(In)sensitivity of leptogenesis with flavour effects to low energy observables

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arXiv:0705.1503 (PRL 99:161801,2007) + work in progress

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1. Introduction

Neutrino masses naturally explained by the seesaw mechanism $\longrightarrow$ generation of the BAU via leptogenesis $\longrightarrow$ CP violation in the lepton sector

Question: Is the baryon asymmetry sensitive to the PMNS matrix phases? ,i.e., assuming the BAU is generated from the decay of the lightest RH neutrino, can an allowed range of the PMNS phases be obtained?

Answer: No, in the type I seesaw without flavour effects in leptogenesis

G. Branco et al., NPB 617, 475 (2001)

This work: what about flavoured leptogenesis?

A. Abada *et al.*, E. Nardi *et al.* (2006)

$\longrightarrow$ Bottom-up, phenomenological approach

At the heavy N scale,

$$\mathcal{L} = \overline{e_R}^j \mathbf{Y_e}_{ij} H_d \ell^i + \overline{N}^J \lambda_{iJ} H_u \ell^i + \overline{N}^J \frac{\mathbf{M}_{JK}}{2} N^{cK} + h.c.$$

- 21 parameters (6 phases)

In the mass basis of charged letpons and N_I

$$\lambda = V_L^\dagger D_\lambda V_R$$

$D_\lambda \rightarrow$ real and diagonal, and

$V_L, V_R \rightarrow$ unitary matrices (3 phases each)

At low energies $\rightarrow$ light neutrino effective Majorana mass matrix:

$$[m] = \lambda M^{-1} \lambda^T v^2 = U D_m U^T$$

D_m is diagonal with real eigenvalues

U is the PMNS matrix, receives contributions from both, V_L and V_R

- 9 parameters in $[m]$
- 2 mass diferences, and 2 angles of U are measured

2. Flavoured leptogenesis

CP asymmetry in the decay of N_1 to leptons $N_1 \to \ell_\alpha H_u$

$$\epsilon_\alpha = \frac{\Gamma(N_1 \to \ell_\alpha H_u) - \Gamma(N_1 \to \bar{\ell}_\alpha \bar{H}_u)}{\sum_\alpha [\Gamma(N_1 \to \ell_\alpha H_u) + \Gamma(N_1 \to \bar{\ell}_\alpha \bar{H}_u)]}$$

- Flavour effects are relevant in leptogenesis because the final asymmetry depends on which leptons are distinguishable:

- $T \gtrsim 10^{12}$ GeV $\to$ all lepton Yukawa interactions out of equilibrium

- In the temperature range 10^9 GeV $\lesssim T \lesssim 10^{12}$ GeV $\to$ Yukawa τ interactions faster than H $\to$ ℓ_τ doublet is distinguisable.

- In the range $T \lesssim 10^9$ GeV $\to$ both τ and μ Yukawa interactions in equilibrium $\to$ all flavours distinguisable

Unflavoured asymmetry:

$$\epsilon_1 = \sum_\alpha \epsilon_\alpha = \frac{1}{8\pi} \sum_{J \neq 1} \frac{\mathrm{Im}[(\lambda^\dagger \lambda)^2_{J1}]}{(\lambda^\dagger \lambda)_{11}} g(M_J^2/M_1^2)$$

$\lambda^\dagger\lambda = V_R^\dagger D_\lambda^2 V_R$ is controlled by phases of the RH sector only

Flavoured asymmetry:

$$\epsilon_\alpha = \frac{1}{8\pi}\sum_{J\neq 1}\frac{\mathrm{Im}[\lambda_{\alpha 1}\lambda^*_{\alpha J}(\lambda^\dagger\lambda)_{J1}]}{(\lambda^\dagger\lambda)_{11}}g(M_J^2/M_1^2)$$

Now ϵ_α depends on both, RH and LH CP violating phases

• Moreover, the evolution equations for the lepton flavour asymmetries Y_α are now flavour dependent Boltzmann equations, so the total baryon asymmetry is

$$Y_B \simeq \frac{12}{37}\sum_\alpha Y_\alpha = \frac{1}{3g_*}\sum_\alpha \epsilon_\alpha\eta_\alpha$$

$\eta_\alpha \rightarrow$ flavour dependent washout factor

• Strong washout for all flavours:

$K_\alpha \equiv \frac{\Gamma(N_1\to\ell_\alpha H_u)}{H(M_1)} \equiv \frac{\widetilde{m}_\alpha}{m_*} \gg 1$

with $m_\alpha = |\lambda_{\alpha 1}|^2 v^2 / M_1$ and $m_* \simeq 10^{-3}$ eV

Then:

$$\eta_\alpha \simeq 1.3 \left(\frac{m_*}{6 \widetilde{m}_\alpha} \right)^{1.16}$$

- Strong washout for some flavours and weak washout for others $K_\beta \gg 1, K_\alpha \ll 1$

$$\eta_\alpha \simeq 1.3 \left(\frac{\widetilde{m}_\alpha}{3.3 \times 10^{-3} \mathrm{eV}} \right)$$

- Weak washout for all flavours

$$\eta_\alpha \simeq 1.5 \left(\frac{\widetilde{m}_1}{3.3 \times 10^{-3} \mathrm{eV}} \right) \left(\frac{\widetilde{m}_\alpha}{3.3 \times 10^{-3} \mathrm{eV}} \right)$$

where $\widetilde{m}_1 = \sum_\alpha \widetilde{m}_\alpha = (\lambda^\dagger \lambda)_{11} v^2 / M_1$

3. SM + seesaw

Assumptions:

- 10^9 GeV $\lesssim M_1 \lesssim 10^{12}$ GeV $\rightarrow \tau$ Yukawa in equilibrium

$$Y_B \simeq \frac{12}{37}\frac{1}{3g_*}(\epsilon_\tau \eta_\tau + \epsilon_o \eta_o)$$

$\hat{\ell}_o = (\lambda_{\mu 1}\hat{\mu} + \lambda_{e1}\hat{e})/\sqrt{|\lambda_{\mu 1}|^2 + |\lambda_{e1}|^2} \rightarrow$ projection in ℓ_e and ℓ_μ space of the direction into which N_1 decays.

- Hierarchical RH neutrinos:

$$\epsilon_\alpha \simeq -\frac{3M_1}{16\pi v^2 [\lambda^\dagger \lambda]_{11}} \mathrm{Im}\{[\lambda]_{\alpha 1}[m^\dagger \lambda]_{\alpha 1}\}$$

- Strong washout for all flavours:

$$Y_B \simeq Y_B^{bd} \left(\frac{\mathrm{Im}\{\hat{\lambda}_{\dot{\tau}} m \hat{\lambda}_\tau\}}{m_{atm}} + \frac{\mathrm{Im}\{\hat{\lambda}_{\dot{o}} m \hat{\lambda}_o\}}{m_{atm}} + \frac{\mathrm{Im}\{\hat{\lambda}_{\dot{\tau}} m \hat{\lambda}_o\}}{m_{atm}} \left[\frac{|\lambda_o|}{|\lambda_\tau|} + \frac{|\lambda_\tau|}{|\lambda_o|} \right] \right) \frac{1}{A_{\tau\tau}}$$

$\hat{\lambda}_\alpha |\lambda_\alpha| = \lambda^*_{\alpha 1}$, $A_{\tau\tau} \sim 2/3$

$Y_B^{bd} = \frac{12}{37} \frac{M_1 m_{atm}}{16\pi v^2} \frac{m_*}{5 g_* \widetilde{m}}$ $\rightarrow$ upper bound on Y_B without flavour effects in strong washout

$\rightarrow$ Stronger washout in one flavour can increase Y_B

- (Ideally) Measurable parameters: neutrino masses, mixings and phases of U_{PMNS}

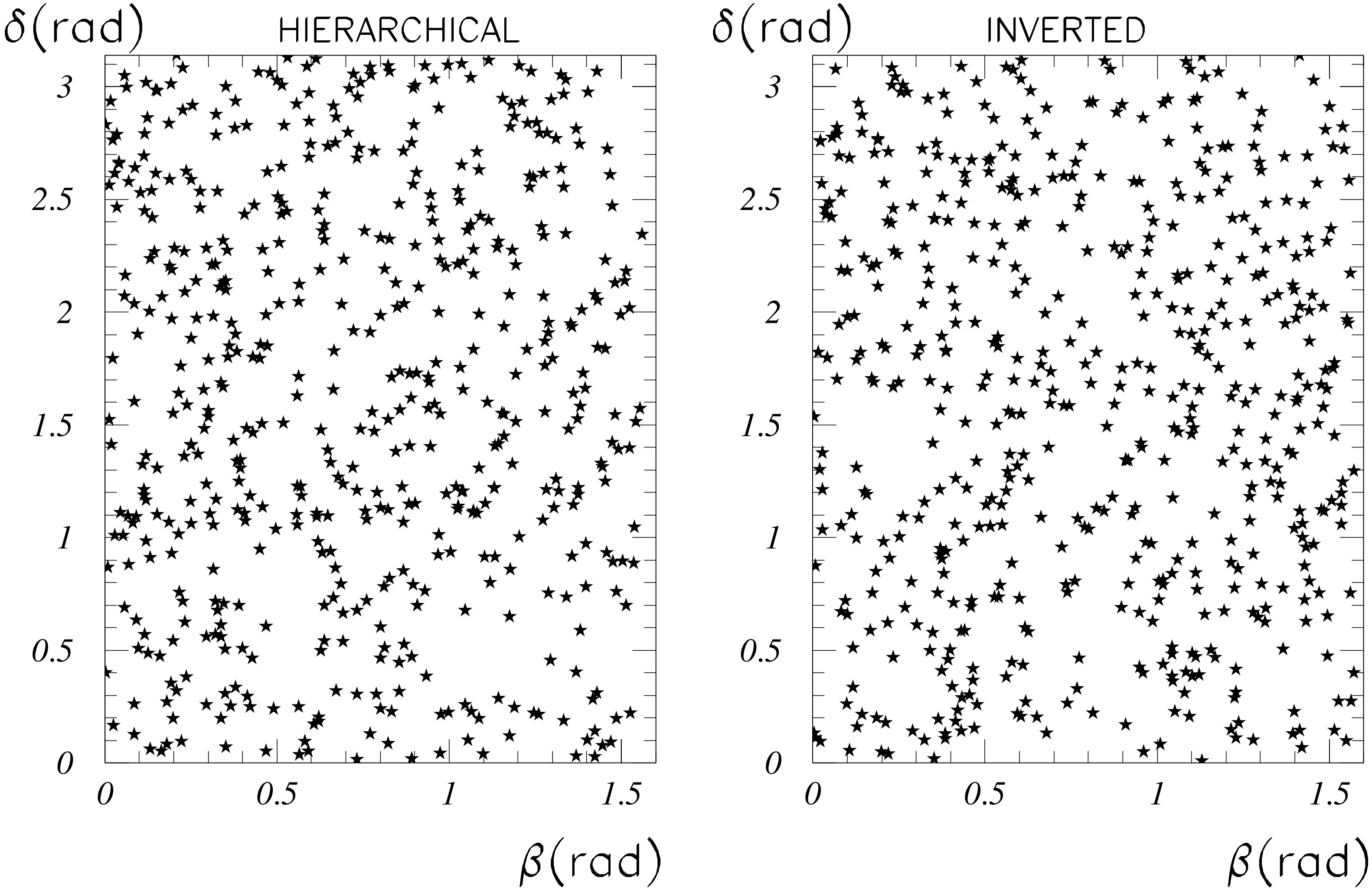
- Unmeasurable parameters $\rightarrow$ Casas-Ibarra parametrization

J.A. Casas and A. Ibarra, Nucl. Phys. B **618** (2001) 171 [arXiv:hep-ph/0103065]

$$\lambda = (U D_m^{1/2} R D_M^{1/2}) v$$

$R \rightarrow$ complex orthogonal matrix

→ Large enough baryon asymmetry can be obtained for any value of the PMNS phases and $M_1 \sim 10^{10}$ GeV



4. MSSM + seesaw

• A non-supersymmetric seesaw suffers from a hierarchy problem

• In a MSUGRA framework, RG running induces LFV soft terms even if universality is imposed at a high scale, M_X

• Non-diagonal contributions $\propto \lambda\lambda^\dagger = V_L^\dagger D_\lambda^2 V_L$

$$(m_L^2)_{\alpha\beta} \simeq -\frac{3}{8\pi^2}(3m_0^2 + A_0^2)(\lambda\lambda^\dagger)_{\alpha\beta} \log\frac{M_X}{M}$$

$M \rightarrow$ RH neutrino scale

• Off-diagonal soft terms lead to LFV low energy processes, namely $\ell_\alpha \rightarrow \ell_\beta\gamma$

$$BR(\ell_\alpha \rightarrow \ell_\beta\gamma) = \frac{12\pi^2}{G_F^2}(|A_L|^2 + |A_R|^2) \simeq \frac{\alpha^3}{G_F^2}\frac{|(m_L^2)_{\alpha\beta}|^2}{m_{SUSY}^8}\tan^2\beta$$

Hisano *et al.*, 1996

Present (future) bounds:

$$BR(\mu \to e\gamma) < 1.2 \times 10^{-11}(10^{-14})$$
$$BR(\tau \to e\gamma) < 1.1 \times 10^{-7}(10^{-9})$$
$$BR(\tau \to \mu\gamma) < 6.8 \times 10^{-8}(10^{-9})$$

MSSM analysis:

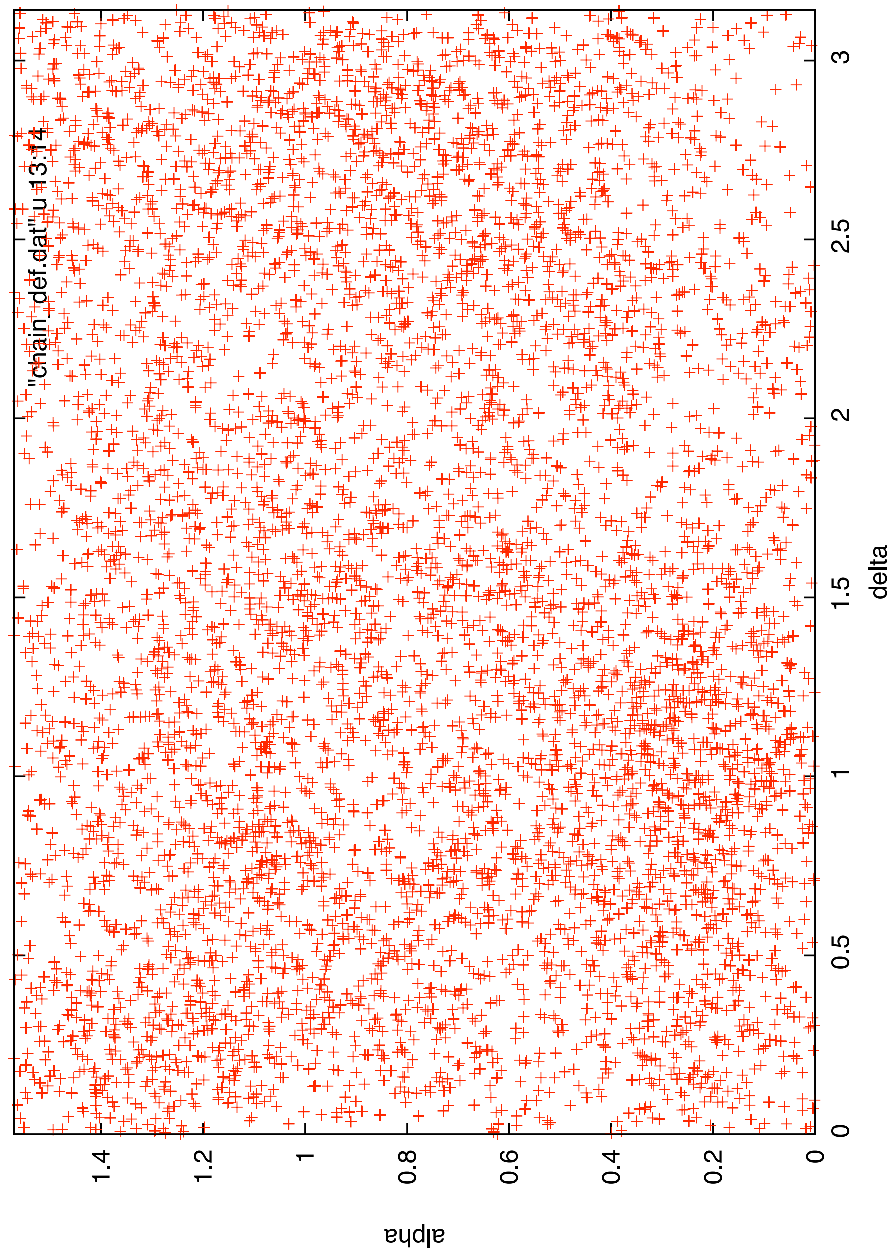
- Inputs: $U_{PMNS}, D_m, V_L, D_\lambda$

- We use a Monte Carlo Markov Chain (MCMC) program to explore regions of parameter space where $BR(\ell_\alpha \to \ell_\beta\gamma)$ are just below current limits, and the BAU is big enough.

- The RH neutrino masses and V_R are obtained by diagonalizing

$$M^{-1} = D_\lambda^{-1} V_L m V_L^T D_\lambda^{-1} = V_R^T D_M^{-1} V_R$$

- Again, no sensitivity of leptogenesis to low energy observables $\longrightarrow$ large enough BAU can be obtained for any U_{PMNS} phases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0.5
1
1.5
2
2.5
3
0.2
0.4
0.6
0.8
1
1.2
1.4

5. Conclusions and outlook

- We find no sensitivity of flavoured leptogenesis to low energy LFV observables

- Analisis of EDMs in progress $\longrightarrow$ seem to be too small once LFV constraints have been imposed