

Georgi-Machacek Model @360 GeV CEPC

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Georgi-Machacek Model

- SM + One complex Triplet + One real Triplet: $\rho \approx 1$

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^+ \\ -\phi^{+*} & \phi^0 \end{pmatrix}, \quad X = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ -\chi^{+*} & \xi^0 & \chi^+ \\ \chi^{++*} & -\xi^{+*} & \chi^0 \end{pmatrix}. \quad v_\phi^2 + 8 v_\chi^2 = v^2 = (246 \text{ GeV})^2$$

$$\cos \theta_H = \frac{v_\phi}{v}$$

$$\sin \theta_H = \frac{2\sqrt{2}v_\chi}{v}$$

- Symmetry $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$
- $\langle \chi^0 \rangle = \langle \xi^0 \rangle$ (Custodial symmetry)
- Physical Spectrum after EWSB:
 - 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, α
 - h as SM-like 125 GeV Higgs.
 - Two custodial **triplets** mix $\rightarrow (H_3^+, H_3^0, H_3^-) + \text{Goldstone } m_3$
 - Similar to H^\pm, A^0 in Type-I 2HDM, $\tan \beta \rightarrow \cot \theta_H$
 - Custodial **fiveplet** $(H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--})$. m_5
 - **Fermiophobic**, $g_{H_5 VV} \propto s_H = \frac{2\sqrt{2}v_\chi}{v}$

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

$$v_\phi^2 + 8 v_\chi^2 = v^2 = (246 \text{ GeV})^2$$

$$\cos \theta_H = \frac{v_\phi}{v}$$

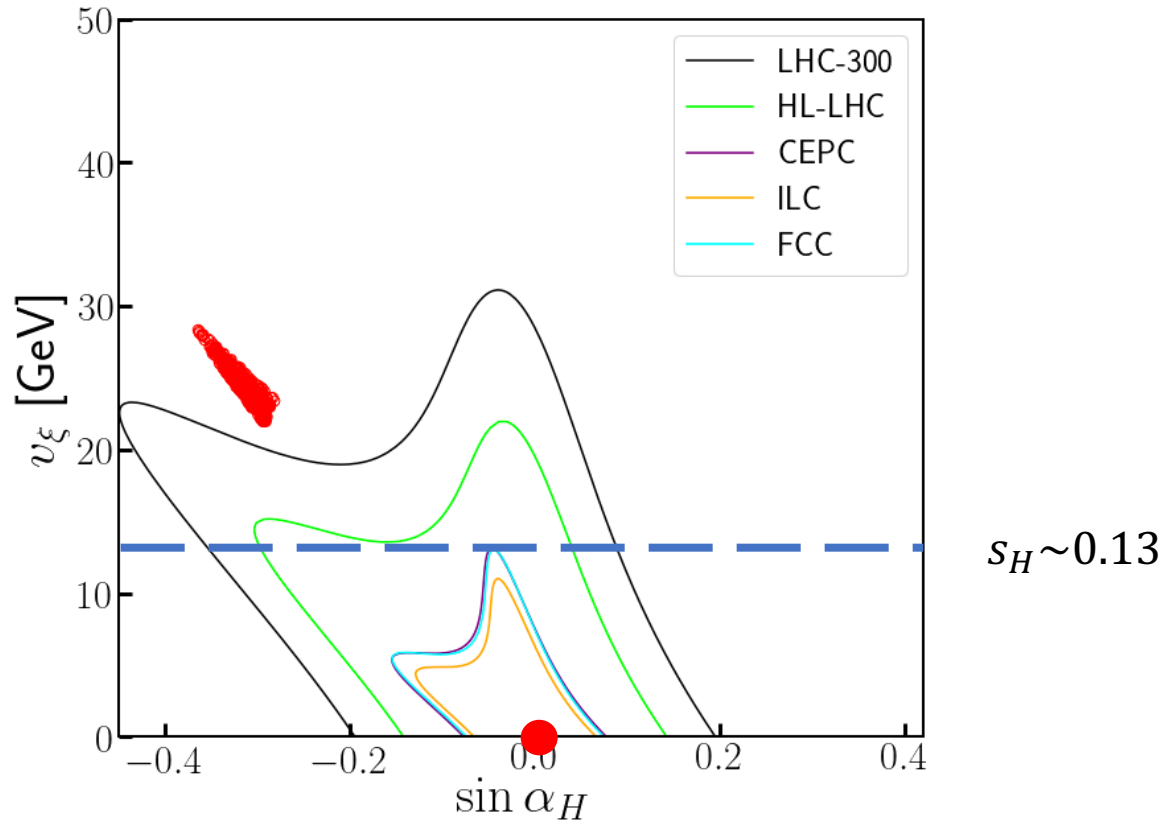
$$\sin \theta_H = \frac{2\sqrt{2}v_\chi}{v}$$

- Symmetry $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$
- $\langle \chi^0 \rangle = \langle \xi^0 \rangle$ (Custodial symmetry)
- Physical Spectrum after EWSB:
 - Singlet: h, H ; Triplet: H_3^0, H_3^\pm ; Fiveplet: $H_5^0, H_5^\pm, H_5^{\pm\pm}$
- Scalar Potential:

$$\begin{aligned} V(\Phi, X) = & \frac{\mu_2^2}{2} \text{Tr}(\Phi^\dagger \Phi) + \frac{\mu_3^2}{2} \text{Tr}(X^\dagger X) + \lambda_1 [\text{Tr}(\Phi^\dagger \Phi)]^2 + \lambda_2 \text{Tr}(\Phi^\dagger \Phi) \text{Tr}(X^\dagger X) \\ & + \lambda_3 \text{Tr}(X^\dagger X X^\dagger X) + \lambda_4 [\text{Tr}(X^\dagger X)]^2 - \lambda_5 \text{Tr}(\Phi^\dagger \tau^a \Phi \tau^b) \text{Tr}(X^\dagger t^a X t^b) \\ & - M_1 \text{Tr}(\Phi^\dagger \tau^a \Phi \tau^b) (U X U^\dagger)_{ab} - M_2 \text{Tr}(X^\dagger t^a X t^b) (U X U^\dagger)_{ab} \\ & v, s_H, \cos \alpha, \boxed{m_h, m_H, m_3, m_5}, M_1, M_2. \end{aligned}$$

Georgi-Machacek Model

- Precision Measurement Constraints



$$\kappa_f = \kappa_g = \frac{c_\alpha}{c_H}$$

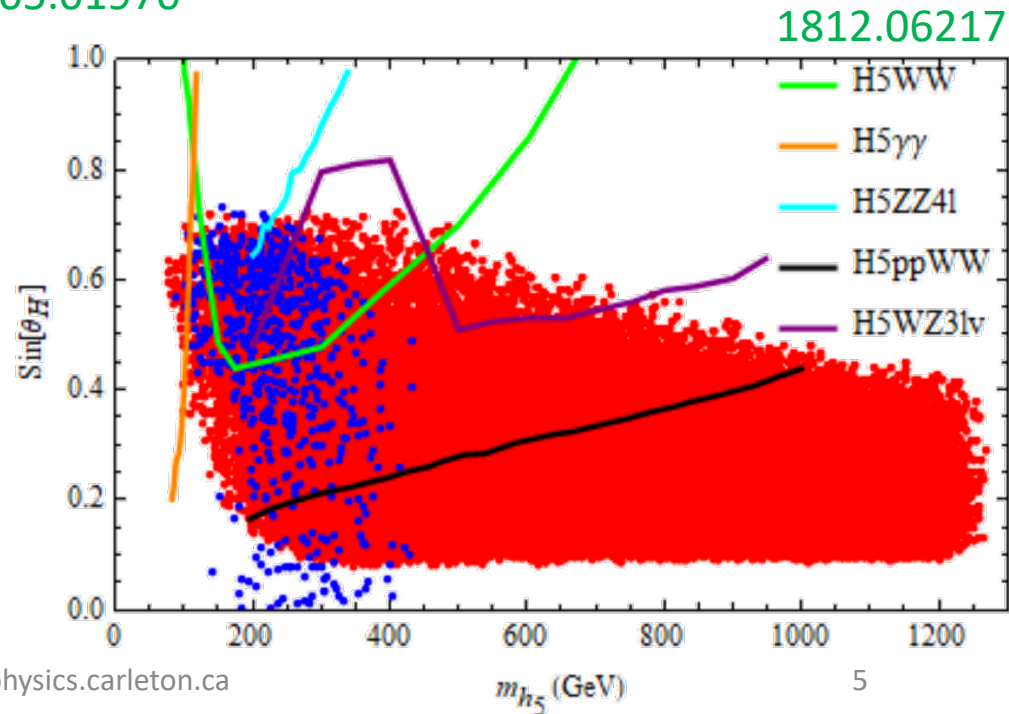
$$\kappa_V = c_\alpha c_H - \sqrt{\frac{8}{3}} s_\alpha s_H$$

$$\kappa_\gamma \sim \frac{\kappa_f F(f) + \kappa_V F(V) + F(S)}{F(f) + F(V)}$$

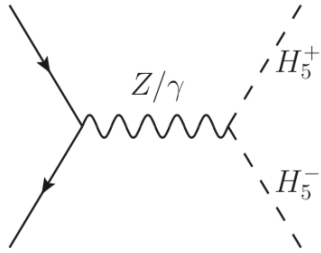
Georgi-Machacek Model

- Exotic Higgs Searches (relevant to **fermiophobic** scalars)
 - Double Charged Scalar: 1808.01899 1709.05822
 - Same-sign W: SS 2-lep channel
 - Single Charged Scalar: 1806.01532 CMS-PAS-SMP-18-001
 - WZ channel: 3-lep
 - Neutral Scalar: 1712.06386 1710.01123 1407.6583 1603.00962
 - WW/ZZ/ $\gamma\gamma$ channel 1805.01970
 - Interpret in GM model:
 - Dependence on $s_H(v_\xi)$

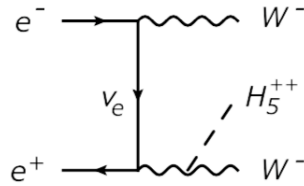
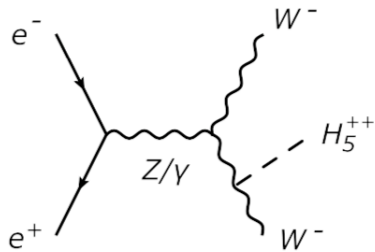
- Strongest: double charged scalar searches
- Weak at low mass region below 200 GeV (Threshold of WW/ZZ)



Production at Lepton Collider

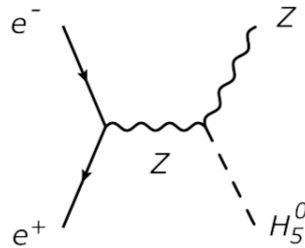
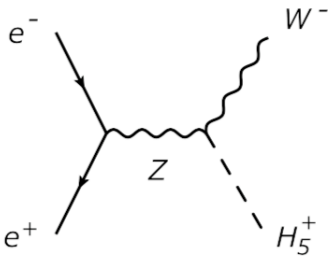


Drell-Yan Gauge Couplings

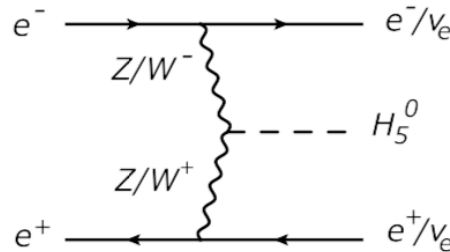
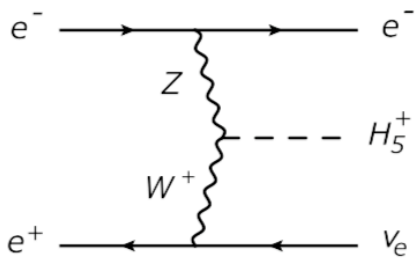


$$g_{H_5 V V} \propto S_H = \frac{2\sqrt{2}v_\chi}{v}$$

Vector Boson Associate



Depends on S_H



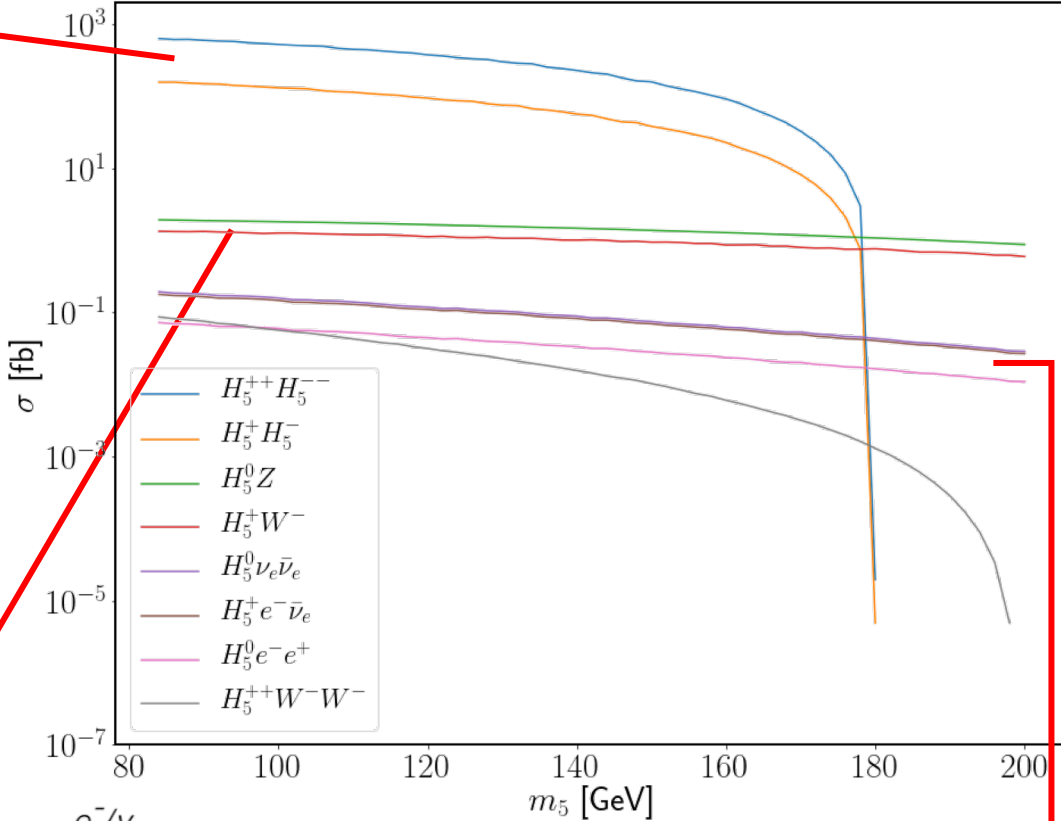
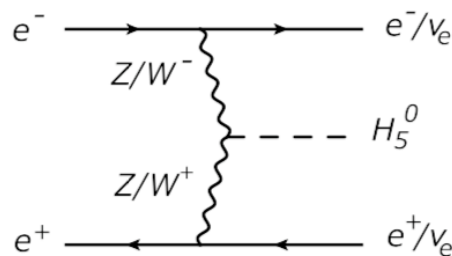
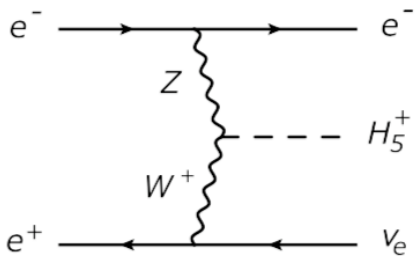
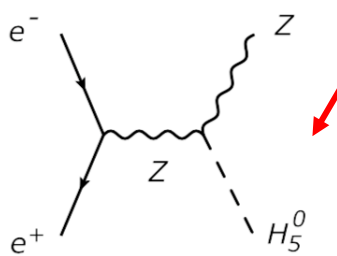
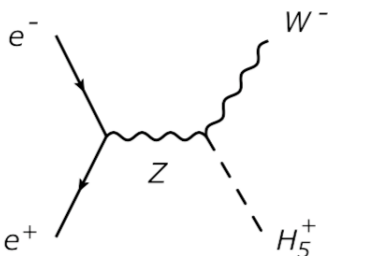
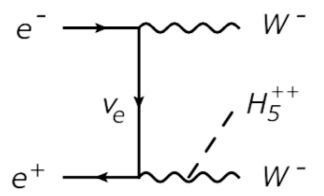
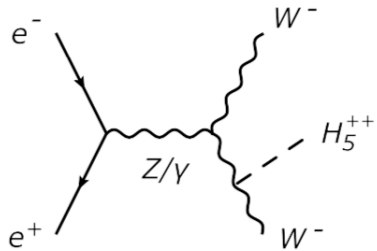
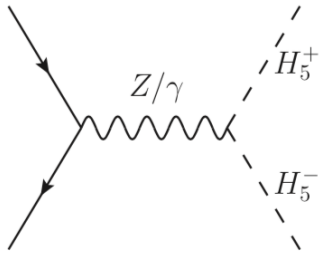
VBF

Production at Lepton Collider

GM_UFO is available

$s_H = 0.1$

@ 360 GeV CEPC

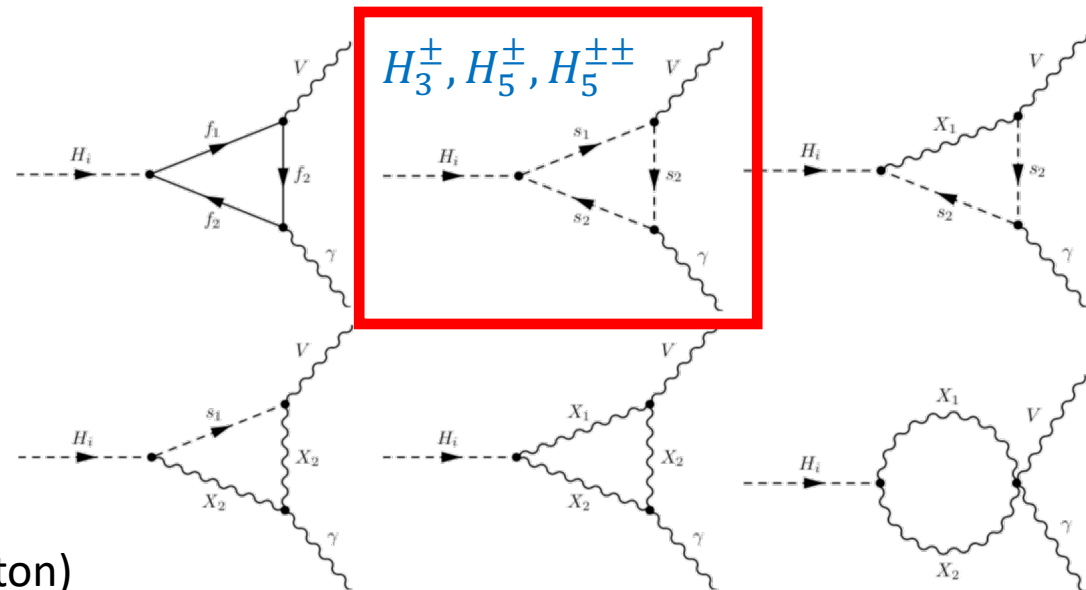


Decay Channels of Fiveplet

GMCalc for BR is available

Assume: $m_3 > m_5$

- H_5^0 :
 - W^+W^-, ZZ → Depends on s_H
 - $\gamma\gamma, Z\gamma$ → Loop Induced
- H_5^\pm :
 - $W^\pm Z$ → Depends on s_H
 - $W^\pm \gamma$ → Loop Induced
- $H_5^{\pm\pm}$:
 - $W^\pm W^\pm$ → Depends on Scalar Cubic Coupling M_2

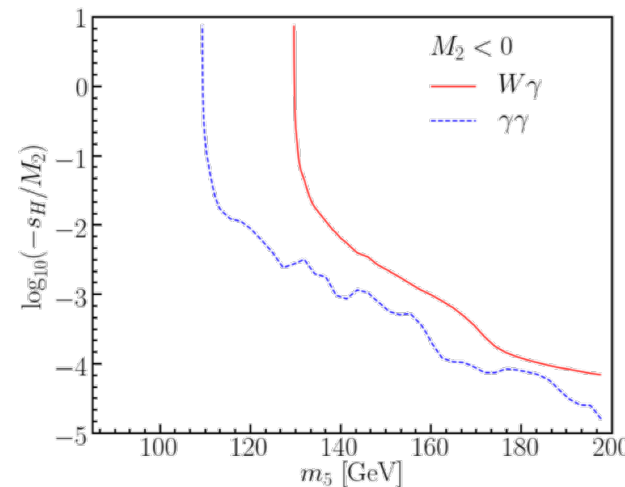
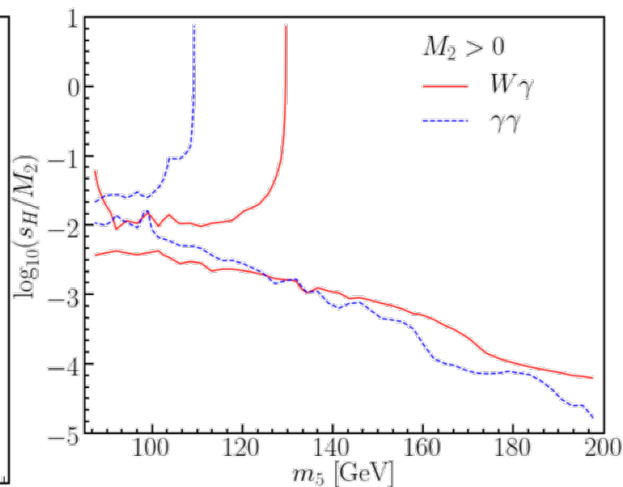
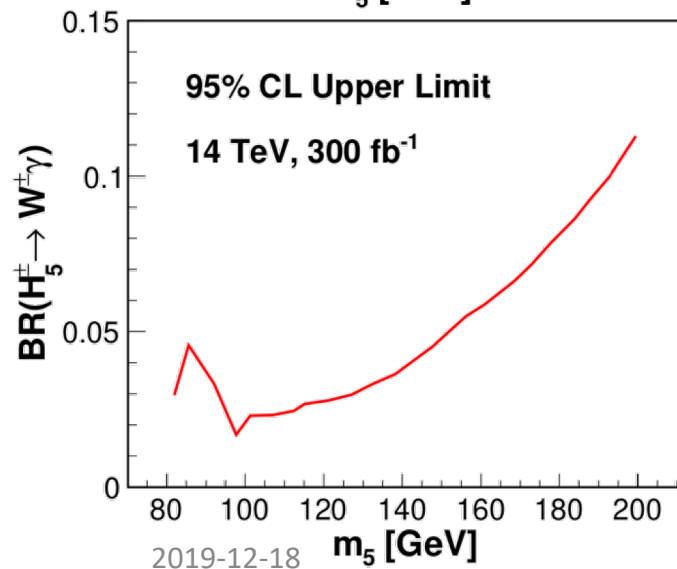
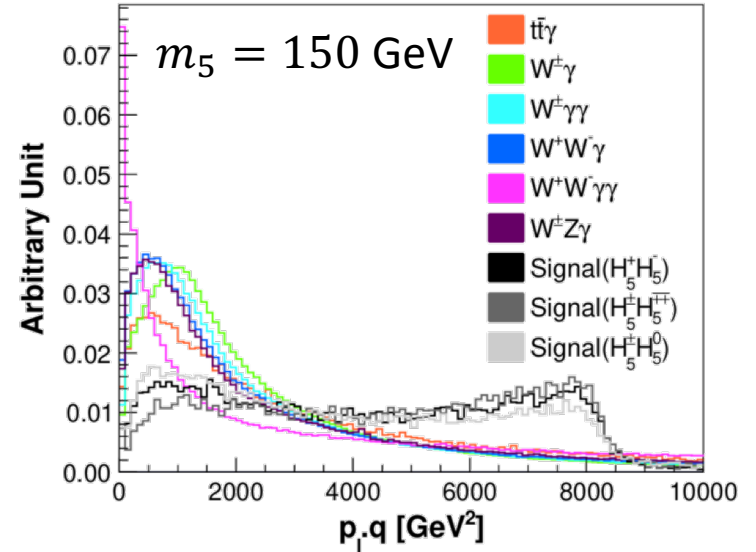
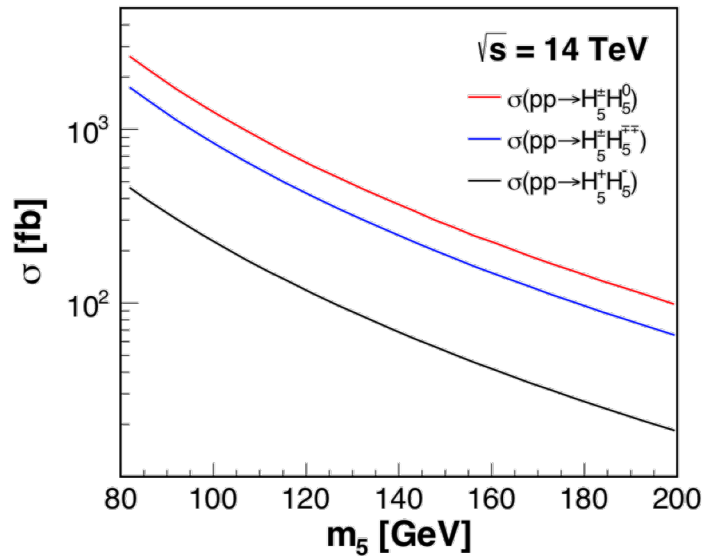


Signals at 360 GeV CEPC

1. Multi-Gauge boson (Multi-lepton)
2. Multi-photon + Gauge boson

$W\gamma$ at the LHC

$$\mathcal{M} = \Gamma^{\mu\nu} \varepsilon_\nu^{W*}(k) \varepsilon_\mu^{\gamma*}(q), \quad \text{with} \quad \Gamma^{\mu\nu} = (g^{\mu\nu} k \cdot q - k^\mu q^\nu) S + i \epsilon^{\mu\nu\alpha\beta} k_\alpha q_\beta \tilde{S},$$



References:

1510.06297: C.-W. Chiang, S. Kanemura, K. Yagyu
@ILC 500 GeV and 1 TeV

1706.01490: Y.-F. Zhang, H. Sun, X. Luo, W.-N. Zhang
@ILC 500 GeV, Fiveplet

1710.00184: B. Li, Z.-L. Han, Y. Liao
@Lepton Collider, Higgs Production/Higgs Pair

1501.04257: C.-W. Chiang, K. Tsumura
@LHC Exotic neutral Higgs

1511.00865: C.-W. Chiang, A.-L. Kuo, T. Yamada
@LHC Exotic Scalar

1809.09217: H. E. Logan, Y. Wu
@LHC $W\gamma$ Channel

Georgi-Machacek Model:

1404.2640: K. Hartling, K. Kumar, H. E. Logan;

Loop induced Decay:

1708.08753: C. Degrande, K. Hartling, H. E. Logan;