Polarised chargino decays from sneutrino pair production

J. A. Aguilar-Saavedra

Centro de Física Teórica de Partículas (CFTP)
Instituto Superior Técnico, Lisbon

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Introduction

Measurement of spin-related quantities
- spin
- spin analysing power const.
- asymmetries
- ...

often difficult

- Particles sometimes produced with low polarisation
  - ☞ Beam polarisation may help
- Production and decay correlated
  - ☞ Spin direction may depend on poorly measured parameters
- Reconstruction of momenta may not be possible due to undetected final state particles

Study of spins of SUSY particles

SUSY particles at ILC

- Squarks, gluinos $\longrightarrow$ too heavy to be produced?
- Sleptons: scalars $\longrightarrow$ test they are scalars with decay angular distributions
- Neutralinos, charginos $\longrightarrow$ measure decay angular distributions

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Study of spins of SUSY particles

Focus on the lightest observable gauginos

In $e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$ the produced charginos are polarised

[Choi et al., EPJC '99]

Determination of spin-related quantities seems difficult:

- Chargino momenta cannot be determined
- Large background $e^+e^- \to W^+W^- \to \ell^\pm \nu jj$
  (3.5 pb at 500 GeV with $P_{e^+} = 0.6$, $P_{e^-} = -0.8$)

In $e^+e^- \to \tilde{\chi}_2^0 \tilde{\chi}_1^0$ the produced neutralinos are polarised too

[Moortgat-Pick et al., EPJC '99]

but the same problems arise

Another possibility:

If $m_{\tilde{\nu}_e} > m_{\tilde{\chi}_1^+}$, use sneutrino decays as a source of polarised charginos

[JAAS, NPB '05]

This process has the advantage that

- Charginos are 100% polarised
- Spin direction is easy to reconstruct kinematically
- $\tilde{\nu}_e$ pair production gives a multi-fermion final state with a large cross section ☞ small SM backgrounds

Analogously, if $m_{\tilde{e}_L} > m_{\tilde{\chi}_2^0}$, $\tilde{e}_L$ decays yield polarised neutralinos

[JAAS, LC-TH '03]

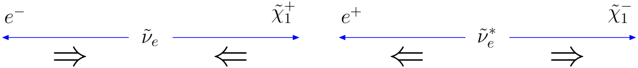
A close look to sneutrino decays

Given by the Lagrangian

$$\mathcal{L}_{\tilde{\nu}_e e \tilde{\chi}_1^-} = -gV_{11}\, \bar{e}\, P_R\, \tilde{\chi}_1^- \; \tilde{\nu}_e - gV_{11}^*\, \overline{\tilde{\chi}_1^-}\, P_L\, e\, \tilde{\nu}_e^*$$

e massless $\Rightarrow$ helicity = chirality

$\tilde{\nu}_e \to e^- \tilde{\chi}_1^+$ $\qquad\qquad$ $\tilde{\nu}_e^* \to e^+ \tilde{\chi}_1^-$



$\tilde{\chi}_1^+ \longrightarrow h = -1$ $\qquad\qquad$ $\tilde{\chi}_1^- \longrightarrow h = 1$

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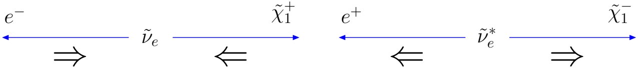

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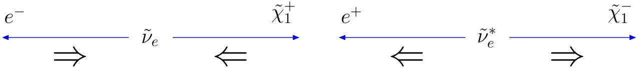

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Sneutrino production and cascade decay

We study the process

See diagrams

$$e^+e^- \to \tilde{\nu}_e^* \tilde{\nu}_e \to e^+ \tilde{\chi}_1^- \, e^- \tilde{\chi}_1^+ \to \left[\begin{array}{l} e^+ \bar{\nu}_\mu \mu^- \tilde{\chi}_1^0 \; e^- q \bar{q}' \tilde{\chi}_1^0 \\ e^+ \bar{q} q' \tilde{\chi}_1^0 \; e^- \nu_\mu \mu^+ \tilde{\chi}_1^0 \end{array} \right.$$

in a SUSY scenario similar to SPS1a with heavier sfermions and complex M_1, μ / $m_{\tilde{\nu}_e} = 252$ GeV, $m_{\tilde{\chi}_1^-} = 178$ GeV

See scenario

Use full $2 \to 8$ resonant matrix elements ☞ Finite width and spin effects included

We consider e^+e^- collisions at an ILC upgrade with 800 GeV with polarised beams $P_{e^+} = 0.6$, $P_{e^-} = -0.8$ and $L = 534$ fb^{-1}

☞ Polarisation not needed but increases cross section

To results

Signal and backgrounds

Signal cross section: 17.56 fb

SUSY backgrounds:

$$e^+e^- \to \tilde{\chi}_1^\pm \tilde{\chi}_2^\mp \to \left[\begin{array}{l} \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp Z \\ \tilde{\chi}_1^\pm \tilde{\chi}_2^0 W^\mp \end{array} \right.$$

$$e^+e^- \to \tilde{\chi}_2^0 \tilde{\chi}_{3,4}^0 \to \chi_2^0 \tilde{\chi}_1^\pm W^\mp$$

with $Z \to e^+e^-$, $\tilde{\chi}_2^0 \to e^+e^-\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ and $W^\mp$ decaying one hadronically and the other leptonically $\longrightarrow$ Total: 0.1 fb

SM background: six-fermion production $e^+e^- \to e^+e^-\mu\nu_\mu q\bar{q}'$

Cross section calculated with `LUSIFER`: 4 fb

☞ Expected to be highly reduced with cuts

To results

Details of the calculation

ISR and beamstrahlung effects are included

We perform a parton-level analysis, with a Gaussian smearing of charged lepton and jet energies

$$\frac{\Delta E^e}{E^e} = \frac{10\%}{\sqrt{E^e}} \oplus 1\% \qquad \frac{\Delta E^j}{E^j} = \frac{50\%}{\sqrt{E^j}} \oplus 4\% \qquad \frac{\Delta E^\mu}{E^\mu} = 0.02\% \, E^\mu$$

Kinematical cuts $p_T \geq 10$ GeV, $|\eta| \leq 2.5$, $\Delta R \geq 0.4$

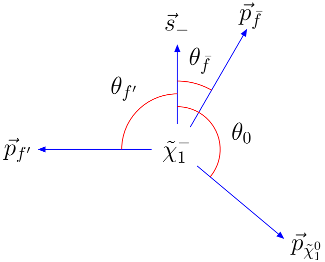
Reconstruct momenta requiring energy-momentum conservation and the kinematics of the two cascade decays

Outcome:

For the hadronic $\tilde{\chi}_1^\pm$ decay $p_{\tilde{\chi}_1^0}$ can be reconstructed

In the leptonic decay only $p_\nu + p_{\tilde{\chi}_1^0}$ can be determined

Description of $\tilde{\chi}_1^-$ decay



$$\Gamma^- \equiv \Gamma(\tilde{\chi}_1^- \to \bar{f} f' \tilde{\chi}_1^0)$$

$$\frac{1}{\Gamma^-} \frac{d\Gamma^-}{d\cos\theta_{\bar{f}}} = \frac{1 + h_{\bar{f}} \cos\theta_{\bar{f}}}{2}$$

$$\frac{1}{\Gamma^-} \frac{d\Gamma^-}{d\cos\theta_{f'}} = \frac{1 + h_{f'} \cos\theta_{f'}}{2}$$

$$\frac{1}{\Gamma^-} \frac{d\Gamma^-}{d\cos\theta_0} = \frac{1 + h_0^- \cos\theta_0}{2}$$

$\bar{f} = \bar{\nu}, \bar{u}, \bar{c}, \quad f' = \mu^-, d, s \quad \vec{s}_-$ is the spin direction

$h_{\bar{f}}, h_{f'}, h_0^-$ constants between -1 and 1

They depend on the scenario parameters and can be calculated

[Djouadi et al., EPJC ’01]

Description of $\tilde{\chi}_1^+$ decay

Angular distributions in $\tilde{\chi}_1^+$ decay given by analogous equations

Determined by constants h_f, $h_{\bar{f}'}$, h_0^+

- If CP is conserved: $h_f = -h_{\bar{f}}, \;\; h_{\bar{f}'} = -h_{f'}, \;\; h_0^+ = -h_0^-$
- If CP is broken, these equalities hold at tree level up to small particle width effects

Determination of angular distributions

Example: $t\bar{t}$ production at LHC

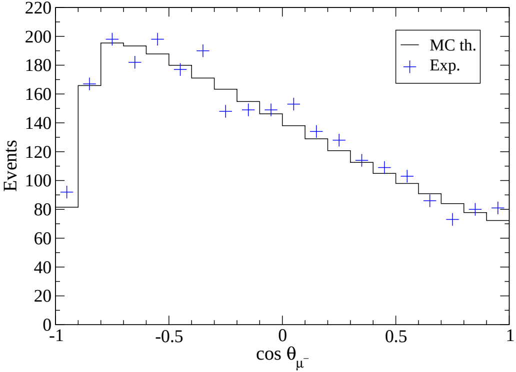
[Hubaut et al., SN-ATLAS '05]
[JAAS et al., ATL-COM in prep.]

- Generate a reference sample of simulated events
- Calculate correction functions F relating theoretical and simulated results
- Apply the correction functions to a second sample

Here:

- Generate a "possible experimental result" according to the expected distribution (using Poisson statistics)
- Calculate h considering only the regions where $F = 1$

Distribution of μ^-



Fit: $h_{\mu^-} = -0.270 \pm 0.016$

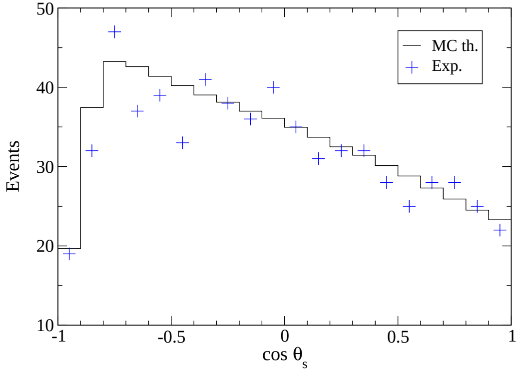
Th: $h_{\mu^-} = -0.252$

Fit performed excluding bins with $\cos\theta_{\mu^-} \simeq -1$

Inclusion of $\tilde{\chi}_1^+ \to \nu_\mu \mu^+ \tilde{\chi}_1^0$ decays would improve statistics

Systematics $\lesssim 5\%$?

Distribution of s quark



Fit: $h_s = -0.151 \pm 0.020$

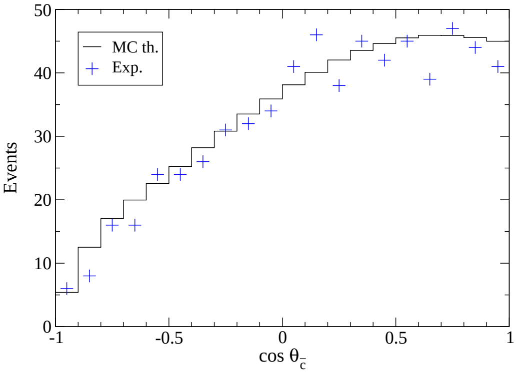
Th: $h_s = -0.149$

Jets distinguished using c tagging and μ charge $\rightarrow$ σ reduced by a factor of 4

Fit performed excluding bins with $\cos\theta_{\mu^-} \simeq -1$

Inclusion of $\tilde{\chi}_1^+ \rightarrow c\bar{s}\tilde{\chi}_1^0$ decays would improve statistics

Distribution of c antiquark



Fit: $h_{\bar{c}} = 0.387 \pm 0.044$

Th: $h_{\bar{c}} = 0.339$

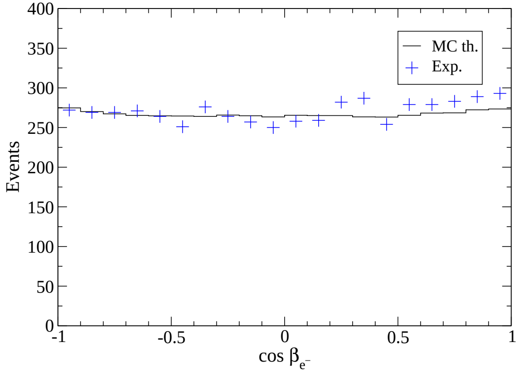
Jets distinguished using c tagging and μ charge $\rightarrow$ σ reduced by a factor of 4

Fit performed excluding bins with $\cos\theta_{\mu^-} \simeq -1, 1$

Inclusion of $\tilde{\chi}_1^+ \rightarrow c\bar{s}\tilde{\chi}_1^0$ decays would improve statistics

Skip e^-

Distribution of e^-



$\beta_{e^-} \longrightarrow$ angle with respect to an arbitrary axis orthogonal to the beam line

Flat distribution indicates that $\tilde{\nu}_e$ is scalar and $\tilde{\chi}_1^+$ has half-integer spin

CP violation in $\tilde{\chi}_1^\pm$ decays

Define triple product

$$Q_{12} = \vec{s}_\pm \cdot (\vec{p}_{\bar{q}_1} \times \vec{p}_{q_2})$$

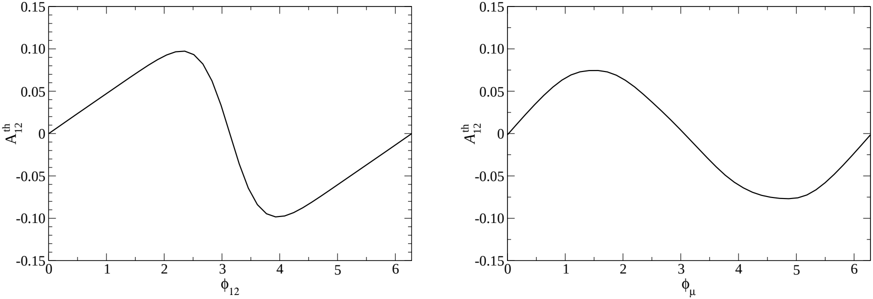
$s_\pm \longrightarrow$ spin of $\tilde{\chi}_1^\pm$
$p_{\bar{q}_1} \longrightarrow$ momentum of $\bar{q}_1 = \bar{c}, \bar{s}$
$p_{q_2} \longrightarrow$ momentum of $q_2 = s, c$

Define the T-odd, CP-odd asymmetry

$$A_{12} = \frac{N(Q_{12} > 0) - N(Q_{12} < 0)}{N(Q_{12} > 0) + N(Q_{12} < 0)}$$

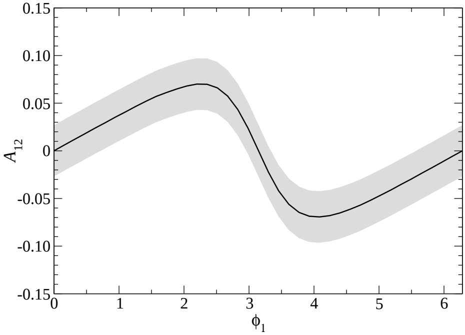
Skip Th.

Theoretical value of the CP asymmetry



Dependence on ϕ_μ non-negligible for ϕ_μ values required by electron EDM

CP asymmetry after reconstruction



- ISR, beamstrahlung and energy smearing corrections included
- Asymmetry reduced by a factor ~ 0.7 with respect to theoretical value
- Gray band represents statistical error in one year
- Maximum significance: $2.6\,\sigma$

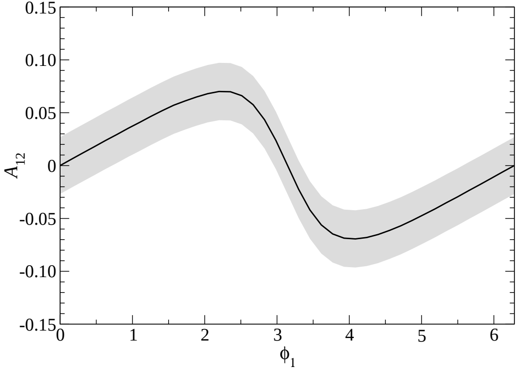
Comparison with other processes

Other CP asymmetries sensitive to ϕ_1

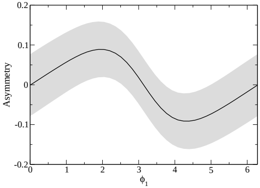
- Triple-product asymmetry in $e^+e^- \to \tilde{\chi}_2^0 \tilde{\chi}_1^0 \to \ell^+\ell^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$ at 500 GeV [Bartl et al., JHEP '04] [JAAS, NPB '04]
- Triple-product asymmetry in selectron cascade decays $\tilde{e}_L \to e\tilde{\chi}_2^0 \to e\mu^+\mu^-\tilde{\chi}_1^0$ at 800 GeV [JAAS, PLB '04]
- Triple-product asymmetry in chargino production [Bartl et al., PLB '04]
- Azimuthal asymmetries with transversely polarised beams [Bartl et al., '05]

We compare with the first two, using the same SUSY scenario and one year of integrated luminosity

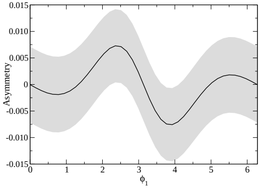
Comparison with other processes



$\tilde{\nu}_e$ cascade decays: $2.6\,\sigma$



$\tilde{e}_L$ decays: $1.3\,\sigma$



$\tilde{\chi}_2^0 \tilde{\chi}_1^0$ production: $1.1\,\sigma$

Summary

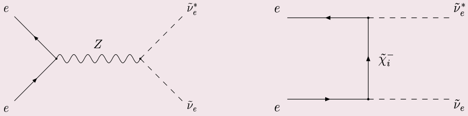
- If kinematically allowed, decays $\tilde{\nu}_e \to e^- \tilde{\chi}_1^+$, $\tilde{\nu}_e^* \to e^+ \tilde{\chi}_1^-$ constitute a source of polarised charginos
- $\tilde{\nu}_e \tilde{\nu}_e^*$ production has a large cross section at ILC, and their decays to charginos yield a multi-fermion final state with small backgrounds
- The kinematics of the process allows for the reconstruction of sneutrino and chargino momenta, and thus the analysis of decay angular distributions in their rest frames

Summary

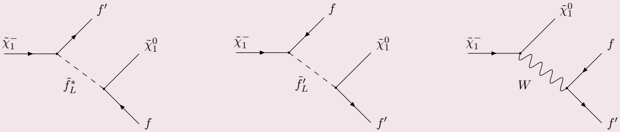
- In chargino decays, the spin analysing power of their decay products can be determined with a relatively good precision (6% for μ)
- A triple-product CP asymmetry can also be built relating $\tilde{\chi}_1^+$ and $\tilde{\chi}_1^-$ decays
- In the SUSY scenario considered, this asymmetry is two times more sensitive to CP-violating phases in the neutralino sector than analogous asymmetries in $\tilde{\chi}_2^0 \tilde{\chi}_1^0$ production in $\tilde{e}_L$ cascade decays

Feynman diagrams

Sneutrino pair production



Chargino decay



Scenario used: decay is three-body but dominated by W exchange

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SUSY scenario

RGE evolution, masses and mixings calculated with SPheno

M_1	$102.0 \;\; e^{i\phi_1}$ GeV
M_2	192.0 GeV
μ	$377.5 \;\; e^{i\phi_\mu}$ GeV
$\tan\beta$	10
$m_{\tilde{\nu}_e}$	252.4 GeV
$m_{\tilde{\mu}_L}$	264.5 GeV
$m_{\tilde{u}_L}, m_{\tilde{c}_L}$	571.5 GeV
$m_{\tilde{d}_L}, m_{\tilde{s}_L}$	577.0 GeV

For $\phi_1 = \phi_\mu = 0$ they correspond to

$$m_{1/2} = 250 \text{ GeV}$$
$$m_{\tilde{E}} = m_{\tilde{L}} = m_{H_i} = 200 \text{ GeV}$$
$$A_E = -200 \text{ GeV}$$

$$m_{\tilde{\chi}_1^0} \simeq 99 \text{ GeV}, \quad m_{\tilde{\chi}_1^-} \simeq 178 \text{ GeV}, \quad m_{\tilde{\chi}_2^-} \simeq 401 \text{ GeV}$$

Back More

(ϕ_1, ϕ_μ) values compatible with the electron EDM

ϕ_1	ϕ_μ	ϕ_1	ϕ_μ
0	0	π	0
$\pi/8$	-0.0476	$7\pi/8$	-0.0454
$\pi/4$	-0.0876	$3\pi/4$	-0.0845
$3\pi/8$	-0.1136	$5\pi/8$	-0.1114
$\pi/2$	-0.1218		

plus $(\phi_1, \phi_\mu) \rightarrow (-\phi_1, -\phi_\mu)$

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