$H \to hh$ in the Georgi-Machacek model

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LHC HXSWG 15th General Assembly Meeting
2018 December 11

Introduction: motivating the Georgi-Machacek model

Can we constrain the possibility that "exotic" Higgs fields (isospin $> 1/2$) contribute to electroweak symmetry breaking?

Generically this is very strongly constrained by the ρ parameter:

$$\rho \equiv \frac{\text{weak neutral current}}{\text{weak charged current}} = \frac{(g^2 + g'^2)/M_Z^2}{g^2/M_W^2} = \frac{v_\phi^2 + a\langle X^0\rangle^2}{v_\phi^2 + b\langle X^0\rangle^2}$$

$$\begin{aligned} a &= 4\left[T(T+1) - Y^2\right] c \\ b &= 8Y^2 \end{aligned}$$

$Q = T^3 + Y$; SM doublet: $Y = 1/2$

Expt: $\rho = 1.00039 \pm 0.00019$ (2018 PDG)

Need to do some model-building; otherwise $v_{\text{exotic}} \ll v_{\text{doublet}}$.

There are only two known approaches:

1) Use the septet $(T, Y) = (3, 2)$: $\rho = 1$ by accident!

Doublet $\left(\frac{1}{2}, \frac{1}{2}\right)$ + septet $(3, 2)$: Scalar septet model

Hisano & Tsumura, 1301.6455; Kanemura, Kikuchi & Yagyu, 1301.7303

2) Use global $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$ imposed on the scalar potential

Global $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \to$ custodial SU(2) ensures tree-level $\rho = 1$

Doublet + triplets $(1, 0) + (1, 1)$: Georgi-Machacek model

Georgi & Machacek 1985; Chanowitz & Golden 1985

Doublet + quartets $\left(\frac{3}{2}, \frac{1}{2}\right) + \left(\frac{3}{2}, \frac{3}{2}\right)$: Generalized Georgi-

Doublet + quintets $(2, 0) + (2, 1) + (2, 2)$: Machacek models

Doublet + sextets $\left(\frac{5}{2}, \frac{1}{2}\right) + \left(\frac{5}{2}, \frac{3}{2}\right) + \left(\frac{5}{2}, \frac{5}{2}\right)$:

Galison 1984; Robinett 1985; HEL 1999; Chang et al 2012; HEL & Rentala 2015

Larger than sextets $\to$ too many large multiplets, violates perturbativity

Can also have duplications, combinations $\to$ ignore that here.

Georgi-Machacek model

Georgi & Machacek 1985; Chanowitz & Golden 1985

SM Higgs (bi-)doublet + triplets $(1,0)+(1,1)$ in a bi-triplet:

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ -\phi^{+*} & \phi^{0} \end{pmatrix} \qquad X = \begin{pmatrix} \chi^{0*} & \xi^{+} & \chi^{++} \\ -\chi^{+*} & \xi^{0} & \chi^{+} \\ \chi^{++*} & -\xi^{+*} & \chi^{0} \end{pmatrix}$$

Global SU(2)$_L\times$SU(2)$_R$ $\rightarrow$ custodial symmetry $\langle\chi^0\rangle = \langle\xi^0\rangle \equiv v_\chi$

Physical spectrum:

Bi-doublet: $2 \otimes 2 \rightarrow 1 \oplus 3$ Bi-triplet: $3 \otimes 3 \rightarrow 1 \oplus 3 \oplus 5$

- Two custodial singlets mix $\rightarrow h$, H m_h, m_H, angle α

  Usually identify $h = h(125)$

- Two custodial triplets mix $\rightarrow (H_3^+, H_3^0, H_3^-)$ m_3 + Goldstones

  Phenomenology very similar to $H^\pm, A^0$ in 2HDM Type I, $\tan\beta \rightarrow \cot\theta_H$

- Custodial fiveplet $(H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--})$ m_5

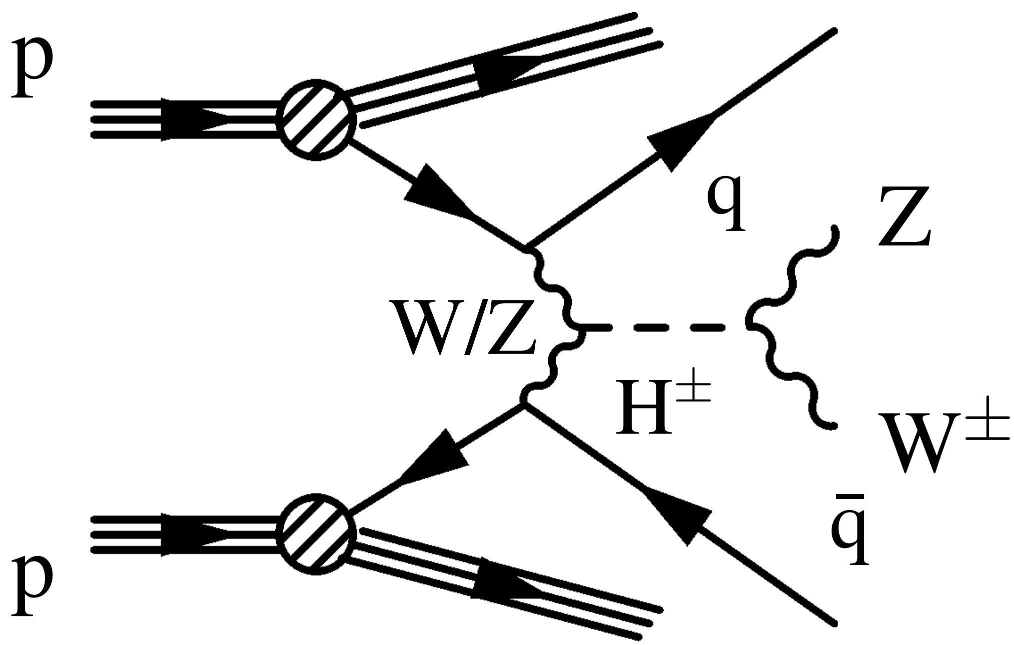
  Fermiophobic; H_5VV couplings $\propto s_H \equiv \sqrt{8}v_\chi/v_{\rm SM}$

  $s_H^2 \equiv$ exotic fraction of M_W^2, M_Z^2

Usual LHC searches:

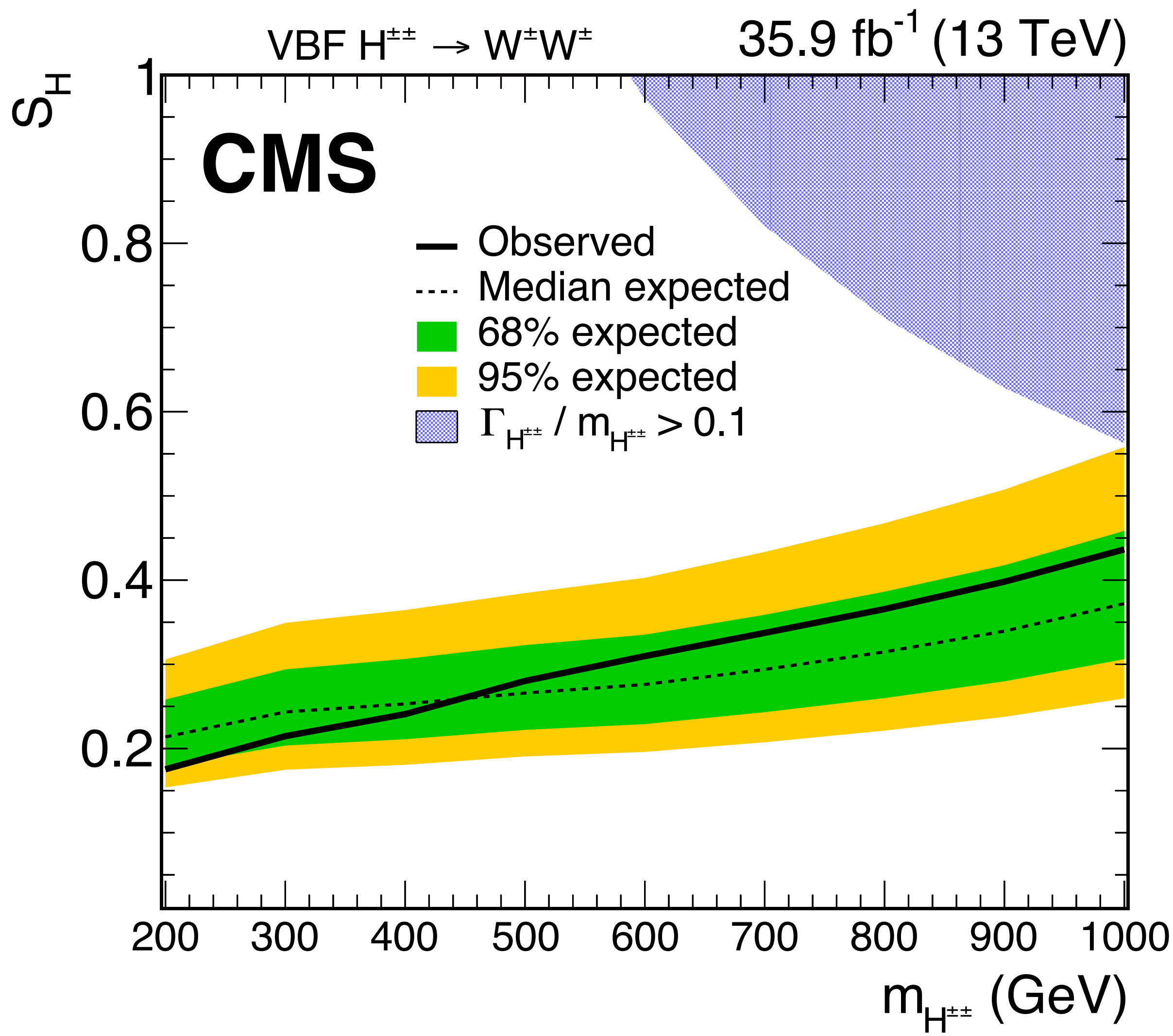
VBF $\rightarrow H_5^{\pm\pm} \rightarrow W^\pm W^\pm$ — VBF + like-sign dileptons + MET

VBF $\rightarrow H_5^{\pm} \rightarrow W^\pm Z$ — VBF + $qq\ell\ell$; VBF + 3ℓ + MET



Cross section $\propto s_H^2 \equiv$ fraction of M_W^2, M_Z^2 due to exotic scalars

Most stringent constraint: CMS, arXiv:1709.05822



Searches for VBF $\to H_5^\pm \to W^\pm Z$: not quite as constraining

Can GM model provide a benchmark for $H \to hh$?

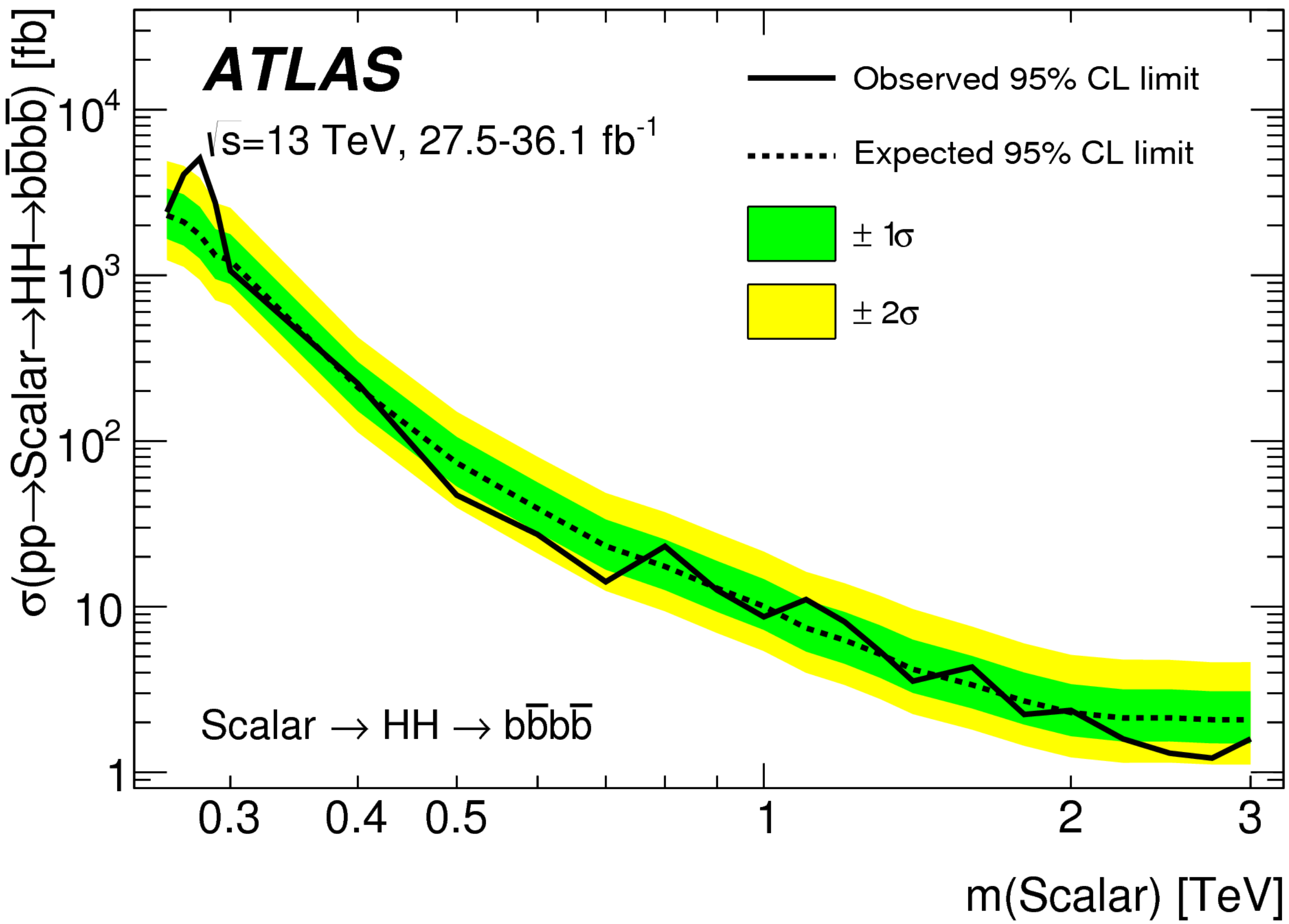
- Custodial singlet H couples to fermion pairs
  $\to$ production via gluon fusion

- Hhh coupling can be substantial

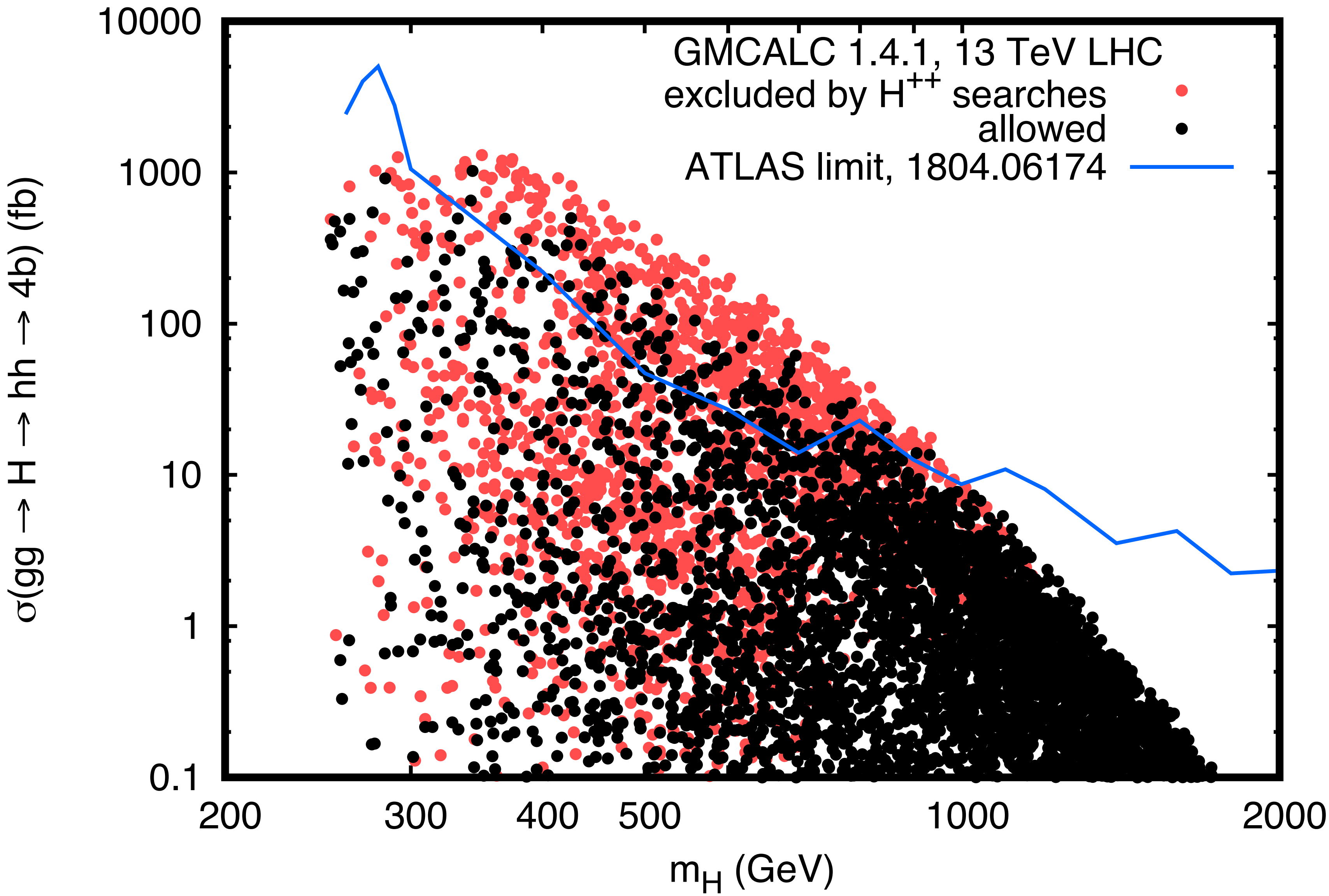
- h BRs are generally SM-like in allowed parameter regions

$Hf\bar{f}$ and Hhh couplings both go to zero in $s_H \to 0$ limit, but direct-search constraints are still far away from this limit.

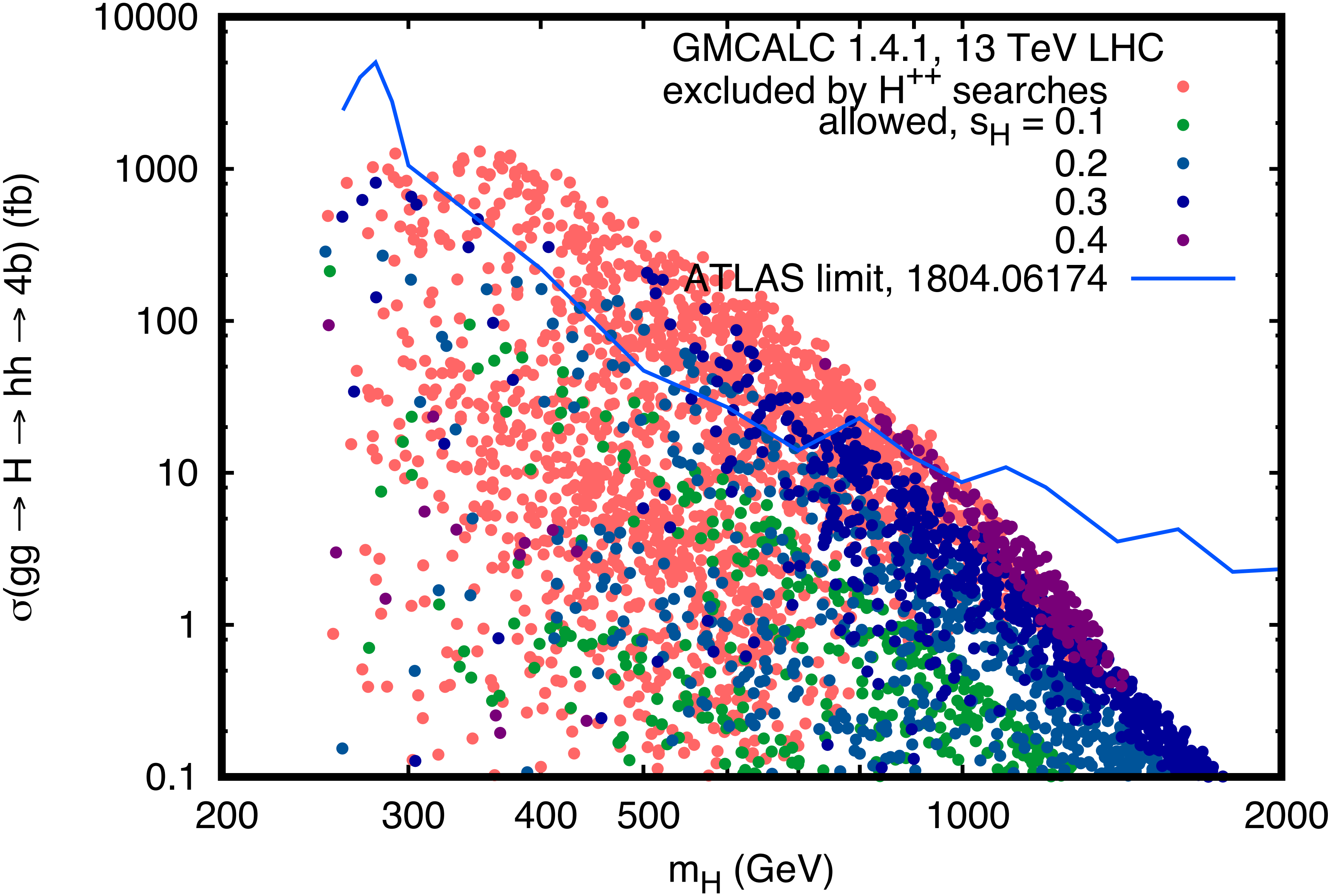
Cross section constrained so far: ATLAS, arXiv:1804.06174



Full parameter scan in GM model: (Preliminary)



Dependence on s_H: (Preliminary)



Summary:

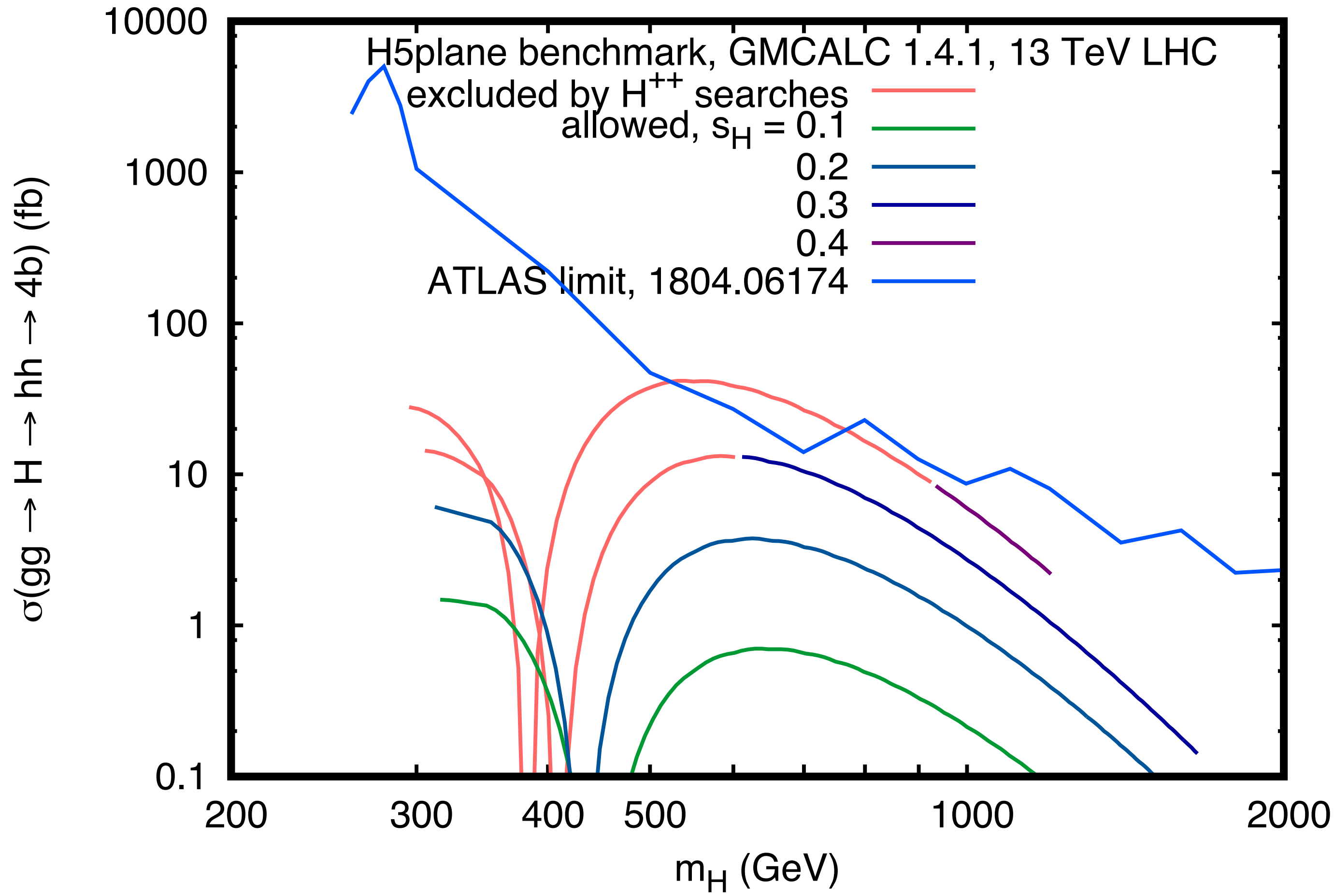
Georgi-Machacek model can provide an interesting benchmark for $gg \to H \to hh$ searches.

Current $H \to hh$ sensitivity ($\lesssim$ 36 fb^{-1}, 13 TeV) probes otherwise-unexcluded model points up to $m_H \sim 1$ TeV!

Feedback wanted: how best to provide this model interpretation to the experiments?

BACKUP SLIDES

The H5plane benchmark is not so interesting for $H \to hh$ searches:



(Preliminary)

H5plane benchmark designed for VBF $\to H_5^{\pm\pm}, H_5^{\pm}$ searches; two free parameters are m_5 and s_H, other parameters fixed

Georgi-Machacek model

Georgi & Machacek 1985; Chanowitz & Golden 1985

SM Higgs (bi-)doublet + triplets $(1,0)+(1,1)$ in a bi-triplet:

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^+ \\ -\phi^{+*} & \phi^0 \end{pmatrix} \qquad X = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ -\chi^{+*} & \xi^0 & \chi^+ \\ \chi^{++*} & -\xi^{+*} & \chi^0 \end{pmatrix}$$

Global SU(2)$_L\times$SU(2)$_R$ $\to$ custodial symmetry $\langle \chi^0 \rangle = \langle \xi^0 \rangle \equiv v_\chi$

Most general scalar potential invariant under SU(2)$_L\times$SU(2)$_R$:

$$\begin{aligned} V(\Phi, X) &= \frac{\mu_2^2}{2}\mathrm{Tr}(\Phi^\dagger\Phi) + \frac{\mu_3^2}{2}\mathrm{Tr}(X^\dagger X) + \lambda_1[\mathrm{Tr}(\Phi^\dagger\Phi)]^2 \\ &+\lambda_2\mathrm{Tr}(\Phi^\dagger\Phi)\mathrm{Tr}(X^\dagger X) + \lambda_3\mathrm{Tr}(X^\dagger X X^\dagger X) \\ &+\lambda_4[\mathrm{Tr}(X^\dagger X)]^2 - \lambda_5\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)\mathrm{Tr}(X^\dagger t^a X t^b) \\ &-M_1\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)(UXU^\dagger)_{ab} - M_2\mathrm{Tr}(X^\dagger t^a X t^b)(UXU^\dagger)_{ab} \end{aligned}$$

9 parameters, 2 fixed by G_F and m_h $\to$ 7 free parameters. Aoki & Kanemura, 0712.4053

Chiang & Yagyu, 1211.2658; Chiang, Kuo & Yagyu, 1307.7526

Hartling, Kumar & HEL, 1404.2640

Both approaches have theoretical "issues":

1) Can't give the septet a vev through spontaneous breaking without generating a physical massless Goldstone boson.

Have to couple it to the SM doublet through a dimension-7 $X\Phi^*\Phi^5$ term Hisano & Tsumura 2013

Need the UV completion to be nearby!

2) Global SU(2)$_L\times$SU(2)$_R$ is broken by gauging hypercharge.

Gunion, Vega & Wudka 1991

Special relations among params of *full* gauge-invariant scalar potential can only hold at one energy scale: violated by running due to hypercharge. Garcia-Pepin, Gori, Quiros, Vega, Vega-Morales, Yu 2014

Need the UV completion to be nearby!

This talk: quantify (2) in the Georgi-Machacek model.