The Mu2e Experiment — Searching for Charged Lepton Flavor Violation

Michael Hedges
Purdue University
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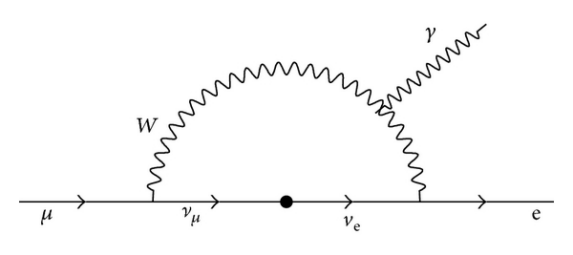
Charged Lepton Flavor Violation

Charged leptons are only fermions without observation of flavor violation

- Quarks mix (CKM)
- Neutrinos oscillate

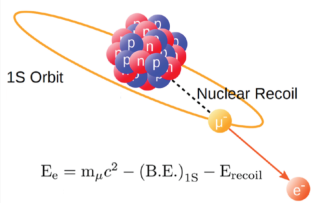
CLFV is allowed in νSM, but ludicrously suppressed

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

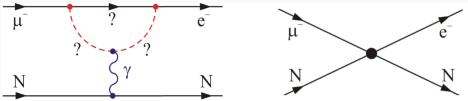


Any experimental observation would unambiguously indicate New Physics

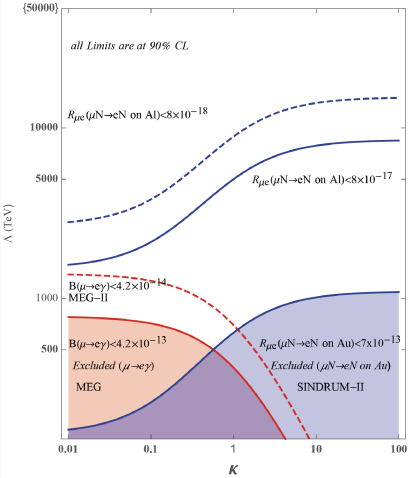
CLFV: $\mu \to e$ conversion



- Monoenergetic ~105 MeV/c conversion-electron (CE)
- Sensitive to energy scales $\mathcal{O}(1000)$ TeV

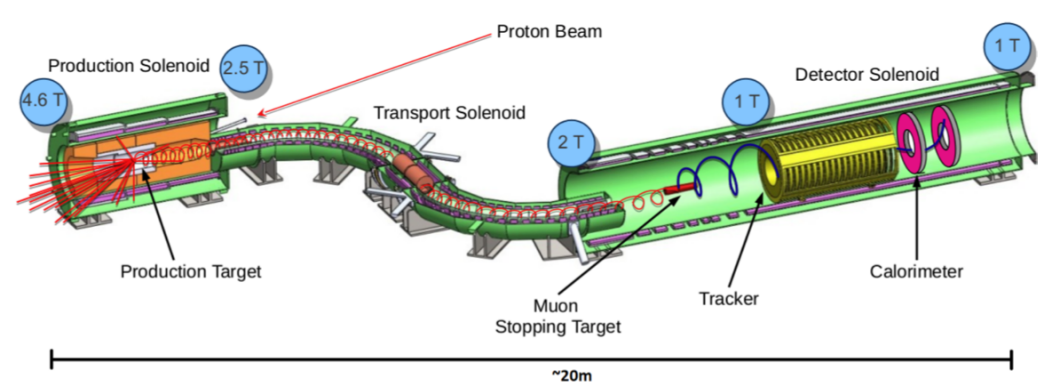


Adapted from A. de Gouvea and P. Vogel,
Progress in Particle and Nuclear Physics 71, 75–92 (2013)



$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L)$$

Mu2e



Discovery potential of $R_{\mu e} = \frac{\Gamma(\mu^- + N(Z,A) \rightarrow e^- + N(Z,A))}{\Gamma(\mu^- + N(Z,A) \rightarrow \nu_\mu + N(Z-1,A))} > 2 \times 10^{-16}$ (5σ)

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

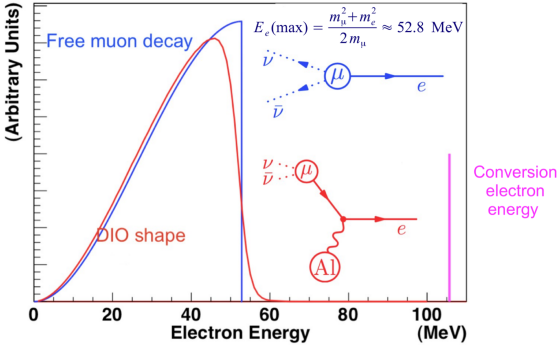
Backgrounds

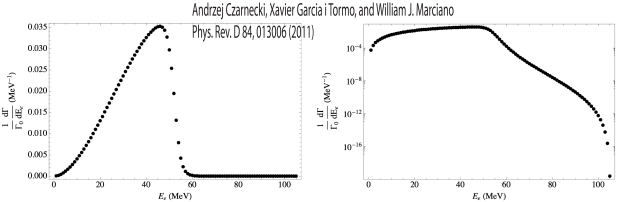
Intrinsic

- μ Decay-in-orbit (DIO)
- Cosmic rays (see talk by Matthew Solt)
- Mitigate with detector design

Beam-induced

- Beam electrons (decays-in-flight)
- Radiative pion capture (pions in μ-target)
- Mitigate with pulsed beam and Al μ-target

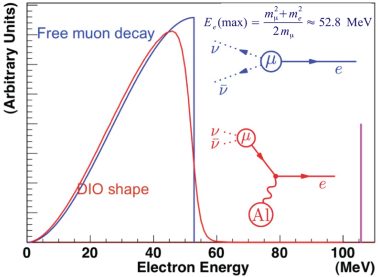


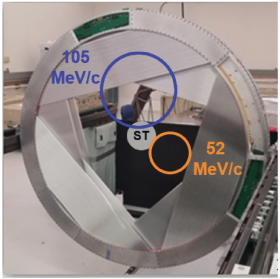


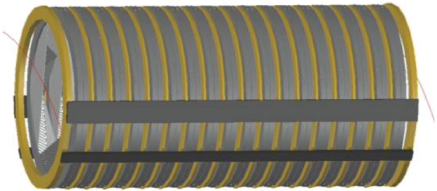
Tracker

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:CO_2 at 1450 V
- $\sim$ 100 keV/c momentum resolution to separate signal from DIO tail



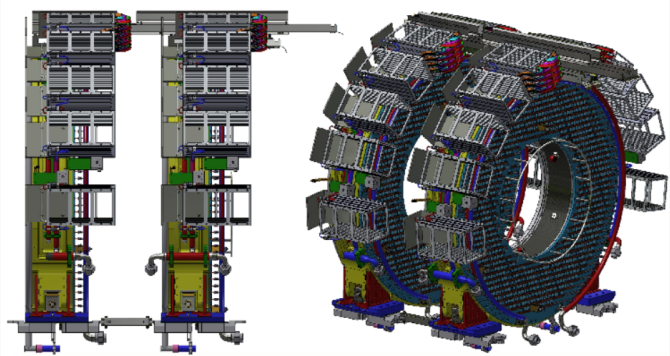




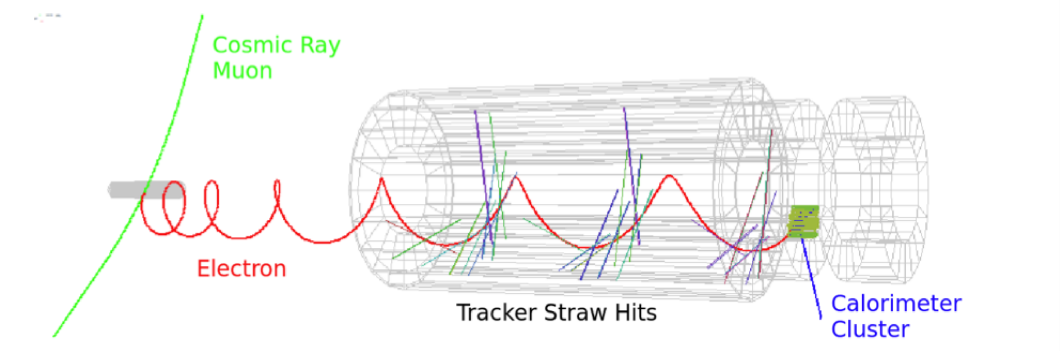
Calorimeter

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



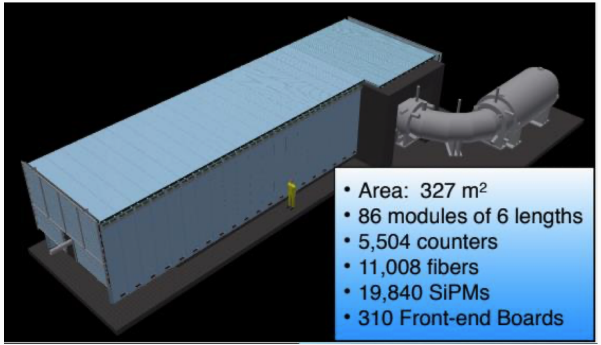
Cosmic ray background



- Old event display showing a cosmic ray background event
  - See later talk by Namitha Chithirasreemadam on updated event display work!

Cosmic Ray Veto

- See later talk by Matthew Solt for more!
- 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



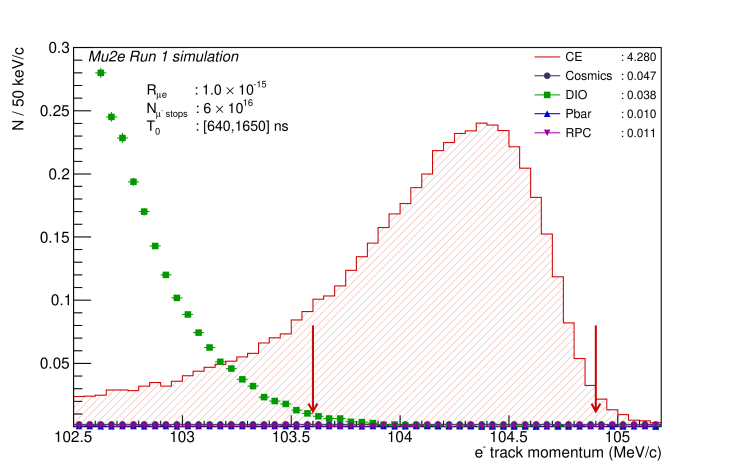
Simulating first physics run (mid-2020s)

Recently completed MC campaign to estimate Run 1 sensitivty

- Draft publication under internal review

Discovery potential at $R_{\mu e} > 1 \times 10^{-15}$ (5σ)

- $R_{\mu e} < 6 \times 10^{-16}$ (90% CL)
- 10^3 improvement over SINDRUM-II



Summary

Searches for CLFV provide excellent opportunity to probe New Physics

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

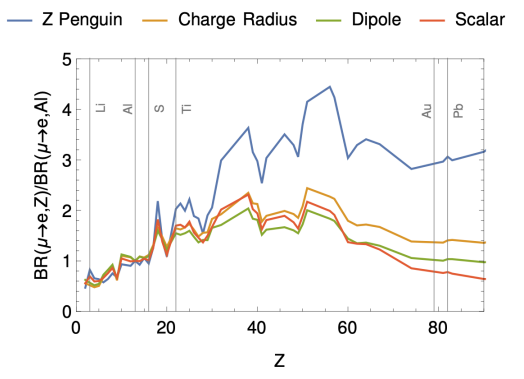
Mu2e is currently under construction and performing system integration tests

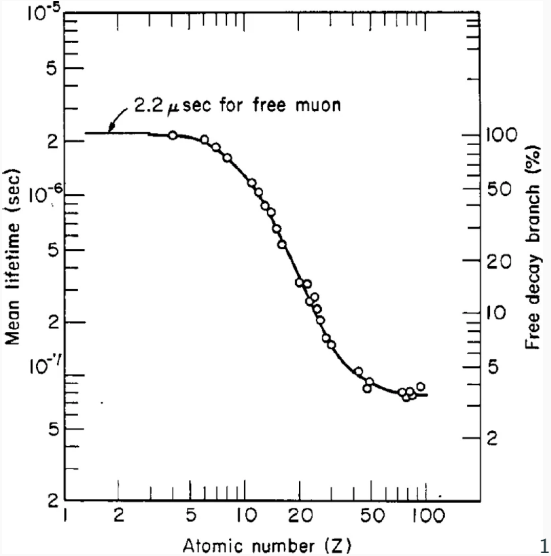
Commissioning and Run 1 expected during the middle of this decade

- Stay tuned!

Backup

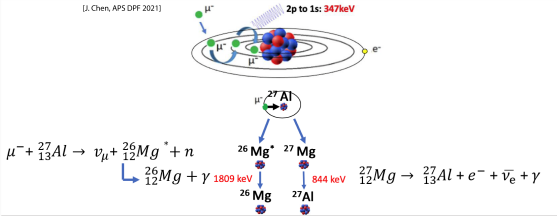
Physics reach and μ-lifetime vs Z

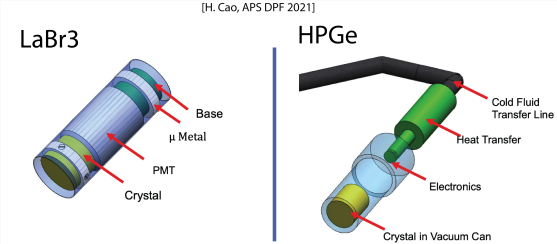




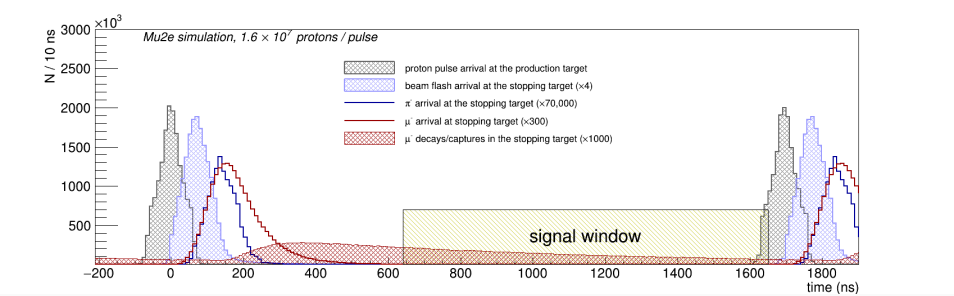
Stopping target monitor

- Need to measure denominator of $R_{\mu e}$
  - Measure rate of muonic atoms to $\mathcal{O}(10\%)$
- System of HPGe and LaBr detectors downstream of Mu2e detect γ spectrum





Beam backgrounds: pulsed beam and aluminum target

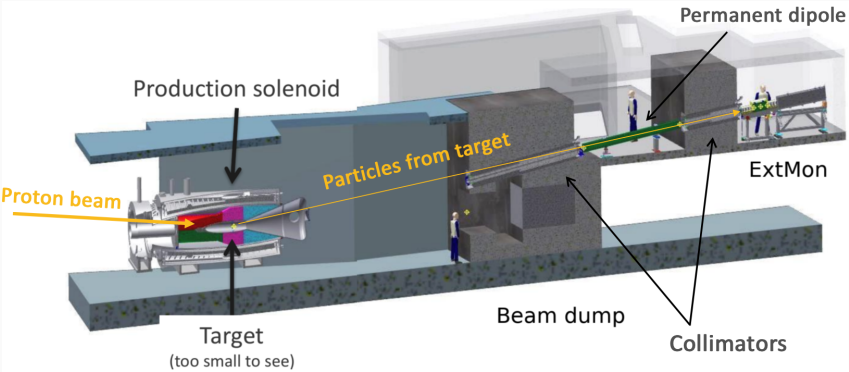


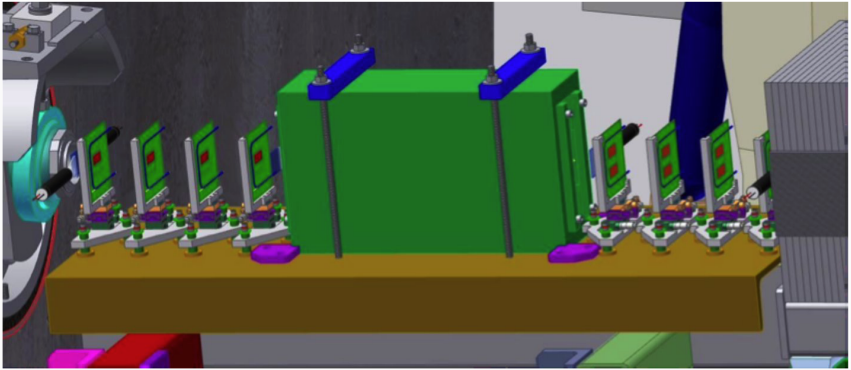
- ∼200 ns pulses of $\sim 10^7$ protons at 8 GeV/c, spaced at ∼1700 ns
- Muonic aluminum lifetime of 864 ns
- Strategy: Extract muon beam onto Al target, wait for prompt backgrounds to decay, search for CLFV signal

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 GeV/c protons and deflect low-energy secondary particles