

A novel approach to the physics of vector boson scattering in the CMS experiment at the Large Hadron Collider

The Standard Model (SM) of particle physics is the most thoroughly tested and the most successful theory in all of science so far. And yet, there is little doubt that it is not the ultimate theory of everything. In addition to several theoretical issues, it is actual astrophysical observations that have most definitely shown the need to go beyond the Standard Model (BSM) to fully describe the Universe. Searches for signals of BSM physics are among the mainstream activities at the Large Hadron Collider (LHC).

The present project fits into this wide spectrum of BSM physics searches conducted at both ATLAS and CMS, the two large omnipurpose particle detectors that operate by the LHC. Here we propose to perform a new model independent search for indirect signatures of BSM physics in the interactions of W and Z bosons, the carriers of the weak nuclear force. The search will be based on data that will be collected by the CMS detector during Run III of the LHC, due to start sometime in 2022. Vector Boson Scattering (VBS), as this class of processes is commonly known to physicists, is particularly interesting because it is the key to understanding the Higgs mechanism which assures that elementary particles have masses. It is sensitive to the properties of the already discovered SM Higgs boson, as well as to the existence of new hypothetical, heavier Higgs-like particles.

There are two general philosophies of BSM searches. One philosophy is to look directly for new particles. Such observation would be the most convincing evidence of new physics. There is however no guarantee that those particles are within kinematic reach of the LHC. On the other hand, quantum physics teaches us that existence of new particles can be also manifest indirectly. In this project we adopt the other philosophy, which is to look for new interactions between known particles. New physics may affect known SM processes by means of modifying their rates and kinematic characteristics with respect to what is expected in the SM. This important complementary approach to BSM searches involves precision measurements of SM processes and comparisons with SM predictions. Potential deviations from the SM can be parameterized in a model independent way by using a mathematical formalism known as the Standard Model Effective Field Theory (SMEFT). Regardless of the underlying physical theory, the phenomenology related to any new physics can be effectively described with the help of a finite set of higher dimension operators. They are interpreted as new BSM interactions whose effective strengths (technically called Wilson coefficients) are subject to measurement. Similarly, agreement with the SM is interpreted as experimental upper limits on the hypothetical BSM interaction strengths.

Indirect searches for BSM physics in the SMEFT framework have already a respectable tradition in CMS. However, in most studies published so far the SMEFT formalism was not used in a fully consistent way, thus limiting the physics interpretability of the results. The SMEFT formalism has some intrinsic technical limitations that need to be rigorously watched in data analysis. In this project we propose specific data analysis techniques that address these issues. One issue concerns the kinematic range of validity of the SMEFT approach. Accordingly, the present data analysis is designed in such way that any numerical results to be obtained will be driven solely from the kinematic region where the SMEFT formalism is indeed applicable. Another issue concerns the separation of potential signals from different SMEFT operators whose phenomenology may be similar. Part of the solution lies in systematic studies of the signatures of longitudinal and transverse polarizations of W and Z bosons in the final state. The other part is combination of data from different VBS processes. Whether BSM physics is detected or not, implementation of the proposed techniques will give us realistic hints about its underlying nature and serve as a model for future data analyses, in particular during the High Luminosity LHC phase.