Higgs pair production in the Two-Higgs-Doublet model of type II

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in collaboration with J. Baglio, U. Nierste & M. Wiebusch,

using *my*Fitter and CKMfitter

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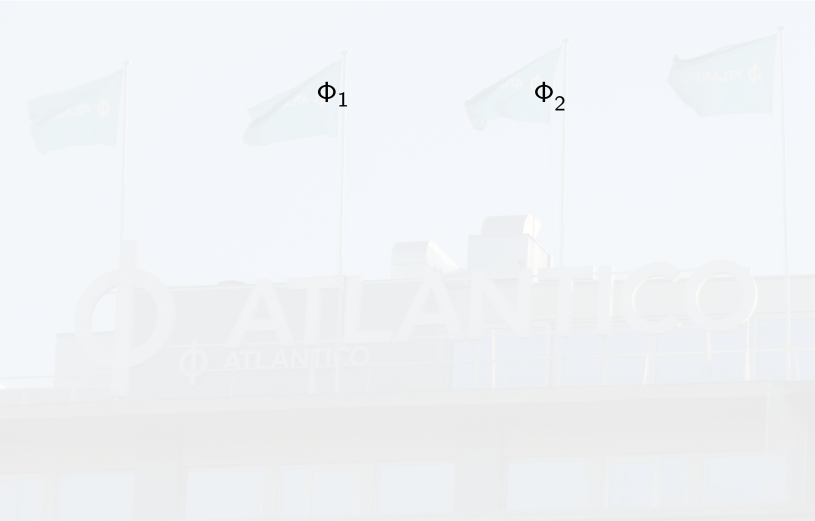
Outline

Lisbon

Model



Model

Scalar potential of the 2HDM of type II:

$$V_H^{2HDM} = m_{22}^2 \Phi_2^\dagger \Phi_2 + m_{11}^2 {\Phi_1}^\dagger \Phi_1 - m_{12}^2 \left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1 \right)$$
$$+ \frac{\lambda_1}{2} \left(\Phi_1^\dagger \Phi_1 \right)^2 + \frac{\lambda_2}{2} \left(\Phi_2^\dagger \Phi_2 \right)^2 + \lambda_3 \left(\Phi_1^\dagger \Phi_1 \right) \left(\Phi_2^\dagger \Phi_2 \right)$$
$$+ \lambda_4 \left(\Phi_1^\dagger \Phi_2 \right) \left(\Phi_2^\dagger \Phi_1 \right) + \frac{\lambda_5}{2} \left[\left(\Phi_1^\dagger \Phi_2 \right)^2 + \left(\Phi_2^\dagger \Phi_1 \right)^2 \right]$$

2HDM II: 8 real parameters assuming
CP conserving scalar sector
and softly broken Z_2 symmetry

$\Phi_1 \to -\Phi_1$ and $u \to -u$

Definitions

Physical parameters of the 2HDM II:

$v \approx 243$ GeV, $m_h = 126$ GeV,

m_H, m_A, m_{H^+}, m_{12}^2, $\tan\beta$, $\beta - \alpha$

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m_H, m_A, m_{H^+}, m_{12}^2, $\tan\beta$, $\beta - \alpha$

Alignment limit: $\beta - \alpha \to \frac{\pi}{2}$

Decoupling limit: $\beta - \alpha \gg \frac{\pi}{2}$ and $m_H \approx m_A \approx m_{H^+} \gg m_h$

[see talk by H. Haber]

Motivation

How large can $c_{hhh} \equiv \frac{\lambda_{hhh}^{\text{2HDM}}}{\lambda_{hhh}^{\text{SM}}}$ be?

How large can the other triple Higgs couplings be?

How large can $gg \to hh$ be?

Theory constraints

- Positivity of the scalar potential [Deshpande, Ma '78]

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  [Nierste, Riesselmann '96; Ginzburg, Ivanov '05;
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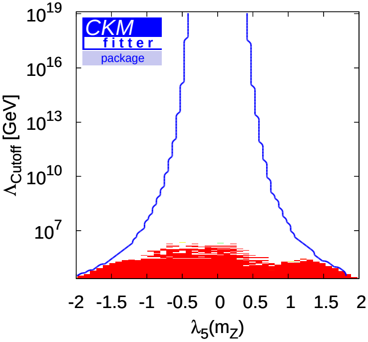

all eigenvalues of $S_{\phi_i\phi_j\to\phi_i\phi_j}$ smaller than $\frac{1}{8}$

at least one eigenvalue of $S_{\phi_i\phi_j\to\phi_i\phi_j} \in [\frac{1}{8}; \frac{1}{4}]$

[Chowdhury, OE '14]

Electroweak precision observables

The oblique parameters S, T, U [Peskin, Takeuchi '90,'92] are only applicable if

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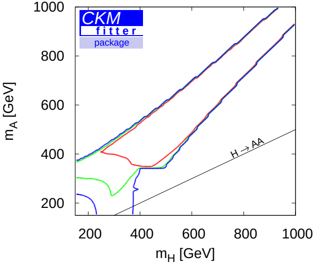
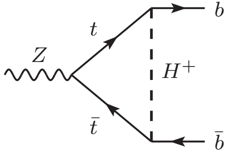
- no NP vertex contributions

Both arguments do not hold for the 2HDM II:





[OE, Nierste, Wiebusch '13]

Electroweak precision observables

So we take the whole set of 14 EWPO

$M_W,\ \Gamma_W,\ \Gamma_Z,\ \sin^2\theta_l^{\text{eff}},\ \sigma_{\text{had}}^0,\ A_{\text{FB}}^{0,l},\ A_{\text{FB}}^{0,c},\ A_{\text{FB}}^{0,b},\ A_l,\ A_c,\ A_b,\ R_l^0,\ R_c^0,\ R_b^0$

[LEP & SLD '06]

using

$$\mathcal{O}_{\text{NP}} = \quad \mathcal{O}_{\text{SM}} \qquad + \delta\mathcal{O}_{\text{NP}}$$

three-loop	one-loop
`Zfitter`	`FeynArts`,`FormCalc`,`LoopTools`

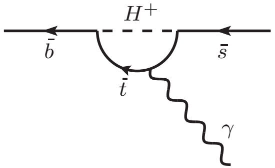
[González, Rohrwild, Wiebusch '12]
[Zfitter '90,'01,'06; Hahn et al. '99,'01,'06]

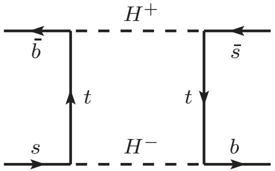
Flavour observables

$b \to s\gamma$
[Hermann, Misiak, Steinhauser '12]

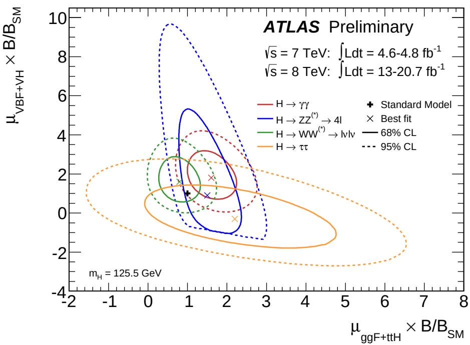
and

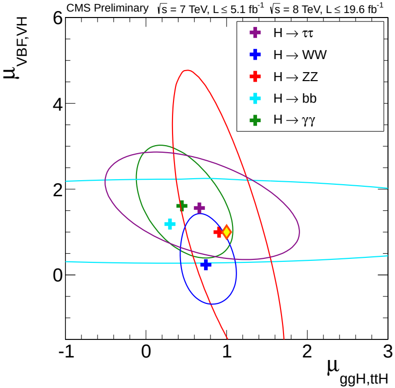
Δm_{B_s}
[Deschamps et al. '09]





Light Higgs signal strengths





[ATLAS-CONF-2013-034; CMS-PAS-HIG-13-005]

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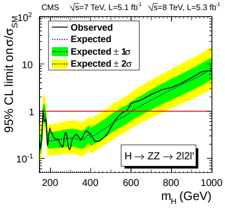
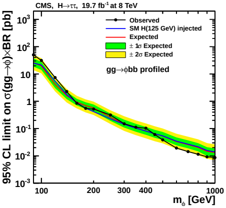
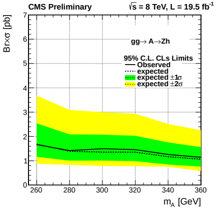
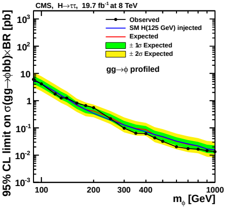
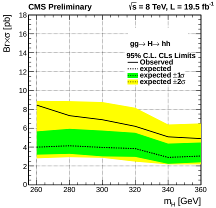
Heavy Higgs exclusion limits











[CMS '13; CMS-PAS-HIG-13-021; CMS-PAS-HIG-13-025]

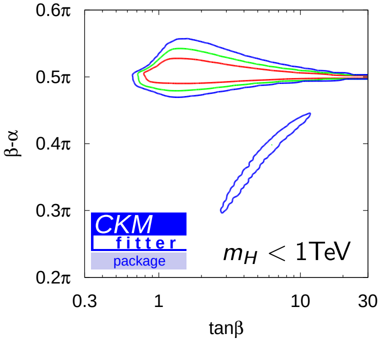
Fitting

We use two different frameworks to cross-check results:
*my*Fitter and the CKMfitter package both are based on the

- frequentist approach and use
- likelihood-ratio tests with a
- simplified *p*-value definition ("$\Delta\chi^2$").

[*my*Fitter '12; CKMfitter '01]

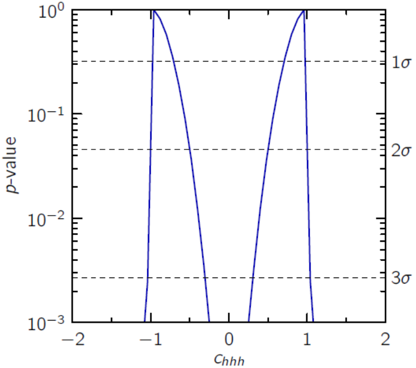
The 2HDM II is close to the alignment limit



[Baglio, OE, Nierste, Wiebusch '14]
[compare also talk by S. K. Kang]

How large can $c_{hhh} \equiv \frac{\lambda_{hhh}^{2HDM}}{\lambda_{hhh}^{SM}}$ be?

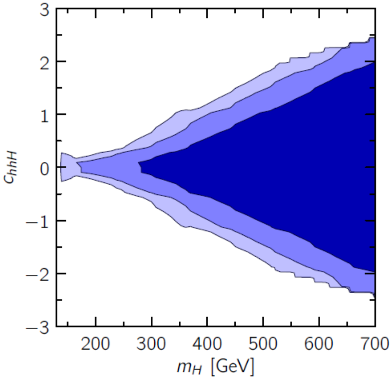
$$c_{hhh} = \frac{\cos^3\alpha}{\sin\beta} - \frac{\sin^3\alpha}{\cos\beta} - \frac{m_{12}^2}{m_h^2}\cos(\beta-\alpha)\left(\frac{\cos^2\alpha}{\sin^2\beta} - \frac{\sin^2\alpha}{\cos^2\beta}\right)$$



[Baglio, OE, Nierste, Wiebusch '14]

How large can $c_{hhH} \equiv \frac{\lambda_{hhH}^{2HDM}}{\lambda_{hhh}^{SM}}$ be?

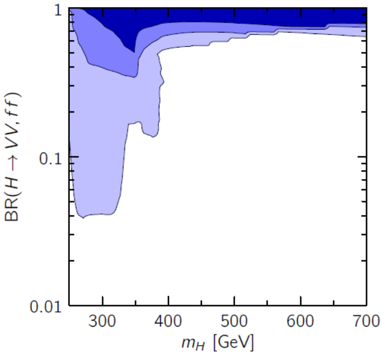
$$c_{hhH} = \frac{\cos(\beta-\alpha)}{\cos\beta\sin\beta}\left[\frac{\cos\alpha\sin\alpha}{3}\left(2+\frac{m_H^2}{m_h^2}\right)+\frac{m_{12}^2}{m_h^2}\left(\frac{1}{3}-\frac{\cos\alpha\sin\alpha}{\cos\beta\sin\beta}\right)\right]$$

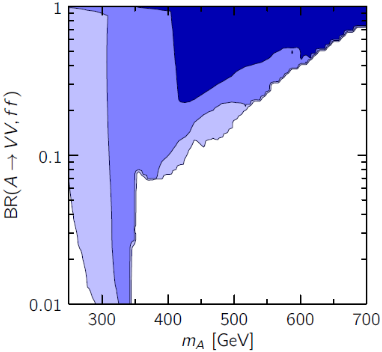


[Baglio, OE, Nierste, Wiebusch '14]

How much could "standard" branching ratios be suppressed?

Branching ratios to vector bosons and fermions:





[Baglio, OE, Nierste, Wiebusch '14]

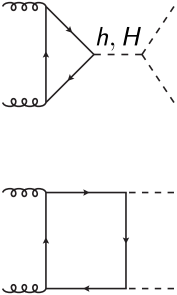
Benchmark points

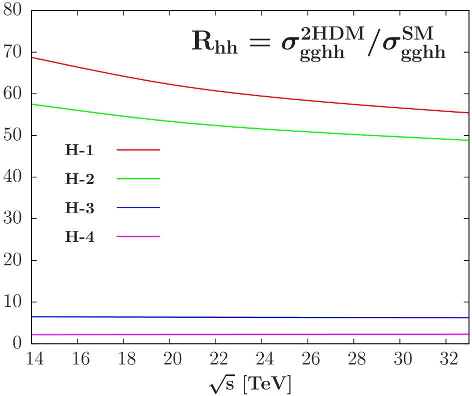
We provide 24 benchmark scenarios
featuring the largest still possible deviations from the SM:

	$\tan\beta$	$(\beta-\alpha)/\pi$	m_H[GeV]	m_A[GeV]	$m_{H^\pm}$[GeV]	m_{12}^2[GeV^2]
a-1	1.50	0.529	700	700	670	180000
...						
H-1	1.75	0.522	300	441	442	38300
H-2	2.00	0.525	340	470	471	44400
H-3	4.26	0.519	450	546	548	43200
H-4	4.28	0.513	600	658	591	76900
A-1	4.61	0.505	346	300	345	23600
A-2	2.74	0.503	131	340	339	6200
A-3	7.02	0.508	290	450	446	11700
A-4	7.44	0.504	490	600	598	31620

[Baglio, OE, Nierste, Wiebusch '14]

$gg \to hh$





Even if the 2HDM II was "aligned",
a large enhancement of $gg \to hh$ would be possible.
[Baglio, OE, Nierste, Wiebusch '14]

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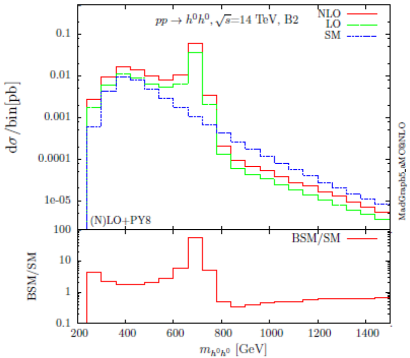
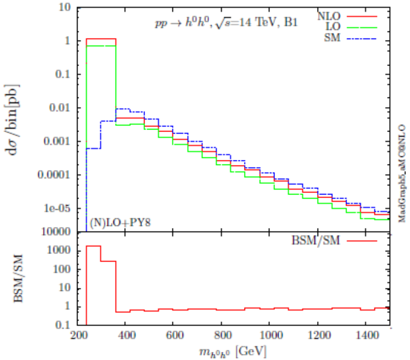
$pp \to hh$

Use of our benchmark scenarios:

a-1



H-1



[Hespel, López-Val, Vryonidou '14]

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Conclusions

2HDM II is strongly constrained.

Large effects in triple Higgs coupling measurements are possibile.

We provide benchmark points in arXiv:1403.1246.

Back-up slides

Literature

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