Higgs Physics - Theory
Lecture 3

From Higgs-boson properties to new physics

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- **Lecture 1: the Standard-Model Higgs boson.**
  - $\hookrightarrow$ EW gauge symmetry, Higgs mechanism.
  - $\hookrightarrow$ Higgs-boson interactions.
  - $\hookrightarrow$ Quantum constraints.
- **Lecture 2: Higgs-boson physics at the LHC.**
  - $\hookrightarrow$ Production and decay modes, what do they probe.
  - $\hookrightarrow$ Theoretical predictions and their accuracy.
- **Lecture 3: from Higgs-boson properties to new physics.**
  - $\hookrightarrow$ Probing specific extensions of the SM.
  - $\hookrightarrow$ Probing classes of interactions within SM boundaries.

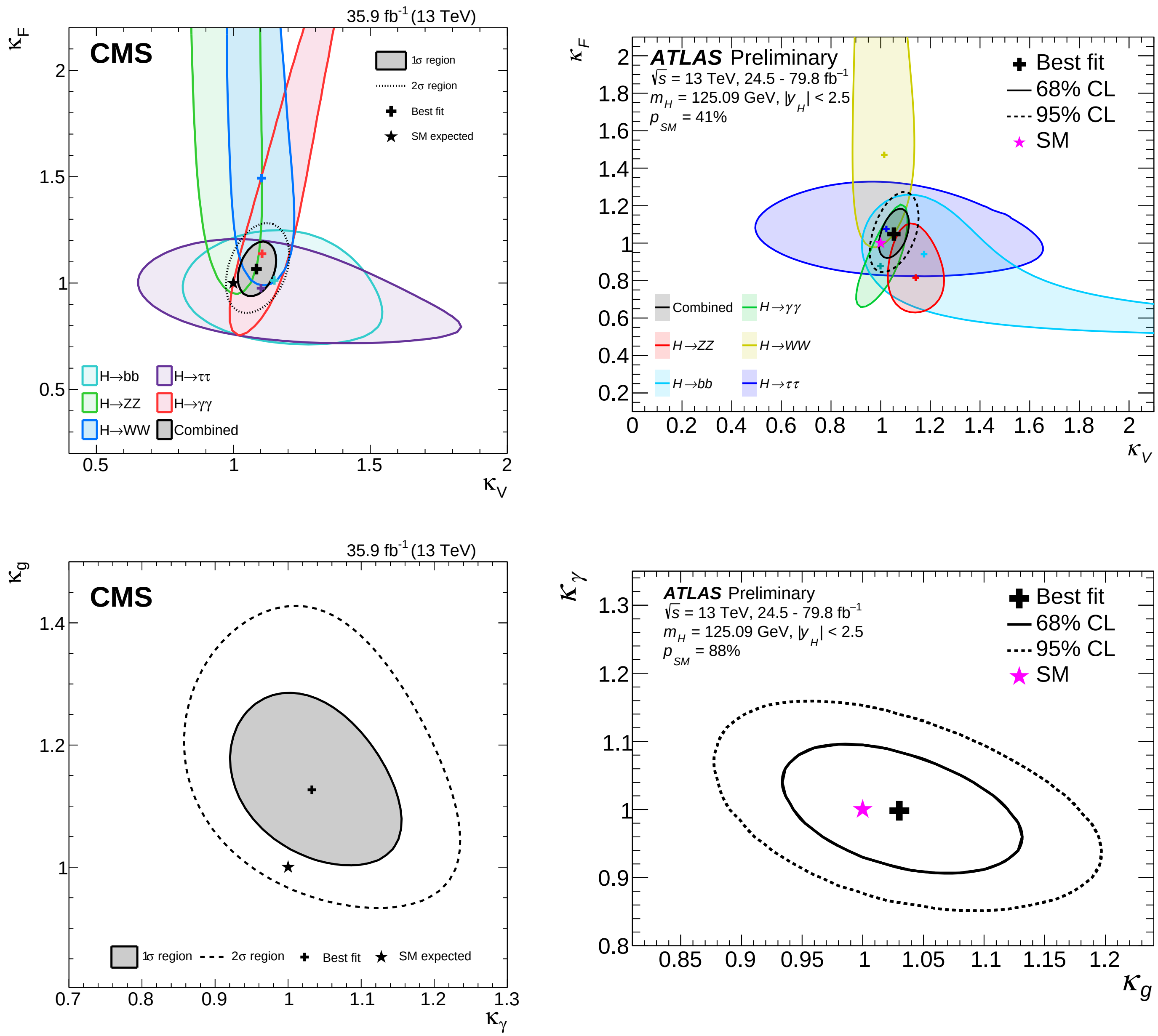
EW+Higgs precision physics in the LHC era:
What does it imply for theory?

Q1: How accurate? $\hookrightarrow$ See yesterday's lecture.

Q2: How to interpret deviations from SM prediction?

- **NP** can just **rescale the Higgs-boson couplings**: $\kappa_i = g_{Hi}/g_{Hi}^{SM}$: only limited scope.
- **NP** can **introduce new structures** in Higgs couplings: how to explore?
  - $\hookrightarrow$ **Model-specific** approach: more stringent, yet arbitrary.
  - $\hookrightarrow$ **Effective Field Theory** approach: less arbitrary, systematic, but less prone to simple prescriptions.
  - $\hookrightarrow$ We may <u>need both</u> ...

Constraining NP via deviations from SM Higgs-boson couplings: rescaling factors (κ_i)



$$\boxed{\kappa_i = g_{Hi}/g_{Hi}^{\rm SM}}$$

$\kappa_V \rightarrow$ all g_{HV}

$\kappa_f \rightarrow$ all g_{Hf}

Constraining κ_i from Higgs data+EWPO

Example:

$\kappa_V \rightarrow$ all g_{HV}

$\kappa_f \rightarrow$ all g_{Hf}

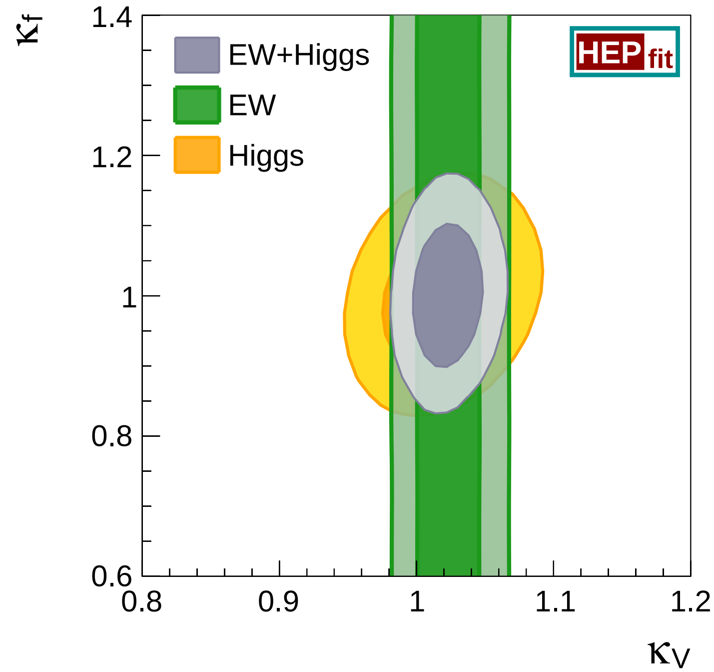
$\longrightarrow$ Main effect on κ_V

Higgs only

	68%	95%	correlation	
κ_V	1.02 ± 0.03	[0.97, 1.08]	1.00	
κ_f	0.98 ± 0.07	[0.84, 1.12]	0.24	1.00

Higgs+EWPO

	68%	95%	correlation	
κ_V	1.02 ± 0.02	[0.99, 1.06]	1.00	
κ_f	1.00 ± 0.06	[0.88, 1.12]	0.14	1.00



$\sigma_i = \sigma_i^{\text{SM}} + \delta\sigma_i$
$\Gamma_j = \Gamma_j^{\text{SM}} + \delta\Gamma_j$

σ_i^{SM}, $\Gamma_j^{\text{SM}} \rightarrow$ from Higgs XS WG (CERN Yellow Report, arXiv:1610.07922)

$\delta\sigma_i \rightarrow$ using Madgraph +K-factors (from Higgs XS WG)

$\delta\Gamma_j \rightarrow$ eHdecay [Contino et al., arXiv:1403.3381]

Constraining NP via SM Effective Field Theory

Extension of the SM Lagrangian by $d > 4$ operators

$$\mathcal{L}_{\mathrm{SM}}^{\mathrm{eff}} = \mathcal{L}_{\mathrm{SM}} + \sum_{d>4} \frac{1}{\Lambda^{d-4}} \mathcal{L}_d = \mathcal{L}_{\mathrm{SM}} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cdots$$

where

$$\mathcal{L}_d = \sum_i C_i \mathcal{O}_i , \quad [\mathcal{O}_i] = d \, ,$$

considering:

- $\rightarrow$ one Higgs doublet of $SU(2)_L$, linearly realized SSB
- $\rightarrow$ no $\mathcal{L}_5$ (only one operator affecting neutrino masses)
- $\rightarrow$ **d = 6 operators only**, obeying SM gauge symmetry, L and B conservation
  - $\hookrightarrow$ expansion in $(p, v)/\Lambda$
  - $\hookrightarrow$ **truncation at linear order** $\rightarrow O((p, v)^2/\Lambda^2)$ **to be verified a posteriori**.

and requiring:

- $\rightarrow$ **flavour universality**: 59 operators

  [basis by Grzadkowski et al., JHEP 1010 (2010) 085 $\rightarrow$ Warsaw basis]
- $\rightarrow$ **CP even** operators only, with at least one Higgs: 27 operators
- $\rightarrow$ **only** operators **contributing to the observables considered**.

$$\mathcal{O}_{\phi G} = (\phi^\dagger \phi)\, G^A_{\mu\nu} G^{A\mu\nu}$$
$$\mathcal{O}_{\phi W} = (\phi^\dagger \phi)\, W^I_{\mu\nu} W^{I\mu\nu}$$
$$\mathcal{O}_{\phi B} = (\phi^\dagger \phi)\, B_{\mu\nu} B^{\mu\nu}$$
$$\mathcal{O}_{\phi WB} = (\phi^\dagger \tau^I \phi)\, W^I_{\mu\nu} B^{\mu\nu}$$
$$\mathcal{O}_{\phi D} = (\phi^\dagger D^\mu \phi)^* \,(\phi^\dagger D_\mu \phi)$$
$$\mathcal{O}_{\phi \Box} = (\phi^\dagger \phi)^* \Box (\phi^\dagger \phi)$$

bosonic operators

$\longrightarrow$ corrections to:

- oblique parameters (in red)
- $HVV \longrightarrow \kappa_V$
- WWZ and $WW\gamma$

$$\mathcal{O}^{(1)}_{\phi L} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{L}\gamma^\mu L)$$
$$\mathcal{O}^{(3)}_{\phi L} = (\phi^\dagger i \overleftrightarrow{D}^I_\mu \phi)(\overline{L}\,\tau^I \gamma^\mu L)$$
$$\mathcal{O}_{\phi e} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{e}_R \gamma^\mu e_R)$$
$$\mathcal{O}^{(1)}_{\phi Q} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{Q}\gamma^\mu Q)$$
$$\mathcal{O}^{(3)}_{\phi Q} = (\phi^\dagger i \overleftrightarrow{D}^I_\mu \phi)(\overline{Q}\,\tau^I \gamma^\mu Q)$$
$$\mathcal{O}_{\phi u} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{u}_R \gamma^\mu u_R)$$
$$\mathcal{O}_{\phi d} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{d}_R \gamma^\mu d_R)$$

single-fermionic-vector-current operators

$\longrightarrow$ corrections to:

- $Vf\bar{f}$ (in blue)
- $HVf\bar{f}$

single-fermionic-scalar-current operators

$$\boxed{\begin{aligned}\mathcal{O}_{e\phi} &= (\phi^\dagger\phi)(\bar{L}\, e_R\phi)\\ \mathcal{O}_{u\phi} &= (\phi^\dagger\phi)(\bar{Q}\, u_R\widetilde{\phi})\\ \mathcal{O}_{d\phi} &= (\phi^\dagger\phi)(\bar{Q}\, d_R\phi)\end{aligned}}$$

$\longrightarrow$ corrections to:

- Yukawa couplings
- $Hf\bar{f} \longrightarrow \kappa_f$

four-fermion operator

$$\boxed{\mathcal{O}_{LL} = (\bar{L}\gamma^\mu L)(\bar{L}\gamma^\mu L)}$$

$\longrightarrow$ corrections to:

- G_F extraction from μ decay

bosonic operator, no ϕ

$$\boxed{\mathcal{O}_W = \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}}$$

$\longrightarrow$ corrections to:

- gauge self-interactions

Notice:

Only highlighted operators (10) enters EWPO, and only 8 combinations can be constrained $\longrightarrow$ “flat directions”

Where effective operators matter ...

They **shift masses and couplings in** $\mathcal{L}_{SM}$ and **introduce new interactions**.

Example: Consider $O_{\phi D}$ and $O_{\phi\Box}$. Upon SSB (unitary gauge):

$$O_{\phi D} = (\phi^\dagger D^\mu \phi)^* \, (\phi^\dagger D_\mu \phi) =$$

$$\frac{v^2}{4}\left(1+\frac{eH}{v}+\frac{H^2}{v^2}\right)(\partial^\mu H)(\partial_\mu H)+\frac{g^2 v^4}{16 c_W^2} Z^\mu Z_\mu \left(1+\frac{4H}{v}+\frac{6H^2}{v^2}+\frac{4H^3}{v^3}+\frac{H^4}{v^4}\right)$$

$$\mathcal{O}_{\phi\Box} = (\phi^\dagger\phi)^*\Box(\phi^\dagger\phi) = -(v^2+4vH+4H^2)(\partial^\mu H)(\partial_\mu H)$$

New interactions: $H(\partial^\mu H)(\partial_\mu H)$, $H^2(\partial^\mu H)(\partial_\mu H)$, ... (notice: $\to$ p-dependence)

and they both affect the H kinetic term $\to$ normalize it by shifting the H field:

$$H = H'\left(1-\frac{1}{4}\hat{C}_{HD}+\hat{C}_{H\Box}\right)$$

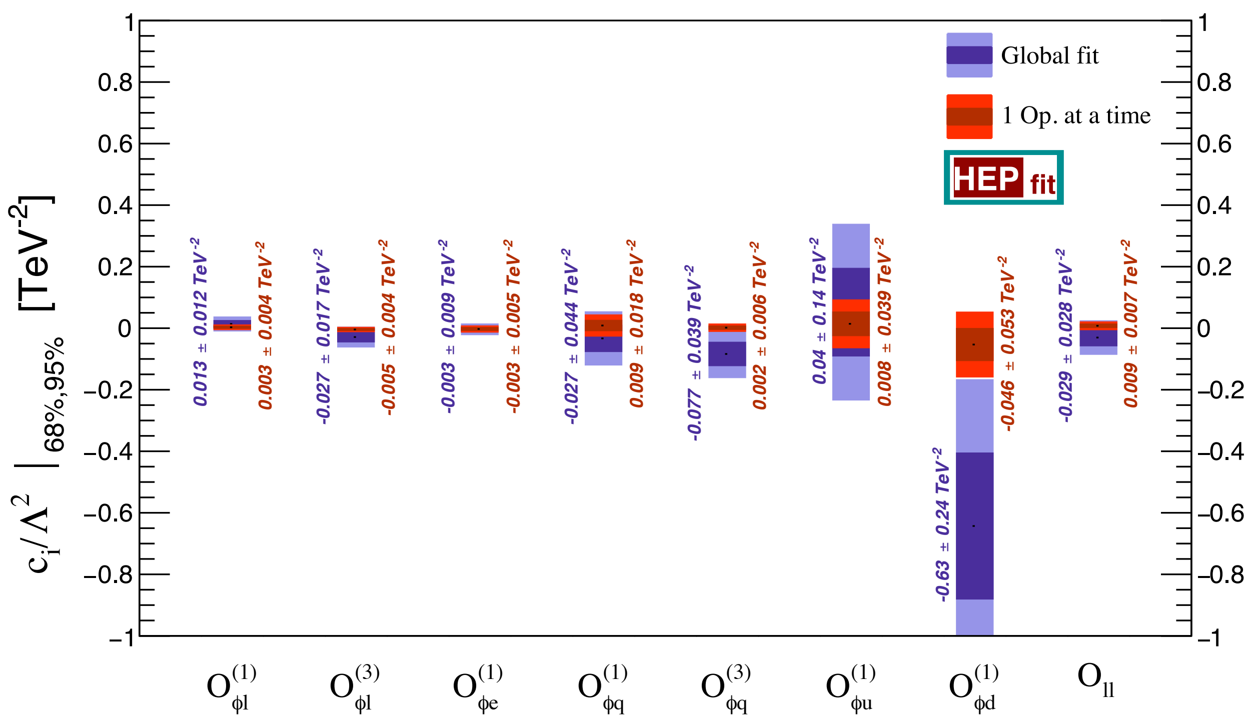
where $\hat{C}_i = C_i v^2/\Lambda^2$. This shift affects the HVV and $Hf\bar{f}$ vertices, and the Higgs mass, now be given by:

$$M_H^2 = 2\lambda v^2\left(1-\frac{3}{2\lambda}\hat{C}_H-\frac{1}{2}C_{HD}+2\hat{C}_{H\Box}\right)$$

Notice: $O_H = (\phi^\dagger\phi)^3$ affects $V(\phi)$ ($\to$ M_H^2). Not among the listed operators since its effect can be observed only by the measurement of both M_H and λ.

Towards Global Fits of d=6 interactions

$\rightarrow$ **Combined global EW fit** of 8 combinations of dim=6 operators.



$$\hat{C}_{\phi l}^{(1)} = C_{\phi l}^{(1)} + \frac{1}{4} C_{\phi D}$$

$$\hat{C}_{\phi l}^{(3)} = C_{\phi l}^{(3)} + \frac{c_w^2}{4 s_w^2} C_{\phi D} + \frac{c_w}{s_w} C_{\phi WB}$$

$$\hat{C}_{\phi q}^{(1)} = C_{\phi q}^{(1)} - \frac{1}{12} C_{\phi D}$$

$$\hat{C}_{\phi q}^{(3)} = C_{\phi q}^{(3)} + \frac{c_w^2}{4 s_w^2} C_{\phi D} + \frac{c_w}{s_w} C_{\phi WB}$$

$$\hat{C}_{\phi e} = C_{\phi e} + \frac{1}{2} C_{\phi D}$$

$$\hat{C}_{\phi u} = C_{\phi u} - \frac{1}{3} C_{\phi D}$$

$$\hat{C}_{\phi d} = C_{\phi d} + \frac{1}{6} C_{\phi D}$$

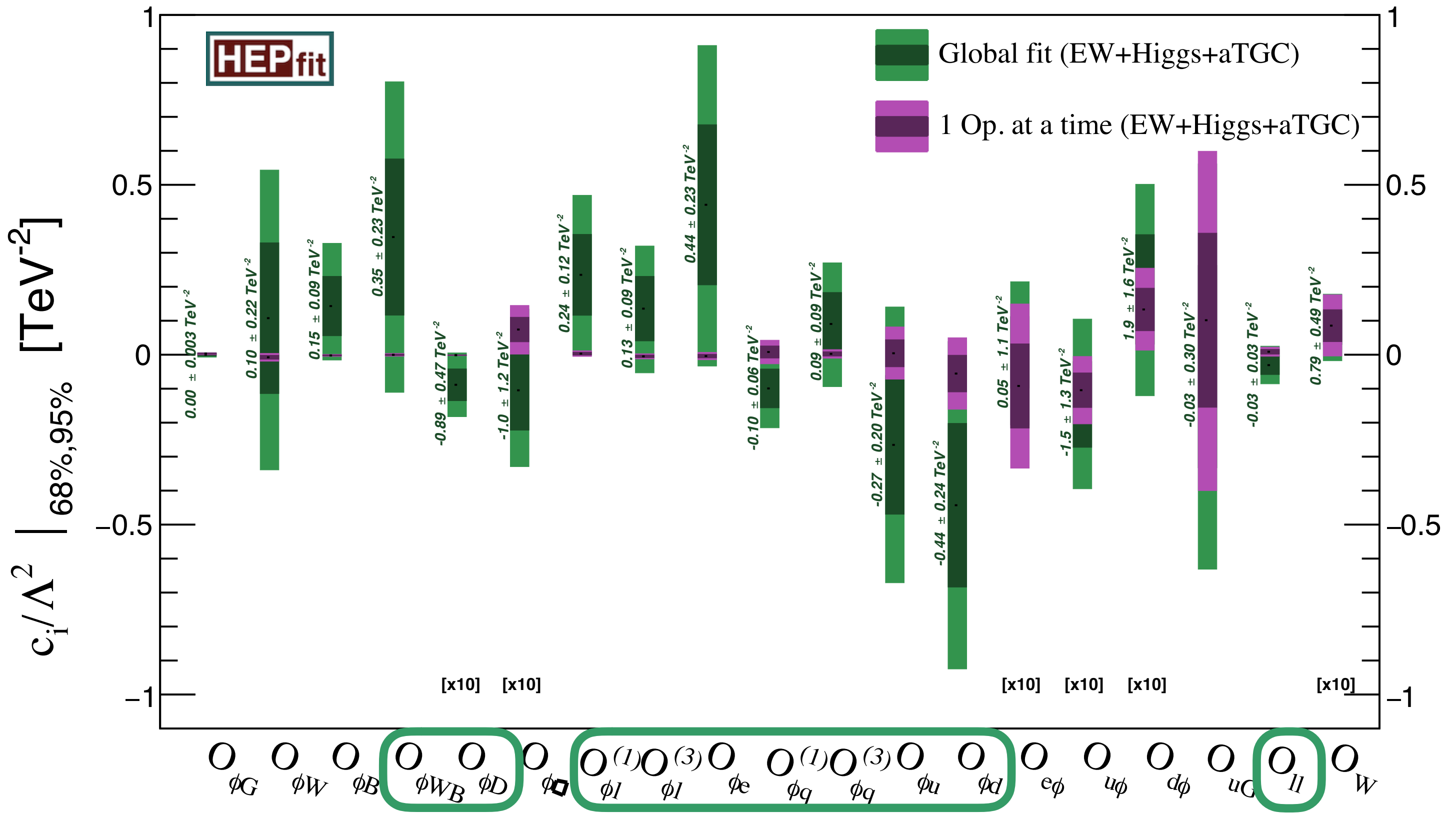
$$\hat{C}_{ll} = C_{ll}$$

$$(O_i \rightarrow \hat{O}_i)$$

[J. de Blas, talk at Lepton-Photon 2019]

Large difference between global and individual bounds $\rightarrow$ Large correlations

$\rightarrow$ **Combined global EW+Higgs fit** of extended set of operators



[J. de Blas, talk at Lepton-Photon 2019]

$\hookrightarrow$ Lifted degeneracy among EWPO operators.

$\hookrightarrow$ Large difference between global and individual bounds $\rightarrow$Large correlations

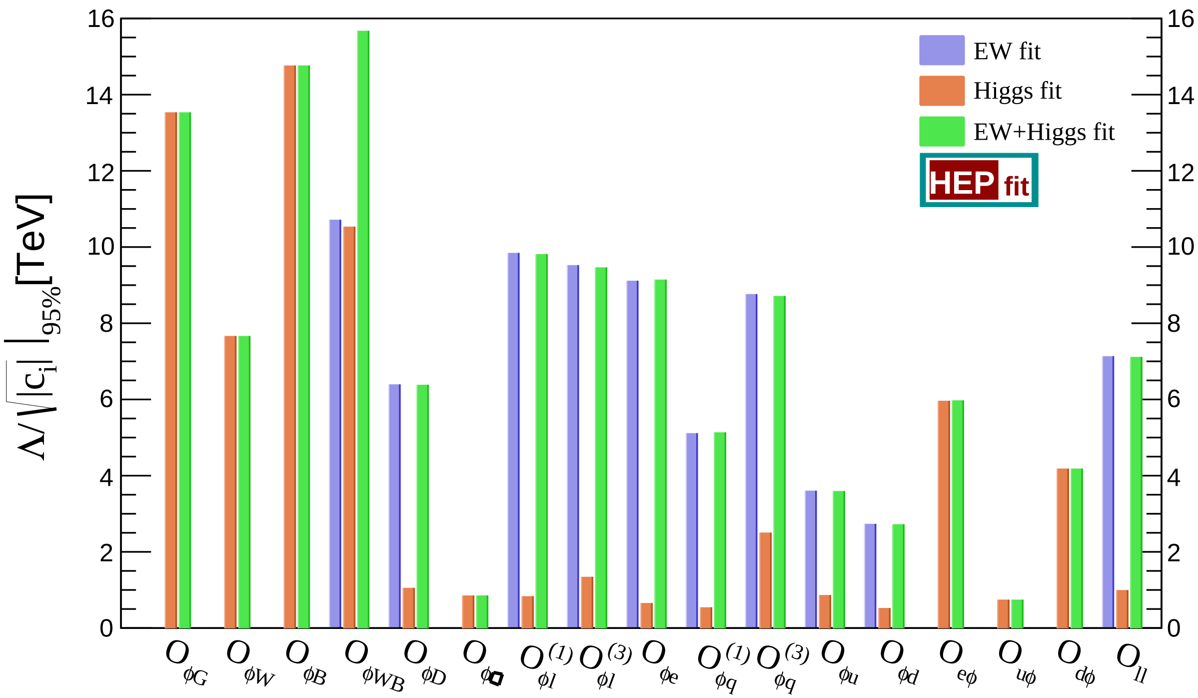
$\hookrightarrow$ Studies should **aim for global fit** of all necessary operators.

$\hookrightarrow$ Increasing precision can boost effectiveness in constraining new physics.

Bounds on operators can be translated in bounds on Λ_{NP}

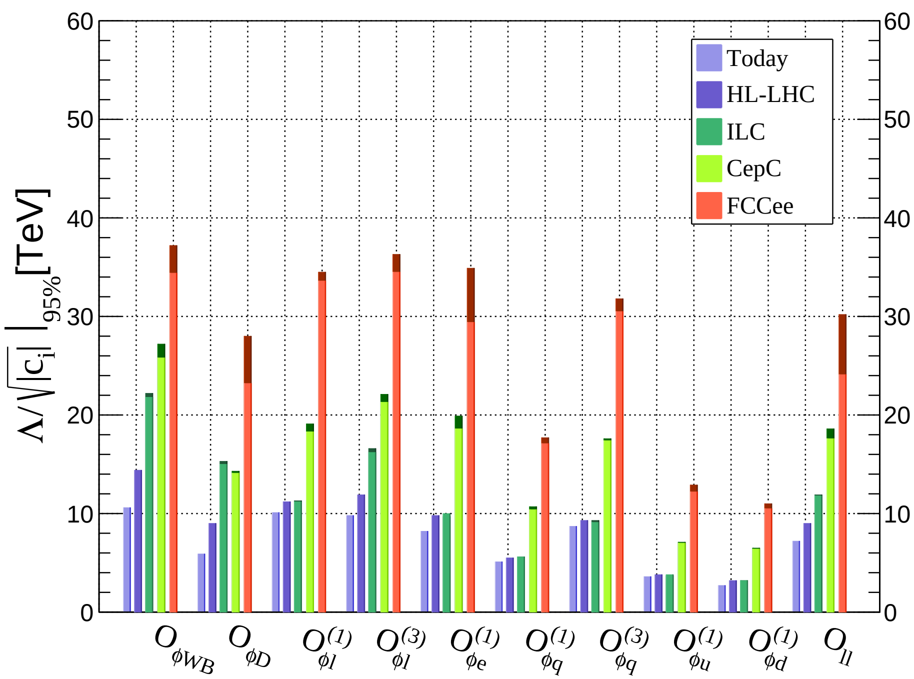
$\rightarrow$ Extended set of operators, switching on **one operator at a time**

Coefficient	95% prob. range C_i/Λ^2 [TeV^{-2}]	95% prob. lower bound on Λ [TeV] ($\lvert C_i\rvert = 1$)
$C_{\phi G}$	$[-0.00029, 0.0059]$	13.5
$C_{\phi W}$	$[-0.019, 0.0040]$	7.63
$C_{\phi B}$	$[-0.0051, 0.0011]$	14.7
$C_{\phi WB}$	$[-0.0045, 0.0038]$	15.7
$C_{\phi D}$	$[-0.027, 0.00092]$	6.38
$C_{\phi\Box}$	$[0.015, 1.4]$	0.85
$C_{\phi L}^{(1)}$	$[-0.0052, 0.012]$	9.81
$C_{\phi L}^{(3)}$	$[-0.013, 0.0030]$	9.46
$C_{\phi e}^{(1)}$	$[-0.015, 0.0070]$	9.14
$C_{\phi Q}^{(1)}$	$[-0.027, 0.043]$	5.13
$C_{\phi Q}^{(3)}$	$[-0.0111, 0.015]$	8.71
$C_{\phi u}$	$[-0.072, 0.082]$	3.59
$C_{\phi d}$	$[-0.16, 0.050]$	2.72
$C_{e\phi}$	$[-0.034, 0.015]$	5.97
$C_{u\phi}$	$[-2.0, -0.050]$	0.74
$C_{d\phi}$	$[0.0031, 0.061]$	4.18
C_{LL}	$[-0.0048, 0.022]$	7.11

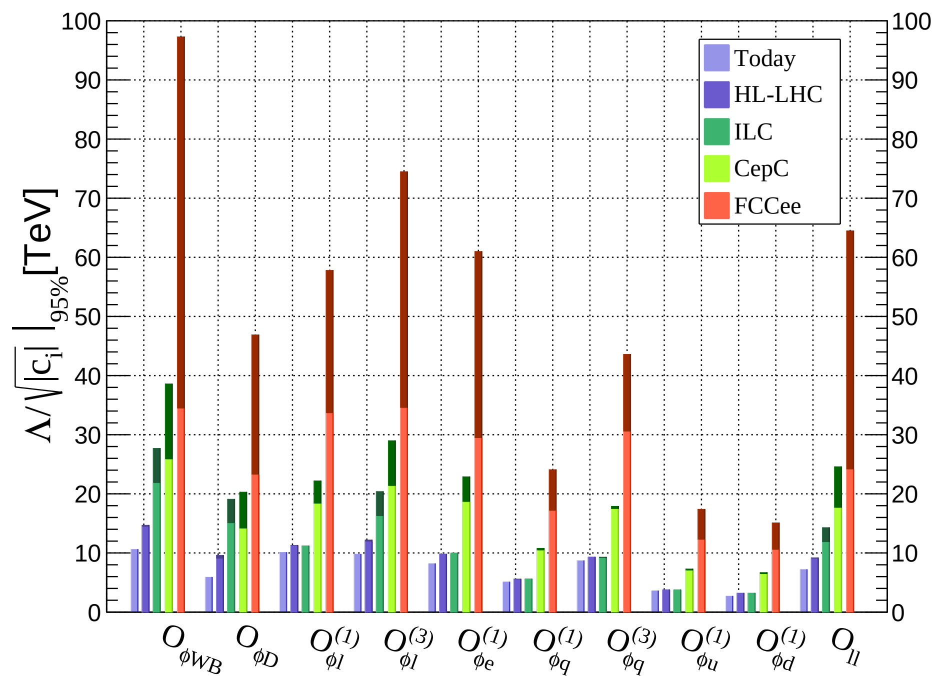


- EWPO constraints still more stringent: **Higgs bounds $\leq$ EWPO bounds**
- Increasing precision in constraining the C_i can greatly boost the reach in Λ!
  - $\hookrightarrow$ Need to incrementally move towards more **global fits**.
  - $\hookrightarrow$ Need to use **more observables**: Higgs kinematic distributions, EW triple-gauge-coupling measurements, ...
  - $\hookrightarrow$ incrementally **release flavour universality** $\rightarrow$ t-quark observables (b, τ).
  - $\hookrightarrow$ Include NLO QCD/EW corrections and running of C_i.
  - $\hookrightarrow$ Explore validity of linear vs quadratic approximation : is it consistent?

Projected bounds for Λ at future colliders



with/without theoretical errors



with/without theoretical and parametrical errors

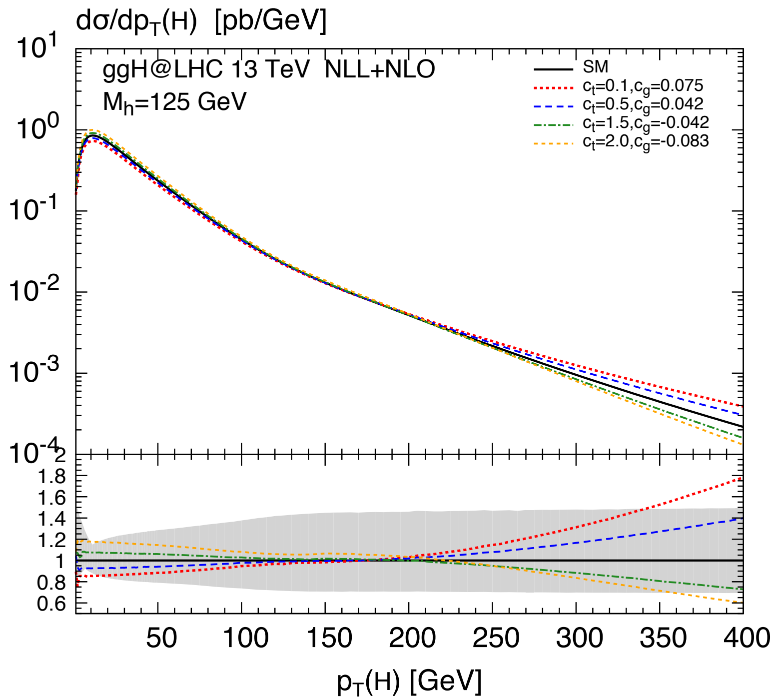
$\hookrightarrow$ **Most recent study**:

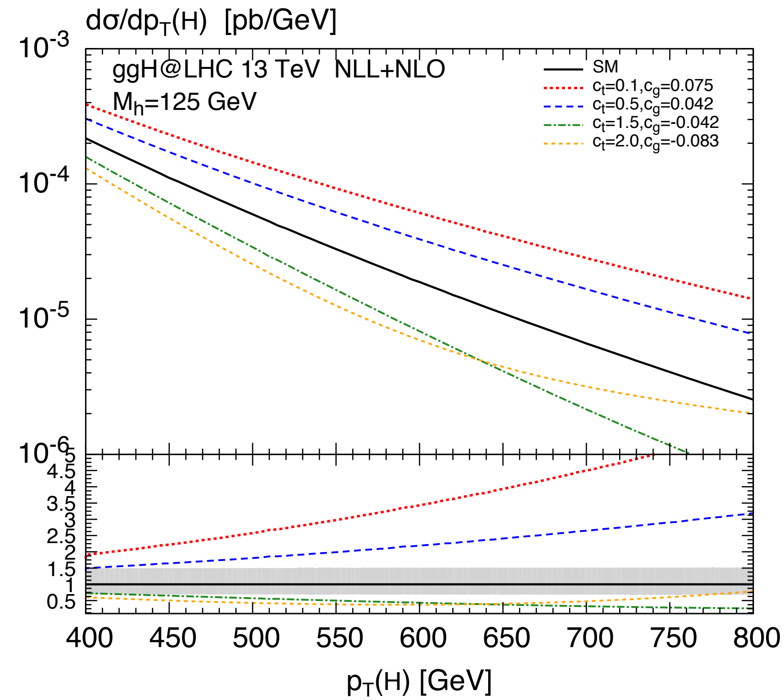
J. de Blas et al., Higgs boson studies at future particle colliders, arxiv:1905.03764 prepared for the

"*Symposium on the Update of the European Strategy for Particle Physics*", Granada, May 13-16 2019.

Effect of new interactions: Higgs p_T in $gg \to H$

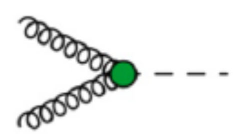
Not visible in the inclusive cross sections, but in the shape of distributions.



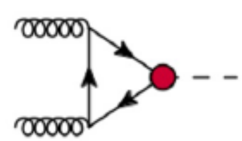


[Grazzini et al., arXiv:1612.00283]

$$O_{\phi G} = (\phi^\dagger \phi) G^a_{\mu\nu} G^{a.\mu\nu} \quad \longrightarrow \quad \frac{\alpha_s}{\pi v} c_g \, h G^a_{\mu\nu} G^{a,\mu\nu} \; \leftarrow$$

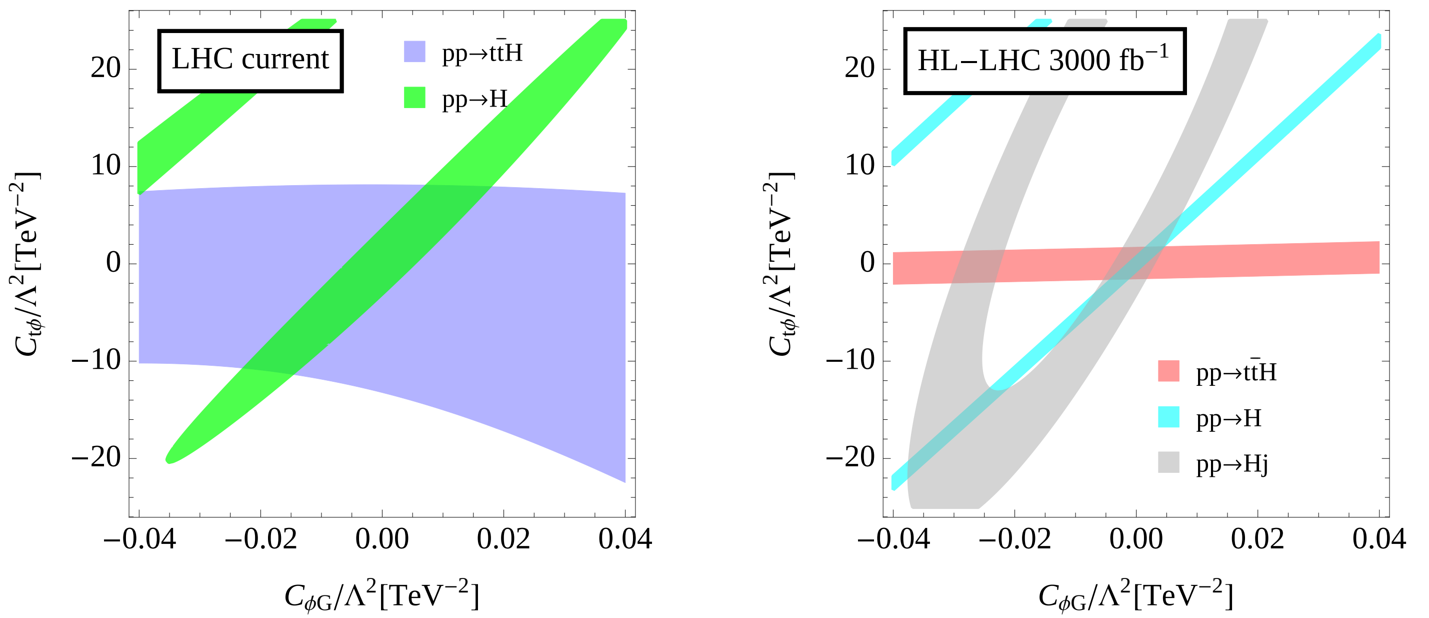


$$O_{u\phi} = (\phi^\dagger \phi) \bar{Q}_L u_R \tilde{\phi} \quad \longrightarrow \quad \frac{m_t}{v} c_t \, h t \bar{t} \; \leftarrow$$

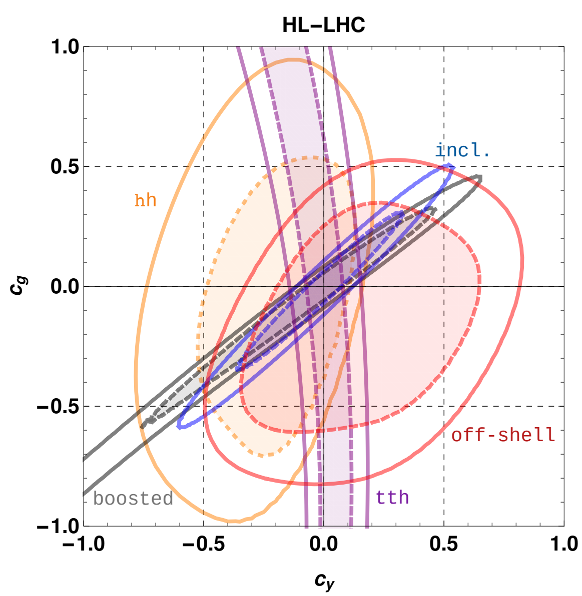


Include $O_{\phi G}$ and $O_{u\phi}$ in NLO+NLL computation: **simultaneous effects of two or more operators affects high-energy tail of the spectrum**.

Probing the gluon-Higgs vs top-Higgs interactions



[Maltoni et al., arXiv:1607.05330]



Combining:

inclusive H

ttH

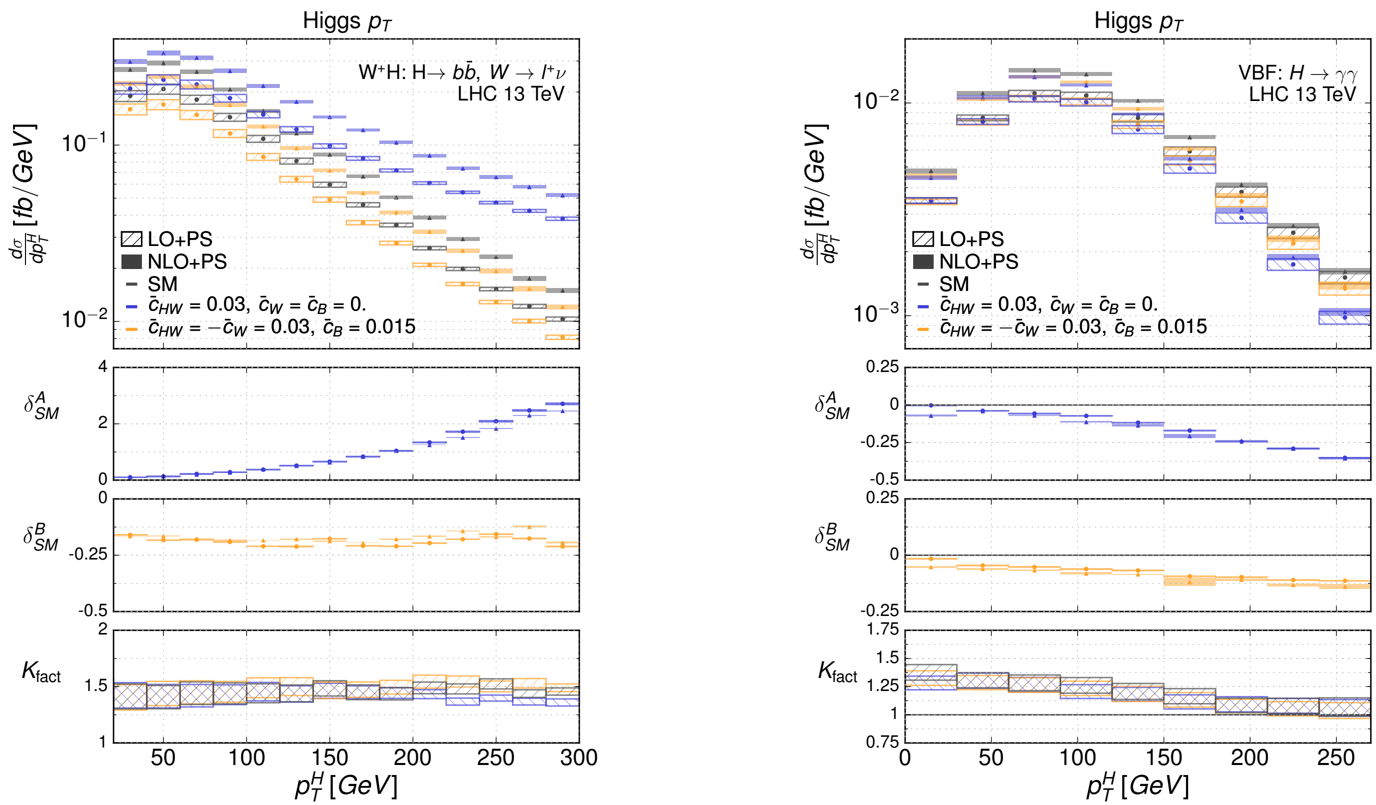
HH

boosted H

off-shell H

[Azatov et al., arXiv:1608.00977]

Effect of new interactions: Higgs p_T in VH and VBF



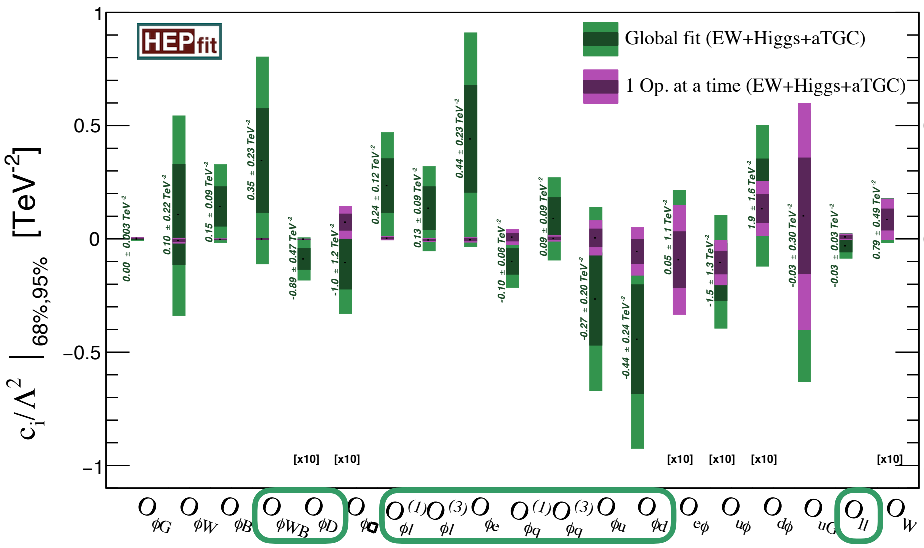
[Degrande et al., arXiv:1612.00283]

↪ Includes NLO QCD matched to PS, validated with both MG5aMC@NLO and POWHEG-BOX.

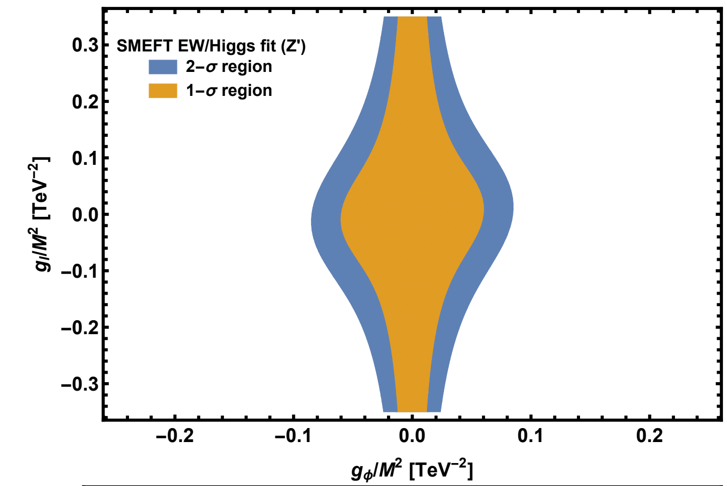
↪ **Question: consistency of EFT**.

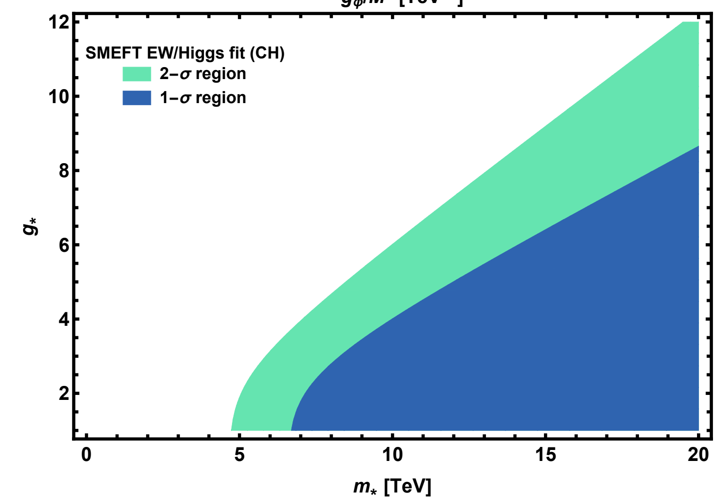
From SM-EFT to specific models

$\boxed{\text{Specific model} \to \{O_i\}} \longrightarrow \boxed{\text{bounds on } \{C_i\} \to \text{bounds on the mode}}$



$\longrightarrow$

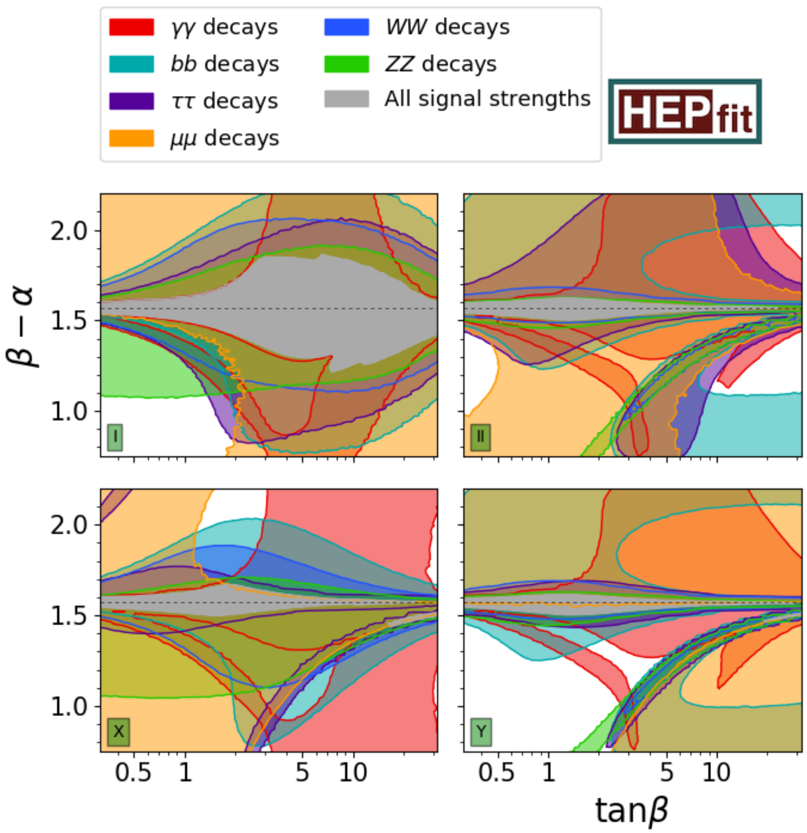


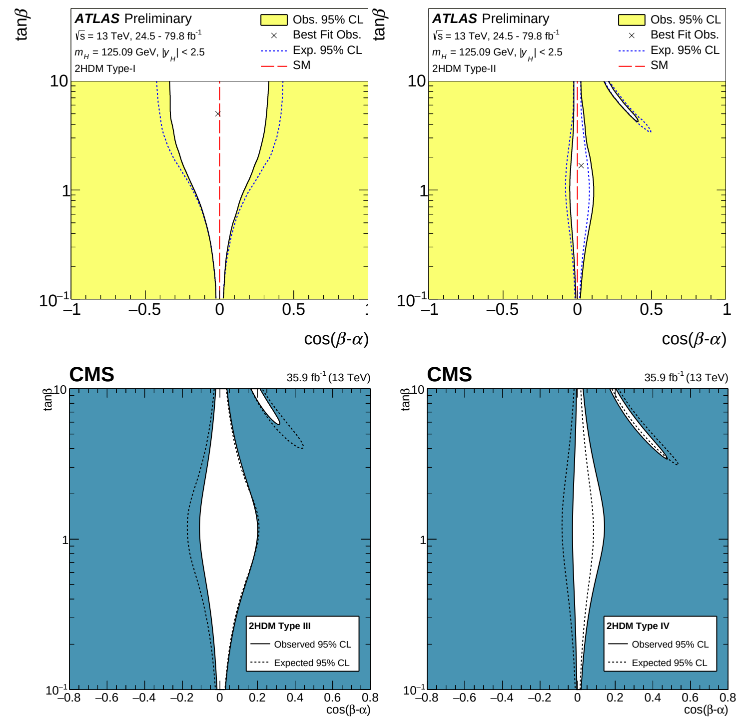


[J. de Blas, talk at Lepton-Photon 2019]

Broad spectrum of searches, old and new ideas

2HDM: natural extension, MSSM motivated, FC scalar currents





[Eberhardt, Chowdhury, arXiv:1711.02095]

Favor alignement scenario $\longrightarrow$ consistent with SM-like couplings and EWPO

Towards a **decoupling scenario**: $M_h \ll M_H, M_A, M_{H\pm}$, i.e. spectrum of very heavy scalars.

2HDM - Type II, MSSM-like, quick guide

Two complex $SU(2)_L$ doublets, with hypercharge $Y=\pm 1$:

$$\Phi_u = \begin{pmatrix} \phi_u^+ \\ \phi_u^0 \end{pmatrix} \quad , \quad \Phi_d = \begin{pmatrix} \phi_d^0 \\ \phi_d^- \end{pmatrix}$$

and (super)potential (Higgs part only):

$$\begin{aligned} V_H &= (|\mu|^2 + m_u^2)|\Phi_u|^2 + (|\mu|^2 + m_d^2)|\Phi_d|^2 - \mu B \epsilon_{ij}(\Phi_u^i \Phi_d^j + h.c.) \\ &+ \frac{g^2 + g'^2}{8}\left(|\Phi_u|^2 - |\Phi_d|^2\right)^2 + \frac{g^2}{2}|\Phi_u^\dagger \Phi_d|^2 \end{aligned}$$

The EW symmetry is spontaneously broken by choosing:

$$\langle \Phi_u \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_u \end{pmatrix} \quad , \quad \langle \Phi_d \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} v_d \\ 0 \end{pmatrix}$$

normalized to preserve the SM relation: $\boxed{M_W^2 = g^2(v_u^2 + v_d^2)/4 = g^2 v^2/4}$.

Five physical scalar/pseudoscalar degrees of freedom:

$$\begin{aligned} h^0 &= -(\sqrt{2}\mathrm{Re}\Phi_d^0 - v_d)\sin\alpha + (\sqrt{2}\mathrm{Re}\Phi_u^0 - v_u)\cos\alpha \\ H^0 &= (\sqrt{2}\mathrm{Re}\Phi_d^0 - v_d)\cos\alpha + (\sqrt{2}\mathrm{Re}\Phi_u^0 - v_u)\sin\alpha \end{aligned}$$

$$A^0 = \sqrt{2}\left(\mathrm{Im}\Phi_d^0 \sin\beta + \mathrm{Im}\Phi_u^0 \cos\beta\right)$$

$$H^\pm = \Phi_d^\pm \sin\beta + \Phi_u^\pm \cos\beta$$

where $\boxed{\tan\beta = v_u/v_d}$.

All masses can be expressed (at tree level) in terms of $\boxed{\tan\beta \text{ and } M_A}$:

$$M_{H^\pm}^2 = M_A^2 + M_W^2$$

$$M_{H,h}^2 = \frac{1}{2}\left(M_A^2 + M_Z^2 \pm ((M_A^2 + M_Z^2)^2 - 4M_Z^2 M_A^2 \cos^2 2\beta)^{1/2}\right)$$

Notice: tree level upper bound on M_h: $\boxed{M_h^2 \leq M_Z^2 \cos 2\beta \leq M_Z^2}$!

Higgs boson couplings to SM gauge bosons:

Some phenomenologically important ones:

$$g_{hVV} = g_V M_V \sin(\beta-\alpha) g^{\mu\nu} \quad , \quad g_{HVV} = g_V M_V \cos(\beta-\alpha) g^{\mu\nu}$$

where $g_V = 2M_V/v$ for $V = W, Z$, and

$$g_{hAZ} = \frac{g\cos(\beta-\alpha)}{2\cos\theta_W}(p_h - p_A)^\mu \quad , \quad g_{HAZ} = -\frac{g\sin(\beta-\alpha)}{2\cos\theta_W}(p_H - p_A)^\mu$$

Notice: $\boxed{g_{AZZ} = g_{AWW} = 0}$, $\boxed{g_{H^\pm ZZ} = g_{H^\pm WW} = 0}$

Decoupling limit: $\boxed{M_A \gg M_Z} \longrightarrow \left\{ \begin{array}{c} M_h \simeq M_h^{max} \\ M_H \simeq M_{H^\pm} \simeq M_A \end{array} \right.$

$$\cos^2(\beta-\alpha) \simeq \frac{M_Z^4 \sin^2 4\beta}{M_A^4} \longrightarrow \left\{ \begin{array}{l} \cos(\beta-\alpha) \to 0 \\ \sin(\beta-\alpha) \to 1 \end{array} \right.$$

<u>The only low energy Higgs is $h \simeq H_{SM}$.</u>

Higgs boson couplings to quarks and leptons:

Yukawa type couplings, Φ_u to up-component and Φ_d to down-component of $SU(2)_L$ fermion doublets. Ex. ($3^{\rm rd}$ generation quarks):

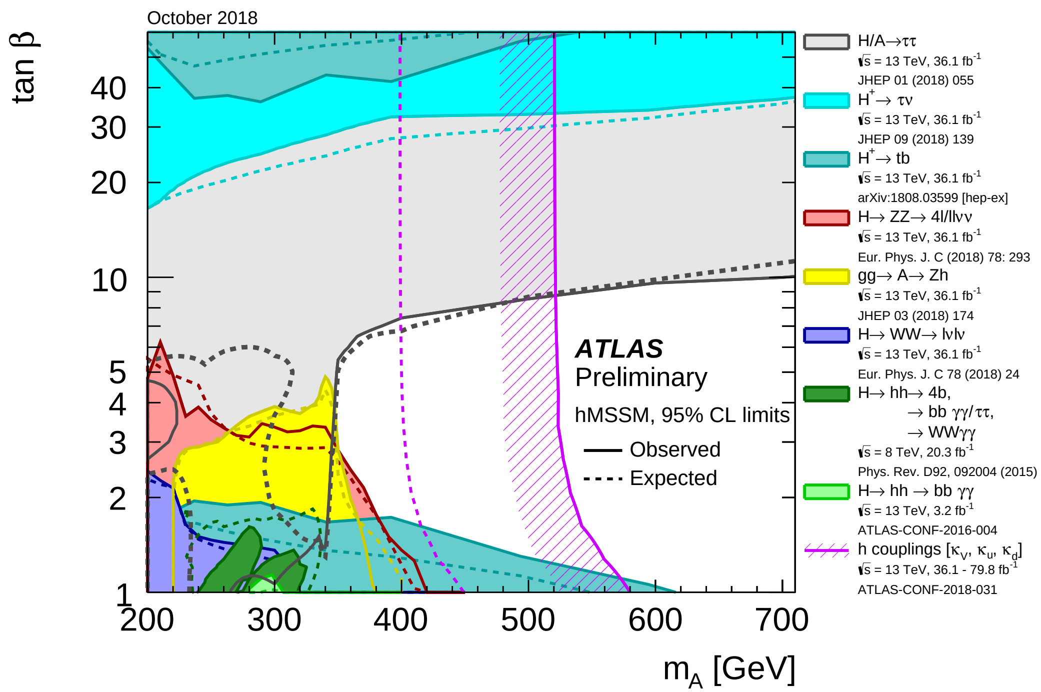
$$\mathcal{L}_{Yukawa} = h_t \left[\bar{t} P_L t \Phi_u^0 - \bar{t} P_L b \Phi_u^+\right] + h_b \left[\bar{b} P_L b \Phi_d^0 - \bar{b} P_L t \Phi_d^-\right] + \text{h.c.}$$

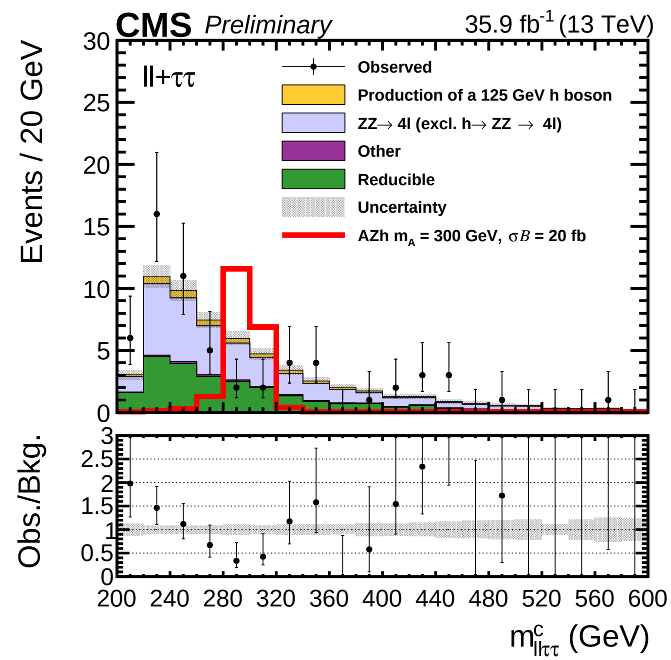
and similarly for leptons. The corresponding couplings can be expressed as ($y_t, y_b \to$ SM):

$$\begin{aligned}
g_{ht\bar{t}} &= \frac{\cos\alpha}{\sin\beta} y_t = \left[\sin(\beta-\alpha) + \cot\beta\cos(\beta-\alpha)\right] y_t \\
g_{hb\bar{b}} &= -\frac{\sin\alpha}{\cos\beta} y_b = \left[\sin(\beta-\alpha) - \tan\beta\cos(\beta-\alpha)\right] y_b \\
g_{Ht\bar{t}} &= \frac{\sin\alpha}{\sin\beta} y_t = \left[\cos(\beta-\alpha) - \cot\beta\sin(\beta-\alpha)\right] y_t \\
g_{Hb\bar{b}} &= \frac{\cos\alpha}{\cos\beta} y_b = \left[\cos(\beta-\alpha) + \tan\beta\sin(\beta-\alpha)\right] y_b \\
g_{At\bar{t}} &= \cot\beta y_t \quad , \quad g_{Ab\bar{b}} = \tan\beta y_b \\
g_{H^\pm t\bar{b}} &= \frac{g}{2\sqrt{2}M_W}\left[m_t\cot\beta(1+\gamma_5) + m_b\tan\beta(1-\gamma_5)\right]
\end{aligned}$$

Notice: consistent decoupling limit behavior.

Heavy-scalar and charged-scalar searches further explore parameter space.

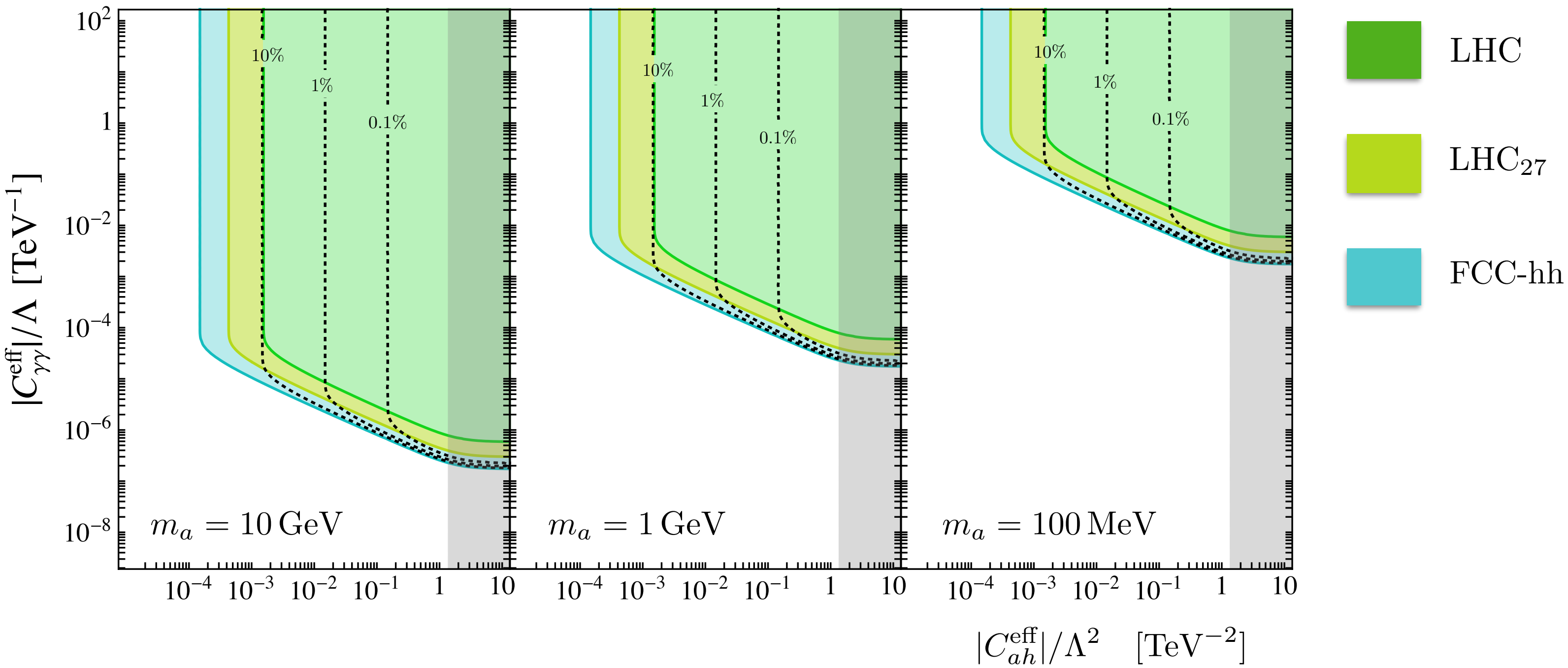




More exotic scenarios

- Higgs FCNC decays ($H \to e\tau$, $H \to \mu\tau$, $t \to Hc$, $\ldots$)
- Higgs decays to BSM gauge bosons ($U(1)_{\text{dark}}$)
- Higgs decays to light scalars ($H \to aa$, a = axion-like particle or ALP)

Axion-like particles (ALP)



[Bauer et al., arXiv:1808.10323]

ALP: pseudo-Goldstone bosons of SB global symmetry (NP at scale Λ)

↪ *light* pseudoscalar messangers of NP

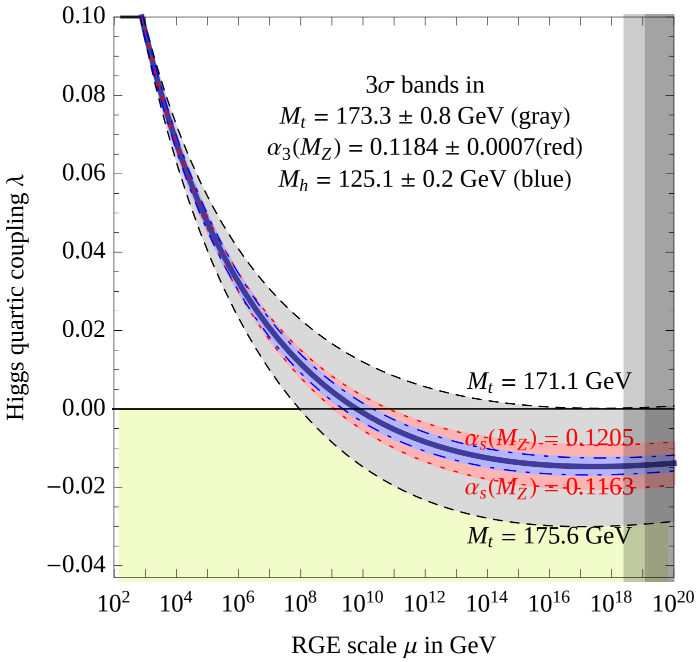
$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm a} + \cdots + \frac{C_{\gamma\gamma}}{\Lambda} a F^{\mu\nu} \tilde{F}_{\mu\nu} + \cdots + \frac{C_{ah}}{\Lambda^2} (\partial^\mu a)(\partial_\mu a) \phi^\dagger \phi + \frac{C_{aZ}}{\Lambda^3} (\partial^\mu a)(\phi^\dagger i D_\mu \phi) \phi^\dagger \phi + \cdots$$

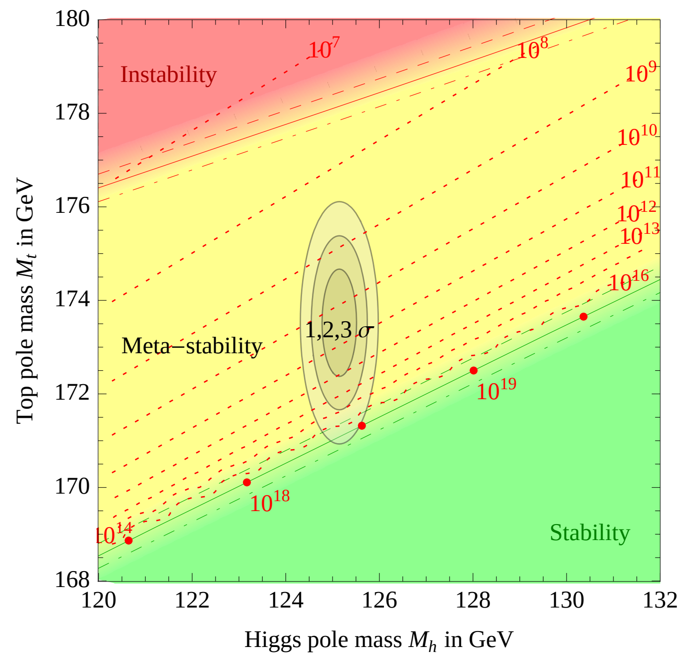
LHC gives access in particular to: $H \to Za \to l^+ l^- 2\gamma$ and $H \to aa \to 4\gamma$

↪ models with extra singlet-scalar very important templates for future collider studies!

[see e.g, Heinemann and Nir, arXiv:1905.00382]

Could new physics be beyond reach?





Buttazzo et al., arXiv:1307.3536

Including quantum effects in the study of the Higgs potential, for $M_h \approx 125$ GeV, a condition of **criticality** $(\lambda \to 0)$ is **reached for** $\boldsymbol{\Lambda \approx 10^{10} - 10^{12}}$ **GeV**.

Is this a signal of NP below the Planck scale?

Outlook

- After the discovery of the Higgs-boson during Run I of the LHC, a major effort to **develop a full-fledged precision program to measure its couplings** has been growing.
- **Indirect evidence of new physics** from Higgs-boson and EW precision measurements could come from the synergy between
  - $\rightarrow$ accurate theoretical prediction,
  - $\rightarrow$ a systematic approach to the study of new effective interactions,
  - $\rightarrow$ the intuition and experience of many years of Beyond SM searches!
- **Increasing the precision of input parameters** could **allow to test higher scales** of new physics: a factor of 10 in precision could give access to scales as high as 100 TeV.
- **Direct evidence** of new physics will boost this process, as the discovery of a Higgs-boson has prompted and guided us in this new era of LHC physics.
- Even **no new discovery** and just **indirect evidence** would mean a lot!