Sensitivity on Anomalous Neutral Triple Gauge Couplings via ZZ Production at FCC-hh

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Abstract

We investigate the effects of dimension-eight operators of the anomalous neutral triple gauge boson interactions in ZZ production at 100 TeV centre of mass energy of circular hadron collider, namely FCC-hh. The analysis is performed on four-lepton final state including the realistic detector effects. The sensitivities to the charge-parity (CP)-conserving $C_{\tilde{B}W}/\Lambda^4$ and CP-violating C_{BW}/Λ^4 are obtained at 95% C.L through the analysis of invariant mass distribution of 4l system and the results are compared with the latest experimental limits from the LHC.

Introduction

The dimension-eight (**dim-8**) effective Lagrangian for nTGC in the scope of EFT assuming the local $U(1)_{EM}$ and Lorentz symmetry can be written as [1]

$$\mathcal{L}^{nTGC} = \mathcal{L}_{SM} + \sum_i \frac{C_i}{\Lambda^4}(\mathcal{O}_i + \mathcal{O}_i^\dagger) \qquad (1)$$

where i is the index of equations running over the operators. Two of them are given as

$$\mathcal{O}_{\tilde{B}W} = iH^\dagger \tilde{B}_{\mu\nu} W^{\nu\rho}\{D_\rho, D^\nu\}H, \quad (2)$$

$$\mathcal{O}_{BW} = iH^\dagger B_{\mu\nu} W^{\nu\rho}\{D_\rho, D^\nu\}H \quad (3)$$

The coefficients of these **dim-8** operators describing aNTGC are CP-conserving $C_{\tilde{B}W}/\Lambda^4$ and CP-violating C_{BW}/Λ^4 couplings. They are related to dimension-six operators aNTGC as described in Ref. [1].

Feynman diagrams of ZZ production for signal including an aNTGC vertex depicted by a red dot and for the SM background are given in Fig.1.

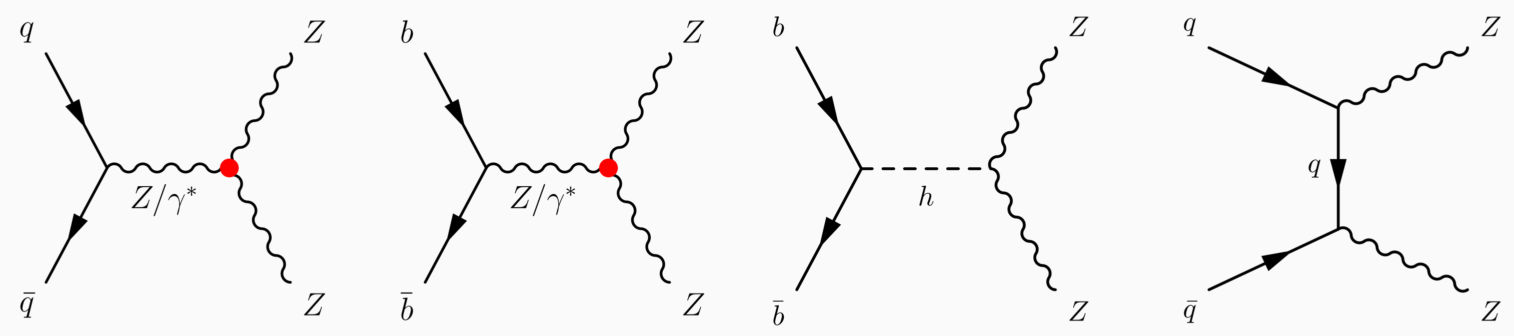

Fig. 1: Contributing diagrams to the process

Cross sections for $pp \to ZZ$ production in the 4ℓ channel with aNTGCs including CP-conserving and CP-violating terms in the Lagrangian are given in Fig. 2.

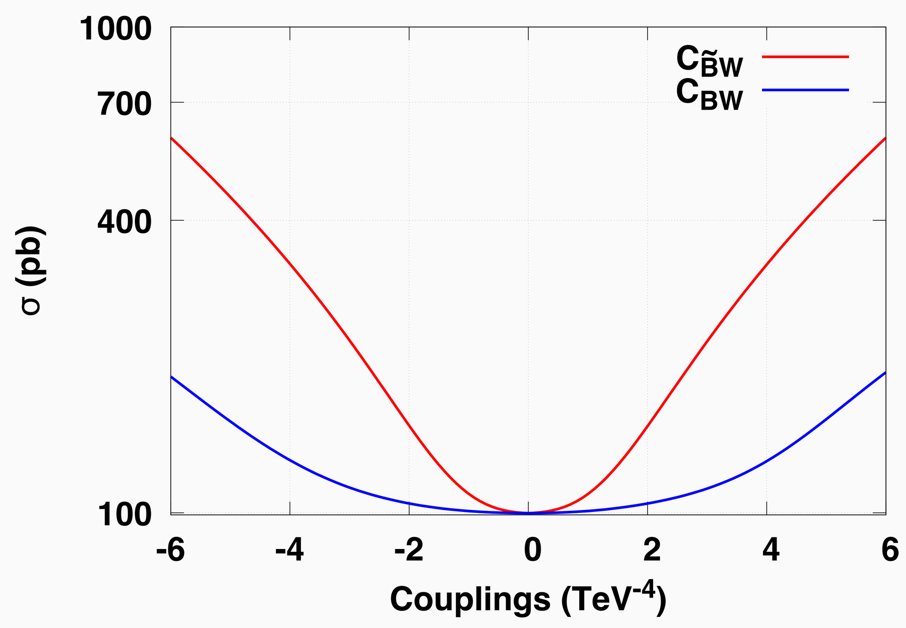

Fig. 2: The signal cross sections of $pp \to ZZ$ production in the 4ℓ channel depending on dimension-8 couplings at FCC-hh.

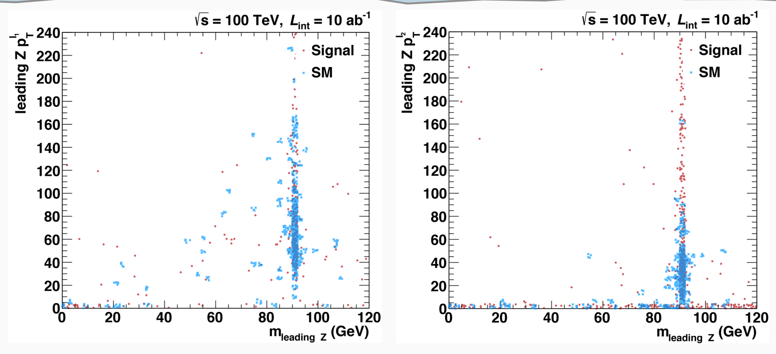

Fig. 3: p_T of ℓ^1 (first plot) and ℓ^2 (second plot) from *leading* Z vs. $m_{leading\,Z}$

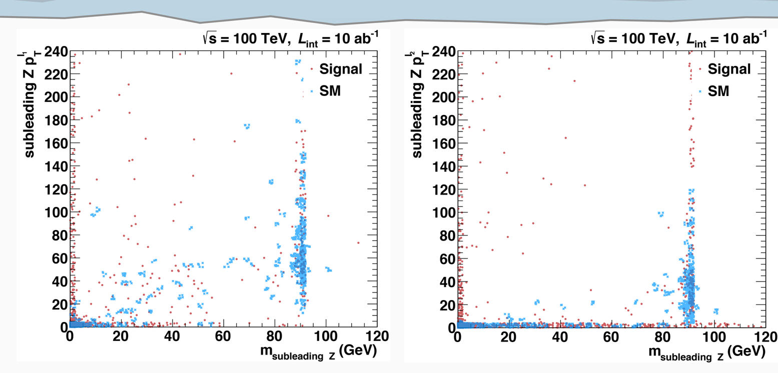

Fig. 4: p_T of ℓ^1 (first plot) and ℓ^2 (second plot) from *subleading* Z vs. $m_{subleading\,Z}$

Generation of signal and background events

Signal and background events produced by **MadGraph5_aMC @NLO v2.6.4** [2]. → Parton Shower and Hadronization by **PYTHIA v8.2** [3]. → Fast Simulation by **Delphes v3.4.1** with FCC-hh Detector Card [4]. → All events are analyzed by **ExRootAnalysis** utility [5] with **ROOT v6.16** [6].

Event selection

- Considering 4ℓ final state, including three possible options; $e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$, and $e^+e^-\mu^+\mu^-$
- Requiring the presence of a pair of leptons of the same or different flavors
- All permutations of leptons giving a pair of Z/γ^* candidates are considered within each event.

The cut flow steps in the analysis for selecting the events are summarized in Table 1.

Cuts	Definition
Cut-0	Preselection: $N_{\ell_{(e,\mu)}} >= 4$ and two same-flavor opposite-charge lepton pairs
Cut-1	Dileptons minimizing $\lvert m^a_{\ell\ell} - m_Z\rvert + \lvert m^b_{\ell\ell} - m_Z\rvert$ are taken as Z boson pair candidates
Cut-2	Transverse momentum: $p_T^{\ell 1} > 20$ GeV, $p_T^{\ell 2} > 12$ GeV (10 GeV) for $e\,(\mu)$ and $p_T^{\ell 3,4} > 5$ GeV
Cut-3	Pseudo-rapidity: $\lvert\eta^\ell\rvert < 2.5$
Cut-4	$\Delta R > 0.02$ between all leptons
Cut-5	Invariant mass: $80 < M_{inv}^{rec}$(leading Z)< 100 GeV and $60 < M_{inv}^{rec}$(subleading Z)< 110 GeV

Tab. 1: Preselection and a set of cuts for the analysis of signal and background events.

Results

We use invariant mass distributions of the reconstructed four-lepton invariant mass m_{ZZ} to get χ^2 values with and without systematic errors.

$$\chi^2 = \sum_i^{n_{bins}} \left(\frac{N_i^{NP} - N_i^B}{N_i^B \Delta_i}\right)^2 \qquad (4)$$

$$\Delta_i = \sqrt{\delta_{sys}^2 + 1/N_i^B} \qquad (5)$$

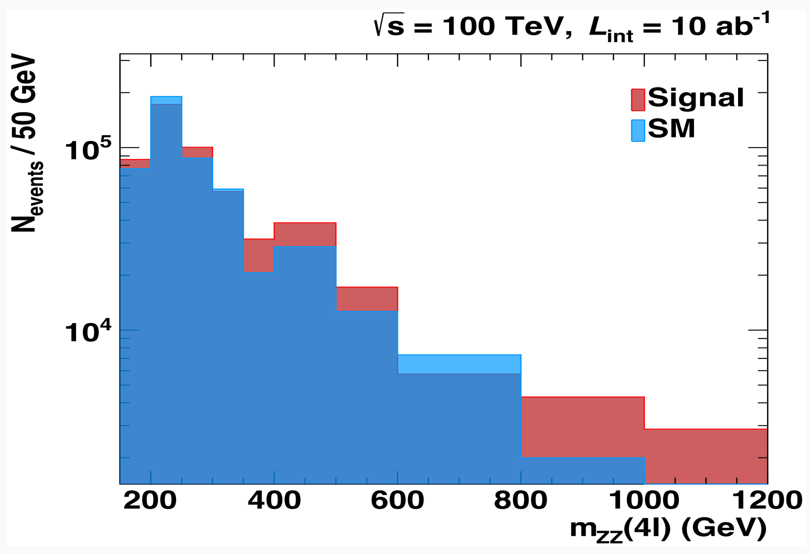

Fig. 5: Distributions of the reconstructed four-lepton invariant mass m_{ZZ}. In the m_{ZZ} distribution, bin contents are normalized to the bin widths.

Conclusion and Discussion

In this study we present a phenomenological cut based analysis for probing the limits on the CP-conserving $C_{\tilde{B}W}/\Lambda^4$ and CP-violating C_{BW}/Λ^4 `dim-8` aNTG couplings via $ZZ \to 4\ell$ (where $\ell = e$ or μ) production at the FCC-hh.

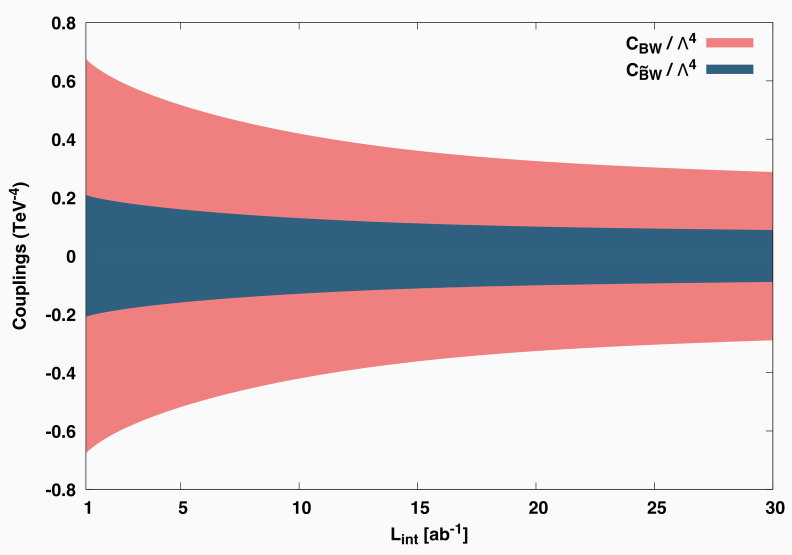

Fig. 6: Estimated sensitivity on aNTG couplings at 95% C.L. as a function of integrated luminosity where there is only one coupling varied at a time from its SM value.

The obtained 95% C.L. limits on the couplings with and without a systematic error are given in Table 2.

Couplings (TeV^{-4})	Limits at 95% C.L. $ZZ \to 4\ell$ [7]	$Z\gamma \to \nu\bar{\nu}\gamma$ [8]	$\delta_{sys} = 0\%$	$\delta_{sys} = 3\%$
$C_{\tilde{B}W}/\Lambda^4$	$-5.9, +5.9$	$-1.1, +1.1$	$[-0.315, +0.315]$	$[-0.544, +0.544]$
C_{BW}/Λ^4	$-3.3, +3.3$	$-0.65, +0.64$	$[-1.036, +1.036]$	$[-1.788, +1.788]$

Tab. 2: Estimated one dimensional 95% C.L. limits on aNTG couplings with and without a systematic error at $L_{int} = 10\,ab^{-1}$. For each single anomalous coupling, all parameters other than the one under study are set to zero.

- Even with 3% systematic errors, the obtained bounds at 95% C.L. for $C_{\tilde{B}W}/\Lambda^4$, C_{BW}/Λ^4 with an $\mathcal{L}_{int} = 10$ ab^{-1} at FCC-hh are better than the current LHC results on these couplings.

References

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