# Seeking for a multiscalar sector

David López-Val

CP3 - Université Catholique de Louvain

**IAP meeting** - Louvain–la–Neuve - **December 19th 2013**

# Outline

1. Motivation & context
2. Structures
3. Probes
   - Fits to LHC data
   - Signal strength correlations
   - Direct production & interference
   - Electroweak precision
4. Summary

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# Motivation & context

We are building on an evidence . . .

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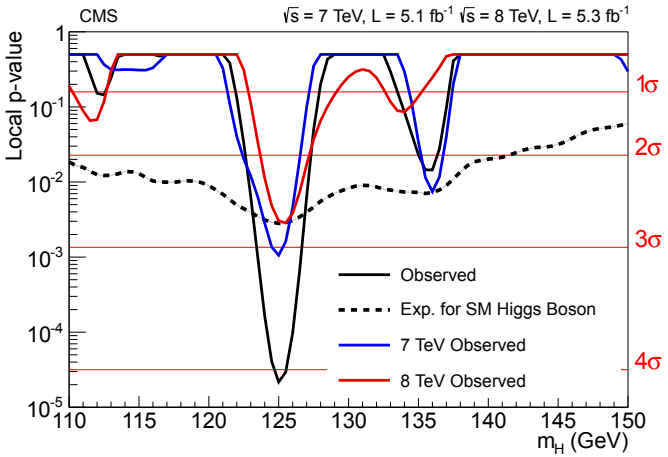
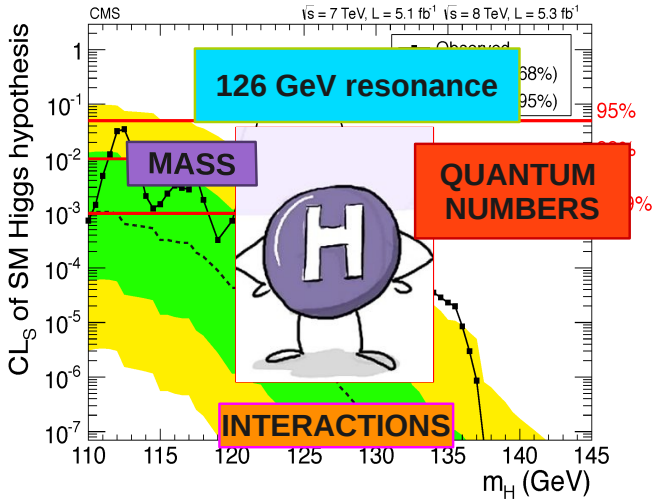


# Whys and wherefores



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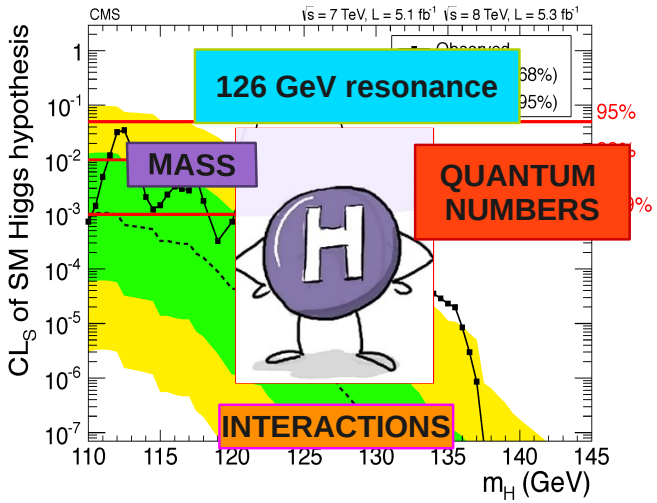


## This is not the **end** . . . this is the **beginning**

- fundamental , composite , mixed ?
- spinless ? *CP*–even ?
- single or multiple ? – heavier , lighter , hidden partners ?
- perturbative or strongly coupled ?
- How does it confront with naturalness , with $\Lambda_{DE}$ ?

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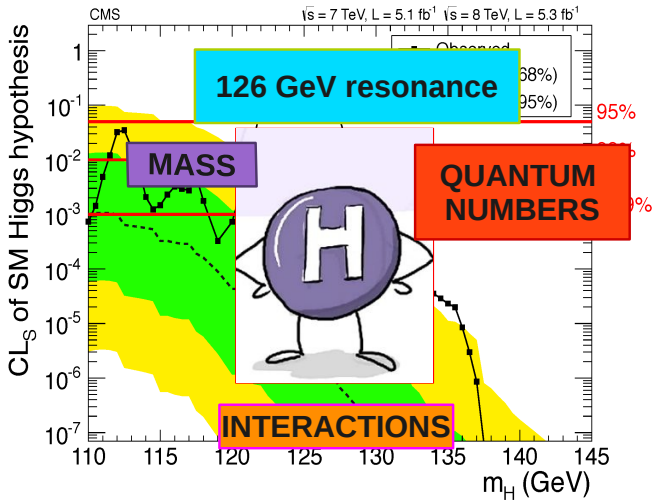


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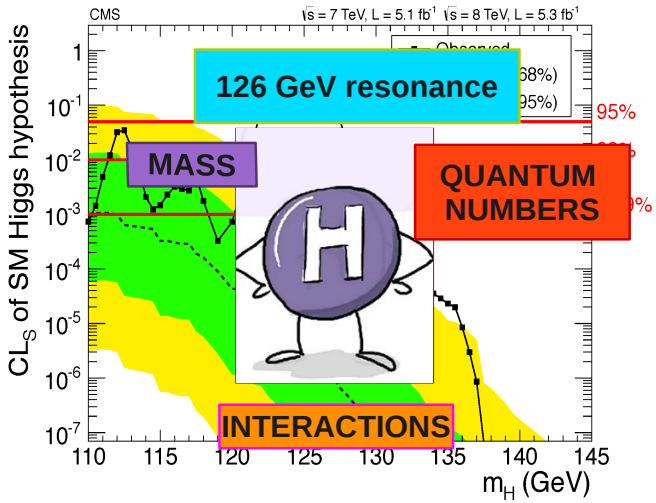


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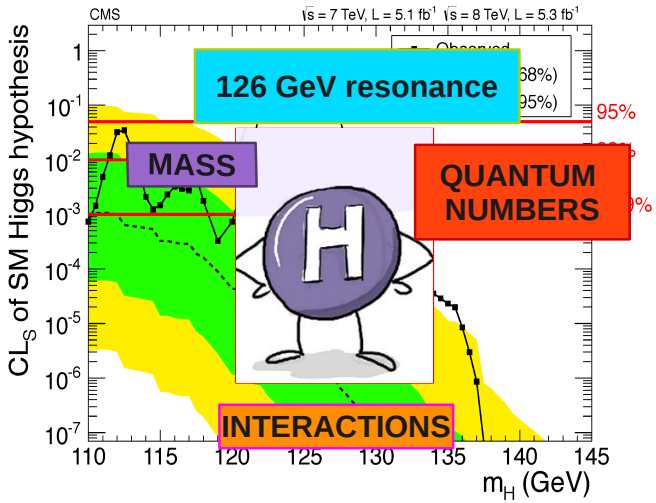


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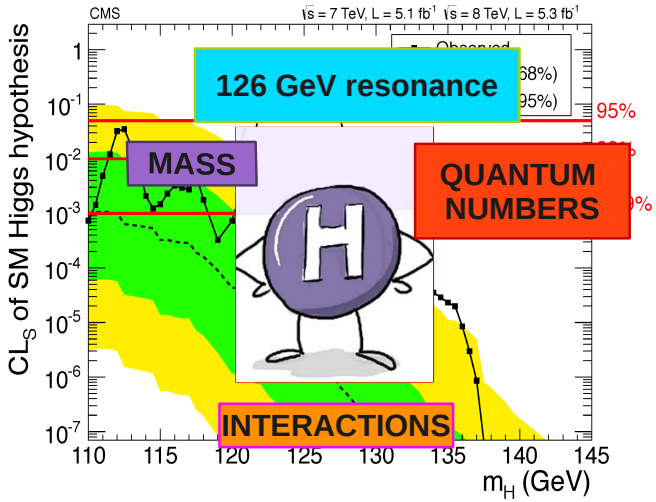


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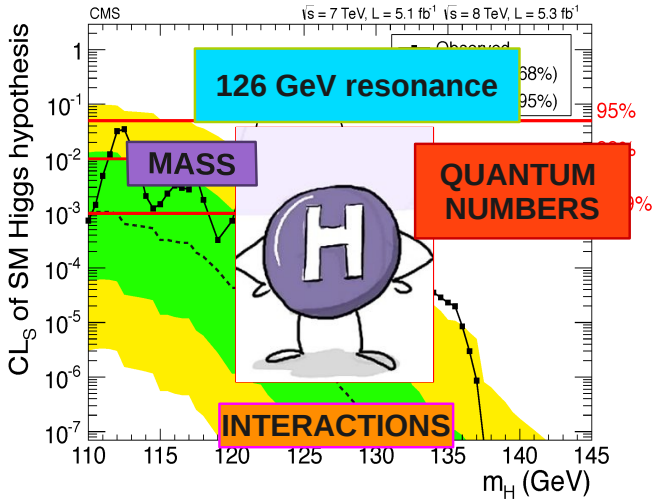


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# The quest for multiscalar sectors

## THEORY

♠ **coupling deviations**

$$g_{xxH} = g^{\mathrm{SM}}_{xxH}(1 + \Delta_x)$$

♠ **novel states**

$\mathrm{H}^0, \mathrm{H}^{\pm}, \mathrm{A}^0, \mathrm{H}_{\mathrm{DM}}, \ldots$

## OBSERVATIONS

♠ **Modified $\mathrm{h}^0$ production & decay**

$$pp(\mathrm{GF,VBF}) \to h \to \gamma\gamma, \tau\tau, VV^*$$

♠ **Direct $\mathrm{H}^{\mathrm{BSM}}$ production**

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$$\mu_i^p \equiv \frac{\sigma_p \times BR_i}{\sigma_p \times BR_i^{\mathrm{SM}}} = \left(\frac{\sigma_p}{\sigma_p^{\mathrm{SM}}}\right)\left(\frac{\Gamma_i}{\Gamma_i^{\mathrm{SM}}}\right)\left(\frac{\Gamma_{\mathrm{H}}^{\mathrm{SM}}}{\Gamma_{\mathrm{H}}}\right) \mu_i^p \equiv 1 + \delta\,\mu_i^p$$

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## BSM models

- Adding one $SU(2)_L$ singlet: **dark singlet, real(complex) singlet, Higgs portal ...**
- Adding one $SU(2)_L$ doublet: **Inert 2HDM, Types I - II 2HDM; leptophobic & flipped, vectorphobic; Type III; aligned ...)**
- Adding one $SU(2)_L$ triplet:
- Parameterizing strongly interacting EWSB: **SILH, MCHM ...**

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

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## BSM patterns $\Longleftrightarrow$ signal strength deviations

- ♠ mixing
- ♠ new charged/colored states
- ♠ degenerate states
- ♠ hidden sectors

- ♠ $\Delta_x^{\mathbf{tree}}, \Delta_x^{\mathbf{loop}}$
- ♠ $\Delta_x^{\mathbf{loop}}$
- ♠ $\Delta_\phi \rightarrow \Delta_{\mathsf{h0}} + \Delta_{\mathsf{H0}}$
- ♠ $\Gamma_{\mathbf{inv}}$

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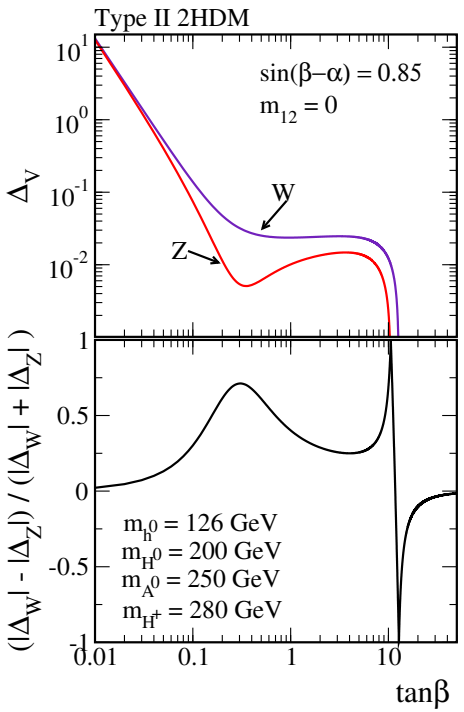
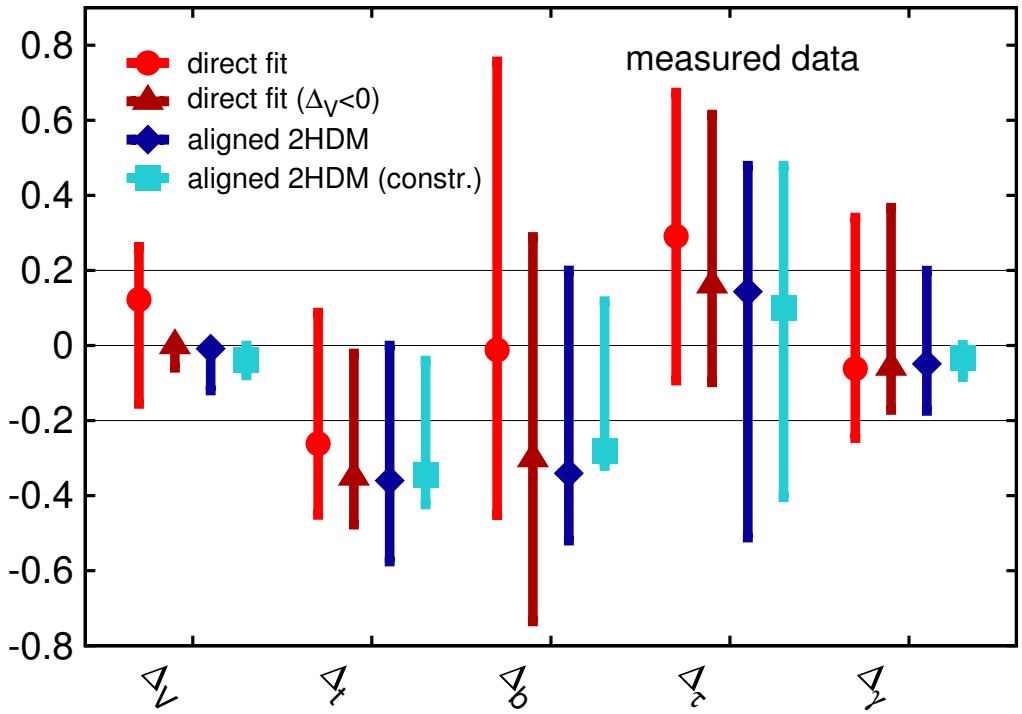
| $g_{xxH} = g^{\text{SM}}_{xxH}(1+\Delta_x)$ | | $hVV$ | | | |
|---|---|---|---|---|---|
| **EXTENSION** | **MODEL** | universal rescaling | | non-universal rescaling | |
| **singlet** | inert ($v_S = 0$) | | | | |
| | EWSB ($v_S \neq 0$) | $\theta$ | $\Delta_V < 0$ | | |
| **doublet** | inert ($v_d = 0$) | | | | |
| | 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** | | | | $\alpha, \beta_n, \beta_c$ | $\Delta_V \gtrless 0$ |

# Free coupling setup: minimal UV embedding



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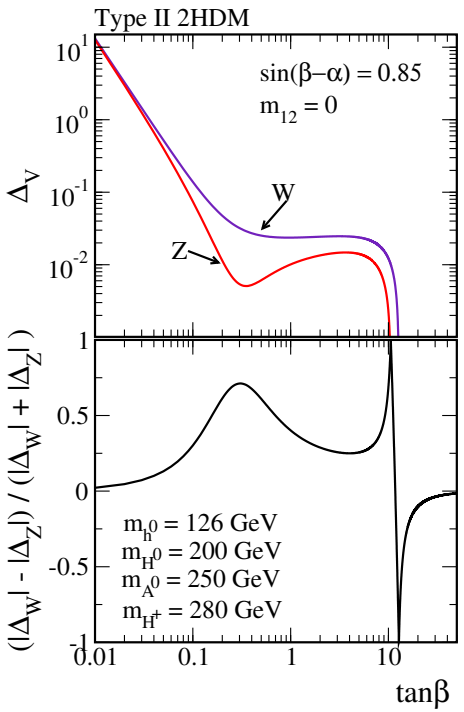


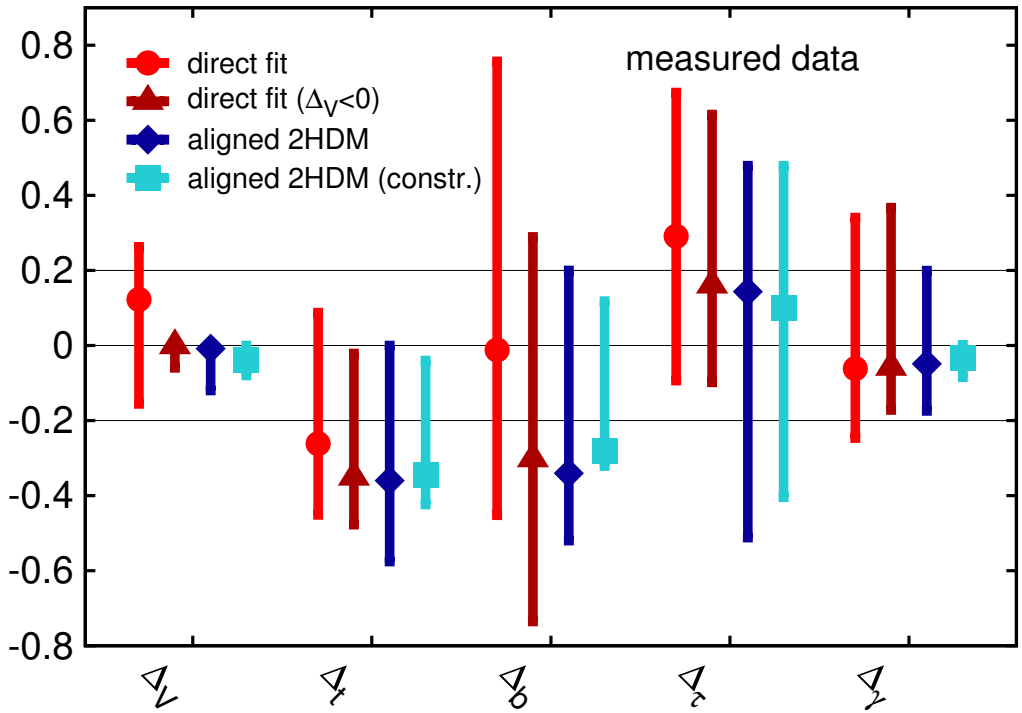


♠ a Two-Higgs-Doublet Model with

♡ **aligned** Yukawa couplings

♡ folded with **quantum effects**

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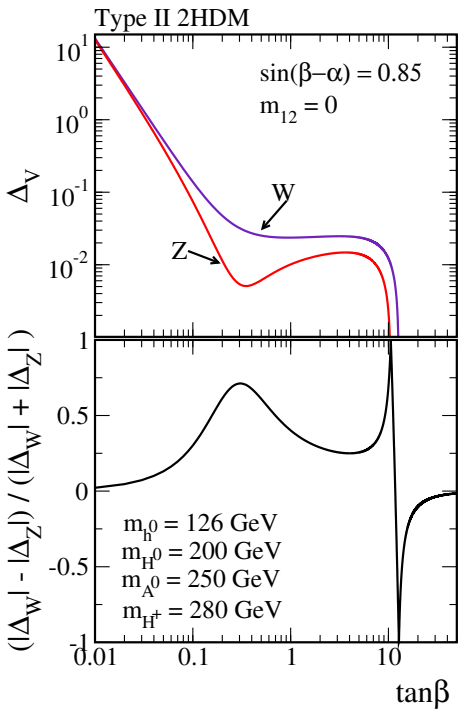


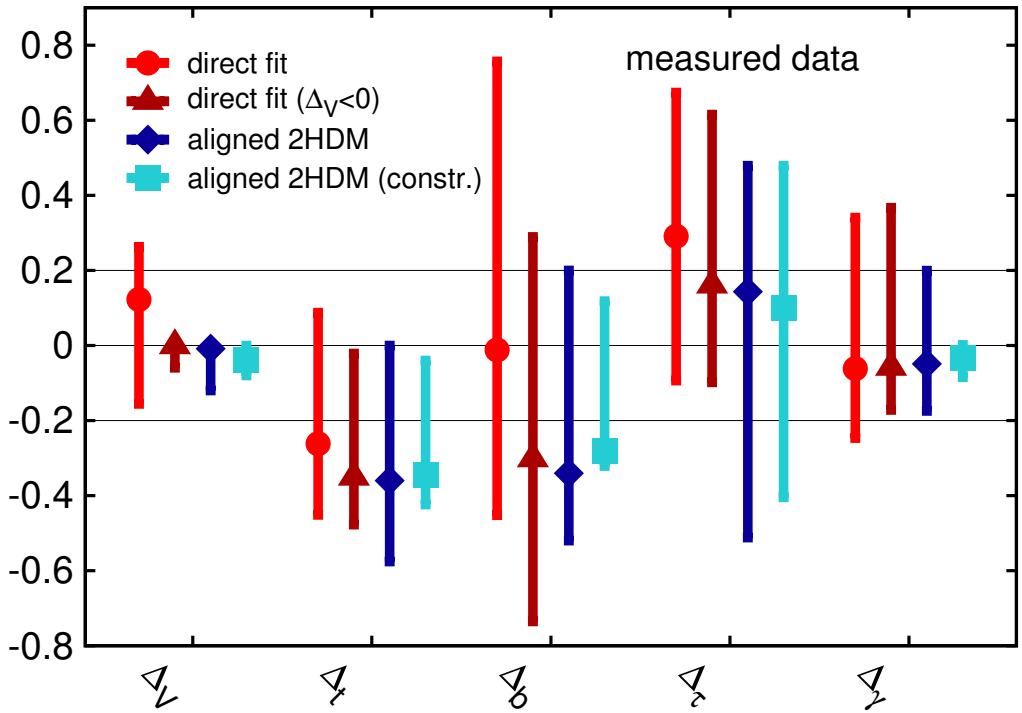


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**simplest, perturbative mutiscalar sector allowing independent h(126) couplings**

DLV, T. Plehn, M. Rauch ['13]

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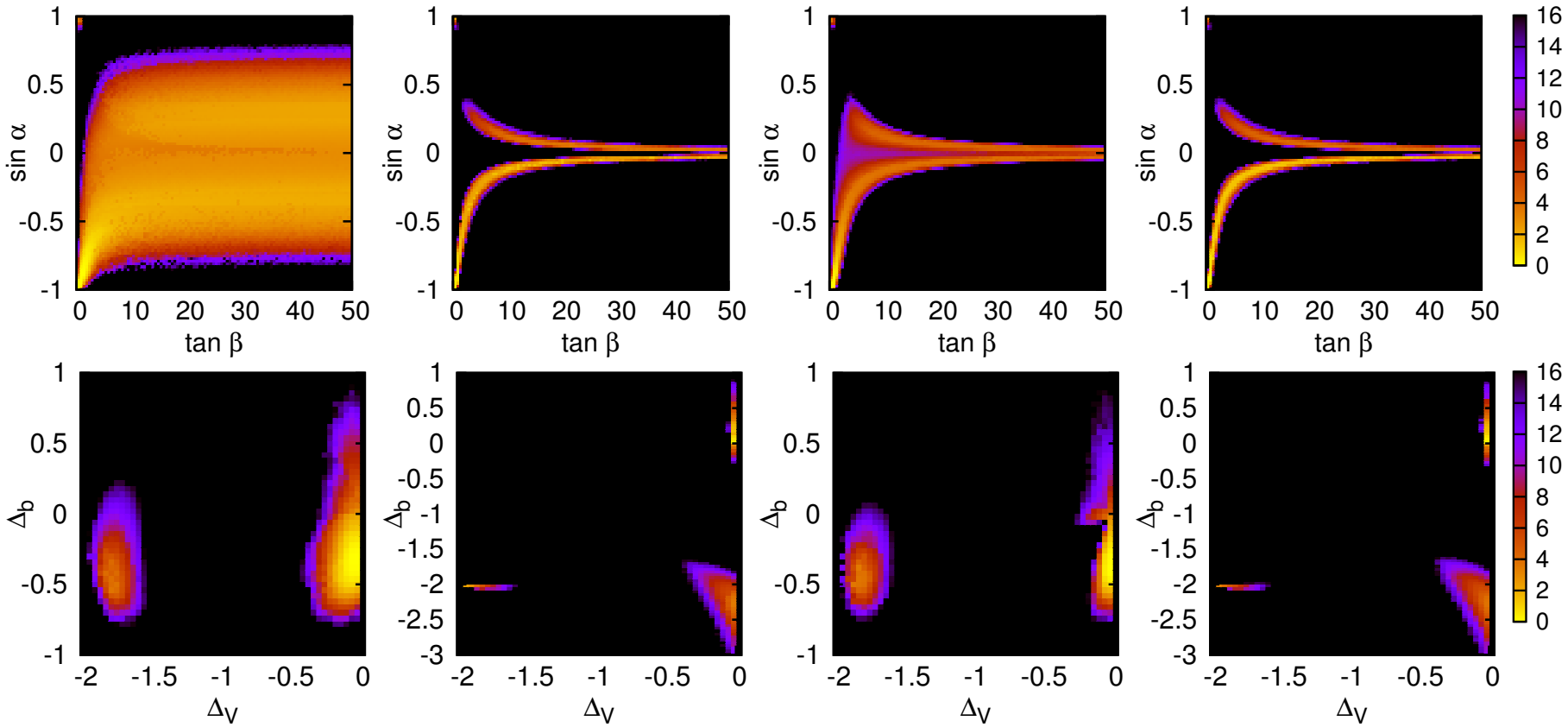
# Probes for a multiscalar sectors

- **Fitting** models to data
- **Correlating** signal strength measurements
- **Seeking** for **direct** hints
  - production - Interference
- **Seeking** for **indirect** hints
  - Electroweak precision observables

# 2HDM versus LHC data – natural flavor conservation

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

Type I | Type II | lepton–specific | flipped

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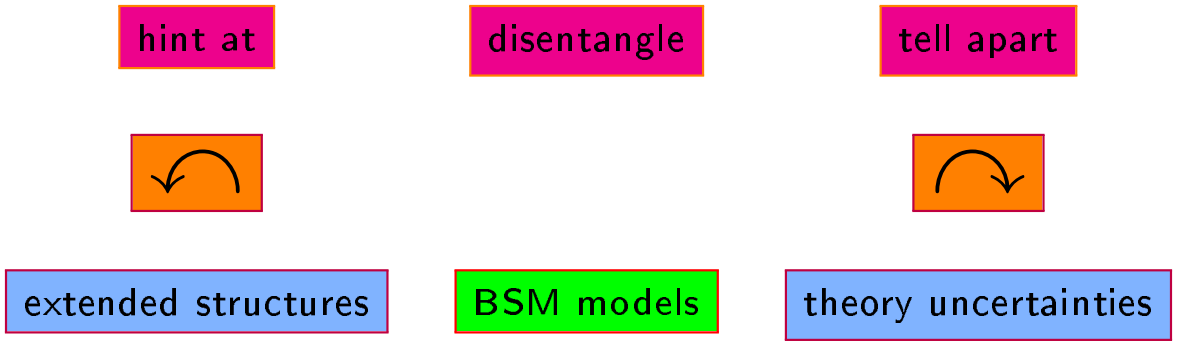
# Signal strength correlations

- **Correlations** in the **signal strength plane**



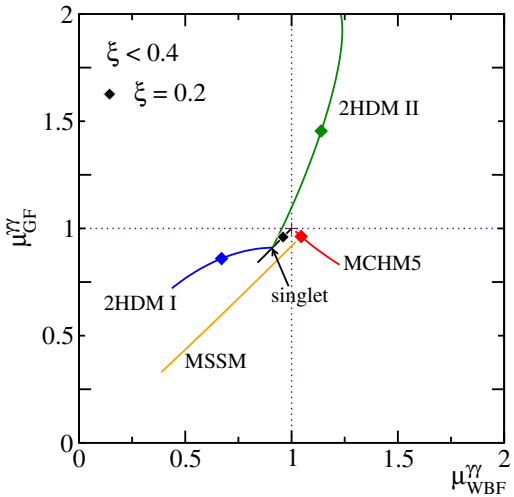
# Signal strength correlations

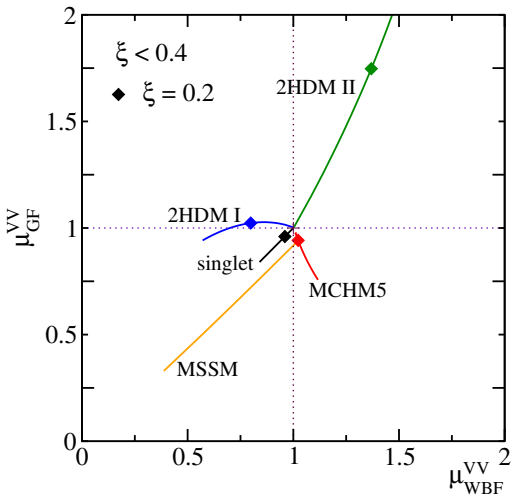
- **Correlations** in the **signal strength plane**

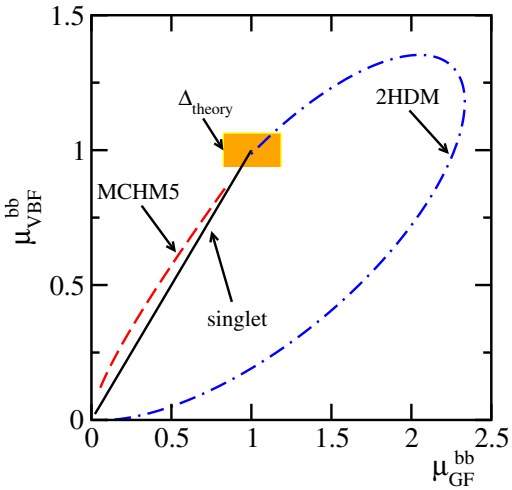
**hint at** ↶ **extended structures**

**disentangle** **BSM models**

**tell apart** ↷ **theory uncertainties**




[K. Cranmer, S. Kreiss, DLV, T. Plehn, in preparation]

# Heavy scalars: predictions, tools & searches

New signatures $\Leftarrow$ **HEAVY SCALARS** $\Rightarrow$ Deviations from SM

## Manifold onworking directions @ CP3

- Automated & improved predictions for loop–induced channels: [Hespel, Maltoni, Vryonidou]
- NLO predictions for EFT's: [Demartini, Maltoni]
- **S-B Interference** & **finite** $\Gamma$ effects: [Buarque Franzosi, Frixione, DLV, Maltoni, Zhang]
- Direct searches: $pp \to \mathbf{H^0} \to \mathbf{A^0}(b\bar{b}, \tau\bar{\tau})\mathbf{Z}^0$ [Delaere, Castello, Caudron, du Pree; Bruno, Jez, Perrini, Quertenmont]

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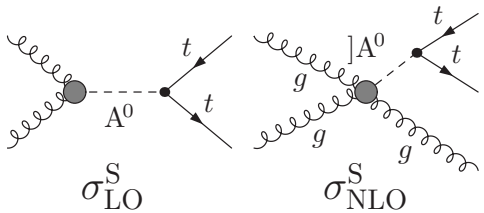


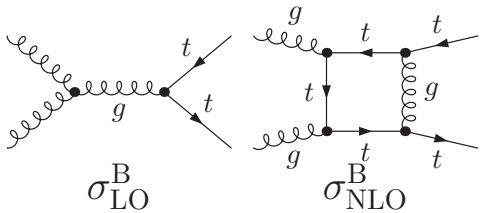


♠ $S - B$ interference

♠ Finite $\Gamma(A^0)$ effects

# Electroweak precision observables

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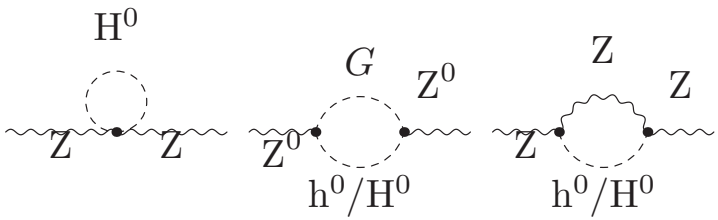


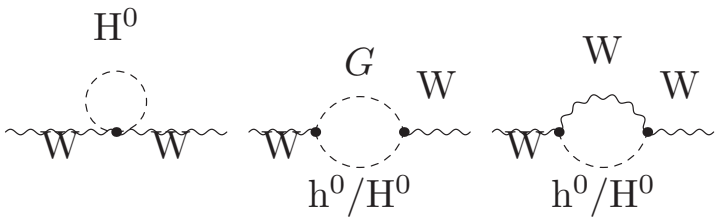


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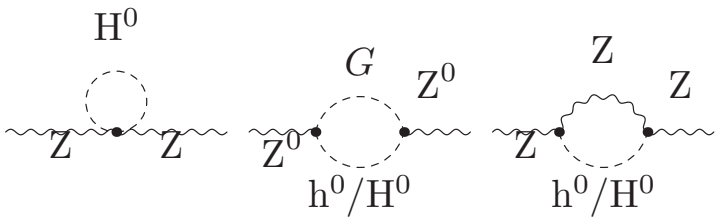


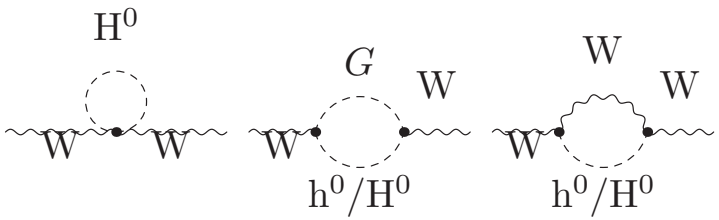


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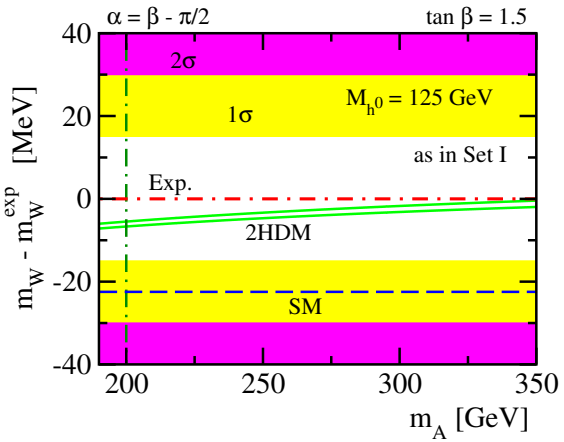


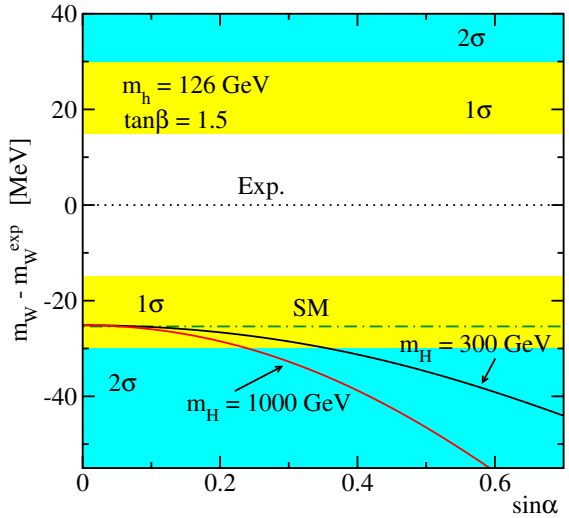


DLV, J. Solà ['12]; DLV, in progress

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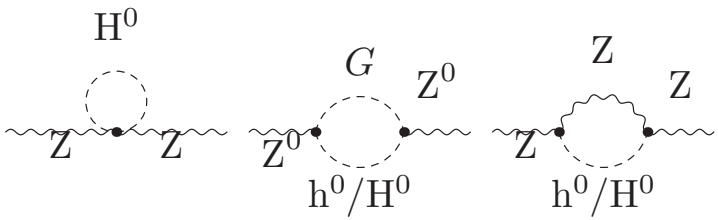
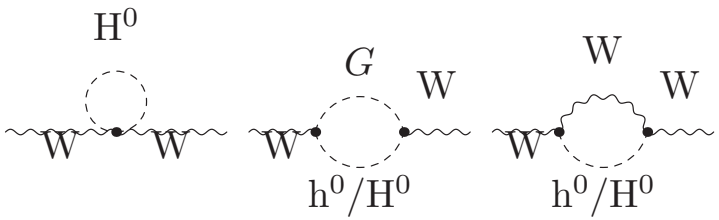
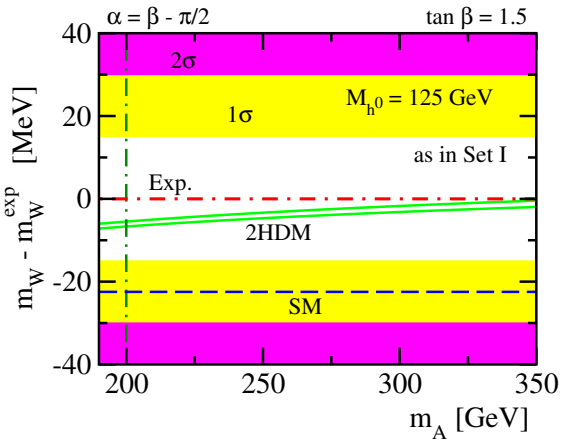
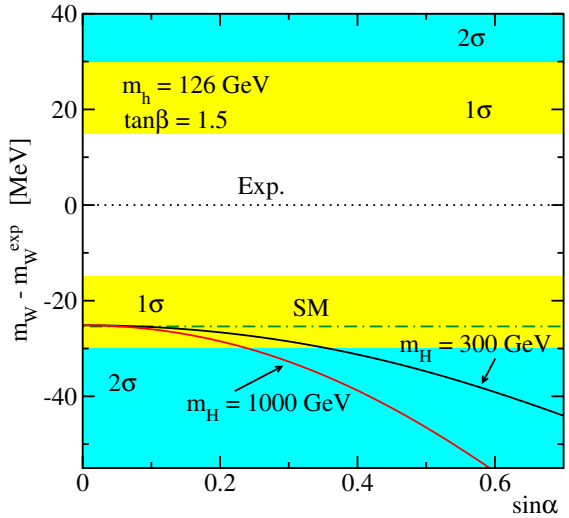



$$m_{\text{W}}^2 \left(1 - \frac{m_{\text{W}}^2}{m_Z^2}\right) = \frac{\pi\alpha}{\sqrt{2}G_F}\,(1+\Delta r)\ .$$

$$\delta m_{\text{W}}^{\text{BSM}} \simeq -\frac{1}{2}\,m_{\text{W}}\,\frac{s_W^2}{c_W^2 - s_W^2}\,\delta(\Delta r^{\text{BSM}})\,,$$




DLV, J. Solà ['12]; DLV, in progress

More @CP3: multiscalar sectors & flavor physics [Cerveró, Gérard]

# Outline

1. Motivation & context
2. Structures
3. Probes
   - Fits to LHC data
   - Signal strength correlations
   - Direct production & interference
   - Electroweak precision
4. Summary

# Take–home ideas

## Multiscalars into context

- Building on an **evidence** – 126 **GeV** resonance with **SM–like** decays
- Underpinning its **identity** – mass – quantum numbers – interactions
- Back to basics: – single or multiple ? fundamental or composite ?
  weakly or strongly coupled ? what about its mass ? what about its VEV ?

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**Telltale footprints**

- ♠ modified coupling patterns
- ♠ heavy resonances

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♣ At CP3 we are keen on multiscalars – stay with us! We'll keep reporting!

# Thank you & Merry Christmas !