

$$H_5^\pm \rightarrow W^\pm \gamma$$

in Georgi-Machacek Model

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Outline

- GM Model
- H5 decay
- H5 productions
- UFO Model Files For MG5

GM model

- One complex doublet + two Triplets:
 - One Real triplet + One Complex triplet

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

- After EWSB, under the custodial SU(2):
 - Two singlets: h and H
 - A triplet: H3 (+/0/-)
 - A fiveplet: H5 (++/+/0/-/--)
- Fiveplet has no component from doublet:
 - H5s (++/+/0/-/--) are fermionphobic.

Model parameters:

- Scalar Potential:

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

$$\mu_2^2, \mu_3^2, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, M_1, M_2.$$

- Physical Parameters:

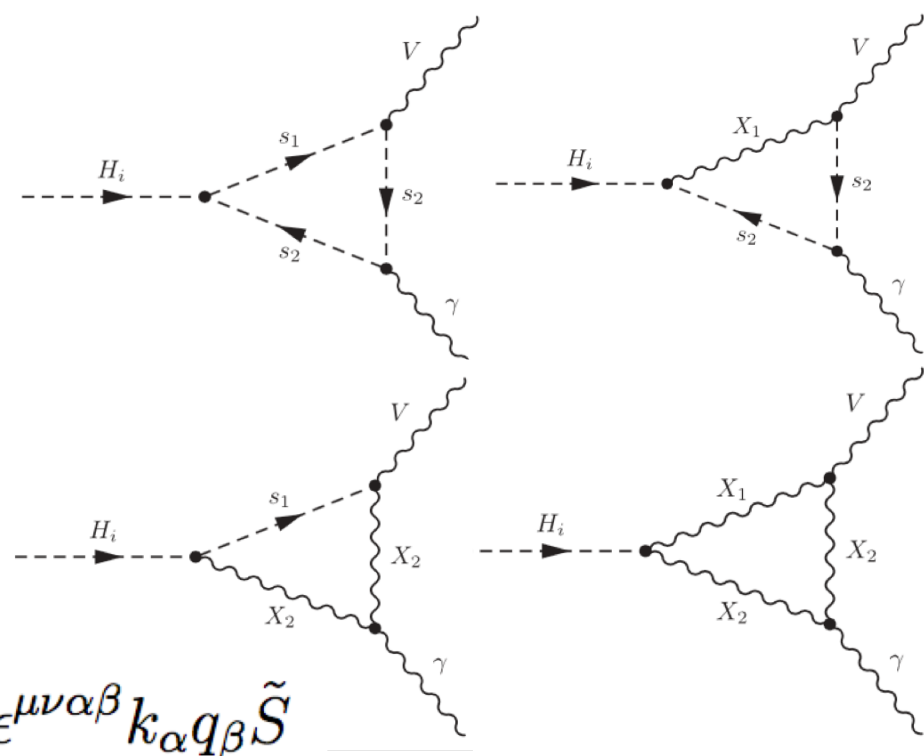
$$v, \sin \theta_h, \cos \alpha, m_h, m_H, m_{H_3}, m_{H_5}, M_1, M_2$$

Similar to $\tan \beta$ in SUSY/2HDM

Gauge Coupling of H5

H_5^\pm Decay:

- Tree level: H_3 Heavier Than H_5
 - $H_3^\pm H_3^0 \quad H_3^\pm Z \quad W^\pm H_3^0$
 - $W^\pm Z \propto \sin\theta_h$
- Loop Induced:
 - $W^\pm \gamma$



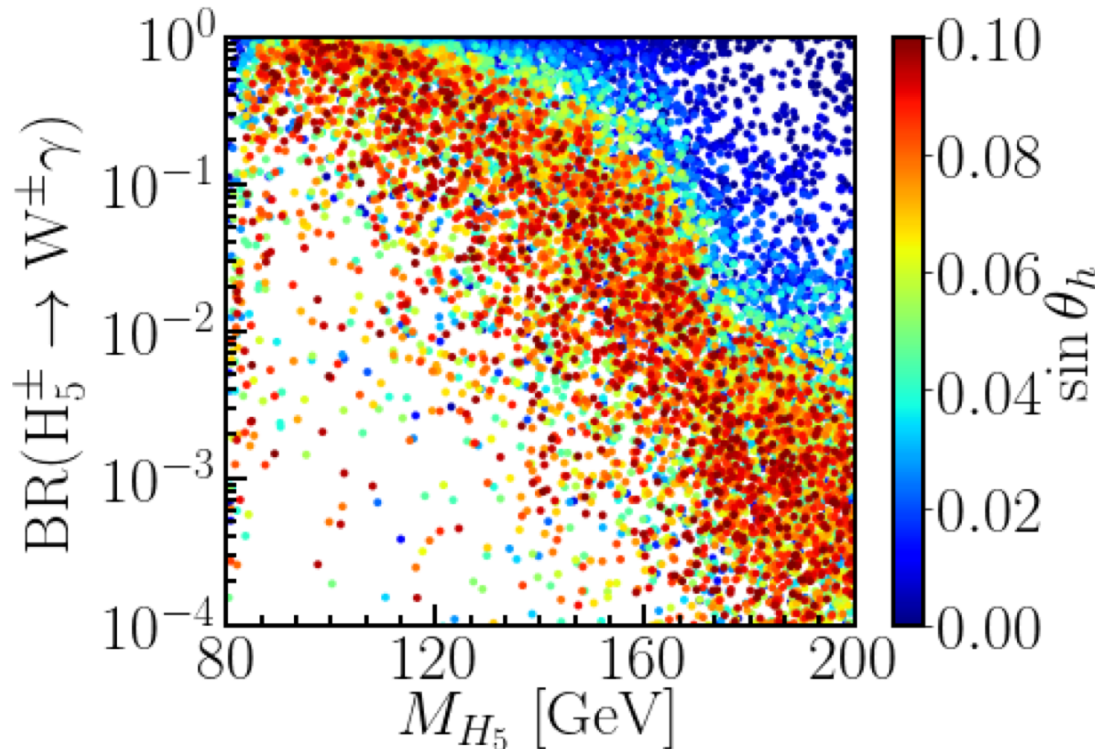
$$\Gamma^{\mu\nu} = (g^{\mu\nu} k \cdot q - k^\mu q^\nu) S + i\epsilon^{\mu\nu\alpha\beta} k_\alpha q_\beta \tilde{S}$$

$$S_{H_5^\pm \rightarrow W^\pm \gamma} \xrightarrow{\sin\theta_h \rightarrow 0} -\frac{\alpha_{em}}{\pi} \frac{3\sqrt{2}}{2} \frac{M_2}{s_w} \left(\frac{I_1(\tau_5, \lambda_5)}{4m_{H_5}^2} - \frac{I_1(\tau_3, \lambda_3)}{4m_{H_3}^2} \right)$$

Diagram	Formfactor	Particles
$s_1 s_2 s_2$	S	$H_3^0 H_3^- H_3^-, H_5^0 H_5^- H_5^-, H_5^- H_5^- H_5^-, H_5^{++} H_5^+ H_5^+, ZH_5^- H_5^-, W^- H_5^- H_5^-$
$X s s$	S	
$s X X$	S	
$X_1 X_2 X_2$	S	$H_5^0 W^- W^-, H_5^{++} W^+ W^+, ZW^- W^-$

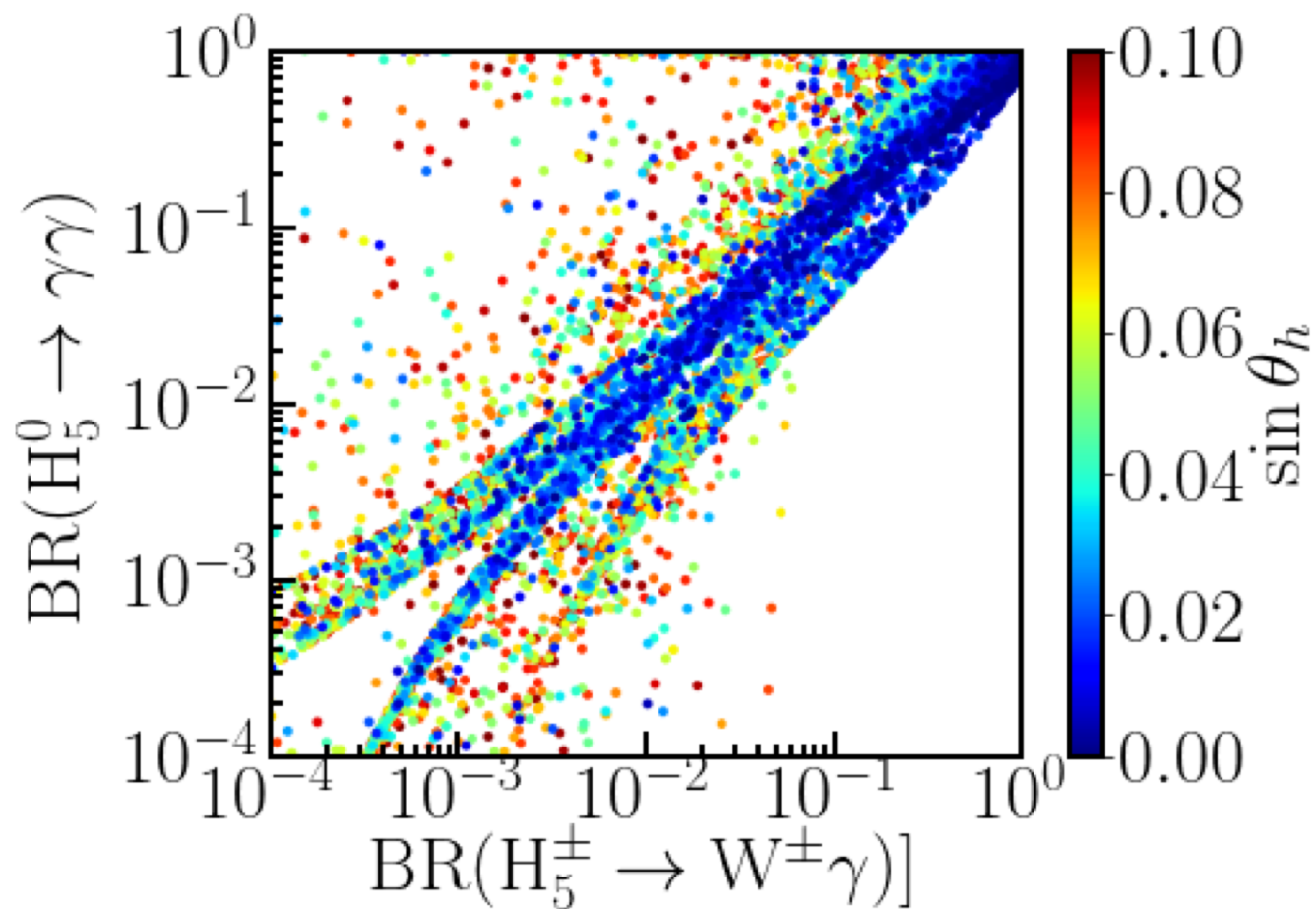
H_5^\pm Decay:

- Parameter Scan: (GMcalc-1.3.0)
 - $M_h=125$ GeV && $M_{H_5} < 200$ GeV && $\sin\theta_h < 0.1$
 - Theoretical Constraints
 - Unitarity/BFB/Global Minimum
 - Current Experimental Constraints:
 - S parameter/b $\rightarrow s\gamma$ /LEP diphoton search / Same Sign $W^+ W^+$



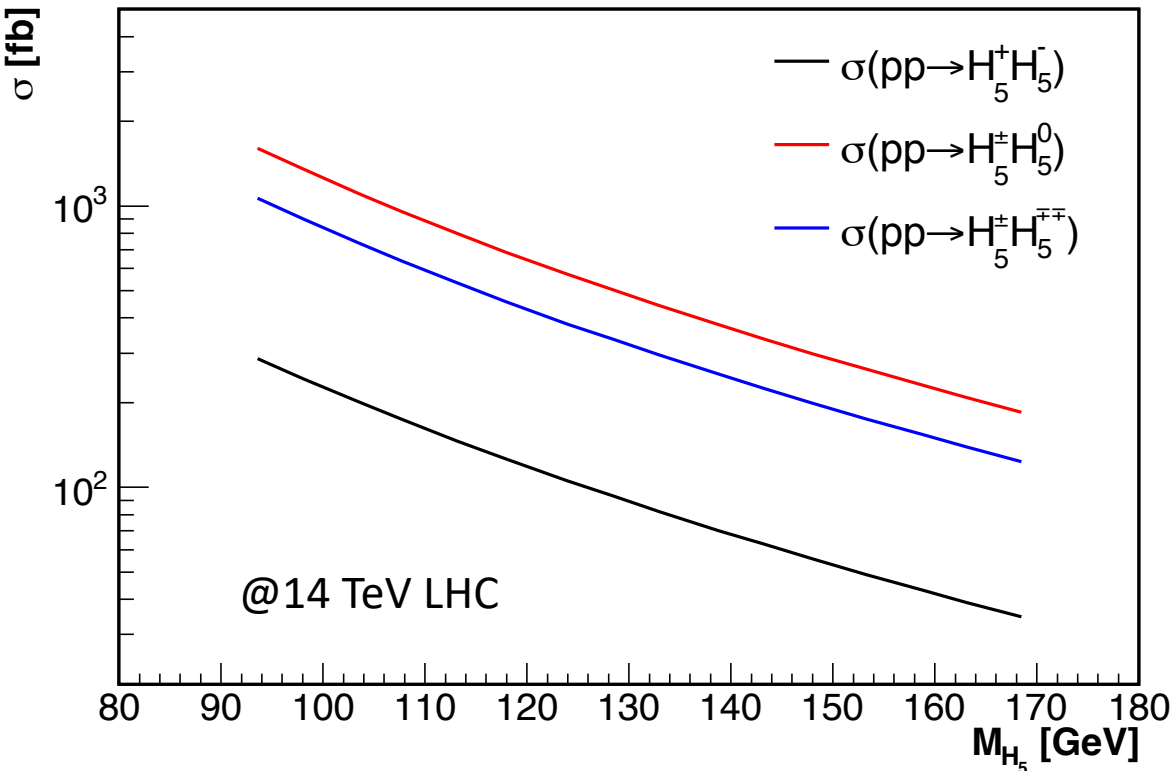
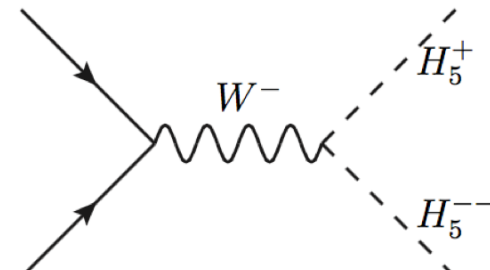
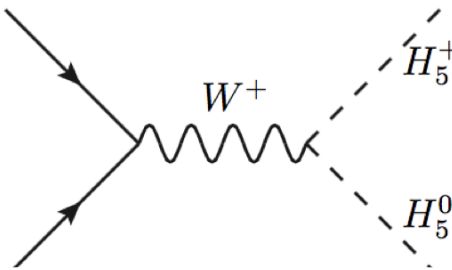
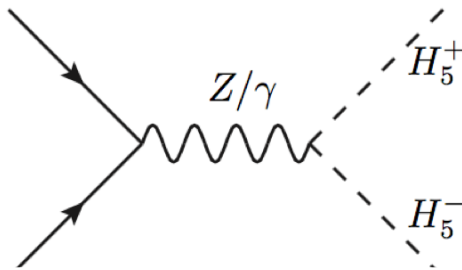
$$H_5^{++} \rightarrow W^+W^+$$

$$H_5^0 \rightarrow \gamma\gamma$$



H_5^\pm Production:

- Consider Small $\sin\theta_h$ (<0.1) region:
 - Drell-Yan, only depend on Mass



Final States:

1. $W\gamma + 2\gamma$
2. $W\gamma + WW(SS)$
3. $W\gamma + W\gamma$

UFO Model Files For MG5

- New:
 - Loop Induced SVV coupling:

$$\Gamma^{\mu\nu} = (g^{\mu\nu} k \cdot q - k^\mu q^\nu) S + i\epsilon^{\mu\nu\alpha\beta} k_\alpha q_\beta \tilde{S}$$

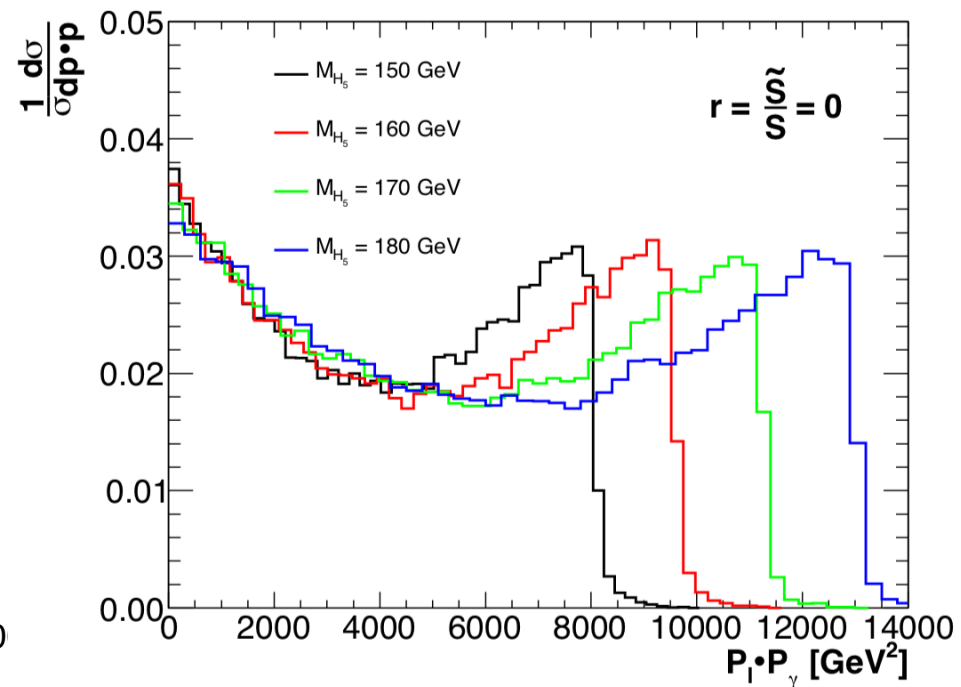
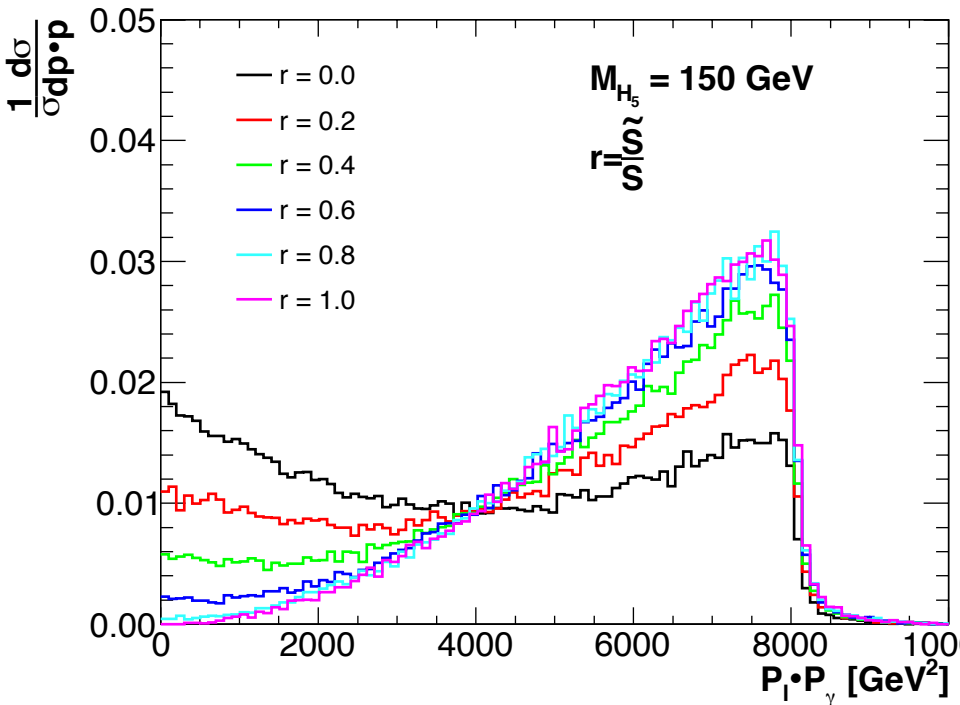
- With S/S-tilde as External input (calculated from GMCalc)
- GMCalc Updated accordingly:
 - Generate the corresponding Parameter Card for MG5
 - Extra S/S-tilde Block.
 - Decay Table for Scalars(h/H/H3/H5) including loop induced channels.

Simple Simulation Result

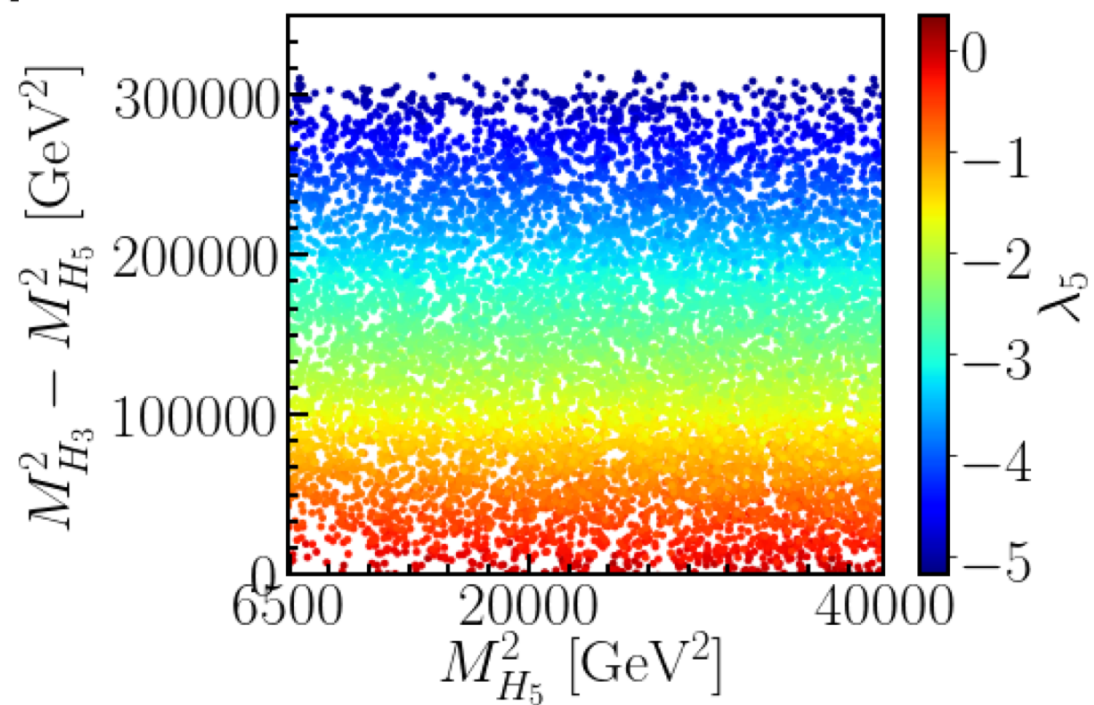
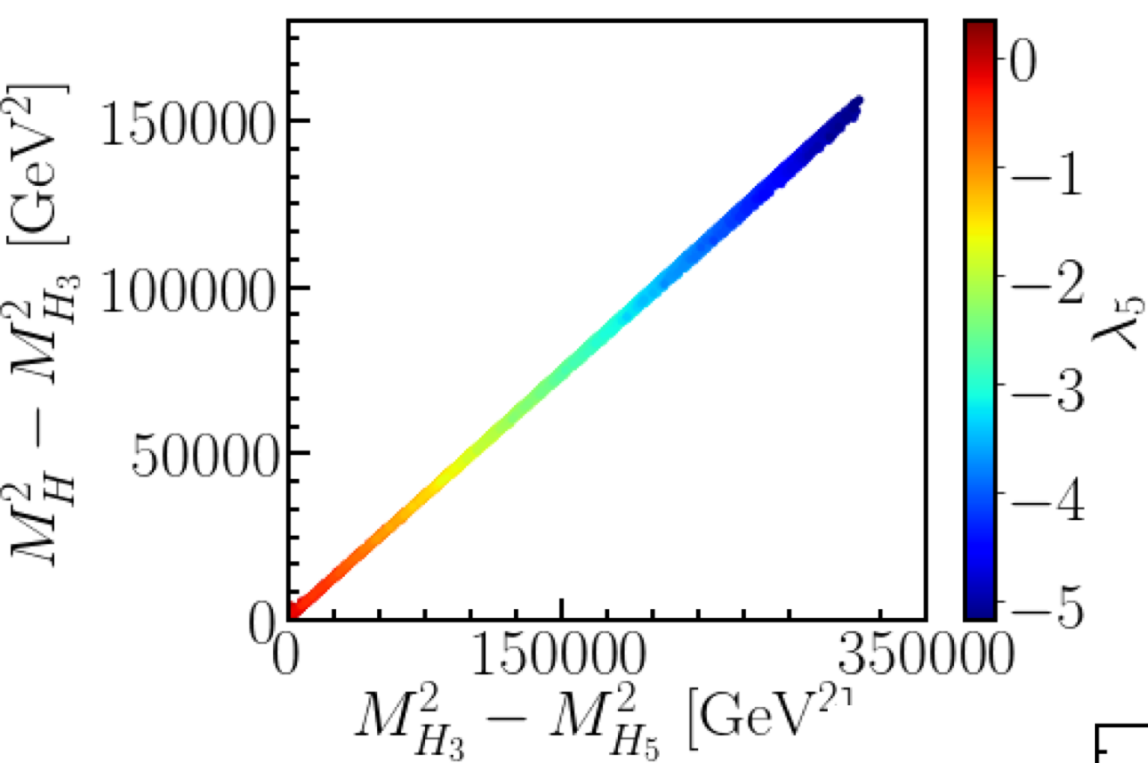
- Correlation between the lepton and the gamma:

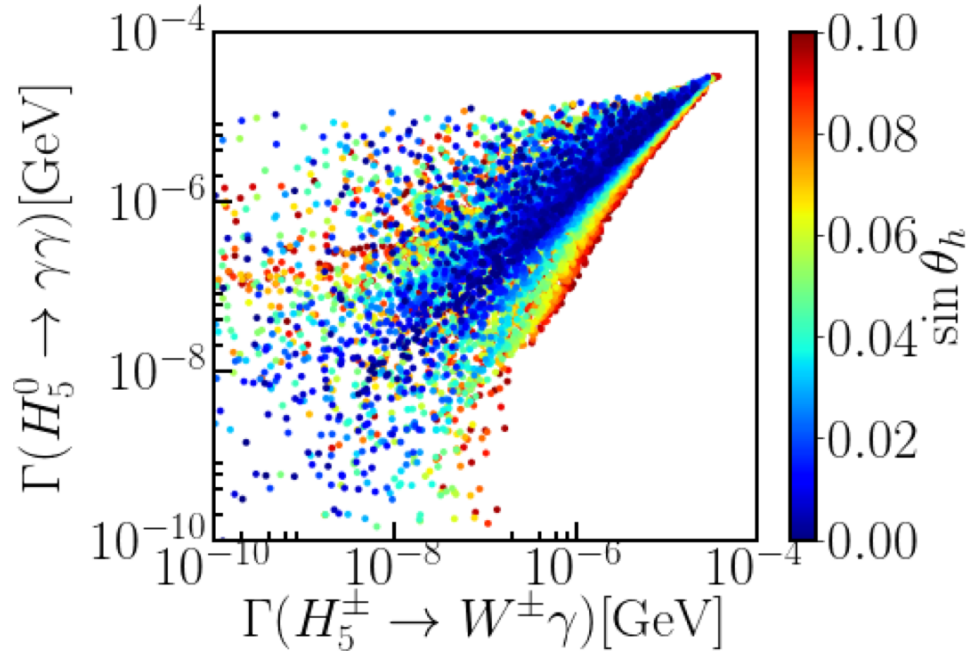
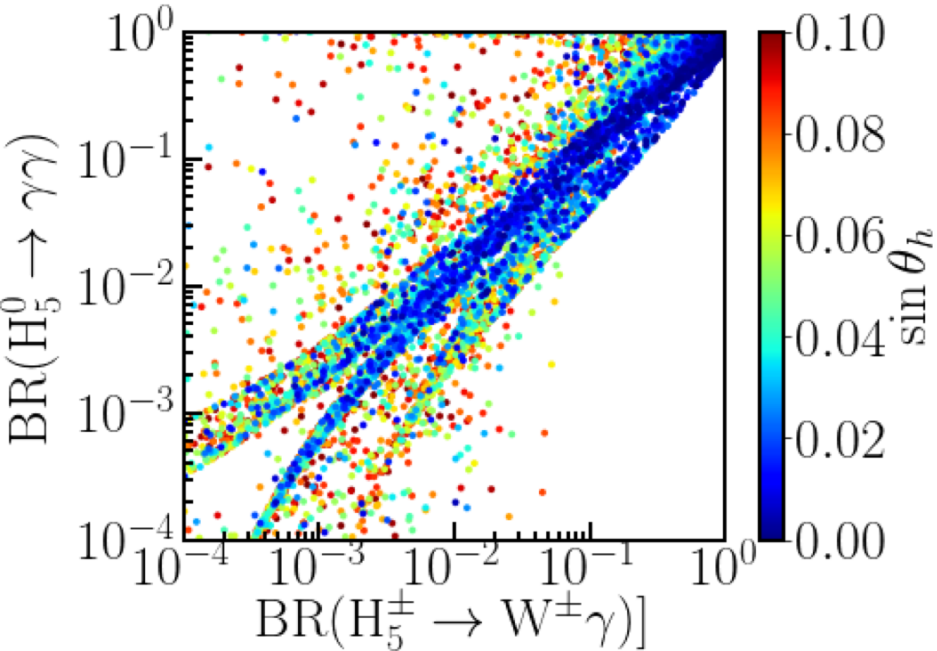
$$\begin{aligned}
 |\mathcal{M}|^2 &= \Gamma^{\mu\nu}\Gamma^{*\rho\sigma}\epsilon_\mu^{\gamma*}\epsilon_\rho^\gamma \mathbf{Tr}(\not{p}_\nu\gamma_\sigma P_L\not{p}_\ell\gamma_\nu) \\
 &= \frac{M_W^2}{2} \left(8(|S|^2 + |\tilde{S}|^2)(p_\ell \cdot q)^2 - 4(M_{H_5}^2 - M_W^2) \left(|S|^2 + |\tilde{S}|^2 - 2\mathbf{Re}(S\tilde{S}^*) \right) p_\ell \cdot q \right. \\
 &\quad \left. + (M_{H_5}^2 - M_W^2)^2 \left(|S|^2 + |\tilde{S}|^2 - 2\mathbf{Re}(S\tilde{S}^*) \right) \right) \quad (5.2)
 \end{aligned}$$

For H_5 , $\tilde{S} = 0$



Thanks!





$$S_{H_5^\pm \rightarrow W^\pm \gamma} \xrightarrow{\sin \theta_h \rightarrow 0} -\frac{\alpha_{em}}{\pi} \frac{3\sqrt{2}}{2} \frac{M_2}{s_w} \left(\frac{I_1(\tau_5, \lambda_5)}{4m_{H_5}^2} - \frac{I_1(\tau_3, \lambda_3)}{4m_{H_3}^2} \right)$$

$$S_{H_5^0 \rightarrow \gamma\gamma} \xrightarrow{\sin \theta_h \rightarrow 0} \frac{\alpha_{em}}{2\pi} \frac{\sqrt{6}}{2} M_2 \left(\frac{F_0(\tau_3)}{m_{H_3}^2} + \frac{7F_0(\tau_5)}{m_{H_5}^2} \right)$$