Flavour-Changing Decays of a 125 GeV Higgs-like Particle

Based on: G.B., J. Ellis, G.Isidori arXiv:1202.5704

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IFAE 2012 - Incontri di Fisica delle Alte Energie

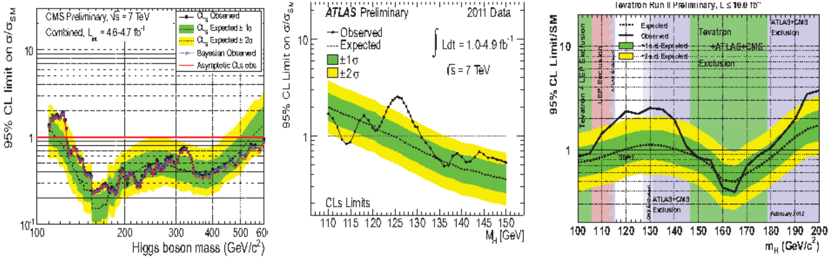
Outline

1. The Higgs boson
   - Experimental situation
   - Higgs and flavor
2. Flavor changing Higgs couplings
   - Low energy bounds
   - Higgs decay at LHC

Hints for the Higgs Boson

After winter conferences **several hints** for Higgs boson from ATLAS, CMS, CDF and D0

- excess in many channels: $h \to \gamma\gamma$, $h \to WW$, $h \to ZZ$, $h \to b\bar{b}$, $h \to \tau\bar{\tau}$

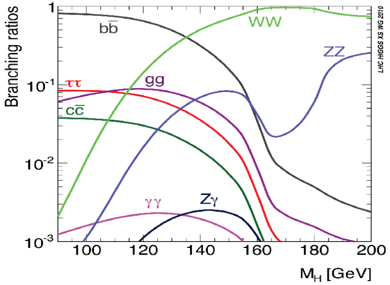


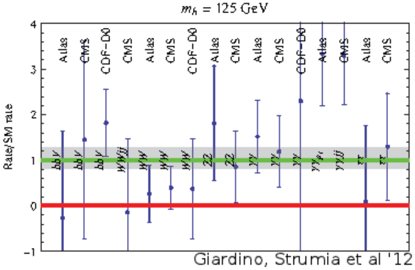
Excluded region: $122.5 < M_H < 127.5$ GeV

Is it the Standard Model Higgs?

Discovering the properties

125 GeV Higgs is a particularly fortunate value for the LHC, because **many decay channels** are open for that mass





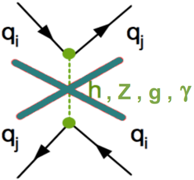
It is possible to test the Higgs in many channels and to **check if it** is exactly as in the **SM**

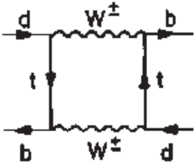
Higgs and flavor in the SM

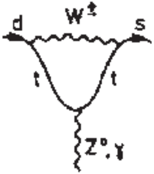
Standard Model Higgs couplings to fermions

$$\left(\overline{\psi}^{i}_{u} Y^{ij}_{u} \psi^{j}_{u} + \overline{\psi}^{i}_{d} Y^{ij}_{d} \psi^{j}_{d} + \overline{\psi}^{i}_{e} Y^{ij}_{e} \psi^{j}_{e}\right) \frac{v + h}{\sqrt{2}} \qquad (1)$$

$\rightarrow$ when you diagonalize masses you **diagonalize Higgs-fermion** interactions



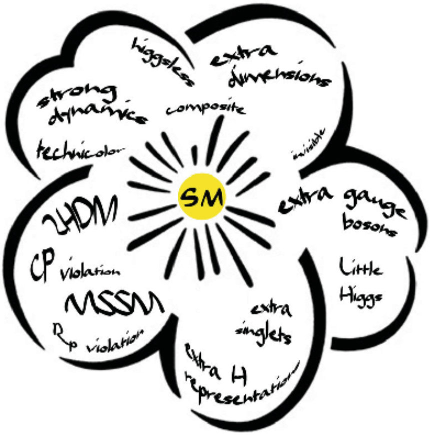




Flavor Changing Neutral Currents are very suppressed

- loop suppressed
- mass (GIM) suppressed
- CKM suppressed

Higgs and flavor Beyond the SM



S. Kraml et al., CERN-2006-009, hep-ph/0608079

Many **BSM models** predict **Flavor Changing** Higgs couplings

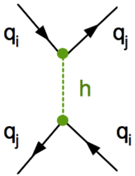
- multi Higgs dublets model (eg 2HDM in non decoupling limit)
- pseudo-dilaton (Goldberger et al '07)
- composite Higgs in which Yukawa are function of the Higgs field (Giudice et al '08)
- ...

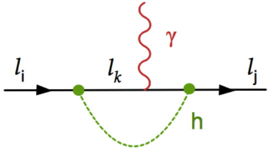
Flavor Changing Higgs

Effective Flavor Changing Higgs couplings

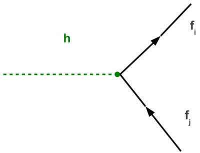
$$\mathcal{L}_{\text{eff}} = \sum_{i,j=d,s,b(i\neq j)} c_{ij}\, \bar{d}_L^i d_R^j h + \sum_{i,j=u,c,t(i\neq j)} c_{ij}\, \bar{u}_L^i u_R^j h + \sum_{i,j=e,\mu,\tau(i\neq j)} c_{ij}\, \bar{\ell}_L^i \ell_R^j h \quad (2)$$

Which are the FC Higgs couplings **allowed** by the data?





Is it possible to observe a FC Higgs decay at LHC?



Quark sector

Bounds from $\Delta F = 2$ processes

$m_h = 125$ GeV

Operator	Eff. couplings	95% C.L. Bound $\lvert c_{eff}\rvert$	95% C.L. Bound $\lvert Im(c_{eff})\rvert$	Observables
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	$c_{sd}\, c^*_{ds}$	1.1×10^{-10}	4.1×10^{-13}	$\Delta m_K;\ \epsilon_K$
$(\bar{s}_R d_L)^2,\ (\bar{s}_L d_R)^2$	$c^2_{ds},\ c^2_{sd}$	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}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{c}_R u_L)^2,\ (\bar{c}_L u_R)^2$	$c^2_{uc},\ c^2_{cu}$	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}	$\Delta m_{B_d};\ S_{B_d \to \psi K}$
$(\bar{b}_R d_L)^2,\ (\bar{b}_L d_R)^2$	$c^2_{db},\ c^2_{bd}$	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}	

+ similar bounds from rare B decays ($B \to \mu^+\mu^-$)

Bounds on FC Higgs coupling very strong:

it is impossible to see at LHC a FC Higgs decay into quarks

Lepton sector: tree level

Three body decays and $\mu \to e$ conversion in nuclei

$m_h = 125$ GeV

Operator	Eff. couplings	Bound	Constraint
$(\bar{\mu}_R e_L)(\bar{q}_L q_R)$, ...	$\lvert c_{\mu e}\rvert^2$, $\lvert c_{e\mu}\rvert^2$	3.0×10^{-8} [*]	$\mathcal{B}_{\mu\to e}(\mathrm{Ti}) < 4.3 \times 10^{-12}$
$(\bar{\tau}_R \mu_L)(\bar{\mu}_L \mu_R)$, ... $(\bar{\tau}_R e_L)(\bar{\mu}_L \mu_R)$, ...	$\lvert c_{\tau\mu}\rvert^2$, $\lvert c_{\mu\tau}\rvert^2$ $\lvert c_{\tau e}\rvert^2$, $\lvert c_{e\tau}\rvert^2$	2.0×10^{-1} [*] 4.8×10^{-1} [*]	$\Gamma(\tau \to \mu\bar{\mu}\mu) < 2.1 \times 10^{-8}$ $\Gamma(\tau \to e\bar{\mu}\mu) < 2.7 \times 10^{-8}$
$(\bar{\tau}_R e_L)(\bar{\mu}_L e_R)$, ... $(\bar{\tau}_R e_L)(\bar{\mu}_R e_L)$, ...	$\lvert c_{\mu e} c^*_{e\tau}\rvert$, $\lvert c_{\mu e} c_{\tau e}\rvert$ $\lvert c^*_{e\mu} c^*_{e\tau}\rvert$, $\lvert c^*_{e\mu} c_{\tau e}\rvert$	0.9×10^{-4}	$\Gamma(\tau \to \bar{\mu} e e) < 1.5 \times 10^{-8}$
$(\bar{\tau}_R \mu_L)(\bar{e}_L \mu_R)$, ... $(\bar{\tau}_R \mu_L)(\bar{e}_R \mu_L)$, ...	$\lvert c_{e\mu} c^*_{\mu\tau}\rvert$, $\lvert c_{e\mu} c_{\tau\mu}\rvert$ $\lvert c^*_{\mu e} c^*_{\mu\tau}\rvert$, $\lvert c^*_{\mu e} c_{\tau\mu}\rvert$	1.0×10^{-4}	$\Gamma(\tau \to \bar{e}\mu\mu) < 1.7 \times 10^{-8}$

- ... $\to$ other possible operators of the same type but with different chiral structures
- [*] $\to$ assuming diagonal couplings as in the SM $\to c_{\ell\ell} = y_\ell \equiv \frac{\sqrt{2} m_\ell}{v}$

Lepton sector: 1 loop

- logarithmically-divergent **corrections to the lepton masses**

$$\delta m_\ell = \frac{1}{(4\pi)^2} \sum_{j \neq \ell} c_{\ell j} c_{j\ell} m_j \log\left(\frac{m_h^2}{\Lambda^2}\right) \quad \rightarrow \quad |\delta m_\ell| < m_\ell \tag{3}$$

- **anomalous magnetic moments** and **electric diapole moments**

$$|\delta a_\ell| = \frac{4 m_\ell^2}{m_h^2} \frac{1}{(4\pi)^2} \sum_{j \neq \ell} \mathrm{Re}(c_{\ell j} c_{j\ell}) \frac{m_j}{m_\ell} \left(\log \frac{m_h^2}{m_j^2} - \frac{3}{2}\right), \tag{4}$$

$$|d_\ell| = \frac{2 m_\ell}{m_h^2} \frac{e}{(4\pi)^2} \sum_{j \neq \ell} \mathrm{Im}(c_{\ell j} c_{j\ell}) \frac{m_j}{m_\ell} \left(\log \frac{m_h^2}{m_j^2} - \frac{3}{2}\right) \tag{5}$$

- **Lepton Flavor Violating decays**

$$\Gamma(l_i \to l_j \gamma) = m_i^3 \frac{e^2}{16\pi} (|A_{ij}^L|^2 + |A_{ij}^R|^2) \tag{6}$$

with coefficients

$$|A_{\mu e}^R| = \frac{1}{(4\pi)^2} |c_{e\tau} c_{\tau\mu}| \frac{m_\tau}{m_h^2} \left(\log \frac{m_h^2}{m_\tau^2} - \frac{3}{2}\right), \quad |A_{\mu e}^L| \text{ for } c_{ij} \to c_{ji} \tag{7}$$

$$|A_{\tau\ell}^R| = \frac{1}{(4\pi)^2} |c_{\ell\tau}| y_\tau \frac{m_\tau}{m_h^2} \left(\log \frac{m_h^2}{m_\tau^2} - \frac{4}{3}\right), \quad |A_{\tau\ell}^L| \text{ for } c_{ij} \to c_{ji} \tag{8}$$

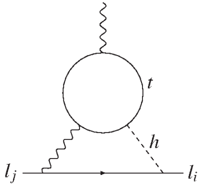
Lepton sector: 1 loop

$m_h = 125$ GeV

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})	$\lvert d_e\rvert < 1.6\times10^{-27}$ ecm
$\lvert c_{\mu\tau}c_{\tau\mu}\rvert$	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	$\lvert d_\mu\rvert < 1.2\times10^{-19}$ ecm
$\lvert c_{e\tau}c_{\tau\mu}\rvert$, $\lvert c_{\tau e}c_{\mu\tau}\rvert$	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} [*]	$\mathcal{B}(\tau\to e\gamma) < 3.3\times10^{-8}$

Lepton sector: 2 loops

Loop suppressed but proportional to only one lepton **Yukawa (enanched)**



Eff. couplings	Bound	Constraint
$\|c_{e\mu}\|^2$, $\|c_{\mu e}\|^2$	1×10^{-11} [*]	$\mathcal{B}(\mu \to e\gamma) < 2.4 \times 10^{-12}$
$\|c_{\mu\tau}\|^2$, $\|c_{\tau\mu}\|^2$	5×10^{-4} [*]	$\mathcal{B}(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$
$\|c_{e\tau}\|^2$, $\|c_{\tau e}\|^2$	3×10^{-4} [*]	$\mathcal{B}(\tau \to e\gamma) < 3.3 \times 10^{-8}$

$m_h = 125$ GeV

Conclusions

Higgs FC decay

$$\frac{\mathcal{B}(h \to f_i \bar{f}_j)}{\mathcal{B}(h \to \tau\bar{\tau})} \approx N_f \times \frac{|c_{ij}|^2 + |c_{ji}|^2}{2y_\tau^2} = 0.48 \times 10^4 \times N_f \left(|c_{ij}|^2 + |c_{ji}|^2\right) \quad (9)$$

- $\mathcal{B}(h \to q_i q_j) < \mathcal{B}(h \to b\bar{s},\ \bar{s}b) < 4 \times 10^{-4}$
- $\mathcal{B}(h \to \tau\bar{\mu} + \bar{\mu}\tau) \to \mathcal{O}(10\%)$
  - CPV phases can be even $O(1)$
  - not unnatural couplings needed ($|c_{\mu\tau}|, |c_{\tau\mu}| \lesssim y_\tau$)
  - if $|c_{e\tau(\tau e)}/c_{\mu\tau(\tau\mu)}| < 10^{-2}$
- $\mathcal{B}(h \to \tau\bar{e} + \bar{e}\tau) \to \mathcal{O}(10\%)$
  - if neglgleble CPV phases (edms)
  - if $|c_{\mu\tau(\tau\mu)}/c_{e\tau(\tau e)}| < 10^{-2}$
- the two before not togheter ($\mu \to e\gamma$)
- $\mathcal{B}(h \to \bar{\mu}e + e\bar{\mu}) < 3 \times 10^{-9}$ ($\mu \to e$ conversion and $\mu \to e\gamma$)

To our experimental collegue:

consider these dedicated searches!!

Thank you for the attention