WG1 Discussion on C: Non-SM-like Higgs C': Also find something else

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Non-SM-like Higgs

- Non-SM-like Higgs without anything new
  - Example: $U(1)_X$ hidden sector
- Non-SM-like Higgs with new particles
  - Example: MSSM, ...

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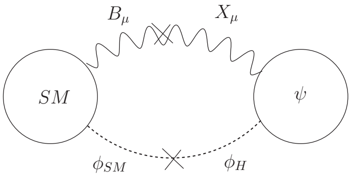
- Altered SM production and decay channels
  - $gg \to h \to b\bar{b}$, $gg \to h \to W^+W^-$
- New particles decaying to Higgs
  - h in SUSY cascade decays
- Higgs decaying to new particles
  - $h \to$ hidden sector

[SG, Seung Lee, James Wells, Ongoing]

SM $\times U(1)_X$

$U(1)_X sector : GaugeBoson(X_\mu), Scalar(\Phi_H), Fermion(\psi)$



SM $\leftrightarrow U(1)_X$ communication

$\mathcal{L} \supset -\alpha \, |\Phi_{SM}|^2 |\Phi_H|^2 + \frac{\chi}{2} \, X_{\mu\nu} B^{\mu\nu}$

Here focus on Higgs Mixing route

$\mathcal{V}$ is such that

$SU(2)_L \times U(1)_Y$ breaking : $\langle \phi_{SM} \rangle = v$

$U(1)_X$ breaking : $\langle \phi_H \rangle = \xi$

Causes $\phi_H \leftrightarrow \phi_{SM}$ mixing (masses: m_h, m_H)

$$\begin{pmatrix} \phi_{SM} \\ \phi_H \end{pmatrix} = \begin{pmatrix} c_h & s_h \\ -s_h & c_h \end{pmatrix} \begin{pmatrix} h \\ H \end{pmatrix}$$

$U(1)_X$ fermion sector (Effective Theory)

Vector-like or chiral fermions.
After $U(1)_X$ breaking, with ϕ_H real d.o.f :

$$\mathcal{L} \supset \overline{\psi} i\gamma^\mu D_\mu \psi + \kappa\, \phi_H \overline{\psi}\psi + M_\psi \overline{\psi}\psi$$

Accidental Z_2 symmetry : $\psi \to -\psi$, $SM \to SM$, $\phi_H \to \phi_H$

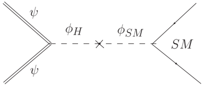
- So ψ cosmologically stable $\Longrightarrow$ Dark Matter
- ψ Vector-like or Chiral. Dirac or Majorana

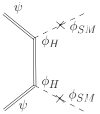
Parameters :

$M_\psi, \kappa, s_h, m_h, m_H$

Self-annihilation and Dark Matter

- Self-annihilation & Relic density





$\psi\psi \to b\bar{b}\,, W^+W^-\,,\, ZZ\,,\, hh\,,\, t\bar{t}$

Obtain analytical thermally averaged c.s. and relic density

Cross-check with micrOMEGAs [Belanger, Boudjema, Phukov, Semenov]

Match to observations : $\Omega_0 = 0.222 \pm 0.02$ [PDG '08]

Self-annihilation and Dark Matter

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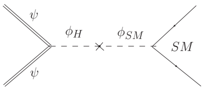

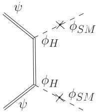

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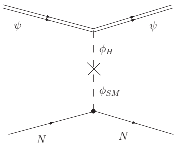
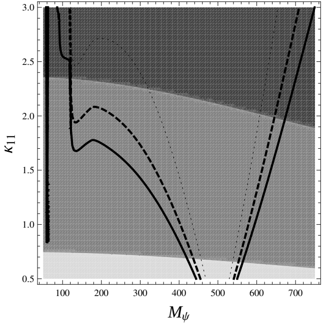
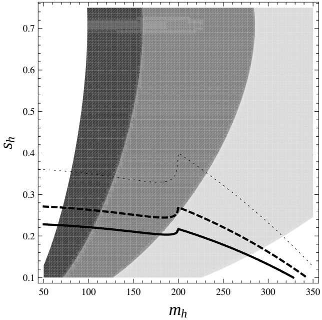
- Direct detection:



Preferred regions





$M_\psi = 200\,GeV,\, m_h = 120\,GeV,\, \kappa_{11} = 2.0,\, s_h = 0.25,\, \kappa_{3\phi} = 1,\, m_H = 1\,TeV$

Contours of $\Omega_{dm0} = 0.1,\ 0.2,\ 0.3$ (dotted, thick-dash, solid)
Shaded $\sigma_{Dir} \gtrsim 10^{-43}\ \mathrm{cm}^2$ (dark-gray) $\gtrsim 10^{-44}\ \mathrm{cm}^2$ (med-gray) $\gtrsim 10^{-45}\ \mathrm{cm}^2$ (light-gray)

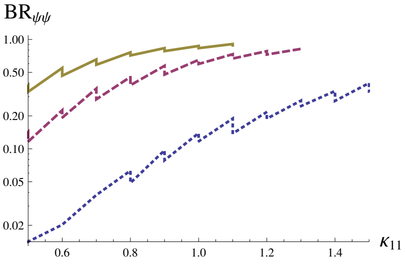
Higgs Invisible Decay

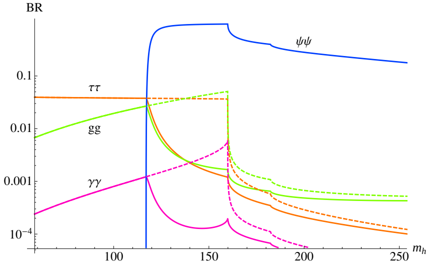
If $m_h > 2M_\psi$: $h \to \psi\overline{\psi}$ Invisible Decay!

$h \to \psi\bar{\psi}$, $b\bar{b}$, WW , ZZ , $t\bar{t}$

Scan with Ω_{dm} , σ_{DirDet} enforced

SM channels suppressed





$M_\psi \approx 60\text{GeV}$, $m_h = 120\text{GeV}$

$h \longrightarrow INV$ LHC Signature (qqh - WBF)

[O. J. P. Eboli and D. Zeppenfeld, 2000]

$$p_T^j > 40 \ , \ |\eta_j| < 5.0 \ , \ |\eta_{j_1} - \eta_{j_2}| > 4.4 \ , \ \eta_{j_1} \cdot \eta_{j_2} < 0 \ ,$$
$$\not{p}_T > 100 \text{ GeV} \ , \ M_{jj} > 1200 \text{ GeV} \ , \ \phi_{jj} < 1 \ .$$

For $s_h = 0.25$, $BR_{INV} = 0.25$:

m_h (GeV)	$\sigma_S BR_{inv}(fb)$	$\sigma_B(fb)$	$\mathcal{L}_{5\sigma}$ (fb^{-1})
120	22.7	167	8
200	18	167	12.8
300	13.2	167	23.7

$h \to INV$ LHC signature (Zh)

[H. Davoudiasl, T. Han and H. E. Logan, 2004]

$$p_{T\,\ell} > 10\ ,\ |\eta_\ell| < 2.5\ ,\ \not{p}_T > 100\ \mathrm{GeV}\ ,\ |M_{\ell^+\ell^-} - m_Z| < 10\ \mathrm{GeV}\ .$$

For $s_h = 0.25\ ,\ BR_{INV} = 0.25$:

m_h (GeV)	$\sigma_S BR_{inv}(fb)$	$\sigma_B(fb)$	$\mathcal{L}_{5\,\sigma}$ (fb^{-1})
120	2.1	26.3	146
200	0.8	26.3	1059
300	0.26	26.3	–

2HDM and MSSM

- Altered $ht\bar{t}$ and $hb\bar{b}$ couplings can change $\sigma(gg \to h)$
  - $y_b \sim \frac{m_b}{v}\sqrt{1 + tan^2\beta}(-s_\alpha) \qquad y_t \sim \frac{m_t}{v}\frac{\sqrt{1+tan^2\beta}}{tan\beta}c_\alpha$
- Altered hWW and hZZ couplings
  - $c_{hWW} \sim g^2 v \frac{(tan\beta\, c_\alpha - s_\alpha)}{\sqrt{1+tan^2\beta}}$
- How well can the LHC determine these couplings
  - Given these error bars, are there regions of MSSM parameter space can lead to larger deviations?
- $BR(h \to b\bar{b})$, $BR(h \to b\bar{b})$ also should be taken into account
  - How well is $(\sigma * BR)\,(gg \to h \to XX)$ known?

Other Scenarios

Additional scalar doublets
Adding singlets that mix with the Higgs doublet
Couple to Higgs triplet