A global view on the Higgs self-coupling at lepton colliders

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based on S. Di Vita, G. Durieux, C. Grojean, J. Gu, Z. Liu, G. P., M. Riembau and T. Vantalon '17

The Higgs self-interaction

Measuring the **Higgs self-interactions** is an essential step to understand the structure of the **Higgs potential**

$$\mathcal{L} = -\frac{1}{2} m_h^2 h^2 - \lambda_3 \frac{m_h^2}{2v} h^3 - \lambda_4 \frac{m_h^2}{8v^2} h^4 \qquad \kappa_\lambda \equiv \frac{\lambda_3}{\lambda_3^{\mathrm{SM}}}$$

- distortions expected in many BSM scenarios
- related to order of EW phase transition (relevant for cosmology)
- limited precision at LHC due to small statistics $\lambda_3 \in [0, 2]$ at $1\,\sigma$

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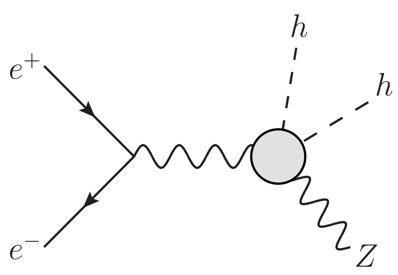
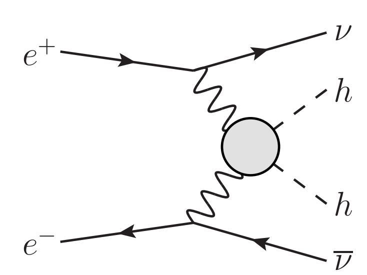
✦ at high-energy lepton machines accessible mainly in **HH production**



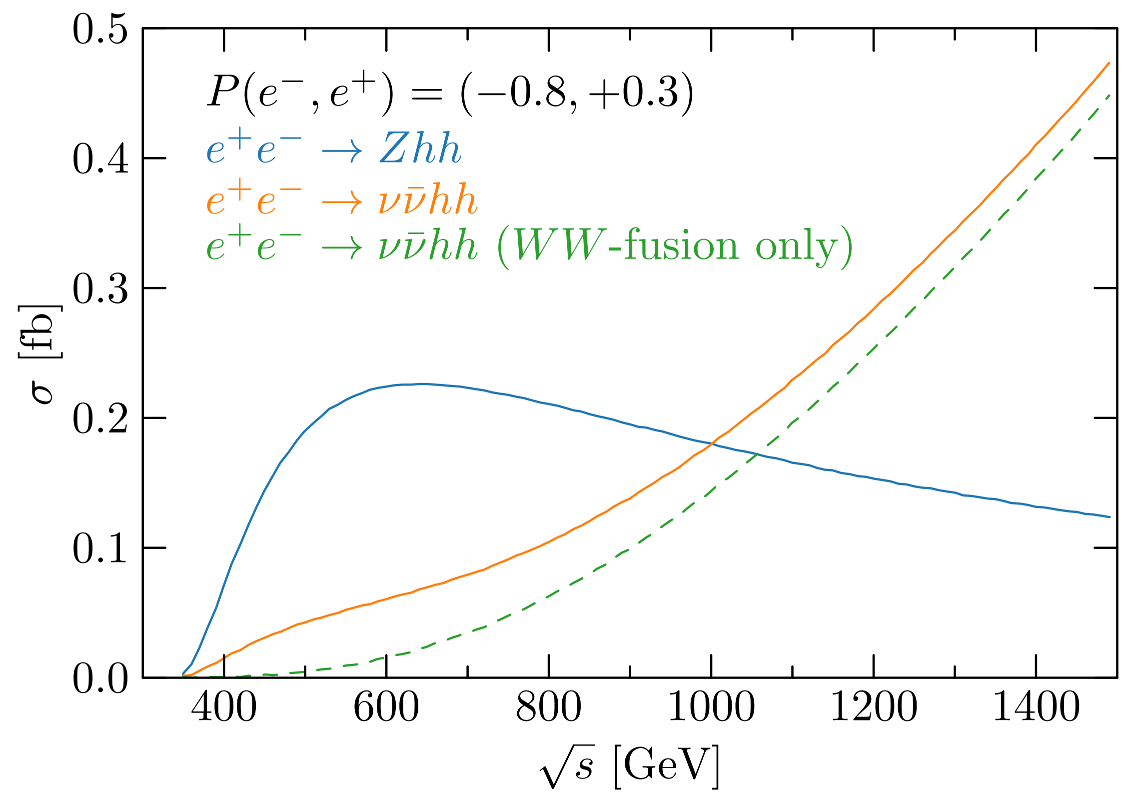
✦ additional bonus: test **strength of Higgs couplings** at high energy (VVHH coupling)



Main double-Higgs channels

Two main channels

ZHH and $\nu\bar{\nu}$HH



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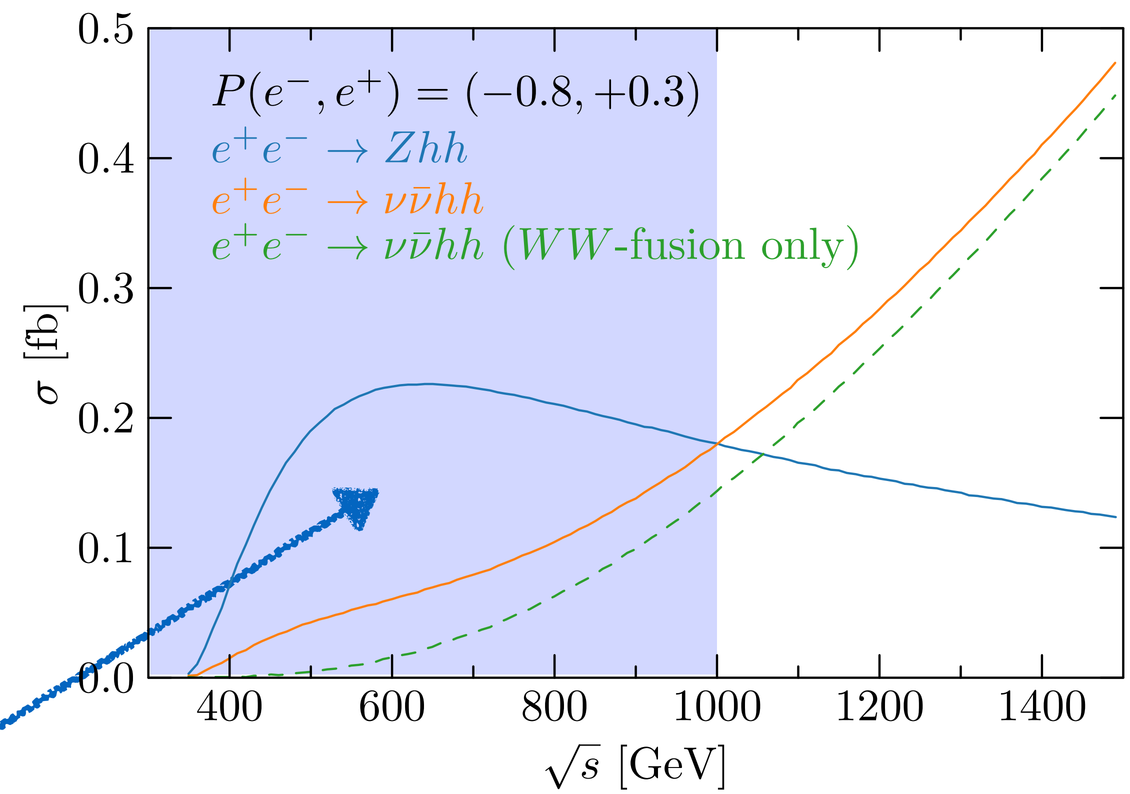
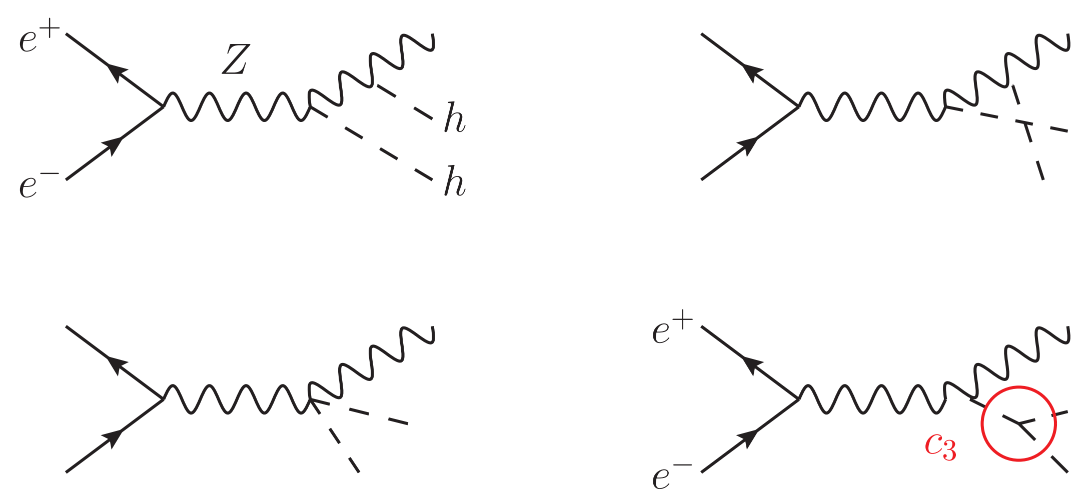


Double Higgs-strahlung (DHS)

dominant below 1 TeV



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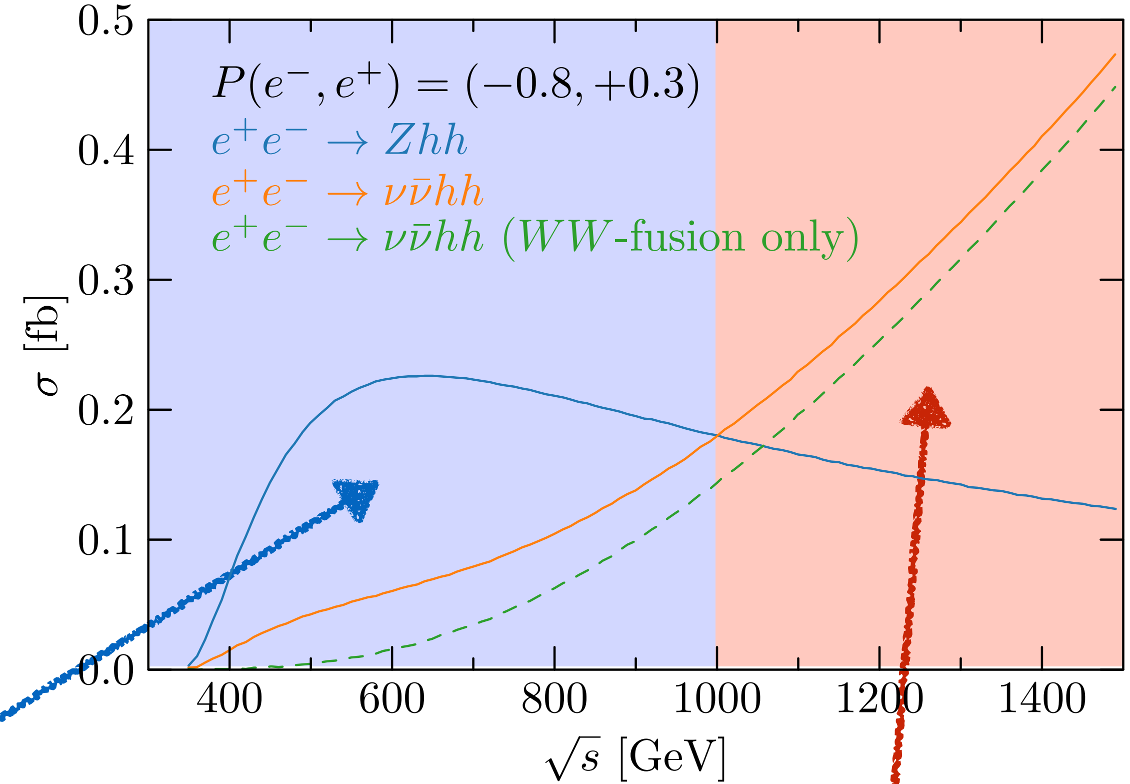

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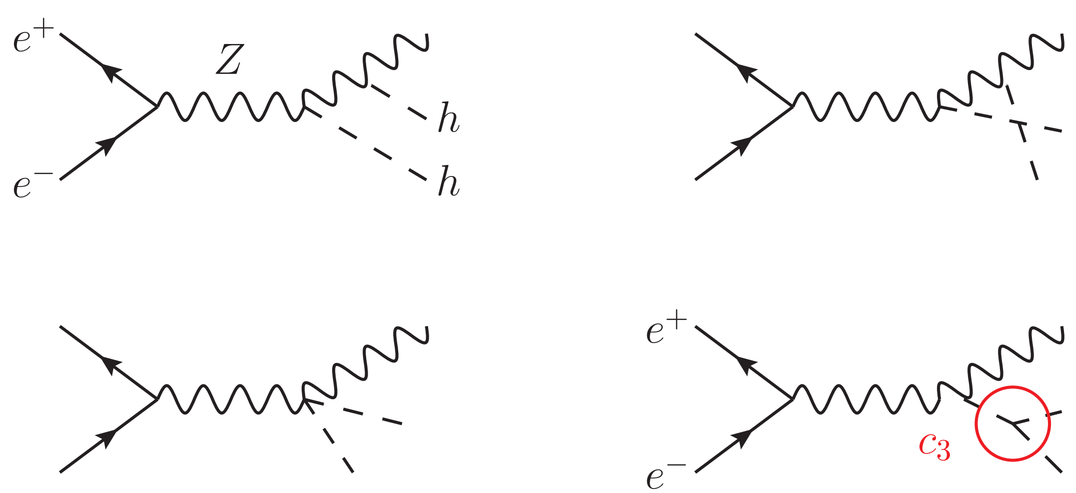
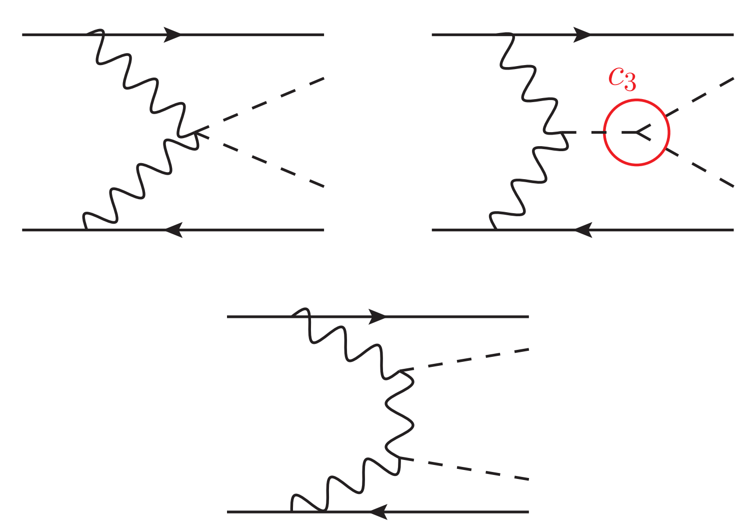


Vector Boson Fusion (VBF)

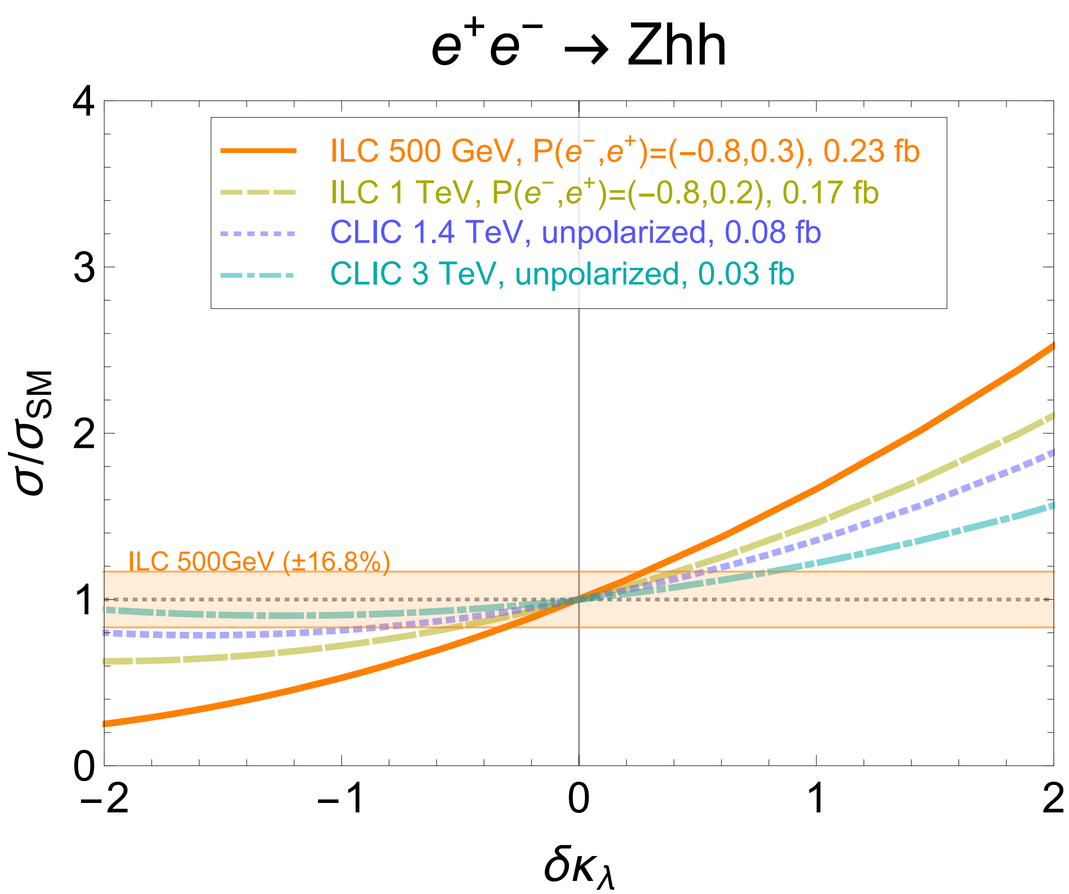
dominant above 1 TeV

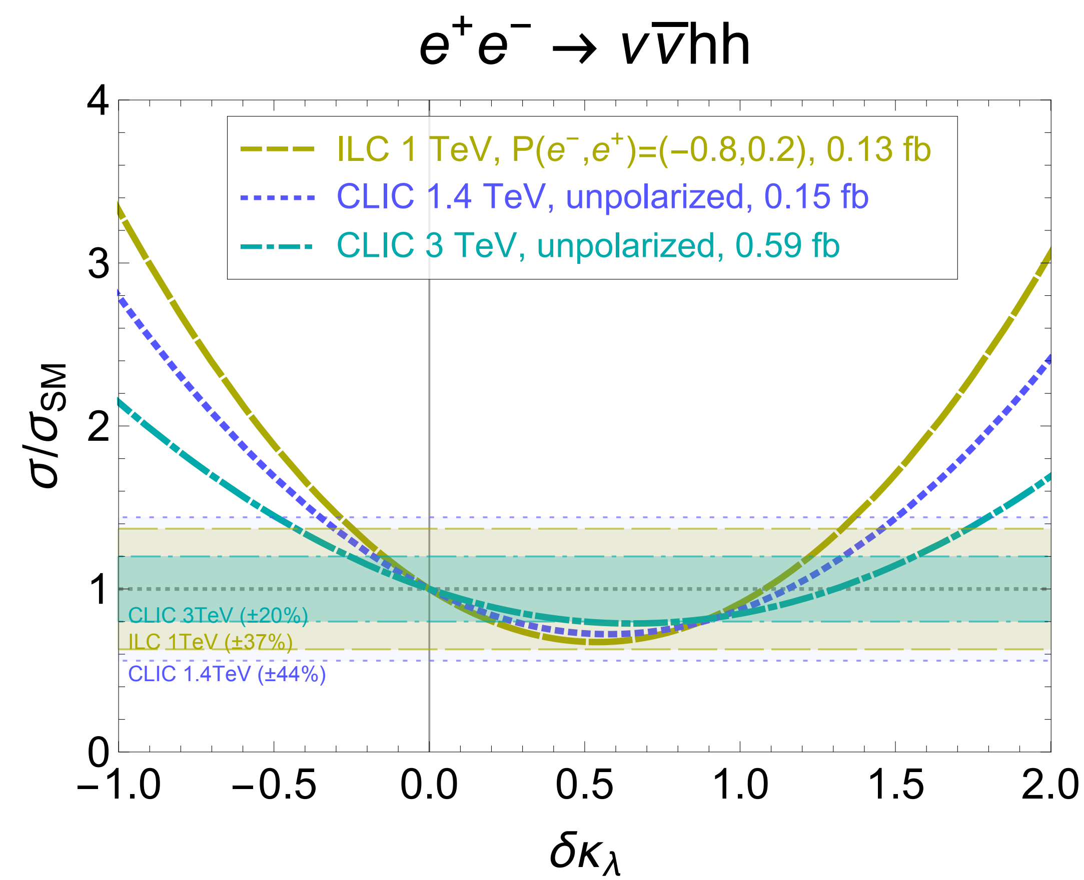


Sensitivity to Higgs self-coupling

The two channels provide complementary information

- ✦ ZHH gives stronger constraints on $\delta\lambda_3 > 0$
- ✦ $\nu\overline{\nu}$HH gives stronger constraints on $\delta\lambda_3 < 0$





- ‣ dependence on $\delta\lambda_3$ stronger at lower COM energy, maybe worth collecting more luminosity at CLIC 1.4 TeV

Precision reach at CLIC

CLIC 1.4 TeV (1.5 ab^{-1}) + 3 TeV (2 ab^{-1}), unpolarized beams, $e^+e^- \to \nu\bar{\nu}hh$		
bounds on $\delta\kappa_\lambda$	68% CL	95% CL
CLIC 1.4 TeV	$[-0.35, 1.51]$	$[-0.60, 1.76]$
CLIC 3 TeV	$[-0.26, 0.50] \cup [0.81, 1.56]$	$[-0.46, 1.76]$
CLIC combined	$[-0.22, 0.36] \cup [0.90, 1.46]$	$[-0.39, 1.63]$
$+Zhh$	$[-0.22, 0.34] \cup [1.07, 1.28]$	$[-0.39, 1.56]$

Precision at CLIC **~25% at 68% CL** (combining 1.4 TeV and 3 TeV runs)

… but inclusive measurements at CLIC can not resolve the **additional minimum** at $\delta\lambda_3 \sim 1$

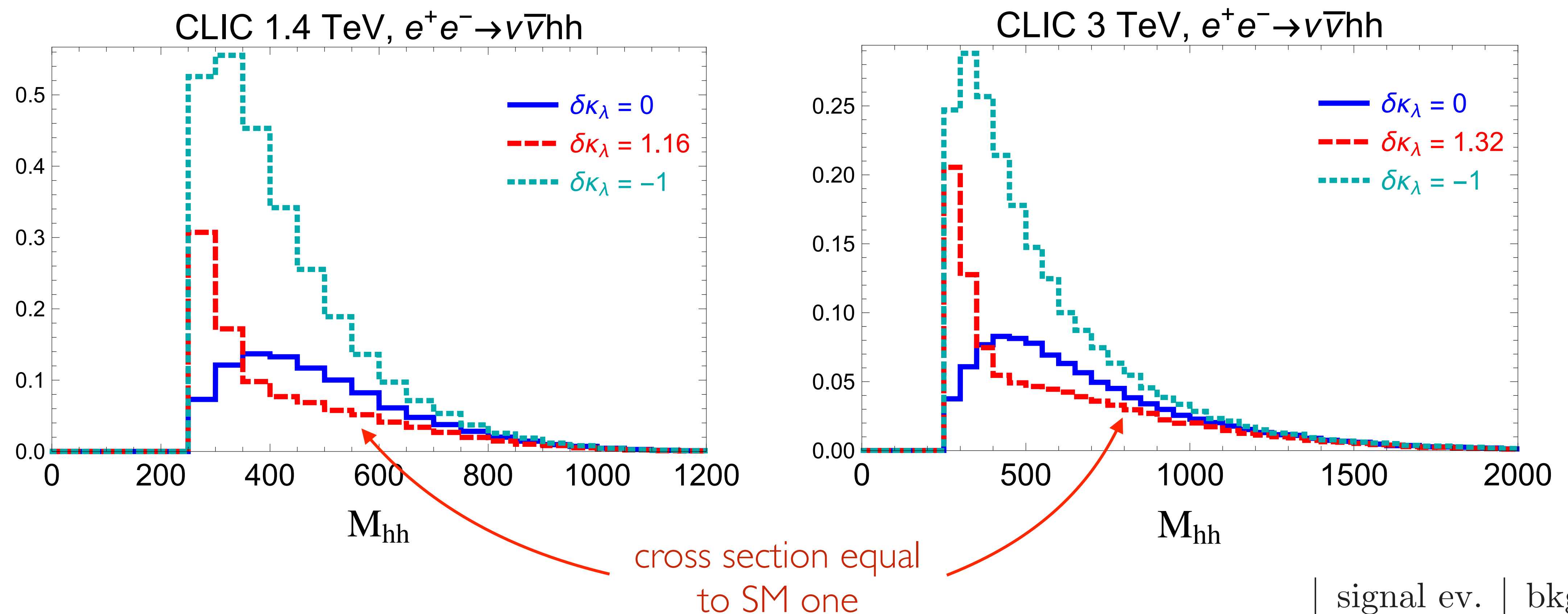
- ZHH helps to test the second minimum, but has impact (due to small cross section)

Additional improvement:

- consider **differential distributions**

Differential HH distributions

The Higgs trilinear coupling strongly modifies the distributions



	signal ev.	bkg. ev.
CLIC 1.4 TeV	~ 20	~ 40
CLIC 3 TeV	~ 60	~ 100

- differential analysis can exclude the second minimum

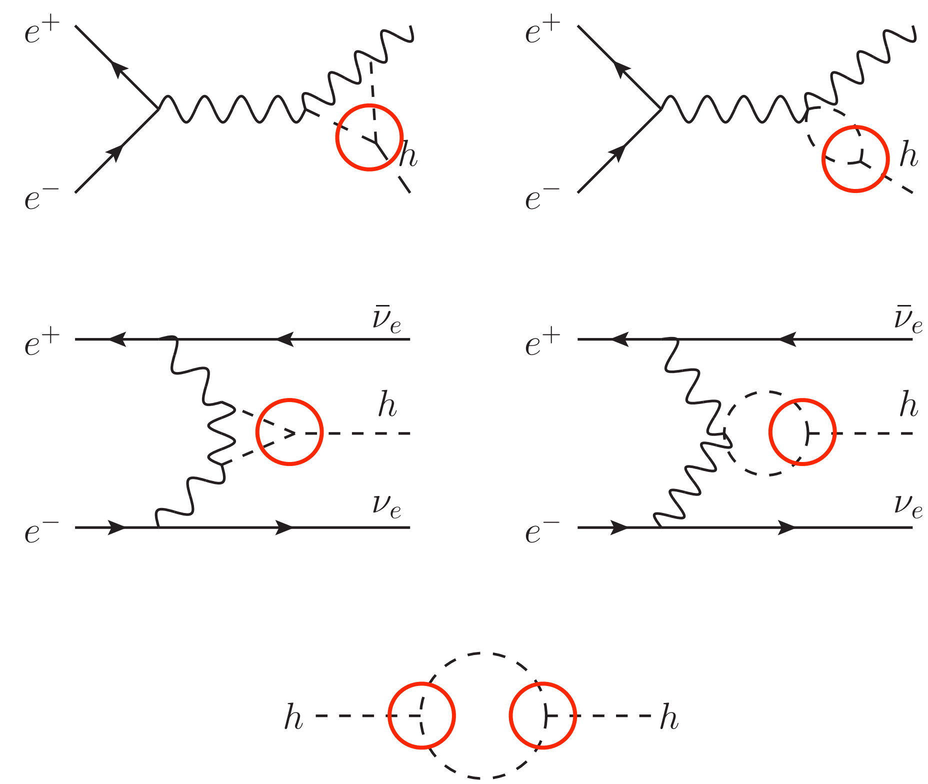
bounds on $\delta\kappa_\lambda$	68% CL	95% CL
CLIC inclusive	$[-0.22, 0.34] \cup [1.07, 1.28]$	$[-0.39, 1.56]$
2 bins in $\nu\bar{\nu}hh$	$[-0.19, 0.31]$	$[-0.33, 1.23]$
4 bins in $\nu\bar{\nu}hh$	$[-0.18, 0.30]$	$[-0.33, 1.11]$

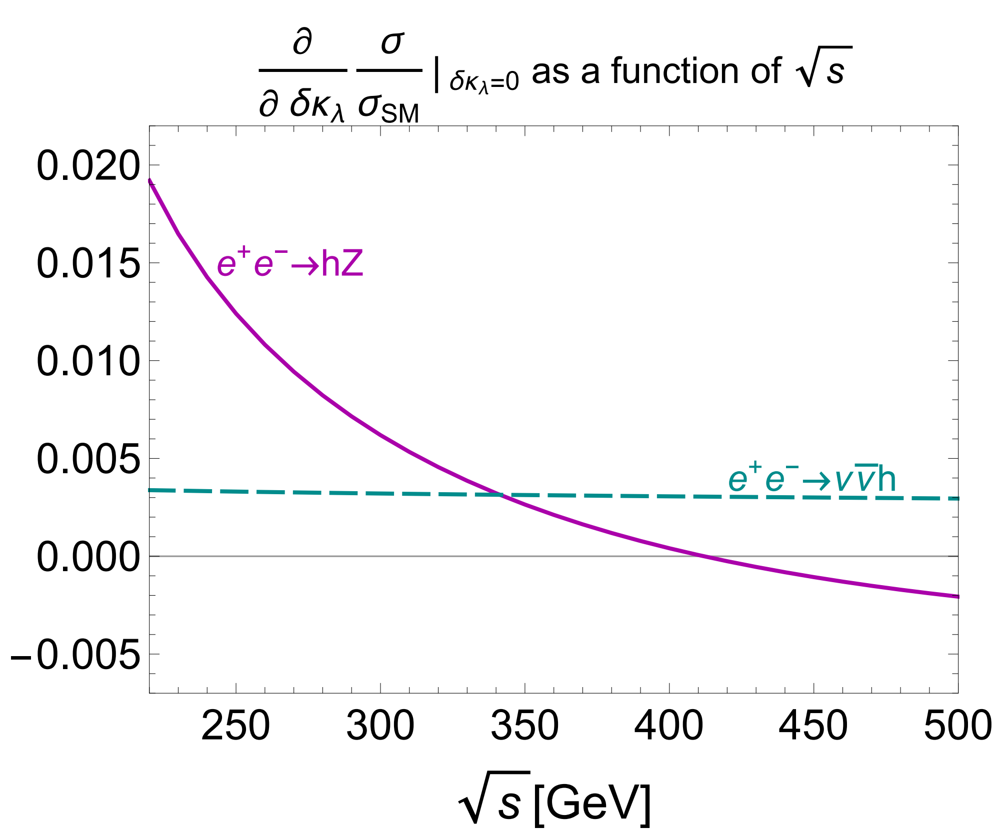
Help from Single Higgs?

Self-Interaction from Single Higgs

Higgs self-interaction can be also probed indirectly through single-Higgs processes

[McCullough '13]





Good sensitivity at low energy in HZ (and $\nu\bar{\nu}$H) channels

- eg. exclusive analysis at TLEP 240 GeV:

$$|\delta\lambda_3| \lesssim 28\%$$

Single Higgs global analysis

Corrections to Higgs trilinear are usually **not alone:** accompanied by modifications of single Higgs couplings

↓

global analysis is needed!

Several couplings can affect single-Higgs production

Minimal set in the Warsaw basis: 12 operators

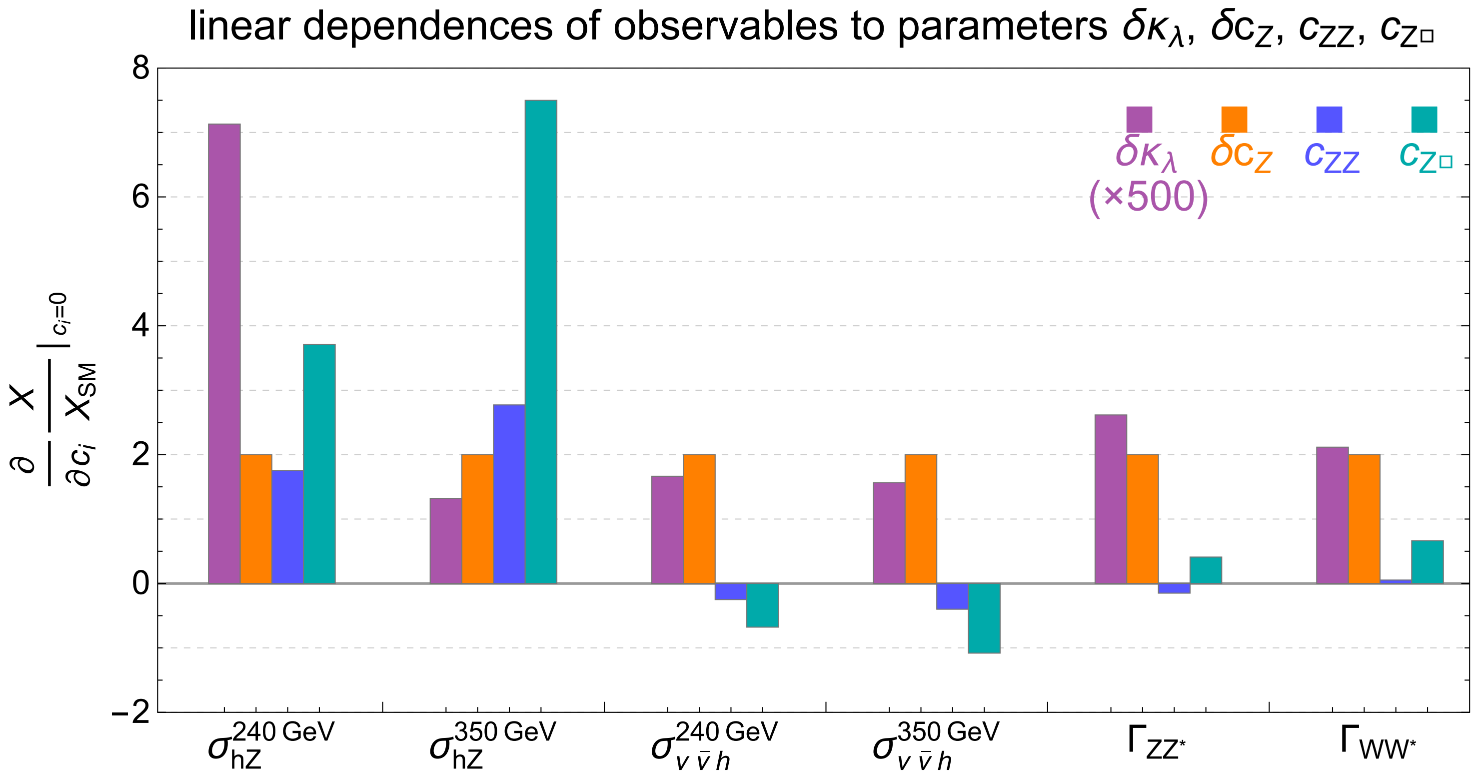
- Higgs couplings to gauge bosons $\delta c_z,\ c_{zz},\ c_{z\Box},\ c_{z_\gamma},\ c_{\gamma\gamma},\ c_{gg}$
- Yukawa's $\delta y_t,\ \delta y_b,\ \delta y_c\ \delta y_\tau,\ \delta y_\mu$
- triple gauge couplings λ_z

Single Higgs global analysis

All the 12 operators can be well constrained by a global fit

Higgs self interaction can also be added to the list: 12+1 operators

- can be distinguished thanks to different impact on various processes

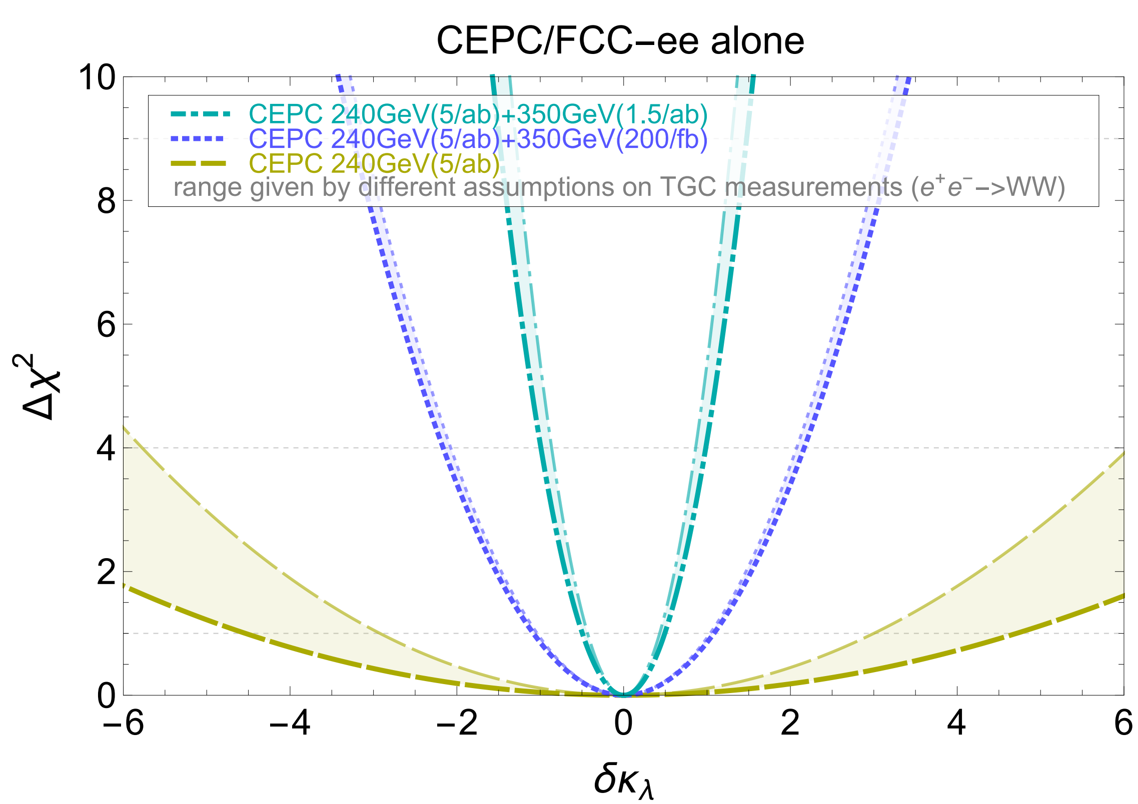


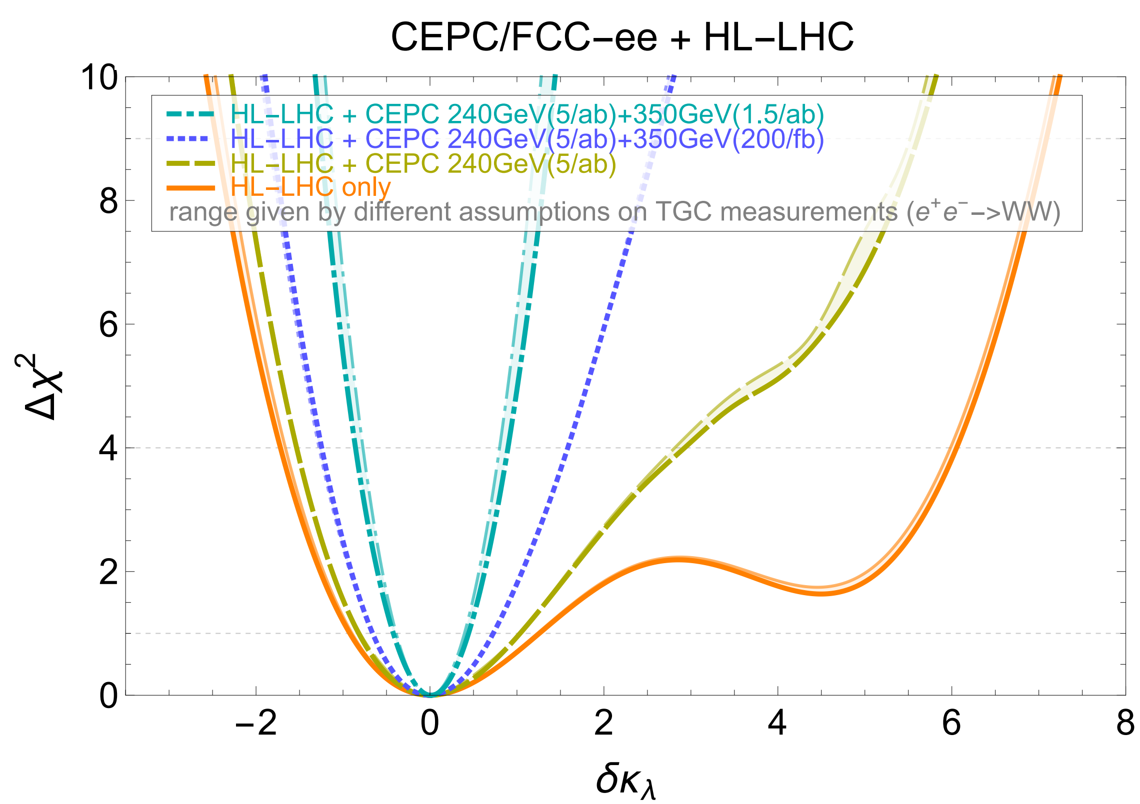
Single Higgs global analysis

- Single-Higgs channels are important for **low-energy colliders**

eg. combination of 240 GeV and 350 GeV can lead to ~50% precision on Higgs trilinear

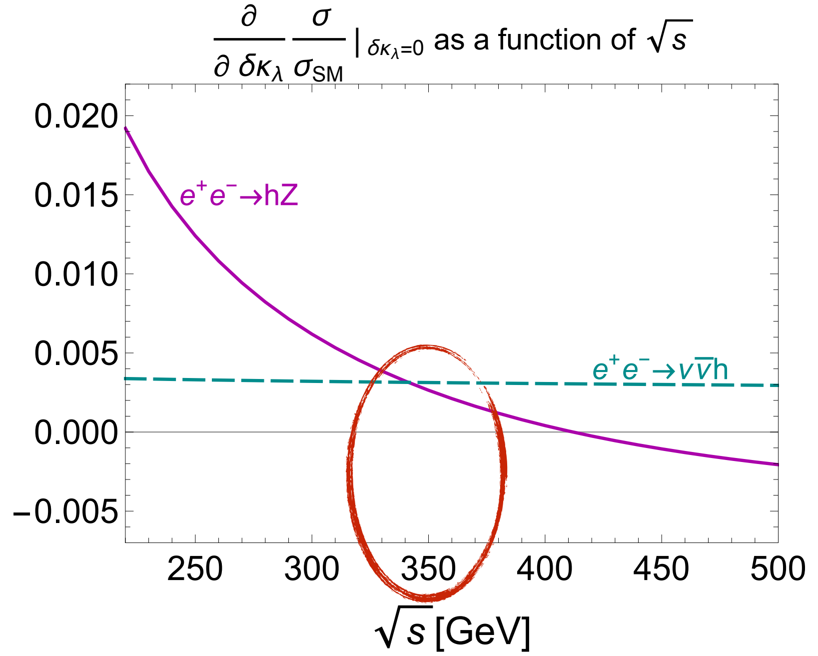
Further improvement with combination with HL-LHC
(helps to lift additional HL-LHC minimum at $\delta\lambda_3 \sim 5$)





Single Higgs global analysis

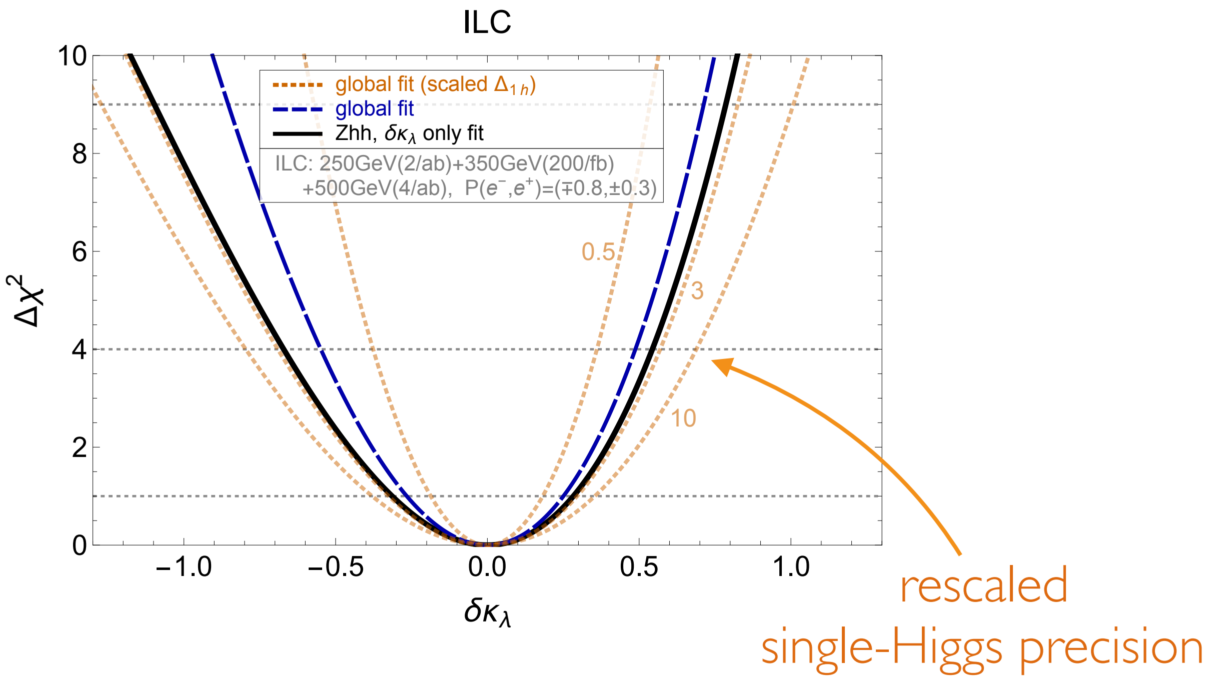
- ✦ Single-Higgs channels have a **small impact on high-energy colliders** that can access double-Higgs production



  - ▸ small dependence on Higgs trilinear at a 350 GeV CLIC run

Global analysis still important to assess **robustness** of the result

eg. ILC determination of $\delta\lambda_3$ is affected if single-Higgs precision is modified

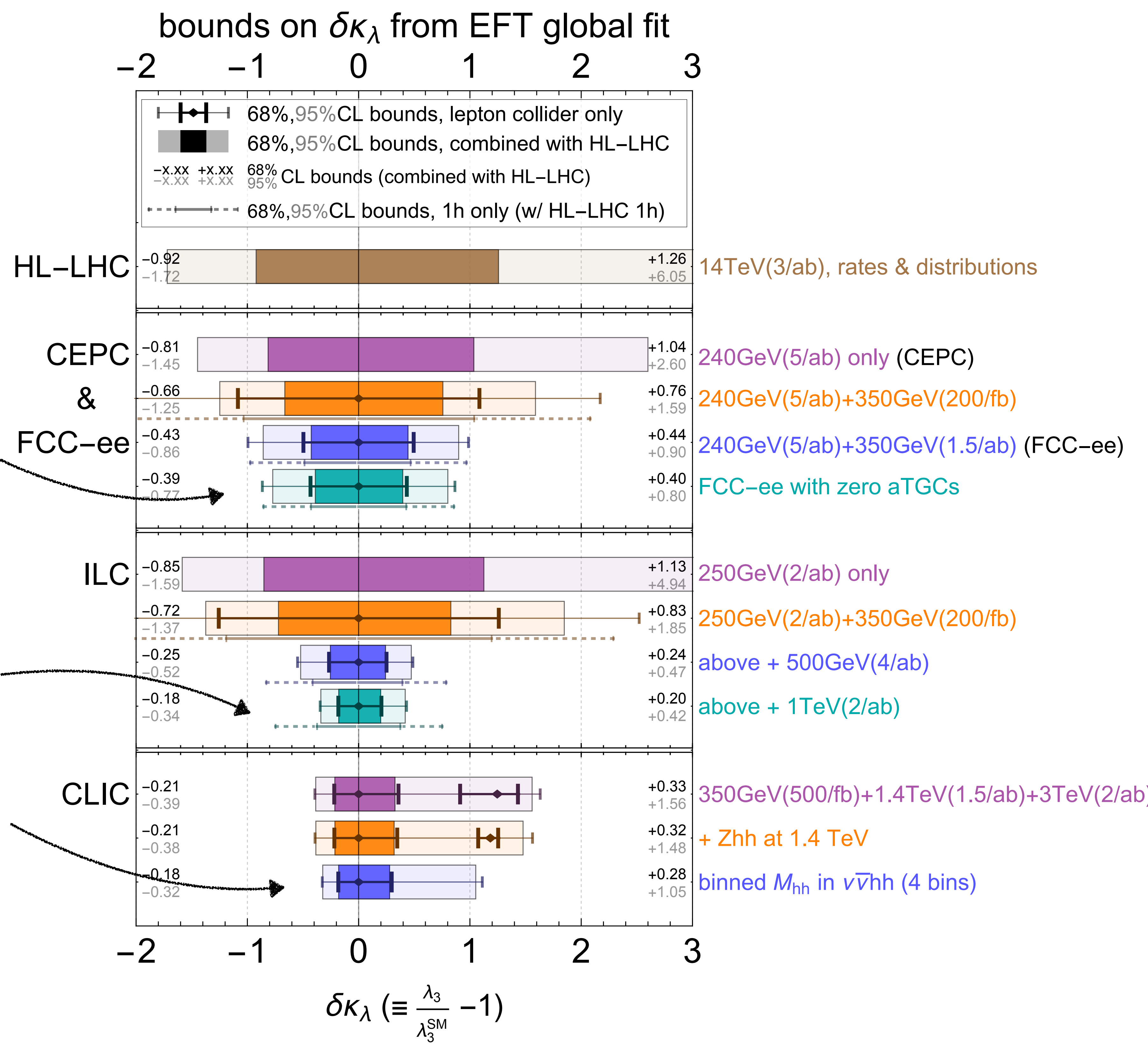


Comparison of different colliders

Reach at different colliders

CEPC and **FCC-ee** can reach **~40%** precision

Combined global fit at **ILC** or **CLIC** can reach **~20%** precision and select "correct" minimum



Conclusions

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Lepton colliders allow to measure the **Higgs trilinear self-coupling**

- first "precision" determination (only O(1) possible at HL-LHC)
- VBF main channel at high-energy machines (COM > 1 TeV)
- differential distributions useful to improve measurement
  (remove additional minimum in the fit)
- CLIC could reach a **~25% precision** at 68% CL