Precise Prediction for the W-Boson mass in BSM

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Based on work together with Georg Weiglein

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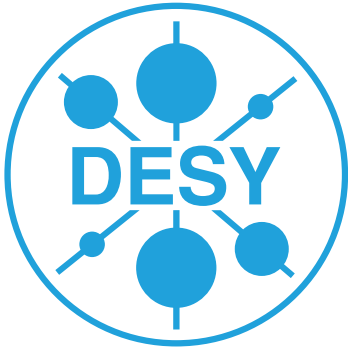

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Introduction

How to find new physics? Which BSM model is realized?

1. Search for new particles
2. Search for virtual effects of new particles

Advantage of indirect search

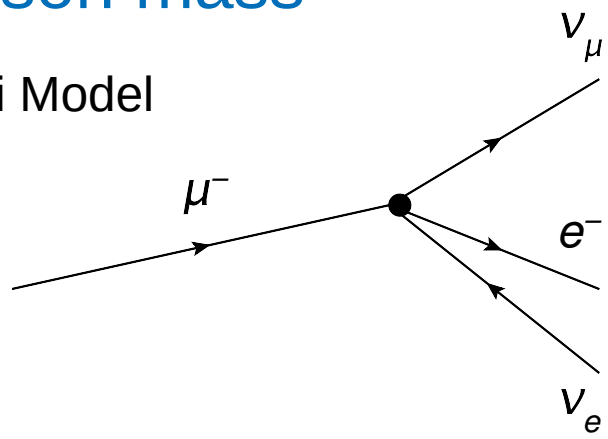
- High sensitivity to quantum effects of the entire particle spectrum
- Distinction between different models
- If particles will be directly detected: Good cross-check

Electroweak precision observables

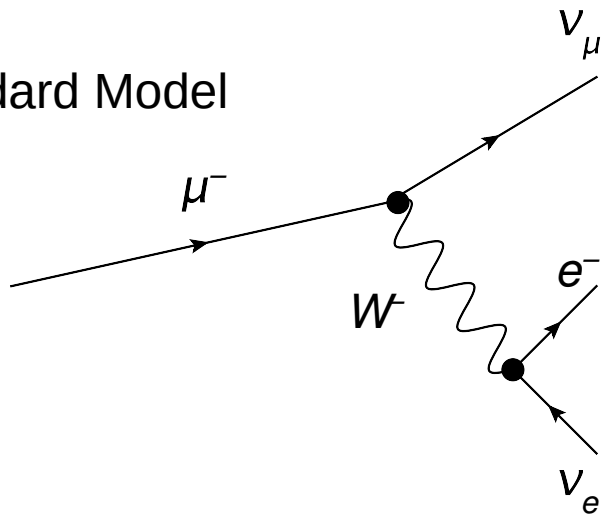
- Corrections to M_W, Γ_Z, $\sin\Theta_W^{eff}$
- Needed: Precision measurement and precise theoretical prediction
- Current exp. value: $M_W^{exp} = 80.399 \pm 0.023\text{GeV}$ (0.03 % precision accuracy), LHC prospect: $\delta M_W^{exp} \approx 10\text{MeV}$

W-boson mass

Fermi Model



Standard Model



- Compare Born amplitudes:

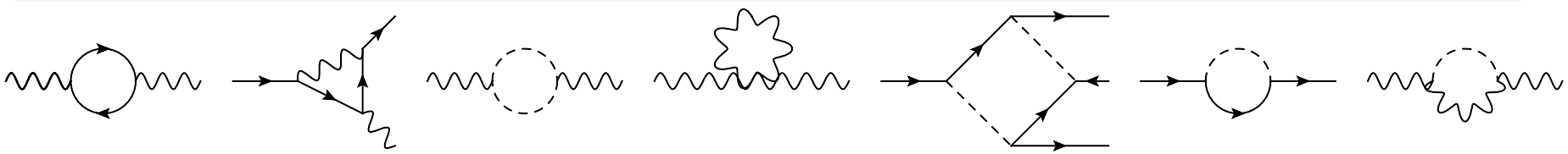
$$\frac{G_F}{\sqrt{2}} = \frac{e^2}{8 s_W^2 M_W^2}$$

G_F contains the QED corrections in the Fermi model

- All other loop corrections can be written as $\mathcal{M}_{Loops} = \Delta r \; \mathcal{M}_{Born}$

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

- X model dependend!



Current status of Δr

SM:

- Complete two-loop result
- leading higher orders corrections

MSSM:

- One-loop result
- some two-loop corrections

Our work

- New stand-alone One Loop calculation in SM and cMSSM (most general case/complex phases/no GUT assumptions)
- Incorporation of all known SM and SUSY higher order corrections

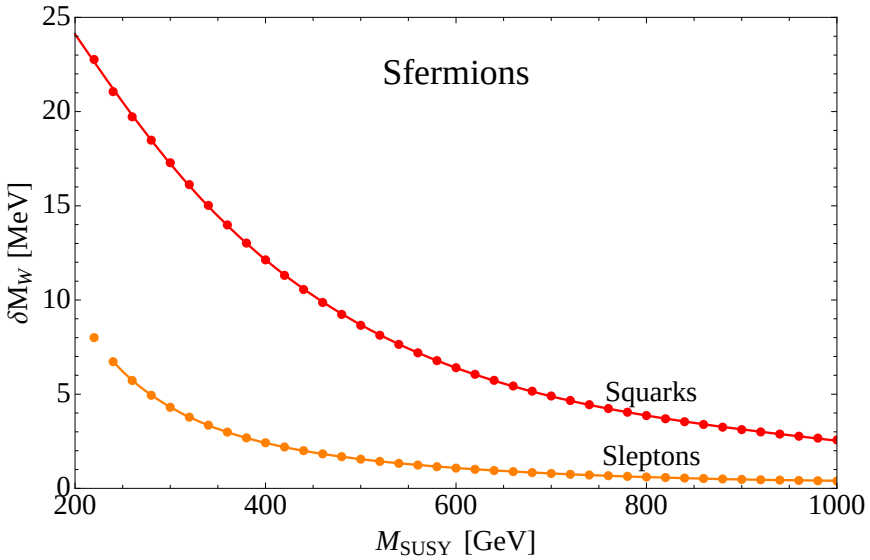
Δr Calculation

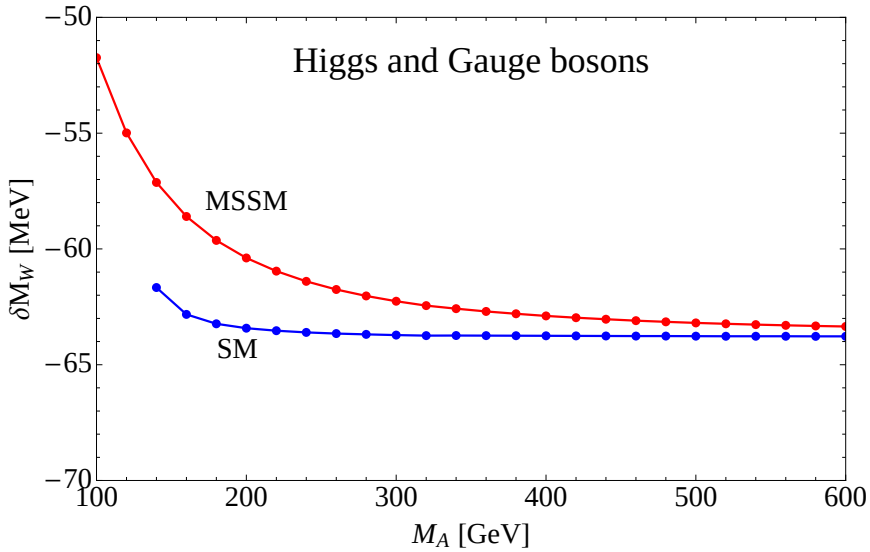
$$\Delta r^{MSSM} = \Delta r^{SM} + \Delta r^{SUSY}$$

Δr^{SM}: Most advanced result in SM
Δr^{SUSY}: All known SUSY corrections

$\Longrightarrow$ Most exact MSSM prediction for M_W

- Check and confirm earlier calculations
- Analytic mathematica functions for all contributions
- Easily extendable to new models
  NMSSM, Models with 4th fermion generation, 2HDM, InertDM
- Different models comparable in one framework





Input parameters

$M_t = 172.5\text{GeV}$ m_h^{SM} = mass of the MSSM Higgs that couples SM-like $\approx 123\text{GeV}$

$\tan\beta = 10$ $M_{SUSY} = \mu = M_2 = M_3 = M_A = 500\text{GeV}$ $A_t = 2 \times M_{SUSY}$

Programs: FeynArts / FormCalc FeynHiggs

One Loop Contribution of the various SUSY sectors

- Contribution of gauge boson Higgs sector numerically similar to SM contribution
- Leading SUSY contributions from Sfermion sector (Stop/Sbottom Loops)
- Chargino Neutralino Contribution ≈ 1.8 MeV
  (For lighter masses up to 15 MeV)

Results and Check of One-Loop Calculation

Check with previous calculations

- One Loop Result compared to prior result

  [Heinemeyer, Hollik,Stöckiger, Weber, Weiglein '06]

- Results in perfect agreement

New in our calculation

- Free choice of light fermion masses
- Δm_b corrections included
- Very small difference in $\Delta r^{(\alpha)}_{MSSM}$: $< 10^{-7}$

SM higher order corrections

$$\Delta r^{SM} = \Delta r^{(\alpha)} + \Delta r^{(\alpha\alpha_s)} + \Delta r^{(\alpha\alpha_s^2)} + \Delta r^{(\alpha^2)}_{ferm} + \Delta r^{(\alpha^2)}_{bos} + \Delta r^{(G_\mu^2\alpha_s m_t^4)} + \Delta r^{(G_\mu^3 m_t^6)} + \Delta r^{(G_\mu m_t^2 \alpha_s^3)}$$

- $\Delta r^{\alpha\alpha_s}$ and $\Delta r^{\alpha\alpha_s^2}$: Two- and three Loop QCD corrections

  [Chetyrkin, Kuhn, Steinhauser '95, Djouadi, Verzegnassi '88, ...]

- $\Delta r^{\alpha^2}_{ferm}$ and $\Delta r^{\alpha^2}_{bos}$: Fermionic and bosonic electroweak two-loop corrections

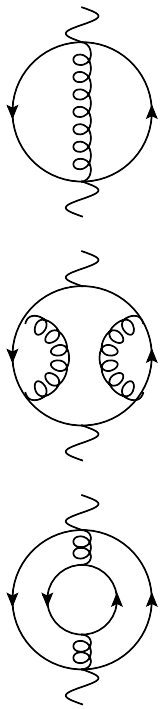
  New fitting formula: Exact result within maximal deviations of 2.7×10^{-5}

  [Awramik, Czakon, Freitas '06]

- $\Delta r^{G_\mu^2\alpha_s m_t^4}$ and $\Delta r^{G_\mu^3 m_t^6}$: Three Loop Top Quark contributions

  [Faisst, Kuhn, Seidensticker, Veretin '03]

- $\Delta r^{(G_\mu m_t^2 \alpha_s^3)}$: 4L QCD Correction [Boughezal '06]



Check with previous calculations

- SM result in agreement with M_W-fitting formula

  [Heinemeyer, Hollik,Stöckiger, Weber, Weiglein '06]

SUSY higher order corrections

Supersymmetric 2-Loop contributions

- Irreducible supersymmetric 2-Loop contributions
  - SUSY QCD corrections of $O(\alpha\alpha_s)$:

    (S)quark Loops with Gluon and Gluino exchange [Djouadi et. al '98]
  - Two Loop Yukawa contributions $O(\alpha_t^2), O(\alpha_t\alpha_b), O(\alpha_b^2)$:

    (S)quark Loops with Higgs and Higgsino exchange [Haestier, Heinemeyer, Stoeckinger, Weiglein '05]
- Leading reducible two-loop corrections [Consoli, Hollik, Jegenlehner '89]

Check with previous calculations

- Complete Δr_{MSSM} result perfectly agrees with previous result

  [Heinemeyer, Hollik,Stöckiger, Weber, Weiglein '06]

  (Uncertainty much smaller than higher order uncertainties $\delta M_W = (4.7 - 9.9)$ MeV)

Impact of higher order corrections

One-Loop Results

$$M_W{}^{SM(1L)} = 80.476\text{GeV}$$

$$M_W{}^{MSSM(1L)} = 80.490\text{GeV}$$

Conclusion

- SM QCD two- and three Loop corrections dominate
- SUSY Corrections sizable
- SM and SUSY $O(\alpha\alpha_s)$ contributions have opposite sign

Higher Order corrections not negligible!

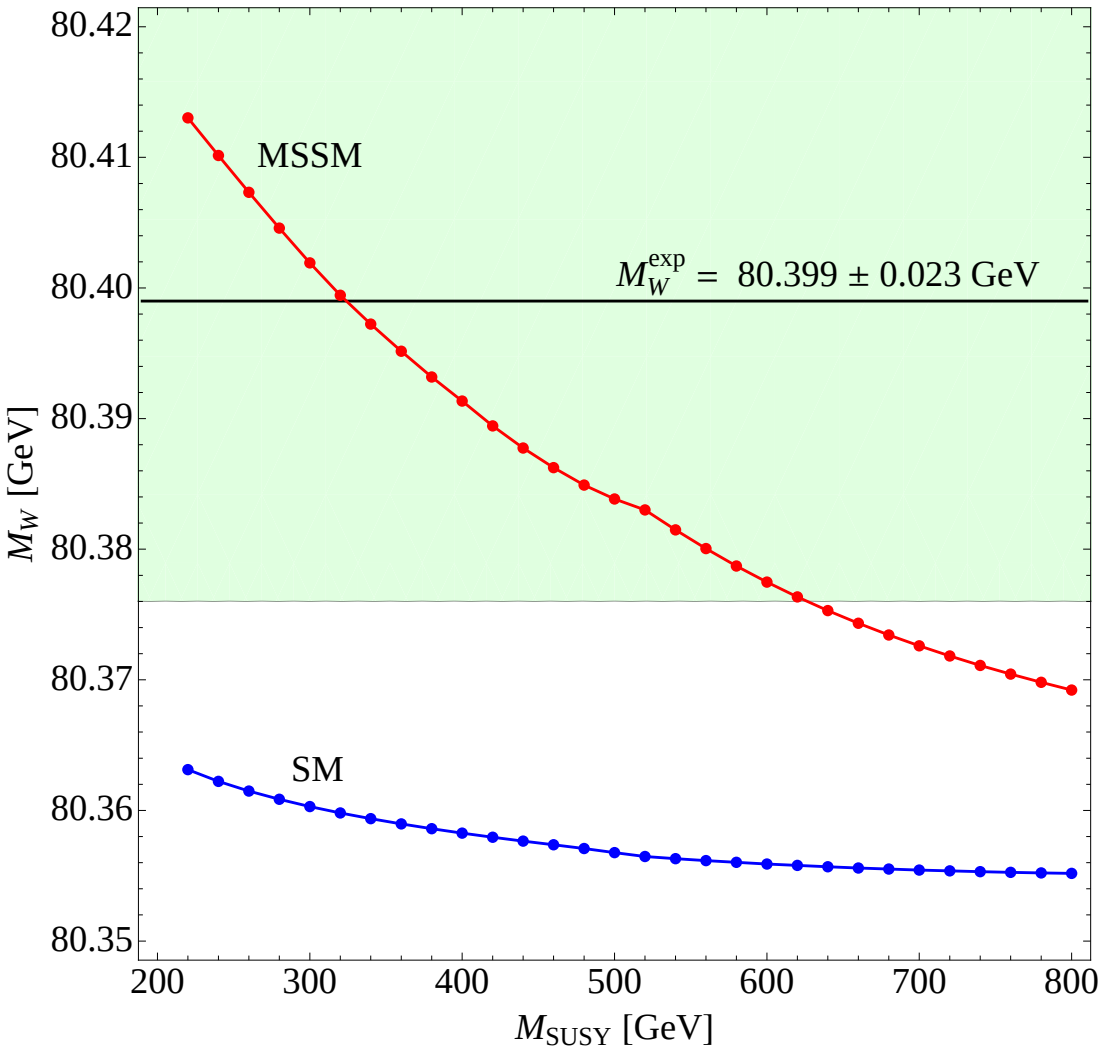
Size of higher order SM corrections

Δr Correction	δM_W [MeV]
$\Delta r^{(\alpha^2)}_{ferm} + \Delta r^{(\alpha^2)}_{bos}$	-46.83
$\Delta r^{(\alpha\alpha_s)} + \Delta r^{(\alpha\alpha_s^2)}$	-66.26
$\Delta r^{(G_\mu^2\alpha_s m_t^4)} + \Delta r^{(G_\mu^3 m_t^6)}$	2.51
$\Delta r^{(G_\mu m_t^2 \alpha_s^3)}$	-1.97

Size of higher order SUSY corrections

Δr Correction	δM_W [MeV]
$\Delta r^{(\alpha\alpha_s)}_{Gluon} + \Delta r^{(\alpha\alpha_s)}_{Gluino}$	13.04
$\Delta r^{(\alpha_t^2)} + \Delta r^{(\alpha_b^2)} + \Delta r^{(\alpha_t\alpha_b)}$	0.37
Reducible (α^2) correction	0.15

Result for the W-Boson mass



Results

- Light M_{SUSY} favored
- Preference for MSSM over SM!

Conclusion and Outlook

Which model is the right one?

- Needed: Precise calculation of the precision observables

Our contribution

- Complete SM and MSSM One Loop Calculation
- Incorporation of all known higher order corrections
  - Most precise and general M_W in MSSM
- Calculation in a framework that allows extensions to other models

MSSM result

- Preference for MSSM over SM
- Light SUSY preferred

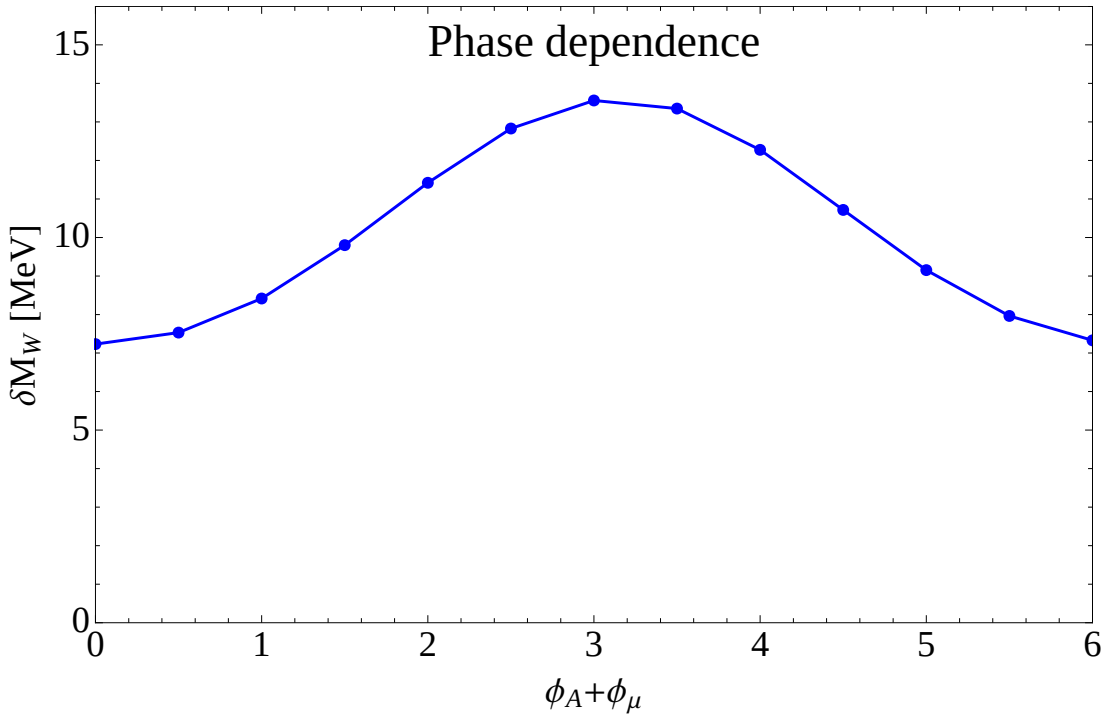
Plan

- Extension to other BSM models with same accuracy:
  NMSSM, 4th generation model - work in progess!

Back up

- Back up material

Phase dependence



Phase dependence

Stop Sbottom contribution to δM_W as a function of $\phi_A + \phi_\mu$, where $\phi_{A_t} = \phi_{A_b} =: \phi_A$

Resummation formula

One-Loop formula

- 1-Loop result dominated by fermionic contributions

$$\Delta r = \Delta\alpha - \frac{c_W^2}{s_W^2}\Delta\rho + \Delta r_{rem}$$

- $\Delta\alpha$: Shift of the fine structure constant
- $\Delta\rho = \frac{\Sigma_T^Z(0)}{M_Z^2} - \frac{\Sigma_T^W(0)}{M_W^2} \propto m_t^2$
  - Contains Top/Bottom corrections

Leading reducible two Loop corrections

- Resummation formula:

$$1 + \Delta r = \frac{1}{(1-\Delta\alpha)(1+\frac{c_W^2}{s_W^2}\Delta\rho) - \Delta r_{rem}}$$