W-BOSON MASS IN THE MSSM

SUSY 2005

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OUTLINE

INTRODUCTION

- W-mass can be measured in experiment.
  - Error today: 34MeV (LHC 15MeV, ILC 7MeV)
- W-mass can also be calculated from μ-decay, using the Fermi constant G_F as input.
  - G_F is known with negligible error.
- Comparison of theoretical value for M_W and experiment allows to test the Standard Model (SM).

$\Rightarrow$ Bounds on Higgs mass due to quantum corrections.

- Loop effects in μ-decay are also sensitive to beyond SM physics.

$\Rightarrow$ Possibility to investigate influence of MSSM particle spectrum on W-mass.

Present status of W-mass calculation

- SM:
  - Full two-loop calculation was accomplished [Freitas, Hollik, Walter, Weiglein] & [Awramik, Czakon].
  - Three-loop $O(\alpha_s G_F^2 m_t^4), O(G_F^3 m_t^6)$ $\Delta\rho$-terms are also known [Faisst, Kühn, Seidensticker, Veretin].
  - Best SM result is summarised in compact expression for M_W [Awramik, Czakon, Freitas, Weiglein].

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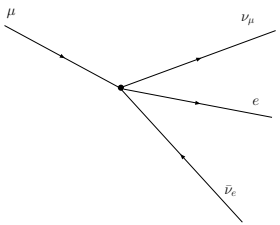
  - Best SM result is summarised in compact expression for M_W [Awramik, Czakon, Freitas, Weiglein].
- MSSM:
  - One-loop result by [Chankowski, Dabelstein, Hollik, Mösle, Pokorski, Rosiek] & [Garcia, Solà].
  - MSSM $O(\alpha\alpha_s), O(\alpha_t^2), O(\alpha_t\alpha_b), O(\alpha_b^2)$ $\Delta\rho$ two-loop results contained in program POMSSM [Heinemeyer, Weiglein].

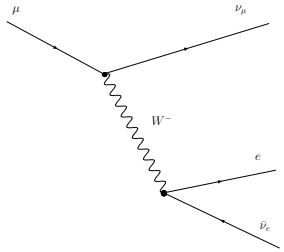
- We will present an independent MSSM one-loop calculation. No restrictions on MSSM parameters are made. All complex phases are taken into account.
- All available beyond one-loop contributions from SM and MSSM are considered.

$\Rightarrow$ Most precise MSSM prediction for the W-mass.

Born level



$$\frac{G_F}{\sqrt{2}} = \frac{e^2}{8 s_W^2 M_W^2}$$



- Need to take radiative corrections into account.
- Fermion masses only occur of order $\frac{m_f^2}{M_W^2}$.

  $\Rightarrow$ Neglect light fermion masses and external momenta, summarise radiative corrections by Δr.

Loop order

$$\frac{G_F}{\sqrt{2}} = \frac{e^2}{8 s_W^2 M_W^2}(1 + \Delta r)$$

One-loop result Δr^{1L} is commonly decomposed into leading and remainder terms:

$$\Delta r^{1L} = \Delta\alpha - \frac{c_w^2}{s_w^2}\Delta\rho + \Delta r^{1L}_{rem}$$

- $\Delta\alpha$:
  - Originates from the charge renormalisation.
  - Gets main contributions from light fermions.
- $\Delta\rho$:
  - Originates from weak mixing angle renormalisation.
  - Gets large contributions from (s)top (s)bottom doublet.
  - Parametrises the leading universal contributions to many electroweak precision observables.

Basic strategy

- Calculate Δr in the Standard Model/MSSM.
- Find W-boson mass M_W using

$$M_W^2 = M_Z^2 \left(\frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\alpha\pi(1 + \Delta r(M_W, M_Z, m_t, \Delta\alpha_{had}^{(5)}, X, \dots))}{\sqrt{2} G_F M_Z^2}} \right) .$$

$$\begin{aligned} \text{SM: } X &= M_H \\ \text{MSSM: } X &= M_{h^0}, M_{H^0}, M_{A^0}, M_{H^\pm}, M_{\tilde{f}}, M_{\tilde{\chi}^{0,\pm}}, \\ &\quad \tan\beta, \sin\alpha, \text{mixing angles, complex phases} \dots \end{aligned}$$

CALCULATIONS

- Full MSSM one-loop result for Δr is calculated.
- Leading second order SUSY contributions to Δr are included in terms of $\Delta\rho$.
- Best available SM result (includes corrections up to three-loop order) is taken into account by applying

$$\Delta r^{1L}_{SUSY} = \Delta r^{1L}_{MSSM} - \left[\Delta r^{1L}_{SM}\right]_{M_H=M_{h0}} .$$

$$\Rightarrow \Delta r^{best}_{MSSM} = \left[\Delta r^{best}_{SM}\right]_{M_H=M_{h0}} + \Delta r^{1L}_{SUSY} - \frac{c_w^2}{s_w^2}\Delta\rho^{2L}_{SUSY}$$

MSSM one-loop result

- contributions from
  - Sfermion self energies (leading contributions from stop and sbottom squark).
  - Neutralinos and chargino self energies, vertex and box diagrams.
  - MSSM gauge boson self energies, vertex and box corrections.
- All one-loop contributions are calculated using the Mathematica packages FeynArts [Hahn], OneCalc [Weiglein] and FormCalc [Hahn].
- Most general MSSM parameters are used.
- In particular no restrictions on complex phases are made.

SUSY corrections via $\Delta\rho$

One-loop contributions

- One-loop result for $\Delta\rho$ is highly sensitive to mass splitting between fermions from the same family.

$\Rightarrow$ Large contributions from (s)top and (s)bottom (s)quarks

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Two-loop contributions

- QCD corrections
  - Gluon exchange diagrams in stop-sbottom loops of $\Sigma_T^{ZZ,WW}(0)$.
  - Gluino insertions in stop-sbottom loops of $\Sigma_T^{ZZ,WW}(0)$.
  - $m_{\tilde{b}_1}$ mass shift; not all four sfermion masses can be renormalized independently.

  [Djouadi, Gambino, Heinemeyer, Hollik, Jünger, Weiglein]

- Yukawa contributions of $O(\alpha_t^2),\ O(\alpha_t\alpha_b),\ O(\alpha_b^2)$
  - Top-bottom quark loops with MSSM-Higgs exchange.
  - Stop-sbottom squark loops with MSSM-Higgs exchange.
  - (S)top-(s)bottom loops with Higgsino exchange.

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  [Haestier, Heinemeyer, Stöckinger, Weiglein]
- Resummation of leading SUSY one-loop terms according to

$$1 + \Delta r = \frac{1}{(1 - \Delta\alpha)(1 + \frac{c_w^2}{s_w^2}\Delta\bar{\rho}) - \Delta r_{rem}}$$

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- Extract best available SM result for Δr from compact formula for M_W^{SM} [Awramik, Czakon, Freitas, Weiglein].

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- Extract best available SM result for Δr from compact formula for M_W^{SM} [Awramik, Czakon, Freitas, Weiglein].
- Use Higgs masses from FeynHiggs (www.feynhiggs.de) [Hahn, Heinemeyer, Hollik, Weiglein].

RESULTS

Δr **one-loop**

- One-loop results were compared with POMSSM.
- Acceptable agreement was found, despite the fact that very different conventions were used.
- Leading contributions from squark sector.
- Smaller, but non negligible contributions from neutralinos, charginos and MSSM-Higgs sector.

$\Rightarrow$ Further discussion will focus on sfermion sector, although for calculation of M_W the full MSSM particle spectrum was taken into account.

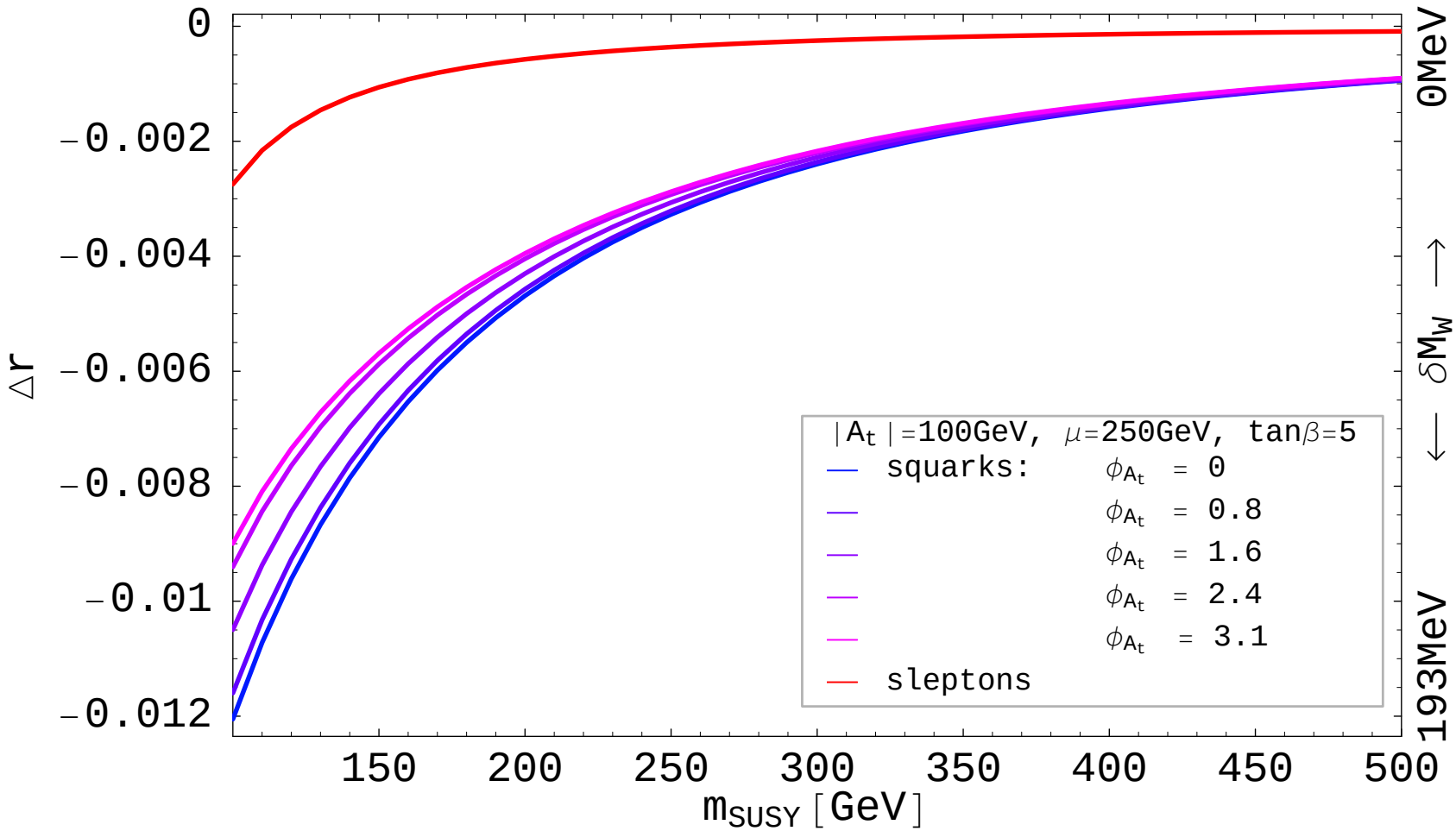
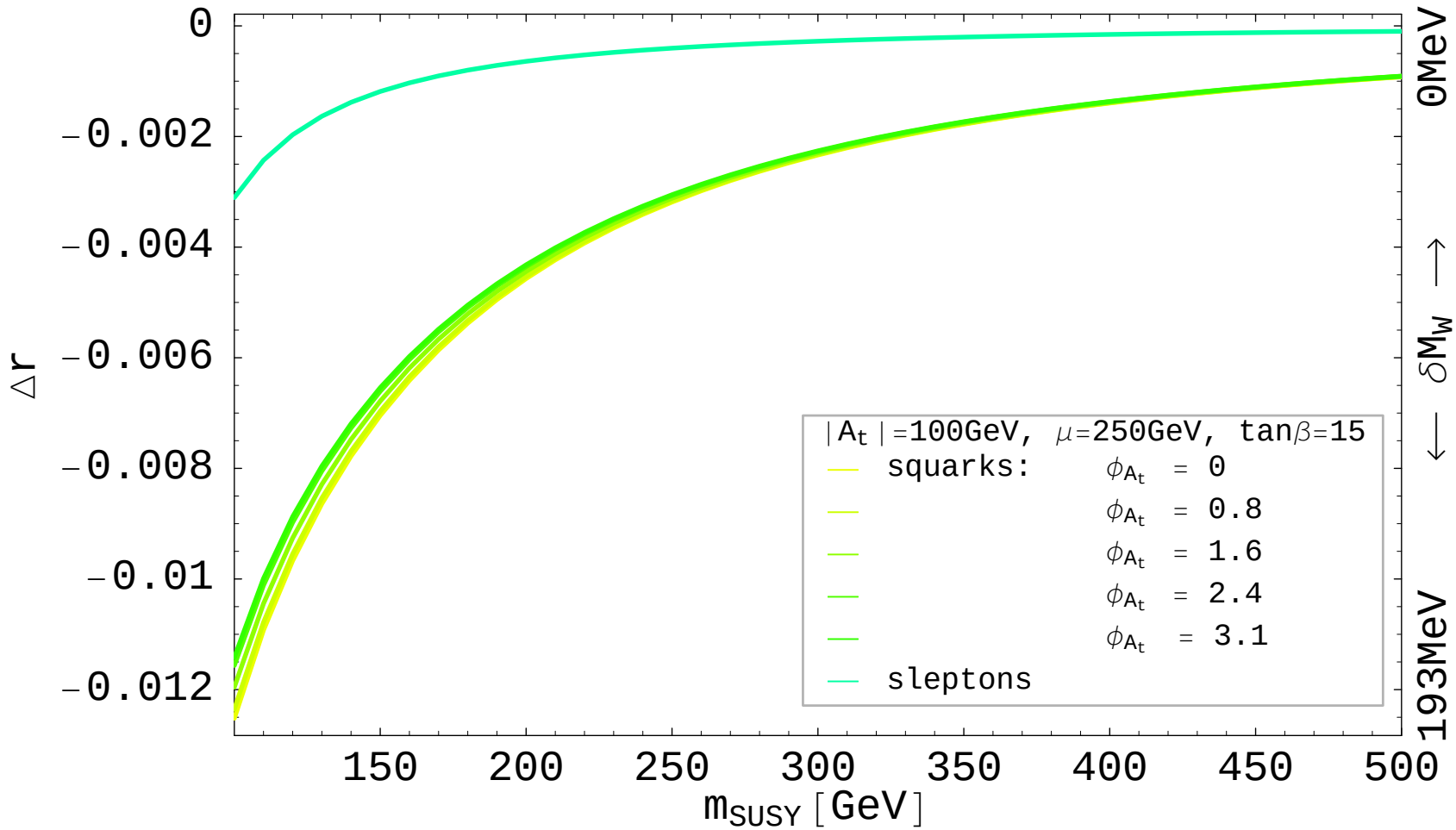


FIGURE: Sfermion contributions to Δr^{1L}



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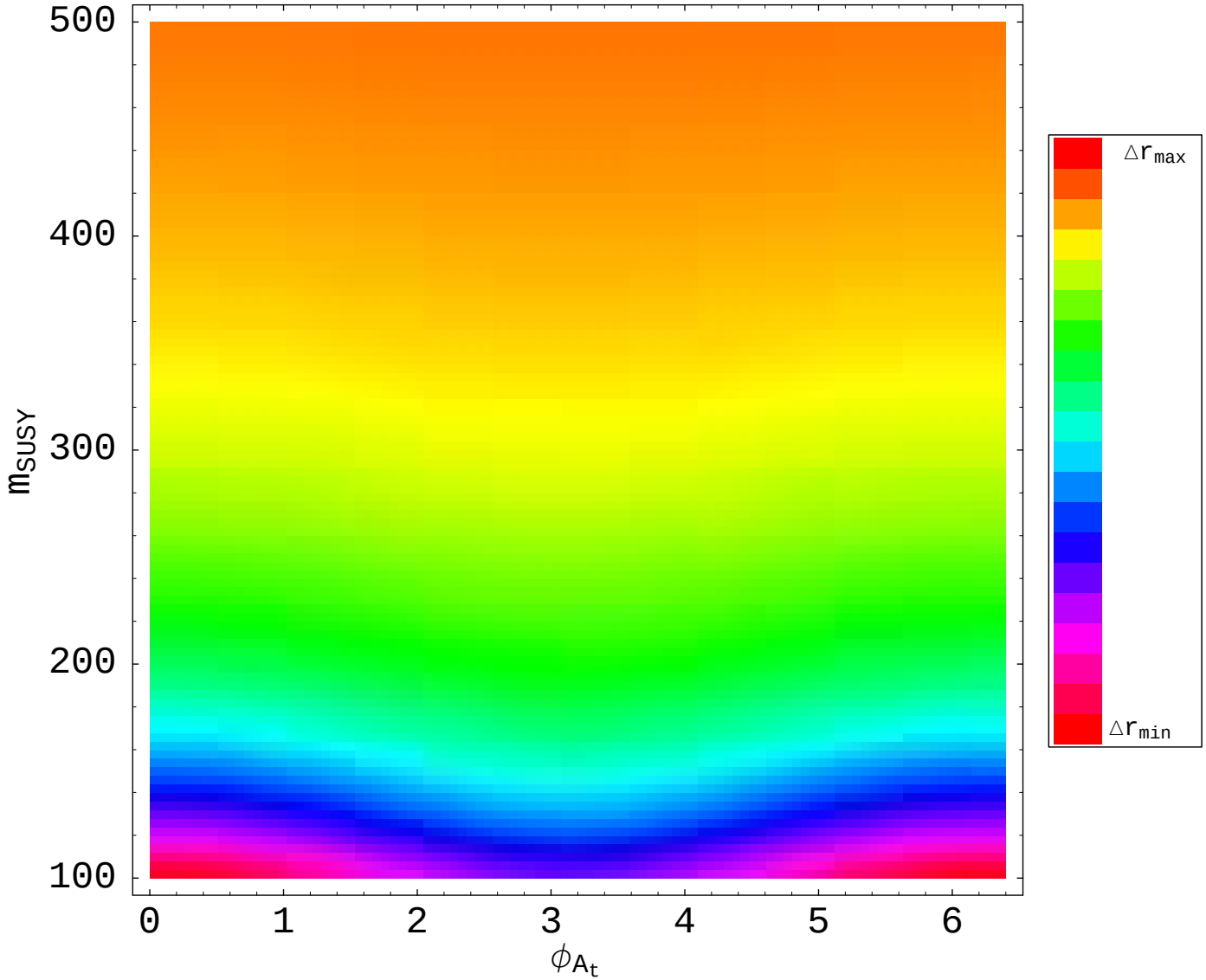

FIGURE: Sfermion contributions to Δr^{1L} ($\tan\beta = 5$)

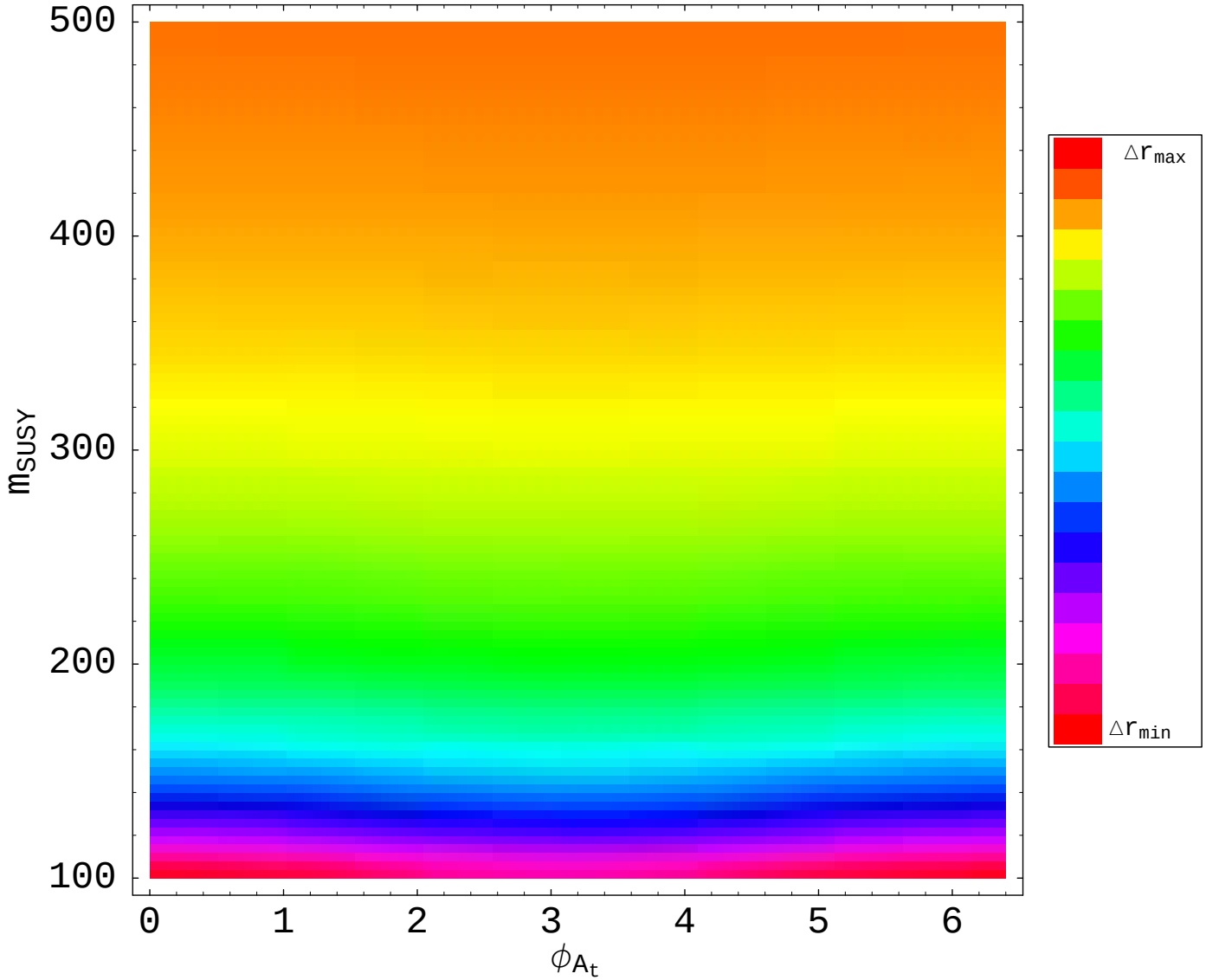

FIGURE: Sfermion contributions to Δr^{1L} ($\tan\beta = 15$)

SUSY $\Delta\rho$ two-loop contributions

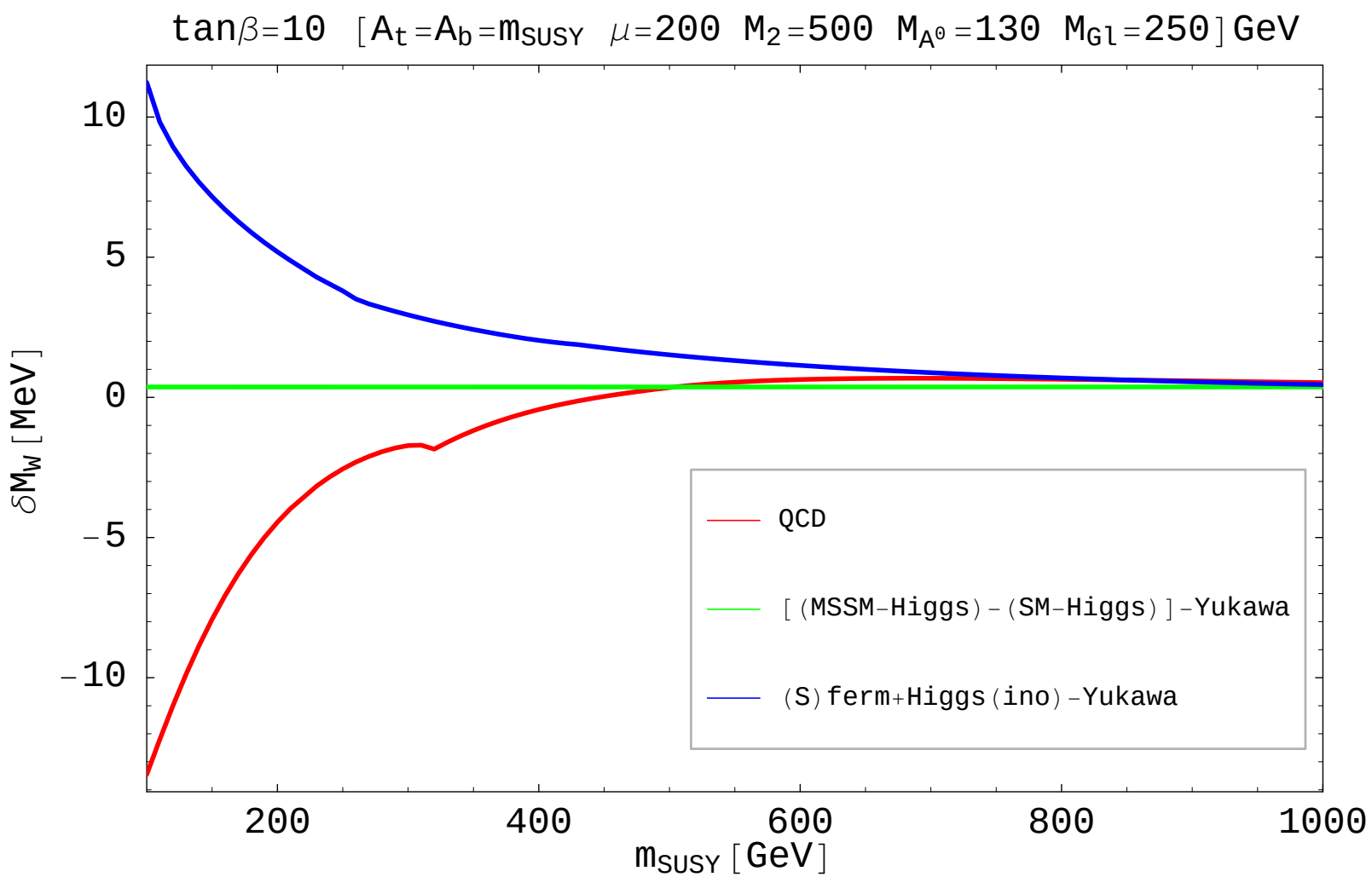

FIGURE: δM_W induced by $\Delta\rho_{SUSY}$ two-loop results

W-boson mass

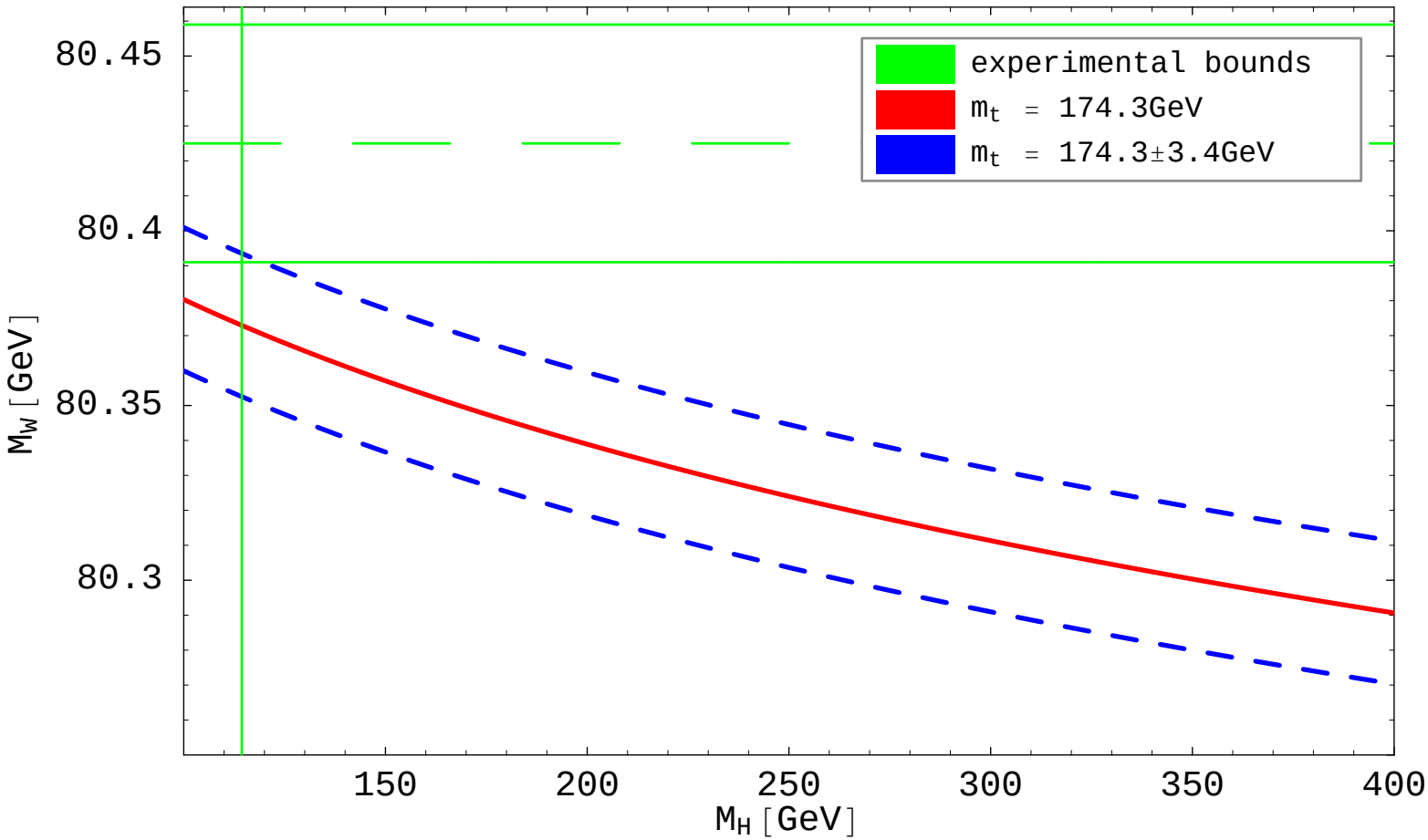

FIGURE: SM W-Boson mass using compact formula by Awramik, Czakon, Freitas & Weiglein

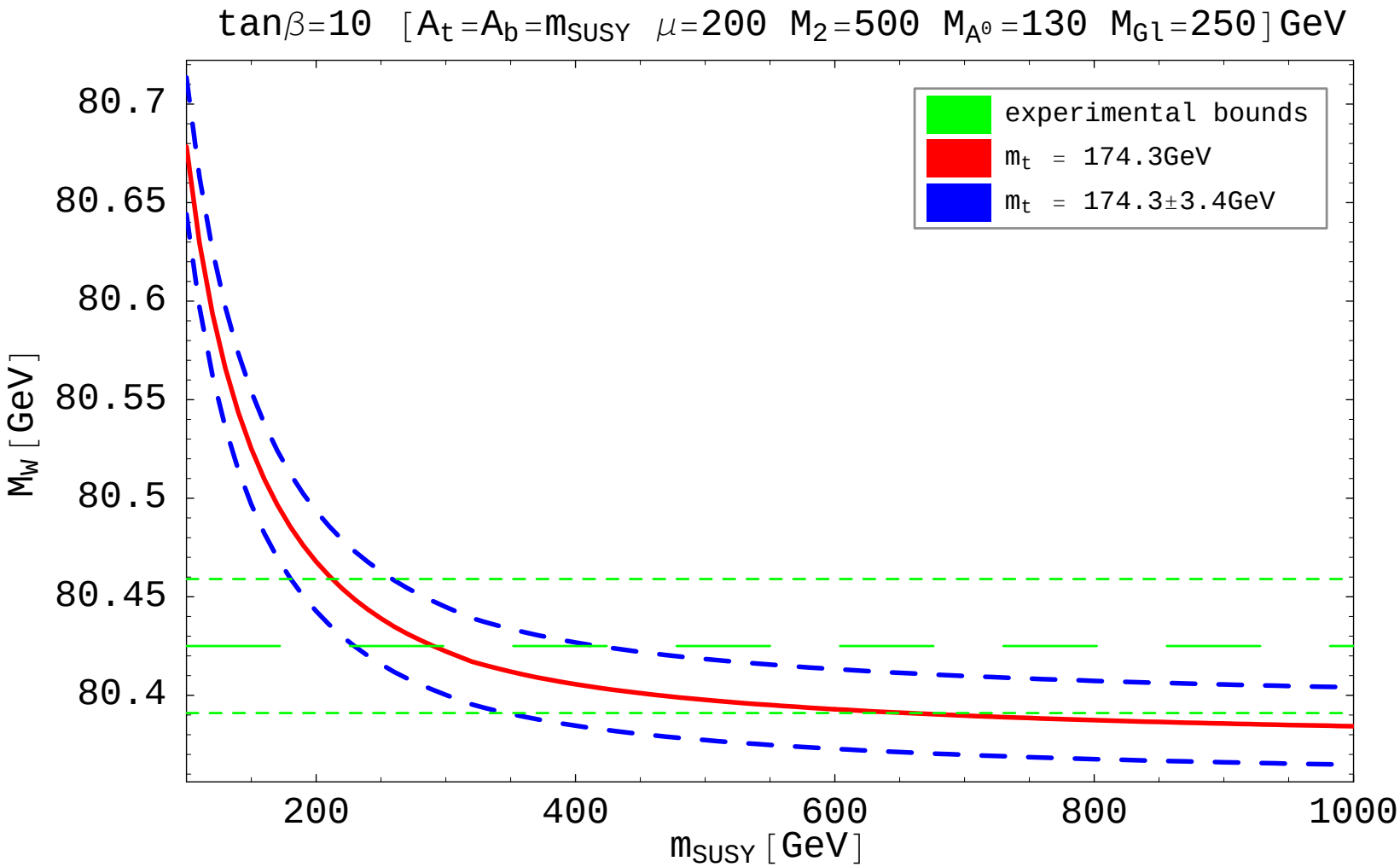

FIGURE: MSSM result for $M_W(m_{SUSY})$

CONCLUSIONS

- The one-loop result for M_W was obtained in an independent calculation.
- Numerical effects of complex MSSM input parameters were analyzed.
- State of the art beyond one-loop corrections were taken into account.
- Two-loop results gave non negligible contributions to Δr.
- SUSY corrections lead to values for M_W well inside the the experimental range, even for SUSY masses below 1TeV.
- Most precise MSSM W-mass prediction provides important input for many MSSM precision observables (e.g. Higgs mass, $sin\theta_{eff}$, $\Gamma_Z \ldots$).

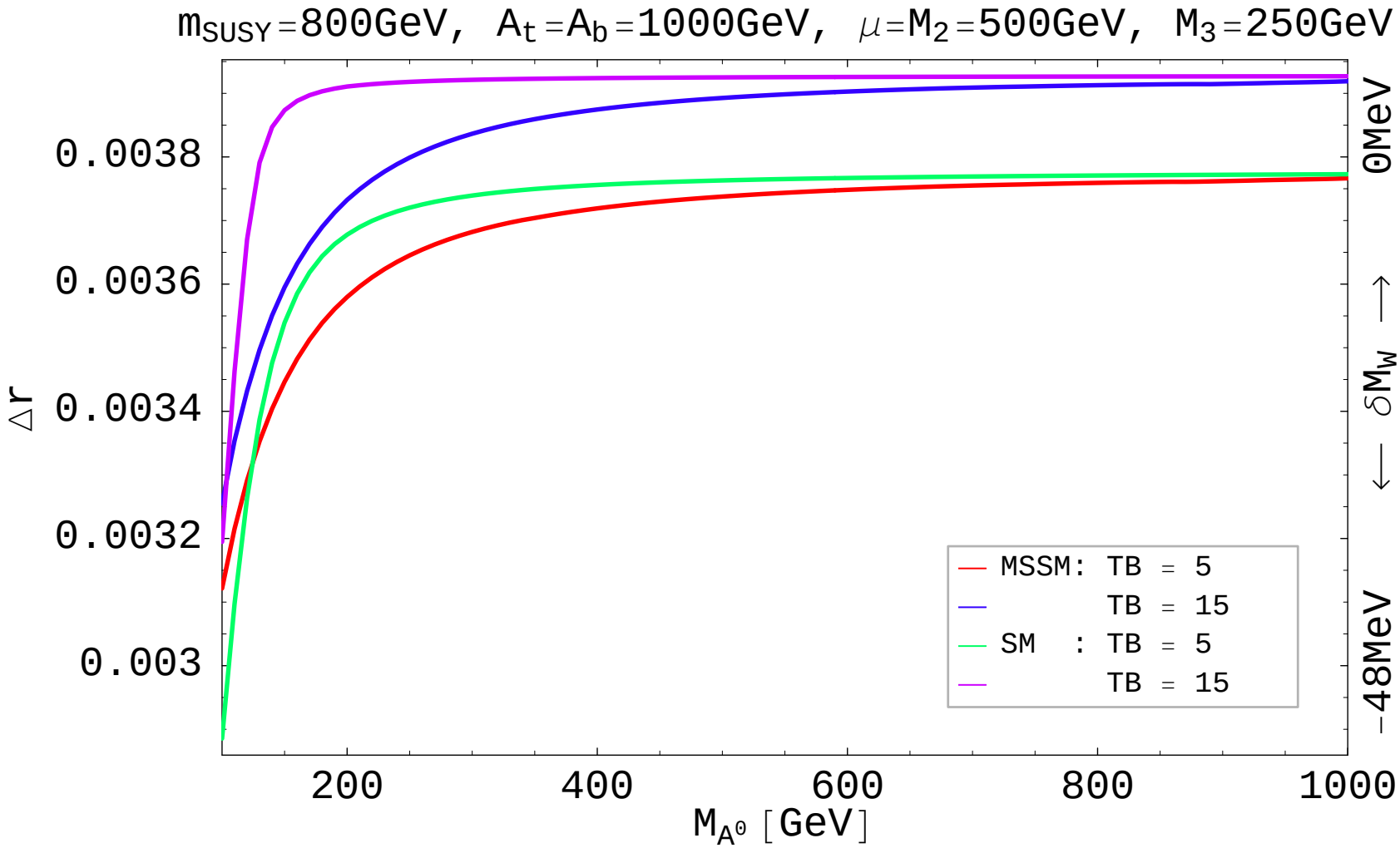

FIGURE: Gauge boson & Higgs contributions to Δr^{1L}

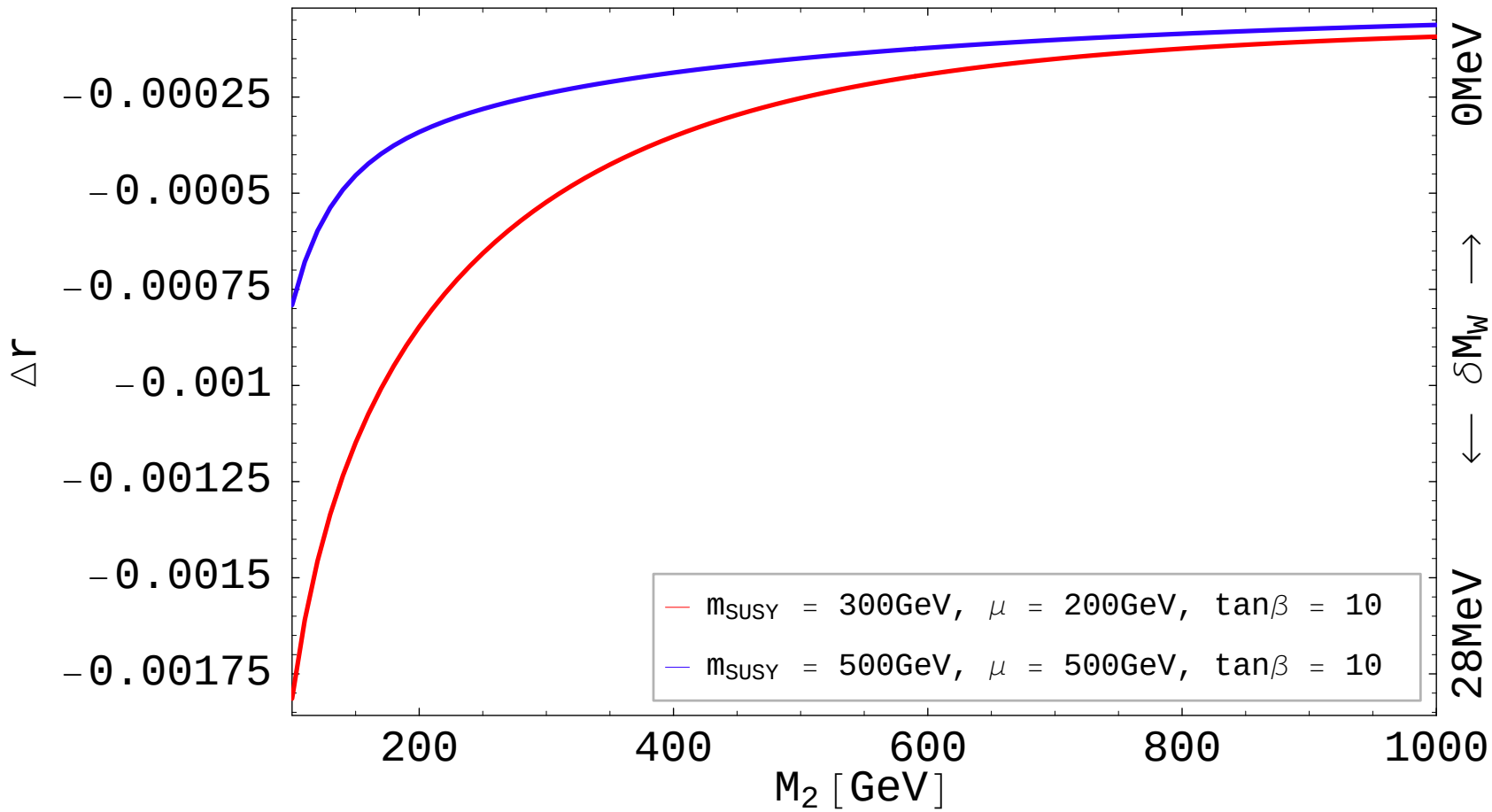

FIGURE: Neutralino & chargino contributions to Δr^{1L}

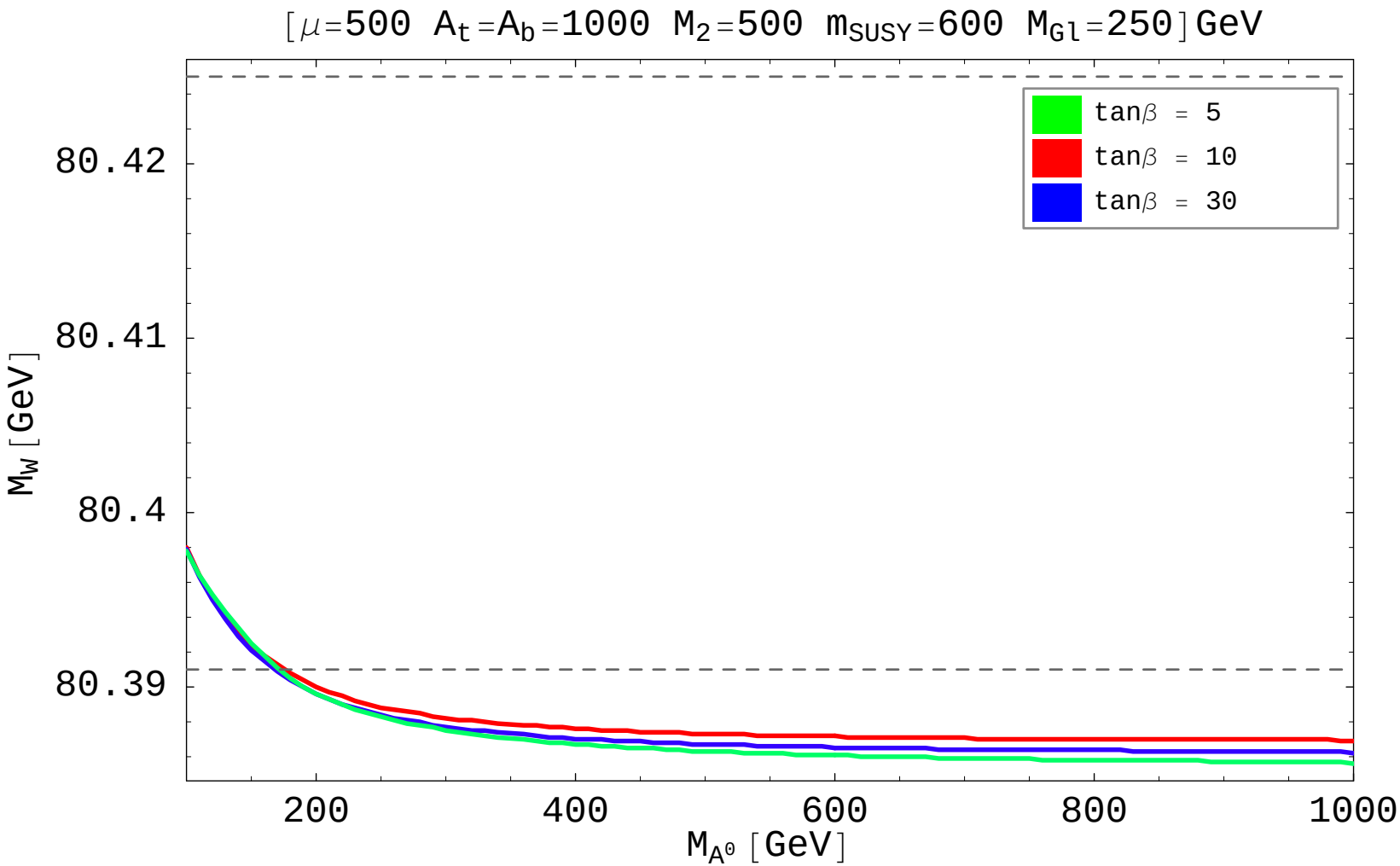

FIGURE: Best MSSM result for $M_W(M_{A^0})$