National University
The Graduate University
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Sensitivity of the ILC to Anomalous Couplings btw Higgs and Gauge Bosons

HWW Decay Process

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 …

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

arXiv:1011.5805

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.

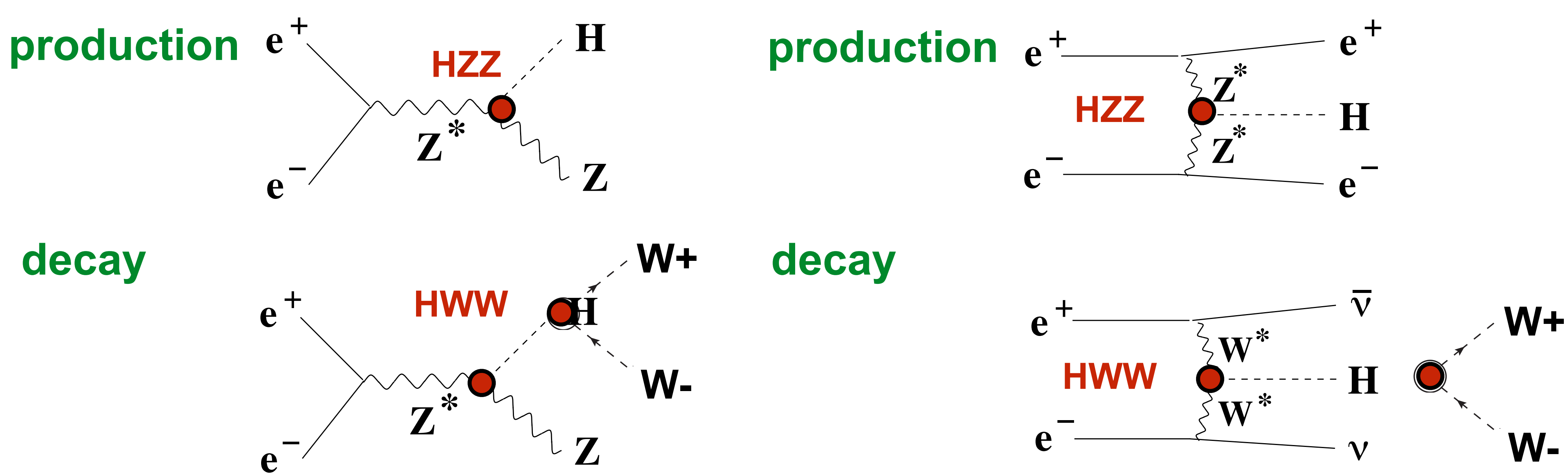
Process

>. 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 .

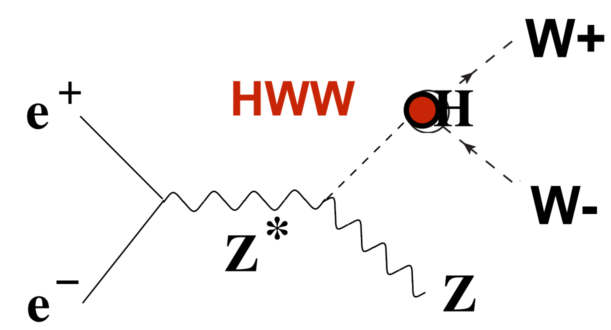
>. In the lepton collider environment,

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



Using decay Processes @ 250GeV

- Need high performance on flavor tag.

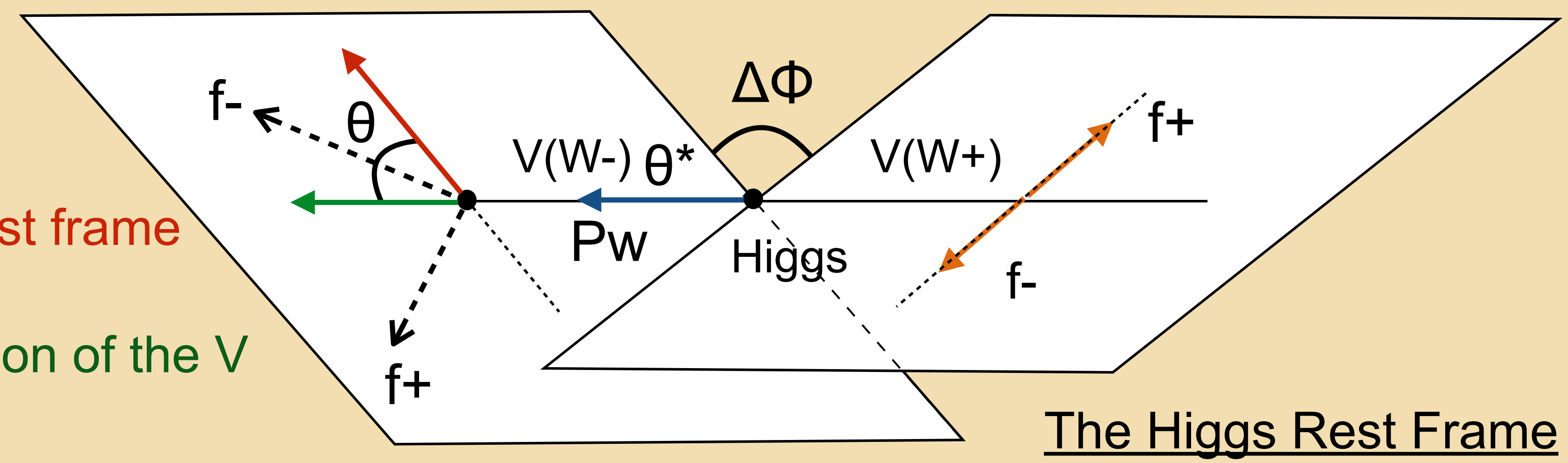


Definition of Sensitive Parameters

>. Definition of parameters which are sensitive to anomalous couplings on the higgs decay process.

The direction of motion of
the daughter fermion in the H rest frame

The direction of motion of the V
in the H rest frame



>. Pw : W momentum in the Higgs rest frame.

>. θ : The angle between .
the direction of motion of the daughter fermion in the V rest frame and
the direction of motion of the V in the H rest frame. (polar angle)

>. ΔΦ : The angle between two decay/~~production~~ planes defined
in the Higgs rest frame. (azimuthal angle)

Definition of Sensitive Parameters

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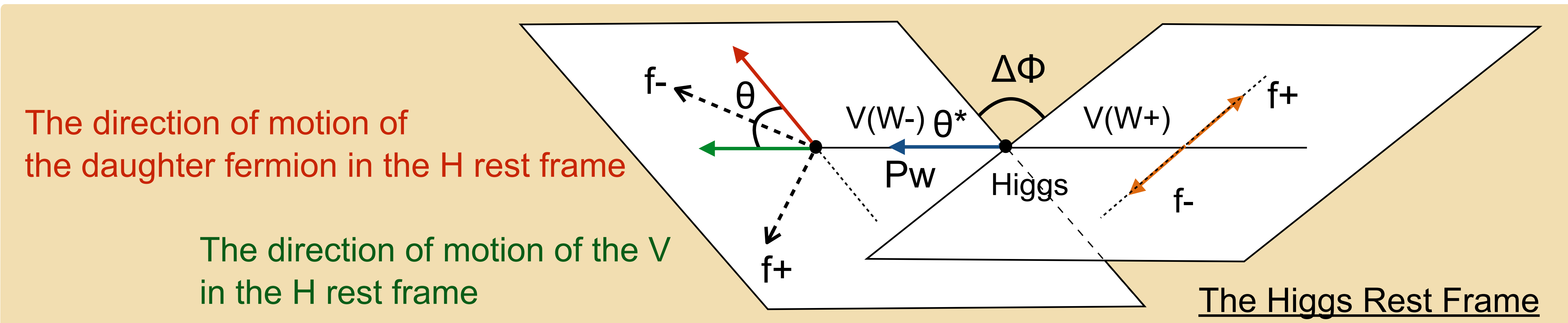
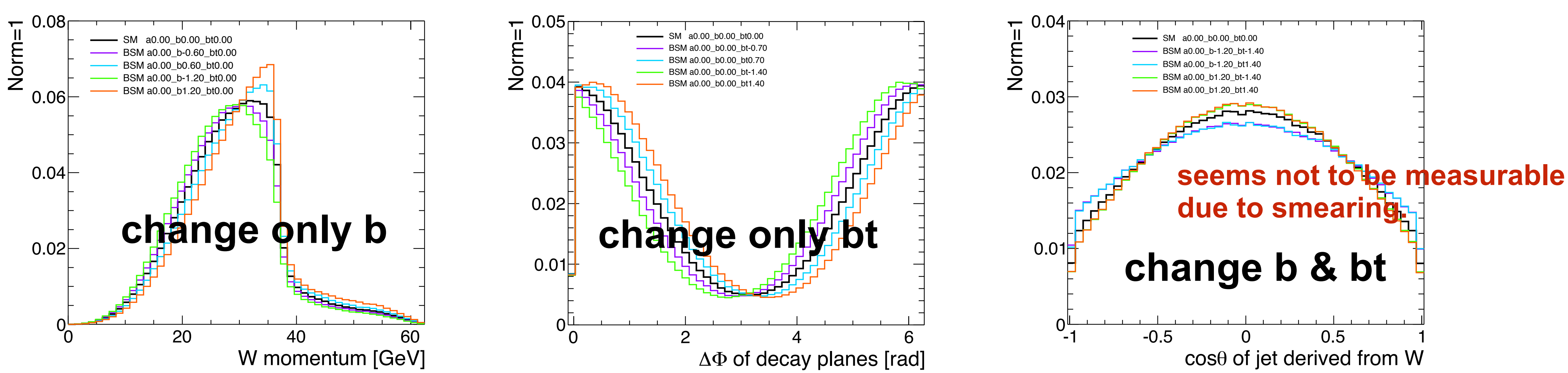


>. Comparison of the shape itself of each distribution.

>. Parameters are changed slightly and each distribution are normalized to 1.



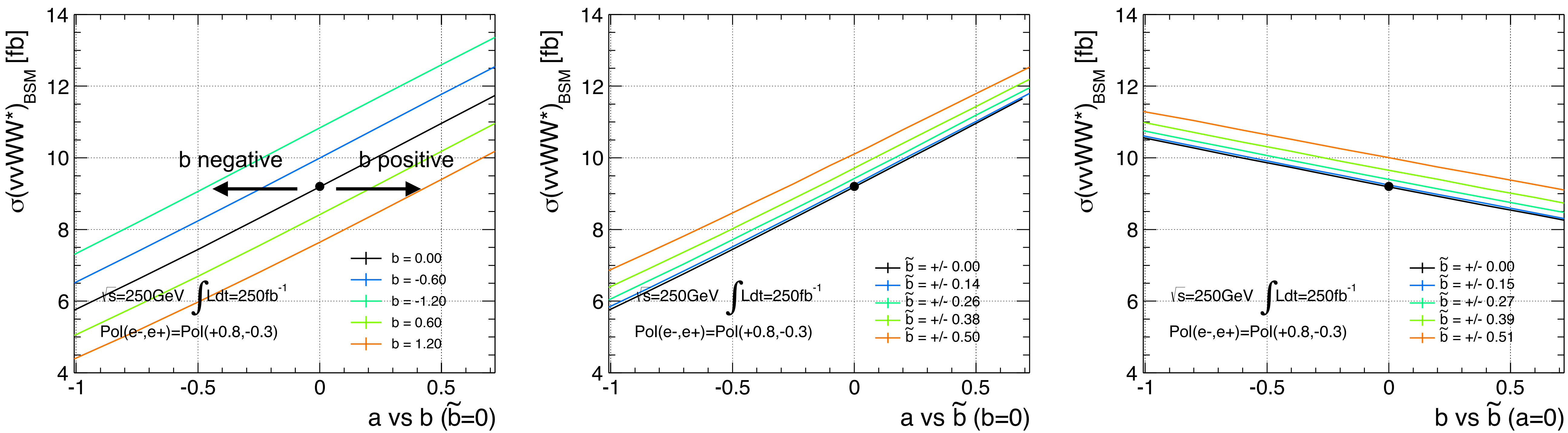
Difference of Cross Section (vvH; H➡WW*)

>. Comparison of the cross section with 250GeV, 250fb-1.

- Anomalous coupling is included in decay vertex. Only branching ration changes due to it.

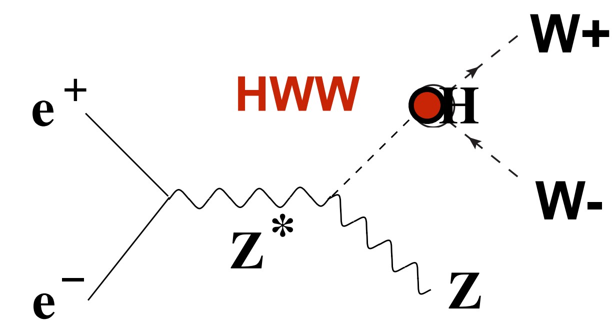
>. (a vs b) if parameter a changes to 0.1, the cross section changes < ~5 %.

>. (b vs bt) if parameter b changes to 0.1, the cross section changes < ~2 %.



>. The difference of cross section is small on “a vs bt” and “b vs bt”.

Simulation



>. Signal is ZH -> vvWW* -> vvc(xbar)(cbar)x. (σ: LR ~ 1.9 fb / RL ~ 1.1 fb)

● Signal : Physisim generater. ● Bkgs: DBD official samles

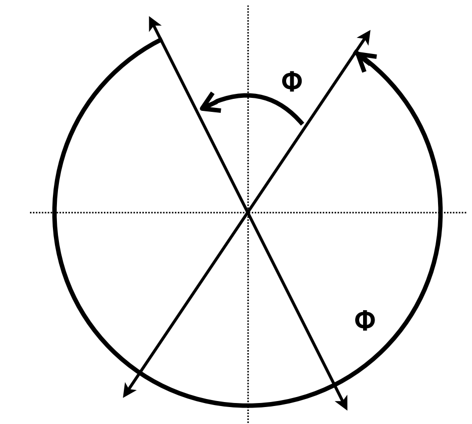
>. The key detector performance is c-tagging.

● ccbar decay events need to be selected for the correct reconstruction of ΔΦ.

We want to know c➡cbar

c or cbar from W+/W-

cbar or c from W-/W+



>. c and cbar can not be distinguish (for the moment).

● ILC should be able to identify the charge of c/cbar by counting changed tracks.

➡ ΔΦ can be calculated only as the opening angle between two-jets.

➡ sensitive region of ΔΦ is; 0 ~ π [rad]

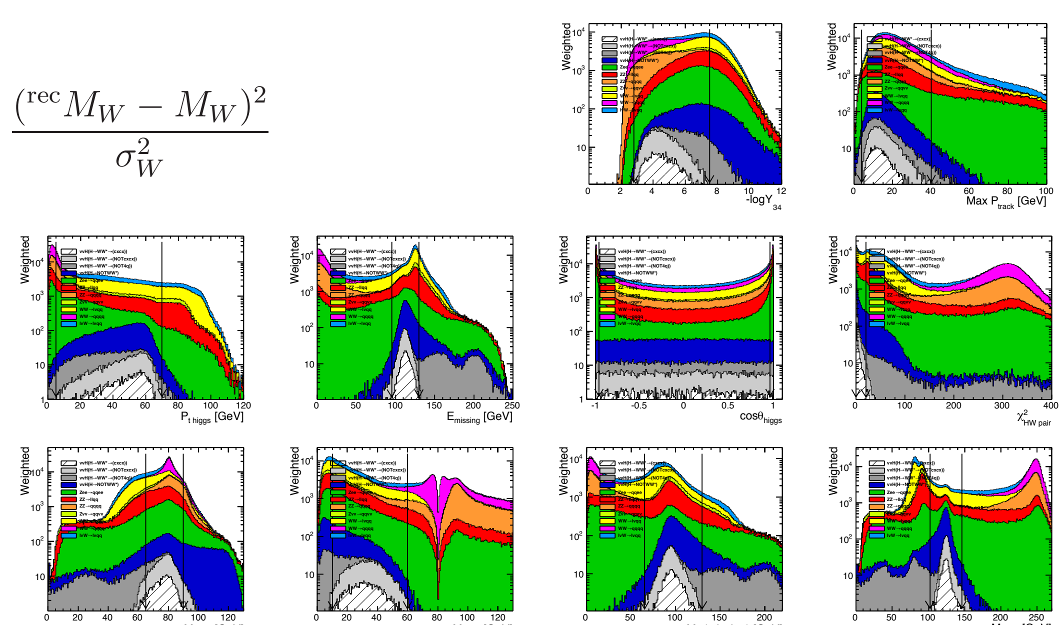
>. Reconstruction & Bkgs suppression

>. Remove isolated lepton (>12GeV) and Use Durham Jet clustering: 4-jets & 2-jets

● 2-jets is mainly for removing H->bb

>. Pairing jets using x^2 value with 4-jets case: $$\chi^2 = \frac{({}^{\mathrm{rec}}M_H - M_H)^2}{\sigma_H^2} + \frac{({}^{\mathrm{rec}}M_W - M_W)^2}{\sigma_W^2}$$

>. Background suppression:



● Topology Cut.
- #Isoleps - #PFOs
- Clustering parameters
- Y2➡3 - Y3➡4

● Kinematical Cut.
- Missing energy
- Missing mass.
- PTrackMax

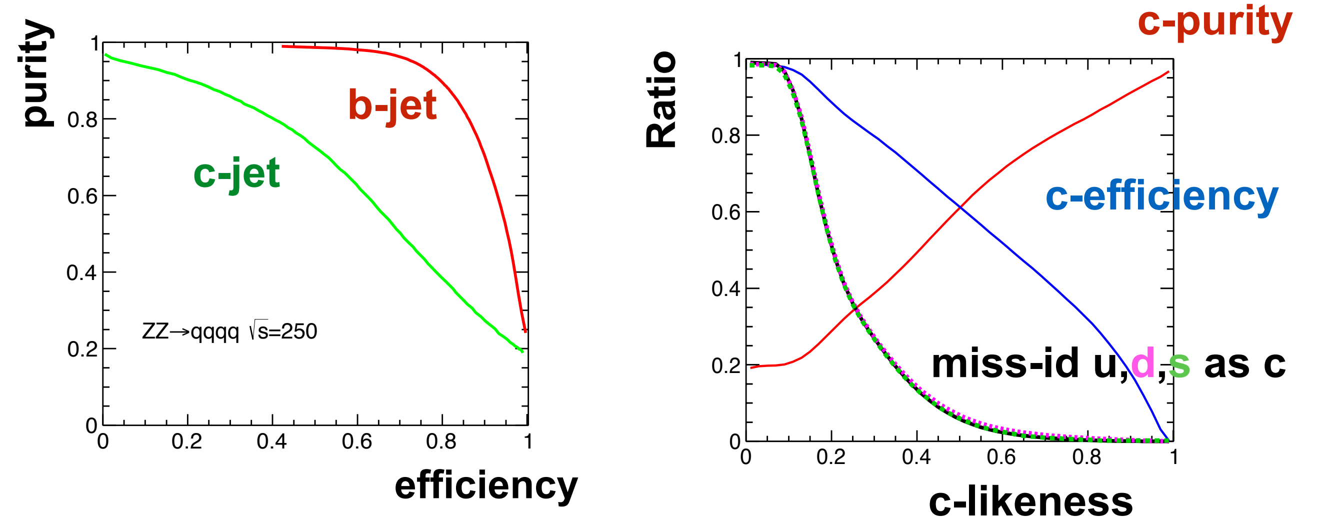
● Physical Cut.
- M_w, - M_w*, - M_h.
- cosθHiggs ,
- PtHiggs , - χ2 value .
+ MVA output

ΔΦ Reconstruction (c/c-bar and c-tag)

>. **Performance of c-tagging is not high compared with b-tagging**

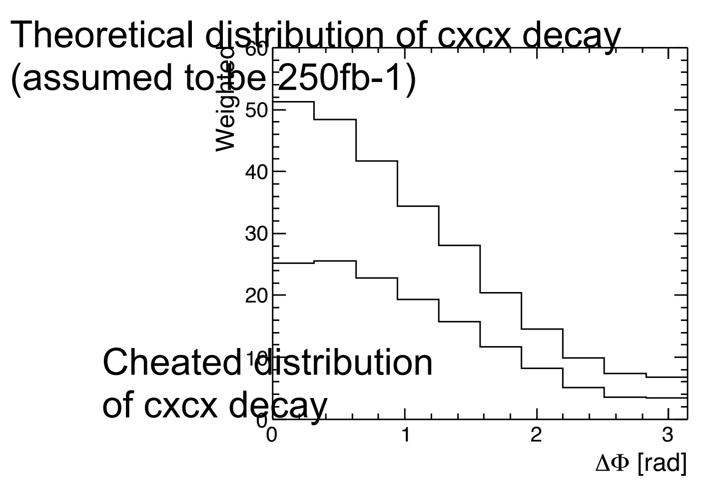
- If high efficiency is required, purity is worse on the other hand.
- . In the case c-likeness is required to be 0.5, miss identification happens for each light jet around 5%.

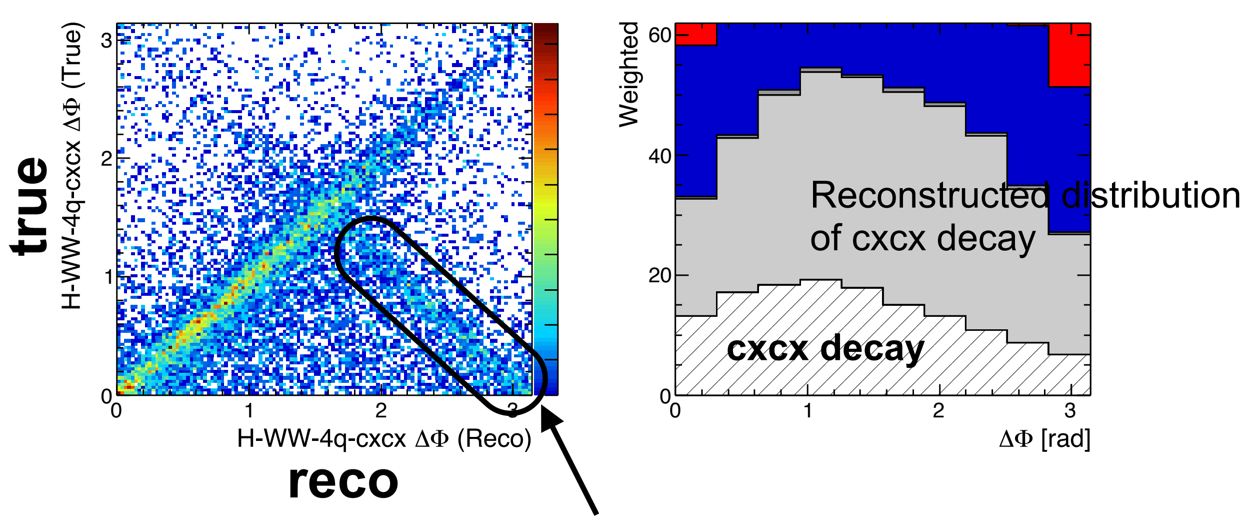
Flavor tag performance
ZZ->qqqq 250GeV

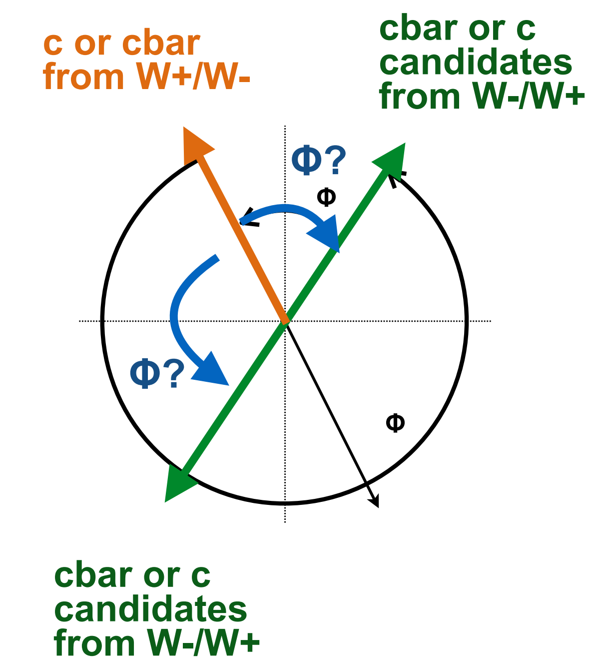


>. **(e.g.) In the case low c-likeness is applied to select ccbar decay for keeping high efficiency.**

- c-likeness is > 0.2 for both W and W*.
- If there are two candidates for W or W*, a jet which has greater c-likeness is taken.







>. **Miss identification sometimes happens (identify light jet s/d as c).**

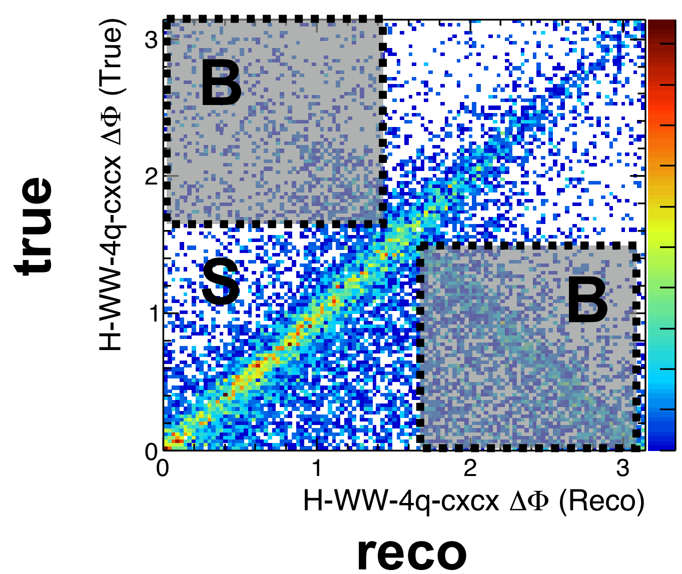
ΔΦ Reconstruction (c/c-bar and c-tag)

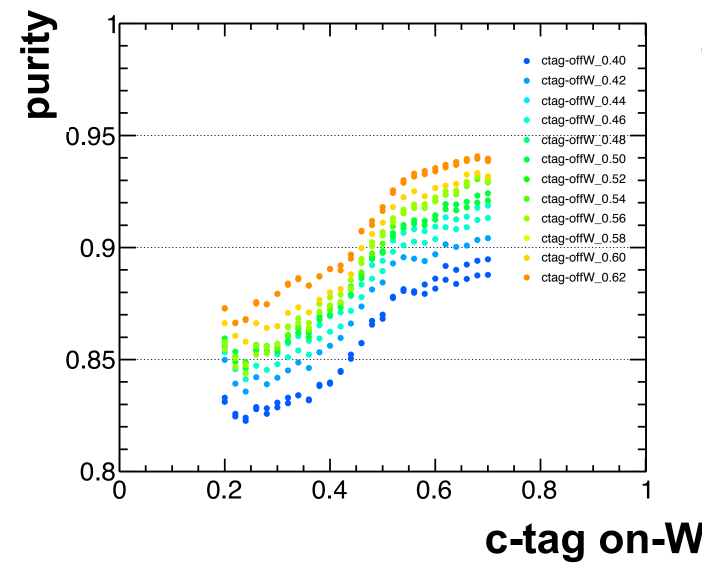
>. Optimization of c-tag is needed to extract pure cxcx events.

- **We need correct ccbar events to reconstruct correct angle ΔΦ.**
- Restriction; only one c-candidate is identified for both W and W*.

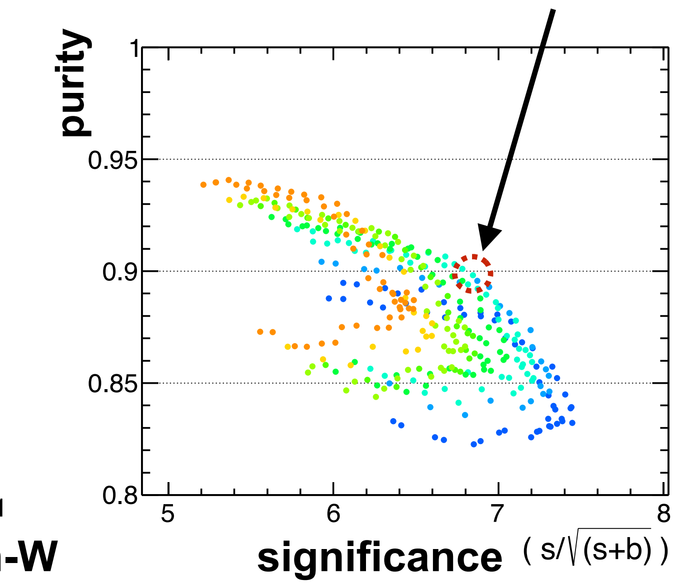
We want to keep both performance ;
efficiency; because N_expected is less.
purity ; because correct ΔΦ is needed.

- **Personal definition;**

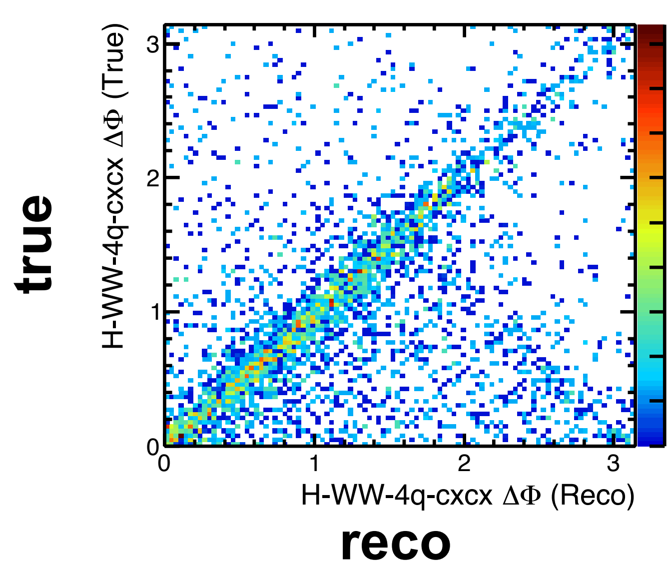


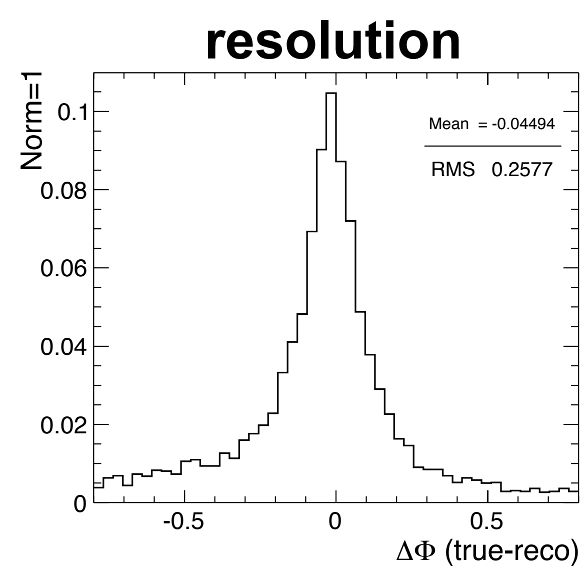


Optimized point
c-tag ~ 0.52 for W
c-tag ~ 0.44 for W*



- **After c-tag optimization;**





>. Still miss reconstructions are there.
(due to performance c-tagging).

>. Resolution of ΔΦ is not so good.
(due to performance Jet-clustering).

>. Remaining events.

ww->cxcx (sig):		**57.54**
ww-> not cxcx	**:**	**29.40**
h-> not ww	**:**	**32.73**
SM bkgs	**:**	**310.5**

Estimation of #Signal Events & Detector Acceptance (η)

>. Estimation of #Signal events of each bin

>. Parameters are divided into 10 bins.

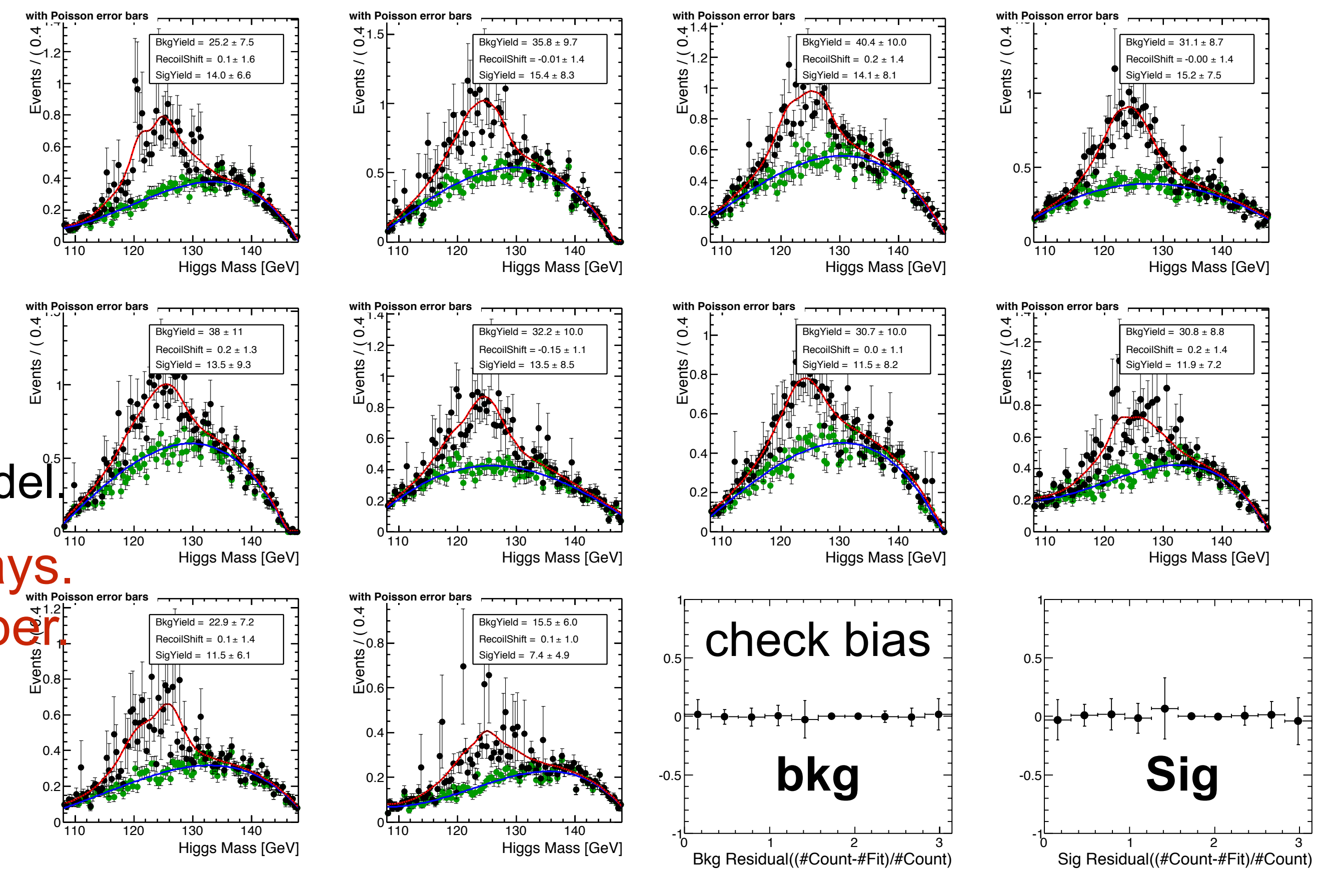
>. Kernel function (for sig)

>. 3rd Pol function (for bkg)

● Bkg of each bin is regenerated based on the fitted model.

※ Signal is contaminated with the other higgs decays.
Subtract these effect by using the counted number.

N_cxcx = N_sig(fit)
- N_not-cxcx(count) - N_h->others(count)



$$\frac{N_{count} - N_{fit}}{N_{count}}$$

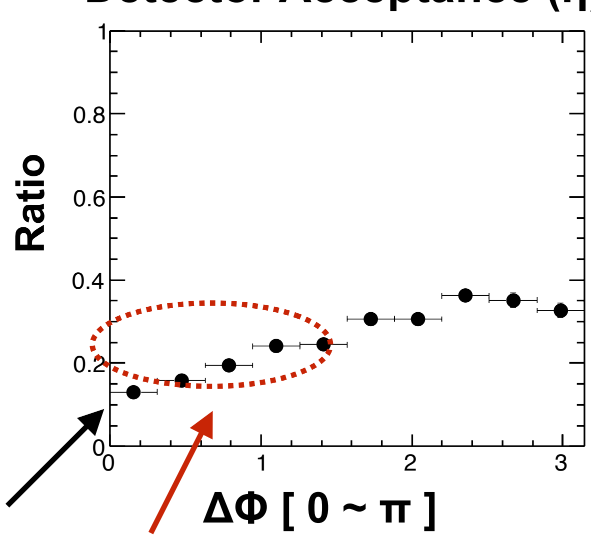
>. Detector acceptance.

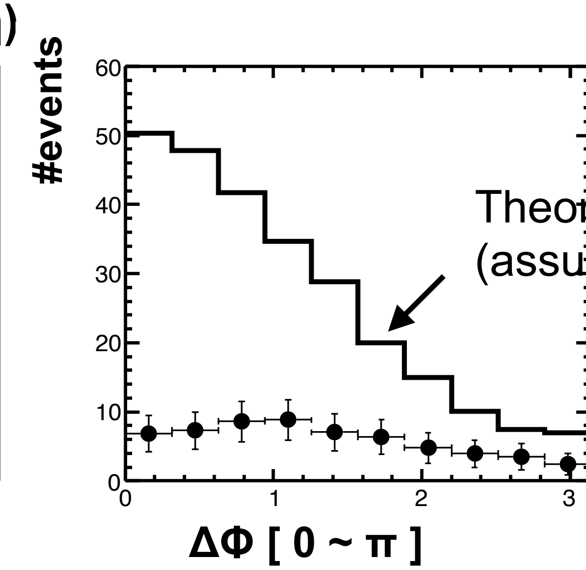
$$\text{Acceptance} \ \ \eta_{x_{bin}} = \frac{N^{observed}_{x_{bin}}}{N^{theoretically}_{x_{bin}}},$$

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

Detector acceptance estimated from fitting

Detector Acceptance (η)





Theoretical distribution of cxcx decay (assumed to be 250fb-1)

Expected Ncxcx with SM

>. In the case ΔΦ is small, efficiency drops down.

➡ Small angle separation is not easy with the current jet clustering technic.

χ2 Test with Different Models

>. Detector acceptance gat from analysis, perform ToyMC with several physics models.

- y_{bin}^{SM-MC}; The observed mean with SM-MC. (fitting result.)
- σ_{bin}^{SM-MC}; The variance related to y_{bin}. (its error if fitting result is used.)
- $f^{theory}(x_{bin}; a, b, \tilde{b})$: The predicted model from the theory/model.
- $f^{theory\ w/accep}(x_{bin}; a, b, \tilde{b})$: The predicted model which is applied detector acceptance.

$$f^{theory}(x_{bin}; a, b, \tilde{b}) = \left(\int_{x_{bin}}^{x_{bin+1}} L \cdot \frac{d\sigma}{dx_{bin}} dx_{bin}\right)$$

(contents of each bin)

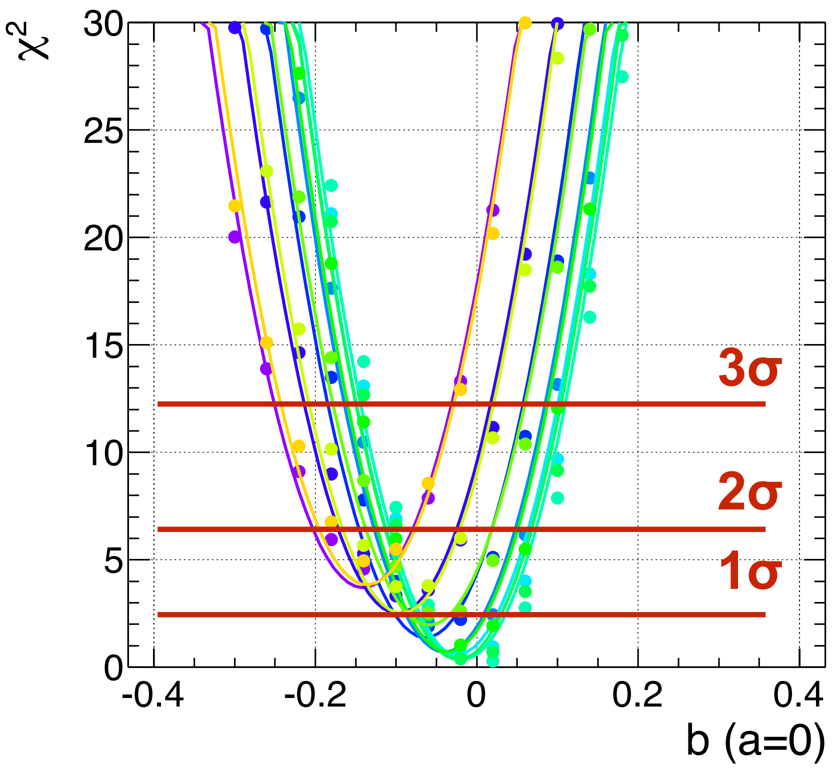
$$\text{Acceptance}\ \ \eta_{x_{bin}} = \frac{N_{x_{bin}}^{observed}}{N_{x_{bin}}^{theoretically}}, \qquad \Delta\eta = \frac{\sqrt{\eta_{x_{bin}}(1-\eta_{x_{bin}})}}{\sqrt{N_{x_{bin}}^{generated}}}$$

$$f^{theory\ w/accep}(x_{bin}; a, b, \tilde{b}) = \left(\int_{x_{bin}}^{x_{bin+1}} L \cdot \frac{d\sigma}{dx_{bin}} dx_{bin}\right) \cdot \eta_{x_{bin}}$$

(expected #signals)

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

different color, different bt



Sensitivity to Anomalous Couplings (HWW)

>. Sensitivity is not large basically because the observed signal yields are not much.

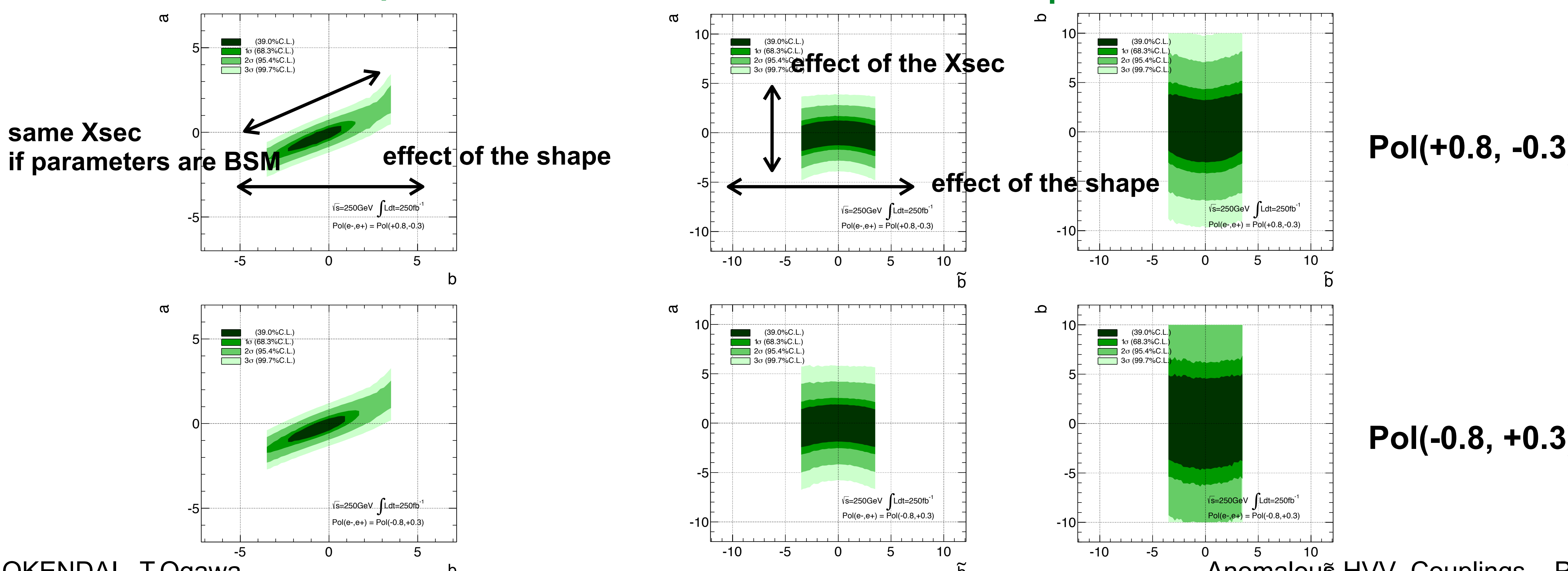
※ But this sensitivity is estimated by using only vvWW*->vvcxcx process.

>. In the left-handed case, tight cut is needed because WW bkgs are huge.

>. (a vs b) The difference of Pw distribution is large for the small changing of “b”,
we can have sensitivity along b-axis.
Cross sections on the diagonal region are same, we cannot have.

>. (a vs bt) The difference of angular distribution large for the small changing of “bt”.
But we do not have much sensitivity along bt-axis because we lose sensitivity due to jet clustering / charge of c .

estimation from parameter “Pw” **estimation from parameter “ΔΦ”**



Summary and Prospect

>. 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.

>. In the case of HWW analysis using WW*->ccbar decay process, the c-tagging is the most important detector performance for the reconstruction of sensitive angle $\Delta\Phi$.

>. For the moment, the sensitivity of anomalous coupling on HWW is not good. We believe that there is still room for improvement on c-tag performance.

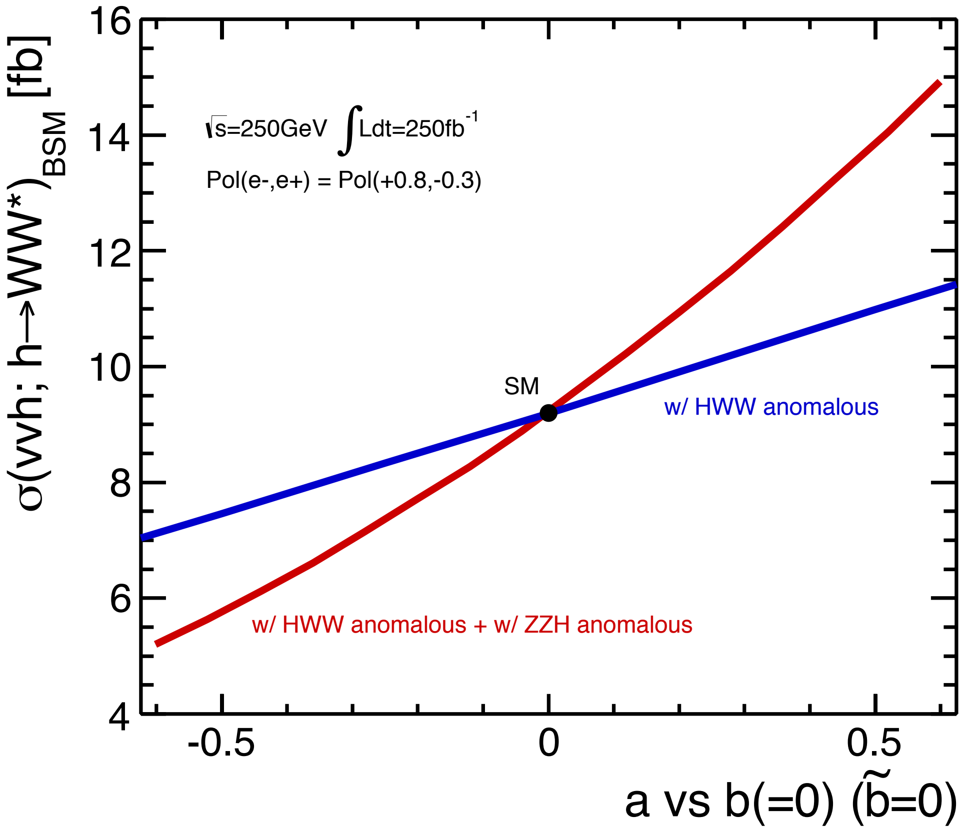
>. It will be also necessary to consider which region corresponds to what kinds of model.

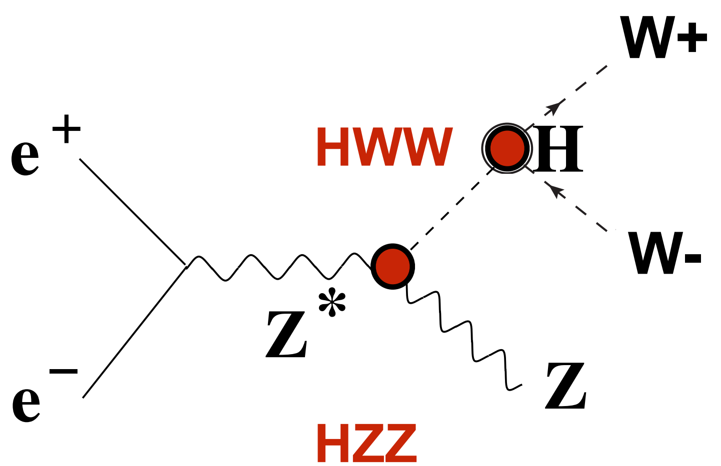
test

Consideration of Anomaly on Production Vertex

>. Analysis up to here is not included with the anomalous coupling on the production vertex (HZZ).

>. More naturally Anomalous HWW couplings should imply anomalous contributions to the HZZ because the underlying theory is gauge invariant.



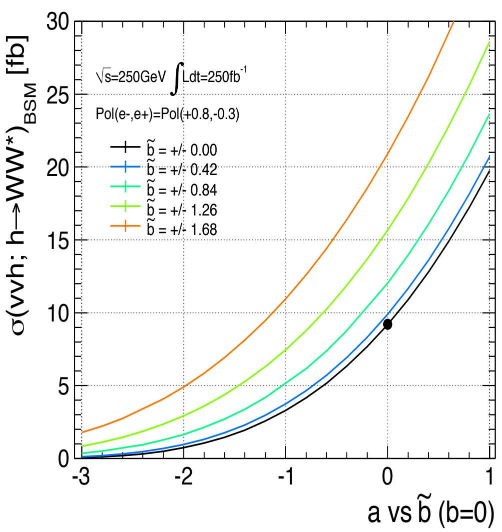


>. The difference of cross section become large

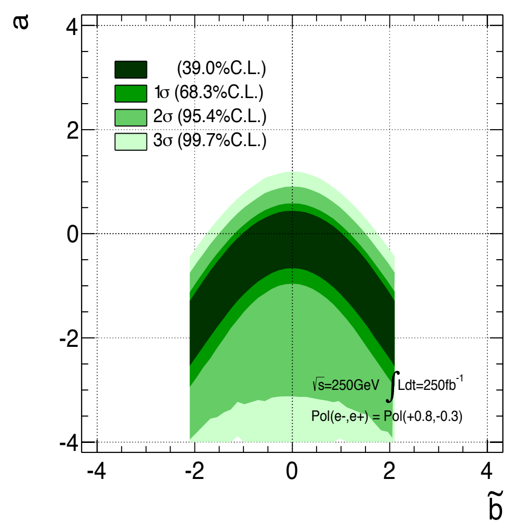
Result (very temporary)

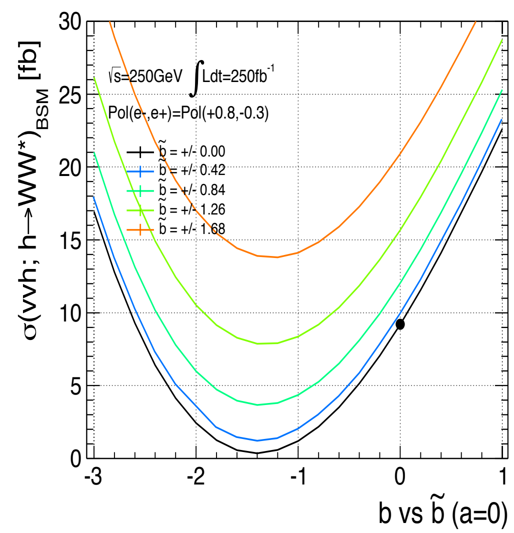
>. Anomalous coupling on production(HZZ) vertex is included in consideration.

>. Sensitive region is restricted bit tighter because of the changing of the cross section.



estimation from parameter "ΔΦ"





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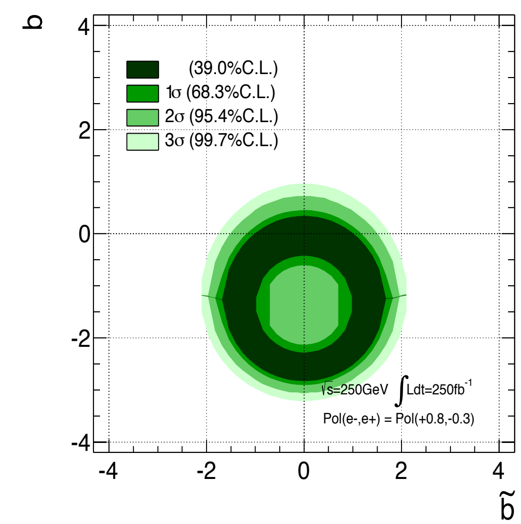

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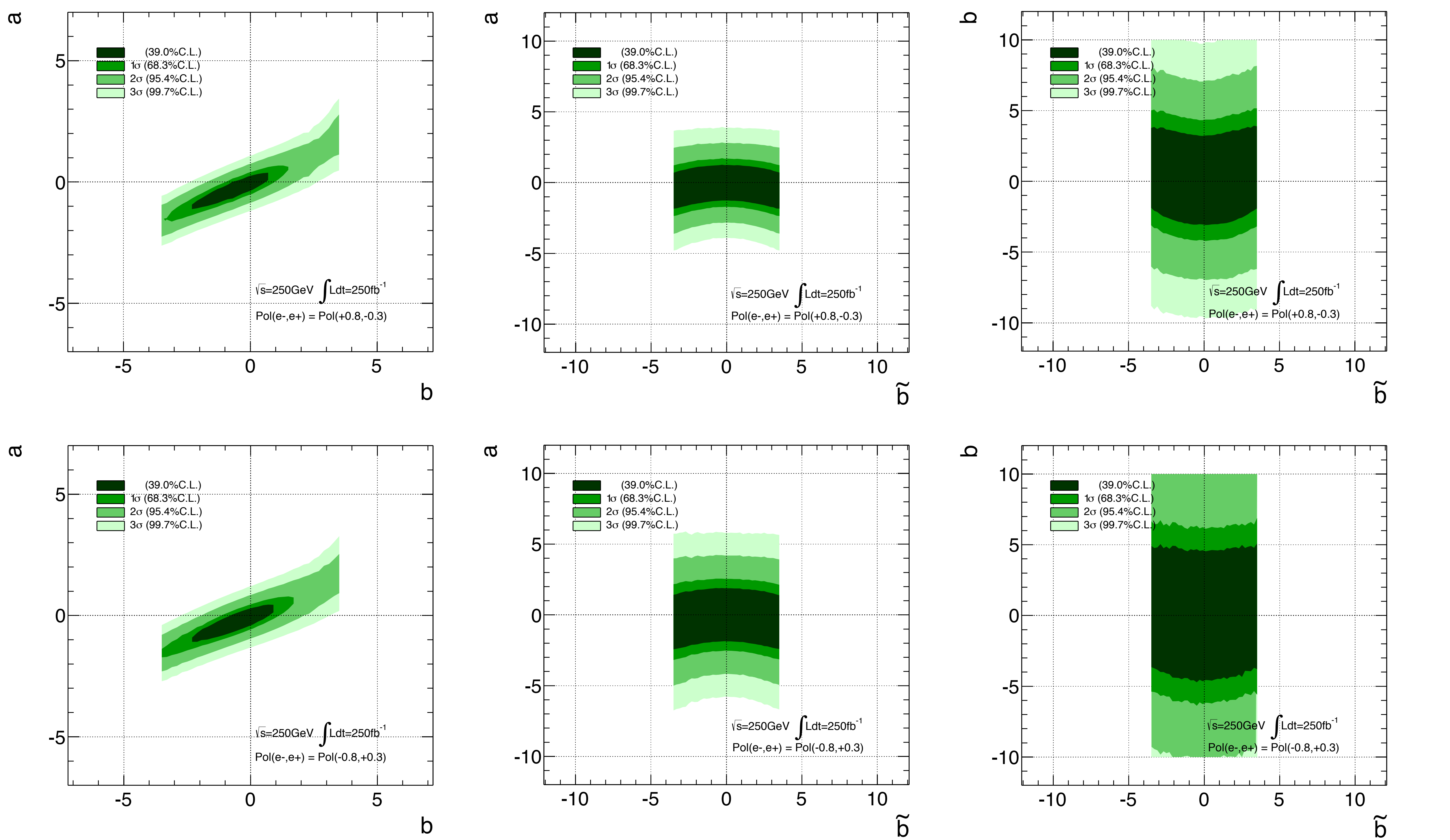
>. For the moment, the sensitivity of anomalous coupling on HWW is not good. We believe that there is still room for improvement on c-tag performance.

ΔΦ Reconstruction (c/c-bar and c-tag)

Cut Table Summary

# cut&process	vvh_cc	vvh_Ncc	vvh_N4q	vvH_Nww	Zee_sl	ZZ_sl	ZZ_h	Zvv_sl	WW_sl	WW_h	lvW_sl
# raw data	#29993	#90826	#138359	#151717	#324933	#534595	#500963	#147395	#1960681	#110688	#2007008
# xsection	1.05	3.16	4.99	33.39	299.68	467.19	402.98	92.50	758.38	600.37	445.42
# xsection*L	263	789	1247	8347	74921	116797	100745	23125	189596	150092	111356
! RecoEvent	100.000	100.000	88.521	97.606	99.996	99.974	100.000	99.966	100.000	100.000	100.000
+ nisoleps	99.823	99.740	41.569	95.999	31.535	78.400	99.820	99.859	46.495	99.891	42.941
+ allpfos	98.566	98.266	20.179	86.033	16.584	61.377	80.525	71.093	36.962	88.650	33.632
+ logy23	94.685	95.520	15.686	35.003	12.956	33.057	71.747	25.183	30.325	83.263	28.608
+ logy34	92.662	94.029	14.451	30.051	11.511	26.547	63.563	21.499	22.659	76.798	19.411
+ maxtracke	89.628	89.902	13.443	29.271	3.641	18.773	48.304	20.452	15.960	54.597	6.151
+ hptmom	89.628	89.902	13.443	29.271	3.641	18.773	48.304	20.452	15.960	54.597	6.151
+ missinge	85.623	85.995	11.944	27.327	0.074	10.337	4.172	15.640	12.156	1.412	4.341
+ chi2pair	81.419	82.332	2.034	23.288	0.005	4.391	0.013	7.059	5.398	0.001	0.982
+ onwmass	78.312	79.738	1.404	20.428	0.004	2.029	0.010	2.737	3.681	0.001	0.545
+ offwmass	75.531	77.046	1.346	17.502	0.004	1.853	0.009	2.471	3.452	0.001	0.521
+ zmass	74.867	76.281	1.297	17.185	0.003	1.623	0.008	2.336	2.291	0.001	0.276
+ mvaoutput	73.224	76.013	1.232	17.023	0.003	1.569	0.008	2.294	2.048	0.001	0.267
+ bjets	67.376	66.685	1.023	6.146	0.001	0.935	0.002	1.344	1.791	0.001	0.202
+ btag2jet	65.745	66.199	1.002	5.827	0.001	0.908	0.002	1.324	1.756	0.001	0.198
+ cjets onw	39.236	19.391	0.367	1.376	0.000	0.211	0.001	0.279	0.654	0.000	0.054
+ cjets offw	21.932	3.729	0.102	0.395	0.000	0.053	0.000	0.060	0.128	0.000	0.005
+ hmass	21.932	3.729	0.102	0.395	0.000	0.053	0.000	0.060	0.128	0.000	0.005
# Evts(remain)	**#57.54**	**#29.40**	**#1.14**	**#32.73**	**#0.00**	**#57.46**	**#0.40**	**#12.71**	**#234.59**	**#0.00**	**#5.71**



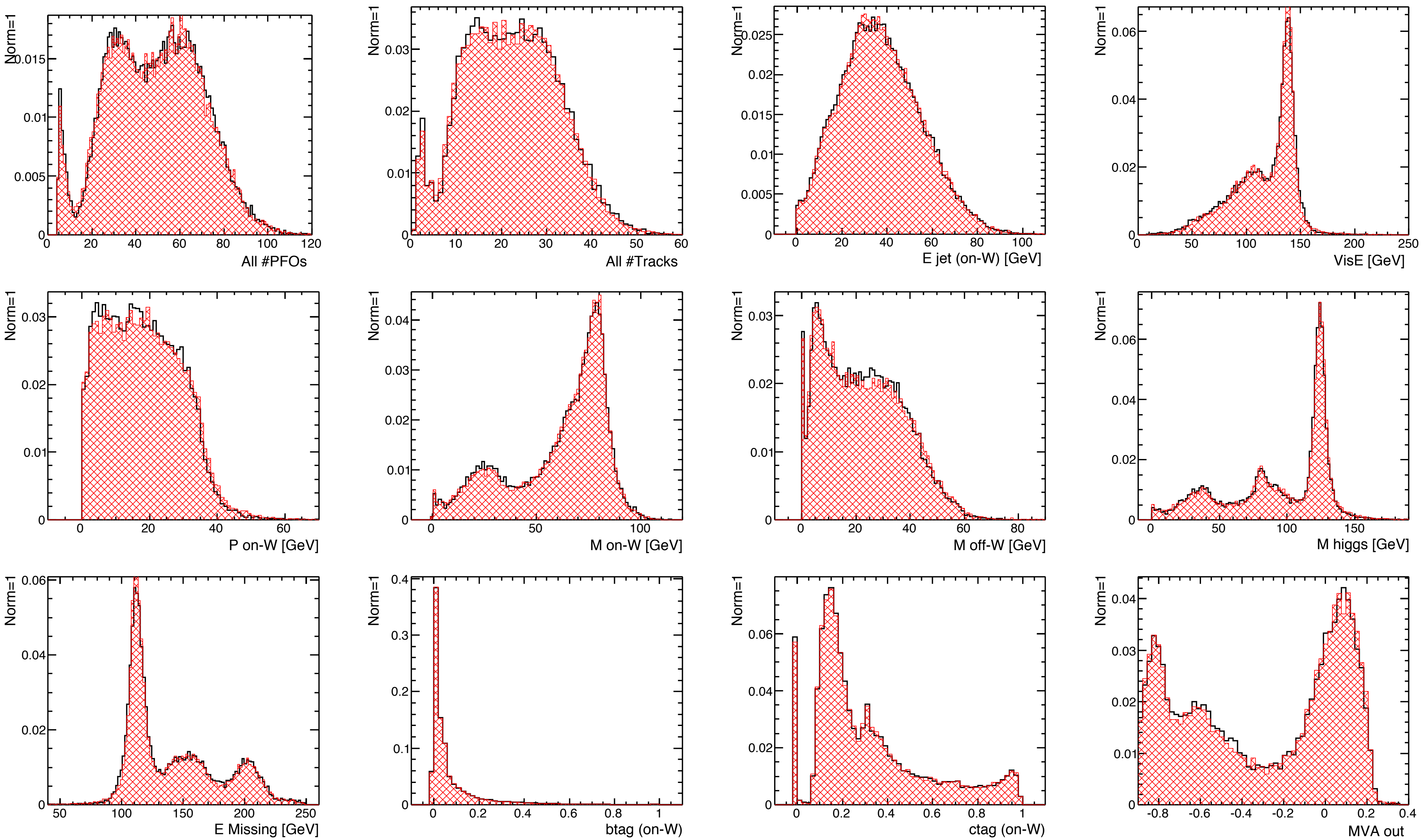
(39.0%C.L.)
1σ (68.3%C.L.)
2σ (95.4%C.L.)
3σ (99.7%C.L.)
√s=250GeV ∫Ldt=250fb⁻¹
Pol(e-,e+) = Pol(+0.8,-0.3)
Pol(e-,e+) = Pol(-0.8,+0.3)
a
b
b̃

Comparison of Samples DBD & Physsim

>. — DBD samples

>. — Physsim samples

>. Process is vvH ➡ vvWW* @ 250 GeV.

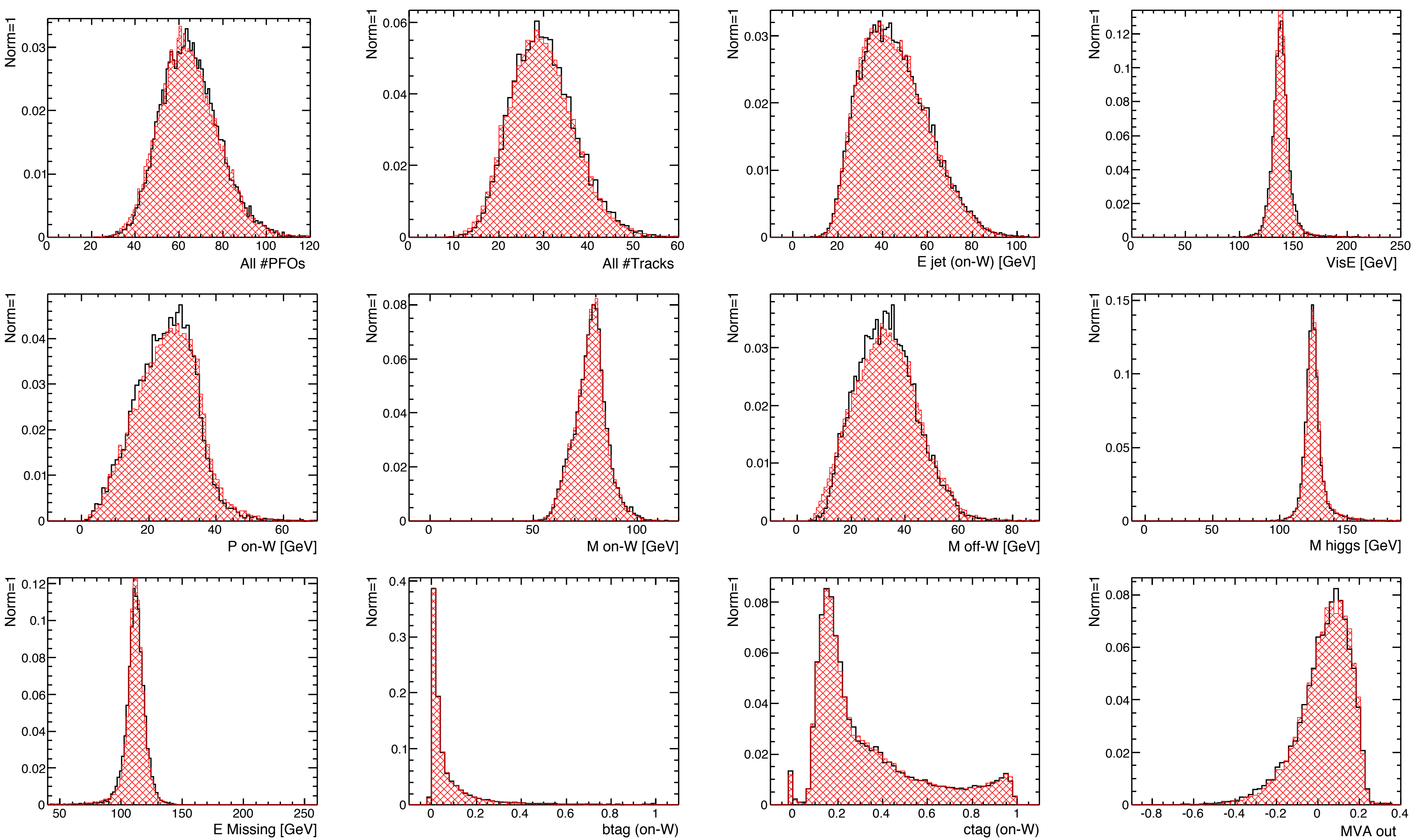


Comparison of Samples DBD & Physsim

>. — DBD samples

>. — Physsim samples

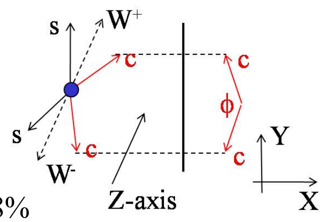
>. Process is vvH ➡ vvWW* ➡ vvqqqq @ 250 GeV.

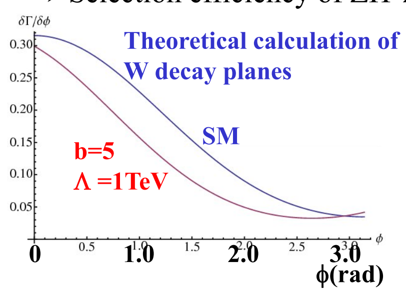


Previous Study by Takubo-san

Calculation of plane angle

- Angle of W decay planes was evaluated by the angle of the two up-type quarks.
  - There is a peak at 0 rad..
  - The distribution shape changes with the anomalous coupling.
- Two c-jet is selected with c-tagging.
  - Selection efficiency of ZH→ννcxcx is 88%



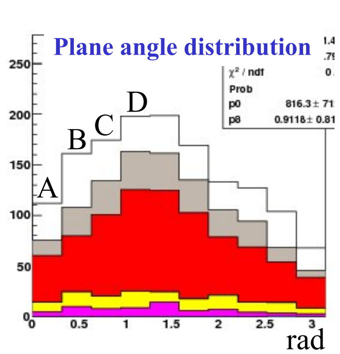


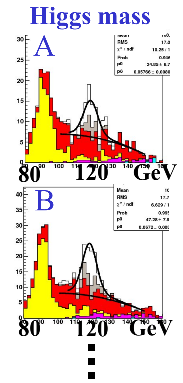
	Before c-tag	After c-tag
ZH→ννcxcx	81	71
ZH→others	675	475
SM-BG	1,367	874

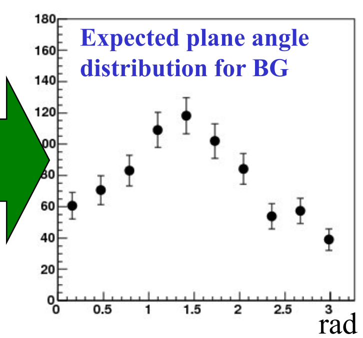
BG estimation

- # of BG is estimated, fitting M_H distributions prepared for each bin of the plane angle distribution.
- Fitting function: double gaussian + 2nd order polynomials.

→ The expected background distribution was compared with the original distributions.



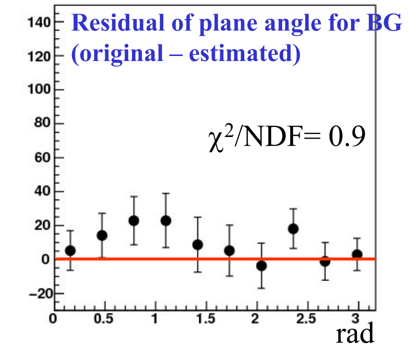


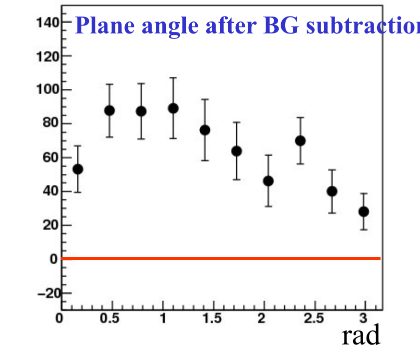


Angular dist. After BG subtraction

- The estimated BG distribution is consistent with the original dist..

  → The plane angle for ZH events was obtained, subtracting estimated BG.
- Next step: Comparison of the angular distribution, including the anomalous coupling.



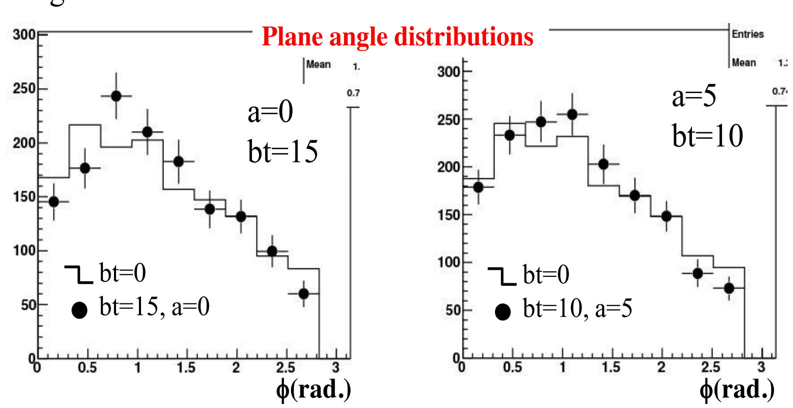


Shape difference of the plane angle

The shape of the distribution was compared.

- The normalization of SM is set to that of events with the anomalous coupling.
- The difference can be seen.

→ The significance of the difference was evaluated.

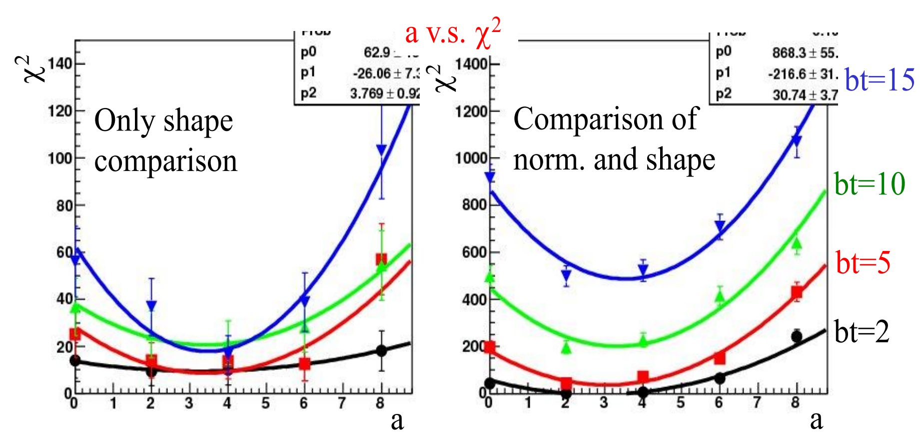


Shape difference of the plane angle

The difference of the distribution shape was evaluated.

- The significance of the difference becomes large with bt.
- The difference of the shape would e be able to be observed.

  → The contour plot for a v.s. bt will be made.



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