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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 $\left(A_{FB}^{t}\right)$ [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.

2. Calculation of all Higgs-like Bosons Couplings to Quarks

The calculation is based on the quark compositeness model described in detail in reference[11]. The model considers that each quark is composed of two primons (prequarks) and, thus, we need 4 primons to describe the 6 quarks. It is assumed that primons should have the baryon number B=1/6, of course. As to electric charges p_1 has charge equal to +5/6 and primons p_2, p_3, p_4 have each charge equal to -1/6. Using the modified Gell-Mann and Nishijima relation

$$Q = 2B + \frac{1}{2}\left(P_1 + P_2 + P_3 + P_4\right) \tag{1}$$

for a system of primons (a quark), where, $P_1 = +1$, for primon p_1, and $P_j = -1$ $(j = 2,3,4)$ for the other primons, we obtain,

$$\frac{2}{3} = 2\times\left(\frac{1}{6}+\frac{1}{6}\right)+\frac{1}{2}\left(1+(-1)\right) \tag{2}$$

for quarks u,c,t, and

$$-\frac{1}{3} = 2\times\left(\frac{1}{6}+\frac{1}{6}\right)+\frac{1}{2}\left(-1+(-1)\right) \tag{3}$$

for quarks d,s,b.

As quarks quarks u and d have isospins equal to $+1/2$ and $-1/2$, respectively, we have to have $I_3 = \pm 1/4$ for primons, p_1, p_2 and p_3. Using the modified Gell-Mann—Nishijima relation

$$Q = I_3 + \frac{1}{2}\left(B + \Sigma_3\right) \tag{4}$$

for primons, we obtain

$$\frac{5}{6} = \frac{1}{4}+\frac{1}{2}\left(\frac{1}{6}+1\right) \tag{5}$$

for primon p_1, and

$$\begin{aligned} -\frac{1}{6} &= \frac{1}{4}+\frac{1}{2}\left(\frac{1}{6}+(-1)\right) \\ -\frac{1}{6} &= -\frac{1}{4}+\frac{1}{2}\left(\frac{1}{6}+0\right) \end{aligned} \tag{6}$$

for p_2, p_3 and p_4 assuming that p_4 has also

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$I_3 = \pm 1/4$. Therefore, Σ_3 can assume the values $-1, 0$ and $+1$ and, thus, these values can be considered as the projections of $\Sigma = 1$ (Table 1).

Table 1. Projections of the isospin I and of the quantum number Σ

	I_3	Σ_3
p_1	$+\frac{1}{4}$	$+1$
p_j	$+\frac{1}{4}$	-1
$(j = 2,3,4)$	$-\frac{1}{4}$	0

In terms of Σ and Σ_3 a quark has the four possible states $\left|\Sigma, \Sigma_3\right\rangle$ (described in detail in ref.[11]):

$$\boxed{\begin{array}{l} c,t : \left|1,+1\right\rangle \\ \;d : \left|1,0\right\rangle \quad u : \left|0,0\right\rangle \\ s,b : \left|1,-1\right\rangle \end{array}}$$

Organizing the values of I_3 and Σ_3 for quarks on a table we obtain Table 2 below.

Table 2. Assignments of the values of I_3 and Σ_3 for quarks

	I_3	Σ_3
c,t	0	$+1$
u	$+1/2$	0
d	$-1/2$	0
s,b	0	-1

Taking into account the charges of primons and the assignments of Σ_3 for primons from Table 1 we obtain that there should exist the Higgs-like bosons H^0, H^+, H^- for generating quark masses, as shown on Table 3 below.

Table 3. The generators of quark masses

Quark	Mass (GeV)	Charge	Higgs-like boson
$u(p_1 p_2)$	0.3	$+2/3$	H^+, H^-
$c(p_1 p_3)$	1.5	$+2/3$	H^+, H^-
$t(p_1 p_4)$	170	$+2/3$	H^+, H^-
$d(p_2 p_3)$	0.3	$-1/3$	H^0
$s(p_2 p_4)$	0.5	$-1/3$	H^0
$b(p_3 p_4)$	4.5	$-1/3$	H^0

With the values of Σ_3 for quarks from Table 2 and making use of the Higgs-like bosons identifications in terms of the quarks we obtain Table 4 below.

Table 4. The quantum numbers of the Higgs-like bosons

	H^0	H^+, H^-
Σ_3	$\pm 1(s,b)$	$\pm 2(u)$
	$0(d)$	$\pm 1(c,t)$

According to Table 4 the neutral Higgs-like boson H^0 is a triplet in which each member belongs to one of three possible values of Σ_3 which are $-1, 0, +1$. Because of this feature let us use a subscript for assigning the different values of Σ_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,

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

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 Σ_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,

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

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 Σ_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 5.

Table 5. Interactions involving equal quarks

$q_j q_j$	Interacting bosons
uu	$2H_2$
dd	$2H^0_0$
ss	$2H^0_1$
cc	$2H_1$
bb	$2H^0_1$
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 6, 7, 8, 9 and 10.

Table 6. Interactions involving the u quark

$q_j q_k$	Interacting bosons
ud	H^0_0, H_1, H_2
us	H^0_1, H_1, H_2
uc	H^0_0, H_1, H_2
ub	$H^0_0, H^0_1, 2H_1$
ut	H^0_1, H_1, H_2

Table 7. Interactions involving the d quark, excluding ud

$q_j q_k$	Interacting bosons
ds	$H^0_0, 2H^0_1$
dc	H^0_0, H_1, H_2
db	$H^0_0, 2H^0_1$
dt	$2H^0_1, H_1, H_2$

Table 8. Interactions involving the s quark, excluding us and ds

$q_j q_k$	Interacting bosons
sc	H^0_0, H^0_1, H_1, H_2
sb	$H^0_0, 2H^0_1$
st	H^0_1, H_1, H_2

Table 9. Interactions involving the c quark, excluding uc, dc and sc

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

Table 10. Interaction involving the b quark, excluding ub, db, sb and bt

$q_j q_k$	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 11. 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 11. Interactions involving 2 charged bosons

$q_j q_k$	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. Conclusions

All couplings of the Higgs-like bosons to quarks have been identified. With them we are able to evaluate 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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