Anomalous VVH couplings at the ILC

ZZH with 250GeV processes

2017/04/05

Motivation

Complete understanding of the Lorentz structure of the VVH couplings is one of the key point to understand the electroweak symmetry breaking, and it will be a compass to the New physics.

- In the SM one neutral Higgs appears, although several new theories require the effect of the CP-odd contribution of the Higgs

- Since the CP-odd contribution of the Higgs to the couplings of VVH is included by roop corrections, it is expected to be small.

  - How far the ILC can observe?

Effective field theory

A general starting point to think about interactions induced by the new physics is the effective field theory with higher dimensional operators which include a mass scale of Λ of the new physics.

$$\begin{aligned} \mathcal{L} &= \mathcal{L}_{SM} + \mathcal{L}_{eff} \\ \mathcal{L}_{eff} &= \sum_i \sum_{n\geq} \frac{f_i}{\Lambda^{n-4}} \mathcal{O}_i^{(n)} \end{aligned}$$

Taking D=6, based on Warsaw basis,

Tim Barklow (lcws16)

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

now I try to understand this part

expanding the formula and extracting relevant terms for ZZH
with simplified our convenient convention, we can get D=5 operators

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

Angular information

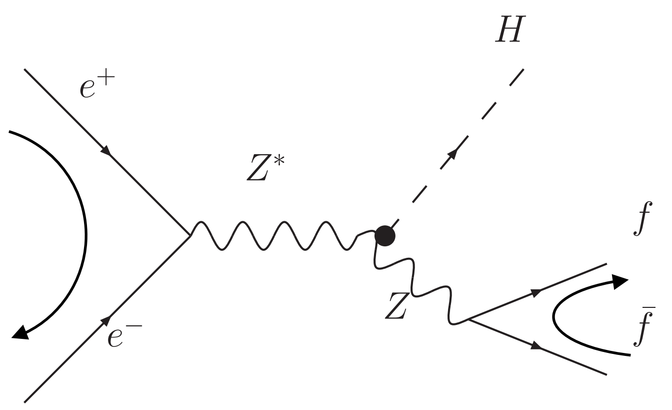
The first term just rascals overall normalization of certain ZZH process,
Latter two terms give some impact on angular information, also momenta of particles.

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

The initial and final state pairs imitate an electric dipole at the interaction,

two terms can be returned to an EM field strength.

$$F_{\mu\nu}F^{\mu\nu} \;\propto\; \mathbf{B_i}\cdot\mathbf{B_f}-\mathbf{E_i}\cdot\mathbf{E_f}$$
$$F_{\mu\nu}\widetilde{F}^{\mu\nu} \;\propto\; \mathbf{E_i}\cdot\mathbf{B_f}$$



Angular distribution will be deviated from the SM one

Processes

The main process we can use for VVH are;

ZZH   at 250GeV

ee -> ZH -> eeH

ee -> ZH -> mmH

ee -> ZH -> qqH(Hbb)

ee -> ZZ -> eeH(Hbb)

The main observables are;

1. Z production angle
2. Helicity angle of Z daughters
3. Dphi.

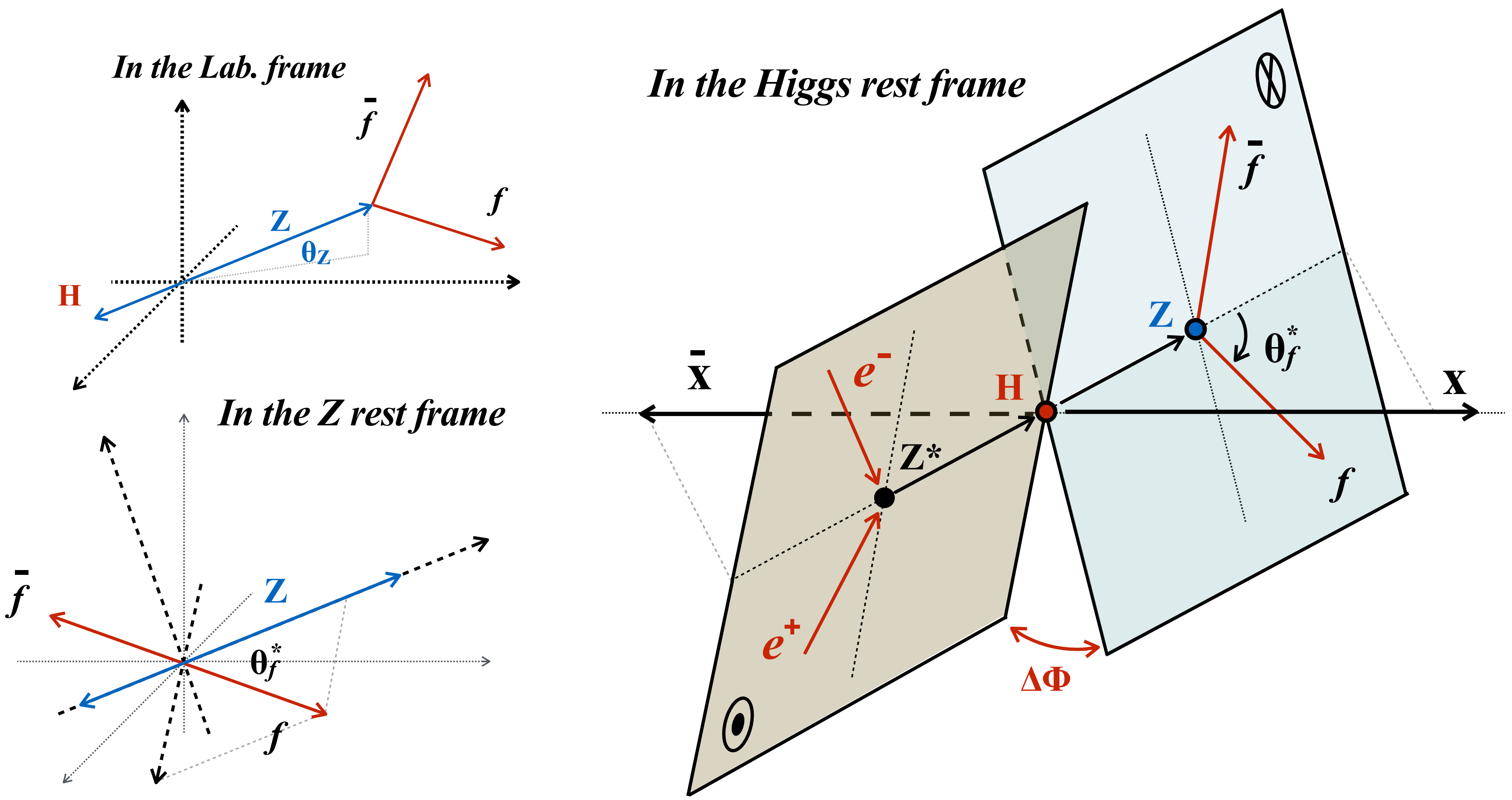


Figure 2: Schematic view of the process $e^+e^- \to ZH \to f\bar{f}H$.

ee → ZH → ffH (f=lepton) at 250GeV

Angular and momentum distributions with different parameters

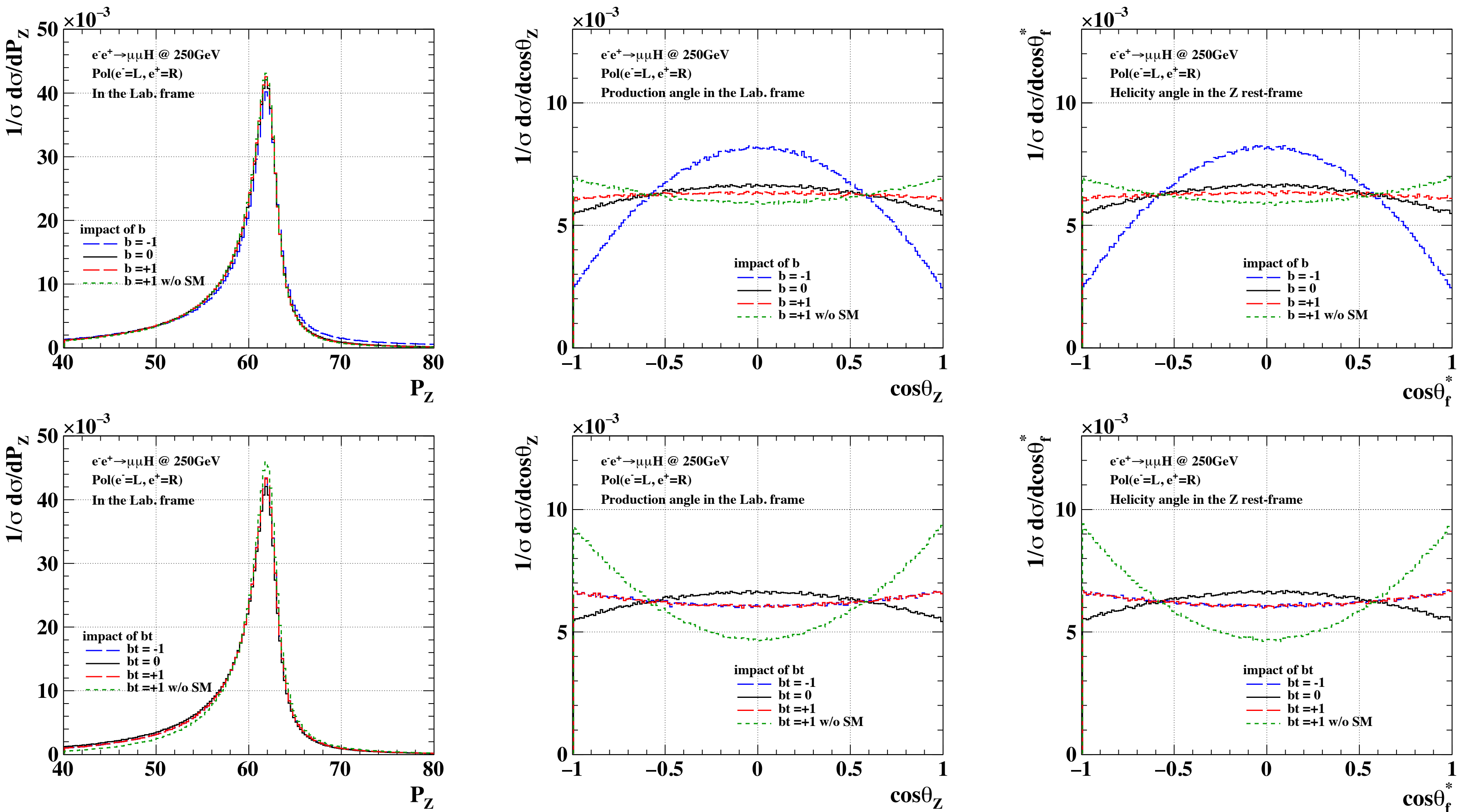
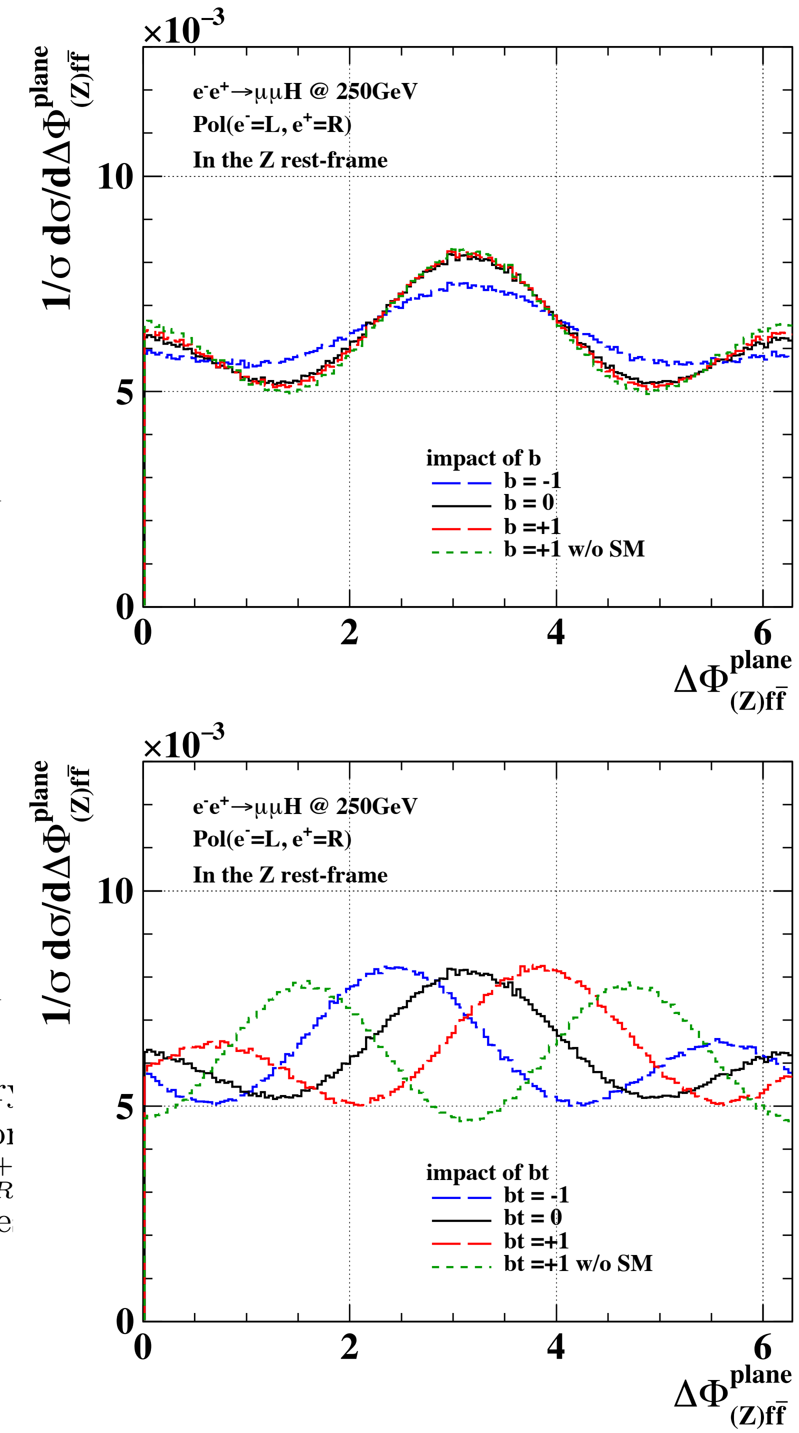


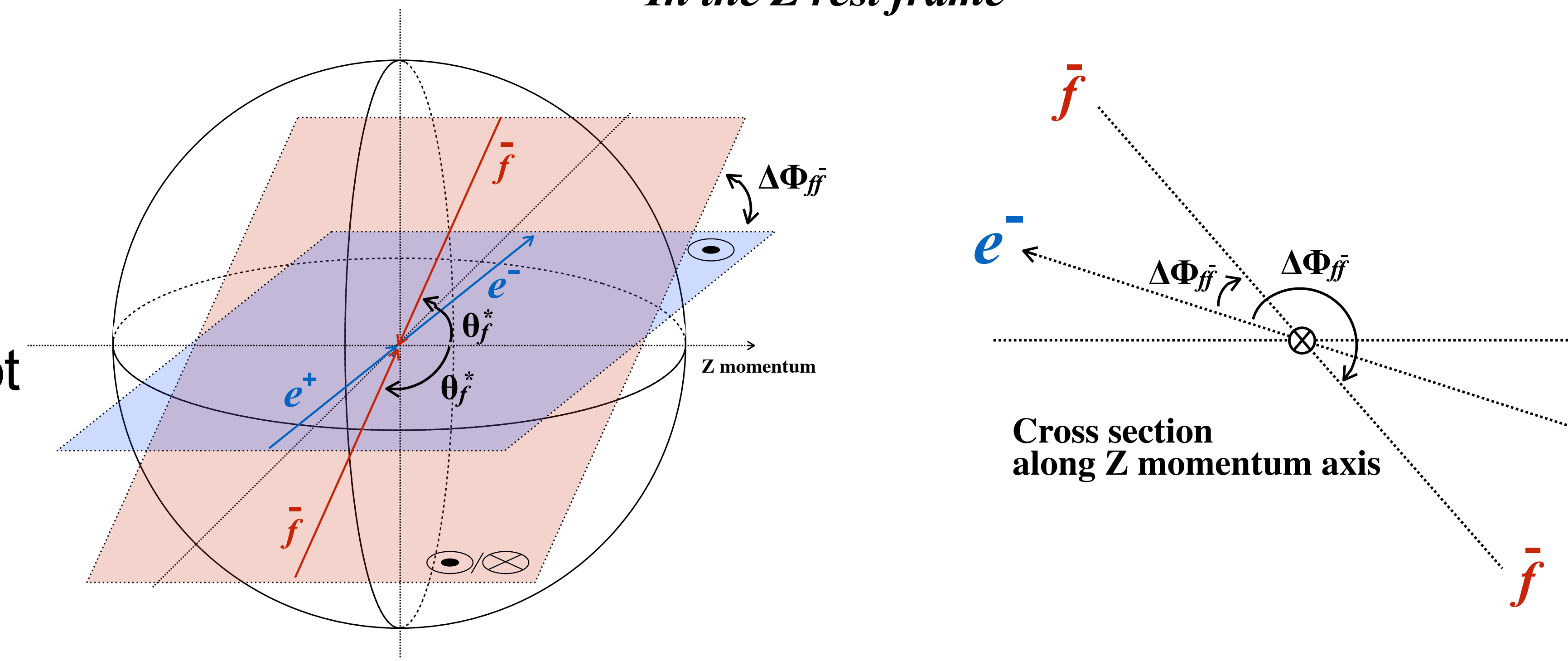
Figure 4: From left to right, distributions of a Z momentum and its production angle calculated in the laboratory frame, and a helicity angle of the final state lepton calculated with its direction in the Z rest frame and Z direction in the laboratory frame. The process is $e^+e^- \to ZH \to llH$ at $\sqrt{s} = 250$GeV with the beam polarization of $e^-_L e^+_R$. The difference of upper and lower row correspond to input parameters. Similarly black, green, blue and red line show the SM scalar, pseudo-scalar, and mixed state, respectively.

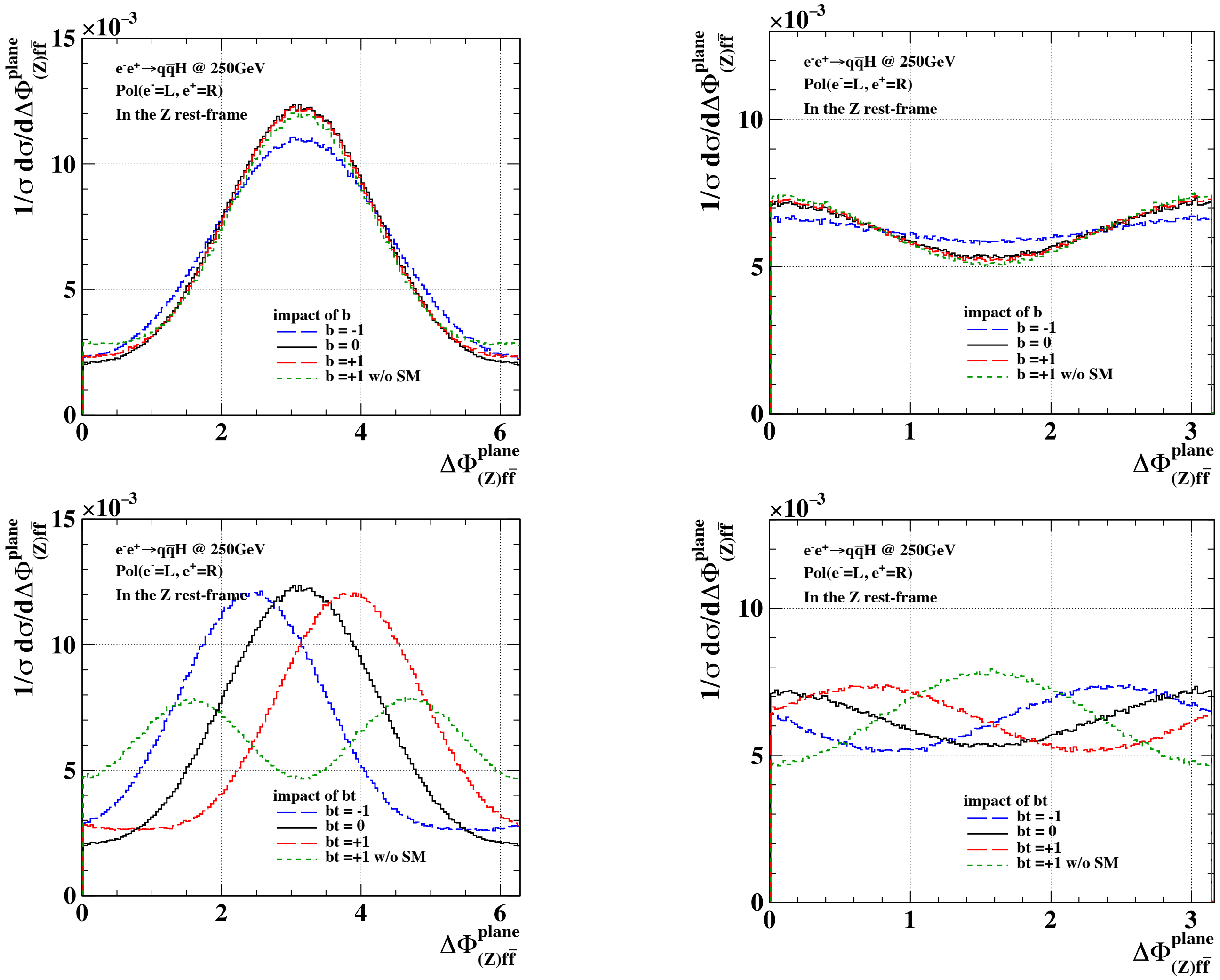


ee → ZH → ffH (f=quack) at 250GeV

In the Z rest frame

With no charge identification
a direction of both planes can not
be defined.





e 11: Schematic view of the process $e^+e^- \to ZH \to qqH$.

Sensitivity become 0 ~ π

Strategy of the estimation

We performed chi2 test to check the deviation from the SM distribution.

Definition of chi2 equation

This is the shape term

acceptance

$$\chi^2 = \sum_{i=1}^{n}\left[\frac{N_{SM}\cdot\frac{1}{\sigma}\frac{d\sigma}{dX}(x_i)\cdot f_i - N_{SM}\cdot\frac{1}{\sigma}\frac{d\sigma}{dX}(x_i;a,b,\tilde{b})\cdot f_i}{\delta N_{SM}(x_i)}\right]^2 \qquad (7)$$

where n and i denote the number of bins and certain bin number, then a, b and $\tilde{b}$ 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 deviation 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. Since a high energy experiment is basically a experiment which counts the number of events, this $\delta N_{SM}(x_i)$ I can be obtained as a simple error based on Poisson statistics, or it is also possible to estimate it by constructing probability density functions for the signal process and backgrounds process at each bin.

Migrations due to the detector resolution

The “real” observed distributions have the effects of detector resolution, efficiency and so on → Migration effect.

Need to know the probability of the migration

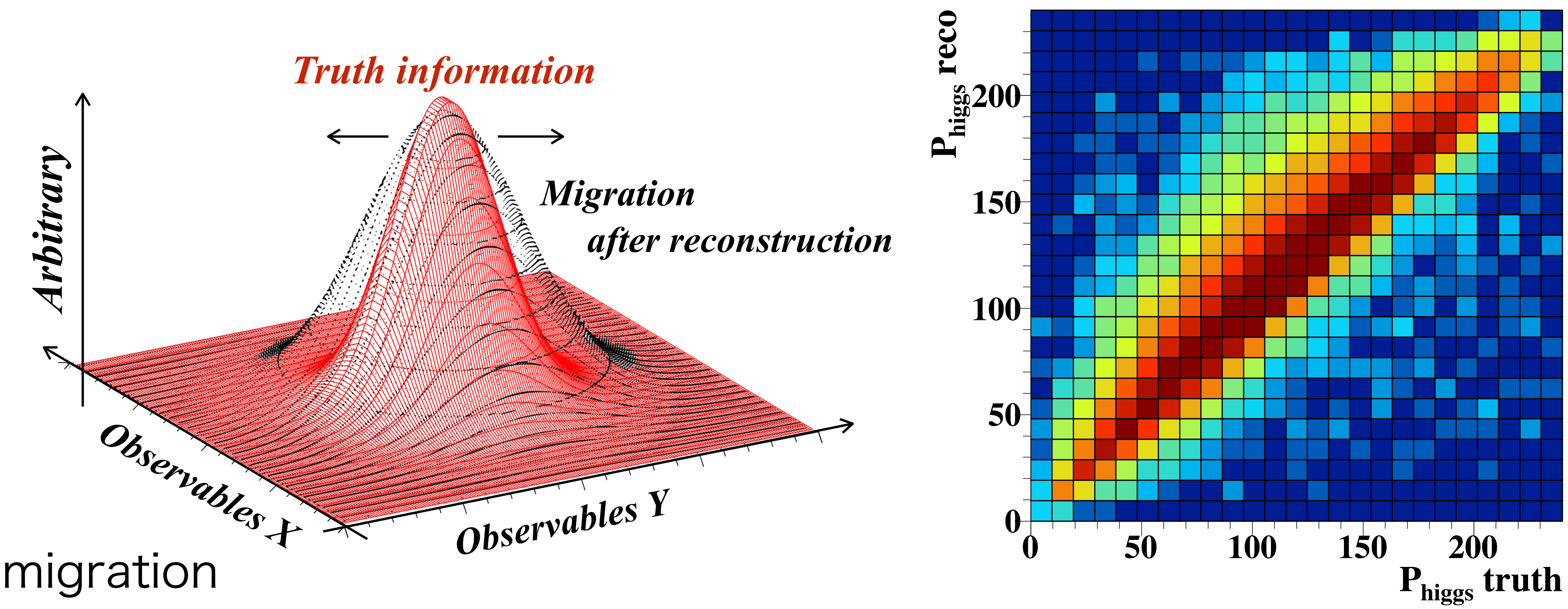


Figure 38: A schematic view of the migration effect due to the detector finite resolution and misidentified or undetectable particles (Left). Correlation between generated and reconstructed information on the Higgs momentum distribution P_{higgs} in the process $e^+e^- \to ZZ \to eeH$ at 500 GeV, which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

Generated distributions have to get these effect and be compared with the SM distributions → We should make “detector-level” distribution.

↓

2D migration matrix is constructed from the full detector simulation.

Event acceptance & Migration matrix

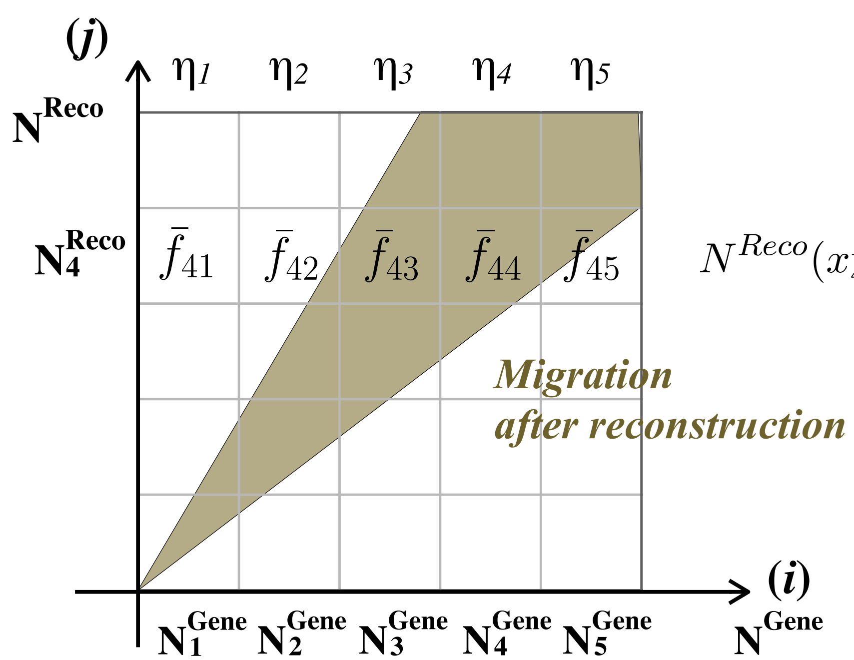
$$N^{Reco}(x_j^{Reco}) = \sum_i f(x_j^{Reco}, x_i^{Gene}) \cdot N^{Gene}(x_i^{Gene})$$

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

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

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

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

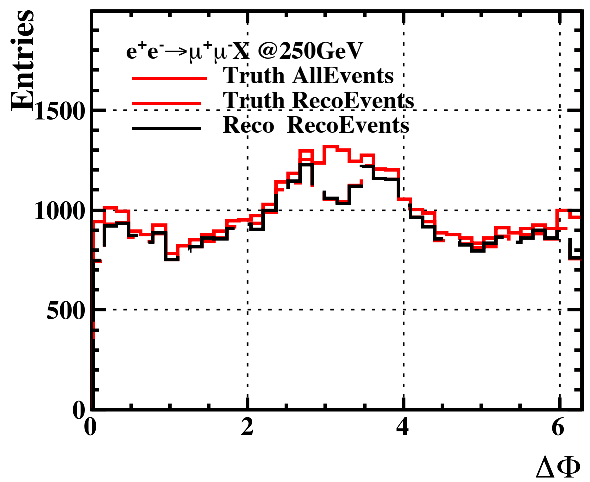


$$N^{Reco}(x_4^{Reco}) = \sum_i \bar{f}_{4i} \cdot \eta_i \cdot N_i^{Gene}$$
$$= \eta_1 \bar{f}_{41} \cdot N_1^{Gene} + \eta_2 \bar{f}_{42} \cdot N_2^{Gene} + \eta_3 \bar{f}_{43} \cdot N_3^{Gene}$$
$$+ \eta_4 \bar{f}_{44} \cdot N_4^{Gene} + \eta_5 \bar{f}_{45} \cdot N_5^{Gene}$$

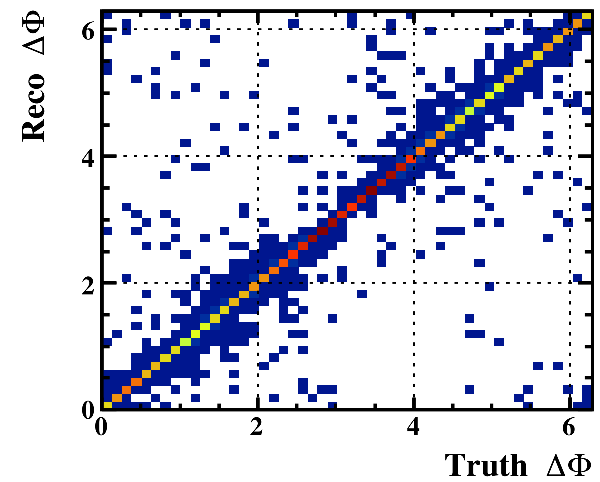
Figure 39: An example of calculation using the migration matrix. When an observable is divided into 5 bins, a 5×5 matrix is needed to predict a distribution of the observable including the migration effect.

Event acceptance & Migration matrix (e.g. μμH channel)

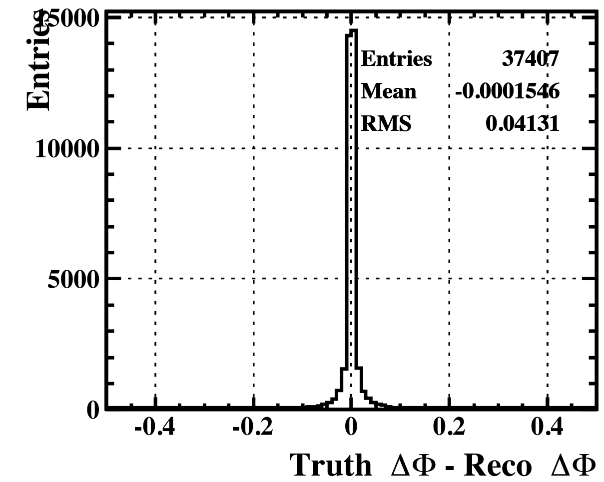
An example of 1-dimensional observable (ΔΦ)



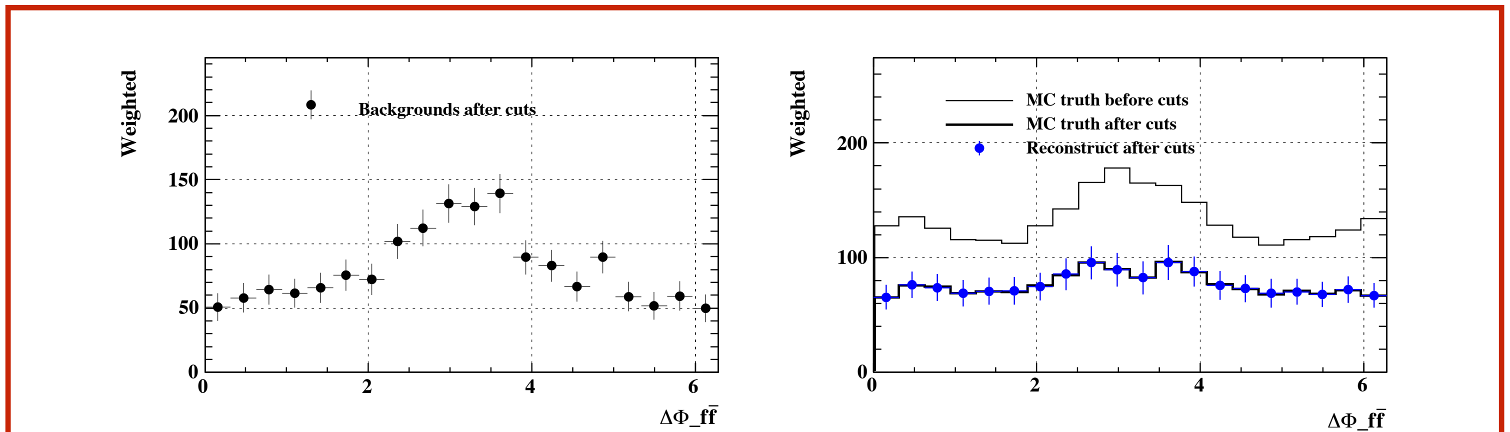
MC vs Reco



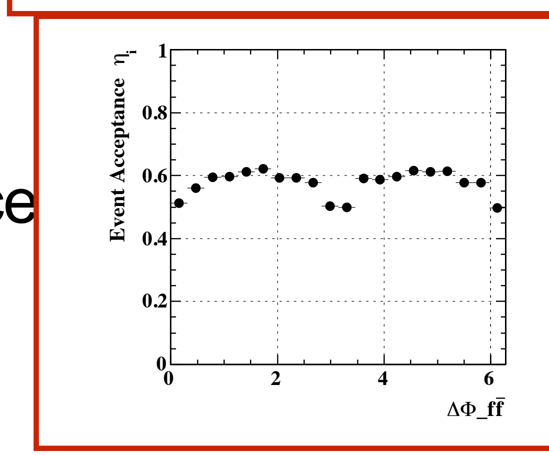
Resolution

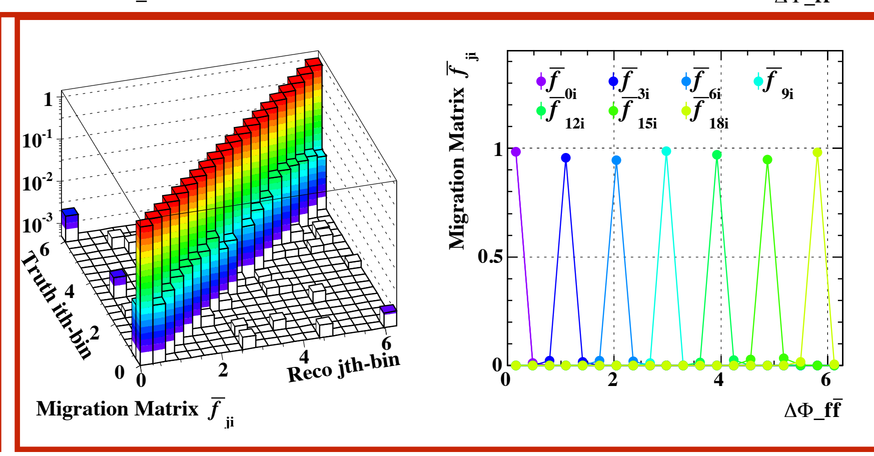


Remaining signal and backgrounds after BKGs suppression



Event acceptance





Migration matrix and examples on several bins

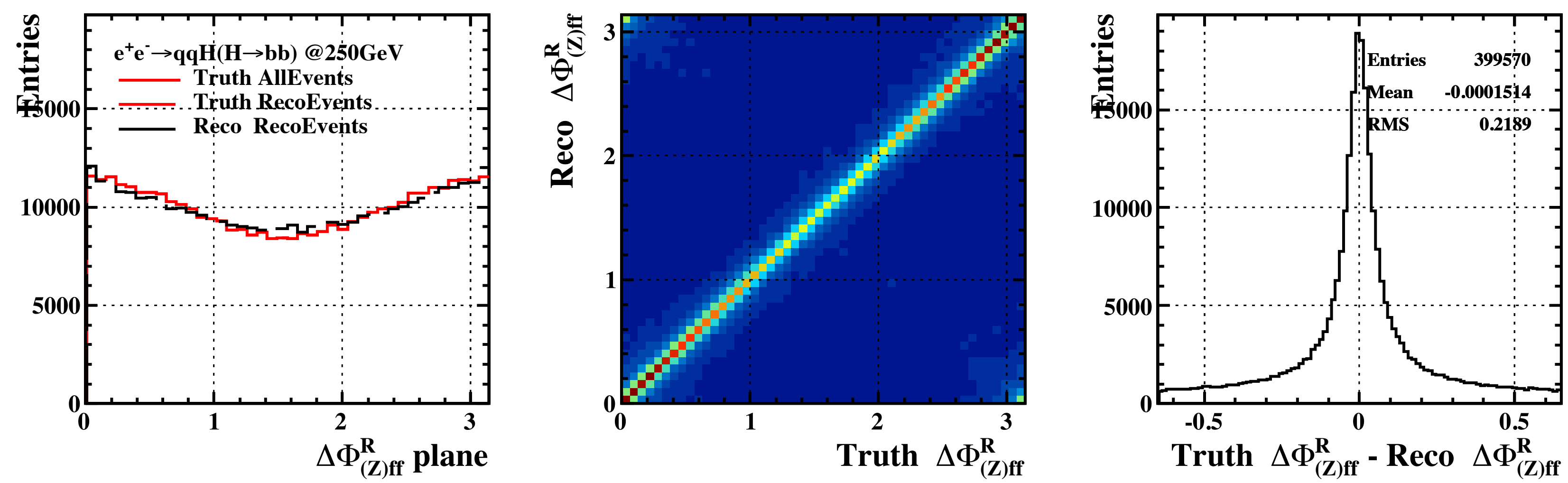
Figure 58: (Top left and right) The remaining backgrounds and signal distribution of the difference of the angle between production planes $\Delta\Phi_{f\bar{f}}$ after backgrounds suppression is applied $ZH \to eeH$. The error on each point are calculated based on the Poisson error $\pm\sqrt{N_{obs}}$. (Bottom left) The event acceptance function η_i of the generated(MC truth) $\Delta\Phi_{f\bar{f}}$ with signal events, which simply shows whether each signal event on each bin are successfully accepted or not after backgrounds suppression. (Bottom center and right) The migration matrix $\bar{f}_{ji}$ between the generated and reconstructed $\Delta\Phi_{f\bar{f}}$, and several examples of the function $\bar{f}_{ji}$.

Event acceptance & Migration matrix (e.g. qq channel)

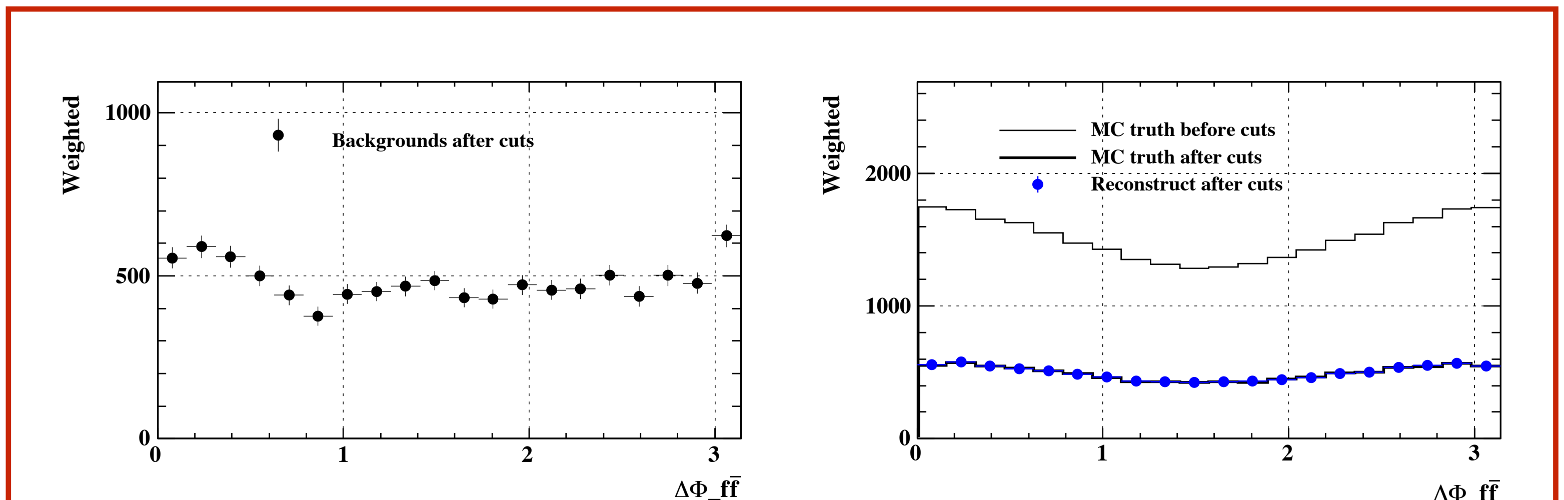
An example of 1-dimensional observable (ΔΦ)

MC vs Reco

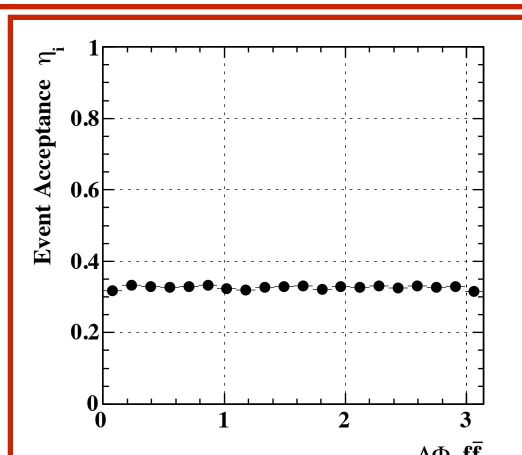
Resolution

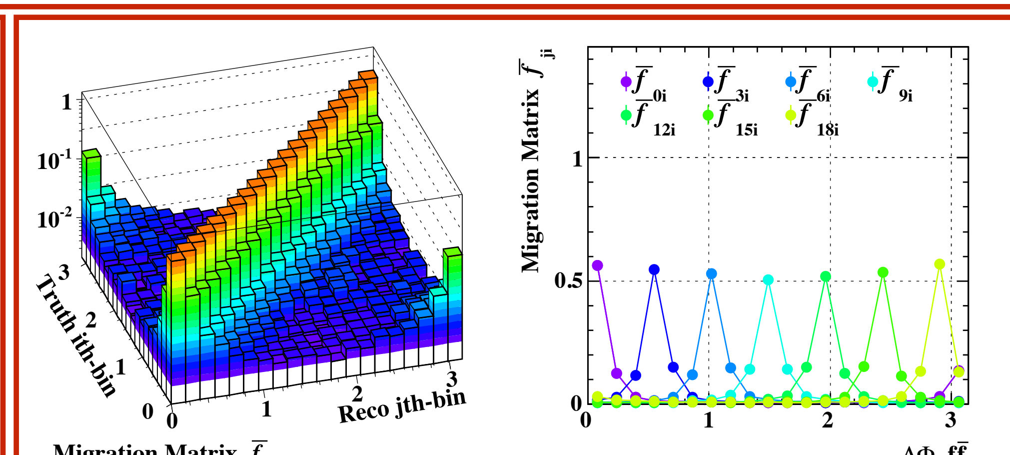


Remaining signal and backgrounds after BKGs suppression



Event acceptance



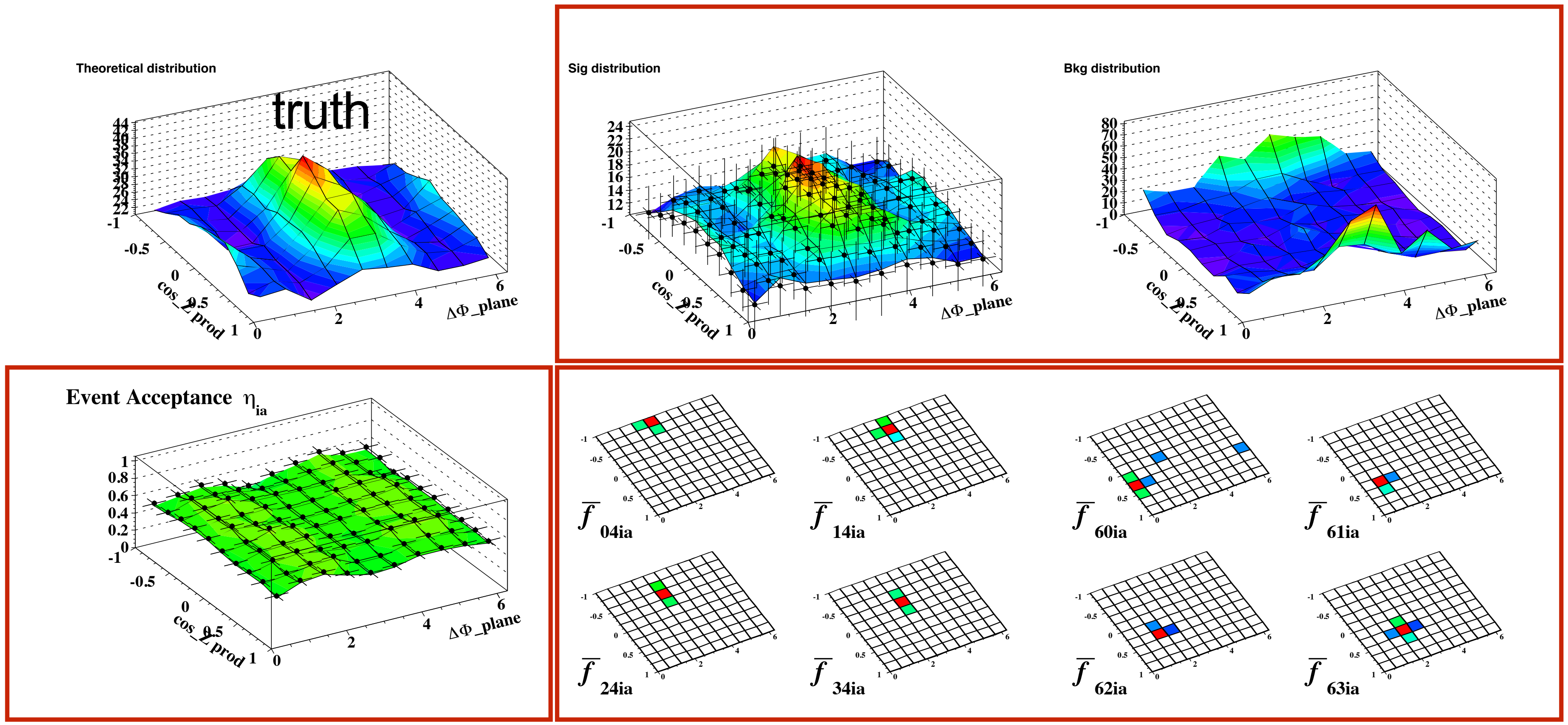


Migration matrix and examples on several bins

Event acceptance & Migration matrix (μμ or qq channel)

2-dimensional observable (ΔΦ vs cosZ)

Remaining signal and backgrounds

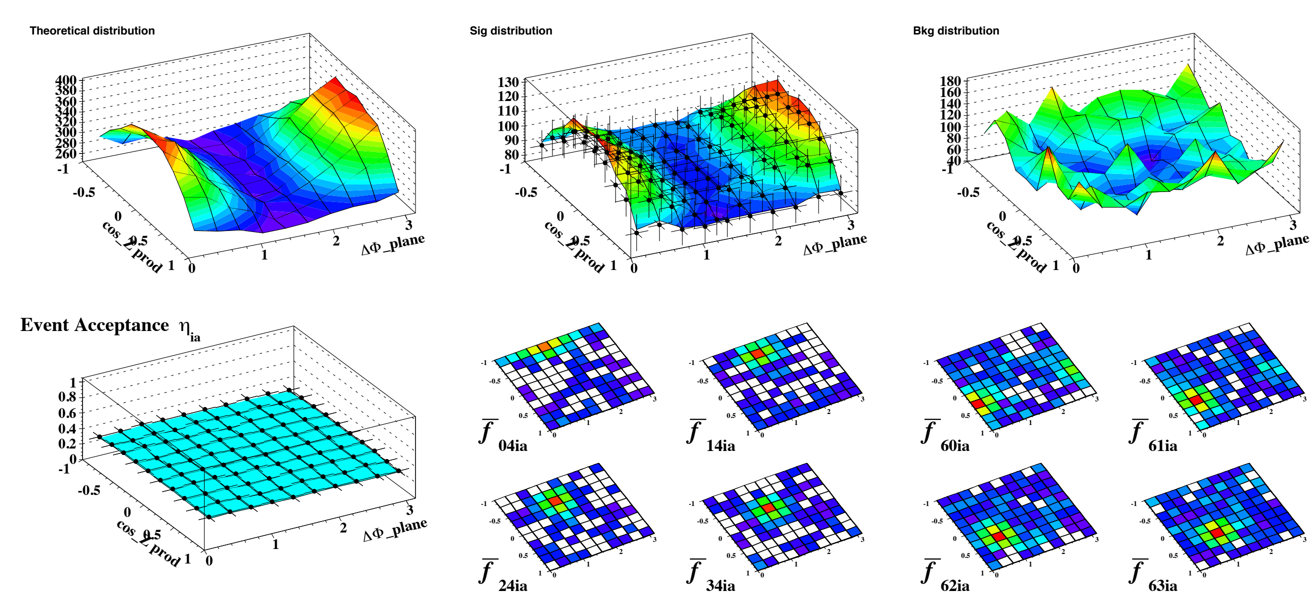


Event acceptance

Figure 59: ssssssss.

Migration matrix

qq channel



Sensitivity on anomalous ZZH couplings (μμ or qq channel)

Sensitivity of 1 parameter space with "only" shape information

a is no difference

b changes asymmetry

bt changes symmetry

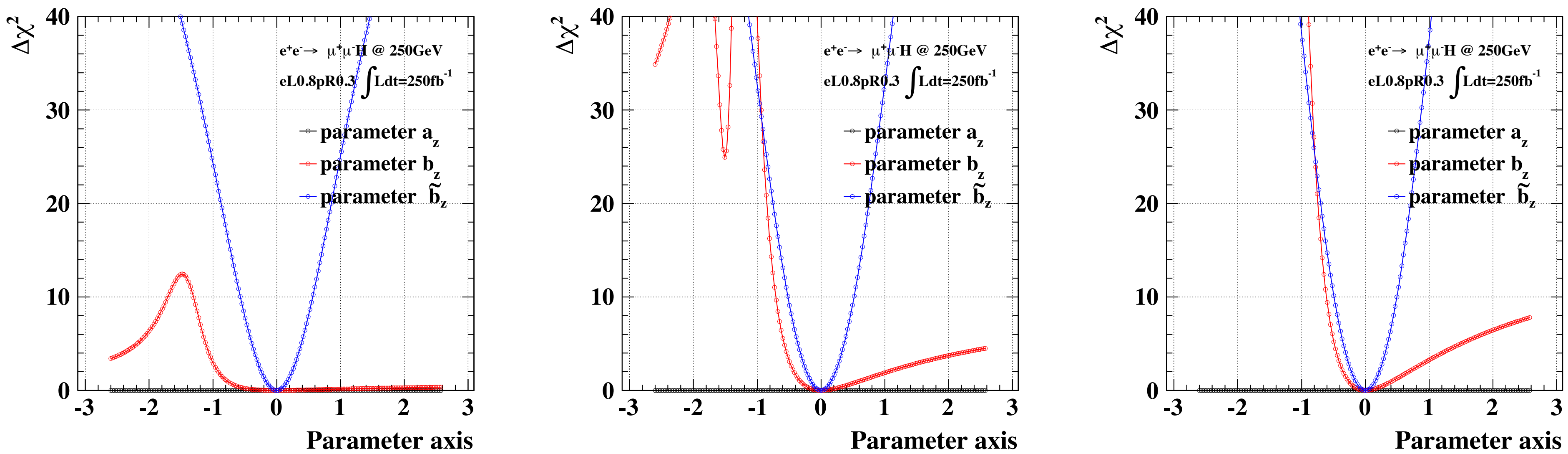


Figure 53: $\Delta\chi^2$ distributions as a function of parameters of the anomalous couplings. A black, red and blue line corresponds to the parameters a, b, and $\tilde{b}$. Only shape information is considered for estimation here. Upper and lower plots are assumed that beam polarization is $e^-_L e^+_R$ and $e^-_R e^+_L$ respectively, and the integrated luminosity is 250 fb^{-1}. Difference of each column correspond to an inputted distibution for $\Delta\chi^2$ estimation. From left to right plots, one dimensional distribution $f(\Delta\Phi_{f\bar{f}})$, two dimensional distribution $f(\cos\theta_Z, \Delta\Phi_{f\bar{f}})$, and three diminutional distribution $f(\cos\theta^*_f, \cos\theta_Z, \Delta\Phi_{f\bar{f}})$ are used.

qq channel

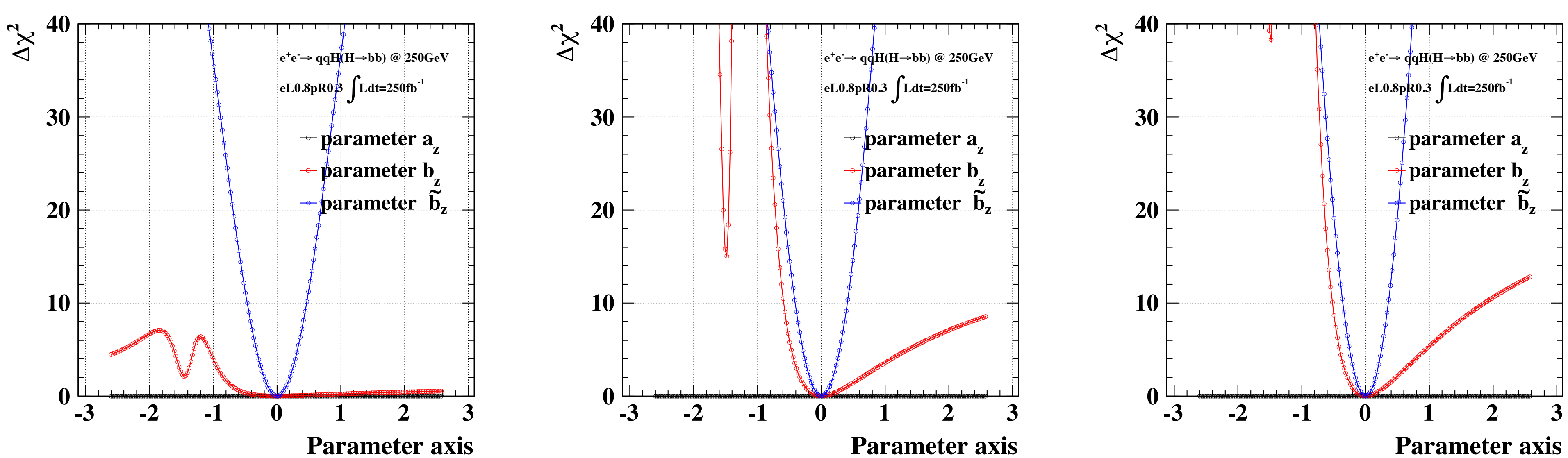


Figure 68: ssssssss.

Sensitivity on anomalous ZZH couplings with 4 processes

Sensitivity of 2 parameter space
with the shape information and the cross section information

P_{LR} L=250fb^{-1}
a & b are
strongly correlated

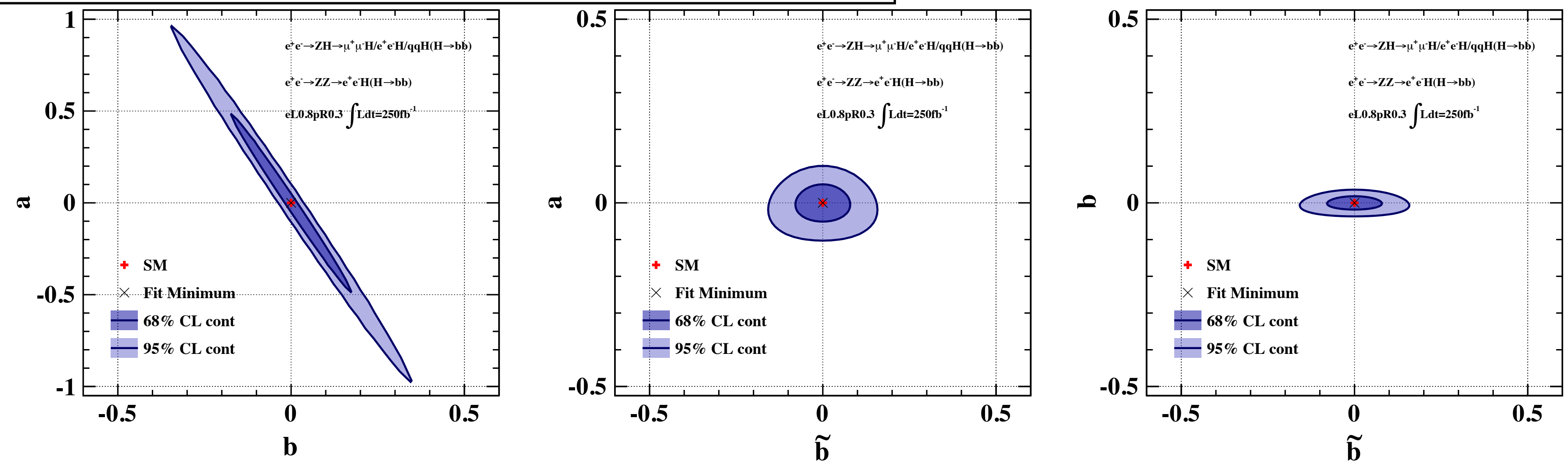


Figure 81: Contours plots in the anomalous parameters space a vs b, a vs $\tilde{b}$, and a vs $\tilde{b}$ with the third parameter set to 0. The center-of-mass energy and the integrated luminosity are set to 250 fb^{-1} and $e^-_L e^+_R$, respectively. Here both impacts, the shape and the cross section information, are considered. Similary four process are used for estimation, and Input distributions are the $f(\cos\theta^*_f, \cos\theta_Z, \Delta\Phi_{f\bar{f}})$ for the ZH process and the $f(\Delta\Phi_{f\bar{f}})$ for the ZZ-fusion process.

Sensitivity of 3 parameter space
with the shape information and the cross section information

P_{LR} L=250fb^{-1}

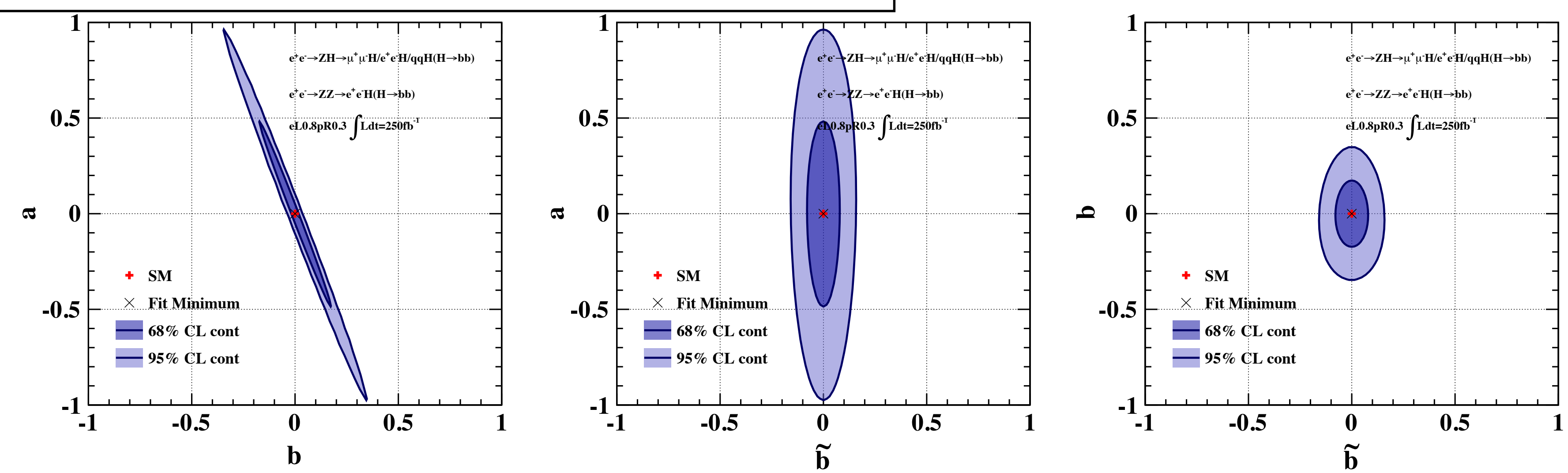


Figure 82: Contours plots in the anomalous parameters space a vs b, a vs $\tilde{b}$, and a vs $\tilde{b}$ with the three free parameters. The center-of-mass energy and the integrated luminosity are set to 250 fb^{-1} and $e^-_L e^+_R$, respectively.

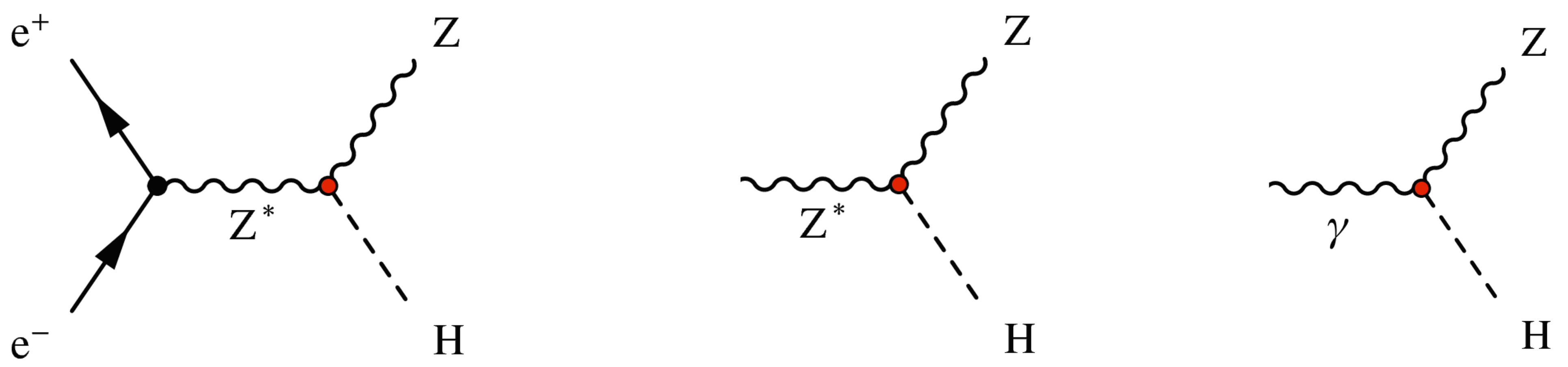
Sensitivity on anomalous ZZH couplings with 4 processes

full simulation results (2 ab-1 @ 250 GeV):

$$\Delta a = 0.027 \qquad \frac{\Delta b}{\Lambda} = \frac{0.039}{\text{TeV}} \qquad \frac{\Delta \tilde{b}}{\Lambda} = \frac{0.016}{\text{TeV}}$$

Scale to H20, some checks are needed to fix the results.

Anomalous AZH couplings on the ZH process



Using two beam polarization state we can give constraints for AZH.

Summary

Based on EFT, we tested sensitivity to anomalous VVH couplings.

full simulation results (2 ab-1 @ 250 GeV):

$$\Delta a = 0.027 \qquad \frac{\Delta b}{\Lambda} = \frac{0.039}{\mathrm{TeV}} \qquad \frac{\Delta \tilde{b}}{\Lambda} = \frac{0.016}{\mathrm{TeV}}$$

Currently we got the sensitivity for ZZH couplings for both 250GeV and 500GeV, but we need a bit more time to fix the results.

We have also got the results on AZH couplings, the situation is similar.

Anyway, We are now in a final step for ZZH analysis and preparing a paper for this analysis.