Probing the Higgs trilinear self-coupling via single Higgs production and precision observables

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Based on: P.P. Giardino, F. Maltoni, D. Pagani, G. D. JHEP 1612 (2016) 080
M. Fedele, P.P. Giardino, G.D. JHEP 1704 (2017) 155

ROMA TRE UNIVERSITÀ DEGLI STUDI

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Outline

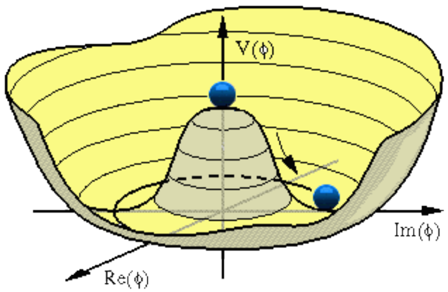
- Status of the Higgs sector of the SM
- Getting information on the trilinear Higgs self-coupling looking at loop effects in:
  i) single Higgs production and decay processes
  ii) Precision Observables
- Perspective for the future
- Conclusions

The Higgs sector, what we know

EWSB is achieved in the SM via the Higgs mechanism realized in the most economical and simple way, i. e. with the introduction of a single elementary $SU(2)_L$ scalar doublet with a Φ^4 potential

$$\mathcal{L}_{Higgs} = (\lambda_{ij}\bar{\psi}_i\psi_j\phi + h.c) + |D^\mu\phi|^2 - V(\phi)$$

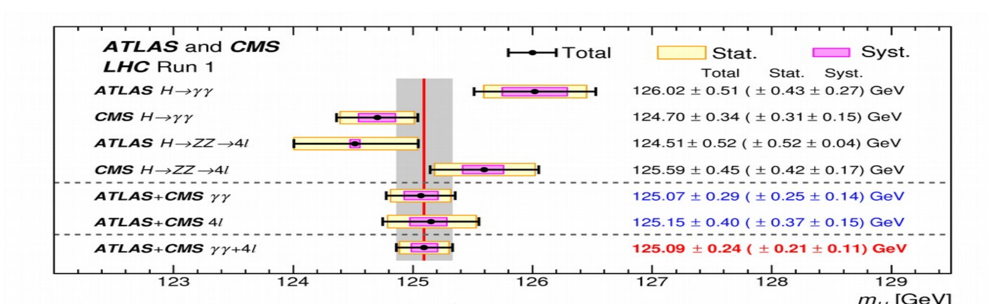
EWSB: m_f, $hf\bar{f}$ — $m_{W,Z}$, HVV, HHVV — m_H, HHH, HHHH,...



The ground state of the potential known since long time

$$G_\mu = \frac{1}{2v^2}$$

$$v = \langle\phi^\dagger\phi\rangle^{1/2} \sim 246 \text{ GeV}$$



$$\frac{\delta m_H}{m_H} \sim 2 \cdot 10^{-3}$$

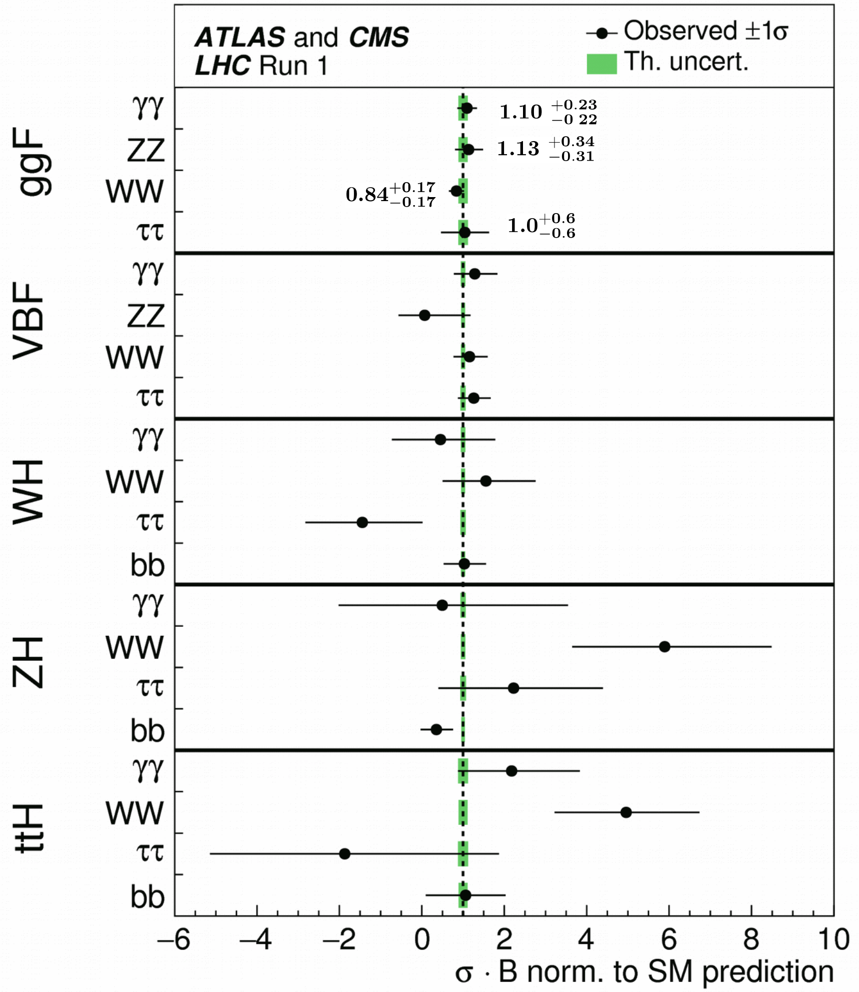
4th July 2012: the mass

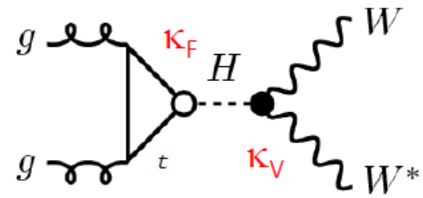
$$V^{SM}(H) = \frac{1}{2}m_H^2 H^2 + \frac{m_H^2}{2\,v}H^3 + \frac{m_H^2}{2\,v^2}H^4$$

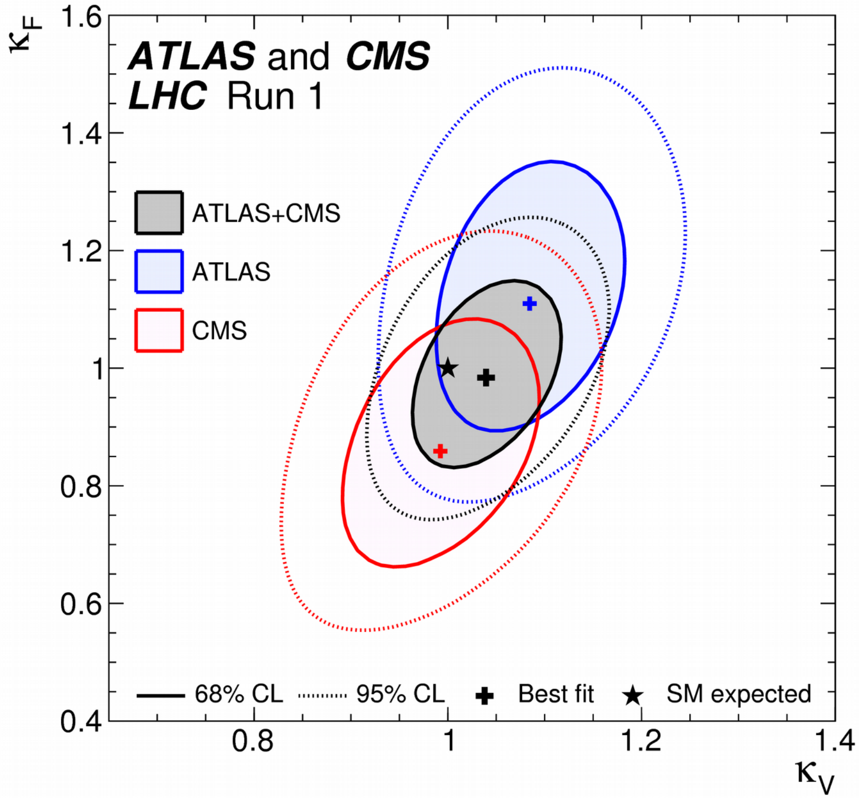
fixed

Testing $\mathcal{L}_{Higgs}$: $(\lambda_{ij}\bar{\psi}_i\psi_j\phi + h.c) + |D^\mu\phi|^2$

HVV (Hff̄) couplings



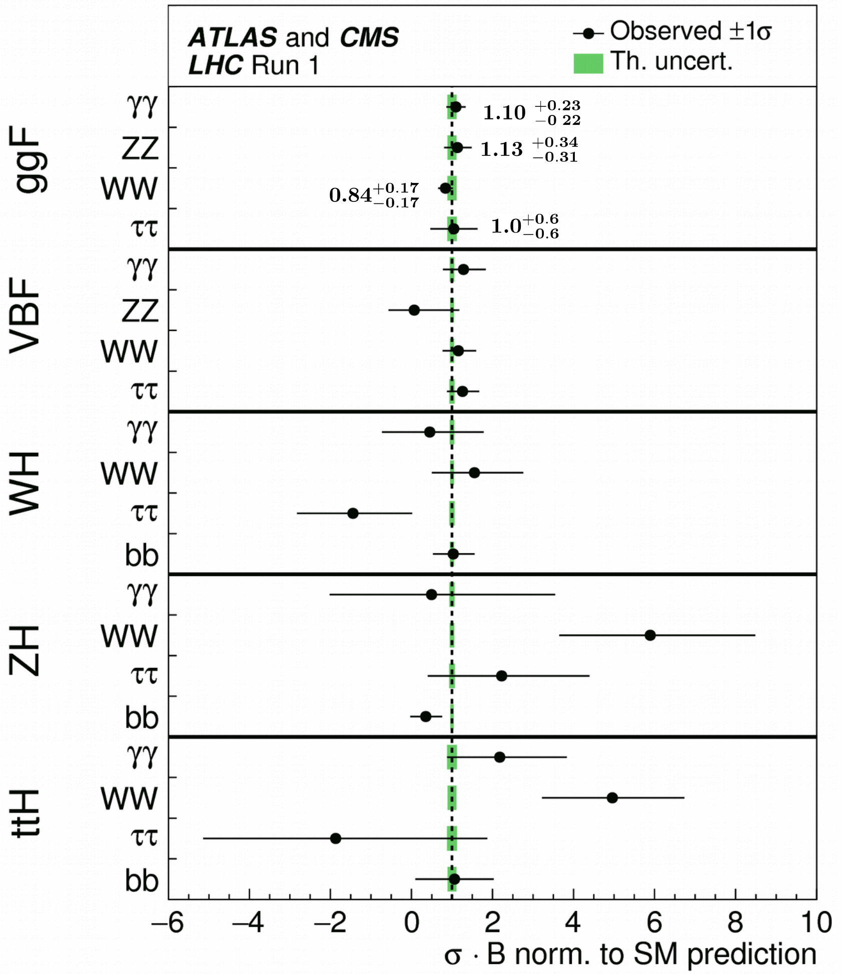




$\mu_i \equiv \frac{\sigma_i}{(\sigma_i)_{SM}}$ $\quad \mu^f \equiv \frac{B^f}{(B^f)_{SM}}$ $\quad \mu_i^f = \mu_i \times \mu^f$

HVV, $Hf\bar{f}$ couplings perspectives

Run I



HL-LHC: 14 TeV 3/ab int. luminosity

Process		Combination	Theory	Experimental
$H \to \gamma\gamma$	ggF	0.07	0.05	0.05
	VBF	0.22	0.16	0.15
	$t\bar{t}H$	0.17	0.12	0.12
	WH	0.19	0.08	0.17
	ZH	0.28	0.07	0.27
$H \to ZZ$	ggF	0.06	0.05	0.04
	VBF	0.17	0.10	0.14
	$t\bar{t}H$	0.20	0.12	0.16
	WH	0.16	0.06	0.15
	ZH	0.21	0.08	0.20
$H \to WW$	ggF	0.07	0.05	0.05
	VBF	0.15	0.12	0.09
$H \to Z\gamma$	incl.	0.30	0.13	0.27
$H \to b\bar{b}$	WH	0.37	0.09	0.36
	ZH	0.14	0.05	0.13
$H \to \tau^+\tau^-$	VBF	0.19	0.12	0.15

Estimated relative uncertianties

Di Vita et al. (17) arXiv 1704.01953

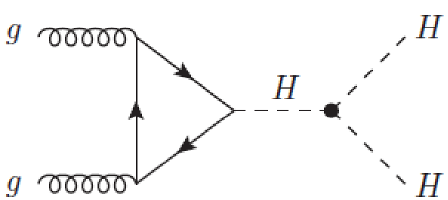
Testing $\mathcal{L}_{Higgs}$: $V(H) = \frac{m_H^2}{2} H^2 + \lambda_3 v H^3 + \frac{\lambda_4}{4} H^4 + \ldots$

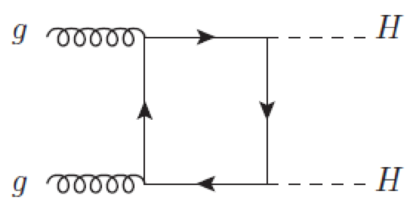
The shape of V(H): Higgs self couplings

n-Higgs production probes (n+1)-Higgs self-coupling

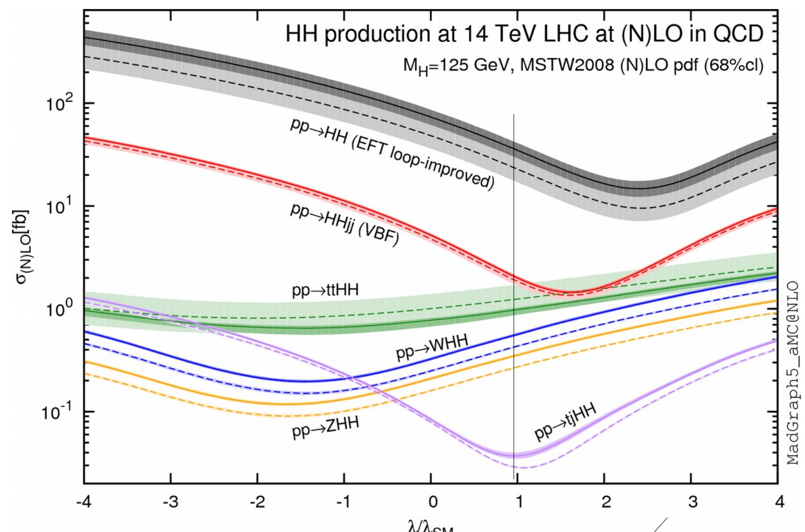
In the SM at tree-level only λ_3 and λ_4 fixed by: $\lambda_3 = \lambda_4 = \lambda = m_H^2/(2v^2) \quad v = \left(\sqrt{2} G_\mu\right)^{-1/2}$

λ_3: double Higgs production





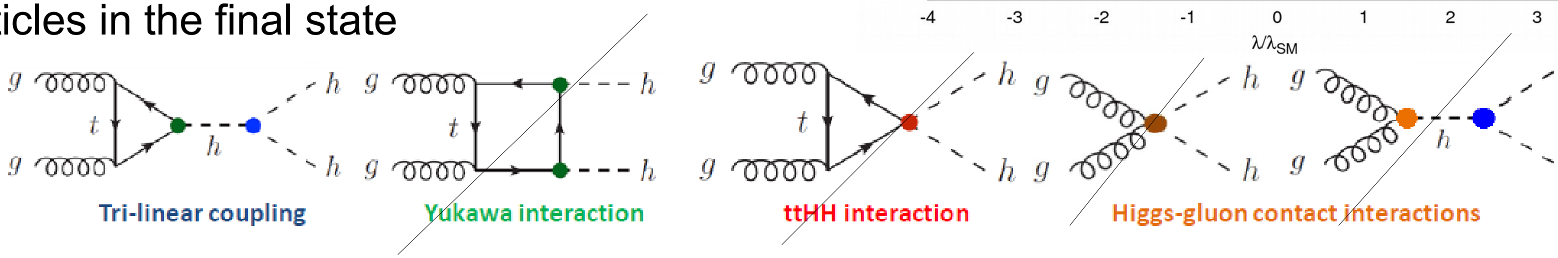
Frederix et al. (14)



destructive interference, small cross section

$\sigma(pp \to HH)_{SM} \sim 35\, fb$

4 particles in the final state

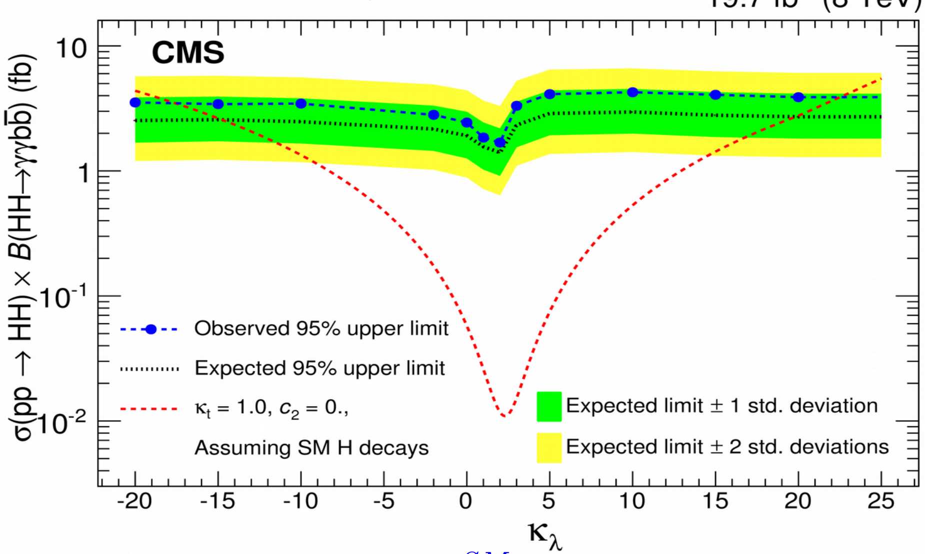


λ_4: triple Higgs production $\sigma(pp \to HHH)_{SM} \sim 0.1\, fb$ too small

λ_3 status : "best" channels $gg \to HH \to bb\gamma\gamma$, $gg \to HH \to bb\tau\tau$

$\kappa_\lambda \equiv \lambda_3/\lambda_3^{SM}$

Run I



$\sigma(gg \to HH) \sim 70\,\sigma^{SM}(gg \to HH)$

$\kappa_\lambda = [-17.5,\ 22.5]$

Run II

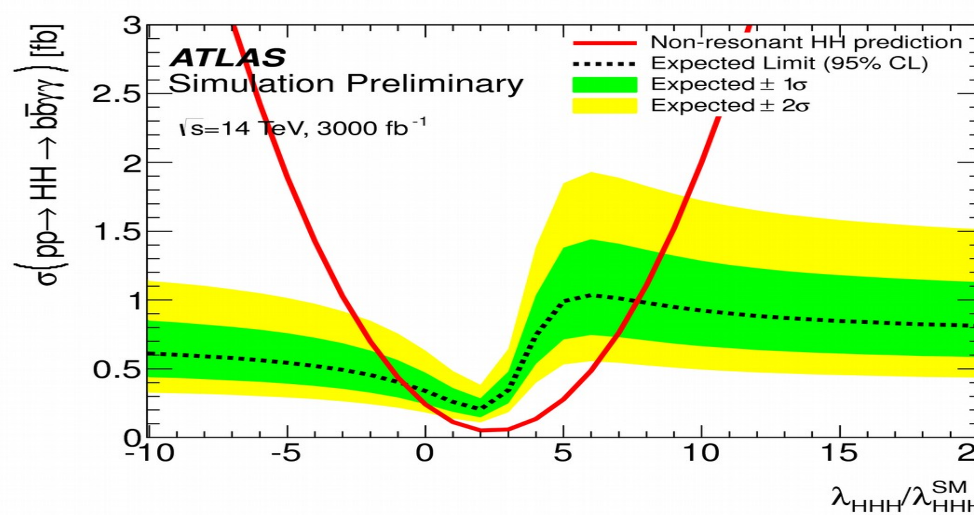
HH to	SM observed (expected) σ/σ_{SM} 95% CL limits	BSM (excluded phase space)	PAS
bbbb	342 (308)	-	CMS-PAS-HIG-16-026
bblvlv	79 (89)	-	CMS-PAS-HIG-17-006
bbττ	28 (25)	K_λ (<-18;>26) with k_t =1.	CMS-PAS-HIG-17-002*
bbγγ	19 (17)	K_λ (<-8;>15) with k_t =1. K_t>=2 if K_λ=1.	CMS-PAS-HIG-17-008

λ_3 perspective :

HL-LHC, 3000 fb^{-1}, <μ>=200

No systematic

$\kappa_\lambda = [-0.8,\ 7.7]$



Remark: we can envisage a scenario such that at the end of the HL-LHC program the couplings of the Higgs to gauge fields and fermions will be known O(≤ 10%) while λ_3 will be known O(1)

QUESTION

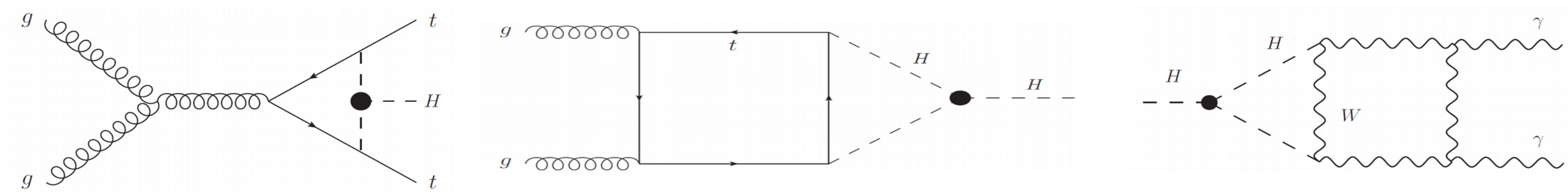
Can we use alternative information with respect to double Higgs production in order to constraint λ_3 today?

(Obviously some assumptions are needed)

Notice: $\frac{\sigma(pp \to H)_{SM}}{\sigma(pp \to HH)_{SM}} = \frac{\sim 50\,pb}{\sim 35\,fb} \sim \frac{1}{1400} \sim \mathcal{O}\left(\frac{\alpha}{4\pi}\right)$

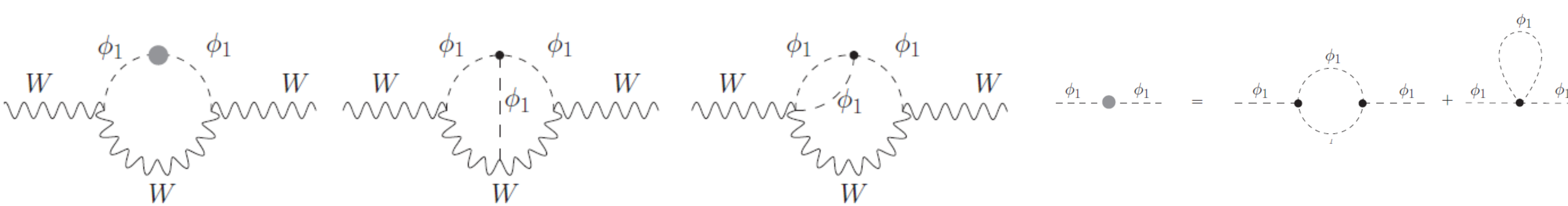
Idea Constrain λ_3 via loop effects:

Exploit the dependence of single Higgs (total and differential) cross sections and decay rates upon the trilinear Higgs self coupling at NLO EW



See also: M. McCullough (13) $(e^+e^- \to ZH)$; M. Gorbahn, U. Haisch (16) $(gg \to H,\ H \to \gamma\gamma)$;
W. Bizon, M. Gorbahn, U. Haisch, G. Zanderighi (1610.05771), (WH, ZH, VBF)

Use the sensitivity of precision observables to λ_3 at NNLO EW



See also: Kribs et al. (1702.07678)

Working assumption:

only the Higgs self-couplings are modified, i.e. $\lambda_3^{SM} \to \lambda_3 = \kappa_\lambda \lambda_3^{SM}$, equivalently any modification of the Higgs coupling to fermion and bosons is much smaller.

$$\Phi = \begin{pmatrix} \phi^+ \\ \frac{v+H+i\phi_2}{\sqrt{2}} \end{pmatrix}$$

N unspecified, C_{2n} arbitrary

$$\mathcal{L} = \mathcal{L}_{\lambda_3} \equiv \mathcal{L}_{SM} - \sum_{n=3}^{N} c_{2n} (\Phi^\dagger \Phi)^n \quad \neq \quad \mathcal{L}_{EFT} \equiv \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \mathcal{L}^{D=6} + \ldots$$

$$\kappa_\lambda = 1 + \frac{2\,v^2}{3m_H^2} \sum_{n=3}^{N} c_{2n}\, n(n-1)(n-2) \left(\frac{v^2}{2}\right)^{n-2}$$

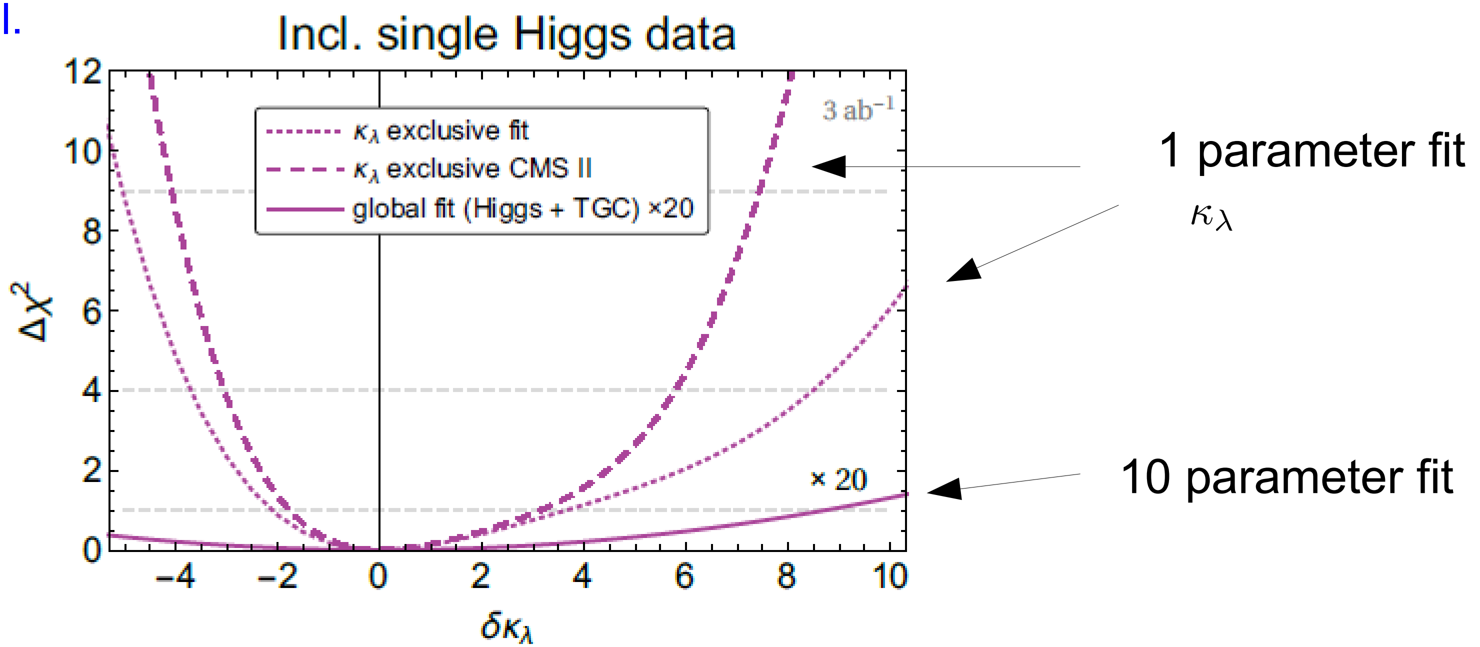
$$\kappa_\lambda = 1 + c_6 \frac{2\,v^2}{m_H^2} \frac{v^2}{\Lambda^2} \sim \mathcal{O}(\pm 5)$$

Far from probing this case

Not the most general assumption: but it can be relaxed in the future when information on the other Higgs couplings will become more accurate.

It is the best we can do today.

1704.01953
Di Vita et al.

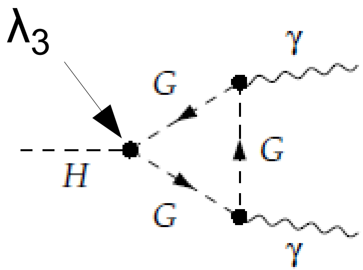


$$
\begin{aligned}
\mathcal{L} \supset \frac{h}{v}\Big[& \delta c_w \frac{g^2 v^2}{2} W^+_\mu W^{-\mu} + \delta c_z \frac{(g^2+g'^2)v^2}{4} Z_\mu Z^\mu \\
& + c_{ww}\frac{g^2}{2} W^+_{\mu\nu} W^{-\mu\nu} + c_{w\Box} g^2 \left(W^-_\mu \partial_\nu W^{+\mu\nu} + \text{h.c.}\right) + \hat{c}_{\gamma\gamma}\frac{e^2}{4\pi^2} A_{\mu\nu}A^{\mu\nu} \\
& + c_{zz}\frac{g^2+g'^2}{4} Z_{\mu\nu}Z^{\mu\nu} + \hat{c}_{z\gamma}\frac{e\sqrt{g^2+g'^2}}{2\pi^2} Z_{\mu\nu}A^{\mu\nu} + c_{z\Box} g^2 Z_\mu \partial_\nu Z^{\mu\nu} + c_{\gamma\Box} g g' Z_\mu \partial_\nu A^{\mu\nu} \Big] \\
& + \frac{g_s^2}{48\pi^2}\left(\hat{c}_{gg}\frac{h}{v} + \hat{c}^{(2)}_{gg}\frac{h^2}{2v^2}\right) G_{\mu\nu}G^{\mu\nu} - \sum_f \left[m_f \left(\delta y_f \frac{h}{v} + \delta y_f^{(2)} \frac{h^2}{2v^2}\right) \bar{f}_R f_L + \text{h.c.}\right] \\
& - (\kappa_\lambda - 1)\lambda_3^{SM} v h^3 \,, \qquad (2.5)
\end{aligned}
$$

Identifying λ_3 contributions

In the SM in an R_ξ gauge not only the *HHH* vertex is proportional to λ_3 but also the vertices with unphysical scalars $H\,\phi^+\phi^-,\ H\,\phi_2\phi_2$
Identification of the λ_3 is not straightforward.

$$\Phi = \begin{pmatrix} \phi^+ \\ \frac{v+H+i\phi_2}{\sqrt{2}} \end{pmatrix}$$



Solution: Go to the Unitary gauge
Gauge-dependent result? See later

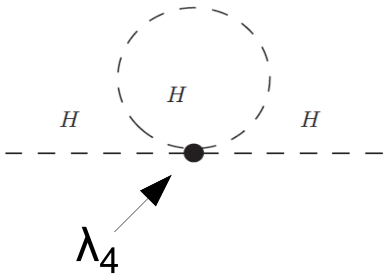
λ_4, λ_5 …..

At the level of (N)NLO EW corrections, i.e.:

1-loop corrections for $\sigma_{VBF}, \sigma_{VH}, \sigma_{t\bar{t}H}, \Gamma_{VV}, \Gamma_{f\bar{f}}$

2-loop corrections for: $\sigma_{gg},\ \Gamma_{gg},\ \Gamma_{\gamma\gamma},\ M_W, \sin^2\theta_{\rm eff}^{\rm lep}$

the Higgs quartic self interaction enters only through the Higgs mass correction diagram



Canceled by the Higgs mass counterterm
No dependence on λ_4

At the (N)NLO level λ_5, λ_6 …. interactions do not contribute

Technical remark:

The unitary gauge is a tricky gauge: one is interchanging

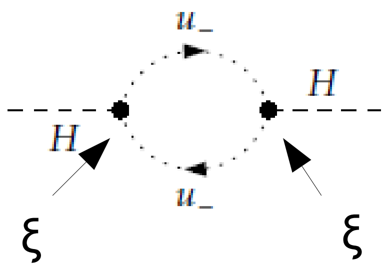
$$\lim_{\xi\to\infty}\int d^n k \longrightarrow \int d^n k \lim_{\xi\to\infty}$$

Vector boson propagator: $$\frac{-i}{k^2-M_V^2+i\epsilon}\left[g^{\mu\nu}+(\xi-1)\frac{k^\mu k^\nu}{k^2-\xi M_V^2}\right]\longrightarrow -i\frac{g^{\mu\nu}-k^\mu k^\nu/M_V^2}{k^2-M_V^2+i\epsilon}$$

Ghost, unphysical scalar propagator $$\frac{-i}{k^2-\xi M_V^2+i\epsilon}\longrightarrow 0$$

No ghosts, no unphysical in an UG calculation

However, in R_ξ , in principle, there can be residues from the ξ in the denominators from the propagators and the one in the numerators from vertices of higgses with ghosts



$$\lim_{\xi\to\infty}\int d^n k\frac{\xi^2}{(k^2-\xi\, m_W^2)^2}=\int d^n k\frac{1}{m_W^4}=0$$

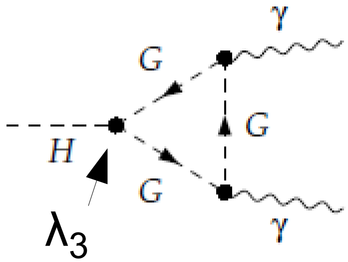
DR

Finiteness of κ_λ

Although our theory is not renormalizable the result for κ_λ at the level of (N)NLO EW corrections is finite, i.e. it does not depend on Λ

Reason: the "Born" results do not depend upon λ_3. Renormalization of λ_3 is not needed

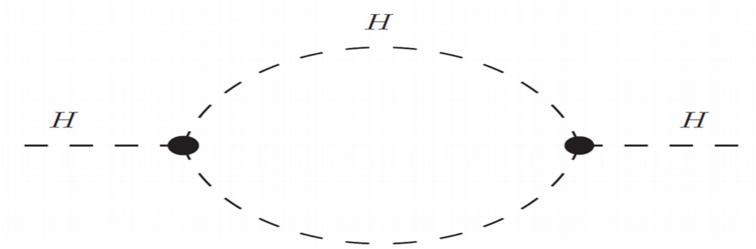
What about



?

In UG is not there; you are trading a coupling for a kinematical mass

NLO λ_3-dependent diagram:



Finite after Higgs mass renormalization

What is my scenario?

My scenario is described by the SM Lagrangian with a modified scalar potential:

$$V^{NP} = \sum_{n=1}^{N} c_{2n} (\Phi^\dagger \Phi)^n \qquad \Phi = \begin{pmatrix} \phi^+ \\ \frac{v+H+i\phi_2}{\sqrt{2}} \end{pmatrix}$$

N unspecified. C_{2n} arbitrary

Limit to EFT:

N=3,4.. $c_{2n+2} \sim c_{2n}/\Lambda^2$

$$m_H^2 = v^2 \sum_{n=1}^{N} c_{2n}\, n(n-1) \left(\frac{v^2}{2}\right)^{n-2}$$

$$\begin{aligned} V_{4\phi}^{NP} &= \frac{m_H^2}{2v^2}\left[\phi^+\phi^-(\phi^+\phi^- + \phi_2^2) + \frac{1}{4}\phi_2^4\right] + \left(\frac{m_H^2}{2v^2} + d\lambda_4\right)\frac{1}{4}H^4 \\ &+ \left(\frac{m_H^2}{2v^2} + 3\, d\lambda_3\right) H^2 \left[\phi^+\phi^- + \frac{1}{2}\phi_2^2\right] + \left(\frac{m_H^2}{2v} + v\, d\lambda_3\right) H^3 \\ &+ \frac{m_H^2}{2v} H\left(\phi_2^2 + 2\phi^+\phi^-\right) + \frac{1}{2} m_H^2\, H^2 \end{aligned}$$

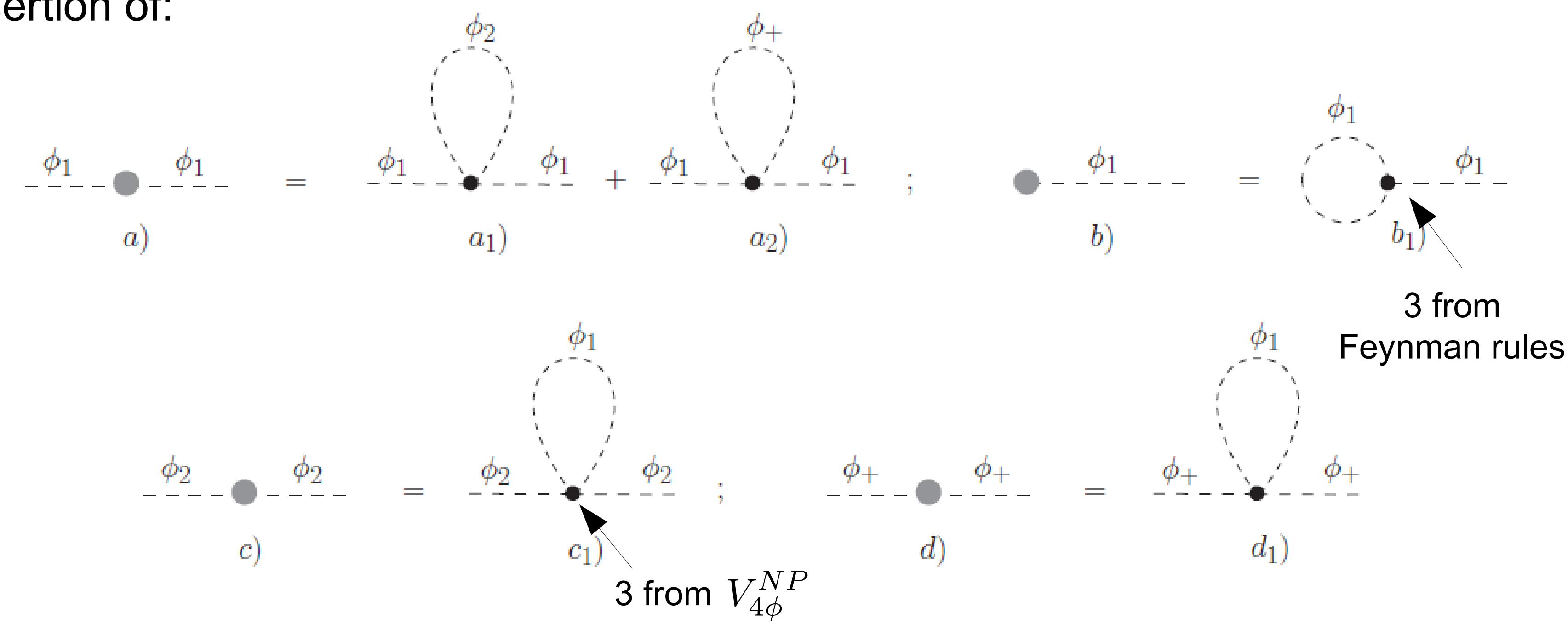
$\kappa_\lambda = 1 + 2v^2/m_H^2\, d\lambda_3$

Few couplings modified with respect to the SM and there are correlations

$$\begin{aligned} d\lambda_3 &= \frac{1}{3}\sum_{n=3}^{N} c_{2n}\, n(n-1)(n-2)\left(\frac{v^2}{2}\right)^{n-2}, \\ d\lambda_4 &= \frac{2}{3}\sum_{n=3}^{N} c_{2n}\, n^2(n-1)(n-2)\left(\frac{v^2}{2}\right)^{n-2} \end{aligned}$$

Diagrams that in R_ξ can give additional contributions with respect to the UG result

Insertion of:



All these contributions are canceled by the mass renormalization counterterms

$$\delta m_\phi^2 = \delta m_V^2 + \delta T$$

Tadpole contribution

What scenario can be probed ?

- We expect to probe "large" values of κ_λ, however they cannot be too large otherwise there is a problem with perturbativity $|\kappa_\lambda| \lesssim 20$.

- The results at the NLO (single H) and NNLO (EW observables) level are finite, gauge-invariant and only dependent on λ_3 . But the theory is not renormalizable. Λ-dependent contributions will appear in higher order of perturbation theory as well as λ_4, λ_5… terms.

- To estimate the cutoff scale of this scenario one can look at

$$V_L V_L \longrightarrow V_L V_L H^n$$

$$\Lambda \lesssim \frac{4\pi v}{\sqrt{|\kappa_\lambda - 1}} \sqrt{\frac{32\pi}{15} \frac{v}{m_H}} \to \Lambda \lesssim 3 \text{ TeV}, \ |\kappa_\lambda| \lesssim 20$$

A. Falkowski, R. Rattazzi in preparation

Single Higgs processes

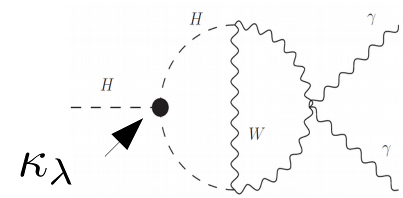
Master Formula

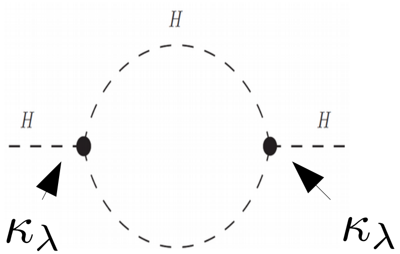
$$\Sigma_{\rm NLO} = Z_H \Sigma_{\rm LO} \left(1 + \kappa_\lambda C_1\right)$$

universal

dressed with QCD

Process and kinetic dependent





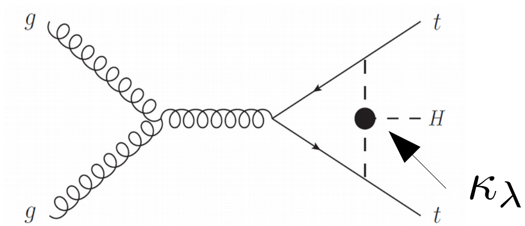
$$= \kappa_\lambda^2 \delta Z_H ,$$

$$\delta Z_H = -\frac{9}{16} \frac{G_\mu \, m_H^2}{\sqrt{2}\,\pi^2} \left(\frac{2\pi}{3\sqrt{3}} - 1\right)$$

$$Z_H = \frac{1}{1 - \kappa_\lambda^2 \, \delta Z_H}$$

Resumming requires $|\kappa_\lambda| \lesssim 25$

$$C_1^\Gamma = \frac{\int d\Phi \;\; 2\Re\left(\mathcal{M}^{0*}\mathcal{M}^1\right)}{\int d\Phi \;\; |\mathcal{M}^0|^2}$$



$$C_1^\sigma = \frac{\sum_{i,j} \int dx_1 dx_2 f_i(x_1) f_j(x_2)\, 2\Re\left(\mathcal{M}_{ij}^{0*}\mathcal{M}_{ij}^1\right) d\Phi}{\sum_{i,j} \int dx_1 dx_2 f_i(x_1) f_j(x_2)\, |\mathcal{M}_{ij}^0|^2 d\Phi}$$

$$\delta\Sigma \equiv \frac{\Sigma_{\rm NLO} - \Sigma_{\rm NLO}^{\rm SM}}{\Sigma_{\rm LO}} = (\kappa_\lambda^2 - 1) C_2 + (\kappa_\lambda - 1) C_1$$

$$C_2 = \frac{\delta Z_H}{(1 - \kappa_\lambda^2 \delta Z_H)}$$

overall and universal

Process and kinetic dependent

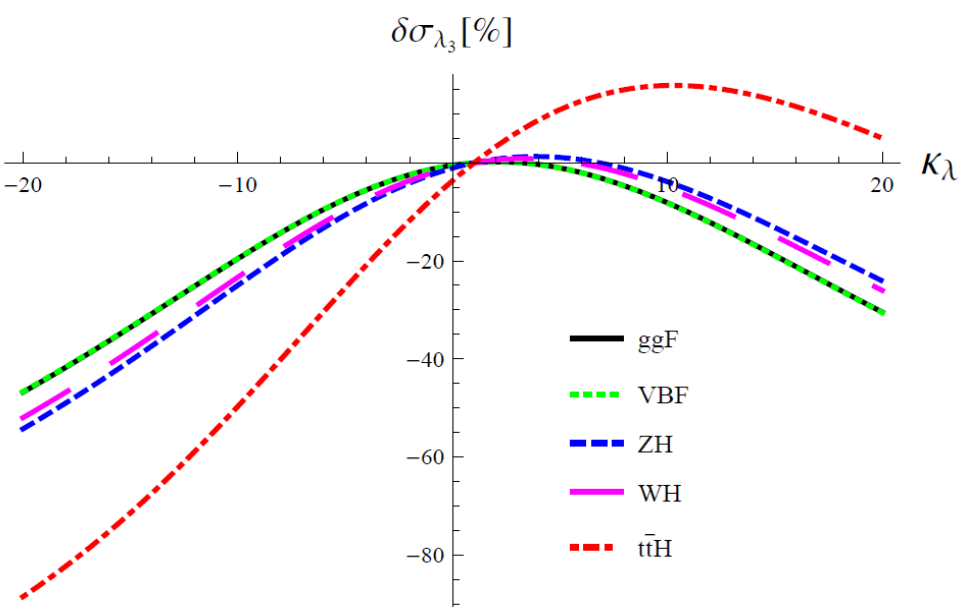
Results: total cross sections

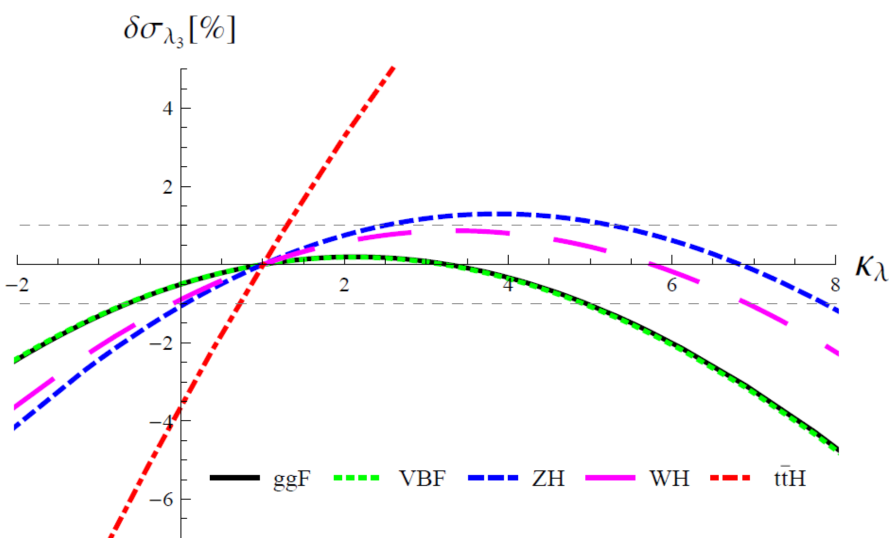
$$\delta\sigma = (\kappa_\lambda^2 - 1)C_2 + (\kappa_\lambda - 1)C_1$$

$$C_2 = -9.14 \cdot 10^{-4}, \quad \kappa_\lambda = \pm 20$$
$$C_2 = -1.53 \cdot 10^{-3}, \quad \kappa_\lambda = \pm 1$$

$C_1^\sigma[\%]$	ggF	VBF	WH	ZH	$t\bar{t}H$
8 TeV	0.66	0.65	1.05	1.22	3.78
13 TeV	0.66	0.64	1.03	1.19	3.51

Largest effects in $t\bar{t}$H and VH





Only $t\bar{t}$H receive sizable positive corrections

Results: differential cross sections

Kinematical dependence of the C_1 coefficient.

C_1^σ [%]	25 GeV	50 GeV	100 GeV	200 GeV	500 GeV
WH	1.71 (0.11)	1.56 (0.34)	1.29 (0.72)	1.09 (0.94)	1.03 (0.99)
ZH	2.00 (0.10)	1.83 (0.33)	1.50 (0.71)	1.26 (0.94)	1.19 (0.99)
$t\bar{t}H$	5.44 (0.04)	5.14 (0.17)	4.66 (0.48)	3.95 (0.84)	3.54 (0.99)

$p_T(H) < p_{T,\mathrm{cut}}$

Table 1: C_1^σ at 13 TeV obtained by imposing the cut $p_T(H) < p_{T,\ \mathrm{cut}}$, for several values of $p_{T,\mathrm{cut}}$. In parentheses the fraction of events left after the quoted cut is applied.

C_1^σ [%]	1.1	1.2	1.5	2	3
WH	1.78 (0.17)	1.60 (0.36)	1.32 (0.70)	1.15 (0.89)	1.06 (0.97)
ZH	2.08 (0.19)	1.86 (0.38)	1.51 (0.72)	1.31 (0.90)	1.22 (0.98)
$t\bar{t}H$	8.57 (0.02)	7.02 (0.10)	5.11 (0.43)	4.12 (0.76)	3.64 (0.94)

$m_{\mathrm{tot}} < K \cdot m_{\mathrm{thr}}$

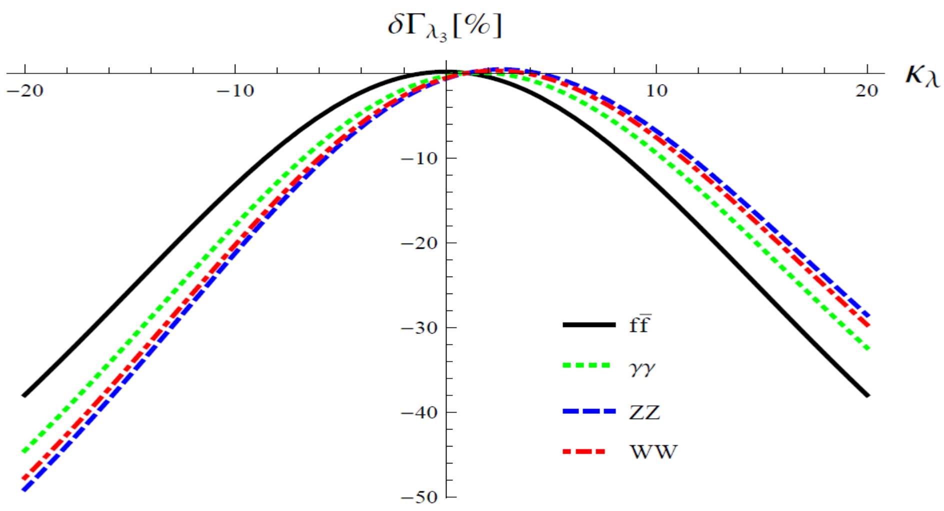
Table 1: C_1^σ at 13 TeV obtained by imposing the cut $m_{\mathrm{tot}} < K\ t m_{\mathrm{thr}}$, for several values of K. In parentheses the fraction of even ts left after the quoted cut is applied.

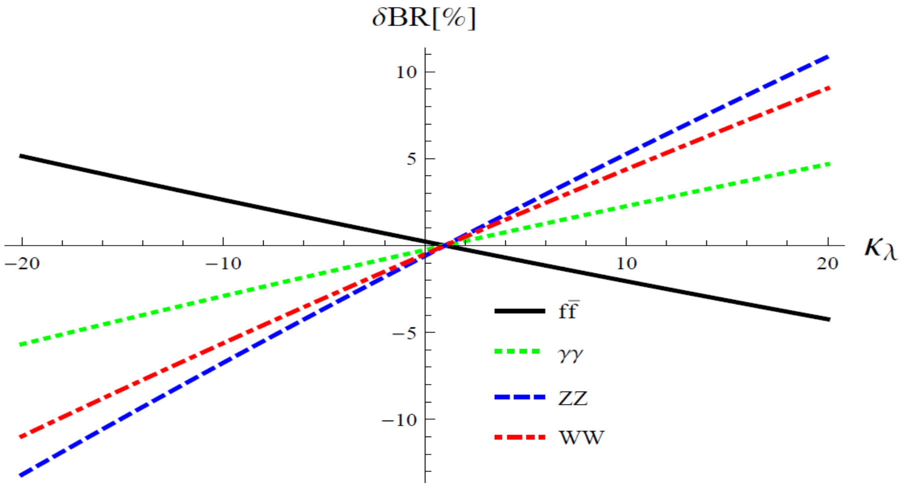
Results: decay rates

$C_1^\Gamma[\%]$	$\gamma\gamma$	ZZ	WW	$f\bar{f}$	gg
on-shell H	0.49	0.83	0.73	0	0.66

$$C_1^{\Gamma_{\rm tot}} \equiv \sum_j {\rm BR}^{\rm SM}(j) C_1^\Gamma(j) = 2.3 \cdot 10^{-3}$$

$$\delta{\rm BR}_{\lambda_3}(i) = \frac{(\kappa_\lambda - 1)(C_1^\Gamma(i) - C_1^{\Gamma_{\rm tot}})}{1 + (\kappa_\lambda - 1) C_1^{\Gamma_{\rm tot}}}$$





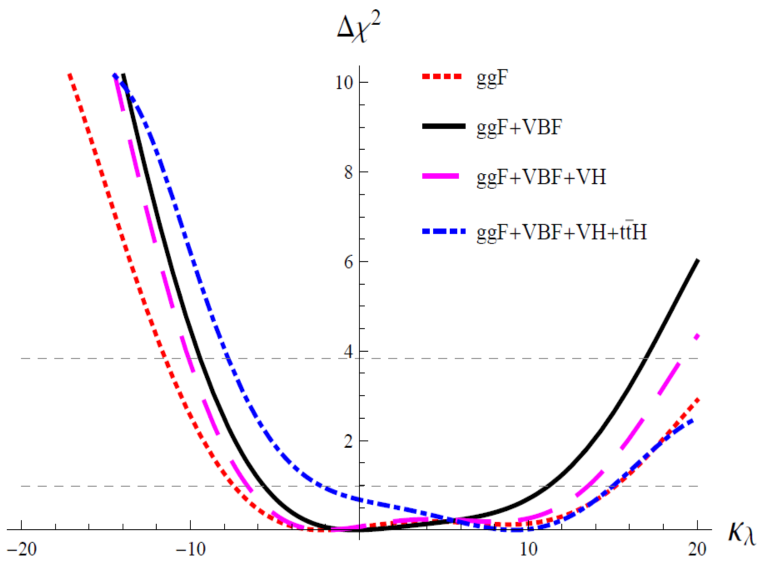
Much milder dependence on κ_λ in the BR because no C_2 contribution

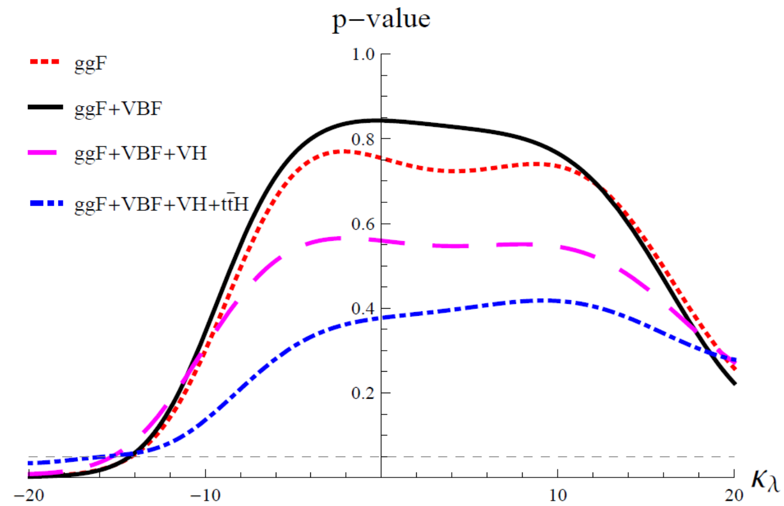
Constraints on λ_3 from 8 TeV data

Using signal strength results from the combination of ATLAS and CMS we can make a one-parameter fit to estimate the limit that can be set on κ_λ

$$\chi^2(\kappa_\lambda) \equiv \sum_{\bar{\mu}_i^f \in \{\bar{\mu}_i^f\}} \frac{(\mu_i^f(\kappa_\lambda) - \bar{\mu}_i^f)^2}{(\Delta_i^f(\kappa_\lambda))^2}$$

$$\begin{aligned} \mu_i^f(\kappa_\lambda) &= \mu_i(\kappa_\lambda) \times \mu^f(\kappa_\lambda) \\ \mu_i(\kappa_\lambda) &= 1 + \delta\sigma_{\lambda_3}(i) \\ \mu^f(\kappa_\lambda) &= 1 + \delta \mathrm{BR}_{\lambda_3}(f) \end{aligned}$$





ggF + VBF $\quad \kappa_\lambda^{\mathrm{best}} = -0.24\,, \quad \kappa_\lambda^{1\sigma} = [-5.6, 11.2]\,, \quad \kappa_\lambda^{2\sigma} = [-9.4, 17.0]$

$$p\text{-value}(\kappa_\lambda) = 1 - F_{\chi^2_{(n)}}(\chi^2(\kappa_\lambda))\,,$$

$p > 0.05 \quad \kappa_\lambda > -14.3$

Precision Observables

λ_3-dependent contributions in m_W and $\sin^2\theta_{\rm eff}^{\rm lep}$

m_W and the effective sine are obtained from α, G_μ and m_z via

$$m_W^2 = \frac{\hat\rho\, m_Z^2}{2}\left\{1+\left[1-\frac{4\hat A^2}{m_Z^2\hat\rho}(1+\Delta\hat r_W)\right]^{1/2}\right\}$$

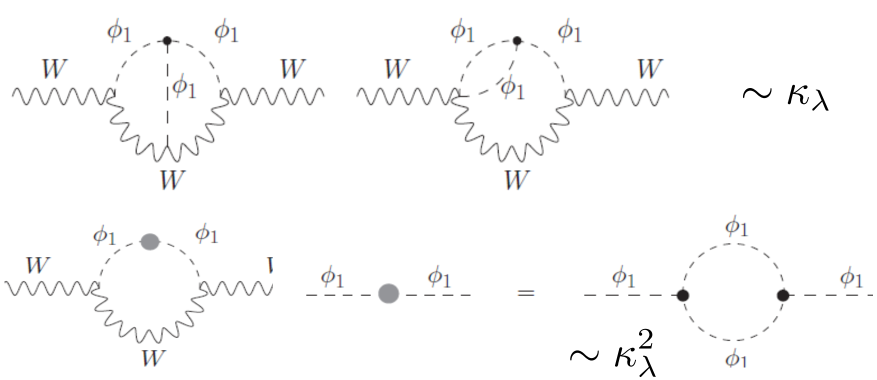
$$\sin^2\theta_{\rm eff}^{\rm lep} \sim \frac{1}{2}\left\{1-\left[1-\frac{4\hat A^2}{m_Z^2\hat\rho}(1+\Delta\hat r_W)\right]^{1/2}\right\}$$

$$\begin{aligned}\hat A &= (\pi\hat\alpha(m_Z)/(\sqrt{2}G_\mu))^{1/2}\\ \hat\alpha(m_Z) &= \frac{\alpha}{1-\Delta\hat\alpha(m_Z)}\\ \frac{G_\mu}{\sqrt{2}} &= \frac{\pi\hat\alpha(m_Z)}{2m_W^2\hat s^2}(1+\Delta\hat r_W)\\ \hat\rho &= \frac{1}{1-Y_{\overline{MS}}}\end{aligned}$$

λ_3-dependent contributions appear at two-loop in the W and Z self-energies

$$\Delta\hat r_W^{(2)} = \frac{\mathrm{Re}\,A_{WW}^{(2)}(m_W^2)}{m_W^2}-\frac{A_{WW}^{(2)}(0)}{m_W^2}+\ldots$$

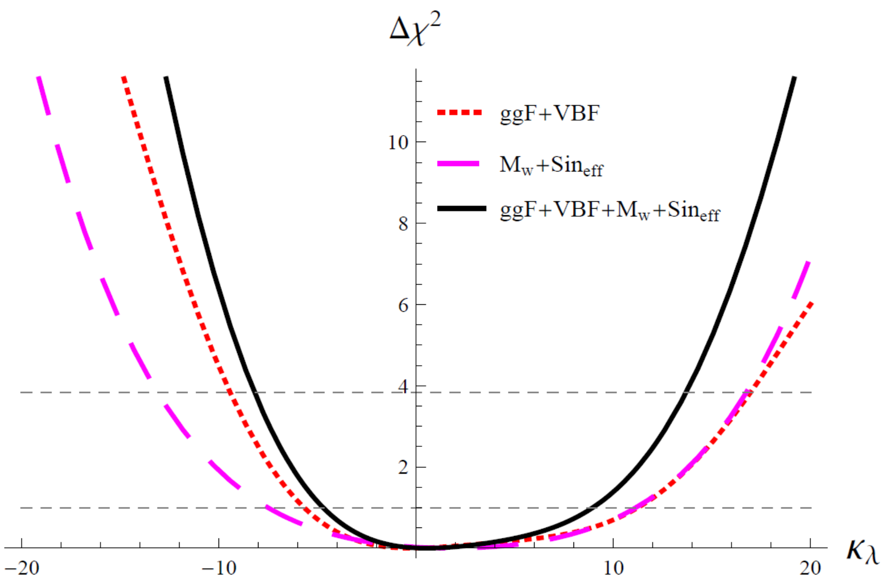
$$Y_{\overline{MS}}^{(2)} = \mathrm{Re}\left[\frac{A_{WW}^{(2)}(m_W^2)}{m_W^2}-\frac{A_{ZZ}^{(2)}(m_Z^2)}{m_Z^2}\right]+\ldots$$

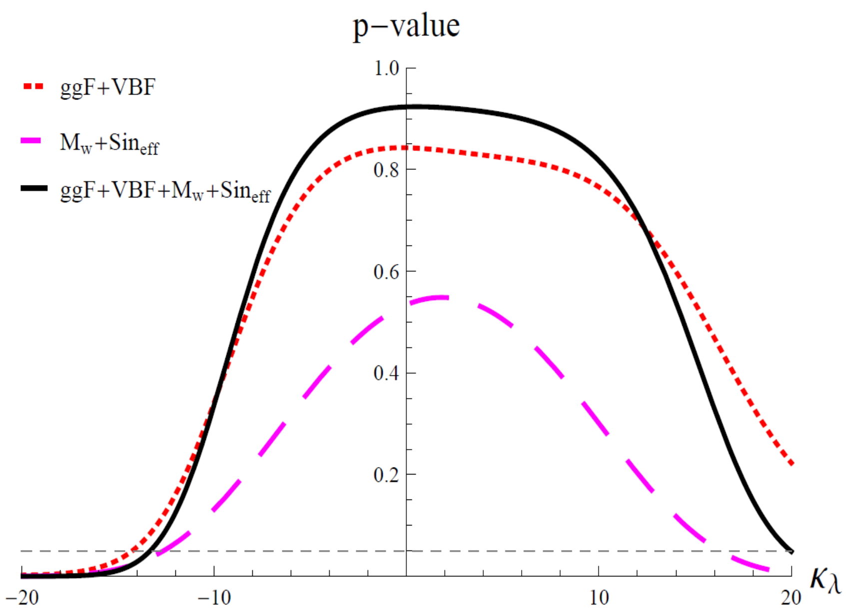


Constraints on λ_3 from P.O. and 8 TeV data

$$O = O^{\rm SM}\left[1 + (\kappa_\lambda - 1)C_1 + (\kappa_\lambda^2 - 1)C_2\right]$$

	C_1	C_2
m_W	6.27×10^{-6}	-1.72×10^{-6}
$\sin^2\theta_{\rm eff}^{\rm lep}$	-1.56×10^{-5}	4.55×10^{-6}





P.O. + ggF +VBF $\quad \kappa_\lambda^{\rm best} = 0.5\,, \quad \kappa_\lambda^{1\sigma} = [-4.7, 8.9]\,, \quad \kappa_\lambda^{2\sigma} = [-8.2, 13.7]$

$p > 0.05 \quad \kappa_\lambda > -13.3, \quad \kappa_\lambda < 20$

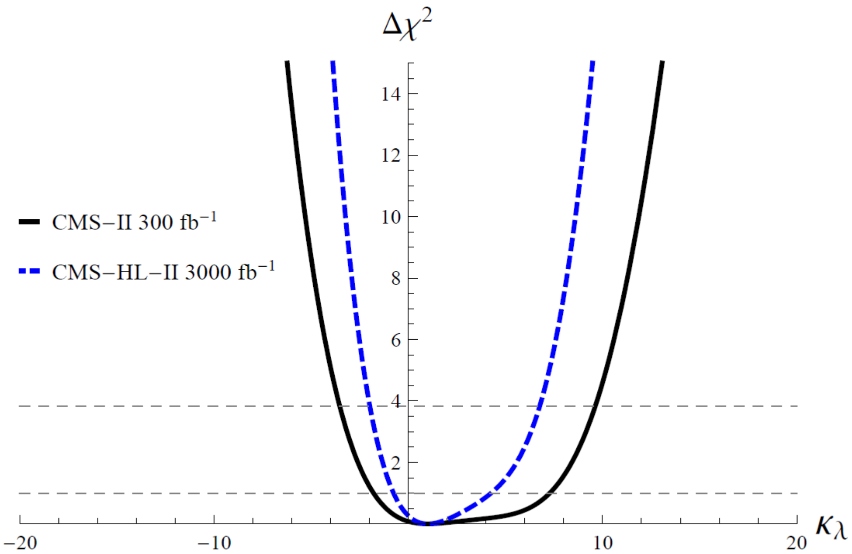
ggF + VBF $\quad \kappa_\lambda^{\rm best} = -0.24\,, \quad \kappa_\lambda^{1\sigma} = [-5.6, 11.2]\,, \quad \kappa_\lambda^{2\sigma} = [-9.4, 17.0]$

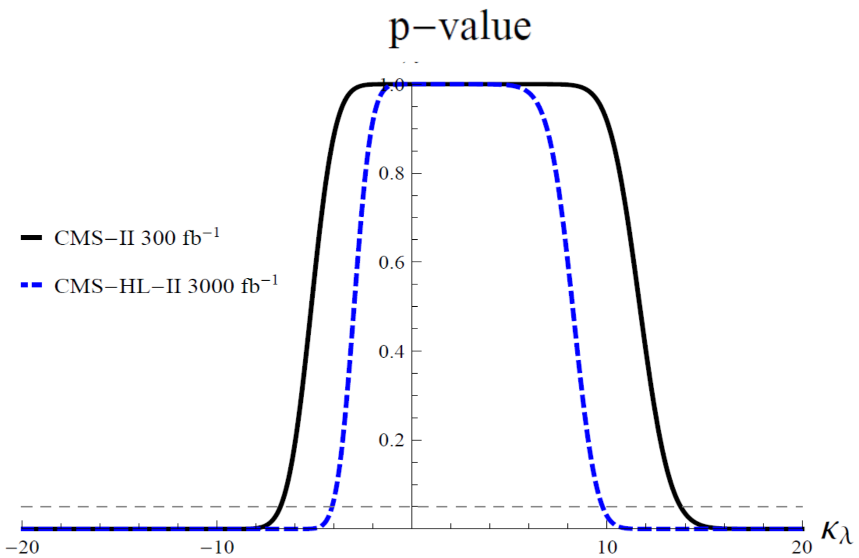
$p > 0.05 \quad \kappa_\lambda > -14.3$

Perspectives for the future

Exercise: $\mu_i^f = 1 \longrightarrow \kappa_\lambda^{\rm best} = 1$ central values are SM

Relative uncertainties as estimated in Peskin arXiv: 1312.4974





CMS-II (300 fb^{-1}) $\kappa_\lambda^{1\sigma} = [-1.8, 7.3]\,,$ $\kappa_\lambda^{2\sigma} = [-3.5, 9.6]$ $\kappa_\lambda^{p>0.05} = [-6.7,\, 13.8]$

CMS-HL-II (3000 fb^{-1}) $\kappa_\lambda^{1\sigma} = [-0.7, 4.2]\,,$ $\kappa_\lambda^{2\sigma} = [-2.0, 6.8]$ $\kappa_\lambda^{p>0.05} = [-4.1,\, 9.8]$

Conclusions

- The shape of the Higgs potential is presently very poorly known and the bounds on the trilinear self couplings from double Higgs production do not allow to test weakly coupled models.

- I presented the idea of using the sensitivity to the Higgs trilinear coupling of single Higgs processes and precision observables in order to gather information on the Higgs potential.

- These kind of studies can be competitive and complementary to the direct double Higgs measuremets

- Our studies rely on some assumptions (some of which are in common with the double Higgs analyses) that can be in the future progressively relaxed.