The measurement of Higgs CP-mixture by recoil method at the ILC

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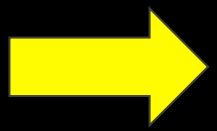
Theoretical Introduction

- To explain the asymmetry between matter and anti-matter in universe, much larger CP violation source is needed.
- Assuming general $ZZ\phi$ coupling, CP mixture happens which can be described that 125GeV Higgs can be a linear combination of CP even h and CP odd A.

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



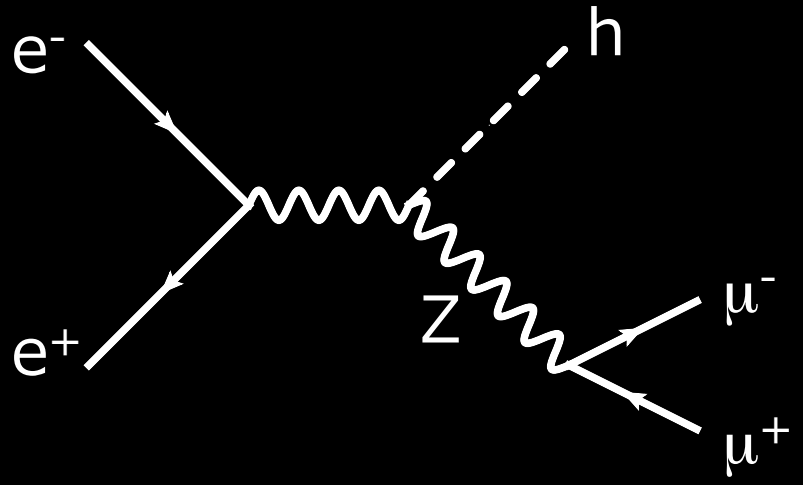
Higgs can be another source of CP violation beyond SM.

Method

- If η has non-zero value, it can cause forward backward asymmetry of Z boson in $e^+e^- \rightarrow Zh$ events.

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

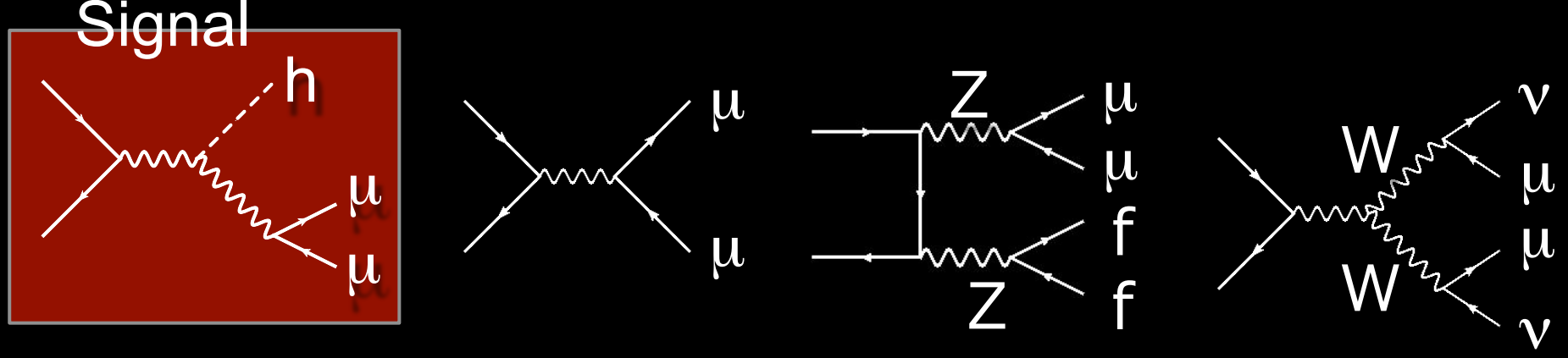
mixing term



- At the ILC, we can extract number of signal by recoil method so that reconstruct Z production angle distribution, independently of other models.

Conditions

Higgs mass	Center of mass energy	Integrated Luminosity	Detector simulation
125 [GeV]	250 [GeV]	250 fb^{-1}	ILD_01_v05 (DBD ver.)



- Signal is Zh→μμh event.
- Any other events with di-muon are considered as BG.

Procedure

- To obtain efficiency distribution, full simulated events were reconstructed.
  - Any quantities for BG rejection should have no correlation with Z production angle cosθ.
  - It is desirable that selection is independent of Higgs decay model.
  - Recoil mass shape was decided from reconstructed information.
- cosθ Toy-MC was generated from theoretical distribution.
  - Efficiency distribution was multiplied.
  - Signal toy events were obtained extracting number of signal from recoil mass distributions in each bins of cosθ.
- $\eta_{measured}$ for a Toy-MC was estimated as fitting parameters of 2^{nd} order polynomial for signal Toy-MC.

Event Reconstruction

- Baseline is same with Higgs recoil mass analysis. (talked in LCWS2014@Beograd)

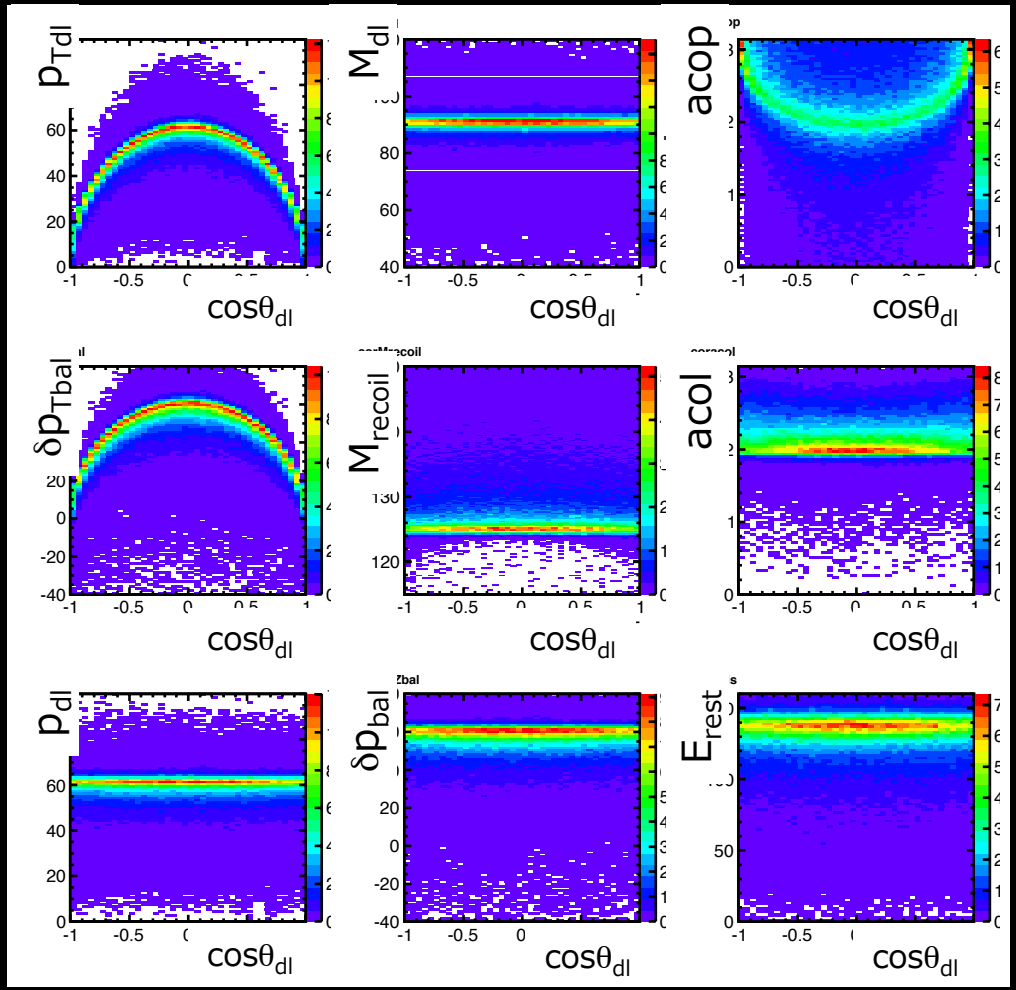
	p_{track}	E_{ECAL}/E_{total}	E_{total}/p_{track}
μ selection	>15GeV	<0.5	<0.3

- Impact parameter $D_0/\delta D_0<5$.
- Some quantities for BG rejection was optimized for this study.
- To reject large l^+l^- BG, cosθ region is restricted (-0.95, 0.95).

BG rejection

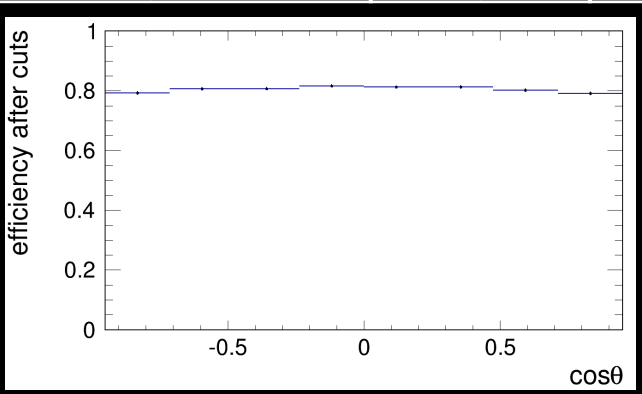
- p_{Tdl}, acop and δp_{Tbal} are changed 3dimensional quantities.
- $\cos\theta_{missing}$ has correlation with $\cos\theta$ and is not used.
- $E_{visible}$ has bias for Higgs invisible decay and is not used.

recoil mass study	CP-mixture study
p_{Tdl} →	p_{dl}
M_{dl}	M_{dl}
acop →	acol
δp_{Tbal} →	δp_{bal}
$\cos\theta_{missing}$	
M_{recoil}	M_{recoil}
Likelihood	
$E_{visible}$	



Selection Result

cosθ region	-0.95 ~ -0.7125		-0.7125 ~ -0.475		-0.475 ~ -0.2375		-0.2375 ~ 0		0 ~ 0.2375		0.2375 ~ 0.475		0.475 ~ 0.7125		0.7125 ~ 0.05	
	sig	BG	sig	BG	sig	BG	sig	BG	sig	BG	sig	BG	sig	BG	sig	BG
di-μ	267	135k	285	67k	297	53k	304	49k	302	48k	296	53k	287	67k	264	136k
p_{dl}	265	73k	283	38k	295	31k	302	28k	300	28k	294	31k	285	38k	262	74k
M_{dl}	241	28k	257	13k	267	9702	275	8617	273	8658	266	9570	259	13k	238	28k
acol	239	12k	255	5866	265	4515	272	4141	271	4087	264	4487	256	5959	234	12k
δp_{bal}	237	6472	253	3421	263	2567	270	2295	268	2275	262	2491	254	3500	233	6356
M_{recoil}	232	1997	248	1130	258	927	266	890	264	891	257	930	250	1190	229	1992



- 8 binning cosθ region are chosen for assure at least 200 signal events.
- Efficiency distribution is obtained dividing reconstruction by MC.
- It can be used also for CP mixing case, because it depends on only detector response.

Procedure

- To obtain efficiency distribution, full simulated events were reconstructed.
  - Any quantities for BG rejection should have no correlation with Z production angle $\cos\theta$.
  - It is desirable that selection is independent of Higgs decay model.
  - Recoil mass shape was decided from reconstructed information.
- $\cos\theta$ Toy-MC was generated from theoretical distribution.
  - Efficiency distribution was multiplied.
  - Signal toy events were obtained extracting number of signal from recoil mass distributions in each bins of $\cos\theta$.
- $\eta_{measured}$ for a Toy-MC was estimated as fitting parameters of 2^{nd} order polynomial for signal Toy-MC.

Toy-MC Study Chart

η input

Theoretical $d\sigma/d\cos\theta$ distribution for Zh

generate $\sigma_{tot} \cdot L$

$\cos\theta$ Toy-MC
(= N_{sig} in each bins)

times efficiency
& make Toy-MC

…

recoil mass Toy-MC for each bin

DBD BG

reconstruct

recoil mass distribution

fit by 3rd order polynomial
& make Toy-MC

- Fit total distribution and extract N_{sig}
- Efficiency correction (1/eff.)

➡ signal $\cos\theta_{Toy}$ at generator level

Full simulated recoil analysis

- decide PDF shape
  - Signal : GPET⊗Novosibirsk
  - BG : 3rd order polynomial
- obtain efficiency distribution for $\cos\theta$

Procedure

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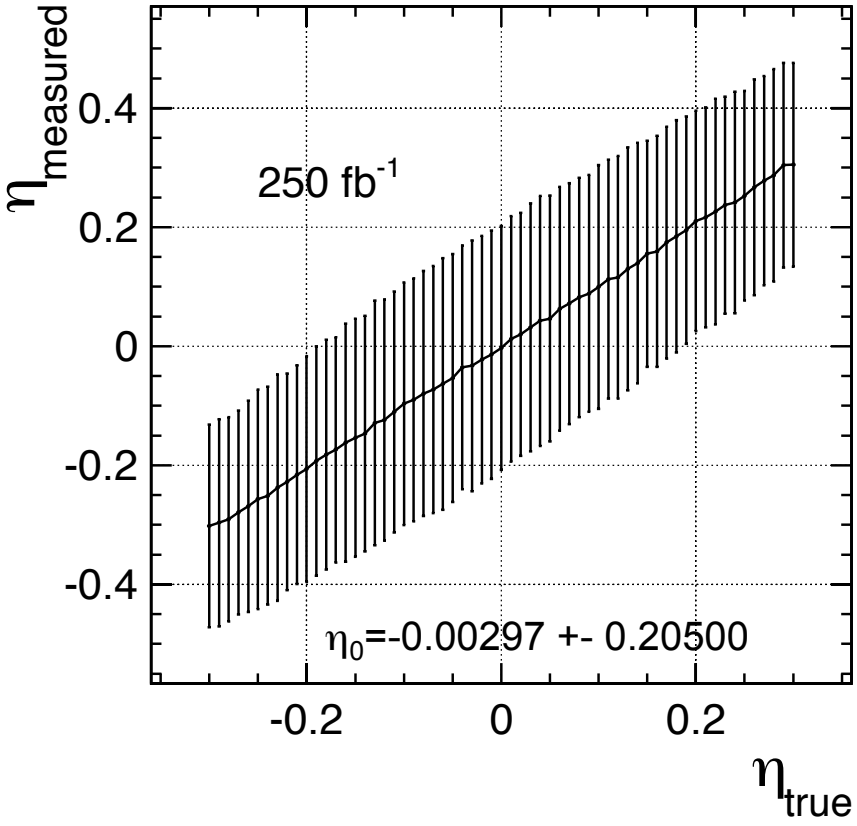
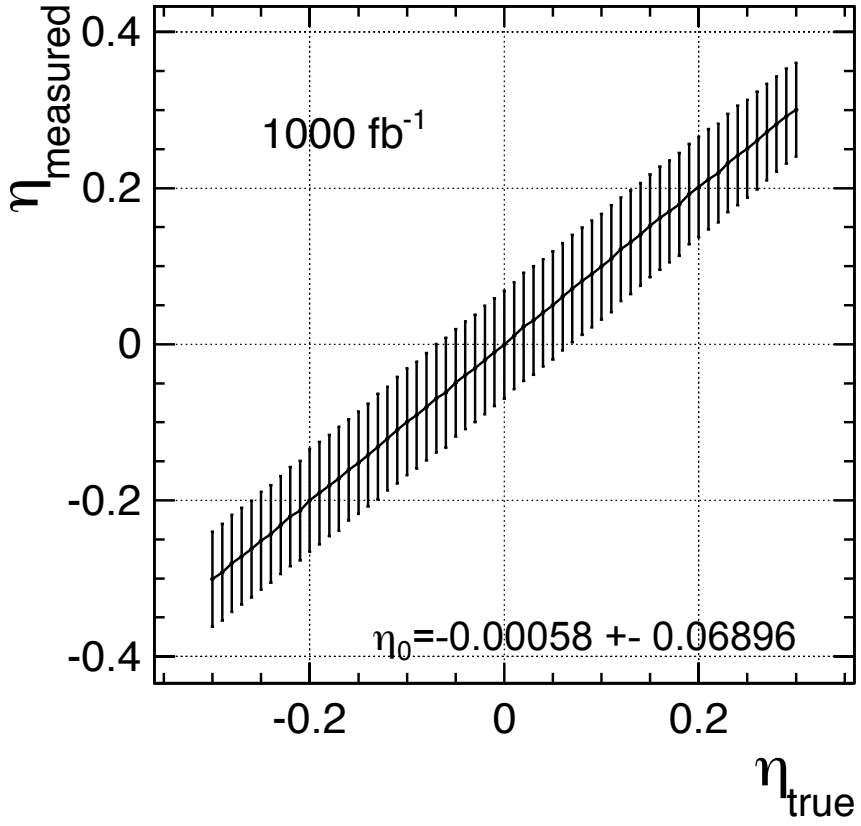
Measured η Estimation

- Fit signal cosq Toy-MC obtained by previous method by $f(x)=Y\{A+B\eta^2+C\eta x+(D+E\eta^2)x^2\}$.
- A~E are physical constants from theory.
- η(asymmetry) and Y(like yields) are free parameters.

- Input η is varied as -0.30, -0.29, …, 0.29, 0.30.
- Integrated luminosity is considered 250fb^{-1} and 1000fb^{-1}.

Results





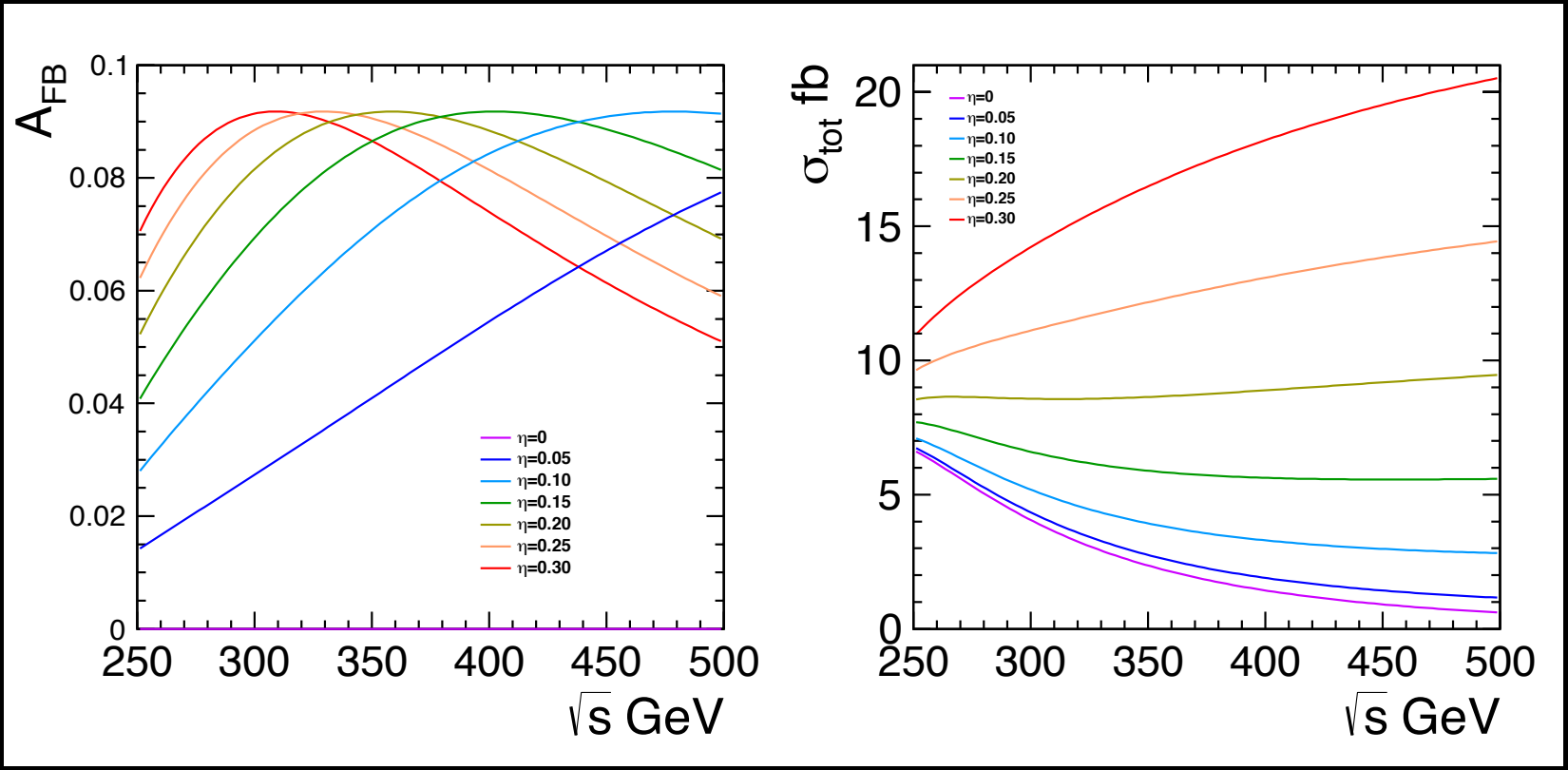
- 250fb^{-1} case has quite large error and seems to be unavailable.
- 1000fb^{-1} case may be able to restrict η.

Summary

- The mixing of CP odd Higgs(A) in models with general $ZZ\phi$ coupling is one of the candidates of additional CP violation source to explain asymmetry between matter and anti-matter.
- Higgs CP-mixture η, which is defined as coefficient of the amplitude for ZA coupling, can be estimated by measuring Z production angle $\cos\theta$ in $ee \rightarrow Zh$ events.
- I analyzed statistical error to estimate η from $\cos\theta$ obtained by recoil method, and find that more than 250fb^{-1} statistics may be needed at least using only μ channel at 250GeV.

Next Plan

- Higher center of mass energy may be suitable to estimate η value.
- Here, $A_{FB} = (N_{forward}-N_{backward})/(N_{forward}+N_{backward})$



Next Plan

- I should understand correlation between η and more natural parameters for Higgs CP mixing. (maybe a, b, and b~)
- In this analysis, there are 2 free parameters in fitting, but total cross section is also function of η.
  ➡ So I can consider η as a only free parameter.
  - But some bias exists to measure η if another parameter is fixed, so further investigation is needed.
  - η^2 can be measured more precisely by total cross section.

- Also many remaining BG events affects final statistical error, so additional selections may be effective ($E_{visible}$ for example)