Implications of tribimaximal lepton mixing for leptogenesis

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Based on

[arXiv:0908.0907] NPB827,34

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Introduction
- Baryon asymmetry
- Origin of the BA
- Baryogenesis in the SM
- Possible approaches
- Standard leptogenesis

Leptogenesis and low-energy observables

Implementation

Conclusions

Introduction

Baryon asymmetry

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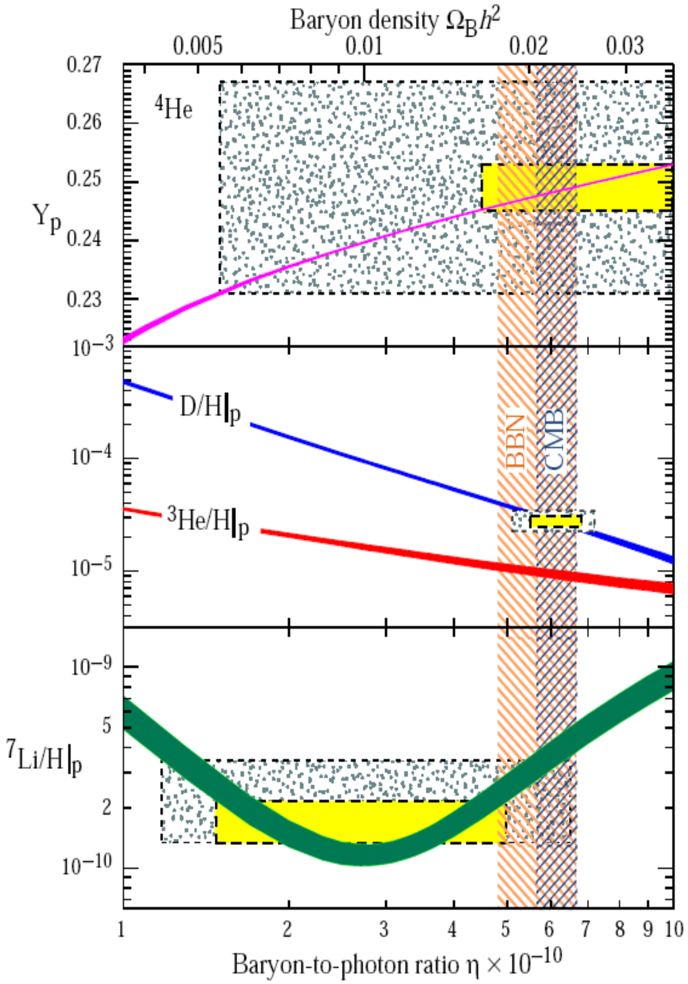
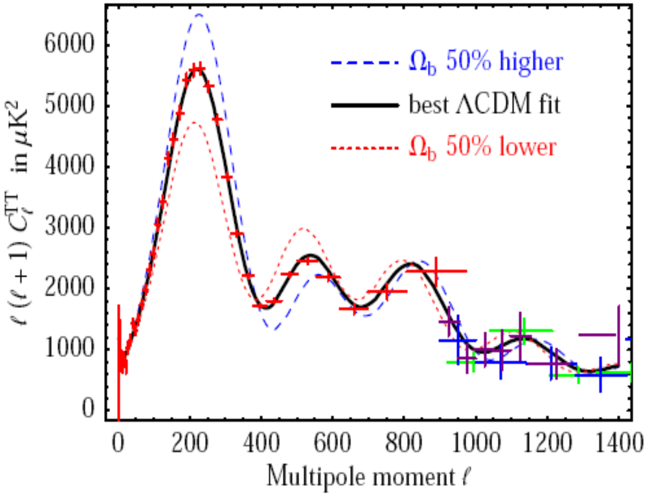
The cosmic Baryon Asymmetry (BA) is derived from measurements of light elements abundances (D, ^{3}He, ^{4}He, ^{7}Li) and the CMB





$$\eta = \frac{n_B - n_{\bar{B}}}{n_\gamma} \simeq (6.21 \pm 0.16) \times 10^{-10}$$

$$\eta = 2.74 \times 10^{-8} \Omega_B h^2$$

$$Y_{\Delta_B} = \frac{n_B - n_{\bar{B}}}{s} \simeq \frac{\eta}{7.04}$$

$$\boxed{Y_{\Delta_B} \simeq (8.75 \pm 0.23) \times 10^{-11}}$$

7-year WMAP, arXiv:1001.4538

Origin of the BA

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☐ Could be an initial condition?... A crucial ingredient of ΛCDM is inflation... Any primordial B asymmetry would be diluted.

☐ The origin of the Baryon Asymmetry should be dynamic (Baryogenesis):

Sakharov Conditions

Pisma Zh.Eksp.Teor.Fiz. 5 (1967) 32-35

❶ The Baryon Asymmetry generating interations must violate B.

❷ The Baryon Asymmetry generating interactions must break CP.

❸ The Baryon Asymmetry generating interactions must departure -at some point- from Thermodynamical Equilibrium.

Any model satisfying these conditions -in principle- constitutes a framework for baryogenesis

Baryogenesis in the SM

Qualitatively

- B is broken at the non-perturbative level (sphalerons processes)
- CP violation is provided by the CKM quark mixing matrix
- Departure from TEQ provided by the electro-weak phase transition.

Quantitatively

- CP violation to small ✘
- Succesful baryogenesis requires strongly $1^{\underline{st}}$ order phase transition $\Rightarrow$

$m_h < 40$ GeV while LEP: $m_h > 115$ GeV **(Kajantie et. al. PRL,77,2887)** ✘

The SM fails at the quantitative level

Explanation of $Y_{\Delta B}$ requires BSM physics

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Possible approaches

A large number of mechanisms (models) for baryogenesis exist. Among them two of the most widely studied are:

EW baryogenesis **(Cohen, Kaplan, Nelson, PLB,245,561)**

EW baryogenesis models “cure” the SM pitfalls via extended scalar sectors

$$V_{\text{SM}}(\Phi) \longrightarrow V(S_i,\Phi_i) \Rightarrow \begin{cases} \text{Strongly } 1^{\underline{\text{st}}} \text{ order EWPT: relaxing } m_h^{\text{max}} \\ \text{Additional CP violating sources} \end{cases}$$

SM+S, 2HDMs, MSSM... EWB will be tested at the LHC!

Leptogenesis: **(Fukugita, Yanagida, PLB,174,45)**

$$Y_{\Delta_L} \to Y_{\Delta_B}$$

$B+L$ violating EW sphalerons interactions

$$\mathcal{O}_{B+L} = \prod_{i=1,2,3} (q_{L_i} q_{L_i} q_{L_i} \ell_{L_i})$$

Qualitatively (quantitatively in some cases) viable in models of Majorana neutrino masses. Linked with the origin of neutrino masses!

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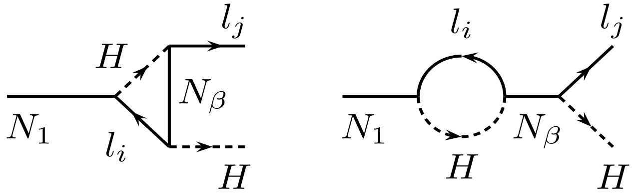
Standard leptogenesis

Leptogenesis in the standard seesaw model (type-I seesaw) with $M_1 \ll M_{2,3}$. Y_{Δ_L} proceeds via N_{R1} decays

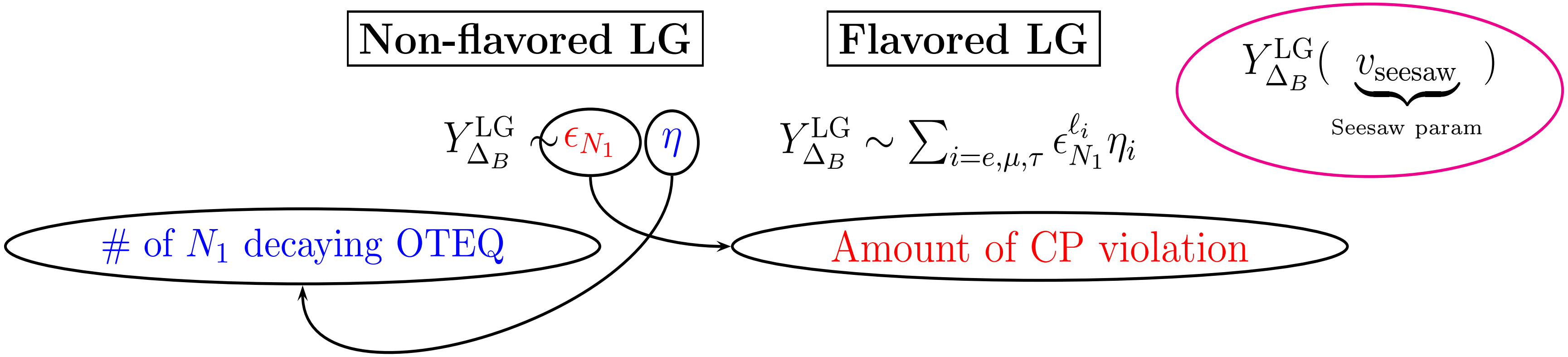
$$\Gamma_D = \Gamma(N_{R1} \to \ell\tilde{H}, \bar{\ell}\tilde{H}^\dagger) = \frac{M_1^2}{8\pi v^2} \sum_{i=e,\mu,\tau} \tilde{m}_{i1} \qquad \boxed{\tilde{m}_{i\alpha} \propto \lambda^*_{i\alpha}\lambda_{i\alpha}}$$

- Majorana mass term m_R is a L violating source ($\Delta L = 2$).
- $\lambda_{i\alpha} \longrightarrow$ contain new physical CPV phases. CPV asymmetries arise at the one-loop level **(Covi, Roulet, Vissani, PLB384, 169)**

$$\boxed{\epsilon_{N_1}^{\ell_i} = \frac{\Gamma_i - \bar{\Gamma}_i}{\Gamma_i + \bar{\Gamma}_i}}$$



- Departure from thermal equilibrium provided by the expansion. $\Gamma_D \lesssim H(z = M/T = 1)$



Non-flavored LG

$Y_{\Delta_B}^{\text{LG}} \sim \epsilon_{N_1}\, \eta$

Flavored LG

$Y_{\Delta_B}^{\text{LG}} \sim \sum_{i=e,\mu,\tau} \epsilon_{N_1}^{\ell_i}\eta_i$

$Y_{\Delta_B}^{\text{LG}}(\underbrace{v_{\text{seesaw}}}_{\text{Seesaw param}})$

of N_1 decaying OTEQ

Amount of CP violation

Introduction

Leptogenesis and low-energy observables
- An attempt
- Constrained scenarios

Implementation

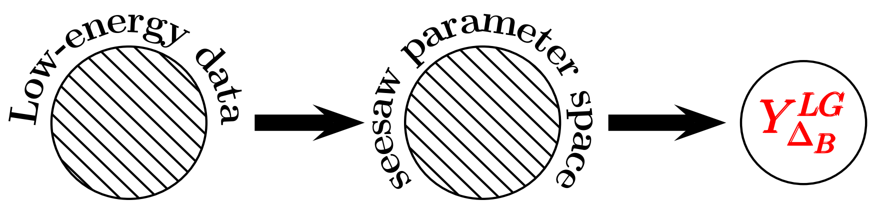
Conclusions

Leptogenesis and low-energy observables

An attempt

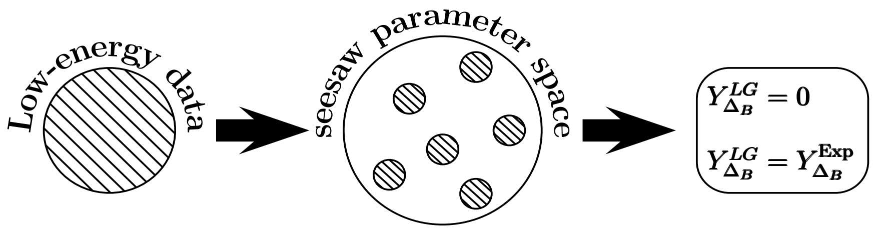
- Standard LG relies in physics near Λ_{GUT} $\Rightarrow$ A direct test not possible.

- Indirect test Use low-energy mesurements to make statements -hopefully definitive- on the Y_{Δ_B} produced via LG:



Ideal picture: E.g. $\delta, \phi_{1,2} = 0 \quad \Rightarrow \quad Y_{\Delta_B}^{LG} = 0$

Does not WORK!



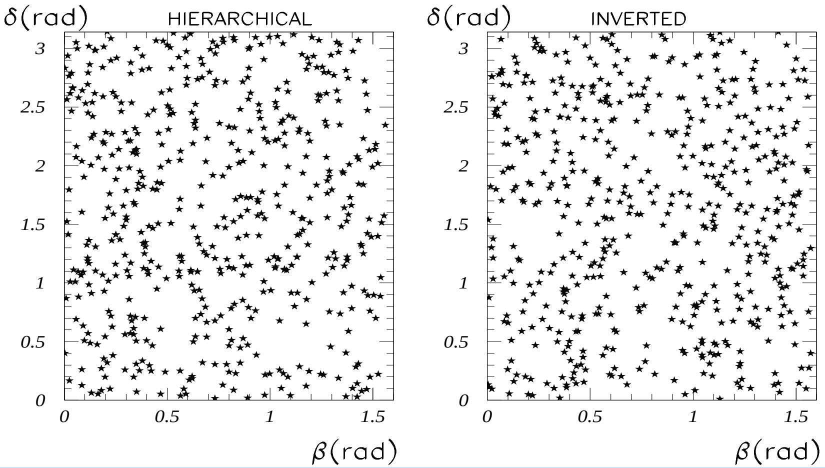
18 parameters and 9 measurements

No constraints on 9-dim space

$Y_{\Delta_B}^{LG}$ can always be fitted

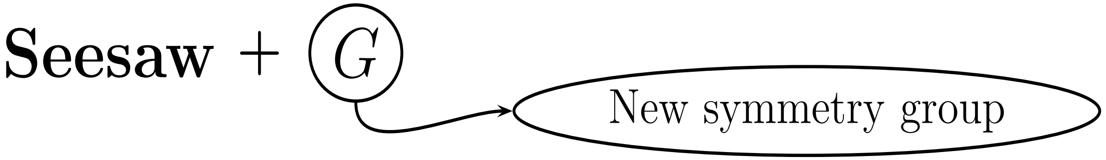
This attempt FAILS!

G. Branco et. al. (hep-ph/0107164)
S. Davidson et. al. (arXiv:0705.1503)



Constrained scenarios

New symmetries may put additional contraints:



G ➧ $d' = n\,\textbf{dim},\ n < 18$

Which G ?

Current neutrino data indicates that lepton mixing is close to the TB mixing pattern

$$\sin^2\theta_{13}^{TB} = 0 \quad \sin^2\theta_{23}^{TB} = 1/2 \quad \sin^2\theta_{12}^{TB} = 1/3$$

$$U_{TB} = \begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -1/\sqrt{6} & 1/\sqrt{3} & -1/\sqrt{2} \\ -1/\sqrt{6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix}$$

PROGRAM

Fix $G = G_{TBM}$ and see what kind of statements about leptogenesis can be established from low-energy data

Introduction

Leptogenesis and low-energy observables

Implementation
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- Structure of the matrices
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- Avoiding vanishing CPVA

Conclusions

Implementation

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Setup

$$m_\nu^{\text{eff}} = -\boxed{m_D}\, M_N^{-1}\, {m_D}^T \qquad \boxed{\bar{L}\, m_D\, N_R} \qquad \boxed{m_D = v\lambda}$$

Exact TB diagonalization implies:

$$m_\nu^{\text{eff}} = \begin{pmatrix} m_{\nu 22} + m_{\nu 23} - m_{\nu 12} & m_{\nu 12} & m_{\nu 12} \\ \cdot & m_{\nu 22} & m_{\nu 23} \\ \cdot & \cdot & m_{\nu 22} \end{pmatrix}$$

$$\boxed{D}\, U_{\text{TB}}^T\, m_\nu^{\text{eff}}\, U_{\text{TB}}\, D = \overbrace{\hat{m}_\nu}^{\text{Real}}$$

$$\boxed{\text{diag}(e^{i\varphi_1}, e^{i\varphi_2}, 1)}$$

Diagonalization of m_D and M_N:

$$\left.\begin{array}{r} L \to U_L\, L \\ N_R \to U_R\, N_R \end{array}\right\} \qquad {U_L}^\dagger\, m_D\, U_R = \underbrace{\hat{m}_D}_{\text{Real}} \qquad \Rightarrow \qquad m_D = U_L\, \hat{m}_D\, {U_R}^\dagger$$

$$N_R \to V_R\, N_R \quad \} \qquad {V_R}^T\, M_N\, V_R = \underbrace{\hat{M}_N}_{\text{Real}} \qquad \Rightarrow \qquad {M_N}^{-1} = V_R\, {\hat{M}_N}^{-1}\, {V_R}^T$$

$$\hat{m}_\nu = -D\, \left({U_{TB}}^T\, U_L\right)\, \hat{m}_D\, \left({U_R}^\dagger\, V_R\right)\, {\hat{M}_N}^{-1}\, \left({V_R}^T\, {U_R}^*\right)\, \hat{m}_D\, \left({U_L}^T\, U_{TB}\right)\, D$$

Structure of the matrices

$(U_{TB})_{ij}$ are square roots of fractions while charged lepton masses m_ℓ and $\Delta m_{12,23}$ do not have such a fractional relationship:

Presence of $\boldsymbol{G_{TB}}$ $\Rightarrow$ $\boldsymbol{m_D}$ and $\boldsymbol{M_R}$
Form-diagonalizable

The mixing angles are independent

of the mass eigenvalues

C. I. Low and R. R. Volkas (hep-ph/0305243)

$\Rightarrow$ $\boldsymbol{U_{L,R}}$ and $\boldsymbol{V_R}$ independent from $\boldsymbol{\hat{m}_D}$ and $\boldsymbol{\hat{M}_N}$

$$\hat{\boldsymbol{m}}_{\boldsymbol{\nu}} = -\boldsymbol{D} \underbrace{\left(\boldsymbol{U_{TB}}{}^T \boldsymbol{U_L}\right)}_{P_L O_{D_i}} \hat{\boldsymbol{m}}_{\boldsymbol{D}} \underbrace{\left(\boldsymbol{U_R}{}^\dagger \boldsymbol{V_R}\right)}_{O_{D_i}{}^\dagger P_R O_{R_m}} \hat{\boldsymbol{M}}_{\boldsymbol{N}}{}^{-1} \underbrace{\left(\boldsymbol{V_R}{}^T \boldsymbol{U_R}{}^*\right)}_{O_{R_m}{}^T P_R O_{D_i}{}^*} \hat{\boldsymbol{m}}_{\boldsymbol{D}} \underbrace{\left(\boldsymbol{U_L}{}^T \boldsymbol{U_{TB}}\right)}_{O_{D_i}{}^T P_L} \boldsymbol{D}$$

☞ $\boldsymbol{P_{L,R}} = \text{diag}\left(e^{\alpha_1^{L,R}}, e^{\alpha_2^{L,R}}, e^{\alpha_3^{L,R}}\right)$

$$\boxed{\alpha^L_{1,2} + \alpha^R_{1,2} + \varphi_{1,2} = n\pi \ , \ \alpha^L_3 + \alpha^R_3 = k\pi}$$

☞ $\boldsymbol{O_{D_i}}$: Unitary, rotates “i” degenerate eigenvalues of $\boldsymbol{m_D}$

☞ $\boldsymbol{O_{R_m}}$: Real orthogonal (preserves canonical kinetic terms), rotates “m” degenerate eigenvalues of $\boldsymbol{M_N}$

No degeneracy $\boldsymbol{O_{D_i,R_m}}$ $=$ **Ident**

Introduction

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Conclusions

Dirac matrix and leptogenesis

In the basis in which $\boldsymbol{M_N}$ is diagonal:

$$m_D^R = m_D V_R = U_L \hat{m}_D U_R^\dagger V_R \qquad \begin{cases} U_L = U_{TB} P_L O_{D_i} \\ U_R^\dagger = O_{D_i}^\dagger P_R O_{R_m} V_R^\dagger \end{cases}$$

$$m_D^R = \overbrace{U_{TB} P_L \underbrace{O_{D_i} \hat{m}_D O_{D_i}^\dagger}_{\hat{m}_D} P_R O_{R_m} V_R^\dagger}^{m_D} V_R$$

$$\boxed{m_D^R = U_{TB} P_L \hat{m}_D P_R O_{R_m}}$$

The CPV asymmetry

$$\epsilon_{N_1} \propto \sum_{\beta\neq\alpha} \mathrm{Im}\left[\left(m_D^{R\dagger} m_D^R\right)_{\beta\alpha}\right] \qquad m_D^{R\dagger} m_D^R = \underbrace{O_{R_m}^T \hat{m}_D^2 O_{R_m}}_{\text{Real}} \quad \Rightarrow \quad \boxed{\epsilon_{N_1} = 0}$$

The same result holds for the CPV flavored asymmetries $\epsilon_{N_1}^{\ell_i}$

In the limit of exact TBM the leptogenesis scenario does not work

Bertuzzo, Di Bari, Feruglio, Nardi (arXiv:0908.0161)

DAS, Bazzocchi, de Medeiros, Merlo, Morisi (arXiv:0908.0907)

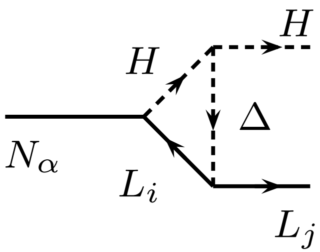
Gonzalez Felipe, Serodio (arXiv:0908.2947)

Avoiding vanishing CPVA

- **NLO corrections** Due to these corrections $\boldsymbol{m_\ell}$, $\boldsymbol{m_D}$ and $\boldsymbol{M_N}$ are “shifted”:

$$\underbrace{m_D^{R\dagger\prime} m_D^{R\prime}}_{\text{No longer }\mathbf{Real}} = m_D^{R\dagger} m_D^{R} + m_D^{R\dagger}\Big(U_\ell^{(1)\dagger}\, m_D^{R} + U_L\, U_L^{(1)}\, \hat{m}_D\, U_R{}^\dagger\, V_R + U_L\, \hat{m}_D'\, U_R{}^\dagger\, V_R + \cdots$$

- **New degrees of freedom** E.g. an interplay between (I + II) seesaw:

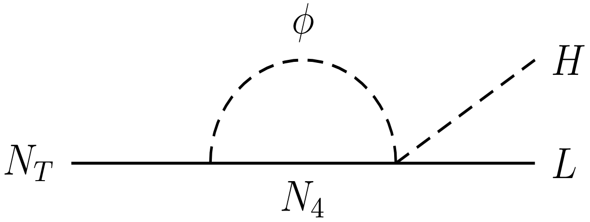


$$\boxed{\begin{aligned} \epsilon_{N_1}^{\Delta} &\propto \text{Im}\left[m_D^{R}\, m_D^{R}\, Y_\Delta{}^\dagger\, \mu\right] \\ \epsilon_{N_1}^{\text{Full}} &= \underbrace{\epsilon_{N_1}}_{=0} + \epsilon_{N_1}^{\Delta} \neq 0 \end{aligned}}$$

- **Via Flavons** Induce new CPVA

(DAS, Nardi, Losada arXiv:arXiv:0705.1489)

(DAS, F. Bazzocchi, Reiner de Alderhat, work in progress)



$$\boxed{\epsilon_{N_T} \not\propto \text{Im}\left[m_D^{R\dagger} m_D^{R}\right] \;\Rightarrow\; \epsilon_{N_T} \neq 0}$$

Quite generically an indirect test of leptogenesis is not possible

Introduction

Leptogenesis and low-energy observables

Implementation

Conclusions
- Final remarks

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Final remarks

Introduction
Leptogenesis and low-energy observables
Implementation
Conclusions
● Final remarks

- Analysis of constrained standard seesaw models (seesaw + G_{TB}) have shown the CPV asymmetry vanishes. The result holds for any pattern in which the mass matrices are enforced to be **“Form diagonalizable”**.

- Several paths to a non-vanishing CPV asymmetry may be constructed:
  - ✔ Inclusion of NLO corrections **(higher dimensional effective operators)**
  .
  - ✔ New contributions to CP violating asymmetries **(beyond standard seesaw + G_{TB})**
  .
  - ✔ Flavon dynamics.

- In general an indirect test not possible... in particular realizations a bridge between low-energy measurements and leptogenesis is possible.