Search for the coherent neutrinoless transition of a muon to an electron in a muonic atom with the COMET experiment at J-PARC

Master 2 Research Internship at Laboratory of Physics of Clermont (LPCA)
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Research background:

Several experiments are looking for Beyond the Standard Model (BSM) signals through charged lepton flavour violation (cLFV) searches. Since cLFV is forbidden in the Standard Model (SM) and its minimal extensions yet arises naturally in many BSM scenarios, it serves as **an exceptionally sensitive probe for New Physics**. Moreover, it is **deeply intertwined with fundamental questions**, including the origin of neutrino masses, the mechanism of baryogenesis, and the underlying structure of flavour, **establishing it as a cornerstone of both current and future particle physics research**.

The neutrinoless muon-to-electron conversion in a muonic atom (μ^-+ (A, Z) → e^- +(A, Z)) has already been used to set stringent limits on cLFV by the SINDRUM experiment (7×10^{-13}) [1]. This process is expected to offer the greatest potential for future improvement, with up to four orders of magnitude or more in sensitivity anticipated to be achievable by a new generation of experiments, including Mu2e [2] at Fermilab (FNAL) and **COMET [3] (COherent Muon to Electron Transition) at the Japan Proton Accelerator Research Complex (J-PARC)**.

In COMET, an intense beam of low energy muons is produced is produced by directing a pulsed 8 GeV proton beam onto a proton target located inside a 5 T solenoid (Pion Capture Solenoid)**.** The high-gradient magnetic field efficiently captures backward-produced, low-momentum pions and muons**.** A curved solenoid with a dipolar component, the Muon Transport Solenoid, acts as Pion Decay line and selects the lowest-momentum μ^-**.** When these low momenta muons impinge on an aluminium target, some form muonic atoms. If cLFV occurs, a bound muon could undergo neutrinoless conversion into an electron in addition to SM processes. In such a case, the emitted electron is mono-energetic, carrying most of the rest mass of the muon and appears delayed by approx. 800 ns with respect to the proton beam pulse. A Cylindrical Drift Chamber placed into a 1 T Detector Solenoid measures the signal electron with a resolution better than 200 MeV/c, distinguishing it from the SM background. A Cylindrical Trigger Hodoscope (CTH) provides the trigger and the timing for the CDC.

The main source of background affecting the measurement is due to the atmospheric muons. The Cosmic Ray Veto (CRV) system is critical for rejecting this background: it covers as hermetically as possible the technologies: four layers of scintillation slabs on lower radiation areas (e.g top and sides of CDC), and 5 layers of Resistive Plate Chambers (RPC) based on the iRPC design [4] developed for the CMS Muon System on the upstream and downstream sides that suffer from much higher radiation rates.

Research Internship Topic:

The trainee will contribute to improving the sensitivity of **COMET Phase-I** by developing a **global analysis framework**. COMET Phase-I is expected to begin data taking at the **end of 2027 or the beginning of 2028**, aiming to achieve a **single-event sensitivity (SES) of the order of 10^{-15}**. Currently, the experiment is refining its **running and analysis strategies** to further optimize this sensitivity

The work will focus on **optimally incorporating all experimental inputs that impact the** single-event sensitivity (SES), including geometric acceptances**,** trigger and DAQ efficiencies**,** reconstruction performance**, and** background rejection. The uncertainties associated with these inputs will be **quantified**, and strategies to minimize their impact will be explored.

In practice this will require the trainee to master the COMET simulation and analysis framework, ICEDUST [3], which is based on GEANT4 [5] and ROOT [6], and to interact with the various COMET working groups focusing on the individual topics (eg reconstruction, subdetectors).

Requirements:

In addition to the usual academic requirements (a good understanding of particle and detector physics, basics of C++ coding and data analysis techniques, advanced statistical tools), a good command of (scientific) English is required as the internship involves close collaboration with COMET collaborators from Japan (KEK, University of Osaka, Kyushu University), Germany (Dresden Technical University) and the UK (Imperial College London).

The trainee is expected to spend at least one month at KEK during the internship. An interest / aptitude for interdisciplinary research (e.g. nuclear physics, atomic physics, computing science, statistics) will be a definite advantage.

Follow up:

A successful Master 2 Internship is expected to lead to a PhD on cLFV search with COMET. The PhD candidate will be ideally positioned to take a leading role in the analysis of the COMET Phase-I data, with the potential for the experiment to become the world leader in muon cLFV research.

Bibliography:

[1] SINDRUM II Collab, EPJ C, vol. 47, no 3, pp. 337–346 (2006), DOI: 10.1140/epjc/s2006-02582-x
[2] Mu2e Collab, Universe 9 (1) (2023), https://www.mdpi.com/2218-1997/9/1/54
[3] COMET Collab, PTEP 2020 (3) (2020) 033C01 https://doi.org/10.1093/ptep/ptz125
[4] CMS Collab, “The Phase-2 Upgrade of the CMS Muon Detectors”, TDR
[5] GEANT4, https://geant4.web.cern.ch
[6] ROOT, https://root.cern