Global fit to Higgs signal strengths and couplings
A BSM perspective

David López-Val

based on work together with K. Cranmer & S. Kreiss (NYU New York),
M. Rauch (KIT Karlsruhe), T. Plehn (ITP Heidelberg)

1308.1979 & **1401.0080**

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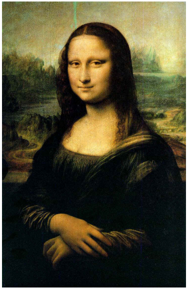
Higgs Couplings 2014, Torino - **October 2nd 2014**

Outline

1. Coupling patterns
2. Fits to data
3. Free coupling setup
4. Theory uncertainties
5. Summary

The Higgs portray

- Mass
- Width
- Couplings
- Quantum numbers



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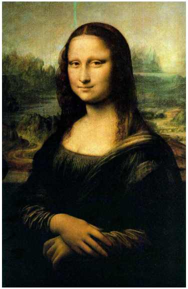

A *Standard* portray? . . .

. . . or a deeper meaning ?

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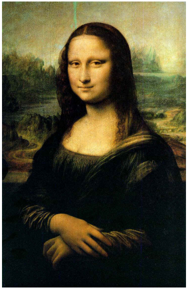

A *Standard* portray? . . .

. . . or a deeper meaning ?

fundamental

single

weakly coupled

natural

admixture

light partners

strongly coupled

stable

composite

heavy partners

Seeking for BSM imprints

$$\boxed{\mathcal{L}_{\mathsf{SM}} \longrightarrow \mathcal{L}[g'_{\mathsf{SM}}, g_{\mathsf{BSM}}, \phi_{SM}, \phi_{\mathsf{BSM}}]}$$

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$$\boxed{g_{xxH} = g_{xxH}^{\mathsf{SM}}(1 + \Delta_x)}$$

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BSM patterns $\Longleftrightarrow$	signal strength deviations
mixing	$\Delta_x^{\mathsf{tree}}, \Delta_x^{\mathsf{loop}}$
new charged/colored states	Δ_x^{loop}
degenerate states	$\Delta_\phi \to \Delta_{\mathsf{h}^0} + \Delta_{\mathsf{H}^0}$
hidden sectors	Γ_{inv}

Seeking for BSM imprints

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BSM patterns $\Longleftrightarrow$ signal strength deviations

- mixing — $\Delta_x^{\mathsf{tree}}, \Delta_x^{\mathsf{loop}}$
- new charged/colored states — Δ_x^{loop}
- degenerate states — $\Delta_\phi \to \Delta_{\mathsf{h^0}} + \Delta_{\mathsf{H^0}}$
- hidden sectors — Γ_{inv}

- Scale $\Lambda \sim 0.55 - 2.5$ TeV
- Size $\Delta \sim 0.01 - 0.2$

MODEL

- Structure
- Correlations

Englert et al. 1403.7191

Seeking for BSM imprints

♠ Higgs signal strength & coupling deviations a window to BSM

Target questions

- What are the **key BSM imprints** and to which **structures** are these linked?
- What are their typical **sizes** and distinctive **correlations**?
- What is the *minimal* perturbative UV–completion to a **free Higgs coupling setup**?
- How do these confront to **data**?
- How do these differ from **theoretical uncertainties**?

Outline

Coupling patterns – overview

♠ Multiscalar sectors induce **distinctive** coupling shifts

Coupling patterns – overview

♠ Multiscalar sectors induce **distinctive** coupling shifts

Higgs couplings to gauge bosons

$g_{xxH} = g^{\text{SM}}_{xxH}(1+\Delta_x)$		hVV			
EXTENSION	**MODEL**	universal rescaling		non-universal rescaling	
singlet	inert ($v_S = 0$)				
	EWSB ($v_S \neq 0$)	θ	$\Delta_V < 0$		
doublet	inert ($v_d = 0$)				
	type-I	$\alpha - \beta$	$\Delta_V < 0$	$\mathcal{O}(y_f, \lambda_H)$	$\Delta_V \gtrless 0$
	type-II-IV	$\alpha - \beta$	$\Delta_V < 0$	$\mathcal{O}(y_f, \lambda_H)$	$\Delta_V \gtrless 0$
	aligned, MFV	$\alpha - \beta$	$\Delta_V < 0$	$\mathcal{O}(y_f, \lambda_H)$	$\Delta_V \gtrless 0$
singlet+doublet		$\alpha - \beta, \theta$	$\Delta_V < 0$	$\mathcal{O}(y_f, \lambda_H)$	$\Delta_V \gtrless 0$
triplet				α, β_n, β_c	$\Delta_V \gtrless 0$

Coupling patterns – overview

♠ Multiscalar sectors induce **distinctive** coupling shifts

Higgs couplings to fermions

$g_{xxH} = g_{xxH}^{\mathsf{SM}}(1+\Delta_x)$		$hf\bar{f}$			
extension	model	universal rescaling		non-universal rescaling	
singlet	inert ($v_S = 0$)	θ	$\Delta_f < 0$		
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	type-II			$\alpha - \beta$, $\mathcal{O}(y_f, \lambda_H)$	$\Delta_f \gtrless 0$
	aligned/MFV	y_f,	$\Delta_f \gtrless 0$	$y_f, \mathcal{O}(y_f, \lambda_H)$	$\Delta_f \gtrless 0$
singlet+doublet		y_f, θ	$\Delta_f \gtrless 0$	$y_f, \mathcal{O}(y_f, \lambda_H)$	$\Delta_f \gtrless 0$
triplet		β_n	$\Delta_f \gtrless 0$	$\mathcal{O}(y_f, \lambda_H)$	$\Delta_f \gtrless 0$

Outline

Dark singlet

♠ The simplest extension . . .

DARK SINGLET

Dark singlet

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DARK SINGLET

$$\boxed{V(\Phi, S) = \mu_1^2\,(\Phi^\dagger\,\Phi) + \lambda_1\,|\Phi^\dagger\Phi|^2 + \lambda_3\,|\Phi^\dagger\,\Phi|S^2}$$ – e.g. McDonald ['94]

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$$\Gamma_{\textsf{inv}} = \frac{\lambda_3^2 v^2}{32\pi\, m_h}\sqrt{1-\frac{4m_s^2}{m_h^2}} \equiv \xi^2\,\Gamma_{\textsf{SM}} \qquad \text{with} \qquad \mu_{p,d} = \frac{\Gamma_{\textsf{SM}}}{\Gamma_{\textsf{SM}}+\Gamma_{\textsf{inv}}} = 1-\xi^2+\mathcal{O}(\xi^3)\;.$$

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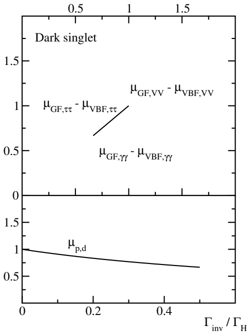
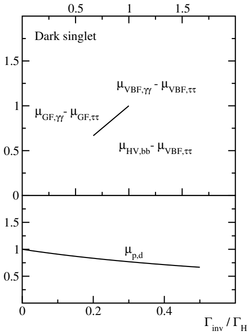
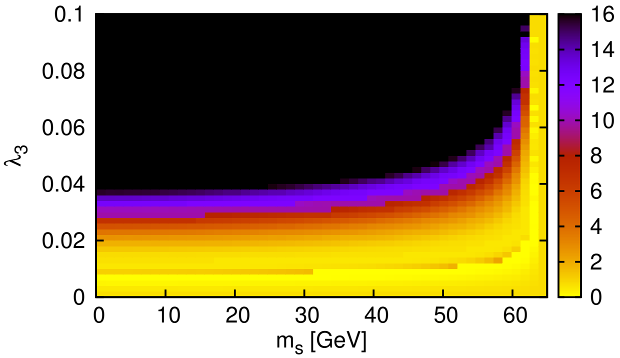




Dark singlet

Correlated relative log-likelihood $-2\Delta \log \mathcal{L}$



Hierarchical 2HDM

♠ Increasing complexity . . . NFC 2HDM at decoupling

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$$\xi \equiv \cos(\beta - \alpha) \simeq \frac{v^2}{M^2_{\text{heavy}}} \qquad \boxed{\xi \ll 1 \Rightarrow \sin\alpha \sim \cos\beta} \qquad \xi \simeq \frac{2\tan\beta}{1+\tan^2\beta}$$

Hierarchical 2HDM

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$\boxed{1+\Delta_v \simeq 1-\xi^2/2}$ $\boxed{1+\Delta_t \simeq 1+\cot\beta\,\xi-\xi^2/2}$ $\boxed{1+\Delta_b \simeq 1+\cot\beta\,\xi-\xi^2/2}$

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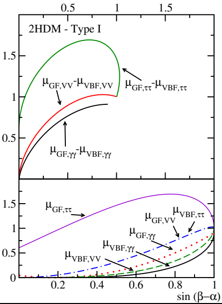
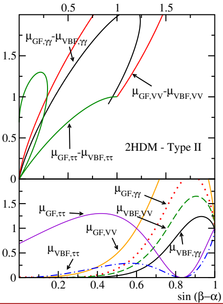


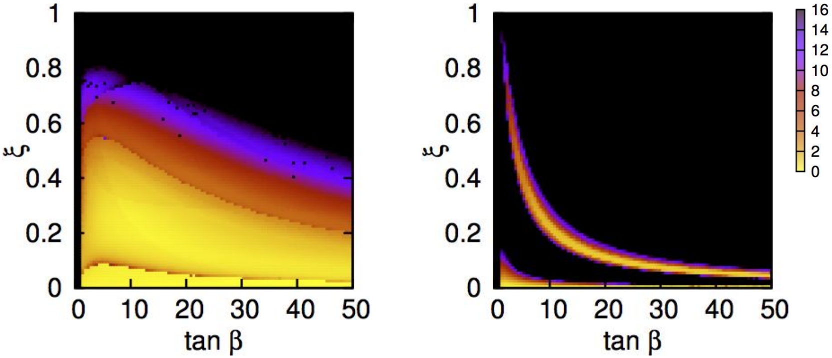


Hierarchical 2HDM

Correlated relative log-likelihood $-2\Delta \log \mathcal{L}$

Type I

Type II



DLV, Plehn, Rauch 1308.1979

Aligned 2HDM

♠ Aligned 2HDM Pich, Tuzón ['09]

Aligned 2HDM

♠ Aligned 2HDM   Pich, Tuzón ['09]

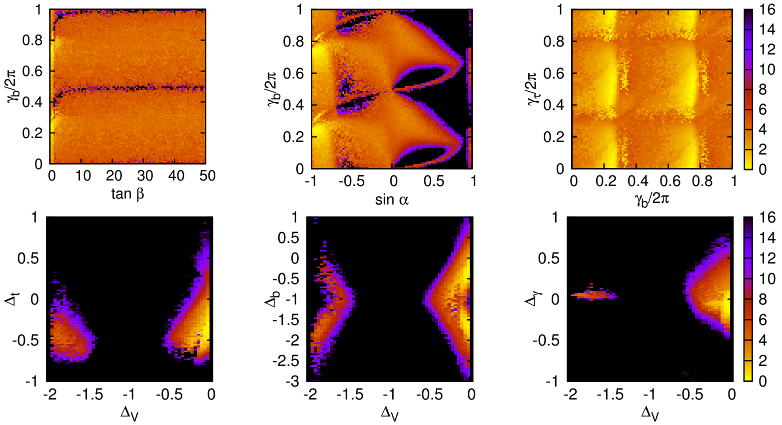
Analytical dependence

	h^0	H^0	A^0
$1+\Delta_W$	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	0
$1+\Delta_Z$	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	0
$1+\Delta_t$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{1}{\tan\beta}$
$1+\Delta_b$	$-\frac{\sin(\alpha-\gamma_b)}{\cos(\beta-\gamma_b)}$	$\frac{\cos(\alpha-\gamma_b)}{\cos(\beta-\gamma_b)}$	$\tan(\beta-\gamma_b)$
$1+\Delta_\tau$	$-\frac{\sin(\alpha-\gamma_\tau)}{\cos(\beta-\gamma_\tau)}$	$\frac{\cos(\alpha-\gamma_\tau)}{\cos(\beta-\gamma_\tau)}$	$\tan(\beta-\gamma_\tau)$
$1+\Delta_\gamma$	$\Delta_\gamma(\alpha,\tan\beta,m_{12}^2,m_{H^\pm}^2)$	$\Delta_\gamma(\alpha,\tan\beta,m_{12}^2,m_{H^\pm}^2)$	$\Delta_\gamma(\alpha,\tan\beta)$
$1+\Delta_g$	$\Delta_g(\Delta_t,\Delta_b)$	$\Delta_g(\Delta_t,\Delta_b)$	$\Delta_g(\Delta_t,\Delta_b)$

Type I: $\gamma_{b,\tau}=\pi/2$ **Type II:** $\gamma_{b,\tau}=0$

Aligned 2HDM

Correlated relative log-likelihood $-2\Delta \log \mathcal{L}$



DLV, Plehn, Rauch 1308.1979

Aligned 2HDM

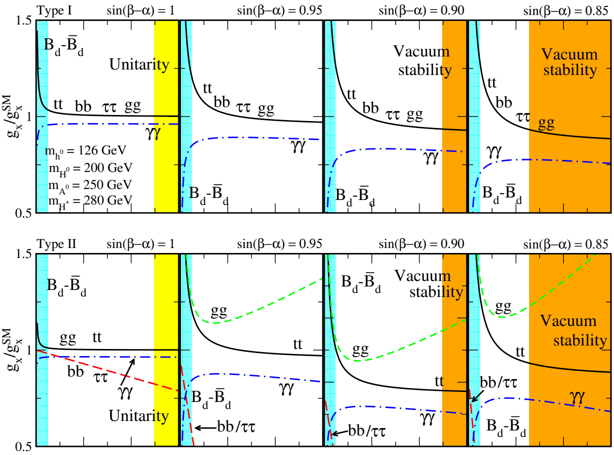
	unconstrained		constrained	
	$\tan < 1$	$\tan\beta > 1$	$\tan\beta < 1$	$\tan\beta > 1$
$\tan\beta$	0.338	1.231	0.890	1.324
$\sin\alpha$	-0.977	-0.871	-0.900	-0.810
$\gamma_b/(2\pi)$	0.744	0.261	0.732	0.267
$\gamma_\tau/(2\pi)$	0.389	0.070	0.542	0.678
M_H	750.5	257.3	587.2	487.4
$\tilde{\lambda}$	-3.00	0.44	3.80	2.88
Δ_V	-0.006	-0.069	-0.038	-0.044
Δ_t	-0.332	-0.367	-0.345	-0.265
Δ_b	-0.298	-0.412	-0.281	-0.318
Δ_τ	0.176	0.107	0.099	-0.102
Δ_γ	-0.058	-0.045	-0.034	-0.031
$\Delta_\gamma^{\text{tot}}$	0.023	-0.036	0.009	-0.017
$-2\log\mathcal{L}$	26.6	26.9	27.1	28.5

DLV, Plehn, Rauch 1308.1979

Outline

Higgs Coupling in the 2HDM – LO patterns

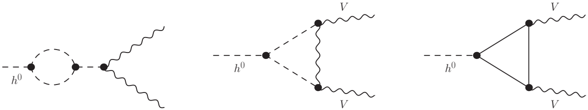
♠ **Higgs coupling deviations** – a parameter space portray



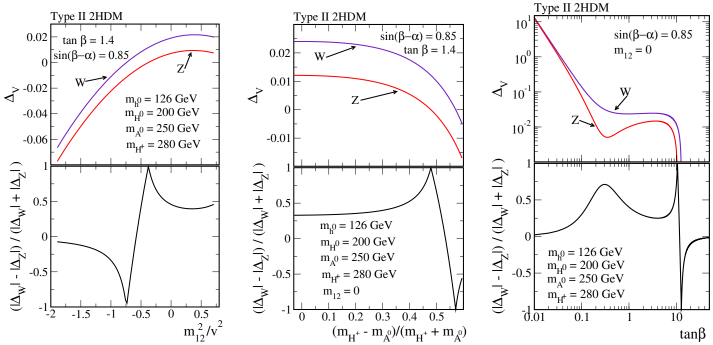
Over tan β

Higgs Coupling in the 2HDM: quantum effects

♠ **Higgs coupling deviations – adding quantum effects**

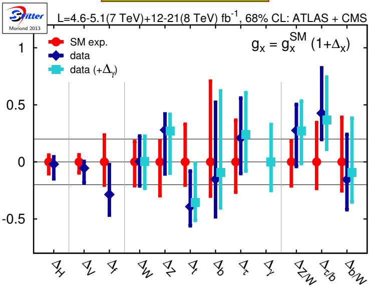


♠ fermionic loops essential for $\Delta_V > 0$ and $\Delta_Z \neq \Delta_W$

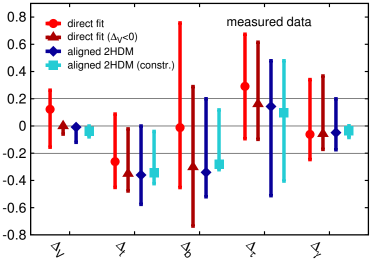


LHC data: free couplings VS 2HDM

Free couplings



2HDM

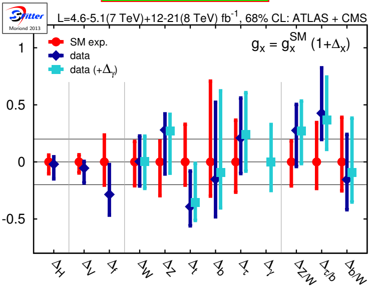


♠ a **2HDM** with **aligned Yukawas** & **quantum effects**

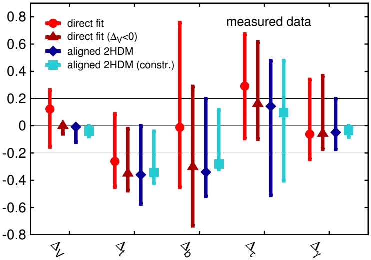
$\Rightarrow$ Yukawa alignment – Pich, Tuzón ['09]

LHC data: free couplings VS 2HDM

Free couplings



2HDM



- a **2HDM** with aligned Yukawas & quantum effects

  $\Rightarrow$ Yukawa alignment – Pich, Tuzón ['09]

- Renormalizable, perturbative, UV–complete embedding for **fully independent Higgs couplings**

- For quantum effects on Higgs couplings cf. S. Kanemura's talk.

Outline

A word on theory uncertainties

♠ BSM & TH uncertainties ⇔ **Coupling shifts** ⇔ Signal strength correlations

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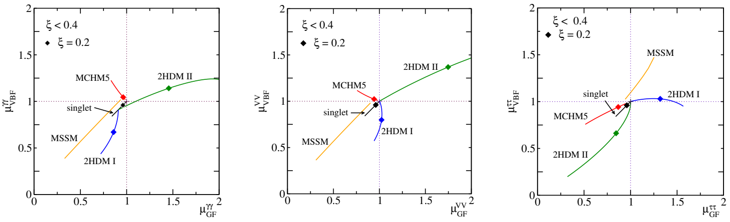

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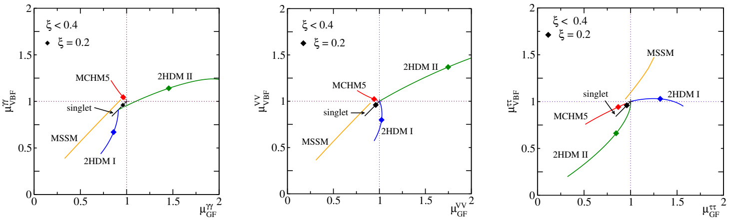

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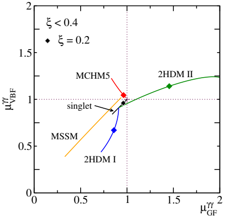
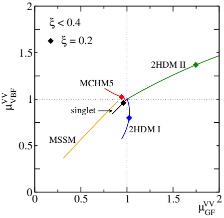
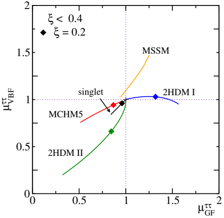
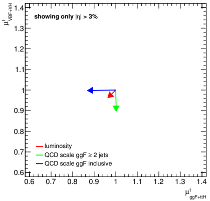
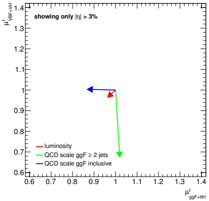
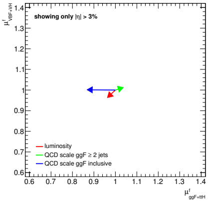






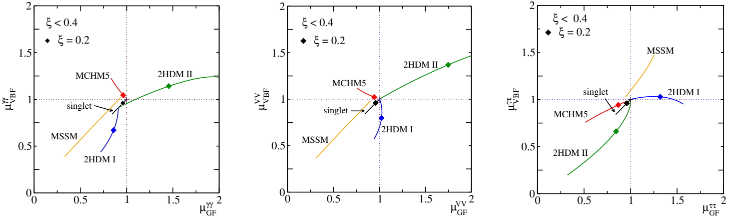


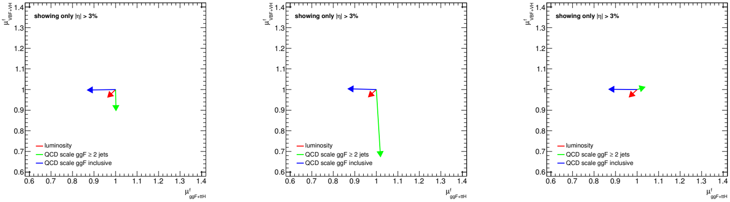




A word on theory uncertainties

♠ BSM & TH uncertainties ⇔ Coupling shifts ⇔ Signal strength correlations





Geometry in the $\mu_p^i - \mu_{p'}^{i'}$ plane ⇔ ket to tell apart BSM from uncertainties

Cranmer, Kreiss, DLV, Plehn 1401.0080

Outline

Summary

BSM models – Coupling structure

- Extended Higgs sectors give rise to characteristic coupling shifts $\boxed{g_{xxh} = g_{xxh}(1+\Delta_x)}$
- with distinctive **sizes** $\boxed{\Delta_x \sim \mathcal{O}(v^2/\Lambda^2)}$ and **correlations** $\boxed{\Delta_x - \Delta_y}$
- different from theory uncertainties

Summary

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- different from theory uncertainties

LHC data – Higgs signal strength

- Generic multiscalar sectors $\Rightarrow$ compatible with data – if decoupling limit can be realized
- The Aligned 2HDM @ NLO EW $\Rightarrow$ **minimal** ultraviolet completion of a SM-like Higgs sector with **free couplings**
  - Preference for decoupling limit – strong $\tan\beta - \sin\alpha$ correlation
  - Trademark scenarios **excluded** – *e.g. fermiophobia*
  - Trademark scenarios **allowed** – *e.g. sign–flipped bottom Yukawas*
  - Constraints are tigher for Type-II 2HDM
  - Best–fit points favor $\tan\beta \simeq 1$ and alignment parameters in between the NFC limits.