Leptogenesis with type II see-saw in SO(10)

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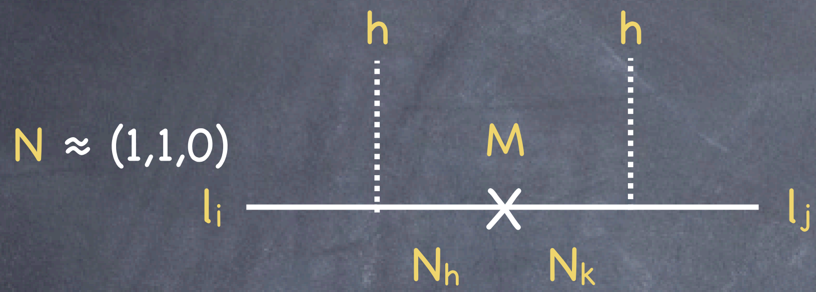
Frigerio Hosteins Lavignac R, arXiv:0804.0801

The baryon asymmetry

- $\eta_B \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma} = \frac{n_B}{n_\gamma} = (6.15 \pm 0.25) \times 10^{-10}$ (1 number)
- Generated dynamically if
  - B is violated
  - C and CP are violated
  - out of equilibrium evolution
- Models of Baryogenesis
  - Planck
  - GUT
  - Through leptogenesis
  - Electroweak
  - Affleck-Dine
  - ...

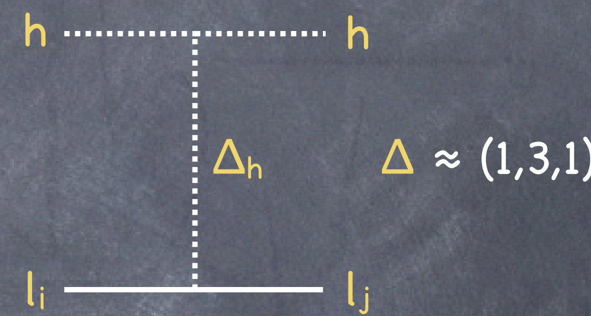
See-saw induced neutrino masses

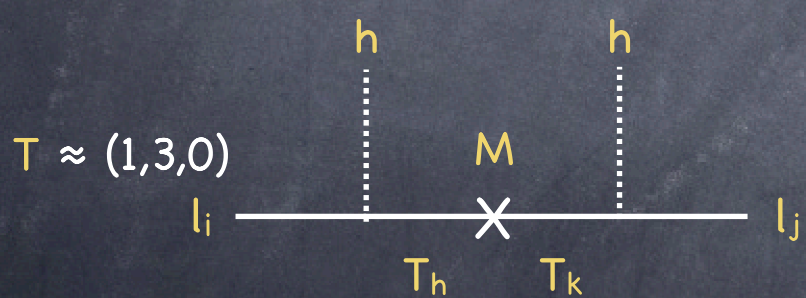
$$\mathcal{L}^{\rm eff}_{E\ll\Lambda} = \mathcal{L}^{\rm ren}_{\rm SM} + \frac{a_{ij}}{2\Lambda}(h\,l_i)(h\,l_j) + \ldots$$



See-saw type I

See-saw type II





See-saw type III

(Any number of N_h, T_h, Δ_h)

$(SU(3)_c, SU(2)_L, Y)$

Model dependence in see-saw type-I

- Relevant interactions: $\lambda^E_{ij} e^c_i l_j h_d + \lambda^N_{ij} N_i l_j h_u + \frac{M_{ij}}{2} N_i N_j \quad \left[m_\nu = -v_u^2 \, \lambda_N^T \frac{1}{M} \lambda_N \right]$
- Overall size of neutrino Yukawa couplings

$$\begin{matrix} \lambda_N \to k\,\lambda_N \\ M \to k^2 M \end{matrix} \Rightarrow \begin{matrix} m_\nu \to m_\nu \\ \mathrm{BR}(e_i \to e_j \gamma) \to k^4 \log k \, \mathrm{BR}(e_i \to e_j \gamma) \end{matrix}$$

- Unknown flavour structure

$v_d \lambda_E, \; v_u \lambda_N, \; M$ — 21 physical parameters

$m_e \, m_\mu \, m_\tau, \; m_{\nu_1} \, m_{\nu_2} \, m_{\nu_3}, \; U$ — 12 known or measurable parameters

e.g. $v_u \lambda_N = v_u \lambda_N^{\mathrm{diag}} V_N$ or M^{diag}, $R = 1/\sqrt{M^{\mathrm{diag}}} \, v_u \lambda_N \, U^\dagger / \sqrt{M^{\mathrm{diag}}}$ — 9 unknowns = 3 masses + 3 angles + 3 phases

- Type-II: LFV more predictive [Rossi 02], leptogenesis as well in SO(10)

Type-II see-saw in SO(10)

- $\Delta \approx (1,3,1) \subset 15_{SU(5)}$ $\Delta + \overline{\Delta} \subset 54_{SO(10)} = 15_{SU(5)} + \overline{15}_{SU(5)} + 24_{SU(5)}$ (or $\subset 126 + \overline{126}$ or > 500)
- Note: $10 \times 10 = 1_s + 45_a + 54_s$ $54 < 252$ (perturbativity)
- 54 does not couple to 16×16
- But it does couple to 10×10, and $10 \supset (1,2,-½) \approx l$

Reminder: SM embedding

$16_{SO(10)} = \overline{5}_{SU(5)} + 10_{SU(5)} + 1_{SU(5)}$ $10_{SO(10)} = \overline{5}_{SU(5)} + 5_{SU(5)}$

$\overline{5}_{SU(5)} = l + d^c = h_d + H_3$

$10_{SU(10)} = q + u^c + e^c$

A predictive Type II SO(10) model

- SO(10): $10_{i\,SU(5)} \subseteq 16_{i\,SO(10)}$, $\bar{5}_{i\,SU(5)} \subseteq 10_{i\,SO(10)}$

- $$W \supseteq \frac{y_{ij}}{2} 16_i 16_j 10 + h_{ij} 16_i 10_j 16 + \frac{f_{ij}}{2} 10_i 10_j 54 + \frac{\sigma}{2} 10\,10\,54 + W_{\text{vev+NR}}$$

<16> pairs up the spare components in 16_i 10_i

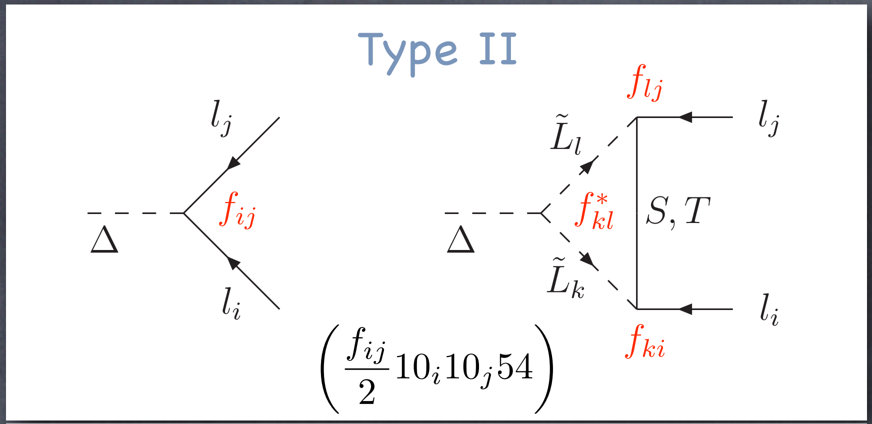
$$h_{ij} 16_i 10_j 16 \to V_{16}\, h_{ij} \bar{5}_i^{16} 5_j^{10} = V_{16}\, h_{ij} (\bar{L}_i L_j + \bar{D}_i^c D_j^c)$$

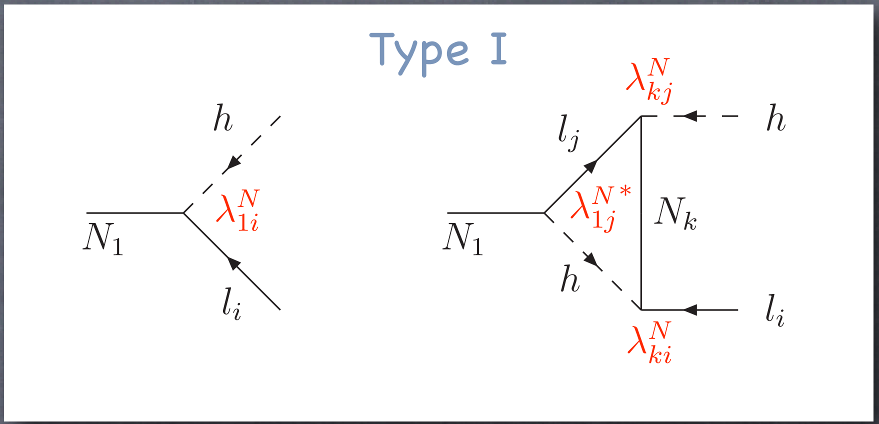
- $$\begin{cases} m_{ij}^U = v_u\, y_{ij} \\ m_{ij}^E = v_d\, h_{ij} \\ m_{ij}^\nu = \sigma \dfrac{v_u^2}{2M_\Delta} f_{ij} \quad \text{(pure type II)} \end{cases}$$

- W is R_P invariant, generic up to mass terms; no type-I

- Below M_{GUT}: SM + $(5_i + \bar{5}_i)$ + $(15 + \overline{15} + 24)$ (+ N_i)
  LNV from Δ (and N_i) $M_\Delta = M_{15} < M_{24}\ M_N$

CP asymmetry





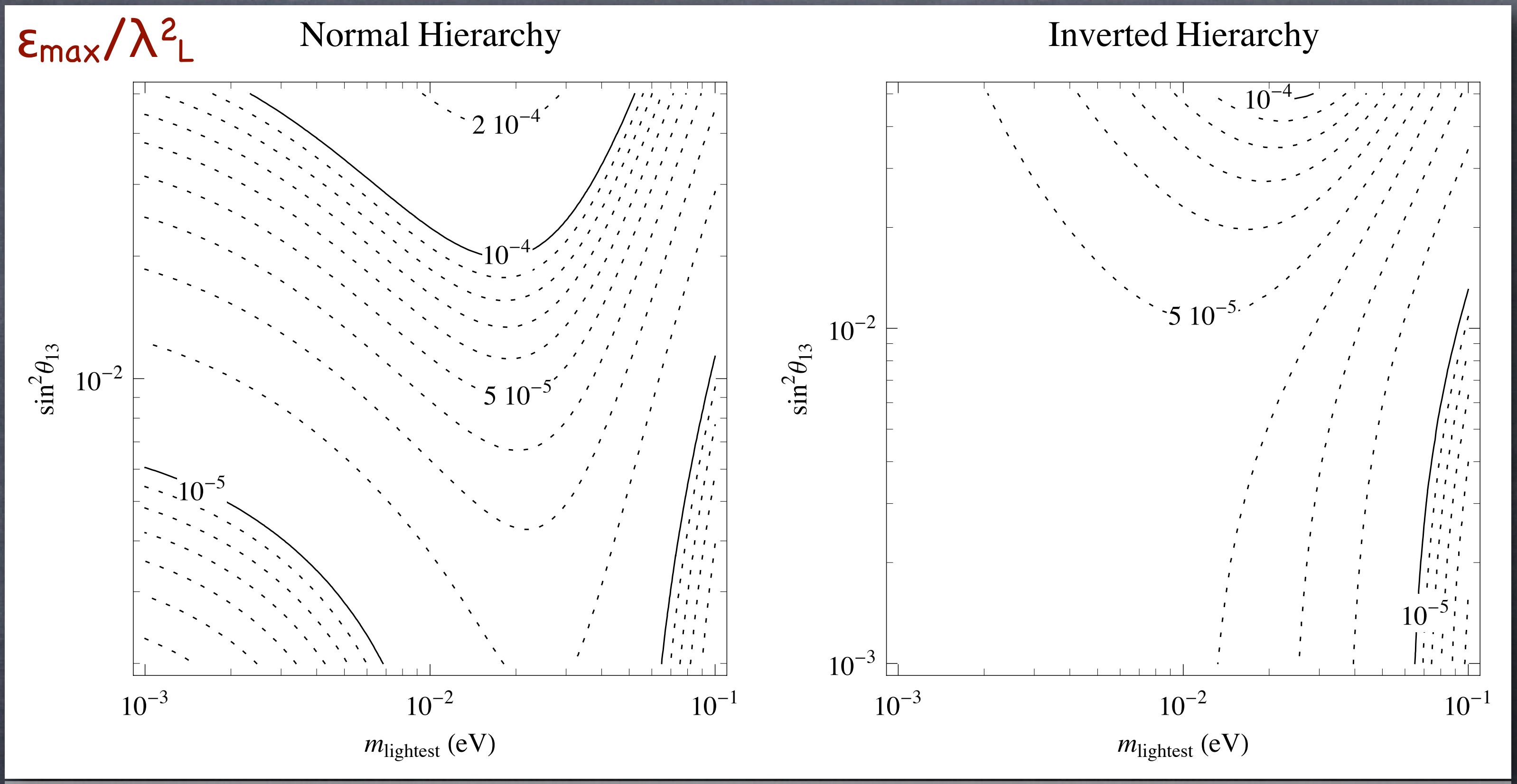
- f_{ij}, M^L_{ij} from m_ν, m_E (up to overall factors, W_{NR})
- L_1 lighter than $M_\Delta/2$? $M_{L_1} \sim h_1 V_{16} \sim \frac{0.5 \cdot 10^{11}\,\text{GeV}}{\cos\beta}\left(\frac{V_{16}}{2\cdot 10^{16}\,\text{GeV}}\right)$ ✓
- $M_{L1} < M_\Delta < M_{L2}, M_{24}$: $\epsilon \approx \frac{1}{10\pi}\frac{M_\Delta}{M_{24}}\frac{\lambda_l^4}{\lambda_l^2+\lambda_h^2}\frac{\text{Im}[m^*_{11}(mm^*m)_{11}]}{(\sum_i m_i^2)^2}$

(in the diagonal m_E basis)

$$\left(\begin{array}{c}\lambda_l^2 \equiv \sum_{ij}|f_{ij}|^2, \quad \lambda_h^2 \equiv |\sigma|^2 \\ \epsilon \equiv 2\frac{\Gamma(\Delta\to l^* l^*)-\Gamma(\Delta^*\to ll)}{\Gamma_\Delta+\Gamma_{\Delta^*}}\end{array}\right)$$

Maximal CP asymmetry

Need: $\eta\,\epsilon \approx 10^{-8}$



Maximal efficiency

- Δ kept in equilibrium by gauge interactions ($\Delta\bar{\Delta} \leftrightarrow$ SM) and especially decays ($\Delta \leftrightarrow l^* l^*$, $h_u h_u$, $\tilde{L}^*_1 \tilde{L}^*_1$)
  ($\rightarrow$ no dependence on initial conditions!)

- Still, a quasi-maximal efficiency can arise if one (decoupled) decay channel is out of equilibrium [Hambye Raidal Strumia 05]

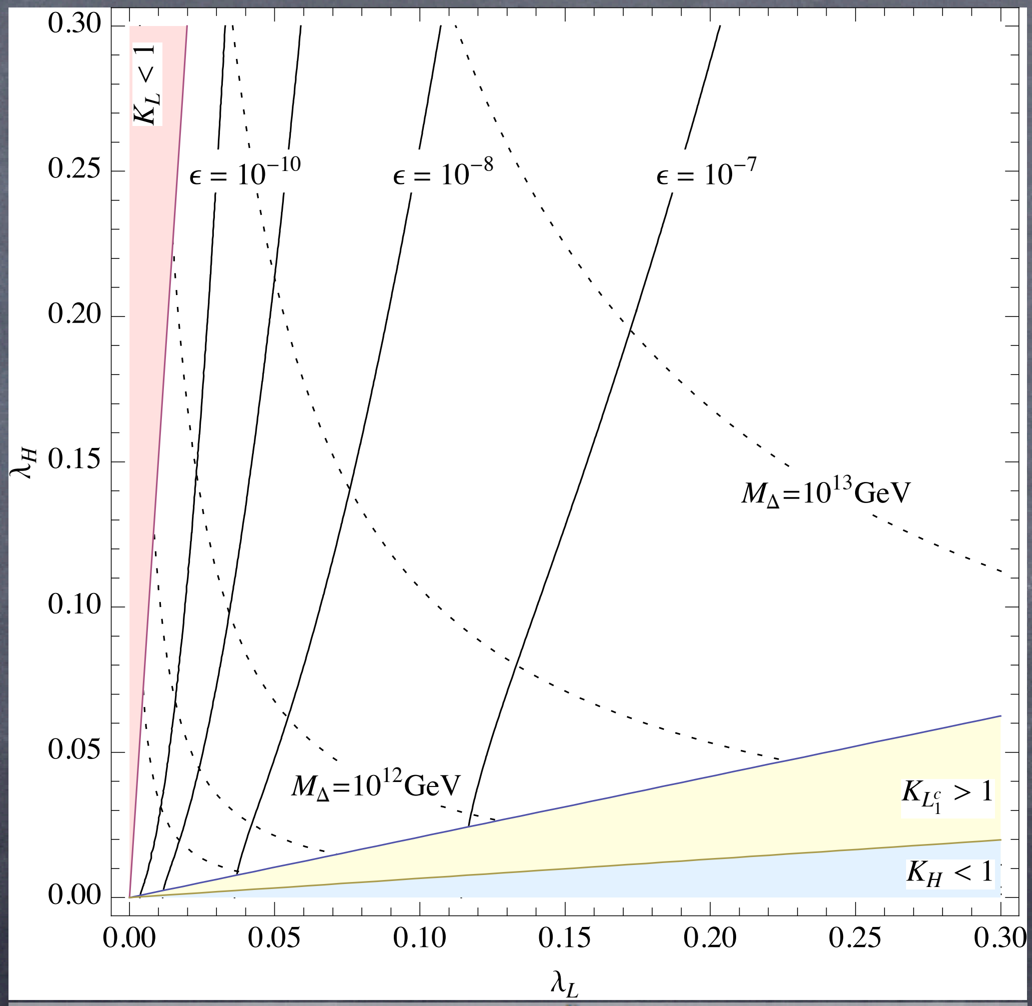
- In our case: $\Delta \leftrightarrow \tilde{L}^*_1 \tilde{L}^*_1$

$$\frac{\Gamma(\Delta \to 2l^*)}{H} \cdot \frac{\Gamma(\Delta \to 2h_u)}{H} \sim \frac{2.2\,10^2}{\sin^4\beta} \frac{\sum_i m_i^2}{\Delta m_{23}^2} > 2.2\,10^2, \qquad \frac{\Gamma(\Delta \to 2\tilde{L}_1^*)}{\Gamma(\Delta \to 2l^*)} \sim \frac{|m_{ee}|^2}{\sum_i m_i^2}$$

- O(1) efficiency if $|f_{11}|$ is sufficiently small: $|f_{11}| \lesssim \left(\frac{M_\Delta}{0.5 \cdot 10^{16}\,\mathrm{GeV}} \right)^{1/2}$

O(1) efficiency region

$m_1 \ll m_2 \ll m_3$, $M_\Delta / M_{24} = 0.1$, $\sin 2\sigma = 1$, $\sin^2\theta_{13} = 0.05$, $\tan\beta = 10$



(K = Γ/H)

Analytical estimate of η

$Y_X \equiv n_X/s$

$\Delta_X \equiv Y_X - Y_{\bar{X}}$

$\Sigma_X \equiv Y_X + Y_{\bar{X}}$

- Toy model: no SUSY, no GUT (SM + Δ + L_iL_i)
- Define $\Delta_{\tilde{L}_1} = \eta_0 \epsilon \Sigma_\Delta^{\rm eq}(T \gg M_\Delta), \quad \eta_0 = \mathcal{O}(1)$
- $\eta_0 \to 1$ in the limit: $\gamma_A \ll \gamma_D$ (✓) + $B_L \ll 1$ (see eqs)
- Hypercharge conservation: $\Delta_{\tilde{L}_1} = 2\Delta_\Delta - \Delta_l + \Delta_h$
- Lepton number asymmetry at $T \ll M_\Delta$: $\Delta_{\rm lep} = \Delta_l + \Delta_{\tilde{L}_1} = \Delta_h$
- If both $\Delta \leftrightarrow l^* l^*$, hh are in equilibrium: $\frac{\Delta_l}{Y_l^{\rm eq}} + \frac{\Delta_\Delta}{\Sigma_\Delta^{\rm eq}} \approx 0, \quad \frac{\Delta_h}{Y_h^{\rm eq}} - \frac{\Delta_\Delta}{\Sigma_\Delta^{\rm eq}} \approx 0$
- Then:

$$\Delta_{B-L} = -\Delta_h \approx \frac{Y_h^{\rm eq}}{Y_h^{\rm eq} + Y_l^{\rm eq}} \Delta_{\tilde{L}_1} = \frac{4}{7} \eta_0 \epsilon \Sigma_\Delta^{\rm eq}(T \gg M_\Delta) \quad \eta = \frac{4}{7}\eta_0$$

- $(n_B/s)_{\rm exp} \Rightarrow \eta_0 \varepsilon \approx 2\ 10^{-8}$

FCNCs

- New effects from new heavy fields below M_{GUT}: $(5_i+\bar{5}_i)$ + 54

$$m_l^2 = (m_l^2)_{\rm MSSM} - \frac{1}{(4\pi)^2}\left(2m_{\mathbf{10}}^2 + m_{54}^2\right) f^\dagger \left[3\ln\frac{M_{\rm GUT}^2}{M_\Delta^2} + \frac{9}{10}\ln\frac{M_{\rm GUT}^2}{M_\Delta^2 + M_L M_L^\dagger} + \frac{3}{2}\ln\frac{M_{\rm GUT}^2}{M_\Delta^2 + M_{D^c} M_{D^c}^\dagger}\right] f$$

$$m_{d^c}^2 = (m_{d^c}^2)_{\rm MSSM} - \frac{1}{(4\pi)^2}\left(2m_{\mathbf{10}}^2 + m_{54}^2\right) f^\dagger \left[3\ln\frac{M_{\rm GUT}^2}{M_\Delta^2} + \ln\frac{M_{\rm GUT}^2}{M_\Delta^2 + M_L M_L^\dagger} + \frac{7}{5}\ln\frac{M_{\rm GUT}^2}{M_\Delta^2 + M_{D^c} M_{D^c}^\dagger}\right] f.$$

$$m_{e^c}^2 = (m_{e^c}^2)_{\rm MSSM} - \frac{c^2}{(4\pi)^2}\left(2m_{\mathbf{16}}^2 + m_{h_d}^2\right) y^\dagger \left[2\ln\frac{M_{\rm GUT}^2}{M_L M_L^\dagger}\right] y$$

$$m_q^2 = (m_q^2)_{\rm MSSM} - \frac{c^2}{(4\pi)^2}\left(2m_{\mathbf{16}}^2 + m_{h_d}^2\right) y^\dagger \left[\ln\frac{M_{\rm GUT}^2}{M_{D^c} M_{D^c}^\dagger}\right] y,$$

SO(10) breaking and 2-3 splitting

$$W_{\rm vev} = W^{(1)}_{\rm vev} + W^{(2)}_{\rm vev}$$

$$W^{(1)}_{\rm vev} = \frac{\sigma_1}{2} 54' 45_1^2 + (\lambda_S S + \sigma_{12} 54)\, 45_1 45_2 + \frac{\lambda}{3}\, 54'^3 + \overline{16}(M_{16} + g\, 45_1) 16$$

$$W^{(2)}_{\rm vev} = h 10' 45_1 10 + \frac{M_{10}}{2} 10'^2 - \frac{\eta}{2}\, \overline{1616} 10$$

new implementation of the DW mechanism

room to suppress D=5 proton decay

Gravitinos

- Weak washout → $M_\Delta \gtrsim 10^{11}$ GeV
  - Large T_{RH} and SUSY
    - T_{RH} up to few 10^{10} GeV:
      - $m_{3/2} > 100$ TeV (e.g. anomaly mediation)
      - gravitino LSP (specific NLSP or RPV)
    - $T_{RH} > 10^{11}$ GeV
      - $m_{3/2} < 16$ eV + CDM
      - $m_{3/2} \gg 100$ TeV
      - No sugra/SUSY
  - Small T_{RH}
    - Δ from reheating, preheating, other mechanisms
    - Lower M_Δ (strong washout)

Model dependence

- $m_D = m_E^T$ only (approximately) compatible with 3rd family
- No surprise it does not work for lighter families: small Yukawas are sensitive to higher dimensional operators, possibly involving SO(10) breaking fields
- Such operators also affect the relation between light and heavy leptons in a model-dependent way
- The quantitative effect is negligible in leptogenesis unless $M_\Delta \approx M_i$, mild in FCNC because it is O(1) and enters logarithmically; negligible if the triplet is heavier than the second heavy family

Conclusions

- By implementing type-II see-saw in SO(10) we improve on
  - dependence on unknown parameters
  - dependence on initial conditions
  - perturbativity
  - D=5 proton decay
- Baryogenesis closer to be testable