Resonances all over the place? (II)

G. Moultaka

Laboratoire Univers & Particules de Montpellier (LUPM)
CNRS & University of Montepllier

work in collaboration with A. Kundu & P. Mondal

and a lot...a lot of discussions with F. Richard

PASCOS2024
ICISE, Quy Nhon, Vietnam, July 7-13 2024

Large number of searches for new resonances at the LHC

$\Downarrow$

Excesses $\gtrsim 2\sigma$

fluctuations or smoking guns?

THIS TALK IS AN EXERCISE

THIS TALK IS AN EXERCISE

assuming several excesses are smoking guns

for two, perhaps three, new scalar resonances

&

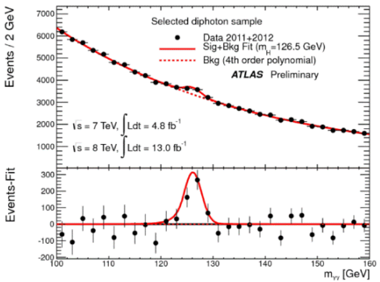
Implications

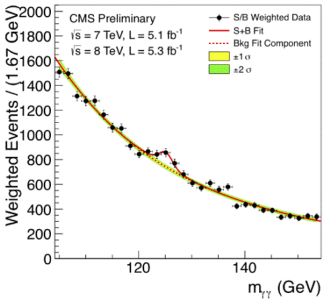
Outline

Introductory motivations

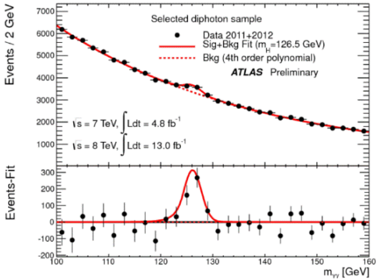
Many motivations to go beyond the SM, that we all know!

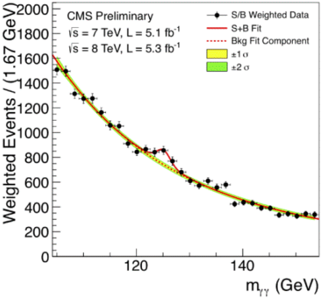
Introductory motivations





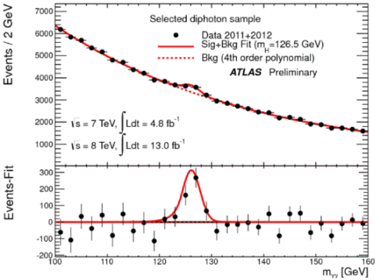
Introductory motivations

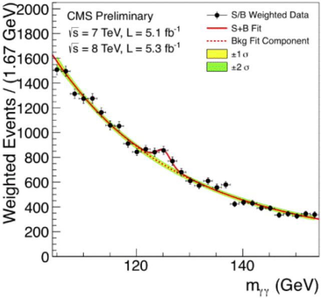




a 'theorem' by Nelson Mandela

Introductory motivations

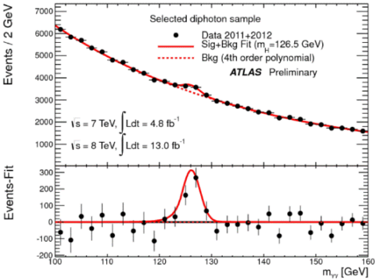


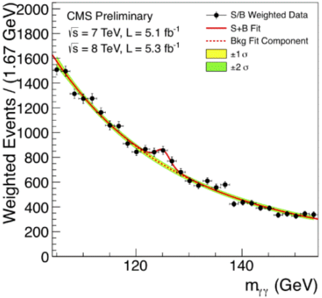


a 'theorem' by Nelson Mandela

(not to be confused with the Coleman-Mandula theorem)

Introductory motivations





The experimental indications

New scalar	Process studied	Local Significance	Global Significance	Combined Significance	Reference
h_{95}	$\to \gamma\gamma$	2.9σ	1.3σ		[6, 7, 18]
	$\to \tau^+\tau^-$	2.6-3.1 σ	2.3-2.7 σ	2.4-2.75 σ	[8]
	$Z^* \to Zh_{95} \to Zb\bar{b}$	2.3σ	not quoted	3.1-3.4 σ	[33]
H_{650}	VBF, $\to W^+W^-$	3.8σ	$(2.6 \pm 0.2)\,\sigma$		[12]
	$\to ZZ$	2.4σ	0.9σ	$\left(4.08^{+0.12}_{-0.11}\right)\sigma$	[10, 11]
	$\to h_{95}h_{125}$	3.8σ	2.8σ		[13]
	$\to A_{400}Z \to \ell^+\ell^- t\bar{t}$	2.85σ	2.35σ		[16]
A_{400}	$\to t\bar{t}$	3.5σ	1.9σ	3.17σ	[14]
	$\to ZH_{320} \to Zh_{125}h_{125}$	3.8σ	2.8σ		[15]

Combined Significance= our combination of global significances

[6,7,18] CMS-PAS-HIG-14-037; CMS [arXiv:1811.08459 [hep-ex]]; T. Biekötter et al. [arXiv:2203.13180 [hep-ph]]; + many more
[8] CMS-PAS-HIG-21-001
[33] LEP [arXiv:hep-ex/0306033 [hep-ex]]
[12] CMS-PAS-HIG-20-016
[10,11] ATLAS [arXiv:2009.14791 [hep-ex]], [arXiv:2103.01918 [hep-ex]]
[13] CMS-PAS-HIG-21-011
[16] ATLAS [arXiv:2311.04033 [hep-ex]]
[14] CMS [arXiv:1908.01115 [hep-ex]]
[15] ATLAS-CONF-2022-043

Before proceeding with the exercise, let us exorcise something...

A 750 syndrome?

2015 data: diphoton narrow resonance @ $M_{\mathcal{F}} \simeq 750 GeV$
$\rightarrow$ s.d. : ATLAS 3.8-3.9 (2.1) AND CMS 3.4 (1.6)
$\rightarrow$ 'combined' gave $\sim$ 4.9s.d. AND $\mathcal{O}\left(\frac{2}{3} M_{\mathcal{F}}/(1 GeV)\right)$ theory papers with as many models interpreting the observation!!

A 750 syndrome?

2015 data: diphoton narrow resonance @ $M_{\mathcal{F}} \simeq 750 GeV$
$\rightarrow$ s.d. : ATLAS 3.8-3.9 (2.1) AND CMS 3.4 (1.6)
$\rightarrow$ 'combined' gave $\sim$ 4.9s.d. AND $\mathcal{O}\left(\frac{2}{3} M_{\mathcal{F}}/(1 GeV)\right)$ theory papers with as many models interpreting the observation!!

2016 data:

A 750 syndrome?

2015 data: diphoton narrow resonance @ $M_{\mathcal{F}} \simeq 750 GeV$
$\rightarrow$ s.d. : ATLAS 3.8-3.9 (2.1) AND CMS 3.4 (1.6)
$\rightarrow$ 'combined' gave $\sim$ 4.9s.d. AND $\mathcal{O}\left(\frac{2}{3} M_{\mathcal{F}}/(1 GeV)\right)$ theory papers with as many models interpreting the observation!!

2016 data:

A 750 syndrome?

2015 data: diphoton narrow resonance @ $M_{\mathcal{F}} \simeq 750 GeV$
$\rightarrow$ s.d. : ATLAS 3.8-3.9 (2.1) AND CMS 3.4 (1.6)
$\rightarrow$ 'combined' gave $\sim$ 4.9s.d. AND $\mathcal{O}\left(\frac{2}{3} M_{\mathcal{F}}/(1 GeV)\right)$ theory papers with as many models interpreting the observation!!

2016 data:

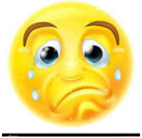
can we ever hope for such another Syzygy??

A 750 syndrome?

2015 data: diphoton narrow resonance @ $M_{\mathcal{F}} \simeq 750 GeV$
$\rightarrow$ s.d. : ATLAS 3.8-3.9 (2.1) AND CMS 3.4 (1.6)
$\rightarrow$ 'combined' gave $\sim$ 4.9s.d. AND $\mathcal{O}\left(\frac{2}{3} M_{\mathcal{F}}/(1 GeV)\right)$ theory papers with as many models interpreting the observation!!

2016 data:

can we ever hope for such another Syzygy??



CMS PAS HIG-20-016 (2022/03/11)

Table 3: Summary of the signal hypotheses with highest local significance for each f_{VBF} scenario. For each signal hypothesis the resonance mass, production cross sections, and the local and global significances are given.

Scenario	Mass [GeV]	ggF cross sec. [pb]	VBF cross sec. [pb]	Local signi. [σ]	Global signi. [σ]
SM f_{VBF}	800	0.16	0.057	3.2	1.7 ± 0.2
$f_{VBF} = 1$	650	0.0	0.16	3.8	2.6 ± 0.2
$f_{VBF} = 0$	950	0.19	0.0	2.6	0.4 ± 0.6
floating f_{VBF}	650	2.9×10^{-6}	0.16	3.8	2.4 ± 0.2

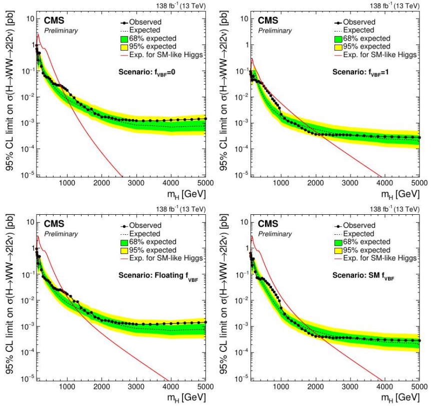


Figure 4: Limits using the combined Run 2 data set for the $f_{VBF} = 0$ (top left), $f_{VBF} = 1$ (top right), floating f_{VBF} (bottom left) and the SM f_{VBF} scenarios (bottom right).

11 Summary

We performed a search for a high mass Higgs boson decaying into a pair of W bosons in the dileptonic channel. We observe an upward fluctuation of data compared to the expected background. The signal hypothesis with the highest significance corresponds to a resonance mass of 650 GeV in the scenario where only VBF production is considered. The global significance of this excess is 2.6 σ.

The presence of a heavy SM-like Higgs boson is excluded at 95% CL up to 2100 GeV, assuming the relative contribution of ggF and VBF production is SM-like and also assuming only VBF production. The exclusion is up to about 800 GeV when considering only ggF production. In the case where the ratio between ggF and VBF production is left floating in the fit, an exclusion of up to 900 GeV is observed.

In MSSM scenarios the analysis is sensitive at low values of m_A and $\tan\beta$ and the exclusion limits extend up to $m_A = 450$ GeV. For m_A between 150 GeV and 400 GeV, we exclude values of $\tan\beta$ between 10 and 3. The sensitivity is similar between the M_h^{125}, $M_h^{125}(\tilde{\chi})$, $M_h^{125}(\tilde{\tau})$, $M_{h,EFT}^{125}$ and $M_{h,EFT}^{125}(\tilde{\chi})$ scenarios. In the M_h^{125}(alignment) scenario, the exclusion limits reach to about $m_A = 400$ GeV.

In THDM scenarios, the limits show an exclusion of up to 750 GeV in THDMs of both Type-I and Type-II. For $\cos(\beta - \alpha) = 0.1$, the limits in $\tan\beta$ extend up to 4 in Type-II and up to 5 in Type-I, with the sensitivity generally becoming lower for higher masses of H. The sensitivity over $\tan\beta$ varies more strongly as a function of $\cos(\beta - \alpha)$.

Extrapolation studies were performed to evaluate the expected gain in sensitivity for the Phase-2 operations of the HL-LHC. The upper limits on the product of the cross section and branching ratio of a new resonance are expected to be improved by almost one order of magnitude. The expected exclusion range in MSSM scenarios increases by only about 50 GeV along the m_A axis. The increase in sensitivity is more noticeable for a general THDM, with the exclusion extending from 1000 GeV up to 1500 GeV for low values of $\tan\beta$.

Models?...Model?

Models?...Model?

- While an h_{95} object could be accounted for within several (SUSY or non-SUSY) model settings, doublets,...

Models?...Model?

- While an h_{95} object could be accounted for within several (SUSY or non-SUSY) model settings, doublets,...
- H_{650} is more rebellious!

Models?...Model?

- While an h_{95} object could be accounted for within several (SUSY or non-SUSY) model settings, doublets,...

- H_{650} is more rebellious!

- coupling to WW very close to SM-like $\rightarrow$ potential violation of unitarity sum rules for WW scattering!

Models?...Model?

- While an h_{95} object could be accounted for within several (SUSY or non-SUSY) model settings, doublets,...
- H_{650} is more rebellious!
- coupling to WW very close to SM-like $\rightarrow$ potential violation of unitarity sum rules for WW scattering!

$$\underset{\text{(SM)}}{g^2_{WWh}} = \sum_i g^2_{W^+W^-\phi^0_i}$$

Models?...Model?

- While an h_{95} object could be accounted for within several (SUSY or non-SUSY) model settings, doublets,...
- H_{650} is more rebellious!
- coupling to WW very close to SM-like $\rightarrow$ potential violation of unitarity sum rules for WW scattering!

$$\underset{\text{(SM)}}{g^2_{WWh}} = \sum_i g^2_{W^+W^-\phi_i^0} - \sum_k |g_{W^-W^-\phi_k{}^{++}}|^2$$

$\rightarrow$ at least one doubly-charged scalar is needed!

Models?...Model?

$\rightarrow$ a consistent model needs (at least one) $\mathrm{SU(2)_L}$ triplet

Models?...Model?

$\rightarrow$ a consistent model needs (at least one) $\mathrm{SU(2)_L}$ triplet

$\rightarrow$ only one (e.g. Type II seesaw) would not work: $\rho \simeq 1 \Rightarrow$ single production of H_{650} suppressed

Models?...Model?

$\rightarrow$ a consistent model needs (at least one) $\mathrm{SU}(2)_{\mathrm{L}}$ triplet

$\rightarrow$ only one (e.g. Type II seesaw) would not work: $\rho \simeq 1 \Rightarrow$ single production of H_{650} suppressed

$\rightarrow$ two (e.g. Georgi-Machacek) disfavored, $H_{650}ZZ \sim 2.6 \times H_{650}WW$

Models?...Model?

$\rightarrow$ a consistent model needs (at least one) $\mathrm{SU(2)_L}$ triplet

$\rightarrow$ only one (e.g. Type II seesaw) would not work: $\rho \simeq 1 \Rightarrow$ single production of H_{650} suppressed

$\rightarrow$ two (e.g. Georgi-Machacek) disfavored, $H_{650}ZZ \sim 2.6 \times H_{650}WW$

$\rightarrow$ two triplets + one extra doublet?

Models?...Model?

$\rightarrow$ a consistent model needs (at least one) $\mathrm{SU}(2)_{\mathrm{L}}$ triplet

$\rightarrow$ only one (e.g. Type II seesaw) would not work: $\rho \simeq 1 \Rightarrow$ single production of H_{650} suppressed

$\rightarrow$ two (e.g. Georgi-Machacek) disfavored, $H_{650}ZZ \sim 2.6 \times H_{650}WW$

$\rightarrow$ two triplets + one extra doublet?

$\rightarrow$ opens up new possibilities: can fit the three (CP-even) states h_{125}, h_{95}, H_{650} + an extra H_{320}

a Model

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix}, \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}, X = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ -\chi^{+*} & \xi^0 & \chi^+ \\ \chi^{++*} & -\xi^{+*} & \chi^0 \end{pmatrix}$$

$$\begin{pmatrix} \mathcal{H}_1 \\ \mathcal{H}_2 \\ \mathcal{H}_3 \\ \mathcal{H}_4 \end{pmatrix} = \mathcal{X}_{4\times 4} \begin{pmatrix} \mathrm{Re}\phi_1^0 \\ \mathrm{Re}\phi_2^0 \\ \mathrm{Re}\chi^0 \\ \xi^0 \end{pmatrix}, \quad \mathcal{X}^\dagger \mathcal{X} = \mathcal{X}\mathcal{X}^\dagger = 1, \quad [\mathcal{X}]_{ij} \equiv x_{ij}$$

a Model

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix}, \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}, X = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ -\chi^{+*} & \xi^0 & \chi^+ \\ \chi^{++*} & -\xi^{+*} & \chi^0 \end{pmatrix}$$

$$\begin{pmatrix} \mathcal{H}_1 \\ \mathcal{H}_2 \\ \mathcal{H}_3 \\ \mathcal{H}_4 \end{pmatrix} = \mathcal{X}_{4\times 4} \begin{pmatrix} \mathrm{Re}\phi_1^0 \\ \mathrm{Re}\phi_2^0 \\ \mathrm{Re}\chi^0 \\ \xi^0 \end{pmatrix}, \quad \mathcal{X}^\dagger \mathcal{X} = \mathcal{X}\mathcal{X}^\dagger = 1, \quad [\mathcal{X}]_{ij} \equiv x_{ij}$$

$\rightarrow$ Identify $\mathcal{H}_{a=1,\dots,4} = (h_{95}, h_{125}, H_{320}, H_{650})$

a Model

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix}, \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}, X = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ -\chi^{+*} & \xi^0 & \chi^+ \\ \chi^{++*} & -\xi^{+*} & \chi^0 \end{pmatrix}$$

$$\begin{pmatrix} \mathcal{H}_1 \\ \mathcal{H}_2 \\ \mathcal{H}_3 \\ \mathcal{H}_4 \end{pmatrix} = \mathcal{X}_{4\times 4} \begin{pmatrix} \mathrm{Re}\phi_1^0 \\ \mathrm{Re}\phi_2^0 \\ \mathrm{Re}\chi^0 \\ \xi^0 \end{pmatrix}, \quad \mathcal{X}^\dagger \mathcal{X} = \mathcal{X}\mathcal{X}^\dagger = 1, \ \ [\mathcal{X}]_{ij} \equiv x_{ij}$$

→ Identify $\mathcal{H}_{a=1,\ldots,4} = (h_{95}, h_{125}, H_{320}, H_{650})$

→ extended Georgi-Machacek, $\langle \phi_1^0 \rangle \sim v_1, \langle \phi_2^0 \rangle \sim v_2, \langle \chi \rangle = \langle \xi \rangle \sim u$

→ 4 CP-even, 2 CP-odd, 3 charged and 1 doubly-charged scalars

a Model

Coupling to two gauge bosons

$$\mathcal{L}_{\rm cubic} = \frac{g^2 v_1}{2\sqrt{2}} S_1 \, W \cdot W + \frac{g^2 v_2}{2\sqrt{2}} S_2 \, W \cdot W + \frac{2 g^2 u}{\sqrt{3}} S_3 \, W \cdot W + g^2 u \, [W \otimes W] \cdot F$$

$$\begin{aligned} v \kappa_W^{\mathcal{H}_a} =& v_1 x_{a1} + v_2 x_{a2} + 2u(x_{a3} + \sqrt{2} x_{a4}), \\ v \kappa_Z^{\mathcal{H}_a} =& v_1 x_{a1} + v_2 x_{a2} + 4u x_{a3}, \\ v^2 =& v_1^2 + v_2^2 + 4u^2 \simeq \left(\frac{246}{\sqrt{2}}\right)^2, \end{aligned}$$

Yukawa couplings:

$$\text{Type}-\text{II 2HDM}-\text{like}: \quad \kappa_d^{\mathcal{H}_a} = \frac{v}{v_1} x_{a1} \, , \quad \kappa_u^{\mathcal{H}_a} = \frac{v}{v_2} x_{a2}$$

$$\text{Type}-\text{I 2HDM}-\text{like}: \quad \kappa_d^{\mathcal{H}_a} = \kappa_u^{\mathcal{H}_a} = \frac{v}{v_2} x_{a2}$$

SM-like h_{125}

$$v\kappa_W^{h_{125}} = v_1 x_{21} + v_2 x_{22} + 2u(x_{23} + \sqrt{2}x_{24}),$$
$$v\kappa_Z^{h_{125}} = v_1 x_{21} + v_2 x_{22} + 4u x_{23}$$
$$v^2 = v_1^2 + v_2^2 + 4u^2 \simeq \left(246/\sqrt{2}\right)^2$$

$$\kappa_W^{h_{125}} \simeq \kappa_Z^{h_{125}} \simeq 1 \Rightarrow x_{23} - \sqrt{2}x_{24} = 0$$

$$\mathrm{Type-II\,2HDM} \Rightarrow u^2 = \frac{3}{4}\frac{1-\kappa_Z^{h_{125}}}{3 - sign(u)2\sqrt{6}} v^2 \Rightarrow u\,\mathrm{verysmall} \rightarrow \mathrm{disfavored}$$

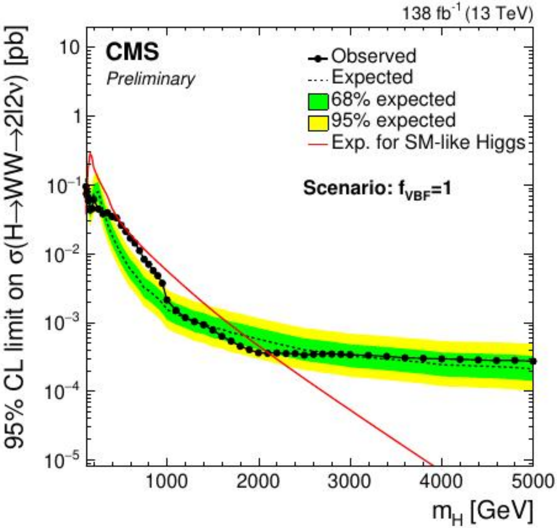
scan strategy

- Stick to Type-I 2HDM-like
- Take $\mathcal{X}$ real, orthogonal
- Needs 6 input: e.g. $\kappa_t^{h_{125}}, \kappa_Z^{h_{125}}, \kappa_W^{h_{125}}, \kappa_t^{h_{95}}, \kappa_W^{h_{95}}, \kappa_W^{H_{650}}$
- $h_{125} \Rightarrow u, v_1, v_2, x_{2i}{}'s$
- subspace orthogonal to x_{2i}, and $h_{95} \Rightarrow x_{1i}{}'s$
- subspace orthogonal to x_{1i}, x_{2i}, and $H_{650} \Rightarrow$ determines $x_{3i}{}'s$ and $x_{4i}{}'s$, four-fold solutions.
- check compatibility with experimental indications

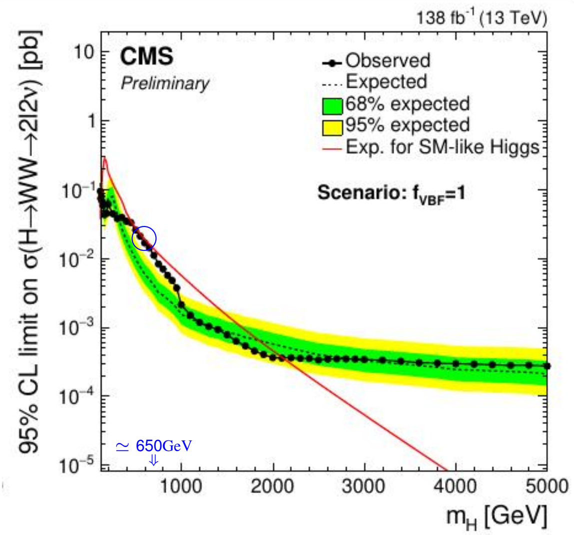
$$\mu_{\gamma\gamma} = \frac{\sigma(pp \to h_{95} \to \gamma\gamma)}{\sigma(pp \to \phi \to \gamma\gamma)} = 0.33^{+0.19}_{-0.12} \,, \qquad \text{[LHC } h_{95}\text{]}$$

$$\mu_{\tau^+\tau^-} = \frac{\sigma(pp \to h_{95} \to \tau^+\tau^-)}{\sigma(pp \to \phi \to \tau^+\tau^-)} = 1.2 \pm 0.5 \,, \qquad \text{[LHC } h_{95}\text{]}$$

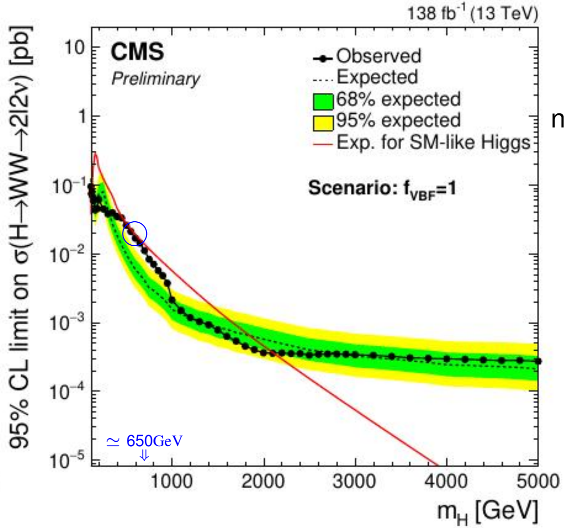
$$\mu_{b\bar{b}} = \frac{\sigma(e^+e^- \to Zh_{95} \to Zb\bar{b})}{\sigma(e^+e^- \to Z\phi \to Zb\bar{b})} = 0.117 \pm 0.057 \qquad \text{[LEP } h_{95}\text{]}$$



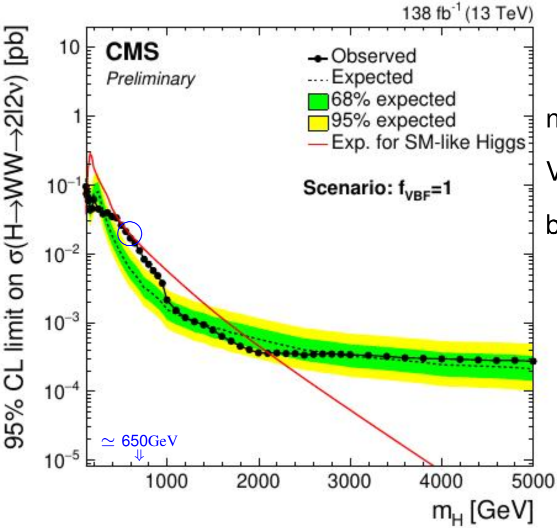
138 fb^{-1} (13 TeV)
CMS
Preliminary
Observed
Expected
68% expected
95% expected
Exp. for SM-like Higgs
Scenario: f_{VBF}=1
95% CL limit on σ(H→WW→2l2ν) [pb]
m_H [GeV]



138 fb-1 (13 TeV)
CMS
Preliminary
Observed
Expected
68% expected
95% expected
Exp. for SM-like Higgs
Scenario: f_VBF=1
≃ 650GeV
95% CL limit on σ(H→WW→2l2ν) [pb]
m_H [GeV]
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
1000
2000
3000
4000
5000



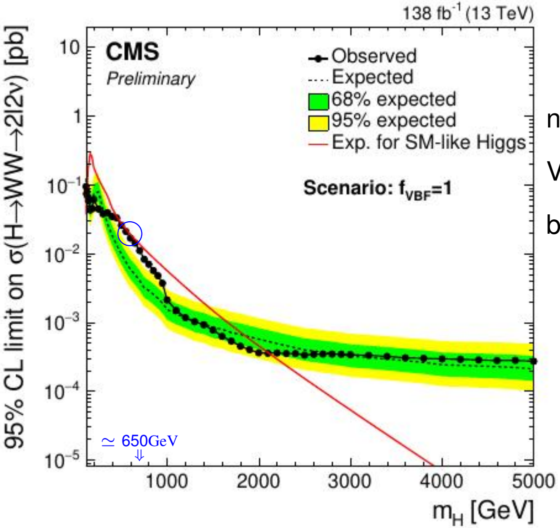
need to separate WBF and ZBF



need to separate WBF and ZBF

VBF-cuts reduce ggF

but also VBF Z/W interference

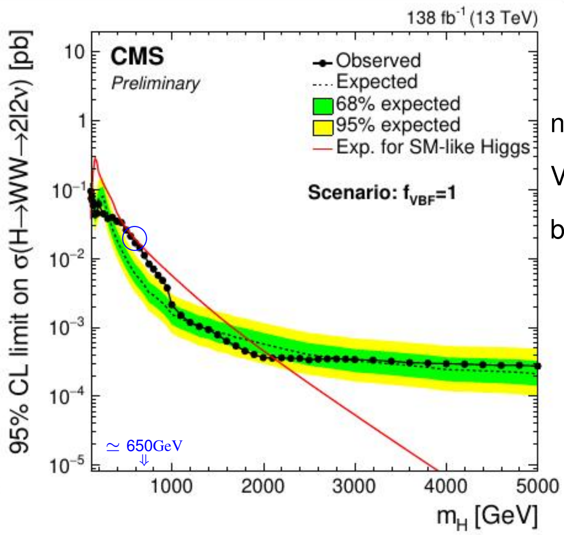


need to separate WBF and ZBF

VBF-cuts reduce ggF

but also VBF Z/W interference

$$\sigma_{\rm VBF} \times {\rm BR}^*{}_{H_{650}\to W^+W^-} = c\,\sigma_{\rm VBF}^{\rm (SM)} \times {\rm BR}^*{}^{\rm (SM)}_{H_{650}\to W^+W^-}$$



need to separate WBF and ZBF

VBF-cuts reduce ggF

but also VBF Z/W interference

$$\sigma_{\rm VBF} \times {\rm BR^*}_{H_{650} \to W^+ W^-} = c\, \sigma^{\rm (SM)}_{\rm VBF} \times {\rm BR^*}^{\rm (SM)}_{H_{650} \to W^+ W^-}$$

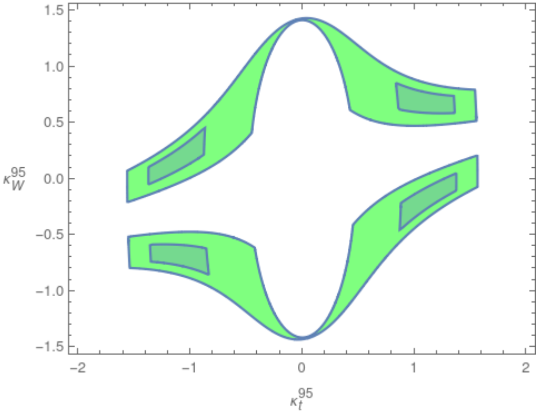
correlations: $\left|\kappa_W^{H_{650}}\right|, \left|\kappa_Z^{H_{650}}\right|, \left|\kappa_t^{H_{650}}\right|, \Rightarrow \left|\kappa_W^{H_{650}}\right| \in [.96, 1.1[$

solutions

- Type-I 2HDM-like
- $\kappa_t^{h_{125}} = .99, \kappa_Z^{h_{125}} = 1.04, \kappa_W^{h_{125}} = 1.02$ [CMS c.v.]
- $|\kappa_t^{h_{95}}| \lesssim 1.6, |\kappa_W^{h_{95}}| \lesssim 1.5$ [LHC h_{95}]
- fixe $\kappa_W^{H_{650}} \Rightarrow |\kappa_Z^{H_{650}}| \left(|\kappa_t^{H_{650}}|\right)$

solutions

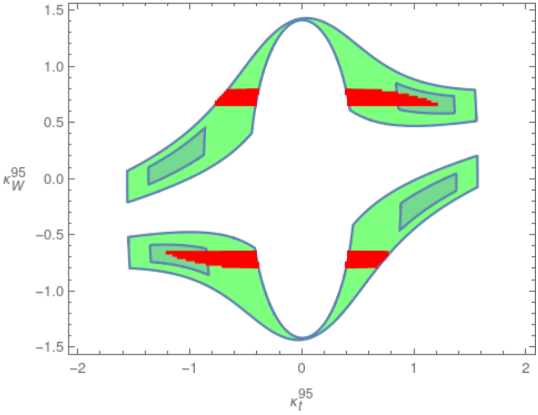
e.g. $\kappa_W^{650} = .97 \rightarrow u \simeq 78\,\text{GeV},\ v_1 \simeq 16\,\text{GeV},\ v_2 \simeq 76\,\text{GeV}$



_ LHC h_{95}

solutions

e.g. $\kappa_W^{650} = .97 \rightarrow u \simeq 78$ GeV, $v_1 \simeq 16$ GeV, $v_2 \simeq 76$ GeV

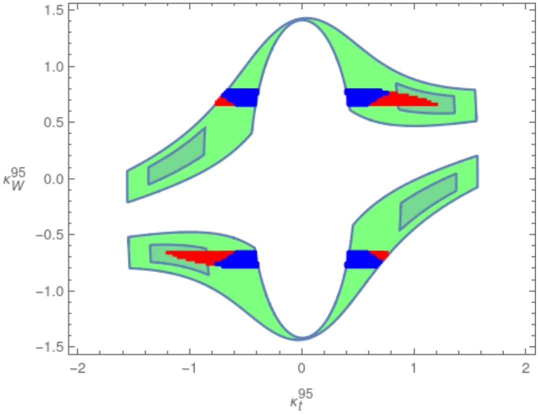


— LHC h_{95}

— $|\kappa_W^{H_{320}}|, |\kappa_Z^{H_{320}}| \leq .45$

solutions

e.g. $\kappa_W^{650} = .97 \rightarrow u \simeq 78$ GeV, $v_1 \simeq 16$ GeV, $v_2 \simeq 76$ GeV



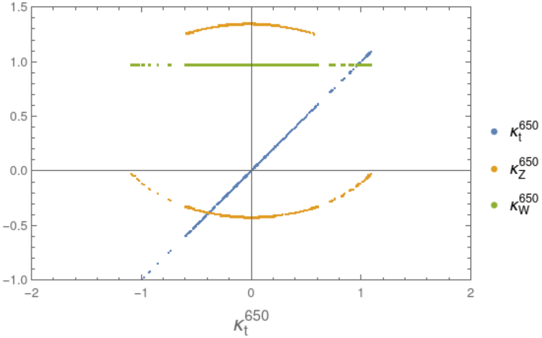
— LHC h_{95}

— $|\kappa_W^{H_{320}}|, |\kappa_Z^{H_{320}}| \leq .45$

— LEP h_{95}

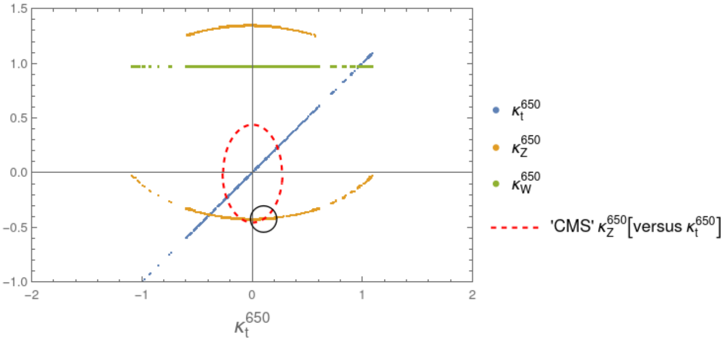
solutions

e.g. $\kappa_W^{650} = .97 \rightarrow u \simeq 78$ GeV, $v_1 \simeq 16$ GeV, $v_2 \simeq 76$ GeV



solutions

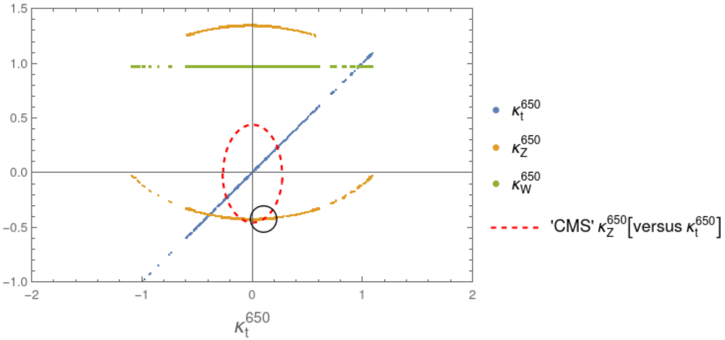
e.g. $\kappa_W^{650} = .97 \rightarrow u \simeq 78$ GeV, $v_1 \simeq 16$ GeV, $v_2 \simeq 76$ GeV



solutions

e.g. $\kappa_W^{650} = .97 \rightarrow u \simeq 78$ GeV, $v_1 \simeq 16$ GeV, $v_2 \simeq 76$ GeV

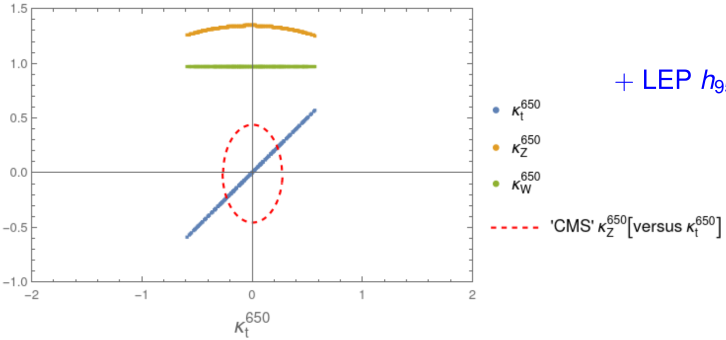
	x_{i1}	x_{i2}	x_{i3}	x_{i4}	κ_t	κ_Z	κ_W
h_{95}	0.6	-0.25	-0.76	-0.01	-0.58	-1.41	-0.74
h_{125}	0.73	0.43	0.44	0.29	0.99	1.04	1.02
H_{320}	0.17	-0.86	0.43	0.2	-1.98	0.4	0.27
H_{650}	-0.26	0.05	-0.23	0.93	0.1	-0.42	0.97



solutions

e.g. $\kappa_W^{650} = .97 \rightarrow u \simeq 78\,\text{GeV},\ v_1 \simeq 16\,\text{GeV},\ v_2 \simeq 76\,\text{GeV}$

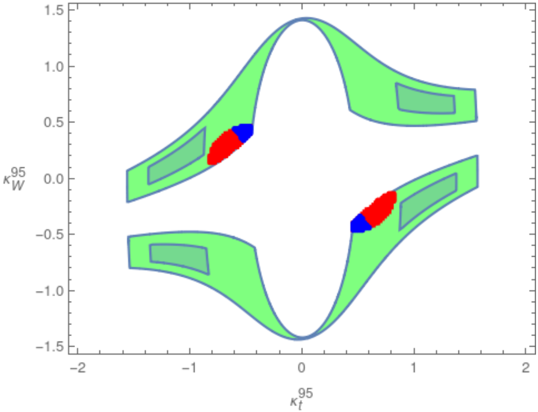
	x_{i1}	x_{i2}	x_{i3}	x_{i4}	κ_t	κ_Z	κ_W
h_{95}	0.6	-0.25	-0.76	-0.01	-0.58	-1.41	-0.74
h_{125}	0.73	0.43	0.44	0.29	0.99	1.04	1.02
H_{320}	0.17	-0.86	0.43	0.2	-1.98	0.4	0.27
H_{650}	-0.26	0.05	-0.23	0.93	0.1	-0.42	0.97



+ LEP h_{95}

solutions

e.g. $\kappa_W^{650} = 1. \rightarrow u \simeq 69\,\text{GeV},\ v_1 \simeq 14\,\text{GeV},\ v_2 \simeq 104\,\text{GeV}$



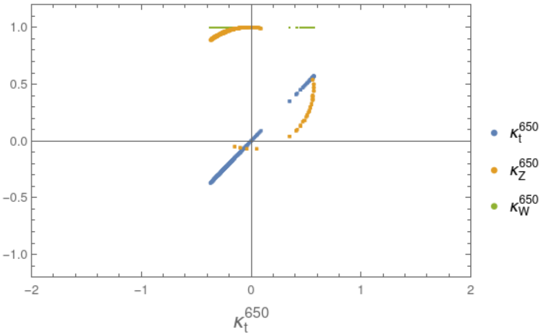
_ LHC h_{95}

_ $|\kappa_W^{H_{320}}|, |\kappa_Z^{H_{320}}| \leq .45$

_ LEP h_{95}

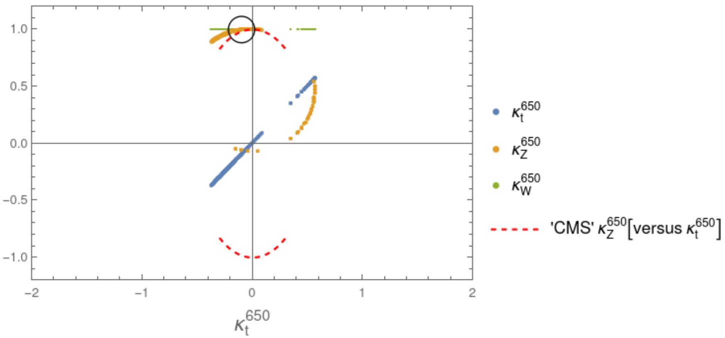
solutions

e.g. $\kappa_W^{650} = 1. \rightarrow u \simeq 69\,\text{GeV},\ v_1 \simeq 14\,\text{GeV},\ v_2 \simeq 104\,\text{GeV}$



solutions

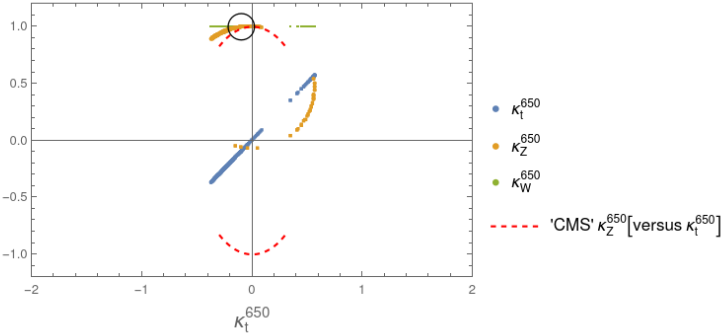
e.g. $\kappa_W^{650} = 1. \rightarrow u \simeq 69\,\mathrm{GeV},\ v_1 \simeq 14\,\mathrm{GeV},\ v_2 \simeq 104\,\mathrm{GeV}$



solutions

e.g. $\kappa_W^{650} = 1. \rightarrow u \simeq 69$ GeV, $v_1 \simeq 14$ GeV, $v_2 \simeq 104$ GeV

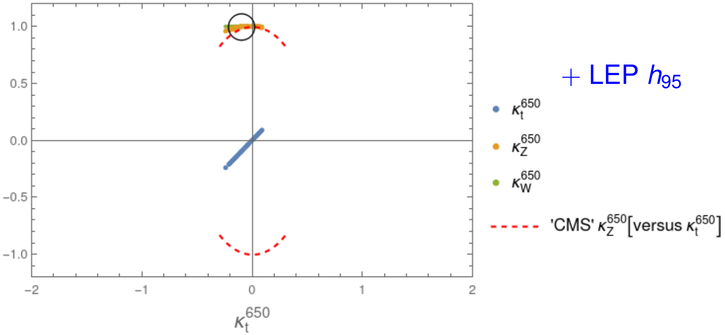
	x_{i1}	x_{i2}	x_{i3}	x_{i4}	κ_t	κ_Z	κ_W
h_{95}	0.23	−0.34	−0.42	0.81	−0.56	−0.85	0.4
h_{125}	0.65	0.59	0.4	0.26	0.99	1.04	1.02
H_{320}	−0.47	0.73	−0.46	0.2	1.21	−0.33	0.26
H_{650}	−0.55	−0.06	0.68	0.48	−0.1	1.	1.



solutions

e.g. $\kappa_W^{650} = 1. \rightarrow u \simeq 69\,\mathrm{GeV},\ v_1 \simeq 14\,\mathrm{GeV},\ v_2 \simeq 104\,\mathrm{GeV}$

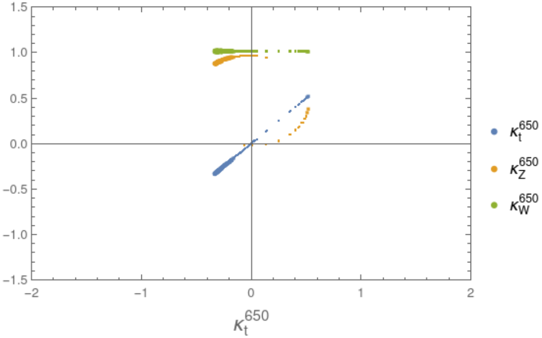
	x_{i1}	x_{i2}	x_{i3}	x_{i4}	κ_t	κ_Z	κ_W
h_{95}	0.23	−0.34	−0.42	0.81	−0.56	−0.85	0.4
h_{125}	0.65	0.59	0.4	0.26	0.99	1.04	1.02
H_{320}	−0.47	0.73	−0.46	0.2	1.21	−0.33	0.26
H_{650}	−0.55	−0.06	0.68	0.48	−0.1	1.	1.



$+$ LEP h_{95}

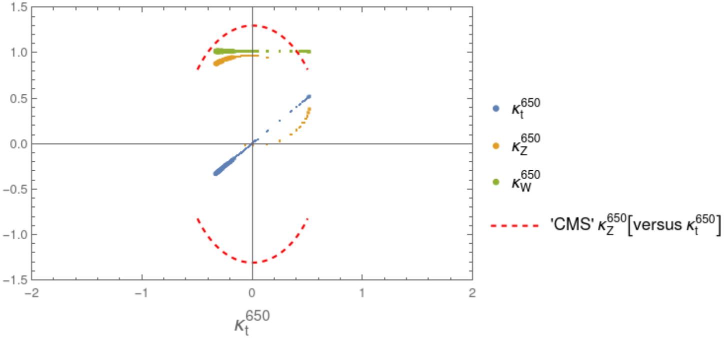
solutions

e.g. $\kappa_W^{650} = 1.015 \rightarrow u \simeq 69$ GeV, $v_1 \simeq 14$ GeV, $v_2 \simeq 104$ GeV

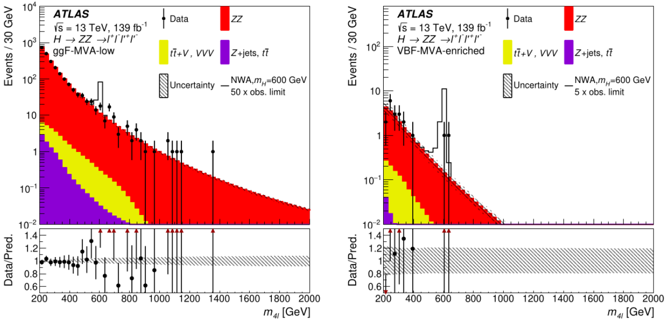


solutions

e.g. $\kappa_W^{650} = 1.015 \rightarrow u \simeq 69$ GeV, $v_1 \simeq 14$ GeV, $v_2 \simeq 104$ GeV



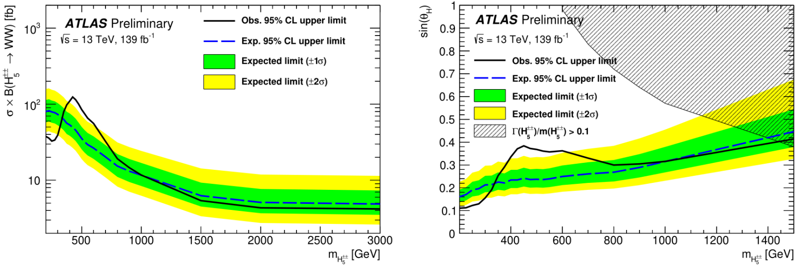
What else? $H_{650} \to ZZ$?



For the VBF production, the maximum deviation is for a signal mass hypothesis around 620 GeV, with a local significance of 2.4 standard deviations and a global significance of 0.9 standard deviation.

Still awaiting CMS to release its ZZ/4lepton analysis!

What else? H^{++}?



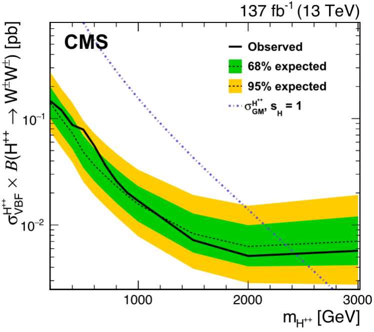
(a) (b)

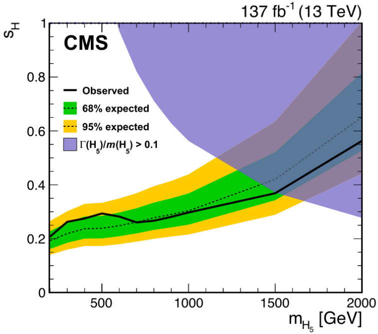
ATLAS-CONF-2023-023: Local excess at a resonance mass around 450 GeV, 2.5σ (global).

BUT $\sin\theta_H \lesssim 0.4 \rightarrow u \lesssim 35$ GeV $\rightarrow$ too small!

Perhaps other decay channels, e.g. to singly charged Higgs, or allow complex $\mathcal{X} \rightarrow$ possible new sources of CP-violation?

What else? H^{++}?

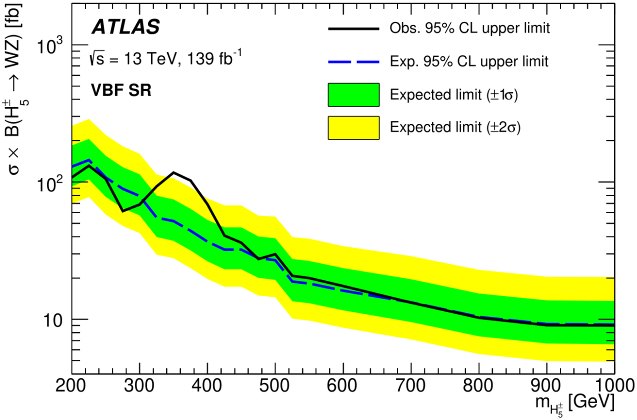




Eur.Phys.J.C 81 (2021) 8, 723

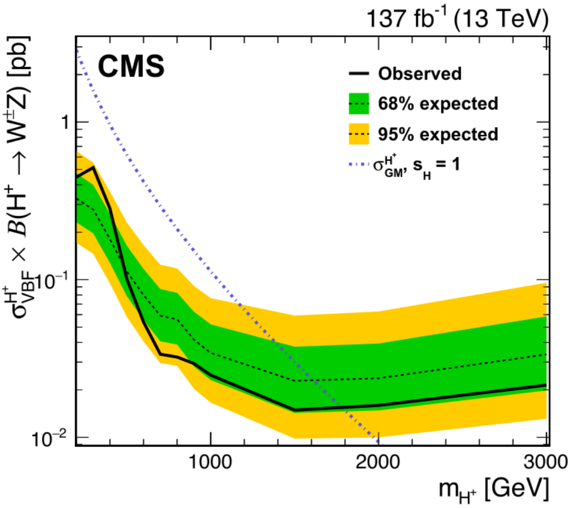
Situation unclear!

What else? H^+?



2207.03925: Local excess around 370 GeV.

What else? H^+?



is there something?

Conclusions

- Given the huge data taking at LHC, excesses are occasionally observed in searches for new resonances, that might or might not stand the test of time.
- But if they occur at roughly the same invariant mass, maybe something real is round the corner
- Recent indications for a 650 GeV in various channels, 4σ combined (global) implies $SU(2)_L$ triplets $\rightarrow$ new neutral, charged, and doubly-charged scalars to look for.
- But not easy to implement $\rightarrow$ extended Georgi-Machacek, including consistently, the 125 GeV, and a 95 GeV (an old friend), and perhaps a $\simeq$ 300 GeV CP-even neutral scalars.
- wait and see what happens with future data...

I'm not an ambulance chaser. I'm usually there before the ambulance.

— *Melvin Belli* —