Positivity bounds on quartic-gauge-boson couplings

Snowmass letter of interest

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Dim-8 Wilson coefficients in the Standard Model Effective Field Theory (SMEFT) are not allowed to take arbitrary values. By assuming that the SMEFT admits a UV completion that satisfies the fundamental principles of quantum field theory (QFT), including analyticity, unitarity, crossing symmetry, locality and Lorentz invariance, the so-called positivity bounds can be derived [1], determining the signs of certain linear combinations of dim-8 coefficients. Since the ultimate goal of the SMEFT is to determine its UV completion, one should restrict the search for operators only within these bounds, and optimize the search strategy accordingly. Alternatively, one might also use these bounds to experimentally test the fundamental principles of QFT [2]. In either case, the LHC has started to probe the dim-8 SMEFT operators in many occasions, while the currently proposed future lepton colliders are expected to provide even more such opportunities. Therefore it has become increasingly important to understand the positivity bounds on SMEFT Wilson coefficients.

A particular relevant topic at the LHC is the vector boson scattering (VBS) and the measurement of the quartic-gauge-boson couplings (QGCs). Searching for possible beyond the SM physics in the form of anomalous QGCs is one of the main goals of the current as well as the future electroweak program at the LHC and the HL-LHC. These couplings can be measured in the VBS or the triboson production channels. Knowing their bounds from positivity will undoubtedly provide guidance for relevant future theoretical and experimental studies.

The conventional approach to derive positivity bounds makes use of the elastic 2-to-2 forward scattering amplitude. One can show that its second derivative w.r.t. s, the Mandelstam variable, is positive, and this leads to, at the tree level, a set of linear homogeneous inequalities for dim-8 coefficients. This approach has been adopted in Refs. [3–5], and the allowed parameter space of the Wilson coefficients has been reduced to only about 2%. However, these results are still far from complete. The reason is that the notion of elasticity depends on the particle basis, and therefore, in order to obtain the full set of elastic positivity bounds, scattering amplitudes between arbitrarily superposed particle states need to be explored. So far, this procedure has not been done systematically. Only a limited set of superposed states have been investigated in the literature.

Recently, we have proposed an alternative approach to extract positivity bounds [6], which has the advantage that one is guaranteed to obtain the best bounds allowed by the fundamental QFT principles. Indeed, bounds tighter than the full set of elastic positivity

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bounds can be obtained in certain cases, and an explicit example has been presented in [6]. In this approach, instead of using elastic channels to probe the bounds, one essentially describes the allowed parameter space as a convex cone via the *extremal representation* of cones, and thus we call it the extremal positivity approach. This approach is efficient because the extremal rays of the cone can be directly written down via group theoretical considerations, and the parameter space can be determined by the convex hull of these rays. So far, this approach has been applied to the 4-W and the 4-H operator sets in Ref. [6]. More general applications of this approach are yet to be explored.

For Snowmass 21, we propose to study the full set of positivity bounds on aQGC operators in the SMEFT framework, by applying the new extremal positivity approach. We expect these results to unify and supersede all previous results in the literature. While providing guidance for future theoretical and experimental studies on VBS and relevant SMEFT fits, we also hope that this study will establish the general methodology for obtaining complete positivity bounds for dim-8 SMEFT operators.

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