Global scan in the superweak extension of the standard model[1]

Zoltán Péli
Institute for Theoretical Physics, ELTE Eötvös Loránd University

in collaboration with
Josu Hernández-García and Zoltán Trócsányi

LHC Higgs WG3 subgroup meeting
2022.11.16

[1] Zoltán Péli and Zoltán Trócsányi. "Vacuum stability and scalar masses in the superweak extension of the standard model". In: *Phys. Rev. D* 106 (5 Sept. 2022), p. 055045. DOI: 10.1103/PhysRevD.106.055045. URL: https://link.aps.org/doi/10.1103/PhysRevD.106.055045.

Outline

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Introduction - SW field content[2]

Group representations and charges of the fermions and scalars

field	$\mathrm{SU}(3)_\mathrm{c}$	$\mathrm{SU}(2)_\mathrm{L}$	$\mathrm{U}(1)_Y$	$\mathrm{U}(1)_z$
Q_L	**3**	**2**	$\frac{1}{6}$	$\frac{1}{6}$
u_R	**3**	**1**	$\frac{2}{3}$	$\frac{7}{6}$
d_R	**3**	**1**	$-\frac{1}{3}$	$-\frac{5}{6}$
L_L	**1**	**2**	$-\frac{1}{2}$	$-\frac{1}{2}$
ℓ_R	**1**	**1**	-1	$-\frac{3}{2}$
N_R	**1**	**1**	0	$\frac{1}{2}$
ϕ	**1**	**2**	$\frac{1}{2}$	1
χ	**1**	**1**	0	-1

New in the model:

- $U(1)_z$ gauge group $\Rightarrow$ superweak force
- Weaker than the weak interaction
- Mediated by Z' boson
- New scalar χ
- Right handed neutrinos N_R

[2] Zoltán Trócsányi. In: *Symmetry* 12.1 (2020), p. 107. arXiv: 1812.11189 [hep-ph].

New terms in the Lagrangian

- Gauge sector:

$$\mathcal{L} \supset -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} - \frac{\epsilon}{2}F^{\mu\nu}F'_{\mu\nu}\,,$$
$$\mathcal{D}_\mu^{\mathrm{U}(1)} = -\mathrm{i}(yg_yB_\mu + zg_zB'_\mu)$$

- Scalar sector:

$$-\mathcal{L} \supset= V_0 - \mu_\phi^2|\phi|^2 - \mu_\chi^2|\chi|^2 + (|\phi|^2, |\chi|^2)\begin{pmatrix}\lambda_\phi & \frac{\lambda}{2}\\ \frac{\lambda}{2} & \lambda_\chi\end{pmatrix}\begin{pmatrix}|\phi|^2\\ |\chi|^2\end{pmatrix}$$

- Neutrino sector:

$$-\mathcal{L}_Y^\ell = \frac{1}{2}\overline{\nu_R}\mathbf{Y}_N(\nu_R)^c\chi + \overline{\nu_R}\mathbf{Y}_\nu\varepsilon_{ab}L_a\phi_b + \mathrm{h.c.}$$

New parameters

- Gauge sector: kinetic mixing and new gauge coupling **or** mixing angle between neutral gauge bosons and Z' mass.

$$(\epsilon, g_z) \Longleftrightarrow (\theta_z, M_{Z'})$$

- Scalar sector: scalar quartic couplings **or** mixing angle between the scalar fields and new scalar mass and portal coupling or ratio of VEVs.

$$(\lambda_\phi, \lambda_\chi, \lambda) \Longleftrightarrow (\theta_s, M_s, \lambda \text{ or } \tan\beta = \frac{w}{v})$$

- Neutrino sector: sterile neutrino masses **or** their Yukawa couplings

$$M_{N,i} \Longleftrightarrow y_{x,i}$$

Outline

Search results from colliders

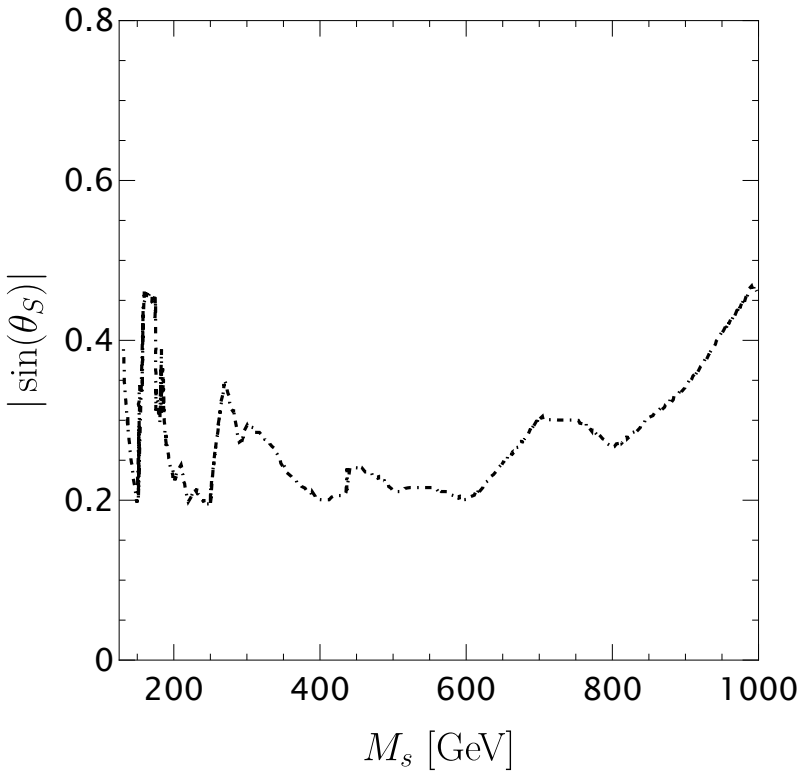

Figure: Limit on singlet scalar extension from LHC SM Higgs searches

- `HiggsBounds`[a] is an excellent tool
- Stringent constraints on $M_s - |\sin\theta_s|$ plane for the singlet scalar extension.[b] New channels in the SWSM:

$$h/s \to Z'Z' \text{ and } h/s \to N_i N_i$$

- HB gives 95% CL cuts in the parameter space, but one needs χ^2 values to use it in a global scan.

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[a] Philip Bechtle et al. In: *Eur. Phys. J. C* 80.12 (2020), p. 1211. arXiv: 2006.06007 [hep-ph].

[b] Tania Robens. In: arXiv: 2203.17016 [hep-ph].

Need for some data from decay channels

- *In a global scan it would be useful to have χ^2 values at least for some relevant channels*
- For a heavy new scalar it is

$$s \to V\ V$$

- For a light Z' boson and sterile neutrinos it is

$$h \to \text{ invisible}$$

- At LO, the partial width for the new channels are

$$\Gamma(h \to Z' Z') = \frac{G_F M_h^3}{16\sqrt{2}\pi} \left(\frac{\sin\theta_s}{\tan\beta}\right)^2 \text{ for } M_{Z'} \ll M_h\,,$$

$$\Gamma(h \to N_i N_i) = \frac{G_F M_h M_{N,i}^2}{8\sqrt{2}\pi} \left(\frac{\sin\theta_s}{\tan\beta}\right)^2 \left(1 - \frac{4M_{N,i}^2}{M_h^2}\right)^{3/2}.$$

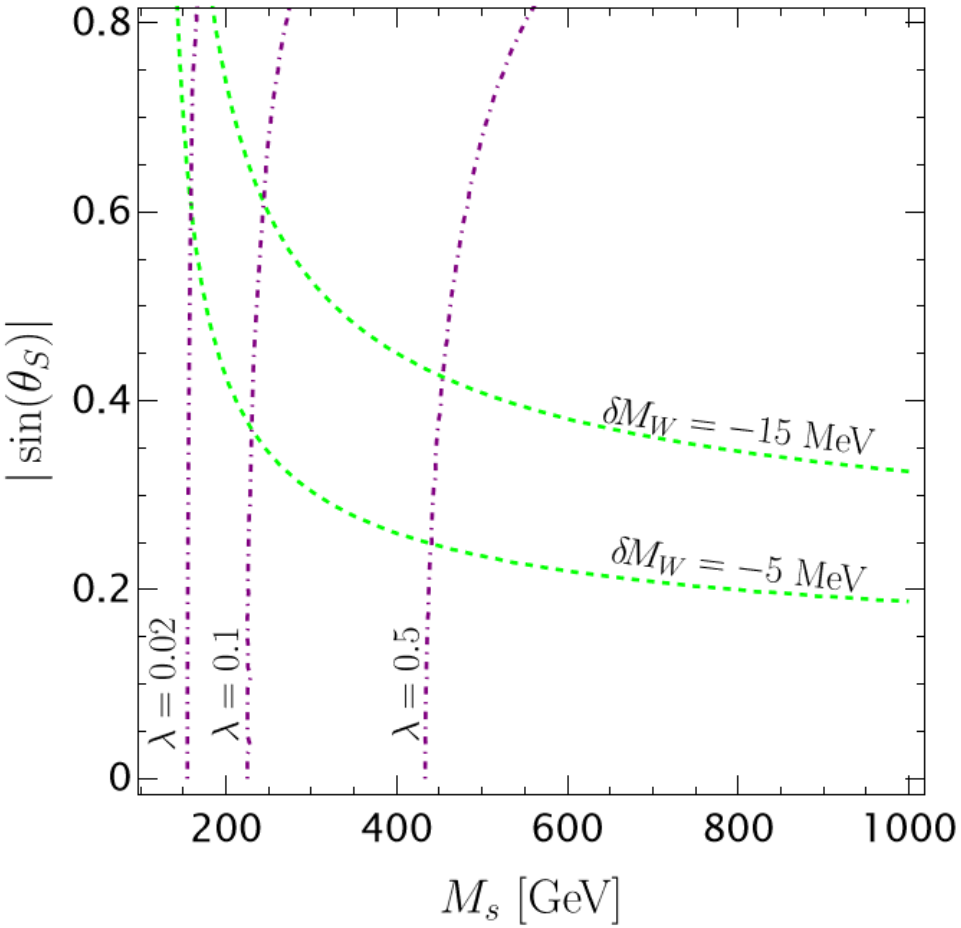
What else can we use in a global scan?

- In the SM at tree level one has $\rho = 1$.
- The ρ parameter is already corrected at the tree level:

$$\rho = \frac{M_W^2}{M_Z^2 c_w^2} = \frac{1}{1+\kappa^2+\tau^2}\left(1+\frac{M_{Z'}^2}{M_Z^2}\right),$$

  where $\kappa(\epsilon, g_z)$ and $\tau(g_z, \tan\beta)$ and $M_Z(\kappa,\tau)$, $M_{Z'}(\kappa,\tau)$.
- This gives a good constraint on the new gauge sector parameters.
- This means, that δM_W receives tree level corrections from the extended gauge sector. What is the interplay of these tree level corrections and the loop corrections from the new scalar s?

What else can we use in a global scan?



- **Electroweak precision observables**. Especially δM_W (green curve: 1-loop δM_W from the extended scalar sector only)
- Limit from the total **width of the Higgs-boson** $\Gamma_h = 3.2^{+2.8}_{-2.2}$ MeV.
- Purple curve:

$$\Gamma(h \to Z'Z') = 9 \text{ MeV}$$

Summary

- The superweak extension adds to the (i) gauge sector, (ii) scalar sector and (iii) neutrinos
- Six new parameters: $(M_{Z'}, \theta_z, M_s, \theta_s, \tan\beta, M_{N,i})$
- Introduces new decay channels to the Higgs-boson
- *To include limits from collider searches, we need χ^2 values from at least some search channels*
- Combine limits for direct searches with EWPO (W-boson mass shift and Higgs-boson decay width are especially interesting)