

Proposal for a benchmark for $H_5^{0,\pm,\pm\pm}$
searches in the Georgi-Machacek model

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Georgi-Machacek model with isospin triplets

Georgi & Machacek 1985; Chanowitz & Golden 1985

SM Higgs bidoublet + two isospin-triplets in a **bitriplet**:

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

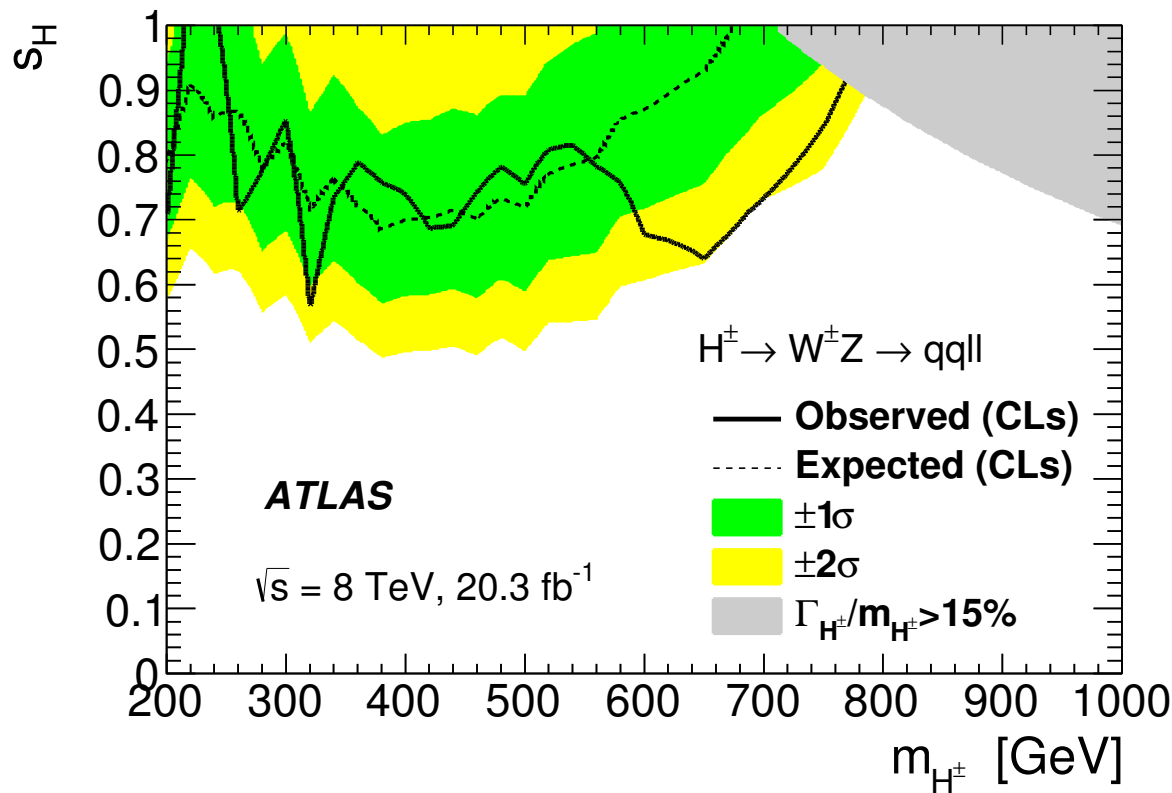
Physical spectrum:

- Two custodial singlets $\rightarrow h^0, H^0$ m_h, m_H \leftarrow very similar
- Custodial triplet $\rightarrow (H_3^+, H_3^0, H_3^-)$ m_3 \leftarrow to 2HDM
- Custodial fiveplet $(H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--})$ m_5 \leftarrow new!

\rightarrow Focus on direct searches for H_5 states

Custodial fiveplet ($H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--}$) is distinctive feature of Georgi-Machacek (GM) model.

- Fermiophobic but vector-philic: interesting to search in VBF
- Couplings to VV proportional to $s_H \equiv 2\sqrt{2}v_\chi/v_{SM}$
 $s_H^2 =$ fraction of M_W^2 and M_Z^2 coming from the triplet vev



ATLAS 1503.04233

Goal: a fully-specified benchmark for direct H_5 searches

- benchmark plane varying s_H and m_5

the most relevant parameters for H_5 direct searches

- compatible with spectrum calculator [GMCALC 1412.7387](#)

INPUTSET = 4: m_h, m_5, s_H among the inputs

- *** satisfies theoretical constraints as much as possible ***

largest possible region of m_5-s_H plane theoretically accessible (the main challenge)

- $m_3 > m_5$ so that only $H_5 \rightarrow VV$ decays present at tree level

Higgs-to-Higgs $H_5 \rightarrow H_3V, H_3H_3$ decays are kinematically forbidden – this is a choice

⇒ compatible with cross section and total width recommendations in [LHCHXSWG-2015-001](#)

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

9 input parameters \Rightarrow “H5plane” benchmark

$$G_F = 1.16637 \times 10^{-5} \text{ GeV}^{-2} \text{ [YR1]}$$

$$m_h = 125 \text{ GeV}$$

$$m_5 \in [200, 2000] \text{ GeV}$$

$$s_H \in (0, 1)$$

$$\lambda_2 = 0.4(m_5/1000 \text{ GeV})$$

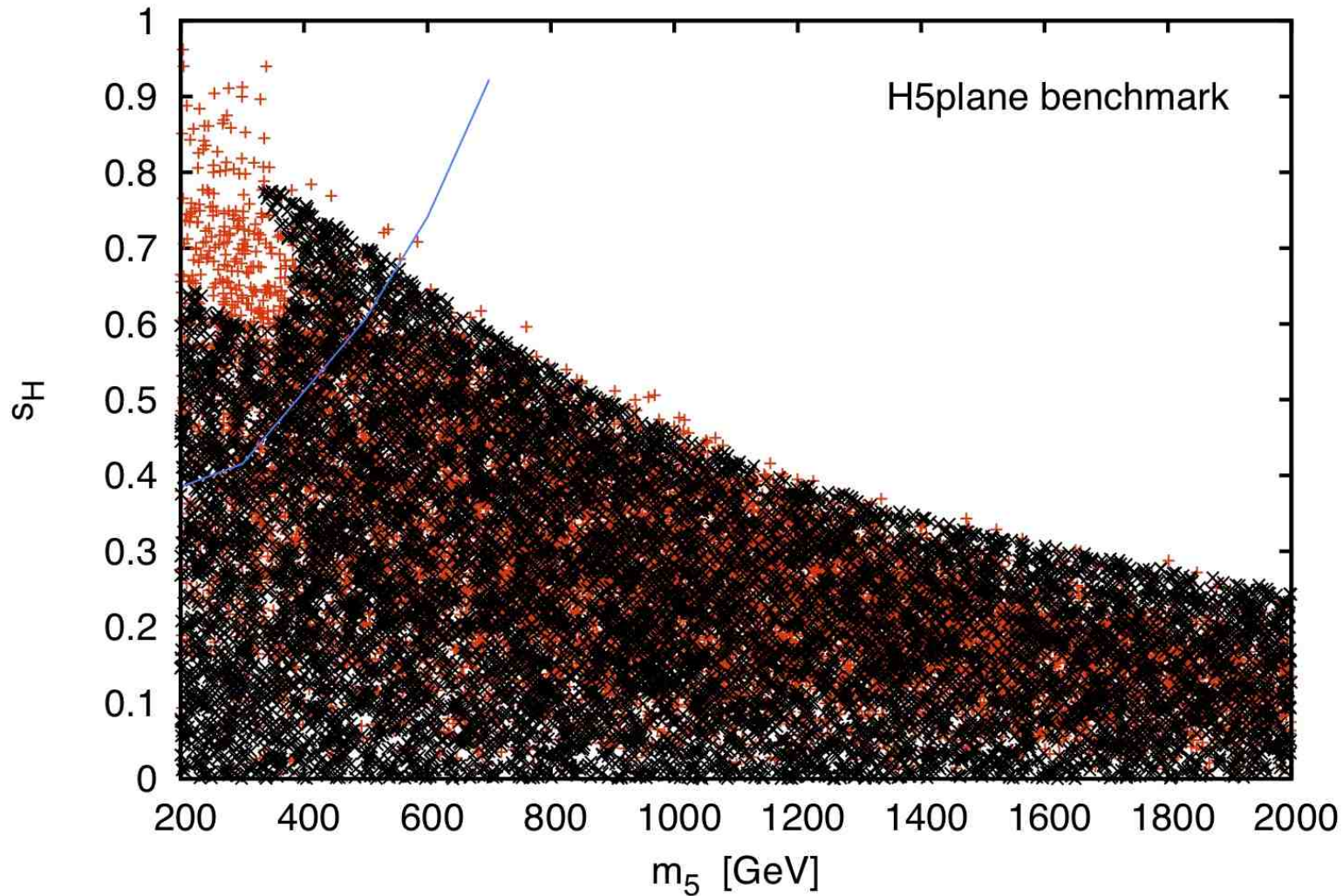
$$\lambda_3 = -0.1$$

$$\lambda_4 = 0.2$$

$$M_1 = \frac{\sqrt{2}s_H}{v} (m_5^2 + v^2)$$

$$M_2 = M_1/6.$$

Can input these parameters directly using INPUTSET = 4 in GMCALC.



Red points: full scan of GM model

Black points: "H5plane" benchmark

Region above blue line excluded by ATLAS VBF $W^\pm W^\pm$ xsec: [Chiang et al 1407.5053](#)

Heather Logan (Carleton U.) H5plane benchmark (Georgi-Machacek) HXSWG, Sept 2015

Features of “H5plane” benchmark:

- Populates the m_5 – s_H plane as much as a full model scan.
- “Loose” constraint from $b \rightarrow s\gamma$ (see [1410.5538](#)) doesn’t further constrain the plane.
- Not unreasonably constrained by $h(125)$ coupling measurements: region in which $|\kappa_i^h - 1| < 0.1$ ($i = f, V, \gamma$) essentially the same as in full scan.
- $m_3 \gtrsim m_5 + 10$ GeV over the whole benchmark plane so that $\text{BR}(H_5 \rightarrow VV) = 1$ to a very good approximation.
- $m_H \gtrsim m_5 + 12$ GeV over the whole benchmark plane.

Note that there is a large parameter region $m_5 \gtrsim 600$ GeV and $0.07 \lesssim s_H \lesssim 0.6$ in which $\Gamma_{\text{tot}}(H_5^0), \Gamma_{\text{tot}}(H) > m_H - m_5$, so that the lineshapes overlap and interfere. Need dedicated study for neutral $H_5^0, H \rightarrow WW, ZZ$.

BACKUP

Phenomenology of H_5 states:

H_5 states come from isospin triplets: fermiophobic! no gluon fusion

H_5VV couplings are nonzero: production in VBF; $W\phi/Z\phi$

$$\begin{aligned}
 H_5^0 W_\mu^+ W_\nu^- &: i \frac{2M_W^2}{v} \left[\frac{s_H}{\sqrt{3}} \right] g_{\mu\nu}, \\
 H_5^0 Z_\mu Z_\nu &: i \frac{2M_Z^2}{v} \left[-\frac{2s_H}{\sqrt{3}} \right] g_{\mu\nu}, \\
 H_5^+ W_\mu^- Z_\nu &: i \frac{2M_W M_Z}{v} [-s_H] g_{\mu\nu}, \\
 H_5^{++} W_\mu^- W_\nu^- &: i \frac{2M_W^2}{v} \left[\sqrt{2}s_H \right] g_{\mu\nu},
 \end{aligned}$$

$s_H \equiv \frac{2\sqrt{2}v\chi}{v}$ related to h^0VV , H^0VV couplings by $VV \rightarrow VV$ unitarization sum rule:

$$(\kappa_V^h)^2 + (\kappa_V^H)^2 - \frac{5}{3}(s_H)^2 = 1$$

Falkowski, Rychkov & Urbano, 1202.1532 (see also Higgs Hunter's Guide)

Decays of H_5 states: (Fermiophobic: no decays to $f\bar{f}$)

- Tree-level decays to $V^{(*)}V^{(*)}$:

$$H_5^{\pm\pm} \rightarrow W^\pm W^\pm \text{ only (by charge conservation)}$$

$$H_5^\pm \rightarrow W^\pm Z$$

$$H_5^0 \rightarrow W^+ W^-, ZZ$$

Tables of total widths and H_5^0 BRs in LHCHSWG-2015-001 for $m_5 \geq 200$ GeV

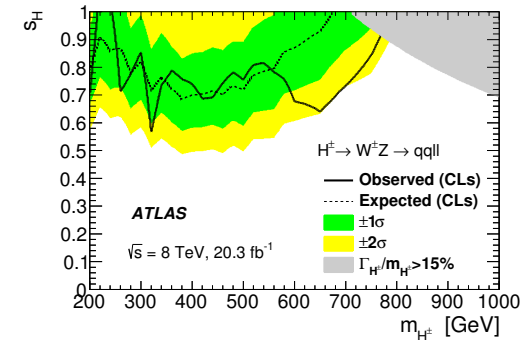
H.E. Logan & M. Zaro

Production of H_5 states:

- VBF $\rightarrow H_5^{\pm\pm}, H_5^\pm, H_5^0$:

Tables of cross sections at NNLO in LHCHXSWG-2015-001 for $m_5 \geq 200$ GeV, 8 and 13 TeV

Natural parameter plane: m_5 vs. s_H



- VH_5 associated production: $H_5^{\pm\pm}W^\mp, H_5^\pm W^\mp, H_5^\pm Z, H_5^0 W^\pm, H_5^0 Z$

Plan to produce tables of cross sections (NLO)

Natural parameter plane: m_5 vs. s_H

- Electroweak pair production: $H_5^{\pm\pm}H_5^{\mp\mp}, H_5^{\pm\pm}H_5^\mp, H_5^\pm H_5^\mp, H_5^\pm H_5^0$

Plan to produce tables of cross sections (NLO)

Cross section depends only on m_5

NLO model implementation for MadGraph5_aMC@NLO being validated

C. Degrand, K. Hartling, H.E. Logan, A. Peterson & M. Zaro + K. Kumar