Particle Identification Using Plastic Scintillation Counters in the COMET Phase-I Experiment

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Introduction

The COMET experiment searches for muon to electron (μ-e) conversion with aluminium nuclei [1]. The process is strictly forbidden in the Standard Model, while many new physics models predict the increased conversion rate up to 10^{-15}. COMET Phase-I will investigate this process with a single event sensitivity of 3×10^{-15} , ×100 better than the current upper limit, 7×10^{-13} [2]. If the μ-e conversion occurs, a single 105 MeV e^- is emitted from an Al nucleus.

In COMET Phase-I, a curved muon transport solenoid (MTS) is adopted to suppress π induced prompt backgrounds. A detector system locates at the end of the MTS to stop muons and detect signal-like e^-.

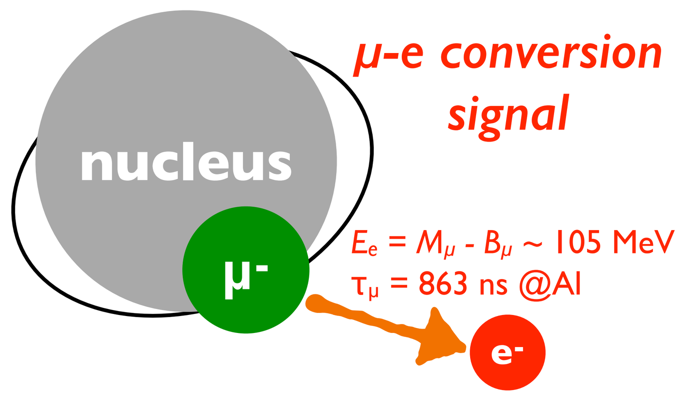


Fig 1. Illustration of the μ-e conversion with a nucleus

The e^- momentum is determined by a Cylindrical Drift Chamber (CDC), and the timing is measured by a set of Cylindrical Trigger Hodoscopes (CTH) as shown in Fig 2.

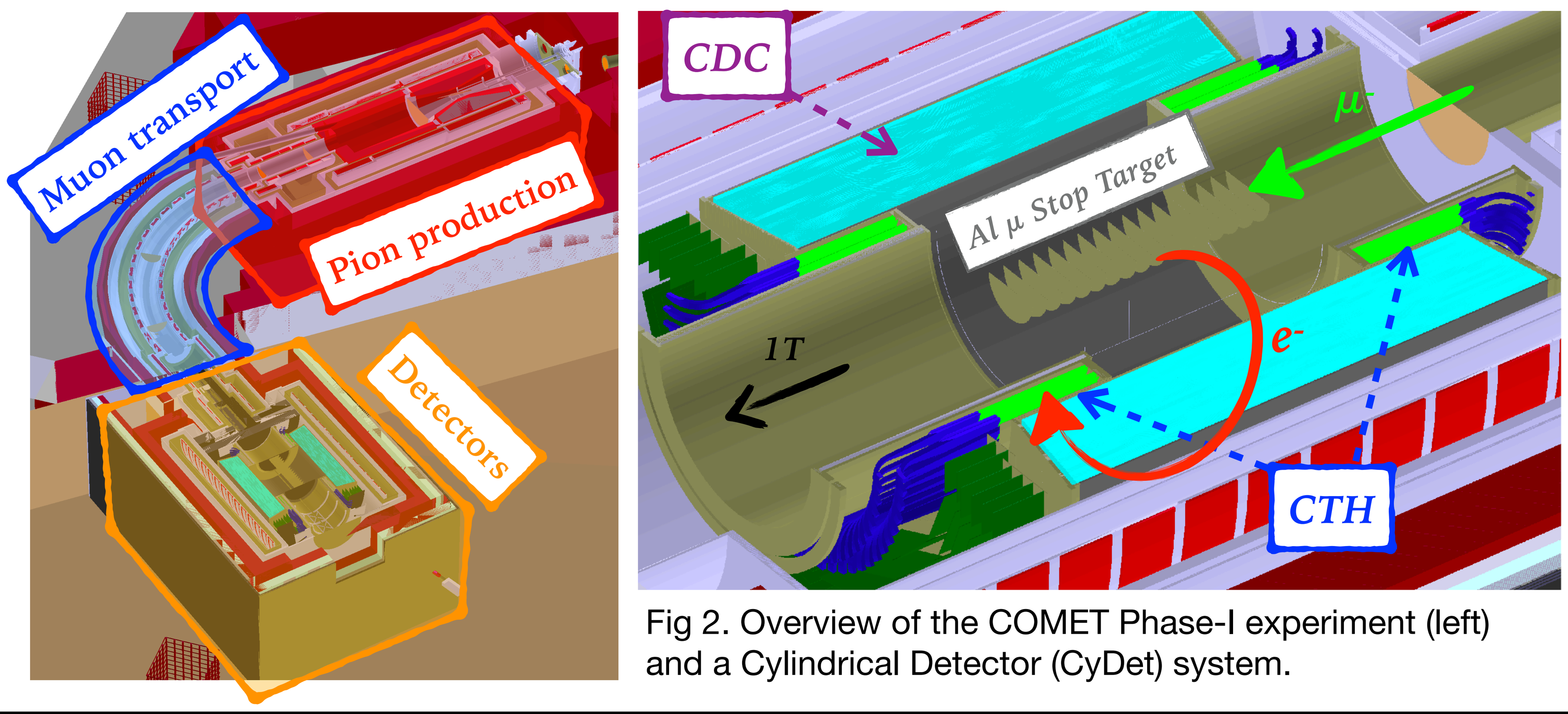


Fig 2. Overview of the COMET Phase-I experiment (left) and a Cylindrical Detector (CyDet) system.

CTH & Prototype

CTH is designed to measure the e^- timing with <1 ns resolution and suppress accidental coincidence w/ four-fold coincidence by using two concentric rings consisting of 64 segmented plastic scintillators (BC-408) [3,4].
Scintillation photons are extracted through a 5/7.5 m-long fibre bundle and read by silicon photomultipliers (SiPM) avoiding rad-hard area.
CTH also aims to reduce the background cosmic-ray muons by using dE/dx information as muons can be one of the major backgrounds.

A full-scale partial CTH prototype was built to evaluate the performance of CTH, and sent to PSI for the beam test in Nov 2023.

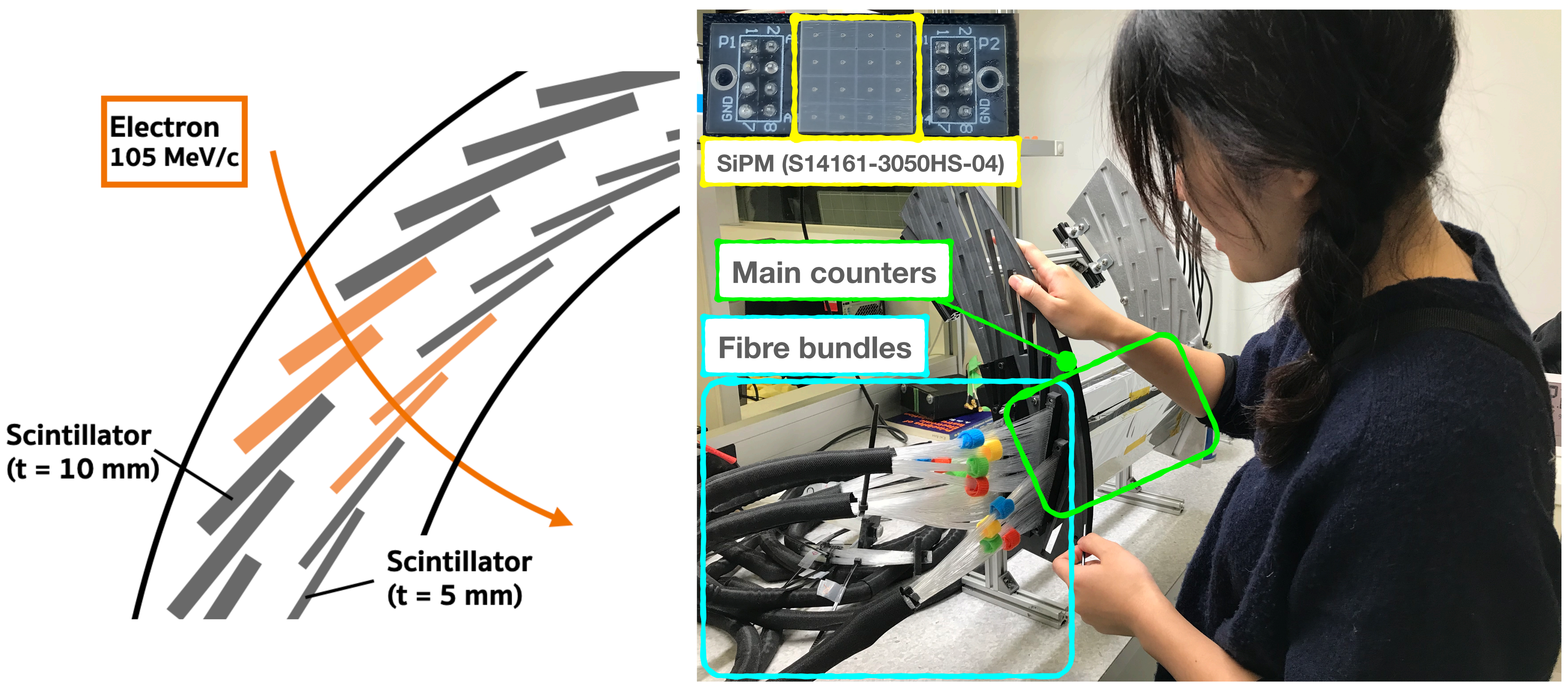
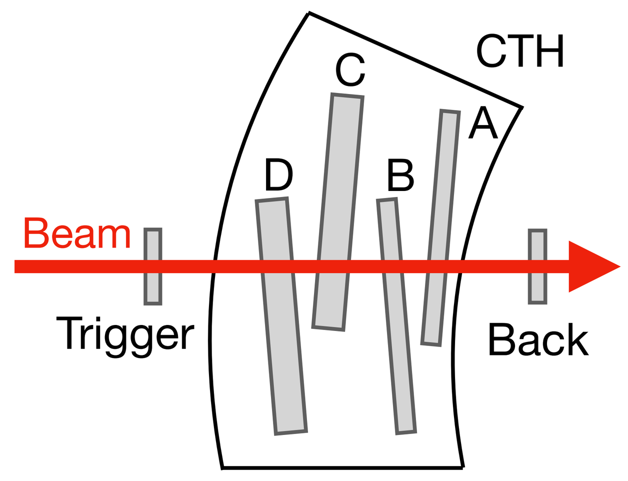


Fig 3. Conceptual cross section view of the CTH (left) and a full scale prototype being built (right).

Performance test

In Paul Scherrer Institut (PSI), $e/\mu/\pi$ mixed beam is provided with an adjustable momentum range between 0.1–0.5 GeV/c at the πM1 beam-line.
The CTH prototype was positioned at the end of the beamline, between a trigger & a back counter.
All counters' signals and a 50 MHz accelerator timing signal were read by waveform digitisers (PicoScope 6403E) to measure the light yield (∝deposited energy) and their time of flight (TOF) for PID.



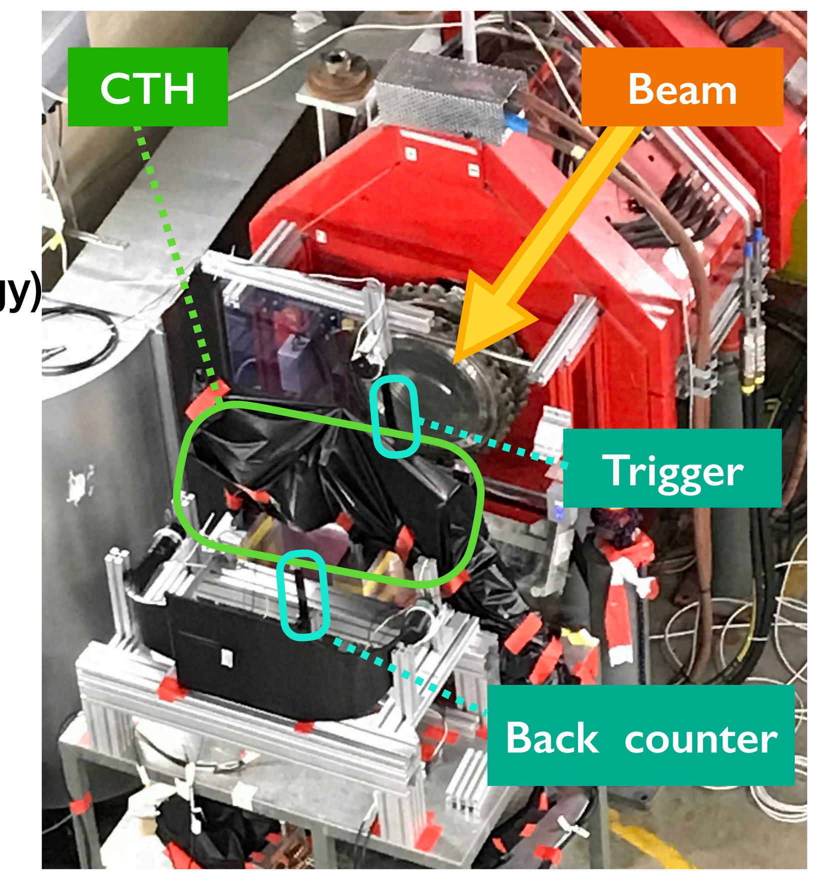


Fig 4. Diagram of the CTH test beam setup (left) and a picture taken from above (right).

Analysis & Results

The μ/e data samples are separated by using the relative TOF at the trigger counter w.r.t. the accelerator timing.

At 105 MeV/c, μ/e samples are fully resolved by the above TOF technique w/ a trigger counter as shown in Fig 5.

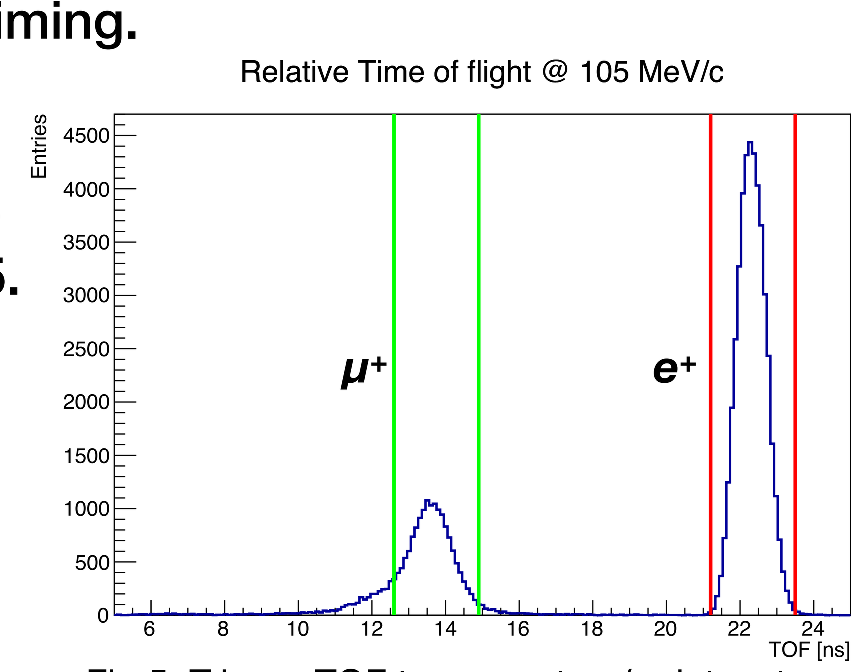
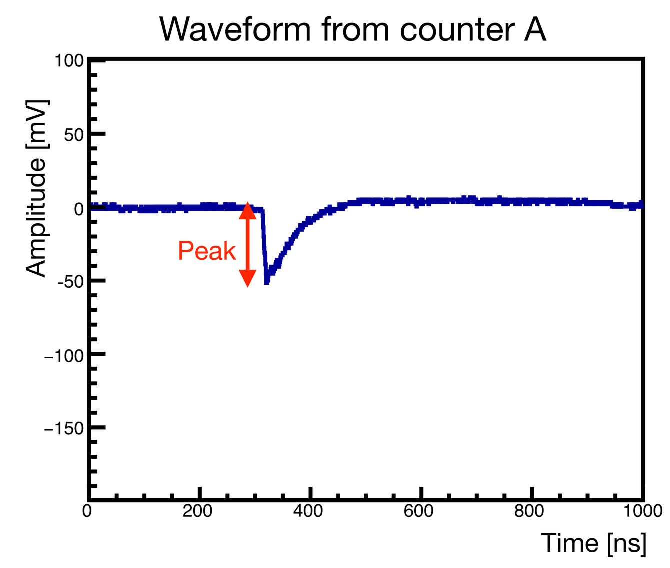


Fig 5. Trigger TOF to separate μ/e datasets

In main 4 CTH counters, all peak amplitudes are recorded for each PID and they are summed up linearly.

As a result, CTH showed more than factor **10 muon BG suppression** with ~90% signal efficiency.



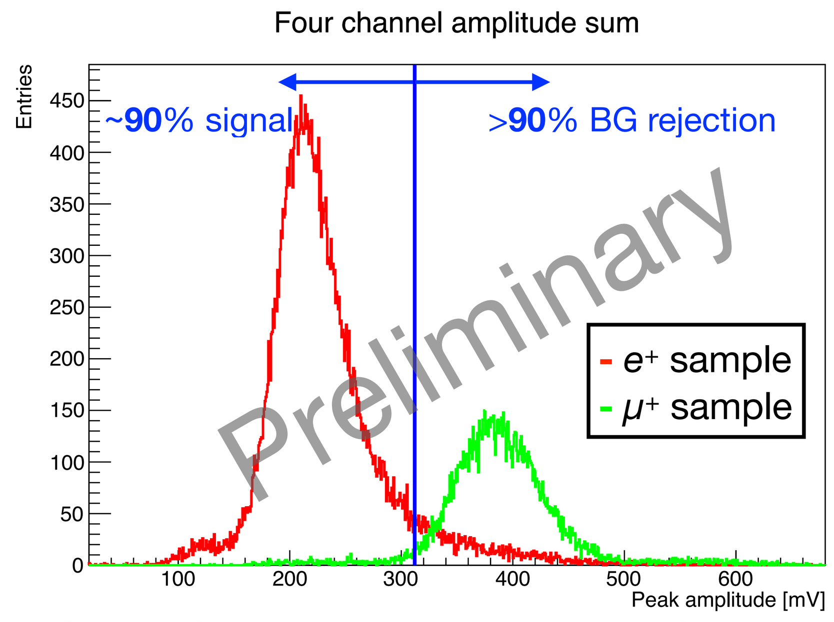


Fig 6. En example waveform to extract the peak amplitude from one channel (left) and the summed up results (right).

Conclusions

- COMET Phase-I searches for μ-e conversion with 100 times better sensitivity than before
- Cosmic-ray muons could become dangerous BG in COMET, and CTH plays an essential role to suppress them
- With simple linear summation, we achieve almost **90%** signal efficiency with >90% BG rejection power
- Further analysis and hardware improvements are expected

Acknowledgement

Many thanks to PSI πM1 beamline operators and coordinator for delivering a stable beam and providing us many helps.

Reference

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