

14th International Workshop
on e^+e^- collisions from Phi to Psi 2026

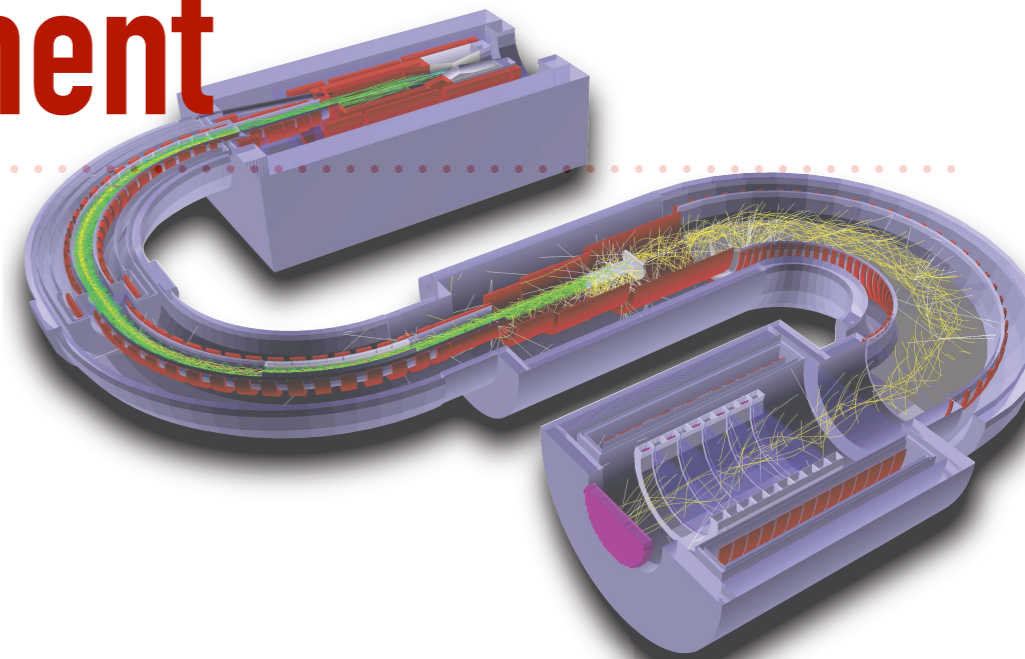
Phipsi26

8-11 June 2026, Pisa, Italy



Search for charged lepton flavor violation with the COMET experiment

Manabu MORITSU (NIT, Akashi)
on behalf of the COMET Collaboration



14th International Workshop on e^+e^- collisions from Phi to Psi 2026 (PhiPsi26)
8—11 Jun. 2026, Scuola Normale Superiore, Pisa, Italy

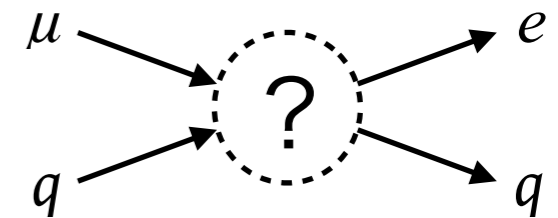
Contents

- ▶ Overview of the COMET experiment
- ▶ Accelerator & Beam
- ▶ Muon Source
- ▶ COMET Strategy
- ▶ Magnets & Detectors
- ▶ Beam Commissioning
- ▶ Schedule

μ -e conversion & COMET

▶ Muon-to-electron conversion:

- ▶ Neutrinoless coherent transition in a nuclear field
- ▶ Violates the Lepton Flavor conservation
- ▶ Search for NEW physics beyond the Standard Model

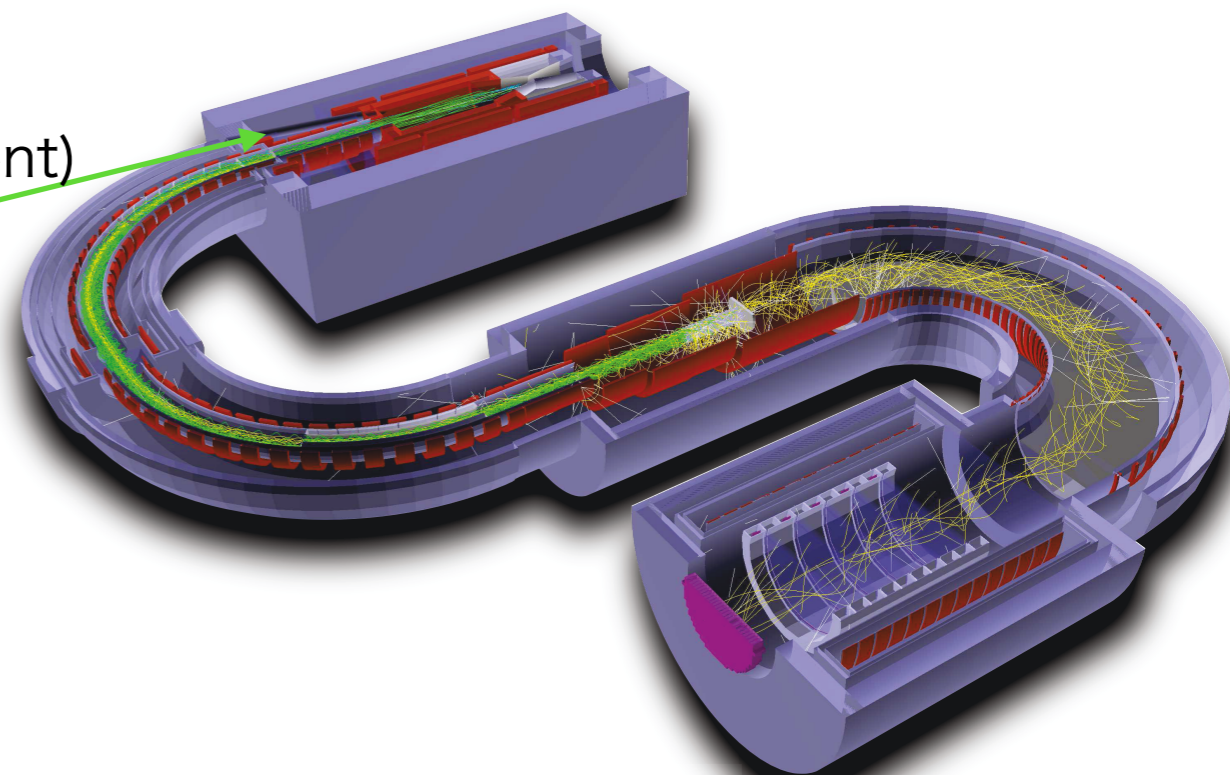


▶ The COMET experiment:

- ▶ Explores μ -e conversion at **J-PARC** with the single event sensitivity of
 - ▶ Phase-I: 3×10^{-15} ($\times 100$ improvement)
 - ▶ Phase-II: 2×10^{-17} ($\times 10,000$ improvement)



8 GeV proton beam



Technical Design Report

PTEP 2020, 033C01

μ -e conversion & COMET

- ▶ Muon-to-electron conversion:
 - ▶ Neutrinoless coherent transition in a
 - ▶ Violates the Lepton Flavor conservat
 - ▶ Search for NEW physics beyond the
- ▶ The COMET experiment:

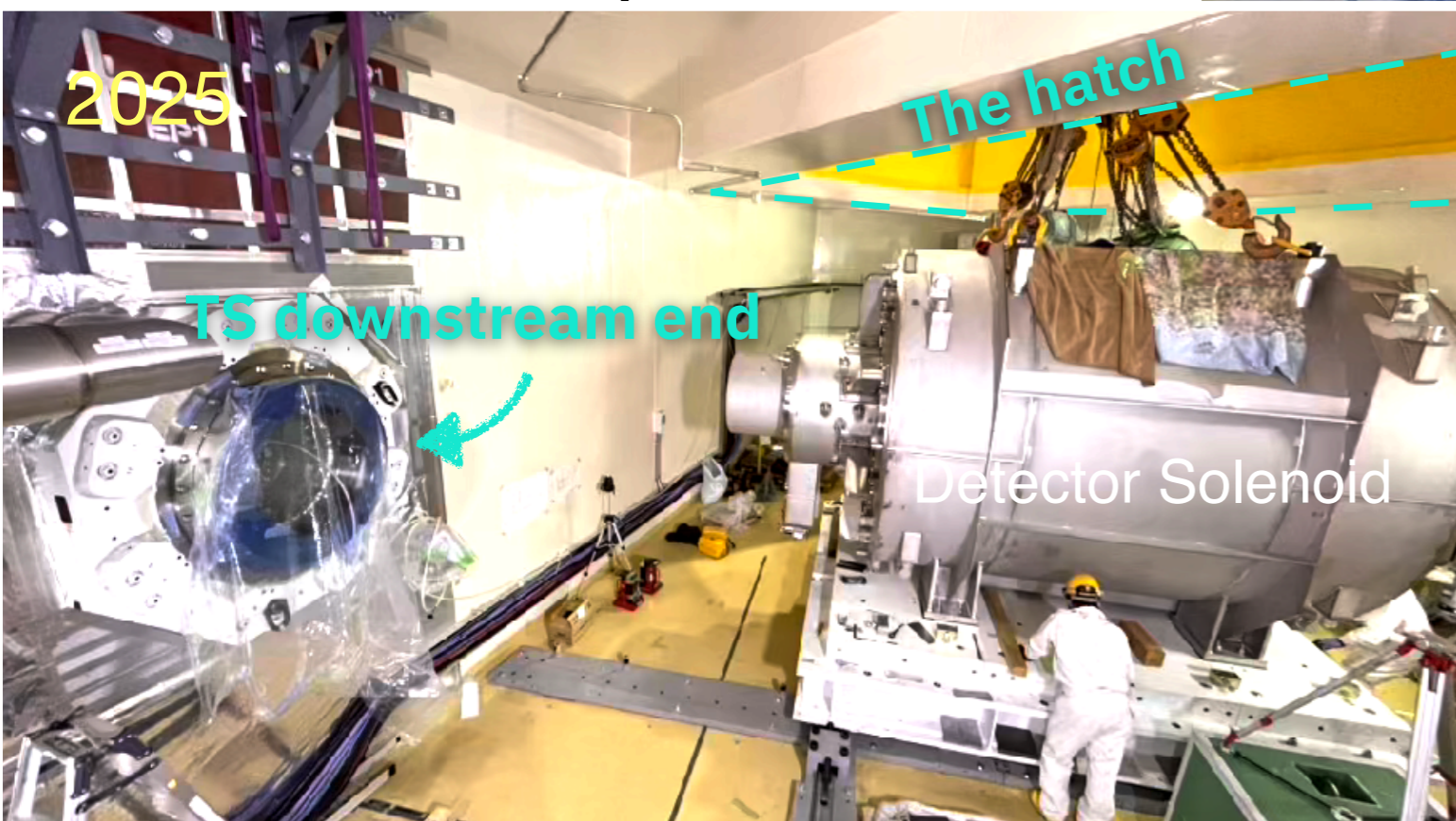


Muon Transport Solenoid

Pion Capture Solenoid

Nov. 2024

Photo taken at 44th Collaboration Meeting



2025

The hatch

TS downstream end

Detector Solenoid



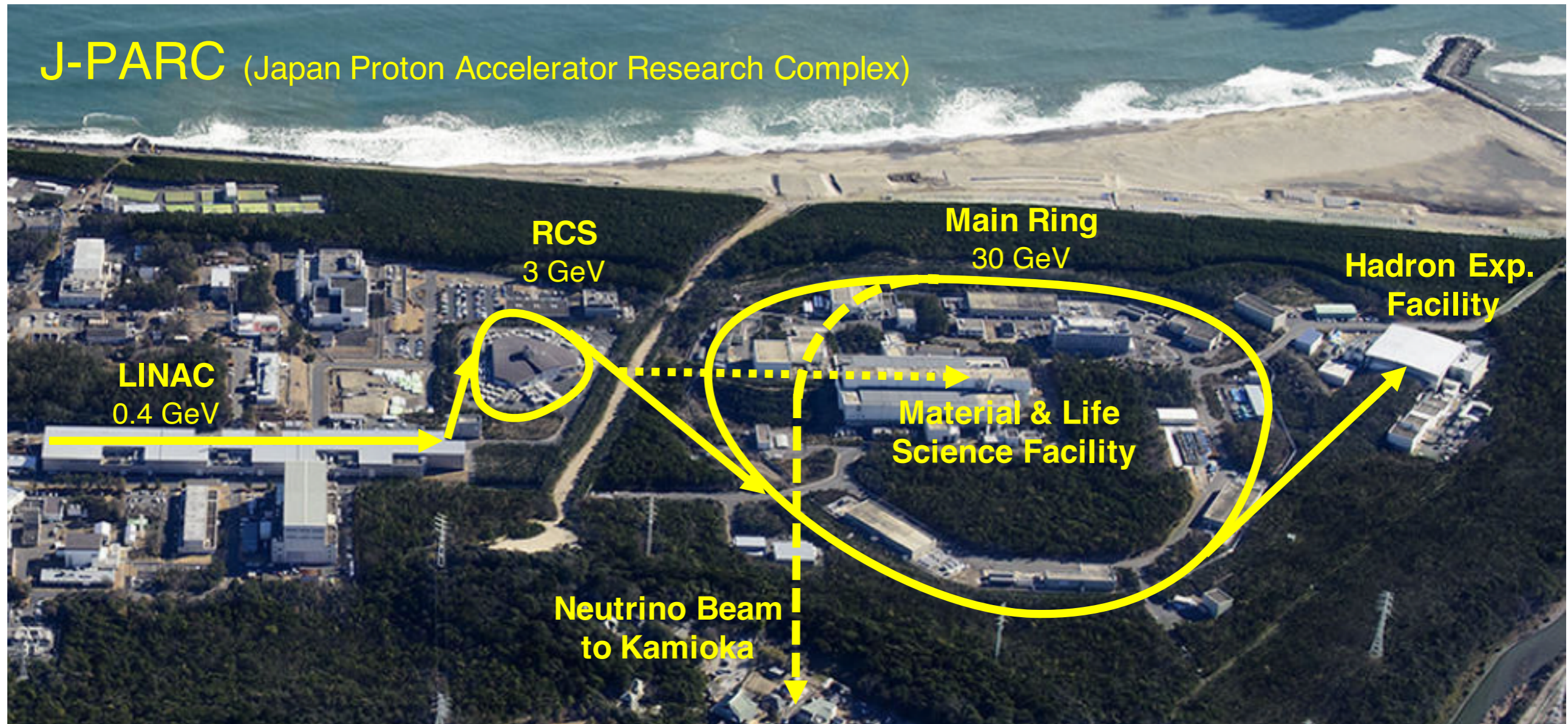
Accelerator & Beam

J-PARC

J-PARC (Japan Proton Accelerator Research Complex)

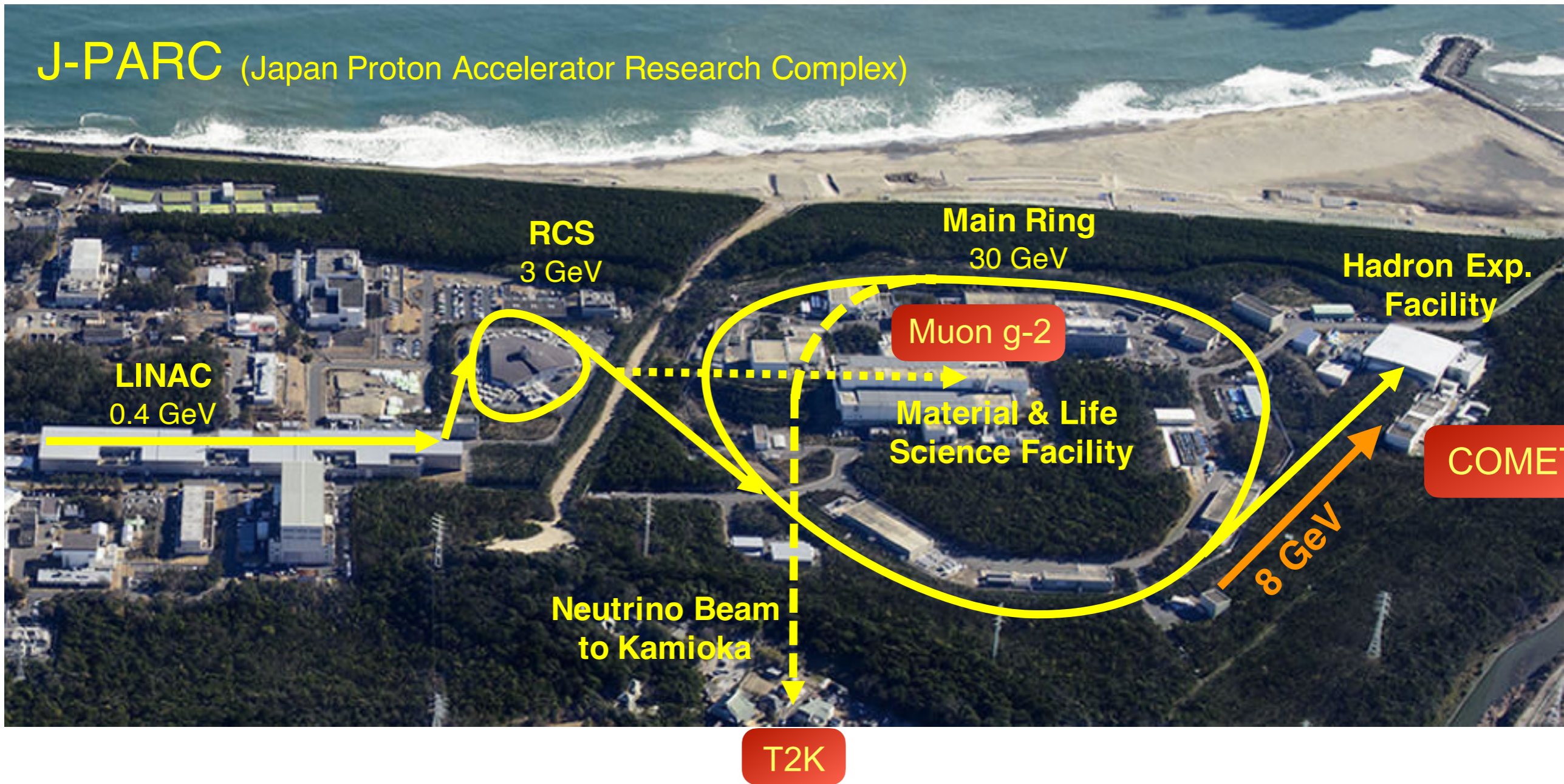


J-PARC

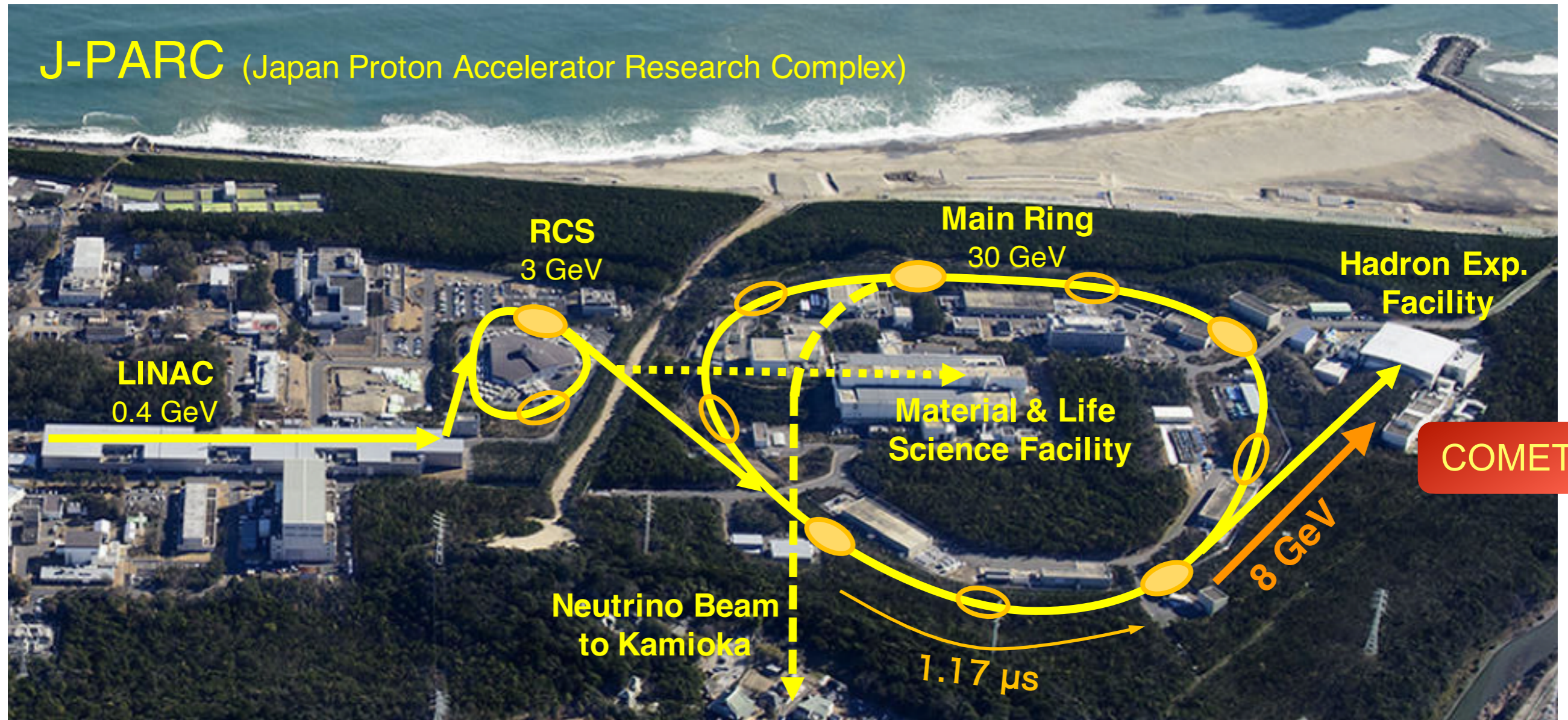


J-PARC MR provides a proton beam of normally 30 GeV, or 8 GeV for COMET.

J-PARC

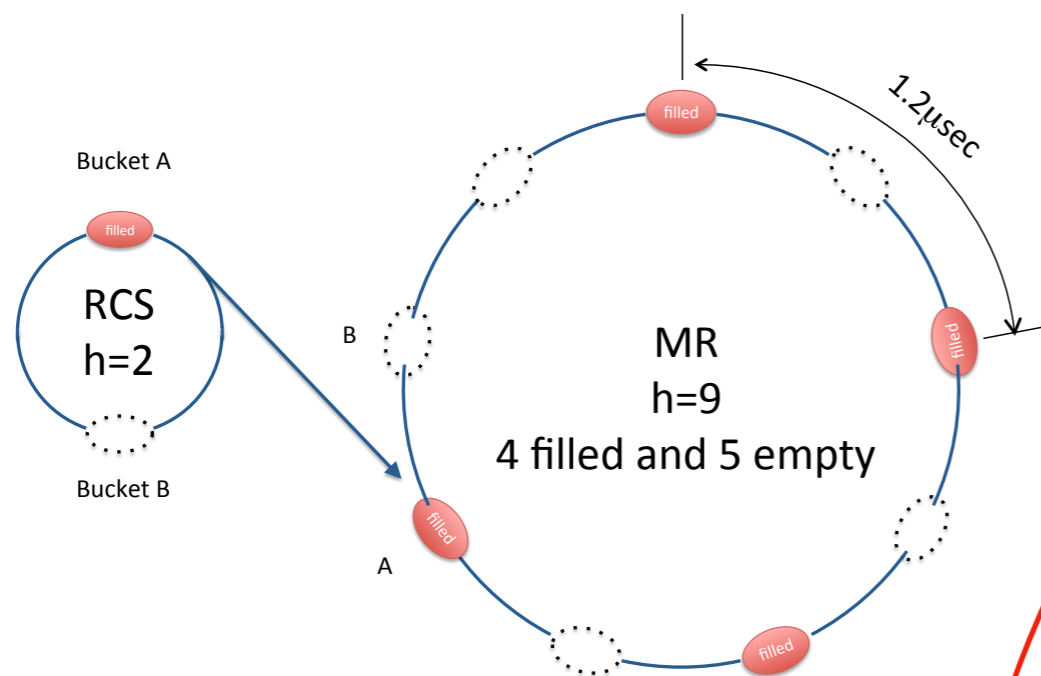


J-PARC



COMET requires a specialized beam operation.
 Only 4 of 9 bunches of MR are filled to realize a $\sim 1 \mu\text{s}$ interval.

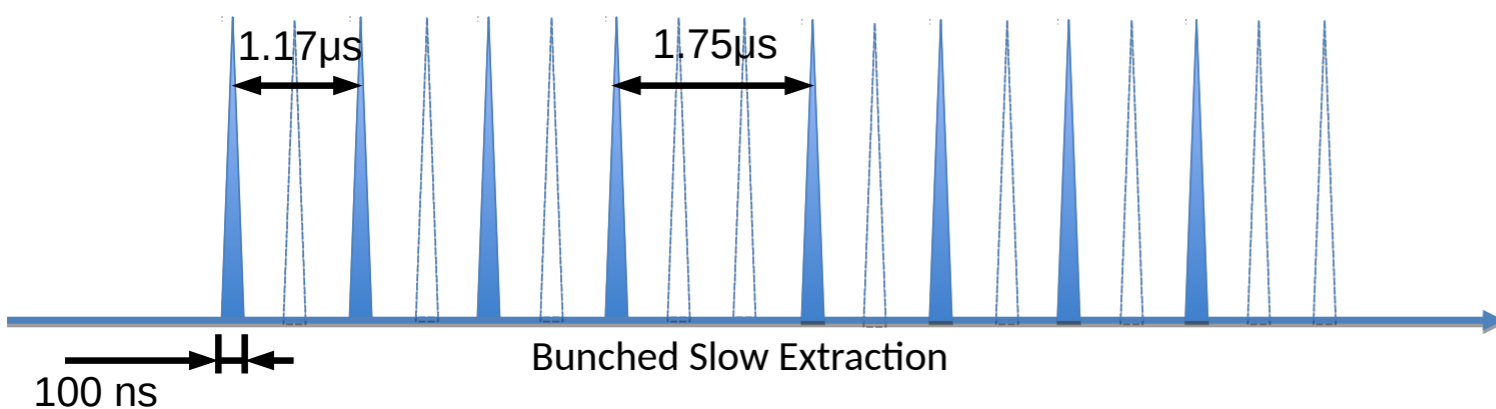
Proton beam for COMET



✓ Extinction factor $< 10^{-10}$

$$R_{\text{ext}} = \frac{\# \text{ of protons in between pulses}}{\# \text{ of protons in pulses}}$$

Leaked protons are dangerous to make BG in the timing window (see next page.)

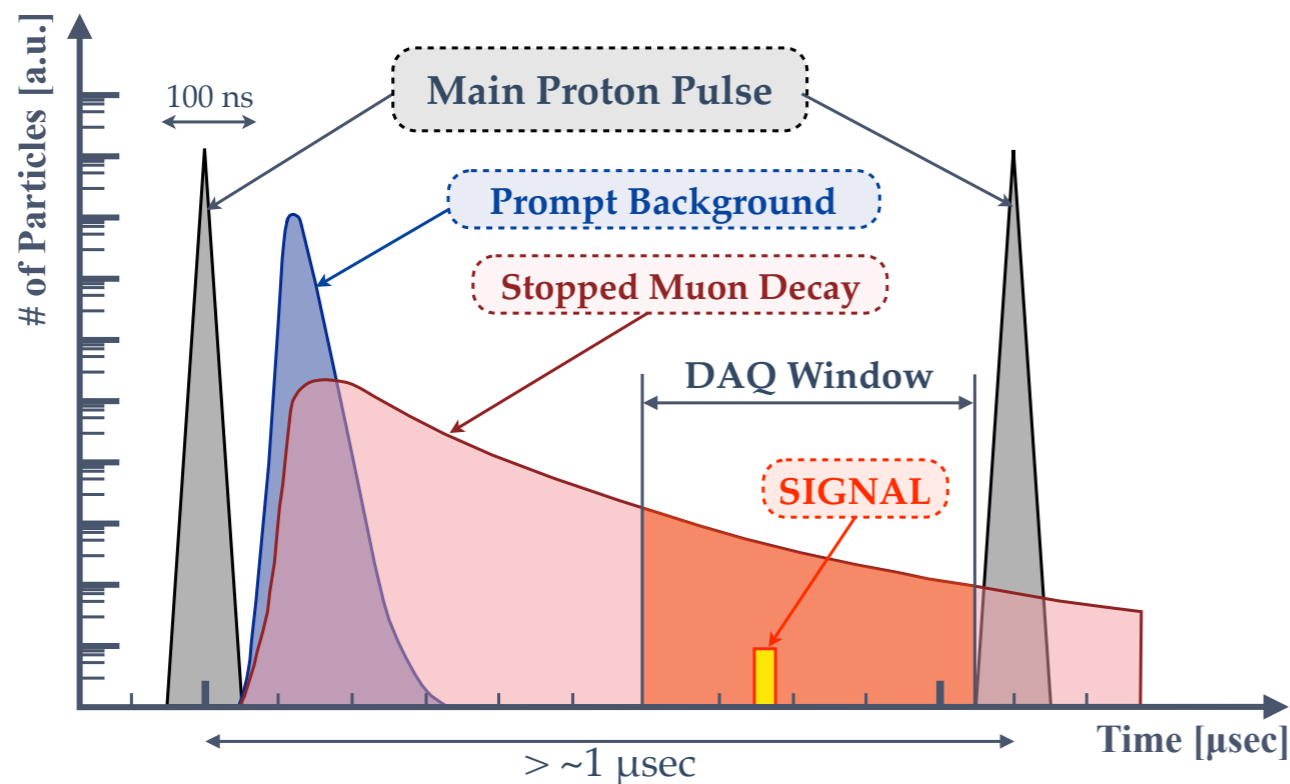


Bunched Slow Extraction

Beam-related BG

Muon beam is contaminated by pions, and the momentum is spreading in a wide range.

- Radiative pion capture, $\pi^- (A,Z) \rightarrow (A,Z-1) \gamma, \gamma \rightarrow e^+ e^-$
 - Muon decay in flight, $p_\mu > 75 \text{ MeV}/c$
 - etc.
- } correlated with beam timing



- ✓ Pulsed beam
- ➔ Delayed-timing measurement

Lifetime of the muonic atom should be comparable to the pulse interval

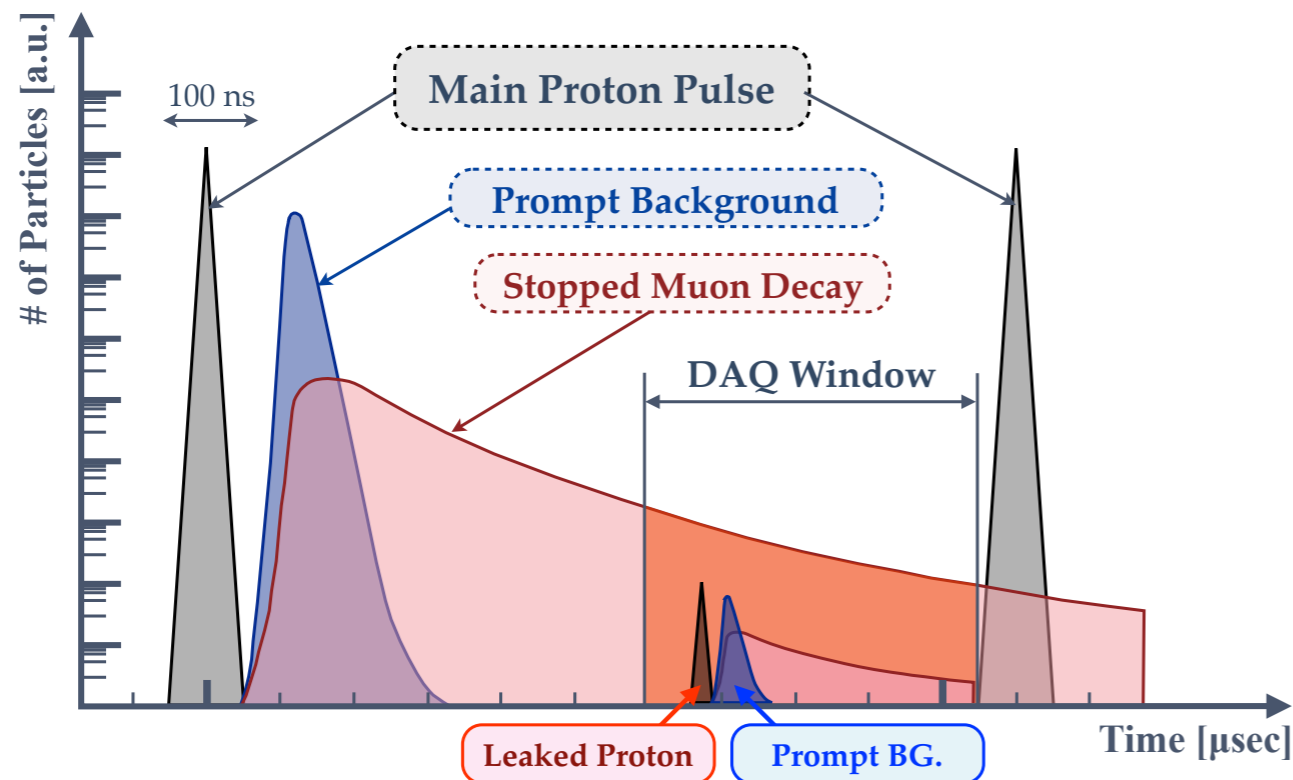
$$\text{Cf.) } \tau_\mu(\text{Al}) = 0.9 \mu\text{sec}$$

- # Beam-related BG occurs promptly after the beam timing.
- # Stopped muon decay happens according to the lifetime of the muonic atom.
- # DAQ runs only in the delayed timing window.

Beam-related BG

Muon beam is contaminated by pions, and the momentum is spreading in a wide range.

- Radiative pion capture, $\pi^- (A,Z) \rightarrow (A,Z-1) \gamma, \gamma \rightarrow e^+ e^-$
 - Muon decay in flight, $p_\mu > 75 \text{ MeV}/c$
 - etc.
- } correlated with beam timing



If there are leaked protons in between the pulses, they might make the BG in the timing window.

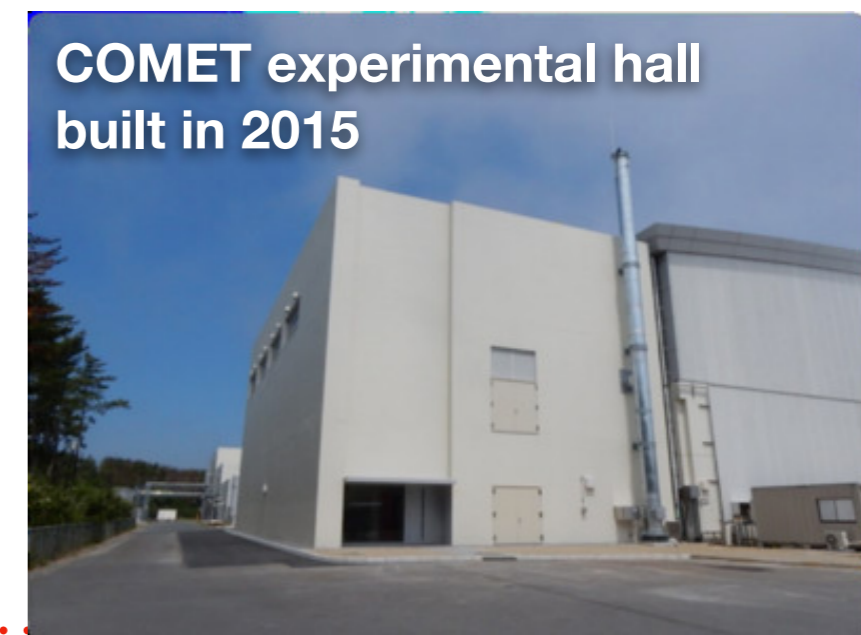
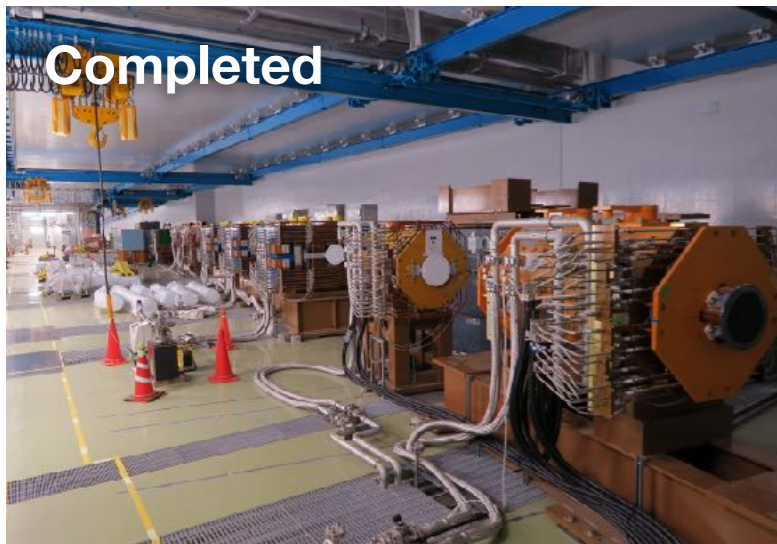
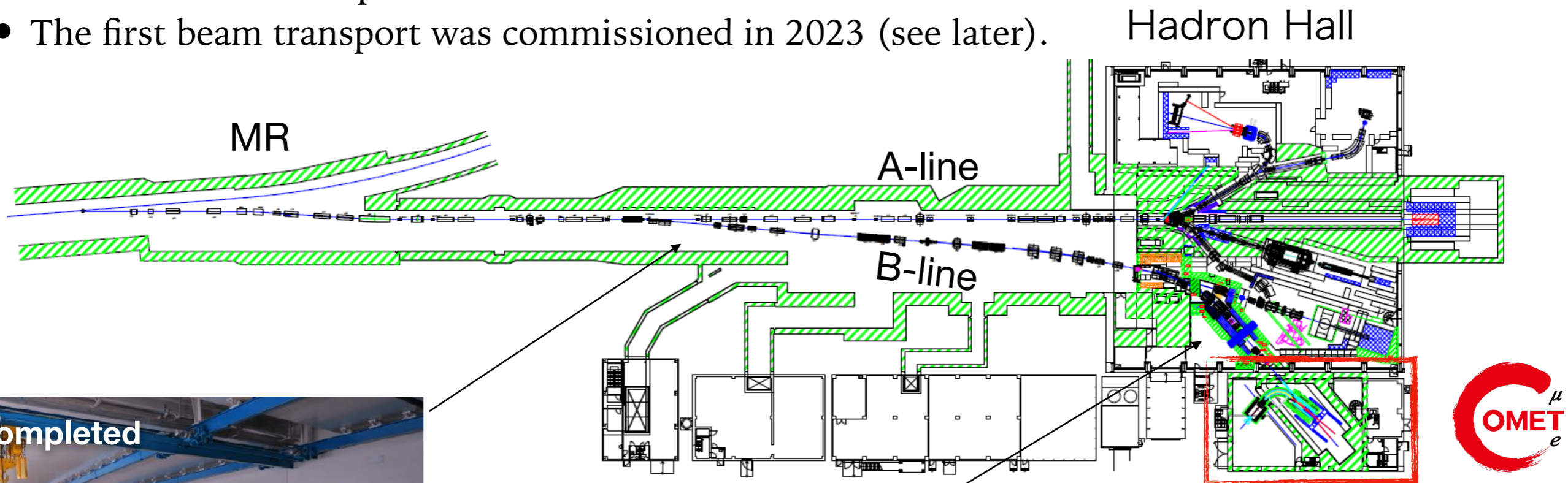
- ✓ Pulsed beam
- ➔ Delayed-timing measurement

We achieved $R_{\text{ext}} < 10^{-10}$
in the test beam campaign in 2021.



Beam line

- New beam line & experimental hall were constructed.
- The first beam transport was commissioned in 2023 (see later).

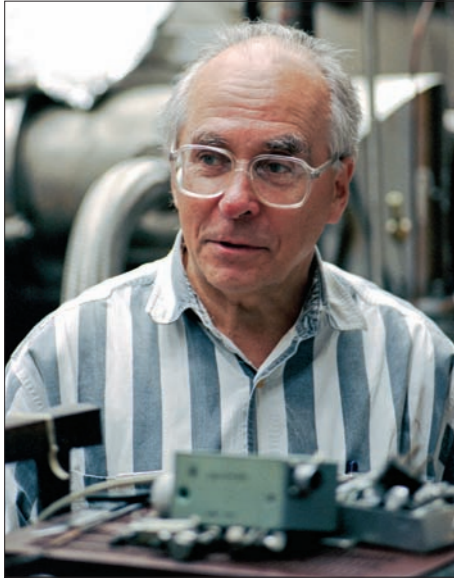




Muon Source

Ancestor of COMET/Mu2e

Vladimir Lobashev 1934–2011



Vladimir Lobashev. (Image credit: INR.)

CERN Courier 51, 8 (2011)

Yad. Fiz. 49, 622 / Sov. J. Nucl. Phys. 49, 384 (1989)

LETTERS TO THE EDITOR

On the search for the $\mu \rightarrow e$ conversion process in a nucleus

R. M. Dzhilkibaev and V. M. Lobashev

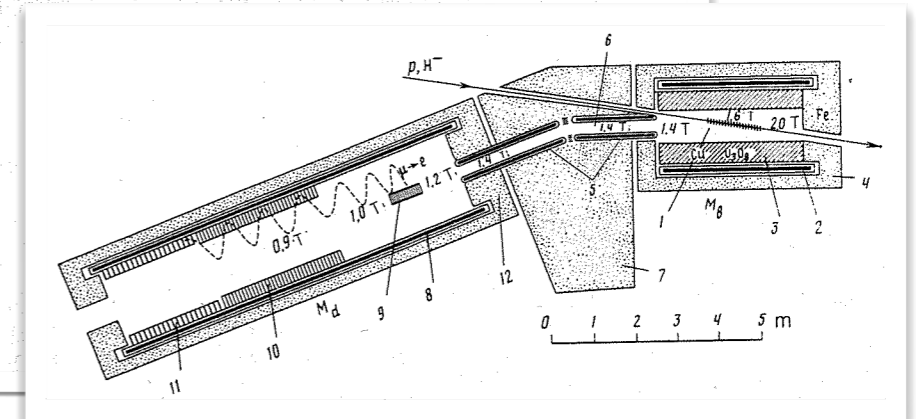
Institute of Nuclear Research, USSR Academy of Sciences

(Submitted 21 June 1988)

Yad. Fiz. 49, 622–624 (February 1989)

Among the most important problems of elementary-particle physics is the problem of searching for nonconservation of leptonic quantum numbers. In the $\mu \rightarrow e$ conversion process in a nucleus the muon and electron numbers are not conserved, and therefore this process does not occur in the standard electroweak theory. At the same time in a number of extensions of the minimal model¹ nonconservation of lepton numbers is a natural property of the theory.

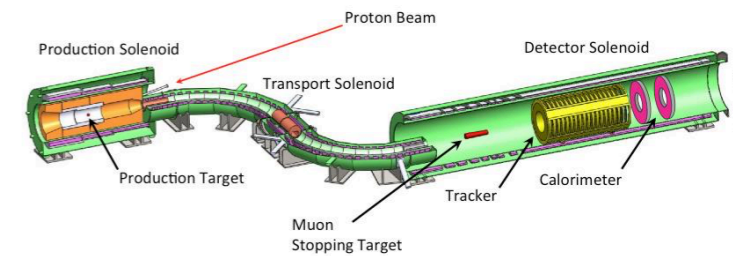
The signature of $\mu \rightarrow e$ conversion is the appearance of a



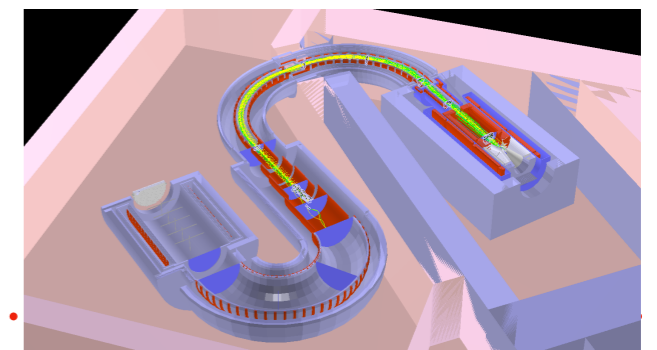
MELC@INR, Moscow
proposed (1992)

MECO@BNL
cancelled (2005)

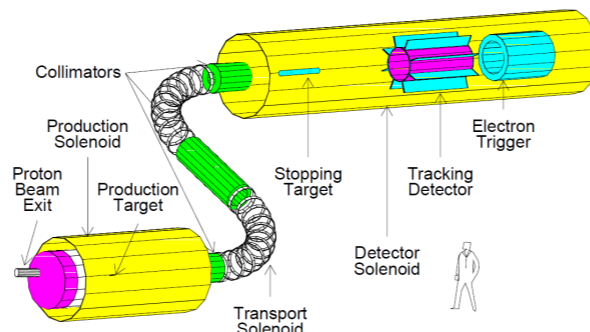
Mu2e@FNAL



COMET@J-PARC



> 35 years from
First Idea



Pion Capture Solenoid

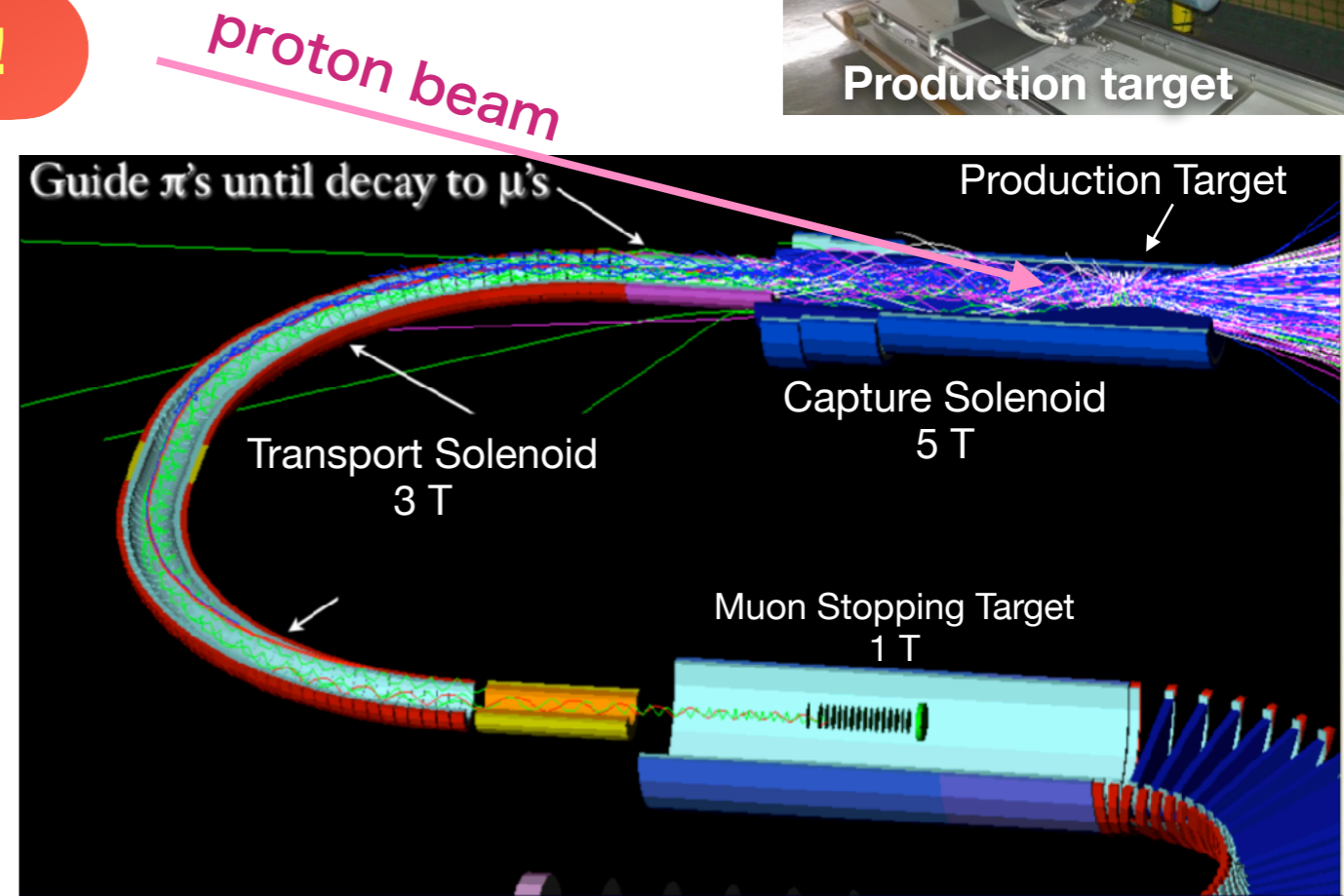
Powerful muon source is mandatory !!

To achieve 10^{-17} sensitivity,

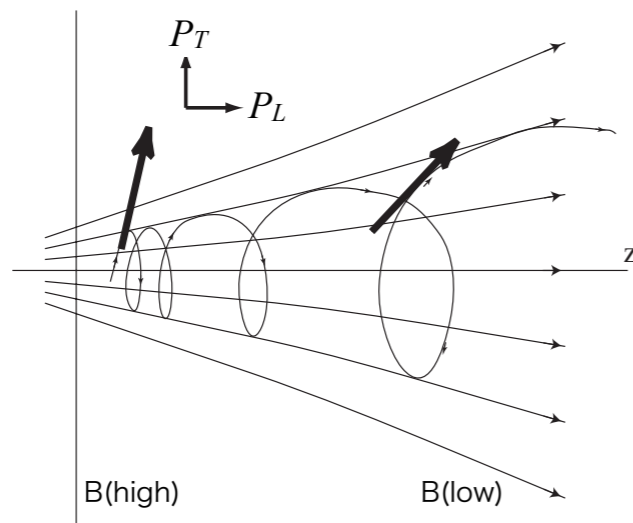
$\sim 10^{11}$ muons/sec

(with 10^7 sec running time.)

- ▶ Long production target
- ▶ Capture solenoid
 - **Backward generated pion** \rightarrow muon



Capture solenoid



Gradient magnetic field

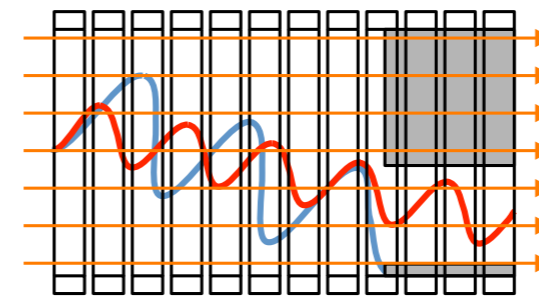
makes the direction of particles aligned to the axis.

Muon Transport Solenoid

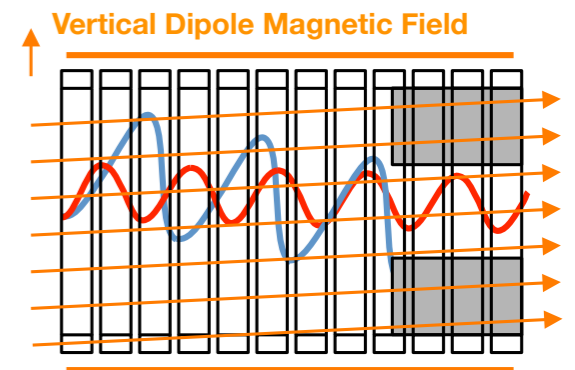
- ▶ Curved Transport solenoid
- Particles are subject to vertical drift according to its momentum & charge

$$D = \frac{1}{qB} \left(\frac{s}{R} \right) \frac{p_L^2 + \frac{1}{2}p_T^2}{p_L},$$

Transport solenoid



— High momentum track
— Low momentum track

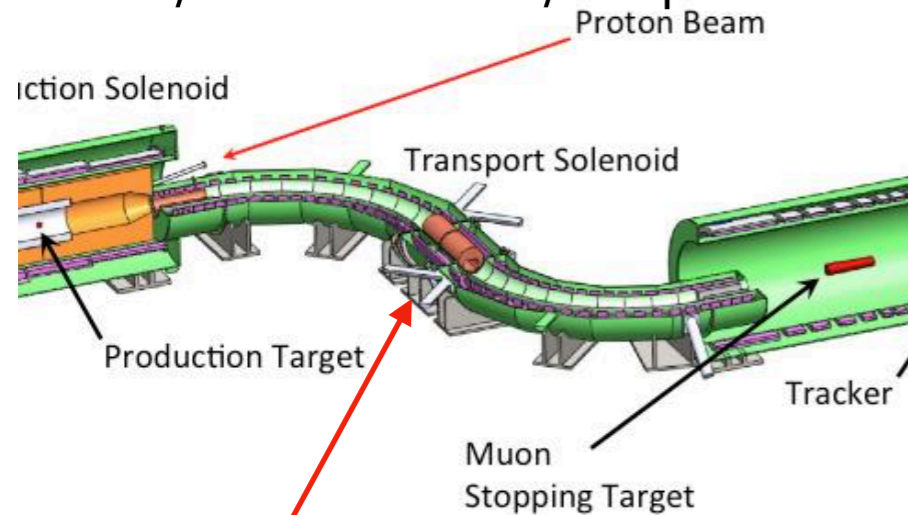


Beam collimator

$$B_{\text{comp}} = \frac{1}{qR} \frac{p_0}{2} \left(\cos \theta_0 + \frac{1}{\cos \theta_0} \right)$$

Mu2e: S-shape

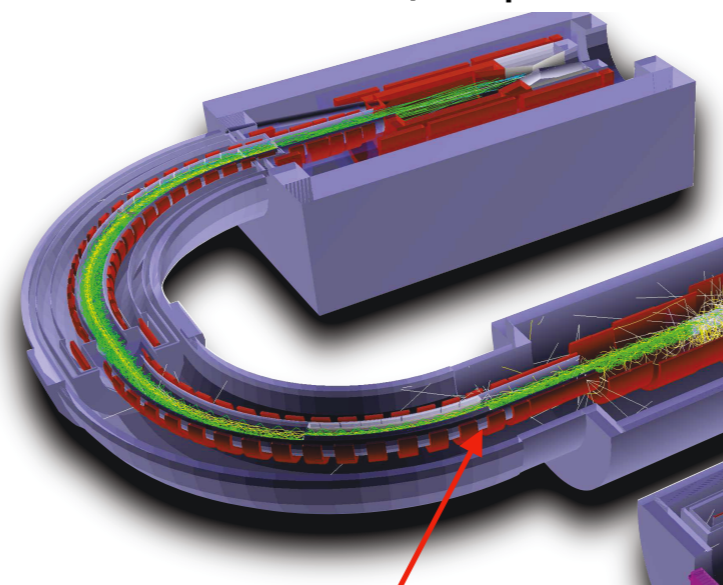
+90° / -90° bend w/o dipole



Collimator in the middle

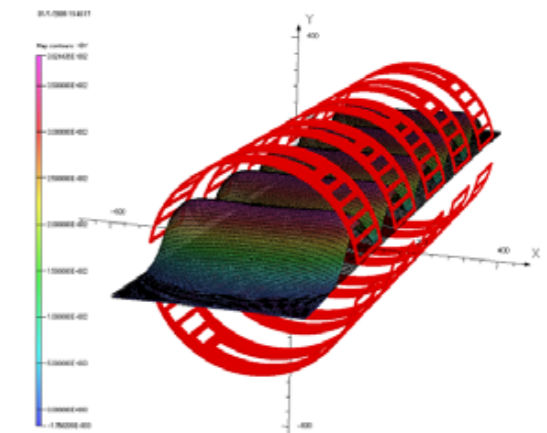
COMET: C-shape

180° bend w/ dipole



Collimator at the exit

Correction Dipole Field



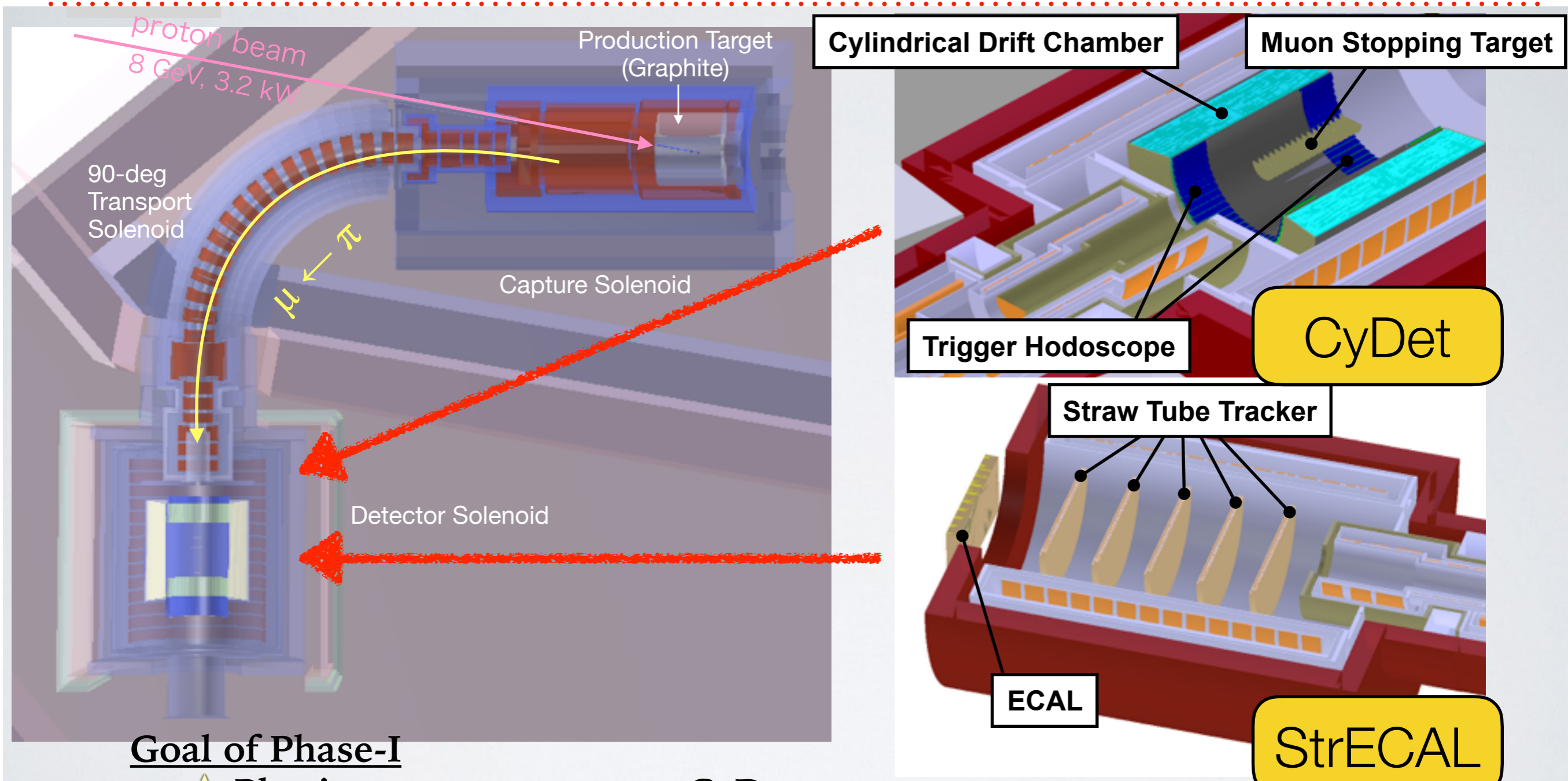
Only a company has the technology



COMET Strategy

Staging Approach

COMET Phase-I



Goal of Phase-I

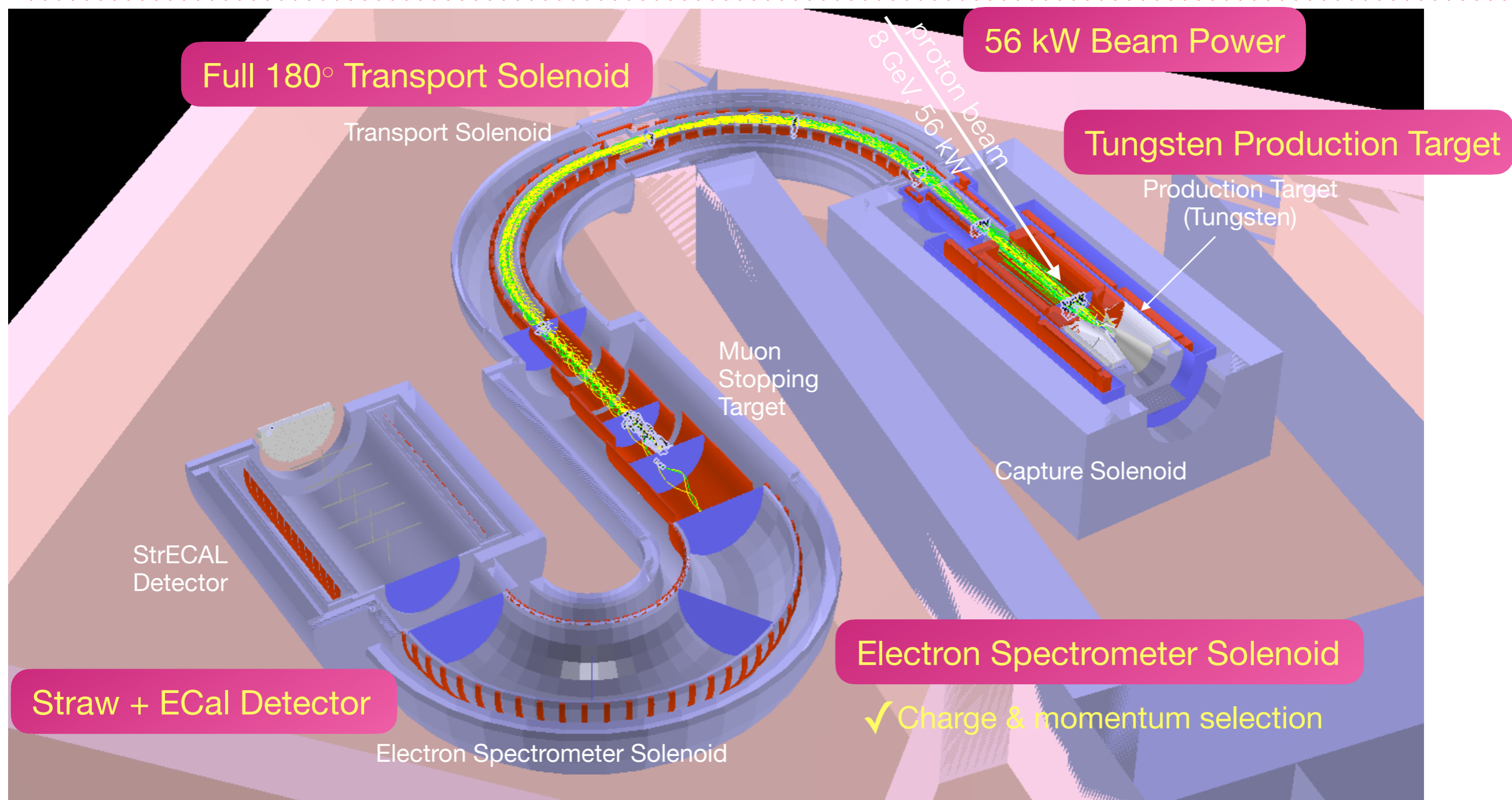
★ Physics measurement → CyDet

- μ -e conversion search, SES: 3×10^{-15} ($\times 100$ improve), 150 days running

★ Beam measurement → StrECAL

- to understand beam quality and background (PID, momentum, timing)

COMET Phase-II



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

Sensitivity

Technical Design Report, PTEP 2020 033C01 (2020).

$$B(\mu^- + \text{Al} \rightarrow e^- + \text{Al}) = N_\mu \cdot f_{\text{cap}} \cdot f_{\text{gnd}} \cdot A_{\mu-e}$$

Number of muons stopped inside targets $\rightarrow N_\mu$
 Fraction of μ -e conversion to the ground state = 0.9 $\rightarrow f_{\text{gnd}}$
 Fraction of muons to be captured by Al target = 0.61 $\rightarrow f_{\text{cap}}$
 Detector acceptance + efficiency $\rightarrow A_{\mu-e}$

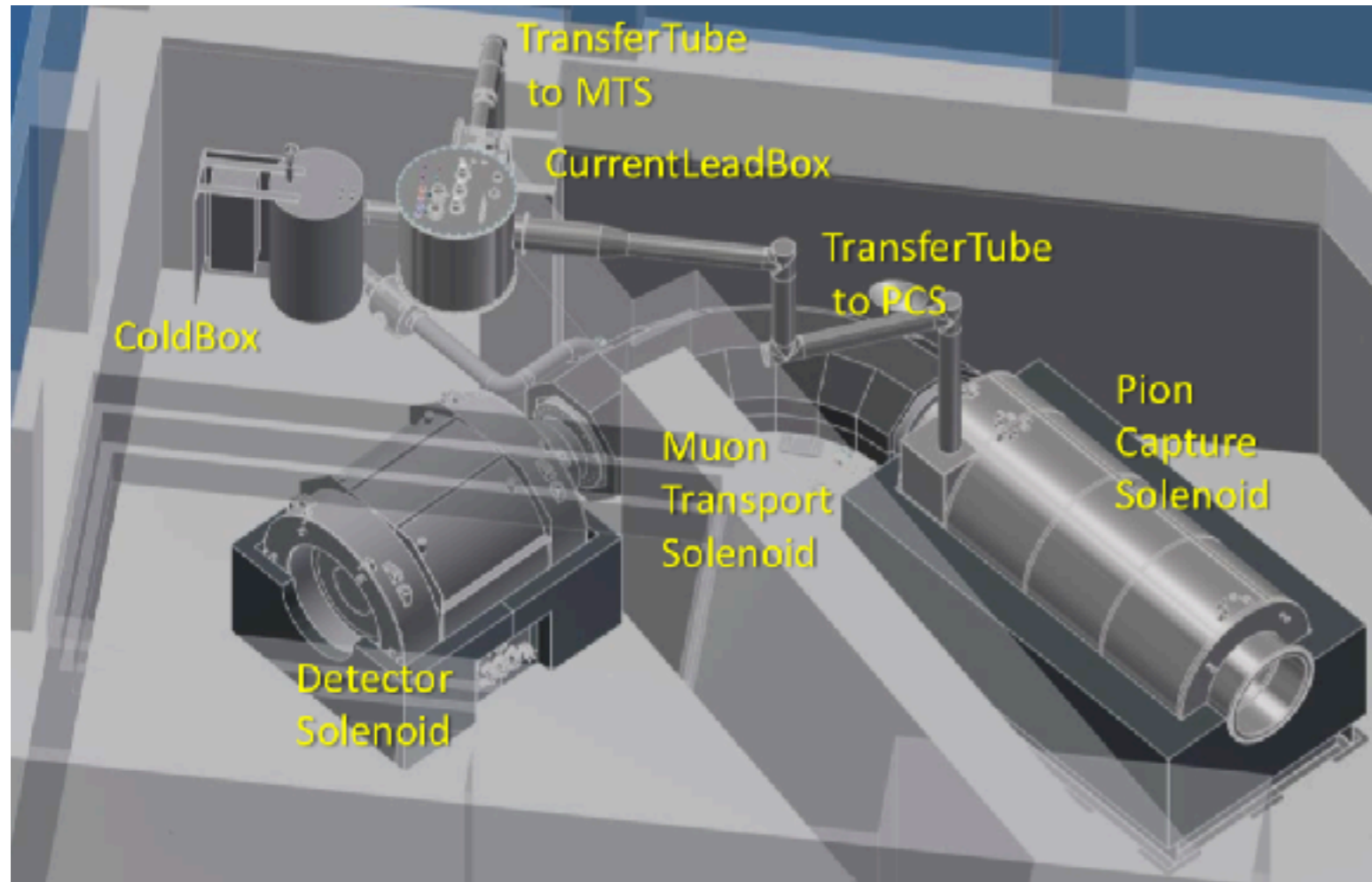
	Phase-I	Phase-II
Proton Beam Power	3.2 kW	56 kW
DAQ time	150 days	~ 1 year
Total muons stop, N_μ	1.5×10^{16}	1.4×10^{18}
Detector Acceptance+Efficiency, $A_{\mu-e}$	0.041	0.057
S.E.S.	3.0×10^{-15}	2.0×10^{-17}
# of BG	0.032	< 1

The Phase-II sensitivity is comparable with Mu2e.



Magnets & Detectors

Solenoid magnet status



Pion Capture Solenoid 2024

- **Pion Capture solenoid:**
 - Leak tests of LHe- & water-cooling pipes were successful.
 - Excitation test after installation of return yoke & transfer tube.
- **Muon Transport solenoid:**
 - Ready to operate.
- **Detector solenoid:**
 - Basic performance was successfully tested.
 - Magnetic field measurement will be performed in this year.

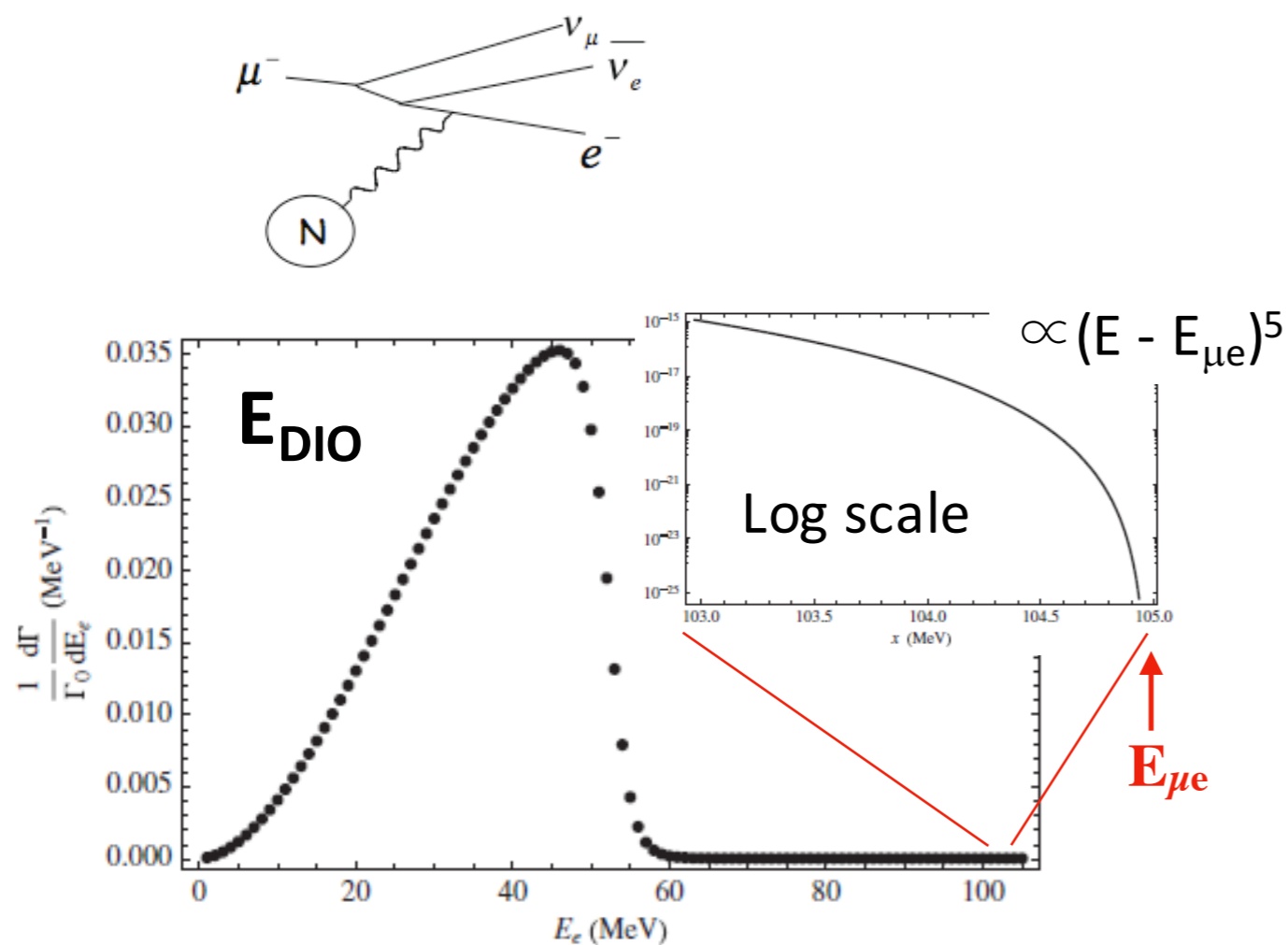


Detector Solenoid 2025

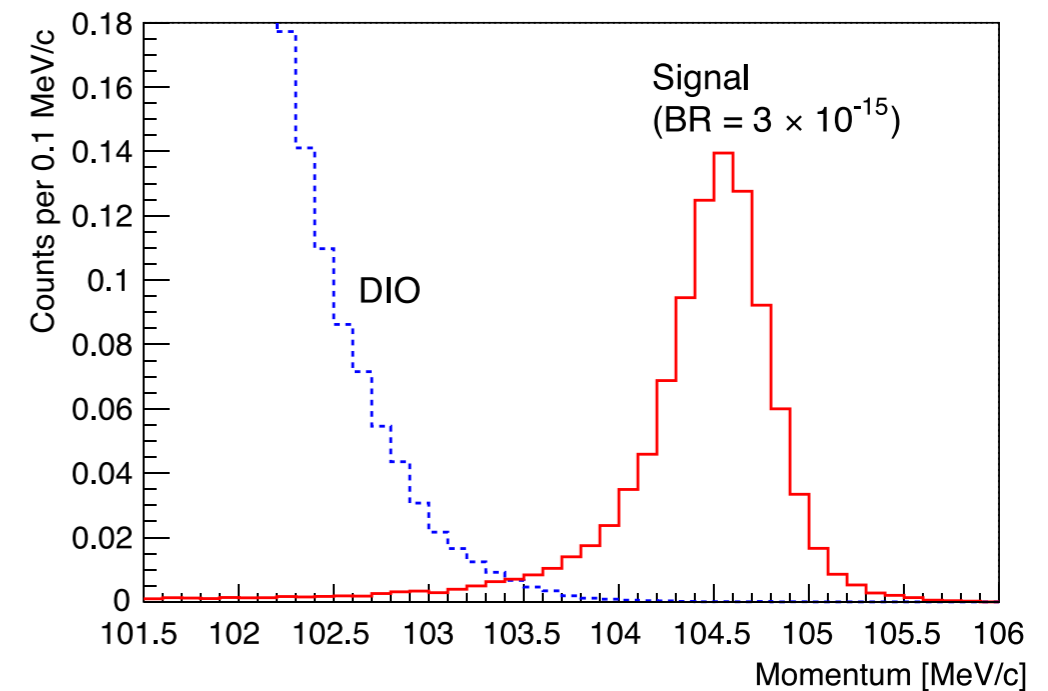
Requirement for detectors

Intrinsic physics background

Muon decay in orbit



A.Czarnecki, X.G.i Tormo, W.J.Marciano, PRD 84, 013006 (2011).



Required momentum resolution

$$\Delta p < 200 \text{ keV/c}$$

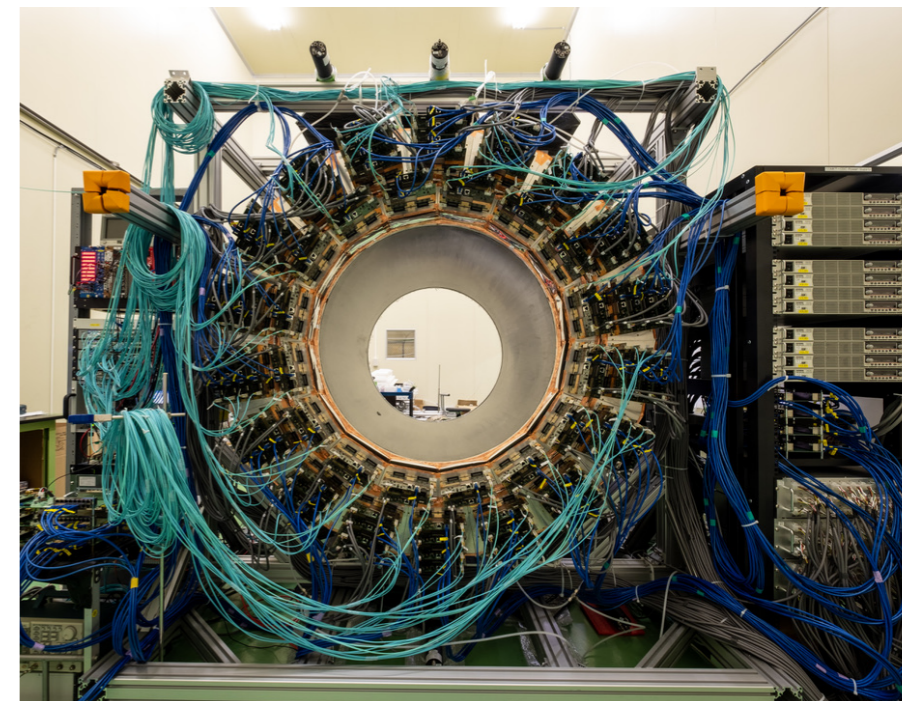
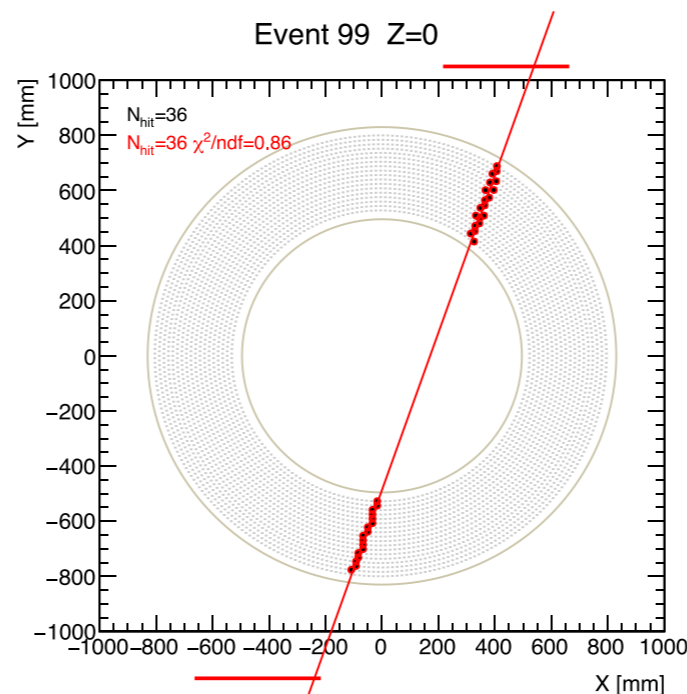
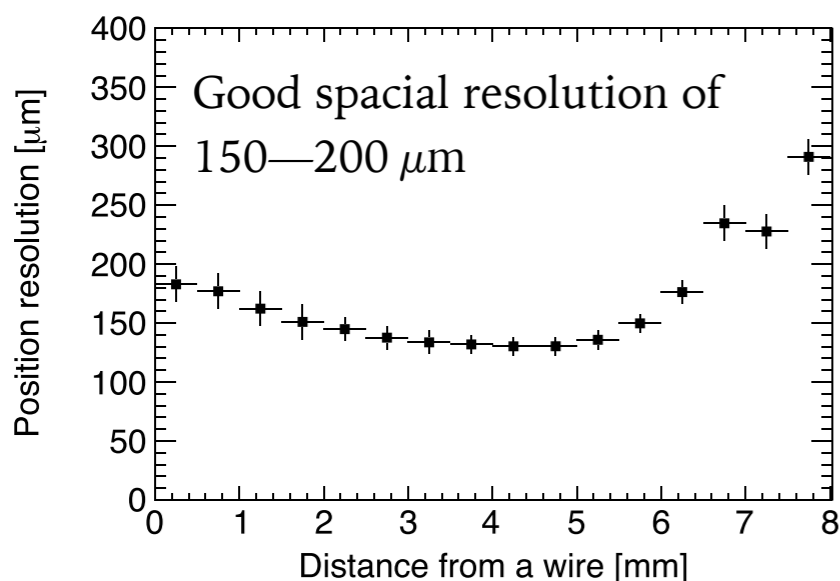
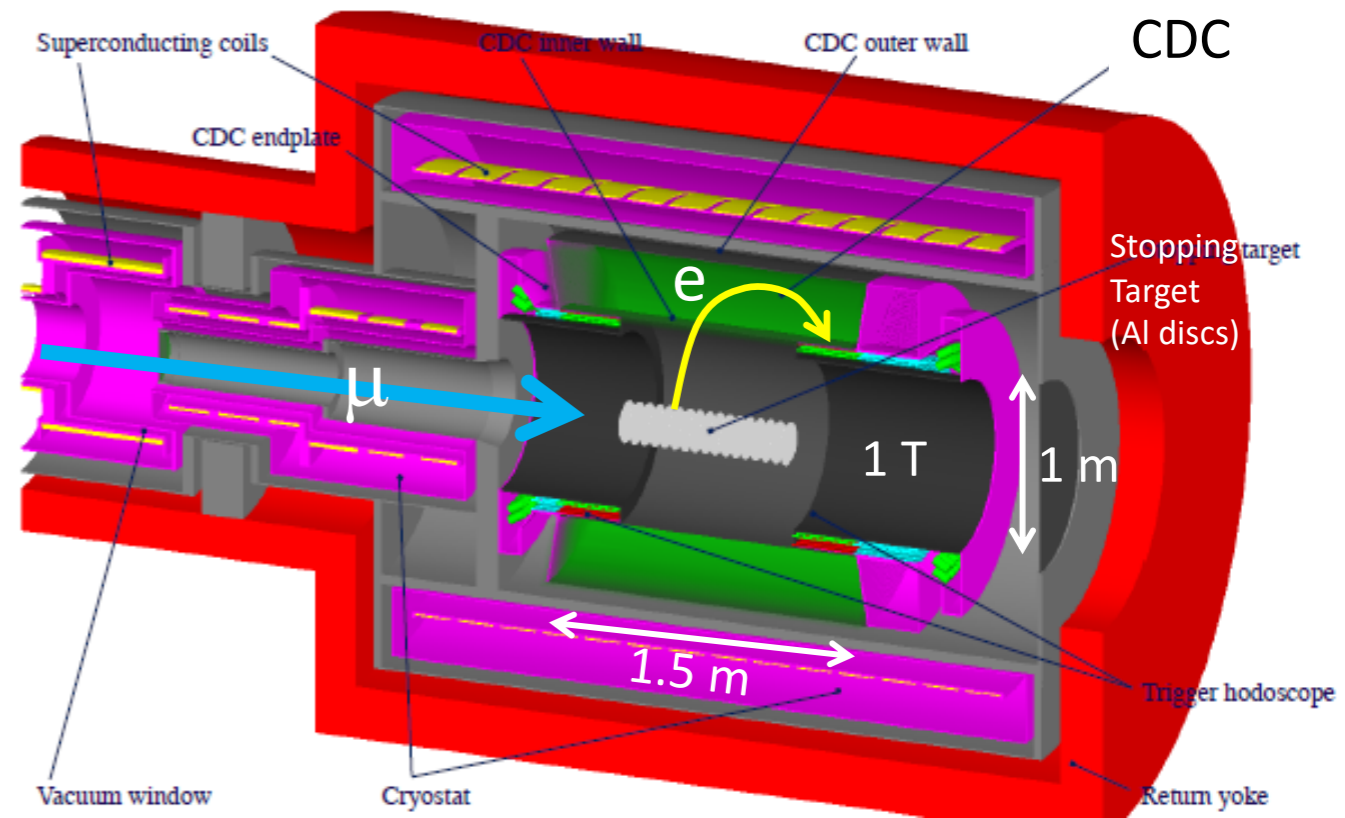
for 105 MeV/c electrons

CDC Cylindrical Drift Chamber for Phase-I

A.Sato et al., NIM A 1069, 169926 (2024).

■ CDC

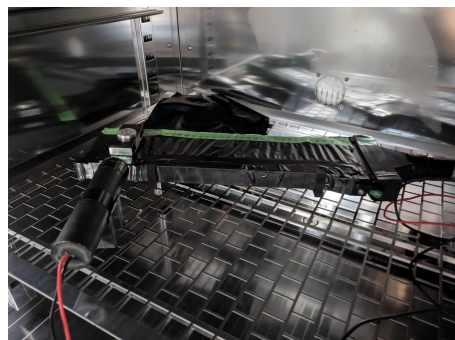
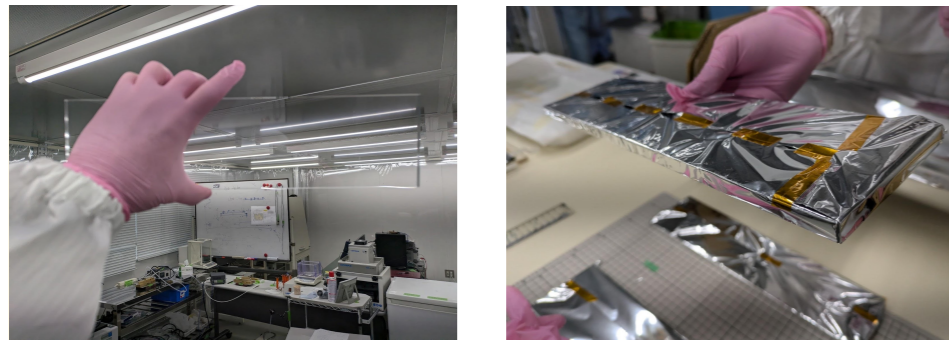
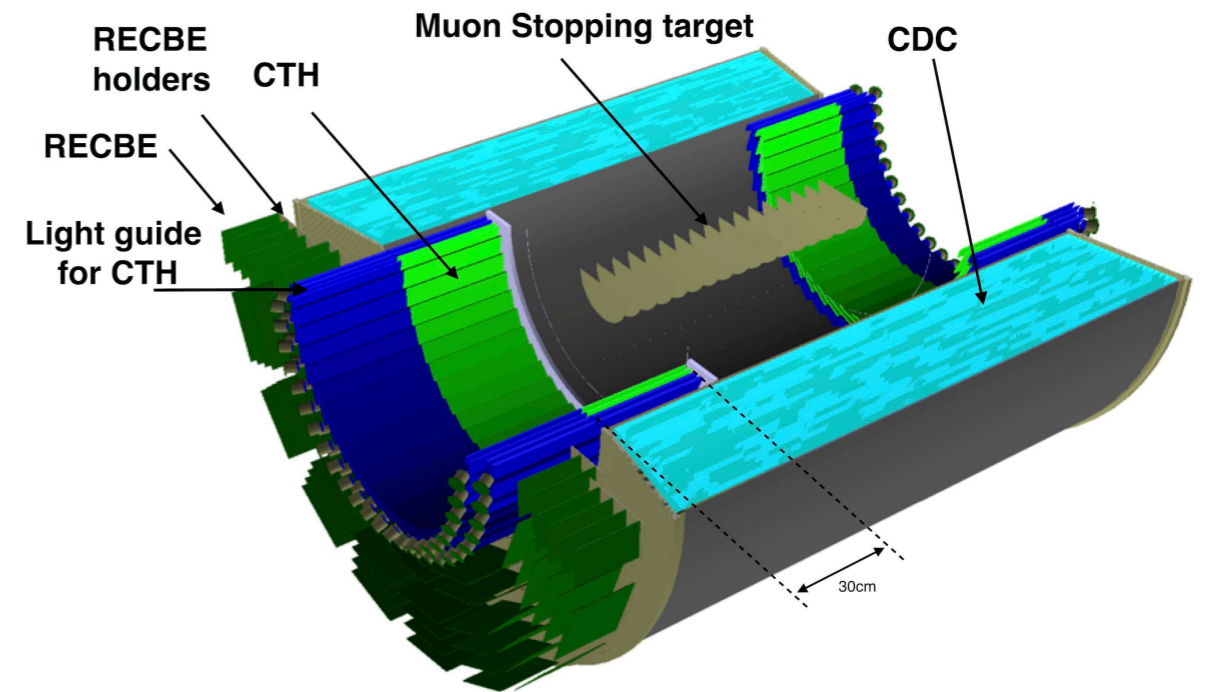
- electron tracking in 1 T
- $\Delta p = 200 \text{ keV}/c$ (for $p=105 \text{ MeV}/c$)
- Low-mass chamber
 - He:i-C₄H₁₀ (90:10)
 - 0.5-mm CFRP inner wall
 - Al field wire, 126 μm , 4986
 - Au-W sense wire, 25 μm , 14562
- Alternating all stereo layer
 - 20 layers, $\pm 64\sim 75 \text{ mrad}$



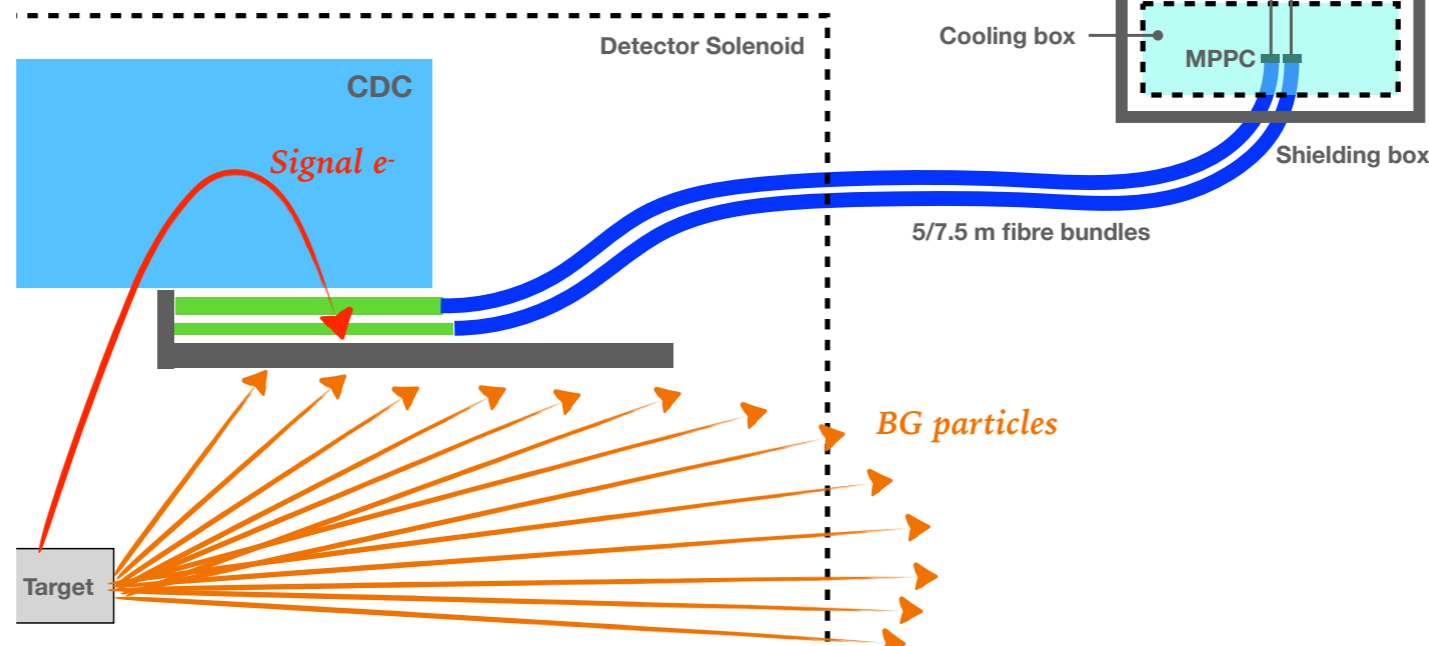
CTH Cylindrical Trigger Hodoscopes for Phase-I

CTH

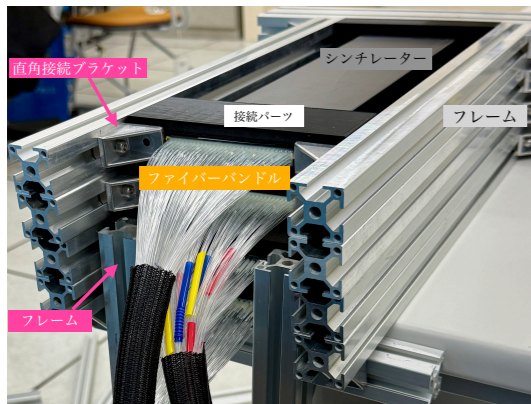
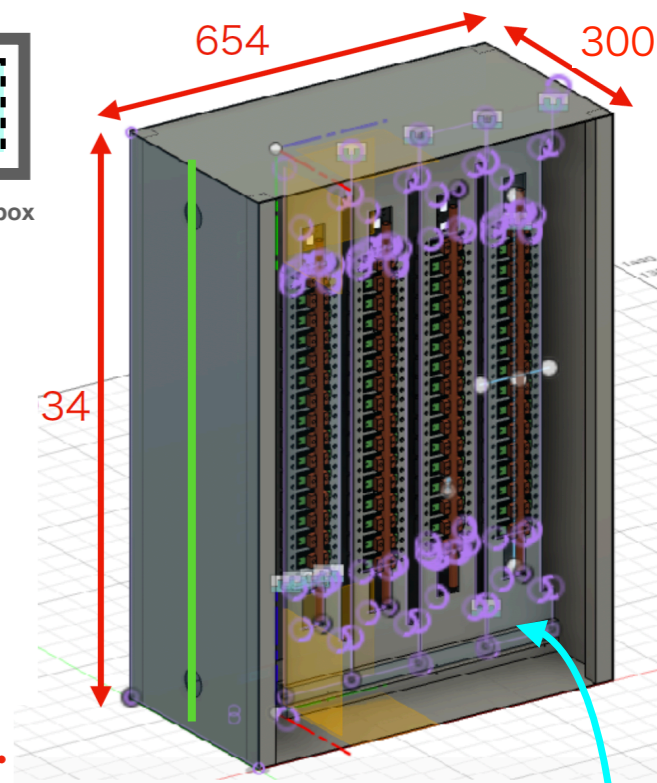
- 128 Plastic Scintillators + Fiber bundle
- SiPM readout with cooling
- 4-fold coincidence trigger



Conceptual design



MPPC cooling box

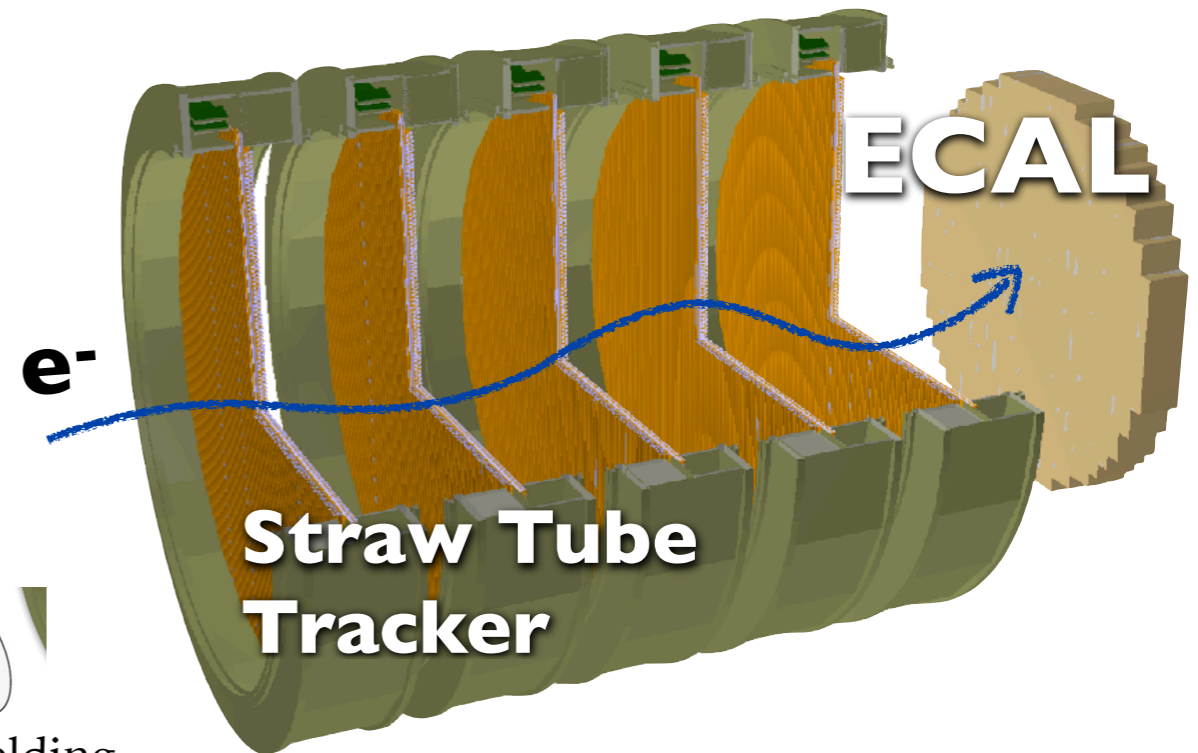
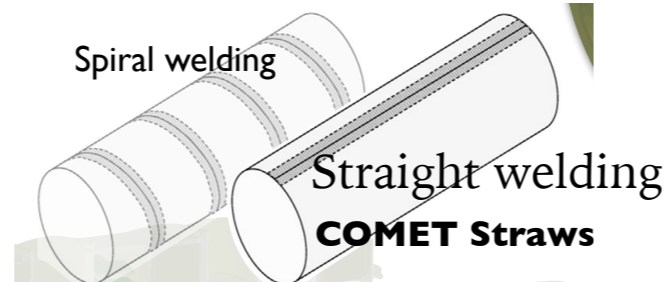


StrECAL system

Detectors for beam measurement in Phase-I,
and μ -e search in Phase-II

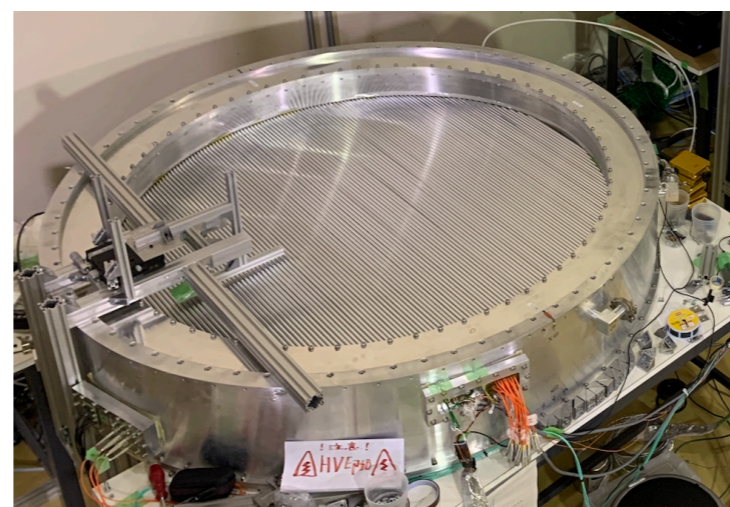
■ Straw Tube Tracker

- Operational in vacuum in 1 T
- $\Delta p = 150 \sim 200 \text{ keV}/c$ (for $p = 105 \text{ MeV}/c$)
- Straw tube
 - $20 \mu\text{m}$ thick, 9.75 mm diameter for Phase-I
 - $12 \mu\text{m}$ thick, 5 mm diameter for Phase-II
- 5 stations ($xx'yy' \times 5$)
- Ar:C₂H₆ (50:50)

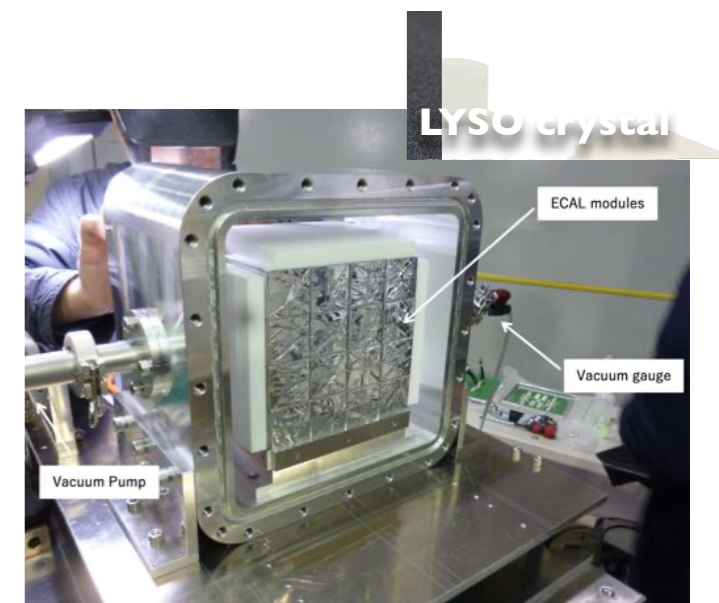


■ Electron Calorimeter

- 1,920 LYSO crystals
 - $2 \times 2 \times 12 \text{ cm}$ (10.5 radiation length)
- APD readout
- $\Delta E/E = 5\%$ (for $E = 105 \text{ MeV}$)
- 40-ns decay time



Straw Tracker
3 of 5 stations were completed

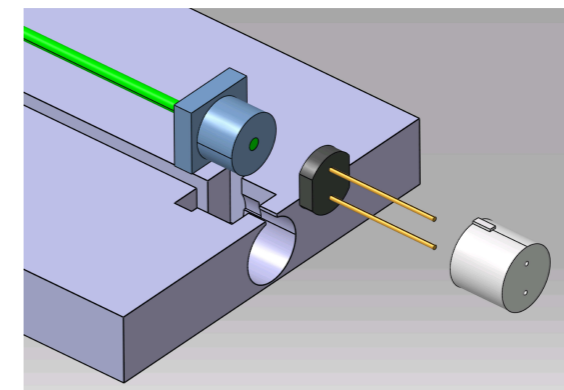
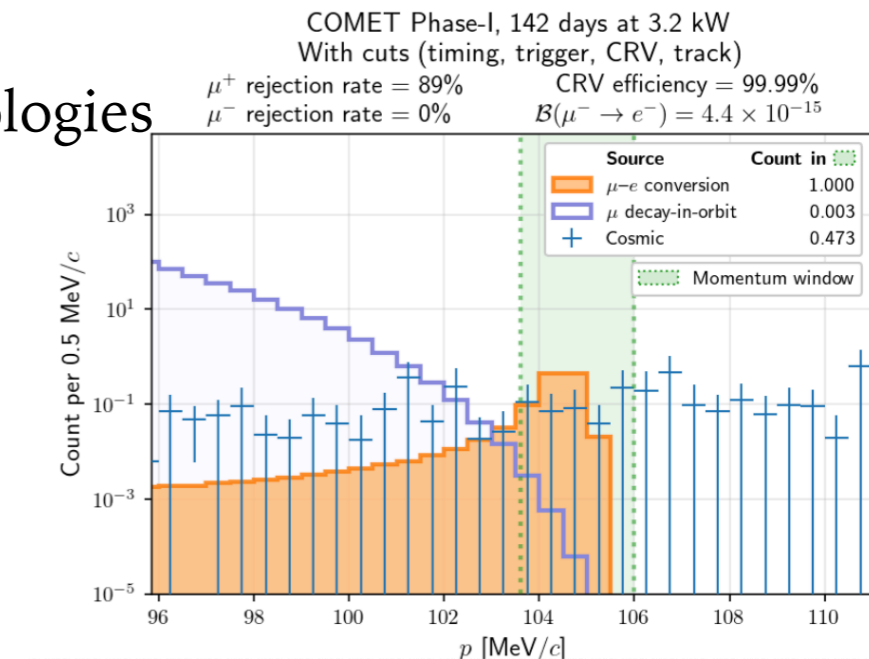
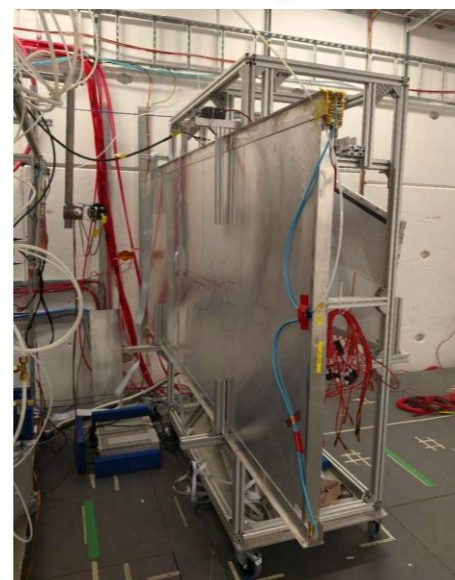
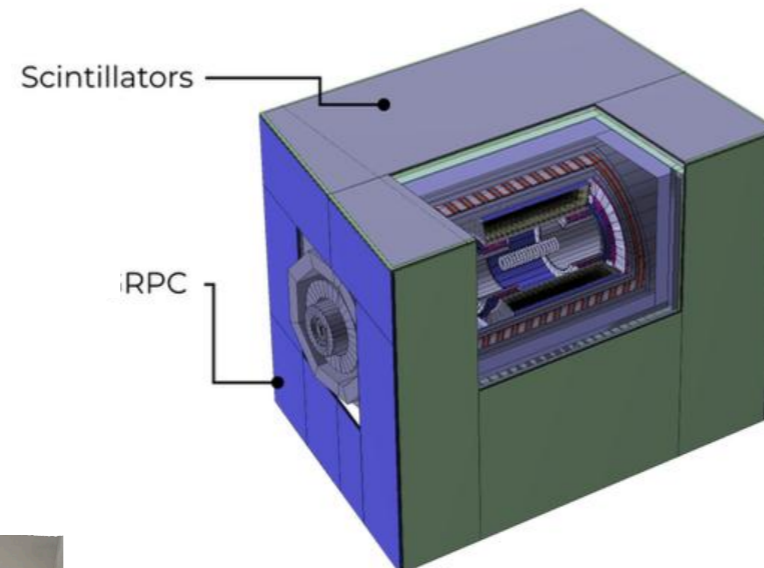


ECAL prototype:
QA/QC of the crystals and
APDs are ongoing.

CRV Cosmic Ray Veto

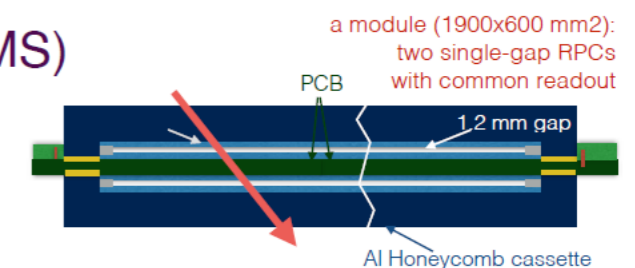
CRV

- Full coverage except the beam holes, using different technologies
- Top CRV: plastic scintillator arrays
- Side CRV: recycled RPC modules
- Upstream/Downstream CRV: RPC with CMS technology



coupling mechanism
of SiPM to WLS fibre

iRPC CRV (© CMS)
A tracker module: 5 detector modules (baseline)





Beam commissioning

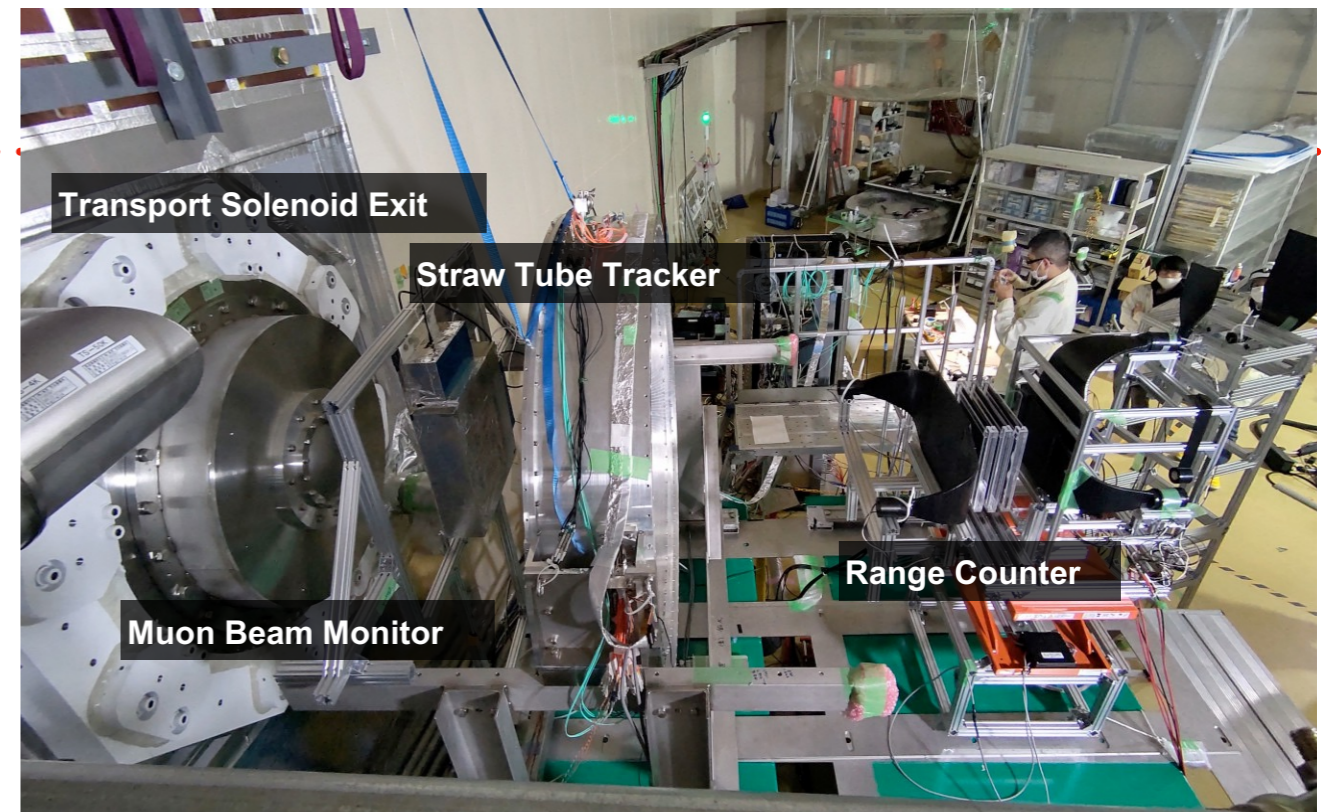
Phase- α

The **1st beam commissioning** in 2023 for

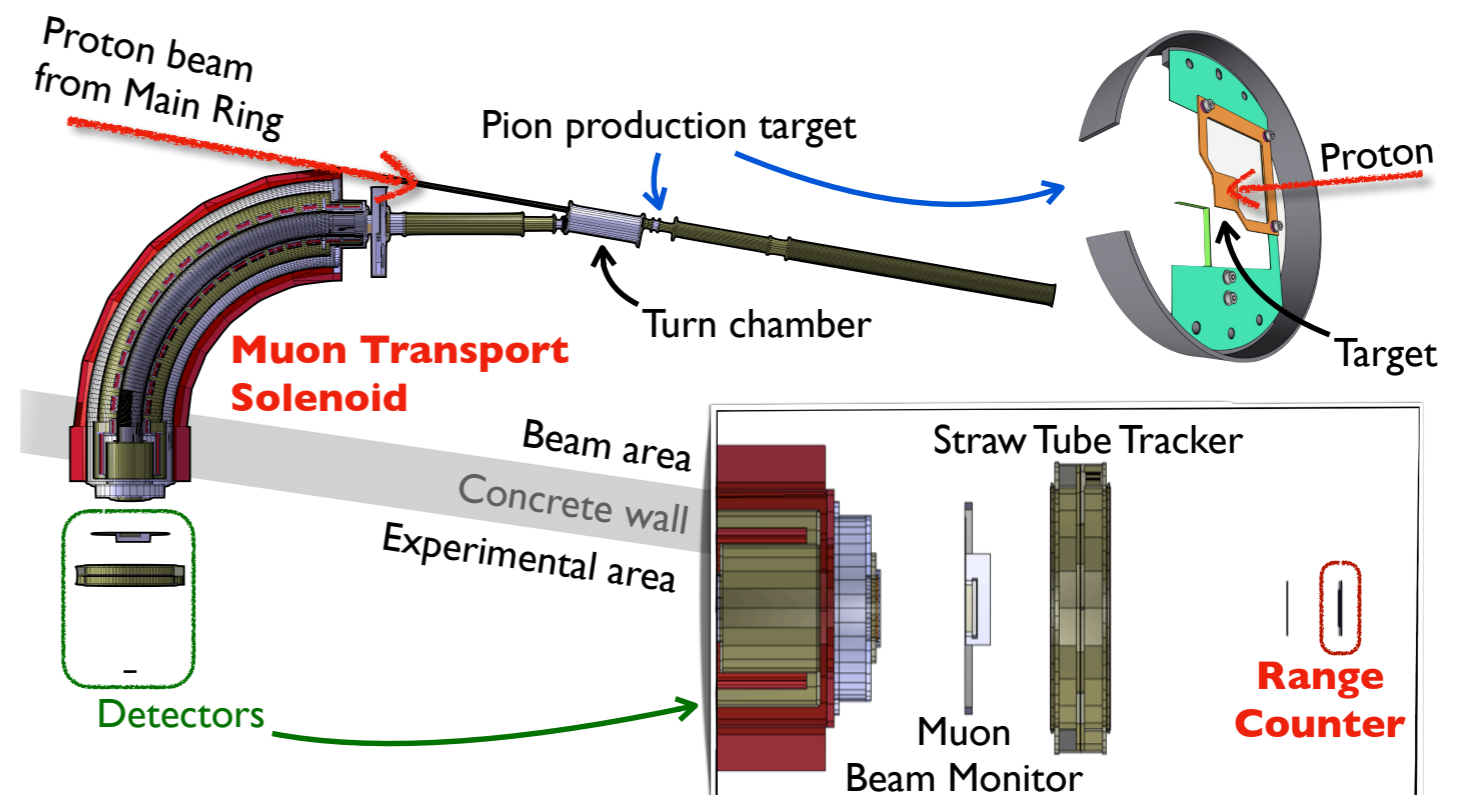
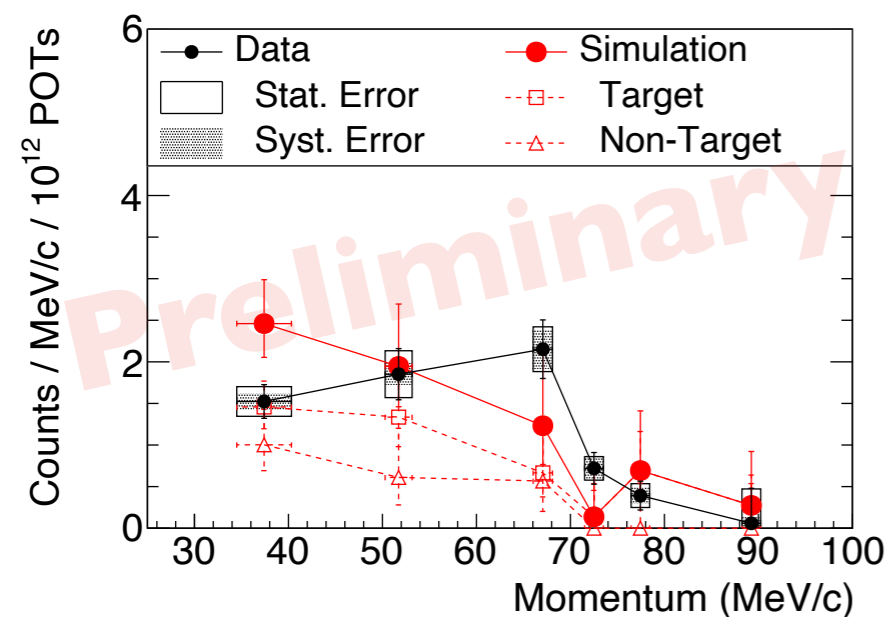
- COMET proton beam line
- Muon Transport Solenoid
- (w/o Pion Capture Solenoid)

Observed muon yields are consistent with simulation (preliminary).

The final results will be published soon.



K. Oishi, J-PARC Symposium 2024

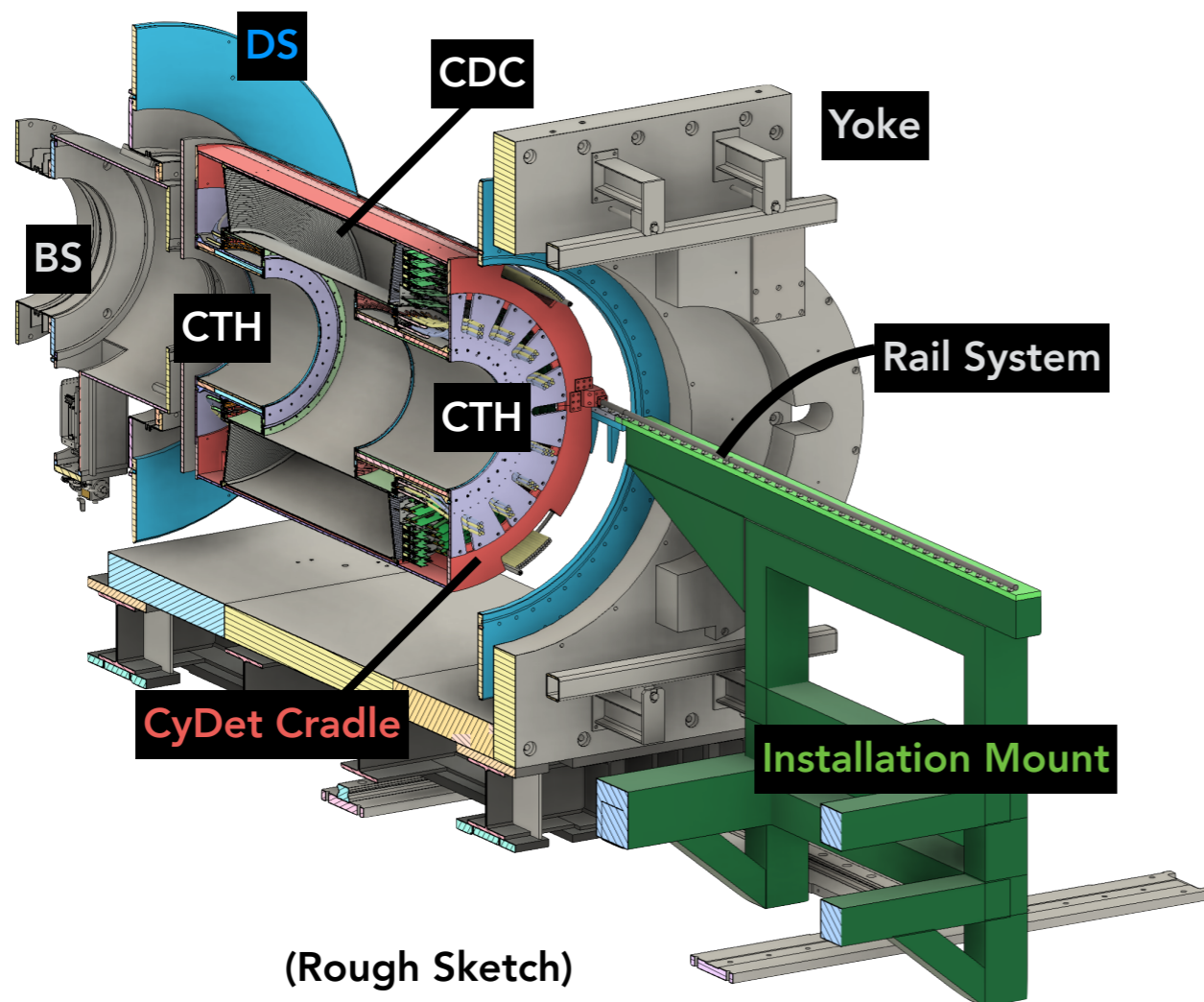




Schedule and Summary

Detector Integration

- Detectors will be installed in a stainless-steel support frame in 2027.
- The frame is already constructed and now testing a scheme of the integration.



Summary

- ▶ COMET aims to search for μ -e conversion with sensitivity of 3×10^{-15} / 2×10^{-17} at Phase-I / II.
- ▶ All the solenoid magnets including **PCS** & **DS** were installed. The commissioning is ongoing.
- ▶ The first beam commissioning (**Phase- α**) data has been finalized. The results will be published soon.
- ▶ COMET aims to start Phase-I with low intensity in 2028.



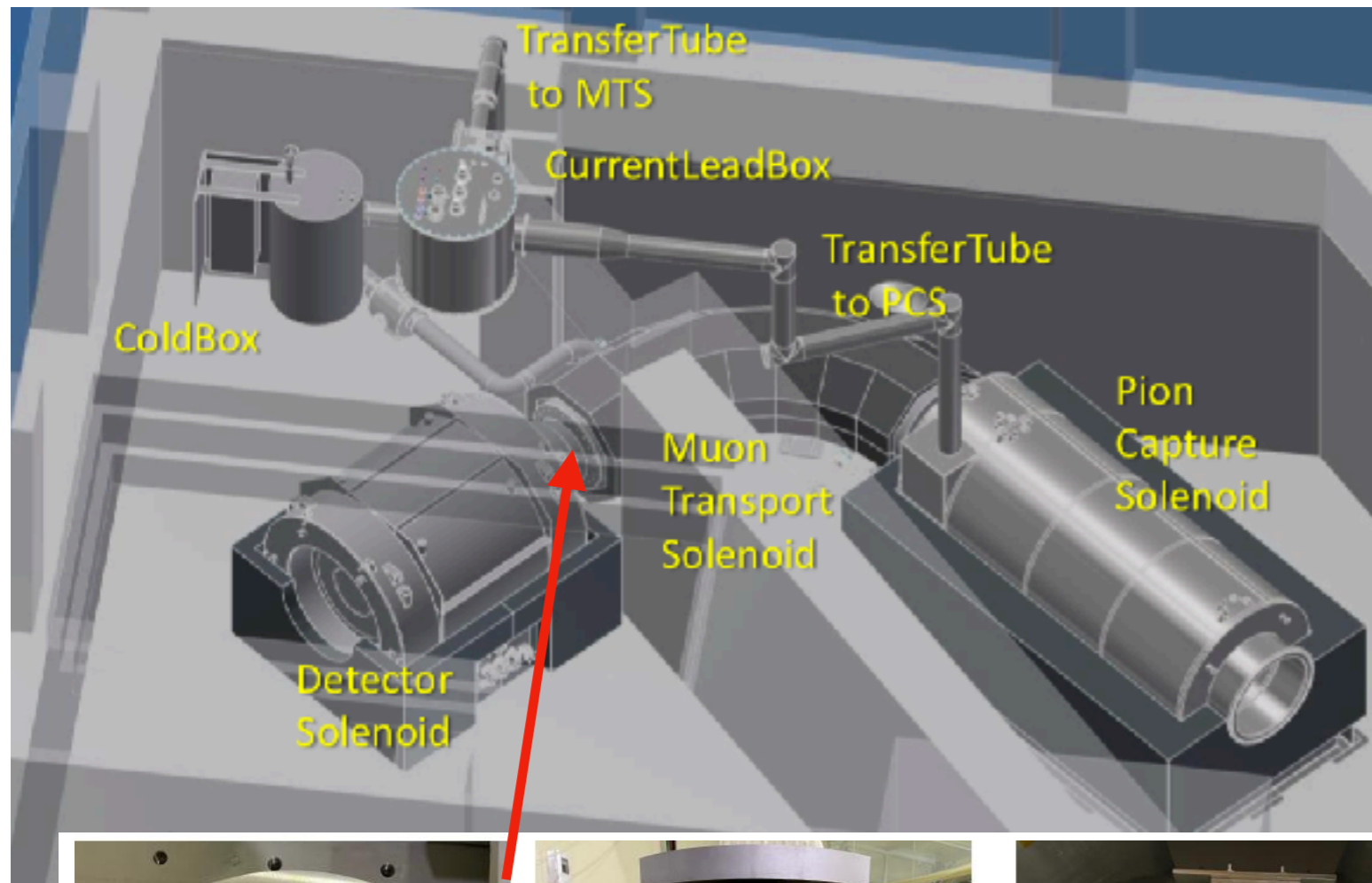
Thank you for listening



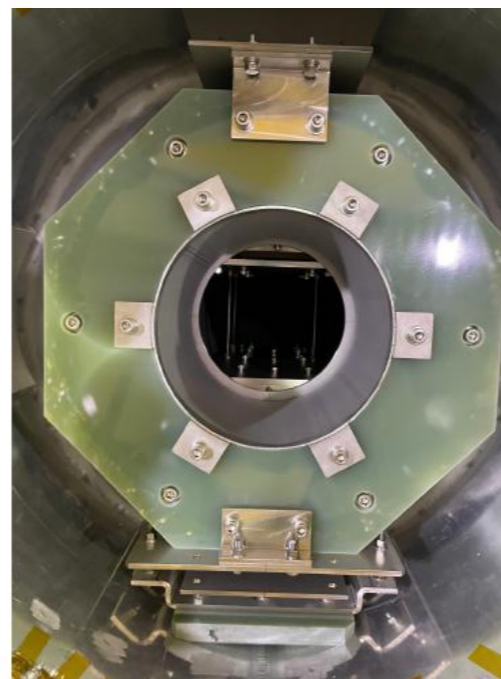
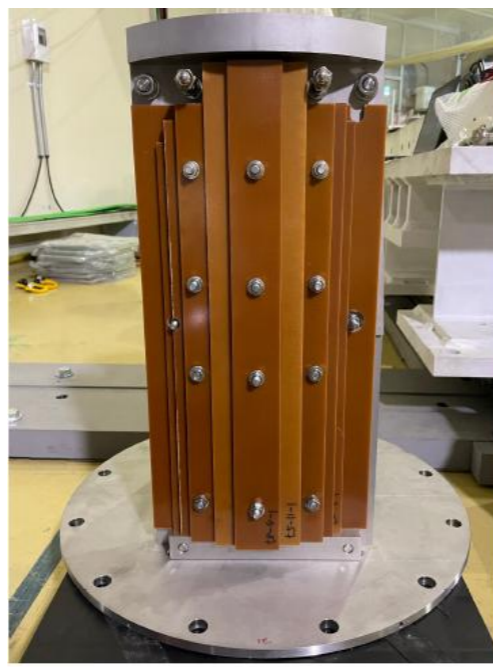
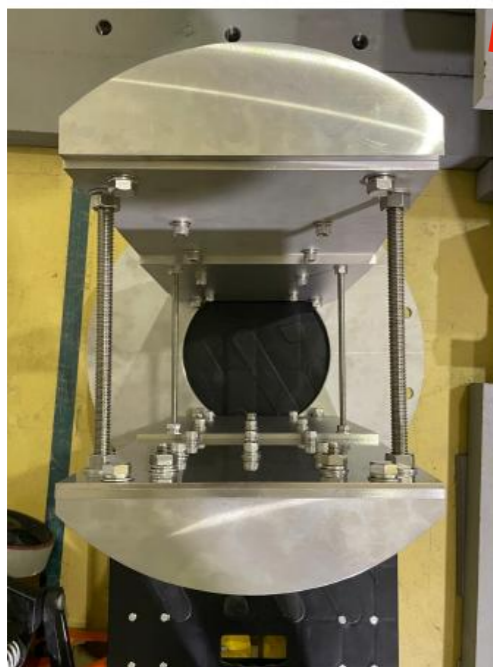
~200 collaborators,
19 countries

Backup

Muon beam collimator



- Optimized muon collimator was constructed based on recent studies.
- Installation of the collimator was completed.



Related (byproduct) measurements



B.Yeo, Kuno, MJ.Lee, Zuber,
PRD96, 075027 (2017)

- Lepton Number Violation process.
- Target nucleus mass relation is required: $M(A, Z - 2) < M(A, Z - 1)$,
- to eliminate radiative muon capture BG
- 10,000× sensitivity improvement is possible.
- Promising isotopes: ^{40}Ca , ^{32}S



Koike, Kuno, J.Sato, Yamanaka,
PRL105, 121601 (2010).
Uesaka, Kuno, J.Sato, T.Sato, Yamanaka,
PRD93, 076006 (2016), PRD97, 015017 (2018).

- The Coulomb attraction from the nucleus in a heavy muonic atom leads to significant enhancement in its rate.
- Z dependence could be used to distinguish interaction types.

Summary of COMET Phase-I / II

	Phase-I	Phase-II #
Proton Beam Power	3.2 kW (8 GeV×0.4 μA)	56 kW (8 GeV×7 μA)
# of protons / acc. cycle	6.2×10^{12} / 2.48 sec	4.4×10^{13} / 1.0 sec
DAQ time	1.26×10^7 sec (146 days)	2.0×10^7 sec (231 days)
Total protons on target	3.2×10^{19}	9.0×10^{20}
# of muons stop / proton	4.7×10^{-4}	1.6×10^{-3}
Total muons stop	1.5×10^{16}	1.4×10^{18}
Detector Acceptance+Efficiency	0.041	0.057
S.E.S.	3.0×10^{-15}	2.0×10^{-17}
# of BG	0.032	< 1

Phase-II parameters are tentative, more improvement under study

Sensitivity

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	$103.6 < p_e < 106.0 \text{ MeV}/c$
Timing window (ϵ_{time})	0.3	$700 < t_e < 1170 \text{ ns}$
Total	0.041	

@ Phase-I

$$B(\mu^- + \text{Al} \rightarrow e^- + \text{Al}) = N_\mu \cdot f_{\text{cap}} \cdot f_{\text{gnd}} \cdot A_{\mu-e}$$

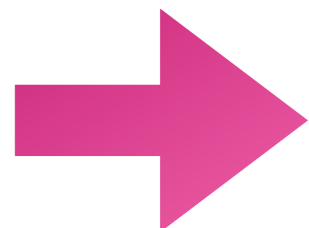
= 3×10^{-15}

Number of muons stopped inside targets

Fraction of μ -e conversion to the ground state = 0.9

Fraction of muons to be captured by Al target = 0.61

$N_\mu = 1.5 \times 10^{16} \rightarrow$ **150 days by 3.2 kW**



@ Phase-II

1 year by 56 kW

+ Tungsten production target
+ 180° Transport Solenoid
+ Electron Spec. Solenoid

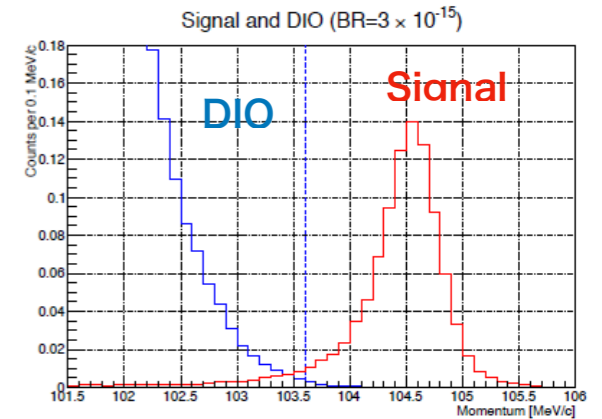
S.E.S

= 2×10^{-17}

Background estimation

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
	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
Total		0.032

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



$$103.6 < p_e < 106.0 \text{ MeV}/c$$

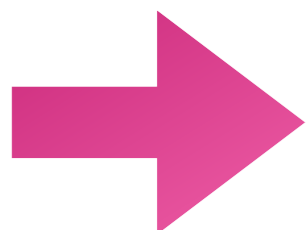
Assuming

$$R_{\text{ext}} = 3 \times 10^{-11}$$

$$700 < t_e < 1170 \text{ ns}$$

@ Phase-I

BG is small enough

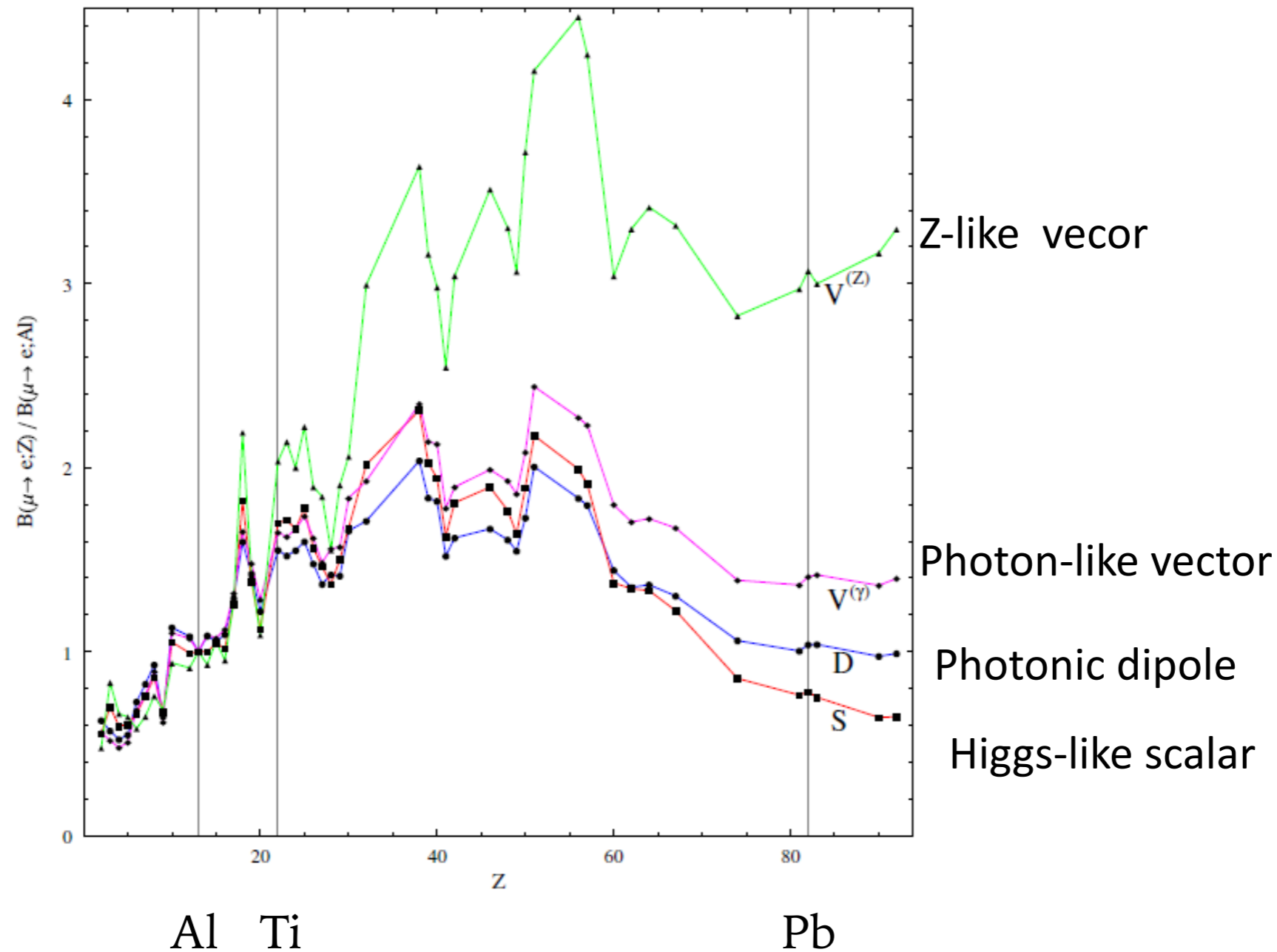


@ Phase-II

BG is still less than 1 by simulation

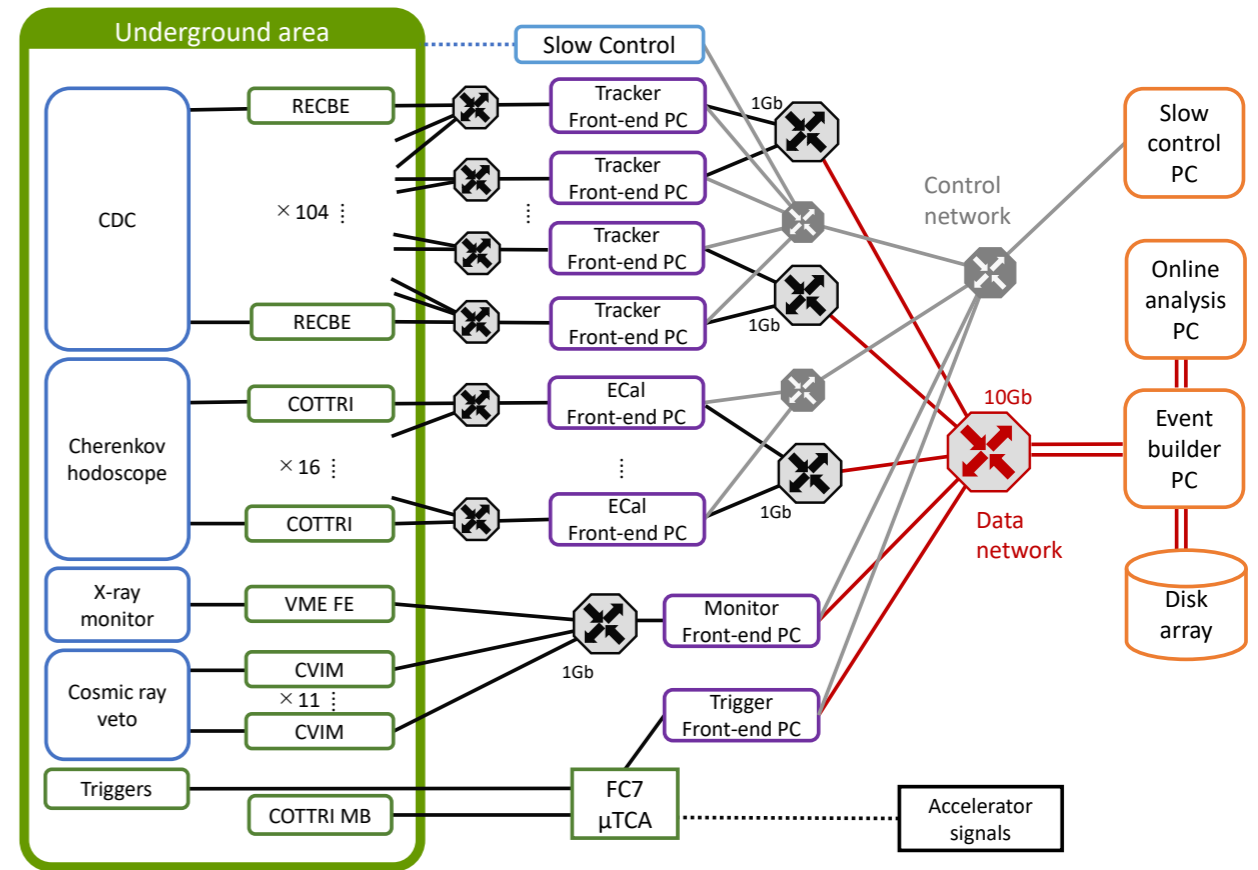
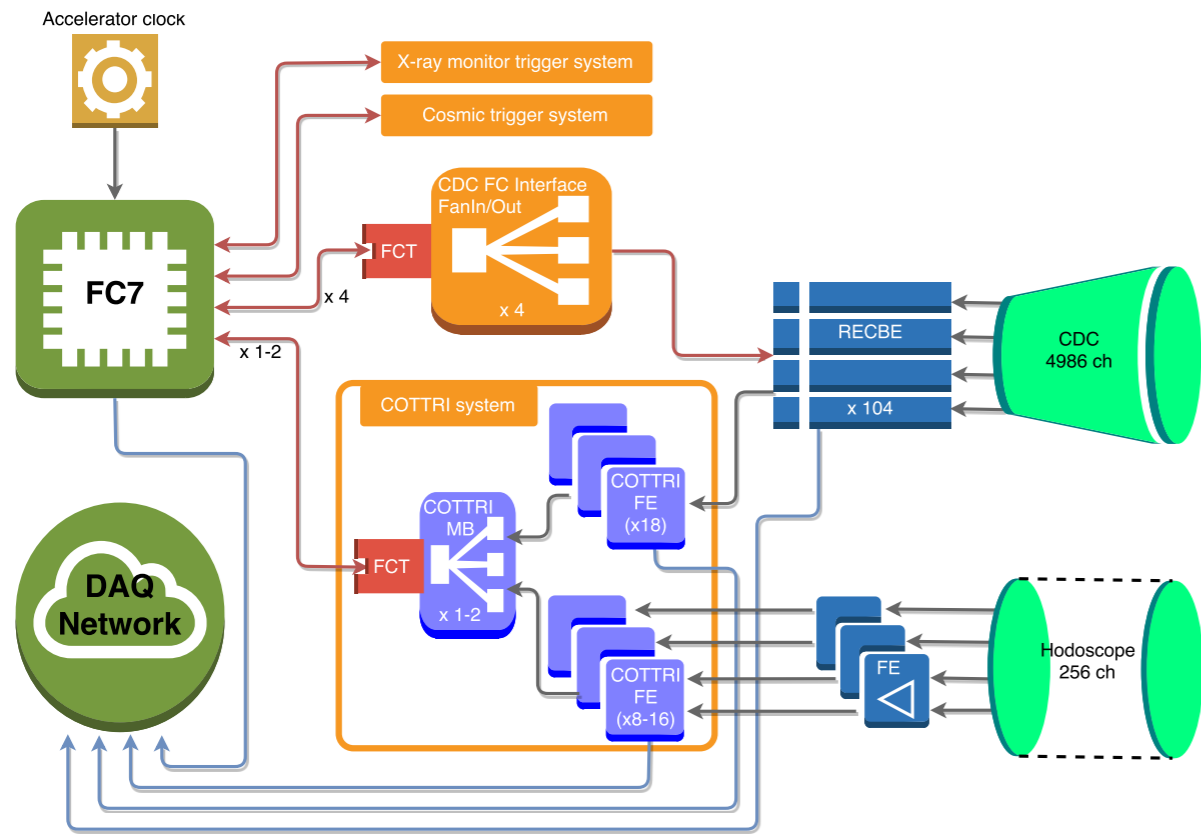
to be confirmed by Phase-I Beam Measurement

Target dependence to discriminate interactions

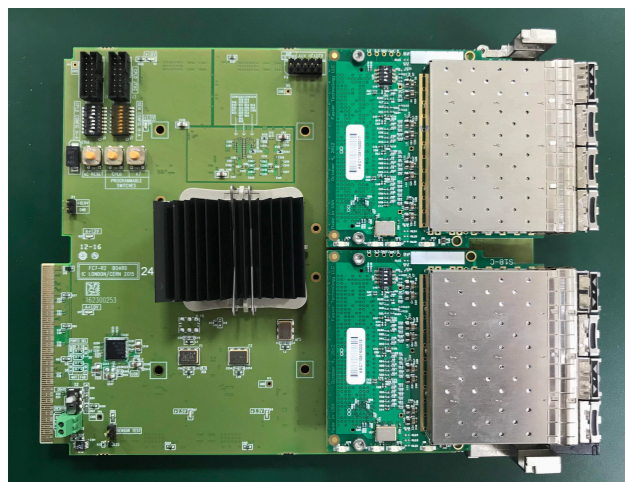


V. Cirigliano, R. Kitano, Y. Okada, and P. Tuzon, Phys. Rev. D 80, 013002 (2009).

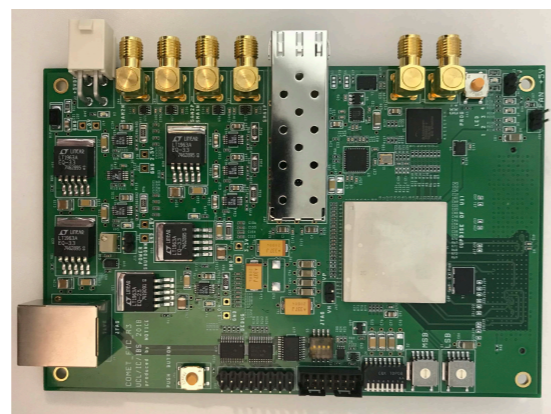
Trigger & DAQ



FC7



FCT



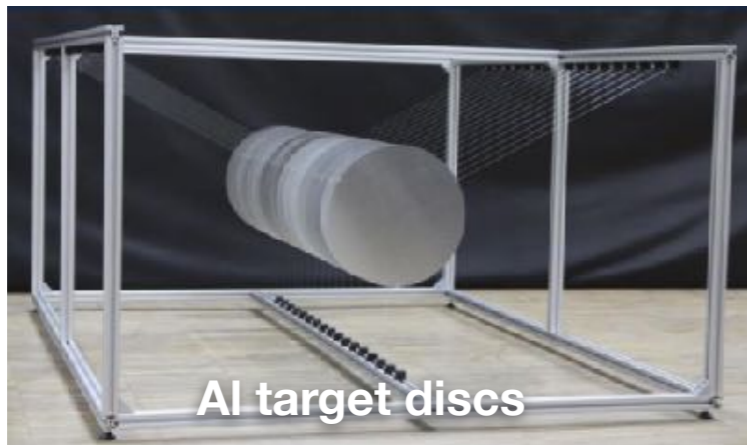
I/F board for FCT & RECBE



Muon Stopping Target

■ Stopping Target

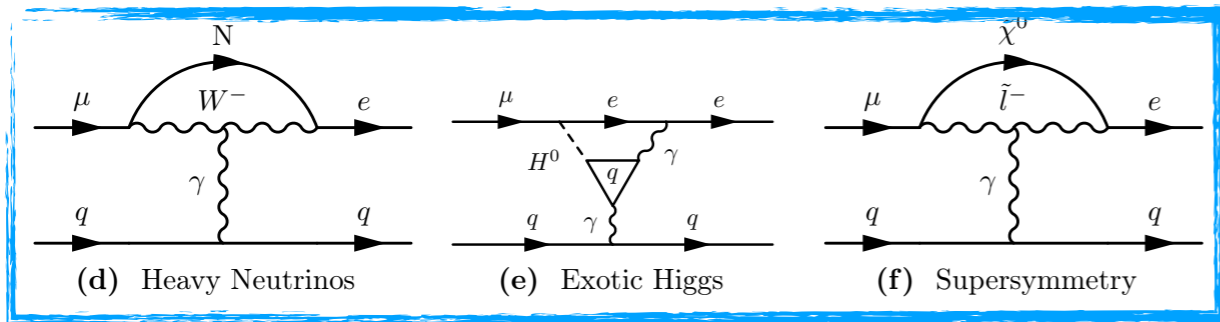
- **Al target** consists of 17 discs
- 100-mm radius, 0.2-mm thickness, 50-mm spacing.



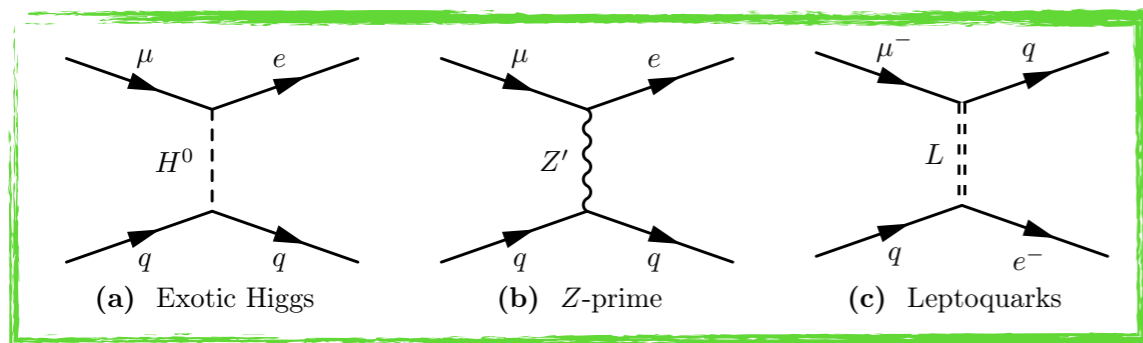
CLFV and New Physics

New Physics contributions

Photonic (dipole) term



4-fermion (contact) term

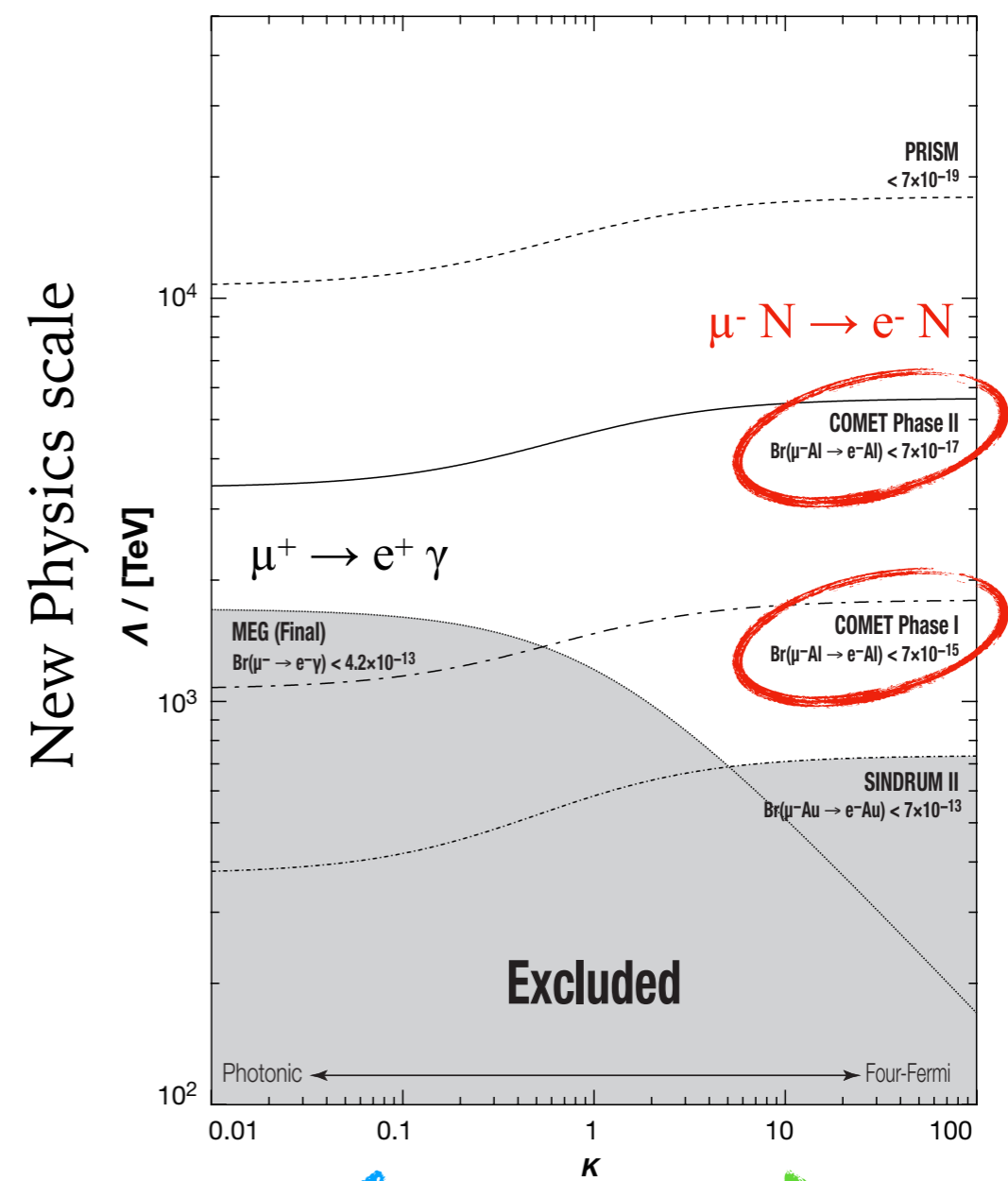


Effective Lagrangian

$$\mathcal{L} = \frac{1}{1 + \kappa} \frac{m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu} + \frac{\kappa}{1 + \kappa} \frac{1}{\Lambda^2} (\bar{\mu}_L \gamma^\mu e_L) (\bar{q}_L \gamma_\mu q_L)$$

Photonic

4-fermion



- ✓ Different measurements are complementary.
- ✓ μ - e conversion is sensitive to both contributions.

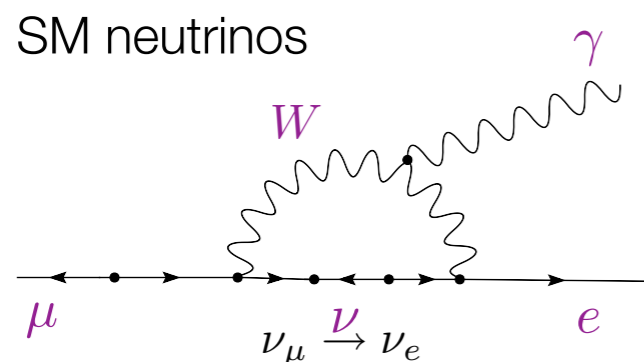
We can explore NP scale beyond 1000 TeV !!

Photonic ← → 4-fermion

Charged Lepton Flavor Violation in Muon

3 Major Processes

- $\mu^+ \rightarrow e^+ \gamma$
- $\mu^+ \rightarrow e^+ e^+ e^-$
- $\mu^- N \rightarrow e^- N$ (μ -e conversion)



$$B(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{i=2,3} U_{\mu i}^* U_{ei} \frac{\Delta m_{i1}^2}{M_W^2} \right|^2$$

$$\lesssim 10^{-54}$$

due to small mass ratio of neutrino to weak boson

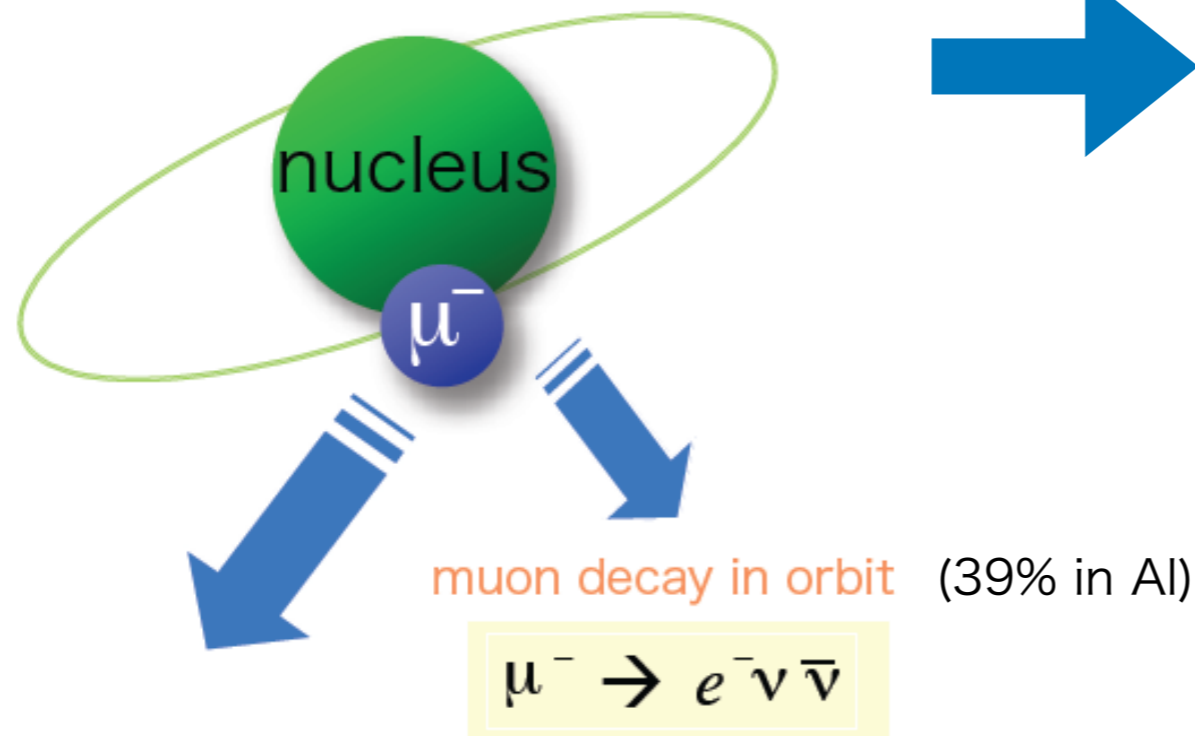
Since the SM contribution is negligibly small,

Observation of CLFV indicates a clear evidence of **New Physics**.

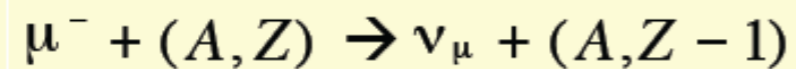
Muon-to-electron conversion

Fate of muonic atom

1s state in a muonic atom



nuclear muon capture (61% in Al)



μ-e conversion



single mono-energetic electron

$$E_{\mu e} = m_\mu - B_\mu - E_{\text{rec}} = 104.97 \text{ MeV for Al}$$

Current upper limit

SINDRUM-II, EPJ C47, 337 (2006)

$$\text{Br}(\mu^- \text{ Au} \rightarrow e^- \text{ Au}) < 7 \times 10^{-13}$$

