Electroweak-scale Right-handed Neutrino Model And 126 GeV Higgs-like Particle

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(paper in preparation)

University of Virginia

27th February, 2013

Outline

- Motivation

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- Overview of the Electroweak-scale Right-handed Neutrino (EWν_R) model

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- An extended EWν_R

- Two most pressing problems in particle physics
  - Nature of spontaneous breaking of the electroweak symmetry
  - Nature of neutrino masses and mixings

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  - Nature of spontaneous breaking of the electroweak symmetry
  - Nature of neutrino masses and mixings
- Discovery of a new 126 GeV particle could be significant step in unfolding the first mystery

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Dirac mass

Majorana mass

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possible! **[PQ, PLB 649 (2007)]**

What's next option after a singlet ν_R?

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Majorana

$$\mathcal{L}_M = g_M \big(l_R^{M,T} \sigma_2 \big) \big(i\, \tau_2\, \widetilde{\chi} \big) l_R^M + h.c.$$

$$\widetilde{\chi}\ \Big(3,\ \frac{Y}{2} = 1\Big)$$

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$$M_R = g_M v_M; < \chi^0 >= v_M \sim \Lambda_{EW}$$

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$$Z \text{ width} \Rightarrow\ M_R > M_Z\ /\ 2$$

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Dirac

$$\mathcal{L}_S = g_{sl} \bar{L}_L \phi_S L_R^M + h.c.$$

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Dirac

$$\mathcal{L}_S = g_{sl} \bar{L}_L \phi_S L_R^M + h.c.$$

$$\phi_S \; (1, \; \frac{Y}{2} = 0)$$

$$m_\nu^D = g_{Sl} v_S$$

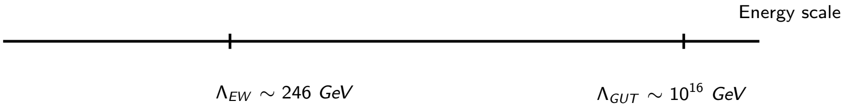
$$< \phi_S >= v_S << v_M$$

$$m_\nu \leq 1eV \; \Rightarrow \; v_S \sim 10^{5-6} eV$$

Energy scale

$\Lambda_{EW} \sim 246 \ GeV$

$\Lambda_{GUT} \sim 10^{16} \ GeV$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$$\rho = \frac{M_W^2}{M_Z^2 cos\theta_W^2}$$

$$\rho = \frac{M_W^2}{M_Z^2 cos\theta_W^2} = \frac{\sum_{T,Y}[4T(T+1) - Y^2]|V_{T,Y}|^2 c_{T,Y}}{\sum_{T,Y} 2Y^2|V_{T,Y}|^2}$$

Tree level; $c_{T,Y} = 1,\ (1/2)$ for (T,Y) complex (real) rep.

[*The Higgs Hunter's Guide*, Gunion et.al.]

$$\rho = \frac{M_W^2}{M_Z^2 cos\theta_W^2} = 1 \qquad \Rightarrow$$

Tree level

$$\rho = \frac{M_W^2}{M_Z^2 cos\theta_W^2} = 1 \qquad \Rightarrow \quad \text{add} \quad \xi \quad (3,\ \frac{Y}{2} = 0)$$

Tree level

Fermions

SM Fermions			EWν_R Mirror Fermions		
SM Fields	$SU(2)_W$	$U(1)_Y$	Additional Fields	$SU(2)_W$	$U(1)_Y$
$L_{Li} = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}_i$	2	-1	$L^M_{Ri} = \begin{pmatrix} \nu_R \\ e^M_R \end{pmatrix}_i$	2	-1
$Q_{Li} = \begin{pmatrix} u_L \\ d_L \end{pmatrix}_i$	2	$(1/3)$	$Q^M_{Ri} = \begin{pmatrix} u^M_R \\ d^M_R \end{pmatrix}_i$	2	$(1/3)$
e_{Ri}	1	-2	e^M_{Li}	1	-2
u_{Ri}	1	$(4/3)$	u^M_{Li}	1	$(4/3)$
d_{Ri}	1	$-(2/3)$	d^M_{Li}	1	$-(2/3)$

Scalars

Field	$SU(2)_W$	$U(1)_Y$	VEV
χ	3	2	v_M
ξ	3	0	v_M
Φ	2	1	$v_2/\sqrt{2}$
ϕ_S	1	0	v_S

$$\phi^0 \equiv \frac{1}{\sqrt{2}}(v_2 + \phi^{0r} + i\phi^{0i}), \qquad \chi^0 \equiv v_M + \frac{1}{\sqrt{2}}(\chi^{0r} + i\chi^{0i}),$$

$$v = \sqrt{v_2^2 + 8v_M^2} \approx 246\text{GeV}$$

$$cos(\theta_H) = c_H \equiv v_2/v \qquad sin(\theta_H) = s_H \equiv 2\sqrt{2}v_M/v$$

$$SU(2)_L \times SU(2)_R$$

$$\phi^0 \equiv \frac{1}{\sqrt{2}}(v_2 + \phi^{0r} + i\phi^{0i}), \qquad \chi^0 \equiv v_M + \frac{1}{\sqrt{2}}(\chi^{0r} + i\chi^{0i}),$$

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$$H_5^{++} = \chi^{++}, \quad H_5^{+} = \frac{1}{\sqrt{2}}(\chi^+ - \xi^+), \quad H_5^0 = \frac{1}{\sqrt{6}}\left(2\xi^0 - \sqrt{2}\chi^{0r}\right),$$

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with $H_5^{--} = (H_5^{++})^\star$, $H_5^{-} = -(H_5^{+})^\star$, $H_3^{-} = -(H_3^{+})^\star$ and $H_3^0 = -(H_3^0)^\star$

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doublet ϕ & triplet χ; 0^-

Only doublet ϕ; 0^+

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Does EWν_R agree with EW precision measurements?

Constraints Oblique Parameters

S, T, U

Oblique Parameters

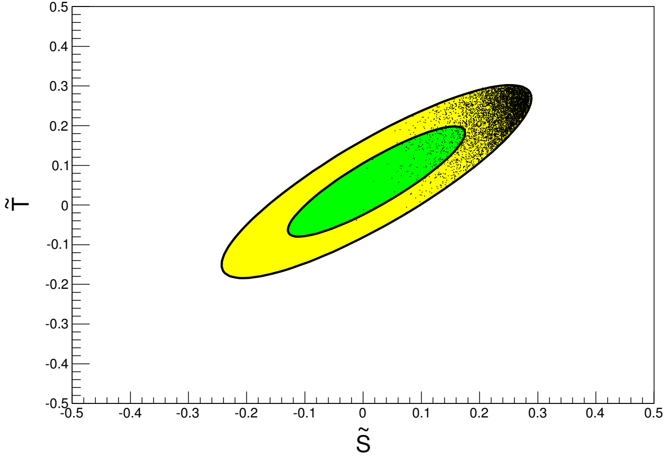
$S \rightarrow$ **Difference between** Z **self-energy at** $q^2 = M_Z^2$ **and at** $q^2 = 0$

$T \rightarrow \sim \left(1 - \rho\right)$; **Difference between isospin currents** Π_{11} **and** Π_{33} **at** $q^2 = 0$

$U \rightarrow$ **Difference between** W **and** Z **self-energies at** $q^2 = M_Z^2$ **and at** $q^2 = 0$

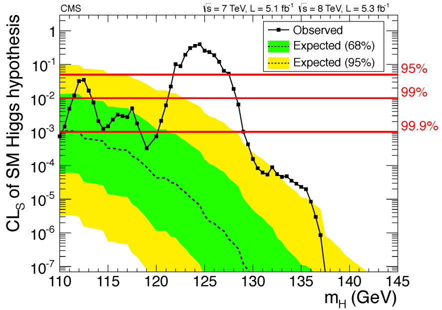
Agreement with Precision Measurements

New Physics contributions, $\widetilde{S}$ and $\widetilde{T}$, to S, T due to EWν_R model are seen to, indeed, satisfy the constraints from precision measurements [Plotted by Vinh Hoang]



126 GeV Higgs-like Particle

[CMS collaboration, PLB **716**, 2012]



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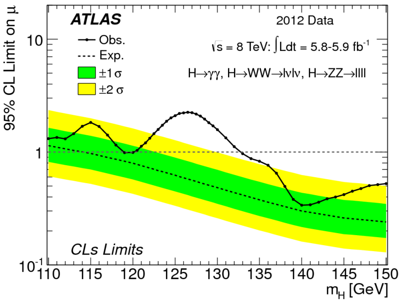

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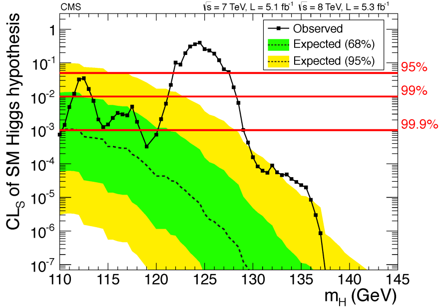

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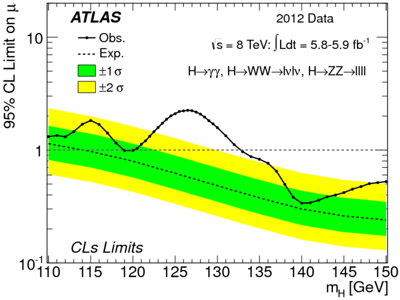

$$\sigma(\text{decay channel}) = \sigma_{\text{production}} \times \text{Branching Ratio(decay channel)}$$

How EWν_R model accommodates this

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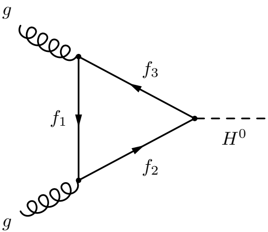
$gg \to H$ Production Channel



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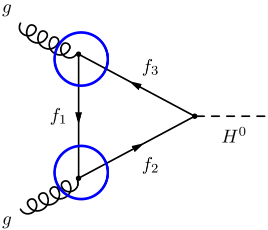

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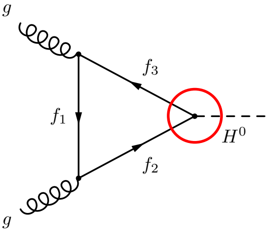

CP-even Physical Scalar in EWν_R

- $g_{H_1^0 t\bar{t}} = -i \dfrac{m_t \; g}{2 \; M_W \;\; \cos\theta_H}; \qquad g_{H_1^0 q^M \bar{q}^M} = -i \dfrac{m_{q^M} \; g}{2 \; M_W \;\; \cos\theta_H}$

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- Back of the envelope: if mirror quarks contribute as much as top quark

$$\sigma\left(gg \to H_1^0\right) \sim \mathbf{49} \times \frac{1}{\cos^2\theta_H} \, \sigma_{SM}\left(gg \to H\right) \qquad !!$$

Cannot be compensated for all the branching ratios

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  Cannot be compensated for all the branching ratios

- H_1^0 **in EW**ν_R **cannot** be the new 126 GeV particle

CP-odd Physical Scalar in EWν_R

- $g_{H_3^0 t\bar{t}} = i \dfrac{m_t \; g \; \sin\theta_H}{2 \; M_W \; \cos\theta_H} \gamma_5$
- $g_{H_3^0 u_i^M \bar{u}_i^M} = -i \dfrac{m_{u_i^M} \; g \; \sin\theta_H}{2 \; M_W \; \cos\theta_H} \gamma_5$; $\qquad g_{H_3^0 d_i^M \bar{d}_i^M} = i \dfrac{m_{d_i^M} \; g \; \sin\theta_H}{2 \; M_W \; \cos\theta_H} \gamma_5$

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$$\sigma\left(gg \to H_3^0\right) \sim \tan^2\theta_H \, \sigma_{SM}\left(gg \to H\right) \qquad !!$$

CP-odd Physical Scalar in EWν_R

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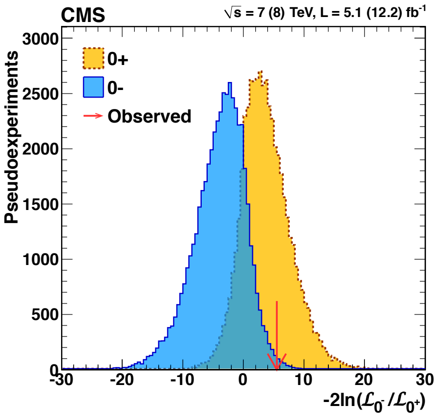
- Thus, for $\tan^2\theta_H \sim 1$, H_3^0 could reproduce $\sigma_{SM}\left(gg \to H\right)$

Recent Spin-Parity Result from CMS

[CMS collaboration, PRL **110**, 081813]



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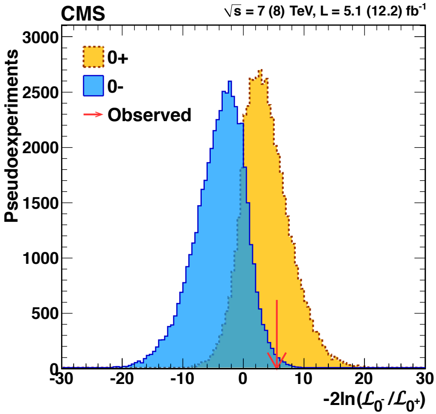

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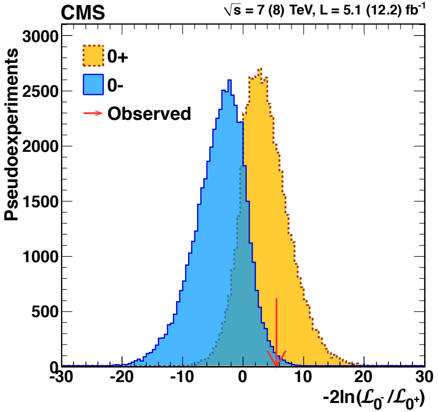

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- More data needed for this analysis

How EWν_R accommodates 126 GeV particle as CP-even (0^+) Higgs

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Not with the minimal EWν_R model just explained

Simplest Extension to EWν_R Model

$\phi_{singlet}$ $(1, Y/2 = 0)$

Simplest Extension to $\mathrm{EW}\nu_R$ Model

$\Phi_{doublet} \;\; (2, Y/2 = 1)$

Simplest Extension to $EW\nu_R$ Model

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- Known from 2 Higgs doublet model: 1 light Higgs and 1 heavy Higgs

Simplest Extension to $EW\nu_R$ Model

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- Known from 2 Higgs doublet model: 1 light Higgs and 1 heavy Higgs
- But remember: $g_{H_1^0 q^M \bar{q}^M} = -i \dfrac{m_{q^M}\ g}{2\ M_W\ \cos\theta_H}$

An Extended EWν_R

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- Add another $SU(2)$ scalar doublet $(Y/2 = 1)$

An Extended $EW\nu_R$

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- With a global $U(1)_{SM} \times U(1)_{MF}$ symmetry such that

$$U(1)_{SM} \quad : \quad \begin{aligned} \Phi^L &\rightarrow e^{i\alpha_{SM}}\, \Phi^L \\ l_L^{SM} &\rightarrow e^{i\alpha_{SM}}\, l_L^{SM}\,, \end{aligned}$$

and

$$U(1)_{MF} \quad : \quad \begin{aligned} \Phi^R &\rightarrow e^{i\alpha_{MF}}\, \Phi^R \\ l_R^{M} &\rightarrow e^{i\alpha_{MF}}\, l_R^{M}\,. \end{aligned}$$

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- Also under $U(1)_{\mathrm{SM}} \times U(1)_{\mathrm{MF}}$

$$\phi_S \to e^{-i(\alpha_{MF} - \alpha_{SM})}\, \phi_S\,,$$

and other fields are singlets under this symmetry.

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χ	3	2	v_M
ξ	3	0	v_M
Φ^L	2	1	$v_1^L/\sqrt{2}$
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- Physical states of $SU(2)_D$ custodial: a five-plet $H_5^{\pm\pm,\pm,0}$, *two* triplets $H_{3,1}^{\pm,0}$, $H_{3,2}^{\pm,0}$ and *three* singlets $H_1^{0,L}$, $H_1^{0,R}$, $H_1^{0\prime}$.

- $g_{H_1^{0,L} t\bar{t}} = -i \dfrac{m_t \; g}{2 \; M_W \; (v_1^L/v)}; \quad g_{H_1^{0,R} q^M \bar{q}^M} = -i \dfrac{m_{q^M} \; g}{2 \; M_W \; (v_2^R/v)}$

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- Back of the envelope

$$\sigma\left(gg \to H_1^{0,L}\right) \sim \left(\frac{v}{v_1^L}\right)^2 \times \sigma_{SM}\left(gg \to H\right)$$

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- Singlets mix to form Mass eigenstates

- Back of the envelope

$$\sigma(gg \to H_{1,1}^0) \sim |a_1|^2 \left(\frac{v}{v_1^L}\right)^2 \times \sigma_{SM}(gg \to H) \; ,$$

with singlet mixing parameter $a_1^2 \sim 1$ and $v_1^L \sim v$.

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- Makes Seesaw mechanism testable at LHC and near future colliders
- Does not violate constraints from EW precision measurements
- The new 126 GeV particle can be accommodated as CP-odd Higgs in minimal EWν_R model (modulo spin-parity result from CMS) and as CP-even Higgs in an extended EWν_R model

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- In progress:
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  - EW Dynamical Symmetry Breaking in the model

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- Next:
  Experimental signals of EWν_R model at LHC, e.g. like-sign double β-decay

Thank You!


HEY, LOOKS LIKE THIS ONE CAN ACCOMMODATE YOU TOO!
EW ν_R MODEL
THEN LET'S DRIVE TOGETHER
EW ν_R
126 GeV
PARITY
A.S.Kamat 02/26/13