National University
The Graduate University
for Advanced Studies [SOKENDAI]

Sensitivity of the ILC to Anomalous Couplings btw Higgs and Gauge Bosons

Short report on HZZ by using recoil analysis at 250GeV

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)…

$$\mathcal{L}_{\rm HWW} = 2M_W^2 \left(\frac{1}{v} + \frac{a}{\Lambda}\right) H\ W_\mu^+ W^{-\mu} + \frac{b}{\Lambda} H\ W_{\mu\nu}^+ W^{-\mu\nu} + \frac{\tilde{b}}{\Lambda} H\ \epsilon^{\mu\nu\sigma\tau} W_{\mu\nu}^+ W_{\sigma\tau}^- \ ,$$

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

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

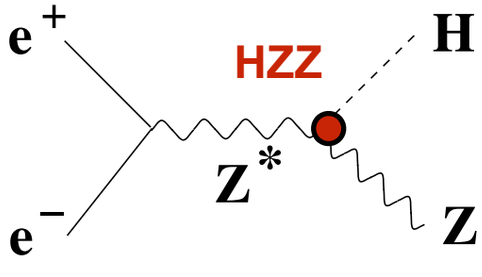
- **2HDM; h(CP-even), A(CP-odd)**
- **MSSM; h and H(CP-even), A(CP-odd)**

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

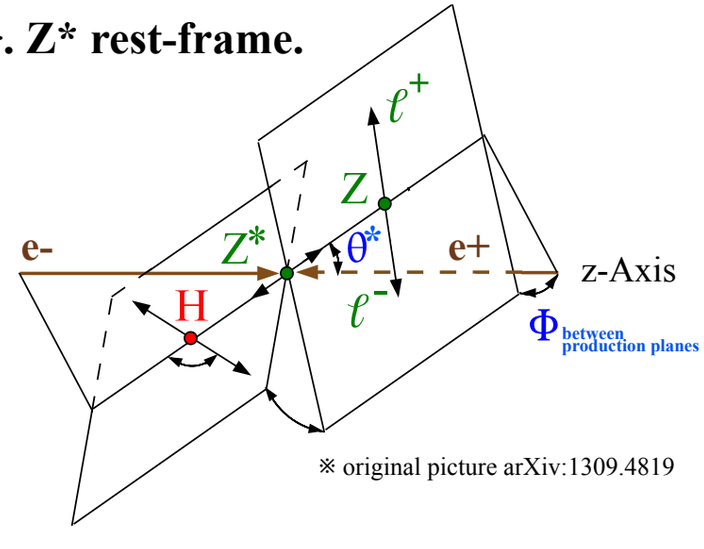
>. If the higgs has small anomalous components, It's not easy to measure with LHC.
Lepton collider experiment is the best environment for the precision measurement.

Process.

>. 250GeV ZH-strahlung.



>. Z* rest-frame.



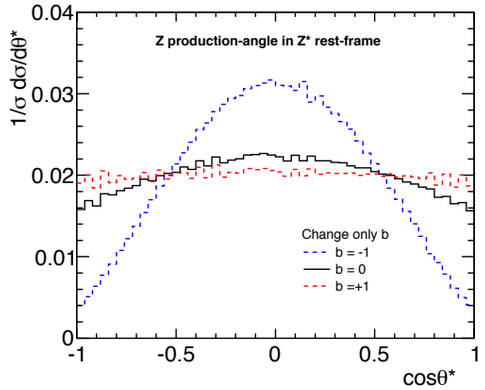
※ original picture arXiv:1309.4819

>. Definition of angles.

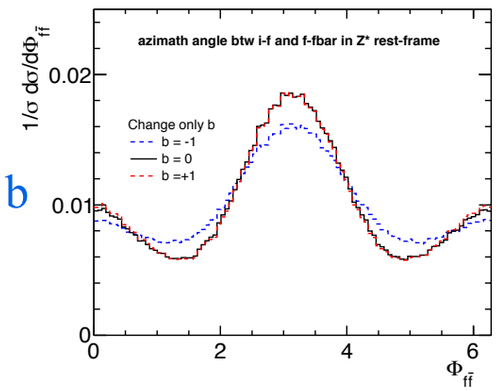
>. θ* : The production angle of Z in Z* rest-frame.
>. Φ : The angle between two production planes defined in the Z* rest-frame.

>. Difference of the angular distribution.

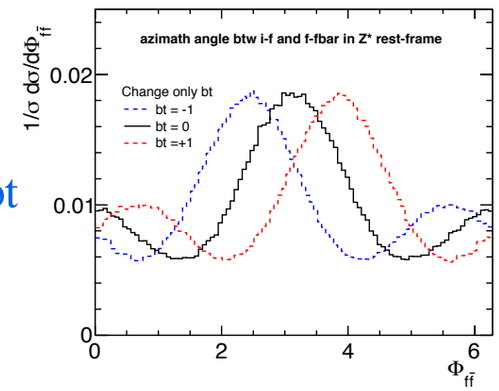
change b



change b

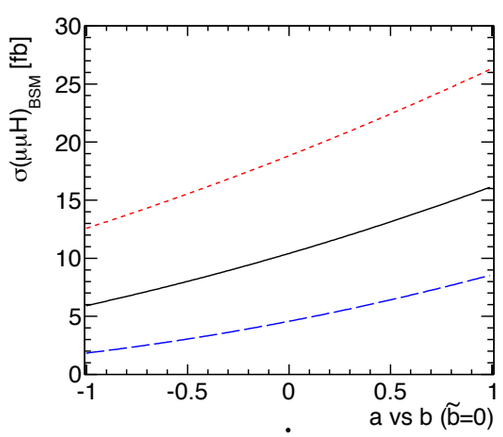


change bt



>. Difference of the cross section.

b affect σ strongly

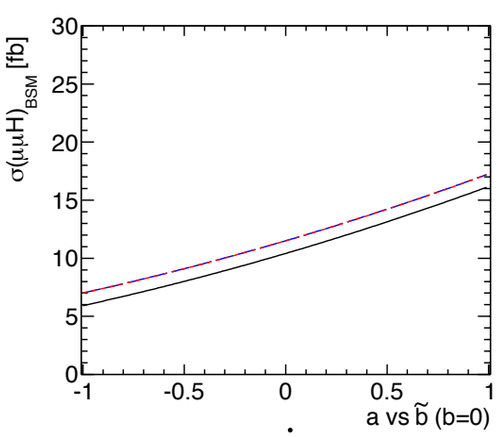


b =+1

b = 0

b = -1

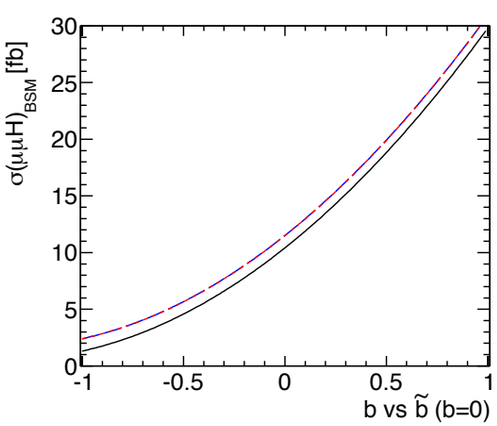
x axis: a



bt =+1

bt = -1

x axis: a

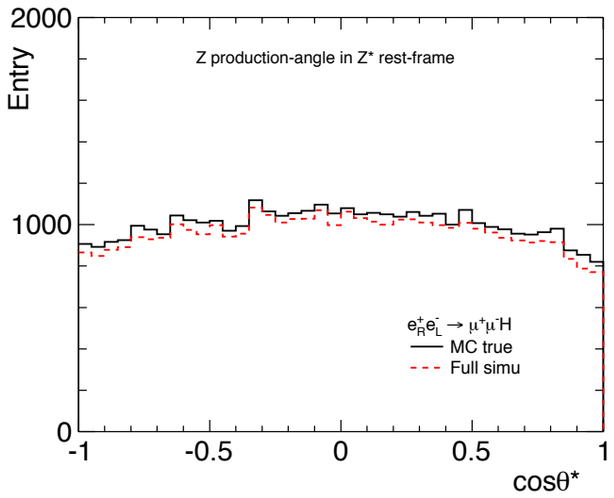


Reconstructed distribution.

>. Z production angle θ*

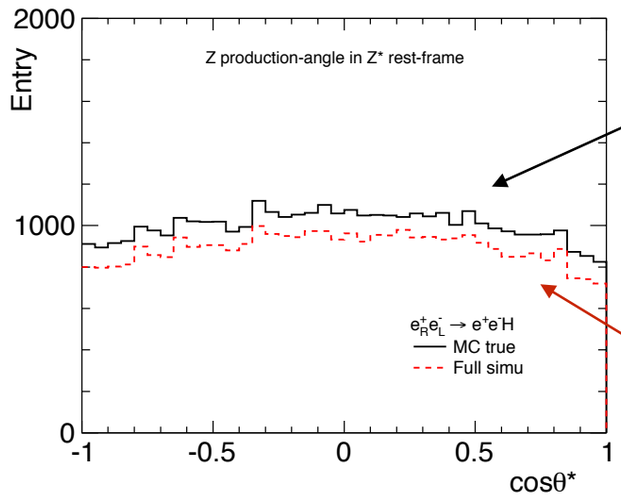
mmh

reconstruct successfully ~ 96%



eeh

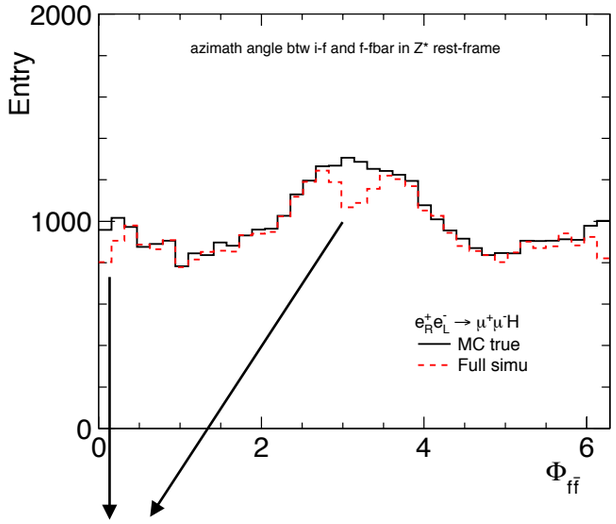
reconstruct successfully ~ 90%

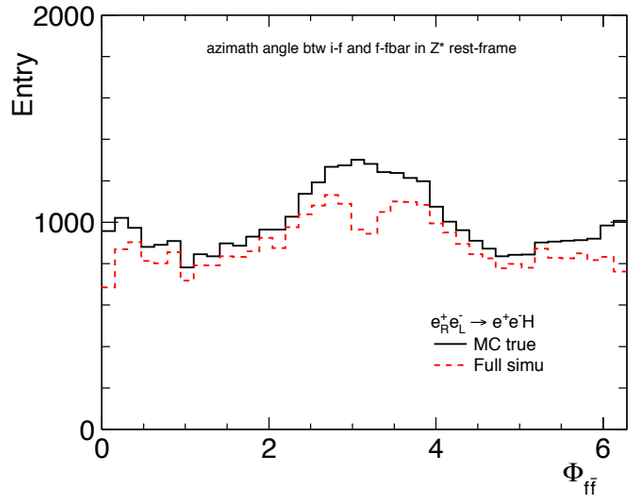


MC true

Reconstructed

>. Angle Φ btw H production planes





Z* rest-frame
0, pi, 2pi are beam direction.

➡ We lose sensitivity to some extent.

Background Suppression.

>. This is recoil mass analysis but keeping model independence is not needed.

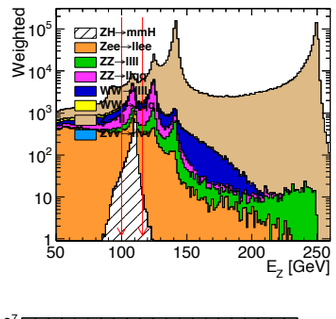
>. We need to keep detector acceptance in all region while suppressing Bkgs as possible as we can.

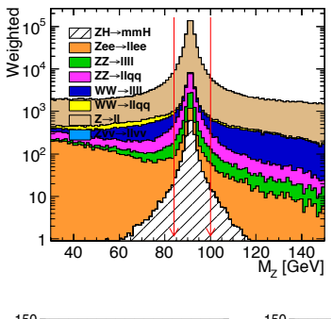
>. Any angle cuts should not be used although they are useful to suppress Bkgs. ➡ Keep sensitivity.

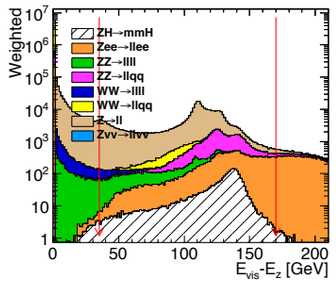
>. Main Bkgs are ZZ➡qqll (dominant). / Z➡ll (huge)

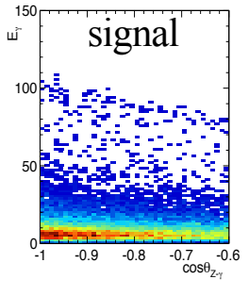
Cut: Ntacks<=4 (suppress Z➡ll / Z(γ)➡ll(ll))
Cut: Mz and Ez (extract signal)
Cut: Evis - Ez (suppress radiative return Z➡ll w/ ISR)
Cut: Eγ vs cosθzγ (suppress Z(γ)➡ll, look γ)

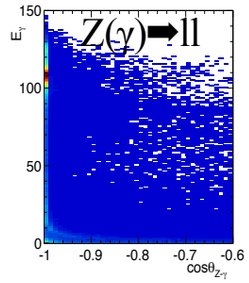
mmh process





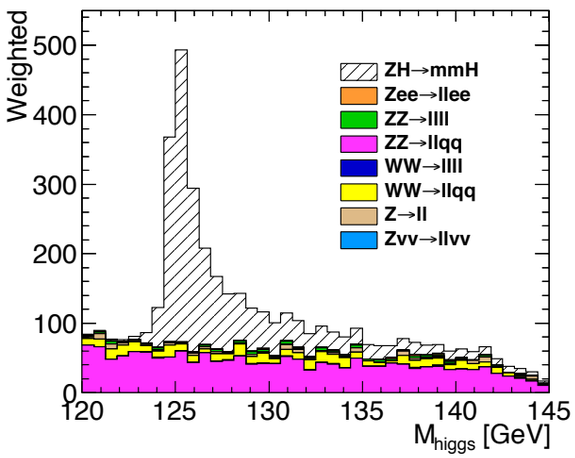






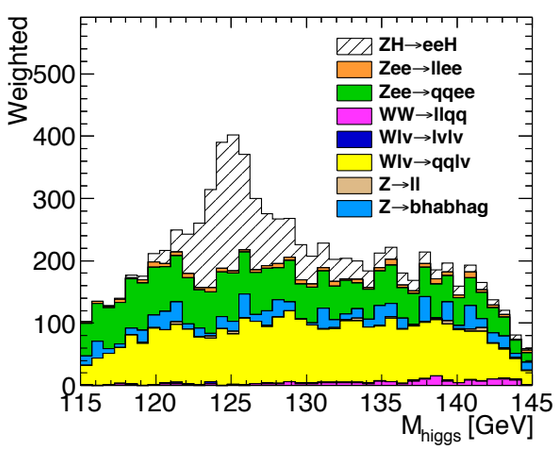
>. Apply similar strategy for both mmh/eeh

mmh process



Nsig : 2001.9
Nbck : 2334.8
Significance : 30.40

eeh process



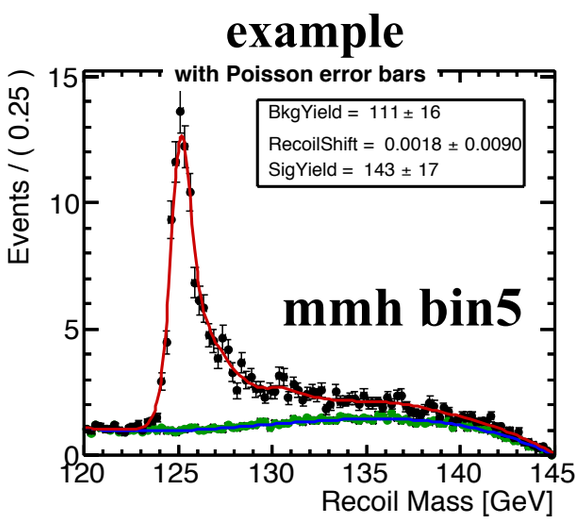
Nsig : 1768.5
Nbck : 6605.2
Significance : 19.32

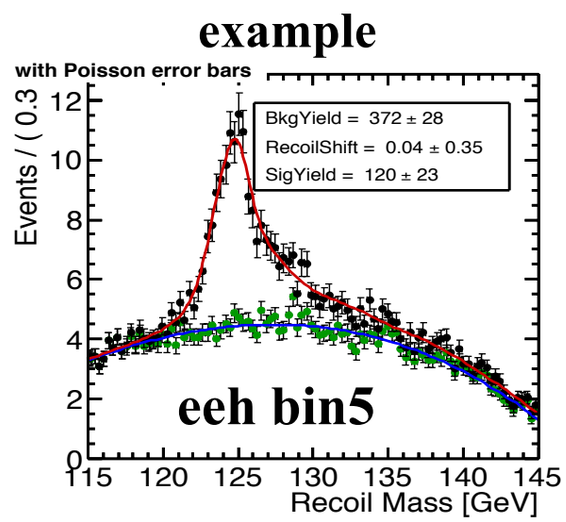
Detector Acceptance (η)

>. Estimation of #sig is needed for each bin (15 bins).

>. Fitting was used for the estimation of the error of #sig

➡ KerNel + 3rdPol

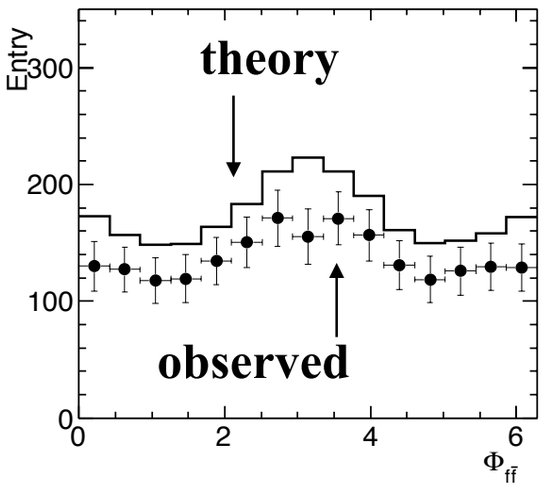


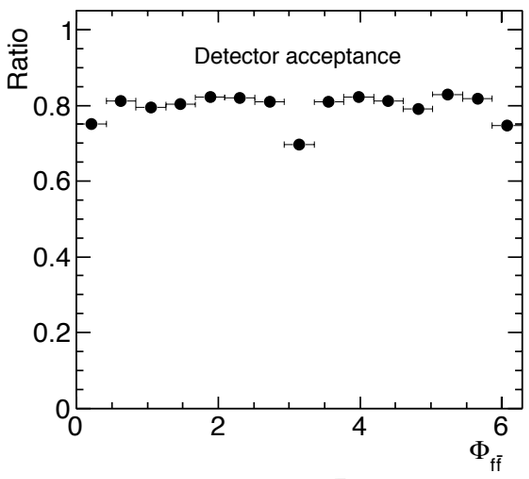


>. Get an acceptance function (15 bins).

$$\text{Acceptance } \eta_{x_{bin}} = \frac{N_{x_{bin}}^{observed}}{N_{x_{bin}}^{theoretically}},$$

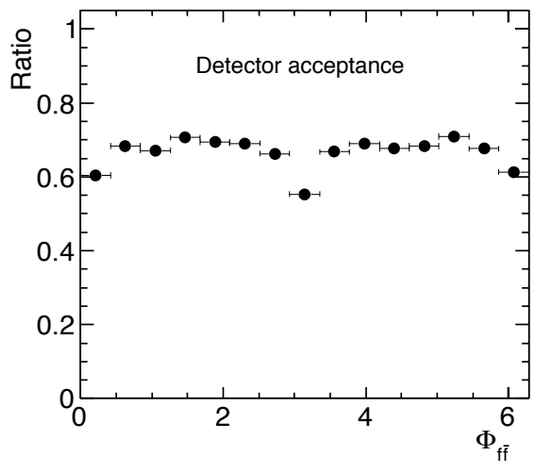
$$\Delta\eta = \frac{\sqrt{\eta_{x_{bin}}(1-\eta_{x_{bin}})}}{\sqrt{N_{x_{bin}}^{generated}}}$$





mmh

keep high efficiency and flatness
Bks are almost removed



eeh

keep high efficiency and flatness
Bks are not removed enough

Sensitivity to Anomalous Couplings.

>. Apply χ2 test with different models by using detector acceptance.

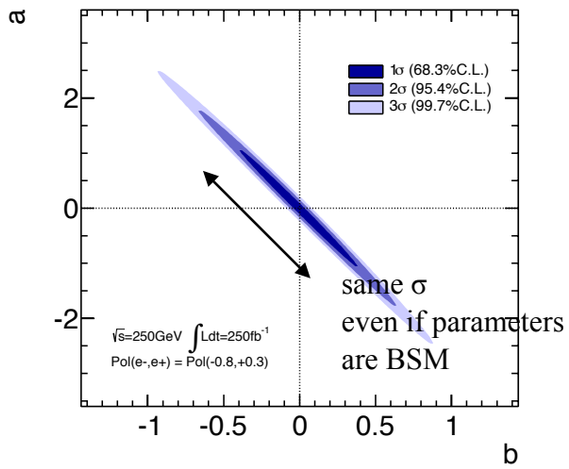
SM dist. w/ acceptance **BSM dist. w/ acceptance**

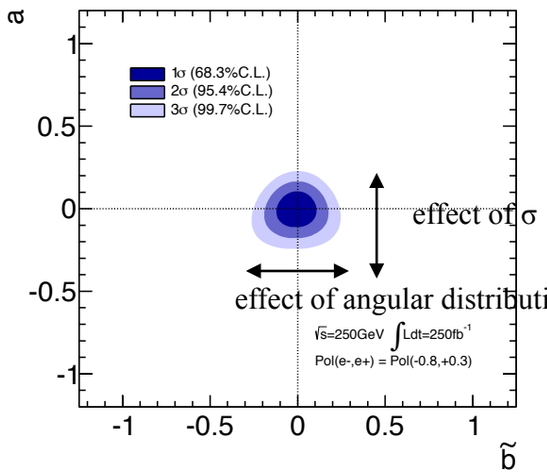
$$\chi^2 = \sum_{bin=1}^{15} \left(\frac{y_{bin}^{SM-MC} - f^{theory\ w/accep}(x_{bin}; a, b, \tilde{b})}{\sigma_{bin}^{SM-MC}} \right)^2$$

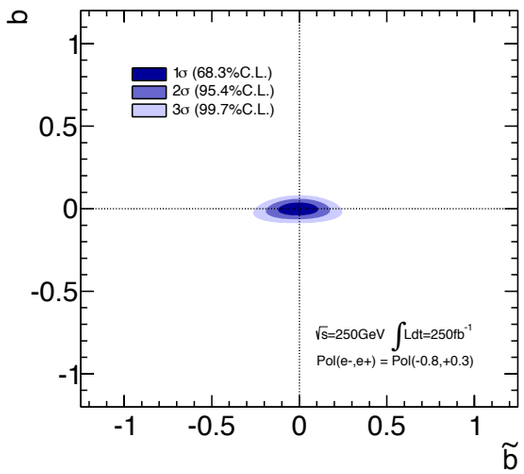
err of fitting result

estimated by using cosθ* **estimated by using Φ**

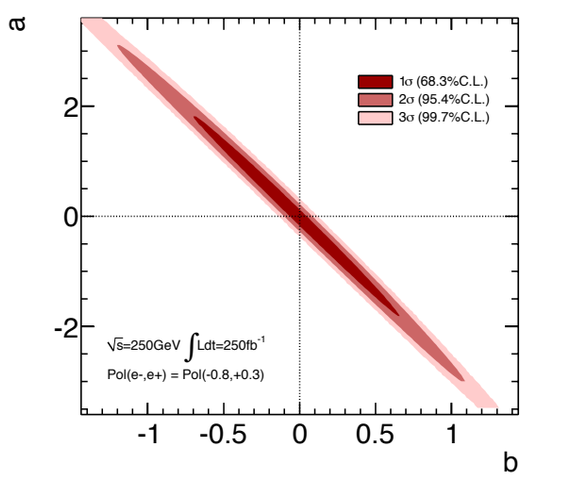
mmh

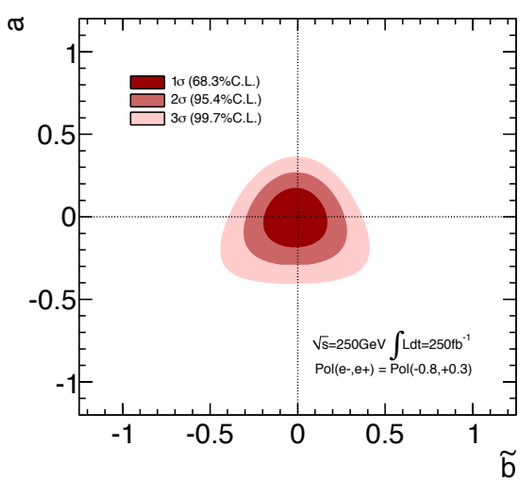


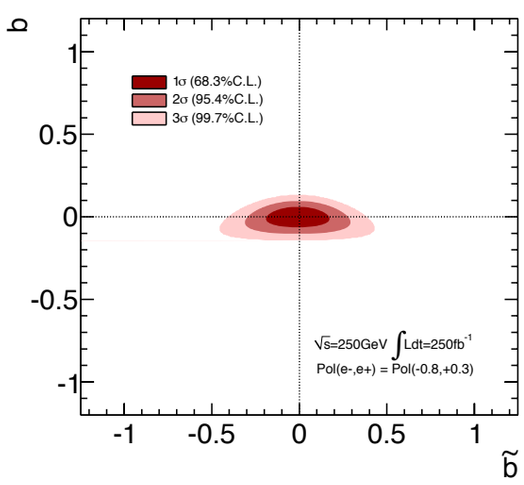




eeh

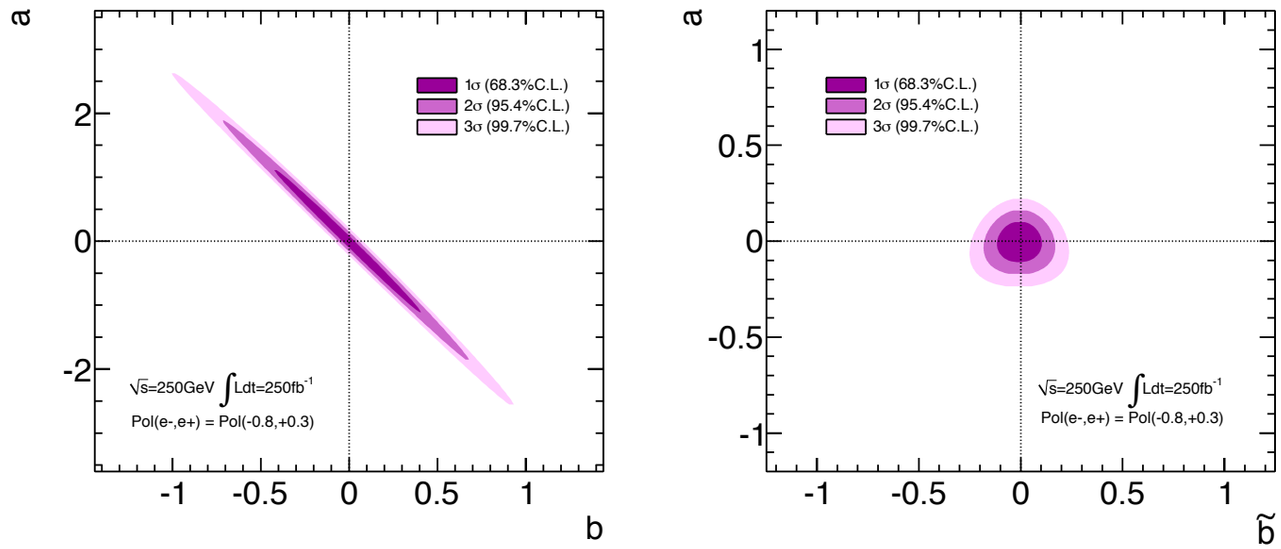






Combined Result & Summary

>. Combined results (mmh and eeh (recoil analysis)).



>. On a and b, we can not achieve much sensitivity along diagonal region only with two processes.
However, We can distinguish anomalous components ~ O(0.1) on a and bt.

>. 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 are testing it by using full simulation and estimate its sensitivity.

>. It will be also necessary to consider which region corresponds to what kinds of model.

Back up

Cut Table Summary

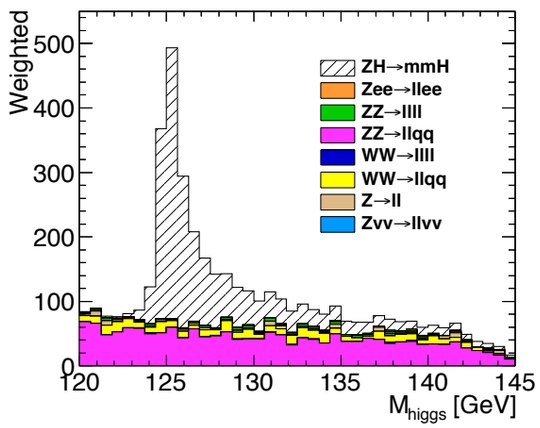
# cut&process	mmh	zee_l	zz_l	zz_sl	ww_l	ww_sl	z_l	zvv_l
# raw data	#50000	#1036137	#70000	#535103	#409207	#1962649	#3772761	#80000
# xsection	10.4	1053.4	95.9	856.9	915.6	10992.9	12993.9	114.1
# xsection*L	2603	263361	23972	214232	228894	2748229	3248466	28534
recoevent	96.14	9.88	45.95	18.71	11.36	0.29	41.20	22.13
+ ntracks	95.50	7.41	26.74	18.71	1.09	0.29	4.04	2.05
+ zenergy	89.01	1.17	5.20	6.72	0.20	0.06	0.13	0.76
+ zbosonmass	83.94	0.12	1.87	1.18	0.09	0.02	0.07	0.19
+ vise-ze	81.60	0.11	1.47	1.06	0.01	0.02	0.02	0.02
+ opposit_g	81.52	0.11	1.44	1.06	0.01	0.02	0.02	0.02
+ recoil	81.29	0.09	1.08	0.74	0.01	0.01	0.01	0.02
# Evts(Remain)	#2117.6	#278.2	#272.6	#1685.0	#22.9	#395.4	#489.4	#4.7

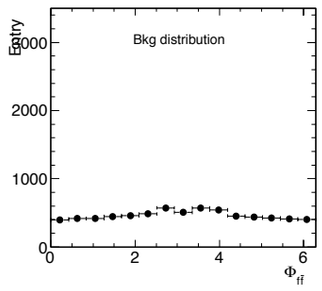
Nsig (->Integral()): 2117.6
Nbck (->Integral()): 3148.2
Significance : 29.18

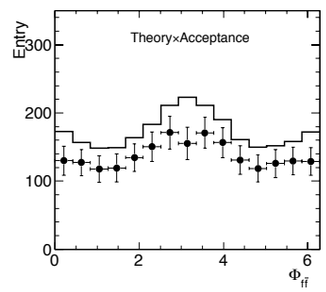
Cut Table Summary

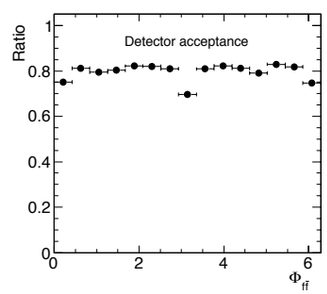
# cut&process	mmh	zee_l	zz_l	zz_sl	ww_l	ww_sl	z_l	xvv_l
# raw data	#50000	#1036137	#70000	#535103	#409207	#1962649	#3772761	#80000
# xsection	10.4	1053.4	95.9	856.9	915.6	10992.9	12993.9	114.1
# xsection*L	2603	263361	23972	214232	228894	2748229	3248466	28534
recoevent	96.14	9.88	45.95	18.71	11.36	0.29	41.20	22.13
+ ntracks	89.42	1.62	8.33	18.69	0.32	0.29	1.16	0.63
+ zenergy	83.39	0.25	1.87	6.72	0.05	0.06	0.04	0.22
+ zbosonmass	78.64	0.03	0.55	1.18	0.03	0.02	0.02	0.06
+ vise-ze	77.11	0.02	0.44	1.06	0.01	0.02	0.00	0.01
+ opposit_g	77.07	0.02	0.44	1.06	0.01	0.02	0.00	0.01
+ recoil	76.86	0.02	0.33	0.74	0.01	0.01	0.00	0.01
# Evts(Remain)	#2001.9	#47.4	#87.9	#1685.0	#12.0	#395.4	#104.7	#2.3

Nsig (->Integral()): 2001.9
Nbck (->Integral()): 2334.8
Significance : 30.40





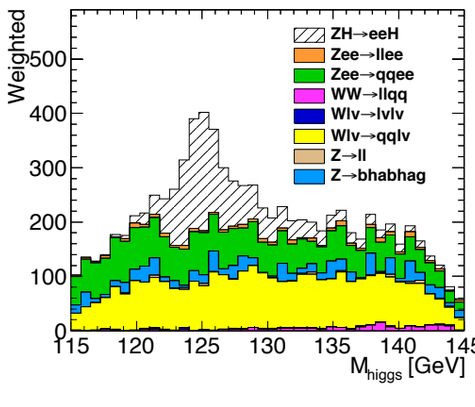


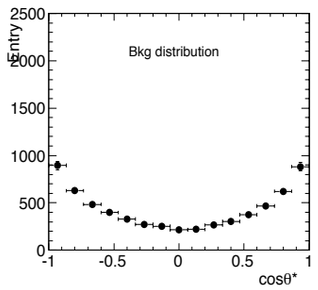


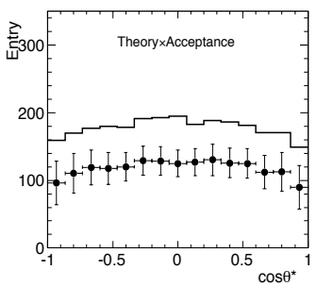
 # Cut Table Summary

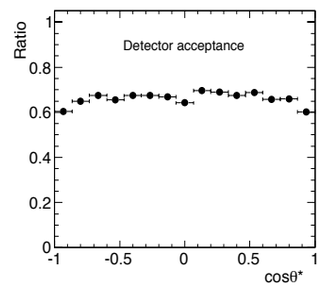
# cut&process	eeh	zee_l	zee_sl	ww_sl	sw_l	sw_sl	z_l	bhbha
# raw data	#49945	#1036137	#325217	#1962649	#865717	#2009011	#3772761	#1996718
# xsection	10.9	1053.4	378.3	10992.9	1967.0	5898.2	12993.9	25183.4
# xsection*L	2729	263361	94570	2748229	491743	1474542	3248466	6295840
recoevent	89.47	47.00	56.35	0.45	6.50	3.73	1.29	59.64
+ ntracks	83.43	8.10	56.02	0.45	0.36	3.73	0.22	2.58
+ zenergy	75.65	0.45	9.72	0.02	0.07	0.76	0.06	0.13
+ zbosonmass	69.86	0.12	2.14	0.01	0.03	0.24	0.00	0.03
+ vise-ze	66.38	0.07	1.87	0.01	0.01	0.22	0.00	0.01
+ opposit_g	66.36	0.07	1.85	0.01	0.01	0.22	0.00	0.01
+ recoil	66.23	0.07	1.76	0.01	0.01	0.21	0.00	0.01
# Evts(Remain)	#1768.5	#200.5	#2256.5	#166.1	#33.3	#3204.7	#57.9	#686.2

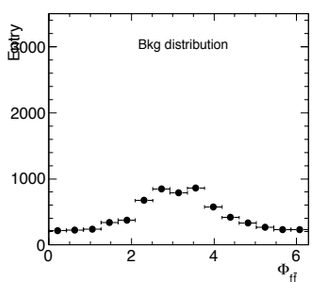
 # Nsig (->Integral()): 1768.5
 # Nbck (->Integral()): 6605.2
Significance :19.32

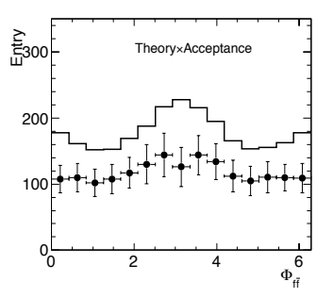


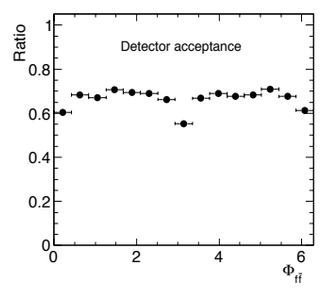












Detector Acceptance (η)

>. Estimation of #Signal events of each bin (15 bins).

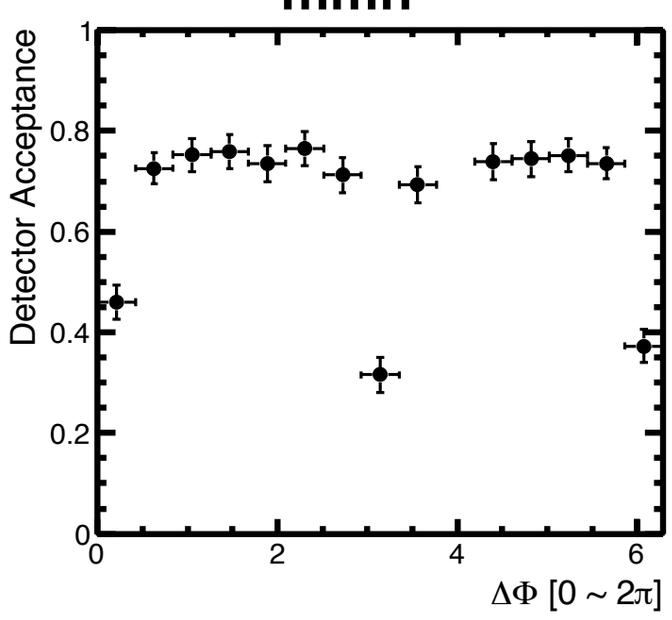
$$\text{Acceptance } \eta_{x_{bin}} = \frac{N^{observed}_{x_{bin}}}{N^{theoretically}_{x_{bin}}},$$

$$\Delta\eta = \frac{\sqrt{\eta_{x_{bin}}(1-\eta_{x_{bin}})}}{\sqrt{N^{generated}_{x_{bin}}}}$$

>. Recoil mass

Acceptance drop down
due to some angular cut

mmh



eeh