Probing Baryogenesis through the Higgs Self-Coupling

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Based on: arXiv:1711.00019

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Higgs Couplings 2017

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Where do we come from?

- We observe a huge matter-antimatter asymmetry in the universe

$$n_B/n_\gamma \approx 6 \cdot 10^{-10}$$

- Need baryogenesis
  - at the electroweak phase transition
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Can in principle be realised at the electroweak phase transition (EWPT)

but EWPT is second-order in Standard Model

Add new physics such that we get a strong first-order EWPT: $\phi_c / T_c \geq 1$

Shaposhnikov (1986)

Beyond Standard Model physics via the Higgs potential

$$V_{k=\Lambda}(\phi) = \frac{\mu^2}{2}\,\phi^2 + \frac{\lambda_4}{4}\,\phi^4 + \Delta V(\phi)$$

- Polynomial modifications

$$\Delta V_6 = \lambda_6\,\frac{\phi^6}{\Lambda^2} \qquad\qquad \Delta V_8 = \lambda_6\,\frac{\phi^6}{\Lambda^2} + \lambda_8\,\frac{\phi^8}{\Lambda^4}$$

Grojean, Servant, Wells (2005)

- Logarithmic modifications

$$\Delta V_{\ln,2} = -\lambda_{\ln,2}\,\frac{\phi^2\Lambda^2}{100}\;\ln\left(\frac{\phi^2}{2\Lambda^2}\right)$$

- Exponential modifications

$$\Delta V_{\exp,4} = \lambda_{\exp,4}\,\phi^4\exp\left(-\frac{2\Lambda^2}{\phi^2}\right)$$

Our setup

Method: Functional renormalisation group Wetterich (1993)

- Non-perturbative computation at finite temperature
- Start at scale $\Lambda = 1 - 5$ TeV and flow to IR
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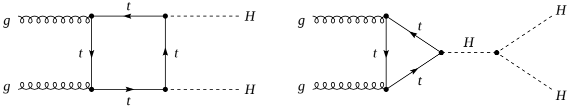
Standard Model

- Full Higgs-potential $V(\phi)$ via grid code
- Top-Yukawa coupling y_t
- $SU(3)$ coupling g_3 & fiducial coupling g_F mimicking $SU(2)xU(1)$

Eichhorn, Gies, Jaeckel, Plehn, Scherer, Sondenheimer (2015)

Measurement of the Higgs self-coupling

Higgs pair production in gluon fusion



U. Baur, T. Plehn, D.L. Rainwater (2003)

Destructive interference at tree-level coupling:

$$\mathcal{A} \propto \frac{\alpha_s}{12\pi v} \left(\frac{\lambda_{H^3}}{s - m_H^2} - \frac{1}{v} \right) \overset{\lambda_{H^3}=\lambda_{H^3,0}}{\longrightarrow} 0$$

Next LHC run: measurement with the precision

$$\lambda_{H^3}/\lambda_{H^3,0} = \quad 0.4 \ldots 1.7 \qquad \text{at } 68\% \text{ CL},$$

F. Kling, T. Plehn, P. Schichtel (2016)

Higgs self-coupling in the Standard Model

- Tree-level couplings are given by

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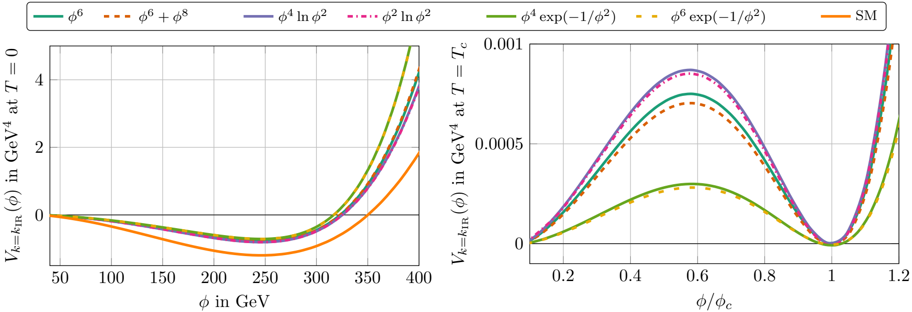
- Standard Model with Coleman-Weinberg corrections

$$\lambda_{H^3}/\lambda_{H^3,0} \approx 0.92 \qquad \lambda_{H^4}/\lambda_{H^4,0} \approx 0.68$$

First observations – IR potentials with $\phi_c/T_c = 1$

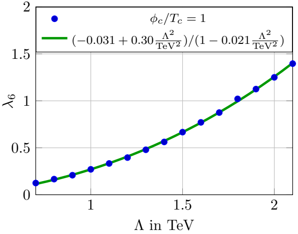


$T = 0$ $\qquad$ $T = T_c$

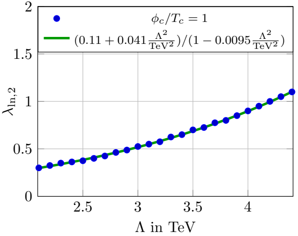
Smaller bump at $T = T_c$ leads to steeper potential at $T = 0$

Scale of new physics

ϕ^6



$\phi^2 \ln \phi^2$



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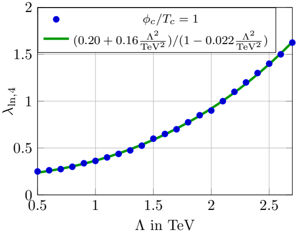

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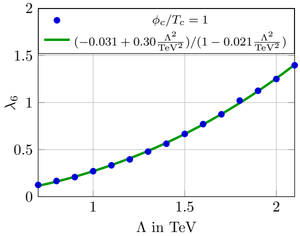

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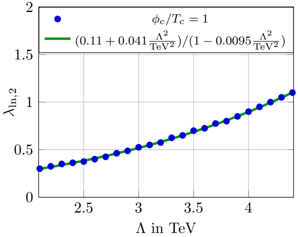

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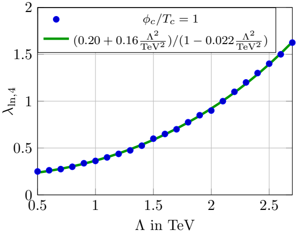
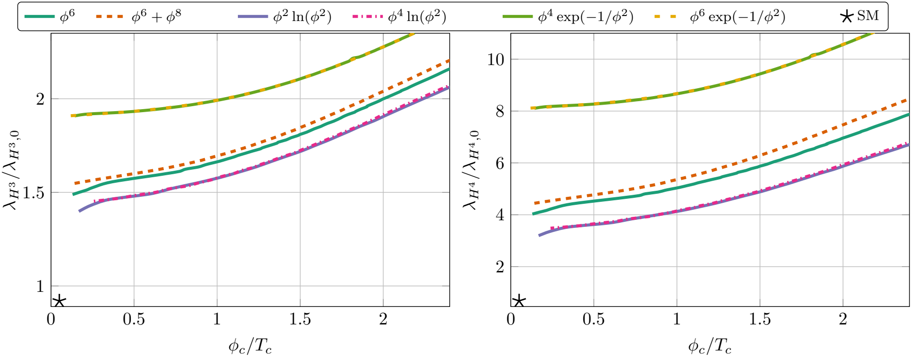


Fit function: $\lambda_j(\Lambda^2) = \frac{a_1 + a_2\Lambda^2}{1 + b_1\Lambda^2}$

$\Lambda_6^{\text{crit}} = 7.0\,\text{TeV}$ $\quad$ $\Lambda_{\ln,2}^{\text{crit}} = 10\,\text{TeV}$ $\quad$ $\Lambda_{\ln,4}^{\text{crit}} = 6.8\,\text{TeV}$

Scale where the system becomes strongly coupled

Higgs self-coupling with baryogenesis



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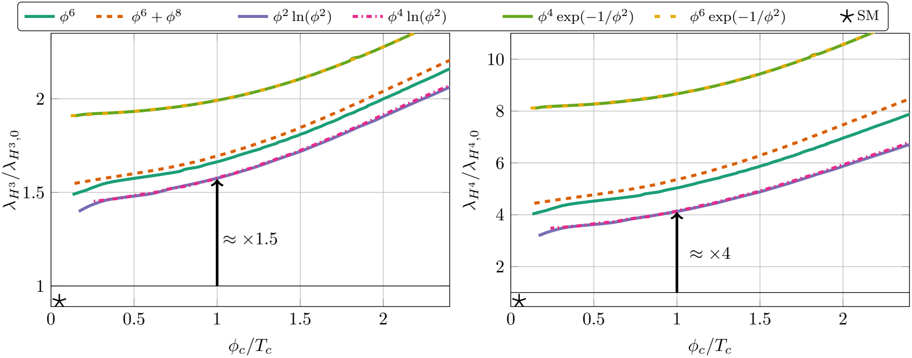

- Strongly enhanced Higgs self-coupling for all models

  $\lambda_{H^3}/\lambda_{H^3,0} \geq 1.5$ and $\lambda_{H^4}/\lambda_{H^4,0} \geq 4$

- All ln- and exp-modifications fall into one class, respectively

Possible scenarios for the upcoming LHC measurement

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  $\Rightarrow$ inconclusive, requires study of microscopic model

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- $2 > \lambda_{H^3}/\lambda_{H^3,0}$: $\phi_c/T_c > 1$ for all investigated models

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Summary and outlook

- We parameterised many models of new physics via the Higgs potential
- All models show a strongly enhanced Higgs self-coupling
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- The LHC will soon determine the Higgs self-coupling precisely enough!

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Stay tuned!

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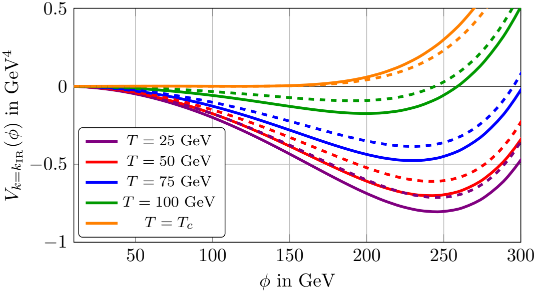
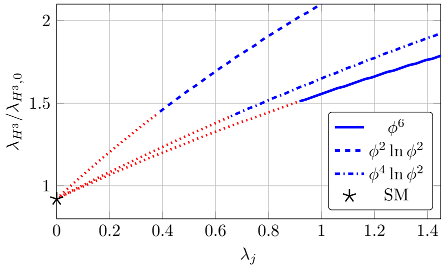
$\Delta V_{\exp,4} = \lambda_{\exp,4}\phi^4 \exp\left(-\frac{2\Lambda^2}{\phi^2}\right)$ $\qquad$ $\Delta V_{\exp,6} = \lambda_{\exp,6}\frac{\phi^6}{\Lambda^2} \exp\left(-\frac{2\Lambda^2}{\phi^2}\right)$

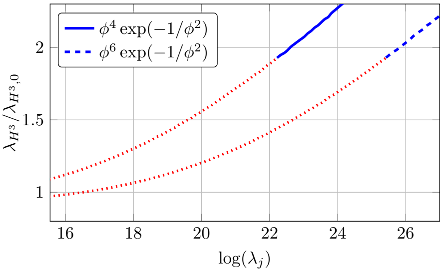
Evolution of potential



- Soid lines: $\phi^4 \ln \phi^2$
- Dashed lines: $\phi^4 \exp(-1/\phi^2)$

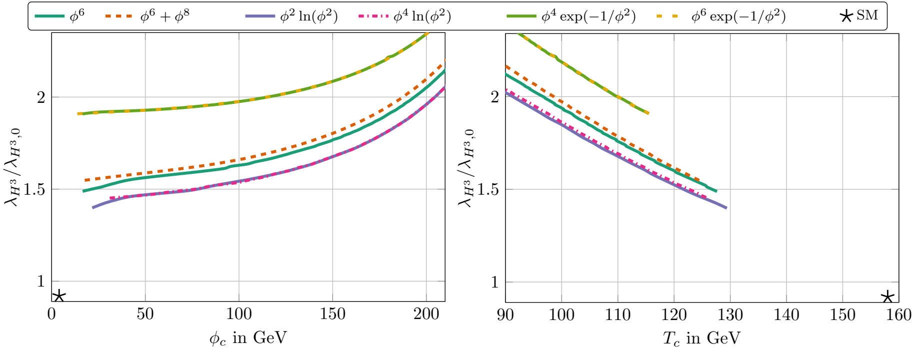
Higgs self-coupling vs coefficients



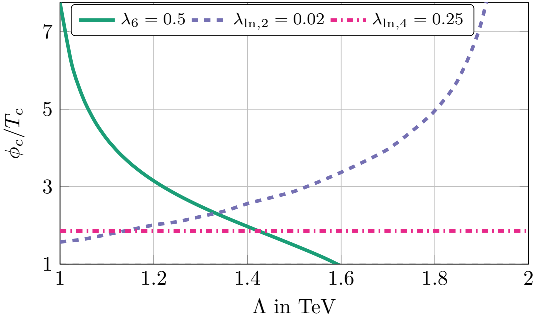


- Red dashed lines = second-order phase transition
- Blue lines = first-order phase transition

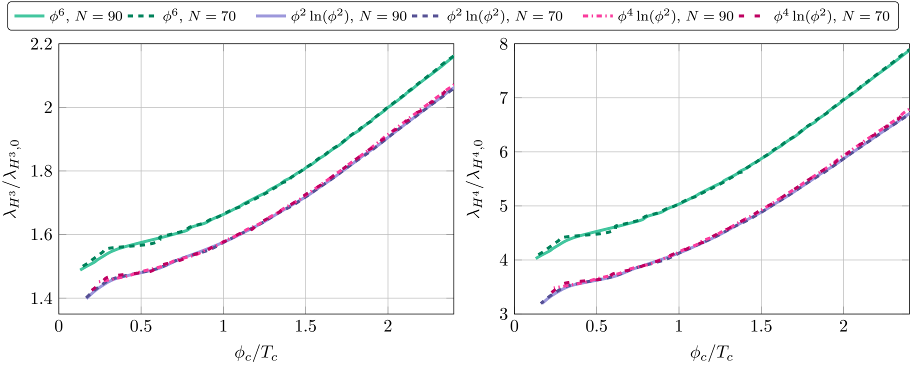
Higgs self-coupling with baryogenesis



Failure of mean-field methods



Benchmark of results



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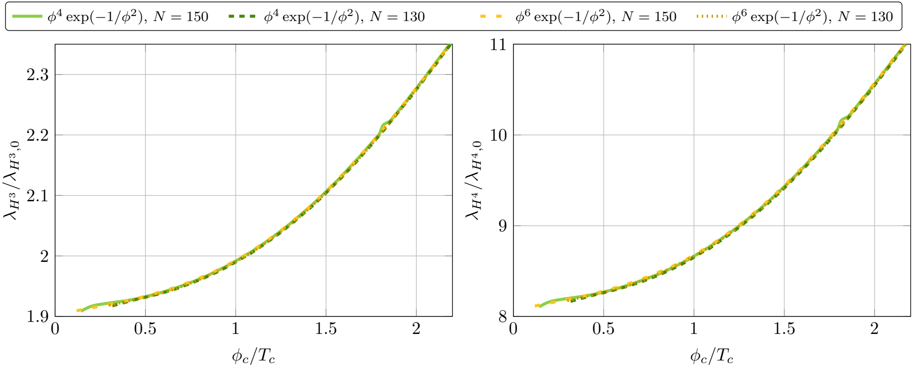

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