Vacuum stability from generalized Higgs interactions

René Sondenheimer

Theoretisch-Physikalisches Institut
Friedrich-Schiller-Universität Jena

In collaboration with: J. Borchardt, A. Eichhorn, H. Gies, C. Gneiting, J. Jäckel, T. Plehn, M. Scherer, M. Warschinke

Δ-Meeting, April 28^{th} 2016

seit 1558

Research Training Group
Quantum and Gravitational Fields

LHC run II already started!

- search for new physics beyond the standard model

http://people.physics.tamu.edu/kamon/research/refColliders/LHC/LHC_is_back.html

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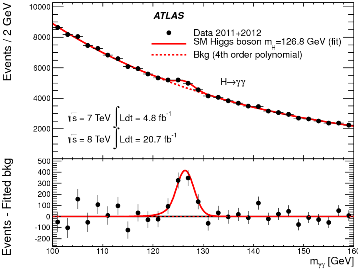
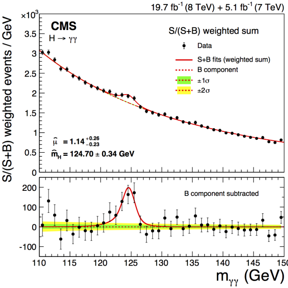
LHC run II already started!

- search for new physics beyond the standard model (750 GeV?)
- detailed studies of the Higgs

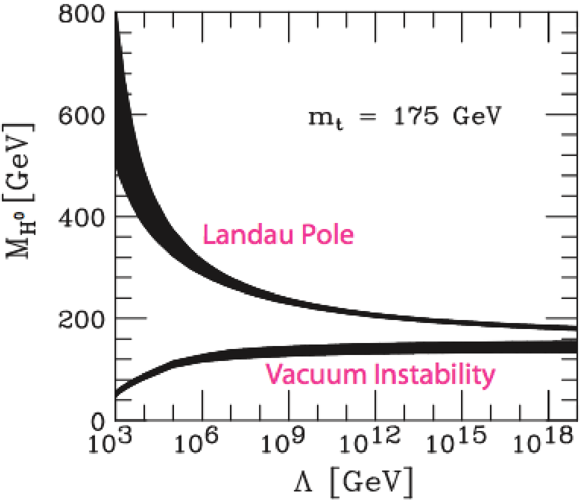
http://people.physics.tamu.edu/kamon/research/refColliders/LHC/LHC_is_back.html

Highlight LHC run I: $m_{\mathrm{H}} = 125.09^{\pm 0.21(stat)}_{\pm 0.11(sys)}\,\mathrm{GeV}$





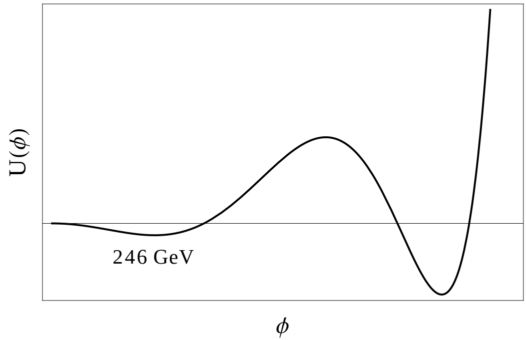
Higgs mass bounds & vacuum stability

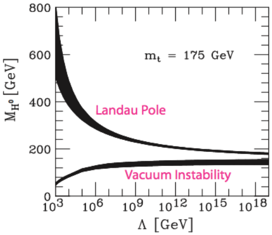


Hagiwara et al '02

Krive, Linde '76
Maiani et al '78
Krasnikov '78
Politzer, Wolfram '78
Cabibbo et al. '79
Hung '79
Linde '80
Lindner '85
Wetterich '87
Lindner et al '89
Sher '89
Ford et al 93
Altarelli, Isidori '94
Espinosa, Quiros '95
Schremp, Wimmer '96
...

Higgs mass bounds & vacuum stability





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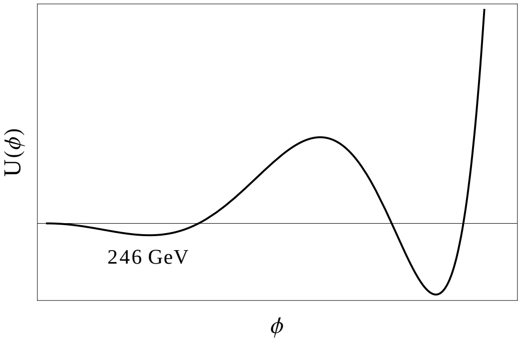

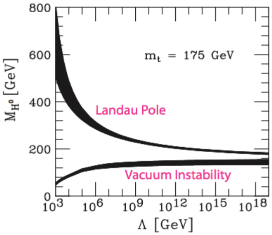

Hagiwara et al '02

- second minimum occurs at a trans-Planckian scale? Gabrielli et al '13
- discrepancy to lattice studies Holland, Kuti '04; Fodor et al '13
- implicit renormalization conditions in conflict with a well defined partition function Branchina, Faivre '05

Higgs-Top Model

$$S = \int d^d x \left[\frac{1}{2}(\partial_\mu \phi)^2 + U(\phi^2) + \bar{\psi} i \partial\!\!\!/ \psi + i h \phi \bar{\psi} \psi \right]$$

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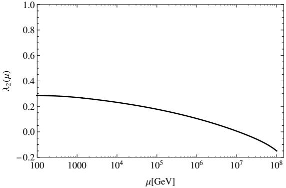

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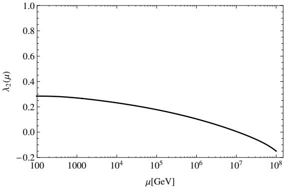

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$$U^S_{\text{eff}}(\phi) = -\frac{m^2}{2}\phi^2 + \frac{\lambda(\mu = \phi)}{8}\phi^4$$

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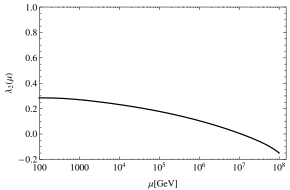

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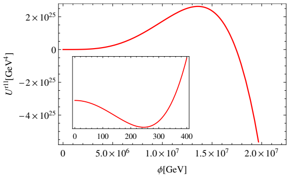

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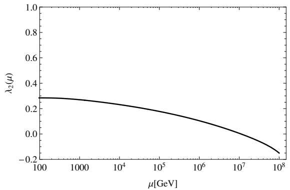

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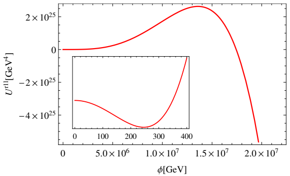

BUT:

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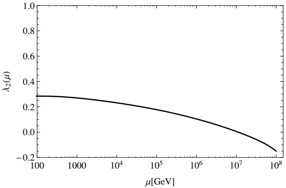

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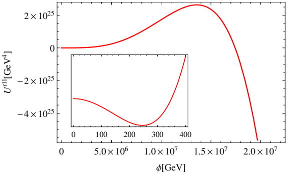


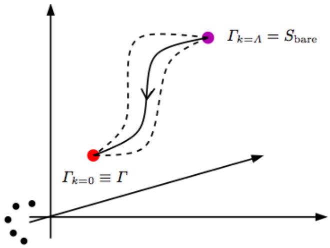
BUT:

- interaction part of the fermion determinant is strictly positive Gies, RS '14
- multi-scale problem $U(\mu; \phi)$ Borchardt, Gies, RS '16

Functional renormalization group

$$\partial_k \Gamma_k = \frac{1}{2}\mathrm{STr}\left[\frac{\partial_k R_k}{\Gamma_k^{(2)} + R_k}\right]$$

Wetterich '93



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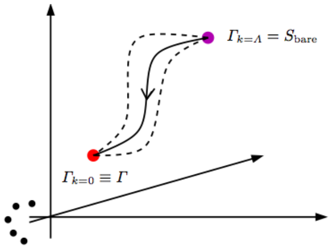

- nonperturbative flow equations, e.g.,

$$\partial_k U(k,\phi) = \beta_U, \qquad \partial_k h^2 = \beta_{h^2}$$

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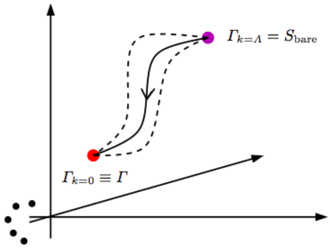

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$$U_\Lambda = \frac{\lambda_{1\Lambda}}{2}\phi^2 + \frac{\lambda_{2\Lambda}}{8}\phi^4 \qquad or \qquad U_\Lambda = \frac{\lambda_{2\Lambda}}{8}(\phi^2 - v_\Lambda^2)^2$$

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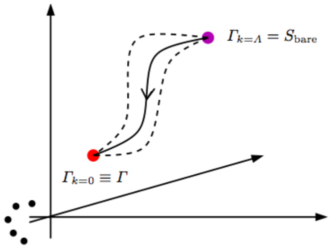

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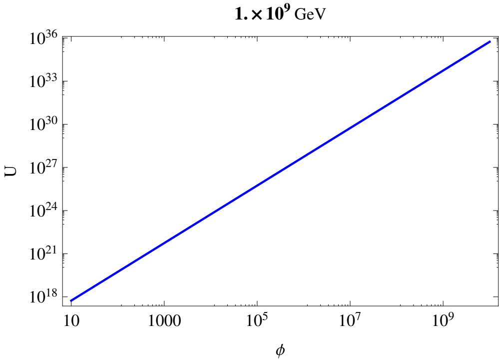
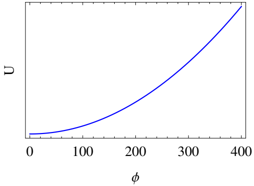
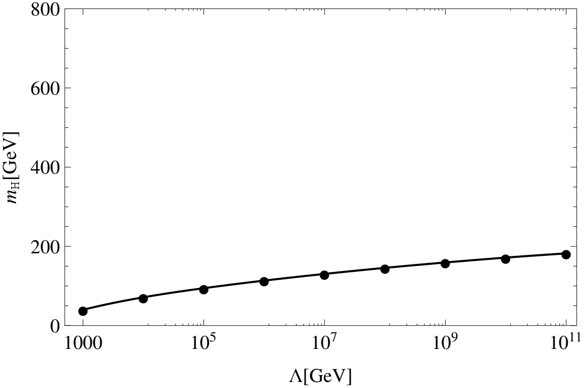
$$\lambda_{1\Lambda}\ (\text{or } v_\Lambda) \to v_0 = 246\,\text{GeV}$$
$$h_\Lambda \to m_{\text{top}} = 173\,\text{GeV}$$

RG flow of the Higgs potential





Nonperturbative Higgs mass bounds



$\lambda_{2\Lambda} = 0$

Gies, Gneiting, RS '13

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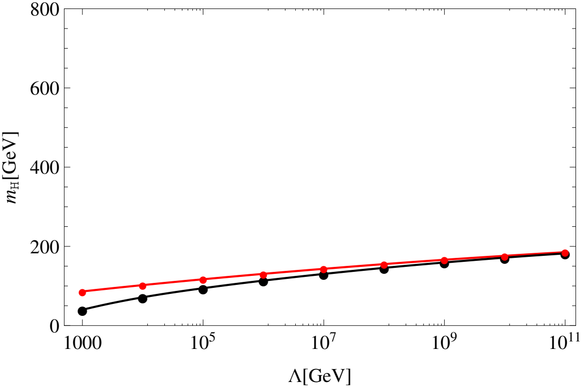

$\lambda_{2\Lambda} = 0$
$\lambda_{2\Lambda} = 0.1$

Gies, Gneiting, RS '13

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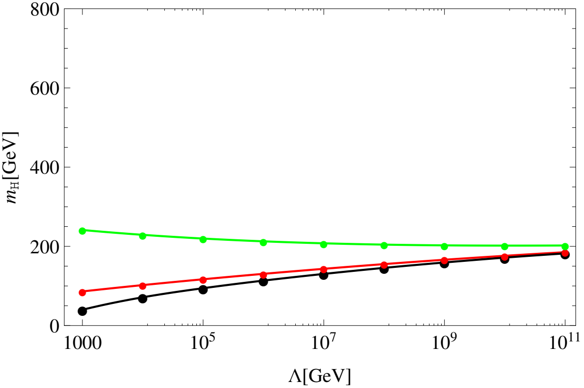

$\lambda_{2\Lambda} = 0$
$\lambda_{2\Lambda} = 0.1$
$\lambda_{2\Lambda} = 1$

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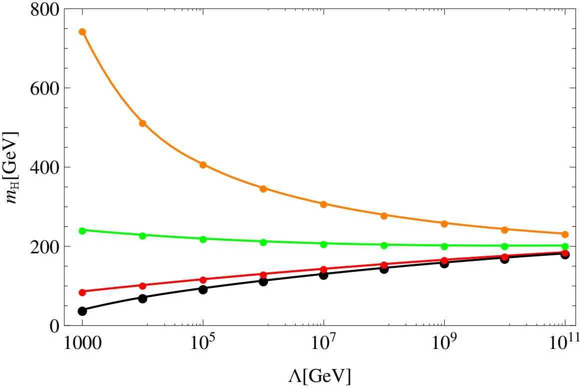

$\lambda_{2\Lambda} = 0$
$\lambda_{2\Lambda} = 0.1$
$\lambda_{2\Lambda} = 1$
$\lambda_{2\Lambda} = 10$

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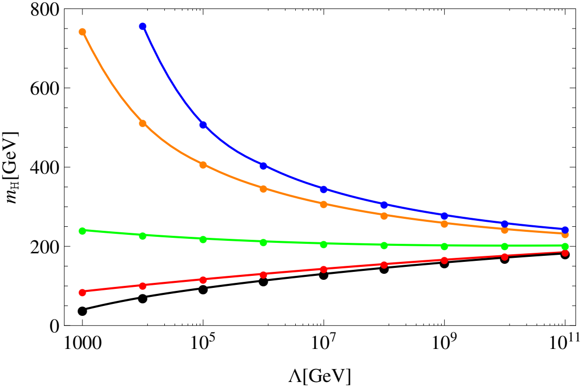

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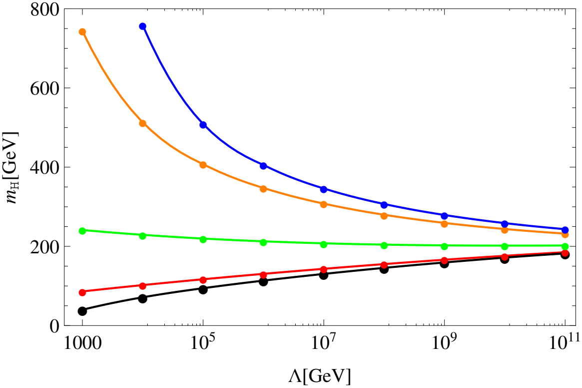

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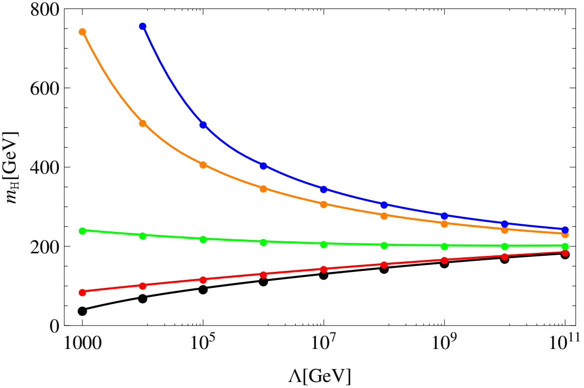

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Gies, Gneiting, RS '13

- $m_{\rm H}(\lambda_{2\Lambda})$ is monotonically increasing
- natural lower bound for quartic bare potentials $\lambda_{2\Lambda}\,\phi^4$ (cf. lattice simulations Gerhold et al. '07)

Generalized UV potentials

$$U_\Lambda = \frac{\lambda_{1\Lambda}}{2}\phi^2 + \frac{\lambda_{2\Lambda}}{8}\phi^4 + \frac{\lambda_{3\Lambda}}{48\Lambda^2}\phi^6$$

- we can choose $\lambda_{2\Lambda} < 0$, if the potential is stabilized by $\lambda_{3\Lambda} > 0$

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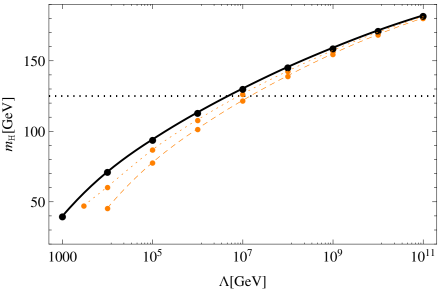

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$\lambda_{2\Lambda} = -0.05, \ \lambda_{3,\Lambda} = 3$

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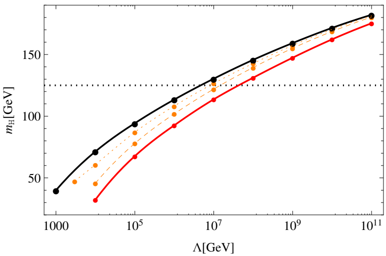

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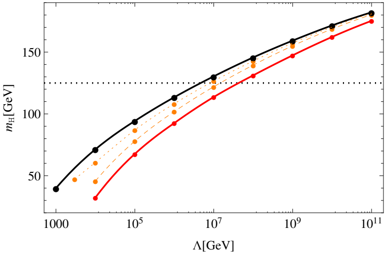

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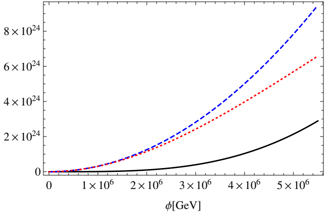
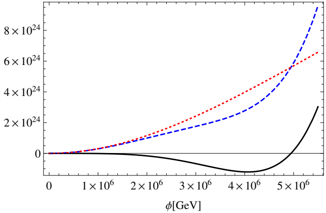
ϕ^4-type bare potential

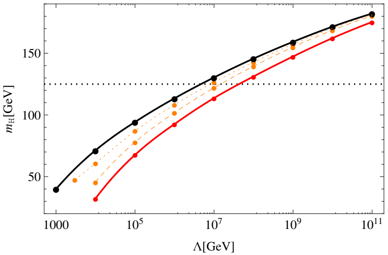


ϕ^6-type bare potential (below red curve)



Borchardt, Gies, RS '16

Generalized UV potentials



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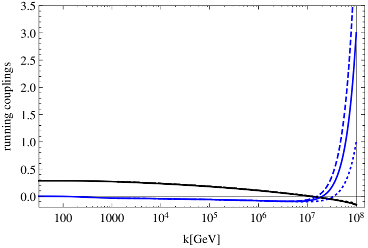

Generalized UV potentials

PRELEMINARY results for the SM: shift of the lower bound by 1 GeV at the Planck scale for polynomial bare potentials

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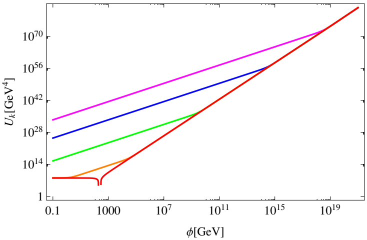
Beyond polynomial bare actions (@ mean-field level):

- $\Delta U_\Lambda = \frac{\alpha}{4}\phi^4 \ln \frac{\phi^2}{2\Lambda^2}$
- $\Delta U_\Lambda = -\frac{\alpha^2}{16\pi^2}\phi^4 \ln \left(1 + \frac{2\Lambda^2}{\alpha\phi^2}\right)$



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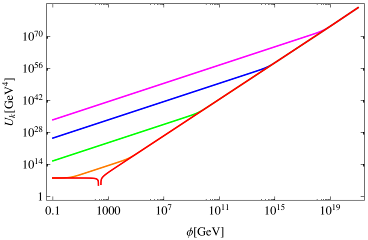
- $$\Delta U_\Lambda = \alpha\Lambda^4\Big[6\cos(8\pi\phi/\Lambda)\,\mathrm{Ci}(8\pi\phi/\Lambda) + 6\sin(8\pi\phi/\Lambda)\,\mathrm{Si}(8\pi\phi/\Lambda) -3\left(1 - 32\pi^2\frac{\phi^2}{\Lambda^2} + \frac{512\pi^4}{3}\frac{\phi^4}{\Lambda^4}\right)\ln\frac{\phi^2}{\Lambda^2}\Big]$$



Conclusions & Outlook

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- The form of the UV potential can exert a significant influence on the mass bounds.
- A lot of improvements can be done!

Thanks for your attention!