



National University  
The Graduate University  
for Advanced Studies [SOKENDAI]

## **Sensitivity of Anomalous Couplings between Higgs and Gauge Bosons**

- >. Report about HZZ.**
- >. Focus on  $mmH$  process.**

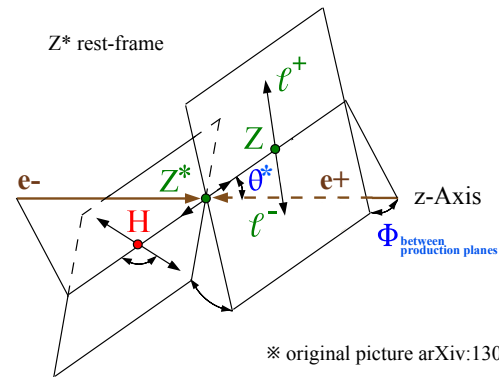
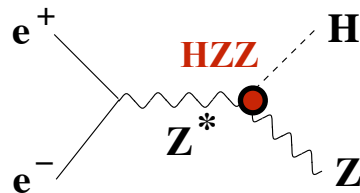
# Previous Report on HZZ Study

- >. Using higher dimension operators, new physics can be represented. (arXiv:1011.5805)
- >. L is parametrized by three kinds of parameters.

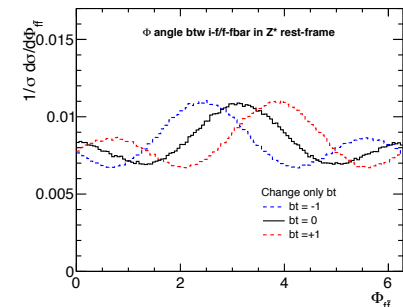
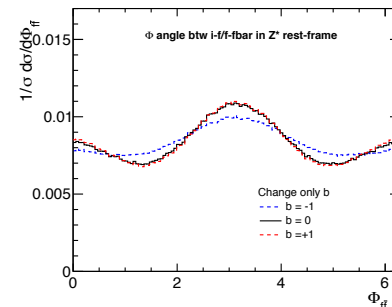
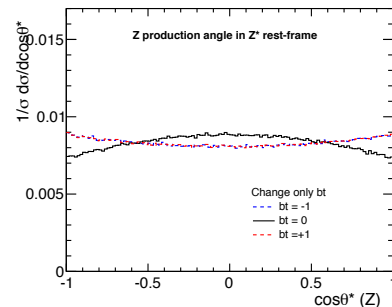
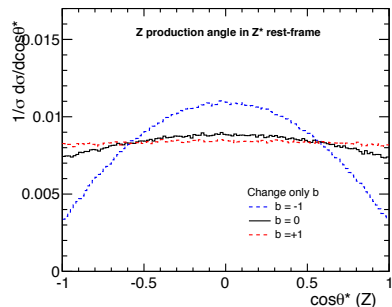
$$\mathcal{L}_{HVV} = 2M_V^2 \left( \frac{1}{v} + \frac{a}{\Lambda} \right) HV_{\mu}^+ V^{-\mu} + \frac{b}{\Lambda} HV_{\mu\nu}^+ V^{-\mu\nu} + \frac{\tilde{b}}{\Lambda} H \epsilon^{\mu\nu\rho\sigma} V_{\mu\nu}^+ V_{\rho\sigma}^-$$

**SM (CP-even)**  
**Correction [a]**
**Tensor Couplings**  
**CP-even [b]**
**Tensor Couplings**  
**CP-odd [bt]**

>. production process



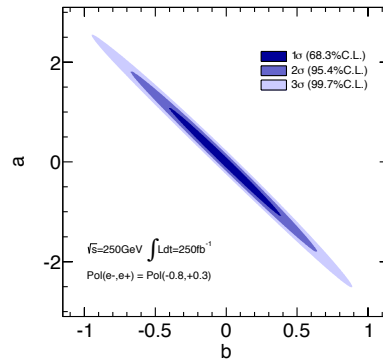
- >.  $\theta^*$  : The production angle of Z in  $Z^*$  rest-frame.
- >.  $\Phi$  : The angle between two production planes defined in the  $Z^*$  rest-frame.



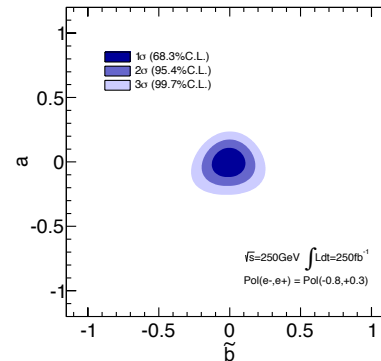
# Previous Report on HZZ Study

>. Sensitivity of parameters a, b and bt ( assume 250fb-1 )

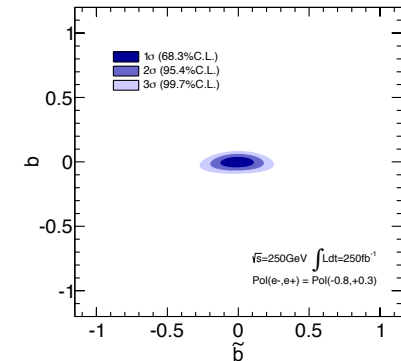
>. 250GeV, Zh  $\Rightarrow$   $\mu\mu h$



$\Rightarrow$  Using  $\cos\theta^*$  and  $\sigma$



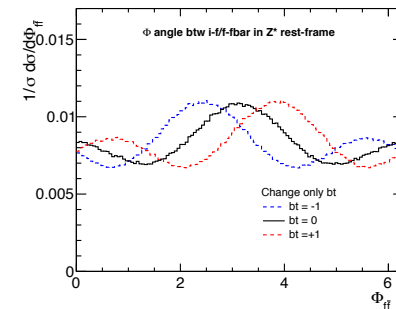
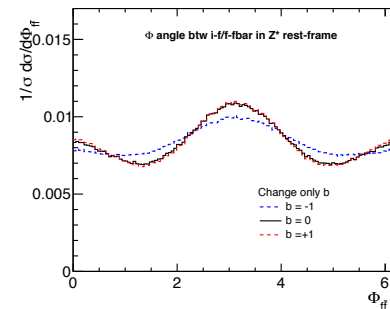
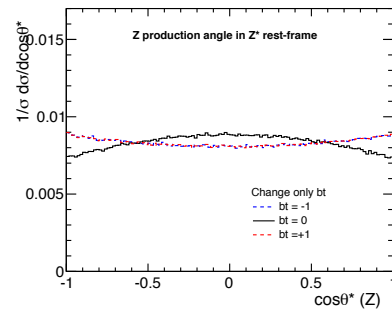
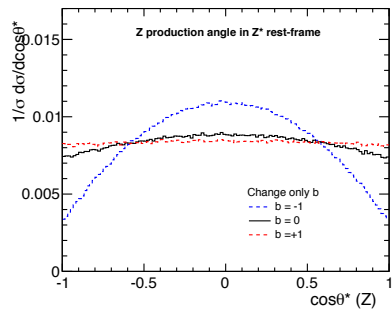
$\Rightarrow$  Using  $\Phi$  and  $\sigma$



$\Rightarrow$  Each parameters can be measured  $\sim O(0.1)$  at ILC.

>.  $\theta^*$  : The production angle of Z in  $Z^*$  rest-frame.

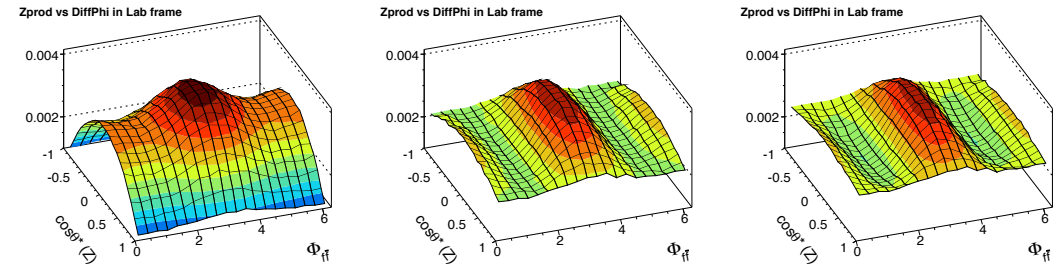
>.  $\Phi$  : The angle between two production planes defined in the  $Z^*$  rest-frame.



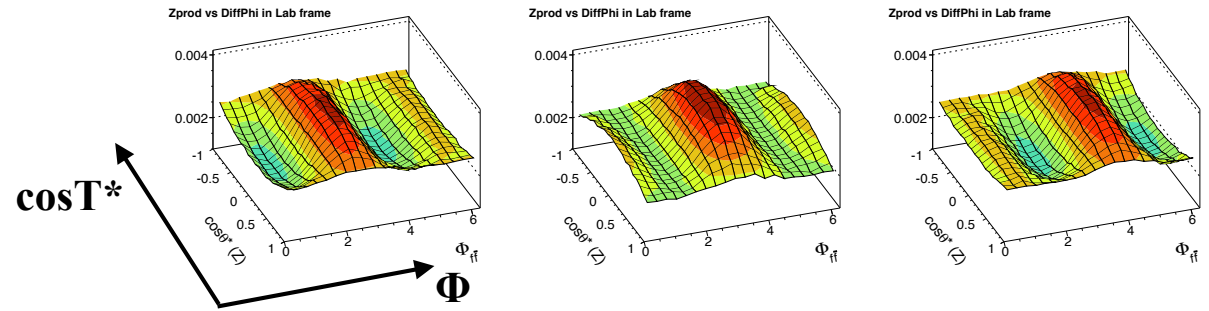
# Update of Analysis

- >. Both angles are sensitive to anomalous.
- They should be considered same time.
- ➔ Use 2d-distribution.

>. Change only  $b$ ; -1, SM, +1

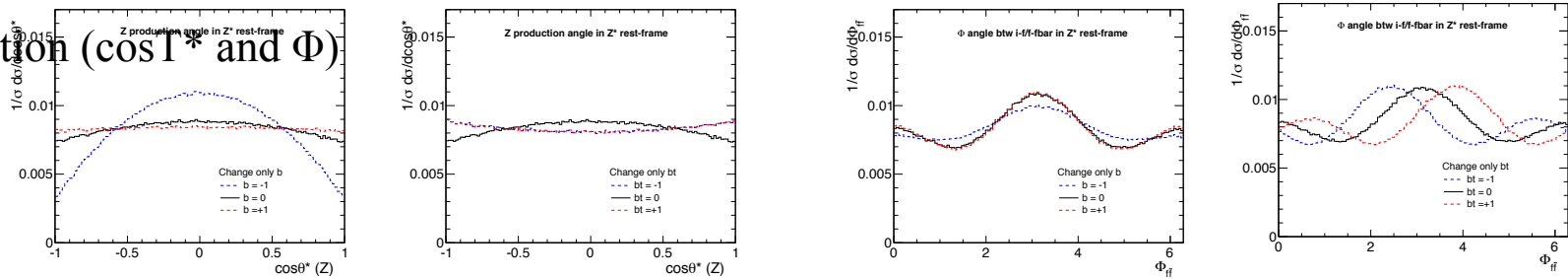


>. Change only  $bt$ ; -1, SM, +1

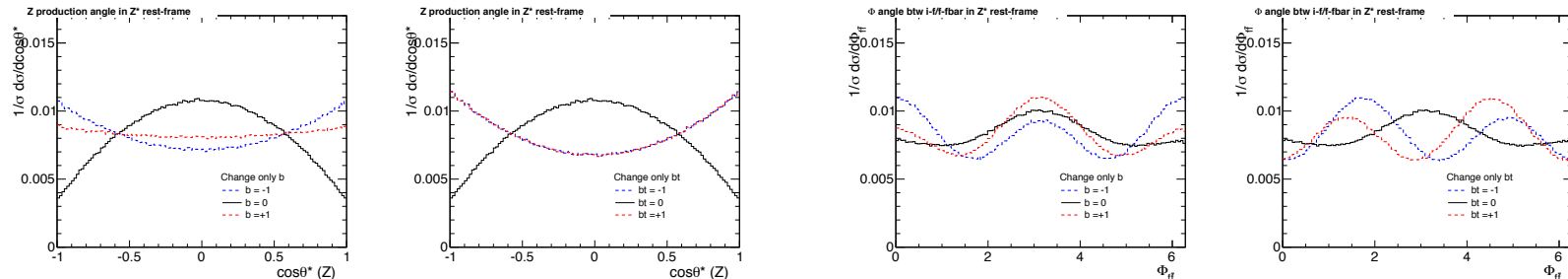


- >. Momentum of  $V$  affects anomalous couplings.
- ➔ 500GeV process should be included in results.

>. Angular distribution ( $\cos T^*$  and  $\Phi$ ) 250GeV.



and 500GeV.



# Procedure of Analysis

- >. What we want to do : Estimate the sensitivity of anomalous components using  $\chi^2$  test (MC simulation)
- >. What we have to do : Estimate the detector acceptance for sensitive parameters “ $\theta^*$  and  $\Phi$ ” without bias as less as possible (Full simulation)
- >. For less bias : Any angular cut (also related to angles) for Bkgs suppression should not be used.
- >. For less error : Values of each cut variables for Bkgs suppression are set to take the maximum significance (overall significance).  $Signif = \frac{N_{sig}}{\sqrt{N_{sig} + N_{bkg}}}$
- >. For much sensitivity : Calculate the sum of significance for each bin on histograms of parameters ( $\theta^*$  and  $\Phi$ ) .

$$\sum_i^{bins} \left( \frac{S_{obs,i}}{\Delta S_{obs,i}} \right)^2 \quad \text{Observed \#signal and its error.}$$

If fitting is difficult, error is calculated  $\sqrt{(s+b)}$

- >. Calculation of  $\chi^2$  which is divided into 2 parts.

Use distribution generated by Bases.  
 Include detector acceptance in both.  
 Unify its normalization with SM.

#N and #N are the number of expected events  
 after Bkg suppression

$$\chi^2 = \sum_{bin=1}^n \left( \frac{y_{bin}^{SM \ w/accept} - f^{BSM \ w/accept}(x_{bin}; a, b, \tilde{b})}{\delta y_{bin}^{SM}} \right)^2 + \left( \frac{N^{SM} - N^{BSM}}{\delta\sigma \cdot N^{SM}} \right)^2$$

Use error estimated by fitting for each bin.

$\delta\sigma$  is set 2.0% or 3.0%

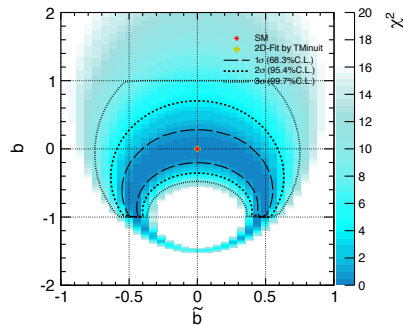
Effect of angular distribution

Effect of cross section

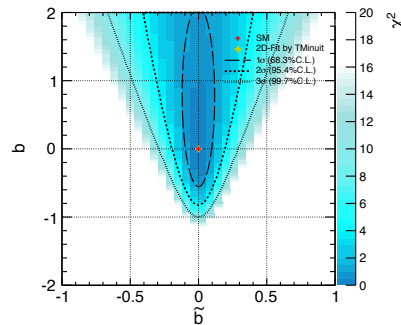
# Effect of Shape & Cross Section

> . 250GeV (b vs bt)

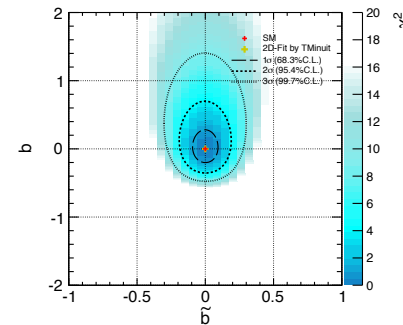
Use only  $\cos T^*$



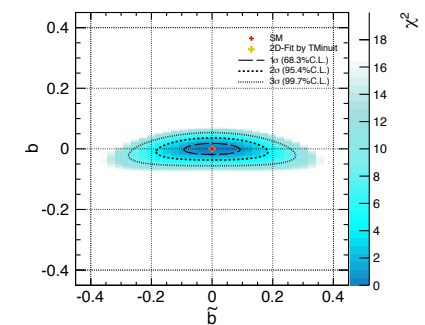
Use only  $\Phi$



2D  
Use both  $\cos T^*$  &  $\Phi$



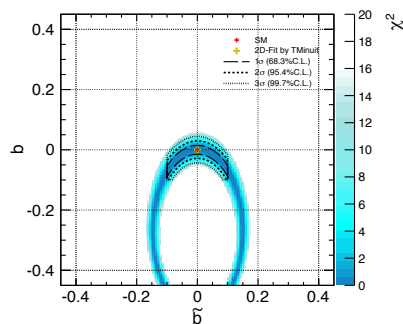
Include the effect of X  
X is assumed to be 250fb<sup>-1</sup>



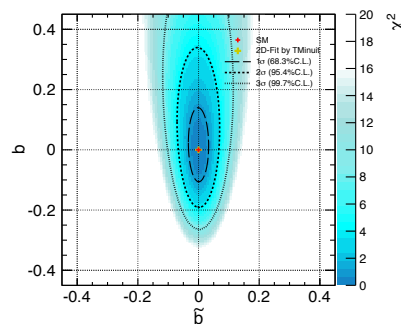
! Please ignore black line

> . 500GeV (b vs bt)

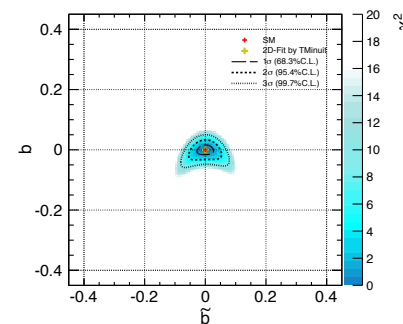
Use only  $\cos T^*$



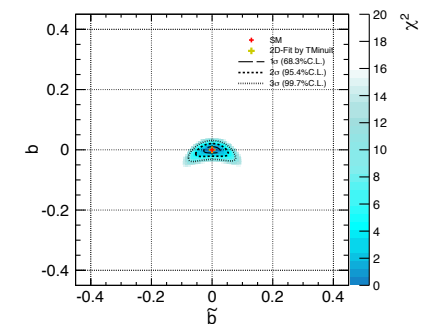
Use only  $\Phi$



2D  
Use both  $\cos T^*$  &  $\Phi$



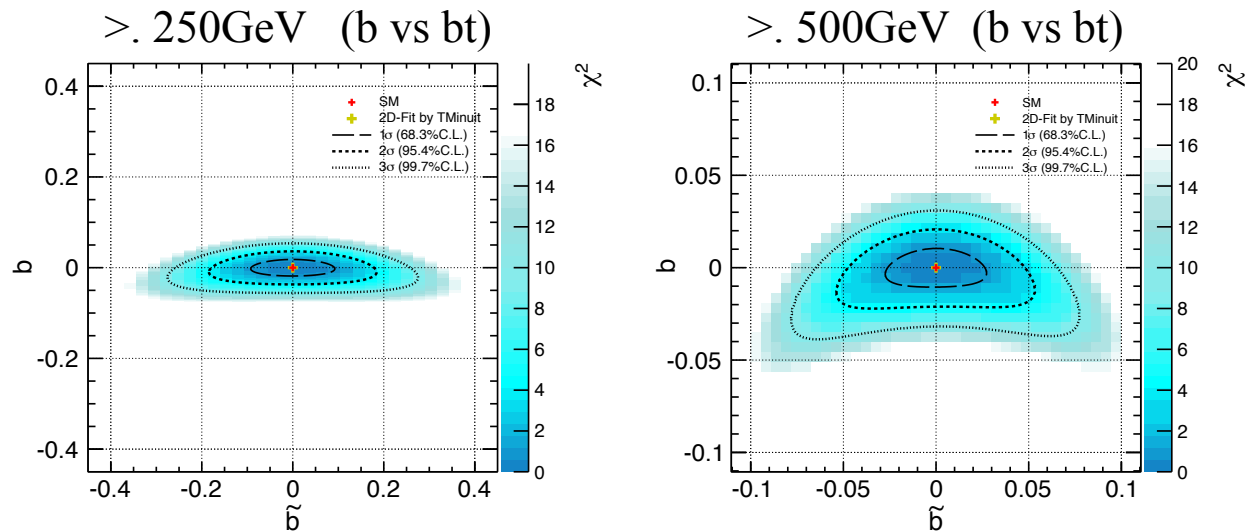
Include the effect of X  
X is assumed to be 500fb<sup>-1</sup>



! Cut values on 500GeV process are not optimized.  
These are first look and temporary results.

# Summary

- >. Two sensitive angles were included into analysis same time.  
Also the effect of shape itself was checked
- >. Results on 500GeV are probably very sensitive to anomalous components.  
If we include them into combined results, sensitivity can be achieved  $\sim O(0.01)$ ?



- >. Prospects  
Finish HZZ study as possible as I can.  
(250GeV mmh, eeh, qqbb  
500GeV mmh, eeh, qqbb, eebb(ZZ-fusion) )

**back up**  
**(Previous Report)**



# Motivation.

> **The KEY to probe the new physics is to clarify the origin of the EWSB.** (the Higgs mechanism)

- > Measurement of the Higgs boson properties with high precision is necessary.
- > The physics of SSB which gives mass to the weak bosons is expected to be sensitive to new physics.

> **Extension of the SM and Effective Lagrangian with a Higgs doublet..**

- > New physics can be represented by higher dimension operators.
  - The lowest operator which is considered the coupling which couples to only weak boson is dim-5.

Relevant term is (arXiv:1011.5805)...

$$\mathcal{L}_{HVV} = 2M_V^2 \left( \frac{1}{v} + \frac{a}{\Lambda} \right) HV_\mu^+ V^{-\mu} + \frac{b}{\Lambda} HV_{\mu\nu}^+ V^{-\mu\nu} + \frac{\tilde{b}}{\Lambda} H \epsilon^{\mu\nu\rho\sigma} V_{\mu\nu}^+ V_{\rho\sigma}^-$$

**SM (CP-even)**
**Tensor Couplings**
**Tensor Couplings**

**Correction [a]**
**CP-even [b]**
**CP-odd [bt]**

> **The CP-odd state higgs boson (A) appears in many extensions of SM** (the Higgs sector(h)).

- **2HDM; h(CP-even), A(CP-odd)**
- **MSSM; h and H(CP-even), A(CP-odd)**

> **The purpose is to estimate how the ILC is sensitive to these parameters.**

- > If the higgs has small anomalous components, It's not easy to measure with LHC.  
Lepton collider experiment is the best environment for the precision measurement.

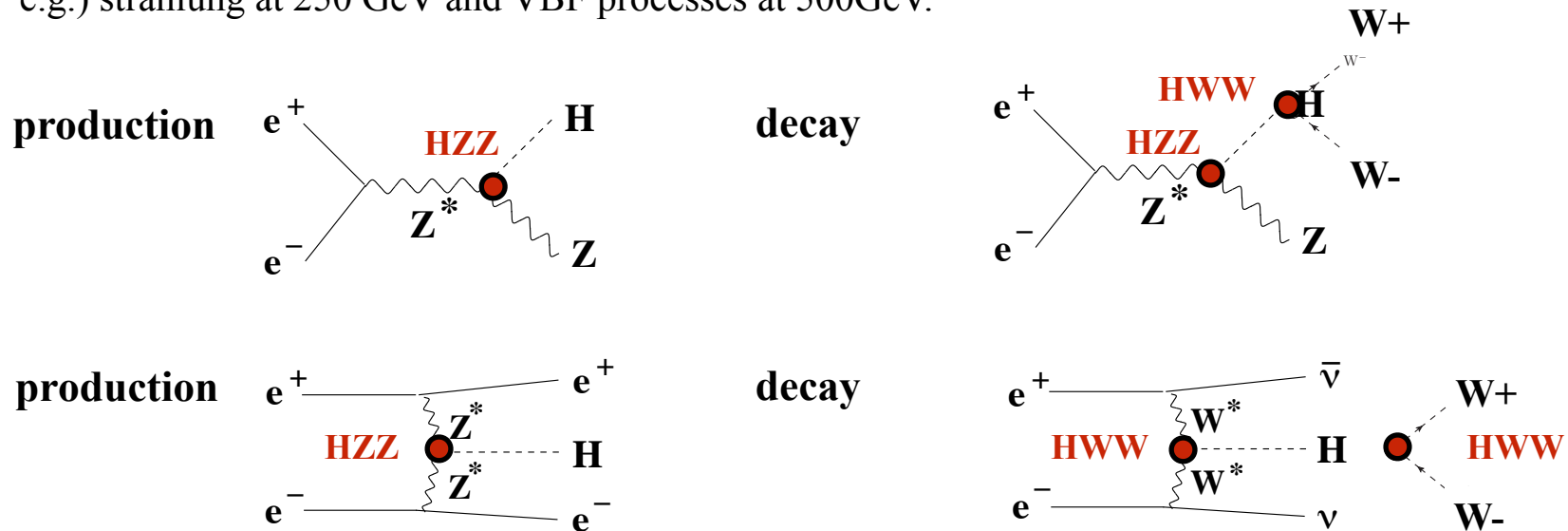
# Processes

> **Anomalous components (spin-parity) restrict the type of interactions between the higgs and other particles.**

- > Kinematic distributions change for either the decay particles of the higgs and the particles which are associated to the higgs.
- > To observe such restriction, the information of final state momentum spectra, angular distributions are useful for .

> **In the lepton collider environment,**

- > Several processes can be used for testing anomalous component on HVV.  
e.g.) strahlung at 250 GeV and VBF processes at 500GeV.



# Production process

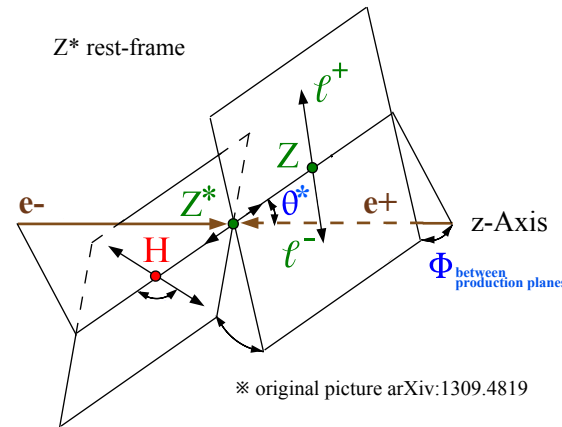
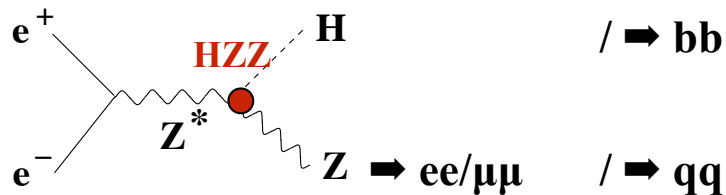
> Definition of the angles ( in the  $Z^*$  rest-frame ~ Lab frame ).

>  $\theta^*$  : The production angle of  $Z$  in  $Z^*$  rest-frame. (  $\theta$  : higgs production angle. )

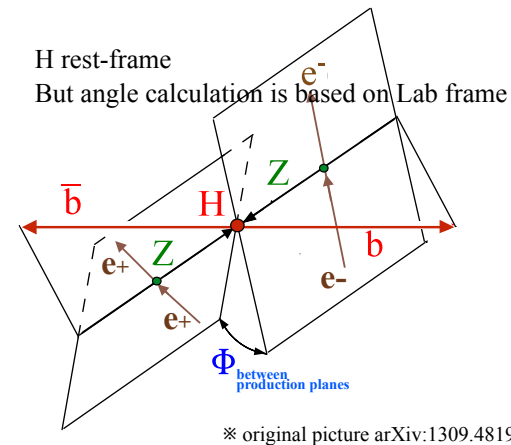
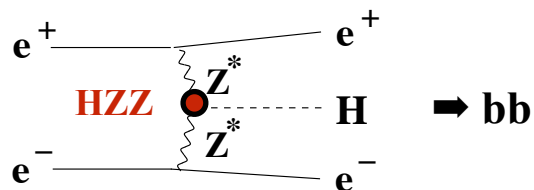
>  $\Phi$  : The angle between two production planes defined in the  $Z^*$  rest-frame.

> . 250GeV,  $Zh \Rightarrow eeh/\mu\mu h$  (recoil analysis )

> . 250GeV,  $Zh \Rightarrow qqbb$  (hadronic process)



> . 500GeV,  $eeh \Rightarrow eebb$  ( ZZ-fusion )



# Difference of the Angle Distributions ( calculation is based on Lab frame )

> . 250GeV,  $Zh \rightarrow eeh/\mu\mu h$  (recoil analysis )

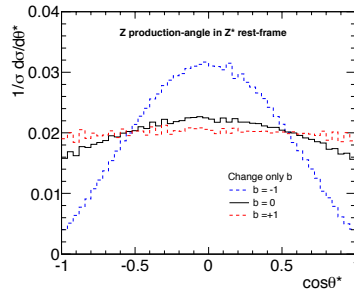
> . Parameter “b” is changed

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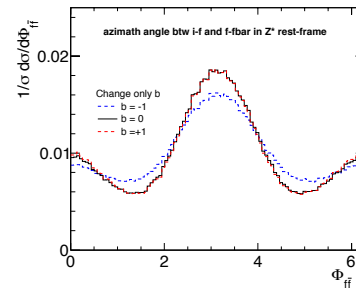
> . Parameter “bt” is changed

— SM  
 — parameter: -1  
 — parameter: +1

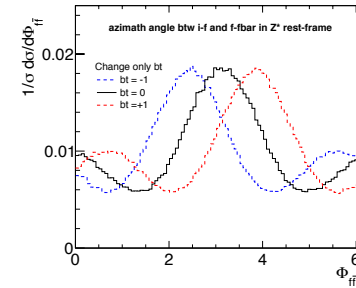
$\cos\theta^*$



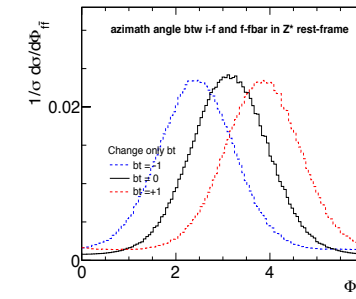
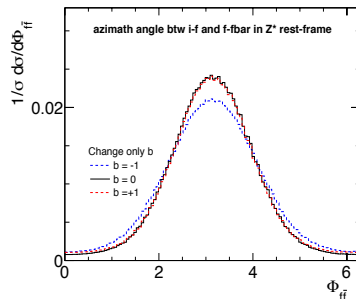
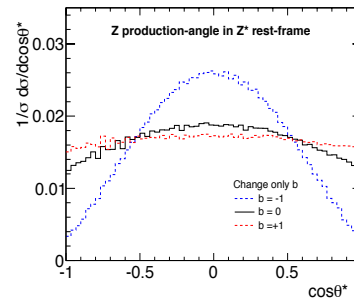
$\Phi$



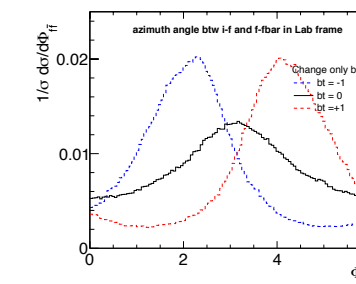
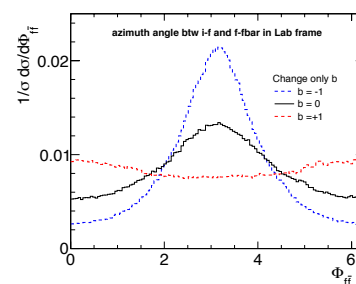
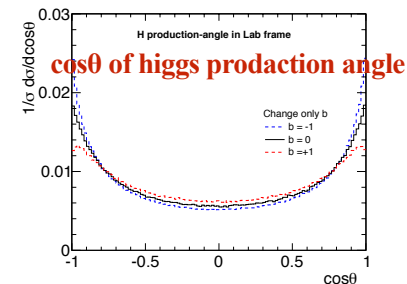
$\Phi$



> . 250GeV,  $Zh \rightarrow qqbb$  (hadronic process)



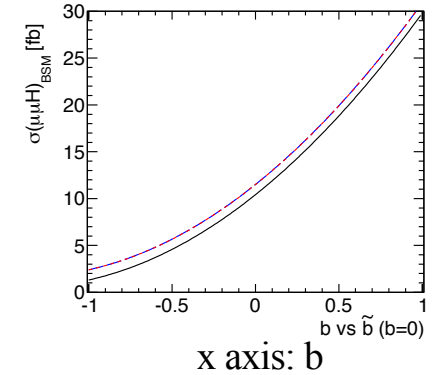
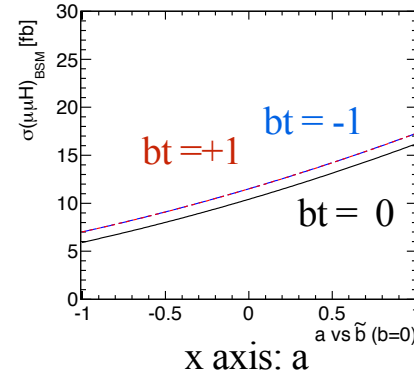
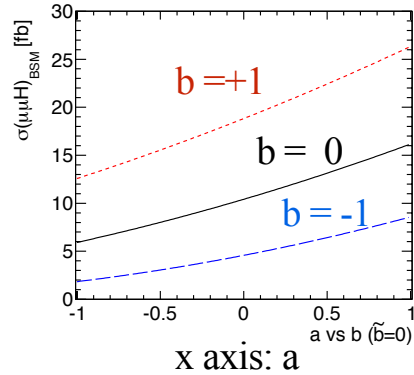
> . 500GeV,  $eeh \rightarrow eebb$  ( ZZ-fusion )



# Difference of the Cross Section

>. 250GeV,  $Zh \rightarrow eeh/\mu\mu h$  (recoil analysis )

b affect  $\sigma$  strongly



>. 250GeV,  $Zh \rightarrow qqbb$  (hadronic process)

>. 500GeV,  $eeh \rightarrow eebb$  (ZZ-fusion)

# Simulation Test

## >. Procedure

- >. What we want to do : Estimate the sensitivity to anomalous components with several parameters using  $\chi^2$  test (MC simulation)
- >. What we have to do : Estimate the detector acceptance for each sensitive parameter “ $\theta^*$  and  $\Phi$ ” with bias as less as possible (Full simulation)

$$\chi^2 = \sum_{bin=1}^{Nbins} \left( \frac{y_{bin}^{SM-MC} - f \text{ Theory model } (x_{bin}; a, b, \tilde{b})}{\sigma_{bin}^{SM-MC}} \right)^2$$

- >. For less bias : Any angle cut (also related to angles) for Bkgs suppression should not be used.
- >. For less error : Values of each cut variables for Bkgs suppression are set to take the maximum significance.

# Simulation Test

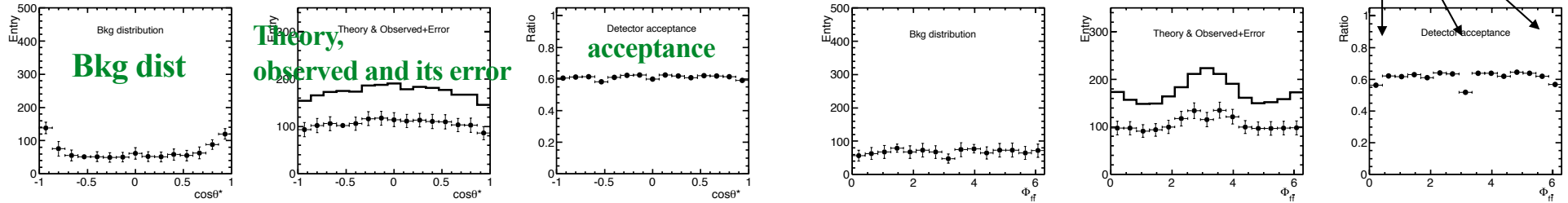
>. Detector acceptance ( divided into 15 bins )

In  $Z^*$  rest-frame  
 $0, \pi, 2\pi$  are beam direction.  
 ➔ sensitivity are lost to some extent  
 in reconstruction step.

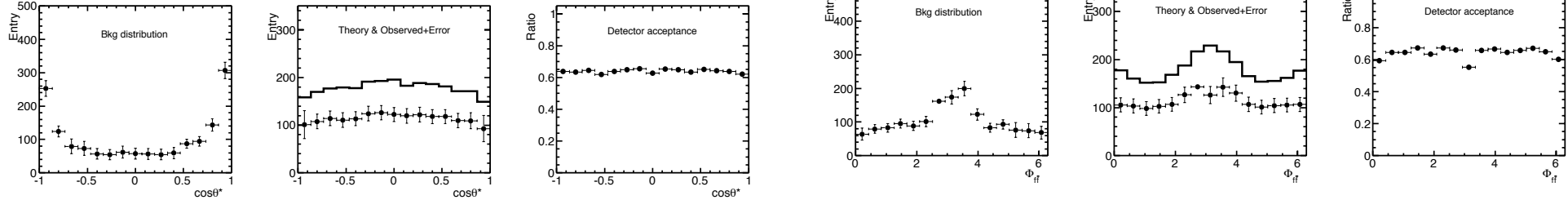
>. 250GeV,  $Zh \rightarrow \mu\mu h$

$\cos\theta^*$

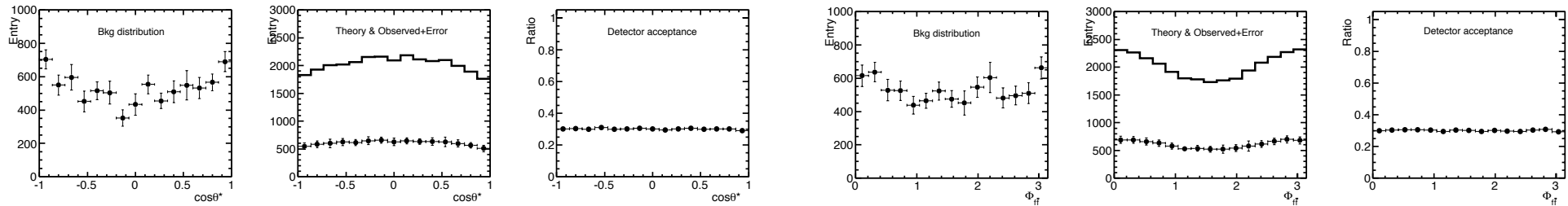
$\Phi$



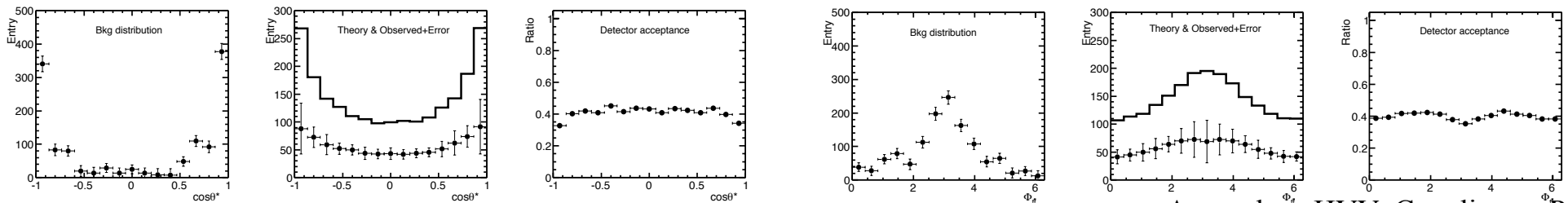
>. 250GeV,  $Zh \rightarrow eeh$



>. 250GeV,  $Zh \rightarrow qqbb$



>. 500GeV,  $eeh \rightarrow eebb$



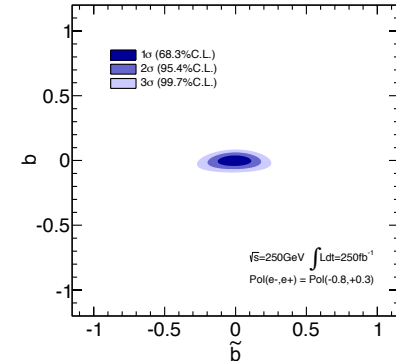
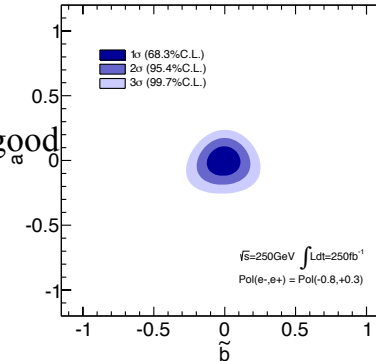
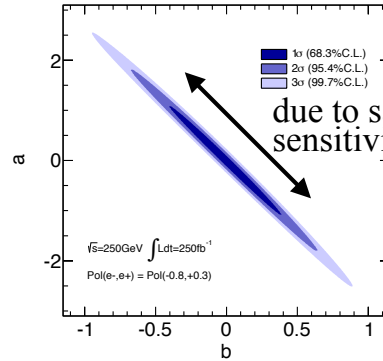
# Simulation Test

>. Sensitivity ( assume 250fb<sup>-1</sup> )

using  $\cos\theta^*$  and  $\sigma$

using  $\Phi$  and  $\sigma$

>. 250GeV,  $Zh \rightarrow \mu\mu h$

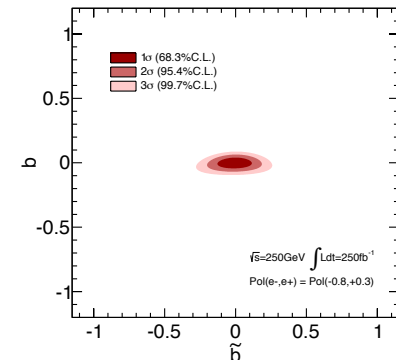
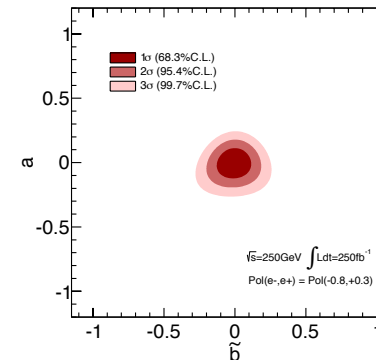
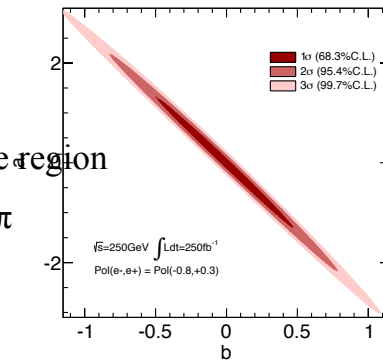


>. 250GeV,  $Zh \rightarrow ee h$

More Bkgs remain in sensitive region compared with  $\mu\mu h$ .

$\theta^*$ : at -1 and +1,  $\Phi$ : around  $\pi$

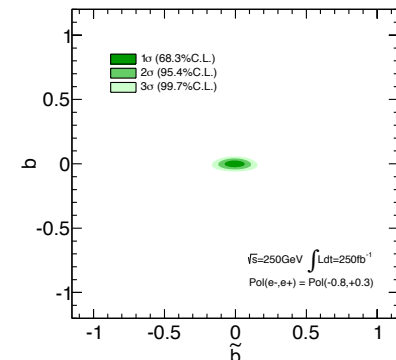
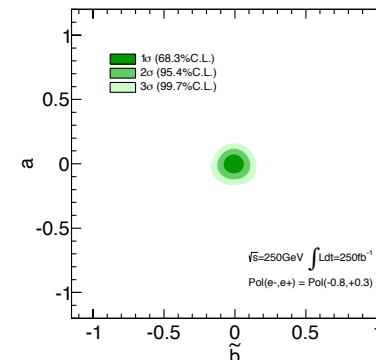
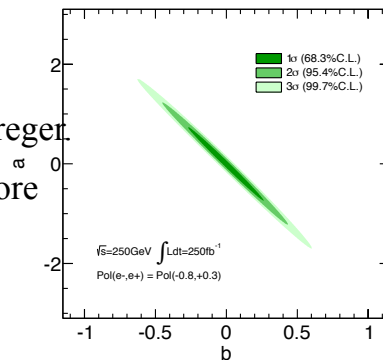
➔ Error is larger than  $\mu\mu h$



>. 250GeV,  $Zh \rightarrow qqbb$

Sensitivity to parameters is larger.

Remaining #Sigs are much more than llh. processes

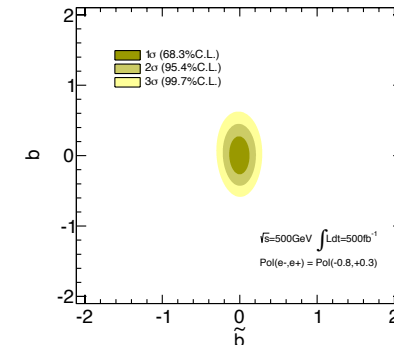
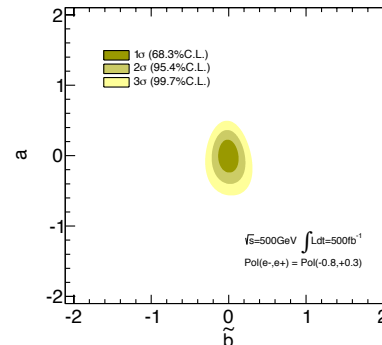
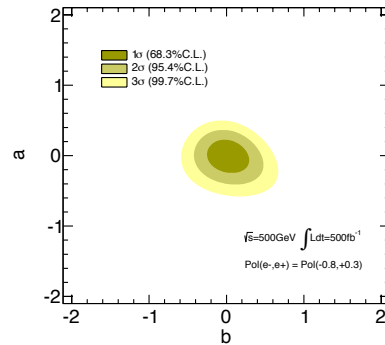




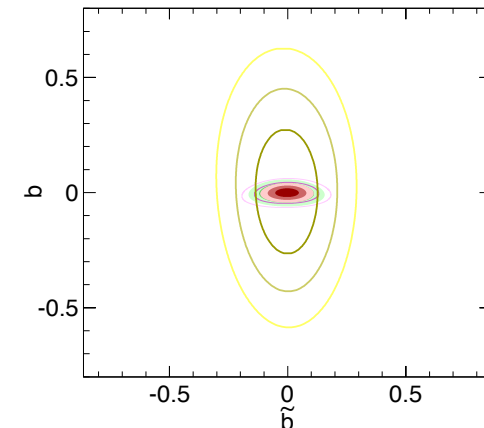
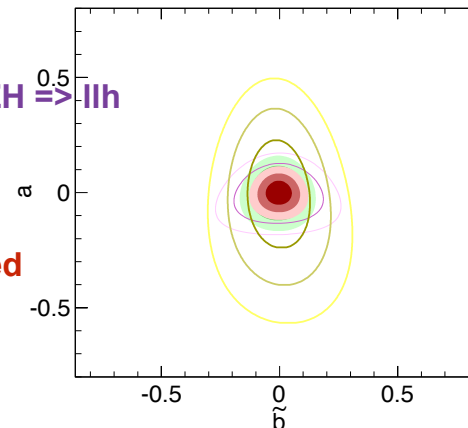
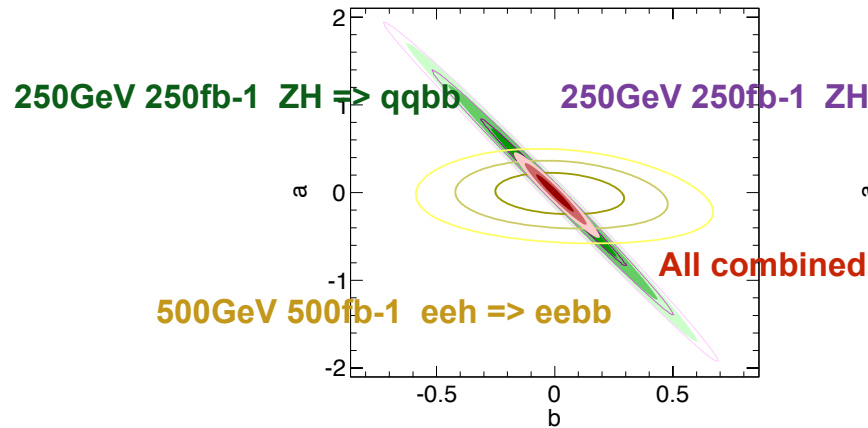
# Simulation Test

>. Sensitivity ( assume 500fb-1 )

>. 500GeV, eeh  $\rightarrow$  eebb



>. Combine 4 processes



>. Sensitivity is  $\sim O(0.1)$  for each parameters.

## Summary

- >. Since we have interest in the couplings btw the higgs and gage bosons and the sensitivity where the ILC can reach(mainly if the higgs has small anomalous components), we tested it by using full simulation and estimated its sensitivity.
- >. We can distinguish anomalous components  $\sim O(0.1)$  for each parameters on HZZ.

## Future Plan

- >. Analysis on HWW is needed.
- >. It will be also necessary to consider the connection of BSM theories.  
(which region corresponds to what kinds of model.)