Leptophilic New Physics

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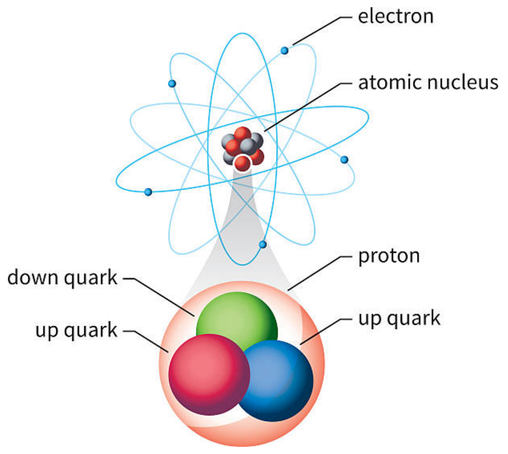
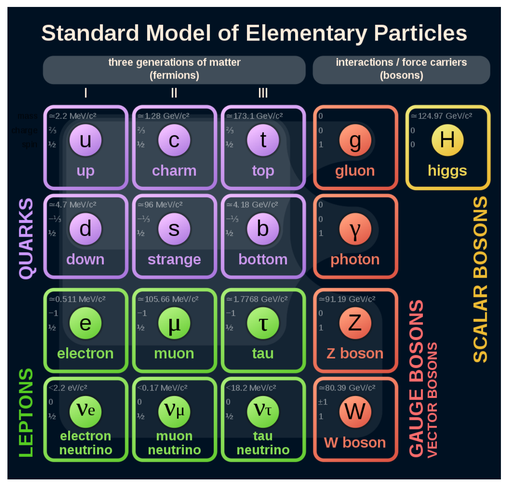
Flavour Physics

Only one generation of matter fields are needed for atoms:



But 3 generations are observed:



⇒ **Why are there 3 generations of matter?**

⇒ **What are the similarities/differences between the generations?**

⇒ **How do the particles of the different generations interact?**

These are the kind of questions addressed by flavour physics.

Flavour Universality

What are the similarities/differences between the generations?

$$\mathcal{L}_{SM} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{Yukawa}}$$

$\mathcal{L}_{\text{gauge}}$ Gauge boson interactions
Flavour universal (do not distinguish between generations)

$\mathcal{L}_{\text{Yukawa}}$ Interaction of Higgs with matter fields
Distinguish between generations
⇒ different masses for different matter fields

Lepton Flavour Universality Violation (LFUV)

What are the similarities/differences between the generations?

Recent hints for Lepton Flavour Universality Violation:

$$R\left(D^{(*)}\right) = \frac{Br(\overline{B}\to D^{(*)}\tau\overline{\nu}_\tau)}{Br(\overline{B}\to D^{(*)}\ell\overline{\nu}_\ell)}, \quad \ell = e,\mu \qquad 3\,\sigma \text{ deviation from SM}^{(\dagger)}$$

$$R\left(K^{(*)}\right) = \frac{Br(\overline{B}\to K^{(*)}\mu\mu)}{Br(\overline{B}\to K^{(*)}ee)} \qquad 4\,\sigma \text{ dev. from SM}$$

$(g-2)_\mu$? $4\,\sigma$ dev. from SM
Cabibbo Angle Anomaly ? $3\,\sigma$ dev. from SM
Leptonic τ-decays ? $2\,\sigma$ dev. from SM

(†) SM: Standard Model of particle physics

⇒ **Hints for new physics that distinguishes between e, μ, τ?**

Cabibbo Angle Anomaly (CAA)

CKM quark mixing matrix:
Describes quark flavour mixing:

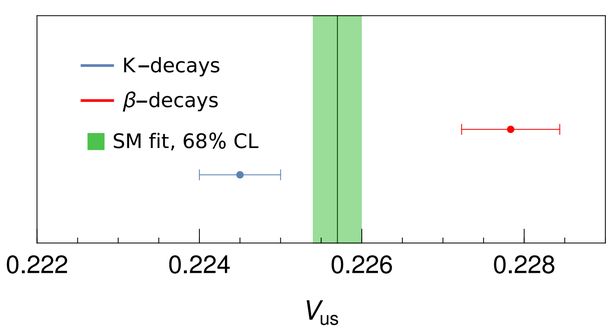
mass eigenstates / gauge eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

In the SM, the CKM-matrix is unitary.

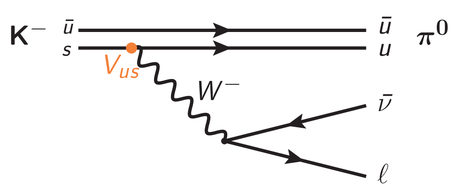
$$\Rightarrow |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

Cabibbo Angle Anomaly:

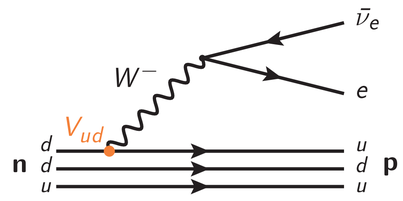


$\approx 3\,\sigma$ tension (PDG) between

- V_{us} from K-decays



- "V_{us} from β decays": V_{ud} extracted from β decays

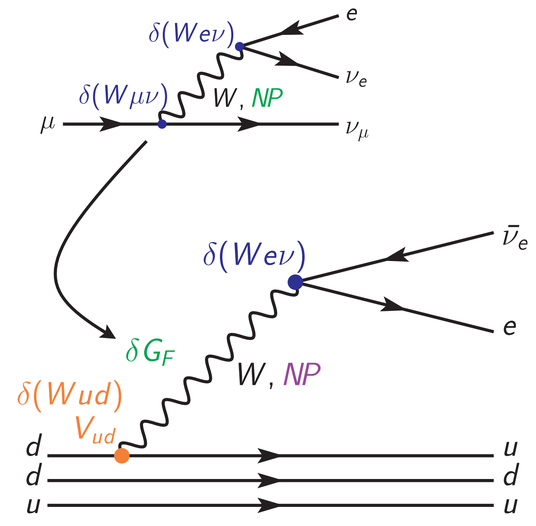


⇒ Applying CKM unitarity:

$$V_{us} \sim \sqrt{1 - V_{ud}^2}$$

$(V_{ub} \approx 0.0037 \sim 0)$

New Physics Interpretations of the CAA



- Direct contributions to β-decays
- Modified Wud-coupling
- Modified $W\ell\nu$-coupling $(\star)$
- Contributions to μ-decays $(\star)$
  $\Rightarrow$ Modified Fermi constant, G_F

$$\delta(\mu \to e\bar{\nu}\nu) = \frac{\mathcal{A}_{NP}(\mu \to e\bar{\nu}\nu)}{\mathcal{A}_{SM}(\mu \to e\bar{\nu}\nu)}$$

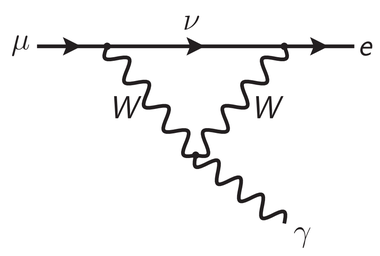
$$\Rightarrow \boxed{G_F = G_F^{\text{SM}}\left(1 + \delta(\mu \to e\bar{\nu}\nu)\right)}$$

$(\star)$ **Leptophilic new physics**:
Extensions of the Standard Model that modify the lepton sector.

Lepton Flavour Violation (LFV)

How do the particles of the different generations interact?

Standard Model:

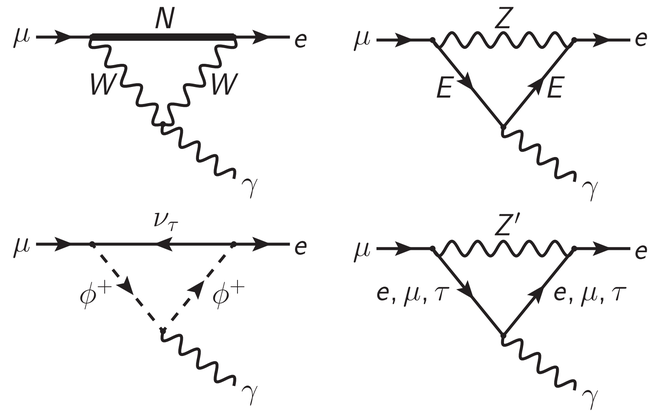


Only in the neutrino sector

Only if $m_\nu \neq 0$

$$\boxed{\text{Br}\left(\mu \to e\gamma\right) \sim \frac{m_\nu^4}{M_W^4} < 10^{-54}}$$

Leptophilic new physics:

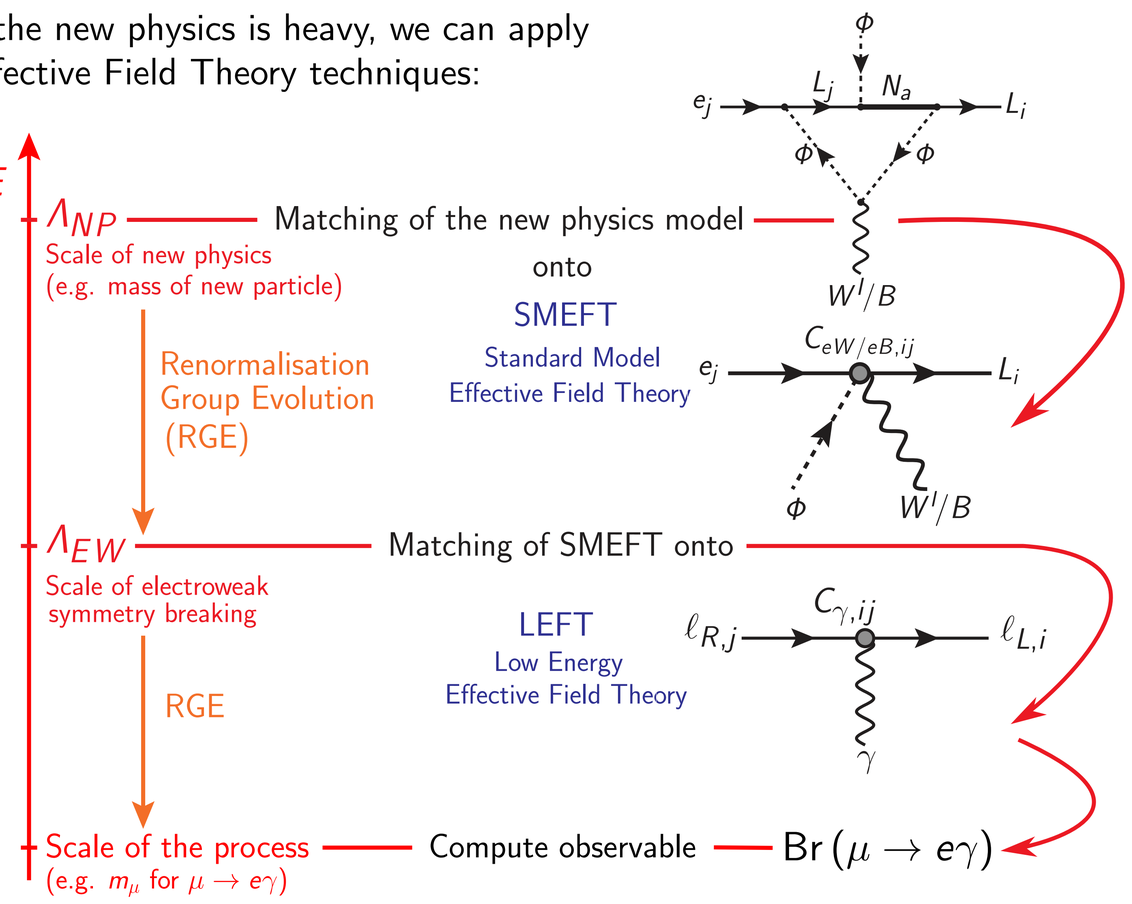


(and many more...)

World leading upper bound by **MEG@PSI**, ongoing efforts with **MEG II**

Effective Field Theories for LFV

If the new physics is heavy, we can apply Effective Field Theory techniques:



Conclusions

Hints for **LFUV**, in particular the Cabibbo Angle Anomaly, call for **leptophilic new physics**.

LFV is forbidden in the SM and strongly constrained by experiment but provides clean discovery channels.

Come to our LF(U)V workshop!

We are organising a **3-day workshop** on the subject of **Lepton Flavour (Universality) Violation**. It will take place **@ UZH** from **12th-14th January 2022** and will be aimed at young theorists & experimentalists working in the field, however, everybody is welcome. Would be nice if you came too!

Register today!