$e^+e^- \to \gamma\ \tilde{\chi}_1^0\tilde{\chi}_1^0$

Koichi Murase (B4, University of Tokyo)

2009年12月10日

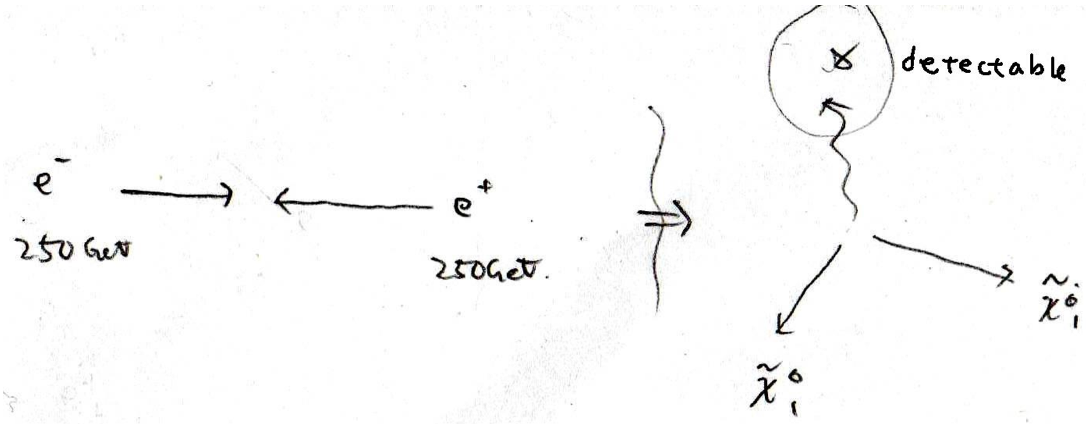
1

Introduction

Introduction

Energy of the ILC will reach to 500GeV, and then new physics can be expected to be observed. In particular, processes involving LSP (Lightest SUSY Particles) are important.

We consider the scenario in which the LSP is the only accessible SUSY particle, and evaluate if this processes $e^+e^- \rightarrow \gamma\ \tilde{\chi}_1^0\tilde{\chi}_1^0$can be seen at the ILC.



A photon is the only detectable particle in a process.

Question: Is it possible to say based on the ILC experiment results that there are significantly the target processes?

2 Method

Event generation	
↓	
MC Simulation	Simulating detector response using Mokka
↓	
Reconstruction	Reconstructing events using Marlin (Pandora pfo, etc.)
↓	
Event selection	Selecting events in which the only detected particle is a photon using Marlin (original processor)
↓	
Analysis	Applying cut, evaluating significance, etc. using ROOT

Event selection

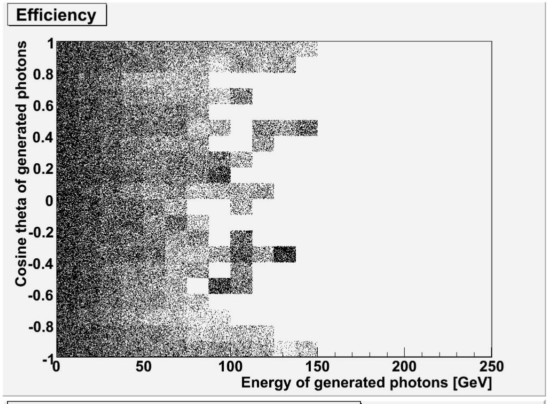
Selecting events under following conditions (event in which only one photon is detected)

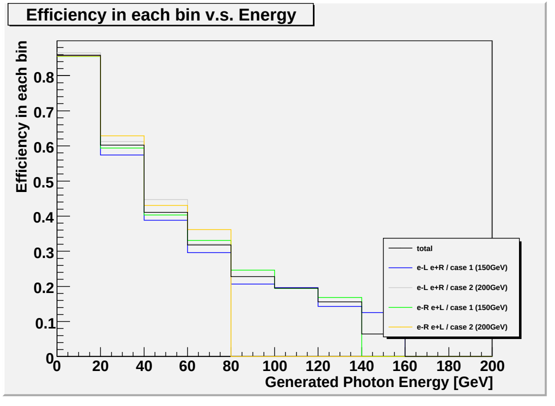
- The number of reconstructed particles is one.
- The charge of the particle is neutral.
- $\frac{\Delta E_{\mathrm{ECAL}}}{\Delta E_{\mathrm{ECAL}}+\Delta E_{\mathrm{HCAL}}} \geq 0.8$
  where ΔE_{ECAL} and ΔE_{HCAL} are the energy deposits in ECAL and HCAL, respectively.

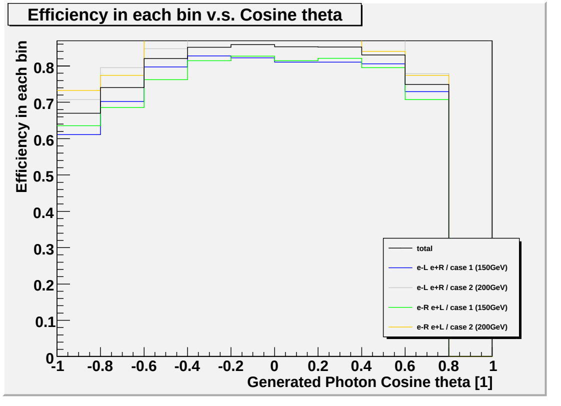
Usable independent variables are <u>the energy</u> and <u>$\cos\theta$</u> of the photon.

Efficiency of the selection

$$\frac{N_{\rm ev}(\text{after selection})}{N_{\rm ev}(\text{generated})}$$





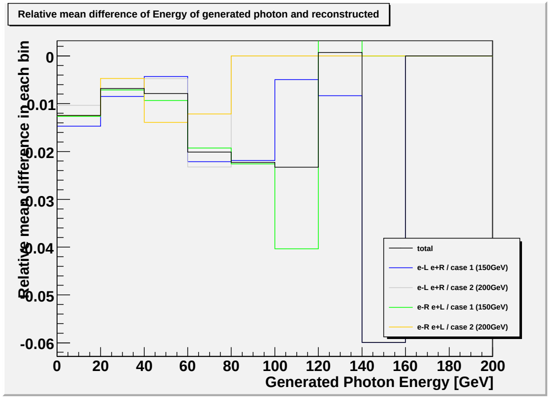


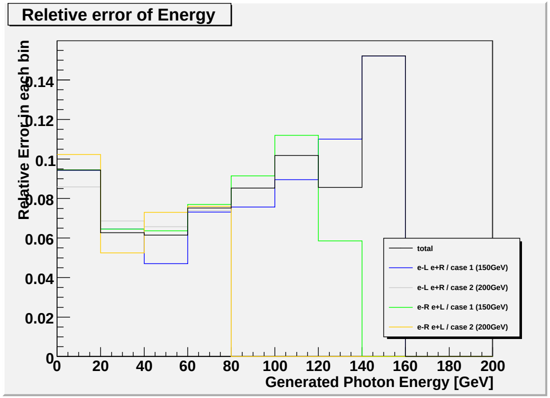
As a generated photon energy increases, the efficiency decreases.

Difference between generated photons and reconstructed photons

- $E_{\rm gen}$: Generated photon energy
- $E_{\rm rec}$: Reconstructed photon energy

Relative Bias: $\frac{\langle E_{\rm rec} - E_{\rm gen} \rangle}{\langle E_{\rm gen} \rangle}$ RMS/Mean: $\frac{\sqrt{\langle (E_{\rm rec} - E_{\rm gen})^2 \rangle}}{\langle E_{\rm gen} \rangle}$



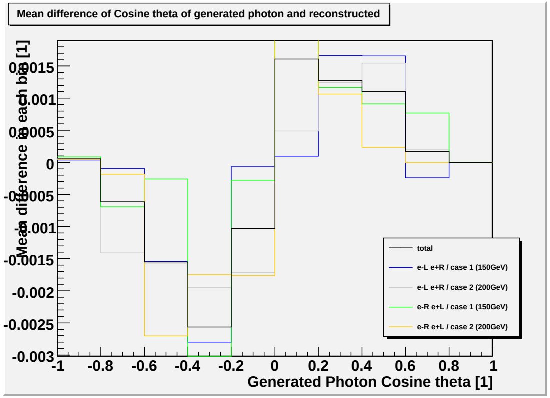


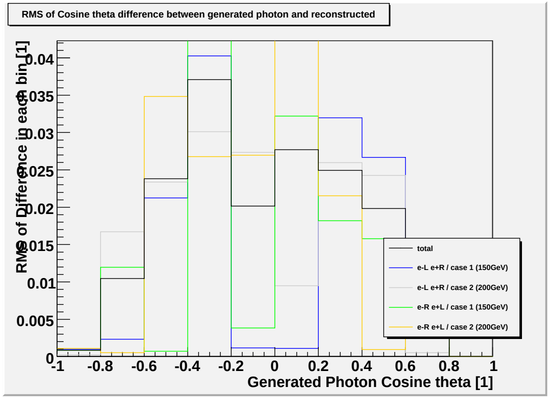
- $E_{\rm rec}$s are lower than $E_{\rm gen}$s by 2-3%.
- RMS of the $(E_{\rm rec} - \langle E_{\rm rec} \rangle)$ is about 10% of $E_{\rm gen}$.

Difference between generated photons and reconstructed photons

- $\cos\theta_{\rm gen}$: $\cos\theta$ of a generated photon
- $\cos\theta_{\rm rec}$: $\cos\theta$ of the reconstructed photon corresponding to the generated photon

$$\text{Bias: } \frac{\langle \cos\theta_{\rm rec} - \cos\theta_{\rm gen}\rangle}{\langle \cos\theta_{\rm gen}\rangle} \qquad \text{RMS: } \frac{\sqrt{\langle (\cos\theta_{\rm rec} - \cos\theta_{\rm gen})^2\rangle}}{\langle \cos\theta_{\rm gen}\rangle}$$



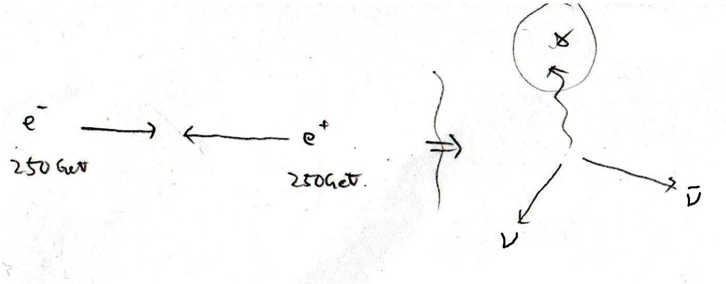


- RMS of the $(\cos\theta_{\rm rec} - \langle\cos\theta_{\rm rec}\rangle)$ is small when $|\cos\theta_{\rm gen}| \sim 1$.

Main background processes after event selection

Althogh standard model processes are taken into account, few processes have a large fraction of the background event number.

- n1n1a, n2n2a, n3n3a, n1n1aa, ...



- e1a_e1a, ae1_e1a, ...
- aa_e3e3, aa_e1e1, aa_e2e2, ...

3

Results 1

Results without cuts

Results without cutting by energy or $\cos\theta$.

	id	Process name	Cross section	Number of events	
				$500\mathrm{fb}^{-1}$	$1000\mathrm{fb}^{-1}$
	case 1	ne1ne1a_500_ep-1.0_em+1.0_p1	11.8718	5935.88	11871.8
	case 1	ne1ne1a_500_ep+1.0_em-1.0_p1	0.0232709	11.6355	23.2709
	case 2	ne1ne1a_500_ep-1.0_em+1.0_p2	3.79893	1899.47	3798.93
	case 2	ne1ne1a_500_ep+1.0_em-1.0_p2	0.00680909	3.40455	6.80909
	background	total of background	49625.1	2.48126e+07	4.96251e+07
	w11730	e1a_e1a_500_ep+0.0_em-1.0	9441.11	4.72056e+06	9.44111e+06
	w11731	e1a_e1a_500_ep+0.0_em-1.0	7595.69	3.79785e+06	7.59569e+06
	w11732	e1a_e1a_500_ep+0.0_em+1.0	1019.05	509526	1.01905e+06
	w11733	e1a_e1a_500_ep+0.0_em+1.0	916.003	458002	916003
	w11734	ae1_e1a_500_ep-1.0_em+0.0	3562.82	1.78141e+06	3.56282e+06
	w11735	ae1_e1a_500_ep-1.0_em+0.0	2883.87	1.44193e+06	2.88387e+06
Polarization “Left”	w11736	ae1_e1a_500_ep+1.0_em+0.0	6566.2	3.2831e+06	6.5662e+06
	w11737	ae1_e1a_500_ep+1.0_em+0.0	5388.49	2.69425e+06	5.38849e+06
	w12150	aa_e1e1_500_ep+0.0_em+0.0	150.005	75002.6	150005
	w12151	aa_e1e1_500_ep+0.0_em+0.0	129.984	64991.9	129984
	w12152	aa_e1e1_500_ep+0.0_em+0.0	53.4053	26702.7	53405.3
	w19092	aa_e3e3_500_ep+0.0_em+0.0	780.011	390006	780011
	w19093	aa_e3e3_500_ep+0.0_em+0.0	434.945	217473	434945
	w19094	aa_e3e3_500_ep+0.0_em+0.0	450.008	225004	450008
	w19095	aa_e3e3_500_ep+0.0_em+0.0	170	85000	170000
	w11739	n1n1a_500_ep+1.0_em-1.0	9962.1	4.98105e+06	9.9621e+06
	w11740	n1n1a_500_ep-1.0_em+1.0	0.813478	406.739	813.478
	w11743	n2n2a_500_ep+1.0_em-1.0	20.8574	10428.7	20857.4
	w11744	n2n2a_500_ep-1.0_em+1.0	0.814216	407.108	814.216
	w11747	n3n3a_500_ep+1.0_em-1.0	21.6796	10839.8	21679.6
	w11748	n3n3a_500_ep-1.0_em+1.0	0.80045	400.225	800.45

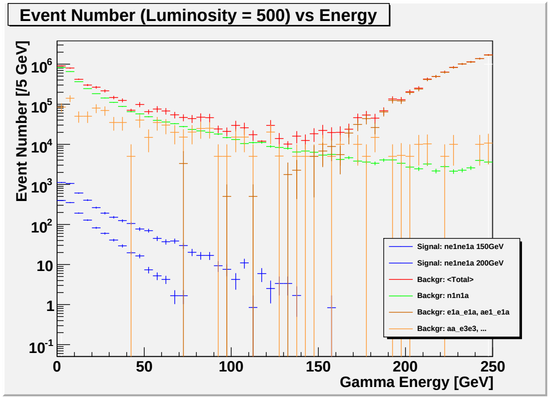
	id	Process name	Cross section	Number of events 500fb^{-1}	1000fb^{-1}
	case 1	ne1ne1a_500_ep-1.0_em+1.0_p1	0.710395	355.197	710.395
	case 1	ne1ne1a_500_ep+1.0_em-1.0_p1	0.388971	194.485	388.971
	case 2	ne1ne1a_500_ep-1.0_em+1.0_p2	0.227328	113.664	227.328
	case 2	ne1ne1a_500_ep+1.0_em-1.0_p2	0.113823	56.9115	113.823
	background	total of background	40580.2	2.02901e+07	4.05802e+07
	w11730	e1a_e1a_500_ep+0.0_em-1.0	1049.01	524507	1.04901e+06
	w11731	e1a_e1a_500_ep+0.0_em-1.0	843.984	421992	843984
	w11732	e1a_e1a_500_ep+0.0_em+1.0	9171.44	4.58572e+06	9.17144e+06
	w11733	e1a_e1a_500_ep+0.0_em+1.0	8244.03	4.12201e+06	8.24403e+06
	w11734	ae1_e1a_500_ep-1.0_em+0.0	6616.84	3.30842e+06	6.61684e+06
	w11735	ae1_e1a_500_ep-1.0_em+0.0	5355.75	2.67787e+06	5.35575e+06
Polarization "Right"	w11736	ae1_e1a_500_ep+1.0_em+0.0	3535.58	1.76779e+06	3.53558e+06
	w11737	ae1_e1a_500_ep+1.0_em+0.0	2901.5	1.45075e+06	2.9015e+06
	w12150	aa_e1e1_500_ep+0.0_em+0.0	150.005	75002.6	150005
	w12151	aa_e1e1_500_ep+0.0_em+0.0	129.984	64991.9	129984
	w12152	aa_e1e1_500_ep+0.0_em+0.0	53.4053	26702.7	53405.3
	w19092	aa_e3e3_500_ep+0.0_em+0.0	780.011	390006	780011
	w19093	aa_e3e3_500_ep+0.0_em+0.0	434.945	217473	434945
	w19094	aa_e3e3_500_ep+0.0_em+0.0	450.008	225004	450008
	w19095	aa_e3e3_500_ep+0.0_em+0.0	170	85000	170000
	w11739	n1n1a_500_ep+1.0_em-1.0	596.829	298414	596829
	w11740	n1n1a_500_ep-1.0_em+1.0	13.5958	6797.89	13595.8
	w11743	n2n2a_500_ep+1.0_em-1.0	1.24781	623.907	1247.81
	w11744	n2n2a_500_ep-1.0_em+1.0	13.6077	6803.85	13607.7
	w11747	n3n3a_500_ep+1.0_em-1.0	1.29698	648.49	1296.98
	w11748	n3n3a_500_ep-1.0_em+1.0	13.3801	6690.05	13380.1

Dominant background processes are `e1a_e1a`, `ae1_ae1`, `aa_e3e3`, `n1n1a`, etc.

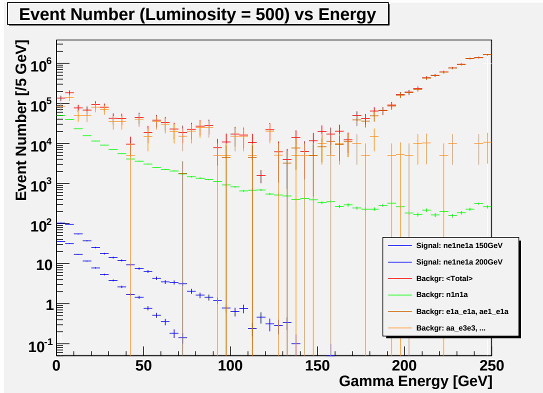
Results without cuts

Event number vs. photon energy

Polarization “Left”



Polarization “Right”

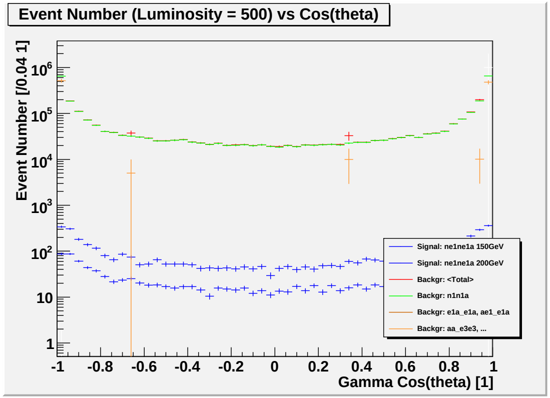


`e1a_e1a` has a large contribution in a high energy region.

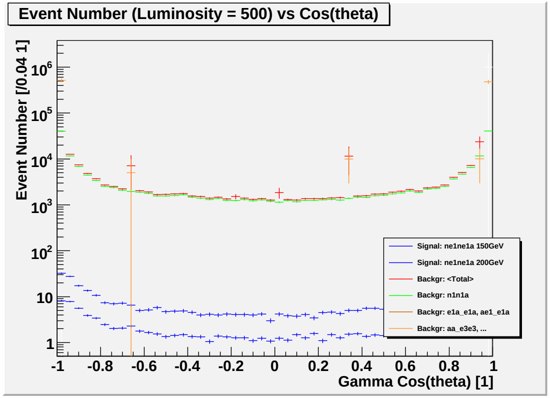
Results without cuts

Event number vs. $\cos\theta$ of a photon

Polarization "Left"



Polarization "Right"



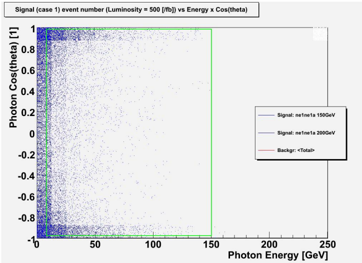
`e1a_e1a/ae1_ae1/aa_e1e1` processes will vanish on cutting $|\cos\theta| > 0.99$

Results without cuts

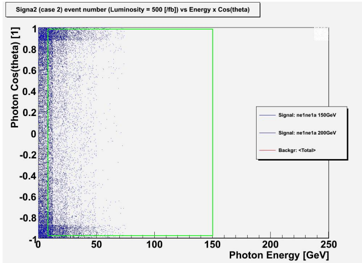
Event number vs. $(E, \cos\theta)$

Polarization "Left"

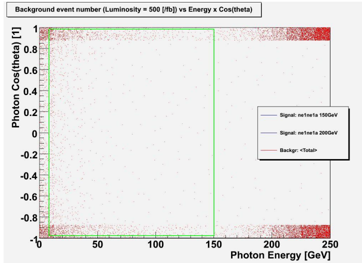
Signal Case 1



Signal Case 2

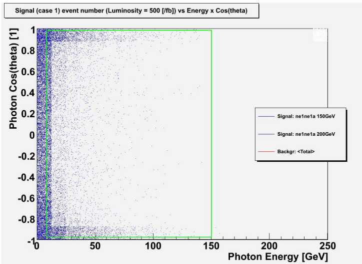


Background

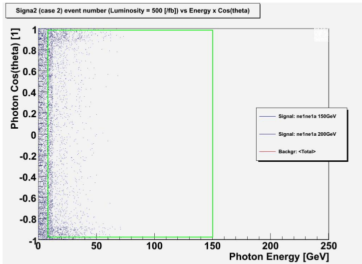


Polarization "Right"

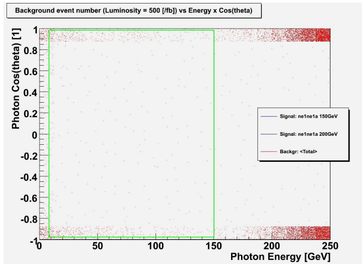
Signal Case 1



Signal Case 2



Background



Green rectangles indicate the region $\{(E, \cos\theta) |\ E > 8\text{GeV and } |\cos\theta| < 0.99\}$.

4

Results 2

Results with cut ($E > 8$GeV and $|\cos\theta| < 0.99$)

Results without cutting by energy or $\cos\theta$.

	id	Process name	Cross section	Number of events 500fb^{-1}	Number of events 1000fb^{-1}
	case 1	ne1ne1a_500_ep-1.0_em+1.0_p1	4.9128	2456.4	4912.8
	case 1	ne1ne1a_500_ep+1.0_em-1.0_p1	0.00968184	4.84092	9.68184
	case 2	ne1ne1a_500_ep-1.0_em+1.0_p2	1.37957	689.786	1379.57
	case 2	ne1ne1a_500_ep+1.0_em-1.0_p2	0.00250562	1.25281	2.50562
	background	total of background	2607.92	1.30396e+06	2.60792e+06
Polarization "Left"	w11739	n1n1a_500_ep+1.0_em-1.0	2552.67	1.27634e+06	2.55267e+06
	w11740	n1n1a_500_ep-1.0_em+1.0	0.628519	314.259	628.519
	w11743	n2n2a_500_ep+1.0_em-1.0	16.0734	8036.7	16073.4
	w11744	n2n2a_500_ep-1.0_em+1.0	0.621575	310.787	621.575
	w11747	n3n3a_500_ep+1.0_em-1.0	16.7402	8370.11	16740.2
	w11748	n3n3a_500_ep-1.0_em+1.0	0.61703	308.515	617.03
	w11751	n1n1aa_500_ep+1.0_em-1.0	15.2325	7616.24	15232.5
	w12202	e1a_e1n2n2_500_ep+0.0_em-1.0	1.80355	901.774	1803.55
	w12204	e1a_e1n2n2_500_ep+0.0_em+1.0	0.100687	50.3434	100.687
	w12263	ae1_e1n2n2_500_ep-1.0_em+0.0	0.696301	348.15	696.301
	w12264	ae1_e1n2n2_500_ep+1.0_em+0.0	0.650646	325.323	650.646
	w12265	ae1_e1n2n2_500_ep+1.0_em+0.0	0.650381	325.191	650.381
	w12268	ae1_e1n3n3_500_ep+1.0_em+0.0	0.650426	325.213	650.426
	w12269	ae1_e1n3n3_500_ep+1.0_em+0.0	0.64978	324.89	649.78

	id	Process name	Cross section	Number of events	
				$500 fb^{-1}$	$1000 fb^{-1}$
	case 1	ne1ne1a_500_ep-1.0_em+1.0_p1	0.293932	146.966	293.932
	case 1	ne1ne1a_500_ep+1.0_em-1.0_p1	0.161829	80.9143	161.829
	case 2	ne1ne1a_500_ep-1.0_em+1.0_p2	0.0825381	41.269	82.5381
	case 2	ne1ne1a_500_ep+1.0_em-1.0_p2	0.0418784	20.9392	41.8784
	background	total of background	190.7	95350.1	190700
Polarization "Right"	w11739	n1n1a_500_ep+1.0_em-1.0	152.771	76385.3	152771
	w11740	n1n1a_500_ep-1.0_em+1.0	10.5048	5252.42	10504.8
	w11743	n2n2a_500_ep+1.0_em-1.0	0.961681	480.841	961.681
	w11744	n2n2a_500_ep-1.0_em+1.0	10.3886	5194.32	10388.6
	w11747	n3n3a_500_ep+1.0_em-1.0	1.00157	500.784	1001.57
	w11748	n3n3a_500_ep-1.0_em+1.0	10.3137	5156.83	10313.7
	w11751	n1n1aa_500_ep+1.0_em-1.0	0.911269	455.635	911.269
	w12202	e1a_e1n2n2_500_ep+0.0_em-1.0	0.200394	100.197	200.394
	w12204	e1a_e1n2n2_500_ep+0.0_em+1.0	0.906181	453.09	906.181
	w12263	ae1_e1n2n2_500_ep-1.0_em+0.0	1.29313	646.565	1293.13
	w12264	ae1_e1n2n2_500_ep+1.0_em+0.0	0.350348	175.174	350.348
	w12265	ae1_e1n2n2_500_ep+1.0_em+0.0	0.350205	175.103	350.205
	w12268	ae1_e1n3n3_500_ep+1.0_em+0.0	0.350229	175.115	350.229
	w12269	ae1_e1n3n3_500_ep+1.0_em+0.0	0.349881	174.941	349.881

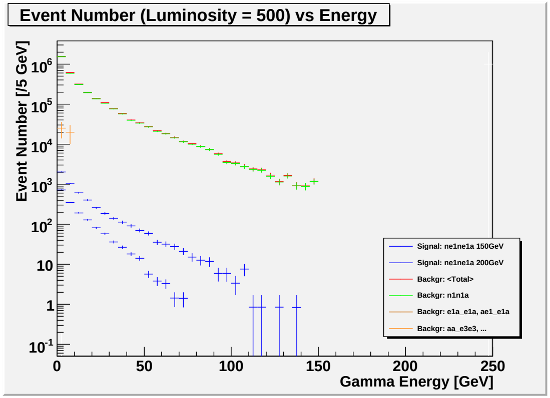
Dominant background processes are `n1n1a, n2n2a, n3n3a` etc.

Contributions from `e1a_e1a, ae1_e1a, aa_e3e3` vanished.

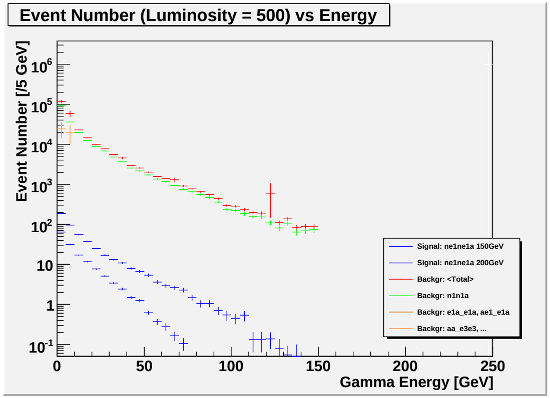
Results with cut ($E > 8\text{GeV}$ and $|\cos\theta| < 0.99$)

Event number vs. photon energy

Polarization "Left"



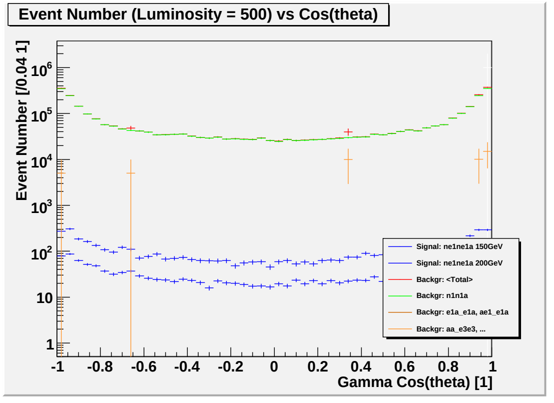
Polarization "Right"



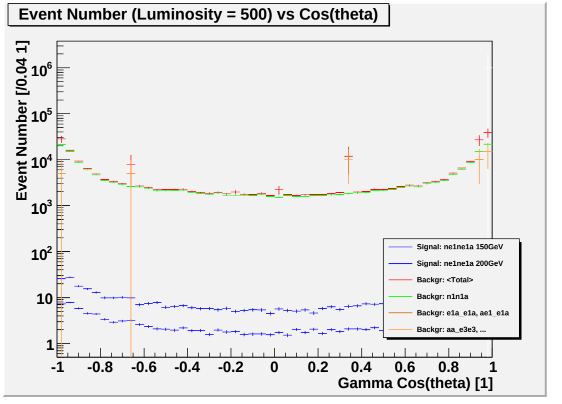
Results with cut ($E > 8\text{GeV}$ and $|\cos\theta| < 0.99$)

Event number vs. $\cos\theta$ of a photon

Polarization “Left”



Polarization “Right”



Cuts and significances

Best cuts when the luminosity is 500fb^{-1}

Polarization Cut	N_{ev} of background	N_{ev} of signal (case 1) Significance (case 1)	N_{ev} of signal (case 2) Significance (case 2)
Left $\lvert\cos\theta\rvert < 0.99$ and $9 \le E < 110$	1.19225e+06	2273.05 <u>2.08173</u>	622.548 0.570149
Left $\lvert\cos\theta\rvert < 0.99$ and $9 \le E < 50$	1.05585e+06	2034.98 1.98043	606.894 <u>0.590625</u>
Right $\lvert\cos\theta\rvert < 0.99$ and $9 \le E < 110$	86967.6	210.434 0.713571	56.419 0.191314
Right $\lvert\cos\theta\rvert < 0.99$ and $9 \le E < 50$	76526.7	187.679 0.678438	54.8826 0.198394
Left † $\lvert\cos\theta\rvert < 0.98$ and $0.7 \le E < 110$	3.15291e+06	5094.59 <u>2.86915</u>	1630.01 0.917981
Left † $\lvert\cos\theta\rvert < 0.95$ and $0.7 \le E < 50$	2.46996e+06	4375.37 2.78401	1473.96 <u>0.937869</u>

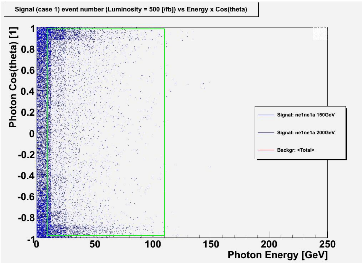
† There were no reconstructed data for `n2n2a`, `n3n3a`, ... events whose photon energy is under 8GeV, and used the scaled differential cross section of `n1n1a` instead of that of `n2n2a`, `n3n3a`, ...

Results with cut

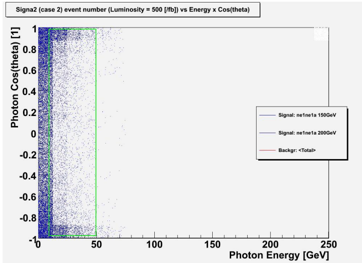
Event number vs. $(E, \cos\theta)$

Polarization “Left”

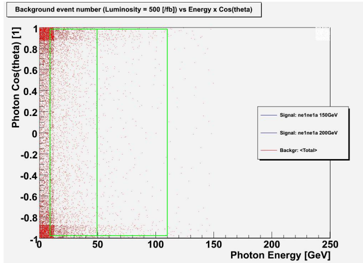
Signal Case 1



Signal Case 2

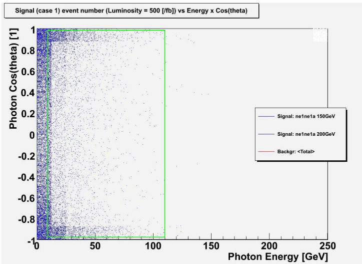


Background

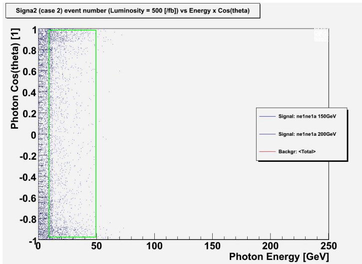


Polarization “Right”

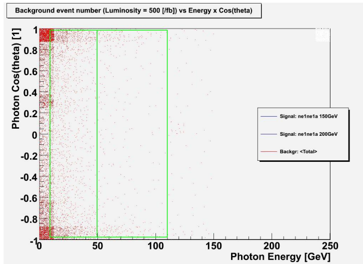
Signal Case 1



Signal Case 2



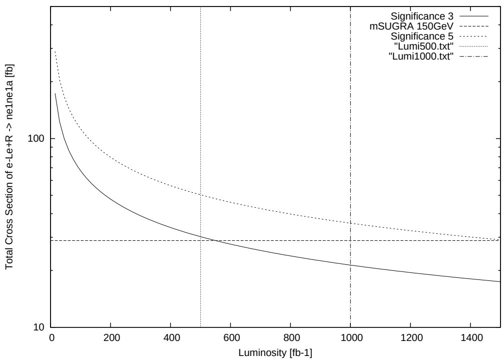
Background



Significance and the cross section of the signal

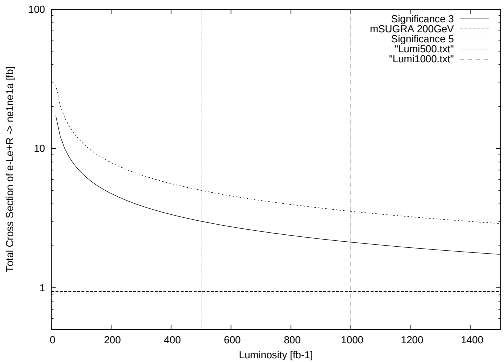
There are some degrees of freedom in SUSY parameters, and the cross section of the signal may vary as the paramters changed and thus the significance can be changed. Assume that the differential cross section by energy and angle only scales and does not change the distribution form under the parameters' changing.

the mass of LSP: 150GeV



Type	Cross Section
mSUGRA	28.8fb
Significance 3 at 500 fb^{-1}	$\sim$ 30fb
Significance 5 at 500 fb^{-1}	$\sim$ 60fb

the mass of LSP: 200GeV



Type	Cross Section
mSUGRA	0.939fb
Significance 3 at 500 fb^{-1}	$\sim$ 3.5fb
Significance 5 at 500 fb^{-1}	$\sim$ 6fb

5

Summary and future plans

5.1 Summary

- Significance in the “left” polarization experiment is higher than that in the “right”.
- When events in which the photon energy is higher than 8GeV is used, the upper bound of significance will be nearly 2 if the mass of LSP is 150GeV, and be nearly 0.6 if the mass is 200GeV.
- If events of the low energy photon are included, the upper bound of significance will be nearly 3 if the mass of LSP is 150GeV, and be nearly 1 if the mass is 200GeV.

5.2 Plans

- Take into account **`n2n2a, n3n3a`** events.
  Simulate and reconstruct **`n2n2a, n3n3a`** events involving a photon whose energy is lower than 8GeV.
- Mass reconstruction
  Reconstruct the mass of LSP using differential cross section dependencies for mass.
  Estimate the error of the reconstructed mass.
- Other SUSY parameters