^- + N$$

single mono-energetic electron

$$E_{\mu e} = m_\mu - B_\mu - E_{\rm rec} = 105 \text{ MeV for Aluminum}$$



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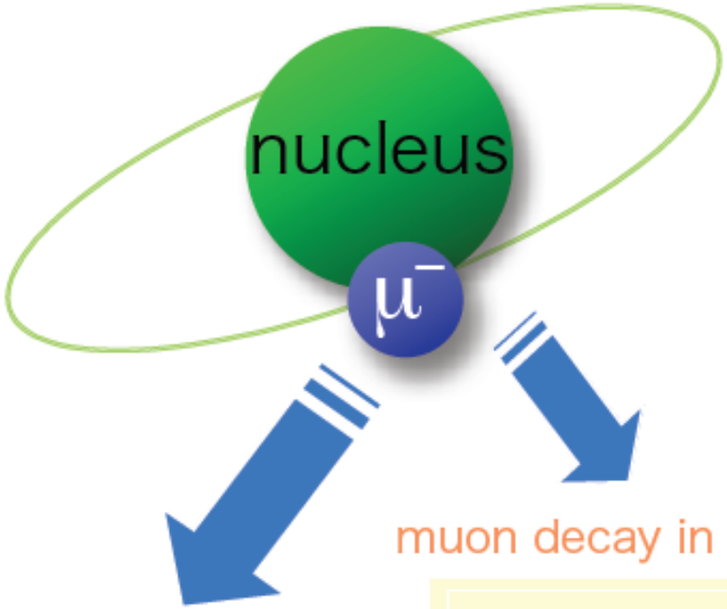

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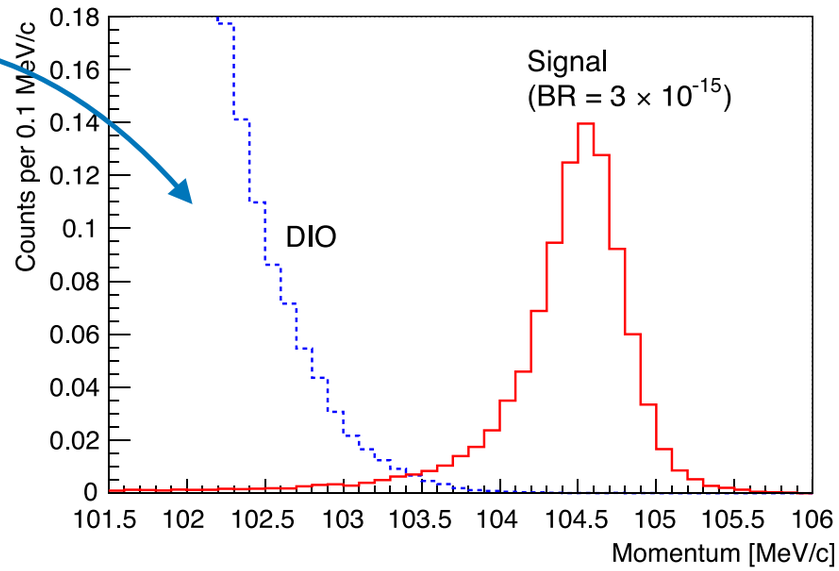


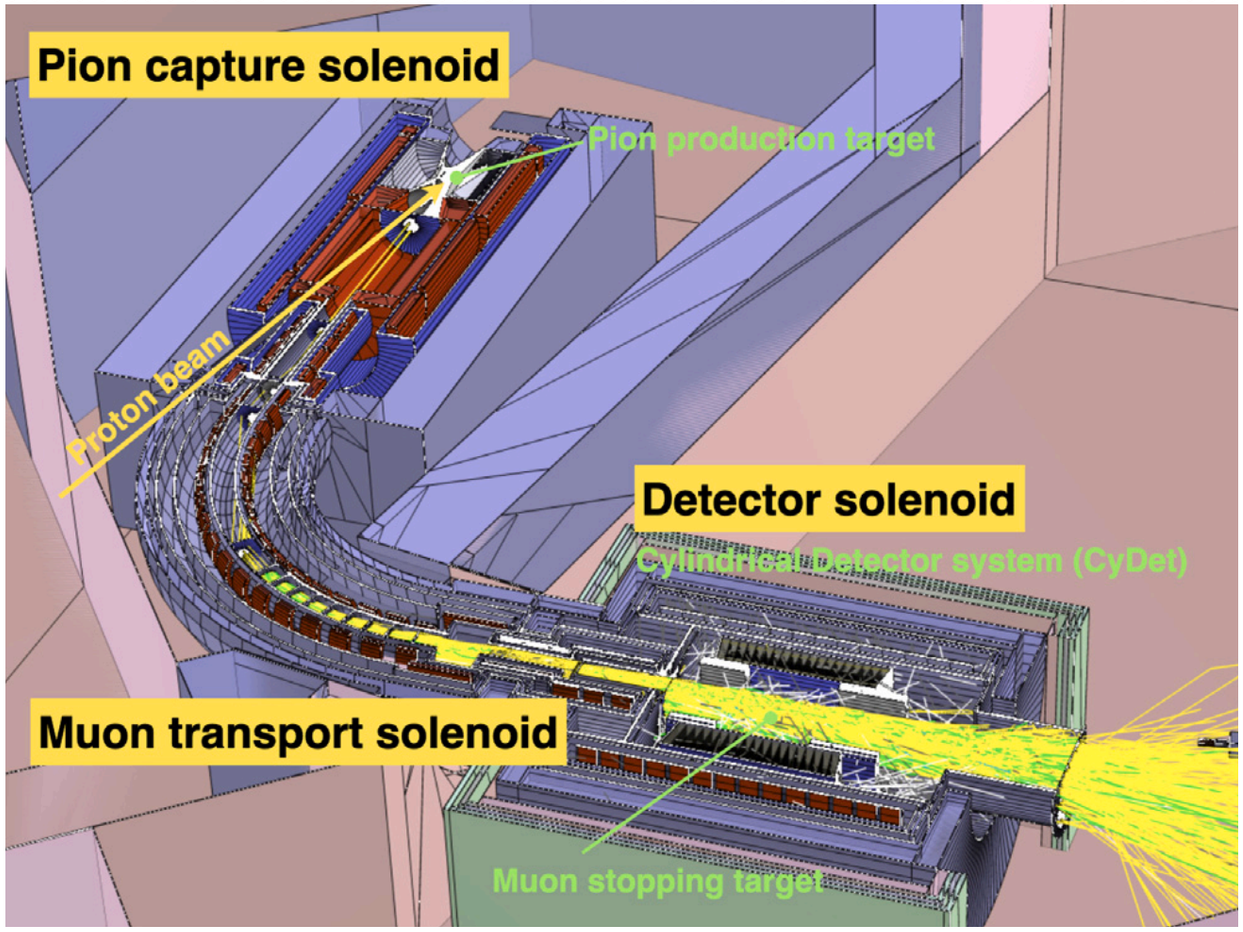
I skipped other BGs in this talk:

- Beam-related BG
- Cosmic-ray BG, etc.

Required momentum resolution

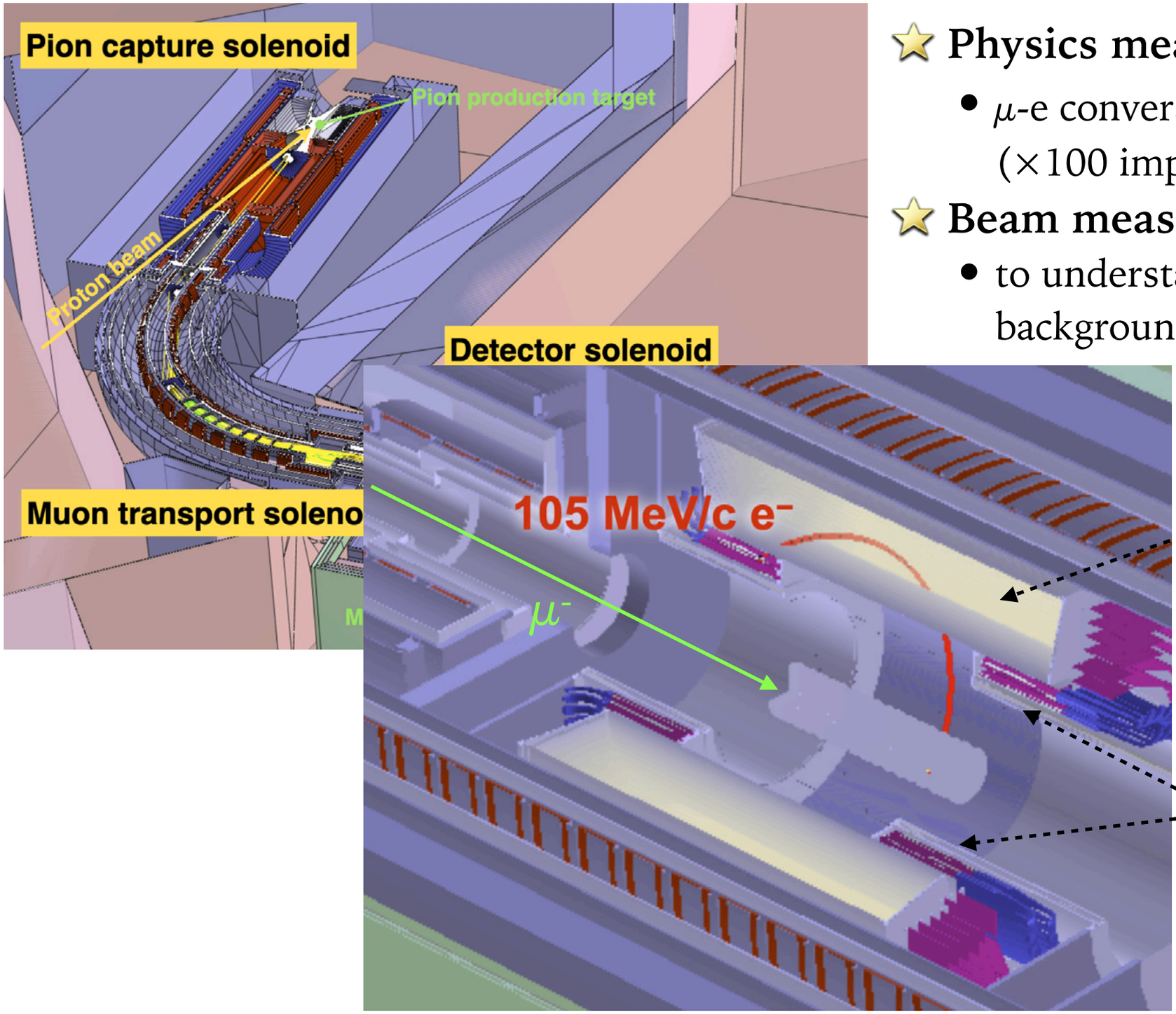
Δp < 200 keV/c for 105 MeV/c electrons

COMET Phase-I



- ☆ **Physics measurement**
  - μ-e conversion search, SES: 3×10^{-15} (×100 improve), 150 days running
- ☆ **Beam measurement**
  - to understand beam quality and background (PID, momentum, timing)

COMET Phase-I



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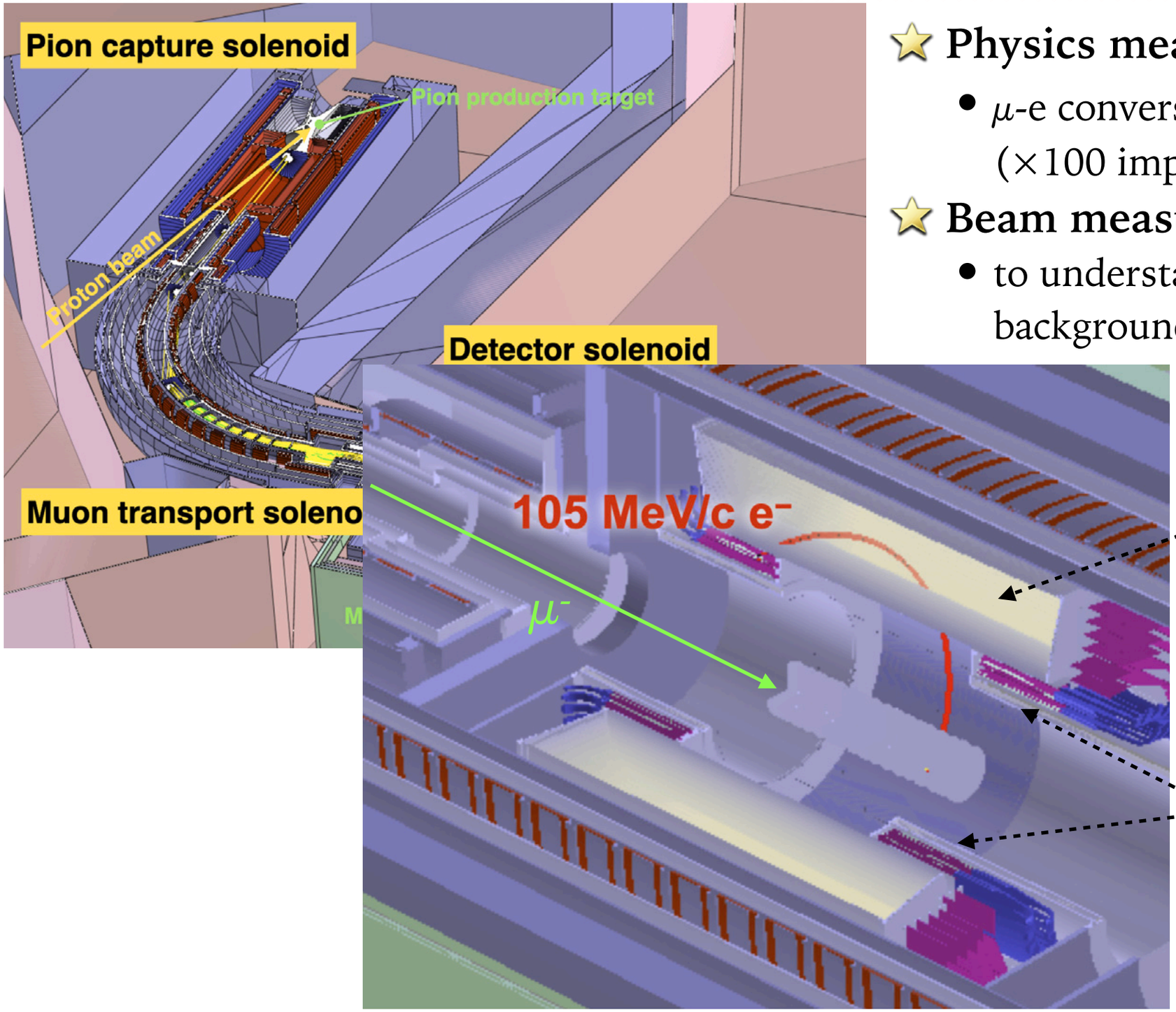
CDC

Cylindrical Drift Chamber
He:iC_4H_{10} (90:10)
All-stereo 20 layers

CTH

Cylindrical Trigger Hodoscopes
Plastic scintillator
64 segments × 2 layers × 2 ends
readout by MPPC

COMET Phase-I



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Activity in KU ①

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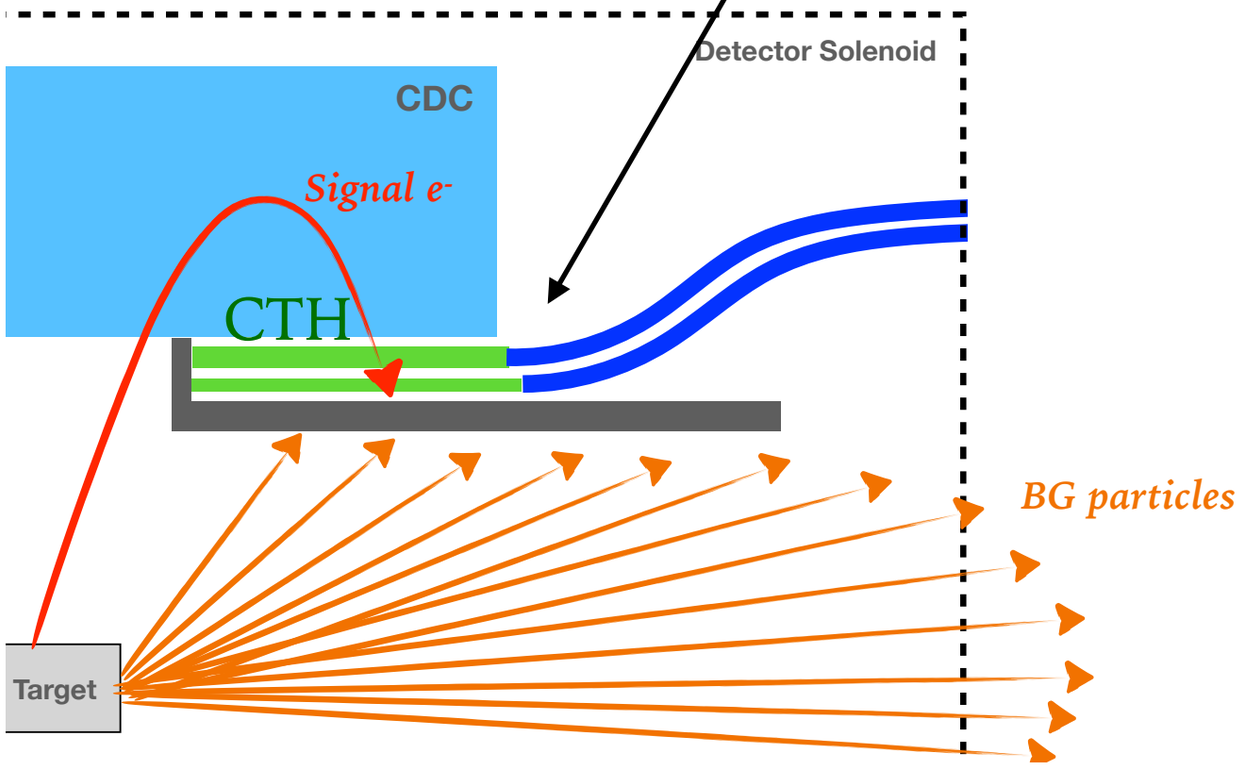
Activity in KU ①

MPPC does not work in 10^{12} $\mathbf{neutrons_{1MeV}/cm^2}$ radiation level

Conceptual design



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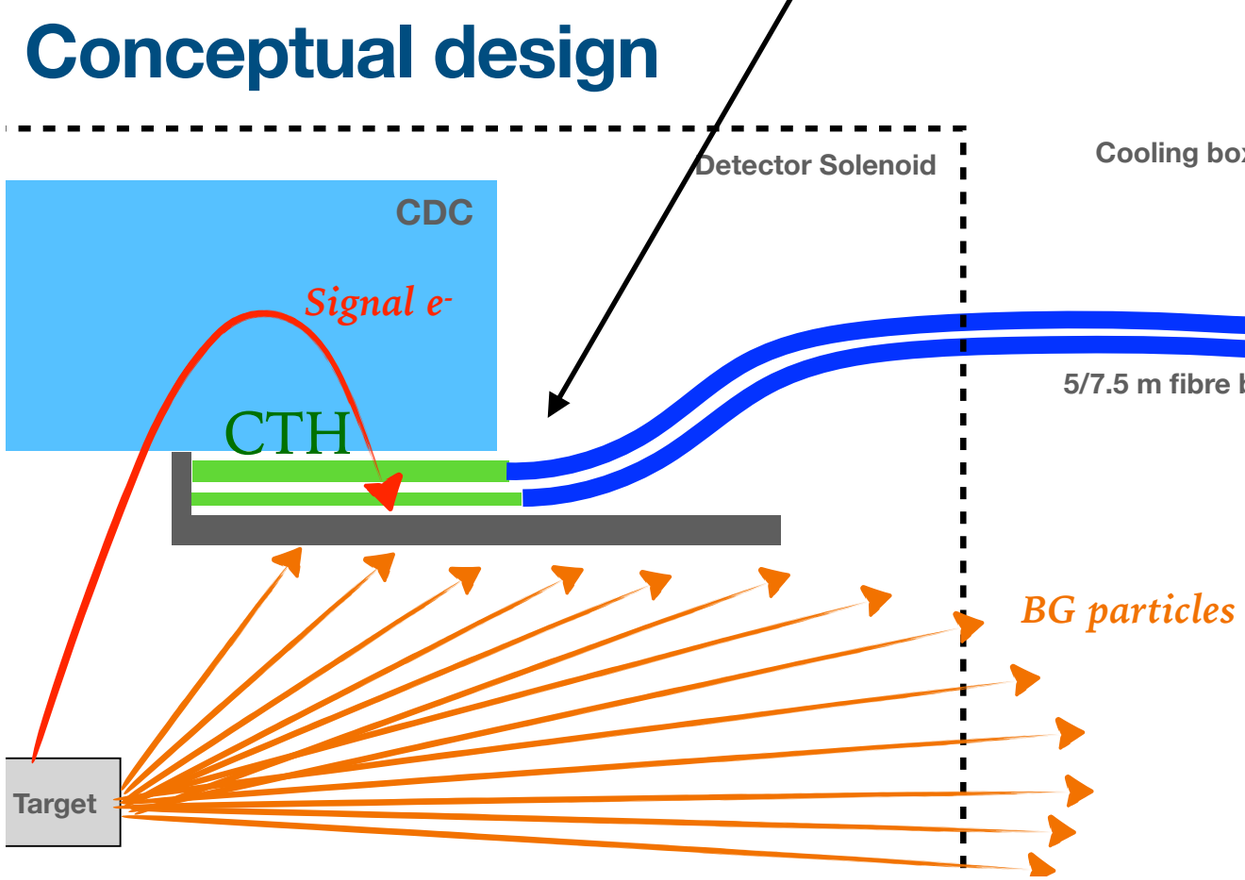
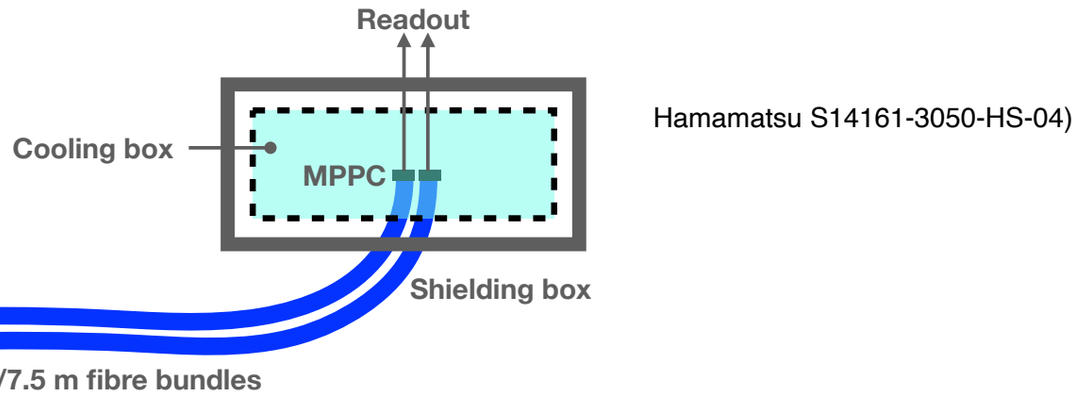




Hamamatsu S14161-3050-HS-04)

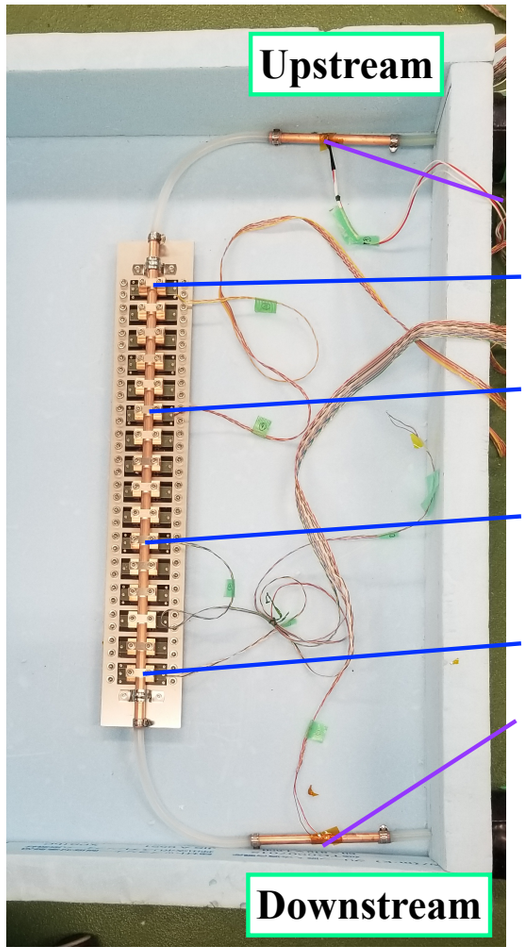
- connected through optical fibers outside the solenoid
- readout by MPPC inside a shield box
- however, neutron radiation is still high: $\mathbf{10^{10}\ n_{1MeV}/cm^2}$
- → operated with **cooling at -40◦C** to keep dark current low enough

MPPC cooling system

Activity in KU ①

by T. Mizuno (PD)

Cooling test



We flowed -40°C ethanol and measured temperature for 6 points.

-39.5℃ (Copper pipe surface)

-36.6℃ (MPPC side)

-34.2℃

-34.3℃

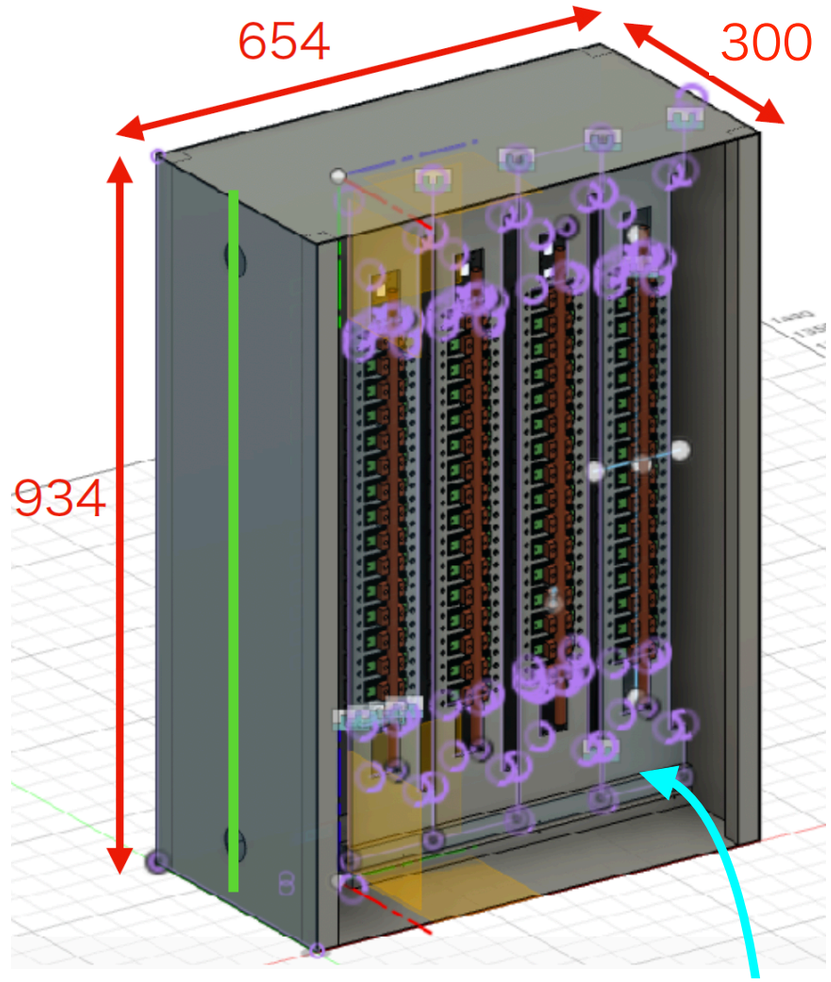
-34.7℃

-40.1℃

In the case of saddle band to fix the pipe

We could cool the board to around -34°C.

Contact between copper block and circuit board should be very tight.



Scintillator quality control

Activity in KU ①

by T. Bouillaud (PD)

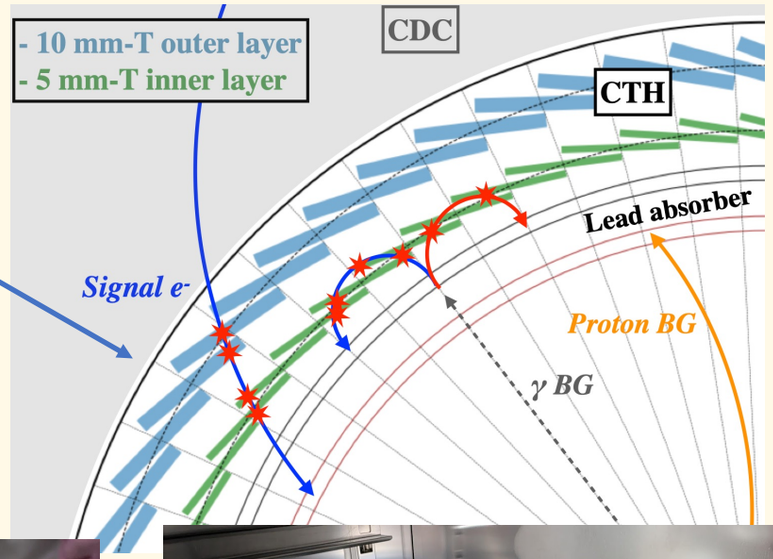
Objectives of the scintillator QC

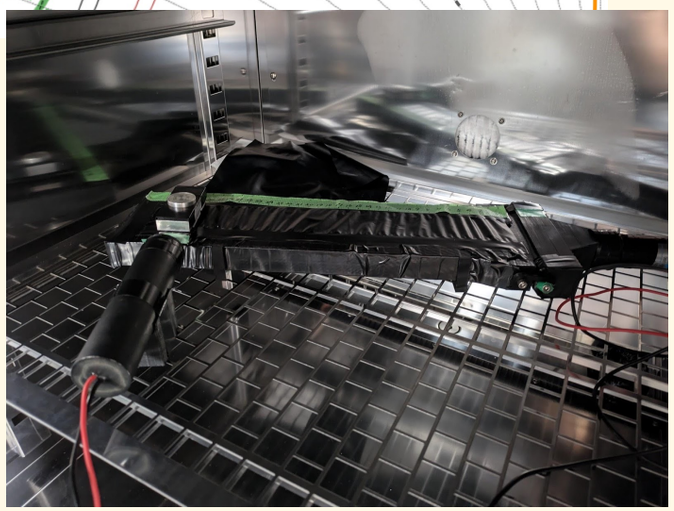
Plastic scintillator BC-408

Quality control of the 256 Scintillator Counters (SC) of the CTH is ongoing at Kyushu University.

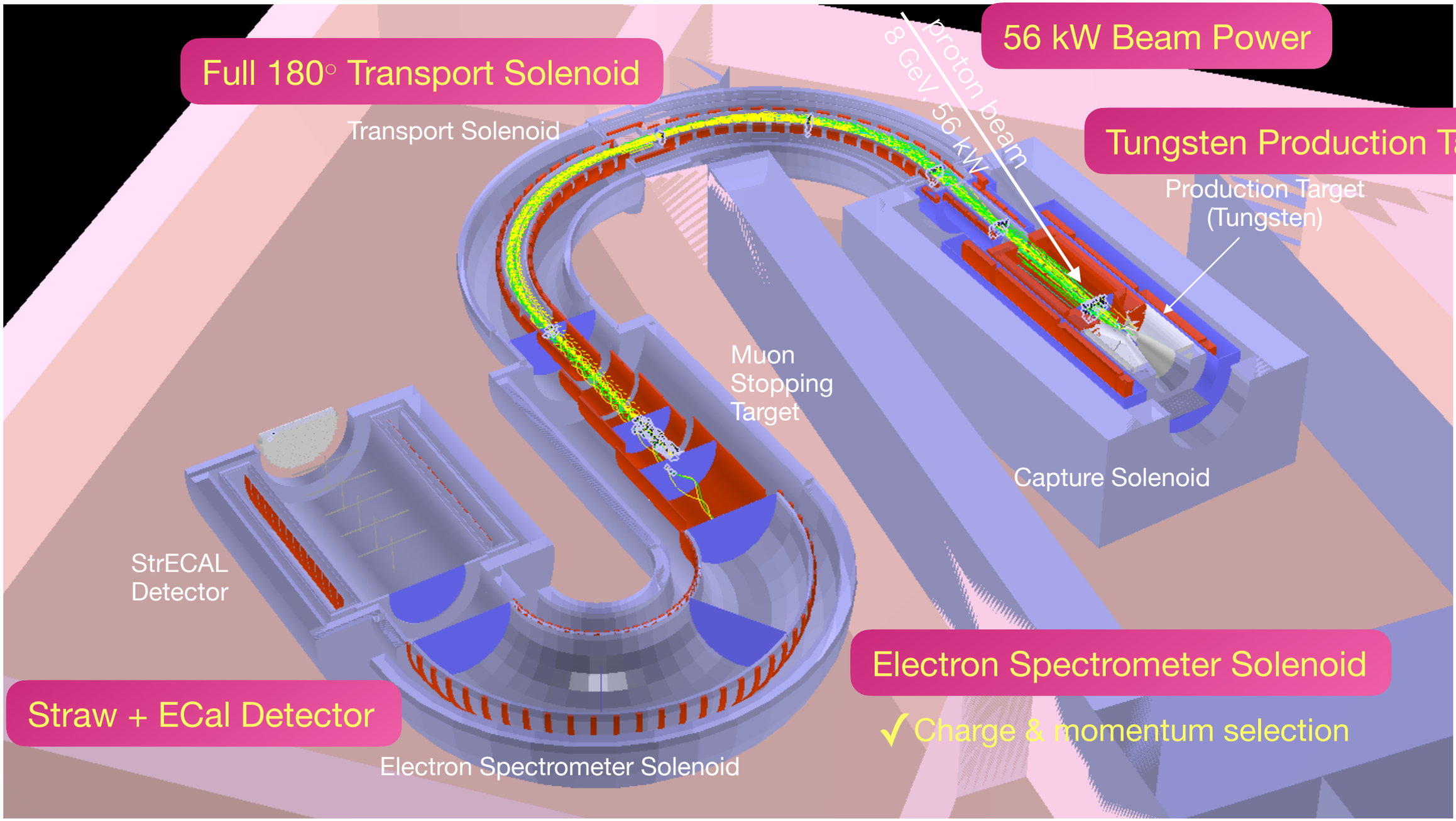
Objectives of the QC:

- Wrap the 256 scintillator counters in aluminized mylar
- Measure their **light yield** and **timing resolution**
  - To detect defective scintillators
  - To ensure the performance requirements of the CTH can be met



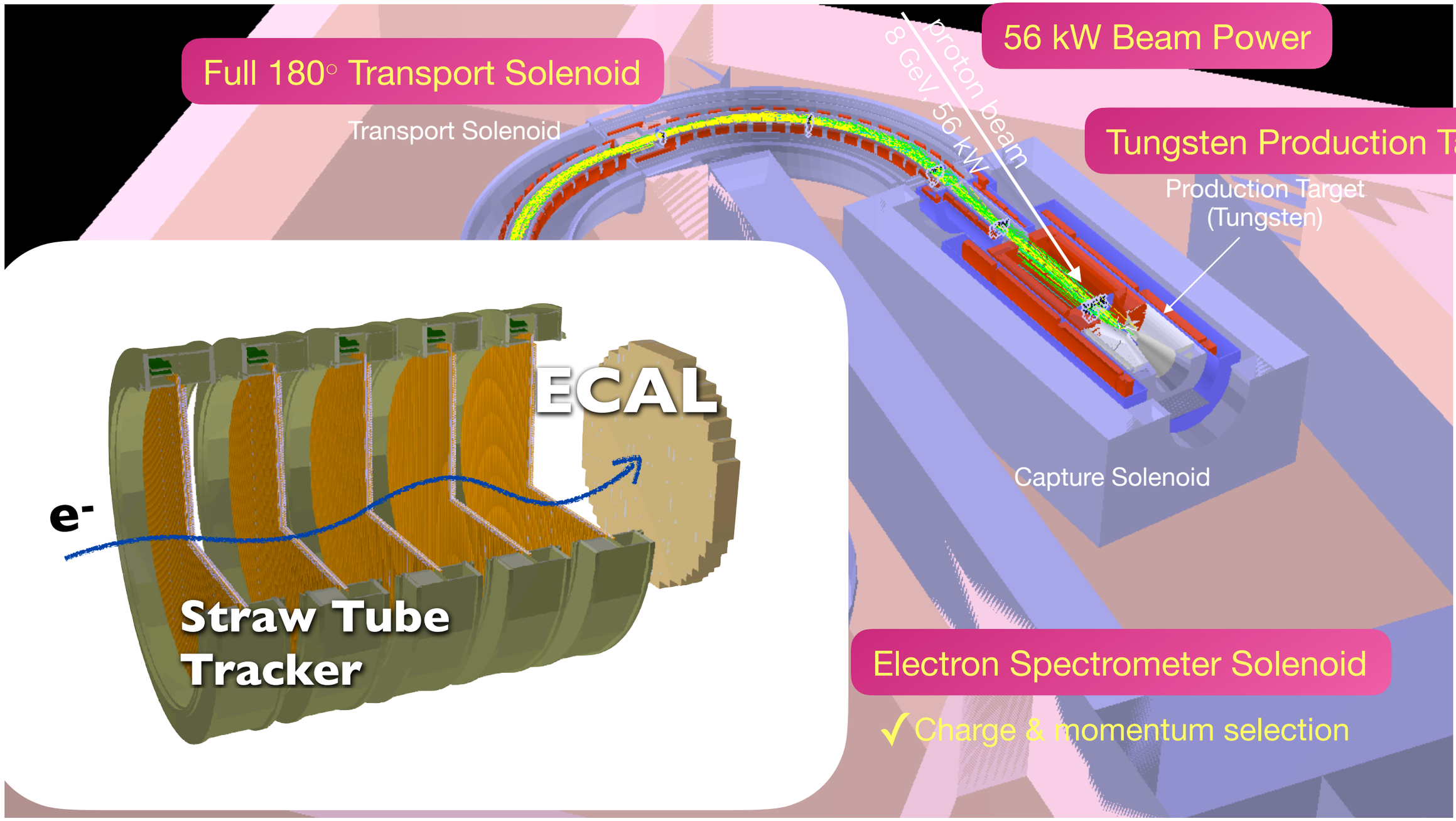


COMET Phase-II



- SES: 2×10^{-17} (×10,000 improve)
- 1 year running

COMET Phase-II



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- 1 year running

COMET Phase-II

Full 180° Transport Solenoid

Transport Solenoid

56 kW Beam Power

proton beam
8 GeV, 56 kW

Tungsten Production Target

Production Target
(Tungsten)

Capture Solenoid

ECAL

e-

Straw Tube
Tracker

Activity in KU ②

Electron Spectrometer Solenoid

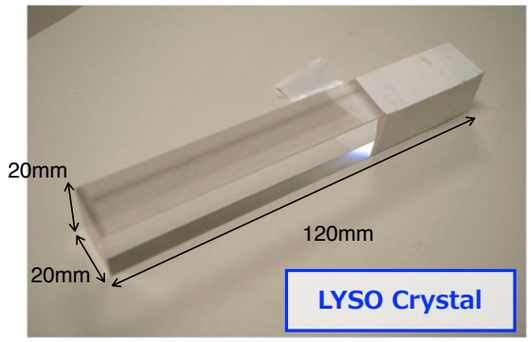
✓Charge & momentum selection

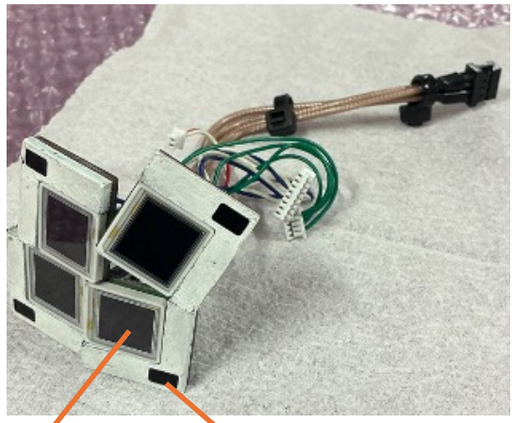
- SES: 2×10^{-17} (×10,000 improve)
- 1 year running

Electron Calorimeter (ECAL)

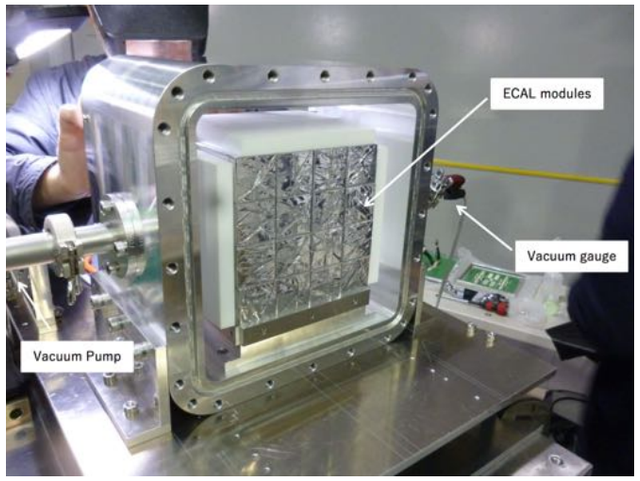
Activity in KU ②

- Measure energy, timing & position
  - $\Delta E/E < 5\%$ for 105 MeV
  - $\Delta t < 1$ ns
  - $\Delta x = \Delta y < 10$ mm
- Provide trigger signal
- LYSO ($Lu_{2(1-x)}Y_{2x}SiO_5$)
  - ~500(2000) crystals in Phase-I(II)
  - 2×2×12 cm (10.5 radiation length)
- APD: HPK S8664-1010

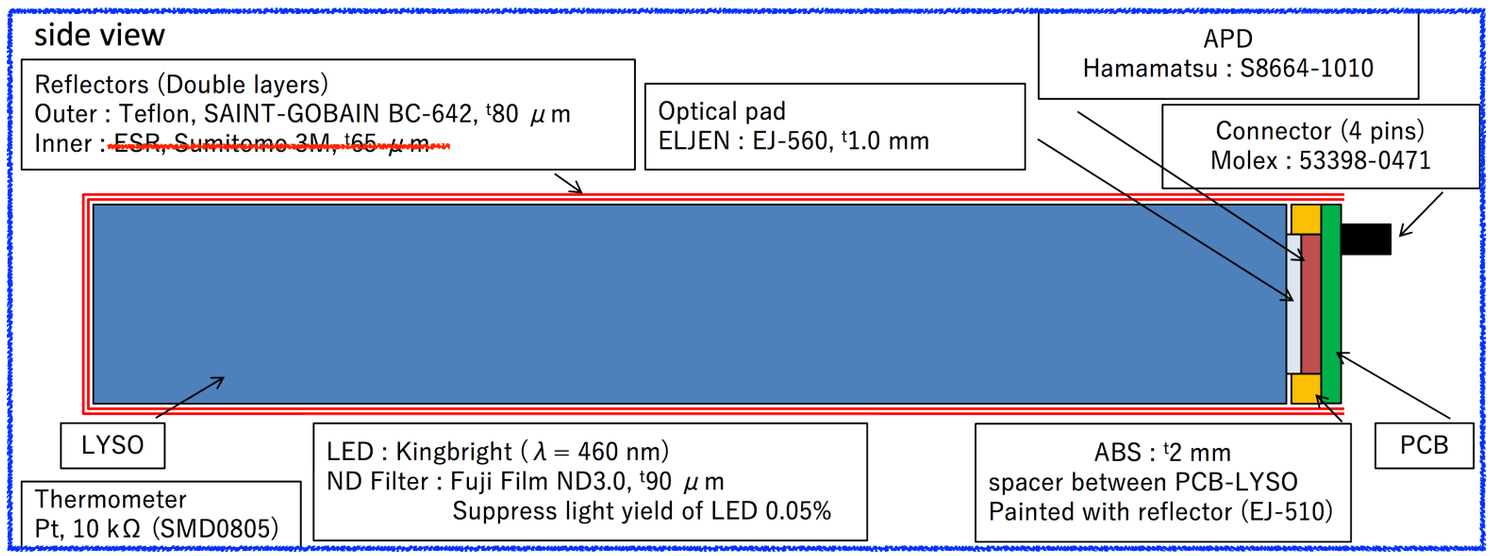


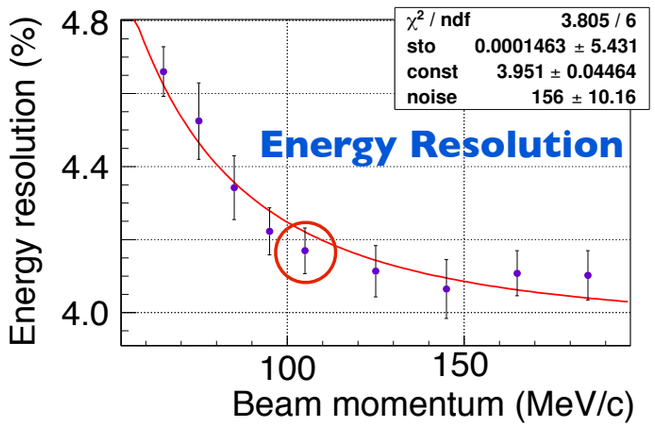


ECAL prototype



Module structure





Good performance has been achieved in a prototype test.

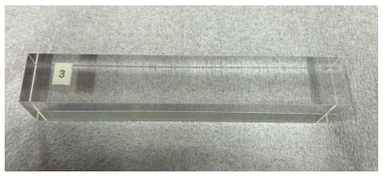
Wrapping & APD quality control

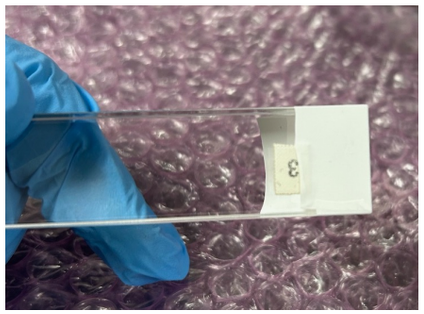
Activity in KU ②

by D. Yoshikawa (M2)

A crystal is wrapped with double layers of PTEF

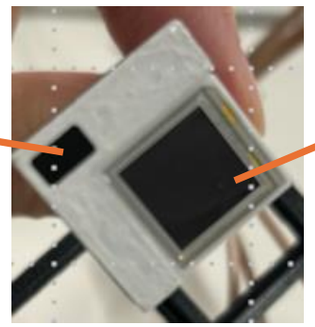
[PTEF]



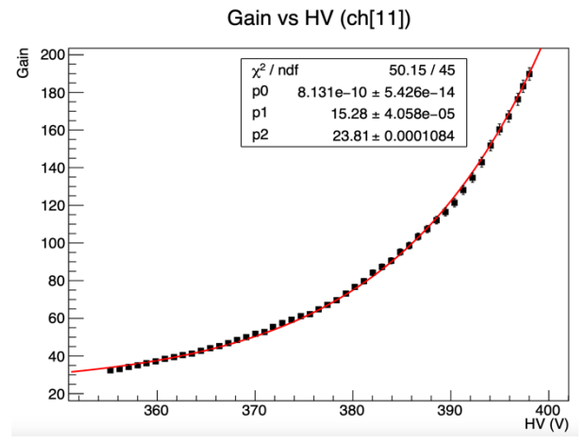


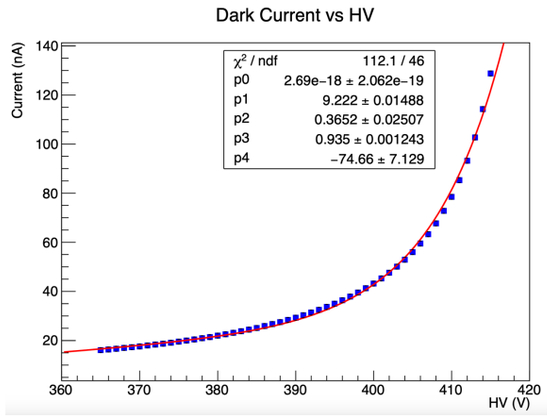
Combination of wrapping materials is studied

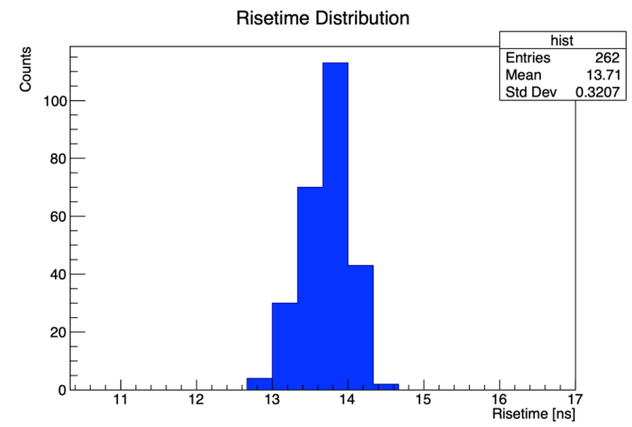
APD QC method has been established



APD: HPK S8664-1010





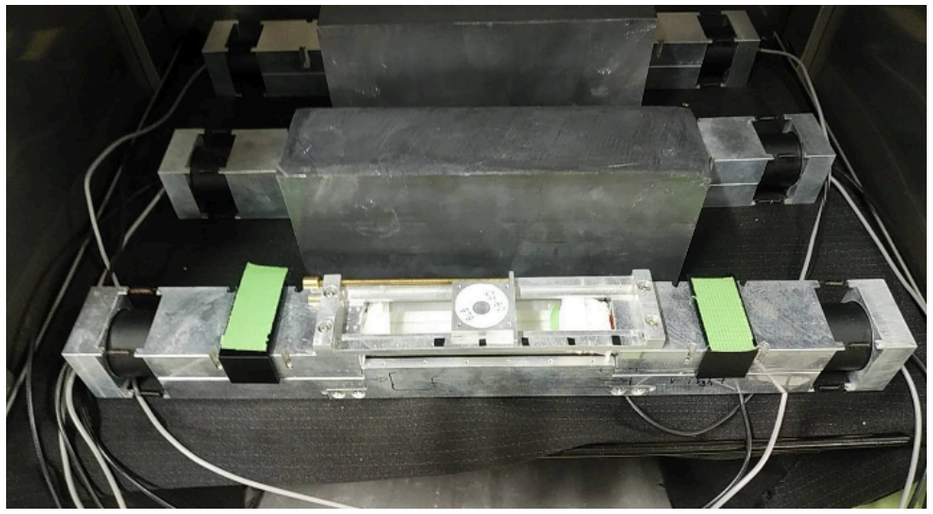


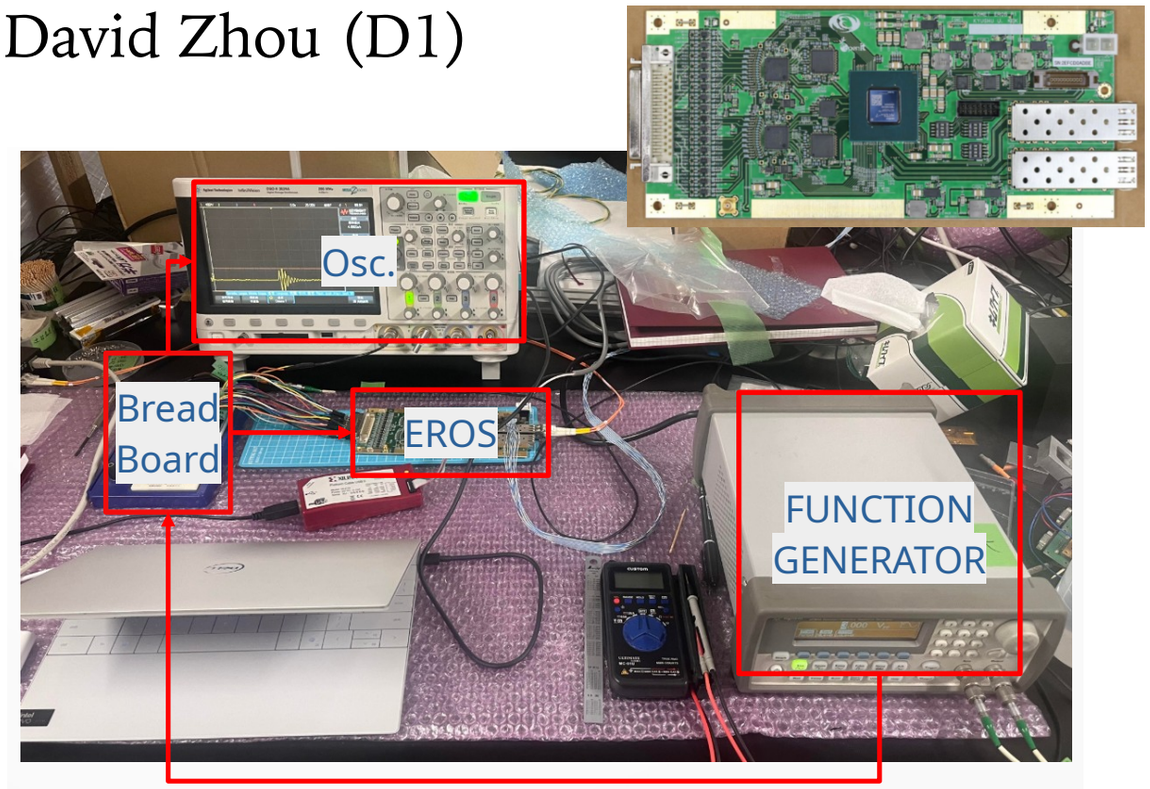
Almost ready for construction

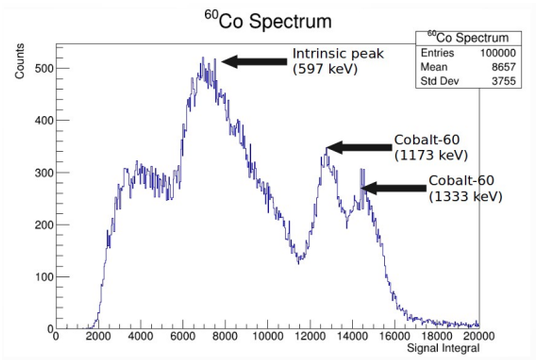
Crystal & Electronics quality control

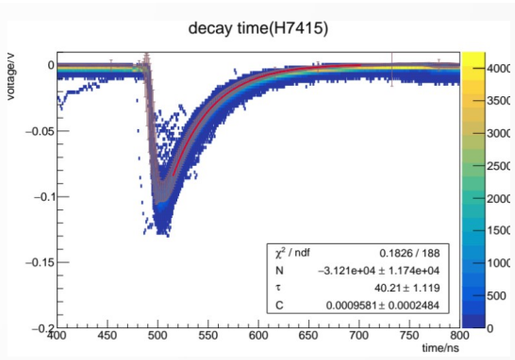
Activity in KU ②

by David Zhou (D1)



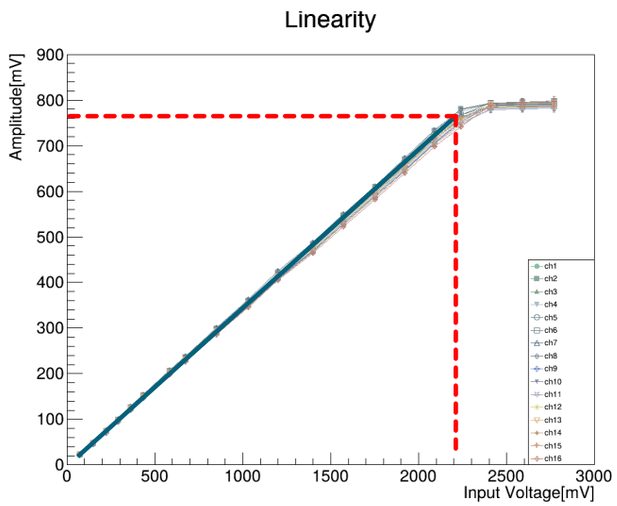


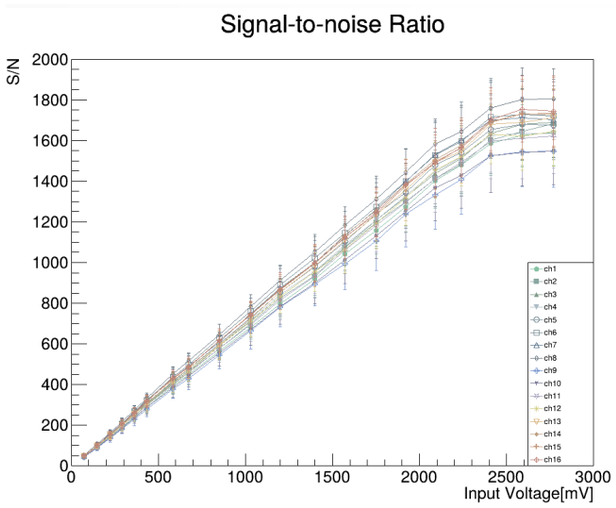




Evaluation Items:

1. Light Yield (1173keV peak of ^{60}Co)
2. Decay Time (Fitting of the average waveform)
3. Energy Resolution (σ/x of the 1173keV peak)
4. Position Dependency ((Max-Min)/Mean of the light yield in 5 measurements)



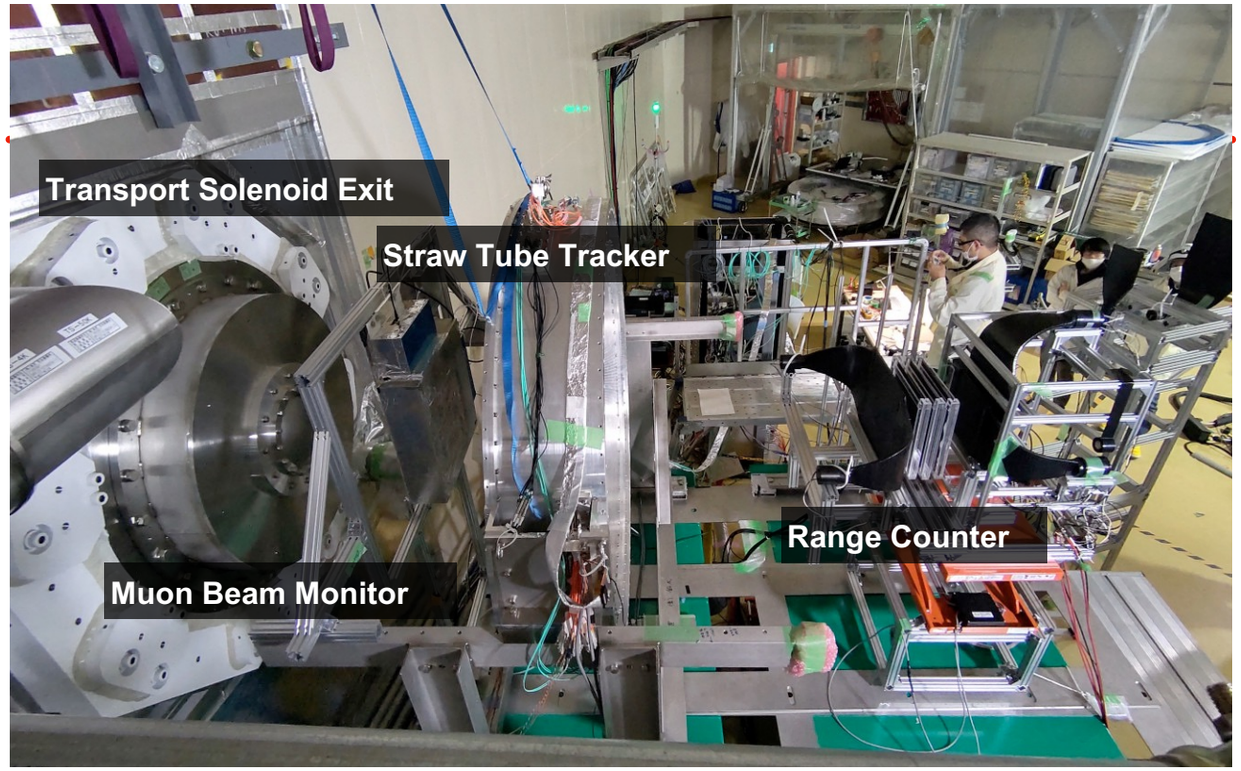


QC of 48 boards has been completed

Phase-α

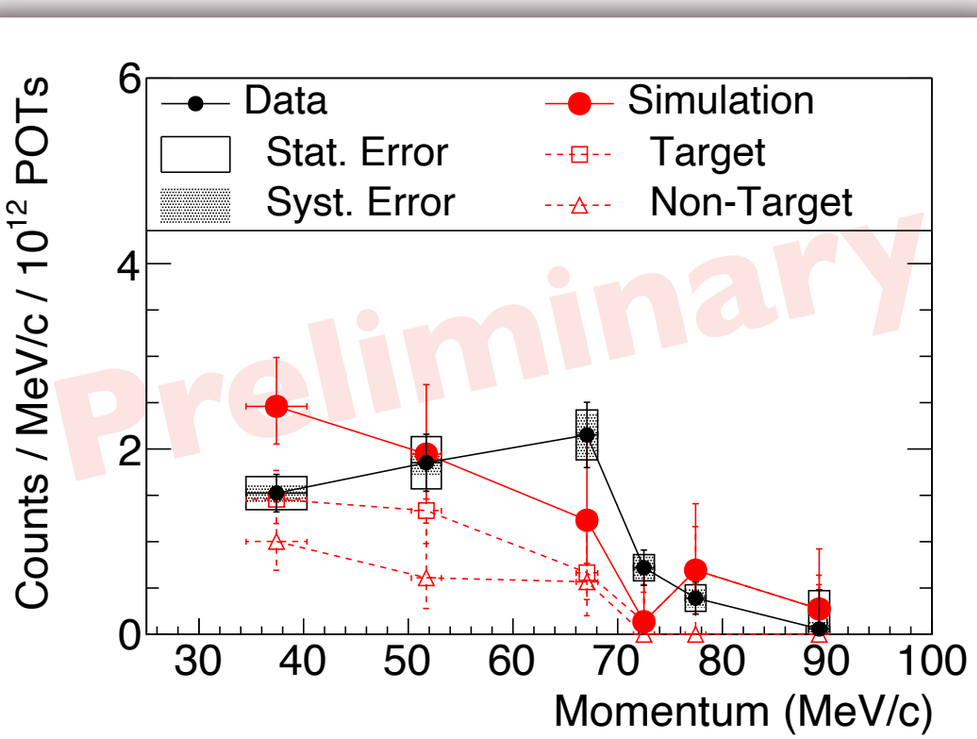
The **1st commissioning** in 2023 for

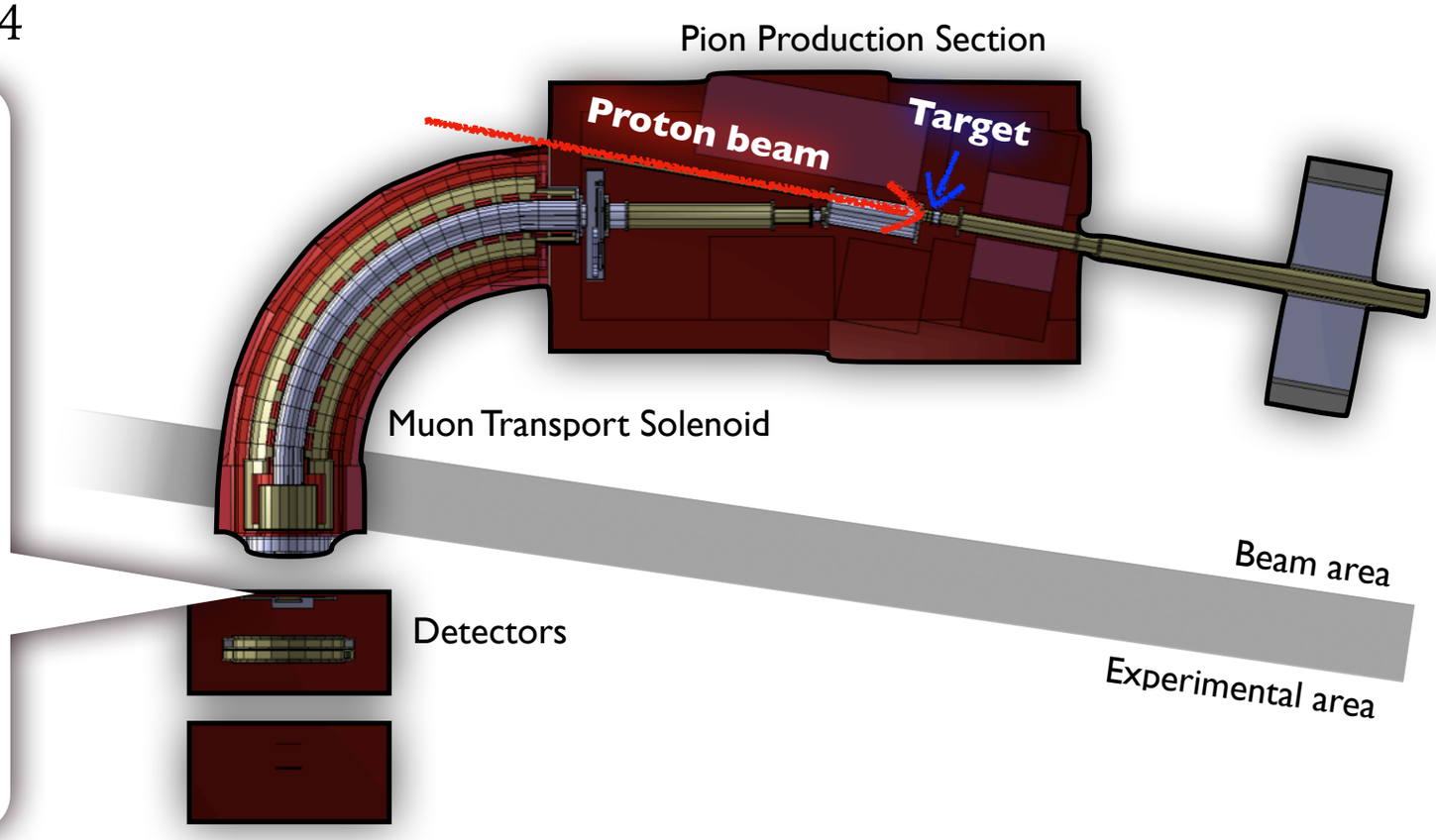
- COMET proton beam line
- Muon Transport Solenoid
- (w/o Pion Capture Solenoid)



Observed muon yields are consistent with simulation (preliminary).

K. Oishi, J-PARC Symposium 2024





Summary

- COMET searches for muon-to-electron conversion with sensitivity of 100× (10,000×) better than the current limit in Phase-I (II).
  - Pion Capture Solenoid has been completed recently!
- KU has been playing a key role in the development of CTH & ECAL. → move on to construction stage
- Phase-I will start in JFY2026. Stay tuned!