Leptogenesis Through a Scalar Field UV Completion of the Weinberg Operator

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4 May 2020

The Positive Electron

CARL D. ANDERSON, *California Institute of Technology, Pasadena, California*
(Received February 28, 1933)

Out of a group of 1300 photographs of cosmic-ray tracks in a vertical Wilson chamber 15 tracks were of positive particles which could not have a mass as great as that of the proton. From an examination of the energy-loss and ionization produced it is concluded that the charge is less than twice, and is probably exactly equal to, that of the proton. If these particles carry unit positive charge the curvatures and ionizations produced require the mass to be less than twenty times the electron mass. These particles will be called positrons. Because they occur in groups associated with other tracks it is concluded that they must be secondary particles ejected from atomic nuclei.

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Matter $\gg$ Antimatter

Primordial Baryon Asymmetry

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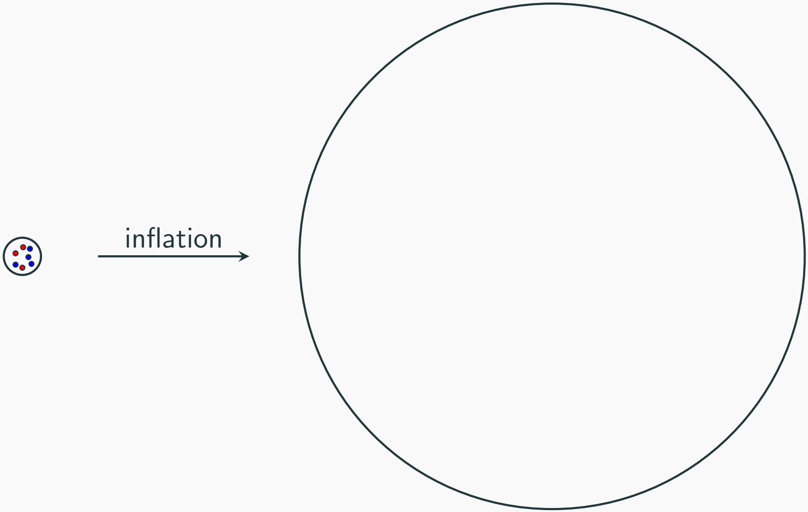

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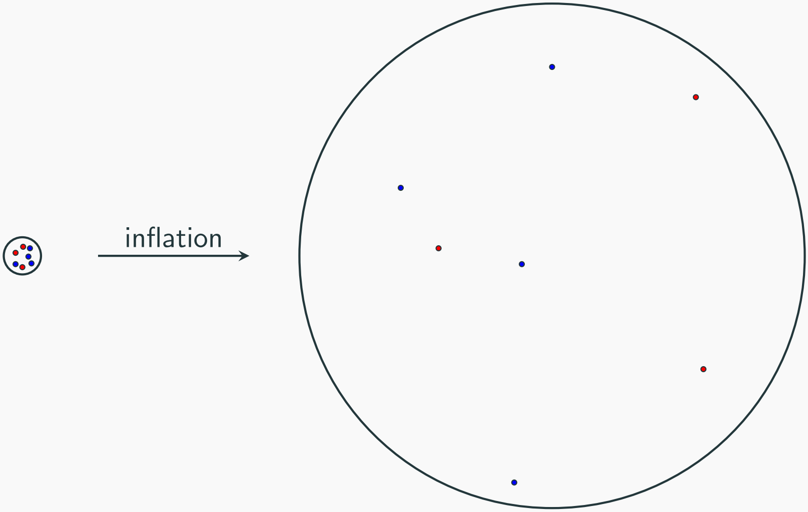

(Decay-Based) Baryogenesis

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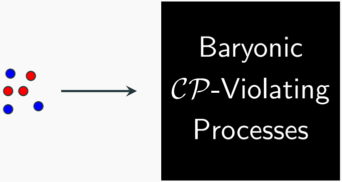

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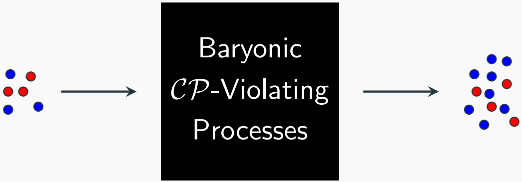

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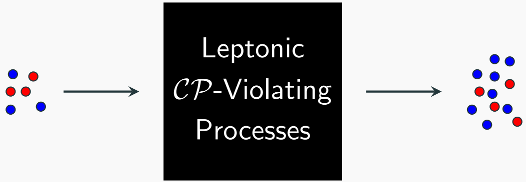


(Decay-Based) Leptogenesis

$\phi \to$ leptons $\qquad \phi \to$ antileptons

(Decay-Based) Leptogenesis

$$\Gamma(\phi \to \text{leptons}) \qquad \Gamma(\phi \to \text{antileptons})$$

(Decay-Based) Leptogenesis

$$\Gamma(\phi \to \text{leptons}) \; > \; \Gamma(\phi \to \text{antileptons})$$

(Decay-Based) Leptogenesis

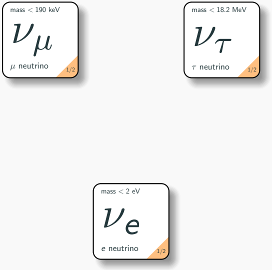
$$\Gamma(\phi \to \text{leptons}) \; > \; \Gamma(\phi \to \text{antileptons})$$

Quantify degree of the leptonic asymmetry with the $\mathcal{CP}$ **source**:

$$\epsilon \equiv \frac{\Gamma\left(\phi \to \text{leptons}\right) - \Gamma\left(\phi \to \text{antileptons}\right)}{\Gamma\left(\phi \to \text{leptons}\right) + \Gamma\left(\phi \to \text{antileptons}\right)}$$

Neutrino Physics: Neutrino Oscillations

"left-handed Weyl spinors"



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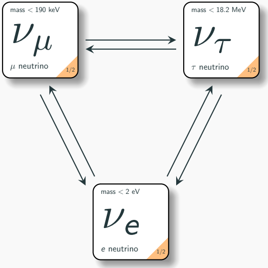

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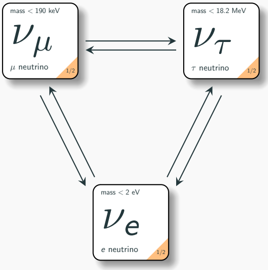

Neutrino Oscillations

flavor eigenstate

mass eigenstate

$$|\nu_\mu\rangle = \mathbf{U}_{\mu k}|\nu_k\rangle$$
$$|\nu_\tau\rangle = \mathbf{U}_{\tau k}|\nu_k\rangle$$
$$|\nu_e\rangle = \mathbf{U}_{ek}|\nu_k\rangle$$

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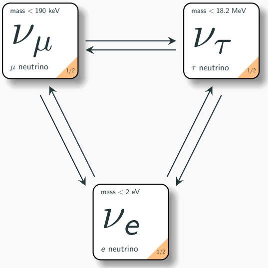

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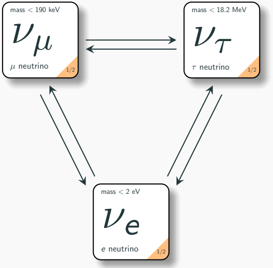

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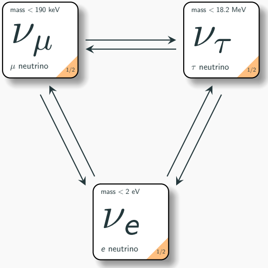

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$$\boxed{m_1 \neq m_2}$$

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Neutrino Mass Types

Dirac Mass Potential

$$-D_{\alpha I}\nu_\alpha N_I + \text{h.c.}$$

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$\mathcal{L}_{\text{ESM}}$

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$$\cup$$

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Unfortunately, this requires

$$|F_{\alpha I}| \sim 10^{-12}$$

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Hence, "see-saw effect" whereby

$$M_I \text{ sufficiently large} \implies M^{\nu}_{\alpha\beta} \text{ sufficiently small}$$

The Weinberg Operator

$$\mathcal{L}_{\mathsf{ESM}} \supset -F_{\alpha I}\left(\widetilde{H}\cdot L_{\alpha}\right)N_I - \frac{1}{2}M_I N_I N_I + \text{h.c.}$$

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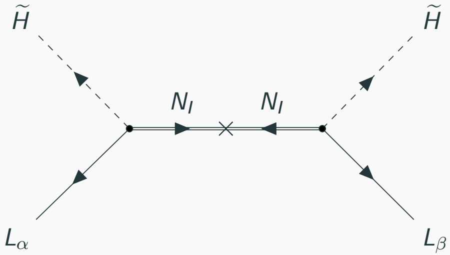

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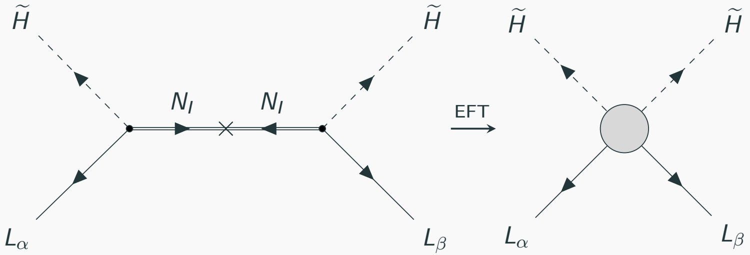

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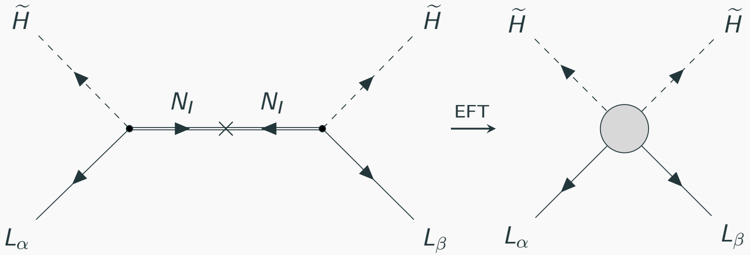

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UV Completing the Weinberg Operator

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The Weinberg operator appears through the decay channel

$$\phi \to N_I N_I \to \left(\widetilde{H} \cdot L_\alpha \right) \left(\widetilde{H} \cdot L_\beta \right)$$

A Leptogenesis Model?

Leptonic $\mathcal{CP}$ violation through the decay channel

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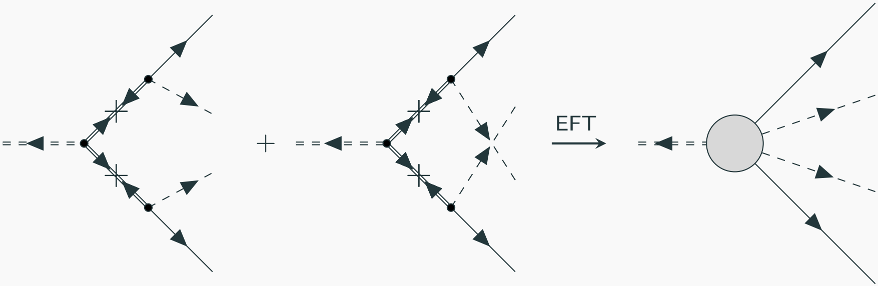

$\mathcal{CP}$-Violating Amplitudes

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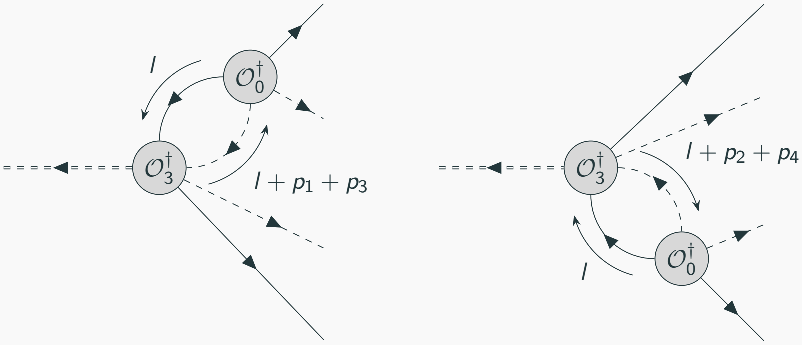

Generating an Asymmetry

“Procedure”

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Future Work

- Verify tree-loop interferences
- Tell `Mathematica` what to integrate and get ϵ

Acknowledgements

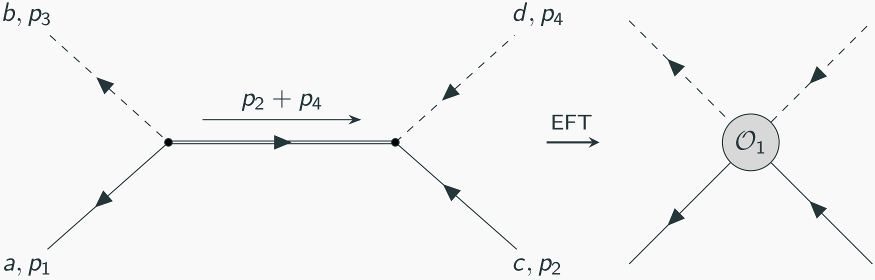
Brian Shuve

Carlos Tamarit (Technische Universität München)

All of you!

Effective Operators

In EFT limit $m_\phi \ll |M_I|$:



$$\mathcal{O}_1 = \sum_I \frac{F_{\beta I} F^*_{\alpha I}}{M_I^2} \partial_\mu \left(\widetilde{H}^\dagger \cdot L_\alpha^\dagger \right) \sigma^\mu \left(\widetilde{H} \cdot L_\beta \right)$$

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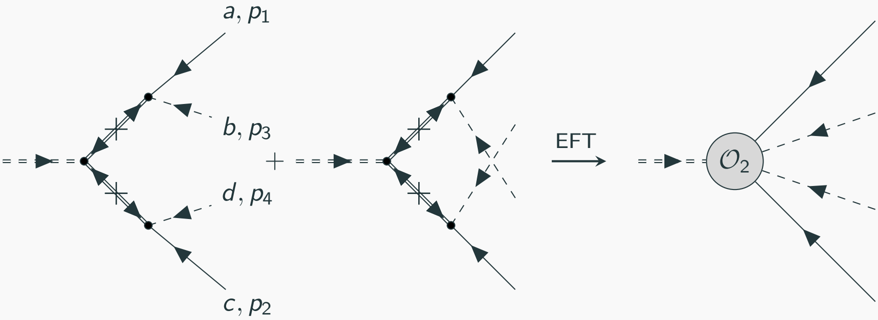

$$\mathcal{O}_2 = -\frac{1}{2} \sum_I \frac{F_{\alpha I} F_{\beta I} Y_I}{M_I^2} \phi \left(\widetilde{H} \cdot L_\alpha \right) \left(\widetilde{H} \cdot L_\beta \right)$$

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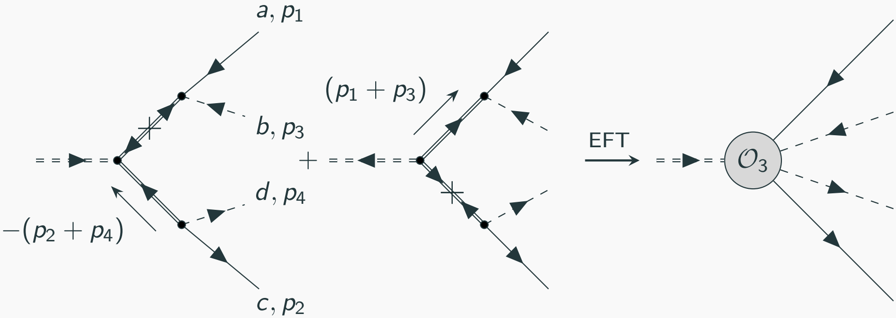

$$\mathcal{O}_3 = -\sum_I \frac{F_{\alpha I} F^*_{\beta I} Y_I}{M_I^3} \phi \left[\partial_\mu \left(\widetilde{H}^\dagger \cdot L^\dagger_\beta\right) \overline{\sigma}^\mu \left(\widetilde{H} \cdot L_\alpha\right) - \left(\widetilde{H}^\dagger \cdot L^\dagger_\beta\right) \overline{\sigma}^\mu \partial_\mu \left(\widetilde{H} \cdot L_\alpha\right)\right]$$