Neutrino mass generation and Higgs to diphoton with scalar multiplets

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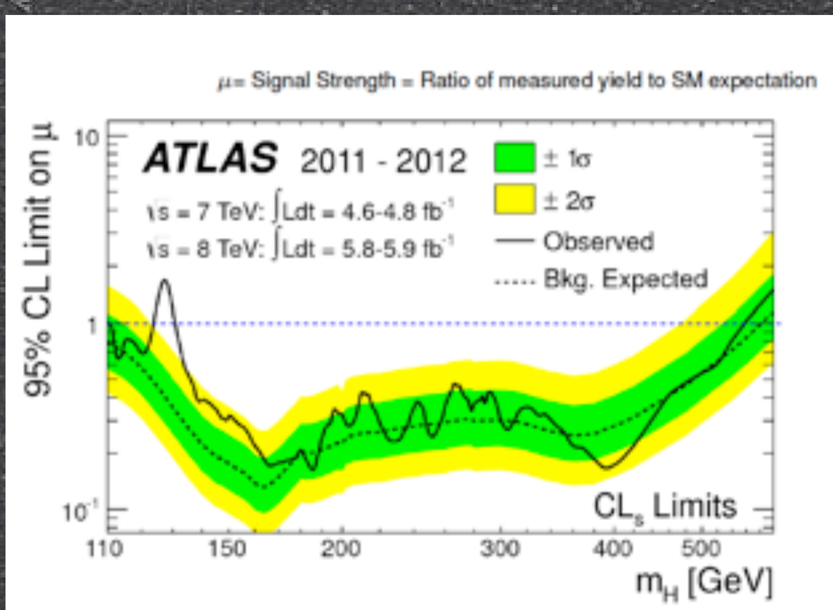
Based on in collaboration with C.Q.Geng,Da Huang and Lu-Hsing Tsai,
arXiv:1212.6208,1301.4694

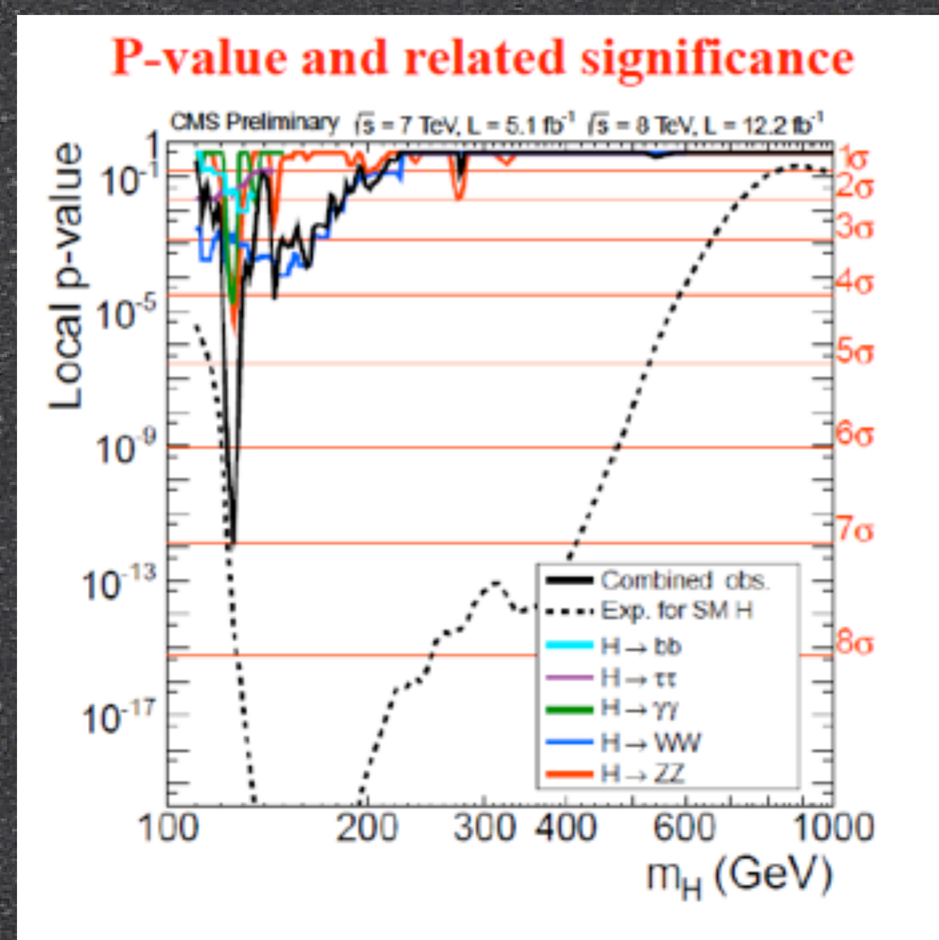
Introduction

- Two big discoveries in particle physics in 2012 are : (1) 125 SM Higgs-like particle and (2) large θ_{13} angle of neutrino mixings.

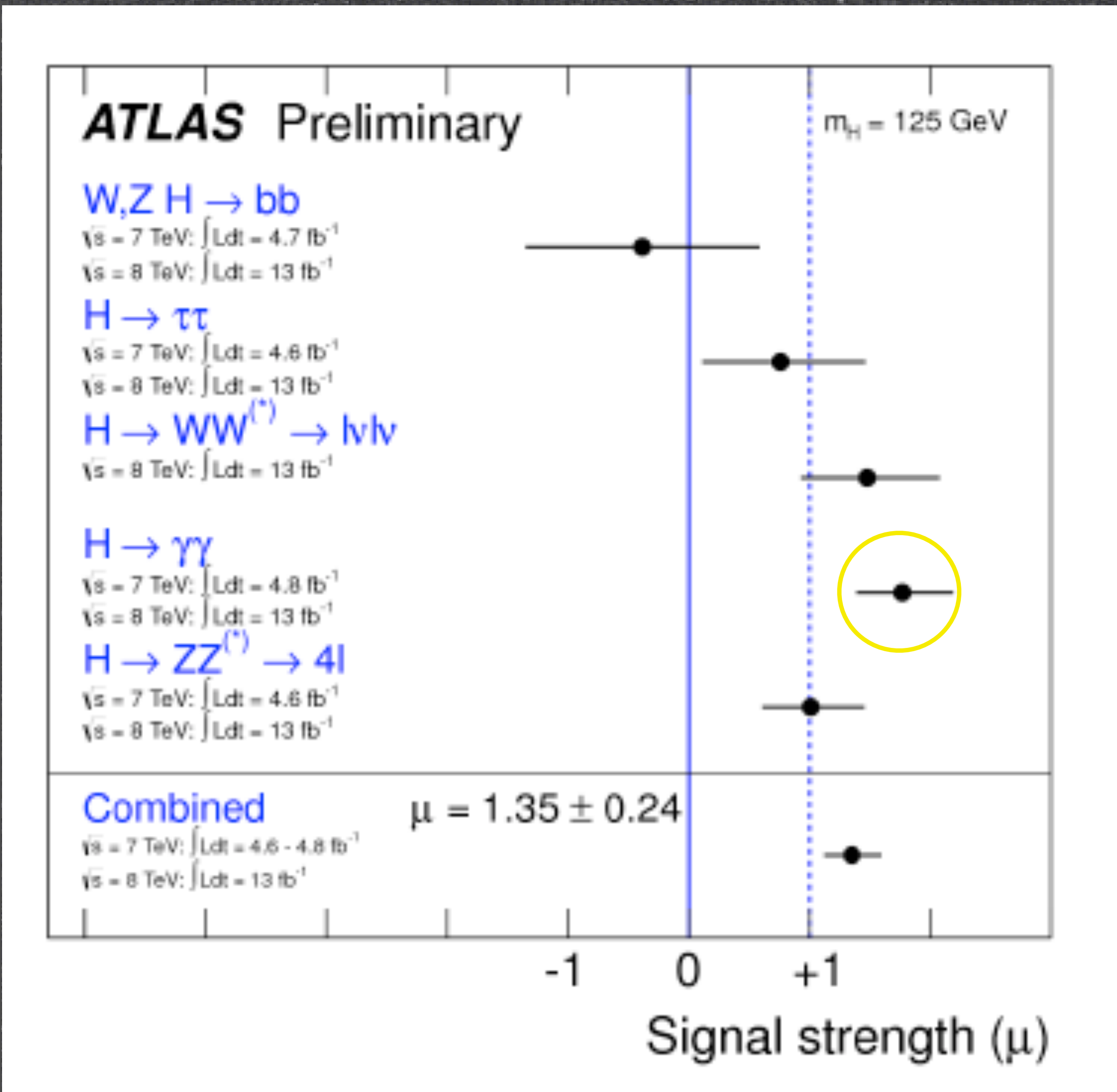
EWS breaking and mass origin

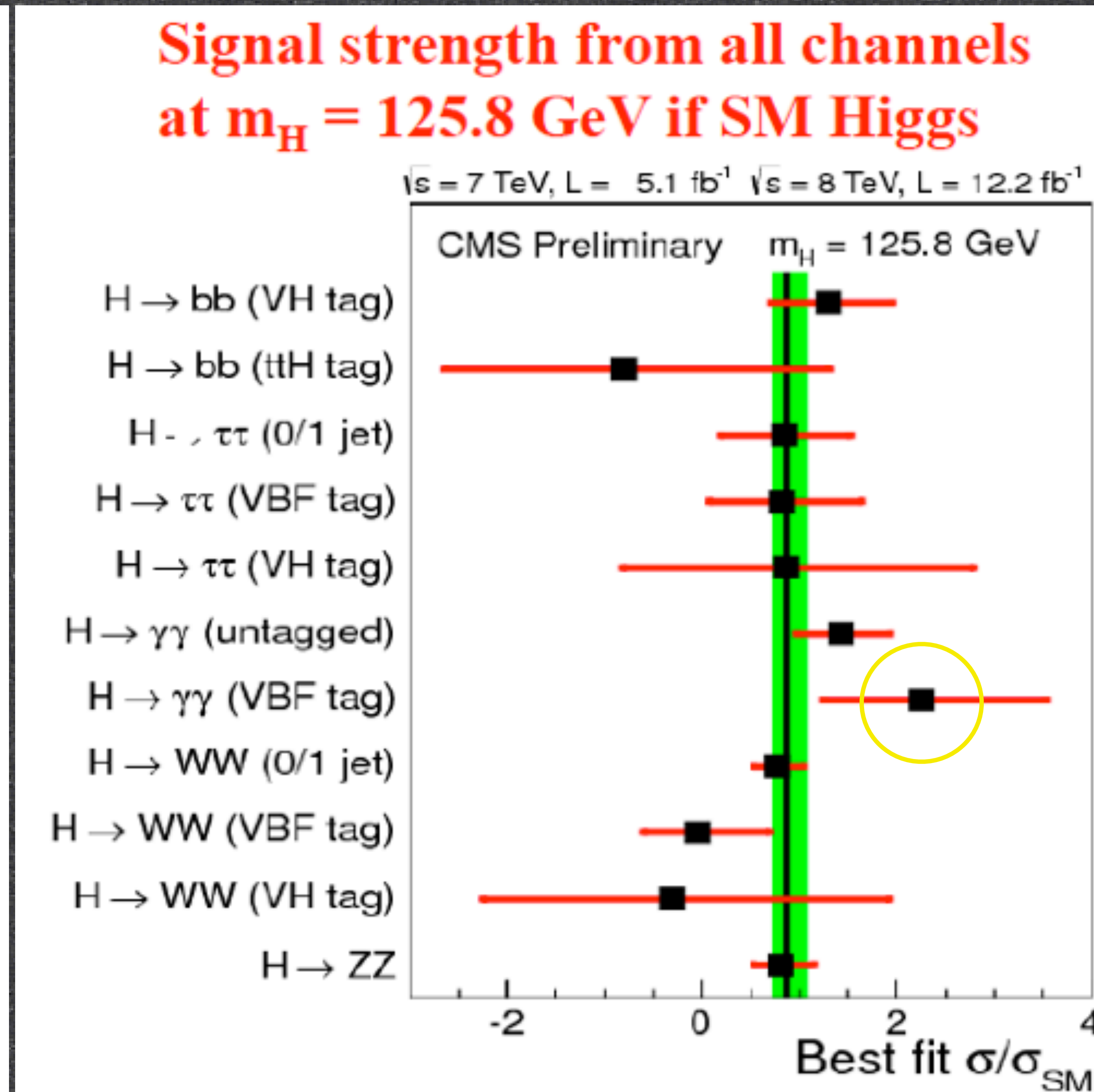
Mass hierarchy and CP violation





Combined results





W.Bhimji N.Van Remortel

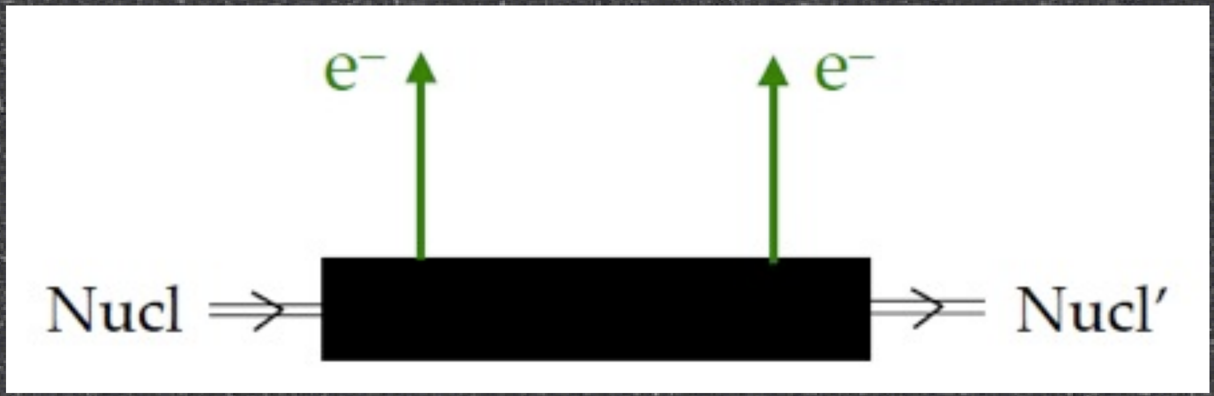
For neutrino

- Neutrino oscillations indicate physics beyond the Standard Model - masses from zero to non-zero
- Questions to address are absolute scale, mass hierarchy, CP phases, and the Nature of neutrino-Dirac or Majorana fermion
- Different ν oscillation experiments would be able to answer the first three questions thanks to the large θ_{13}

Nature of neutrino <-> lepton number conservation

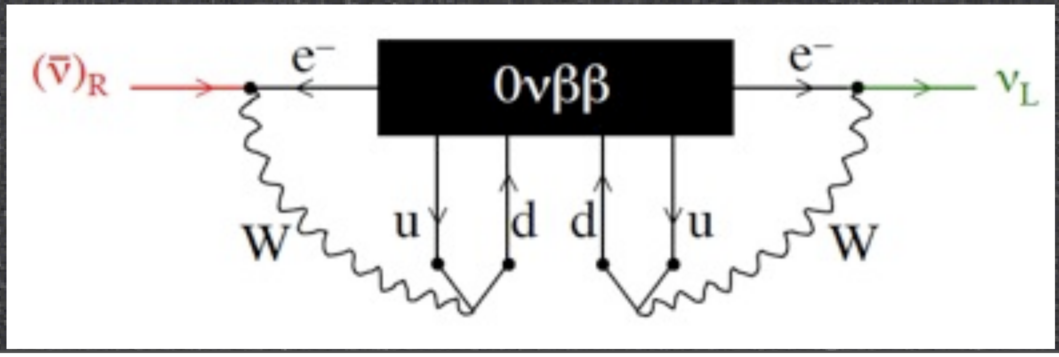
Experimental side :

- The smoking gun signal to reveal the property of neutrino is “neutrinoless double beta decays”



Theoretical side :

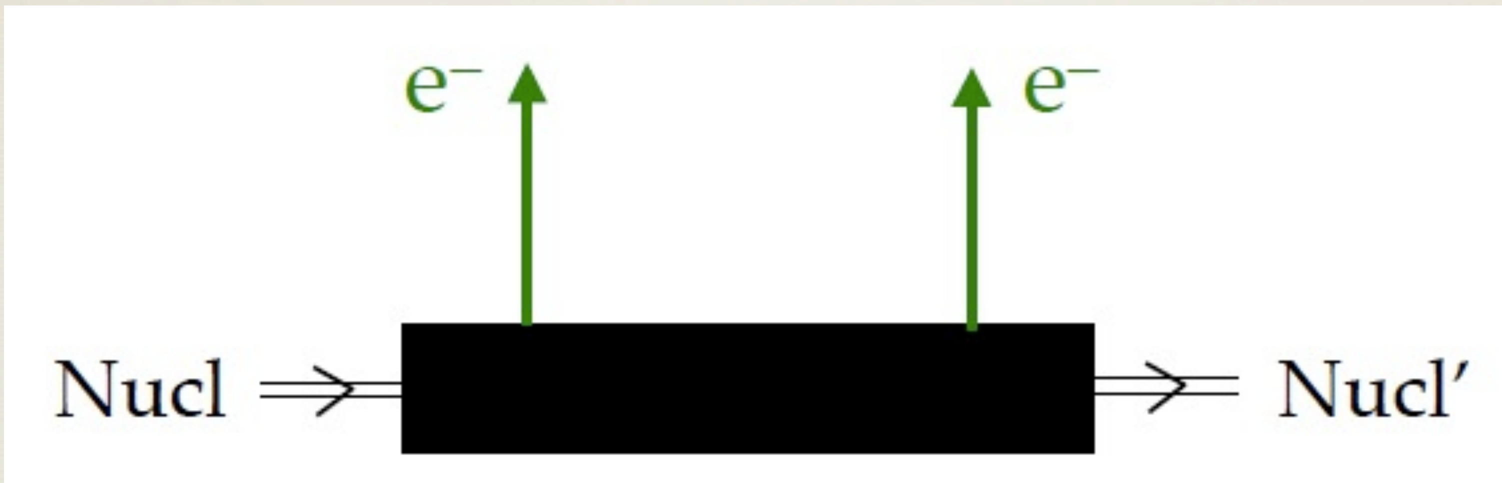
- The chiralities of out-going electrons can be LL,LR,and RR



Black box theorem
Schechter and Valle,1982

LHC meets neutrinos - Whether neutrinos are Majorana fermions

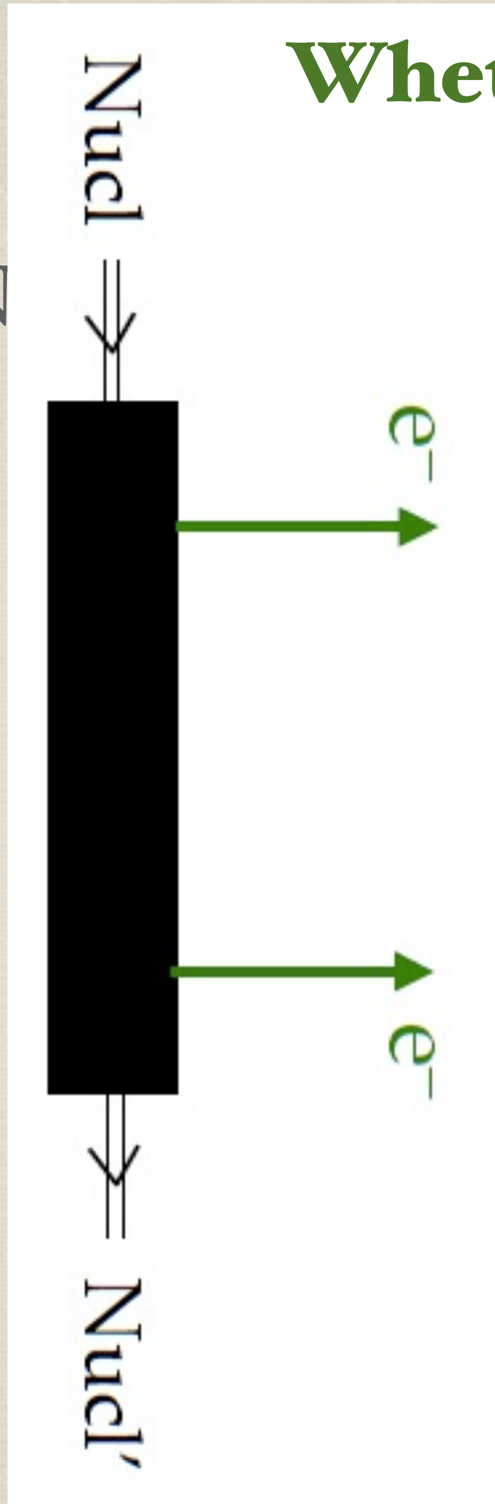
* Neutrinoless double beta decay ($0\nu\beta\beta$)



Looking for small Majorana masses. Thus we need a lot of parent nuclei (say one ton of them)

Lepton number is violated

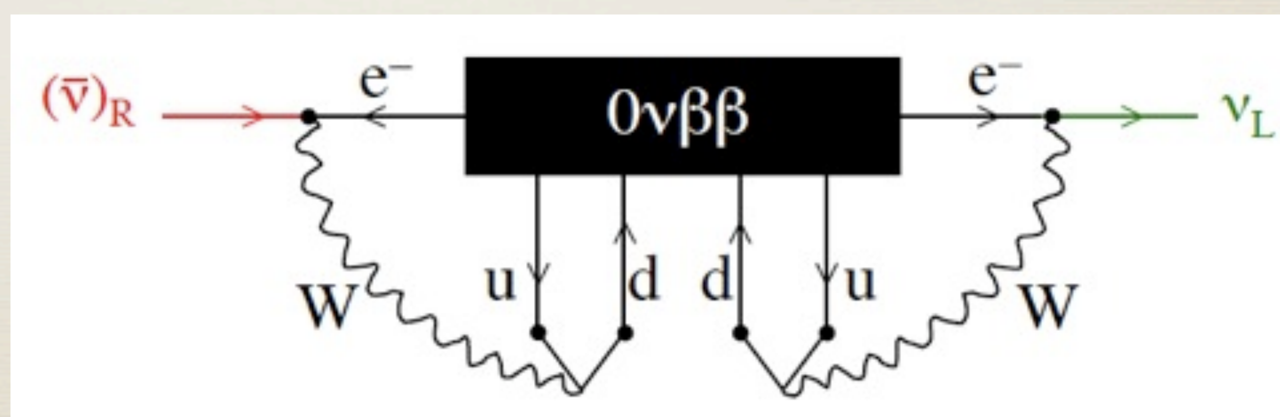
LHC meets neutrinos - Whether neutrinos are Majorana fermions



* N ouble beta decay (oνββ)

One can study the possibility of lepton number violation processes at LHC as well

As long as the oνββ is observed, it implies the existence of Majorana mass term (Schechter and Valle)

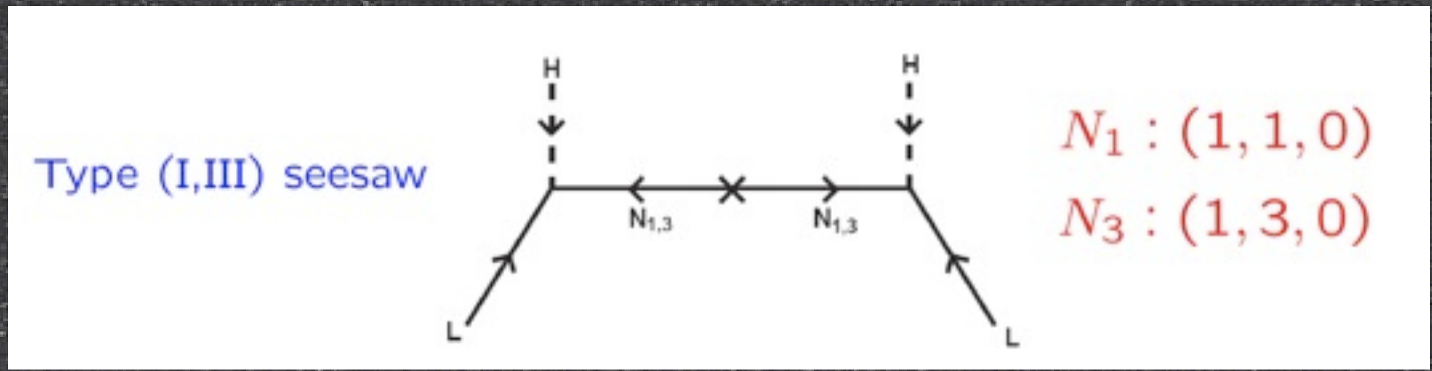


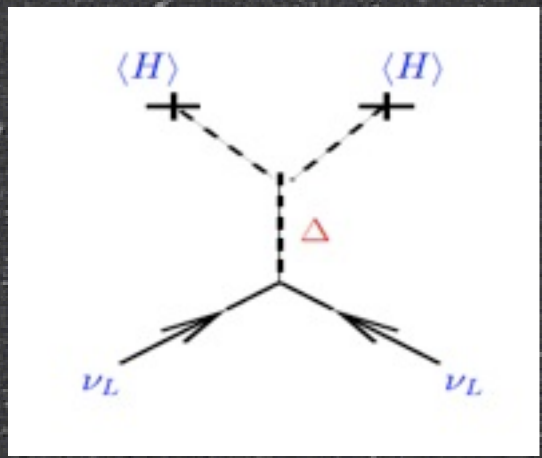
Theoretical aspects of ν model:

- Dirac neutrino : $\bar{\psi}_L H \psi_R$
- Majorana : tree level

Seesaw mechanism

Minkowski 1977 Foot,Lew,He,Joshi 1989





Type II seesaw

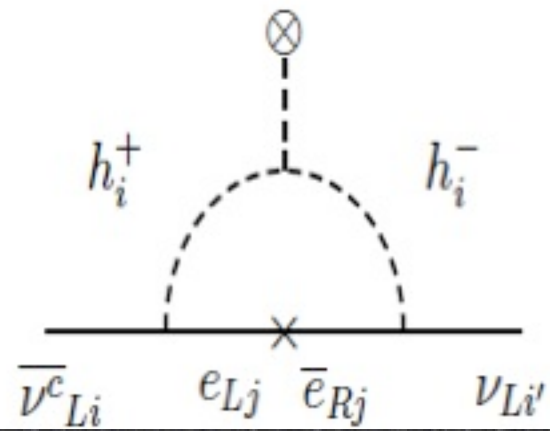
Schechter & Valle, 1980, 1982
Cheng & Li, 1980
Mohapatra, Senjanovic, 1981
...

Loop level

Zee, 1981:

2 Higgs doublets

+ 1 charged singlet

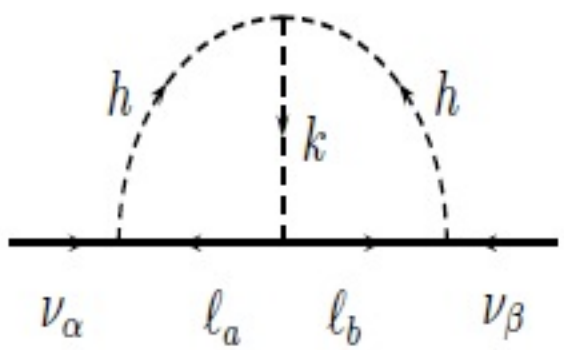


$f_{ab}\bar{L}_a^c L_b s^+$

Cheng & Li, 1980; Zee, 1985; Babu, 1988:

1 singly charged singlet

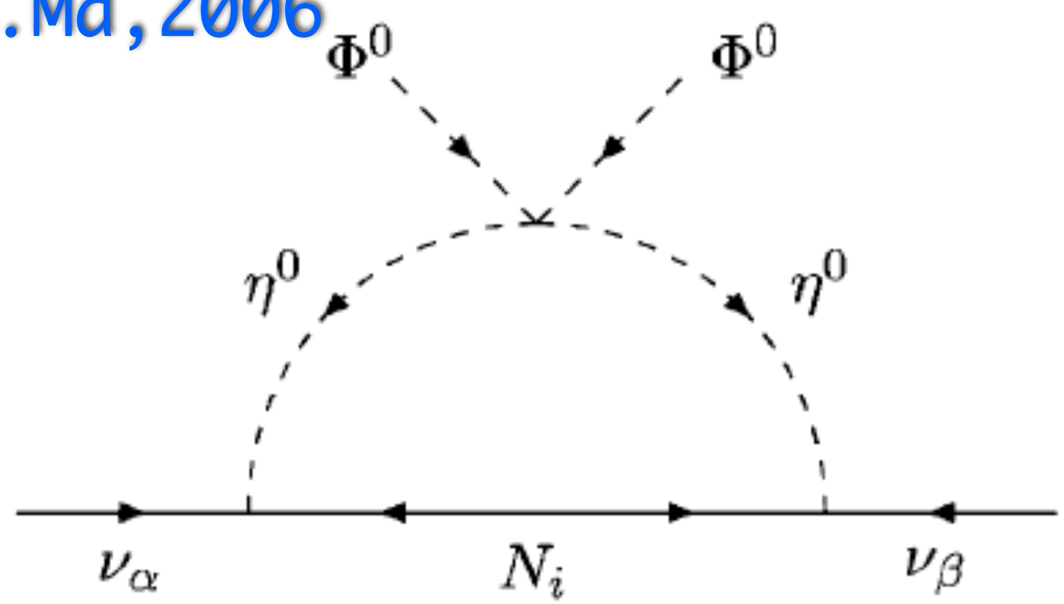
+ 1 doubly charged singlet



$f_{ab}\bar{L}_a^c L_b s^+$

$y_{ab}\bar{l}^c_{R_a} l_{R_b} \Phi^{++}$

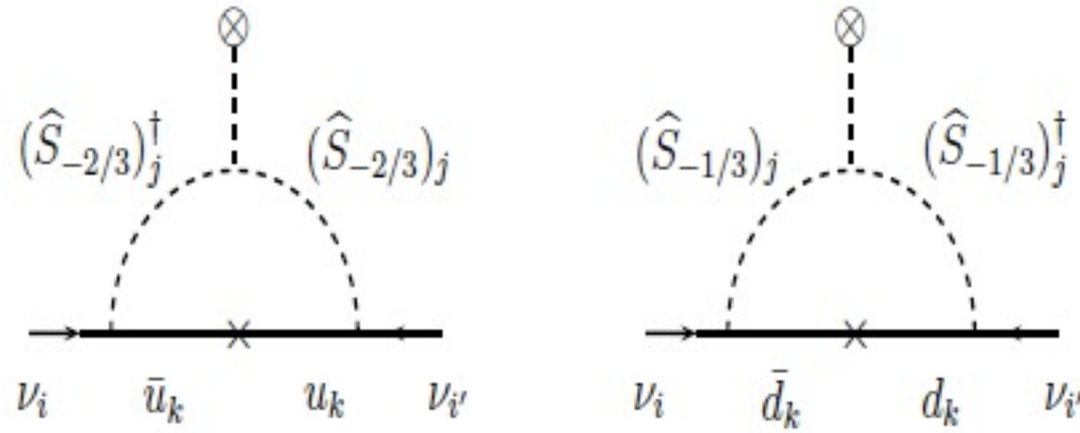
E.Ma,2006



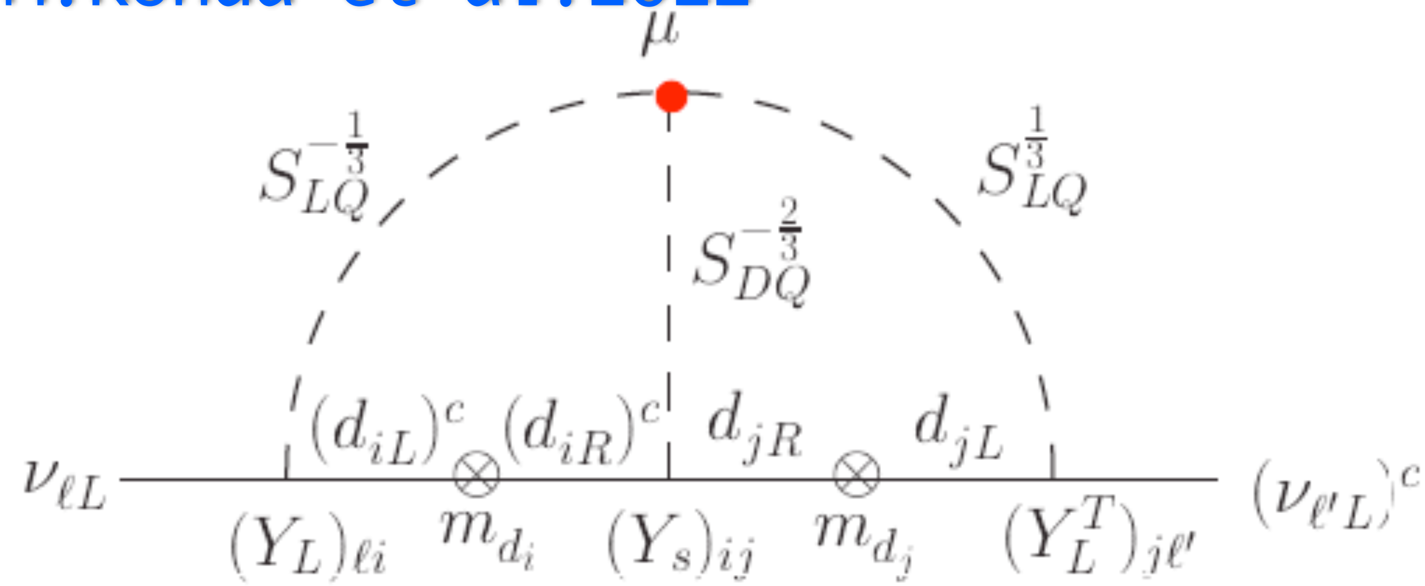
$\bar{\psi}_L H \psi_R$

Hirsch et al. 1996, Aristizabal et al. 2008

Leptoquarks



M.Kohda et al.2012



Idea and model

Our goal is to construct a model based on

1. Assuming scalars do not participate the strong interaction

   $\bar{\psi}_L H \psi_R$ $\quad$ $f_{ab}\bar{L}_a^c L_b s^+$ $\quad$ $g_{ab}\bar{L}_a^c L_b T$ $\quad$ $y_{ab}\bar{l}_{R_a}^c l_{R_b} \Phi^{++}$

2. The enhancement of Higgs to diphoton mode indicates the existence of higher charged particles

3. Extending the SM as minimal as possible - parameters and fields

- We introduce a scalar field ξ

ξ>4,(4,5,6,7,…) under $SU(2)_L$ with hypercharge Y=2, $Q=I_3+Y/2$

- The scalar potential reads

$$\begin{aligned} V(H,\xi,\Phi^{\pm\pm}) &= -\mu_H^2|H|^2+\lambda_H|H|^4-\mu_\xi^2|\xi|^2+\lambda_\xi|\xi|^4 \\ &+ \mu_\Phi^2|\Phi|^2+\lambda_\Phi|\Phi|^4+\lambda_{H\xi}|H|^2|\xi|^2 \\ &+ \lambda_{H\Phi}|H|^2|\Phi|^2+\lambda_{\xi\Phi}|\xi|^2|\Phi|^2 \\ &+ [\mu\xi\xi\Phi + \text{h.c.}], \end{aligned}$$

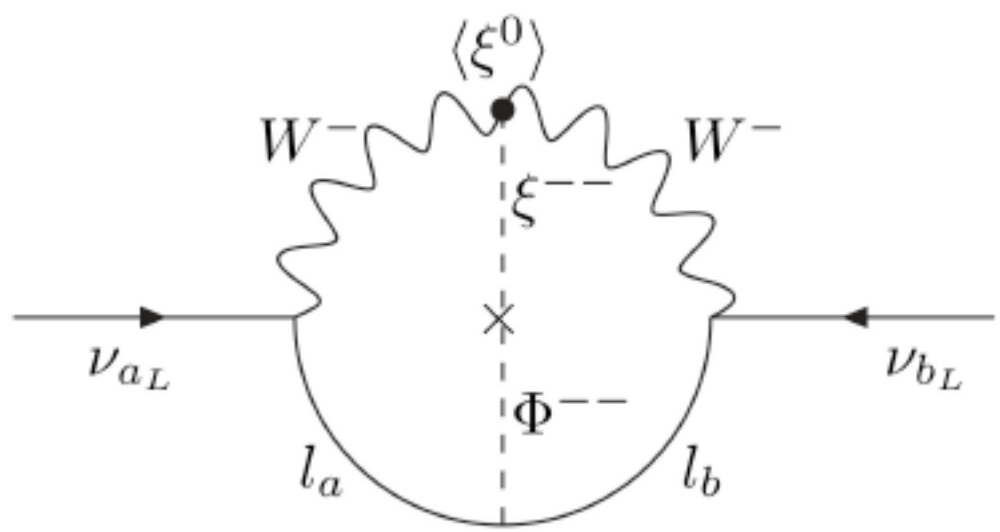
$$\begin{aligned} \xi\xi &= \epsilon_{ii'}\epsilon_{jj'}\epsilon_{kk'}\ldots\xi_{ijk\ldots}\xi_{i'j'k'\ldots} \\ &= -\epsilon_{i'i}\epsilon_{j'j}\epsilon_{k'k}\ldots\xi_{ijk\ldots}\xi_{i'j'k'\ldots} = 0 \end{aligned}$$

for ξ=4,6,8,10,…, even dimension

$$\langle \xi^0 \rangle = \frac{v_\xi}{\sqrt{2}} \text{ and } \langle H^0 \rangle = \frac{v}{\sqrt{2}},$$

tree level ρ parameter

$$\rho = \frac{\sum_i [I_i(I_i+1) - \frac{1}{4}Y_i^2] v_i^2}{\sum_i \frac{1}{2} Y_i^2 v_i^2}$$



$$\text{PDG } \rho = 1.0004^{+0.0003}_{-0.0004}$$

↓

$$\langle \xi^0 \rangle \leqslant \mathcal{O}(1) \text{ GeV}$$

$$I(M_W^2, M_{P_i}^2) = \int \frac{d^4q}{(2\pi)^4} \int \frac{d^4k}{(2\pi)^4} \frac{1}{k^2} \frac{1}{k^2 - M_W^2} \times \frac{1}{q^2 - M_W^2} \frac{1}{q^2} \frac{1}{(k-q)^2 - M_{P_i}^2} \simeq \frac{1}{(4\pi)^4} \frac{1}{M_{P_i}^2} \log^2\left(\frac{M_W^2}{M_{P_i}^2}\right),$$

$$m_{\nu_{ab}} = \frac{1}{\sqrt{2}} g^4 m_a m_b v_\xi y_{ab} \sin 2\theta \times [I(M_W^2, M_{P_1}^2) - I(M_W^2, M_{P_2}^2)]$$

$$\begin{pmatrix} -\frac{1}{4}(v^2\lambda_{H\xi}^{(2)} + v_\xi^2 \lambda_\xi^{(2)}) & \sqrt{2}\mu v_\xi \\ \sqrt{2}\mu v_\xi & \mu_\Phi^2 + \frac{1}{2}\lambda_{\xi\Phi} v_\xi^2 + \frac{1}{2}\lambda_{H\Phi} v^2 \end{pmatrix}$$

$$(\xi^{++}, \Phi^{++})$$

- We rewrite neutrino mass matrix

$$m_\nu = \widetilde{f}(M_{P_1}, M_{P_2}) \times \begin{pmatrix} m_e^2 Y_{ee} & m_e m_\mu Y_{e\mu} & m_e m_\tau Y_{e\tau} \\ m_e m_\mu Y_{e\mu} & m_\mu^2 Y_{\mu\mu} & m_\tau m_\mu Y_{\mu\tau} \\ m_e m_\tau Y_{e\tau} & m_\tau m_\mu Y_{\mu\tau} & m_\tau^2 Y_{\tau\tau} \end{pmatrix}$$
$$= f(M_{P_1}, M_{P_2}) \times \begin{pmatrix} 2.6\times 10^{-7}\, Y_{ee} & 5.4\times 10^{-5}\, Y_{e\mu} & 9.1\times 10^{-4}\, Y_{e\tau} \\ 5.4\times 10^{-5}\, Y_{e\mu} & 1.1\times 10^{-2}\, Y_{\mu\mu} & 0.19\, Y_{\mu\tau} \\ 9.1\times 10^{-4}\, Y_{e\tau} & 0.19\, Y_{\mu\tau} & 3.17\, Y_{\tau\tau} \end{pmatrix}$$

- The neutrino mass spectrum is predicted to be

Normal hierarchy spectrum !

$$\begin{pmatrix} 2.6\times 10^{-7}\, Y_{ee} & 5.4\times 10^{-5}\, Y_{e\mu} & 9.1\times 10^{-4}\, Y_{e\tau} \\ 5.4\times 10^{-5}\, Y_{e\mu} & 1.1\times 10^{-2}\, Y_{\mu\mu} & 0.19\, Y_{\mu\tau} \\ 9.1\times 10^{-4}\, Y_{e\tau} & 0.19\, Y_{\mu\tau} & 3.17\, Y_{\tau\tau} \end{pmatrix} \sim \begin{pmatrix} \varepsilon' & \varepsilon & \varepsilon \\ \varepsilon & 1+\eta & 1+\eta \\ \varepsilon & 1+\eta & 1+\eta \end{pmatrix}$$

Normal hierarchy spectrum

$$m_1, \quad m_2 = \sqrt{m_1^2 + \Delta m_{21}^2}, \quad m_3 = \sqrt{m_1^2 + \Delta m_{21}^2 + \Delta m_{32}^2}.$$

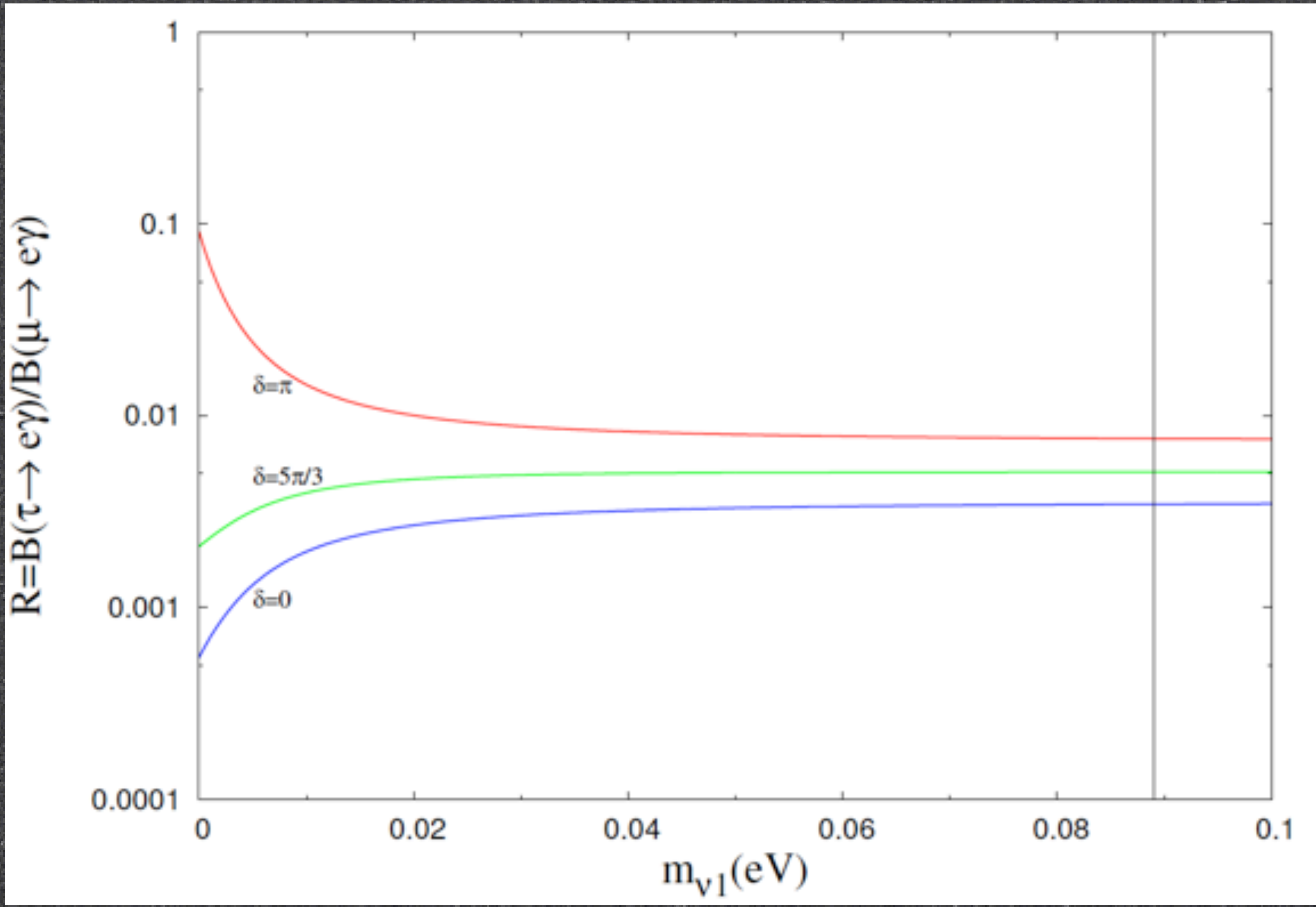
Majorana phases

$$M_\nu = U_{PMNS} \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 e^{i\psi_1} & 0 \\ 0 & 0 & m_3 e^{i\psi_2} \end{pmatrix} U_{PMNS}^T$$

$$m_{\nu_{ab}} = U_{\mathrm{PMNS}} m_{\nu_{diag}} U_{\mathrm{PMNS}}^\dagger \propto y_{ab},$$

After applying the more and more precise neutrino oscillation data one is able to pin down the neutrino parameters such as absolute scale and CP phase via the leptonic processes

- For example,



	Free Fluxes + RSBL		Huber Fluxes, no RSBL	
	bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	0.30 ± 0.013	$0.27 \to 0.34$	0.31 ± 0.013	$0.27 \to 0.35$
$\theta_{12}/^\circ$	33.3 ± 0.8	$31 \to 36$	33.9 ± 0.8	$31 \to 36$
$\sin^2\theta_{23}$	$0.41^{+0.037}_{-0.025} \oplus 0.59^{+0.021}_{-0.022}$	$0.34 \to 0.67$	$0.41^{+0.030}_{-0.029} \oplus 0.60^{+0.020}_{-0.026}$	$0.34 \to 0.67$
$\theta_{23}/^\circ$	$40.0^{+2.1}_{-1.5} \oplus 50.4^{+1.2}_{-1.3}$	$36 \to 55$	$40.1^{+2.1}_{-1.7} \oplus 50.7^{+1.1}_{-1.5}$	$36 \to 55$
$\sin^2\theta_{13}$	0.023 ± 0.0023	$0.016 \to 0.030$	0.025 ± 0.0023	$0.018 \to 0.033$
$\theta_{13}/^\circ$	$8.6^{+0.44}_{-0.46}$	$7.2 \to 9.5$	$9.2^{+0.42}_{-0.45}$	$7.7 \to 10.$
$\delta_{CP}/^\circ$	300^{+66}_{-138}	$0 \to 360$	298^{+59}_{-145}	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ eV^2}$	7.50 ± 0.185	$7.00 \to 8.09$	$7.50^{+0.205}_{-0.160}$	$7.04 \to 8.12$
$\frac{\Delta m^2_{31}}{10^{-3}\ eV^2}$ (N)	$2.47^{+0.069}_{-0.067}$	$2.27 \to 2.69$	$2.49^{+0.055}_{-0.051}$	$2.29 \to 2.71$
$\frac{\Delta m^2_{32}}{10^{-3}\ eV^2}$ (I)	$-2.43^{+0.042}_{-0.065}$	$-2.65 \to -2.24$	$-2.47^{+0.073}_{-0.064}$	$-2.68 \to -2.25$

T.Schwetz, et al

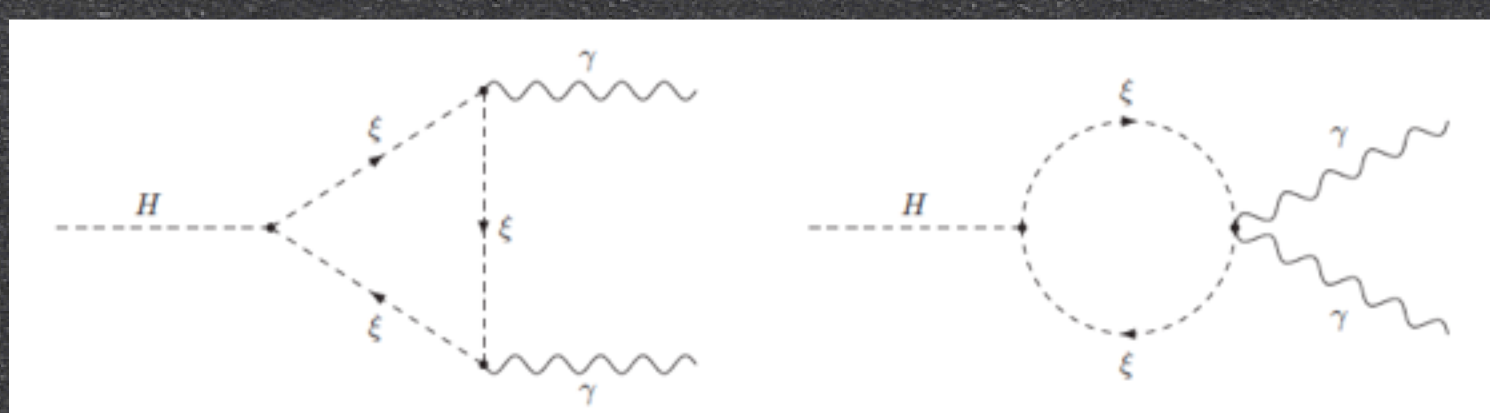
Some collider phenomenologies

One of the neutral scalars is SM-like

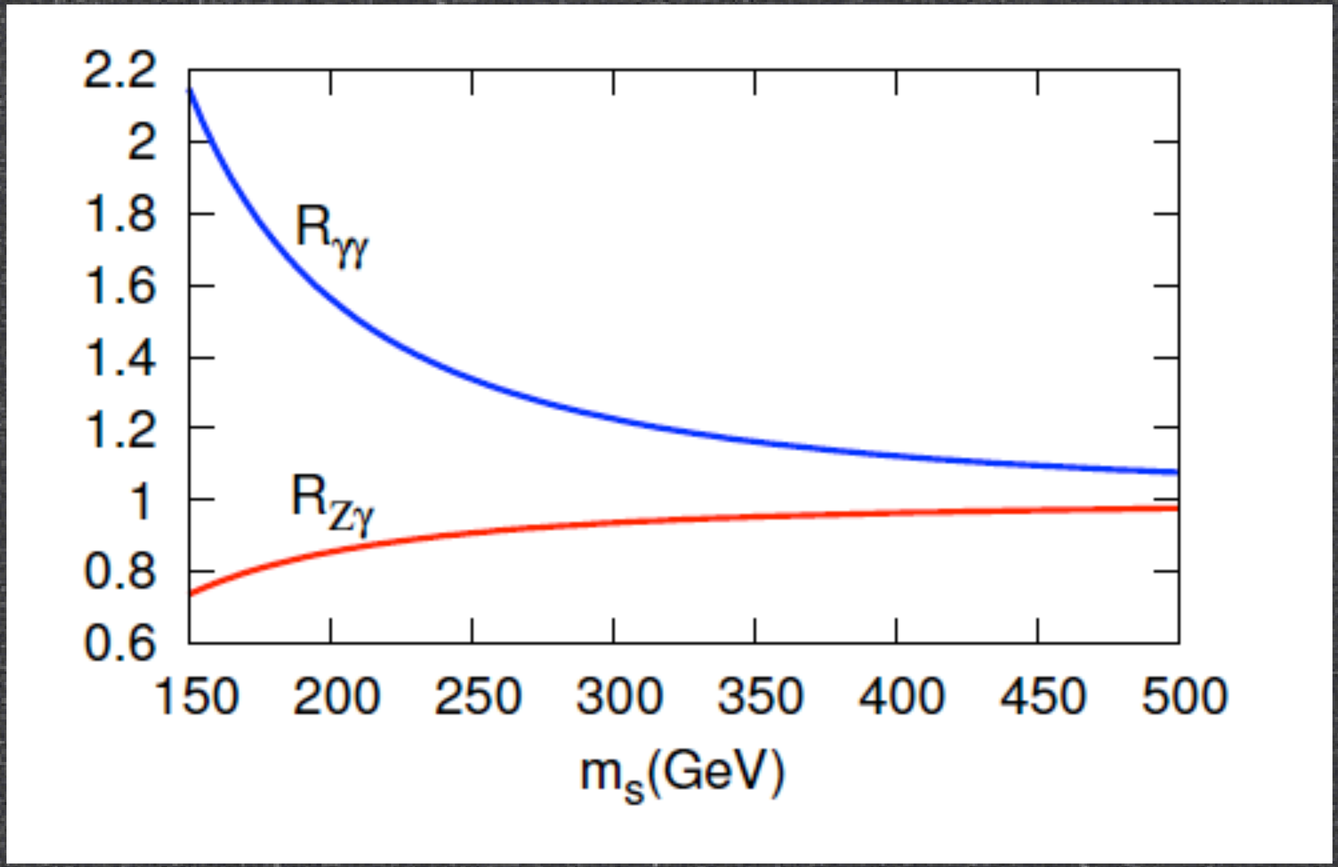
The recent 125 GeV resonance at LHC decays to ZZ and γγ channels are consistent with the SM Higgs prediction, though a 1.6 times excess of the diphoton mode is observed

$$\Gamma(H \to \gamma\gamma) = \frac{G_F \alpha^2 m_h^3}{128\sqrt{2}\pi^3} \Big| \sum_f N_f^c Q_f^2 A_{1/2}(\tau_f) + A_1(\tau_W) + \sum_{I_3} (I_3+1)^2 \frac{v}{2} \frac{\mu_s}{m_s^2} A_0(\tau_s) \Big|^2 ,$$

$I_3 = \frac{-n+3}{2}$ to $\frac{n+1}{2}$



Enhancement of the Higgs to diphoton



Trilinear coupling = -100 GeV

$$R_{\gamma\gamma} \equiv \Gamma(H \to \gamma\gamma)/\Gamma(H \to \gamma\gamma)_{\rm SM}$$

$$R_{Z\gamma} \equiv \Gamma(H \to Z\gamma)/\Gamma(H \to Z\gamma)_{\rm SM}$$

Interestingly,we recalculate the new scalar contribution to the h to Zγ with arbitrary electroweak quantum numbers

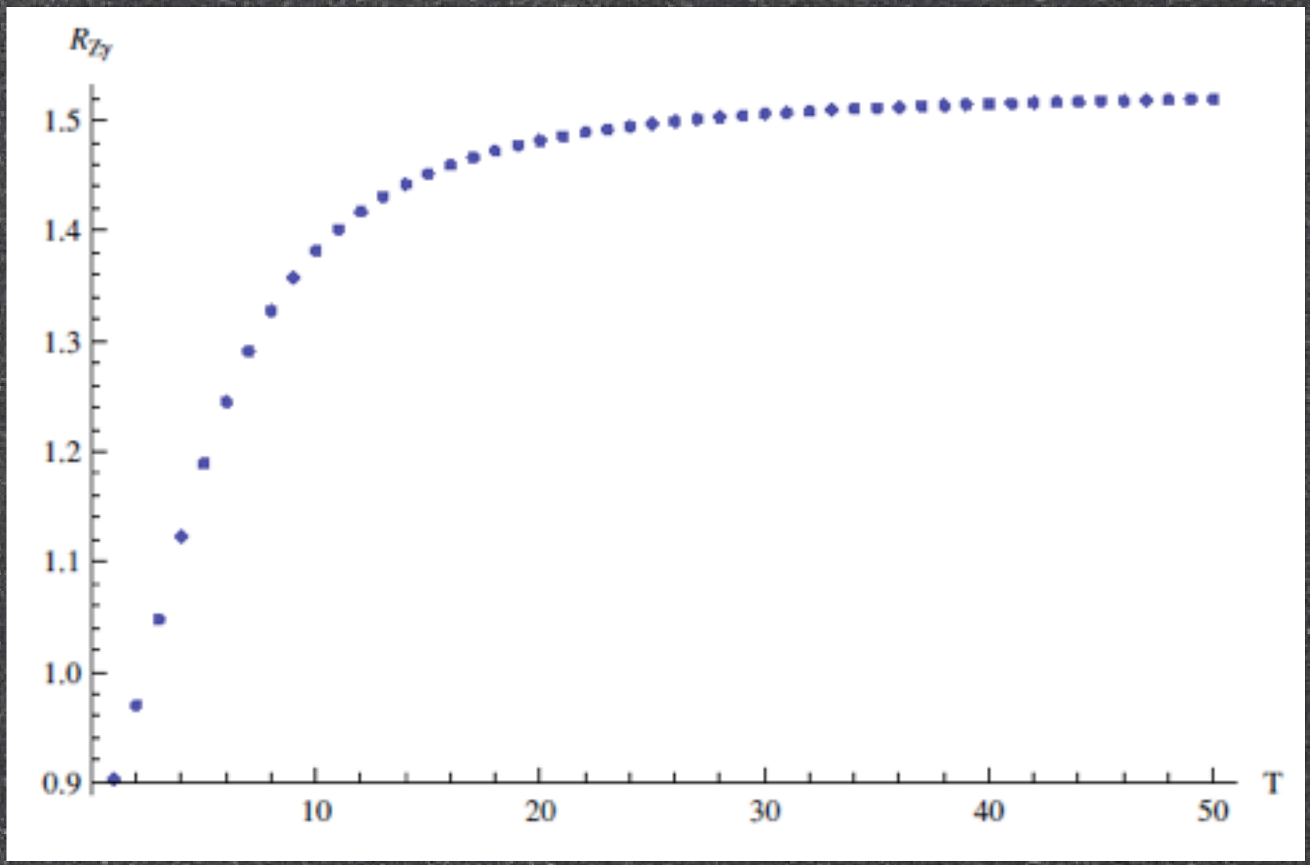
$$\Gamma(h \to Z\gamma) = \frac{\alpha^2}{512\pi^3} m_h^3 \left(1 - \frac{m_Z^2}{m_h^2}\right)^3 \left| \mathcal{A}_{SM}^{Z\gamma} - \frac{\lambda_{HS} v}{m_S^2} (2 \sum_{T_3} Q_S \cdot g_{ZSS}) A_0^{Z\gamma}(\tau_S, \lambda_S) \right|^2,$$

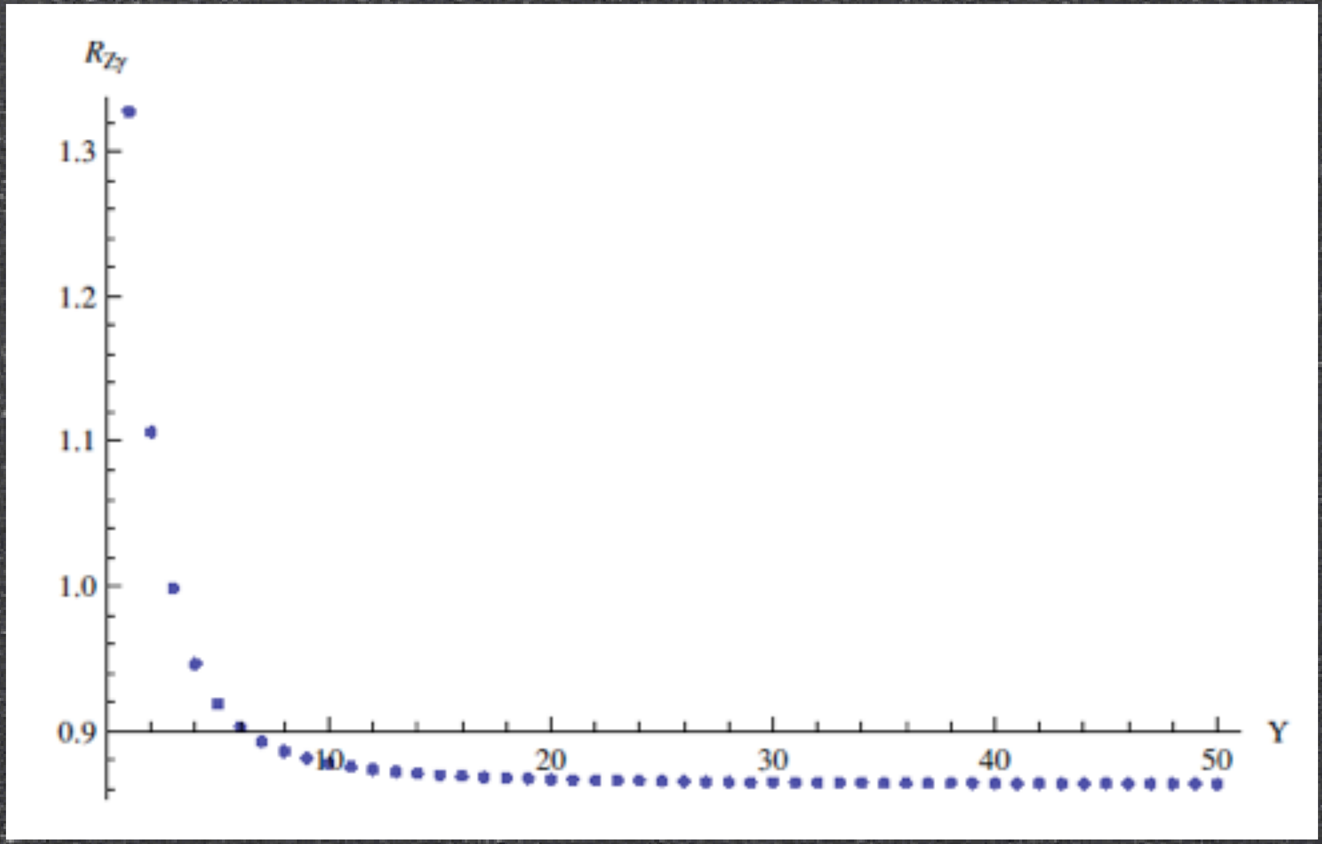
$$R_{Z\gamma} \equiv \frac{\Gamma(h \to Z\gamma)}{\Gamma_{SM}(h \to Z\gamma)} = \left| 1 - \tilde{N} \lambda_{HS} \frac{v^2}{m_S^2} \left(2 \sum_{T_3} Q_S \cdot g_{ZSS} \right) \frac{A_0^{Z\gamma}(\tau_S, \lambda_S)}{v \mathcal{A}_{SM}^{Z\gamma}} \right|^2$$

$$R_{\gamma\gamma} \equiv \frac{\Gamma(h \to \gamma\gamma)}{\Gamma_{SM}(h \to \gamma\gamma)} = \left| 1 + \tilde{N} \frac{\lambda_{HS}}{2} \frac{v^2}{m_S^2} \left(\sum_{T_3} Q_S^2 \right) \frac{A_0^{\gamma\gamma}(\tau_S)}{A_1^{\gamma\gamma}(\tau_W) + N_c Q_t^2 A_{1/2}^{\gamma\gamma}(\tau_t)} \right|^2$$

$$Q_S \cdot g_{ZSS} = \frac{1}{s_W c_W} \left(T_3 + \frac{Y}{2} \right) \left(T_3 c_W^2 - \frac{Y s_W^2}{2} \right)$$

Correlations between h to γγ and h to Zγ



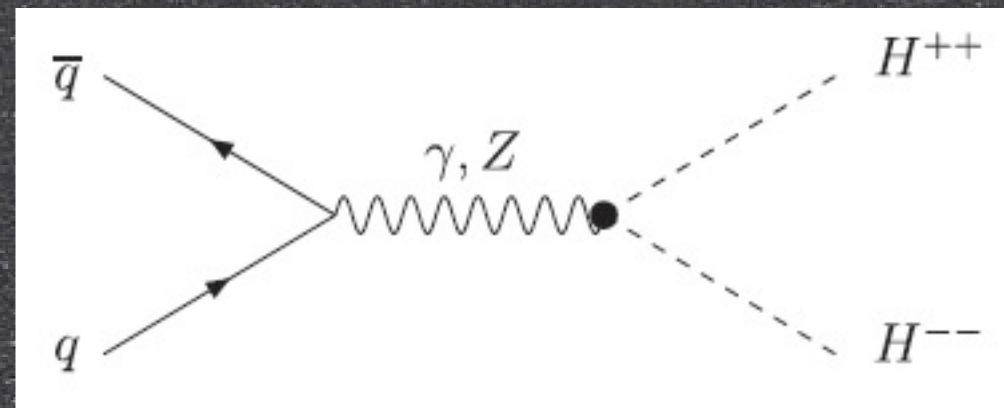


$R_{\gamma\gamma} = 1.5$ and $m_S = 300$ GeV

A generic bound

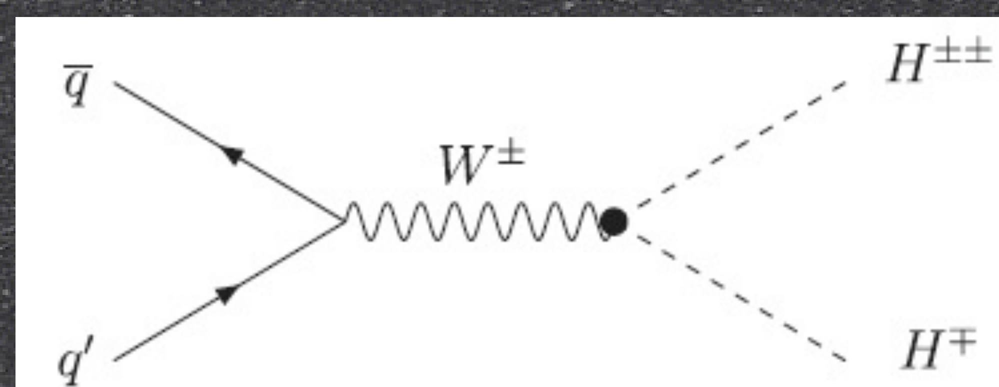
$$-0.31 < \frac{\sqrt{R_{Z\gamma}} - 1}{\sqrt{R_{\gamma\gamma}} - 1} < 1.04.$$

Production of doubly charged Higgs



$$\sigma_{\rm LO}(q\overline{q} \to H^{++}H^{--}) = \frac{\pi\alpha^2}{9Q^2}\beta_1^3\left[e_q^2 e_H^2 + \frac{e_q e_H \mathrm{v}_q \mathrm{v}_H (1 - M_Z^2/Q^2) + (\mathrm{v}_q^2 + \mathrm{a}_q^2)\mathrm{v}_H^2}{(1 - M_Z^2/Q^2)^2 + M_Z^2\Gamma_Z^2/Q^4}\right].$$

$$\sqrt{1 - 4m_{H^{\pm\pm}}^2/Q^2}$$

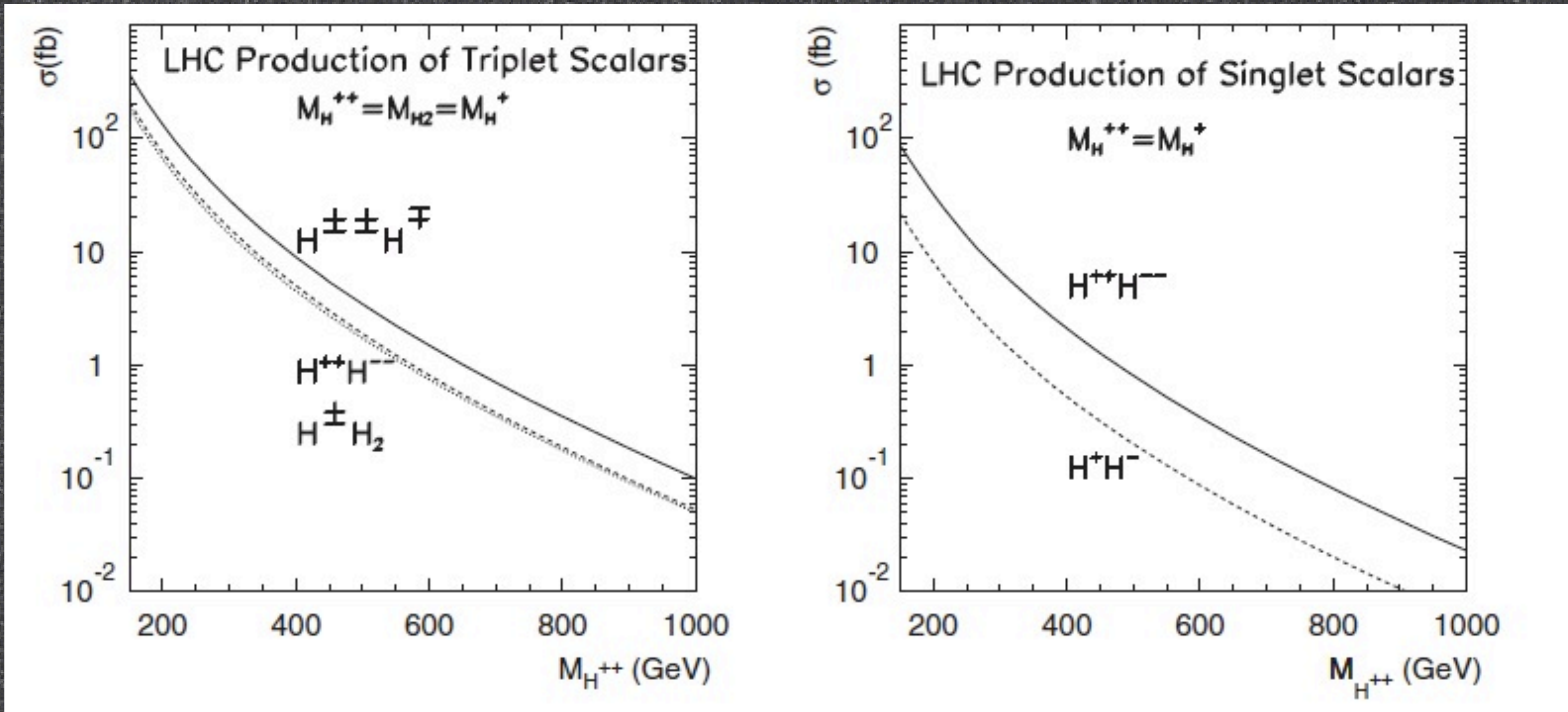


$$\sigma_{\rm LO}(q'\overline{q} \to H^{++}H^{-}) = \frac{\pi\alpha^2}{144 s_W^4 Q^2} C_T^2 p_W^2 \beta_2^3.$$

$$C_T = 2$$

$$p_W = Q^2/(Q^2 - M_W^2)$$

$$\sqrt{(1 - (m_{H^\pm} + m_{H^{\pm\pm}})^2/Q^2)(1 - (m_{H^\pm} - m_{H^{\pm\pm}})^2/Q^2)}$$

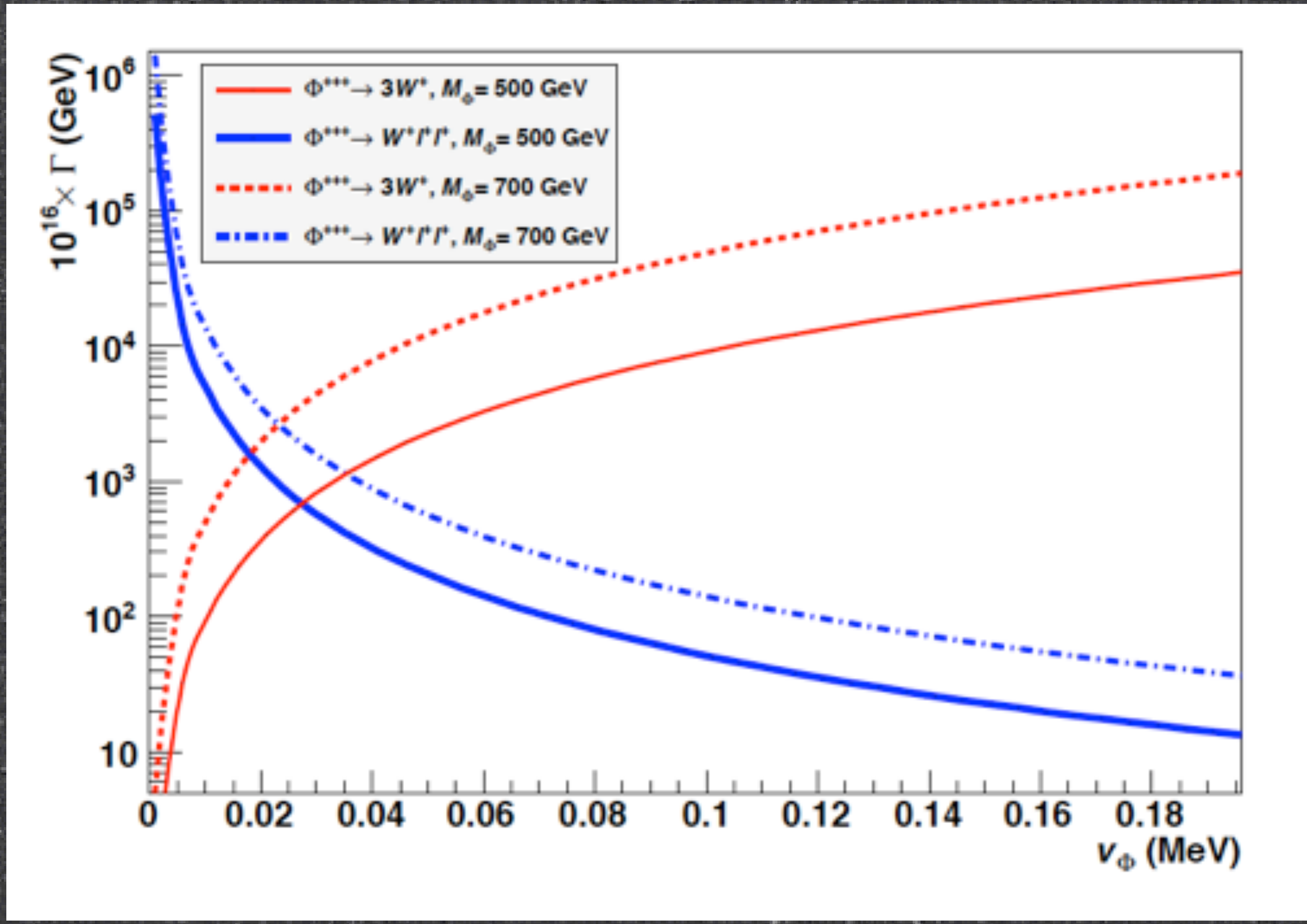


Doubly charged scalars could decay into both left-handed and right-handed lepton pairs

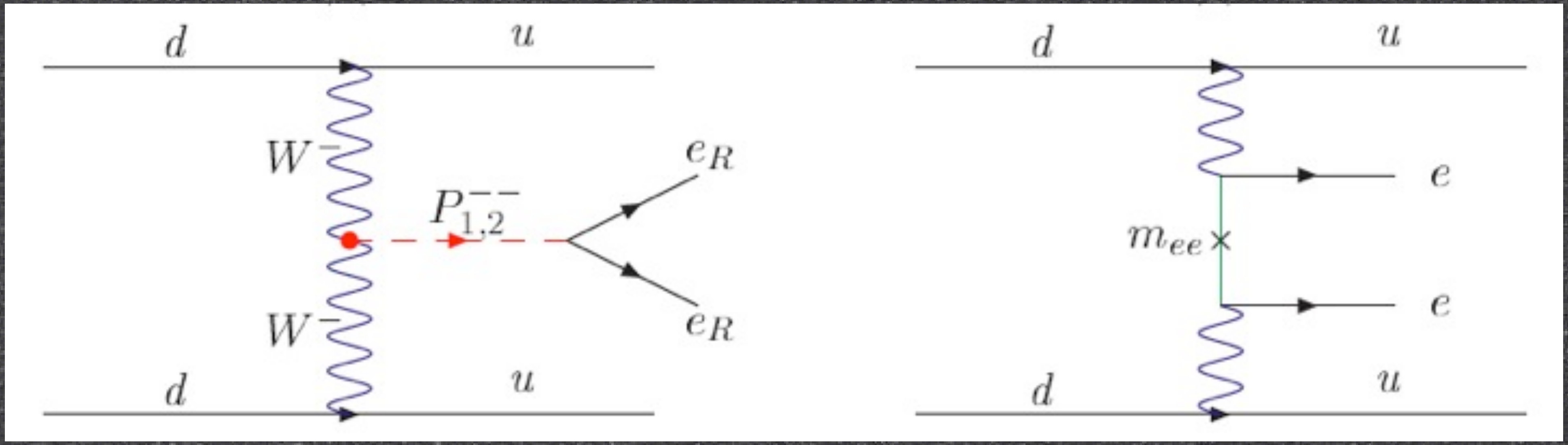
Triply charged scalar decays

$$\Gamma(\Phi^{+++} \to 3W) = \frac{3g^6}{2048\pi^3}\frac{v_\Phi^2 M_\Phi^5}{m_W^6}$$

$$\Gamma(\Phi^{+++} \to W^+\ell^+\ell^+) = \frac{g^2}{6144\pi^3}\frac{M_\Phi \sum_i m_i^2}{v_\Phi^2}$$



- A similar results for our model may apply to low energy neutrinoless double beta decay



The quark level amplitude due to the neutrino exchange is

$$A_\nu \sim \frac{g^4}{M_W^4} \frac{m_{ee}}{< p >^2}$$

<p> is average momentum of light neutrino exchange, typically <p> ~ 0.1 GeV

The doubly charged scalar exchange amplitude is

$$A_{P_{1,2}^{--}} \sim \frac{g^4 Y_{ee} v_T \sin 2\delta}{16\sqrt{2} M_W^4} \left(\frac{1}{M_{P_1}^2} - \frac{1}{M_{P_2}^2} \right)$$

We estimate that $A_\nu / A_{P_{1,2}^{--}} \lesssim 10^{-7}$

A remark of 0νββ in Type-II seesaw:

VOLUME 47, NUMBER 24 PHYSICAL REVIEW LETTERS 14 DECEMBER 1981

New Contribution to Neutrinoless Double Beta Decay in Gauge Models

R. N. Mohapatra
Department of Physics, City College of the City University of New York, New York, New York 10031

and

J. D. Vergados
Department of Physics, University of Ioannina, Ioannina, Greece

(Received 28 September 1981)

It is pointed out that in a general class of gauge models, there exist new contributions to neutrinoless double β transitions, that do not involve a Majorana neutrino but the decay of a doubly charged Higgs boson to electrons. Explicit calculations for the case $^{48}Ca \rightarrow {}^{48}Ti$ indicate that for reasonable choice of parameters, this new contribution may dominate over that involving light or heavy Majorana neutrinos.

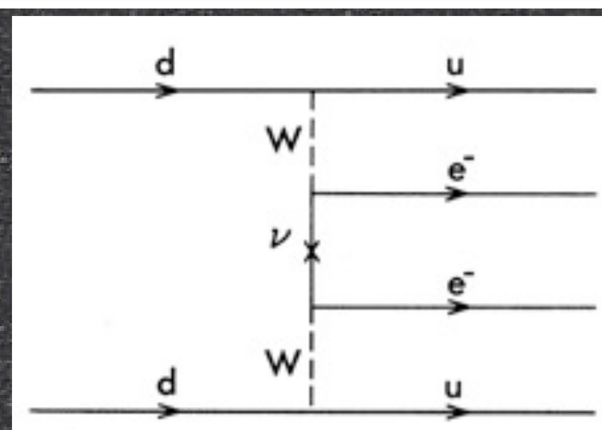
PHYSICAL REVIEW D VOLUME 26, NUMBER 9 1 NOVEMBER 1982

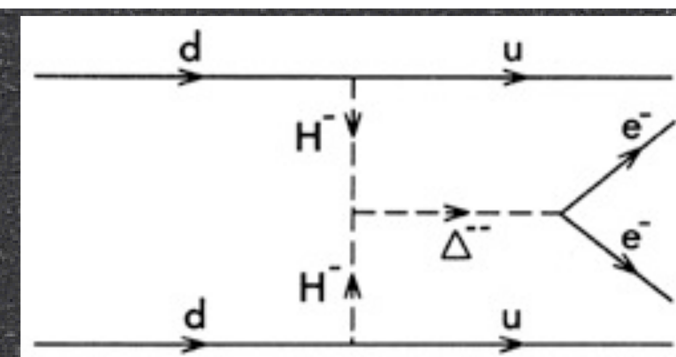
Triplet scalar bosons and double-β decay

Lincoln Wolfenstein
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

(Received 1 June 1982)

If triplet Higgs bosons provide a mechanism for a Majorana neutrino mass, Mohapatra and Vergados have suggested that diagrams involving these bosons might be comparable in importance to those involving virtual neutrinos. Arguments are given that the effective coupling associated with the boson diagrams is negligibly small.





(b)

conclusion

- We invented a class of models of neutrino generated at two-loop level in a minimal extension of the SM.
- The class of models predicts normal hierarchical spectrum of neutrino masses.
- Leptonic processes closely relate to the elements of neutrino mass matrix which enable one to pin down the important parameters of neutrinos.
- Correlations between h to γγ and h to Zγ are studied.
- Some novel signatures of the model can be probed at the LHC.

Thank you !