Automation of calculations for the search for new physics in flavor $SU(2)$

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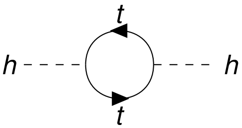
October 10, 2023

The Standard Model of particle physics

$m_\nu \neq 0$



$\theta_s \approx 0$

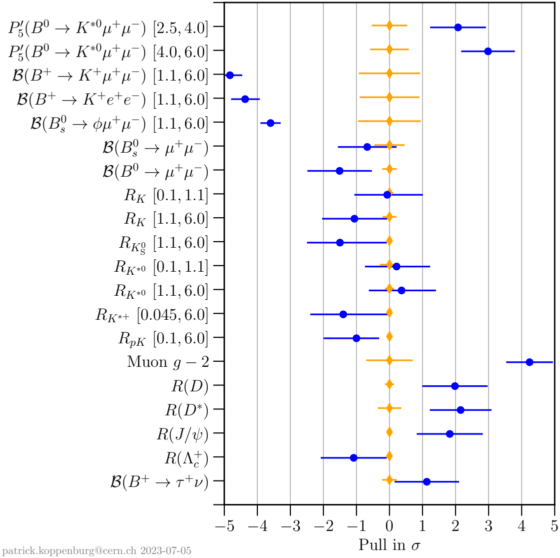
$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi + |D_\mu\Phi|^2 - V(\Phi) + \Psi_i Y_{ij}\Psi_j\Phi + h.c.$$

$$+\,???$$

Ω_Λ

a_μ

Flavor anomalies



Leptonic $SU(2)_f$: Model-building

- Simplest nonabelian extension of the SM.
- No artificial charge tuning.
- 20 anomaly-free sets of charges with only the *SM* fermions.
- This work: Leptonic $SU(2)_f$, generations 1 and 2 are charged in two chiral doublets.
- Mass diagonalization: mixing between all 3 generations of fermions parameterized by angular spurions θ^X_{ij}.

$$\mathcal{L} \ni -g_f V^a_\mu \left(\bar{\ell}_L Q^a_L \gamma^\mu \ell_L + \bar{\nu}_L Q^a_L \gamma^\mu \nu_L + \bar{\ell}_R Q^a_R \gamma^\mu \ell_R\right)$$

$$Q^a_X = V^\dagger_X T^a V_X, \quad V_X = V^X_{12} V^X_{23} V^X_{13}, \quad V^X_{12} = \begin{pmatrix} \cos\theta^X_{12} & -\sin\theta^X_{12} & 0 \\ \sin\theta^X_{12} & \cos\theta^X_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Interesting case: $V_X \sim \mathbb{1}$, small spurions.

Effective theory

Effective Lagrangian

$$\mathcal{L}_{eff} \ni F_X^{\alpha\beta} \left(\bar{\ell}^\alpha \sigma^{\mu\nu} P_X \ell^\beta\right) F_{\mu\nu} + A_X^{\alpha\beta} \left(\bar{\ell}^\alpha \gamma_\mu P_X \ell^\beta\right) \partial_\nu F^{\mu\nu} + C_{XY}^{\alpha\beta\gamma\delta} \mathcal{O}^{XY}_{\alpha\beta\gamma\delta} + \text{h.c.}$$

$$\mathcal{O}^{XY}_{\alpha\beta\gamma\delta} = \left(\bar{\ell}^\alpha \gamma^\mu P_X \ell^\beta\right) \left(\bar{\ell}^\gamma \gamma_\mu P_Y \ell^\delta\right).$$

Wilson coefficients are derived from the existing literature,

$$C_{XY}^{\alpha\beta\gamma\delta} = \frac{g_f^2}{M_V^2} \sum_c Q_{X,c}^{\alpha\beta} Q_{Y,c}^{\gamma\delta}$$

$$A_X^{\alpha\beta} = \frac{g_f^2}{16\pi^2 M_V^2} \sum_{\gamma,c} Q_{X,c}^{\gamma\alpha} (Q_{X,c}^{\gamma\beta})^* \frac{6\log(x_\gamma) - 1}{9}$$

$$F_X^{\alpha\beta} = \frac{g_f^2 e}{48\pi^2 M_V^2} \sum_{\gamma,c} \left[3 Q_{\bar{X},c}^{\alpha\gamma} (Q_{X,c}^{\beta\gamma})^* m_\gamma - Q_{X,c}^{\alpha\gamma} (Q_{X,c}^{\beta\gamma})^* m_\alpha - Q_{\bar{X},c}^{\alpha\gamma} (Q_{\bar{X},c}^{\beta\gamma})^* m_\beta\right]$$

Good way to test the capabilities of MARTY !

Observables

- Nonradiative decays $\ell_\alpha \to \ell_\beta \ell_\gamma \bar{\ell}_\delta$

$$\mathcal{B}(\ell_\alpha \to \ell_\beta \ell_\gamma \bar{\ell}_\delta) = \frac{S m_\alpha^5}{1536\pi^3 \Gamma_\alpha}\Big(\left|C_{LL}^{\beta\alpha\gamma\delta} + C_{LL}^{\gamma\alpha\beta\delta}\right|^2 + \left|C_{LR}^{\beta\alpha\gamma\delta}\right|^2 + \left|C_{LR}^{\gamma\alpha\beta\delta}\right|^2 \\ \left|C_{RL}^{\beta\alpha\gamma\delta}\right|^2 + \left|C_{RL}^{\gamma\alpha\beta\delta}\right|^2 + \left|C_{RR}^{\beta\alpha\gamma\delta} + C_{RR}^{\gamma\alpha\beta\delta}\right|^2 \Big)$$

  Exp. limits: $\mathcal{B}(\mu \to e e \bar{e}) < 1.0 \times 10^{-12}$, $\mathcal{B}(\tau \to \ell\ell\bar{\ell}) \lesssim 10^{-8}$.

- Radiative decays $\ell_\alpha \to \ell_\beta \gamma$

$$\mathcal{B}(\ell_\alpha \to \ell_\beta \gamma) = \frac{(m_\alpha^2 - m_\beta^2)^3}{4\pi m_\alpha^3 \Gamma_\alpha}\left(\left|F_L^{\alpha\beta}\right|^2 + \left|F_R^{\alpha\beta}\right|^2 \right)$$

  Exp. limits: $\mathcal{B}(\mu \to e\gamma) < 4.2 \times 10^{-13}$, $\mathcal{B}(\tau \to \ell\gamma) \lesssim 3 \times 10^{-8}$.

- Anomalous magnetic moments a_α

$$a_\alpha = \frac{4 m_\alpha}{e}\, \mathrm{Re}(F_L^{\alpha\alpha} + F_R^{\alpha\alpha})$$

  Exp.: $a_\mu = -251(59) \times 10^{-11}$, $a_e^{Cs} = -87(36) \times 10^{-14}$, $a_e^{Rb} = 48(30) \times 10^{-14}$.

MARTY calculations

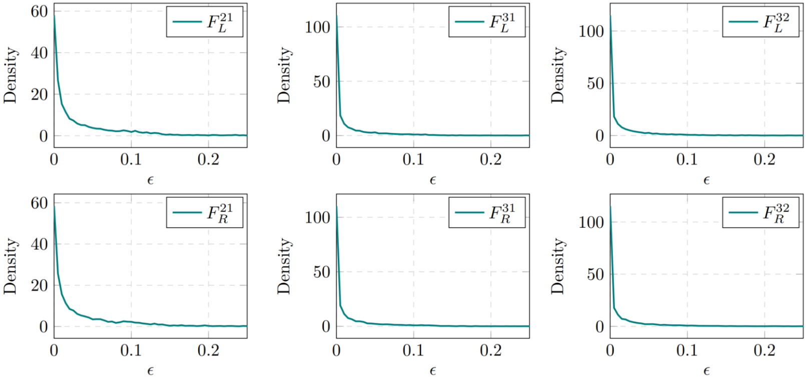


Figure 3.4: Relative error distribution between MARTY's evaluation and analytical expressions of the dipole effective coefficients.

MARTY calculations

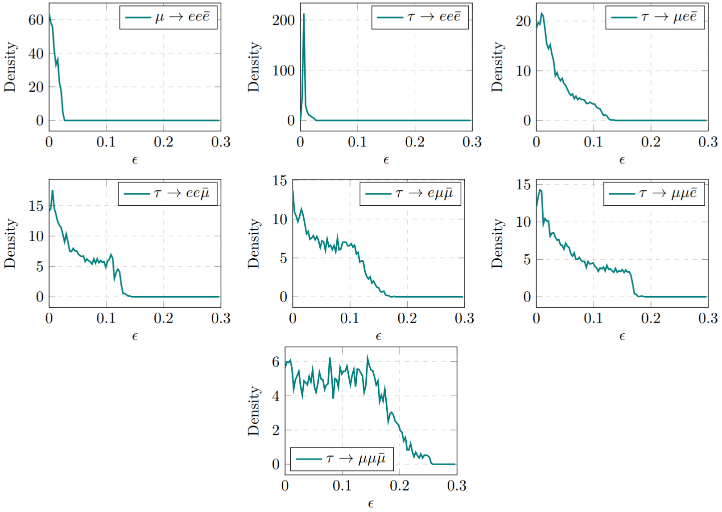


Figure 3.5: Relative error distribution between MARTY's evaluation and analytical expressions of the leptonic three-body decays' branching fractions.

Phenomenology in the small spurion limit

Small spurions $\theta_{ij}^X \approx 0$, $\Lambda = M_V/g_f = 1$ TeV (from a_α bounds) yields limits from lepton decays

$$|\theta_{12}^L| < 4.7 \times 10^{-5}, \quad \sqrt{{\theta_{13}^L}^2 + {\theta_{13}^R}^2} < 1.7 \times 10^{-2}, \quad \sqrt{{\theta_{23}^L}^2 + {\theta_{23}^R}^2} < 1.8 \times 10^{-2},$$

and from 2σ magnetic moments

$$\begin{aligned} -0.28 < \theta_{13}^L\theta_{13}^R + 2\theta_{23}^L\theta_{23}^R < -0.13 \quad (a_e^{Cs}) \\ -0.13 < \theta_{13}^L\theta_{13}^R + 2\theta_{23}^L\theta_{23}^R < -0.012 \quad (a_e^{Rb}) \\ -1.5 < 2\theta_{13}^L\theta_{13}^R + \theta_{23}^L\theta_{23}^R < -0.51 \quad (a_\mu). \end{aligned}$$

A priori incompatible. . .

Whole parameter space scan

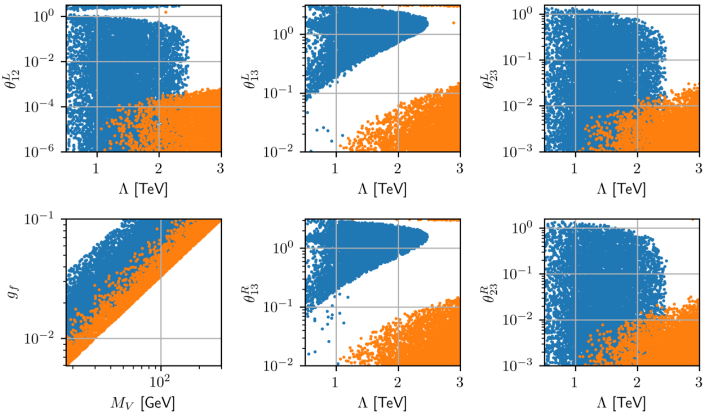


Figure 3.6: Parameter space scan including current limits from lepton decays and 3σ magnetic moments. Blue points pass all magnetic moments constraints, and orange points pass all lepton decay constraints. No point was found satisfying both sets of constraints.

Conclusions I

1. MARTY is well-suited for the phenomenological study of models in the $SU(2)_f$ class. More time will be spent on the latter.
2. Although the leptonic $SU(2)_f$ model is not the most interesting of this class, it demonstrates the interesting features of the $SU(2)$ structure of the interactions, in particular the suppression of LFUV operators in the small spurion limit.

Interfaces with other pheno codes

- Something has been tried by Luc and Mark Goodsell to interface MARTY with BSMArt using the FLHA files machinery.
- Integrating MARTY into existing ecosystems will drastically improve its competitivity (at least its usability).
- I will spend part of my PhD working on this.

MARTY's whishlist

- Idea: create a "wishlist" where the people using MARTY at the lab can post the features they would like to see implemented in MARTY, so that I can prioritize what to do.
- Let's talk about it! I have coffee.