Nailing Higgs Couplings at Future Colliders

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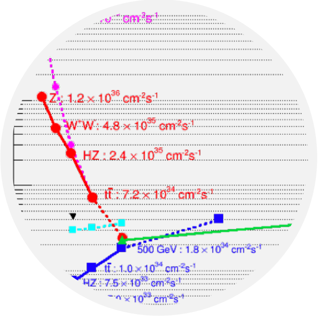
Overview



The Colliders

a brief overview of the legacy we can leave behind for the future generations

The Framework

a discussion of the theoretical and statistical framework that we use

The Results

elaborations and interpretations of our projections for the future

Disclaimer: This is an academic study of the physics that can be probed at future lepton colliders.
I do not make any prediction on which ones will exist in reality or their final run configurations.

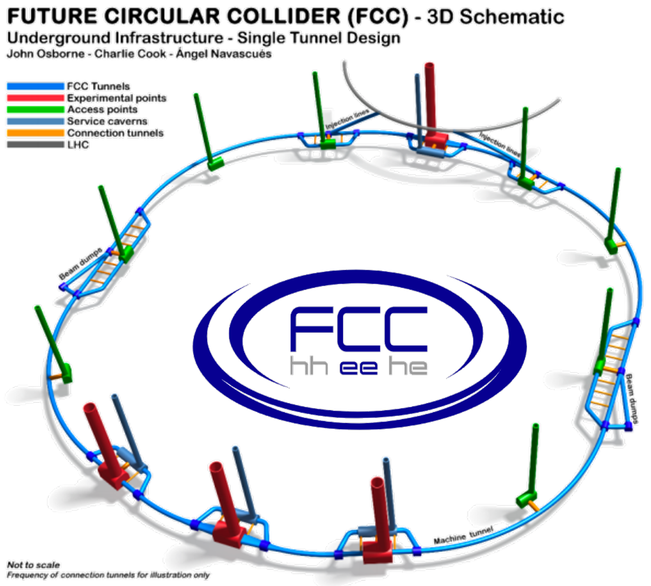
Future Lepton Colliders

a brief overview of the possible future lepton colliders and the configurations we explore

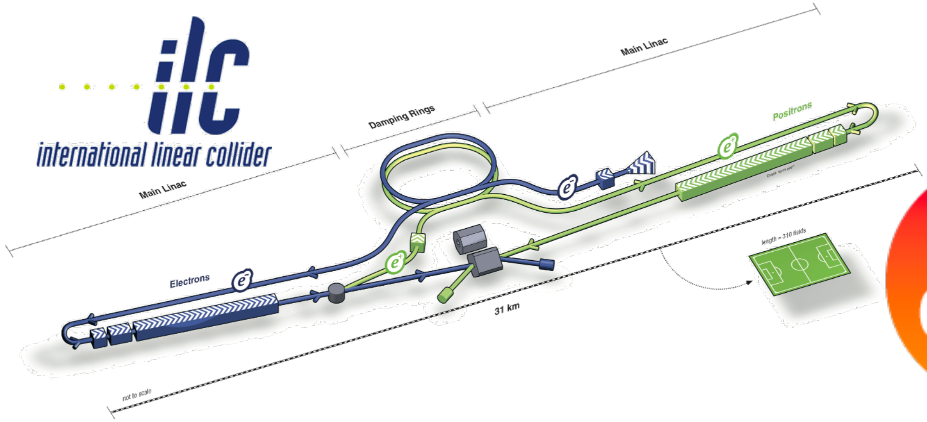
Based on:
J. de Blas, G. Durieux, C. Grojean, J. Gu, and A. Paul
"On the future of Higgs, Electroweak and Diboson measurements at Lepton Colliders"
JHEP 12 (2019) 117 [arXiv:1907.04311]

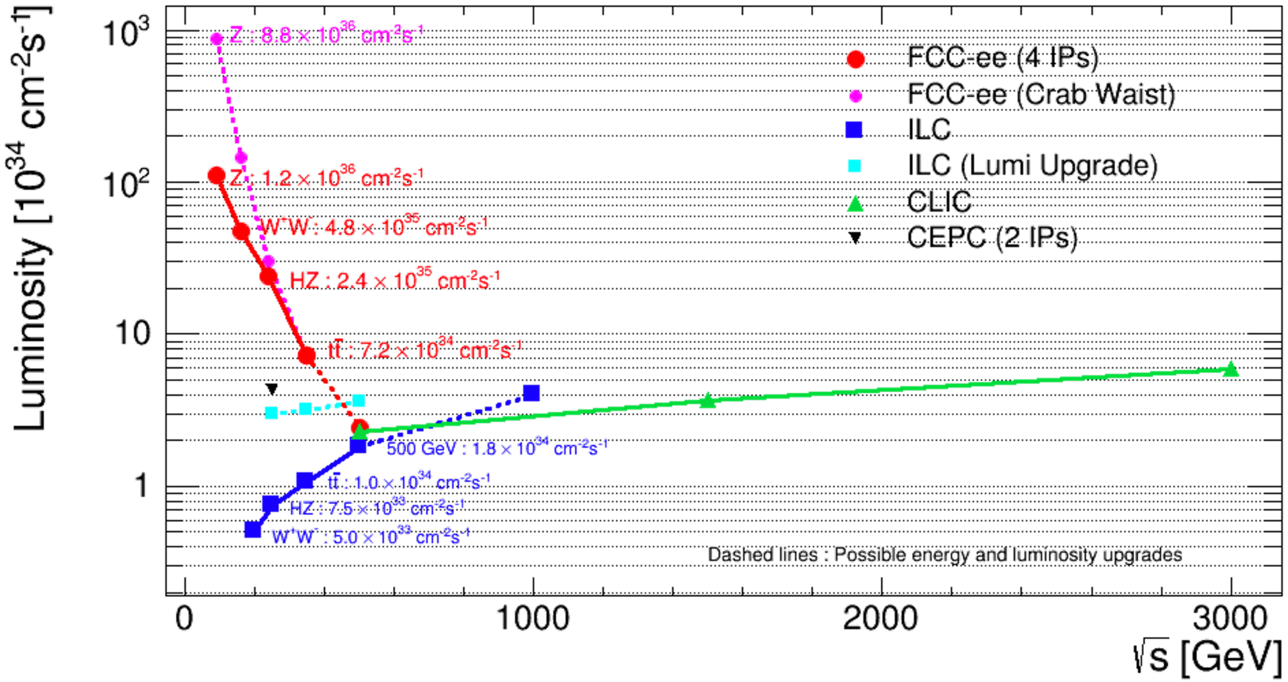
proposed colliders

circular colliders → higher luminosity at lower energies

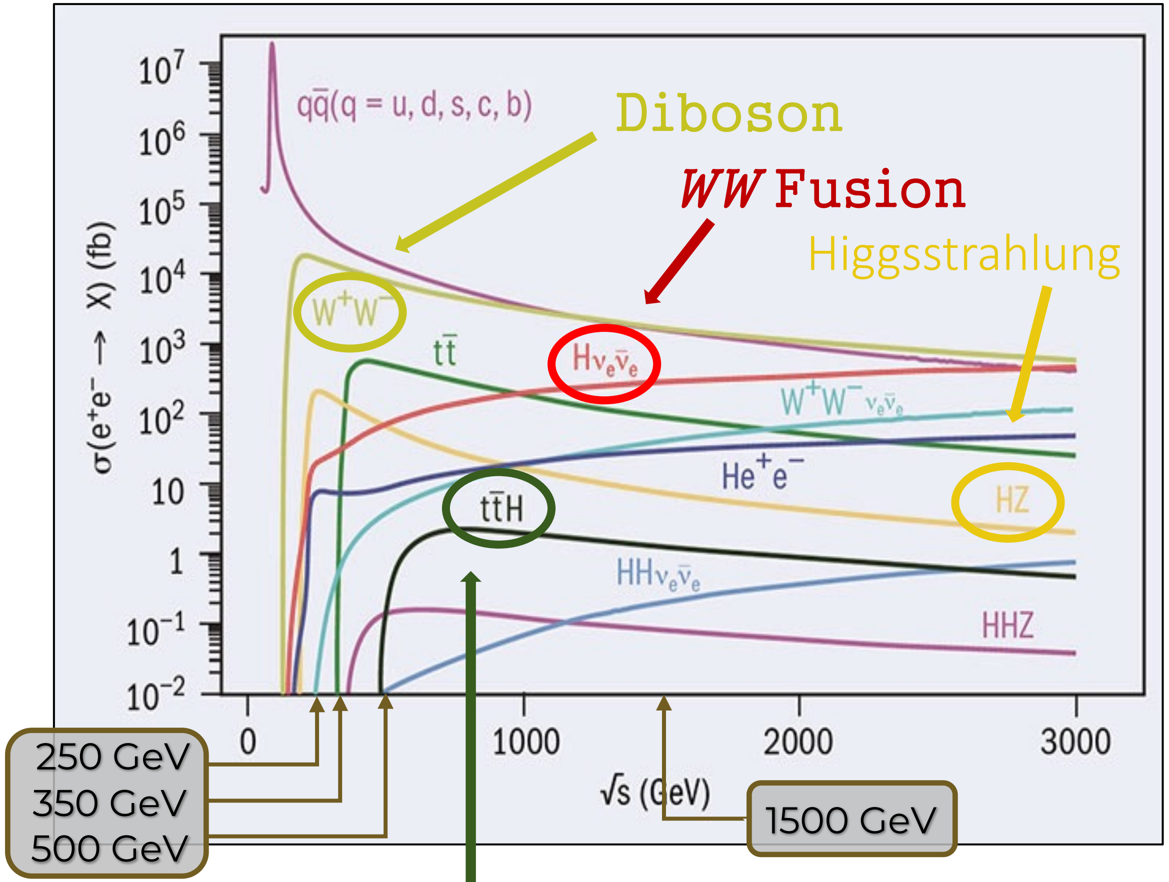


linear colliders → higher energy reach

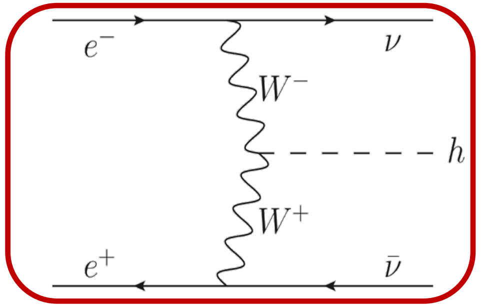


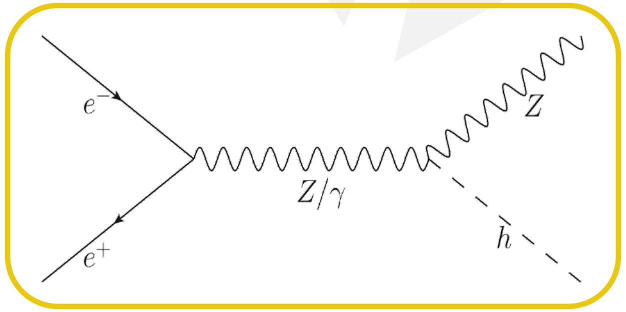


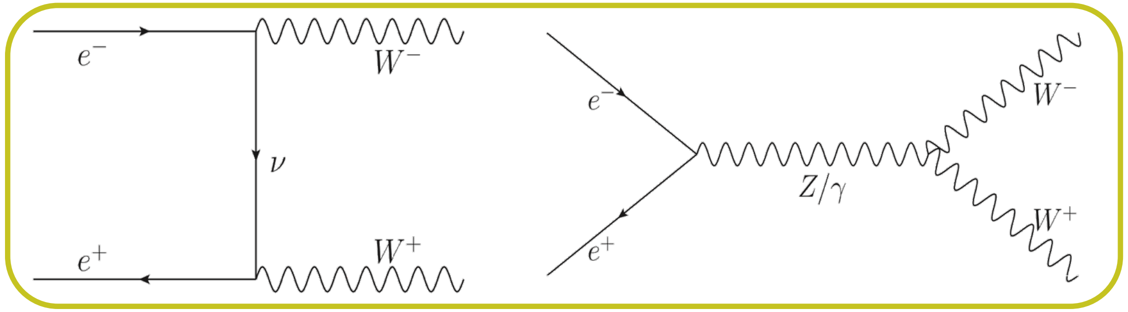
single Higgs production

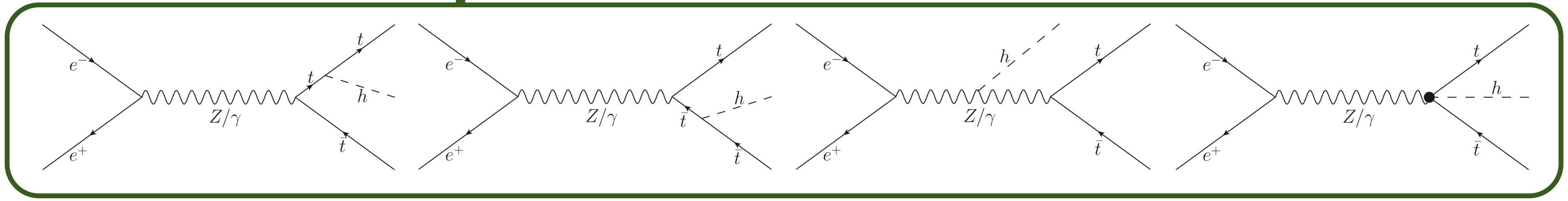


Primary production modes

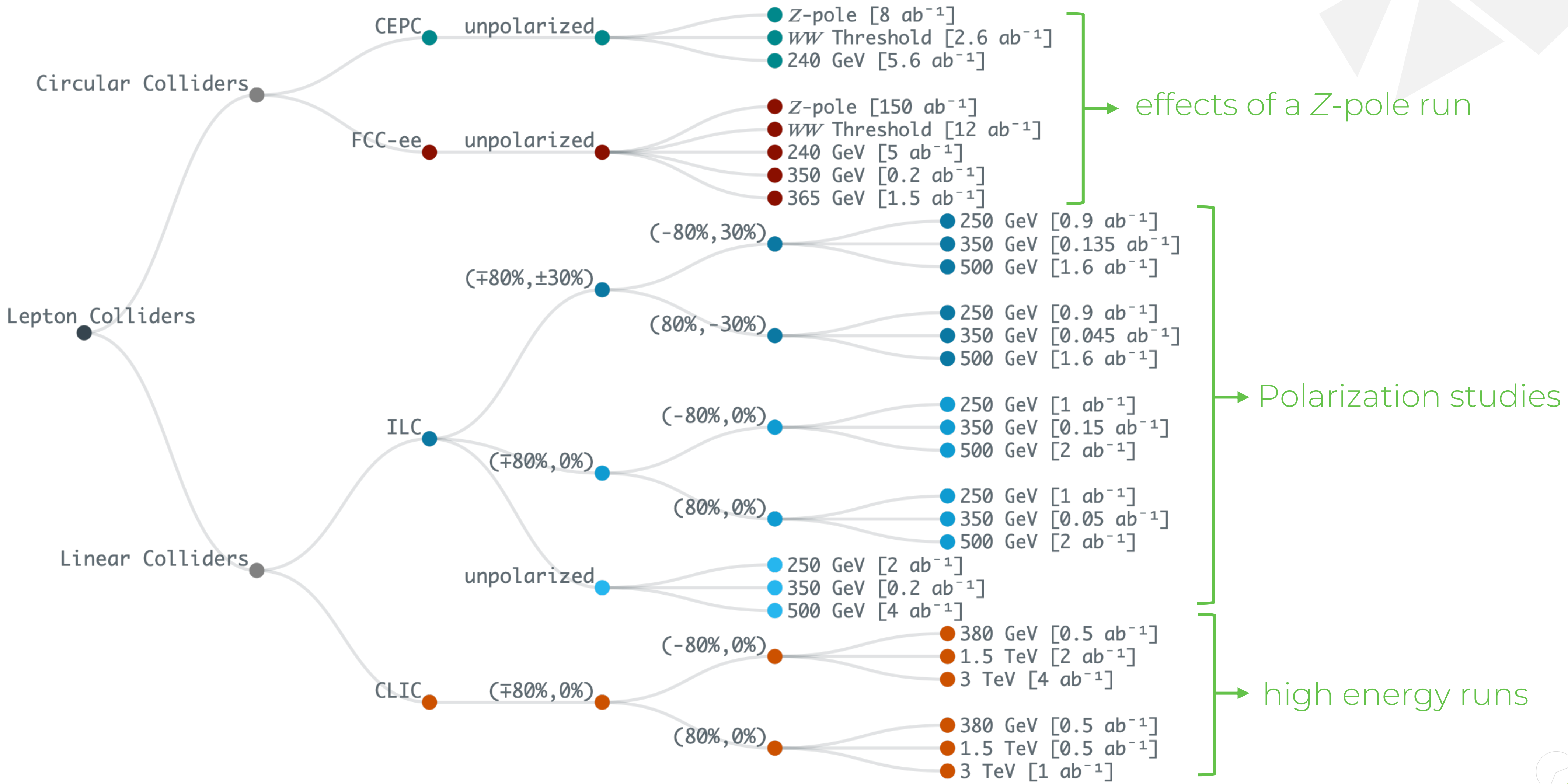








collider configurations



Theoretical & Statistical Framework

introducing the SMEFT and the analysis framework used

“what?”, “why?” and “how?”

the problems

- traditionally Higgs fits are done in the “κ” framework.
- this works if:
  - Higgs and EW couplings are decoupled
  - one ignores questions like custodial protection in the gauge couplings of the Higgs (i.e., hZZ and hWW independent)
- for the Higgs sector to be decoupled from the EW sector one has to assume infinite precision in the EW couplings
- the question is: are LEP/SLD measurements precise enough for the goodness of this assumption?
- can precision measurement of the Higgs couplings complete with the precision in EWPO

the solution

- focus on HL-LHC + lepton collider + LEP/SLD
- study scenarios with and without *Z*-pole runs at future circular colliders
- study effects of polarization and measurements from radiative returns at ILC
- study the effects of higher energy runs at CLIC
- use the SMEFT d-6 framework varying all possible operators for the Higgs and EW sector but assuming U(2) symmetry in the light quark couplings ($[C_{Hu}^{(1,3)}]_{11} = [C_{Hu}^{(1,3)}]_{22}$)
- fits were done in both **`HEPfit`** and an independent home-grown code in two different statistical framework.

EFT Basis

Basis of operators in an EFT

$\mathcal{O}_H = \frac{1}{2}(\partial_\mu \lvert H^2 \rvert)^2$	$\mathcal{O}_{GG} = g_s^2 \lvert H \rvert^2 G^A_{\mu\nu} G^{A,\mu\nu}$
$\mathcal{O}_{WW} = g^2 \lvert H \rvert^2 W^a_{\mu\nu} W^{a,\mu\nu}$	$\mathcal{O}_{y_u} = y_u \lvert H \rvert^2 \bar{q}_L \tilde{H} u_R + \text{h.c.}$ $(u \to t, c)$
$\mathcal{O}_{BB} = g'^2 \lvert H \rvert^2 B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{y_d} = y_d \lvert H \rvert^2 \bar{q}_L H d_R + \text{h.c.}$ $(d \to b)$
$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$	$\mathcal{O}_{y_e} = y_e \lvert H \rvert^2 \bar{l}_L H e_R + \text{h.c.}$ $(e \to \tau, \mu)$
$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$	$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W^{a\,\nu}_{\mu} W^b_{\nu\rho} W^{c\,\rho\mu}$
$\mathcal{O}_W = \frac{ig}{2}(H^\dagger \sigma^a \overleftrightarrow{D}_\mu H) D^\nu W^a_{\mu\nu}$	$\mathcal{O}_B = \frac{ig'}{2}(H^\dagger \overleftrightarrow{D}_\mu H) \partial^\nu B_{\mu\nu}$
$\mathcal{O}_{WB} = gg' H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{H\ell} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{\ell}_L \gamma^\mu \ell_L$
$\mathcal{O}_T = \frac{1}{2}(H^\dagger \overleftrightarrow{D}_\mu H)^2$	$\mathcal{O}'_{H\ell} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{\ell}_L \sigma^a \gamma^\mu \ell_L$
$\mathcal{O}_{\ell\ell} = (\bar{\ell}_L \gamma^\mu \ell_L)(\bar{\ell}_L \gamma_\mu \ell_L)$	$\mathcal{O}_{He} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{e}_R \gamma^\mu e_R$
$\mathcal{O}_{Hq} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{q}_L \gamma^\mu q_L$	$\mathcal{O}_{Hu} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{u}_R \gamma^\mu u_R$
$\mathcal{O}'_{Hq} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{q}_L \sigma^a \gamma^\mu q_L$	$\mathcal{O}_{Hd} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{d}_R \gamma^\mu d_R$

not present in the SILH' basis

not present in the modified-SILH' basis

not present in the Warsaw basis

- Any theoretical framework comes with some assumptions and an EFT is not an exception!
- However, it is a consistent framework to relate physics in at different scales for different productions and decays.
- In the absence of a coherent UV-completion, an EFT framework can miss the correlations between different operators in any basis
- An EFT is an attempt to minimize "model assumptions", not to completely remove it.
- A global fit has to be able to incorporate measurements in different sectors, like the Higgs and EW, simultaneously.
- An EFT fit and a "κ" fit should present the same physics results if the Higgs and EW sectors are decoupled (as it is with current measurement).

HEPfit: a MCMC based Bayesian analysis framework

HEPfit website:
http://hepfit.roma1.infn.it

Results & Interpretations

discussions of the effects of EW measurements on the Higgs couplings and the effects of beam polarization

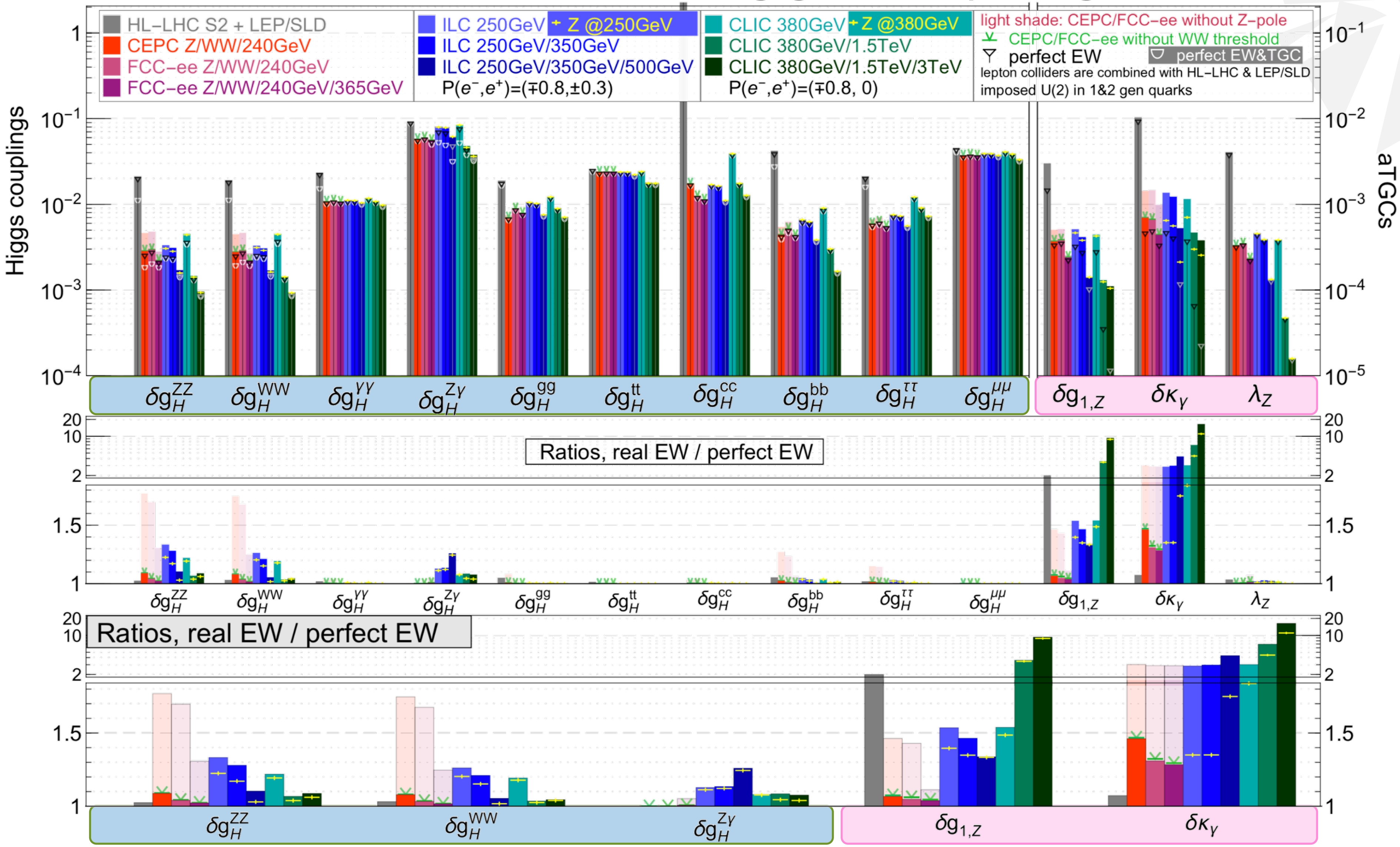
$$\delta g_H^{\mu\mu},\quad \delta g_H^{\tau\tau},\quad \delta g_H^{cc},\quad \delta g_H^{tt},\quad \delta g_H^{bb},$$
$$\delta g_H^{ZZ},\quad \delta g_H^{WW},\quad \delta g_H^{\gamma\gamma},\quad \delta g_H^{Z\gamma},\quad \delta g_H^{gg},$$

$$\delta g_{1,Z},\quad \delta\kappa_\gamma,\quad \lambda_Z,$$

$$\delta g_{Z,L}^{ee} \equiv (\delta g_{Z,L}^{\ell})_{11},\quad \delta g_{Z,L}^{\mu\mu} \equiv (\delta g_{Z,L}^{\ell})_{22},\quad \delta g_{Z,L}^{\tau\tau} \equiv (\delta g_{Z,L}^{\ell})_{33},$$
$$\delta g_{Z,R}^{ee} \equiv (\delta g_{Z,R}^{\ell})_{11},\quad \delta g_{Z,R}^{\mu\mu} \equiv (\delta g_{Z,R}^{\ell})_{22},\quad \delta g_{Z,R}^{\tau\tau} \equiv (\delta g_{Z,R}^{\ell})_{33},$$
$$\delta g_{W}^{e\nu} \equiv (\delta g_{W}^{\ell})_{11},\quad \delta g_{W}^{\mu\nu} \equiv (\delta g_{W}^{\ell})_{22},\quad \delta g_{W}^{\tau\nu} \equiv (\delta g_{W}^{\ell})_{33},$$
$$\delta g_{Z,L}^{uu} \equiv (\delta g_{Z,L}^{u})_{11} = (\delta g_{Z,L}^{u})_{22},\quad \delta g_{Z,L}^{dd} \equiv (\delta g_{Z,L}^{d})_{11} = (\delta g_{Z,L}^{d})_{22},\quad \delta g_{Z,L}^{bb} \equiv (\delta g_{Z,L}^{d})_{33},$$
$$\delta g_{Z,R}^{uu} \equiv (\delta g_{Z,R}^{u})_{11} = (\delta g_{Z,R}^{u})_{22},\quad \delta g_{Z,R}^{dd} \equiv (\delta g_{Z,R}^{d})_{11} = (\delta g_{Z,R}^{d})_{22},\quad \delta g_{Z,R}^{bb} \equiv (\delta g_{Z,R}^{d})_{33},$$

$$\delta g_H^{x} \equiv \sqrt{\frac{\Gamma(h\to x)}{\Gamma(h\to x)^{\rm SM}}} - 1$$

constraints on Higgs couplings



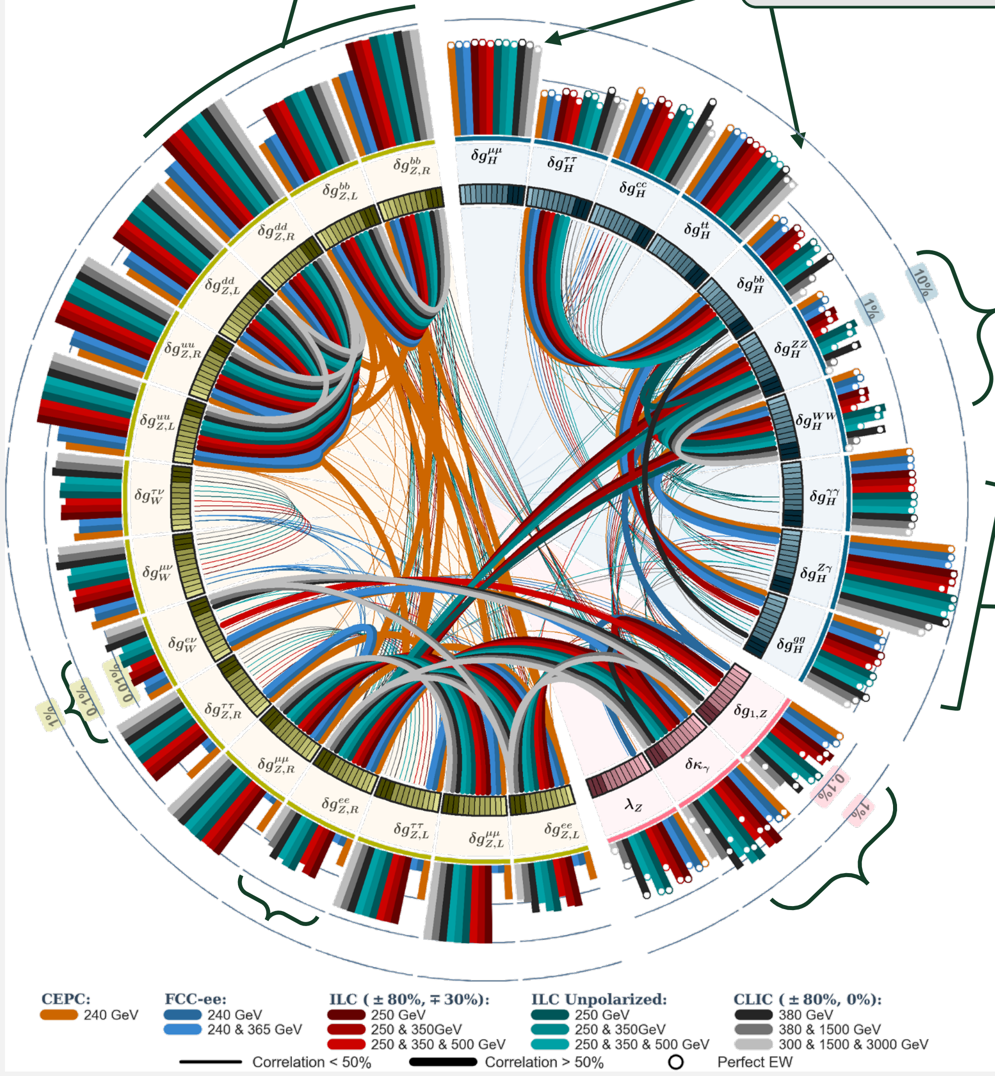
correlations between the different sectors

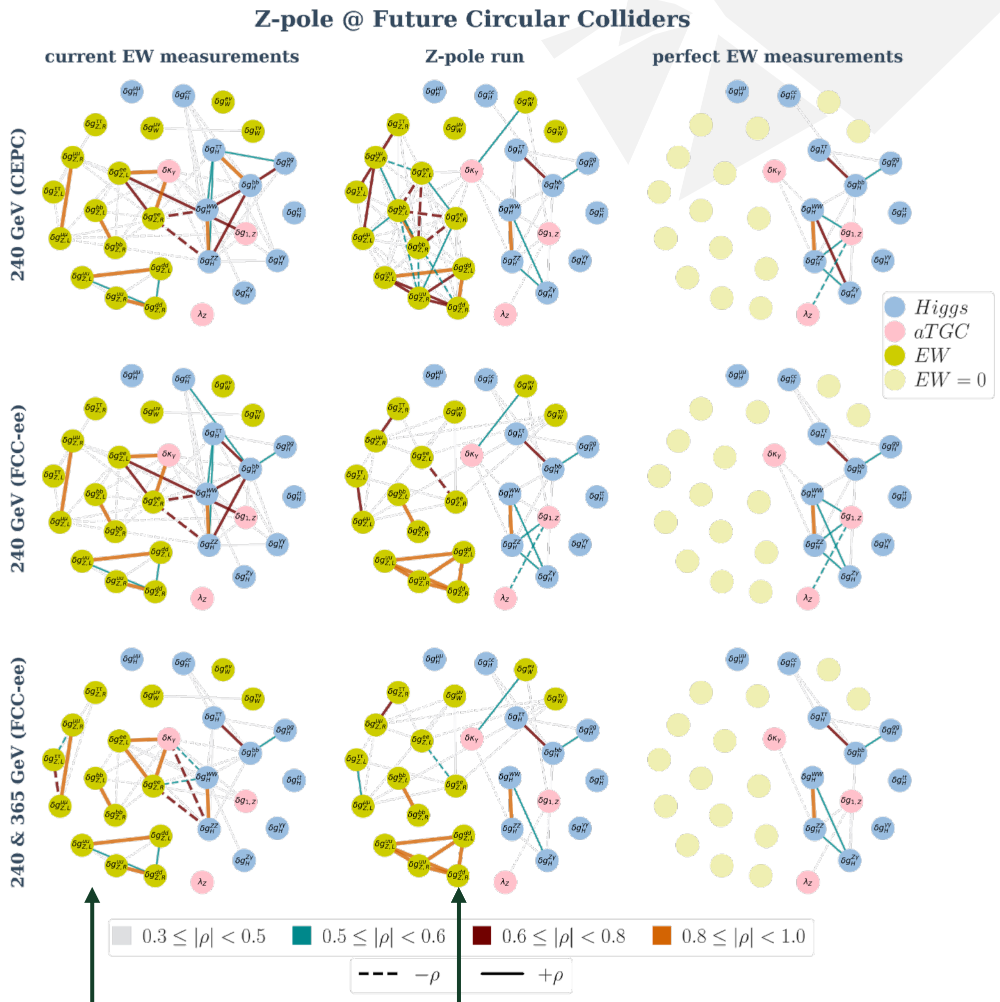
correlations differ between CEPC and FCC-ee because of different inputs

dominated by HL-LHC measurements

correlations between the Higgs and EW couplings

significant constraints from HL-LHC

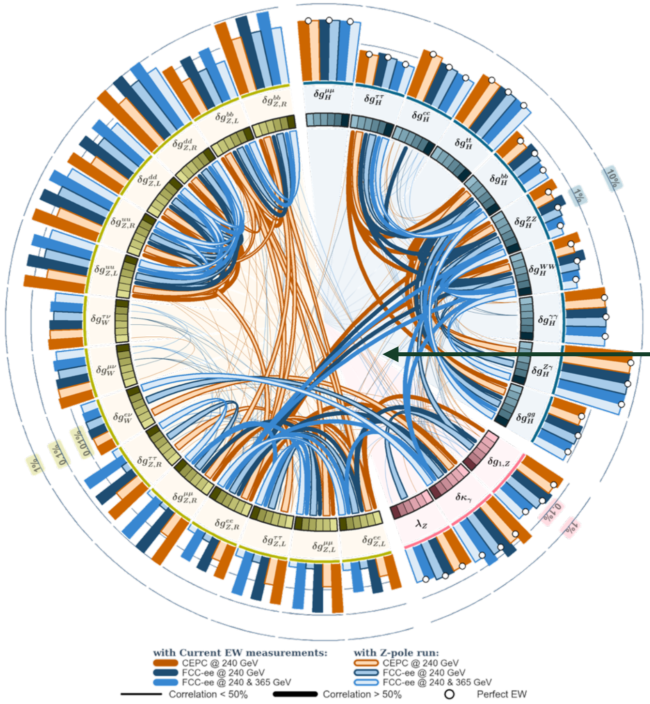




Higgs and EW sectors get decorrelated after inclusion of Z-pole measurements

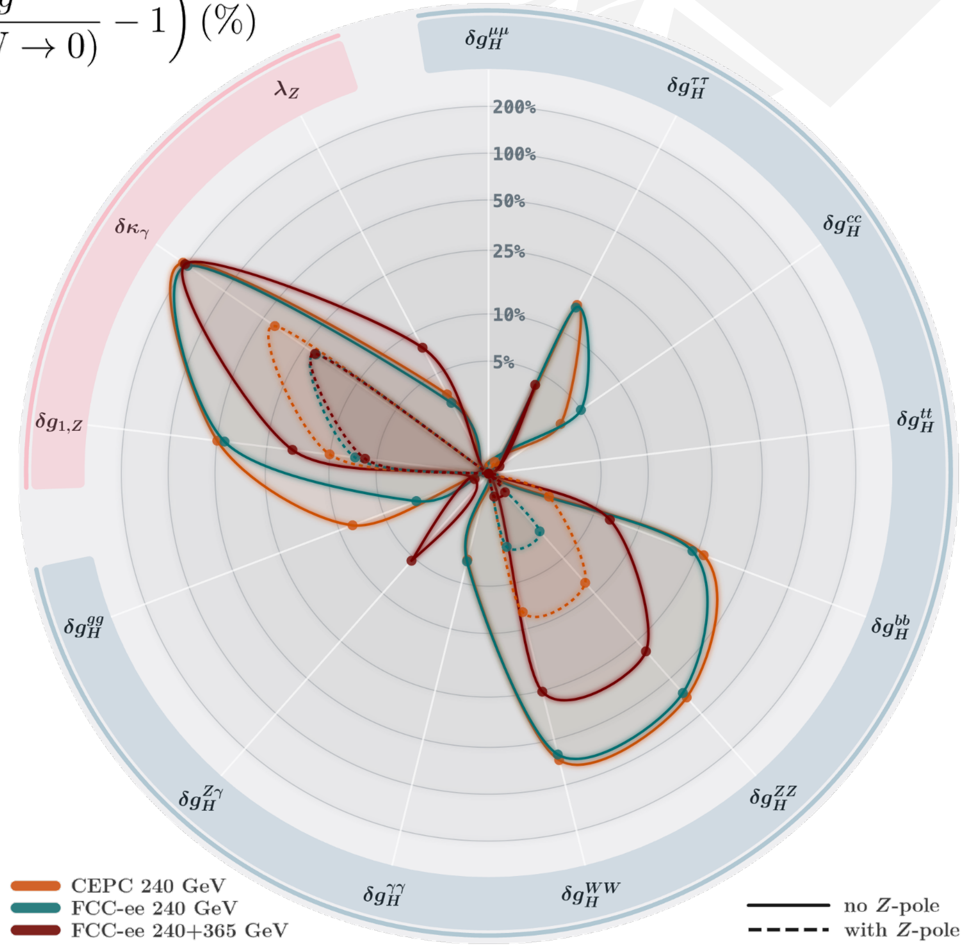
effects of EW measurements on Higgs couplings

- Without EW measurements beyond LEP/SLD the Higgs and EW sectors are correlated.
- Decoupling them, essentially requires more precise EWPO measurements which can be done at the circular colliders.
- For the effective Higgs couplings, there are almost no differences between the case of a Z-pole run and the assumption of perfect EW measurements.
- For the aTGCs, even a Z-pole run does not completely eliminate the differences from the assumption of perfect EW measurement.



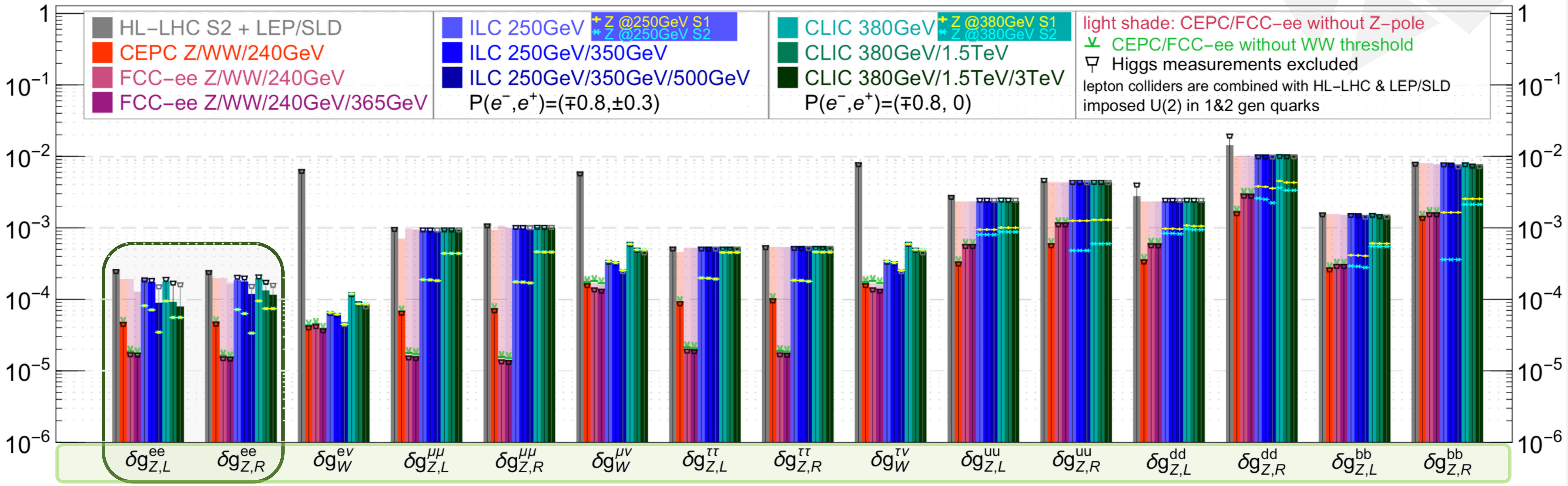
correlations between the Higgs and EW sectors in the absence of Z-pole run at FCC-ee and CEPC at all energies

$$\left(\frac{\delta g}{\delta g(\mathrm{EW}\to 0)} - 1\right)(\%)$$



shift in constraints to couplings when compared with those assuming perfect EW measurement (in %)

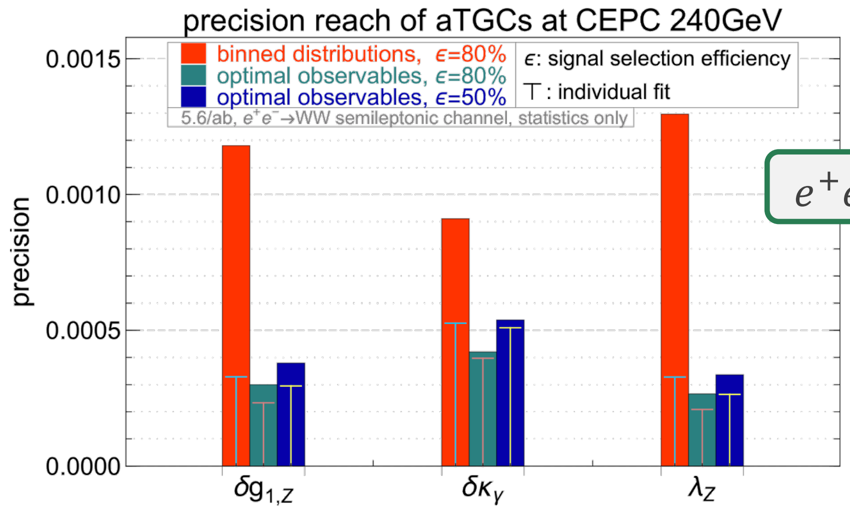
constraints on EW couplings



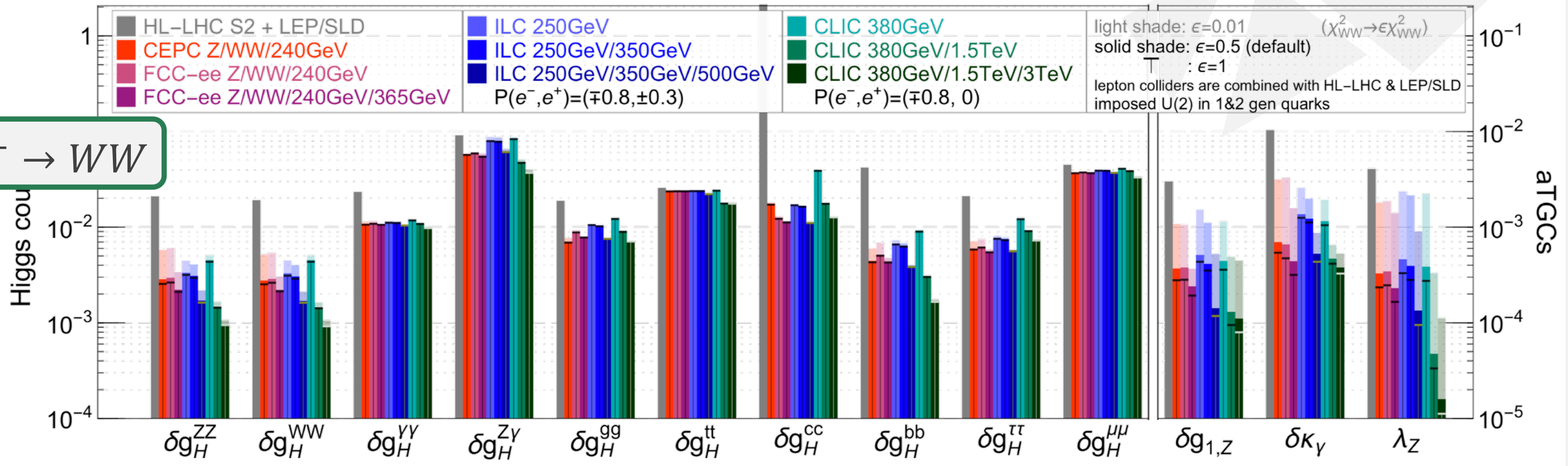
Z-pole run included for both CEPC and FCC-ee

EWPO measurements from radiative return for ILC@250 GeV and CLIC@380 GeV included
(S1: same systematics as FCC-ee, S2: systematics estimated by ILC/CLIC)

diboson analysis



$e^+e^- \to WW$



$$S_0(\Phi) + C_i S_i(\Phi)$$

$$O_i \equiv \sum_{k \text{ events}} \frac{S_i(\Phi_k)}{S_0(\Phi_k)}$$

$$\text{cov}(O_i, O_j) = \mathcal{L} \int d\Phi \frac{S_i(\Phi) S_j(\Phi)}{S_0(\Phi)} + \mathcal{O}(C_k)$$

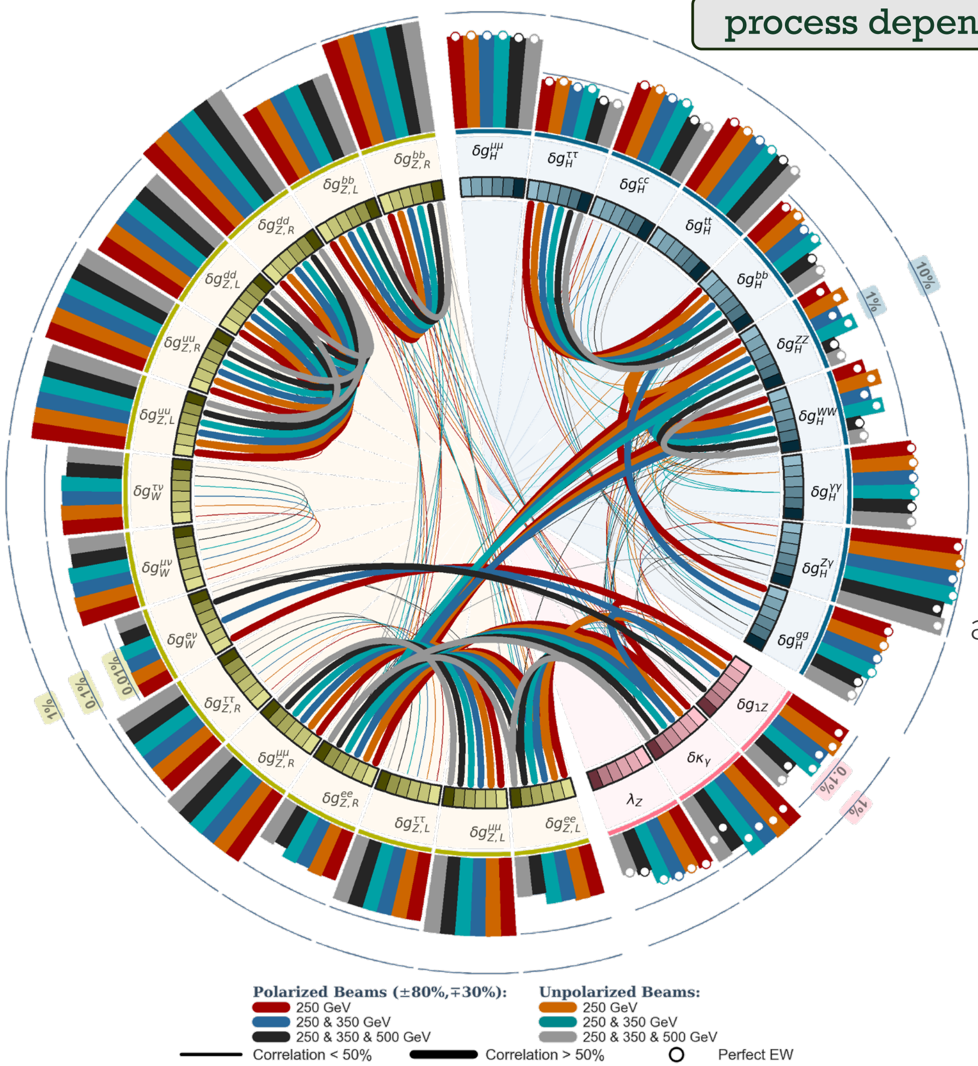
- Optimal Observables exploit the full angular correlation in $e^+e^- \to WW$ and perform much better than a simple binned analysis. (bases on the definition of statistically optimal observables)
- For our analysis we assume 50% signal efficiency.
- Assumption on efficiency only affects the hWW and hZZ couplings and the aTGCs, but not very drastically.

effects of polarization

$$\sigma_{P_{e^+}P_{e^-}} = \sigma_0(1 - P_{e^+}P_{e^-})\left[1 - A_{LR}\frac{P_{e^-} - P_{e^+}}{1 - P_{e^+}P_{e^-}}\right]$$

process dependent

$$A_{LR}^{Zh} = 0.151$$
$$A_{LR}^{\nu\bar{\nu}h} = 1$$
$$A_{LR}^{WW} = 0.98$$



statistical scaling factor ≃1.24 when summed over both polarization with equal luminosities as in the ILC 250 GeV run

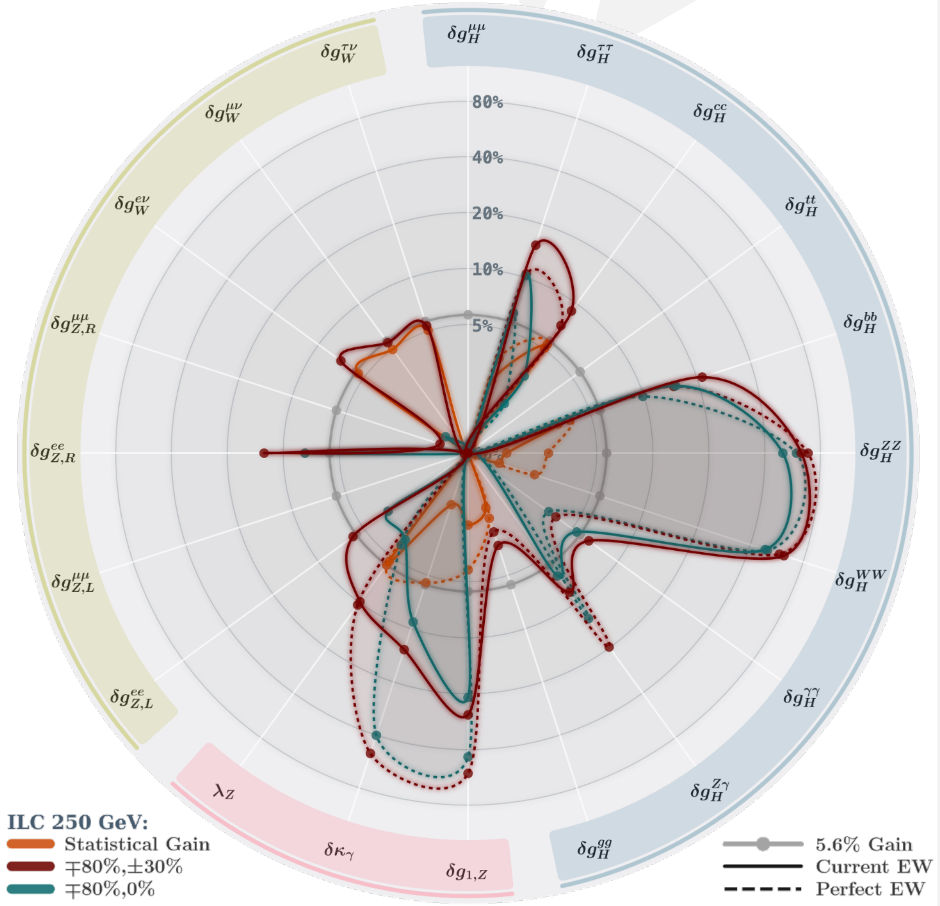
effective Higgs couplings get decorrelated from EW at higher energies.

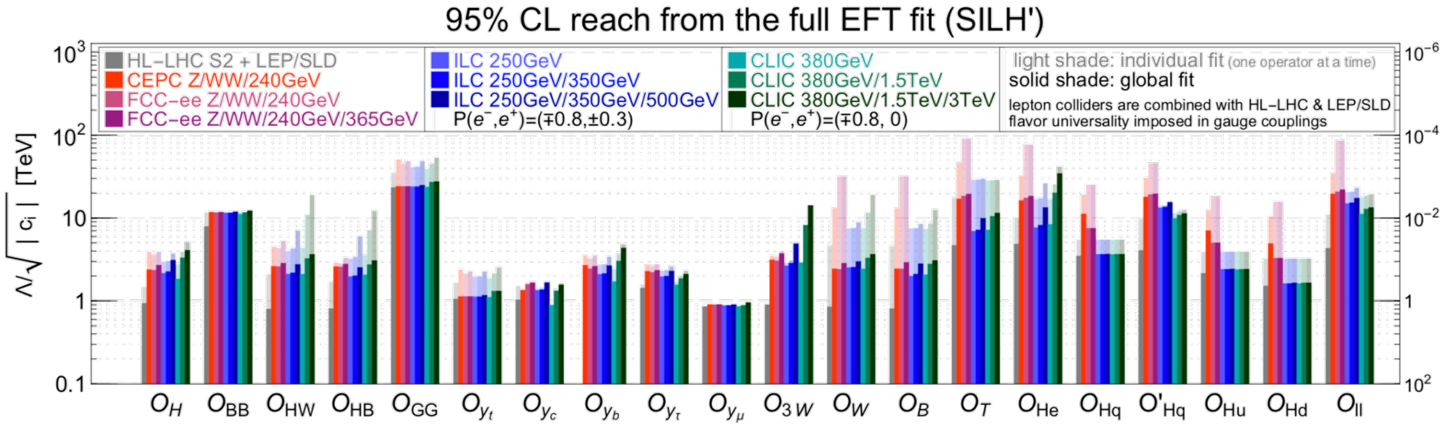
aTGCs retain correlation with EW at higher energies

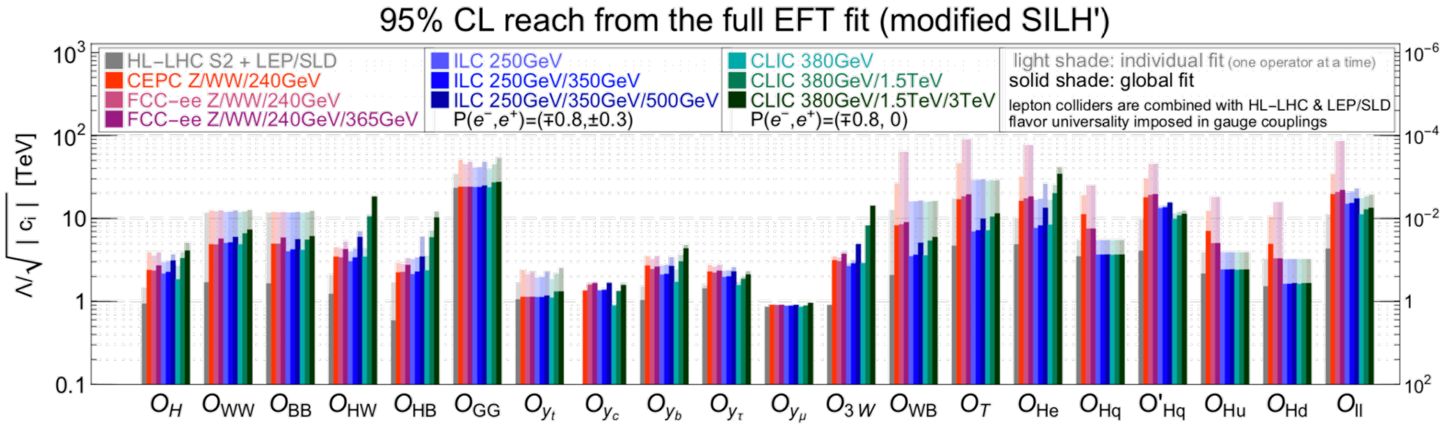
polarization does not fully compensate for the absence of EW measurements

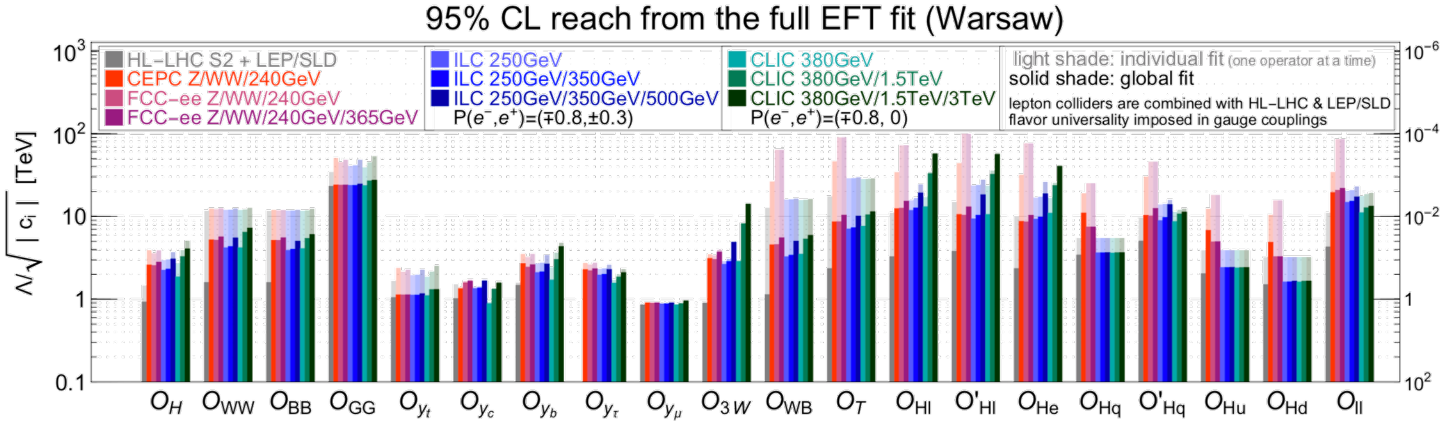
polarization is important mostly for 250 GeV

$$\left(\frac{\delta g\ (\text{unpolarized})}{\delta g\ (\text{polarized})} - 1\right)(\%)$$

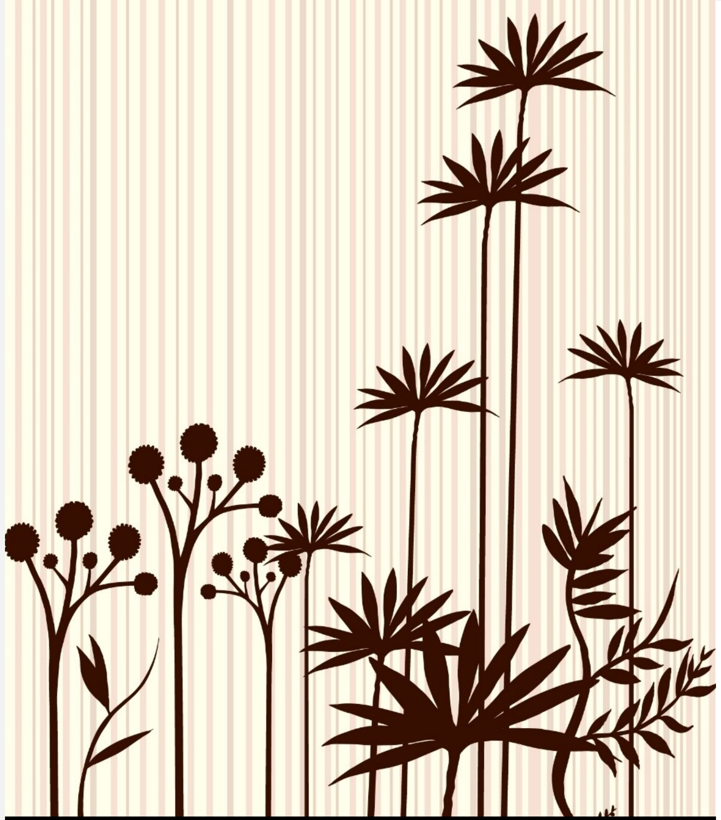








Your favourite basis



Summary

build the collider(s)!

- When precision in Higgs coupling measurement come close to the precision of EWPO then there is significant cross-talk between the two sectors.
- We study several scenarios in all the proposed future lepton colliders to see what effect a *Z*-pole run, a WW threshold run and polarization can have on Higgs couplings measurements.
- We use the SMEFT d-6 framework varying all necessary operators and perform fits in two completely independent implementations.

- To disentangle the two sectors one way out is to measure EWPO with much greater precision. This is possible at circular colliders.
- At linear colliders this can possibly be compensated by higher energy runs for the effective Higgs couplings but not for all the aTGCs.
- Polarization is important at 250 GeV as it gives a significant boost to constraints on the couplings. With higher energies the benefits of polarization diminish.

The Contributors

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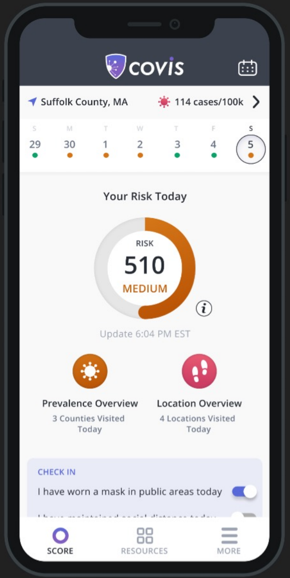
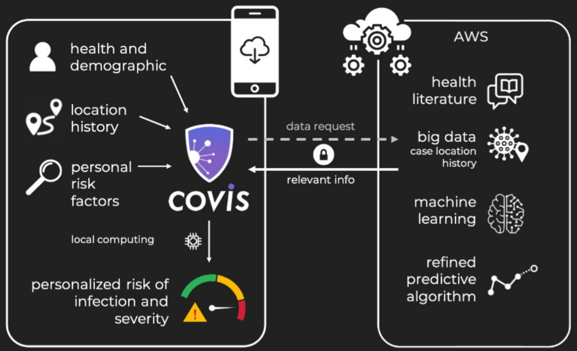
*idea shamelessly stolen from Jiayin



Real-time COVID-19 risk assessment using public data, medical knowledge and AI algorithms



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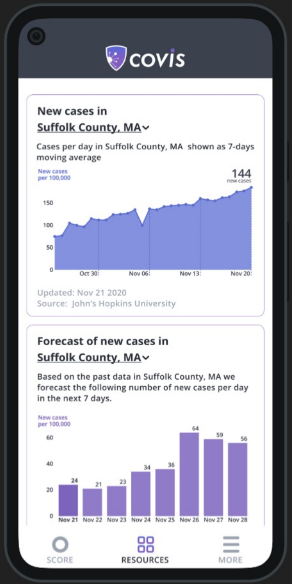

app features

app features

What CoVis brings to you:

- Real-time risk assessment as you go about your day.
- 7-days prediction of COVID-19 cases for USA, Germany and Austria by the county/district.
- User score history and risk breakdown to understand what risks you have been facing.
- Global Information resources and international travel advisory at your fingertips.

What's your score?

Funded by DESY Strategy Fund for Corona Response

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covishealth

Developed With
Sidebench

CoVis - the future of disease risk management

Spin-off by DESY.

Thank you!

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To my Mother and Father, who showed me what I could do,

and to Ikaros, who showed me what I could not.

"To know what no one else does, what a pleasure it can be!"

– adopted from the words of

Eugene Wigner.