SUSY Working Group:
Summary Report

Jan Kalinowski, Warsaw University

Two SUSY sessions:

Ian Jack	3-loop RGE and SPS benchmarks
Dominik Stöckinger	Renormalization of the MSSM
Stefan Hesselbach	T-odd asymmetries in $\tilde{\chi}^{\pm}/\tilde{\chi}^{0}$ production and decay
J.A. Aguilar-Saavedra	Can CP-violation be observed in $\tilde{\chi}^{0}$ production and decay?
Diego Restrepo	Sneutrino production and decay in $e^{+}e^{-}$
Albert Villanova del Moral	Invisible Higgs decays in spontaneously broken R_p
Lali Rurua	Lepton flavour violation and perspectives for TESLA
Hanna Nowak	Scalar top studies
Gudrid Moortgat-Pick	Distinguishing between MSSM and NMSSM via combined LHC/LC analyses

and sessions with other WG

SUSY/$\gamma\gamma$ Physics/Generators

Wilfried sa Silva	$2l$+2q production in 2γ collisions
Markus Roth	Lowest-order prediction for $\gamma\gamma \to 4f(+\gamma)$
Alexander Oh	$e\gamma \to \tilde{e}\tilde{\chi}^0$
Huber Nieto-Chaupis	SUSY branching ratios at the photon collider
Jan Kalinowski	Signals of H/A mixing in CP-violating SUSY at the PLC

SUSY/Cosmology

Wim de Boer	Evidence for WIMP DM
Genevieve Belanger	Impact of collider data on uncertainties in relic densities
Francois Richard	Alternate SUSY approaches to dark matter

SUSY/Generators

Peter Skands	SUSY Les Houches Accord
all	SLHA / SPA / Tools discussion

Peter Zerwas: The SPA – well-defined platform for ex+th SUSY analyses

SPA

SUPERSYMMETRY PARAMETER ANALYSIS

Ian Jack

SPS Benchmarks and 3-loop RGEs

With Tim Jones and Ahmad Farzaneh-Kord

ECFA 2004, Durham

Outline

1. N=1 supersymmetry
2. Soft supersymmetry breaking
3. Results for β-functions
4. Snowmass Benchmark Points

The β-functions

The renormalisation of a supersymmetric theory is governed by the gauge β-function(s) $\beta_g(g, Y, Y^*)$ and the matter multiplet anomalous dimension $\gamma^i{}_j(g, Y, Y^*)$; the latter governs both mass and Yukawa β-functions.

$$\begin{aligned} \beta_Y^{ijk} &= Y^{p(ij}\gamma^{k)}{}_p = Y^{ijp}\gamma^k{}_p + (k \leftrightarrow i) + (k \leftrightarrow j) \\ \beta_\mu^{ij} &= \mu^{p(i}\gamma^{j)}{}_p \end{aligned}$$

In DRED (Dimensional Reduction) β_g has been calculated through four loops and γ^i_j through three loops in general and through four loops in the ungauged case. (In QCD four loops marks the first appearance in β_g of higher order group invariants; these cancel in the supersymmetric case).

Retaining the top Yukawa only:

$$\begin{aligned} \beta_{y_t} &= 6y_t^3 - 22y_t^5 + [102 + 36\zeta(3)]y_t^7 \\ &- [678 + 696\zeta(3) - 216\zeta(4) + 1440\zeta(5)]\, y_t^9. \end{aligned}$$

Note the increasing coefficients, and the sign alternation.

Examples

SPS5 benchmark point: $(m_t = 174.3\text{GeV})$

Particle	1 loop	2 loops	3 loops	AKP
$\tilde{g}$	743	729	727	718-728
$\tilde{u}_L$	684	677	668	676-684
$\tilde{u}_R$	658	656	646	653-660
$\tilde{t}_2$	243	257	240	232-258
LSP	128	120	120	119-121
h	115	115	115	112-119

SPS5 benchmark point: $(m_t = 178.0\text{GeV})$

Particle	1 loop	2 loops	3 loops	AKP
$\tilde{g}$	743	729	727	719-729
$\tilde{u}_L$	684	677	668	676-685
$\tilde{u}_R$	658	656	646	655-660
$\tilde{t}_2$	265	278	263	258-280
LSP	128	120	120	119-120
h	117	118	118	116-122

The light stop mass is very sensitive to the input top quark mass here.

SPS1a benchmark point:

Particle	1 loop	2 loops	3 loops	AKP
$\tilde{g}$	628	613	611	604-612
$\tilde{u}_L$	573	565	557	565-569
$\tilde{u}_R$	552	548	539	547-549
$\tilde{t}_2$	400	399	391	396-401
LSP	104	97	97	95.6-97.4
h	114	114	114	112-115

Conclusions

The LHC and an e^+e^- linear collider will measure sparticle masses with high accuracy. Very precise theoretical calculations will be required to disentangle the parameters of the underlying theory from the observations, and to distinguish, for example, nonuniversal boundary conditions from extra matter in the Desert or R-parity violation. By LHC-time state-of-the-art calculations will consist of complete two-loop mass-shell/threshold effects (with some three loop effects), plus the three loop running presented here.

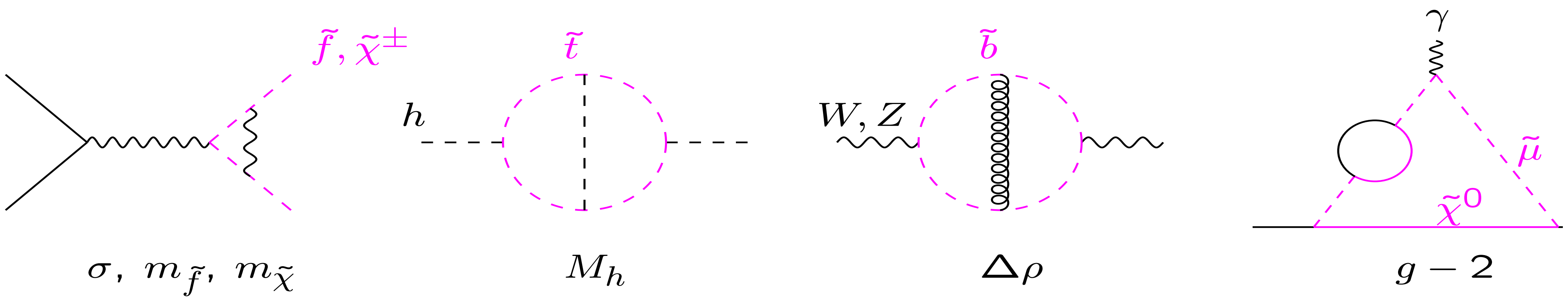
Renormalization scheme of the MSSM

Dominik Stöckinger, Durham

in collaboration with Sven Heinemeyer and Georg Weiglein

- Motivation — the need for a consistent definition of SUSY parameters
- General problems, our proposal & discussion

Precise measurement of SUSY observables



$\leftrightarrow$ determination of SUSY parameters $\tan\beta,\ \mu,\ \theta_{\tilde t},\ A_b, \ldots$

SUSY parameters in $\mathcal{L}$ $\longleftrightarrow$ Observables

$\rightarrow$ SPA project, talk by P. Zerwas

SUSY parameters are
- not directly observable
- not a priori unambiguously defined

Problem 1: QCD vs EW corrections

QCD: large corrections

- scheme should not give rise to artificially large corrections

EW: spontaneous symmetry breaking

- many schemes are gauge dependent

$\longrightarrow$ Conflict

Problem 2: On-shell scheme for masses

$$m^2 = \text{pole of propagator}, \qquad \delta m^2 = \Sigma(p^2 = m^2)$$

$\longrightarrow$ Gauge independent

SM: all masses independent $\Rightarrow$ on-shell scheme possible

MSSM: Mass relations , $m_{\tilde{b}_1} = f(m_{\tilde{t}_1}, m_{\tilde{t}_2}, m_{\tilde{b}_2})$, $M_h, m_{\chi^0_{2,3,4}} = f(\ldots)$

$\Rightarrow$ on-shell scheme only for 3 out of 4 masses possible

$\Rightarrow$ on-shell scheme not possible for all masses

$\Rightarrow$ unsymmetric selection necessary

but remain good alternatives since gauge independent and physically motivated

Problem 3: Definition of "difficult parameters"
tan β, A_b, mixing angles $\theta_{\tilde{t}}, \theta_{\tilde{b}}, \ldots$

Many different definitions in literature, e.g.

$$\delta\theta_{\tilde{t}} = \frac{\Sigma_{12}(m_1) + \Sigma_{12}(m_2)}{2(m_1^2 - m_2^2)}, \qquad \overline{DR}: \ \delta\theta_{\tilde{t}}^{\text{fin}} = 0, \qquad \delta \tan\beta \propto \frac{\Sigma_{A^0 Z}(M_A^2)}{\cos^2\beta}$$

$\Rightarrow$ no direct relation to physical quantity

These and many other schemes: gauge dependent for EW corrections

Renormalization scheme: Properties

SM parameters	e, $M_{W,Z}$, m_f, α_s:	as in the SM
Higgs parameters	$\tan\beta$:	$\overline{DR}$
	M_A:	on-shell
	Tadpoles:	$T + \delta t = 0$
Sfermion/Cha/Neu	μ, soft parameters : ($M_{1,2,3}$, $M_{Q,U,D,L,E}$, A_f)	$\overline{DR}$ scheme

- uniform, implicit definition of susy masses / mixing angles
- gauge independent even for EW corrections (except $\tan\beta$)
- easy to use, numerically o.k.

T-odd Asymmetries in Chargino and Neutralino Production and Decay

Stefan Hesselbach
Institut für Theoretische Physik der Universität Wien

A. Bartl, H. Fraas, K. Hohenwarter-Sodek, G. Moortgat-Pick

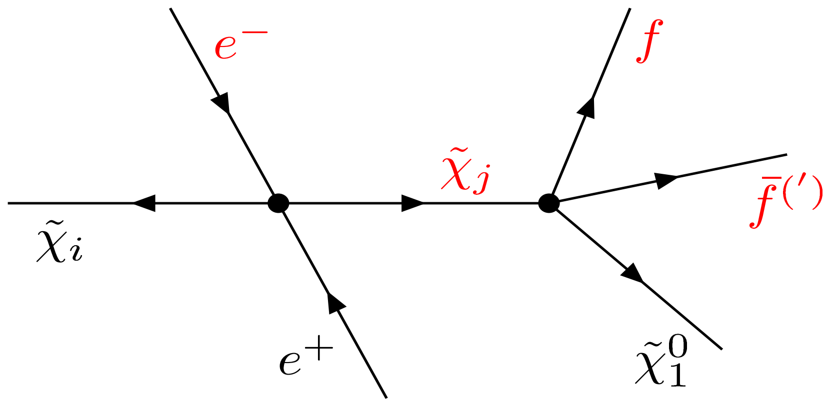
hep-ph/0406190, to be published in JHEP

ECFA Linear Collider Workshop, Durham

September 1, 2004

T-odd asymmetries in $\tilde{\chi}^{\pm}$, $\tilde{\chi}^{0}$ sectors

Triple products: $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_f \times \vec{p}_{\bar{f}^{(\prime)}})$ or $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\tilde{\chi}_j} \times \vec{p}_f)$



$\rightarrow$ T-odd asymmetry:
$$A_T = \frac{\sigma(\mathcal{T} > 0) - \sigma(\mathcal{T} < 0)}{\sigma(\mathcal{T} > 0) + \sigma(\mathcal{T} < 0)} = \frac{\int \text{sign}(\mathcal{T}) |T|^2 d\text{Lips}}{\int |T|^2 d\text{Lips}}$$

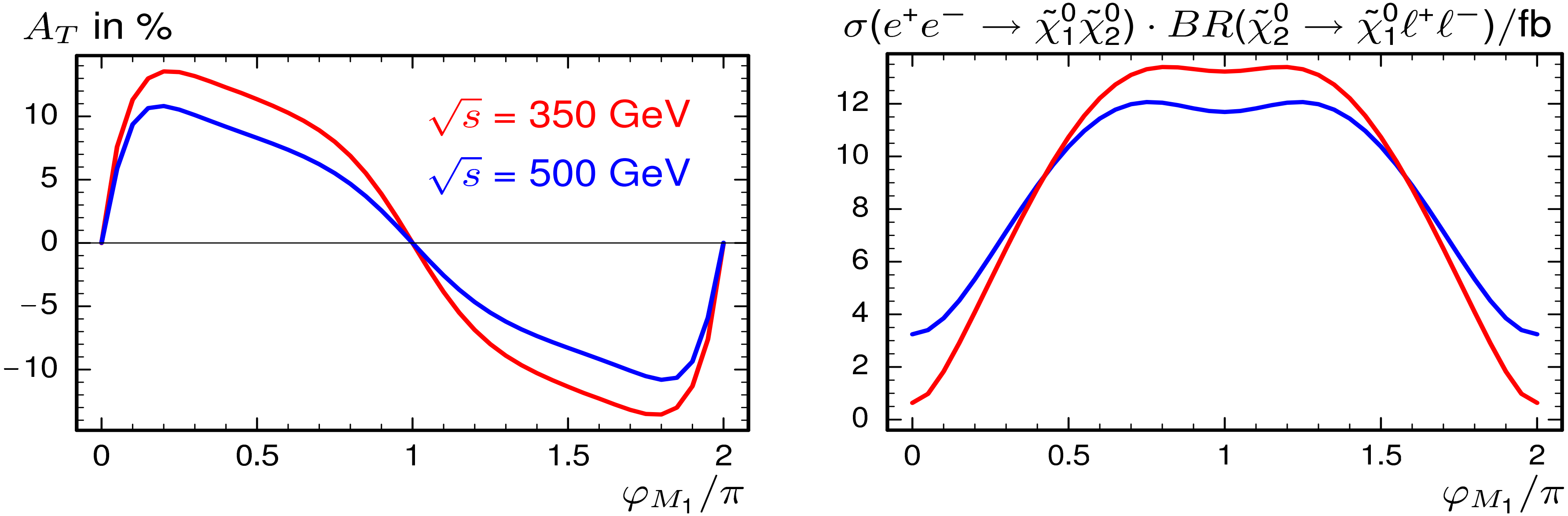
$\rightarrow$ CP-odd, if final state interactions and finite-widths effects can be neglected

T-odd asymmetry in $\tilde{\chi}^0$ sector

Asymmetry A_T for $e^+e^- \to \tilde{\chi}_i^0 \tilde{\chi}_2^0 \to \tilde{\chi}_i^0 \tilde{\chi}_1^0 \ell^+\ell^-$, $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\ell^+} \times \vec{p}_{\ell^-})$

[Bartl, Fraas, SH, Hohenwarter-Sodek, Moortgat-Pick, hep-ph/0406190]

- $e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^+\ell^-$ for
  $\tan\beta = 10$, $M_2 = 300$ GeV, $|M_1| = 150$ GeV, $|\mu| = 200$ GeV, $\varphi_\mu = 0$
  $m_{\tilde{e}_L} = 267.6$ GeV, $m_{\tilde{e}_R} = 224.4$ GeV, $P_{e^-} = -0.8$, $P_{e^+} = +0.6$



$\to$ A_T larger closer to threshold (spin correlations)

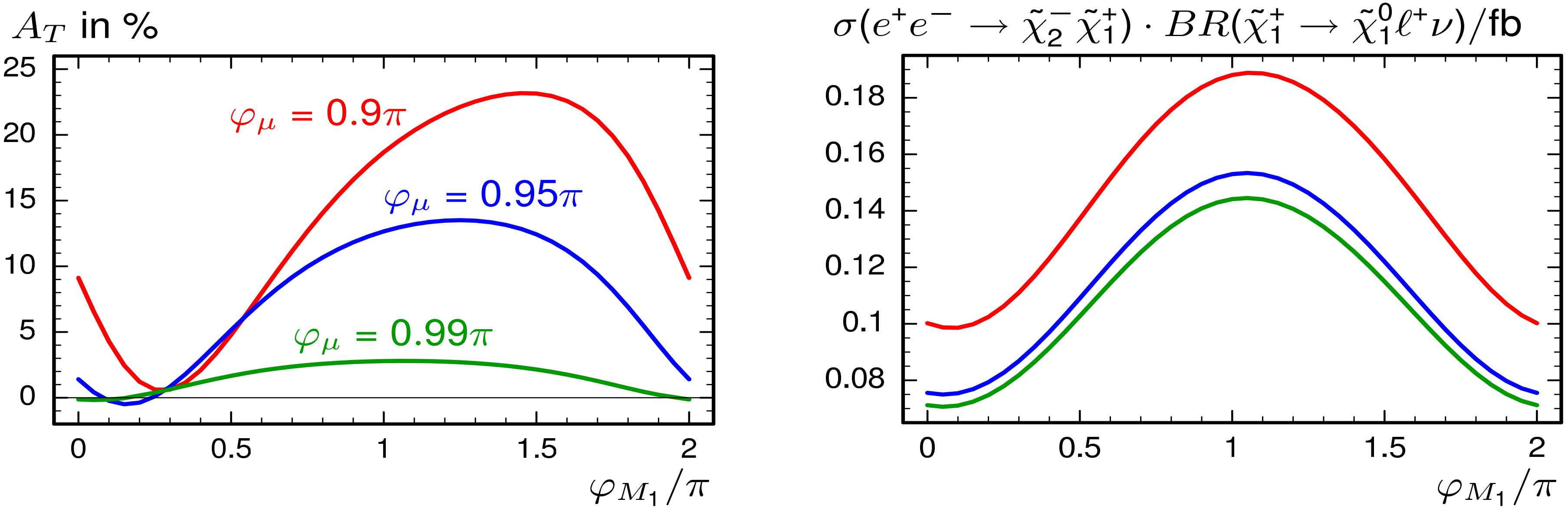
T-odd asymmetry in $\tilde{\chi}^{\pm}$ sector

Asymmetry A_T for $e^+e^- \to \tilde{\chi}_j^- \tilde{\chi}_1^+ \to \tilde{\chi}_j^- \tilde{\chi}_1^0 \ell^+ \nu$, $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\tilde{\chi}_1^+} \times \vec{p}_{\ell^+})$

$\to$ reconstruction of $\vec{p}_{\tilde{\chi}_1^+}$ with information from $\tilde{\chi}_j^-$ decay

- $e^+e^- \to \tilde{\chi}_2^- \tilde{\chi}_1^+ \to \tilde{\chi}_2^- \tilde{\chi}_1^0 \ell^+ \nu$ for

  $\tan\beta$ = 5, M_2 = 120 GeV, $|M_1|$ = $M_2\, 5/3 \tan^2\theta_W$, $|\mu|$ = 320 GeV, $m_{\tilde{\nu}}$ = 250 GeV, $m_{\tilde{u}_L}$ = 500 GeV, $\sqrt{s}$ = 500 GeV, P_{e^-} = −0.8, P_{e^+} = +0.6



Conclusions and outlook

- Aim: revealing the CP structure of the underlying model
- T-odd asymmetries in chargino and neutralino sectors
  - based on triple product correlations
  - full spin correlations between production and decay necessary
  - for three-body and two-body decays
- Asymmetries of $\mathcal{O}(30\,\%)$ ($\tilde{\chi}^{\pm}$) and $\mathcal{O}(10\,\%)$ ($\tilde{\chi}^{0}$) possible

  $\Rightarrow$ important tool for $\longrightarrow$ search for CP violation in SUSY

  $\longrightarrow$ determination of SUSY phases
- Monte Carlo study in neutralino sector $\longrightarrow$ next talk

  [Aguilar-Saavedra, hep-ph/0404104]
- Outlook: incorporation in strategies for parameter determination

Can CP violation be observed in $\tilde{\chi}_2^0$ production and decay?

Based on
J.A.A.-S. PLB 596, 247 (2004)
J.A.A.-S. NPB 697, 207 (2004)

★ Short answer: "yes" ☺

★ Not-so-short answer:

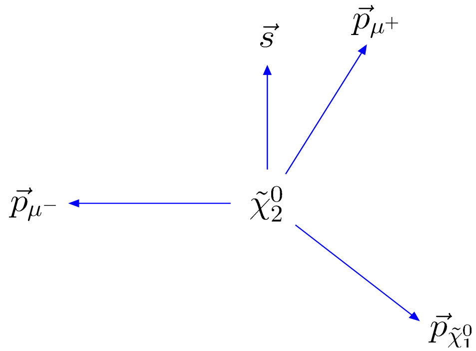
- Two processes: $\tilde{e}_L \to e\tilde{\chi}_2^0 \to e\tilde{\chi}_1^0\mu^+\mu^-$
  $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$
- Define CP-violating asymmetries
- Observability depends on SUSY scenario
- Important backgrounds

J. A. Aguilar-Saavedra, IST Lisbon   Durham, Sept. 1^{st} 2004

Processes:

★ Selectron cascade decays

$\tilde{e}_L \longrightarrow e\tilde{\chi}_2^0 \longrightarrow e\tilde{\chi}_1^0\mu^+\mu^-$

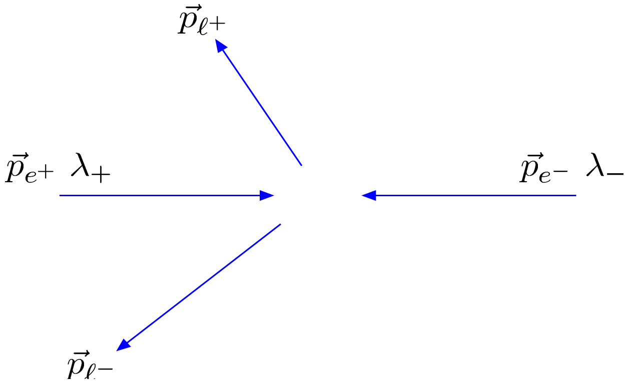


CP-odd, T-odd product $Q_1 = \vec{s}\cdot(\vec{p}_{\mu^-} \times \vec{p}_{\mu^+})$

also: CP-odd T-even product $Q_2 = \vec{s}\cdot(\vec{p}_{\mu^-} + \vec{p}_{\mu^+})$

★ $\tilde{\chi}_1^0\tilde{\chi}_2^0$ production

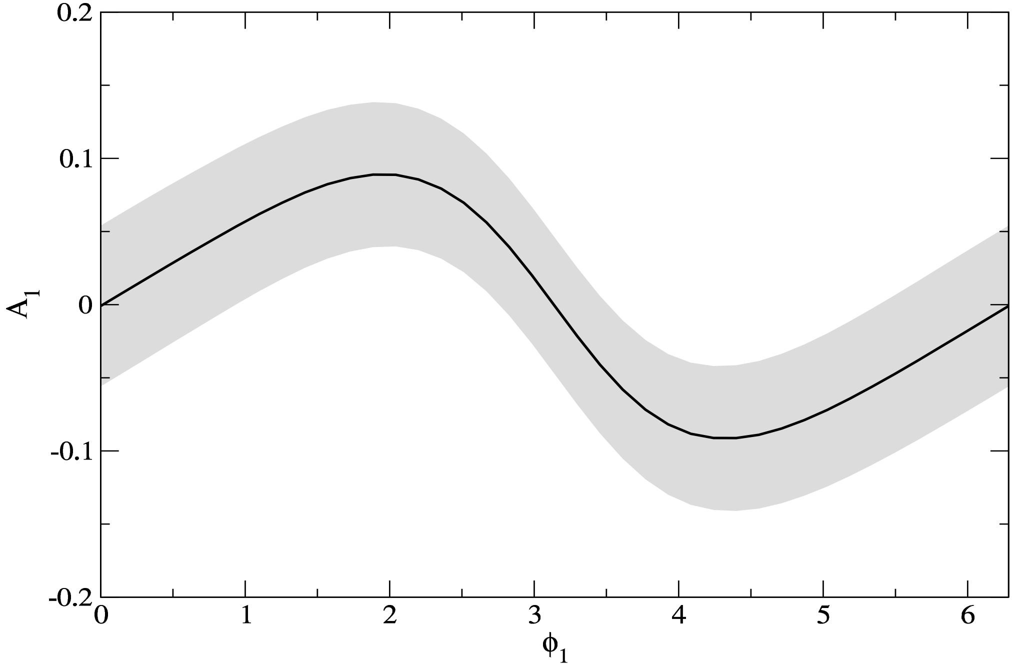
$e^+e^- \longrightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$



CP-odd, T-odd product $Q_1 = \vec{p}_{e^+}\cdot(\vec{p}_{\ell^-} \times \vec{p}_{\ell^+})$

also: CP-odd T-even product $Q_2 = \vec{p}_{e^+}\cdot(\vec{p}_{\ell^-} + \vec{p}_{\ell^+})$

CP asymmetry

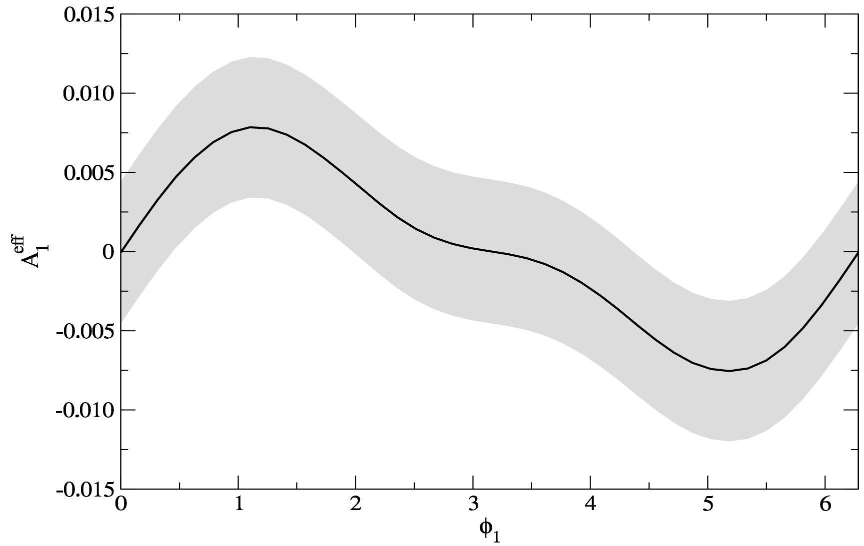


- Including ISR, etc.
- Summing all contributions
- Including backgrounds

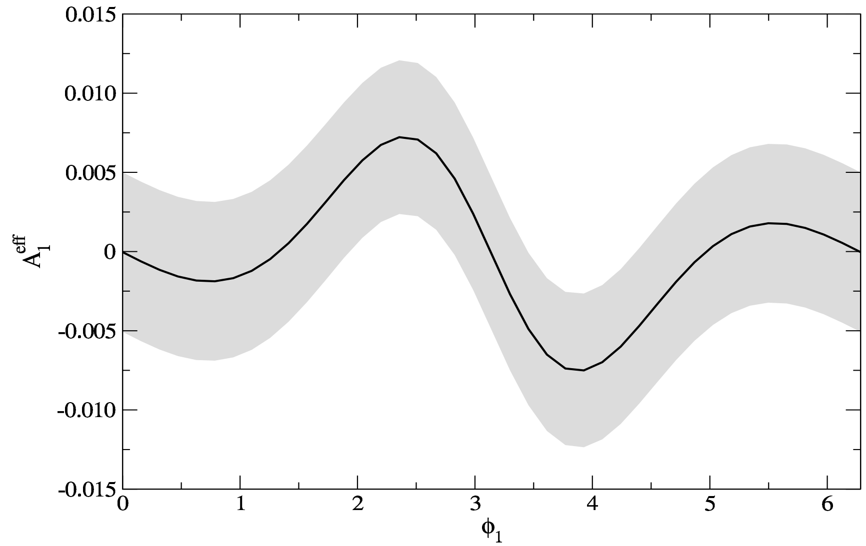
- Statistical error for 2 years of running
- Maximum: $1.8\,\sigma$

Observed CP asymmetry

Scenario 1



Scenario 2



- Including ISR, etc.
- Including backgrounds
- Statistical error for 2 years
- Maximum: $1.8\,\sigma$, $1.5\,\sigma$

Summary

★ $\tilde{e}_L \to e\tilde{\chi}_2^0 \to e\tilde{\chi}_1^0\mu^+\mu^-$

- Small cross section
- Small backgrounds which can be further reduced
- Negligible asymmetry in Sc. 1
  Asymmetry $O(0.1)$ in Sc. 2
- $\tilde{e}_L$ must be produced on shell: higher CM energy required

★ $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$

- Large cross section
- Huge backgrounds
- $A_1 \sim O(0.1)$ in both scenarios
  but $A_1^{\text{eff}} \sim O(0.01)$
- Process possible at lower CM energies

SUSY studies at the TESLA $\gamma\gamma$ collider

H. Nieto-Chaupis & G. Klämke

(In collaboration with K. Mönig, H. Nowak, and A. Stahl.)

DESY-Zeuthen

After cuts (250/300 GeV) : N_{signal} = 529/1919 , N_{backg} = 6951/46206 ,

Eff = 20.2/24.1% , Pur = 7.07/3.99 % $\frac{\Delta N}{N}(1000\ fb^{-1})$ = 16.3/11.4%

$$\Rightarrow \Delta BR(\tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0) = 8.2\%\ (250\ GeV)$$
$$5.7\%\ (300\ GeV)$$

Fittino: general fit of MSSM parameters by using the LC observables (e.g. cross-sections & masses).

Some MSSM parameters are fitted with FITTINO (others fixed):

Parameter	Input Value	Fit-Error without BR	Fit-Error with BR (5.7%)
tan β	9.0	6.29%	4.69%
M_1	99.54	0.092%	0.073%
M_2	192.57	0.140%	0.083%

$\Rightarrow$ the measurement of BR($\tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0$) can improve the error of the fitted MSSM parameters!

R_p violating decays of the sneutrinos

Diego Restrepo

Consejo Superior de Investigaciones Científicas
Universitat de València
IFIC - INSTITUTO DE FISICA CORPUSCULAR

Neutrino mass

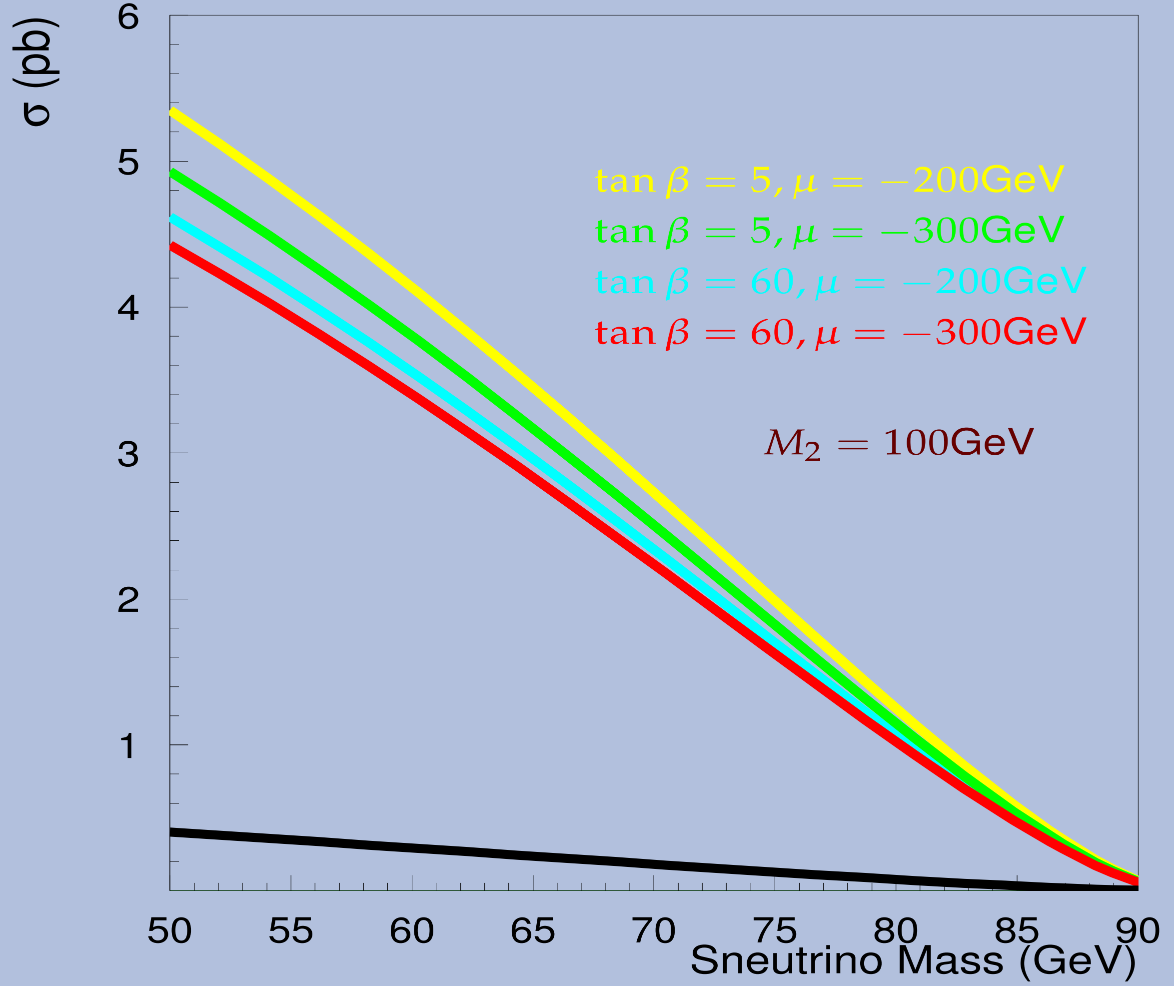
The mixing $\tilde{\chi}^0_1$–ν induce the mass

$$m_\nu \approx 2\frac{m_W^2}{M_2}\frac{\sin^2\xi}{1+\tan^2\beta}$$

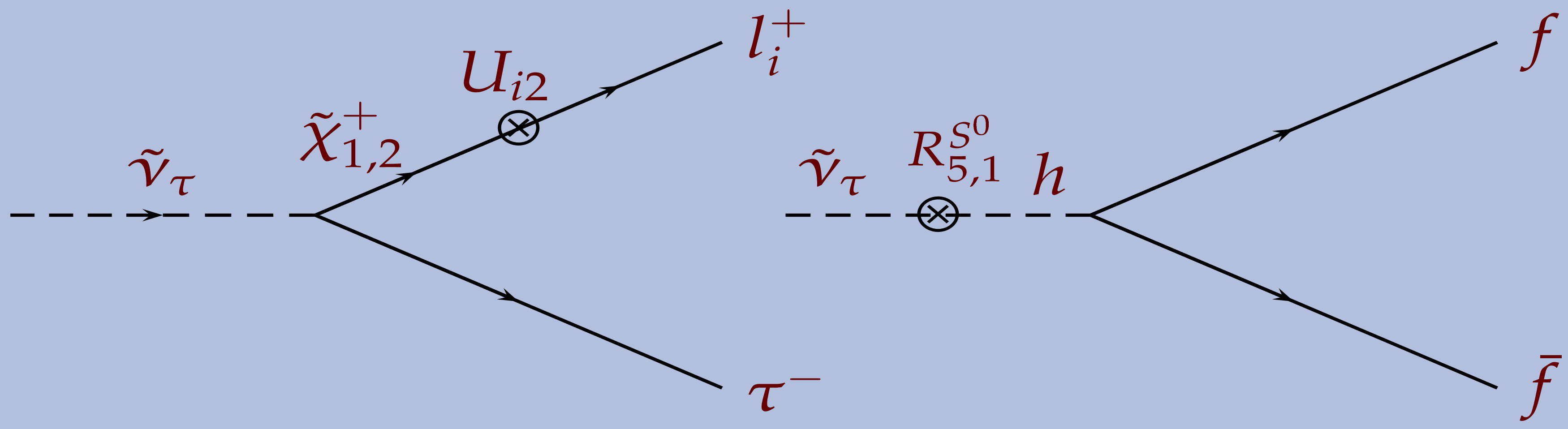
$$\sin^2\xi = \frac{\sum_i \Lambda_i^2}{\mu^2+v_d^2} = \frac{\sum_i(\mu_0 v_i - \mu_i v_0)^2}{(\mu_0^2+\sum_i \mu_i^2)(v_0^2+\sum_i v_i^2)}$$

where $v_0 = \langle L_0\rangle = \langle H_d\rangle,\ v_i = \langle L_i\rangle,\ \epsilon_i = -\mu_i$

Sneutrino Production



Sneutrino decay



$$\frac{\Gamma(\tilde{\nu}_\tau \to \tau^\pm e^\mp)}{\Gamma(\tilde{\nu}_\tau \to \tau^\pm \mu^\mp)} \approx \frac{\epsilon_1^2}{\epsilon_2^2} \approx \tan^2\theta_{\rm sol}$$

Conclusions

- Enhanced $\tilde{\nu}_e$ production
- $\tilde{\nu}_e \longrightarrow b\bar{b}$ like a Higgs
- Bilinear R-parity Violation
  - Correlations of $\tilde{\nu}_\tau$ decays with neutrino physics
  - $\tilde{\nu}_\tau \longrightarrow \tau\tau \neq 0$
  - Measurable invisible decays

Invisible Higgs Boson Decays in Spontaneously Broken R-Parity

A. Villanova del Moral

Based on paper:

M. Hirsch, J. Romão, J. W. F. Valle and A. Villanova del Moral, arXiv:hep-ph/0407269.

ECFA 2004

Workshop on "Physics and Detectors for a Linear Collider"

Durham, 1-4 September, 2004

Consejo Superior de Investigaciones Científicas
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Particle Content

MSSM superfields

+

3 Isosinglets

	$\widehat{\nu}^c$	$\widehat{S}$	$\widehat{\Phi}$
$L =$	-1	$+1$	0

$\widehat{\nu}^c \Rightarrow$ neutrino Dirac mass term

$\widehat{S} \Rightarrow$ large mass for $\widehat{\nu}^c$

$\widehat{\Phi} \Rightarrow$ it enlarges invisible Higgs boson decay

$\Rightarrow$ possible solution to the μ problem

Vacuum Expectation Values

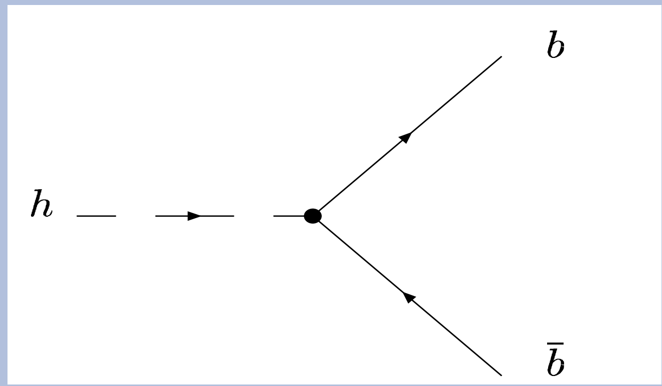
$$\langle H_u^0 \rangle \equiv v_u/\sqrt{2}, \qquad \langle H_d^0 \rangle \equiv v_d/\sqrt{2},$$

$$\langle \widetilde{\nu}_i \rangle \equiv v_{Li}/\sqrt{2} \quad (i =, 1 \ldots, 3),$$

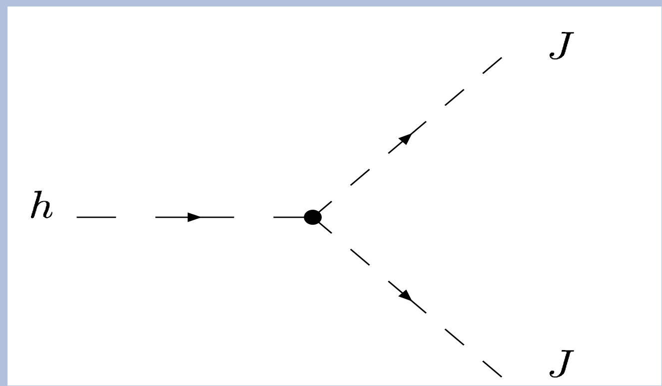
$$\langle \widetilde{\nu}^c \rangle \equiv v_R/\sqrt{2}, \qquad \langle \widetilde{S} \rangle \equiv v_S/\sqrt{2}, \qquad \langle \Phi \rangle \equiv v_\Phi/\sqrt{2}$$

$$v_{Li} \ll v_d, v_u \ll v_R, v_S, v_\Phi$$

Higgs Decays

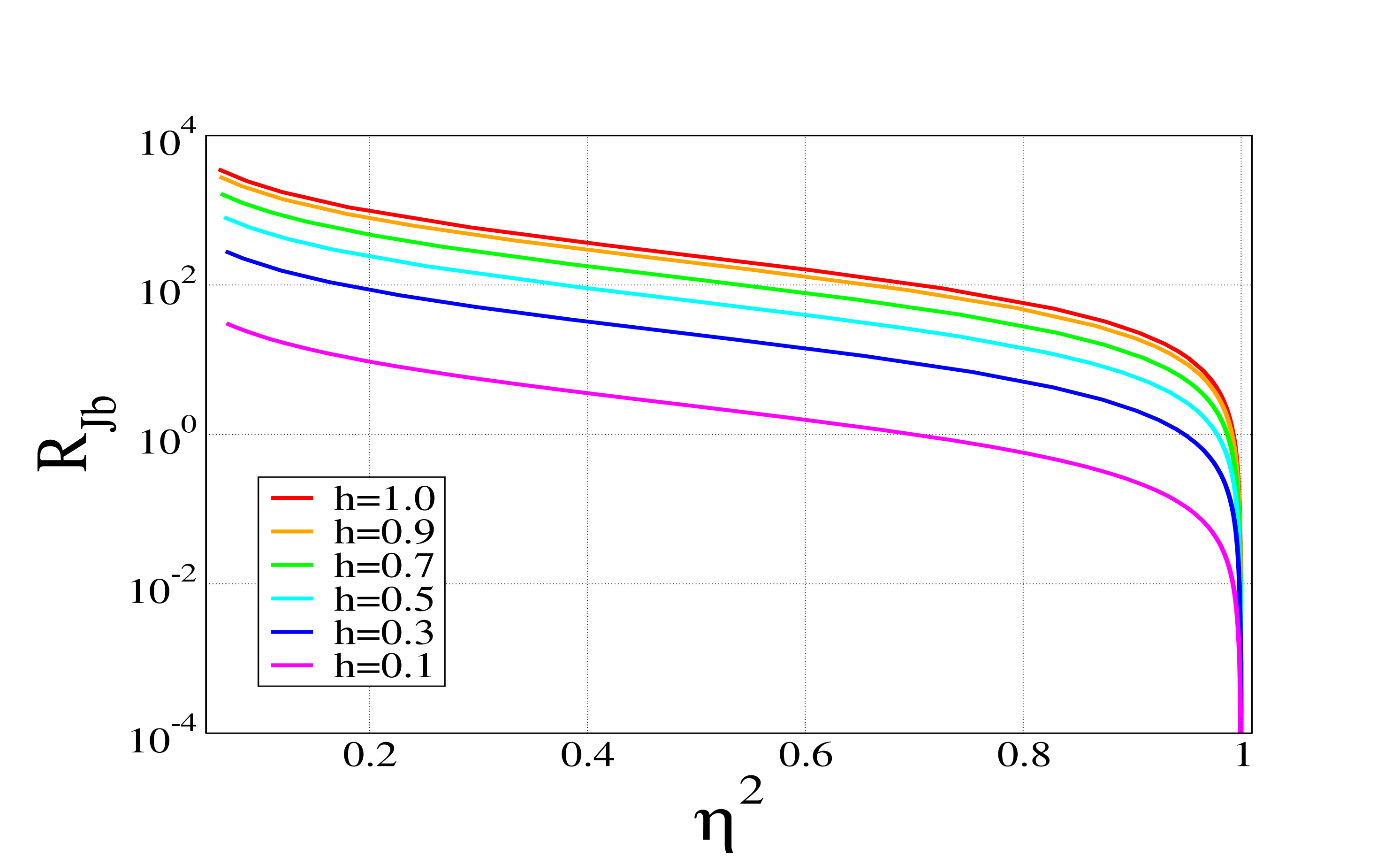


Visible Higgs decay.



Invisible Higgs decay.

Numerical Results (general W)



R_{Jb} as a function of η^2 for all the parameters fixed (SPS1a) except v_R, for different values of h.

Neutrinos vs Lepton Flavour Violation Decays

to be Probed at TESLA

To Gain Insight into the Theoretical Problems of ν Nature:

1. Double Beta Neutrinoless Decay;
2. Massive ν Oscillations: Solar and Atmospheric ν's;
3. Possible Theoretical Interpretations;
4. Dark Matter Candidates: ν's and $\tilde{\chi}_1{}^0$;
5. ν_L flips due to magnetic moment into ν_R;
6. Lepton Flavour Violation Decays in the Charge Lepton Sector;
7. Preliminary: SUSY LFV Signatures Expected at Tesla;
8. Preliminary: A Model Parameter Space to be Probed at Tesla.
9. Aims and preliminary outlines.

DESY, FLC

CERN CERN

SUSY LFV ℓ, $\tilde{\chi}_i^0$ and $\tilde{\chi}_j^{\pm}$ decays and Signatures

The Decays:

1. $e^+e^- \longrightarrow \tilde{e}\tilde{\mu}$
2. $e^+e^- \longrightarrow \tilde{\tau}\tilde{\mu}$
3. $e^+e^- \longrightarrow \tilde{e}\tilde{\tau}$
4. $\tilde{\ell}^i_{L,R} \longrightarrow \ell_j\gamma$
5. $\tilde{\ell}^i_{L,R} \longrightarrow \ell_i\tilde{\chi}^0_1$
6. $\tilde{\chi}_2 \longrightarrow \tilde{\tau}\mu$
7. $\tilde{\tau} \longrightarrow \mu\gamma$

DESY, FLC

Stop Searches at ILC - Status and Critical Rewiew

Hanna Nowak (DESY Zeuthen)

Alex Finch and André Sopczak (Lancaster University)

SPS 5 Stop at 220 GeV

SPS 5 is the only scenario with a light stop

four different methods of mass determination
see Alex's talk at Paris
see also ICHEP'04 contribution 12-0438

all for $e^+e^- \longrightarrow \tilde{t}_1\bar{\tilde{t}}_1 \rightarrow c\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0$
M(stop) = 220.7 GeV and $m_{\chi_1^0} = 120$ GeV with beam polarization

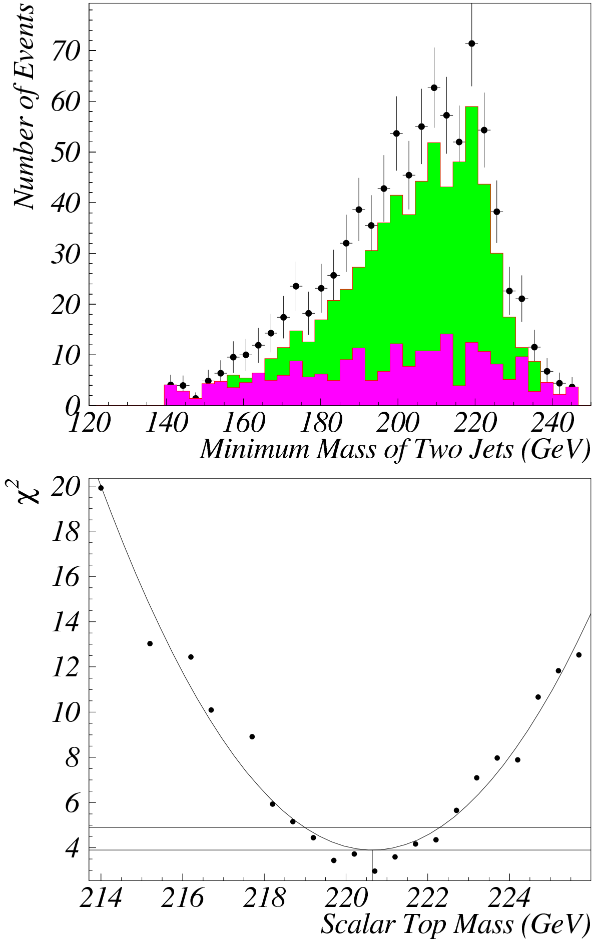
The Analysis in Brief

- 500 fb^{-1} for each polarization state at 500 GeV cms energy
- Detector simulation with SIMDET 4.03
- Thorsten's b/c tagging
- Either IDA selection
- or cut based selection

SPS 5 Stop at 220 GeV

Cut Based Analysis **Minimum Mass Method**

the minimum allowed mass of the two jets peaks at M(stop)



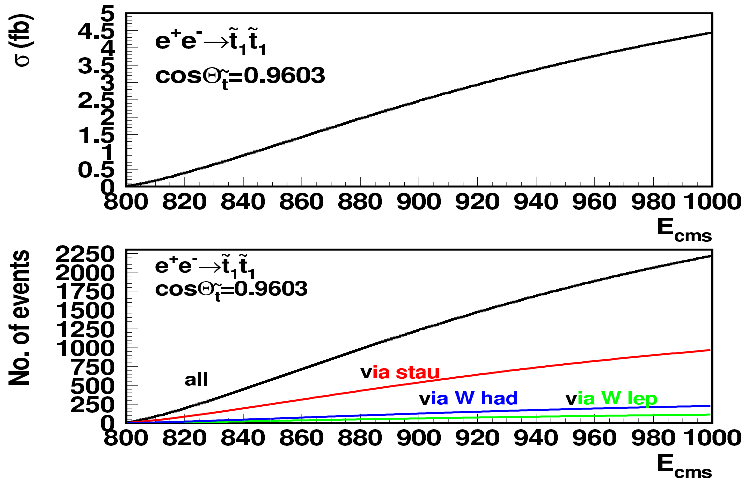
$\Delta M(stop) = 1.5$ **GeV**

SPS1a Stop at 400 GeV

SPA Scenario - high stop mass

needs 1 TeV and more dedicated analysis
- other decay modes and SUSY backgrounds

stop decays via stau or chargino



dependence of the cross section from the stop mass, the mixing angle and no polarization CALVIN32 from the Vienna SUSY group) - study at 1 TeV possible but hard to do

Generation of background and signal just started

Distinguishing between MSSM and NMSSM via combined LHC/LC analyses

– ('work in progress') –

Gudrid Moortgat-Pick (IPPP Durham)

S. Hesselbach, F. Franke, H. Fraas

Susy Session

'ECFA04'@Durham, September 2nd, 2004

- The question:
  → MSSM - NMSSM separation with light particles
  → numerical example (including some exp. errors)
  → assumption: no separation@LC_{500} possible
- The answer:
  → LHC/LC interplay
  → motivation for using LC_{650}
- Conclusions

Our example: mass spectra in MSSM and NMSSM

- We use $M_1 \gg M_2$ – no GUT relation!

	M_1	M_2	$\tan\beta$	μ ($\mu_{eff} = \lambda x$)	κ
NMSSM	360	147	10	457.5	0.2
MSSM	375	152	8	360	–

- derived mass spectra:

	$\tilde{\chi}^{\pm}_1$	$\tilde{\chi}^{\pm}_2$	$\tilde{\chi}^0_1$	$\tilde{\chi}^0_2$	$\tilde{\chi}^0_3$	$\tilde{\chi}^0_4$	$\tilde{\chi}^0_5$
NMSSM	139	474	138	337	367	468	499
MSSM	139	383	138	344	366	410	–

$\Rightarrow$ masses are rather close

$\Rightarrow$ at $\sqrt{s} = 500$ GeV: only $\tilde{\chi}^0_1\tilde{\chi}^0_2$, $\tilde{\chi}^{\pm}_1\tilde{\chi}^{\mp}_1$ pairs can be produced

at $\sqrt{s} = 400$ GeV: only $\tilde{\chi}^{\pm}_1\tilde{\chi}^{\mp}_1$ accessible

$\Rightarrow$ polarised beams and both energies needed to resolve ambiguities and to improve statistics/errors

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How to find a possible inconsistency?

$\Rightarrow$ predict heavier particles and let them find from LHC or ...?

Predictions, consistent with parameter tuples:

$m_{\tilde{\chi}^0_3}$/GeV = [410,730]
$m_{\tilde{\chi}^0_4}$/GeV = [420,800]
$m_{\tilde{\chi}^\pm_2}$/GeV = [420,750]

$\Rightarrow$ all heavier gauginos/higgsinos larger than 410 GeV!

- Could LHC measure the masses and confirm the model?

$\rightarrow$ heavy gauginos reconstructed in decay chains
e.g. via dilepton edges (strongly dependent on $m_{\tilde{\chi}^0_1}$!)
LC input: $m_{\tilde{\chi}^0_1}$ and mass predictions extremely helpful Desch etal'04, Polesello'

- What do we expect here?

$\Rightarrow$ Since $\tilde{\chi}^0_3 \sim 43\%(\tilde{H},\tilde{S})$–like, but $\tilde{\chi}^0_4 > 98\%$ $(\tilde{H},\tilde{S})$–like and even $\tilde{\chi}^0_5 > 93\%$ $(\tilde{H},\tilde{S})$–like

$\rightarrow$ probably only $\tilde{\chi}^0_3$ observable in cascades and perhaps – if lucky – also $\tilde{\chi}^0_5$.

$\Rightarrow$ we assume that $\delta m^{\rm LHC}_{\tilde{\chi}^0_3} \sim 2\%$: $m_{\tilde{\chi}^0_3} = 367 \pm 7$ GeV from LHC$\leftrightarrow$LC!

$\Rightarrow$ obvious contradiction with LC prediction ($m_{\tilde{\chi}^0_3} > 410$ GeV)!

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Motivation for using a further LC option

- use subsequently higher energy but low luminosity LC option: $LC_{650}^{\mathcal{L}=1/3}$

$\rightarrow$ production cross sections [fb] for heavier $\tilde{\chi}_1^0\tilde{\chi}_i^0$ pairs and also $\tilde{\chi}_1^\pm\tilde{\chi}_2^\mp$:

$\sqrt{s} = 650$ GeV	$\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_3^0)$	$\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_4^0)$	$\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_5^0)$
unpolarised	15.1±0.7	6.3±0.4	0.03±0.03
$P(e^-) = -90\%$, $P(e^+) = +60\%$	45.8±1.2	17.1±0.7	0.07±0.05
$P(e^-) = +90\%$, $P(e^+) = -60\%$	0.7±0.1	2.3±0.3	0.009±0.02

$\sqrt{s} = 650$ GeV	$\sigma(e^+e^- \to \tilde{\chi}_1^\pm\tilde{\chi}_2^\mp)$
unpolarised	27.8±0.9
$P(e^-) = -90\%$, $P(e^+) = +60\%$	83.2±1.6
$P(e^-) = +90\%$, $P(e^+) = -60\%$	2.6±0.3

$\rightarrow$ only statistical error given based on $\mathcal{L}/3 = 100/3$ fb^{-1} for each configuration.

$\Rightarrow$ at least $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$ and $\tilde{\chi}_2^\pm$ accessible!
expected: masses (e.g. $m_{\tilde{\chi}_3^0}$!) and rates precisely measureable

$\Rightarrow$ With LHC+$LC_{650}^{\mathcal{L}=1/3}$: strong evidence if deviations from MSSM!
application of more general fits will probably nail down the NMSSM

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Conclusions:
Crucial Synergy of LHC/LC in Susy Searches

- Example for new physics searches/determination where simultaneous running of $LHC+LC_{[1.stage,500,650]}$ may be decisive!

- Here@LC_{500} only: measured observables do not point to NMSSM!
$\rightarrow$ not obvious that the MSSM is the wrong model!

  - Key points:
    LC: analysis of non-coloured light particle sector
    $\rightarrow$ prediction (!) of heavier states ('Telling the LHC, where to look!')
    LHC: prediction leads to increase of statistical sensitivity!
    test of a fixed hypotheses
    $\Rightarrow$ 'Feeding back to LC analysis'

  - Important consistency tests of the new physics (NP) model at an ear stage! $\Rightarrow$ outline for future search analysis strategies

  - $LHC \leftrightarrow LC_{500}$ interplay motivates the use of the low luminosity option $LC_{650}^{\mathcal{L}=1/3}$!