What can the top threshold run do for Higgs couplings?

(in the EFT framework)

Jiayin Gu (顾嘉荫)

JGU Mainz

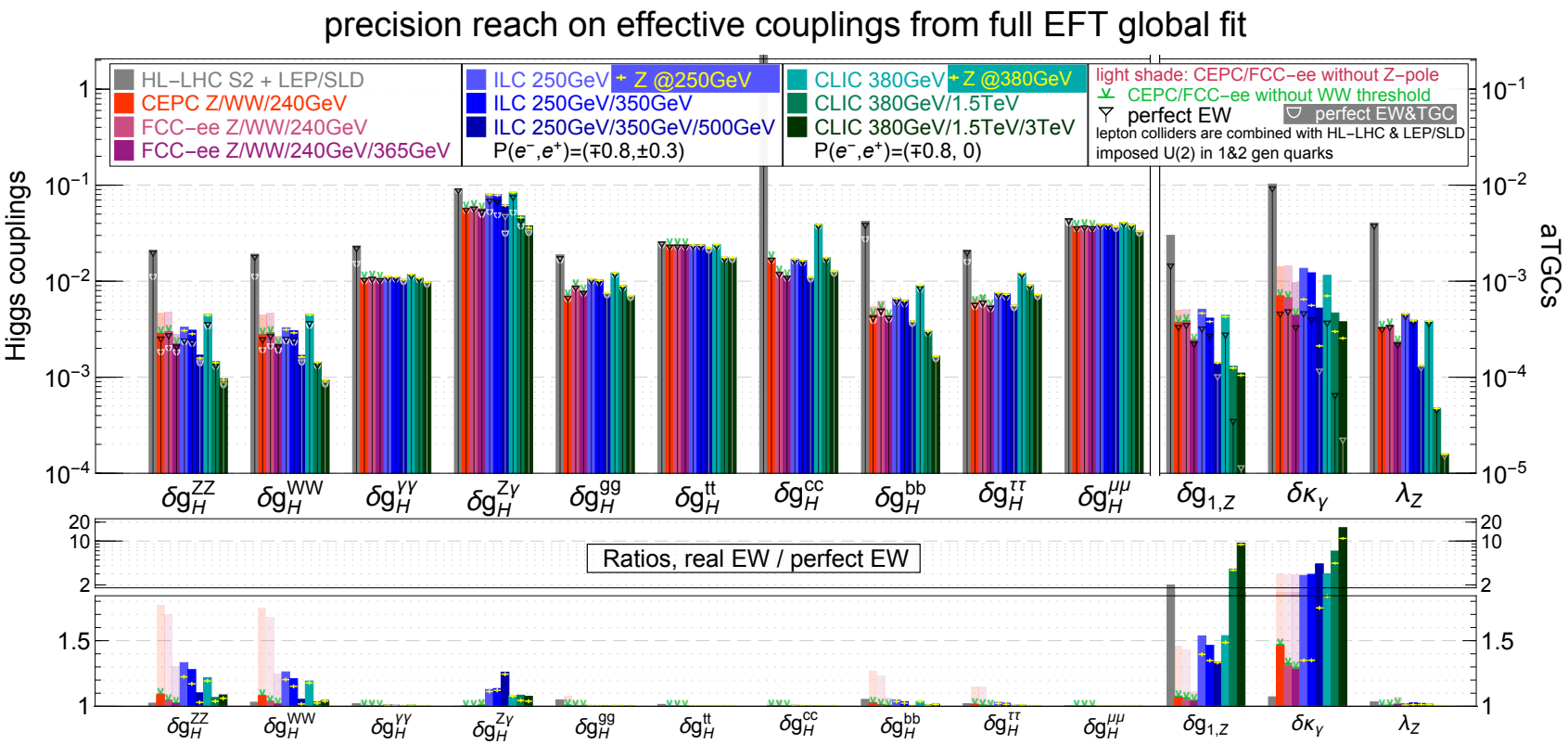
CEPC meeting
Dec 18, 2019

[arXiv:1907.04311] J. de Blas, G. Durieux, C. Grojean, JG, A. Paul
[arXiv:1711.03978] Di Vita, Durieux, Grojean, JG, Liu, Panico, Riembau, Vantalon
[arXiv:1809.03520] G. Durieux, JG, E. Vryonidou, C. Zhang

Big picture

- Better measurement on the hWW coupling due to an increase on the WW fusion cross section.
  - Less important in the EFT framework, as the hZZ and hWW couplings are related.
  - Any deviation from $\kappa_Z = \kappa_W$ is strongly constrained by the Z-pole and W mass measurements.
- Measuring $e^+e^- \to hZ$ and $e^+e^- \to WW$ at a different (and higher) energy.
  - Smaller cross section, but more sensitive to some operators.
  - Helps the discrimination of different operators (*e.g.* $hZ^\mu Z_\mu$ *vs* $hZ^{\mu\nu} Z_{\mu\nu}$).
- **Triple Higgs coupling**
  - probed indirectly via its loop contribution to $e^+e^- \to hZ$ ($\sim 35\%$ precision with inclusive hZ at 240GeV, assuming all other couplings SM like).
  - Runs at a higher energy helps the discrimination with other parameters.
- **Top operators**
  - Some top operators are not very well constrained without a top threshold run,
  - in which case their 1-loop contribution to the Higgs and EW processes could be non-negligible.

“Full fit” projected on the Higgs couplings and aTGCs

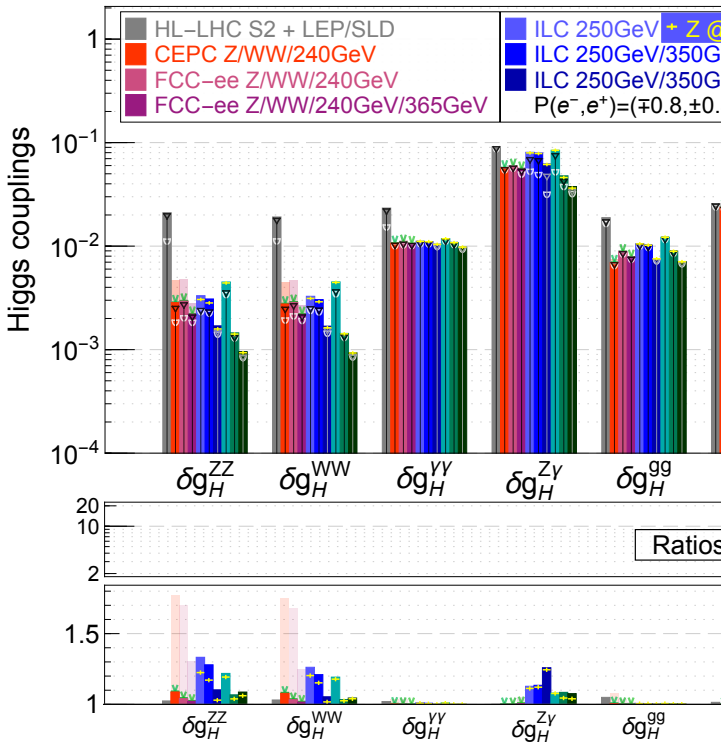


- FCC-ee: $5\,\mathrm{ab}^{-1}@240\,\mathrm{GeV} + 0.2\,\mathrm{ab}^{-1}@350\,\mathrm{GeV} + 1.5\,\mathrm{ab}^{-1}@365\,\mathrm{GeV}$

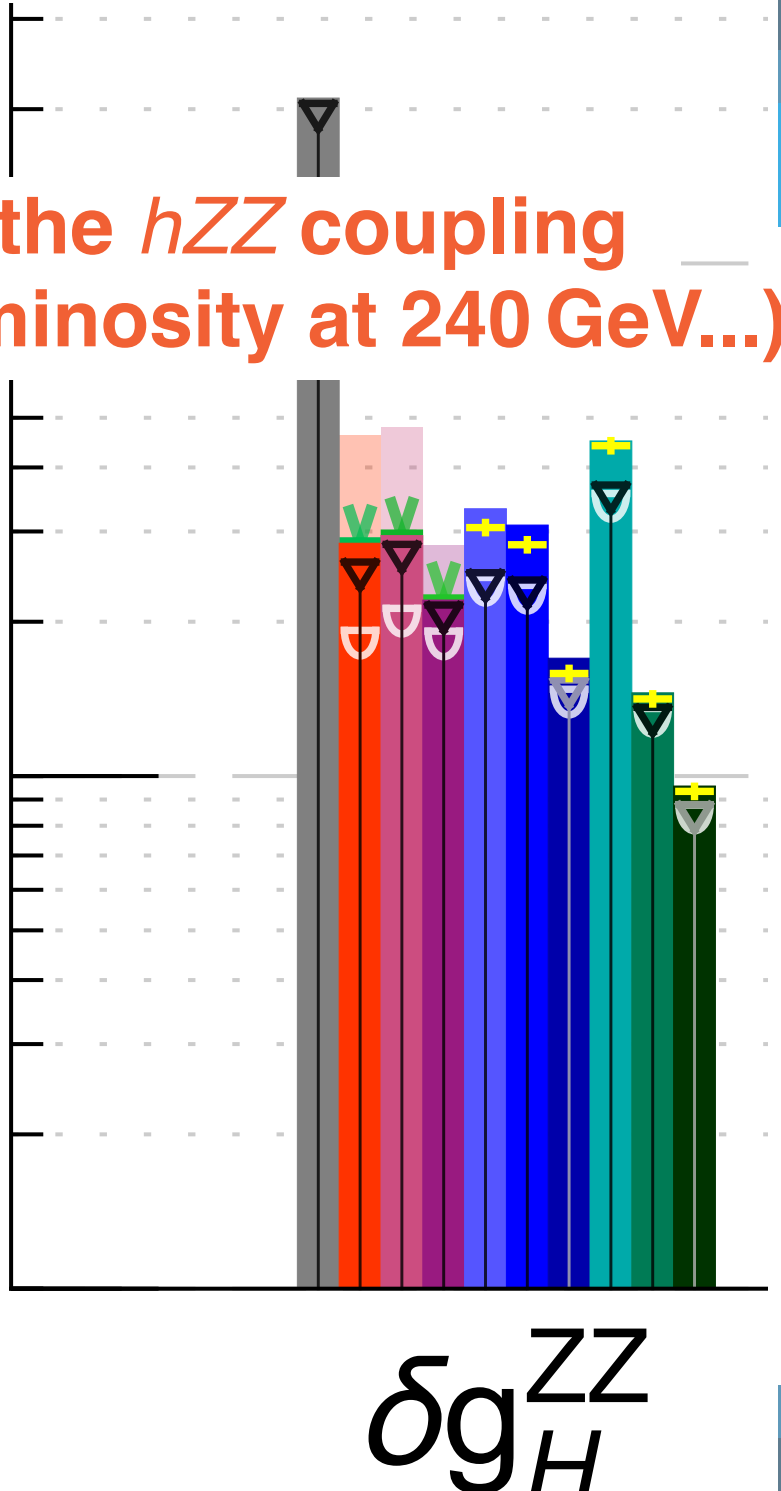
"Full fit" projected on the Higgs

$\sim 30\%$ improvement on the *hZZ* coupling

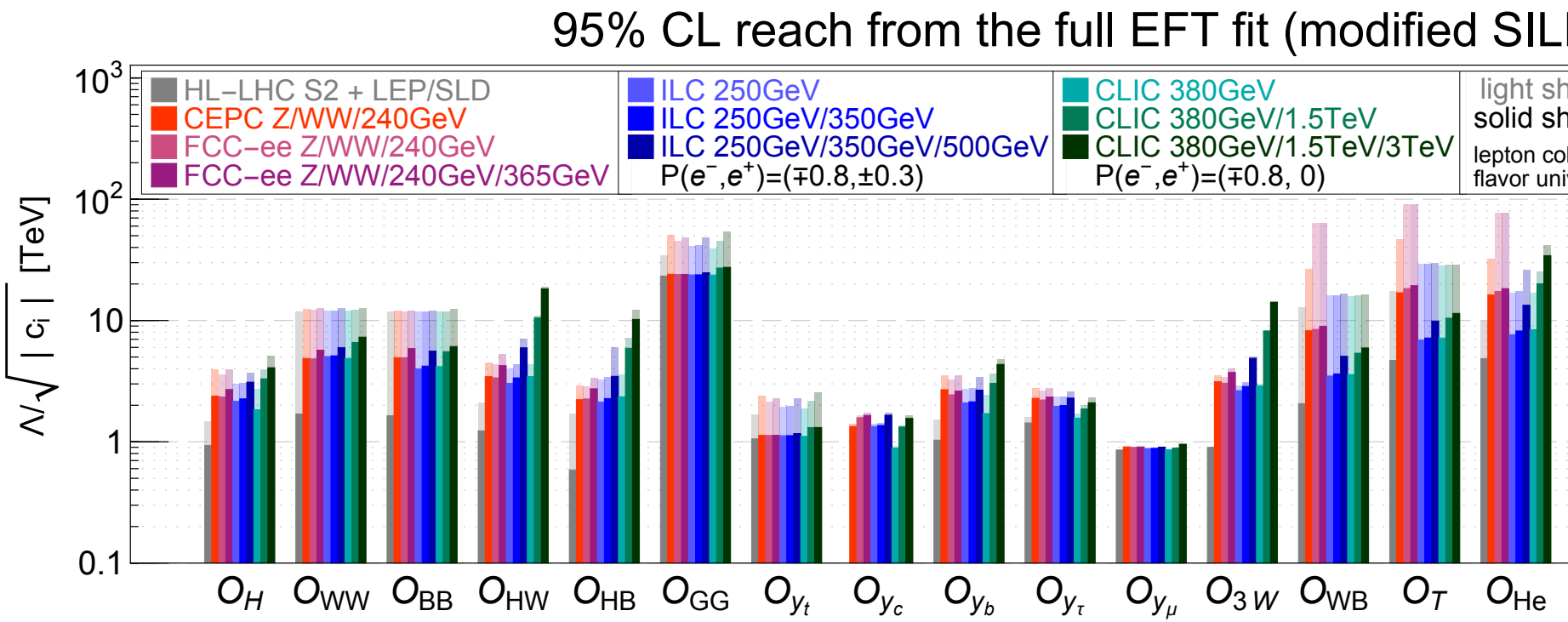
(We can also double the luminosity at 240 GeV...)



- FCC-ee: $5\,\mathrm{ab}^{-1}@240\,\mathrm{GeV}+$

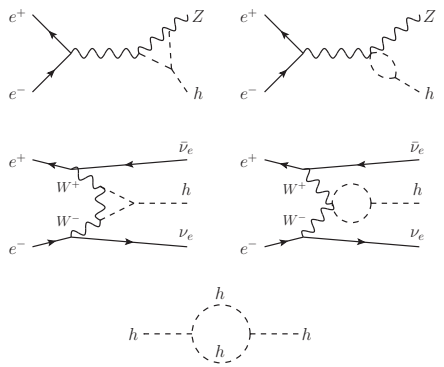


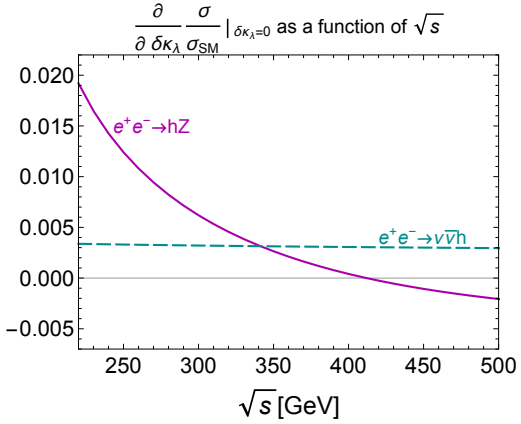
In a different basis...

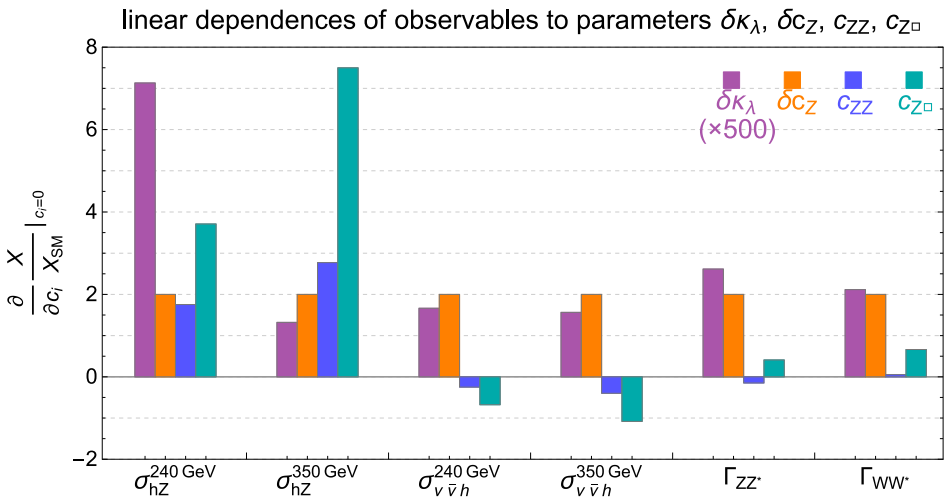


- ~ 15-25% **improvement** on the reach of the new physics scale for $\mathcal{O}_H$, $\mathcal{O}_{WW}$ and $\mathcal{O}_{BB}$, $\mathcal{O}_{HW}$ and $\mathcal{O}_{HB}$.
- **Note:** $\Lambda \sim \sqrt{1/g_{\text{eff}}}$ **!**

Triple Higgs coupling at circular colliders (240 & 350 GeV)

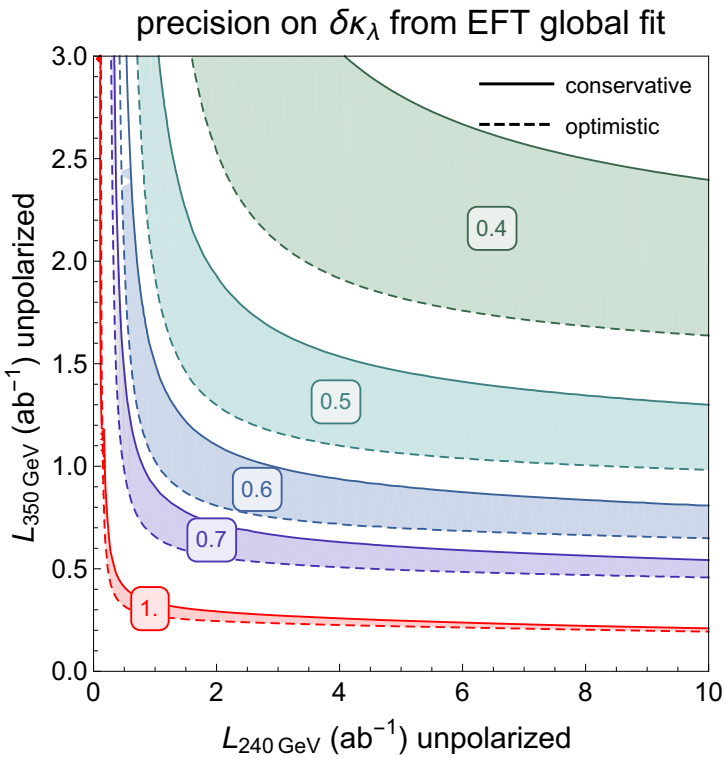






- One loop corrections to all Higgs couplings (production and decay).
- 240 GeV: *hZ* near threshold (more sensitive to $\delta\kappa_\lambda$)
- at 350 GeV:
  - WW fusion
  - *hZ* at a different energy
- $h \to WW^*/ZZ^*$ also have some discriminating power (but turned out to be not enough).

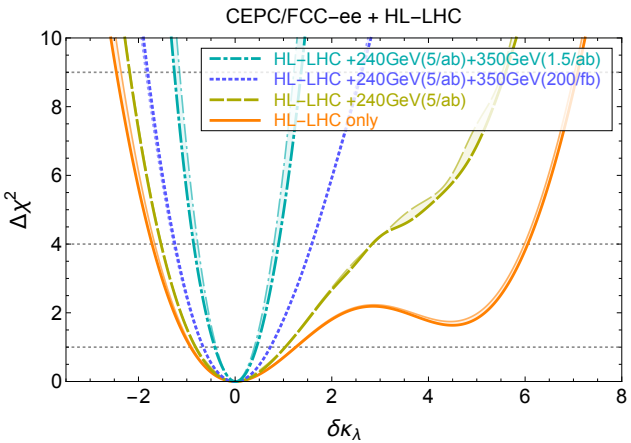
Triple Higgs coupling at circular colliders



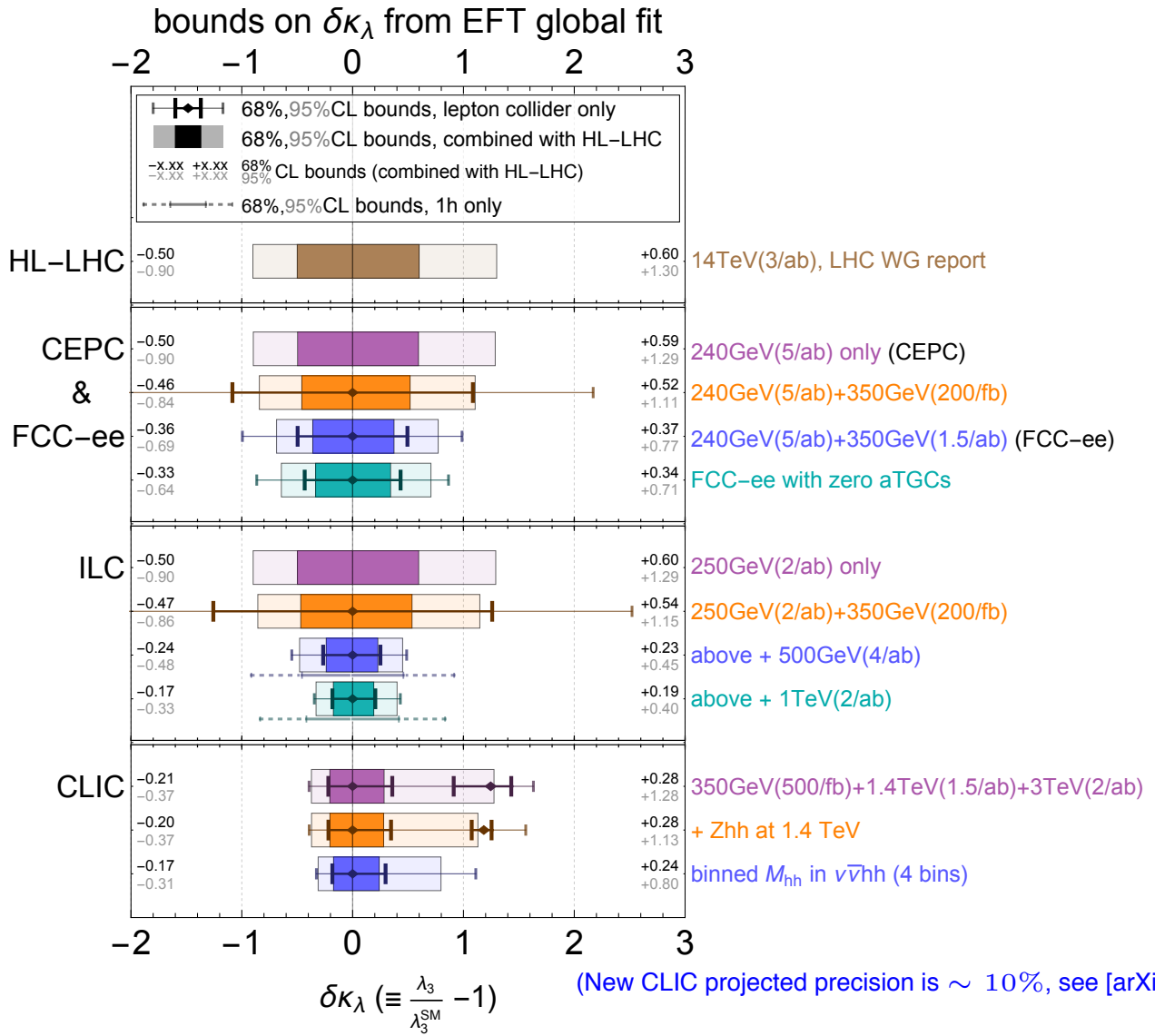
- Runs at both 240 GeV and 350 GeV are needed to obtain good constraints on $\delta\kappa_\lambda$!
- Bounds are further improved if combined with HL-LHC measurements.

	CEPC alone		CEPC + HL-LHC	
	non-zero aTGCs	zero aTGCs	non-zero aTGCs	zero aTGCs
HL-LHC alone			$[-0.92, +1.26]$	$[-0.90, +1.24]$
240 GeV ($5\,\mathrm{ab}^{-1}$)	$[-4.55, +4.72]$	$[-2.93, +3.01]$	$[-0.81, +1.04]$	$[-0.82, +1.03]$
+350 GeV ($200\,\mathrm{fb}^{-1}$)	$[-1.08, +1.09]$	$[-1.04, +1.04]$	$[-0.66, +0.76]$	$[-0.66, +0.74]$
+350 GeV ($1.5\,\mathrm{ab}^{-1}$)	$[-0.50, +0.49]$	$[-0.43, +0.43]$	$[-0.43, +0.44]$	$[-0.39, +0.40]$

Note: HL-LHC bounds are outdated

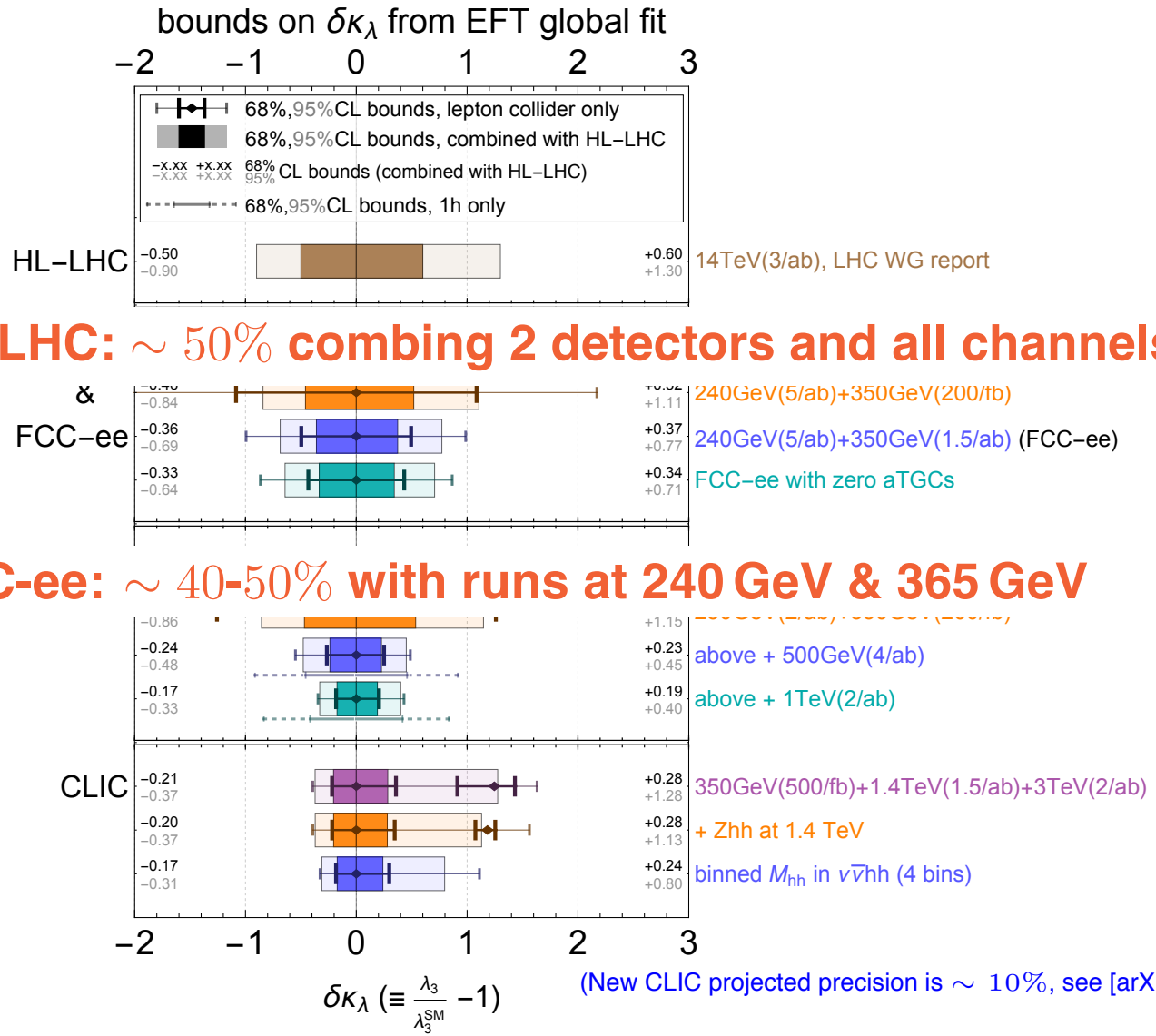


A summary of the projected reaches on $\delta\kappa_\lambda$ (with updated HL-LHC projection)



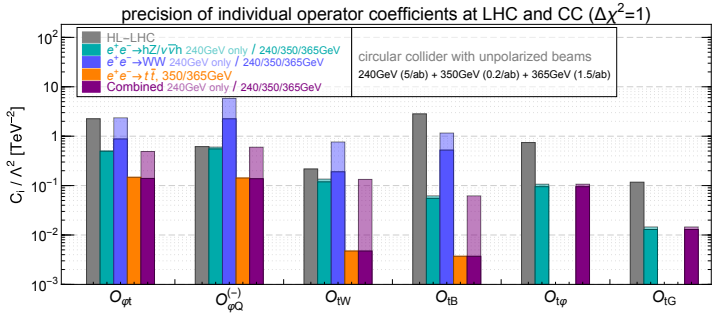
(New CLIC projected precision is $\sim 10\%$, see [arXiv:1901.05897] Roloff *et al.*)

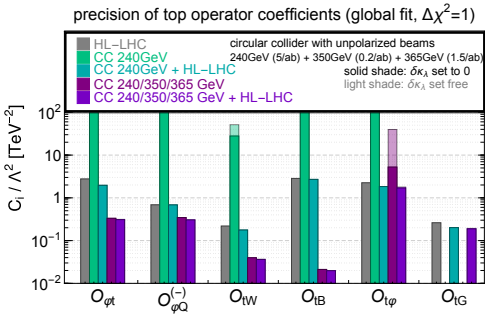
A summary of the projected reaches on $\delta\kappa_\lambda$ (with updated HL-LHC projection)

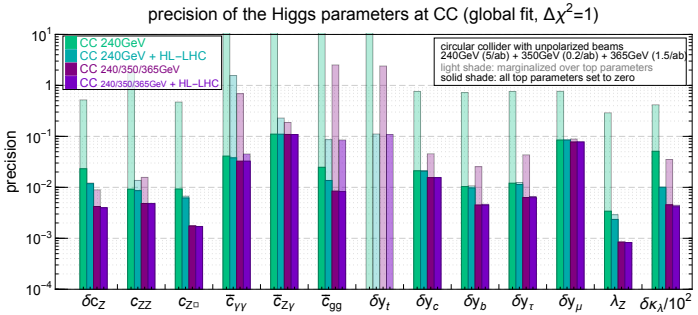


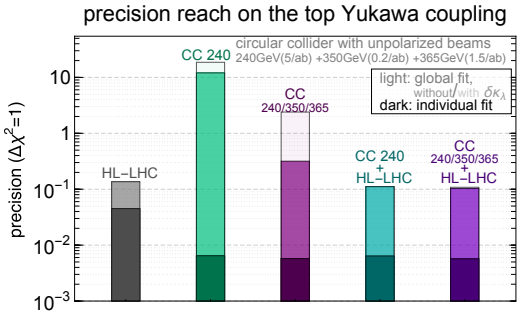
(New CLIC projected precision is $\sim$ 10%, see [arXiv:1901.05897] Roloff *et al.*)

Top operators in loops





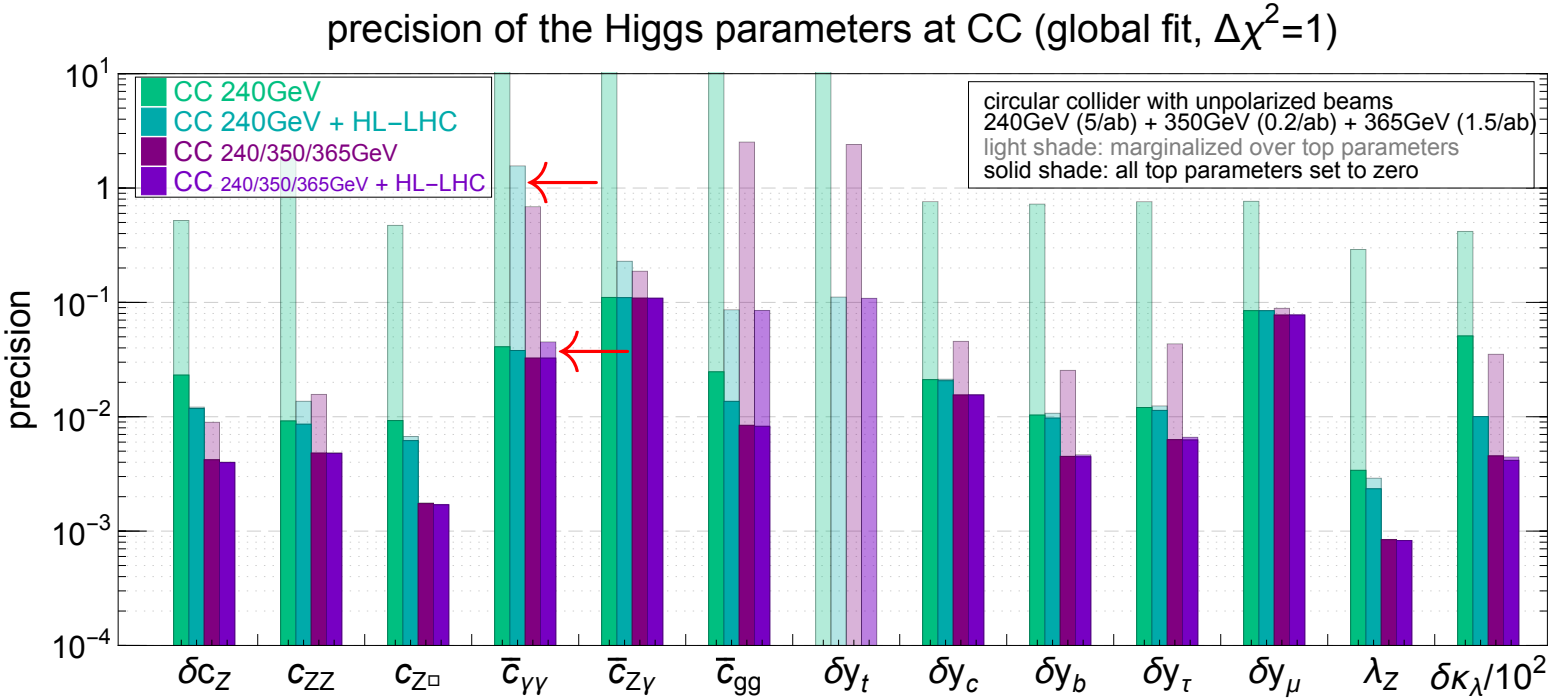


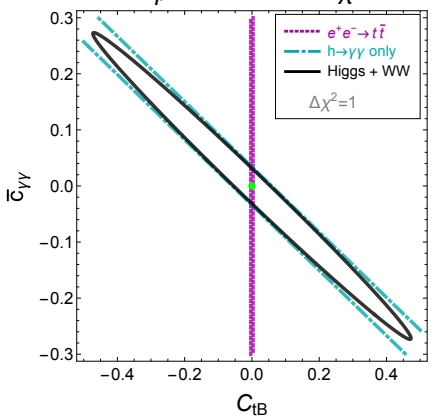


$$O_{t\varphi} = \bar{Q}t\tilde{\varphi}\,(\varphi^\dagger\varphi) + h.c.,$$
$$O_{\varphi Q}^{(1)} = (\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{Q}\gamma^\mu Q),$$
$$O_{\varphi Q}^{(3)} = (\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{Q}\gamma^\mu \tau^I Q),$$
$$O_{\varphi t} = (\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{t}\gamma^\mu t),$$
$$O_{tW} = (\bar{Q}\sigma^{\mu\nu}\tau^I t)\,\tilde{\varphi}W^I_{\mu\nu} + h.c.,$$
$$O_{tB} = (\bar{Q}\sigma^{\mu\nu} t)\,\tilde{\varphi}B_{\mu\nu} + h.c.,$$
$$O_{tG} = (\bar{Q}\sigma^{\mu\nu} T^A t)\,\tilde{\varphi}G^A_{\mu\nu} + h.c..$$

- Higgs precision measurements have sensitivity to the top operators in the loops, but it is challenging to discriminate many parameters in a global fit.
- HL-LHC helps, but a Top threshold run is better.
- **Note: For the $e^+e^- \to WW$ distribution, only the production polar angle is included!**

Top operators in loops





- $O_{tB} = (\bar{Q}\sigma^{\mu\nu} t)\, \tilde{\varphi} B_{\mu\nu} + h.c.$ is not very well constrained at the LHC, and it generates dipole interactions that contributes to the $h\gamma\gamma$ vertex.

To do list

- EW + Higgs **(Easy!)**
- EW + Higgs + 1-loop triple Higgs **(Easy!)**
- EW + Higgs + top + 1-loop triple Higgs + 1-loop top
  (Can be hard depending on how far we want to go, but we don't have to do everything at once....)