Optimization of the Muon Stopping Target of the Mu2e Experiment

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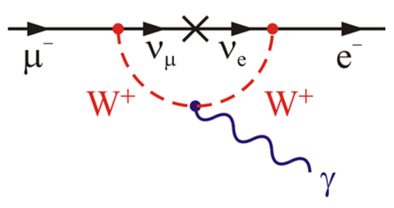
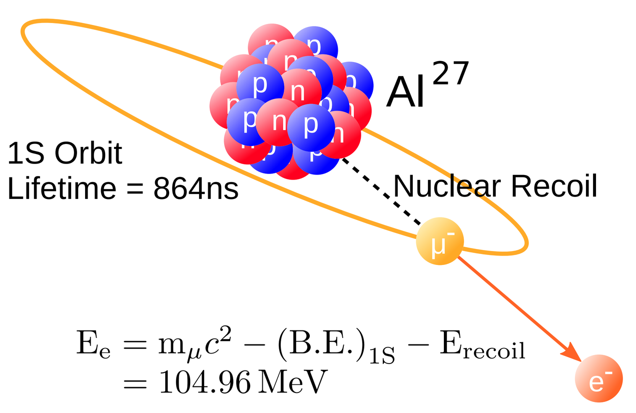
The Mu2e experiment being constructed at Fermilab will search for the coherent neutrino-less conversion of muons to electrons in the field of an atomic nucleus. Mu2e will probe for this charged lepton flavor violating process at a sensitivity of a few parts in 10^{-17}. This sensitivity is an improvement of four orders of magnitude compared to previous experiments and provides a unique probe for physics beyond the Standard Model up to the $10^4\,\mathrm{TeV}$ scale. An essential part of the Mu2e experiment is the aluminum muon stopping target. The predominantly negative Mu2e muons come to rest in the stopping target and are then captured by a positive nucleus. Mu2e needs to stop as many muons as possible, calling for a large target mass. However, the greater the target mass, the greater the stochastic energy loss, smearing the signal and increasing backgrounds. In the interplay with the muon beam, the magnetic field and the active detector components such as the straw tube tracker, the muon stopping target significantly affects the achievable sensitivity of the overall Mu2e experiment. On this poster, we present the results of computational simulation studies carried out to optimize performance of the muon stopping target.

Charged Lepton Flavor Violation

In the Standard Model (SM), charged lepton flavor violation (CLFV) can emerge by the intermediate mixing of massive neutrinos. Due to the tiny finite mass of neutrinos, the SM rates of CLFV processes are negligibly small, i.e. $<10^{-50}$ for both $\mu^+ \to e^+\gamma$ and $\mu^- N \to e^- N$. Many models of physics beyond the SM predict significantly enhanced CLFV rates. Any experimental detection of a CLFV signal would point to new physical phenomena.



Conversion of Muons to Electrons



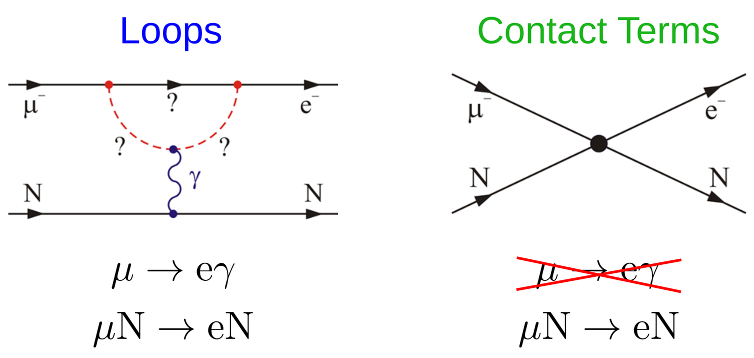
The conversion of muons to electrons in the field of an atomic nucleus is a coherent process and has the kinematics of a two-body decay. The conversion electron is mono-energetic with an energy slightly below the muon mass. Corrected for the nuclear recoil and the binding energy in aluminum, the experimental signature is a single 104.96 MeV electron.

Sensitivity to Charged Lepton Flavor Violation

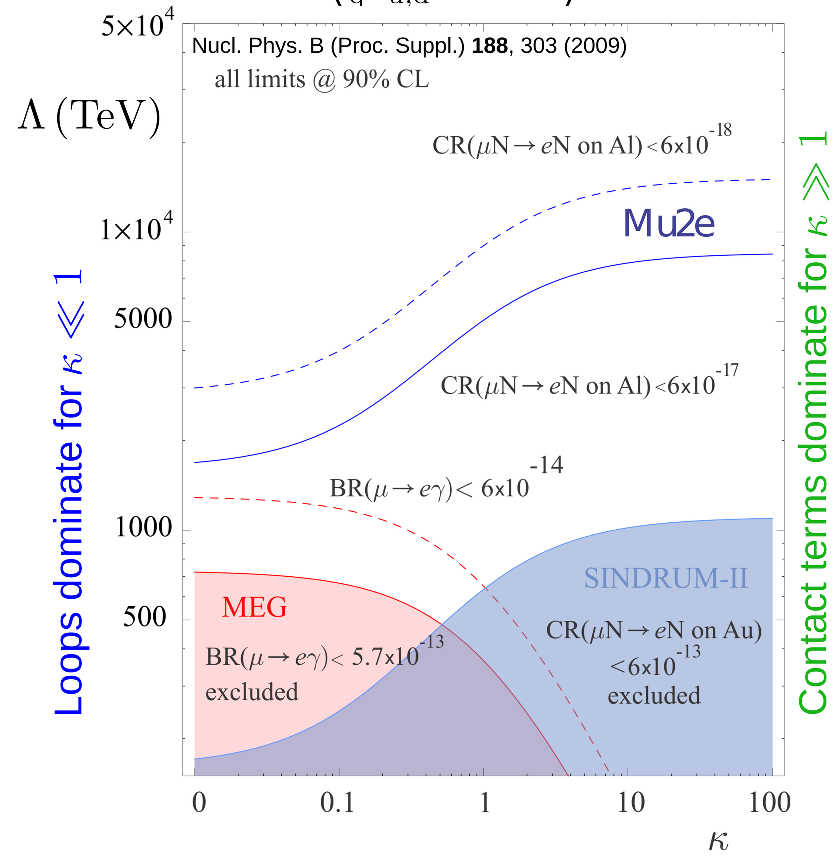
Effective Lagrangian:

$$\mathcal{L}_{CLFV} = \frac{m_\mu}{(1+\kappa)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\sum_{q=u,d}\bar{q}_L\gamma^\mu q_L\right)$$

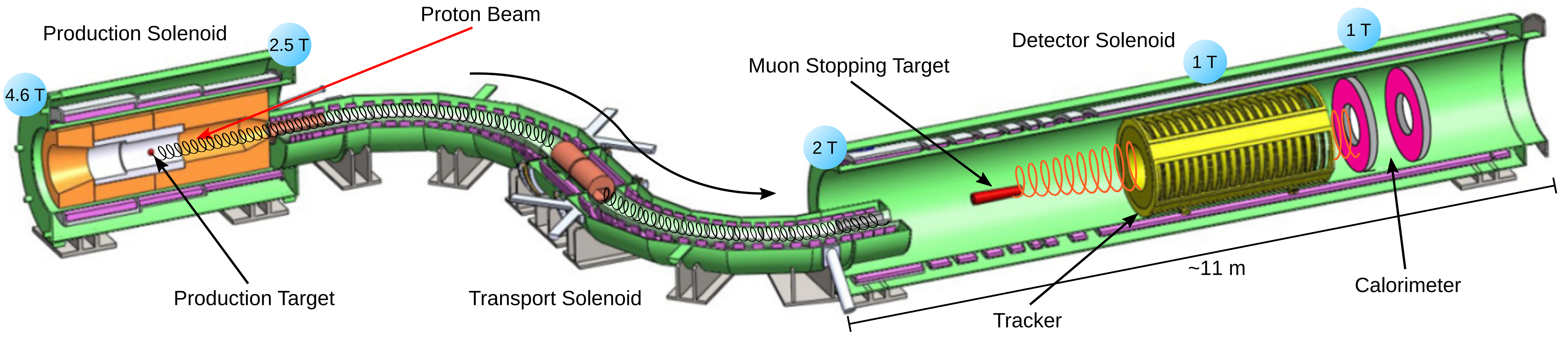
Two types of amplitudes contribute to CLFV:



The $\mu N \to eN$ and $\mu \to e\gamma$ processes have complementary sensitivity to physics beyond the SM. It is important to experimentally search for both CLFV processes to be able to disentangle the underlying physics.



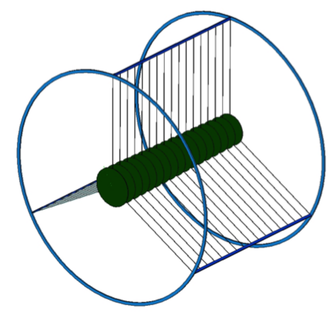
Experimental Apparatus



Cosmic ray veto and beam monitoring systems not shown

The Baseline Muon Stopping Target

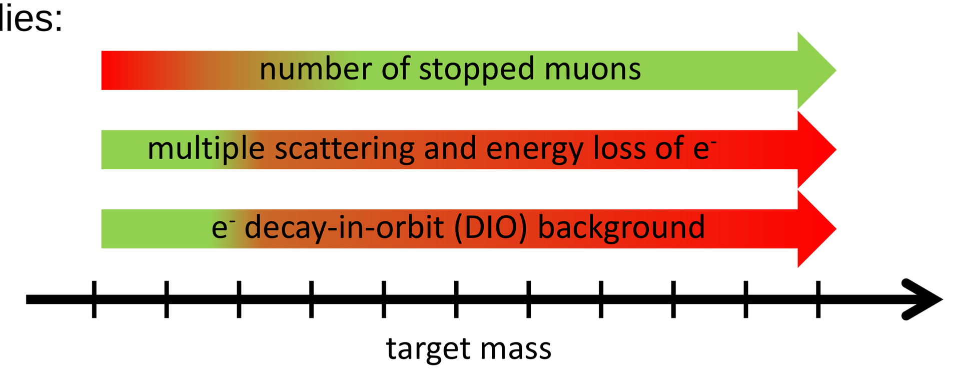
The baseline design of the Mu2e stopping target consists of thin aluminum foils supported by tungsten wires that are attached to the inner detector solenoid.



Goals of the optimization studies:
1. Improve the design of the foil target.
2. Explore the potential of alternative configurations and topologies

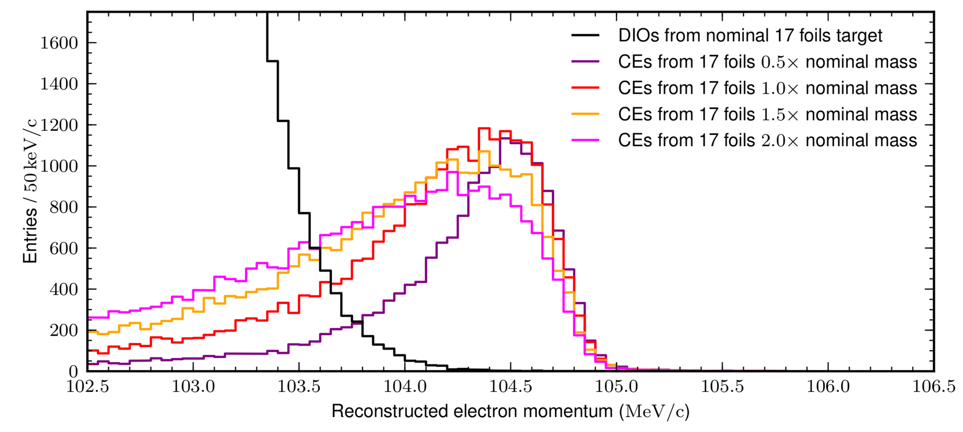
Physics Effects Related to the Target

Several competing effects need to be considered in the optimzation studies:



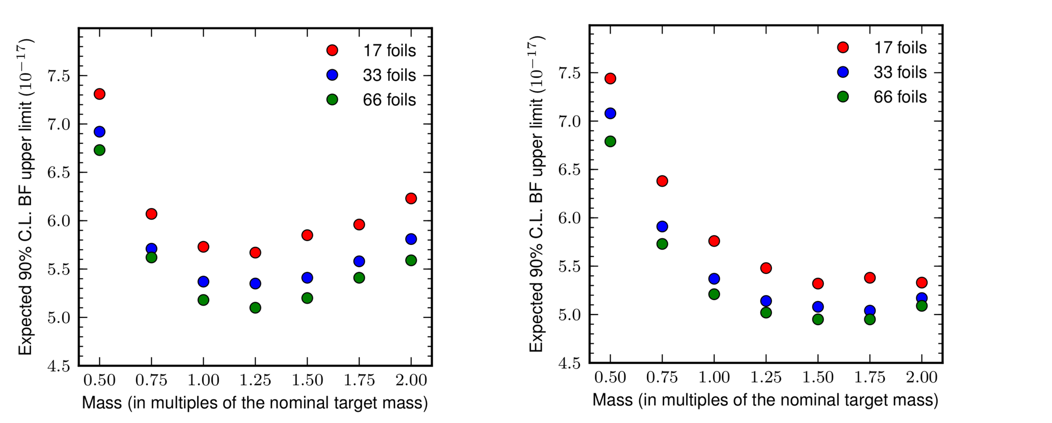
Further first and higher order effects:
- Matter distribution and geometry (foil thickness, tapering, radii, ...)
- Target position within the magnetic bottle and tracker entrance
- Effects of further background sources (e.g. radiative pion captures)

Examples of Electron Momentum Spectra



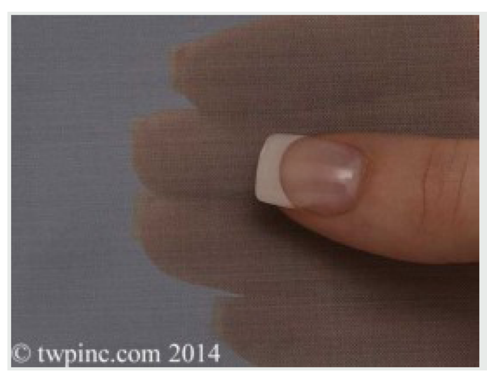
Examples of electron spectra of signal conversion electrons (CE) and decay-in-orbit (DIO) background electrons for stopping targets composed of 17 foils at different masses. The different signal shapes induced by multiple Coulomb scattering are apparent.

Effects of the Target Mass and the Number of Foils



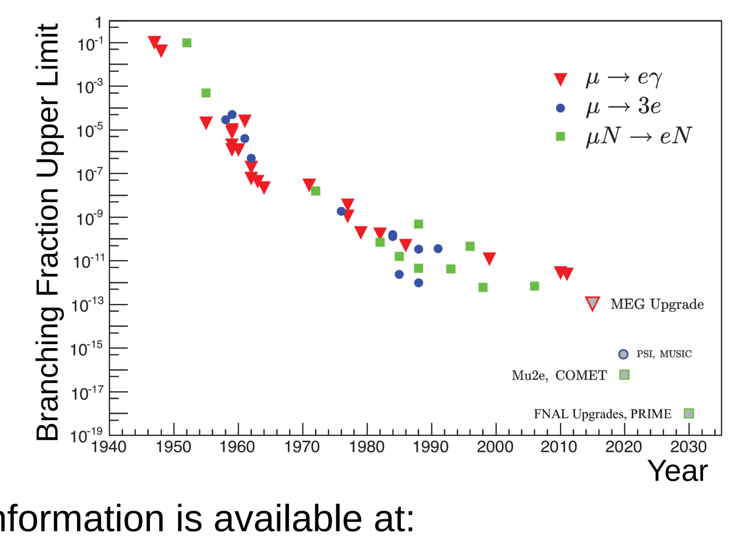
The optimization studies are performed with the expected upper limit on the conversion branching fraction as figure of merit. Overall, stopping targets composed of thinner and more foils perform better.

Alternative Stopping Targets



Further improvements over the foil design are possible by stopping targets with low effective densities, e.g. realized by materials composed of fine aluminum filaments. Lower densities enable to further reduce the effect of multiple Coulomb scattering, and to increase the target mass and the number of stopped muons.

Prospects of CLF Violation Searches



Further information is available at:
[1] http://mu2e.fnal.gov
[2] Mu2e Technical Design Report, arXiv:1501.05241

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