Michel parameters for muon decay in SMEFT and LEFT

Exposé for a Master's thesis

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Since the experimental discovery of the Higgs boson in 2013, not much has changed for particle physics on the base level: Neither has the zoo of elementary particles welcomed new inhabitants nor have the long-time residents started to behave differently. The Standard Model (SM) of physics, which directs the microscopic ballet of nature's ensemble of fundamental building blocks by Lorentz-invariant quantum field operators, seems to be complete. Rivaling models, hoping to exceed the SM in terms of mathematical beauty, simplicity, naturalness, or gravitas, hitherto have failed to make correct predictions, any predictions at all, or at least such ones that could be tested by reasonable experimental means anytime soon.

Is the search for physics beyond the SM over and plans for new particle colliders, without anything specific to look for, blind groping around in the fog? The chances are high that this is a bit too pessimistic a view. One of the biggest virtues of the SM has not yet been fully actualized: The virtue that lies in its own becoming. As a matter of fact, some of the particle interactions it currently models as mediated by virtual heavy bosons, for example in beta decay, were successfully described by effective field theories long before. The whole process of beta decay, where a neutron decays into a proton, an electron, and an antineutrino, was already remarkably well characterized as a direct interaction between four fermions [2]. Only the need to restore unitarity at higher energies (as well as gauge theoretic considerations) made the refinement of the 4-Fermi action by a mediating W^- boson necessary.

If a low energy effective field theory, however, guided physicists to the present day SM, could this model not be itself an effective theory, merely enveloping a plethora of yet unknown particles? The idea of the Standard Model effective field theory (SMEFT) has met with growing interest in the last decade, as it provides a transparent and unbiased guidance on the quest for new physics. Instead of envisioning completely new models from scratch, the SMEFT is oriented towards a simple principle: New physics will show up first in the form of effective SM operators. In its present-day canonical form, however, the SM consists of the most general renormalizable quantum field theory that could be constructed from the SM field content respecting Lorentz invariance and $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge invariance. So the current SM Lagrangian contains all possible symmetry conserving combinations of the stipulated set of matter and force mediating fields - but only up to mass dimension 4. All higher-dimensional operators were deemed inadmissible, as they would need infinitely many counterterms to render the theory finite with respect to ultraviolet divergences.

However, if the Standard Model is viewed as an effective field theory that is only valid up to an energy scale Λ, the need for a complete and fully renormalizable theory is eliminated: Physic's potentiality to keep changing its dynamical content at higher energies is simply acknowledged. Higher-dimensional operators therefore enter the Lagrangian of the SMEFT, which encode new physics and whose effects are constrained by experimental data on lower energies.

In this Master thesis project, we want to evaluate the effects of SMEFT dimension 6 operators on the Michel parameters of the muon decay, which determine the form of the emitted electron's energy spectrum. They were first introduced [4] in the context of 4-Fermi theory to trace the effects of different (scalar, vector, tensor) formulations of 4-Fermi interaction to the electron spectrum and take on specific values in the Standard Model's V-A formulation. Present-day experiments strongly support the V-A weak interaction of the Standard Model [5], but this should only encourage further investigation: Which dimension 6 SMEFT operators would alter the Michel parameters and therefore to what extent are their effects constrained by experimental data? In order to observe the SMEFT operators' traces in the effective 4-Fermi interaction, the SMEFT is matched to the LEFT: The low energy effective field theory (LEFT) integrates out the heavy bosons as well as the top quark and reduces to a theory analogous, but more general, than the original fermi theory. Full Matching of the SMEFT onto the LEFT, i.e. adjusting their coefficients so they effectively describe the same amplitudes, has been presented in a paper from 2018 [3]. We use the results to determine Michel parameters for the LEFT and find constraints for the SMEFT. The thesis will have the following structure:

1. Theoretical background

    a) SM, SMEFT and LEFT: The Standard model is introduced briefly [7] and subsequently, in a minor change of perspective, presented as an effective field theory [1]. Since muon decay is taking place at much lower energies, we take a look at LEFT as well and how the matching to its operators from the SMEFT on tree level is performed [3].

    b) Michel parameters: The Michel parameters are introduced [4] and their value for the SM calculated [6] and compared to experimental data [5].

2. Michel parameters for muon decay in SMEFT and LEFT

    a) Which SMEFT operators influence the LEFT description of muon decay?

    b) How are they altering the Michel parameters of muon decay?

    c) How does the current experimental data place constraints on the energy scaling of the SMEFT operators?

3. Outlook

   a) How should the energy constraints for the SMEFT operators be interpreted in the context of present day and planned experiments?

   b) Is SMEFT the way to go for particle physics?

References

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