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The Mu2e experiment: a new high-sensitivity muon to electron conversion search at Fermilab

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Abstract. Mu2e will search for coherent, neutrino-less conversion of muons into electrons in the field of a nucleus to a few parts in 10^{17}, a sensitivity improvement by a factor of 10,000 over existing limits. Muon-electron conversion provides unique windows into new physics inaccessible to other lepton flavor violation searches and probes up to mass scales $\mathcal{O}10^4$ TeV, far beyond the reach of present or planned high energy colliders.

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The Mu2e experiment [1] will search for a coherent muon to electron conversion on a nucleus. This process does not conserve charged lepton flavor. The Standard Model (SM) rate for the conversion is more than 30 orders of magnitude below the projected sensitivity of the experiment. Therefore a positive signal would be an unambiguous sign of New Physics. Many New Physics models predict an observable conversion rate. Examples include supersymmetry with and without R-parity conservation, models with second Higgs doublet, Z', leptoquarks, extra dimensions, etc. [2, 3]. The effective non-SM vertex mediating conversion can be an electromagnetic or four-fermion contact interaction depending on the model. A simple effective theory Lagrangian

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

where Λ is the mass scale of the new physics, and the dimensionless parameter κ represents the importance of the contact term, is used to illustrate the physics reach of muon LFV searches on Fig. 1 [4]. The present state of muon flavor violation searches is: $Br(\mu^+ \to e\gamma) < 2.4 \times 10^{-12}$ [5], $Br(\mu^+ \to e^+e^-e^+) < 1 \times 10^{-12}$ [6], $R_{\mu e} < 7 \times 10^{-13}$ [7]. The goal of Mu2e is to improve the conversion measurement by 4 orders of magnitude, which puts it near the 10^{-16} conversion rate line on Fig. 1. Mu2e will provide an improvement over a range of models, and will be sensitive to mass scales of thousands of TeV. The complementarity of Mu2e and LHC searches is discussed in [8].

The concept of the Mu2e measurement is to generate a pulsed beam of low momentum negative muons, stop the muons in thin foils and capture them into muonic atoms, wait for prompt backgrounds to decay, and measure the electron spectrum from the muonic atoms. The signal is a monoenergetic line at about 105 MeV. The lifetime of muonic aluminum is 864 ns, which sets the scale for an appropriate beam repetition rate.

The existing Tevatron infrastructure at Fermilab will be re-used to deliver 8 GeV protons with 1694 ns bunch spacing to the experiment, with about 3×10^7 protons per

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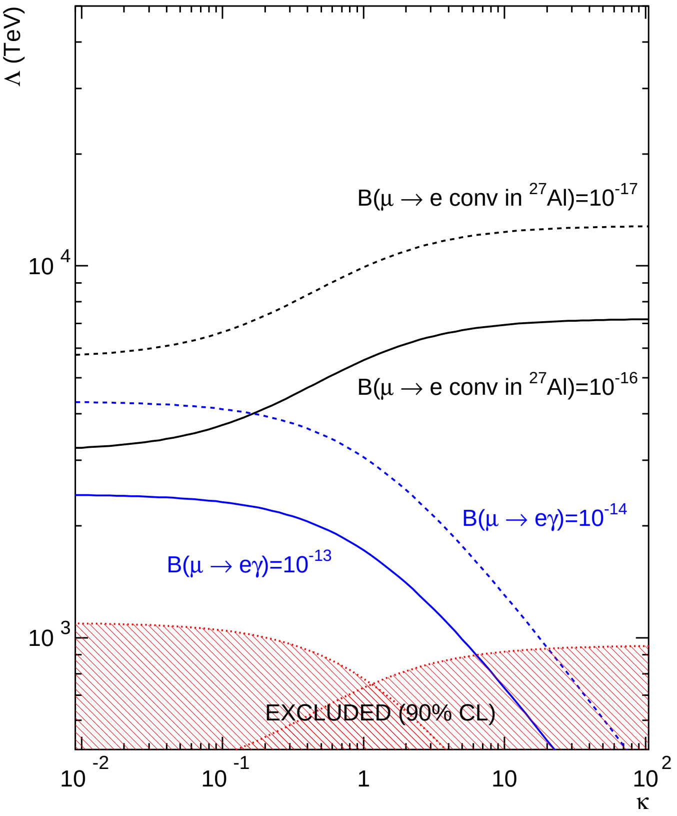

FIGURE 1. Physics reach of muon lepton flavor violation searches. The shaded region on the left is excluded by MEG [5], and on the right by SINDRUM II [7]

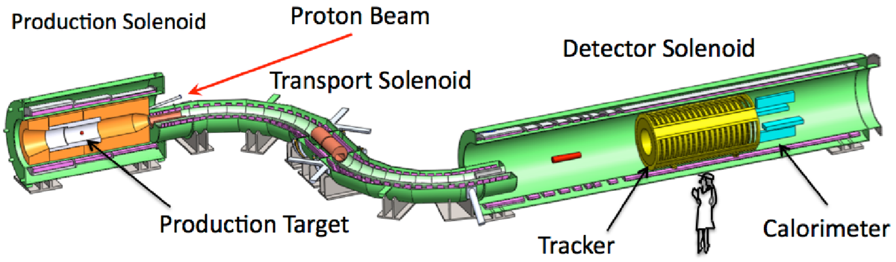

FIGURE 2. Mu2e setup. Cosmic ray veto system and some other parts of the apparatus are not shown.

bunch and duty factor of 1/3. The Mu2e experimental setup is shown in Fig. 2. Pions and muons produced inside the production solenoid are collected to the S-shaped muon beamline. Most pions decay inside the 13 m long beamline. About 40% of muons exiting the beamline will be stopped in the aluminum target. The expected rate is about 0.0016 stopped muons per proton. The Mu2e tracker will use straw tubes in vacuum. Only tracks with transverse momentum above 53 MeV/c will produce any hits. The intrinsic momentum resolution of the tracker is well represented by a core Gaussian with sigma 115 keV/c and a tail of 2% with sigma 176 keV/c, predicted using a G4 simulation of the detector. Because of energy loss and straggling in materials upstream of the tracker

TABLE 1. Mu2e backgrounds for 3.6×10^{20} protons

Background process	**Number of expected events**
Muon decay in orbit	0.22 ± 0.06
Antiproton induced	0.10 ± 0.035
Cosmic rays	0.05 ± 0.025
Radiative pion capture	0.03 ± 0.007
Muon decay in flight	0.027 ± 0.013
Pion decay in flight	0.003 ± 0.0015
Beam electrons	0.0006 ± 0.0003
Radiative muon capture	$< 1 \times 10^{-6}$
Total	0.45 ± 0.08

width of the signal is about 1 MeV/c FWHM. Mu2e will also use a calorimeter made from scintillating crystals to provide a cross check on signal candidates.

There are several classes of backgrounds: prompt, muon induced, and cosmic rays. An example of a prompt background is π^- radiative capture and subsequent conversion of the γ in the stopping target material, which can produce a 105 MeV electron. To suppress this background Mu2e requires the fraction of protons outside the beam pulse to be less than 10^{-10}, which will be achieved with and monitored with dedicated systems. The electron spectrum from bound muons decaying in orbit (DIO) extends up to the signal region at the kinematic end point [9]. The spectrum is sharply falling, and DIO background is reduced by improving the momentum resolution of the electron spectrum.

The expected backgrounds in Mu2e after 3 years of running at 8 kW beam power are summarized in Table 1. The single event sensitivity with the present preliminary software is 5×10^{-17}. It is expected that the sensitivity will become about 2×10^{-17} due to the future software improvements.

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