Constraining BSM models using high precision observables

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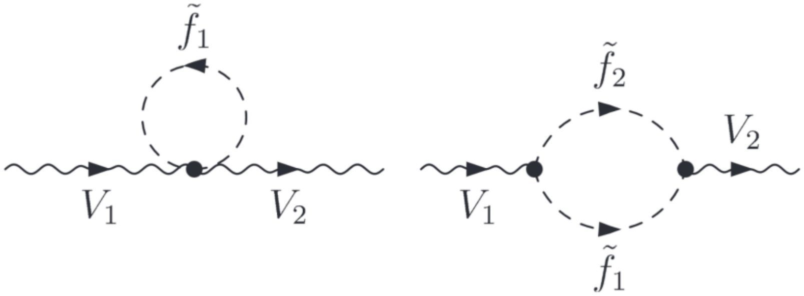
Electroweak precision observables

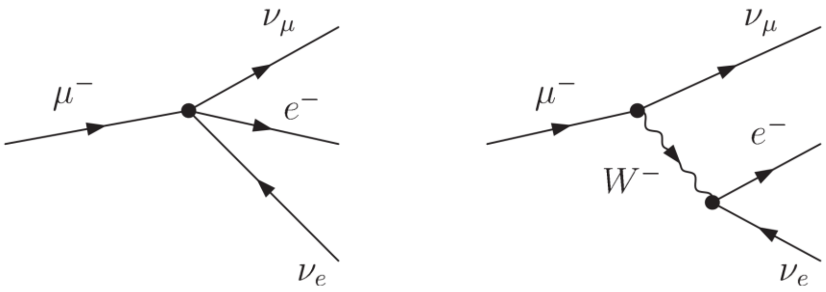
$M_W, \sin^2\theta_{\text{eff}}$

- Direct searches have not resulted in any signals so far
- Indirect constraints of the parameter space

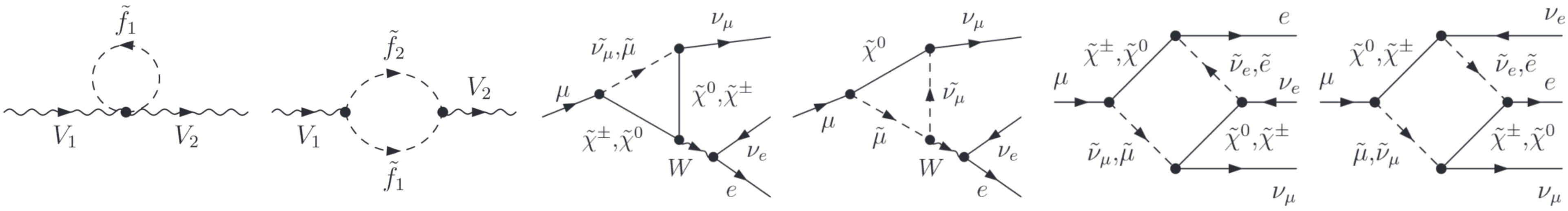
- Highly sensitive to quantum corrections of physics beyond the Standard Model



M_W

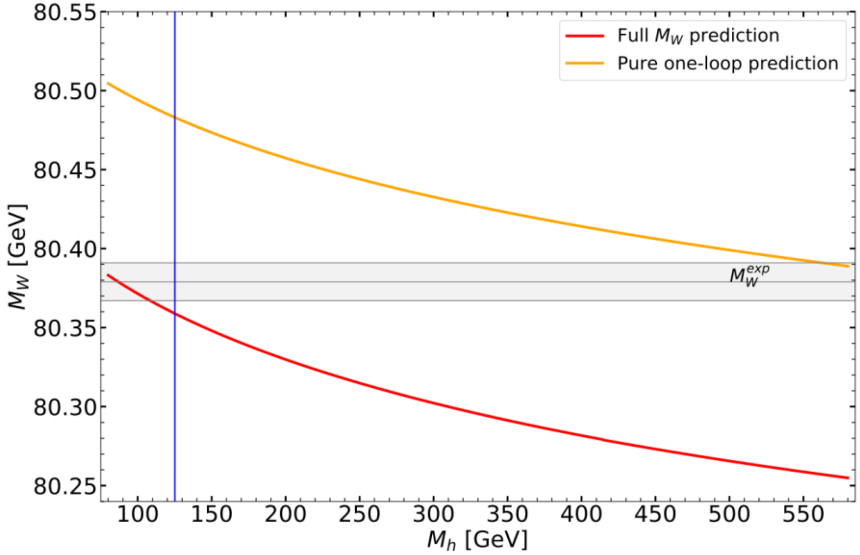


- Comparing the muon-decay amplitude
- $$\frac{G_\mu}{\sqrt{2}} = \frac{M_Z^2\, e^2}{8\, M_W^2\, (M_Z^2 - M_W^2)} (1 + \Delta r(M_W, M_Z, m_t, \ldots, X))$$
- $$M_W^2 = M_Z^2 \left(\frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\alpha\pi}{\sqrt{2} G_\mu M_Z^2} (1 + \Delta r)} \right)$$
- Δr contains all loop diagrams contributing to the muon-decay amplitude



M_W in the SM

- Why looking beyond the SM?



- $M_W^{\rm SM} = 80.358$ GeV
- Current experimental bounds: $M_W = 80.379 \pm 0.012$ GeV [PDG]

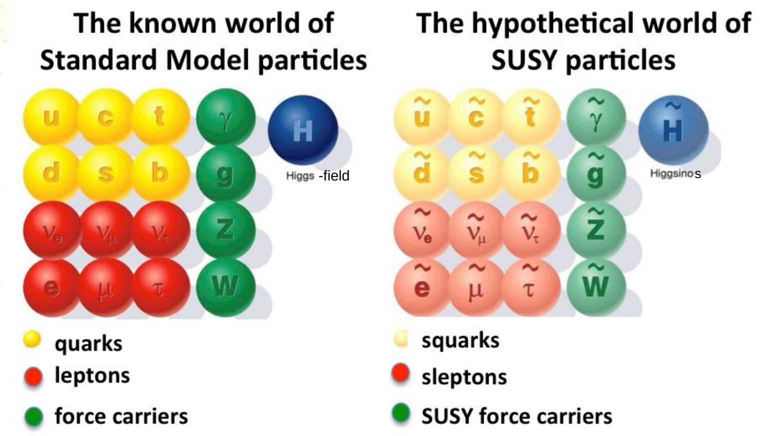
MSSM

Minimal Supersymmetric Standard Model (MSSM)

- Higgs-doublets

$$H_1 = \begin{pmatrix} H_1^0 \\ H^- \end{pmatrix}, \quad H_2 = \begin{pmatrix} H^+ \\ H_2^0 \end{pmatrix}$$

- Higgs mass is not a free parameter
- R-Parity conservation
  - LSP is stable
- Symmetry broken



Δr

- In the SM we include contributions up to four-loop order

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

- In the MSSM we include the full one-loop contributions with higher-order corrections

$$\Delta r^{\mathrm{MSSM}} = \Delta r^{\mathrm{MSSM}(\alpha)} + \Delta r^{\mathrm{MSSM(h.o.)}}$$
$$\Delta r^{\mathrm{MSSM(h.o.)}} = \Delta r^{\mathrm{SM(h.o.)}} + \Delta r^{\mathrm{SUSY(h.o.)}}$$

  - One-loop can be split into groups

1. Gauge boson self-energies containing sfermions in the loop
2. Contributions from the Higgs and gauge boson sector
3. Contributions from the chargino and neutralino sector

Numerical evaluation

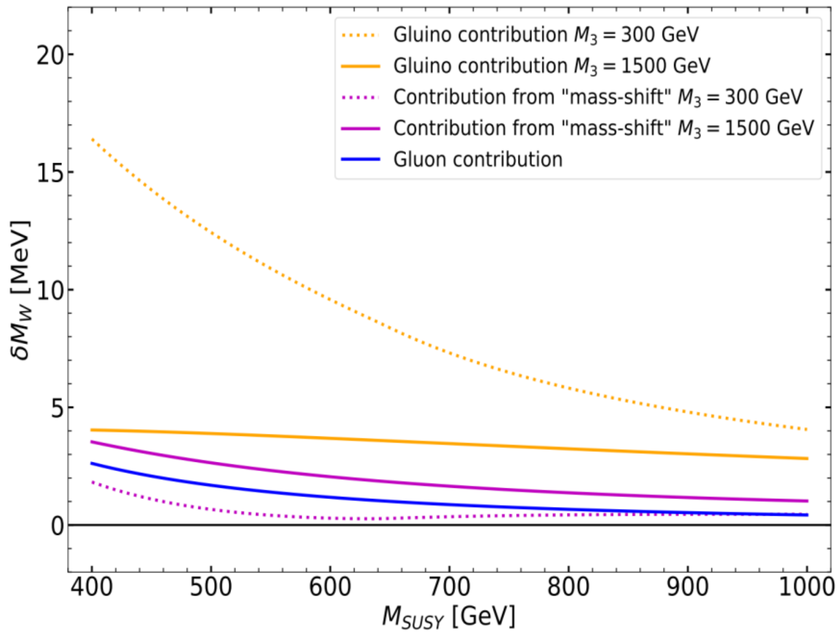
- Developed a standalone Mathematica code
  - Use FeynHiggs for the Higgs masses
- Implemented parts from the current FeynHiggs code
- New sfermion contributions
- Shift due to specific contributions

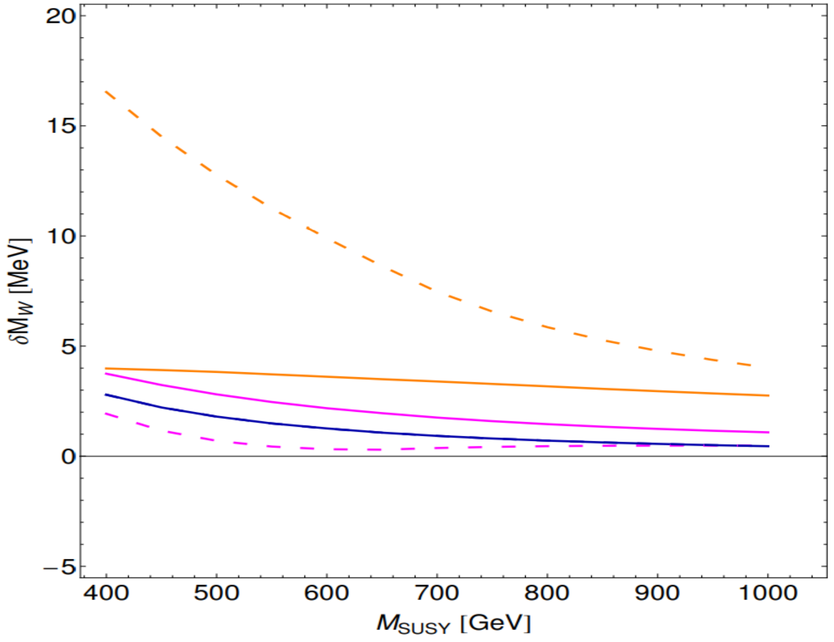
$$\delta M_W = -\frac{M_W^{\text{ref}}}{2} \frac{s_W^2}{c_W^2 - s_W^2} \Delta r^{\text{SUSY}}(M_W^{\text{ref}}).$$

Numerical evaluation

Parameters								
m_e	m_μ	m_τ	m_u	m_c	m_t	m_d	m_s	m_b
$\Delta\alpha$	e	G_μ	$M_{h_{\text{SM}}}$	M_Z	M_W	$\alpha_S(M_Z)$	Version	
M_1	M_2	M_3	$\tan\beta$	μ	M_h	M_H	M_A	$M_{H^\pm}$
M_q	M_u	M_d	M_l	M_e	A_f	$\sin\alpha$		

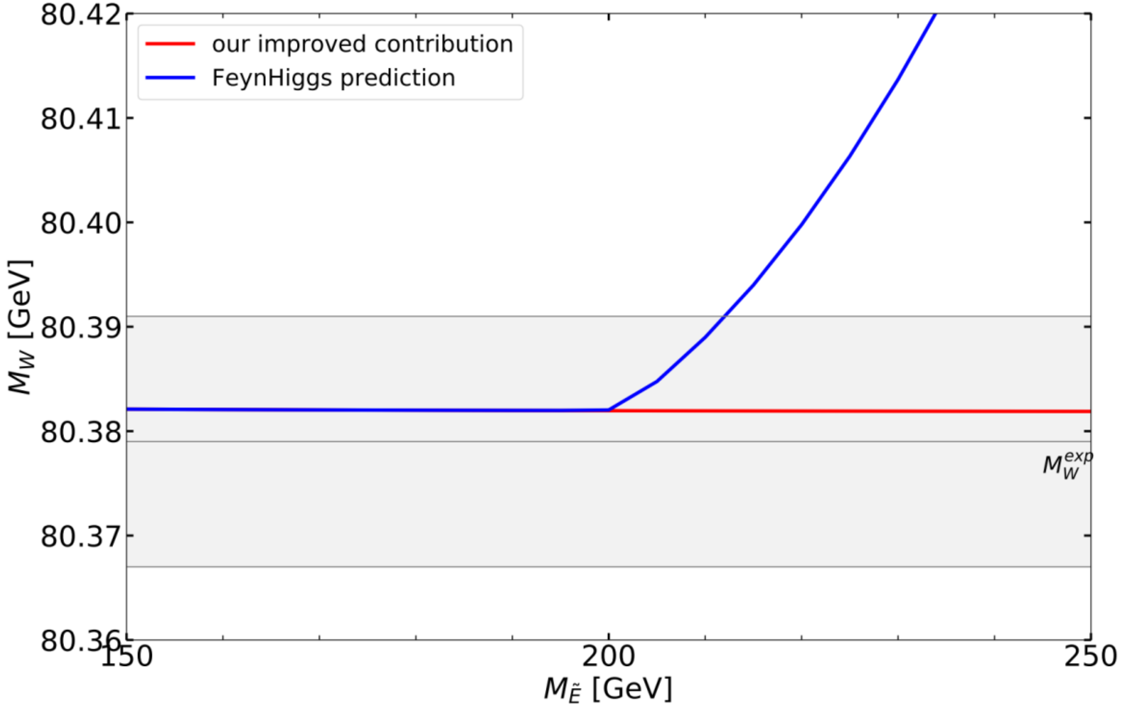
Comparison with literature – Gluion/Gluon/Massshift





Comparison graphs were taken from
'Constraining supersymmetric models using Higgs physics, precision observables and direct searches'
L. Zeune (2014)

Sfermion contribution to M_W



$$M_{\tilde{L}} = 200 \text{ GeV}$$

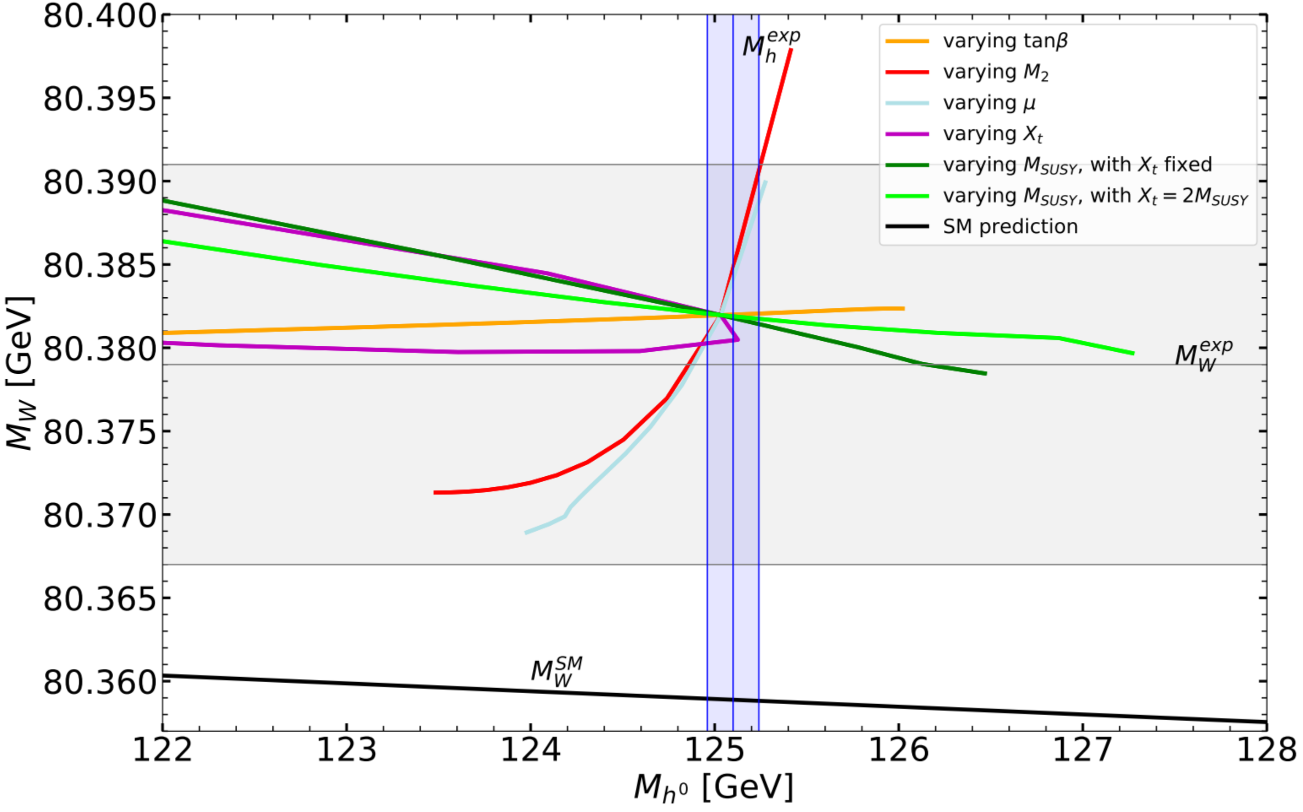
Parameter	fixed	varying
m_t	172.76 GeV	-
$\tan\beta$	20	5 - 25
μ	200 GeV	100 - 1200 GeV
$M_{\tilde{L}/\tilde{E}}$	200 GeV	-
$M_{\tilde{Q}/\tilde{U}/\tilde{D}_{1,2}}$	1500 GeV	-
$M_{\text{SUSY}} = M_{\tilde{Q}/\tilde{U}/\tilde{D}_3}$	1250 GeV	850 - 1650 GeV
X_t	2500 GeV	1500 - 3500 GeV
M_2	200 GeV	100 - 1200 GeV
M_3	1500 GeV	-
M_A	1500 GeV	-

$$M_{h^0} = 125.033 \text{ GeV}$$

$$M_W = 80.382 \text{ GeV}$$

experimental bounds: $M_W = 80.379 \pm 0.012 \text{ GeV}$ [PDG]

M_W in the MSSM



Conclusion

- Electroweak precision observables are a very powerful tool for testing models
- Use alongside other exclusion methods to narrow done the parameter space
- We presented a new standalone Mathematica code and a scenario to study the impact of MSSM input parameters

Outlook

- Easy to operate public version
  - Implementing FeynHiggs in the code for the Higgs masses

Thank you for listening

Sfermions

Mass-matrix:

$$\mathbf{M}_{\tilde{f}} = \begin{pmatrix} M_L^2 + m_f^2 & m_f X_f^* \\ m_f X_f & M_R^2 + m_f^2 \end{pmatrix}$$

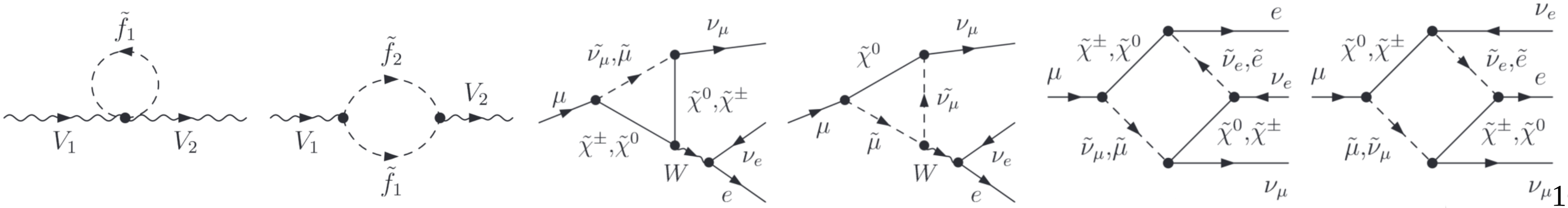
- Diagonalizing with 2×2 unitary matrix $U_{\tilde{f}}$

$$\begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \end{pmatrix} = U_{\tilde{f}} \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix}$$

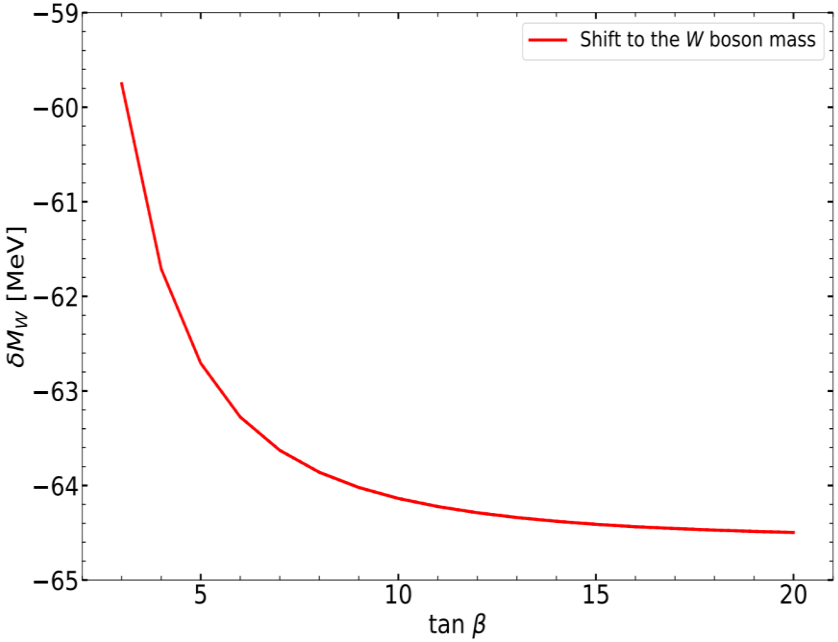
- Only demand $m_{\tilde{f}_1} \leq m_{\tilde{f}_2}$

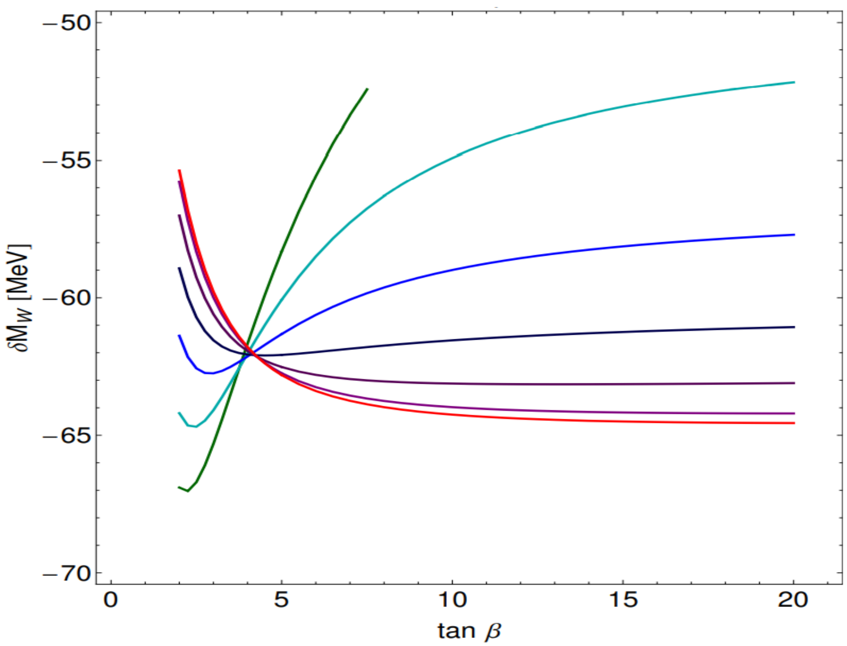
Δr one-loop

- $$\Delta r^{(\alpha)} = \frac{\Sigma_T^{WW}(0) - \mathrm{Re}(\Sigma_T^{WW}(M_W^2))}{M_W^2} + \Pi^{AA}(0) - \frac{c_W^2}{s_W^2}\mathrm{Re}\left[\frac{\Sigma_T^{ZZ}(M_Z^2)}{M_Z^2} - \frac{\Sigma_T^{WW}(M_W^2)}{M_W^2}\right] + 2\frac{s_W}{c_W}\frac{\Sigma_T^{AZ}(0)}{M_Z^2} + \text{ Vertex } + \text{ Box } - \frac{1}{2}\mathrm{Re}(\Sigma_L^{\mu}(0) + \Sigma_L^{e}(0) + \Sigma_L^{\nu_\mu}(0) + \Sigma_L^{\nu_e}(0))$$
  - On-shell renormalization
- Is done separately for the different groups $\mathcal{M}_{\mathrm{Loop},i} = \Delta r_i \mathcal{M}_{\mathrm{Born}}$
- Vertex- and box-diagrams only with charginos/neutralinos



Comparison with literature – Higgs sector





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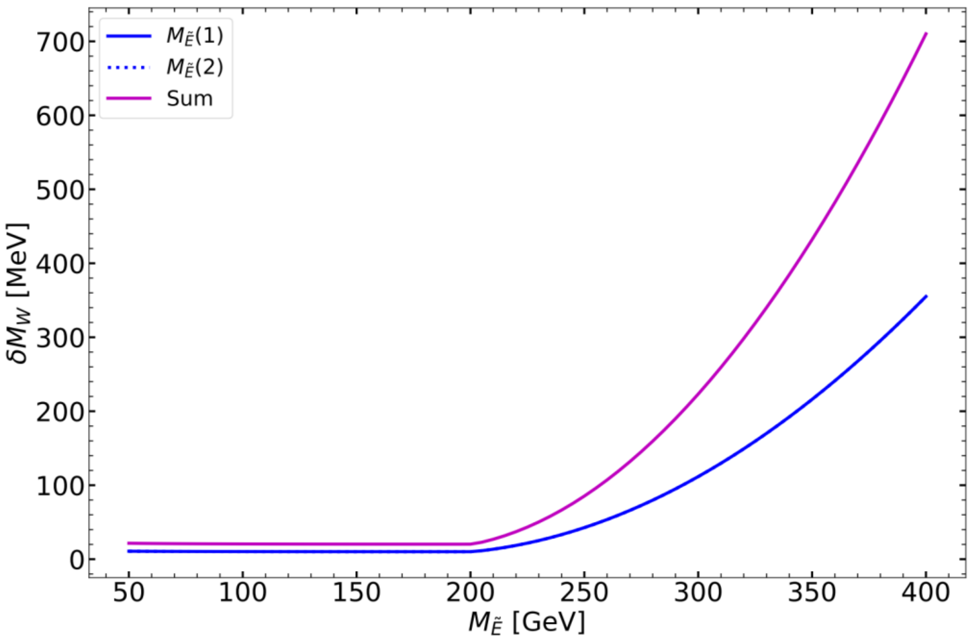
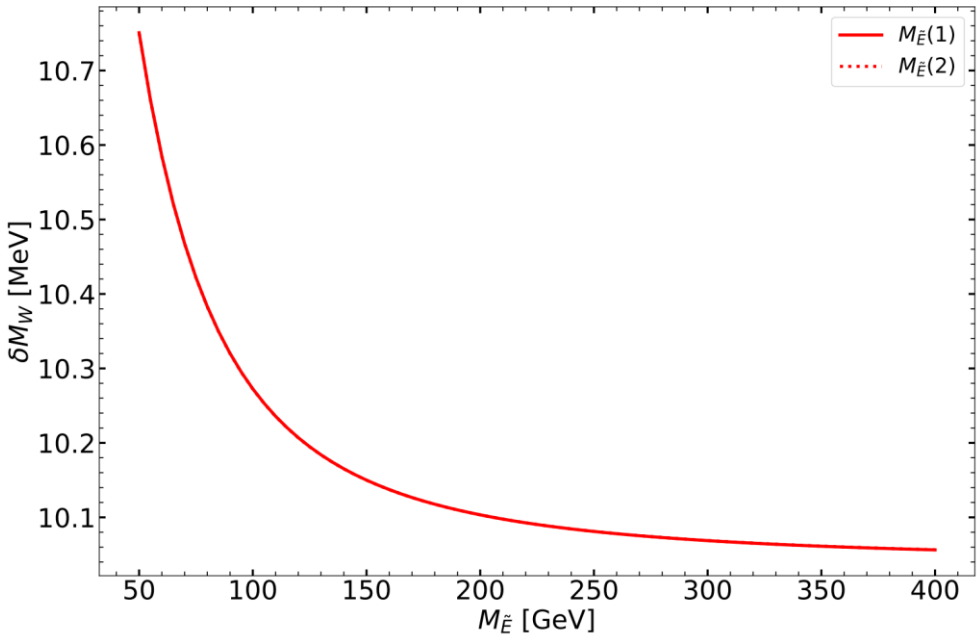
Slepton contribution





$$M_{\tilde{L}} = 200\ \mathrm{GeV}$$

- ‘Improved prediction for the mass of the W boson in the NMSSM’

  O. Stål, G. Weiglein, L. Zeune (2015)