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Flavour-changing decays of a 125 GeV Higgs-like particle

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Summary. — We study possible flavour-violating couplings of a 125 GeV Higgs boson. We consider all the constraints from low-energy flavour processes and we find that some lepton-flavour–violating Higgs decays are in the reach of LHC.

PACS `12.60.Fr` – Extensions of electroweak Higgs sector.
PACS `12.15.Mm` – Neutral currents.

1. – Introduction

The LHC experiments ATLAS and CMS have reported indications of an apparent excess of events compatible with the Higgs boson with a mass around 125 GeV. If this signal is confirmed it will be very important to understand its nature through the study of all its couplings. In particular within the SM, flavour-changing decays of the Higgs are expected to be strongly suppressed and well beyond the LHC reach, but in many New Physics models relatively large flavour-changing couplings are possible. Therefore we explore the possible existence and the allowed magnitudes of flavour-changing couplings of a neutral 125 GeV scalar particle h, looking for possible deviations from SM predictions.

2. – Effective Lagrangian and bounds in the quark sector

In this paper we adopt a phenomenological bottom-up approach, considering the following effective Lagrangian to describe the possible flavour-changing couplings of a neutral scalar boson h to SM quarks and leptons:

$$(1)\qquad \mathcal{L}_{\text{eff}} = \sum_{i,j=d,s,b\,(i\neq j)} c_{ij}\,\bar{d}^i_L d^j_R h + \sum_{i,j=u,c,t\,(i\neq j)} c_{ij}\,\bar{u}^i_L u^j_R h + \sum_{i,j=e,\mu,\tau\,(i\neq j)} c_{ij}\,\bar{\ell}^i_L \ell^j_R h.$$

The field h can be identified with the physical Higgs boson of the SM or, more generally, with a mass eigenstate resulting from the mixing of other scalar fields present in the underlying theory with the SM Higgs (if it exists).

TABLE I. – *Bounds on combinations of the flavour-changing h couplings defined in* (1) *obtained from $\Delta F = 2$ processes* [2], *assuming that $m_h = 125\,\text{GeV}$.*

Operator	Eff. couplings	95% CL Bound		Observables
		$\lvert c_{\text{eff}}\rvert$	$\lvert\text{Im}(c_{\text{eff}})\rvert$	
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	$c_{sd}\; c^*_{ds}$	1.1×10^{-10}	4.1×10^{-13}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)^2$, $(\bar{s}_L d_R)^2$	c^2_{ds}, c^2_{sd}	2.2×10^{-10}	0.8×10^{-12}	
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	$c_{cu}\; c^*_{uc}$	0.9×10^{-9}	1.7×10^{-10}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)^2$, $(\bar{c}_L u_R)^2$	c^2_{uc}, c^2_{cu}	1.4×10^{-9}	2.5×10^{-10}	
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	$c_{bd}\; c^*_{db}$	0.9×10^{-8}	2.7×10^{-9}	Δm_{B_d}; $S_{B_d \to \psi K}$
$(\bar{b}_R\, d_L)^2$, $(\bar{b}_L d_R)^2$	c^2_{db}, c^2_{bd}	1.0×10^{-8}	3.0×10^{-9}	
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	$c_{bs}\; c^*_{sb}$	2.0×10^{-7}	2.0×10^{-7}	Δm_{B_s}
$(\bar{b}_R\, s_L)^2$, $(\bar{b}_L s_R)^2$	c^2_{sb}, c^2_{bs}	2.2×10^{-7}	2.2×10^{-7}	

In the quark sector, strong bounds on all the effective couplings in (1) involving light quarks (*i.e.*, excluding the top) can be derived from the tree-level contributions to meson-antimeson mixing. The derived limits, shown in table I, forbid any flavour-changing decay of the h into a pair of quarks with a branching ratio exceeding 10^{-3}. The $\Delta F = 1$ bounds from B decays, as shown in table II of [1], are also very strong, *if* the flavour-diagonal couplings of the h are the same as the SM Yukawa couplings.

3. – Bounds in the lepton sector

In the lepton sector we do not have an analogous of the $\Delta F = 2$ constraints, leaving more room for sizeable non-standard contributions.

TABLE II. – *Bounds from charged-lepton-flavour-violating decays* [3].

Operator	Eff. couplings	Bound	Constraint
$(\bar{\mu}_R\, e_L)(\bar{q}_L q_R)$, $(\bar{\mu}_L\, e_R)(\bar{q}_L q_R)$	$\lvert c_{\mu e}\rvert^2$, $\lvert c_{e\mu}\rvert^2$	3.0×10^{-8}	$\mathcal{B}_{\mu\to e}(\text{Ti}) < 4.3 \times 10^{-12}$
$(\bar{\tau}_R\, e_L)(\bar{\mu}_L e_R)$, $(\bar{\tau}_L\, e_R)(\bar{\mu}_L e_R)$	$\lvert c_{\mu e} c^*_{e\tau}\rvert$, $\lvert c_{\mu e} c_{\tau e}\rvert$	0.9×10^{-4}	$\Gamma(\tau \to \bar{\mu} e e) < 1.5 \times 10^{-8}$
$(\bar{\tau}_R\, e_L)(\bar{\mu}_R e_L)$, $(\bar{\tau}_L\, e_R)(\bar{\mu}_R e_L)$	$\lvert c^*_{e\mu} c^*_{e\tau}\rvert$, $\lvert c^*_{e\mu} c_{\tau e}\rvert$		
$(\bar{\tau}_R\, \mu_L)(\bar{e}_L \mu_R)$, $(\bar{\tau}_L\, \mu_R)(\bar{e}_L \mu_R)$	$\lvert c_{e\mu} c^*_{\mu\tau}\rvert$, $\lvert c_{e\mu} c_{\tau\mu}\rvert$	1.0×10^{-4}	$\Gamma(\tau \to \bar{e} \mu\mu) < 1.7 \times 10^{-8}$
$(\bar{\tau}_R\, \mu_L)(\bar{e}_R \mu_L)$, $(\bar{\tau}_L\, \mu_R)(\bar{e}_R \mu_L)$	$\lvert c^*_{\mu e} c^*_{\mu\tau}\rvert$, $\lvert c^*_{\mu e} c_{\tau\mu}\rvert$		

Table III. – *Bounds from one loop LFV processes* [3]

Eff. couplings	Bound	Constraint
$\lvert c_{e\tau}c_{\tau e}\rvert$ ($\lvert c_{e\mu}c_{\mu e}\rvert$)	1.1×10^{-2} (1.8×10^{-1})	$\lvert\delta m_e\rvert < m_e$
$\lvert\mathrm{Re}(c_{e\tau}c_{\tau e})\rvert$ ($\lvert\mathrm{Re}(c_{e\mu}c_{\mu e})\rvert$)	0.6×10^{-3} (0.6×10^{-2})	$\lvert\delta a_e\rvert < 6\times10^{-12}$
$\lvert\mathrm{Im}(c_{e\tau}c_{\tau e})\rvert$ ($\lvert\mathrm{Im}(c_{e\mu}c_{\mu e})\rvert$)	0.8×10^{-8} (0.8×10^{-7})	$\lvert d_e\rvert < 1.6\times10^{-27}\ e\,\mathrm{cm}$
$\lvert c_{\mu\tau}c_{\tau\mu}\rvert$	2	$\lvert\delta m_\mu\rvert < m_\mu$
$\lvert\mathrm{Re}(c_{\mu\tau}c_{\tau\mu})\rvert$	2×10^{-3}	$\lvert\delta a_\mu\rvert < 4\times10^{-9}$
$\lvert\mathrm{Im}(c_{\mu\tau}c_{\tau\mu})\rvert$	0.6	$\lvert d_\mu\rvert < 1.2\times10^{-19}\ e\,\mathrm{cm}$
$\lvert c_{e\tau}c_{\tau\mu}\rvert$, $\lvert c_{\tau e}c_{\mu\tau}\rvert$	1.7×10^{-7}	$\mathcal{B}(\mu\to e\gamma) < 2.4\times10^{-12}$
$\lvert c_{\mu\tau}\rvert^2$, $\lvert c_{\tau\mu}\rvert^2$	0.9×10^{-2} [*]	$\mathcal{B}(\tau\to\mu\gamma) < 4.4\times10^{-8}$
$\lvert c_{e\tau}\rvert^2$, $\lvert c_{\tau e}\rvert^2$	0.6×10^{-2} [*]	$\mathcal{B}(\tau\to e\gamma) < 3.3\times10^{-8}$

We start by analyzing the tree-level contributions of h to lepton-flavour–violating (LFV) decays of charged leptons and to $\mu\to e$ conversion in nuclei. In most cases bounds can be derived only with the assumption that the flavour-diagonal couplings are the SM Yukawas, $c_{\ell\ell} = y_\ell \equiv \frac{\sqrt{2}m_\ell}{v}$, even if this must not be the case in general. This leads to the limits reported in table II. As it can be seen, all the bounds except that derived from $\mu\to e$ conversion are quite weak.

Next we proceed to analyze one-loop-induced amplitudes. We consider logarithmically-divergent corrections to the lepton masses δm_ℓ [1], that in absence of fine tuning we expect $|\delta m_\ell| < m_\ell$. The most significant bounds thus derived, setting the cut-off $\Lambda = 1\,\mathrm{TeV}$, are reported in table III. In the same table are also shown the limits from the anomalous magnetic moments, $a_\ell = (g_\ell - 2)/2$ and the electric dipole moments, d_l [1]. As can be seen, with the exception of the bound from the electron edm, which can easily be evaded assuming real couplings, the limits are still rather weak. Radiative one loop LFV decays [1] are more constraining and in particular the strong and model-independent bound from $\mu\to e\gamma$ prevents the $h\bar{\tau}\mu$ and $h\bar{\tau}e$ couplings to be both large at the same time, table III. Finally we consider the bounds coming from two-loop diagrams of Barr-Zee type, with a top-quark loop, in table 5 of [1].

4. – Higgs decays

For a Higgs boson with $m_h = 125\,\mathrm{GeV}$ we get

$$\mathcal{B}(h\to f_i\bar{f}_j) \approx 3.1\times10^2\times N_f\left(|c_{ij}|^2 + |c_{ji}|^2\right), \tag{2}$$

where $N_q = 3$ and $N_\ell = 1$. In the quark sector, in the most favourable case we get $\mathcal{B}(h\to b\bar{s},\,\bar{b}s) < 4\times10^{-4}$, which is beyond the reach of the LHC. However, the situation is much more favourable in the lepton sector, where we obtain that $\mathcal{B}(h\to\tau\bar{\mu},\,\bar{\tau}\mu)$ or $\mathcal{B}(h\to\tau\bar{e},\,\bar{\tau}e)$ can be of order 10% (the last case only if negligible CP-violating phases are assumed). The strong bounds which come from $\mu\to e\gamma$ and $\mu\to e$ conversion forbid detectable branching ratios for the clean μe modes and the possibility of observing both the two decays in $\tau\mu$ and τe

In conclusion at LHC LFV Higgs decays are possible and are comparable to the expected branching ratio for $h \to \tau^+\tau^-$ in the SM, which is already close to the sensitivity of the experiments. We therefore urge our experimental colleagues to make dedicated searches for these interesting flavour-violating decays of the possible h particle with mass 125 GeV.

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