Vacuum Stability in the Standard Model and Beyond

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in collabortation with
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[arXiv 2401.08811]

Higgs 2024
Uppsala, November 5th 2024

Motivation

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» Higgs discovery in 2012 [ATLAS,CMS 2012] $\longrightarrow$ Metastability [Buttazzo et al, 2013]
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» Can Stability be excluded?

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Outline

» Stability in the SM – An update
» BSM solutions

How to compute vacuum stability

1. Observables

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   - Higgs mass M_h
   - Top mass M_t
   - Strong coupling $\alpha_s^{(5)}(M_Z)$
   - Z mass M_Z
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PDG 2024

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$\underbrace{\qquad\qquad\qquad}$

PDG 2024

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

$\longrightarrow$ running couplings at a referce scale $\alpha_x(\mu_{\mathrm{ref}})$

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4. ~~Compute Decay Rate for Metastability~~

   only interested in absolute stability

Effective Potential

– pontential of classical field h & quantum effects, RG invariant, physical extrema

$$V_{\text{eff}}(h,\, \mu) = \tfrac{1}{4}\lambda(\mu)h^4 + \mathcal{O}(\alpha^2)$$

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– evolve $\lambda_{\rm eff}$ to $h \gg h_0$

$$\lambda_{\rm eff}(h) = \lambda_{\rm eff}(h_0) + \int_{h_0}^{h}\frac{{\rm d}h'}{h'}\sum_i \bar\beta_i\frac{\partial}{\partial\bar\alpha_i(h')}\lambda_{\rm eff}(h')$$

4L gauge (+ 5L QCD)

[Davies,Herren,Poole,Steinhauser,Thomsen, 2019]

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

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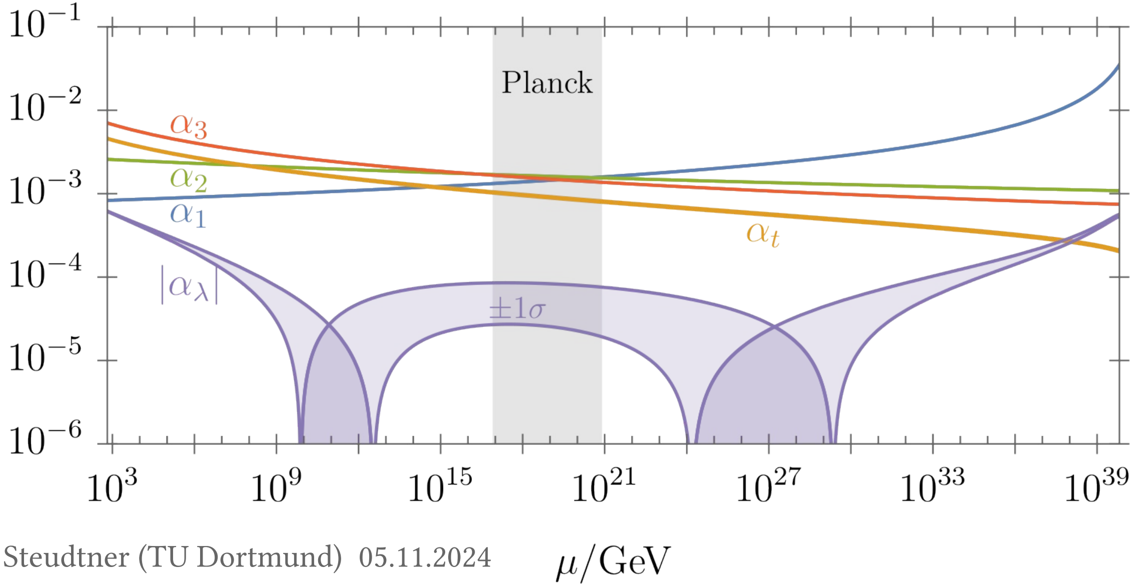

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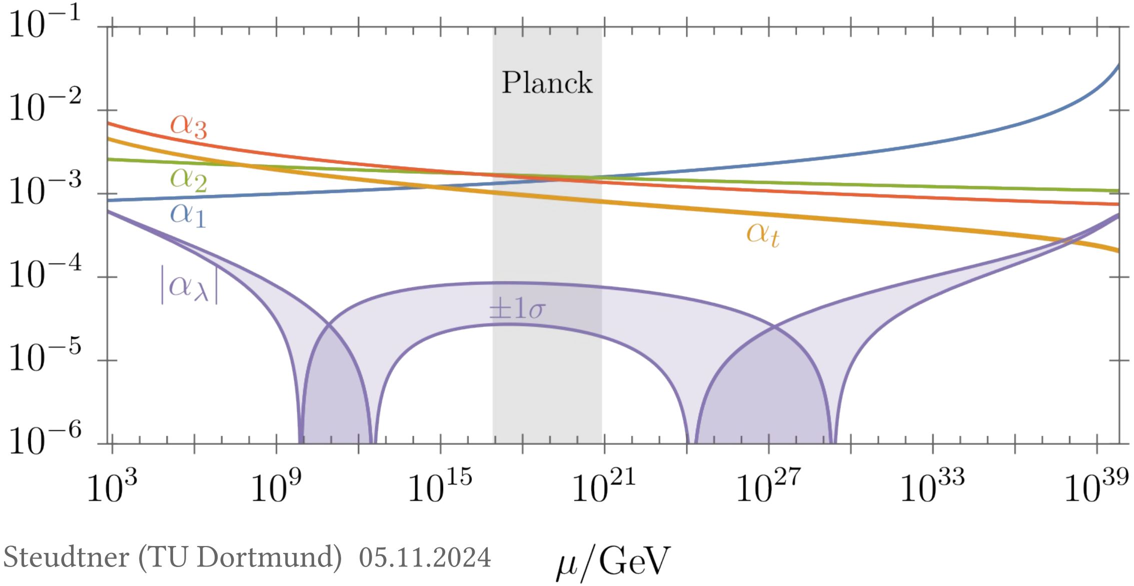

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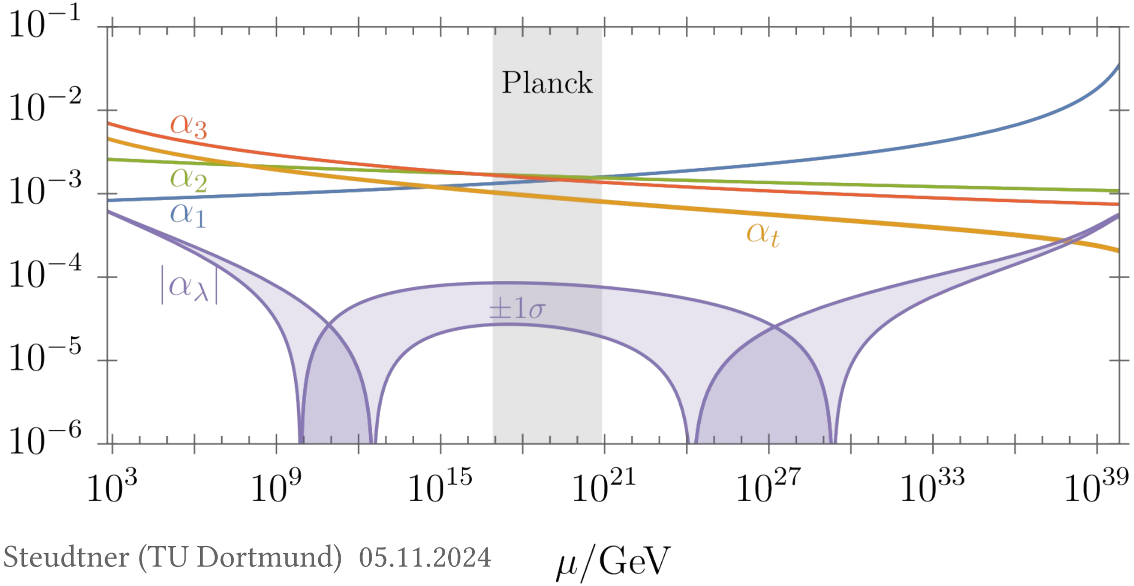

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1. Observables PDG 2024
   - Higgs mass $M_h = 125.20(11)$ GeV — Uncertainty small $+24\ \sigma$
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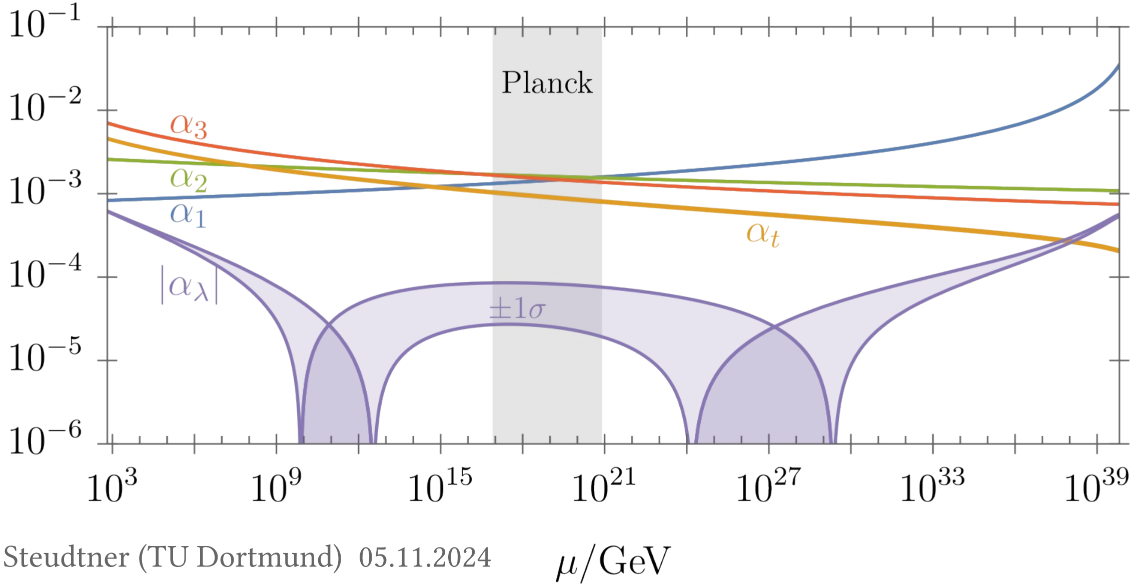

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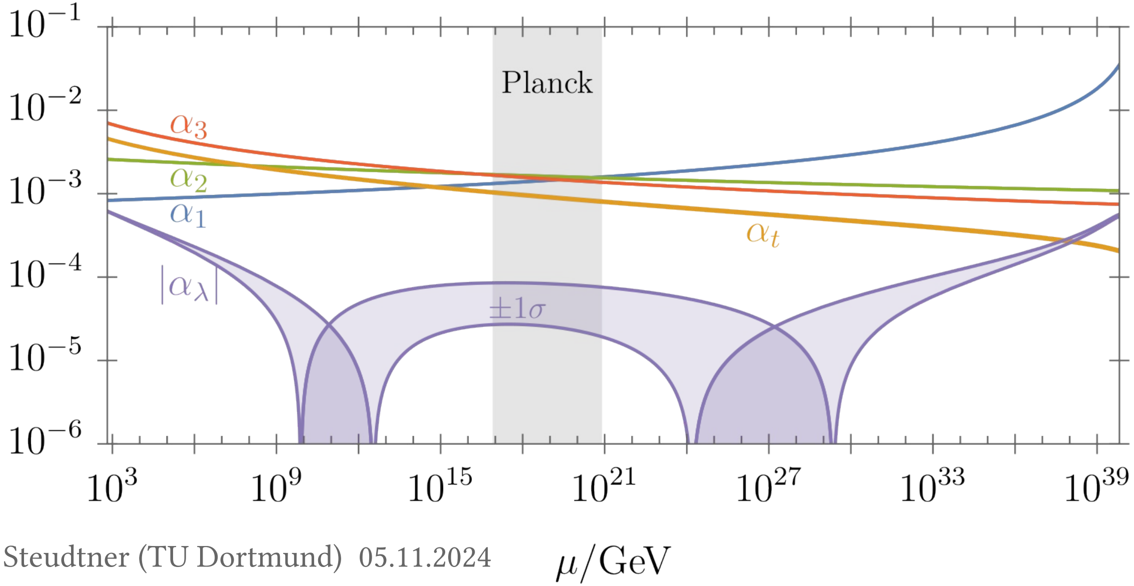

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– Top mass $M_t^\sigma = 172.40(70)$ GeV $-1.9\ \sigma$

$M_t^{\mathrm{MC}} = 172.57(29)$ GeV   which one? $-5.1\ \sigma$

~~– Z mass M_Z~~

~~– Fermi constant G_F~~   Uncertainty small

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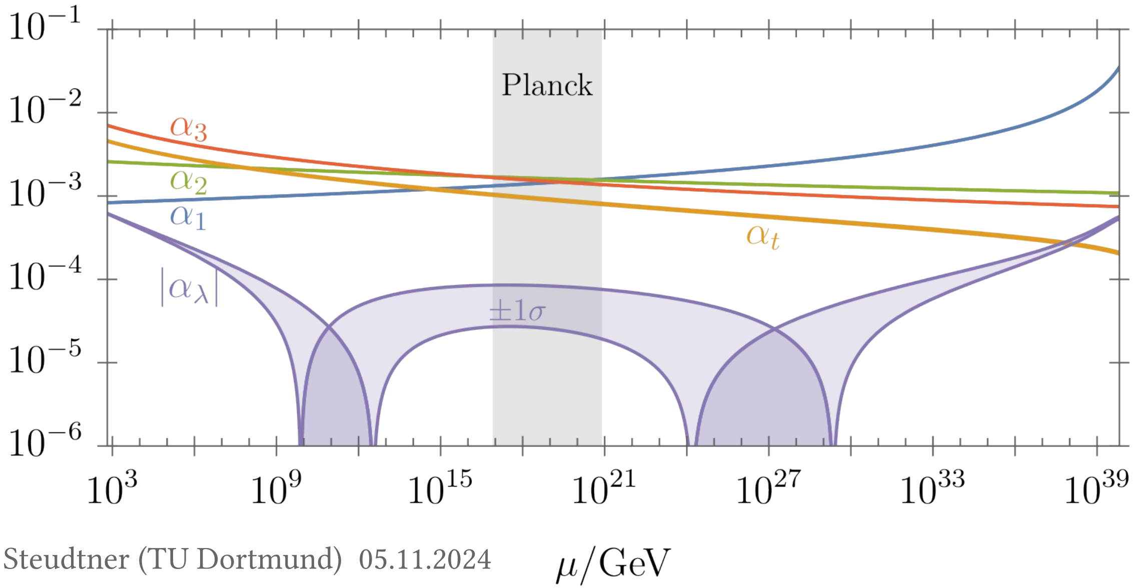
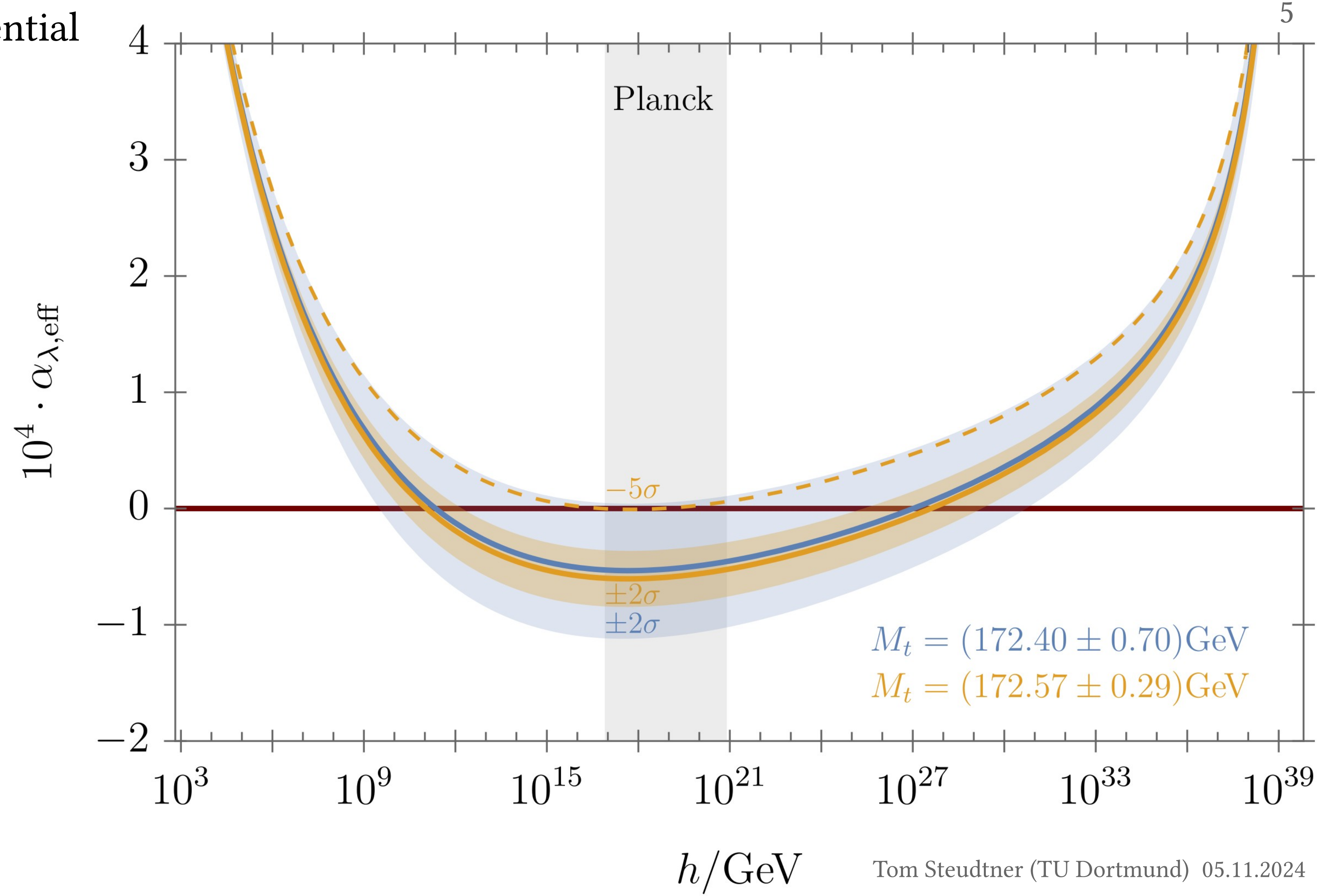
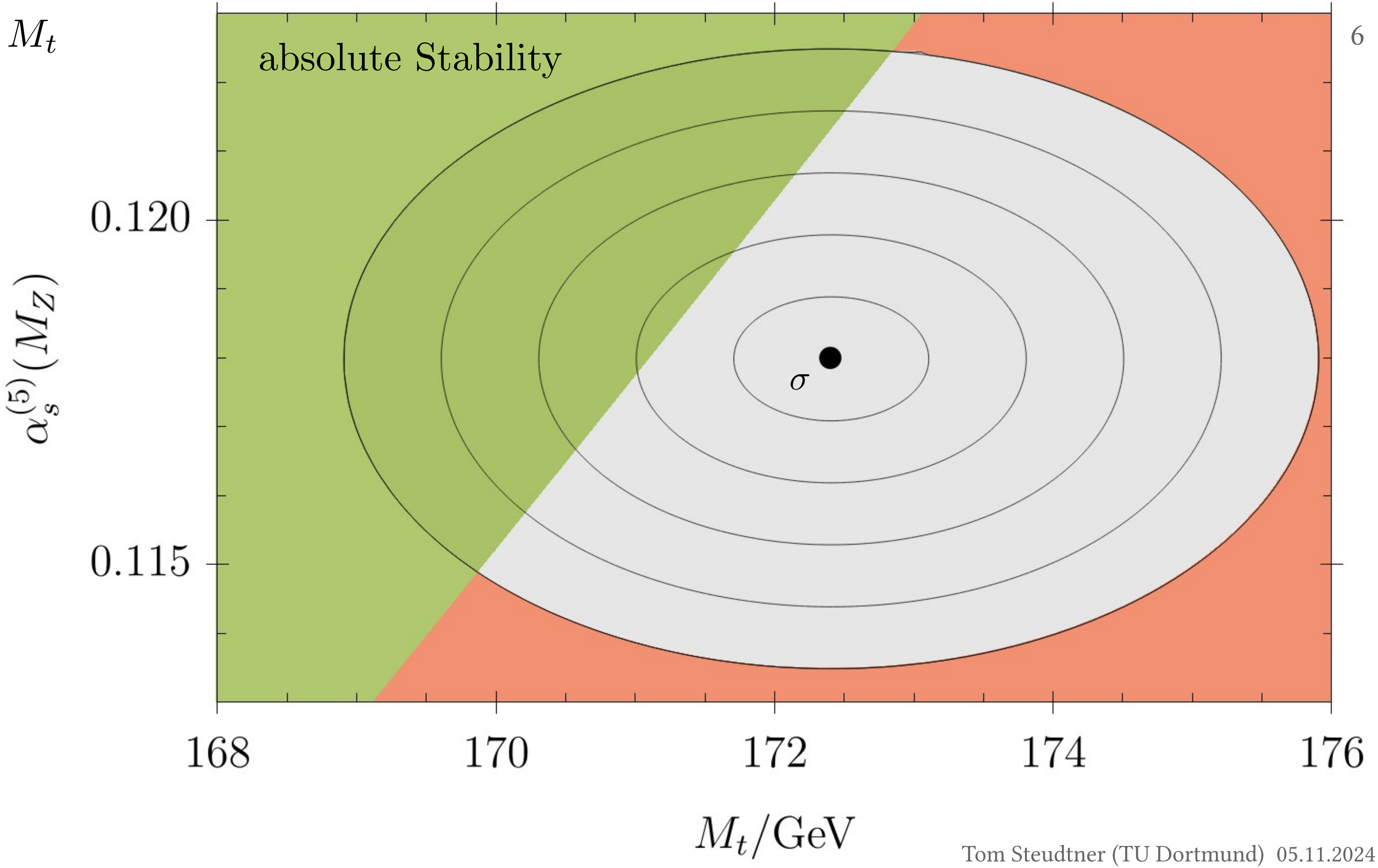
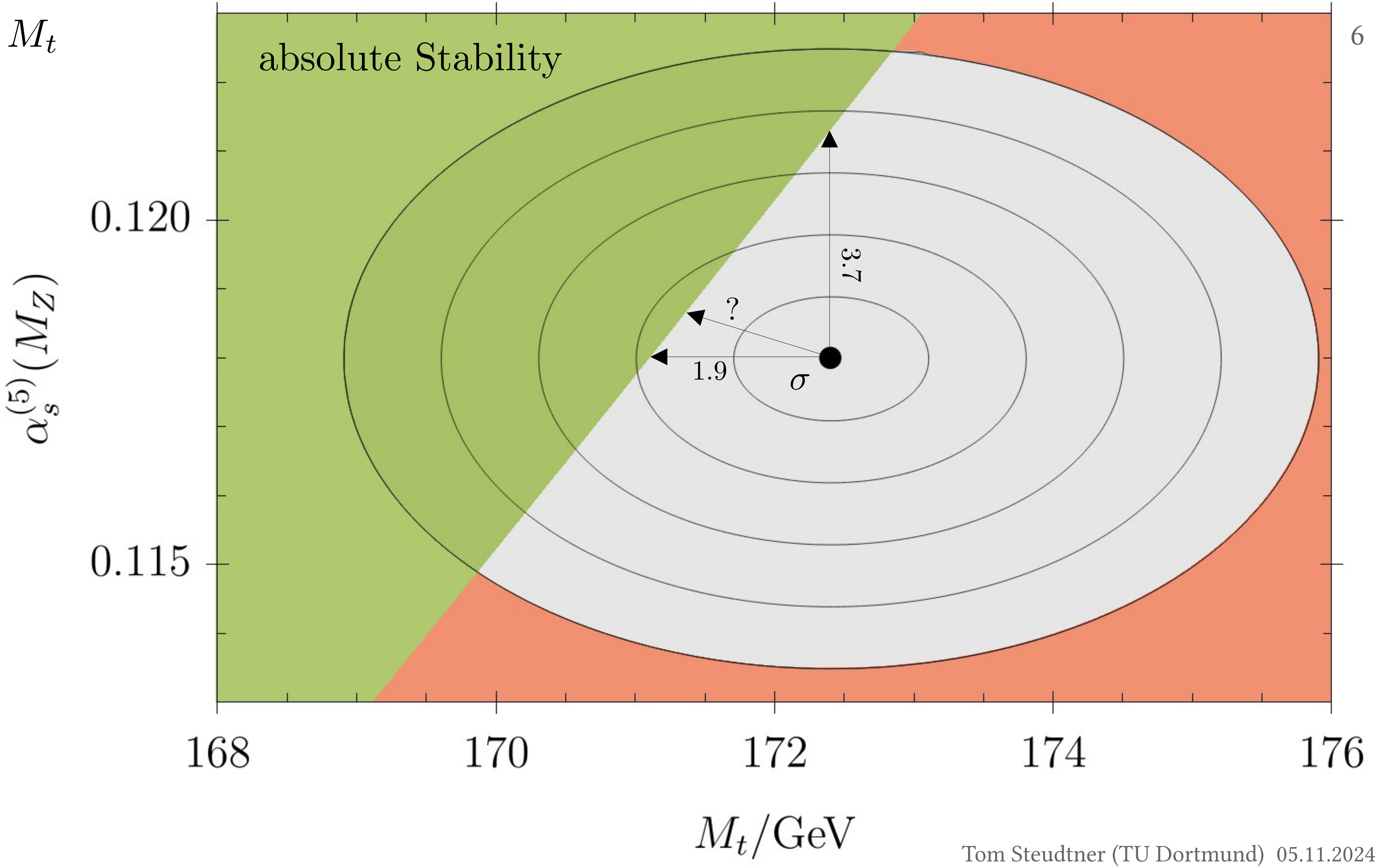


Effective Potential




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



absolute Stability
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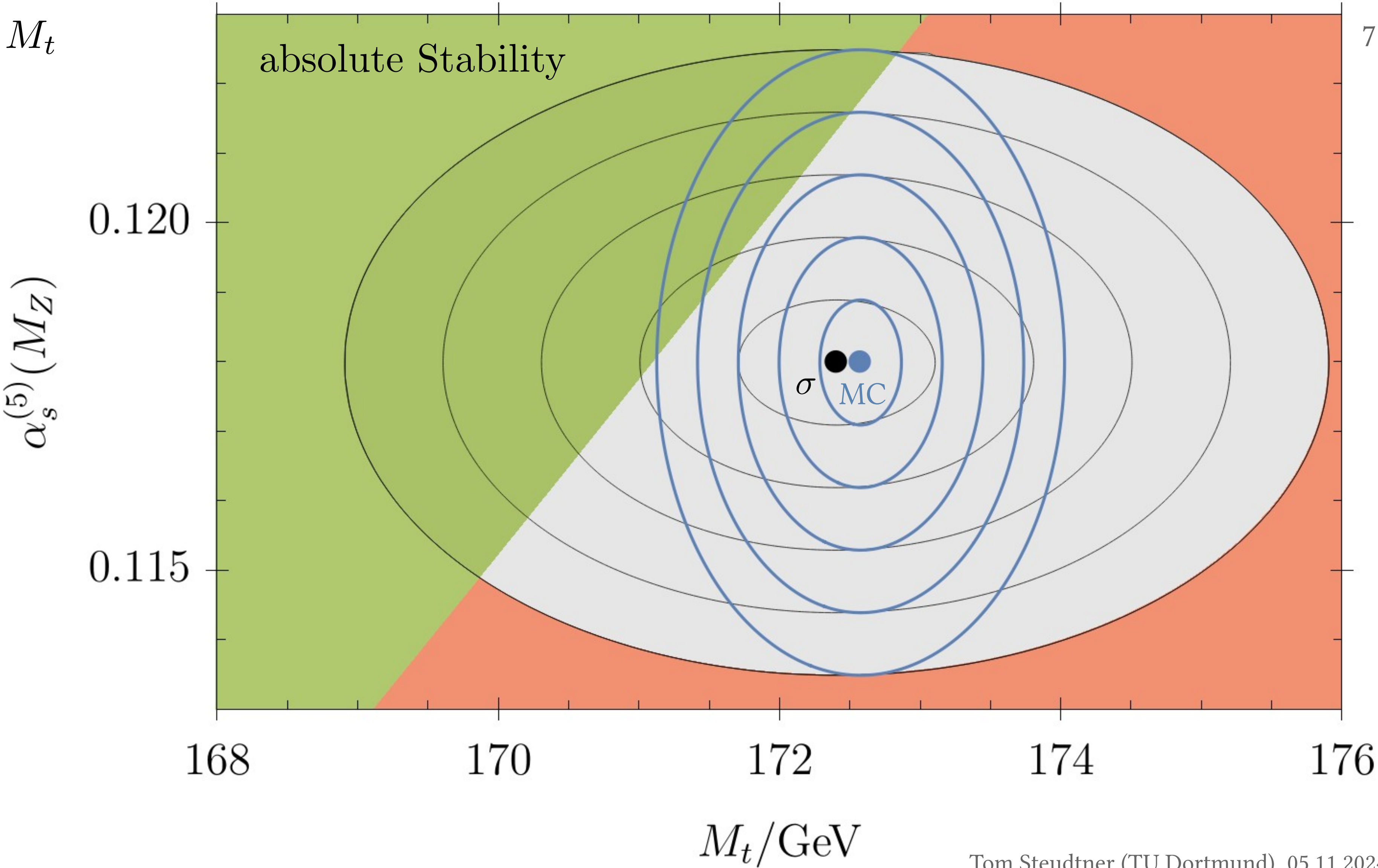
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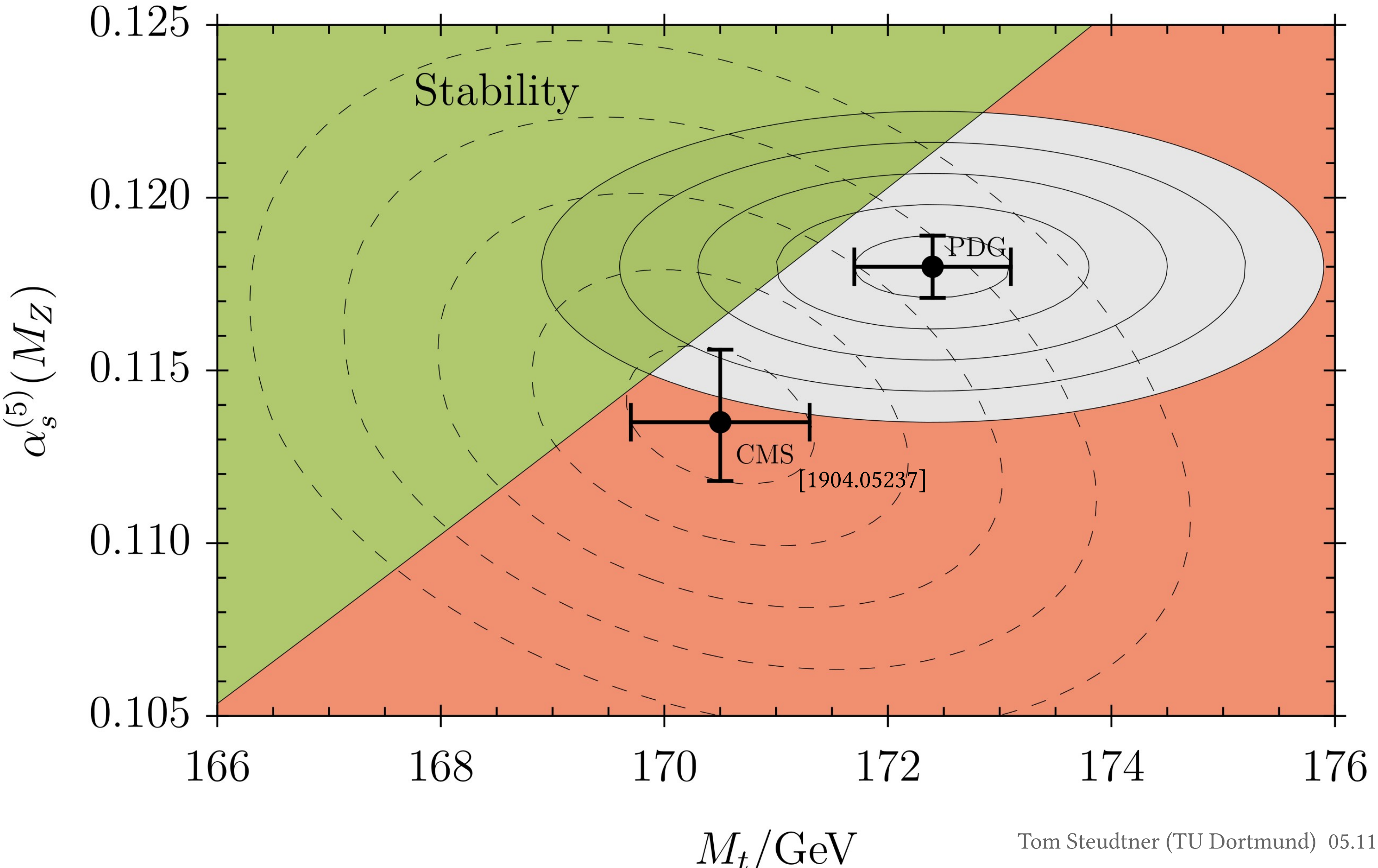
Stability
PDG
CMS
[1904.05237]
0.125
0.120
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0.110
0.105
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Stability via BSM?

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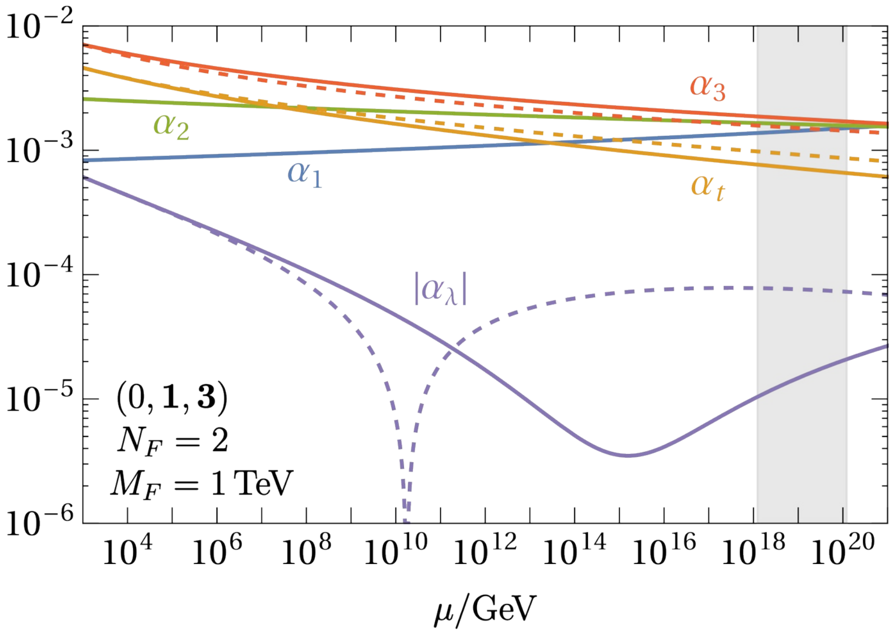
» Gauge Portal – adding new charged fermions
[Hiller, Höhne, Litim, TS 2022]



Stability via BSM?

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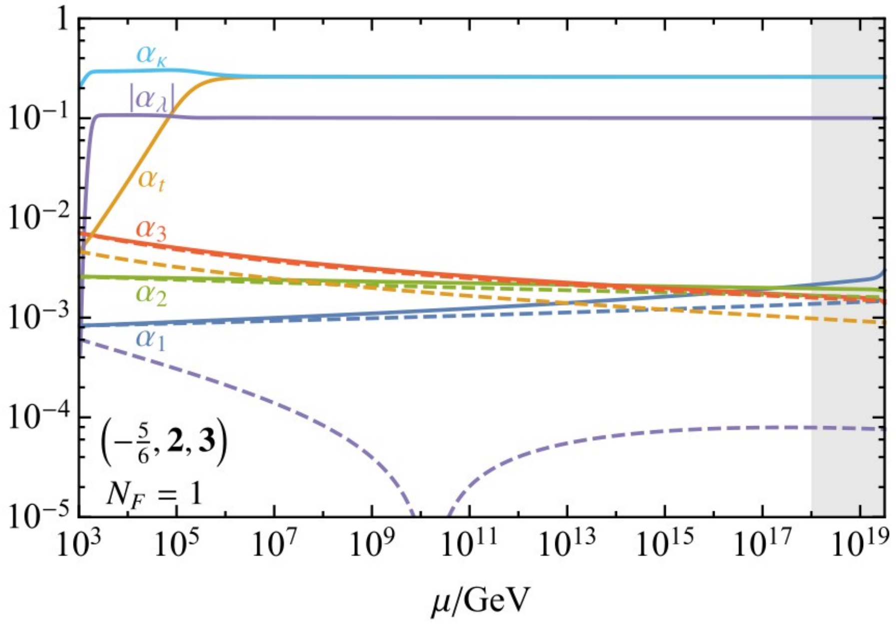

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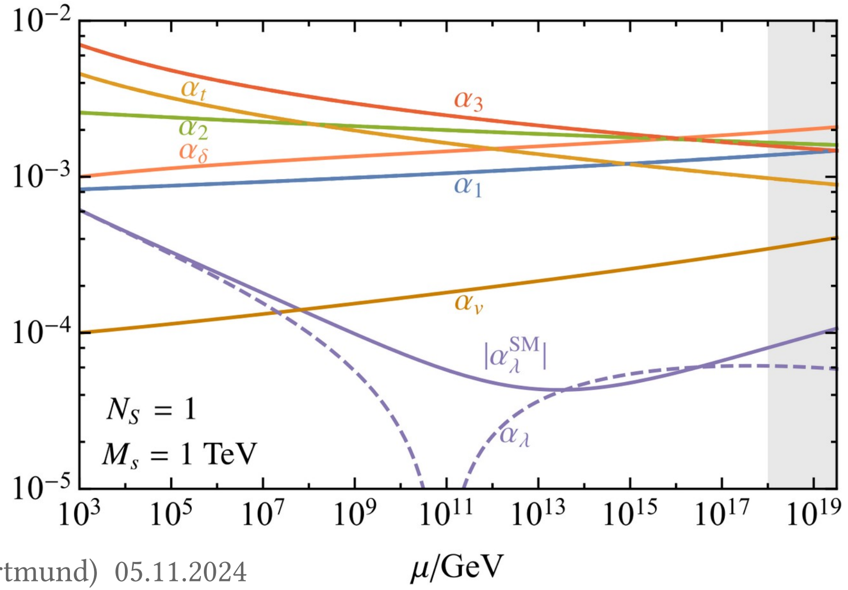
» Scalar Portal
[Hiller, Höhne, Litim, TS 2024]

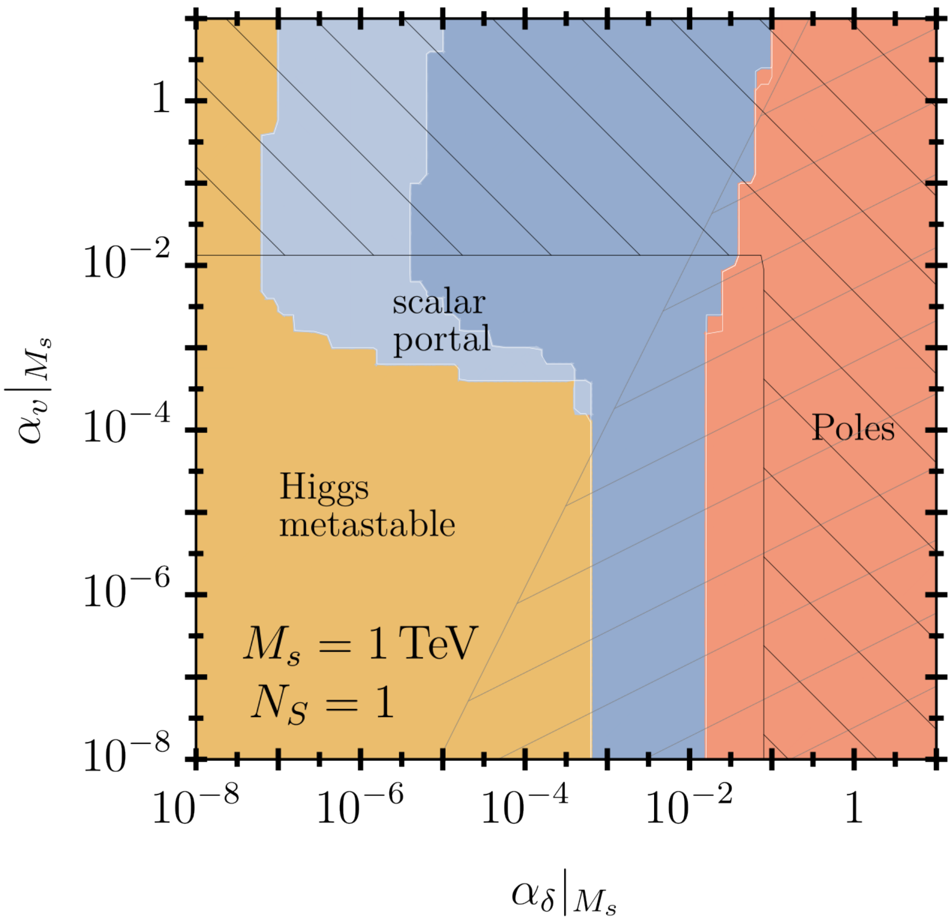
$$V_{H,S} = \lambda\,(H^\dagger H)^2 + \delta\,(H^\dagger H)(S^T S) + v\,(S^T S)^2$$

Portal coupling

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



Scalar Portal Mechanism



Scalar Portal – Signatures

» BSM scalar obtains VEV ⟶ Mixing with SM Higgs

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» BSM scalar obtains VEV $\longrightarrow$ Mixing with SM Higgs

» signal strength measurement

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

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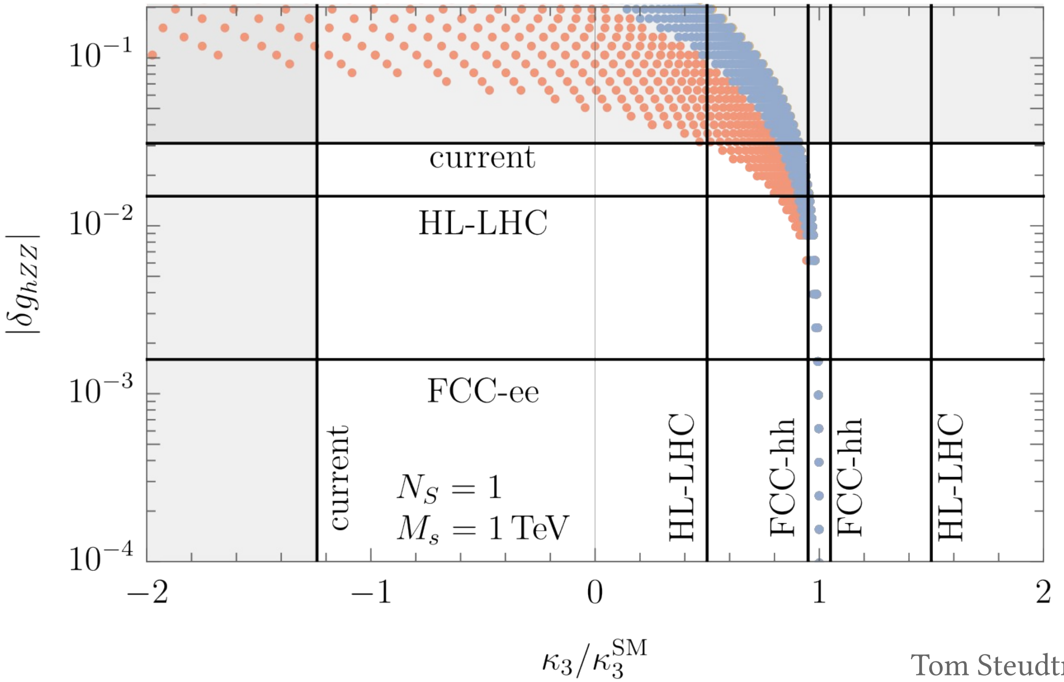

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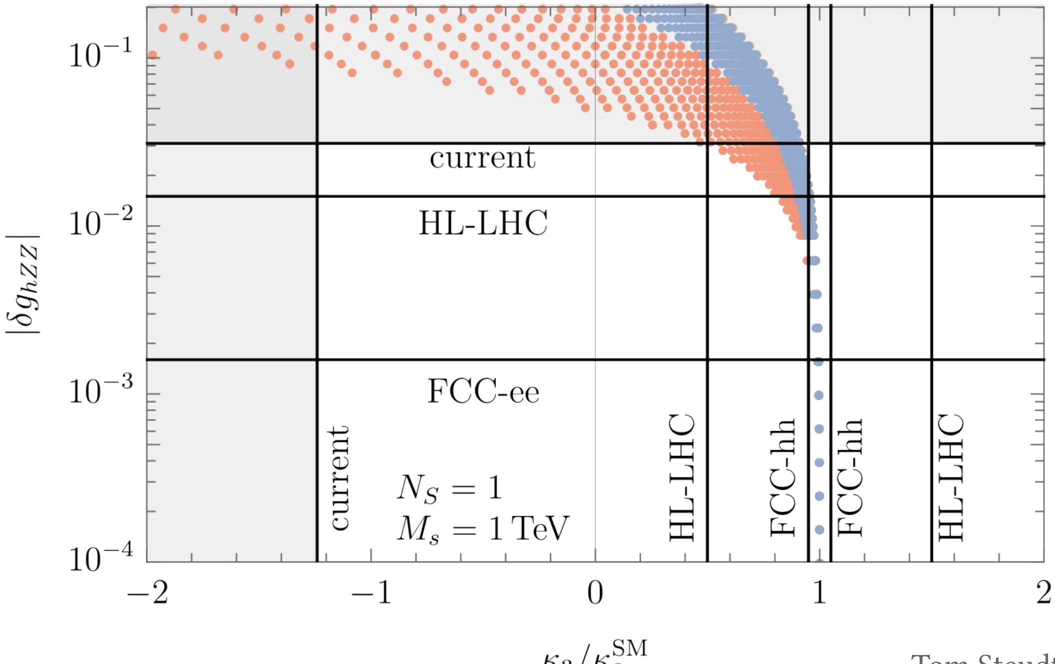

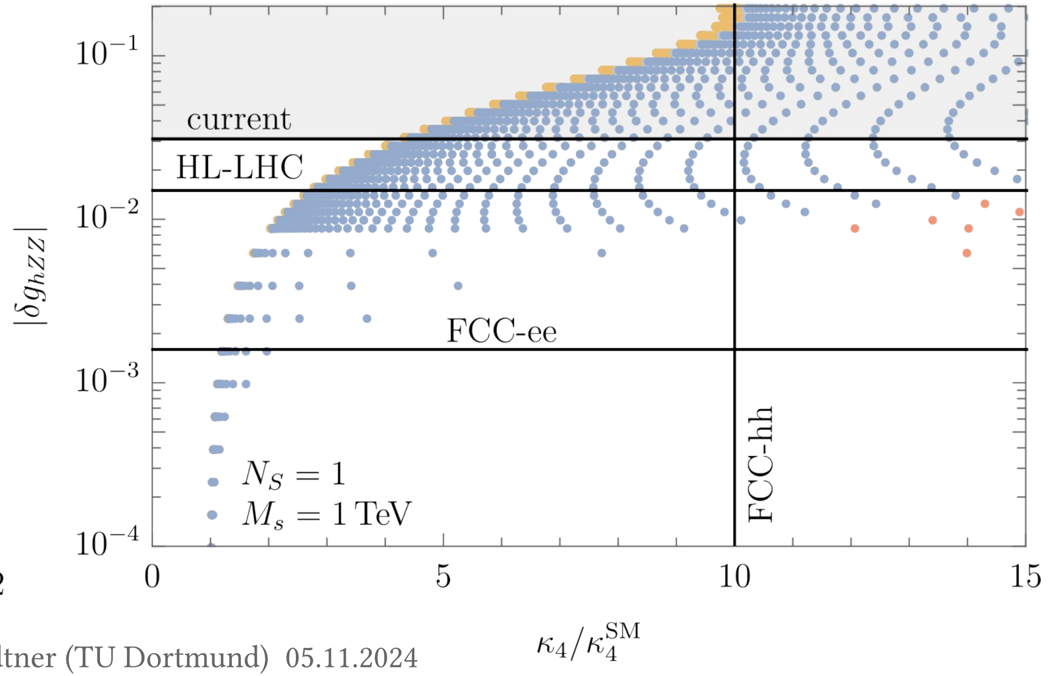

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» many BSM approaches to address SM instability
» can be valid until Planck scale
» testable at current and future colliders