The precise measurement of Higgs mass and cross section by recoil method

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Target

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

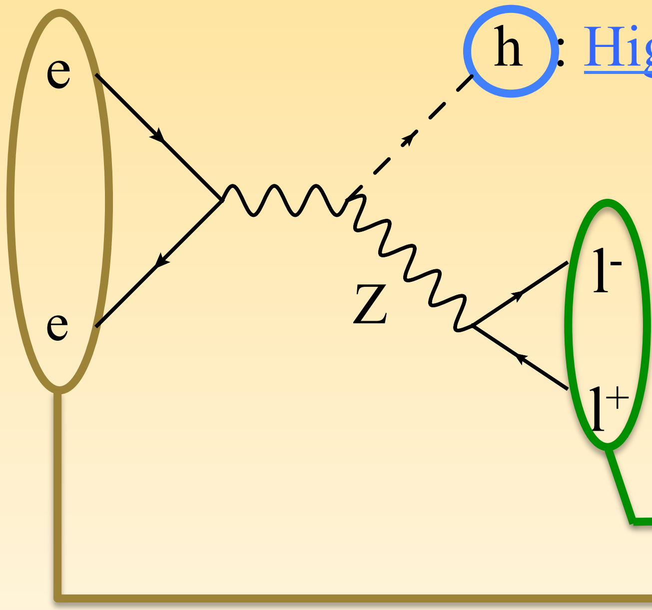
- How precise can we measure Higgs mass and cross section by this method? The considered situations are …

Production Mode	Higgs mass (GeV)	E_{CM} (GeV)	Integrated Luminosity	Spin Polarization	Detector Simulation
e^+e^-->Zh-> μμh, eeh	125	250	250 fb^{-1}	$P(e^-, e^+) = (\mp 0.8, \pm 0.3)$	ILD_01_v05 (DBD ver.)

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

What's the Recoil Method?

- ILC is a **lepton collider**
  = We already know initial state 4 momentum



: Higgs (any decay mode is allowed)

$$p_h = p_{e-} + p_{e+} - p_Z$$

✧ We can calculate the 4momentum of Higgs.

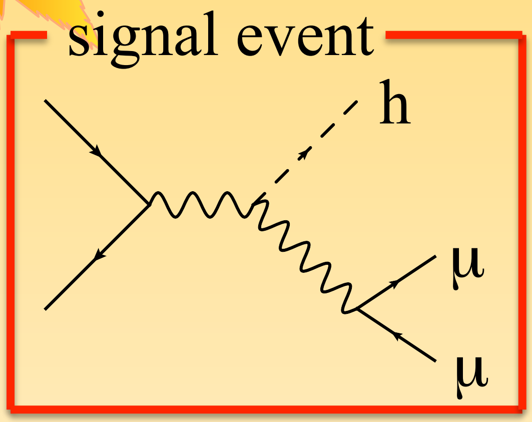
Aim for Higgs σ measurement

- Directly — It depends on the model of Higgs decay
- Recoil method — We can measure Higgs model independently

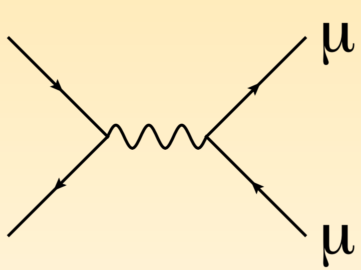
Keywords of the Study

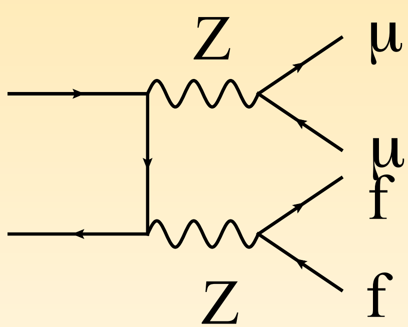
1. Model independent analysis
   – This means unbiased selections should be used
   = The bias of signal efficiency for each major Higgs decay must be suppressed at least within uncertainty of σ measurement
2. Precise measurement
   – Maximize precision while staying model independent
   – Comparison between different polarization cases
3. Mass template method
   – This method is tried in order to estimate Higgs mass ignoring systematic uncertainty

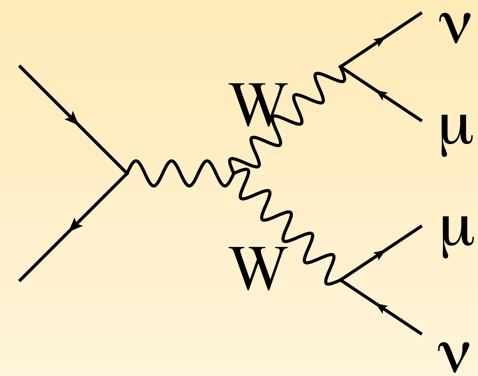
Signal and Background Events



- These are μμh channel signal & BGs.
- For eeh channel study, character of "μ" and "ν" are altered appropriately.







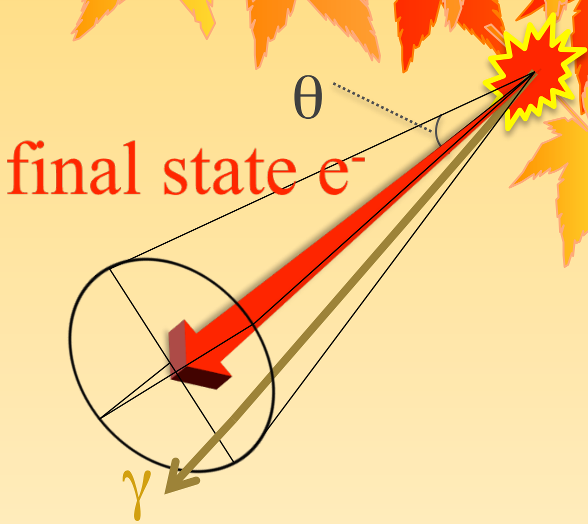
- Dominant Background is "μμ", "μμνν", "μμff" events, and other BG is rejected significantly.

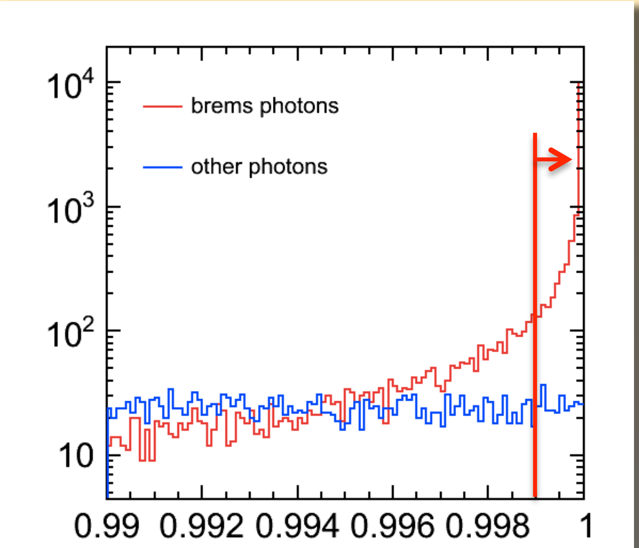
Lepton Selection

- Muon (electron) selection
  - based on deposited energy in calorimeter
- Good track selection
  - based on error in forward / barrel
- Impact parameter (only for muon)
  - To suppress muons from tau decays
- Bremsstrahlung recovery (only for electron)
  - Photons emitted from electron are recovered.

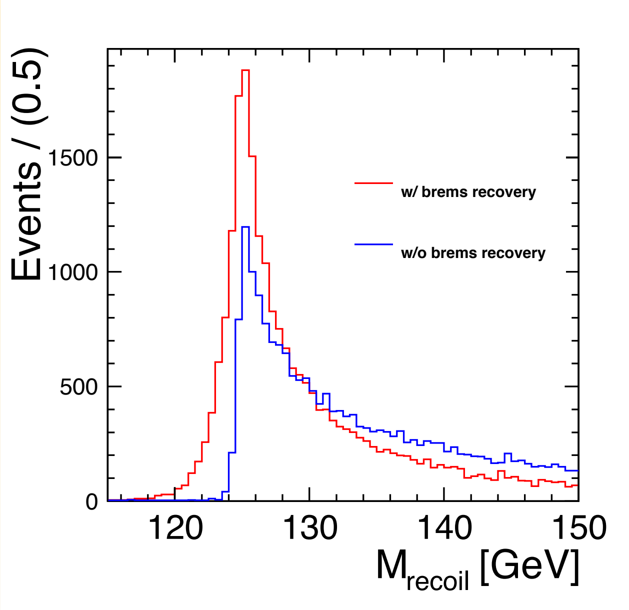
Bremsstrahlung Recovery

- Only for eeh channel, momentum of photon around final state electron is added to the electron.
  - $\cos\theta > 0.9995$
  - $\cos\theta > 0.999$ && $E_{photon}/E_{electron} > 0.03$
  - not split photon
- This process contributes to the distribution of recoil mass significantly.





$\cos\theta$ b/w $e^{\pm}$ and γ



※ For mass analysis, it is effective not to perform the recovery.

BG Rejection

- $p_{Tdl} > 20GeV$ — μμ
- $M_{dl} \in (80, 100)[GeV]$ — μμνν
- $acop \in (0.2, 3.0)$ — μμ
- $\delta p_{Tbal} \notin (-10, 10)[GeV]$ — μμγ
- $\cos\theta_{missing} < 0.99$ — μμγ
- $M_{recoil} \in (115, 150)$ [GeV] — μμ, μμνν, μμff
- Likelihood — μμ, μμνν, μμff

BG Rejection

Left Handed Case

μμh	signal	ll	llνν	llff	others
No Cut	2603	3.2M	507166	390041	7.1M
After Cut	1386	322	1479	1054	3

eeh	signal	ll	llνν	llff	others
No Cut	2729	7.8M	520624	404279	2.5M
After Cut	1190	1496	2203	937	4

Right Handed Case

μμh	signal	ll	llνν	llff	others
No Cut	1756	2.6M	51768	330876	6.3M
After Cut	1113	287	323	650	3

eeh	signal	ll	llνν	llff	others
No Cut	1844	7.3M	52853	358595	1.5M
After Cut	742	927	230	393	1

BG with neutrino is suppressed significantly

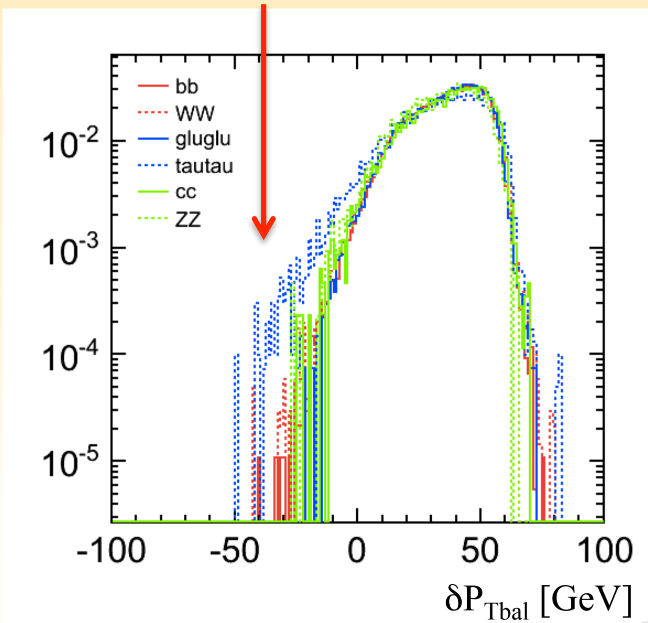
Unbiased Selection

- Signal efficiencies should be same for each Higgs decay modes, but h->ττ mode tends to have a bias

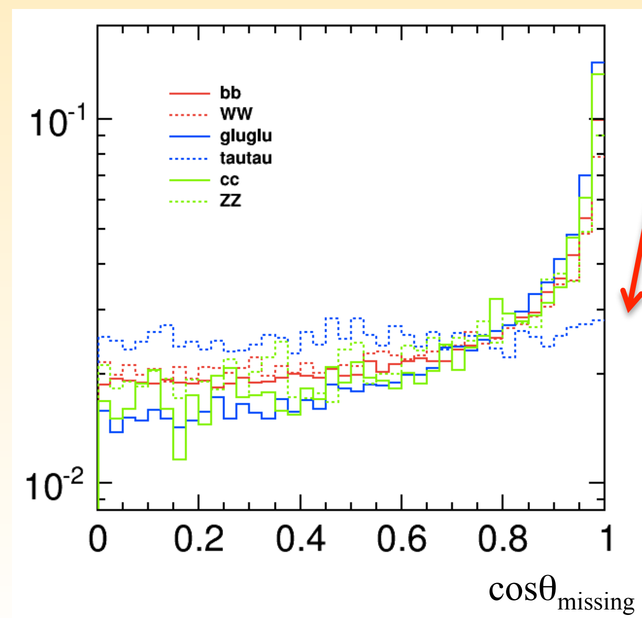
δP_{Tbal}

$\cos\theta_{missing}$

- $\delta P_{Tbal} = P_{Tdl} - P_{T\ photon} \notin (-10,10)$
- h->ττ has long tail

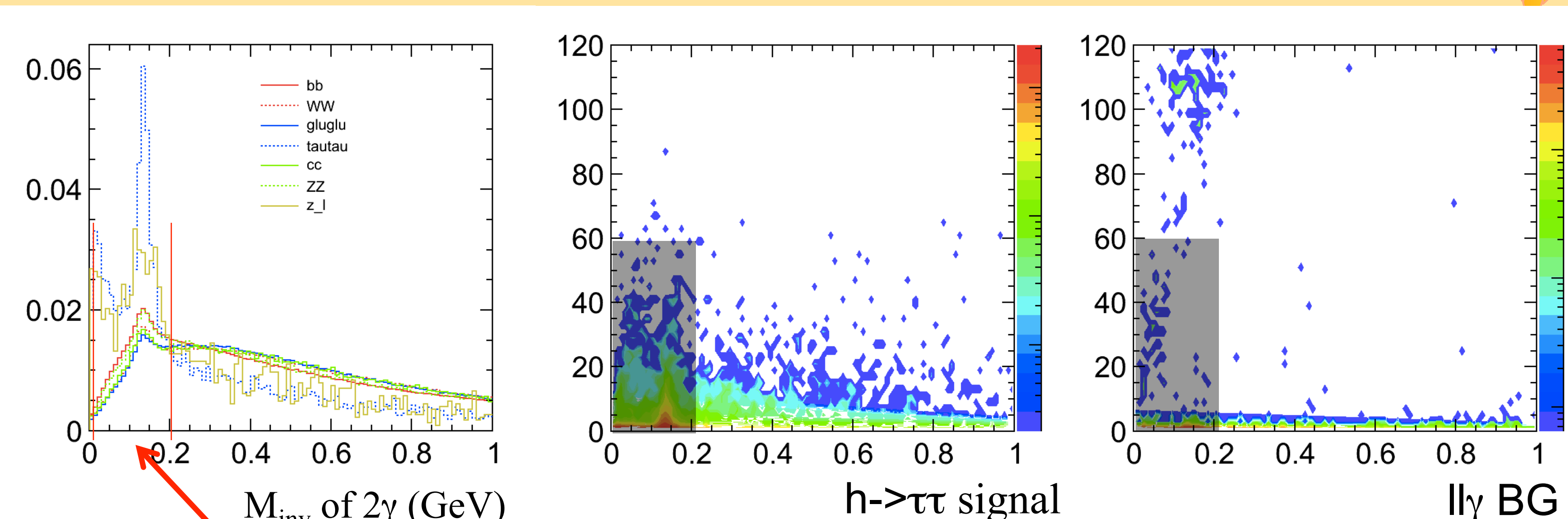


- cosθ of all PFOs < 0.99
- h->ττ has uniform distribution



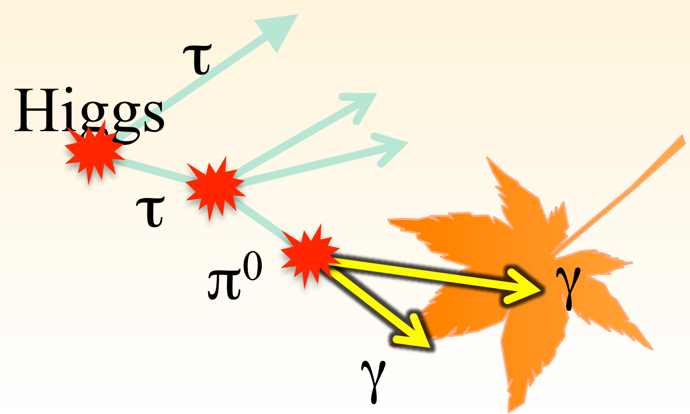
Bias Suppression (for δP_{Tbal})

- We can suppress this bias using Energy of photon and invariant mass of each photon pair.

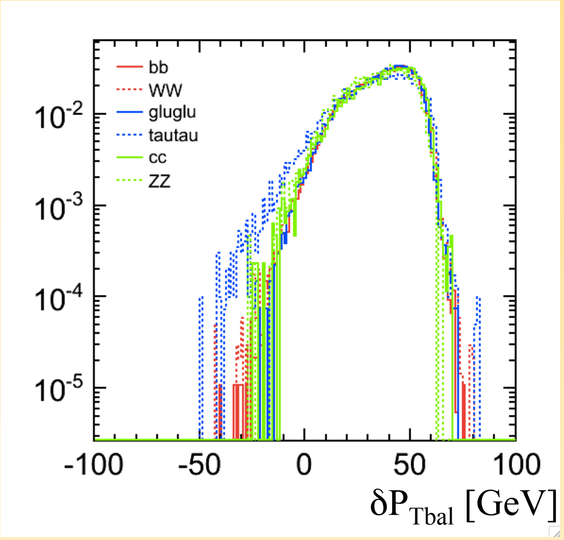


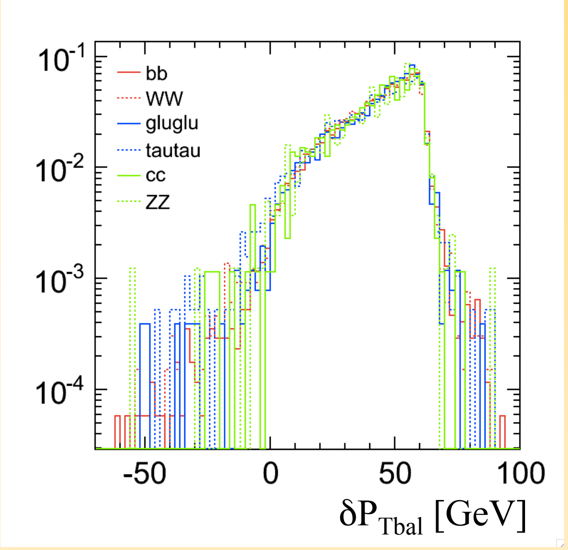
In h→ττ, there is a peak at $m_{2\gamma} \sim m_{\pi}$

condition of used γ
$m_{2\gamma} > 0.2$ [GeV]
or $E_{\gamma} > 60$ [GeV]



Bias Suppression (for δP_{Tbal})

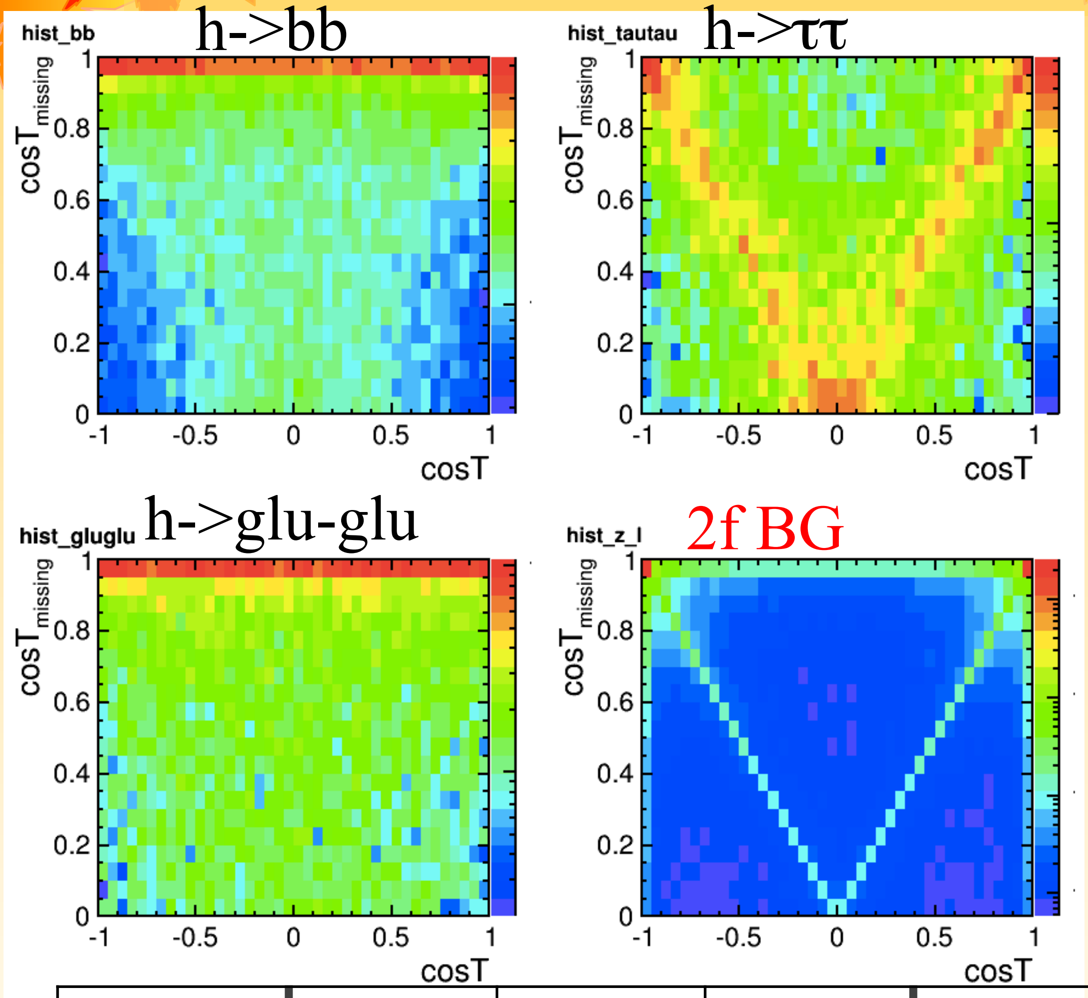




Comparison old & new	**efficiency of dPT_{bal} cut**			
	bb	ττ	cc	z_l (BG)
Simple calc.	99.4%	95.3%	99.0%	14.5%
My calc.	99.8%	97.8%	99.6%	22.2%

- In new calculation of δP_{Tbal}, bias will decrease.

Bias Suppression (for $\cos\theta_{missing}$)



- $\cos\theta$ of Z boson as additional variable is useful to suppress the bias.
  - $|\cos\theta_{missing}|<0.99$
  - or $|\cos\theta_{Z\ boson}|<0.8$
- Using these additional condition, efficiency of BG rejection is sacrificed, but it can avoid the bias.

	bb	glu-glu	ττ	BG (ll)	
$\cos\theta_{miss} < 0.99$	95.1%	92.8%	99.2%	41.1%	← Previous
$\cos\theta_{miss}<0.99$ or $\lvert\cos\theta\rvert<0.8$	99.3%	99.1%	99.8%	74.6%	← New

Signal Efficiency

- After that, bias of signal efficiency for Higgs decay is eliminated.

H decay mode	μμh efficiency [%]	eeh efficiency [%]
bb	55.61	45.62
WW	55.39	44.95
gluglu	55.16	45.02
ττ	55.42	44.49
cc	55.60	45.14
ZZ	54.04	45.51

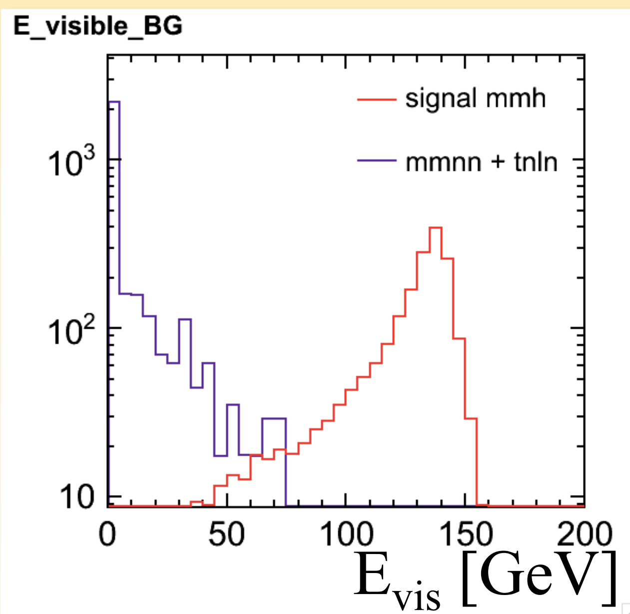
- Systematic error due to efficiency in decay modes is 3%.
- (If we could use the information on measured cross section for higgs decay modes, the error should be much smaller)

Visible Energy Selection (Semi-MI analysis)

μμh	signal	ll	llνν	llff	others
After Cut	1386	322	1479	1054	3

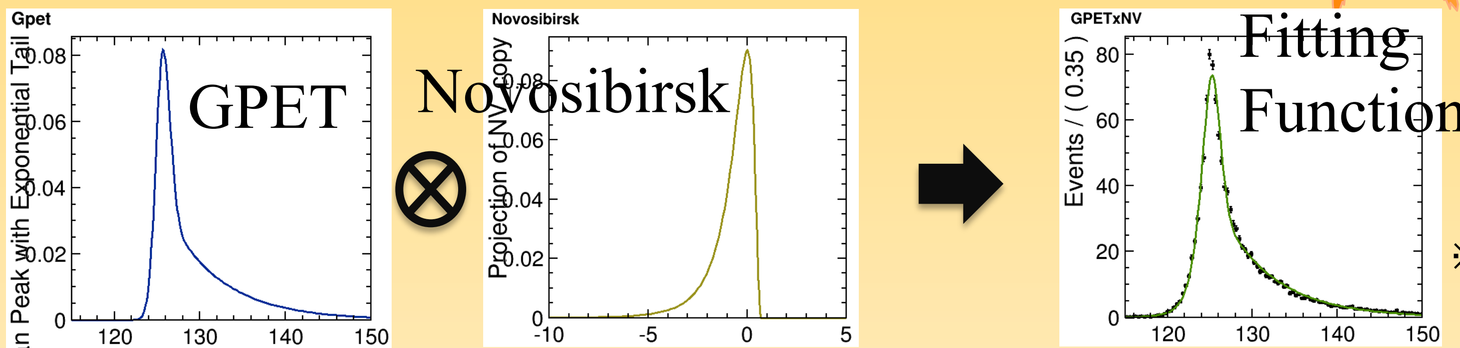
		ll	llνν	llff	others
		1496	2203	937	4

There seems to be large number of remaining llνν BG.



- 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.

Fitting Function

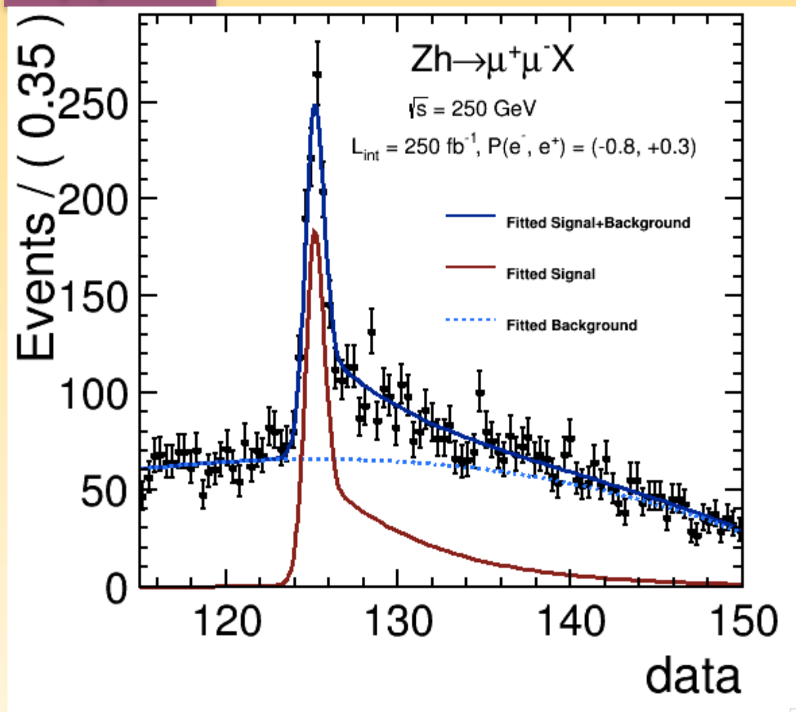


※eeh distribution

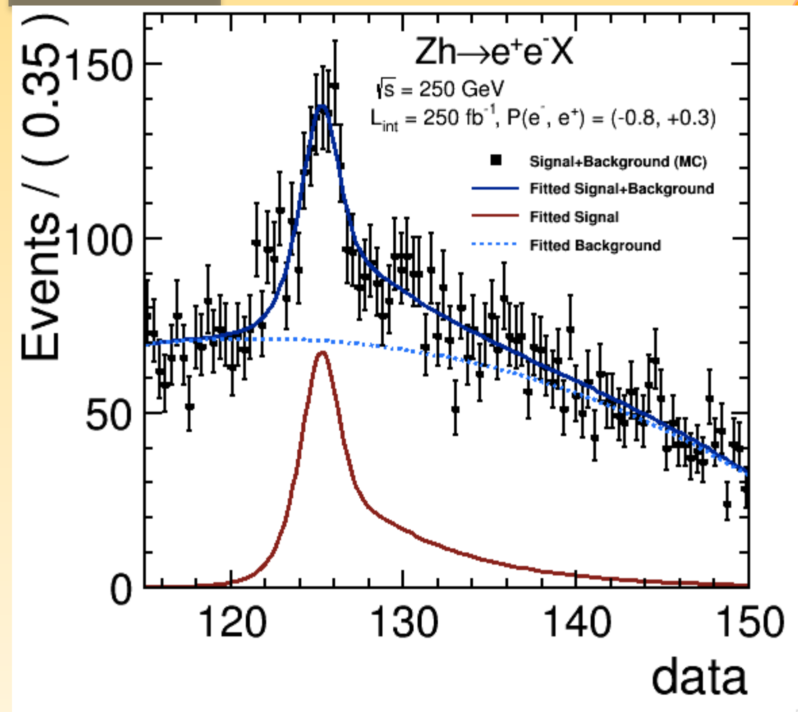
- GPET is constructed by Gaussian peak and exponential tail.
- Novosibirsk can express uncertainty of lepton detection.
  - For detail of Novosibirsk function, please check [Nuclear Instruments and Methods in Physics Research A 441 (2000) 401-426]
- For BG fitting, 3rd order polynomial is used. (BG shape is determined separately from signal shape determination)
- In pseudo-experiments, PDF shape is fixed and only number of signal and BG is floated.

Fitting Results (Left Handed)

μμh



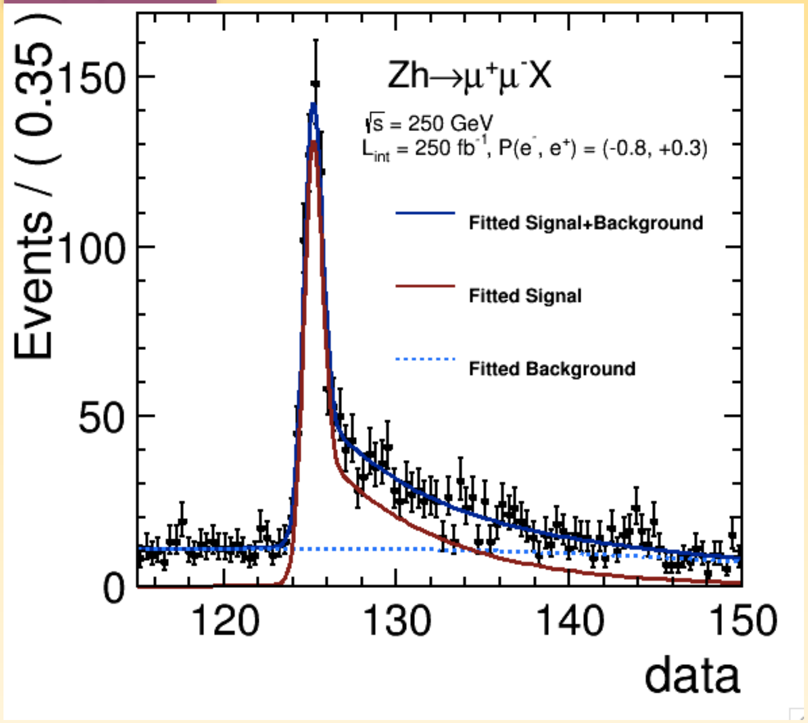
eeh



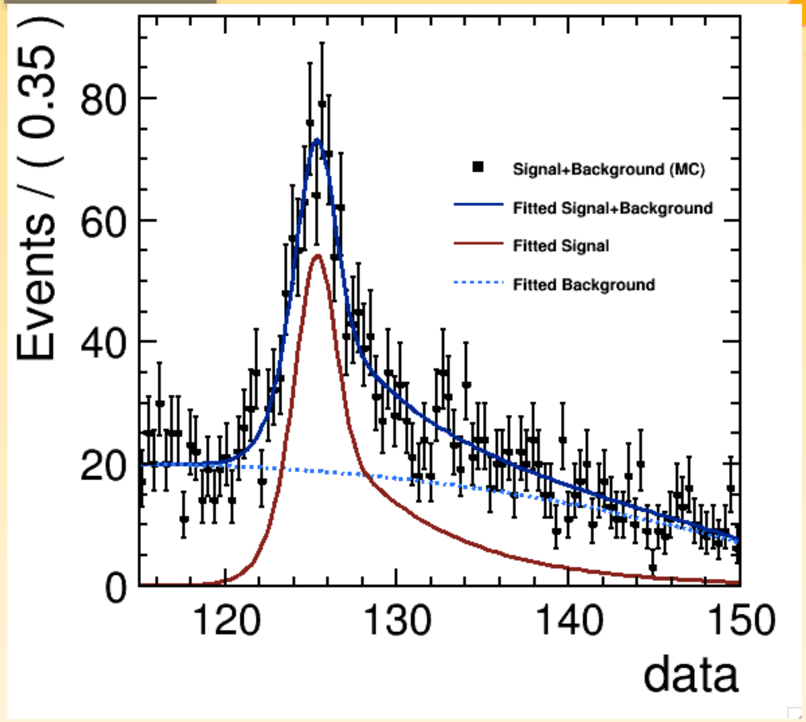
L=250fb^{-1} P(e-,e+)=(-0.8,+0.3)	μμh		eeh		combined	
	MI	semi-MI	MI	semi-MI	MI	semi-MI
Δσ/σ	4.2%	3.8%	6.0%	5.6%	3.4%	3.1%
Δmass [MeV]	34	33	231	89	34	31

Fitting Results (Right Handed)

μμh



eeh

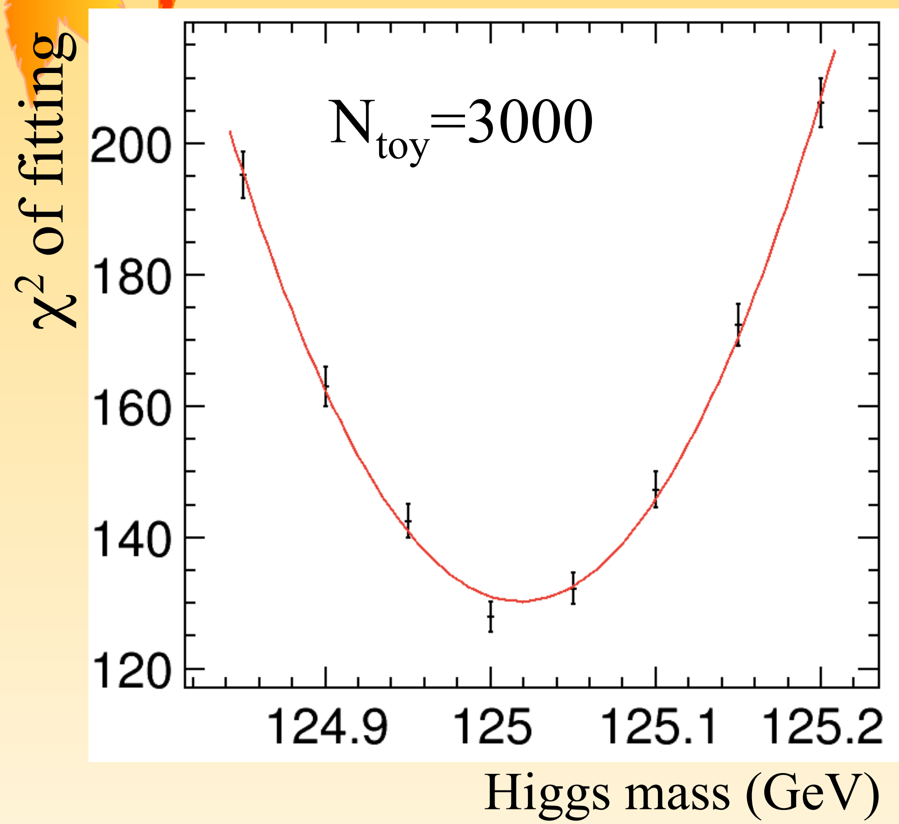


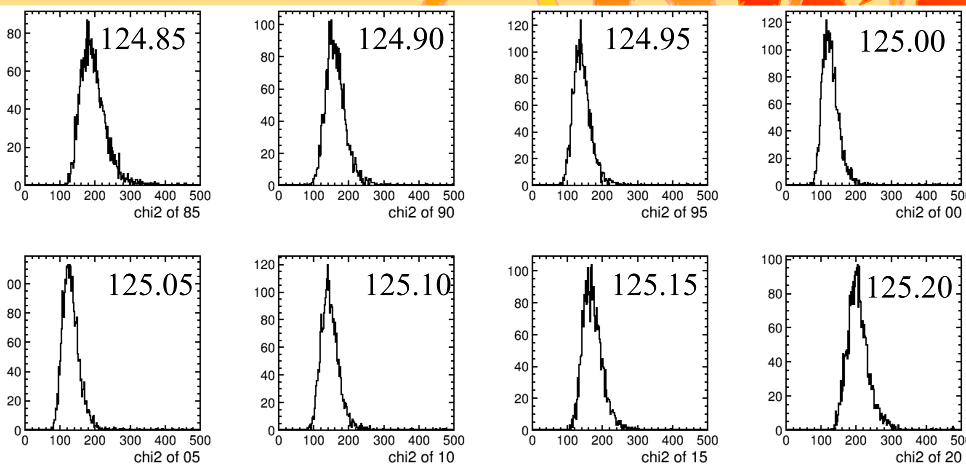
$L=250fb^{-1}$ P(e-,e+)=(-0.8,+0.3)	μμh	eeh	combined
Δσ/σ	3.8%	6.0%	3.2%
Δmass [MeV]	31	214	31

Mass Template Method

- To avoid systematic bias of mass parameter, mass template method is tried.
- Fit dataset by PDFs from template samples with different Higgs mass.
- Template samples with M_{Higgs} = 124.85, 124.90, 124.95, 125.00, 125.05, 125.10, 125.15, and 125.20 are used (8points).
- Signal PDF is used as histograms reconstructed from template samples.
- BG PDF is used as 3rd order polynomial from DBD sample fitting.
- Toy-MC is made for data points, and mean of χ^2 values is plotted and fitted by parabola.
- Mass value at minimum χ^2 point is estimated Higgs mass.

Fitting Result





histograms of χ^2

- Minimum position :
  $x = 125.018 \pm 0.021$ (GeV)

Summary and Next Plan

- The recoil mass technique is an important feature at the ILC to measure Higgs mass and cross section of ZH.

μμh, eeh @250GeV		**μμh**		**eeh**		**combined**	
		Left	Right	Left	Right	Left	Right
MI	cross section	4.2%	3.8%	6.0%	6.0%	3.4%	3.2%
	mass [MeV]	34	31	231	214	34	31
semi-MI	cross section	3.8%		5.6%		3.1%	
	mass [MeV]	33		89		31	

- Using the mass template method, the Higgs mass can be decided within 21MeV.
- I will estimate also the sensitivity to Higgs CP-mixture, which can obtain a non-zero value from anomalous coupling in 2HDM, from the Z production angle.

BACK UP SLIDES

2014/10/07

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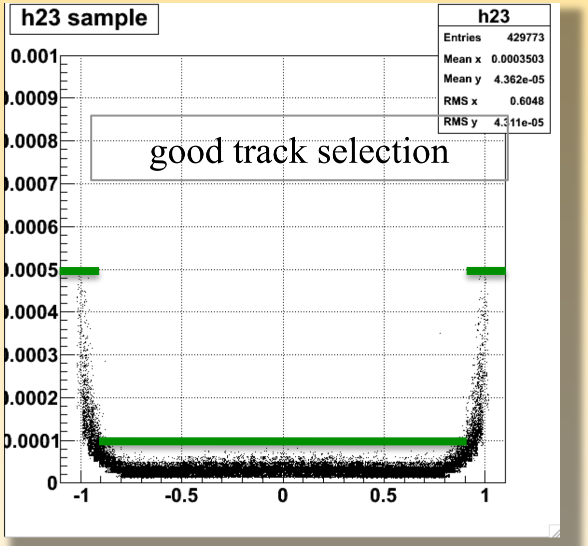
Lepton Selection

- Muon (electron) selection
  - Momentum $p > 15$ [GeV]
  - Small (Large) energy deposited in calorimeters
    - $E_{ecal} / E_{total} < 0.5$ (> 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 $\cos\theta > 0.78$)



dp / p^2

- Impact parameter (only for muon)
  - To suppress muons from tau decays which tend to have large impact parameters.
    $D_0 / dD_0 < 5$

Efficiency of $E_{visible}$

H decay mode	μμh (E_{vis} eff.)	After all cut	eeh (E_{vis} eff.)	After all cut
bb	100%	66.31%	98.68%	39.14%
WW	100%	66.00%	98.31%	38.67%
gluglu	100%	65.40%	98.67%	38.82%
ττ	99.94%	65.66%	98.43%	37.82%
cc	100%	66.32%	98.25%	39.43%
ZZ	96.64%	63.98%	94.84%	37.90%

Bias as expected from SM.

※ Some selections are optimized for semi-MI analysis, so that eff. is different from MI case.