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Flavor problem at low and high energy scales

Abstract :

Despite being a very successful theory, the Standard Model (SM) of Particle Physics cannot be the final theory of Nature. Various puzzles remain unexplained, including the issue of hierarchy of scales and the flavor problems, which call for New Physics (NP) beyond the Standard Model. Recent experimental hints of lepton flavor universality violation in semileptonic B-meson decays through charged and neutral currents sealed the flavor sector as a critical laboratory for studying physics beyond the SM.

In this work, we propose several new observables the measurement of which could be relevant for flavor physics and set relevant constraints onto NP, both in the model-independent framework via Effective Field Theories (EFT) and with explicit scenarios, involving low-energy Leptoquarks.

After pointing out the main features of the SM and the EFTs that we use to parametrize NP, we focus on the semileptonic and leptonic decays of pseudoscalar mesons involving charged currents, and propose observables that are mostly free of hadronic uncertainties and that are independent of the CKM matrix elements. Using available experimental results, we derive bounds on several effective couplings to new physics. We then study in great details the semileptonic decays of heavy baryons, especially the perspectives they offer in terms of new observables that can be extracted from angular distributions. We make several predictions for quantities related to $Lambda_b oLambda_c auar{u}$ in the SM and its several extensions. That decay is currently studied at LHCb.

Complementary to the low-energy processes, we also study the high-energy ones. We systematically analyze the flavor constraints that arise from the tail of the differential cross-section $pp oellell'$ at ATLAS and CMS. Due to the energy enhancement of these processes, brought by NP compared to the SM, we find constraints that are often complementary and competitive with low-energy precision observables, and in some cases even better. We create and develop a new package ``HighpT'', designed to automatize this analysis for a generic EFT up to and including operators of dimension 8. Furthermore, we extend that to any (propagating) tree-level mediator. Comparing the two approaches allows us to explicitly check the validity of the EFT expansion in collider studies, and show that it can introduce uncertainties even for non-resonant processes.

Finally, we study some concrete examples of explicit NP scenarios involving $mathcal{O}$(1 TeV) leptoquarks (LQ) than can accommodate all of the available constraints. Among the 3 scalar and 2 vector LQs we consider, we show that only the vector singlet LQ can accommodate a plethora of low-energy experimental data as constraints, including both B-anomalies and remain compatible with direct searches $pp o ellell'$ high-p_T tails. We also propose and demonstrate that a scenario involving a pair of scalar LQs, R_2 and S_3, can also satisfy all constraints. Such a scenario is even better since it remains renormalizable and no UV-completion needs to be specified to compute the loop effects.