Heavy BSM Higgs: mixing with EW singlet

An attempt for a strategy and many questions

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the next step

❑ Considering mixing with EW singlet (once this is settled we can move to next obvious extension: 2HDM)

All work based on the document in preparation by Grojean, Kumar, Logan for the YR3

• Starting the most direct/minimalistic extension of the SM case

-> **simple reinterpretation of the results of SM heavy Higgs search** (no new optimization)

• We need something "reasonable": this is not about precision measurement, we want just **the most optimal way to set limits**:

if something is not known, we just need to assume **proper systematics** to cover it

if excess observed we will have to go back and be more specific/detailed

SM Higgs mixed with EW singlet

Two resonances with couplings rescaled wrt to SM

- coupling of h126 (h) = C × SM
- coupling of heavy Higgs (H) ~ C' × SM

(same rescaling for couplings to fermions and bosons)

- unitarization: $C'^2 + C^2 = 1$, ie $C' = \cos\theta$, $C = \sin\theta$ **-> 1 free parameter: θ mixing angle**

- heavy Higgs **width and cross-section directly rescaled with $\cos^2\theta$**

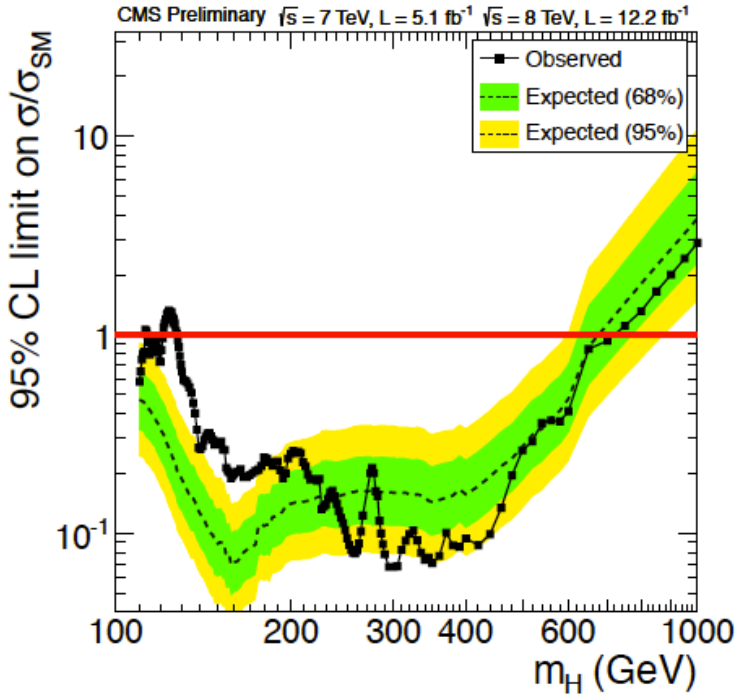
$\mu_H' = \cos^2\theta \times \mu_H^{SM}$

signal strength rescaled

$\Gamma_H' = \cos^2\theta \times \Gamma_H^{SM}$

very narrow width possible

- direct heavy Higgs search can be reinterpreted in this BSM scenarios as limit on mixing angle
  - different width and different rescaling of S and I with $\cos\theta$
  - a UL plot on μ_H' (ie $\cos^2\theta$) for each m_H (similarly to the SM case)



Limits on BSM heavy Higgs from h126 couplings

CMS HIG-12-045, ATLAS-CONF 2012-170

❑ Observation of **h126 put experimental limits on value of mixing angle** (on possible width and xsec range for heavy mass search)

Measured signal strength (HCP):

$\mu_{CMS} = 0.88 \pm 0.21$

$\mu_{ATLAS} = 1.35 \pm 0.24$

$\mu_h' = 1 - \mu'_H$ -> $\mu'_H < 0.37$ (0.75) at 3σ in ATLAS (CMS)

❑ **Common fit to low mass observed h126 and direct high mass searches**

Decay to new particle

HXSWG, in preparation

Two resonances with couplings rescaled wrt to SM

- coupling of h126 (h) = C × SM
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(same rescaling for couplings to fermions and bosons)

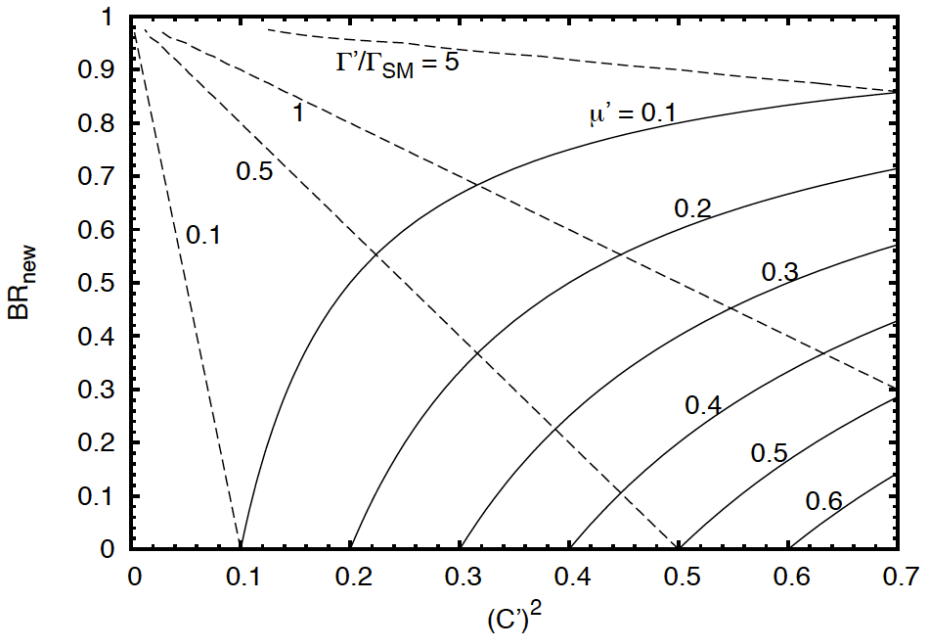
- unitarization: $C'^2 + C^2 = 1$, ie $C' = \cos\theta$, $C = \sin\theta$ **-> 1 free parameter: θ mixing angle**
- considering **H->h1 h1 decay (+ new unknown decays)**

-> 1 additional free parameter (BR_{new})

➢ heavy Higgs search in **2 parameters space for each mH hypotesis**

$$\mu' = C'^2(1 - \mathrm{BR}_{new})$$
$$\Gamma'_{tot} = \frac{C'^2}{(1 - \mathrm{BR}_{new})}\Gamma_{\mathrm{SM}}.$$

width may be even larger than SM



BR_{new}

CAN WE CONSIDER THE ORIGINAL MODEL WITH EW SINGLET MIXING WITHOUT BR_{new} ??? WHAT ABOUT H->hh ??

BR_{new}=0

-> just one free parameter: width and couplings are directly related
(ie scan in width is equivalent to scan in couplings)

BR_{new}>0

-> width can change separately, independent from couplings
If so, is there any limit on BR_{new} from direct measurements or from theoretical constraint?
(BR_{new} -> 1 gives infinite width)

Lineshape and interference

- Proper MC is under development
  - gg2VV, aMC@NLO
  - attempt in CMS to use MCFM (see CMS talk)

- Reweigthing to reuse existing MC

  - SM lineshape using CPS -> fit with running Breit-Wigner -> rescale the width of the fit results and use that as new shape

    PROBLEM: NO CLEAR CONNECTION BETWEEN THE FIT WIDTH AND THE SM WIDTH (do we care?)

  - Interference from LO SM MC rescaled by $S_{SM} \times \cos^2\theta + I_{SM} \times \cos\theta$

    QUESTION: WOULD THE S/I RESCALING BE DIFFERENT IF Brnew>0 , ie IF THE WIDTH IS LARGER THAN $\cos^2\theta \times \Gamma_H^{SM}$?

- Since the width may be narrow, does it make sense to go above mH = 1 TeV?

(N)NLO effects

❑ How to treat NLO effects in this BSM model ? Everything as in the SM, except one additional resonance at high mass

- **CAN WE KEEP SAME XSEC UNCERTAINTY AS FOR SM CASE?**
- **CAN WE KEEP SAME PT SPECTRUM AND UNCERTAINTY AS IN SM?**
- **CAN WE KEEP SAME LINESHAPE REWEIGTHING STRATEGY AS IN SM?**

$K \times S_{SM} \times \cos^2\theta + K' \times I_{SM} \times \cos\theta$ (central)

$K \times S_{SM} \times \cos^2\theta + I_{SM} \times \cos\theta$ (additive)

$K \times S_{SM} \times \cos^2\theta + K \times I_{SM} \times \cos\theta$ (multiplicative)

or would also K and K' be different than SM in this BSM model?

Questions

- Can we use the current SM MCs by rescaling the width? Which width? The CPS?
- Or do we need new MC samples to include a new lagrangian with new couplings?
- Which are the constraints on the possible width (a part from not being bigger than SM width)?
- Can we start by considering BR'=0 (i.e no H->hh decay)or should it be treated as a free parameter?
- How do the other BR change wrt SM? Do they scale as a function of theta?
- How to account for the interference effect? Can we put a limit and saying that it cannot be bigger than the SM case?
- Can we build a recipe similar to the SM case?
- Could we just extrapolate from the SM case like
  - K * S_sm *sinTheta^2+ K' * I_sm *sinTheta : central
  - K * S_sm *sinTheta^2+ I_sm *sinTheta: additive
  - K * S_sm *sinTheta^2+ K * I_sm *sinTheta: multiplicative

  or would also K and K' be rescaled?
- In these BSM models when the width is narrow, does it make sense to go above 1 TeV?

Heavy Higgs benchmarks

How the interference effect rescale with the width?

Under the assumption that the Heavy Higgs coupling is modified wrt SM, but has the same SM structure

- The cross sections scale like

$$\sigma_B \longrightarrow |\mathcal{A}_{\rm box}|^2 \ ,$$
$$\sigma_H \longrightarrow |\mathcal{A}_{\rm Higgs}|^2 \ ,$$
$$\sigma_i \longrightarrow 2{\rm Re}\left(\mathcal{A}_{\rm Higgs}\mathcal{A}^*_{\rm box}\right) \ ,$$
$$\sigma_{H,i} = \sigma_H + \sigma_i \ .$$

- The interference term $\mathcal{A}_{\rm Higgs}$ depends also from the widths that scale with couplings like

$$\Gamma(h_1 \to WW) = (C_W^{h_1})^2 \Gamma(H_{\rm SM} \to WW)$$

If the Higgs coupling is rescaled
→ $\mathcal{A}_{\rm Higgs}$ will be rescaled
→ ***It is important to study the interference effect as a function of the couplings***