# Massless Preheating and Electroweak Vacuum Metastability

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[arXiv:2105.06939]

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- Current measurements of SM parameters suggest the Higgs self-coupling $\lambda_h(\mu)$ **runs *negative*** at energy scales $\mu \gtrsim 10^{10}\,\mathrm{GeV}$

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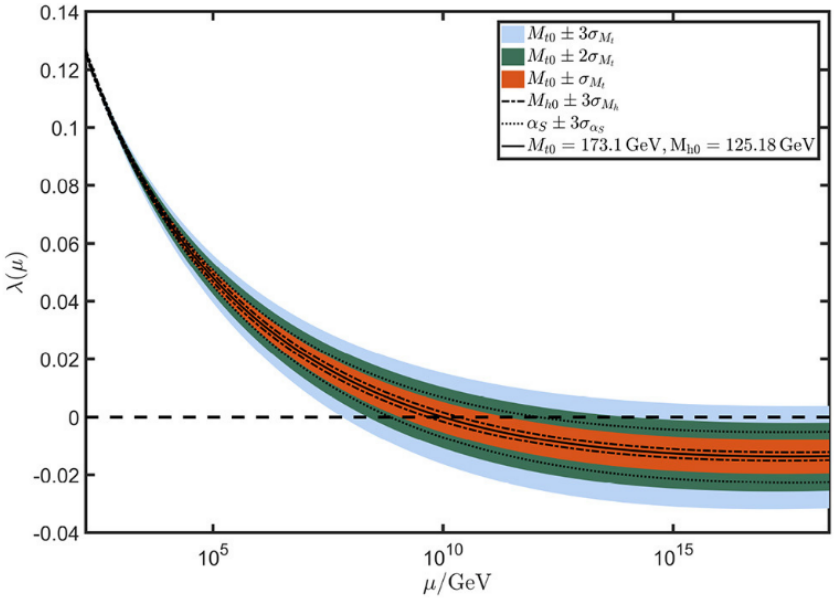

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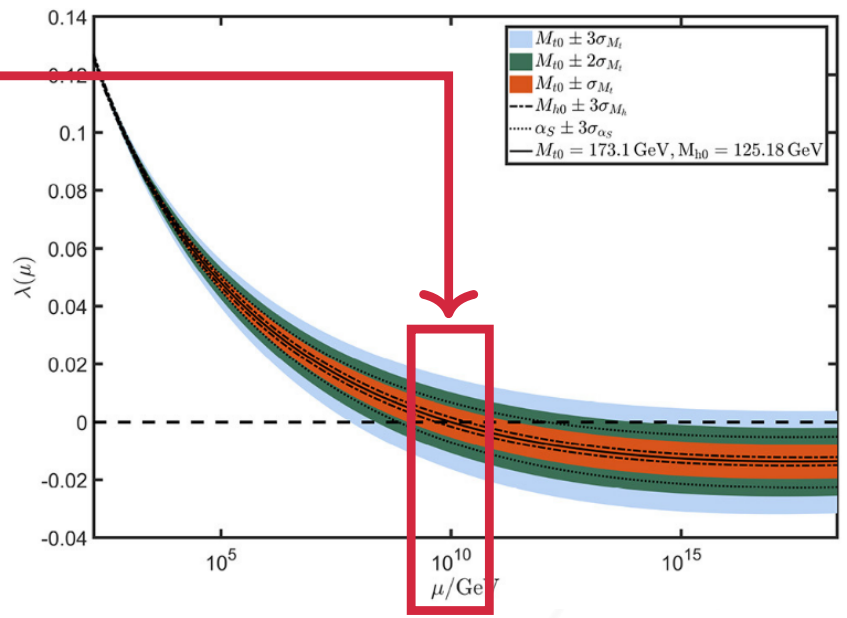

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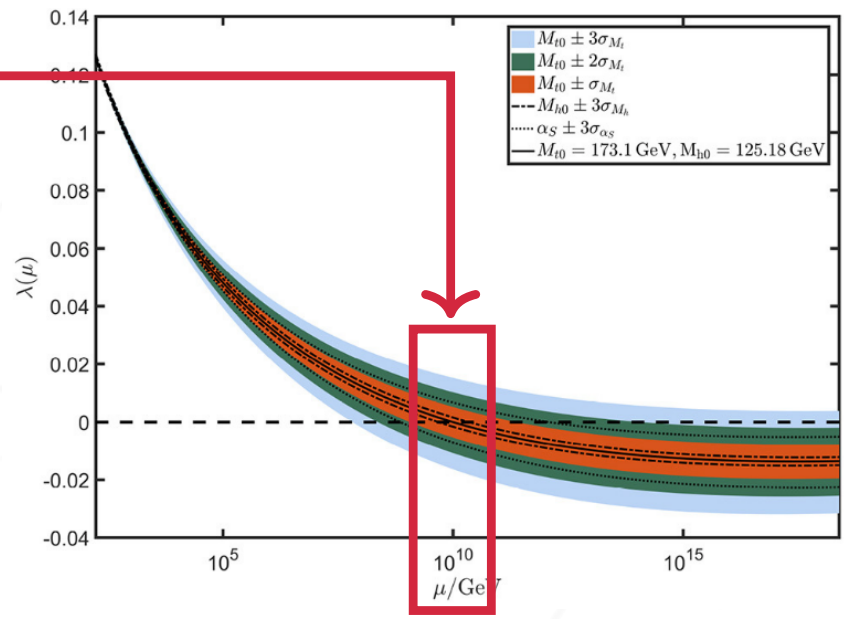

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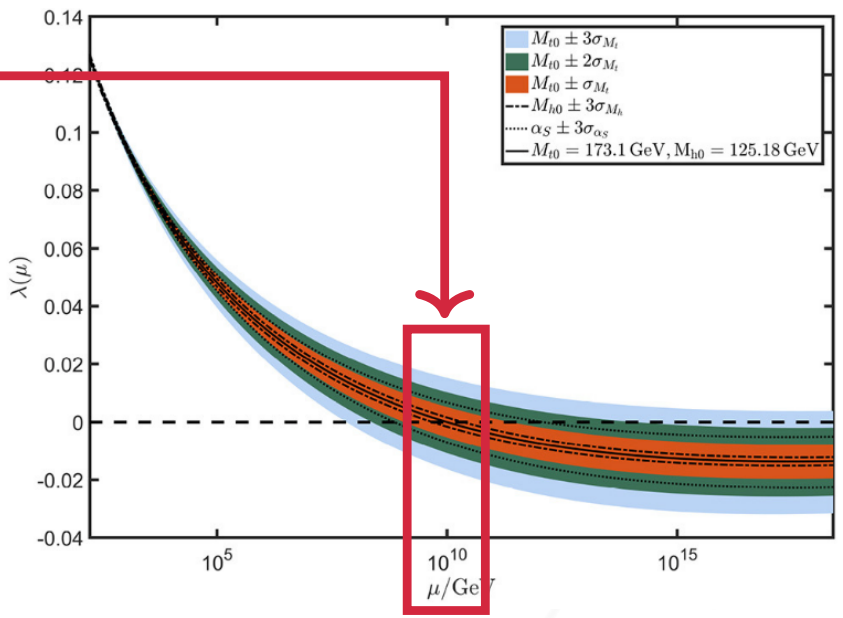


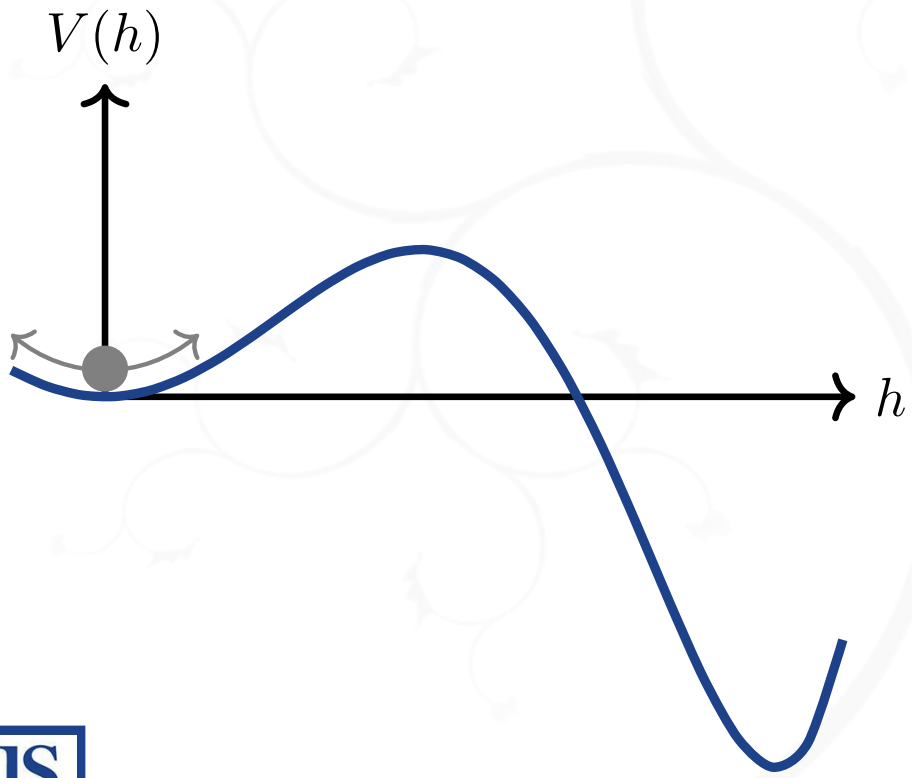

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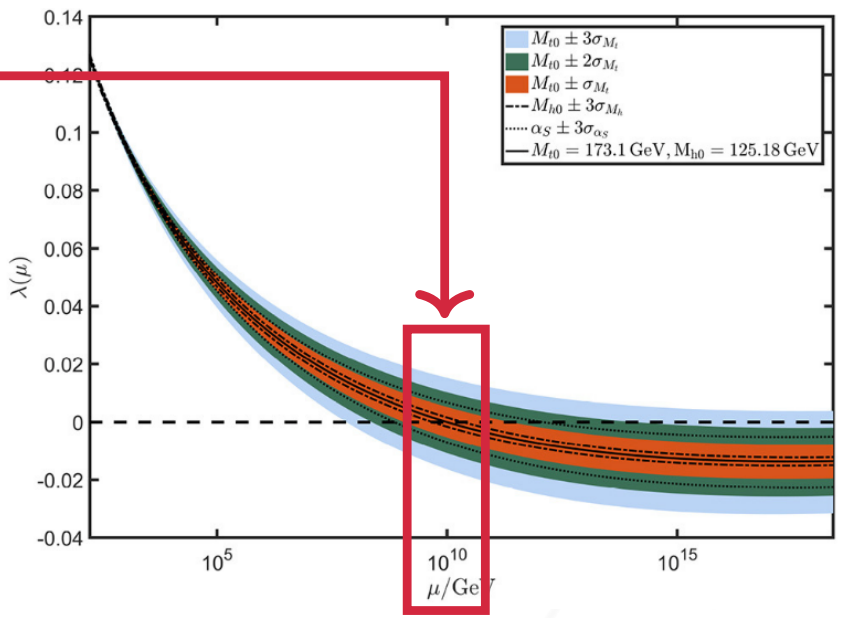


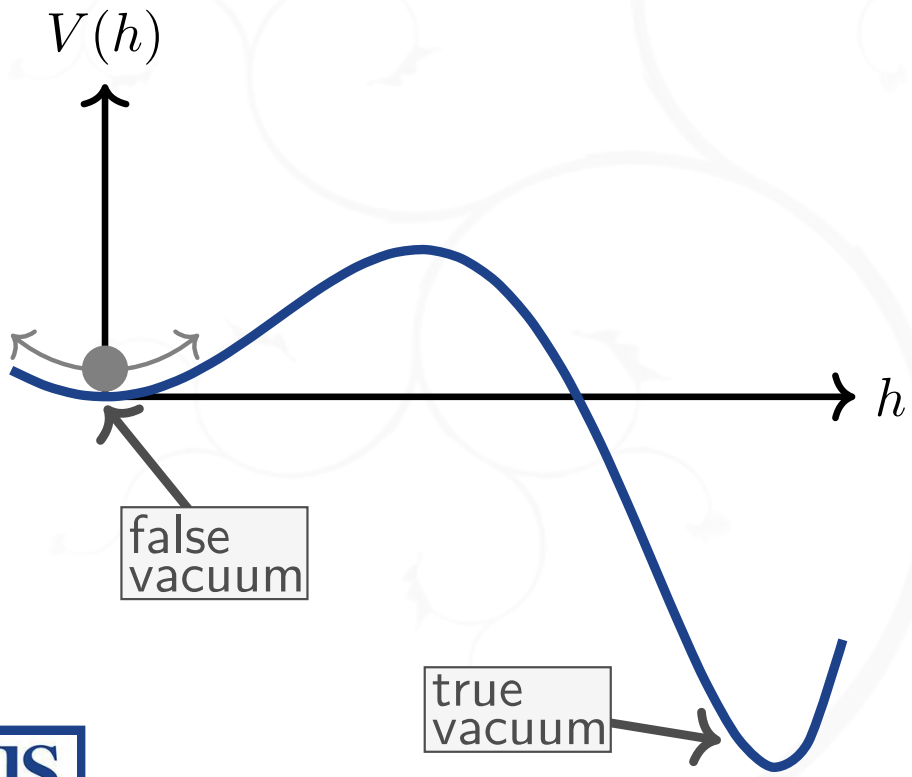

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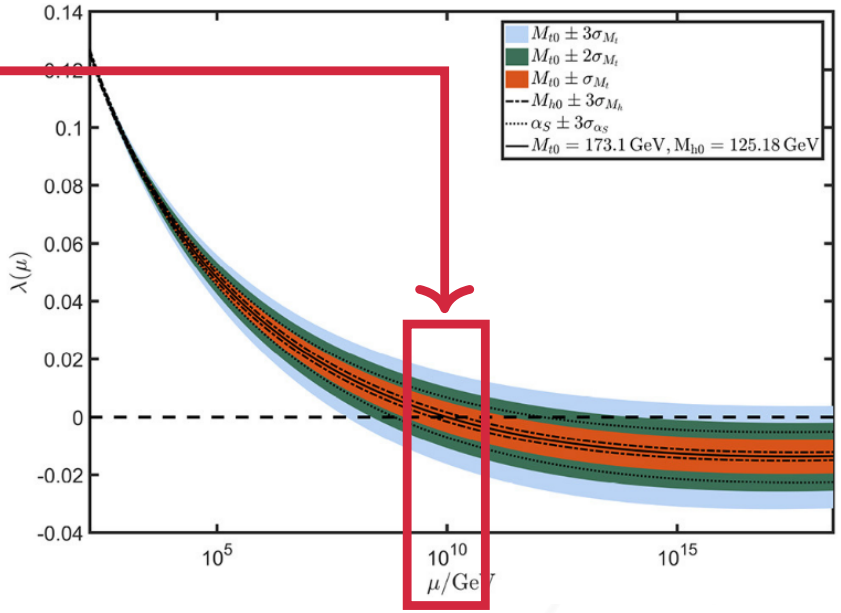


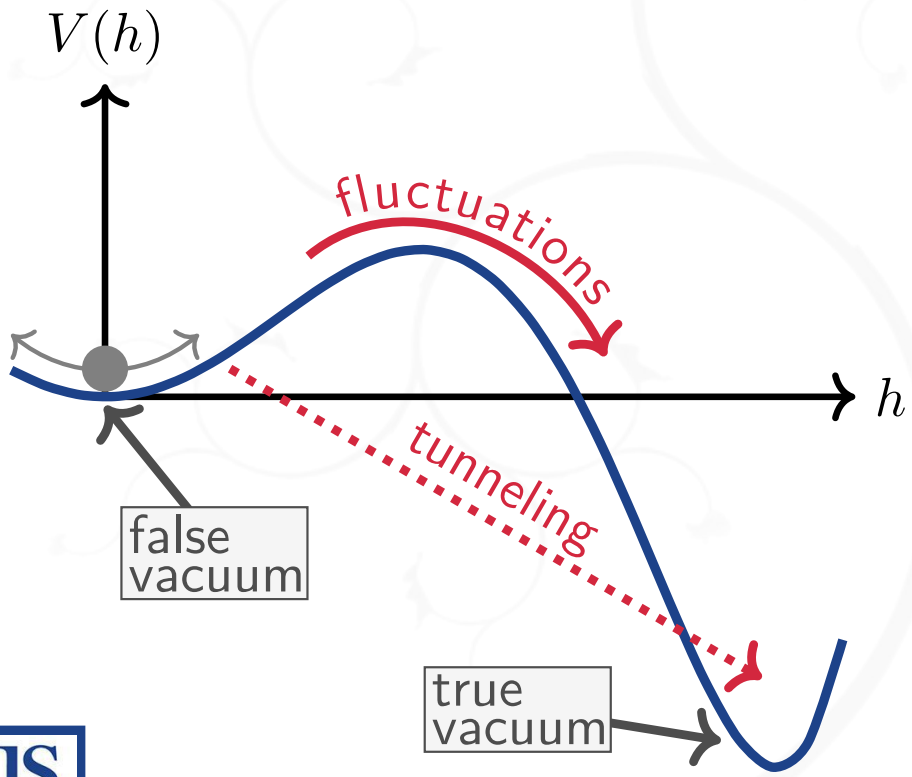

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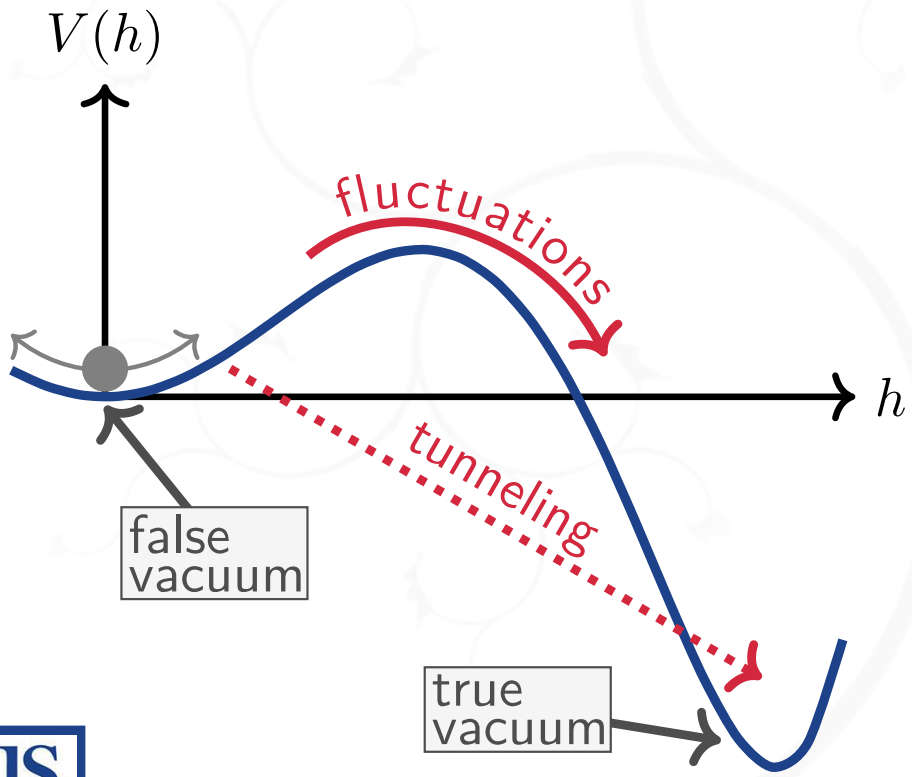


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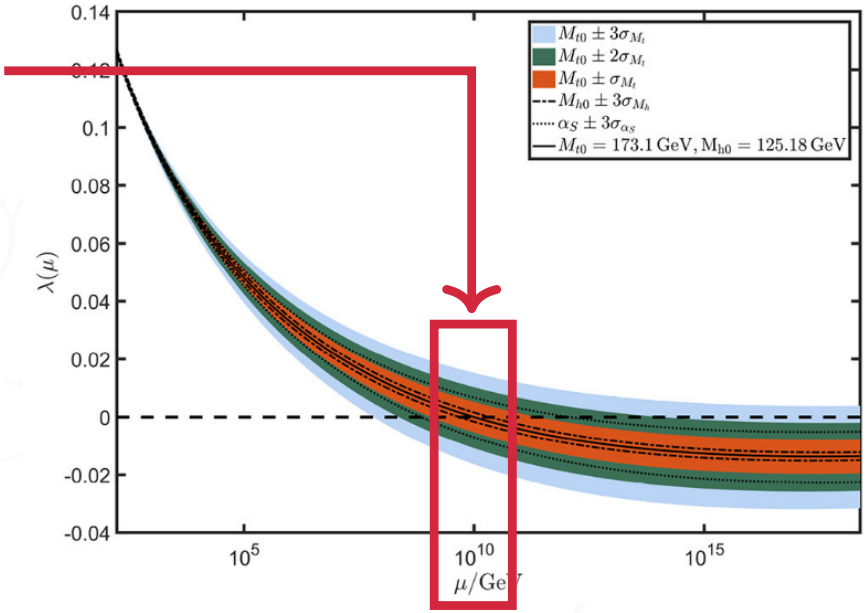


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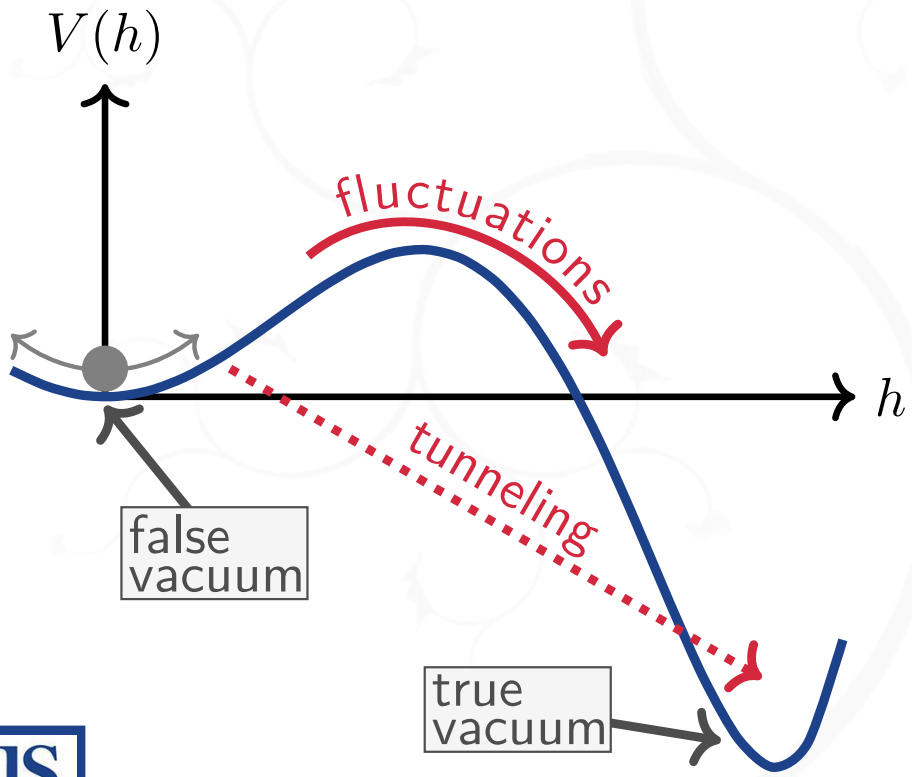


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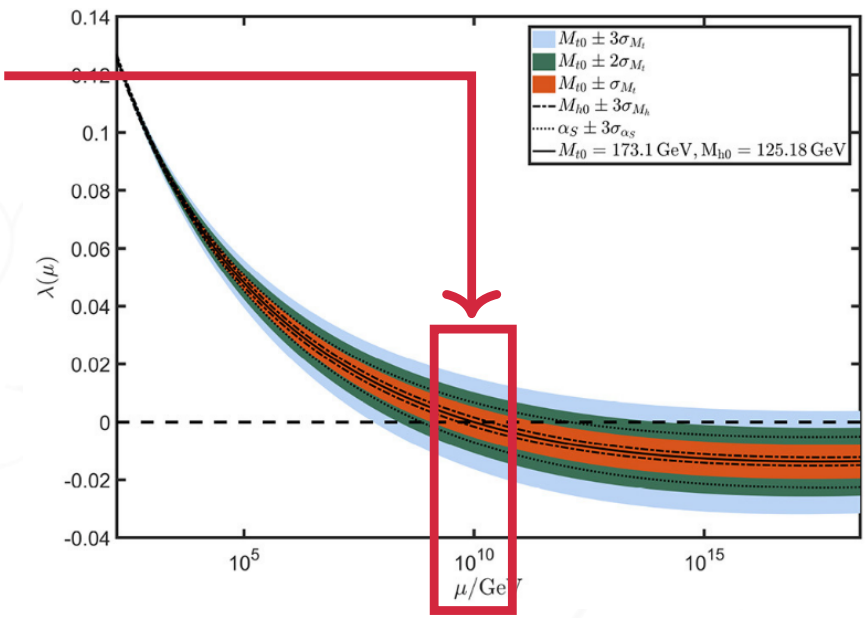


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The fact that false vacuum has persisted may provide ***window*** into early-universe dynamics involving the Higgs field.

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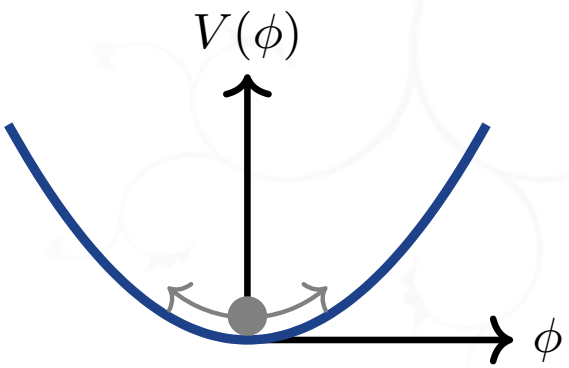


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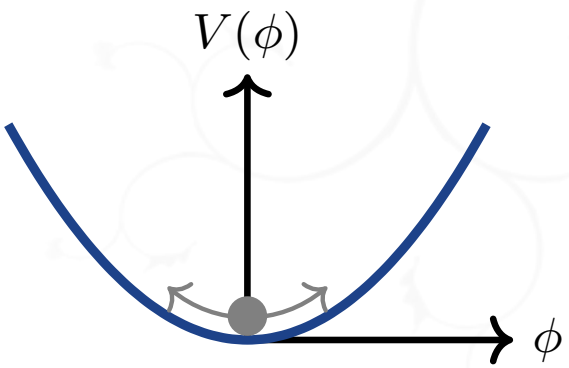


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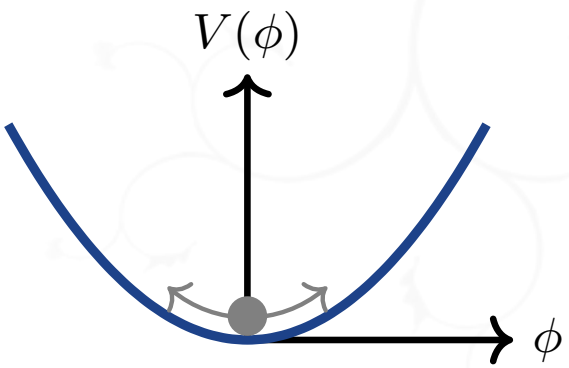


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for conformal time $\eta$ and $\varphi \equiv a\phi$

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Similarly, Higgs fluctuations grow *steadily* and ***uninterrupted***—appears catastrophic for EW metastability.

on closer inspection,
is there a **regime of viability** for massless preheating?

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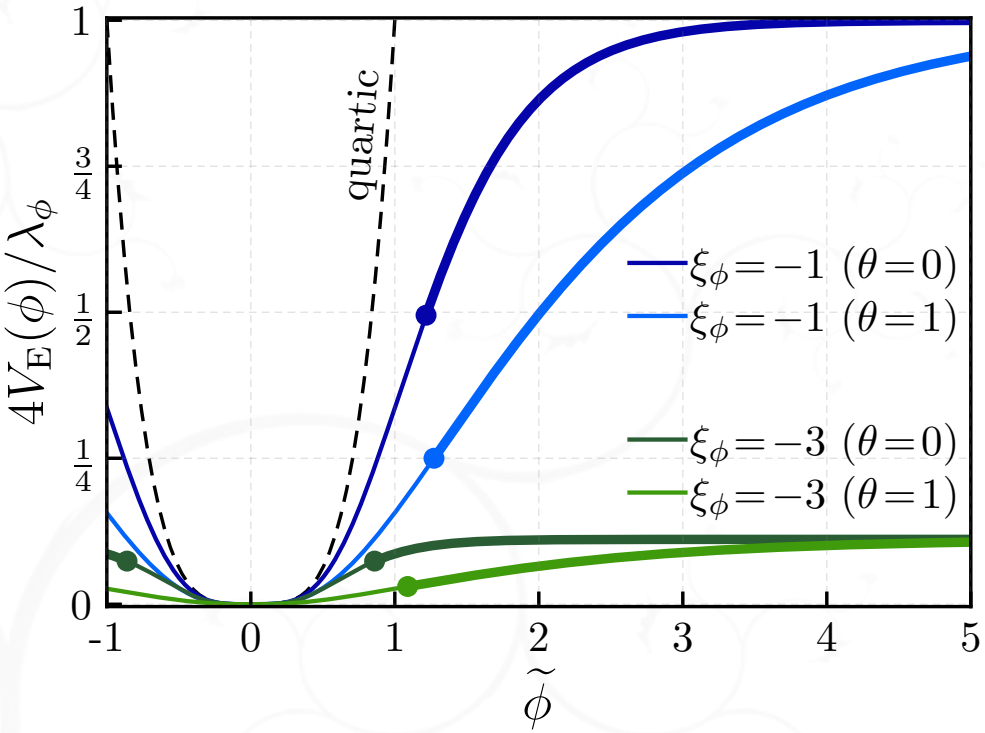

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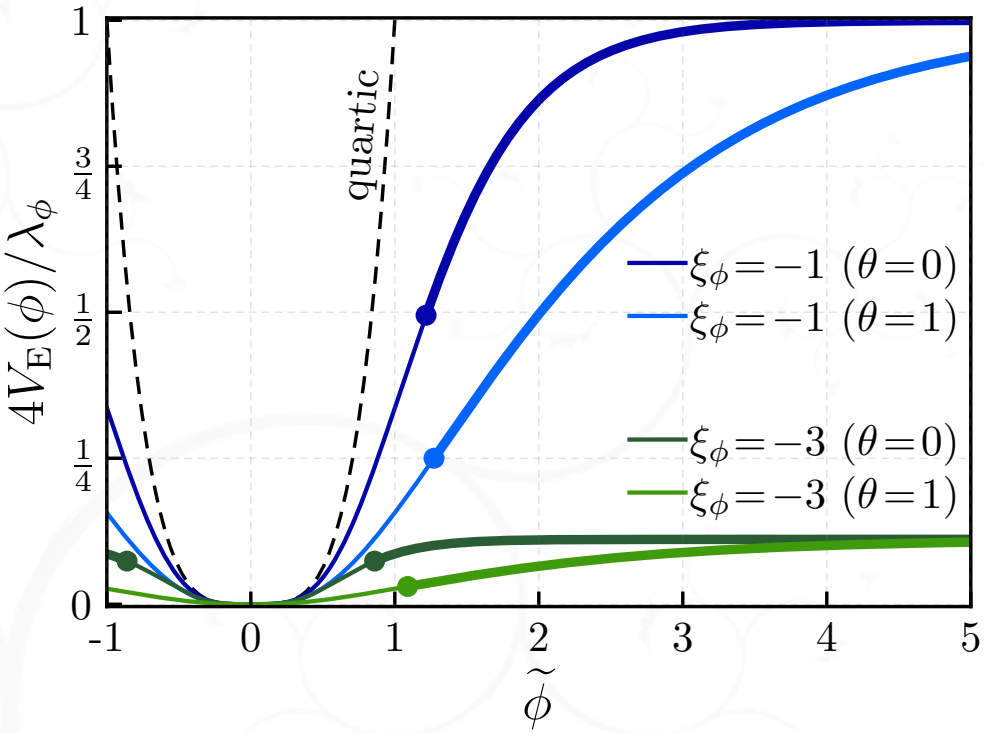

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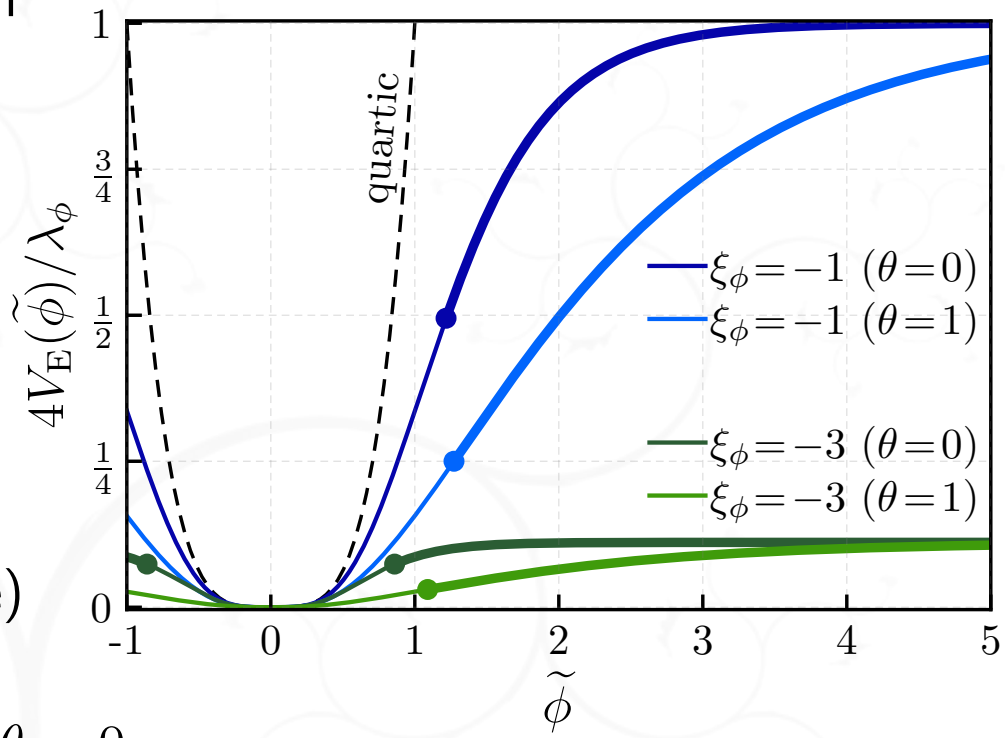


- Overall, we have the (Einstein-frame) potential in the inflationary regime

$$V_{\rm E}(\widetilde{\phi}) = \frac{\lambda_\phi}{4\xi_\phi^2} \begin{cases} \tanh^4\left(\sqrt{-\xi_\phi}\widetilde{\phi}\right) & \text{for} \quad \theta = 0 \\ \left(1 - e^{-\sqrt{\frac{2}{3}}\widetilde{\phi}}\right)^2 & \text{for} \quad \theta = 1 \end{cases}$$

where $\widetilde{\phi}$ is the canonical inflaton field.

# Production of Higgs Particles

- The effective masses of Higgs fluctuations (in Einstein frame) are

$$\omega^2_{\mathcal{H}_k} = k^2 + g^2\varphi^2\left(1 + \xi_\phi \frac{\varphi^2}{a^2}\right) + \xi a^2 R$$

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1. **tachyonic production** driven by curvature interactions
   [relatively short lived since terms dissipate as $1/a^2$]

$$n_h \simeq \frac{1}{8}\left(\sqrt{\lambda_\phi}\overline{\varphi}\right)^3 \left(\frac{3^{9/4}\sqrt{\xi}}{2\pi x^2}\right)^{3/2} \left(\frac{x}{x_0}\right)^{4\sqrt{\frac{2\xi}{3\sqrt{3}}}} \quad \text{for } x \lesssim \sqrt{6\xi} \text{ (and } \xi > 0)$$

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2. **parametric resonance** driven by quartic interaction
   [*terms do not dissipate* due to scale invariance $\Rightarrow$ unimpeded Higgs production]

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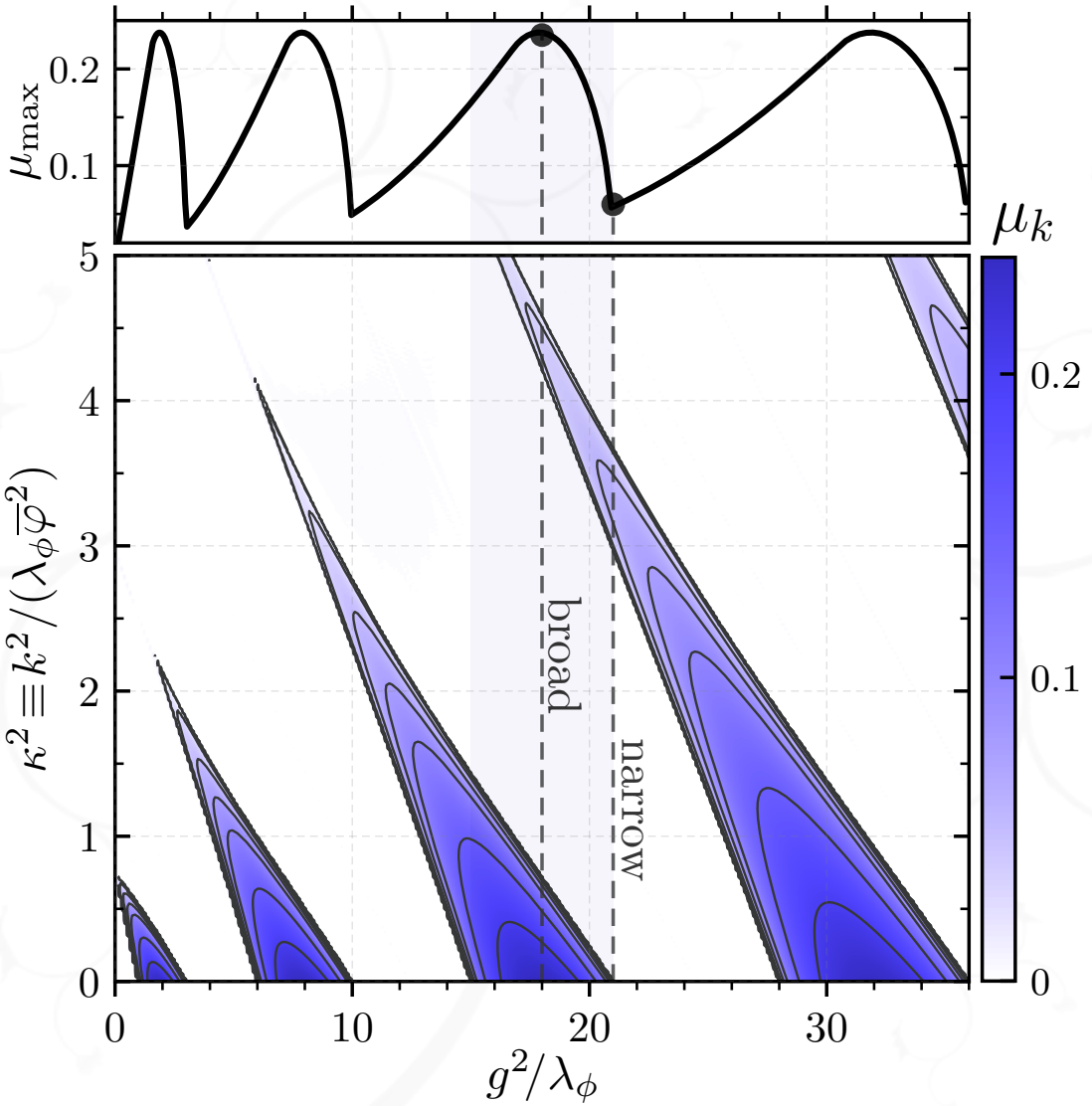
growth rate $\mu_{\max}$ has non-trivial dependence on coupling $g^2/\lambda_\phi$

## Higgs modes grow as $n_{h_k} \propto e^{2\mu_k x}$

[for parametric resonance]



Two important effects neglected thus far:

1. **perturbative decays** of produced Higgs particles
2. **backreaction** of particle production on the system

# 1 Perturbative Higgs Decays

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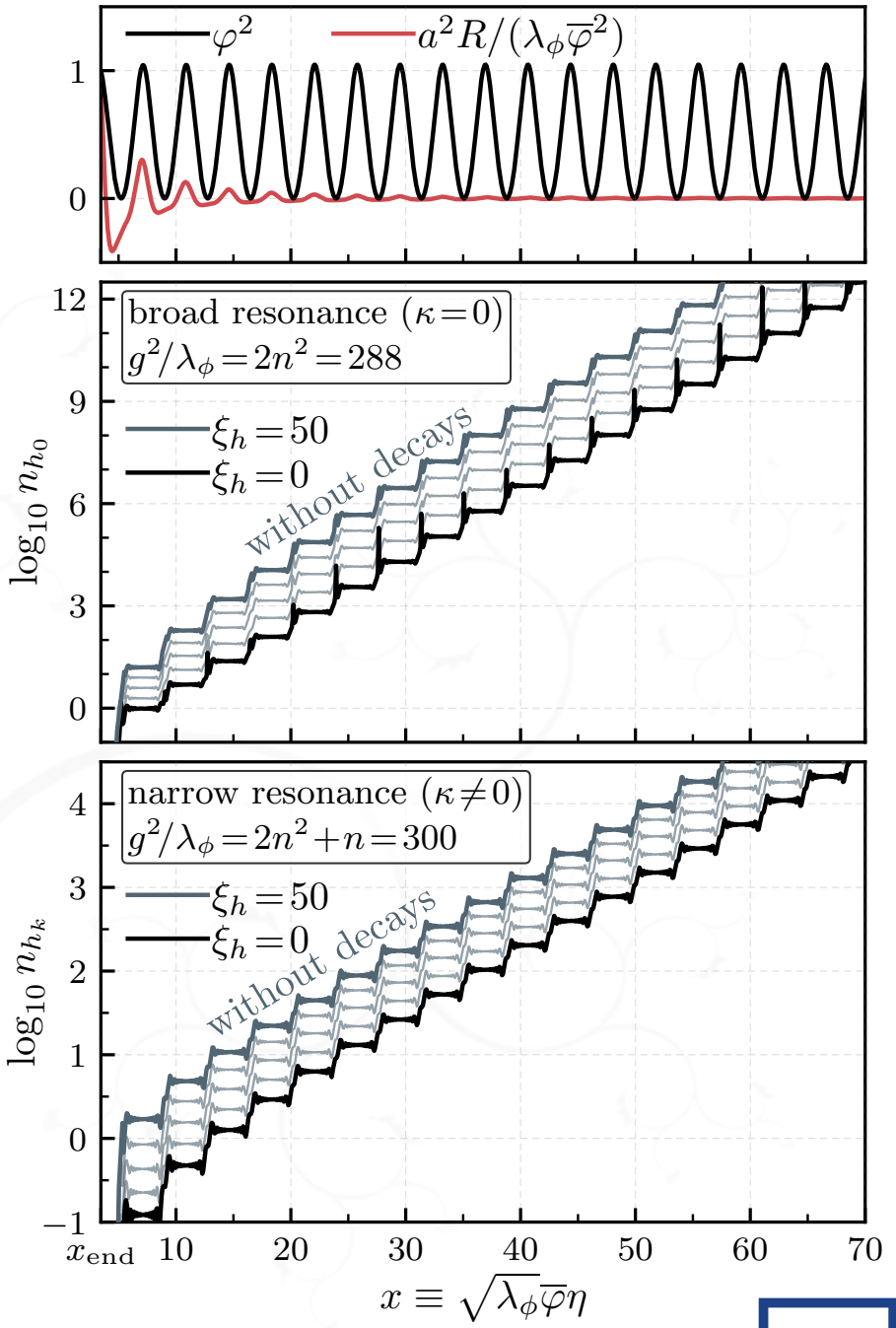

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- The dominant decay channel is into top quarks with the (rest-frame) decay rate

$$\Gamma_h = \frac{3y_t^2 m_h}{16\pi}$$

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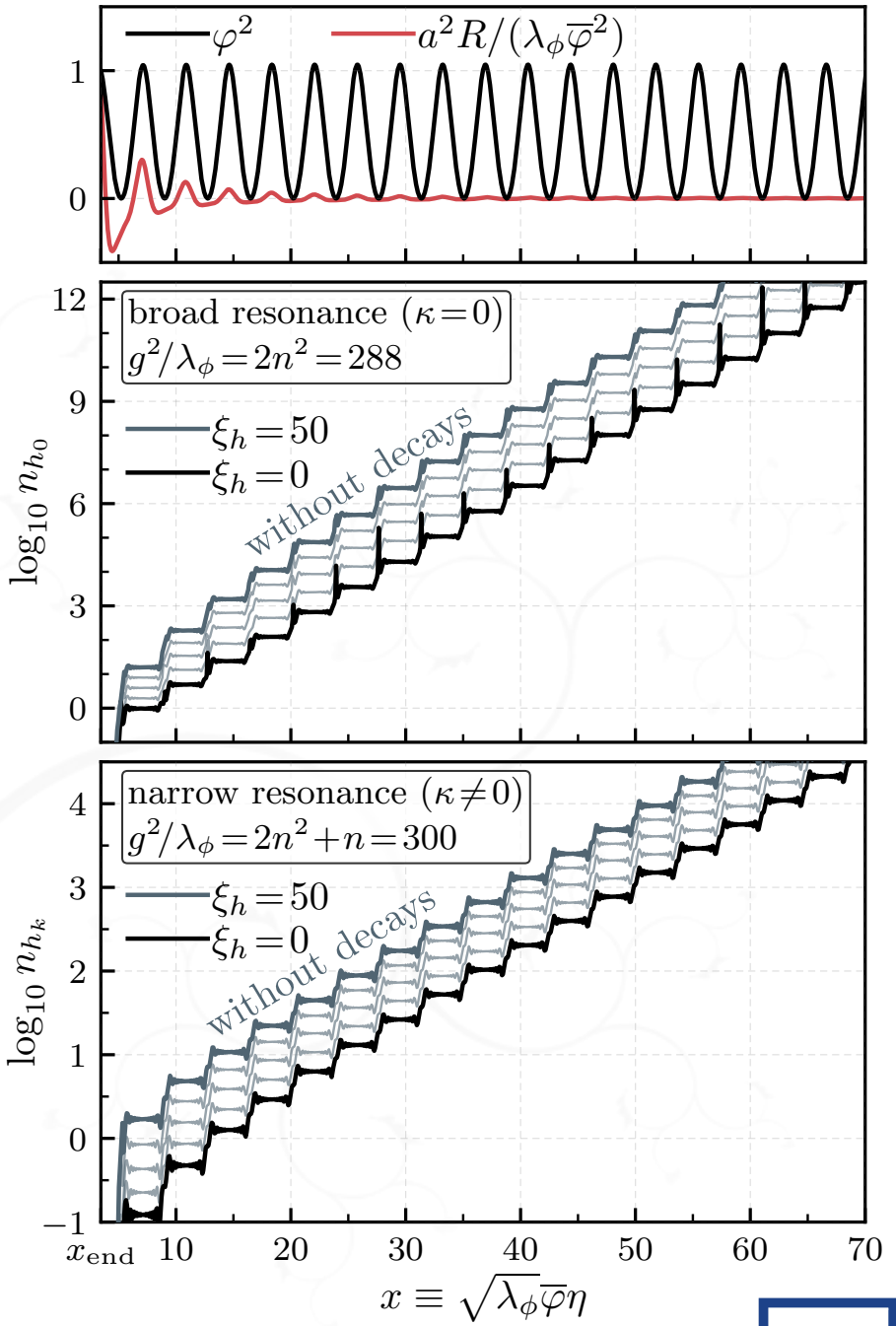

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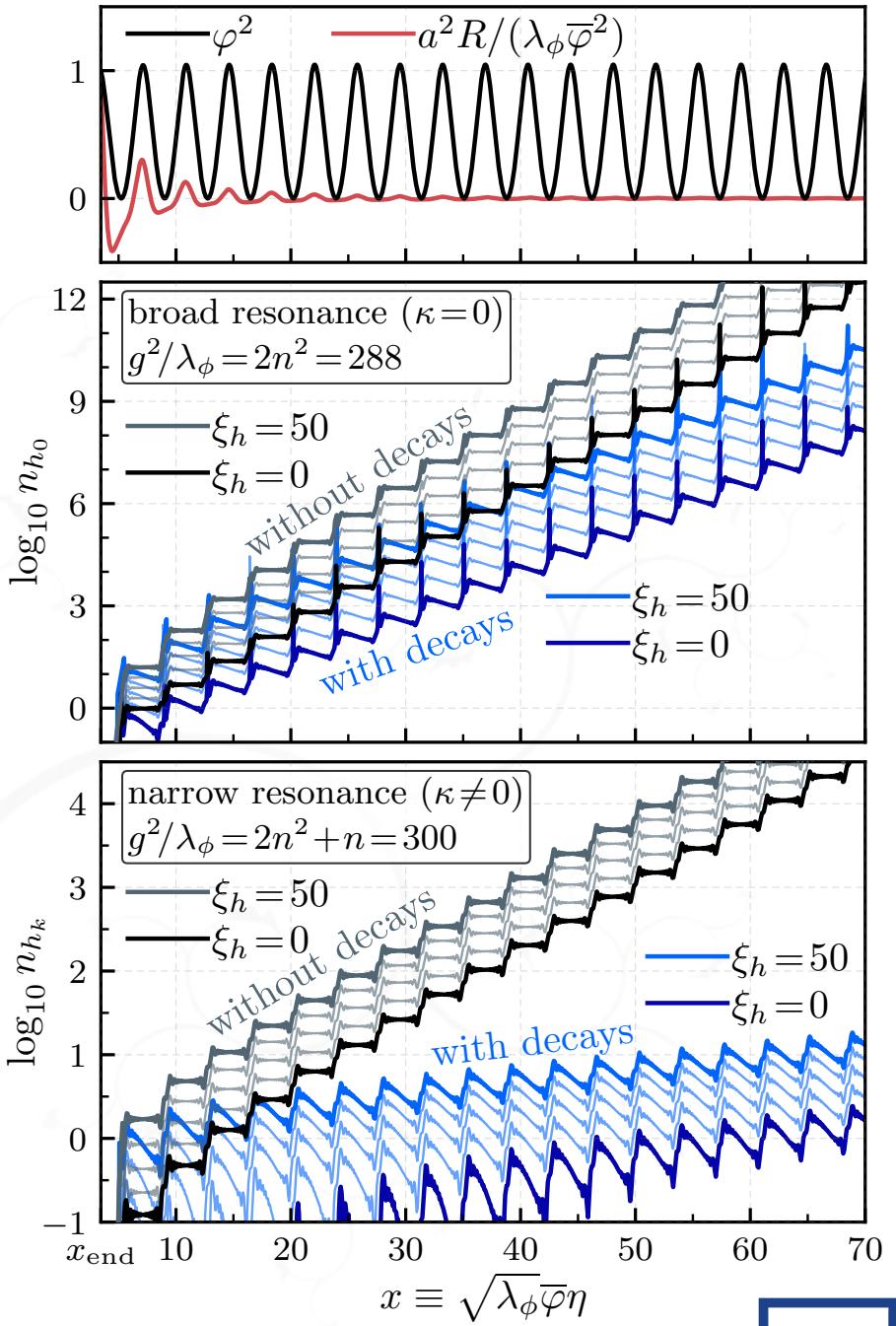

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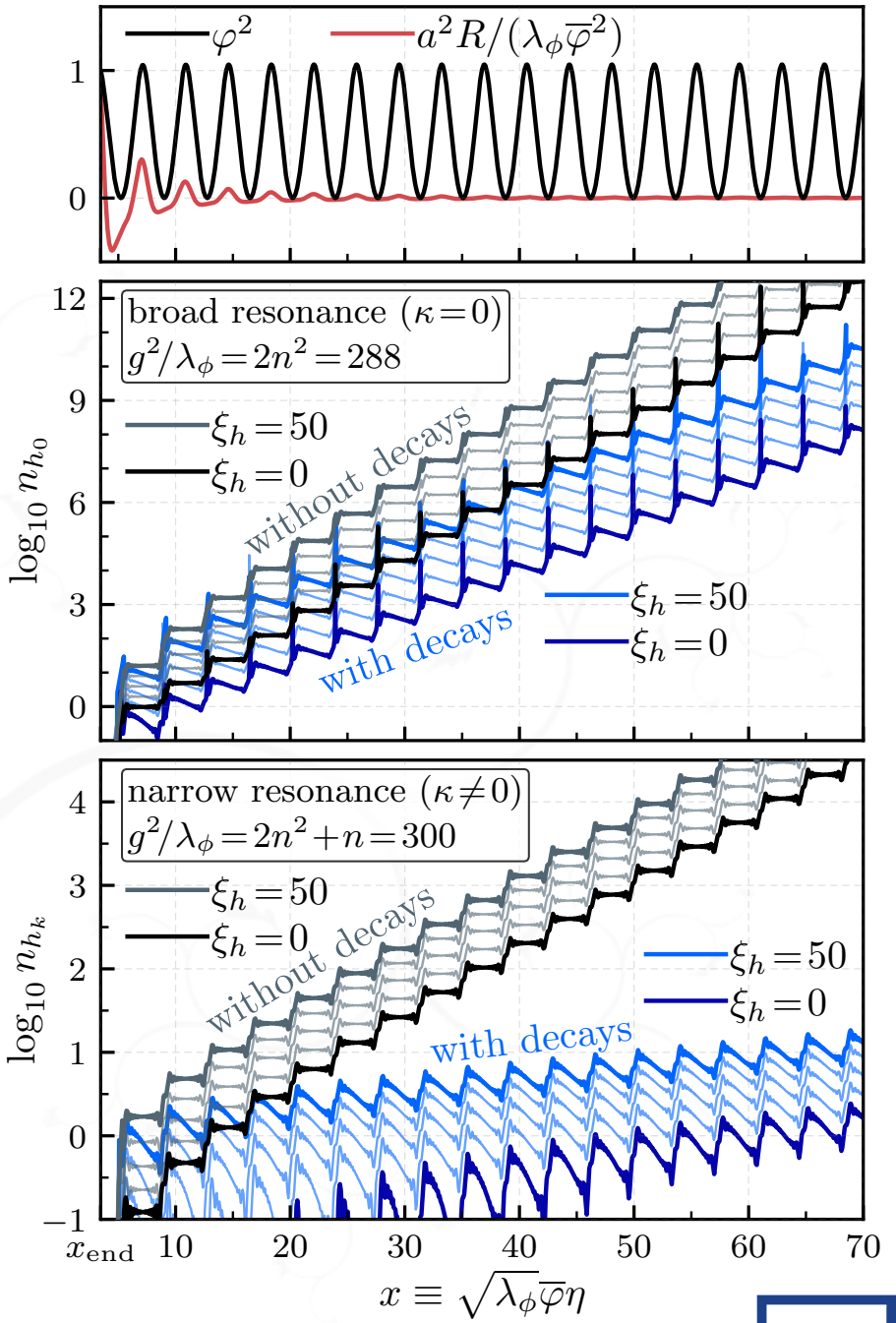
The decay exponent depends linearly on time, *same* as growth exponents $2\mu_k x$.
$\Rightarrow$ decays could *entirely* ***suppress*** **production** of Higgs particles.

**does *not* occur** in massive preheating



# ② Backreaction

• Although fluctuations grow unimpeded, eventually their energy density will be comprable to inflaton background

variance of fluctuations

$$\ddot{\phi} + 3H\dot{\phi} + \lambda_\phi \phi^3 + \underbrace{\left(3\lambda_\phi \langle \phi^2 \rangle + g^2 \langle h^2 \rangle\right)\phi}_{\text{backreaction on inflaton}} = 0$$

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⇒ tachyonic contriubtion ($3\lambda_h \langle h^2 \rangle < 0$) can destabilize Higgs prior to $x_{\rm NL}$.

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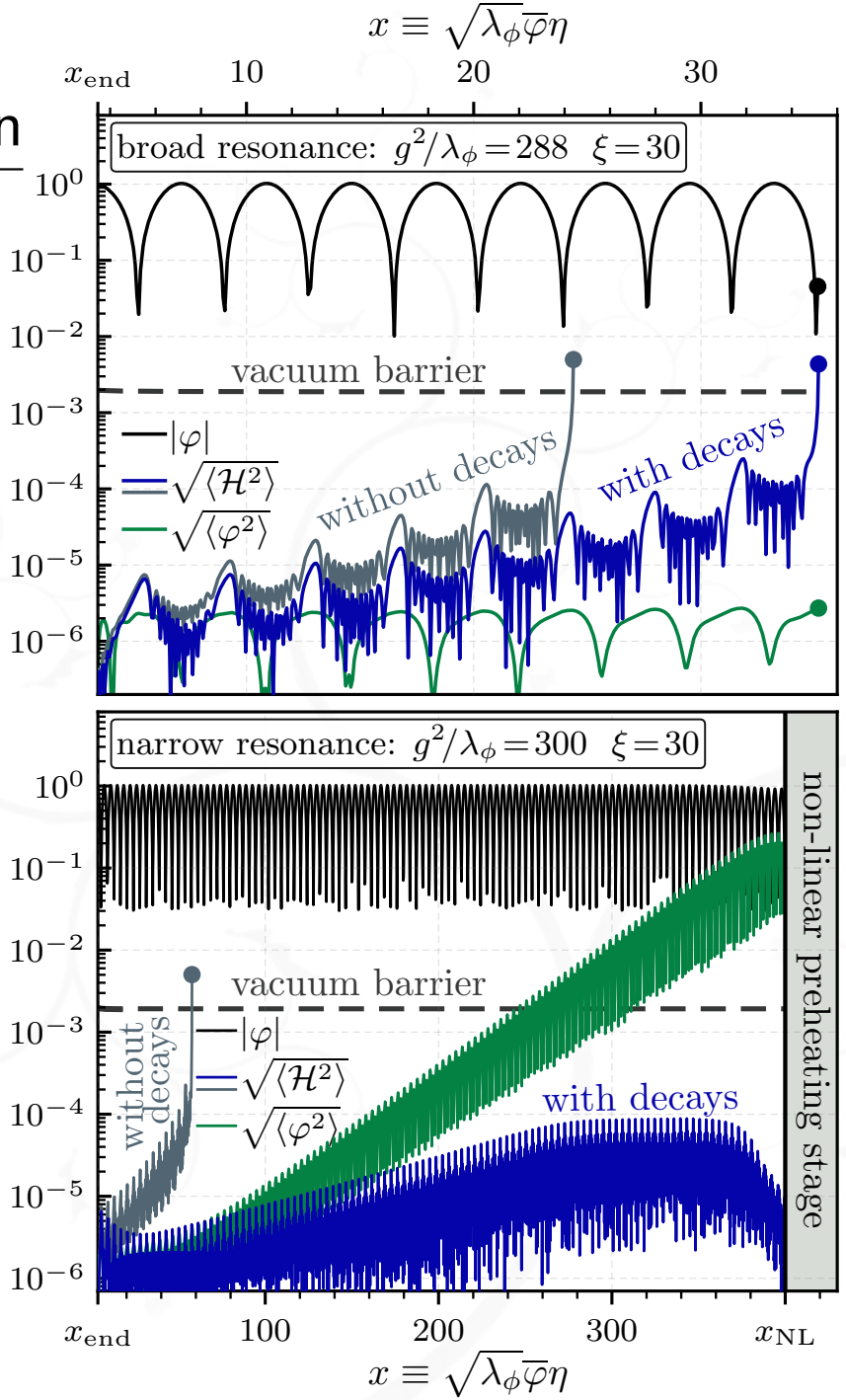

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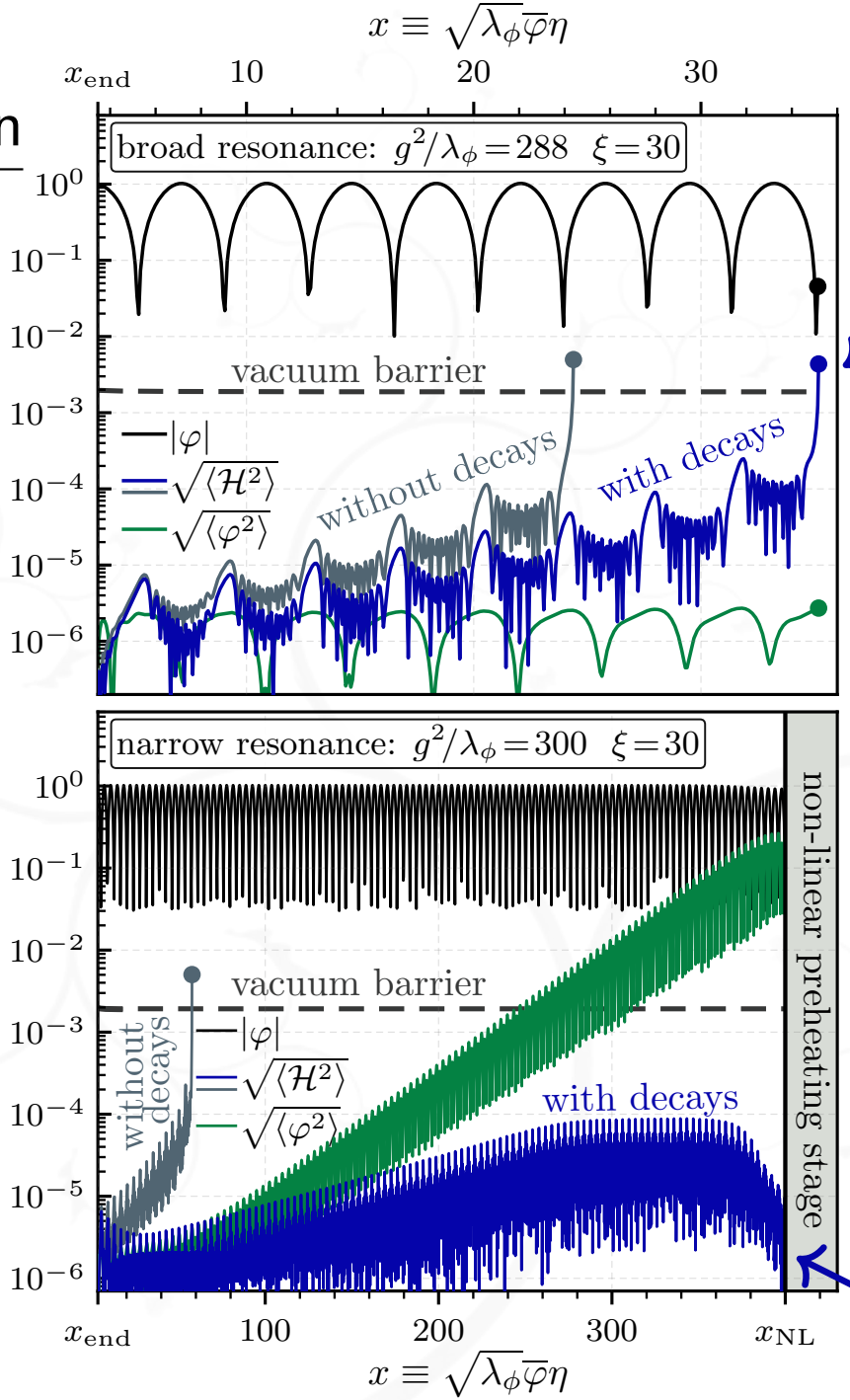


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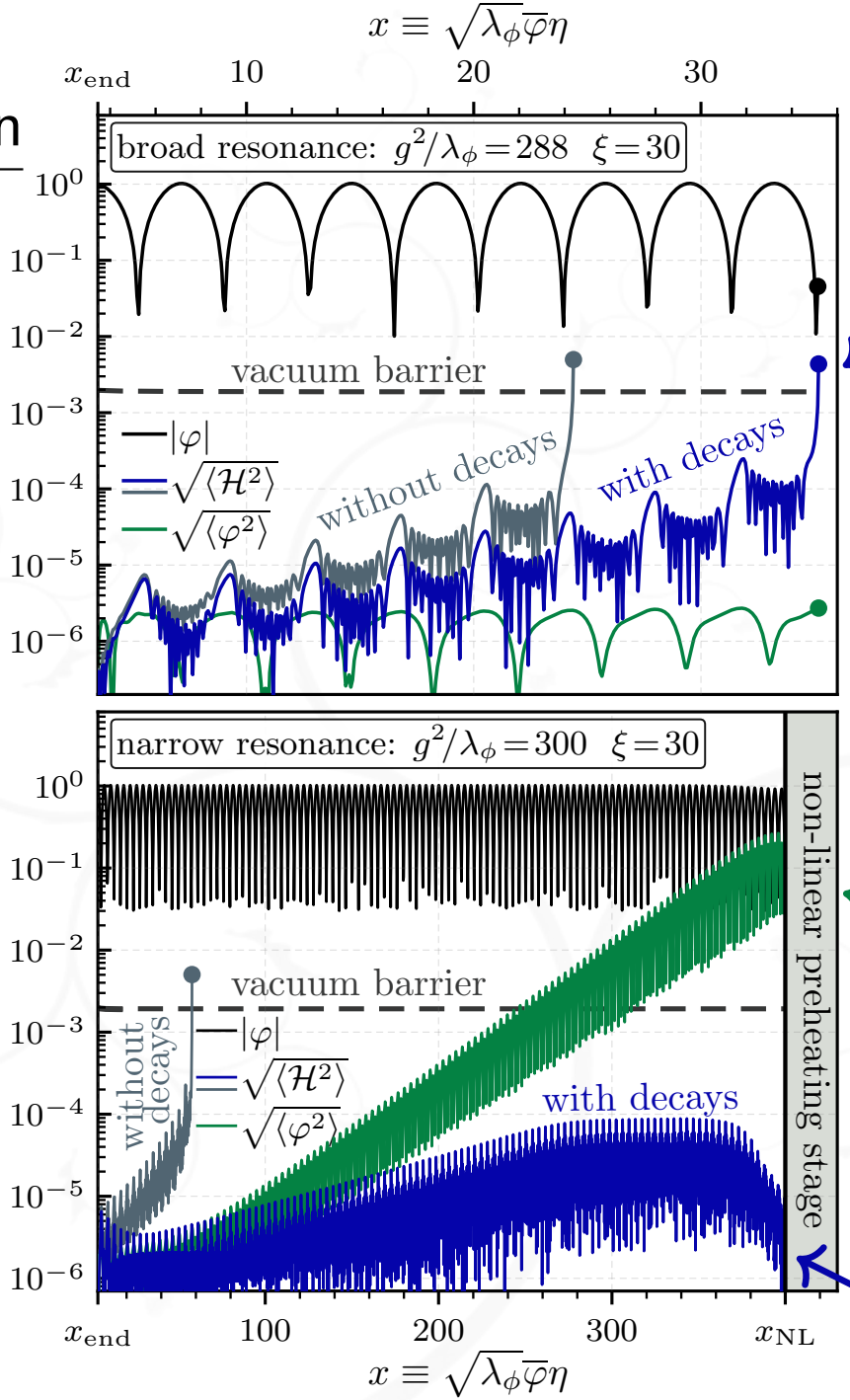


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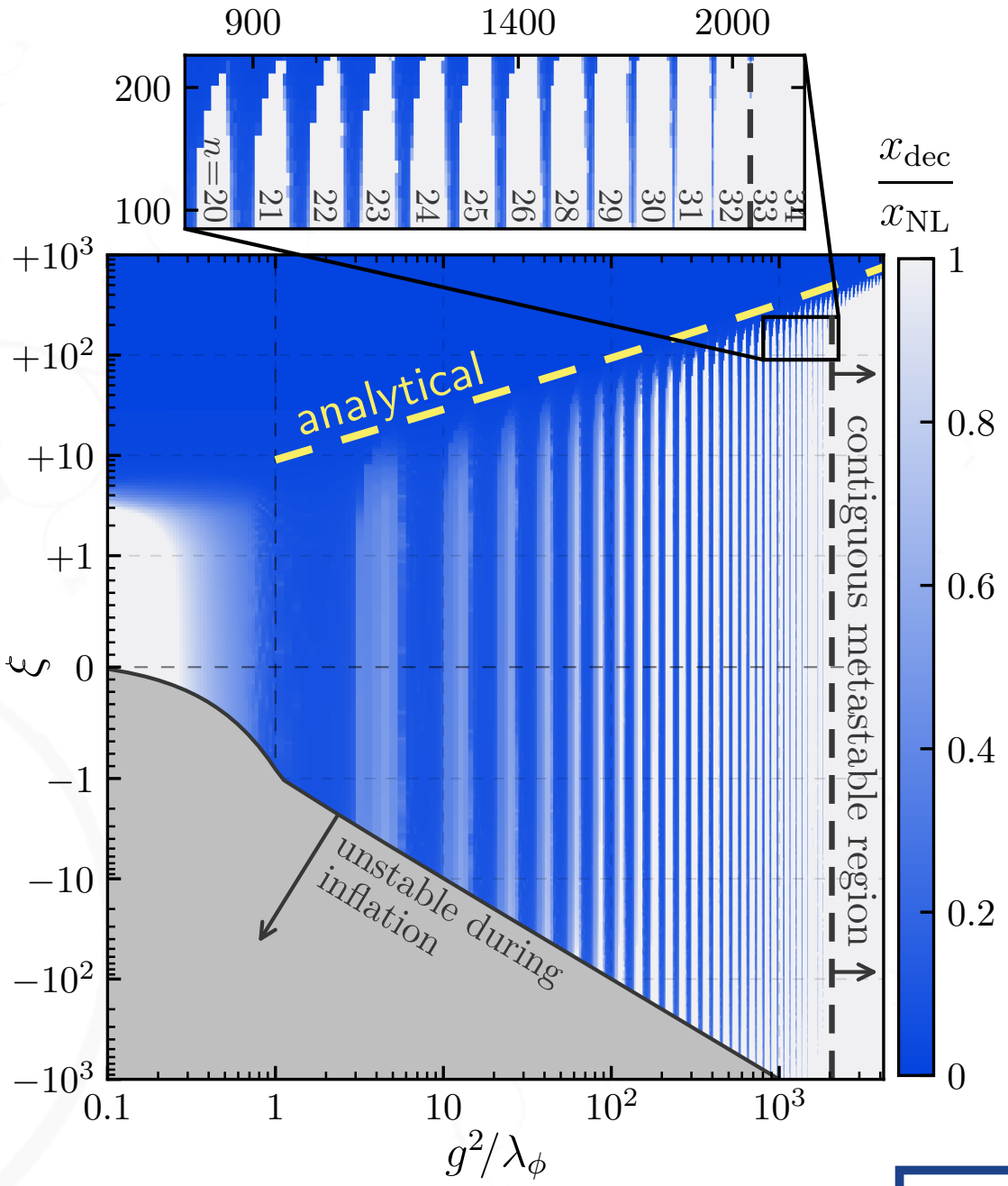
Calculate vacuum decay time $x_{\rm dec}$ numerically over parameter space of $\{g^2/\lambda_\phi, \xi\}$ Higgs couplings.



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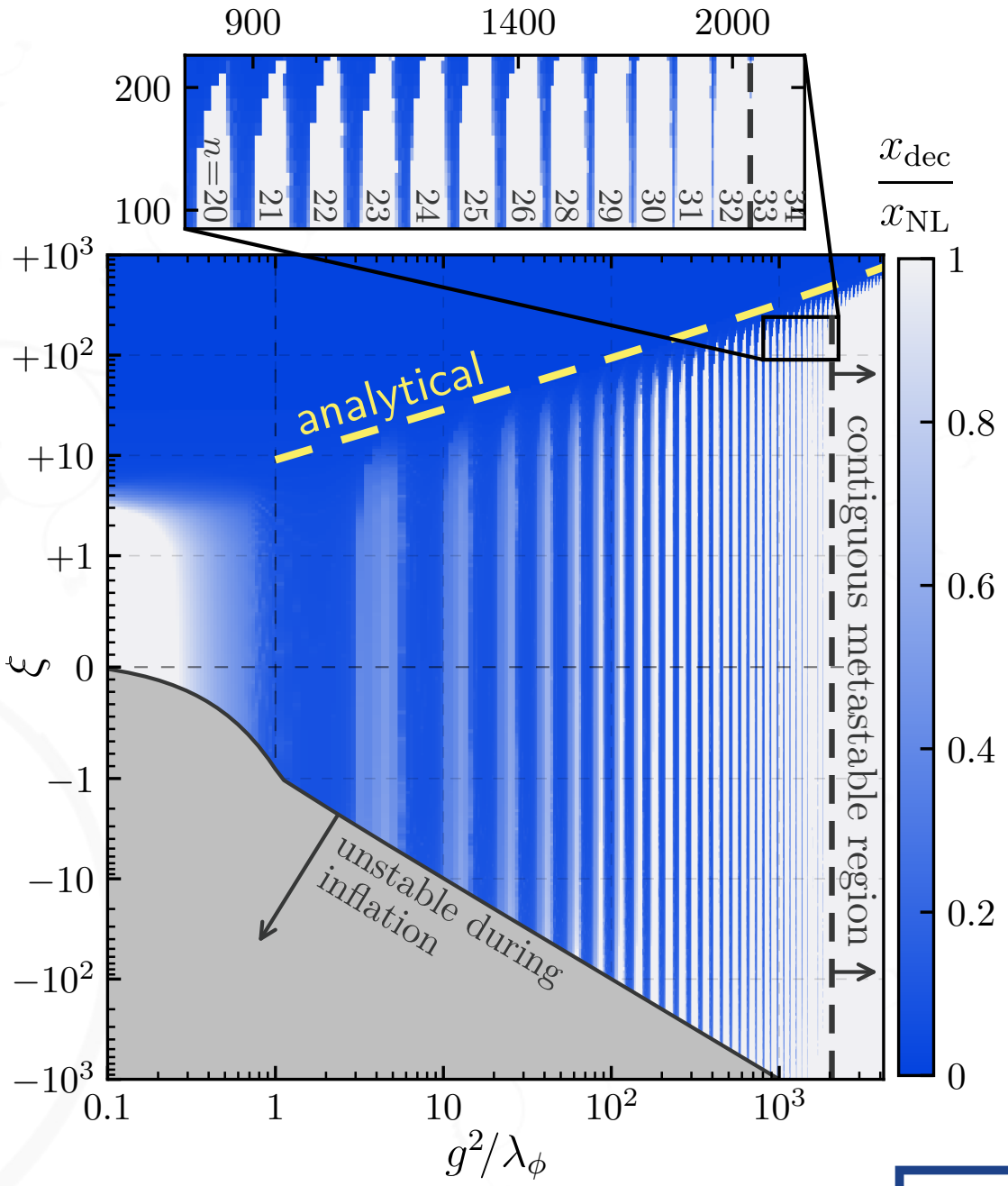

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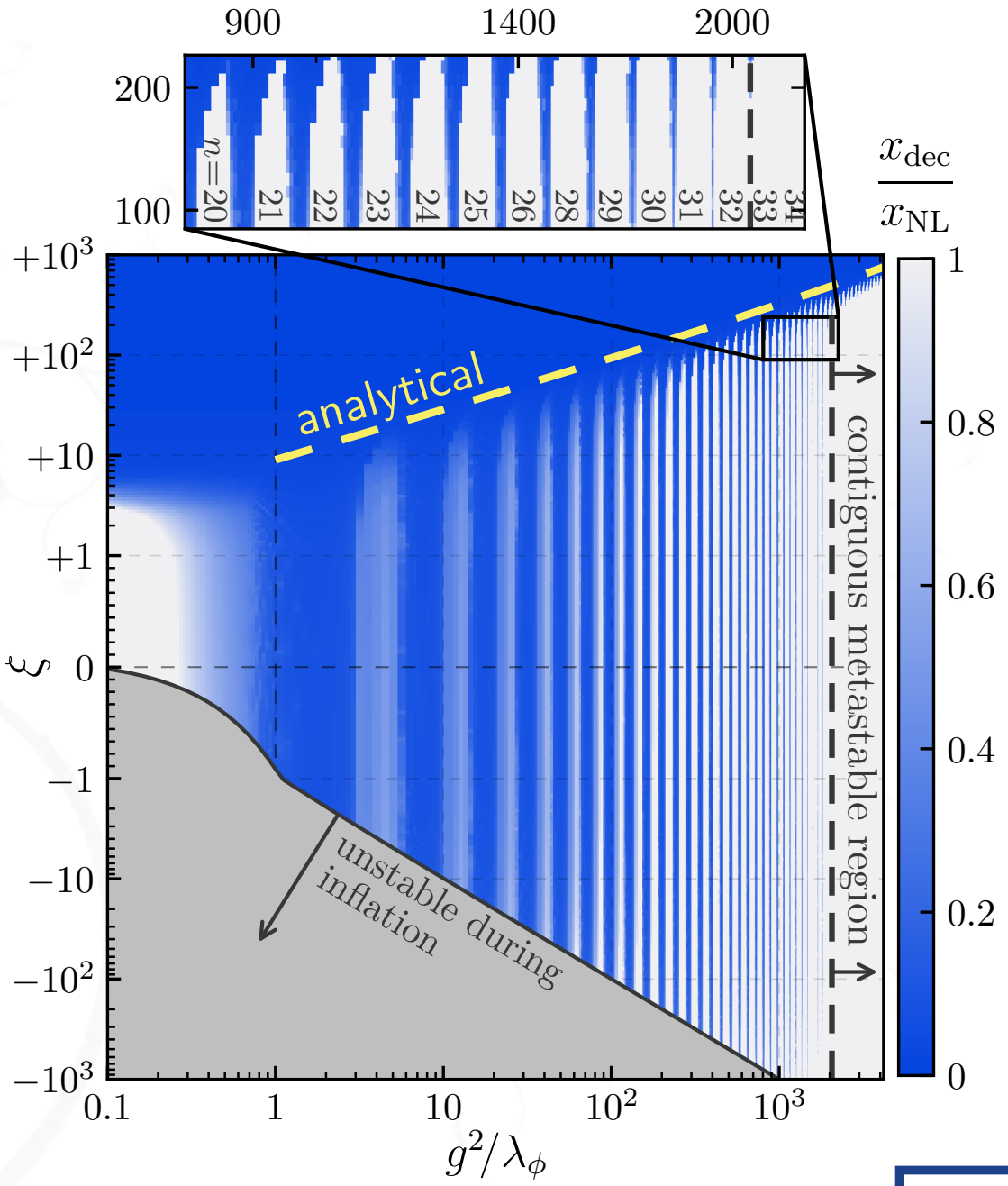

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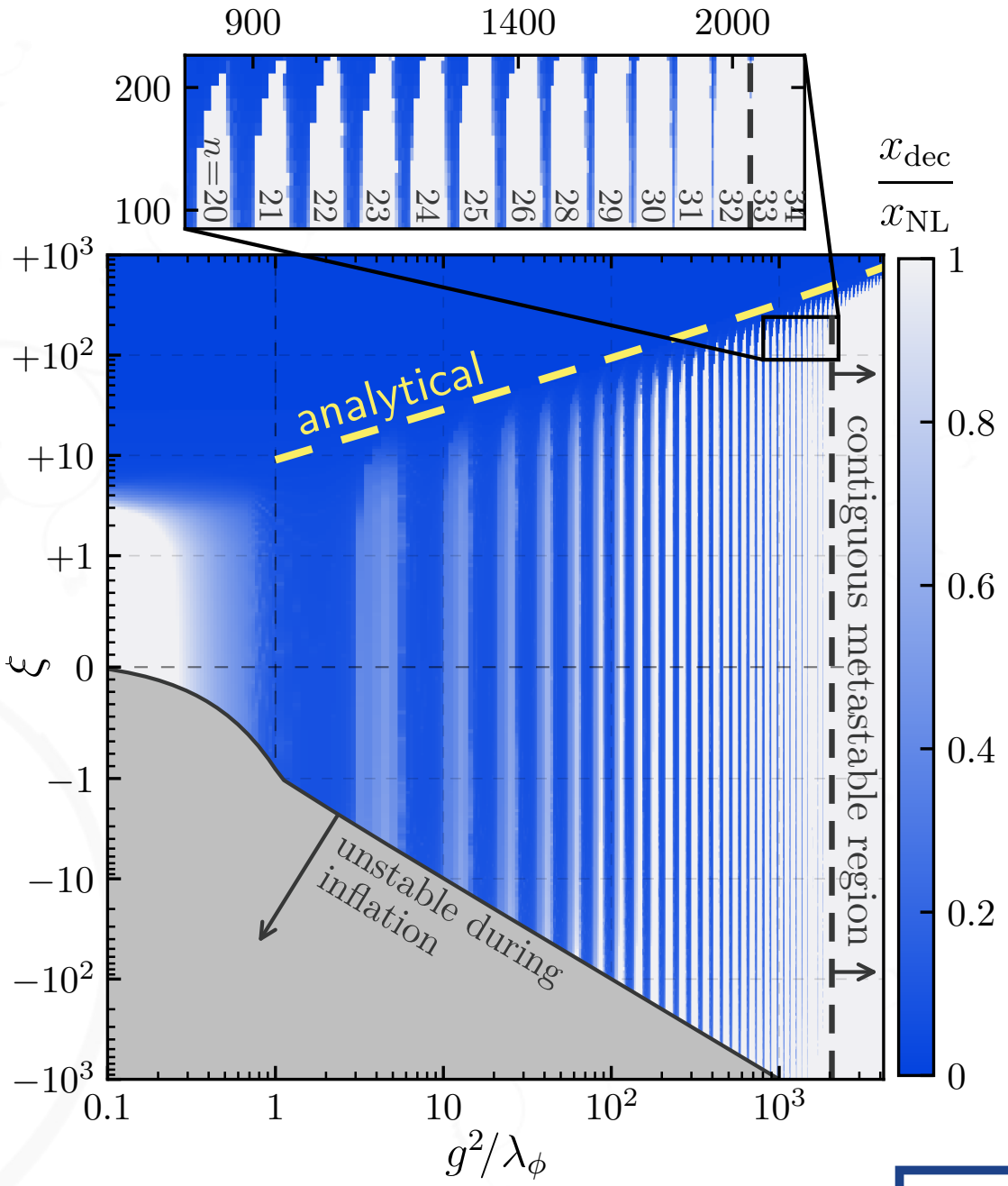

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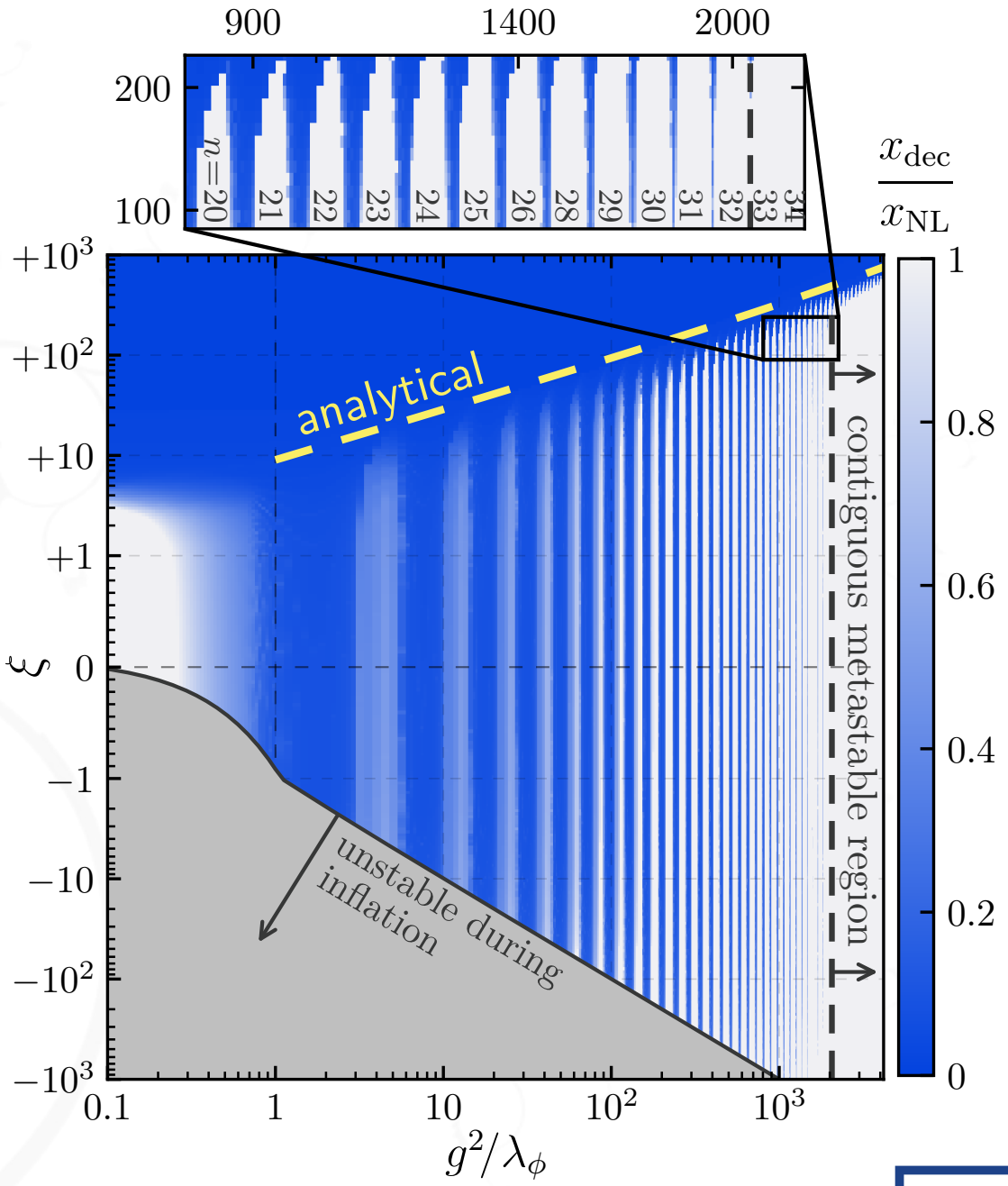

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## THANK YOU FOR YOUR ATTENTION!