Reconciling Leptogenesis with observable $\mu \to e\gamma$

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based on JHEP 1004:023,2010 with S. Blanchet and T. Hambye

GDR Neutrino, 11-12/10/2010, IPN

Type I Seesaw

$$\mathcal{L} \supset - \overline{\nu_L}_\alpha \, m_D^{\alpha i} \, N_{R\,i} - \frac{1}{2} \overline{N_{R\,i}} \, M_N^{ij} \, N_{R\,j}^c$$

Light-Heavy Neutrino mixing: $V_{\alpha i} = \left(m_D . M^{-1} \right)_{\alpha i}$

Light Neutrino mass: $m_\nu = -V.M.V^T$

$$|m_\nu| \lesssim 0.1 \, \mathrm{eV}$$

$$|V_{\alpha i}| \lesssim 10^{-10} \left(\frac{10^{10} \, \mathrm{GeV}}{M_i} \right)^{1/2} \simeq 10^{-6} \left(\frac{100 \, \mathrm{GeV}}{M_i} \right)^{1/2}$$

Experimental constraints:

Abada *et al*, '07

$$|V.V^\dagger| \lesssim \left(\begin{array}{ccc} 10^{-2} & 7.0 \, 10^{-5} & 1.6 \, 10^{-2} \\ 7. \, 10^{-5} & 10^{-2} & 1. \, 10^{-2} \\ 1.6 \, 10^{-2} & 1.0 \, 10^{-2} & 10^{-2} \end{array} \right) .$$

Low-scale Seesaw

For observable low-energy effects: $|V_{\alpha i}| \gtrsim 0.01$

This would imply: $m_\nu \sim 10^7\,\mathrm{GeV}\left(\frac{M}{100\,\mathrm{GeV}}\right)\left(\frac{|V|}{0.01}\right)^2$

A cancellation has to occur in m_ν

In a 2 RHN case: $m_\nu^{\alpha\beta} = 0 \Leftrightarrow \frac{m_D^{1\alpha}\, m_D^{1\beta}}{M_1} + \frac{m_D^{2\alpha}\, m_D^{2\beta}}{M_2} = 0$

Buchmuller&Wyler, '90

Implying: - proportionality of Yukawa couplings

- non-trivial cancellation $\frac{y_1^2}{M_1} + \frac{y_2^2}{M_2} = 0$

Strongly suggests an underlying symmetry

Low-scale Seesaw

Integrating out the heavy N

$$\mathcal{L}_{d=5} = \frac{1}{2}\,\mathcal{C}^{\alpha\beta}_{d=5}\left(\overline{\ell^c_{L\,\alpha}}\,\tilde{\phi}^*\right)\left(\tilde{\phi}^\dagger \ell_{L\,\beta}\right). \quad \mathcal{C}_{d=5} \propto V.M^{-1}.V^T$$

$$\mathcal{L}_{d=6} = \mathcal{C}^{\alpha\beta}_{d=6}\left(\overline{\ell_{L\,\alpha}}\tilde{\phi}\right) i\partial\!\!\!/ \left(\tilde{\phi}^\dagger\,\ell_{L\beta}\right). \quad \mathcal{C}_{d=6} \propto V^\dagger.V/v^2$$

$\mathcal{L}_{d=5}$: - violates Lepton number by 2 units $\Delta L = 2$
- leads to light Neutrino masses
- leads to LNV processes

$\mathcal{L}_{d=6}$: - conserves L
- leads to LFV processes

By introducing a new scale at which L is broken: $\mu \ll v$

$\mathcal{C}_{d=5}$ picks up an extra suppression factor $\propto \mu/M$

$\Rightarrow$ LNV and Light Neutrino mass suppression

$\mathcal{C}_{d=6}$ unsuppressed

Approximate L conservation

A case study: 2RHNs with approximate L symmetry $L(N_1) = L(\ell) = -L(N_2)$ Branco *et al* , '89

$$\mathcal{L}_L \supset -Y_\alpha \overline{N_1}\,\tilde{\phi}\,\ell_{L\alpha} - \frac{1}{2} M\,\overline{N_1} N_2^c$$

$$\mathcal{L}_{\not{L}} \supset -\mu_1 \overline{N_1} N_1^c - \mu_2 \overline{N_2} N_2^c - \tilde{Y}_\alpha \overline{N_2}\,\tilde{\phi}\,\ell_{L\,\alpha}$$

In the L-conserving limit, $\mu_1 = \mu_2 = 0\,, \tilde{Y} = 0$

$$\Rightarrow m_\nu = 0 \quad \& \quad M_1 = M_2$$

Small L-violating parameters: $|\mu_1| \sim |\mu_2| \ll M \qquad |\tilde{Y}| \ll | Y|$

$$m_\nu = v^2\,\mathcal{C}_{d=5} = M\left(\tilde{V}^T.V + V^T.\tilde{V}\right) - \mu_2\,V^T.V$$

$$M_{1,2} = M \pm \frac{\mu}{2}\,, \quad \mu \equiv |\mu_1 + \mu_2|$$

$$\mathcal{C}_{d=6} = V^\dagger.V/v^2$$

Approximate L-symmetry: suppressed LNV, unsuppressed LFV

Leptogenesis

BAU depends on :

- the CP asymmetry in N decays: $\epsilon_{i\alpha} = \dfrac{\Gamma^{N_i}_{\ell_\alpha} - \Gamma^{N_i}_{\bar{\ell}_\alpha}}{\Gamma^{N_i}_{\ell_\alpha} + \Gamma^{N_i}_{\bar{\ell}_\alpha}}$
- Strength of decays/inverse decays:

$$K_{i\alpha} \equiv \frac{\Gamma\left(N_i \to \ell_\alpha\right)}{H(M_i)} \simeq 10^{10} \times \left(\frac{|V|}{0.01}\right)^2 \frac{M_i}{250\mathrm{GeV}}$$

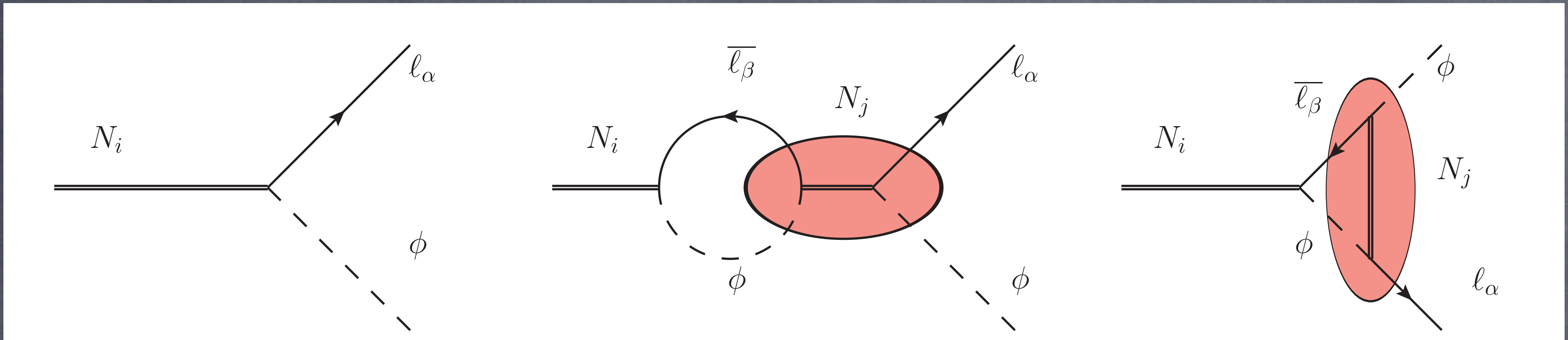
According to: $Y_B \simeq 10^{-3} \sum_{i\,,\alpha} \epsilon_{i\,\alpha} \dfrac{1}{K_{i\alpha}^{1.16}}$

Should explain the observed value: $8.1 \times 10^{-11} \lesssim Y_B \lesssim 9.5 \times 10^{-11}$

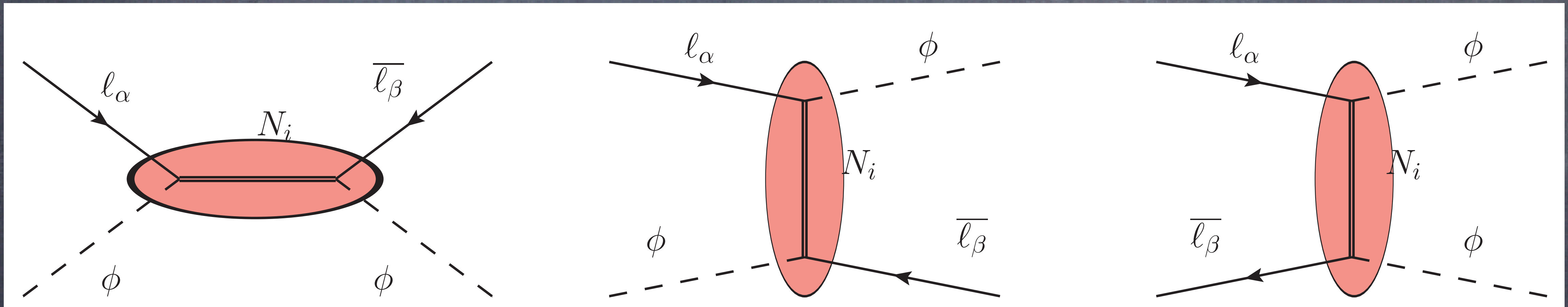
Low-Scale Seesaw implies huge washouts: leptogenesis is hardly successful

Leptogenesis with approximate L-convervation

CP asymmetry in RHNs decays: $\propto \mathcal{C}^{\alpha\beta}_{d=5}$



Washouts from ΔL=2 scatterings: $\propto \mathcal{C}^{\alpha\beta}_{d=5}$



Expected suppression in approximate L-conserving models.

Suppression of washout

Subtle interference effect:

$$\sigma^{tot}_{\Delta L=2} = \sigma^{11}_{\Delta L=2} + \sigma^{22}_{\Delta L=2} + \sigma^{12}_{\Delta L=2} + \sigma^{21}_{\Delta L=2}$$

- $\sigma^{ii}_{\Delta L=2}$ provides the «usual» washout from N_i
- $\sigma^{ij}_{\Delta L=2}$ is an interference term stemming from N1-N2 mixing

Partial Cancellation of the different contributions

$$\delta \equiv (M_2 - M_1)/\Gamma_{N_1} \qquad K^{eff}_{i\alpha} \simeq \delta^2 \, K_{i\alpha}$$

$$\delta \sim 10^{-4} \Rightarrow K^{eff}_{i\alpha} \sim 10^2$$

CP-asymmetry

N1-N2 quasi-degeneracy:

resonant contribution of the self-energy correction

Pilaftsis&Underwood, '03
Anisimov *et al*, '05

$$f_{self} \sim \frac{M_2^2 - M_1^2}{(M_2^2 - M_1^2)^2 + \left(\sqrt{M_2 \Gamma_{N_2}} - \sqrt{M_1 \Gamma_{N_1}}\right)^2} \simeq \left(2\,\delta\,\frac{\Gamma_{N_1}}{M_1}\right)^{-1}$$

$$\epsilon_{1\alpha} = \epsilon_{2\alpha} \simeq -\frac{|Y_\alpha|^2}{4\pi}\left\{\sin\left(\alpha\frac{\mu_1\mu_2}{2\mu M}\right) + \frac{\sum_\beta \mathrm{Im}(Y_\beta \tilde{Y}_\beta^* \mathrm{e}^{\mathrm{i}\phi})}{\sum_{\beta'} |Y_{\beta'}|^2}\right\} f_{\mathrm{self}}$$

- Suppressed by the small L-violating parameters
- Suppression balanced by the resonant self-energy

$$\delta \sim 10^{-4} \Rightarrow \epsilon \sim 10^{-6}$$

Baryon Asymmetry

For small N1-N2 splitting $\delta \ll 1$

- suppressed washouts $K^{eff} \sim 10^2$
- unsuppressed CP-asymmetry $\epsilon \sim \text{few}\, 10^{-6}$

BAU is within the observed range

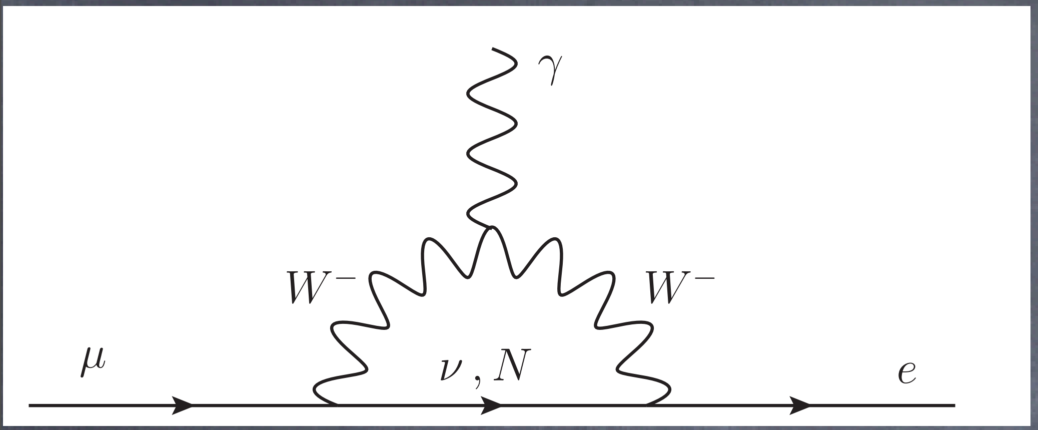
Using Casas-Ibarra parametrization: Casas&Ibarra, '01

$$Y_\alpha \propto e^{z_b} e^{-i\, z_a}\, f\left(\frac{M_i}{v}, \frac{m_i}{v}, U_{\rm PMNS}\right), \tilde{Y}_\alpha \propto e^{-z_b} e^{i\, z_a}\, g\left(\frac{M_i}{v}, \frac{m_i}{v}, U_{\rm PMNS}\right),$$

$$Y_B \simeq 3 \times 10^{-5}\, \frac{e^{-4.32\, z_b}}{\delta^{3.32}}\, \sin 2\, z_a$$

$$\delta \sim 10^{-3}, z_B \sim 8, z_a \sim \pi/4 \Rightarrow Y_B \sim 10^{-10}$$

LFV: $\mu \to e\gamma$

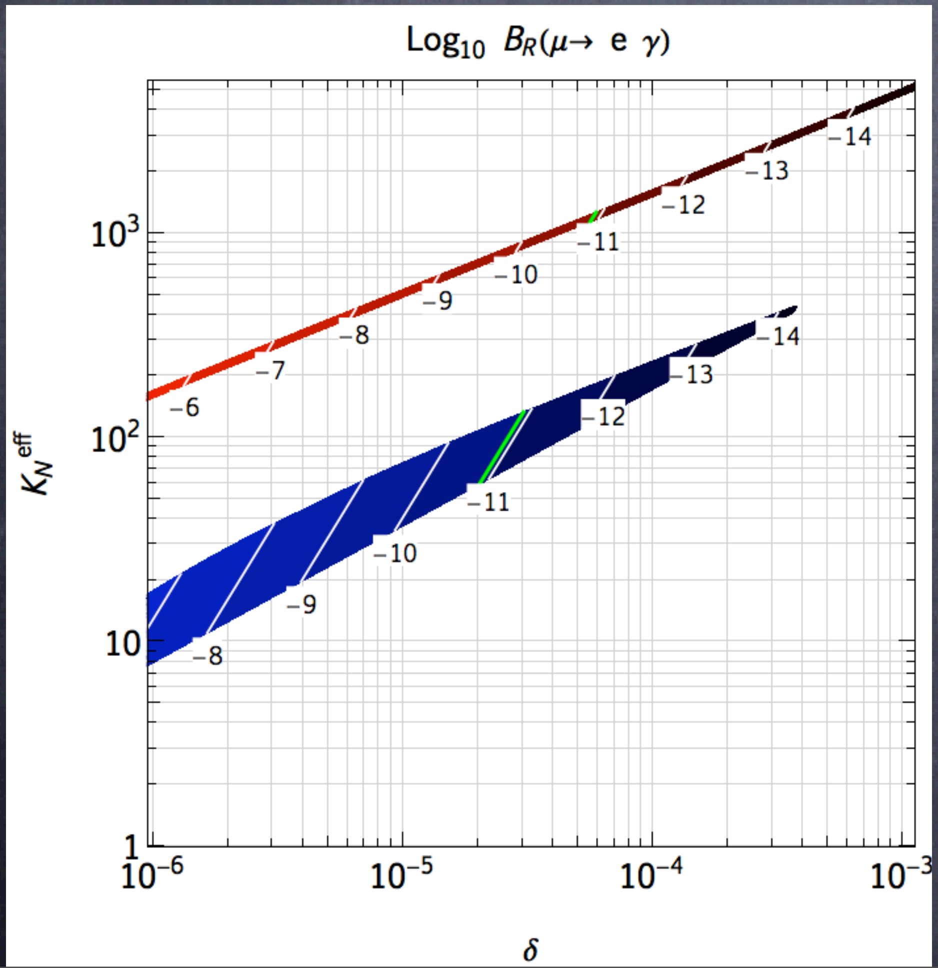


$$Br\,(\mu \to e\gamma) \simeq \frac{3\alpha}{32\pi}\,(2\,v^2)^2\left|\frac{Y_{1e}Y^*_{1\mu}}{M_1^2}+\frac{Y_{2e}Y^*_{2\mu}}{M_2^2}\right|^2$$

$$Br\,(\mu \to e\gamma) \simeq 10^{-30}\left(\frac{250\,\mathrm{GeV}}{M}\right)^2 e^{4\,z_b}$$

Requiring successful leptogenesis:

$$Br\,(\mu \to e\gamma) \simeq 10^{-12}\times\left(\frac{250\,\mathrm{GeV}}{M}\right)^2\left(\frac{10^{-4}}{\delta}\right)^{3.1}\sin\,(2z_a)^{0.93}$$



For: $M \sim 250\,\mathrm{GeV} - 1000\,\mathrm{GeV}$

$\mu \sim 100\,\mathrm{eV}\,,\quad z_b \sim 10$

implying $\quad \delta \sim 10^{-4}\,,\quad K^{eff} \sim 10^2$

Successful Leptogenesis and Observable LFV

$Y_B \sim 10^{-10} \qquad Br \sim 10^{-11} - 10^{-13}$

Conclusion

In approximate L-conserving models,
for small N1-N2 mass splitting $\delta \ll 1$

- Rather easy to generate large enough BAU

- Large LNC Yukawas imply large LFV rates

- Small LNV parameters imply suppressed LNV processes