EFT Analysis of the VVV process:
a Letter of Interest for Snowmass 2021

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Thematic Areas:
■ (EF04) Electroweak precision physics and constraining new physics
■ (EF05) QCD and strong interactions: Precision QCD
■ (TF02) Effective field theory techniques
■ (TF07) Collider phenomenology

Abstract

The discovery of triboson production [1] is a major milestone in Standard Model (SM) physics. Triboson production occurs through the trilinear, quartic and the Higgs mediated modes. These varied modes of production make the physics content of these processes rich. We propose to perform an Effective Field Theory (EFT) based exploration of this final state in order to constrain indirect beyond the SM (BSM) contributions to these processes. Due to the complexity of this final state, a multiprocess exploration of EFTs has not been carried out in the context of tribosons till date.

1 Introduction: Statement of the problem

The production of VVV, where V is a heavy gauge boson (W or Z), proceeds through the quartic, trilinear and the Higgs mediated modes as shown in the Feynman diagrams in Fig. 1. Last year, the ATLAS Collaboration [2] reported the evidence (with an observed significance of 4.1 σ) of VVV production. This year, the CMS Collaboration reported the discovery of three massive vector boson production at $\sqrt{s} = 13$ TeV with 137 fb^{-1} of data [1] with an observed significance of 5.7 σ. This marks an important achievement in the physics of multiboson production and is expected to lead to more detailed analysis of these extremely rare and complex final states.

The SM Lagrangian is based on operators of dimension-4. The production of tribosons involves various vertices which could acquire contributions from higher dimensional operators (Fig. 1). The EFT framework operates under the assumption that new physics

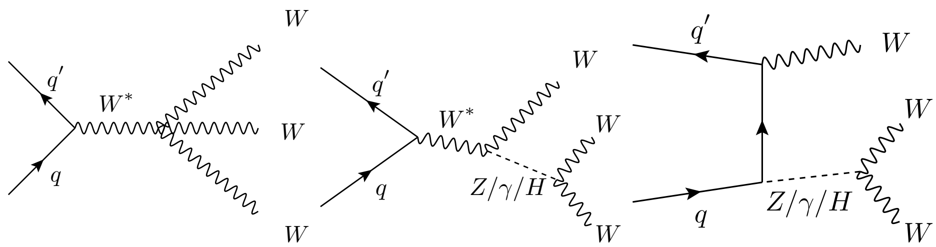

Figure 1: Feynman diagrams associated with the production of WWW. The production proceeds through the quartic, trilinear and the Higgs mediated mode. An additional diagram, not shown here, involves the radiation of three W bosons from a quark line. The quartic vertex is forbidden in the case of ZZZ production.

exists at scales currently inaccessible at the LHC, but whose indirect effects can be detected as excesses of events in the tails of distributions. The EFT framework extends the SM Lagrangian in an expansion in inverse powers of the scale of new physics as shown in Eqn. 1.

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \sum_j \frac{f_j}{\Lambda^4}\mathcal{O}_j + \ldots \tag{1}$$

The coefficients c_i and f_j are the Wilson coefficients associated with dimension-6 and dimension-8 operators respectively.

Since a global Standard Model EFT (SMEFT) analysis is expected to be one of the legacies of the LHC, we propose to carry out a detailed exploration with the following physics-based motivation:

⇒ How does the VVV process constrain anomalous triple and quartic gauge couplings? How is the sensitivity to one SMEFT operator, assuming all others vanish? How does that change if more operators have non-vanishing coefficients?

⇒ How does the VVV process contribute to the global SMEFT fit?

⇒ Is there any sensitivity to dimension-8 operators, given no dimension-6 contributions?

⇒ What is the range of validity of the EFT approach with respect to the VVV processes?

⇒ Which observables are good (for theory, i.e. constraining Wilson coefficients; for experiment, i.e. to be extracted well from experimental data)?

⇒ What is a consistent way to combine the perturbative expansion with the EFT expansion? Is SM + NLO QCD/EW + dim-6 tree consistent? If dim-6 at 1-loop is needed, do we need 2-loop QCD?

2 What should a solution look like?

The ultimate goal would be to express the VVV differential cross section in terms of all the Wilson coefficients. A numerical result that only has the Wilson coefficients as parameters, as was done in [3] for double-Higgs production, is also a sufficient solution. We would then be able to identify meaningful observables to constrain (combinations of) Wilson coefficients. The results of the VV process [4–6] can also serve as guideline.
In any case, the result should not only be usable now, but also for global fit efforts in the HL-LHC future.

3 How do we plan to find the solution?

There are different possible approaches. We could either derive the expressions by hand, or use various existing tools that automate SMEFT computations. One option would be using the `.ufo` files of [7] and then deriving the Feynman rules and amplitudes, similar to the chain described in [8, 9]. Another option is following `https://github.com/UniMiBAnalyses/D6EFTStudies` or using the new `SMEFTNLO` [10]. Final distributions and sensitivity to observables can be studied with MadGraph. In addition, there are several approximations / simplifications we could consider:

- Similar to the SM-theory papers [8, 9], it would make sense to focus on on-shell gauge fields first.
- Focus on LO in QCD and electroweak first. However, recent work on including corrections [10] indicate that QCD K-factors are potentially large.
- Consider a subset of operators, with various motivations to find said subset. We will work in the Warsaw basis [11] and follow the recommendations of the new LHC-EFT-WG, `https://lpcc.web.cern.ch/lhc-eft-wg`. Since this group is in a nascent stage, we can use other available resources like the one described in Ref. [12].

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