Abstract

There are strong arguments in favour of the point of view that the Standard Model (SM) of elementary interactions is only an effective theory, a low-energy approximation of a more fundamental one. One of the very important processes that may shed light on a deeper theory is the scattering of the electroweak vector bosons, W and Z. It is indirectly accessible in the LHC experiments, particularly with its high luminosity (HL-LHC) or high energy (HE-LHC) phase, through the process $pp \rightarrow 2\text{jets} + 2\text{lepton pairs}$. The process of vector bosons scattering is the most direct test of the mechanism of the electroweak symmetry breaking and also is sensitive to the existence of new particles interacting electroweakly.

There are two general approaches to the search for a beyond the SM theory. One is to propose and investigate explicit models, the other one is based on the so-called Effective Field Theory (EFT) approach. The strength and the effectiveness of the EFT approach follows from the fact that one can study the discovery potential of the physics beyond the SM without knowing complete theories. EFT is particularly useful as long as no new particles are directly discovered experimentally but their existence could manifest itself at energies much lower than their masses Λ ($E << \Lambda$) as corrections to the SM predictions suppressed as (E/Λ). These corrections can be parametrized by non-renormalizable operators added to the SM Lagrangian. The EFT approach relies on the justified assumption that a limited number of certain operators provides a good approximation to certain classes of complete models when $E << \Lambda$. Each choice of a limited set of operators, with their (Wilson) coefficients taken at some (arbitrary) fixed values, defines an EFT "model" to be tested for its discovery potential. At this point expected magnitude of deviations with respect to the SM predictions can be estimated as well as the effects of different non-renormalizable operators on kinematic distributions studied. Once the future data are available and feature significant deviations from the SM, the analysis in the framework of EFT "models" shall serve as a guide towards concrete deeper models. The general novel element of this work, important for both discussed above aspects of using EFT, is determination of the region of validity of the EFT approach to gauge boson scattering. The latter is strongly constrained by the partial wave unitarity bound applied in presence of non-renormalizable operators.

Two main classes of effective Lagrangians can be considered, depending on how the electroweak symmetry breaking is assumed to be realized: linearly for elementary Higgs particle embedded as a component of the SM scalar doublet (Standard Model Effective Field Theory, SMEFT) or non-linearly, on the three Goldstone bosons constituting the longitudinal components of the $W^{\pm}$ and Z gauge fields (Higgs Effective Field Theory, HEFT). In the latter case the physical Higgs field is a singlet of the symmetry group. The non-linear EFT is particularly suitable for low-energy effective description of models in which the Higgs particle is a fundamental or composite (pseudo) Nambu-Goldstone bosons arising from the spontaneous breaking of some global symmetry in the deeper theory.

In this work the vector boson scattering process is investigated through the reaction $pp \rightarrow 2\text{jets} + W^*W^* \rightarrow 2\text{jets} + l\nu_l l'\nu_l'$, where W^* denote in general off-shell W^+, in the EFT approach with the HL-LHC and HE-LHC experiments in mind. We have investigated the discovery potential of certain classes of the EFT "models" of both the SMEFT and HEFT bases with the particular emphasis on using the EFT "models" in their region of validity. A novel method has been proposed for determining the discovery regions of physics beyond the SM, described by the EFT "models". Independent of the basis chosen, the discovery regions are found to be non-empty. We then compare differences in experimental signatures between SMEFT and HEFT, which is an important step for distinguishing between the two hypotheses in the future data. Finally, we investigated what the effect on the discovery regions is when increasing the pp collision energy.