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Minimal Lepton Flavour Violation and Leptogenesis with low-energy CP Violation

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S.U., hep-ph/0612262

Outline

- Minimal Flavour Violation in the Lepton Sector (MLFV)
- Radiative Resonant Leptogenesis & Flavoured Leptogenesis
- Leptogenesis with 3 quasi-degenerate heavy Majorana Neutrinos:

    - with CP Violation at low and high Energies

    - with CP Violation exclusively at low Energies

In the Lepton Sector:

Cirigliano, Grinstein, Isidori, Wise (2005)

Minimal Lepton Flavour Violation (MLFV)

Flavour symmetry

$$SU(3)_L \times SU(3)_{e_R} \times O(3)_{\nu_R}$$

Lepton Yukawa couplings break the Flavour symmetry

Right-handed Majorana particles

included in MFV Hypothesis

$$L_{Mass} = -\tfrac{1}{2}\bar{\nu}^c_R M_R \nu_R + h.c$$

Lepton Number Violation

Majorana mass matrix has a trivial structure

$$M_R = M_\nu \mathbf{1}_{3\times 3}$$

Yukawas only flavour non-diagonal objects

- SM field content
- 3 degenerate heavy right-handed Majorana neutrinos

Cirigliano, Isidori, Porretti (2006)
Branco, Buras, Jäger, S.U., Weiler (2006)

Our Setup

Radiative corrections spoil the degeneracy of Majorana Masses:

$$M_R = M_R(\mu)$$

MLFV Hypothesis + a choice of degeneracy scale (BBJUW)

$$M_R(\Lambda_{GUT}) = M_\nu \mathbf{1}_{3\times 3}$$

+ high-energy CP violation	Lepton *number* violating scale	Lepton *flavour* violating scale
GUT scale	**Majorana scale**	$B(\mu \to e\gamma)$
Λ_{GUT} ⟷	Λ_{LN} ⟷	Λ_{LFV}
$\sim 10^{16}\, GeV$	$\sim 10^{5} - 10^{14}\, GeV$	$\sim 1 - 10\, TeV$

Radiative Resonant Leptogenesis

Felipe, Joaquim, Nobre (2004)
Turzynski (2004)
Branco, Felipe, Joaquim, Nobre (2006)
Branco, Buras, Jäger, S.U., Weiler (2006)

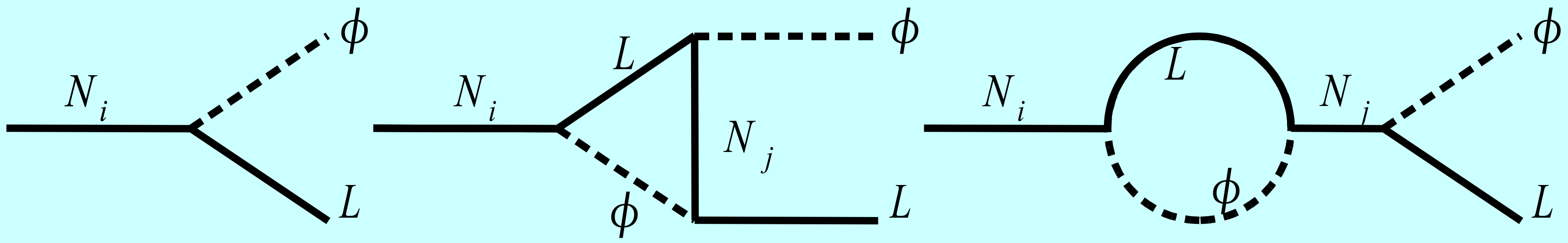
Radiative Resonant Leptogenesis

Thermal Leptogenesis

Fukugita, Yanagida (1986)

CP-violating out-of-equilibrium decays of right-handed heavy Majorana neutrinos:

➡ Excess in lepton number ➡ Lepton asymmetry ➡ Baryon asymmetry



Radiatively induced Mass splittings at Majorana scale

Resonant Leptogenesis

Pilaftsis (1997)
Pilaftsis, Underwood (2003)
Anisimov, Broncano, Plümacher (2005)
Blanchet, Di Bari (2006)

$|M_i - M_j| \sim \Gamma_{i,j}$ $\Gamma_i \sim M_i Y_\nu Y_\nu^+$

Resonant enhancement of the CP asymmetries (due to self-energy contribution)
Automatically fulfilled in our setup

Flavour Effects and Leptogenesis

Barbieri, Creminelli, Strumia, Tetradis (1999)
Pilaftsis, Underwood (2005)
Nardi, Nir, Roulet, Racker (2006)
Abada, Davidson, Josse-Michaux, Losada, Riotto (2006)
Blanchet, Di Bari (2006)
...

$M_i < (10^9 - 10^{12})\, GeV$

μ and τ charged lepton Yukawa interactions much faster than expansion *H* below some temperature.

⇨ μ and τ Yukawa couplings in equilibrium

⇨ Solution of flavour-specific Boltzmann equations required

(BBJUW)

$M_i < 10^{10}\, GeV$ Flavour-specific treatment

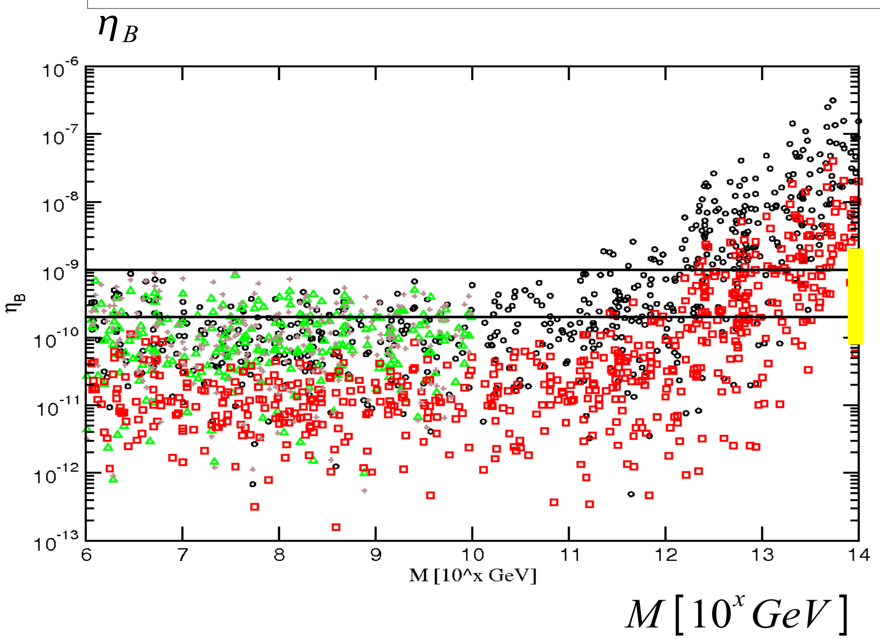
$M_i > 10^{10}\, GeV$ Single flavour

$M_\nu \approx 10^{10}\, GeV$

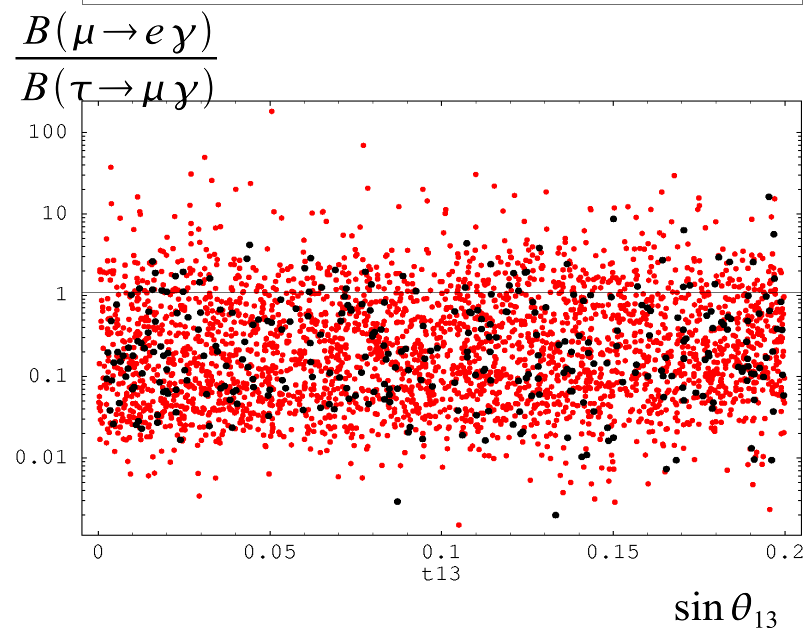
Leptogenesis with low- and high-energy CP Violation for 3 quasi-degenerate heavy Majorana Neutrinos

Branco, Buras, Jäger, S.U., Weiler (2006)

Baryon Asymmetry of the Universe



Ratios of LFV Decays



Successful Leptogenesis independent from Majorana scale

Flavour effects enhance the BAU

Leptogenesis constraint does not significantly reduce range of ratio

No testable relation

Leptogenesis with low-Energy CP Violation

Nardi, Nir, Roulet, Racker (2006)
Branco, Felipe, Joaquim (2006) (hierarchical)
Pascoli, Petcov, Riotto (2006) (hierarchical and 2 quasi-degenerate)
Branco, Buras, Jäger, S.U., Weiler (2006) (3 quasi-degenerate)
S.U. (2006)

$$\varepsilon_i^l = \frac{1}{(Y_\nu Y_\nu^+)_{ii}} \sum_j \Im\left(\left(Y_\nu Y_\nu^+\right)_{ij} \left(Y_\nu\right)_{il} \left(Y_\nu^+\right)_{lj}\right) g\left(M_i^2, M_j^2, \Gamma_j^2\right)$$

un-summed term relevant in flavour specific region

$$Y_\nu = \frac{i}{v} \sqrt{M_\nu}\, R \sqrt{m_\nu}\, U_{PMNS}^+$$

Casas, Ibarra (2001)

R encodes high-energy CP violation
(3 physically relevant complex parameters)

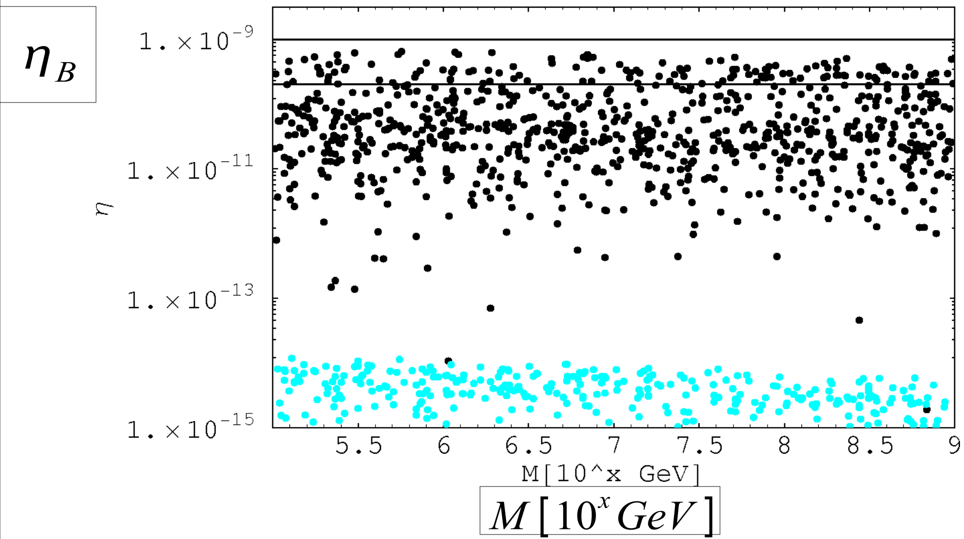
$$R(\Lambda_{GUT}) = \mathbf{1}_{3\times3}$$

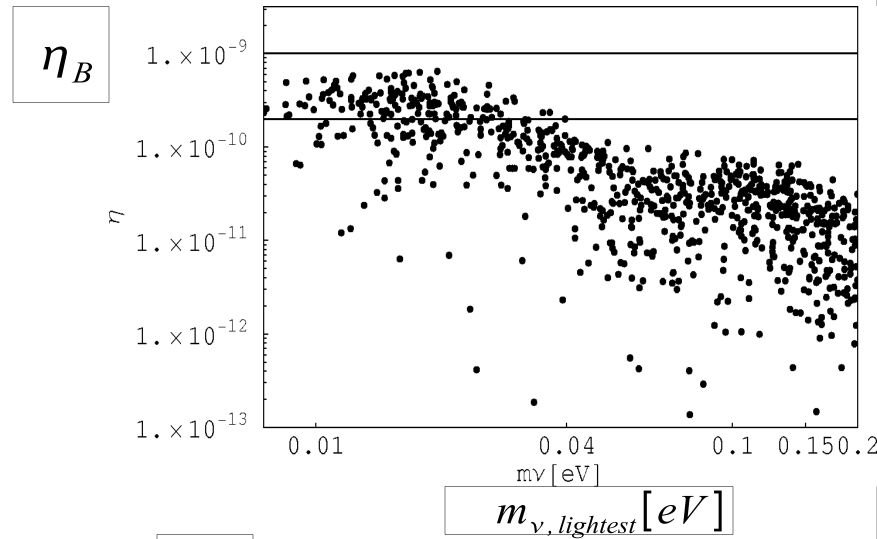
➡ only low-energy CP violation via PMNS phases

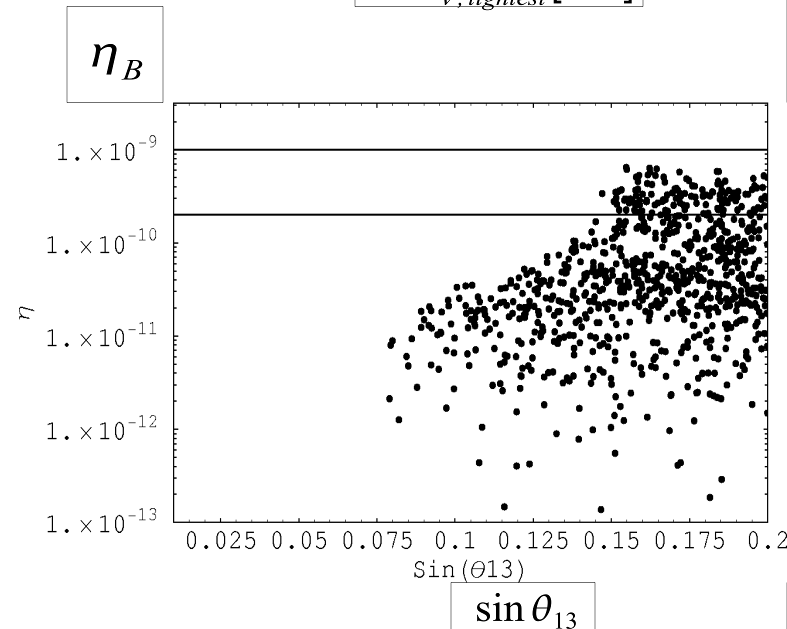
$$U_{PMNS} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}c_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -s_{23}c_{12} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} e^{i\alpha/2} & 0 & 0 \\ 0 & e^{i\beta/2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Leptogenesis with low-Energy CP Violation

S.U. (2006)







Clear constraints for successful leptogenesis

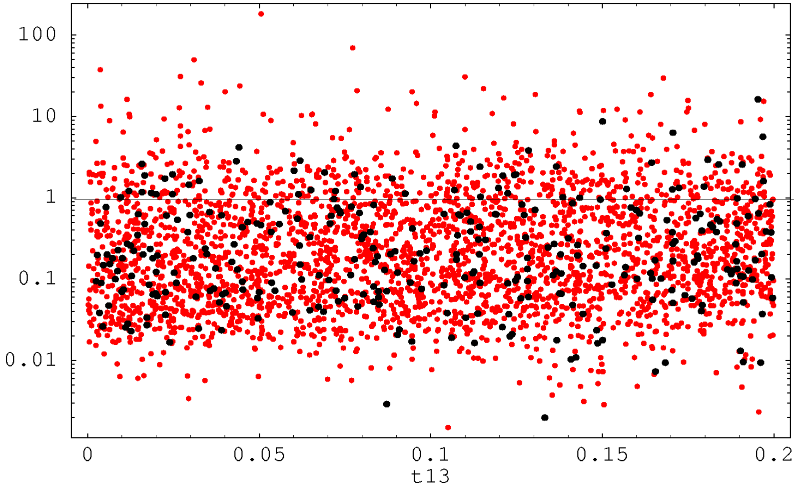
- Consideration of Flavour effects (BBJUW)
- Normal hierarchy of light neutrino masses
- A single non-vanishing Majorana phase
- $\sin\theta_{13} > 0.13$ $\quad$ $m_{\nu,\,lightest} < 0.04\,eV$

Story of Predictivity

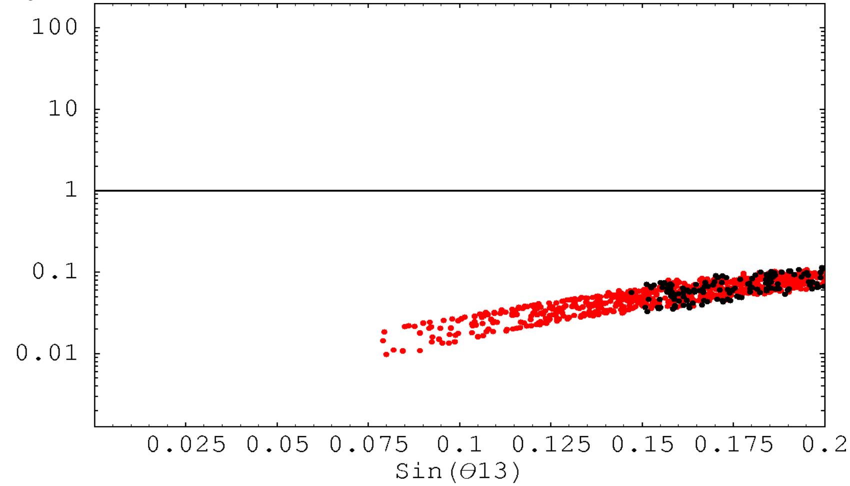
S.U. (2006)

Low- and high-energy CPV	Low-energy CPV

$$\frac{B(\mu \to e\gamma)}{B(\tau \to \mu\gamma)}$$



$\sin\theta_{13}$



$\sin\theta_{13}$

wide range	< 1

Conclusions

In the framework of MLFV & RRL the BAU can successfully be generated with CP Violation at low and high Energies.
Correlation to low-energy Observables is weak.

With the Flavour Effects it is possible to generate the BAU with low-energy CP Violation alone.

This special Case requires clear Relations and Properties of Neutrino Parameters that can be falsified.
Correlations to low-energy Observables exist.