Precise Prediction for M_W in the MSSM

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Outline

INTRODUCTION

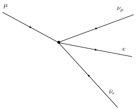
- W-mass can be measured in experiment.
    - Error today: 32MeV (LHC 15MeV, ILC 7MeV)
- W-mass can also be calculated from μ-decay, using the Fermi constant G_F as input (as well as $M_Z, \alpha \ldots$).
    - G_F is known with negligible error.
- Comparison of theoretical value for M_W and experiment allows to test the Standard Model (SM).

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

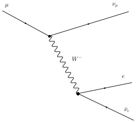
- Loop effects in μ-decay are also sensitive to beyond SM physics.

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

Born level



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



- Need to take radiative corrections into account.
- Summarise radiative corrections by Δr.

Loop order

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

The quantity Δr

$$\Delta r = \Delta r(M_W, M_Z, m_t, \alpha, \alpha_s, X, \ldots)$$

$$X = M_H \quad \text{(SM)}$$

$$X = M_{h^0}, M_{H^0}, M_{A^0}, M_{H^\pm}, \tan\beta, M_{\tilde{f}}, m_{\chi^{0,\pm}}, A_f, \ldots \text{(MSSM)}$$

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$$\begin{aligned} X &= M_H \quad \text{(SM)} \\ X &= M_{h^0}, M_{H^0}, M_{A^0}, M_{H^\pm}, \tan\beta, M_{\tilde{f}}, m_{\chi^{0,\pm}}, A_f, \ldots \text{(MSSM)} \end{aligned}$$

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 charge renormalisation.
$\Delta\rho$: Originates from weak mixing angle renormalisation.

Present status of W-mass calculation

- SM:
  - Full two-loop calculation was accomplished [Freitas, Hollik, Walter, Weiglein] & [Awramik, Czakon] & [Onishchenko, Veretin].
  - 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].
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- MSSM:
  - One-loop result by [Garcia, Solà] & [Chankowski, Dabelstein, Hollik, Mösle, Pokorski, Rosiek].
  - Original code by [Dabelstein, Hollik, Mösle] supplemented with MSSM $O(\alpha\alpha_s), O(\alpha_t^2), O(\alpha_t\alpha_b), O(\alpha_b^2)$ $\Delta\rho$ two-loop terms in programme 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.

CALCULATIONS

MSSM one-loop corrections

- Contributions from
  - Sfermion self energies (leading contributions from stop and sbottom squark).
  - Neutralino and chargino self energies, vertex and box diagrams.
  - MSSM gauge boson self energies, vertex and box corrections.
- Most general MSSM parameters are used.
- No restrictions on complex phases are made.

Combining SM and MSSM contributions

- Decompose MSSM contributions into SM and (MSSM-SM) part.

$$\Delta r^{MSSM} = [\Delta r^{SM}]_{M_H = M_{h0}} + \Delta r^{MSSM-SM}$$

- Replace SM like part by best available SM result to incorporate all known SM corrections.

$$\Delta r^{MSSM}_{\text{best}} = [\Delta r^{SM}_{\text{best}}]_{M_H = M_{h0}} + \Delta r^{MSSM-SM}$$

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

SUSY two-loop corrections

Via $\Delta\rho$*:*

- QCD corrections
  - (S)top-(s)bottom loops with gluon & gluino exchange.

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

- Yukawa contributions of $O(\alpha_t^2),\ O(\alpha_t\alpha_b),\ O(\alpha_b^2)$
  - (S)top-(s)bottom loops with Higgs(ino) exchange.

  [Haestier, Heinemeyer, Stöckinger, Weiglein]

- Leading SUSY one-loop terms resummed according to

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

  [Consoli, Hollik, Jegerlehner]
- Higgs masses from FeynHiggs.
  [Hahn, Heinemeyer, Hollik, Weiglein]

RESULTS

$\delta M_W/\Delta r$ one-loop

- Comparison of one-loop results with POMSSM gave acceptable agreement.
- Leading contributions from squark sector.
- Smaller, but non negligible, contributions from neutralinos, charginos and MSSM-Higgs sector.

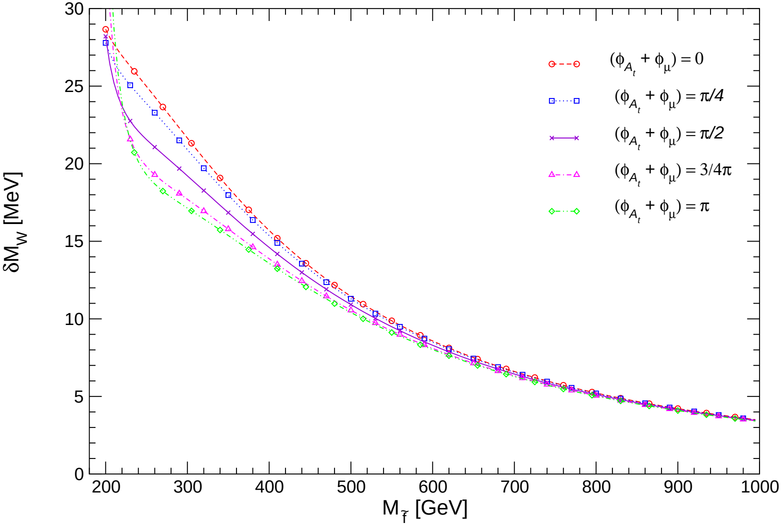

FIGURE: Squark contributions to δM_W.
$|A_{t,b}| = 350\text{GeV}, |\mu| = 300\text{GeV}, \phi_{A_b} = 0, \tan\beta = 10$

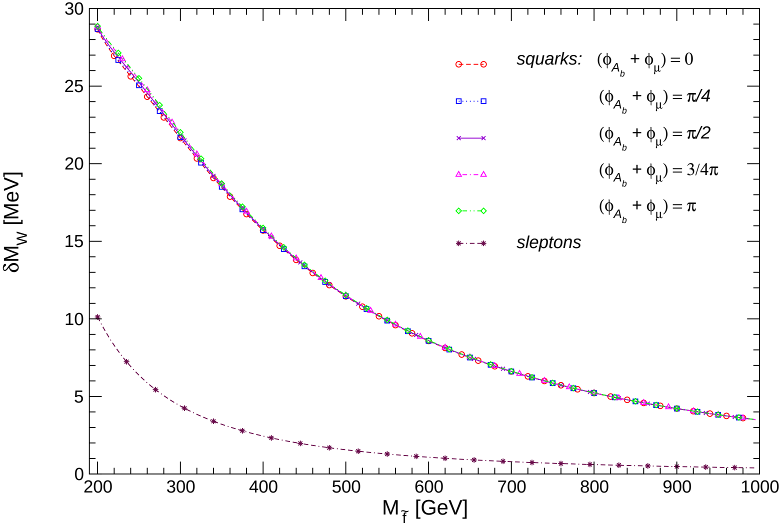

FIGURE: Squark and slepton contributions to δM_W.
$|A_{t,b}| = 350\text{GeV}, |\mu| = 300\text{GeV}, \phi_{A_t} = 0, \tan\beta = 10$

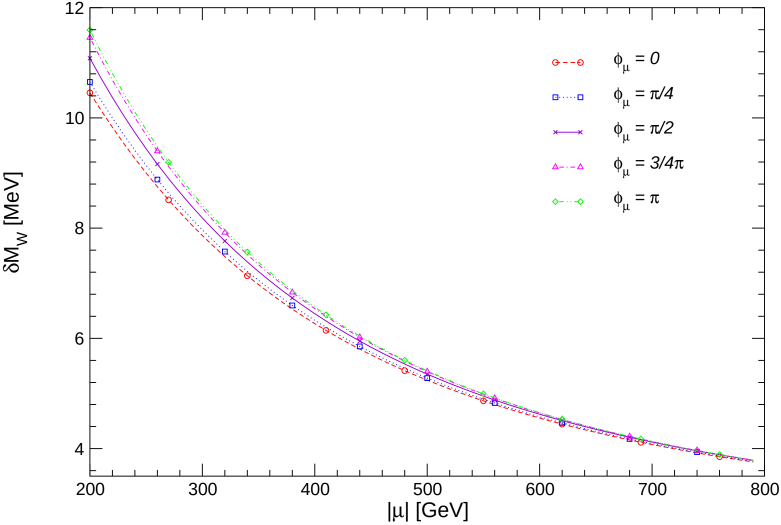

FIGURE: Neutralino and chargino contributions to δM_W.
$M_1 = M_2 = 200\text{GeV}, \tan\beta = 10, M_{\tilde{f}} = 500\text{GeV}$

SPS benchmark scenarios

- Benchmark points and slopes within "typical" constrained MSSM scenarios.
- SPS scenarios fix low-energy MSSM parameters.
- *here:*

$$M_{A^0} = \text{scalefactor} \cdot M_{A^0}^{\text{SPS}},\ M_{\tilde{F},\tilde{F}'} = \text{scalefactor} \cdot M_{\tilde{F},\tilde{F}'}^{\text{SPS}},$$
$$A_{t,b} = \text{scalefactor} \cdot A_{t,b}^{\text{SPS}},\ \mu = \text{scalefactor} \cdot \mu^{\text{SPS}},$$
$$M_{1,2,3} = \text{scalefactor} \cdot M_{1,2,3}^{\text{SPS}}.$$

W-boson mass

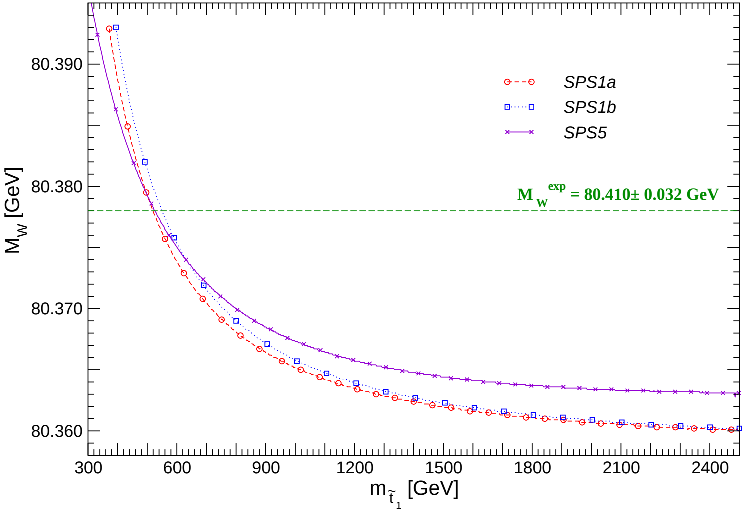

FIGURE: SPS points varied over a common mass scale.

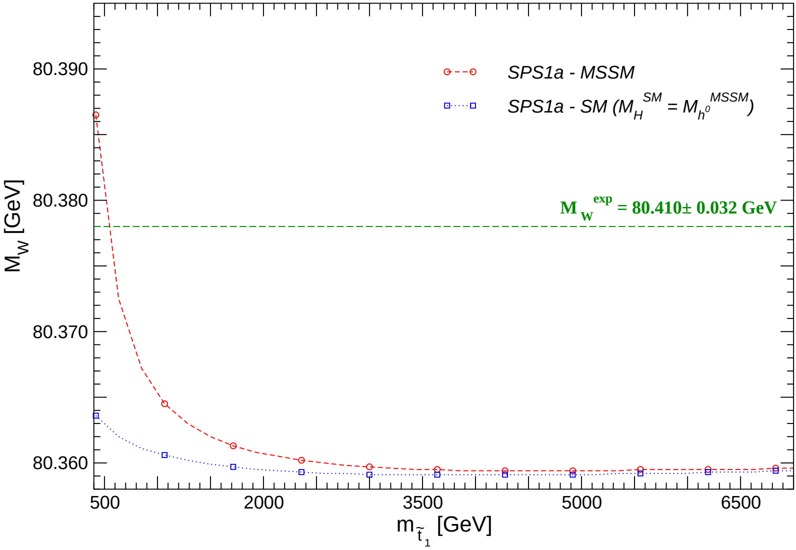

FIGURE: M_W in the decoupling limit.

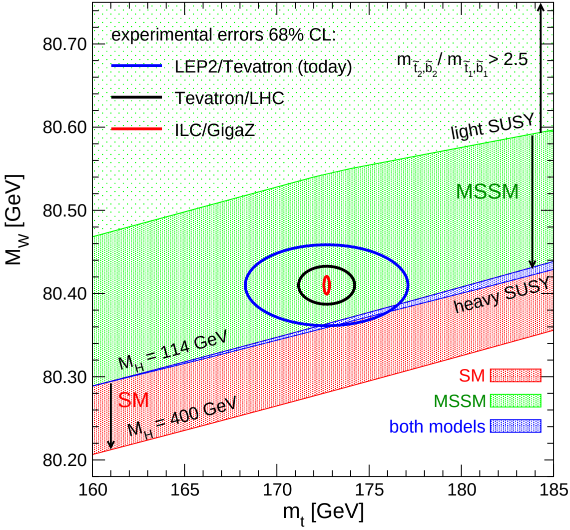

FIGURE: MSSM parameter scan.

[Chankowski, Dabelstein, Hollik, Mösle, Pokorski, Rosiek],
update: [Heinemeyer, Hollik, Stöckinger, AMW, Weiglein]

Conclusions

- The one-loop result for M_W was obtained in an independent calculation and extended to complex parameters.
- Numerical effects of complex MSSM input parameters were analysed.
- State of the art beyond one-loop corrections were taken into account.
- M_W predicted within 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, $sin\theta^2_{eff}$, $\Gamma_Z \ldots$).
- Programme will become publicly available.