Search for The cLFV by Muon to Electron Conversion on COMET

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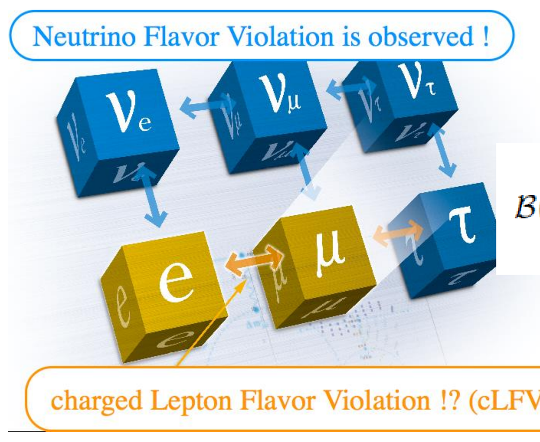
Introduction

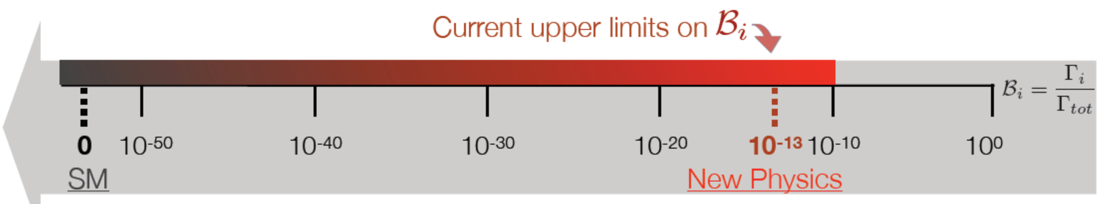
Charged Lepton Flavor Violation



cLFV highly suppressed in SM+m_ν:

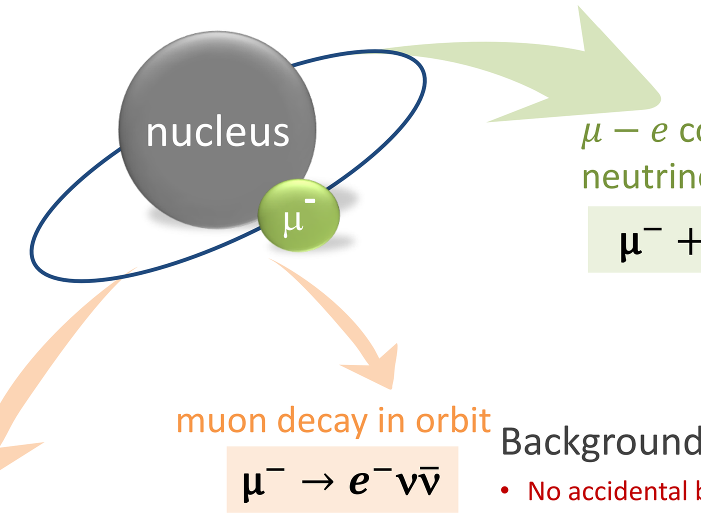
$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M_W^2}\right|^2 \sim 10^{-54}$$

S.T. Petcov, Sov.J. Nucl. Phys. 25 (1977) 340



μN → eN Conversion

1st state in a muonic atom



$\mu - e$ conversion:
neutrinoless muon nuclear capture

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

muon decay in orbit

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

Nuclear muon capture

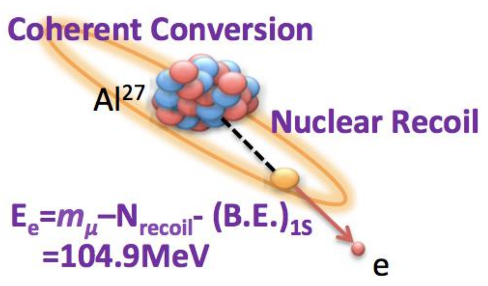
$$\mu^- + (A,Z) \to \nu_\mu + (A, Z-1)$$

Background signature
- No accidental background. Can utilize high luminosity
- Beam background can be suppressed by pulsed beam
- Physics background can be handled with current detector technology

What to Measure

$$R_{\mu e} = \frac{\mu^- + {}^{27}_{13}Al \to e^- + {}^{27}_{13}Al}{\mu^- + {}^{27}_{13}Al \to \text{nuclear capture}}$$

The ratio of muon to electron conversion to the total rate of muon captures by nuclei.

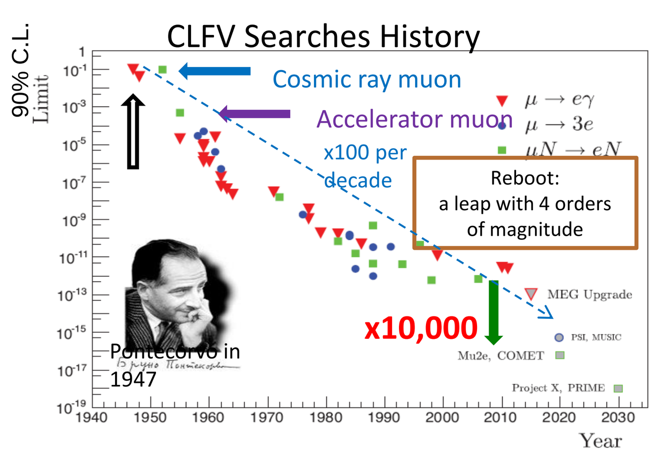


$E_e = m_\mu - N_{recoil} - (B.E.)_{1S}$
$=104.9$MeV

The experimental signature is a mono-energetic of **105MeV electron**

Clean field to search for new physics!

Muon CLFV Search History

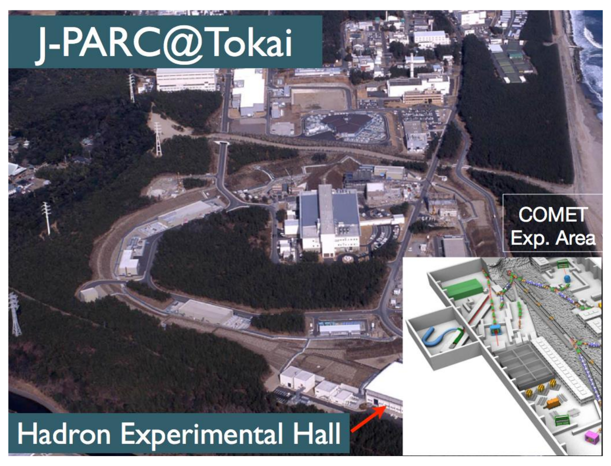


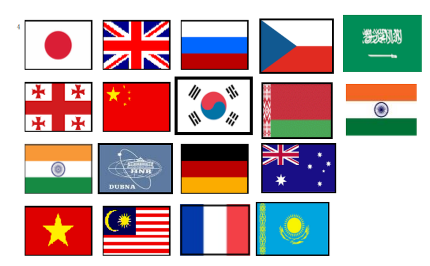
R. H. Bernstein & P. S. Cooper, Phys. Rept. 532 (2013) 27

- Current best limit : **MEG <4.2x10^{-13} (90%C.L.)**
- COMET goal <6x10^{-17} (90%C.L.)
- Next generation experiments ...

The COMET Experiment

The COMET(COherent Muon Electron Transition) experiment located in the Japan Proton Accelerator Research Complex (J-PARC) in Tokai, Japan.

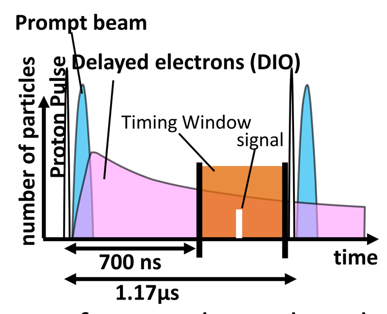




16+ countries,
39+ University or institute,
~200 collaborators

COMET Proton Beam

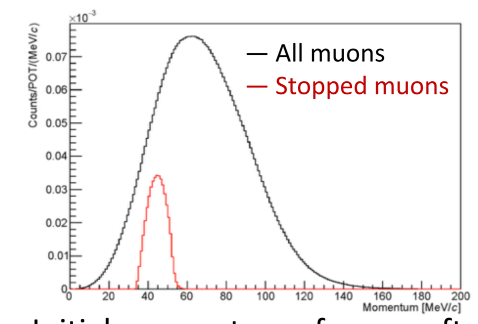
Bunched SX proton beam at 8 GeV.
- Extremely purely pulsed beam
  - Extinction factor < O(10^{-10}))
- Two-staged approach:
  - Phase I, 3.2 kW beam
  - Phase II, 56 kW beam



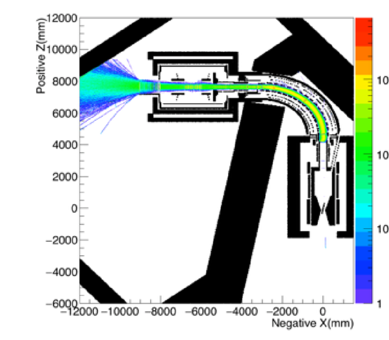
Time structure of proton beam bunch

COMET Muon Beam

- 90 degree and long muon transport solenoid



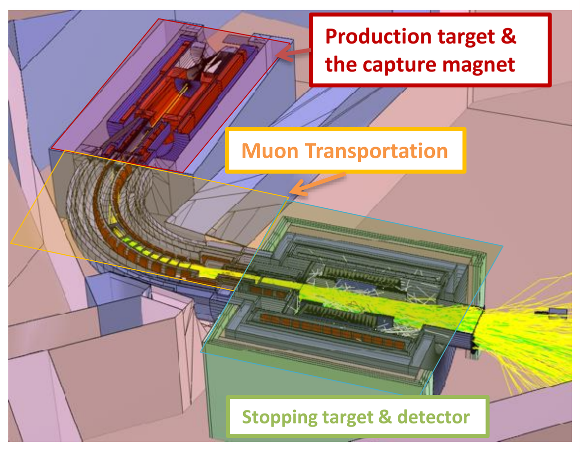
Initial momentum of muon after muon transport section and stopped



The bird view of muon beam intensity

Yield (per proton):	After muon transport section	Stopped in muon target
Muons	5.0×10^{-3}	4.7×10^{-4}
Pions	3.5×10^{-4}	3.0×10^{-6}

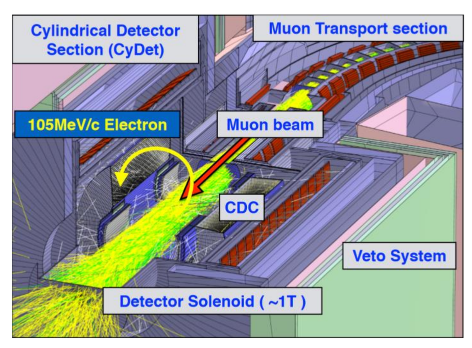
COMET Phase-I



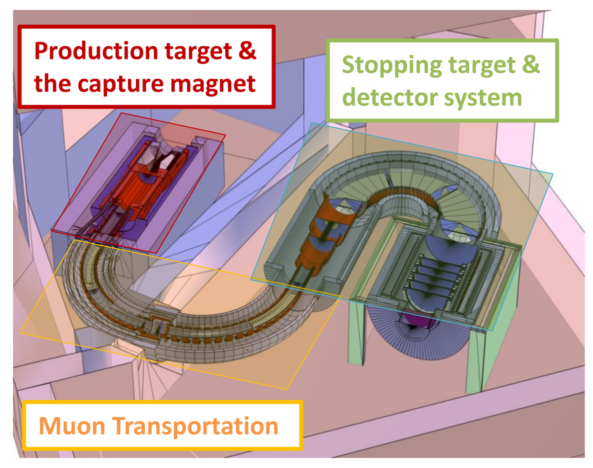
Graphite as pion production target
Search for μ-e conversion with SES of **3.1×10^{-15}**

Background measurements and Beam characterization

Detectors
drift chamber +Straw Tracker + ECAL

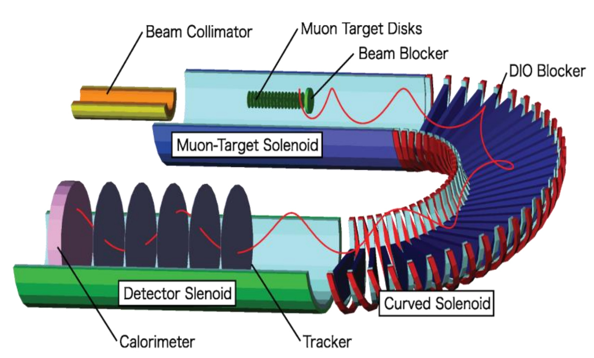


COMET Phase-II



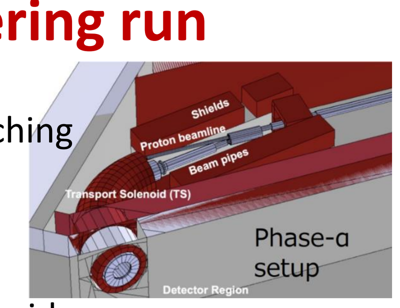
- **Tungsten alloy** as pion production target
- **Search for μ-e conversion** with SES **2.6×10^{-17}** which is 10,000 better than the current limit. The study to reach SES ~10^{-18} is in progress.

Detectors
- 12μm thin straw-tube tracker
- LYSO calorimeter providing trigger, TOF and PID



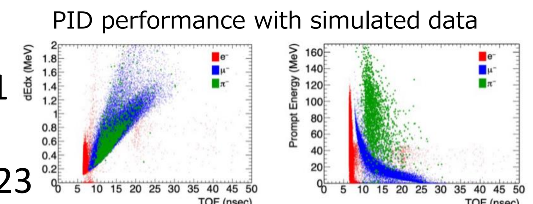
COMET Phase α: engineering run

- Estimate the number of muons(and $\pi^\pm$,$e^\pm$) reaching the muon stopping target
  - Backward production in the p+A @8GeV
  - Anti-proton production measurement
- Proton beam diagnostics w/o pion capture solenoid
  - Beam profile and extinction factor



Schedule
- 8GeV test & R_{ext} measurement in 2021
- Phase-α engineering run in JFY2022
- Phase-I detector commission in JFY2023
- Phase-I physics run in JFY2024

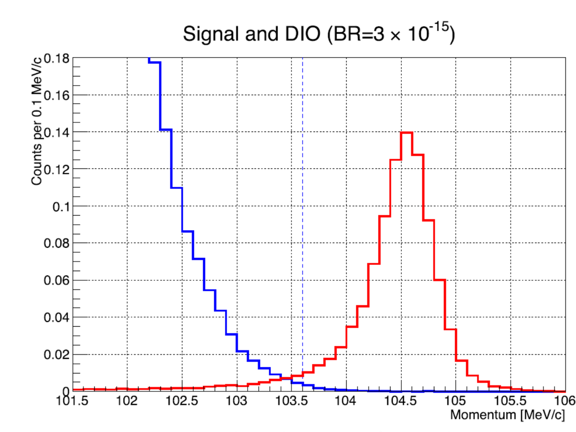
PID performance with simulated data



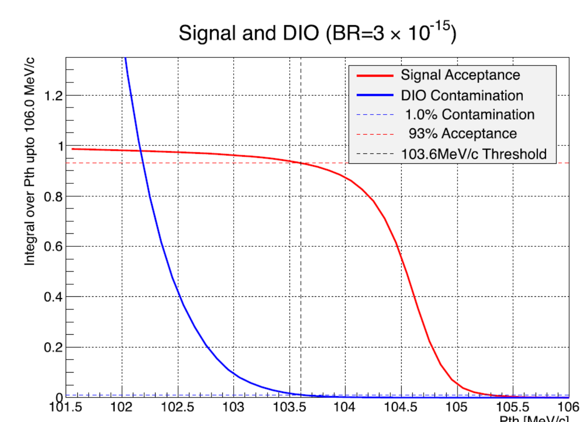
Phase-I Signal and Background

Background is estimated with Monte Carlo studies. TDR* was published

COMET Phase-I Single Event Sensitivity(S.E.S) =3.1 x 10^{-15} @
- Total acceptance of signal is **0.041**
- At momentum window p_e=103.6~106MeV/c, yielding a signal acceptance of **0.93**
- **Total excepted background= 0.032** with 99.99% CRV efficiency
- **Average trigger rate** ~10kHz trigger with drift chamber hits



Momentum distribution of signal and DIO



Signal and background acceptance

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 (ε_{time})	0.3
Total	0.041

Event selection efficiency

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
	Anti-proton induced backgrounds	0.0012
Others	Cosmic rays†	< 0.01
Total		0.032

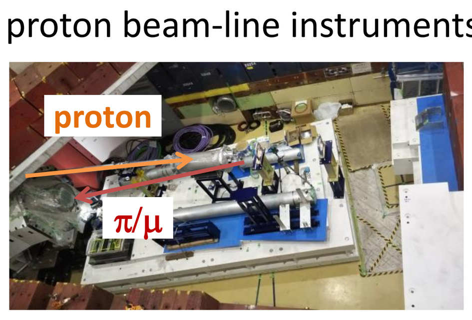
† This estimate is currently limited by computing resources.

Background estimation

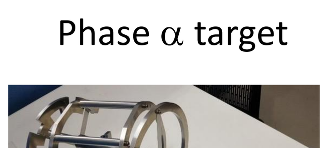
*COMET Phase-I technical design report, *PTEP*, 2020(3), 033C01

COMET Status

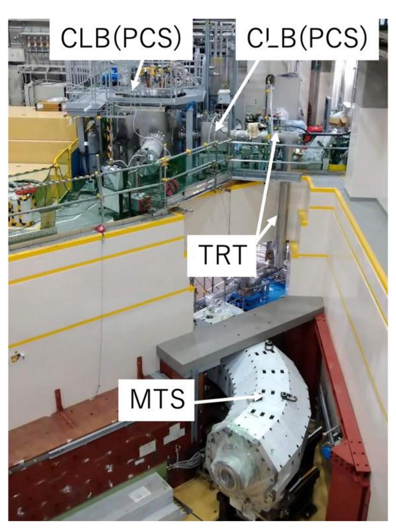
All proton beam-line instruments were installed.



Phase α target

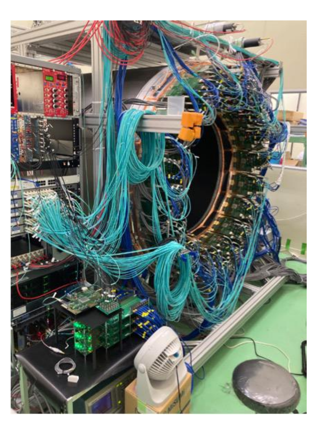


Phase-I target



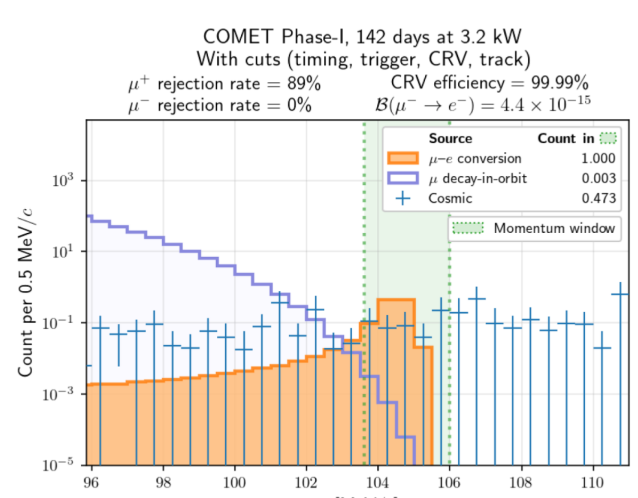
Solenoid magnets

Drift chamber, CTH and muon stopping target is under test



Drift chamber

Analysis and simulation is ongoing



Summary

COMET search for μ-e conversion with sensitivities 3.1 x 10^{-15} for Phase-I and < 2.6 x 10^{-17} for Phase-II

COMET Phase α engineering run is going to start in JFY 2022

COMET cryogenics system started successfully

Capture solenoid will be installed after Phase α

Detectors, DAQ & trigger, analysis, simulation is ready

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