Charged Lepton Flavour Violation: An Introduction

Miles Kidson

University of Cape Town

kdsmil001@myuct.ac.za

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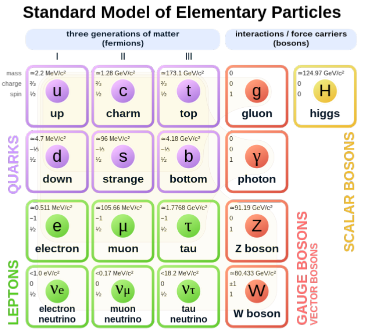
Standard Model conserved quantities

There are a few quantities that are strictly conserved in SM processes:

- Electric & colour charge
- Baryon number B
- Lepton number L

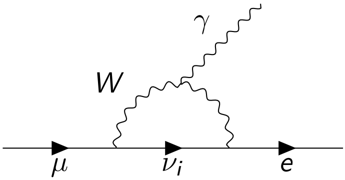
If neutrinos were massless, individual lepton flavour numbers L_e, L_μ, and L_τ would be conserved[1]. With massive neutrinos, only L is conserved. (Provided neutrinos are Dirac fermions and not Majorana fermions)



[1] M.E. Peskin, 2018, p.286

Charged Lepton Flavour Violation (CLFV)

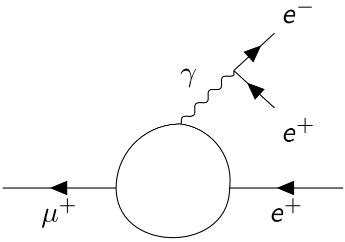
- We already see lepton flavour being violated in neutrino oscillation
- Best estimates of $\mu \to e\gamma$ rates by the same mechanism are $< 10^{-54}$, which are not realistically measurable[2]. Similar for other processes
- Thus observing these processes implies new physics is at play!
- Example processes would be $\mu \to e\,e\,e$, $\mu \to e\gamma$, and $\tau \to \mu, e + X$
- Muons are much easier to study than tau leptons

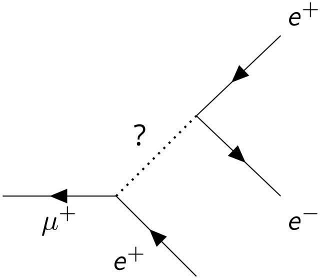


[2] de Gouvea, A., & Vogel, P. (2013). Lepton Flavor and Number Conservation, and Physics Beyond the Standard Model.

$\mu \to e\, e\, e$

- We could see this as $\mu^+ \to e^+ e^+ e^- \nu_\mu \overline{\nu}_e$ and not be new physics
- Thus we look for this with no energy loss
- Could be $\mu \to e\gamma$ with more steps, or could be something else entirely
- The SINDRUM experiment puts a rate limit of 10^{-12} with future experiments aiming for 10^{-16}.[3]

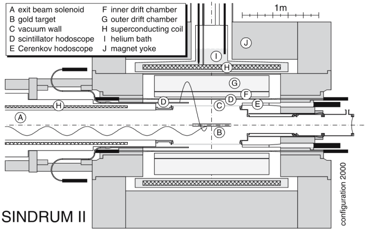




[3] Bellgardt, U. et al. (1988). Search for the decay $\mu+ \to$ e+e+e-.

$\mu^- N \to e^- N$

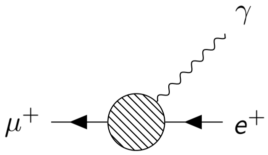
- Conversion of a muon captured by a nucleus into an electron
- Bombarding a nucleus with muons to see an outgoing electron
- Should result in a monoenergetic electron, $\approx 104.96\,\mathrm{MeV}$ for most nuclei
- Important to ignore $\mu^- \to e^- \overline{\nu}_e \nu_\mu$
- Rates for gold and titanium are $\lesssim 10^{-13}$ from SINDRUM-II[4]



[4] Bertl, W., Engfer, R., Hermes, E. et al. A search for μ-e conversion in muonic gold. (2006)

$\mu^+ \to e^+\gamma$

- Longest studied process and with the most potential to reduce limits
- Background events are $\mu^+ \to e^+\overline{\nu}_e\nu_\mu$
- Must look for total energy of $e + \gamma$ to be m_μ
- MEG experiment found limits of $< 4.2 \times 10^{-13}$ in 2016
- MEG-II aims to bring that down to 6×10^{-14}



MEG detector?

Best theories for explaining it

Conclusion