SCALARS 2013
12-16 September 2013
Warsaw, Poland

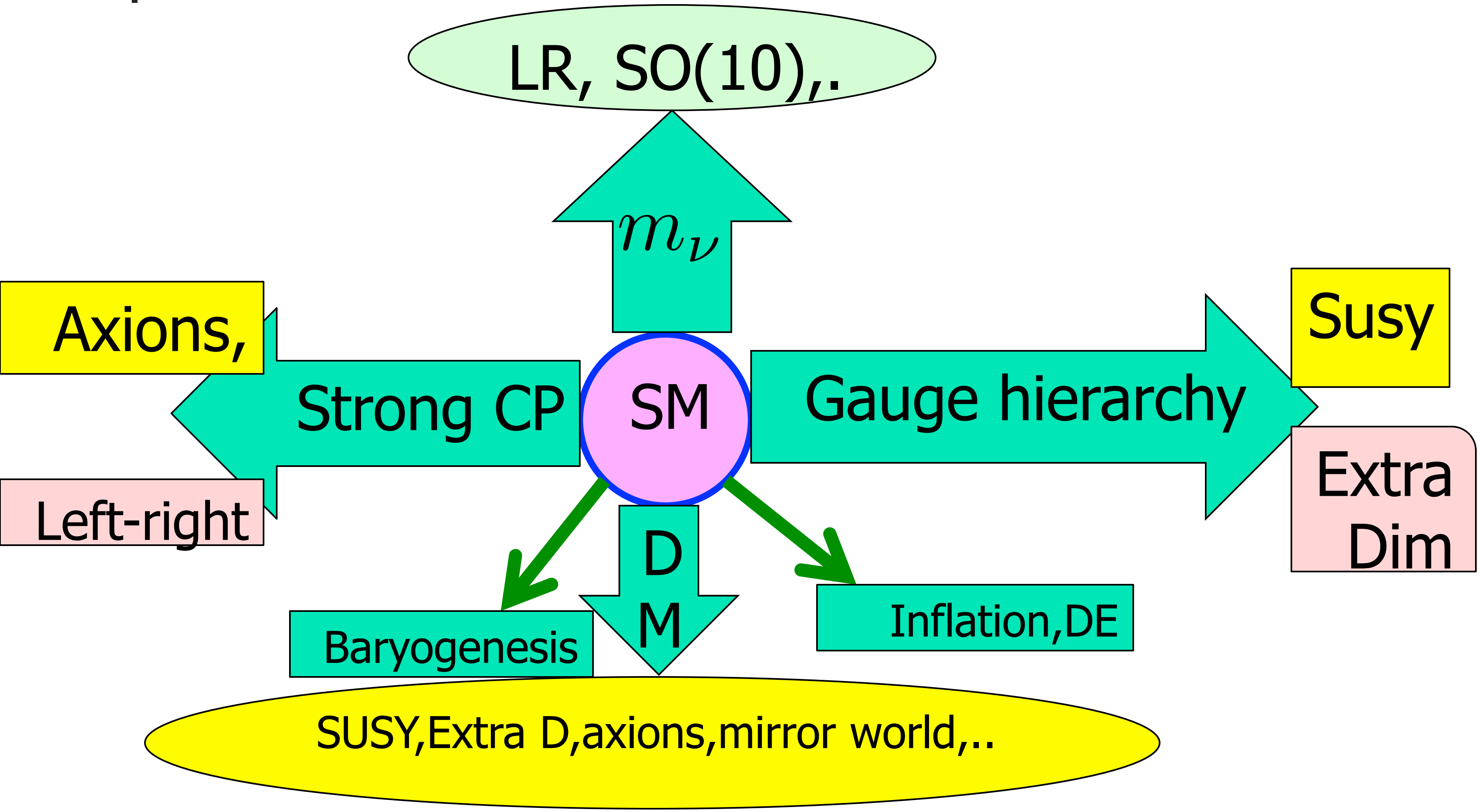
Probing TeV Scale Left-Right Seesaw

R. N. Mohapatra

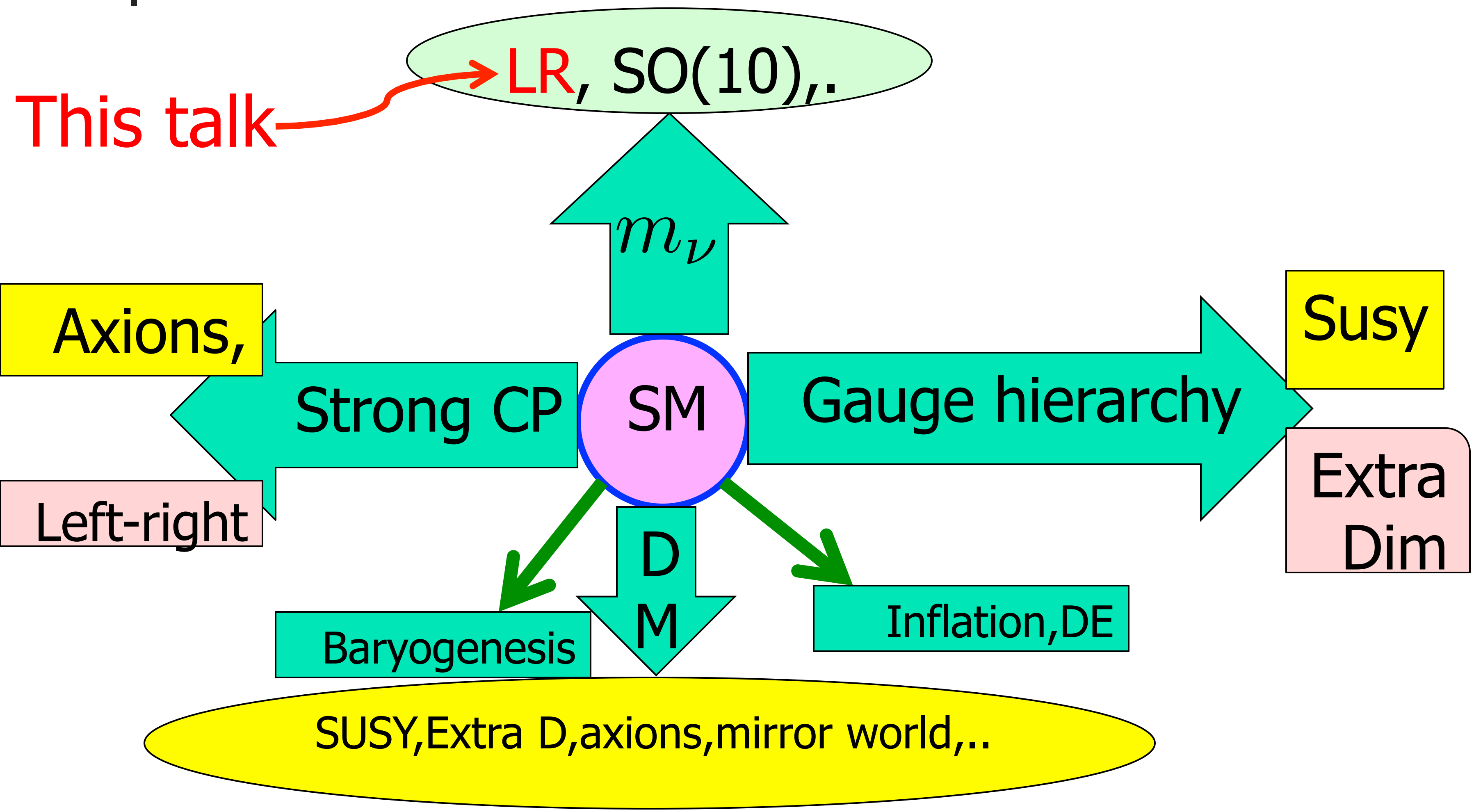
UNIVERSITY OF MARYLAND

Scalars 2013, Warsaw

BSM Particle physics landscape



BSM Particle physics landscape



Where does neutrino mass come from ?

- For charged fermions, mass comes from the Higgs vev

$$m_f = h_f v_{wk} \qquad v_{wk} = < h^0 >$$

Discovery of the 125 GeV Higgs h^0 confirms this.

- For neutrinos, this formula gives too large a mass- requires $h_\nu \sim 10^{-12}$!!

- There is a second mass problem !!

Weinberg Effective operator as a clue

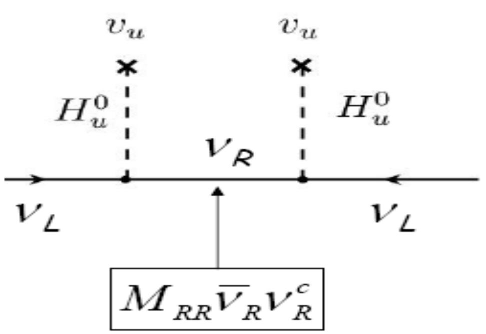
- Weinberg effective operator: $\lambda \frac{LHLH}{M}$

→ $$\boxed{m_\nu = \lambda \frac{v_{wk}^2}{M}}$$

- $\lambda \sim 1; M$ big → $m_\nu \ll m_f$ naturally !
- What is the Physics of M?
- To explore this, seek UV completion of Weinberg operator→ seesaw→**M-physics**

Type I SEESAW

- UV completion by adding SM singlet heavy Majorana neutrinos N to SM



$$\rightarrow \quad \boxed{m_\nu \cong -\frac{{h_\nu}^2 {v_{wk}}^2}{M_R}}$$

$$m_D = h v_{wk}$$

(Minkowski'77; Gell-Mann, Ramond, Slansky; Yanagida;Glashow; Mohapatra,Senjanovic'79)

Questions raised by seesaw

- Where did N come from ?
- Where did the seesaw scale come from ?

- Two theories that provide answers to these questions very economically are:

(i) Left-right model where N is the parity partner of ν and seesaw scale is $SU(2)_R$ scale !!

(ii) SO(10) GUT where N+15 SM fermions =16 spinor and seesaw scale = GUT scale.

Seesaw scale and testing seesaw experimentally

(ii) GUT embedding e.g. SO(10)→ very natural

since $h_\nu \sim h_q$ due to q-l unif.

but since , $M_R \sim 10^{14}$ GeV: very hard to test!!

(ii) Left-right can have M_R TeV scale: many tests !

However, even here, Generic theory→ $h_\nu \leq 10^{-5.5}$

Leaves out a lot of seesaw parameter space

e.g. theories with larger $h_\nu \sim 0.1 - 0.01$ would

allow access to it ! Are there such theories ?

Testing TeV seesaw

- Neutrino Matrix:

$$\begin{array}{c} \begin{pmatrix} \nu & N \end{pmatrix} \\ \mathcal{M}_\nu = \begin{pmatrix} 0 & m_D \\ m_D^T & M_N \end{pmatrix} \end{array}$$

$$m_D = h_\nu v_{wk}$$

- Two ways:

(i) Majorana mass M_N (breaks L):

(ii) $\nu - N$ mixing: $V_{\ell N} = \dfrac{h_\nu v_{wk}}{M_N}$

Two points of the talk:

- Are there natural models which have $h_\nu \sim .01$ yet have both tiny $m_\nu \sim .1\ eV$ so that $V_{\ell N}$ is large i.e. Allows excess to a larger part of seesaw parameter space !

- What are the tell-tale experimental signatures of such a scenario ?

A Strategy for large $V_{\ell N}$ with TeV M_N

$$m_D = \begin{pmatrix} m_1 & \delta_1 & \epsilon_1 \\ m_2 & \delta_2 & \epsilon_2 \\ m_3 & \delta_3 & \epsilon_3 \end{pmatrix} \qquad M_N = \begin{pmatrix} 0 & M_1 & 0 \\ M_1 & M_2 & 0 \\ 0 & 0 & M_3 \end{pmatrix}$$

(Kersten, Smirnov'07)

- Note if $\epsilon_i, \delta_i, M_2 = 0$ → $m_{\nu_i} = 0$ (sym lim.)
- sym. Br. $\delta_i, \epsilon_i \ll m_i$; $M_2 \ll M_{1,3}$
- Seesaw → $m_\nu \sim \frac{m_i m_j M_2}{M_1^2} + \frac{\epsilon_i \epsilon_j}{M_1}$ << $m_{e,q}$
- For $m_{i,j}$~1-10 GeV, $M_{1,3}$ > 100 GeV,→ $V_{\ell N}$<.1-.01

(other ex.: Pilaftsis,Underwood'05; Soni, Kiers..'06; Haba, Mimura ..'11; He et al'09; Mitra et al.'11)

Left-Right Model embedding

- LR basics: Gauge group: $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

- Fermions

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} \overset{P}{\Leftrightarrow} \begin{pmatrix} u_R \\ d_R \end{pmatrix} \quad \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \overset{P}{\Leftrightarrow} \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$$

$$L = \frac{g}{2}[\vec{J}_L^{\ \mu} \cdot \vec{W}_{\mu L} + \vec{J}_R^{\ \mu} \cdot \vec{W}_{\mu R}]$$

- Parity a spontaneously broken symmetry: $M_{W_R} \gg M_{W_L}$

Scalar sector and seesaw

- $SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y$ by $\Delta = \begin{pmatrix} \frac{1}{\sqrt{2}}\Delta^+ & \Delta^{++} \\ \Delta^0 & -\frac{1}{\sqrt{2}}\Delta^+ \end{pmatrix}_R$

(Mohapatra and Senjanovic; Minkowski)

Vev: $<\Delta>= \begin{pmatrix} 0 & 0 \\ v_R & 0 \end{pmatrix} \rightarrow M_N = f v_R$

- SM Higgs is in: $\phi = \begin{pmatrix} \phi_1^{\ 0} & \phi_2^{\ +} \\ \phi_1^{\ -} & \phi_2^{\ 0} \end{pmatrix}$ $\phi = \begin{pmatrix} \kappa & 0 \\ 0 & \kappa' \end{pmatrix}$

- Leads to seesaw matrix:

Parity breaking and neutrino mass

- Seesaw formula from parity breaking:
- $$\boxed{M_{\nu,N} = \begin{pmatrix} 0 & h\kappa \\ h\kappa & f v_R \end{pmatrix}} \rightarrow \quad m_\nu \simeq -\frac{(h\kappa)^2}{f v_R}$$

$$M_{W_R} = g v_R$$

- Generic version **(I)** needs $h \leq 10^{-5.5}$ and small $V_{\ell N}$
- $M_{W_R} \geq 2.9 TeV$ (CMS, ATLAS)

Realistic LR embedding of enhanced $V_{\ell N}$ (II)

- New model based on $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times (Z_4)^3$

$$\mathcal{L}_Y^\ell = h_{\alpha 1}\bar{L}_\alpha \tilde{\phi}_1 R_1 + h_{\alpha 2}\bar{L}_\alpha \phi_3 R_2 + h_{\alpha 3}\bar{L}_\alpha \phi_2 R_3 + f_{12}R_1 R_2 \Delta_{R,1} + f_{33} R_3 R_3 \Delta_{R,2} + h.c.$$

- Sym lim. $< \phi_a >= \begin{pmatrix} 0 & 0 \\ 0 & \kappa_a \end{pmatrix}$; $< \Delta^0_{R,i} >= v_{R,i}$

$$M_\ell = \begin{pmatrix} 0 & h_{12}\kappa_3 & h_{13}\kappa_2 \\ 0 & h_{22}\kappa_3 & h_{23}\kappa_2 \\ 0 & h_{32}\kappa_3 & h_{33}\kappa_2 \end{pmatrix}$$

→ $m_{e=0}$; $m_{\nu_i} = 0$

$$M_D = \begin{pmatrix} h_{11}\kappa_1 & 0 & 0 \\ h_{21}\kappa_1 & 0 & 0 \\ h_{31}\kappa_1 & 0 & 0 \end{pmatrix} \quad M_R = \begin{pmatrix} 0 & M_1 & 0 \\ M_1 & 0 & 0 \\ 0 & 0 & M_2 \end{pmatrix}$$

(Lee,Dev, RNM'13)

Realistic LR embedding of enhanced $V_{\ell N}$ (II)

- Break Discrete sym. $< \phi_i >= \begin{pmatrix} \delta_i & 0 \\ 0 & \kappa_i \end{pmatrix}$

  with $\delta_i \ll \kappa_i$ by sym.

- Leads naturally to

$$m_D = \begin{pmatrix} m_1 & \delta_1 & \epsilon_1 \\ m_2 & \delta_2 & \epsilon_2 \\ m_3 & \delta_3 & \epsilon_3 \end{pmatrix} M_R = \begin{pmatrix} 0 & M_1 & o \\ M_1 & \delta M & 0 \\ 0 & 0 & M_2 \end{pmatrix} \quad \delta_i, \epsilon_i \ll m_i$$

→ $$m_e \neq 0; m_{\nu_{ij}} \sim \frac{\delta_i \epsilon_j}{M_i}, \frac{\delta_i \delta_j}{M_i}, \frac{\epsilon_i \epsilon_j}{M_i} \sim eV$$

Model as theory of leptons: Inputs and outputs

- Model has 12 parameters:

- Outputs: 3 charged lepton masses, 3 nu masses, 3 mixing angles+must satisfy unitarity constraints on 9 $V_{\ell_i N_j}$ + $V_{e_R 12}$ which enters into $\mu \to 3e$

- Hence predictive and testable !!

NEUTRINO FITS AND ENHANCED $V_{\ell N}$ -TYPICAL SOLN.

$$M_D = \begin{bmatrix} 2.42239 & 2.23962\times10^{-10} & -0.000108617 \\ -1.81165 & 1.46738\times10^{-9} & 4.54245\times10^{-7} \\ -13.6056 & 6.21681\times10^{-10} & 0.000161672 \end{bmatrix}$$

$$M_e = \begin{pmatrix} 0.000266007 & 0.0151488 & -0.98912 \\ -0.000198941 & 0.0992534 & 0.00413658 \\ -0.00149406 & 0.0420506 & 1.47226 \end{pmatrix}$$

$$M_R = \begin{bmatrix} 0 & 813.254 & 0 \\ 813.254 & 1.29732\times10^{-9} & 0 \\ 0 & 0 & -2488.96 \end{bmatrix}$$

- $$V_{PMNS\,(fit)} = V_e^T V_\nu = \begin{pmatrix} 0.819226 & -0.553122 & 0.151304 \\ 0.35545 & 0.696887 & 0.622884 \\ -0.450027 & -0.456456 & 0.767386 \end{pmatrix}$$

- $V_{\ell N} \sim 10^{-2}$

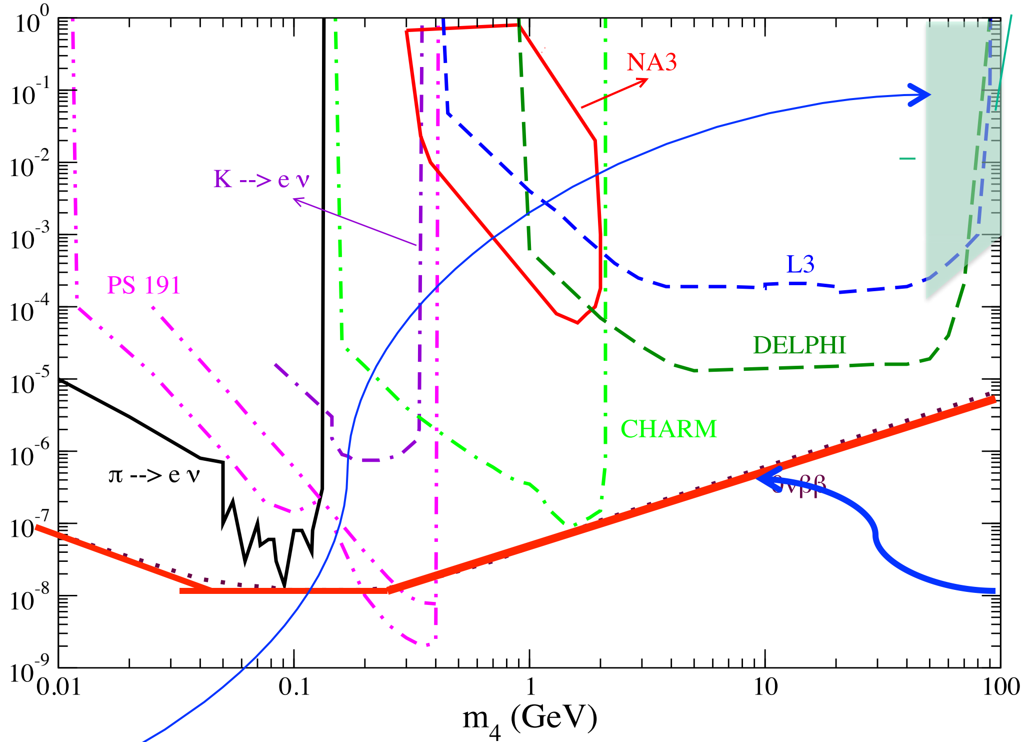
(Lee, Dev, RNM'13)

Current constraints on $V_{\ell N}$ for sub-TeV M_N

Constraints:

$$\frac{|U_{eN}|^2}{M_N} \leq 5\times 10^{-5} TeV^{-1}$$

$$|U_{\mu N}|^2 \leq 3\times 10^{-3}$$



nost relevant for seesaw

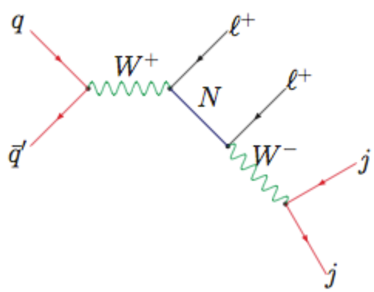
(Atre, Han, Pascoli, Zhang)

Bounds from LHC Higgs decay to $e^+e^- \not{E}_T$ from $pp\to h\to \ell N$, $N\to W^+\ell^-, Z+\nu$

(Dev, Francischini, RNM'12)

Testing in Colliders: SM Seesaw

- Signal of SM seesaw: $\ell^{\pm}\ell^{\pm}jj$ "Golden channel"



$$\propto |V_{\ell N}|^2$$

Signal strength depends on how big $V_{\ell N}$ is:

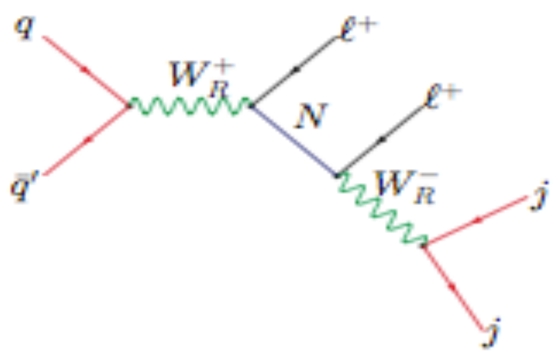
- $V_{\ell N}$ typically tiny;
- Even if it is big, less effective for M_N > 200 GeV

(del Aguila, Aguilar Saavedra)

Situation changes with LR seesaw:

- New contribution via WR production: $u\bar{d} \to W_R \to l^+ N$
- Subsequent N-decay via (a) νN mixing and/or (b) W_R exchange
- <u>Generic type I</u> $\theta_{\nu N} << 10^{-3}, M_{W_R} < 4TeV$ (a) negligible;
- Dominant

  graph(b)



$$N \to l^\pm jj$$

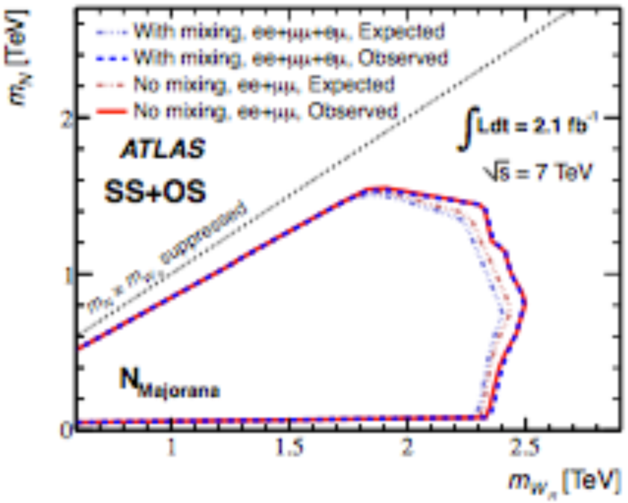
(RR diagram)

(Keung, Senjanovic'82)

- Same signal: valid for $M_N >> 200$ GeV.

Current LHC analysis: only W_R graph but not large $V_{\ell N}$

- Current limits from CMS, ATLAS 2.5-2.9 TeV;

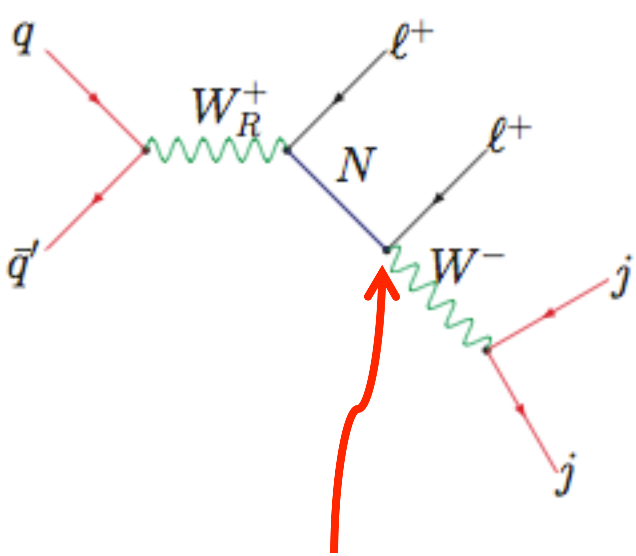


- Theory papers: Datta, Guchait,Roy; A.Ferrari et al., S. N. Gninenko, M. M. Kirsanov, N. V. Krasnikov and V. A. Matveev, A.Maiezza, M.Nemevsek, F.Nesti and G.Senjanovic, Y.Zhang;V.Tello, M.Nemevsek, F.Nesti, G.Senjanovic and F.Vissani; J.Chakrabortty, J.Gluza, R.Sevillano and R.Szafron; P.Das, F.F.Deppisch, O.Kittel and J.W.F.Valle; T. Han, I. Lewis, R. Ruiz, Z. Si; Joaquim, Aguilar-Saavedra;
- 14-TeV LHC reach for M_{WR} 6 TeV with 300 fb^{-1}

New graph for golden channel with "large" $V_{\ell N}$

$V_{\ell N} \sim 0.01 - 0.001$ can be probed:

- New graphs can dominate WR signal (Chen, Dev, RNM' arXiv: 1306.2342- PRD)



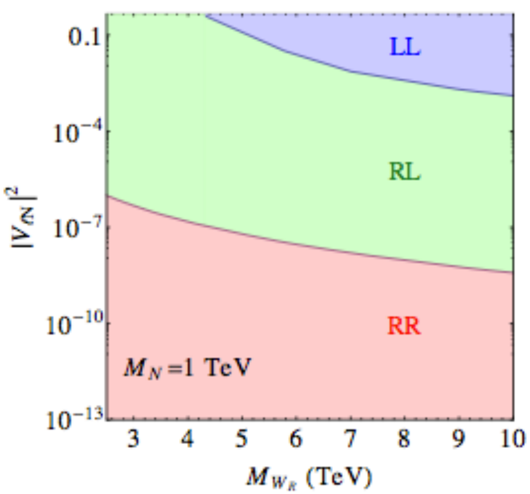
$$q\bar{q} \to W_R \to \ell + N;$$
$$N \to \ell W_L$$

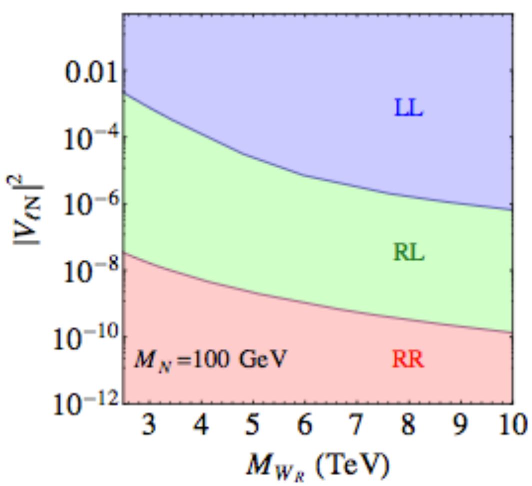
(RL diagram)

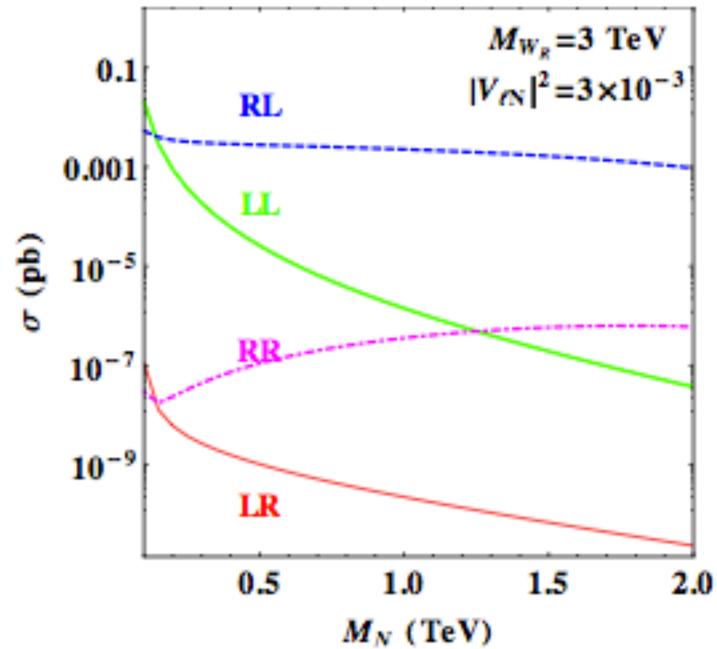
- Flavor dependence will probe Dirac mass M_D profile:

Domains where mixing dominates over RR

- Phase diagram:



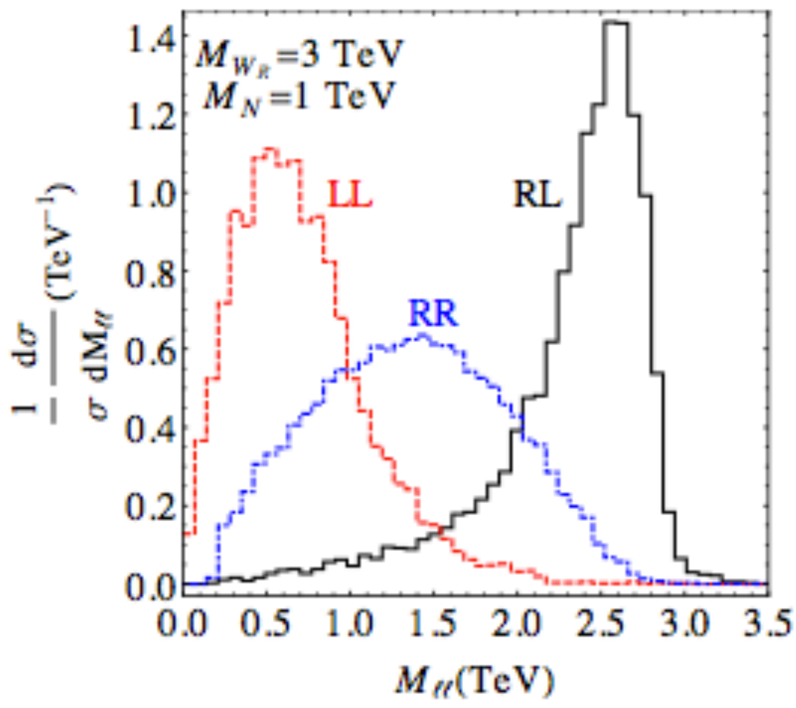




- Relative signal strength: RR vs RL: (mu channel)

Distinguishing RR from RL

- Dilepton invariant mass plots:



(Han, Lewis, Ruiz, Si)

CLFV in left-right seesaw

- New contribution to CLFV for generic seesaw from in LRSM(I) (Riazuddin, Marshak, RNM'81; Cirigliano,Kurylov,Musolf,Vogel'04)

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left(\frac{m_{W_L}^2}{m_{W_R}^2}\right)^4 \left(\sin\theta' \cos\theta' \frac{m_{N_2}^2 - m_{N_1}^2}{m_{W_L}^2}\right)^2 < 10^{-14}$$

$$M_{N_1} \ll M_{N_2} = 400\ GeV$$

- $$B(\mu^- \to e^-) = 10^{-6}\epsilon^2 \sin^2\theta' \cos^2\theta' < 10^{-12}$$

(M_2=100 GeV)

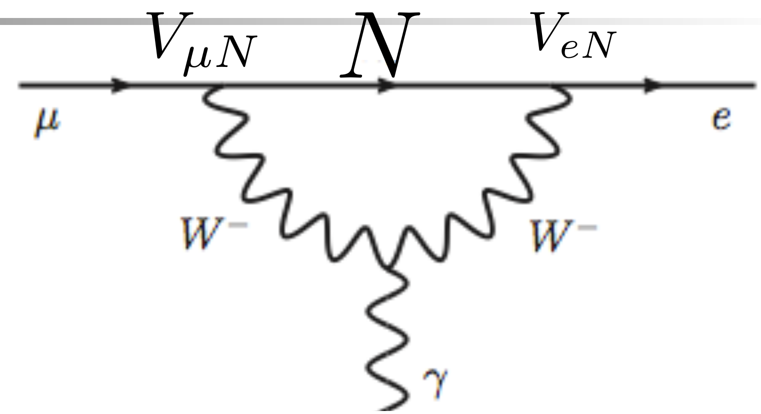
$$\epsilon = \frac{m_2^2 - m_1^2}{\sin^2\theta_W m_{W_L}^2}\left(\frac{m_{W_L}^2}{m_{W_R}^2}\right)^2 \left(\ln\frac{m_{W_R}^2}{M^2} - 2\right)$$

→ Can probe W_R and M_N to 10-30 TeV scale !!

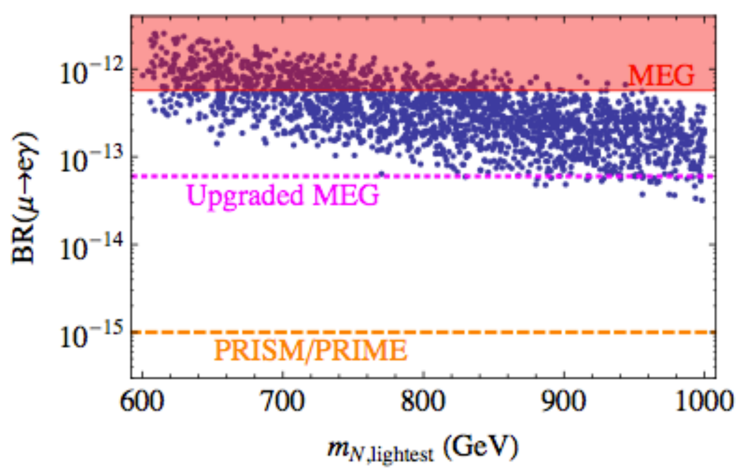
"Large" $V_{\ell N}$ and $\mu \to e + \gamma$

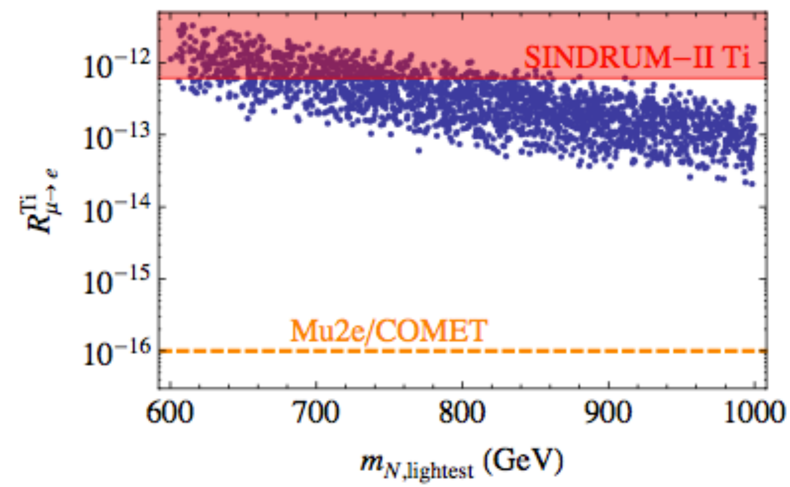
- New graphs:

(Pilaftsis; de Gouvea; Alonso, Gavela, Dhen, Hambye;…)



- Predictions of the model





- Testable in the current round

Testable next round e.g. PJX

Scalar spectrum

(i) New Higgs fields: $\Delta^{++}, \Delta^{+}, \Delta^{0}$

- They track the seesaw profile and N spectrum:
- Decays $f_{\alpha\beta}\ell_{\alpha}\ell_{\beta}\Delta^{++}$
- Have new effects on $\mu \to 3e \propto f_{ee}f_{e\mu}$

$$\beta\beta_{0\nu} \propto f_{ee}\frac{v_R}{M_{\Delta}^2 M_{W_R}^4}$$

(ii) Sub-TeV lepto-philic SM like Higgs tests

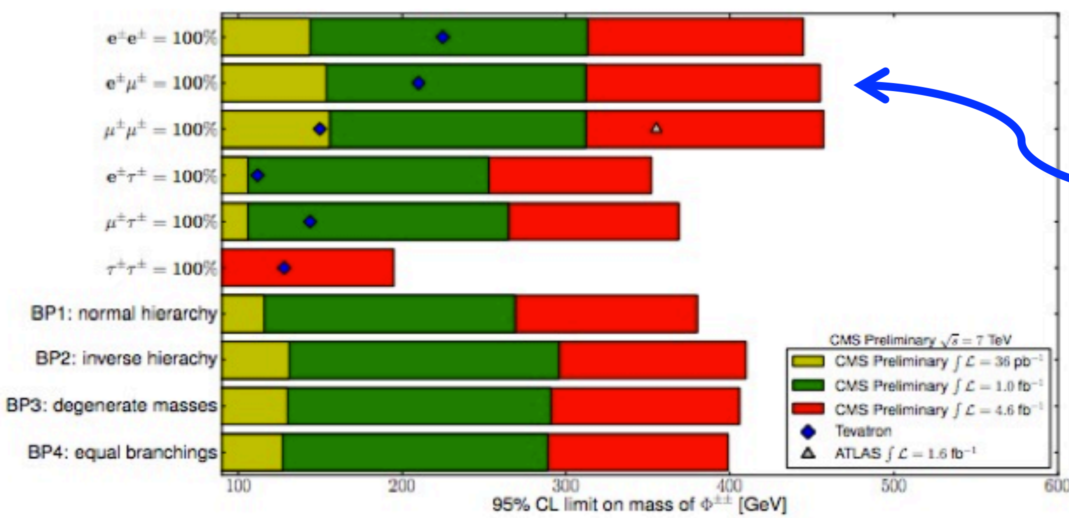
(iii) Analog of SM Higgs: $S \equiv Re(\Delta_R^0)$

LHC limits

- Pair production: cross section ~ fb at 350 GeV mass

  $pp \to \Delta^{++}\Delta^{--}$

CMS PAS HIG-12-005



This model:

$\Delta^{++} \to e^+ \mu^+$

M > 450 GeV

Flavor dependent result assuming 100% $\Delta^{++} \to \ell^+ \ell^+$ decay

Why sub-TeV leptophilic SM-Like Higgs ?

- $[Z_4]^3$ family sym for leptons allows only terms in Higgs potential of form: $\lambda_a Tr[\phi_a^\dagger \tilde{\phi}_a \phi_a^\dagger \tilde{\phi}_a]$

- As $\lambda_a \to 0$, Z_4 gets promoted to $U(1)_a$ so that EWSB leads to Goldstone states. Their masses are therefore of order $\lambda_a \kappa_a^2$ and hence sub-TeV.

- They couple only to leptons- hence lepto-philic !!
- LHC: $\sigma(pp \to Z^* \to AH) \sim 50\ fb$ (Aoki, Kanemura, Tsumura, Yagyu)

  $4\tau, 4\mu$ final states

Conclusion:

- **Seesaw:** Compelling big picture for nu masses;
A new Left-right model provides a natural TeV scale UV completion of seesaw with "large" $V_{\ell N}$!

- LHC could probe both Majorana mass as well as non-generic m_D via $\ell^+\ell^+$jj mode.
--Has 2 components: RR and RL due to $V_{\ell N}$; can be separated allowing a test of such models !!

- The set of models we predict $\mu \to e + \gamma$ and $\mu + N \to e + N$ slightly below the current limits

- Sub-TeV SM like leptophilic Higgs states.

Extra slides

New Higgs Effects in LR seesaw

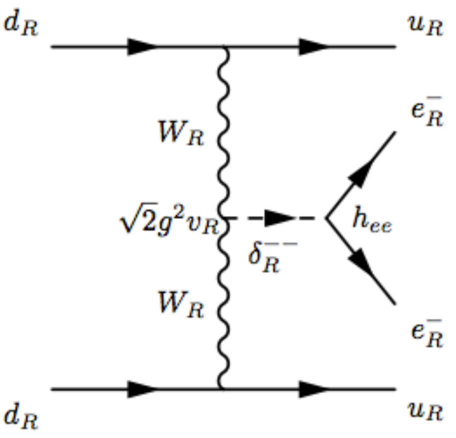
(i) Extra Higgs doublet: M_H in multi-TeV range.

(ii) Triplet Higgs: $\boxed{\Delta = \begin{pmatrix} \delta^+/\sqrt{2} & \delta^{++} \\ \delta^0 & -\delta^+/\sqrt{2} \end{pmatrix}_{L,R}}$

- δ^{++} in $\beta\beta_{0\nu}$ decay: (RNM, Vergados'81; piccioto, Zahir'82; lNemesvek, Nesti, Senjanovic, Tello, Vissani'12; Goswami et al;12; Awasthi,Parida,Patra'12; Barry,Rodejohann'12)

- $$\frac{M_N}{M^2_{\delta^{++}}} \leq 10^{-2} \text{ GeV}^{-1}$$

(for M_{WR} =3 TeV)



Future Sensitivities

- Experiment

No.	Observable	Upper Limit	Future Sensitivity
1.	$B(\mu \to e\gamma)$	2.4×10^{-12} [1]	$1 - 2 \times 10^{-13}$ [6], 10^{-14} [6]
2.	$B(\mu \to eee)$	10^{-12} [2]	10^{-16} [8], 10^{-17} [7]
3.	$R^{\mathrm{Ti}}_{\mu e}$	4.3×10^{-12} [3],	$3 - 7 \times 10^{-17}$ [10, 9], 10^{-18} [11, 7]
4.	$R^{\mathrm{Au}}_{\mu e}$	7×10^{-13} [4]	$3 - 7 \times 10^{-17}$ [10, 9], 10^{-18} [11, 7]
5.	$B(\tau \to e\gamma)$	3.3×10^{-8} [5]	$1 - 2 \times 10^{-9}$ [13, 12]
6.	$B(\tau \to \mu\gamma)$	4.4×10^{-8} [5]	2×10^{-9} [13, 12]
7.	$B(\tau \to eee)$	2.7×10^{-8} [5]	2×10^{-10} [13, 12]
8.	$B(\tau \to e\mu\mu)$	2.7×10^{-8} [5]	10^{-10} [12]
9.	$B(\tau \to \mu\mu\mu)$	2.1×10^{-8} [5]	2×10^{-10} [13, 12]
10.	$B(\tau \to \mu ee)$	1.8×10^{-8} [5]	10^{-10} [12]

Table 1: Current upper limits and future sensitivities of CLFV observables under study.

Beyond left-right : Quark-lepton Unif.

- If Q-L unified at the seesaw scale, a model is

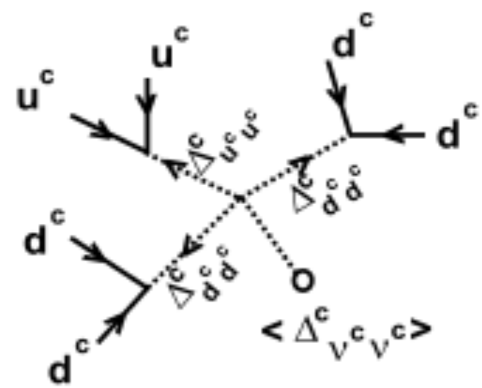
$$SU(2)_L \times SU(2)_R \times SU(4)_c \begin{pmatrix} u & u & u & \nu \\ d & d & d & e \end{pmatrix}_{L,R}$$

→SU(4) generalization of the seesaw Higgs field Δ_R has partners Δ_{qq} connecting to quarks:

→leads to neutron-anti-neutron oscillation: (Mohapatra,Marshak'80)

→No proton decay.

-Example of nu mass-NNbar connection

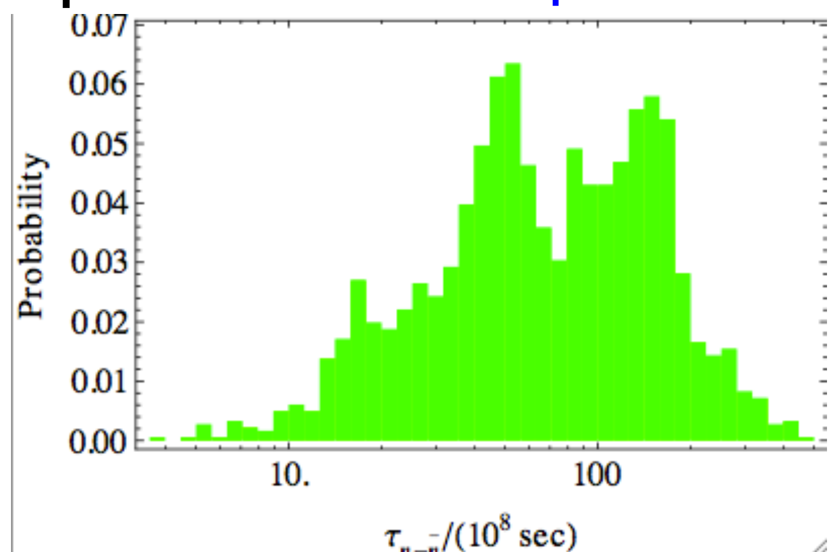


$$\frac{\lambda f^3 v_{BL}}{M_\Delta^6}$$

observable for TeV sextets

Baryogenesis constraints

- If NN-bar is observable, it will erase all pre-existing baryon asymmetry: need to generate baryons below weak scale:
- Baryogenesis via higher dim operators: Post-sphaleron baryogenesis: (Babu,Nasri, RNM'07)
- upper bound on Nnbar transition time $< 5\text{x}10^{10}$sec. (Babu,Dev,Fortes,RNM'arXiv:1303.6918)



- Predicts ~TeV color sextet fields for LHC.

CLFV that directly relates to neutrino Majorana mass

- $\mu \to e\gamma, \mu \to 3e, \mu^- \to e^-$ conserve L and are not true tests of Majorana nu mass.
- However $\mu^- \to e^+, \mu^- \to \mu^+$ are $\Delta L \neq 0$

$$B(\mu^- Ti \to e^+ Ca) \leq 3.6 \times 10^{-11}$$

- Flavor analog of $\beta\beta_{0\nu}$ decay
- Small in minimal type I
- Other related processes: $K^+ \to \pi^- e^+ e^+, \pi^- e^+ \mu^+$

$V_{\ell N}$ constraints from 125 GeV Higgs for >100 GeV M_N

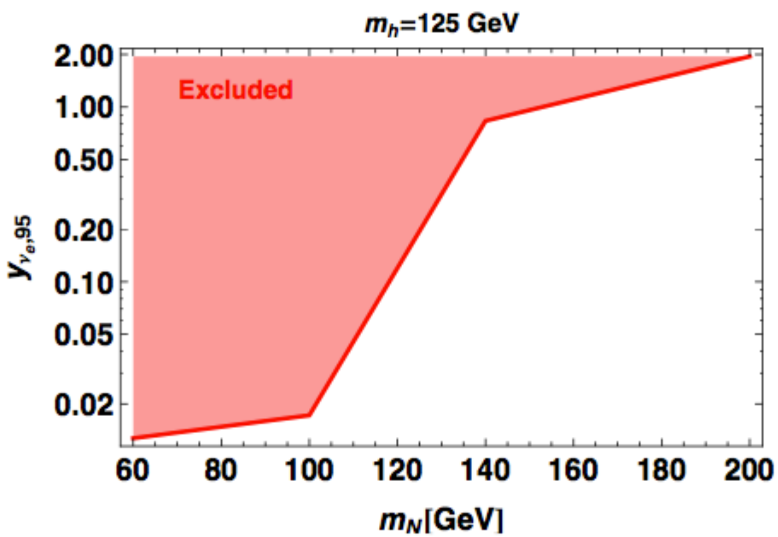
- 125 Higgs bound on $V_{\ell N}$

$$\mathcal{L}_h = h_\nu \bar{\nu} N h \rightarrow pp \to h \to \ell N$$

$$N \to W^+\ell^-, Z+\nu$$

LHC Higgs search final states → $e^+e^- \not{E}_T$

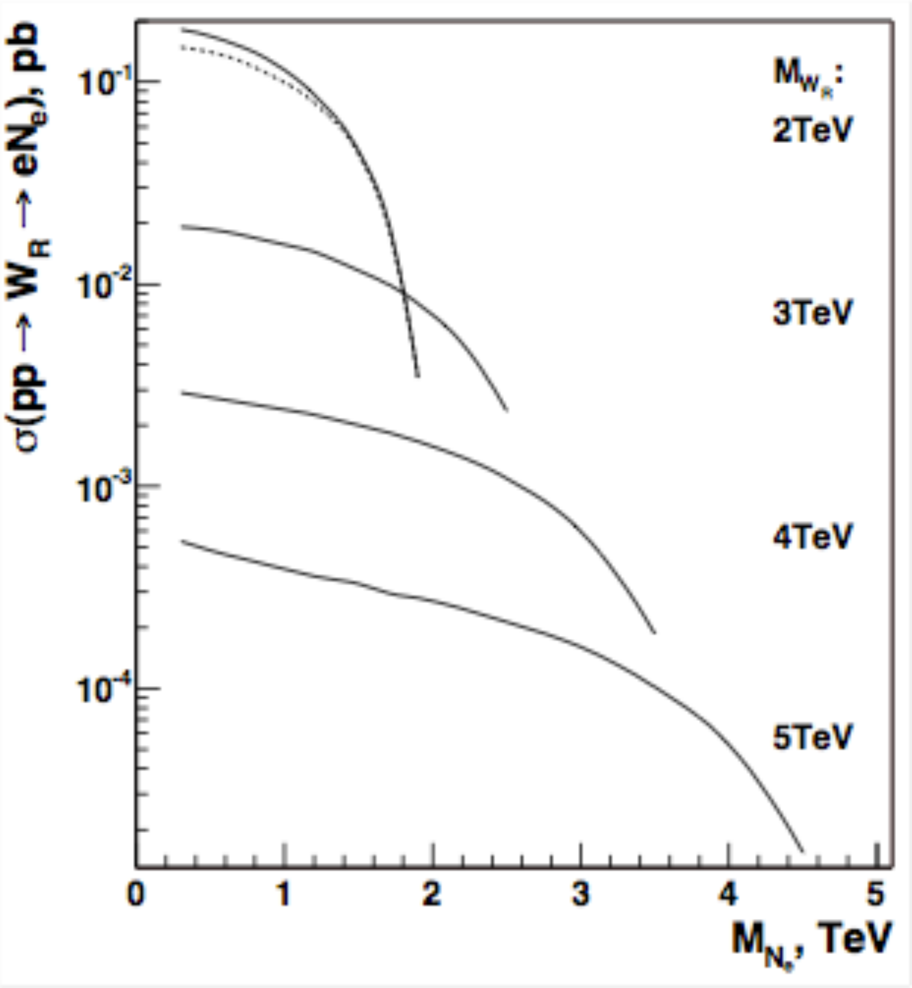
(Dev, Franceschini, RNM'12)



- **Bounds very weak for >100 GeV N !!**

WR production cross section at LHC

- Ginienko et al.

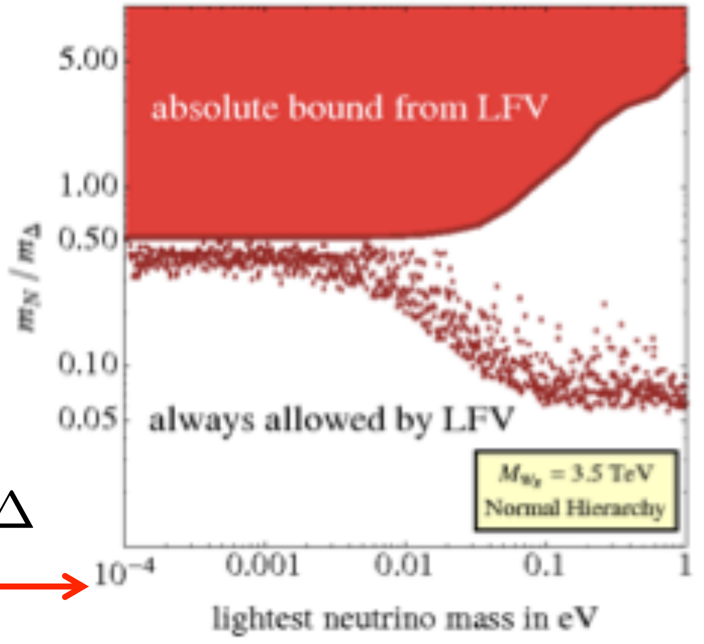


LR Higgs induced CLFV : Generic case (I)

- (V. Tello,Nemevsek,Nesti,Senjanovic,Vissani'12; Cirigliano, Kurylov,Ramsey-Musolf, Vogel'04)
- Loops involving δ^{++} and δ^{+}

→ $\mu \to e|_{Au}$, $\mu \to e\gamma$

$$B(\mu Au \to eAu) \simeq 5 \times 10^{-10} \left(\frac{3.5\mathrm{TeV}}{M_{W_R}}\right)^4 \left|\frac{M_N M_N^*}{m_\Delta^{++}}\right|^2_{e\mu}$$



(Tello,..)

- Bounds the mass ratio: M_N / M_Δ

- Muonium-anti-muonium osc.

Unique signature $G_{M-\bar{M}} \sim \dfrac{f_{ee} f_{\mu\mu}}{8M^2_{\Delta^{++}}}$ PSI Limit : $\leq 3G_F 10^{-3}$

Properties of Seesaw-Higgs

$$S \equiv Re(\Delta_R^0)$$

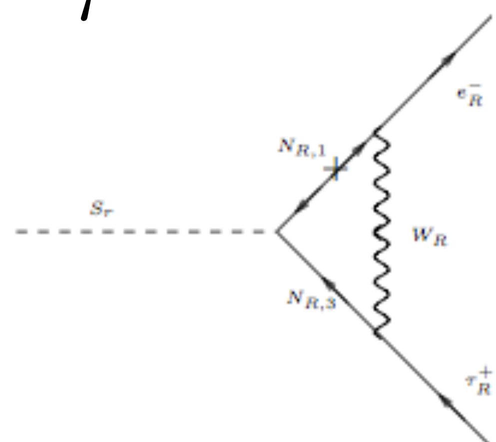
- Production: $pp \to Z^{'*} \to Z' + S$

  $\sigma \sim$

- Decay: $S \to Zf\bar{f}\,, ZZ, hh$

  $S \to \mu^+\mu^-, e^+e^-, \tau^+\tau^-$

- Displaced vertices for some range of parameters



Maximally testable seesaw

- Has both M_N sub-TeV-TeV ; $V_{\ell N}$ "large" .

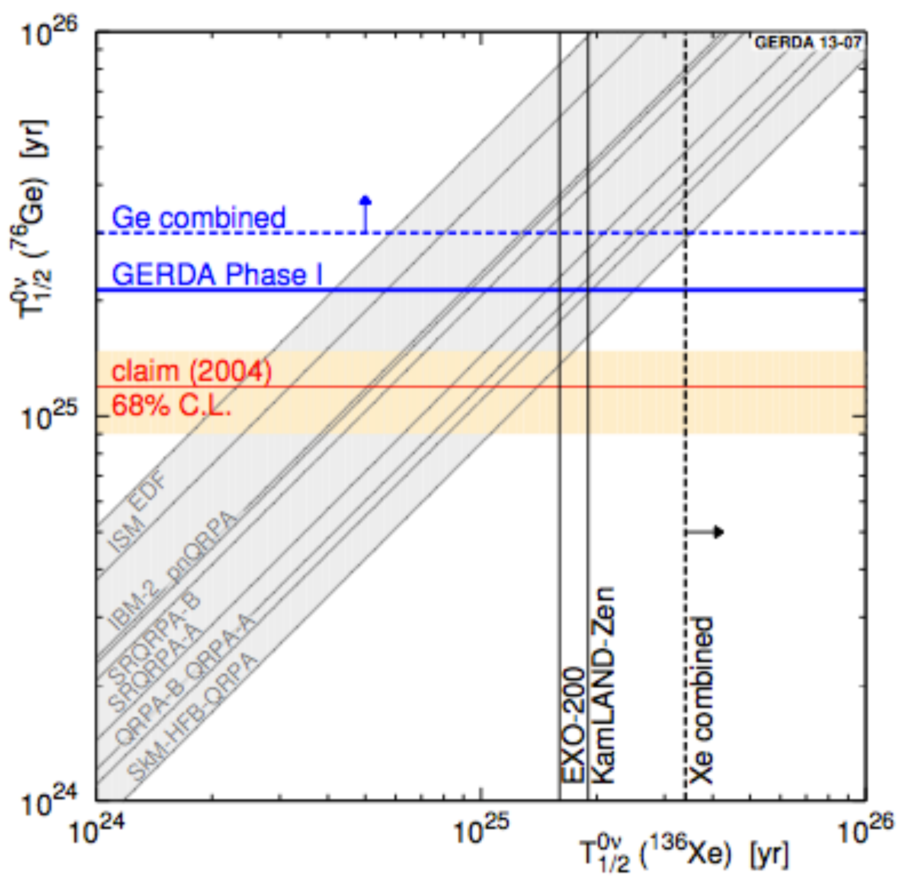
- Situation in generic models with $M_N \sim TeV$

(i) $m_\nu \simeq \dfrac{(h_\nu v_{wk})^2}{M_N}$ ~.1 eV → $h_\nu \leq 10^{-5}$

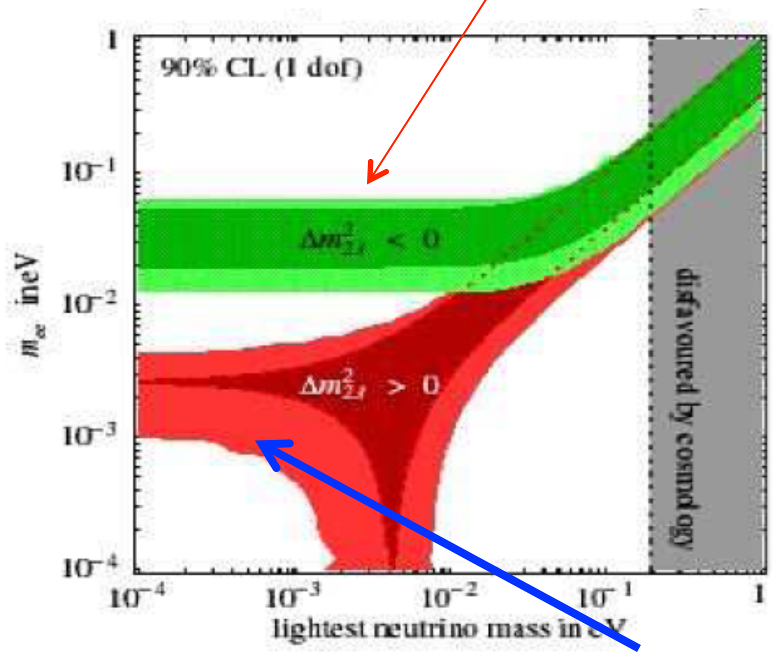
(ii) Small h_ν → $V_{\ell N} = \dfrac{h_\nu v_{wk}}{M_N} \simeq \sqrt{\dfrac{m_\nu}{M_N}} \sim 10^{-6}$

Other tests of TeV WR: manifestation in $\beta\beta_{0\nu}$

- Usual light Majorana nu contribution:



IH



NH

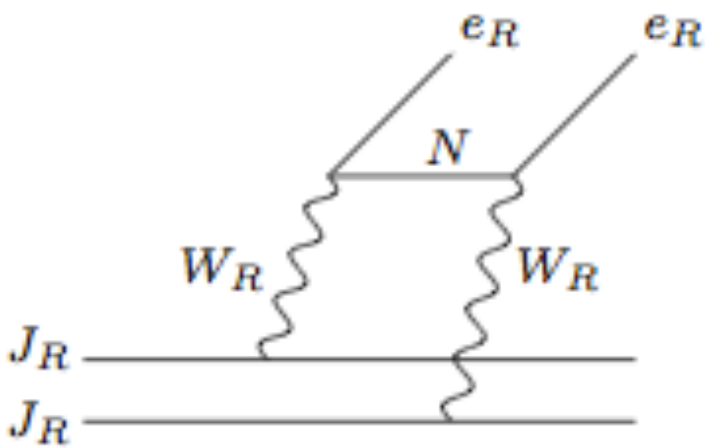
Current limits:

TeV WR manifesting in $\beta\beta_{0\nu}$

- W_R contribution- generic LR models

(RNM, Senjanovic'79; (Nemevsek, Nesti,Te
Dev, Goswami, Mitra, Rodejohann'13)

)



+LR+ Δ

$$\boxed{|(M_N)_{ee}| \gtrsim 10\,\mathrm{GeV} \times \left(\frac{3.5\ \mathrm{TeV}}{M_{W_R}}\right)^4}$$

$$\boxed{|\sum_i V_{eN_i}^2/M_{N_i}| < 5 \times 10^{-5}\ \mathrm{TeV}^{-1}}$$ **(LL)**

- Nonzero signal for $\beta\beta_{0\nu}$ + NH →could be TeV WR

- This model→contribution small !!