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# Prospects for little Higgs models at the LHC

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**Abstract.** The ATLAS Collaboration at the LHC is presently investigating the possibility to detect particles predicted by Little Higgs models. In this talk, the possibility to detect the heavy gauge boson $Z_H$ and its subsequent decay into $Zh$ is reviewed.

## 1 Introduction

Little Higgs models have been recently proposed as a possible solution to the hierarchy problem. They try to explain the smallness of the Higgs boson mass by introducing new particles at the 1 TeV scale. In the so-called 'littlest Higgs model' [1], these new particles are scalars ($\Phi^0$, $\Phi^+$, $\Phi^{++}$), gauge bosons ($W_H$, $Z_H$, $A_H$) and a heavy top quark ($T$). The masses and couplings of all these new particles are completely fixed (except for $A_H$) once the scale $f$ and a set of couplings called $v'$, $\theta$, $\theta'$ and $\lambda_1$ are specified.

## 2 Phenomenology at the LHC

Branching ratios and cross-sections at the LHC have been computed in [2]. From these calculations it is possible to extract some conclusions concerning experimental strategies in order to test Little Higgs models with LHC experiments:

- The scalar $\Phi^{++}$ is produced in $W^+W^+$ fusion (VBF mechanism). The cross-section is proportional to $(v'/v)^2$, where $v = 244$ GeV is the Fermi scale, but $v'/v$ is expected to be small. The dominant decay mode would be $\Phi^{++} \to W^+W^+$, and the Standard Model background for this mode is rather large, so this particle is difficult to observe.
- The heavy top quark $T$ is produced according to $bq \to Tq'$ via W exchange in the t-channel ($Wb$ fusion mechanism). The cross-section is proportional to $\lambda_1^2$ and $\lambda_1$ is expected to be of order 1, but the $b$-quark content of the proton is small so the cross-section is also small. Therefore this particle is also difficult to observe.
- The gauge boson $Z_H$ is produced in $q\bar{q}$ annihilation, in the same way as a normal $Z$ boson. The cross-section is proportional to $(cot\theta)^2$, the mixing angle $\theta$ being the only free parameter of the theory once the mass of $Z_H$ is fixed. For a mass of 2 TeV and $cot\theta = 1$, the cross-section is 1 pb, so $Z_H$ is copiously produced at the LHC. The charged gauge boson $W_H$ is also produced in $q\bar{q}'$ collisions, the same as the $W$, and the production cross-section is also large. The production cross-section for the gauge boson $A_H$ is more difficult to calculate since the couplings are not entirely fixed by the model.

In the following we concentrate in the experimental search for $Z_H$ using the ATLAS experiment at the LHC.

## 3 Experimental search for $Z_H$

Once the heavy gauge boson $Z_H$ is produced, it decays into quark or lepton pairs. Taking into account the universality of the coupling and neglecting fermion masses, BR($Z_H \to l^+l^-$=1/24=4.2% ,where $l$ is any charged lepton. At small values of $cot\theta$, however, the decay $Z_H \to Zh$, where $h$ is the Higgs boson, is dominant.

The decay $Z_H \to e^+e^-$ provides the best signature to detect $Z_H$ at the LHC, since the relative invariant mass resolution, $\sigma(M)/M$, does not degrade for electrons with increasing mass (contrary to the muon case). The background, mainly Drell-Yan pairs, is much smaller than the signal over a wide range of $cot\theta$ values. Fig.1 shows the region in the $M - cot\theta$ plane where a discovery of $Z_H$ is possible at the LHC, using the ATLAS detector. A luminosity of $3 \cdot 10^5$ pb$^{-1}$ corresponding to 3 years of running at high luminosity has been assumed. If a signal is detected, it would also be possible to measure $cot\theta$ via the cross-section and the width of $Z_H$. Indeed, as mentioned before, the cross-section is proportional to $(cot\theta)^2$, and the total width of $Z_H$ is:

$$\Gamma/M = [3.4(cot\theta)^2 + 0.071(cot2\theta)^2]\%$$

In this expression the first term accounts for the decay of $Z_H$ into fermions and the second term for the decay $Z_H \to Zh$.

## 4 Search for the decay $Z_H \to Zh$

The observation of the decay $Z_H \to Zh$ is essential to test Little Higgs models. The amplitude of the decay is not

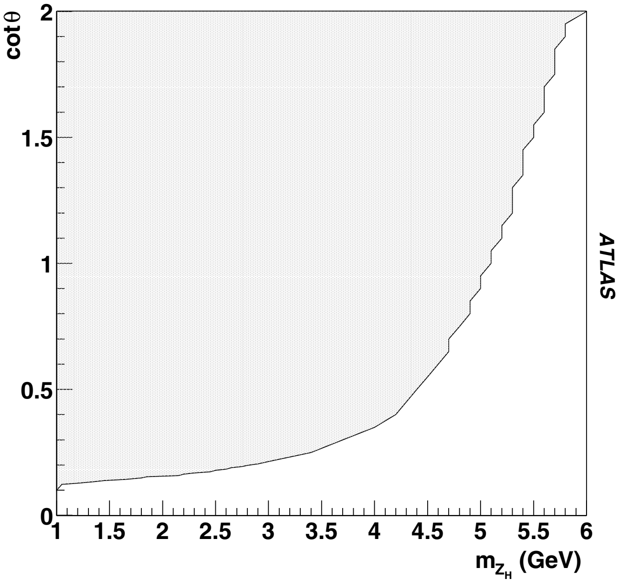

**Fig. 1.** Region where a discovery of the decay $Z_H \to e^+e^-$ is possible using the ATLAS detector at the LHC. An integrated luminosity of $3 \cdot 10^5$ pb$^{-1}$ has been assumed. The discovery region corresponds to a significance of the signal larger than 5.

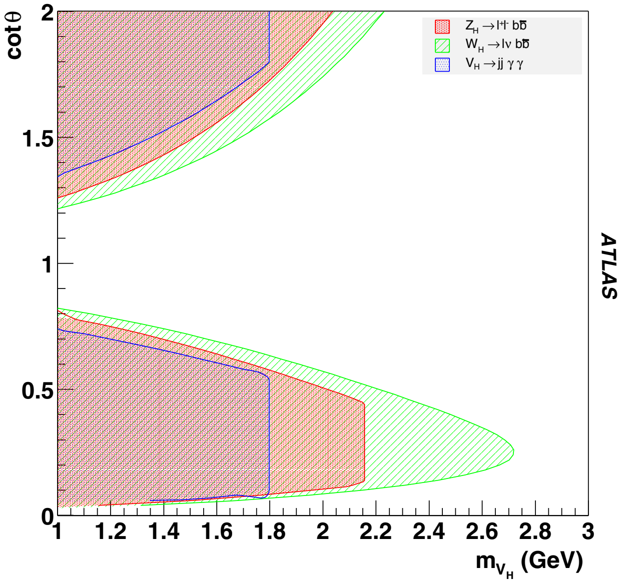

**Fig. 2.** Region where a discovery of the decay $Z_H \to Zh$ is possible using the ATLAS detector at the LHC. The Higgs boson $h$ is assumed to decay into either $b\bar{b}$ or $\gamma\gamma$. An integrated luminosity of $3 \cdot 10^5$ pb$^{-1}$ has been assumed. The discovery region corresponds to a significance of the signal larger than 5. The decay $W_H \to Wh$ is considered as well. $V_H$ is either $Z_H$ or $W_H$.

proportional to $(cot\theta)^2$ as for fermions, but to $(cot2\theta)^2$. Unfortunately, this $(cot2\theta)^2$ factor in the branching ratio has a tendency to cancel the $(cot\theta)^2$ factor in the $Z_H$ production cross-section. As a result, the $Zh$ event yield is rather small, except for $cot\theta$ values around 0.3. In particular, the event yield completely vanishes for both $cot\theta = 0$ and $cot\theta = 1$.

The experimental signature of $Zh$ events depends on the mass of the Higgs boson. In the following M($h$)=120 GeV is assumed, so the dominant decay of the Higgs boson is $h \to b\bar{b}$. In this case the final state consists of a pair of $b$-jets and a pair of leptons from the $Z$ decay. The main background is $Z$ production in association with jets. As the mass of $Z_H$ increases, the two $b$-jets from the $h$ decay have a tendency to merge into a double $b$-quark jet with very high $p_T$. In order to identify these events, b-tagging at high $p_T$ is therefore extremely important. The result of full-detector simulation studies show that it would be possible to tag these double $b$-quark jets with very high $p_T$, by simply requiring a reduced tagging efficiency (40% instead of the usual 50%). Fig.2 shows the region in the $M - cot\theta$ plane where the decay $Z_H \to Zh$ can be detected at the LHC, using the ATLAS detector and a luminosity of $3 \cdot 10^5$ pb$^{-1}$. The figure includes also the decay $b \to \gamma\gamma$ and the result obtained using the decay $W_H \to Wh$, assuming that $W_H$ and $Z_H$ have exactly the same mass. If the mass of the Higgs boson is larger than 120 GeV, the decays into $W^+W^-$ and $ZZ$ have to be considered as well.

## 5 Summary and outlook

A short summary of the prospects for detecting at the LHC the heavy gauge boson $Z_H$, predicted by the Little Higgs model, has been presented. The possibility to detect the decay $Z_H \to Zh$ is discussed as well, assuming that the mass of the Higgs boson is 120 GeV. Work concerning the production and decay of other particles predicted by the model, namely $A_H$, $W_H$, $T$ and $\Phi^{++}$, is in progress. Other Little Higgs models including two Higgs doublets, rather than just one, will be considered as well.

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