

A calculation of the $Z_H \rightarrow \gamma H$ decay in the Littlest Higgs Model

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Abstract. New heavy neutral gauge bosons are predicted in many extensions of the Standard Model, those new bosons are associated with additional gauge symmetries. We present a preliminary calculation of the branching ratio decay for heavy neutral gauge bosons (Z_H) into γH in the most popular version of the Little Higgs models. The calculation involves the main contributions at one-loop level induced by fermions, scalars and gauge bosons. Preliminary results show a very suppressed branching ratio of the order of 10^{-6} .

1. Introduction

The standard model of fundamental interactions (SM) is a non-abelian gauge theory, based on the gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$. The model is used to describe the interactions of fundamental particles and fundamental forces. The theory agrees with experimental data. Moreover, the discovery of the Higgs boson at the Large Hadron Collider (LHC) in 2012 was an exciting moment on particle physics. The mechanism proposed by Francois Englert and Peter Higgs ingeniously explains how the Higgs field gives mass to both particles that constitute matter as well as particles that mediate forces among particles [1]. These scientists answered the fundamental question: *Why do particles have mass?* in the middle sixties. After nearly 50 years Englert and Higgs won the nobel prize in 2013 for this contribution. To search for the Higgs boson, the physicists needed to build a bigger collider than Tevatron at Fermilab, with higher center energy of mass. The Tevatron was operating at a center of mass energy of 1.96 TeV, corresponding to an integrated luminosity of 9.45 fb^{-1} in proton anti-proton collisions. Even though the LHC was operating at half capacity (7 TeV), it was able to collect enough data to observe a resonance around 125 GeV corresponding to the evidence of the presence of the Higgs boson [2].

Recently, the LHC has been improved and the four detectors that are within it have been reconditioned. With these improvements it will be possible to explore the region of TeV's. At the TeV's scale, there exist theories beyond the SM which are based on non-linear realization of some global symmetry G broken down to H . In this sense, the so-called Littlest Higgs (LH) model [3, 4] represents a new attempt to solve the problem of quadratic divergences on the mass of the Higgs boson. The LH model predicts new heavy particles, such as the Z_H gauge boson.



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In this work we are specially interested on the $Z_H \rightarrow H\gamma$ decay mediated by the SM particles and the new heavy particles.

2. The Littlest Higgs Model

In the SM, the Higgs boson mass receives corrections at one-loop level, the most significant correction is due to the top quark loop. The contributions coming from loops of the electroweak gauge bosons and of the Higgs boson itself are smaller than the top quark contributions. It means that the Higgs boson mass is sensitive to high energy scales. If we assume the SM is valid up to Fermi scale, the parameters in the theory need to be carefully fine-tuned to keep the Higgs mass at an acceptable value of at most a one hundred GeV. The problem above is known as *hierarchy problem*. In order to solve this problem, there are a number of scenarios where the quadratic divergences of the Higgs boson are cancelled by means of new heavy particles. The most famous one is the supersymmetric theory.

The Little Higgs models (LHM) have been proposed as alternative to solve the hierarchy problem [3]. These models are characterized by a set of global and gauge symmetries which are spontaneously broken to the Standard Model gauge group. In these models there is a set of new particles that play the role of partners of the SM gauge bosons and the SM fermions. These new particles contributions cancel the quadratic divergences to the Higgs boson mass, m_H , arising at one-loop from the exchange of SM particles. The most economical version of these models is called *Littlest Higgs model* [4]. The LH model is a nonlinear sigma model with a global symmetry under the $SU(5)$ group, the global symmetry is broken down to $SO(5)$ by a vacuum expectation value (VEV) f of the order of TeV's. Since the model should be an extension of the SM, the unbroken symmetry group should contain the $SU(2) \times U(1)$ group.

The LH model contain a lot of free parameters, below we list the relevant parameters for our calculation [5]:

- $SU(2)_H$ couplings: $\tan \theta = s/c = g_1/g_2$.
- $U(1)_H$ couplings: $\tan \theta' = s'/c' = g'_1/g'_2$.
- Scalar triplet VEV Φ : v' ($v' < v^2/4f$).
- Top partner mass m_T .

The particle content is presented in Table 1.

Particle	Spin	Squared mass
$\Phi^0, \Phi^P, \Phi^+, \Phi^-, \Phi^{++}, \Phi^{--}$	0	$\frac{2m_H^2 f^2}{v^2 \left[1 - \left(\frac{4v'f}{v^2} \right)^2 \right]}$
T	$\frac{1}{2}$	$\frac{v^2}{m_T^2} (\lambda_1 \lambda_2 f)^2$
A_H	1	$m_Z^2 s_W^2 \left(\frac{f^2}{5s'^2 c'^2 v^2} - 1 \right)$
Z_H	1	$m_W^2 \left(\frac{f^2}{s^2 c^2 v^2} - 1 \right)$
W_H^+, W_H^-	1	$m_W^2 \left(\frac{f^2}{s^2 c^2 v^2} - 1 \right)$

Table 1. The new particles predicted by the LH model.

3. The $Z_H \rightarrow \gamma H$ decay

At the tree level, the extra neutral gauge boson Z_H decay into γ and Higgs boson is absent in the theory. The process is induced at one-loop level. In this work we present a preliminary result of the branching ratio for the $Z_H \rightarrow \gamma H$ decay in the context of the LH model. We have

considered the main contributions at one-loop level coming from fermions, scalars and charged gauge bosons from the SM. The heavy masses of the particles previously mentioned are also considered. We can appreciate their contributions in Fig. 1.

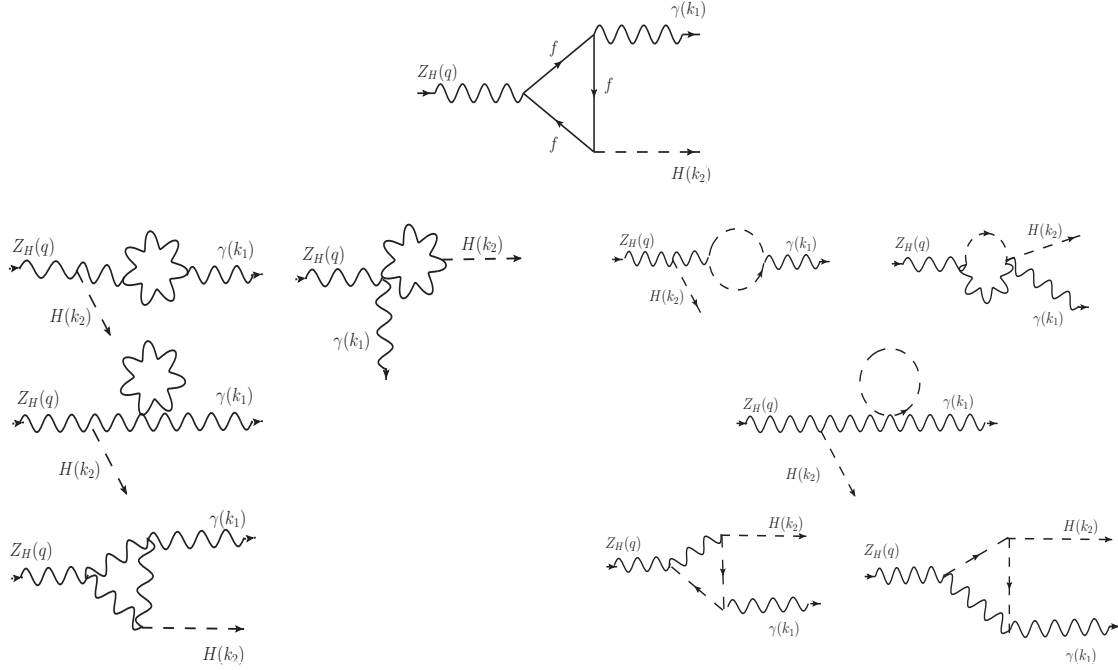


Figure 1. Feynman diagrams contributing to the $Z_H \rightarrow \gamma H$ decay at one-loop level in the LH model. (a) Fermionic contribution (solid lines). (b) Charged gauge bosons contribution (undulating lines). (c) Scalar contribution (dashed lines).

The associated decay amplitude is given by:

$$\mathcal{M}(Z_H \rightarrow \gamma H) = \mathcal{M}_T^{\mu\nu} \epsilon_\mu(q) \epsilon_\nu(k_1), \quad (1)$$

where

$$\mathcal{M}_T^{\mu\nu} = \mathcal{A}_T g^{\mu\nu} + \mathcal{B}_T \hat{k}_1^\mu \hat{q}^\nu, \quad (2)$$

being $\hat{k}_1 \equiv k_1/m_{Z_H}$ and $\hat{q} \equiv q/m_{Z_H}$. $\mathcal{M}_T^{\mu\nu}$ is the tensorial amplitude corresponding to three sets of Feynman diagrams shown in Fig. 1. The polarization vectors associated to the gauge bosons Z_H and γ are given by $\epsilon_\mu(q)$ and $\epsilon_\nu(k_1)$, respectively. The \mathcal{A}_T and \mathcal{B}_T form factors are given in terms of Passarino-Veltman scalar functions. Explicitly, $\mathcal{A}_T = \sum_f \mathcal{A}_f + \sum_{i=1}^3 \mathcal{A}_{G_i} + \sum_{i=1}^2 \mathcal{A}_{S_i}$ and $\mathcal{B}_T = \sum_f \mathcal{B}_f + \sum_{i=1}^3 \mathcal{B}_{G_i} + \sum_{i=1}^2 \mathcal{B}_{S_i}$. Here, f includes all charged fermions, G_i represents charged gauge bosons (W , W_H), and S_i symbolizes charged scalars (ϕ^+ , ϕ^- , ϕ^{++} and ϕ^{--}) [6]. The associated decay width is given by:

$$\Gamma(Z_H \rightarrow \gamma H) = \frac{\mathcal{A}_T^2 \left(1 - \frac{m_H^2}{m_{Z_H}^2}\right)}{8\pi m_{Z_H}}. \quad (3)$$

It is very important to mention that all the \mathcal{A}_i form factors in \mathcal{A}_T are free of ultraviolet divergences and the Lorentz structure in Eq. (2) satisfies the Ward identity $k_{1\nu} \mathcal{M}_T^{\mu\nu} = 0$. For

more details of the calculation and the corresponding numerical evaluation consult Ref. [6]. Preliminary results on the evaluation of the branching ratio for the $Z_H \rightarrow \gamma H$ decay tell us that around of $m_{Z_H} \sim 5$ TeV, the branching ratio is of the order of 10^{-5} .

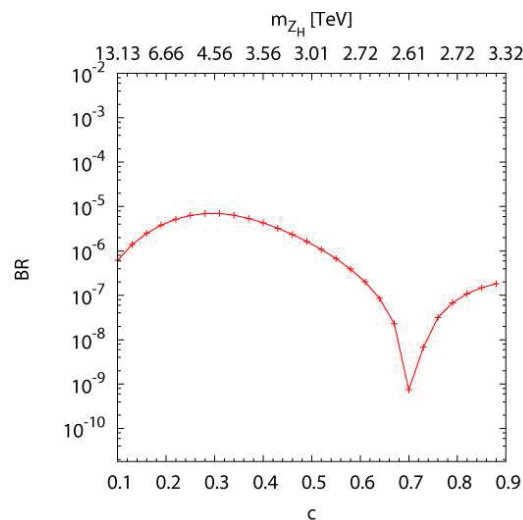


Figure 2. Branching ratio for the $Z_H \rightarrow \gamma H$ decay as a function of the c parameter for $f = 4$ TeV.

4. Conclusions

We have presented a brief description of the LH model, which predicts the existence of a new neutral massive gauge boson identified as the Z_H gauge boson. Since the existence of an extra neutral massive gauge boson is being tested at the LHC it provides one of many variants to study the presence of the Z_H gauge boson via the $Z_H \rightarrow \gamma H$ decay. The preliminary numerical analysis suggests that this process is suppressed as it has an associated branching ratio of the order of 10^{-5} at most.

Acknowledgments

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