The Flavor of (New) Physics

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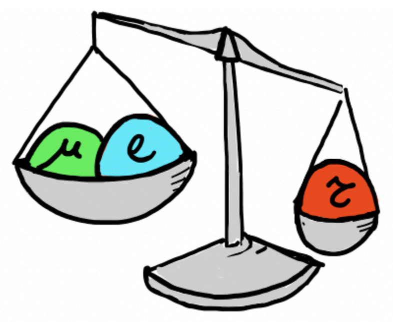
The Flavor Puzzle of the Standard Model

The **Standard Model** (SM) describes the fundamental interactions of the elementary constituents of matter, quarks and leptons.

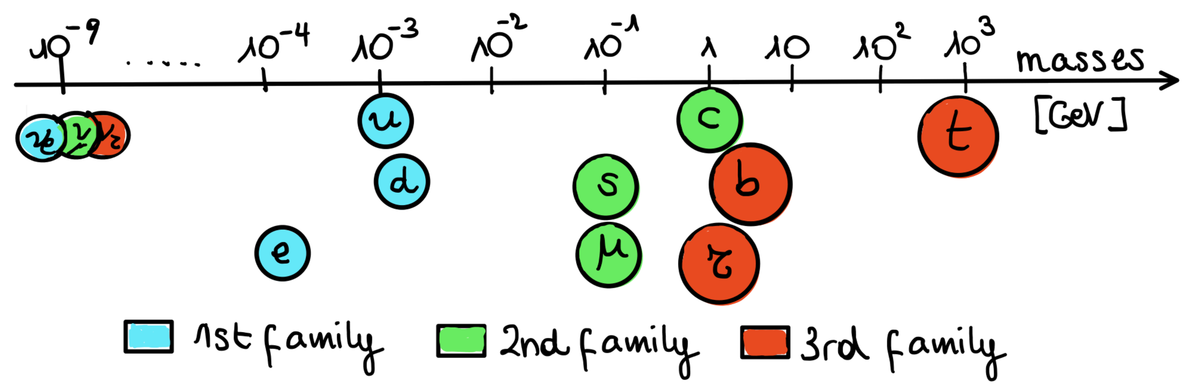


Each matter particle comes in three copies, known as families or **flavors**, that differ only in their mass.

In the SM, the behavior of elementary particles under the three **fundamental forces** (electromagnetic, strong and weak) is simple: it is completely determined by symmetry principles and it is **flavor-universal**.

The only interaction that distinguishes between flavors is the one with the Higgs field, the **Yukawa** interaction, via which particles acquire their non-universal masses.

The observed masses span many orders of magnitude and have a strongly **hierarchical pattern**, with the 3rd family being much heavier than the other two.



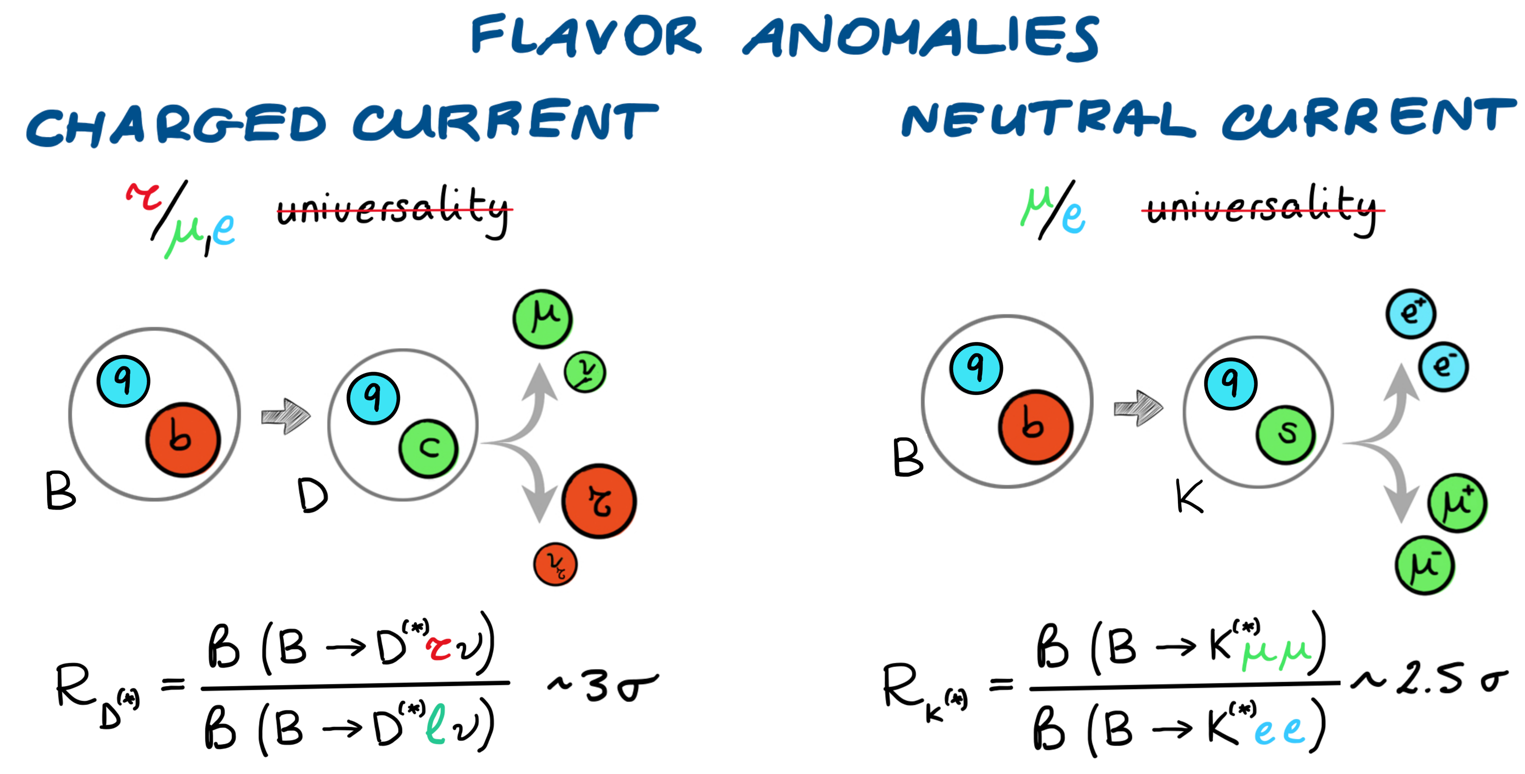
Flavor problem

Why do we observe three **families** of quarks and leptons?
Why are their **masses** so different? Is there a **mechanism** behind this hierarchy?

Puzzling data

A series of recent measurements performed by the LHCb experiment at CERN and at the B-factories Belle and BaBar challenge the SM prediction of **flavor universality.**

Some semi-leptonic B decays, differing only in the flavor of the leptons involved, seem to happen at a different rate with respect to the SM prediction.



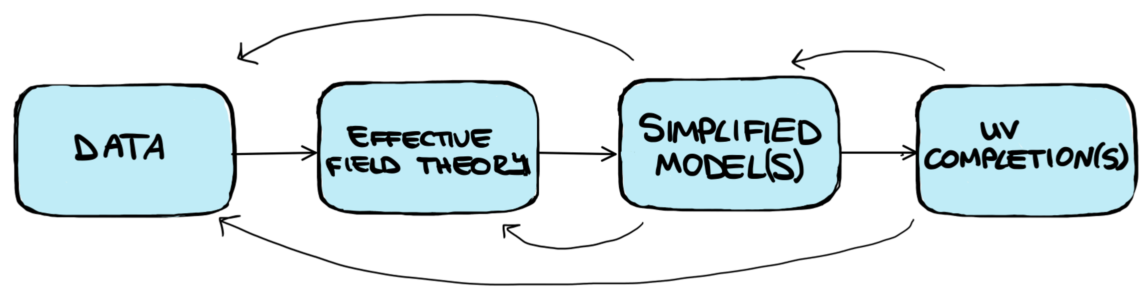
No single measurement is significant by itself. However, the discrepancies appear consistently in different experiments and observables. Updates from LHCb and Belle II will come soon!

Flavor anomalies

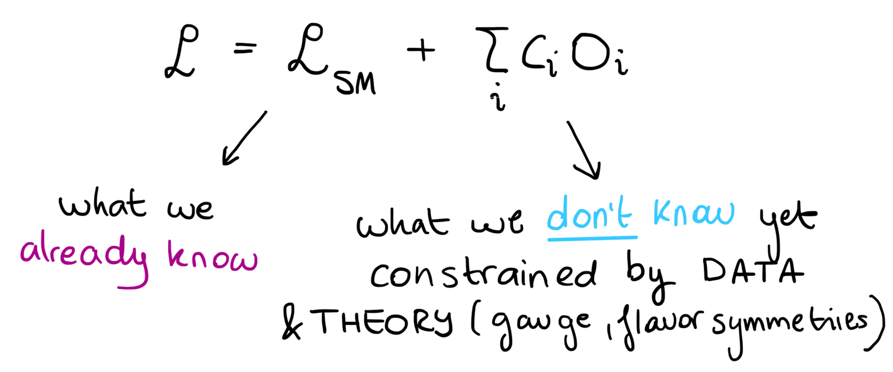
Is it **New Physics**? Are they connected to the only other source of flavour non-universality in the SM, the **Yukawa** interaction?

The Toolkit of the New Physics Hunter

We address old and new puzzles with a **bottom-up** approach, starting from experimental results and climbing all the way up to complete New Physics (NP) models.

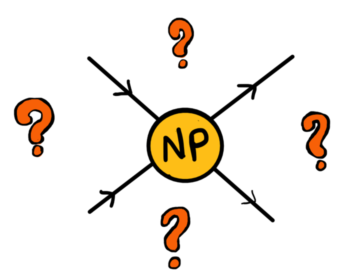


An important role is played by **Effective Field Theories** (EFTs), which provide a model independent parametrisation of NP contributions to observable quantities. Data constrains these effects and sheds light on possibly underlying NP model(s).



The Vector Leptoquark Solution to Flavor Anomalies

Taken together, flavor anomalies represent a coherent set of deviations from the SM, and a common NP origin of the two is very interesting from the theoretical point of view.

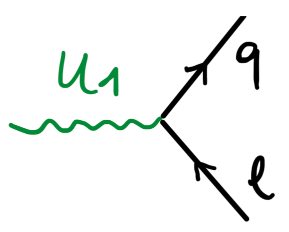


To achieve this the new mediator(s) need to be..

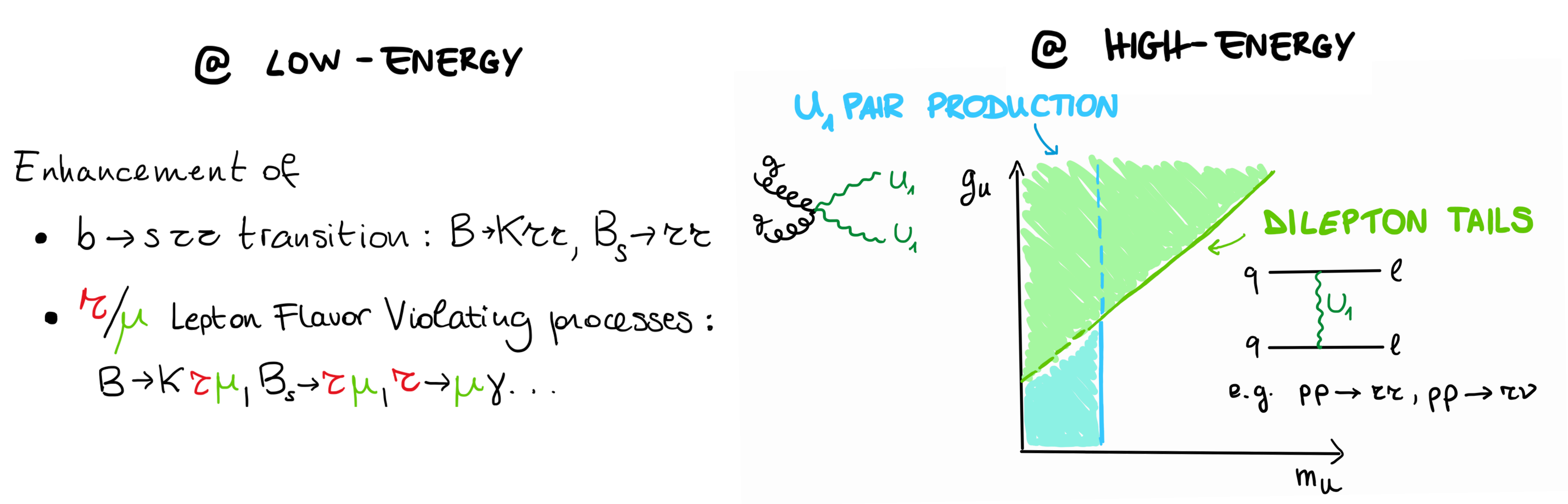
…relatively **light** (TeV scale)

…coupled dominantly to the **3rd family**.

One of the most successful candidates for a combined explanation of flavor anomalies is a massive vector boson, the **vector leptoquark** U_1.



The U_1 has a rich high- and low-energy **phenomenology**, that can be probed complementarily at flavor experiments and at the LHC:

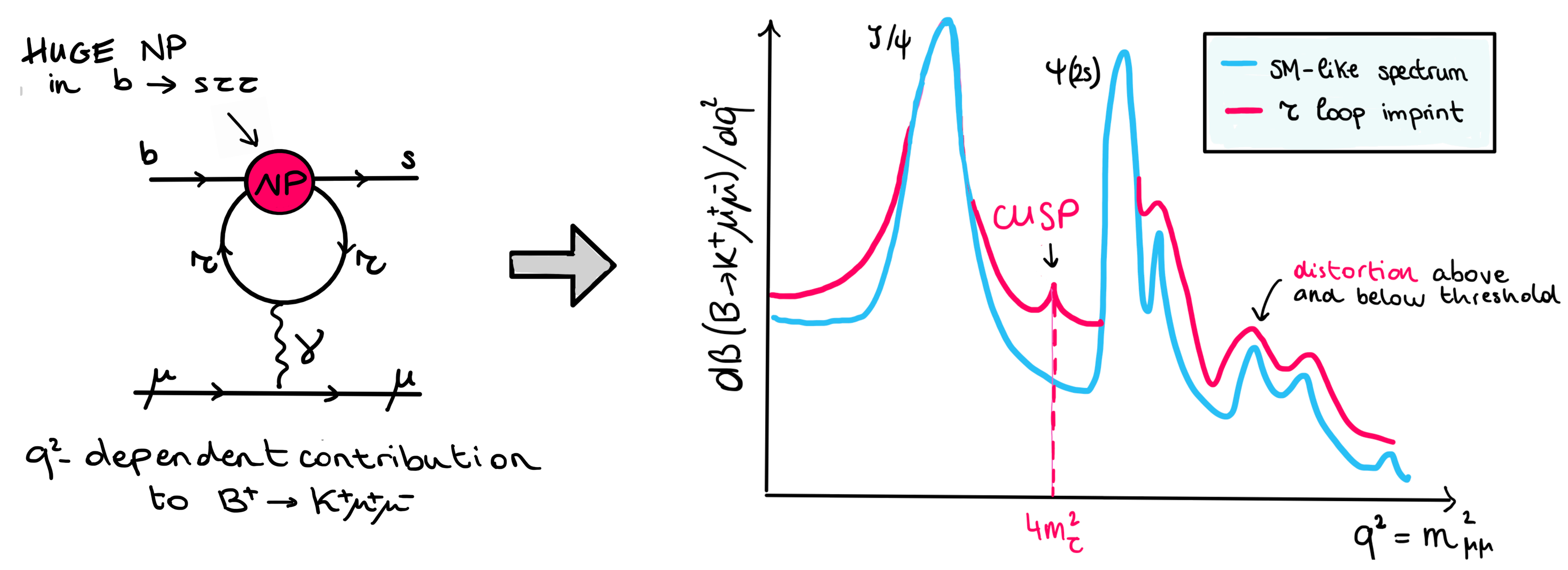


Hunting τ loops in $B\to K\mu\mu$

Models aiming at a combined explanation of both sets of flavor anomalies typically predict a huge NP contribution in the $b\to s\tau^+\tau^-$ transition.

Probing this coupling **directly** is experimentally **challenging** due to the difficult reconstruction of the τ pair in the final state. Current bounds on $B^+\to K^+\tau^+\tau^-$ and $B_s\to\tau^+\tau^-$ are weak, about four orders of magnitude above the SM prediction.

Idea: constrain NP in $b\to s\tau^+\tau^-$ **indirectly**, via its imprint on the $B^+\to K^+\mu^+\mu^-$ di-muon spectrum



The expected sensitivity at LHCb - with full Run II statistics - yields a bound **competitive** with the direct one.

Model Building for Flavor Hierarchies and Flavor Anomalies

Flavor anomalies and fermion masses follow a similar pattern: large effects in the 3rd generation, smaller effects in the other two.

Can we build a model beyond the SM to explain dynamically both flavor hierarchies and flavor anomalies?

A possible direction is given by **flavor non-universal gauge interactions**:

- flavor universality of strong, weak and electromagnetic forces is an "accidental" low-energy property
- the difference in the masses we observe hints at something more fundamental: in the UV completion of the SM the three **families** are **intrinsically different**, each being charged under its own gauge group.