New Ideas on SUSY Searches at Future Linear Colliders

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International Europhysics Conference on High Energy Physics, HEP2003

Aachen, July 17 – 23, 2003

Abstracts: 254, 296, 318, 319

Introduction

Linear collider: $\longrightarrow$ high precision determination of SUSY parameters

$\longrightarrow$ SUSY breaking mechanism, unification?

Summary of results within ECFA/DESY LC study/SUSY group:

$\longrightarrow$ Polarisation in sfermion decays: Determining $\tan\beta$ and A_f

E. Boos, H.-U. Martyn, G. Moortgat-Pick, M. Sachwitz, A. Sherstnev, A. Vologdin, P.M. Zerwas

$\longrightarrow$ MSSM with complex parameters: Determining the phases

A. Bartl, H. Fraas, S. Hesselbach, K. Hidaka, T. Kernreiter, O. Kittel, W. Majerotto, W. Porod

$\longrightarrow$ Analysis of the chargino/neutralino mass parameters at one-loop level

W. Öller, H. Eberl, W. Majerotto, C. Weber

Parameters in Minimal Supersymmetric Standard Model (MSSM)

Mass mixing and parameters in sfermion sector

$$\mathcal{L}_M^{\tilde{f}} = -(\tilde{f}_L^*, \tilde{f}_R^*) \begin{pmatrix} M^2_{\tilde{f}_{LL}} & M^2_{\tilde{f}_{LR}} \\ M^2_{\tilde{f}_{RL}} & M^2_{\tilde{f}_{RR}} \end{pmatrix} \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix}$$

with

$$M^2_{\tilde{f}_{RL}} = (M^2_{\tilde{f}_{LR}})^* = m_f \left(A_f - \mu^* (\tan\beta)^{-2T_f^3} \right)$$

A_f : trilinear couplings of sfermions $\longrightarrow |A_f|, \varphi_{A_f}$

μ : Higgs-higgsino mass parameter $\longrightarrow |\mu|, \varphi_\mu$

$\tan\beta = \dfrac{v_2}{v_1}$: ratio of Higgs vevs

Mass mixing and parameters in chargino/neutralino sector

Chargino mass matrix: $$X = \begin{pmatrix} M_2 & \sqrt{2}\, m_W\, s_\beta \\ \sqrt{2}\, m_W\, c_\beta & \mu \end{pmatrix}$$

Neutralino mass matrix:

$$Y = \begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ 0 & M_2 & m_Z c_W c_\beta & -m_Z c_W s_\beta \\ -m_Z s_W c_\beta & m_Z c_W c_\beta & 0 & -\mu \\ m_Z c_W c_\beta & -m_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

$s_\beta \equiv \sin\beta$, $c_\beta \equiv \cos\beta$

μ : Higgs-higgsino mass parameter $\longrightarrow$ $|\mu|$, φ_μ

M_1 : U(1) gaugino mass parameter $\longrightarrow$ $|M_1|$, φ_{M_1}

M_2 : SU(2) gaugino mass parameter

Determining tan β and A_f in sfermion sector

Abstract No. 318, E. Boos et al., hep-ph/0211040, hep-ph/0303110

Chargino/neutralino sector: $\longrightarrow$ determination of M_2, M_1 and μ

[hep-ph/0108117, hep-ph/0202039]

$\longrightarrow$ weak dependence on high $\tan\beta$

Third generation sfermions: $\longrightarrow$ $M^2_{\tilde{f}_{RL}}$ depends strongly on $\tan\beta$ and A_f

$\longrightarrow$ measurement of (high) $\tan\beta$ via polarisation of decay fermion

$\longrightarrow$ analysis concerning determination of A_f

$\longrightarrow$ study done for real MSSM

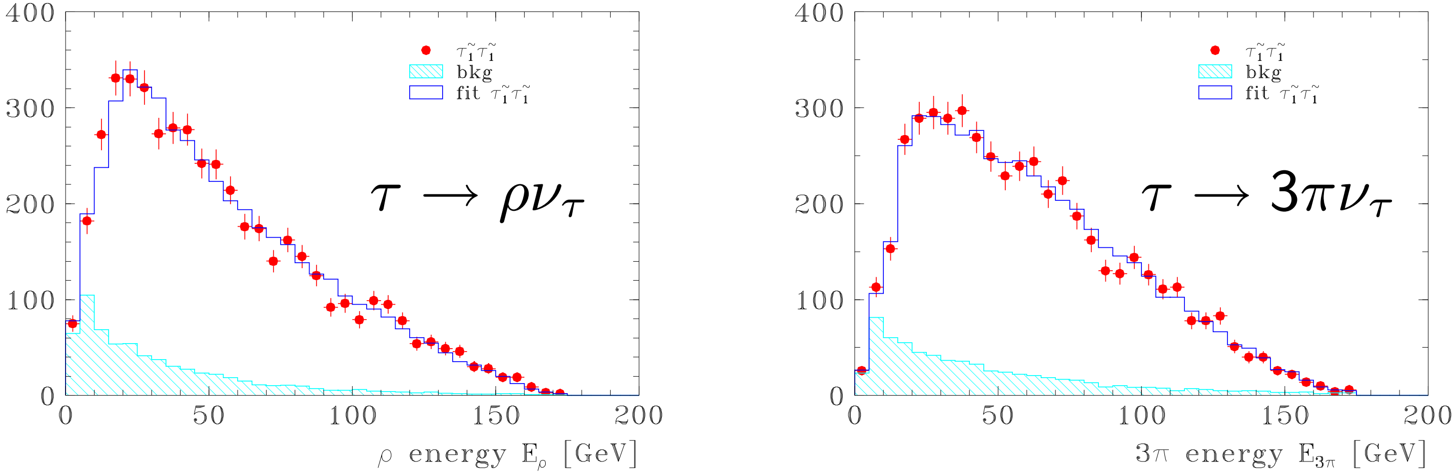
Simulations in $\tilde{\tau}$ sector

Reference scenario: $m_{\tilde{\tau}_1} = 155$ GeV, $m_{\tilde{\tau}_2} = 305$ GeV, $M_1 = 99$ GeV,
(SPS1a motivated) $M_2 = 193$ GeV, $\mu = 140$ GeV, $\tan\beta = 20$, $A_\tau = -254$ GeV

Process: $e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1 \to \tau^+\tau^-\tilde{\chi}^0_1\tilde{\chi}^0_1$

$\longrightarrow$ Hadron energy spectra:

$\sqrt{s} = 500$ GeV, $P_{e^-} = +80\,\%$, $P_{e^+} = -60\,\%$, $\mathcal{L} = 250$ fb^{-1}



$\longrightarrow$ Fit $\Rightarrow$ $m_{\tilde{\tau}_1} = 155.2 \pm 0.8$ GeV $\qquad$ $m_{\tilde{\tau}_1} = 154.8 \pm 0.5$ GeV

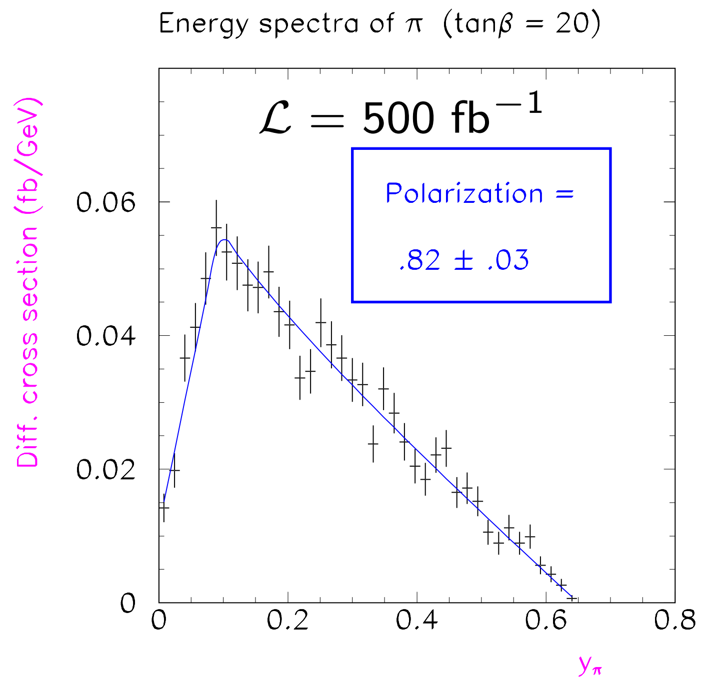
$\longrightarrow$ $\delta\sigma(e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1)/\sigma(e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1) \sim 3\,\%$

→ Beam polarisation: resolves ambiguities
(e.g. in determination of $\tilde{\tau}$ mixing angle)

→ Energy spectra of π^-
for $\tau^- \to \pi^- \nu\tau$

→ Fit ⇒ precise determination
of τ polarisation
$P_\tau = 82 \pm 3\,\%$

→ Inversion ⇒ $\tan\beta = 22 \pm 2$



→ In principle: get A_τ from $M^2_{\tilde{f}_{RL}}$
However: large mass difference and small mixing angle
$\Rightarrow \delta(A_\tau) \sim 2700$ GeV, for scenarios with larger mixing angle: ~ 400 GeV

Analyses in $\tilde{b}$ and $\tilde{t}$ sectors $\sqrt{s} = 1.9$ TeV, $\mathcal{L} = 2000$ fb^{-1}

$\tilde{b}$ studies: $\longrightarrow$ use t polarisation in decay $\tilde{b}_i \to \tilde{\chi}_j^- t$

$\longrightarrow$ analogously to $\tilde{\tau}$ sector

$\longrightarrow$ $\tan\beta = 17.5 \pm 4.5$ $\delta(A_b)/A_b \sim 60\,\%$

$\tilde{t}$ studies: $\longrightarrow$ use t polarisation in decay $\tilde{t}_i \to \tilde{\chi}_j^0 t$

$\longrightarrow$ but: $Y_t \sim 1/\sin\beta \Rightarrow$ not very sensitive to high $\tan\beta$

$\longrightarrow$ with $\tan\beta$ from $\tilde{b}$ sector: $\delta(A_t)/A_t \sim 10\,\%$

Determination of $\tan\beta$ without assumption about SUSY breaking

Third generation sfermion decays in complex MSSM

Abstract No. 254, A. Bartl et al.,
hep-ph/0204071, hep-ph/0207186, hep-ph/0306281

General MSSM: $\longrightarrow$ A_f, μ, M_1 may be complex

Impact of phases on two-body decays of $\tilde{\tau}$, $\tilde{t}$ and $\tilde{b}$

$\longrightarrow$ emphasis on $\varphi_{A_\tau}, \varphi_{A_t}, \varphi_{A_b}$

$\longrightarrow$ possible determination of $|A_f|$, φ_{A_f} or Re(A_f), Im(A_f)

Phase in sfermion sector:

$$\varphi_{\tilde{f}} = \arg\left[M^2_{\tilde{f}_{RL}}\right] = \arg\left[A_f - \mu^*(\tan\beta)^{-2T^3_f}\right]$$

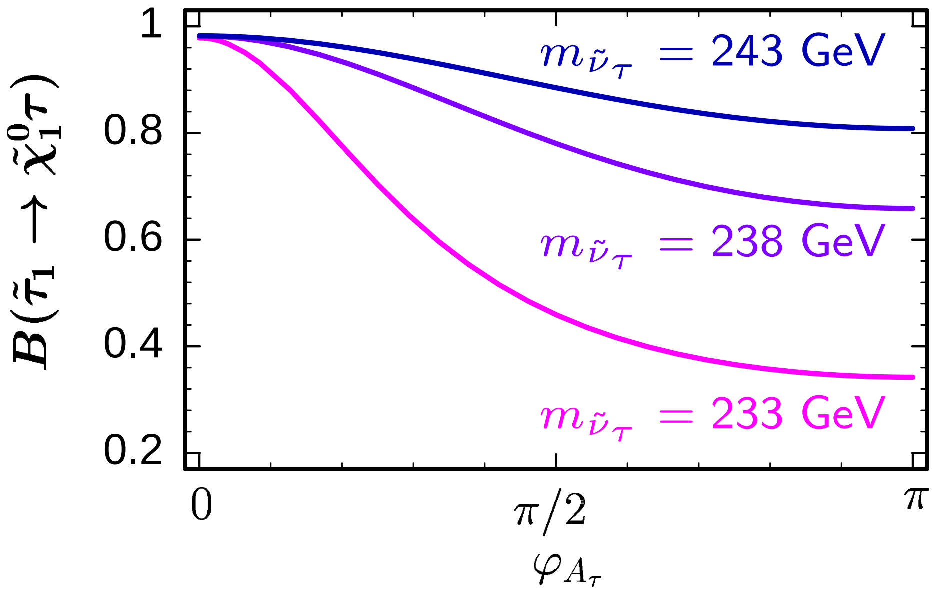
$\tilde{\tau}$ sector

Branching ratio $B(\tilde{\tau}_1 \to \tilde{\chi}^0_1 \tau)$ in scenario:

$m_{\tilde{\tau}_1} = 240$ GeV, $|A_\tau| = 1$ TeV, $|\mu| = 300$ GeV, $\varphi_\mu = 0$,

$M_2 = 200$ GeV, $|M_1| = M_2 5/3 \tan^2\theta_W$, $\varphi_{M_1} = 0$, $\tan\beta = 3$

- $\longrightarrow$ strong phase dependence
- $\longrightarrow$ caused by mixing angle
- $\longrightarrow$ $\tilde{\tau}_1$: $\tilde{\tau}_R \longrightarrow \tilde{\tau}_L$ for $m_{\tilde{\nu}_\tau} = 233$ GeV
- $\longrightarrow$ occurs for $M_{\tilde{\tau}_{LL}} \approx M_{\tilde{\tau}_{RR}}$ *and* $|A_\tau| \approx |\mu| \tan\beta$



Global fit of many observables

$\longrightarrow$ branching ratios and production cross sections $\sigma(e^+e^- \to \tilde{\tau}_i\tilde{\tau}_j)$ for $\sqrt{s} = 800$ GeV and polarized beams in scenario:

$m_{\tilde{\tau}_1} = 150$ GeV, $m_{\tilde{\tau}_2} = 350$ GeV, $|A_\tau| = 800$ GeV, $\varphi_{A_\tau} = 3/4\pi$

$|\mu| = 250$ GeV, $\varphi_\mu = 0$, $M_2 = 280$ GeV, $|M_1| = M_2 5/3 \tan^2\theta_W$, $\varphi_{M_1} = 0$

$\Rightarrow$ $\tan\beta = 3$: $\delta(\mathrm{Im}(A_\tau))/|A_\tau| = 9\,\%$, $\delta(\mathrm{Re}(A_\tau))/|A_\tau| = 22\,\%$

$\tan\beta = 30$: $\delta(\mathrm{Im}(A_\tau))/|A_\tau| = 3\,\%$, $\delta(\mathrm{Re}(A_\tau))/|A_\tau| = 7\,\%$

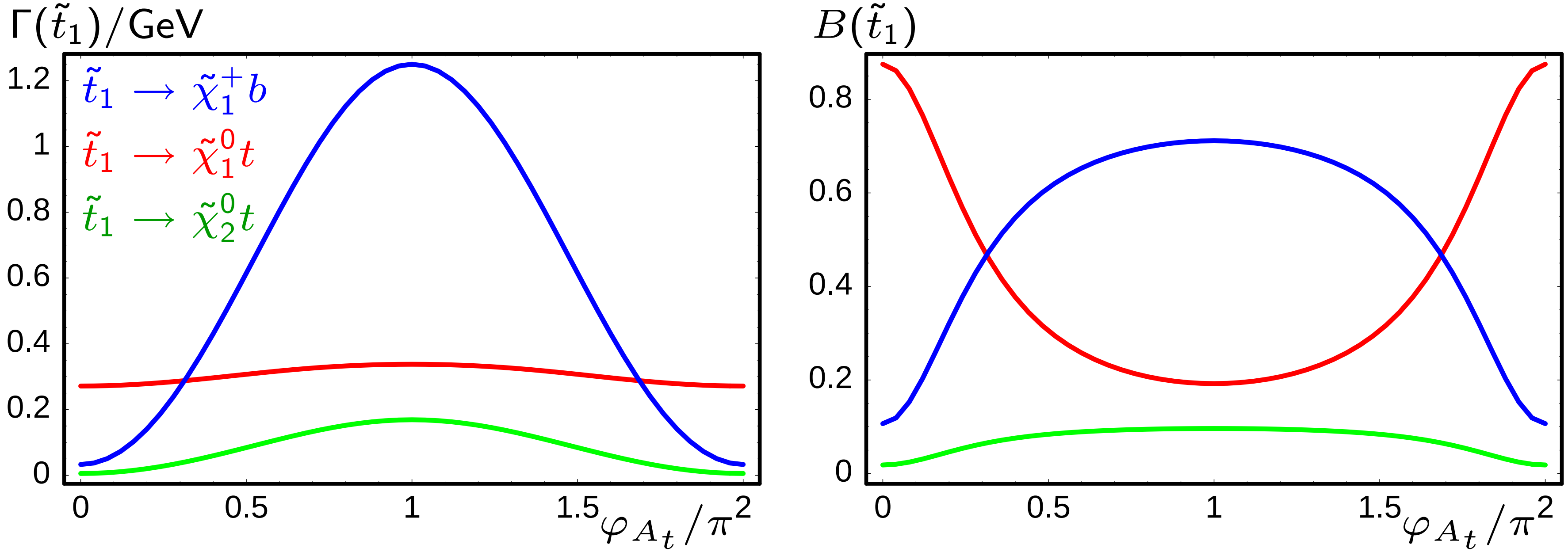
$\tilde{b}$ sector

Strong dependence on φ_{A_b} of partial decay widths into Higgs bosons

$\tilde{t}$ sector

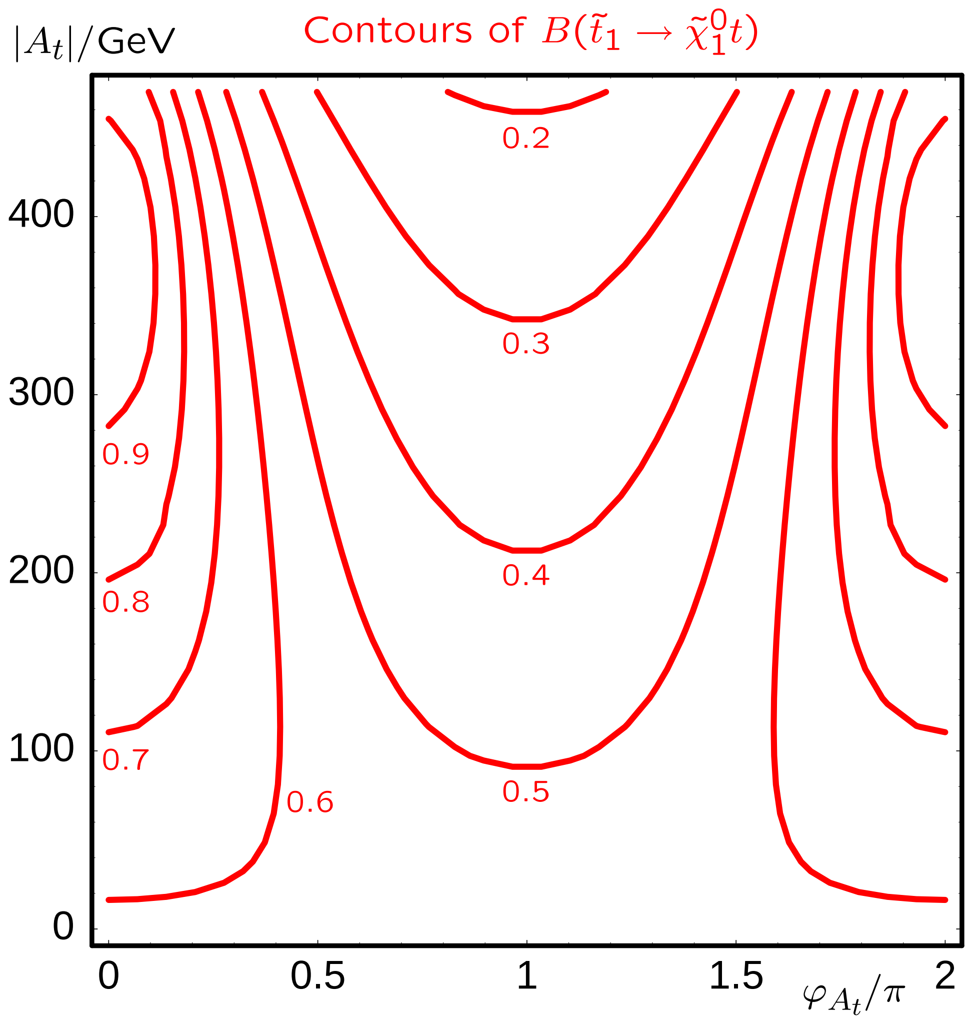
Partial decay widths and branching ratios of $\tilde{t}_1$ in SPS 1a inspired scenario:

$m_{\tilde{t}_L} > m_{\tilde{t}_R}$, $m_{\tilde{t}_1} = 379$ GeV , $m_{\tilde{t}_2} = 575$ GeV, $m_{\tilde{b}_1} = 492$ GeV,
$|A_t| = 466$ GeV, $|A_b| = 759$ GeV, $\varphi_{A_b} = 0$, $|\mu| = 352$ GeV, $\varphi_\mu = 0$,
$M_2 = 193$ GeV, $|M_1| = M_2 5/3 \tan^2\theta_W$, $\varphi_{M_1} = 0$, $\tan\beta = 10$



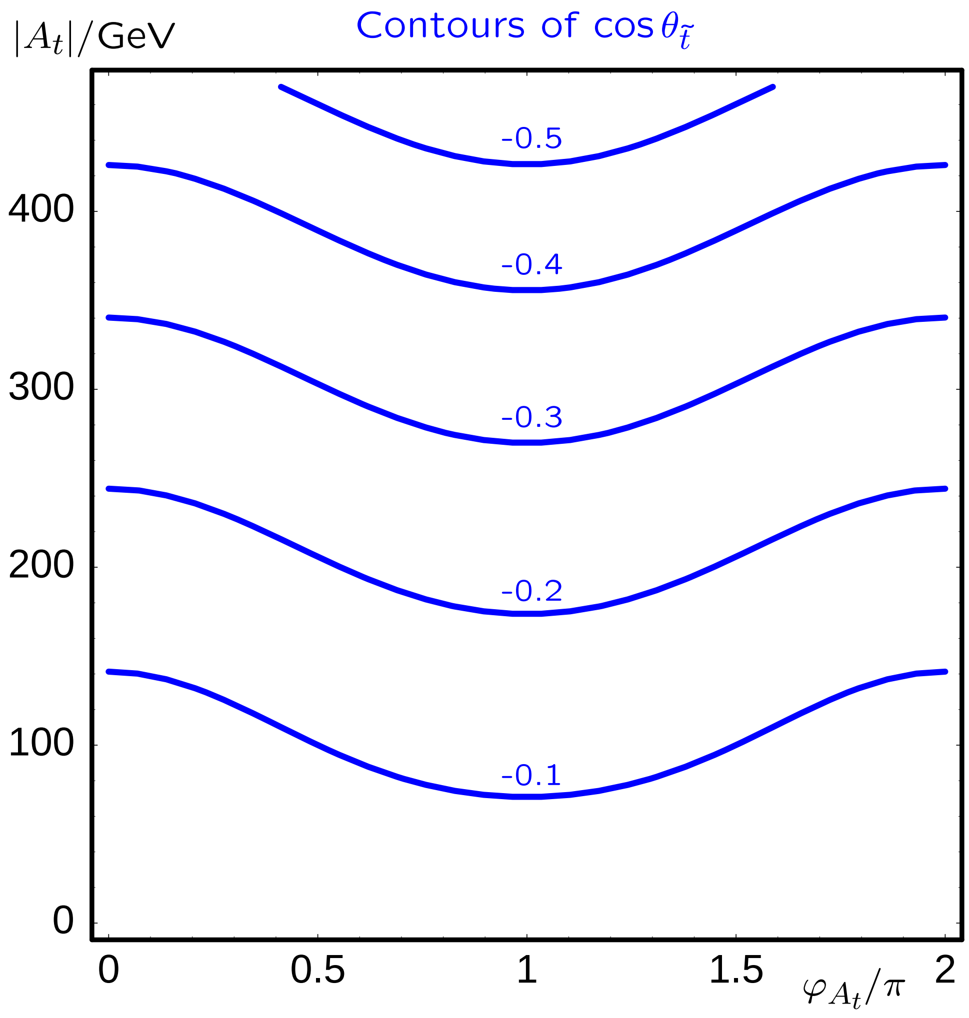
$\longrightarrow$ pronounced phase dependence of $\Gamma(\tilde{t}_1 \to \tilde{\chi}_1^+ b)$: effect of $\varphi_{\tilde{t}} \sim \varphi_{A_t}$

Contours of $B(\tilde{t}_1 \to \tilde{\chi}^0_1 t)$



Contours of $B(\tilde{t}_1 \to \tilde{\chi}^0_1 t)$

Contours of mixing angle



Contours of $B(\tilde{t}_1 \to \tilde{\chi}^0_1 t)$

Contours of mixing angle

Example:

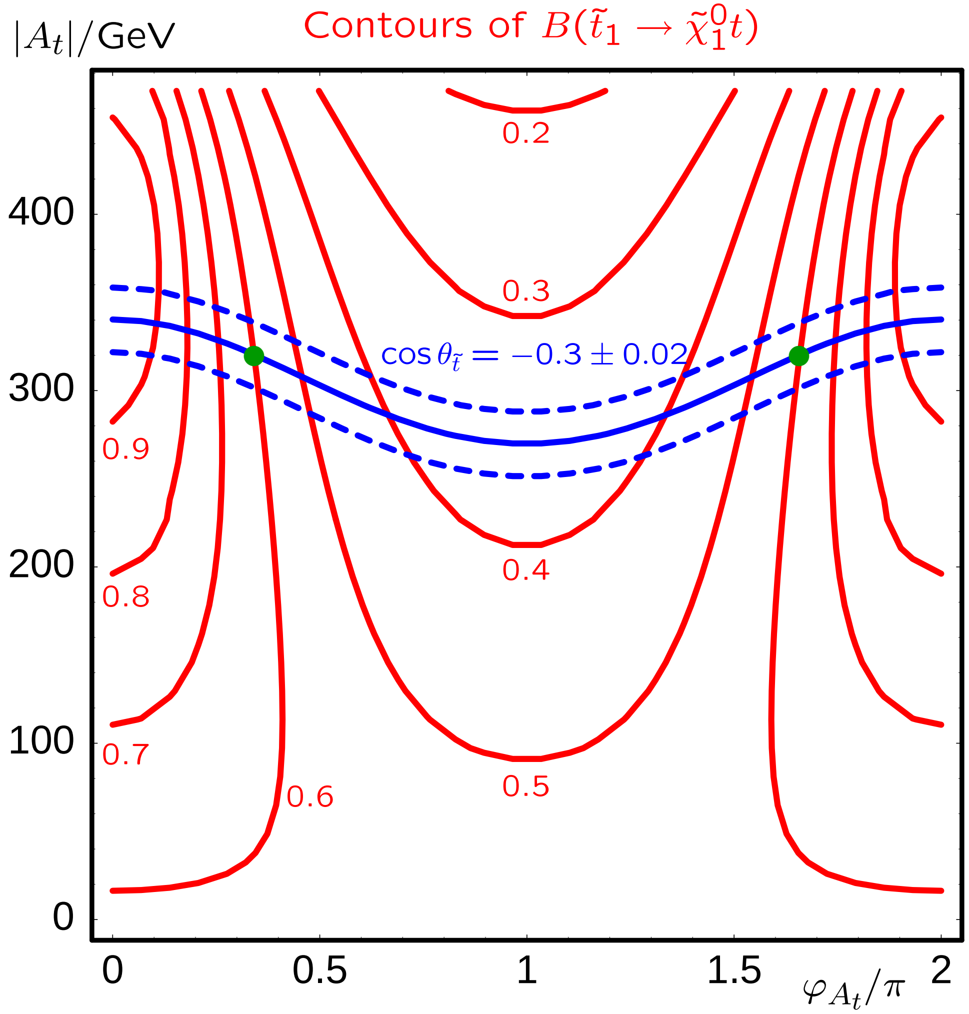
$\to B = 0.6 \pm 0.1$

$\to |\cos\theta_{\tilde{t}}| = 0.3 \pm 0.02$

$\Rightarrow$ $\delta(\varphi_{A_t}) \sim 0.1\pi$

$\delta(|A_t|) \sim 20$ GeV

ambiguity in φ_{A_t}



CP violation in MSSM with complex parameters

Abstract No. 296, A. Bartl et al., hep-ph/0202198, hep-ph/0306304

Direct method to detect CP violating phases: CP sensitive observables

$\longrightarrow$ Triple products $\mathcal{T} = \vec{p}_i \cdot (\vec{p}_j \times \vec{p}_k)$

of measured momenta and spins in production and decay process

$\longrightarrow$ T-odd asymmetry

$$A = \frac{\sigma(\mathcal{T} > 0) - \sigma(\mathcal{T} < 0)}{\sigma(\mathcal{T} > 0) + \sigma(\mathcal{T} < 0)} = \frac{\int \mathrm{Sign}[\mathcal{T}]\, |T|^2\, d\mathrm{Lips}}{\int |T|^2\, d\mathrm{Lips}}$$

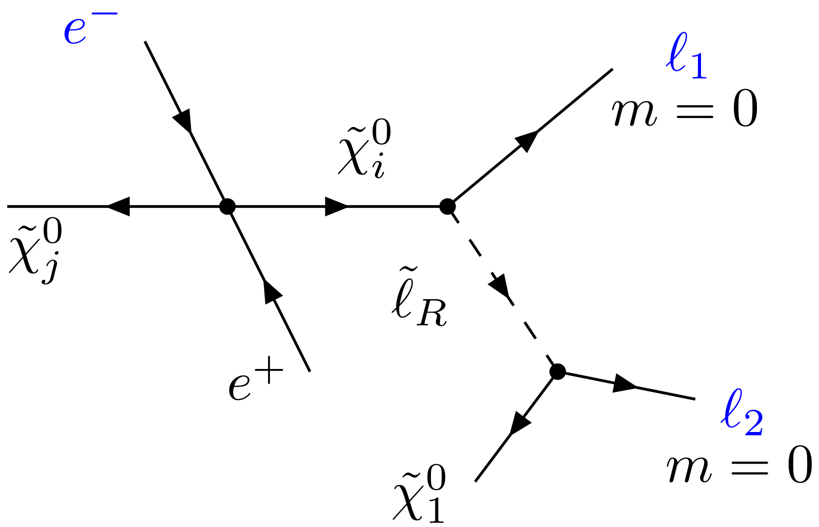
$\longrightarrow$ analysed in sfermion and neutralino/chargino sectors

T asymmetry in neutralino production and decay

Scenario: $|M_1| = M_2 5/3 \tan^2\theta_W$, $\tan\beta = 10$, $m_0 = 100$ GeV

Process: $e^+e^- \to \tilde{\chi}_1^0 + \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \tilde{\ell}_R l_1$; $\tilde{\ell}_R \to \tilde{\chi}_1^0 l_2$

$\to \mathcal{T} = \vec{p}(e^-) \cdot [\vec{p}(\ell_1) \times \vec{p}(\ell_2)]$

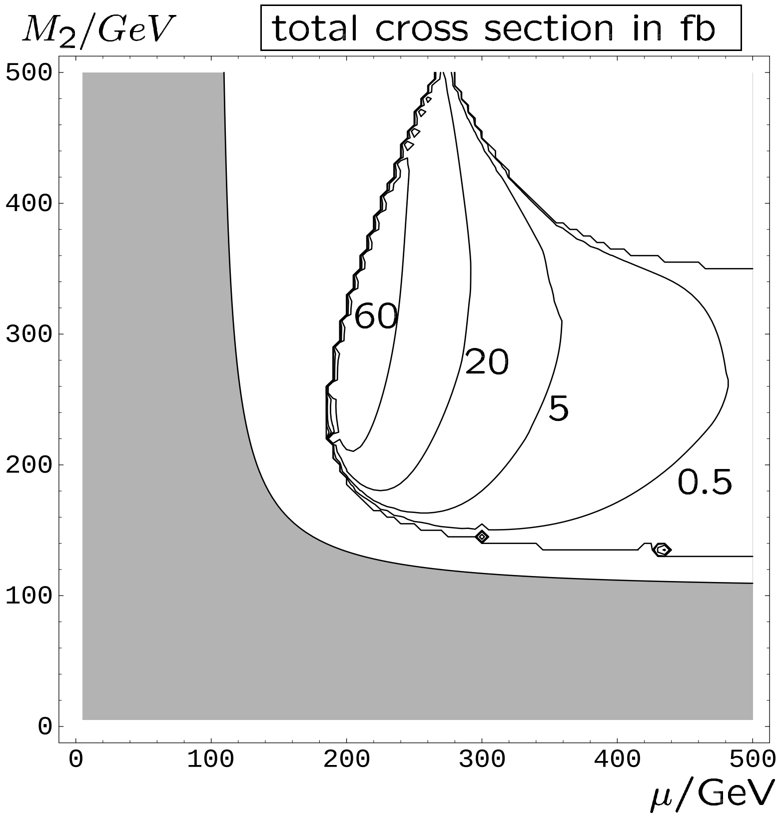


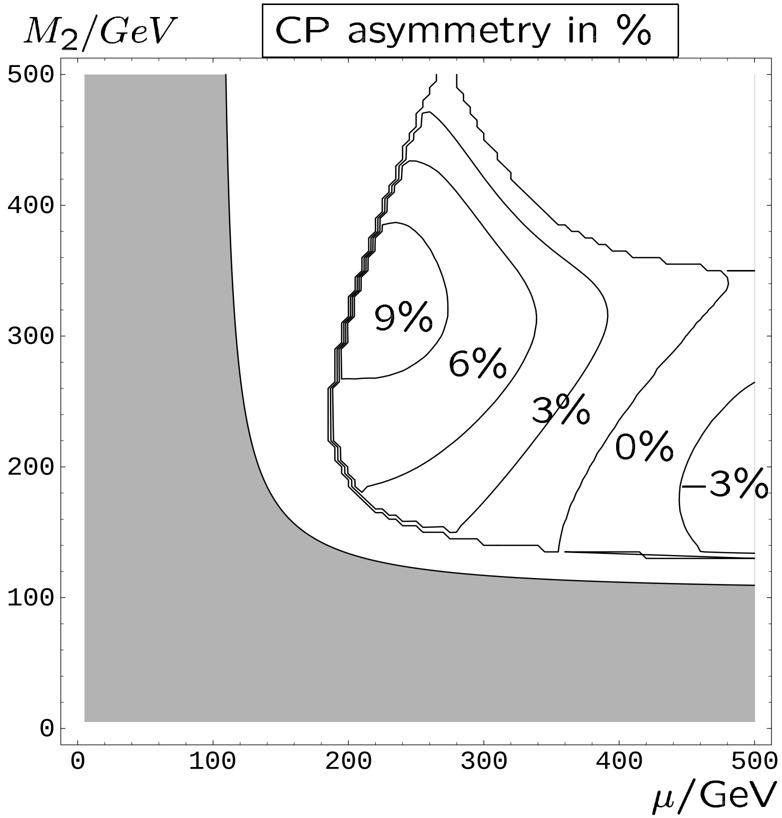
Scenario: $|M_1| = M_2 5/3 \tan^2\theta_W$, $\tan\beta = 10$, $m_0 = 100$ GeV

Process: $e^+e^- \to \tilde{\chi}^0_1 + \tilde{\chi}^0_2 \to \tilde{\chi}^0_1 + \tilde{\ell}_R l_1$; $\tilde{\ell}_R \to \tilde{\chi}^0_1 l_2$

$\sqrt{s} = 500$ GeV, $P_{e^-} = 0.8$, $P_{e^+} = -0.6$ $m_{\tilde{\chi}^\pm_1} < 104$ GeV in shaded area

$\varphi_\mu = 0$, $\varphi_{M_1} = 0.5\pi$





Chargino/neutralino mass parameters at one-loop level

Abstract No. 319, W. Öller et al., hep-ph/0304006

Analysis of μ, M_2 and M_1 at one-loop in real MSSM

$\longrightarrow$ necessary for high precision measurements at linear collider

Mass matrices X at $\overline{\text{DR}}$-scheme, on-shell and tree-level:

$$\hat{X}(Q) = X + \delta X(Q) =: \tilde{X} + \delta_C \tilde{X}(Q)$$

$\Rightarrow$ one-loop corrections: $X = \tilde{X} + \delta_C \tilde{X} - \delta X = \tilde{X} + \Delta X$

$\Rightarrow$ X cannot be written in tree-level form

μ and M_2 from $\tilde{\chi}^+$ or $\tilde{\chi}^0$ sector:

$$\begin{aligned}
\hat{M}_2(Q) &= M_2^{\tilde{\chi}^+} + \delta X_{11} &&= M_2^{\tilde{\chi}^0} + \delta Y_{22} \\
\hat{\mu}(Q) &= \mu^{\tilde{\chi}^+} + \delta X_{22} &&= \mu^{\tilde{\chi}^0} - \delta Y_{34} \\
\Delta M_2 &\equiv M_2^{\tilde{\chi}^+} - M_2^{\tilde{\chi}^0} &&= \delta Y_{22} - \delta X_{11} \\
\Delta \mu &\equiv \mu^{\tilde{\chi}^+} - \mu^{\tilde{\chi}^0} &&= -(\delta Y_{34} + \delta X_{22})
\end{aligned}$$

$\rightarrow$ μ and M_2 depend on whether determined in $\tilde{\chi}^+$ or $\tilde{\chi}^0$ sector

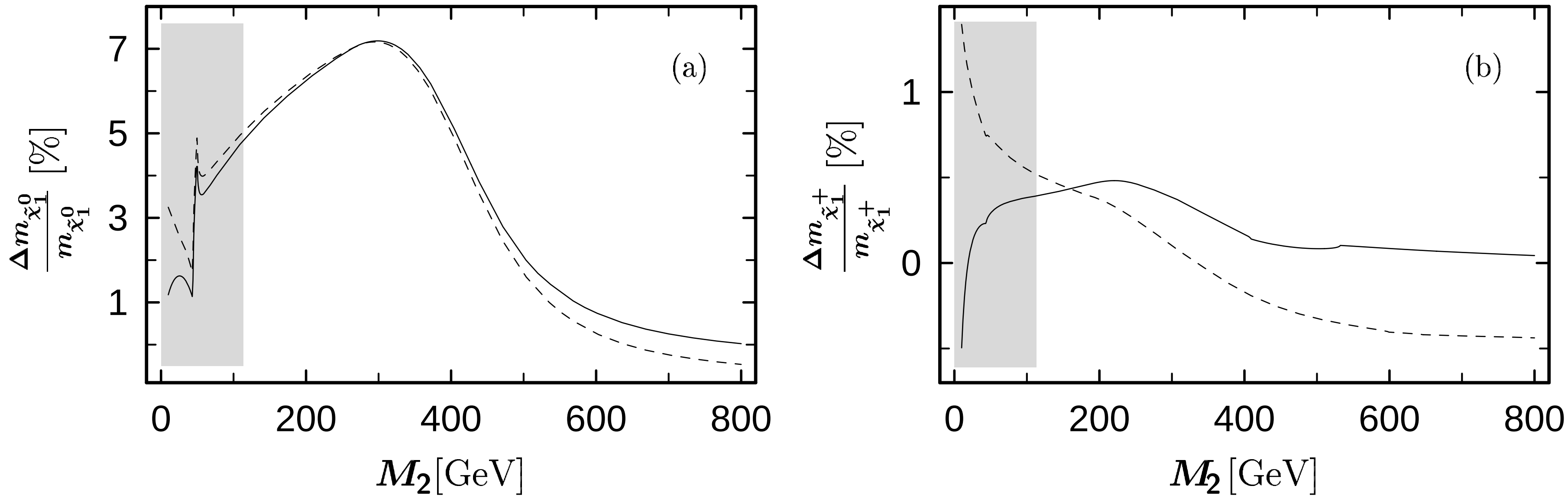
M_1 fixed in neutralino sector: $\hat{M}_1(Q) = M_1^{\tilde{\chi}^0} + \delta Y_{11}$

Mass corrections

Scenario: $m_{A^0} = 500$ GeV, $\tan\beta = 40$, $M_{Q_{1,2,3}} = 300$ GeV, $A = -400$ GeV,
$\mu = -220$ GeV

$m_{\tilde{\chi}_1^\pm} < 100$ GeV in shaded area

Full lines: $M_2^{\tilde{\chi}^+}$, $\mu^{\tilde{\chi}^+}$; dashed lines: $M_2^{\tilde{\chi}^0}$, $\mu^{\tilde{\chi}^0}$



SU(5) GUT test

SU(5) GUT relation holds for $\overline{\text{DR}}$ parameters: $\hat{M}_1(Q) = \frac{5}{3} \tan^2 \hat{\theta}_W \, \hat{M}_2(Q)$

$\Rightarrow$ finite shift for on-shell parameters: $M_1 = \frac{5}{3} \tan^2 \theta_W \, M_2 + \Delta Y_{11}$

Scenario: $m_{A^0} = 600$ GeV, $\tan\beta = 20$, $M_{Q_{1,2,3}} = 350$ GeV, $A = 500$ GeV

$m_{\tilde{\chi}_1^\pm} = 135$ GeV, $m_{\tilde{\chi}_1^0} = 120$ GeV

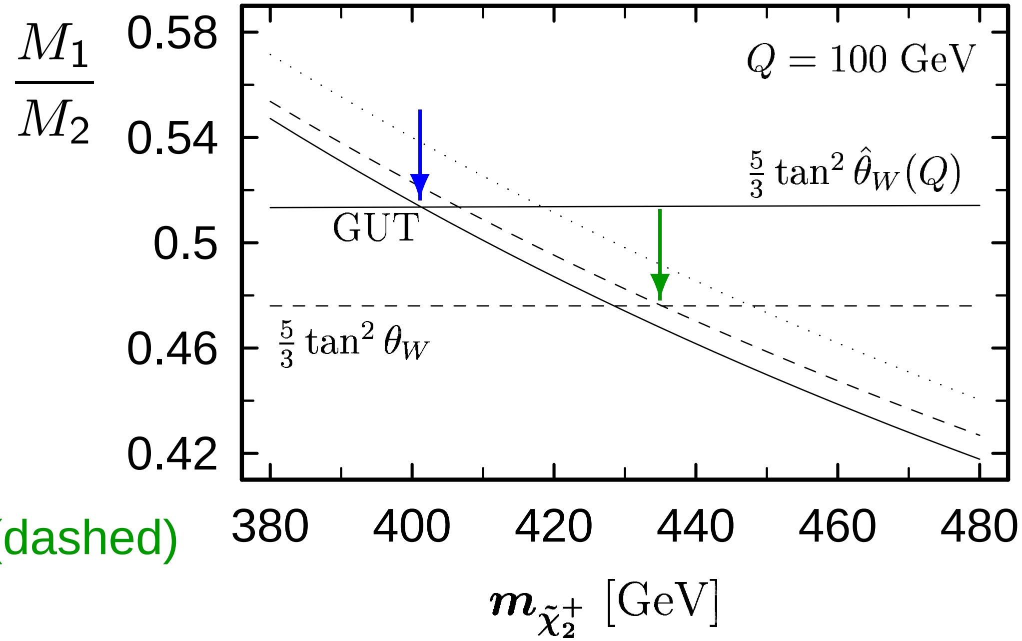
Input: $m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^\pm}, m_{\tilde{\chi}_1^0}$

$\tan\beta$ from Higgs sector

$\longrightarrow$ calculate $\overline{\text{DR}}$ and on-shell parameters

$\Rightarrow$ $\overline{\text{DR}}$: $m_{\tilde{\chi}_2^\pm} = 402$ GeV (full)

on-shell: $m_{\tilde{\chi}_2^\pm} = 437$ GeV (dashed)



Conclusion

Determination of (high) tan β in sfermion decays

$\longrightarrow$ polarisation of decay fermion: $\delta(\tan\beta)/\tan\beta \sim 10\,\%$

$\longrightarrow$ $\delta(A_t)/A_t \sim 10\,\%$

Sfermion decays in complex MSSM

$\longrightarrow$ strong phase dependences of branching ratios

$\longrightarrow$ $\delta(\mathrm{Im}/\mathrm{Re}(A_\tau))/A_\tau \sim 10\,\%$, $\delta(\varphi_{A_t}) \sim 0.1\pi$

T-odd asymmetry in neutralino production and decay

$\longrightarrow$ asymmetries $\sim 10\,\%$ possible

Chargino and neutralino mass parameters at one-loop level

$\longrightarrow$ μ and M_2 depend on whether fixed in $\tilde{\chi}^+$ or $\tilde{\chi}^0$ sector