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Radiative Corrections
to
SUSY processes in the MSSM

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- Why bother about radiative corrections, when no SUSY particle found yet?

  - Experimental accuracy at LC$<$ few percent

    At Tesla: $\Delta m_{\tilde{\chi}^{\pm,0}} = 0.1$ - 1 GeV, $\Delta m_{\tilde{l},\tilde{\nu}} = 0.05$ - 0.3 GeV

    $\Rightarrow$ need precise predictions

  - in some cases corrections relatively large > 50 %

  - still some 'technical' problems to be solved:

    appropriate renormalization conditions:

      fixing of counter terms for SUSY parameters in the on-shell scheme

      should be process independent, symmetry conserving (SUSY + gauge symmetry) and numerically stable

- Here: Practitioner's point of view

For a general discussion on the renormalization of the MSSM using an algebraic method, see W. Hollik, E. Kraus, M. Roth, hep-ph/0204350

Discuss:

$$e^+ e^- \to \tilde{\chi}_i^+ \tilde{\chi}_j^-$$
$$\to \tilde{\chi}_l^0 \tilde{\chi}_k^0$$
$$e^+ e^- \to \tilde{f}_i \tilde{f}_j \qquad f = l, q \quad (q = b, t)$$
$$e^+ e^- \to q \bar{\tilde{q}} \tilde{g} (g) \qquad \text{(light quarks)}$$

Decays:

$$\tilde{f}_{1,2} \to f \tilde{\chi}_l^0$$
$$\to f' \tilde{\chi}_i^\pm$$
$$\tilde{f}_i \to \tilde{f}_j + (W, Z, H_l)$$
$$H_l \to \tilde{\chi}_i \tilde{\chi}_j, \quad \tilde{\chi}_i \to \tilde{\chi}_j + H_l$$
$$H_l \to \tilde{q}_i \overline{\tilde{q}}_j \qquad H_l = \{h^0, H^0, A^0, H^\pm\}$$

GENERAL METHOD

$$\mathcal{L} = \mathcal{L}_{\text{MSSM}} + \mathcal{L}_{\text{gauge fixing}} + \mathcal{L}_{\text{ghost}}$$

all fields $\phi_i \to \sqrt{Z_i}\,\phi_i = (1 + \frac{1}{2}\delta Z_i)\,\phi_i$

all parameters $c_k \to c_k + \delta c_k$

$$\mathcal{L}^{\text{ren}} = \mathcal{L} - \delta\mathcal{L}$$

$\delta\mathcal{L}$ ... counter term part renders $\mathcal{L}$ finite contains all counter terms which have to be fixed appropriately.

We use here:

- **$\overline{\text{DR}}$ (dimensional reduction) scheme**
  $n = 4 - r\epsilon\,,\ r = 0\,,$ conserves SUSY at least up to first order
- **on-shell scheme:** particle masses are pole masses, no scale dependence
- **R_ξ gauge**

Special feature of MSSM:

Scalars/fermions are mixed:

$$\chi_i = U_{ij}\,\psi_j \qquad U_{ij}\ldots \text{unitary}$$

mass eigenstates (χ_i) — interaction states (ψ_j)

Need counterterm δU

- **Mixing angle of sfermions $\tilde{f}$**

$$\tilde{f} = \{\tilde{t}, \tilde{b}, \tilde{\tau}, \ldots\}$$

$\tilde{f}_L$, $\tilde{f}_R$ mix with each other by $SU(2) \times U(1)$ breaking

mass eigenstates: $\tilde{f}_i\,,\quad i = 1, 2$

$$\tilde{f}_i = R\,\tilde{f}_\alpha \qquad \text{with } \tilde{f}_i = \begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \end{pmatrix},\ \tilde{f}_\alpha = \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix}$$

$$R = \begin{pmatrix} \cos\theta_{\tilde{f}} & \sin\theta_{\tilde{f}} \\ -\sin\theta_{\tilde{f}} & \cos\theta_{\tilde{f}} \end{pmatrix}$$

mixing angle $\theta_{\tilde{f}}$ is measurable.

Potential V (at tree level)

$$V = (\tilde{f}_L^*, \tilde{f}_R^*) \underbrace{\begin{pmatrix} m_{LL}^2 & m_{LR}^2 \\ m_{RL}^2 & m_{RR}^2 \end{pmatrix}}_{\mathcal{M}} \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix} + h.c.$$

$$= \tilde{f}_i\,(\mathcal{M}_D)_{ii}\,\tilde{f}_i \qquad \mathcal{M}_D = R\,\mathcal{M}\,R^\dagger = \begin{pmatrix} m_{\tilde{f}_1}^2 & 0 \\ 0 & m_{\tilde{f}_2}^2 \end{pmatrix}$$

Renormalize by

$$\tilde{f}_i^0 = \left(1 + \tfrac{1}{2}\delta Z\right)\tilde{f}_i$$
$$R^0 = R + \delta R = (1 + \delta r)\, R$$
$$\mathcal{M}^0 = \mathcal{M} + \delta\mathcal{M}$$

Since R^0 and R are unitary $\longrightarrow$ $\delta r = -\delta r^\dagger$, antihermitian

On the other hand one can decompose the wave function renormalization counter term into:

$$\delta Z = \frac{1}{2}\left(\delta Z + \delta Z^\dagger\right) + \frac{1}{2}\left(\delta Z - \delta Z^\dagger\right)$$

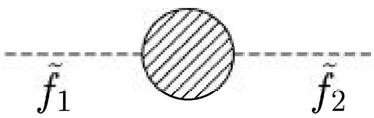
δr is fixed such that it cancels the antihermitian part of δZ, i.e.

$$\boldsymbol{\delta R = \frac{1}{4}\left[\delta Z^{\tilde{f}} - \left(\delta Z^{\tilde{f}}\right)^\dagger\right] R}$$

$$\rightarrow \quad \boldsymbol{\delta\theta_{\tilde{f}} = \frac{1}{4}\left(\delta Z^{\tilde{f}}_{12} - \delta Z^{\tilde{f}}_{21}\right)}$$

$$\boldsymbol{= \frac{1}{4}\,\frac{\Sigma_{12}(m^2_{\tilde{f}_1}) + \Sigma_{12}(m^2_{\tilde{f}_2})}{2\left(m^2_{\tilde{f}_1} - m^2_{\tilde{f}_2}\right)}}$$

Σ_{12} ... non-diagonal self-energies of $\tilde{f}_i$:



This is a process independent fixing nowadays conventionally used: (*Hollik et al, Eberl et al, Guasch et al,*)

- A priori gauge dependent:

  Can be made gauge independent by pinch technique (Y. Yamada, hep-ph/0103046.) or equivalently calculate in $\xi = 1$ gauge

- Mixing angle α in the h^0–H^0 system can be treated similarly as above:

$$\delta\alpha = \frac{1}{4}(\delta Z_{12} - \delta Z_{21})$$

(index 1 for H^0, 2 for h^0)

Chargino sector

- **Mass matrix (at tree level)**

$$X = \begin{pmatrix} M & \sqrt{2} m_W \sin\beta \\ \sqrt{2} m_W \cos\beta & \mu \end{pmatrix}$$

X diagonalized by two real (2×2) matrices U and V

$$U\, X\, V^T = \mathcal{M}_D = \begin{pmatrix} m_{\tilde{\chi}_1^+} & 0 \\ 0 & m_{\tilde{\chi}_2^+} \end{pmatrix}$$

with $\begin{matrix} \chi_i^L = V_{ij}\, \psi_j^L \\ \chi_i^R = U_{ij}\, \psi_j^R \end{matrix}$, Dirac spinor: $\tilde{\chi}_i^+ = \begin{pmatrix} \chi_i^L \\ \bar{\chi}_i^R \end{pmatrix}$,

- **Proceed as before . . .**

$$\begin{aligned} U^0 &= U + \delta U \\ V^0 &= V + \delta V \\ X^0 &= X + \delta X \\ \psi^0_{L,R} &= \left(1 + \frac{1}{2}\delta Z^{\chi^+}_{L,R}\right) \psi_{L,R} \\ \delta U &= \frac{1}{4}\left[\delta Z_R^{\chi^+} - \left(\delta Z_R^{\chi^+}\right)^T\right] U \\ \delta V &= \frac{1}{4} V^T \left[\left(\delta Z_L^{\chi^+}\right)^T - \delta Z_L^{\chi^+}\right] \end{aligned}$$

where $\delta Z^{\chi^+}_{L,R}$ are the wave-function renormalization constants

$s \neq p\,;\quad s\,,p\,=\,1\,,2$

$$\left(\delta Z_R^{\tilde\chi^+}\right)_{sp} = \frac{2}{m_s^2 - m_p^2}\, Re\Big\{\Pi_{sp}^R(m_p^2)\, m_p^2 \,+\, \Pi_{sp}^L(m_p^2)\, m_p\, m_s + \Pi_{sp}^{S,R}(m_p^2)\, m_s \,+\, \Pi_{sp}^{S,L}(m_p^2)\, m_p\Big\}$$

$$\left(\delta Z_L^{\tilde\chi^+}\right)_{sp} = \text{by replacing } L \leftrightarrow R$$

$$\delta m_s = \frac{1}{2}\, Re\Big\{m_s[\Pi_{ss}^L(m_s^2) + \Pi_{ss}^R(m_s^2)] + \Pi_{ss}^{S,L}(m_s^2) + \Pi_{ss}^{S,R}(m_s^2)\Big\}$$

where Π_{sp} are self-energies according to the decomposition of the two-point function of charginos $\tilde\chi_s^+$ and $\tilde\chi_p^+$:

$$i\,\hat\Gamma_{sp}(k) = i\,\delta_{sp}\,(\not k - m_{f_p}) \,+\, i\not k\Big[P_L\hat\Pi_{sp}^L(k^2) + P_R\hat\Pi_{sp}^R(k^2)\Big] + i\,\hat\Pi_{sp}^{S,L}(k^2)P_L \,+\, i\,\hat\Pi_{sp}^{S,R}(k^2)P_R$$

- Mass matrix $X = U^T M_D V$, $\delta X = \delta U^T M_D V + U^T \delta M_D V + U^T M_D \delta V$

$$(\delta X)_{sp} = \frac{1}{2}\sum_{i,j} U_{is}V_{jp}\, Re\Big[\Pi_{ij}^L(m_i^2)m_i^2 + \Pi_{ij}^R(m_j^2)m_j^2 + \Pi_{ij}^{S,L}(m_i^2) + \Pi_{ji}^{S,R}(m_j^2)\Big]$$

$$\Pi_{ij}^{S,L} = \Pi_{ji}^{S,R}$$

(H. Eberl, M. Kincel, W. M., Y. Yamada, PRD **64**, 115013 (2001))

- Renormalization of M and μ

  In principle we can fix M and μ by chargino or neutralino sector, choose chargino sector:

$$\boldsymbol{\delta M} = \boldsymbol{(\delta X)_{11}}$$
$$\boldsymbol{\delta \mu} = \boldsymbol{(\delta X)_{22}}$$

Neutralino sector

- **Mass matrix (at tree level)**

$$Y = \begin{pmatrix} M' & 0 & -m_Z \sin\theta_W \cos\beta & m_Z \sin\theta_W \sin\beta \\ 0 & M & m_Z \cos\theta_W \cos\beta & -m_Z \cos\theta_W \sin\beta \\ -m_Z \sin\theta_W \cos\beta & m_Z \cos\theta_W \cos\beta & 0 & -\mu \\ m_Z \sin\theta_W \sin\beta & -m_Z \cos\theta_W \sin\beta & -\mu & 0 \end{pmatrix} .$$

Diagonalized by:

$$N\,Y\,N^T = Y_D = \begin{pmatrix} m_{\chi_1^0} & 0 & 0 & 0 \\ 0 & m_{\chi_2^0} & 0 & 0 \\ 0 & 0 & m_{\chi_3^0} & 0 \\ 0 & 0 & 0 & m_{\chi_4^0} \end{pmatrix}$$

Shift for the rotation matrix N:

$$\delta N = \frac{1}{4}\left[\delta Z^{\chi^0} - \left(\delta Z^{\chi^0}\right)^T\right] N$$

$\left(\delta Z_L^{\chi^0} = \delta Z_R^{\chi^0}\right.$ due to Majorana nature$\left.\right)$

- **Renormalization of M'**

Fix $$\delta M' = (\delta Y)_{11} = \delta\left(N^T\,Y_D\,N\right)_{11}$$
$$= \sum_{j=1}^{4} \epsilon_j \left[\delta m_{\chi_j^0}\,(N_{j1})^2 + 2\,m_{\chi_j^0}\,N_{j1}\,\delta N_{j1}\right]$$

ϵ_i . . . sign of $m_{\chi_i^0}$

Chargino mass matrix at one-loop in the on-shell scheme

(H. Eberl, M. Kincel, W. M., Y. Yamada, PRD **64**, 115013 (2001))

In the $\overline{\text{DR}}$ scheme: D. Pierce et al., NPB 491, 3 (1997)

Has to distinguish three types of mass matrix:

X^0	'bare' mass matrix (or $\overline{\text{DR}}$ running three-level matrix)
X_{tree}	tree-level mass matrix in terms of on-shell input parameters $(M,\, \mu,\, m_W,\, \tan\beta)$
X	one-loop corrected mass matrix

$$X^0 = X_{\text{tree}} + \delta_p X$$

(δ_p means the variation of the (on-shell) parameters)

$$X^0 = X + \delta X$$

Eliminating X^0, we get

$$X = X_{\text{tree}} + \delta_p X - \delta X = X_{\text{tree}} + \Delta X$$

with the UV **finite** shift ΔX

- We have already fixed M, μ ($\delta M = (\delta X)_{11}$, $\delta\mu = (\delta X)_{22}$)
- m_W fixed as the physical (pole) masses

- Renormalization of $\tan\beta$

  Fixed by $\mathrm{Im}\{\hat{\Pi}_{A^0Z^0}(m^2_{A^0})\} = 0$

$$\rightarrow \frac{\delta\tan\beta}{\tan\beta} = -\frac{1}{m_Z\sin 2\beta}\,\mathrm{Im}\Pi_{A^0Z^0}(m^2_{A^0})$$

  (P. H. Chankowski, S. Pokorski, J. Rosiek, Nucl. Phys. B **423** (1994) 437;
  A. Dabelstein, Z. Phys. C **67** (1995) 495.)

  Gauge dependence and other schemes,

  see Y. Yamada, hep-ph/9608382

  hep-ph/0112251 + parallel session

  A. Freitas, D. Stöckinger, hep-ph/0205281

One gets:

$$\begin{aligned}
\Delta X_{11} &= 0 \\
\Delta X_{12} &= \left(\frac{\delta m_W}{m_W} + \cos^2\beta\,\frac{\delta\tan\beta}{\tan\beta}\right) X_{12} - \delta X_{12} \\
\Delta X_{21} &= \left(\frac{\delta m_W}{m_W} - \sin^2\beta\,\frac{\delta\tan\beta}{\tan\beta}\right) X_{21} - \delta X_{21} \\
\Delta X_{22} &= 0
\end{aligned}$$

- **Procedure in practice:**

  $m_{\chi_1^\pm}$, $m_{\chi_2^\pm}$ known from experiment

  1. Calculate X_{tree}, M_{tree}, μ_{tree}, U_{tree}, V_{tree}
  2. δU, δV
  3. ΔX_{12}, ΔX_{21}
  4. X has to give the pole masses $m_{\chi^\pm_{1,2}}$ $\rightarrow$ correct on shell M and μ

Neutralino mass matrix at one-loop

Y^0 'bare' mass matrix ($\overline{\mathrm{DR}}$ running tree-level matrix)

Y_{tree} tree-level mass matrix in terms of on-shell parameters

Y one-loop corrected mass matrix

Y diagonalized by the real (4×4) matrix N,

$$M_D = N\, Y\, N^T$$

We have

$$Y = Y_{\mathrm{tree}} + \Delta Y$$

$$\Delta Y = \delta_p Y - \delta Y$$

δ_p means variation of the parameters.

- **Fixing of parameters:**

  M, μ, $\tan\beta$ already fixed

  m_Z fixed as the physical (pole) mass,

  $$\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$$

  $$M': \quad Y_{11} = M'\,,\ \delta M' = (\delta Y)_{11} \ \rightarrow \ \Delta Y_{11} = 0$$

$$\begin{aligned}
\Delta Y_{11} &= 0 \\
\Delta Y_{12} &= -\delta Y_{12} \\
\Delta Y_{13} &= \left(\frac{\delta m_Z}{m_Z} + \frac{\delta\sin\theta_W}{\sin\theta_W} - \sin^2\beta\,\frac{\delta\tan\beta}{\tan\beta}\right) Y_{13} - \delta Y_{13} \\
\Delta Y_{14} &= \left(\frac{\delta m_Z}{m_Z} + \frac{\delta\sin\theta_W}{\sin\theta_W} + \cos^2\beta\,\frac{\delta\tan\beta}{\tan\beta}\right) Y_{14} - \delta Y_{14} \\
\Delta Y_{22} &= \delta M - \delta Y_{22} \\
\Delta Y_{23} &= \left(\frac{\delta m_Z}{m_Z} - \tan^2\theta_W\,\frac{\delta\sin\theta_W}{\sin\theta_W} - \sin^2\beta\,\frac{\delta\tan\beta}{\tan\beta}\right) Y_{23} - \delta Y_{23} \\
\Delta Y_{24} &= \left(\frac{\delta m_Z}{m_Z} - \tan^2\theta_W\,\frac{\delta\sin\theta_W}{\sin\theta_W} + \cos^2\beta\,\frac{\delta\tan\beta}{\tan\beta}\right) Y_{24} - \delta Y_{24} \\
\Delta Y_{33} &= -\delta Y_{33} \\
\Delta Y_{34} &= -\delta\mu - \delta Y_{34} \\
\Delta Y_{44} &= -\delta Y_{44}\,,
\end{aligned}$$

Notice that $Y_{12} = Y_{21}$, Y_{33}, and Y_{44} are **no more zero**!

- **M' related to M (as in GUT models)**

$\rightarrow \quad \Delta Y_{11}$ is no more zero!

E.g. SUSY SU(5): $M' = \frac{5}{3}\tan^2\theta_W M$ for $\overline{\text{DR}}$ parameters

If for on-shell M' and M the same relation holds, one has

$$\Delta Y_{11} = \left(\frac{2}{\cos^2\theta_W}\frac{\delta\sin\theta_W}{\sin\theta_W} + \frac{\delta M}{M}\right) Y_{11} - \delta Y_{11} .$$

This relation is also valid in other models, e.g. in the anomaly mediated SUSY breaking models, where $M' = 11\tan^2\theta_W M$

- Method appropriate for extracting and studying the fundamental SUSY parameters (M, μ, $\ldots$)

Eberl et al.

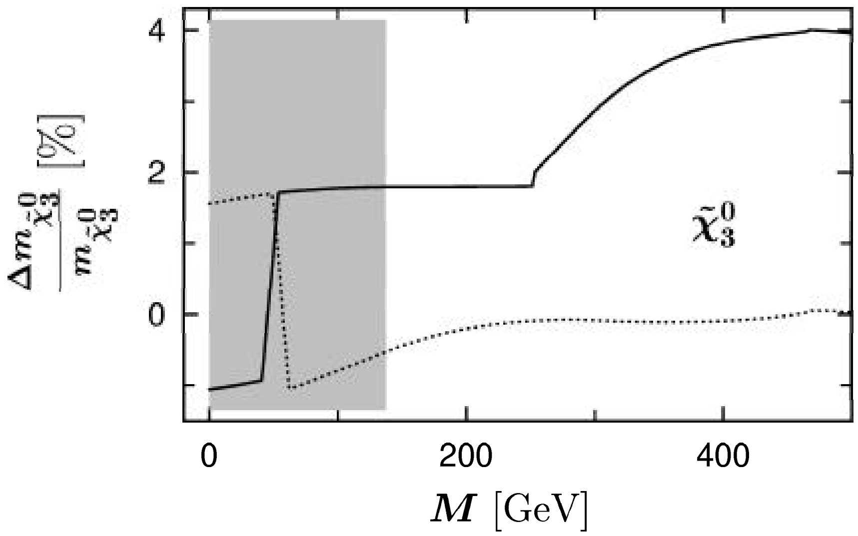
Neutralino mass corrections: Gaugino unification

$\tan\beta = 7$, $\{M_{\tilde{Q}_1}, M_{\tilde{Q}}, A\} = \{300, 300, -500\}$ GeV

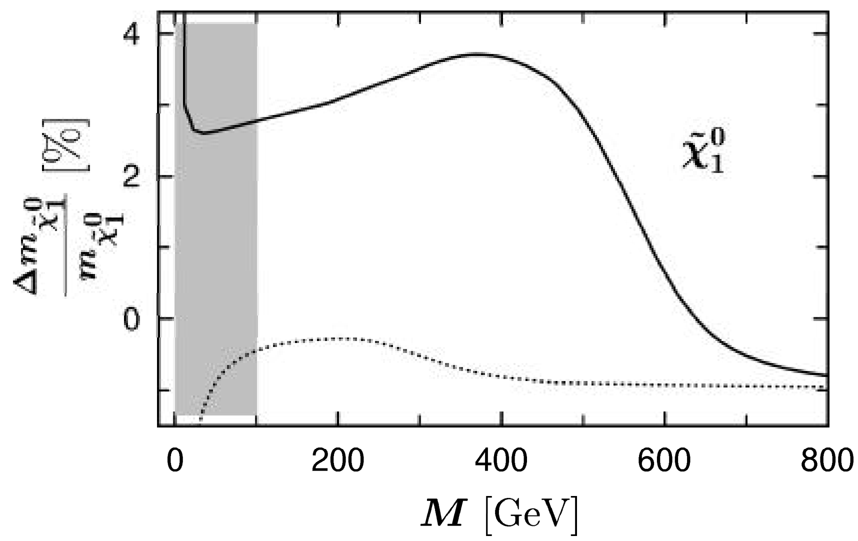
full lines: SUSY SU(5) GUT relation is assumed for the $\overline{\mathrm{DR}}$ parameters M and $M' = \frac{5}{3}\tan^2\theta_W M$

dotted lines: M' is independent parameter, set to 0.498 M

$\mu = -110$ GeV



$\mu = -300$ GeV



Other method of renormalizing chargino/neutralino system

(**T. Fritzsche** and **W. Hollik**, hep-ph/0203159, see also J. Guasch, W. Hollik, J. Solà, PLB **510** (2001) 211.)

Charginos:

Input: (physical) chargino masses $m_{\tilde{\chi}_1^\pm}$, $m_{\tilde{\chi}_2^\pm}$

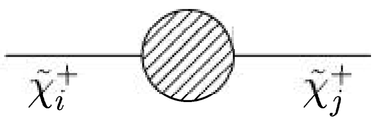
Start from tree-level form of X,

$$X = \begin{pmatrix} M & \sqrt{2}\, m_W \sin\beta \\ \sqrt{2}\, m_W \cos\beta & \mu \end{pmatrix}$$ and diagonalize

$$U^* X\, V^\dagger \;=\; \mathrm{diag}\left(m_{\tilde{\chi}_1^\pm}\,, m_{\tilde{\chi}_2^\pm}\right)$$

Using the on-shell condition

$$\mathbf{Re}\,\hat{\boldsymbol{\Gamma}}_{ij}(\boldsymbol{p})\boldsymbol{u}_j(\boldsymbol{p}) = \mathbf{0}$$



for $p^2 = m^2_{\tilde{\chi}_j^\pm}$ for the renormalized two-point function of the charginos $\hat{\boldsymbol{\Gamma}}_{ij}(\boldsymbol{p})$, one gets the counter terms for δM and $\delta\mu$.

They are different from those of Eberl et al.

Neutralinos:

One again starts from the tree-level form of the mass matrix Y

$$Y = \begin{pmatrix} M' & 0 & -m_Z \sin\theta_W \cos\beta & m_Z \sin\theta_W \sin\beta \\ 0 & M & m_Z \cos\theta_W \cos\beta & -m_Z \cos\theta_W \sin\beta \\ -m_Z \sin\theta_W \cos\beta & m_Z \cos\theta_W \cos\beta & 0 & -\mu \\ m_Z \sin\theta_W \sin\beta & -m_Z \cos\theta_W \sin\beta & -\mu & 0 \end{pmatrix} .$$

diagonalizing it: $N\,Y\,N^T = \mathrm{diag}\,(\mathrm{m}_1\,,\mathrm{m}_2\,,\mathrm{m}_3\,,\mathrm{m}_4) = M_D$

where $\left(N\,Y\,N^T\right)_{11} = m_{\tilde{\chi}^0_1}$ (pole mass)

with the appropriate on shell condition for the neutralino self-energies $\rightarrow$ fix the counter terms, especially $\delta M'$

- **Note** that only $m_1 = m_{\tilde{\chi}^0_1}$ (pole mass), $m_2\,, m_3\,, m_4$ are not pole masses

The pole masses $m_{\tilde{\chi}^0_i}$, $i = 2, 3, 4$ are found by the condition:

$$Re\left[\hat{\Gamma}^{(2)}_{ii}\,(p_i)\right] u\,(p_i) = 0$$

with $$\hat{\Gamma}^{(2)}_{ij}\,(p) = (\not{p} - m_i)\,\delta_{ij} + \hat{\Sigma}_{ij}\,(p)$$

$\hat{\Gamma}^{(2)}_{ij}$ . . . two-point vertex function

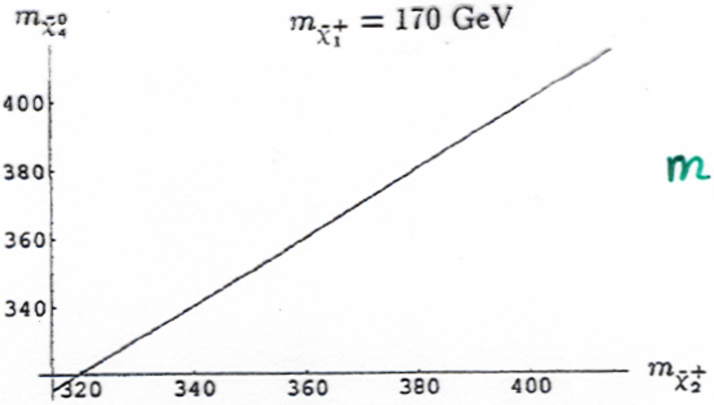
- **Note** that the parameters M, M', μ, are different from those of Eberl et al.!

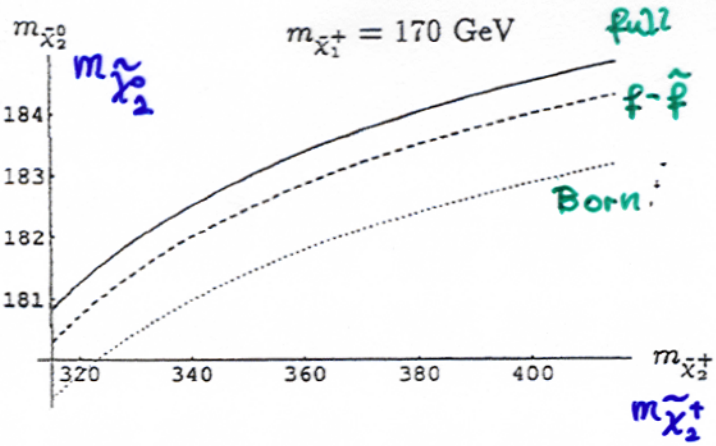
Observables (cross-sections, branching ratios, ...) should be the same in both methods

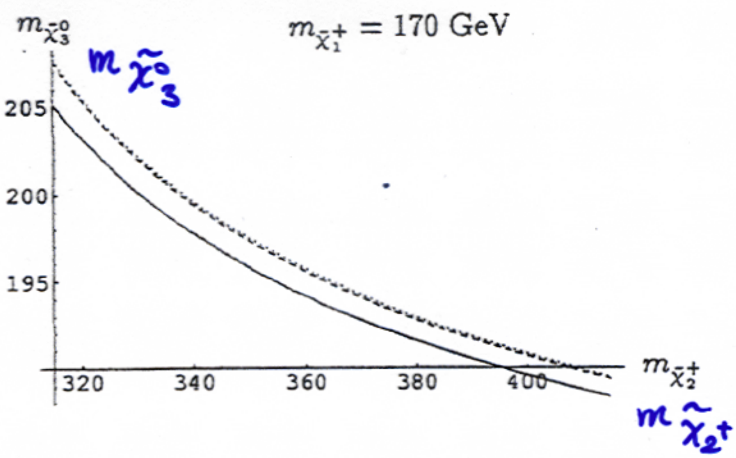
Fritzsche-Hollik

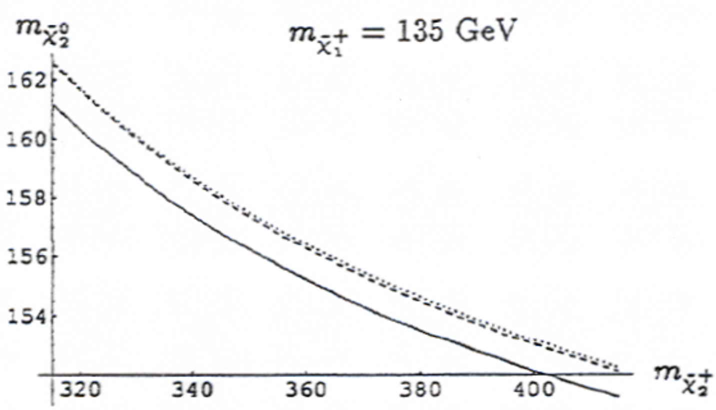
Dependence of neutralino masses on chargino masses

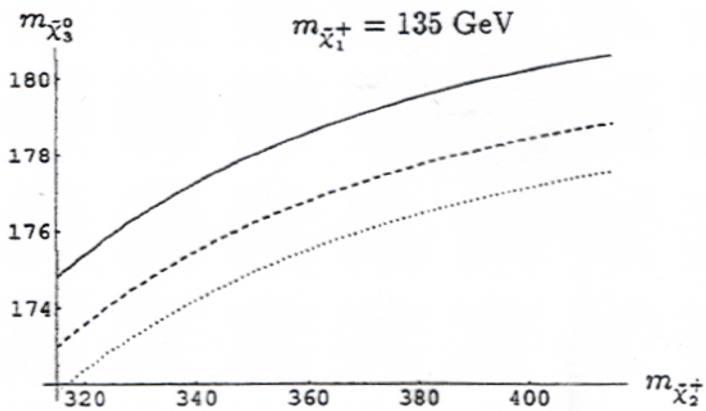
$m_{\tilde{\chi}^0_1} = 110$ GeV

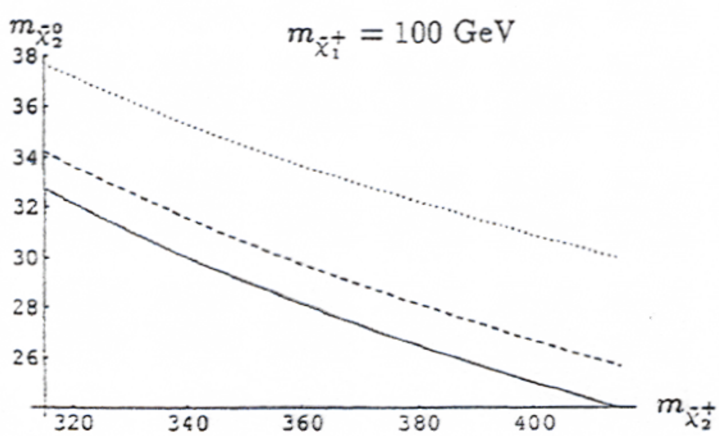


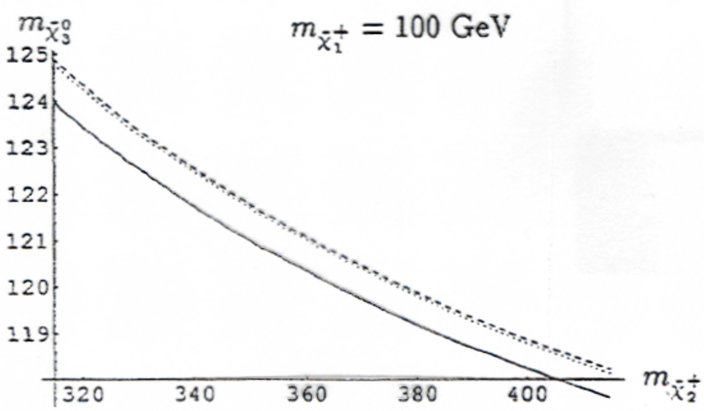












- $e^+e^- \to \tilde{\chi}_i^+ \tilde{\chi}_j^-$ complete one-loop correction:
  T. Blank, W. Hollik
  M. A. Diaz, D. A. Ross

- $e^\pm e^- \to \tilde{\mu}^\pm \tilde{\mu}^-$ full electroweak correction: A. Freitas,
  $\to \tilde{e}^\pm \tilde{e}^-$ A. v. Manteuffel, P. M. Zerwas '01,'02

- $e^+e^- \to \tilde{q}_i \bar{\tilde{q}}_j$ QCD correction: A. Bartl et.al.
  Yukawa corrections: H. Eberl et.al.

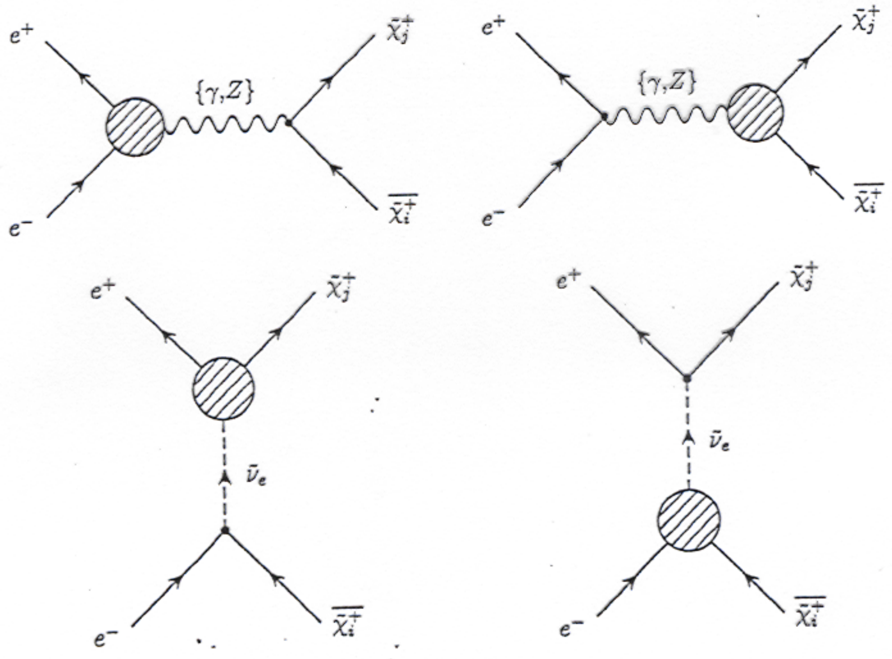
- $e^+e^- \to \tilde{q} \bar{\tilde{q}} X$ $X = g,\, gg,\, q\bar{q}$ (light quarks)
  $\to q \bar{\tilde{q}} \tilde{g}(g)$ SUSY-QCD corrections:
  A. Brandenburg et al.

Blank-Hollik

$e^+ e^- \to \tilde{\chi}_j^+ \tilde{\chi}_i^-$

- Vertex corrections:

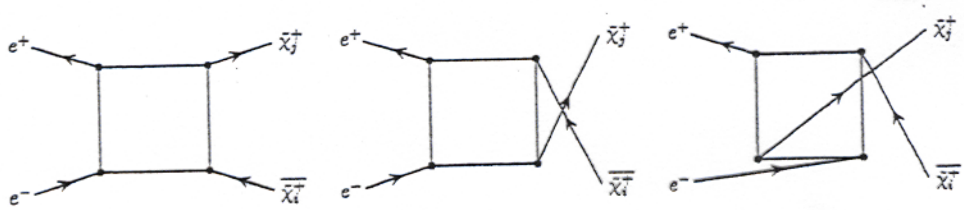
Vertex + wave f. corr.



The bubbles summarize the one-particle irreducible 3-point functions including their counterterms, together with the wave-function renormalization of the external lines and chargino mixing.

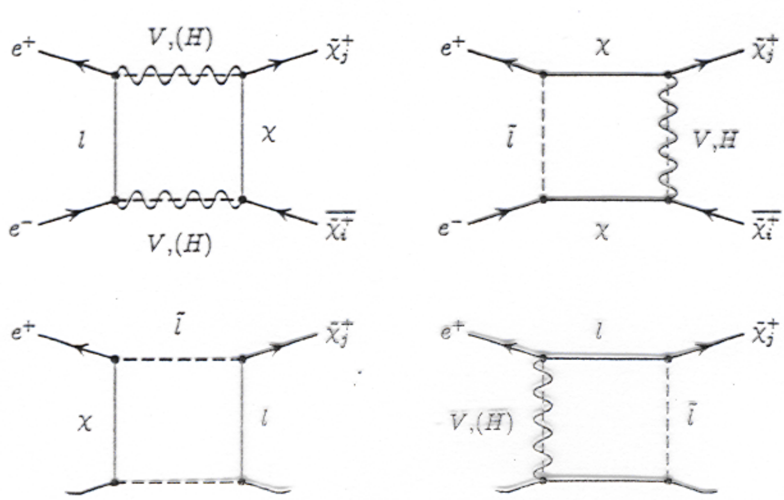
- Box-diagram contributions:

Box diagr.



For illustration, the particle insertions for the first box topology are depicted (with gauge bosons V, Higgs bosons H, charginos/neutralinos χ, leptons l, and sleptons $\tilde{l}$):

For illustration:



Blank - Hollik

Corrections to $e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$

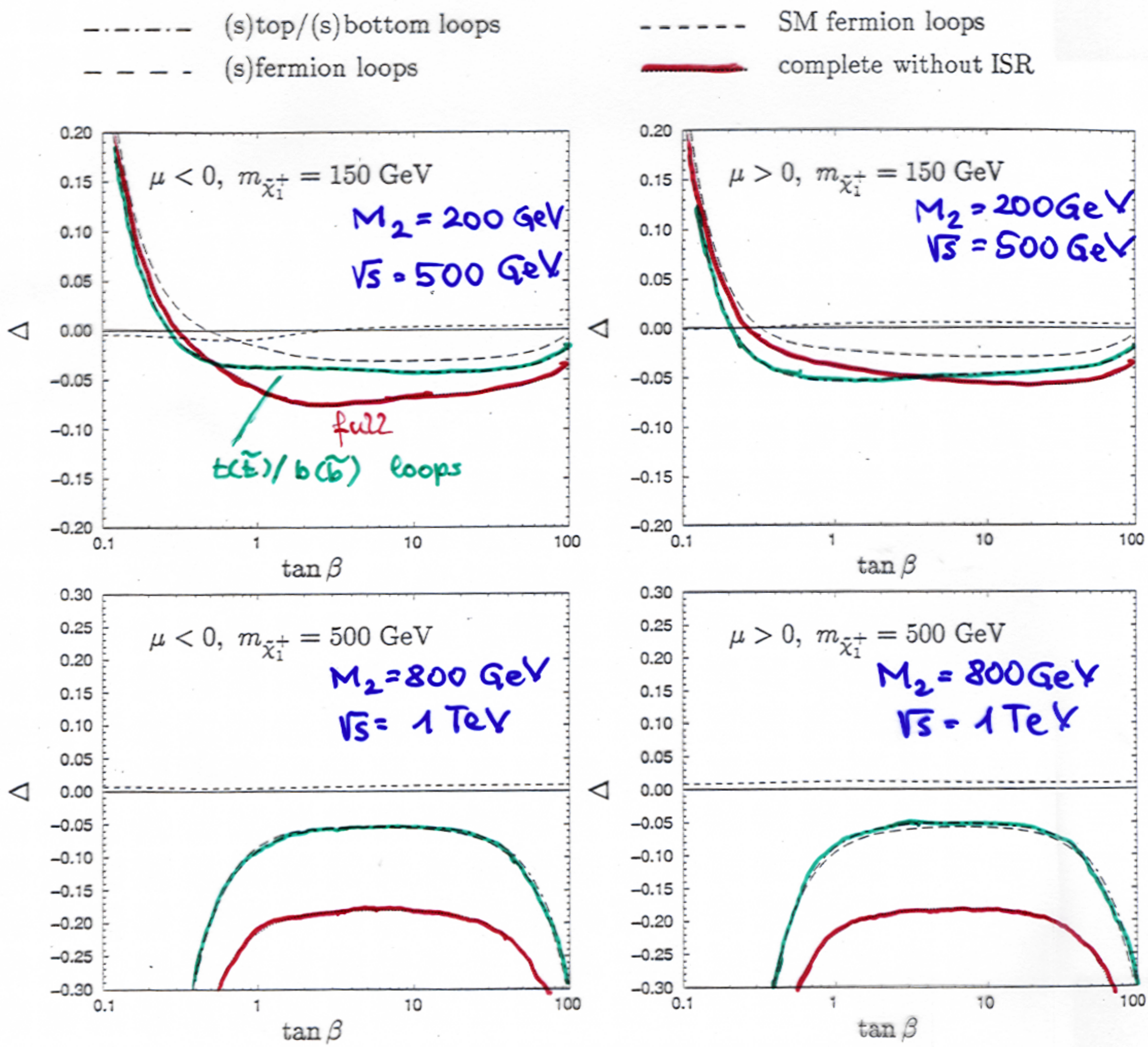
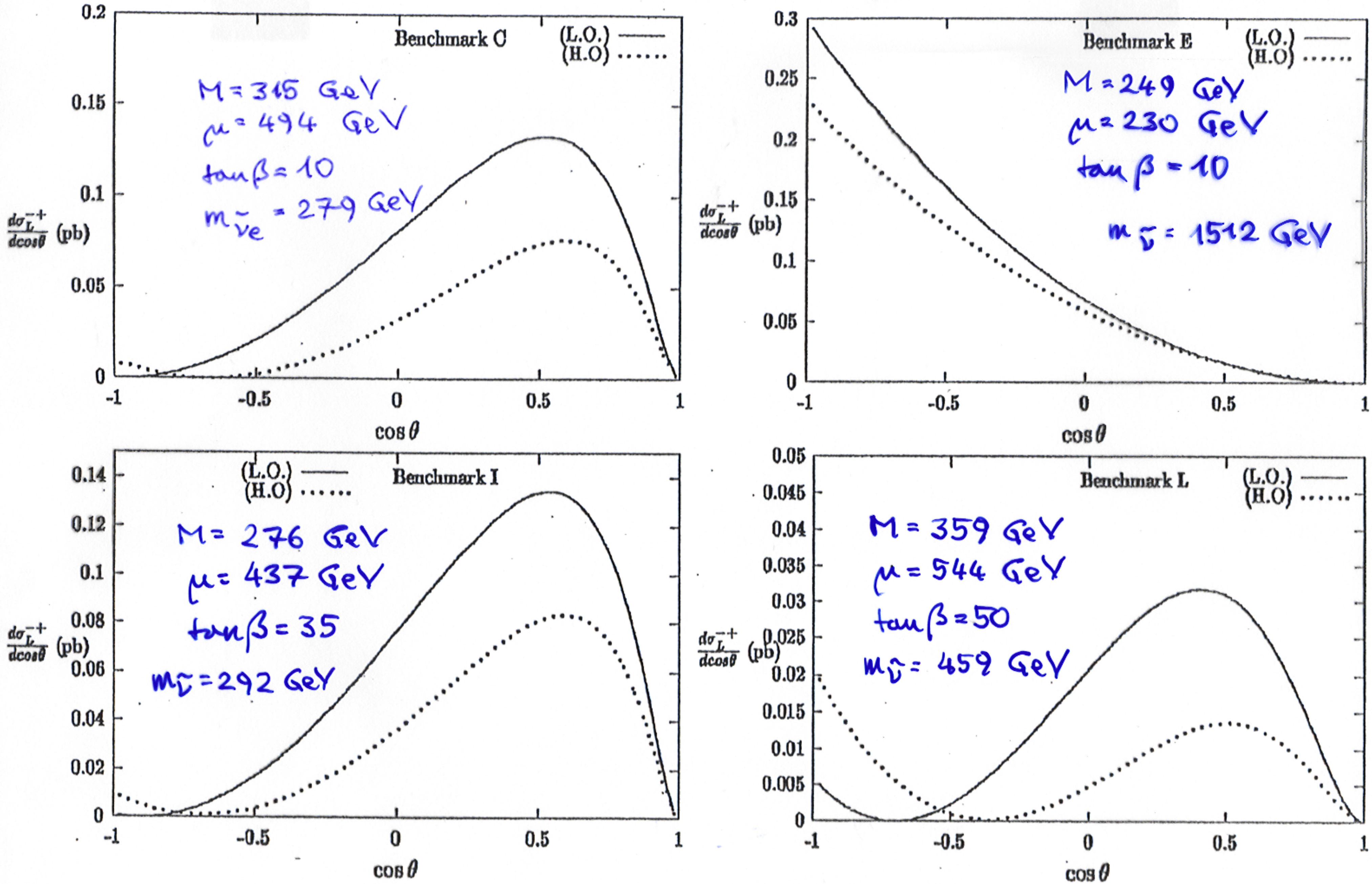


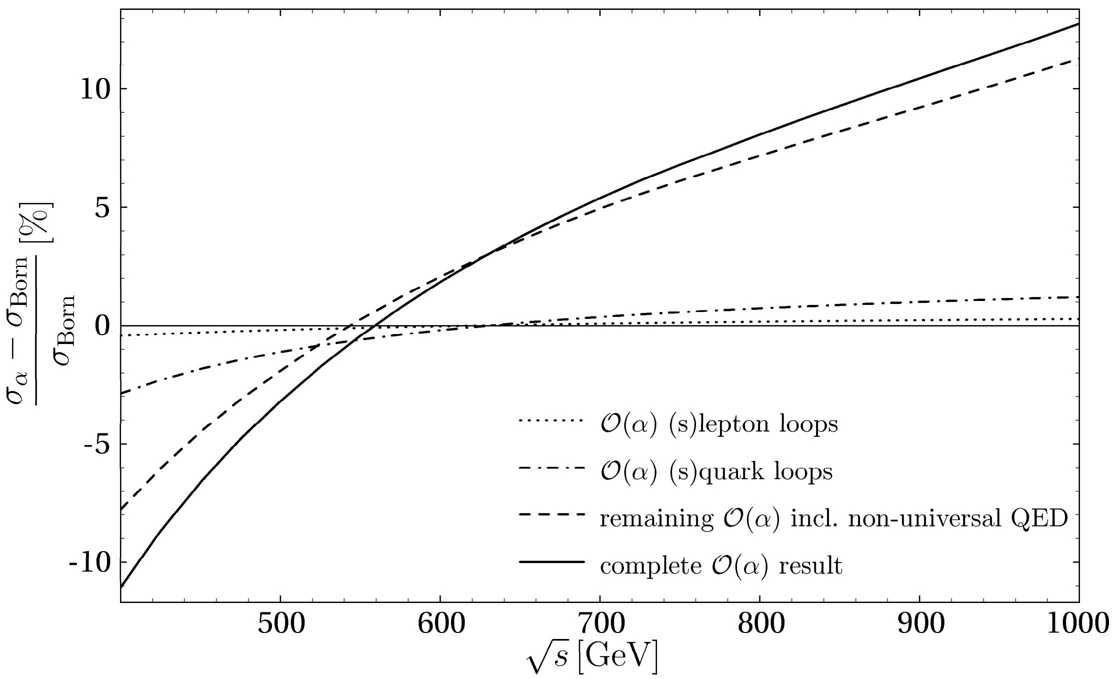
Figure 2: One-loop corrections to the chargino-pair production cross section, normalized to the Born approximation. The various lines show the contributions from different subsets of diagrams. Upper (lower) row: $M_2 = 200$ GeV (800 GeV), $\sqrt{s} = 500$ GeV (1 TeV), $M_{\rm SUSY} = 500$ GeV.

$$\Delta = \frac{\sigma - \sigma_{\rm Born}}{\sigma_{\rm Born}}$$

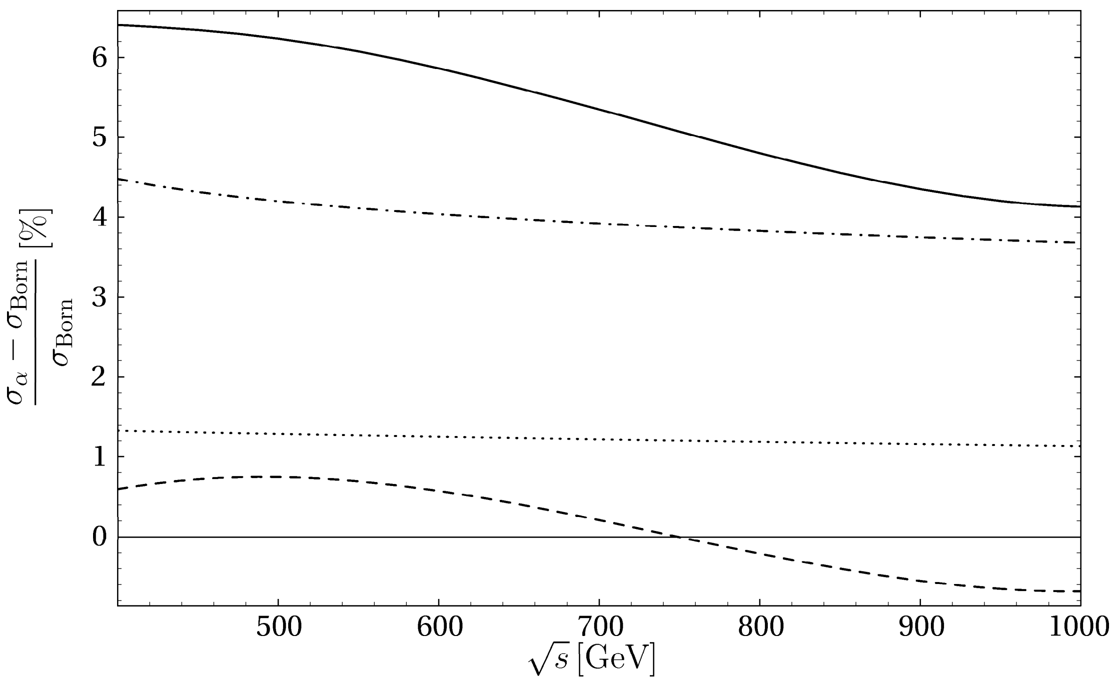
Diaz - Ross

σ_L^{+-} for $e^+ e^-_L \to \tilde{\chi}_1^+(\lambda=-)\,\tilde{\chi}_1^-(\lambda=+)$

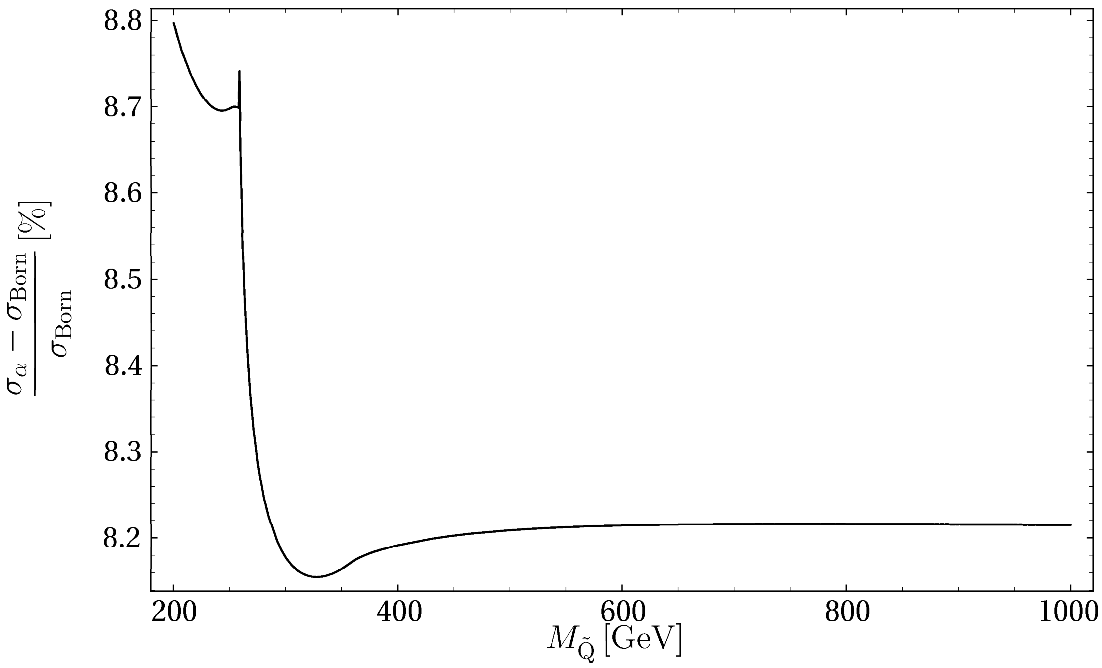




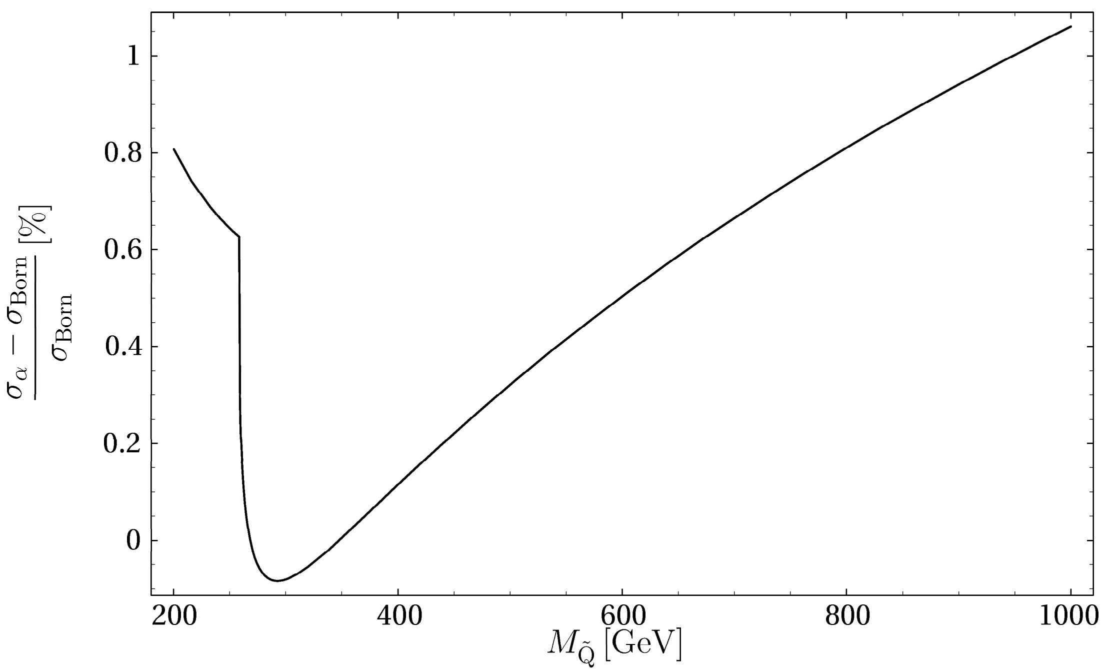
Electroweak corrections to the cross-section for $e^+e^- \to \tilde{e}^+_{\rm R}\tilde{e}^-_{\rm R}$*, relative to the Born cross-section. Besides the full* $\mathcal{O}(\alpha)$ *result, contributions from different subsets of diagrams are shown. Input parameters taken from SPS1 scenario.*



Electroweak corrections to the cross-section for $e^-e^- \to \tilde{e}^-_{\rm R}\tilde{e}^-_{\rm R}$*, similar to the figure above*



Dependence of the relative one-loop corrections Δ_α to $\tilde{\mu}_R^+\tilde{\mu}_R^-$ production on the universal squark soft-breaking parameter $M_{\tilde{Q}}$ for $\sqrt{s}$ = 500 GeV. Values of other parameters from SPS1 scenario.



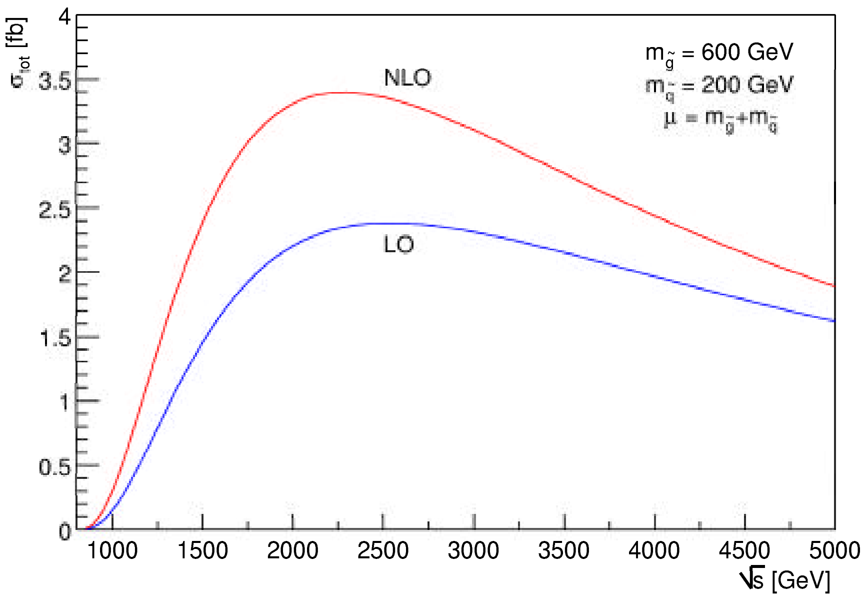
Dependence of the relative one-loop corrections Δ_α to $\tilde{e}_R^-\tilde{e}_R^-$ production on the universal squark soft-breaking parameter $M_{\tilde{Q}}$ for $\sqrt{s}$ = 400 GeV. Values of other parameters from SPS1 scenario.

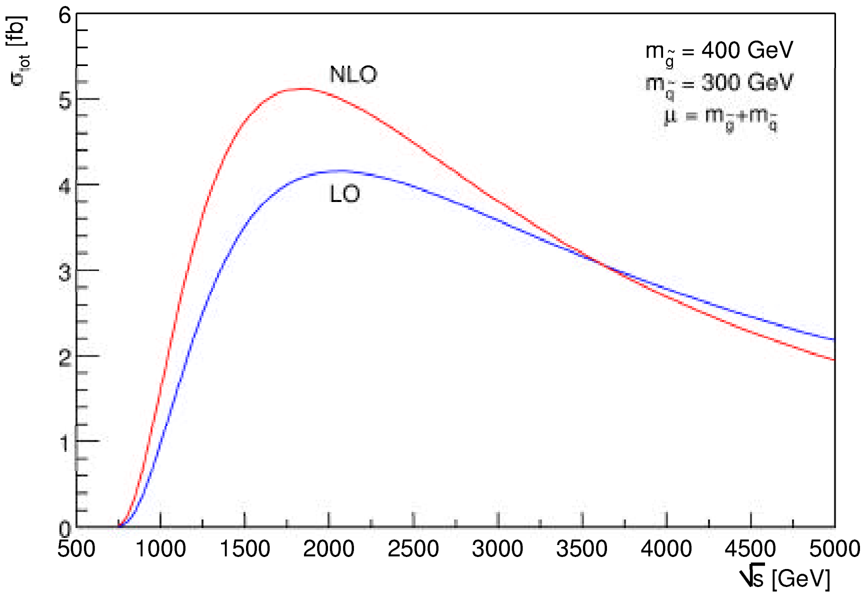
SUSY-QCD corrections

2. $e^+e^- \longrightarrow \tilde{q}\bar{q}\tilde{g}X$:

Total cross section: Case $m_{\tilde{g}} > m_{\tilde{q}}$

$$\sigma_{\rm tot} \equiv \sum_X \sum_{h=L,R} \sum_q \left\{ \sigma(e^+e^- \longrightarrow \tilde{q}_h\bar{q}\tilde{g}X) + \sigma(e^+e^- \longrightarrow q\bar{\tilde{q}}_h\tilde{g}X) \right\}$$





- $\tilde{q}_i \rightarrow q^{(\prime)} \tilde{\chi}_k$ SUSY-QCD corrections:

  A. Djouadi, W. Hollik, C. Jünger '96

  S. Kraml et al. '96

  W. Beenakker et al. '97

  full electroweak:

  J. Guasch, W. Hollik, J. Solà

- $\tilde{q}_i \rightarrow q\,\tilde{g}$
  $\tilde{g} \rightarrow \tilde{q}_i\, q$ SUSY-QCD corrections:

  W. Beenakker, R. Höpker, P. M. Zerwas '96

  $\mathcal{O}(m_q^2)$ Zhang et al.

- $\tilde{q}_i \rightarrow \tilde{q}_j^{(\prime)}\, H_l$
  $H_l \rightarrow \tilde{q}_i\, \tilde{q}_j^{(\prime)*}$

  $H_l = \{h^0, H^0, A^0, H^\pm\}$

  SUSY-QCD corrections:

  A. Bartl et al.

  A. Arhrib et al. '98

  Y. Yamada et al. '00

  Yukawa corrections:

  Li et al.

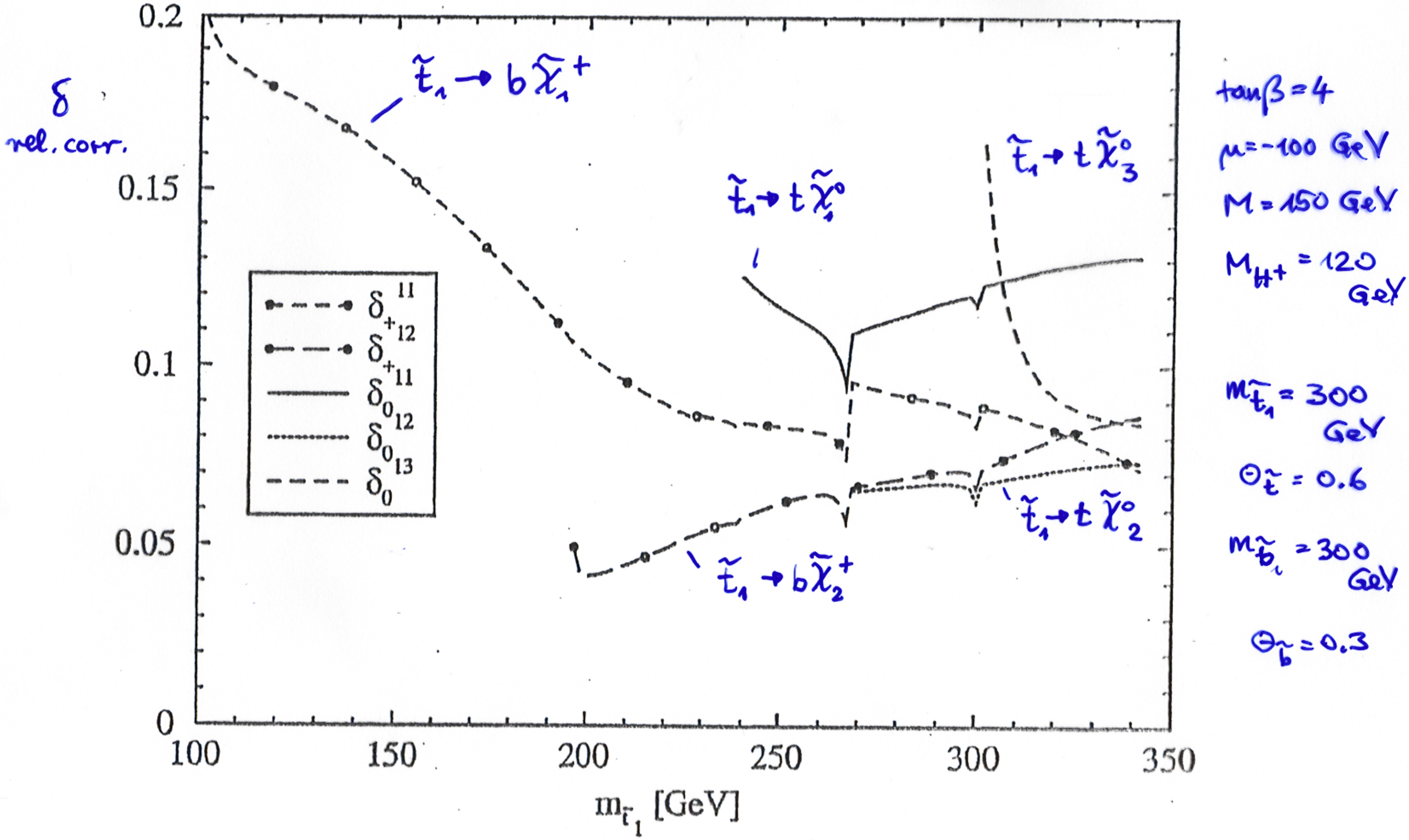
- $H_l \rightarrow \tilde{\chi}_i\, \tilde{\chi}_j$
  $\tilde{\chi}_i \rightarrow H_l\, \tilde{\chi}_j$ all fermion-sfermion loops: H. Eberl et al. '01

  Zhang et al. '02

- $\tilde{q}_i \rightarrow \tilde{q}_j^{(\prime)} (W, Z^0)$ SUSY-QCD corr.: A. Bartl et al. '97

Guasch - Hollik - Sola

Full ew corrections to $\Gamma(\tilde{t}_1 \to b\,\tilde{\chi}_{1,2},\ \tilde{t}_1 \to t\,\tilde{\chi}^0_i)$



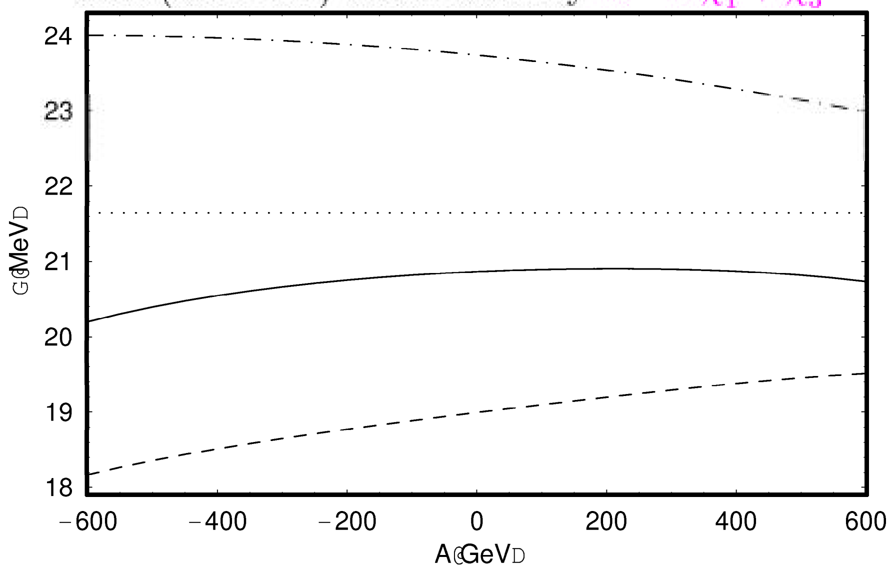
Higgs boson decay corrections: A and $\tan\beta$ dependences

$$\{M_{\tilde{Q}_1},\ M_{\tilde{Q}},\ M,\ \mu\} = \{500,\ 500,\ 300,\ 300\}\ \text{GeV}$$
$$\tan\beta = 50$$

Tree-level (dotted) MM-corr. (dashed), 3P-corr. (dash-dotted) and the total (solid line) width of decay $A^0 \to \tilde{\chi}_1^0 + \tilde{\chi}_3^0$

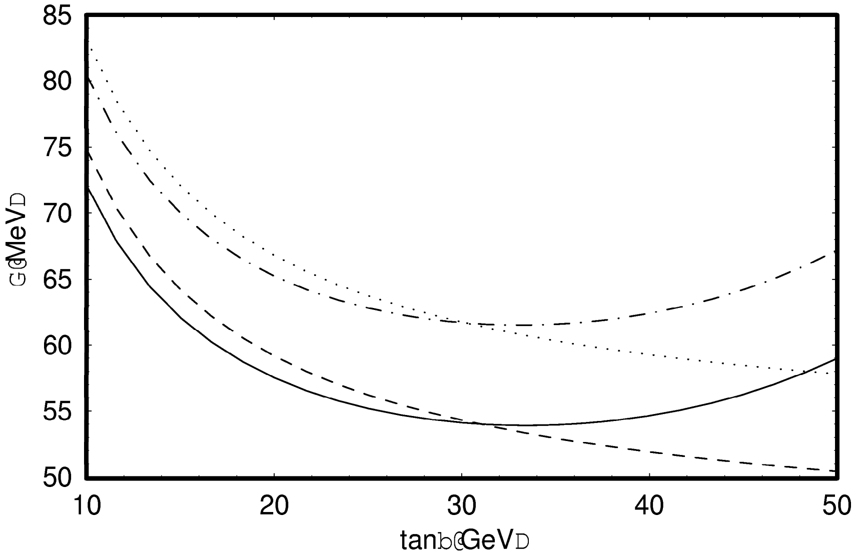
Eberl et al.

all f-$\tilde{f}$ loops



$$\{M_{\tilde{Q}_1},\ M_{\tilde{Q}},\ A,\ M,\ \mu\} = \{500,\ 500,\ 300,\ 500,\ 250\}\ \text{GeV}$$

Tree-level (dotted) MM-corr. (dashed), 3P-corr. (dash-dotted) and the total (solid line) width of decay $H^0 \to \tilde{\chi}_1^0 + \tilde{\chi}_2^0$



Summary

- Have discussed the on-shell renormalization of the MSSM
- Inclusion of radiative corrections to SUSY-processes is necessary
- Full electroweak corrections already calculated for a few processes, usually 5-10% but in some parameter regions even larger, comparable to the size of QCD corrections
- Calculation of full electroweak corrections very complex and cumbersome
- Suitable approximation should be found