A benchmark for LHC searches for $H_5^{\pm\pm}$, $H_5^{\pm}$, and H_5^0 in the Georgi-Machacek model including masses below 200 GeV

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Introduction

Exotic contributions to electroweak symmetry breaking (EWSB)

- Can we have some significant fraction of EWSB from $SU(2)_L$ representations larger than doublet?
- Yes, models include Georgi-Machacek model (GM), generalizations of GM to higher isospin and septet model
- common feature: all contain fermiophobic singly and double charged Higgs bosons

Georgi-Machacek model

- adds real and complex triplets to SM higgs sector
- Fermiophobic scalars so-called custodial fiveplet $H_5^{\pm\pm}$, $H_5^{\pm}$, and H_5^0, degenerate with mass m_5
- coupling to vector bosons is parameterized by s_H which is proportional to triplets vev

Searches for H_5 states

Current searches for H_5 production focus on masses of 200 GeV and above where decays to vector bosons are on shell

- In particular, ATLAS search for Drell-Yan production of $H_5^{++}H_5^{--}$ to like-sign W only for masses above 200 GeV (arXiv:1808.01899)
  - If extended below 200 GeV and using full Run 2 data-set would probe entire low mass region independent of s_H
  - Could excluded all H_5 masses below 200-300 GeV
- Need a benchmark valid in low mass region

Low m_5 benchmark

Fixed inputs	Variable parameters	Other parameters
$G_F = 1.1663787 \times 10^{-5}$	$m_5 \in (50, 550)$ GeV	$\lambda_2 = 0.08(m_5/100\ \mathrm{GeV})$
$m_h = 125$ GeV	$s_H \in (0, 1)$	$\lambda_3 = -1.5$
		$\lambda_4 = -\lambda_3 = 1.5$
		$\lambda_5 = -4\lambda_2 = -0.32(m_5/100\ \mathrm{GeV})$
		$M_2 = 10$ GeV

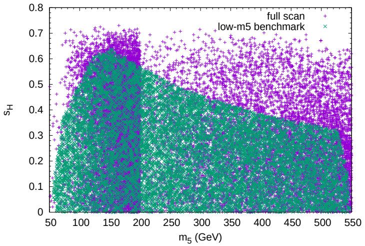
Design consideration of the benchmark

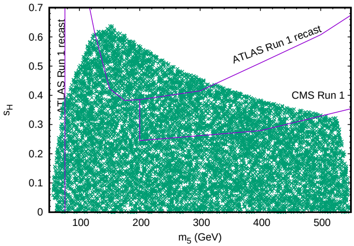
- Couplings of h should to be close to SM values
  - Need to avoid modification from scalar loops of $h \to \gamma\gamma$
- m_5 should be less than m_3
- Sufficiently large portion of $m_5 - s_H$ plane should be allowed by theoretical and indirect constraints for m_5 below 200 GeV

(Still a work in progress and all plots should be considered preliminary)

Populated range in $m_5 - s_H$ plane and existing constraints

Theoretically allowed points in a scan of the benchmark versus a general parameter scan with and without Run 1 constraints for H_5^{++}

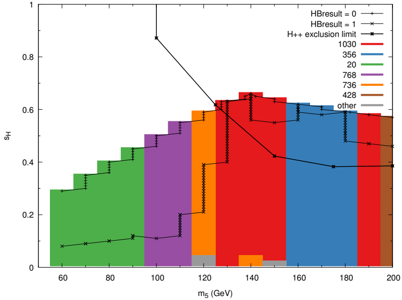


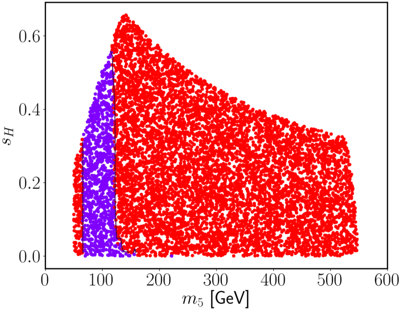


- Below 200 GeV populates almost entire theoretically allowed region
- Falls off above 200 GeV but covers full range where expect senstivity of Run 2 search for Drell-Yan $H_5^{++}H_5^{--}$

Populated range in $m_5 - s_H$ plane and existing constraints

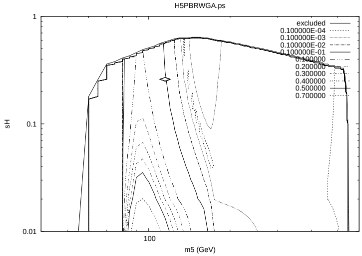
Constraints from neutral H_5

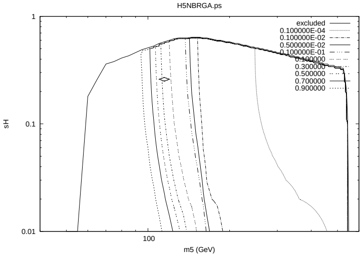




- $H_5^0 \to \gamma\gamma$ excludes masses below 130 GeV and $s_H \gtrsim 0.1$
- Drell-Yan $H_5^0 H_5^+$ with $H_5^0 \to \gamma\gamma$ excludes m_5 between 65 and 120 GeV

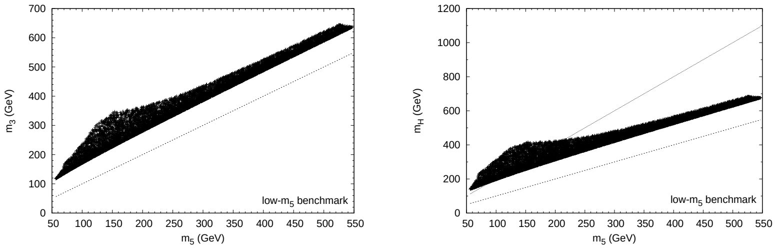
Decays of the H_5





- Only allowed H_5^{++} decay is to W^+W^+
- H_5^+ decays to WZ at tree level but below 200 GeV loop decay to W γ becomes large
- H_5^0 decays to VV at tree level but below 200 GeV loop decay to $\gamma\gamma$ becomes large
  - exclusion at branching ratio of around 10%

Mass splittings within the benchmark



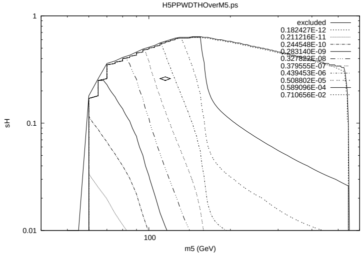
- Have $m_5 < m_3$ and $m_5 < m_H$ as required
- But for m_5 below 210 GeV have $m_H > 2m_5$ so $H \to H_5 H_5$ is allowed
- Can have contribution to total H_5 pair production rate from H decaying to H_5 pairs
  - Model dependent effect and can be ignored when setting bounds on $H_5^{++} H_5^{--}$ Drell-Yan production

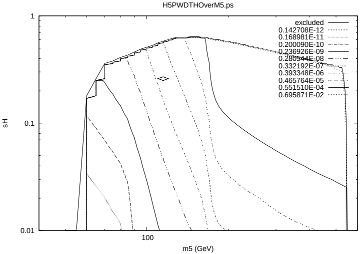
Conclusions

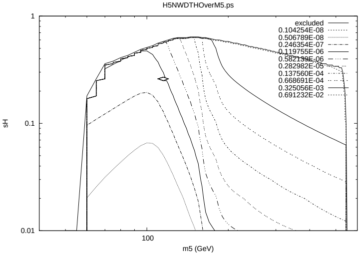
- Have viable low mass benchmark scenario which populates almost all of allowed parameter space
- A low mass H_5^{++} search could excluded entire parameter space
- We are planning a more complete benchmark characterization study and any feedback would be appreciated

Thank You

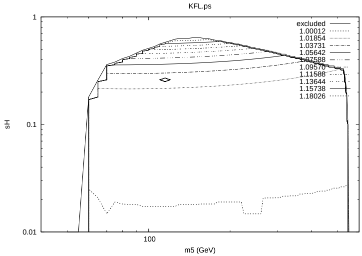
Backup Slides- H5N Decay Widths

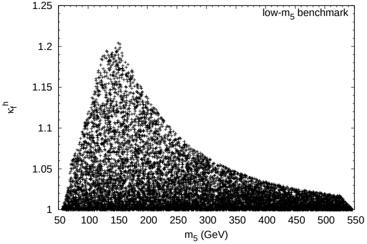


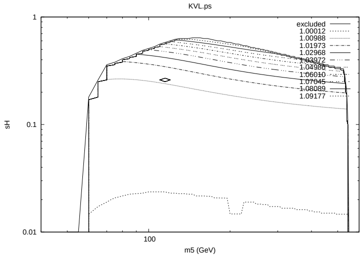


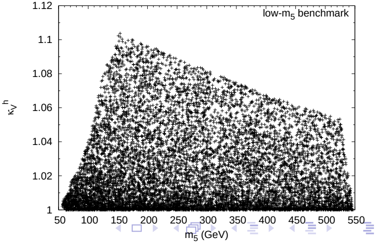


Backup Slides- h couplings

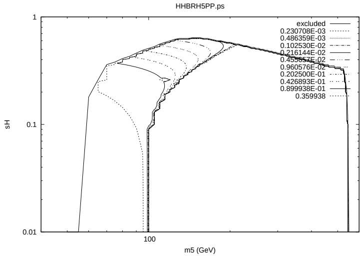


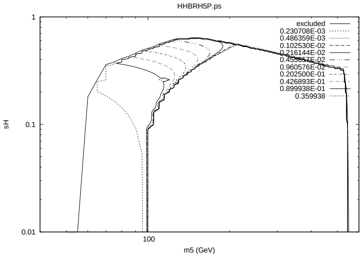


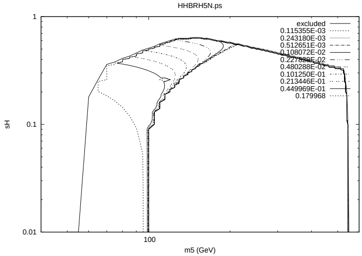


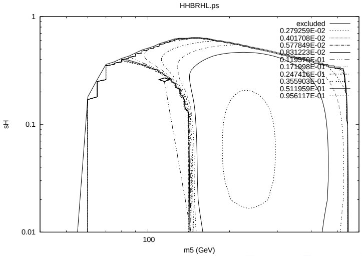


Backup Slides- H Decays to scalars









Backup Slides- GM

Add real triplet ξ and complex triplet χ to SM doublet ϕ. To make global $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$ symmetry explicit, we write

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ -\phi^{+*} & \phi^{0} \end{pmatrix}, \quad (1)$$

$$X = \begin{pmatrix} \chi^{0*} & \xi^{+} & \chi^{++} \\ -\chi^{+*} & \xi^{0} & \chi^{+} \\ \chi^{++*} & -\xi^{+*} & \chi^{0} \end{pmatrix}. \quad (2)$$

The vevs are defined by $\langle \Phi \rangle = \frac{v_\phi}{\sqrt{2}} I_{2\times 2}$ and $\langle X \rangle = v_\chi I_{3\times 3}$, where $I_{n\times n}$ is the unit matrix and the W and Z boson masses constrain

$$v_\phi^2 + 8 v_\chi^2 \equiv v^2 = \frac{4 M_W^2}{g^2} \approx (246\ \mathrm{GeV})^2. \quad (3)$$

Backup Slides- GM-2

Scalar potential is:

$$
\begin{aligned}
V(\Phi, X) \quad = \quad & \frac{\mu_2^2}{2}\mathrm{Tr}(\Phi^\dagger\Phi) + \frac{\mu_3^2}{2}\mathrm{Tr}(X^\dagger X) + \lambda_1[\mathrm{Tr}(\Phi^\dagger\Phi)]^2 \\
& +\lambda_2\mathrm{Tr}(\Phi^\dagger\Phi)\mathrm{Tr}(X^\dagger X) + \lambda_3\mathrm{Tr}(X^\dagger X X^\dagger X) + \lambda_4[\mathrm{Tr}(X^\dagger X)]^2 \\
& -\lambda_5\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)\mathrm{Tr}(X^\dagger t^a X t^b) - M_1\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)(UXU^\dagger)_{a\ldots} \\
& -M_2\mathrm{Tr}(X^\dagger t^a X t^b)(UXU^\dagger)_{ab} \qquad (4
\end{aligned}
$$

and the masses are given by:

$$
\begin{aligned}
m_5^2 \quad &= \quad \frac{M_1}{4v_\chi}v_\phi^2 + 12M_2v_\chi + \frac{3}{2}\lambda_5v_\phi^2 + 8\lambda_3v_\chi^2, \\
m_3^2 \quad &= \quad \frac{M_1}{4v_\chi}(v_\phi^2 + 8v_\chi^2) + \frac{\lambda_5}{2}(v_\phi^2 + 8v_\chi^2) = \left(\frac{M_1}{4v_\chi} + \frac{\lambda_5}{2}\right)v^2. (5)
\end{aligned}
$$