

# Charged Lepton Flavour Violation: An Introduction

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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  $L_e$ ,  $L_\mu$ , and  $L_\tau$  would be conserved<sup>1</sup>. With massive neutrinos, only  $L$  is conserved. (Provided neutrinos are Dirac fermions and not Majorana fermions)

Standard Model of Elementary Particles

three generations of matter (fermions)			interactions / force carriers (bosons)	
I		II	III	
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	$\approx 124.97 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	$0$
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$1$
	<b>u</b>	<b>c</b>	<b>t</b>	<b>g</b>
	up	charm	top	gluon
	$\approx 4.7 \text{ MeV}/c^2$	$\approx 96 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	$0$
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$0$
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$1$
	<b>d</b>	<b>s</b>	<b>b</b>	<b>γ</b>
	down	strange	bottom	photon
	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$
	$-1$	$-1$	$-1$	$0$
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$1$
	<b>e</b>	<b>μ</b>	<b>τ</b>	<b>Z</b>
	electron	muon	tau	Z boson
	$< 1.0 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.433 \text{ GeV}/c^2$
	$0$	$0$	$0$	$\pm 1$
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$1$
	<b>ν<sub>e</sub></b>	<b>ν<sub>μ</sub></b>	<b>ν<sub>τ</sub></b>	<b>W</b>
	electron neutrino	muon neutrino	tau neutrino	W boson

QUARKS

LEPTONS

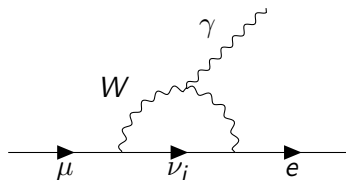
SCALAR BOSONS

GAUGE BOSONS  
VECTOR BOSONS

<sup>1</sup>M.E. Peskin, 2018, p.286

# Charged Lepton Flavour Violation (CLFV)

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

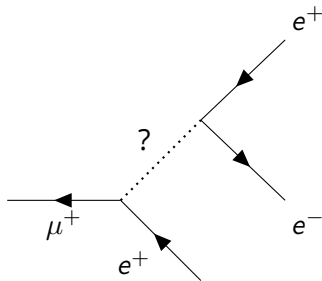
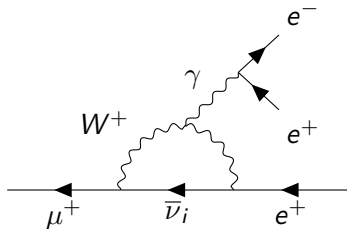


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<sup>2</sup>de Gouvea, A., & Vogel, P. (2013). Lepton Flavor and Number Conservation, and Physics Beyond the Standard Model.

$$\mu \rightarrow e e e$$

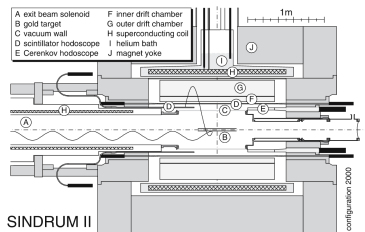
- We could see this as  $\mu^+ \rightarrow e^+ e^+ e^- \nu_\mu \bar{\nu}_e$  and not be new physics
- Thus we look for this with no energy loss
- Could be  $\mu \rightarrow e \gamma$  with more steps, or could be something else entirely
- The SINDRUM experiment puts a rate limit of  $10^{-12}$  with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



<sup>3</sup>Bellgardt, U. et al. (1988). Search for the decay  $\mu^+ \rightarrow e^+ e^+ e^-$ .

$$\mu^- N \rightarrow e^- N$$

- 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,  $\approx 104.96$  MeV for most nuclei
- Important to ignore  $\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$
- Rates for gold and titanium are  $\lesssim 10^{-13}$  from SINDRUM-II<sup>4</sup>



<sup>4</sup>Bertl, W., Engfer, R., Hermes, E. et al. A search for  $\mu$ -e conversion in muonic gold. (2006)

$$\mu^+ \rightarrow e^+ \gamma$$

- Longest studied process and with the most potential to reduce limits
- Background events are  
 $\mu^+ \rightarrow e^+ \bar{\nu}_e \nu_\mu$

# MEG detector?

# Best theories for explaining it



# Conclusion