PROCEEDINGS OF SCIENCE

Measurement of ZZ production cross section 13 TeV and anomalous gauge couplings limits in 2l2ν decay channel

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The electroweak sector of the Standard Model (SM) is explored through vector boson scattering (VBS) processes. This study focuses on the electroweak production of two Z bosons and two jets in the final state, with one Z boson decaying into charged leptons (electrons or muons) and the other into neutrinos. The analysis measures the production cross-section of the ZZ system at 13 TeV and constrains anomalous quartic gauge couplings (aQGCs) using higher-dimension operators from the Standard Model Effective Field Theory (SMEFT).

Dimension-8 and dimension-6 operators are studied to search for Beyond the Standard Model (BSM) effects. Limits on these operators are derived using distributions of key kinematic variables, with likelihood scans providing 68

The results highlight the sensitivity of operators such as cW, chl3, chq3 , and emphasize the importance of unitarity constraints. This work represents a significant step in probing the electroweak symmetry breaking mechanism and potential new physics beyond the SM

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1. Introduction

The electroweak sector of the Standard Model (SM) of particle physics provides a critical framework for understanding the interactions of fundamental particles. Vector boson scattering (VBS) processes serve as a unique probe of the electroweak symmetry breaking mechanism, a cornerstone of the SM. These processes allow for precise tests of the SM and offer opportunities to explore deviations indicative of physics Beyond the Standard Model (BSM).

This study focuses on the electroweak production of two Z bosons in association with two jets (ZZ+2j) at a center-of-mass energy of 13 TeV. The final state includes two opposite-sign, same-flavor leptons from one Z boson decay and a pair of neutrinos from the other, accompanied by two well-separated jets. This clean signature enables robust analysis while presenting challenges due to significant background contributions from processes such as diboson (WW, WZ, ZZ), top quark, and triboson production.

Beyond the SM, the study incorporates the Standard Model Effective Field Theory (SMEFT) to parameterize potential new physics contributions. Anomalous quartic gauge couplings (aQGCs) are studied through dimension-8 operators, while dimension-6 operators provide additional sensitivity to new physics effects. This framework allows for systematic exploration of deviations in gauge boson interactions and the derivation of constraints on SMEFT operators.

By measuring the production cross-section of ZZ+2j and setting limits on dimension-6 and dimension-8 operators, this analysis contributes to precision electroweak measurements and enhances our understanding of potential new physics scenarios. This work represents an important step in probing the SM at high precision and expanding the search for BSM phenomena.

1.1 Event selection and background modeling

The final state of VBS ZZ to $\ell\ell\nu\nu jj$ is characterized by an opposite sign same-flavor (OSSF) lepton pair and a large missing transverse energy(MET) associated with 2 large η separated jets. The leptons in final state are restricted to electrons and muons, and a tau veto is applied to reject hadronic taus. The OSSF leptons are used to reconstruct one of the Z bosons while the other Z boson decays into a pair of neutrinos. The Z boson is required to have a minimum pT of 60 GeV and a mass range between 76 and 106 GeV. MET needs to be at least 70 GeV to reduce DY background while not removing significant signals. b-jet veto is applied to reduce top processes. In order to reduce QCD backgrounds, events with two or more jets are selected, and the dijet system needs to have a mass larger than 400 GeV and delta η larger than 2.5. We defined a signal region to isolate our ZZ to 2l2 signal, while control regions are established to validate background estimations and ensure accurate modeling of non-signal processes such as DY WW and WZ. The selection in the signal region and the control regions is summarized in Table 1.

The background of this analysis is either from the processes which have similar final states as signal or from the processes which have one or more lepton candidates that are misidentified. The major background are from DY, WZ, $t\bar{t}$ and WW processes.

Background comes from the Z+jets process. This process can fake the missing transverse energy and hence pass the event selection. In order to estimate the Z+jet contribution, a data-driven estimation based on a dedicated single-photon control region is used.

Table 1: Selection requirement for different event categories: signal region (SR), Drell-Yan Control Region (DY CR), 3-lepton Control Region (3ℓ CR) and Non-resonant background Control Region (NRB CR). The asterisks (*) indicate that emulated P_T^{miss} is used in place of P_T^{miss}.

Quantity/Region	SR	DY CR	3ℓ CR	NRB CR
leptons	2 OSSF	2 OSSF	2 OSSF + 1	2 OSOF
$P_T(\ell_1)$	25 GeV	25 GeV	25 GeV	25 GeV
$P_T(\ell_2)$	20 GeV	20 GeV	20 GeV	20 GeV
$P_T(\ell_3)$	veto	veto	10 GeV	veto
$m(\ell\ell)$	76-106 GeV	76-106 GeV	76-106 GeV	76-106 GeV
P_T^{miss}	> 120 GeV	50-100 GeV	> 100GeV*	> 100 GeV
$P_T(\ell\ell)$	60 GeV	60 GeV	60 GeV	60 GeV
$P_T(jet)$	> 30GeV	> 30GeV	> 30GeV	> 30GeV
N_{jets}	≥ 2	≥ 2	≥ 2	≥ 2
$m(jj)$	> 400GeV	> 400GeV	> 400GeV	> 400GeV
$\lvert\Delta\eta(jj)\rvert$	> 2.5	> 2.5	> 2.5	> 2.5
min $\Delta\phi(P_T(j), P_T^{miss})$	> 0.5	> 0.5	> 0.5*	-
$\lvert\Delta\phi(P_T(\ell\ell), P_T^{miss})\rvert$	> 1.5	> 1.5	> 1.5	> 1.5
bjet	veto	veto	veto	veto
hadronic τ decay	veto	veto	veto	veto

Other major background contributions come from WZ events where only two leptons are detected from Z boson and a lepton from W boson is not reconstructed and it mimics the signal process. This background is estimated from simulation in a dedicated 3ℓ-CR. For the nonresonant background, WW and $t\bar{t}$ are constrained by using simulation in a dedicated CR with all selections similar to the signal region, with the exception that an emu pair is required. All other minor backgrounds are estimated directly from the simulation. An example of background composition for the 2018 datasets is shown in Figs. **??** and **??**.

1.2 Study of Effective field theory

The effective theory brings additional terms to the SM lagrangian:

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_{n=5}^{\infty} \sum_{i} \frac{f_i^{(n)}}{\Lambda^{n-4}} O_i^{(n)} , \tag{1}$$

where $O_i^{(n)}$ denotes operators of dimension n, $f_i^{(n)}$ are the associated Wilson coefficients, and Λ represents the cutoff scale.

We search for anomalous quadratic gauge coupling in VBS ZZ to the $2l2\nu$ channel, which sets limits on several transverse, longitudinal and mixed dimension-8 operators. Table 2 lists the operators available used in this study.

The MC samples used in this study were produced by Madgraph with an imported external model of UFO which defines new parameters and couplings.

S0	$[(D_\mu\Phi)^\dagger D_\nu\Phi] \times [(D^\mu\Phi)^\dagger D^\nu\Phi]$	T0	$Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times Tr[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}]$
S1	$[(D_\mu\Phi)^\dagger D^\mu\Phi] \times [(D_\nu\Phi)^\dagger D^\nu\Phi]$	T1	$Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times Tr[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}]$
S2	$[(D_\mu\Phi)^\dagger D_\nu\Phi] \times [(D^\nu\Phi)^\dagger D^\mu\Phi]$	T2	$Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}] \times Tr[\hat{W}_{\beta\nu}\hat{W}^{\mu\alpha}]$
M0	$Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times [(D_\beta\Phi)^\dagger D^\beta\Phi]$	T5	$Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times \hat{B}_{\alpha\beta}\hat{B}^{\alpha\beta}$
M1	$Tr[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}] \times [(D_\beta\Phi)^\dagger D^\nu\Phi]$	T6	$Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times \hat{B}_{\mu\beta}\hat{B}^{\alpha\nu}$
M2	$[\hat{B}_{\mu\nu}\hat{B}^{\mu\nu}] \times [(D_\beta\Phi)^\dagger D^\beta\Phi]$	T7	$Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}] \times \hat{B}_{\beta\nu}\hat{B}^{\mu\alpha}$
M3	$[\hat{B}_{\mu\nu}\hat{B}^{\nu\beta}] \times [(D_\beta\Phi)^\dagger D^\mu\Phi]$	T8	$\hat{B}_{\mu\nu}\hat{B}^{\mu\nu}\hat{B}_{\alpha\beta}\hat{B}^{\alpha\beta}$
M4	$[(D_\mu\Phi)^\dagger\hat{W}_{\beta\nu}D^\mu\Phi] \times \hat{B}^{\beta\nu}$	T9	$\hat{B}_{\alpha\mu}\hat{B}^{\mu\beta}\hat{B}_{\beta\nu}\hat{B}^{\mu\alpha}$
M5	$[(D_\mu\Phi)^\dagger\hat{W}_{\beta\nu}D^\nu\Phi] \times \hat{B}^{\beta\mu}$	M7	$[(D_\mu\Phi)^\dagger\hat{W}_{\beta\nu}\hat{W}^{\beta\mu}D^\nu\Phi]$

Table 2: Longitudinal, transverse, and mixed operator coefficients from dimension-8 used in this analysis

The limit-setting uses the M_T distribution defined from the $\vec{p}_T^{\,Z}$ and $\vec{p}_T^{\,miss}$ variables:

$$M_T = \sqrt{2 \cdot p_T^Z \cdot p_T^{miss} \cdot [1 - \cos\Delta\phi(\vec{p}_T^{\,Z}, \vec{p}_T^{\,miss})]} \qquad (2)$$

A likelihood calculation has been performed to estimate the expected limits on each operator at 68% and 95% confidence levels.

Dimension-6 operators can also have impact on the final state. The operators used in this study are on a Warsaw basis. The study of dimension-6 shares the same goal as dimension-8 but adopts a distinct methodology to compute the limits, with results presented at the level of LHE rather than detector level

2. Conclusion

In dimension-8, final expected limit is extracted at detector level an additional step is to calculate the unitarity bound above which the EFT is no longer valid. The dimension-6 study is performed at the LHE level. The operators associated with the coefficients cW, cHl3, and cHq3 demonstrate the best sensitivities among the operators