Stability of the Higgs Potential in the Standard Model and Beyond

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Technische Universität Dortmund

in collabortation with
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[arXiv 2207.07737] [arXiv 2401.08811]

Matter To The Deepest 2025

Katowice, September 16th 2025

technische universität dortmund

Motivation

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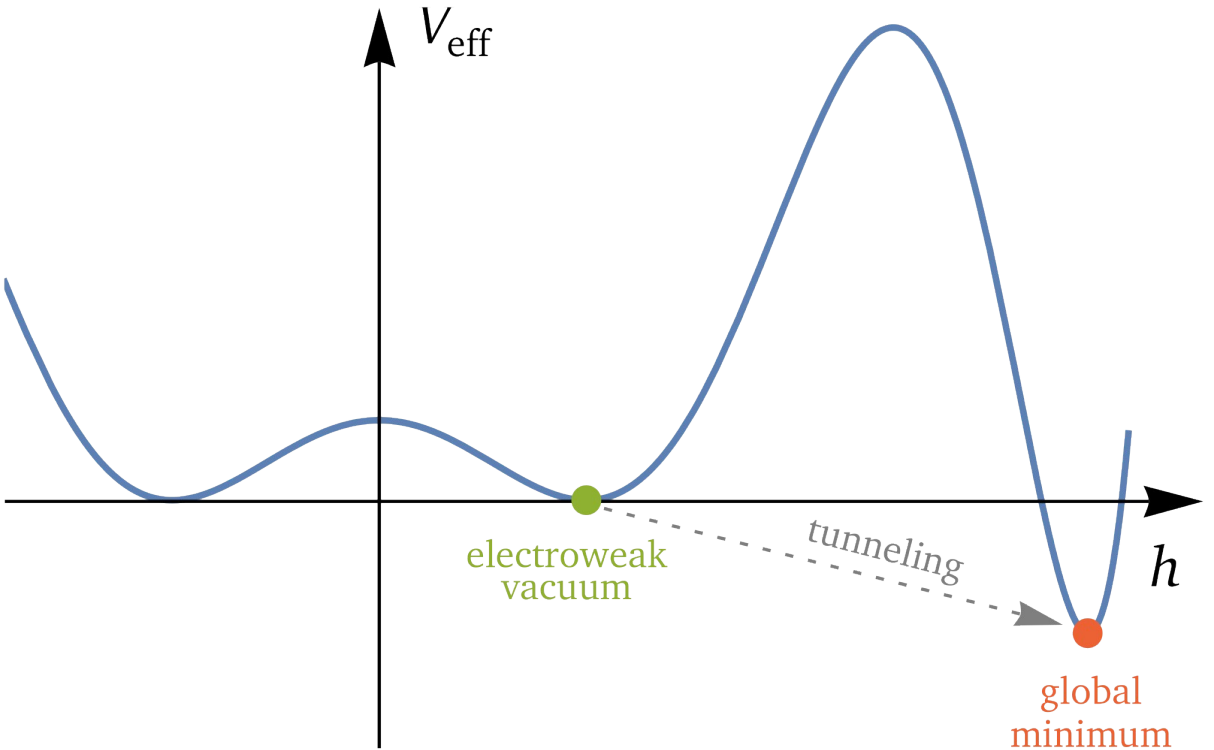

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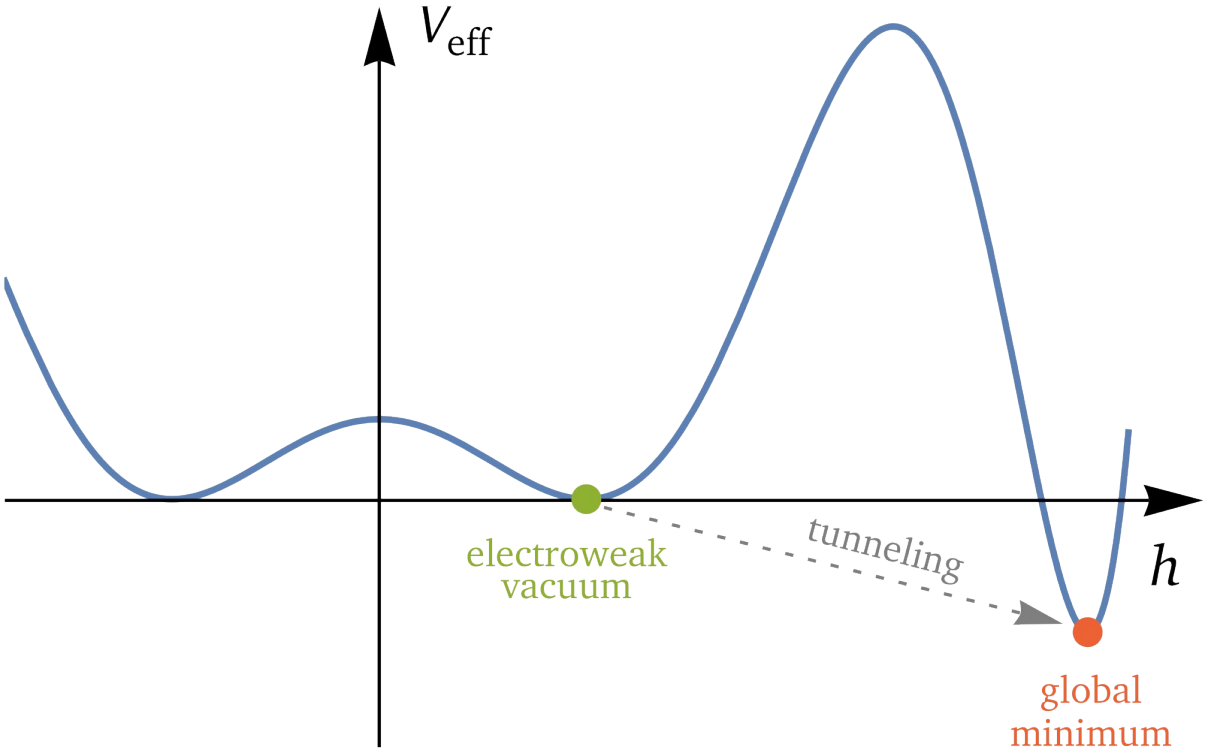

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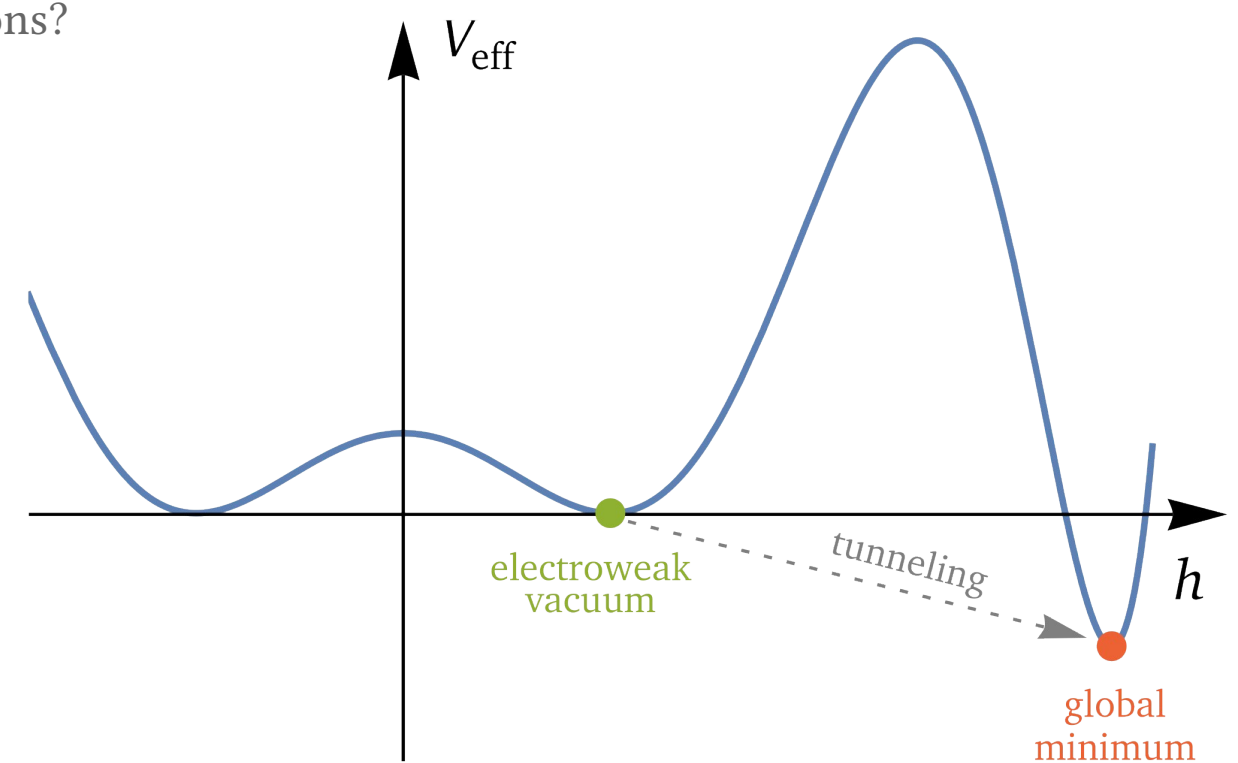

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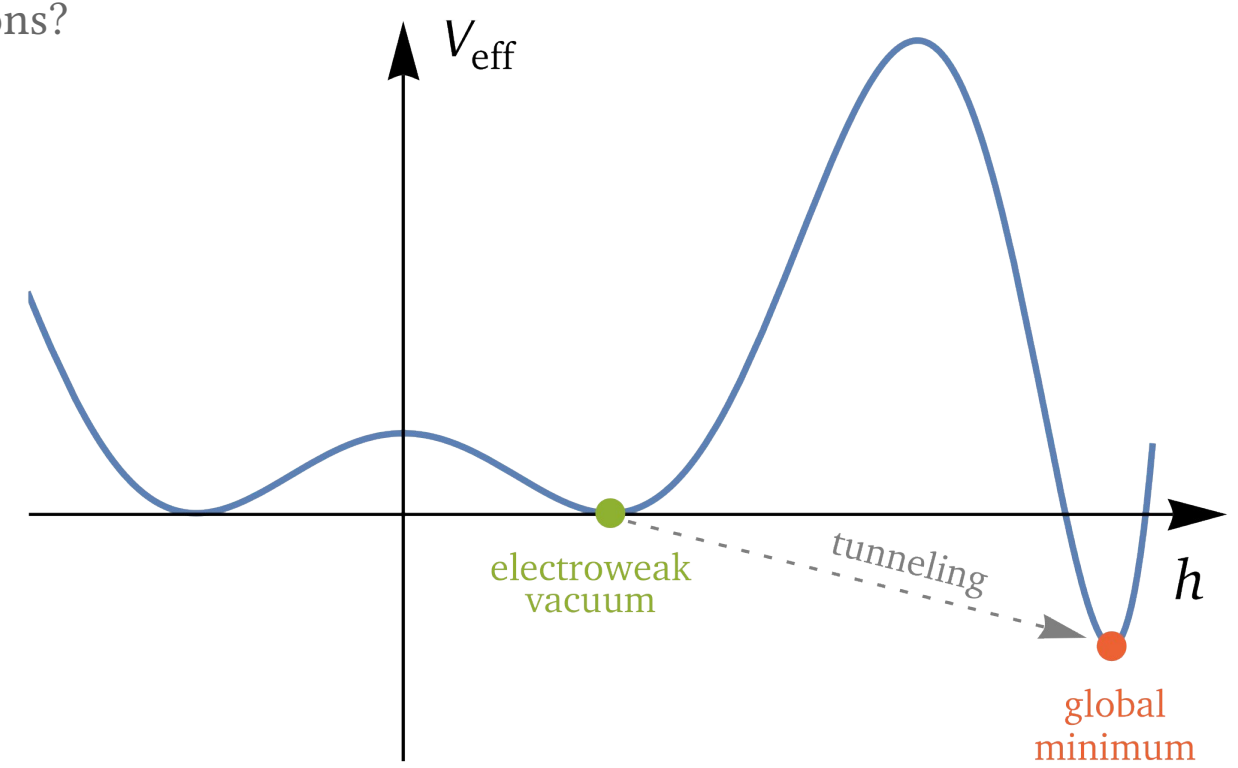

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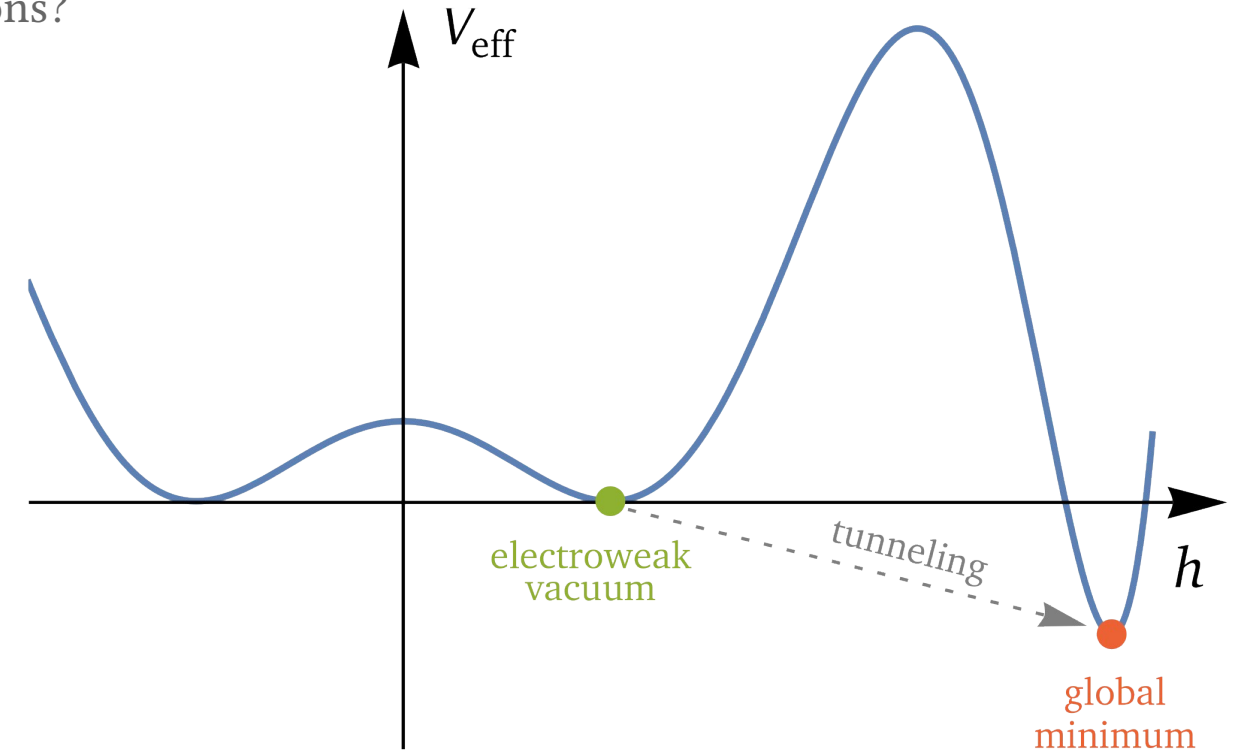
Outline

» Stability in the SM – An update
» BSM solutions



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PDG 2024

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   at least 2L + 3L QCD [Martin, Patel, 2018]

   → running couplings at a reference scale $\alpha_x(\mu_{\text{ref}})$

   $\mu_{\text{ref}} = 200\,\text{GeV}$

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only interested in absolute stability

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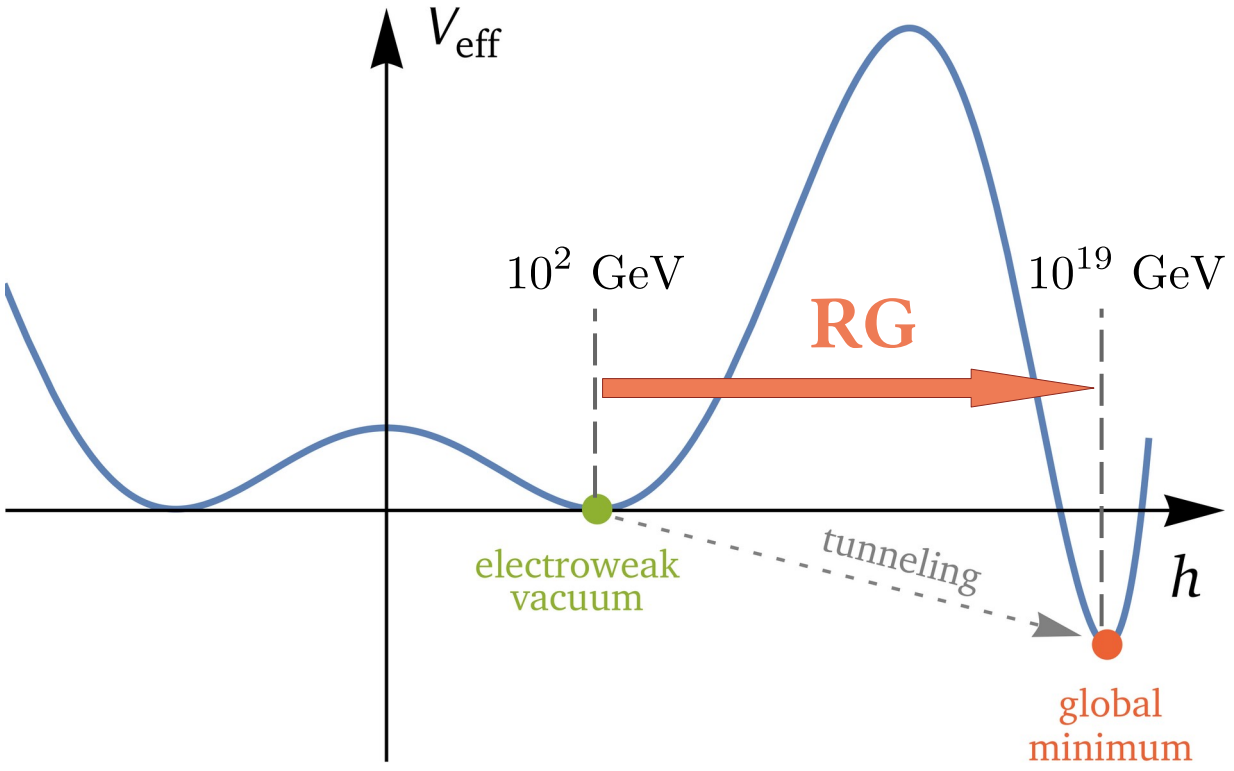

$$\log \frac{h}{\mu_{\text{ref}}} \approx \log 10^{17}$$

→ use RG for resummation

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– evolve λ_{eff} to $h \gg h_0$

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$\longrightarrow$ completely resum all logs $\ln h/\mu_{\text{ref}}$

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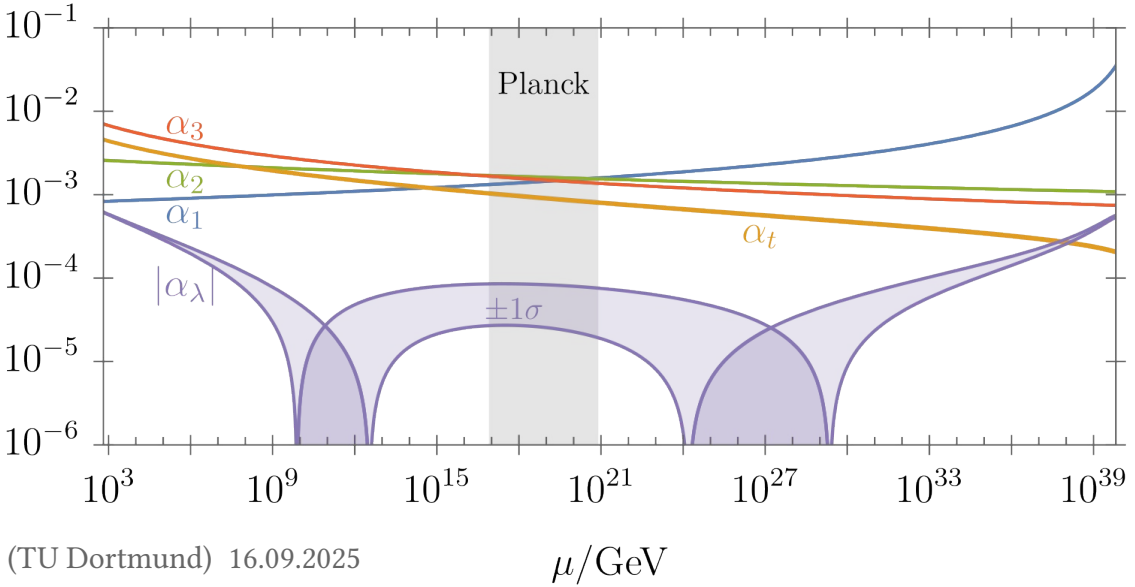

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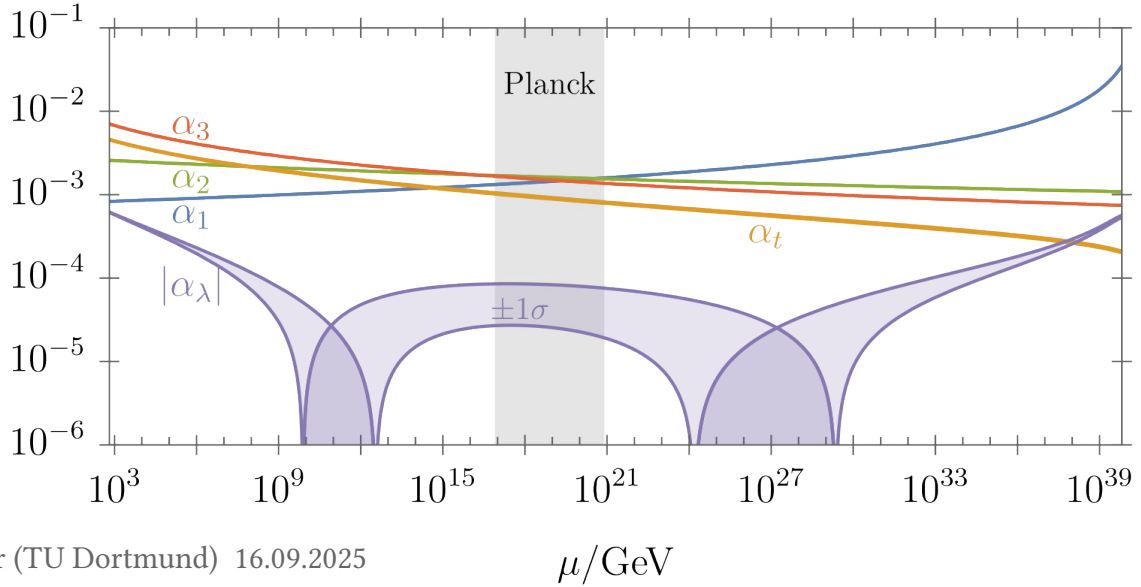

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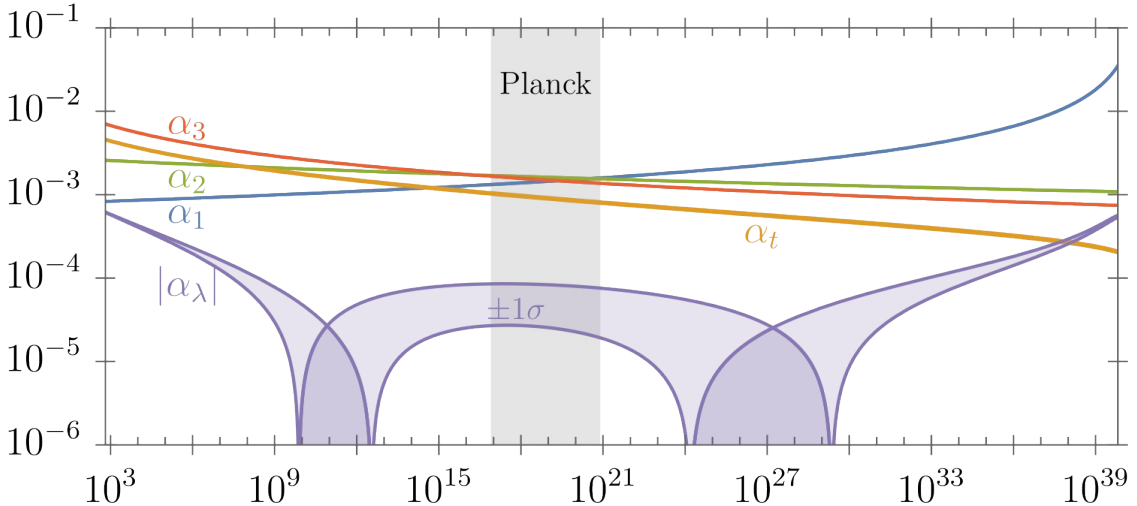

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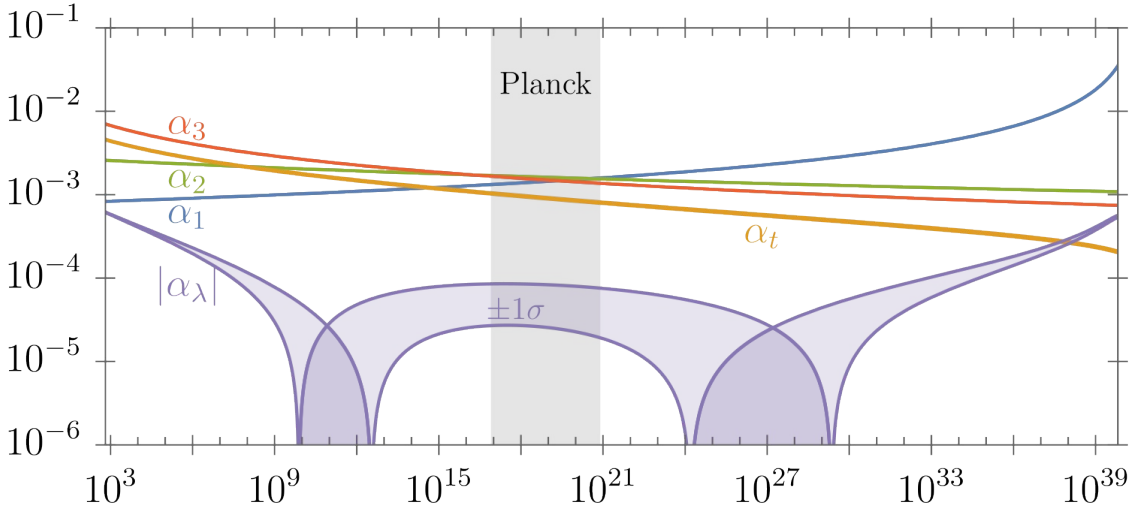

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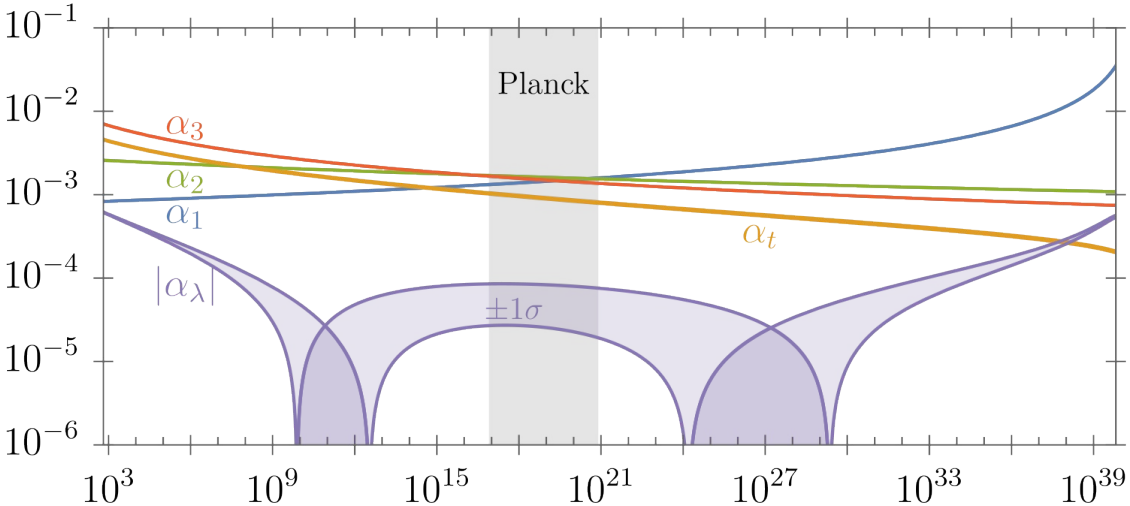

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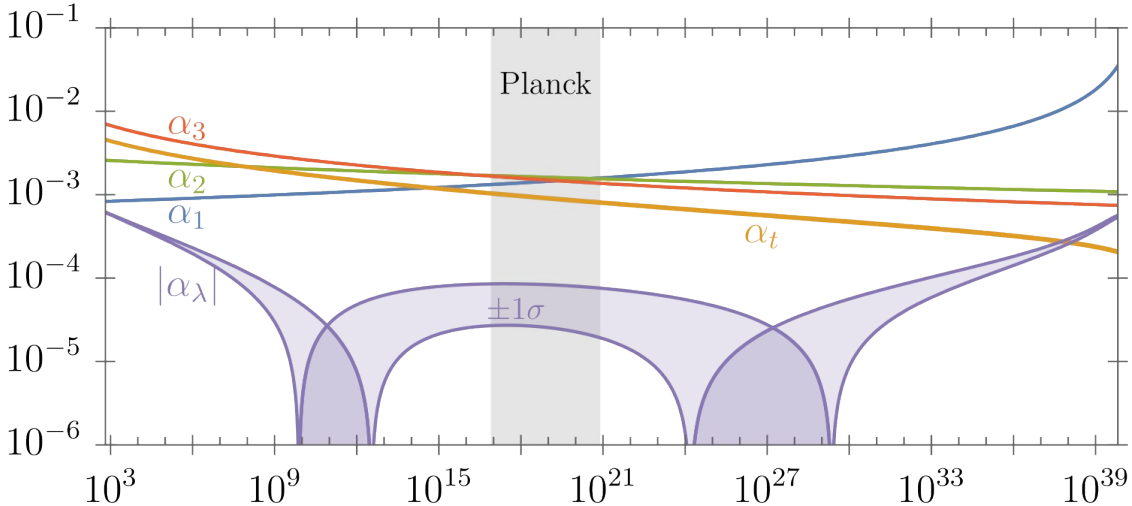

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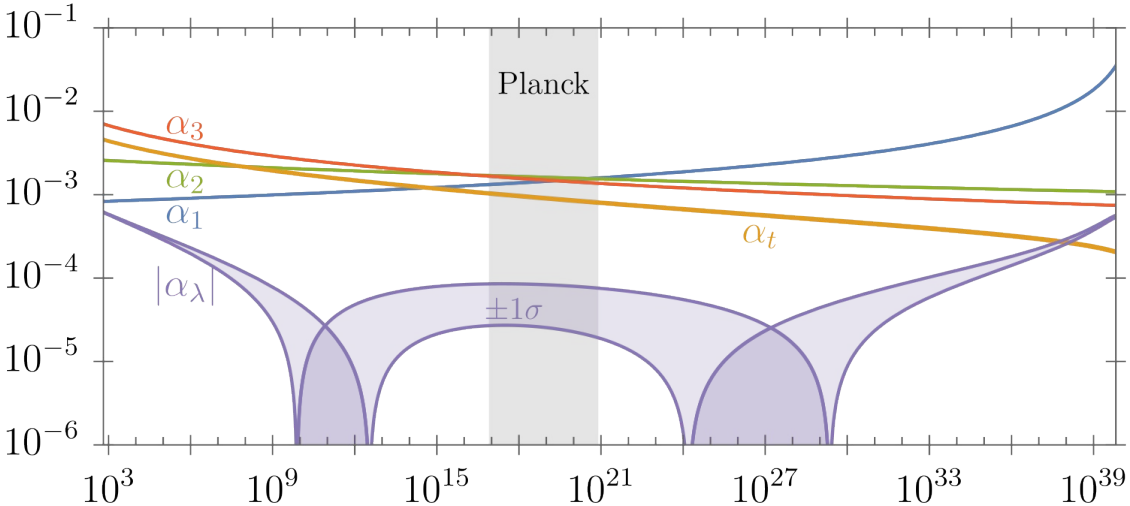

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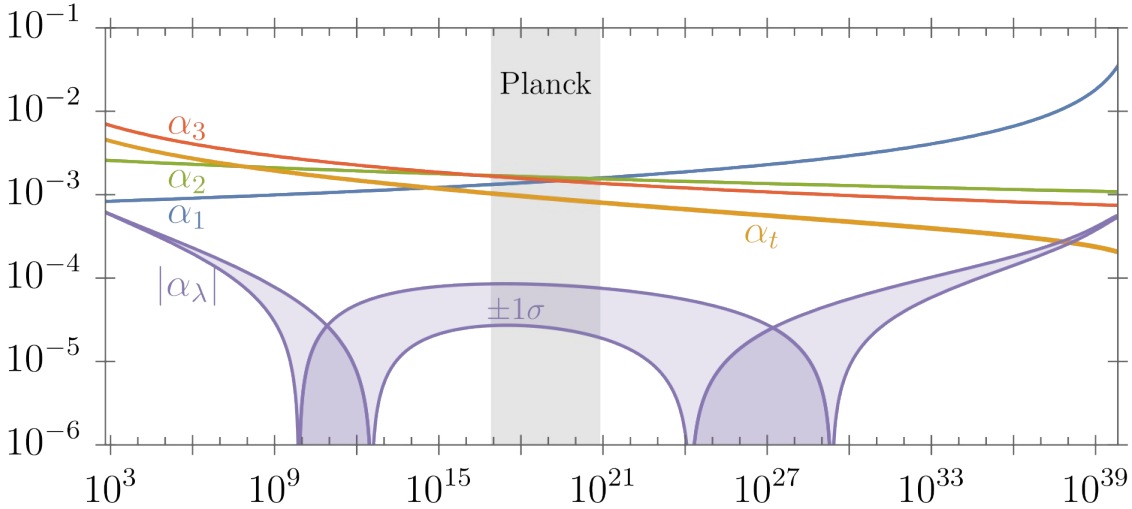
   - Strong coupling $\alpha_s^{(5)}(M_Z) = 0.1180(9)$ $+3.7\ \sigma$
   - Top mass $M_t^{\sigma} = 172.40(70)\ \text{GeV}$ which one? $-1.9\ \sigma$
     $M_t^{\text{MC}} = 172.57(29)\ \text{GeV}$ ± 0.5 GeV $-5.1\ \sigma$
     interpretation? MC modeling

~~- Z mass M_Z~~
~~- Fermi constant G_F~~ Uncertainty small
~~- Fine structure & hadronic threshold $\alpha_e,\ \Delta\alpha_e^{(5),\text{had}}$~~

~~- Lepton masses $M_{e,\mu,\tau}$~~
~~- Light quark $\overline{\text{MS}}$ masses~~ Impact small
~~$m_b(m_b),\ m_c(m_c),\ m_{u,d,s}(2\text{GeV})$~~



What Observables impact vacuum stability?

1. Observables PDG 2024

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which one?

pole mass: non-perturbative effects $\pm\Lambda_{\text{QCD}}$

interpretation? ± 0.5 GeV MC modeling

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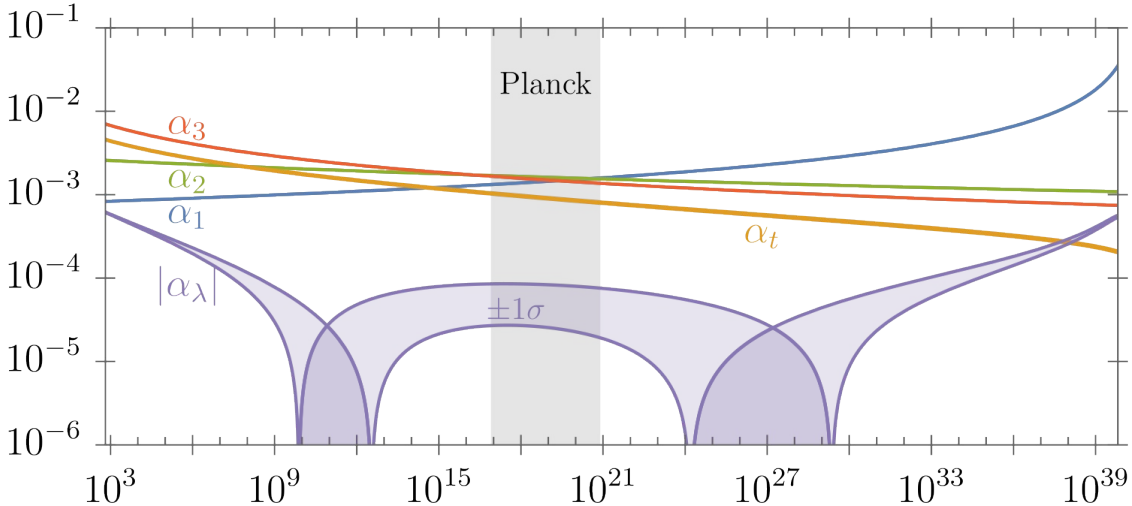
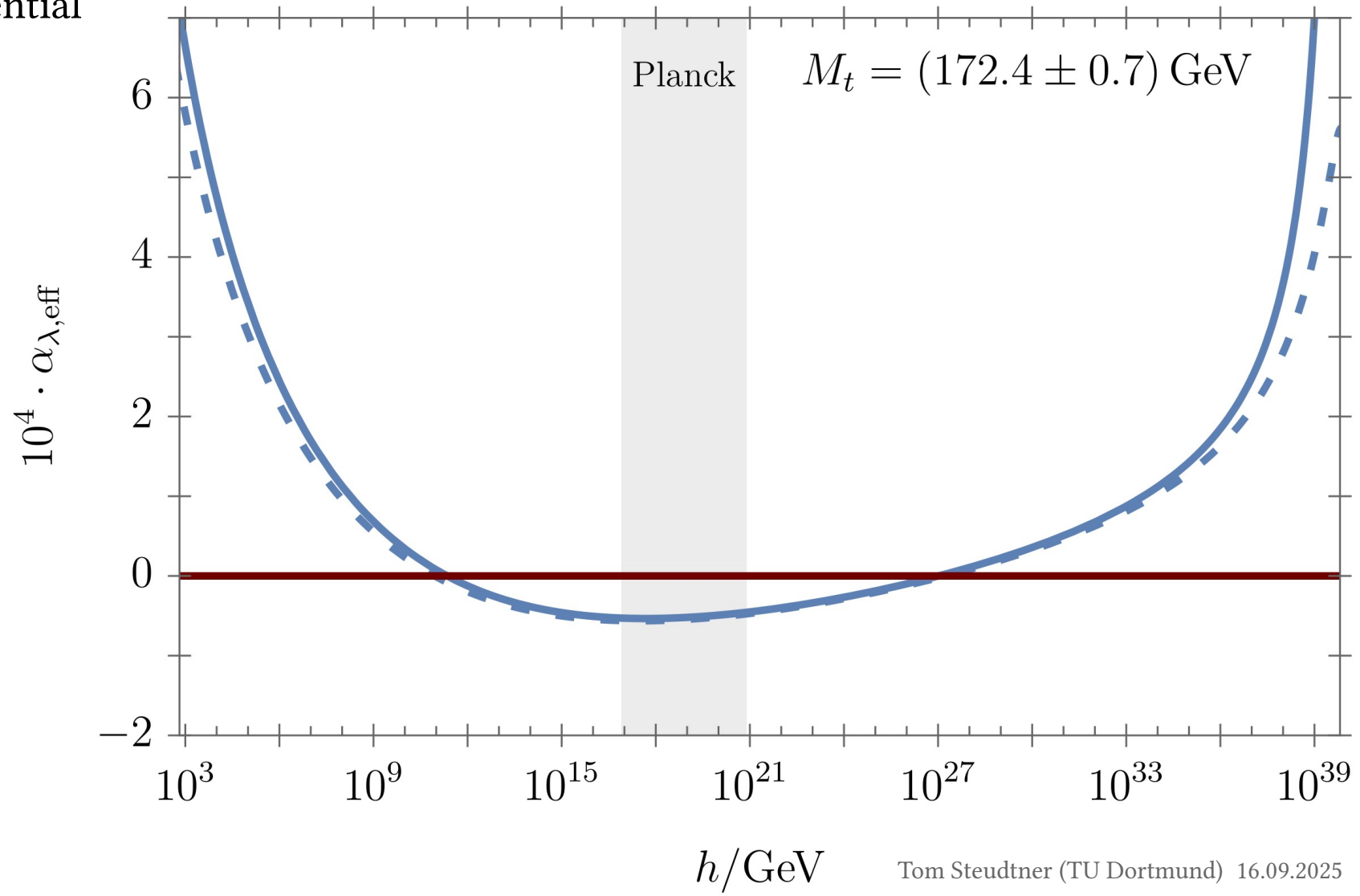


Effective Potential



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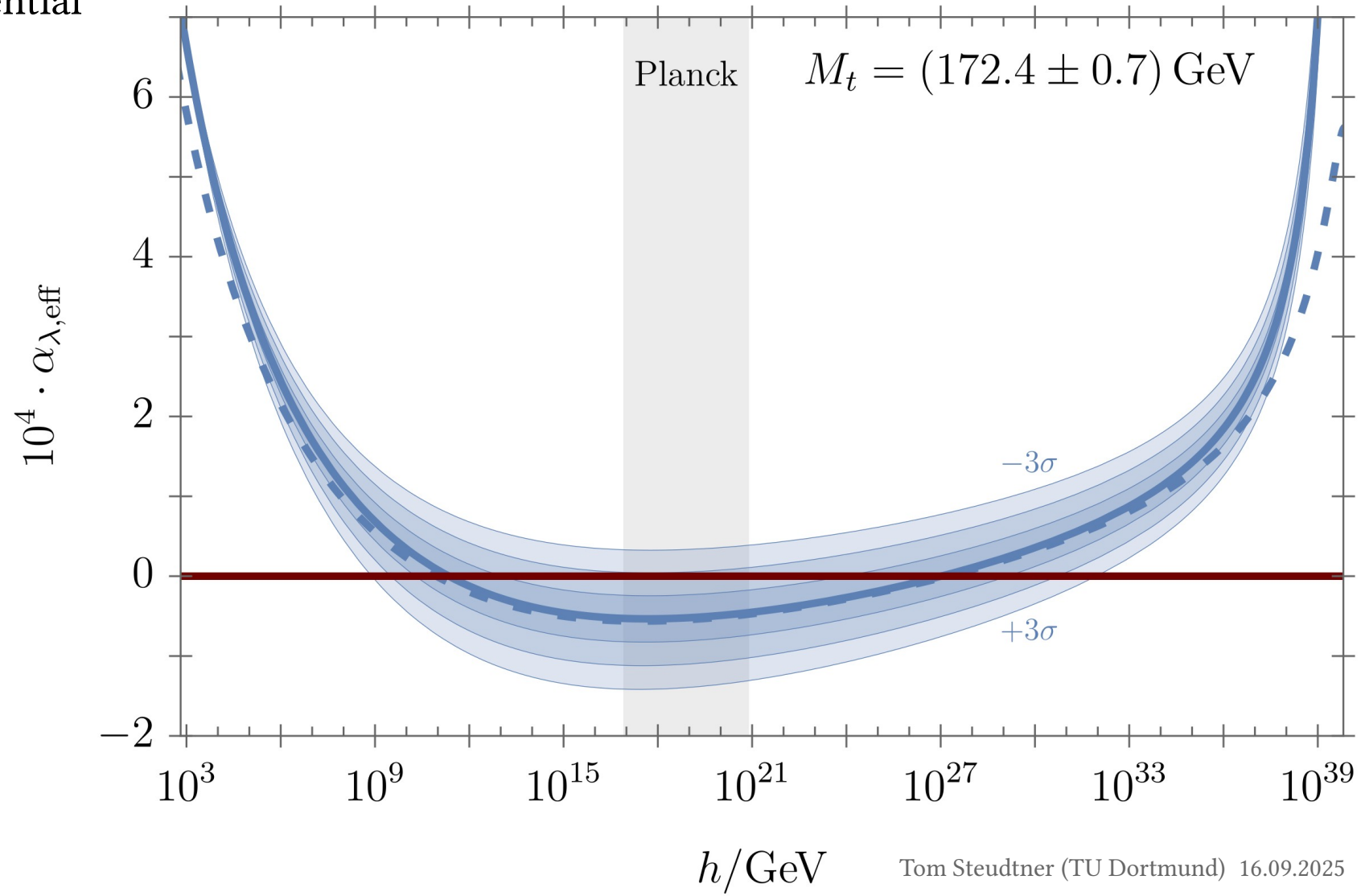

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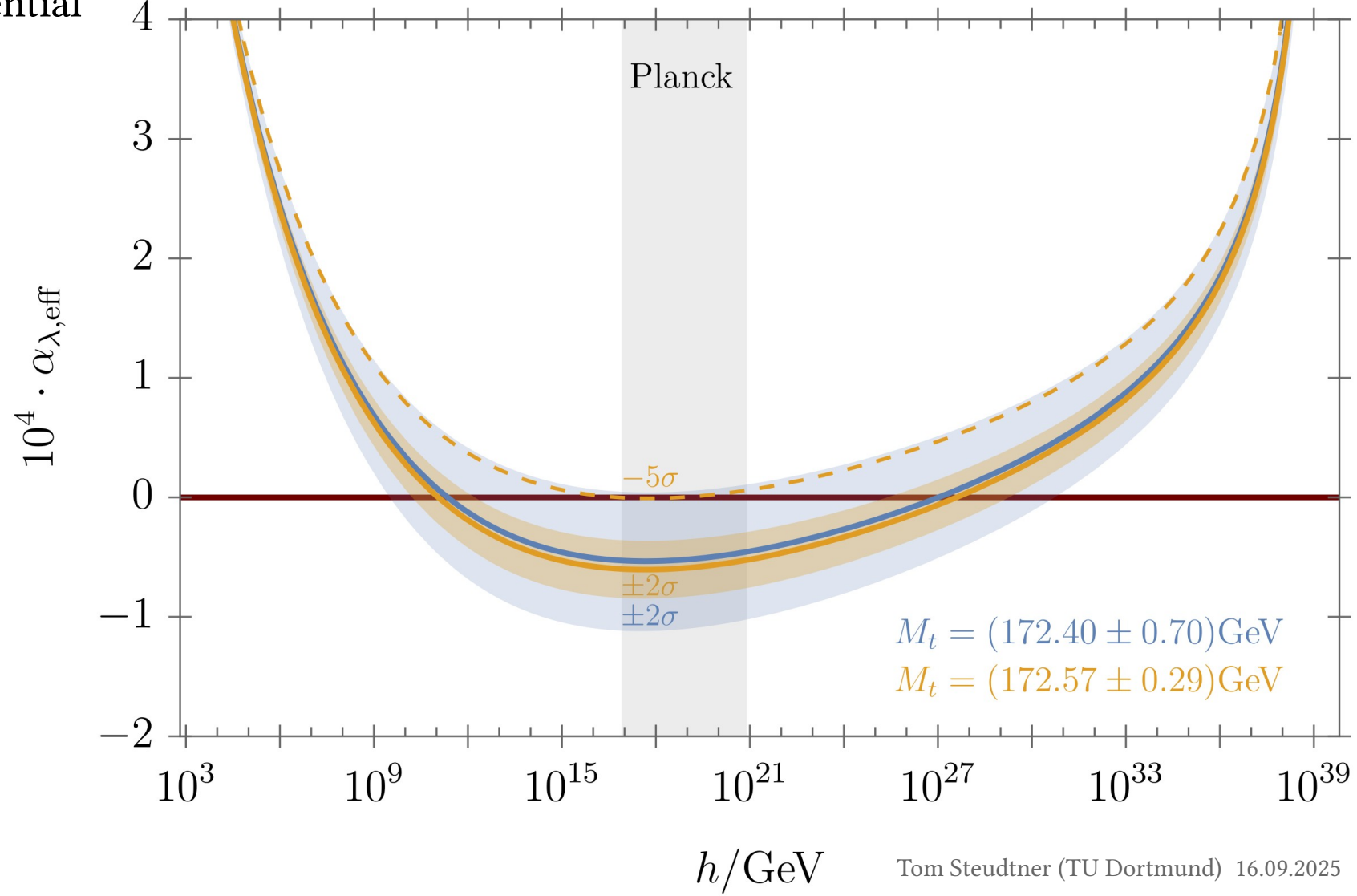
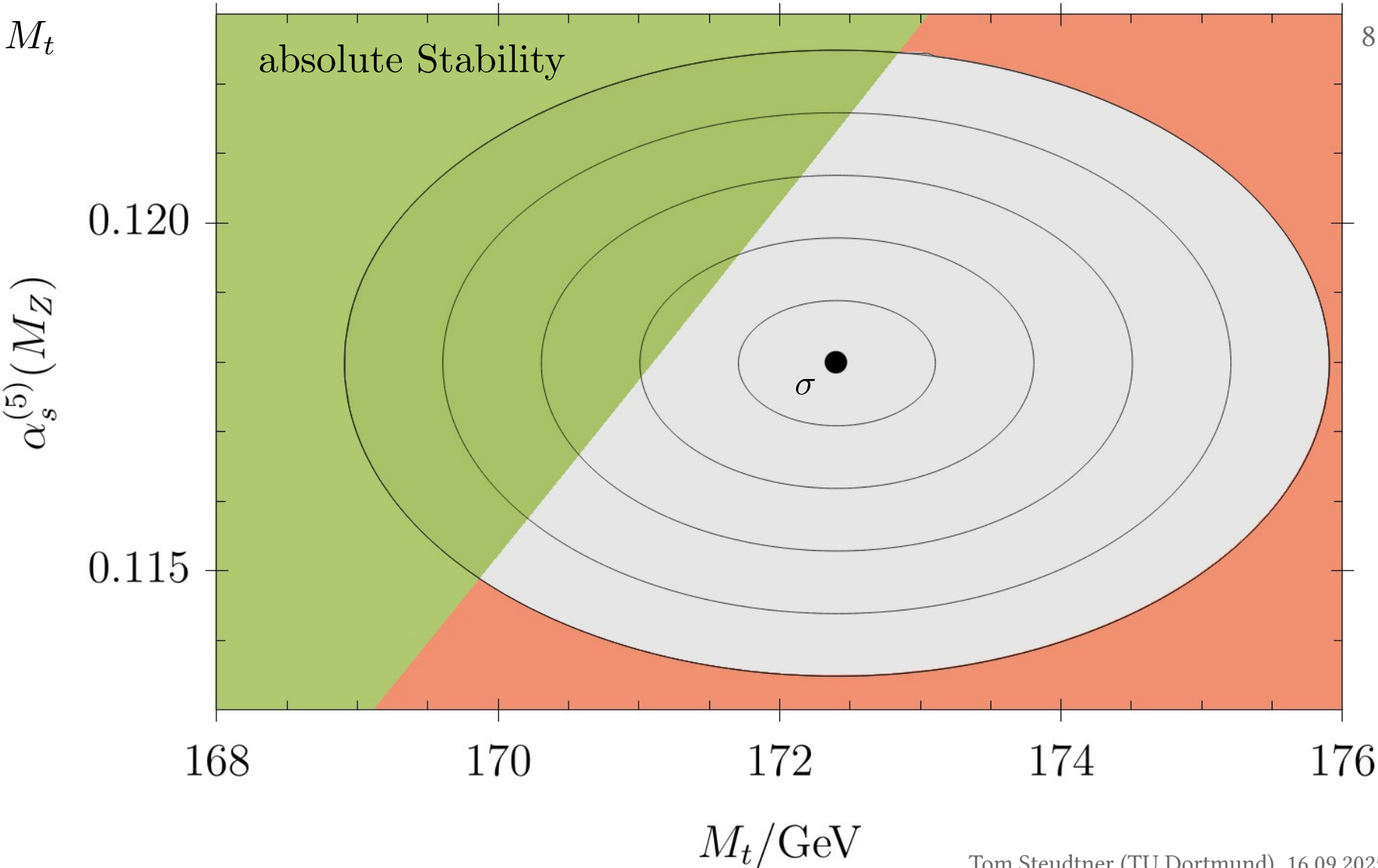
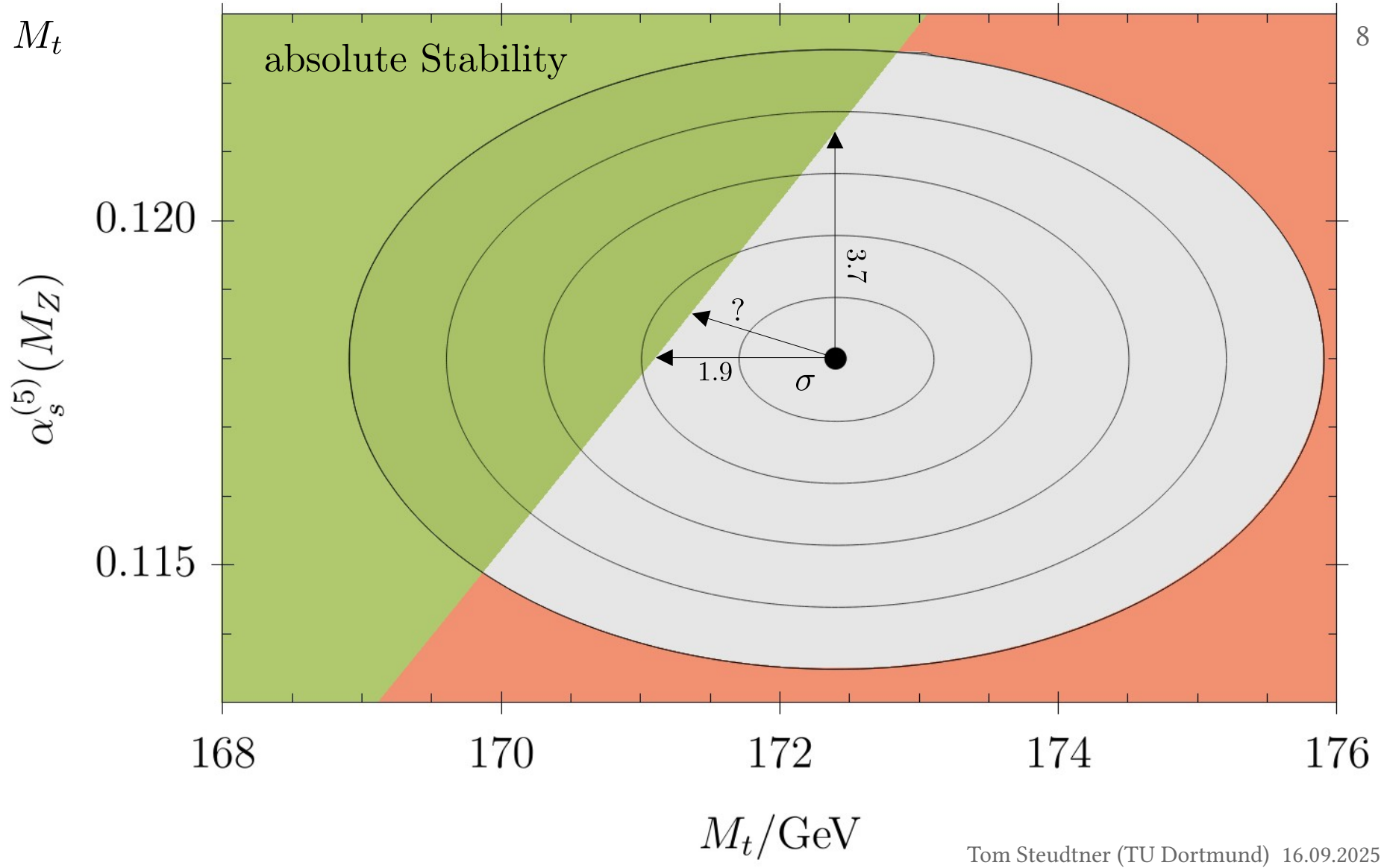


α_s vs. M_t


absolute Stability
σ
0.120
0.115
$\alpha_s^{(5)}(M_Z)$
168
170
172
174
176
M_t/GeV

α_s vs. M_t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0.120
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168
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3.7
?
1.9
σ

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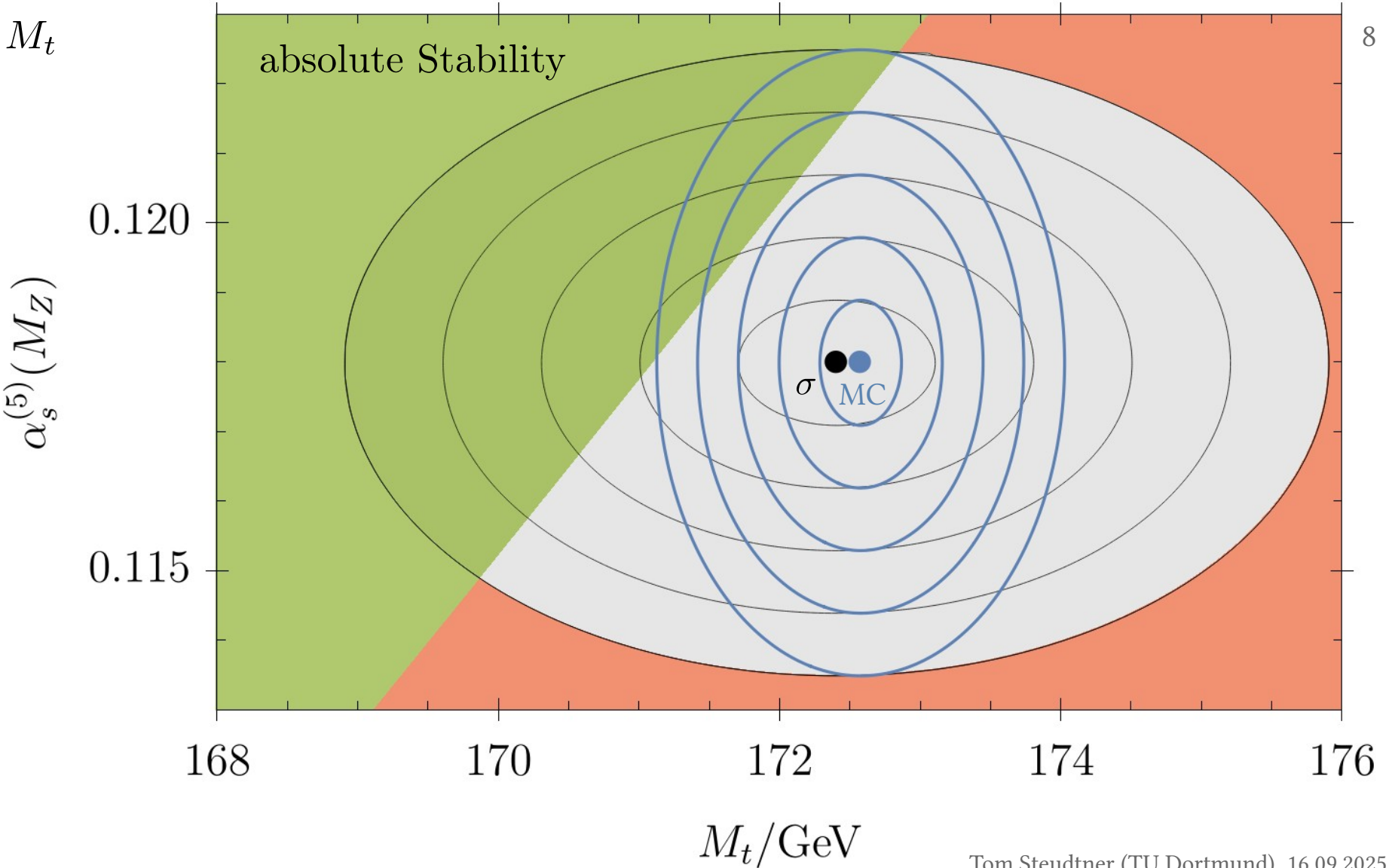
absolute Stability
0.120
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168
170
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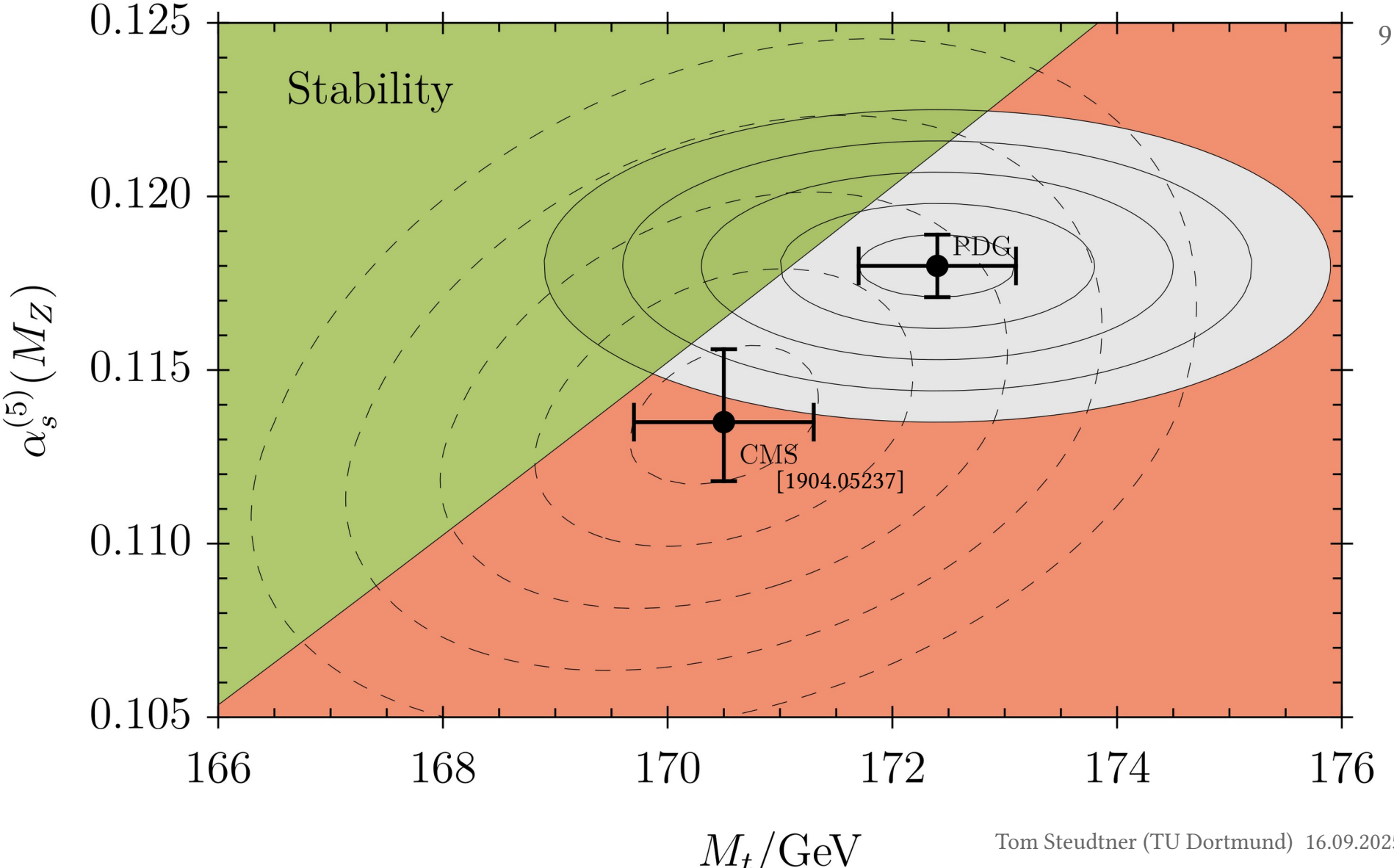
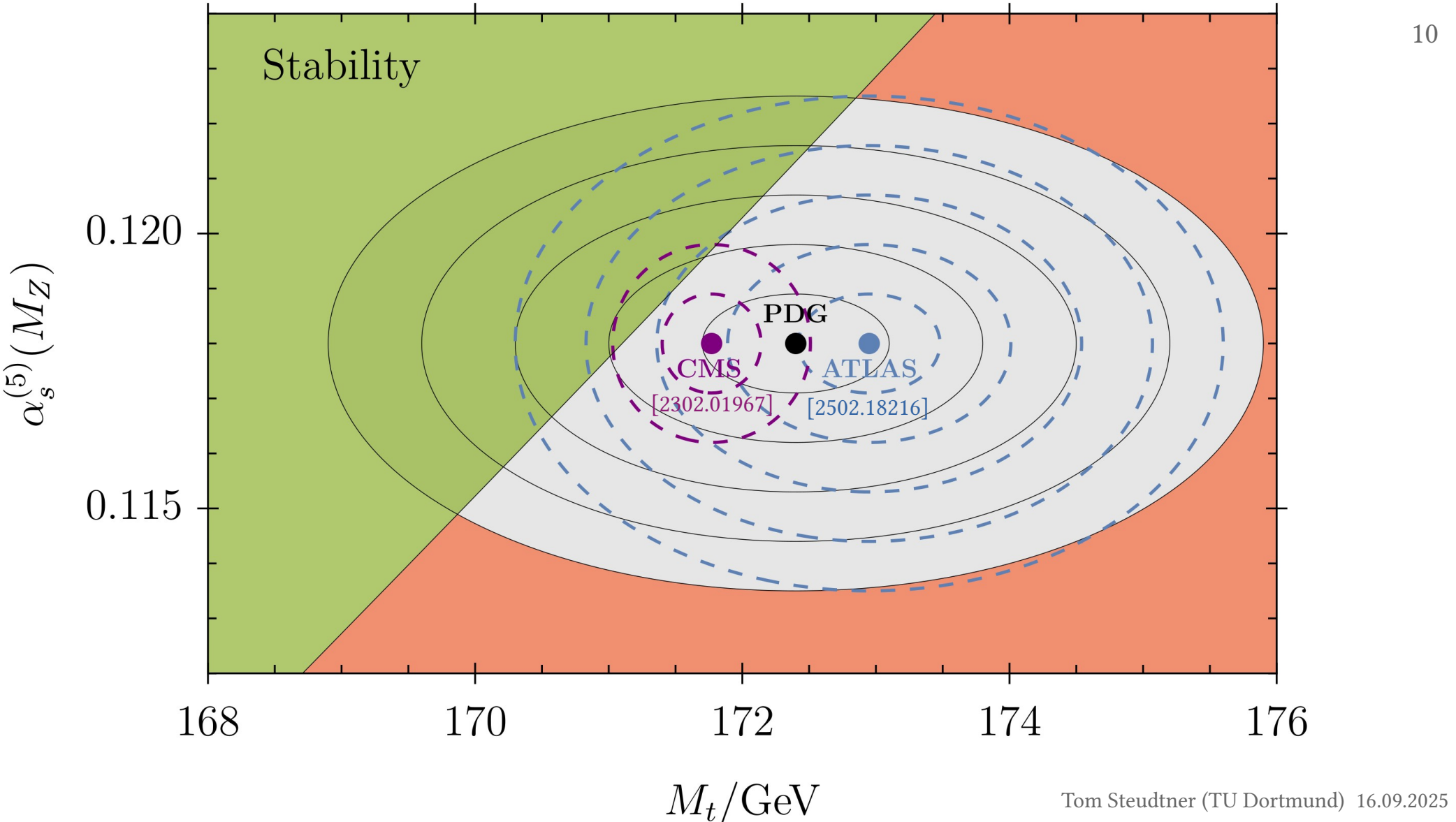
M_t/GeV
σ
MC


Stability
PDG
CMS
[1904.05237]
0.125
0.120
0.115
0.110
0.105
166
168
170
172
174
176
$\alpha_s^{(5)}(M_Z)$
M_t/GeV


Stability
PDG
CMS
[2302.01967]
ATLAS
[2502.18216]
0.120
0.115
$\alpha_s^{(5)}(M_Z)$
168
170
172
174
176
M_t/GeV

Stability is still within reach / not excluded!

How to stabilise the Higgs potential?

» Scalar Portal [Hiller, Höhne, Litim, TS 2024]
» Gauge Portal [Hiller, Höhne, Litim, TS 2022]
» Yukawa Portal [Hiller, Höhne, Litim, TS 2022]

Scalar Portal

» Scalar Portal: Additional scalar fields (uncharged)

[Hiller, Höhne, Litim, TS 2024]

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$$V_{H,S} = \lambda\,(H^\dagger H)^2 + \delta\,(H^\dagger H)(S^T S) + v\,(S^T S)^2$$

Portal coupling

$$\beta_\lambda = \beta_\lambda{}^{\mathrm{SM}} + \mathcal{N}\delta^2$$

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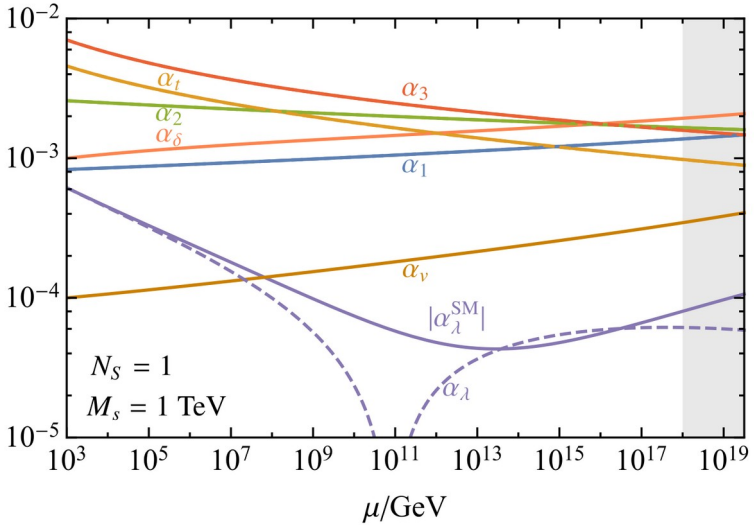

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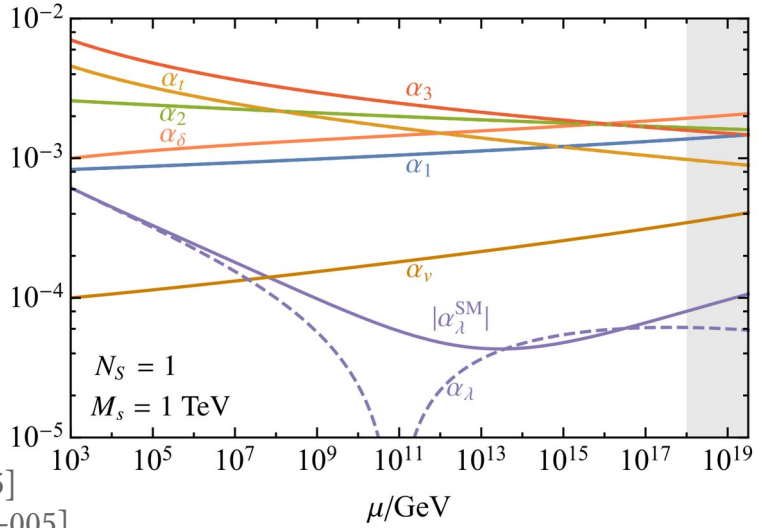
→ signal strength measurement $|\sin\beta| \leq 0.2$ [ATLAS 1909.02845] [CMS PAS HIG-19-005]



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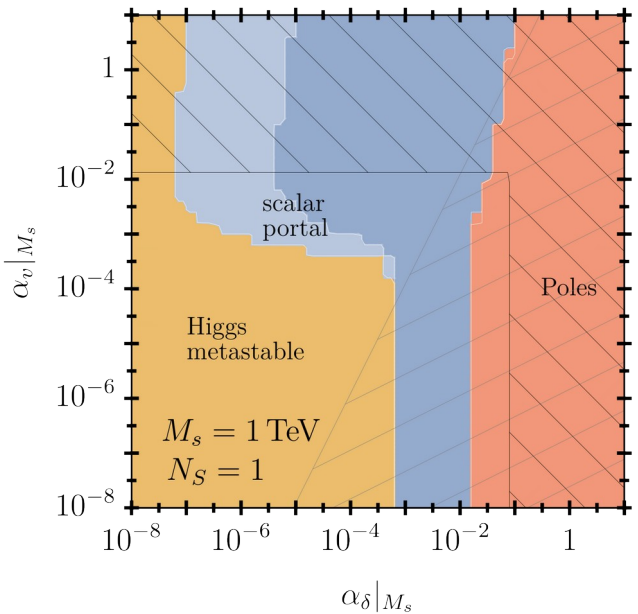

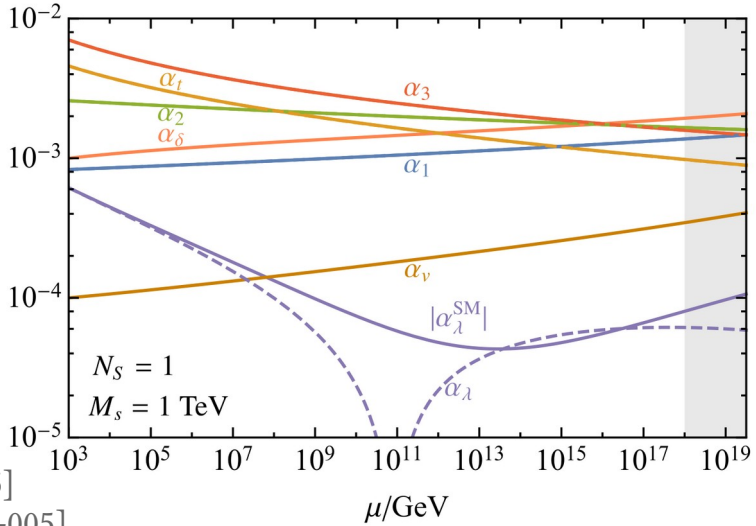

Gauge Portal

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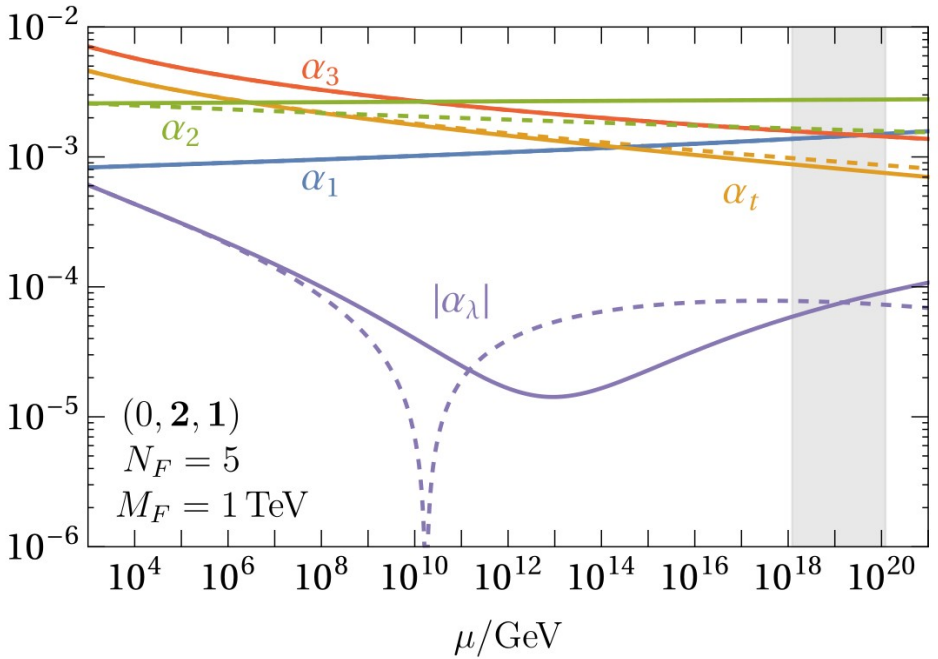

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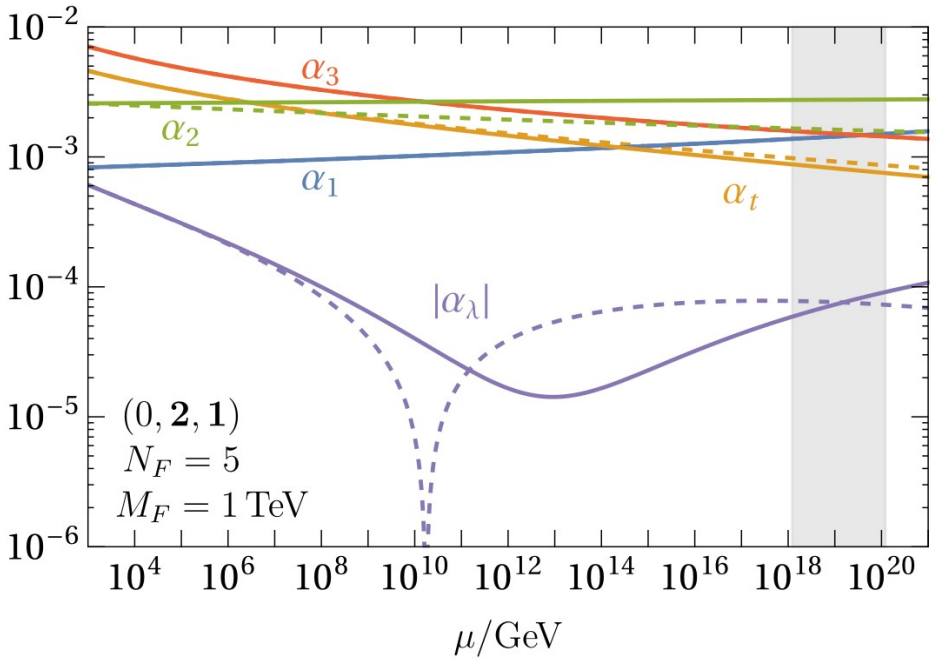
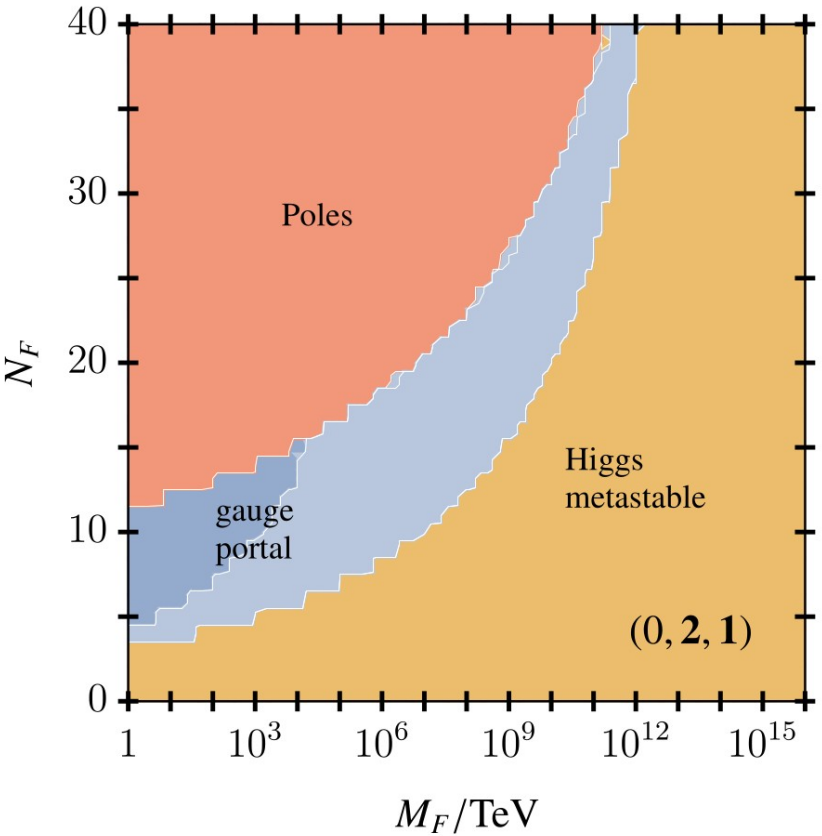
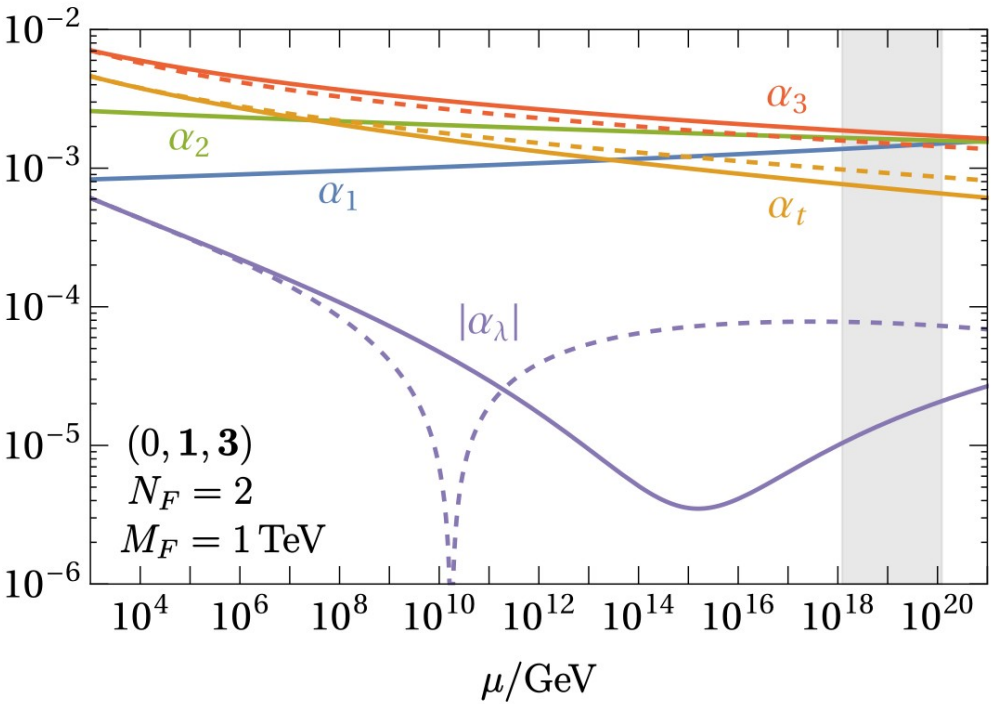




Gauge Portal

» VLQ



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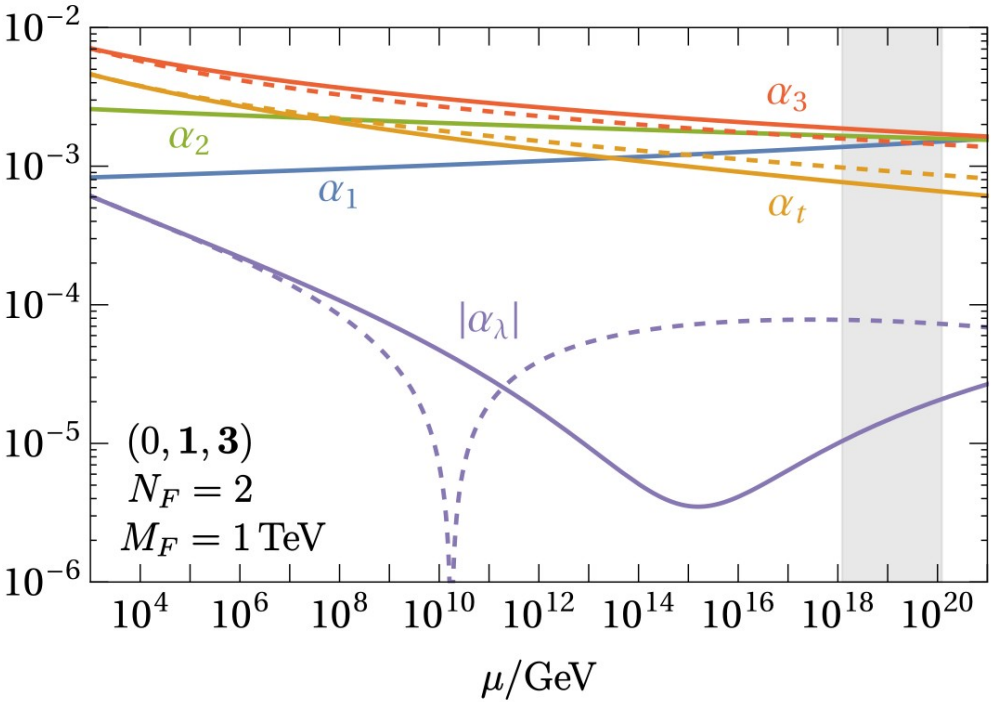

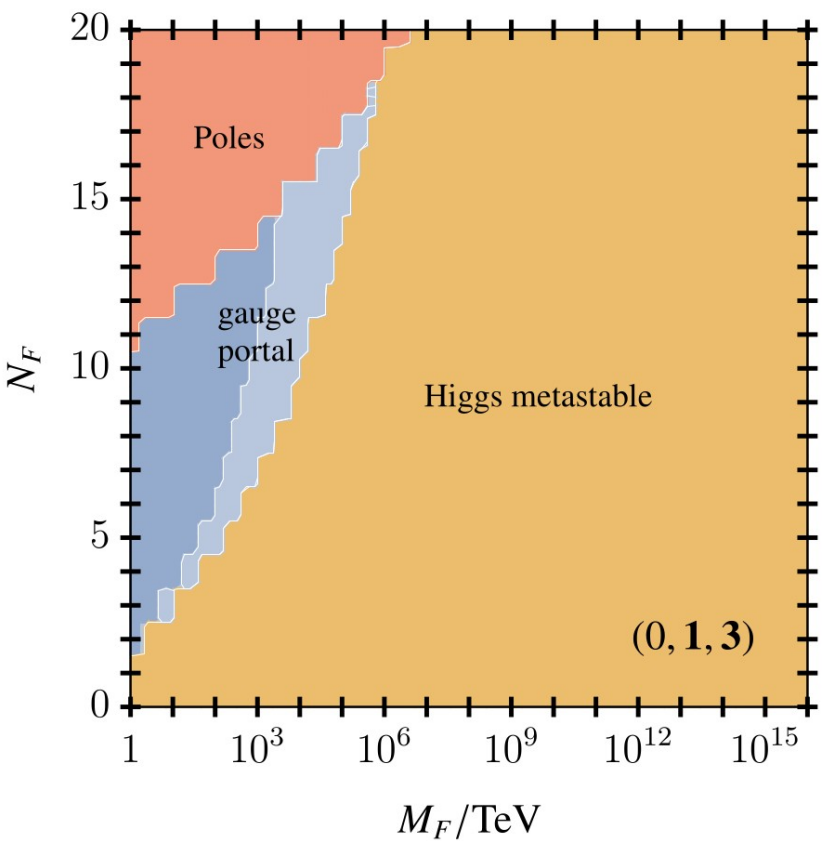

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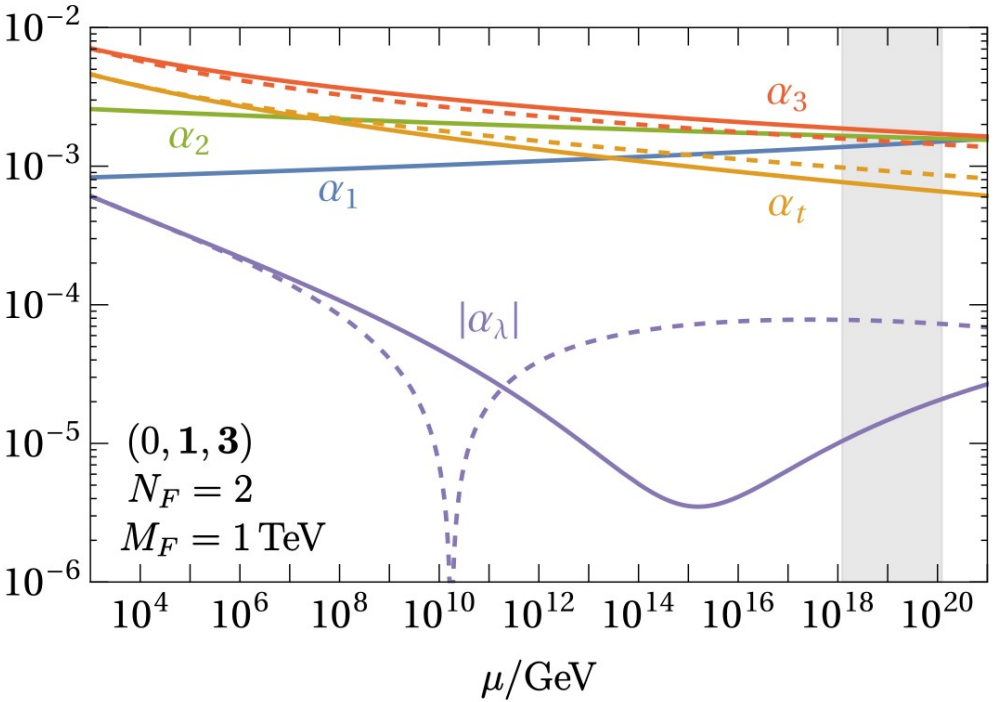

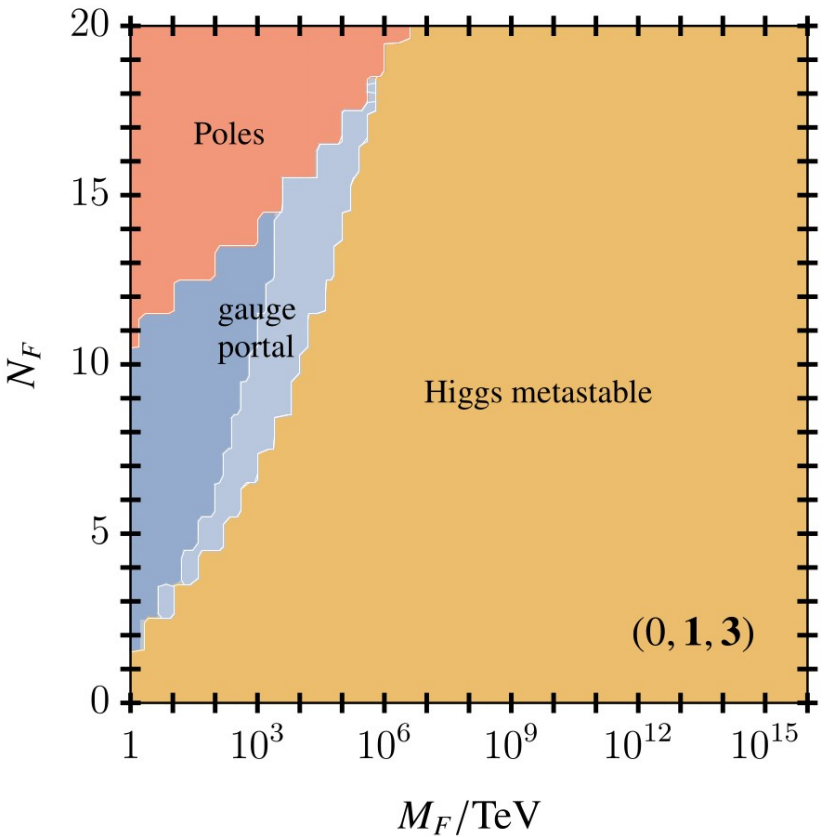

» VLF searches, oblique corrections

Yukawa Portal?

» new Yukawa with SM Higgs and VLF $\kappa_{ij}\,\bar{\psi}_L^i H^c D^j + \text{h.c.}$

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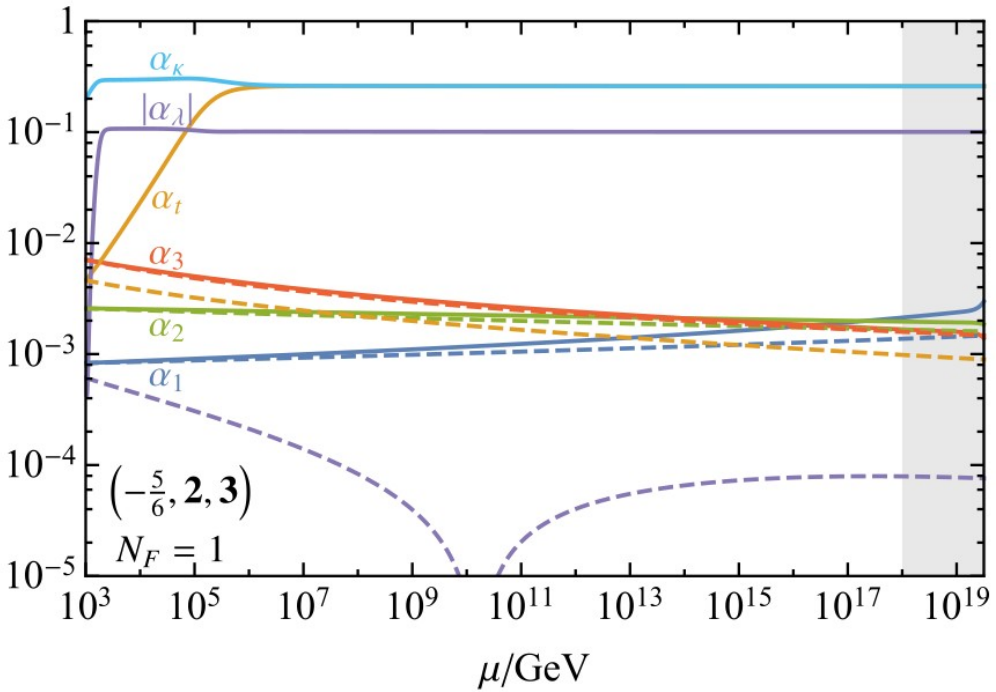

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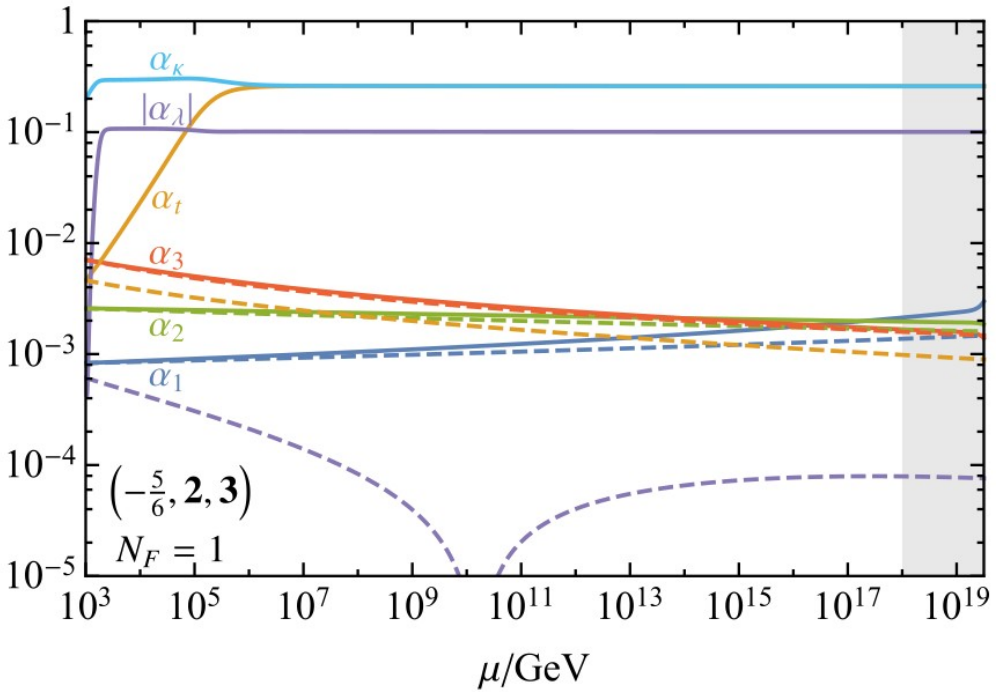

← walking regime

» requires higher loops to confirm

Summary

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» many BSM approaches to address SM instability
» can be valid until Planck scale
» testable at current and future colliders