Electroweak precision observables in the MSSM with NMFV

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based on collaboration with
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1. Introduction
2. Results for M_W and $\sin^2\theta_{\text{eff}}$
3. Results for m_h
4. Conclusions

1. Introduction

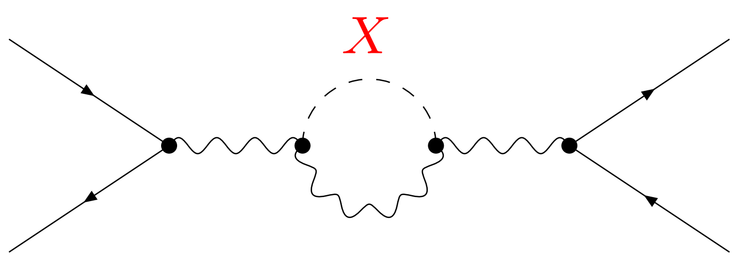
Precision Observables (POs):

Comparison of electro-weak precision observables with theory:

EW Precision data:		Theory:
$M_W, \sin^2\theta_{\text{eff}},\ m_h$	$\leftrightarrow$	SM, MSSM, extensions

$$\Downarrow$$

Test of theory at quantum level: Sensitivity to loop corrections

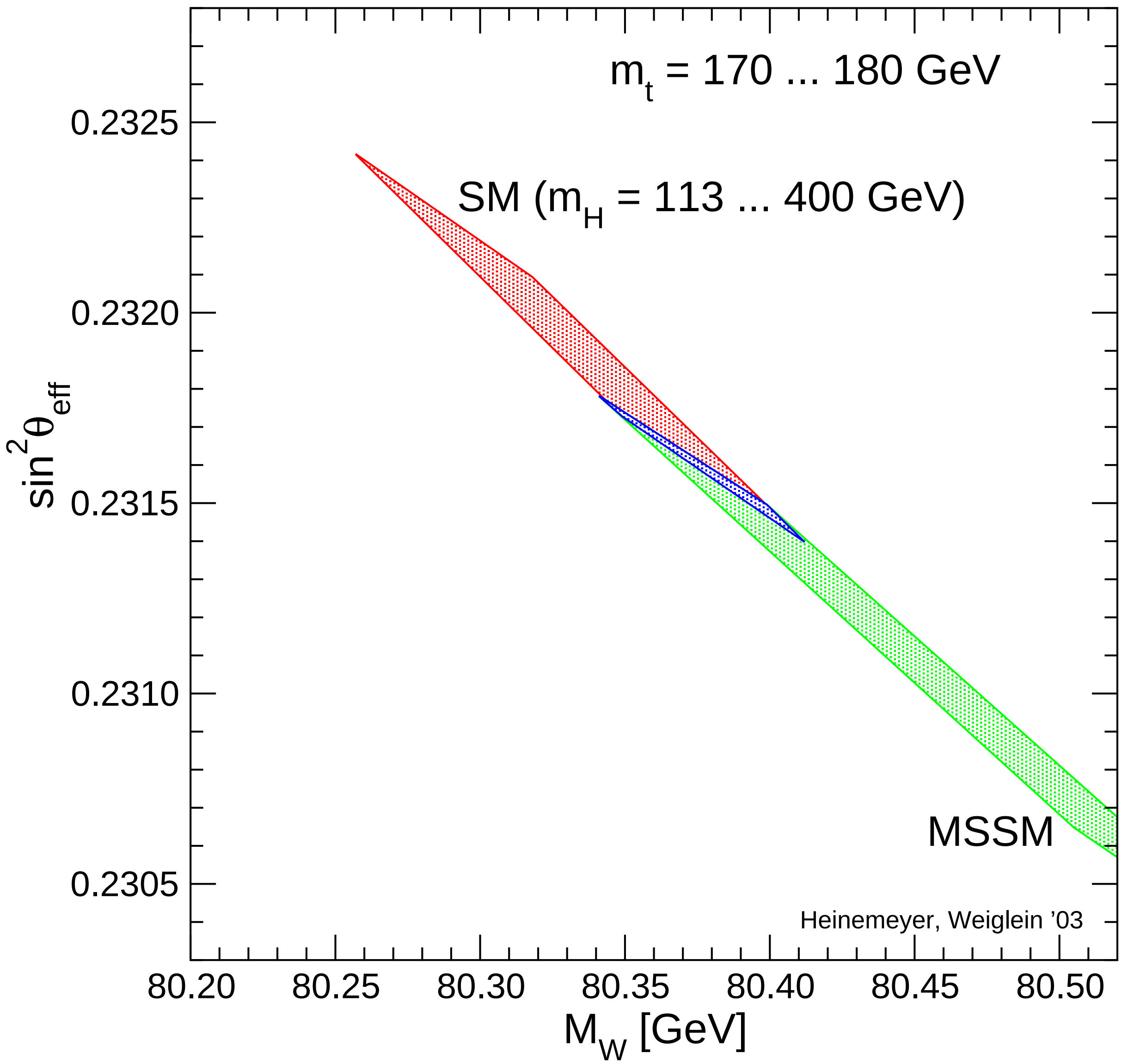


$$\Downarrow$$

Very high accuracy of measurements and theoretical predictions needed

- Which model fits better?
- Does the prediction of a model contradict the experimental data?

Example: Prediction for M_W and $\sin^2\theta_{\rm eff}$ in the SM and the MSSM :



MSSM uncertainty:
unknown masses
of SUSY particles

SM uncertainty:
unknown Higgs mass

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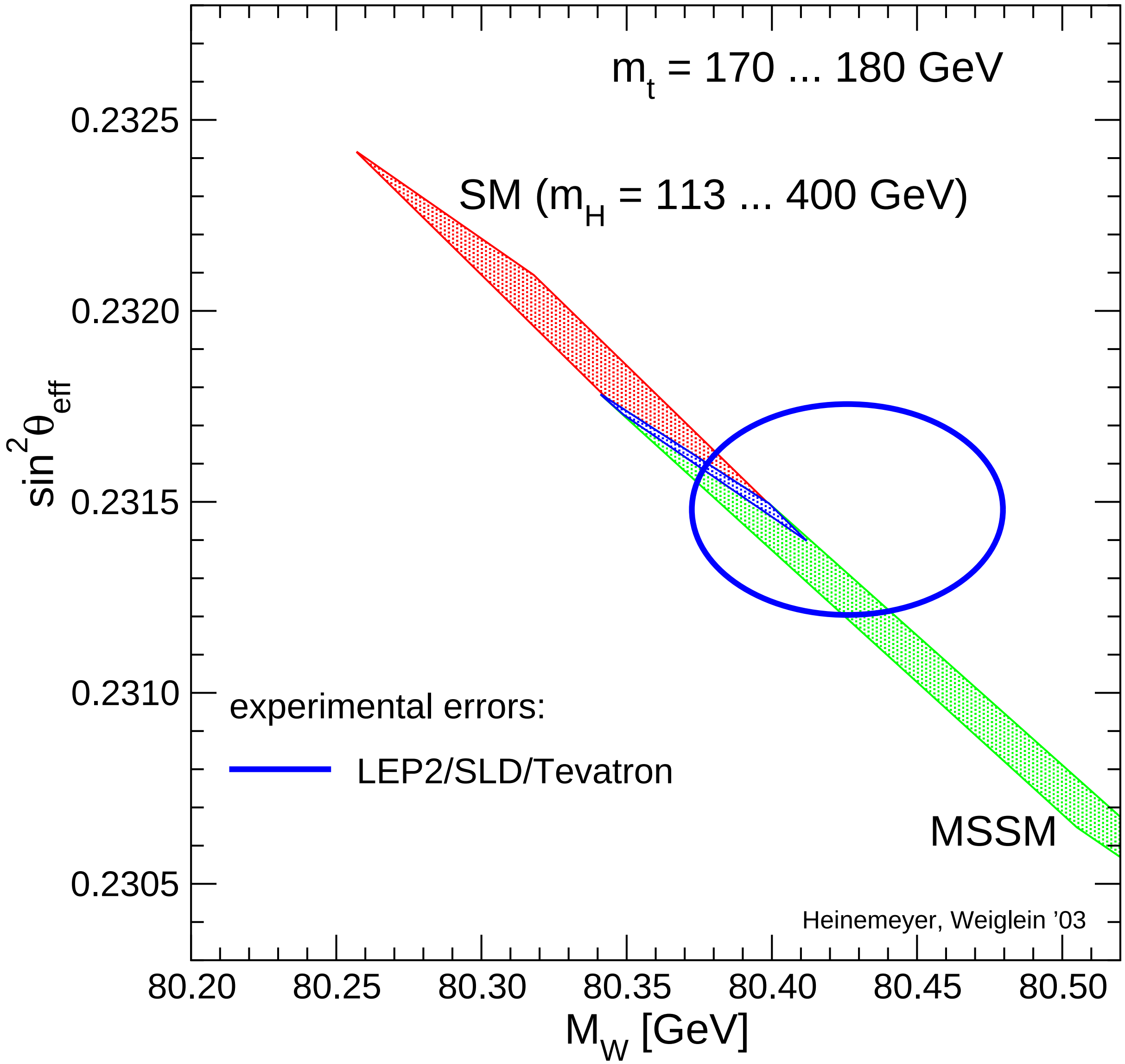

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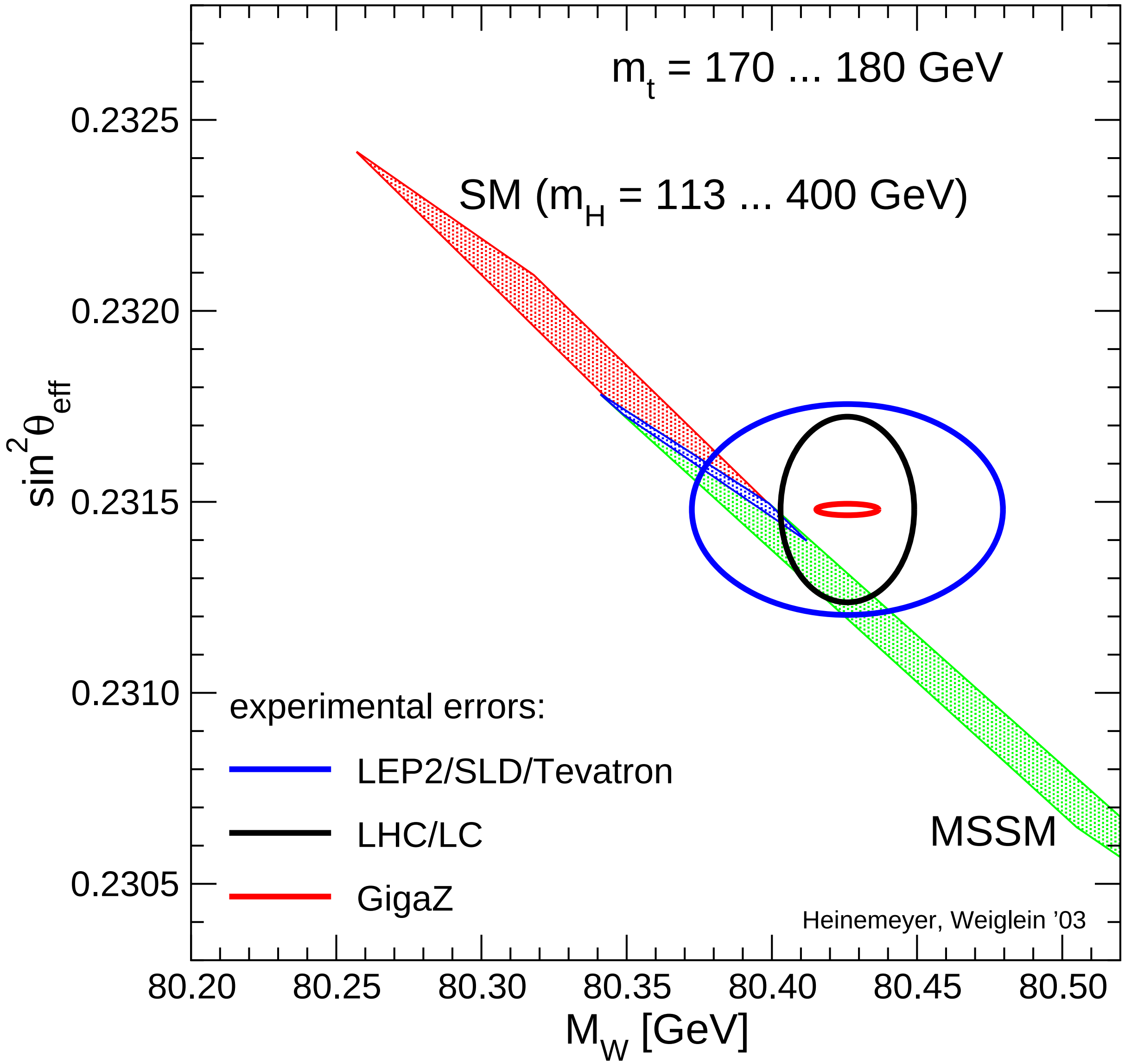

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The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

$$\left[u, d, c, s, t, b\right]_{L,R} \quad \left[e, \mu, \tau\right]_{L,R} \quad \left[\nu_{e,\mu,\tau}\right]_L \qquad \text{Spin } \tfrac{1}{2}$$

$$\left[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\right]_{L,R} \quad \left[\tilde{e}, \tilde{\mu}, \tilde{\tau}\right]_{L,R} \quad \left[\tilde{\nu}_{e,\mu,\tau}\right]_L \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^\pm, H^\pm} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin 1 / Spin 0}$$

$$\tilde{g} \quad \tilde{\chi}^\pm_{1,2} \quad \tilde{\chi}^0_{1,2,3,4} \qquad \text{Spin } \frac{1}{2}$$

Enlarged Higgs sector: Two Higgs doublets

Problem in the MSSM: many scales

Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$V = m_1^2 H_1\bar{H}_1 + m_2^2 H_2\bar{H}_2 - m_{12}^2(\epsilon_{ab}H_1^a H_2^b + \text{h.c.}) + \underbrace{\frac{g'^2 + g^2}{8}}(H_1\bar{H}_1 - H_2\bar{H}_2)^2 + \underbrace{\frac{g^2}{2}}|H_1\bar{H}_2|^2$$

gauge couplings, in contrast to SM

physical states: $h^0, H^0, A^0, H^\pm$

Goldstone bosons: $G^0, G^\pm$

Input parameters:

$$\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2(\tan\beta + \cot\beta)$$

NMFV in the MSSM

NMFV: Non Minimal Flavor Violation

$\rightarrow$ Mixing of scalar quark families (beyond CKM)

Mixing of stop/scharme and of sbottom/sstrange:

$$(\tilde{t}_L, \tilde{t}_R, \tilde{c}_L, \tilde{c}_R) \begin{pmatrix} \widetilde{T} & 0 \\ 0 & \widetilde{C} \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \\ \tilde{c}_L \\ \tilde{c}_R \end{pmatrix} \qquad (\tilde{b}_L, \tilde{b}_R, \tilde{s}_L, \tilde{s}_R) \begin{pmatrix} \widetilde{B} & 0 \\ 0 & \widetilde{S} \end{pmatrix} \begin{pmatrix} \tilde{b}_L \\ \tilde{b}_R \\ \tilde{s}_L \\ \tilde{s}_R \end{pmatrix}$$

$\downarrow$ add NMFV $\downarrow$

$$(\tilde{t}_L, \tilde{t}_R, \tilde{c}_L, \tilde{c}_R) \begin{pmatrix} \widetilde{T} & \neq 0 \\ \neq 0 & \widetilde{C} \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \\ \tilde{c}_L \\ \tilde{c}_R \end{pmatrix} \qquad (\tilde{b}_L, \tilde{b}_R, \tilde{s}_L, \tilde{s}_R) \begin{pmatrix} \widetilde{B} & \neq 0 \\ \neq 0 & \widetilde{S} \end{pmatrix} \begin{pmatrix} \tilde{b}_L \\ \tilde{b}_R \\ \tilde{s}_L \\ \tilde{s}_R \end{pmatrix}$$

$\neq 0$:

- experimentally only partially restricted
- can e.g. be induced by RGE running in mSUGRA
- changes Higgs-squark couplings
- changes Gauge boson-squark couplings

Analytical result:

evaluation with arbitrary NMFV couplings

Numerical result:

$$\tilde{t}/\tilde{c}: \quad \begin{pmatrix} \lambda\sqrt{\tilde{T}_{LL}\tilde{C}_{LL}} & 0 \\ 0 & 0 \end{pmatrix} \qquad \tilde{b}/\tilde{s}: \quad \begin{pmatrix} \lambda\sqrt{\tilde{B}_{LL}\tilde{S}_{LL}} & 0 \\ 0 & 0 \end{pmatrix}$$

$SU(2)$: $\tilde{T}_{LL} \approx \tilde{B}_{LL}$, $\tilde{C}_{LL} \approx \tilde{S}_{LL}$

$\longrightarrow$ suggested by RGE analysis

$\longrightarrow$ no relevant experimental bounds on λ

2. Results for M_W and $\sin^2\theta_{\rm eff}$

1.) Theoretical prediction for M_W in terms of $M_Z, \alpha, G_\mu, \Delta r$:

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\,\alpha}{\sqrt{2}\,G_\mu}\left(\frac{1}{1-\Delta r}\right)$$

$\Updownarrow$

loop corrections

2.) Effective mixing angle:

$$\sin^2\theta_{\rm eff}=\frac{1}{4\,|Q_f|}\left(1-\frac{\mathrm{Re}\,g_V^f}{\mathrm{Re}\,g_A^f}\right)$$

Higher order contributions:

$$g_V^f\to g_V^f+\Delta g_V^f,\quad g_A^f\to g_A^f+\Delta g_A^f$$

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

$\rightarrow$ can be approximated with the **ρ-parameter:**

ρ measures the relative strength between neutral current interaction and charged current interaction

$$\rho = \frac{1}{1 - \Delta\rho} \qquad\qquad \Delta\rho = \frac{\Sigma_Z(0)}{M_Z^2} - \frac{\Sigma_W(0)}{M_W^2}$$

(leading, process independent terms)

$\Delta\rho$ gives the main contribution to EW observables:

$$\Delta M_W \approx \frac{M_W}{2} \frac{c_\text{W}^2}{c_\text{W}^2 - s_\text{W}^2} \Delta\rho,$$

$$\Delta \sin^2\theta_W^{\text{eff}} \approx -\frac{c_\text{W}^2 s_\text{W}^2}{c_\text{W}^2 - s_\text{W}^2} \Delta\rho$$

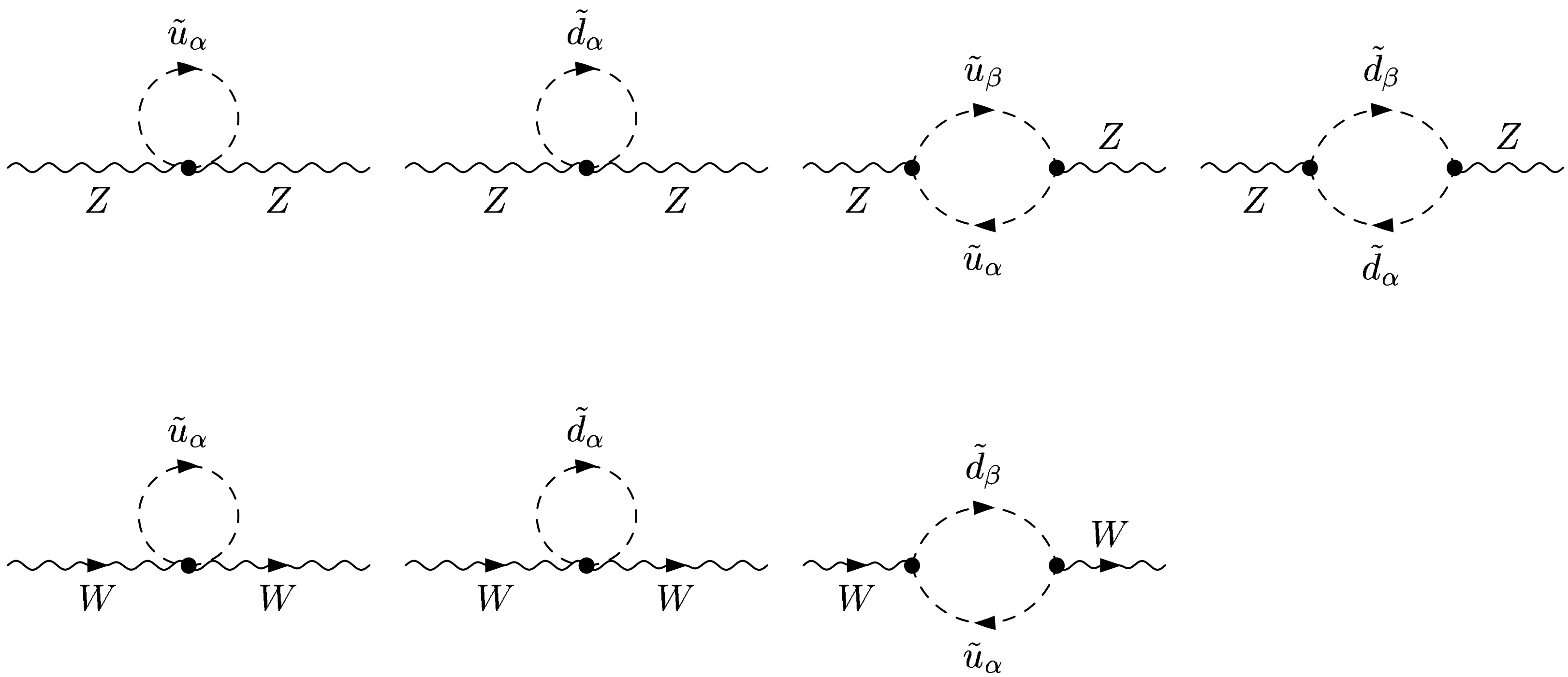
$\Rightarrow$ Experimental bound: $\Delta\rho \lesssim 2 \times 10^{-3}$

Numerically veryfied:

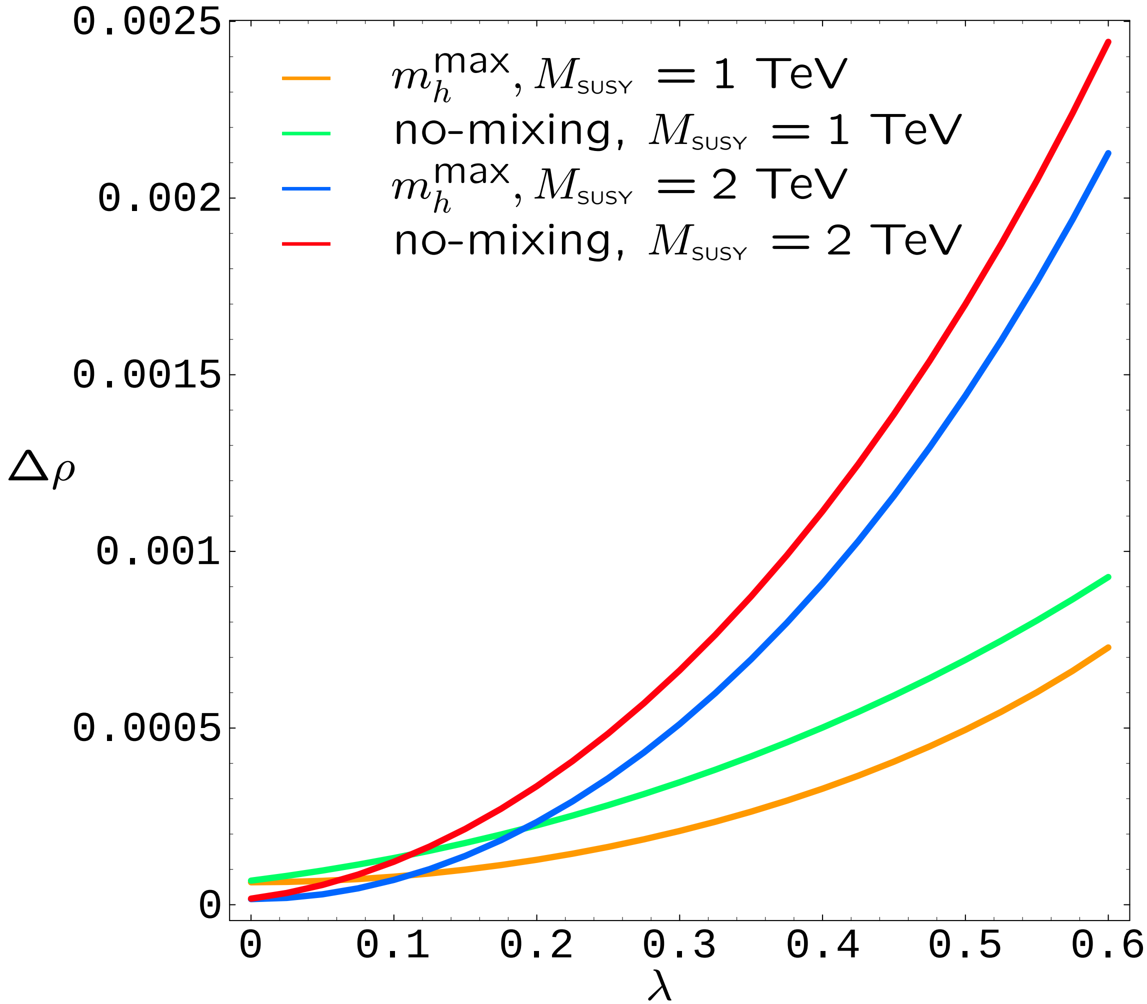
$\Delta\rho$ is an excellent approximation for the full calculation

$\Rightarrow$ concentrate on $\Delta\rho$
(but full calculation is available)

Feynman diagrams for $\Delta\rho$:



$\Delta\rho$ as a function of λ:

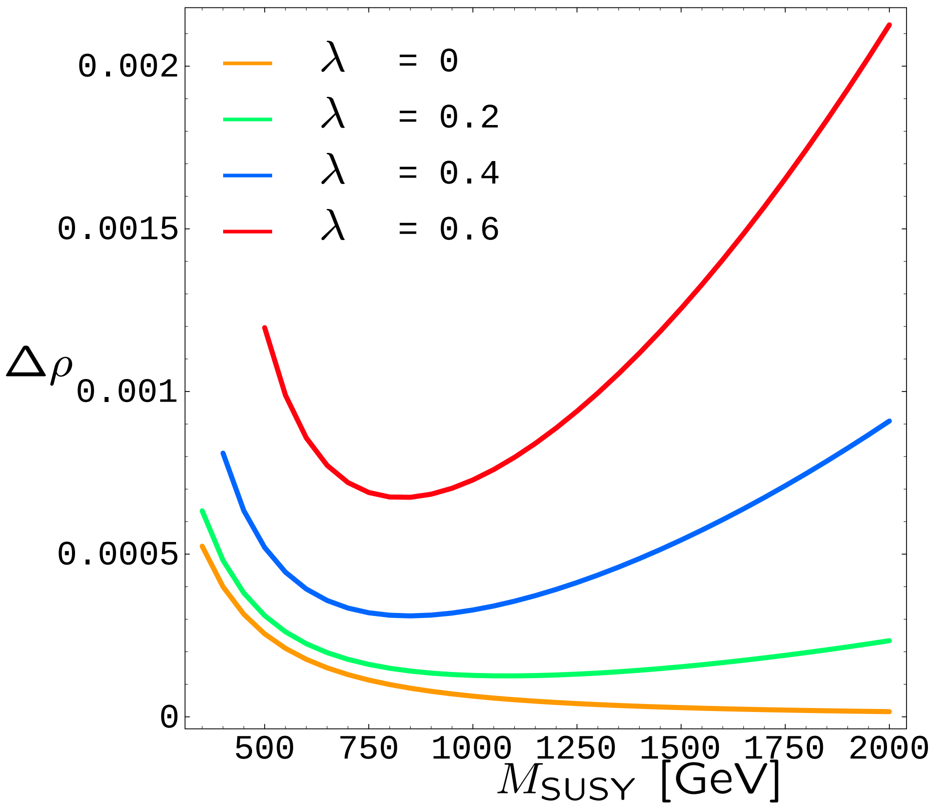


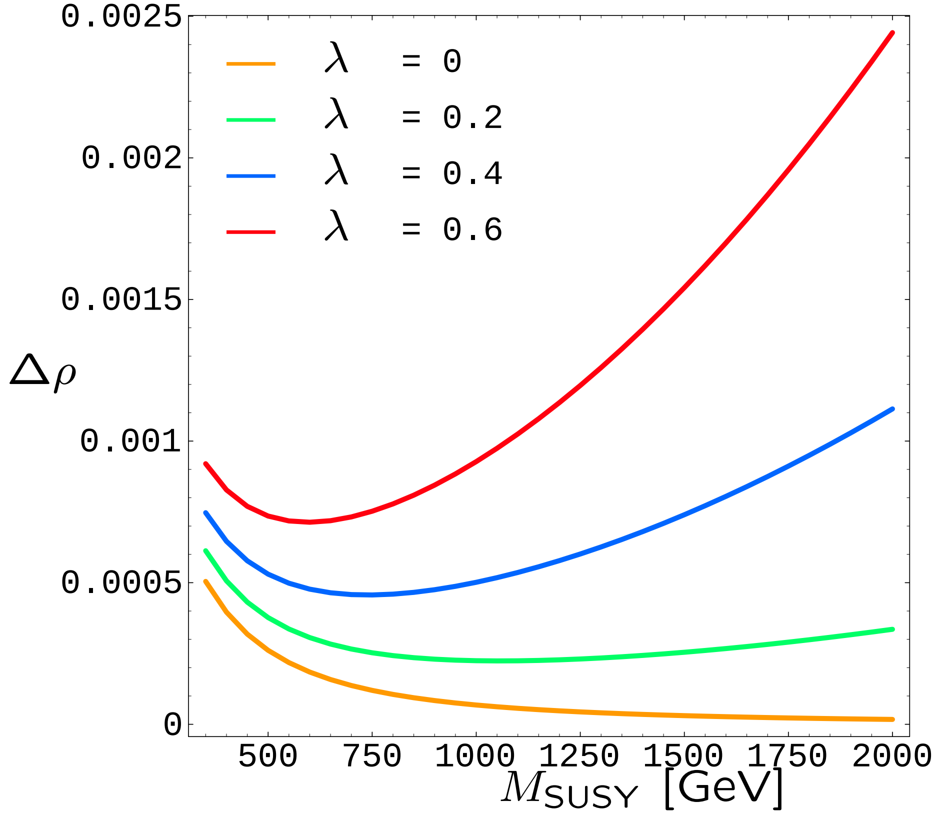
increasing λ
$\Rightarrow$ increasing mixing
$\Rightarrow$ increasing $\Delta\rho$

increasing M_{SUSY}
$\Rightarrow$ increasing mixing
$\Rightarrow$ increasing $\Delta\rho$

$\Delta\rho \lesssim 2 \times 10^{-3}$ can be saturated

$\Delta\rho$ as a function of M_{SUSY}:



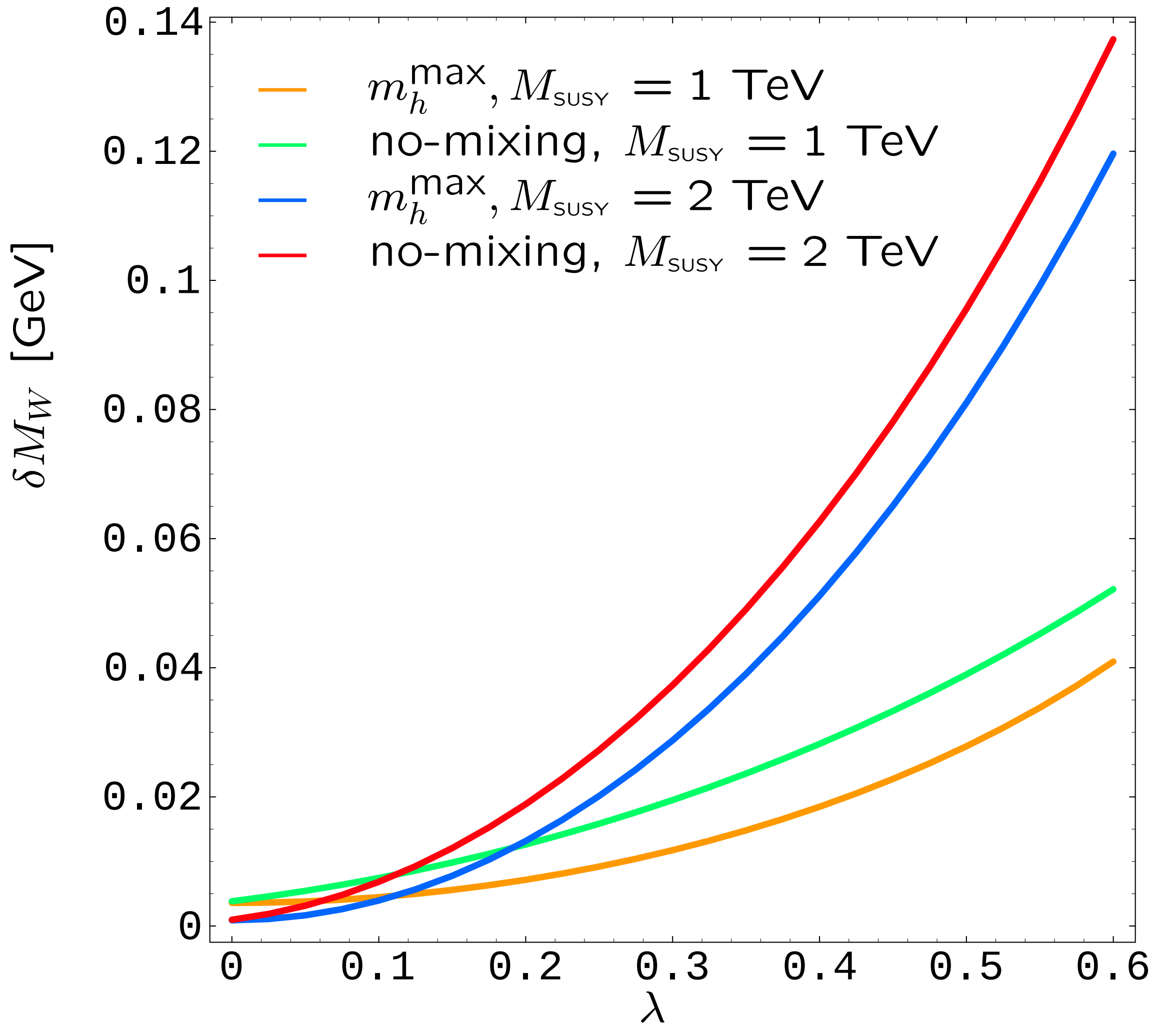


$\rightarrow$ decoupling for $\lambda = 0$ as expected

$\rightarrow$ $\lambda \neq 0$: minimum at moderate M_{SUSY}

increase for large M_{SUSY} (due to enlarged mixing)

δM_W as a function of λ:



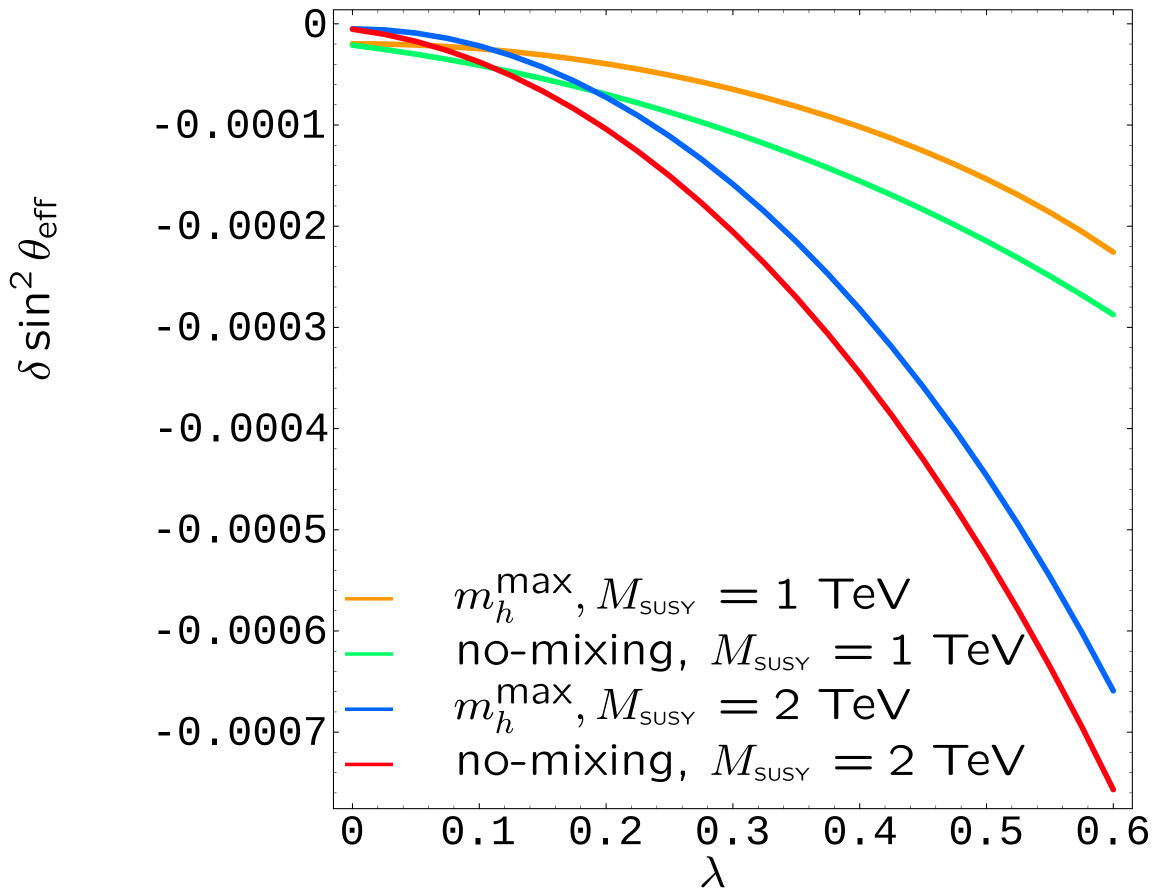
follows the behavior of $\Delta\rho$

$\delta M_W^{\rm exp,today} = 34$ MeV

$\delta M_W^{\rm exp,future} = 7$ MeV

$\Rightarrow$ extreme parameter regions already ruled out

$\delta \sin^2\theta_{\rm eff}$ as a function of λ:



follows the behavior of $\Delta\rho$

$\delta \sin^2\theta_{\rm eff}^{\rm exp,today} = 17 \times 10^{-5}$

$\delta \sin^2\theta_{\rm eff}^{\rm exp,future} = 1.3 \times 10^{-5}$

$\Rightarrow$ extreme parameter regions already ruled out

$\Rightarrow$ highly sensitive test in the future

3. Results for m_h

Contrary to the SM: m_h is not a free parameter

MSSM tree-level bound: $m_h < M_Z$, excluded by LEP Higgs searches

Large radiative corrections:

Dominant one-loop corrections: $\sim G_\mu m_t^4 \ln\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right)$

> The MSSM Higgs sector is connected to all other sector via loop corrections (especially to the scalar top sector)

Measurement of m_h, Higgs couplings $\Rightarrow$ test of the theory

LHC: $\Delta m_h \approx 0.2$ GeV
LC: $\Delta m_h \approx 0.05$ GeV

$\Rightarrow$ m_h will be (the best?) electroweak precision observable

For not too large $\tan\beta$: only $\tilde{t}/\tilde{c}$ sector relevant

⇒ Evaluation of Σ_h, Σ_H, Σ_{hH}, Σ_A, T_h, T_H

(contributions from $t/\tilde{t}$ and $c/\tilde{c}$ only) → T

⇒ Results implemented in

*FeynHiggs*2.1

www.feynhiggs.de

Higgs boson sector analysis performed in 5 benchmark scenarios

[*M. Carena, S.H., C. Wagner, G. Weiglein '02*]

– m_h^{max} (to maximize the lightest Higgs boson mass)

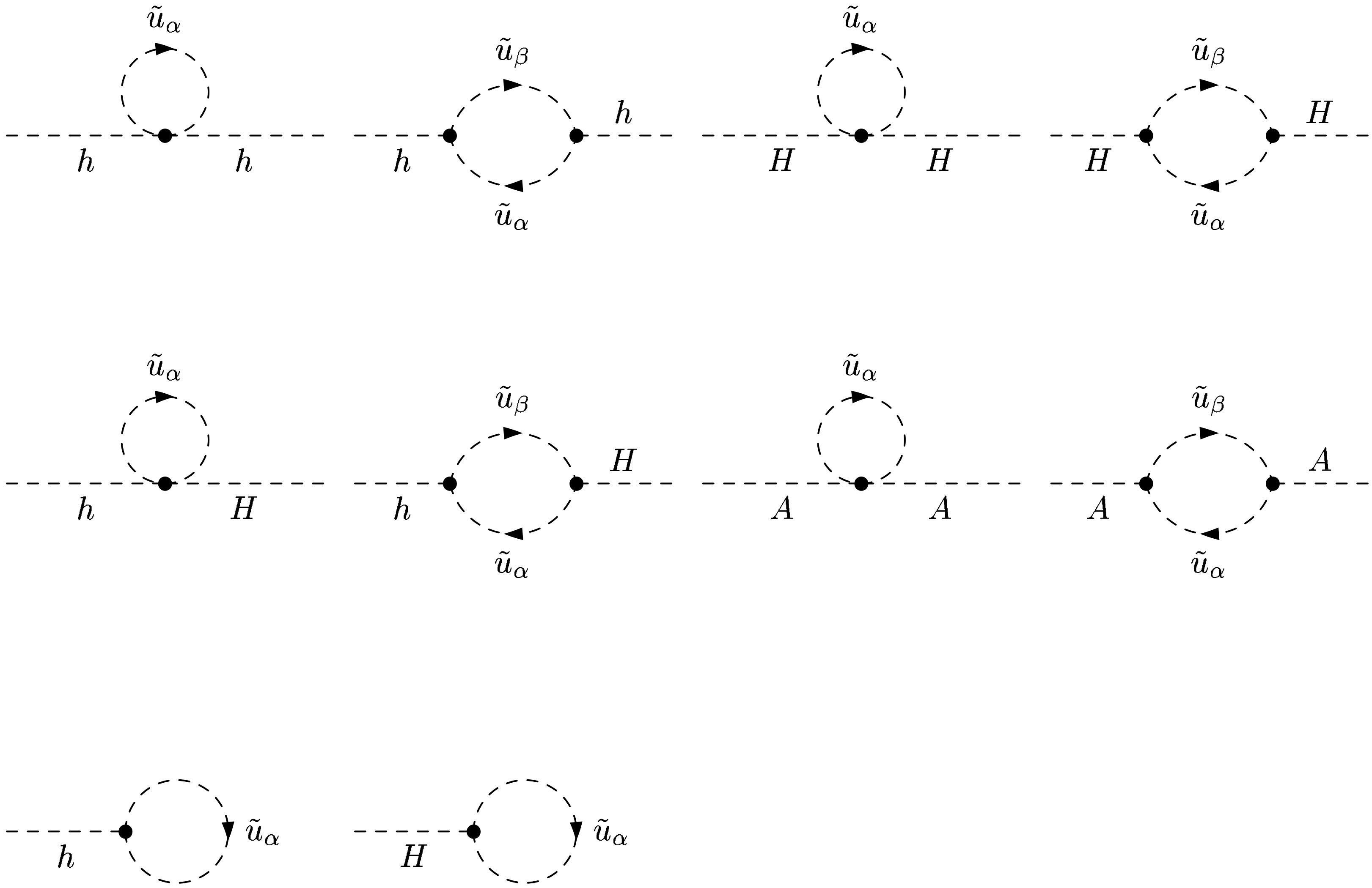
– constrained m_h^{max} (with $X_t/M_{\text{SUSY}} = -2$ for $b \to s\gamma$)

– no-mixing (with no mixing in the MFV $\tilde{t}$ sector)

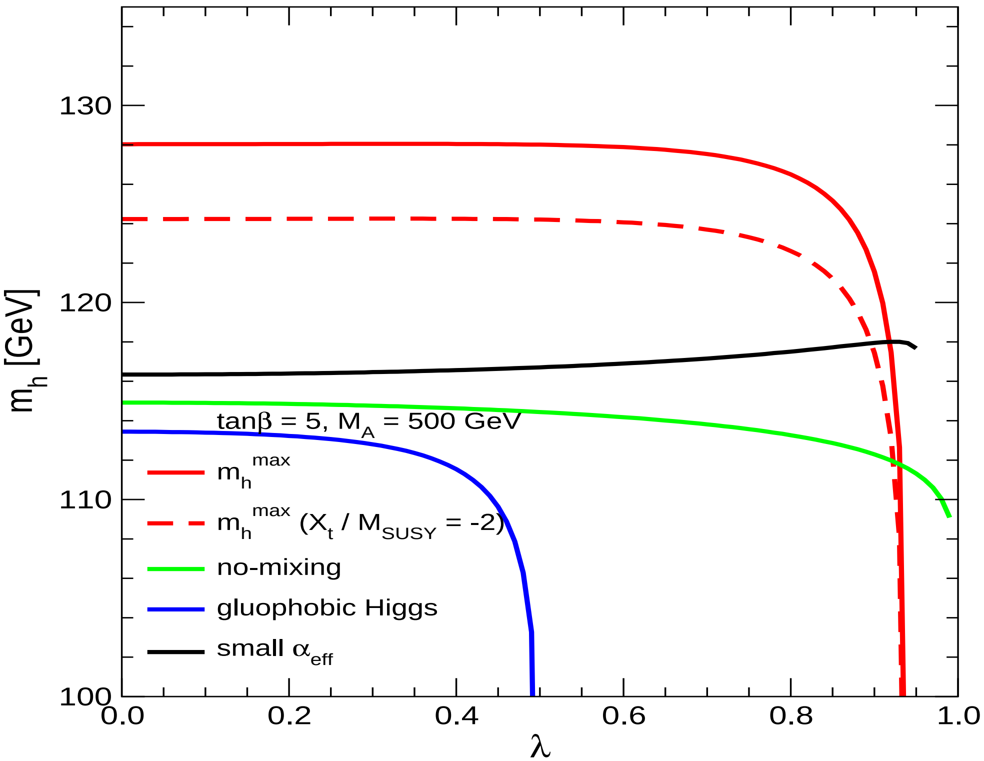
– gluophobic Higgs (with reduced ggh coupling)

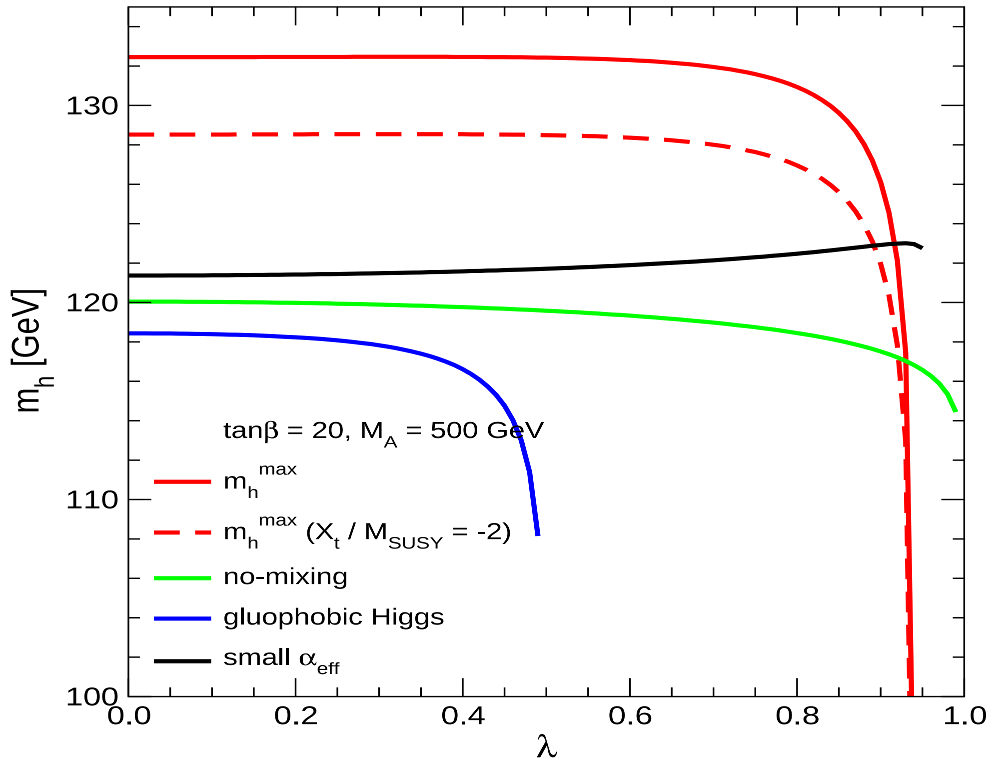
– small α_{eff} (with reduced $h\bar{b}b$ and $h\tau^+\tau^-$ coupling)

Feynman diagrams for m_h: evaluation of Σ_h, Σ_H, Σ_{hH}, Σ_A, T_h, T_H



Effects in benchmark scenarios:





$\Rightarrow$ small effects for small/moderate λ

$\Rightarrow$ $\delta m_h = \mathcal{O}(5 \text{ GeV})$ only for very large λ

$\rightarrow$ mostly decreasing m_h, but also increase possible
(e.g. in small α_{eff} scenario)

4. Conclusinos

- Precision observables can
  - give valuable information about the "true" Lagrangian
  - constrain MSSM parameter space already today

- MSSM with NMFV:

  mixing in the $\tilde{t}/\tilde{c}$ and in the $\tilde{b}/\tilde{s}$ sector

- $\Rightarrow$ Evaluation of M_W, $\sin^2\theta_{\rm eff}$, m_h in NMFV MSSM

- Analytical results: for arbitrary mixing

  Numerical results: only for LL mixing, parametrized with λ corresponds to $(\delta_{LL})_{23}$

- large effects possible for M_W, $\sin^2\theta_{\rm eff}$: $\lambda \lesssim 0.2 \Rightarrow \delta M_W \lesssim 20$ MeV

  $\lambda \lesssim 0.2 \Rightarrow \delta\sin^2\theta_{\rm eff} \lesssim 10^{-4}$

- moderate effects possible for m_h only for large λ