Chargino and Neutralino Masses at ILC

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Introduction

- Physics Process: (SUSY point 5 in ILC Benchmarking processes)

  $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 q\bar{q}q\bar{q}$

  $e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 Z^0Z^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 q\bar{q}q\bar{q}$

parameter	value
m_0	206 GeV
$m_{1/2}$	293 GeV
$\tan\beta$	10
A	0
μ	375 GeV
$M_{\tilde{\chi}_1^0}$	115.7 GeV
$M_{\tilde{\chi}_1^\pm}$	216.5 GeV
$M_{\tilde{\chi}_2^0}$	216.7 GeV

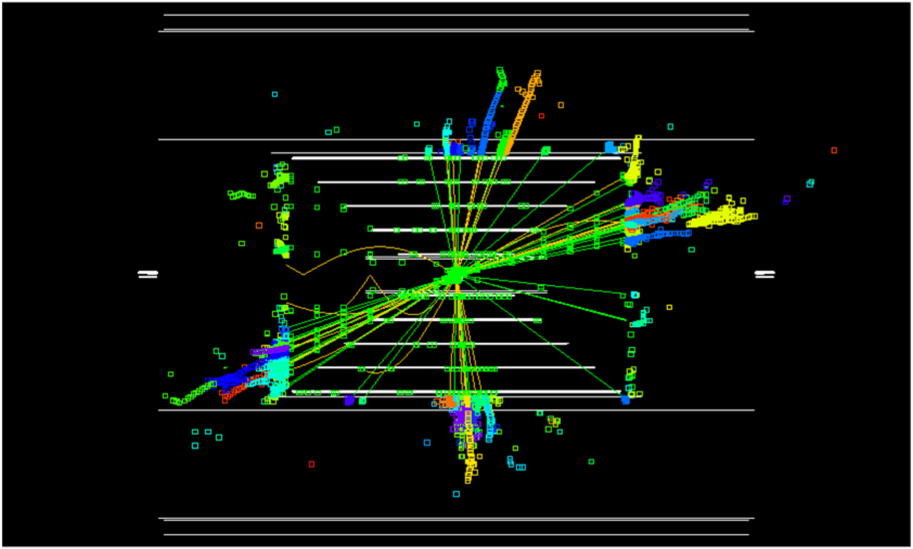
- $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ decay into on-shell W/Z dominantly
- Cross-section not too small:

  $\tilde{\chi}_1^+\tilde{\chi}_1^- \sim 100fb$, $\tilde{\chi}_2^0\tilde{\chi}_2^0 \sim 10fb$
- The gauge boson energy depends on the parent and LSP mass

  $\Rightarrow$ Precision measurement of SUSY parameters

- Signature: 4 jets (from 2 acoplanar W/Z) + missing energy
  - WW/ZZ separation
  - For SiD: good PFA performance required

$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 s\bar{s}d\bar{d}$



Samples

- All samples are generated using SiD full detector simulation
- SUSY samples:
  - $\sqrt{s} = 500GeV$, $500fb^{-1}$ luminosity, $\sim 1.2M$ events/sample
  - Polarization: $80\% e^-$ L, $30\% e^+$ R
  - Backgrounds: $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0$, slepton pair production
  - Standard template and mass-shifted templates:

Template	$M_{\tilde{\chi}_1^0}$ (GeV)	$M_{\tilde{\chi}_1^\pm}$ (GeV)	$M_{\tilde{\chi}_2^0}$ (GeV)
standard	115.7	216.7	216.6
$\tilde{\chi}_1^0 + \Delta M$	115.7 + ΔM		
$\tilde{\chi}_1^\pm + \Delta M$	115.7	216.7 + ΔM	216.6
$\tilde{\chi}_2^0 + \Delta M$	115.7	216.7	216.6 + ΔM

$\Delta M = -0.5/0.5/2GeV$

- Inclusive SM background: $500GeV$, $\sim 4.7M$ events

Signal selection

cut	value
Total visible energy	< 250 GeV
Number of tracks	> 20
Thrust	< 0.85
$\cos\theta_{thrust}$	< 0.9
E_{jet}	< 10 GeV
Fraction of EM energy in each jet	$< 80\%$
lepton energy in jet 1	< 40 GeV
lepton energy in jet 2	< 40 GeV
lepton energy in jet 3	< 30 GeV
lepton energy in jet 4	< 20 GeV
$\theta(1, 2)$	$> 60^\circ$
$\theta(1, 3)$, $\theta(1, 4)$, $\theta(1, 3)$	$> 40^\circ$
$\theta(2, 4)$, $\theta(3, 4)$	$> 20^\circ$
Acoplanarity of two reconstructed gauge bosons	$> 10^\circ$

Before $\tilde{\chi}_1^+\tilde{\chi}_1^-$ / $\tilde{\chi}_2^0\tilde{\chi}_2^0$ separation:

	$\tilde{\chi}_1^+\tilde{\chi}_1^-$ signal	$\tilde{\chi}_2^0\tilde{\chi}_2^0$ signal	SM background
Efficiency	60.1%	59.3%	0.0004%
Composition	36.7%	6.9%	53.5%

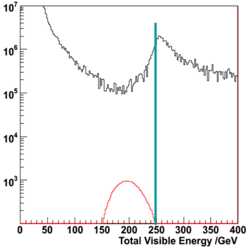


Figure: Total visible energy

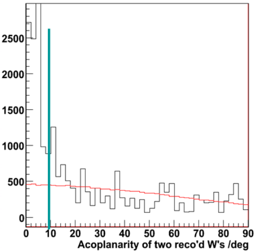
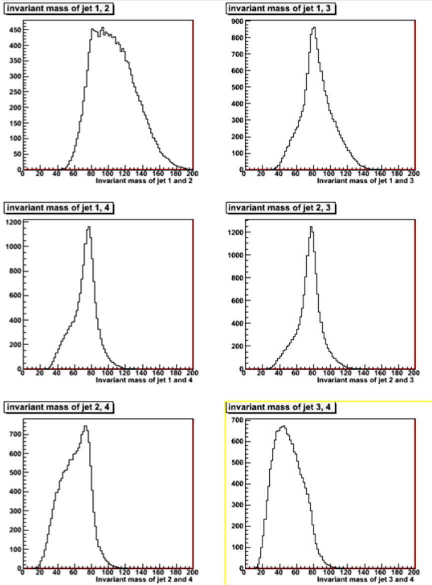


Figure: Acoplanarity between 2 W's

W/Z Reconstruction - Jet Pairing



- $\tilde{\chi}_1^+\tilde{\chi}_1^- / \tilde{\chi}_2^0\tilde{\chi}_2^0$ signal separation is based on two reconstructed boson masses
- Need to pair jets correctly
- Jet pairing optimization: Choose the combination minimizing:

  $$(M_{i,j} - M_W)^2 + (M_{m,n} - M_W)^2$$

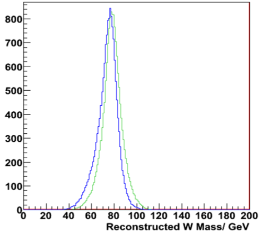
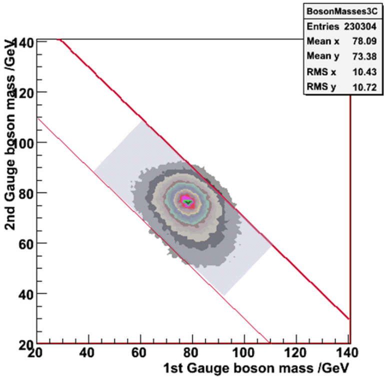
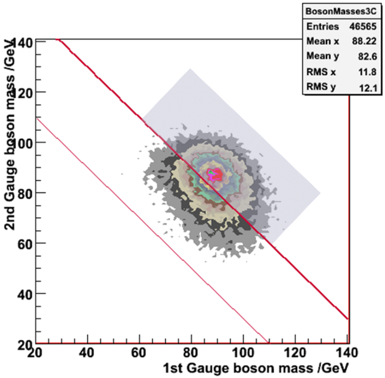


Figure: Green: Reconstructed mass of the 1st W; Blue: Reconstructed mass of the 2nd W.

Chargino/Neutralino Event Separation

Correlation of two di-jet masses is a powerful selection criteria





$\tilde{\chi}_1^+\tilde{\chi}_1^-$ event signal:

$130GeV < M_{W_1} + M_{W_2} < 172GeV$

$\tilde{\chi}_2^0\tilde{\chi}_2^0$ event signal:

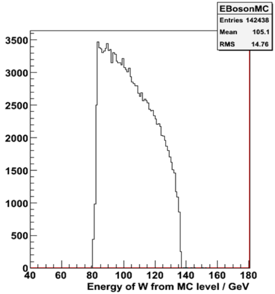
$M_{W_1} + M_{W_2} > 172GeV$

Chargino/Neutralino Mass - Strategy

- For $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 + W^\pm$, in $\tilde{\chi}_1^\pm$ rest frame, the W is monochromatic

$$E_{W^\pm} = \frac{|M^2_{\tilde{\chi}_1^\pm} + M^2_{W^\pm} + M^2_{\tilde{\chi}_1^0}|}{2M_{\tilde{\chi}_1^\pm}}$$

- In lab frame the W energy is boosted but still depends on the chargino mass
- The same arguments applies for $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + Z$
- Therefore we can extract the chargino/ neutralino mass by comparing the W/Z energy spectrum with the MC templates



Kinematic Fitting

- Kinematic fitting with one constraint $M_{W/Z,1} = M_{W/Z,2}$ helps to improve the boson energy distribution
- Kinfit in Marlinreco package is used
- Fitting parameters:
  $dE = 50\%/\sqrt{E}$, $d\theta = 0.1rad$, $d\phi = 0.1rad$

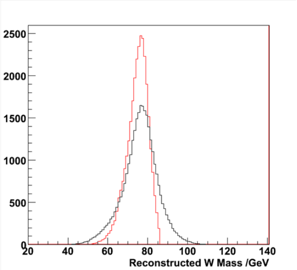


Figure: Reconstructed W mass

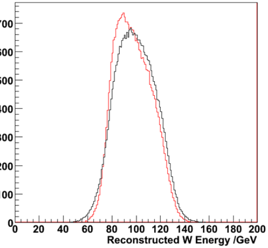
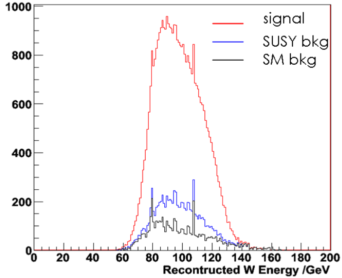


Figure: Reconstructed W energy

Chargino selection: **Before/After** Kinfit

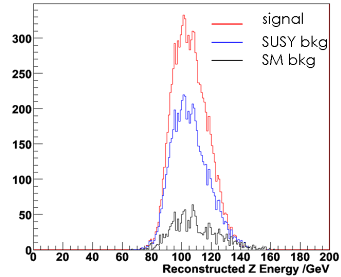
Boson Energy Spectrum

$\tilde{\chi}_1^+\tilde{\chi}_1^-$ seclection:



Purity	75.3%
Efficiency	53.8%
X-section error	0.9%

$\tilde{\chi}_2^0\tilde{\chi}_2^0$ seclection:



Purity	33.7%
Efficiency	30.2%
X-section error	4.2%

Mass Uncertainty - Template Fitting

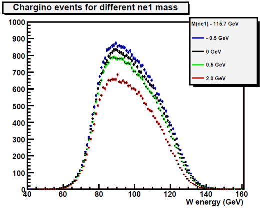


Figure: W energy for different $\tilde{\chi}_1^0$ mass. (SM background not included)

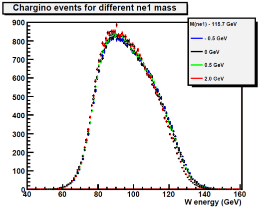


Figure: W energy for different $\tilde{\chi}_1^0$ mass, normalized to the same cross-section

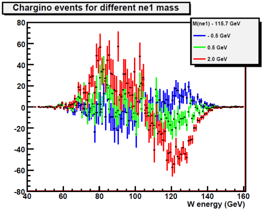
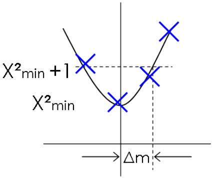


Figure: Difference of shape for normalized W energy spectrum w.r.t $\tilde{\chi}_1^0$ mass

$$\chi_1^2 = \sum_{i=0}^{Nbins} \frac{(y_{template1,i} - y_{data,i} + \delta)^2}{\sigma^2_{template1,i} + \sigma^2_{data,i} + \sigma^2_{SM,i}}$$



Mass Uncertainty (Cont.)

- Mass uncertainty results:

$\tilde{\chi}_1^+\tilde{\chi}_1^-$	
$\tilde{\chi}_1^\pm$	472 MeV
$\tilde{\chi}_1^0$	156 MeV
$\tilde{\chi}_2^0\tilde{\chi}_2^0$	
$\tilde{\chi}_2^0$	$\gtrsim 2 GeV$
$\tilde{\chi}_1^0$	279 MeV

- Stable results against binning
- High precision $< 0.5 GeV$ in general

  ... *except for* $\tilde{\chi}_2^0$ *?*
  - The number would be 406 MeV using cross section information!
  - Efficiency info also available
  - Need a template with larger mass shift - ΔM=6 GeV sample is being produced

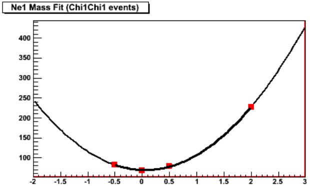


Figure: Chi-square fit for templates with different $\tilde{\chi}_1^0$ masses.

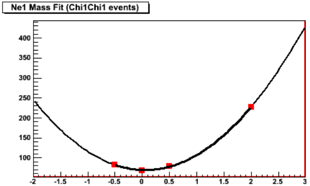


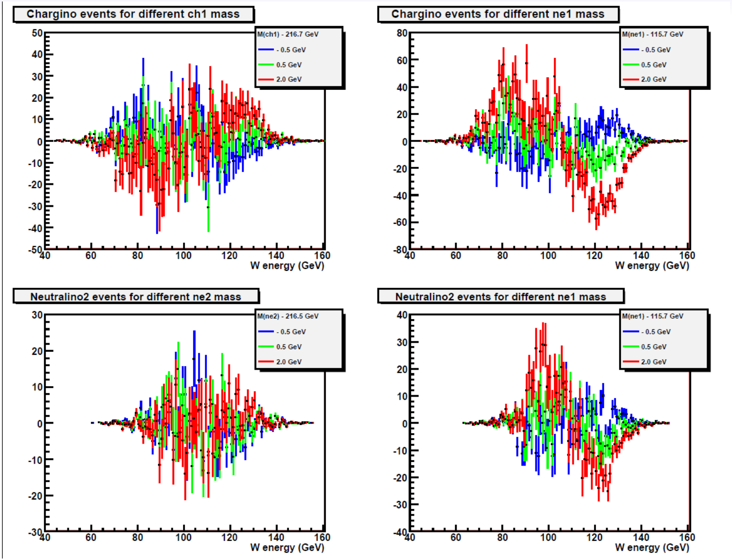
Figure: Same as above, except for χ^2 calculated with histograms rebinned by 5.

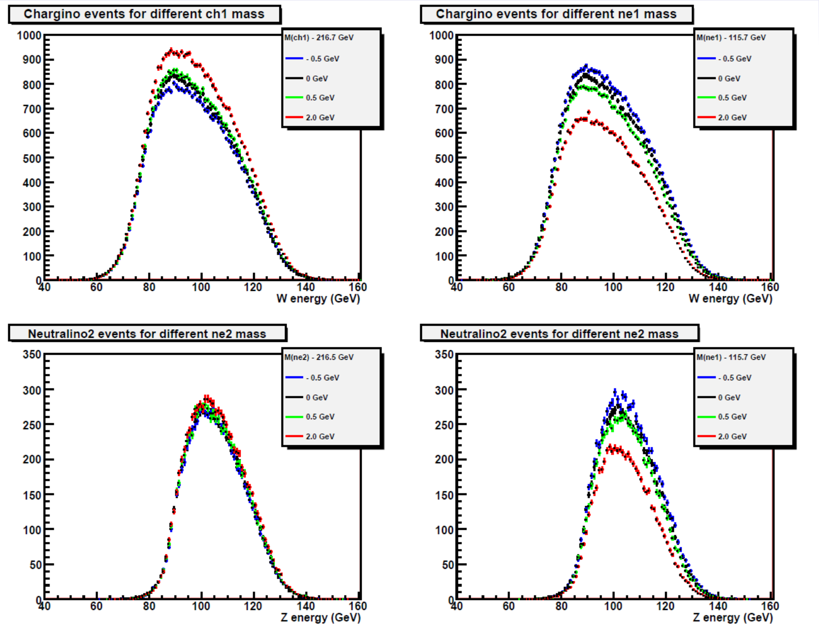
Summary

- Chargino/neutralino events can be identified at the presence of SM background, and separated from each other
- The cross-section uncertainty of chargino/neutralino signals are 0.9%/4.2%
- The statistical error of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ mass is within 500 MeV using template fitting method.

More details on this analysis is found at SiD LoI

Backup Slides


Chargino events for different ch1 mass
M(ch1) - 216.7 GeV
- 0.5 GeV
0.5 GeV
2.0 GeV
W energy (GeV)
Chargino events for different ne1 mass
M(ne1) - 115.7 GeV
- 0.5 GeV
0.5 GeV
2.0 GeV
W energy (GeV)
Neutralino2 events for different ne2 mass
M(ne2) - 216.5 GeV
- 0.5 GeV
0.5 GeV
2.0 GeV
W energy (GeV)
Neutralino2 events for different ne1 mass
M(ne1) - 115.7 GeV
- 0.5 GeV
0.5 GeV
2.0 GeV
W energy (GeV)


Chargino events for different ch1 mass
M(ch1) - 216.7 GeV
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W energy (GeV)
Chargino events for different ne1 mass
M(ne1) - 115.7 GeV
- 0.5 GeV
0 GeV
0.5 GeV
2.0 GeV
W energy (GeV)
Neutralino2 events for different ne2 mass
M(ne2) - 216.5 GeV
- 0.5 GeV
0 GeV
0.5 GeV
2.0 GeV
Z energy (GeV)
Neutralino2 events for different ne2 mass
M(ne1) - 115.7 GeV
- 0.5 GeV
0 GeV
0.5 GeV
2.0 GeV
Z energy (GeV)

chi1chi1									
dM ch						**dM ne1**			
binning fac	GeV/bin	dm /GeV	min-chi2position			binning fac	GeV/bin	dm /GeV	min-chi2position
0	1	0.5011	-0.6666			0	1	0.154901	0.0532
2	2	0.4623	-0.3286			2	2	0.1572	0.0664
5	5	0.4322	0.1166			5	5	0.1552	0.0743
10	10	0.4937	-0.2084			10	10	0.1571	0.0920
		0.4723						**0.1561**	
sel neu2neu2									
dM ne2						**dM ne1**			
binning fac	GeV/bin	dm /GeV	min-chi2position			binning fac	GeV/bin	dm /GeV	min-chi2position
0	1	nan	-1.3390			0	1	0.2684	-0.0261
2	2	2.1036	2.4500			2	2	0.2798	-0.1278
5	5	nan	2.8446			5	5	0.2755	-0.0542
10	10	1.1821	0.2137			10	10	0.2901	-0.1254
		1.6428						**0.2785**	

chi1chi1							
dM ch				**dM ne1**			
binning fac	GeV/bin	dm /GeV	min-chi2position	binning factor	GeV/bin	dm /GeV	min-chi2position
0	1	0.0766	0.0303	0	1	0.050838	0.0286
2	2	0.0767	0.0488	2	2	0.0508	0.0276
5	5	0.0766	0.0680	5	5	0.0509	0.0207
10	10	0.0770	0.0614	10	10	0.0509	0.0214
		0.0768				**0.0509**	
sel neu2neu2							
dM ne2				**dM ne1**			
binning fac	GeV/bin	dm /GeV	min-chi2position	binning factor	GeV/bin	dm /GeV	min-chi2position
0	1	0.4206	0.1940	0	1	0.0953	0.0599
2	2	0.3924	0.2504	2	2	0.0960	0.0273
5	5	0.4211	0.1214	5	5	0.0957	0.0213
10	10	0.3881	0.2350	10	10	0.0962	0.0150
		0.4056				**0.0958**	