Leptogenesis in the superweak extension of the Standard Model

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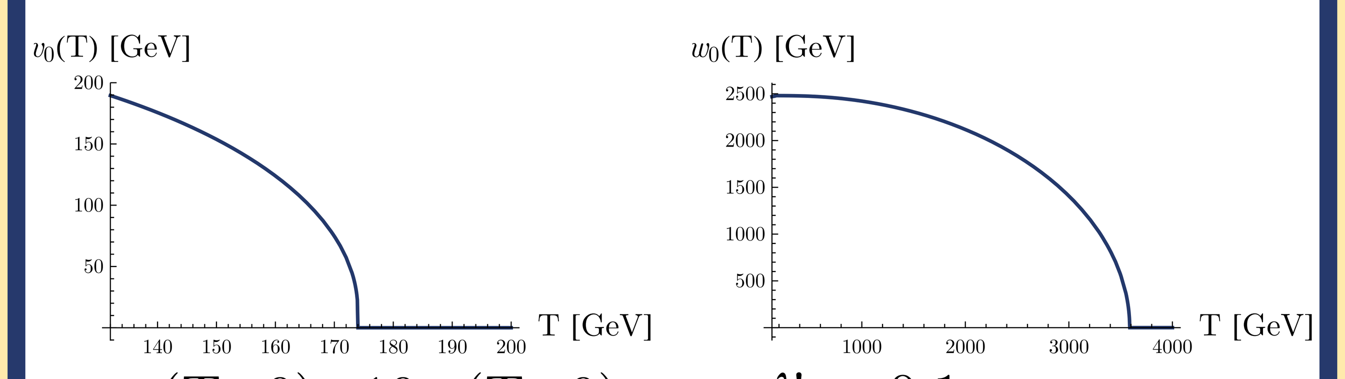
Phase transitions [1,2]

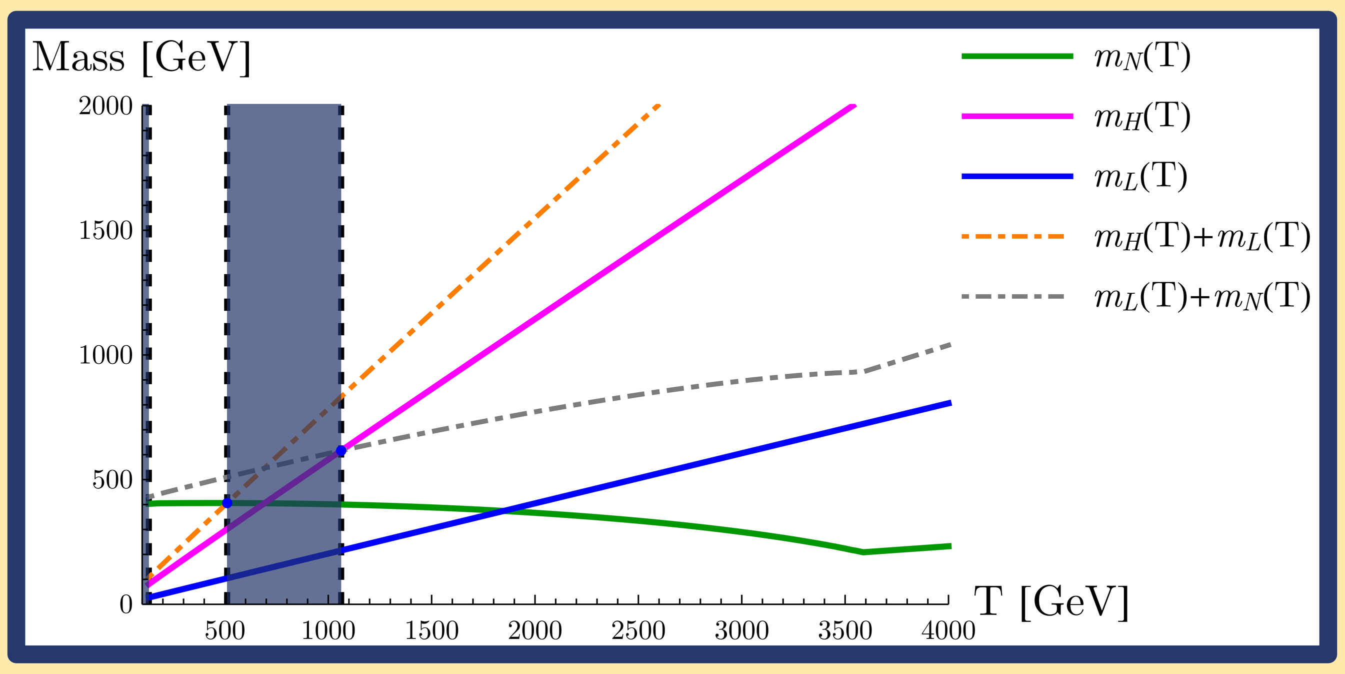
- $\mathcal{V}[\phi,\chi] = \mu_\phi^2|\phi|^2 + \lambda_\phi|\phi|^4 + \mu_\chi^2|\chi|^2 + \lambda_\chi|\chi|^4 + \lambda'|\phi|^2|\chi|^2$



- $w_0(T{=}0) = 10 v_0(T{=}0)$
- $M_\chi = 650$ GeV
- $\lambda' = 0.1$
- $M_N = 400$ GeV

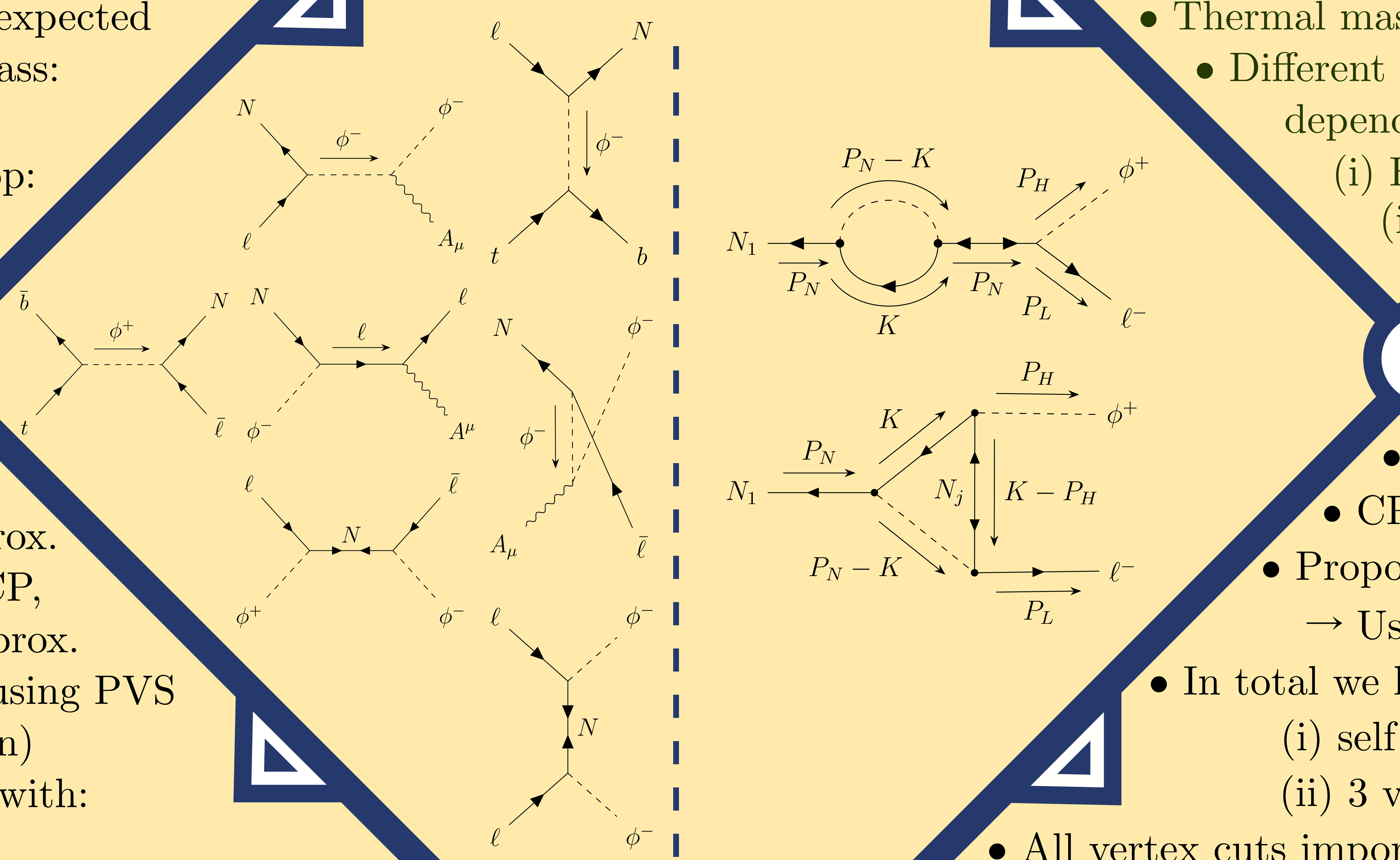
- Two-step phase transition (PT) signature: $G_{SM}\times U(1)_z \to G_{SM} \to SU(3)_c\times U(1)_{EM}$
- Strong first order PT **not** expected
- Sterile neutrino vacuum mass: $m_N{}^2 \approx Y_N{}^2 w_0{}^2(T)/2$
- Running couplings at 2 loop: $g(\mu) = g(2\pi T)$
- **Real potential** via OPT

Thermal masses [1]



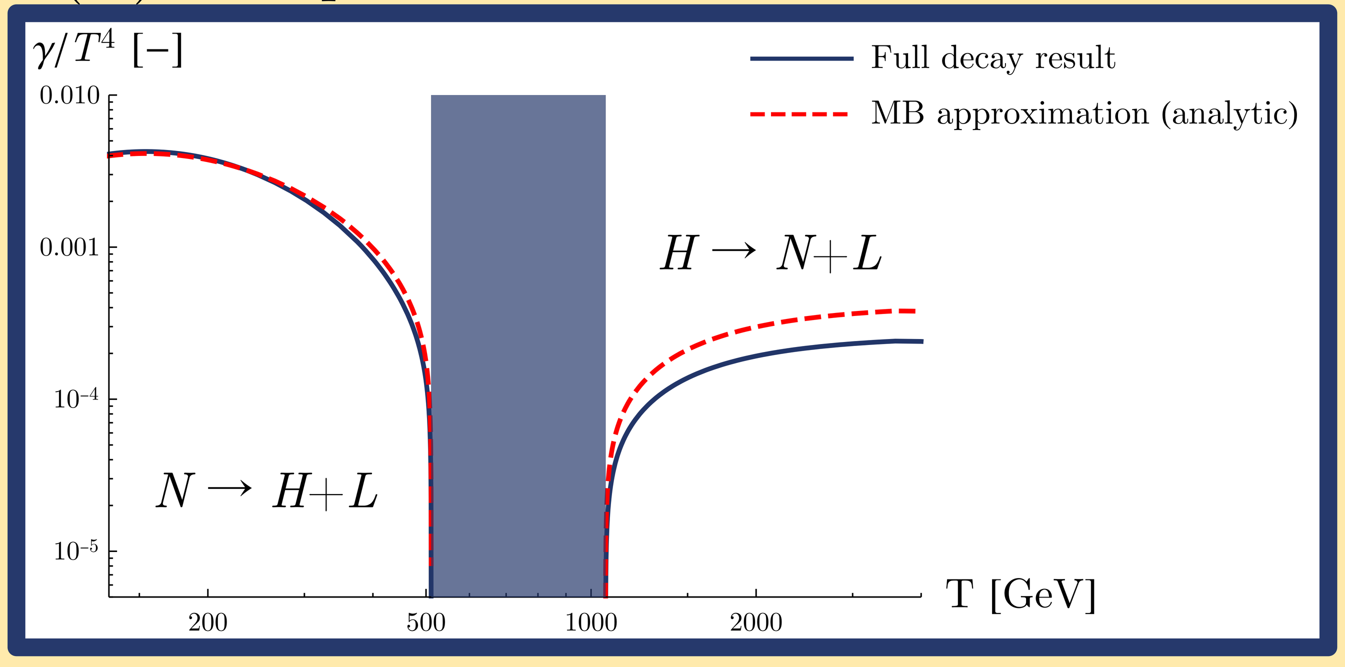
- At high temperature, i.e. $T > m_i(T{=}0)$: mass = thermal mass + vacuum mass
- Thermal mass: $m_T \sim gT$
- Different decay channels are open depending on T:
  (i) High T: $H \to N{+}L$
  (ii) Intermediate T: ✗✗✗
  (iii) Low T: $N \to H{+}L$

Feynman diagrams



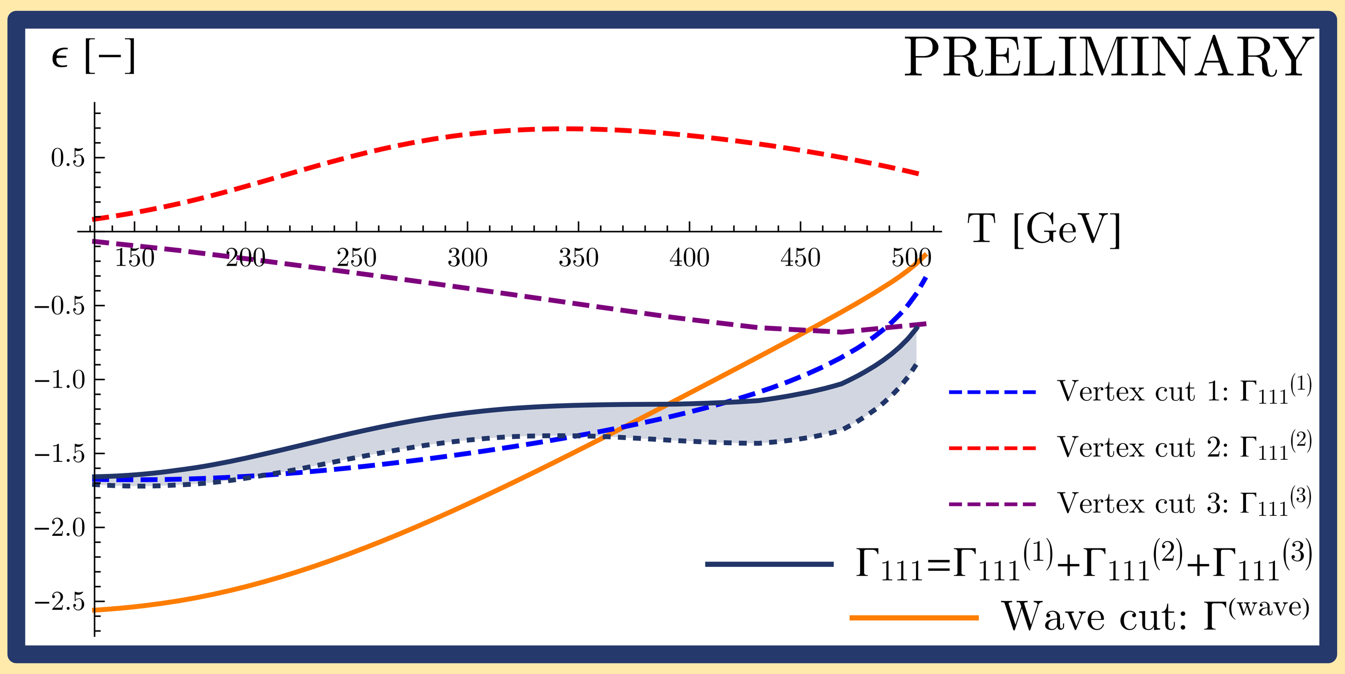
Reaction rates

- Decays and scatterings
- **Decays**: most important, semi-analytic without approx.
- **Scatterings**: washout of CP, semi-analytic with MB approx.
- Avoid double counting by using PVS (principal value subtraction)
- Calculate at tree level but with:
  (i) Thermal masses
  (ii) Running couplings $g(2\pi T)$
  (iii) Multiplicative factor for CP violation in decays



Thermal CP

- CP violation at T=0 OK
- CP violation needed at T>0
- Proportional to imaginary part: → Use finite T cutting rules [3]
- In total we have 4 cuts:
  (i) self energy cut (wave)
  (ii) 3 vertex cuts
- All vertex cuts important when $M_N/T = O(1)$
- Must use rotation to find physically meaningful ε



Boltzmann equations

- ΔL generated at $T > T_{sph} \approx 132$ GeV is converted into ΔB
- Baryon-to-photon ratio: $\eta = n_B/n_\gamma = 6.14(19)\cdot 10^{-10}$
- Boltzmann equation gives: $\mathcal{Y}_{\Delta L} = n_B/s \propto \eta$
- Account for all heavy sterile neutrino flavors
- Linearized (in ε) Boltzmann equations [4]:

$$sHz\frac{\mathrm{d}\mathcal{Y}_{\Delta L}}{\mathrm{d}z} \simeq \gamma_D\left[\epsilon\left(\frac{\mathcal{Y}_N}{\mathcal{Y}_N^{eq}}-1\right) - \frac{\mathcal{Y}_{\Delta L}}{\mathcal{Y}_\ell^{eq}}\right] - \frac{\mathcal{Y}_{\Delta L}}{\mathcal{Y}_\ell^{eq}}\left[2\gamma_{N,s}^{sub.} + 4\gamma_{N,t} + \gamma_{\phi,s}\frac{\mathcal{Y}_N}{\mathcal{Y}_N^{eq}} + 2\gamma_{\phi,t}\right]$$

$$sHz\frac{\mathrm{d}\mathcal{Y}_N}{\mathrm{d}z} \simeq \left(1 - \frac{\mathcal{Y}_N}{\mathcal{Y}_N^{eq}}\right)(\gamma_\chi + \gamma_D + 2\gamma_{\phi,s} + 4\gamma_{\phi,t})$$

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References:

[1] K. Seller et al., JHEP 04 (2023) 096
[2] Z. Trócsányi, Symmetry 12 (2020) 1 107
[3] R. L. Kobes and G. W. Semenoff, Nucl.Phys.B 260 (1985) 714-746.
[4] G. F. Giudice et al., Nucl.Phys.B 685 (2004) 89-149.

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