B-anomalies, leptoquarks, flavour, and all that

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The Standard Model

The Standard Model (SM) is a mathematical model specifying the fundamental interactions of the elementary constituents of matter, leptons and quarks.

The matter particles come in three generations or flavours. In the SM, the force carriers do not distinguish between different generations .

	Leptons		Quarks		Force carriers	
1st gen.	e electron	ν_e electron neutrino	u up	d down	γ	electromagnetism
2nd gen.	μ muon	ν_μ muon neutrino	c charm	s strange	g	strong force
3rd gen.	τ tau	ν_τ tau neutrino	t top	b bottom	W, Z	weak force

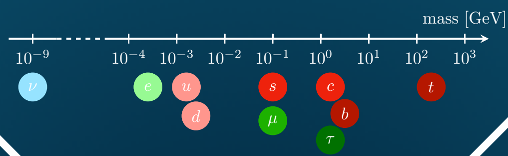
$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

The only interactions that distinguish different flavours are the ones with the Higgs boson - giving elementary matter particles different masses.

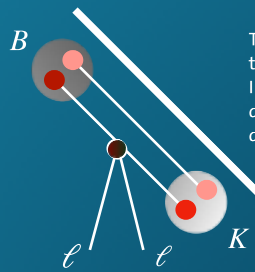
H Higgs

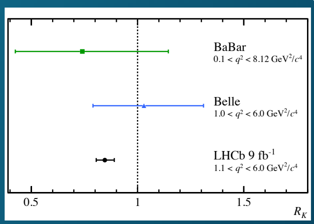
Discovered in 2012, it was the last piece to complete the SM.

Since the couplings of all leptons to the Higgs are small, the SM is almost exactly Lepton Flavour Universal (LFU), meaning that the three lepton generations behave in the same way. A violation of this universality (LFUV) would therefore be a clear signal of New Physics (NP).



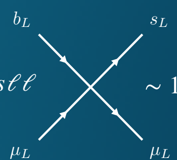
Why are the masses so hierarchical?
Why there are three generations in the first place?





$\sim 3.1\sigma$

$$R_{K^*} = \frac{\mathcal{B}(B \to K\mu\mu)}{\mathcal{B}(B \to Kee)}$$



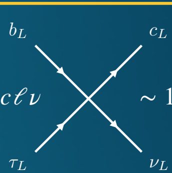
$b \to s\ell\ell$ $\quad \sim 10^{-5}\ G_F$

Hints towards LFUV

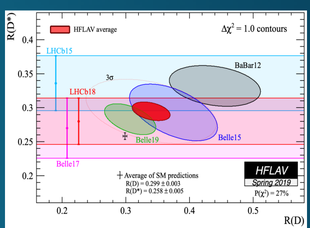
Recently, a series of measurements challenged LFU, suggesting NP that dominantly affects the 3rd generation of matter particles.

The overall significance of the NP hypothesis is rising, with a first single measurement at 3σ deviation from the SM prediction.

The ongoing experiments will be able to clarify the puzzling data in the next few years.

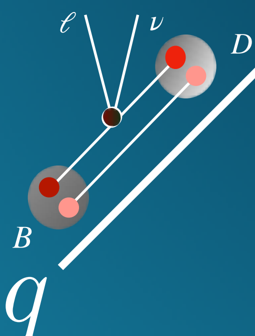


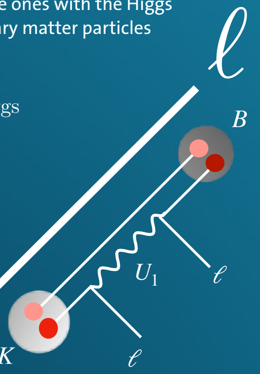
$b \to c\ell\nu$ $\quad \sim 10^{-2}\ G_F$



$$R_{D^*} = \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to D\ell\nu)}$$

$\sim 3.1\sigma$



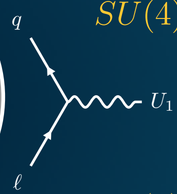


The deviations in the SM predictions in the semi-leptonic decays of B mesons, the so called B-anomalies, seem to follow a pattern similar to the fermion masses:

Effects $\sim 3^{rd} \gg 2^{nd} \gg 1^{st}$

The possible direction to dynamically explain both B-anomalies and fermion hierarchies are flavour non-universal interactions.

$$SU(4)_3 \times SU(3)_{1+2} \times SU(2)_Y \times U(1)_X$$



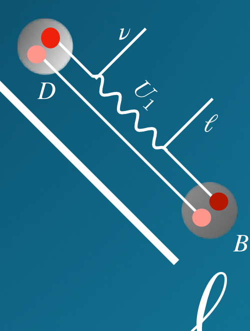
Leptoquark and 4321 Models

$SU(4)_3$ represents a possible new fundamental force, coupled to the third generation, to which we can associate new force carriers:

U_1 leptoquark $\quad g'$ coloron $\quad Z'$

In addition to this, these models usually introduce new matter fields responsible for carrying the effect of the new force to the first two generations.

Analogously to the SM, we also need new scalar particles (like the Higgs) which mediate the 4321 $\to$ SM breaking.

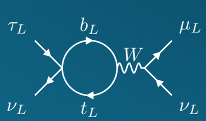


Phenomenological predictions

The imprints of U_1 leptoquark could be probed both at low- and high-energy experiments. Some of the most striking signatures, affecting the 3rd generation, are the following:

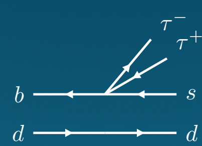
LFUV in τ-decays

A new semi-leptonic interaction generally leads to a modification of the W-coupling to leptons, resulting in possible LFU violations.



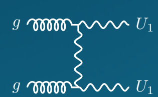
Modification of $\mathcal{B}(B \to K\tau\tau)$

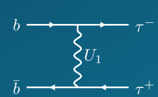
An analogous process to $B \to K\mu\mu$ is the decay of a B meson to a K and a pair of τ leptons, which receives a large enhancement.

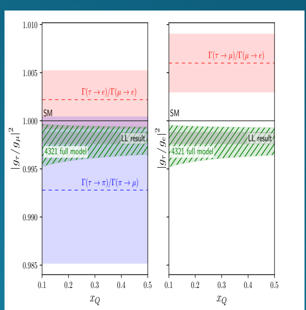


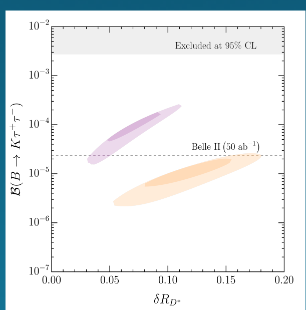
Direct and indirect detection

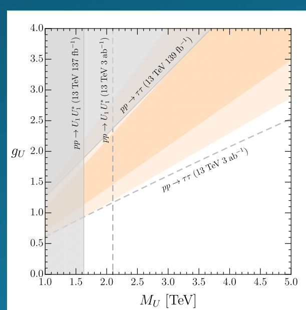
The U_1 leptoquark, with a mass of ~ 5 TeV, could be produced directly at the LHC, or give rise to indirect high-energy effects like modifications of τ lepton distributions.











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