Projects for master's theses in particle physics

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1 Gradient flow for CP-violating effective operators

The neutron electric dipole moment (nEDM) is a very sensitive probe of CP-violating physics beyond the Standard Model. Within an effective-field-theory framework, the indirect effects of heavy physics beyond the Standard Model on the nEDM are described in terms of higher-dimension CP-violating operators. In order to translate the experimental bounds into constraints on the coefficients of these operators and thereby constrain models for new physics, one needs to know the neutron matrix elements of these operators, which are ideally computed with lattice QCD.

The goal of this project is to work out for a certain operator the matching at one loop between the familiar $\overline{\text{MS}}$ scheme and a gradient-flow scheme, a modern way to regulate UV divergences that can be implemented on the lattice.

2 Master formulae for hadronic light-by-light scattering

The anomalous magnetic moment of the muon, $(g-2)_\mu$, is one of the few observables, where a tension between the Standard Model prediction and experiment is observed, currently at the level of 4.2σ. The contribution of hadronic light-by-light scattering (HLbL) is one of the dominant sources of uncertainty in the Standard Model prediction. In order to reduce this uncertainty and help to decide if the discrepancy points towards physics beyond the Standard Model, big research efforts are invested both in lattice-QCD computations and analytic calculations based on dispersion relations.

The goal of this project is to establish a connection between the two master formulae for the HLbL contribution to $(g-2)_\mu$: the one employed in lattice computations is written in position space, while the master formula used for the dispersive approach is in momentum space. Ideally, establishing the exact connection will allow a more in-depth comparison of the two approaches.

3 EFTs for nonlinearly realized electroweak symmetry

The most popular effective field theory (EFT) for physics beyond the Standard Model is the SMEFT, which assumes that the Higgs boson is part of an electroweak doublet as in the Standard Model. A more generic formulation is based on a nonlinear realization of electroweak symmetry, which leads to an EFT similar to chiral perturbation theory. Multiple competing groups have established their own version of such a nonlinear EFT, which mainly differ in the formulation of the power counting.

The goal of this project is to understand the different EFT formulations and perform a detailed comparison of the underlying assumptions, in order to decide if and where the different formulations lead to different predictions. In addition, the matching of the nonlinear theory to the low-energy EFT below the weak scale (LEFT) will be studied.