A Search for a Charged Lepton Flavour Violating Process; Muon to Electron Conversion in COMET

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The $\mu$-e Conversion

- A flavour violating process in a muonic atom
  - Strongly suppressed in the SM $< 10^{-50}$
  - New physics allow the detectable conversion rate up to $10^{-14}$
- Clear signal of new physics
- Simple kinematics
  - $E_{\mu e} = M_\mu - E_B - E_{\text{recoil}} \sim 105$ MeV
- Current Upper Limit: $7 \times 10^{-13}$ by SINDRUM-II (2006)
  - New physics may be almost there
- COMET aims **100 & 10,000** times better sensitivity in Phase-I & Phase-II
Key Challenges

• **Statistics**
  - Require $>10^{17}$ of stopping muons
    ➔ Powerful beam

• **Background reduction**
  - Decay In Orbit (DIO)
    ➔ Good momentum resolution
  - Beam related BG
    ➔ Pulsed beam
  - Cosmic-ray BG
    ➔ Veto detector

• **Technical issues**
  - High radiation environment
    ➔ Rad-hard electronics/detectors
  - High rate (hit/trigger/DAQ)
    ➔ Trigger system, offline pileup rejection, etc

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Momentum [MeV/c]

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Signal and DIO (BR=3 $\times 10^{-15}$)

- **Signal**
- **DIO BG**

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Details in K. Ueno’s poster
Details in Y. Nakazawa’s slides
COMET Overview

- Aiming $O(10^{-17})$ sensitivity, $x10,000$ better than the current upper limit
- C-shape transport solenoid to suppress beam BG
- Curved Electron spectrometer to suppress DIO+beam BG

**8GeV, 54kW Proton Beam**

**Production Target + Pion Capture Solenoid ~5T**

**Muon Stopping Target**

**Muon Transport Solenoid ~3T**

**Electron Spectrometer ~1T**

**Detector Solenoid ~1T**
COMET Phase-I

8GeV, 3.2kW Proton Beam

- Aiming $O(10^{-15})$ sensitivity, x100 better than the current upper limit using a set of Cylindrical Detectors
- First 90° of transport solenoid
- Direct profile measurement for the muon beam w/ StrECAL (Straw-tube tracker + ECAL)
J-PARC

J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA

*design value
Experimental Facility

- COMET building, beam-line shields are almost completed
- Beam-line and magnets are under construction

Figure 2: Proton beamline of J-PARC Hadron Facility.

Figure 3: Beam size at the position of the beam monitors.

Figure 4: Shot-by-shot beam extent and divergence as a function of time.

A comparison of the beam size and the simulated beam envelope for a typical shot (one cycle of the beam extraction) is displayed in Fig. 3. The shot-by-shot width of the beam extent and divergence was calculated for about 24 hours to evaluate stability of the beam and the results are shown in Fig. 4. A shift around 11:00 was due to power recycle of a beamline magnet. Frequent deviation with interval of 20 – 30 minutes was caused by instability of a debuncher of the accelerator. Mean values of width of horizontal extent, its divergence, vertical extent and its divergence were 11.7 (0.09) mm, 0.067 (0.0054) mrad, 3.7 (0.07) mm and 1.25 (0.019) mrad, respectively. Numbers in parenthesis are root-mean-square of each fluctuation. Resulting horizontal and vertical emittance were 0.78 (0.063) $\pi$ mm mrad and 4.6 (0.14) $\pi$ mm mrad, respectively.

Based on the measured beam emittance, the beam optics of the new proton beamline for the COMET experiment was...
Proton/Muon Beam

- A Bunched Slow Extraction (BSX) operation w/ 8GeV protons has been established for COMET @ J-PARC Main Ring
- Preparation for the muon beam-line is going well

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CyDet

- Cylindrical Drift Chamber (CDC) consists of ~5k sense wires, all stereo, He:iC$_5$H$_{10}$=90:10
  - Already constructed and being tested using cosmic-rays → Details reported by M. Moritsu
  - All readout electronics were produced
  - $\sigma_x \sim 170 \mu$m
- CyDet Trigger Hodoscope (CTH) is a set of 48(64) staggered pairs of a scintillator bar & a Cherenkov radiator
  - $\sigma_t < 1$ns
  - Almost ready for the final production

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StrECAL

• Phase-I beam measurement + Phase-II physics measurement
• **Straw-tube Tracker** consists of 2.4k straw tubes operational in vacuum
  • 20µm thick/10mmφ straws are ready for assembly (more details in Michail Kravchenko’s poster)
  • $\sigma_x \sim 150\mu m$
• **ECAL** is a primary trigger detector
  • Measure the energy and timing of e- using ~2k LYSO crystals
  • $\sigma_E \sim 4.5\%$, $\sigma_t < 1\text{ns}$ @105MeVe-
Phase-II Straw Tube

- Succeeded to manufacture **12µm** thick/ 5mmφ straw tubes
- Achieve the vacuum tightness against 4 bar pressure
- Further studies are ongoing @JINR

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• Extinction factor is measured w/ 8GeV BSX mode @J-PARC in 2018
• Reason for the last bunched leakage protons was confirmed and fixed in 2019 (IPAC’19, H. Nishiguchi)
• Excellent extinction factor*, $<6 \times 10^{-11}$ is achievable!

* (#of residual protons)/(#of protons in a pulse)

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Online Tracking Trigger

- Online trigger based on CDC information is being developed to achieve <10kHz trigger rate in COMET Phase-I
- Succeeded to take cosmic-rays w/ almost final ver. trigger/DAQ electronics
- See more details in Y. Nakazawa’s talk
COMET Phase-II Study

- Revisited Phase-II configuration to maximise the physics sensitivity
- Original sensitivity: $\sim 3 \times 10^{-17}$
- Being optimise:
  1. Production target
  2. Magnetic fields
  3. Stopping target
  4. Electron Spectrometer
  5. Detectors
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- Change geometry/location of production target, B-fields
  - $1.7 \times 10^{-3} \rightarrow 2.2 \times 10^{-3}$ $\mu$-/POT
- Increase # of discs, Modify geometry of stopping target
  - $2.2 \times 10^{-3} \rightarrow 6.4 \times 10^{-3}$ $\mu$-/POT
- More room to improve
Summary & Prospects

• Summary
  - COMET searches for the µ-e conversion to tackle the yet-unknown BSM physics
    - Phase-I preparation is ongoing to achieve $3 \times 10^{-15}$ of single event sensitivity
    - Phase-II will follow with a $\times 100$ better sensitivity (& $\times 10$ further improvement)

• Prospects
  - COMET Phase-I will start in the early 2020s
  - Phase-II will follow soon after
  - New generation CLFV searches will come in 2020s, Stay tuned!

[Diagram of Searches for Charged-Lepton Flavor Violation in Experiments using Intense Muon Beams]
Backup