Post-Inflationary Higgs Relaxation Leptogenesis

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University of Minnesota

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A. Kusenko, LP, L. Young, PRL 114 (2015) 6, 061302.

The Motivation

The Higgs Potential

- LHC measurements suggest a Higgs boson with mass $\sim$ 125 GeV.

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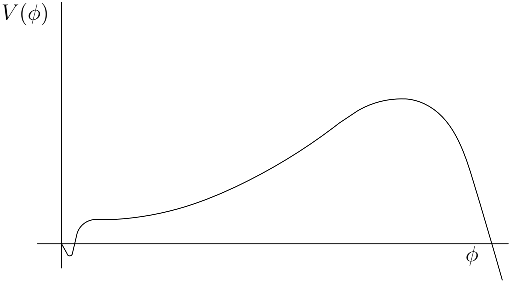
- LHC measurements suggest a Higgs boson with mass ~ 125 GeV.
- If we evolve the Standard Model RGE equation out to high scales, the Higgs potential becomes shallow, and even appears to have a second minimum.



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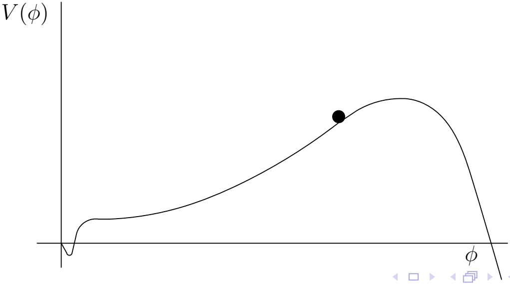

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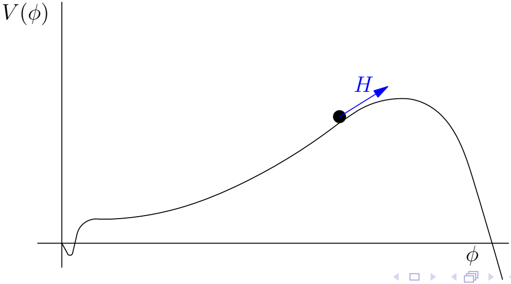
- Hubble friction from expansion of universe prevents from rolling back down

$$\ddot{\phi} + 3H\dot{\phi} + V'_\phi = 0$$



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Higgs Relaxation

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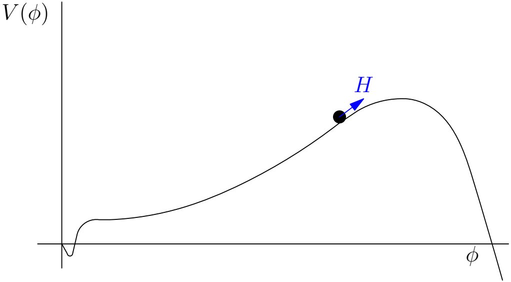

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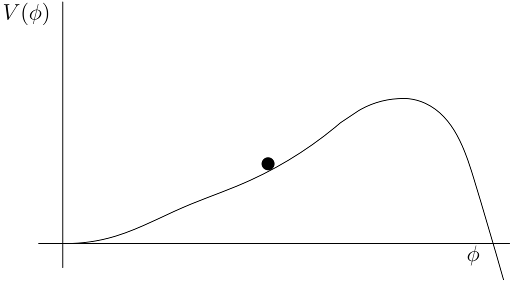

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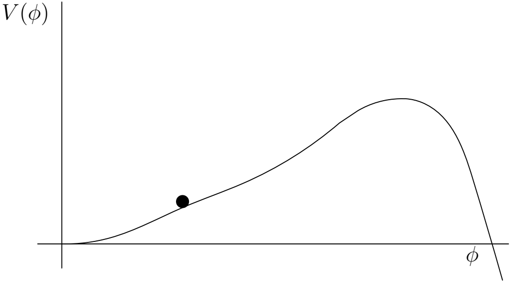

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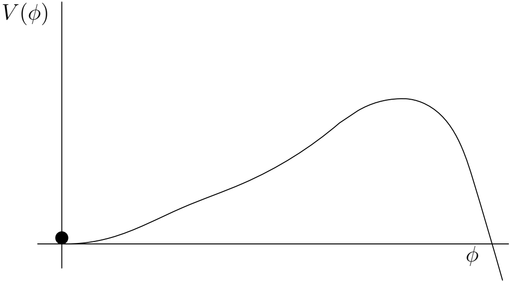

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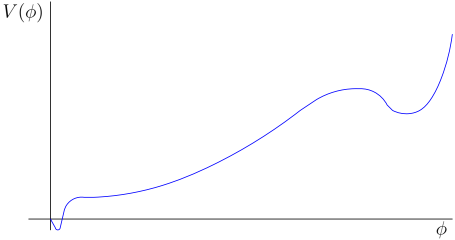

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- At large VEVs, the Higgs potential may be sensitive to higher dimensional operators, which are suppressed by large mass powers.
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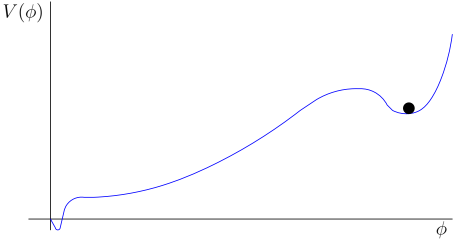
- The Higgs VEV could be trapped in it during inflation (assuming it takes a stochastic distribution of values).



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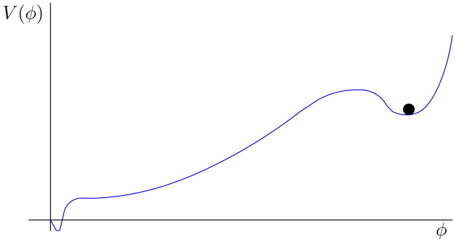
Second Minimum at Large VEVs

- If reheating is sufficient to destabilize this false vacuum, then the Higgs VEV will roll down to the finite-temperature minimum at $\phi = 0$.



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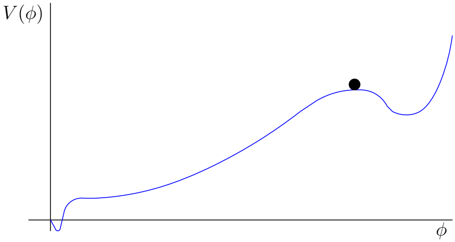

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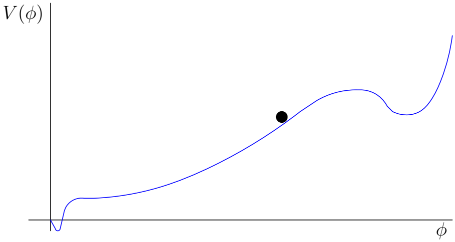

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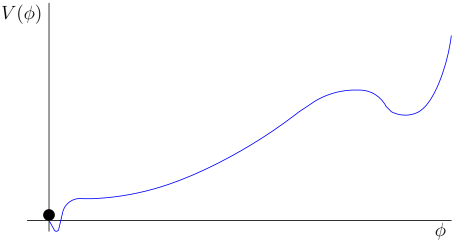

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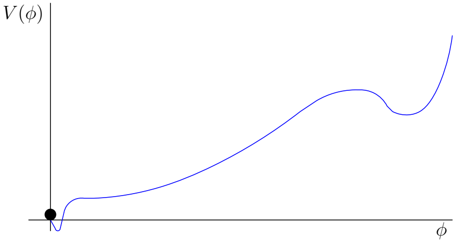
Second Minimum at Large VEVs

- If reheating is sufficient to destabilize this false vacuum, then the Higgs VEV will roll down to the finite-temperature minimum at $\phi = 0$.
- **A post-inflationary epoch of Higgs relaxation is fairly common in inflationary models.**



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  3. Baryon/Lepton number violation: Right-handed Majorana neutrinos, others...

Effective Chemical Potential

Effective Operator

- Consider the effective operator:

$$\mathcal{O}_6 = -\frac{1}{\Lambda_n^2}\phi^2\left(g^2 A\tilde{A} - g'^2 B\tilde{B}\right),$$

where A and B are the $\mathrm{SU_L}(2)$ and $\mathrm{U_Y}(1)$ gauge fields.

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- Scale Λ_n: Mass M or temperature T

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- This operator actually breaks CPT & is similar to one used in spontaneous baryogenesis scenarios.

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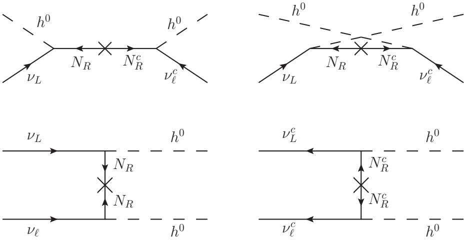

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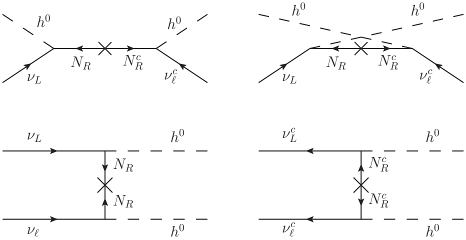
- ...but ensure $T \ll M_R$ to suppress standard leptogenesis.



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- (However, since the Higgs VEV evolves quickly, $\partial_t \phi^2$, and hence the chemical potential, is large).
- The system won't reach the equilibrium asymmetry, but approaches it:

$$\frac{d}{dt} n_L + 3 H n_L \cong -\frac{2}{\pi^2} T^3 \sigma_R \left(n_L - \frac{2}{\pi^2} \mu_{\text{eff}} T^2 \right).$$

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- Include running couplings, one-loop correction, and finite temperature corrections in potential.

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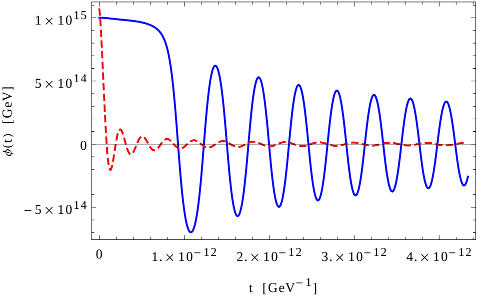

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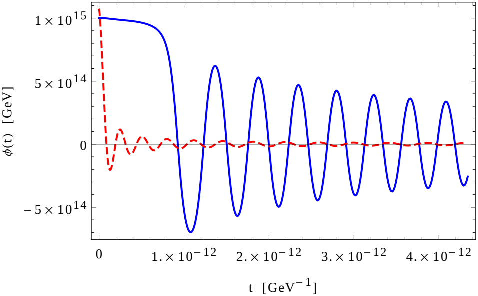

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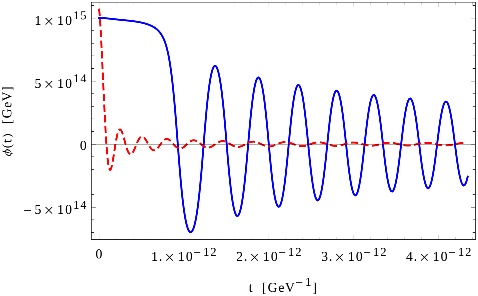

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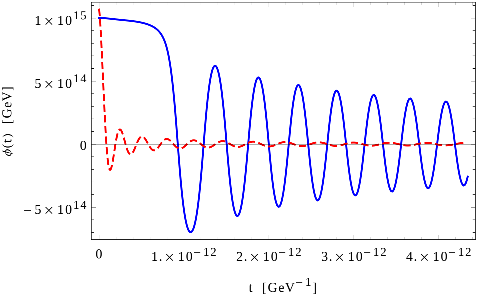

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- Effects of condensate decay negligible

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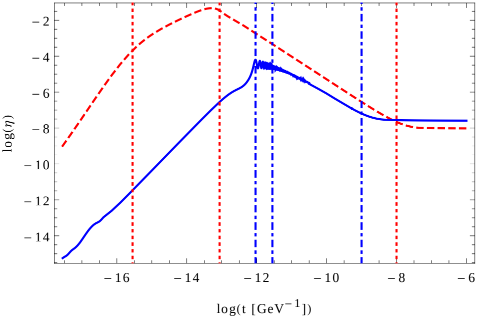

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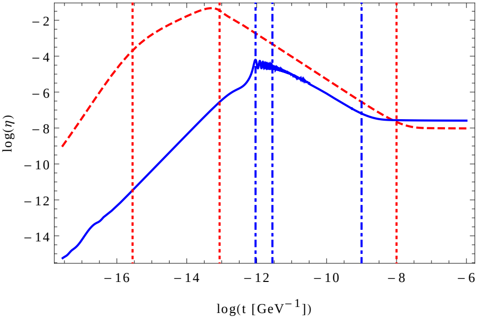

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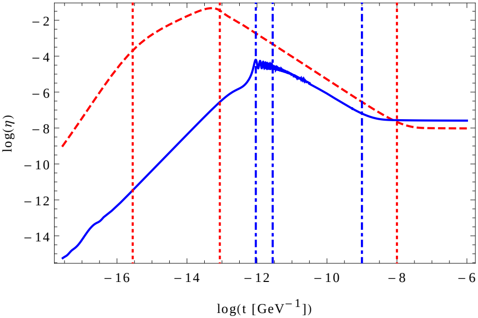

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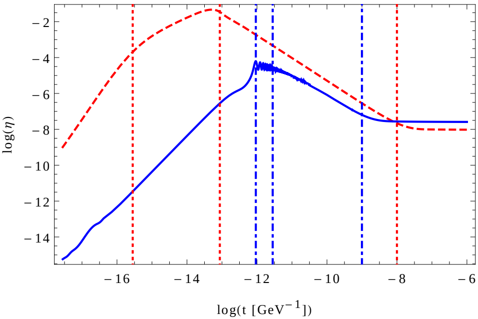

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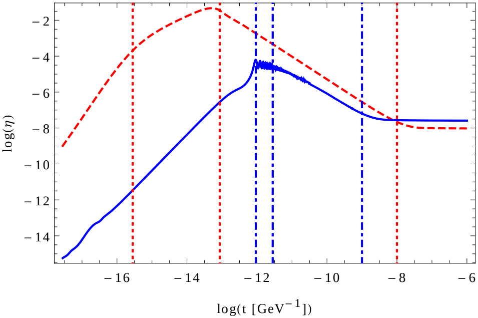

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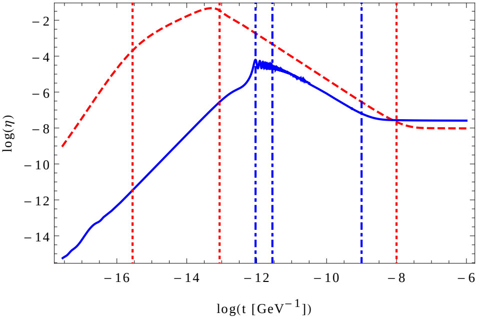

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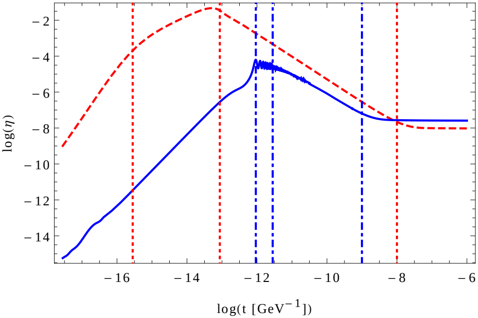

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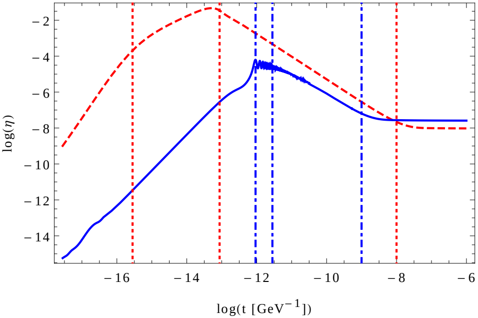

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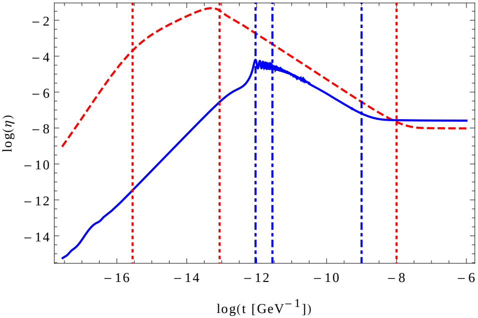

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- Generally requires relatively fast reheating (preheating?)

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Thank you! Questions?

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- Temperature of plasma from radiation density:

$$\rho_R = \frac{g_* \pi^2}{30} T^4$$

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1. Initial relaxation of the Higgs VEV ($\mu_{\text{eff}} \neq 0$).
2. Partial washout by ongoing heavy neutrino exchanges.
3. Subsequent cooling of the universe ($\mu_{\text{eff}} \approx 0$).

Lepton Asymmetry: Analytical Approximations

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- Equilibrium value of the lepton asymmetry:

$$n_{L,\mathrm{eq}} \sim \mu_{\mathrm{eff}} T^2 \sim \frac{\sqrt{\lambda}\phi_0^3 T_{\mathrm{max}}^2}{M_n^2}$$

- Max asymmetry generated:

$$n_{L,\mathrm{eq}} \sigma_R T_{\mathrm{rlx}}^3 t_{\mathrm{rlx}}$$

rlx: Time when $\mu_{\mathrm{eff}} \approx 0$.

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- From Boltzmann equation:

$$\frac{dN_L}{dt} = -\frac{2}{\pi^2} T^3 \sigma_R N_L,$$

(N_L: Lepton number per comoving volume).

Lepton Asymmetry: Analytical Approximations

Washout & Subsequent Cooling

- Typically negligible, as $T \ll M_R$ implies cross sections are small.
- From Boltzmann equation:

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(N_L: Lepton number per comoving volume).

- Asymptotic value:

$$N_L(T \to 0) = N_L(T_{\rm rlx}) \exp\left[-\left(\frac{24 + 3\sqrt{15}}{\sqrt{3 g_* \pi^7}} \right) \sigma_R M_P T_R \right].$$

Lepton Asymmetry: Analytical Approximations

Asymmetry

- Analytical approxiation for lepton asymmetry as $T \to 0$:

$$\eta = \frac{45}{2\pi^2} \frac{\sqrt{\lambda}\phi_0^3 \Lambda_I}{M_n^2 T_R^2} t_{\mathrm{rlx}}^2 \Gamma_I^2 \times \min\left\{1,\, T_{\mathrm{rlx}}^3 t_{\mathrm{rlx}} \sigma_R\right\} \exp\left[-\left(\frac{24+3\sqrt{15}}{\sqrt{3 g_* \pi^7}}\right) \sigma_R M_P T_R\right],$$

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- Decreases by about another order of magnitude as SM degree of freedom go out of equilibrium.
- Electroweak sphalerons redistribute between leptons and baryons.