Single-Electron signal from Anomaly Mediated Supersymmetry Breaking at a future Linear Collider

Dilip Kumar Ghosh*
Department of Physics, National Taiwan University, Taipei
Stefano Moretti†
CERN Theory Division‡
Graham W. Wilson§
Department of Physics and Astronomy, University of Kansas, Lawrence

We study the pair production of sleptons (both neutral and charged) at a next generation Linear Collider (LC) in the Anomaly Mediated Supersymmetry Breaking Model. The main signal analysed is one charged electron or positron and large missing energy.

1. Introduction

Understanding how Supersymmetry (SUSY) breaks in the real world from a deeper, more fundamental standpoint is a major challenge in theoretical high energy physics today. An interesting recent idea in this direction has been that of Anomaly Mediated SUSY Breaking (AMSB) [1] – [15].

AMSB occurs when, in a higher dimension, one has a Supergravity theory defined on two separated parallel 3-branes (3+1 dimensional subspaces) in a way that the Standard Model (SM) particles are localized on one of these while the SUSY breaking sector is localized on the other. There are no tree-level couplings between these two branes. Gravity propagates in the bulk and the breakdown of SUSY is communicated from the hidden sector to the visible one through the loop-induced super-Weyl anomaly. In the absence of tree-level interactions between the two 3-branes, this is the dominant contribution to the soft SUSY breaking parameters. All the masses (of gauginos and scalars) generated through this mechanism are proportional to the corresponding gauge coupling strengths. In fact, these masses become renormalization group invariant with slepton becoming tachyonic. The latter fact is the most severe problem in the AMSB scenario and there are several proposals in the literature to solve it. We shall focus here on the minimal [1] model of AMSB where the problem of tachyonic sleptons is tackled by adding a universal constant term m_0^2 to the expressions for squared scalar masses, *i.e.*, m_0^2 contributes equally to the squared masses of all scalars present in the theory. One can now solve the tachyonic slepton problem through a suitably chosen m_0^2 making all squared slepton masses positive, the scale invariance of the expressions for scalar masses being lost. The evolution of scalar masses governed by the corresponding Renormalization Group Equations (RGEs), starting from a very high energy scale, must therefore be taken into account. However, except for the addition of an extra parameter, this is quite a feasible procedure.

This model is characterized by several distinct features with important phenomenological consequences: a rather massive gravitino ($\sim$ a few TeV) and nearly mass-degenerate left and right selectrons and smuons, while the staus split into two distinct mass eigenstates with the $\tilde{\tau}_1$ being the lightest charged slepton. Most importantly, the model has gaugino masses proportional to the β-functions of the gauge couplings. The latter lead to the existence of a neutral near-Wino as the Lightest Supersymmetric Particle (LSP) $\tilde{\chi}_1^0$ and closely mass-degenerate with it a pair of charged near-Winos as the lighter charginos $\tilde{\chi}_1^{\pm}$. A tiny mass difference ΔM (< 1 GeV) arises between them from loop corrections and a weak gaugino-higgsino mixing at the tree level. Because of the

*dghosh@phys.ntu.edu.tw
†stefano.moretti@cern.ch
‡Institute for Particle Physics Phenomenology, University of Durham, UK
§graham@fnal.gov

small magnitude of ΔM, $\tilde{\chi}_1^{\pm}$, if produced in a detector, will be long-lived. Such a chargino then is likely to produce [16] a displaced vertex X_D and/or a characteristic soft pion from the decay $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 + \pi^{\pm}$.

2. Example AMSB signal at a future LC

As discussed above, we see that specific AMSB models can often lead to the lighter chargino having a distinctive experimental signature, despite, or rather because of the small mass difference. If such additional signatures would occur, experimental detection of an extremely clean signal with negligible background should be trivial. However the exact signature and how it will be detected will depend crucially on the lifetime and details of the experimental apparatus.

In order to focus our efforts on some channels which will lead to useful conclusions beyond the narrow confines of AMSB, we have chosen to take a more inclusive approach to the detection of SUSY. In a worst-case scenario, the chargino may have too short a lifetime to be experimentally resolvable and the resulting soft pion may not be easily distinguished from overlapping gamma-gamma events. In this context, the most promising approach to detection of AMSB would be slepton production. In particular, given the couplings of $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^{\pm}$, the selectron and sneutrino rates can be enhanced significantly from t-channel exchanges. Put it another way, this means that slepton production (particularly with polarised beams) can test directly the W-ino nature of these particles.

There have been previous studies of di-electron signals from selectron pair production within mSUGRA models. In this contribution we have chosen to focus on the complementary "single-electron" experimental topology of one detected electron or positron with significant missing energy. In the AMSB model, $\tilde{\nu}_e\tilde{\nu}_e$, $\tilde{e}_L\tilde{e}_L$ and $\tilde{e}_R\tilde{e}_L$ production can all lead to significant cross-sections for the final state $e\nu\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$ which, if the chargino goes undetected, leads to a single electron and missing energy. In order to measure the relevant production cross-sections and branching ratios, it will be necessary to measure and constrain all decay modes, making the measurement of this major topological cross-section mandatory.

The main source of SM background to the single-electron topology is from the process $e^-e^+ \to e^-e^+\nu_e\overline{\nu_e}$. This process includes many different Feynman diagrams - not just from W$e\nu$, but also Zee, Z $\nu\overline{\nu}$, ZZ and WW. The background rates including also the experimentally indistinguishable contributions from $e^-e^+ \to e^-e^+\nu_\mu\overline{\nu_\mu}$ and $e^-e^+ \to e^-e^+\nu_\tau\overline{\nu_\tau}$, have been estimated by running WPHACT [17] with the single-electron acceptance cuts detailed in section IIIA. The energy and charge-signed angular distributions are shown in Figure 1. The cross-sections are summarised in Table I. We are surprised that the RR cross-section is so large - and studies continue to gain some insight.

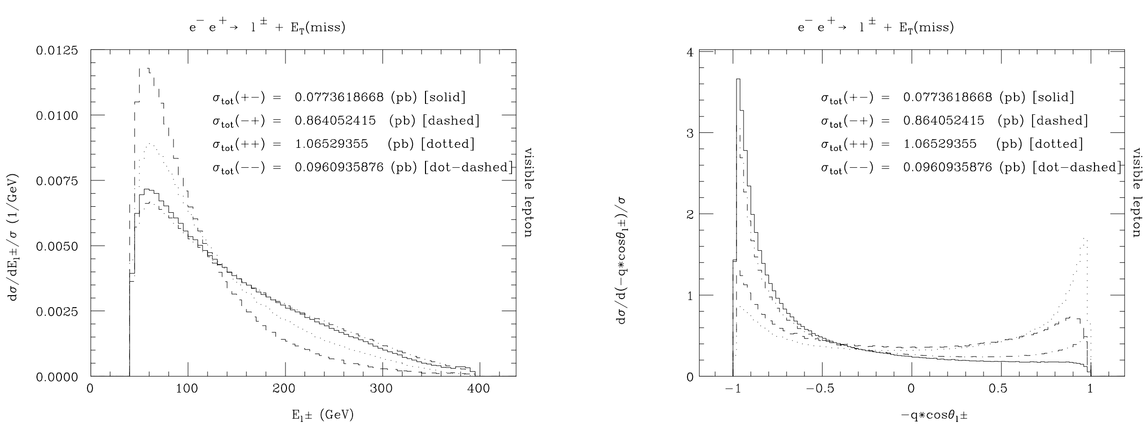

Figure 1: The energy and $q\cos\theta$ distributions (where q is the electromagnetic charge of the lepton) are shown for pure LR $(-+)$, RL $(+-)$, LL $(--)$, RR $(++)$ for the calculated SM processes.

Consequently, the cross-sections for various possible polarisation options are given in Table II.

Signal rates for AMSB SUSY parameters of $m_0 = 360$ GeV, $m_{3/2} = 48$ TeV, $\tan\beta = 7.5$ and $\mu > 0$ have been evaluated with ISAJET 7.58 [18]. The parameters were chosen to be on a line similar to

Table I Accepted cross-sections in fb calculated with WPHACT for $e^- e^+ \to e^- e^+ \nu_\ell \overline{\nu}_\ell$ with $\ell = e, \mu$.

$e^-_L e^+_R$	864
$e^-_R e^+_L$	77.4
$e^-_L e^+_L$	96.1
$e^-_R e^+_R$	1065

Table II Accepted cross-sections in fb for various "feasible" polarisation configurations assuming electron polarisation of 80% and positron polarisation of 60%.

unpolarised	526
L (80% e^- pol. only)	489
R (80 % e^- pol. only)	562
LR	726
RL	272
LL	252
RR	852

model line G of Ref. [19] and within the reach of a 800 GeV LC. Events were generated including initial state radiation and beamstrahlung based on the TESLA parameters. Four samples were produced each of 100 fb^{-1} with the four different possible helicity combinations using electrons with a polarisation of 80% and positrons with a polarisation of 60%. All slepton-pair production processes were generated.

3. Case Study Details

3.1. Cuts

Single-electron candidates were defined as follows:

- At least one electron or positron with $|\cos\theta| < 0.99$ and transverse momentum above 40 GeV.
- No additional electron or positron with energy exceeding 20 GeV detected at polar angles above 30 mrad.
- Energy of all other stable detectable particles with $|\cos\theta| < 0.99$ less than 20 GeV.

Di-electron candidates were defined in a similar but orthogonal manner.

3.2. Model Details

The masses of sparticles relevant to this study are given in Table III. The important branching ratios are:

- $\tilde{\nu}_e \to e\tilde{\chi}^{\pm}_1$: 66.9 %;
- $\tilde{\nu}_e \to \nu\tilde{\chi}^{0}_1$: 33.1 %;
- $\tilde{e}_R \to e\tilde{\chi}^{0}_1$: 99.9 %;
- $\tilde{e}_L \to e\tilde{\chi}^{0}_1$: 33.7 %;
- $\tilde{e}_L \to \nu\tilde{\chi}^{\pm}_1$: 66.3 %;
- $\tilde{\chi}^{0}_2 \to$ sleptons: 99 %.

Table III SUSY masses in GeV.

$\tilde{\chi}_1^0$	141.78
$\tilde{\chi}_1^\pm$	141.95
$\tilde{\chi}_2^0$	437
$\tilde{\nu}_e$	295
$\tilde{e}_R$	295
$\tilde{e}_L$	305
$\tilde{\nu}_\tau$	291
$\tilde{\tau}_1$	279
$\tilde{\tau}_2$	309

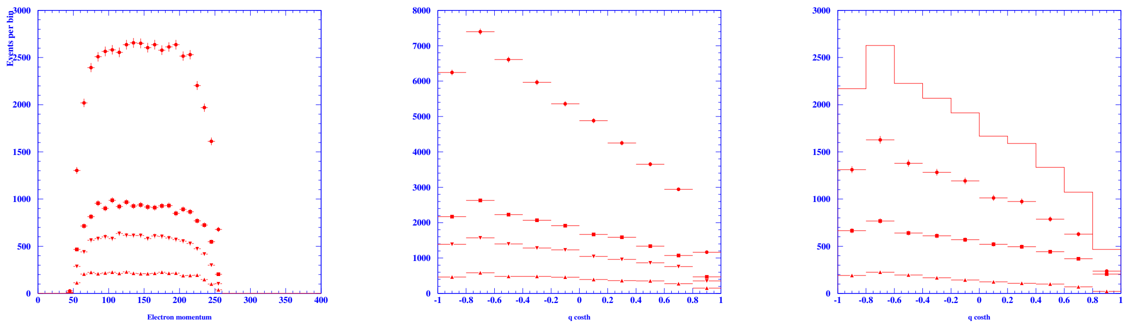

Figure 2: The energy and $q\cos\theta$ distributions are shown for single-electrons for LR (dots), RL (up-triangles), LL (squares), RR (down-triangles). Separately we show the $q\cos\theta$ distribution for LL with the individual contributions from $\tilde{\nu}_e\tilde{\nu}_e$ (dots), $\tilde{e}_L\tilde{e}_L$ (triangles) and $\tilde{e}_L\tilde{e}_R$ (squares).

Table IV Accepted single electron cross-sections in fb from slepton production for the four possible beam polarisation configurations assuming 80% electron polarisation and 60% positron polarisation.

Channel	(e^-e^+) LR	RL	LL	RR
$\tilde{\nu}_e\tilde{\nu}_e$	414	14.9	104	47.2
$\tilde{e}_R\tilde{e}_R$	-	-	-	-
$\tilde{e}_L\tilde{e}_L$	49.6	3.5	13.4	5.8
$\tilde{e}_L\tilde{e}_R$	19.2	19.9	52.8	55.0
$\tilde{X}_\tau\tilde{X}_\tau$	2.0	1.7	0.8	0.6
Total	485	40.0	171	109

The accepted cross-sections for each topology and for each beam polarisation combination and for each sparticle-pair are shown in Tables IV–V. Distributions of the energy and charge-signed angular distribution are shown in Figure 2.

In the single-electron topology, the residual background from stau and tau sneutrino processes (denoted $\tilde{X}_\tau\tilde{X}_\tau$) is about 1 fb. Associated neutralino-pair production leads to a background of about 2 fb (estimated for unpolarised beams).

One can see that the single-electron signal cross-section is greatest for the LR beam polarisation combination and in this case leads to a prolific 500 fb cross-section, most of it arising from $\tilde{\nu}_e\tilde{\nu}_e$ production.

3.3. Observations

For the example model point chosen, the single-electron signal from sleptons will be seen clearly as a box-like energy distribution on top of a falling background. However, due to the high level of mass degeneracy of the various sleptons, it will be difficult to separate the individual contributions.

Table V Accepted di-electron plus missing p_T cross-sections in fb from slepton production for the four possible beam polarisation configurations assuming 80% electron polarisation and 60% positron polarisation.

Channel	(e^-e^+) LR	RL	LL	RR
$\tilde{\nu}_e\tilde{\nu}_e$	428	15.1	106	48.7
$\tilde{e}_R\tilde{e}_R$	6.3	10.8	2.6	3.2
$\tilde{e}_L\tilde{e}_L$	13.3	0.8	3.1	1.4
$\tilde{e}_L\tilde{e}_R$	9.3	10.5	27.8	28.0
$\tilde{X}_\tau\tilde{X}_\tau$	0.3	0.2	0.1	0.1
Total	457	37.4	140	81.4

Polarisation offers some help. It should be possible to enhance $\tilde{e}_L\tilde{e}_R$ by choosing the LL configuration while taking advantage of a reduced SM background. However, as might be expected, it doesn't offer a silver bullet for separating $\tilde{\nu}_e\tilde{\nu}_e$ from $\tilde{e}_L\tilde{e}_L$. The angular distributions show some differences among processes, but not enough to offer substantial discrimination.

Information from threshold scans and using different initial beams e^-e^-, $e^-\gamma$ and $\gamma\gamma$ may provide better and more complete ways of measuring all the relevant observables.

Identification of the charged pion from the chargino decay will help to separate di-electrons from selectron production from those from $\tilde{\nu}_e\tilde{\nu}_e$ production.

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