Study of fermion pair events at the 250 GeV ILC

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Abstract

Precise measurements of electroweak processes at the International Linear Collider (ILC) will provide unique opportunities to explore new physics beyond the standard model. Fermion pair production events are sensitive to new interactions involving a new heavy gauge boson or an electroweak interacting massive particle (EWIMP).We studied the mass reach of new particles at the ILC with $\sqrt{s} = 250$ GeV by using $e^+e^- \to e^+e^-$and $e^+e^- \to \mu^+\mu^-$ events. We obtained the new mass reaches BSM particles with 90% confidence level using a toy Monte Carlo technique.

1 Introduction

The International Linear Collider (ILC)[1] is an electron-positron linear collider, which is planned to be constructed in Japan. The main purposes of the ILC are discoveries of new particles and precise measurement of the Higgs boson and the top quark. The center of mass energy will be 250 GeV with 20 km tunnel length. In the future, the center of mass energy can be upgraded to 1 TeV with 50 km tunnel length.

We know that the reaction of $e^+e^- \to 2f$ events involve the emission and absorption or exchange of Z bosons in the Standard Model. In some models beyond the Standard Model (BSM), additional particles can also contribute to the interaction. Precise measurements of electroweak processes at the ILC can search these particles.

In this paper, We studied effects of new heavy gauge bosons (Z' particles) with five BSM models and electroweak WIMPs with three BSM models.We calculated the mass reach of new particles at the ILC with $\sqrt{s} = 250$ GeV by using $e^+e^- \to e^+e^-$and $e^+e^- \to \mu^+\mu^-$ events. We observed the effect of BSM models on the cross section of the final state leptons and the angular distributions. We calculated the mass limit of each model with toy Monte Carlo technique to make pseudo experiments.

2 Models

In this study, we considered five types of Z', which are Sequential Standard Model (SSM), E_6 group (χ model, ψ model, η model), and Alternative Left-Right symmetry (ALR)[2]. These Z' bosons are exchanged between leptons, like Z boson, when electroweak interactions occur (See Fig.1).

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We also considered three EWIMP models, which are Minimal Dark Matter (MDM), Higgsino, and Wino[3]. These particles couple to the Z' boson in a loop contribution (See Fig.2), which affects the $e^+e^- \to 2f$ interaction. The quantum numbers of each EWIMP models are shown in Table 1.

Table 1: Quantum numbers of each model

model	$SU(2)_L$	$U(1)_\gamma$ hypercharge
MDM	$n = 5$ (pentet)	0
Higgsino	$n = 2$ (doublet)	$\pm 1/2$
Wino	$n = 3$ (triplet)	0

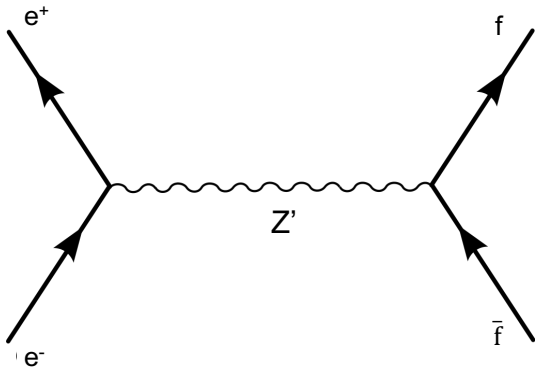

Figure 1: Feynman diagram involving Z'

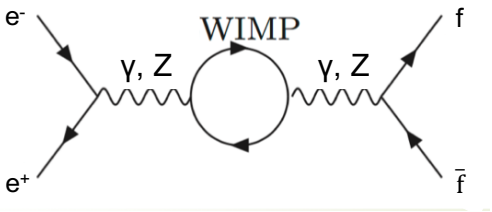

Figure 2: Feynman diagram involving EWIMP

3 Simulation

In this study, we used the ILCsoft[4] v01-16-p10 for the simulation and reconstruction. We used samples prepared for Detailed Baseline Design (DBD) of International Large Detector (ILD)[5] concept. The samples were generated by WHIZARD 1.95[6], and simulated by Mokka, with detector geometry of ILD_v1_o5. There is a special treatment of $e^+e^- \to e^+e^-$ samples, which includes preselection of xxxxxx. It was also prepared with weighted production, which produces the same amount of events for each $\cos\theta$ bins of 0.1 width. The ILD detector consists of vertex detector, a tracking detector, an electromagnetic calorimeter, and a hadron calorimeter. These detectors are located inside a superconducting solenoid with 3.5 Tesla magnetic field. The magnetic flux of the coil is returned in an iron yoke, equipped with a muon detector.The center of mass energy is $\sqrt{s} = 250$ GeV and the total luminosity is 2000 fb^{-1}. The beam polarization was set to 80% left-handed for the electron beam and 30% right-handed for the positron beam. The luminosity of left-handed electron and right-handed positron is 900 fb^{-1}, and right-handed electron and left-handed positron is also 900 fb^{-1}. After the detector simulation, the events are reconstructed by Marlin[7], including Pandora PFA[8] for track-cluster matching.

4 Event selection

In this section, we explain the separation of background events from signal events.

4.1 $e^+e^- \to e^+e^-$

To select the $e^+e^- \to e^+e^-$ events, we considered five cut terms. The final states of background events are $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \tau^+\tau^-$, and $e^+e^- \to 4f$ events, with only lepton in the final states. Firstly, we selected tracks with energy $E_{tr} > 15$ GeV. Events which do not have positive and negative tracks meeting the requirement are removed. If there are more than one pair of such tracks, the track of highest energies are selected for both positive and negative charge. After that, we applied following selection conditions.

- The ratio of energy deposit at calorimeter to the energy of track : $E_{\rm cal}/E_{\rm tr} > 0.8$ to reject muon events.
- $E_{\rm ecal}/(E_{\rm ecal} + E_{\rm hcal}) > 0.85$ to separate hadrons and muons. $E_{\rm ecal}$ is the energy deposit at the electromagnetic calorimeter, and $E_{\rm hcal}$ is the energy deposit at the hadron calorimeter.
- The energy sum of two tracks : $E_{\rm sum} > 230$ GeV to exclude 4 fermion events and tau events.
- $|\cos\theta| < 0.95$ to cut t-channel $e^+e^- \to e^+e^-$ events which have huge cross section at the forward angle. θ is the angle of the track with respect to the beam axis.

The result of event selection is shown in Table 2. Most of background events can be excluded by these cut terms.

Table 2: Event selection of electron channel

Cut terms	signal(e^+e^-)	$\mu^+\mu^-$	$\tau^+\tau^-$	$4f$
all events	8.26×10^8	9.73×10^6	1.17×10^7	7.73×10^6
$E_{\rm tr} > 15$ GeV	8.18×10^8	9.36×10^6	1.17×10^7	6.39×10^6
$E_{\rm cal}/E_{\rm tr} > 0.8$	8.18×10^8	2.91×10^4	1.17×10^7	2.60×10^6
$E_{\rm ecal}/(E_{\rm ecal} + E_{\rm hcal}) > 0.85$	8.17×10^8	1.22×10^4	1.17×10^7	1.66×10^6
$E_{\rm sum} > 230$ GeV	3.68×10^8	14	21	1.14×10^4
$\lvert\cos\theta\rvert < 0.95$	2.57×10^7	14	21	1.14×10^4

4.2 $e^+e^- \to \mu^+\mu^-$

We selected most energetic tracks of positive and negative charge with $E_{\rm tr} > 15$ GeV as same as $e^+e^- \to e^+e^-$ case, then we applied following selection conditions.

- $E_{\rm cal}/E_{\rm tr} < 0.3$ and $E_{\rm ecal}/(E_{\rm ecal} + E_{\rm hcal}) < 0.45$ to reject electrons and hadrons.
- $E_{\rm sum} > 230$ GeV to exclude 4 fermion and tau events.
- $|\cos\theta| < 0.95$ to cut t-channel $e^+e^- \to e^+e^-$ events.

The result of event selection is shown in Table 3. We could also exclude most of background events.

5 Analysis

After the event selection, we obtained the angular distribution for each channel with 20 bins, shown in Fig.3 and Fig.4. Vertical axis of the electron channel is logarithmic scale, and vertical axis of the muon channel is linear scale. The mass reach of new particle were calculated using these angular distributions.

Table 3: Event selection of muon channel

Cut terms	signal($\mu^+ u^-$)	e^+e^-	$\tau^+\tau^-$	$4f$
all events	9.73×10^6	8.26×10^8	1.17×10^7	7.73×10^6
$E_{\rm tr} > 15$ GeV	9.36×10^6	8.18×10^8	1.17×10^7	6.39×10^6
$E_{\rm cal}/E_{\rm tr} < 0.3$	9.26×10^6	1.49×10^6	8.97×10^5	3.35×10^6
$E_{\rm ecal}/(E_{\rm ecal} + E_{\rm hcal}) < 0.45$	2.91×10^6	1.49×10^6	7.80×10^5	1.33×10^6
$E_{\rm sum} > 230$ GeV	7.49×10^5	56	4.52×10^3	32
$\lvert\cos\theta\rvert < 0.95$	7.48×10^5	56	4.48×10^3	32

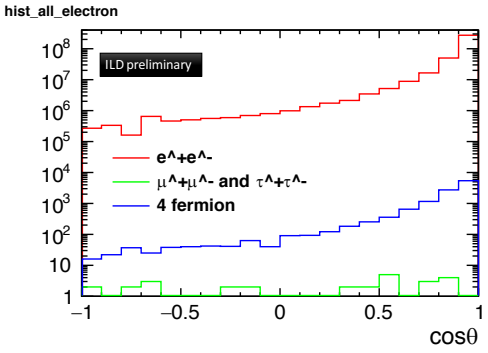

Figure 3: Angular distribution of electron channel

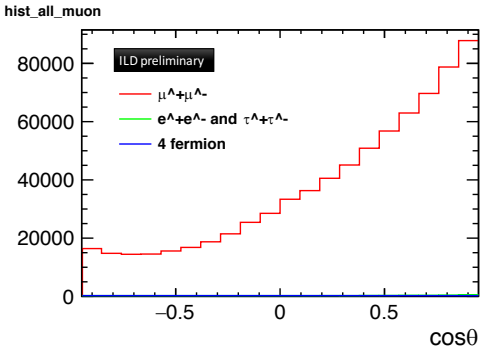

Figure 4: Angular distribution of muon channel

First, we calculated deviations of particle cross section with each BSM model at each bin. Second, we made pseudo experiments for each bin using SM angular distribution with fluctuation of the Poisson distribution. Third, we calculated χ^2 between the pseudo experiments and the each BSM model to obtain probability. At this time, 0.1% systematics are assumed for each bin. The distributions of probability are shown in Fig.5 and Fig.6. Finally, We obtained medians from the probability distributions of each BSM model. Mass dependence of the probability for each particles is shown in Fig.7 and Fig.9. The blue lines where the probability is 0.1 show 90% confidence level mass limit. These values for each particle are shown in Table 4 and Table 5.

Table 4: Mass reach of Z'

BSM	mass reach (90% CL)
SSM	3.4 TeV
ALR	5.0 TeV
χ	3.5 TeV
ψ	1.7 TeV
η	1.7 TeV

Table 5: Mass reach of EWIMP

BSM	mass reach (90% CL)
MDM	500 GeV
Higgsino	180 GeV
Wino	240 GeV

The mass reaches of Z' are comparable to LHC. Thus we have to conclude that the CM energy should be much higher than 250 GeV to obtain significant gain of measurement from LHC results. The mass reaches of EWIMP are bigger than 125 GeV, which is the limited direct search, so we think the $e^+e^- \to 2f$ can be a powerful prove to look for such a new physics.

6 Summary

We are investigating the effects from BSM models on $e^+e^- \to 2f$ final states at e^+e^- colliders. We obtained the mass reach of the new BSM particles at 90% confidence level at ILC with $\sqrt{s} = 250$ GeV. In this paper, we considered the mass reach using $e^+e^- \to e^+e^-$ and $e^+e^- \to \mu^+\mu^-$, but we didn't include $e^+e^- \to \tau^+\tau^-$. We expect that better mass reach can be obtained by including tau and hadron channel.

Acknowledgements

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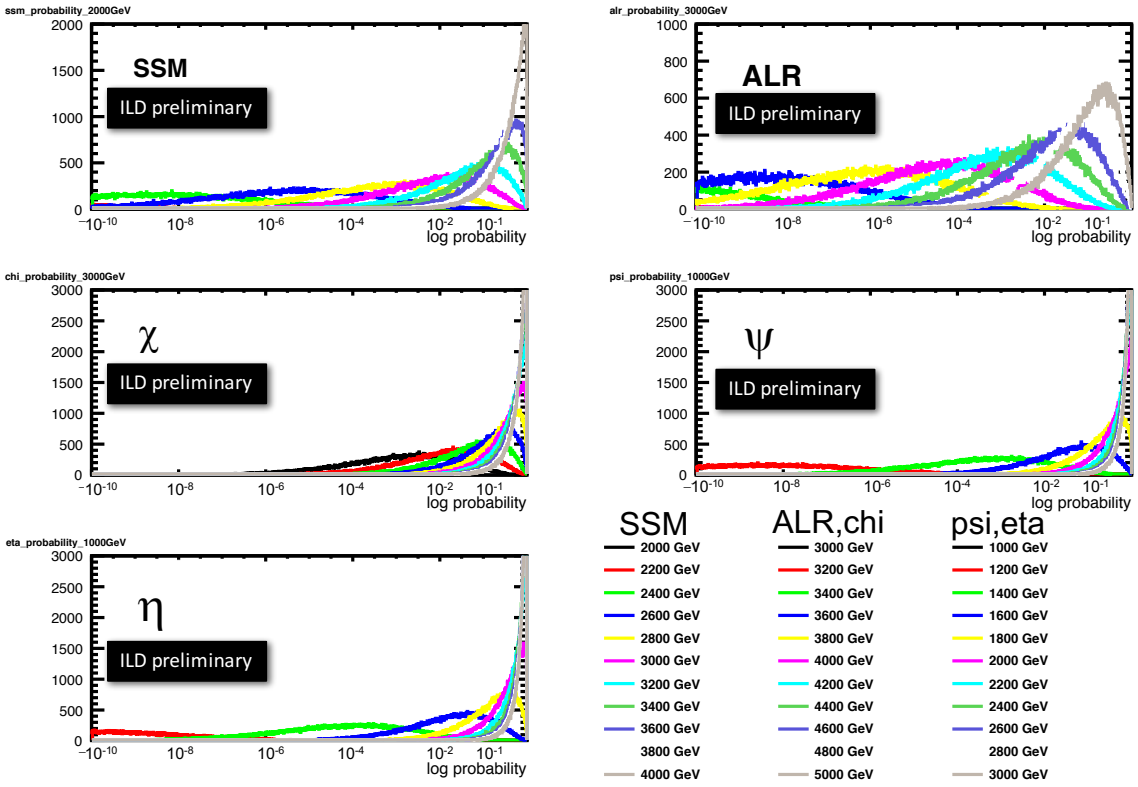

Figure 5: Probability distribution of Z' models with 100,000 pseudo experiments. The colors show different masses of Z' bosons as shown in the legend.

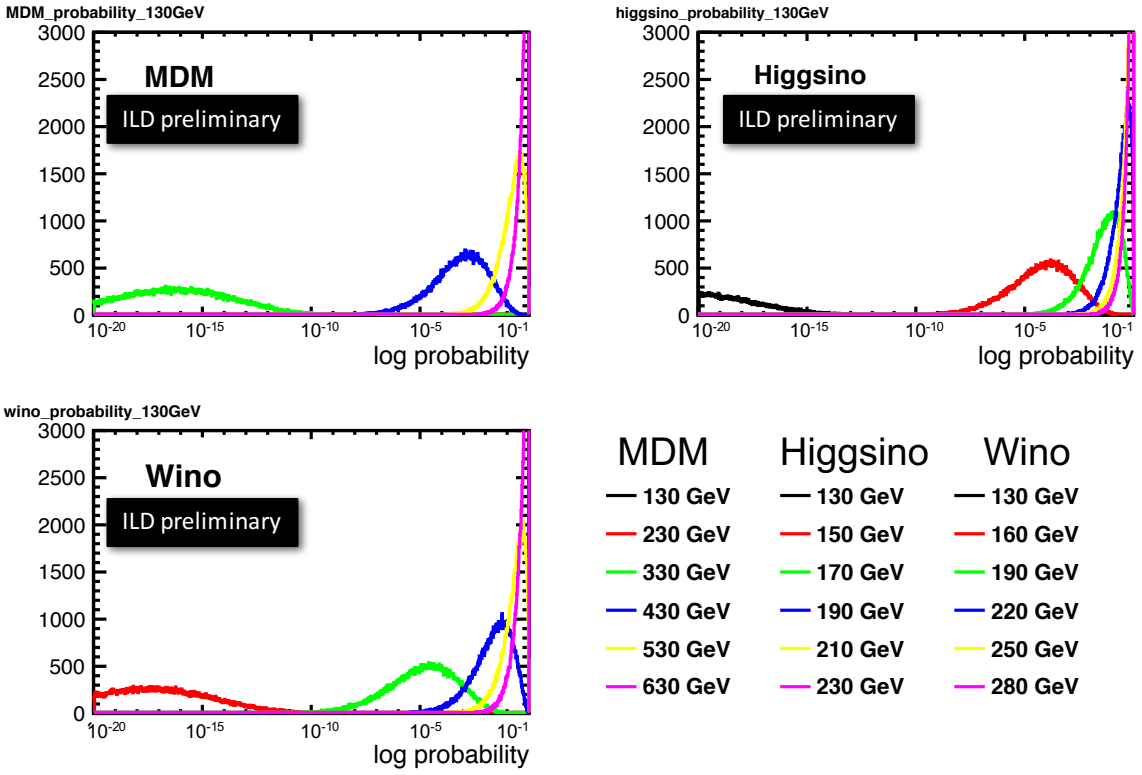

Figure 6: Probability distribution of EWIMP models with 100,000 pseudo experiments. The colors show different masses of EWIMPs as shown in the legend.

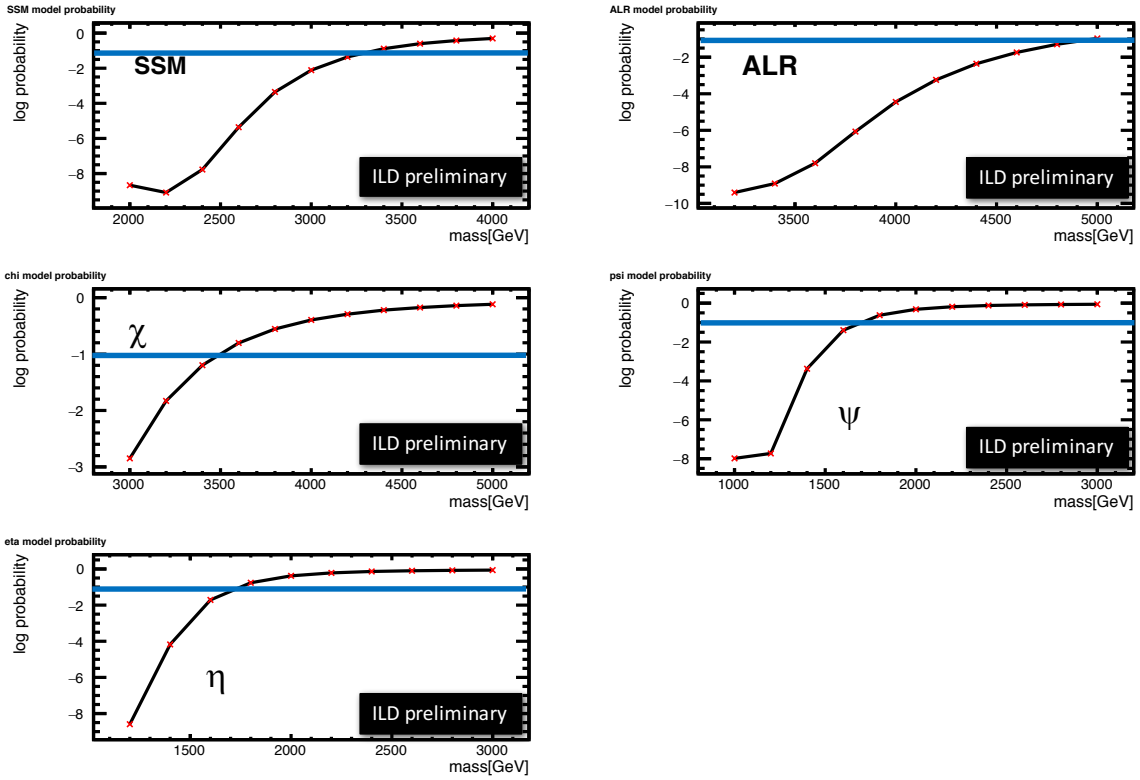

Figure 7: Median of the probability distribution obtained by pseudo experiments with Z' models. The blue lines show exclusion limit at 90% confidence level.

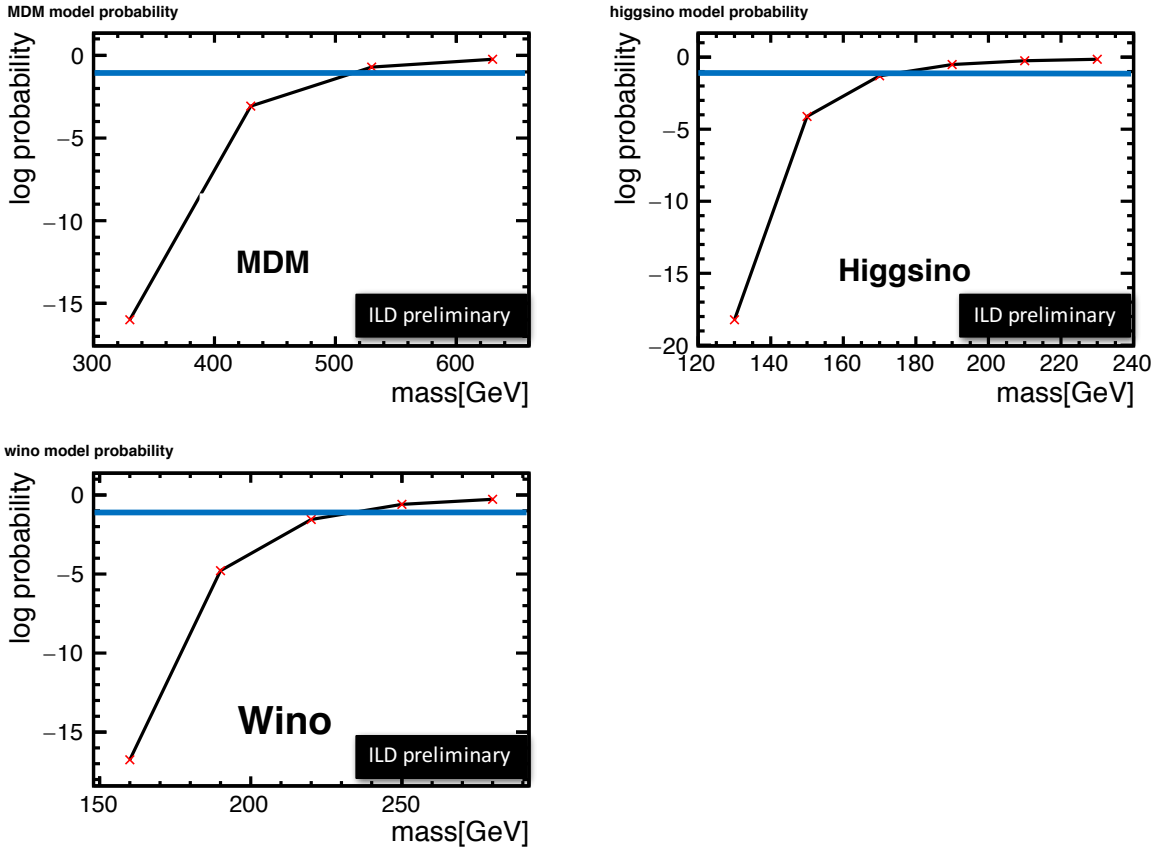

Figure 8: Median of the probability distribution obtained by pseudo experiments with EWIMP models. The blue lines show exclusion limit at 90% confidence level.