

## Vector boson scattering of two same-sign W bosons in a final state with one hadronically decaying $\tau$ lepton at the CMS experiment

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**Summary.** — Scattering between two same-sign W bosons is an extremely promising channel for the study of electroweak symmetry breaking (EWSB) sector. Resonant and non-resonant background for this process can be controlled, proving this measurement particularly sensitive to trilinear and quartic gauge boson vertices. Here, for the first time for experiments at the Large Hadron Collider (LHC), we consider one of the W bosons into a hadronically decaying  $\tau$  lepton ( $\tau_h$ ) at the Compact Muon Solenoid (CMS) experiment (see CMS COLLABORATION, *JINST*, **3** (2008) S08004).

### 1. – Introduction

The observation of a Higgs boson with a mass of about 125 GeV [1] established that the W and Z gauge bosons acquire mass via the Brout–Englert–Higgs mechanism [2,3]. Modifications of this mechanism are possible, making the EWSB sector very interesting to investigate in search for new physics: a key role in this investigation is played by measurements of Vector Boson Scattering (VBS) processes.

VBS at the LHC is characterized by the emission of a vector boson  $V = W, Z$  from each of the two initial-state quarks, providing  $qq \rightarrow qqVV$ . Two classes of processes contribute to this final state at lowest order (LO). The first one is the so-called electroweak (EWK) induced production which is  $\mathcal{O}(\alpha^4)$ , where  $\alpha$  refers to the EW coupling. It features diagrams where vector bosons self interact (fig. 1, first three diagrams). This is one of the most suitable processes to investigate the EWSB sector [4]. The second one is QCD production,  $\mathcal{O}(\alpha^2\alpha_s^2)$ @LO, in which self-coupling between vector bosons does not appear, but which produces the same the final state (fig. 1, rightmost diagram).

VBS processes are also particularly sensitive to BSM physics: only the exact SM coupling between vector bosons and the Higgs boson guarantees that the cross section does not diverge, leaving this class of processes sensitive to modifications to this coupling. In addition, anomalous triple and quartic gauge couplings can be probed by this process,

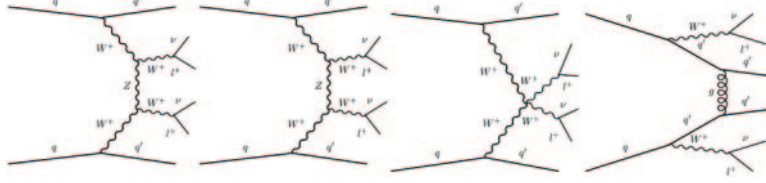


Fig. 1. – Feynman diagrams for purely electroweak VBS processes (first three diagrams) and QCD-mediated one (the last one).

thanks to the self interactions between vector bosons. Deviations from the SM parameters in any of these sectors could alter the yields of VBS events. In particular, the Effective Field Theory (EFT) approach is used to quantify the possible new physics effects without relying on specific theories, since it assumes the SM as a low energy effect of a general ultra violet complete theory. In particular, the Standard Model EFT (SMEFT) framework is used. This specific EFT framework expands the SM lagrangian based on a cutoff  $\Lambda$  expansion, where  $\Lambda$  is the scale at which new physics should appear. Estimating the sensitivity to new physics in this framework is equivalent to setting limits on the expansion coefficients (the so-called *Wilson coefficients* [5]) for the operators.

In this work, only scattering of two same-sign Ws (ssWW) will be considered because of its smaller background with respect to the other VBS processes. Feynman diagrams for this process are shown in fig. 1. For the first time, we consider a final state in which a W boson decays into a hadronically decaying  $\tau$  lepton ( $\tau_h$ ) in the CMS detector. We thus consider the final state  $qq\ell\tau_h\nu_\ell\nu_\tau$  ( $\ell = e, \mu$ ). Both a cut-based and a machine learning (ML) approach to this new final state will be discussed, estimating also sensitivity to SM process and BSM effects in the SMEFT framework.

## 2. – Signal and background discrimination

**2.1. Signal process.** – We are considering as signal only EWK VBS ssWW processes in which one of the W bosons decays to a  $\tau_h$  ( $\sigma_{ssWW}^{EWK} \simeq 2\text{fb}$ ). In the final state considered we have thus two jets in the forward region, an  $\ell - \tau_h$  same-sign pair and two neutrinos, identified as missing transverse momentum ( $p_T^{miss}$ ). The two final-state jets have a peculiar topology at LHC, with large dijet invariant mass ( $M_{jj}$ ) and large angular separation, usually measured by the separation in pseudorapidity ( $\eta$ ) between the two jets ( $\Delta\eta_{jj}$ ).

**2.2. Background processes.** – The processes which mimic the final state taken into account can be divided into two main categories, which will be called:

- 1) *physics*: processes in which all the particles in the final state are produced from the decay of particles arising from the proton-proton collisions. Main contributions come from dileptonic  $t\bar{t}$  pair production and WZ associated production;
- 2) *instrumental*: processes in which not all the final state particles are produced and need additional particles to mimic the signal. Missing particles are mainly added by instrumental effects, like the incorrect reconstruction of particles from the algorithms (*e.g.*, a jet from an up quark reconstructed as a  $\tau_h$ ), or additional pile-up events. Main contributions come from W, Z and  $\gamma$  production in association with jets.



Fig. 2. – Diagram showing the cut-based selection, starting from the event and displaying the requirements for the definition of the SR and the CR for different backgrounds.

Physics backgrounds contribution can be estimated through simulation. The intrinsic nature of instrumental backgrounds instead makes them extremely difficult to model by simulations, due to the necessity to take into account inefficiencies of the detector and the algorithms, ending up in misreconstruction of real objects. A data-driven approach proved to be more reliable to model this class of backgrounds as described in [6].

**2.3. Signal and background discrimination.** – A cut-based approach to create a region dominated by signal (signal region, SR) and some control regions (CRs), orthogonal to the SR, are identified and described in fig. 2. In order to maximize the signal-over-background ratio in the signal region, a series of cuts are applied aiming at reducing some particular backgrounds, like the veto on jets coming from a b quark, needed to remove  $t\bar{t}$  contribution, and cuts to enhance the characteristic of the signal, like the one on  $M_{jj}$  and  $\Delta\eta_{jj}$  exploiting the discussed topology of the jets. CRs for the main backgrounds are defined to validate the analysis procedure and to constrain particular processes by performing a simultaneous fit across the different phase-spaces. A CR for instrumental background is obtained by reversing the cut on  $p_T^{miss}$  and adding a lower limit on the transverse mass of the  $p_T^{miss} - \ell$  system, thus obtaining a phase space enriched with multi jet with low contribution from real leptons. A CR for processes with the same final state as the signal but with an opposite-sign  $\ell - \tau_h$  pair is created by reversing the pair’s charge request. This CR is once more divided in a  $t\bar{t}$  enriched region by requesting the presence of a jet originating from a b-quark.

### 3. – SM process and BSM effects sensitivity

**3.1. Standard model preliminary sensitivity.** – To estimate the sensitivity to SM process, significance with respect to the background-only hypothesis has been calculated. This can be done by fitting signal and control regions simultaneously, to keep the background yield under control. A Boosted Decision Tree (BDT) has been trained using kinematic variables for the particles in the process to discriminate between signal (SM VBS EWK production) and two of the main backgrounds:  $t\bar{t}$  and W + jets production. Preliminary fits to estimate the expected significance in a blind signal region have been performed using two different variables:  $M_{jj}$  and the BDT discriminator output. The results obtained show how the BDT discriminator enhances by a factor two the estimated significance.

**3.2. Limits on SMEFT operators.** – Two classes of operators in SMEFT theories have been investigated up to this time: dimension-6 and dimension-8 operators. Among all the possible operators, usually just the CP conserving ones are considered, and among those we have chosen a set of three operators as benchmark of the capabilities of this final state: the two dimension-6 operators which arise using the Higgs field and the Higgs and W field, with coefficients  $c_H$  and  $c_{HW}$ , and the dimension-8 operator  $f_{T2}$ . As for the SM scenario, a BDT has been trained in order to discriminate between signal (EWK VBS production + dim > 4 operators) and backgrounds ( $t\bar{t}$  and W + jets). The profiled likelihood for each operator can be obtained by a fit on the BDT discriminator output. By a preliminary evaluation of the expected estimated limits on these operators, it arises that the ones obtained by this channel are comparable with the ones previously set by VBS analyses [7] with a fully leptonic final state, despite the lower statistics of this channel due to the branching ratio and reconstruction efficiency for  $\tau_h$ . The access to a new phase-space given by the use of  $\tau_h$  and the high mass of this particle, and for this reason with a preferential coupling to the Higgs boson, could provide improved limits on new physics. An additional approach which could lead to interesting results is to investigate the different W's polarization: dividing the contribution from different SMEFT operators for each polarization state could help strengthen the limits. The angular distribution of the  $\tau_h$  decays could provide a preferential probe to  $\tau$ 's, and then W's, polarization.

#### 4. – Conclusions

An analysis strategy and an ML approach have been described for the first study of VBS processes of two same-sign W bosons in a final state including hadronic decay of  $\tau$  lepton with the CMS experiment at the LHC. Higher backgrounds due to the increase of hadronic objects with respect to fully leptonic analysis and inefficiencies in the  $\tau_h$  decays reconstruction play a key role in the definition of this analysis. Even a simple ML approach could nonetheless enhance our sensitivity and more complex methods (*e.g.*, deep neural network) to improve the signal discrimination have to be explored. Estimate of new physics contribution, however, is probably the field in which this channel can give its best sensitivity. Other than exploiting the aforementioned  $\tau$  mass, the angular distribution of the decay products of this particle can be used to investigate  $\tau$  and W polarization, which could help in the search for new physics. A first search for ssWW VBS processes with a  $\tau_h$  in the final state is being performed with data taken with CMS during Run 2. Given the high backgrounds of the final state here considered, data that will be collected during the upcoming Run 3 and, in the future, by High-Luminosity LHC will provide the necessary statistics to fill the gap between this final state and the fully leptonic one.

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