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Efectos de Nueva física en el autoacoplamiento hhh inducido por fermiones espejos del MHP+T

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BUAP, 23 de mayo de 2016

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INTRODUCTION

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

CMS Collaboration *

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Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

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$\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012.

A R T I C L E I N F O

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A B S T R A C T

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV

$H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$

HIGGS PHYSICS

Higgs Decay modes at LHC

Direct measurement

$h^0 \to ZZ^* \to 4\ell$

$h^0 \to \gamma\gamma^* \to 4\ell$

ATLAS, Phys.Lett. B 716, 1 (2012) $m_h = 126.0 \pm 0.4 \pm 0.4 GeV$

ATLAS, Phys.Rev.D 90, 052004 (2014) $m_h = 125.36 \pm 0.41 GeV$

CMS, Phys.Rev.Lett. 114 191803 (2015) $m_h = 125.09 \pm 0.21 \pm 0.11 GeV$

$h^0 \to WW^* \to \nu\ell\nu\ell$ *CMS, Phys.Lett.B 716, 30 (2012)* $m_h = 125.3 \pm 0.4 \pm 0.5 GeV$

$\ell = e, \mu$

$h^0 \to \tau\tau,\ \tau \to \ell\nu\bar{\nu},\ \tau \to had. + \bar{\nu}$

CMS, Nature Phys. 10 557 (2014) $m_h = 125 GeV$

ATLAS, JHEP 1504, 117 (2015) $m_h = 125.36 GeV$

$h^0 \to b\bar{b}$

ATLAS, JHEP **1501**, 069 (2015) $m_h = 125.36 GeV$

CMS, Phys.Rev.D 92 032008 (2015) $m_h = 125 GeV$

Upper bound

$h^0 \to \mu\mu$ *ATLAS, Phys.Lett.B 738, 68 (2014)* $m_h = 125 GeV$

$h^0 \to \mu\mu(ee)$ *CMS, Phys.Rev.D 92 032008 (2015)* $m_h = 120 - 150 GeV$

$h^0 \to Z\gamma \quad Z \to \ell\ell$

ATLAS, Phys.Lett.B 732, 8 (2014) $m_h = 120 - 150 GeV$

CMS, Phys.Lett.B 753 341 (2016) $m_h = 125 GeV$

HIGGS PHYSICS

Higgs Decay modes at LHC

Direct measurement

$h^0 \to ZZ^* \to 4\ell$

$h^0 \to \gamma\gamma^* \to 4\ell$

$h^0 \to WW^* \to \nu\ell\nu\ell$

$\ell = e, \mu$

$h^0 \to \tau\tau, \quad \tau \to \ell\nu\bar{\nu}, \quad \tau \to had. + \bar{\nu}$

$h^0 \to b\bar{b}$

Upper bound

$h^0 \to \mu\mu$

$h^0 \to \mu\mu(ee)$

$h^0 \to Z\gamma \quad Z \to \ell\ell$

"Τηε δατα αρε φουνδ το βε χομπατιβλε ωιτη τηε Σταν δαρδ Μοδελ εξπεχτατιονσ φορ α Ηιγγσ βοσον ατ α μασσ οφ 125.36 Γες… Τογετηερ τηεψ αχχουντ φορ αππροξιματελψ 88 % οφ αλλ δεχαψσ οφ α ΣΜ Ηιγγσ βοσον." *ATLAS,* Eur. Phys. J. C (2016) 76:6

Exploring electroweak symmetry breaking at the LHC.

$$\mathcal{L}_{ME+h} = \mathcal{L}_{Fermionic} + \mathcal{L}_{Gauge} - V(\Phi)$$

Higgs self-couplings

$$V(\Phi) = -\lambda v^2 \Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2$$
$$= \lambda v^2 h^2 + \lambda v h^3 + \tfrac{1}{4}\lambda h^4$$

Higgs Decay modes at LHC

Direct measurement

$$h^0 \to ZZ^* \to 4\ell$$
$$h^0 \to \gamma\gamma^* \to 4\ell$$
$$h^0 \to WW^* \to \nu\ell\nu\ell$$
$$\ell = e, \mu$$

$$h^0 \to \tau\tau, \quad \tau \to \ell\nu\bar{\nu}, \quad \tau \to had. + \bar{\nu}$$
$$h^0 \to b\bar{b}$$

Upper bound

$$h^0 \to \mu\mu$$
$$h^0 \to \mu\mu(ee)$$
$$h^0 \to Z\gamma \quad Z \to \ell\ell$$

"Τηε δατα αρε φουνδ το βε χομπατιβλε ωιτη τηε Σταν δαρδ Μοδελ εξπεχτατιονσ φορ α Ηιγγσ βοσον ατ α μασσ οφ 125.36 Γες… Τογετηερ τηεψ αχχουντ φορ αππροξιματελψ 88 % οφ αλλ δεχαψσ οφ α ΣΜ Ηιγγσ βοσον." *ATLAS*, Eur. Phys. J. C (2016) 76:6

Exploring electroweak symmetry breaking at the LHC.

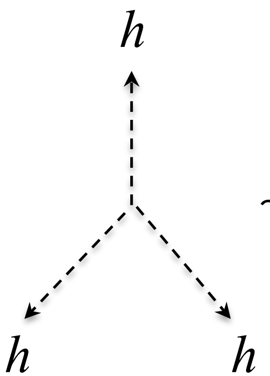
"Σεαρχηεσ φορ βοτη ρεσοναντ ανδ νονρεσοναντ Ηιγγσ βοσον παιρ προδυχτιον… Νο εϖιδενχε οφ τηειρ προδυχτιον ισ οβσερϖεδ" *ATLAS, Phys. Rev. D 92, 092004 (2015)*

Higgs self-couplings

$$V(\Phi) = -\lambda v^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2$$
$$= \lambda v^2 h^2 + \boxed{\lambda v h^3} + \tfrac{1}{4}\lambda h^4$$

HHH AT ONE LOOP LEVEL IN SM

Self-coupling *hhh* at tree and one loop level in SM

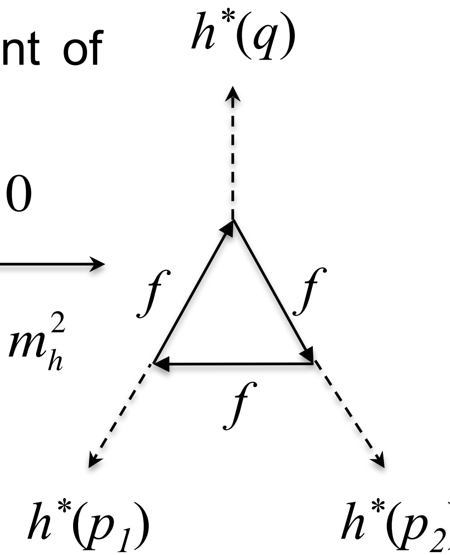


At tree level the self-coupling hhh is independent of the higgs bosons 4-momentum.

$$\sim \frac{3m_h^2}{v}$$

$$q + p_1 + p_2 = 0$$

$$q^2 \neq p_1^2 \neq p_2^2 \neq m_h^2$$



At one loop level and with off-shell Higgs, we need more driagram to satisfy the Bose symmetry.

$$+\begin{pmatrix} q \\ p_1 \rightleftarrows p_2 \end{pmatrix} + \begin{pmatrix} q \rightleftarrows p_1 \\ p_2 \end{pmatrix} + \begin{pmatrix} q \rightleftarrows p_2 \\ p_1 \end{pmatrix} + \begin{pmatrix} p_1 \rightleftarrows p_2 \\ q \rightleftarrows p_1 \end{pmatrix} + \begin{pmatrix} p_1 \rightleftarrows p_2 \\ q \rightleftarrows p_2 \end{pmatrix}$$

$$= \Gamma_{h^* h^* h^*}(q^2, p_1^2, p_2^2) = \frac{3m_h^2}{v}\lambda_{hhh}$$

Here $\lambda_{\eta\eta\eta}$ is the correction to self-coupling hhh.

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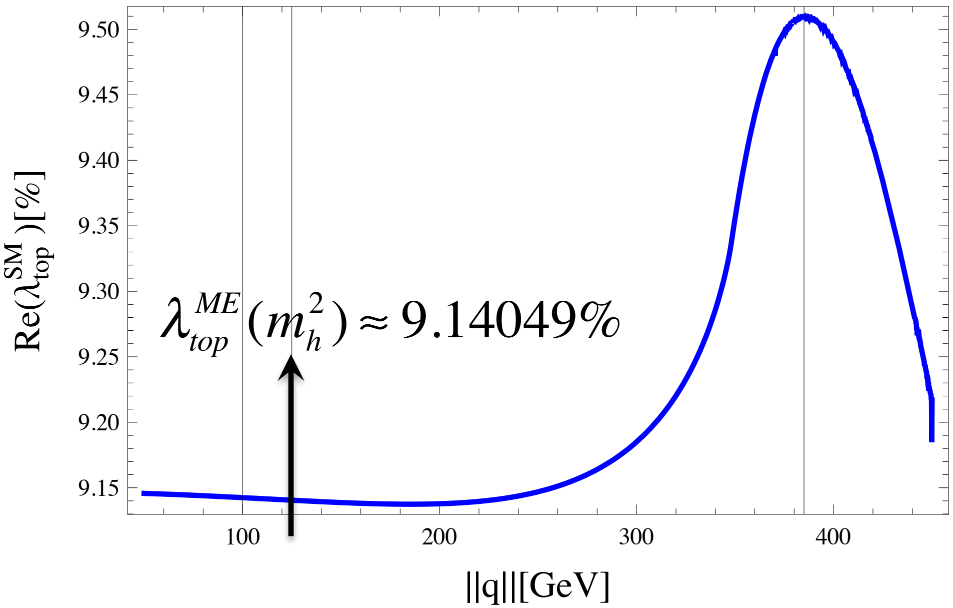
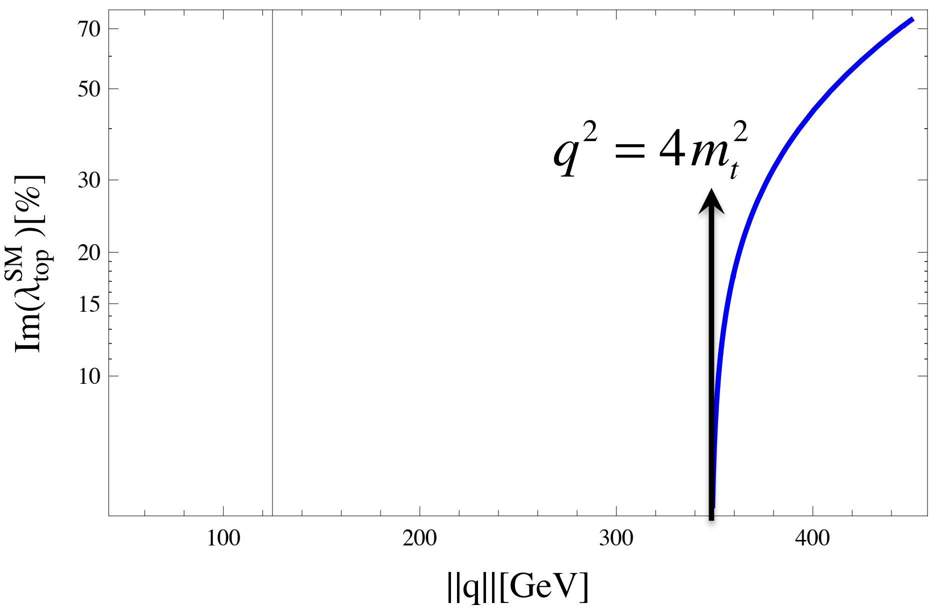
HHH AT ONE LOOP LEVEL IN SM

Self-coupling *hhh* at tree and one loop level in SM

The leading one loop contribution of the top quark to self-coupling is derived as:

$$\lambda_t^{ME}(q^2) = \frac{g m_t^2 s_t^2 N_c}{3! 16\pi^2 m_W^2}\left[18 - \int_{x=0}^{1}\int_{y=0}^{1-x} \Xi_t^{ME}(x,y,s_t,s_q)\,dxdy\right]$$





Previous results:

$\lambda_{top}^{ME}(m_h^2) \approx 9.14693\%$ *Phys. Lett. B558, 157 (2003)*

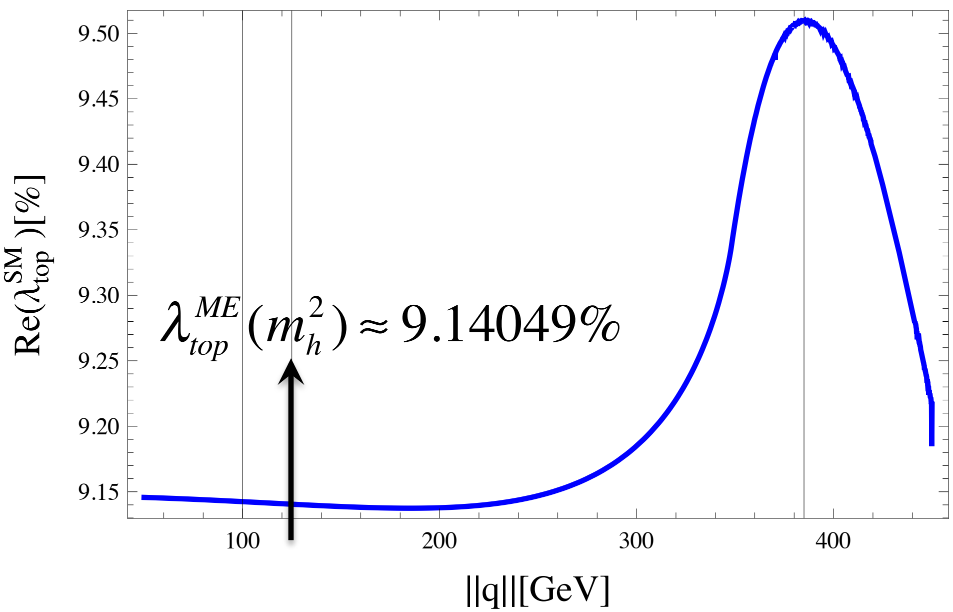
$\lambda_{top}^{ME}(m_h^2) \approx 9.8221\%$ *Eur. Phys. J. C23, 163 (2002)*

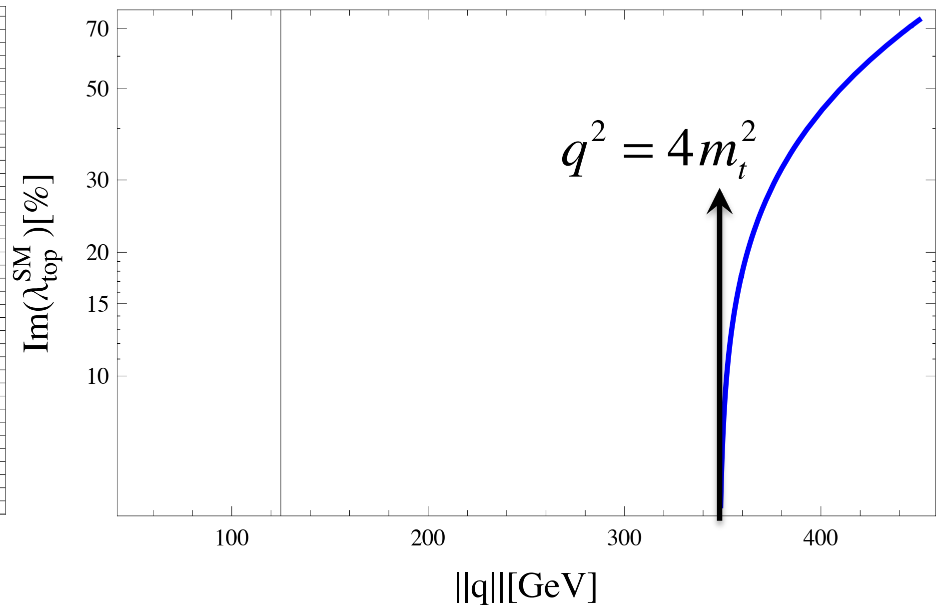
HHH AT ONE LOOP LEVEL IN SM

Self-coupling *hhh* at tree and one loop level in SM

The leading one loop contribution of the top quark to self-coupling is derived as:

$$\lambda_t^{ME}(q^2) = \frac{g m_t^2 s_t^2 N_c}{3!16\pi^2 m_W^2}\left[18 - \int_{x=0}^{1}\int_{y=0}^{1-x} \Xi_t^{ME}(x,y,s_t,s_q)dxdy\right]$$





Another contributions:

$$\lambda_b^{ME}(m_h^2) \approx 3.4\times10^{-6}\% + i6.4\times10^{-9}\%$$

$$\lambda_\tau^{ME}(m_h^2) \approx 2.5\times10^{-8}\% + i7.9\times10^{-12}\%$$

$$\lambda_{Z+W}^{ME}(m_h^2) \approx 0.0726\%$$

$$\lambda_h^{ME}(m_h^2) \approx 1.8397\%$$

LITTLEST HIGGS MODEL WITH T-PARITY

Main ideas

1.- Little higgs models are based on a collective symmetry breaking pattern.

$$\text{(Global)}\ SU(5) \xrightarrow{f \sim O(TeV)} SO(5)$$

$$\text{(Gauged)}\ [SU(2)_1 \otimes U(1)_1] \otimes [SU(2)_2 \otimes U(1)_2] \longrightarrow SU(2) \otimes U(1) \xrightarrow{v_{SM}} U(1)_{EM}$$

2.- There are 14 Goldstone bosons, and are parametrized by a nonlinear sigma model.

3.- After the first symmetry breaking there are four heavy gauge boson: Z_H, A_H, $W_H^{\pm}$.

4.- After the second symmetry breaking we have the SM fields, and seven additional scalars fields.

5.- The LHM had an alternative to hierarchy problem.

6.- The heavy photon is a dark matter candidate. *Phys. Rev. D 88, 075018 (2013)*

7.- A natural way to define the action of T-parity on the gauge fields is:

$$W^a_{1\mu} \leftrightarrow W^a_{2\mu} \qquad B^a_{1\mu} \leftrightarrow B^a_{2\mu}$$

8.- The constraints from Higgs couplings results from the 8 TeV run at the LHC … exclude *f* up to 694 GeV. *JHEP02 (2014) 053*

LITTLEST HIGGS MODEL WITH T-PARITY

Mirror fermions

1.- Little higgs models are based on a collective symmetry breaking pattern.

$$\text{(Global)}\; SU(5) \xrightarrow{f\sim O(TeV)} SO(5)$$

$$\text{(Gauged)}\; [SU(2)_1\otimes U(1)_1]\otimes[SU(2)_2\otimes U(1)_2] \longrightarrow SU(2)\otimes U(1) \xrightarrow{v_{SM}} U(1)_{EM}$$

For each SM $SU(2)_L$ fermion doublet, a fermion doublet under $SU(2)_1$ another under $SU(2)_2$ are introduced. The T-parity even linear combination is associated with the SM, while the T-odd combination is given a mass of order the scale *f*.

The mirror fermion acquire mass through the SU(5) and T invariant Yukawa interaction.

$$\mathcal{L}_{mirror} = -\kappa_{ii} f(\bar{\Psi}^i_2\xi + \bar{\Psi}^i_1\Sigma_0\Omega\xi^\dagger\Omega)\Psi^i_R$$

Then the masses and the Higgs coupling for the u mirror quark and the mirror neutrino are.

$$m_{\ell_H} = m_{d_H} = \sqrt{2}\kappa_{ii} f$$

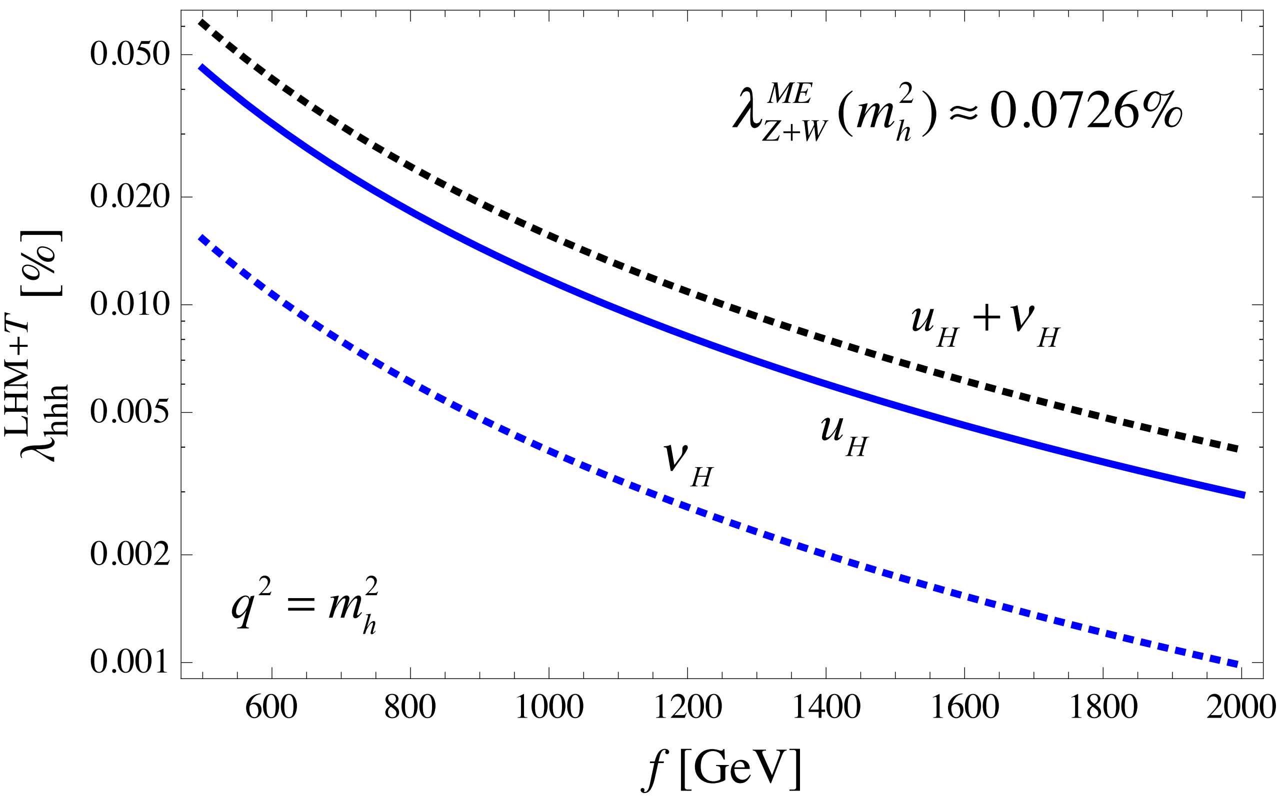
$$m_{\nu_H} = m_{u_H} = \sqrt{2}\kappa_{ii} f\left(1-\frac{v^2}{8f^2}\right)$$

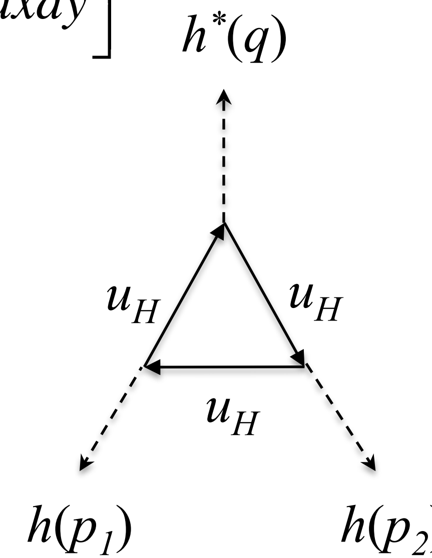
d_H and l_H do not have direct couplings with the Higgs boson.

$$h\bar{u}_H u_H \sim h\bar{\nu}_H\nu_H \sim \frac{i\kappa_{ii}}{2\sqrt{2}}\left(\frac{v}{f}\right)$$

HHH AT ONE LOOP IN LHM WITH T-PARITY

$$\lambda_{u_H,\nu_H}^{LHM+T}(q^2) = \frac{N_c \kappa_{ii}^2 m_{u_H,\nu_H} m_W}{3\pi^2 2^{\frac{11}{2}} 3! g m_h^2} \frac{v^3}{f^3}\left[18 - \int_{x=0}^{1}\int_{y=0}^{1-x} \Xi_{u_H}^{ME}(x,y,s_{u_H,\nu_H},s_q)dxdy\right]$$





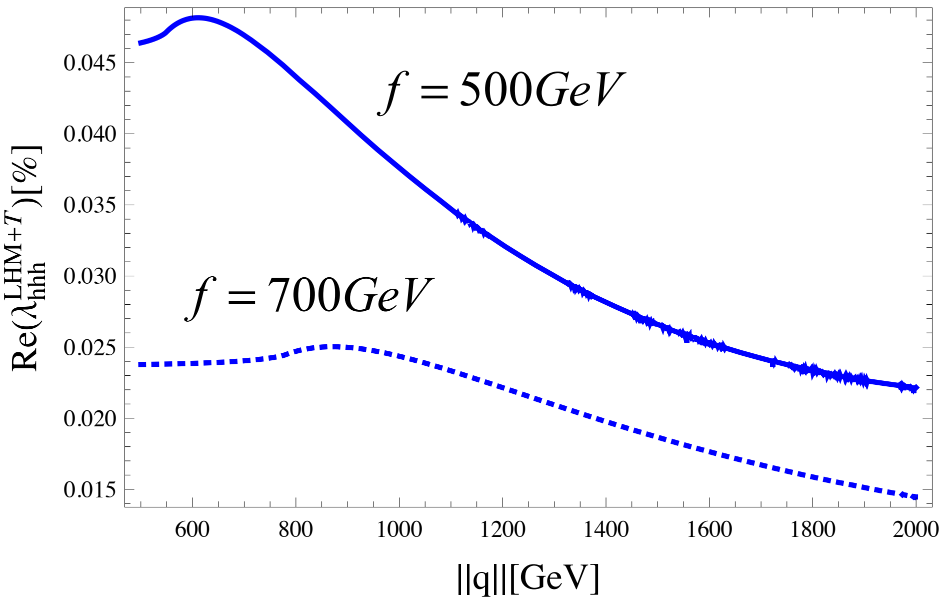
Making the decay $q_H \text{-->} V_H q$ kinematically allowed, this corresponds to κ_{ii}>0.45.

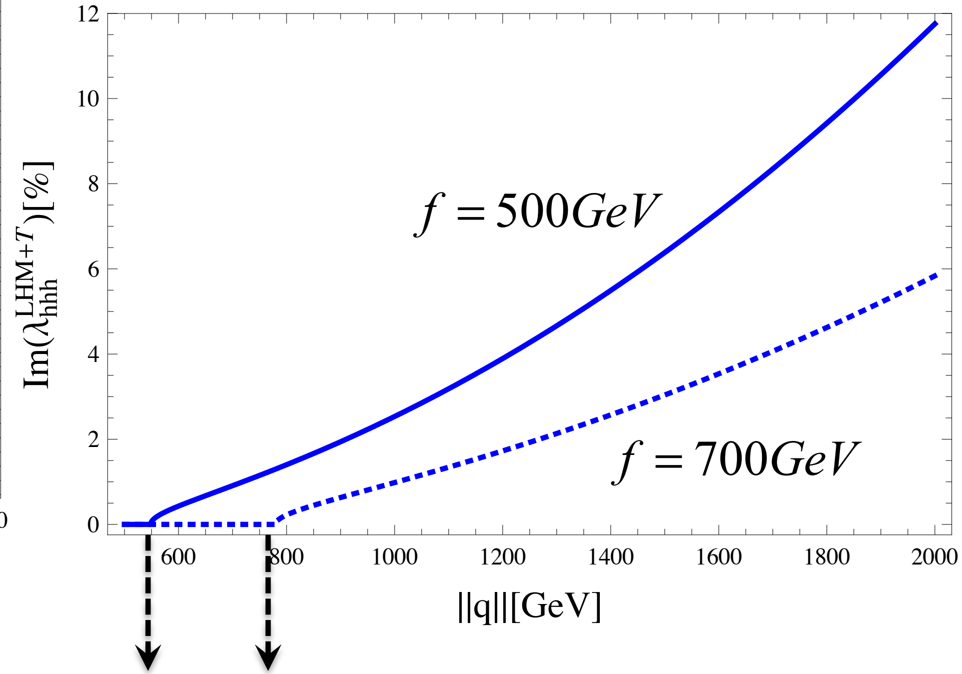
JHEP02 (2014) 053

$$m_{\nu_H} = m_{u_H} = \sqrt{2}\kappa_{ii} f\left(1 - \frac{v^2}{8f^2}\right) \qquad h\bar{u}_H u_H \sim h\bar{\nu}_H \nu_H \sim \frac{i\kappa_{ii}}{2\sqrt{2}}\left(\frac{v}{f}\right)$$

HHH AT ONE LOOP IN LHM WITH T-PARITY

$$\lambda_{u_H,v_H}^{LHM+T}(q^2)=\frac{N_c\kappa_{ii}^2 m_{u_H,v_H} m_W}{3\pi^2 2^{\frac{11}{2}} 3! g m_h^2}\frac{v^3}{f^3}\left[18-\int_{x=0}^{1}\int_{y=0}^{1-x}\Xi_{u_H}^{ME}(x,y,s_{u_H,v_H},s_q)dxdy\right]$$





$$q^2=4m_{u_H}^2$$

$$m_{v_H}=m_{u_H}=\sqrt{2}\kappa_{ii}f\left(1-\frac{v^2}{8f^2}\right)$$

$$h\bar{u}_H u_H \sim h\bar{v}_H v_H \sim \frac{i\kappa_{ii}}{2\sqrt{2}}\left(\frac{v}{f}\right)$$

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CONCLUSIONS

1.- To test the electroweak symmetry breaking sector of the SM, not only should the couplings of the Higgs boson to gauge boson and fermions be measured, but also the self-couplings of the Higgs boson.

2.- In the SM, the one-loop contribution to self-couplings hhh is ≈11%, where the top quark contribution is ≈9.14%

3.- In the LHM+T, the one-loop contribution of mirror fermions to self-coupling hhh is $\approx 2.3\times10^{-2}$ *for* f*=700 GeV.*