Measuring the Higgs Cross Section via the Recoil of Leptonic Z Decays at the ILC

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Target

One of the advantages of the ILC is model independent(MI) analysis of Higgs properties by recoil method.

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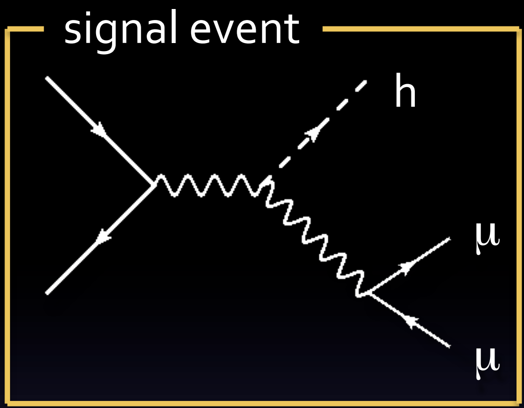
How precise can we measure Higgs mass and cross section by this method? The considered situation is …

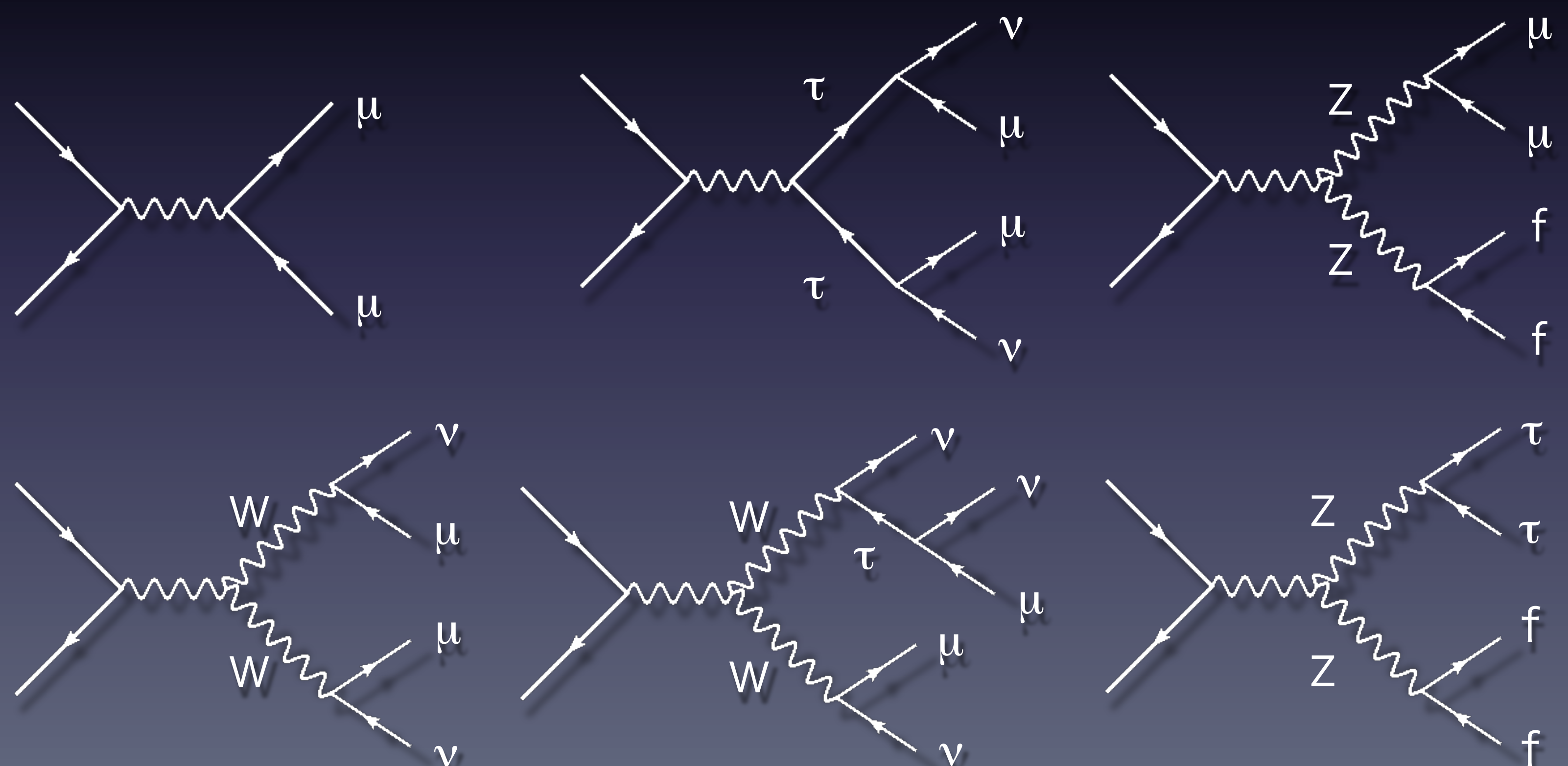
Higgs mass	Center of Mass Energy	Integrated Luminosity	Spin Polarization	Detector Simulation
125 [GeV]	250 [GeV]	250 fb^{-1}	$P(e^-, e^+)$ =(-0.8, +0.3)	ILD_01_v05 (DBD ver.)

Using only Zh -> llh (l=μ, or e) signal event.

Signal and Background Events



- These are μμh channel signal & BGs.
- For eeh channel study, character of "μ" is altered to "e".



Lepton Selection

- Muon (and electron) selection
  - Momentum $p > 15$ [GeV]
  - Small (Large) energy deposite in caloriemeters
    - $E_{ecal} / E_{total} < 0.5$ (> 0.6)
    - $E_{total} / p_{track} < 0.3$ (> 0.9)
- Good track selection
  - Track with small error (different selections between polar angle of tracks, barrel or end cap)

    $dp / p^2 < 2.5 \times 10^{-5} \oplus 8 \times 10^{-4} / p$ (for $\cos\theta < 0.78$)

    $dp / p^2 < 5 \times 10^{-4}$ (for $\cos\theta > 0.78$)
- Impact parameter (only for muon)
  - To suppress muons from tau decays which tend to have large impact parameters.

    $D_0 / dD_0 < 5$

Background Rejection

di-lepton events

$p_{Tdl} > 20GeV$

$M_{dl} \in (80, 100)[GeV]$

$acop \in (0.2, 3.0)$

$\delta p_{Tbal} < 10GeV$

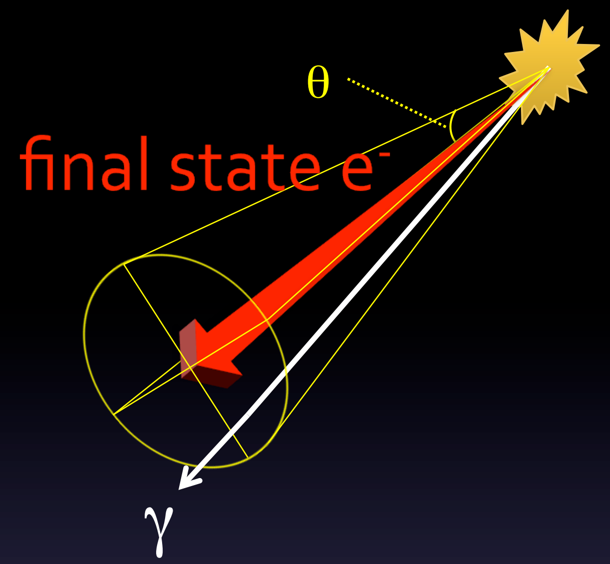
$\cos\theta_{missing} < 0.99$

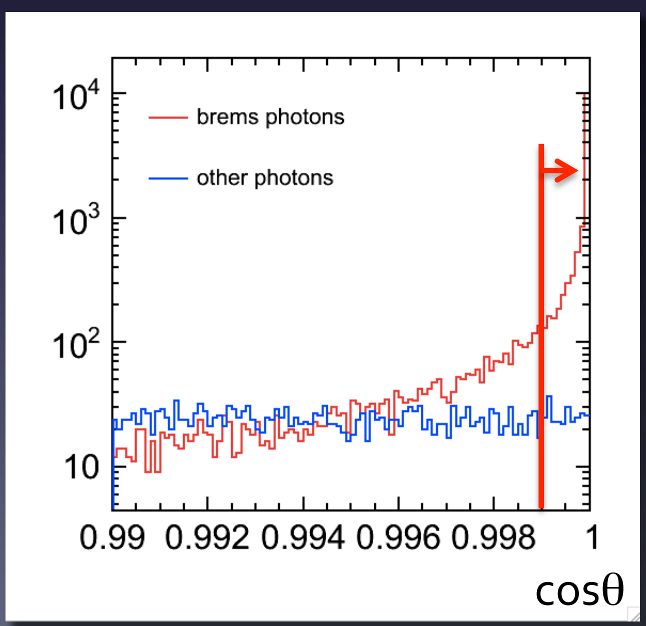
$M_{recoil} \in (115, 150)[GeV]$

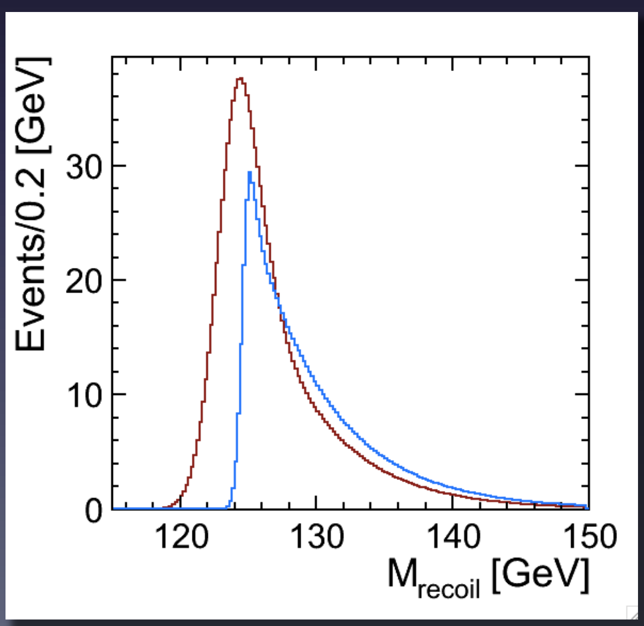
Likelihood

Bremsstrahlung Recovery

- Only for eeh channel cross section measurements, the photon's momentum around final state electron ($\cos\theta > 0.999$) is added to the electron.
- This process contributes the distribution of recoil mass significantly.
- For mass analysis, it is effective not to perform the recovery.







Efficiency Table

μμh	signal		μμνν		μμff		τlνν		τlff		others	
No Cut	2574		149636		160432		596518		83418		~10M	
Selection	2271	88.21%	12467	8.33%	7864	4.90%	3010	0.50%	28	0.03%	14649	0.14%
p_{Tdl}	2160	83.89%	10653	7.12%	6799	4.24%	2706	0.45%	27	0.03%	8907	0.09%
M_{dl}	2050	79.65%	6458	4.32%	5901	3.68%	1404	0.24%	19	0.02%	7518	0.07%
acop	1916	74.43%	6078	4.06%	5370	3.35%	1290	0.22%	11	0.01%	6637	0.06%
dp_{Tbal}	1871	72.70%	5949	3.98%	4965	3.09%	1267	0.21%	11	0.01%	927	0.01%
$cosq_{missing}$	1859	72.22%	5949	3.98%	4705	2.93%	1267	0.21%	11	0.01%	682	0.01%
M_{recoil}	1856	72.10%	3987	2.66%	2643	1.65%	882	0.15%	11	0.01%	453	0.00%
Likelihood	1564	60.77%	2401	1.60%	1734	1.08%	333	0.06%	0	0%	350	0.00%
eeh	**signal**		**eeνν**		**eeff**		**τlνν**		**τlff**		**others**	
No Cut	2701		145891		184568		596518		60970		~10M	
Selection	1924	71.23%	12771	8.75%	8076	4.38%	11996	2.01%	273	0.45%	75814	0.74%
p_{Tdl}	1874	69.39%	11470	7.86%	7175	3.89%	11213	1.88%	196	0.32%	51342	0.50%
M_{dl}	1729	64.01%	6649	4.56%	5243	2.84%	6142	1.03%	122	0.20%	31762	0.31%
acop	1614	59.75%	6339	4.35%	4790	2.60%	5516	0.92%	83	0.14%	25227	0.25%
dp_{Tbal}	1552	57.46%	6038	4.14%	4094	2.22%	5300	0.89%	73	0.12%	7195	0.07%
$cosq_{missing}$	1543	57.13%	6034	4.14%	3848	2.09%	5300	0.89%	72	0.12%	6489	0.06%
M_{recoil}	1523	56.39%	4242	2.91%	2294	1.24%	3997	0.67%	57	0.09%	4419	0.04%
Likelihood	1026	37.97%	1428	0.98%	840	0.46%	966	0.16%	2	0.00%	974	0.01%

* For eeh channel, bremsstrahlung recovery was considered.

Fitting Method

- Fitting function
  - signal -> Gaussian Peak with Exponential Tail (GPET)

$$\begin{cases} Ne^{-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2} & \left(\frac{x-\bar{x}}{\sigma} < k\right) \\ N\left\{be^{-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2} + (1-b)e^{-k\frac{x-\bar{x}}{\sigma}}e^{\frac{b^2}{2}}\right\} & \left(\frac{x-\bar{x}}{\sigma} \geq k\right) \end{cases}$$

  - BG -> 3^{rd} order polynomial

* GPET has 5 parameters

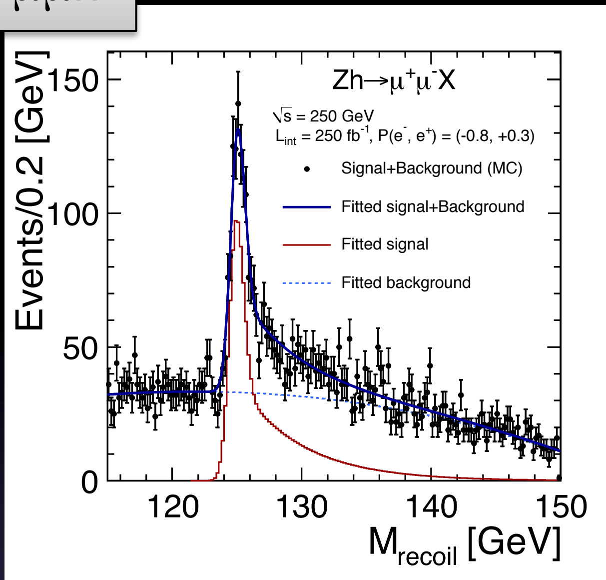
- ✧ **height : N**
- ✧ mean : $\bar{x}$
- ✧ width : s
- ✧ boundary : k
- ✧ junction : b

- Toy-MC study
  - The sum of signal and BG distributions are fitted with the functions above.
  - Make the toy-MC events according to the fitted functions.
  - Fit the distribution again with the same function

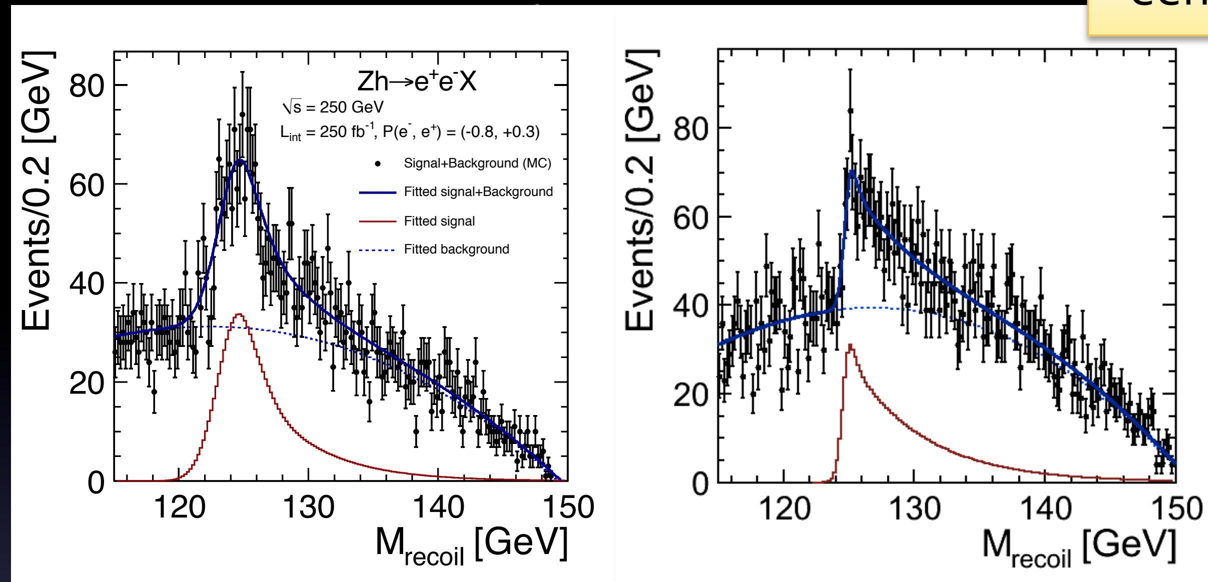
    by floating height and mean of GPET.

Result

μμh



eeh



- [μμh] Statistical Errors :
  - cross section error 3.6%
  - mass error 37MeV
- [eeh] Statistical Errors :
  - cross section error 5.2%
  - mass error 122MeV
- Statistical errors for combination of μμh and eeh results.
  - cross section error 3.0%
  - mass error 35MeV


➔ NEXT STEP

Semi Model Independent Analysis

μμh	signal		mmnn		mmff		tlnn	
No Cut	2574		14963 6		160432		596518	
Selection	2271	88.21%	12467	8.33%	7864	4.90%	3010	0.
p_{Tdl}	2160	83.89%	10653	7.12%	6799	4.24%	2706	0.
M_{dl}	2050	79.65%	6458	4.32%	5901	3.68%	1404	0.
acop	1916	74.43%	6078	4.06%	5370	3.35%	1290	0.
dp_{Tbal}	1871	72.70%	5949	3.98%	4965	3.09%	1267	
$cosq_{missing}$	1859	72.22%	5949	3.98%	4705	2.93%	1267	
M_{recoil}	1856	72.10%	3987	2.66%	2643	1.65%	882	0.
Likelihood	1564	60.77%	2401	1.60%	1734	1.08%	33[illegible]	0.

There seems to be large number of remaining BG events with neutrino.

μμh	sig	μμνν	τlνν
After	1564	2401	333

eeh	signal		eeνν		eeff		τlνν		τlff		others	
No Cut	2701		145891		184568		596518		60970		~10M	
Selection	1924	71.23%	12771	8.75%	8076	4.38%	11996	2.01%	273	0.45%	75814	0.74%
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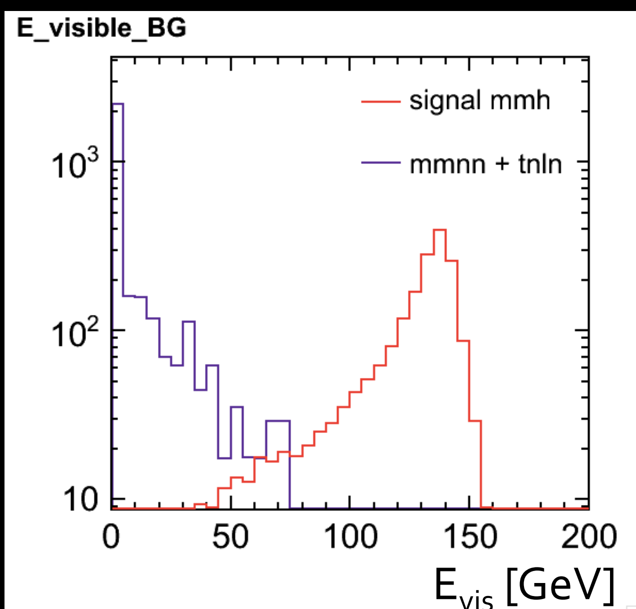
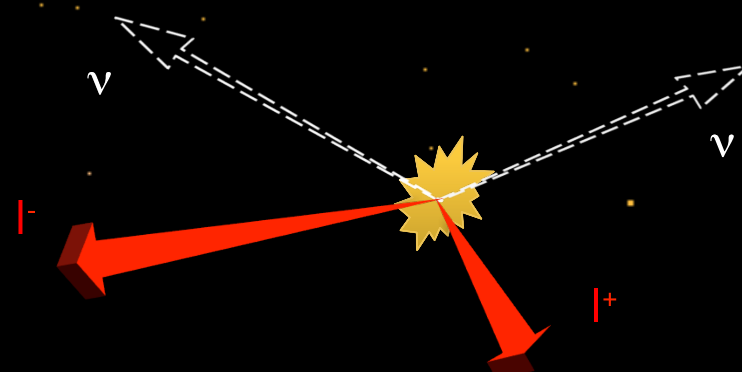
acop	1614	59.75%	6339	4.35%	4790	2.60%	5516	0.92%	83	0.14%	25227	0.25%
dp_{Tbal}	1552	57.46%	6038	4.14%	4094	2.22%	5300	0.89%	73	0.12%	7195	0.07%
$cosq_{missing}$	1543	57.13%	6034	4.14%	3848	2.09%	5300	0.89%	72	0.12%	6489	0.06%
M_{recoil}	1523	56.39%	4242	2.91%	2294	1.24%	3997	0.67%	57	0.09%	4419	0.04%
Likelihood	1026	37.97%	1428	0.98%	840	0.46%	966	0.16%	2	0.00%	974	0.01%

eeh	sig	eeνν	τlνν
After	1026	1428	966

- Since contribution from Higgs invisible decays can be calibrated with data, visible energy selection is effective for reducing these BG.
- $E_{vis} := E_{PFOs} - E_{di\text{-}lepton} > 5$ [GeV]
- Loose selection is applied to avoid bias in signal selection.





Efficiency Table (Semi-MI)

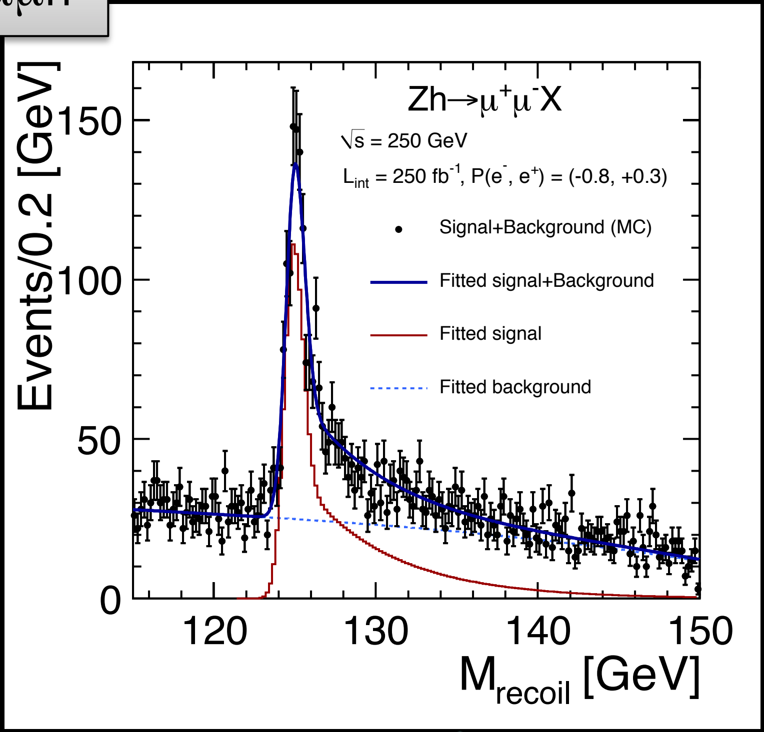
μμh	signal		μμνν		τlνν		others	
No Cut	2574		149636		596518		~10M	
~M_{recoil}	1856	72.10%	3987	2.66%	882	0.15%	3107	0.03%
E_{vis}	1854	72.01%	926	0.62%	137	0.02%	3107	0.03%
Likelihood	1811	70.37%	836	0.56%	103	0.02%	2837	0.03%

eeh	signal		eeνν		τlνν		others	
No Cut	2701		145891		596518		~10M	
~M_{recoil}	1523	56.39%	4242	2.91%	3997	0.67%	6770	0.06%
E_{vis}	1521	56.33%	1410	0.97%	1703	0.29%	6770	0.06%
Likelihood	1262	46.71%	719	0.49%	677	0.11%	2864	0.03%

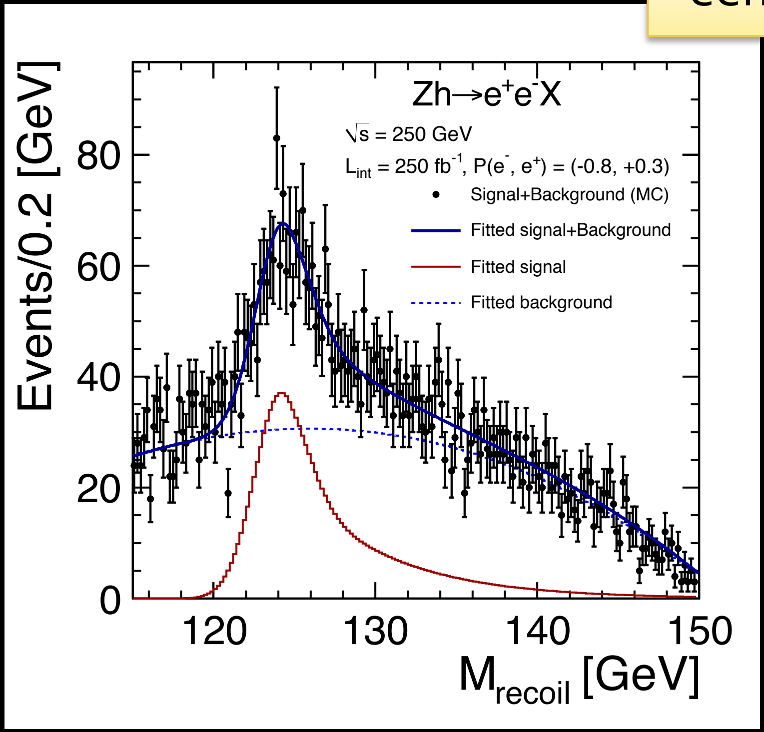
Likelihood limit value is re-optimized for new visible energy selection.

Result (Semi-MI)

μμh



eeh



- Statistical Error :
  - cross section error 3.0%

- Statistical Error :
  - cross section error 4.6%

- Combination of μμh and eeh results :
  - cross section error 2.5%

$E_{visible}$ Selection for Mass Analysis

For mass measurement, it doesn't have to be model independent.

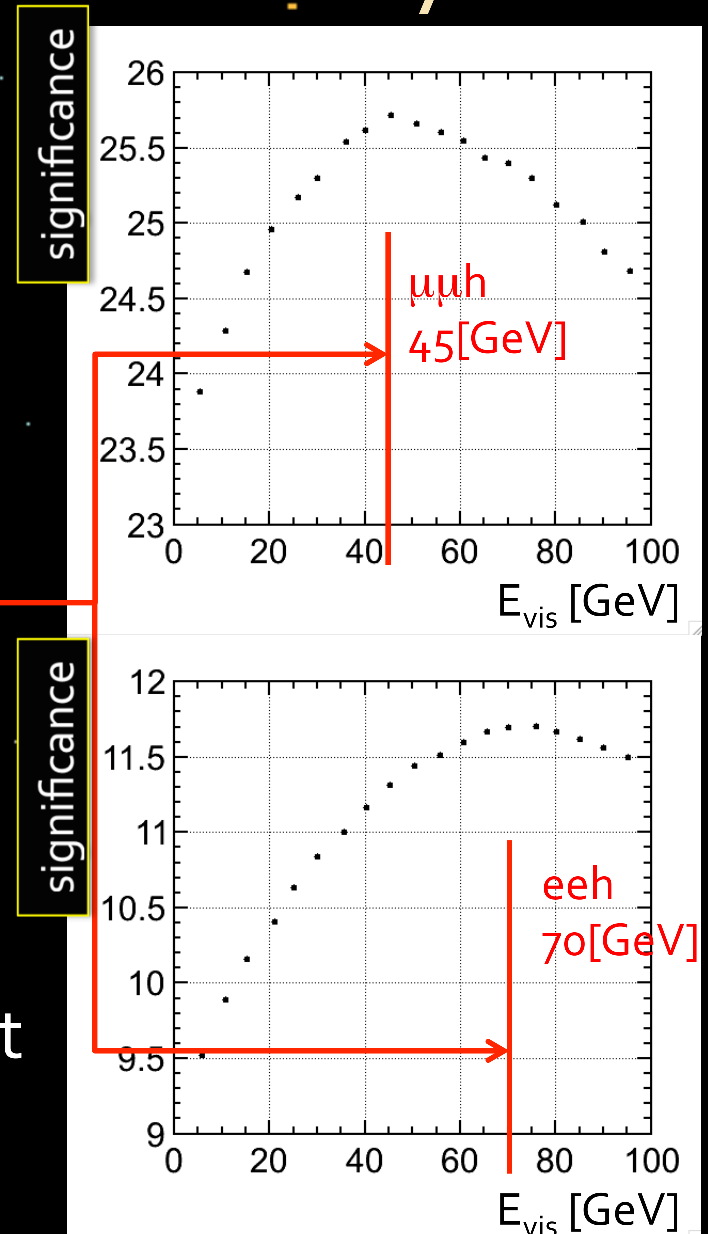
↓

E_{vis} limit value can be set large.

= Maximizing $N_{sig}/\mathrm{sqrt}(N_{sig}+N_{BG})$

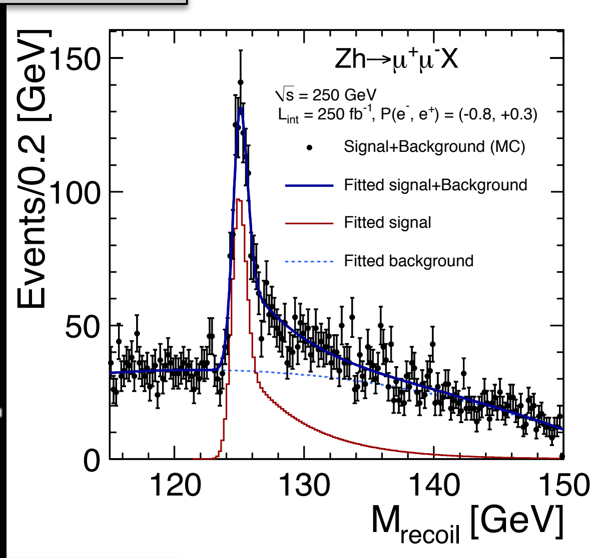
- Mass error result
  - μμh : 33MeV
  - eeh : 92MeV

combined result 31MeV

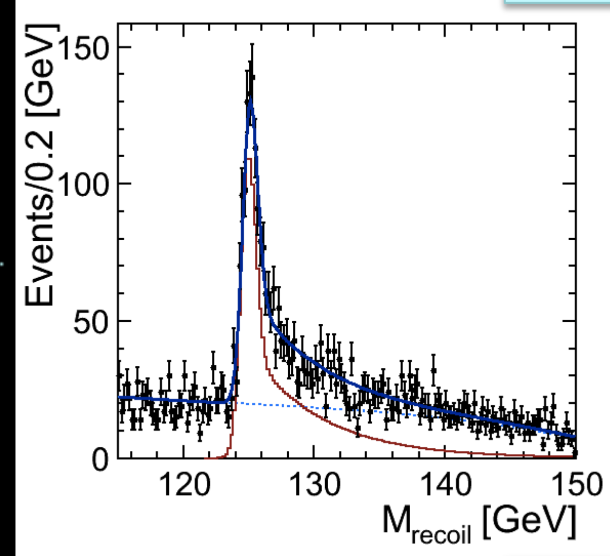


Recoil Mass (MI & MD)

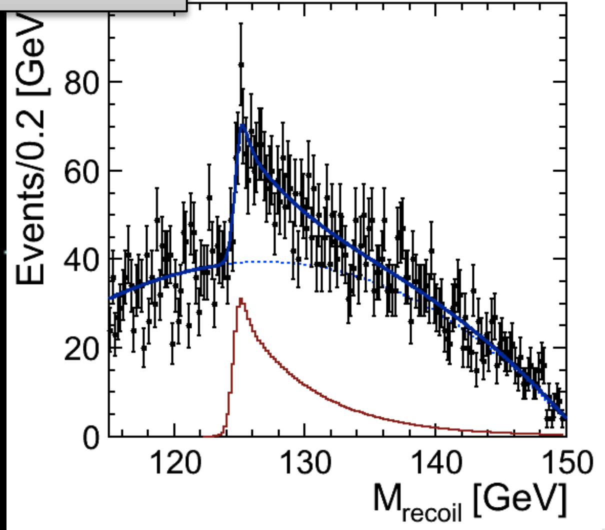
MI μμh



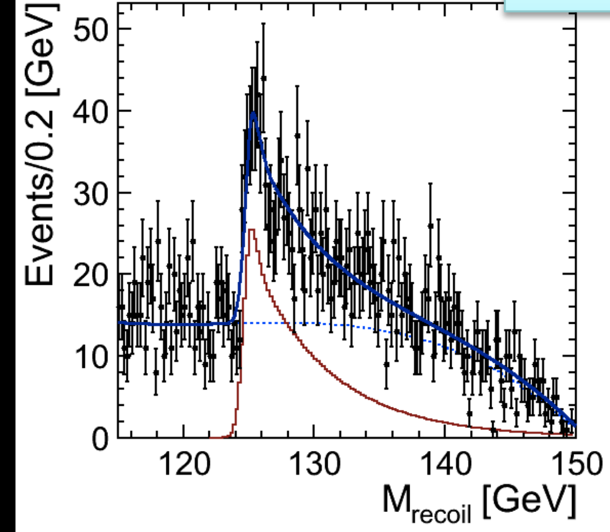
MD μμh



MI eeh



MD eeh



Summary

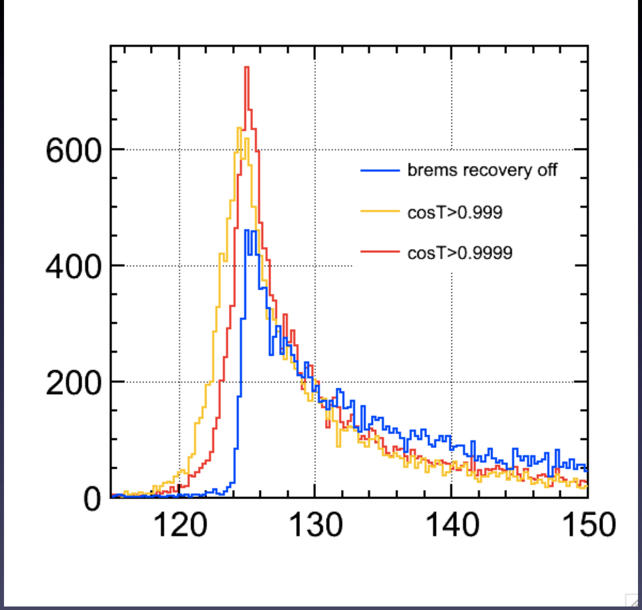
- The recoil mass technique is important feature at the ILC to measure Higgs mass and cross section of Zh event.
- I determine statistical errors of llh channel model independently, and semi-model independent analysis for cross section and model dependent analysis for mass are also performed. The results are summarized in following table.

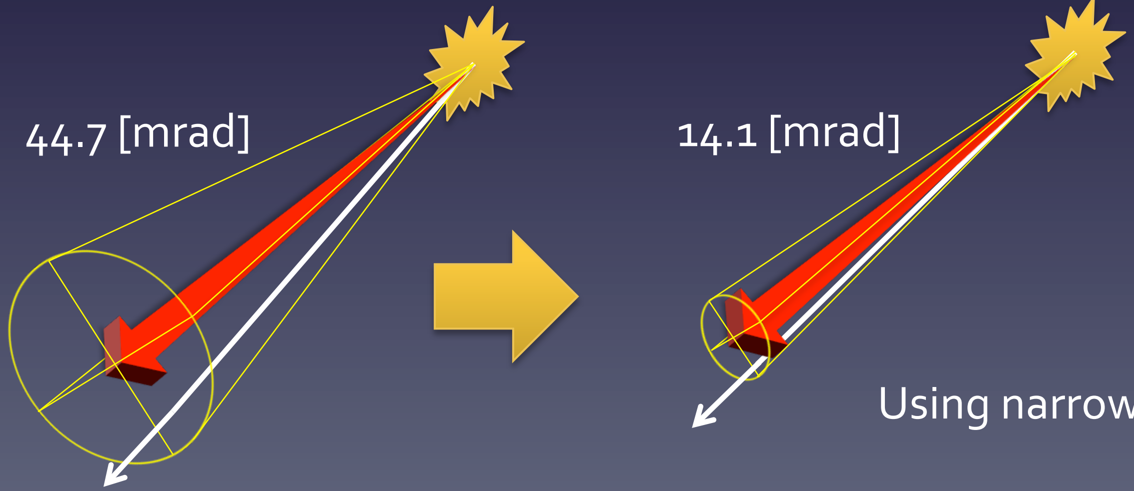
Cross section	μμh	eeh	Combined
MI	3.6%	5.2%	3.0%
semi-MI	3.0%	4.6%	2.5%

Mass	μμh	eeh	Combined
MI	37MeV	122MeV	35MeV
MD	33MeV	92MeV	31MeV

Next Plan

- Maybe fitting function can be optimized more.
- I can make eeX channel distribution shaper by “Partial Bremsstrahlung Recovery”, in which partial photons emitted by signal electron and positron are recovered, to get better sensitivity for cross section.
- Then, to analyze mixture of CP even and odd Higgs bosons, I’ll make the generator.





Using narrower cone for partial recovery

Backup Slides

About eeh channel

	signal	BG
LOI	1491	3394
DBD	1026	4210

The balance of number of remaining BG events = 800

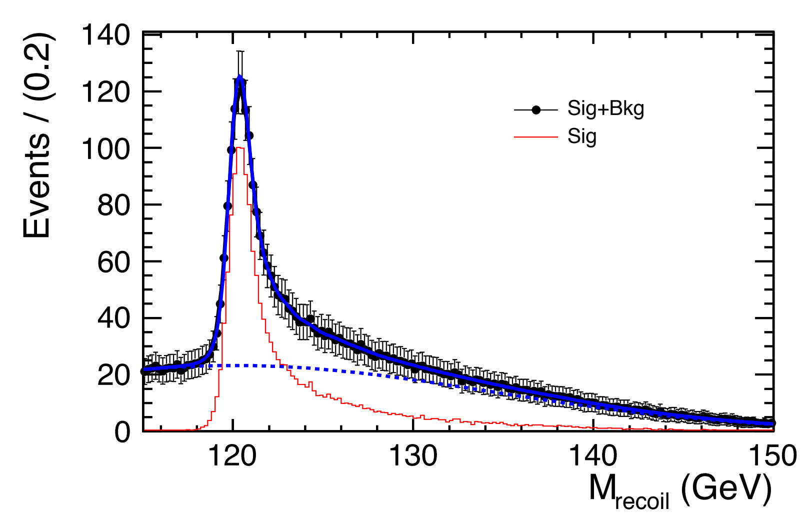
	τνlν	τlff
LOI	0	0
DBD	966	2

The number of remaining τνlν events in this DBD study = 966

This might not be considered, in the first place.

- One of the reasons of worse results (compared with previous LOI study) seems to be τνlν BG events which have not considered in LOI study.
- If I reduce BG arbitrarily to the same order of LOI case, result of cross section error will be improved as LOI result.
- Second reason is smaller number of signal events in DBD study which is originated from difference of Higgs mass and difference of total cross section.
- The reason of wider width of recoil mass distribution in eeh channel is bremsstrahlung recovery.

Various Figures of LOI



top : μμX result of LoI
bottom left : eeX result of LoI
bottom right : eeX result of LoI (brems recovery)