Higgs/EW group meeting.

Sensitivity to Anomalous VVH Couplings.

Introduction, Status and Prospects.

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Introduction:

- **This study is my Ph.D project and tow years has passed already.**

- Main interest is understanding of the Lorentz structure of the couplings between weak bosons.
- The estimation of Higgs CP property with ILC is especially interesting because Higgs CP-odd contribution to VVH is included though radiative/loop correction.

- Taking effective Lagrangian approach and using below Lagrangian which has dim-5 operators.

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

[arXiv:1011.5805]

- The strategy to estimate sensitivity to anomalous parameters is to use kinematical information of final state such as momentum spectra, angular/spin correlations.

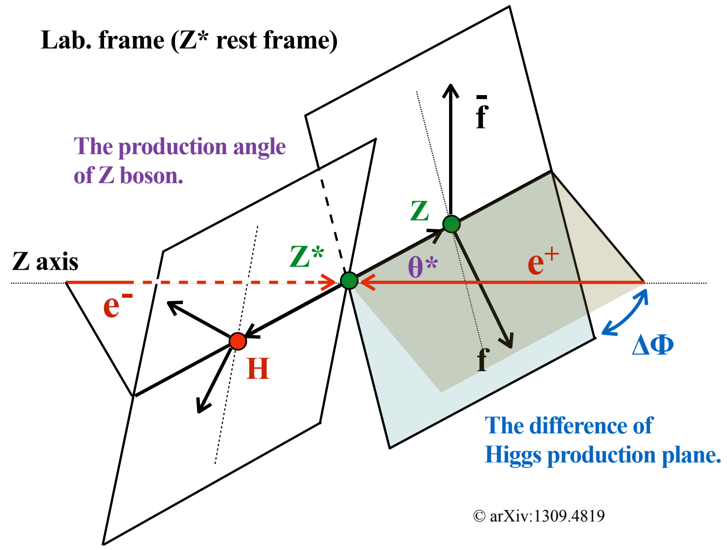
  - “**a**” is the simple normalization parameter which affects the overall cross section of processes.
  - “**b**” has the different Lorentz structure which affects momentum spectra and changes the ratio of couplings to transverse or longitudinal components.
  - **bt**” is the CP-violating parameter which affects angular/spin correlations.

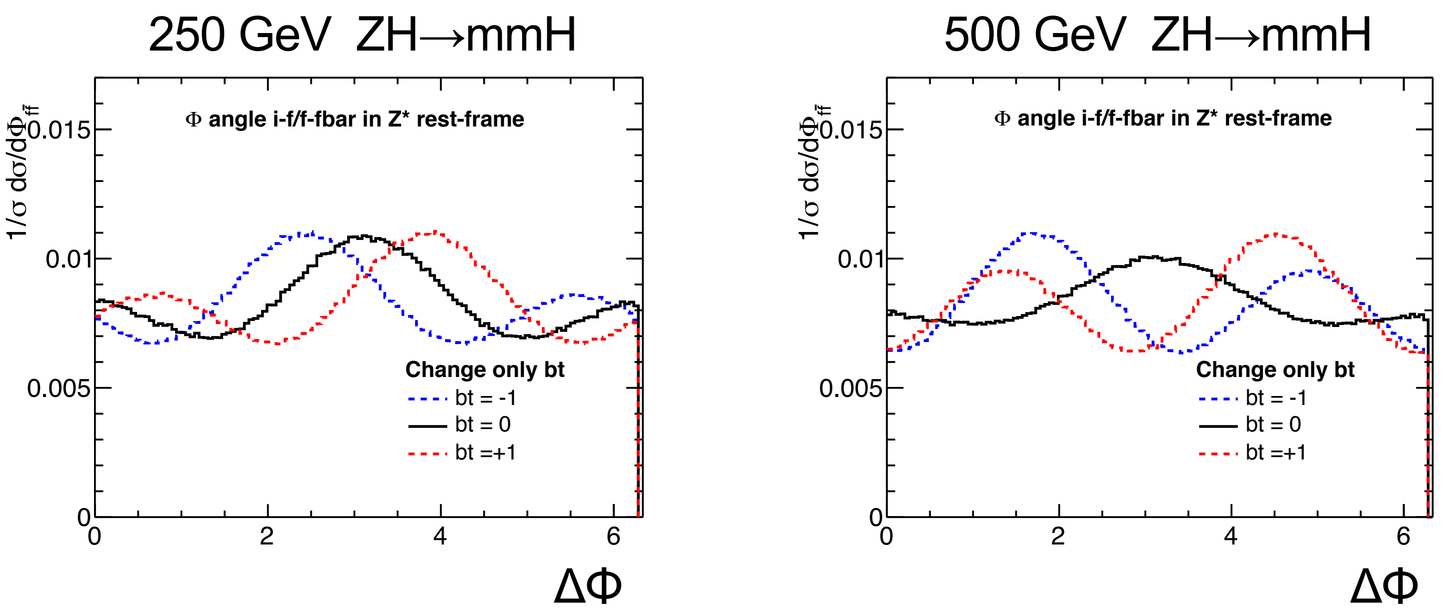
Strategy1: Classical Shape Analysis.

- **Kinematical distributions are calculated analytically.**
  - 6 terms.
  - 3 pure and 3 interference.

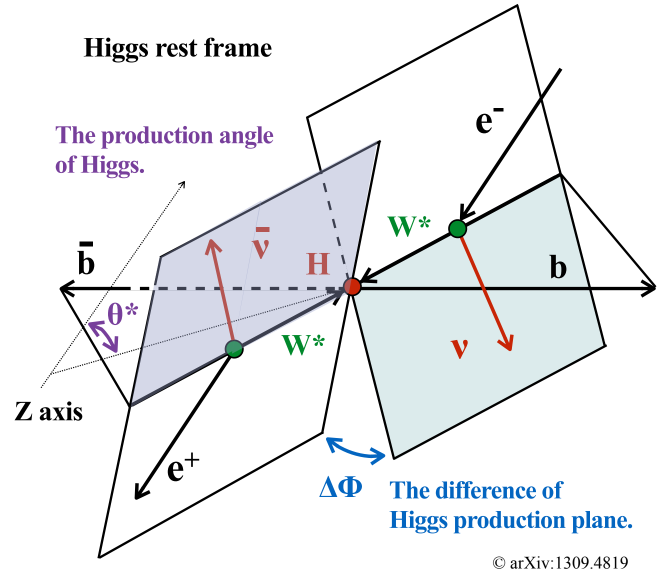
$$\frac{d\sigma}{dX}(x;a,b,\tilde{b}) = \frac{(C+a)^2}{C^2}\cdot\frac{d\sigma}{dX}\bigg|_{\mathrm{SM}} + b^2\cdot\frac{d\sigma}{dX}\bigg|_{\mathrm{b}} + \tilde{b}^2\cdot\frac{d\sigma}{dX}\bigg|_{\tilde{\mathrm{b}}} + \frac{(C+a)b}{C}\cdot\frac{d\sigma}{dX}\bigg|_{\mathrm{Int\_ab}} + \frac{(C+a)\tilde{b}}{C}\cdot\frac{d\sigma}{dX}\bigg|_{\mathrm{Int\_a\tilde{b}}} + b\tilde{b}\cdot\frac{d\sigma}{dX}\bigg|_{\mathrm{Int\_b\tilde{b}}}$$

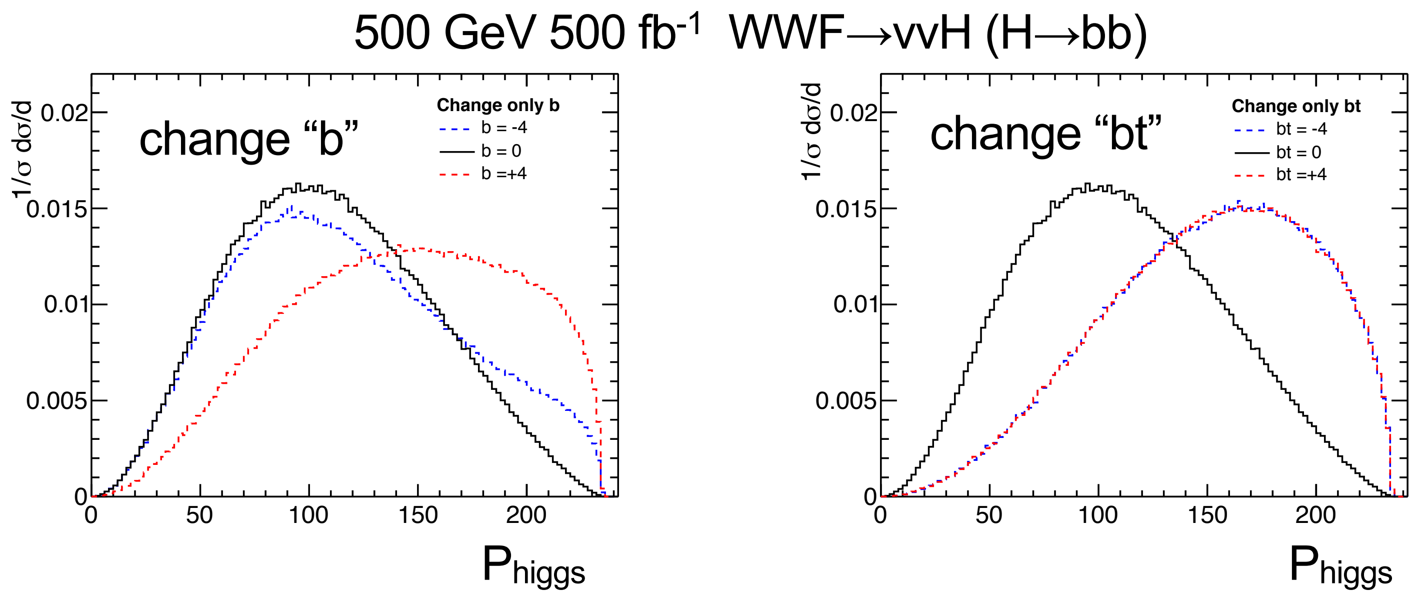
- **Higgs production [Higgs-strahlung]**





- **Higgs production [WW-fusion]**





Status1: with Classical Shape Analysis.

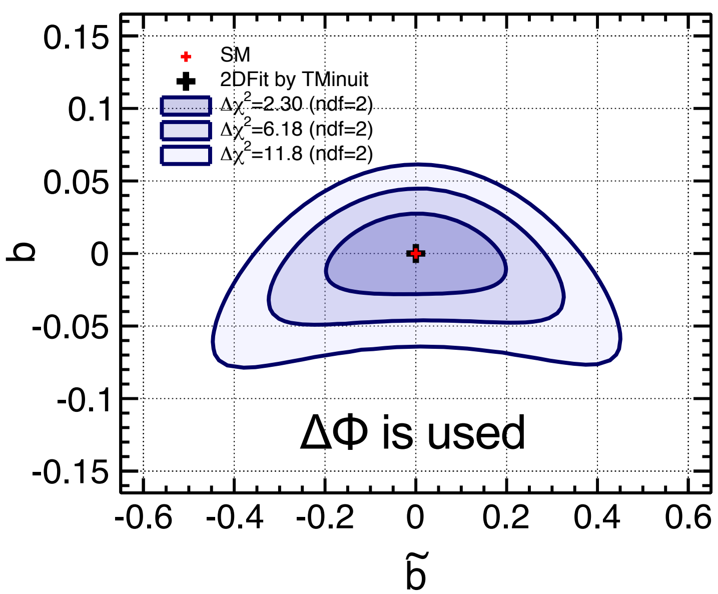
- **The definition of $\chi 2$ function to estimate probability. (2-dim. distribution)**

$$\chi^2 = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\frac{N^{SM}(x_{ij})\cdot f_{ij} - N^{BSM}(x_{ij};a,b,\tilde{b})\cdot f_{ij}}{\delta N^{SM}(x_{ij})}\right]^2 + \left[\frac{N^{SM}\cdot\epsilon - N^{BSM}\cdot\epsilon}{\delta\sigma\cdot N^{SM}\cdot\epsilon}\right]^2$$

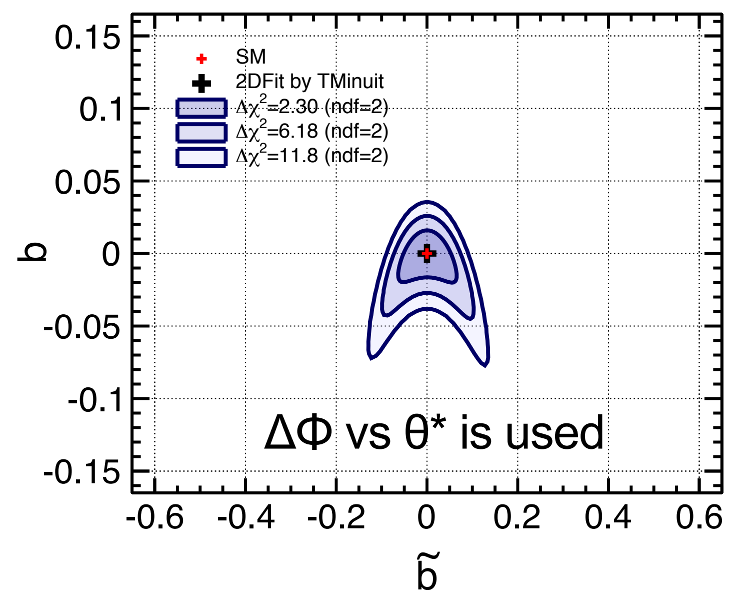
  - f_{ij} is overall acceptance which includes the detector response function.
  - δN is an error of remaining signals for each bin which is estimated by full simu.
  - ε is selection efficiency.
  - δσ is an error of cross sections.

- Several examples

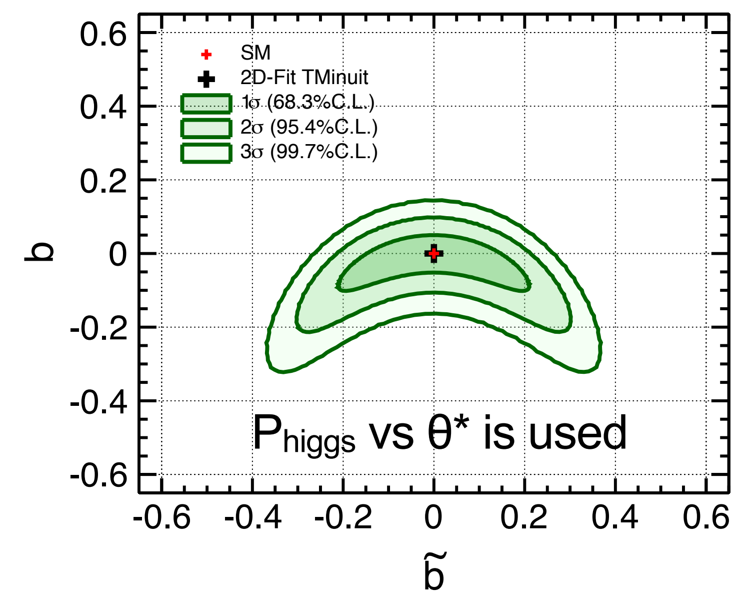
250 GeV 250 fb^{-1} ZH→mmH



500 GeV 500 fb^{-1} ZH→mmH



500 GeV 500 fb^{-1} WWF→vvH (H→bb)



- **Analysis of major processes for ZZH (7 processes) and WWH (4,5 processes) was almost done.**
- The remaining task is to summarize analysis.

Strategy2: Matrix Element Method.

- **All kinematical information are calculated by using final state momentum.**
  - **If we want use all information at the same time, possible way is to apply matrix element method.** (Soft ware is developed by Junping, Keisuke)

The definition of likelihood function is

$$\begin{aligned}
\mathcal{L} &= \mathcal{L}_{shape} \cdot \mathcal{L}_{norm} \\
&= \prod_{i=1}^{\mathrm{RemainN}} P_{shape}(\boldsymbol{x}_i; \boldsymbol{a}) \cdot P_{norm}(\boldsymbol{a}) \\
&= \prod_{i=1}^{\mathrm{RemainN}} \left[\frac{\int d\bar{\boldsymbol{x}}_i \cdot ME(\bar{\boldsymbol{X}}_i; \boldsymbol{a}) \cdot D(\boldsymbol{X}_i; \bar{\boldsymbol{X}}_i)}{\int d\boldsymbol{x}_i \int d\bar{\boldsymbol{x}}_i \cdot ME(\bar{\boldsymbol{X}}_i; \boldsymbol{a}) \cdot D(\boldsymbol{X}_i; \bar{\boldsymbol{X}}_i)} \right] \cdot \left[\frac{\mu(\boldsymbol{a})^N}{N!} \cdot \exp(-\mu(\boldsymbol{a})) \right]
\end{aligned}$$

Each component are represented like below.

$$\begin{aligned}
ME(\bar{\boldsymbol{X}}_i; \boldsymbol{a}) &= \frac{d\sigma}{d\bar{\boldsymbol{X}}_i}(\bar{\boldsymbol{X}}_i; \boldsymbol{a}) \\
D(\boldsymbol{X}_i; \bar{\boldsymbol{X}}_i) &= \theta(\boldsymbol{X}_i \in D) \cdot R(\boldsymbol{X}_i; \bar{\boldsymbol{X}}_i)
\end{aligned}$$

(D : Detector responce function.)

(θ : Step function. A event is accepted or not.)

(R : Resolution function.)

※ In order to simplify the situation, R = 1.

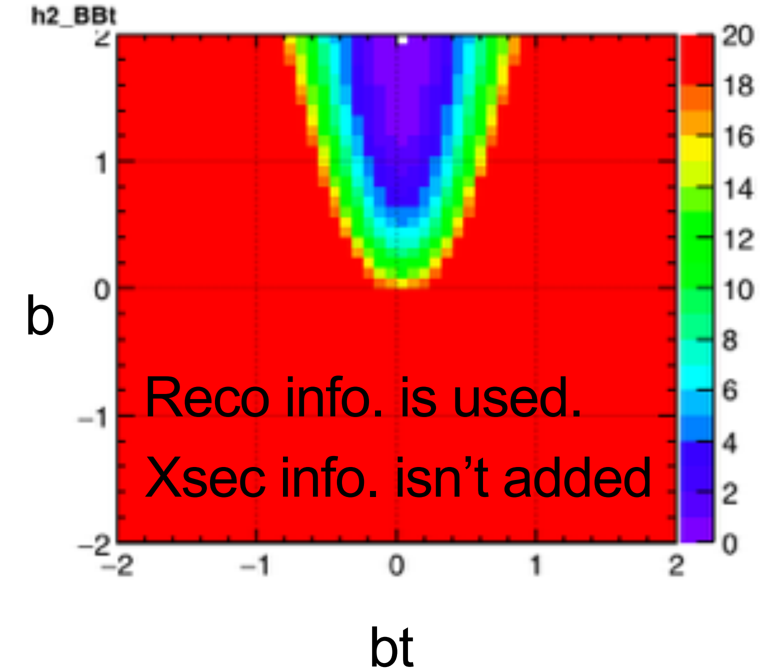
$$\mathcal{L} = \prod_{i=1}^{\mathrm{RemainN}} \left[\frac{L^{MC}}{N(\boldsymbol{a})} \cdot \frac{d\sigma}{d\boldsymbol{X}_i}(\boldsymbol{X}_i; \boldsymbol{a}) \cdot \theta(\boldsymbol{X}_i \in D) \right] \cdot \left[\frac{\mu(\boldsymbol{a})^N}{N!} \cdot \exp(-\mu(\boldsymbol{a})) \right]$$

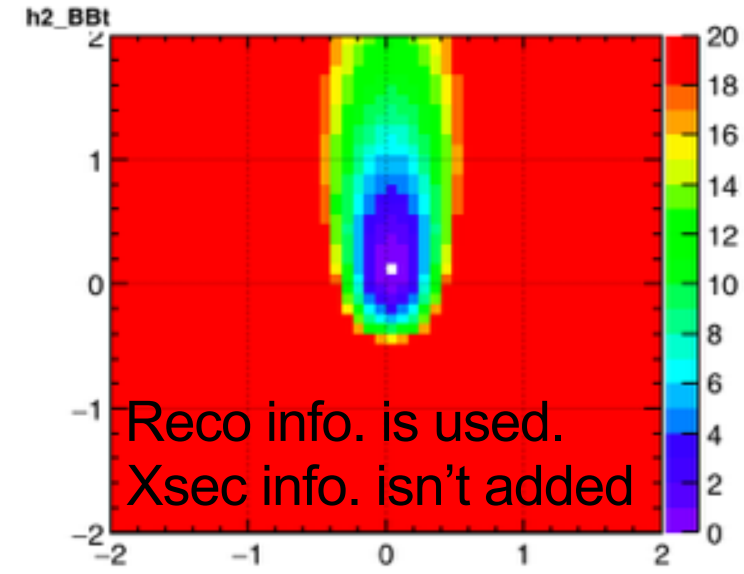
- **The definition of $\chi 2$ function to estimate probability. (ME method)**

$$\chi^2 = -2 \cdot \ln \Delta\mathcal{L} = -2 \cdot w_{pol} \cdot \frac{L^{Exp}\sigma^{SM}}{N^{Gene}} \cdot (\ln \mathcal{L}_{BSM} - \ln \mathcal{L}_{SM})$$

Status2: Matrix Element Method.

$\Delta\chi 2$=0~20





- **First application of MEM was 250GeV ZH→mmH (250 fb^{-1}).**
  - Input information is final state mu+, mu- and its recoil.
  - The sample is SM which corresponds (0,0) in the parameter plane.
  - The minimum point is far from (0,0) due to the effect of ISR.

- **Apply kinematical constraint.**
  - Assume that one gamma(ISR) is emitted along Z-axis and $E\gamma = P_Z\gamma$

Applying kinematic constraints which are based on energy and momentum conservation and assuming that $E_\gamma = P_{L_\gamma}$.

Constraint.

$$\begin{cases} \boldsymbol{P}_{T_{l-}} + \boldsymbol{P}_{T_{l+}} + \boldsymbol{P}_{T_h} = 0 \quad \text{(On the r}\phi\text{ plane)} \\ E_{l^-} + E_{l^+} + E_h + E_\gamma = \sqrt{s} \\ P_{L_{l-}} + P_{L_{l+}} + P_{L_h} + P_{L_\gamma} = 0 \quad \text{(Beam direction)} \\ E_h^2 - (\boldsymbol{P}_{T_h}^2 + P_{L_h}^2) = m_h^2 \end{cases}$$

$$E_\gamma = \frac{-m_h^2 - s - E_Z^2 + 2\sqrt{s}E_Z + P_{xZ}^2 + P_{yZ}^2 + P_{zZ}^2}{2\sqrt{s} + 2P_{T_Z} - 2E_Z}$$

Inputted Higgs info.

$$P^\mu = (P_{x_h},\ P_{y_h},\ -P_{z_Z} - E_\gamma,\ \sqrt{s} - E_Z - E_\gamma)$$

- **Several things we have to take care are;**
  - Consideration of the Bkgs effect.
  - Understanding of the result of ZH → hadronic process.
  - Increase statistics to perform ToyMC.

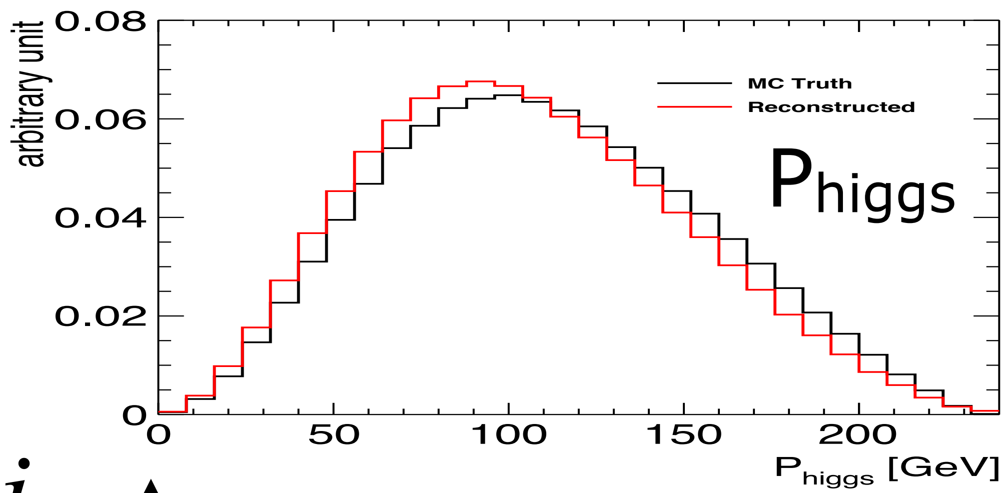
Prospects.

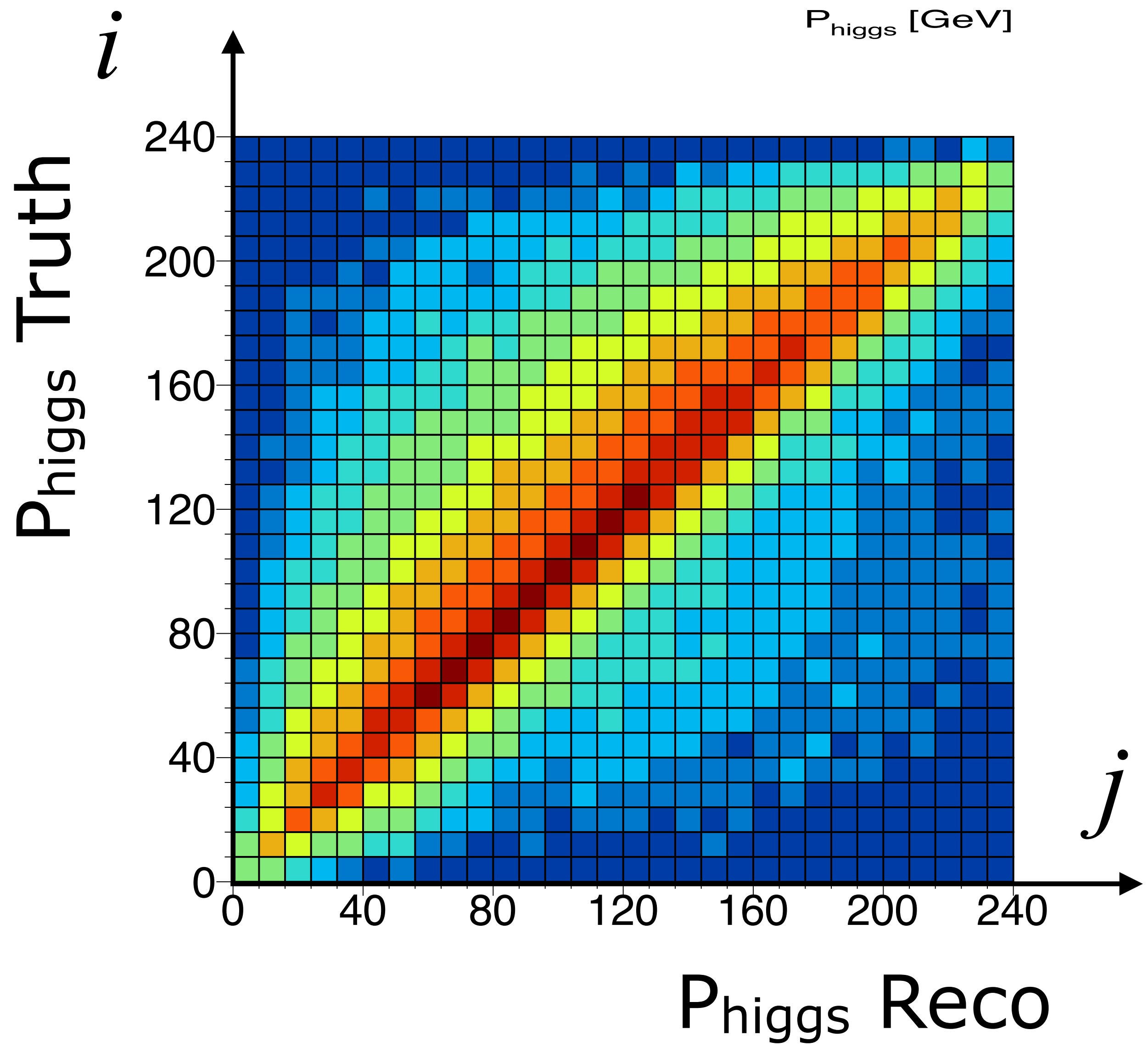
- Analysis1 (Shape analysis) was almost done.
- We are going to summarize and publish “Analysis1” within half year(?)
- Analysis2 (MEM analysis) is ongoing and we have already got several results
- In near future we will summarize “Analysis2” using a few process to demonstrate performance of MEM and its improvement.
- All tasks will finish within 1 year to graduate from Univ.

BACK UP.

Overall Acceptance: f .

>. Kinematical dists are smeared due to the detector and neutrons.





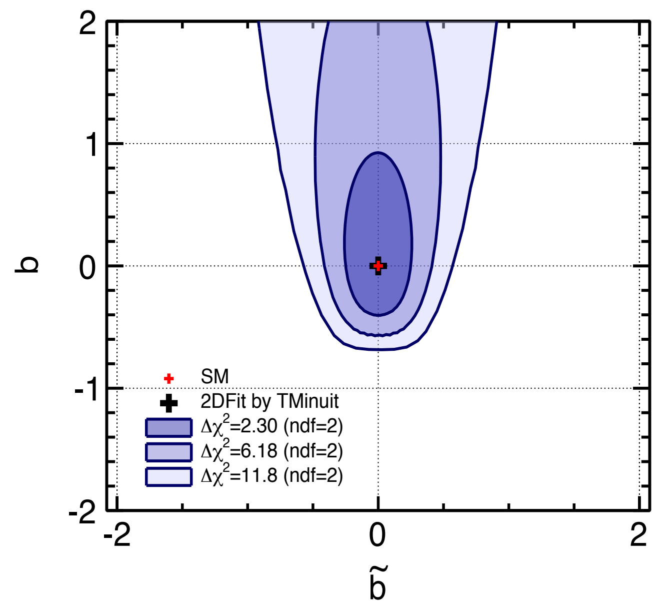
$$\chi^2 = \sum_{i=1}^{n} \left[\frac{N^{SM}(x_i) \cdot f_i - N^{BSM}(x_i; a, b) \cdot f_i}{\delta N^{SM}(x_i)} \right]^2$$

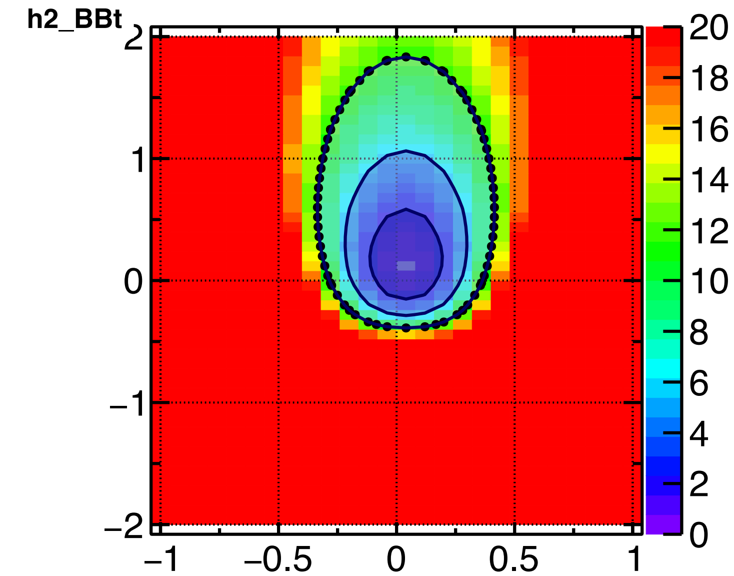
1d

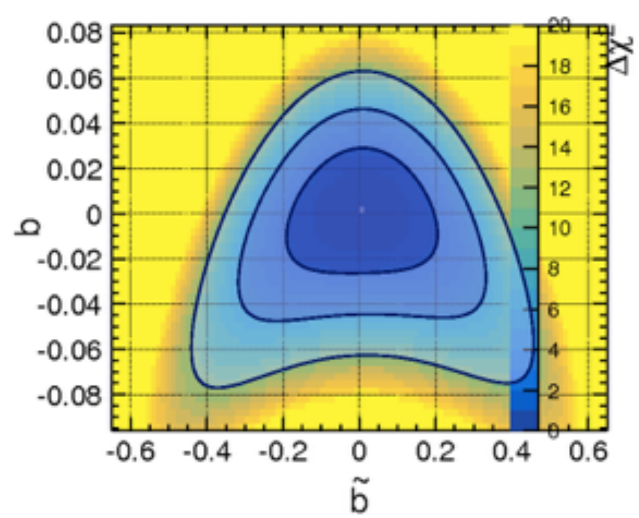
$$\begin{aligned} N^{Reco}(x_j^{Reco}) &= \sum_i f(x_j^{Reco}, x_i^{Gene}) \cdot N^{Gene}(x_i^{Gene}) \\ &= \sum_i f_{ji} \cdot N_i^{Gene} \\ &= \sum_i \bar{f}_{ji} \cdot \eta_i \cdot N_i^{Gene} \\ \eta_i &\equiv \frac{N_i^{Accept}}{N_i^{Gene}} \quad \text{(Event acceptance.)} \\ \bar{f}_{ji} &\equiv \frac{N_{ji}^{Accept}}{N_i^{Accept}} \quad \text{(Detector responce function.)} \end{aligned}$$

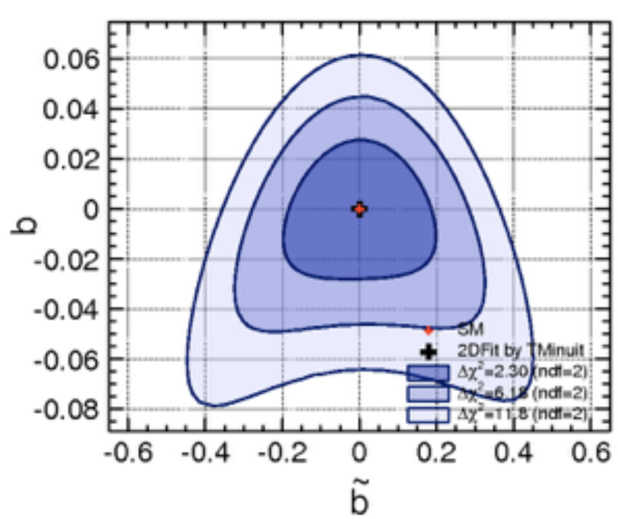
2d

$$\begin{aligned} N^{Reco}(x_{j\beta}^{Reco}) &= \sum_i \sum_\alpha \bar{f}_{j\beta i\alpha} \cdot \eta_{i\alpha} \cdot N_{i\alpha}^{Gene} \\ \eta_{i\alpha} &\equiv \frac{N_{i\alpha}^{Accept}}{N_{i\alpha}^{Gene}} \quad \text{(Event acceptance.)} \\ \bar{f}_{j\beta i\alpha} &\equiv \frac{N_{j\beta i\alpha}^{Accept}}{N_{i\alpha}^{Accept}} \quad \text{(Detector responce function.)} \end{aligned}$$


SM
2DFit by TMinuit
$\Delta\chi^2$=2.30 (ndf=2)
$\Delta\chi^2$=6.18 (ndf=2)
$\Delta\chi^2$=11.8 (ndf=2)
b
$\tilde{b}$


h2_BBt


$\Delta\chi^2$
b
$\tilde{b}$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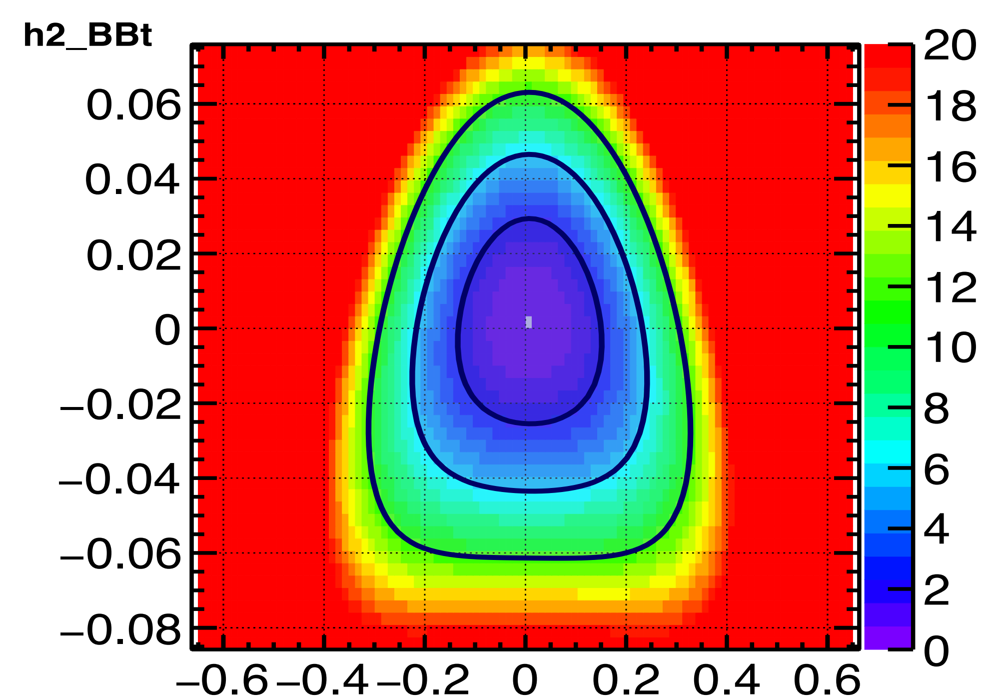
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