Does H — γγ taste like vanilla new physics?

Pedro A N Machado^{1,2}

in collaboration with: Leandro G. Almeida², Enrico Bertuzzo², and Renata Zukanovich Funchal^{1,2}

¹Universidade de São Paulo, ²CEA-Saclay

arXiv:1207.5254

LNGS Sep-13-2012

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Outline

- The Higgs boson and some old news
- $-H \rightarrow YY$
- Conclusions

We cannot write a mass term

 $m \bar{\psi}_L \psi_R$

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 $c \bar{\psi}_L H \psi_R \to c \bar{\psi}_L (H + v) \psi_R \longrightarrow cv \bar{\psi}_L \psi_R$

mass term

We cannot write a mass term

 $m \bar{\psi}_L \psi_R$

 $V(\phi)$

$$
c\,\bar{\psi}_L H \psi_R \to c\,\bar{\psi}_L (H+v)\psi_R \longrightarrow
$$

 $cv \, \bar{\psi}_L \psi_R$

mass term

Gives mass to particles

Breaks SU(2)L

How do you see a Higgs boson?

LNGS Sep-13-2012 http://indico.cern.ch/conferenceDisplay.py?confld=197461PAN Machado 1.98 -9.1 $+1.08$ -9.1

 $\sim \sum \sigma_i(pp \to H + X) \times \text{BR}(H \to \text{whatever})$ *i*

5

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The Higgs boson \mathbf{F} and \mathbf{F} and \mathbf{F}

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LNGS Sep-13-2012 http://www-wisconsin.cern.ch/~wus/talks/mumutalk.pdf PAN Machado 2 <http://www-wisconsin.cern.ch/~wus/talks/mumutalk.pdf> **LNGS Sep-13-2012**

http://theory.fnal.gov/jetp/talks/ejames_jul02_wine_cheese.pdf Source: Fermilab Wine and Cheese seminar July 2nd

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The question is: Is this particle the standard model Higgs?

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Let's see the Higgs signal strength data

$$
\mu_i = \frac{\left[\sum_j \sigma_{j \to h} \times \text{Br}(h \to i)\right]_{observed}}{\left[\sum_j \sigma_{j \to h} \times \text{Br}(h \to i)\right]_{SM}}
$$

Espinosa et al 1207.1717

differs from the previously public 7 TeV signal strength. The previously public 7 TeV signal strength. The pre
The previously public 7 TeV signal strength. The previously public 7 TeV signal strength. The previously publi

Espinosa et al 1207.1717

Espinosa et al 1207.1717

Red: reported 8 TeV *data, or reconstructed* 8 TeV *data.* Espinosa et al 1207.1717

How well this data agrees with the SM expectations?

Corbett, Éboli, Gonzalez-Fraile, Gonzalez-Garcia 1207.1344

LNGS Sep-13-2012 PAN Machado See also Espinosa et al 1207.1717, Carmi et al 1207.1718, Giardino et al 1207.1347, Ellis You p_1 U Sa-NSF grant Physical to P is graded to P is graded to P is P is a formulation of P is P 1207.1693, Banerjee Mukhopadhyay Mukhopadhyaya 1207.3588, Plehn Rauch 1207.6108

$H \rightarrow \gamma \gamma$ would be the perfect channel to find new physics

What sort of new physics would be needed to accomodate such a signal?

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I am *not* interested in the standard model only scenario

• The BR is $\Gamma_{\text{process}}/\Gamma_{\text{total}}$

• Hence, changing an individual Γ_{process} changes Γ_{total}

• But H to yy is < 1% of Γ_{total} , so we do not need to worry

$$
\Gamma(H \to \gamma \gamma) = \frac{\alpha^2 m_H^3}{1024\pi^3} \left| \frac{2}{v} A_1(\tau_W) + \frac{8}{3v} A_{1/2}(\tau_t) + \frac{2g_{Hf\bar{f}}}{m_f} N_{c,f} q_f^2 A_{1/2}(\tau_f) + \frac{g_{HSS}}{m_S^2} N_{c,S} q_S^2 A_0(\tau_S) \right|^2
$$

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$$

These are loop functions,

$$
\tau_x = (\text{m}_{\text{H}}/2\text{m}_{\text{x}})^2, \text{see}
$$

1207.5254 for details

$$
\Gamma(H \to \gamma \gamma) = \frac{\frac{Higgs \text{ mass}}{1024\pi^3} \left| \frac{2}{v} A_1(\tau_W) + \frac{8}{3v} A_1/2(\tau_t) \right|}{\frac{2g_{Hf\bar{f}}}{m_f} N_{c,f} q_f^2 A_{1/2}(\tau_f) + \frac{g_{HSS}}{m_S^2} N_{c,S} q_S^2 A_0(\tau_S) \right|^2}
$$
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\n
$$
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$$
\Gamma(H \to \gamma \gamma) = \frac{\alpha^2 m_H^3}{1024\pi^3} \left| \frac{2}{v} \frac{W}{A_1(\tau_W)} + \frac{8}{3v} \frac{\tau_{\text{top}}}{A_1/2(\tau_t)} \right|
$$

+
$$
\frac{2g_{Hf\bar{f}}}{m_f} N_{c,f} q_f^2 A_{1/2}(\tau_f) + \frac{g_{HSS}}{m_S^2} N_{c,S} q_S^2 A_0(\tau_S) \left| \frac{2g_{Hf\bar{f}}}{\tau_{\text{new fermion}}} N_{c,f} q_f^2 A_{1/2}(\tau_f) + \frac{g_{HSS}}{m_S^2} N_{c,S} q_S^2 A_0(\tau_S) \right|^2
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$$

This will be positive and
Option
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October contribution)

$$
\tau_x = (m_H/2m_x)^2, \text{ see} \qquad 1207.5254 \text{ for details}
$$

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$$
\nThis will be positive and
\n
$$
\gamma_{\text{top}} = \frac{\gamma_{\text{top}}}{\gamma_{\text{top}}}
$$
\n
$$
\frac{\gamma_{\text
$$

$$
\frac{2g_{Hf_i\bar{f}_i}}{m_{f_i}} = \frac{\partial}{\partial v} \log m_{f_i}^2(v)
$$

Ellis Gaillard Nanopoulos 1976, Shifman *et al* 1979

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Eigenvalues of M†M

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We want this coupling to be negative ²*gHfi^f*

Eigenvalues of M†M Ellis Gaillard Nanopoulos 1976, Shifman *et al* 1979

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- LNGS Sep-13-2012 PAN Machado • Assume that these will be the dominant contribution

2–**1** model coupling term with the SM Higgs field and to have mixing. We will examine here the SM Higgs field and the SM H
The SM Higgs field and the SM Higgs field two smallest representations, see Tab. 1. Let us stress that the triplet-doublet case with \mathbf{r} *y* = 1*/*2 corresponds to the supersymmetric Wino-Higgsino case.

Write most general Lagrangean and the mass matrix is

$$
(\bar\psi_R\,\bar\chi_R^u\,\bar\chi_R^d)\begin{pmatrix}m_2\;\;cv\; & 0\\c v\;\;m_1\;\;0\\0\;\; & 0\;\;m_1\end{pmatrix}\begin{pmatrix}\psi_L\\\chi_L^u\\ \chi_L^d\end{pmatrix}
$$

LNGS Sep-13-2012 PAN Machado where *i*^t , *c* is the Yukawa coupling to the Higgs, *PL,R* = **LINGS SEP-15** LNGS Sep-13-2012

3.1 Doublet-singlet model

Write most general Lagrangean and the mass matrix is

$$
(\bar{\psi}_R \,\bar{\chi}_R^u \,\bar{\chi}_R^d) \begin{pmatrix} m_2 & cv & 0 \\ cv & m_1 & 0 \\ 0 & 0 & m_1 \end{pmatrix} \begin{pmatrix} \psi_L \\ \chi_L^u \\ \chi_L^d \end{pmatrix}
$$

$$
M_{\omega_1,\omega_2} = \frac{1}{2} \left[(m_1 + m_2) \mp \sqrt{(m_2 - m_1)^2 + 4c^2v^2} \right]
$$

LNGS Sep-13-2012 PAN Machado where *i*^t , *c* is the Yukawa coupling to the Higgs, *PL,R* = **LINGS SEP-15** LNGS Sep-13-2012 the SM fields are introduced via covariant derivatives are introduced via covariant derivatives are introduced
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$$
(\bar{\psi}_R \, \bar{\chi}_R^u \, \bar{\chi}_R^d) \begin{pmatrix} m_2 \, \mathbf{c} v & 0 \\ \mathbf{c} v & m_1 & 0 \\ 0 & 0 & m_1 \end{pmatrix} \begin{pmatrix} \psi_L \\ \chi_L^u \\ \chi_L^d \end{pmatrix} \\ M_{\omega_1, \omega_2} = \frac{1}{2} \left[(m_1 + m_2) \mp \sqrt{(m_2 - m_1)^2 + 4c^2 v^2} \right]
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(\bar{\psi}_R \bar{\chi}_R^u \bar{\chi}_R^d) \begin{pmatrix} m_2 & c\upsilon & 0 \\ c\upsilon & m_1 & 0 \\ 0 & 0 & m_1 \end{pmatrix} \begin{pmatrix} \psi_L \\ \chi_L^u \\ \chi_L^d \end{pmatrix} \begin{pmatrix} m_1 = m_2 \text{ leads to} \\ \text{largest mixing} \end{pmatrix}
$$

$$
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$$

Prixing is needed to emiance in to yy, but may
be bad for EW precision tests... **Mixing is needed to enhance H to γγ, but may** χ = α
Σ\ Λ / d to
preci **ec** \overline{a}

LNGS Sep-13-2012 PAN Machado where *i*^t , *c* is the Yukawa coupling to the Higgs, *PL,R* = **LINGS SEP-15** the SM fields are introduced via covariant derivatives are introduced via covariant derivatives are introduced
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$$
\frac{2g_{Hf_i\bar{f}_i}}{m_{f_i}} = \frac{\partial}{\partial v} \log m_{f_i}^2(v)
$$

$$
M_{\rm top}^2 = c_{\rm top}^2 v^2
$$

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$$

LNGS Sep-13-2012 PAN Machado *Multimes in the that more mixing leads to higher* The gauge interactions with the SM fields are described by the usual coupling with \mathbf{r} the SM fields are internal covariant derivatives are internal covariant derivatives are internal covariant der Is it true that more mixing leads to higher H to γγ?

⁰⁺ *^µ* [≡] (0 *^W*⁺ where 0*n*×*^m* is a *n* × *m* zero matrix, *W* **2**–**1** model ' 1 *^L* = √ [√]² *^V*22*^L* √2 2 *V*21*^L* 600F $c = 1$ 400 G
↓ ↓ ↓ 400 G 500 \mathcal{N} is discussed the Higgs to diphoton width in the doublet-singlet model and in the \sim 250 GeV $rac{2}{\pi^2} \frac{400}{300}$ 400 $\Gamma(H\to\gamma\gamma)$ 200 GeV $R_{\gamma\gamma} =$ $\Gamma^{\text{SM}}(H\to\gamma\gamma)$ between the width of *H* → γγ with extra states and the width of *H* → γγ in the SM 100 GeV have the feature that fixing the lightest new fermion mass the largest enhancement will be Yes, more mixing means 200 High $R_{\gamma\gamma}$ larger enhancement! Let's focus on $m_1 = m_2$ Low $R_{\gamma\gamma}$

500

600

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200

300

 m_1 (GeV)

400

100

100

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What about the EW precision parameters STU?

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Let's see the $y = 1$ case as an example

3–**2** model \mathbf{r} is two smallest representations, see Tab. 1. Let us stress that the triplet-doublet case with \mathbf{r} *y* = 1*/*2 corresponds to the supersymmetric Wino-Higgsino case.

coupling term with the SM Higgs field and to have mixing. We will examine here the SM Higgs field and the SM H
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g

Write most general Lagrangean and the mass matrix is

$$
M_{3+2}=(\bar{\psi}^u_R\,\bar{\chi}^a_R\,\bar{\psi}^d_R\,\bar{\chi}^b_R\,\bar{\chi}^c_R) \left(\begin{array}{cccc} m_2 & c v & 0 & 0 & 0 \\ c v & m_1 & 0 & 0 & 0 \\ 0 & 0 & m_2 & -c\frac{v}{\sqrt{2}} & 0 \\ 0 & 0 & -c\frac{v}{\sqrt{2}} & m_1 & 0 \\ 0 & 0 & 0 & 0 & m_1 \end{array} \right) \left(\begin{array}{c} \psi^u_L \\ \chi^a_L \\ \psi^d_L \\ \chi^b_L \\ \chi^c_L \end{array} \right)
$$

 $Again, m_1 = m_2$ leads to largest mixing ' The reads to fargoot in [√]² ^χ*^a*

LNGS Sep-13-2012 PAN Machado where *i*^t , *c* is the Yukawa coupling to the Higgs, *PL,R* = **LINGS SEP-15**

where we define *W*

 $\mathsf{DAN1}\mathsf{Machada}$

3–**2** model where 0*n*×*^m* is a *n* × *m* zero matrix, *W ^L* = 1 √2

$$
R_{\gamma\gamma} = \frac{\Gamma(H \to \gamma\gamma)}{\Gamma^{\text{SM}}(H \to \gamma\gamma)}
$$

'

√

2 *V*21*^L*

Again, more mixing means larger enhancement Let's focus on $m_1 = m_2$

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⁰⁺

[√]² *^V*22*^L*

^µ [≡] (0 *^W*⁺

Production (a) LHC

• With $|Q| = 1$ fermions, the H to $\gamma \gamma$ enhancement is limited

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• In a "natural" scenario, a large enhancement of H to $\gamma\gamma$ confront vacuum stability issues (instable below 10 TeV) see Arkani-Hamed Blum Agnolo Fan 1207.4482

the comments of the comments of \blacksquare general suppressed compared to the diagram containing only the diagram containing only the light state of the

mass eigenstate. We will alter that, in the region of parameter space we argue later space we argue later space w
In the region of parameter space we argue later space we argue later space we argue later space we argue lat

• H to γγ is correlated to H to Zγ (same particles in the loop) \bullet H to YY is correlated to H to ZY (same particles in the loop

It is worth pointing out that, unlike in the γγ channel where only the γγ channel where only the electric charge of
The electric charge of the electric charge of the electric charge of the electric charge of the electric

Carena Low Wagner 1206.1082 number. Therefore, simultaneous measurements of the decay widths in the $\gamma\gamma$ and $Z\gamma$ channels would probe the weak isospin charge and the electric charge of the new particles running in the loop.

H to γγ looks unconfortably inconclusive

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This Christmas (or even before), we may receive a precious gift... $\int \int h d\mu k \psi^{\prime}$

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The Higgs boson In this this work we assume that even if the electroweak symmetry is new physics associated with the electrowe
In the electroweak symmetry breaking symmetry breaking symmetry breaking symmetry breaking symmetry breaking s the Higgs boson of a LHC is still part of a SU(2)L doublet, the SM gauge invariance holds and no additional no light states, relevant to the Higgs observables, are present in the spectrum. Under the spectrum. Under the new effects of the new effects of the spectrum. Under the spectrum. Under the new effects of the new effects of th

How to fit the Higgs couplings? that are invariant under linear SU(3)c ⊗ SU(3)c ⊗ SU(3)c ⊗ SU(3)C ⊗ SU(3)c ⊗ SU(3)L ⊗ U(1)Y transformations.
Discussions. In the surface of transformations of transformations. In the surface of transformations. In the s

Dimension-6 operators invariant under SM gauge groups These will lead to anomalous Higgs couplings operators that can be written as $\mathsf{Tr}\,$

$$
\mathcal{L}_{\text{eff}} = \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n
$$

 $LNGS$ Sep-13-2012 Corbett, Éboli, Gonzalez-Fraile, Gonzalez-Garcia 1207.1344

The Higgs boson light states, relevant to the Higgs observables, are present in the spectrum. Under these assumptions the new effects can be parametrized in a model independent way by extending the SM with the addition of higher dimension operators that are invariant under linear SU(3)^c ⊗ SU(2)^L ⊗ U(1)^Y transformations. In this framework the first corrections to the Higgs couplings to gauge bosons are expressed as dimension–six In this work we assume that even if there is new physics associated with the electroweak symmetry breaking sector, the Higgs boson observed at LHC is still part of a SU(2)^L doublet, the SM gauge invariance holds and no additional light states, relevant to the Higgs observables, are present in the spectrum. Under these assumptions the new effects

the Higgs boson observed at LHC is still part of a SU(2)L doublet, the SM gauge invariance holds and no additional Γ

How to fit the Higgs couplings? that are invariant under linear SU(3)c ⊗ SU(3)c ⊗ SU(3)c ⊗ SU(3)C ⊗ SU(3)c ⊗ SU(3)L ⊗ U(1)Y transformations.
Discussions. In the surface of transformations of transformations. In the surface of transformations. In the s

rs invari These will lead to anomalous Higgs couplings fn Dimension-6 operators invariant under SM gauge groups operators that can be written as $\mathsf{Tr}\,$

$$
{\cal L}_{\rm eff}=\sum_n \frac{f_n}{\Lambda^2} {\cal O}_n
$$

 ${\cal O}_{GG} = \Phi^\dagger \Phi \; G^a_{\mu\nu} G^{a\mu\nu} \; , \qquad \quad {\cal O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \; \; , \qquad \quad {\cal O}_{BB} = \Phi^\dagger \hat{B}_{\mu\nu} \hat{B}^{\mu\nu} \Phi \; \; ,$ $\mathcal{O}_{GG} = \Phi^{\dagger} \Phi G^{\alpha}_{\mu\nu} G^{\alpha\mu\nu}$, $\mathcal{O}_{WW} = \Phi^{\dagger} W_{\mu\nu} W^{\mu\nu} \Phi$, $\mathcal{O}_{BB} = \Phi^{\dagger} B_{\mu\nu} B^{\mu\nu} \Phi$,

 $\mathcal{O}_{BW} = \Phi^{\dagger} \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \ , \qquad \quad \mathcal{O}_{W} = (D_{\mu} \Phi)^{\dagger} \hat{W}^{\mu\nu} (D_{\nu} \Phi) \ , \qquad \mathcal{O}_{B} = (D_{\mu} \Phi)^{\dagger} \hat{B}^{\mu\nu} (D_{\nu} \Phi) \ ,$ \hat{C} and \hat{T} and \hat{T} and \hat{C} and \hat{D} and \hat{T} and \hat{T} are only seven dimension-six operators that the \hat{T} $U_{BW} = \Psi^{\dagger} B_{\mu\nu} W^{\mu\nu} \Psi$, $U_W = (D_{\mu} \Psi)^{\dagger} W^{\mu\nu} (D_{\nu} \Psi)$, $U_B = (D_{\mu} \Psi)^{\dagger} B^{\mu\nu} (D_{\mu} \Psi)^{\dagger}$

 $\mathcal{O}_{\Phi,1} = \left(D_\mu \Phi \right)^\dagger \Phi^\dagger \Phi \left(D^\mu \Phi \right) \;\; , \;\; \mathcal{O}_{\Phi,2} = \tfrac{1}{2} \partial^\mu \left(\Phi^\dagger \Phi \right) \partial_\mu \left(\Phi^\dagger \Phi \right) \;\; ,$

Expanding these terms, we get an effective Lagrangean EXPAIRTING CILLEST CONTROL FOR THE BEL AND ENTERED TO LABE AND THE EXPLORE LABORED IN

 $LNGS$ Sep-13-2012 \overline{P} and \overline{P} PAN Machado Corbett, Éboli, Gonzalez-Fraile, Gonzalez-Garcia 1207.1344 $\mathcal{P}_\mathcal{P}$ being respectively the U(1)Y , SU(3)C field strength tensors. We denote the U(1)Y , SU(3)c field strength tensors. We denote the U(1)Y , SU(3)c field strength tensors. We denote the U(1)Y , SU(3)C field str in the unitary gauge are given by

The Higgs boson uv being respectively the U(1)Y , SU(3)Y , SU(3)Y , SU(3)Z and SU(3)C field strength tensors. We denote the U(
Denote the U(1)Y , SU(3)C field strength tensors. We denote the U(1)Y , SU(3)Y , SU(3)Y , SU(3)Y , SU(3)Y , <u>Electrical Diagonal Diagonal diagonal diagonal diagonal diagonal diagonal diagonal di</u> THE ELECTIVE OUR COUPLING in the unitary gauge are given by the unitary gauge are given by α

/2)Bµ^ν and Wˆ ^µ^ν = i(g/2)σaW^a

where $\overline{}$ stands for the Higgs doublet, $\overline{}$ is the covariant derivative, $\overline{}$

^µ^ν , and G^a

 ${\cal L}^{\rm HVV}_{\rm eff} \;=\; g_{Hgg} \; H G^a_{\mu\nu} G^{a\mu\nu} + g_{H\gamma\gamma} \; H A_{\mu\nu} A^{\mu\nu} + g^{(1)}_{HZ\gamma} \; A_{\mu\nu} Z^{\mu} \partial^{\nu} H + g^{(2)}_{HZ\gamma} \; H A_{\mu\nu} Z^{\mu\nu}$ $+ g_{HZZ}^{(1)} Z_{\mu\nu} Z^{\mu} \partial^{\nu} H + g_{HZZ}^{(2)} H Z_{\mu\nu} Z^{\mu\nu} + g_{HZZ}^{(3)} H Z_{\mu} Z^{\mu}$ $+ g_{HWW}^{(1)} (W_{\mu\nu}^+ W^{-\mu} \partial^{\nu} H + \text{h.c.}) + g_{HWW}^{(2)} H W_{\mu\nu}^+ W^{-\mu\nu} + g_{HWW}^{(3)} H W_{\mu}^+ W^{-\mu} ,$

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The Higgs boson uv being respectively the U(1)Y , SU(3)Y , SU(3)Y , SU(3)Z and SU(3)C field strength tensors. We denote the U(
Denote the U(1)Y , SU(3)C field strength tensors. We denote the U(1)Y , SU(3)Y , SU(3)Y , SU(3)Y , SU(3)Y , <u>Electrical Diagonal Diagonal diagonal diagonal diagonal diagonal diagonal diagonal di</u> THE ELECTIVE OUR COUPLING in the unitary gauge are given by the unitary gauge are given by α

/2)Bµ^ν and Wˆ ^µ^ν = i(g/2)σaW^a

,

where $\overline{}$ stands for the Higgs doublet, $\overline{}$ is the covariant derivative, $\overline{}$

 $\frac{1}{2}$

^µ^ν , and G^a

$$
\mathcal{L}_{\text{eff}}^{\text{HVV}} = g_{Hgg} H G_{\mu\nu}^a G^{a\mu\nu} + g_{H\gamma\gamma} H A_{\mu\nu} A^{\mu\nu} + g_{HZ\gamma}^{(1)} A_{\mu\nu} Z^{\mu} \partial^{\nu} H + g_{HZ\gamma}^{(2)} H A_{\mu\nu} Z^{\mu\nu} \n+ g_{HZZ}^{(1)} Z_{\mu\nu} Z^{\mu} \partial^{\nu} H + g_{HZZ}^{(2)} H Z_{\mu\nu} Z^{\mu\nu} + g_{HZZ}^{(3)} H Z_{\mu} Z^{\mu} \n+ g_{HWW}^{(1)} (W_{\mu\nu}^+ W^-^{\mu} \partial^{\nu} H + \text{h.c.}) + g_{HWW}^{(2)} H W_{\mu\nu}^+ W^-^{\mu\nu} + g_{HWW}^{(3)} H W_{\mu}^+ W^-^{\mu} ,
$$

These effective couplings are combination of the previous These effective souplings are sombination of

$$
g_{H\gamma\gamma} \;=\; -\left(\frac{gM_W}{\Lambda^2}\right)\frac{s^2(f_{BB}+f_{WW}-f_{BW})}{2}
$$

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Loop functions Note added: During the finilization of this paper Ref. [35, 36] appeared. APPENDIX: DEFINITIONS OF SOME FUNCTIONS USED IN THIS WORK Note added: During the finilization of this paper Ref. [35, 36] appeared. fermion states in their lowest allowed SU(2)^L × U(1)^Y representions, *i.e.* singlets, doublets and triplets. Once the Appendix: $\mathcal{A}_\mathcal{B}$ and $\$ representation is chosen, their couplings with the SM gauge boson will be basically fixed. The only free parameters will be their couplings to the Higgs, their charges and their masses. We do not study here particles with SU(3)^C

Eboli for useful comments and discussions.

$$
A_1(\tau) = -[2\tau^2 + 3\tau + 3(2\tau - 1)g(\tau)]/\tau^2
$$

\n
$$
A_{1/2}(\tau) = 2[\tau + (\tau - 1)g(\tau)]/\tau^2
$$

\n
$$
A_0(\tau) = -[\tau - g(\tau)]/\tau^2
$$

$$
g(\tau) = \arcsin^2 \sqrt{\tau}, \text{ for } \tau \le 1.
$$

$$
\tau_a\equiv (m_H/2m_a)^2,\ a=W,t,f,S
$$

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PAN Machado fermions and scalars. Since for the W boson contribution *A*1(τ*^W*) → −8*.*3 and for the top quark *A*1*/*2(τ*t*) → +1*.*8, to increase *H* → γγ we need to include a new negative contribution, comparable to the top one.

in connection to an unbroken or nearly unbroken symmetry, exclusive to the new sector. We will consider colorless

EWPT

$$
\alpha(M_Z^2) S^{NP} = \frac{4s_W^2 c_W^2}{M_Z^2} \left[\Pi_{ZZ}^{NP}(M_Z^2) - \Pi_{ZZ}^{NP}(0) - \Pi_{\gamma\gamma}^{NP}(M_Z^2) - \frac{c_W^2 - s_W^2}{c_W s_W} \Pi_{\gamma Z}^{NP}(M_Z^2) \right]
$$

\n
$$
\alpha(M_Z^2) T^{NP} = \frac{\Pi_{WW}^{NP}(0)}{M_W^2} - \frac{\Pi_{ZZ}^{NP}(0)}{M_Z^2}
$$

\n
$$
\alpha(M_Z^2) U^{NP} = 4s_W^2 \left[\frac{\Pi_{WW}^{NP}(M_W^2) - \Pi_{WW}^{NP}(0)}{M_W^2} - c_W^2 \left(\frac{\Pi_{ZZ}^{NP}(M_Z^2) - \Pi_{ZZ}^{NP}(0)}{M_Z^2} \right) - 2s_W c_W \frac{\Pi_{\gamma Z}^{NP}(M_Z^2)}{M_Z^2} - s_W^2 \frac{\Pi_{\gamma\gamma}^{NP}(M_Z^2)}{M_Z^2} \right]
$$

LNGS Sep-13-2012 PAN Machado $t \hbox{ is even}$ prediction on finds the fitted values \mathcal{L}