Measuring Hidden Higgs and Strongly-Interacting Higgs Scenarios

S. BOCK, *R. LAFAYE*, T. PLEHN, M. RAUCH,
D. ZERWAS AND P.M. ZERWAS

Higgs Beyond the Standard Model

New Physics: will very likely modify Higgs couplings

⇒Higgs couplings @LHC

= Test the SM and probe for New Physics

We studied 2 scenarios

- Hidden sector coupling to SM only through Higgs
- Composite Higgs generated by new strong interactions

In those scenarios Higgs couplings wrt SM are reduced either universally or per particle type

The Hidden Sector (HS)

Scalar Higgs links SM (s) and Hidden (h) sectors:

$$\mathcal{V} = \mu_s^2|\phi_s|^2 + \lambda_s|\phi_s|^4 \; + \; \mu_h^2|\phi_h|^2 + \lambda_h|\phi_h|^4 \; + \; \eta_\chi|\phi_s|^2|\phi_h|^2$$

After diagonalizing the Higgs mass matrix:

$$\begin{aligned} H_1 &= \quad \cos\chi\, H_s + \sin\chi\, H_h \\ H_2 &= -\sin\chi\, H_s + \cos\chi\, H_h \end{aligned}$$

If the mixing η_χ is moderate H_1 ~ SM Higgs

With couplings universally suppressed:

$$\Gamma_{\text{vis}} = \cos^2\chi\, \Gamma_{\text{vis}}^{\text{SM}}$$

The Hidden Sector (HS)

Couplings universally suppressed by:

$$\Gamma_{\text{vis}} = \cos^2\chi\,\Gamma_{\text{vis}}^{\text{SM}}$$

H_1 may also decay invisibly:

$$\Gamma_{\text{inv}} = \cos^2\chi\,\Gamma_{\text{inv}}^{\text{SM}} + \Gamma_{\text{hid}}$$

$\Gamma_{\text{inv}}^{\text{SM}}$ is extrapolated from $H \to ZZ \to 4l$ (into $\to 4\nu$)

Higgs observables are compared to SM expectations

using SFITTER

$$\sigma \cdot \text{BR} \propto \frac{\Gamma_p \Gamma_d}{\Gamma_{\text{tot}}} = \kappa \left(\frac{\Gamma_p \Gamma_d}{\Gamma_{\text{tot}}} \right)^{\text{SM}}$$

p: production mode

d: decay mode

SM Higgs @ LHC, 30 fb^{-1}

Signatures included in this analysis (m_H=120 GeV):

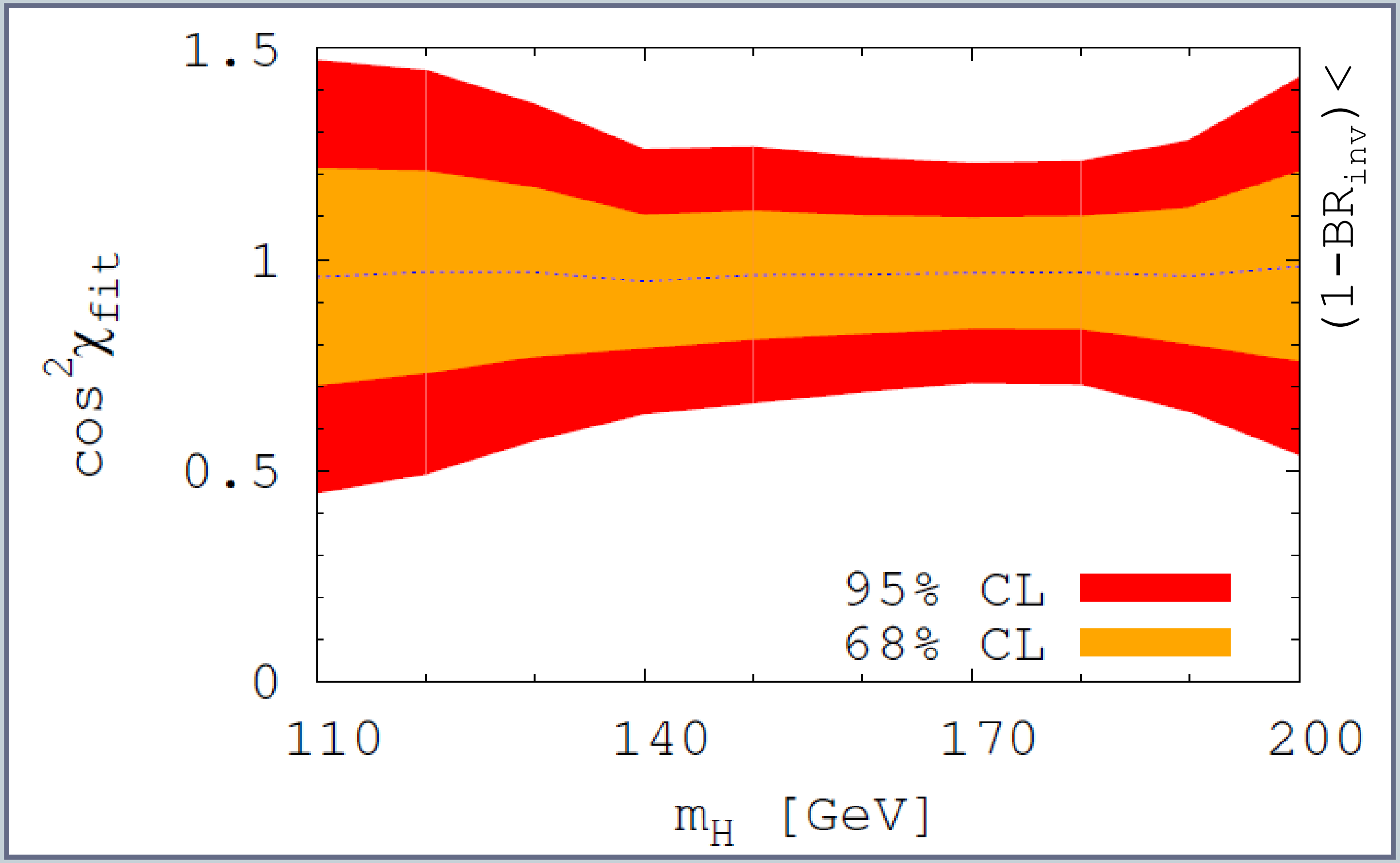
production	decay	$S+B$	B	S	$\Delta S^{(\mathrm{exp})}$	$\Delta S^{(\mathrm{theo})}$
$gg \to H$	ZZ	13.4	6.6 ($\times$ 5)	6.8	3.9	0.8
qqH	ZZ	1.0	0.2 ($\times$ 5)	0.8	1.0	0.1
$gg \to H$	WW	1019.5	882.8 ($\times$ 1)	136.7	63.4	18.2
qqH	WW	59.4	37.5 ($\times$ 1)	21.9	10.2	1.7
$t\bar{t}H$	$WW(3\ell)$	23.9	21.2 ($\times$ 1)	2.7	6.8	0.4
$t\bar{t}H$	$WW(2\ell)$	24.0	19.6 ($\times$ 1)	4.4	6.7	0.6
inclusive	$\gamma\gamma$	12205.0	11820.0 ($\times$ 10)	385.0	164.9	44.5
qqH	$\gamma\gamma$	38.7	26.7 ($\times$ 10)	12.0	6.5	0.9
$t\bar{t}H$	$\gamma\gamma$	2.1	0.4 ($\times$ 10)	1.7	1.5	0.2
WH	$\gamma\gamma$	2.4	0.4 ($\times$ 10)	2.0	1.6	0.1
ZH	$\gamma\gamma$	1.1	0.7 ($\times$ 10)	0.4	1.1	0.1
qqH	$\tau\tau(2\ell)$	26.3	10.2 ($\times$ 2)	16.1	5.8	1.2
qqH	$\tau\tau(1\ell)$	29.6	11.6 ($\times$ 2)	18.0	6.6	1.3
$t\bar{t}H$	$b\bar{b}$	244.5	219.0 ($\times$ 1)	25.5	31.2	3.6
WH/ZH	$b\bar{b}$	228.6	180.0 ($\times$ 1)	48.6	20.7	4.0

Statistic used to extrapolate background

SM Higgs @ LHC, 30 fb^{-1}

$\Gamma_{hid} = 0$

$\cos^2\chi = 1.0$



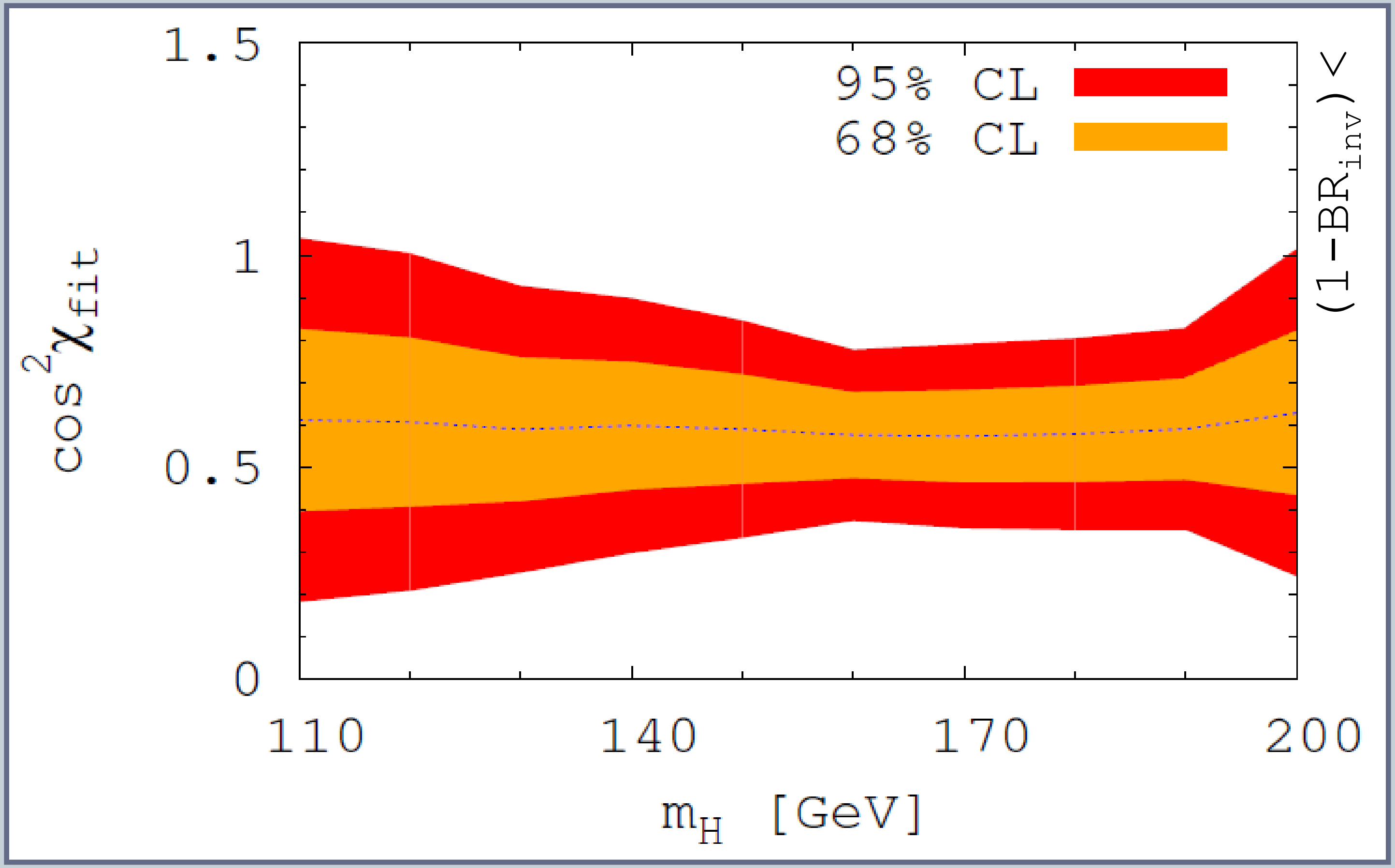
$m_H = 120$GeV

$$\cos^2\chi = 1 \pm 24\%(48\%) \text{ at the } 68\%(95\%) \text{ CL}$$

HS Higgs @ LHC, 30 fb^{-1}

$\Gamma_{hid} = 0$

$\cos^2\chi = 0.6$



SM Higgs excluded if m_H between 120 and 200 GeV

Higgs decaying to Hidden Sector

Note: Even if we do not measure directly *H→invisible*

We can translate the measure of $\cos^2\chi$ into an upper limit: $BR_{inv} \leq 1 - \cos^2\chi$

We choose benchmark $\Gamma_{hid} = \sin^2\chi\, \Gamma^{SM}_{tot}$

Natural mixing suppression ($\sin^2\chi$)

Hidden sector structure similar to SM (Γ^{SM}_{tot})

With 30 fb^{-1} ⇒ No 5σ evidence

for m_H=120 GeV and $\cos^2\chi = 0.4$

production	decay	$S + B$	B	S	$\Delta S^{(\rm exp)}$	$\Delta S^{(\rm theo)}$
qqH	invisible	2165.0	1847.1 (× 1)	317.9	197.8	22.25

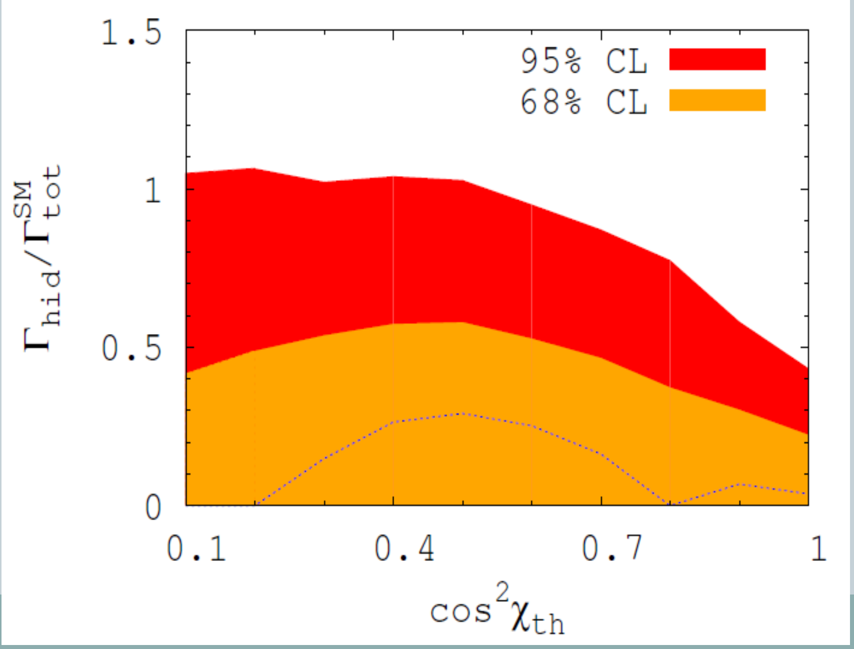
Higgs decaying to Hidden Sector

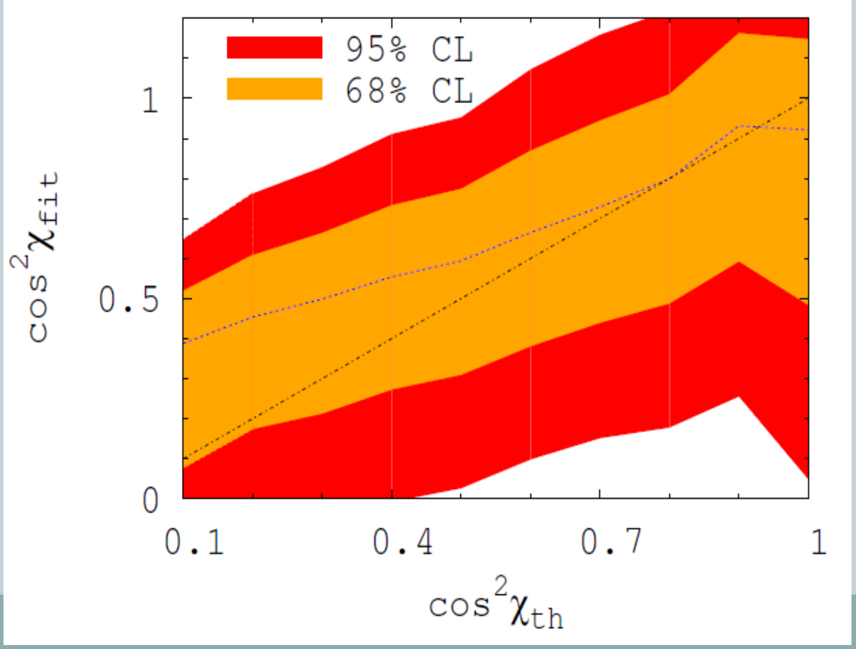
For m_H=120 GeV, 30 fb^{-1}, $\Gamma_{hid} = \sin^2\chi\ \Gamma^{SM}$

Γ_{hid} measurement is always compatible with 0

Parameters Γ_{hid} and $\cos^2\chi$ are clearly correlated

Impact on $\cos^2\chi$ determination: 0 to 0.2 wider, assymetric





The Strongly Interacting Higgs

Light Higgs generated as pseudo-Goldstones

global symmetry breaking

in new strong interaction sector

Magnitude of the Goldstone scale:

$$\xi = \left(\frac{v}{f}\right)^2$$

If couplings suppressed universally:

$$\Gamma_{\text{vis}} = (1 - \xi)\Gamma_{\text{vis}}^{\text{SM}}$$

Case similar to previous one with:

$$\cos^2\chi \to 1 - \xi \qquad \Gamma_{\text{hid}} = 0$$

The Strongly Interacting Higgs

Couplings suppressed per particle type:

$$\Gamma_{\text{vis}} = (1-\xi)\Gamma_{\text{vis}}^{\text{SM}}$$

vectors

$$\Gamma_{\text{vis}} = (1-2\xi)^2/(1-\xi)\Gamma_{\text{vis}}^{\text{SM}}$$

fermions

Now, we have 4 type of observables, depending on

- production mode *(V or f)*
- decay mode *(V or f)*

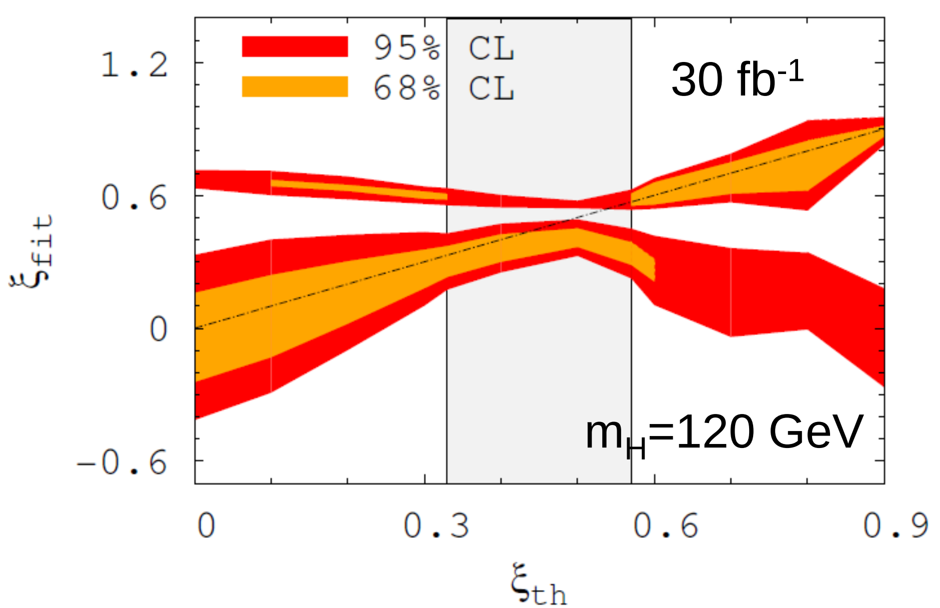
Note: the fermionic factor can be > 1 for $\xi \to 1$

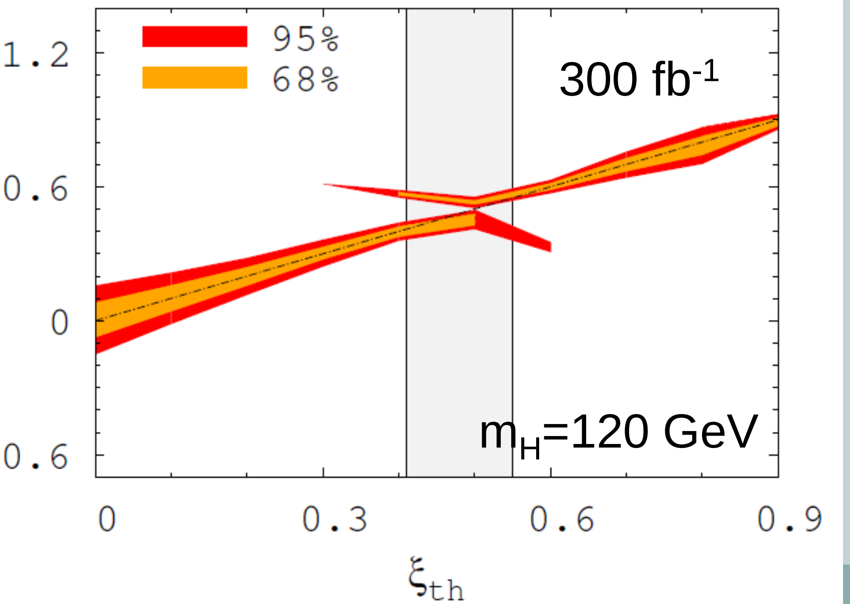
The Strongly Interacting Higgs

At 30 fb^{-1} two solutions are present

At 300 fb^{-1} they can be disentangled for low Higgs masses

At high Higgs masses, most measurements are fermionic production, which can not differentiate between high and low ξ





The Strongly Interacting Higgs

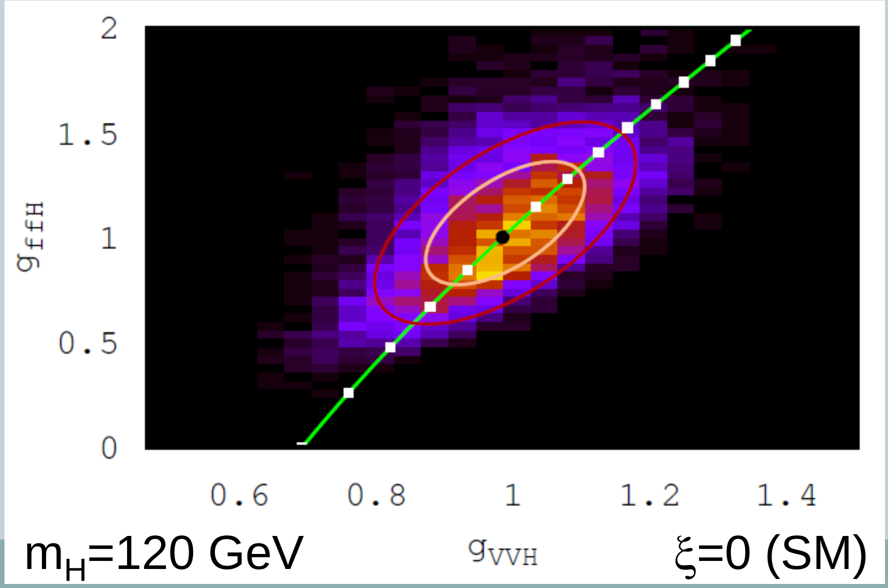
Fitting vector and fermion couplings separately

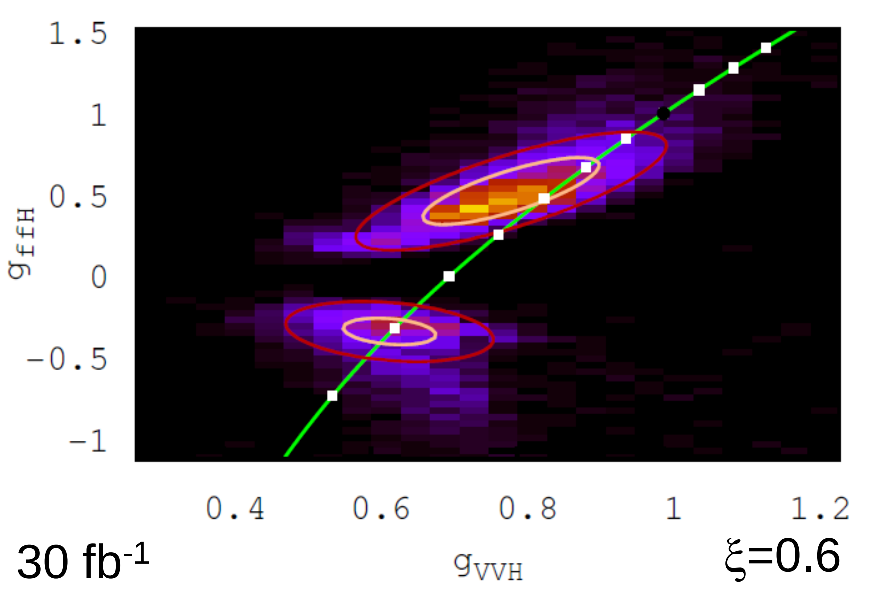
For SM scenario g_{VVH} (g_{ffH}) precision is 0.22 (0.55) @ 95% CL

When ξ is too high the correlation is not following the models

If two solutions: we determine errors and relative probabilities

Green line = strongly interactive Higgs boson models with ξ in steps of 0.1





Conclusion

- With $30fb^{-1}$ @LHC
  - Individual measurements of couplings $\Delta g/g$ @ 20-40%
- This analysis
  - 1 or 2 parameter fit of universal deviation $\Rightarrow$ 10-20%
  - 5σ deviations from SM are within reach
  - Can also be interpreted as upper limit on $H \rightarrow$ invisible

SM Higgs @ LHC

Systematic uncertainties

luminosity measurement	5 %
detector efficiency	2 %
lepton reconstruction efficiency	2 %
photon reconstruction efficiency	2 %
WBF tag-jets / jet-veto efficiency	5 %
b-tagging efficiency	3 %
τ-tagging efficiency (hadronic decay)	3 %
lepton isolation efficiency ($H \to 4\ell$)	3 %

	$\Delta B^{(\text{syst})}$	corr.
$H \to ZZ$	1%	yes
$H \to WW$	5%	no
$H \to \gamma\gamma$	0.1%	yes
$H \to \tau\tau$	5%	yes
$H \to b\bar{b}$	10%	no

Background estimation systematic uncertainties