Probing 6D Operators at Higgs Factories

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In progress…

Higher Dimensional Operator

- New physics can be parametrized as HDOs (totally 59 six-dim ones)

$$\mathcal{L} = \mathcal{L} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_{6,i}$$

- The ones (CP-even) relevant to this study

$$\mathcal{O}_{WW} = g^2 |H|^2 W^a_{\mu\nu} W^{a,\mu\nu}$$
$$\mathcal{O}_{BB} = g'^2 |H|^2 B_{\mu\nu} B^{\mu\nu}$$
$$\mathcal{O}_{WB} = g g' H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu}$$
$$\mathcal{O}_H = \tfrac{1}{2} (\partial_\mu |H|^2)^2$$
$$\mathcal{O}_T = \tfrac{1}{2} (H^\dagger \overleftrightarrow{D}_\mu H)^2$$
$$\mathcal{O}_L^{(3)\ell} = (i H^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu \sigma^a L_L)$$
$$\mathcal{O}_{LL}^{(3)\ell} = (\bar{L}_L \gamma_\mu \sigma^a L_L)(\bar{L}_L \gamma^\mu \sigma^a L_L)$$
$$\mathcal{O}_L^{\ell} = (i H^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu L_L)$$
$$\mathcal{O}_R^{e} = (i H^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$$

$$+ \quad \mathcal{O}_{6H} = (H^\dagger H)^3$$

Contributions to Observables

- Direct contribution to existing vertices
- Contribution by field redefinition
- EW parameter shift (fine-structure constant, mZ, Fermi constant)
- New vertices could be introduced

Partial List of Studies

- Higgs measurement, EWPT, and di-gauge boson production (arXiv: 1507.02238, L. Bian, J. Shu, et. al.)
- E.g., e+e- -> ZH
  - Integrated signal rate (arXiv: 1411.0676, N. Craig et. al; arXiv:1603.03385, S.F Ge, H.J. He, et. al)
  - integrated angular asymmetry (arXiv: 1512.06877, N. Craig, Z. Liu et. al)
  - ……

Fitting Strategy

- Typically single operator is constrained in literatures
- Sometimes the correlation could be important
    - HDOs might exist in the same model or theory
        - Diff HDOs might contribute to the same observable
- We will address this in our analyses
    - Derive LO corrections to the SM predictions
    - cross section data obtained using CalcHEP

Inputs

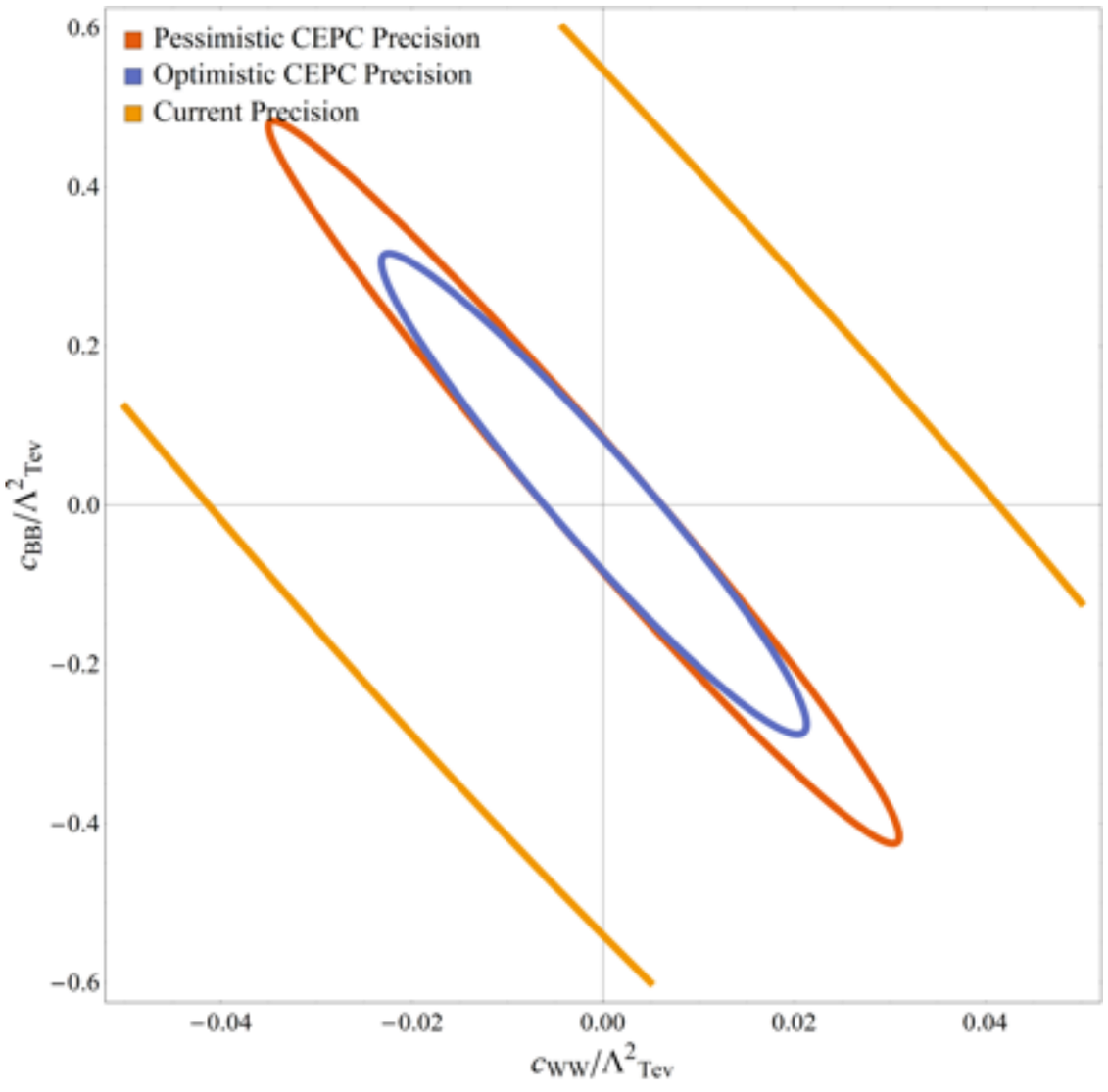
	Current Precision	Expected Precision
M_Z	2.3×10^{-5}	$0.55 - 1.1 \times 10^{-5}$
G_F	5.14×10^{-7}	—
α	3.29×10^{-10}	—
$\sigma(ZH)_{250}$	—	0.51%
$\sigma(\nu\bar{\nu}H)_{350}$	—	0.75% (FCC-ee)
$\sigma(ZHH)_{500}$	—	13.5 – 23.7% (ILC)
M_W	1.87×10^{-4}	$3.7 - 6.2 \times 10^{-5}$
N_ν	0.27%	0.1%
A_{fb}^b	1.7%	0.15%
R_b	0.3%	0.08%
R_τ	0.2%	0.05%
R_μ	0.2%	0.05%
$\sin^2 \theta_W^{\mathrm{eff}}$	0.07%	0.01%

Single Parameter Fit

	N_ν	A_{FB}^b	R_b	R_μ	R_τ	$\sin^2\theta_W^{\text{eff}}$	M_W	$\sigma(ZH)$	$\sigma(\nu\bar{\nu}H)_{350}$
$c_{WW}/\Lambda^2_{\text{TeV}}$	—	0.00908	0.183	0.0223	0.0223	-0.00583	-0.103	0.0224	-0.767
$c_{BB}/\Lambda^2_{\text{TeV}}$	—	0.124	2.532	0.307	0.307	-0.0793	0.473	0.684	—
$c_{WB}/\Lambda^2_{\text{TeV}}$	—	-0.00734	0.238	0.167	0.166	0.00429	-0.00598	0.155	-0.272
$c_T/\Lambda^2_{\text{TeV}}$	0.0297	0.00330	-0.200	0.0894	0.09	-0.00196	0.00141	-0.124	0.0228
$c_{LL}^{(3)l}/\Lambda^2_{\text{TeV}}$	-0.0149	-0.00165	0.100	-0.0448	-0.0451	0.000983	0.00246	0.0172	0.0138
$c_L^{(3)l}/\Lambda^2_{\text{TeV}}$	0.0149	0.00122	-0.100	0.00401	-0.045	0.000721	-0.00246	0.00813	-0.0251
$c_L^l/\Lambda^2_{\text{TeV}}$	—	0.00463	—	0.00367	-0.00400	0.00269	—	0.00469	—
$c_R^e/\Lambda^2_{\text{TeV}}$	—	0.00341	—	0.005	-0.00368	0.001986	—	-0.00699	—
$c_H/\Lambda^2_{\text{TeV}}$	—	—	—	—	—	—	—	-0.0799	-0.131

$c_{WW} - c_{BB}$ fit

- Fit using:
  $\sigma(ZH), M_W$ and $\sin^2\theta_W^{\text{eff}}$
  - Optimistic constraints:
    $5\ \text{ab}^{-1}$ of 250 GeV data at CEPC,
    $100 - 150\ \text{fb}^{-1}$ of precision data,
    minimal systematics for precision EW measurements
- Pessimistic constraints:
  $5\ \text{ab}^{-1}$ of 250 GeV data at CEPC,
  $100 - 150\ \text{fb}^{-1}$ of precision data,
  systematics same order as statistical



$c_{WB} - c_T$ fit

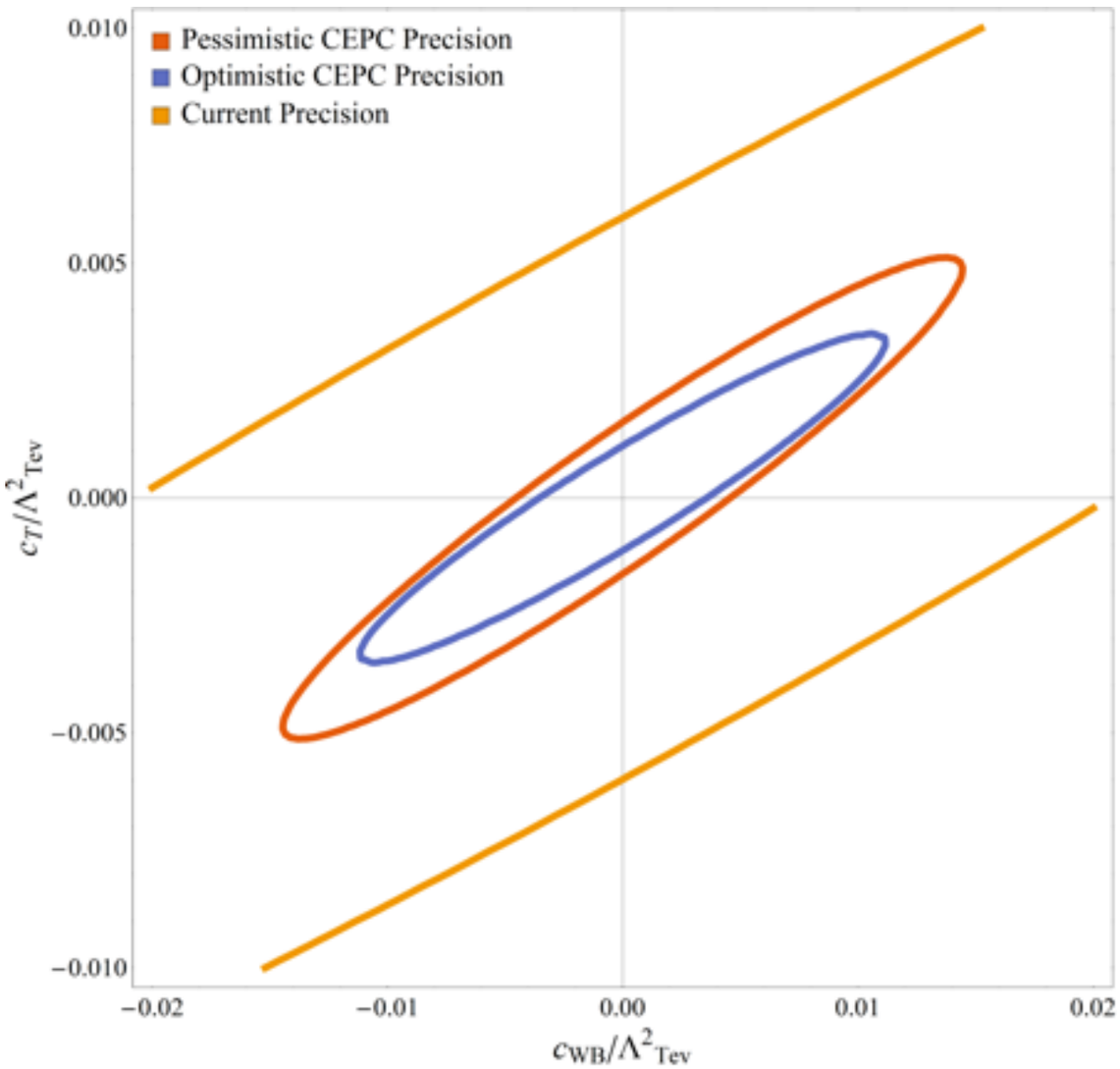
- Fit using: M_W and $\sin^2 \theta_W^{\text{eff}}$
  - Optimistic constraints:

    $150\ \text{fb}^{-1}$ of precision data,

    minimal systematics for Z-Pole and precision EW measurements at CEPC
  - Pessimistic constraints:

    $150\ \text{fb}^{-1}$ of precision data,

    systematics same order as statistical



$c_{LL}^{(3)l} - c_{L}^{(3)l}$ fit

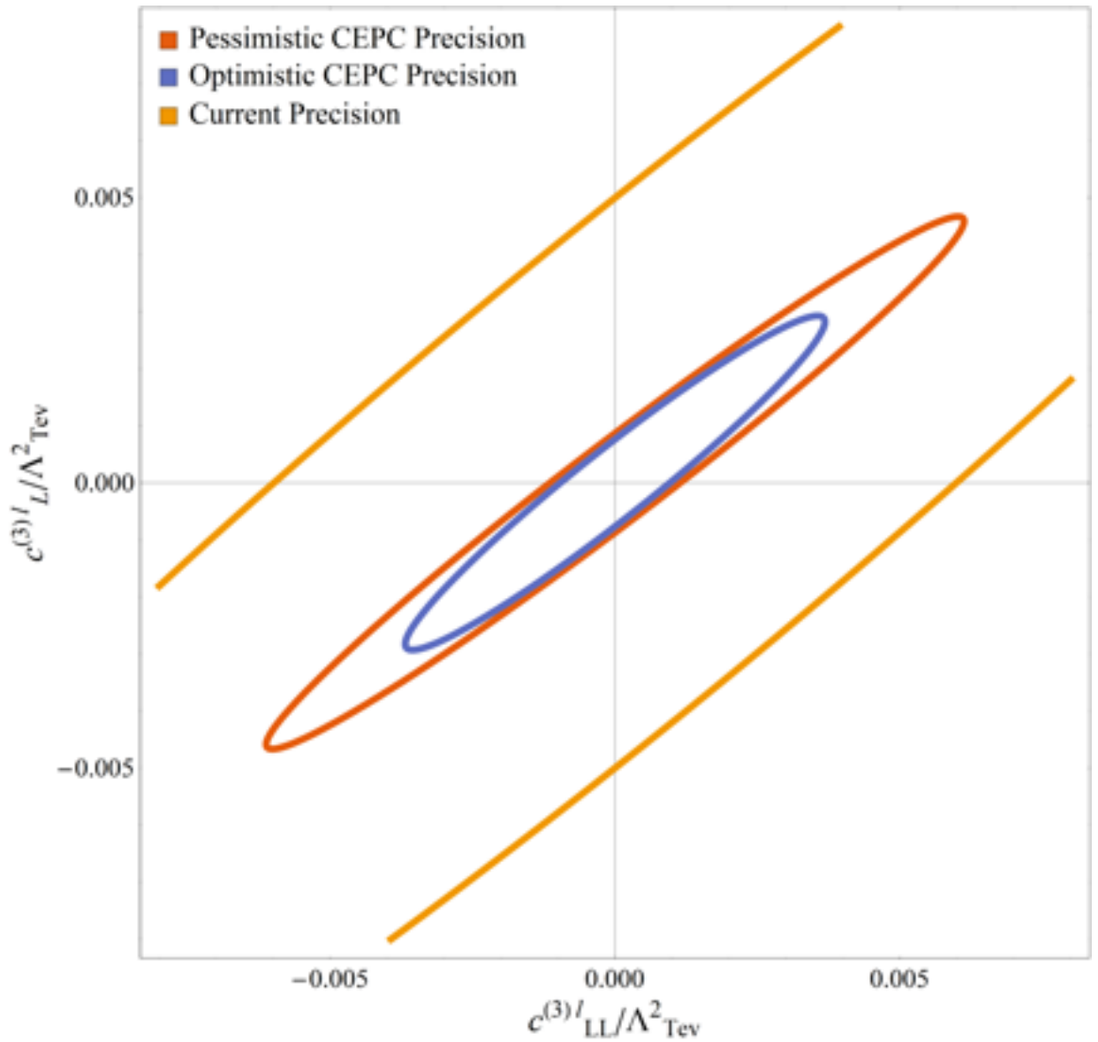
- Fit using: M_W and $\sin^2\theta_W^{\text{eff}}$
  - Optimistic constraints:

    $150\ \text{fb}^{-1}$ of precision data,

    minimal systematics for Z-Pole and precision EW measurements at CEPC
  - Pessimistic constraints:

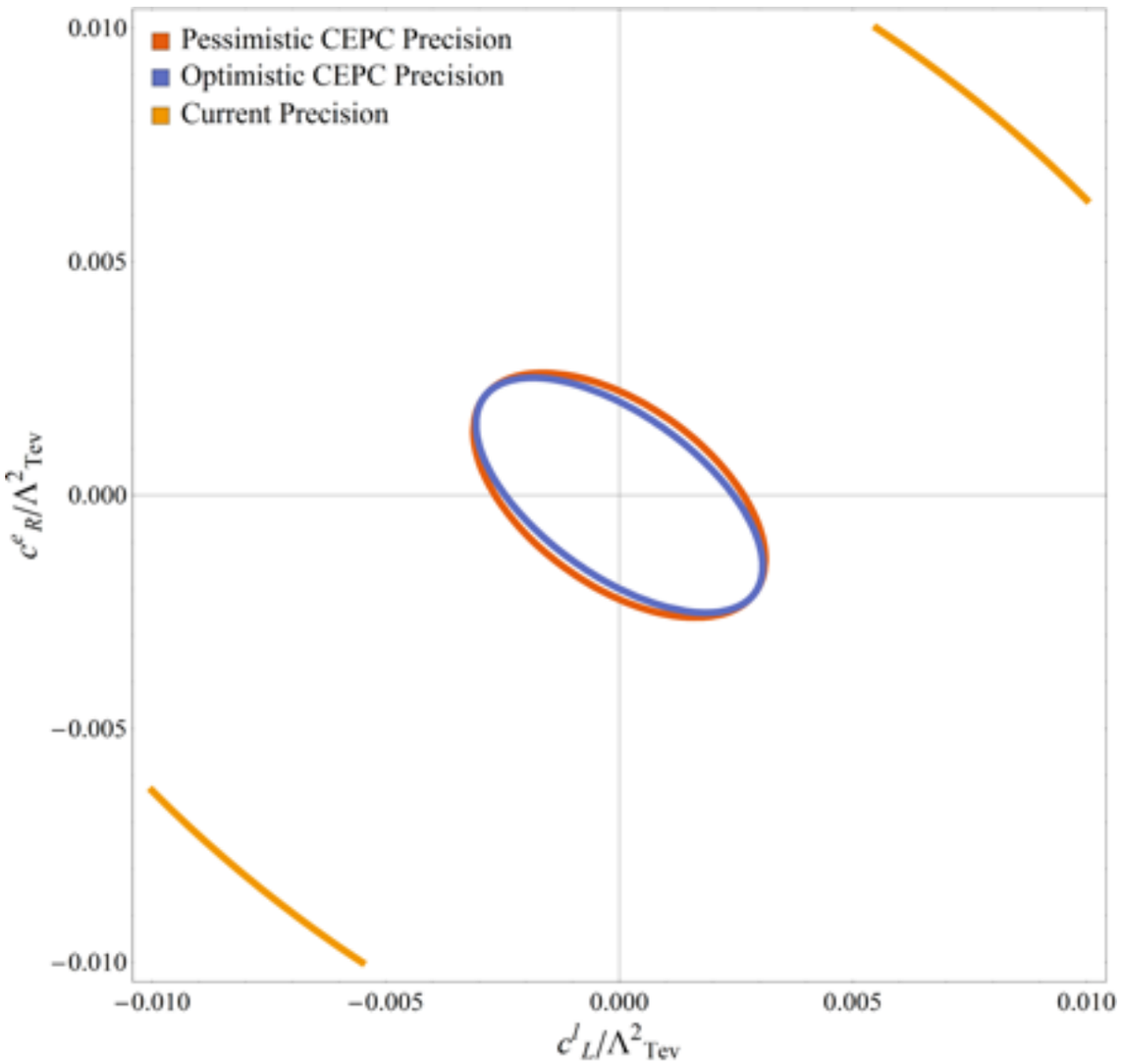
    $150\ \text{fb}^{-1}$ of precision data,

    systematics same order as statistical



$c_L^l - c_R^e$ fit

- Fit using:
  $\sigma(ZH), R_\tau$ and $\sin^2\theta_W^{\text{eff}}$
- Optimistic constraints:
  $5\ \text{ab}^{-1}$ of 250 GeV data at CEPC, $100 - 150\ \text{fb}^{-1}$ of precision data, minimal systematics for Z-Pole and precision EW measurements
- Pessimistic constraints:
  $5\ \text{ab}^{-1}$ of 250 GeV data at CEPC, $100 - 150\ \text{fb}^{-1}$ of precision data, systematics same order as statistical



Effect of O6H

Higgs potential modified

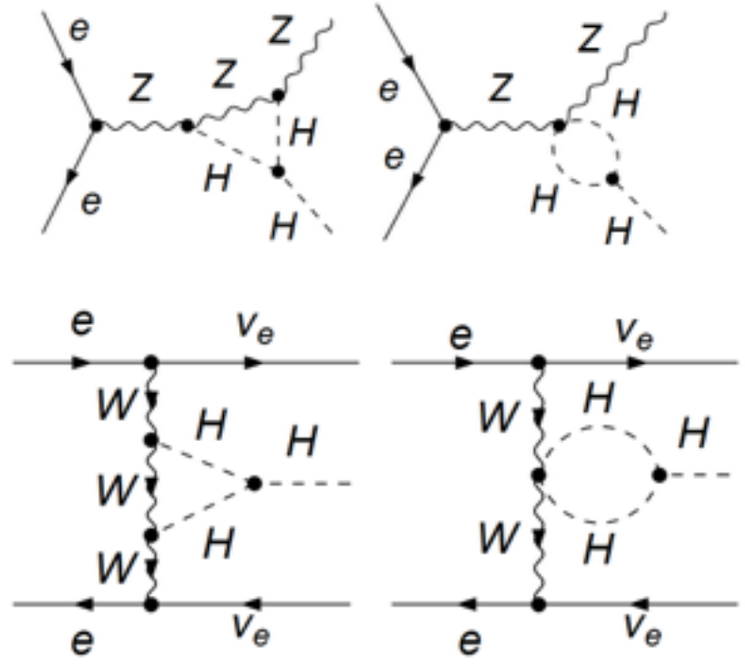
$$V = -\mu^2(H^\dagger H)^2 + \lambda(H^\dagger H)^4 - C_{6H}\frac{(H^\dagger H)^3}{\Lambda^2}$$

But v is invariant⇒ μ and λ are modified

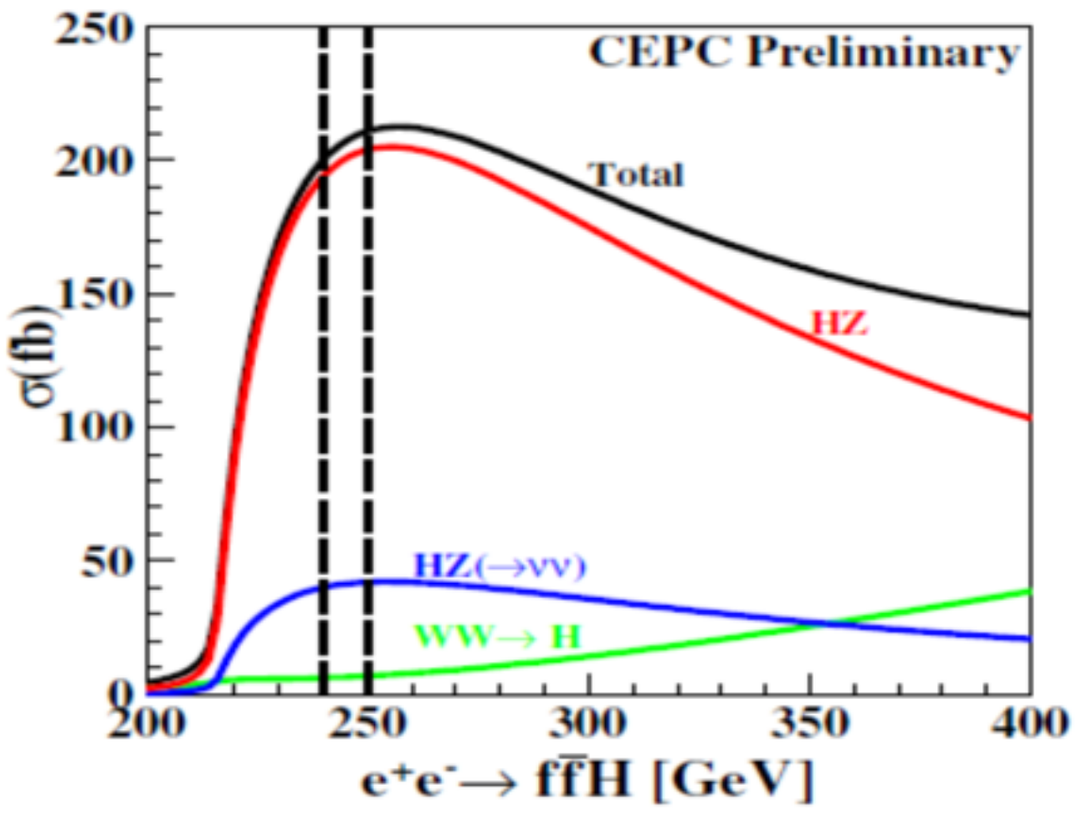
Modified triple Higgs coupling:

$$C_{h^3} = -i\frac{3m_h^2}{v}\left(1 - \frac{2c_{6H}v^4}{m_h^2\Lambda^2}\right)$$

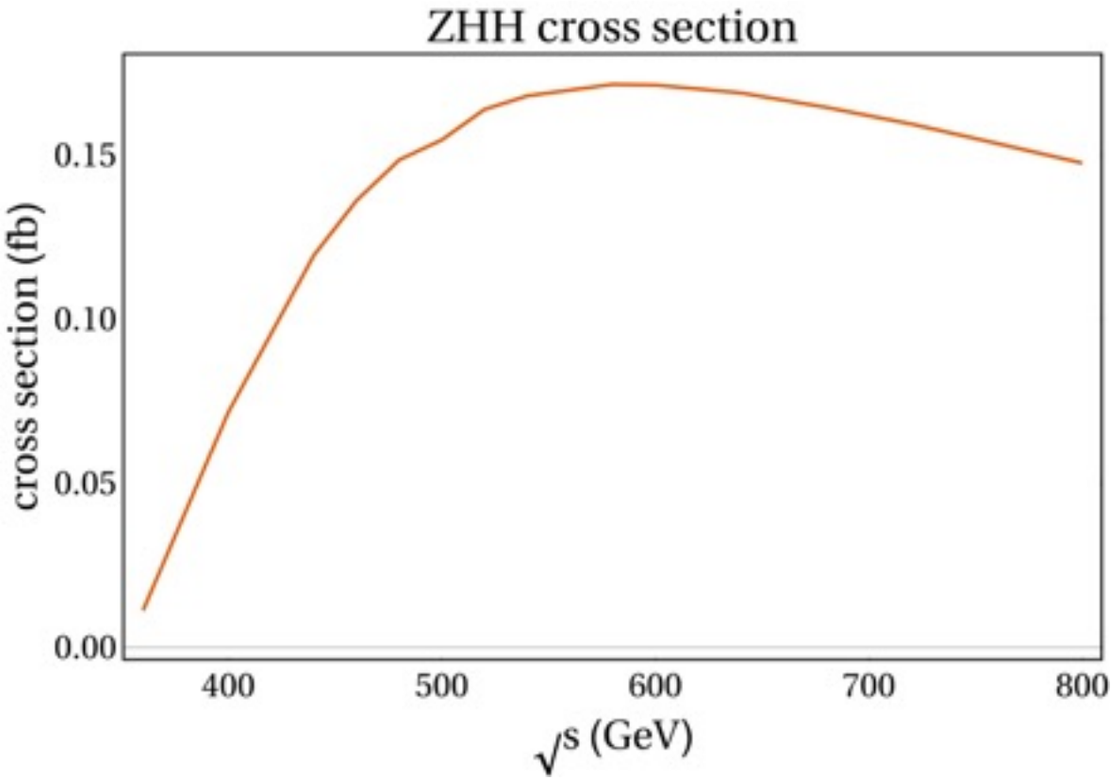
$$= -i\frac{3m_h^2}{v}\left(2 - 0.4703\frac{c_{6H}}{\Lambda^2_{\text{TeV}}}\right)$$

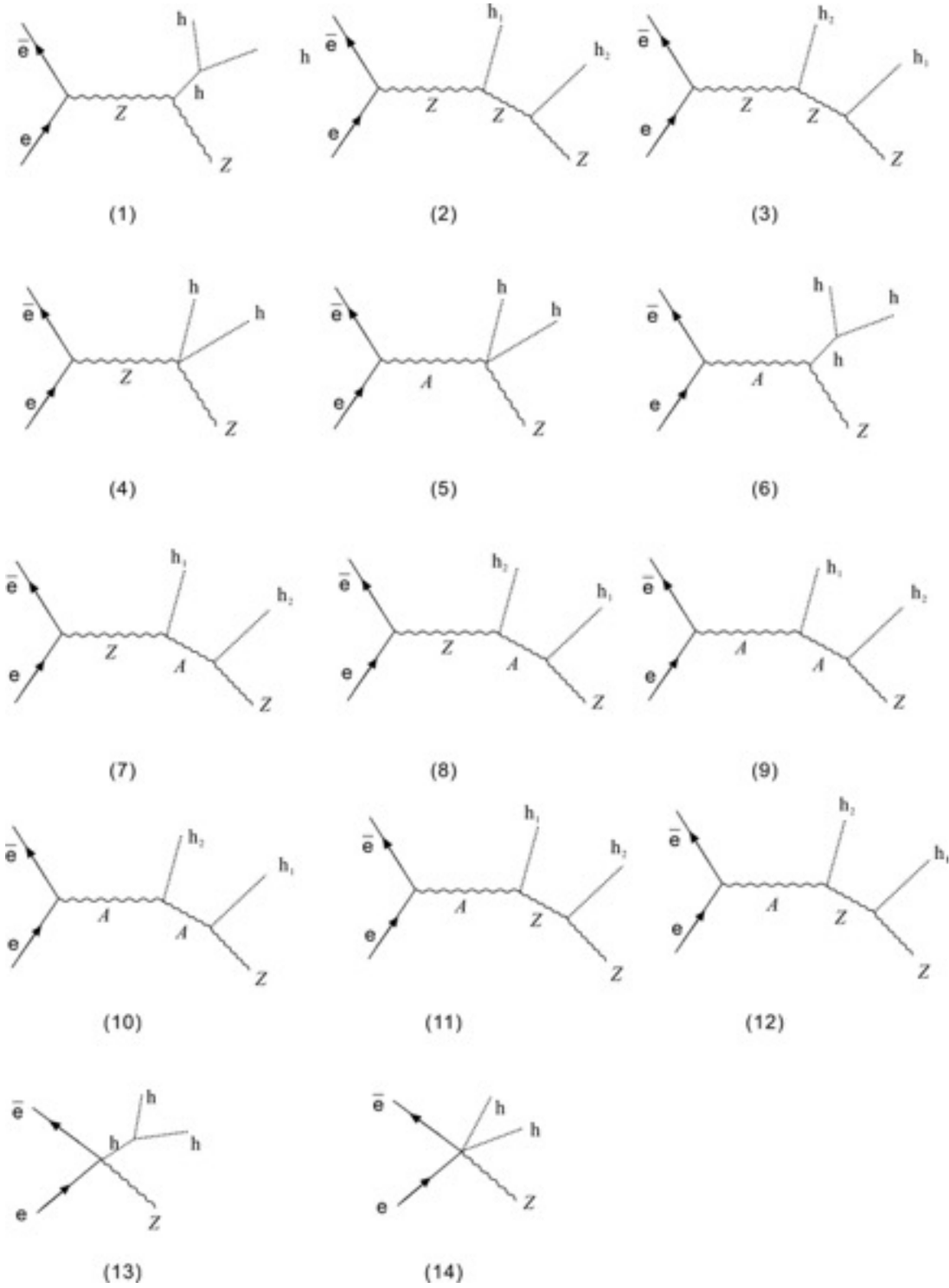


The loop diagrams containing h^3 coupling.
There are no UV divergences



General Comments on ZHH





- Contribute to Zhh at tree level!

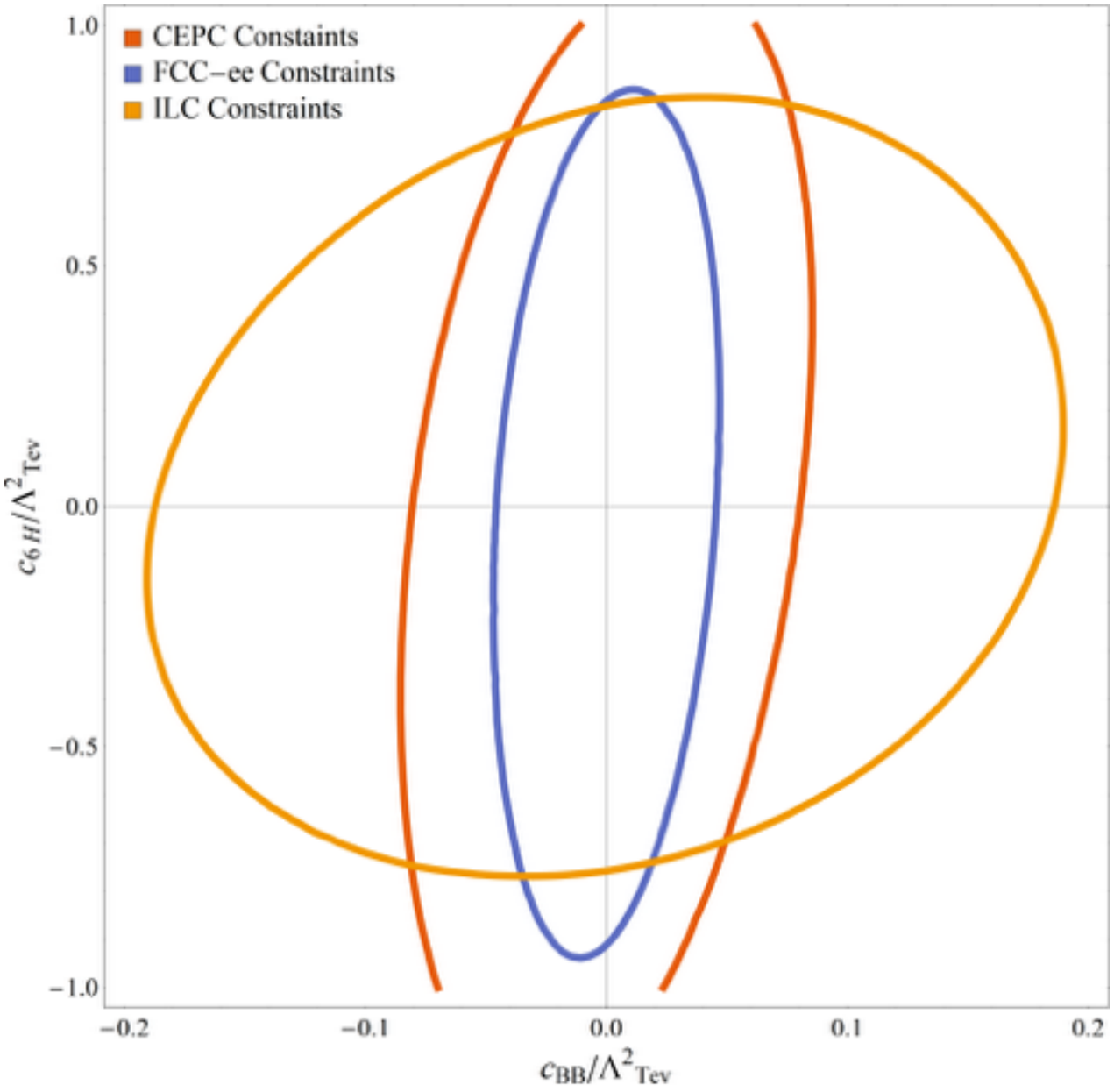
Cross Section Constraints on O6H

Channel	Expected Precision
ZH (250GeV CEPC)	0.5%
ZH(240 GeV FCC-ee)	0.4%
ZH (250GeV 2 ab^{-1}ILC)	0.9%
$\nu\bar{\nu}H$(350GeV FCC-ee)	0.75%
ZHH(500GeV 4 ab^{-1} ILC)	15.1%

arXiv: 1602.05043v2
IHEP-CEPC-DR-2015-01
arXiv: 1506.07830v1
arXiv: 1310.0763v3

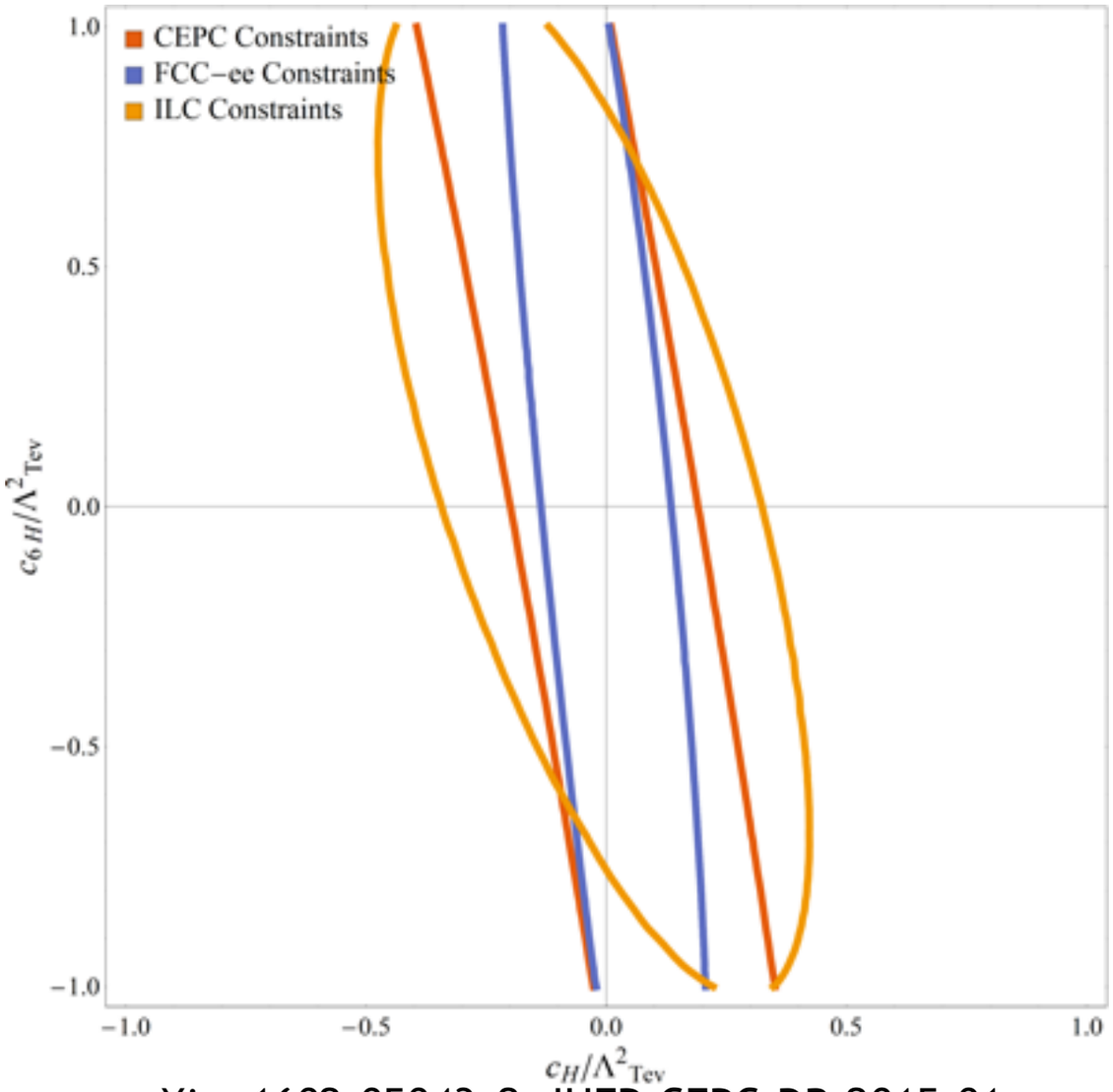
Fitting with O6H

- Fit using:
  $\sigma(ZH), \sigma(ZHH)_{500}$ and $\sin^2\theta_W^{\text{eff}}$
- ILC Constraints:
  $2\ \text{ab}^{-1}$ at 250 GeV, $4\ \text{ab}^{-1}$ at 500 GeV and no Z-Pole measurements
- CEPC constraints:
  $5\ \text{ab}^{-1}$ of 250 GeV data at CEPC, $150\ \text{fb}^{-1}$ of precision data, minimal systematics
- FCC-ee constraints:
  $10\ \text{ab}^{-1}$ of 240 GeV data, $220\ \text{ab}^{-1}$ of precision data



Fitting with O6H

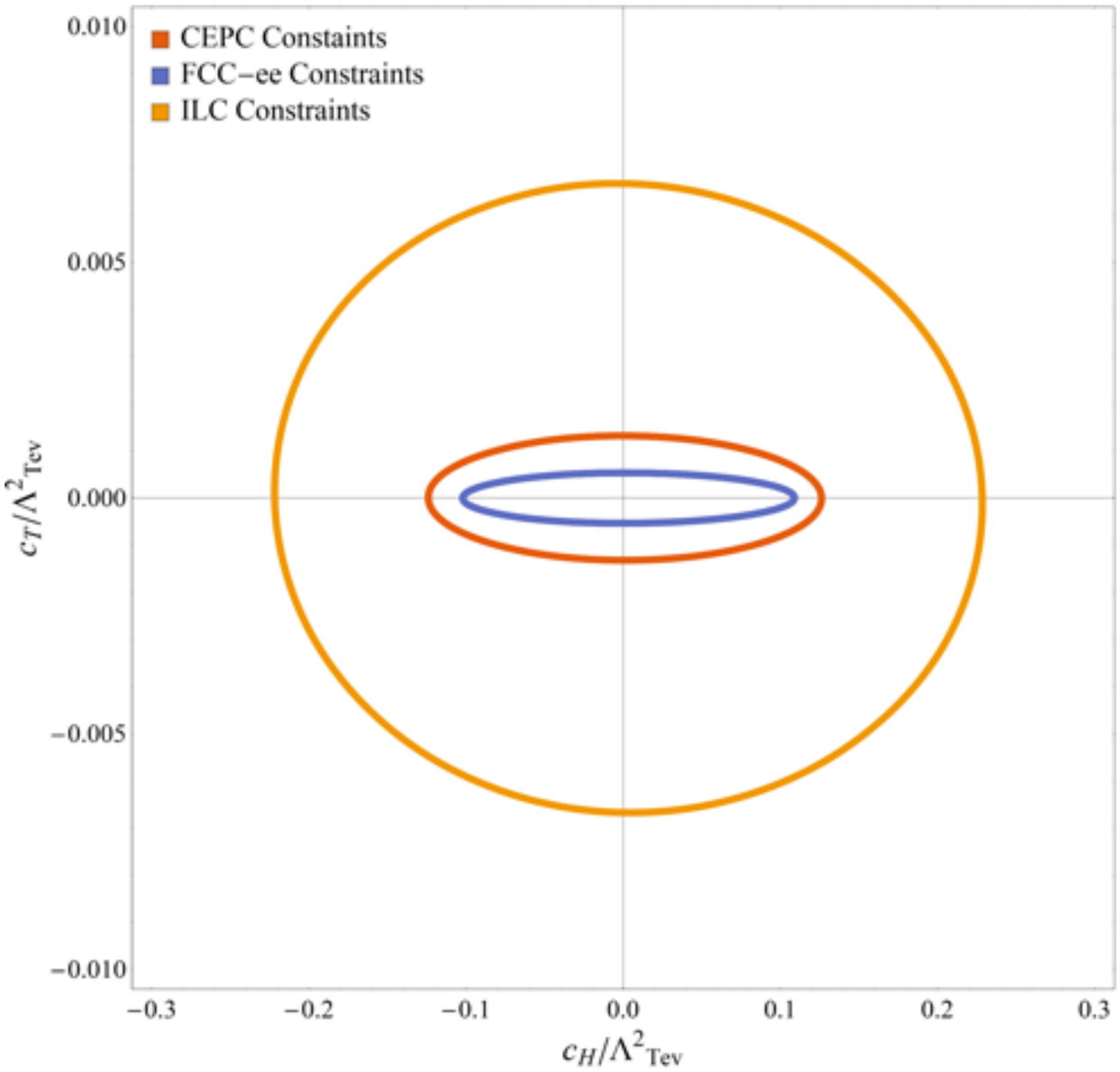
- Fit using: $\sigma(ZH), \sigma(\nu\bar{\nu}H)_{350}$ and $\sigma(ZHH)_{500}$
  - CEPC Constraints:
    $5\ \text{ab}^{-1}$ of 250 GeV data at CEPC
  - FCC-ee constraints:
    $10\ \text{ab}^{-1}$ of 240 GeV data, $2.5\ \text{ab}^{-1}$ of 350 GeV data
  - ILC Constraints:
    $2\ \text{ab}^{-1}$ at 250 GeV and $4\ \text{ab}^{-1}$ at 500 GeV and no Z-Pole measurements



arXiv: 1602.05043v2, IHEP-CEPC-DR-2015-01
arXiv: 1506.07830v1, arXiv: 1310.0763v3

Fitting with O6H

- Fit using:
  $\sigma(ZH), \sigma(\nu\bar{\nu}H)_{350}$ and M_W
  - CEPC constraints:
    $5\ \mathrm{ab}^{-1}$ of 250 GeV data at CEPC, $150\ \mathrm{fb}^{-1}$ of precision data, minimal systematics
- FCC-ee constraints:
  $10\ \mathrm{ab}^{-1}$ of 240 GeV data, $2.5\ \mathrm{ab}^{-1}$ of 350 GeV data, $220\ \mathrm{ab}^{-1}$ of precision data
- ILC Constraints:
  $2\ \mathrm{ab}^{-1}$ at 250 GeV



Summary

- Correlation among the HDOs are important
- This effect should be incorporated while analyzing the sensitivities at future Higgs factories
- A comparative study is on the way ……