Hidden Sector Dark Matter and LHC Signatures

(Ongoing work)

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BNL Forum

Nov. 2008

Motivation

$U(1)_X$ gauge factor appears in many BSM theories
$U(1)_X$ charged Hidden sector :
Gauge Boson (X_μ) , Scalar (Φ_H) , Fermion (ψ)
Hidden sector talks to SM via the Higgs (ϕ_{SM}) (and via B_μ)

- ψ can be Dark Matter
- Direct detection
- LHC implications

Here focus on ψ
(for LHC $h \to X_\mu X_\mu \to \ell^+\ell^-\ell^+\ell^-$ see [SG,Jung,Wells: '08])

Framework

SM $\times U(1)_X$

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

SM $\leftrightarrow U(1)_X$ communication

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

$\mathcal{V}$ 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)

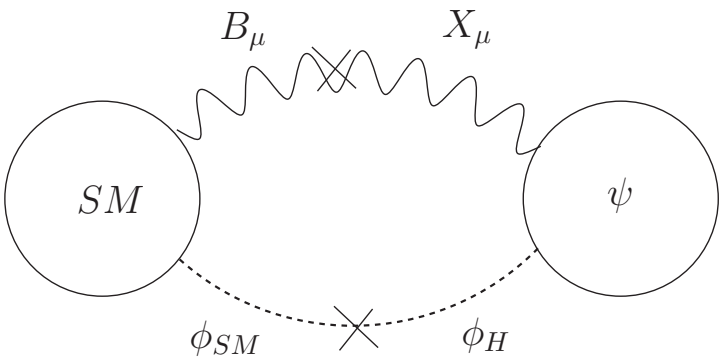
$$\begin{pmatrix} \phi_{SM} \\ \phi_H \end{pmatrix} = \begin{pmatrix} c_h & s_h \\ -s_h & c_h \end{pmatrix} \begin{pmatrix} h \\ H \end{pmatrix}$$

Adding Fermions

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

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

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



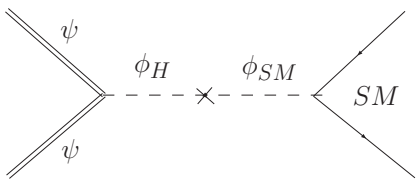
- Here focus on Higgs Mixing route

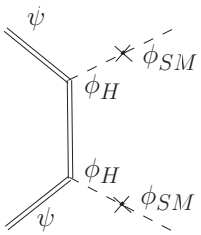
Parameters :

$M_\psi, \kappa, s_h, m_h, m_H$ (decouple H)

Relic Density

Self-annihilation

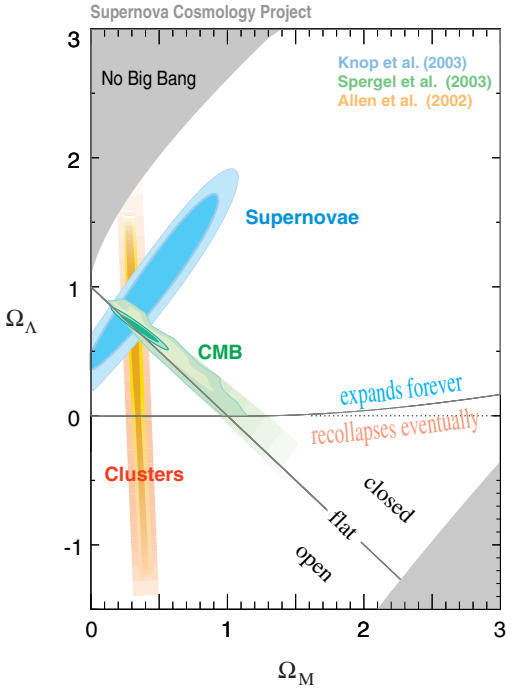




$$\Omega_0 h^2 = 10^{-29} x_f \left(\frac{eV^{-2}}{\langle \sigma v \rangle} \right)$$

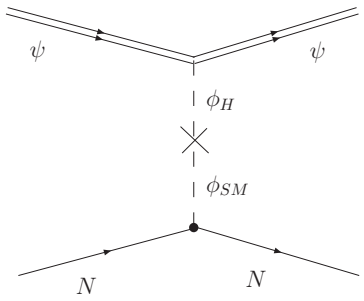
$$\sigma v_{rel} = a + b\ v_{rel}^2 + O(v_{rel}^4)$$

$$\langle \sigma v \rangle = a + b/x_f \qquad x_f \equiv M_\psi / T_f \approx 21$$

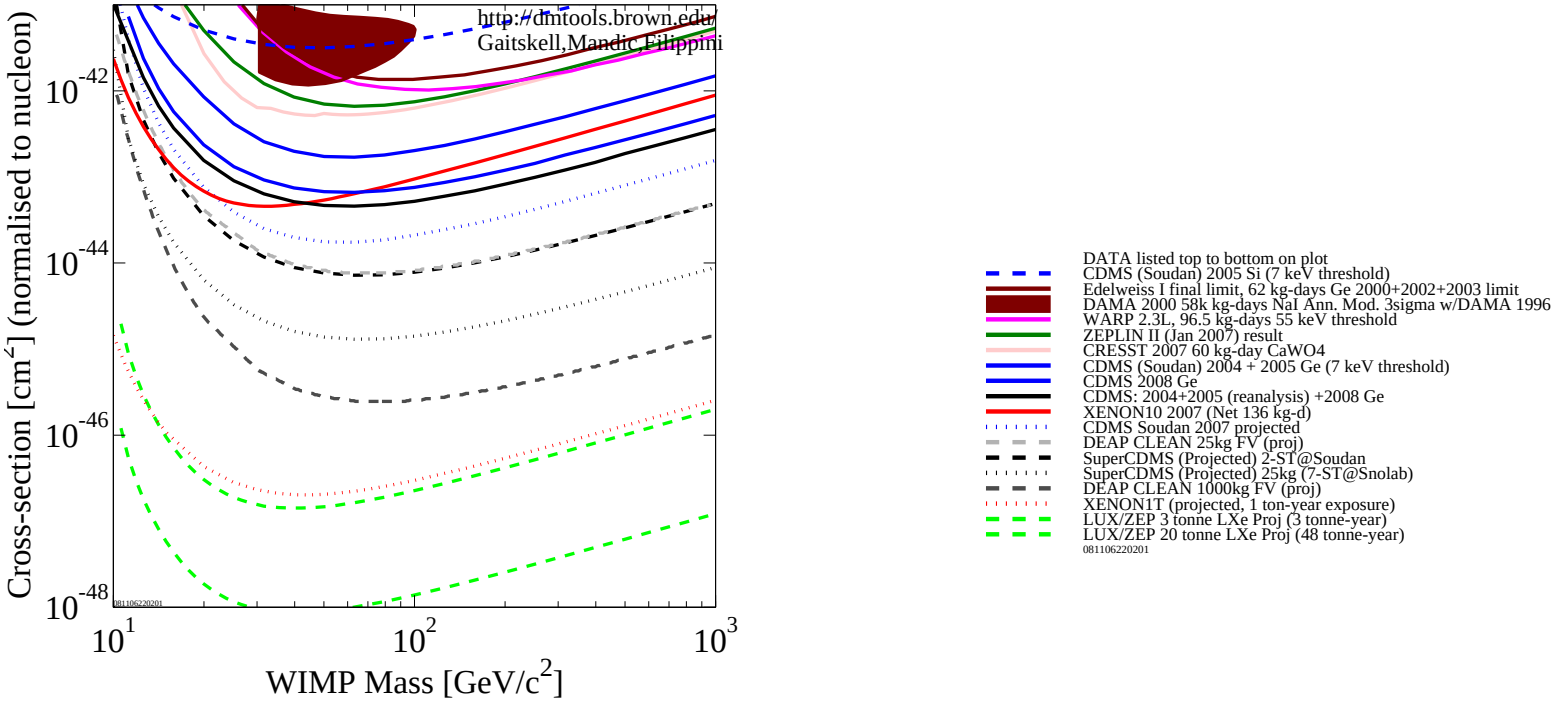


Observations : $\Omega_0 = 0.222 \pm 0.02$ [PDG '08]

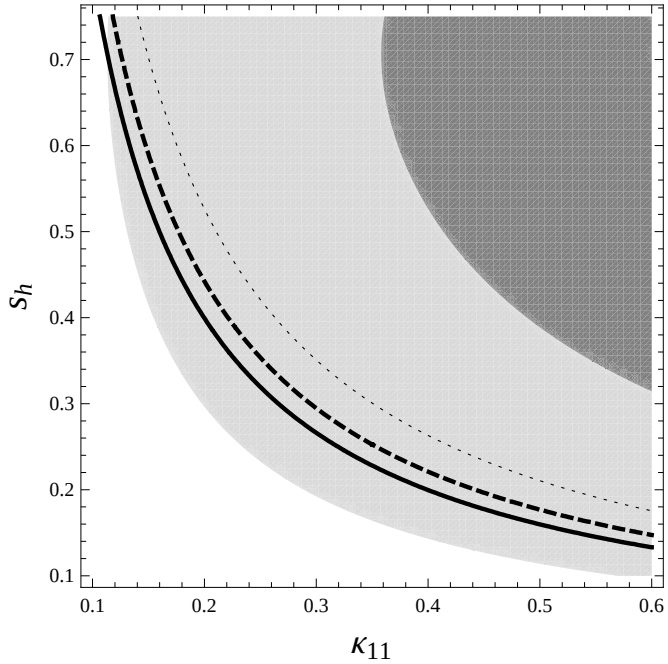
Direct Detection

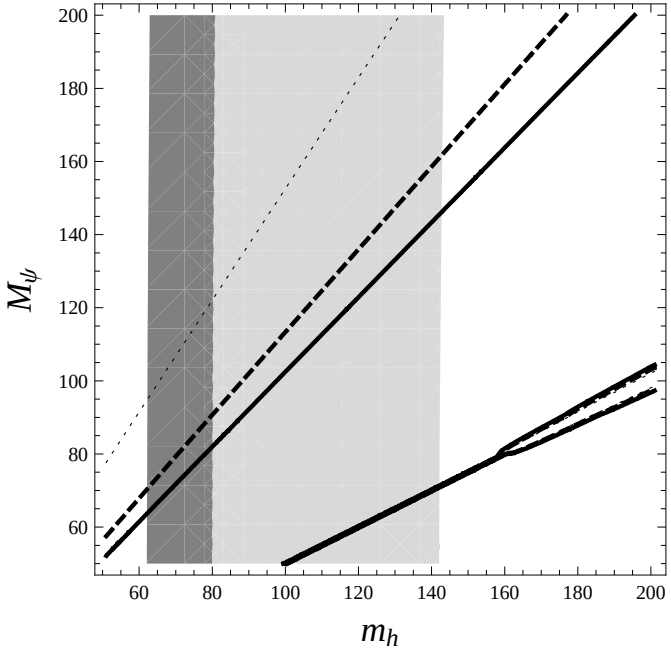


Effective $h\bar{N}N$ coupling $\approx 2 \times 10^{-3}$ [Shifman, Vainshtein, Zakharov (1973)]



ψ Relic Density + Direct Detection

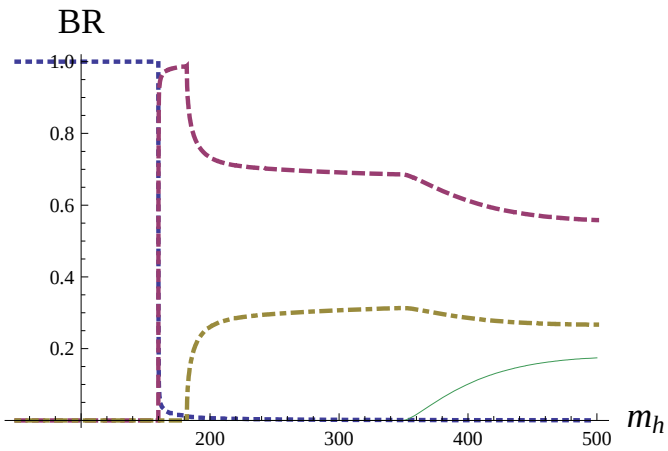


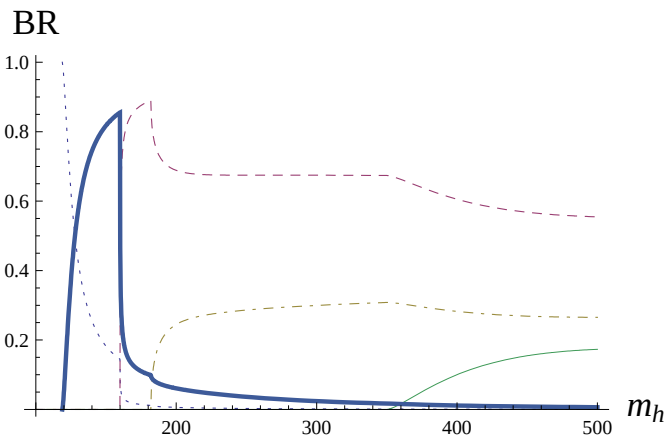


$M_\psi = 125\,GeV$, $m_h = 120\,GeV$, $\kappa_{11} = 1/3$, $s_h = 0.25$, $\kappa_{3\phi} = 1/3$, $m_H = 1\,TeV$
Contours of $\Omega_{dm0} = 0.1,\ 0.2,\ 0.3$ (dotted, thick-dash, solid)
Shaded $\sigma_{Dir} \gtrsim 10^{-44}\ \mathrm{cm}^2$ (med-gray) $\gtrsim 10^{-45}\ \mathrm{cm}^2$ (light-gray)

h BR

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



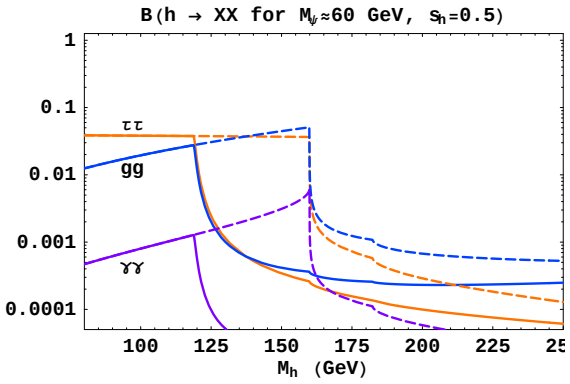


SM (left) and $U(1)_X$ (right) ; $h \to$ INV, bb, WW, ZZ, tt

$M_\psi \approx 60\,GeV, s_h = 0.25, \kappa_{11} = 0.8, \kappa_{3\phi} = 1.0, m_H = 1\,TeV$

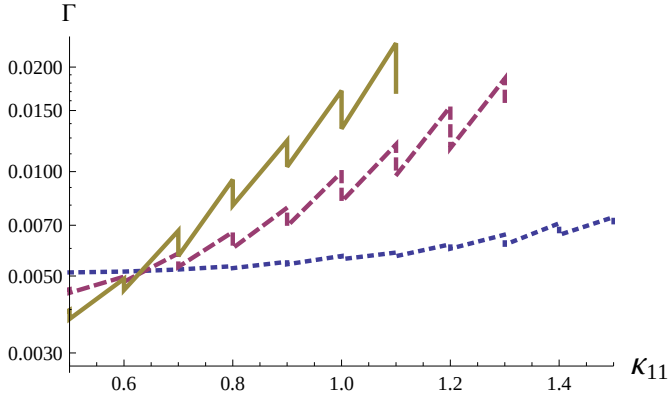
NB: Relic density not enforced

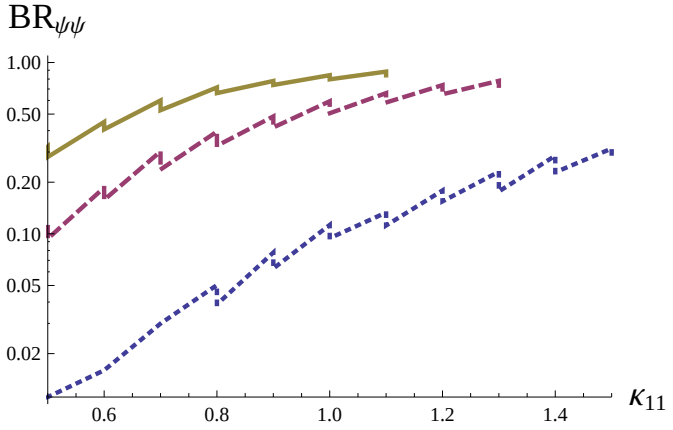
$h \longrightarrow SM$ suppressed



Scan for Width and BR_{INV} ($m_h = 120$)

Correct relic density; Direct detection constraint





Γ (left) and BR_{inv} (right) for $s_h = 0.25, 0.5, 0.707$ (dotted, dashed, solid)

$\kappa = 1/3, m_H = 1\,TeV$;

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

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

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

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	–

Summary

$U(1)_X$ hidden sector *naturally* explains Dark Matter relic density

If $m_h > 2M_\psi$, LHC $h \to INV$

- $h \to$SM suppressed
- Vector Boson Fusion promising

Direct Detection in future experiments