COMET status and plans

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on behaf of the COMET collaboration

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Outline

- Introduction
- Muon to electron conversion
- What is COMET experiment?
- COMET preparation status and plans

Introduction

The discovery of a Higgs boson at the LHC in 2012 provided the missing piece in the Standard Model (SM) to explain electroweak symmetry breaking. However there remain many shortcomings in the SM's description of nature, notably: the lack of a dark-matter candidate, no explanation for the observed matter antimatter asymmetry in the universe, no quantum theory of gravity, no explanation for neutrino masses, ...

- So perhaps Standart Model is only a part of a bigger picture that includes new physics hidden deep in the subatomic world.
- New information from different experiments will help us to find more of these missing pieces.
- All these phenomena highlight the need for physics beyond the SM (BSM) and many of these models predict charged lepton flavour violation (CLFV).

Introduction

- In the SM, neutrinos are massless by construction, and all lepton numbers are conserved; in particular, the SM Lagrangian is invariant under a global $U(1)_e \times U(1)_\mu \times U(1)_\tau$ lepton field rotation.

$$L_e(e^-, \nu_e) = +1,\ L_\mu(\mu^-, \nu_\mu) = +1,\ L_\tau(\tau^-, \nu_\tau) = +1$$

$$L_e(e^+, \bar{\nu}_e) = -1,\ L_\mu(\mu^+, \bar{\nu}_\mu) = -1,\ L_\tau(\tau^+, \bar{\nu}_\tau) = -1$$

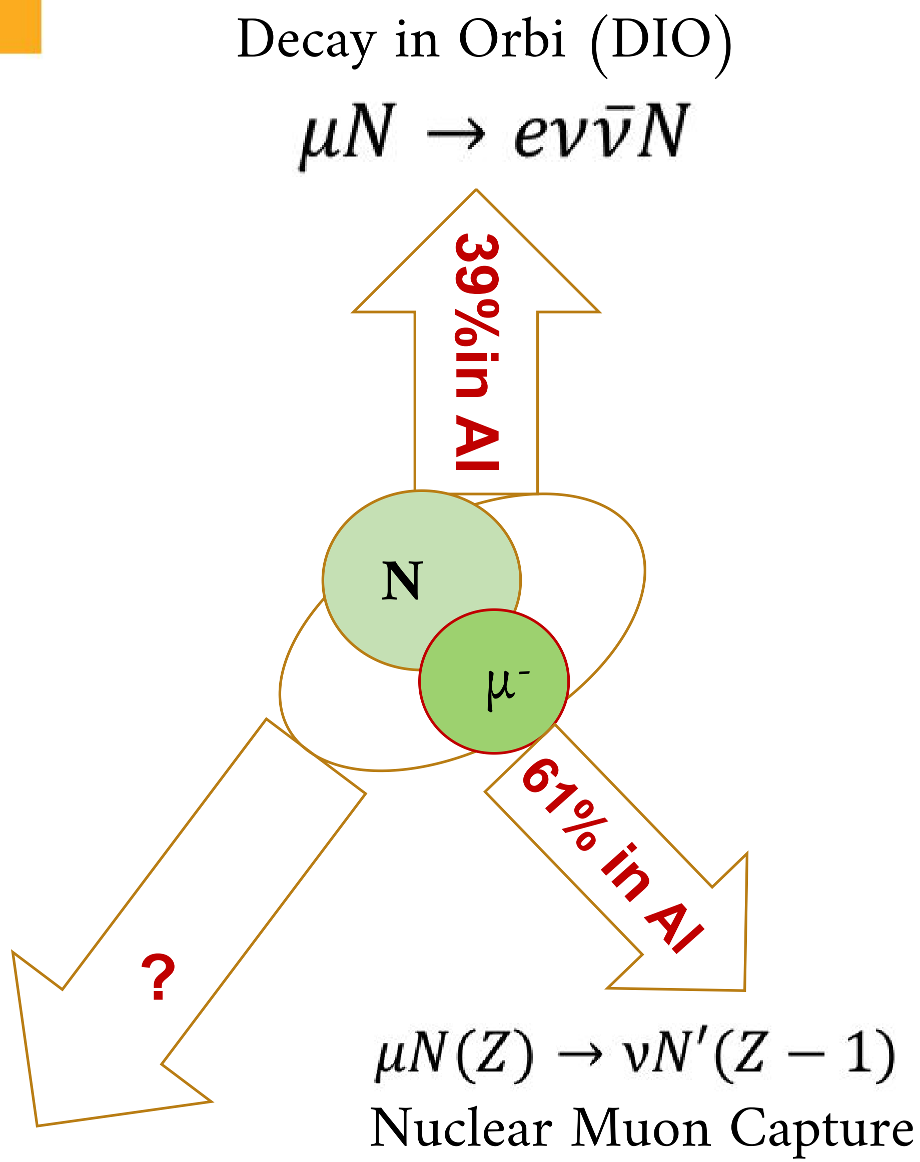
- Moreover, the total lepton number, $L_{total} = L_e + L_\mu + L_\tau$ is also a conserved quantity.
- On the other hand, the lepton flavor violation (LFV) among neutrino species has been experimentally confirmed with the discovery of neutrino oscillations. The observation of neutrino oscillations implies that neutrinos are massive, and that neutral lepton flavours are not conserved hence the SM must be modified so that charged lepton flavor violating (CLFV) can occur.

Muon to electron conversion

The cLFV processes are not forbidden in the SM. But they are extremely suppressed due to the small neutrino mass ($Br<<10^{-54}$) so any signal is a clear indication of new physics(NP). NP scenarios typically give CLFV rate much higher than SM.

One of the most important muon LFV processes is coherent neutrinoless conversion of muons to electrons so called μ^- – e^- conversion.

When a negative muon is stopped by some material, it is trapped by an atom, and a muonic atom is formed. After it cascades down energy levels in the muonic atom, the muon is bound in its 1s ground state.



Experimental signature

Mono-energetic electron

$E_e = m_\mu - m_e - E_{binding}$ = 104,97 MeV (Al target)

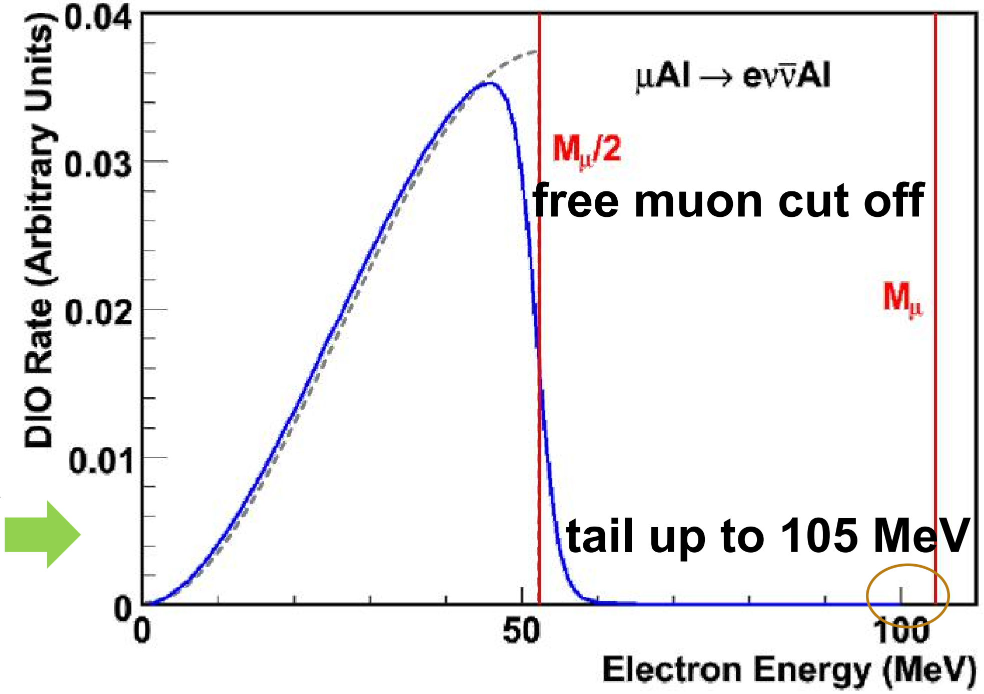
$$\mu^- + (Z,A) \rightarrow e^- + (Z,A)$$

Main Background

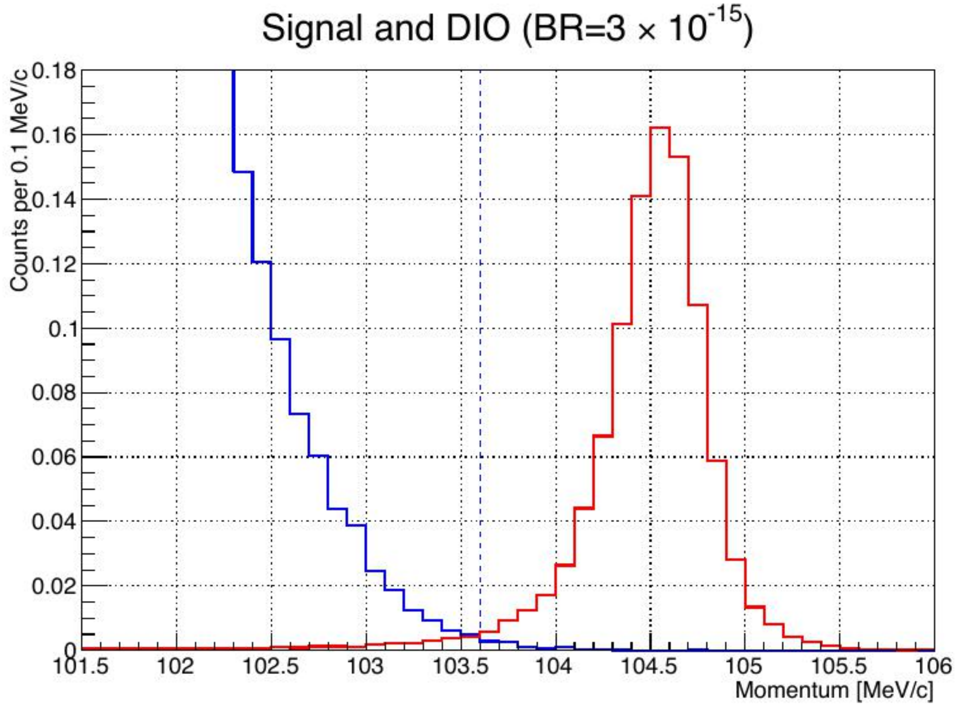
- **Muon Decay in Orbit (DIO)** → **Solution: Momentum resolution!**

$$\mu N \rightarrow e\nu\bar{\nu}N$$

In order to reduce the DIO contribution down to O(10^{-16}), the lower side of the momentum region for μ–e conversion signals should be above about 103.6 MeV for aluminium.



DIO electron energy spectrum

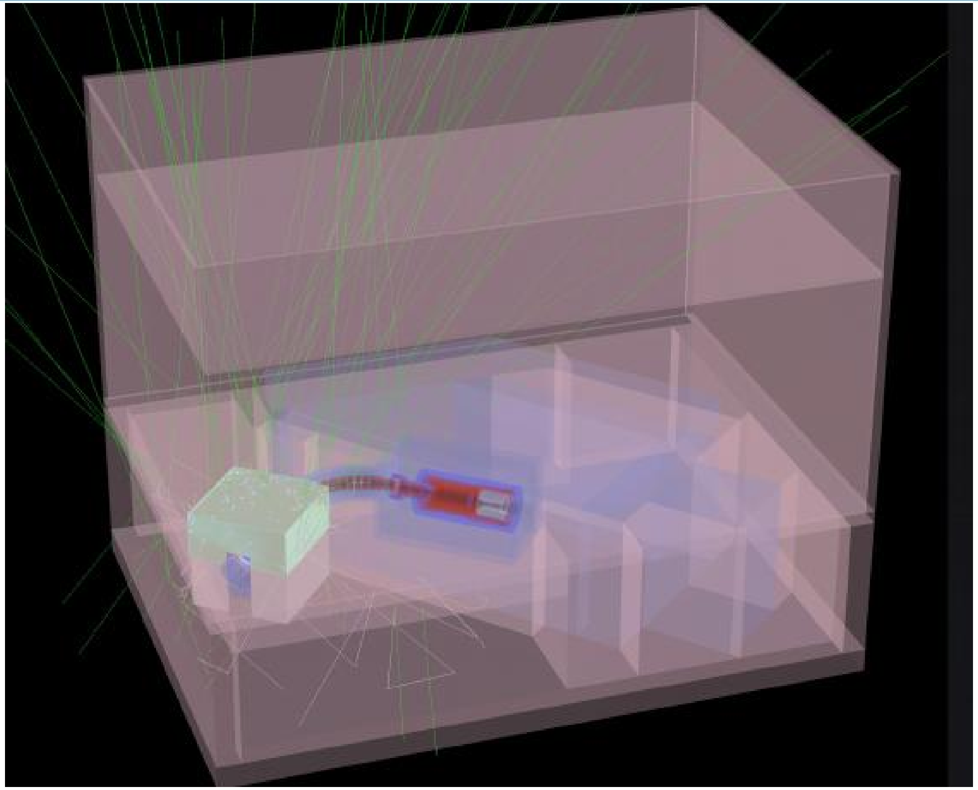


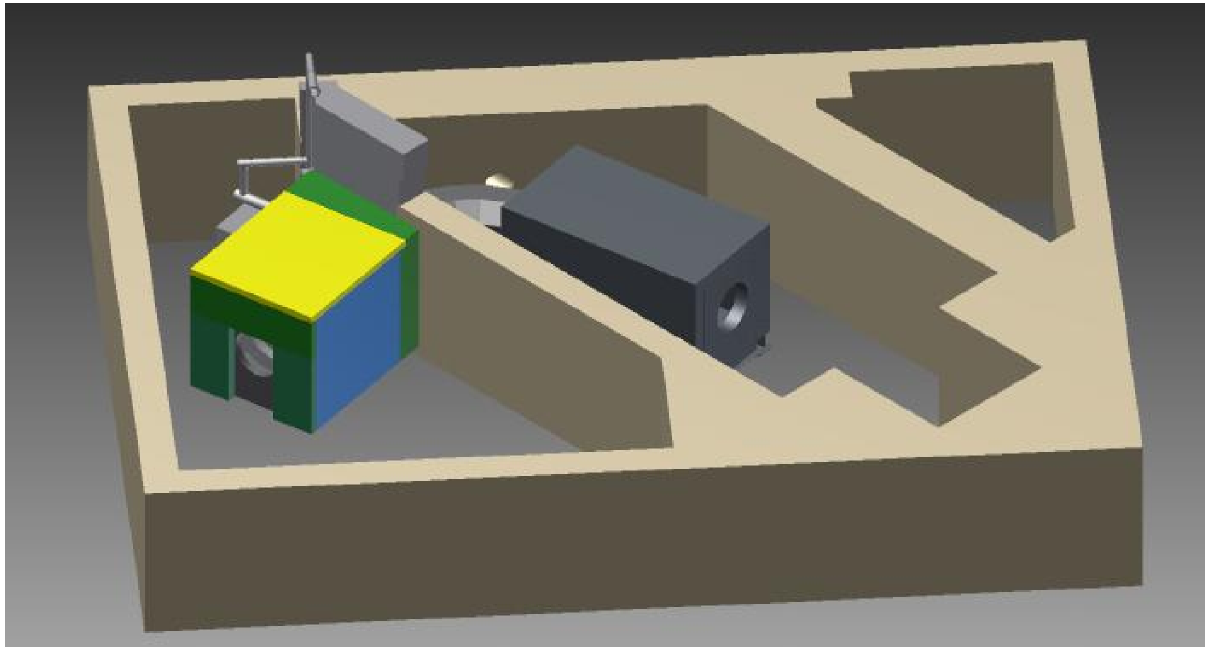
The momentum distributions for the reconstructed μ–e conversion signals and reconstructed DIO events. The vertical scale is normalized such that the integral of the signal curve is equal to one event. This assumes a branching ratio of B(μN → eN) = 3.1 × 10^{-15}.

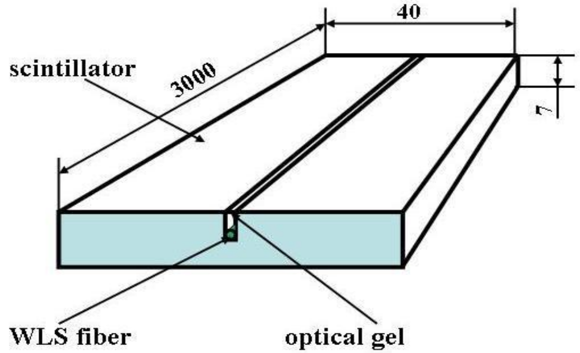
Backgrounds

- **Cosmic Ray** ⟶ **Solution: CRV !**

CR muons can decay in flight or interact with the materials around the area of the muon-stopping target producing signal-like electrons in the detector region. The Cosmic Ray Veto (CRV) based on the scintillator counters must identify CR muons and provide a rejection power of about 10^{-4} for them.







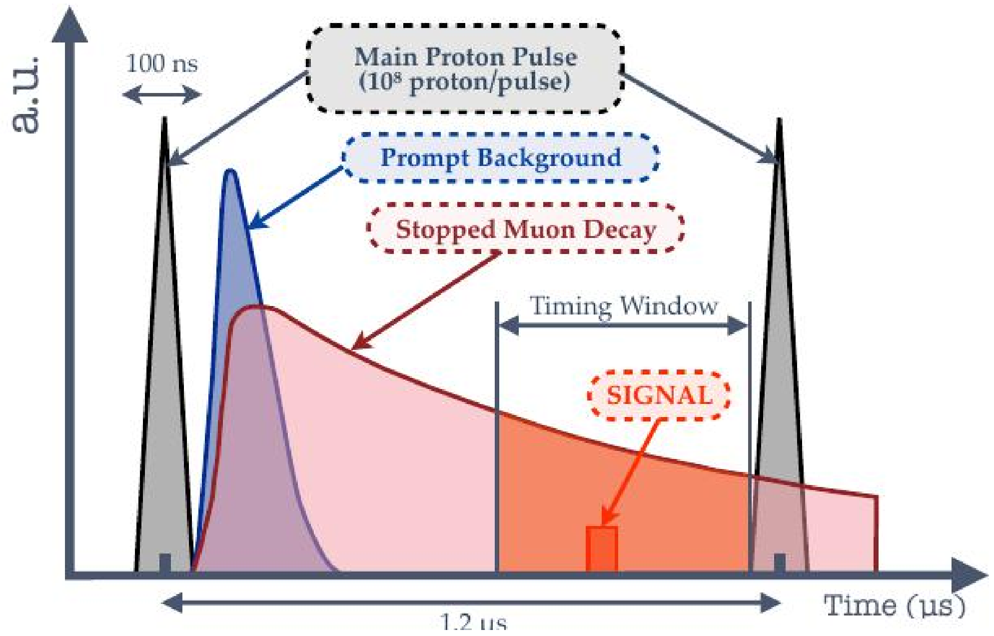
Each side of CRV consists of 4 layers of strips

Backgrounds

- **Beam backgrounds** ⟶ **Solution: Pulsed beam + delayed time wimdow !**

Significant number of prompt e – and π – produced by beam.

In order to suppress the occurrence of such background events, a pulsed proton beam, where proton leakage between pulses is extremely reduced, is proposed. Since a muon in a muonic atom of Aluminium has a lifetime of 864 ns, a pulsed beam with a shorter beam width compared to this lifetime, and a beam repetition comparable to or longer than a muonic atom lifetime would allow removal of prompt beam background events by performing measurements in a delayed time window.



COMET Experiment

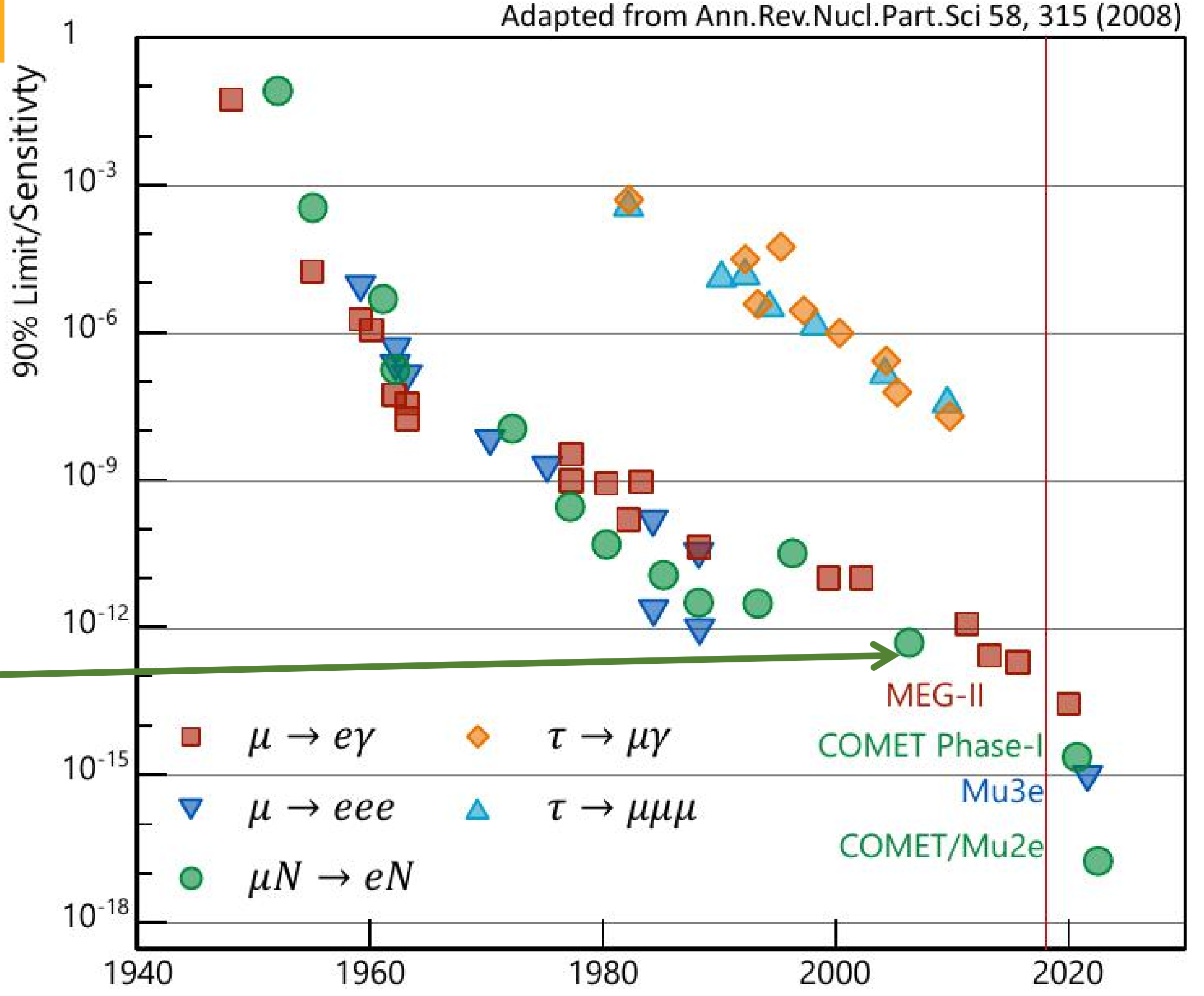
COMET - COherent Muon to Electron Transition

search for μ–e conversion in the field of an aluminium nucleus, $\mu^{-}N \rightarrow e^{-}N$, with a single event sensitivity (SES) of 2.6×10^{-17}

Recent upper limit : 7×10^{-13} (SINDRUM-II at PSI)

COMET goal:
improvement 10,000 !!!

P.s. Now the additional improvement of the SES by one order of magnitude are being considered.



Time evolution of the accuracy increasing of the existing and prospective experiments searching for the CLFV processes

COMET collaboration

COMET Phase-I Technical Design Report: Part 1

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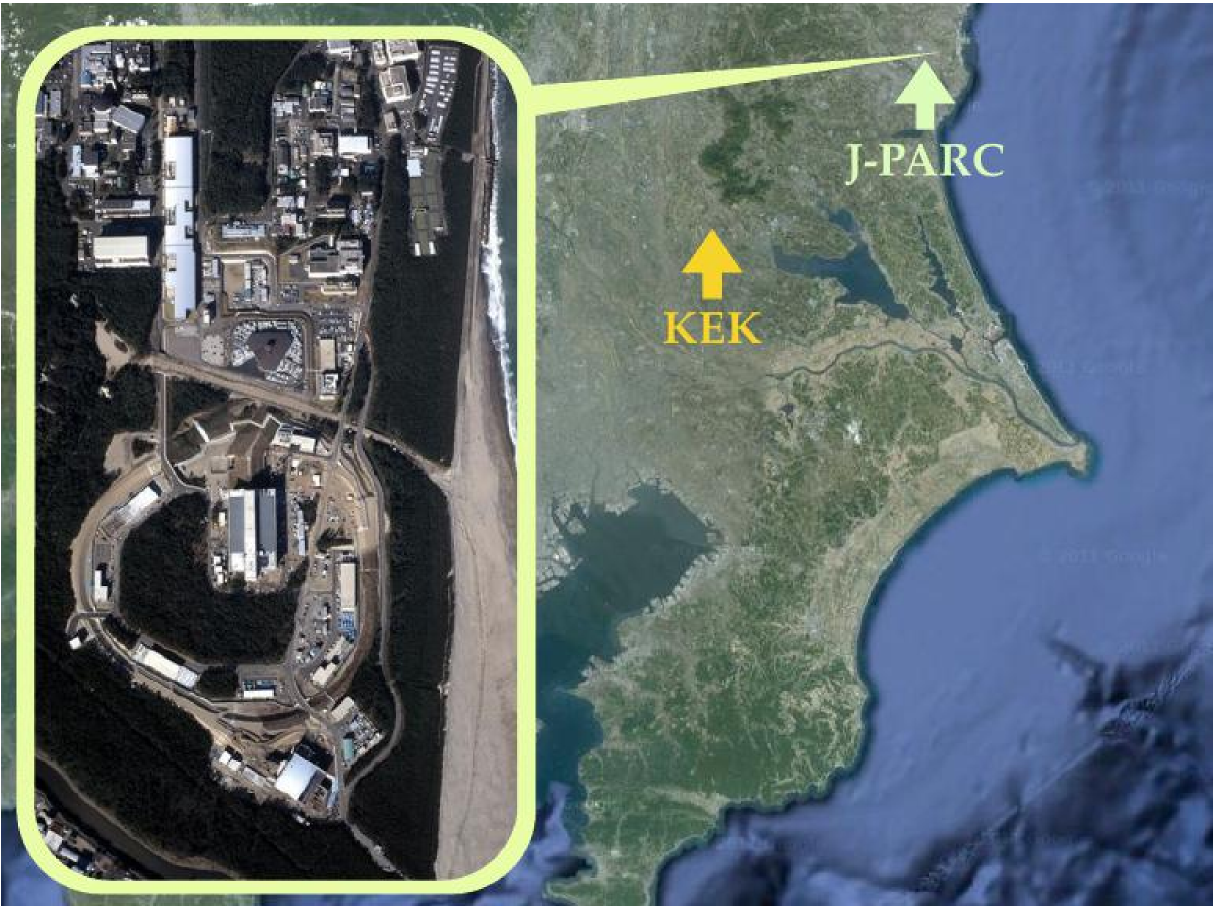
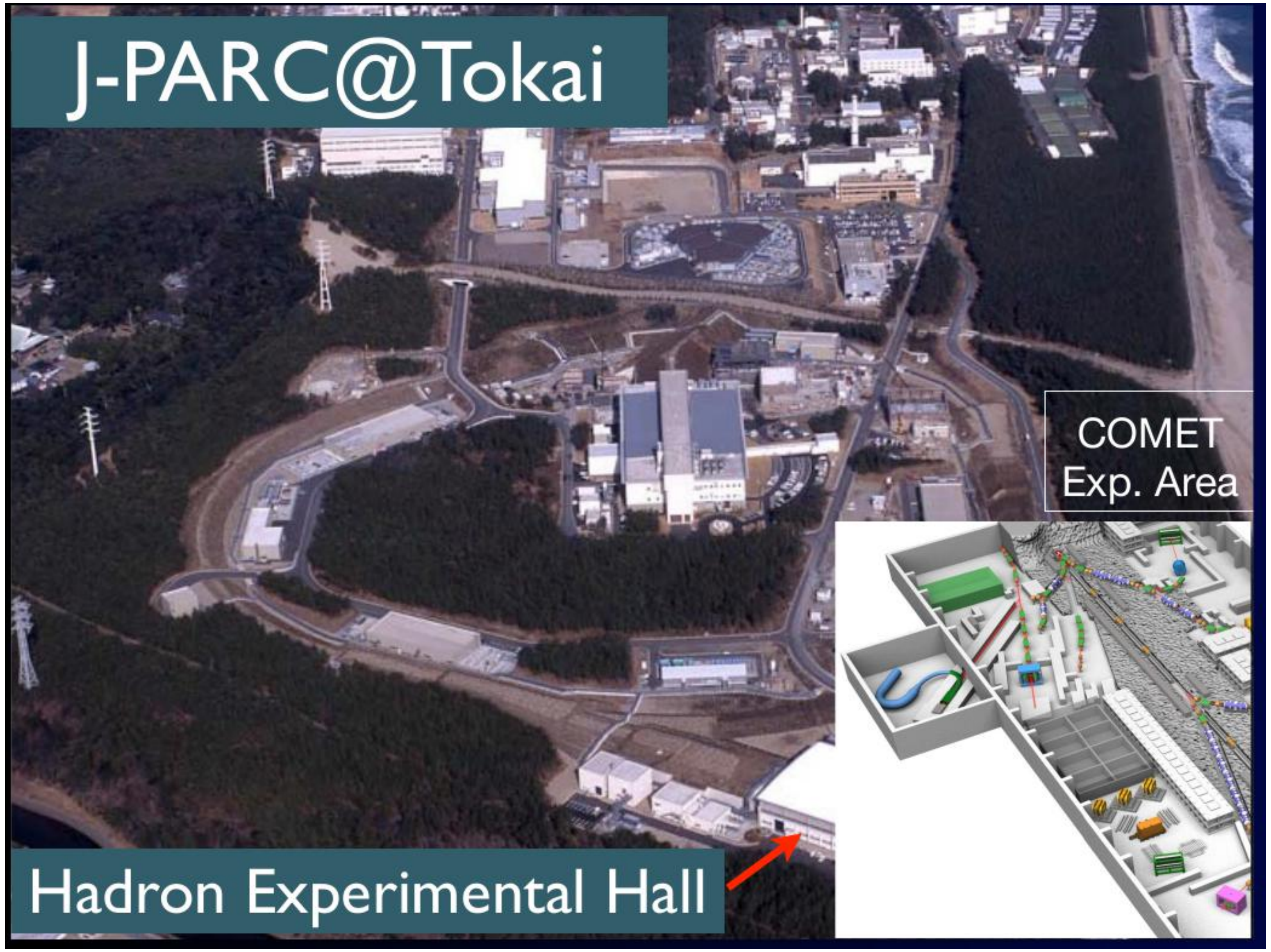
Y. Yuan,[13] Yu. V. Yudin,[3,34] M. V. Zdorovets,[14] J. Zhang,[13] Y. Zhang,[13] and K. Zuber[43]
(The COMET Collaboration)

about 200 collaborators
41 institutes, 17 countries

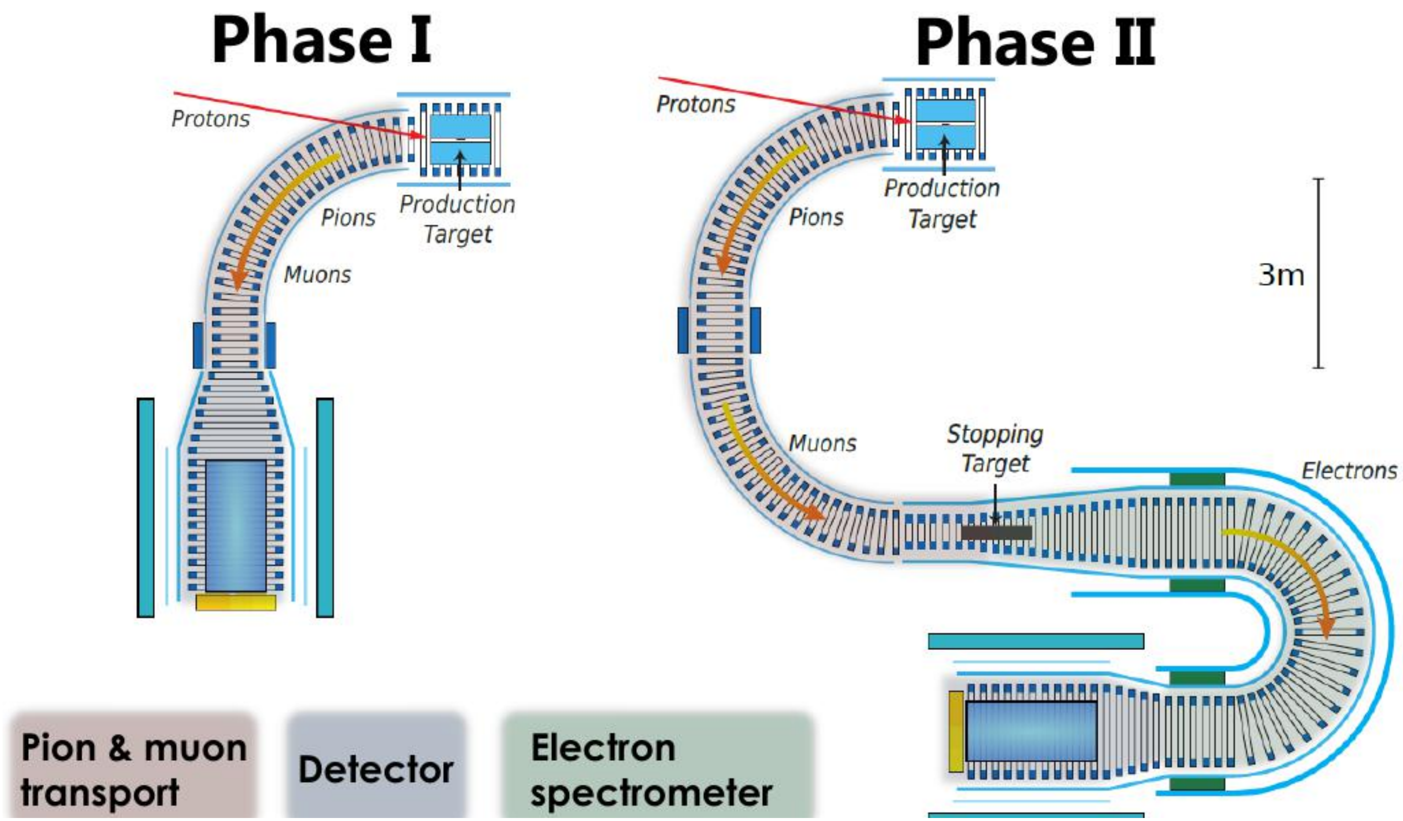
COMET experiment

COMET experiment will be carried out at the Japan Proton Accelerator Researcn Complex (J-PARC) in Tokai, Japan.





Parameter	Phase-I	Phase-II
Bending	90^0 (beam)+0^0(detector)	180^0 (beam)+180^0(detector)
Beam power	3.2 kW (8 GeV)	56 kW (8 GeV)
Running time	$9.5 \bullet 10^6$ sec	$2 \bullet 10^7$ sec
POT	$3.2 \bullet 10^{19}$	$8.5 \bullet 10^{20}$
Stopped muons on target	$1.5 \bullet 10^{16}$	$2 \bullet 10^{18}$
S.E.S.	$3.1 \bullet 10^{-15}$	$2.6 \bullet 10^{-17}$



The COMET experiment will be carried out using a two-staged approach.

1. Powerful pulsed proton beam by J-PARC
2. High-eff. π-capture system
3. C-shape long/bending π/μ/e transports
4. High-resolution electron detector

1. Pions generated in the collisions of the 8 GeV protons with a production target.
2. Pions captured by solenoid.
3. Pions will decay to muons as they are transported to the muon stopping target in the detector solenoid

COMET PHASE-I

Physics Sensitivity for COMET phase-I

$$BR(\mu^- + Al \rightarrow e^- + Al) = 3.1 \times 10^{-15}$$

$$BR(\mu^- + Al \rightarrow e^- + Al) \sim \frac{1}{N_\mu \cdot f_{cap} \cdot A_e}$$

8 GeV, 3.2 KW proton beam

N_μ : # of stopping muons in the muon stopping target

f_{cap} : fraction of muon capture 0.6 for Al

A_e : detector acceptance = 0.04

$N_\mu = 1.5 \times 10^{16}$ number of stopped muons

Running time ~ 150 days

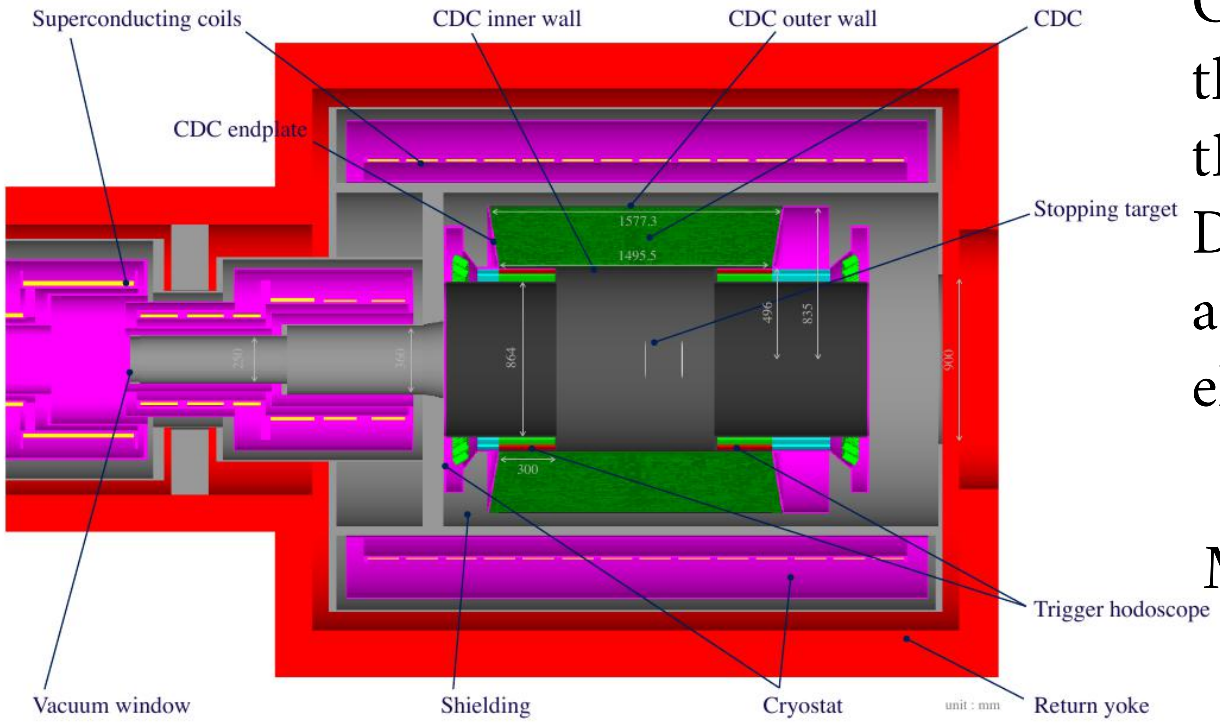
Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	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

Summary of the estimated background events for a single-event sensitivity of 3×10^{-15}

Goal of COMET PHASE-I

1. Search for μ-e conversion

- **a search for μ-e conversion at the intermediate sensitivity which would be 100-times better than the present limit (SINDRUM-II). The primary COMET Phase-I detector is composed of a a cylindrical drift chamber and a set of hodoscope counters for triggering and timing, called the CyDet detector.**



CyDet is located after the bridge solenoid in the muon transport section, and installed inside the warm bore of a large 1 T superconducting Detector Solenoid . The CyDet must accurately and efficiently identify and measure 105 MeV electrons whilst rejecting backgrounds.

Muon stopping target: 17 aluminum disks of 0,2 mm thickness and 100 mm radius with 50 mm spacing

CyDet

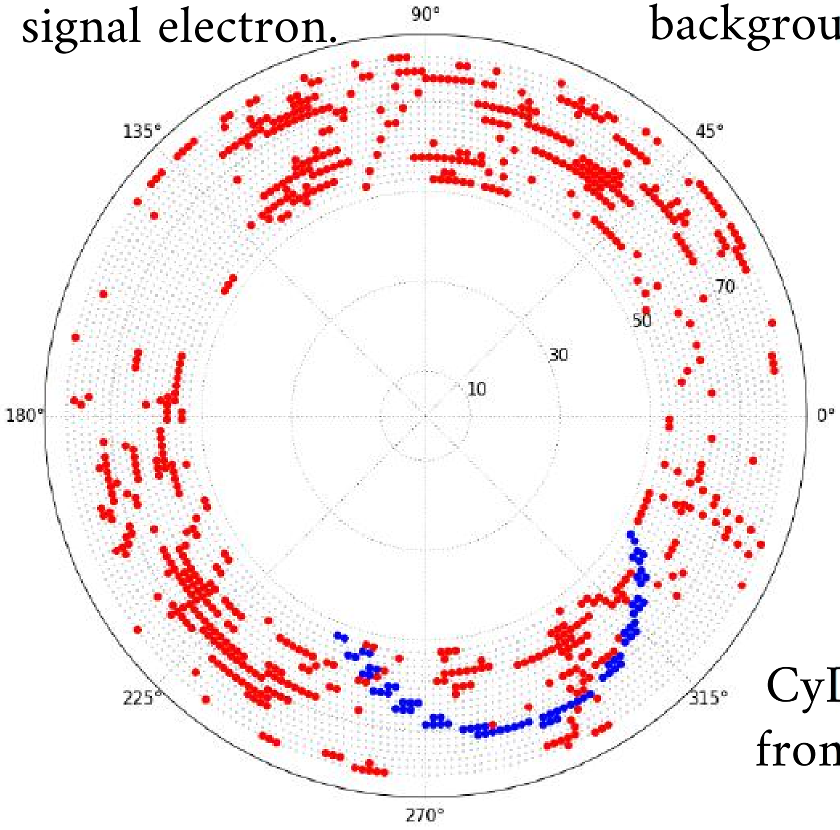
The main drift chamber parameters

Momentum resolution :
better 200 keV/c at 105 MeV/c

Inner wall	Length	1495.5 mm
	Radius	496.0∼496.5 mm
	Thickness	0.5 mm
Outer wall	Length	1577.3 mm
	Radius	835.0∼840.0 mm
	Thickness	5.0 mm
Number of sense layers		20 (including 2 guard layers)
Sense wire	Material	Au plated W
	Diameter	25 μm
	Number of wires	4986
	Tension	50 g
Field wire	Material	Al
	Diameter	126 μm
	Number of wires	14562
	Tension	80 g
Gas	Mixture	He:i-C_4H_{10} (90:10)
	Volume	2084 L

Blue hits correspond to the signal electron.

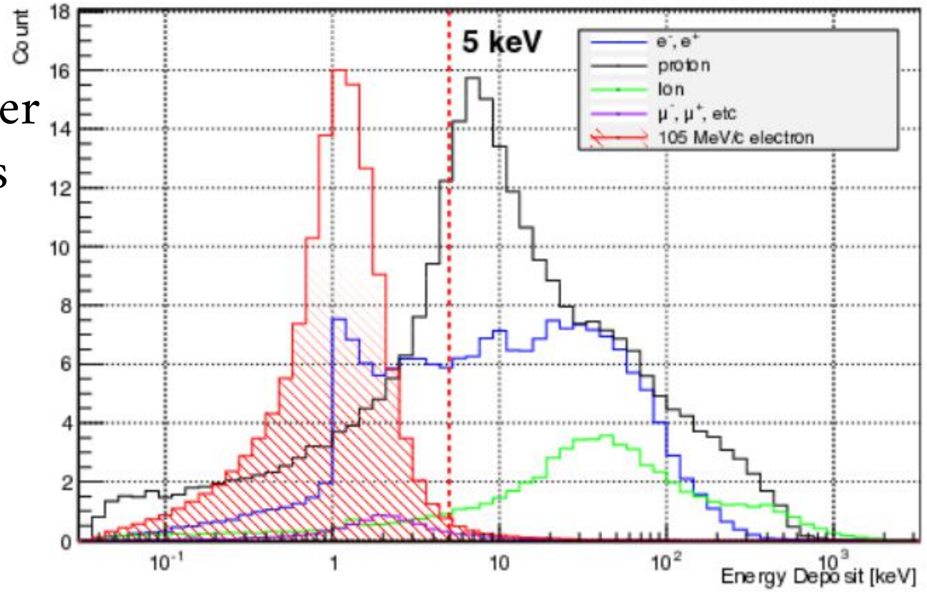
Red points are hits caused from background processes



CyDet event. This is a projected view from the central plane of the detector

Most background hits are rejected based on timing, charge.

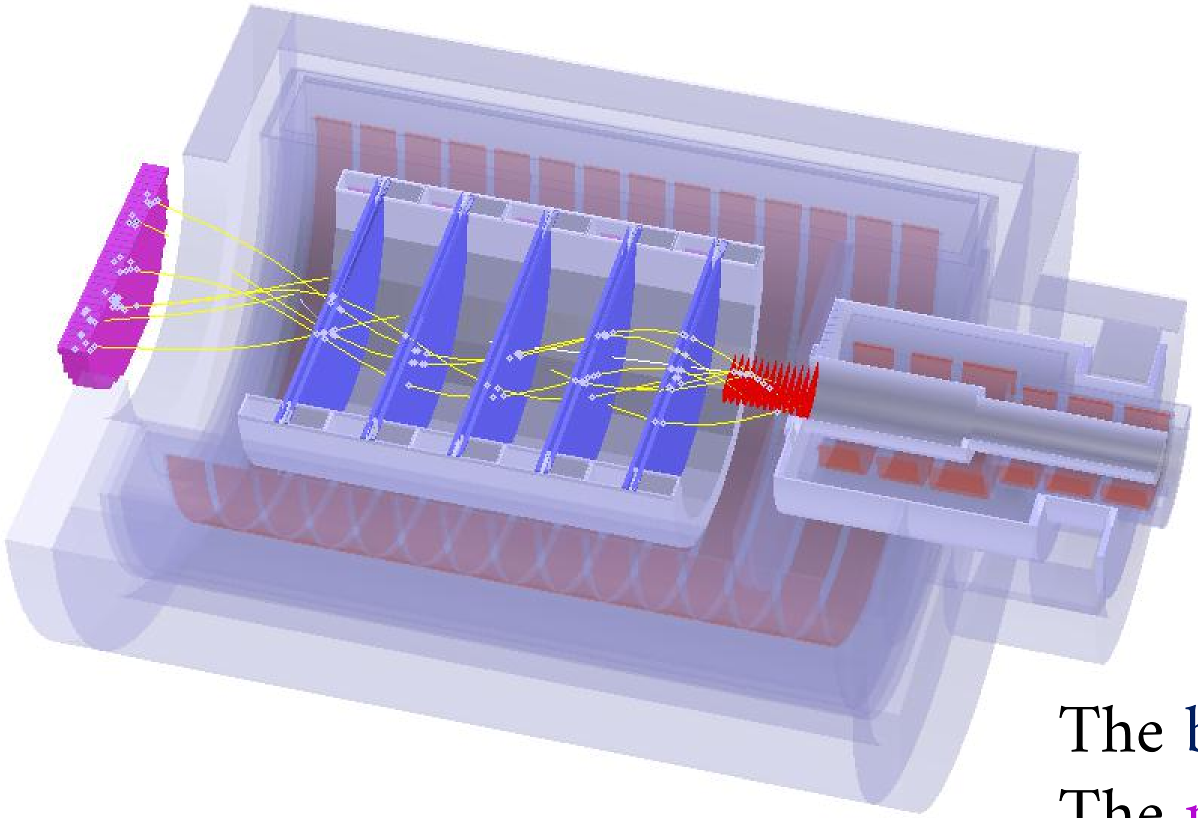
Total energy deposits per cell for signal electrons and noise hits



Goal of COMET PHASE-I

2. Background study for the full COMET (Phase-II)

- **Direct measurement of potential background for the full COMET experiment using prototypes of the Phase-II straw tracker and the electron calorimeter, called StrEcal detector.**



StrEcal detector

Prototype version detector for Phase- I will be install in vacuum and magnetic field of 1T in place of CyDet.

The blue – planes of the straw tubes

The pink – wall of the ecal crystals

StrEcal

Straw tracker

5 station, diameter 9.75 mm, gas mixture 50% Ar and 50% - C_2H_6 thickness 20 μm. (Phase-II diameter 5 mm, thickness 12 μm)

Main goal: Detecton of particle track in magnetic field

Requirements:

- Momentum resolution : σ_p< 200 keV/c for 105 Mev/c electron
- Spatial resolution < 200 μm

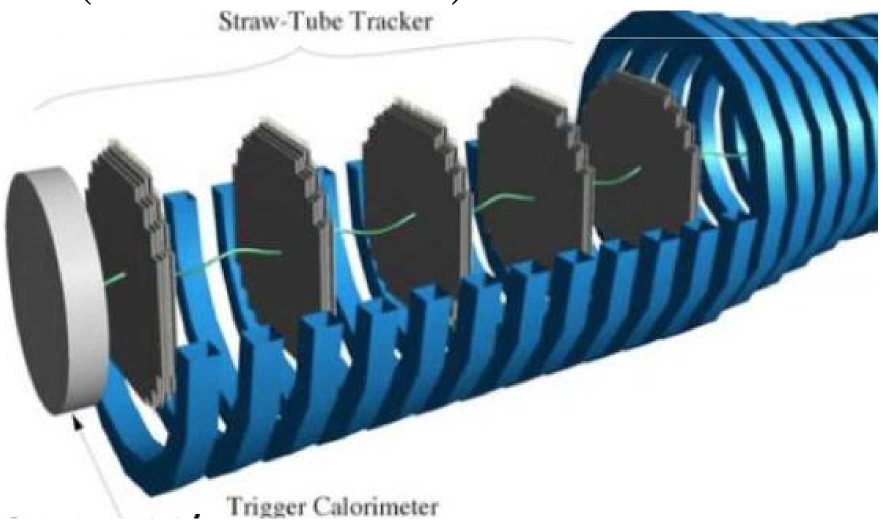
Ecal - consists of segmented scintillating crystals. LYSO crystals ($Lu_{1.8}Y_{.2}SiO_5$:Ce) 2x2x12 cm

Main goal:

- Measure the electron energy
- Provide particle indentification (E/p) with tracker;
- Ecal will also provide trigger signals

Requirements:

- Energy resolution < 5% for 105 Mev/c electron
- Time resolution <= 1 ns
- Cluster position resolution < 1 cm



COMET preparation status

Construction of the COMET building is completed!

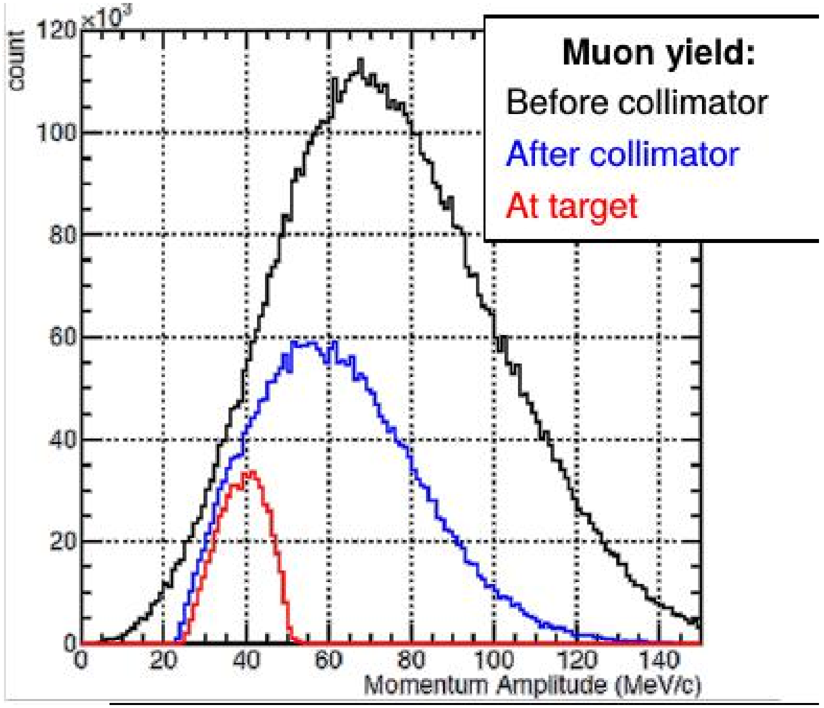
COMET preparation status

- **Main part of COMET transport solenoid is already installed in the COMET hall**

Transport solenoid

The selection of the electric charge and momentum of beam particles can be performed by using curved solenoids which is increasing by using a collimator.

The main goal:
- select low p-muons
- reject high p-muons

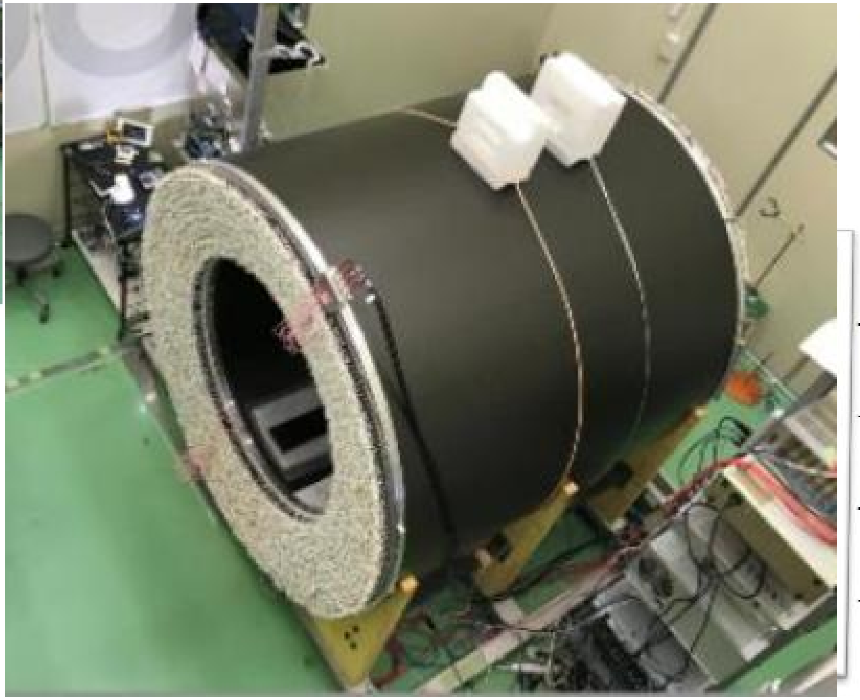


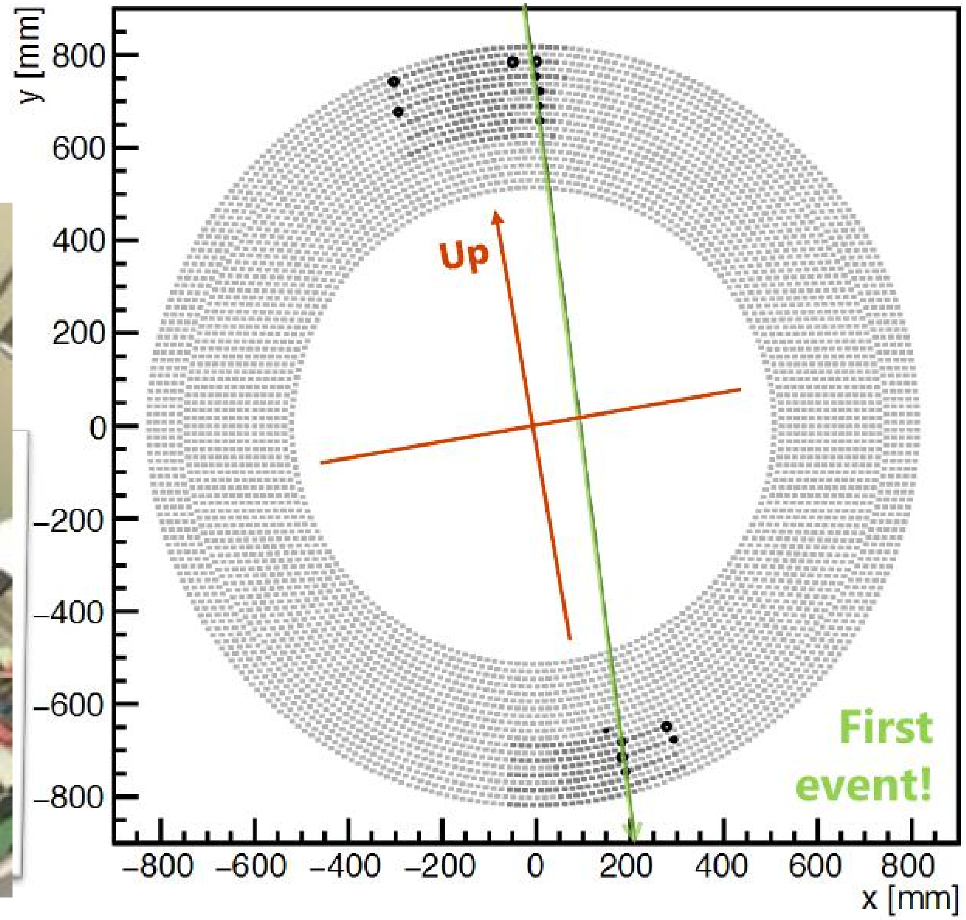
COMET preparation status

CDC constraction is finished. Cosmic Ray test of the setup at KEK is done.

Completion of COMET CDC

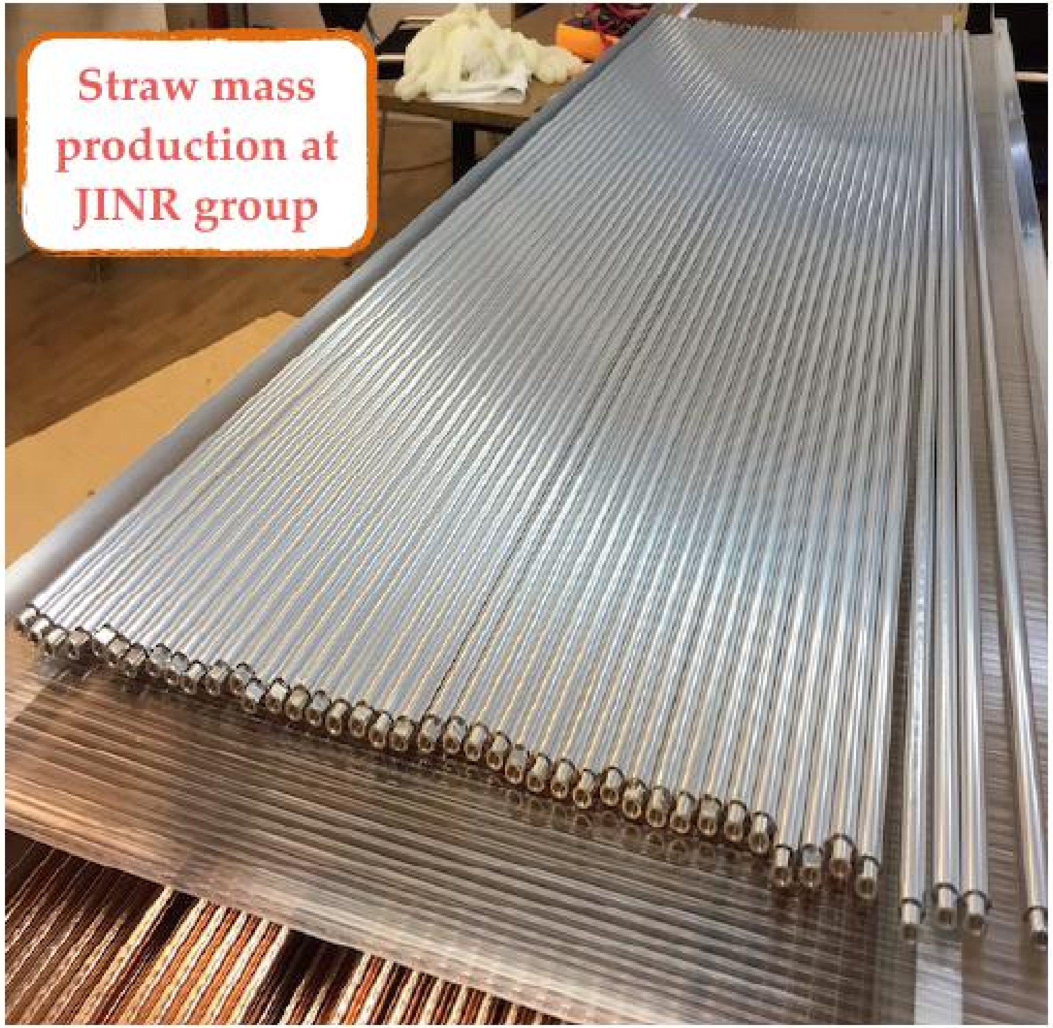
spacial resolution of **170 μm** & efficiency of **95%**

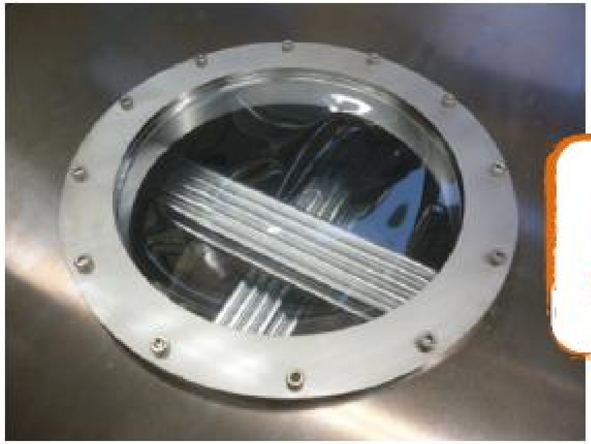




COMET preparation status

Straw mass production for Phase-I is finished at JINR group.



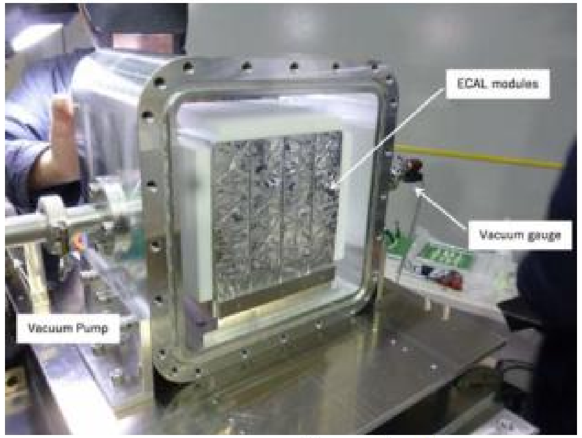


after closed
and pumped

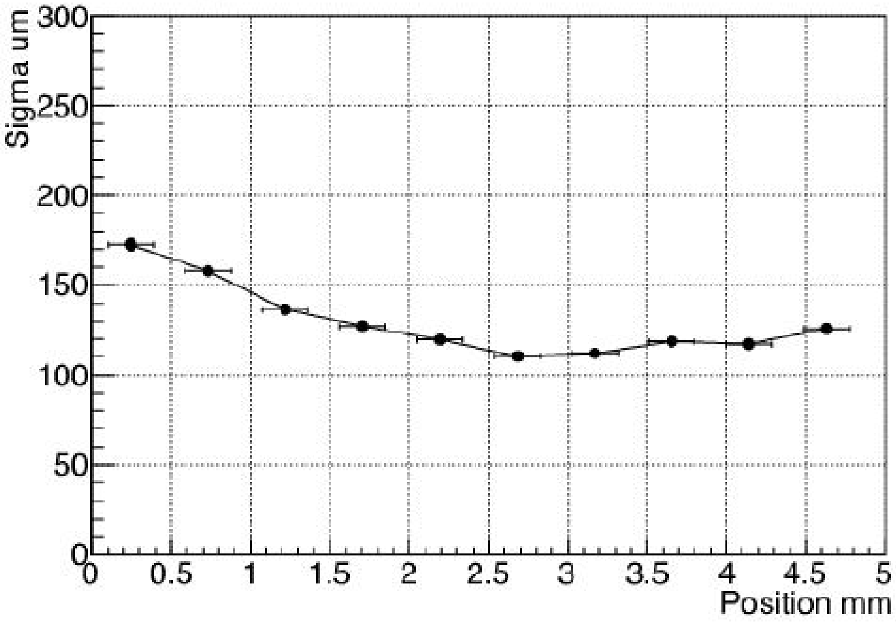
COMET preparation status

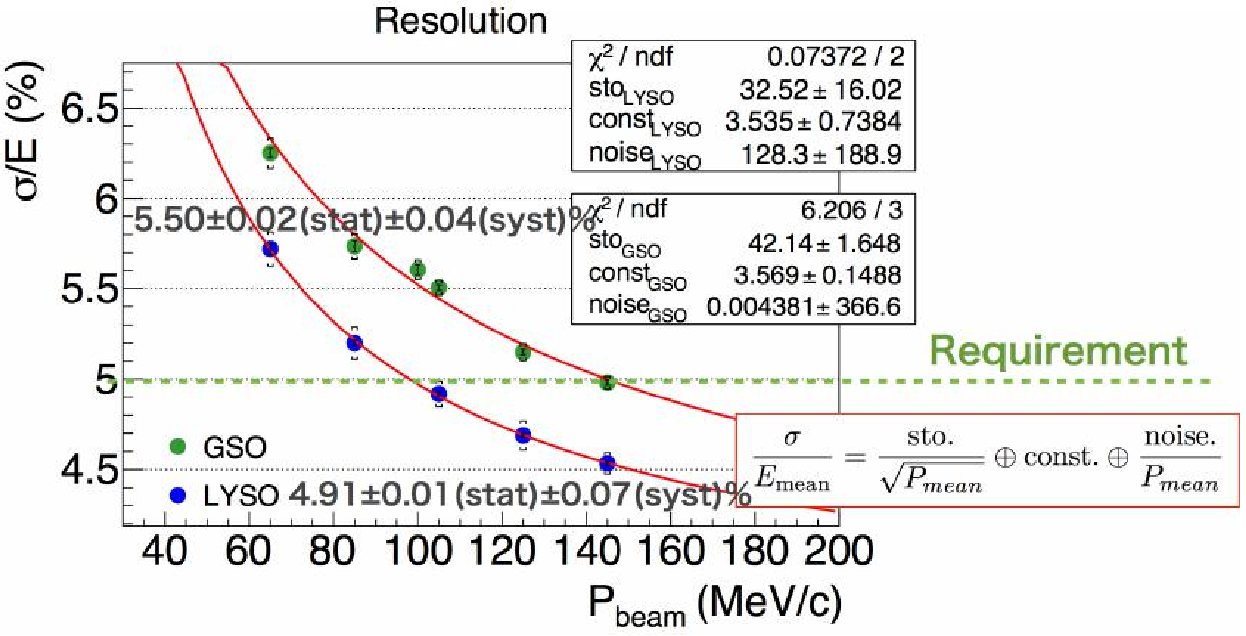
Straw tubes prototype

Ecal prototype



- The StrEcal prototype is successfully tested with electron beam and fulfill the requirements





Summary

- cLFV rate in the SM with non-zero neutrino mass is small to be observed in experiments.
- any signal is a clear indication of new physics
- **COMET experiment** search for μ–e conversion. The sensitivity goal of experiment is a factor of 10 000 better than current limit

COMET status

- Trigger and DAQ: the design in on finish line
- COMET building is completed, CDC constraction is finished.
- Radiation tests:
- the all components were irradiated by neutrons and gammas
- the selection of enough radiation hard components is almost done
- the final tests are in preparation
- The commissioning will start at 2020.