Anomalous gauge couplings of the Higgs boson at the LHC II: Study of additional backgrounds in semileptonic mode of WW scatterings

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In addition to a previous paper [1], we study the backgrounds in which leptons coming from jet hadronization and from τ decay to the process $pp \rightarrow W^+W^-j_1^f j_2^f \rightarrow l^+\nu_{j_1} j_2^f j_1^f j_2^f$ for measuring the anomalous gauge couplings of the Higgs boson at the LHC. We show that these kinds of backgrounds can be effectively suppressed by the cuts already imposed in Ref. [1], so that all the conclusions in Ref. [1] will not be affected by these kinds of backgrounds.

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 Searching for the Higgs boson is of first priority in LHC experiments. Once a Higgs candidate is found, we then need to know whether it is the standard model (SM) Higgs boson or a Higgs boson in new physics beyond the SM. So far we do not know what model of new physics will actually reflect the property of the nature. A model-independent way of measuring the anomalous couplings of the Higgs boson will provide a no-lose underlying theory of new physics.

A model-independent way of measuring the anomalous gauge couplings of the Higgs boson in new physics will actually reflect the property of the nature.

iii, hadronic decay of $W^\pm$: (Single jet $J$ with the largest $p_T$ among the reconstructed jets via $k_T$ algorithm): transverse momentum cut

$$p_T(J) > 200 \text{ GeV}, \quad \eta(J)\eta(l^+) < 0,$$

(3)

iv, hadronic decay of $W^\pm$: invariant mass cuts

$$65 \text{ GeV} < M_{Jl} < 95 \text{ GeV},$$

(4)

v, cuts reconstructing the electroweak scale

$$1.6 < \log(p_T\sqrt{y}) < 2.0$$

(5)

where $y \equiv \frac{d_{12}}{d_{cut}}$, $d_{cut} = 2\min(E_1^2, E_2^2)(1 - \cos \theta_{12})$ [E1, E2, $\theta_{12}$ are the energies and relative angle of the first two sub-jets before emerging into the single jet $J$, clustered by the $k_T$ algorithm, respectively (cf. Ref. [3])], and $d_{cut}$ is the total energy by summing over all the reconstructed jets in each event.

vi, top quark veto in order to suppressing top quark background

$$130 \text{ GeV} < M_{Jj} < 240 \text{ GeV}.$$ 

(6)

vii, $p_T$ balance cuts for reconstructing $l^+ E_{Tjj jj jj}$

$$\sum_{i} p_T^i < \pm 15 \text{ GeV}.$$ 

(7)

viii, minijet veto: vetoing the events containing jets other than the signal jet $J$ from $W^\pm$ decay [satisfying (3) and (4)] in the central rapidity region, $|\eta| < 2$.

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In Ref. [1], the leptons, \(l^+ = e^+, \mu^+\), in the final state of the background processes are considered only from direct \(W^+\) decays. However, in practical data analysis, there are other possibilities that the leptons may come from other sources mimicking the signal leptons, such as from the jet(s) hadronization \(l^+\) comes from the decays of pions, \(\eta\), \(J/\psi\), etc. in the hadronization of jets and from \(\tau\) decay, and thus become additional backgrounds to the signal process. In this short paper, we study these kinds of additional backgrounds and their suppressions for making the whole study more realistic.

The first kind serves as a background only at the hadron level when the hadronization of the jet is taken into account since, at the parton level, the final state particles are not the same as those in the signal process. For this kind of background, we shall study the following processes:

\[
pp \rightarrow Wjjj \rightarrow jjjjl^+ E_T, \quad (8)
\]

\[
pp \rightarrow Zjjj \rightarrow jjjjl^+ E_T, \quad (9)
\]

\[
pp \rightarrow jjjj \rightarrow Jjjjl^+ E_T, \quad (10)
\]

\[
pp \rightarrow jjjjj \rightarrow jjjjl^+ E_T, \quad (11)
\]
in which the lepton \(l^+\) comes from the hadronization of jets, and the two jets \(jjJ\) are chosen to satisfy the forward-jet cuts (2). The remained two jets \(jj\) in (8), (9) and (11) correspond to the jets in \(W(Z) \rightarrow jj\), and will be required to behave as a “single” energetic jet \(J\) satisfying the cuts (3) and (4).

For the second kind of background, we shall study the following backgrounds in addition to those studied in Ref. [1]:

\[
pp \rightarrow Z\tau \rightarrow \tau^+ \tau^- j \rightarrow l^+ j jj j l^+ E_T, \quad (12)
\]

where \(l^+\) is from \(\tau^+\) decay; and

\[
pp \rightarrow Zjj \rightarrow \tau^+ \tau^- jj \rightarrow l^+ jj j j l^+ E_T, \quad (13)
\]

where \(l^+\) is from \(\tau^+\) decay, and the two jets \(jj\) correspond to the jets in \(W(Z) \rightarrow jj\) in the signal process, which should be required to behave as an “single” energetic jet \(J\) satisfying the cuts (3) and (4).

Now we study the above additional backgrounds at the hadron level under the cuts summarized in (1) - (7) and \textit{minijet veto} taking account of both the initial and final state partons radiations, following the parton showers and hadronization of the final state jets by using PYTHIA [2] and the \(k_T\) algorithm [3] with the package ALPGEN [4].

![FIG. 1: (a) \(p_T(l^+)\) distribution in the process (8) and (9) for an integrated luminosity of 100 fb\(^{-1}\): (a) in the process (8), and (b) in the process (11) [those in the processes (8) and (9) are similar to (b)].](image)

In the backgrounds (5) – (11), we naturally estimate that the transverse momenta of such leptons are of the or-
der of the hadronization scale which are much smaller than the transverse momentum of the signal lepton from $W^+$ decays. Thus we expect that the imposed cut (1) can effectively suppress these backgrounds. After the hadronic level calculation using PYTHIA [2] and the $k_T$ algorithm [3] with the package ALPGEN [4], we obtain the $p_T(l^+)$-distributions in the processes $\gamma$ and (11) in FIG. 1. We see that the distribution is indeed

- distributions in (8) are all similar. As an example, we show the $p_T(l^+)$-distribution of the process (10) and (11) in FIG. 1. We see that the distribution is indeed mainly in the low $p_T(l^+)$ region, but there are still some possibilities of being in higher $p_T$ regions. We shall show that, with other cuts in (16–19), these backgrounds are suppressed to be negligibly small.

In FIG. 2 we plot the corresponding $p_T(l^+)$ distributions in the background processes (12–15). We see that, in these three processes, there are $p_T(l^+)$ distributed above 200 GeV. Therefore other cuts in (16–19) and minijet veto are also needed for suppressing these backgrounds.

To have a complete list of the efficiency of the imposed cuts in suppressing all the signals and the backgrounds studied in the present paper and in Ref. [1], we illustrate the complete cut efficiency in TABLE III by taking the case of $m_H = 115$ GeV with $f_W/\Lambda^2 = 4.0$ TeV$^{-2}$ as an example. In TABLE III the column labeled by “particle ID” means that we take only the basic cuts for identifying particles taken in Ref. [1] according to the detecting limits of the detector (ATLAS or CMS) without imposing the kinematic cuts i–viii.

We see from TABLE III that all the additional backgrounds studied in this paper (the first eight rows) are made negligibly small by imposing the first four cuts, i–iv [Eqs. (1)–(4)]. Therefore, with the cuts i–iv and minijet veto already imposed in Ref. [1] (without adding any new cuts), all the conclusions stated in Ref. [1] are not affected by taking account of the additional backgrounds studied in this paper. So we state our final conclusion as follows. With the kinematic cuts imposed in Ref. [1], a model-independent test of the anomalous gauge couplings of the Higgs boson at the 14 TeV LHC via the semileptonic mode of weak-boson scatterings $pp \rightarrow W^+W^-j_1\bar{j}_2\rightarrow l^+\nu_lj_1j_2\bar{j}_1\bar{j}_2$. 

![Graphs](image-url)
can be obtained by imposing the kinematic cuts (1)–(7) and minijet veto. The experimental measurement can start for an integrated luminosity of 50 fb\(^{-1}\). For higher integrated luminosity, say 100 fb\(^{-1}\), the two main anomalous coupling constants \(f_{W}/\Lambda^{2}\) and \(f_{W}/\Lambda^{2}\) can be quantitatively determined separately to a certain accuracy [1] which may provide a clue for figuring out the underlying theory of new physics.

| Cuts          | particle ID | cut-\(i\) | cut-\(ii\) | cut-\(iii\), \(iv\) | cut-\(v\) | cut-\(vi\) | cut-\(vii\) | cut-\(viii\): Minijet veto |
|---------------|-------------|-----------|-----------|---------------------|----------|-----------|-----------|---------------------------|
| W+3j [\(8\)] | 2525616     | 0         | -         | -                   | -        | -         | -         | -                         |
| Z+3j [\(9\)] | 511353      | 0         | -         | -                   | -        | -         | -         | -                         |
| 4j [\(10\)]  | 3299949610  | 24566.5   | 0         | -                   | -        | -         | -         | -                         |
| 5j [\(11\)]  | 572442776   | 0         | -         | -                   | -        | -         | -         | -                         |
| Z+j [\(12\)] | 417519      | 23.57     | 1.47      | 0                   | -        | -         | -         | -                         |
| Z+2j [\(13\)]| 151189      | 45.7752   | 0         | -                   | -        | -         | -         | -                         |
| W+3j [\(14\)]| 420936      | 224.356   | 44.8711   | 0                   | -        | -         | -         | -                         |
| Z+3j [\(15\)]| 3525.88     | 0.818498  | 0.204625  | 0.102312            | 0        | -         | -         | -                         |

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