

Recent Studies of Little Higgs Models in ATLAS

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Abstract. The ATLAS Collaboration at the LHC continues investigating the possibility to detect particles predicted by Little Higgs models. In this talk, the latest results on the $Z/W h$ decays and on the hadronic decays of the new gauge bosons Z_H/W_H are reviewed.

Keywords: Little Higgs, LHC, heavy gauge bosons

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INTRODUCTION

The Higgs sector of the Standard Model (SM) contains an instability due to the radiative corrections to the Higgs boson mass; this is known as the hierarchy problem. Various theories and models have been designed to solve this problem. One of them is called the Little Higgs model and was proposed a few years ago [1]. This is an effective model in which the Higgs is a pseudo-Goldstone boson resulting from a spontaneously broken global symmetry at a very high scale. Such a Higgs boson remains light, protected by the approximate global symmetry. Here we concentrate on one of the several implementations of the model, called the *Littlest Higgs* model [2]. This particular model includes a $SU(5)$ to $SO(5)$ breaking, and the following heavy new particles: scalar particles ϕ^0 , ϕ^+ , ϕ^{++} , new $2/3$ charge heavy quark (T), and heavy partners of the electroweak gauge bosons A_H , Z_H and W_H^\pm .

PHENOMENOLOGY AT THE LHC

The Higgs boson (h) properties remain those of the SM. Production cross sections and branching ratios of the heavy new particles have been computed in [3, 4], leading to the following search strategy:

- The ϕ^{++} scalar is produced in W^+W^- fusion. The dominant decay mode is $\phi^{++} \rightarrow W^+W^-$. The corresponding cross section is small and the SM background large, so this particle would be difficult to observe. Nevertheless, the prospects for its detection have been studied and reported in [5].
- The heavy quark T can be produced singly in the $bq \rightarrow Tq'$ channel via W exchange. The T then decays to tZ or th . The corresponding cross section is small as well, although larger than the cross section for the QCD production of a $T\bar{T}$ pair. How well the T could be detected by ATLAS was studied in [5].
- The gauge bosons Z_H and W_H are produced via $q\bar{q}^{(\prime)}$ annihilation and the cross section is much higher than for the ϕ^{++} and T . Once their mass is fixed (they are

approximately degenerate), the only parameter is θ , the mixing angle between the W triplets, and the cross section is proportional to $(\cot \theta)^2$. The production cross section for the A_H boson is more difficult to predict since the couplings are not entirely fixed by the model. Nevertheless, some results on its search are shown in [5].

In the following, we concentrate on the experimental search of Z_H and W_H using the ATLAS detector. The PYTHIA event generator[6] was used to generate signal and background events. The events were passed through the ATLAS fast simulation[7] which provides a parameterized response of the detector to jets, electrons, muons, isolated photons and missing transverse energy. The integrated luminosity is assumed to be 300 fb^{-1} , which corresponds to data collected during three years of running at high luminosity. The event selection includes the ATLAS trigger criteria.

HEAVY GAUGE BOSON SEARCHES

Once produced, the heavy Z_H and W_H bosons can have two types of decays: the fermionic channels, which are the same channels as their SM partners, and the bosonic channels. Denoting V_H for both Z_H and W_H (and V for Z and W), these are $V_H \rightarrow Vh$ and $Z_H \rightarrow W^+W^-$, $W_H \rightarrow ZW$.

Among the fermionic channels, $Z_H \rightarrow l^+l^-$ and $W_H \rightarrow l\nu$ are clearly the discovery channels. It was shown in [5] that V_H can be discovered at masses of up to 6 TeV if $\cot \theta$ is large. On the other hand, the $V_H \rightarrow q\bar{q}^{(\prime)}$ channel is expected to be more difficult, because of the high level of background. It was studied however, and the results are reported below.

The observation of the $V_H \rightarrow Vh$ decay is essential to test Little Higgs models. Besides, it is dominant at low values of $\cot \theta$. A first study was performed assuming that the Higgs boson is discovered with a mass $m_h = 120 \text{ GeV}$ [5]. The resulting exclusion contour in the $(M_{V_H}, \cot \theta)$ plane is shown on Fig 1 (left). In the next subsection, we report on the results of a more recent study of this decay, which assumes $m_h = 200 \text{ GeV}$.

Search for the decays $V_H \rightarrow Vh$ assuming $m_h = 200 \text{ GeV}$.

When $m_h = 200 \text{ GeV}$, the main Higgs decays are $h \rightarrow W^+W^-$ (73%) and $h \rightarrow ZZ$ (26%). Various Zh and Wh final states have been chosen, as listed in Table 1, resulting from a compromise between cross section and signature [8]. In all the modes, the main background is inclusive top pair production, where both tops decay semi-leptonically and a third lepton can arise from a b jet. In the A1 and A2 modes, the missing transverse momentum is used to reconstruct the Higgs momentum, assuming that the neutrino is colinear to the leptons. In addition, the W mass constraint is applied in the B1 and B3 mode. The A3 and A4 modes have indistinguishable final state. The hadronic decay of high p_T W or Z are reconstructed by looking for two high p_T jets with mass close to the W/Z mass or, if it fails, by taking the jet with the largest p_T .

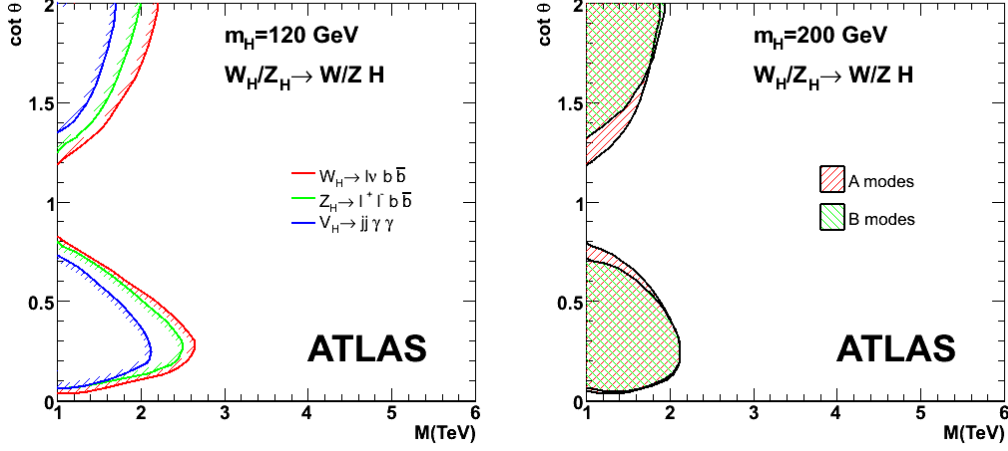


FIGURE 1. Discovery region with the $V_H \rightarrow Vh$ channel (left: $m_h = 120$ GeV, right: $m_h = 200$ GeV) as a function of M_{V_H} and $\cot \theta$.

TABLE 1. Z_H and W_H final states under study. The branching ratios are computed assuming $\cot \theta = 0.5$, the selection efficiencies ϵ assume a gauge boson mass of 1 TeV.

Mode	BR (10^{-4})	Decay	Signature	ϵ
A1	1.0	$Z_H \rightarrow Zh \rightarrow l^+ l^- W^+ W^- \rightarrow l^+ l^- l^+ \nu l^- \nu$	4 leptons + E_T^{miss}	34%
A2	3.0	$W_H \rightarrow Wh \rightarrow l \nu - W^+ W^- \rightarrow l \nu l^+ \nu l^- \nu$	3 leptons + E_T^{miss}	12%
A3	0.4	$Z_H \rightarrow Zh \rightarrow jjZZ \rightarrow jjl^+ l^- l^+ l^-$	4 leptons + jets	26%
A4	0.4	$W_H \rightarrow Wh \rightarrow jjZZ \rightarrow jjl^+ l^- l^+ l^-$	4 leptons + jets	
B1	6.8	$Z_H \rightarrow Zh \rightarrow l^+ l^- W^+ W^- \rightarrow l^+ l^- jjl \nu$	3 leptons + jets + E_T^{miss}	22%
B2	0.8	$Z_H \rightarrow Zh \rightarrow l^+ l^- ZZ \rightarrow l^+ l^- jjl^+ l^-$	4 leptons + jets	17%
B3	2.4	$W_H \rightarrow Wh \rightarrow l \nu ZZ \rightarrow l \nu jjl^+ l^-$	3 leptons + jets	15%

The corresponding discovery reach is summarised on Fig 1(right); it is similar to the $m_h = 120$ GeV case, but the bound on the V_H mass is weaker (6 TeV versus 2 TeV).

Search for hadronic decays

For $\cot \theta \approx 1$, $\text{BR}(V_H \rightarrow Vh)$ vanishes and the branching ratios to heavy quarks are [4]: $\text{BR}(Z_H \rightarrow b\bar{b}) = \text{BR}(Z_H \rightarrow t\bar{t}) = 1/8$ and $\text{BR}(W_H \rightarrow t\bar{b}) = 1/4$. It was shown [9] that no convincing signal can be seen in the Z_H case. However, the $W_H \rightarrow t\bar{b}$ appears visible in the channel where the top decays to the $W(l\nu)b$ final state. One isolated lepton is searched for, and two b -jets tagged, one close to the lepton, one recoiling against the lepton. The neutrino 3-momentum is estimated from the reconstructed missing transverse momentum and assuming it is parallel to the lepton momentum.

The discovery reach is shown on Fig 2 in the same plane as before, together with earlier results on the $Z_H \rightarrow l^+ l^-$ and $W_H \rightarrow l\nu$ discovery channels [5]. The $\cot \theta = 1$ region which was missing in the $V_H \rightarrow Vh$ analyses is well covered up to $M_{W_H} = 2.5$ TeV.

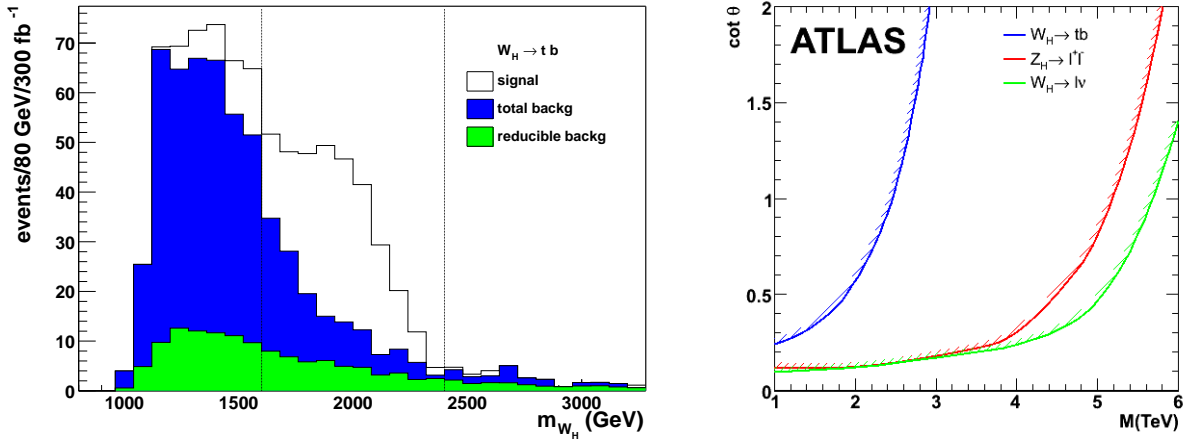


FIGURE 2. Left: reconstructed mass peak for $W_H \rightarrow tb$ ($M_{W_H} = 2$ TeV). Right: discovery region with the fermionic channels as a function of M_{V_H} and $\cot \theta$.

SUMMARY

We have shown the latest examples of channels which can be used to test the predictions of Little Higgs models. The discovery reach is found to be rather good, in particular for the new gauge bosons. However, we are aware that the model family of the particular implementation studied here is actually disfavoured by precision electroweak constraints. The introduction of a discrete symmetry called T-parity would allow to escape them. Unfortunately, since it implies that the heavy partners can only be produced in pairs, the phenomenology is drastically modified and would therefore require a new analysis.

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