Three-Loop Corrections to the Mass of the Light Higgs Boson in the MSSM

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in collaboration with

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Motivation

why consider Higgs sector of MSSM?

- quite predictive
  two new free parameters at tree level

$$M_A, \ \tan\beta$$

- important for possible discovery of MSSM
- experimentally: M_h precision observable
  $\delta M_h \approx 100 - 200\,\text{MeV}$ for light Higgs at LHC
  - need to match this precision!

Higgs Mass in the MSSM

Higgs Potential

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

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

difference to the SM : quartic terms fixed by gauge couplings

- $M_h \leqslant M_Z$ at tree level

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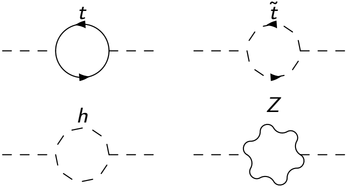
difference to the SM : quartic terms fixed by gauge couplings

- $M_h \leqslant M_Z$ at tree level
- radiative corrections depend on SUSY breaking

Radiative Corrections to M_h



- corrections from heavy particles

  [Ellis,Ridolfi,Zwirner 1991; Haber,Hempfling 1991; Okada,Yamaguchi,Yanagida 1991, Chankowski,Pokorski,Rosiek 1994; Dabelstein 1995; Bagger,Matchev,Pierce,Zhang 1997]

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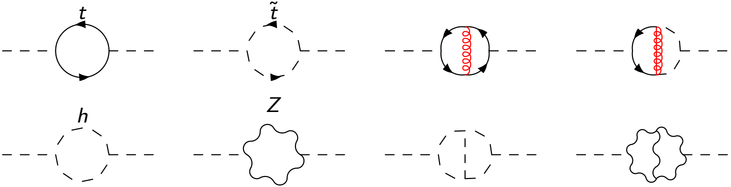

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- even more important at two loops (α_s) [Brignole, Carena, Casas, Dedes, Degrassi, Espinosa, Haber, Hempfling, Heinemeyer, Hoang, Hollik, Martin, Quirós, Riotto, Rzehak, Slavich, Wagner, Weiglein, Zhang, Zwirner, ... '94-today]

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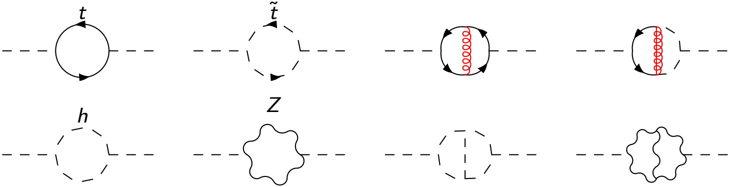

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- 3loop LL and NLL through renormalisation group [Martin '07]
- remaining uncertainty: $\approx 3 - 5\,\text{GeV}$ (LHC: $100 - 200\,\text{MeV}$)

What Can Be Done at the Three-Loop Level?

- full calculation of all three-loop contributions is not feasible
  - use effective potential approximation $(p^2 = 0)$
  - restrict to t and $\tilde{t}$ loops
  - virtual particles: t, $\tilde{t}$, g, $\tilde{g}$, q, $\tilde{q}$

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  - 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

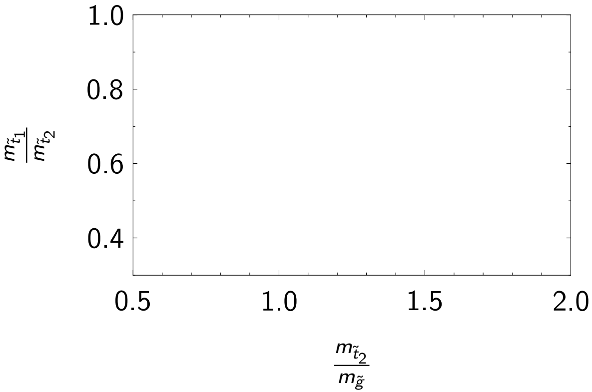
$$m_q = 0, \quad m_t \ll m_{\tilde{t}_1} \approx m_{\tilde{t}_2} \approx m_{\tilde{g}} \approx m_{\tilde{q}}$$
$$m_t \ll m_{\tilde{t}_1} \ll m_{\tilde{t}_2} \approx m_{\tilde{g}} \ll m_{\tilde{q}}$$

nice check: unbroken SUSY

  - asymptotic expansions lead to one-scale integrals

Error due to Expansion – Two Loops

compare expansion with exact result [Degrassi, Slavich, Zwirner '01]



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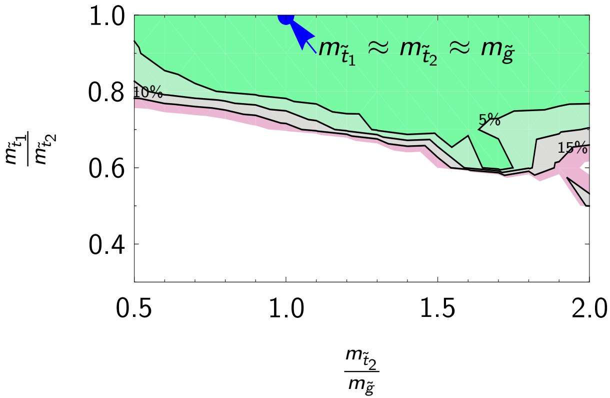

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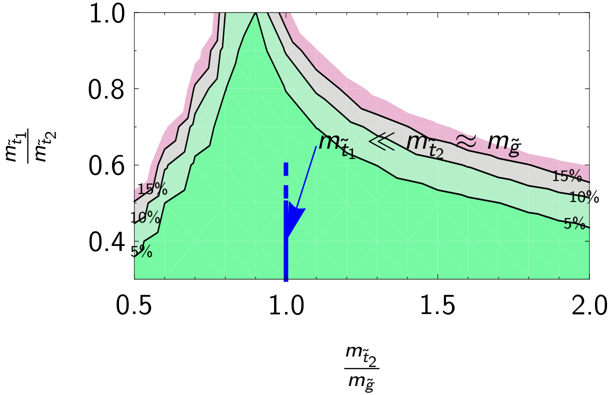

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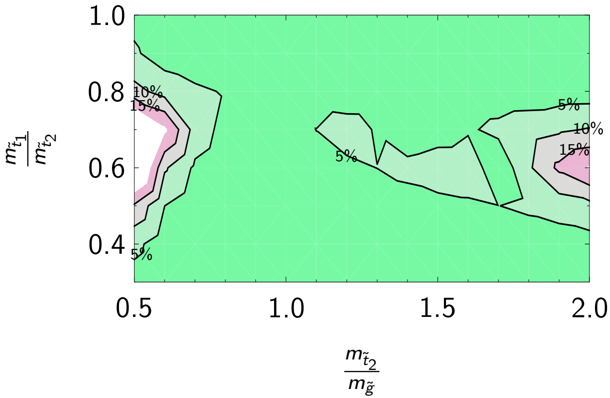

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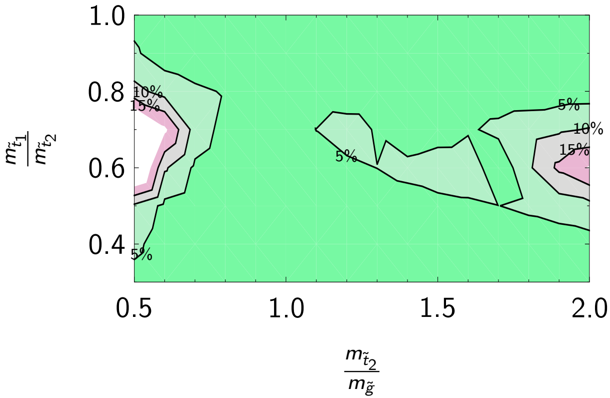

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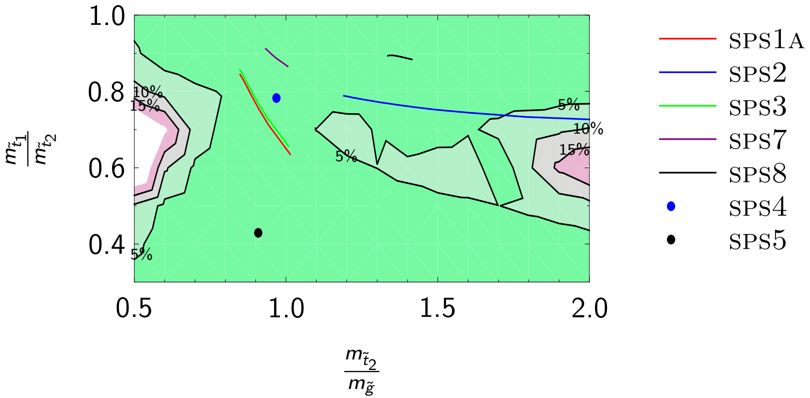
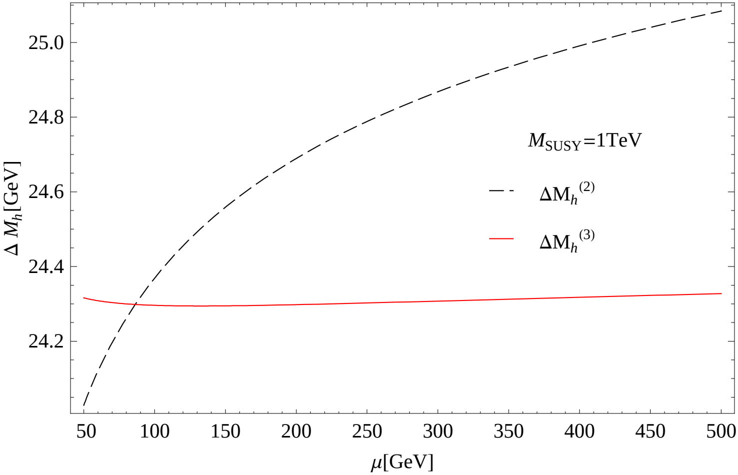


error at two loops: $\lesssim 5\%$

Outline of the Calculation

- generate diagrams ... lots (30.717)
  QGRAF [Nogueira]
- asymptotic expansions
  Q2E, EXP [Harlander, Seidensticker]
- three-loop one-scale integrals
  MINCER, MATAD, FORM [Larin, Tkachov; Steinhauser; Vermaseren]

Reduced Scale Dependency



Renormalisation Scheme Dependence

- regularisation by Dimensional Reduction [Siegel '79]
- renormalisation: minimal subtraction vs. on-shell

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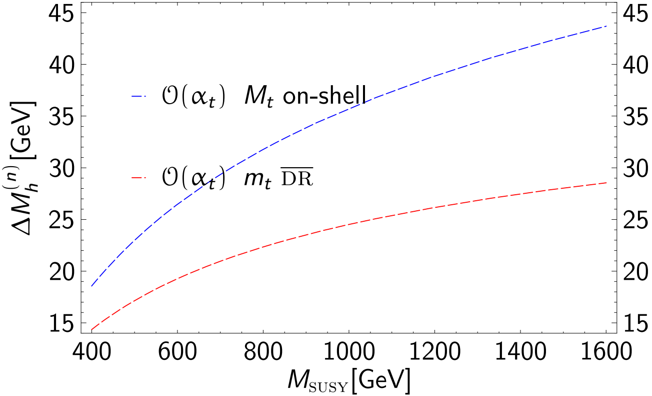

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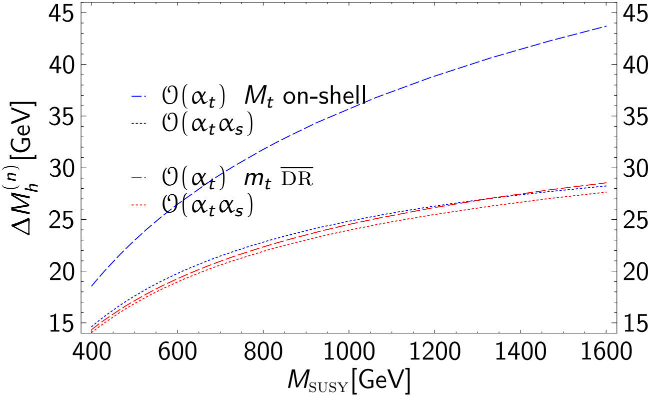

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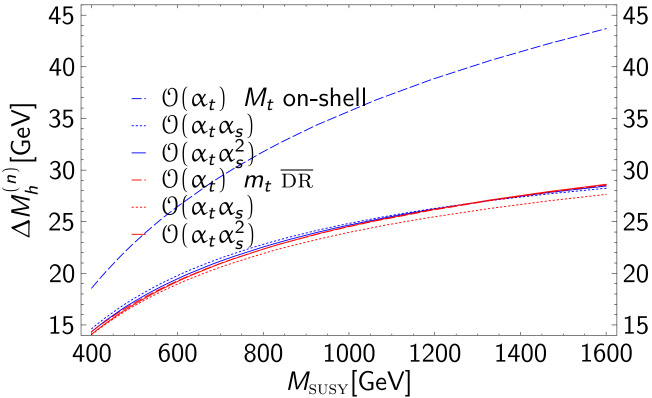

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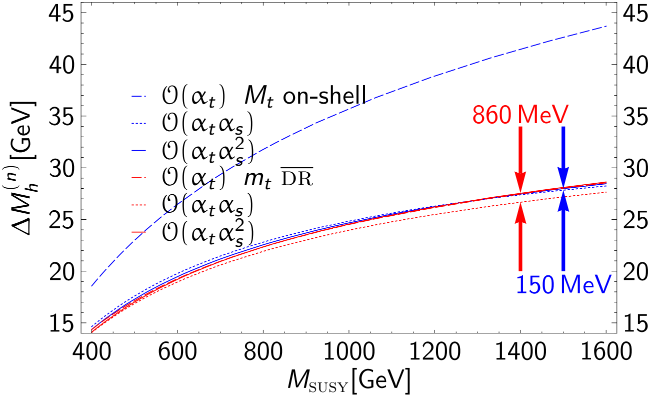
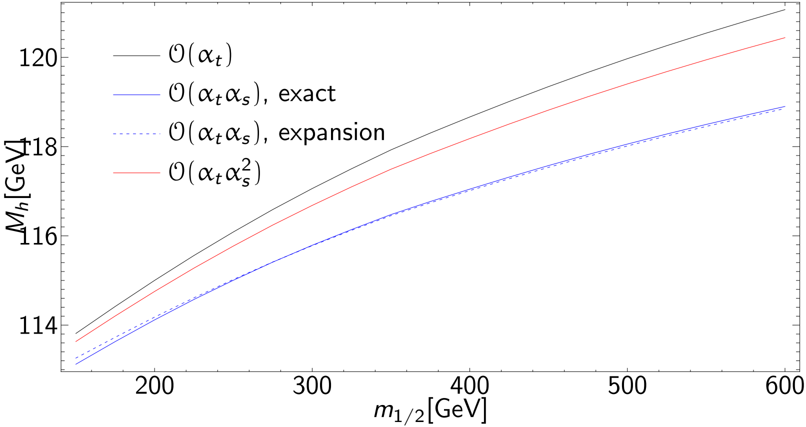


choice: minimal subtraction using Dimensional Reduction ($\overline{\mathrm{DR}}$)

M_h for Benchmark Line SPS2 – PRELIMINARY



Conclusion

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  - effect of about 500 MeV
  - cannot be neglected
- scheme dependency greatly reduced
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  - effect of about 500 MeV
  - cannot be neglected
- scheme dependency greatly reduced
- feasible to cover whole SPS range
- checks to our results:
  - agreement with literature
    two-loop [Degrassi, Slavich, Zwirner '01]
    3-loop LL and NLL [Martin '07]
  - calculated in general covariant gauge
  - calculation in unbroken SUSY: corrections vanish