# High-precision predictions and constraints from vacuum stability


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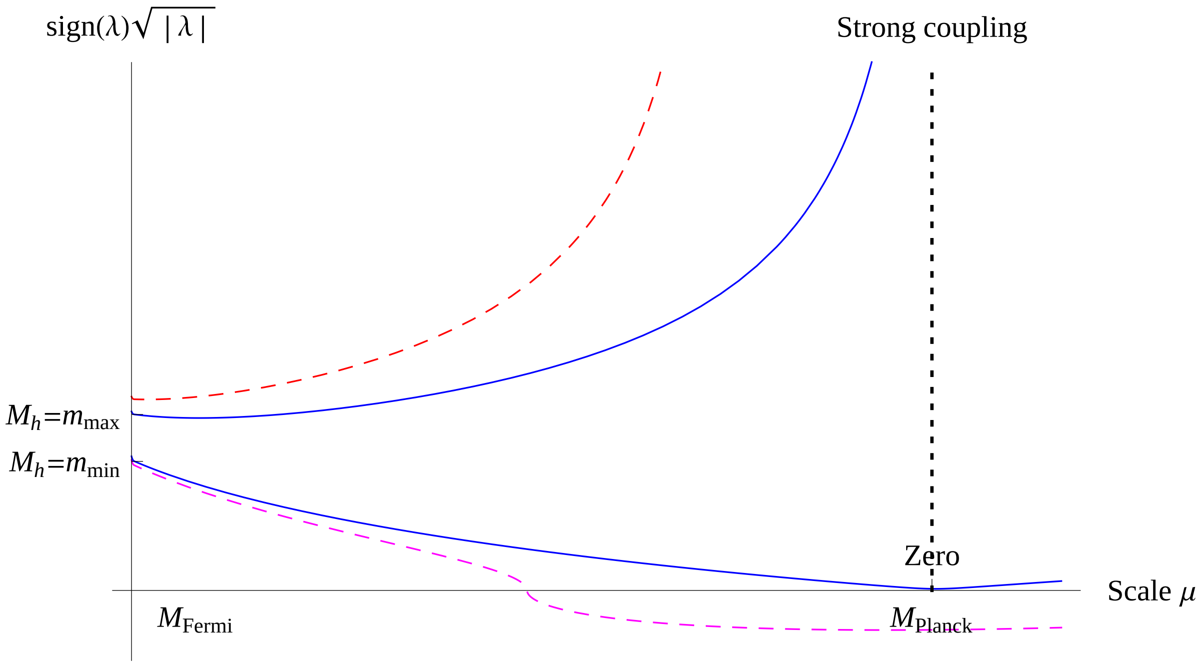
# Vaccum stability condition

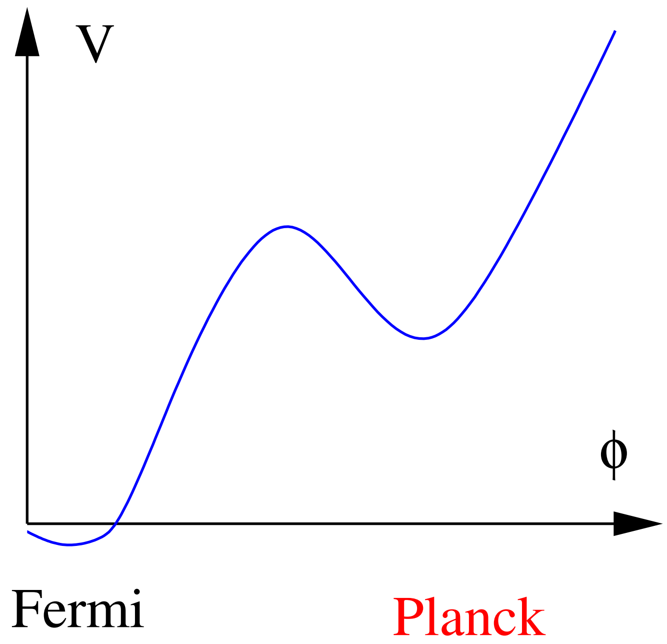


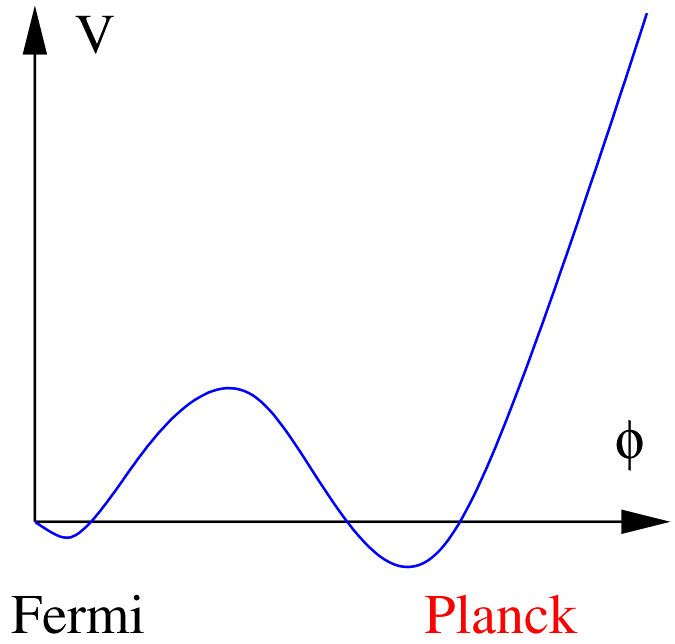

Determine $\mu^{\text{cri}}$ and $M_H^{\text{cri}}$ for given $M_t$ (or $M_t^{\text{cri}}$ for given $M_H$) so that

$$\lambda(\mu^{\text{cri}}) = \beta_\lambda(\lambda(\mu^{\text{cri}})) = 0$$

$\rightsquigarrow$ Vacuum is stable for $M_H \geq M_H^{\text{cri}}$ (or $M_t \leq M_t^{\text{cri}}$).
Caveat: $\mu^{\text{cri}}, M_H^{\text{cri}}, M_t^{\text{cri}}$ are gauge independent, but (slightly) scheme dependent. $\rightsquigarrow$ theoretical uncertainty

# Effective potential




Determine $\tilde{\mu}^{\mathrm{cri}}$ and $\tilde{M}_H^{\mathrm{cri}}$ for given $M_t$ (or $\tilde{M}_t^{\mathrm{cri}}$ for given $M_H$) so that

$$V_{\mathrm{eff}}(\tilde{\mu}^{\mathrm{cri}}) = V_{\mathrm{eff}}(v) \approx 0, \qquad V'_{\mathrm{eff}}(\tilde{\mu}^{\mathrm{cri}}) = 0$$

$\rightsquigarrow$ Vacuum is stable for $M_H \geq \widetilde{M}_H^{\mathrm{cri}}$ (or $M_t \leq \widetilde{M}_t^{\mathrm{cri}}$).

Caveat: Reorganize $V_{\mathrm{eff}}(H)$ in powers of $\hbar$ so that expansion coefficients are gauge independent at its extrema Andreassen *et al.*, PRL113(2014)241801

# Combined results

Selected for a Viewpoint in *Physics*
PRL **115,** 201802 (2015) PHYSICAL REVIEW LETTERS week ending 13 NOVEMBER 2015

**Stability of the Electroweak Vacuum: Gauge Independence and Advanced Precision**

A. V. Bednyakov,[1] B. A. Kniehl,[2] A. F. Pikelner,[2] and O. L. Veretin[2]
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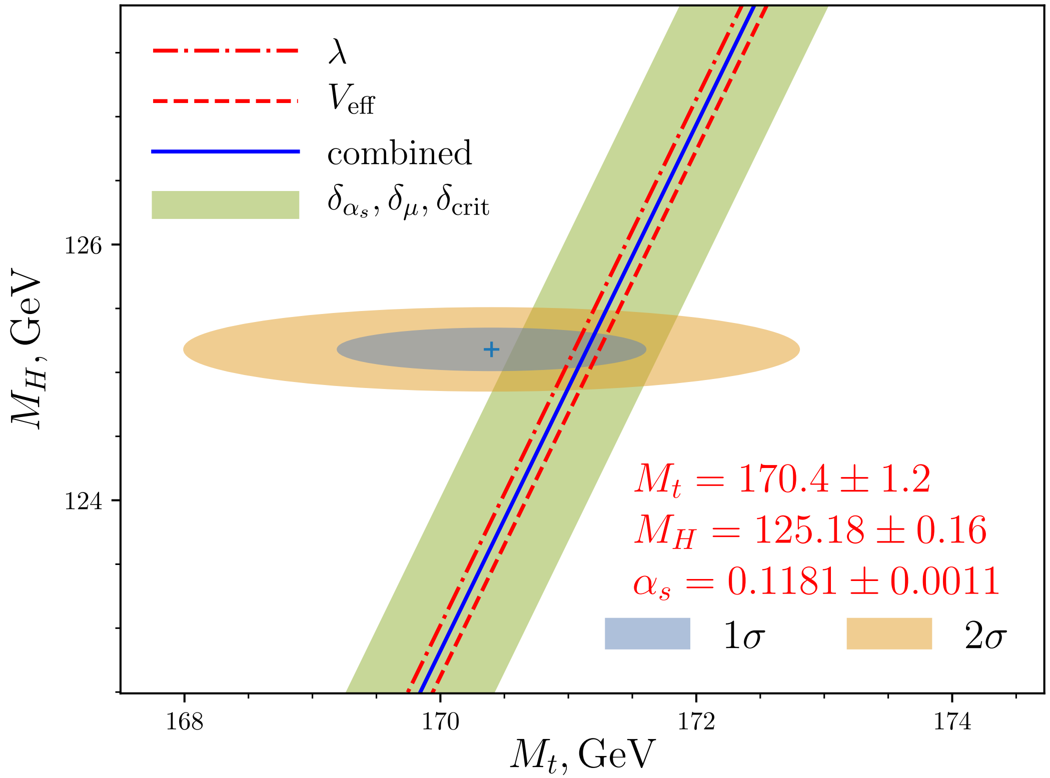
(Received 30 July 2015; revised manuscript received 24 August 2015; published 9 November 2015)

C++ library `mr` BK, Pikelner, Veretin, CPC206(2016)84

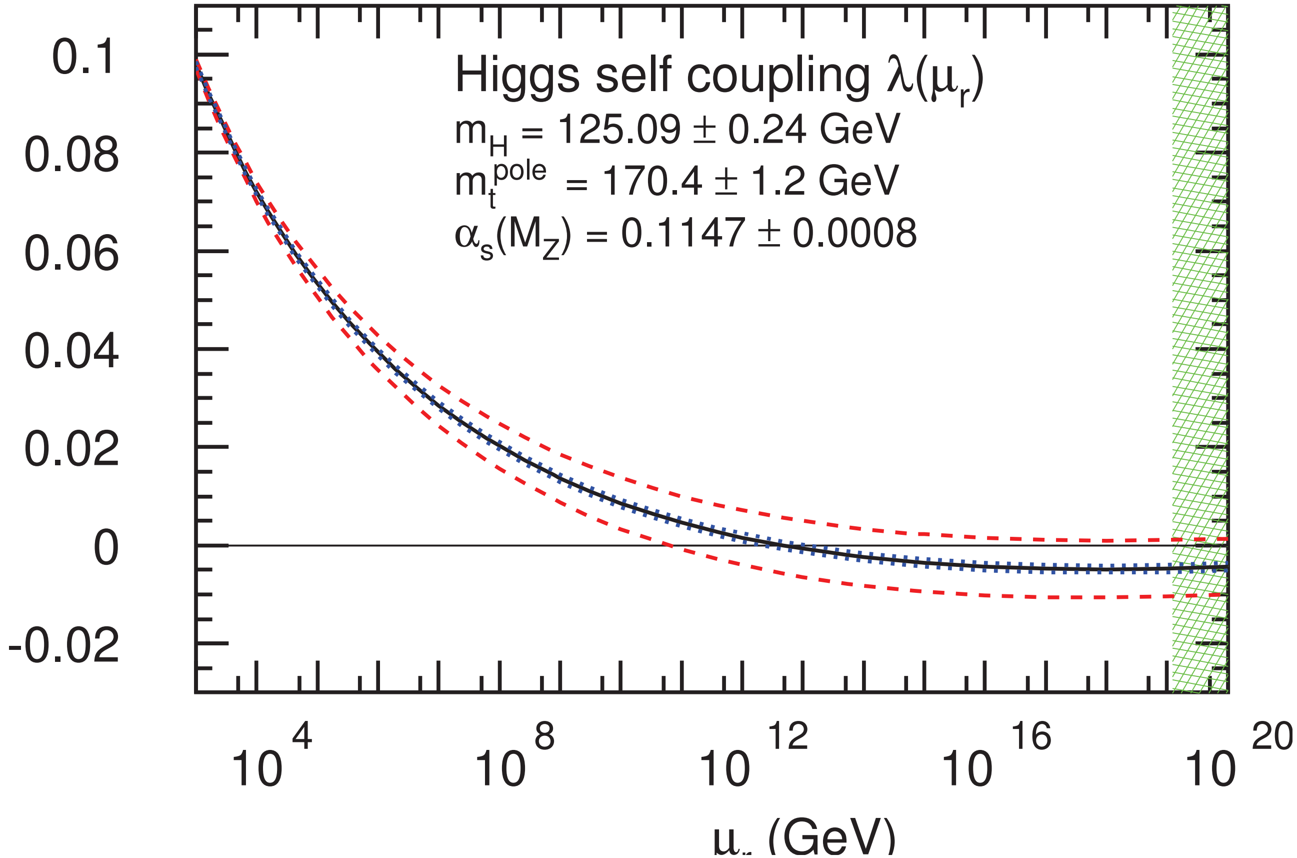
- From $\lambda(\mu)$: $M_t^{\rm cri} = (171.03 \pm 0.30\,^{+0.17}_{-0.36})$ GeV
- From $V_{\rm eff}(H)$: $\widetilde{M}_t^{\rm cri} = (171.23 \pm 0.30\,^{+0.17}_{-0.36})$ GeV
- Combination: $\widehat{M}_t^{\rm cri} = (171.13 \pm 0.30\,^{+0.26}_{-0.41})$ GeV
- NNLO QCD: $M_t = (170.4 \pm 1.2)$ GeV Moch *et al.*, PRD96(2017)014011

# Status quo: SM stable




- PDG 2018 & ABMP $M_t$
- $\lambda(\mu) > 0$ throughout
- Minimum at $\log_{10}\mu = 17.5$ cf. $\log_{10} M_P = 19.1$

# Input parameters crucial




- ABMP $\alpha_s^{\mathrm{NNLO}}(M_Z) = 0.1147 \pm 0.0008$

# Research plans for vacuum stability

- SM RG functions at 4 loops
- threshold corrections at 3 loops w/ full mass dependences
- quantum gravity effects, e.g., via higher-dimensional operators
- Higher precision in $\alpha_s$ and $M_t$
- $V_{\mathrm{eff}}(H)$ at 4 loops in covariant gauge
  first step: 3 loops in general scalar theory BK, Pikelner, Veretin, NPB937(2018)533
- extended Higgs sectors, Higgs portals (SMASH etc.)
- cosmological implications on minimal-inflation models;
  production of stochastic gravitational-wave background

# Research plans for high-precision Higgs observables

- Higgs effective couplings to gluons and quarks: power suppressed $m_t$ terms at 3 loops via full set of (mixed) $D = 6$ composite operators w/ RG resummation
- gluon and quark effective couplings of Higgses w/ odd or indefinite CP
- hadronic decay width at 5 loops, including final states with bottom
- all SM decay channels w/ full mass dependences at 2 loops
- higher-order RC to (differential) production cross sections
- input from QT.2: generalized unitarity methods, massive higher-loop integrals
  first step: 3-loop massive tadpoles and polylogarithms through weight six BK, Pikelner, Veretin, JHEP1708(2017)024
- EFT predictions for differential distributions; implementation of higher-dimensional EFT operators in MC generators; assessment of validiy range of EFT expansion