New physics searches at a Linearcollider with polarized beams

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Summary of the 'polarization' results of
- the ECFA/DESY working groups
- $\tilde{\tau}$, $\tilde{\nu}_\tau$ study of K. Hidaka et al.
- $Z\gamma\gamma$, $ZZ\gamma$ study of I. Ots et al.

1. Introduction

2. Deviations from Standard Model

3. MSSM

4. Other kinds of New Physics

5. Conclusions and outlook

Introduction

Goal of the Linearcollider

'Precision physics in the energy range between LEP and O(1 TeV)'

* High precision measurements of the SM
* Discovery of New Physics (NP) (complementary to Hadroncolliders)
  $\Rightarrow$ LHC/LC Study Group (→ contact: G. Weiglein)
* 'Unveiling' of the NP

$\Rightarrow$ Beam polarization = decisive tool!

GMP, H. Steiner '01

Some technical remarks:

- polarized source: $P(e^-) \approx 80\%$
- helical undulator (TESLA, NLC): $P(e^+) \approx 40 - 60\%$
- Compton polarimetry: $\Delta P(e^\pm) \leq 0.5\%$
- $\mathcal{L} = 300$ fb^{-1}/year at $\sqrt{s} = 500$ GeV, ($\mathcal{L} = 3.4 \cdot 10^{34}$ cm^{-2}s^{-1})
  $\mathcal{L} = 500$ fb^{-1}/year at $\sqrt{s} = 800$ GeV, ($\mathcal{L} = 5.8 \cdot 10^{34}$ cm^{-2}s^{-1})
  10^9 Z's at GigaZ (TESLA design)

Deviations from the SM at high $\sqrt{s}$

Process: $e^+e^- \to W^+W^-$

Rates: $\sigma_{pol} \sim (1 - P_{e^+}P_{e^-})\sigma_u + (P_{e^-} - P_{e^+})\sigma_{pol,L}$

Test of anomalous gauge couplings

e.g. $\mathcal{L} \sim g_V^1 W^*_{\mu\nu} W_\mu A_\nu, \kappa_V W^*_\mu W_\nu F_{\mu\nu}, \lambda_V W^*_{\rho\mu} W_{\mu\nu} F_{\nu\rho}$

error $[10^{-4}]$:	Δg_Z^1	$\Delta\kappa_\gamma$	λ_γ	$\Delta\kappa_Z$	λ_Z
unpolarized beams					
$\sqrt{s} = 500$ GeV	38.1	4.8	12.1	8.7	11.5
$\sqrt{s} = 800$ GeV	39.0	2.6	5.2	4.9	5.1
only electron beam polarized, $\lvert P_{e^-}\rvert = 80\%$					
$\sqrt{s} = 500$ GeV	24.8	4.1	8.2	5.0	8.9
$\sqrt{s} = 800$ GeV	21.9	2.2	5.0	2.9	4.7
both beams polarized, $\lvert P_{e^-}\rvert = 80\%$, $\lvert P_{e^+}\rvert = 60\%$					
$\sqrt{s} = 500$ GeV	15.5	3.3	5.9	3.2	6.7
$\sqrt{s} = 800$ GeV	12.6	1.9	3.3	1.9	3.0

Menges

(TESLA TDR)

$\Rightarrow$ P_{e^-}, $[+P_{e^+}]$ improves sensitivity up to a factor 1.8 [2.5] and can save running time!

Other promising way: $\sigma \sim \sigma_{pol} + P^T_{e^-} P^T_{e^+} \sigma_{pol,T}$

Use of transversal beams $\to$ separates $W_L^+ W_L^-$
$\Rightarrow$ in particular for high $\sqrt{s}$! Fleischer, Kolodziej, Jegerlehner

- study of $A_T \to LL$ mode dominates at high $\sqrt{s}$ ($A_T \sim 10\%$ at $\sqrt{s} = 500$ GeV)
- LL probes electroweak symmetry breaking

Possible $Z\gamma\gamma$ AND $ZZ\gamma$ coupling in $\mathrm{e}^+\mathrm{e}^- \to \mathrm{Z}\gamma$ in a general relativistic density matrix formalism

A method of calculation

In $|\mathcal{M}|^2$

$$\varepsilon_\mu^Z \varepsilon_\nu^{Z\,*} \to \rho_{\mu\nu} = \Lambda_\mu{}^i \rho_{ij} (\Lambda^{-1})^j{}_\nu,$$

$$\rho_{ij} = \frac{1}{3}(\delta_{ij} - \frac{3}{2}\mathrm{i} t_k \epsilon_{ijk} - t_{ij}),$$

t_k – polarization vector, t_{ij} – alignment tensor.

$$|\mathcal{M}|^2 \sim S + V_i t_i + T_{ij} t_{ij},$$

proportional to probability that Z is characterized by ρ with certain t_i, t_{ij}.

The same is expressed as

$$|\mathcal{M}|^2 \sim \mathrm{Tr}\, \rho^Z \rho \sim (1 + \frac{3}{2} t_i^Z t_i + \frac{1}{3} t_{ij}^Z t_{ij}),$$

ρ^Z, t_i^Z, t_{ij}^Z – actual Z boson density matrix, polarization vector and alignment tensor.

Hence,

$$t_i^Z = \frac{2}{3S} V_i, \qquad t_{ij}^Z = \frac{3}{S} T_{ij}.$$

Results

Analytical expressions for Z boson polarization vector ($\vec{t}^Z$) and alignment tensor (t_{ij}^Z) in $e^+e^- \to Z\gamma$ with the contributions from $ZZ\gamma$ and $Z\gamma\gamma$ anomalous couplings have been found in the case of

- polarized initial beams,
- CP-conserving anomalous couplings,
- approximation linear in anomalous couplings form factors $h_i^{Z,\gamma}$,
- $m_e \to 0$,
- CM-system.

From general expressions one can conveniently find possible anomalous contributions in various special cases.

Deviations from the SM at GigaZ

Process: $e^+e^- \to Z \to f\bar{f}$

Measurement of effective mixing angle $\sin\Theta^{\ell}_{eff}$

$$A_{LR} = \frac{2(1-4\sin^2\Theta^{\ell}_{eff})}{1+(1-4\sin^2\Theta^{\ell}_{eff})^2}$$

Gain in statistical power of 'Z-factory' only if $\Delta A_{LR}(pol) < \Delta A_{LR}(stat)$

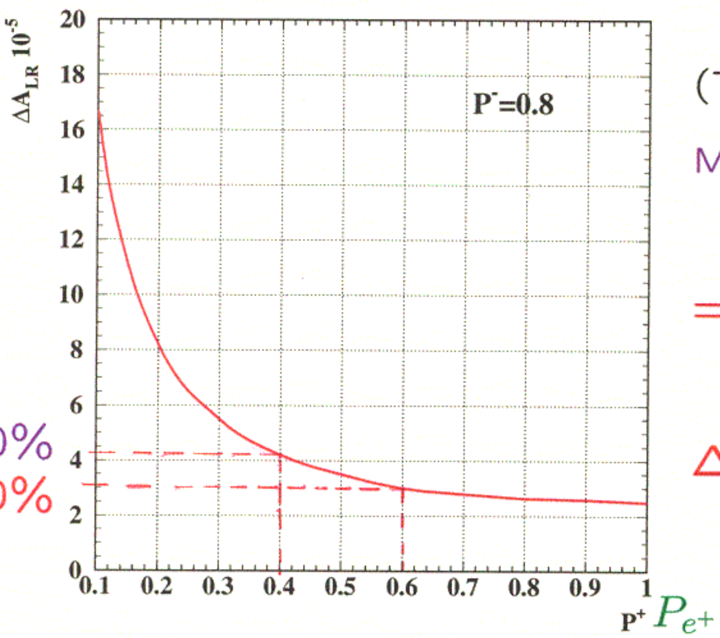
$\Rightarrow \Delta P_{eff} \sim 10^{-4}$ needed!

not possible with only polarimetry.....

Use of Blondel Scheme:

$$A_{LR} = \sqrt{\frac{(\sigma^{++}+\sigma^{+-}-\sigma^{-+}-\sigma^{--})(-\sigma^{++}+\sigma^{+-}-\sigma^{-+}+\sigma^{--})}{(\sigma^{++}+\sigma^{+-}+\sigma^{-+}+\sigma^{--})(-\sigma^{++}+\sigma^{+-}+\sigma^{-+}-\sigma^{--})}} \quad \Rightarrow P_{e^+} \text{ needed!}$$

$\Delta A^{stat}_{LR} 10^{-5}$



$P_{e^+} = 40\%$

$P_{e^+} = 60\%$

(TESLA TDR)

Moenig

$\Rightarrow \Delta A_{LR} \sim 10^{-4}$

$\Delta \sin^2\theta^{\ell}_{eff} = 0.000013$!!!

	LEP2/Tev.	Tev./LHC	LC	GigaZ/WW
M_W	34 MeV	15 MeV	15 MeV	6 MeV
$\sin^2\theta_{eff}$	0.00017	0.00017	0.00017	0.00001
m_t	5 GeV	2 GeV	0.2 GeV	0.2 GeV
m_h	–	0.2 GeV	0.05 GeV	0.05 GeV

CP–violation beyond the SM

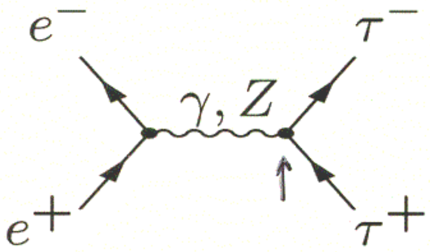
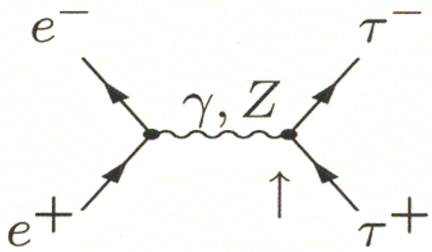
Process: $e^+e^- \to \tau^+\tau^- \to \pi\nu_\tau$ or $\rho\nu_\tau$

Ananthanarayan, Rindani, Stahl

SM: 'in principle' no CP violation in lepton sector!

Limits for $\sqrt{s} = 500$ GeV (from LEP) estimated:

EDM $d_\tau^\gamma \leq 10^{-19}$ ecm, WDM $d_\tau^Z \leq 10^{-20}$ ecm

a)  + b) 

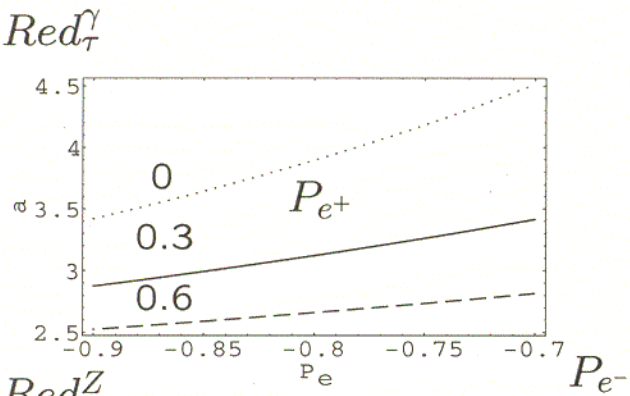
$\bar\tau\gamma^\mu\tau(\gamma/Z)_\mu$ $\qquad$ $d_\tau\bar\tau\sigma^{\mu\nu}\gamma_5\tau F_{\mu\nu}$

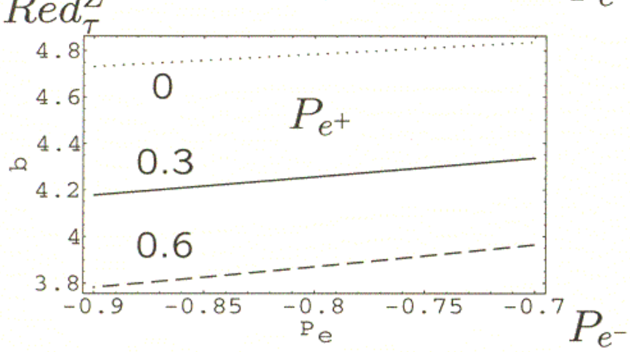
$|a)|^2 \to$ SM, $2\,\mathrm{Re}[a)\cdot b)] \to \not{C}P$, $|b)|^2 \to \Delta\sigma(\tau\tau) \sim d_\tau^2$

Strategy:

CP–odd triple product correlations between p's

$\Rightarrow$ sensitive to $Re(d_\tau^V)$ or $Im(d_\tau^V)$





$\sqrt{s}$ GeV	Red_τ^γ	Red_τ^Z
500	$3.8 \cdot 10^{-19}$	$5.4 \cdot 10^{-19}$
800	$2.7 \cdot 10^{-19}$	$3.9 \cdot 10^{-19}$

$\to$ similar sensitivity as LEP limits but higher q^2!

$\Rightarrow P_{e^-}$ is mandatory, P_{e^+} improves $\sim$ factor 2

$\Rightarrow$ detection of $\underbrace{\not{C}P}_{\text{of } O(10^{-19})}$ seems to be possible!

Unveiling the MSSM

Problem: $m_p \neq m_{\tilde{p}}$

$\Rightarrow$ SUSY has to be broken:
soft breaking terms lead to 105 parameters!

$\Rightarrow$ Schemes: mSUGRA, AMSB, GMSB, ...

$\uparrow$ $\uparrow$ $\uparrow$

4 parameters

5 parameters 5 parameters

Unique task of a LC: 'Fixing of the model!'

$\Rightarrow$ fix parameters without assuming the scheme

$\Rightarrow$ 'proof' of fundamental SUSY assumptions

$\Rightarrow$ separation of different SUSY models

by providing precise masses ($\sim O(100\,\text{MeV})$), σ (% level), BR (% level)

Beam polarization is essential!

Strategy:

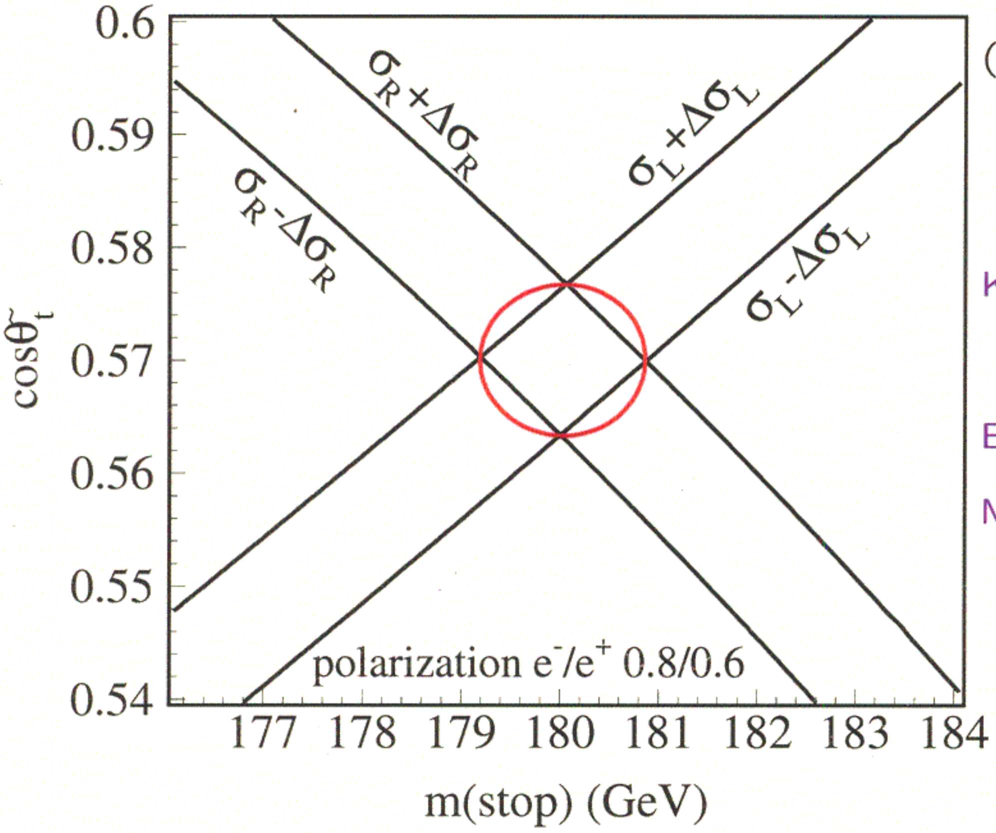
- General MSSM parameters from $\tilde{\chi}^{\pm}$, $\tilde{\chi}^{0}$, $\tilde{\tau}$
- Test of fundamental SUSY assumptions:
  $\rightarrow$ Yukawa couplings of $\tilde{\chi}^0_i$
  $\rightarrow$ Chiral quantum numbers of $\tilde{\ell}$
- What else could be done with $P_{e^{\pm}}$?
  $\rightarrow$ helpful for disentangling NMSSM$\leftrightarrow$MSSM

Warm-up: Stop mixing angle

Process: $e^+e^- \to \tilde{t}_1\tilde{t}_1$
Unknown parameter: $m_{\tilde{t}_1}$ and $\Theta_{\tilde{t}}$:

$$\text{e.g. } \tilde{t}_1 = \tilde{t}_L \cos\Theta_{\tilde{t}} + \tilde{t}_R \sin\Theta_{\tilde{t}}$$

How to derive the mixing angle?
$\Rightarrow$ Study polarized cross sections $\sigma = f(m_{\tilde{t}_1}, \Theta_{\tilde{t}})$



(TESLA TDR)

Keränen,Nowak,Sopczak

Bartl,Eberl,Kraml,
Majerotto,Porod

Due to high $\mathcal{L}$ at TESLA:
$\Rightarrow \Delta m_{\tilde{t}_1} = 0.8$ GeV and $\Delta\cos\Theta_{\tilde{t}} = 0.008$

precise measurement of mass and mixing angle!!!

Test of selectron quantum numbers

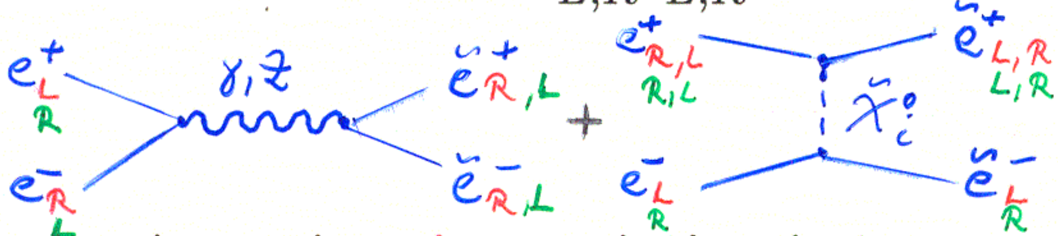
SUSY assumption:
SM $\leftrightarrow$ SUSY have same quantum numbers!

$\Rightarrow e^-_{L,R} \leftrightarrow \tilde{e}^-_{L,R}$ and $e^+_{L,R} \leftrightarrow \tilde{e}^+_{R,L}$

Scalar partners $\leftrightarrow$ chiral quantum numbers!

How to test this association?

Strategy: $\sigma(e^+e^- \to \tilde{e}^+_{L,R}\tilde{e}^-_{L,R})$ with polarized beams

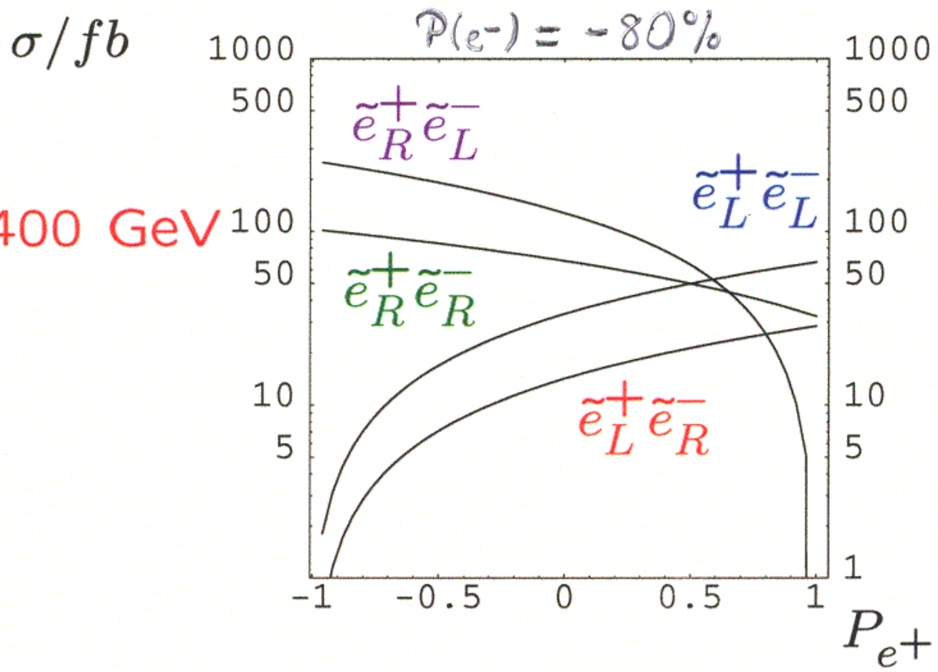


$\Rightarrow$ t–channel: unique relation between
chiral fermion $\longleftrightarrow$ scalar partner

Use e.g. $e^+_L e^-_L$ $\nearrow$ $\tilde{e}^+_R\tilde{e}^-_L$ $\longrightarrow$ $\tilde{e}^+_R$ $\leftrightarrow$ $\tilde{e}^-_L$

$\searrow$ $\rightarrow$ $\longrightarrow$ no s–channel

$\sqrt{s} = 400$ GeV



with ISR and beamstr.

Blöchinger, Fraas GMP, Porod '02

$\Rightarrow$ separation via charge identification

Test of Yukawa couplings

SUSY: $g_{\tilde{W}e\tilde{e}_L} \stackrel{!}{\equiv} g_{Wee}$, $g_{\tilde{B}e\tilde{e}} \stackrel{!}{\equiv} g_{Bee}$

see talk: P. Zerwas

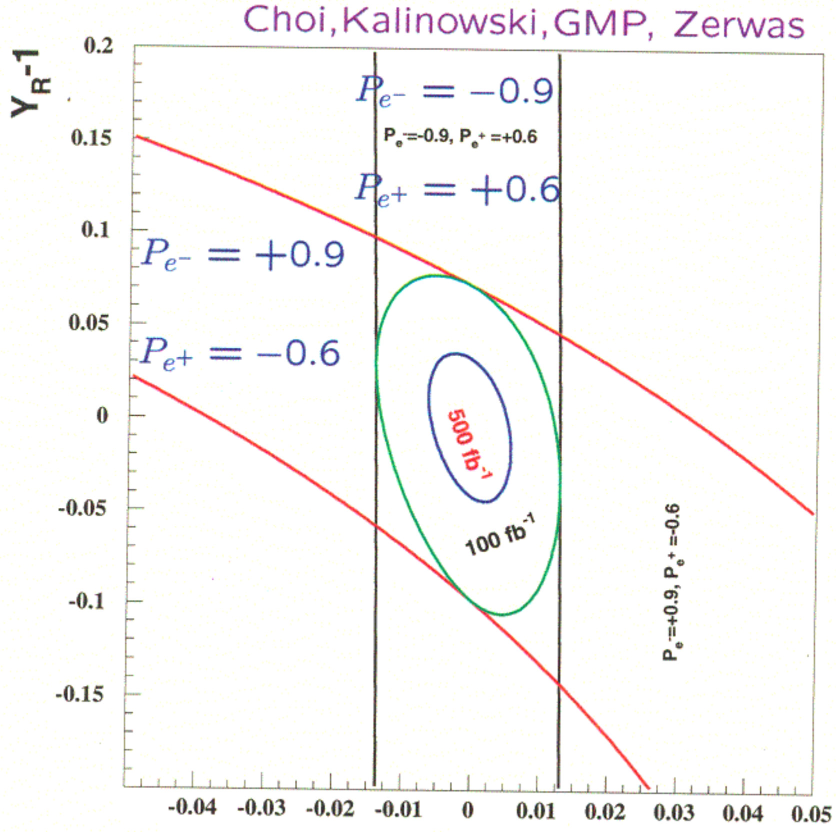
Assumption: M_1, M_2, μ, moderate $\tan\beta$ known
$m_{\tilde{\ell}}$ (even for $m_{\tilde{\ell}} > \sqrt{s}/2$) GMP, Fraas, Bartl, Majerotto

Strategy: $\sigma(\tilde{\chi}^0_1\tilde{\chi}^0_2)$ with polarized beams

$\Rightarrow$ Study of contour lines $\sigma_{L,R} \pm 1\sigma$(stat)

Choi, Kalinowski, GMP, Zerwas

$\frac{g_{\tilde{B}e\tilde{e}}}{g_{Bee}} - 1$



$\frac{g_{\tilde{W}e\tilde{e}}}{g_{Wee}} - 1$ $\quad$ $\mathrm{Y_L}$-1

$\Rightarrow$ High $\mathcal{L} = 500$ fb^{-1}: Y_R, Y_L =O(%)

Now:

Only from light states $\tilde{\chi}^{\pm}_1$, $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$:

→ Choi, Kalinowski, GMP, Zerwas '02

Strategy: $m_{\tilde{\chi}^{\pm}_1}$, $\sigma_{L,R}$ σ_T (or $\sigma_{L,R}$ at two $\sqrt{s}$)

⇒ $c2\Phi_L$, $c2\Phi_R$ uniquely

⇒ boundaries for $m_{\tilde{\chi}^{\pm}_2}$:

$$\frac{1}{2}\sqrt{s} - m_{\tilde{\chi}^{\pm}_1} \le m_{\tilde{\chi}^{\pm}_2} \le \sqrt{m^2_{\tilde{\chi}^{\pm}_1} + 4m^2_W/|c2\Phi_L - c2\Phi_R|}$$

Parameters: Input from neutralinos needed!

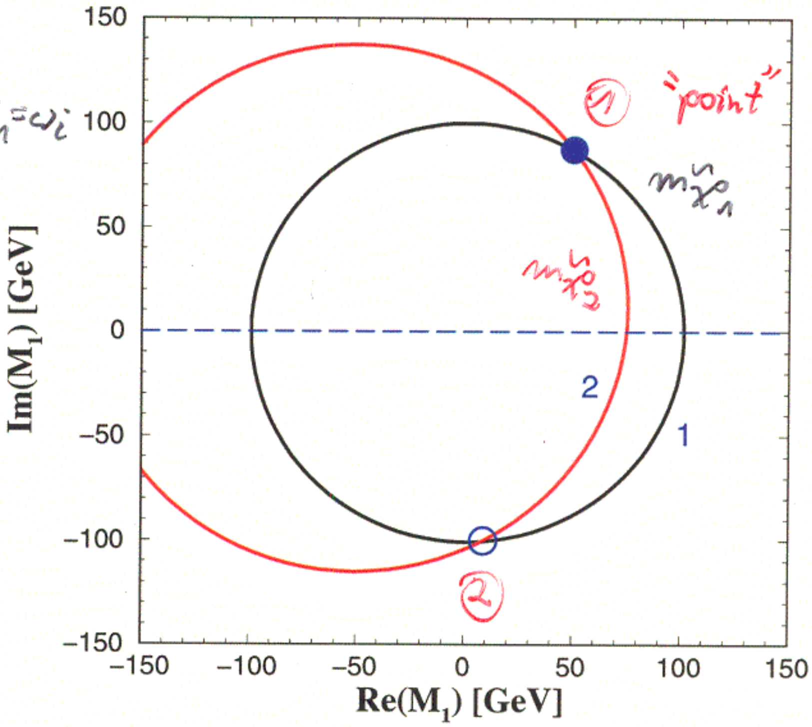
However: $m_{\tilde{\chi}^{\pm}_2}$ unknown → M_2, μ, $\tan\beta$ not uniquely

⇒ 'both' systems merged !

$(\mathrm{Re}\, M_1)^2 + (\mathrm{Im}\, M_1)^2 + u_i \mathrm{Re} M_1 + v_i \mathrm{Im} M_1 = w_i$

Here only: $m_{\tilde{\chi}^0_1}$, $m_{\tilde{\chi}^0_2}$

⇒ ambiguity in M_1 is function of $m_{\tilde{\chi}^{\pm}_2}$!



⇒ Ambiguity in M_1 depends on $m_{\tilde{\chi}^{\pm}_2}$!!

⇒ Fix M_1, M_2, μ, $t\beta$, and $m_{\tilde{\chi}^{\pm}_2}$ uniquely with $\sigma_{L,R}(e^+e^- \to \tilde{\chi}^0_1 \tilde{\chi}^0_2)$

MSSM parameters with the help of τ's

Determination: M_1, Φ_1, M_2, μ, Φ_μ, mod. $\tan\beta$ $\surd$

$\Rightarrow$ even if only light system $\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ accessible!

Choi, Kalinowski, GMP, Zerwas

Assumed accuracy: O(%) reachable

Remark: Higher order corrections not yet included!

Is SUSY renormalizable? $\rightarrow$ YES!

Proof: $\Rightarrow$ Hollik, Kraus, Roth, Rupp, Sibold, Stöckinger

What's about high $\tan\beta$ in the $\tilde{\chi}^\pm$, $\tilde{\chi}^0$ system?

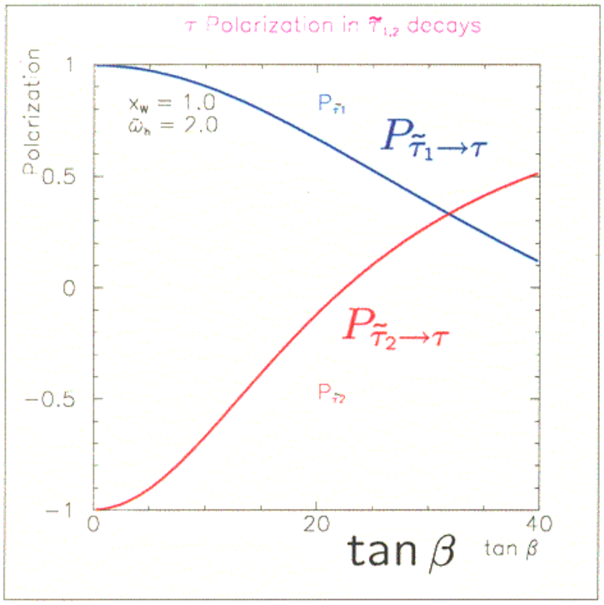
$\Rightarrow$ 'not' sensitive for $\tan\beta > 10$

$\Rightarrow$ Help from $\tilde{\tau}$ sector via $P_{\tilde{\tau}_1 \to \tau}$ Nojiri, Fujii, Tsukamoto

Is $P_{\tilde{\tau}_1 \to \tau}$ always suitable? No!

Boos, Martyn, GMP, Sachwitz, Vologdin, Zerwas'02

$\Rightarrow$ Suitable mixing of $\tilde{\chi}_1^0$ needed!



$\Rightarrow$ High sensitivity to $\tan\beta$!

$x_W \equiv$ gaugino–like

$\tilde{w}_h \equiv$ higgsino–like

$\Rightarrow$ Preliminary: $\delta(\tan\beta) \sim 9\%$ even for $\tan\beta = 40$!

Impact of CP phases on the search for sleptons $\tilde{\tau}$ and $\tilde{\nu}_\tau$

ABS913: ***A. Bartl, K. Hidaka, T. Kernreiter, W. Porod***

(Phys. Lett. B538(2002)137: hep-ph/0204071)

- ***In the MSSM with complex SUSYparameters the CP phases can significantly affect not only CP-violating observables (such as lepton EDM's) but also CP-conserving observables (such as decay branching ratios of SUSY particles).***

- ***The effect of the CP phases (φ_{A_τ} , φ_μ and φ_1) of the complex parameters A_τ , μ and M_1 on the branching ratios of the $\tilde{\tau}_{1,2}$ and $\tilde{\nu}_\tau$ decays can be quite strong in a large region of the MSSM parameter space.*** ***(=> See next Figure.)***

τ trilinear coupling:	$A_\tau = \lvert A_\tau \rvert \, e^{i\varphi_{A_\tau}}$
higgsino mass parameter:	$\mu = \lvert \mu \rvert \, e^{i\varphi_\mu}$
U(1) gaugino mass:	$M_1 = \lvert M_1 \rvert \, e^{i\varphi_1}$

- ***This could have an important impact on***

  (i) the search for $\tilde{\tau}_{1,2}$ and $\tilde{\nu}_\tau$,

  and

  (ii) the determination of the MSSM parameters

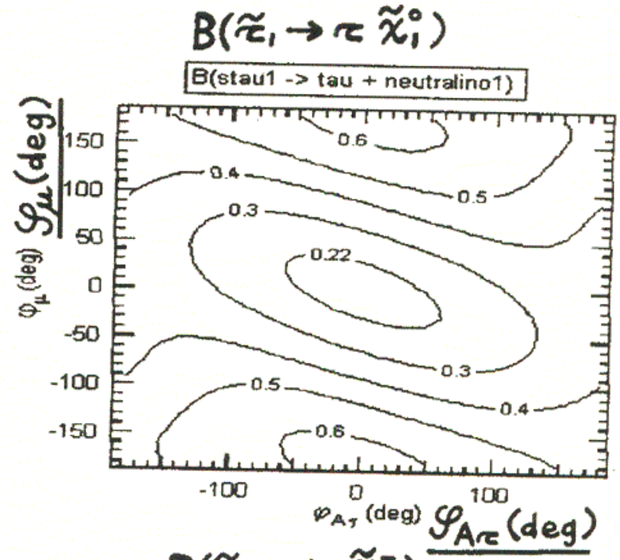
  at future colliders such as LC and LHC.

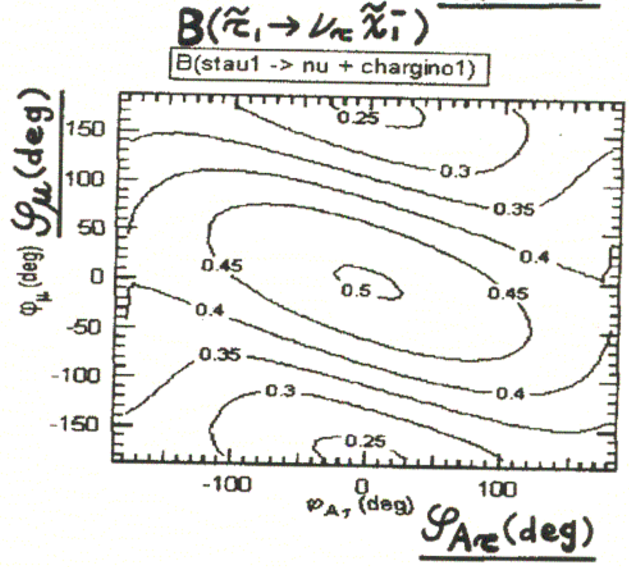
ABS 913: A. Bartl, K. Hidaka, T. Kernreiter, W. Porod

- ***(φ_{A_τ}, φ_μ) dependence of $\tilde{\tau}_1$ decay branching ratios;***

(m_{stau_L} < m_{stau_R})

$\tan\beta = 3$
$M_2 = 200$(GeV)
$\varphi_1 = 0$(rad)
$|\mu| = 350$(GeV)
m_{stau_1} = 240(GeV)
m_{stau_2} = 255(GeV)
$|A_\tau| = 600$(GeV)
$m_{H^+} = 180$(GeV)





↓

The $\tilde{\tau}_1$ decay branching ratios can depend on the phases (φ_{A_τ}, φ_μ) quite strongly !

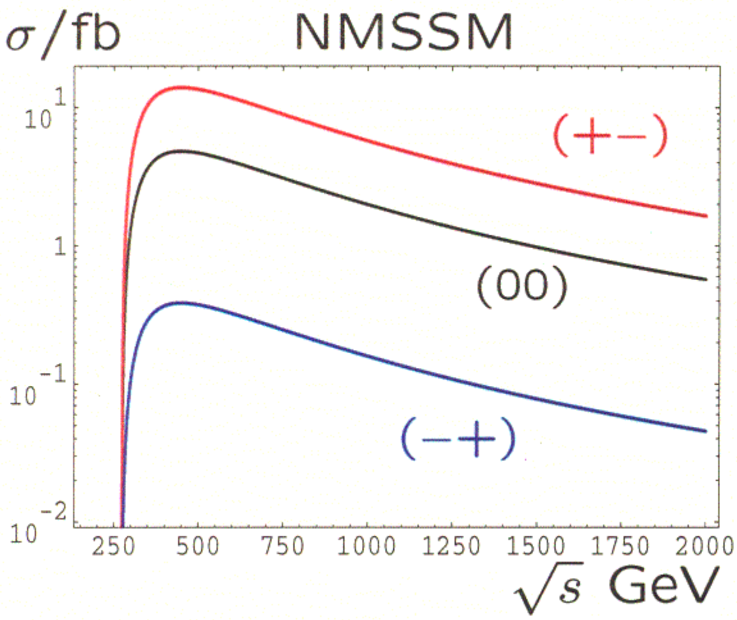
‘Extended’ neutralino sector: NMSSM

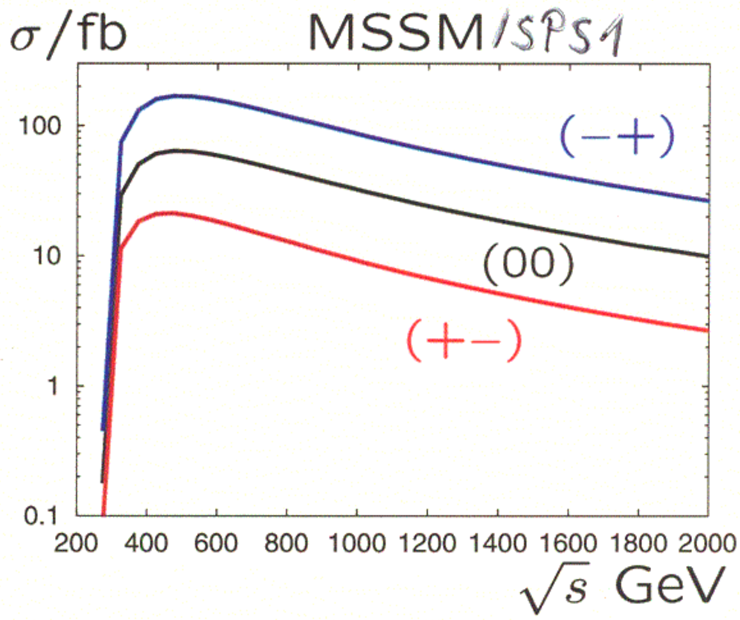
Beam polarization can help disentangling
NMSSM$\leftrightarrow$MSSM

NMSSM: additional Higgs singlet $\rightarrow$ 5 $\tilde{\chi}_i^0$’s
($M_1 = 181$ GeV, $M_2 = 364$ GeV, $\tan\beta = 10$, $\mu_{\text{eff}} = \lambda x = 352$ GeV, $x = 1$ TeV, $\kappa = 0.0493$)

$m_{\tilde{\chi}_1^0} = 96$ GeV, $m_{\tilde{\chi}_2^0} = 177$ GeV as in SPS 1

$\Rightarrow$ $\tilde{\chi}_1^0$ is singlino-like with $|\langle\tilde{\chi}_1^0|\tilde{S}\rangle|^2 = 0.95$



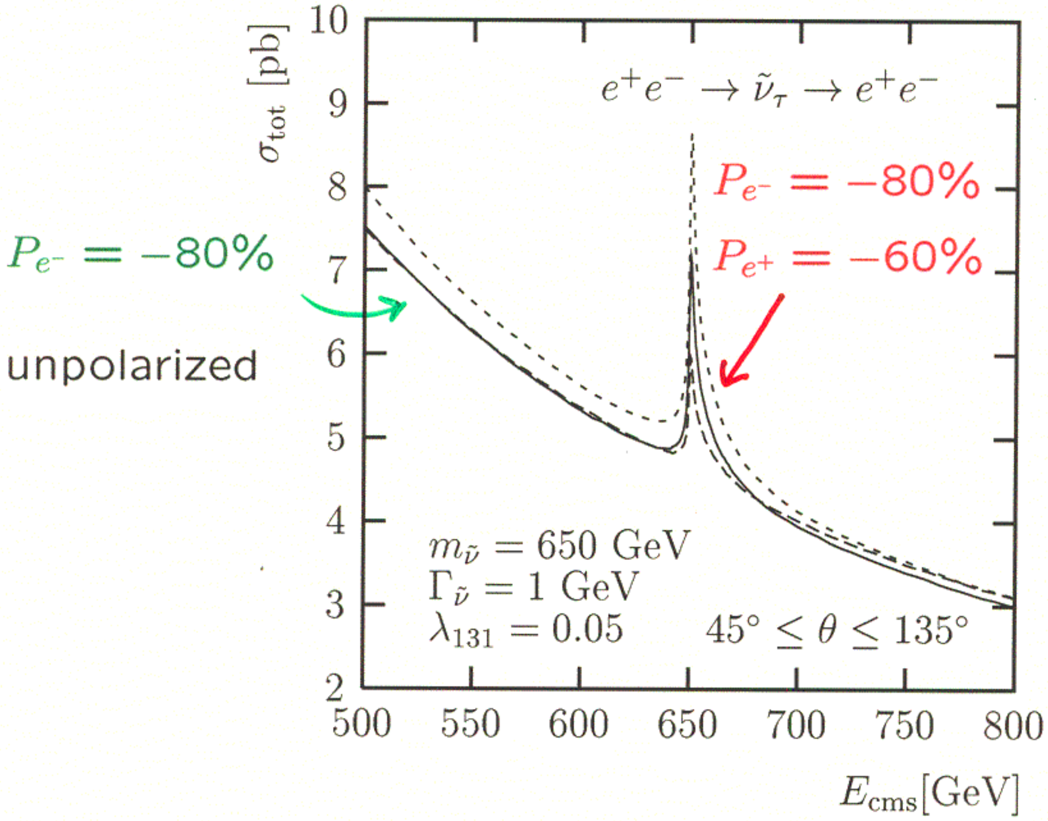


- NMSSM: ‘singlino’–like $\Rightarrow$ small rates
- different polarization dependence as in MSSM
  GMP, Hesselbach, Franke, Fraas’99, Hesselbach, Franke, Fraas’01
- direct production of singlinos (‘99%’) at a LC:
  $\sigma \sim$ fb up to x=0(10 TeV) Franke, Hesselbach’02

Non–standard couplings in $\not{R}$ violating SUSY

$\tilde{\nu}$ exchange in s–channel: $e^+e^- \to \tilde{\nu} \to e^+e^-$

$\Rightarrow e^+_L e^-_L$ needed!



Spiesberger

(TESLA, TDR)

polarization	$\sigma(e^+e^- \to e^+e^-)$ with $\sigma(e^+e^- \to \tilde{\nu} \to e^+e^-)$	Bhabha
unpolarized	7.17 pb	4.49 pb
$P_{e^-} = -80\%$	2% 7.32 pb	4.63 pb
LL: $P_{e^-} = -80\%$, $P_{e^+} = -60\%$	20% 8.66 pb	4.92 pb

$\Rightarrow$ very high sensitivity to non–standard coupling!

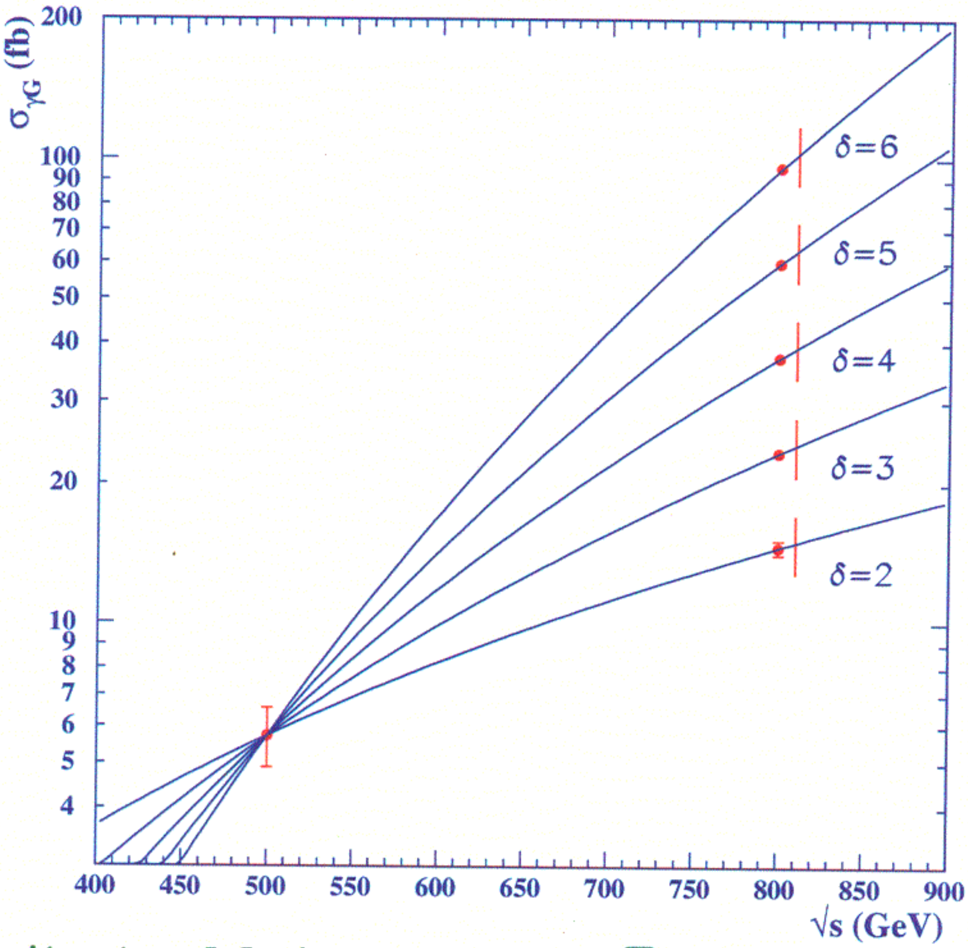
$\Rightarrow$ P_{e^+} is essential (factor 10!)

Same final state also with $e^+e^- \to Z' \to e^+e^-$ possible, however with $e^+_R e^-_L$ or $e^+_L e^-_R$!

$\Rightarrow$ with P_{e^-} and P_{e^+}: fast analysis possible!

Signal for large Extra Dimensions

Process: $e^+e^- \to \gamma G$
Strategy: $n(ED)$ with running at two $\sqrt{s}$!



Wilson

(TESLA, TDR)

Sensitivity to M_* in TeV at $\sqrt{s} = 800$ GeV, 1 ab^{-1}:

Polarization	$\delta = 2$	$\delta = 4$	$\delta = 6$
0	5.9	3.5	2.5
80%(e^-)	8.3	4.4	2.9
80%(e^-), 60%(e^+)	10.4	5.1	3.3

$\Rightarrow$ P_{e^-}, P_{e^+} enlarge the discovery range!

Background: $e^+e^- \to \nu\bar{\nu}\gamma$

$\Rightarrow$ $S/\sqrt{B}$ increases:

by a factor 2.1 for +80%(e^-)
by a factor 4.4 for +80%(e^-), −60%(e^+)

'Highlights':
Beam polarization at a LC very useful for

- Electroweak precision tests with unprecedented accuracy!
  $\rightarrow$ anomalous gauge couplings
  $\rightarrow$ CP–violation
  $\rightarrow$ operating as a Higgs–factory (see TESLA–TDR)

- Discovery and 'unveiling' of SUSY
  $\rightarrow$ fundamental MSSM parameters
  $\rightarrow$ test of SUSY assumptions
  quantum numbers, Yukawa couplings etc.
  $\rightarrow$ disentangling of 'extended' SUSY models

- Discovery of other kinds of New Physics
  $\rightarrow$ extended gauge theories (see TDR)
  $\rightarrow$ large extra dimensions

- Further advantages of $P(e^{\pm})$:
  $\rightarrow$ backround suppression ...
  $\rightarrow$ improves statistics
  $\rightarrow$ extends discovery range for all kinds of NP

But still open questions...

$\Rightarrow$ POWER working group:
close contact between Th/Exp/Machine
($\rightarrow$ http://www.desy.de/~gudrid/power)