Higgs portal valleys, stability and inflation

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RPP at LAPTh, Annecy

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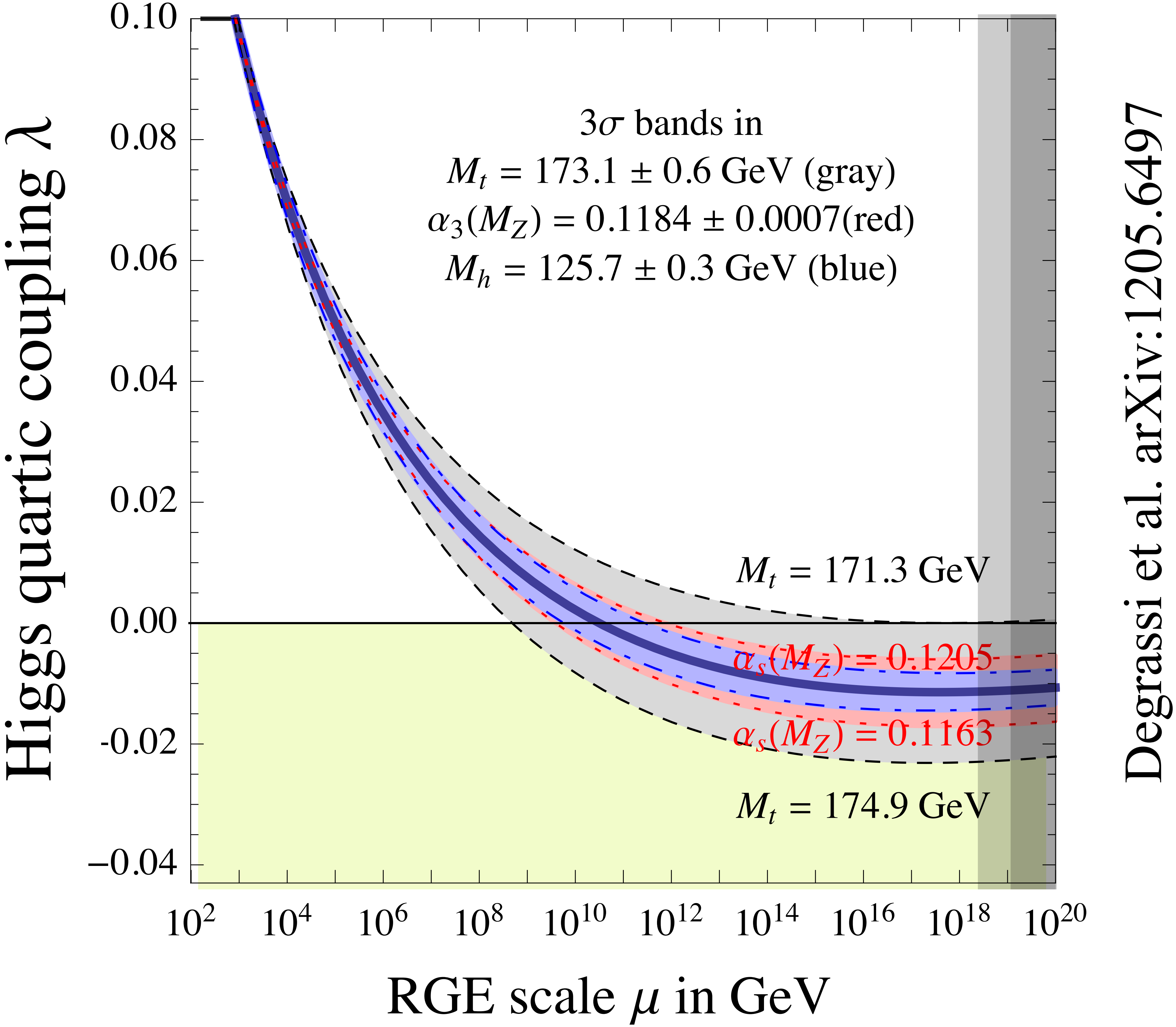
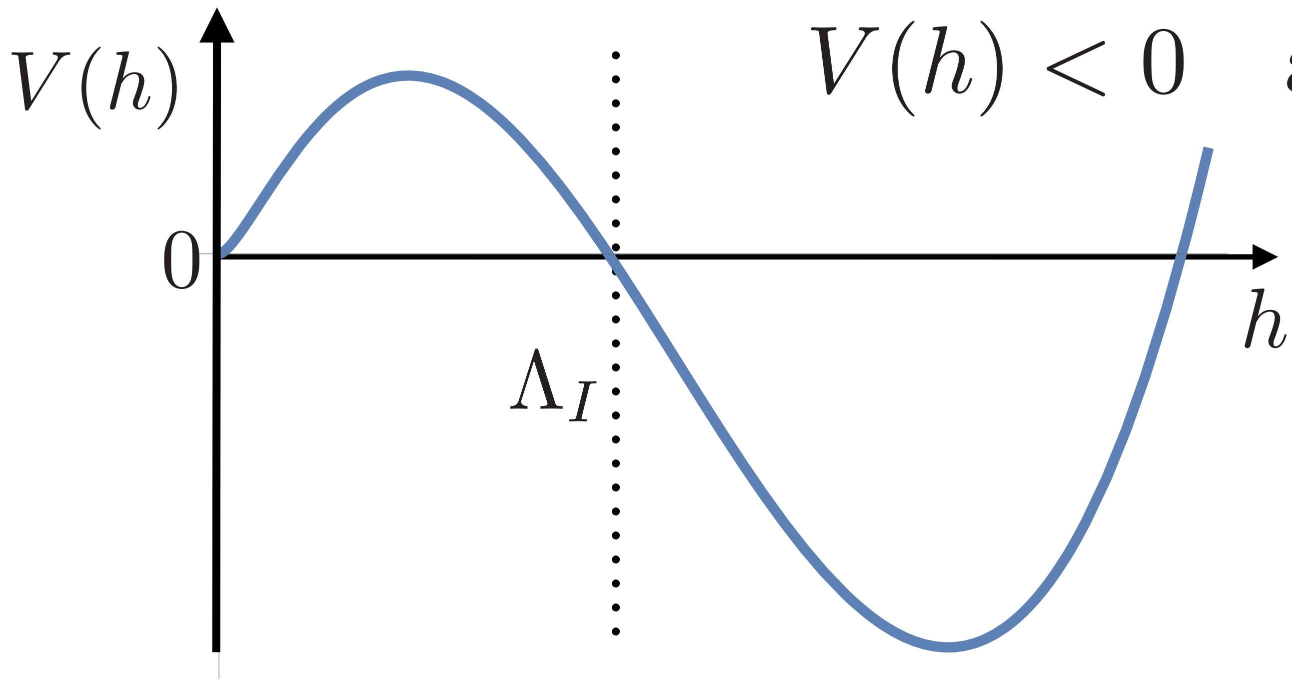


Higgs quartic coupling λ
RGE scale μ in GeV
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
−0.04
10^2
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
3σ bands in
M_t = 173.1 ± 0.6 GeV (gray)
$\alpha_3(M_Z)$ = 0.1184 ± 0.0007(red)
M_h = 125.7 ± 0.3 GeV (blue)
M_t = 171.3 GeV
$\alpha_s(M_Z)$ = 0.1205
$\alpha_s(M_Z)$ = 0.1163
M_t = 174.9 GeV
Degrassi et al. arXiv:1205.6497

Inflation and the Higgs



$$V(h) < 0 \quad \text{at} \quad h = \Lambda_I \sim 10^{11}\text{GeV}$$

$$V(h) \simeq \frac{\lambda(h)}{4} h^4$$

Quantum fluctuations of the Higgs:

$$\sqrt{\langle h^2 \rangle} \sim H \sim \frac{\sqrt{V_{\text{inf}}(\phi)}}{M_P} \sim 10^{-5} M_P \sim 10^{14}\text{GeV} \gg \Lambda_I$$

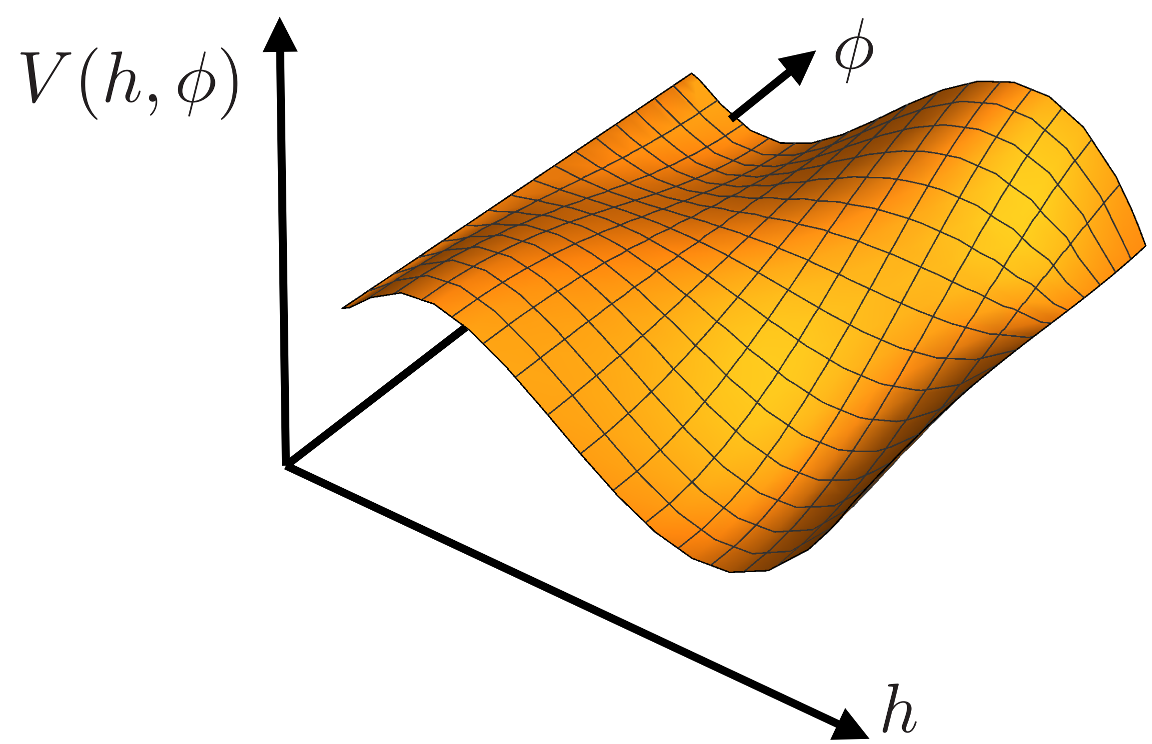
$$M_P = 1/\sqrt{8\pi\, G} \simeq 2.435 \cdot 10^{18}\,\text{GeV}$$

Inflation and the Higgs

Reheating:

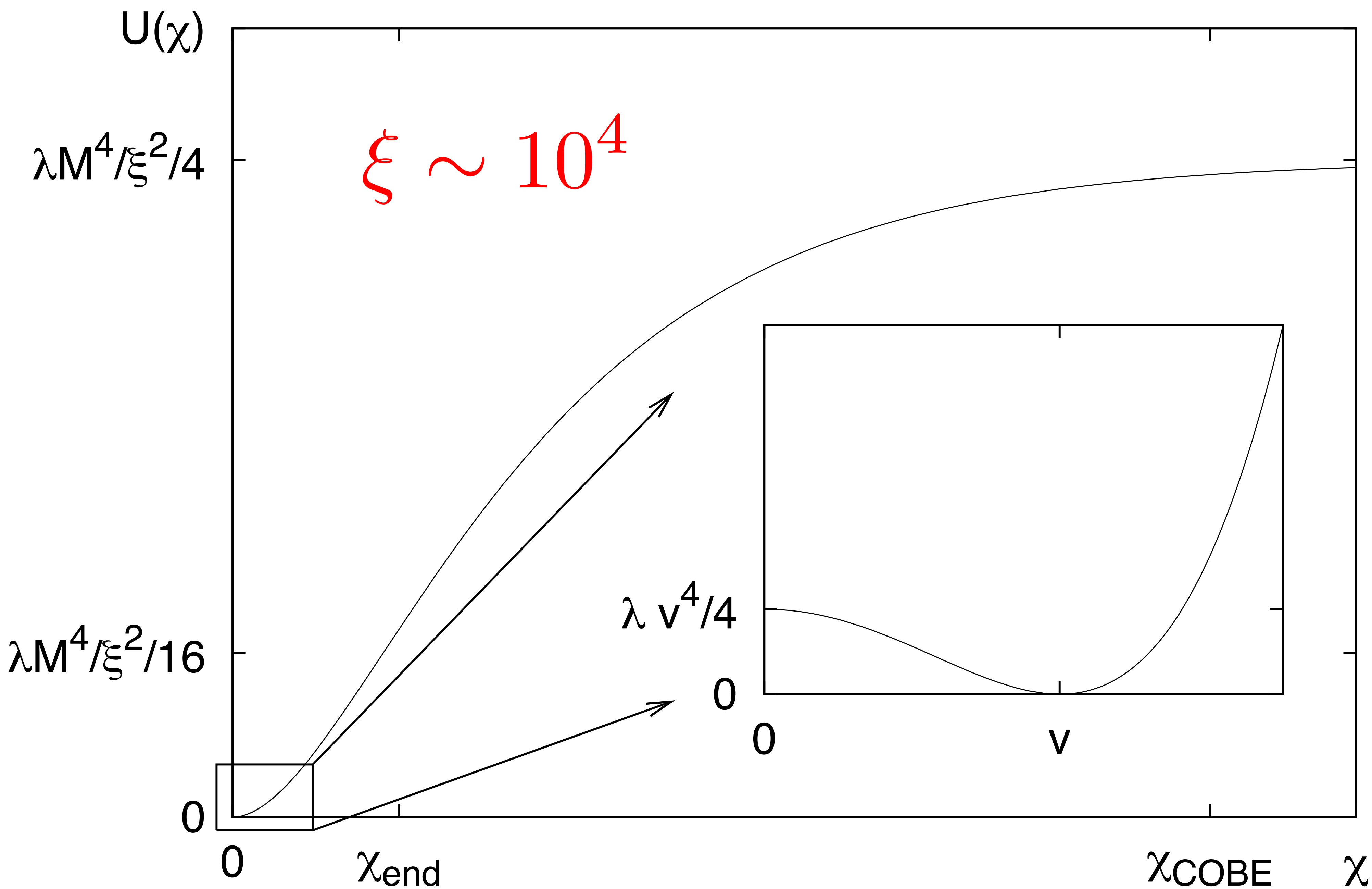
$$\phi \to \mathrm{SM}$$

Classical trajectory in field space:



Inflation and the Higgs

Higgs inflation: $\sqrt{-g}\,\xi\,h^2\,R \subset \mathcal{L}$



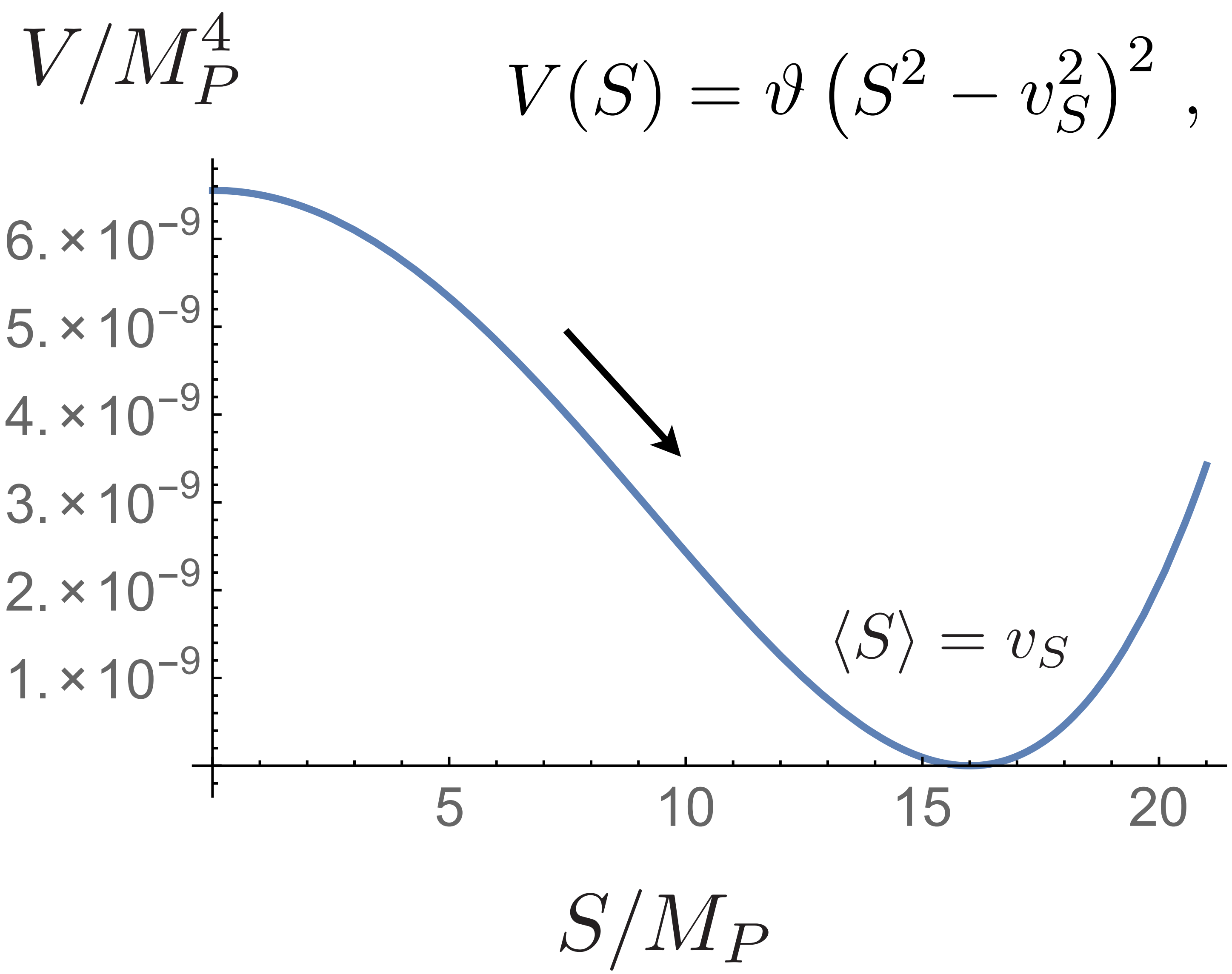
Bezrukov and Shaposhnikov arXiv:0710.3755

Can the inflaton stabilize the potential?

arXiv:1505.07476 Ballesteros and Tamarit

$$V = m_H^2 H^\dagger H + \frac{m_S^2}{2} S^2 + \frac{\lambda}{2}(H^\dagger H)^2 + \frac{\lambda_S}{4!} S^4 + \frac{\lambda_{SH}}{2} H^\dagger H S^2$$

$$V(S) = \vartheta \left(S^2 - v_S^2\right)^2 \ , \quad \vartheta = \frac{\lambda_S}{4!}\frac{\tilde{\lambda}}{\lambda} \lesssim 10^{-13}$$



$$15 M_P \lesssim \langle S \rangle \lesssim 25 M_P$$

$$-m_S^2 \sim 10^{13}\mathrm{GeV}$$

$$0.04 \lesssim r \lesssim 0.07$$

$$V = m_H^2 H^\dagger H + \frac{m_S^2}{2} S^2 + \frac{\lambda}{2}(H^\dagger H)^2 + \frac{\lambda_S}{4!} S^4 + \frac{\lambda_{SH}}{2} H^\dagger H S^2$$

Energies below $|m_S^2|^{1/2}$ $\longrightarrow$ SM, $\quad V^{SM} = \tilde{m}_H^2\, H^\dagger H + \frac{\tilde{\lambda}}{2}(H^\dagger H)^2$

$$V^{SM}(h) = V\left(h, S_{\min}(h)\right)$$

$$\frac{\partial V}{\partial S} = 0 \longrightarrow \lambda_S\, S^2 + 3\lambda_{SH}\, h^2 + 6\, m_S^2 = 0$$ "S-line"

$$\tilde{m}_H^2 = m_H^2 - \frac{3\lambda_{SH}}{\lambda_S} m_S^2\,, \quad \tilde{\lambda} = \lambda - \frac{3\lambda_{SH}^2}{\lambda_S}$$

$$\frac{\partial V}{\partial h} = 0 \longrightarrow \lambda\, h^2 + \lambda_{SH}\, S^2 + 2 m_H^2 = 0$$ "h-line"

$\lambda_{SH} \to 0$: valleys

Stability

$$V = m_H^2 H^\dagger H + \frac{m_S^2}{2} S^2 + \frac{\lambda}{2} (H^\dagger H)^2 + \frac{\lambda_S}{4!} S^4 + \frac{\lambda_{SH}}{2} H^\dagger H S^2$$

At large field values, $V > 0$ requires:

$$\lambda > 0\,, \quad \lambda_S > 0\,, \quad \lambda_{SH} > -\sqrt{\lambda \lambda_S / 3}$$

$$\beta_\lambda = \frac{1}{16\pi^2} \left[-12 y_t^4 + \lambda \left(-\frac{9}{5} g_1^2 - 9 g_2^2 + 12 y_t^2 \right) + \frac{27}{100} g_1^4 + \frac{9}{10} g_2^2 g_1^2 + \frac{9}{4} g_2^4 + 12 \lambda^2 + \lambda_{SH}^2 \right]$$

$$\beta_{\lambda_S} = \frac{1}{16\pi^2} \left[3\lambda_S^2 + 12 \lambda_{SH}^2 \right] \qquad \beta_{\lambda_{SH}} = \frac{1}{16\pi^2} \left[\lambda_{SH} \left(-\frac{9}{10} g_1^2 - \frac{9}{2} g_2^2 + 6\lambda + \lambda_S + 6 y_t^2 \right) + 4 \lambda_{SH}^2 \right]$$

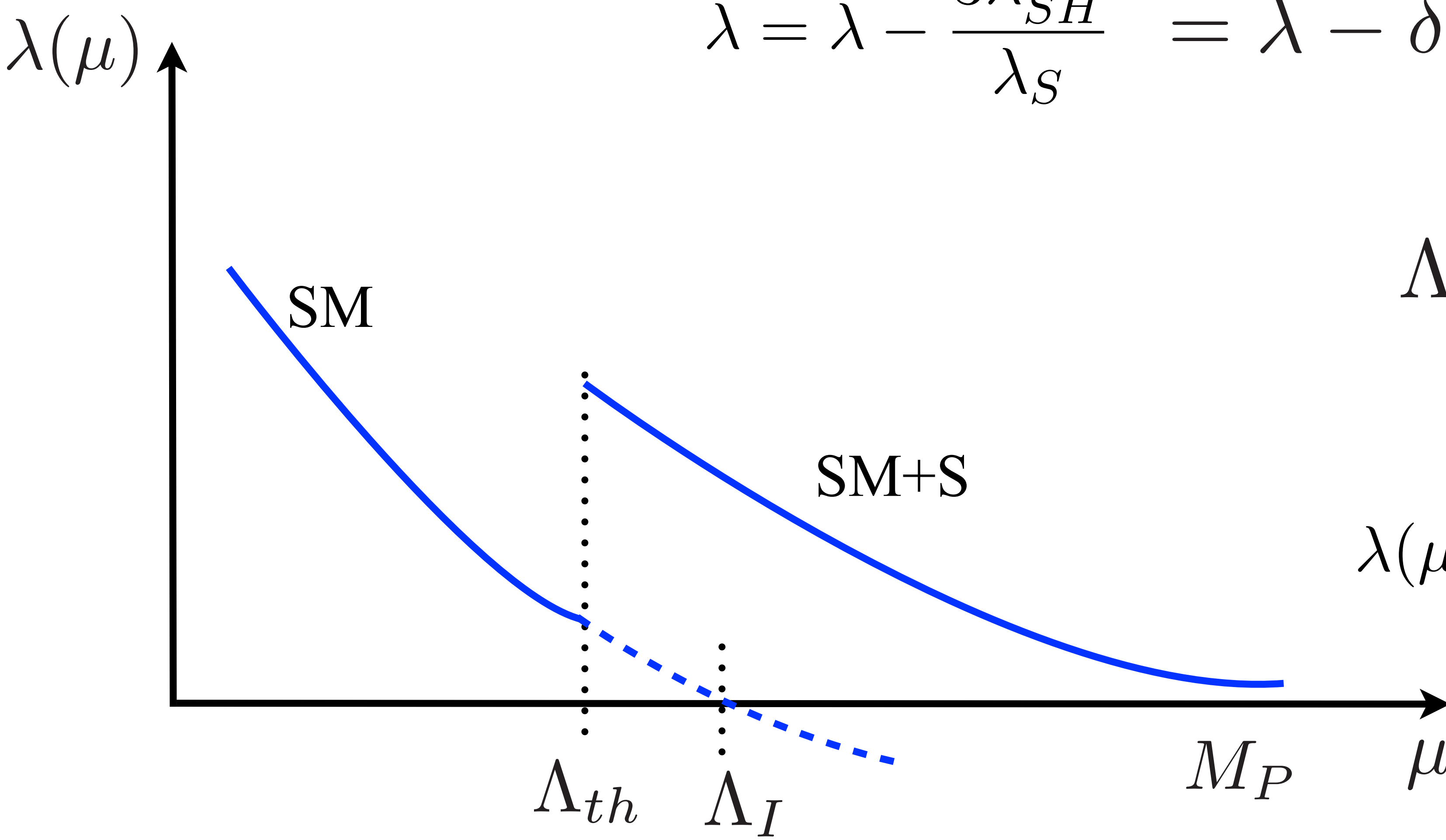
If $\langle S \rangle = 0$, RG-running can stabilize and inflation requires a coupling to R

Threshold stabilization

$$V = m_H^2 H^\dagger H + \frac{m_S^2}{2} S^2 + \frac{\lambda}{2}(H^\dagger H)^2 + \frac{\lambda_S}{4!} S^4 + \frac{\lambda_{SH}}{2} H^\dagger H S^2$$

Lebedev 1203.0156, Elias-Miro et al. 1203.0237

$$\tilde{\lambda} = \lambda - \frac{3\lambda_{SH}^2}{\lambda_S} = \lambda - \delta_{th}$$



$$\Lambda_{th}^2 \sim |m_S^2| < \Lambda_I^2$$

$$\lambda(\mu) > \begin{cases} \delta_{th} & \text{for} \quad \mu \lesssim \Lambda_{th} \\ 0 & \phantom{\text{for}} \quad \mu \gg \Lambda_{th} \end{cases}$$

Threshold stabilization

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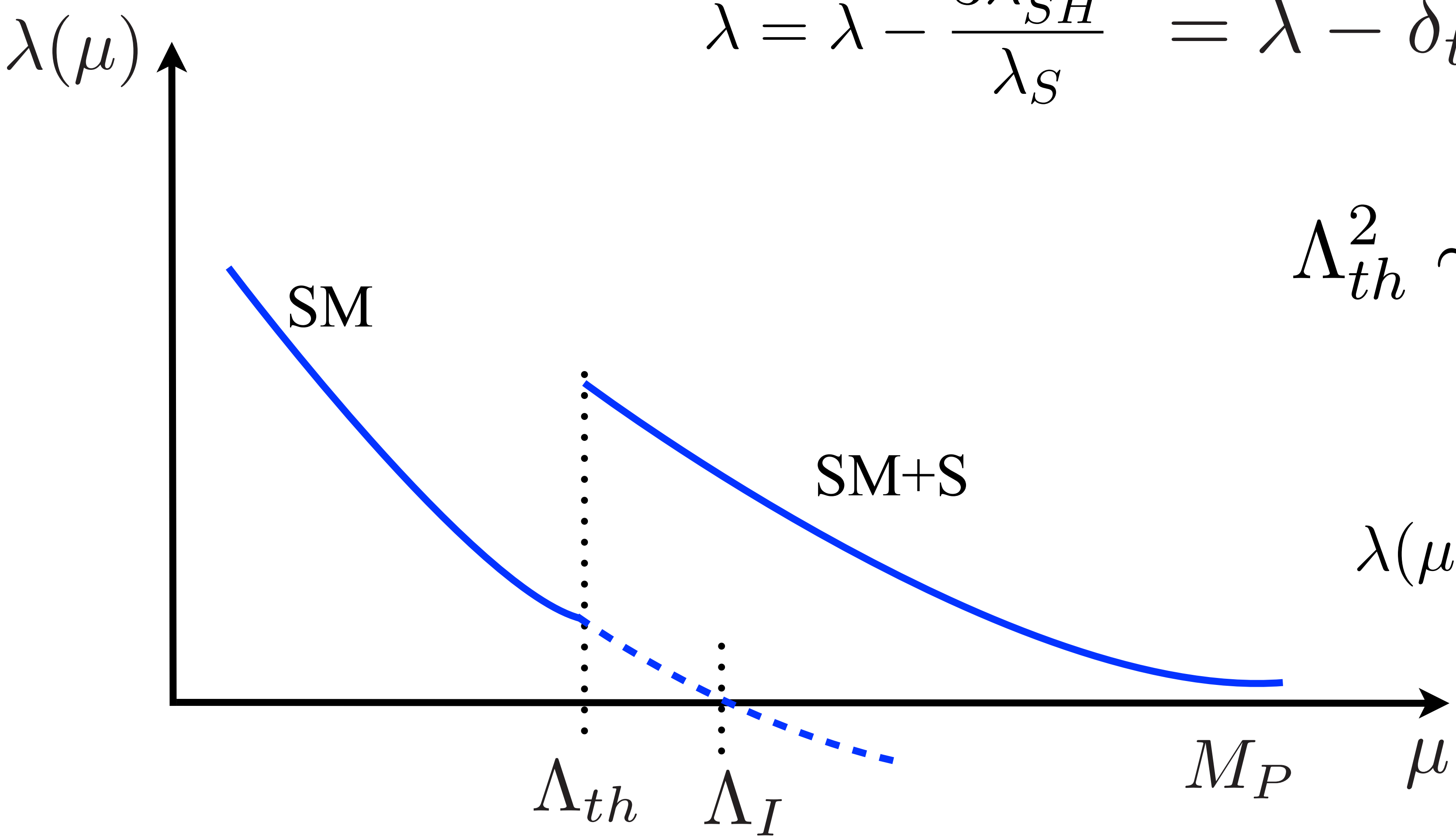

$$\Lambda_{th}^2 \sim 6 \frac{\lambda_{SH}}{\lambda_S \lambda} |m_S^2| < \Lambda_I^2$$

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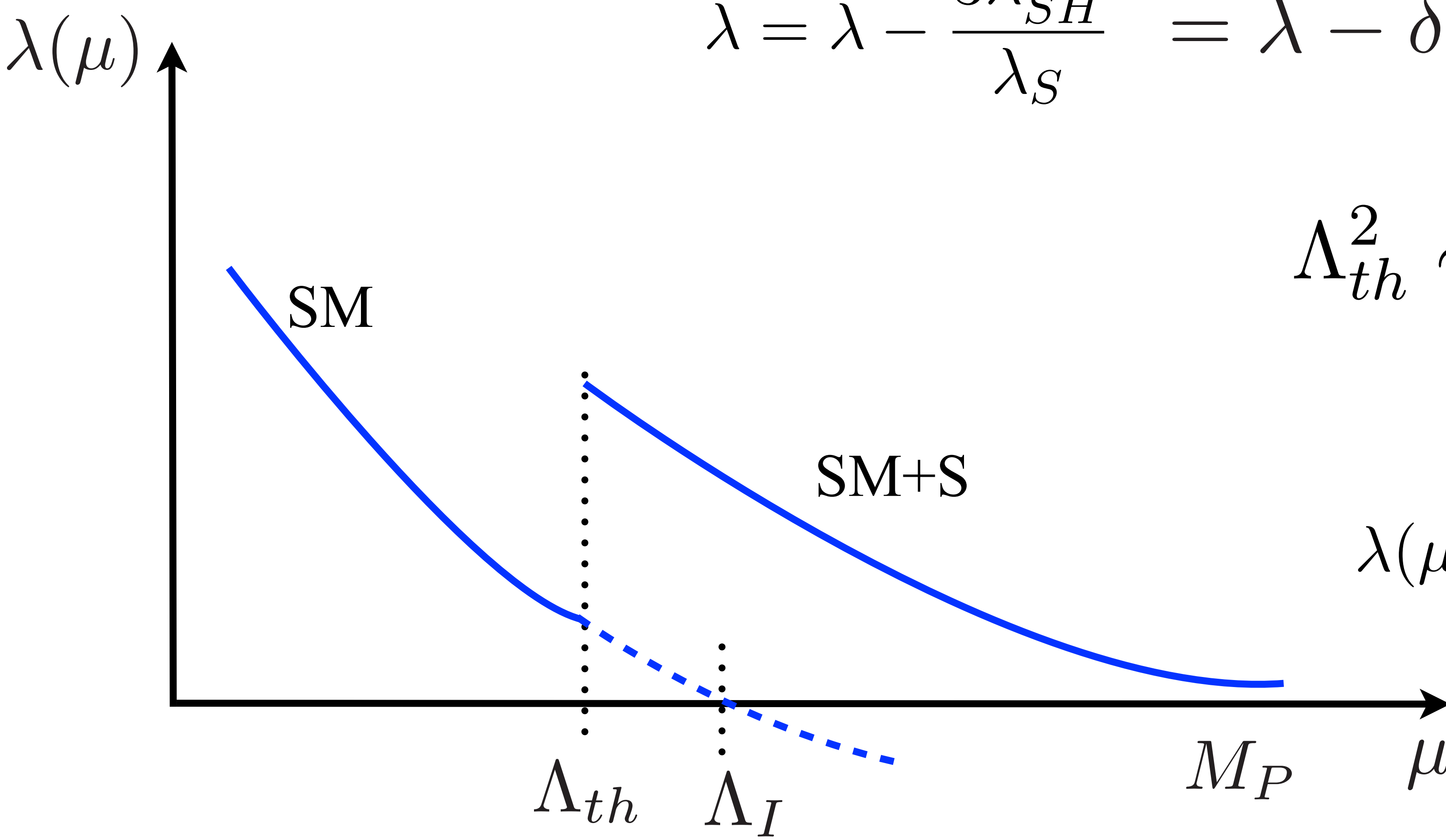

$$\Lambda_{th}^2 \sim 6 \frac{\lambda_{SH}}{\lambda_S \lambda} |m_S^2| < \Lambda_I^2$$

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$$\lambda_{SH} \Lambda_{th}^2 \sim 2\, \delta_{th} \frac{|m_S^2|}{\lambda}$$

Threshold stabilization

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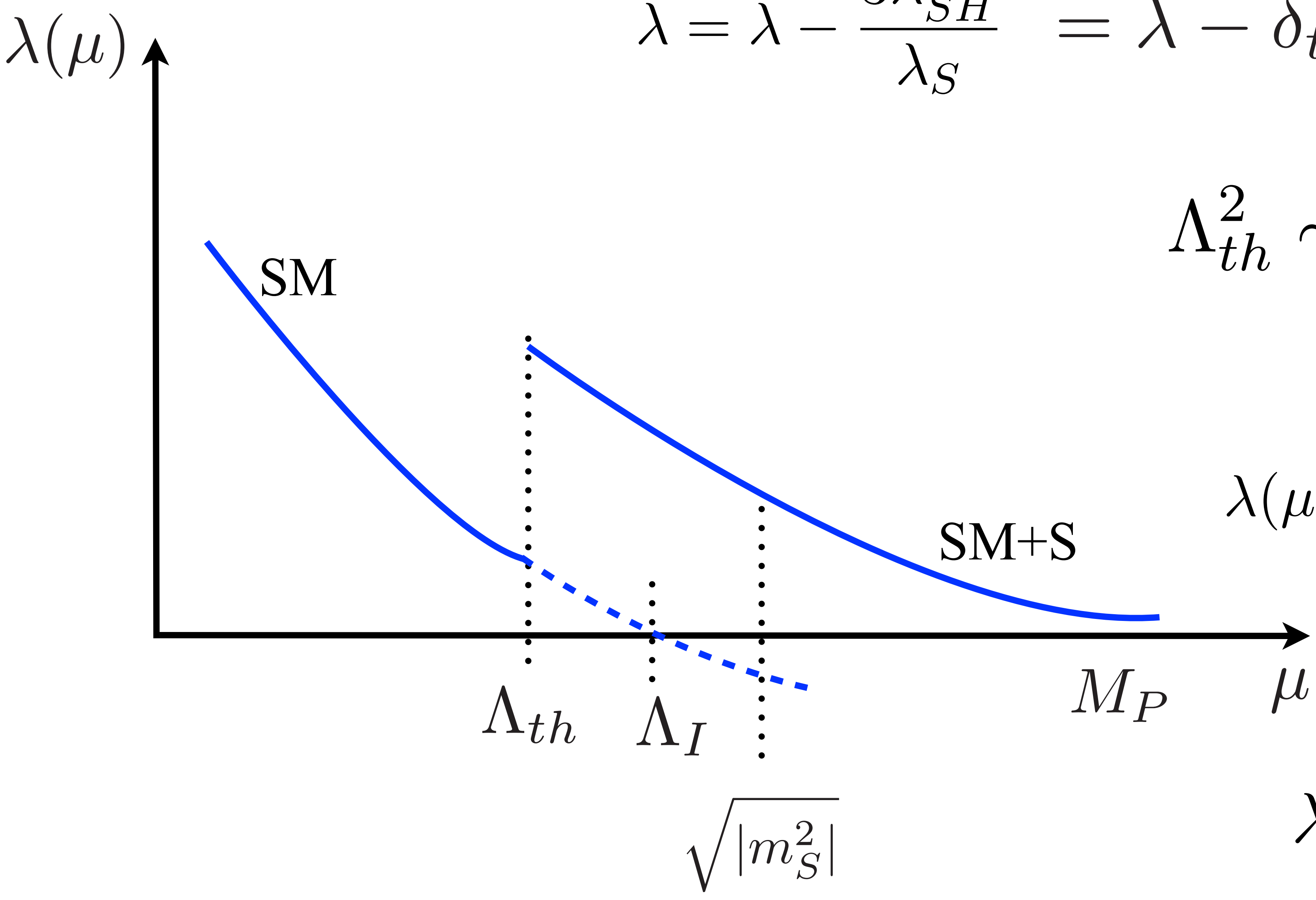

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$$\lambda(\mu) > \begin{cases} \delta_{th} & \text{for} \quad \mu \lesssim \Lambda_{th} \\ 0 & \phantom{\text{for}} \quad \mu \gg \Lambda_{th} \end{cases}$$

$$\lambda_{SH}\, \Lambda_{th}^2 \sim 2\,\delta_{th}\frac{|m_S^2|}{\lambda}$$

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$$\tilde{\lambda} = \lambda - \frac{3\lambda_{SH}^2}{\lambda_S} \quad = \lambda - \delta_{th}$$

$$\Lambda_I \lesssim \mathbf{\Lambda} \sim \mathrm{Max}\left\{\Lambda_{th}\,, \hat{\Lambda}_{th}\right\} \qquad \Lambda_{th}^2 \sim 6\frac{\lambda_{SH}}{\lambda_S \lambda}|m_S^2| \qquad \hat{\Lambda}_{th}^2 \sim \frac{2|m_S^2|}{\lambda_{SH}}$$

$$\lambda(\mu) > \begin{cases} \delta_{th} & \text{for} \quad \mu \lesssim \Lambda \\ 0 & \phantom{\text{for}} \quad \mu \gg \Lambda \end{cases} \qquad\qquad \Lambda_{th} \sim \frac{\delta_{th}}{\lambda}\hat{\Lambda}_{th}$$

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Threshold stabilization

$$V = m_H^2 H^\dagger H + \frac{m_S^2}{2} S^2 + \frac{\lambda}{2}(H^\dagger H)^2 + \frac{\lambda_S}{4!} S^4 + \frac{\lambda_{SH}}{2} H^\dagger H S^2$$

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$$\lambda(\mu) > \begin{cases} \delta_{th} & \text{for} \quad \mu \lesssim \Lambda \\ 0 & \phantom{\text{for}} \quad \mu \gg \Lambda \end{cases} \qquad \Lambda_{th} \sim \frac{\delta_{th}}{\lambda}\hat{\Lambda}_{th}$$

$\sqrt{|m_S^2|} > \Lambda_I$ prevents threshold stabilization

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Conclusions

1) Threshold stabilization mechanism depends on two scales:

$$\Lambda_{th}^2 \sim 6\frac{\lambda_{SH}}{\lambda_S \lambda}|m_S^2| \qquad \& \qquad \hat{\Lambda}_{th}^2 \sim \frac{2|m_S^2|}{\lambda_{SH}}$$

and does not work for arbitrarily small λ_{SH}

2) $10^{13}\mathrm{GeV} \sim \sqrt{|m_S^2|} > \Lambda_I \sim 10^{11}\mathrm{GeV}$

forbids inflation + threshold stabilization with singlet + Higgs portal

ways out:
- small enough top mass
- another singlet
- non-minimal couplings to R