μ -e conversion search at J-PARC^µ Satoshi MIHARA **KEK/J-PARC/SOKENDAI** SOKENDAI -PARC

Outline

- Introduction
 - Physics
 - J-PARC
 - Mu-e conversion search
- COMET Engineering Run (COMET Phase alpha)
- COMET Physics Run (COMET Phase I)
- Summary

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PSI2013



PSI2016

Charged Lepton Flavor Violation

 cLFV rate in the Standard Model with non-zero neutrino mass is too small to be observed in experiments; O(BR) < 10⁻⁵⁴

- No SM Physics Background
- Observation = clear evidence of NP
- Motivated by many kinds of new physics models BSM
- Origin of neutrino mass





μ





Hou, WS., Kumar, G. Charged lepton flavor violation in light of muon g-2

μ -e conversion



• $E_{\mu e}(AI) \sim m_{\mu} - B_{\mu} - E_{rec} = 104.97 MeV$

 $-B_{\mu}$: binding energy of the 1s muonic atom

Japan Proton

J-PARC

Accelerator Complex

J-PARC Facility (KEK/JAEA)

Neutrino beam to Kamioka

COMET

Material and Life Science Facility

Nuclear and Particle Physics Exp. Hall Rapid Cycle Synchrotron Energy : 3 GeV Repetition : 25 Hz Design Power : 1 MW

400 Me\/

Main Ring

Max Energy : 30 GeV Design Power for FX : 0.75 MW Expected Power for SX : > 0 1 M

Recent Upgrade of the Accelerator

- Mainly for higher power operation in FX and SX of the main ring
 - Magnet power supply, RF system, and Injection and Extraction System
- Good for COMET to improve the beam stability

New septum magnet for faster cycling



2nd harmonic cavities for faster cycling





Muon Beam at J-PARC

MLF muon beam

- 25 Hz (2)-pulse operation
- Rotating graphite target

- COMET muon beam
 - 1.2 μ sec pulse-to-pulse width
 - Graphite / metal rods with radiation/water cooling



COMET Experiment

- Precisely pulsed proton beam from J-PARC MR
- Graphite (Phase-I) or Metal (Phase-II) target for pion production
- MELK Proposal (V. M. Lobashev)
 - Pion/Muon collection using a strong and gradient magnetic field, Pion Capture Solenoid (PCS)
 - Pion/Muon transport with a curved solenoid

ELEMENTARY PARTICLES AND FIELDS Experiment

R. M. Djilkibaev" and V. M. Lobashev"

Institute for Nuclear Research, Rawban Academy of Sciences,

pr. Shesildesualliellya Ohtyahran 7a, Maxima, 117312 Rossin

Received March 96, 2010; 14 final Serve, July 18, 90:00

Stack of thin target disks to stop muons





COMET Staging Approach

Target Sensitivity <10⁻¹⁴ with 3.2kW beam

- Proton beam line construction completed in JFY2021
- Graphite as a pion production target
- Pion Capture Solenoid construction is in the 3rd year of multi-year construction contract (FY2020-2022)
- Physics Detector
 - CDC and trigger hodoscope in a solenoid
 - Muon stopping target (Al) at the center of the solenoid
 - Beam engineering run in JFY2022 and physics in JFY2023-2024

Target Sensitivity <10⁻¹⁶ with 56kW beam

- Extension of muon transport solenoid to cope with higher proton beam power
- More efficient beam background suppression
- Much less pion contamination in longer transport
- Tungsten alloy as a pion production target
- Electron spectrometer solenoid to suppress the detector counting rate
- Physics detector
 - Straw-tube tracker and LYSO calorimeter
 - Muon stopping target (AI + others) in a gradient magnetic field for the purpose of signal electron collection with a magnetic mirroring





COMET Rext Measurement

- COMET injection/acceleration/extraction scheme has been studied and tested many times at 8GeV.
- Rext measurement carried out using secondary beam
 - Confirmed Rext < 10⁻¹⁰
 - Sufficiently low for Phase I. Further improvement expected in Phase II







COMET Engineering Run

&

COMET Phase I $E_e = m_{\mu} - B_{\mu} - N_{recoil}$

A | 27

=104.9MeV

COMET Phase α : an engineering run

- Pion Capture Solenoid (PCS)
 is very powerful but complicated
- Simple geometry (w/o PCS) to measure
 - Proton beam profile and R_{ext}
 - Backward pion/muon production rate at 8GeV
 - Anti-proton production



- ~300W proton beam
- 9.2 sec acceleration cycle
- 0.8 sec extraction time with 1.17µsec pulse timing structure



PID performance test with simulated data



Phase- α Beam Masking System

- Movable pin hole collimator composed of two orthogonal slits
- TS transfer matrix
 - 10 free parameters, two unknowns (X',Y')_{initial}
 - 5 meas. relative to the central beamlet setting \rightarrow 6 independent holes
 - 20 equations for 20 unknowns









Entrance

Phase- α Detectors





MBM tested at CSNS

Measurements

- Time and position by the Muon Beam Monitor and Straw Tube Tracker
- Direction by the Straw-tube Tracker.

dE/dx, TOF, and decay time measured by the Range Counter

•For momentum and PID reconstruction



Phase- α detector test at MLF

• COMET Phase- α range counter tested at MLF

104

10²



COMET Phase α in early 2023

- Primary proton beam line is ready and shield closing starts this week
 - Thin graphite target w/o PCS
- Beam mask system to clarify beam transport through the curved solenoid
- Muon Beam Monitor, Range counter and Straw Tube Tracker to do particle ID and profile measurement
- 8 GeV acceleration and extraction test already done in 2021 along with Rext measurement

COMET Physics Run Phase I

Pion Capture Solenoid

- Pion capture with 5T (max) magnetic field
- Pion production target at the center
 - Graphite in Phase I
 - Tangsten alloy in Phase II
- Tolerable against radiation from the target
 - Aluminum stabilized SC cables



COMET design value Size: 4.7x15mm Offset yield point of Al@4K: >85MPa RRR@0T: >500 Al/Cu/SC: 7.3/0.9/1 14 SC strands: 1.15mm dia.





PCS Construction











- ✓ Coil winding started in 2015 and completed in 2019
- \checkmark Cold mass assembly in 2020
- ✓ Cryostat construction in 2021
- ✓ Return yoke construction in 2021
- Magnet assembly and delivery to J-PARC in 2023





Muon Transport Solenoid

- 3T toroid field
- Solenoid + correction dipole
- Cu-stabilized SC wire
 - 1.5mm dia. (w/o insulation)
 - •Cu/NbTi=6
- Indirect cooling with 2-phase LHe pipe
- Cooling and excitation test in 2022 was successful











CyDet: COMET Phase I Physics Detector

- CDC
- CTH
- Muon stopping target



CDC (Osaka, IHEP)





CTH (Monash Univ.)

- Cylindrical array of plastic scintillator
 - read by fibers + SiPMs
- Counter preparation in Monash Univ.
- SiPM cooling mandatory. Tested in neutron irradiation test with success
- Assembly at J-PARC will start after all counter preparation completes









Muon stopping target (Dresden Tech Univ.)

- Target support produced in DTU
- Material purity investigation
 - Effect of impunity?













StrEcal

- Muon beam study in Phase-I and prototype detector system for Phase-II
- Straw-tube tracker
 - 1st station getting ready to be used in Phase-α
 - Electronics mass production
- LYSO Calorimeter
 - Assembly is starting
 - Electronics mass production













CRV

- Full Scale module: 16 strips on 4 layers
 - 1.2mm diam. Kuraray Y11 WLS
 - Hamamatsu S14160-3050HS MPPC
 - 3.5mL, 830 mmW, 57 mmH
 - Ca. 290kG
- 1st module produced at JINR
- Design of a wooden case for transportation in progress





Proton bream monitor R&D

from

proton

beam

:11

- In addition to conventional beam monitor, COMET prepares dedicated beam monitor especially for monitoring the beam extinction
 - Diamond
 - SiC, tested in T78
 - TiO₂





and Phase-I pion production target



Imaging system on the pion production target Contribution by IMP in China What is a target imaging system

Institute Of Modern Physics

It is a kind of 2D View Screen with phosphor coating on target. remote off-axis alignment. optics fiber coupling. Image acquisition & processing system for antiradiation profile and position monitoring



Beam window development

- 3-D printed beam window
- Ti6Al4V (64Ti), > 1MPa achievable





Mises stress @ center: 565MPa Yield strength: 888MPa





thickness distribution



COMET theoretical activity

arXiv:2203.00702

Coefficient-space vector

$$\boldsymbol{v} = \left(\frac{D}{4}, V^{(p)}, S^{(p)}, V^{(n)}, S^{(n)}\right)$$

Misalignment angle

$$\theta_{\rm Al} = \arccos\left(\frac{\boldsymbol{v}\cdot\boldsymbol{v}_{\rm Al}}{|\boldsymbol{v}||\boldsymbol{v}_{\rm Al}|}\right)$$

• Large θ_{AI} means high complementary to AI



Summary

- COMET searches for $\mu\text{-}e$ conversion with sensitivities
 - < 10⁻¹⁴ in Phase I
 - < 10⁻¹⁶ in Phase II
- Engineering run (COMET Phase α) in preparation to start in early 2023
- COMET Cryogenics system operation started successfully
 - TS magnet cooling and excitation.
- Capture solenoid delivery and installation after Phase α to start Phase I timely





COMET trigger system

- Overall schedule is delayed due to international travel restriction by COVID-19
- Targeting the trigger conditioning in Dec. 2023-Feb. 2024



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9 MBM Ingger logic development	SROU		06/01/2023	11/90/2023																														
6 TRO Cable Installation at COMET site	Trigger G/KEK		01/01/2022	08/30/1023																														
5 TBS Installation at COMET site	TIMOT GIKEK		06/01/2023	08/30/2023																							_							
5 TRG Conditioning	Trigger 3		12/01/2023	02/20/2024	1																													

Dec. 2023-Feb. 2024



Analysis and simulation

- "Global COMET Software Week"
 late April
- Balancing fully-detailed simulations and simplified, faster simulations.
- MC6 in preparation
- Many activities;
 - Ex. CR background study



Readiness for Phase α



Followed by Capture solenoid and Phase-I detector installations in JFY2023