The COMET experiment

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on behalf of the collaboration
μ – e conversion [Recap]
**μ to e conversion**

In the SM $\mu N \rightarrow eN$ is suppressed by $O(10^{-54})$ because of the mass disparity between the $W$ and neutrino.

This is ‘accidental’; new physics scenarios typically give CLFV much higher than SM.

**Dipole coupling**

$$\mathcal{L}_d \sim \frac{m_\mu}{\Lambda^2} \bar{\mu} \sigma_{\mu \nu} e \cdot F^{\mu \nu}$$

**Four-fermion coupling**

$$\mathcal{L}_4 \sim \frac{1}{\Lambda^2} \bar{\mu} \gamma_\mu e \cdot \bar{q} \gamma_\mu q$$
A giant leap...

For the full COMET experiment sensitivity improvement over SINDRUM-II is 4 orders of magnitude.

MC of background processes [especially ‘tails’] may not be good enough for optimal design

• Intermediate-scale experiment can measure background sources and inform design.
• Can still do competitive physics with a smaller apparatus

Include in COMET programme:

COMET Phase-I
Muon decays

Muons allowed stop in suitable target.

- Initially **Aluminium**, but other materials (Ti) under study.
- Conversion from 1s orbital: $\mu N \rightarrow eN$ gives a **mono-energetic electron** at 105MeV ($\approx m_\mu - B_{1s}^\mu - E_R$)

‘Normal’ decays are backgrounds

- Nuclear muon capture:
  $$\mu N(Z) \rightarrow \nu N(Z - 1)$$
- **Decay in Orbit [DIO]:**
  $$\mu N \rightarrow e\nu\bar{\nu}N$$

For a free muon, cuts off at $\frac{1}{2}m_\mu$, but bound state has a small tail up to $m_\mu - B_{1s}^\mu - E_R$
Backgrounds

Three main background processes:

- **Decay in orbit**, as before  ► **Momentum resolution**!

- **Decay in flight**:  
  Electrons from energetic free muons can be boosted to 105MeV.  
  – Use momentum selection in muon transport

- **Beam backgrounds**:  
  Significant number of prompt $e^-$ and $\pi^-$ produced by beam. Can eliminate this with timing *if* we have reliably beam-free time windows  ► **Pulsed beam**

Results from SINDRUM-II  
(BR < $7 \times 10^{-13}$ @ 90%CL)
COMET design and construction
COMET, Phase I and II

Phase I

Phase II

Muon transport
Detector
Electron spectrometer
Primary beamline

Main driver of sensitivity: Need lots of low energy muons!

- Use high-power *pulsed proton beam* line (8 GeV) with resonant slow extraction

![Graph](image)

Strict *extinction* requirement of $< 10^{-9}$.

Beam monitored with diamond detector
Muon source

- Collect **backward-going pions** with capture solenoid
- Maximise field at target to give larger solid angle aperture
- Pions decay to muons en-route to stopping target.
- Many neutrons produced, requires careful shielding. The curved transport line helps to eliminate direct line-of sight.
Muon transport is a curved solenoid:

- Particles are channelled in **spiral paths [solenoid]**, which naturally tend **up/down [curvature]** depending on $p$ and charge.
- Dipole keeps desired lower-$p$ muons on level trajectory.
- Gives charge and momentum selection, which is enhanced by using a collimator.
- Eliminates high-$p$ muons (which won’t stop) & other particles.
- Eliminates line-of-sight from production target.

**Muon yield:**

Before collimator
After collimator
At target
Phase I detector (CyDet)

- Aluminium stopping target at centre.
- Particle flux in central region is still very high → **Cylindrical Detector** system:
  - All-stereo-wire drift chamber
  - Hodoscopes for triggering and timing
CyDet construction

Checking wires, Dec '15

installing inner wall

Drift Chamber completed, June '16
CyDet reconstruction

Most **background** hits are rejected based only on timing & local features

▼ **Signal** tracks picked out using Hough transform based discriminator, then given to Kalman filter for reconstruction.

**Typical Event at 12% Occupancy**

**Stereo projections**
COMET Phase II

Upgrade the experiment for $100\times$ better sensitivity

Electron spectrometer selects only high momentum –ive particles
$\rightarrow$ eliminates low energy DIO electrons and residual beam

Longer muon transport for better charge / momentum selection
$\rightarrow$ smaller beam background

‘Central’ detector is possible because of lower backgrounds
In parallel with Phase I construction, Phase II design is being optimised using integrated COMET simulation. Examples:

1. Correcting dipole field strength
2. Collimator positions
3. Target position & shape
Phase II detectors

5 full planes (baseline design) of straw tubes for tracking

Low mass straw design to reduce scattering.

**ECal** at end uses ~2000 LYSO crystals for energy measurement and triggering.

Prototype version detector in development for Phase I, can be installed in place of CyDet.

- Test design (e.g. new straw weld for lower mass) and readout
- Study particle content of secondary beamline to improve MC prediction (esp. for Phase II analysis)
ECal & Straw testing

\[ \sigma_E \sim 4.2\% \text{ in 105 MeV (i.e. signal) region} \]

\[ \sigma_x \sim 150\mu\text{m} \text{ achieved} \]
\[ \Rightarrow \sigma_p \sim 180\text{keV/c} \]

Full-scale prototype for vacuum and performance tests

4 ECal crystals in Teflon + Al-mylar wrapping

ECal 8×8 prototype
Current limit [SINDRUM-II]: \(7 \times 10^{-13} \text{ 90\% U.L.}\)

~2018: Start COMET Phase I; goal \(3 \times 10^{-15} \text{ S.E.S.} \) (\sim 5 \text{ mo})

COMET Phase II goal \(3 \times 10^{-17} \text{ S.E.S.} \) (\sim 1 \text{ year})

Phase I of experiment coming together rapidly!