CP Violation in the τ Lepton Yukawa Coupling and Flavour Symmetries

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Based on **J. Alonso-González**, L. Merlo and S. Pokorski, [arXiv:2103.16569]

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1. $\not{CP}$ τ Yukawa Coupling

Effective Higgs-τ Lagrangian:

$y_\tau = \sqrt{2}m_\tau/v$

$\kappa_\tau^{SM} = 1,\ \tilde{\kappa}_\tau^{SM} = 0$

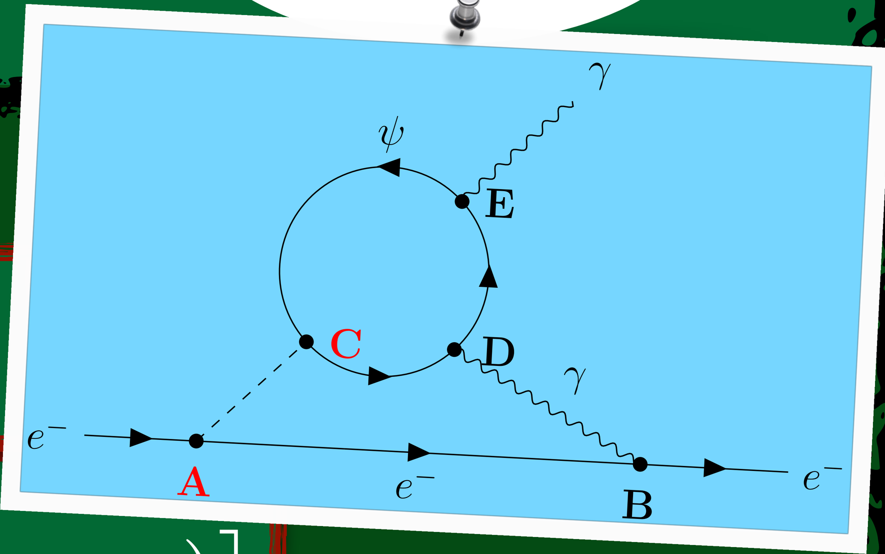
$$\mathscr{L}_{\rm eff} = -\frac{y_\tau}{\sqrt{2}}\left(\kappa_\tau \bar{\tau}\tau + i\,\tilde{\kappa}_\tau \bar{\tau}\gamma_5\tau\right)h$$

$\tilde{\kappa}_\tau \neq 0$ encodes BSM $\not{CP}$ effects:

1. It sources the baryon asymmetry of the Universe (BAU) in EWBG:
   With SMEFT d=6 operators to τ Yukawas, $|\tilde{\kappa}_\tau| \gtrsim 0.08$ can explain the entire BAU!!! [1]
2. It contributes to the electron EDM (eEDM)

2. eEDM Bounds

The Barr-Zee diagram contribution to eEDM [2]:



$$\frac{d_e}{e} = 4\,N_C\,Q_\psi^2\,\frac{\alpha_{\rm em}}{(4\pi)^3}\sqrt{2}\,G_F\,m_e\left[\kappa_e\tilde{\kappa}_\psi f_1(x_{\psi/h}) + \tilde{\kappa}_e\kappa_\psi f_2(x_{\psi/h})\right]$$

ACME II Bound

$|d_e| < 1.1\times 10^{-29}$ e cm, at 90% C.L.

Bounds assuming single NP contribution:

- $\psi = \tau$ and $\tilde{\kappa}_e = 0$ [1]: $|\tilde{\kappa}_\tau| \lesssim 0.3$ — Compatible with BAU!!!
- $\psi = t$ and $\tilde{\kappa}_t = 0$: $|\tilde{\kappa}_e| \lesssim 0.0017$

The strong bound on $\tilde{\kappa}_e$ is translated to $\tilde{\kappa}_\tau$!!

$$|\tilde{\kappa}_\tau| \lesssim 0.0017\,\frac{m_e}{m_\tau}\frac{\text{Im}\,C_{33}}{\text{Im}\,C_{11}}$$

3. Imposing Flavour Symmetries

Assumptions

1. Lepton Yukawas from SMEFT d=4 and d=6 operators
2. $\mathscr{L}$ compatible with flavour symmetry

In the interaction basis:

Λ: effective NP scale

$$\mathscr{L} = -\overline{L'}HY'e'_R - \overline{L'}HC'e'_R\frac{H^\dagger H}{\Lambda^2} + \text{h.c.}$$

Y', C': complex 3x3 matrices in flavor space

$$\tilde{\kappa}_\tau = \frac{v^2}{\Lambda^2}\frac{\text{Im}\,C_{33}}{y_\tau}$$

$$\tilde{\kappa}_e = \frac{v^2}{\Lambda^2}\frac{\text{Im}\,C_{11}}{y_e}$$

In the mass basis, below EWSB scale:

$$Y = V^\dagger\left(Y' + \frac{v^2}{2\Lambda^2}C'\right)U = \sqrt{2}/v\,\text{diag}\,(m_e, m_\mu, m_\tau)$$

$$\mathscr{L} = -\overline{e_L}Ye_R\frac{v}{\sqrt{2}} - \overline{e_L}\left(Y + \frac{v^2}{\Lambda^2}C\right)e_R\frac{h}{\sqrt{2}} + \text{h.c.} + \ldots$$

$C = V^\dagger C' U$

4. Two Concrete Examples

Minimal Flavour Violation

$C' = c'Y'$

c': complex number

$|\tilde{\kappa}_\tau| \lesssim 0.0017$ — Incompatible with BAU!!!

Froggatt-Nielsen Models with horizontal U(1)

U(1) Charges

Flavon : $n_\phi = -1$

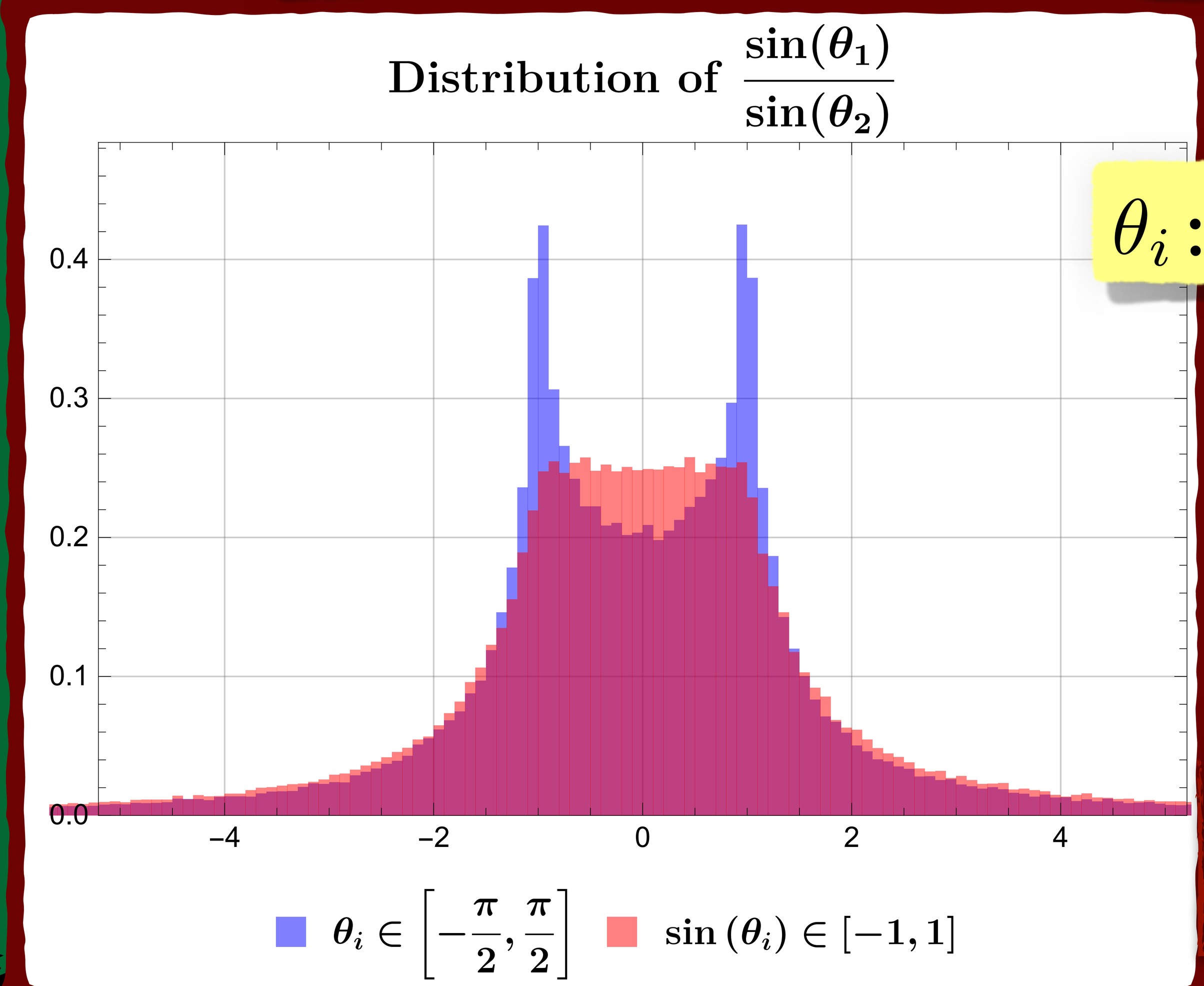
$\overline{L_i}$: $n_{L1} > n_{L2} > n_{L3} > 0$

e_{Ri} : $n_{R1} > n_{R2} > n_{R3} > 0$

$$C_{33} \simeq \mathcal{O}\left(\sqrt{2}\,m_\tau/v\right)e^{i\theta_1}$$

$$C_{11} \simeq \mathcal{O}\left(\sqrt{2}\,m_e/v\right)e^{i\theta_2}$$

θ_i: effective not fixed phases



$$|\tilde{\kappa}_\tau| \lesssim 0.0017\,\frac{\sin\theta_1}{\sin\theta_2}\,\mathcal{O}(1)$$

Incompatible with BAU!!!

[1] JHEP 05 (2020) 056
[2] JHEP 11 (2013) 180