Precise predictions for top-quark flavor-changing neutral interactions at future lepton colliders

Snowmass letter of intent

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While the analysis of the data recorded during the second run of the LHC is still ongoing, no compelling direct evidence for new physics has been observed so far. These null search results have consequently pushed the limits on the masses of any potential particle extending the Standard Model (SM) of particle physics to rather high scales, well within the TeV regime. For this reason, the Standard Model Effective Field Theory (SMEFT) framework, in which new phenomena are parameterised by higher-dimensional operators in the SM fields, has received more and more attention in the last few years. It is today considered as a proper framework to study deviations from the SM, not only in the sense that it is a useful way to parameterise any new physics effects, but also as it could be tested per se. We propose to focus on the SMEFT operators that impact the phenomenology of the top quark, and in particular those involving new flavor-changing neutral interactions. The reason lies behind the large mass of the top quark, so that one expects it to be intimately linked to new physics. Studying the properties of the top quark is therefore of utmost importance for a potential discovery of any new phenomenon.

On the other hand, the high-energy physics community is currently investigating options for collider experiments to be run in the next decades. We position the work envisaged in this letter of interest within this context, focusing on a future lepton collider. Several future lepton collider proposals are under consideration, including the Circular Electron Positron Collider (CEPC) in China, the Future Circular Collider with e^+e (FCC-ee) at CERN, the International Linear Collider (ILC) in Japan, and the Compact Linear Collider (CLIC) at CERN aiming at running at higher center-of-mass energies. We propose to study and compare the potential sensitivity of these future machines to flavour-changing interactions of the top quark, by achieving test-case studies including precision predictions in the global and model-independent SMEFT framework.

While the collider reaches of these interactions have been studied in the past, comprehensive and model-independent studies based on the SMEFT framework and including realistic collider analyses are still missing. Most results in the literature are either based on the anomalous-coupling approach or have ignored the four-fermion contact flavor-changing interactions. These studies are thus less model-independent, in particular as it has been shown that future lepton colliders have a much better reach on the four-fermion interactions compared to LHC and its future upgrades [1, 2]. Furthermore, a complete SMEFT analysis requires higher-order corrections to be consistently incorporated to any desired order, and should hence rely on precision predictions not only for total rates, but as well as for distributions [3]. Both indeed play crucial roles, given the high accuracy measurements expected at those future machines.

Automatic new physics simulations at the next-to-leading-order (NLO) accuracy in QCD are standard for proton-proton collisions, but they still cannot be obtained straightforwardly for e^+e^- collisions, especially for the full set of processes relevant for top-quark flavor-changing interactions. While a subset of relevant operators have been automated at NLO in QCD already quite a while ago [3], an extension including the full set of operators is only very recent [4]. However, the current implementation enforces flavor conservation and has therefore to be extended. Whilst this is in principle feasible by means of public tools, it is on the other hand well-known that beamstrahlung and initial-state radiation effects can both be crucial at a future lepton collider. We therefore also plan to contribute to the extension of the MadGraph5_aMC@NLO framework [5], so that it could be used for precision SMEFT predictions in the context of electron-positron collisions, including not only NLO QCD corrections (as it is already the case), but also beamstrahlung and initial-state radiation effects. While we expect these effects to be important in the work envisaged in this proposal, embedding them into an automatic framework would also allow for general beyond the SM physics to be studied in any future lepton colliders context, and this by relying on much more reliable theory predictions not only for the SM background but also for any class of new physics signal. Our specific study on top-quark flavor-changing interactions could serve as a test case for this goal.

This proposal hence aims to complete a comprehensive study of the neutral flavour-violating effects in the top quark sector, with the global and model-independent SMEFT framework. We hence aim to provide some new inputs to motivate the building of future lepton colliders. Moreover, with this physics goal in mind, we aim at automating NLO QCD computations with MadGraph5_aMC@NLO for lepton collider (including beamstrahlung and initial-state radiation effects) for any class of particle physics models.

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