Status of SPS1 Analysis at Colorado

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for the
Colorado Group

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Introduction

This discussion presents how the SUSYsignals are observed above the background and the observed mass resolution after the background is removed.

The background considered is the full complement of SUSY background, the Standard Model WW background and 2 photon background where the two fast electrons have an angle < 20 mrads. We have not included the background from Beamstrahlung $\gamma\gamma$ collisions producing the appropriate final state particles.

SUGRA Model Parameters

We studied the SUGRA case with the SPS1 parameters given below. The parameters were agreed to by the International Collaboration.

M_0 = 100 GeV $M_{1/2}$ = 250 GeV

A = -100 tan(β) = 10

μ = 352.39

The main characteristic of this point is due to the large value of tan (β) which leads to final states with τ's and hence low energy tracks.

SUSY Masses

SPS Masses

	minimal SUGRA						GMSB		AMSB
	SPS1	SPS2	SPS3	SPS4	SPS5	SPS6	SPS7	SPS8	SPS9
$\tilde{\chi}_1^0$	96.05	79.54	160.55	118.66	119.51	117.50	161.65	137.19	175.51
$\tilde{\chi}_2^0$	176.82	135.34	296.95	218.14	226.33	215.54	260.06	252.33	549.03
$\tilde{\chi}_3^0$	358.81	140.84	512.87	383.91	642.83	398.70	306.26	404.00	874.37
$\tilde{\chi}_4^0$	377.81	269.45	529.57	401.08	652.95	418.06	379.94	426.28	875.97
$\tilde{\chi}_1^+$	176.38	104.03	296.85	218.06	226.33	215.20	256.33	252.03	175.67
$\tilde{\chi}_2^+$	378.23	269.03	529.51	402.28	652.68	418.19	379.45	426.47	877.22
h^0	113.97	115.71	116.95	115.39	119.79	114.71	113.57	114.83	114.83
H^0	394.15	1444.10	573.03	404.63	694.03	457.84	378.37	515.01	912.56
A^0	393.63	1442.95	572.42	404.43	693.86	457.26	377.89	514.49	911.74
H^+	401.77	1446.18	578.30	416.28	698.49	464.40	386.70	521.17	915.83
$\tilde{\nu}_e$	186.00	1454.17	275.99	441.22	244.52	243.25	249.06	347.61	309.71
$\tilde{e}_R$	142.97	1451.69	178.33	416.54	191.45	191.30	127.43	175.87	303.01
$\tilde{e}_L$	202.14	1456.33	287.11	448.40	256.30	255.81	261.47	356.61	319.66
$\tilde{\tau}_1$	133.22	1439.46	170.59	267.61	180.67	184.34	120.45	169.42	271.28
$\tilde{\tau}_2$	206.13	1450.38	289.22	414.91	257.86	258.31	263.40	357.59	322.54
$\tilde{t}_1$	379.11	1003.88	623.83	530.58	220.74	474.12	779.09	957.65	1005.17
$\tilde{t}_2$	574.71	1307.41	819.54	695.88	644.65	659.73	863.00	1058.68	1128.80
$\tilde{b}_1$	491.91	1296.56	757.50	606.86	535.86	589.80	822.17	1021.90	1112.07
$\tilde{b}_2$	524.59	1520.09	791.35	706.45	622.99	623.42	843.35	1048.26	1232.88
$\tilde{u}_R$	520.45	1530.08	791.78	715.10	624.49	621.87	830.54	1033.16	1227.35
$\tilde{u}_L$	537.25	1532.70	816.57	730.24	641.82	638.97	859.66	1080.25	1218.09
$\tilde{g}$	595.19	784.37	914.26	721.03	710.31	708.58	926.04	820.50	1275.18

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SPS1 Cross Sections (fb)

	500 GeV		750 GeV		1000 GeV	
	80% L	80% R	80% L	80% R	80% L	80% R
$\tilde{\chi}_1^0\tilde{\chi}_2^0$	107.	22.4	81.0	15.9	55.3	10.6
$\tilde{\chi}_1^0\tilde{\chi}_3^0$	2.76	13.6	2.04	8.1	1.21	4.38
$\tilde{\chi}_1^0\tilde{\chi}_4^0$	1.08	2.34	5.17	9.14	3.88	6.42
$\tilde{\chi}_2^0\tilde{\chi}_2^0$	138.	15.4	143.	16.0	104.	11.7
$\tilde{\chi}_2^0\tilde{\chi}_3^0$			14.9	6.38	8.91	4.04
$\tilde{\chi}_2^0\tilde{\chi}_4^0$			14.6	1.76	14.2	1.7
$\tilde{\chi}_3^0\tilde{\chi}_3^0$			0.001	0.001	0.007	0.007
$\tilde{\chi}_3^0\tilde{\chi}_4^0$			22.8	18.4	39.5	31.8
$\tilde{\chi}_4^0\tilde{\chi}_4^0$					0.346	0.082
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	311.	35.4	325.	36.8	241.	27.3
$\tilde{\chi}_1^+\tilde{\chi}_2^-$			34.6	8.74	23.6	5.86
$\tilde{\chi}_2^+\tilde{\chi}_1^-$			34.7	8.74	23.7	5.86
$\tilde{\chi}_2^+\tilde{\chi}_2^-$					136.	39.8
$\tilde{e}_R^+\tilde{e}_R^-$	80.2	544.	70.9	520.	54.0	414.
$\tilde{e}_R^+\tilde{e}_L^-$	150.	16.7	88.2	9.8	53.2	5.91
$\tilde{e}_L^+\tilde{e}_R^-$	16.8	151.	9.83	88.5	5.87	52.8
$\tilde{e}_L^+\tilde{e}_L^-$	105.	19.1	253.	38.2	253.	35.4
$\tilde{\mu}_R^+\tilde{\mu}_R^-$	29.8	87.7	19.2	55.4	12.1	34.6
$\tilde{\mu}_L^+\tilde{\mu}_L^-$	37.3	11.5	48.4	15.2	34.8	11.0
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	36.0	88.8	21.9	53.1	13.6	32.8
$\tilde{\tau}_1^+\tilde{\tau}_2^-$	1.63	1.3	1.27	1.01	0.832	0.661
$\tilde{\tau}_2^+\tilde{\tau}_1^-$	1.62	1.29	1.26	1.00	0.832	0.661
$\tilde{\tau}_2^+\tilde{\tau}_2^-$	30.7	11.1	43.6	16.0	31.9	11.8
$\tilde{\nu}_e\bar{\tilde{\nu}}_e$	928.	116.	1251	151.	1071	127.
$\tilde{\nu}_\mu\bar{\tilde{\nu}}_\mu$	17.6	14.0	16.5	13.1	11.2	8.9
$\tilde{\nu}_\tau\bar{\tilde{\nu}}_\tau$	17.9	14.2	16.6	13.2	11.2	8.91
h^0Z^0	66.0	52.5	26.6	21.1	14.5	11.5
H^0A^0					3.23	2.57
H^+H^-					9.51	3.01
$\tilde{b}_1\bar{\tilde{b}}_1$					0.252	0.03
$\tilde{t}_1\bar{\tilde{t}}_1$					9.53	8.92

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- **Selectron Mass Measurement**

New Method

X 10 Resolution Improvement

$$\tilde{e}^{\pm}_{R,L} \rightarrow e^{\pm} + \tilde{\chi}^{0}_{1}$$

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

$$\tilde{e}^{\pm}_{L} \rightarrow \tilde{\chi}^{\pm}_{1} + \nu_{e}$$

Background

The distribution in the next slide fairly much describes what we observe if we are looking at the final states that contain single leptons, like in the search for selectrons, sneutrinos, smuons, etc.

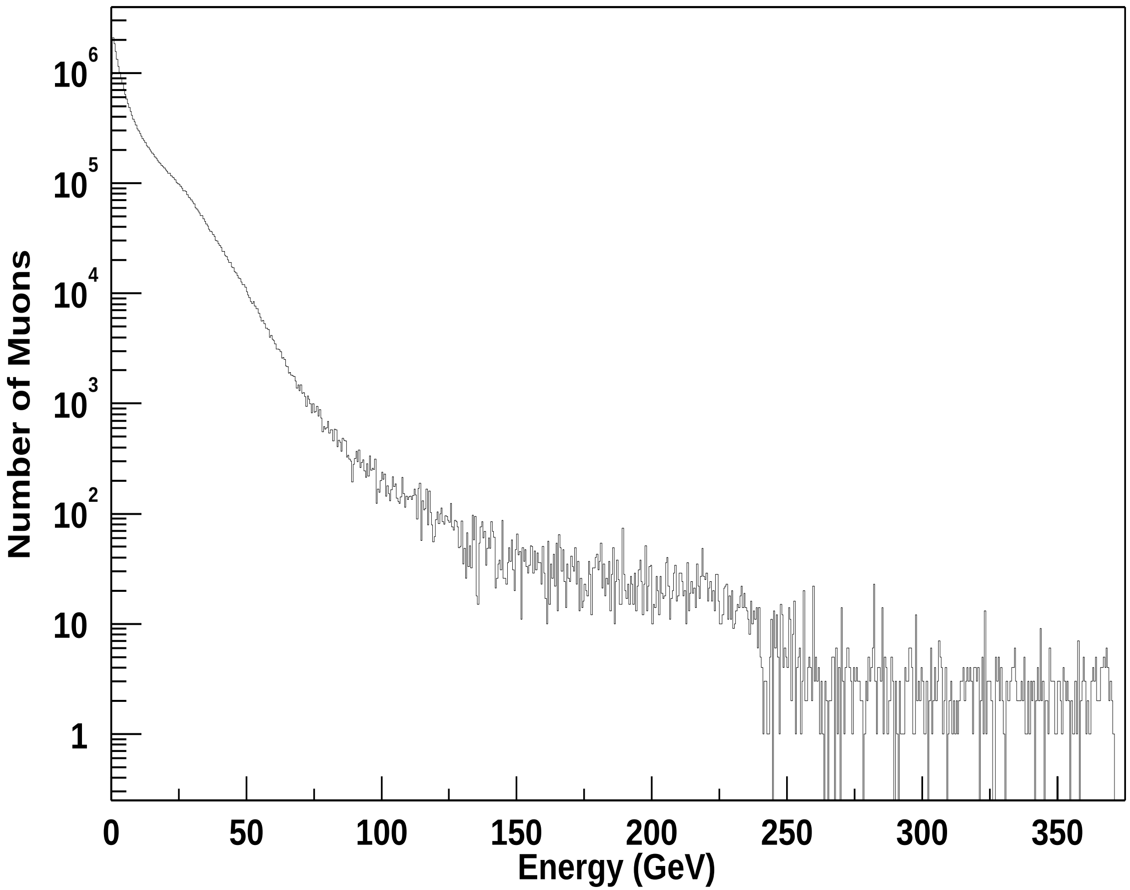
The large low momentum distribution is due to the large cross section for the 2 photon process

$$e^{+} + e^{-} \rightarrow e + e + \gamma + \gamma \rightarrow e + e + \textbf{lepton pair}$$

where the 2 e's are very forward and the lepton pairs are present in the detector.

INITIAL VIEW

Muon Energy for Signal Including Two Photon



All dimuons
Except
$e\ e \rightarrow \mu\ \mu$

Ecm = 750 GeV
Pt($\mu\mu$ from $\gamma\gamma$)<14 GeV

Lum = 50 fb^{-1}

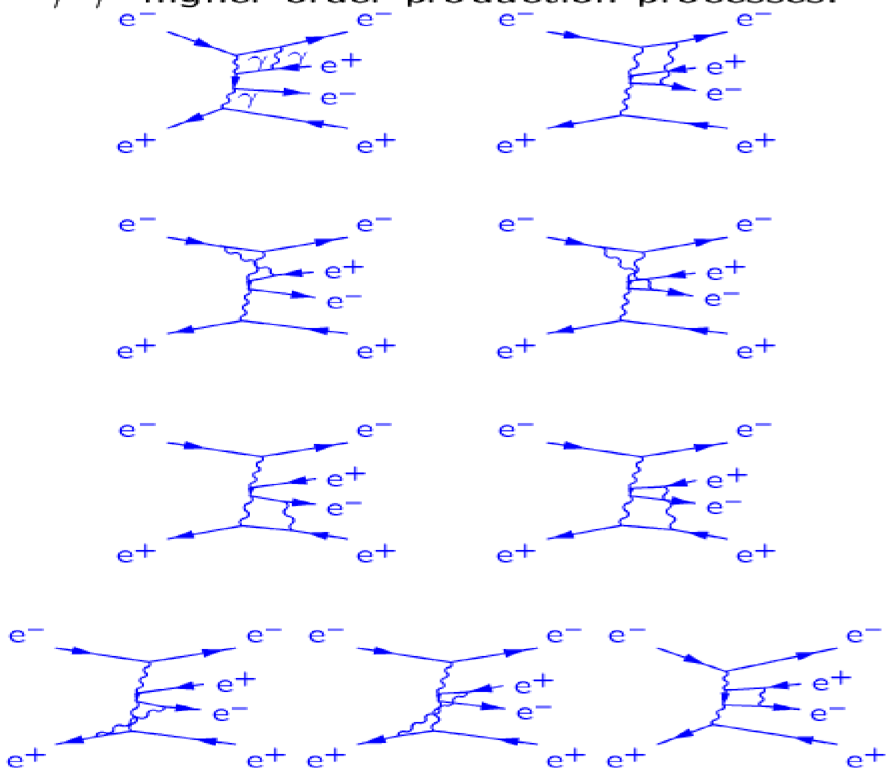
Background issues

The simulation of the background in the previous slide does not include the 2nd order processes shown in the next slide. Hence it is possible that the background in the energy region above 20 GeV might be larger. This needs to be corrected.

BACKGROUND SIMULATION

NLC – The Next Linear Collider Project

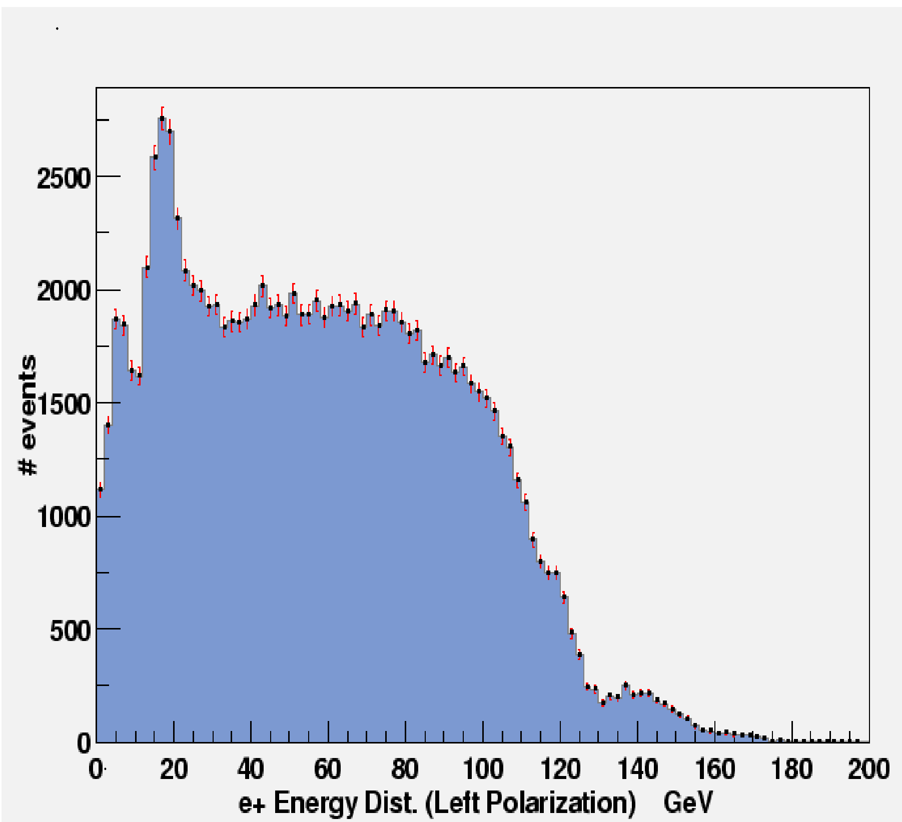
$\gamma^*\gamma^*$ higher order production processes:



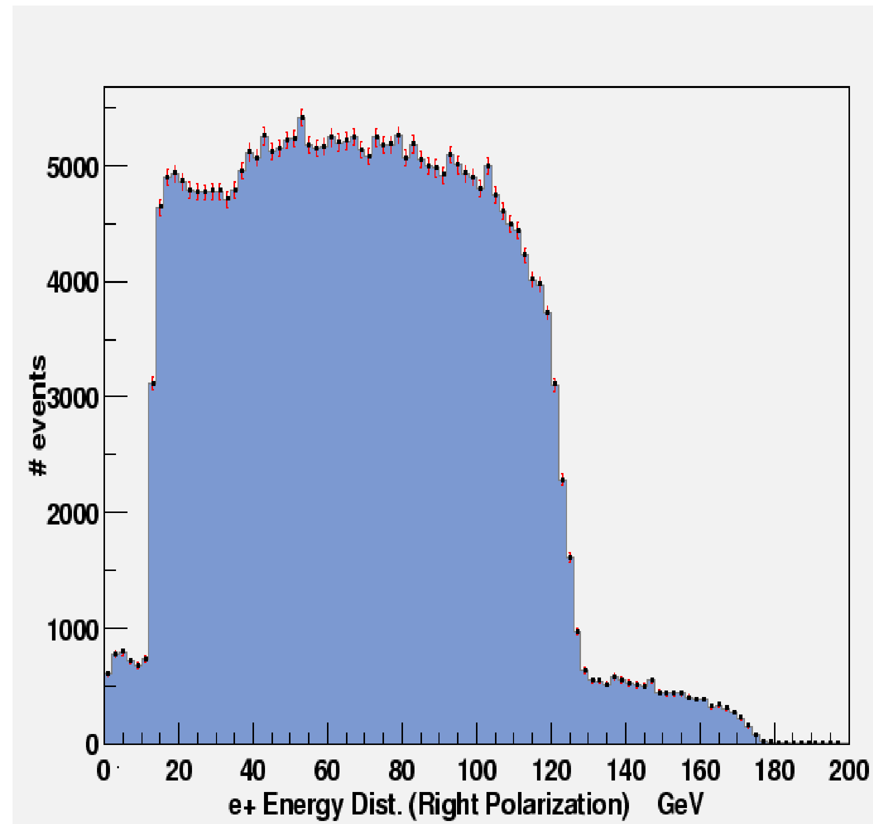
Selectron Spectrum

Positron Energy Spectrum

$L^+ L^- + R^+ R^- + L^+ R^- + L^- R^+$ + SUSY bkg



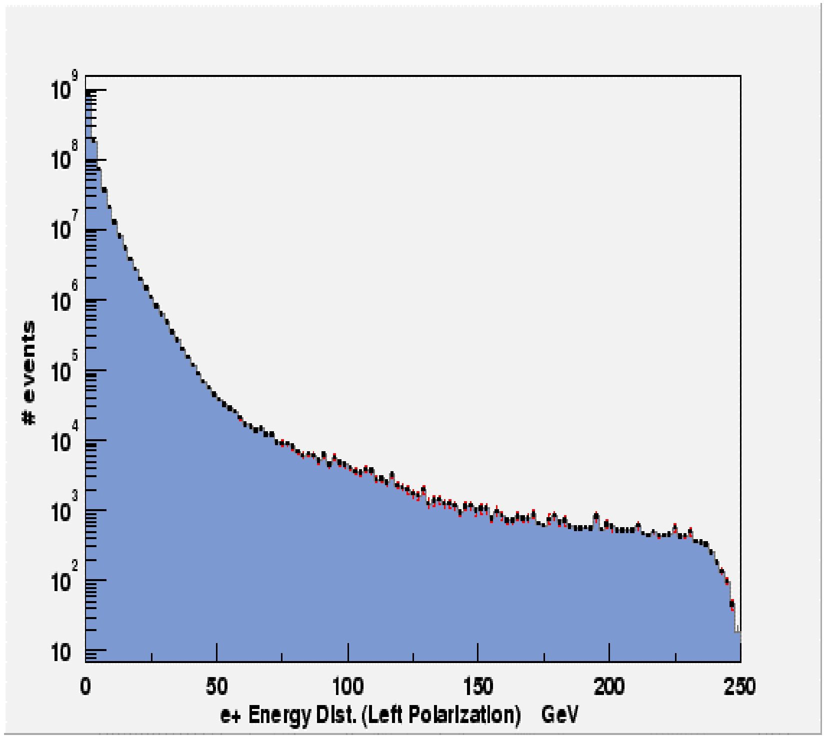
80% L Pol



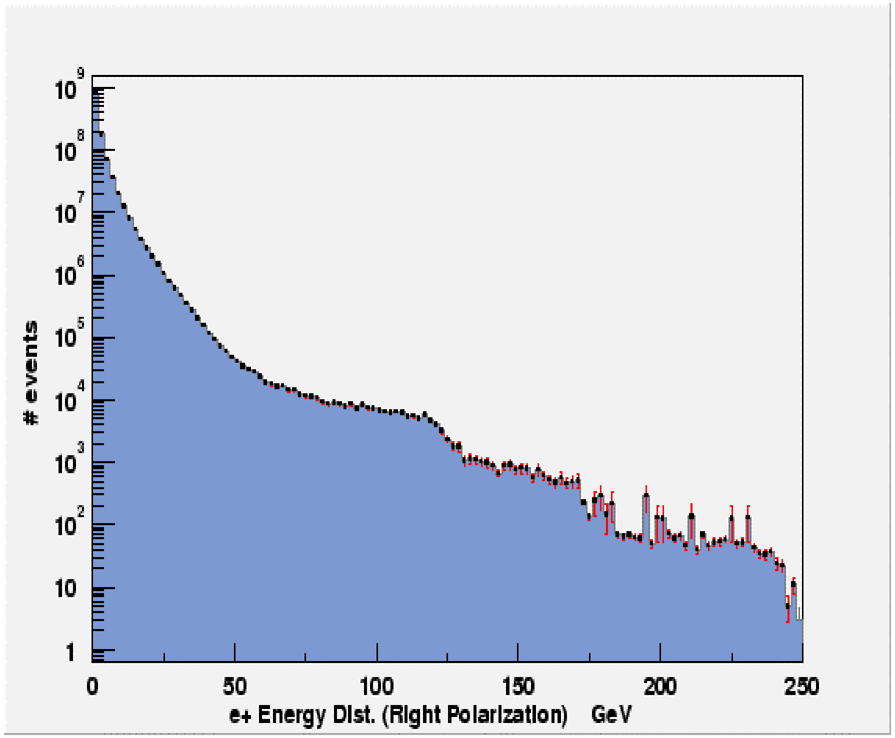
80% R Pol

Positron Energy Spectrum

SUSY + W W $+ \gamma^*\gamma^* \rightarrow e^+e^- + \tau\ \tau(e^+e^-)$



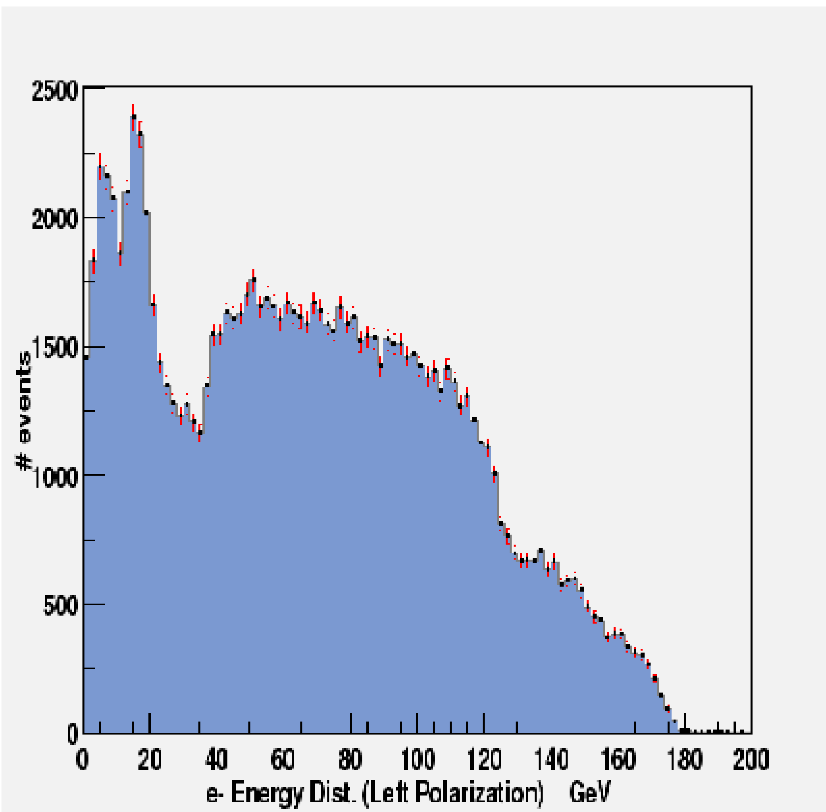
80% L



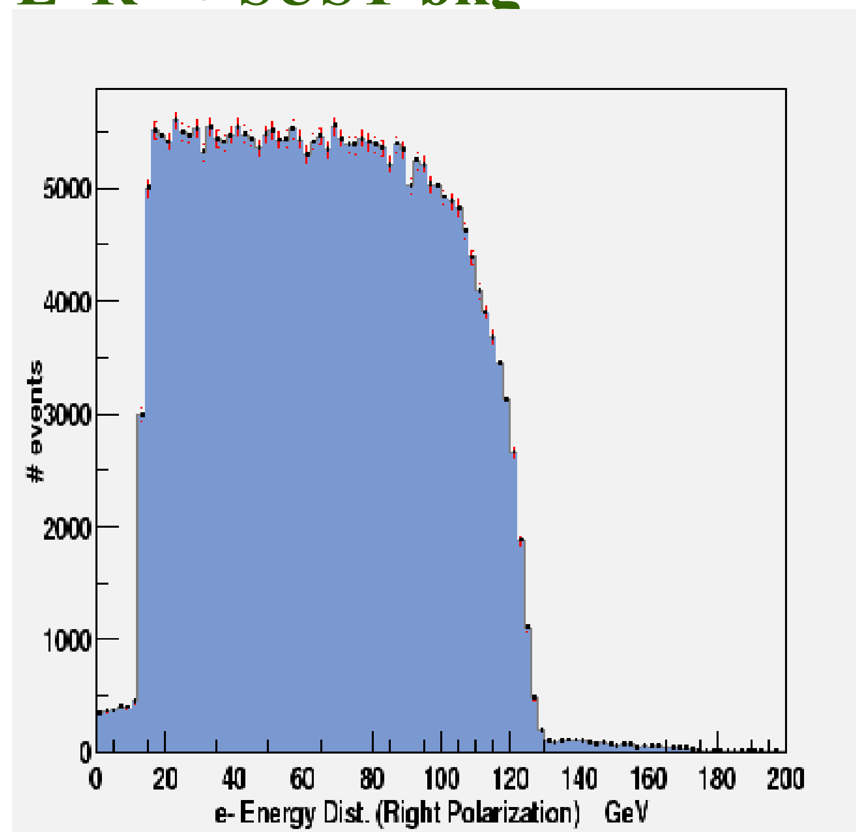
80% R

Selectron Spectrum

- **Electron Energy Spectrum**
  $L^{+} L^{-} + R^{+} R^{-} + L^{+} R^{-} + L^{-} R^{+}$ + SUSY bkg



80% L Pol

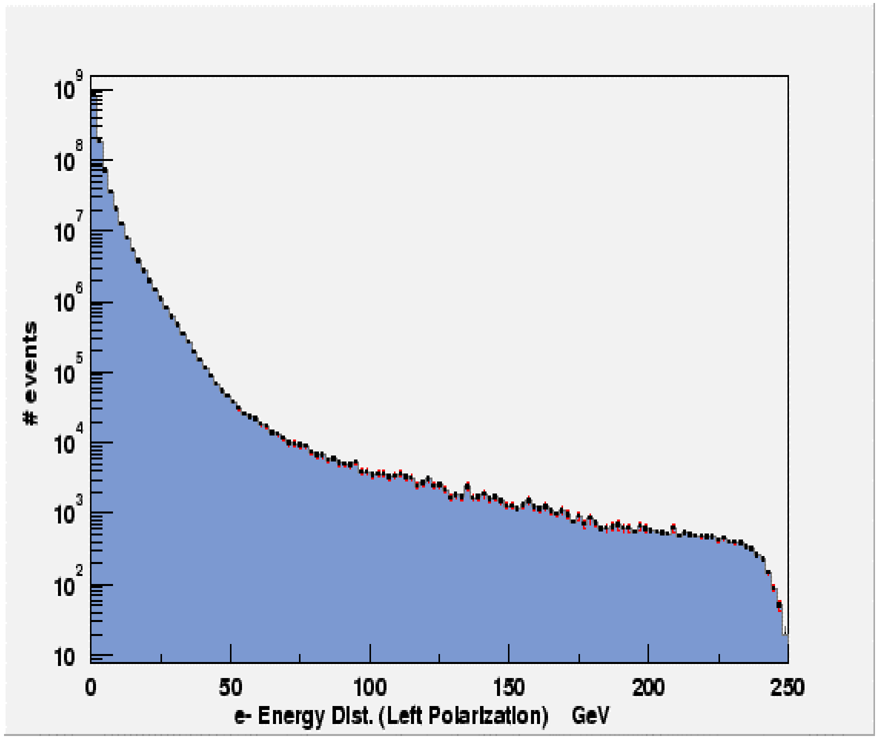


80% R Pol

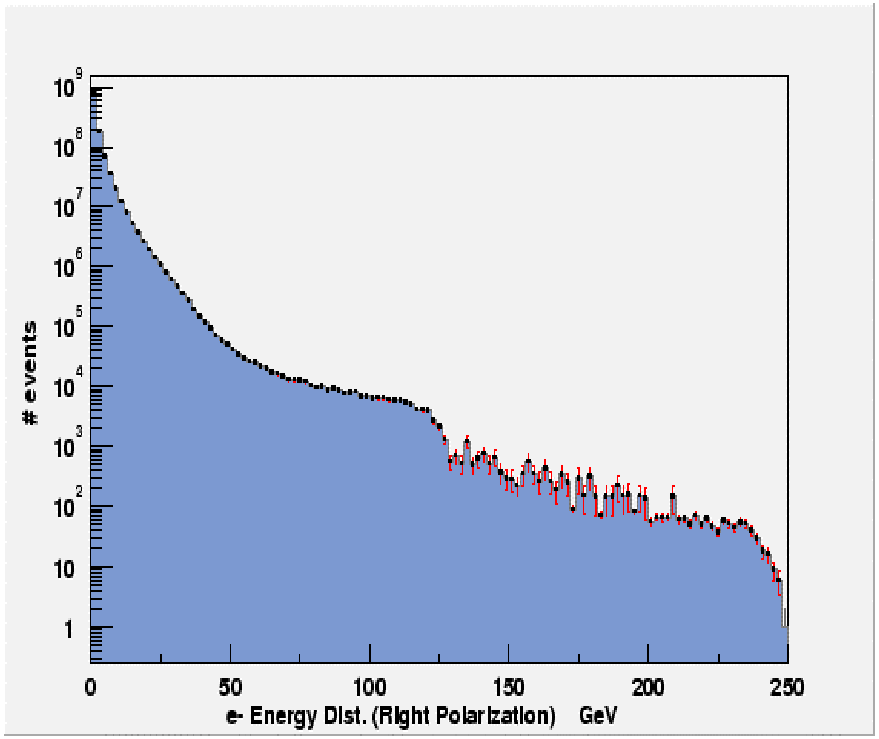
Selectron Spectrum

Electron Energy Spectrum

$$SUSY + W\,W + \gamma^*\gamma^* \rightarrow e^+e^- + \tau\tau(e^+e^-)$$



80% L



80% R

Selectron

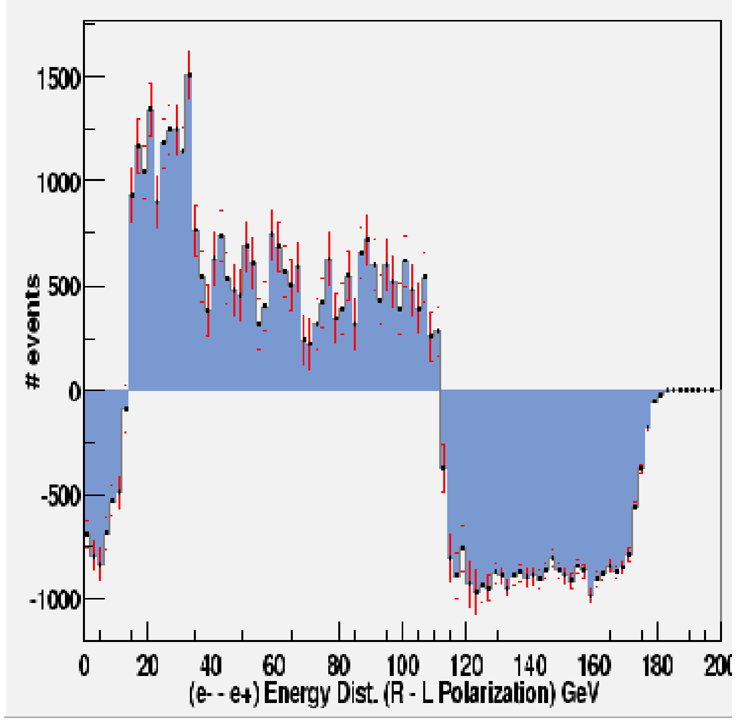
The mass of the SUSY particles depend on observing the minimum and maximum energy of the final state particle. The case discussed now is the selectron and neutralino. See one of our last slides showing the equations. In the distributions before this the edges are obscured by SUSY background channels. In the next slide where we take differences we get the correct edges because the background cancels out.

Selectron Energy Spectrum

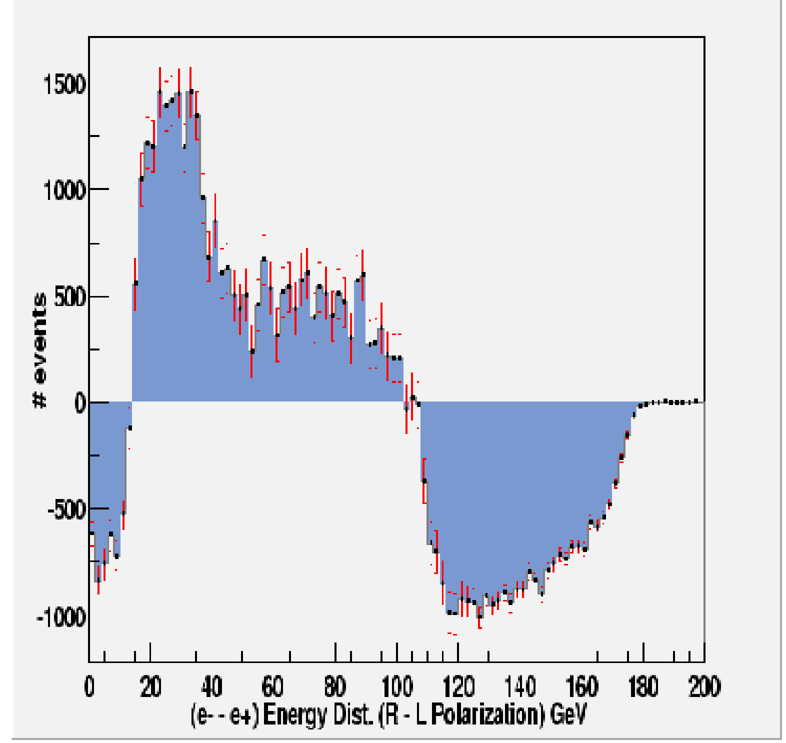
NLC – The Next Linear Collider Project

Energy Spectrum $(e^- - e^+)$(R-L)

No Bremms



Bremms



SELECTRON MASSES RESULTS

Lum = 500 fb^{-1}

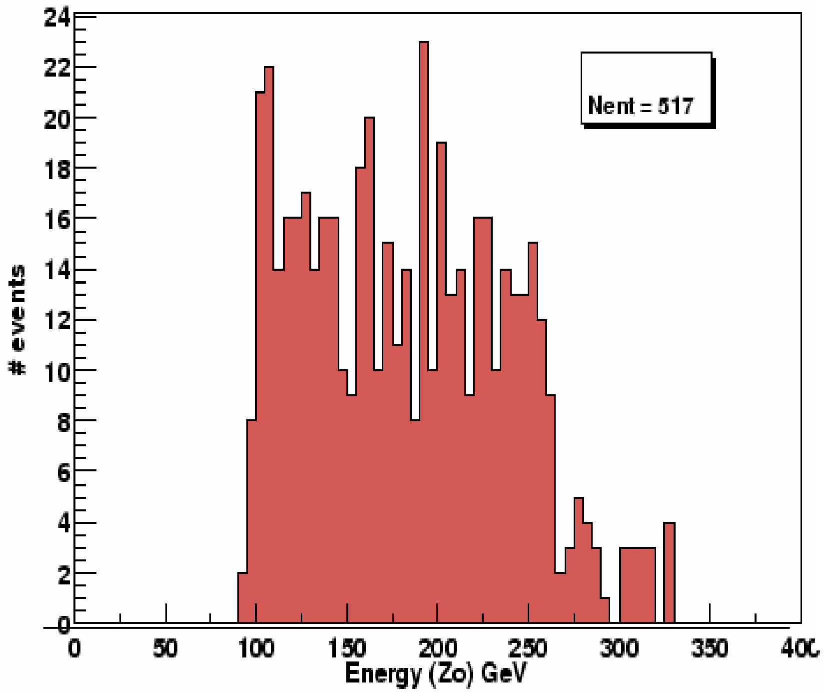
Name	Input Mass GeV		Measured Mass GeV	
$\tilde{e}_R$	143.00	No Brem	141.57	$\pm$ 0.80
		Brem	146.3	$\pm$ 0.8
$\tilde{e}_L$	202.12	No Brem	201.51	$\pm$ 0.80
		Brem	208.6	$\pm$ 0.8
$\tilde{\chi}^0_1$	96.05	No Brem	95.4	$\pm$ 4.0
		Brem	99.9	$\pm$ 3.9

Higher Neutralinos

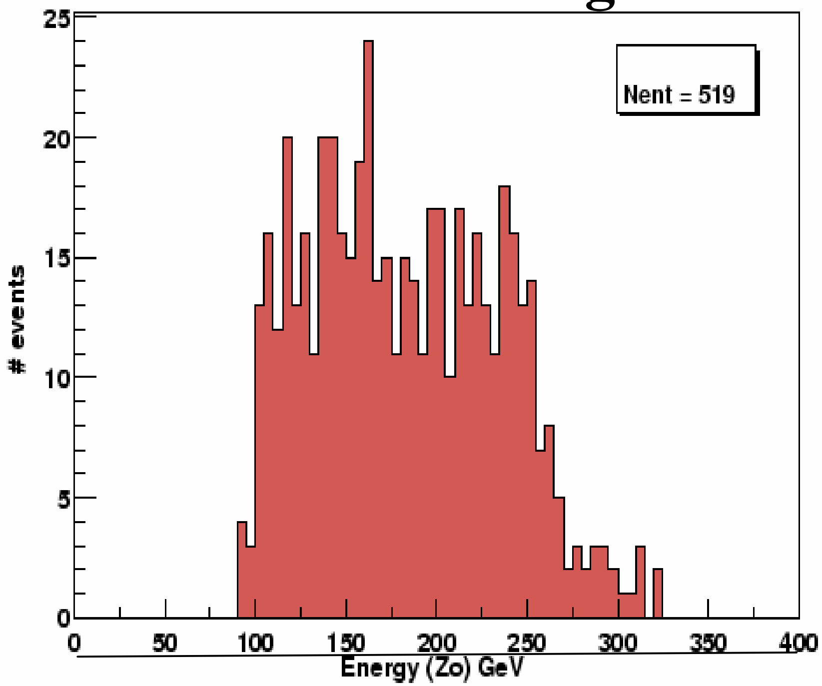
$$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_3^0;\ \tilde{\chi}_3^0 \rightarrow \tilde{\chi}_{2,1}^0 Z\ ;\ Z \rightarrow l^+\, l^-$$

Lum = 2000 fb^{-1}

No Strahlung

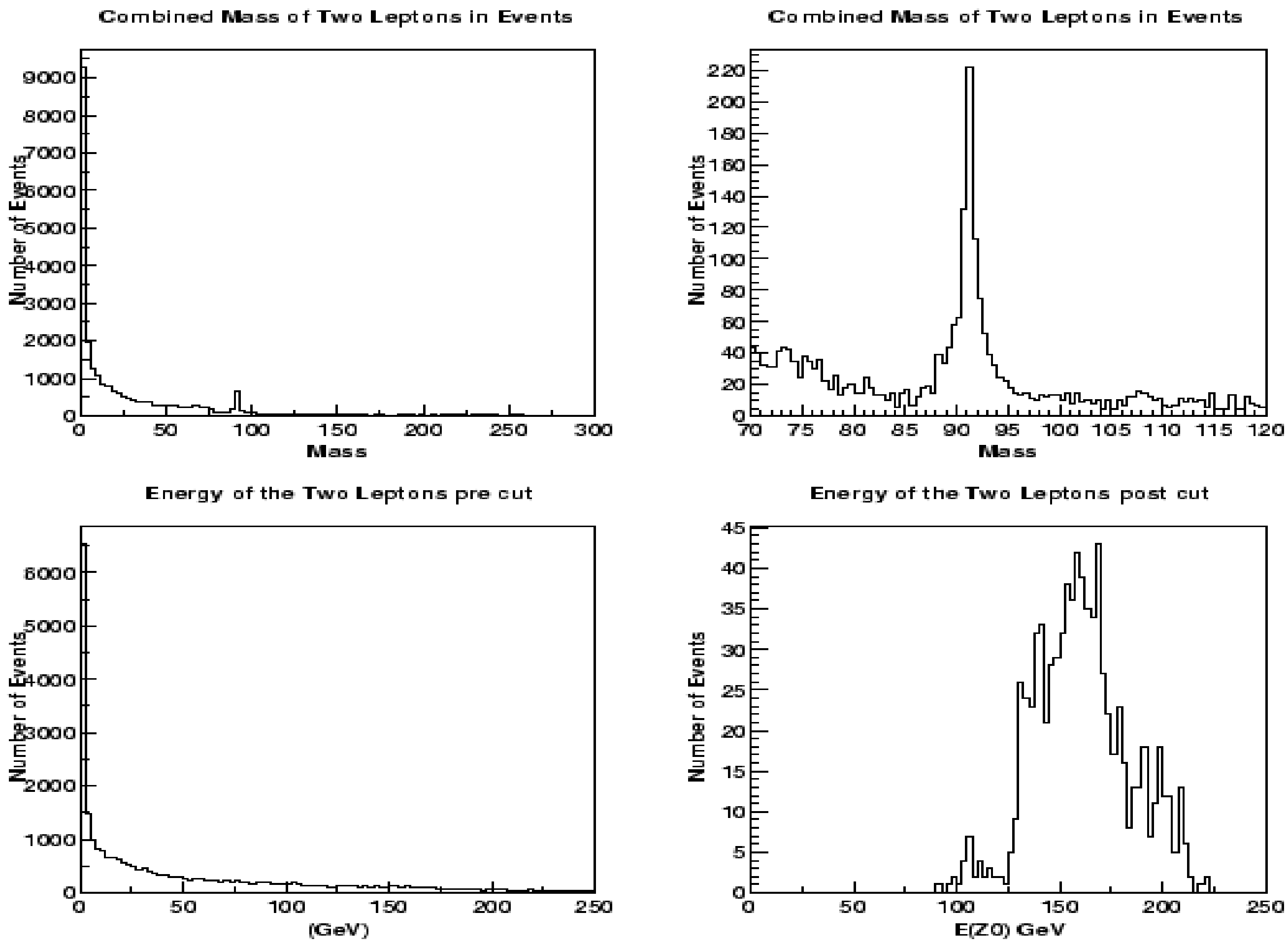


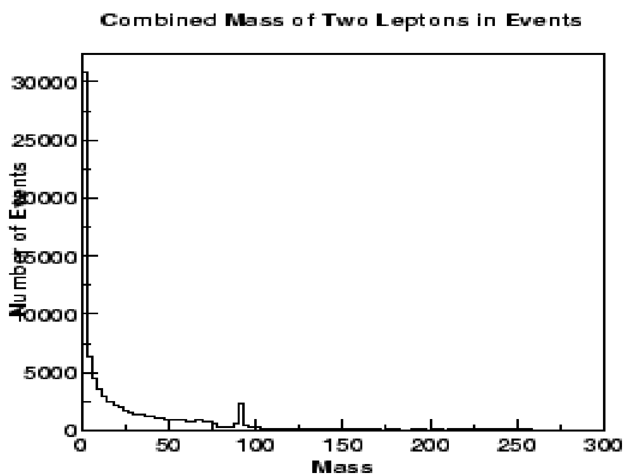
With Strahlung

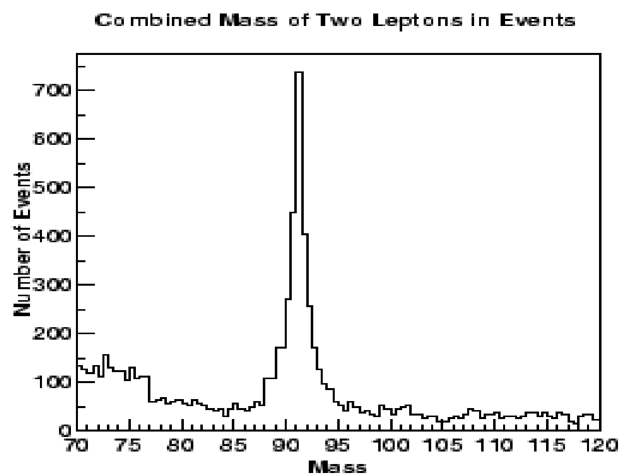


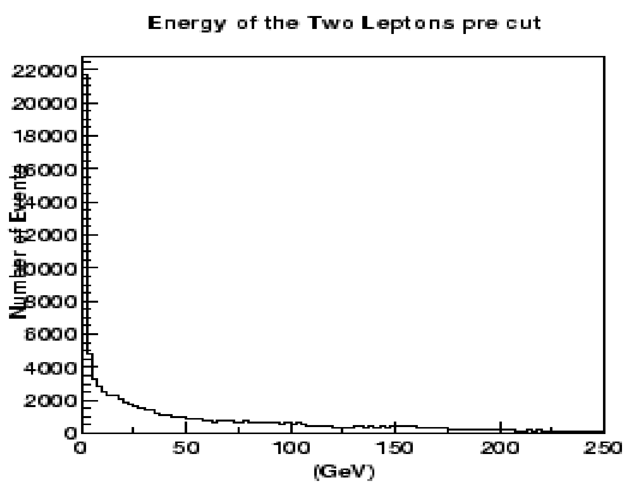
SUSY Particle Masses

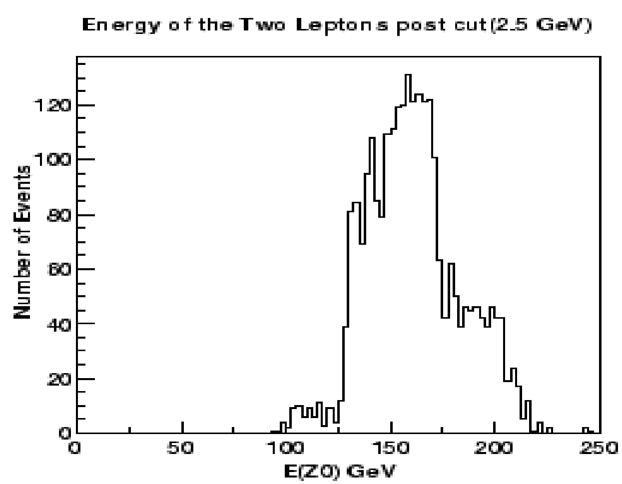
$$e^+ + e^- \to \tilde{\chi}^0_3 + \tilde{\chi}^0_4 \; ; \; \chi_3 \to \chi_1 + Z \; ; \; \chi_3 \to \chi_2 + Z$$




Combined Mass of Two Leptons in Events
Number of Events
Mass
30000
25000
5000
0
0
50
100
150
200
250
300


Combined Mass of Two Leptons in Events
Number of Events
Mass
700
600
500
400
300
200
100
0
70
75
80
85
90
95
100
105
110
115
120


Energy of the Two Leptons pre cut
Number of Events
(GeV)
22000
20000
18000
6000
4000
2000
0
0
50
100
150
200
250


Energy of the Two Leptons post cut(2.5 GeV)
Number of Events
E(Z0) GeV
120
100
80
60
40
20
0
0
50
100
150
200
250

Electron Sneutrinos

$$e^+ + e^- \rightarrow \tilde{\nu}_e + \tilde{\nu}_e$$

$$\tilde{\nu}_e \rightarrow \tilde{\chi}_1^0 + \nu_e \quad 87.9\%$$

$$\tilde{\nu}_e \rightarrow \tilde{\chi}_1^+ + e^- \quad 8.8\%$$

SPS1 Cross Sections (fb)

	500 GeV		750 GeV		1000 GeV	
	80% L	80% R	80% L	80% R	80% L	80% R
$\tilde{\chi}_1^0\tilde{\chi}_2^0$	107.	22.4	81.0	15.9	55.3	10.6
$\tilde{\chi}_1^0\tilde{\chi}_3^0$	2.76	13.6	2.04	8.1	1.21	4.38
$\tilde{\chi}_1^0\tilde{\chi}_4^0$	1.08	2.34	5.17	9.14	3.88	6.42
$\tilde{\chi}_2^0\tilde{\chi}_2^0$	138.	15.4	143.	16.0	104.	11.7
$\tilde{\chi}_2^0\tilde{\chi}_3^0$			14.9	6.38	8.91	4.04
$\tilde{\chi}_2^0\tilde{\chi}_4^0$			14.6	1.76	14.2	1.7
$\tilde{\chi}_3^0\tilde{\chi}_3^0$			0.001	0.001	0.007	0.007
$\tilde{\chi}_3^0\tilde{\chi}_4^0$			22.8	18.4	39.5	31.8
$\tilde{\chi}_4^0\tilde{\chi}_4^0$					0.346	0.082
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	311.	35.4	325.	36.8	241.	27.3
$\tilde{\chi}_1^+\tilde{\chi}_2^-$			34.6	8.74	23.6	5.86
$\tilde{\chi}_2^+\tilde{\chi}_1^-$			34.7	8.74	23.7	5.86
$\tilde{\chi}_2^+\tilde{\chi}_2^-$					136.	39.8
$\tilde{e}_R^+\tilde{e}_R^-$	80.2	544.	70.9	520.	54.0	414.
$\tilde{e}_R^+\tilde{e}_L^-$	150.	16.7	88.2	9.8	53.2	5.91
$\tilde{e}_L^+\tilde{e}_R^-$	16.8	151.	9.83	88.5	5.87	52.8
$\tilde{e}_L^+\tilde{e}_L^-$	105.	19.1	253.	38.2	253.	35.4
$\tilde{\mu}_R^+\tilde{\mu}_R^-$	29.8	87.7	19.2	55.4	12.1	34.6
$\tilde{\mu}_L^+\tilde{\mu}_L^-$	37.3	11.5	48.4	15.2	34.8	11.0
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	36.0	88.8	21.9	53.1	13.6	32.8
$\tilde{\tau}_1^+\tilde{\tau}_2^-$	1.63	1.3	1.27	1.01	0.832	0.661
$\tilde{\tau}_2^+\tilde{\tau}_1^-$	1.62	1.29	1.26	1.00	0.832	0.661
$\tilde{\tau}_2^+\tilde{\tau}_2^-$	30.7	11.1	43.6	16.0	31.9	11.8
$\tilde{\nu}_e\bar{\tilde{\nu}}_e$	928.	116.	1251	151.	1071	127.
$\tilde{\nu}_\mu\bar{\tilde{\nu}}_\mu$	17.6	14.0	16.5	13.1	11.2	8.9
$\tilde{\nu}_\tau\bar{\tilde{\nu}}_\tau$	17.9	14.2	16.6	13.2	11.2	8.91
$h^0 Z^0$	66.0	52.5	26.6	21.1	14.5	11.5
$H^0 A^0$					3.23	2.57
$H^+ H^-$					9.51	3.01
$\tilde{b}_1\bar{\tilde{b}}_1$					0.252	0.03
$\tilde{t}_1\bar{\tilde{t}}_1$					9.53	8.92

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Search Procedure for Electron Sneutrinos

Plot energy distribution of $e^{\pm}$ *when we have only an e and* μ

Selectron and Smuon background removed
Except for Left Selectrons, Smuons that
Decay into a Neutrino and Chargino and
Chargino decays into Staus or Taus.

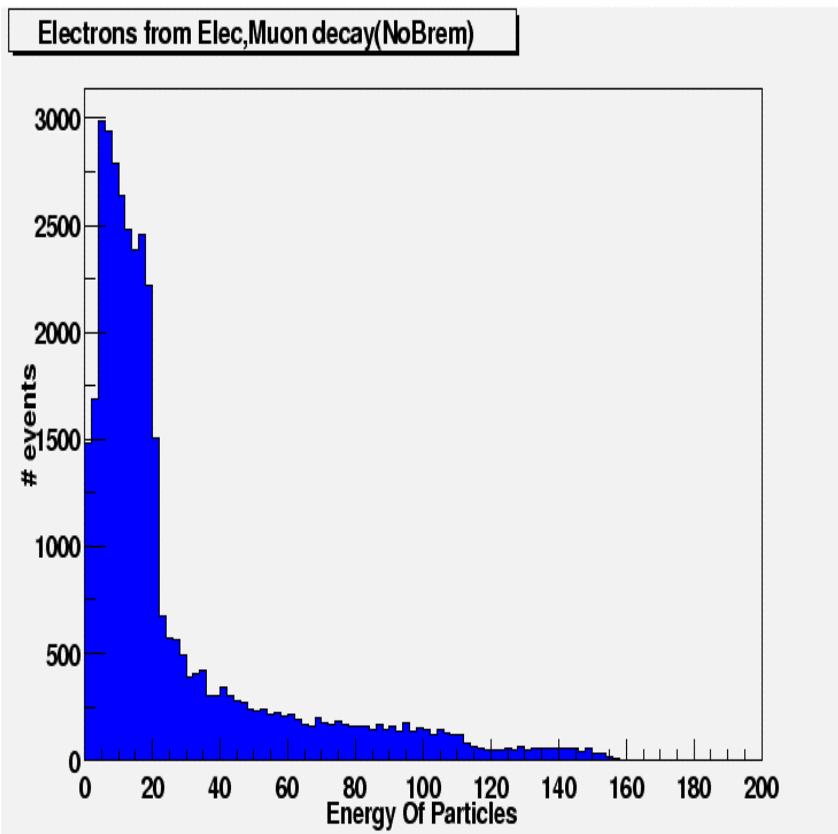
Only $\gamma^{*}\gamma^{*} \rightarrow \tau^{+}\tau^{-}$ *and* $e\ e \rightarrow W\ W$ *remain*

Use μ energy spectrum to remove e background

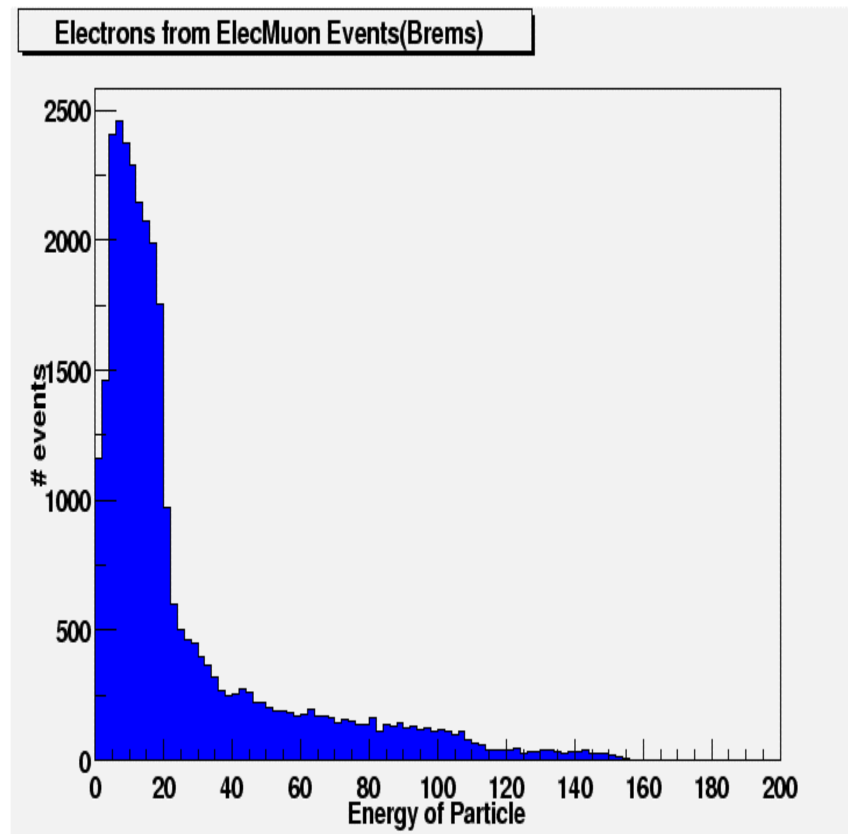
Electron Sneutrinos

$e^{\pm}$ energy spectrum for e + μ events

No Brem

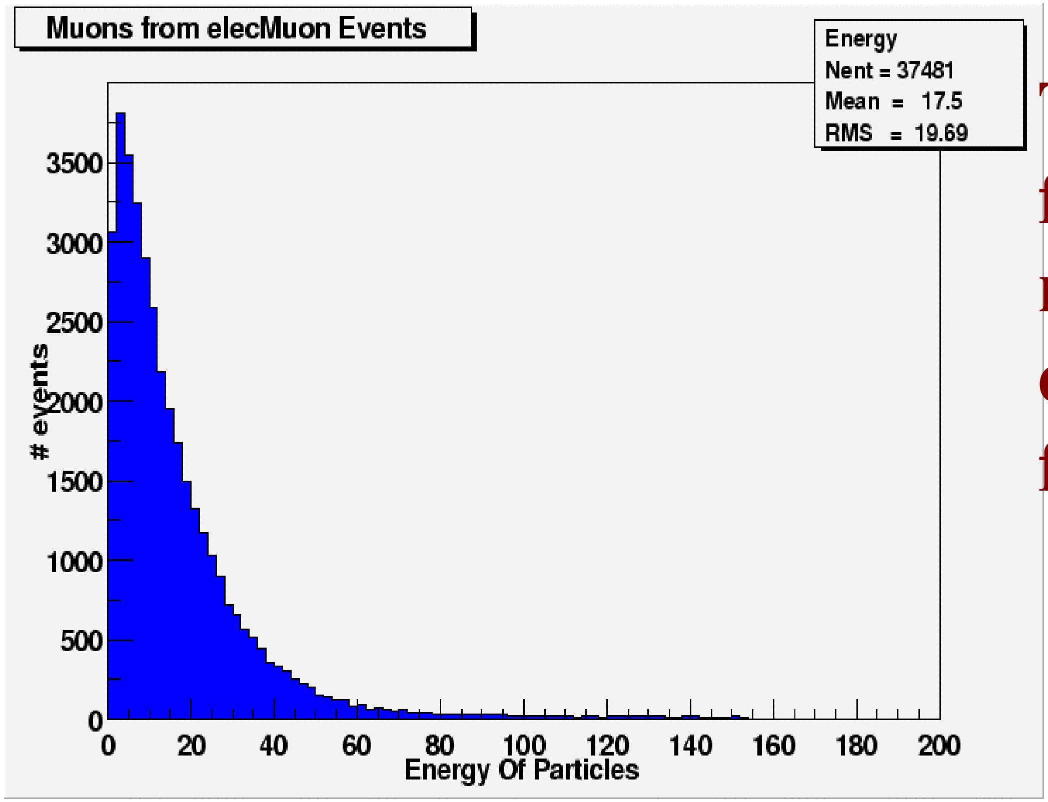


Brem



80% Left Pol., Lum - 500 fb^{-1}

μ Energy Spectrum

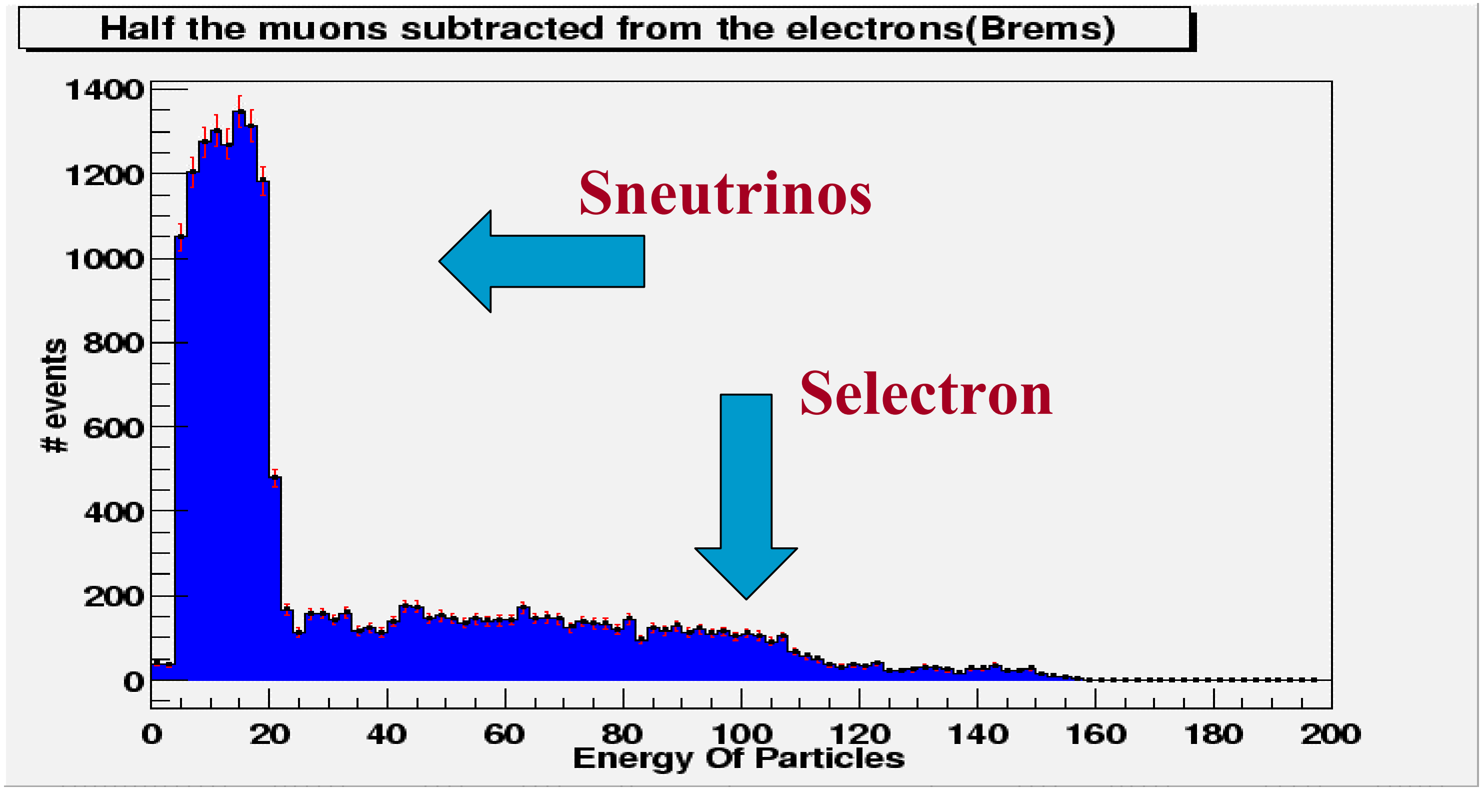


This spectrum comes from τ decays and represents the electron background from this source.

Electron Sneutrinos

Energy Spectrum of e's from eμ events

After μ Spectrum Subtraction



P=80% L

Sneutrino Mass Results

	E_{low}	E_{high}	
No Brem	4.11 ± .04	21.10 ± .09	GeV
Brem	4.22 ± .08	20.40 ± .12	GeV

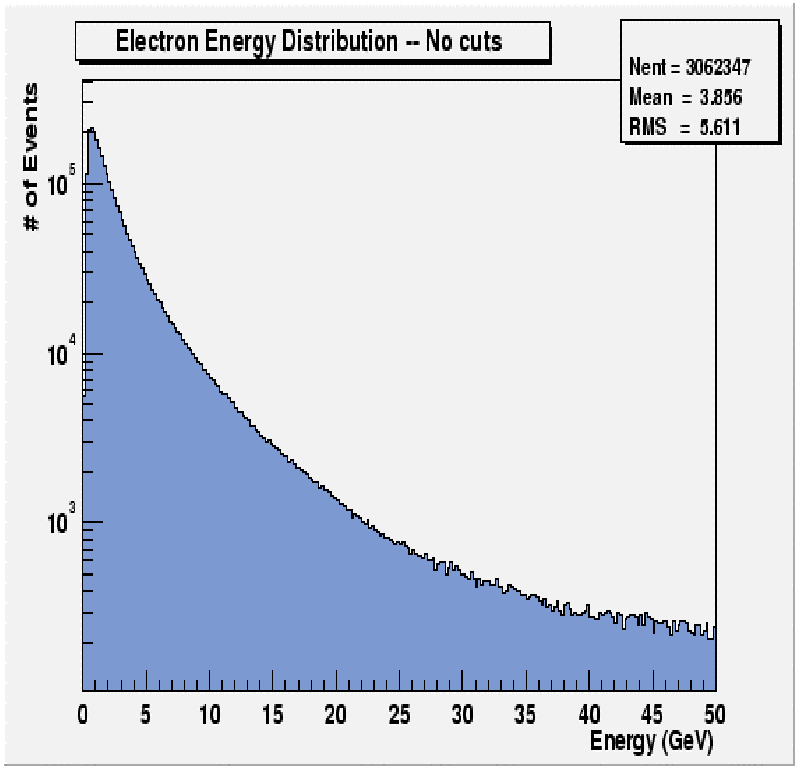
Masses (GeV)

	$M_{\tilde{\nu}}$	$M_{\tilde{\chi}_1^\pm}$
Input	186.00	176.38
No Brem	184.7 ± 0.7	175.1
Brem	188.4 ± 0.7	178.9

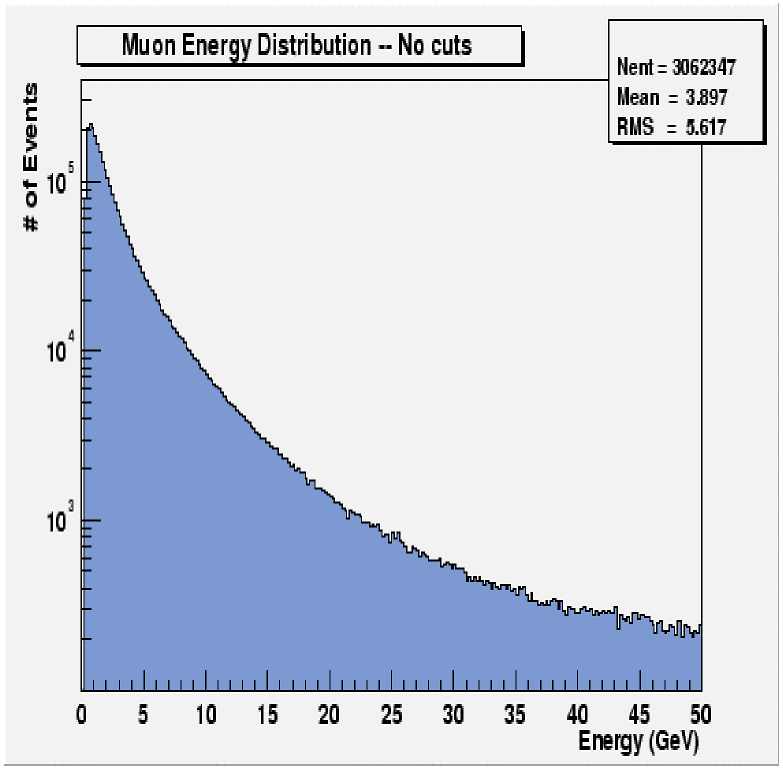
With $\gamma^*\gamma^*\rightarrow\tau\tau\rightarrow\mu e\nu\nu\nu\nu$

Lum = 500 inv fb

Total Electron Spectrum

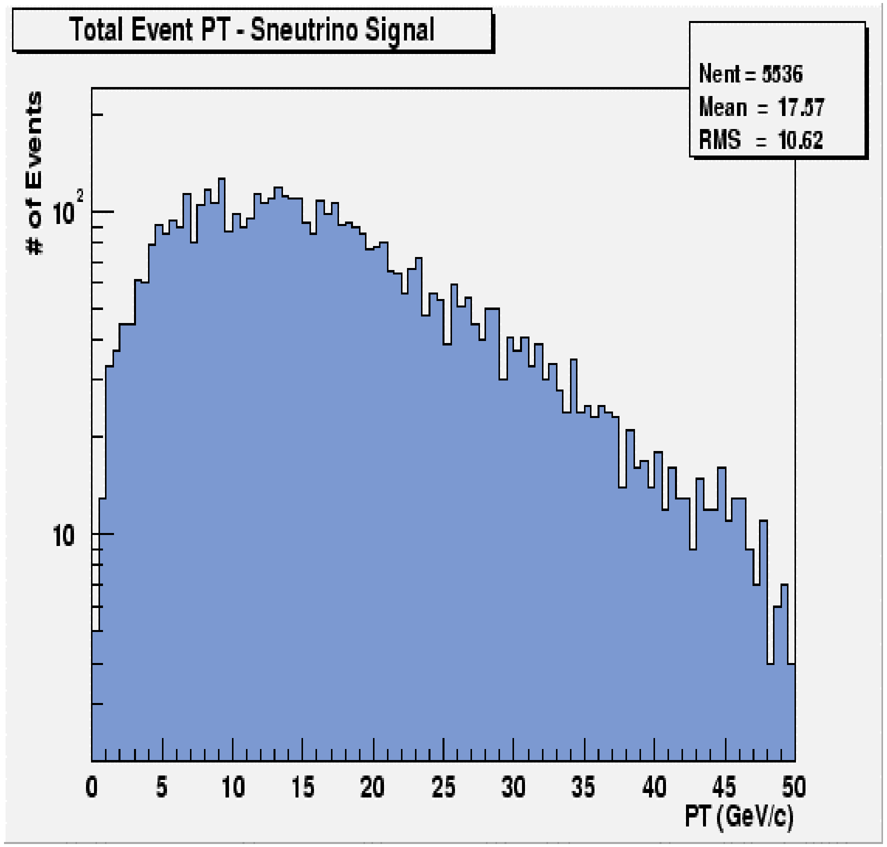


Total Muon Spectrum

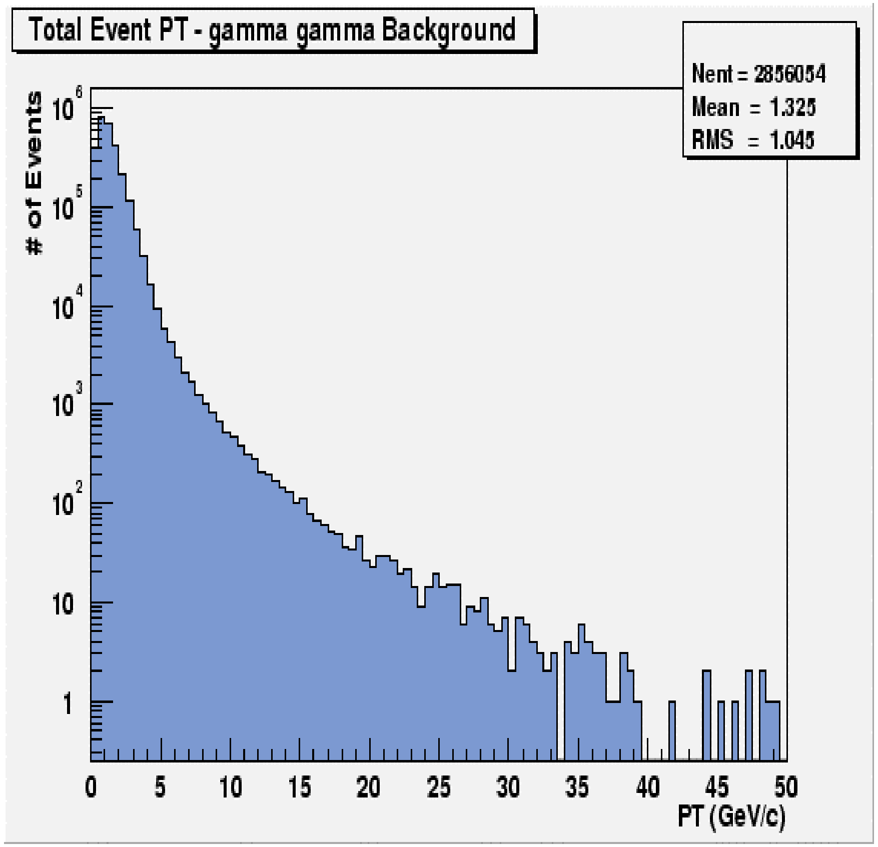


Pt of e + μ

From Sneutrinos

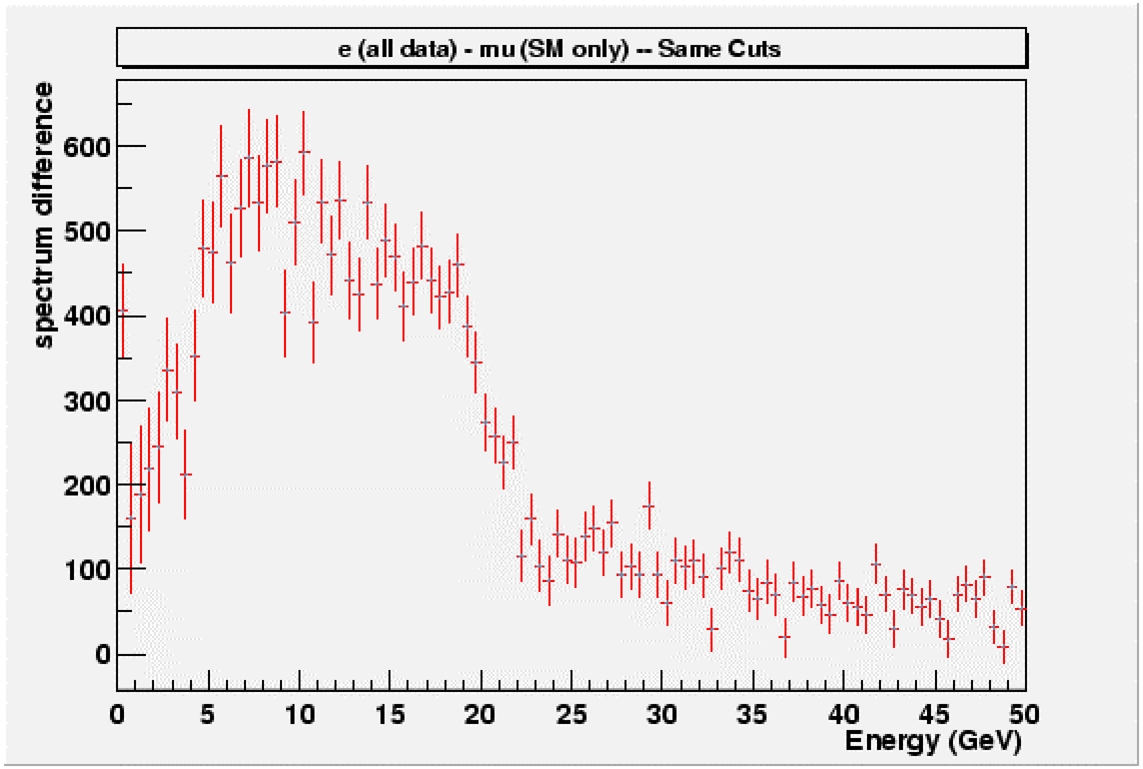


From γ*γ*→ττ→eμνννν



e^+/e^- - SM μ Energy Spectrum

Pt (e+μ) > 6 GeV; E (e or μ) < 50 GeV

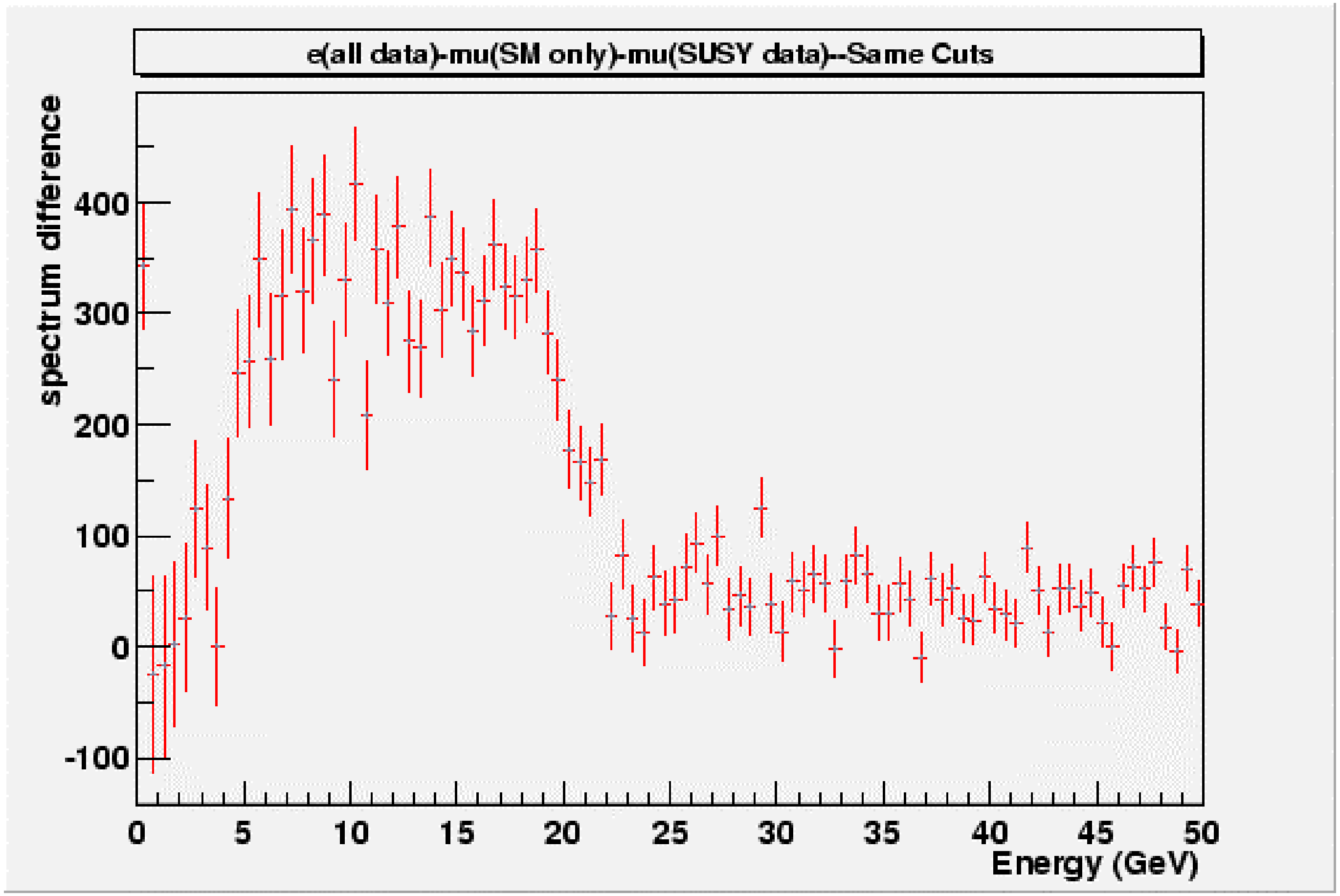


P=80% L

Selectrons

e^+/e^--- (SM+SUSY) μ Energy Spectrum

Pt (e + μ) > 6 GeV ; E (e or μ) < 50 GeV



P=80% L

Smuons

$$e^+e^- \rightarrow \tilde{\mu}_L\tilde{\mu}_L + \tilde{\mu}_R\tilde{\mu}_R$$

Signal

$$\mu^+ \mu^-$$

Backgrounds

W W Decays into μ

$$\gamma^*\gamma^* \rightarrow \mu\ \mu$$

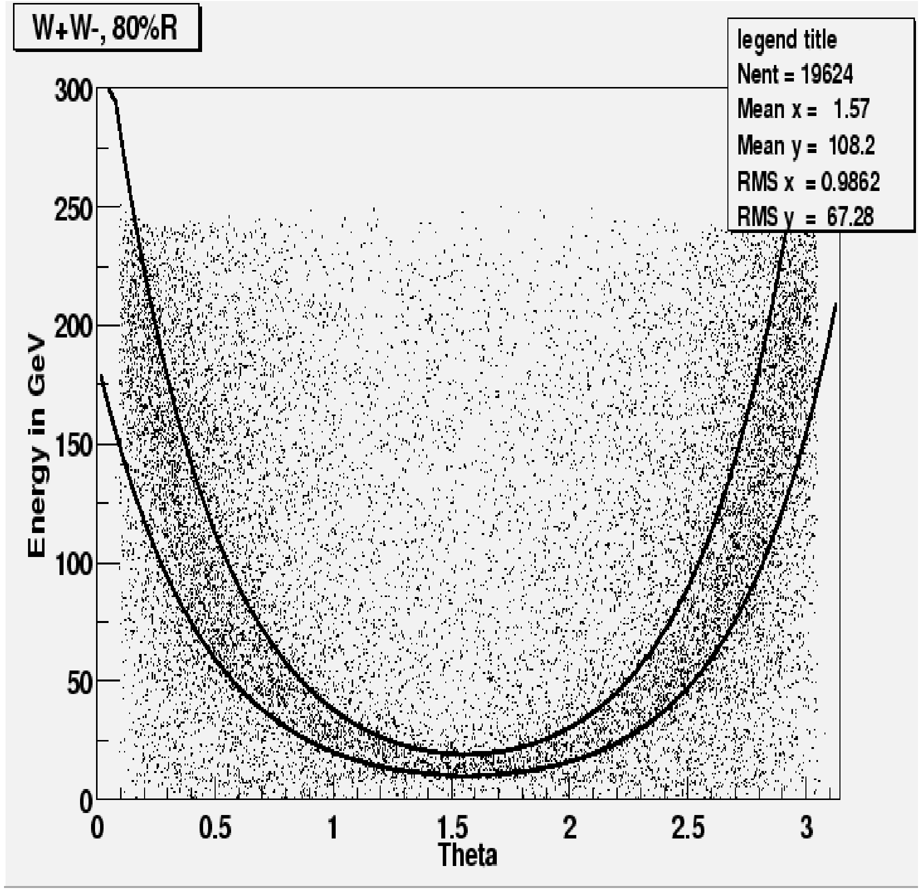
$$e\ e \rightarrow \tau\ \tau \text{ or } \tilde{\tau}\ \tilde{\tau}$$

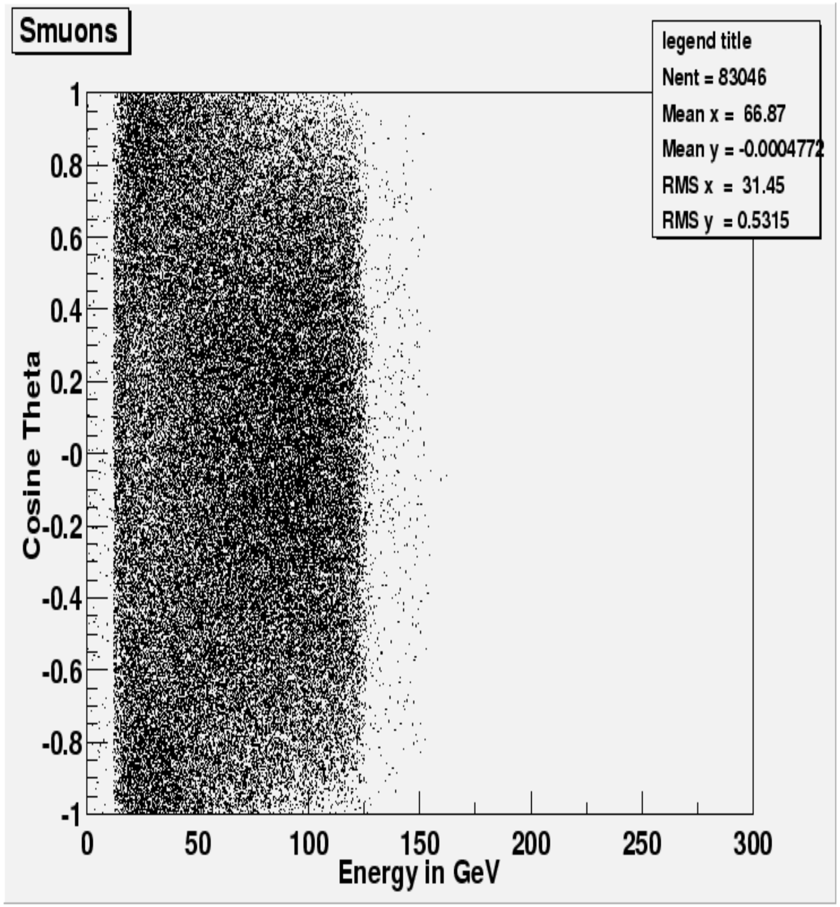
$$e\ e \rightarrow \tilde{\nu}_\mu \tilde{\nu}_\mu$$

Smuon Backgrounds

NLC – The Next Linear Collider Project

Muon Energy versus Angle





WW Background Reduction

- Remove events with energy of either muon $\geq$ 200 GeV
- Remove events with muons in the energy vs θ band

τ τ Background

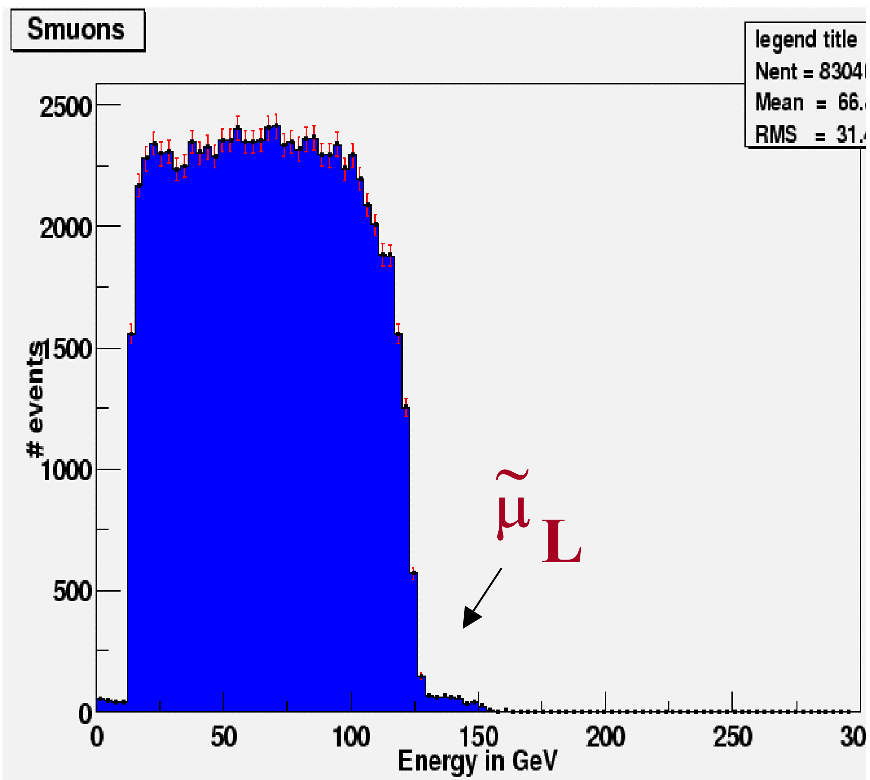
- Rough cut at present

Smuons

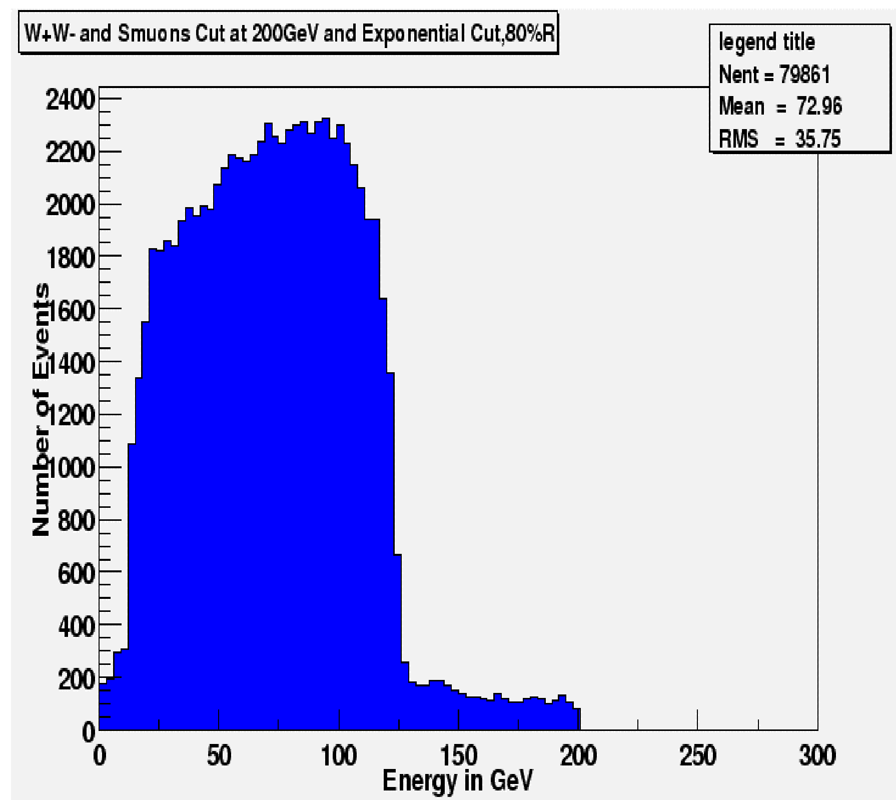
μ *Energy Spectrum*

Pol=80%R, Lum=500 fb^{-1}

Pure Smuons

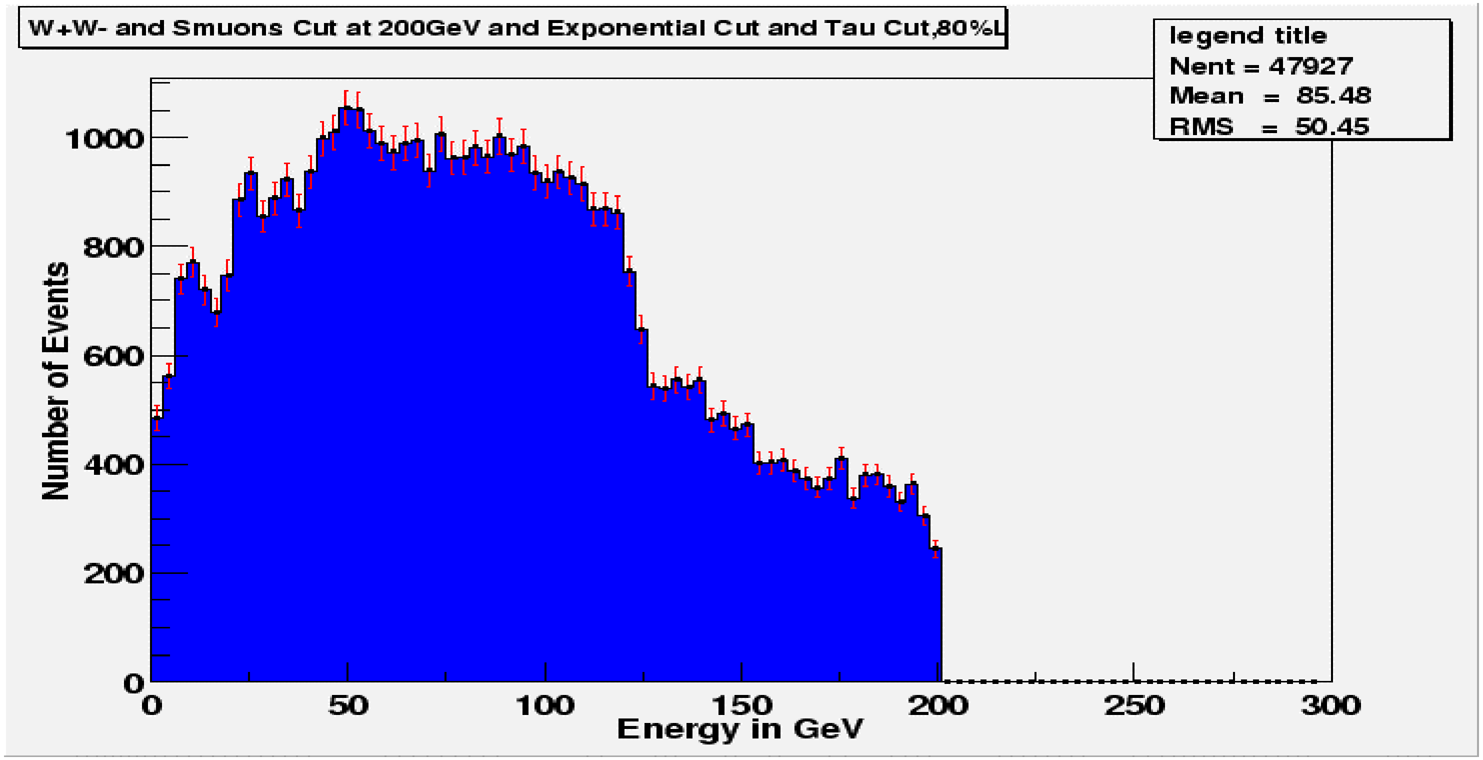


Smuons+WW+Cuts



μ Energy Spectrum

Pol=80%L, Lum=500 fb^{-1}



Beam Energy Resolution

$$A \rightarrow B + C$$

$$M_A = E_{cm} \frac{\{E_c(\text{min})\ E_c(\text{max})\}^{1/2}}{\{E_c(\text{min}) + E_c(\text{max})\}}$$

$$M_B = M_A \left\{1 - \frac{2[E_c(\text{min}) + E_c(\text{max})]}{E_{cm}}\right\}^{1/2}$$

$$\delta(M) \approx 0.35\ \delta(E_{cm})$$

Conclusions

The large number of low energy events is due to the 2 photon background. This can be removed by having a detector in the very forward region that detects all tracks with angles > 20 mrad to the beam direction. Then requiring that the Pt of the tracks in the detector add to > 10 GeV removes this background. In the case of the e μ final state the 2 νs from the τ decay makes this limit more diffuse.

Restricting to lower than 20 mrad is useful to reduce this background. This should be an R&D effort.

Conclusions

SUSY masses can be measure to a fraction of 1 GeV in a few cases and to about 1 GeV in the others.

The tracker should measure momenta to about 1 GeV or better. This leads to similar errors in the mass due to an uncertainty of 0.5% in the center of energy.