THE 2018 INTERNATIONAL WORKSHOP ON HIGH ENERGY CIRCULAR ELECTRON POSITRON COLLIDER

Higgs BSM Interpretations

刘真
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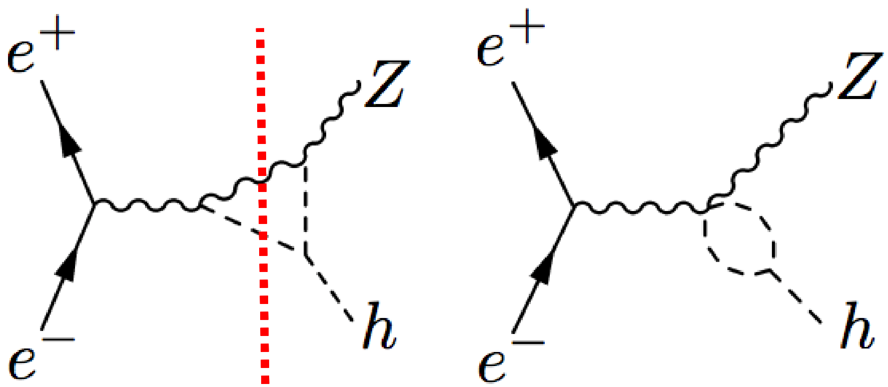
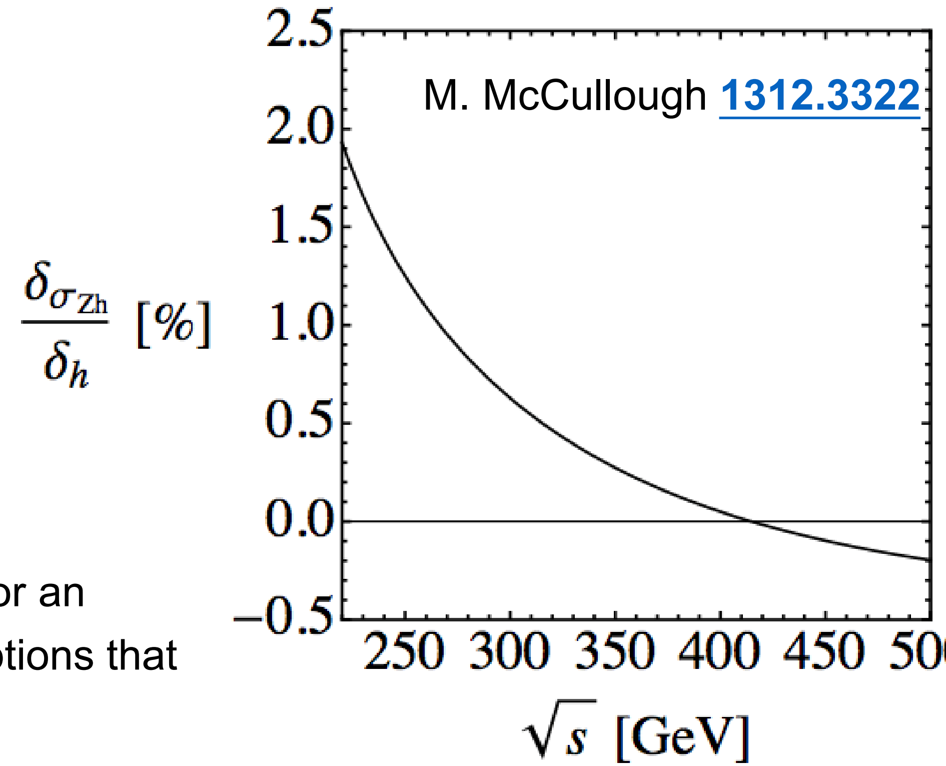
Nov.14, 2018

Based upon:
S. Di Vita, G. Durieux, Grojean, Gu, ZL , G. Panico, M. Riembau, T. Vantalon, 1711.03978,
J. Gu, H. Li, ZL, S. Su, W. Su, 1709.06103

Constraints from $e^+e^- \to ZH$





O(30%) precision achievable, at 5 ab^-1 for an unpolarized e+e- machine, with some assumptions that we will break down in the next few slides;

Constraints from $e^+e^- \to ZH$: discussion

Hard to achieve single O_6 operator from UV point of view;

To gain knowledge about the O_6 in presence of other operators one needs to include more observables;

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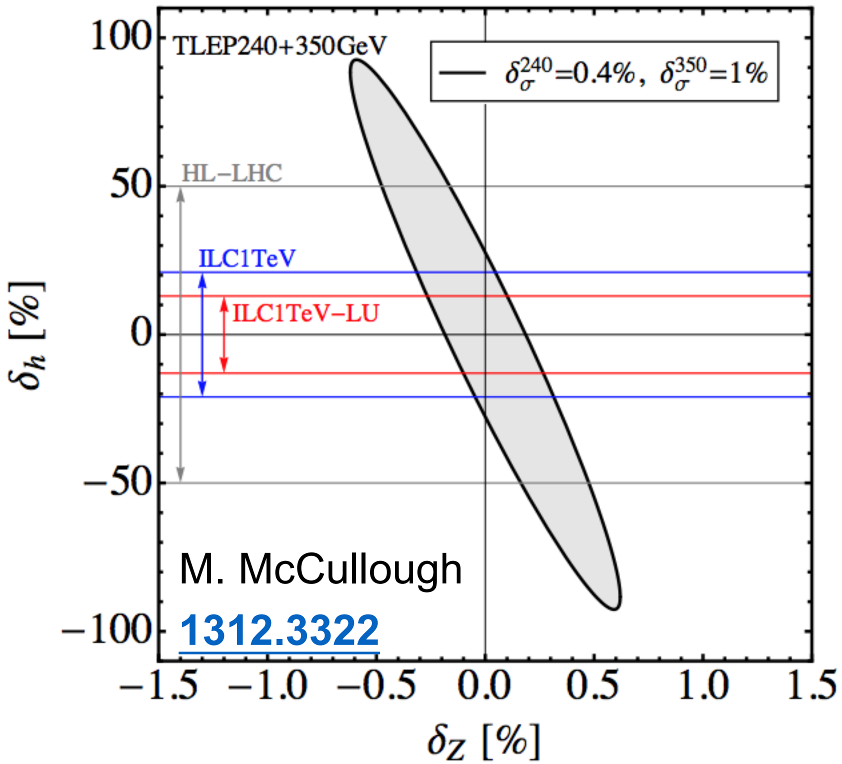


Hard to achieve single O_6 operator from UV point of view;

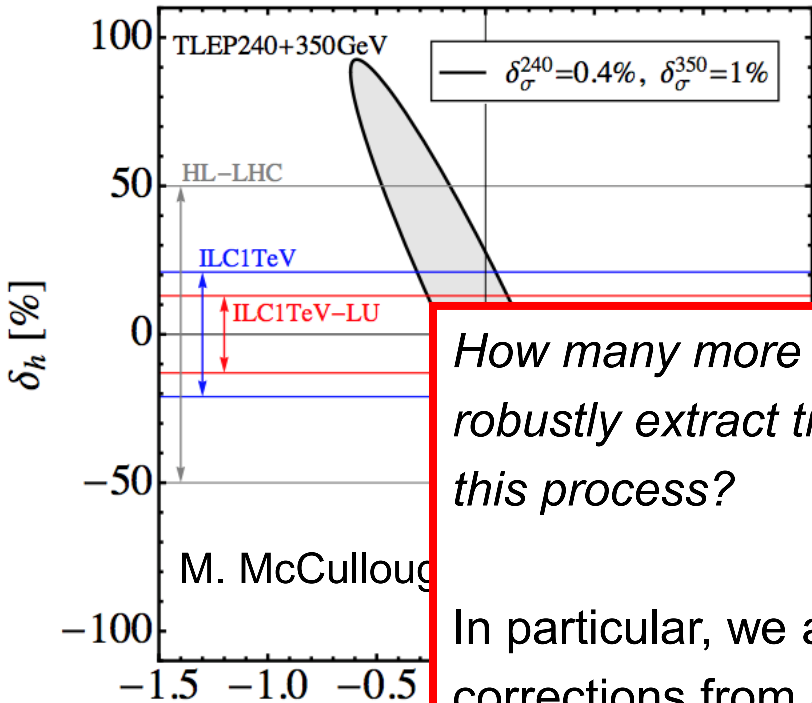
To gain knowledge about the O_6 in presence of other operators one needs to include more observables;

Taking the simplest extension of the SM:

SM+1 singlet O_H and O_6 are simultaneously generated, can be translated into δ_h and δ_Z here;*

One can use the $e^+e^- \to ZH$ cross section at different center of mass energy to constrain the Higgs trilinear coupling.

Constraints from $e^+e^- \to ZH$: discussion



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How many more do we need to include to robustly extract trilinear Higgs couplings from this process?

In particular, we are extracting loop-level corrections from SM corrections on a tree-level process; any imprecise determination of other BSM contributions could spoil this.

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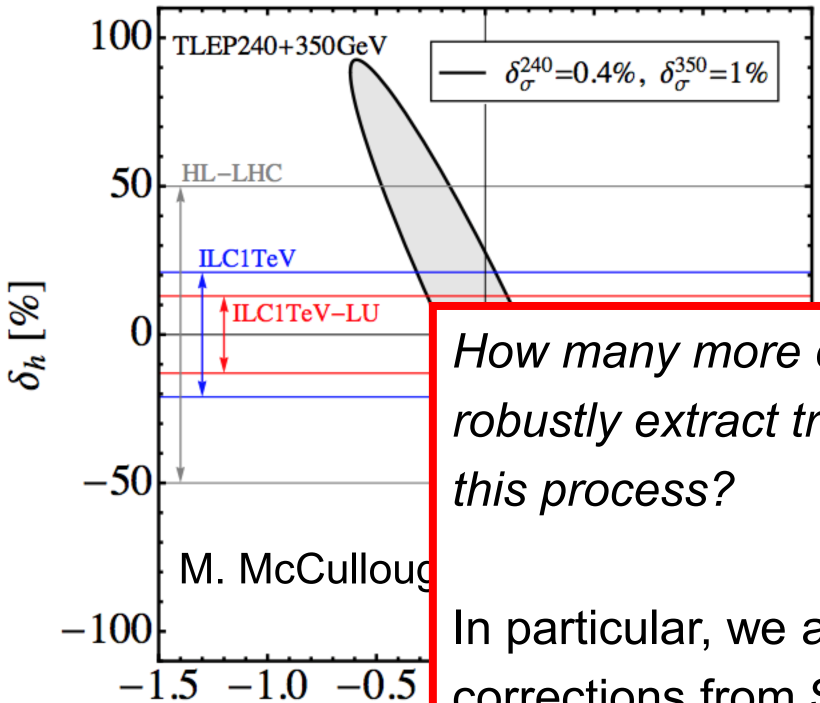

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EFT is a nice framework to address this issue:

a) ``model blind'';

b) Can relate different measurements at different scales and observables, allowing a more consistent/transparent treatment beyond Higgs observables;

more operators

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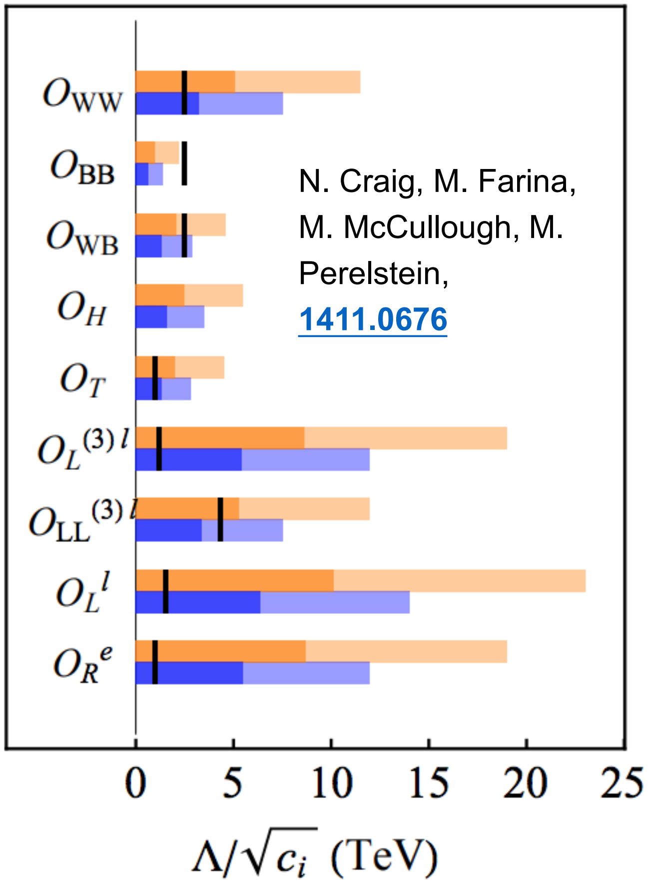
$$\mathcal{O}_{WW} = g^2|H|^2 W^a_{\mu\nu}W^{a,\mu\nu}$$
$$\mathcal{O}_{BB} = g'^2|H|^2 B_{\mu\nu}B^{\mu\nu}$$
$$\mathcal{O}_{WB} = gg' H^\dagger\sigma^a H W^a_{\mu\nu}B^{\mu\nu}$$
$$\mathcal{O}_H = \tfrac{1}{2}(\partial_\mu|H|^2)^2$$
$$\mathcal{O}_T = \tfrac{1}{2}(H^\dagger \overleftrightarrow{D}_\mu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



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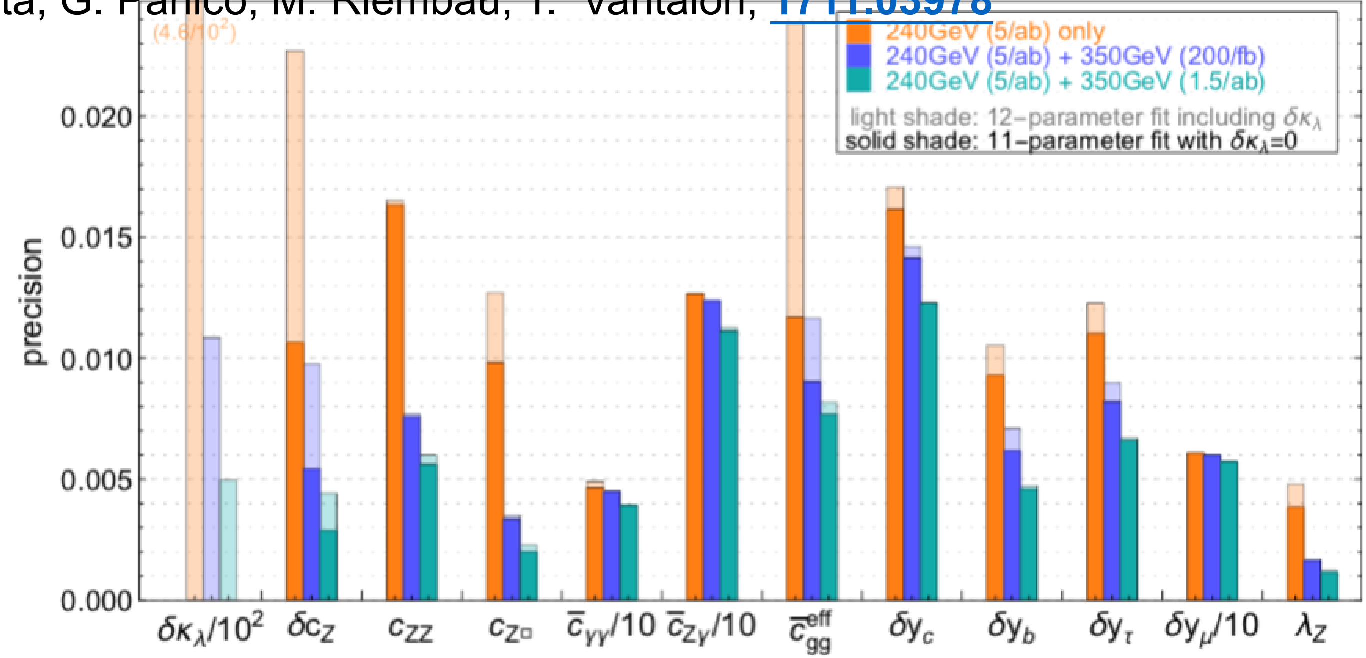
9 tree-level CP even dimension-6 operators contributing at linear level;

<u>and more if we include some of the SM input parameter uncertainties;</u>

Angular asymmetries help probe these operators, see N. Craig, J. Gu, ZL, K. Wang, 1512.06877

more operators

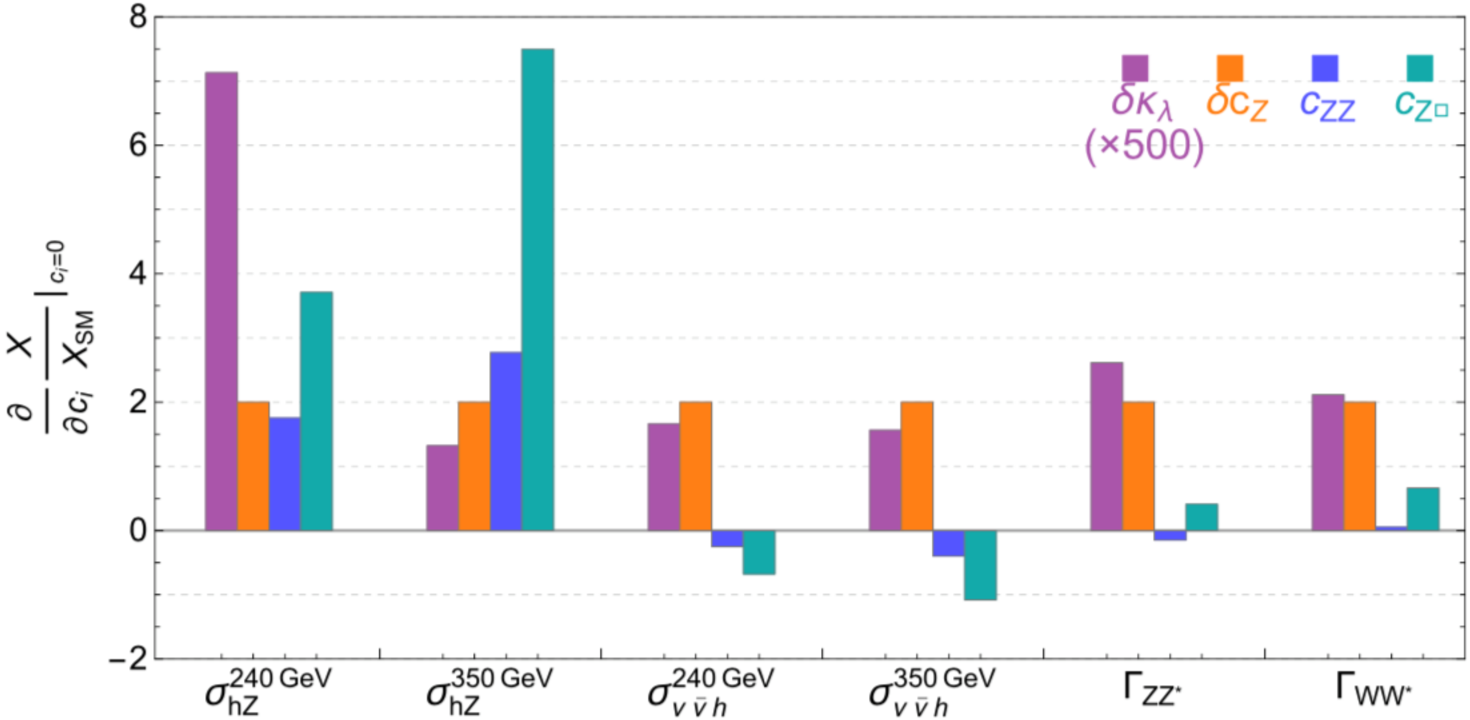
Higgs fit *without* trilinear, see Durieux, Grojean, Gu, Wang, [1704.02333](), Jiayin Gu's talk next , and with trilinear + more observables, +ZL , S. Di Vita, G. Panico, M. Riembau, T. Vantalon, [1711.03978]()



- The impact of adding the new d.o.f. of Higgs trilinear modifications is quite sizable;
- Strong correlations between the trilinear modification and the parameter (hZZ shifting); already seen in the simplest example for the singlet extension;
- Sizable reduction in other ``coupled'' coefficients;

More observables (that are sensitive to Higgs trilinear)

linear dependences of observables to parameters $\delta\kappa_\lambda$, δc_Z, c_{ZZ}, $c_{Z\square}$



New probes:

Cross sections at different c.o.m. energies, 240 GeV & 350 GeV ;

Different production processes, ZH & WW-fusion;

Decay processes, WW^* and ZZ^*;

C_1 linear dependence on trilinear modifications

G. Degrassi, P. Giardino, F. Maltoni, D. Pagani,

1607.04251

C_1	ZZ	WW	$\gamma\gamma$	gg	$f\bar{f}$
on-shell h decay	0.0083	0.0073	0.0049	0.0066	0

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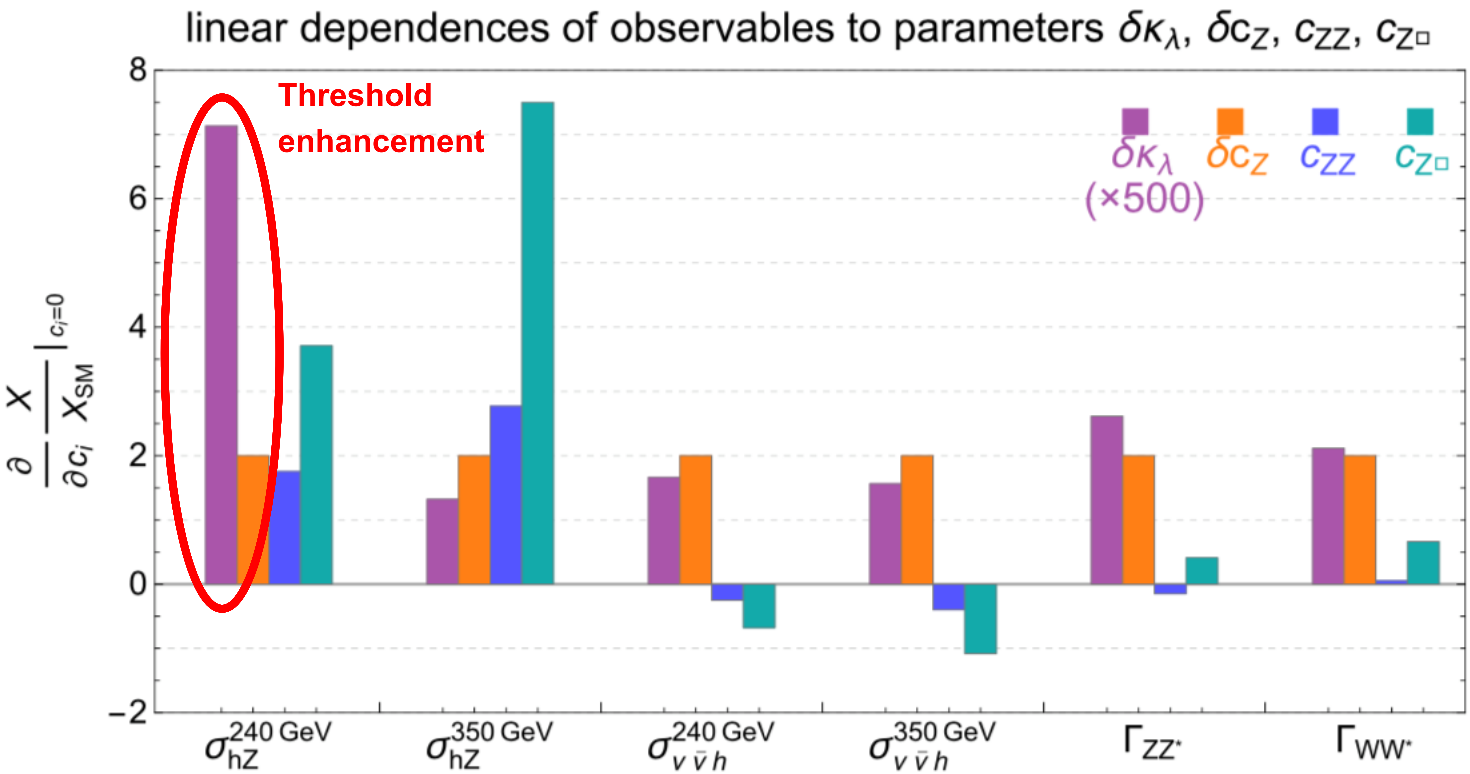

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C_1 linear dependence on trilinear modifications

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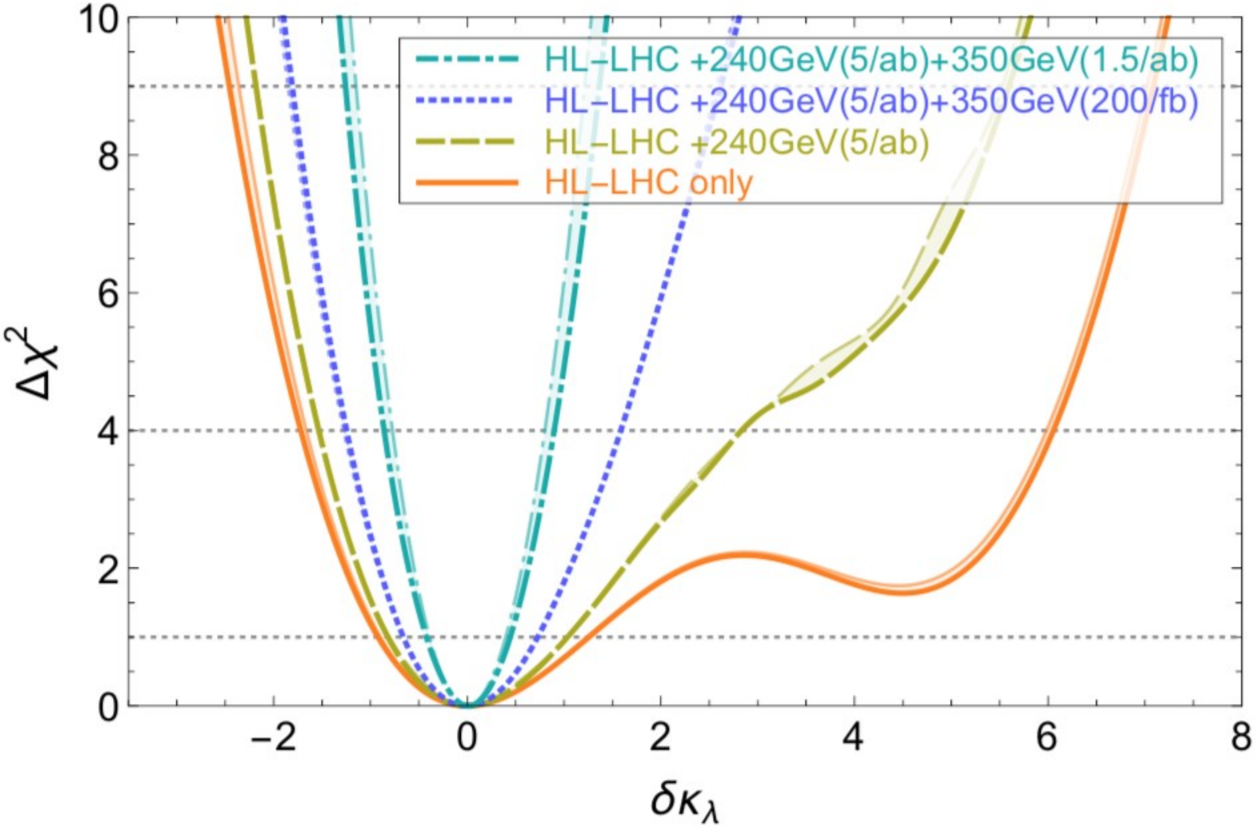
Results

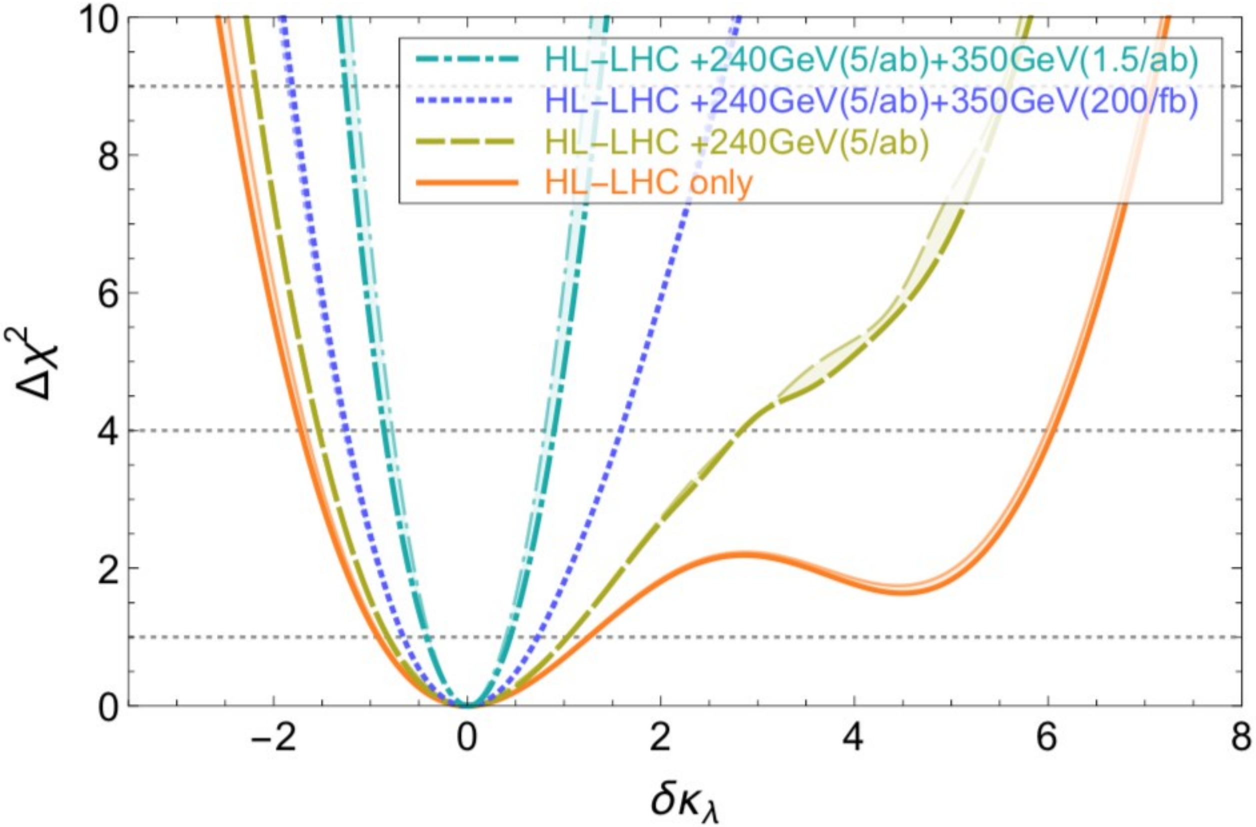


After profiling over the other 12 (11) EFT coefficients, we obtain the $\Delta\chi^2$ distribution of the Higgs trilinear coupling;

CEPC can determine the trilinear coupling to $^{+1.05}_{-0.85}$ in this general EFT framework, after combining with HL-LHC.

*bands corresponds to 0.1% to 1% systematic uncertainties assumed for aTGCs

Results



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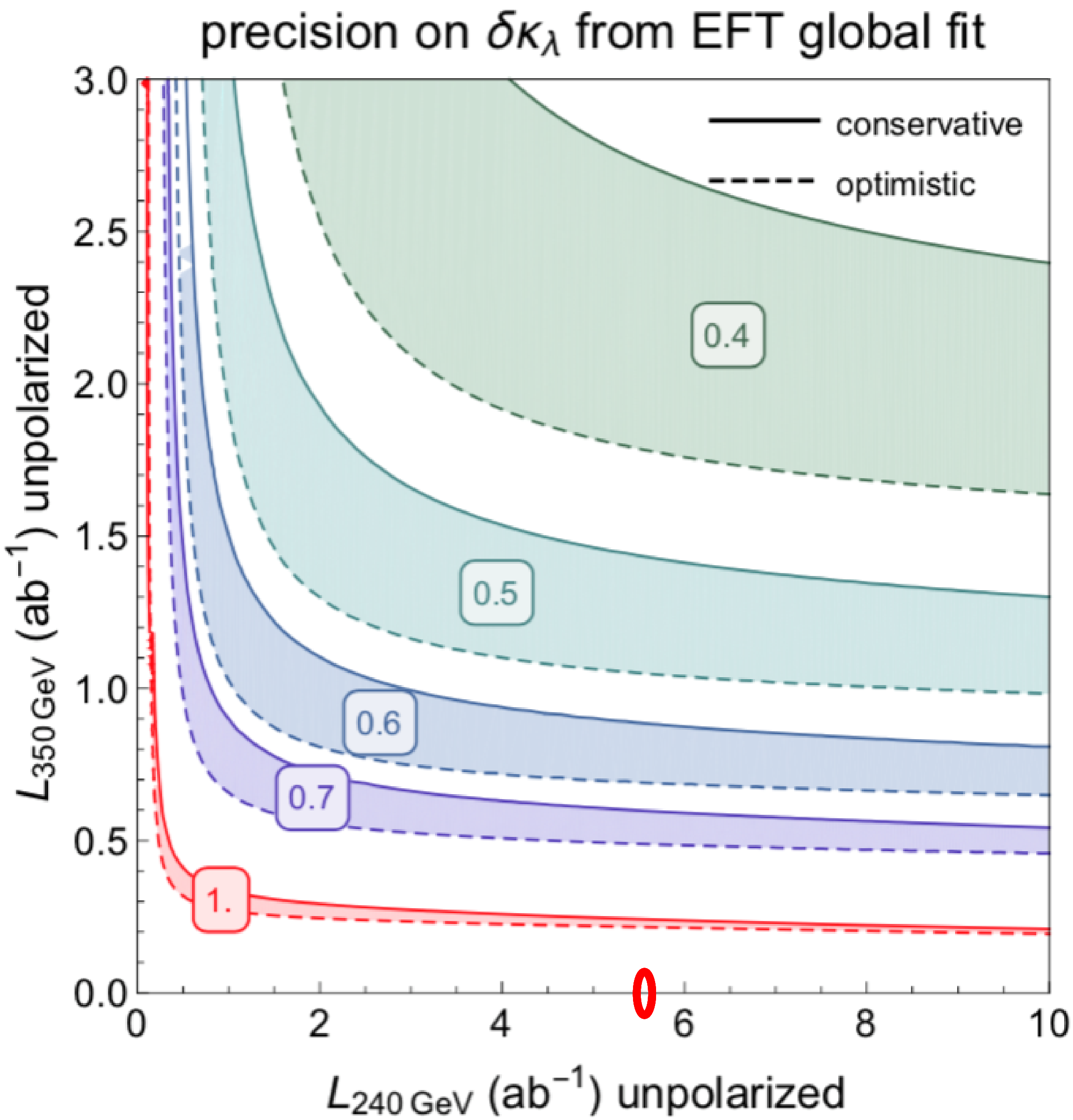
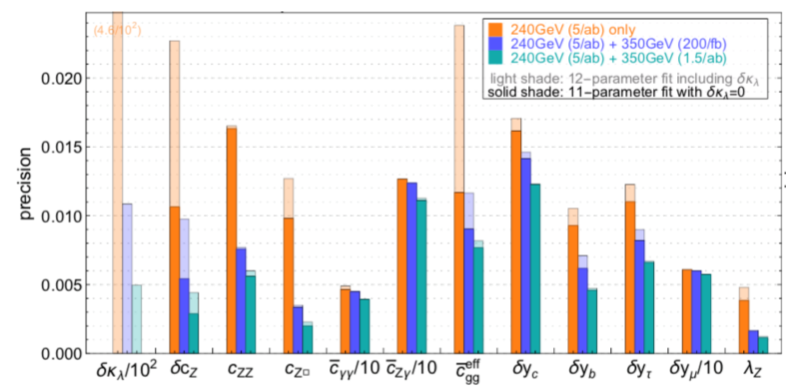
CEPC can determine the trilinear coupling to $^{+1.05}_{-0.85}$ in this general EFT framework, after combining with HL-LHC.

- Higgs precision improves the HL-LHC results on Higgs trilinear coupling significantly;
- Complementary information in the Higgs precision program at 350 GeV c.o.m. further improves the results significantly;

Results: 240 GeV and 350 GeV interplay





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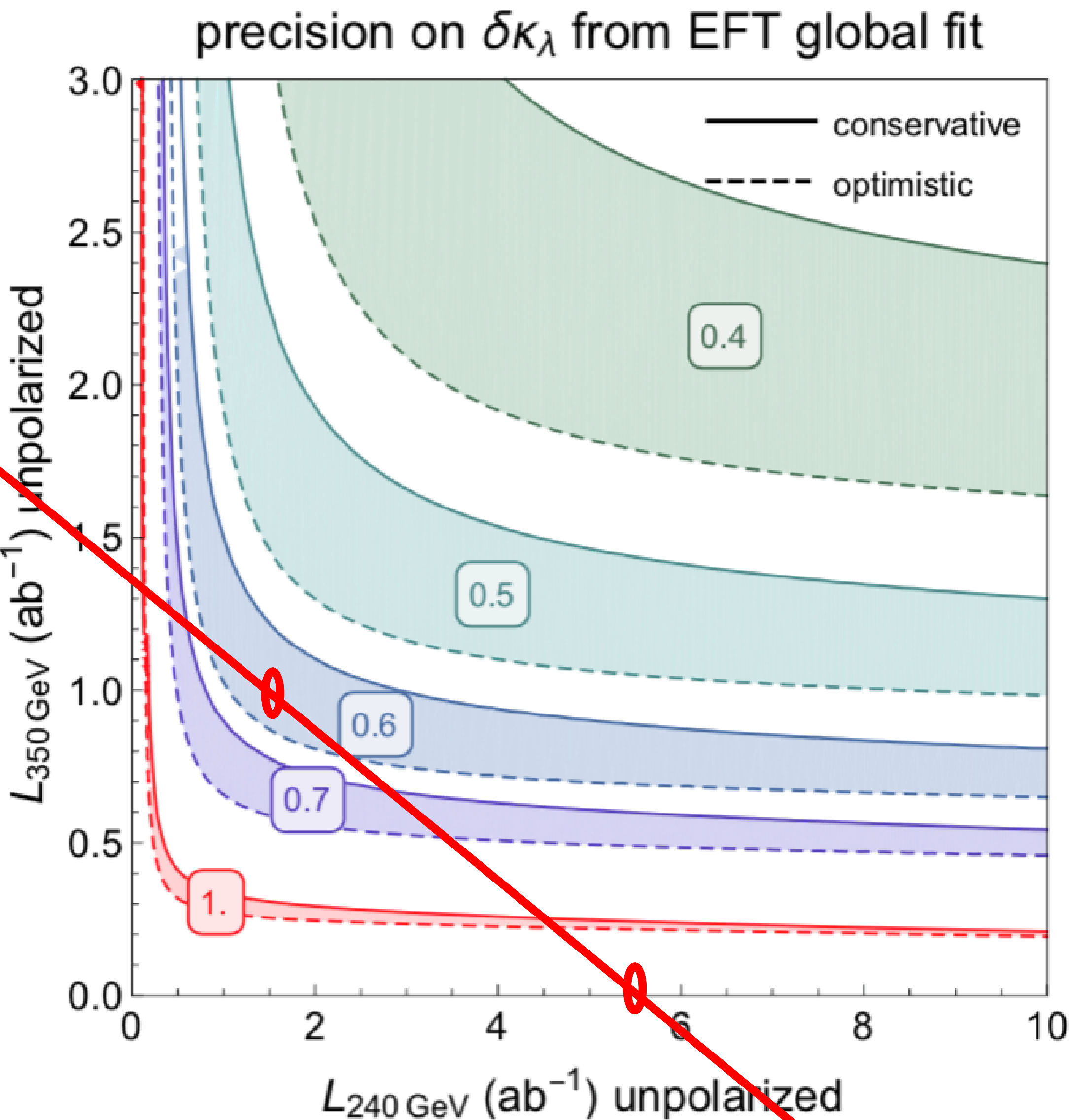
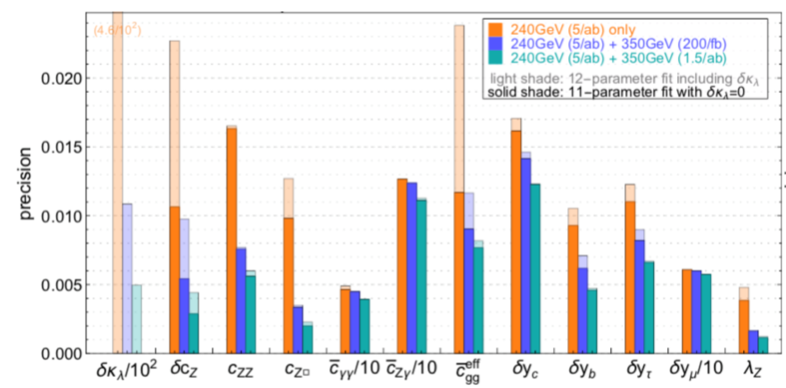


- Assuming that the instantaneous luminosity of 350 GeV is ¼ of 240 GeV run, one can find the optimal running point for the Higgs trilinear;

- Similar practice can be done for many others, physics goals need to be chosen carefully.



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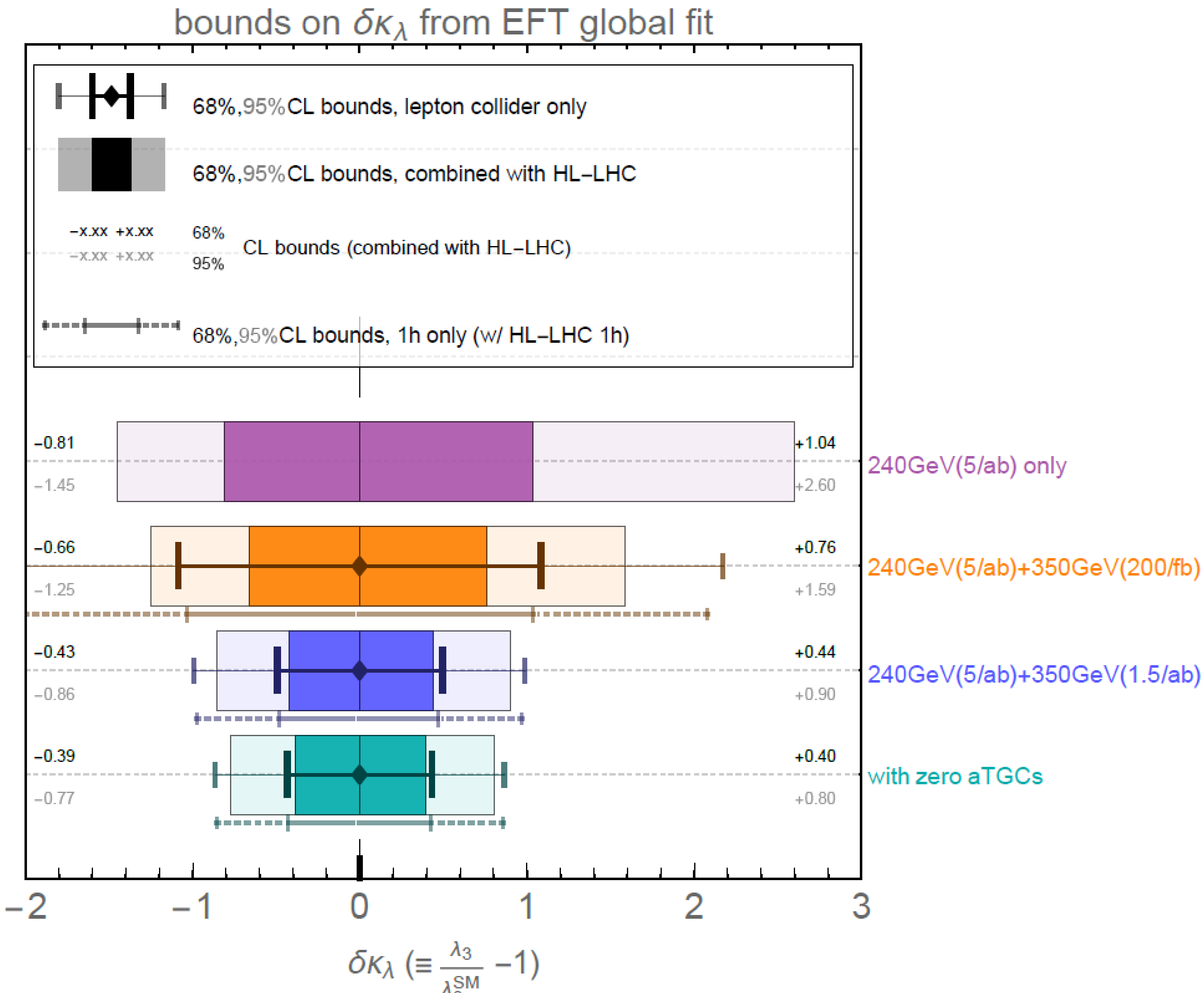
Results: complementarities



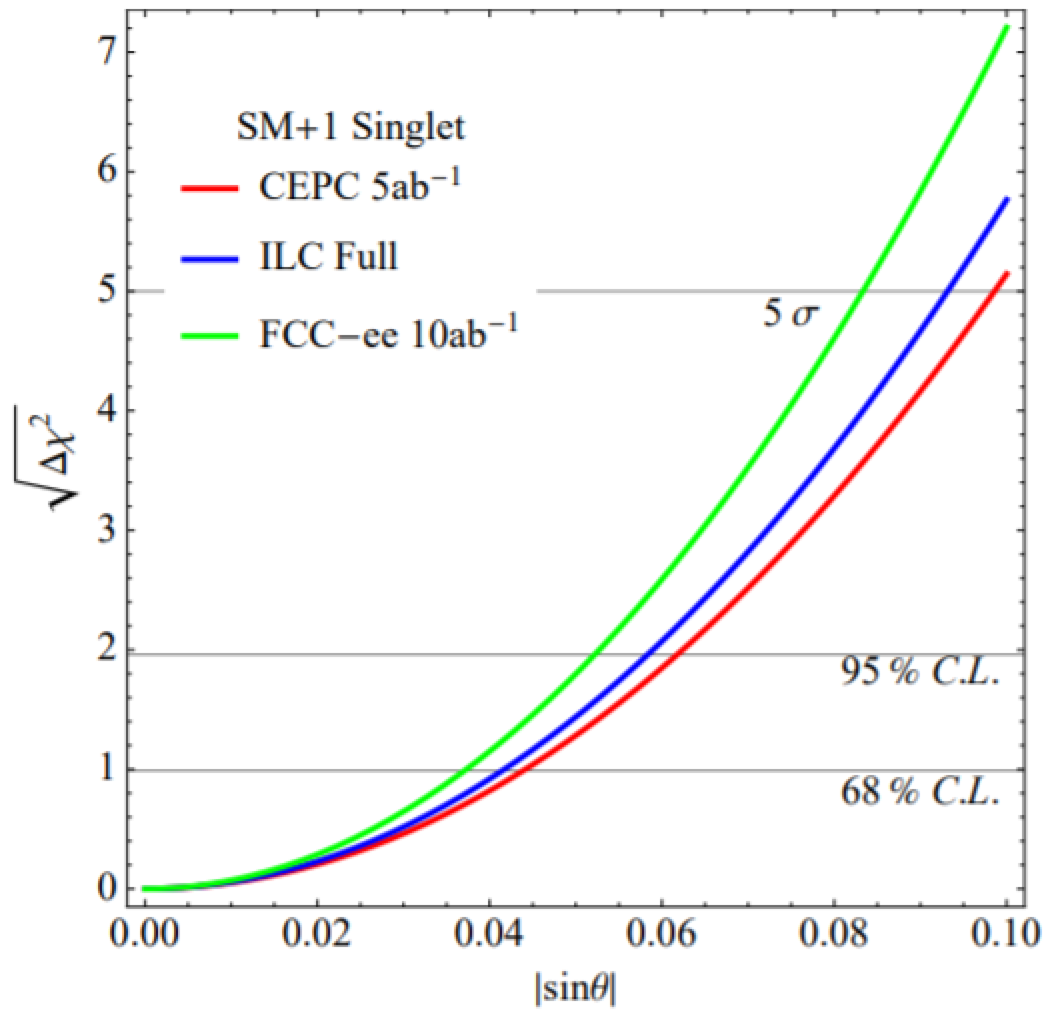
*After profiling over other parameters and use $\Delta\chi^2 = 1$ and 4. we define the 68% and 95% C.L. level:

A UV model does not span the whole EFT space…

Singlet extension of the SM

Part I

$$H \quad = \cos\theta\ h + sin\theta\ S$$



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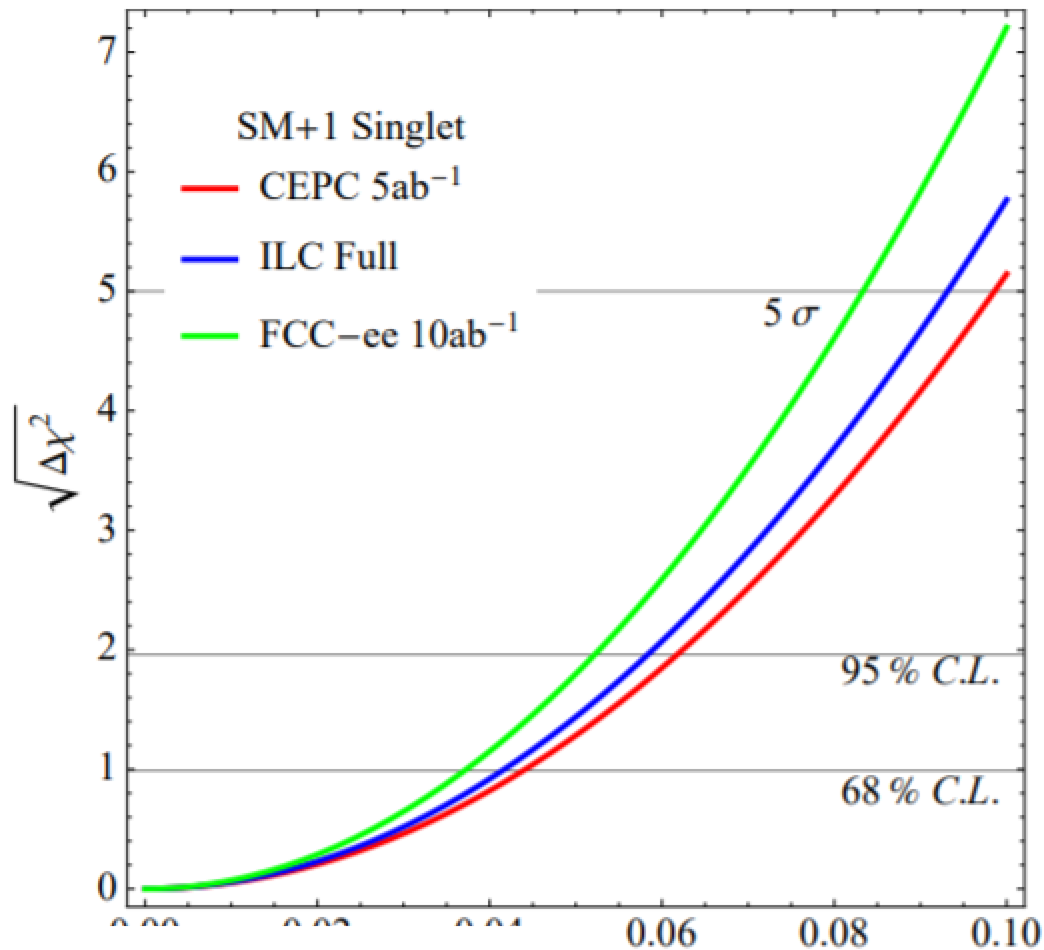
More than Higgs wave-function renormalization



$$\Delta\mathcal{L} = \frac{c_H}{\Lambda^2}\mathcal{O}_H + \frac{c_6}{\Lambda^2}\mathcal{O}_6, \quad \text{with } \mathcal{O}_H \equiv \frac{1}{2}(\partial_\mu |H^\dagger H|)^2, \quad \mathcal{O}_6 \equiv |H^\dagger H|^3.$$ $\sin\theta|$

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 - \Lambda_{SH} S(H^\dagger H) - \frac{1}{2}\lambda_{SH} S^2 (H^\dagger H) - \frac{1}{3!}\Lambda_S S^3 - \frac{1}{4!}\lambda_S S^4$$

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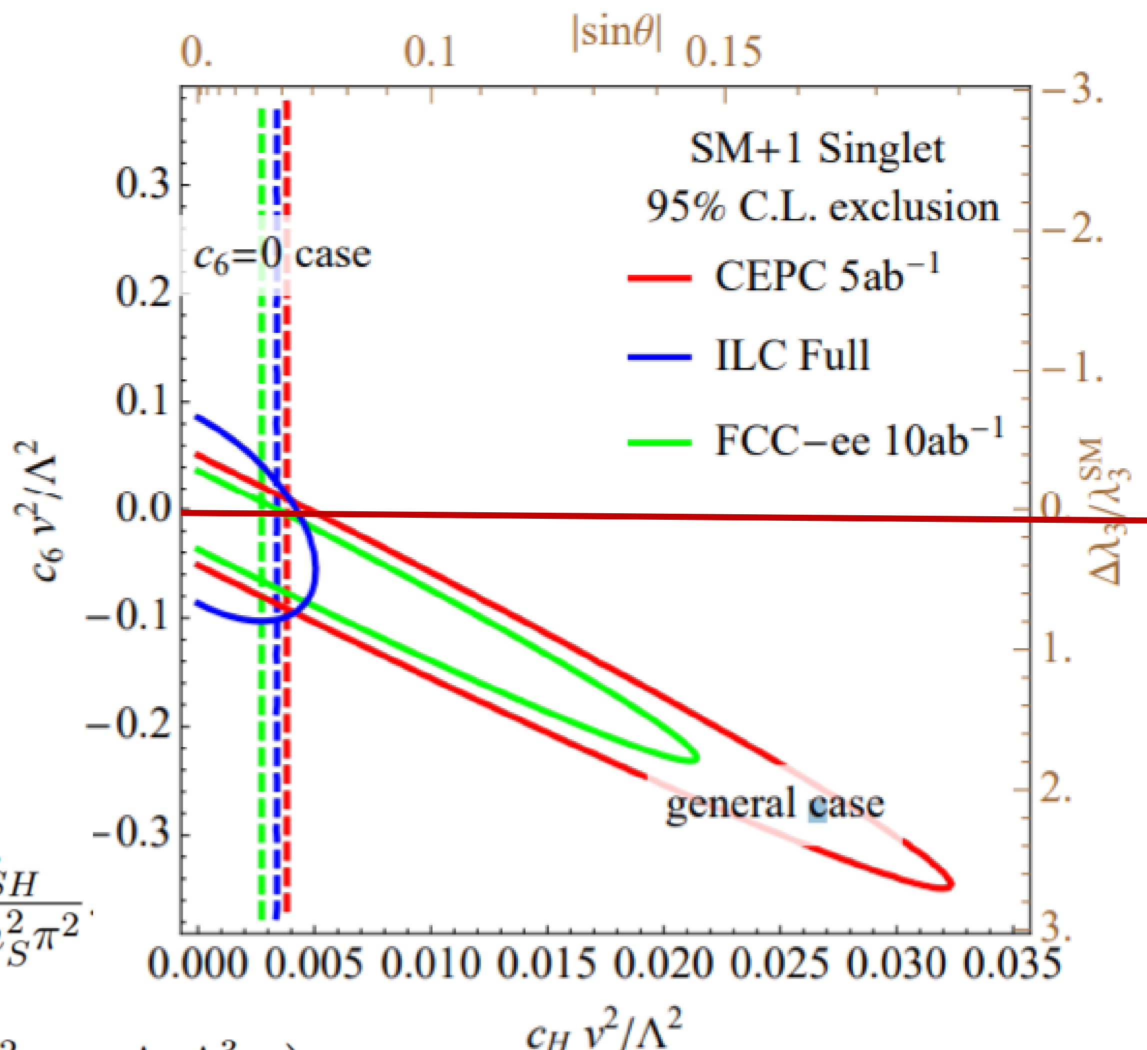
Singlet extension of the S

Part II

Operators generated at booth tree-level and loop-level (leading when Z2 present)

$$\frac{c_H}{\Lambda^2} = \frac{\lambda_{SH}^2}{48 m_S^2 \pi^2}, \qquad \frac{c_6}{\Lambda^2} = -\frac{\lambda_{SH}^3}{48 m_S^2 \pi^2}.$$

$$\frac{c_H}{\Lambda^2} = \frac{\Lambda_{SH}^2}{m_S^4}, \qquad \frac{c_6}{\Lambda^2} = \left(-\frac{\lambda_{SH}\Lambda_{SH}^2}{2m_S^4} + \frac{\Lambda_S \Lambda_{SH}^3}{6m_S^6}\right)$$



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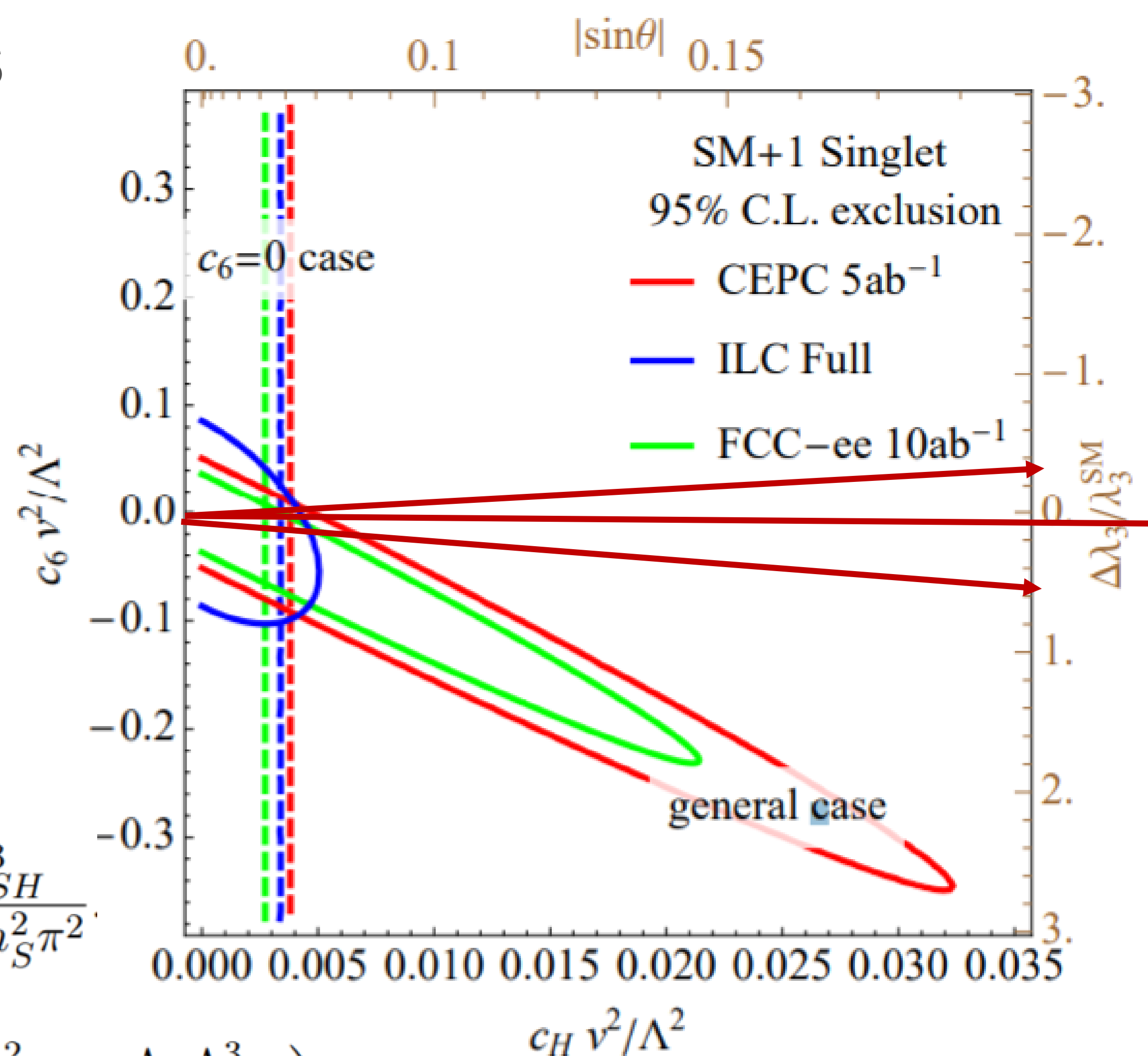

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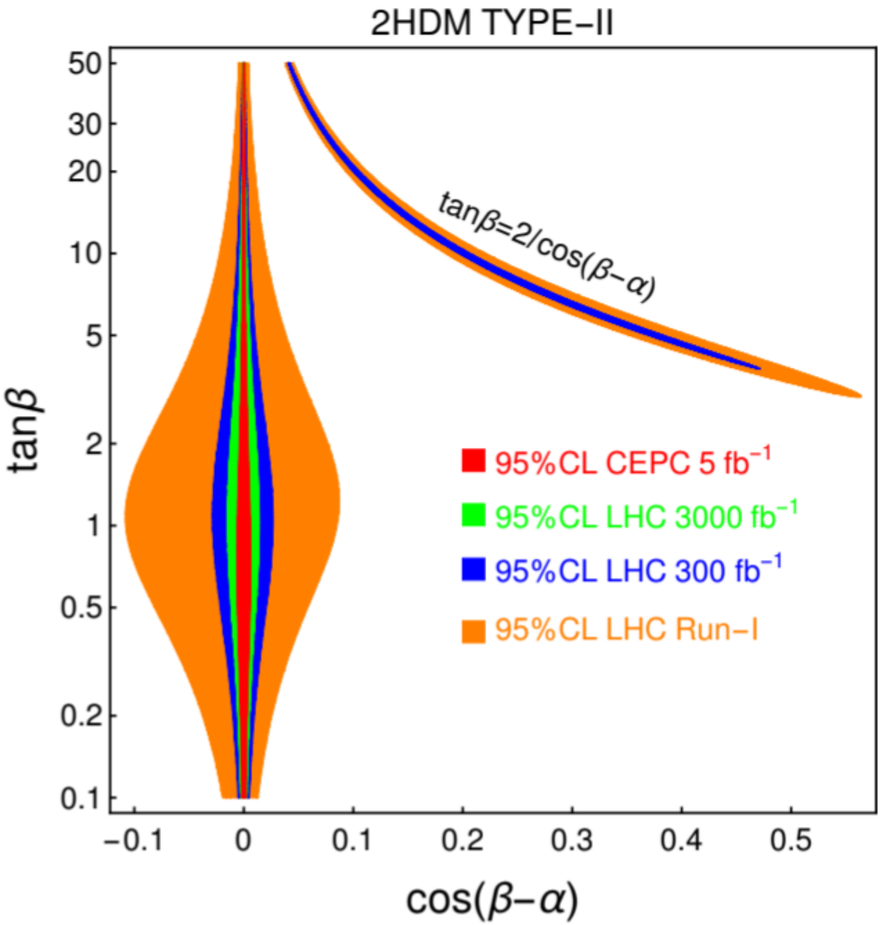
2HDM



Tree-level results through mixing and coupling modifiers

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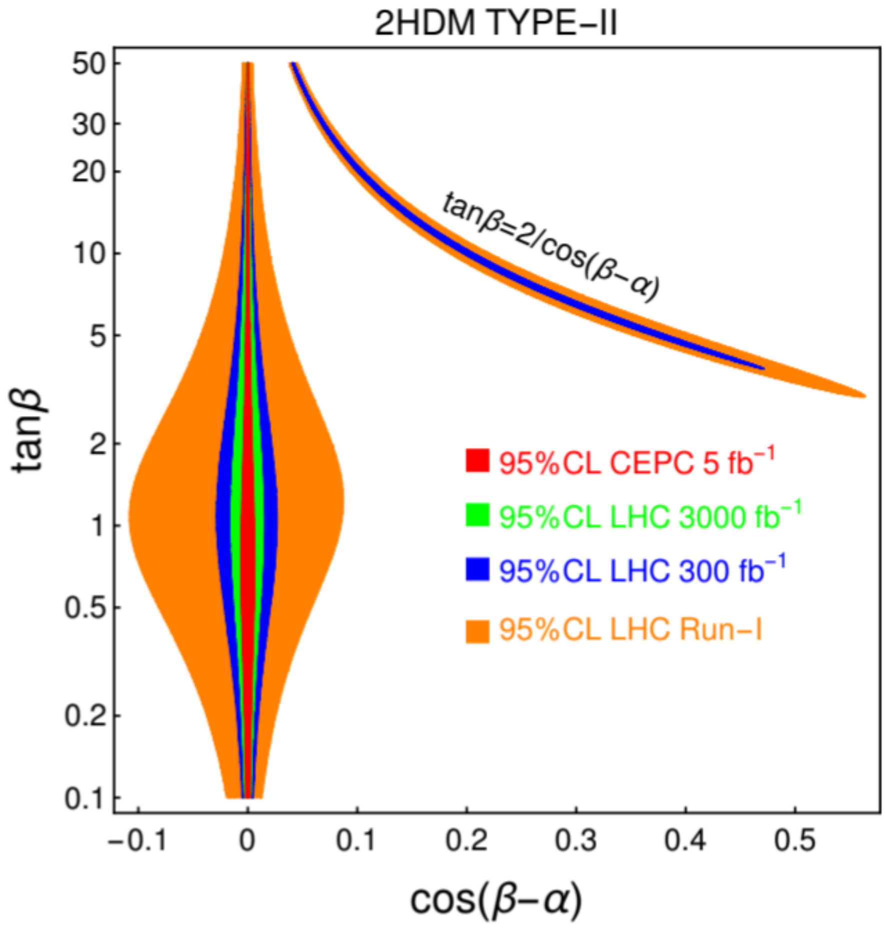

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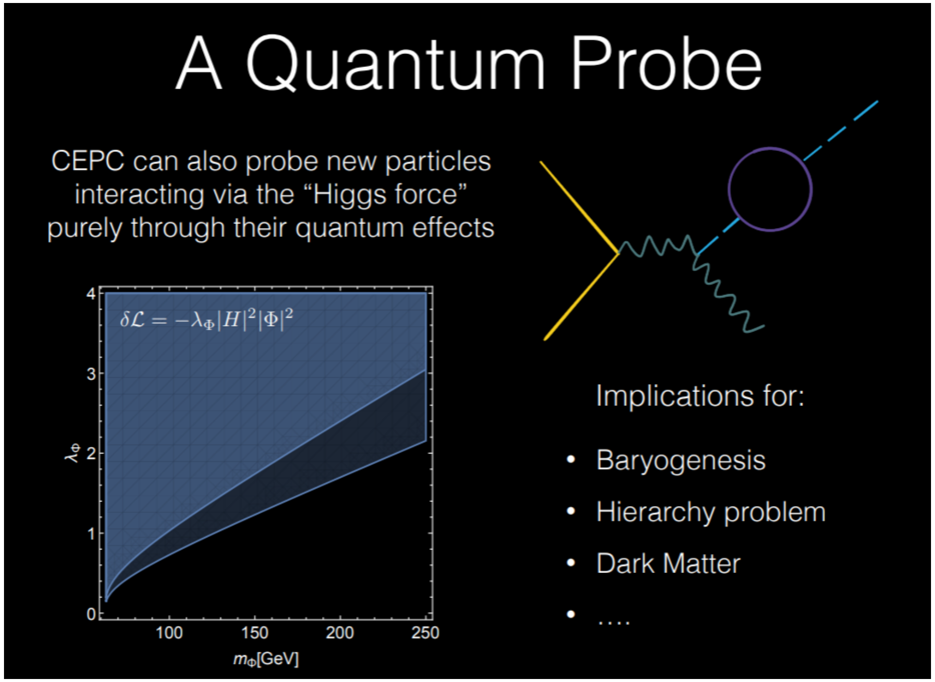

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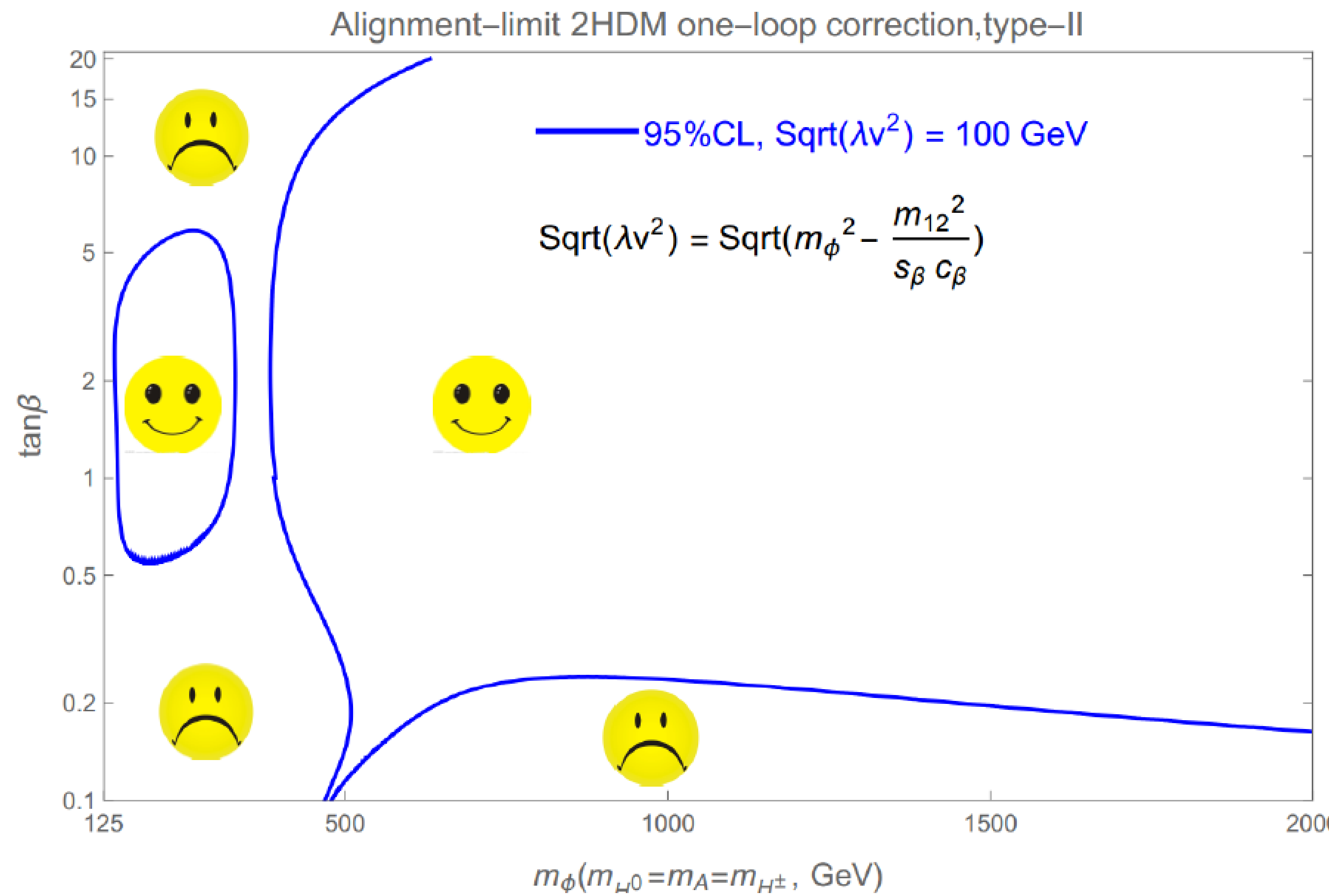

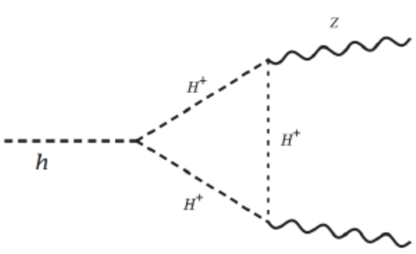

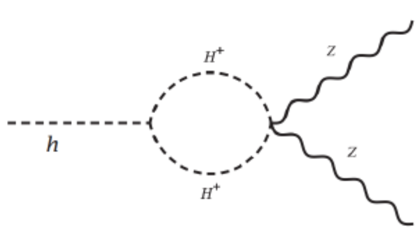

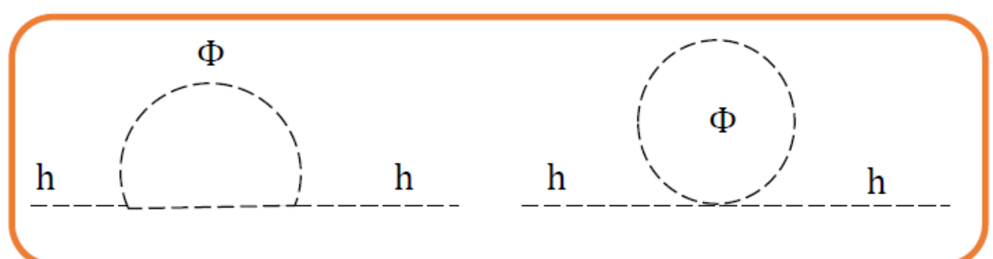

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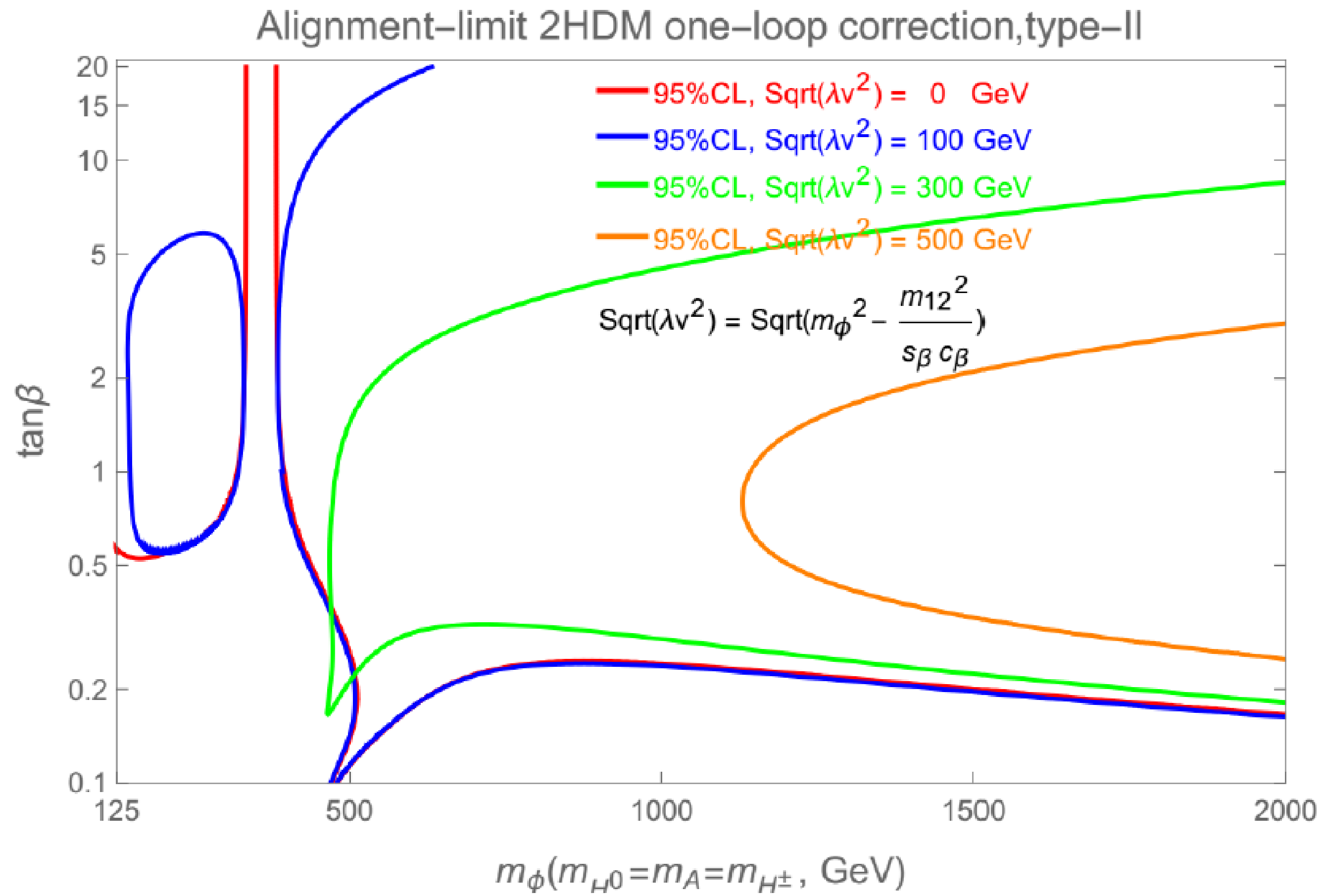

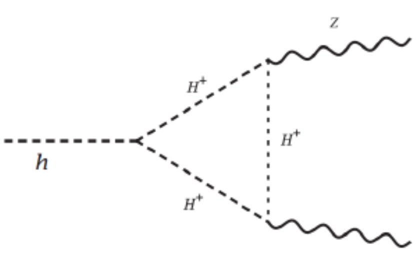

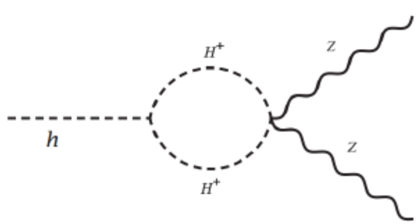

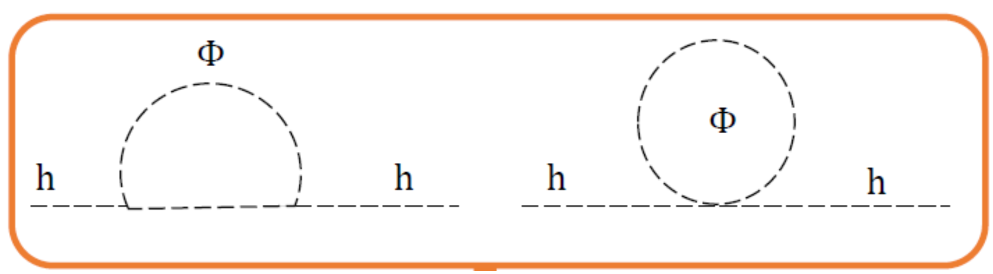

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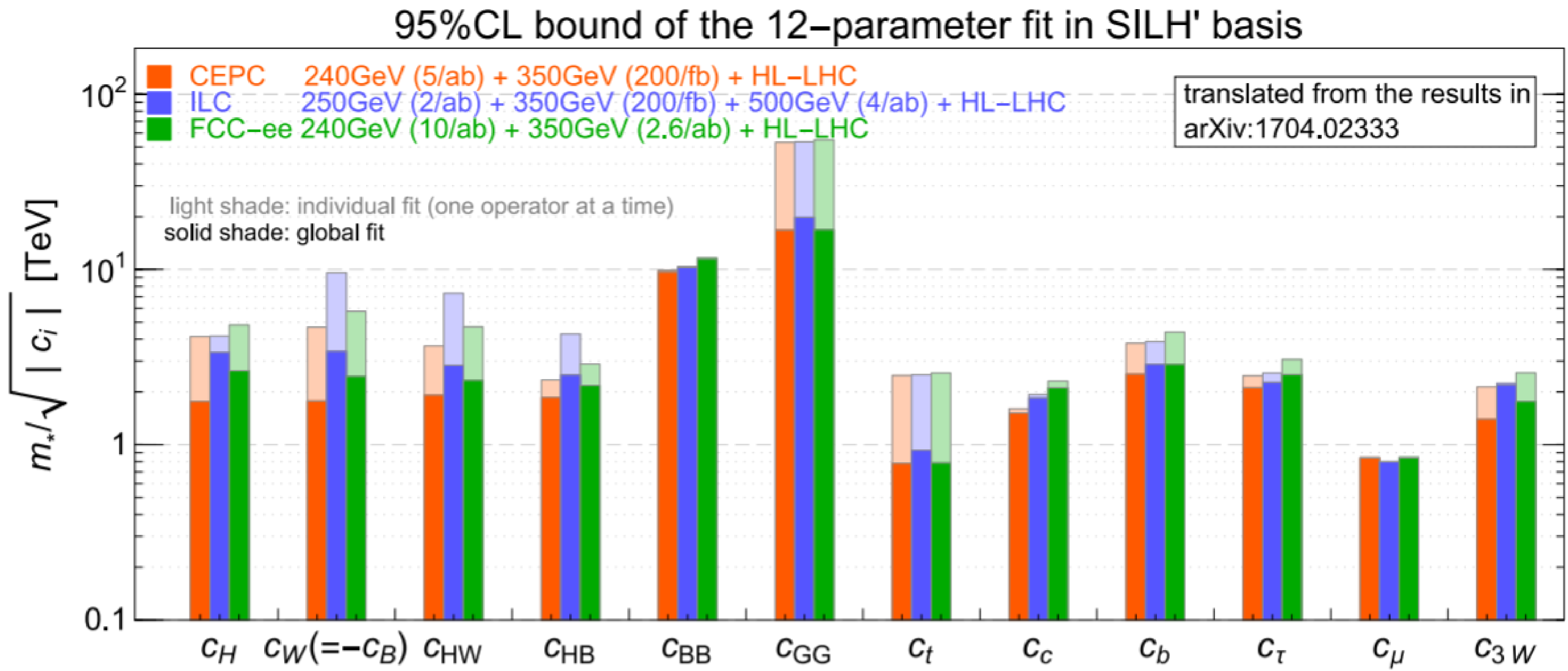
Patterns of strong dynamics, R. Rattazzi, D. Liu, et al.

	$\mathcal{O}_H$	$\mathcal{O}_W$	$\mathcal{O}_B$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{GG}$	$\mathcal{O}_{y_u}$	$\mathcal{O}_{y_d}$	$\mathcal{O}_{y_e}$	$\mathcal{O}_{3W}$
ALH	g_*^2	1	1	1	1	1	1	g_*^2	g_*^2	g_*^2	$\frac{g^2}{g_*^2}$
GSILH	g_*^2	1	1	1	1	$\frac{y_t^2}{16\pi^2}$	$\frac{y_t^2}{16\pi^2}$	g_*^2	g_*^2	g_*^2	$\frac{g^2}{g_*^2}$
SILH	g_*^2	1	1	$\frac{g_*^2}{16\pi^2}$	$\frac{g_*^2}{16\pi^2}$	$\frac{y_t^2}{16\pi^2}$	$\frac{y_t^2}{16\pi^2}$	g_*^2	g_*^2	g_*^2	$\frac{g^2}{16\pi^2}$



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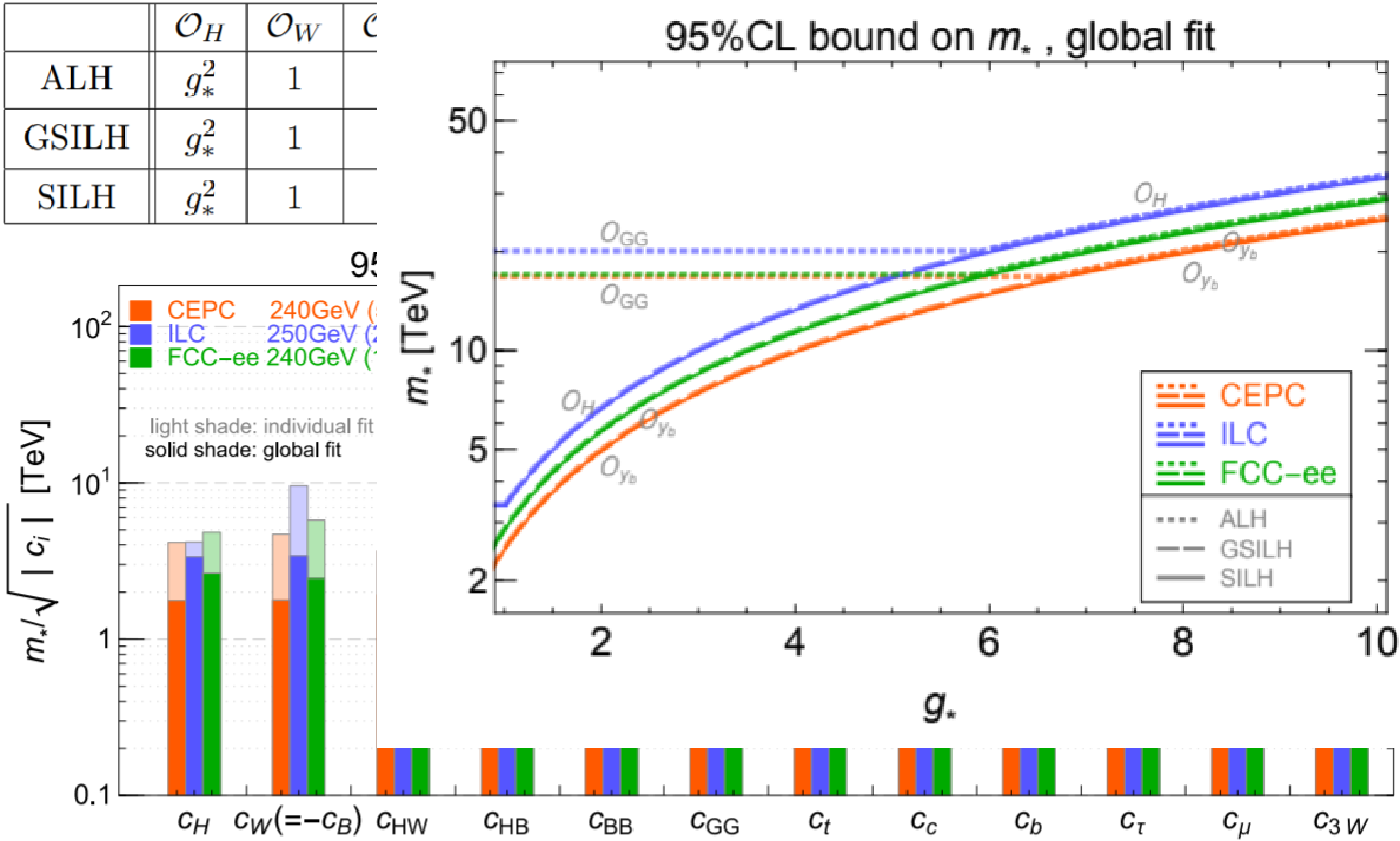
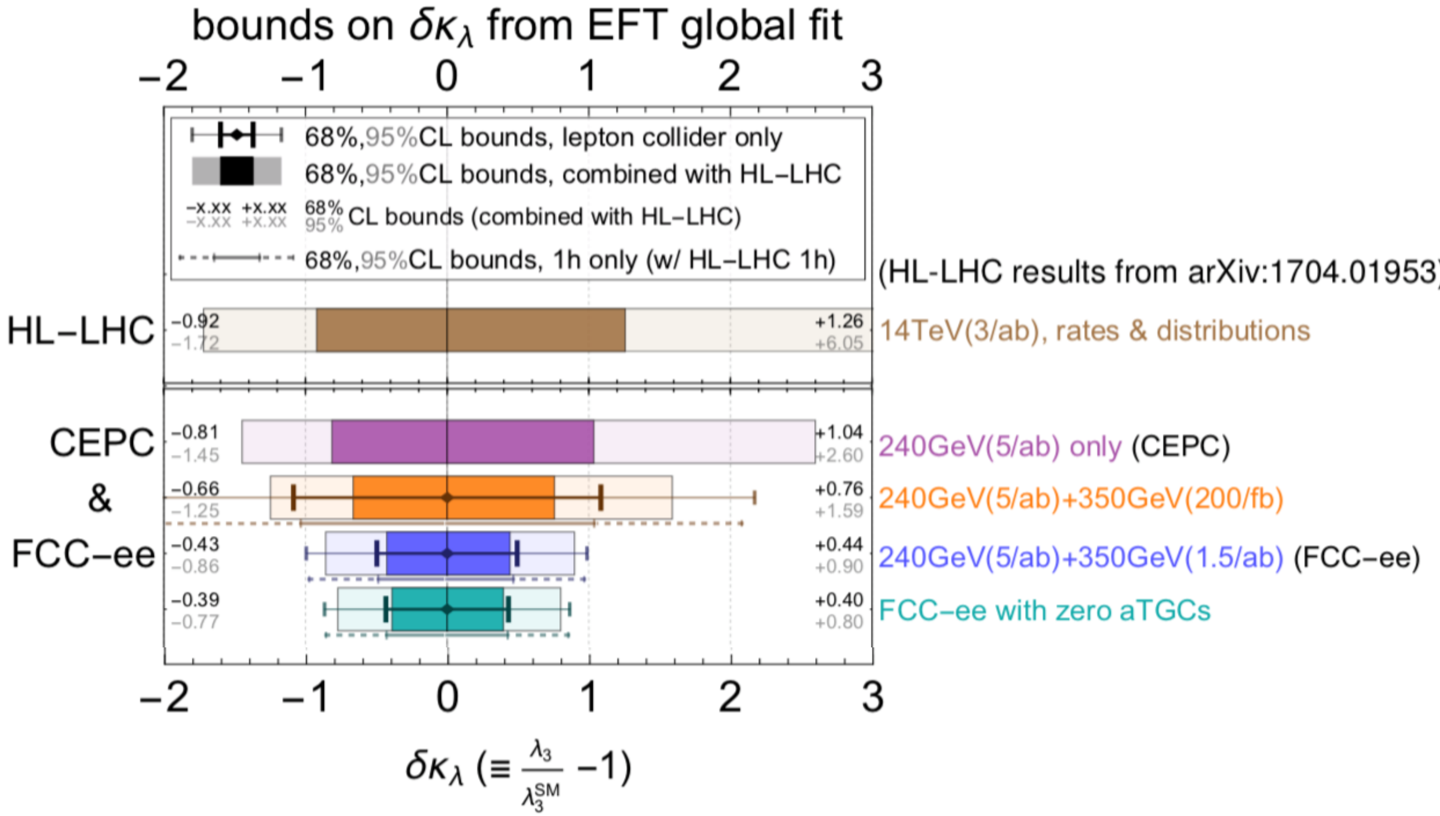
Patterns of strong dynamics, R. Rattazzi, D. Liu, et al.

	$\mathcal{O}_H$	$\mathcal{O}_W$
ALH	g_*^2	1
GSILH	g_*^2	1
SILH	g_*^2	1



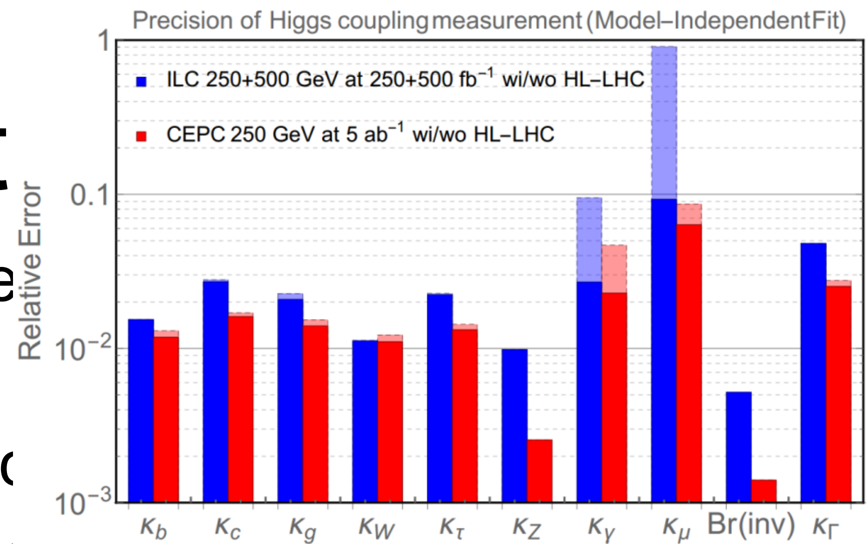
Summary

Thank you!



- Higgs self-couplings are the keys to reveal nature of EWPT and EWBG;
- CEPC could use precision Higgs measures to constrain Higgs trilinear couplings in a robust way in the general EFT framework; we setup the framework and include more observables;
- The observable set and operator set can be further expanded for a fuller treatment, so far we dropped a few of them constrained by EWPO;*
- Interplay between Higgs precision and EWPO, 240 GeV and 350 GeV, CEPC and other future collider programs, can be studied in this framework and provide useful information;
- We also sketch how would representative BSM scenarios look like with CEPC Higgs precision.

Summary and out

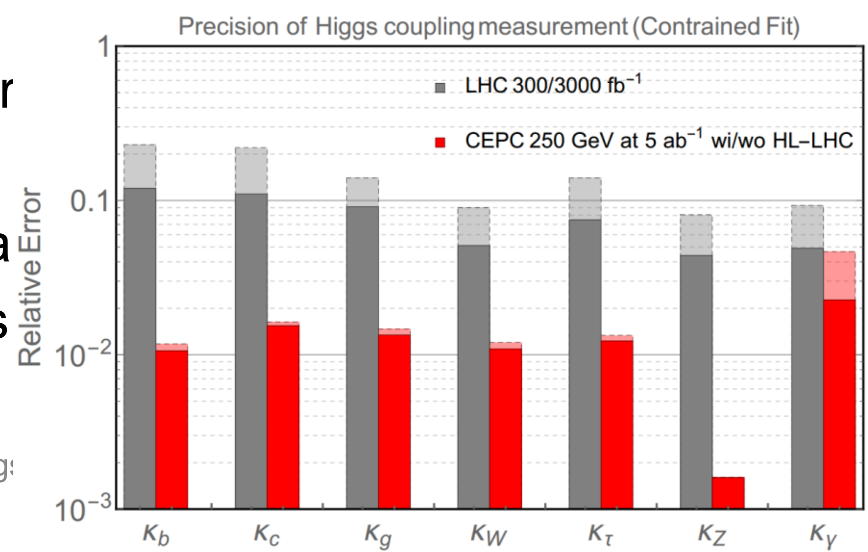


- Higgs physics is rich and challe
  lamppost for our exploration of
- Many efforts from different direc
  promising to provide valuable information through
  Higgs preci
- A lot to exp
  - more sub
    processes
  - detector design and study on jet-r
    identification
  - key background reduction like Ba
  - reducing theoretical uncertainties
  - Study for rare decays, CP, etc.

Looking forward to the great physics at CEPC and SPPC

We all need to contribute!

Thank you!



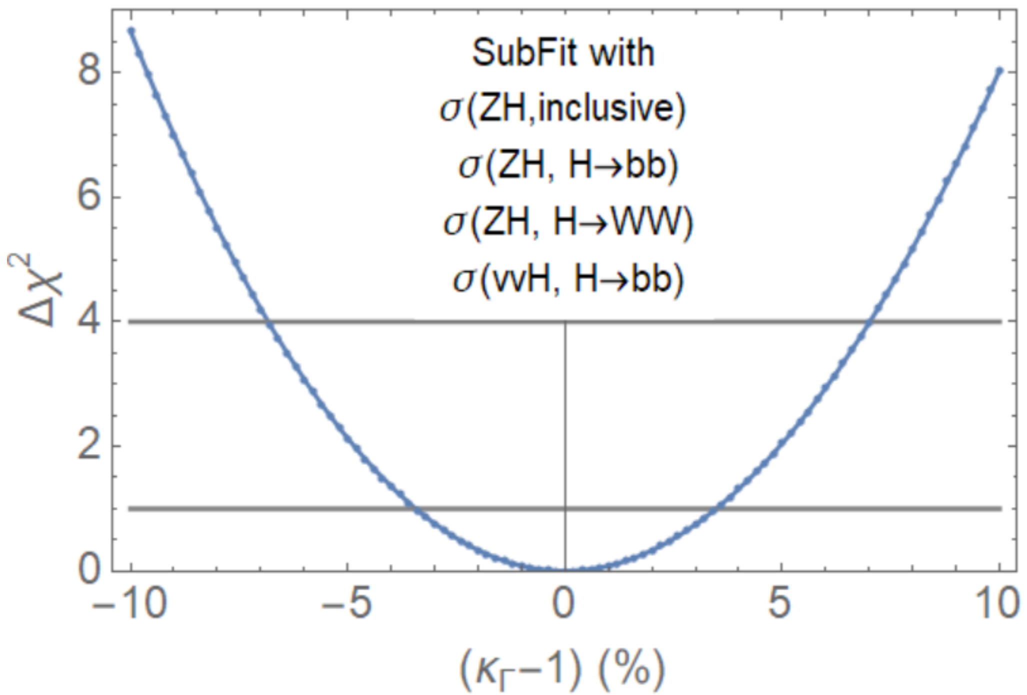
My outlook 3.5 yrs ago

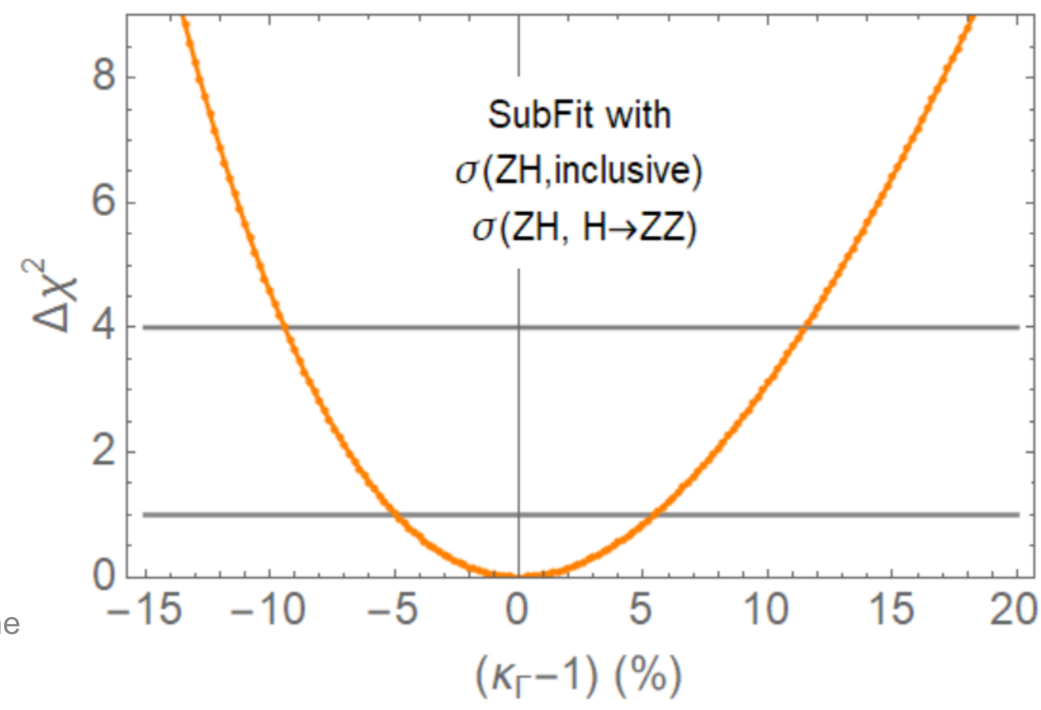
Outlook

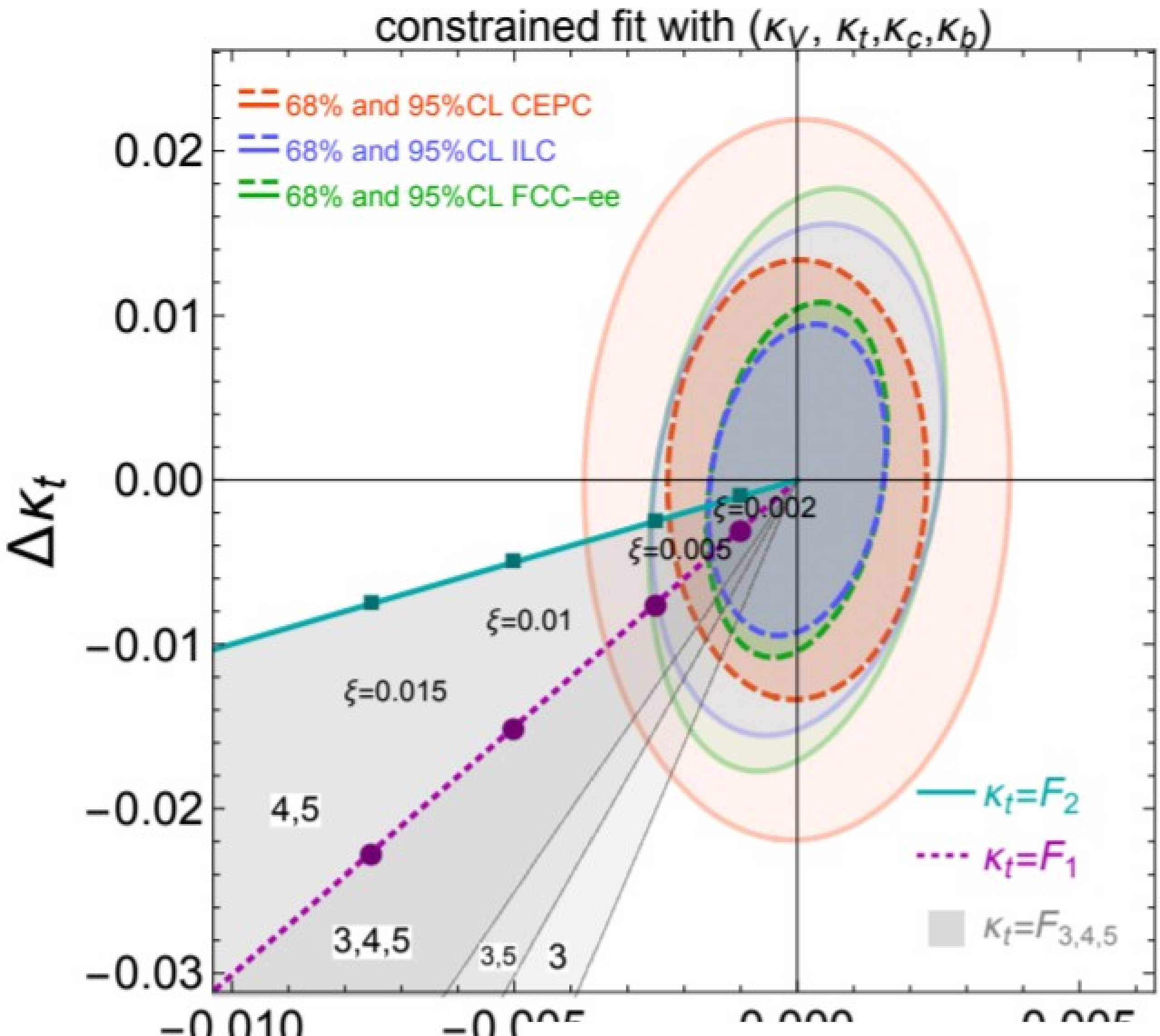
- Jet-clustering/identification at the CEPC, where the picture could be completely different from hadron colliders, and their applications to BSM physics in addition to serving as QCD tests;
- Tau-lepton tag and its polarization at CEPC, and its application to asymmetries at both Z-pole and ZH;
- The CEPC sensitivities to some "not so rare" Higgs exotic decays, especially for these with trigger problems at the LHC (as CEPC triggering efficiency can be considered as 100% for any exotics);
- The CEPC sensitivity to Higgs "CP violation" as it probably is going to pin down the CP phase;
- A longer term plan for fully correlated analysis of Higgs precisions (systematic, interference in signal processes) should be in place.

My outlook 3.5 yrs ago

Relative coupling measurement precision and the 95% CL upper limit on $\mathrm{BR}_{\mathrm{inv}}^{\mathrm{BSM}}$				
	10-parameter fit		7-parameter fit	
Quantity	CEPC	CEPC+HL-LHC	CEPC	CEPC+HL-LHC
κ_b	1.3%	1.0%	1.2%	0.9%
κ_c	2.2%	1.9%	2.1%	1.9%
κ_g	1.5%	1.2%	1.5%	1.1%
κ_W	1.4%	1.1%	1.3%	1.0%
κ_τ	1.5%	1.2%	1.3%	1.1%
κ_Z	0.25%	0.25%	0.13%	0.12%
κ_γ	3.7%	1.6%	3.7%	1.6%
κ_μ	8.7%	5.0%	–	–
$\mathrm{BR}_{\mathrm{inv}}^{\mathrm{BSM}}$	$<0.30\%$	$<0.30\%$	–	–
Γ_H	2.8%	2.3%	–	–


SubFit with
σ(ZH,inclusive)
σ(ZH, H→bb)
σ(ZH, H→WW)
σ(vvH, H→bb)
$\Delta\chi^2$
$(\kappa_\Gamma-1)$ (%)


SubFit with
σ(ZH,inclusive)
σ(ZH, H→ZZ)
$\Delta\chi^2$
$(\kappa_\Gamma-1)$ (%)



MCHM Reps.	5, 10 14-1-10 14-10-10 10-14-10	10-5-10	5-5-10	5-10-10 5-1-10	14-14-10	14-5-10	5-14-10
κ_t, κ_g	F_1	F_2	F_1	F_2	F_3	F_4	F_5
κ_b	F_1	F_1	F_2	F_2	F_1	F_1	F_1