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

Philipp Kant

in collaboration with

R. V. Harlander, L. Mihaila, M. Steinhauser

Universität Karlsruhe, TTP

EPS-HEP 2009, Krakow

Higgs Mass in the MSSM

MSSM Higgs sector: 2 Higgs doublet model h, H, A, $H^{\pm}$ masses and mixings are very constrained

- $M_h \leq M_Z$ at tree level

Higgs Mass in the MSSM

MSSM Higgs sector: 2 Higgs doublet model h, H, A, $H^{\pm}$ masses and mixings are very constrained

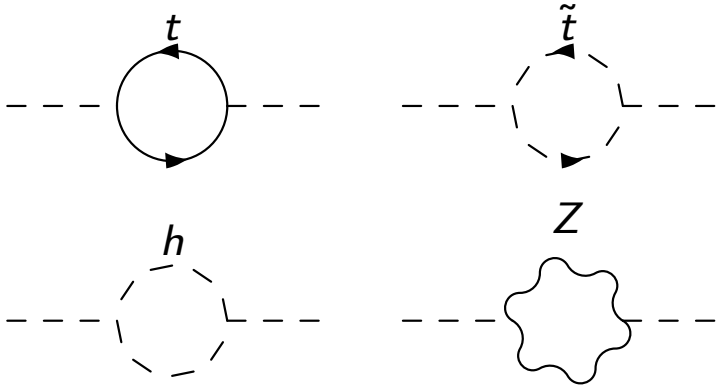
- $M_h \leq M_Z$ at tree level
- radiative corrections depend on SUSY breaking

Higgs Mass in the MSSM

MSSM Higgs sector: 2 Higgs doublet model h, H, A, $H^{\pm}$
masses and mixings are very constrained

- $M_h \leq M_Z$ at tree level
- radiative corrections depend on SUSY breaking
- experimentally: M_h precision observable
  $\delta M_h \approx 100 - 200\,\text{MeV}$ for light Higgs at LHC
  - need to match this precision!

Radiative Corrections to M_h

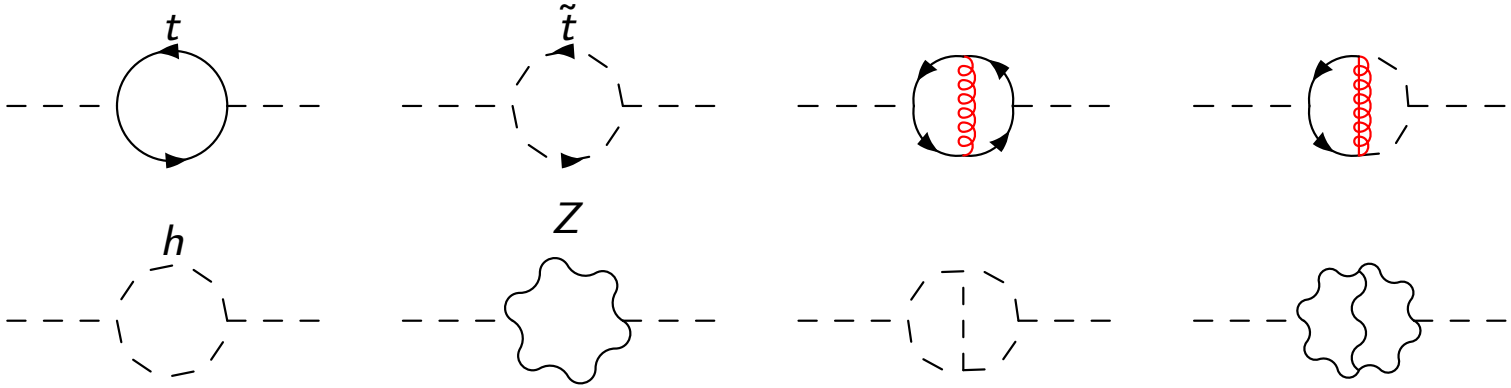


- corrections from heavy particles

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

- top quark and its superpartners dominate: shift of $+35\,\text{GeV}$

Radiative Corrections to M_h

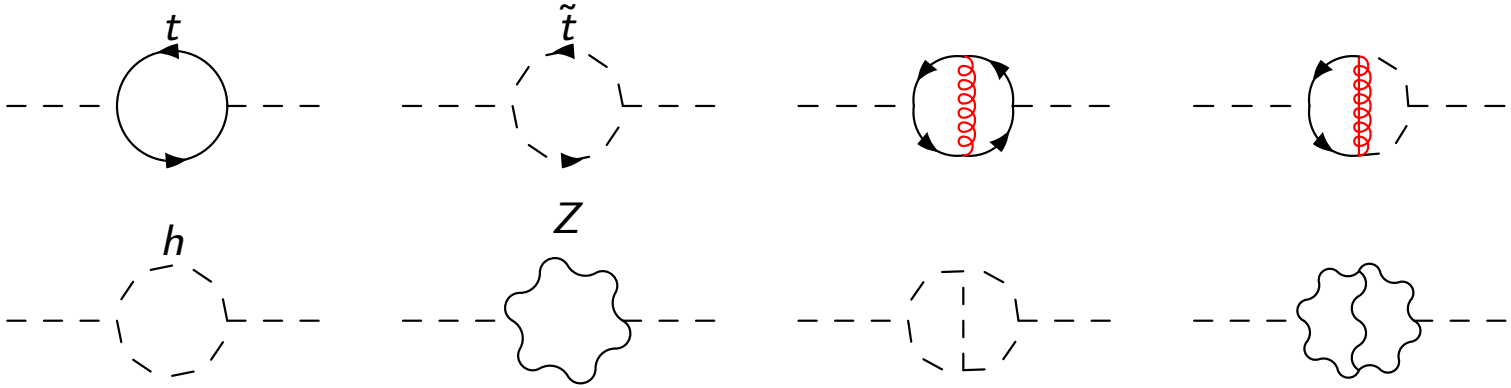


- corrections from heavy particles

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

- top quark and its superpartners dominate: shift of $+35\,\text{GeV}$
- 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]

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]

- top quark and its superpartners dominate: shift of $+35\,\text{GeV}$
- 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]
- 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
  - restrict to t and $\tilde{t}$ loops
  - virtual particles: t, $\tilde{t}$, g, $\tilde{g}$, q, $\tilde{q}$

What Can Be Done at the Three-Loop Level?

- 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

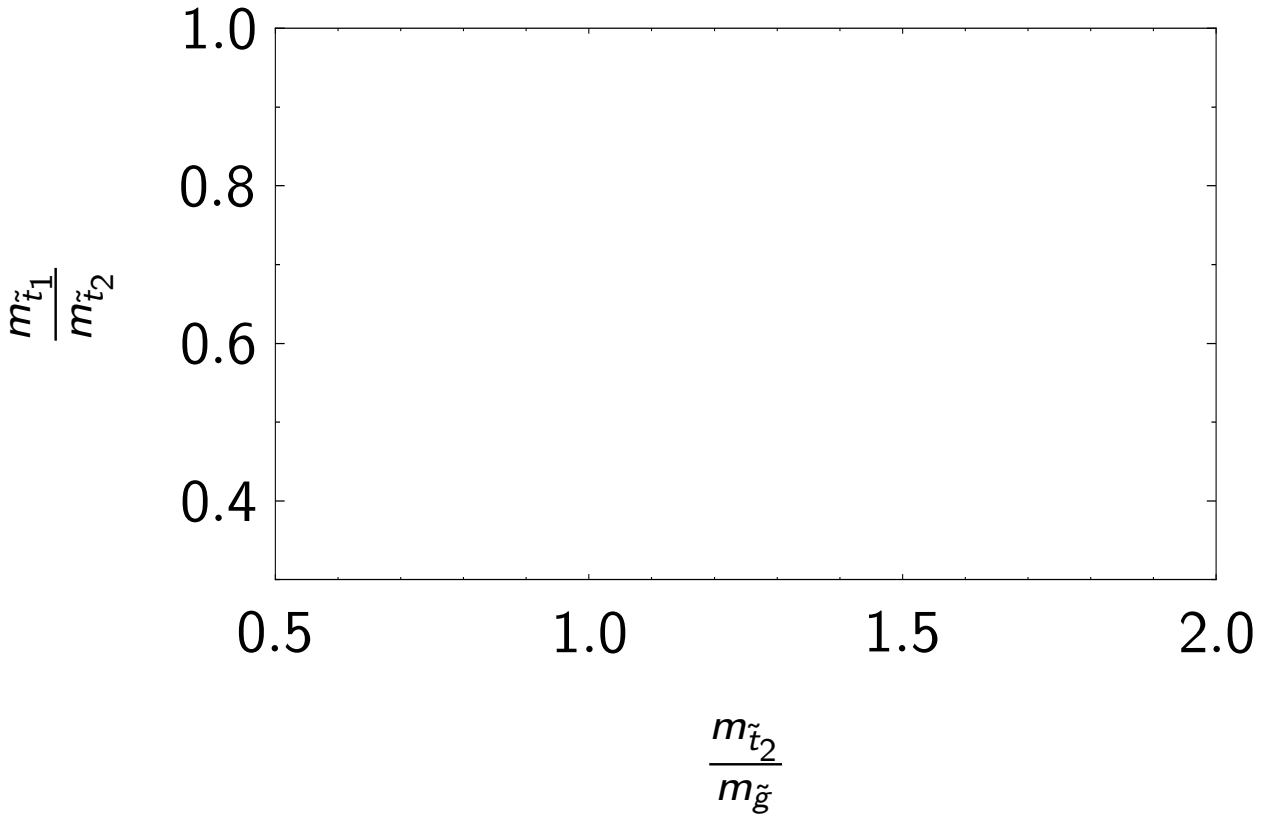
$$m_q = 0, \quad m_t \ll m_{\tilde{t}_1} \approx m_{\tilde{t}_2} \approx m_{\tilde{g}} \approx m_{\tilde{q}}$$
$$m_t \ll m_{\tilde{t}_1} \ll m_{\tilde{t}_2} \approx m_{\tilde{g}} \ll m_{\tilde{q}}$$

  - asymptotic expansions lead to one-scale integrals

Error due to Expansion – Two Loops

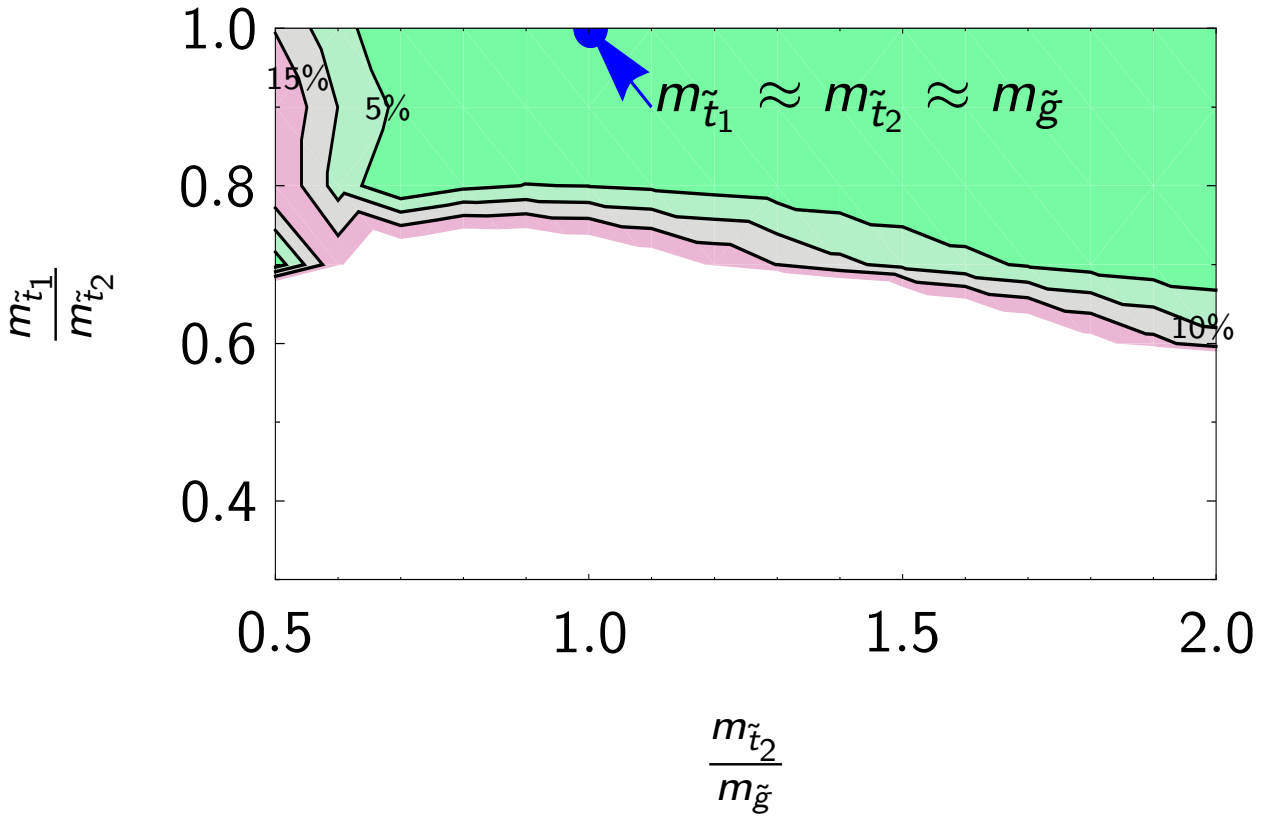
compare expansion with exact result

[Degrassi, Slavich, Zwirner '01]



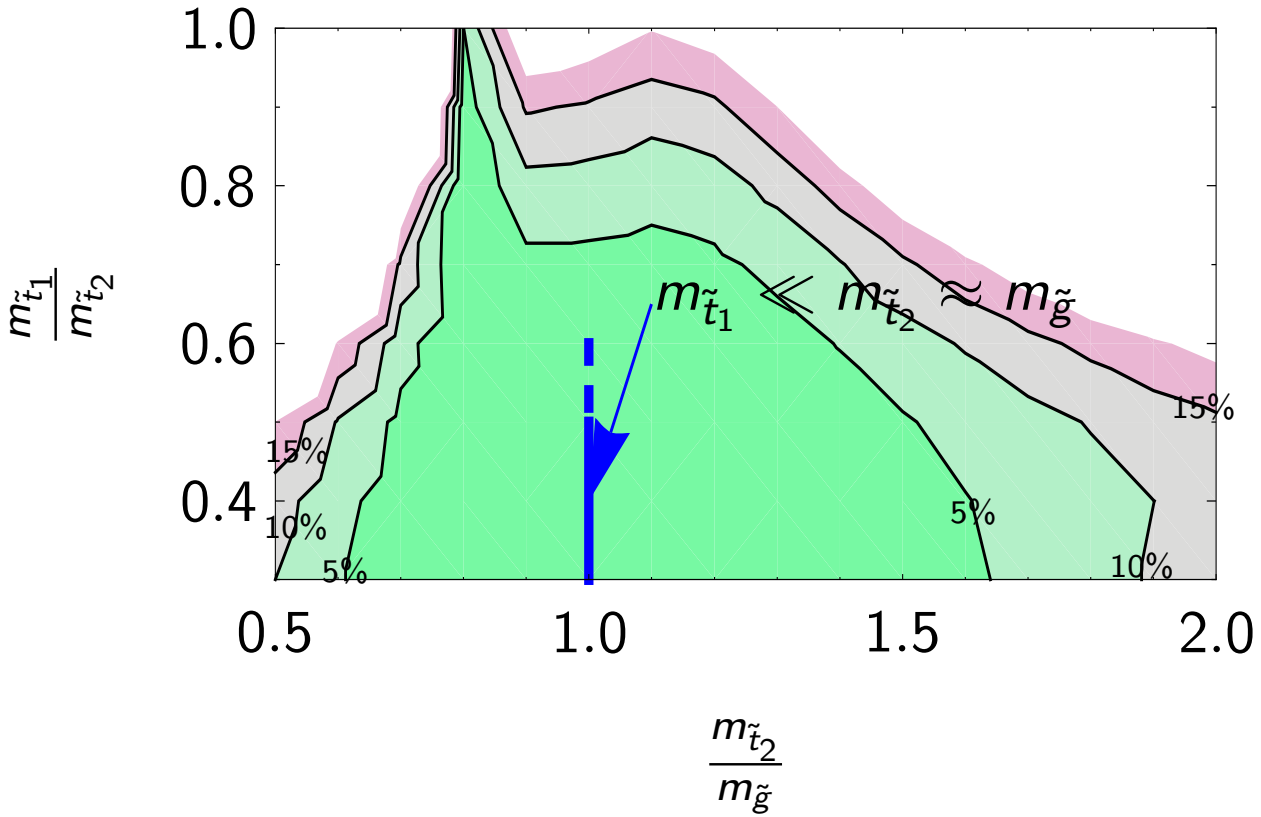
Error due to Expansion – Two Loops

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



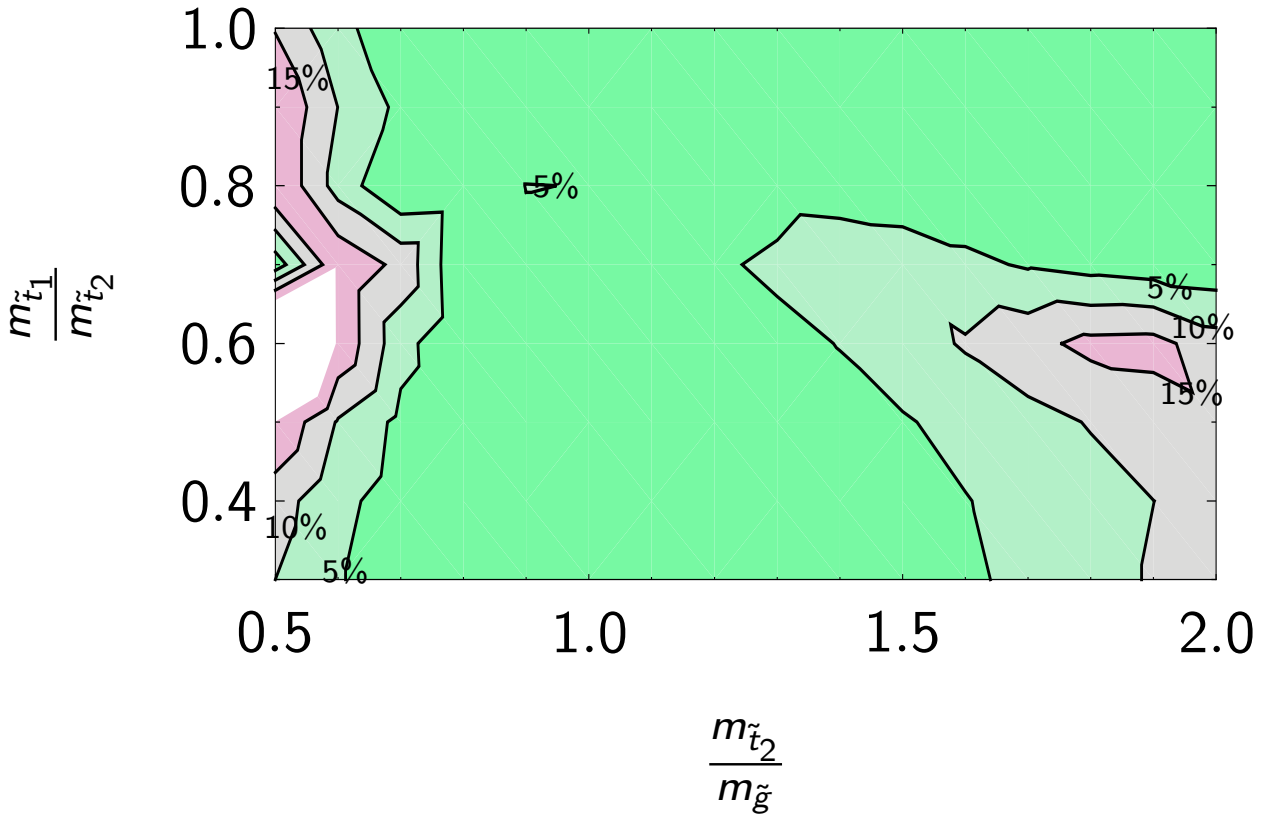
Error due to Expansion – Two Loops

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



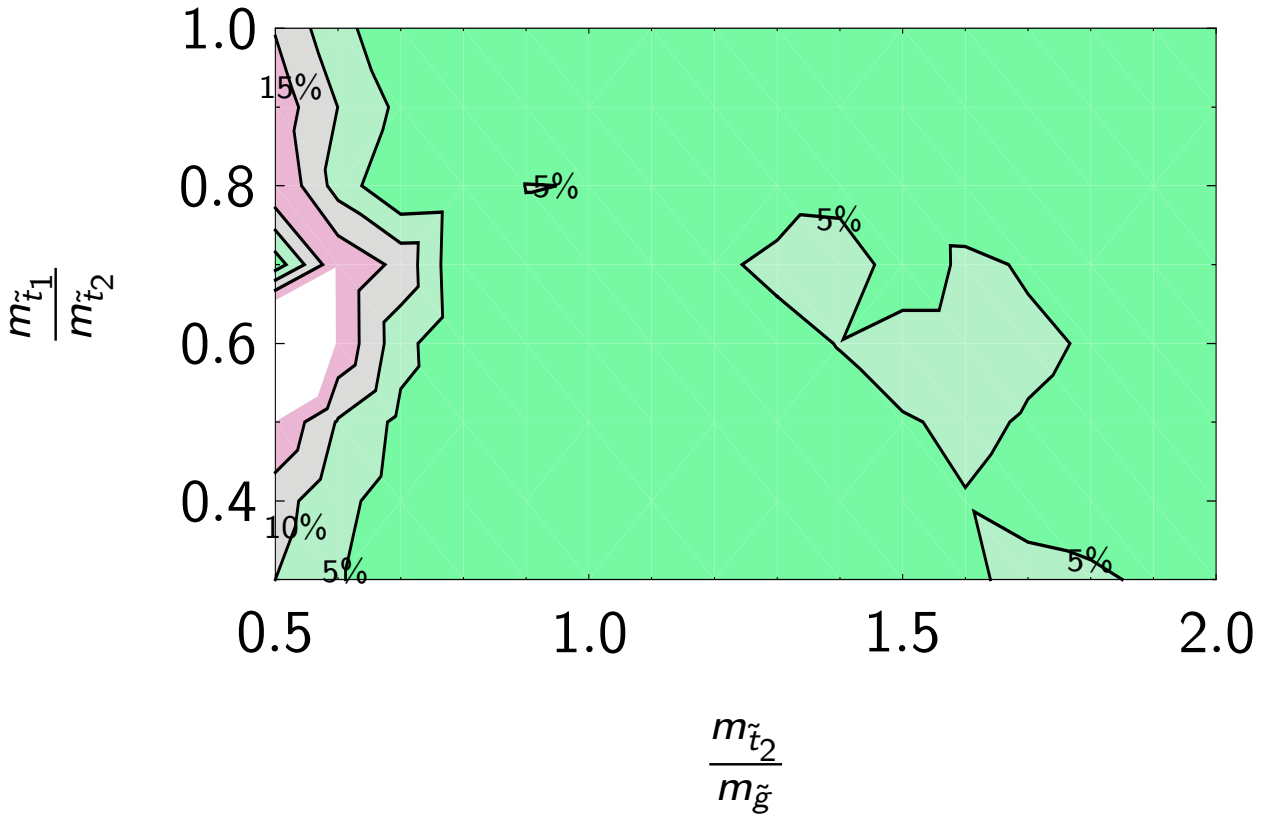
Error due to Expansion – Two Loops

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



Error due to Expansion – Two Loops

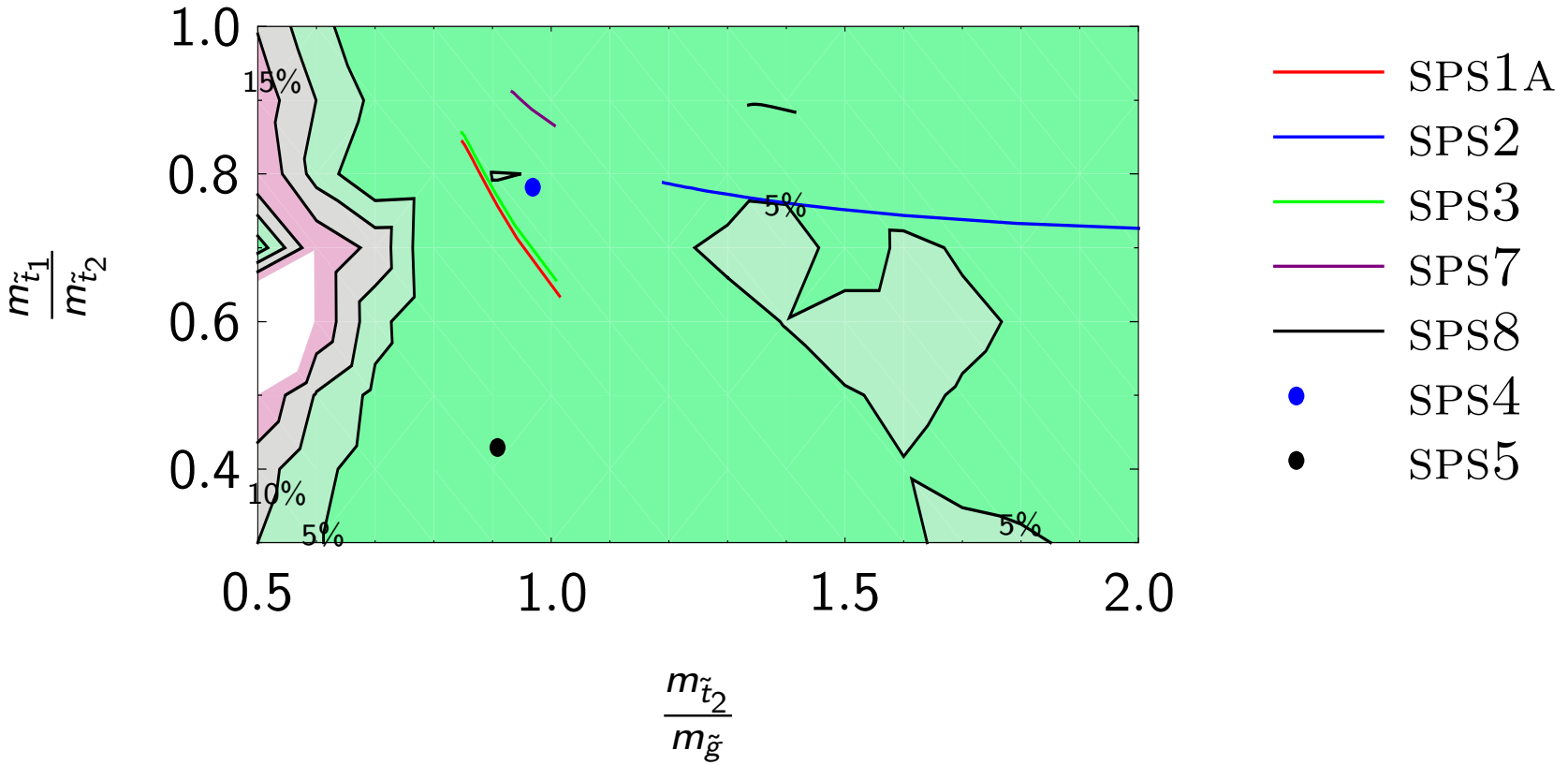
compare expansion with exact result [Degrassi, Slavich, Zwirner '01]



Error due to Expansion – Two Loops

compare expansion with exact result

[Degrassi, Slavich, Zwirner '01]



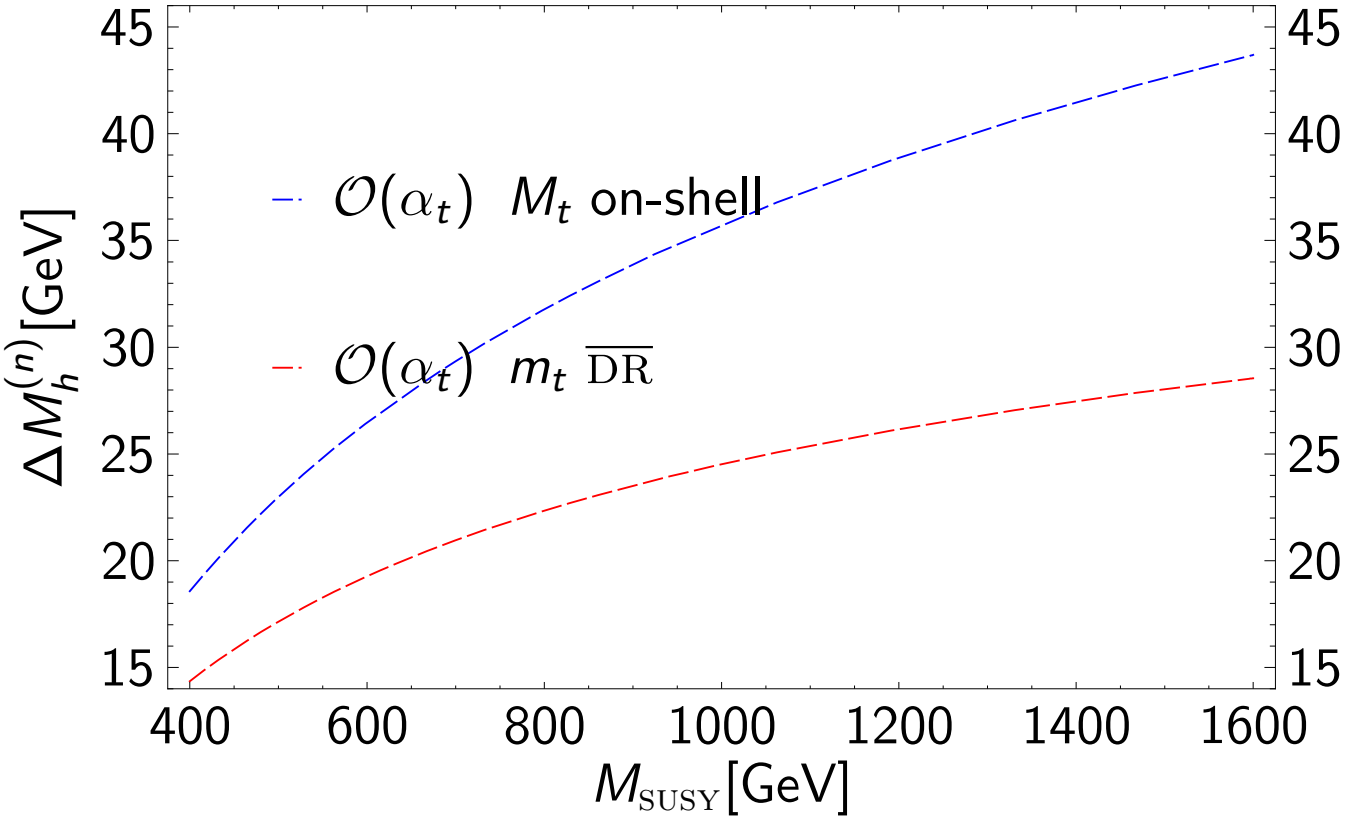
error at two loops: $\lesssim 5\%$

Renormalisation Scheme Dependence

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

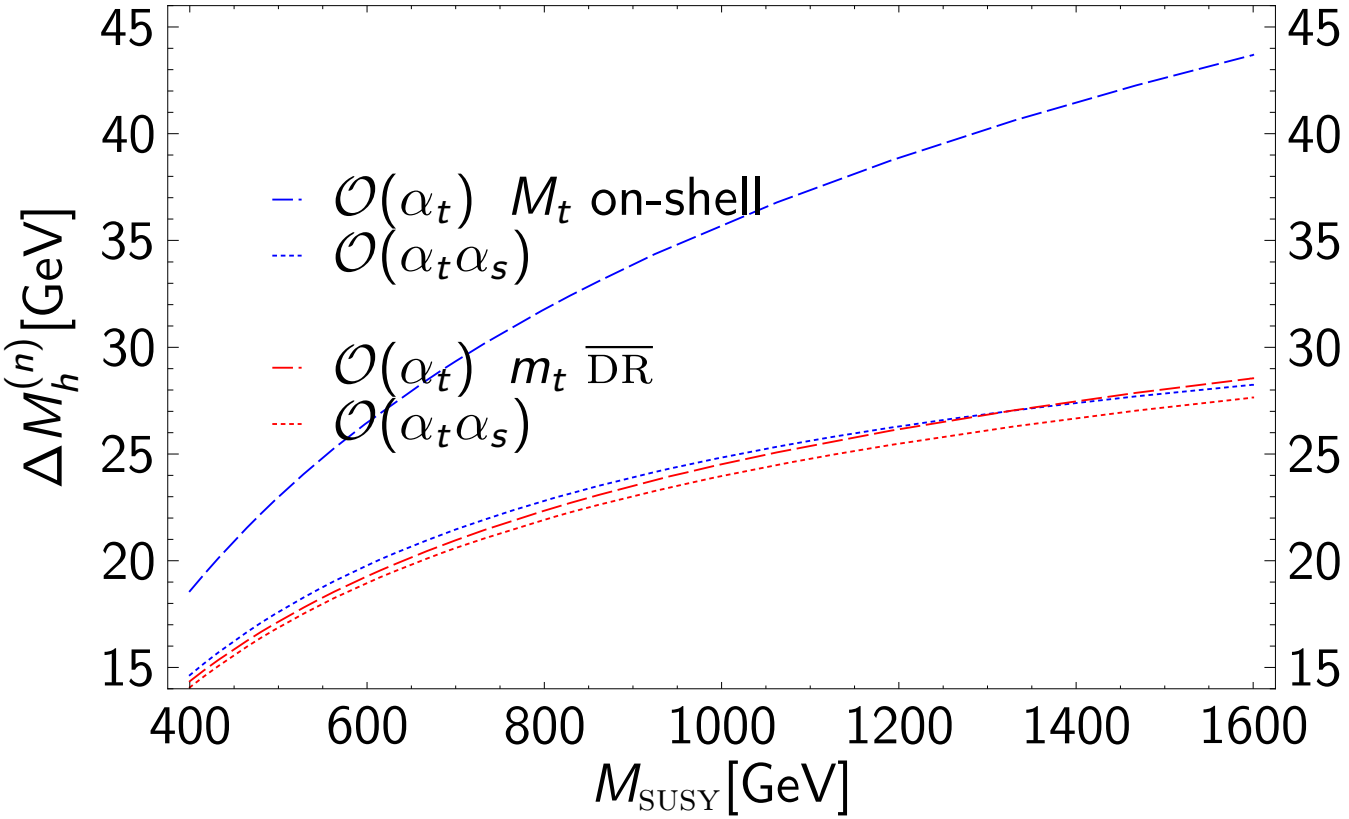
Renormalisation Scheme Dependence

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



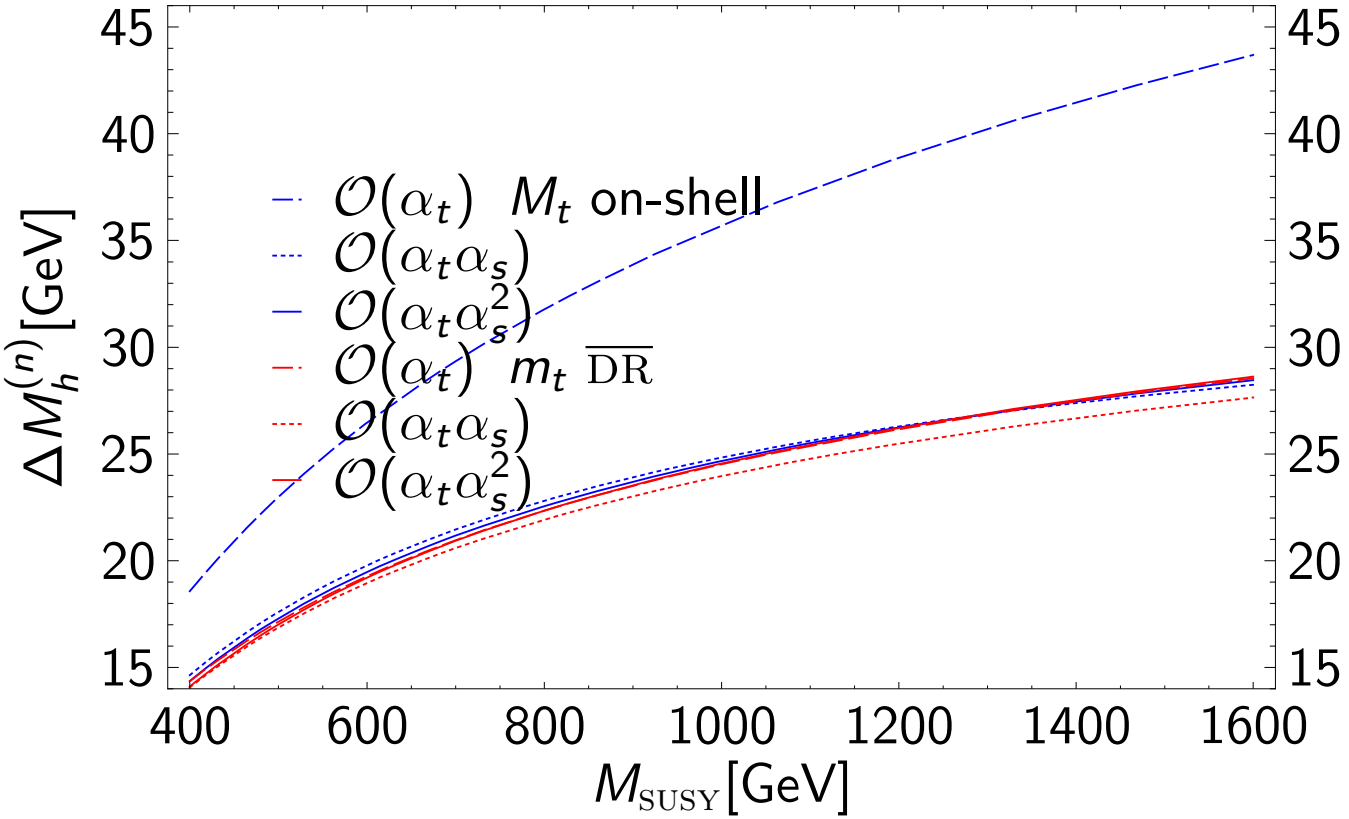
Renormalisation Scheme Dependence

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



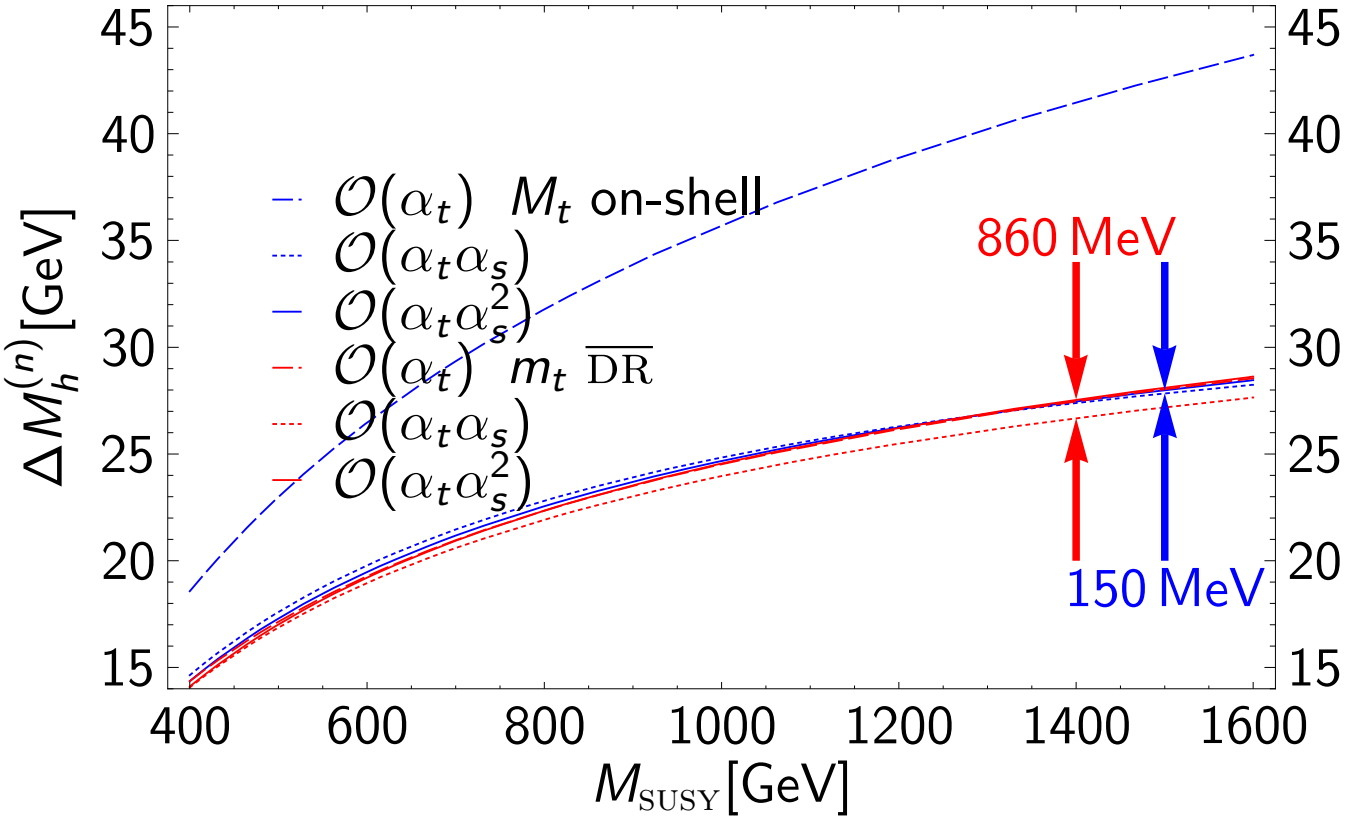
Renormalisation Scheme Dependence

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



Renormalisation Scheme Dependence

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

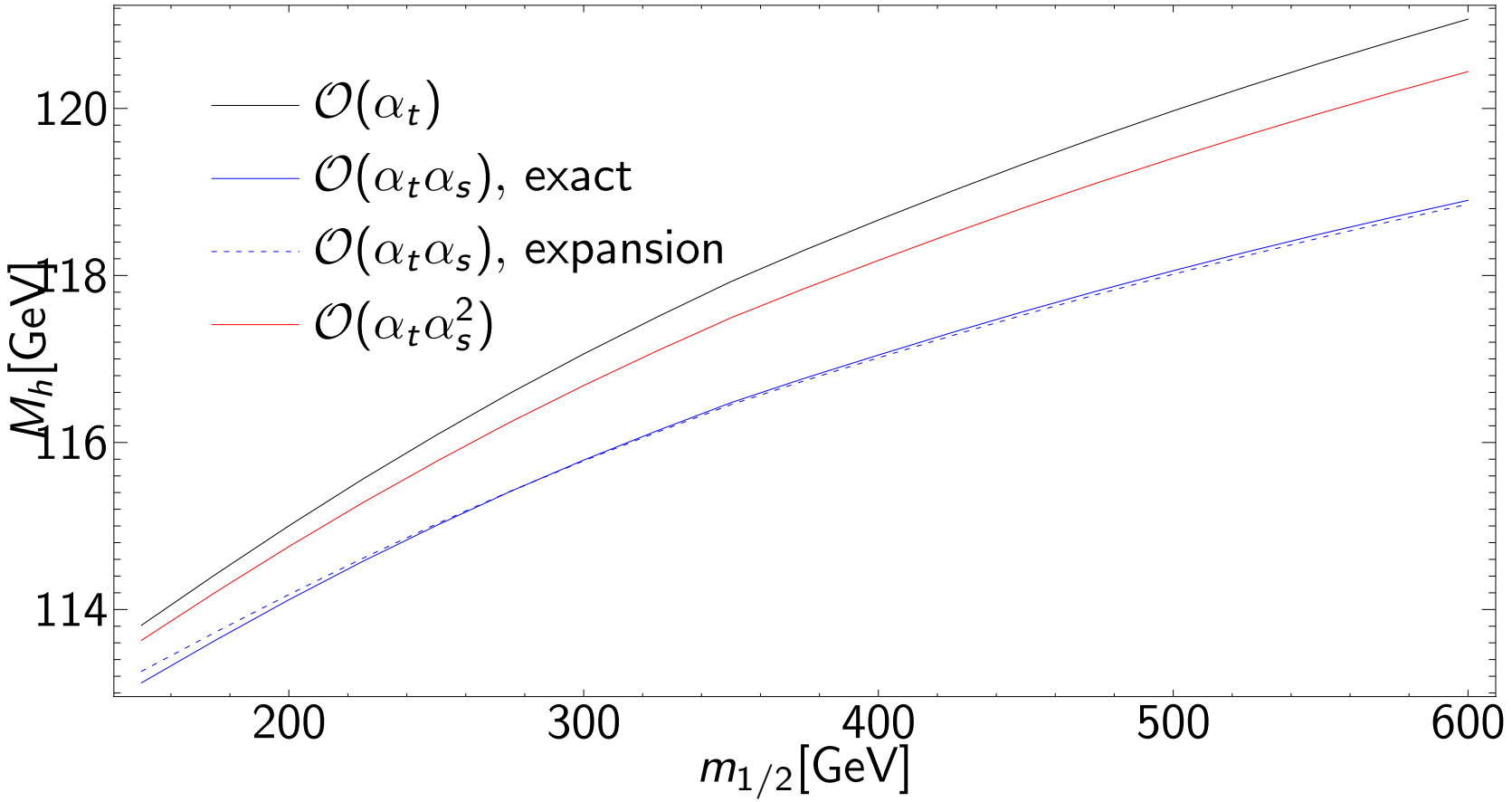


choice: minimal subtraction using Dimensional Reduction ($\overline{\rm DR}$)

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]

M_h for Benchmark Line SPS2 – PRELIMINARY



Conclusion

- three-loop calculation of M_h in the MSSM
  - effect of about 500 MeV
  - cannot be neglected
- scheme dependency greatly reduced
- feasible to cover whole SPS range

Conclusion

- three-loop calculation of M_h in the MSSM
  - 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