Searching for new light higgs-like resonances

ILD Software and Analysis Meeting

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Theoretical Motivation

A higgs boson is found at the LHC in 2012: Whether it is the SM Higgs?
Many BSM extended models predict one or more extra scalars. Fox example:

- General Two Higgs Doublet Model (2HDM...)
  - with 2 scalars: h, H, 1 pheudoscalar A and 2 charge particles
- Next-to-Minimal Supersymmetric Standard Model (NMSSM)
  - with 3 scalars: h1, h2, h3, 2 pheudoscalar A1, A2 and 2 charge particles

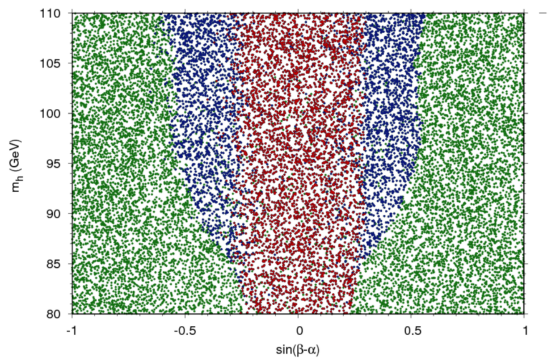
In these models, a scalar lighter than 125 GeV is expected to be found at the ILC.

LHC Higgs boson rather SM-like $\rightarrow$ new higgs coupling to the SM particles is expected to be suppressed.

Past Experiment Results

LEP constrains are set for the SM Higgs, can also be applied to other extended scalars of the SM. But the hZZ coupling should be similar with SM HZZ.
LEP/LHC constrains more rely on the models. For example, for 2HDM $A/H \to \tau\tau$ channel, (arXiv:1408.3316,arXiv:1409.6064, JHEP 1612 (2016) 068)

- $m_{A/H} < 90$ GeV, no limit because of overwhelming SM background
- $m_{A/H} > 90$ GeV, A/H survives at very large $tan\beta$ region.

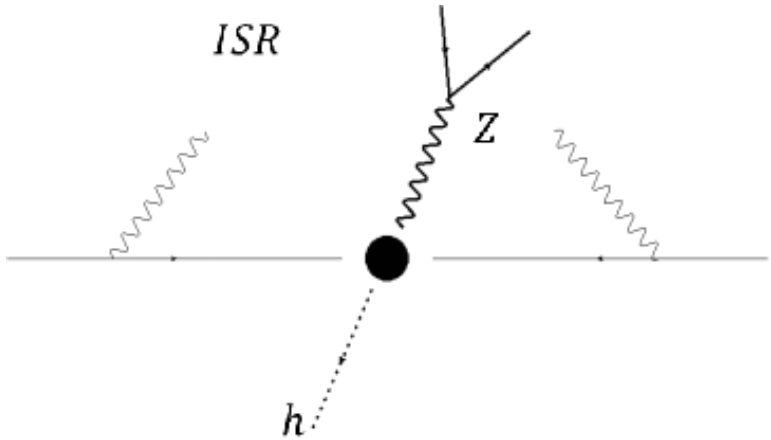


ILC will be more sensitive to lighter higgs with much smaller hZZ coupling.

- higher luminosity, polarised beams, better detectors

Base on the ability of ILC, we can perform a model-independent analysis.

The Recoil Mass at ILC



At an e^+e^- collider, the center-of-mass energy is fixed, So recoil technique can be applied.

$$M^2_{rec} = (\sqrt{s} - E_{l^+l^-})^2 - |\vec{p}_{l^+l^-}|^2 \tag{1}$$

For the Higgsstrahlung process, the invariant mass $M_{\mu\mu} \sim M_Z$ and the peak of recoil mass $M_{rec} \sim M_h$.

Signal and SM Background

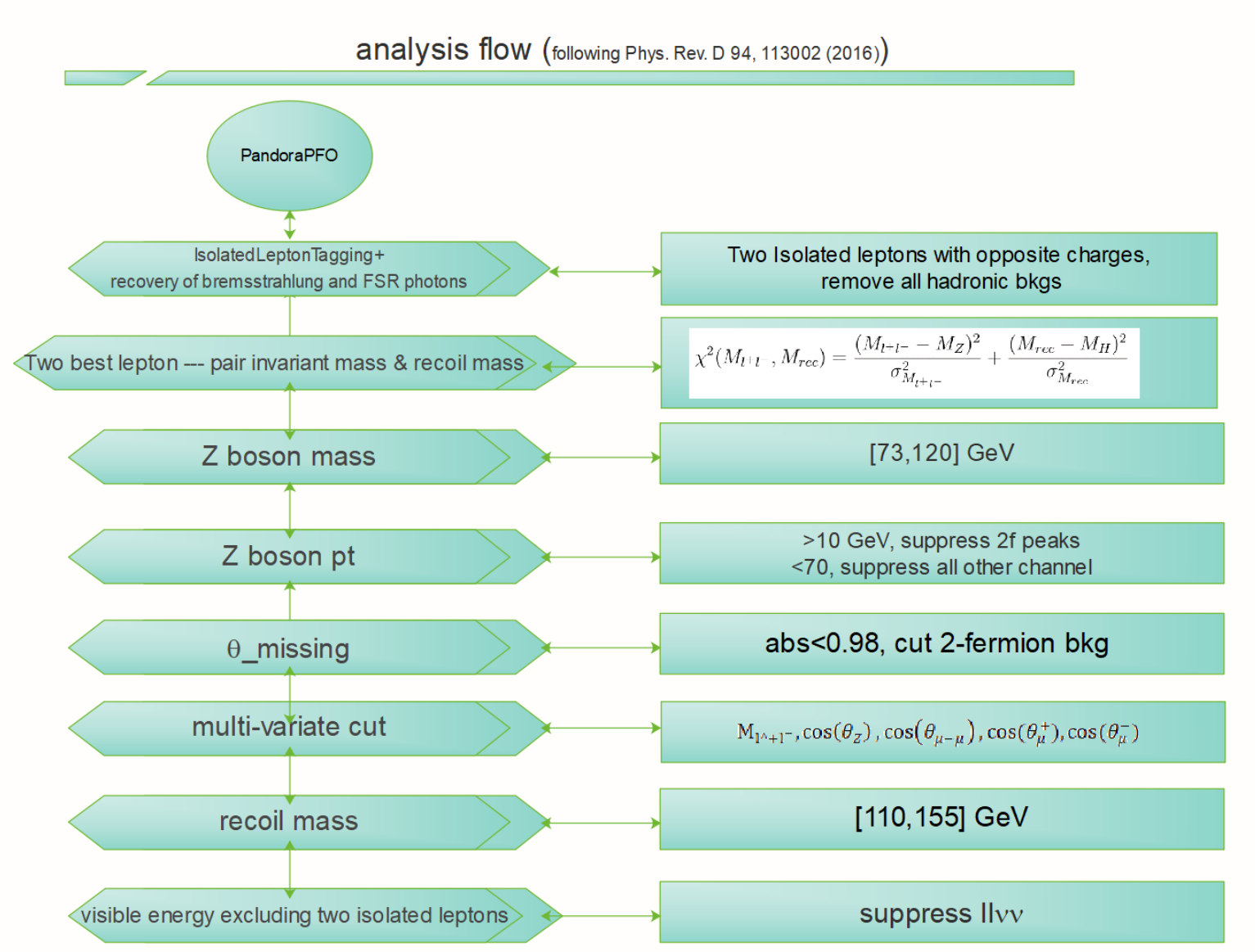
The signal MC samples with m_h from 30 to 115 GeV are used (20 GeV steps now, more events will be needed for further study.); The decay branch ratios are the same as the SM Higgs boson.
Events are generated and showered by WHIZARD-1.95+Pythia, and the simulation and reconstruction by Mokka of iLCSoft v01-17-09.

The background MC samples with DBD mass production:

- 2-fermion, bhabha, single Z leptonic decay
- 4-fermion, leptonic, intermediate state ZZ/WW both leptonic decay
- 4-fermion, semi-lepton, ZZ/WW, one boson leptonic deacy, the other decay to quarks
- (2)4-fermion, hadronic, (two) four quarks.

luminosity is 2000 fb^{-1} at $\sqrt{s} = 250$ GeV, and the beam polarization is $(Pe^-, Pe^+) = (-80\%, +30\%)$.

Analysis Strategy —- Measurement of the Higgs boson mass

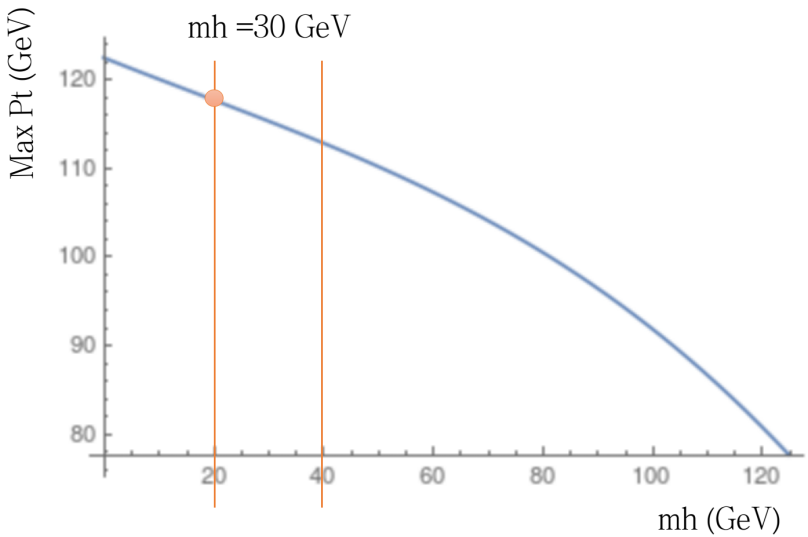


Cuts in my analysis — $M^{\mu^+\mu^-}$ and $P_T^{\mu^+\mu^-}$ cut

$M^{\mu^+\mu^-}$ cut: same with Jackie's [73,120] GeV

$P_T^{\mu^+\mu^-}$ cut

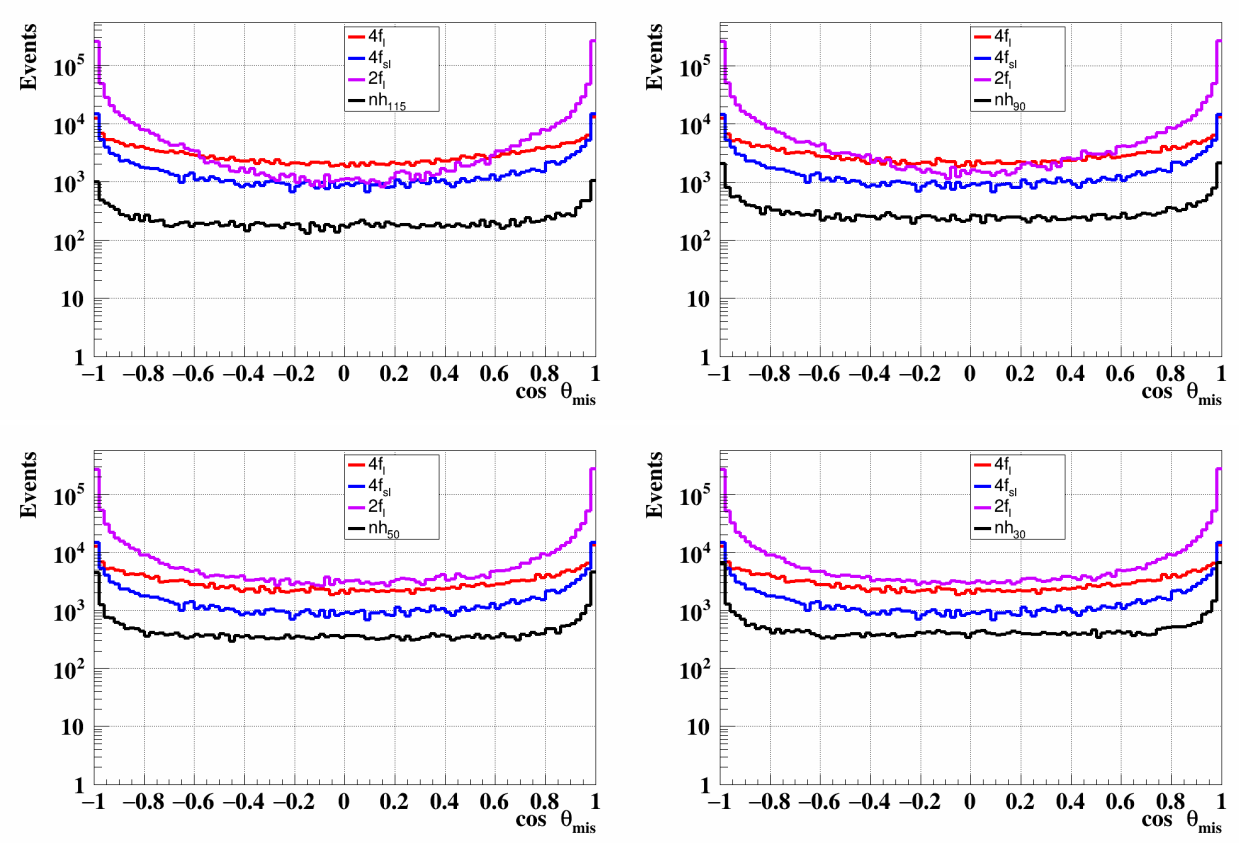
find the maximum pt of reconstructed Z boson in the signal, fit the point and find the largest pt for each mass step.



m_h (GeV)	30	50	70	90	115	125
Max P_T cut (GeV)	120	115	110	100	90	75

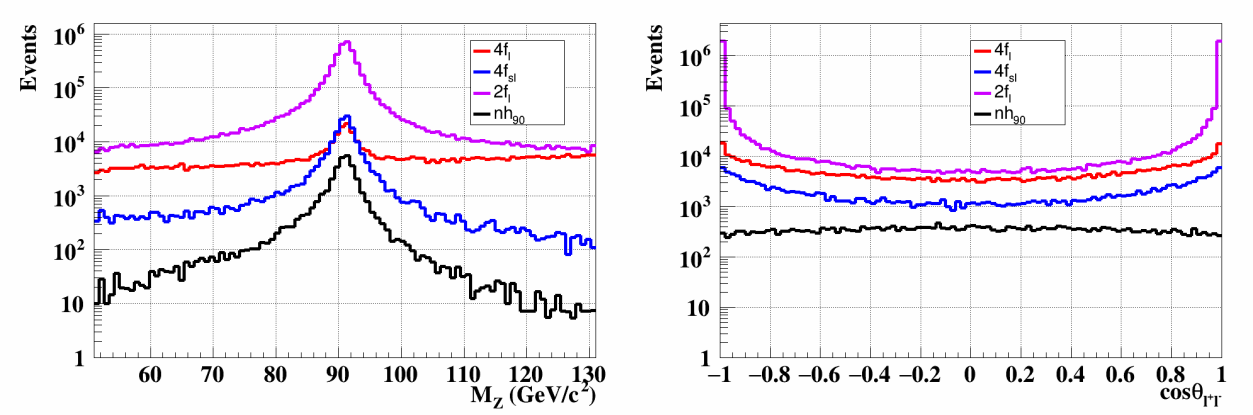
Cuts in my analysis — $cos\theta_{mis}$ cut

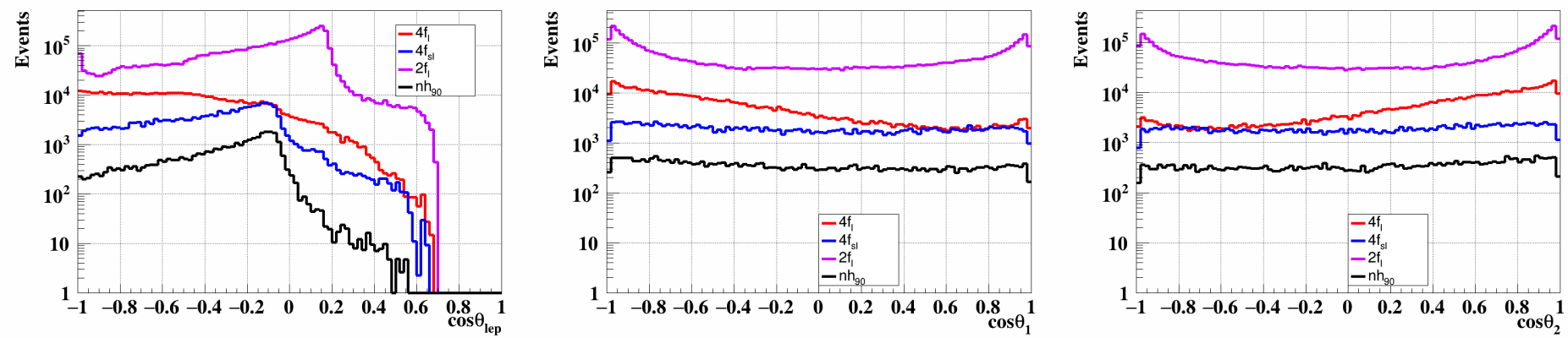
when m_h>50 GeV, the same with Jackie's [-0.98,0.98]
when m_h<50 GeV, the missing energy will more closed to the beam, more signal events will be removed by this cut, so don't apply this cut.



Cuts in my analysis — BDTG variables

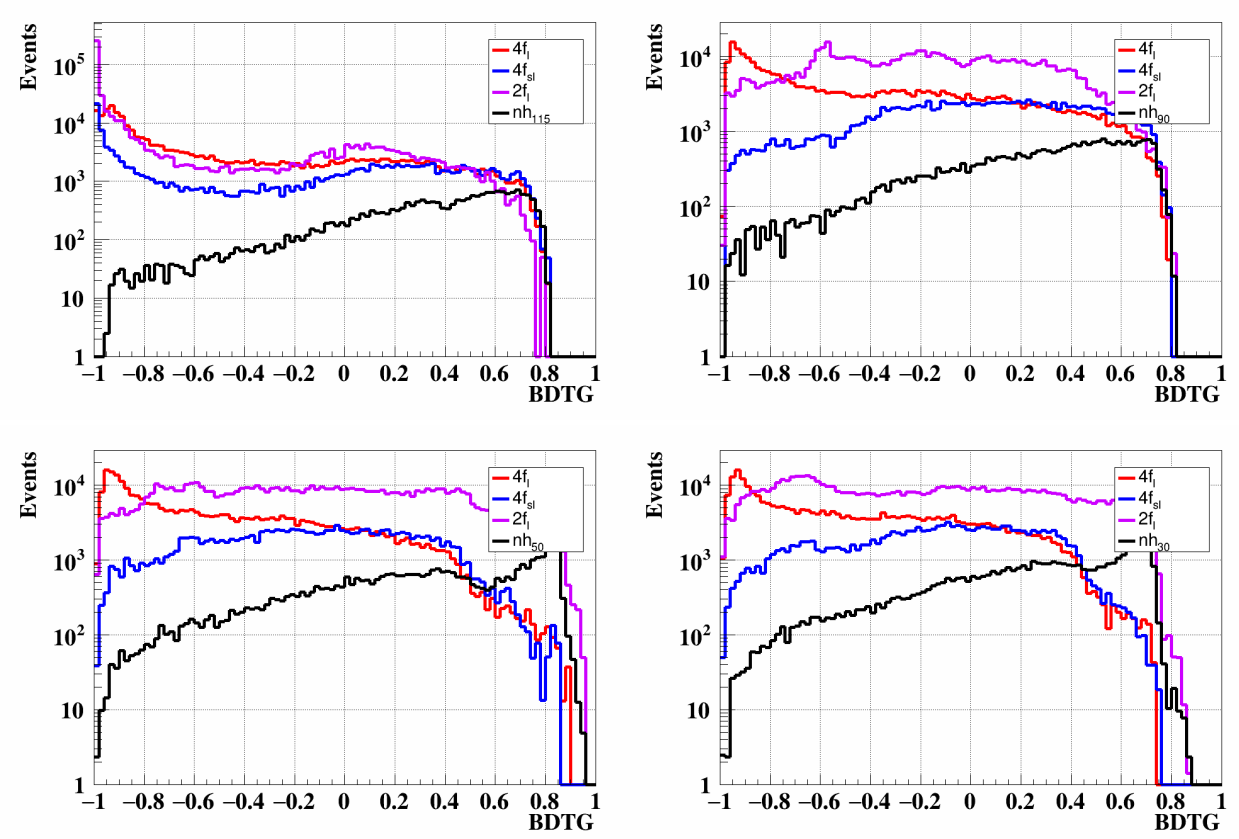
it contains $M_{l^+l^-}$, $cos(\theta_Z)$, $cos(\theta_{\mu^-\mu})$,$cos(\theta_{track+})$ and $cos(\theta_{track-})$.





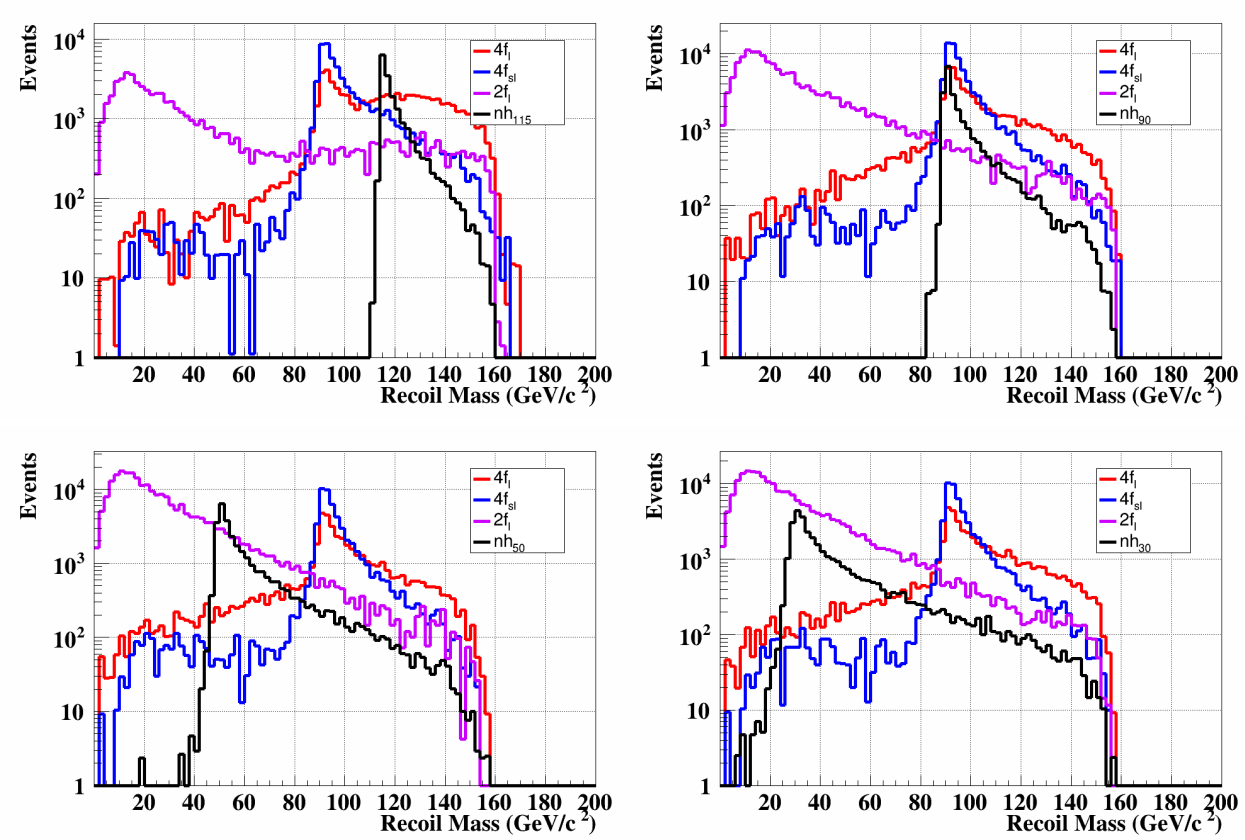
Cuts in my analysis — BDTG cut

- tried many BDTG cuts to find relation between BDTG cut and sensitivities.
- For most higgs masses, no big changes in final sensitivity for BDTG cuts in (-0.3,0.3)
- choose BDTG>0 for all masses



Cuts in my analysis — higgs recoil mass cut

$[(m_h - 20)$ GeV$, 160$ GeV$]$ for significance calculation, but when calculating the final sensitivity from the recoil mass, we use the recoil mass information in each bin.



Cuts in my analysis — E_{vis} cut

Jackie's paper focuses on the Higgs visible decay.
The Higgs invisible decay is studied by Akimasa Ishikawa, "Search for Invisible Higgs Decays at the ILC"
A model-independent analysis in my present study includes higgs visible and invisible decays. So E_{vis} cut is repealed now.

Results after all cuts

The results can be divided into four regions. The main backgrounds are different for these regions.

mass region	main background
$125 > m_h > m_z$	$4f_{zz}^{sl}$,$4fzzww$
$m_h \sim m_z$	$4f_{zz}^{l}$,$4f_{zz}^{sl}$,$4fzzww$
$m_z > m_h > 40$	$2f_l$,$4fzz$,$4fzzww$
$40 > m_h$	$2f_l$

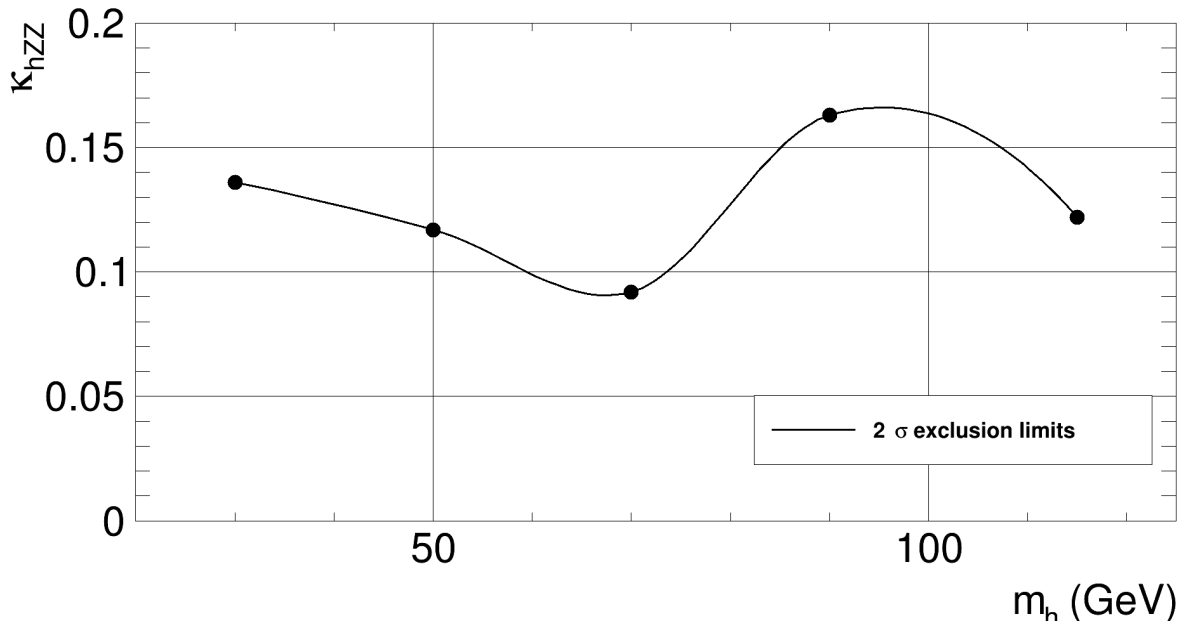
The number of events left after the final cuts for different masses:

$\int Ldt = 2000fb^{-1}$	new higgs	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	cut efficiency	significance
$m_h = 115$ GeV	17419.6	61033.9	53869.4	13877.7	128781	0.67	45.56
$m_h = 90$ GeV	22198.2	63210.7	74563	18514.2	156288	0.59	52.54
$m_h = 70$ GeV	26841.3	51671.6	60357.7	37166.6	149196	0.57	63.97
$m_h = 50$ GeV	30493.5	46128.1	54372.8	80074.4	180575	0.54	66.37
$m_h = 30$ GeV	33843.7	51206.6	55743.3	213184	320134	0.49	56.88

$$\text{significance} = \frac{S}{\sqrt{S+B}}, \text{and } S = \kappa \times \sigma_{h\mu\mu}^{m_h} \times \mathfrak{L}, \text{ where } \kappa = 1 \tag{2}$$

Results for exclusion limits

2 σ exclusion limits with TSysLimit Package.
This package uses the higgs mass information for a bin-by-bin comparison between the recoil mass histogram of signal and backgrounds.



Further Improvement

- find some new methods to suppress 2-fermion background for low higgs mass.
- check the model independency.
- spliting study into visible and invisible higgs decay will be more helpful.
- more signal data for different masses are needed.

Conclusions

- Many BSM models favor a low mass higgs (2HDM, NMSSM).
- A model-independent analysis has been applied to the mass range [10, 125) GeV at the ILC.
- In the low-mass region 2 fermion backgrounds will be dominant.
- 2 σ exclusion limits are shown for benchmark points.

backup

SFor $m_h \in [100, 125)$ mass region

$\int Ldt = 2000 fb^{-1}$	nh_{115}	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	efficiency	significance
$no\ cut$	25840.7	1.1285e+07	3.65687e+07	2.65808e+07	1.24952e+08	1	2.31147
$N_\mu \in [2, 20]$	24135.2	1.22524e+06	247194	1.0289e+07	1.17614e+07	0.933999	7.03033
$N_{\mu+} \in [1, 10]$	24113.3	1.22431e+06	247014	1.02889e+07	1.17602e+07	0.933152	7.02432
$N_{\mu-} \in [1, 10]$	24105.2	1.22335e+06	246812	1.02888e+07	1.1759e+07	0.932838	7.02233
$M_{l^+l^-} \in [73, 120]$	23108.7	345535	175227	4.67269e+06	5.19345e+06	0.894275	10.1177
$P_T^{l^+l^-} \in [10, 90]$	22778.9	315000	168750	1.04661e+06	1.53036e+06	0.881513	18.278
$cos\theta_{mis} \in [-0.98, 0.98]$	20722.4	289445	139279	523116	951839	0.801929	21.0127
$BDTG \in [0, 1]$	17419.6	66732.4	59358.5	82787.2	208878	0.674115	36.6183
$M_{rec} \in [90, 160]$	17419.6	61033.9	53869.4	13877.7	128781	0.674115	45.5579
$all\ cut$	17419.6	61033.9	53869.4	13877.7	128781	0.674115	45.5579

The exclusion limits of κ for ExpCL=0.955 is 0.094.

For $m_h \in [80, 100)$ mass region

$\int Ldt = 2000 fb^{-1}$	nh_{90}	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	efficiency	significance
$no\ cut$	37641.3	1.12861e+07	3.65687e+07	2.65808e+07	1.24953e+08	1	3.36687
2 μ + Pre Cut	35138.4	1.22135e+06	246812	1.02888e+07	1.1757e+07	0.933506	10.2326
$M_{l^+l^-} \in [73, 120]$	33518.3	345084	175217	4.67269e+06	5.19299e+06	0.890466	14.6614
$P_T^{l^+l^-} \in [10, 100]$	33245.4	319656	169706	1.13773e+06	1.62709e+06	0.883216	25.8008
$cos\theta_{mis} \in [-0.98, 0.98]$	28996.9	293723	140165	600722	1.03461e+06	0.770348	28.1165
$BDTG \in [0, 1]$	22198.2	68689.7	76175	211562	356427	0.58973	36.0756
$M_{rec} \in [70, 160]$	22198.2	63210.7	74563	18514.2	156288	0.58973	52.5431
$all\ cut$	22198.2	63210.7	74563	18514.2	156288	0.58973	52.5431

The exclusion limits of κ for ExpCL=0.955 is 0.085.

For $m_h \in [60, 80)$ mass region

$\int Ldt = 2000 fb^{-1}$	nh_{70}	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	efficiency	significance
$no\ cut$	46950.7	1.12883e+07	3.65687e+07	2.65808e+07	1.24955e+08	1	4.19936
2 μ + Pre Cut	43956.6	1.22135e+06	246812	1.02888e+07	1.1757e+07	0.936229	12.7958
$M_{l^+l^-} \in [73, 120]$	41798.4	345602	175217	4.67269e+06	5.19351e+06	0.890261	18.2679
$P_T^{l^+l^-} \in [10, 110]$	41451.6	321478	170128	1.24773e+06	1.73934e+06	0.882875	31.0624
$cos\theta_{mis} \in [-0.98, 0.98]$	35421.7	295309	140586	701332	1.13723e+06	0.754445	32.7104
$BDTG \in [0, 1]$	26843.7	55466.5	62188.8	353583	471238	0.571742	38.0357
$M_{rec} \in [50, 160]$	26841.3	51671.6	60357.7	37166.6	149196	0.571691	63.9737
$all\ cut$	26841.3	51671.6	60357.7	37166.6	149196	0.571691	63.9737

The exclusion limits of κ for ExpCL=0.955 is 0.054.

For $m_h \in [40, 60)$ mass region

$\int Ldt = 2000 fb^{-1}$	nh_{50}	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	efficiency	significance
$no\ cut$	56410.1	1.12832e+07	3.65687e+07	2.65808e+07	1.2495e+08	1	5.04534
2 μ + Pre Cut	52544.6	1.22147e+06	246812	1.02888e+07	1.17571e+07	0.931475	15.2901
$M_{l^+l^-} \in [73, 120]$	49721.9	346087	175217	4.67269e+06	5.19399e+06	0.881436	21.7134
$P_T^{l^+l^-} \in [10, 115]$	49296.7	321709	170128	1.24989e+06	1.74173e+06	0.873898	36.8356
$cos\theta_{mis} \in [-0.98, 0.98]$	40285.2	295495	140586	703409	1.13949e+06	0.714149	37.0891
$BDTG \in [0, 1]$	30495.9	47670.2	55104.3	310663	413438	0.540611	45.7702
$M_{rec} \in [30, 160]$	30493.5	46128.1	54372.8	80074.4	180575	0.540568	66.3736
$all\ cut$	30493.5	46128.1	54372.8	80074.4	180575	0.540568	66.3736

The exclusion limits of κ for ExpCL=0.955 is 0.059.

For $m_h \in [20, 40)$ mass region

$\int Ldt = 2000 fb^{-1}$	nh_{30}	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	efficiency	significance
$no\ cut$	68641.1	1.12832e+07	3.65687e+07	2.68697e+07	1.25239e+08	1	6.13191
2 μ + Pre Cut	63985.6	1.22147e+06	246812	1.02796e+07	1.17479e+07	0.932176	18.6176
$M_{l^+l^-} \in [73, 120]$	59337.5	346162	175217	4.68933e+06	5.21071e+06	0.86446	25.8477
$P_T^{l^+l^-} \in [10, 120]$	58543	321770	170128	1.25047e+06	1.74237e+06	0.852885	43.6243
$cos\theta_{mis} \in [-0.98, 0.98]$	45294.1	295511	140586	705373	1.14147e+06	0.659869	41.5776
$BDTG \in [0, 1]$	33853.5	51434.9	55791.1	273993	381219	0.493196	52.5462
$M_{rec} \in [5, 190]$	33843.7	51206.6	55743.3	213184	320134	0.493053	56.884
$all\ cut$	33843.7	51206.6	55743.3	213184	320134	0.493053	56.884

The exclusion limits of κ for ExpCL=0.955 is 0.077.