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Beyond the Standard Model
A Journey Through the Cosmos of Particle Physics

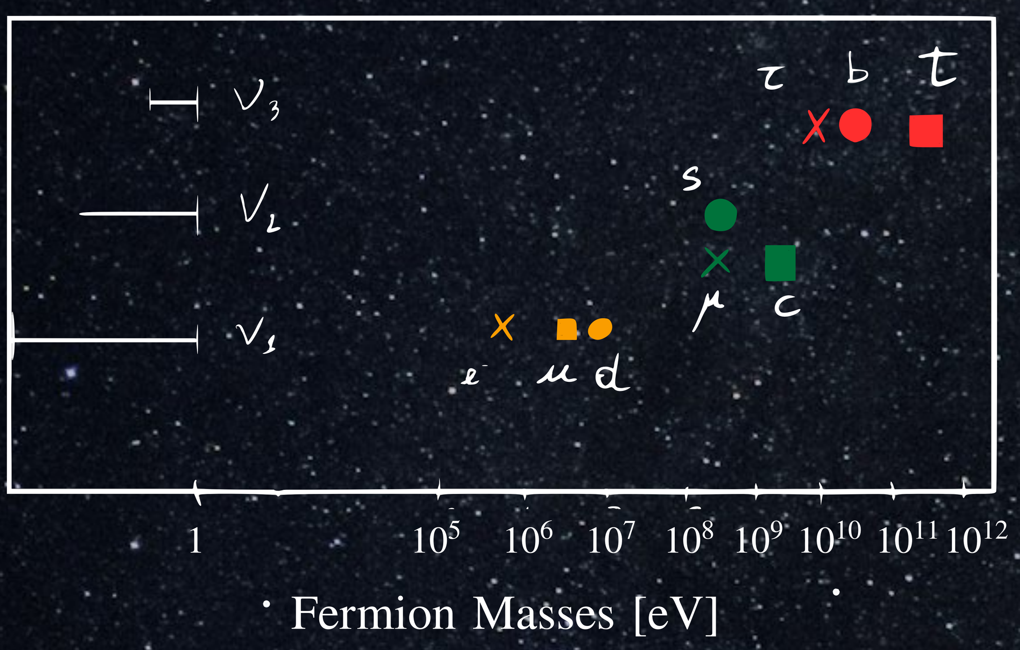
What is the Standard Model?

The Standard Model (SM) is our most powerful tool to study elementary particles and their interactions. Its predictions have been confirmed by discoveries like charm and top quarks, and the Higgs boson.

This beautiful theory sheds light on the nature of matter, composed by quarks and leptons, which interact through the exchange of gauge bosons

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}G^{a}_{\mu\nu}G_{a}^{\mu\nu} - \frac{1}{4}W^{I}_{\mu\nu}W^{I\mu\nu} + i\bar{\psi}\not{D}\psi + (y_{ij}\bar{\psi}_j\phi\psi_i + h.c.) + |D_\mu\phi|^2 - V(\phi)$$

u c t g H
d s b γ
e μ τ Z
ν_e ν_μ ν_τ W



Why go beyond the Standard Model?

Despite its undeniable successes, the SM still fails to account for observed phenomena (matter-antimatter asymmetry, gravity, the strong CP problem and many more...)

What do we investigate?

- ★ Flavor Structure: The SM doesn't predict hierarchies for fermion masses, which span over 12 orders of magnitude.
- ★ Hierarchy Problem: Higgs mass very sensitive to new physics scales. Why so light?
- ★ Neutrino Masses: Observed small neutrino masses indicate BSM physics.

How do we do it?

We look for hints of new physics in processes which are rare in the SM, and therefore sensitive to new particles and interactions. We build models to account for the flavor patterns of the SM and see what phenomenological consequences they have

We have two ways to make sense of these mysteries

EFT APPROACH

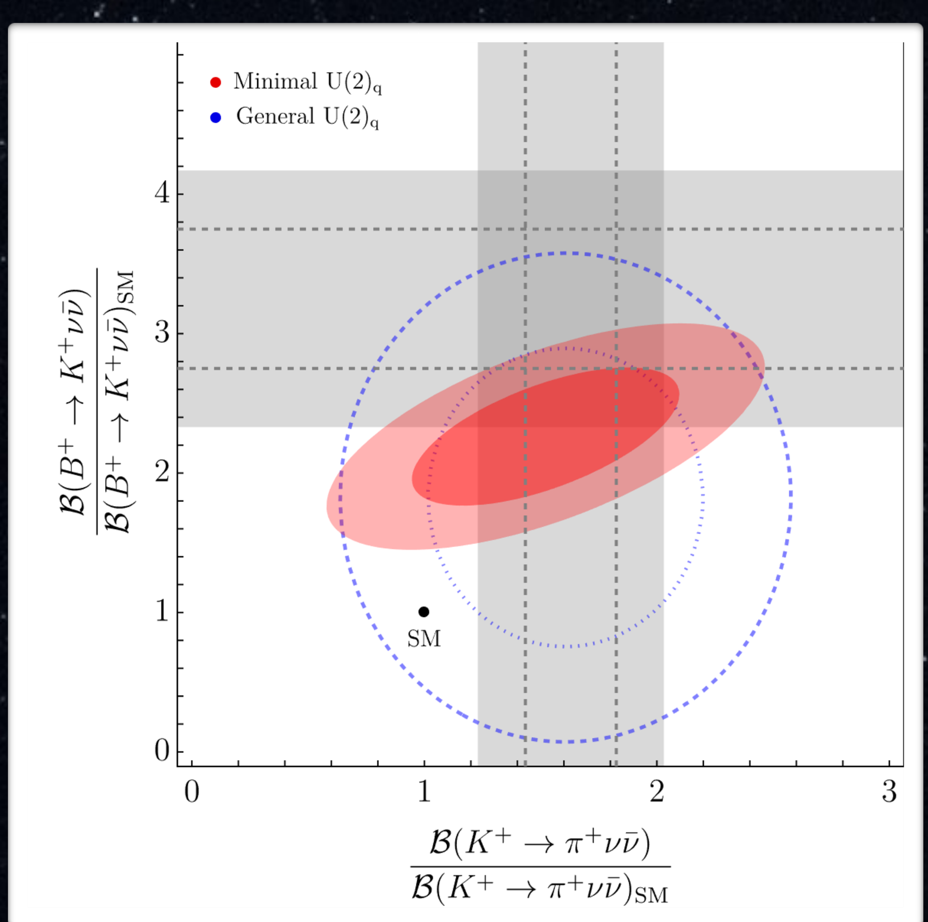
MODEL BUILDING

We explore the effects of UV physics on low energy observables

$$\mathscr{L}_{\rm SMEFT} = \mathscr{L}_{\rm SM} + \frac{1}{\Lambda^2}\sum_i C_i \mathscr{O}_i$$

Probing Third-Generation New Physics with $K \to \pi\nu\bar{\nu}$ and $B \to K^{(*)}\nu\bar{\nu}$

- ★NA62 and Belle-II detected $K^+ \to \pi^+\nu\bar{\nu}$ and $B^+ \to K^+\nu\bar{\nu}$, rare decays sensitive to New Physics (NP), especially at the TeV scale.
- ★The study models NP coupling mainly to third-generation fermions, using a $U(2)_q$ flavor symmetry, addressing flavor hierarchies.
- ★The slight excess observed in both channels supports the hypothesis of nonstandard TeV dynamics of this type.
- ★Di-neutrino modes, with their theoretical precision, could reveal NP with higher accuracy. Future experiments at percent-level precision are critical for NP discovery.



We identify new symmetries and particles that align with experimental hints

$$\mathrm{Sp}(4) \xrightarrow{\Lambda_{\rm HC}} \mathrm{SU}(2)_{\rm L} \times \mathrm{SU}(2)_{\rm R}^{[3]}$$

Flavor Deconstructing the Composite Higgs

- ★Flavor non-universal interactions merged with Higgs compositeness explain flavor hierarchies and stabilize the electroweak scale.
- ★ Treating the Higgs as a composite pseudo Nambu-Goldstone boson protects its mass from UV quantum corrections.
- ★Gauge interactions distinguish flavor, explaining Yukawa couplings and minimal flavor violation.
- ★This model provides a reduced tuning of the Higgs potential, an explaination of the fermion mass hierarchies while keeping new phenomenology at the TeV scale.

$$SU(3)_c \times Sp(4) \times U(1)^{[3]}_{B-L} \times U(1)^{[12]}_{Y}$$

$$\downarrow \Lambda_{\rm HC}$$

$$SU(3)_c \times SU(2)_L \times SU(2)^{[3]}_R \times U(1)^{[3]}_{B-L} \times U(1)^{[12]}_{Y}$$

$$\downarrow \langle\Sigma_R\rangle \quad \langle\Omega\rangle$$

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