The Mu2e Experiment — Searching for Charged Lepton Flavor Violation

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Charged Lepton Flavor Violation

Charged leptons are only fermions without observation of flavor violation

- Quarks mix (CKM)
- Neutrinos oscillate

CLFV is allowed in $\nu$SM, but ludicrously suppressed

- $Br(\mu \to e\gamma) \propto (\frac{\Delta m_{\mu e}^2}{M_W^2})^2 < 10^{-52}$

Any experimental observation would unambiguously indicate New Physics
**CLFV: \( \mu \rightarrow e \) conversion**

- Monoenergetic \( \sim 105 \text{ MeV}/c \)
- Conversion-electron (CE)
- Sensitive to energy scales \( \mathcal{O}(1000) \text{ TeV} \)

\[
E_e = m_\mu c^2 - (\text{B.E.})_{1S} - E_{\text{recoil}}
\]

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Adapted from A. de Gouvea and P. Vogel, Progress in Particle and Nuclear Physics 71, 75–92 (2013)

\[
\mathcal{L}_{\text{CLFV}} = \frac{m_\mu}{(\kappa + 1)\Delta^2} \bar{\mu} R \sigma_{\mu\nu} e_L \gamma_\mu \gamma_\nu + \frac{\kappa}{(\kappa + 1)\Delta^2} \bar{e}_L \gamma_\mu \gamma_\nu (u_L)^T u_L + d_L^T d_L
\]
Discovery potential of $R_{\mu e} = \frac{\Gamma(\mu^- + N(Z,A) \rightarrow e^- + N(Z,A))}{\Gamma(\mu^- + N(Z,A) \rightarrow \nu_\mu + N(Z-1,A))} > 2 \times 10^{-16} \ (5\sigma)$

- $R_{\mu e} < 8 \times 10^{-17} \ (90\% \ CL)$
- $\mathcal{O}(10^4)$ improvement of previous result (SINDRUM-II)
Backgrounds

Intrinsic

- $\mu$ Decay-in-orbit (DIO)
- Cosmic rays
- Mitigate with detector design

Beam-induced

- Beam electrons (decays-in-flight)
- Radiative pion capture (pions in $\mu$-target)
- Mitigate with accelerator design and $\mu$-target choice
Tracker

**Annular disks of straw tubes**

- Inner hole (38 cm) reduces flux of high-intensity, low-momentum particles
- 20k mylar straws (15 µm)
- 1 atm 80:20 Ar:CO₂ at 1450 V
- \( \sim 100 \text{ keV}/c \) momentum resolution to separate signal from DIO tail
2 annular disks of 674 undoped CsI crystals

- Provides $E/p$ (along with tracker)
- $\sigma_E/E = \mathcal{O}(10\%)$
- $\sigma_t < 500$ ps
- $\sigma_{x,y} \leq 1$ cm
- $\tau < 40$ ns
Stopping target monitor

- Need to measure denominator of $R_{\mu e}$
  - Measure rate of muonic atoms to $O(10\%)$
- System of HPGe and LaBr detectors downstream of Mu2e detect $\gamma$ spectrum
Beam backgrounds: pulsed beam and aluminum target

- ~200 ns pulses of $\sim 10^7$ protons at 8 GeV/c, spaced at ~1700 ns
- Muonic aluminum lifetime of 864 ns
- Strategy: Extract muon beam onto Al target, wait for prompt backgrounds to decay, search for CLFV signal
Extinction Monitor

How do we know the signal window is free of residual beam?

- Measure beam **extinction** as ratio of out-of-time beam to in-time beam
- Must achieve extinction level of $10^{-10}$ or better
Extinction Monitor

- Track target-scattered protons using ATLAS silicon pixel sensors and FE-I4b readout chips
- 8 pixel planes and a permanent dipole magnet
  - Detect $\sim 4 \text{ GeV}/c$ protons and deflect low-energy secondary particles
Cosmic ray background
Cosmic Ray Veto

- Expect base rate of $\sim 1$ CE-like event / day from cosmic rays
- Need 99.99% veto efficiency
- Solution: 4 layers of extruded polystyrene scintillators surrounding entire detector area
  - Veto events with triple coincidence
Simulating first physics run (mid-2020s)

Recently completed MC campaign to estimate Run 1 sensitivity

- Draft publication under internal review

Discovery potential at

\[ R_{\mu e} > 1 \times 10^{-15} \ (5\sigma) \]

- \[ R_{\mu e} < 6 \times 10^{-16} \ (90\% \ CL) \]
- 10^3 improvement over SINDRUM-II
Searches for CLFV provide excellent opportunity to probe New Physics

Mu2e will search for CLFV in $\mu \rightarrow e$ conversion and improve previous results by $\mathcal{O}(10^4)$ by the end of the decade

Mu2e is currently under construction and performing system integration tests

Commissioning and Run 1 expected during the middle of this decade

- Stay tuned!
Backup
Physics reach and $\mu$-lifetime vs $Z$

![Graph showing BR(\(\mu\to e,\pi\)) vs Z](image1)

![Graph showing Mean lifetime vs Atomic number (Z) and Free decay branch (%)](image2)

- Z Penguin
- Charge Radius
- Dipole
- Scalar