Anomalous VVH couplings at the ILC

Status report
2017/04/14

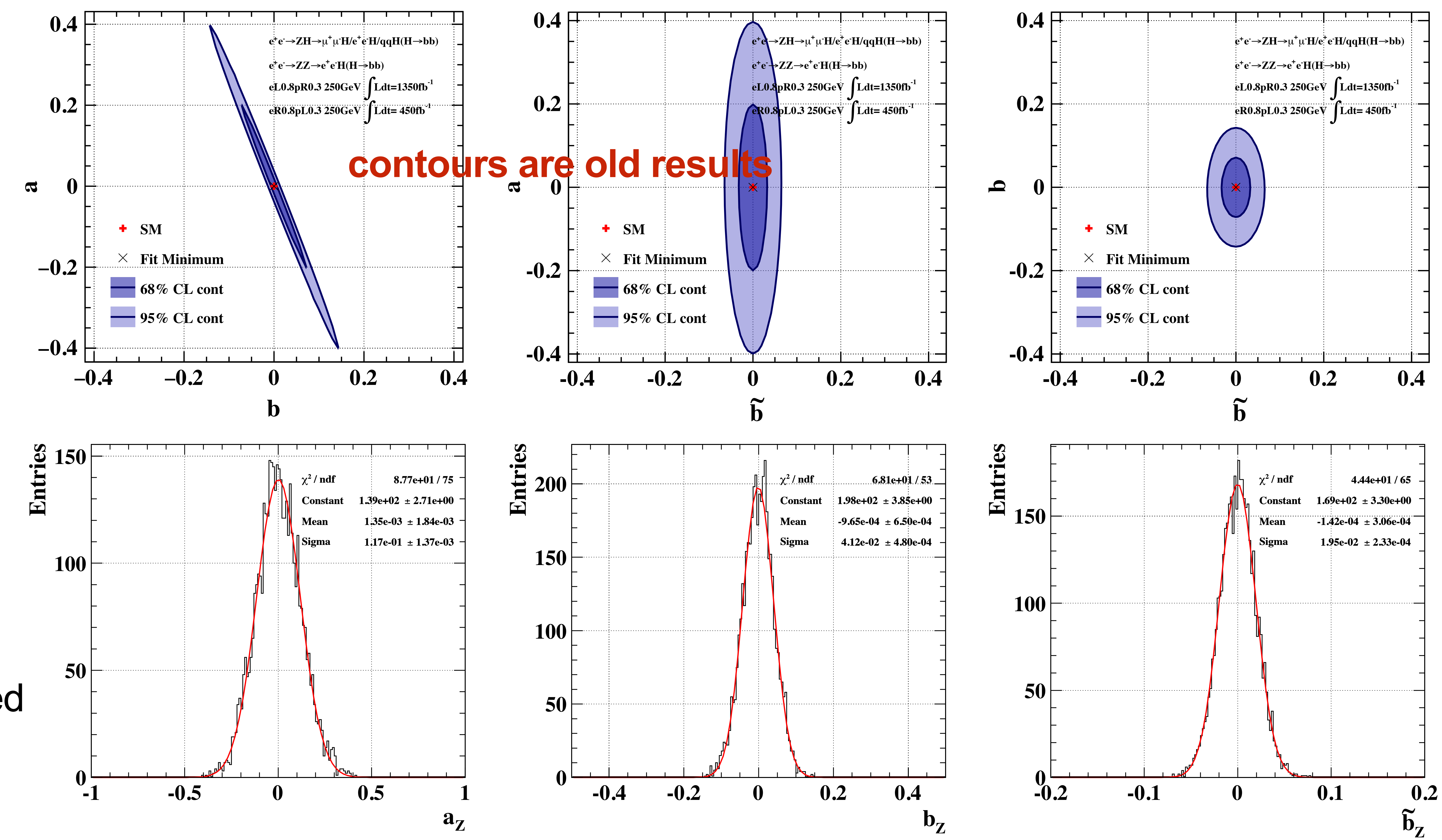
Anomalous ZZH couplings @ 250GeV

A continuation from the ILD analysis mtg.

$$\mathcal{L}_{ZZH} = M_Z^2\left(\frac{1}{v}+\frac{a}{\Lambda}\right)Z_\mu Z^\mu H + \frac{b}{2\Lambda}Z_{\mu\nu}Z^{\mu\nu}H + \frac{\tilde{b}}{2\Lambda}Z_{\mu\nu}\tilde{Z}^{\mu\nu}H$$

Error estimation using “single fit”
is very unstable du to strong correlation
of a and b parameters.
correlation coefficient is close to 1.

------->0 parameter: 0 +/- 0.153627
------->1 parameter: 0 +/- 0.0549416
------->2 parameter: 0 +/- 0.0247242



ToyMC/sudoExp was performed to
get reliable errors for each parameter.

Scenario is H20 and
three free parameter spaces are assumed

1 sigma errors;

$$a = \pm 0.12$$
$$b = \pm 0.042$$
$$\tilde{b} = \pm 0.020$$

Final results on ZZH @250GeV

Anomalous WWH couplings @ 250GeV

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{eff}$$

$$\mathcal{L}_{eff} = \sum_i \sum_{n\geq} \frac{f_i}{\Lambda^{n-4}} \mathcal{O}_i^{(n)}$$

Tim Barklow (lcws16)

$$\Delta\mathcal{L} = \frac{c_H}{2v^2}\partial^\mu(\Phi^\dagger\Phi)\partial_\mu(\Phi^\dagger\Phi) + \frac{c_T}{2v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu\Phi)(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi) - \frac{c_6\lambda}{v^2}(\Phi^\dagger\Phi)^3 + \frac{g^2 c_{WW}}{m_W^2}\Phi^\dagger\Phi W^a_{\mu\nu}W^{a\mu\nu} + \frac{4gg' c_{WB}}{m_W^2}\Phi^\dagger t^a\Phi W^a_{\mu\nu}B^{\mu\nu} + \frac{g'^2 c_{BB}}{m_W^2}\Phi^\dagger\Phi B_{\mu\nu}B^{\mu\nu} + \frac{g^3 c_{3W}}{m_W^2}\epsilon_{abc}W^a_{\mu\nu}W^{b\nu}{}_\rho W^{c\rho\mu} + i\frac{c_{HL}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu\Phi)(\overline{L}\gamma_\mu L) + +4i\frac{c'_{HL}}{v^2}(\Phi^\dagger t^a \overleftrightarrow{D}^\mu\Phi)(\overline{L}\gamma_\mu t^a L) + i\frac{c_{HE}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu\Phi)(\overline{e}\gamma_\mu e) \ .$$

Another vector-Higgs couplings WWH appears based on EFT with dim-6 operators.

After expansion of the Higgs scalar filed and transformation to our convenient convention,
the operators are read off the dimension-5 operators

$$\mathcal{L}_{WWH} = 2M_W^2\left(\frac{1}{v} + \frac{a}{\Lambda}\right)W^+_\mu W^{-\mu}H + \frac{b}{\Lambda}W^+_{\mu\nu}W^{-\mu\nu}H + \frac{\widetilde{b}}{\Lambda}W^+_{\mu\nu}\widetilde{W}^{-\mu\nu}H$$

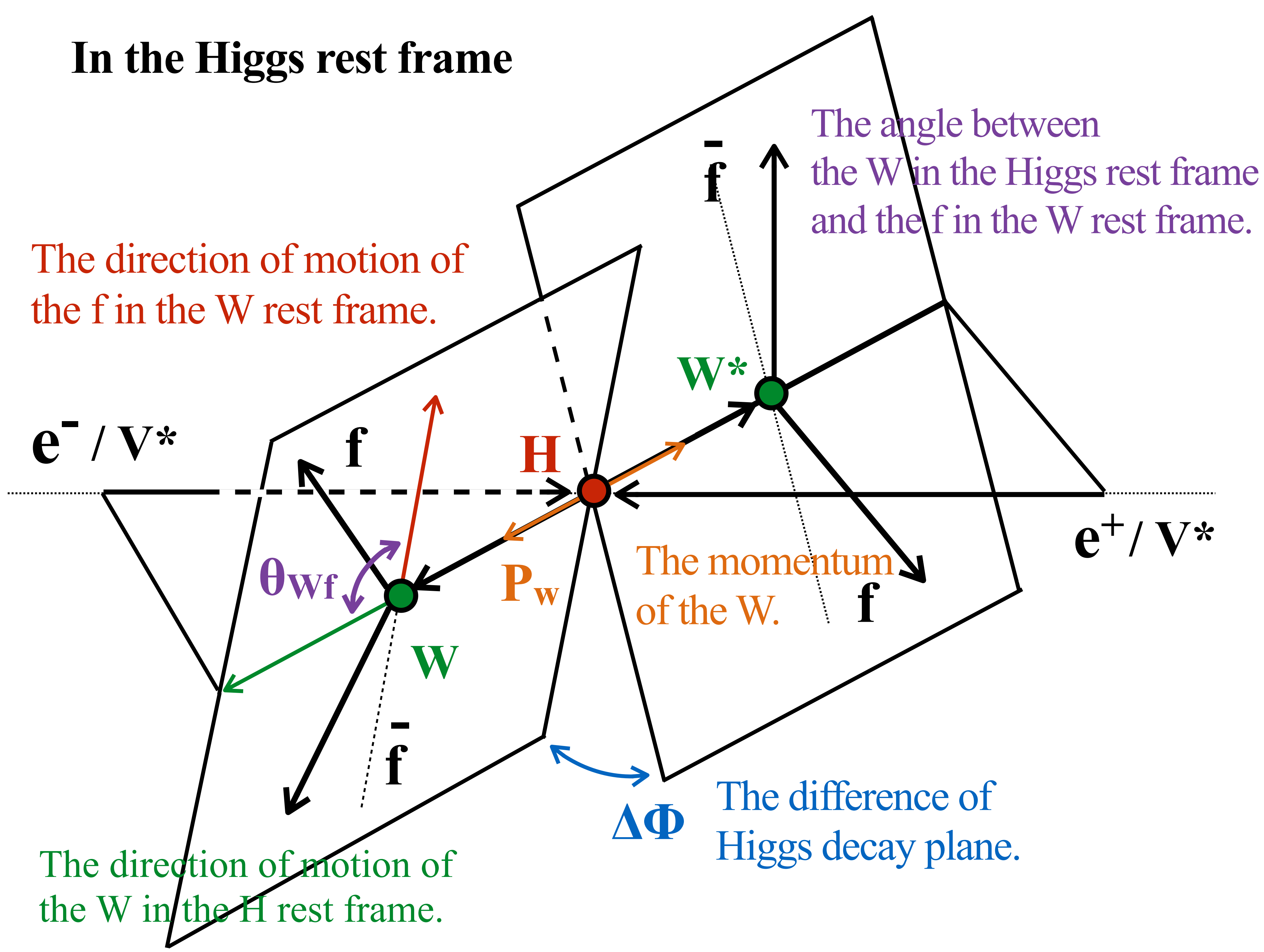
Possible process to verify the structures @ 250GeV

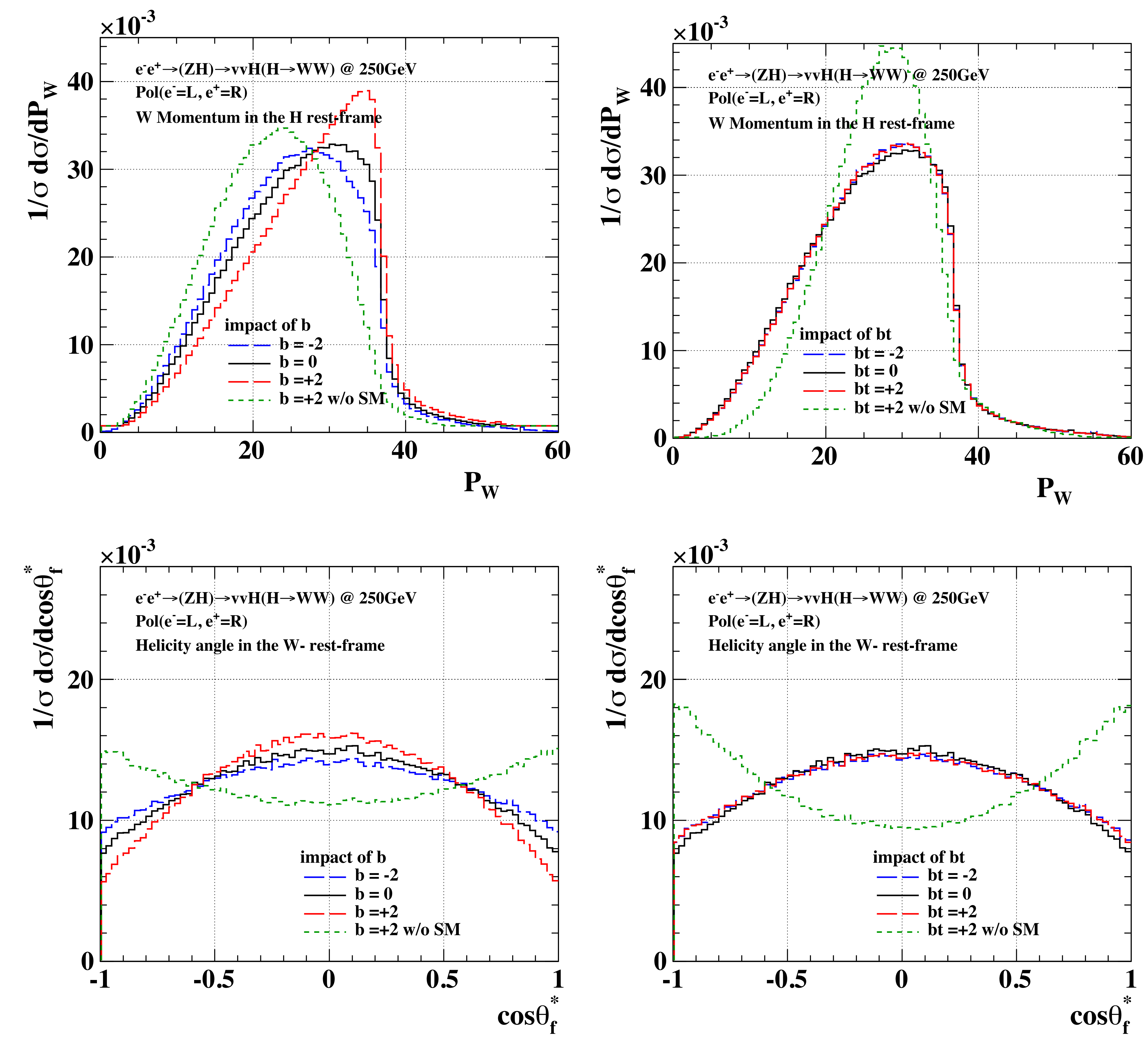
Decay processes
ZH → l l H (H→WW) stat. is too less
ZH → vvH (H→WW → qqqq)
ZH → qqH (H→WW → qqqq)
ZH → qqH (H→WW → qq lv)
ZH → qqH (H→WW → lv lv) much info. is lost

Anomalous WWH couplings @ 250GeV

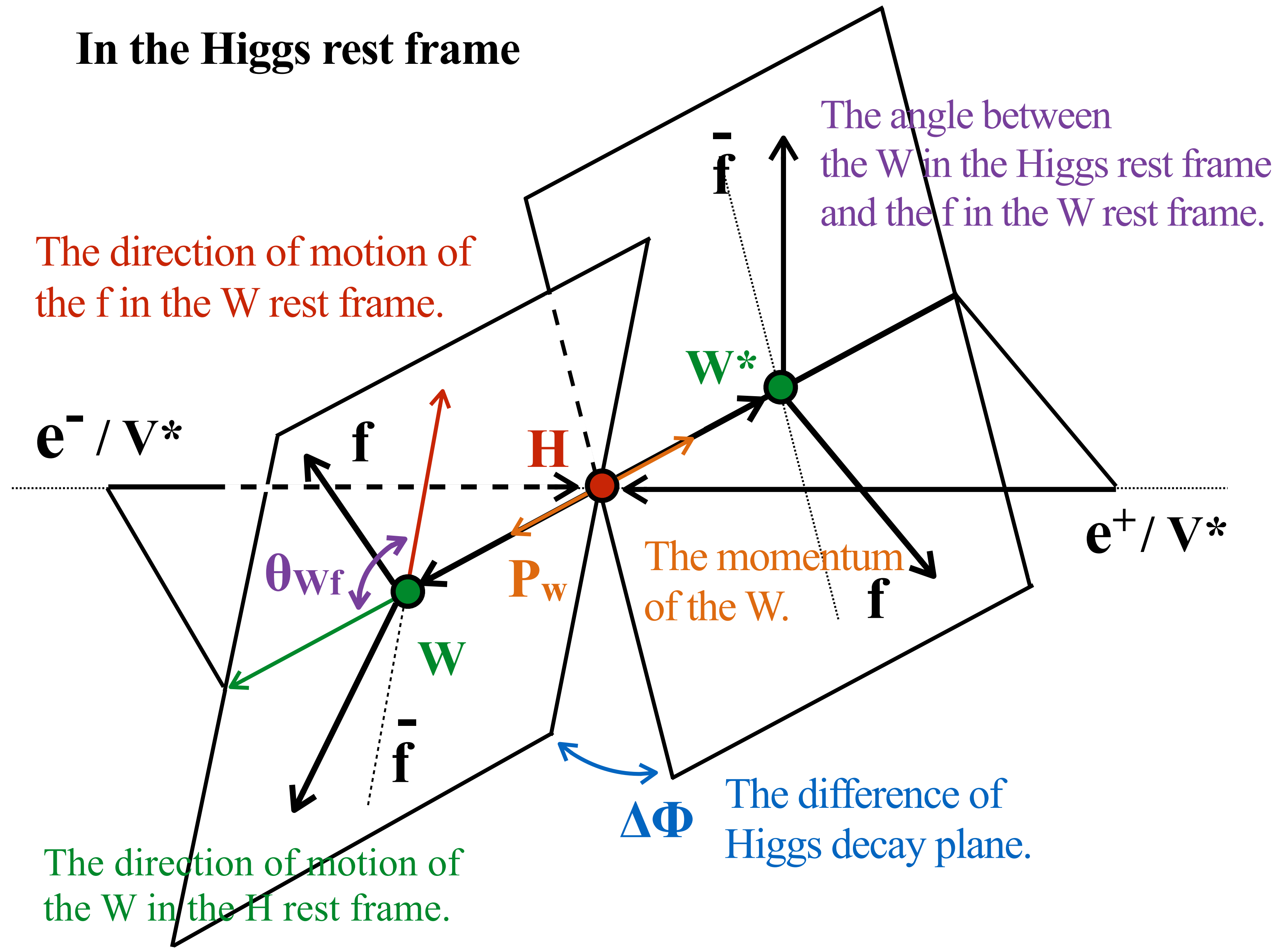
$$\mathcal{L}_{WWH} = 2M_W^2\left(\frac{1}{v}+\frac{a}{\Lambda}\right)W_\mu^+W^{-\mu}H + \frac{b}{\Lambda}W_{\mu\nu}^+W^{-\mu\nu}H + \frac{\tilde{b}}{\Lambda}W_{\mu\nu}^+\widetilde{W}^{-\mu\nu}H$$

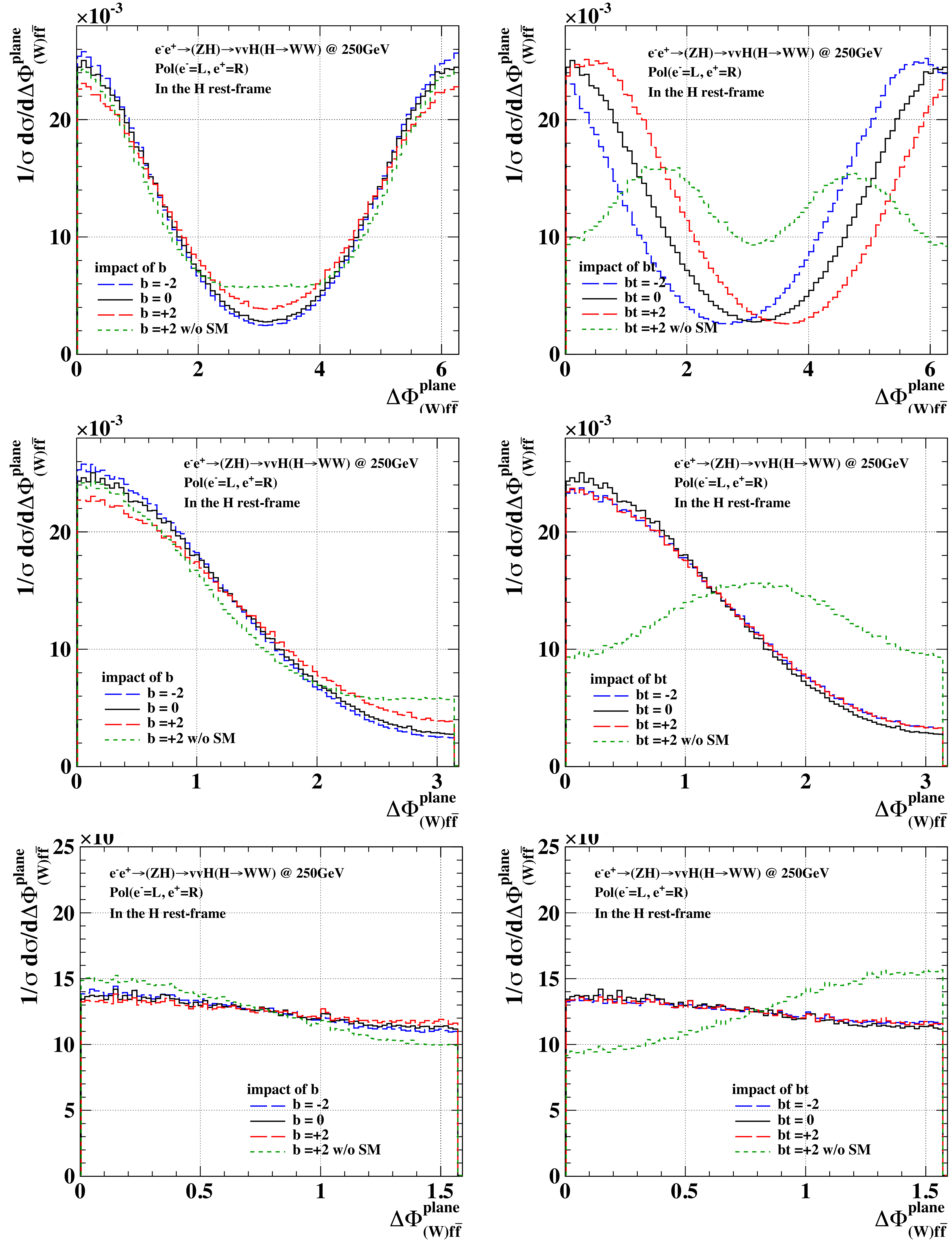
The structures described by the params. b and bt affect angular and momentum distributions of the W boson





Anomalous WWH couplings @ 250GeV





The most effective observable to catch bt is ΔΦ.

ZH → ννH (H→WW → qqqq)
The final state is multi-jet state.

An original idea to keep sensitivity of ΔΦ
is to use Jets deriving
from Cs in the W bosons.

two cjets : sensitivity become harf

No id : sensitivity become quarter.

Verification of Anomalous WWH couplings

chi2 test is implemented for the test of sensitivity

$$\frac{\frac{N_{SM}}{\sigma}\frac{d\sigma}{dX}(x_i)}{\quad}$$

$$\frac{\frac{N_{SM}}{\sigma}\frac{d\sigma}{dX}(x_i;a,b,\tilde{b})\cdot}{\quad}$$

A Distribution we can produce with each anomalous parameter is a “generator-level” distribution.

In realistic pure information is smeared
due to detector resolution and missing particles etc… (Migration)

$$\chi_s^2 = \sum_{i=1}^{n}\left[\frac{\frac{N_{SM}}{\sigma}\frac{d\sigma}{dX}(x_i)\cdot f_i - \frac{N_{SM}}{\sigma}\frac{d\sigma}{dX}(x_i;a,b,\tilde{b})\cdot f_i}{\delta N_{SM}(x_i)}\right]^2 \quad (10)$$

where n and i denote the total number of bins and certain bin number, then a_Z, b_Z and $\tilde{b}_Z$ show parameters for the anomalous couplings. $1/\sigma \cdot d\sigma/dX(x_i)$ is a predicted differential cross section at each bin for an observable X based on a model with the anomalous parameters, which is normalized by a σ and multiply a expected number of events with the SM N_{SM} in order to extract the difference of the shape from the SM prediction. $\delta N_{SM}(x_i)$ shows an error of the observed number of events for a corresponding bin. This $\delta N_{SM}(x_i)$ used here was estimated by full simulation and inputted as a simple error based on Poisson statistics. f_i corresponds to acceptance of events on each bin, which is composed of an event acceptance η_i and a migration matrix $\bar{f}$ explaining later. The cross section corresponding to certain process is also important information to distinguish the existence of the anomalous couplings. Therefore another chi-squared function to include the effect of difference of the cross section,is defined as following.

$$\chi_c^2 = \left[\frac{N_{SM}\cdot\epsilon - N_{BSM}\cdot\epsilon}{\delta\sigma\cdot N_{SM}\cdot\epsilon}\right]^2 \quad (11)$$

where the ϵ shows selection efficiency of the signal events estimated by full simulation, and $\delta\sigma$ shows error extracted from measurement of total cross section which is also estimated by full simulation for each center-of-mass energy $\sqrt{s}$. These values are estimated as 2.5% and 5.0% for $\sqrt{s}$ =250 GeV and 500 GeV, respectively.

Verification of Anomalous WWH couplings

Definition of transformation of a "generator-level" to "detector-level" distribution.

$$N^{Reco}(x_j^{Reco}) = \sum_i f(x_j^{Reco}, x_i^{Gene}) \cdot N^{Gene}(x_i^{Gene})$$

$$N^{Reco}(x_j^{Reco}) = \sum_i f_{ji} \cdot N_i^{Gene} = \sum_i \bar{f}_{ji} \cdot \eta_i \cdot N_i^{Gene}$$

$$\eta_i \equiv \frac{N_i^{Accept}}{N_i^{Gene}} \quad \text{(Event Acceptance)}$$

$$\bar{f}_{ji} \equiv \frac{N_{ji}^{Accept}}{N_i^{Accept}} \quad \text{(Migration Matrix)}$$

where x_j^{Reco} and x_i^{Gene} correspond to the number of reconstructed and generated events on a j-th or i-th bin. The generated events get the migration effect f_{ji} that shows migration of events from i to j, and The reconstructed number of events is summed along i. The f_{ji} is composed of η_i and $\bar{f}_{ji}$. Above equation is for a one-dimensional distribution. A multi-dimensional distribution

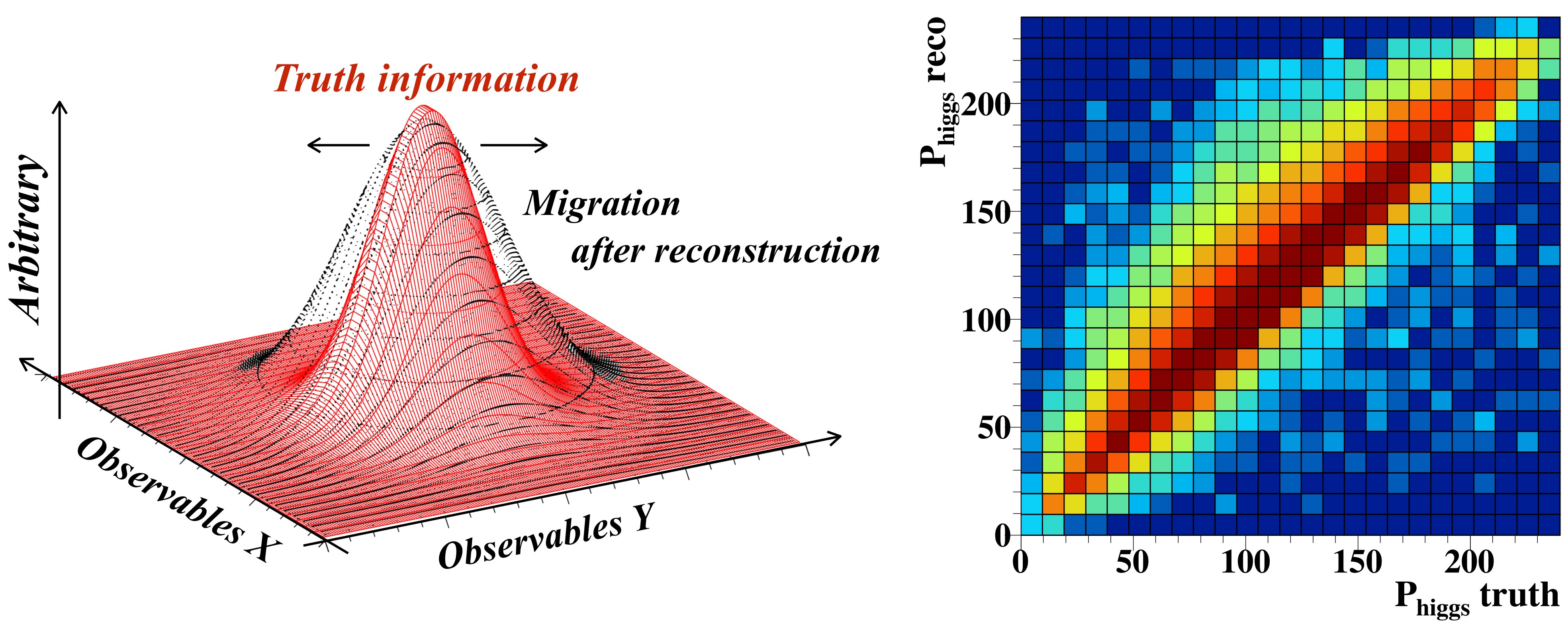
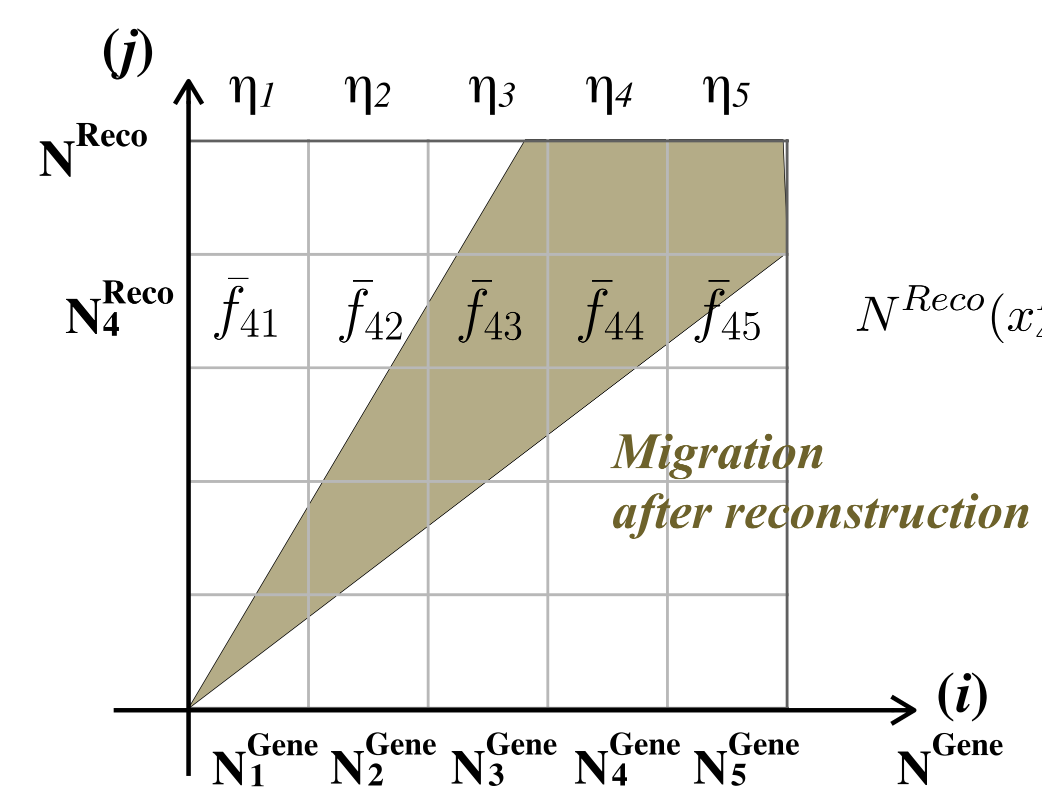


Figure 38: A schematic view of the migration effect due to the detector finite resolution and misidentified or undetectable particles (Left). Correlation between generated and reconstructed information on the Higgs momentum distribution P_{higgs} in the process $e^+e^- \to ZZ \to eeH$ at 500 GeV, which is one clear observable showing the migration effects (Right).

make the "generator-level" distribution transfer to the "detector-level" distribution to get the realistic distribution which includes a kind of migration of several effects.

example:



$$N^{Reco}(x_4^{Reco}) = \sum_i \bar{f}_{4i} \cdot \eta_i \cdot N_i^{Gene}$$
$$= \eta_1 \bar{f}_{41} \cdot N_1^{Gene} + \eta_2 \bar{f}_{42} \cdot N_2^{Gene} + \eta_3 \bar{f}_{43} \cdot N_3^{Gene} + \eta_4 \bar{f}_{44} \cdot N_4^{Gene} + \eta_5 \bar{f}_{45} \cdot N_5^{Gene}$$

Figure 39: An example of calculation using the migration matrix. When an observable is divided into 5 bins, a 5×5 matrix is needed to predict a distribution of the observable including the migration effect.

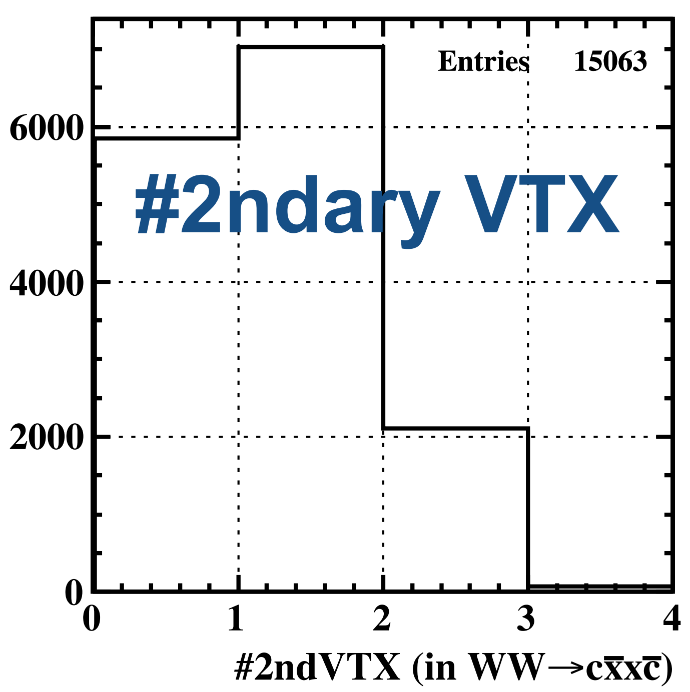
For the calculation of migration nxn matrix is needed.

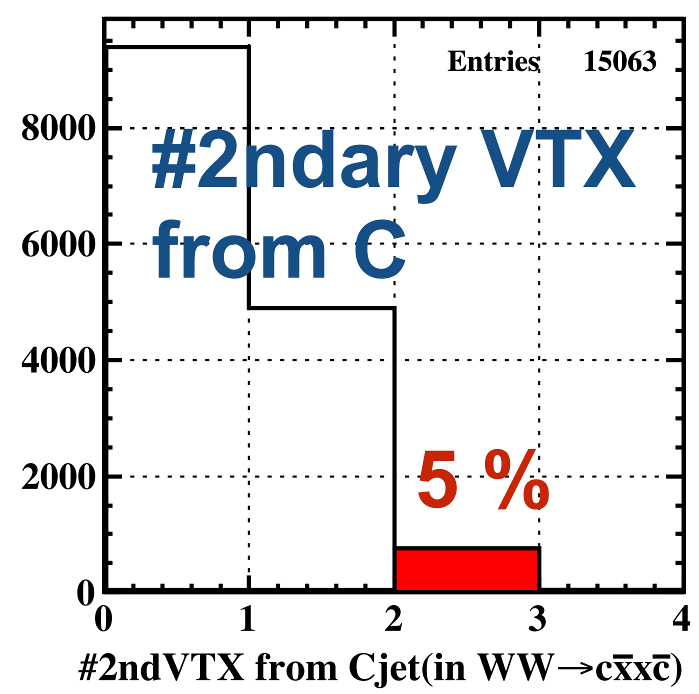
Analysis of processes

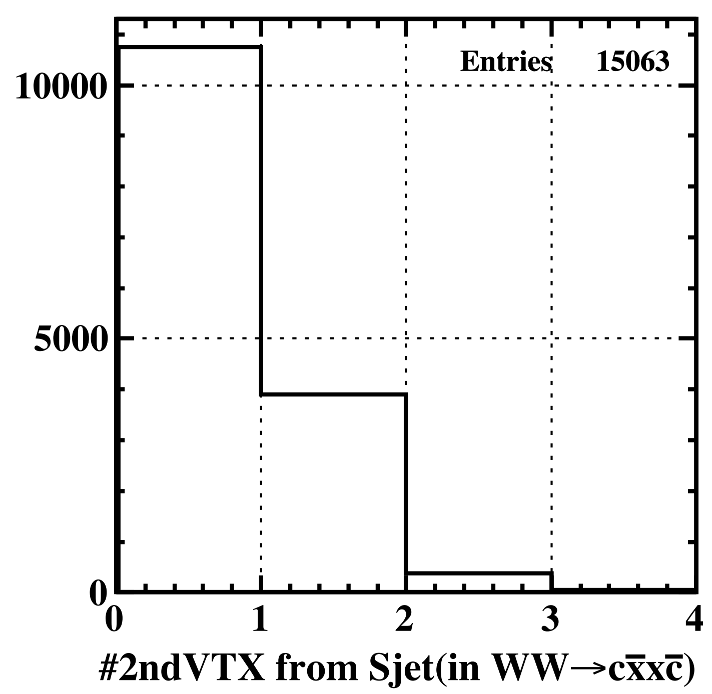
e.g. C-tag performance using ZH → vvH (H→WW → cxcx) @ 250GeV

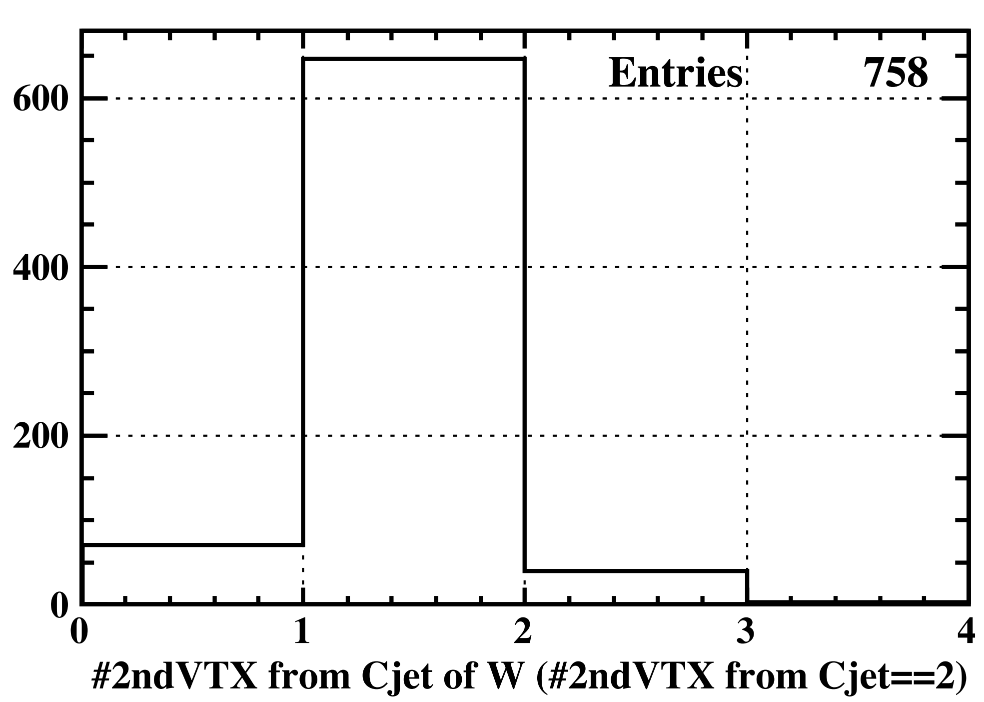
A crucial thing is c-tag:

Check the performance after
extracting only **WW→cxcx** decay events

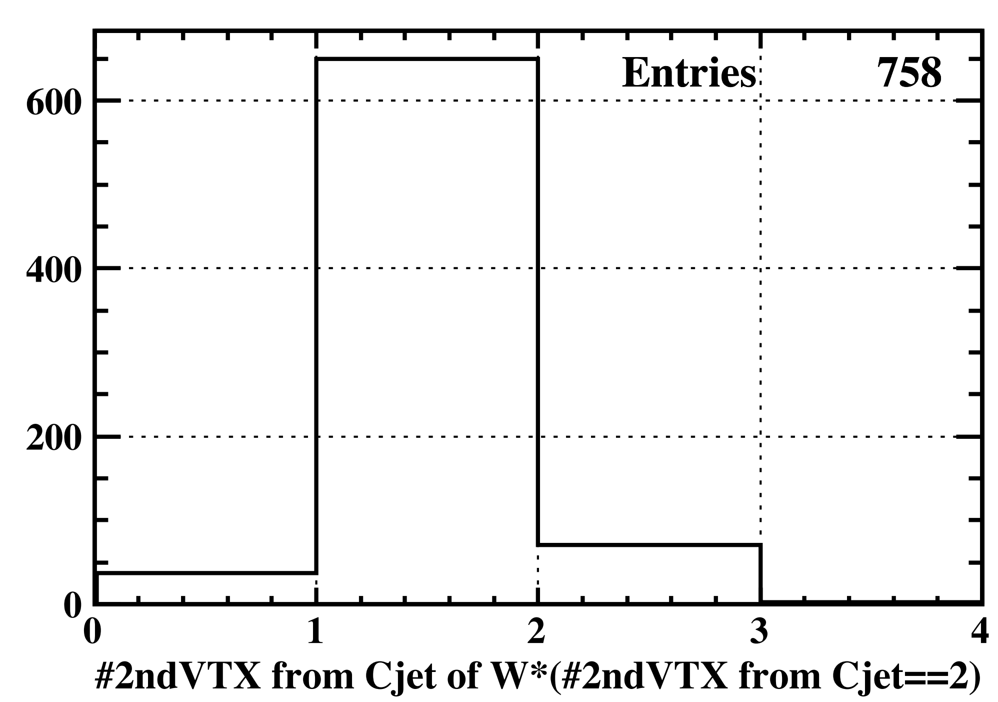








#2ndary VTX
from C of W
in the case #2ndary VTX==1

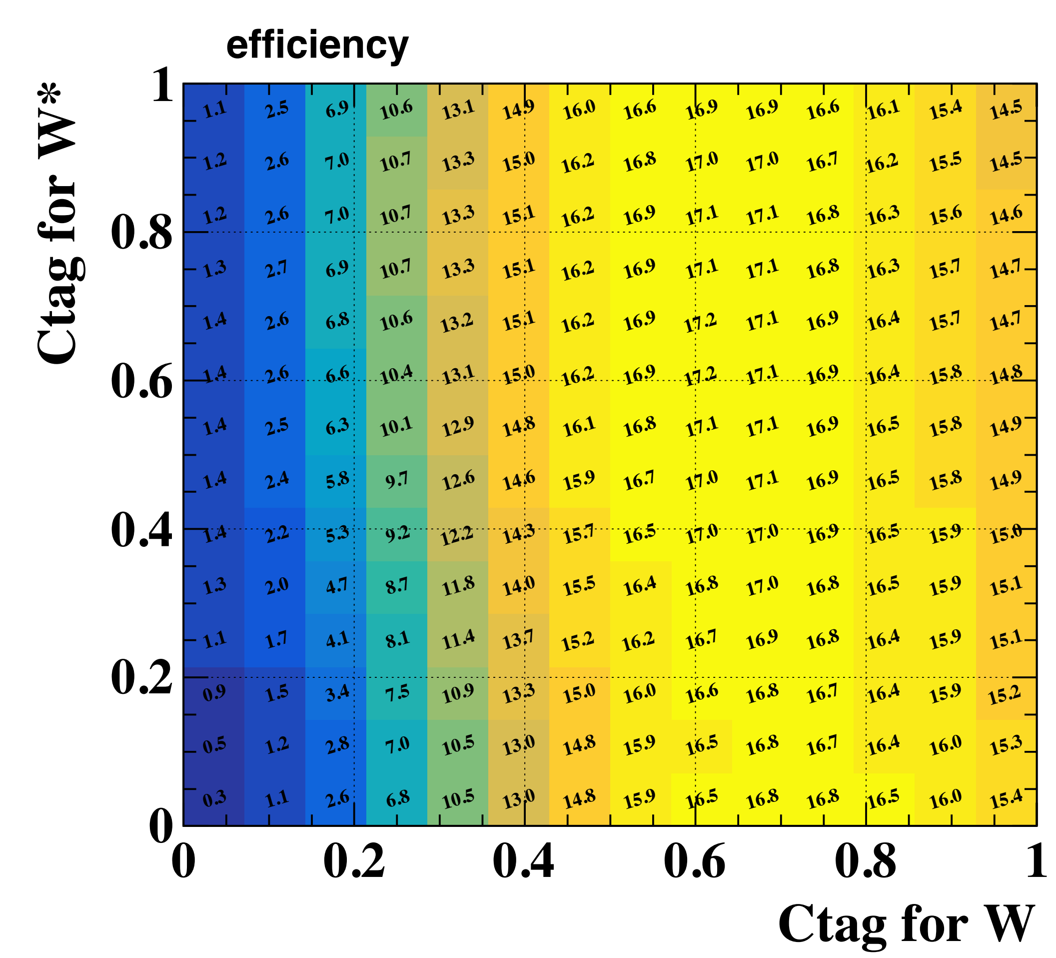


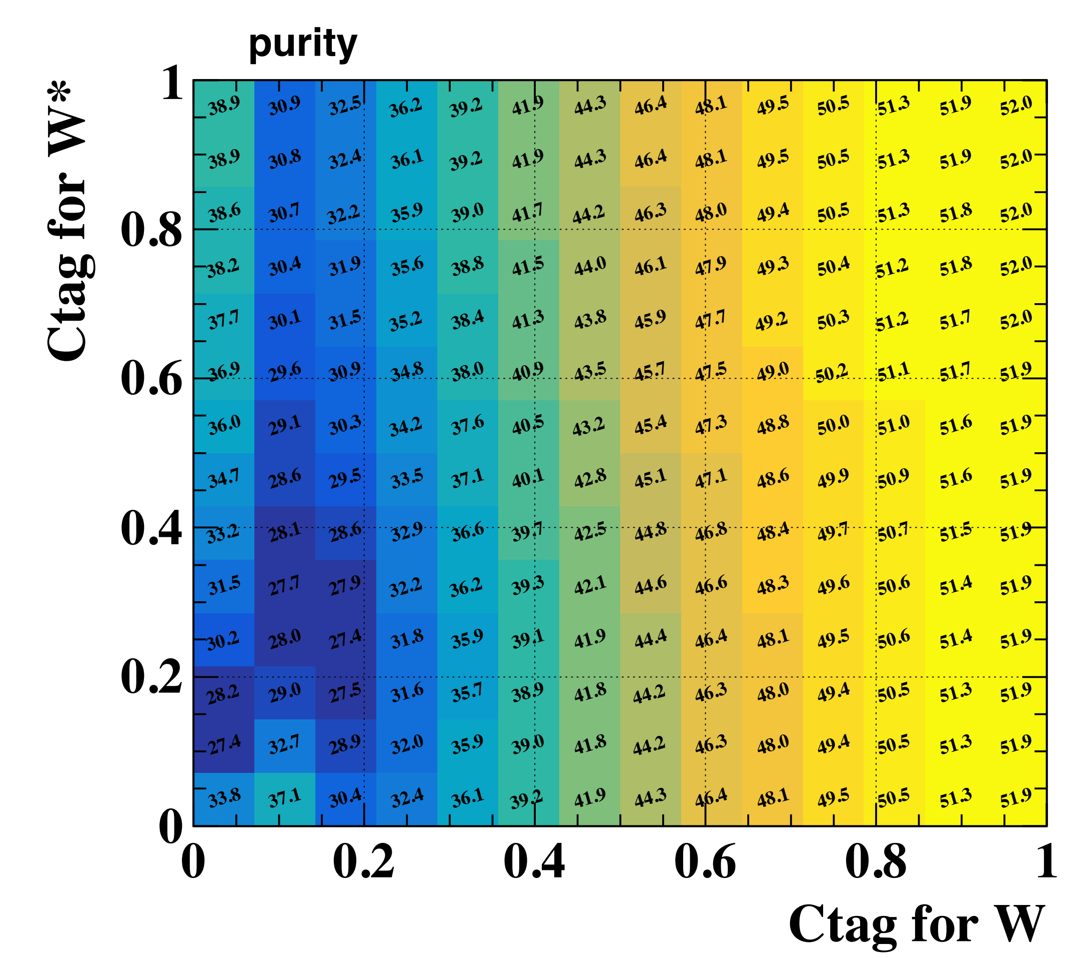
#2ndary VTX
from C of W*
in the case #2ndary VTX==1

Decision of c-tag requirement

$$\text{Efficiency} = \frac{N^{acpt} \cap MC_{c\bar{x}x\bar{c}}}{MC_{c\bar{x}x\bar{c}}}$$

$$\text{Purity} = \frac{N^{acpt} \cap MC_{c\bar{x}x\bar{c}}}{N^{acpt}}$$





c-tag requirement > 0.75

e.g. ZH → vvH (H→WW → qqqq) @ 250GeV with 250^{fb-1}

Cross section of the ZH → vvH (H→WW)
~ 16.7

H → WW → qqqq ~ 7.6 *L ~ 1916 events
(H → WW → cxcx ~ 1.9 *L ~ 479 events)

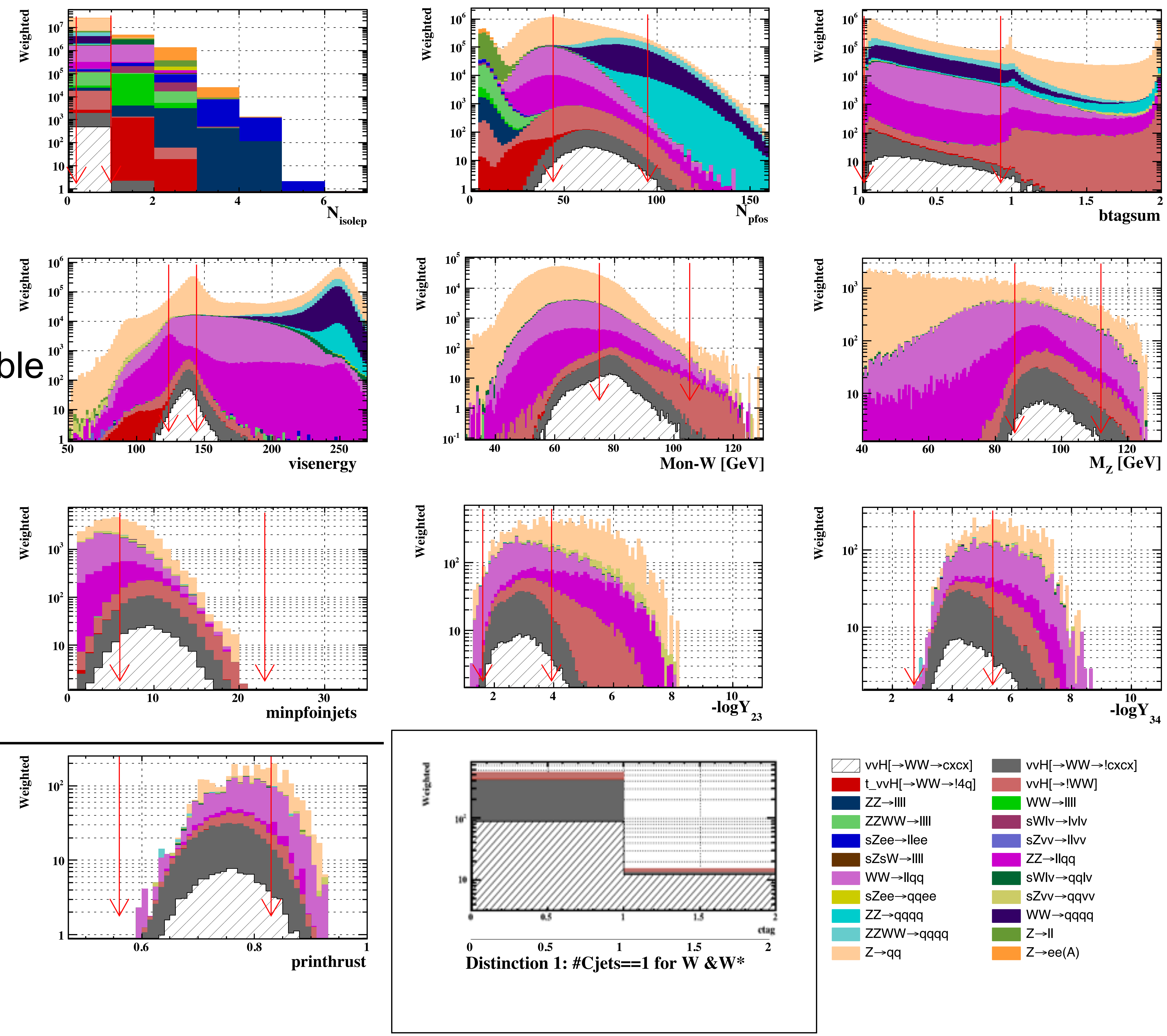
Using several observable except angular observable
Bkgs are suppressed. (scanned to get S_{sig})

selection ~ 20%

Before c-tag distinction ~ 430

Categorization

After c-tag distinction
H → WW → qqqq * L *ε ~ 420
H → WW → cxcx * L *ε ~ 12

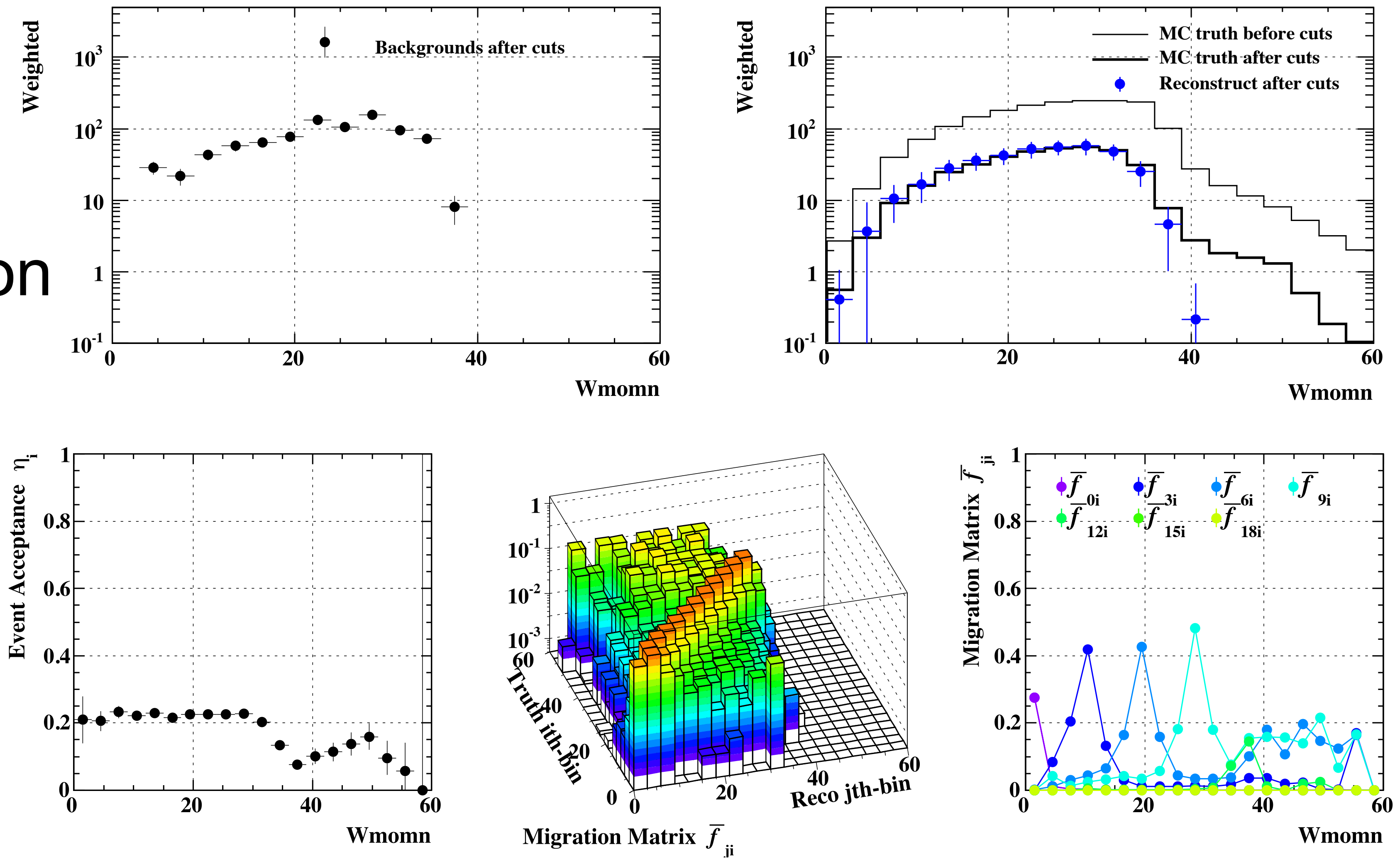


Signif= 10.64

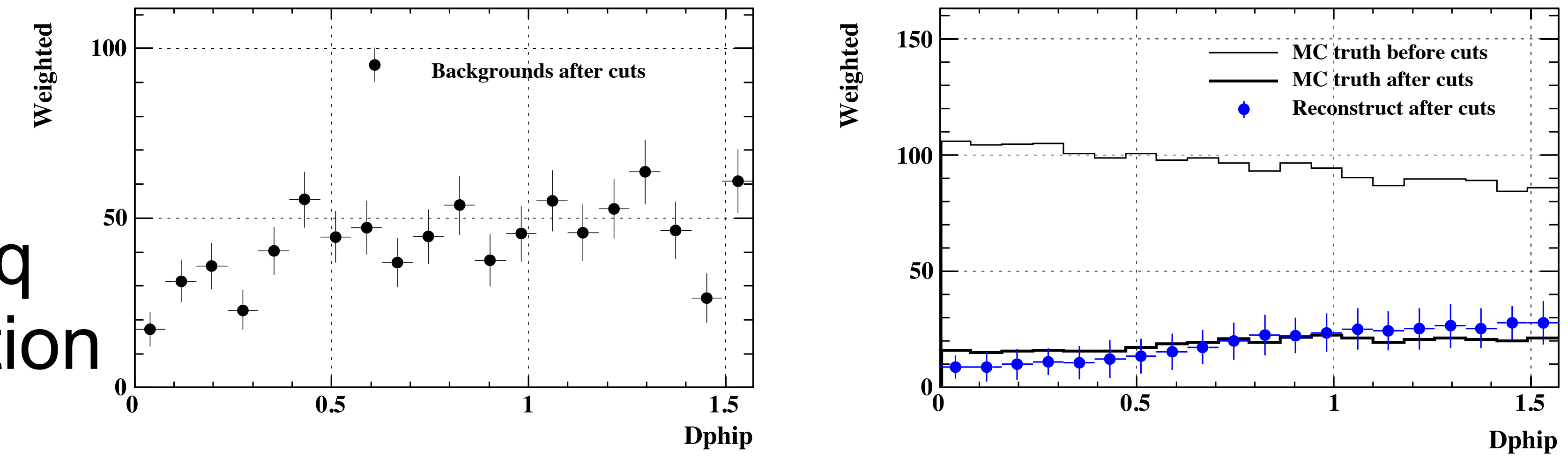
e.g. ZH → vvH (H→WW → qqqq) @ 250GeV with 250^{fb-1}

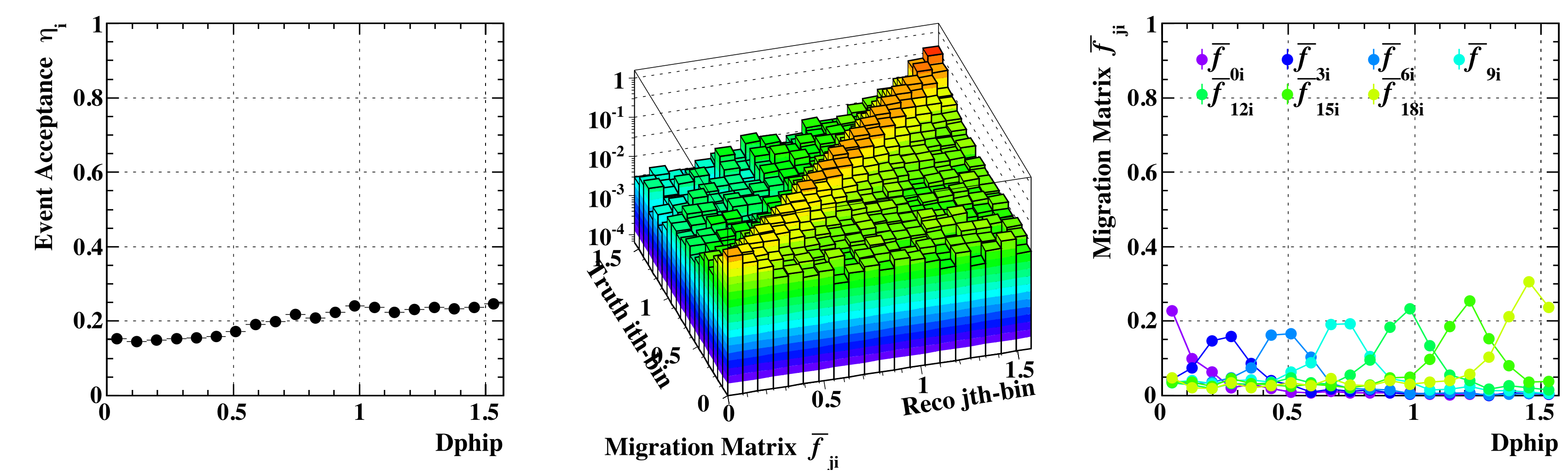
Remaining events, the event acceptance,
the migration matrix and examples of the migration using several bins

WW → qqqq
Pw distribution

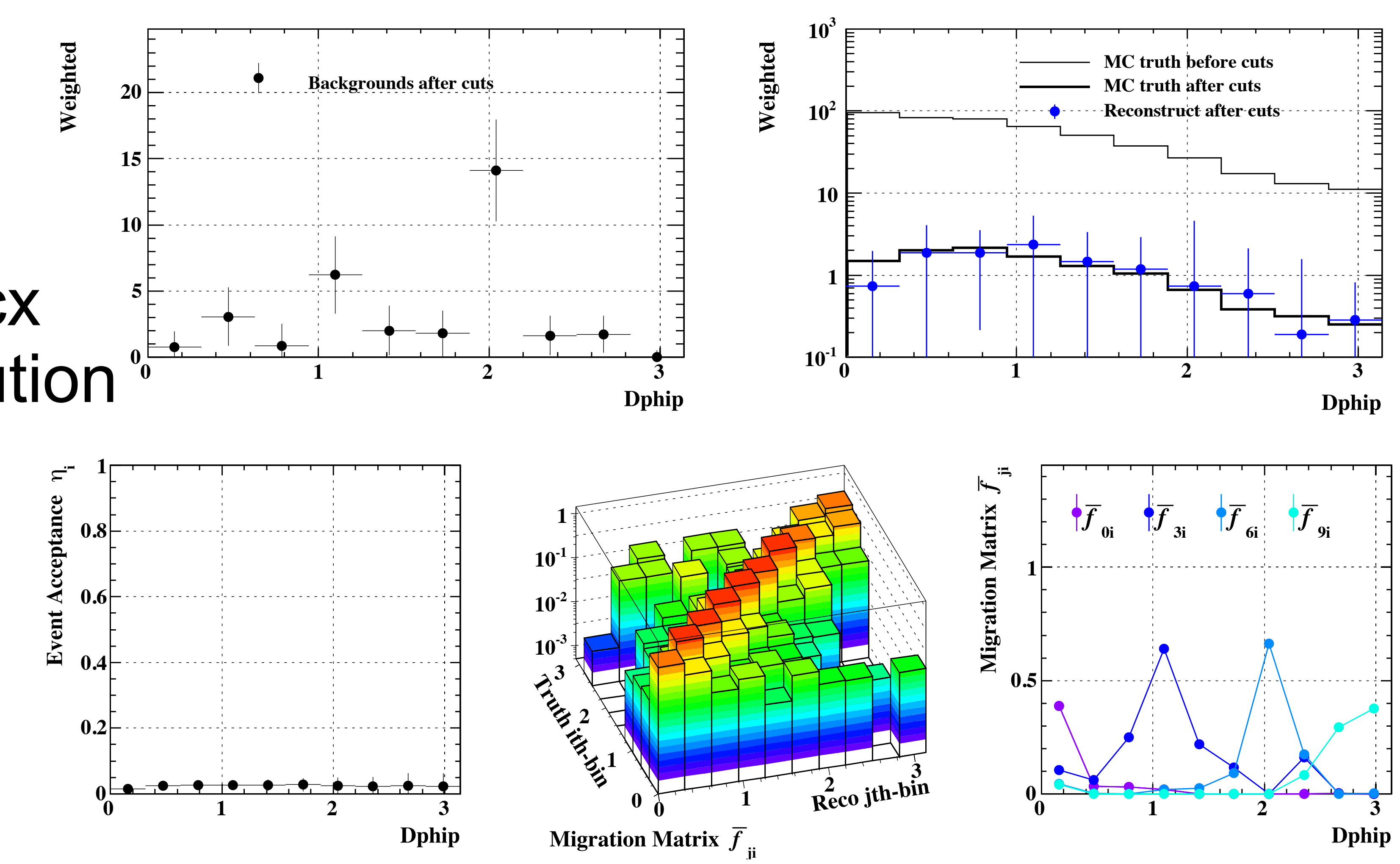


WW → qqqq
ΔΦ distribution





WW → cxcx
ΔΦ distribution



ZH → qqH (H→WW → qqqq) @ 250GeV with 250^{fb-1}

Nsig = 906.34
Nbkg = 13590.48
Signif= 7.53

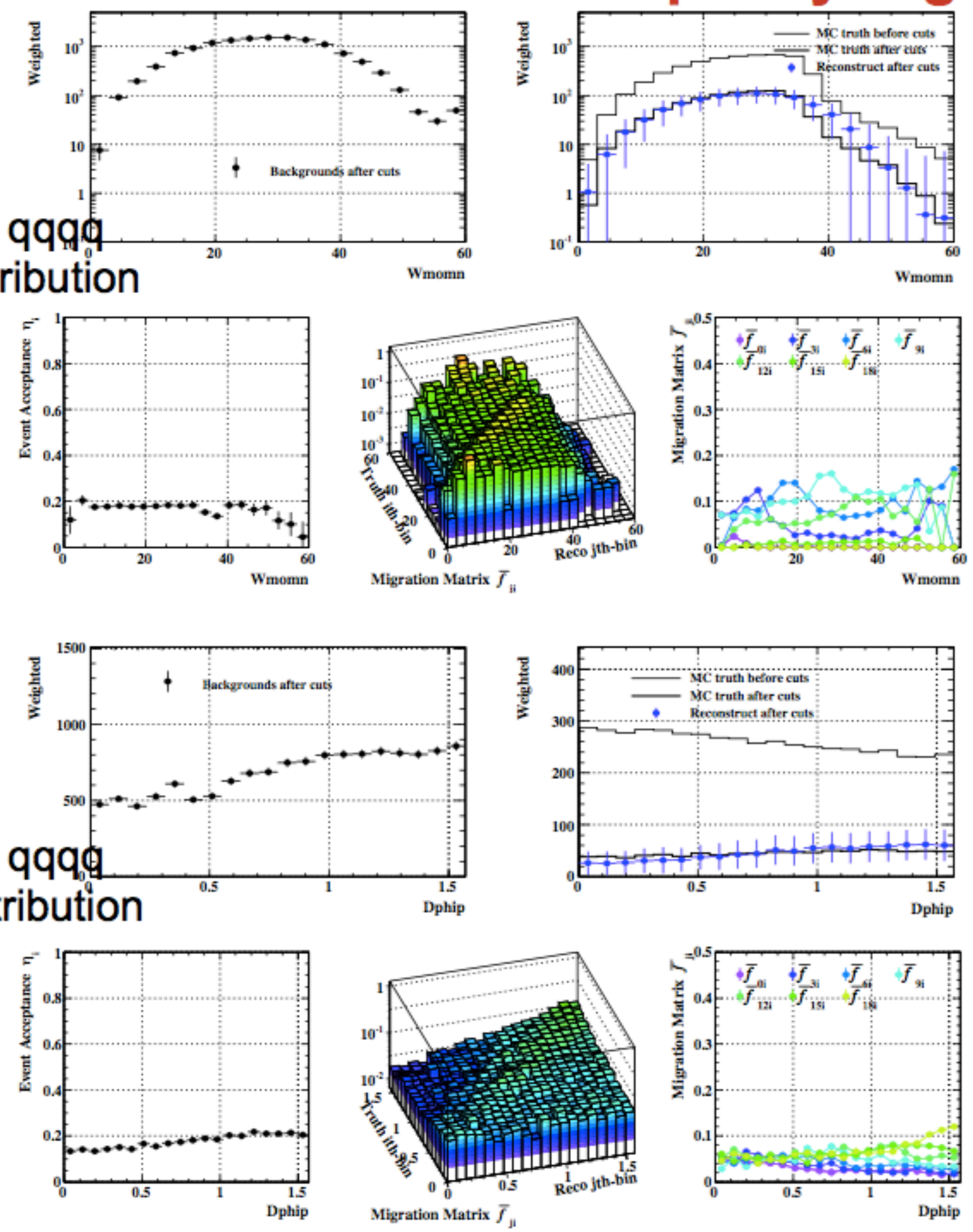
completely migrated

ZH → qqH (H→WW → qqlv) @ 250GeV with 250^{fb-1}

Nsig = 1036.74
Nbkg = 1401.85
Signif= 20.99

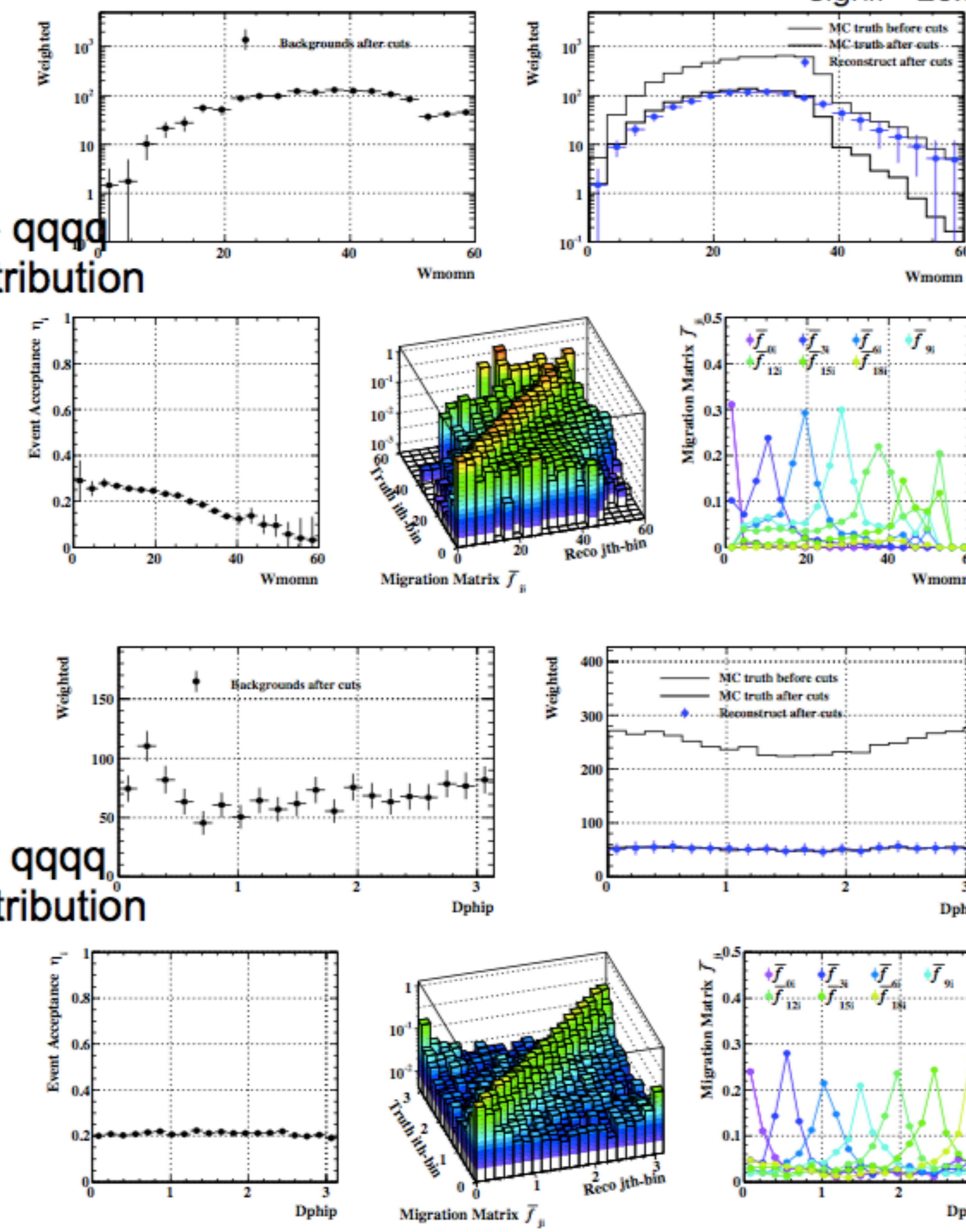
WW → qqqq
Pw distribution

WW → qqqq
ΔΦ distribution



WW → qqqq
Pw distribution

WW → qqqq
ΔΦ distribution

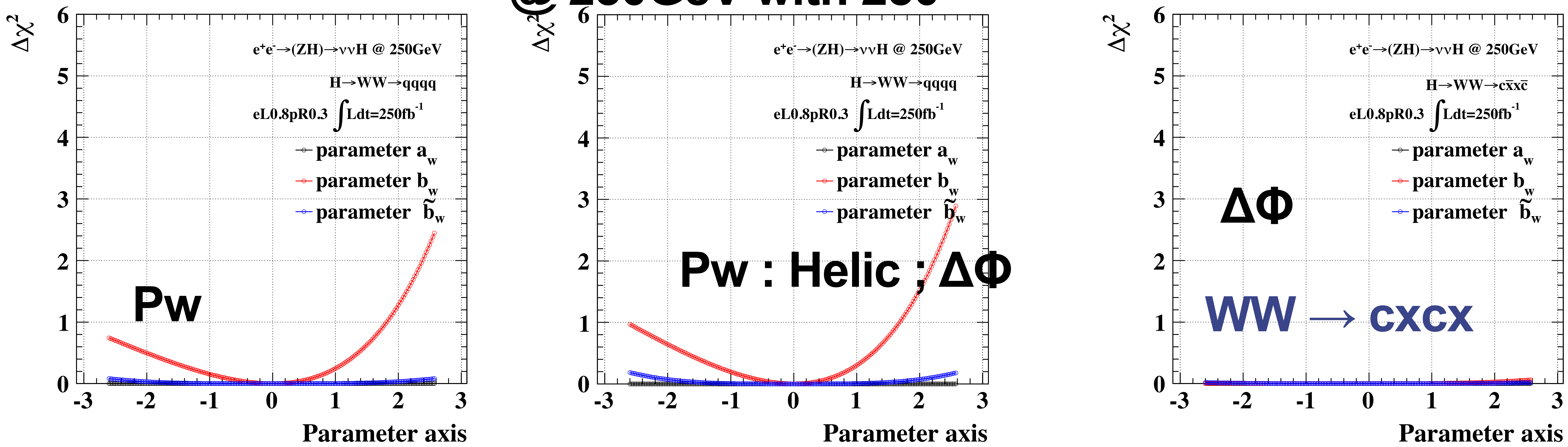


Sensitivity in 1 parameter space

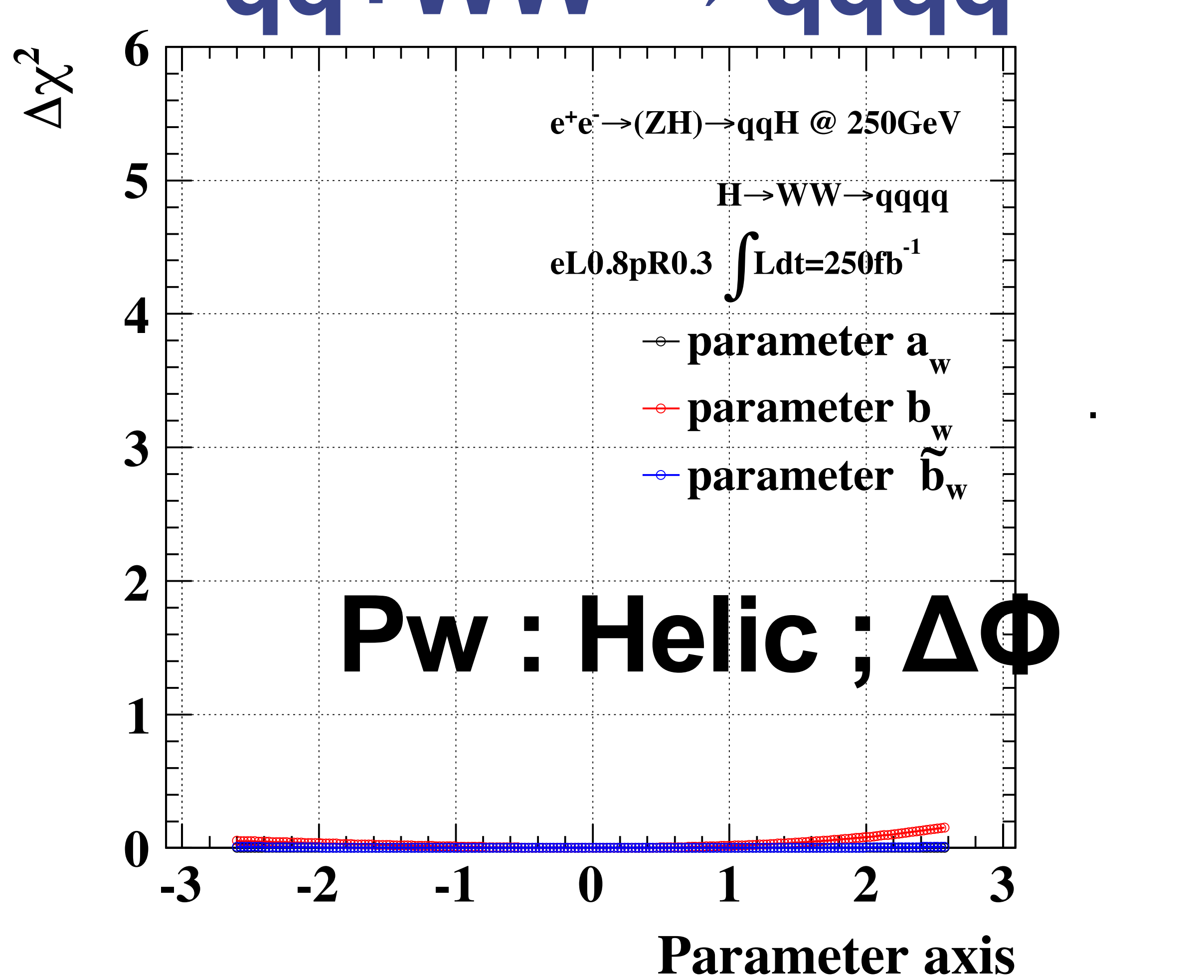
using only shape

$$\chi_s^2 = \sum_{i=1}^{n}\left[\frac{\frac{N_{SM}}{\sigma}\frac{d\sigma}{dX}(x_i)\cdot f_i - \frac{N_{SM}}{\sigma}\frac{d\sigma}{dX}(x_i;a,b,\tilde{b})\cdot f_i}{\delta N_{SM}(x_i)}\right]^2($$

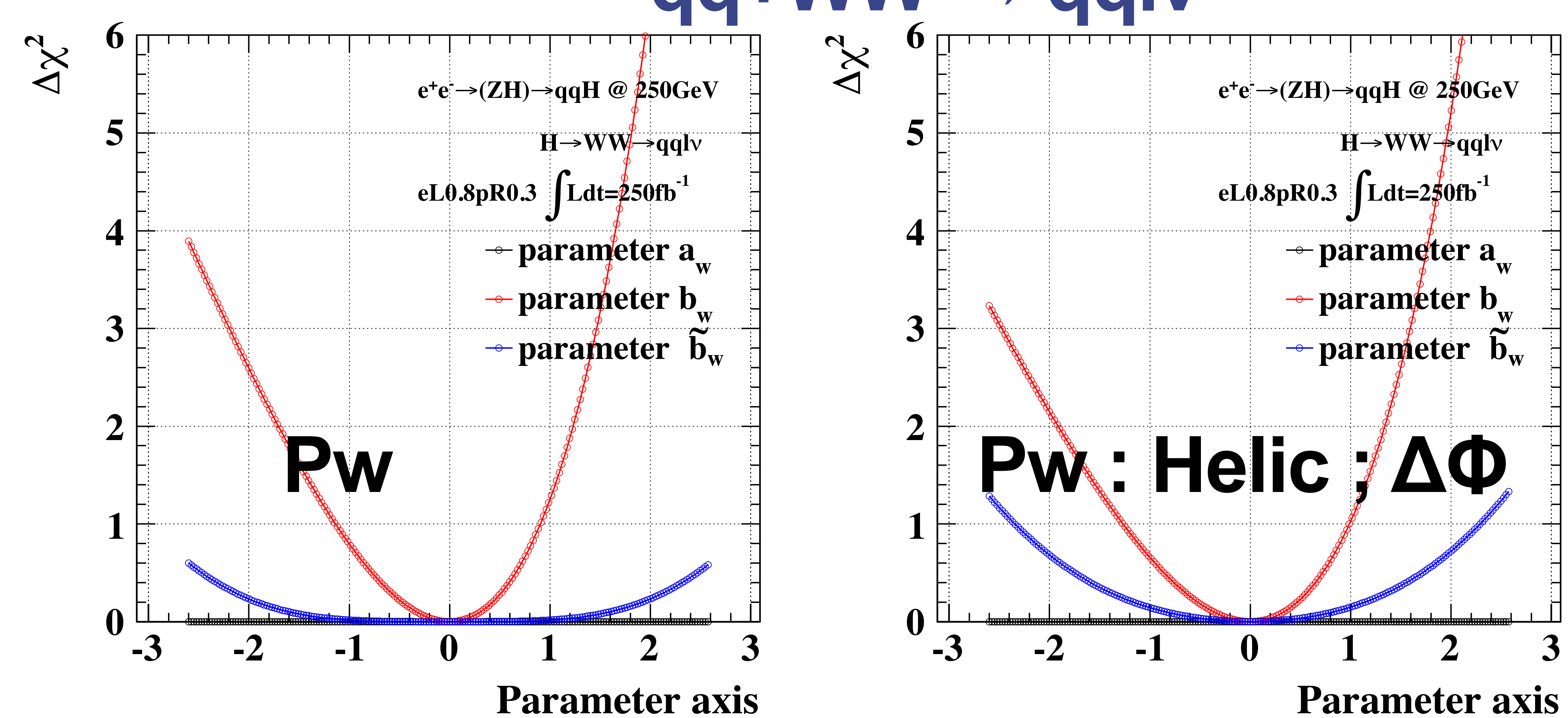
ZH → ννH (H→WW → qqqq) @ 250GeV with 250fb-1



qq+WW → qqqq

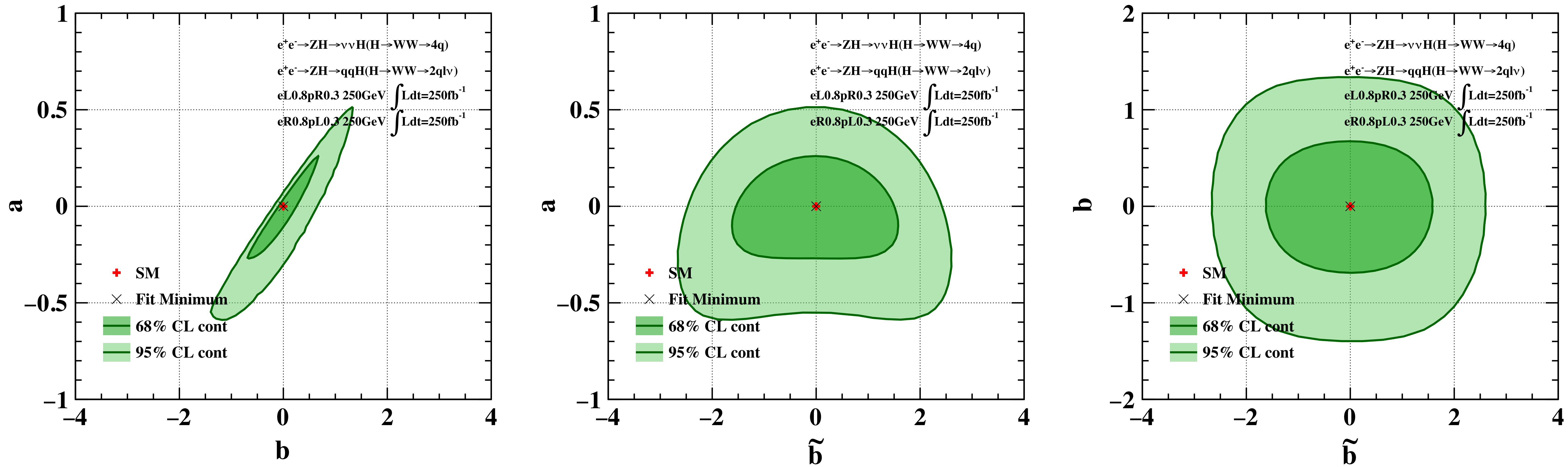


qq+WW → qqlv



Sensitivity in 3 parameter spaces @ 250GeV L=250fb-1 (LR +RL)

vvH (H→WW → qqqq)
qqH (H→WW → qq lv)

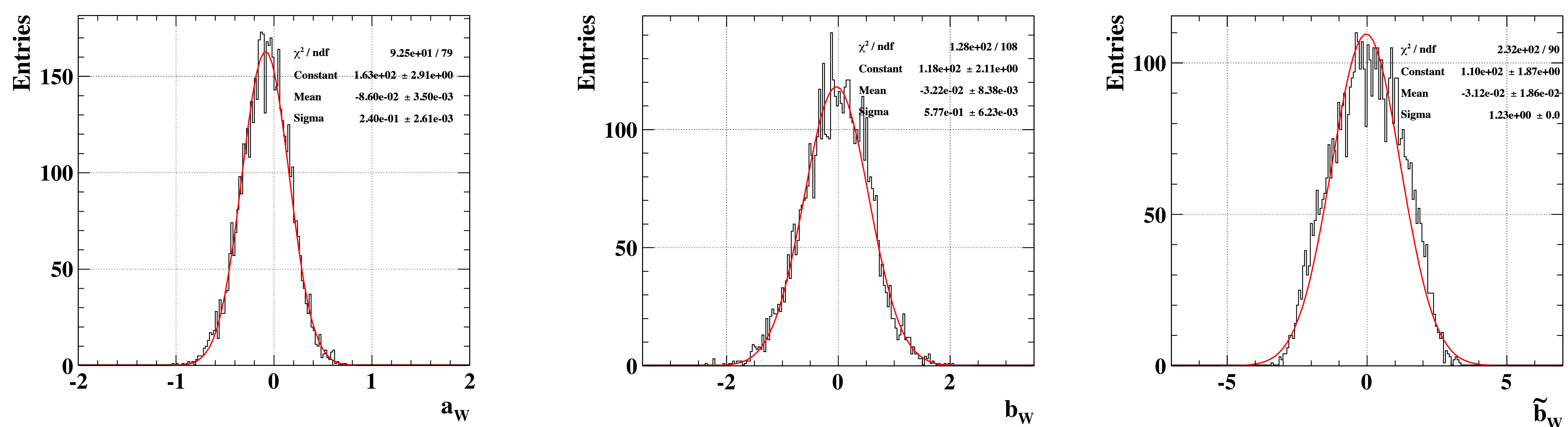


Error estimation using "single fit"

LR	combine
a & b correlation 0.991	a & b correlation 0.991
------->0 parameter: 0 +/- 0.373497	------->0 parameter: 0 +/- 0.264356
------->1 parameter: 0 +/- 0.960523	------->1 parameter: 0 +/- 0.668635
------->2 parameter: 0 +/- 2.58746	------->2 parameter: 0 +/- 1.61939

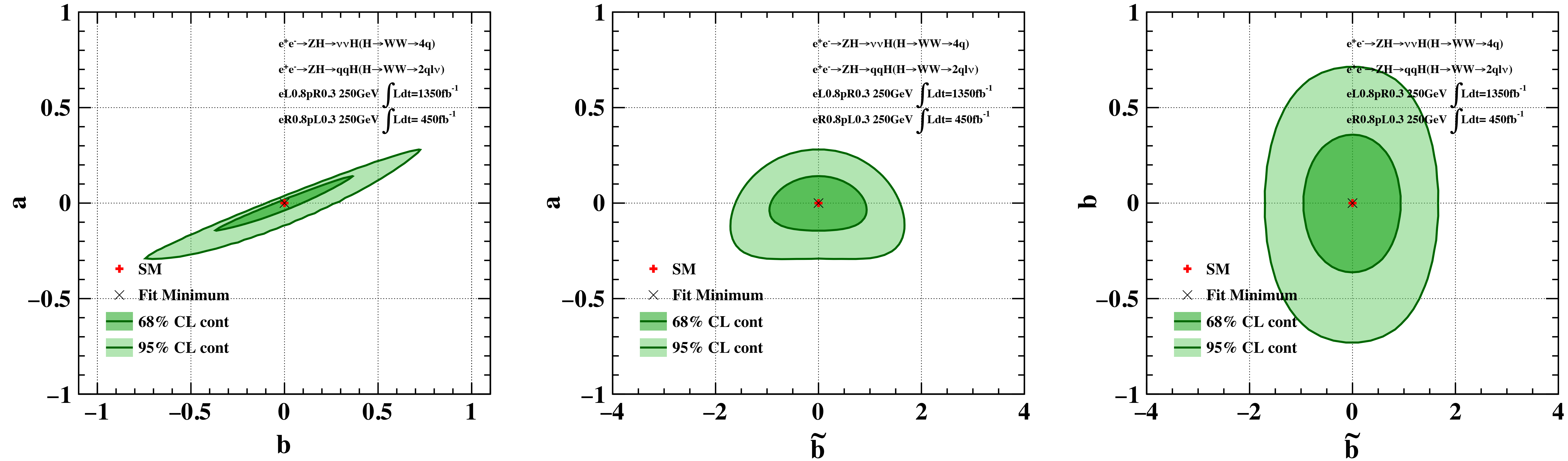
Sudo-Exp

$$a_W = \pm 0.24$$
$$b_W = \pm 0.58$$
$$\tilde{b}_W = \pm 1.23$$



Sensitivity of 3 parameter spaces @ 250GeV H20

vvH (H→WW → qqqq)
qqH (H→WW → qq lv)

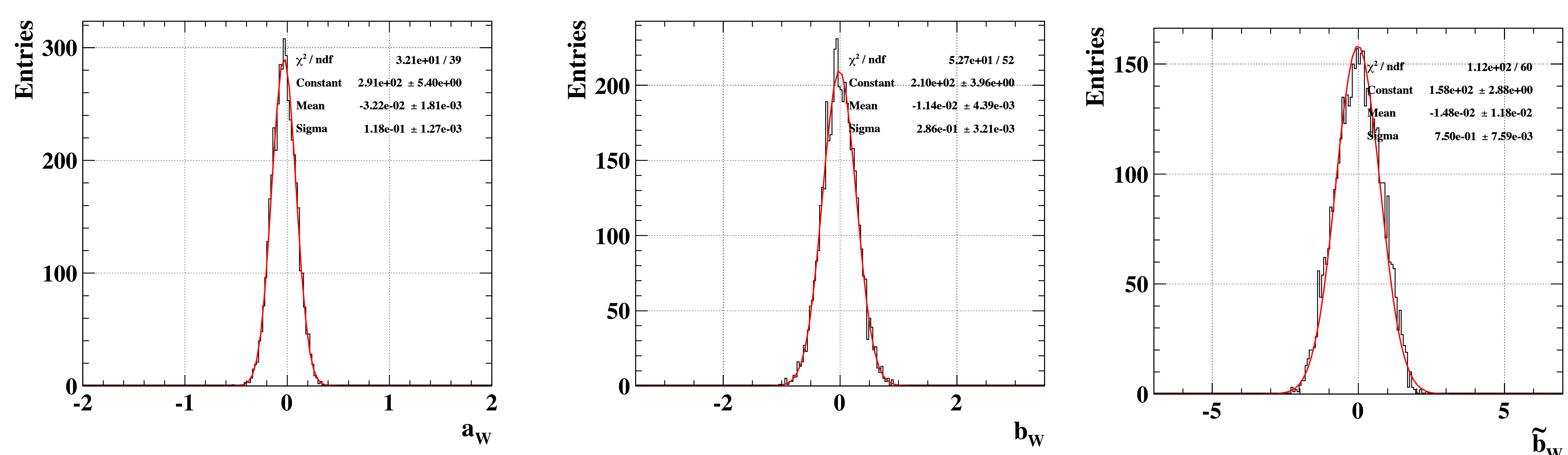


Error estimation using "single fit"

H20

------->0 parameter: 0 +/- 0.139849
------->1 parameter: 0 +/- 0.360156
------->2 parameter: 0 +/- 0.993525

$$a_W = \pm 0.12$$
$$b_W = \pm 0.28$$
$$\tilde{b}_W = \pm 0.75$$



Summary (of the status)

Anomalous ZZH is almost finished with the current strategy. paper is prepared, hopefully, I want to finish it before June.

In parallel WWH is ongoing to finalize analysis with the current strategy.
(it is not a long way)

In parallel, Matrix element will be restarted to get improved results.

Study of sensitivity to anomalous ZZH couplings at the ILC

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(Dated: April 14, 2017)

Just pasted, this will be modified. In this report, we will focus on the measurement of the general Lorentz structure of couplings between Higgs and vector bosons (VVH, V=Z or W) at the ILC,