State-of-the-Art Predictions for the Light Higgs Boson Mass in the MSSM

Philipp Kant

in collaboration with
R. V. Harlander, L. Mihaila, M. Steinhauser

JHEP 1008:104,2010

http://www-ttp.particle.uni-karlsruhe.de/Progdata/ttp10/ttp10-23

HUMBOLDT-UNIVERSITÄT ZU BERLIN

4th Annual Helmholtz Alliance Workshop

Motivation

why consider Higgs sector of MSSM?

- quite predictive
  two new free parameters at tree level

$$M_A,\ \tan\beta$$

- experimental accuracy: M_h will be precision observable immediately upon detection
  $\delta M_h \approx 100 - 200\text{MeV}$ at LHC, $\delta M_h \approx 50\text{MeV}$ at ILC

Higgs Mass in the MSSM

MSSM Higgs sector: 2 Higgs doublet model

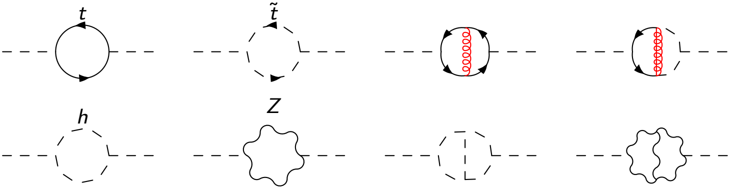
$$V = m_1^2 |H_1|^2 + m_2^2 |H_2|^2 + m_{12}^2 \left(\epsilon_{ab} H_1^a H_2^b + \epsilon_{ab} H_1^{a*} H_2^{b*} \right)$$
$$+ \frac{1}{8} (g_1^2 + g_2^2) \left(|H_1|^2 - |H_2|^2 \right)^2 + \frac{1}{2} g_2^2 |H_1^* H_2|^2$$

spontaneous symmetry breaking: H_1, H_2 acquire vacuum expectation values $\Rightarrow$ gauge bosons and fermions acquire masses.

note : quartic terms fixed by gauge couplings

$$\Rightarrow M_h \text{ can be predicted, tree level: } M_h \leqslant M_z$$

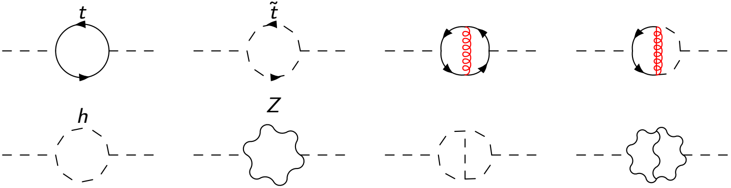
Radiative Corrections to M_h



observations from one- and two-loop corrections:

- most important: top and stop loops ($\propto m_t^4$)
- dependence on the momentum q^2 flowing through the propagator is small at the one-loop level $\mathcal{O}(1\,\mathrm{GeV})$
- remaining uncertainty estimate: $\approx 3 - 5\,\mathrm{GeV}$

Radiative Corrections to M_h



observations from one- and two-loop corrections:

- most important: top and stop loops ($\propto m_t^4$)
- dependence on the momentum q^2 flowing through the propagator is small at the one-loop level $\mathcal{O}(1\,\mathrm{GeV})$
- remaining uncertainty estimate: $\approx 3 - 5\,\mathrm{GeV}$

justifies calculation of M_h at the three loops

- considering contributions from the top/stop sector
- working in the $q^2 = 0$ approximation

Necessary Approximations

- full calculation of all three-loop contributions is not feasible
  - restrict to t and $\tilde{t}$ loops
  - virtual particles: t, $\tilde{t}$, g, $\tilde{g}$, q, $\tilde{q}$

Necessary Approximations

- full calculation of all three-loop contributions is not feasible
  - restrict to t and $\tilde{t}$ loops
  - virtual particles: t, $\tilde{t}$, g, $\tilde{g}$, q, $\tilde{q}$
- can't do integrals for arbitrary masses
  - assume fixed hierarchies among the superpartner masses

$$m_q = 0, \quad m_t \ll m_{\tilde{t}_1} \approx m_{\tilde{t}_2} \approx m_{\tilde{g}} \approx m_{\tilde{q}}$$
$$m_t \ll m_{\tilde{t}_1} \ll m_{\tilde{t}_2} \approx m_{\tilde{g}} \ll m_{\tilde{q}}$$

  - asymptotic expansions lead to one-scale integrals

Necessary Approximations

- full calculation of all three-loop contributions is not feasible
  - restrict to t and $\tilde{t}$ loops
  - virtual particles: t, $\tilde{t}$, g, $\tilde{g}$, q, $\tilde{q}$
- can't do integrals for arbitrary masses
  - assume fixed hierarchies among the superpartner masses

$$m_q = 0, \quad m_t \ll m_{\tilde{t}_1} \approx m_{\tilde{t}_2} \approx m_{\tilde{g}} \approx m_{\tilde{q}}$$

$$m_t \ll m_{\tilde{t}_1} \ll m_{\tilde{t}_2} \approx m_{\tilde{g}} \ll m_{\tilde{q}}$$

  - asymptotic expansions lead to one-scale integrals
  - consider enough different hierarchies to cover parameter space

Necessary Approximations

- full calculation of all three-loop contributions is not feasible
  - restrict to t and $\tilde{t}$ loops
  - virtual particles: t, $\tilde{t}$, g, $\tilde{g}$, q, $\tilde{q}$
- can't do integrals for arbitrary masses
  - assume fixed hierarchies among the superpartner masses

$$m_q = 0, \quad m_t \ll m_{\tilde{t}_1} \approx m_{\tilde{t}_2} \approx m_{\tilde{g}} \approx m_{\tilde{q}}$$
$$m_t \ll m_{\tilde{t}_1} \ll m_{\tilde{t}_2} \approx m_{\tilde{g}} \ll m_{\tilde{q}}$$

  - asymptotic expansions lead to one-scale integrals
  - consider enough different hierarchies to cover parameter space
  - calculate every integral (30.717) for each hierarchy

From Formulae to Numbers

- combine with corrections from other sectors

- automatic choice of appropriate approximation

From Formulae to Numbers

- combine with corrections from other sectors
  - use existing “wheel”: `FeynHiggs`
  - consistent renormalisation of parameters (on-shell vs. modified minimal subtraction)
  - consistent values of parameters
    - spectrum generator (`SOFTSUSY`, `SPheno`, `SuSpect`)
    - evolve α_S (`RunDecSUSY`)
    - convert m_t to $\overline{\mathrm{DR}}$ scheme (`TSIL`)
- automatic choice of appropriate approximation

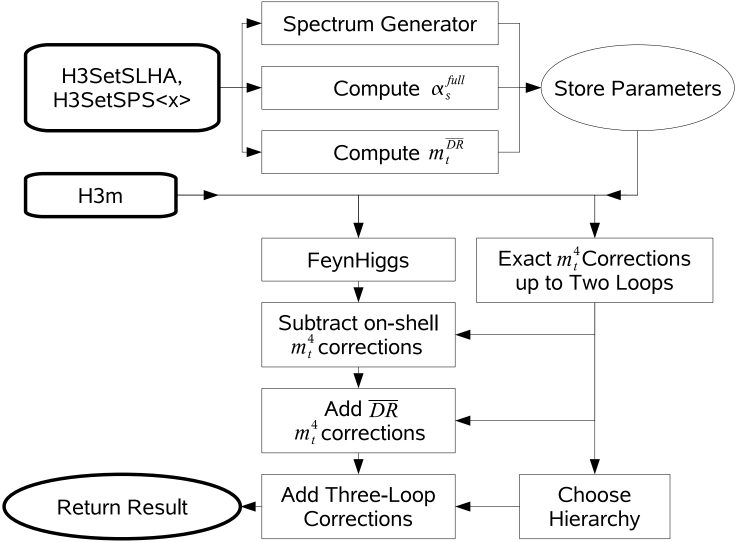
From Formulae to Numbers

- combine with corrections from other sectors
  - use existing “wheel”: `FeynHiggs`
  - consistent renormalisation of parameters (on-shell vs. modified minimal subtraction)
  - consistent values of parameters
    - spectrum generator (`SOFTSUSY`, `SPheno`, `SuSpect`)
    - evolve α_S (`RunDecSUSY`)
    - convert m_t to $\overline{\mathrm{DR}}$ scheme (`TSIL`)
- automatic choice of appropriate approximation
  - compare approximation at two loops with full two loop result

From Formulae to Numbers

- combine with corrections from other sectors
  - use existing "wheel": `FeynHiggs`
  - consistent renormalisation of parameters (on-shell vs. modified minimal subtraction)
  - consistent values of parameters
    - spectrum generator (`SOFTSUSY`, `SPheno`, `SuSpect`)
    - evolve α_S (`RunDecSUSY`)
    - convert m_t to $\overline{\mathrm{DR}}$ scheme (`TSIL`)
- automatic choice of appropriate approximation
  - compare approximation at two loops with full two loop result
- convenience: Susy Les Houches Accord interface

Program Flow

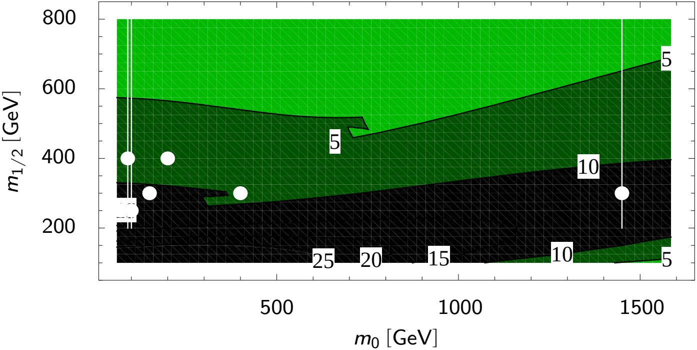


Sample Session

```
In[1]:= Needs["H3`"];

In[2]:= H3SetSPS1a[300.];

In[3]:= H3m[]

Out[3]= {mh -> 114.176}
```

Covering the Parameter Space

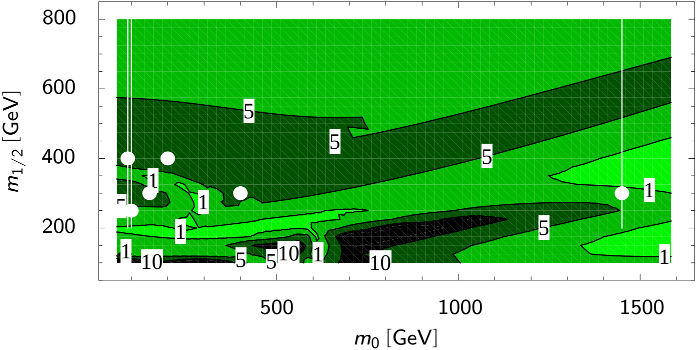
comparison of approximation and full result at two loops using an MSUGRA scenario:



relative error in %

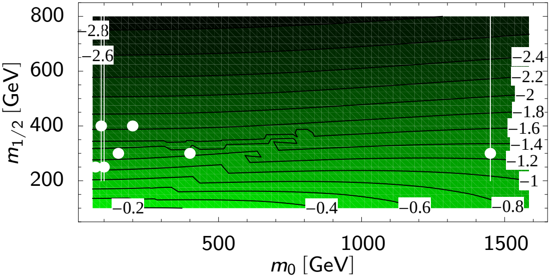
Covering the Parameter Space

comparison of approximation and full result at two loops using an MSUGRA scenario:

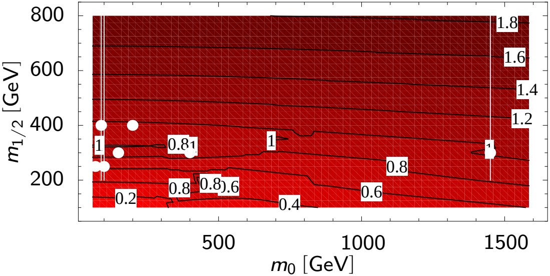


relative error in %

- error due to expansion in masses under control

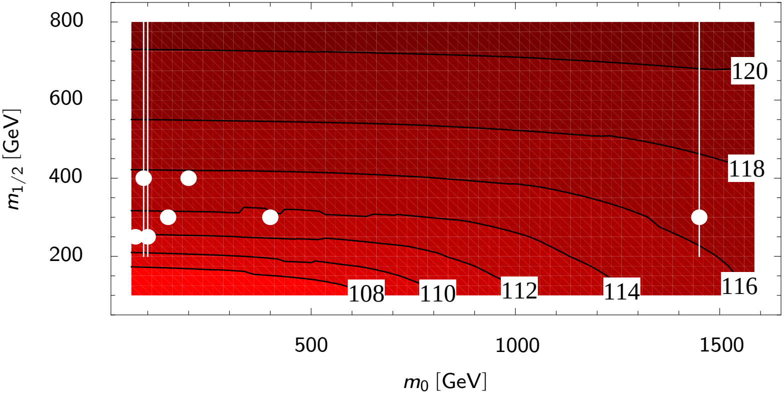


two-loop corrections in GeV



three-loop corrections in GeV

Result for M_h



Status of M_h

- three-loop corrections are sizeable: up to $\approx 3\,\mathrm{GeV}$
- remaining uncertainty:
  unknown higher orders:

  parametric uncertainty:

Status of M_h

- three-loop corrections are sizeable: up to $\approx 3\,\mathrm{GeV}$
- remaining uncertainty:
  unknown higher orders:

$\ll 1\,\mathrm{GeV}$	missing two-loop contributions
$< 200\,\mathrm{MeV}$	approximations at three-loop level
$\approx 100\,\mathrm{MeV}$ to $1\,\mathrm{GeV}$	missing higher order corrections

  parametric uncertainty:

$\approx 350\,\mathrm{MeV}$ to $1\,\mathrm{GeV}$	top mass
$\approx 80\,\mathrm{MeV}$ to $600\,\mathrm{MeV}$	strong coupling
$\approx 500\,\mathrm{MeV}$	stop mass

Status of M_h

- three-loop corrections are sizeable: up to $\approx 3\,\text{GeV}$
- remaining uncertainty:
  unknown higher orders:

$\ll 1\,\text{GeV}$	missing two-loop contributions
$< 200\,\text{MeV}$	approximations at three-loop level
$\approx 100\,\text{MeV}$ to $1\,\text{GeV}$	missing higher order corrections

  parametric uncertainty:

$\approx 350\,\text{MeV}$ to $1\,\text{GeV}$	top mass
$\approx 80\,\text{MeV}$ to $600\,\text{MeV}$	strong coupling
$\approx 500\,\text{MeV}$	stop mass

- parametric and intrinsic uncertainties comparable