Higgs Recoil Study for ILC

2014.11.5

ILD Analysis/Software Meeting

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Outline

Updates to the Higgs Recoil Study m_H = 125 GeV

Recoil Mass Study

- Estimate Higgs mass and cross section model independently.
  → Check cut efficiency uniformity for each Higgs decay modes.
- Improve fitting method.
- Try to estimate mass precision by mass template method.
- Semi-model independent analysis is also tried.
- We compare different polarization scenarios.

CP-mixture Study

- CP-mixture η (coefficient of CP odd Higgs amplitude) can be measured from Z boson production angle.
- Check $\cos\theta$ distribution by extrapolating number of events from recoil mass fitting, and look at the asymmetry.
- η should be calculated also by samples with anomalous coupling for ZZH.

Short Summary for

RECOIL MASS STUDY

Lepton Selections and BG Rejections

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

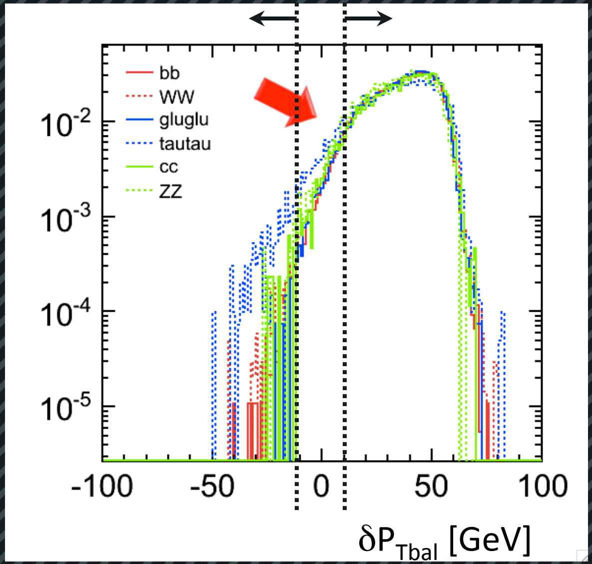
- Lepton selection
  - di-lepton (μ,e) selection : based on deposited energy in CAL
  - Good track selection : based on error in forward/barrel
  - Impact parameter (for di-muon) : to suppress μ from τ decays
  - Bremsstrahlung recovery (for di-electron)
- BG rejection

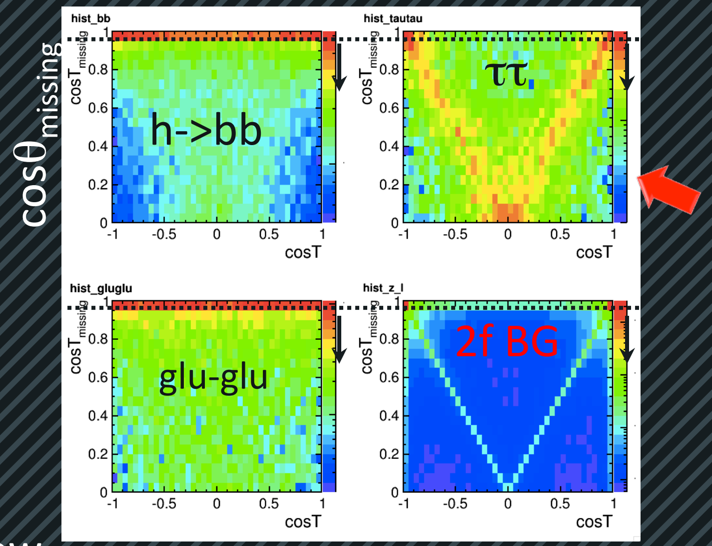
p_{Tdl}	Transverse momentum of di-lepton
M_{dl}	Invariant mass of di-lepton
acoplanarity	Balance of di-lepton azimuth
δP_{Tbal}	Balance b/w PT of di-lepton & photon
$\lvert\cos\theta_{miss}\rvert$	Angle of undetected particles
M_{recoil}	Recoil mass
Likelihood	M_{dl}, $\cos\theta_{dl}$, P_{Tdl}, acolinearity

$\mu\mu$h	signal	ll	$ll\nu\nu$	llff
No Cut	2603	3.2M	507166	390041
After Cut	1386	322	1479	1054
eeh	**signal**	**ll**	**$ll\nu\nu$**	**llff**
No Cut	2729	7.8M	520624	404279
After Cut	1190	1496	2203	937

Unbiased Selection

- δP_{Tbal} and $\cos\theta_{missing}$ cut has bias for Higgs decay modes especially h->ττ.
- To avoid this bias problem, some additional conditions are needed
- $\delta P_{Tbal} = P_{Tdl} - P_{T\ photon}$
  - photon should satisfy ...
    - $m_{2\gamma} > 0.2$ [GeV]
    - or $E\gamma > 60$ [GeV]
- $\cos\theta_{missing}$: cosθ of all PFOs
  - $|\cos\theta_{missing}|<0.99$
  - or $|\cos\theta_{Z\ boson}|<0.8$
- These additional condition avoid bias, but efficiency of BG rejection is sacrificed.





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

←New

Signal Efficiency

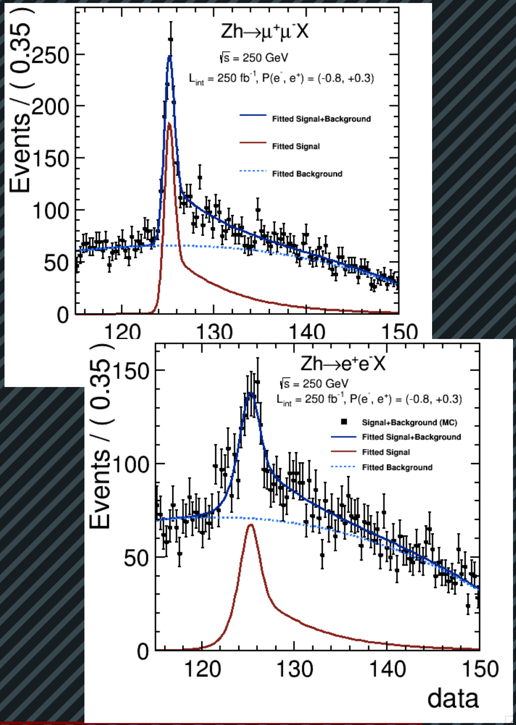
- After that, bias of signal efficiency for Higgs decay is eliminated.

H decay mode	$\mu\mu h$ efficiency [%]	eeh efficiency [%]
bb	55.61	45.62
WW	55.39	44.95
gluglu	55.16	45.02
$\tau\tau$	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)

Fitting and Results

- Fitting functions
  - GPET x Novosibirsk for signal
  - 3rd order polynomial for BG
- Toy-MC study is performed: fixing parameters except mean of Gaussian, signal and BG yields, in order to estimate statistical error of mass and cross section.



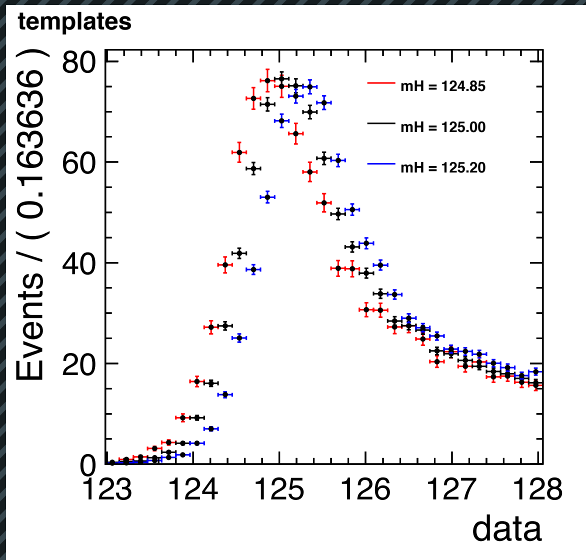
μμh, eeh @250GeV		μμh		eeh		combined	
		Left	Right	Left	Right	Left	Right
MI	cross section	4.2%	3.8%	6.0%	6.0%	3.4%	3.2%
	mass [MeV]	34	31	231	214	34	31
semi-MI	cross section	3.8%		5.6%		3.1%	
	mass [MeV]	33		89		31	

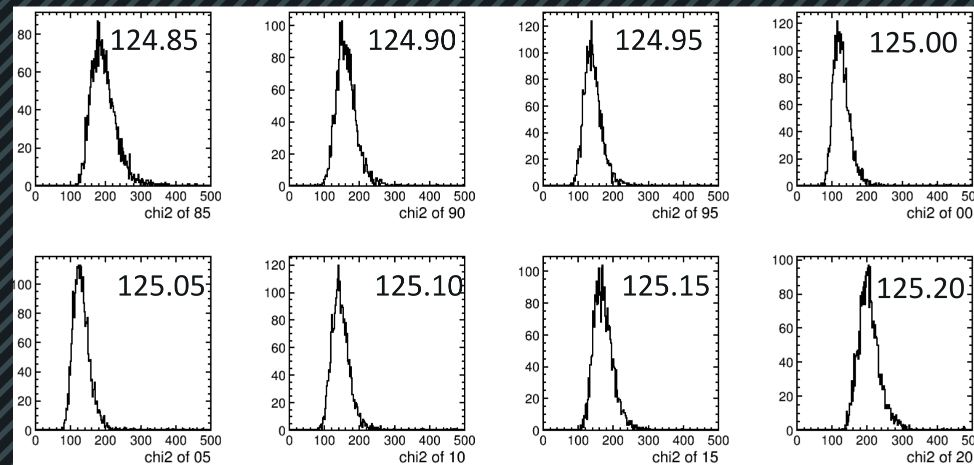
※ semi-MI means that visible energy cut is performed.

Mass Template Method

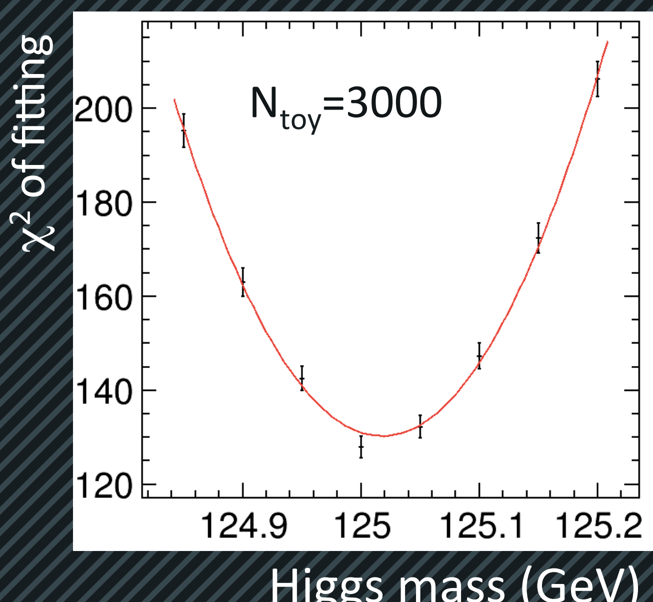
- To avoid systematic bias of mass parameter, mass template method was tried.
- Fit dataset by PDFs from template samples with different Higgs mass.
- Template samples with M_{Higgs} = 124.85, 124.90, 124.95, 125.00, 125.05, 125.10, 125.15, and 125.20 are used (8points).
- Signal PDF is used as histograms reconstructed from template samples.
- BG PDF is used as 3^{rd} 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 so that we can evaluate mass error from that.

Result





histograms of χ^2



- Minimum position :
  x = 125.018 ± 0.021 (GeV)

Next plan for

CP MIXTURE STUDY

Introduction

- In SM CP property of Higgs(h) is purely even.
- In 2HDM, there can be CP purely odd Higgs(A), and it is possible that h and A are mixed.
  - One of the parameters of this mixture is η, which is coefficient of CP odd Higgs amplitude.

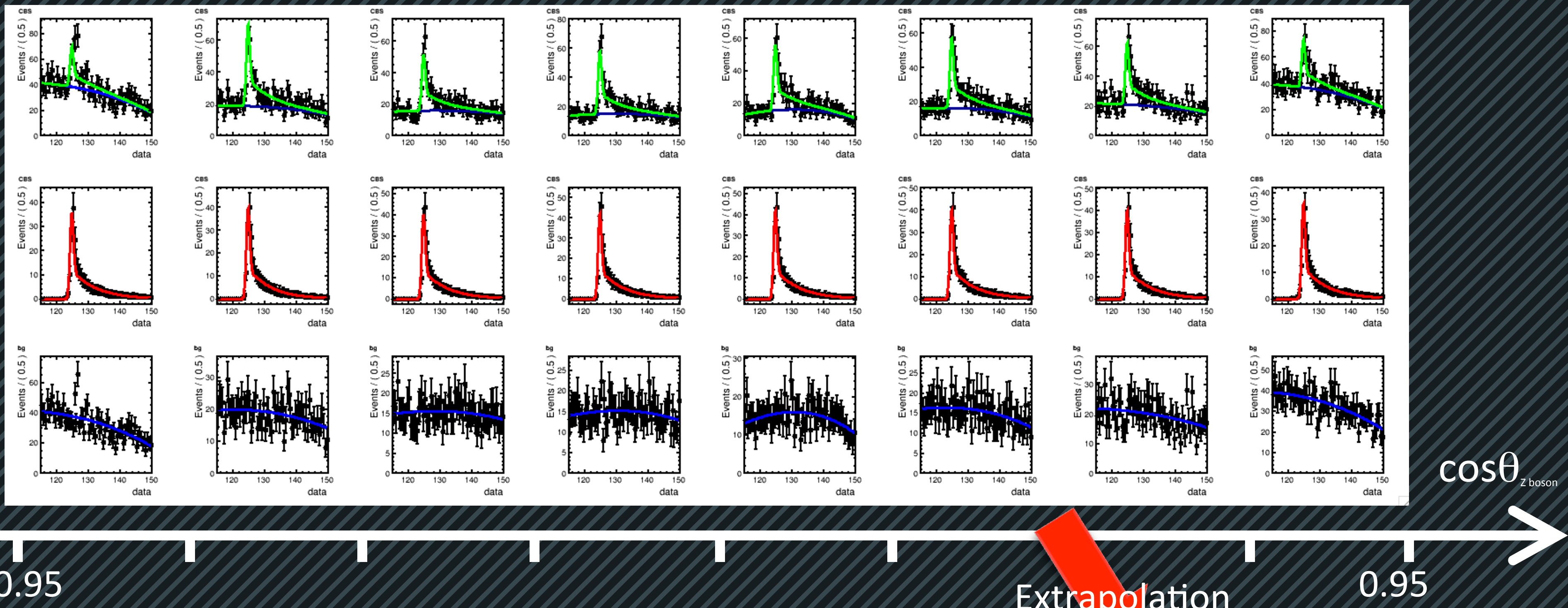
$$\boldsymbol{M_{\phi Z} = M_{hZ} + \eta \cdot M_{AZ}}$$

- When η has non-zero value, it affects Z production angle in ee->Zh event.

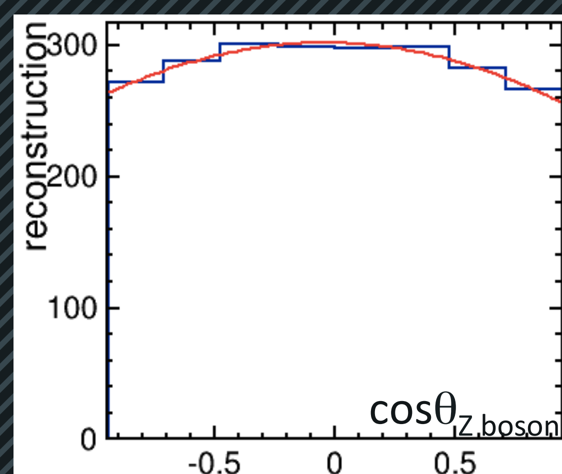
  = We can observe asymmetry

$$\frac{d\sigma}{dcos\theta} = \frac{G_F^2 M_Z^6 \beta}{16\pi}\frac{1}{D_Z(s)}(v_e^2 + a_e^2)\left[1 + \frac{s\beta^2}{8M_Z^2}(1 - cos^2\theta) + \eta\frac{v_e a_e}{v_e^2 + a_e^2}\frac{2s\beta}{M_Z^2}\cos\theta + \eta^2\frac{s^2\beta^2}{4M_Z^4}\left(1 - sin^2\frac{\theta}{2}\right)\right]$$

Procedure of CP-mixture Study



- Look Z production angle of μμh.
- Estimate N_{sig} by recoil mass fitting for each region of $\cos\theta_{Z\ boson}$.
- Fit the obtained distribution by parabola, and check asymmetry.



Re-calculation η

$$\frac{d\sigma}{d\cos\theta} = \frac{G_F^2 M_Z^6 \beta}{16\pi} \frac{1}{D_Z(s)} (v_e^2 + a_e^2) \left[1 + \frac{s\beta^2}{8M_Z^2} (1 - \cos^2\theta) + \eta \frac{v_e a_e}{v_e^2 + a_e^2} \frac{2s\beta}{M_Z^2} \cos\theta + \eta^2 \frac{s^2\beta^2}{4M_Z^4} \left(1 - \sin^2 \frac{\theta}{2} \right) \right]$$

$$※ \begin{cases} v_e - a_e = \dfrac{e}{\cos\theta_w \sin\theta_w} \left(-\dfrac{1}{2} + \sin^2\theta_w \right) \\ v_e + a_e = \dfrac{e}{\cos\theta_w \sin\theta_w} (-\sin^2\theta_w) \end{cases}$$

When define coefficients of pol2 of cosθ distribution as p_1 and p_2, η can be expressed by looking ratio p1/p2.

$$\eta = \frac{M_Z^2}{2s} \left[-\frac{16}{\beta} \frac{v_e a_e}{v_e^2 + a_e^2} \pm \sqrt{\frac{16^2}{\beta^2} \left(\frac{v_e a_e}{v_e^2 + a_e^2} \right)^2 - \frac{4s}{M_Z^2} \frac{p_1}{p_2}} \right] = 0.06654 \times \left[-2.411 \pm \sqrt{5.811 - 30.06 \times \frac{p_1}{p_2}} \right]$$

➡ η=-0.044+-0.105 (SM sample)

or, if $O(\eta^2)$ is ignored…

$$\eta = -\frac{\beta}{16} \frac{v_e^2 + a_e^2}{v_e a_e} \frac{p_1}{p_2} = -0.4148 \ldots \times \frac{p_1}{p_2}$$

➡ η=-0.075+-0.157 (SM sample)

Next Plan

- We have a generator with anomalous ZZH coupling, which is expressed by a, b, b˜ parameters.
  - parameter of a will change only total cross section.
  - b and b~ change cosθ distribution but it is complicated (right figure)
  - I should check the relation between "η" and "a, b, b˜".
- I will try to estimate η value in other calculation.