Unavoidable Higgs coupling deviations in the Z_2-symmetric Georgi-Machacek model

Authors: Carlos Henrique de Lima and Heather E. Logan

Affiliation: Carleton University, Ottawa, Canada.
carloshenriquedelima@cmail.carleton.ca
logan@physics.carleton.ca

ARXIV SOON

Summary

- Introduction and motivation;
- Custodial singlet sector analysis;
- Direct and Indirect Bounds;
- Exclusion of low mass region;
- Analysis of the remaining parameter space;
- Prospects and Conclusion.

Introduction and motivation

- The Georgi-Machacek model has contributions to electroweak symmetry breaking from scalars in SU(2)L representations larger than the doublet.
- Extends SM by one real triplet ξ and one complex triplet χ.
- Avoids strong constraints on triplet vevs from ρ parameter by imposing global SU(2)L×SU(2)R symmetry on Higgs potential. Spectrum preserves custodial symmetry:

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

- Spectrum: $h, S, (H_3^+, H_3^0, H_3^-), (H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--})$
- The model can have $k_V > 1$.
- The Z2 symmetric version is non-decoupling, the spectrum is restricted to be below 1TeV! Past and current experiments should be able to probe deeply into the parameter space.

$$V_{Z2GM} = \frac{\mu_2^2}{2} Tr(\phi^\dagger \phi) + \frac{\mu_3^2}{2} Tr(X^\dagger X) + \lambda_1 Tr(\phi^\dagger \phi)^2 + \lambda_2 Tr(\phi^\dagger \phi) Tr(X^\dagger X) +$$
$$+ \lambda_3 Tr(X^\dagger X X^\dagger X) + \lambda_4 Tr(X^\dagger X)^2 - \lambda_5 Tr(\phi^\dagger \tau^a \phi \tau^b) Tr(X^\dagger t^a X t^b)$$

Custodial singlet sector

- Custodial singlet sector mass matrix before diagonalization:

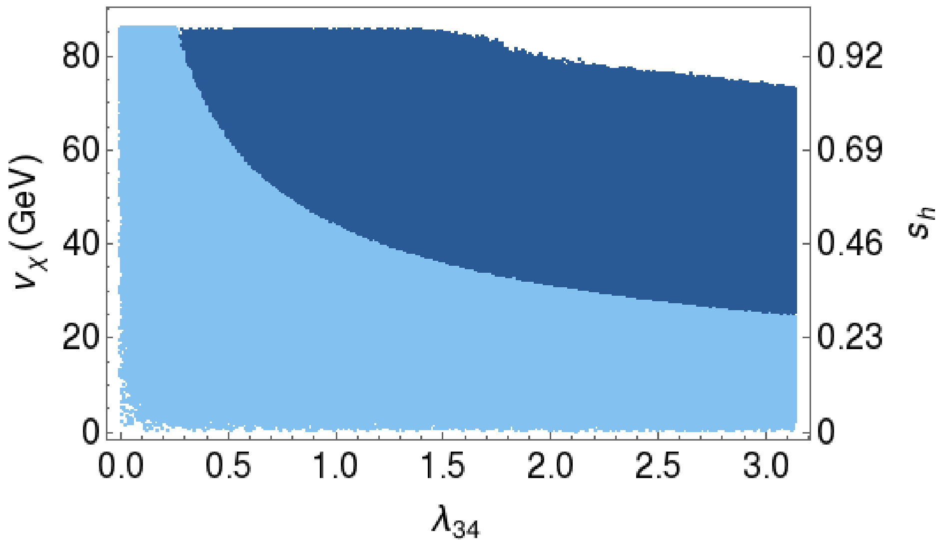
$$\mathbb{M}^2 = \begin{pmatrix} 8\lambda_1 v_\varphi^2 & 2\sqrt{3} v_\chi v_\varphi \lambda_{25} \\ 2\sqrt{3} v_\chi v_\varphi \lambda_{25} & 8 v_\chi^2 \lambda_{34} \end{pmatrix}$$

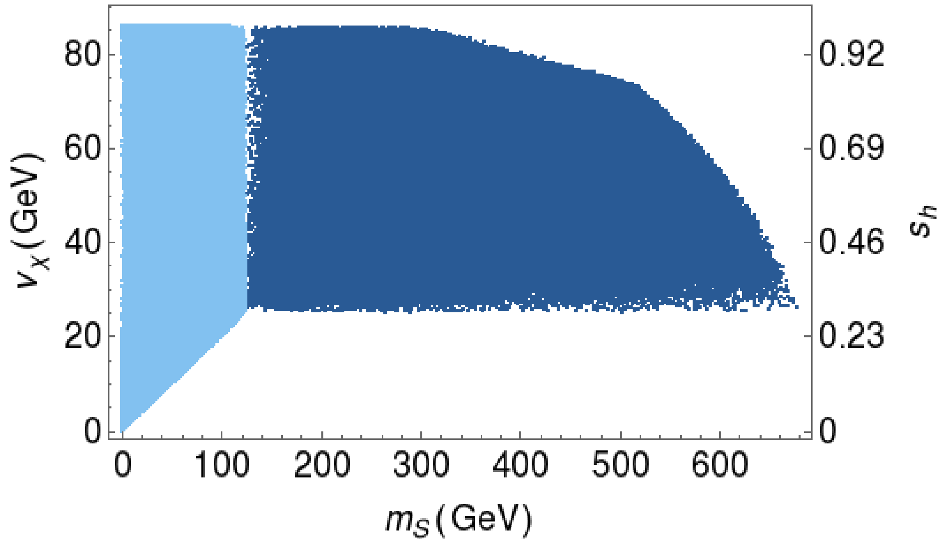
- In the $v_\chi \to 0$ limit we have a light state!
- Fixing one of the singlets to be h(125), we can write a hierarchy equation using the trace and determinant of $\mathbb{M}^2$:

$$m_S^2 - m_h^2 = K + \frac{16\lambda_{25}^2 v_\chi^2 v_\varphi^2}{K} \qquad K = 8\lambda_{34} v_\chi^2 - m_h^2$$

- The sign of K defines the hierarchy! Low v_χ means low m_S!
- Exclusion of low m_S means exclusion of low v_χ and the SM limit: $v_\chi^{min} = {m_S^{min}}/{\sqrt{8\pi}}$ for $m_S < m_h$

$\lambda_{34}^{max} = \pi$ from Pert. Unitarity $\quad \lambda_{25} = (2\lambda_2 - \lambda_5) \quad \lambda_{34} = (\lambda_3 + 3\lambda_4)$

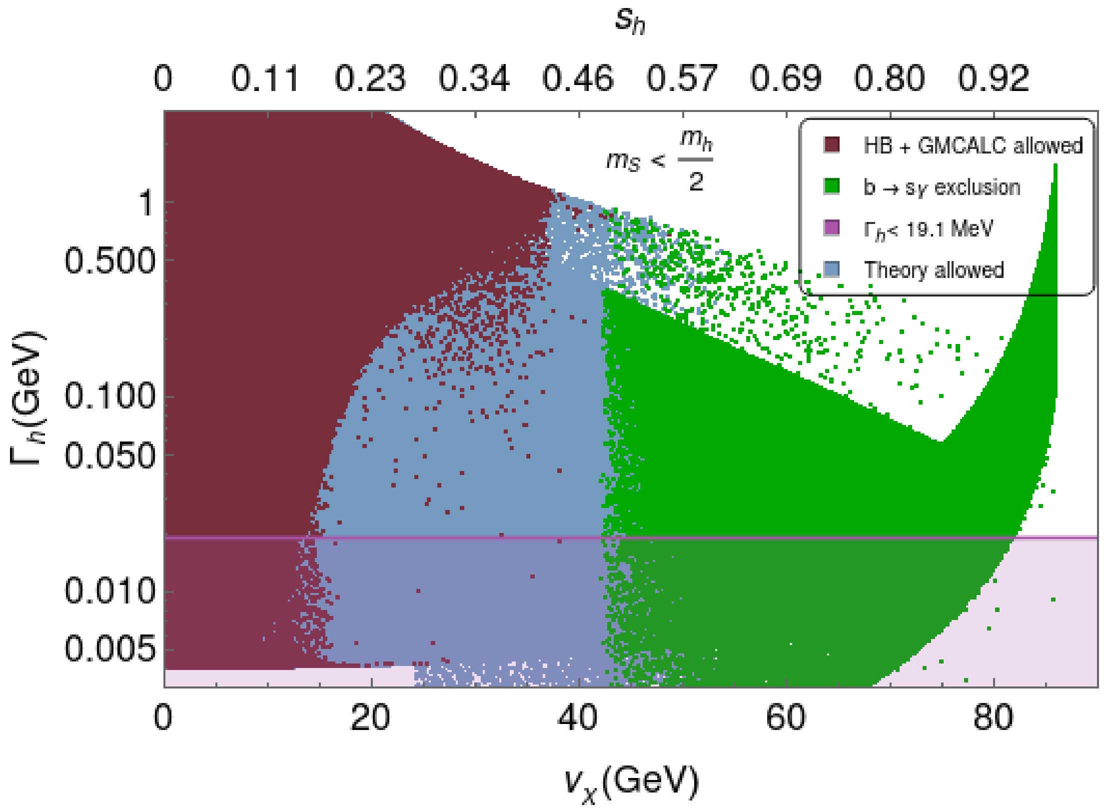




Direct and Indirect Bounds

- GMCALC Direct and Indirect bounds:

- $VBF\ H_5^{\pm\pm} \rightarrow W^{\pm}W^{\pm} \rightarrow$ like−sign dileptons
- Drell-Yan $H_5^{\pm\pm} \rightarrow$ like−sign dileptons
- Drell-Yan $H_5^0\ H_5^{\pm}$with $H_5^0 \rightarrow \gamma\gamma$
- Drell-Yan $H_5^{++}H_5^{--} \rightarrow W^+W^+W^-W^-$
- $b \rightarrow s\gamma$ (excludes large v_χ)

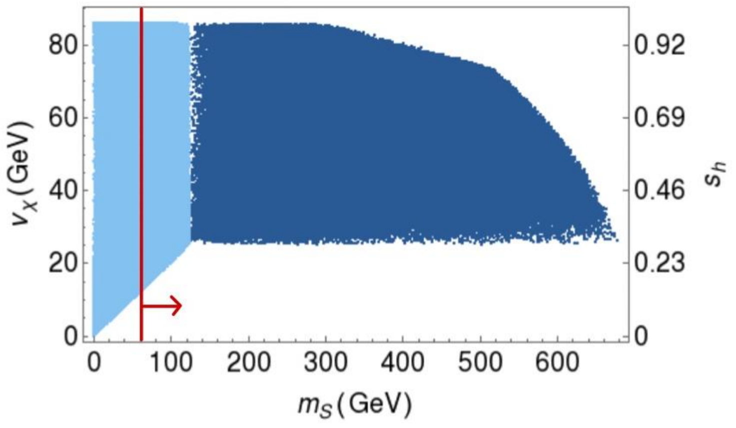


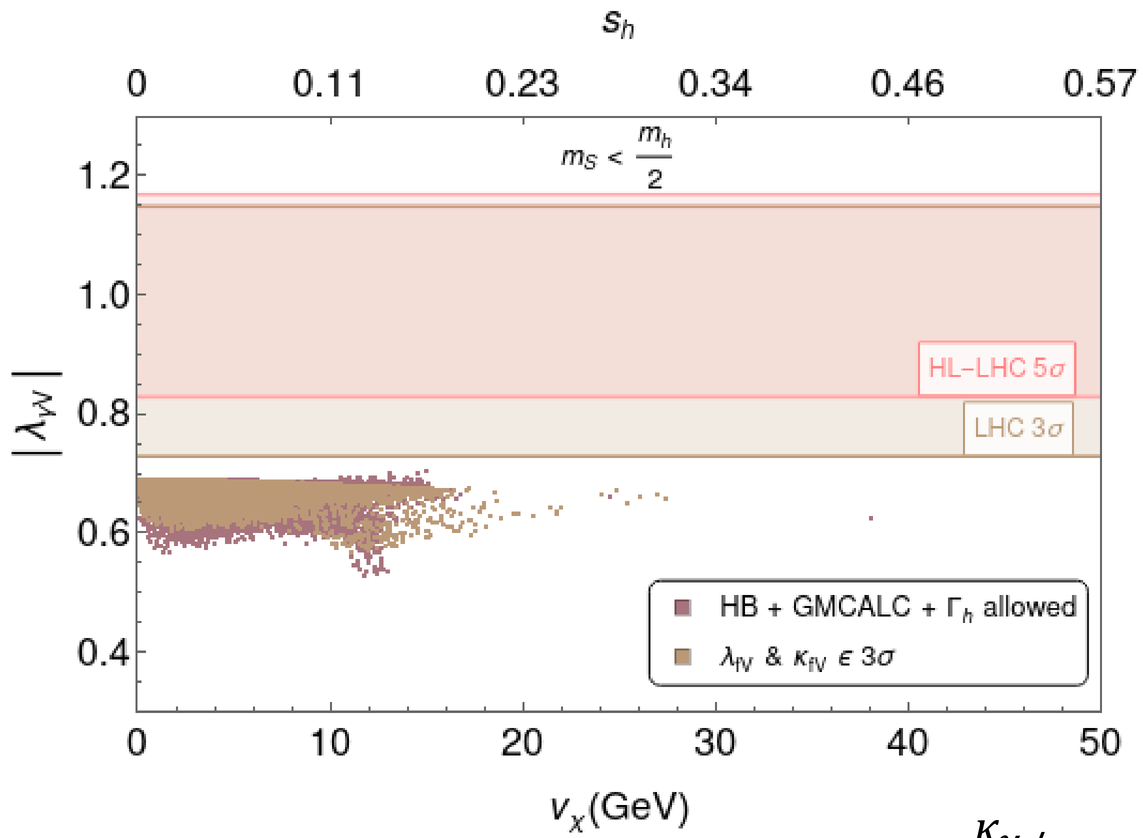
- Higgs to diphoton and coupling modifiers.
- HiggsBounds + Higgs Signals
- Higgs decay to SS ($m_S < {}^{m_h}/_2$):

- $\Gamma_h = \kappa_h^2\Gamma_{SM} + \Gamma_{hSS} < 19.1\ \times 10^{-3}GeV\ (3\sigma)$ from on- and off-shell $(h \rightarrow)ZZ$

Exclusion of $(m_S < {}^{m_h}/_2)$ region

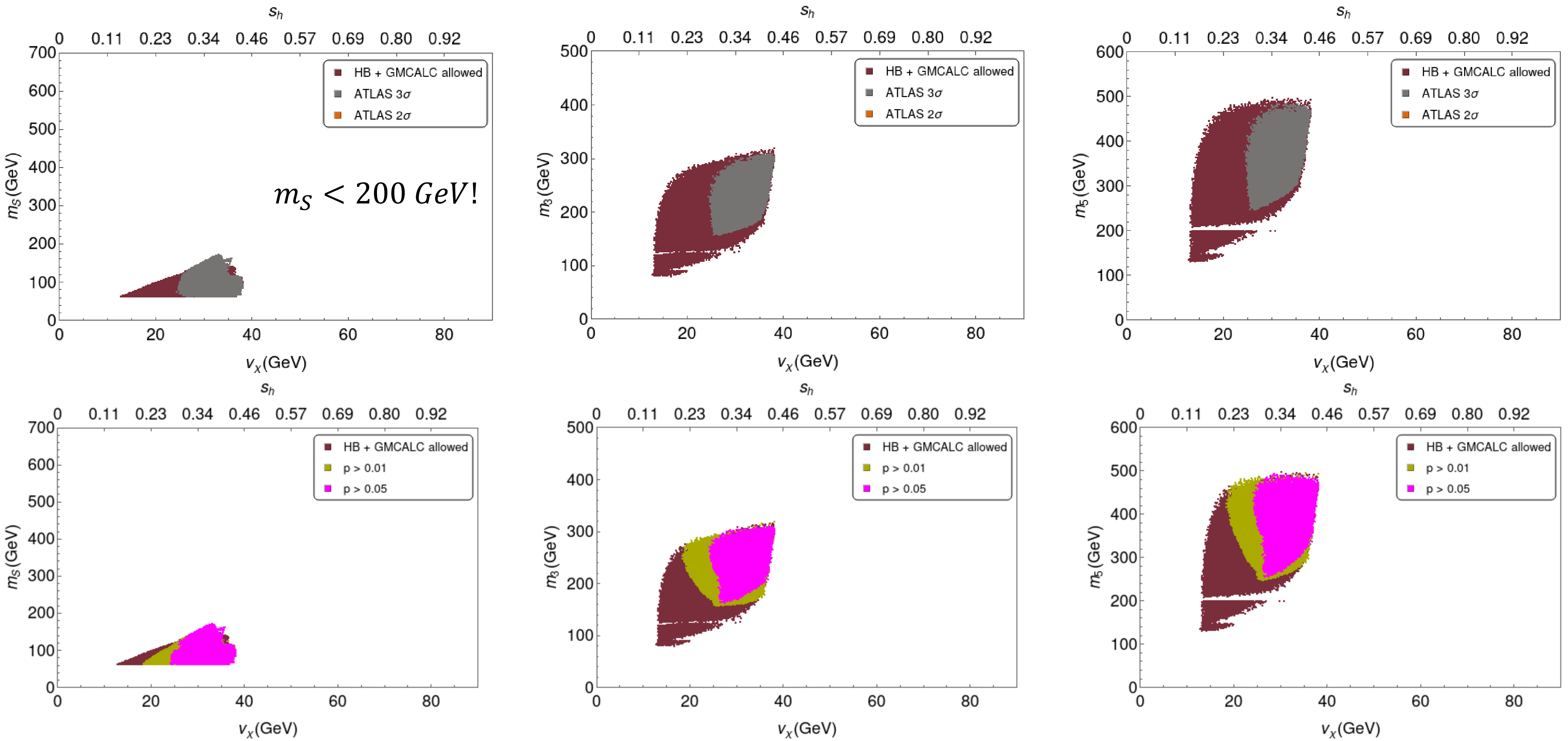
- There is no way to make $h \to \gamma\gamma$ and Γ_h conform with the experimental values at the same time!
- $m_S < {}^{m_h}/_2$ region excluded at 3σ!
- Low m_S exclusion = Low v_χ exclusion! ($v_\chi \gtrsim 12.5$GeV)
- Low v_χ exclusion means that we do not have the SM limit in this model anymore!



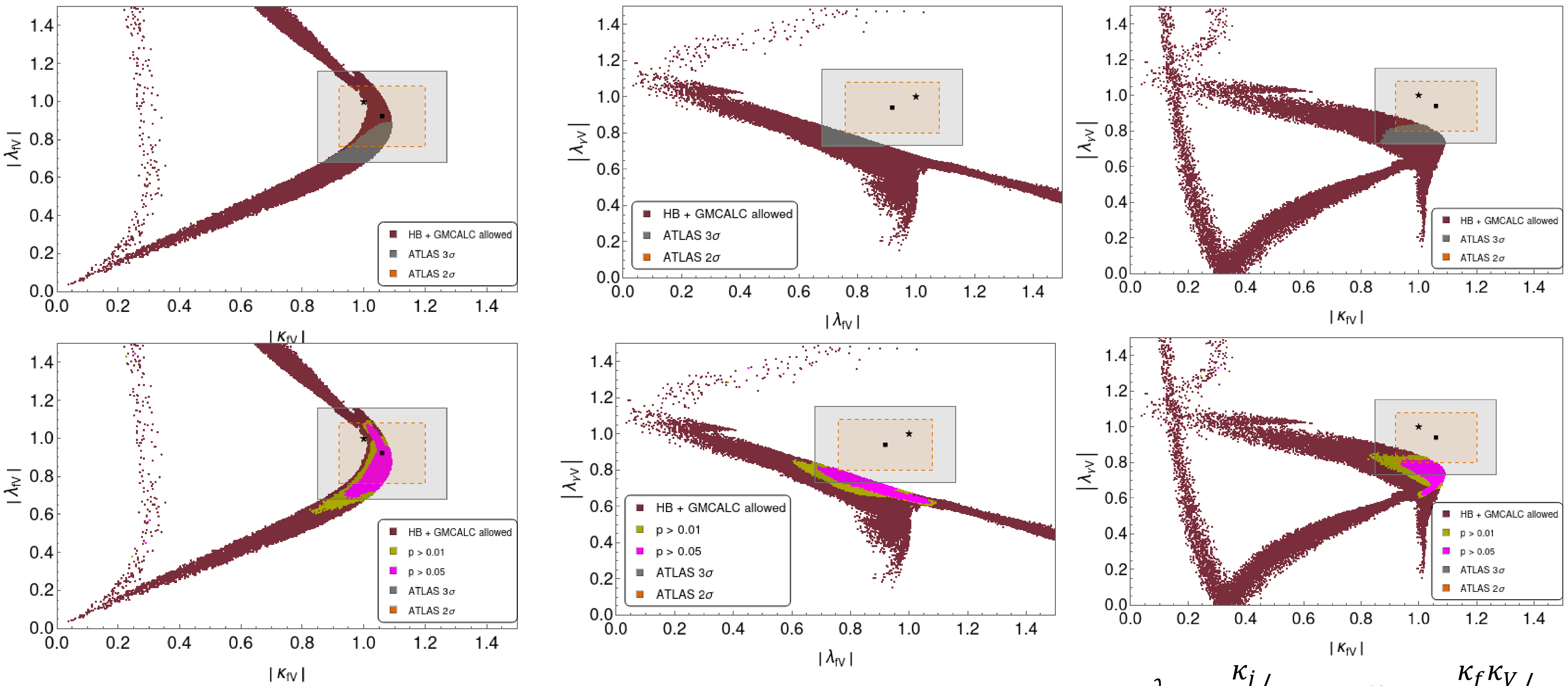


$$\lambda_{\gamma V} = {}^{\kappa_\gamma}/_{\kappa_V}$$

Rest of the parameter space: *h couplings*



Rest of the parameter space: *h couplings*



$\lambda_{ij} = {}^{\kappa_j}/_{\kappa_j}$ $\kappa_{fV} = {}^{\kappa_f \kappa_V}/_{\kappa_h}$

Projection and Conclusion

- We saw that in the Z2GM model, the region where the triplet vev is small is the same as the region where the custodial singlet is light.
- Using the total Higgs width, and together with $h \to \gamma\gamma$ bounds, we can exclude the light custodial singlet region at 99.7%CL. This translates to a lower bound on $v_\chi \gtrsim 12.5$GeV.
- The rest of the parameter space is on the edge of being excluded by h coupling measurements. This remaining region can be easily excluded by searching for singlets below 200 GeV at future lepton colliders.
- The exclusion using coupling modifiers can get to the 5σ level in the HL-LHC!