A summary of Higgs+Top sessions at CEPC workshop

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on behalf of Yaquan FANG Yaquan (IHEP), Zhen Liu (University of Minnesota), Jiayin Gu (Fudan University), Junping Tian (The University of Tokyo)
2022-06-08

北京大學
PEKING UNIVERSITY

Introduction

- Fruitful discussions on Higgs & Top physics related to CEPC and other future lepton colliders
  - Two parallel sessions, ten talks
  - Snowmass, Hbb/cc/gg, Higgs@240/360GeV, Higgs CP, Hjj
  - Higgs+top&self-coupling, EFT with top, top mass, flavor anomalies, singlet

11:00 - 12:40 Parallel-1 Higgs & Top
Zoom link

Conveners: Prof. Yaquan FANG Yaquan (高能所), Zhen Liu (University of Minnesota), Prof. Jiayin Gu (Fudan University), Prof. Xiaohu SUN (Peking University), Junping Tian (The University of Tokyo)
Location: Main Buidling (A511)

11:00 **Snow mass status on Higgs and top physics** *25'*
Speaker: Prof. Jiayin Gu (Fudan University)
Material: Slides

11:25 **Status of H->bb,cc, gg** *20'*
Speaker: 朱永峰
Material: Slides

11:45 **Higgs measurement with 240/360 GeV run** *20'*
Speakers: Kaili Zhang (IHEP), Kaili Zhang (IHEP)
Material: Slides

12:05 **Higgs CP measurement at CEPC** *15'*
Speaker: Qiyu Sha
Material: Slides

12:20 **Deeply Learned Preselection of Dijet Higgs Decays at Future Lepton Colliders** *20'*
Speaker: 文星 张 (Shanghai Jiao Tong University)

14:00 - 16:00 Parallel 5 Higgs/top
Zoom link

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Location: Main Buidling (A511)

14:00 **Higgs probes of top quark contact interactions at the LHC and interplay with the Higgs self-coupling** *25'*
Speaker: Dr. Jorge De Blas (University of Granada)
Material: Slides

14:25 **EFT fits to the top-quark couplings at HL-LHC and future e+e- colliders** *25'*
Speaker: Victor Miralles (I)
Material: Slides

14:50 **top mass measurement at CEPC** *20'*
Speaker: Zhan Li (IHEP)
Material: Slides

15:10 **Implications of the flavor anomalies for CEPC** *25'*
Speaker: Andreas Crivellin (U)

15:35 **The production of a singlet in e+e- collisions** *25'*
Speaker: Anza Mulaudzi

Snowmass EF04

- A good review from the energy-frontier EF04 SMEFT global fit team
- Focus on EW+Higgs with a "global" fit: usually ~20-30 parameters (instead of 2499)

Snowmass status on Higgs + EW SMEFT Fits

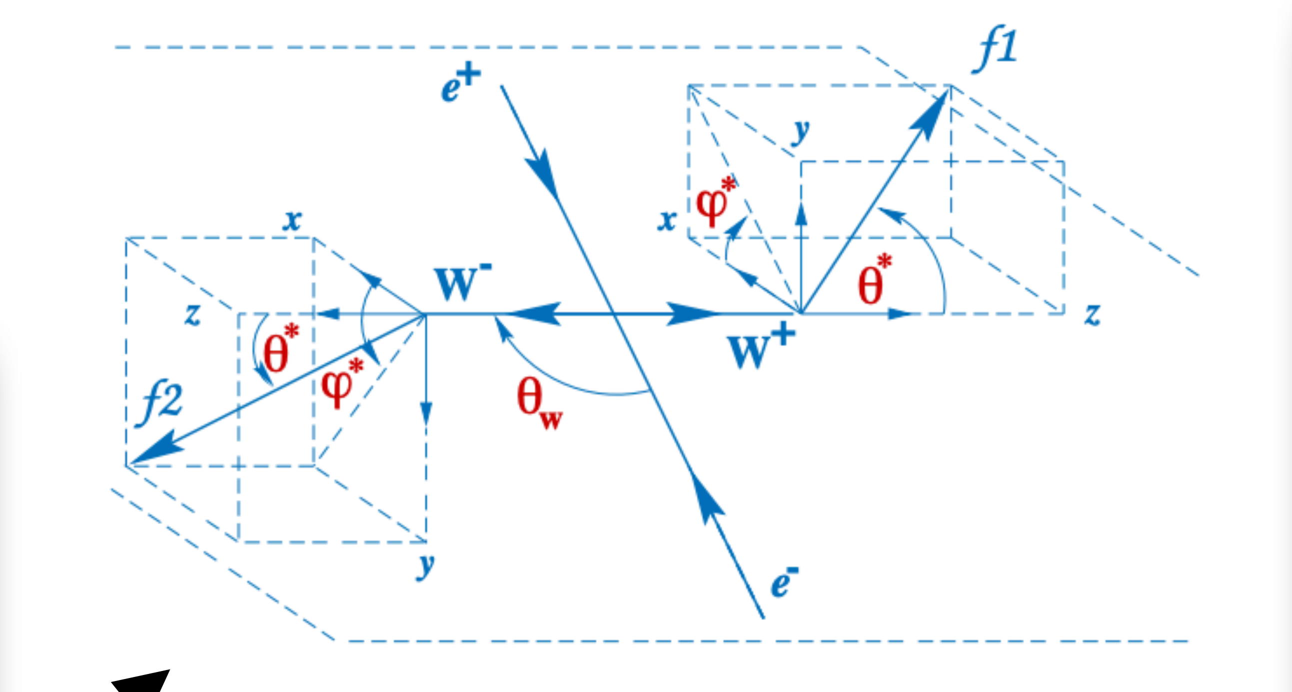
Jiayin Gu (顾嘉荫)

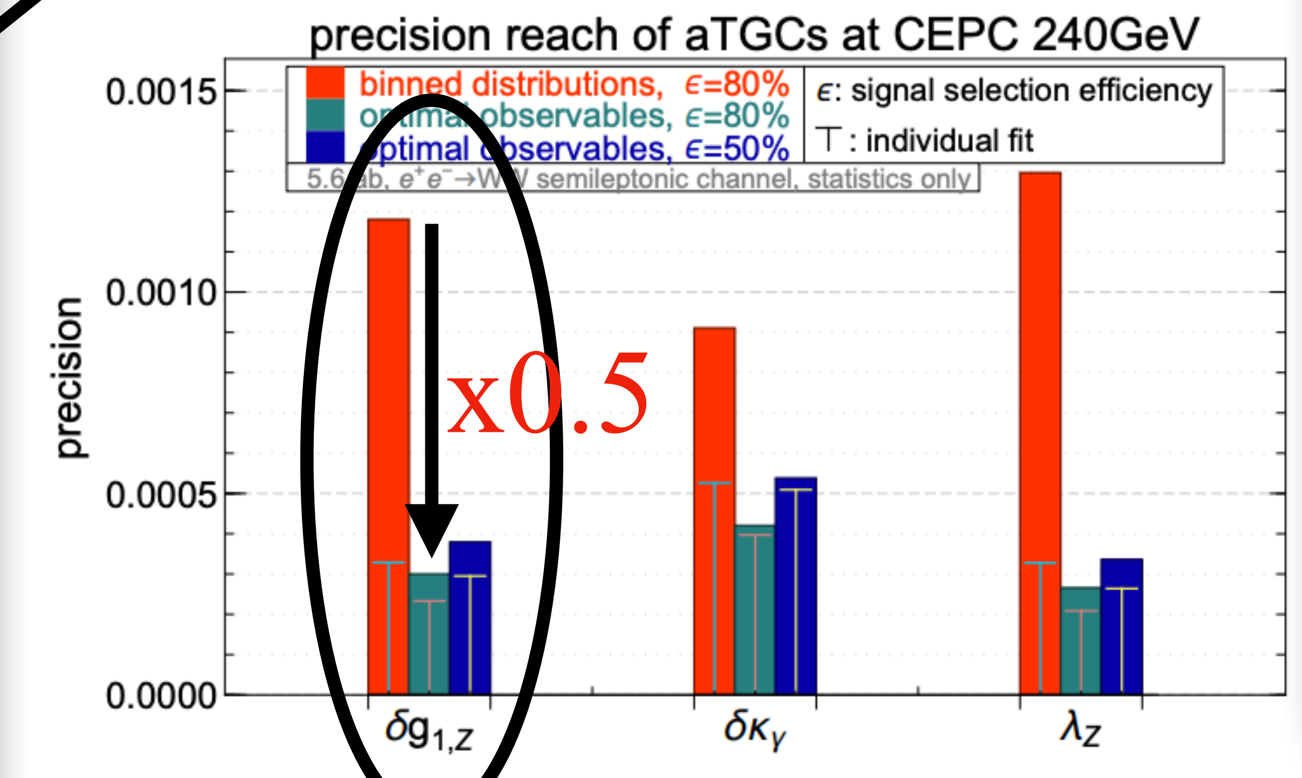
$e^+e^- \to WW$ with Optimal Observables

- What are optimal observables?
  (See *e.g.* Z.Phys. C62 (1994) 397-412 Diehl & Nachtmann)
  - In the limit of large statistics (everything is Gaussian) and small parameters (linear contribution dominates), the best possible reaches can be derived analytically!

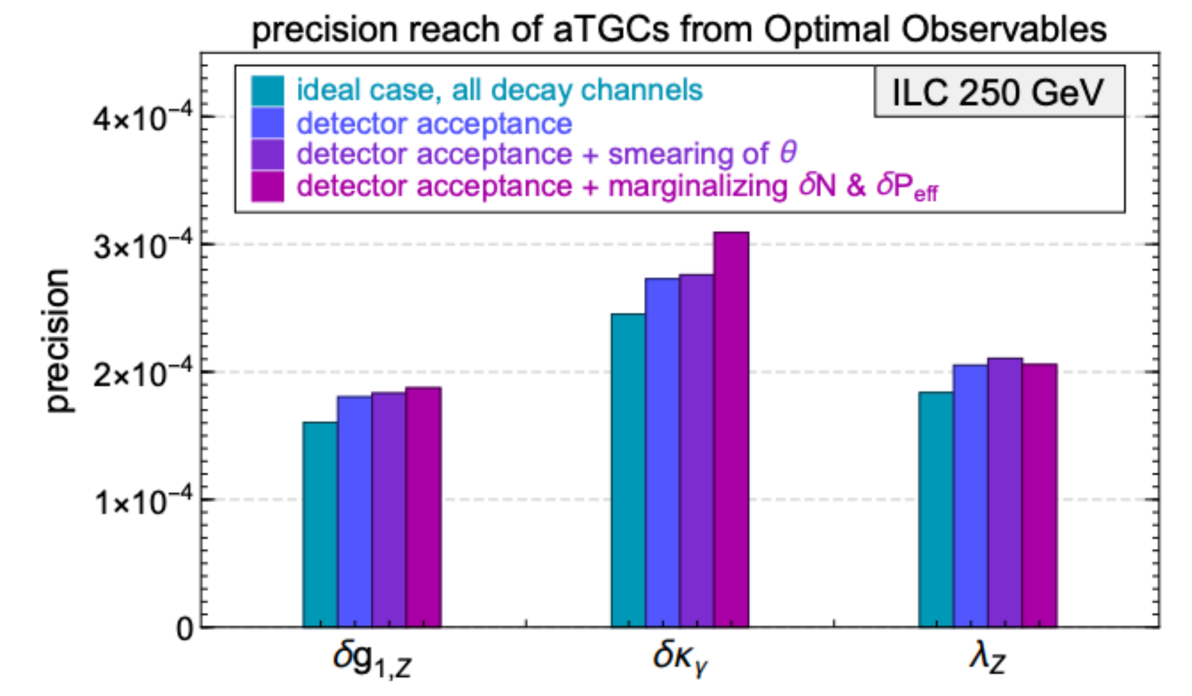
$$\frac{d\sigma}{d\Omega} = S_0 + \sum_i S_{1,i}\, g_i\,, \qquad c_{ij}^{-1} = \int d\Omega \frac{S_{1,i}S_{1,j}}{S_0} \cdot \mathcal{L}\,,$$

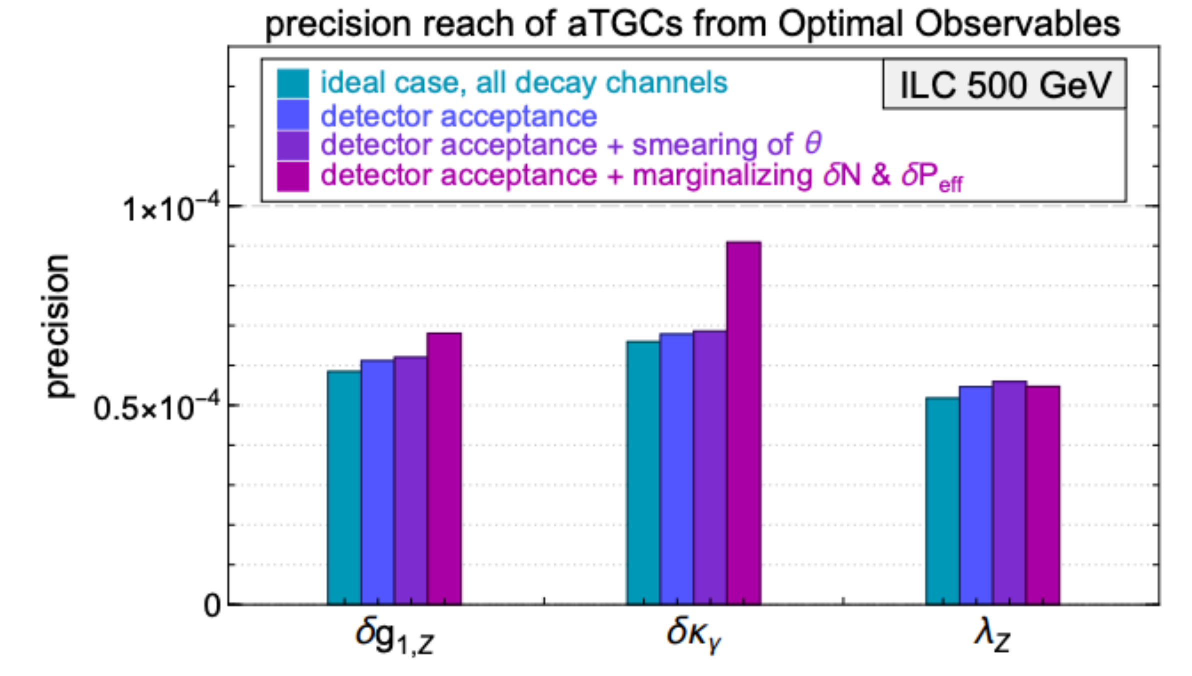
- The optimal observables are given by $\mathcal{O}_i = \frac{S_{1,i}}{S_0}$, and are functions of the 5 angles.





[arXiv:1907.04311] de Blas, Durieux, Grojean, JG, Paul





With optimal observables, can reach $O(10^{-4})$ precision or lower

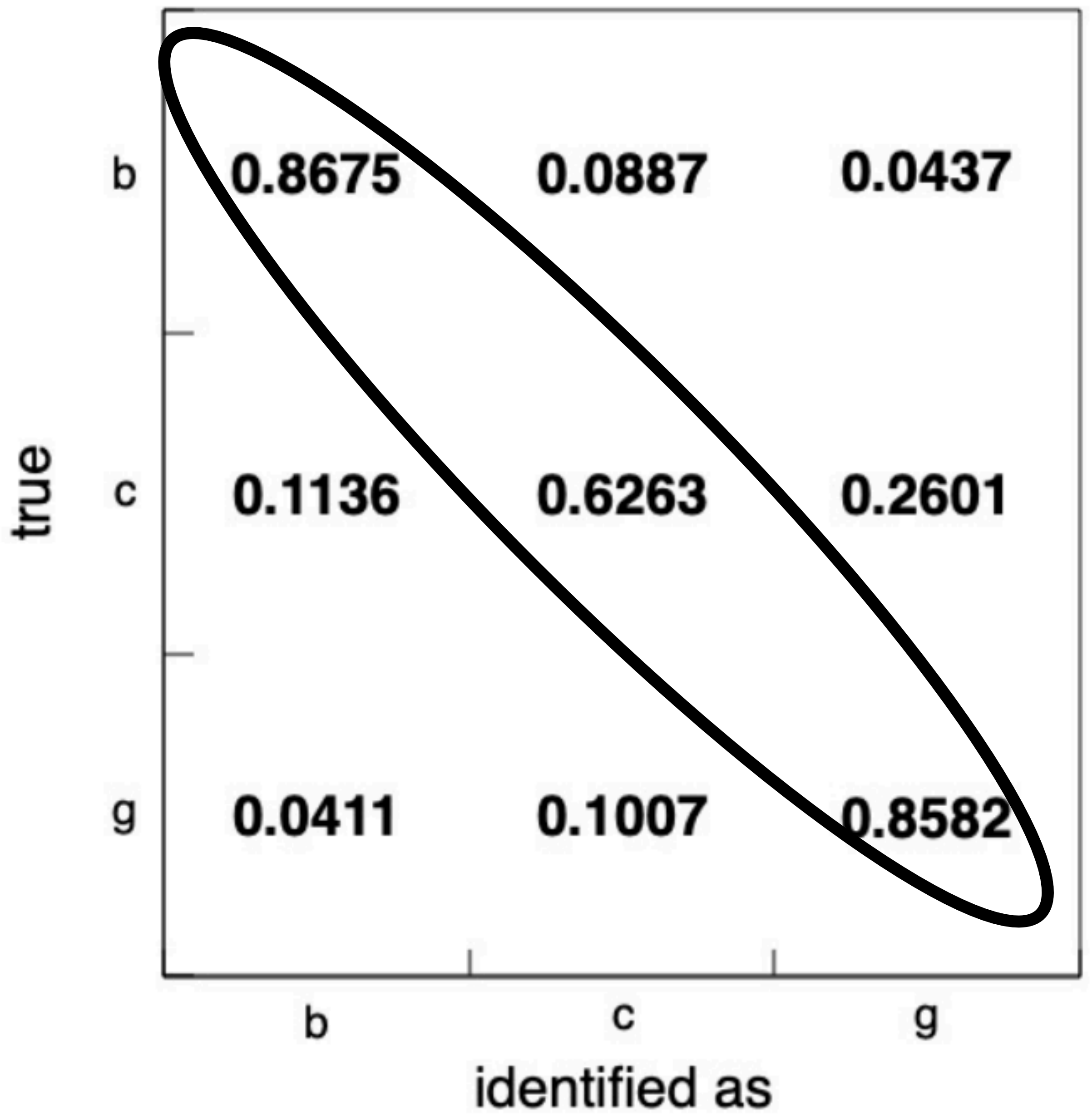
Higgs→bb,cc,gg

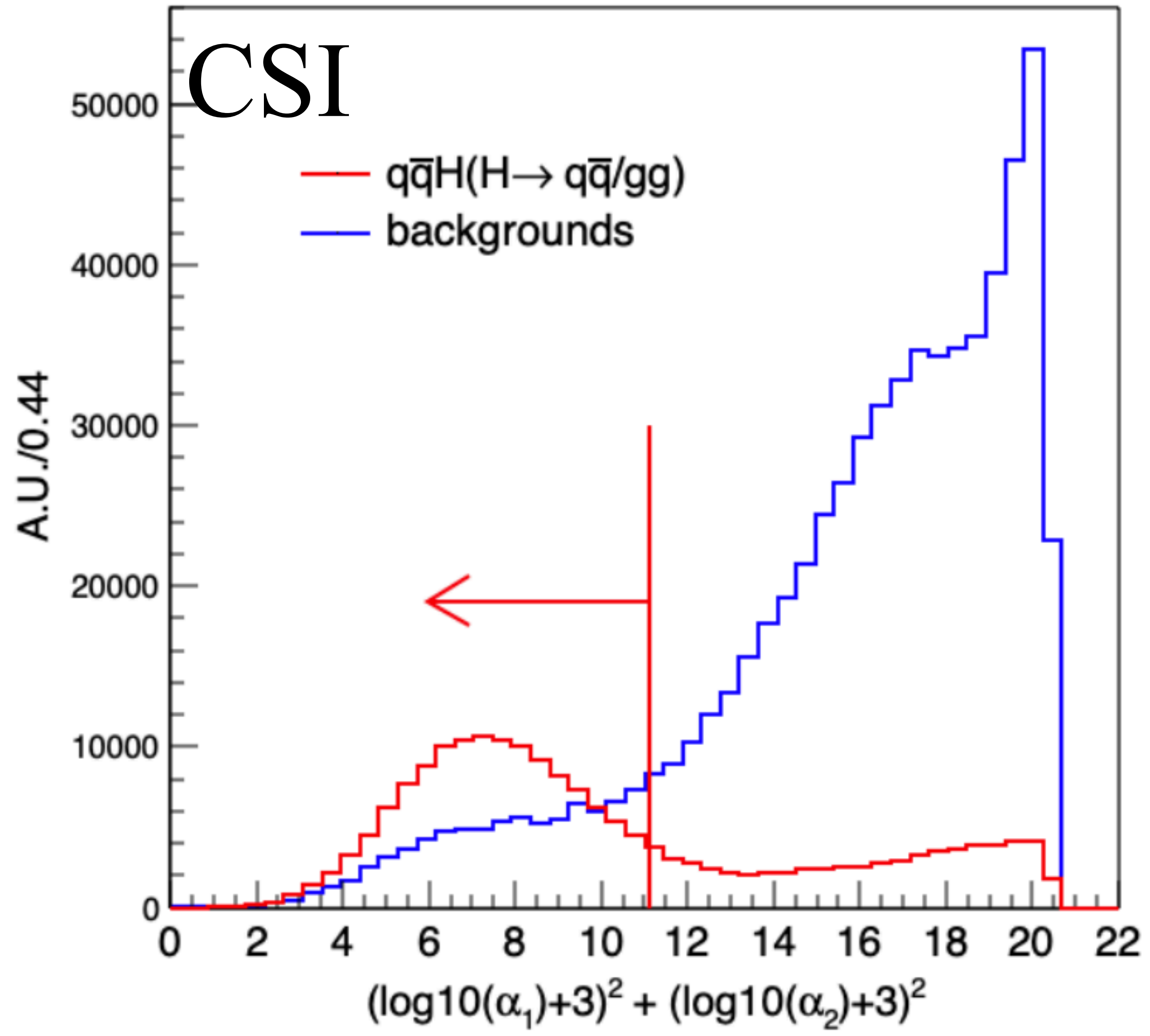
- Particularly study the challenging and important channels with CEPC (240GeV, 5.6/ab): bb, cc, gg
- eeH and mmH were studied before and showed competitive results
- vvH qqH are studied and found very competitive
- The flavor tagging and color singlet identification (CSI) are critical for these benchmarks

The $Higgs \rightarrow b\bar{b}, c\bar{c}, gg$ measuremnet at CEPC
& corresponding optimization studies

Yongfeng Zhu

advisor : Manqi Ruan



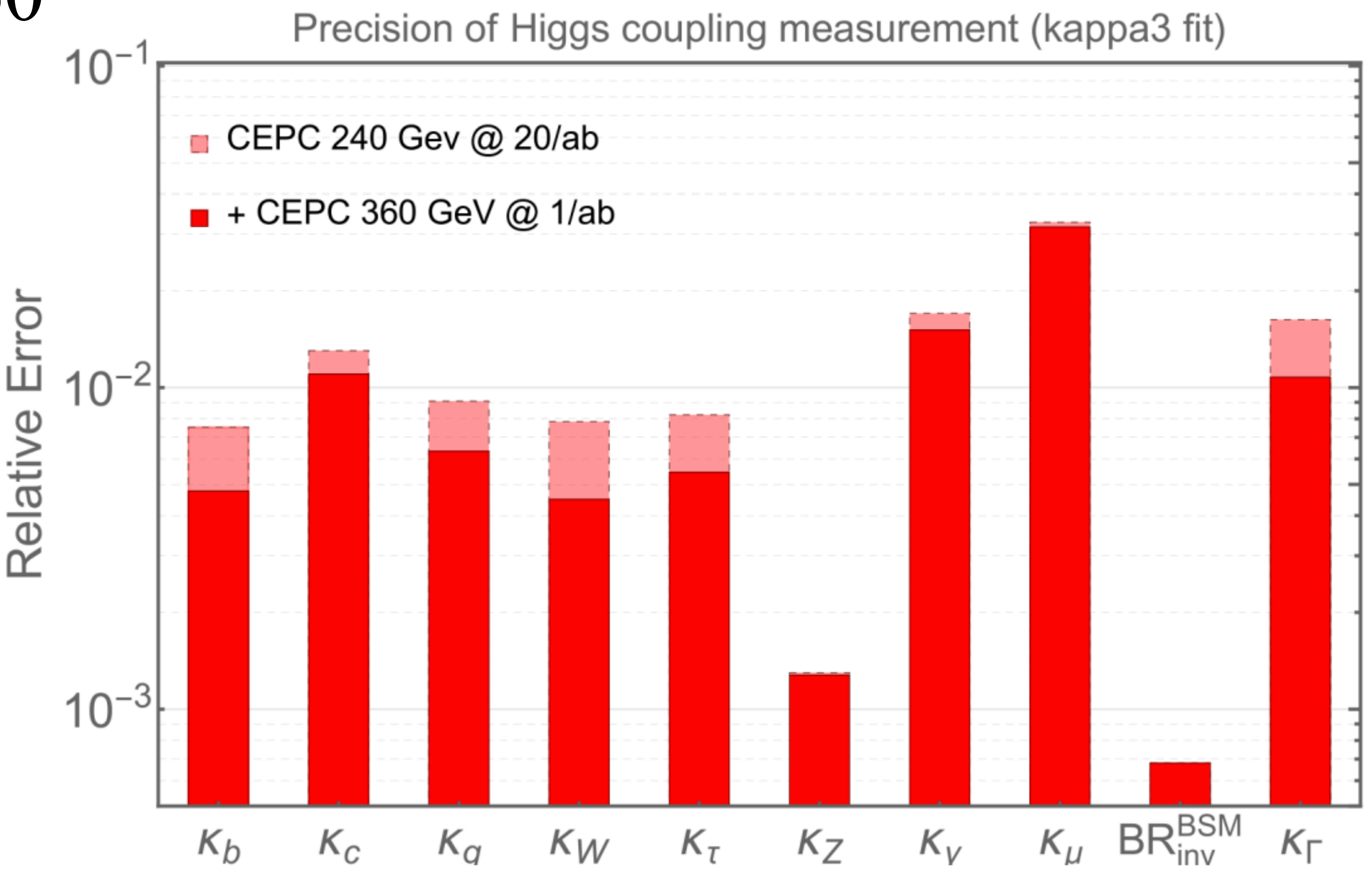


Z decay mode	$H \rightarrow b\bar{b}$	$H \rightarrow c\bar{c}$	$H \rightarrow gg$
$Z \rightarrow e^+e^-$	1.57%	14.43%	10.31%
$Z \rightarrow \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \rightarrow q\bar{q}$	0.35%	7.22%	3.79%
$Z \rightarrow \nu\bar{\nu}$	0.49%	5.35%	1.77%
combination	0.27%	3.82%	1.52%

Higgs coupling @ 240,360GeV

- From 240 GeV to 360 GeV, new production modes are opened
  - Vector boson fusion xs increases significantly
  - Most of the background xs are dropping
- Precisions are improved largely with data taking @ 360 GeV
- Latest results are submitted to snowmass: 2205.08553

fb	240	350	360	365	360/240
ZH	196.9	133.3	126.6	123.0	-36%
WW fusion	6.2	26.7	29.61	31.1	+377%
ZZ fusion	0.5	2.55	2.80	2.91	+460%
Total	203.6		159.0		
Total Events	4M		0.16M		



Higgs CP

- Any evidence of CP violation in Higgs of course leads to new physics
- With large dataset of Higgs bosons at CEPC, one can probe its CP structure, looking for CP-odd Higgs
- The optimal variable approach is taken
- Competitive results in $\tilde{c}_{ZZ}$

Probing Higgs CP properties at the CEPC

Qiyu Sha , Abdualazem Fadol, Fangyi Guo, Jiayin Gu, Gang Li, Xinchou Lou, Yaquan Fang

- **Signal**: $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^- H(\rightarrow b\bar{b}/c\bar{c}/gg)$ channel
- **Background**: Irreducible background which contains the same final states as that in signal.

- Result: 95% CL $\hat{\alpha}_{A\tilde{Z}} \in [-8.27\times10^{-2}, 8.09\times10^{-2}]$ and $\hat{\alpha}_{Z\tilde{Z}} \in [-2.15\times10^{-2}, 2.02\times10^{-2}]$

Optimal variable approach

$$\frac{d\sigma}{d\cos\theta_1 d\cos\theta_2 d\phi} = N \times \left(J_{\text{even}}(\theta_1,\theta_2,\phi) + \hat{\alpha}_{A\tilde{Z}} \times J_{odd_1}(\theta_1,\theta_2,\phi) + \hat{\alpha}_{Z\tilde{Z}} \times J_{odd_2}(\theta_1,\theta_2,\phi)\right)$$

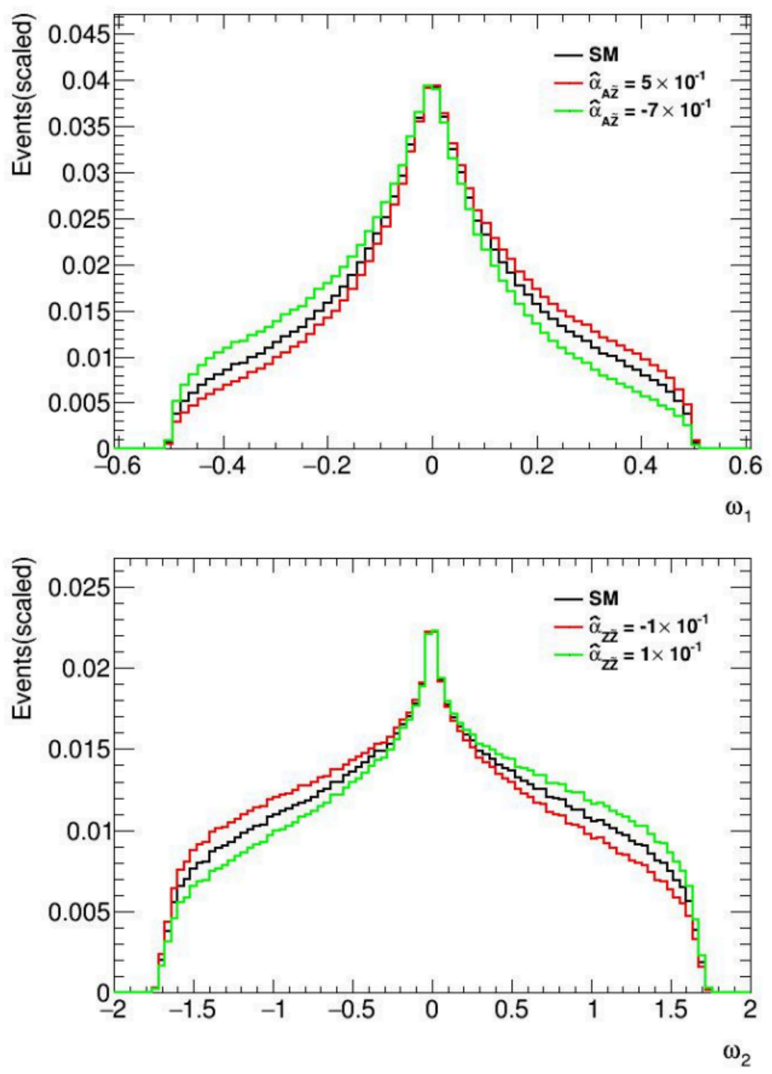
In this formation, we could define Optimal Variable ω which combines the information from $\{\theta_1, \theta_2, \phi\}$:

$$\omega_1 = 1000 \times \frac{J_{odd_1}(\theta_1,\theta_2,\phi)}{J_{\text{even}}(\theta_1,\theta_2,\phi)} \text{ to measure } \hat{\alpha}_{A\tilde{Z}}$$

$$\omega_2 = 1000 \times \frac{J_{odd_2}(\theta_1,\theta_2,\phi)}{J_{\text{even}}(\theta_1,\theta_2,\phi)} \text{ to measure } \hat{\alpha}_{Z\tilde{Z}}$$

(The factor of 1000 is included here only for numerical convenience)

Benefits:
- Combine the information from 3-dimension phase space
- Easier to study



Analysis \ Parameter	$\tilde{c}_{Z\gamma}$	$\tilde{c}_{ZZ}$	Case
HL-LHC (4ℓ, incl.)	[-0.22,0.22]	[-0.33,0.33]	1P
	[-0.25,0.25]	[-0.27,0.27]	$1P_{marg.}$
HL-LHC (4ℓ, diff.)	[-0.10,0.10]	[-0.31,0.31]	1P
	[-0.13,0.13]	[-0.22,0.22]	$1P_{marg.}$
HE-LHC (4ℓ, incl.)	[-0.18,0.18]	[-0.17,0.17]	1P
	[-0.23,0.23]	[-0.20,0.20]	$1P_{marg.}$
HE-LHC (4ℓ, diff.)	[-0.05,0.05]	[-0.13,0.13]	1P
	[-0.06,0.06]	[-0.10,0.10]	$1P_{marg.}$

arXiv:1902.00134

Convert to the parametrization used in the LHC

	$\tilde{c}_{Z\gamma}$	$\tilde{c}_{ZZ}$
68% CL(1σ)	$[-0.36, 0.35]$	$[-0.08, 0.07]$
95% CL(2σ)	$[-0.71, 0.70]$	$[-0.16\ \ 0.15]$

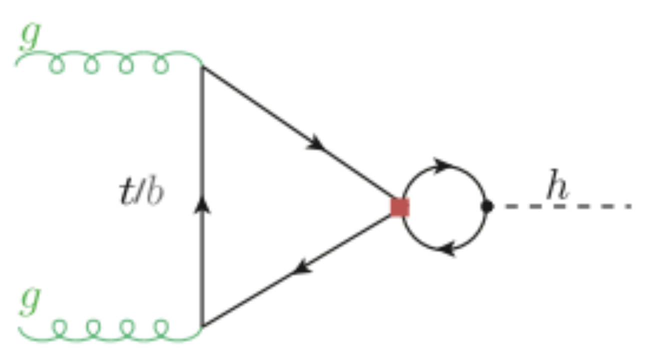
Higgs probes of top-quark contact interactions and self-coupling

- NLO effects give indirect access to interactions not easily accessible
- The interesting 4-fermion operators in SMEFT can be probed at LHC and lepton colliders and they can interplay with Higgs self-coupling

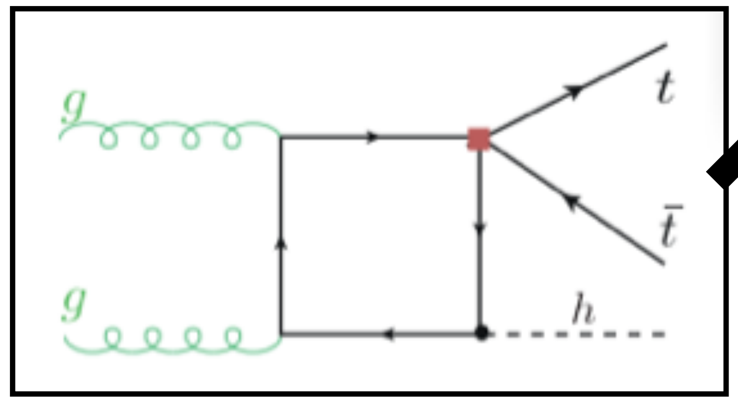
Higgs probes of top-quark contact interactions at the LHC and interplay with the Higgs self-coupling

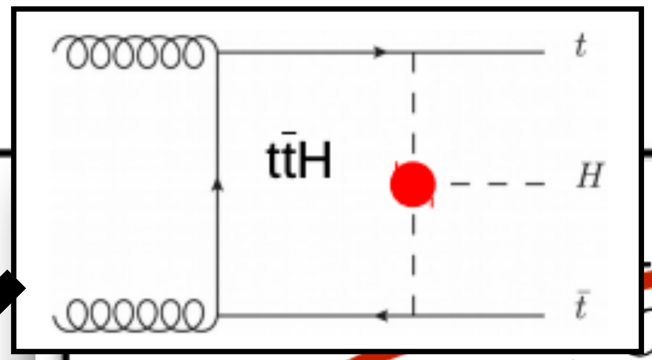
Jorge de Blas

ggh:



tth:





4-Top operators ALSO enter in ggF, *tth*, *h→bb* and *h→γγ* @ NLO and experimental bounds are weak

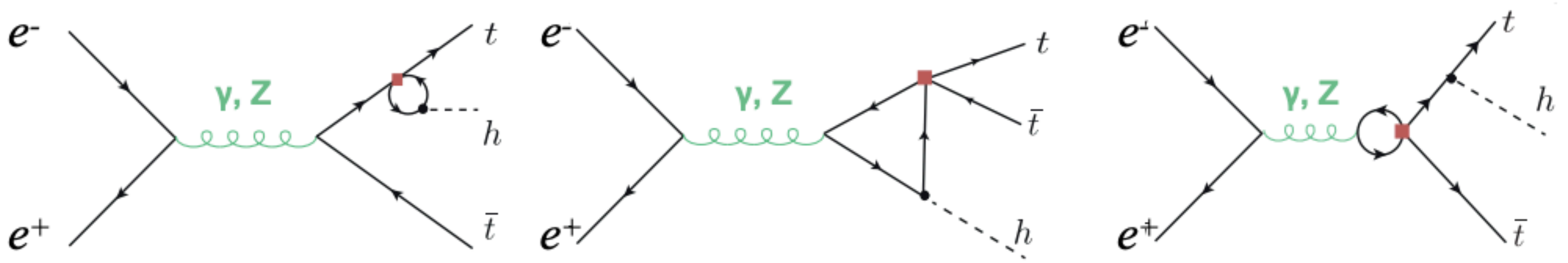
⇒ Can single

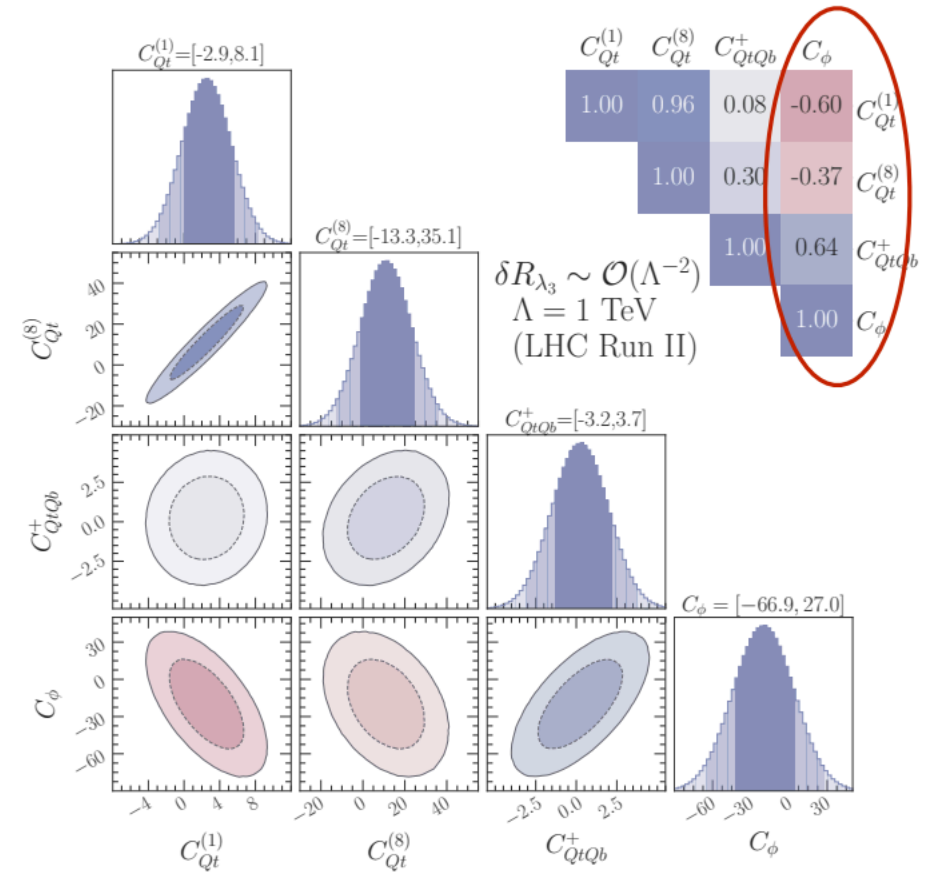
$$+ \frac{C_{bb}}{\Lambda^2}(\bar b_R\gamma_\mu b_R)(\bar b_R\gamma^\mu b_R) + \frac{C_{tb}^{(1)}}{\Lambda^2}(\bar t_R\gamma_\mu t_R)(\bar b_R\gamma^\mu b_R) + \frac{C_{tb}^{(8)}}{\Lambda^2}(\bar t_R T^A\gamma_\mu t_R)(\bar b_R T^A\gamma^\mu b_R)$$
$$+ \frac{C_{Qb}^{(1)}}{\Lambda^2}(\bar Q_L\gamma_\mu Q_L)(\bar b_R\gamma^\mu b_R) + \frac{C_{Qb}^{(8)}}{\Lambda^2}(\bar Q_L T^A\gamma_\mu Q_L)(\bar b_R T^A\gamma^\mu b_R)\,,$$

In pa

Either because chirality or because they only enter in bottom loops, these will have very small effects in Higgs observables and can be neglected

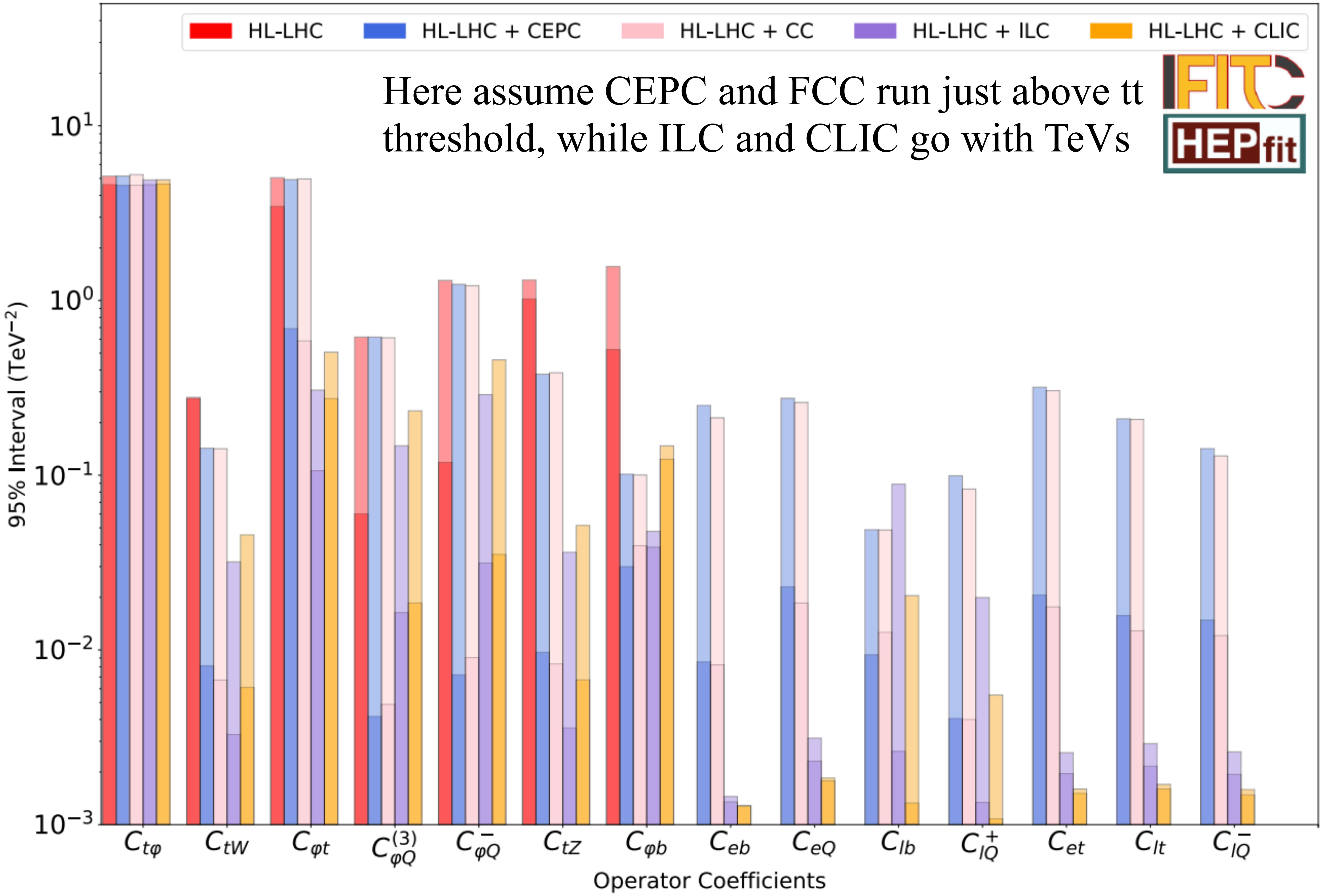
✓ Above the *tth* threshold, however, 4-Top interactions will enter at NLO (as in *qq →tth*)





EFT fits to the top-quark couplings

- Attempt to constrain all top-quark related Wilson coefficients of the SMEFT



EFT fits to the top-quark couplings at HL-LHC and future e^+e^- colliders

Joint Workshop of the CEPC Physics, Software and New Detector Concept in 2022

24th May 2022

Víctor Miralles

An e+e collider can significantly improve bounds on bottom-quark operators, and on top-quark operators if operated above the tt threshold

Circular colliders (FCC-ee and CEPC) operated at and slightly above the tt threshold can improve bottom- and top- operators by factor 5 and 2 for 2-fermion operators.

Top mass @ CEPC

- The top mass measurement team updates continuously with new progresses, mainly on the systematic uncertainties and other properties (width and alpha_S) this time

Top quark properties measurements at CEPC

Zhan Li on behalf of

Xiaohu Sun, Shuiting Xin, Yaquan Fang, Gang Li, Shudong Wang, Zhijun Liang, Yiwei Wang, Hao Zhang

Luminosity/fb^{-1}	Mass precision/MeV	Width precision/MeV
{100, 0}	9.06	342.734
{80, 20}	10.25	57.2656
{50, 50}	12.75	35.918
{20, 80}	19.23	29.6094
{0, 100}	>50	25.8594

Γ_{top}

Luminosity/fb^{-1}	Mass precision/MeV	α_s precision
{100, 0}	9.06	0.000402
{80, 20}	9.94	0.000401
{50, 50}	10.94	0.000399
{20, 80}	12.71	0.000394
{0, 100}	14.32	0.000389

α_S

Impact from LS	Error/MeV
Keep total CEPC LS	9.06
Reduce 20% of the LS	8.94
Reduce 50% of the LS	8.40

Beam energy varies one sigma ~2.6 MeV

	Median Value	Delta
plus	171.4980 GeV	-2 MeV
minus	171.5010 GeV	+1 MeV

Cross-section uncertainty	Error
+1%	+5 MeV
-1%	-9 MeV
+3%	+24 MeV
-3%	-26 MeV

Theory variations

Summary

- Fruitful discussions in the sector of Higgs and top physics at CEPC
- Some highlights:
  - The optimal variable methods significantly improves the measurements in the EW sector of SMEFT
  - vvH and qqH are very competitive wrt eeh mmH benefiting from color singlet identification and flavor tagging
  - A deep look into Higgs CP at CEPC can also help to improve the LHC results largely
  - Circular colliders (FCC-ee and CEPC) operated at and slightly above the tt threshold can help significantly in understanding the top related SMEFT operators
- Many more interesting studies are not included in this summary. And you are encouraged to look at the slides!