

# The Higgs-like Bosons Couplings to Quarks

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**Abstract** The allowed and suppressed Higgs-like bosons couplings to quarks are identified. The relative ratios of strengths of allowed couplings are calculated. The latter is extremely important for experimentalists in the determination of the nature of the recently found Higgs boson and in the search for the charged Higgs-like bosons.

**Keywords** Higgs boson, Higgs-like bosons, Higgs couplings.

## 1. Introduction

In the quest for the predicted Higgs boson Atlas [1,2] and CMS [3] collaborations have found a light narrow resonance with a mass of about 126 GeV. This very important finding has also been supported by data from the Tevatron [4]. However, some properties of the newly found boson differ from those of the predicted Higgs boson. In particular, D0 and CDF collaborations have reported an excess of  $(A'_{FB})$  [5,6] which is the top quark forward-backward asymmetry, and also an increase in the  $Vb\bar{b}$  channel [4], while the LHC has observed an excess in the diphoton channel [7,8]. Moreover, a detailed fitting to the available data up to the end of 2012 [9] has shown that “In short, significant deviations from the SM values are preferred by the currently available data and should be considered viable”.

Therefore, it is very important to identify the Higgs couplings to quarks to determine the true nature of the recently found Higgs-like boson. On the other hand, theoretically, only SUSY models identify the Higgs boson couplings to quarks, as discussed in the article by Blum *et al.* [10]. Considering the work presented in reference [11], which presented Higgs-like bosons in the framework of a composite quark model, we identify all couplings of the Higgs-like bosons to quarks.

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## 2. Calculation of all Higgs-like bosons couplings to quarks

In order to make easier the understanding of the assignment of the Higgs-like bosons couplings to quarks I reproduce below Table 8 and Table 4 (without the 2<sup>nd</sup> column) from reference [11] which are now called Table 1 and Table 2, respectively.

**Table 1. The quantum numbers of the Higgs-like bosons**

	$H^0$	$H^+, H^-$
$\Sigma_3$	$\pm 1(s, b)$	$\pm 2(u)$
	$0(d)$	$\pm 1(c, t)$

**Table 2. Projections of the quantum number  $\Sigma_3$ .**

Primons	$\Sigma_3$
$p_1$	+1
$p_j$	-1
$(j = 2, 3, 4)$	0

The values of  $\Sigma_3$  for primons and quarks are discussed in detail in reference [11]. For example, the  $u$  quark has  $\Sigma_3 = 0$  and its primons  $p_1$  and  $p_2$  have  $\Sigma_3 = +1$  and  $\Sigma_3 = -1$ , respectively.

According to Table 1 the neutral Higgs-like boson  $H^0$  is a triplet in which each member belongs to one of three possible values of  $\Sigma_3$  which are  $-1, 0, +1$ . Because of this feature let us use a subscript for assigning the different values of  $\Sigma_3$ , and thus, there are  $H_0^0$  for the Higgs-like with  $\Sigma_3 = 0$ ,  $H_{-1}^0$  for the Higgs-like with  $\Sigma_3 = -1$ , and  $H_{+1}^0$  for the Higgs-like with  $\Sigma_3 = +1$ . For simplifying matters further, let us call both  $H_{+1}^0$  and  $H_{-1}^0$  by  $H_1^0$ . This way we can say that as a proton and a neutron exchange a pion by means of a strong interaction, primons  $p_2$  and  $p_4$  exchange a  $H_1^0$  and form quark  $s$ , yielding its mass, that is,

$$p_2 \xleftarrow{H_1^0} p_4.$$

According to the above reasoning, there are the charged bosons  $H_{+1}^+$ ,  $H_{-1}^+$ ,  $H_{+2}^+$ ,  $H_{-2}^+$  and also  $H_{+1}^-$ ,  $H_{-1}^-$ ,  $H_{+2}^-$ ,  $H_{-2}^-$ . We can simplify the notation and designate both  $H_{+1}^+$  and  $H_{-1}^+$  by  $H_1^+$  and  $H_{+2}^+$  and  $H_{-2}^+$  by  $H_2^+$ . And for each  $\Sigma_3$  we can drop the plus and minus signs and consider, for example, that the interaction of  $p_1$  and  $p_2$  by means of  $H_2$  produce the  $u$  quark, that is,

$$p_1 \xleftarrow{H_2} p_2.$$

This symbolizes

$$p_1 + H_{-2}^- = p_2$$

and

$$p_2 + H_{+2}^+ = p_1$$

which in terms of the electric charges are, respectively,

$$\frac{5}{6} + (-1) = -\frac{1}{6}$$

and

$$-\frac{1}{6} + (+1) = +\frac{5}{6}$$

and in terms of the  $\Sigma_3$  charges are, respectively,

$$+1 + (-2) = -1$$

and

$$-1 + (+2) = +1.$$

## 2.1 Interactions with equal quarks

Let us begin with the  $q_j q_j$  interactions. For example, the  $u$  quark is the combination  $p_1 p_2$ , and thus between two  $u$  quarks there are two interactions involving  $H_2$ . Between two  $d(p_2 p_3)$  quarks there are two interactions by means of  $H_0^0$ . Doing the same for the other quarks we obtain Table 3.

**Table 3. Interactions involving equal quarks.**

$q_j q_j$	Interacting bosons
$uu$	$2H_2$
$dd$	$2H_0^0$
$ss$	$2H_1^0$
$cc$	$2H_1$
$bb$	$2H_1^0$
$tt$	$2H_1$

## 2.2 Interactions between two different quarks

Since there are too many interactions between two different quarks, we classify them keeping one quark fixed, avoiding repetitions. For example, between quarks  $u(p_1 p_2)$  and  $d(p_2 p_3)$  there are interactions mediated by the bosons  $H_0^0, H_1$  and  $H_2$ . Doing the same for the other quarks we obtain Tables 4, 5, 6, 7 and 8.

**Table 4. Interactions involving the  $u$  quark.**

$q_i q_k$	Interacting bosons
$ud$	$H_0^0, H_1, H_2$
$us$	$H_1^0, H_1, H_2$
$uc$	$H_0^0, H_1, H_2$
$ub$	$H_0^0, H_1^0, 2H_1$
$ut$	$H_1^0, H_1, H_2$

**Table 5. Interactions involving the  $d$  quark, excluding  $ud$** 

$q_i q_k$	Interacting bosons
$ds$	$H_0^0, 2H_1^0$
$dc$	$H_0^0, H_1, H_2$
$db$	$H_0^0, 2H_1^0$
$dt$	$2H_1^0, H_1, H_2$

**Table 6. Interactions involving the  $s$  quark, excluding  $us$  and  $ds$ .**

$q_i q_k$	Interacting bosons
$sc$	$H_0^0, H_1^0, H_1, H_2$
$sb$	$H_0^0, 2H_1^0$
$st$	$H_1^0, H_1, H_2$

**Table 7. Interactions involving the  $c$  quark, excluding  $uc$ ,  $dc$  and  $sc$ .**

$q_i q_k$	Interacting bosons
$cb$	$H_1^0, 2H_1$
$ct$	$H_1^0, 2H_1$

**Table 8. Interaction involving the  $b$  quark, excluding  $ub, db, sb$  and  $bt$ .**

$q_i q_k$	Interacting bosons
$bt$	$H_1^0, 2H_1$

### 2.3 Most Intense Interactions with $H^0$

As we see from the above tables, the most intense interactions involving  $H^0$  are those of the  $b$  quark with the  $d$  quark and the  $s$  quark, and the interaction of the  $d$  quark with the  $s$  quark because they are mediated by one  $H_0^0$  and two  $H_1^0$ . This is an important result from the experimental point of view because we can compare one of these three interactions with an interaction mediated by only one  $H^0$ . For example, comparing the interaction  $s \leftrightarrow b$  with the interaction  $c \leftrightarrow b$ , we obtain a factor of 3 for the relative strength,

$$\frac{s \leftrightarrow b}{c \leftrightarrow b} = 3.$$

And we should also have the ratios

$$\frac{s \leftrightarrow b}{d \leftrightarrow b} = \frac{s \leftrightarrow b}{d \leftrightarrow s} = \frac{d \leftrightarrow b}{d \leftrightarrow s} = 1.$$

### 2.4 Medium Intensity Interactions with $H^0$

We obtain from the above tables, that there are interactions involving two  $H^0$ 's which are the interactions  $d \leftrightarrow d$ ,  $s \leftrightarrow s$ ,  $b \leftrightarrow b$ ,  $u \leftrightarrow b$ ,  $s \leftrightarrow c$  and  $d \leftrightarrow t$ . We can compare them with those of section 2.3 and obtain the important relation (just one of the several ratios)

$$\frac{s \leftrightarrow b}{b \leftrightarrow b} = \frac{3}{2} = 1.5.$$

And we should also have the ratios (just some of the ratios)

$$\frac{d \leftrightarrow d}{s \leftrightarrow s} = \frac{d \leftrightarrow d}{b \leftrightarrow b} = \frac{b \leftrightarrow b}{s \leftrightarrow s} = 1$$

$$\frac{u \leftrightarrow b}{s \leftrightarrow c} = \frac{u \leftrightarrow b}{d \leftrightarrow t} = \frac{s \leftrightarrow c}{d \leftrightarrow t} = 1$$

### 2.5 Less Intense Interactions with $H^0$

From the above tables we obtain that there are interactions involving just one  $H^0$  which are the interactions  $u \leftrightarrow d$ ,  $u \leftrightarrow s$ ,  $u \leftrightarrow c$ ,  $d \leftrightarrow c$ ,  $s \leftrightarrow t$ ,  $c \leftrightarrow b$ ,  $b \leftrightarrow t$ ,  $c \leftrightarrow t$  and  $u \leftrightarrow t$ . We can compare them with those of section 2.3 and 2.4 and obtain the important relation (just some of several ratios)

$$\frac{c \leftrightarrow b}{s \leftrightarrow b} = \frac{d \leftrightarrow c}{d \leftrightarrow b} = \frac{d \leftrightarrow c}{d \leftrightarrow s} = \frac{b \leftrightarrow t}{d \leftrightarrow b} = \frac{1}{3}.$$

And we should also have the ratios (just some of the ratios)

$$\frac{u \leftrightarrow d}{u \leftrightarrow c} = \frac{u \leftrightarrow s}{u \leftrightarrow c} = \frac{u \leftrightarrow c}{d \leftrightarrow c} = \frac{d \leftrightarrow c}{c \leftrightarrow b} = \frac{b \leftrightarrow t}{c \leftrightarrow t} = 1$$

## 2.6 Interactions without $H^0$

We also obtain from the above tables that there are exactly three suppressed interactions involving  $H^0$  which are the interactions  $u \leftrightarrow u$ ,  $c \leftrightarrow c$  and  $t \leftrightarrow t$ . This is an important prediction that can be experimentally tested.

## 2.7 Interactions with the Charged Bosons

With respect to the charged bosons we notice that there is no interaction involving three bosons, that is, the most intense interactions involve two charged bosons. There are 15 of these interactions that are listed on Table 9. It is important to observe that there are interactions that do not involve the charged bosons. These are the six interactions  $s \leftrightarrow b$ ,  $d \leftrightarrow b$ ,  $d \leftrightarrow s$ ,  $d \leftrightarrow d$ ,  $s \leftrightarrow s$  and  $b \leftrightarrow b$ .

**Table 9. Interactions involving 2 charged bosons.**

$q_i q_k$	Interacting bosons $H_1, H_2$
$ud$	$H_1, H_2$
$us$	$H_1, H_2$
$uc$	$H_1, H_2$
$ub$	$2H_1$
$ut$	$H_1, H_2$
$uu$	$2H_2$
$cc$	$2H_1$
$tt$	$2H_1$
$dc$	$H_1, H_2$
$dt$	$H_1, H_2$
$sc$	$H_1, H_2$
$st$	$H_1, H_2$
$cb$	$2H_1$
$ct$	$2H_1$
$bt$	$2H_1$

## 3. Conclusion

All couplings of the Higgs-like bosons to quarks are identified. With them we are able to indicate the relative strengths of the interactions among quarks as well as the suppressed interactions. A very important result is that the search for the charged Higgs-like bosons should not involve

the interactions  $s \leftrightarrow b$ ,  $d \leftrightarrow b$ ,  $d \leftrightarrow s$ ,  $d \leftrightarrow d$ ,  $s \leftrightarrow s$  and  $b \leftrightarrow b$  because they are suppressed for the charged Higgs-like bosons.

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