Higgs couplings after Moriond

Béranger Dumont (LPSC Grenoble)

based on:
G. Belanger, BD, U. Ellwanger, J. F. Gunion, and S. Kraml
[arXiv:1212.5244] and [arXiv:1302.5694]
(update in preparation)

HEFTI Higgs workshop
April 22, 2013
The Higgs boson has been found

- previous update in Moriond (in March)
  → almost all bosonic channels have been updated with full luminosity
- also, final results from Tevatron! (arXiv:1303.6346)
  very competitive for $H \rightarrow bb$

| Decay mode | Expected ($\sigma$) | Observed ($\sigma$) |
|------------|---------------------|---------------------|
| ZZ         | 7.1                 | 6.7                 |
| $\gamma \gamma$ | 3.9                 | 3.2                 |
| WW         | 5.3                 | 3.9                 |
| bb         | 2.2                 | 2.0                 |
| $\tau \tau$ | 2.6                 | 2.8                 |
What we know about it its mass

\[ m_H = 125.5 \pm 0.6 \text{ GeV} \]

naive average: \( m_H = 125.6 \pm 0.3 \text{ GeV} \)

\[ m_H = 125.7 \pm 0.4 \text{ GeV} \]
What we know about it
signal strengths

$$\mu_i = \frac{\left[ \sum_j \sigma_j \rightarrow h \times \text{Br}(h \rightarrow i) \right]_{\text{observed}}}{\left[ \sum_j \sigma_j \rightarrow h \times \text{Br}(h \rightarrow i) \right]_{\text{SM}}}$$
What we know about it
signal strengths

...but New Physics modify not only the Higgs decays but also its production

how can we use the experimental information in a correct way?

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Abstract

Measurements of the mass and couplings of the Higgs-like boson in the two photon decay channel with the ATLAS detector at the LHC are presented. The proton-proton collision datasets used correspond to integrated luminosities of 4.8 fb$^{-1}$ collected at $\sqrt{s} = 7$ TeV and 20.7 fb$^{-1}$ collected at $\sqrt{s} = 8$ TeV. The updated measurements benefit from an increased data sample and an improved analysis. The measured value of the mass of the Higgs-like boson is $126.8 \pm 0.2 \text{(stat)} \pm 0.7 \text{(syst)}$ GeV and the fitted number of signal events is found to be $1.65 \pm 0.24 \text{(stat)}^{+0.25}_{-0.18} \text{(syst)}$ times the value predicted by the Standard Model. Measurements of the signal strengths in different production processes and a fiducial cross section for the observed particle are also presented.
One example: ATLAS $H \to \gamma\gamma$

What do we have in the conf note?

Abstract

Measurements of the mass and couplings of the Higgs-like boson in the decay channel with the ATLAS detector at the LHC are presented. The datasets used correspond to integrated luminosities of 4.8 fb$^{-1}$ and 20.7 fb$^{-1}$ collected at $\sqrt{s} = 8$ TeV. The updated measurements are based on an improved data sample and an improved analysis. The measured value of the Higgs-like boson is $126.8\pm0.2$ (stat)$\pm0.7$ (syst) GeV and the fitted number of $1.65\pm0.24$ (stat)$^{+0.25}_{-0.18}$ (syst) times the value predicted by the Standard Model of the signal strengths in different production processes and all observed particles are also presented.

...but this is the combination of several sub-categories with different sensitivity to the various production mechanisms.
One example: ATLAS $H \rightarrow \gamma\gamma$

Ok, so let's have a look at the 14 sub-categories!

Data 2012, $\sqrt{s} = 8$ TeV

$\int L dt = 20.7$ fb$^{-1}$

$H \rightarrow \gamma\gamma$

$m_H = 126.8$ GeV

| Category               | $N_D$ | $N_S$ | $gg \rightarrow H$ (%) | VBF (%) | $WH$ (%) | $ZH$ (%) | $tH$ (%) |
|------------------------|-------|-------|-------------------------|---------|----------|----------|----------|
| Unconv. central, low $p_T$ | 10900 | 51.8  | 93.7                    | 4.0     | 1.4      | 0.8      | 0.2      |
| Unconv. central, high $p_T$ | 553   | 7.9   | 79.3                    | 12.6    | 4.1      | 2.5      | 1.4      |
| Unconv. rest, low $p_T$ | 41236 | 107.9 | 93.2                    | 4.0     | 1.6      | 1.0      | 0.1      |
| Unconv. rest, high $p_T$ | 2558  | 16.0  | 78.1                    | 13.3    | 4.7      | 2.8      | 1.1      |
| Conv. central, low $p_T$ | 7109  | 33.1  | 93.6                    | 4.0     | 1.3      | 0.9      | 0.2      |
| Conv. central, high $p_T$ | 363   | 5.1   | 78.9                    | 12.6    | 4.3      | 2.7      | 1.5      |
| Conv. rest, low $p_T$ | 38156 | 97.8  | 93.2                    | 4.1     | 1.6      | 1.0      | 0.1      |
| Conv. rest, high $p_T$ | 2360  | 14.4  | 77.7                    | 13.0    | 5.2      | 3.0      | 1.1      |
| Conv. transition | 14864 | 40.1  | 90.7                    | 5.5     | 2.2      | 1.3      | 0.2      |
| Loose high-mass two-jet | 276   | 5.3   | 45.0                    | 54.1    | 0.5      | 0.3      | 0.1      |
| Tight high-mass two-jet | 136   | 8.1   | 23.8                    | 76.0    | 0.1      | 0.1      | 0.0      |
| Low-mass two-jet | 210   | 3.3   | 48.1                    | 3.0     | 29.7     | 17.2     | 1.9      |
| $E_T^{miss}$ significance | 49    | 1.3   | 4.1                      | 0.5     | 35.7     | 47.6     | 12.1     |
| One-lepton | 123   | 2.9   | 2.2                      | 0.6     | 63.2     | 15.4     | 18.6     |
| All categories (inclusive) | 118893 | 395.0 | 88.0                   | 7.3     | 2.7      | 1.5      | 0.5      |
One example: ATLAS $H \rightarrow \gamma\gamma$

Ok, so let's have a look at the 14 sub-categories!

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**ATLAS Preliminary**

Data 2012, $\sqrt{s} = 8$ TeV

$\int L dt = 20.7$ fb$^{-1}$

$H \rightarrow \gamma\gamma$

$m_H = 126.8$ GeV

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| Category                        | $N_D$ | $N_S$ | $gg \rightarrow H$ [%] | VBF [%] | $WH$ [%] | $ZH$ [%] | $tH$ [%] |
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...but what about the correlations between sub-channels? (not given by the experiments)

can we safely neglect them? probably not...

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One example: ATLAS $H \to \gamma\gamma$

Hmm... is there anything else in this conf note? [ATLAS-CONF-2013-012]

In a second step, signal strength parameters for different Higgs boson production modes are introduced to characterise their contributions to the observed excess. To further enhance the sensitivity, the

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One example: ATLAS $H \rightarrow \gamma \gamma$

- grouping VBF and VH=(WH,ZH): usually OK (custodial symmetry)
- grouping ggF and ttH: OK for now (ttH is not precisely probed yet)

but we only have contours...

simplest option: fit Gaussian measurements from one contour

is it a good approximation?

[ATLAS-CONF-2013-012]
One example: ATLAS H→γγ

- grouping VBF and VH=(WH,ZH): usually OK (custodial symmetry)
- grouping ggF and ttH: OK for now (ttH is not precisely probed yet)

![Diagram of CMS experimental 95% CL contour]

- simplest option: fit Gaussian measurements from one contour
- is it a good approximation? ✓ seems fairly good

CMS

experimental 95% CL contour

but we only have contours...

extrapolated 95% CL contour
2D \( \mu \) plots from ATLAS and CMS

whenever possible, we check the validity of the Gaussian approximation
→ usually fairly good (see backup slides!)

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# Experimental data we use

## ATLAS

| Channel | Signal strength $\mu$ | $m_H$ (GeV) | Production mode |
|---------|---------------------|-------------|----------------|
| $H \rightarrow \gamma\gamma$ (4.8 fb$^{-1}$ at 7 TeV + 20.7 fb$^{-1}$ at 8 TeV) [1, 2] | | |
| $\mu(ggF + ttH, \gamma\gamma)$ | 1.60 ± 0.41 | 125.5 | 100% – – – |
| $\mu(VBF + VH, \gamma\gamma)$ | 1.94 ± 0.82 | 125.5 | – 60% 40% – |
| $H \rightarrow ZZ$ (4.6 fb$^{-1}$ at 7 TeV + 20.7 fb$^{-1}$ at 8 TeV) [3, 2] | | |
| $\mu(ggF + ttH, ZZ)$ | 1.50 ± 0.50 | 125.5 | 100% – – – |
| $\mu(VBF + VH, ZZ)$ | 1.50 ± 2.52 | 125.5 | – 60% 40% – |
| $H \rightarrow WW$ (4.6 fb$^{-1}$ at 7 TeV + 20.7 fb$^{-1}$ at 8 TeV) [4, 5] | | |
| $\mu(ggF + ttH, WW)$ | 0.79 ± 0.35 | 125.5 | 100% – – – |
| $\mu(VBF + VH, WW)$ | 1.71 ± 0.76 | 125.5 | – 60% 40% – |
| $H \rightarrow bb$ (4.7 fb$^{-1}$ at 7 TeV + 13.0 fb$^{-1}$ at 8 TeV) [6, 2] | | |
| VH tag | –0.39 ± 1.02 | 125.5 | – – 100% – |
| $H \rightarrow \tau\tau$ (4.6 fb$^{-1}$ at 7 TeV + 13.0 fb$^{-1}$ at 8 TeV) [2] | | |
| $\mu(ggF + ttH, \tau\tau)$ | 2.31 ± 1.61 | 125.5 | 100% – – – |
| $\mu(VBF + VH, \tau\tau)$ | –0.20 ± 1.06 | 125.5 | – 60% 40% – |

Table 1: ATLAS results, as employed in this analysis. The following correlations are included in the fit: $\rho_{\gamma\gamma} = -0.27$, $\rho_{ZZ} = -0.46$, $\rho_{WW} = -0.18$, $\rho_{\tau\tau} = -0.49$. 
### Experimental data we use

#### CMS

| Channel | Signal strength $\mu$ | $m_H$ (GeV) | Production mode |
|---------|---------------------|-------------|-----------------|
| $H \to \gamma\gamma$ (5.1 fb$^{-1}$ at 7 TeV + 19.6 fb$^{-1}$ at 8 TeV) [7, 8] | | | |
| $\mu_{\text{ggF} + \text{ttH}, \gamma\gamma}$ | $0.46 \pm 0.40$ | 125.7 | 100% - - - - |
| $\mu_{\text{VBF} + \text{VH}, \gamma\gamma}$ | $1.68 \pm 0.87$ | 125.7 | - 60% 40% - |
| $H \to ZZ$ (5.1 fb$^{-1}$ at 7 TeV + 19.6 fb$^{-1}$ at 8 TeV) [9] | | | |
| $\mu_{\text{ggF} + \text{ttH}, ZZ}$ | $0.98 \pm 0.46$ | 125.8 | 100% - - - - |
| $\mu_{\text{VBF} + \text{VH}, ZZ}$ | $1.07 \pm 2.37$ | 125.8 | - 60% 40% - |
| $H \to WW$ (up to 4.9 fb$^{-1}$ at 7 TeV + 19.5 fb$^{-1}$ at 8 TeV) [10, 11, 12, 8] | | | |
| $\mu_{\text{ggF} + \text{ttH}, WW}$ | $0.78 \pm 0.23$ | 125.7 | 100% - - - - |
| $\mu_{\text{VBF} + \text{VH}, WW}$ | $0.33 \pm 0.70$ | 125.7 | - 60% 40% - |
| $H \to bb$ (up to 5.0 fb$^{-1}$ at 7 TeV + 12.1 fb$^{-1}$ at 8 TeV) [13, 14, 8] | | | |
| VH tag | $1.31^{+0.68}_{-0.61}$ | 125.7 | - - 100% - |
| ttH tag | $-0.15^{+2.82}_{-2.90}$ | 125.7 | - - - 100% |
| $H \to \tau\tau$ (4.9 fb$^{-1}$ at 7 TeV + 19.4 fb$^{-1}$ at 8 TeV) [15, 8] | | | |
| $\mu_{\text{ggF} + \text{ttH}, \tau\tau}$ | $0.67 \pm 0.79$ | 125.7 | 100% - - - - |
| $\mu_{\text{VBF} + \text{VH}, \tau\tau}$ | $1.59 \pm 0.83$ | 125.7 | - 60% 40% - |

Table 2: CMS results, as employed in this analysis. The following correlations are included in the fit: $\rho_{\gamma\gamma} = -0.48, \rho_{ZZ} = -0.73, \rho_{WW} = -0.21, \rho_{\tau\tau} = -0.47$. 

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A word on CMS $H \rightarrow \gamma\gamma$

|                  | MVA analysis (at $m_H=125\text{ GeV}$) | cut-based analysis (at $m_H=124.5\text{ GeV}$) |
|------------------|----------------------------------------|-----------------------------------------------|
|                  |                                        |                                               |
| 7 TeV            | $1.69^{+0.65}_{-0.59}$                 | $2.27^{+0.80}_{-0.74}$                        |
| 8 TeV            | $0.55^{+0.29}_{-0.27}$                 | $0.93^{+0.34}_{-0.32}$                        |
| 7 + 8 TeV        | $0.78^{+0.28}_{-0.26}$                 | $1.11^{+0.32}_{-0.30}$                        |
Experimental data we use
Tevatron

| Channel      | Signal strength $\mu$ | $m_H$ (GeV) | Production mode |
|--------------|-----------------------|-------------|-----------------|
|              |                       |             | ggF  | VBF | VH | ttH |
| $H \rightarrow \gamma\gamma$ [17] | 5.97$^{+3.39}_{-3.12}$ | 125         | 78%  | 5%  | 17% | -   |
| Combined     |                       |             | ggF  | VBF | VH | ttH |
| $H \rightarrow WW$ [17]          | 0.94$^{+0.85}_{-0.83}$ | 125         | 78%  | 5%  | 17% | -   |
| Combined     |                       |             | ggF  | VBF | VH | ttH |
| $H \rightarrow bb$ [17]           | 1.59$^{+0.69}_{-0.72}$ | 125         | -    | -   | 100%| -   |

Table 3: Tevatron results for up to 10 fb$^{-1}$ at $\sqrt{s} = 1.96$ TeV, as employed in this analysis.

- Tevatron $H \rightarrow \tau\tau$ is omitted (large uncertainties)
- $H \rightarrow \gamma\gamma$ and $H \rightarrow WW$ are approximated as inclusive searches (ratio of inclusive cross sections for $pp\bar{p}$ collisions at 2 TeV)
Combined 2D $\mu$ plots
bosonic channels

\[
\begin{array}{c|c|c}
\mu(\text{ggF + ttH}, Y) & \mu(\text{VBF + VH}, Y) & \rho \\
\hline
\gamma\gamma & 0.99 \pm 0.28 & 1.71 \pm 0.59 & -0.38 \\
VV & 0.91 \pm 0.16 & 1.01 \pm 0.49 & -0.30 \\
\end{array}
\]

identical with or without Tevatron!
Combined 2D $\mu$ plots
fermionic channels

|        | $\mu(\text{ggF + ttH, } Y)$  | $\mu(\text{VBF + VH, } Y)$ | $\rho$    |
|--------|------------------------------|------------------------------|-----------|
| $\bar{b}b/\tau\tau$ | $0.93 \pm 0.64$              | $1.08 \pm 0.36$              | $-0.27$   |
| $bb$   | $-0.22 \pm 2.86$             | $1.13 \pm 0.43$              | $0$       |
| $\tau\tau$ | $1.07 \pm 0.71$              | $0.94 \pm 0.65$              | $-0.47$   |

without Tevatron
we would like to treat the Higgs mass as a nuisance parameter

a priori important for the two high resolution channels (H→ZZ and H→γγ)

unfortunately impossible to use together with the 2D μ information
Higgs couplings

How can we use this information to constrain the couplings of the Higgs?

- We first need to specify a Lagrangian. Our choice:

\[ \mathcal{L} = g \left[ C_V \left( m_W W_\mu W^\mu + \frac{m_Z}{\cos \theta_W} Z_\mu Z^\mu \right) - C_U \frac{m_t}{2m_W} \bar{t}t - C_D \frac{m_b}{2m_W} \bar{b}b - C_D \frac{m_\tau}{2m_W} \bar{\tau}\tau \right] H \]

Scaling factors $C$ parametrize deviations from the SM

- We calculate $\bar{C}_g$ (for gluon-gluon fusion) and $\bar{C}_\gamma$ (for $H \rightarrow \gamma\gamma$) from $C_U$, $C_D$, $C_V$ and we allow for additional particles in the loop: $\Delta C_g$ and $\Delta C_\gamma$

\[ \rightarrow C_g = \bar{C}_g + \Delta C_g \quad \text{and} \quad C_\gamma = \bar{C}_\gamma + \Delta C_\gamma \]

- Total Higgs width: not accessible at the LHC. 2 possibilities:
  1) assume that $\text{BR}(H \rightarrow \text{invisible/undetected}) = 0$
  2) allow for $H \rightarrow \text{invisible/undetected}$
Searches for invisible decays of the Higgs boson

$ZH \rightarrow \ell\ell + \text{invisible}$

$\mathcal{B}(H \rightarrow \text{inv.}) < 0.65$ at 95% CL

[ATLAS-CONF-2013-011]
Searches for invisible decays of the Higgs boson

\[ ZH \rightarrow \ell\ell + \text{invisible} \]

\[ C_V^2 \mathcal{B}(H \rightarrow \text{inv.}) < 0.65 \text{ at } 95\% \text{ CL} \]

see also earlier studies based on e.g. monojet searches [Djouadi et al. '12]
Fitting procedure

- Simple $\chi^2$ fit: $\chi^2 = \sum_k \frac{(\mu_k - \mu_k^{\text{exp}})^2}{\Delta\mu_k^2}$
- ATLAS 95% CL limit on BR(H→invisible) implemented as a hard cut
- $\mu_k$: rescaling of the SM prediction (given by the LHC Higgs XS WG)
- When showing contours of $\Delta \chi^2$: we profile the likelihood over the unseen parameters
A word on $H \rightarrow \gamma \gamma$

- contribution from the $W$ is 5 times larger than from the top quark and with opposite sign
- small contributions from bottom and lighter quarks
- new particles in the loop could change the $H \gamma \gamma$ rate (e.g. charged Higgses, charginos, staus, ...)

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I) $\Delta C_g, \Delta C_\gamma$ fit

- we assume $C_U = C_D = C_V = 1$ — $\Delta C_g$ and $\Delta C_\gamma$ are free to vary
  → new physics as additional particles in the loops
- relevant in the context of Universal Extra Dimensions, VLQ, ...

$\text{BR}(H\rightarrow\text{invisible/undetected}) = 0$

$\text{BR}(H\rightarrow\text{invisible/undetected})$ free
II) $C_U$, $C_D$, $C_V$ fit

- we assume $\Delta C_g = \Delta C_\gamma = 0$ — $C_U$, $C_D$ and $C_V$ are free to vary
  $\rightarrow$ modified Higgs sector + no new particles in the loops
- can arise with extended Higgs sectors (e.g. 2HDM with heavy $H^+$)

$BR(H \rightarrow \text{invisible/undetected}) = 0$

- $C_U < 0$ (sign opposite to $C_V$):
  constructive interference with $W$ disfavored at the level of 2.4$\sigma$
- minimum with $C_D > 0$ and $C_D < 0$ are practically equivalent
II) $C_U$, $C_D$, $C_V$ fit

- we assume $\Delta C_g = \Delta C_\gamma = 0 \quad \rightarrow \quad C_U, C_D$ and $C_V$ are free to vary
  $\rightarrow$ modified Higgs sector + no new particles in the loops
- can arise with extended Higgs sectors (e.g. 2HDM with heavy $H^+$)

$\text{BR}(H \rightarrow \text{invisible/undetected}) = 0$

$\text{BR}(H \rightarrow \text{invisible/undetected})$ free

same global minimum
II) \( C_U, C_D, C_V \) fit

- \( C_V \) tend to be larger for \( C_U > 0 \)
- Common increase of \( C_U, C_D \) and \( C_V \)

Single top production in association with a Higgs boson could help discriminate between \( C_U > 0 \) and \( C_U < 0 \) [Biswas, Gabrielli and Mele '12; Farina et al. '12]
III) $C_U$, $C_D$, $C_V$, $\Delta C_g$, $\Delta C_\gamma$ fit

- general case: $C_U$, $C_D$, $C_V$, $\Delta C_g$ and $\Delta C_\gamma$ are free to vary (but no invisible)
- encompasses a very broad class of models

- determination of $C_D$ is robust
- anticorrelation between $C_U$ and $\Delta C_g$

comes from CMS
$ttH \rightarrow bb$
III) $C_U$, $C_D$, $C_V$, $\Delta C_g$, $\Delta C_{\gamma}$ fit

- general case: $C_U$, $C_D$, $C_V$, $\Delta C_g$, and $\Delta C_{\gamma}$ are free to vary (but no invisible)
- encompasses a very broad class of models

assuming $\mu(t\bar{t}H) = 1 \pm 0.3$

determination of $C_D$ is robust

anticorrelation between $C_U$ and $\Delta C_g$
III) $C_U$, $C_D$, $C_V$, $\Delta C_g$, $\Delta C_\gamma$ fit

- balance between $C_U$ and $\Delta C_\gamma$
- the determination of $C_V$ is robust
Invisible decays of the Higgs boson

- SM+invisible
  \[ \mathcal{B}(H \rightarrow \text{inv.}) < 0.20 \text{ at 95\% CL} \]

- SM+\(C_U > 0\)+\(C_D > 0\)+\(C_V < 1\)+invisible
  \[ \mathcal{B}(H \rightarrow \text{inv.}) < 0.29 \text{ at 95\% CL} \]

- SM+\(\Delta C_g + \Delta C_\gamma\)+invisible
  \[ \mathcal{B}(H \rightarrow \text{inv.}) < 0.35 \text{ at 95\% CL} \]

- SM+\(C_U + C_D + C_V\)+invisible
  \[ \mathcal{B}(H \rightarrow \text{inv.}) < 0.46 \text{ at 95\% CL} \]
Invisible decays of the Higgs boson and dark matter

if invisible = dark matter:
interplay between direct searches and H→invisible

Majorana dark matter

scalar dark matter

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### Goodness-of-fit

| Fit                  | Standard Model | $\Delta C_\gamma, \Delta C_g$ | $C_U, C_D, C_V$ | $C_U, C_D, C_V, \Delta C_\gamma, \Delta C_g$ |
|----------------------|----------------|-------------------------------|-----------------|-----------------------------------------------|
| $\chi^2_{\text{min}}$ | 19.0           | 17.6                          | 17.6            | 17.2                                          |
| $\chi^2_{\text{min}}$/d.o.f. | 0.86           | 0.88                          | 0.93            | 1.01                                          |
| dominant contributions to $\chi^2_{\text{min}}$ | ATLAS $\gamma\gamma$ | CMS $\gamma\gamma$ | ATLAS $\gamma\gamma$ | CMS $\gamma\gamma$ |
|                      | Tevatron $\gamma\gamma$ | ATLAS $\gamma\gamma$ | CMS WW | ATLAS $\gamma\gamma$ |
|                      | CMS WW | Tevatron $\gamma\gamma$ | Tevatron $\gamma\gamma$ | Tevatron $\gamma\gamma$ |

- no improvement of $\chi^2$/d.o.f. (hence the $p$-value) when allowing for additional freedom
- most of the tensions in the fit come from $\gamma\gamma$
Two Higgs Doublet Model

- Model-dependent study: 2HDM type I and II
- 2 parameters (angles): $\alpha$ and $\beta$

| Higgs | Type I and II | Type I | Type II |
|-------|---------------|--------|---------|
| $h$   | $\sin(\beta - \alpha)$ | $\cos \alpha / \sin \beta$ | $\cos \alpha / \sin \beta$ | $\cos \alpha / \sin \beta$ |
| $H$   | $\cos(\beta - \alpha)$ | $\sin \alpha / \sin \beta$ | $\sin \alpha / \sin \beta$ | $\sin \alpha / \sin \beta$ |
| $A$   | 0              | $\cot \beta$ | $- \cot \beta$ | $\cot \beta$ |

- in both cases we have:
  - $|C_V| < 1$
  - $|C_U| < 1.4$ if $\tan \beta > 1$

- both $h$ and $H$ could be the 125.5 GeV observed state
Two Higgs Doublet Model

$h^0$ results

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Two Higgs Doublet Model

$h^0$ results

for the full picture we need to add more constraints: SUP, PEW, B-physics
Conclusion

- previously favored $C_\mu < 0$ region is now disfavored at the level of $2.4\sigma$
  (unless we allow for additional loop contributions to $ggF$)

- overall, the observed Higgs boson seems very SM-like
  (but still waiting for updates, especially in fermionic channels)

- first step in the study of the implications of the new boson
  → time has come to explore the consequences for BSM models
I) $\Delta C_g, \Delta C_\gamma$ fit
before and after Moriond
Invisible decays of the Higgs boson before Moriond

\[ \mathcal{B}(H \rightarrow \text{inv.}) < 0.23 \text{ at } 95\% \text{ CL} \]

\[ \mathcal{B}(H \rightarrow \text{inv.}) < 0.36 \text{ at } 95\% \text{ CL} \]

\[ \mathcal{B}(H \rightarrow g\gamma \text{ inv.}) < 0.61 \text{ at } 95\% \text{ CL} \]

\[ \mathcal{B}(H \rightarrow \text{inv.}) < 0.88 \text{ at } 95\% \text{ CL} \]
Computation of $C_g$ and $C_\gamma$

\[ \bar{C}_g^2 = \frac{C_U^2 \sigma_{ggF}^{tt} + C_D^2 \sigma_{ggF}^{bb} + C_U C_D \sigma_{ggF}^{tb}}{\sigma_{ggF}^{tt} + \sigma_{ggF}^{bb} + \sigma_{ggF}^{tb}} \]

\[ C_g^2 = \left( \sqrt{\bar{C}_g^2} + \Delta C_g \right)^2 \]

\[ \bar{C}_\gamma^2 = \frac{C_V^2 \Gamma_{WW}^{\gamma\gamma} + C_U^2 \Gamma_{\gamma\gamma}^{tt} + C_D^2 \Gamma_{\gamma\gamma}^{bb} + C_D^2 \Gamma_{\gamma\gamma}^{\tau\tau} + \text{interferences}}{\Gamma_{\gamma\gamma}^{WW} + \Gamma_{\gamma\gamma}^{tt} + \Gamma_{\gamma\gamma}^{bb} + \Gamma_{\gamma\gamma}^{\tau\tau} + \text{interferences}} \]

\[ C_\gamma^2 = \left( \sqrt{\bar{C}_\gamma^2} + \Delta C_\gamma \right)^2 \]
2D \( \mu \) plots – ATLAS
validity of the Gaussian approximation

HEFTI Higgs workshop  Béranger Dumont  April 22, 2013
2D $\mu$ plots – CMS
validity of the Gaussian approximation

only 68% CL contours are available
for CMS $H \rightarrow WW$ and $H \rightarrow \tau \tau$