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Erratum: Hunting for vectorlike quarks

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We found a mistake (involving a sign and factor of $\sqrt{2}$) which propagates through tables 2–5 and several equations presented in the appendix. The two lower panels of figure 1 are mildly modified while all other numerical results are unaffected. In tables 3–5 we adopt a more useful parameterization for the branching ratios in the case of a vectorlike quark doublet with couplings to H_u and H_d .

Corrected versions of tables 2–5.

$\frac{64\pi}{m_{t_4}} \Gamma$	doublet	singlet	$\frac{64\pi}{m_{b_4}} \Gamma$	doublet	singlet
$t_4 \rightarrow W^+ b$	$2\lambda_Q^2 c_\beta^2$	$2\kappa_T^2 s_\beta^2$	$b_4 \rightarrow W^+ t$	$2\kappa_Q^2 s_\beta^2$	$2\lambda_B^2 c_\beta^2$
$t_4 \rightarrow Z t$	$\kappa_Q^2 s_\beta^2$	$\kappa_T^2 s_\beta^2$	$b_4 \rightarrow Z b$	$\lambda_Q^2 c_\beta^2$	$\lambda_B^2 c_\beta^2$
$t_4 \rightarrow h t$	$\kappa_Q^2 s_\beta^2$	$\kappa_T^2 s_\beta^2$	$b_4 \rightarrow h b$	$\lambda_Q^2 c_\beta^2$	$\lambda_B^2 c_\beta^2$
$t_4 \rightarrow H t$	$\kappa_Q^2 c_\beta^2$	$\kappa_T^2 c_\beta^2$	$b_4 \rightarrow H b$	$\lambda_Q^2 s_\beta^2$	$\lambda_B^2 s_\beta^2$
$t_4 \rightarrow H^+ b$	$2\lambda_Q^2 s_\beta^2$	$2\kappa_T^2 c_\beta^2$	$b_4 \rightarrow H^+ t$	$2\kappa_Q^2 c_\beta^2$	$2\lambda_B^2 s_\beta^2$

Table 2. Leading dependence of the t_4 and b_4 decay widths on the Lagrangian parameters in the large mass limit. We use the shorthand notation $s_\beta = \sin \beta$ and $c_\beta = \cos \beta$.

	Couplings to H_u only		Couplings to H_d only		Couplings to H_u and H_d	
	doublet	singlet	doublet	singlet	doublet	singlet
$\text{BR}(t_4 \rightarrow W^+ b)$	0	1/2	1	0	$(1-x) \frac{1}{1+x(t_\beta^2-1)}$	1/2
$\text{BR}(t_4 \rightarrow Z t)$	1/2	1/4	0	0	$\frac{x}{2} \frac{t_\beta^2}{1+x(t_\beta^2-1)}$	1/4
$\text{BR}(t_4 \rightarrow h t)$	1/2	1/4	0	0	$\frac{x}{2} \frac{t_\beta^2}{1+x(t_\beta^2-1)}$	1/4
$\text{BR}(b_4 \rightarrow W^+ t)$	1	0	0	1/2	$x \frac{t_\beta^2}{1+x(t_\beta^2-1)}$	1/2
$\text{BR}(b_4 \rightarrow Z b)$	0	0	1/2	1/4	$\frac{1-x}{2} \frac{1}{1+x(t_\beta^2-1)}$	1/4
$\text{BR}(b_4 \rightarrow h b)$	0	0	1/2	1/4	$\frac{1-x}{2} \frac{1}{1+x(t_\beta^2-1)}$	1/4

Table 3. Vectorlike quark branching ratios in the Goldstone boson equivalence limit. When couplings to both H_u and H_d are present the branching ratios are functions of $t_\beta = \tan \beta$ and $x = \kappa_Q^2 / (\kappa_Q^2 + \lambda_Q^2)$.

	Couplings to H_u only		Couplings to H_d only		Couplings to H_u and H_d	
	doublet	singlet	doublet	singlet	doublet	singlet
$\text{BR}(t_4 \rightarrow W^+b)$	0	$\frac{2t_\beta^2}{4t_\beta^2+1}$	1	0	$\frac{2(1-x)}{2+x(2t_\beta^2-1)}$	$\frac{2t_\beta^2}{4t_\beta^2+1}$
$\text{BR}(t_4 \rightarrow Zt)$	$\frac{t_\beta^2}{2t_\beta^2+1}$	$\frac{t_\beta^2}{4t_\beta^2+1}$	0	0	$\frac{xt_\beta^2}{2+x(2t_\beta^2-1)}$	$\frac{t_\beta^2}{4t_\beta^2+1}$
$\text{BR}(t_4 \rightarrow ht)$	$\frac{t_\beta^2}{2t_\beta^2+1}$	$\frac{t_\beta^2}{4t_\beta^2+1}$	0	0	$\frac{xt_\beta^2}{2+x(2t_\beta^2-1)}$	$\frac{t_\beta^2}{4t_\beta^2+1}$
$\text{BR}(t_4 \rightarrow Ht)$	$\frac{1}{2t_\beta^2+1}$	$\frac{1}{4t_\beta^2+1}$	0	0	$\frac{x}{2+x(2t_\beta^2-1)}$	$\frac{1}{4t_\beta^2+1}$
$\text{BR}(b_4 \rightarrow W^+t)$	1	0	0	$\frac{2}{t_\beta^2+4}$	$\frac{2xt_\beta^2}{t_\beta^2+2+x(t_\beta^2-2)}$	$\frac{2}{t_\beta^2+4}$
$\text{BR}(b_4 \rightarrow Zb)$	0	0	$\frac{1}{t_\beta^2+2}$	$\frac{1}{t_\beta^2+4}$	$\frac{1-x}{t_\beta^2+2+x(t_\beta^2-2)}$	$\frac{1}{t_\beta^2+4}$
$\text{BR}(b_4 \rightarrow hb)$	0	0	$\frac{1}{t_\beta^2+2}$	$\frac{1}{t_\beta^2+4}$	$\frac{1-x}{t_\beta^2+2+x(t_\beta^2-2)}$	$\frac{1}{t_\beta^2+4}$
$\text{BR}(b_4 \rightarrow Hb)$	0	0	$\frac{t_\beta^2}{t_\beta^2+2}$	$\frac{t_\beta^2}{t_\beta^2+4}$	$\frac{(1-x)t_\beta^2}{t_\beta^2+2+x(t_\beta^2-2)}$	$\frac{t_\beta^2}{t_\beta^2+4}$

Table 4. Branching ratios of the vectorlike quarks t_4 and b_4 into W , Z , h and H as a function of $t_\beta = \tan \beta$ and $x = \kappa_Q^2/(\kappa_Q^2 + \lambda_Q^2)$. These expressions are an excellent approximation for heavy vectorlike masses and in the limit in which the couplings in table 2 dominate.

	Couplings to H_u only		Couplings to H_d only		Couplings to H_u and H_d	
	doublet	singlet	doublet	singlet	doublet	singlet
$\text{BR}(t_4 \rightarrow W^+b)$	0	$\frac{2t_\beta^2}{4t_\beta^2+2}$	$\frac{1}{t_\beta^2+1}$	0	$\frac{1-x}{1-x+t_\beta^2}$	$\frac{2t_\beta^2}{4t_\beta^2+2}$
$\text{BR}(t_4 \rightarrow Zt)$	1/2	$\frac{t_\beta^2}{4t_\beta^2+2}$	0	0	$\frac{x}{2} \frac{t_\beta^2}{1-x+t_\beta^2}$	$\frac{t_\beta^2}{4t_\beta^2+2}$
$\text{BR}(t_4 \rightarrow ht)$	1/2	$\frac{t_\beta^2}{4t_\beta^2+2}$	0	0	$\frac{x}{2} \frac{t_\beta^2}{1-x+t_\beta^2}$	$\frac{t_\beta^2}{4t_\beta^2+2}$
$\text{BR}(t_4 \rightarrow H^+b)$	0	$\frac{2}{4t_\beta^2+2}$	$\frac{t_\beta^2}{t_\beta^2+1}$	0	$\frac{(1-x)t_\beta^2}{1-x+t_\beta^2}$	$\frac{2}{4t_\beta^2+2}$
$\text{BR}(b_4 \rightarrow W^+t)$	$\frac{t_\beta^2}{t_\beta^2+1}$	0	0	$\frac{2}{2t_\beta^2+4}$	$\frac{xt_\beta^2}{1+xt_\beta^2}$	$\frac{2}{2t_\beta^2+4}$
$\text{BR}(b_4 \rightarrow Zb)$	0	0	1/2	$\frac{1}{2t_\beta^2+4}$	$\frac{1-x}{2} \frac{1}{1+xt_\beta^2}$	$\frac{1}{2t_\beta^2+4}$
$\text{BR}(b_4 \rightarrow hb)$	0	0	1/2	$\frac{1}{2t_\beta^2+4}$	$\frac{1-x}{2} \frac{1}{1+xt_\beta^2}$	$\frac{1}{2t_\beta^2+4}$
$\text{BR}(b_4 \rightarrow H^+t)$	$\frac{1}{t_\beta^2+1}$	0	0	$\frac{2t_\beta^2}{2t_\beta^2+4}$	$\frac{x}{1+xt_\beta^2}$	$\frac{2t_\beta^2}{2t_\beta^2+4}$

Table 5. Branching ratios of the vectorlike quarks t_4 and b_4 into W , Z , h and $H^\pm$ as a function of $t_\beta = \tan \beta$ and $x = \kappa_Q^2/(\kappa_Q^2 + \lambda_Q^2)$. These expressions are an excellent approximation for heavy vectorlike masses and in the limit in which the couplings in table 2 dominate.

Bottom two panels of figure 1.

Correct version of several equations.

$$\begin{pmatrix} G \\ A \end{pmatrix} = \begin{pmatrix} \cos \beta & \sin \beta \\ -\sin \beta & \cos \beta \end{pmatrix} \begin{pmatrix} \sqrt{2}(\text{Im} H_d^0) \\ \sqrt{2}(-\text{Im} H_u^0) \end{pmatrix}. \quad (\text{A.40})$$

$$\begin{aligned} \mathcal{L}_A = & -\frac{i}{\sqrt{2}} \bar{u}_L V_L^{u\dagger} Y_u^A V_R^u \hat{u}_R (-A \cos \beta) \\ & -\frac{i}{\sqrt{2}} \bar{d}_L V_L^{d\dagger} Y_d^A V_R^d \hat{d}_R (-A \sin \beta) + \text{h.c.}, \end{aligned} \quad (\text{A.54})$$

$$\lambda_{u_a u_b}^A = -i \cos \beta (V_L^{u\dagger} Y_u^A V_R^u)_{ab}, \quad (\text{A.57})$$

$$\begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix} = \begin{pmatrix} \cos \beta & \sin \beta \\ -\sin \beta & \cos \beta \end{pmatrix} \begin{pmatrix} H_d^\pm \\ -H_u^\pm \end{pmatrix}. \quad (\text{A.60})$$

$$\begin{aligned} \mathcal{L}_{H^\pm} = & -\bar{u}_L V_L^{u\dagger} Y_d^{H^\pm} V_R^d \hat{d}_R H^+ \\ & -\bar{d}_L V_L^{d\dagger} Y_u^{H^\pm} V_R^u \hat{u}_R H^- + \text{h.c.}, \end{aligned} \quad (\text{A.61})$$

$$Y_u^{H^\pm} = -\cos \beta \begin{pmatrix} y_t & 0 & \kappa_T \\ \kappa_Q & 0 & \kappa \\ 0 & \bar{\lambda} \tan \beta & 0 \end{pmatrix} \quad \text{and} \quad Y_d^{H^\pm} = -\sin \beta \begin{pmatrix} y_b & 0 & \lambda_B \\ \lambda_Q & 0 & \lambda \\ 0 & \bar{\kappa} / \tan \beta & 0 \end{pmatrix}. \quad (\text{A.62})$$

$$\mathcal{L}_{H^\pm} = -\bar{u}_{La} \lambda_{u_a d_b}^{H^\pm} \hat{d}_{Rb} H^+ - \bar{d}_{La} \lambda_{d_a u_b}^{H^\pm} \hat{u}_{Rb} H^- + \text{h.c.}, \quad (\text{A.63})$$

$$\begin{aligned}\lambda_{t_4 b}^{H^\pm} = & -\sin\beta \cdot \left[y_b(V_L^u)^\dagger_{43}(V_R^d)_{33} + \lambda_B(V_L^u)^\dagger_{43}(V_R^d)_{53} + \lambda_Q(V_L^u)^\dagger_{44}(V_R^d)_{33} + \lambda(V_L^u)^\dagger_{44}(V_R^d)_{53} \right] \\ & - \cos\beta \bar{\kappa}(V_L^u)^\dagger_{45}(V_R^d)_{43},\end{aligned}\quad (\text{A.66})$$

$$\begin{aligned}\lambda_{bt_4}^{H^\pm} = & -\cos\beta \cdot \left[y_t(V_L^d)^\dagger_{33}(V_R^u)_{34} + \kappa_T(V_L^d)^\dagger_{33}(V_R^u)_{54} + \kappa_Q(V_L^d)^\dagger_{34}(V_R^u)_{34} + \kappa(V_L^d)^\dagger_{34}(V_R^u)_{54} \right] \\ & - \sin\beta \cdot \bar{\lambda}(V_L^d)^\dagger_{35}(V_R^u)_{44},\end{aligned}\quad (\text{A.67})$$

$$\begin{aligned}\lambda_{b_4 t}^{H^\pm} = & -\cos\beta \cdot \left[y_t(V_L^d)^\dagger_{43}(V_R^u)_{33} + \kappa_T(V_L^d)^\dagger_{43}(V_R^u)_{53} + \kappa_Q(V_L^d)^\dagger_{44}(V_R^u)_{33} + \kappa(V_L^d)^\dagger_{44}(V_R^u)_{53} \right] \\ & - \sin\beta \cdot \bar{\lambda}(V_L^d)^\dagger_{45}(V_R^u)_{43},\end{aligned}\quad (\text{A.68})$$

$$\begin{aligned}\lambda_{tb_4}^{H^\pm} = & -\sin\beta \cdot \left[y_b(V_L^u)^\dagger_{33}(V_R^d)_{34} + \lambda_B(V_L^u)^\dagger_{33}(V_R^d)_{54} + \lambda_Q(V_L^u)^\dagger_{34}(V_R^d)_{34} + \lambda(V_L^u)^\dagger_{34}(V_R^d)_{54} \right] \\ & - \cos\beta \bar{\kappa}(V_L^u)^\dagger_{35}(V_R^d)_{44}.\end{aligned}\quad (\text{A.69})$$

$$\begin{aligned}\Gamma(t_i \rightarrow H^\pm b_j) = & \frac{m_{t_i}}{32\pi} \sqrt{\lambda\left(1, \frac{m_{H^\pm}^2}{m_{t_i}^2}, \frac{m_{b_j}^2}{m_{t_i}^2}\right)} \left\{ \left(|\lambda_{t_i b_j}^{H^\pm}|^2 + |\lambda_{b_j t_i}^{H^\pm}|^2 \right) \left(1 + \frac{m_{b_j}^2 - m_{H^\pm}^2}{m_{t_i}^2} \right) \right. \\ & \left. + 2 \left((\lambda_{t_i b_j}^{H^\pm})^* \lambda_{b_j t_i}^{H^\pm} + \lambda_{t_i b_j}^{H^\pm} (\lambda_{b_j t_i}^{H^\pm})^* \right) \frac{m_{b_j}}{m_{t_i}} \right\}.\end{aligned}\quad (\text{A.74})$$

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