

Snowmass2021 - Letter of Interest

[COMET]

Thematic Areas: (check all that apply ☐/☒)

- ☐ (RF1) Weak decays of b and c quarks
- ☐ (RF2) Weak decays of strange and light quarks
- ☐ (RF3) Fundamental Physics in Small Experiments
- ☐ (RF4) Baryon and Lepton Number Violating Processes
- ☒ (RF5) Charged Lepton Flavor Violation (electrons, muons and taus)
- ☐ (RF6) Dark Sector Studies at High Intensities
- ☐ (RF7) Hadron Spectroscopy
- ☐ (Other) *[Please specify frontier/topical group]*

Contact Information: (authors listed after the text)

Submitter Name/Institution: Yoshitaka Kuno / Osaka University

Collaboration (optional): COMET collaboration

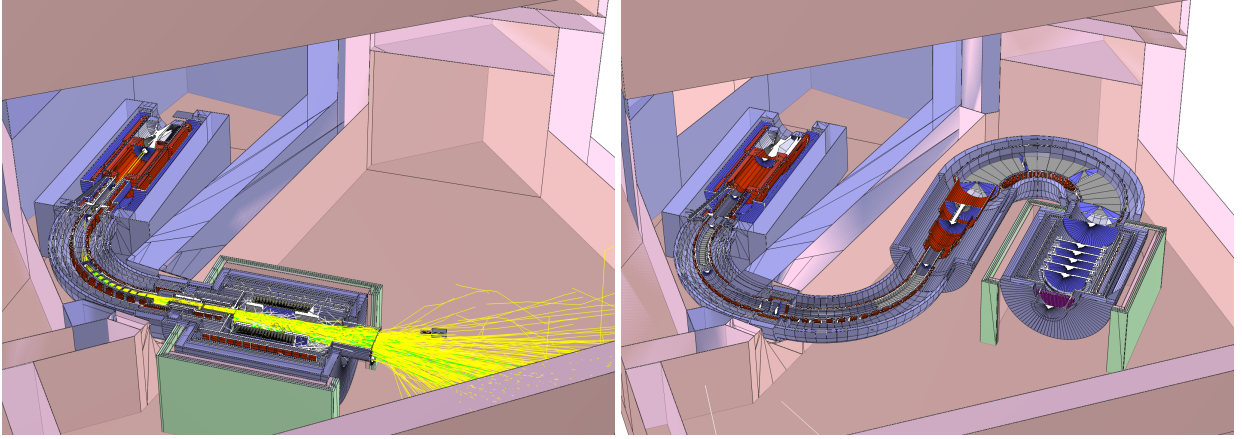
Contact Email: kuno@phys.sci.osaka-u.ac.jp

Abstract: (must fit on this page)

The search for charged lepton flavour violation (CLFV) has enormous discovery potential in probing new physics Beyond the Standard Model (BSM). The observation of a CLFV transition would be an undeniable sign of the presence of BSM physics which goes beyond non-zero masses for neutrinos. Furthermore, CLFV measurements can provide a way to distinguish between different BSM models, which may not be possible through other means. So far muonic CLFV processes have the best experimental sensitivity because of the huge number of muons which new muon beam-lines will be built in the near future, leading to increases in beam intensity by several orders of magnitude. Among the muonic CLFV processes, $\mu \rightarrow e$ conversion is one of the most important processes, having several advantages compared to other such processes.

We describe the COMET experiment, which is searching for $\mu \rightarrow e$ conversion in a muonic atom at the J-PARC proton accelerator laboratory in Japan. The COMET experiment has taken a staged approach; the first stage, COMET Phase-I, is currently under construction at J-PARC, and is aiming at a factor 100 improvement over the current limit. The second stage, COMET Phase-II is seeking another factor 100 improvement, allowing a single event sensitivity (SES) of 2.6×10^{-17} with 2×10^7 seconds of data-taking. Further improvements by one order of magnitude (a total of 100,000), which arise from refinements to the experimental design and operation, are being considered whilst staying within the originally-assumed beam power. Such a sensitivity could be translated into probing many new physics constructions up to $\mathcal{O}(10^4)$ TeV energy scales, which would go far beyond the level that can be reached directly by collider experiments. The search for CLFV $\mu \rightarrow e$ conversion is thus highly complementary to BSM searches at the LHC.

Overview We describe the COMET experiment (J-PARC E21), which is searching for coherent neutrinoless $\mu \rightarrow e$ conversion in a muonic atom, a charged lepton flavour violating (CLFV) process, at the Japan Proton Accelerator Research Complex (J-PARC) in Tokai, Japan¹⁻⁴. COMET stands for COherent Muon to Electron Transition. The COMET experiment has taken a staged approach; the first stage, COMET Phase-I, is currently under construction, and is aiming at a factor 100 improvement over the current limit of 7×10^{-13} which was obtained by SINDRUM-II at PSI⁵. The second stage, COMET Phase-II is seeking another factor 100 improvement, allowing a single event sensitivity (SES) of 2.6×10^{-17} with 2×10^7 seconds of data-taking at 56 kW proton beam power. Further improvements by one order of magnitude (a total of 100,000), which arise from refinements to the experimental design and operation, are being considered whilst staying within the originally-assumed beam power⁶. Such a sensitivity could be translated into probing many new physics constructions up to an energy scale of $\mathcal{O}(10^4)$ TeV, which would go far beyond the level that can be reached directly by collider experiments, and is not affected by theoretical Standard Model backgrounds. The search for CLFV $\mu \rightarrow e$ conversion is thus highly complementary to the Beyond Standard Model (BSM) searches at the LHC.



Cutaway views of the Phase-I (left) and Phase-II (right) layouts for the COMET experiment.

Methodology The COMET experiment will make use of a dedicated 8 GeV, 7 μ A pulsed proton beam (with a power of 56 kW), which is slow-extracted from the J-PARC Main Ring. The proton beam energy of about 8 GeV has been chosen in order to reduce anti-proton production which might cause background events.

Schematic layouts for the COMET Phase-I and Phase-II are shown above. Muons will be produced from the pions generated in the collisions of the 8 GeV protons with a production target made of tungsten. The yield of low-momentum muons transported to the experimental area is enhanced using a 5 T superconducting pion-capture solenoid surrounding the proton target in the pion capture section. Muons are momentum- and charge-selected using 180° curved superconducting solenoids in the muon transport section, before being stopped in an Aluminium target located in the target section. The curved solenoid sections for COMET are equipped with dipole coils which superimpose a vertical magnetic field on them; this allows the momentum and the charge of the particles which travel preferentially through the centre of the solenoids to be varied. The signal

electrons from the muon stopping target are transported through the electron spectrometer composed of more than 180° curved superconducting solenoids to the detector section, which lies in a 1 T magnetic field. The curved electron spectrometer will be used to transport the signal electrons to the detector section with high efficiency and to eliminate low-energy background electrons. The 180° curved solenoid in the electron spectrometer also ensures that there is no line of sight between the target and the detector systems, eliminating all neutral particles from the muon stopping target hitting the detectors.

The detector for signal electron detection is a combination of a straw-tube tracker and an electron calorimeter with fast-scintillating LYSO crystals (the StrECAL system). To eliminate cosmic-ray induced background events, both passive and active shielding will be used.

Phased Deployment The COMET Collaboration has opted to use a staged approach to experiment deployment, to ensure that detailed measurements of this novel muon beam production facility can be made (in the form of COMET Phase-I⁷), before embarking on the full COMET configuration (COMET Phase-II). The Phase-I facility will have the pion capture section, and the muon transport section up to the end of the first 90° bend. Detectors will be installed after the end of this 90° bend. The layout for COMET Phase-I is shown in the left-hand figure. COMET Phase-I has the dual goals of studying the novel muon production beam line so that it is fully understood in preparation for Phase-II, and of making measurements of $\mu \rightarrow e$ conversion with a sensitivity that is approximately 100 times better than the previous limit, at a SES of 3×10^{-15} . COMET Phase-I will utilise a 8-GeV proton beam of $0.4 \mu\text{A}$, yielding a beam power of 3.2 kW. The pion production target is made of graphite, instead of the tungsten used in Phase-II. With a total number of protons on target (POT) of 3.2×10^{19} (which corresponds to about 150 days), about 1.5×10^{16} muons in total will be stopped, which is sufficient to reach the design single event sensitivity of COMET Phase-I.

The primary COMET Phase-I detector for searching for the $\mu \rightarrow e$ conversion signals is composed of a cylindrical drift chamber and a set of trigger hodoscope counters (the CyDet system). As well as providing valuable experience with the detectors, the CyDet and a form of the StrECAL adapted to Phase-I will be used to characterise the backgrounds to the signal of neutrinoless $\mu \rightarrow e$ conversion to ensure that the Phase-II SES can be realised.

Prospects The J-PARC proton beam will arrive at the COMET experimental area in early 2023, when Phase-I beam studies and integration will commence, and Phase-I physics data-taking and analysis will follow. By the mid-2020s, it is expected that the full Phase-II experiment will be deployed and running. If $\mu \rightarrow e$ conversion is observed, COMET Phase-II will seek to measure it with different, heavier, target materials, with nuclei of up to medium-heavy weight, to identify which effective interaction is responsible^{8–10}. The Phase-II muon beam facility, providing 2×10^{11} muons per second, will also be the world’s most intense pulsed muon source. Moreover, with its double curved solenoid and dipole field configuration, the Phase-II muon beam facility will produce extremely high-quality beams of variable momentum.

Summary The COMET experiment is searching for the CLFV process of $\mu \rightarrow e$ conversion in a muonic atom at J-PARC in Japan. This search would be sensitive to BSM physics at energy scales of $\mathcal{O}(10^4)$ TeV.

References

- [1] Y. Kuno *et al.* [COMET Collaboration], Letter of Intent (LOI) for “An Experimental Search for the $\mu \rightarrow e$ Conversion at a Sensitivity of 10^{-16} with a Slow-Extracted Bunched Proton Beam”, December 15, (2006).
- [2] D. Bryman *et al.* [COMET Collaboration], Proposal for “An Experimental Search for Lepton Flavor Violating $\mu \rightarrow e$ Conversion at a Sensitivity of 10^{-16} with a Slow-Extracted Bunched Proton Beam”. November 30, (2007).
- [3] Y.G. Cui *et al.* [COMET Collaboration], Conceptual Design Report (CDR) for “Experimental Search for Lepton Violating $\mu \rightarrow e$ Conversion at Sensitivity of 10^{-16} with a Slow-Extracted Bunched Proton Beam (COMET), J-PARC P21”. June 23, (2009).
- [4] B. Krikler, PhD Thesis, Imperial College London (2016).
- [5] W. Bertl *et al.* [SINDRUM-II Collaboration], Eur.Phys.J. C47 337 (2006).
- [6] Y. Fujii *et al.*, COMET Techical Note No 164 (2018), unpublished.
- [7] R. Abramishvili *et al.* [COMET Collaboration],
“COMET Phase-I Technical Design Report,” PTEP **2020**, no.3, 033C01 (2020)
- [8] R. Kitano, M. Koike and Y. Okada, Phys. Rev. D **66**, 096002 (2002), Erratum: [Phys. Rev. D **76**, 059902 (2007)].
- [9] V. Cirigliano, S. Davidson and Y. Kuno, Phys. Lett. B **771**, 242 (2017).
- [10] S. Davidson, Y. Kuno and A. Saporta, Eur. Phys. J. C **78**, no. 2, 109 (2018).

Authors: (names and institutions)

The COMET collaboration