The measurements of Higgs recoil mass and cross section at the E_{CM} = 250GeV

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Target

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

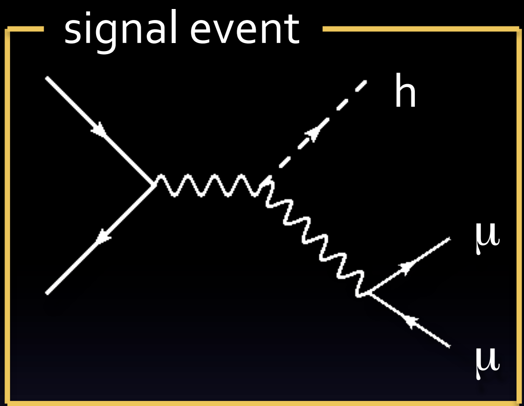
↓

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

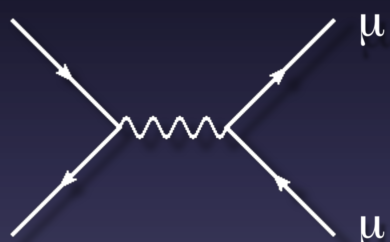
Higgs mass	Center of Mass Energy	Integrated Luminosity	Spin Polarization	Detector Simulation
125 [GeV]	250 [GeV]	250 fb^{-1}	$P(e^-, e^+)$ =(-0.8, +0.3)	ILD_01_v05 (DBD ver.)

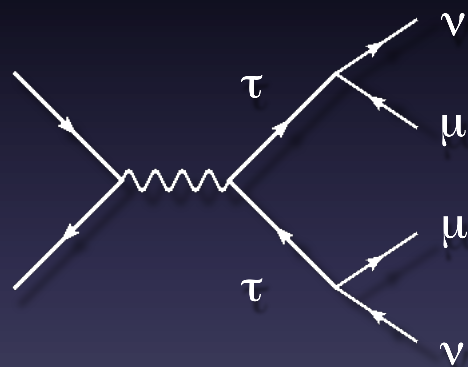
Using only Zh -> llh (l=μ, or e) signal event.

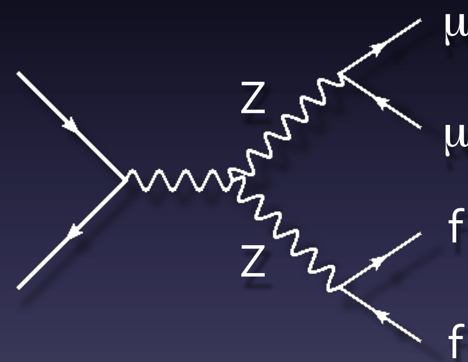
Signal and Background Events

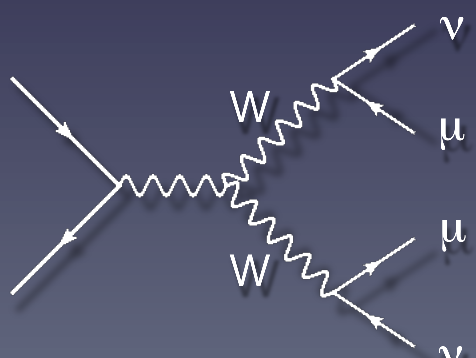


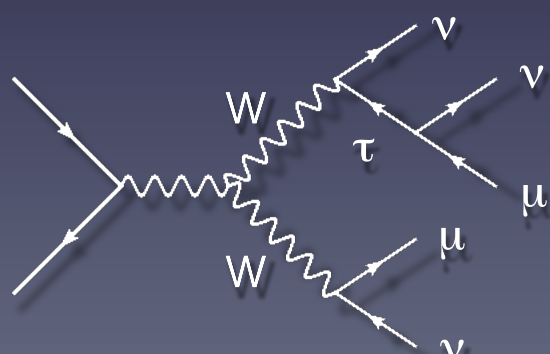
- These are μμh channel signal & BGs.
- For eeh channel study, character of "μ" is altered to "e".

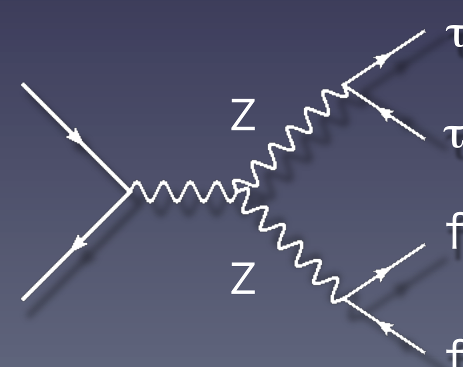












Lepton Selection

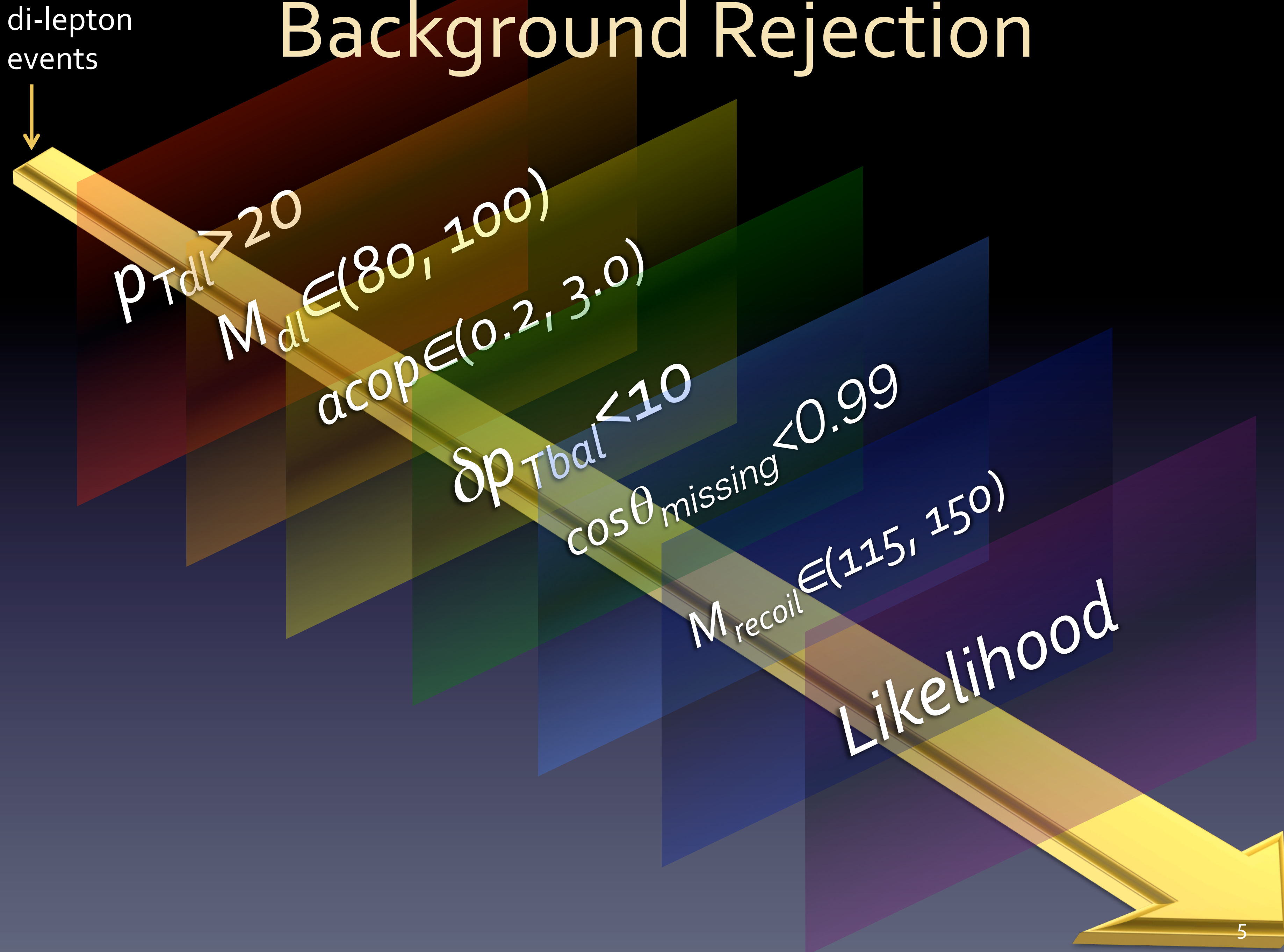
- Muon (and electron) selection
  - Momentum $p > 15$ [GeV]
  - Small (Large) energy deposite in caloriemeters
    - $E_{ecal} / E_{total} < 0.5$ (> 0.6)
    - $E_{total} / p_{track} < 0.3$ (> 0.9)
- Good track selection
  - Track with small error (different selections between polar angle of tracks,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

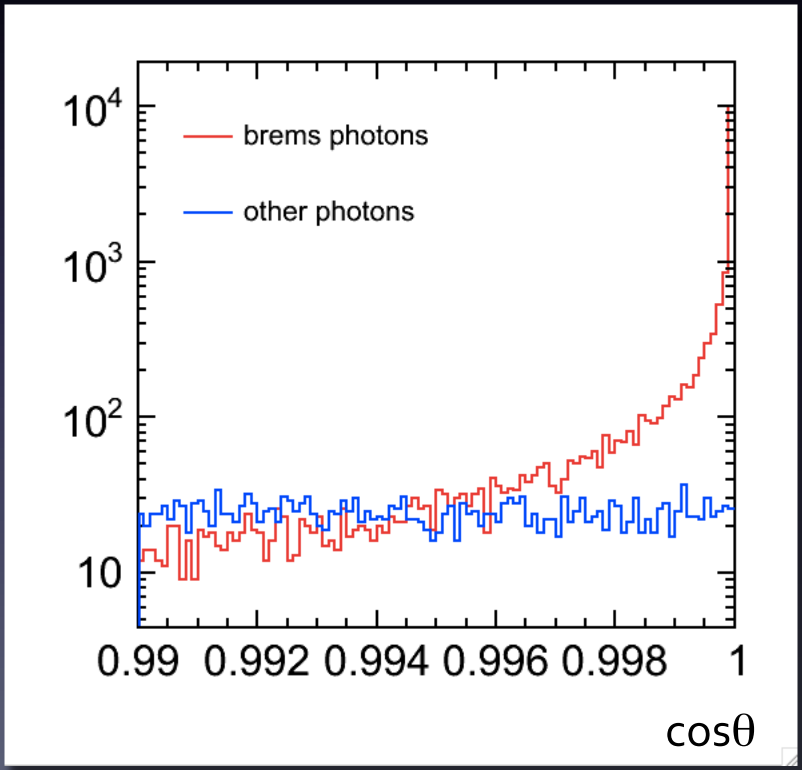
    $D_0 / dD_0 < 5$

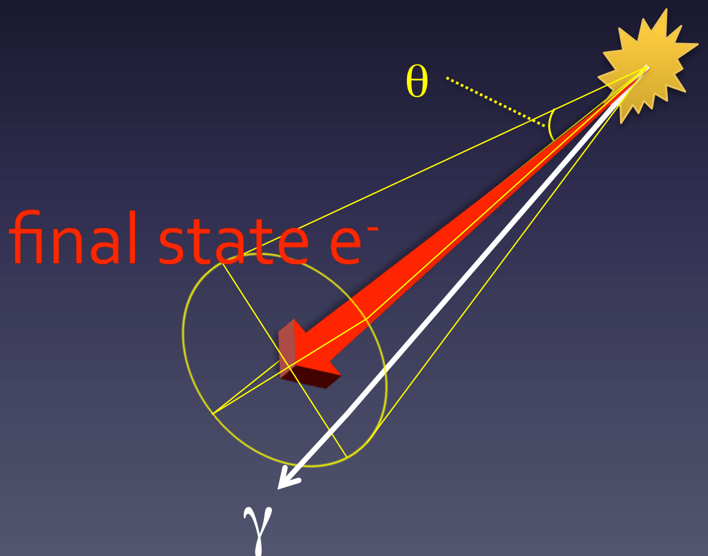
Background Rejection



Bremsstrahlung Recovery

- Only for eeh channel, 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.





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%

Fitting Method

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

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

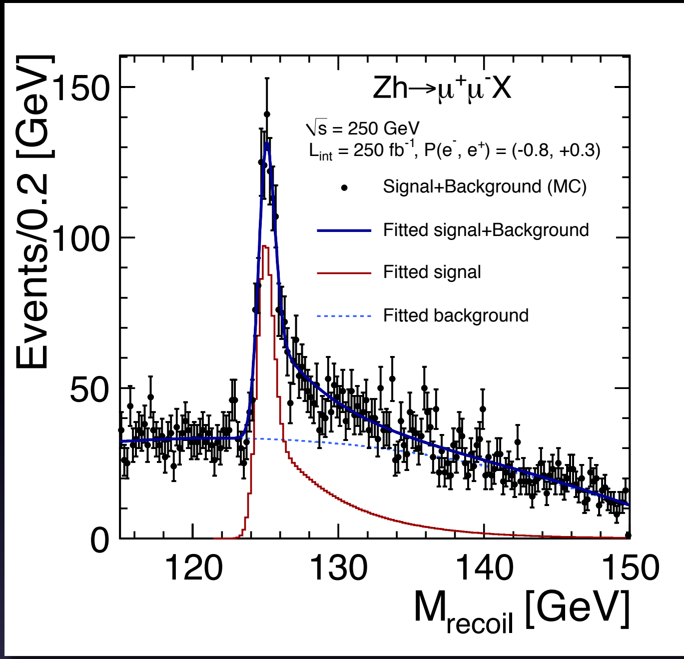
* GPET has 5 parameters
  - ✧ **height : N**
  - ✧ mean : $\bar{x}$
  - ✧ width : s
  - ✧ boundary : k
  - ✧ junction : b

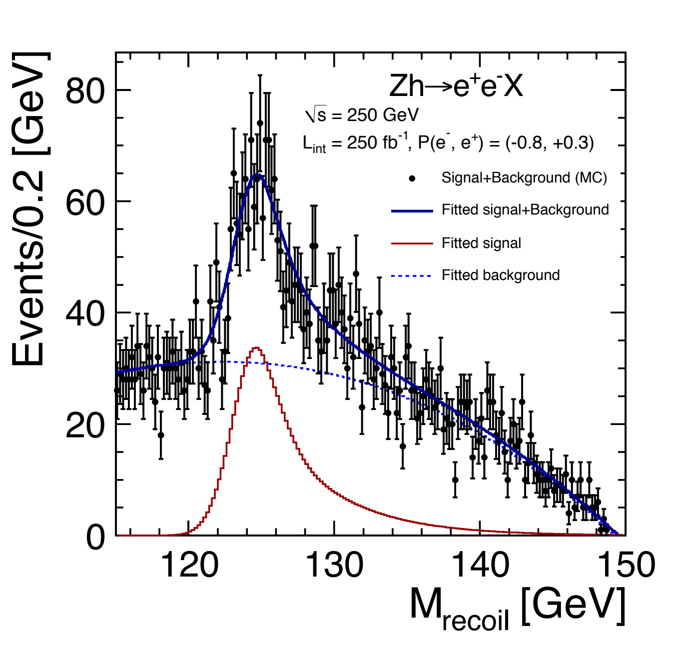
  - BG -> 3^{rd} order polynomial

- 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)





- Statistical Errors :
  - cross section error 3.6%
  - mass error 37MeV
- Statistical Errors :
  - cross section error 5.2%
  - mass error 147MeV
- Statistical errors for combination of μμh and eeh results.
  - cross section error 3.0%
  - mass error 36MeV

➜ NEXT STEP

Semi Model Independent Analysis

μμh	signal		mmnn		mmff		tlnn	
No Cut	2574		149636		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	0.

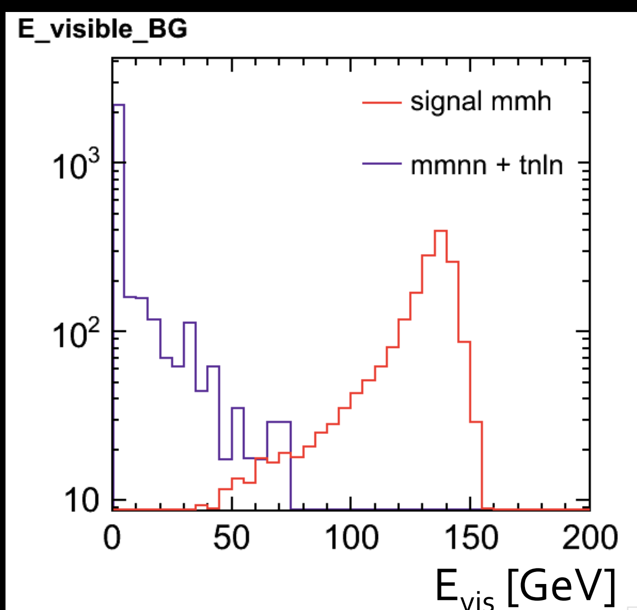
There seems to be large number of remaining BG events with neutrino.

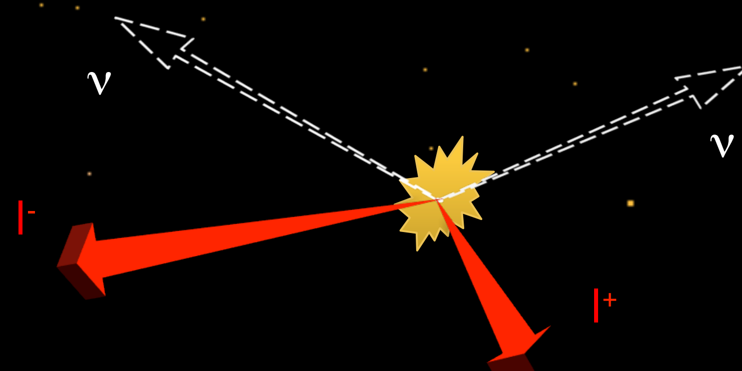
eeh	signal		eeνν		eeff		τlνν		τlff		others	
No Cut	2701		145891		184568		596518		60970		~10M	
Selection	1924	71.23%	12771	8.75%	8076	4.38%	11996	2.01%	273	0.45%	75814	0.74%
p_{Tdl}	1874	69.39%	11470	7.86%	7175	3.89%	11213	1.88%	196	0.32%	51342	0.50%
M_{dl}	1729	64.01%	6649	4.56%	5243	2.84%	6142	1.03%	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%

μμh	sig	μμνν	τlνν
After	1564	2401	333

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)

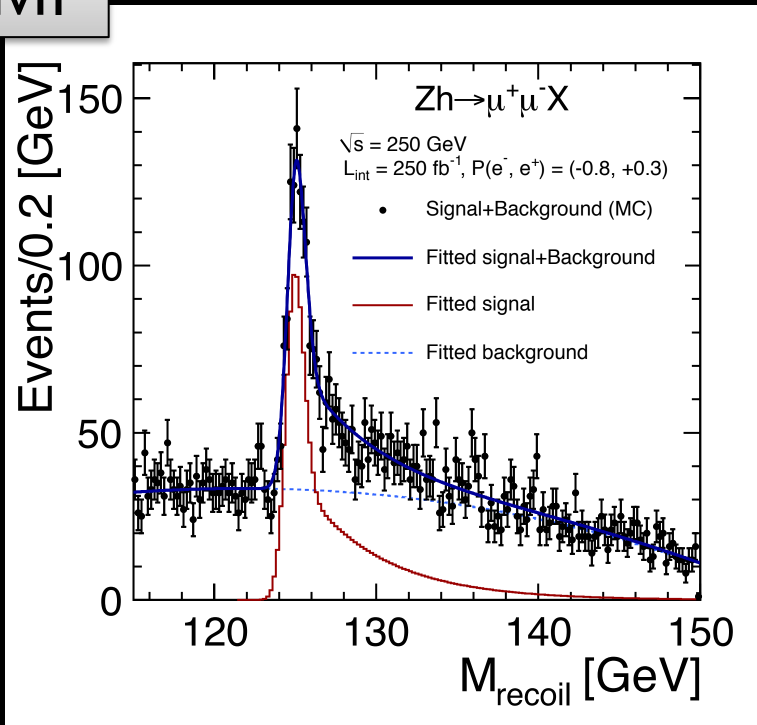
μμh	signal		μμνν		τlνν		others	
No Cut	2574		149636		596518		~10M	
$\sim M_{recoil}$	1856	72.10%	3987	2.66%	882	0.15%	3107	0.03%
E_{vis}	1854	72.01%	926	0.62%	137	0.02%	3107	0.03%
Likelihood	1811	70.37%	836	0.56%	103	0.02%	2837	0.03%

eeh	signal		eeνν		τlνν		others	
No Cut	2701		145891		596518		~10M	
$\sim M_{recoil}$	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%

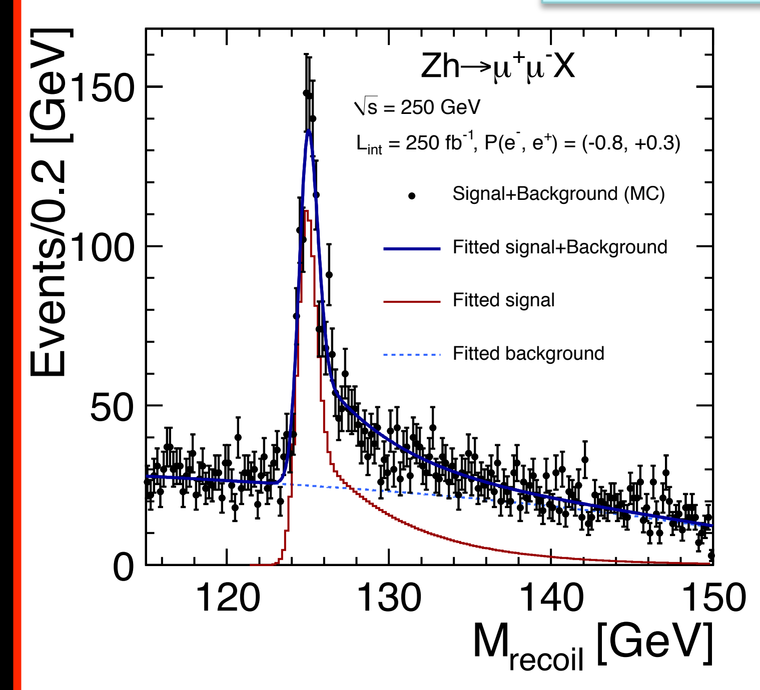
Likelihood limit value is re-optimized for new visible energy selection.

Result (Semi-MI) μμh

MI



semi MI

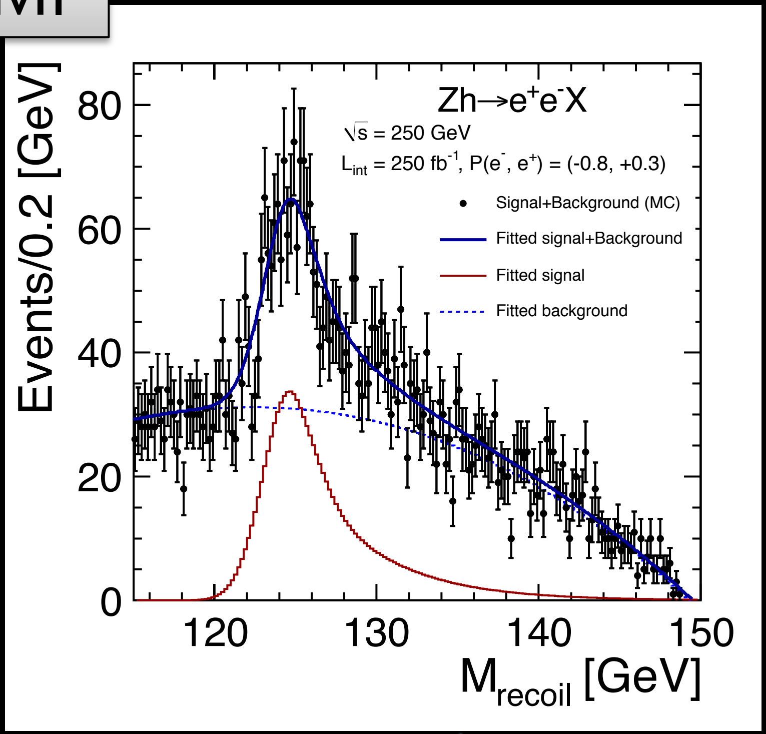


- Statistical Error :
  - cross section error 3.6%

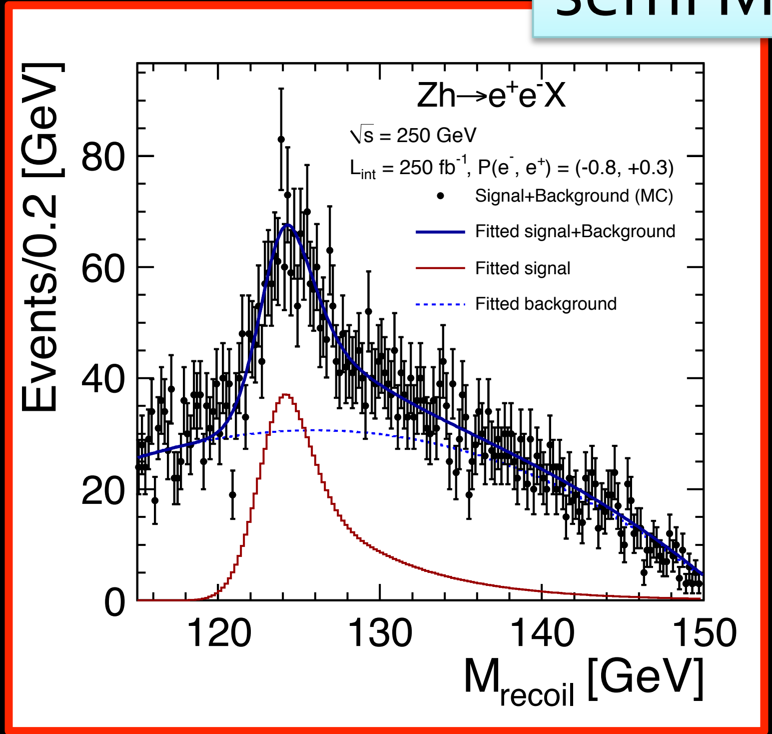
- Statistical Error :
  - cross section error 3.0%

Result (Semi-MI) eeh

MI



semi MI



- Statistical Error :
  - cross section error 5.2%

- Statistical Error :
  - cross section error 4.6%

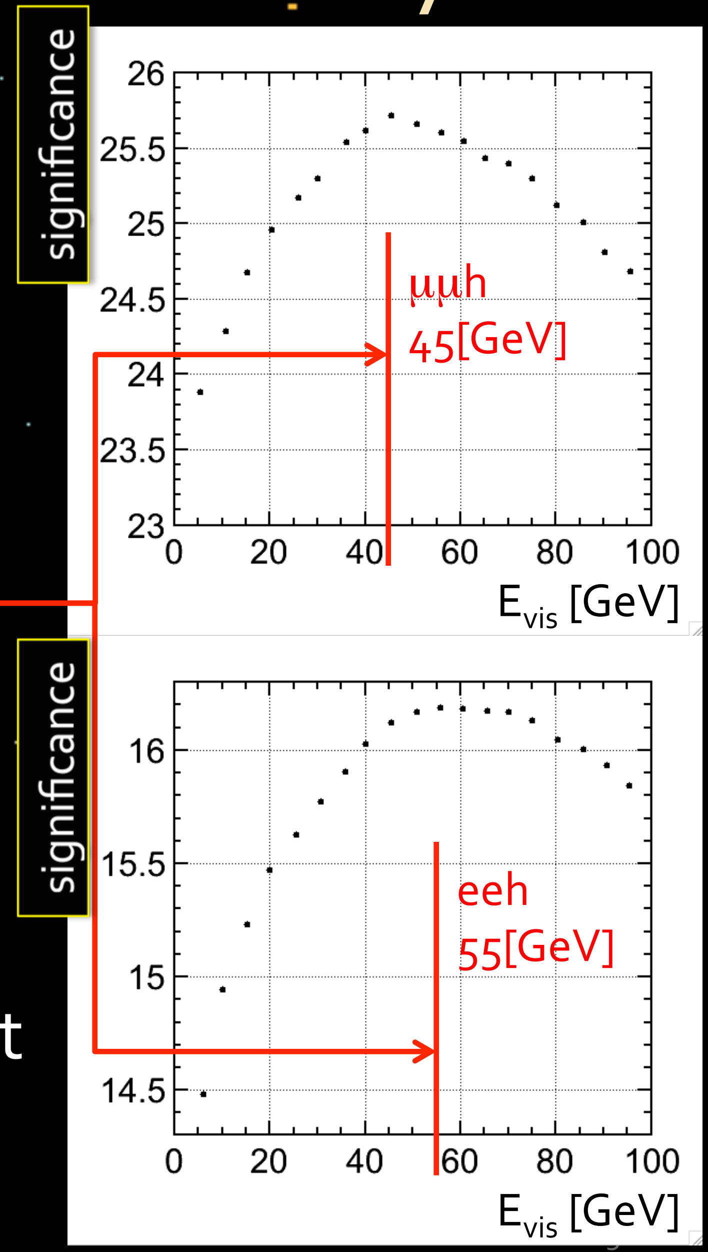
- Combination of mmh and eeh results :
  - cross section error 2.5%

$E_{visible}$ 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 : 123MeV

combined result 32MeV

Summary of Results

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

Mass	mmh	eeh	Combined
MI	37MeV	147MeV	36MeV
semi-MI	33MeV	123MeV	32MeV

Summary

- The recoil mass technique is important feature at the ILC to measure Higgs mass and cross section of Zh event.
- The measurement errors are …
  - Cross section error : ± 3.0%
  - Mass error : ± 36MeV
- Visible energy selection is very effective to suppress BG.
  - Higgs invisible decays can be calibrated with data.
  - Cross section error : ± 2.5% (E_{vis} > 5GeV)
  - Mass error : ± 32MeV (E_{vis} > 45GeV for μμh, 55GeV for eeh)