Probing Higgs CP properties with Higgs signal rates using HiggsSignals-2

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in collaboration with

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IRN Terascale Meeting - Montpellier, 2017

1. HiggsSignals
   - Motivation and Introduction
   - Validation of 13 TeV data in HS-2

2. Probing deviations from the SM with HiggsSignals
   - Higgs-coupling scale factors
   - Pure CP even scenario
   - CP mixing scenario

Motivation

- The discovery of a Higgs boson by **ATLAS** and **CMS** ($m \approx 125\,\text{GeV}$) has opened a new era in particle physics!
- Thus far, it is in good agreement with the **Standard Model (SM) Higgs boson**.

  $\Rightarrow$ Standard model finally complete!

- Many well motivated BSM theories feature an extended Higgs sector.

  $\Rightarrow$ possible deviations in the couplings/signal rates from the SM Higgs, and/or additional Higgs states may be discovered in future LHC searches.

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  $\Rightarrow$ possible deviations in the couplings/signal rates from the SM Higgs, and/or additional Higgs states may be discovered in future LHC searches.

  $\Rightarrow$ **model-independent** tools to confront:

Theory predictions vs. **Experimental results**

Motivation

precise predictions of Higgs signal rates and Higgs mass

precision measurements of Higgs signal rates and Higgs mass

Theo. $\Longleftrightarrow$ vs. **Exp.**

predictions for additional Higgs states

searches for additional Higgs states

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searches for additional Higgs states

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Theo. $\Longleftrightarrow$ vs. **Exp.**

predictions for additional Higgs states

HiggsBounds

searches for additional Higgs states

The HiggsSignals code

- Current version: HiggsSignals-1.4.0 (HiggsSignals-2.1.0beta)
- Website: `http://higgsbounds.hepforge.org.`
- Documentation:
  Eur.Phys.J. C74 (2014) 2711 [arXiv:1305.1933]
  Eur.Phys.J. C74 (2014) 2693 [arXiv:1311.0055]
- Applications: [arXiv:1403.1582], [arXiv:1608.00638], + many more

HiggsSignals: Basic Idea

- Take predictions for physical quantities of given Higgs sector:

$$m_k, \Gamma_k^{tot}, \sigma_i(pp \to H_k), BR(H_k \to XX),$$

for each neutral Higgs boson $k = 1, ..., N$ and production cross-section $(i \in \{\mathrm{ggH, VBF, WH, ZH, ttH}\})$ as user input.

- Calculate the predicted signal strength μ for every observable

$$\mu_{H_k \to XX} = \frac{\sum_i \epsilon^i_{model} \left[\sigma_i(pp \to H_k) \times \mathrm{BR}(H_k \to XX)\right]_{model}}{\sum_i \epsilon^i_{SM} \left[\sigma_i(pp \to H) \times \mathrm{BR}(H \to XX)\right]_{SM}}$$

(zero-width approximation $(\sigma \cdot \mathrm{BR})(i \to f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_{tot}}$ assumed)

- χ^2 test of model predictions against all available data from signal rate and mass measurements from the Tevatron and LHC.

HiggsSignals: Input

Theoretical Input:

- Predictions for physical quantities of given Higgs sector:

$$m_k, \Gamma_k^{tot}, \sigma_i(pp \to H_k), BR(H_k \to XX),$$

  σ, BR given via effective couplings or at hadronic level (using the HiggsBounds framework).
- Optional: Uncertainties for $m_k, \sigma_i(pp \to H_k), BR(H_k \to XX)$.
- Input for specific models can be provided by other tools (e.g. FeynHiggs, CPsuperH, 2HDMC, SARAH/SPheno, ...)

Experimental Input:

- Signal strength measurements $(\sigma \cdot \mathrm{BR})(ii \to H \to ff)$ (usually normalized to SM prediction) with efficiencies ϵ_i (fraction of events passing the analysis cuts).

HiggsSignals: χ^2 Evaluation

- Global χ^2 for the signal strength measurement is given by

$$\chi^2_\mu = (\hat{\boldsymbol{\mu}} - \boldsymbol{\mu})(\boldsymbol{Cov})^{-1}_\mu(\hat{\boldsymbol{\mu}} - \boldsymbol{\mu}).$$

- Correlations of major systematic uncertainites are taken into account (if publicly known):

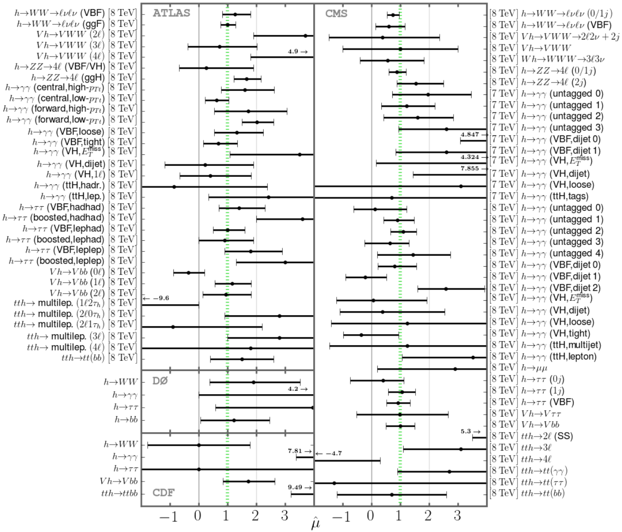
$$\Delta\sigma_i^{theo.},\ \Delta\mathrm{BR}_i^{theo},\ \Delta\mathcal{L},\ \ldots$$

- Correlations between different μ measurements $\Rightarrow (\boldsymbol{Cov})_\mu$

With increasing statistics, systematics will become more important!

Validation of 13 TeV data in HS-2

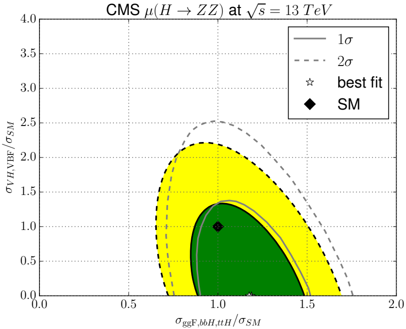
- **HS-1.4.0:** All μ measurements from the LHC at $\sqrt{s} = 7/8$ TeV and Tevatron.



Observables included in HiggsSignals

13 TeV

- **HS-1.4.0:** All μ measurements from the LHC at $\sqrt{s} = 7/8\,\text{TeV}$ and Tevatron.
- **HS-2.1.0 (Beta):** First LHC results at $\sqrt{s} = 13\,\text{TeV}$ included.



- **Reasonable agreement** between the official contours (gray) and HS-2 contours (colored).

$\Rightarrow$ Could do better if CMS would provide mass dependence of μ for individual categories.

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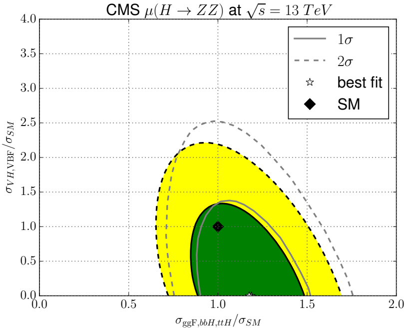
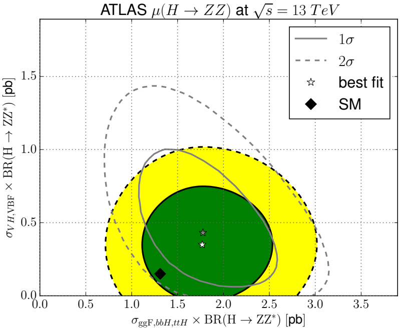




- **Reasonable agreement** between the official contours (gray) and HS-2 contours (colored).

$\Rightarrow$ Could do better if CMS would provide mass dependence of μ for individual categories.

- Correlation between production modes **not** reproduced due to **missing information**.

$\Rightarrow$ Could do better if ATLAS would provide subchannel information (ϵ_i, μ_i).

Probing deviations from the SM with HiggsSignals

Higgs coupling scale factors

- Test the compatibility of the present data with the SM.
- What is the allowed range for possible deviations?

Coupling scale factors κ's (phenomenological descripton)

$$\sigma_{ii} = \kappa_i^2 \cdot \sigma_{ii}^{SM}, \qquad \Gamma_{ff} = \kappa_f^2 \cdot \Gamma_{ff}^{SM}$$

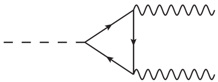
$$\Rightarrow (\sigma \cdot \mathrm{BR})\,(ii \to H \to ff) = (\sigma \cdot \mathrm{BR})^{SM}\,(ii \to H \to ff) \cdot \frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}$$

- Profile likelihood fits within the Higgs coupling scale factor parametrization (LHC Higgs XS WG [1307.1347]):

$$\kappa_Z, \kappa_W, \kappa_u, \kappa_d, \kappa_\ell, \ldots$$

- Loop-induced couplings

$$\kappa_g^2 = \kappa_g^2(m_H, \kappa_i)\ , \ \ i = t, b$$
$$\kappa_\gamma^2 = \kappa_\gamma^2(m_H, \kappa_i)\ , \ \ i = t, b, \tau, W$$



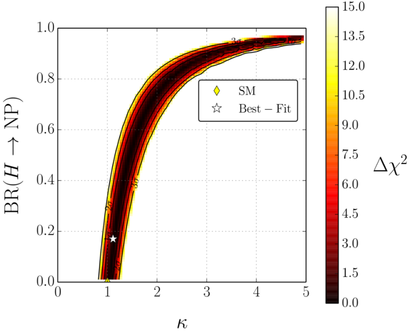
either be derived or be free parameters κ_g, κ_γ.

Total width of the Higgs boson at the LHC

- Uncertainty on width: $\Delta\Gamma_H \gg \Gamma_H^{SM}$.
  $\rightarrow$ Room for new physics decays.
- No model independent determination of $\kappa_H^2(m_H, \kappa_i) = \frac{\Gamma_H}{\Gamma_H^{SM}}$ at the LHC.

$$\frac{(\sigma \cdot BR)}{(\sigma \cdot BR)^{SM}}(ii \rightarrow H \rightarrow ff) = \frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}$$

[arXiv:1403.1582]



$\Rightarrow$ Only ratios of scale factors can be measured at the LHC.

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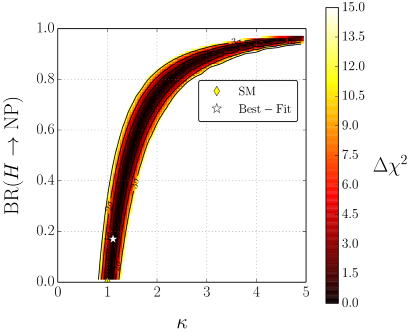

$\Rightarrow$ Only ratios of scale factors can be measured at the LHC.

- Possible assumptions to remove one dof:
  - No decays into states of new physics (NP)
  - BR($H \rightarrow NP$) = BR($H \rightarrow inv.$) (Dark Matter?)
  - $\kappa_V \leq 1$ (well motivated by many BSM Modells)

7/8 TeV

Probing deviations from the SM with HiggsSignals: Pure CP even scenario

Probing deviations from the SM with HS

7/8 TeV

Motivation:

1. Validation of the implementation of the 7/8 TeV data in HS.
2. Test: Do ATLAS and CMS provide enough information to reproduce their results?

Alternative parametrization in terms of ratios of κ's:

- Reference channel $(\sigma \cdot \mathrm{BR})(gg \to H \to ZZ)$: $\boldsymbol{\kappa_{gZ}} = \frac{\kappa_g \cdot \kappa_Z}{\kappa_H}$
  (little background and one of the smallest overall sys. uncertainties).
- Probe of production measurements: $\boldsymbol{\lambda_{Zg}} = \frac{\kappa_Z}{\kappa_g}$, $\boldsymbol{\lambda_{tg}} = \frac{\kappa_t}{\kappa_g}$
- Decay modes $H \to ii$ $(i = W, \tau, b, \gamma)$: $\boldsymbol{\lambda_{iZ}} = \frac{\kappa_i}{\kappa_Z}$
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- Assumption: No Higgs decays into states of new physics.

$\Rightarrow$ Use **HiggsSignals** to produce a fit of these parameter to ...

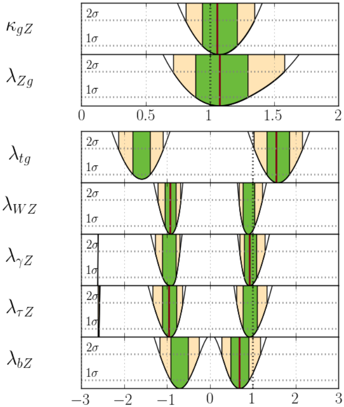
1. all signal rate measurements by ATLAS and CMS at 7/8 TeV.
2. the 7/8 TeV ATLAS + CMS combination data. [arXiv:1606.02266]
   ($\to$ new routine included in HS-2).

χ^2 profiles for 7-dimensional fit

7/8 TeV

- Experimental Input:

  Individual signal rate measurements by ATLAS and CMS at 7/8 TeV.



- Data is compatibles with the SM.
- largest deviation: λ_{tg}.

χ^2 profiles for 7-dimensional fit

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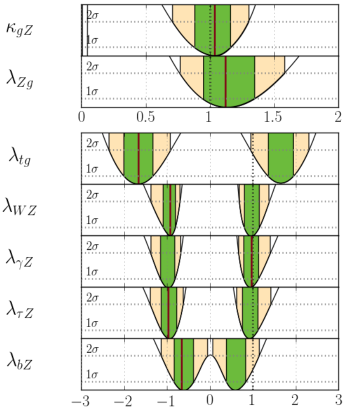
- Experimental Input:

  Combined signal rate measurements from ATLAS and CMS at 7/8 TeV.

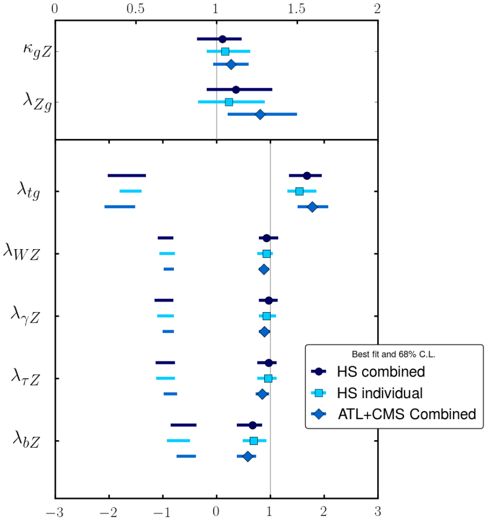
  JHEP08(2016)045 [arXiv:1606.02266]



- Data is compatibles with the SM.
- largest deviation: λ_{tg}.
  - $\Delta\chi^2$ profiles from fit to **combined** data are in very good agreement to fits to **individual** measurements!
  - Still plenty of room for possible deviations.

Comparison to official ATLAS + CMS result

7/8 TeV



- Good agreement with the official ATLAS + CMS result.
- Official 1σ intervals are slightly smaller for almost all parameters.
- Idea to explain the discrepancy: Uncertainties $\Delta\mu$ are assumed be Gaussian in HS.

7/8 TeV

Probing deviations from the SM with HS: CP mixing scenario

Motivation

Spin 0 particle my be either

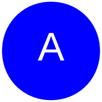
- Pure CP even

SM-like

Spin 0 particle my be either

- Pure CP even
- Pure CP odd

SM-like



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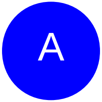
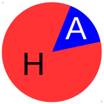


- Mixture



- Pure CP odd Higgs already excluded!
- CP mixing in the Higgs Sector can appear in many extension of the SM, e.g.
  - 2HDM
  - SUSY

Higgs couplings and CP properties

- SM predicts the couplings of the Higgs to **all** known particles

SM Lagrangian: $\mathcal{L}_{SM} = \mathcal{L}_{YM} + \mathcal{L}_{ferm} + \mathcal{L}_{H} + \mathcal{L}_{Yuk}$

$$\mathcal{L}_{Yuk} = -\overline{q_L} Y_u u_R \tilde{H} - \overline{q_L} Y_d d_R H - \overline{\ell_L} Y_\ell \ell_R H + h.c.$$

- Example: SM coupling to τ: $\overline{\tau_L} Y_\ell \tau_R H$

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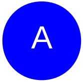
- CP-odd Higgs coupling to τ: $\overline{\tau_L} Y_\ell^p \tau_R A$



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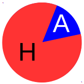
$+$



- CP-odd Higgs coupling to τ: $\overline{\tau_L} Y_\ell^p \tau_R A$

Parametrization

- Φ can be a mixture of a **CP even scalar H** and a **CP odd pseudoscalar A**

$$\Phi = \cos\alpha H + \sin\alpha A$$

Modified Yukawa Lagrangian:

CP even $\rightarrow$

CP odd $\rightarrow$

$$\begin{aligned}\mathcal{L}_{Yuk} = & - \kappa_{u_s} \overline{u_L} Y_u^{SM} u_R H - \kappa_{d_s} \overline{d_L} Y_d^{SM} d_R H - \kappa_{\ell_s} \overline{\ell_L} Y_\ell^{SM} \ell_R H \\ & - i\kappa_{u_p} \overline{u_L} Y_u^{SM} u_R A - i\kappa_{d_p} \overline{d_L} Y_d^{SM} d_R A - i\kappa_{\ell_p} \overline{\ell_L} Y_\ell^{SM} \ell_R A \\ & + h.c.\end{aligned}$$

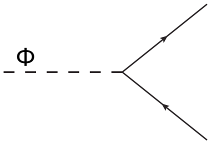
[arXiv:1211.1980]

- SM corresponds to: $\alpha = \kappa_{u_p} = \kappa_{d_p} = \kappa_{\ell_p} = 0$ and $\kappa_{u_s} = \kappa_{d_s} = \kappa_{\ell_s} = 1$

Pure CP even scenario

$$\Phi = H$$

Examples for **tree-level** partial decay widths

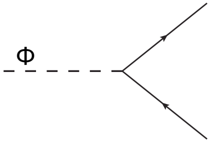


- $\frac{\Gamma_{VV}}{\Gamma_{VV}^{SM}} = \kappa_V^2$
- $\frac{\Gamma_{\tau\tau}}{\Gamma_{\tau\tau}^{SM}} = \kappa_\ell^2$
- $\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{SM}} = \kappa_u^2$
- $\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_d^2$

CP mixture scenario

$$\Phi = \cos\alpha H + \sin\alpha A$$

Examples for **tree-level** partial decay widths



- $\frac{\Gamma_{VV}}{\Gamma_{VV}^{SM}} = \kappa_V^2 \cdot \cos^2\alpha$
- $\frac{\Gamma_{\tau\tau}}{\Gamma_{\tau\tau}^{SM}} = \kappa_{\ell_s}^2 \cdot \cos^2\alpha + \kappa_{\ell_p}^2 \cdot \sin^2\alpha$
- $\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{SM}} = \kappa_{u_s}^2 \cdot \cos^2\alpha + R^{cc}\kappa_{u_p}^2 \cdot \sin^2\alpha$
- $\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_{d_s}^2 \cdot \cos^2\alpha + R^{bb}\kappa_{d_p}^2 \cdot \sin^2\alpha$

[arXiv:1211.1980]

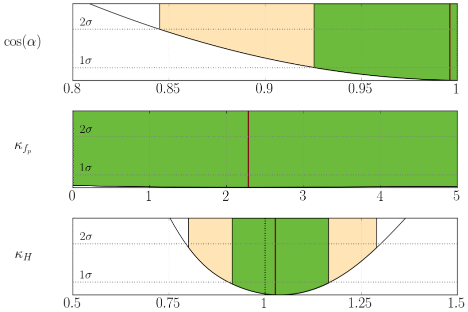
(QCD Corrections $R^{ii} \approx 1$)

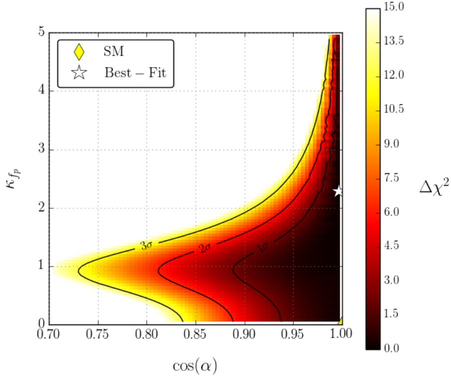
$\Rightarrow$ fit parameters: $BR(H \to NP), \alpha, \kappa_V, \kappa_{\ell_s}, \kappa_{\ell_p}, \kappa_{u_s}, \kappa_{u_p}, \kappa_{d_s}, \kappa_{d_p}$

Simple example with SM scalar couplings

7/8 TeV + Tevatron

- Only two free parameters: $\cos\alpha, \kappa_{f_p}$
- No decays into states of new physics: $\mathrm{BR}(H \to \mathrm{NP}) = 0$.
- $\kappa_V = \kappa_{f_s} = 1$.





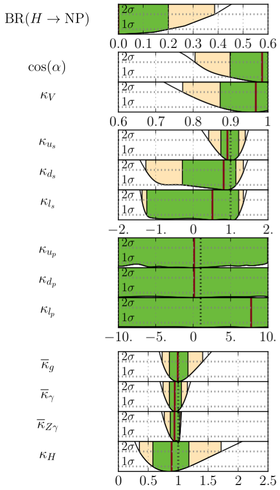
- $\chi^2_{min}/\mathrm{ndf} = 69.3/84 \Rightarrow \mathcal{P} = 87.6\%$.
- flat 1dimensional $\Delta\chi^2$ profile for κ_{f_p}.

Probing Yukawa structure

7/8 TeV
+ Tevatron

- Free parameters: $\cos\alpha, \mathrm{BR}(H \to \mathrm{NP}), \kappa_V, \kappa_{u_s}, \kappa_{d_s}, \kappa_{\ell_s}, \kappa_{u_p}, \kappa_{d_p}, \kappa_{\ell_p}$
- $\kappa_V \leq 1$
- $\kappa_g, \kappa_\gamma, \kappa_{Z\gamma}$ derived

- Couplings to pseudoscalar component flat.



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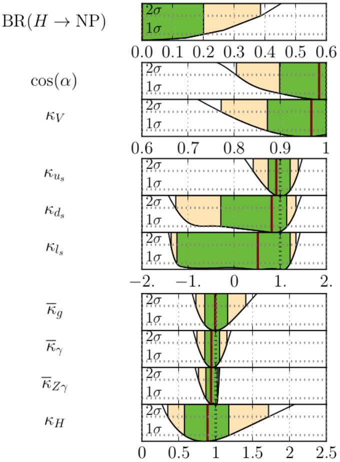
- $\kappa_V \leq 1$
- $\kappa_g, \kappa_\gamma, \kappa_{Z\gamma}$ derived

- Couplings to pseudoscalar component flat.
- Deviation from pure CP even Higgs still compatible with data.
- Negative values for κ_{u_s} strongly disfavored (H-γ effective couplings ($\kappa_V > 0$)).
- Sign degeneracy of κ_{d_s} slightly broken (κ_g is sensitive to relative sign of κ_t, κ_b).
- Vanishing $\kappa_{\ell_s}, \kappa_{d_s}$ compatible with data.

$\Rightarrow$ $\chi^2_{min}/\mathrm{ndf} = 68.6/77 \Rightarrow \mathcal{P} = 74.2\%$



Probing Yukawa structure

7/8 TeV
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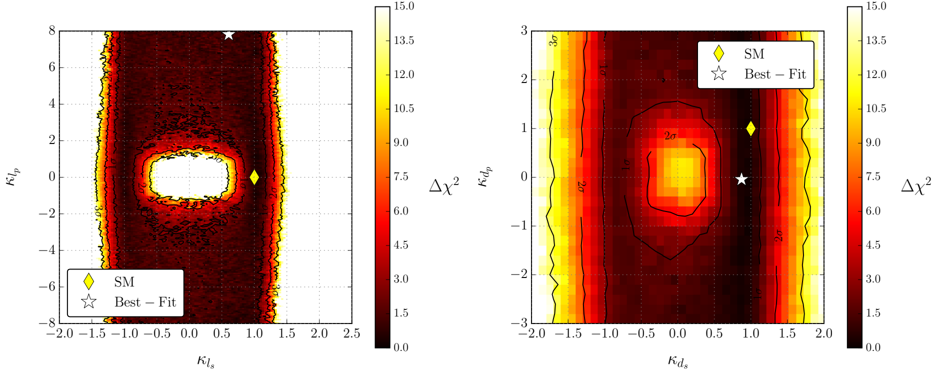
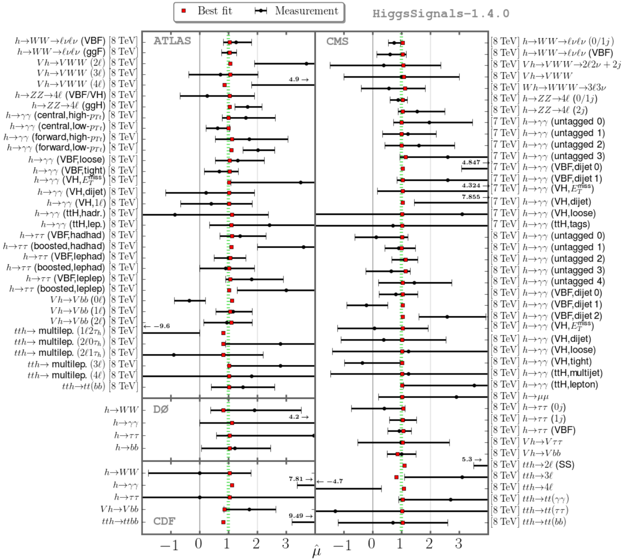


- Vanishing couplings to scalar Higgs component can be compensated by non-vanishing coupling to the pseudoscalar component.

Probing Yukawa structure

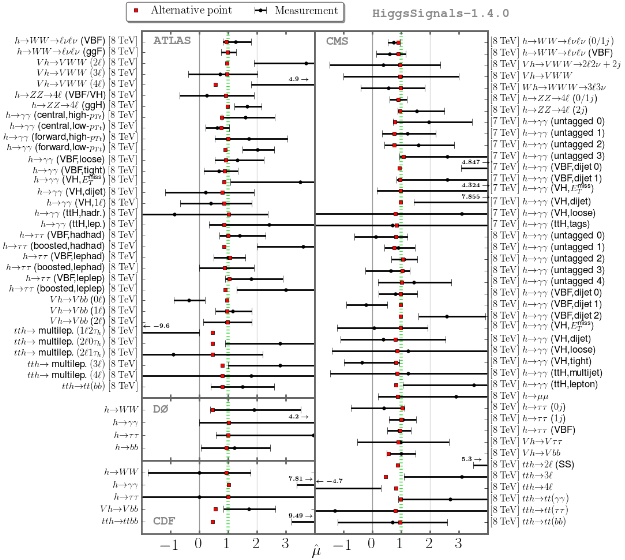
7/8 TeV
+ Tevatron



Fit parameter	best-fit
$\mathrm{BR}(H\to\mathrm{NP})$	0.0
$\cos(\alpha)$	0.984
κ_V	0.967
κ_u^s	0.915
κ_d^s	0.815
κ_ℓ^s	0.514
κ_u^p	0.125
κ_d^p	0.125
κ_ℓ^p	7.744
χ^2	**68.6**

Probing Yukawa structure

7/8 TeV + Tevatron



Fit parameter	alternative
$\mathrm{BR}(H \to \mathrm{NP})$	0.166
$\cos(\alpha)$	0.891
κ_V	0.990
κ_u^s	1.080
κ_d^s	0.0
κ_ℓ^s	0.0
κ_u^p	−0.046
κ_d^p	−1.472
κ_ℓ^p	1.957
χ^2	**72.6**

Summary

- HiggsBounds and HiggsSignals are excellent tools for confronting theory vs. experiment (also for extended Higgs sectors).
- Transparent information about signal efficiencies ϵ_i and correlations of systematic uncertainties is **very valuable**!
- Good agreement between HS-1 and official ATLAS+CMS result.
- For 13 TeV we miss some information in order to do better.
- Sizable CP-odd couplings of the Higgs are still allowed by signal rates.

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Available at `http://higgsbounds.hepforge.org`!

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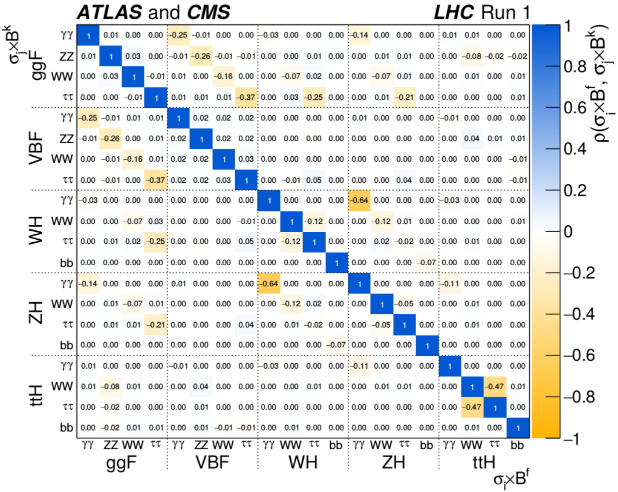
Thanks for your attention!

Backup: Combined measurements

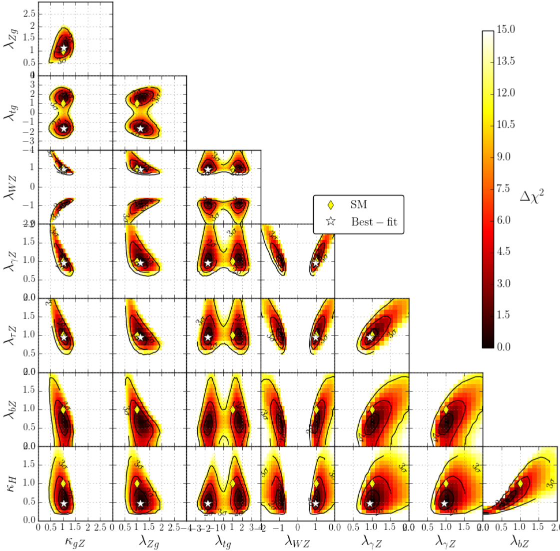
Production process		$H \to \gamma\gamma$ [fb] Best fit value	Stat	Syst	$H \to ZZ$ [fb] Best fit value	Stat	Syst	$H \to WW$ [pb] Best fit value	Stat	Syst	$H \to \tau\tau$ [fb] Best fit value	Stat	Syst	$H \to bb$ [pb] Best fit value	Stat	Syst
ggF	Measured	$48.0^{+10.0}_{-9.7}$	$^{+9.4}_{-9.4}$	$^{+3.2}_{-2.3}$	580^{+170}_{-160}	$^{+170}_{-160}$	$^{+40}_{-40}$	$3.5^{+0.7}_{-0.7}$	$^{+0.5}_{-0.5}$	$^{+0.5}_{-0.5}$	1300^{+700}_{-700}	$^{+400}_{-400}$	$^{+500}_{-500}$	–		
		$(^{+9.7}_{-9.5})$	$(^{+9.4}_{-9.4})$	$(^{+2.5}_{-1.6})$	$(^{+150}_{-130})$	$(^{+140}_{-130})$	$(^{+30}_{-20})$	$(^{+0.7}_{-0.7})$	$(^{+0.5}_{-0.5})$	$(^{+0.5}_{-0.5})$	$(^{+700}_{-700})$	$(^{+400}_{-400})$	$(^{+500}_{-500})$	–		
	Predicted	44 ± 5			510 ± 60			4.1 ± 0.5			1210 ± 140			11.0 ± 1.2		
	Ratio	$1.10^{+0.23}_{-0.22}$	$^{+0.22}_{-0.21}$	$^{+0.07}_{-0.05}$	$1.13^{+0.34}_{-0.31}$	$^{+0.33}_{-0.30}$	$^{+0.09}_{-0.07}$	$0.84^{+0.17}_{-0.17}$	$^{+0.12}_{-0.12}$	$^{+0.12}_{-0.11}$	$1.0^{+0.6}_{-0.6}$	$^{+0.4}_{-0.4}$	$^{+0.4}_{-0.4}$	–		
VBF	Measured	$4.6^{+1.9}_{-1.8}$	$^{+1.8}_{-1.7}$	$^{+0.6}_{-0.5}$	3^{+46}_{-26}	$^{+46}_{-25}$	$^{+7}_{-7}$	$0.39^{+0.14}_{-0.13}$	$^{+0.13}_{-0.12}$	$^{+0.07}_{-0.05}$	125^{+39}_{-37}	$^{+34}_{-32}$	$^{+19}_{-18}$	–		
		$(^{+1.8}_{-1.6})$	$(^{+1.7}_{-1.6})$	$(^{+0.5}_{-0.4})$	$(^{+60}_{-39})$	$(^{+60}_{-39})$	$(^{+8}_{-5})$	$(^{+0.15}_{-0.13})$	$(^{+0.13}_{-0.12})$	$(^{+0.07}_{-0.06})$	$(^{+39}_{-37})$	$(^{+34}_{-32})$	$(^{+19}_{-18})$	–		
	Predicted	3.60 ± 0.20			42.2 ± 2.0			0.341 ± 0.017			100 ± 6			0.91 ± 0.04		
	Ratio	$1.3^{+0.5}_{-0.5}$	$^{+0.5}_{-0.5}$	$^{+0.2}_{-0.1}$	$0.1^{+1.1}_{-0.6}$	$^{+1.1}_{-0.6}$	$^{+0.2}_{-0.2}$	$1.2^{+0.4}_{-0.4}$	$^{+0.4}_{-0.3}$	$^{+0.2}_{-0.2}$	$1.3^{+0.4}_{-0.4}$	$^{+0.3}_{-0.3}$	$^{+0.2}_{-0.2}$	–		
WH	Measured	$0.7^{+2.1}_{-1.9}$	$^{+2.1}_{-1.8}$	$^{+0.3}_{-0.3}$	–			$0.24^{+0.18}_{-0.16}$	$^{+0.15}_{-0.14}$	$^{+0.10}_{-0.08}$	-64^{+64}_{-61}	$^{+55}_{-50}$	$^{+32}_{-34}$	$0.42^{+0.21}_{-0.20}$	$^{+0.17}_{-0.16}$	$^{+0.12}_{-0.11}$
		$(^{+1.9}_{-1.8})$	$(^{+1.9}_{-1.8})$	$(^{+0.1}_{-0.1})$	–			$(^{+0.16}_{-0.14})$	$(^{+0.14}_{-0.13})$	$(^{+0.08}_{-0.07})$	$(^{+67}_{-64})$	$(^{+60}_{-54})$	$(^{+30}_{-32})$	$(^{+0.22}_{-0.21})$	$(^{+0.18}_{-0.17})$	$(^{+0.12}_{-0.11})$
	Predicted	1.60 ± 0.09			18.8 ± 0.9			0.152 ± 0.007			44.3 ± 2.8			0.404 ± 0.017		
	Ratio	$0.5^{+1.3}_{-1.2}$	$^{+1.3}_{-1.1}$	$^{+0.2}_{-0.2}$	–			$1.6^{+1.2}_{-1.0}$	$^{+1.0}_{-0.9}$	$^{+0.6}_{-0.5}$	$-1.4^{+1.4}_{-1.4}$	$^{+1.2}_{-1.1}$	$^{+0.7}_{-0.8}$	$1.0^{+0.5}_{-0.5}$	$^{+0.4}_{-0.4}$	$^{+0.3}_{-0.3}$
ZH	Measured	$0.5^{+2.9}_{-2.4}$	$^{+2.8}_{-2.3}$	$^{+0.5}_{-0.2}$	–			$0.53^{+0.23}_{-0.20}$	$^{+0.21}_{-0.19}$	$^{+0.10}_{-0.07}$	58^{+56}_{-47}	$^{+52}_{-44}$	$^{+20}_{-16}$	$0.08^{+0.09}_{-0.09}$	$^{+0.08}_{-0.08}$	$^{+0.04}_{-0.04}$
		$(^{+2.3}_{-1.9})$	$(^{+2.3}_{-1.9})$	$(^{+0.1}_{-0.1})$	–			$(^{+0.17}_{-0.14})$	$(^{+0.16}_{-0.14})$	$(^{+0.05}_{-0.04})$	$(^{+49}_{-40})$	$(^{+46}_{-38})$	$(^{+16}_{-12})$	$(^{+0.10}_{-0.09})$	$(^{+0.09}_{-0.08})$	$(^{+0.05}_{-0.04})$
	Predicted	0.94 ± 0.06			11.1 ± 0.6			0.089 ± 0.005			26.1 ± 1.8			0.238 ± 0.012		
	Ratio	$0.5^{+3.0}_{-2.5}$	$^{+3.0}_{-2.5}$	$^{+0.5}_{-0.2}$	–			$5.9^{+2.6}_{-2.2}$	$^{+2.3}_{-2.1}$	$^{+1.1}_{-0.8}$	$2.2^{+2.2}_{-1.8}$	$^{+2.0}_{-1.7}$	$^{+0.8}_{-0.6}$	$0.4^{+0.4}_{-0.4}$	$^{+0.3}_{-0.3}$	$^{+0.2}_{-0.2}$
ttH	Measured	$0.64^{+0.48}_{-0.38}$	$^{+0.48}_{-0.38}$	$^{+0.07}_{-0.04}$	–			$0.14^{+0.05}_{-0.05}$	$^{+0.04}_{-0.04}$	$^{+0.03}_{-0.03}$	-15^{+30}_{-26}	$^{+26}_{-22}$	$^{+15}_{-15}$	$0.08^{+0.07}_{-0.07}$	$^{+0.04}_{-0.04}$	$^{+0.06}_{-0.06}$
		$(^{+0.45}_{-0.34})$	$(^{+0.44}_{-0.33})$	$(^{+0.10}_{-0.05})$	–			$(^{+0.04}_{-0.04})$	$(^{+0.04}_{-0.04})$	$(^{+0.02}_{-0.02})$	$(^{+31}_{-26})$	$(^{+26}_{-22})$	$(^{+16}_{-13})$	$(^{+0.07}_{-0.06})$	$(^{+0.04}_{-0.04})$	$(^{+0.06}_{-0.05})$
	Predicted	0.294 ± 0.035			3.4 ± 0.4			0.0279 ± 0.0032			8.1 ± 1.0			0.074 ± 0.008		
	Ratio	$2.2^{+1.6}_{-1.3}$	$^{+1.6}_{-1.3}$	$^{+0.2}_{-0.1}$	–			$5.0^{+1.8}_{-1.7}$	$^{+1.5}_{-1.5}$	$^{+1.0}_{-0.9}$	$-1.9^{+3.7}_{-3.3}$	$^{+3.2}_{-2.7}$	$^{+1.9}_{-1.8}$	$1.1^{+1.0}_{-1.0}$	$^{+0.5}_{-0.5}$	$^{+0.8}_{-0.8}$

JHEP08(2016)045 [arXiv:1606.02266]

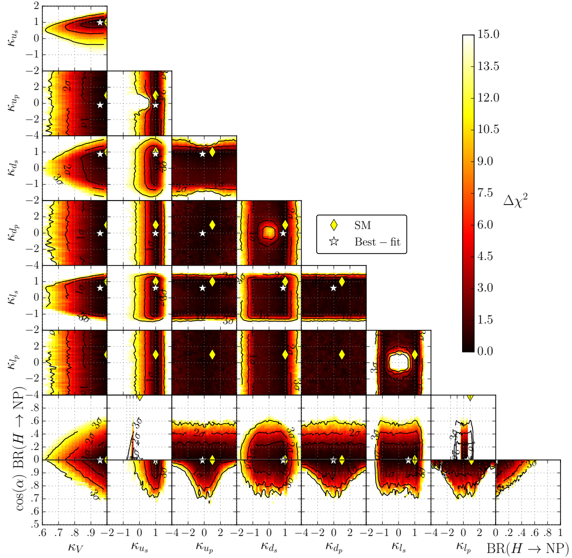


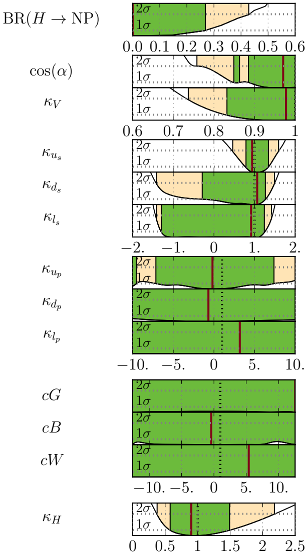
JHEP08(2016)045 [arXiv:1606.02266]

Backup: 2D profiles for λ-fit



Backup: 2D profiles for 'Yukawa structure'





$$\mathcal{L}_{dim5} = \frac{1}{4}\frac{c_G}{(4\pi^2)v} A G_{\mu\nu}\widetilde{G}^{\mu\nu} + \frac{1}{4}\frac{c_B}{(4\pi^2)v} A B_{\mu\nu}\widetilde{B}^{\mu\nu} + \frac{1}{4}\frac{c_W}{(4\pi^2)v} W B_{\mu\nu}\widetilde{W}^{\mu\nu}$$

with $\widetilde{X}^{\mu\nu} = \epsilon^{\mu\nu\alpha\beta} X_{\alpha\beta}$

A. Freitas, P. Schwaller [arXiv:1211.1980]