Dark matter and collider phenomenology of gauged $U(1)_B$ and $U(1)_L$ models

P. Fileviez Perez, S. Ohmer, **HP**, PLB 735 (2014) 283

S. Ohmer, **HP**, PRD 92 (2015) 055020

Sept 30, 2015

DESY Workshop

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Basic idea of gauged $U(1)_{B,L}$ models

Classically conserved currents in the Standard Model:

$$J^\mu_{\rm B} = \sum_q \frac{1}{3}\bar{q}\gamma^\mu q$$

$$J^\mu_{\rm L} = \sum_{\ell,\nu}(\bar{\ell}\gamma^\mu \ell + \bar{\nu}\gamma^\mu \nu)$$

Can they source gauge fields?

Quantum mechanically anomalous:

$$\partial_\mu J^\mu_{\rm B} = \frac{g^2}{16\pi^2}\frac{3}{2}\widetilde{\vec{W}}_{\mu\nu}\cdot \vec{W}^{\mu\nu} - \frac{g'^2}{16\pi^2}\frac{3}{2}\widetilde{B}_{\mu\nu}B^{\mu\nu}$$

$$\partial_\mu J^\mu_{\rm L} = \quad \text{— same —}$$

Can't consistently couple currents to gauge fields*:

$$\mathcal{L} = -g_B Z'_\mu J^\mu_B \quad \text{or} \quad -g_L Z'_\mu J^\mu_L$$

(not counting B–L)

Add additional fermions to modify currents:

$$J^\mu_B \longrightarrow J^\mu_{\rm B,\,tot} = \sum_q \frac{1}{3}\bar{q}\gamma^\mu q + J^\mu_{\rm B,ext}$$

$$J^\mu_{\rm L} \longrightarrow J^\mu_{\rm L,\,tot} = \underbrace{\sum_{\ell,\nu}(\bar{\ell}\gamma^\mu \ell + \bar{\nu}\gamma^\mu \nu)}_{\text{SM part}} + J^\mu_{\rm L,ext}$$

Total currents are anomaly free:

$$\partial_\mu J^\mu_{\rm B,\,tot} = 0$$

$$\partial_\mu J^\mu_{\rm L,\,tot} = 0$$

$$\boxed{\mathcal{L} = -g_B Z'_\mu J^\mu_B \quad \text{and} \quad -g_L Z'_\mu J^\mu_L \qquad \text{OK}}$$

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Motivation (Features)

1. Leads to viable (thermal) dark matter candidate

P. Fileviez Perez, M. Wise, PRD 82, 011901 (2010)

2. New possibilities for baryogenesis

– modified EW sphaleron $(QQQL)^3 \longrightarrow (QQQL)^3\psi\ldots$

= changed relationship between B and L asymmetries in eq.

P. Fileviez Perez, HP, PLB 731, 232 (2014)

P. Fileviez Perez, S. Ohmer, HP, PLB 735, 283 (2014)

– extended Higgs sector + CPV in fermion sector

= electroweak baryogenesis?

3. Extended gauge group

$$\mathrm{SU}(3)_C \otimes \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y \otimes \mathrm{U}(1)_B \otimes \mathrm{U}(1)_L$$

leads to possibility for low scale unification, <u>without</u> proton decay

P. Fileviez Perez, S. Ohmer, PRD 90 037701 (2014)

Formulation

Common to both models

$\mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y \otimes \mathrm{U}(1)_\mathrm{B} \otimes \mathrm{U}(1)_\mathrm{L}$

Gauge fields:		$\vec{W}^\mu$	B^μ	Z^μ_B	Z^μ_L
Right handed neutrinos	$\bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\tau$	$\mathbf{1}$	0	0	-1
Leptonic Higgs	S_L	$\mathbf{1}$	0	0	2
Baryonic Higgs	S_B	$\mathbf{1}$	0	3	3

Leptobaryon Model VA

M. Duerr P. Fileviez Perez, M. Wise
PRL 110, 231801 (2013)

"Lepto-baryons"

	$\mathrm{SU}(2)_L$	$U(1)_Y$	$U(1)_\mathrm{B}$	$U(1)_\mathrm{L}$
Ψ	$\mathbf{2}$	$-1/2$	B_1	L_1
$\overline{\Psi}$	$\overline{\mathbf{2}}$	$1/2$	$-B_2$	$-L_2$
η	$\mathbf{1}$	-1	B_2	L_2
$\overline{\eta}$	$\mathbf{1}$	-1	$-B_1$	$-L_1$
χ	$\mathbf{1}$	0	B_2	L_2
$\overline{\chi}$	$\mathbf{1}$	0	$-B_1$	$-L_1$

anomaly cancellation constraint: $L_1 - L_2 = -3$, $B_1 - B_2 = -3$

Leptobaryon Model A

P. Fileviez Perez, S. Ohmer, **HP**,
PLB 735 (2014) 283

	$\mathrm{SU}(2)_L$	$U(1)_Y$	$U(1)_\mathrm{B}$	$U(1)_\mathrm{L}$
Ψ	$\mathbf{2}$	$1/2$	$3/2$	$3/2$
$\overline{\Psi}$	$\overline{\mathbf{2}}$	$-1/2$	$3/2$	$3/2$
$\vec{\Sigma}$	$\mathbf{3}$	0	$-3/2$	$-3/2$
χ	$\mathbf{1}$	0	$-3/2$	$-3/2$

Focus of this talk

Formulation of model A

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Simplify:

Lepton breaking scale very high $\Lambda_{\rm L} \gg \Lambda_{\rm B}$

	$\mathrm{SU}(2)_L$ $\vec{W}^\mu$	$U(1)_Y$ B^μ	$U(1)_{\rm B}$ $\boxed{Z_{\rm B}^\mu}$	$\cancel{U(1)_{\rm L}\ Z_{\rm L}^\mu}$
$\cancel{\bar{\nu}_{e,\mu,\tau}}$	$\cancel{1}$	$\cancel{0}$	$\cancel{0}$	$\cancel{1}$
$\cancel{S_{\rm L}}$	$\cancel{1}$	$\cancel{0}$	$\cancel{0}$	$\cancel{2}$
$S_{\rm B}$	1	0	3	$\cancel{3}$
Ψ	$\mathbf{2}$	$1/2$	$3/2$	$\cancel{3/2}$
$\overline{\Psi}$	$\overline{\mathbf{2}}$	$-1/2$	$3/2$	$\cancel{3/2}$
$\vec{\Sigma}$	$\mathbf{3}$	0	$-3/2$	$\cancel{-3/2}$
χ	1	0	$-3/2$	$\cancel{-3/2}$

Focus on baryonic sector

Lagrangian

$$\mathcal{L} = \cdots - \cancel{\frac{1}{2}\sin(\epsilon) B_{\mu\nu} Z_{\rm B}^{\mu\nu}}$$

neglect kinetic mixing

$$D_\mu S_{\rm B} = (\partial_\mu + 3 i g_{\rm B} Z_{{\rm B}\mu}) S_{\rm B}$$

$$\mathcal{L}_{\rm Yuk} = -y_\psi S_{\rm B}^* \bar{\Psi}\Psi - \frac{y_\Sigma}{2} S_{\rm B} \vec{\Sigma}\cdot\vec{\Sigma} - \frac{y_\chi}{2} S_{\rm B}\chi\chi + \text{c.c.}$$

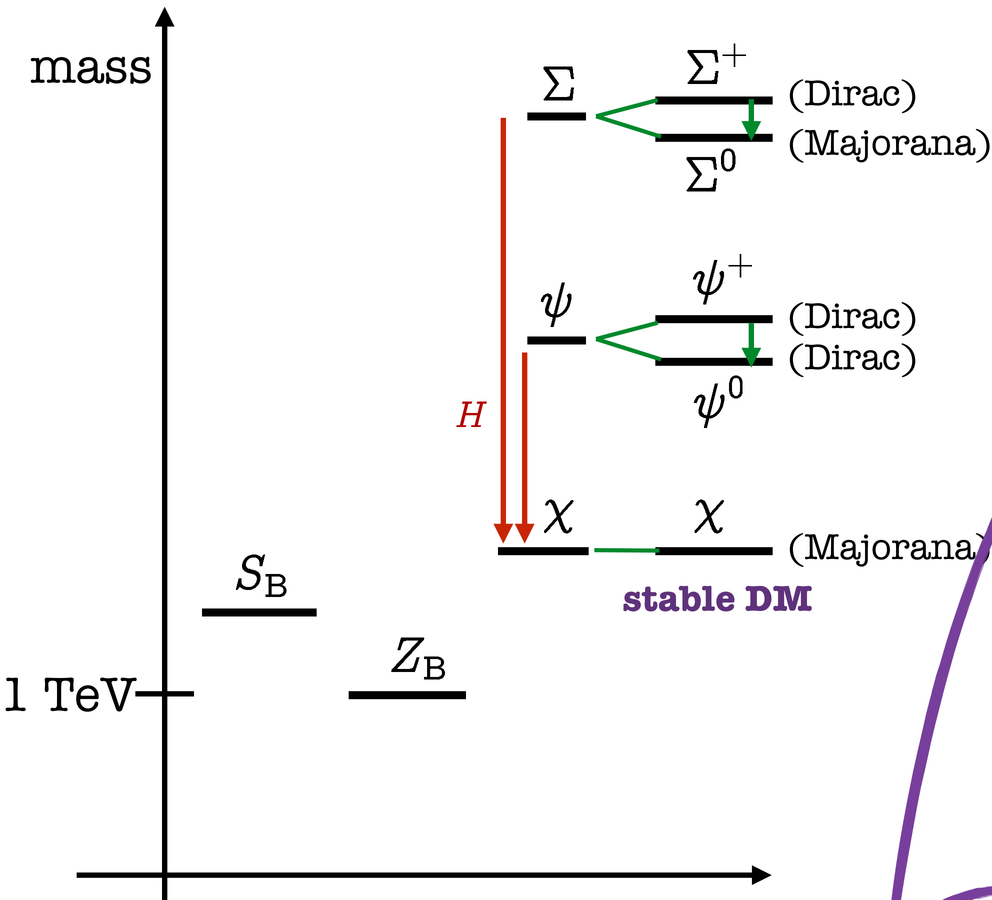
EW/Baryon spontaneous symm. breaking

$$V = -\mu^2 |H|^2 + \lambda |H|^4 - \mu_S^2 |S_{\rm B}|^2 + b|S_{\rm B}|^2 + a|H|^2|S_{\rm B}|^2$$

Formulation of model A

P. Fileviez Perez, S. Ohmer, **HP**,
PLB 735 (2014) 283

Spectrum



$J^{PC} = 0^{++}$

$\Sigma \to -\Sigma$ accidental Z_2
$\Psi \to -\Psi$ symmetry
$\chi \to -\chi$ $\Rightarrow$ stable DM

Lagrangian

$$\mathcal{L} = \cdots - \cancel{\frac{1}{2}\sin(\epsilon) B_{\mu\nu} Z_B^{\mu\nu}}$$ neglect kinetic mixing

$$D_\mu S_B = (\partial_\mu + 3 i g_B Z_{B\mu}) S_B$$

$$\mathcal{L}_{\text{Yuk}} = -y_\psi S_B^* \bar{\Psi}\Psi - \frac{y_\Sigma}{2} S_B \vec{\Sigma}\cdot\vec{\Sigma} - \frac{y_\chi}{2} S_B \chi\chi + \text{c.c.}$$

EW/Baryon spontaneous symm. breaking

$$V = -\mu^2 |H|^2 + \lambda |H|^4 - \mu_S^2 |S_B|^2 + b |S_B|^2 + a |H|^2 |S_B|^2$$

$$\boxed{\Rightarrow S_B,\, Z_B,\, \Sigma,\, \psi,\, \chi \text{ masses}}$$

Electroweak fine structure splitting
$\Rightarrow$ no charged relics

$$\mathcal{L}_{\text{H.Yuk}} = -\lambda_1 (H\bar{\Psi})\chi - \lambda_2 (H^\dagger \Psi)\chi - \lambda_3 H^\dagger (\vec{T}\cdot\vec{\Sigma})\Psi - \lambda_4 \bar{\Psi}(\vec{T}\cdot\vec{\Sigma}) H + \text{c.c.}$$

take $\lambda_1 \ldots \lambda_4$ small enough

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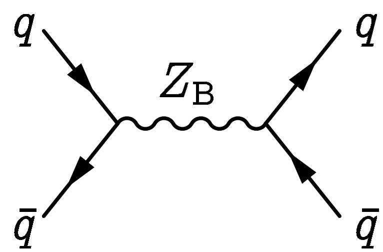
Constraining baryonic gauge coupling

Z_B couples to quarks:

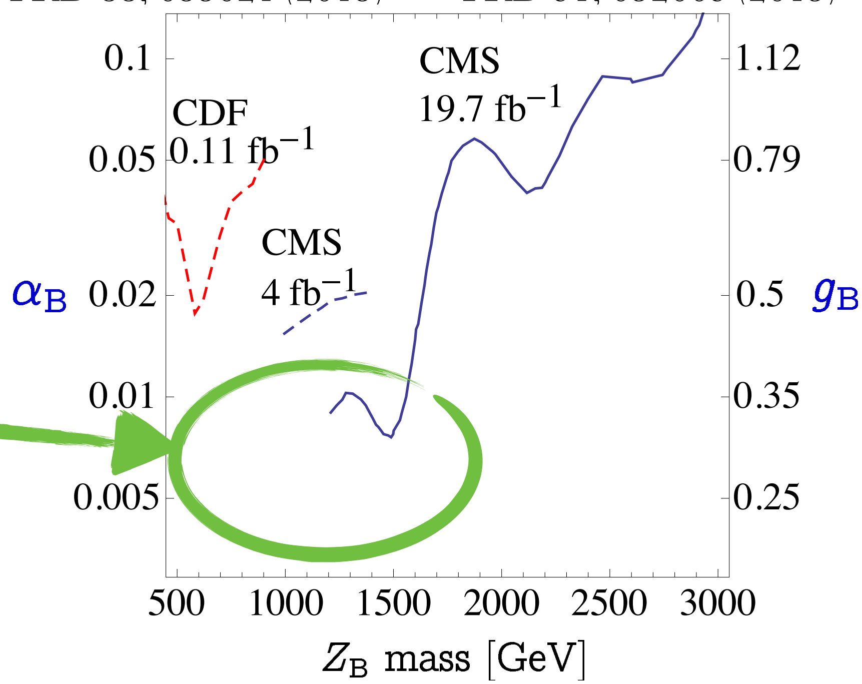
$$\mathcal{L} = -g_\mathrm{B} Z_{\mathrm{B}\mu} \Big(\sum_q \frac{1}{3} \bar{q} \gamma^\mu q + \dots \Big)$$



Constrain g_B with jj resonance search:

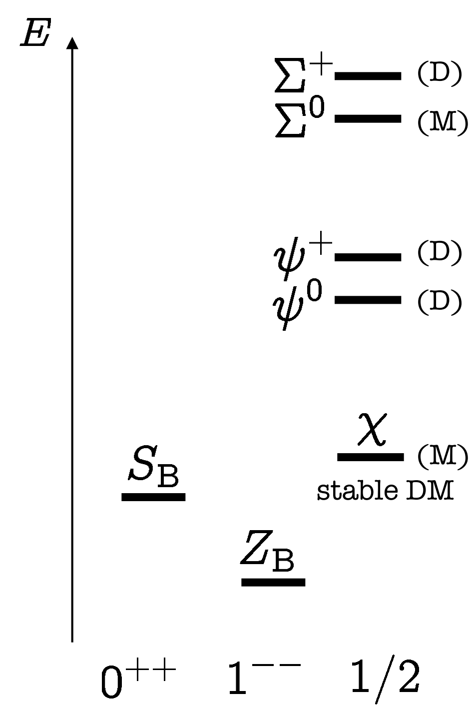
B. Dobrescu, F. Yu.
PRD 88, 035021 (2013)

CMS collab.
PRD 91, 052009 (2015)



for $m_{Z_\mathrm{B}} \lesssim 1500$ GeV,
$\alpha_\mathrm{B} \lesssim 0.015$ allowed

Spectrum



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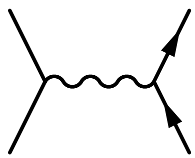
Majorana Dark Matter (χ)

Thermally produced CDM

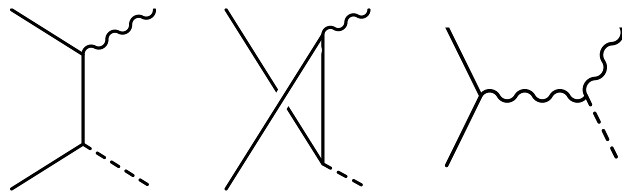
Resonant annihilation

$$\chi\chi \to Z_{\rm B} \to \sum q\bar{q}$$



Nonresonant annihilation

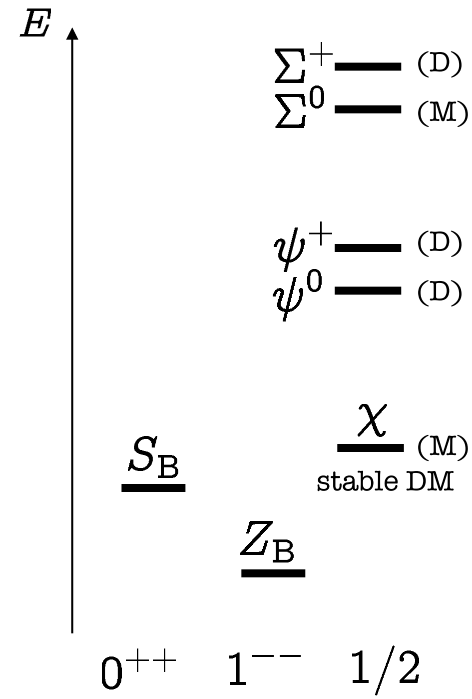
1. $\chi\chi \longrightarrow Z_{\rm B} S_{\rm B}$ (dominant)

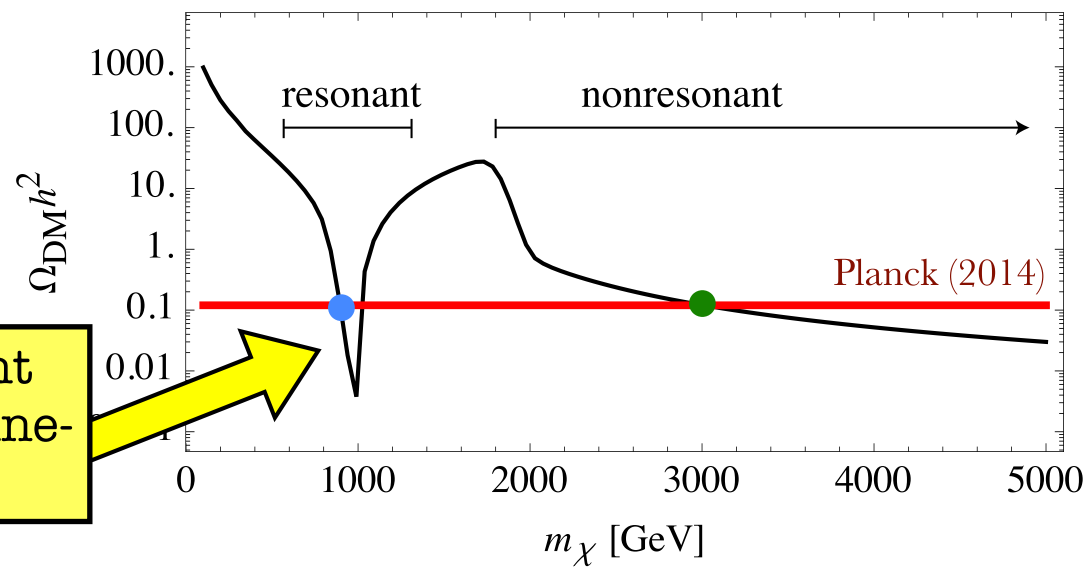


2. $\chi\chi \longrightarrow Z_{\rm B} Z_{\rm B}$
3. $\chi\chi \longrightarrow S_{\rm B} S_{\rm B}$ (vel. suppr.)

Relic abundance determined by: $m_\chi, m_{S_{\rm B}}, m_{Z_{\rm B}}, \alpha_B$.

Spectrum





Resonant region fine-tuned

Nonresonant region more 'natural'

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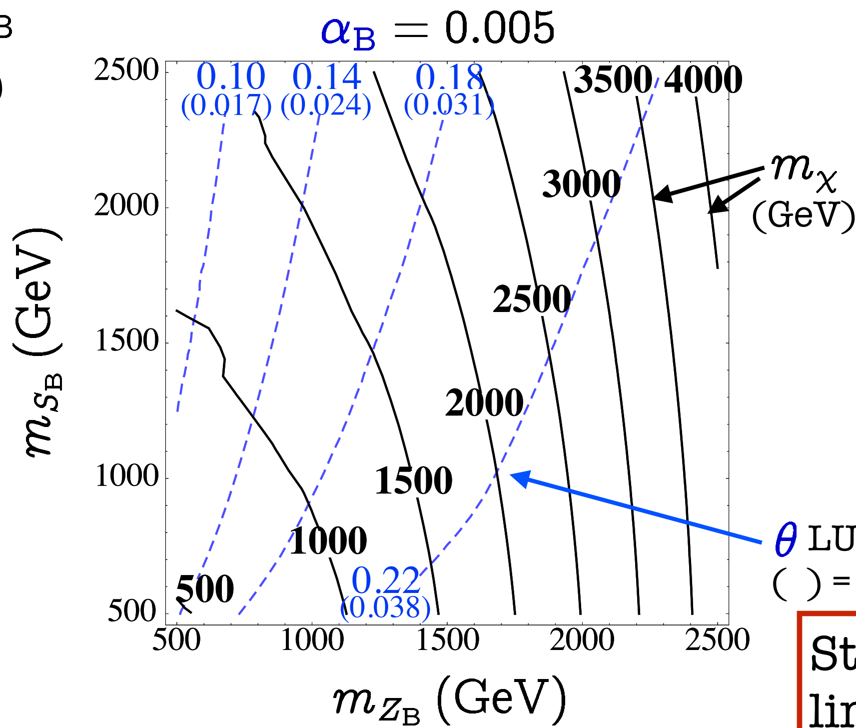
Majorana Dark Matter (χ)

Nonresonant region: $\boxed{m_\chi \gtrsim m_{Z_B}, m_{S_B}}$

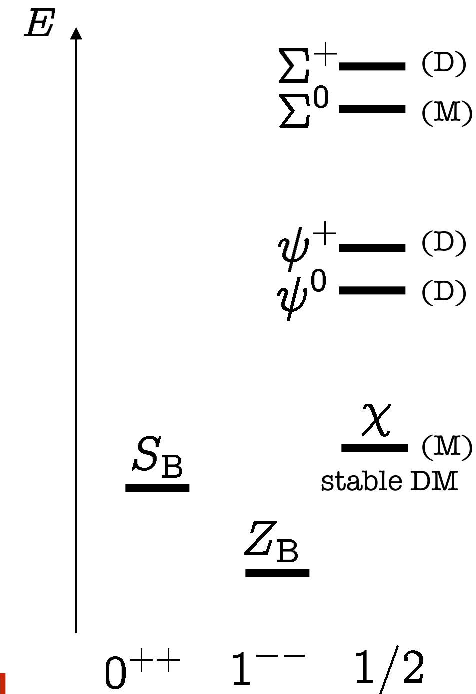
$\chi\chi \longrightarrow Z_B S_B$
(dominant)



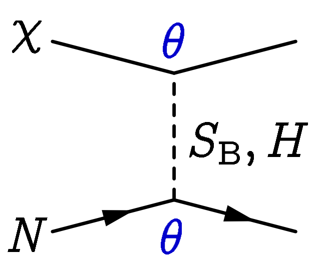
θ LUX upper limit.
( ) = XENON1T proj.

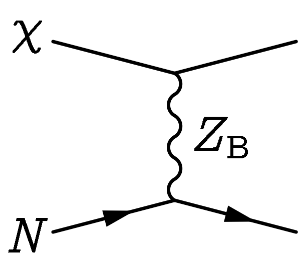
Stronger than limits from LHC Higgs

Spectrum



Direct detection channels:





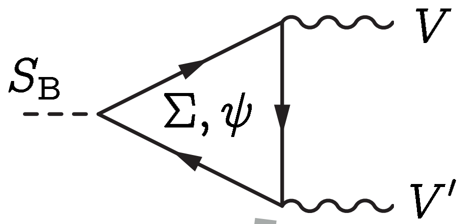
(vel. suppr.)

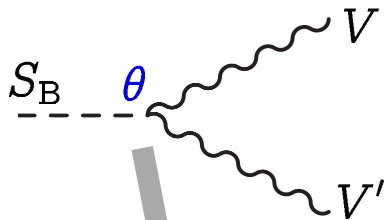
For fixed $m_\chi, m_{S_B}, m_{Z_B}, \alpha_B$, LUX null results give upper limit on θ.

Baryonic Higgs and Leptobaryons

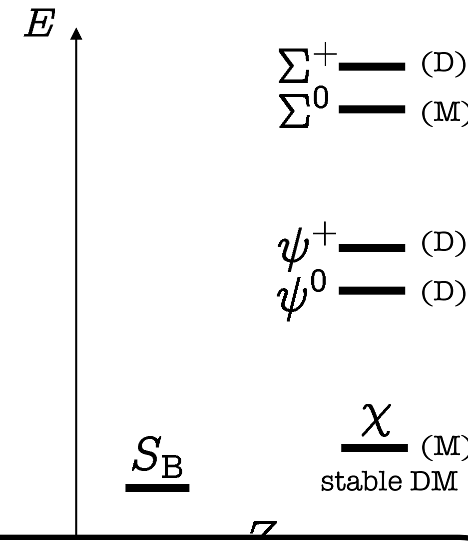
Heavy $\chi \Rightarrow$ very heavy $\Sigma^{0,\pm}, \psi^{0,\pm}$
(unlikely to be produced at LHC)

Observe indirectly by observing baryonic Higgs production/decay. (loop dominated at small angles)



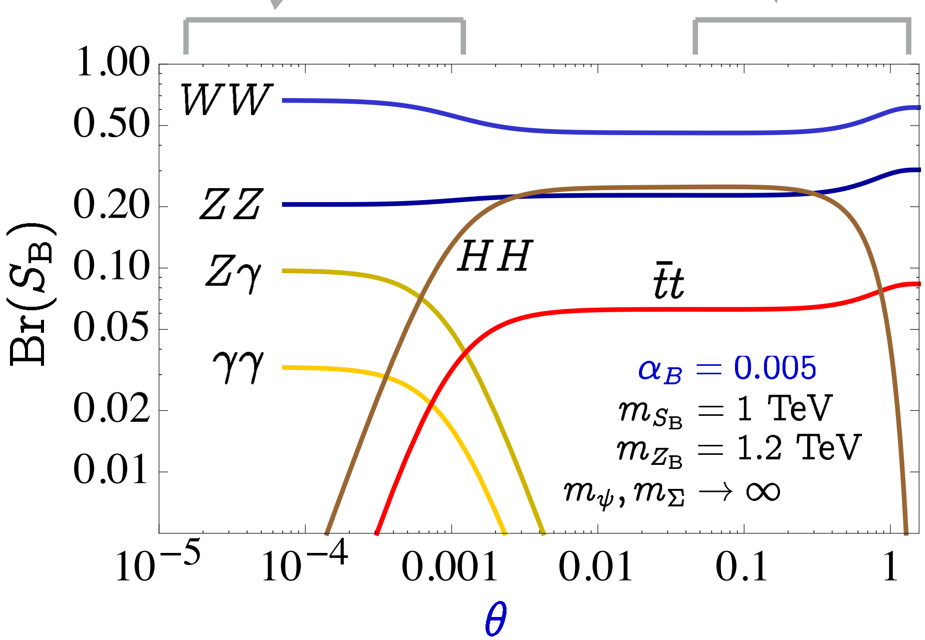


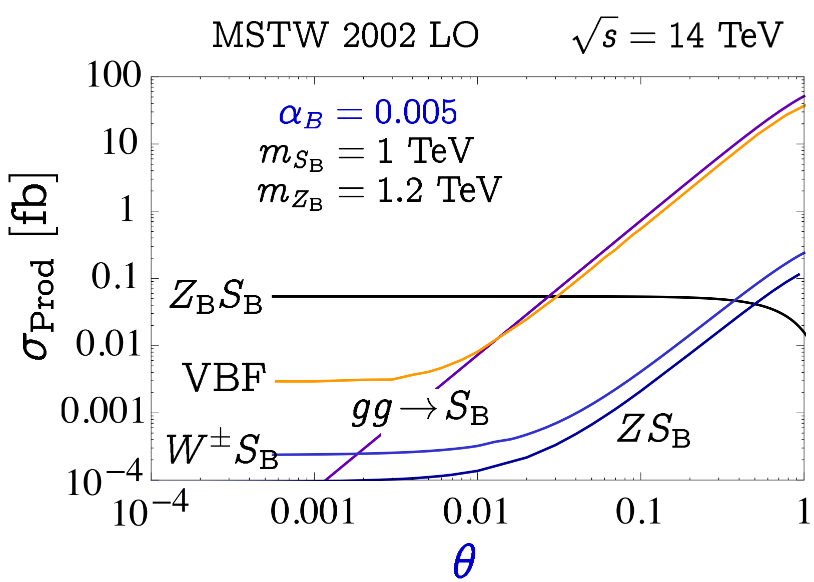
Spectrum



leptobaryon-sensitive

SM-like





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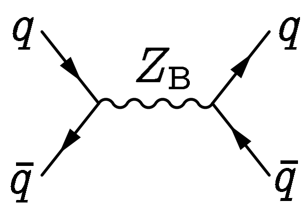
Summary

Introduced and motivated gauged $U(1)_B$ and $U(1)_L$ models:

Leptobaryon model A and VA

Phenomenology:

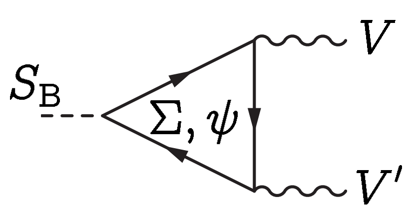
1) Absence of jj (Z_B) resonance $\Rightarrow \alpha_B \lesssim 0.015$



2) Thermal CDM relic abundance:
nonresonant: $\chi\chi \longrightarrow Z_B S_B$

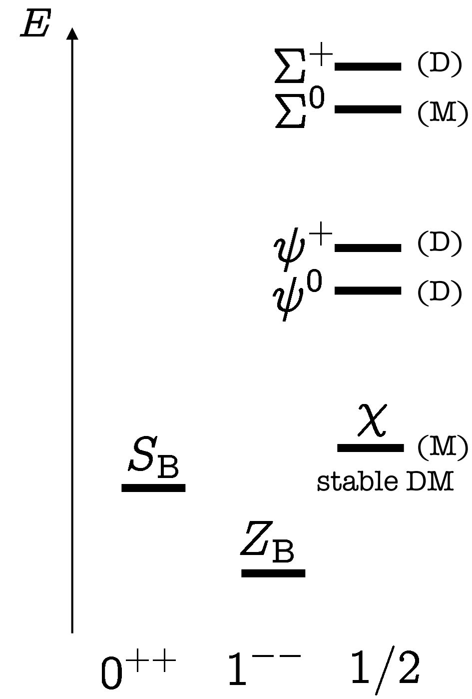
$\Rightarrow m_\chi \gtrsim m_{Z_B}, m_{S_B}$ and $\theta \lesssim 0.22$

3) Observe leptobaryons indirectly through S_B decay/production



(small mixing angle)
[Can distinguish model A from VA]

Spectrum



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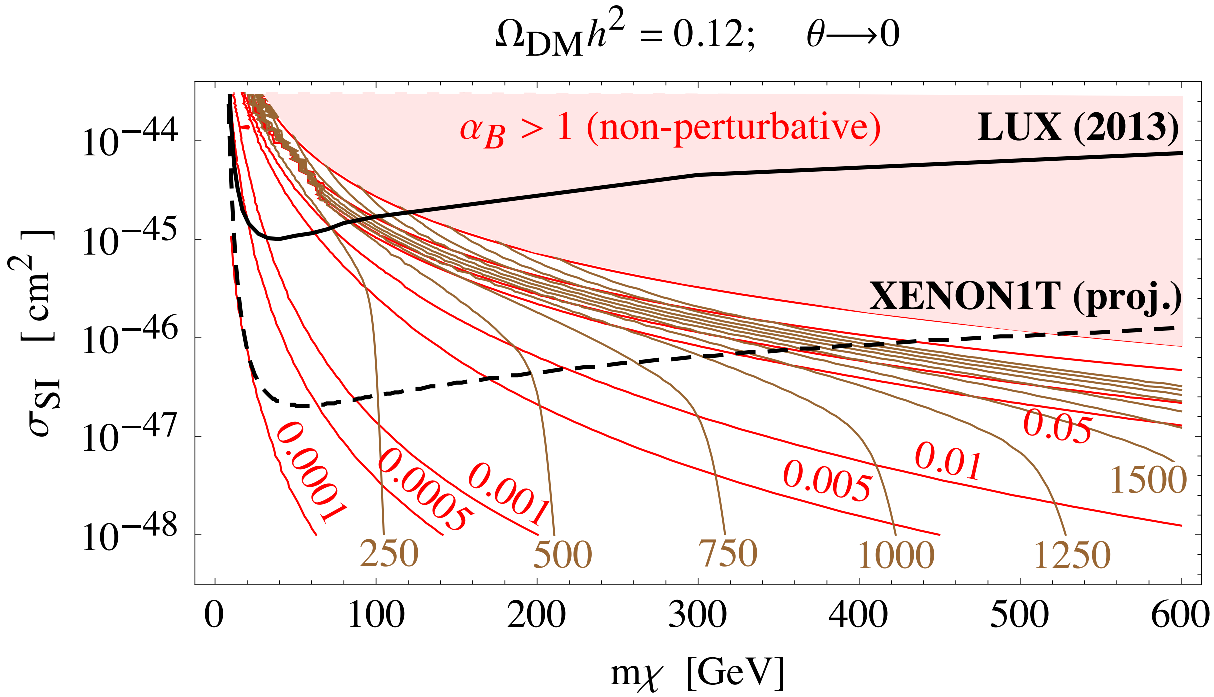
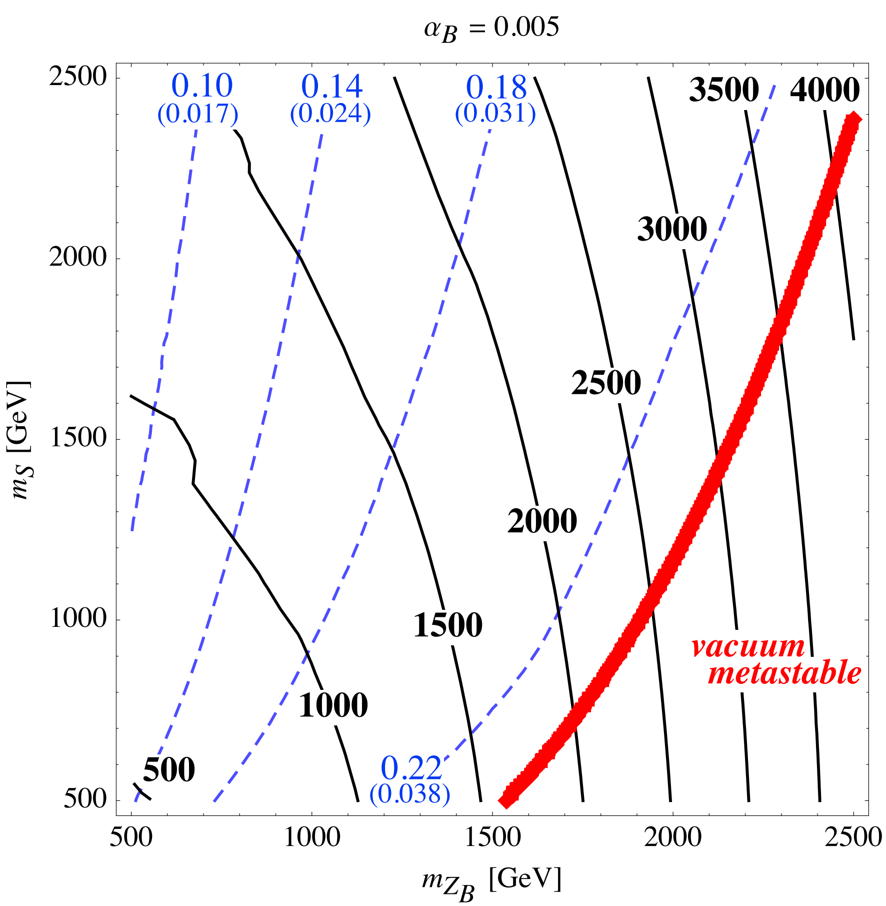
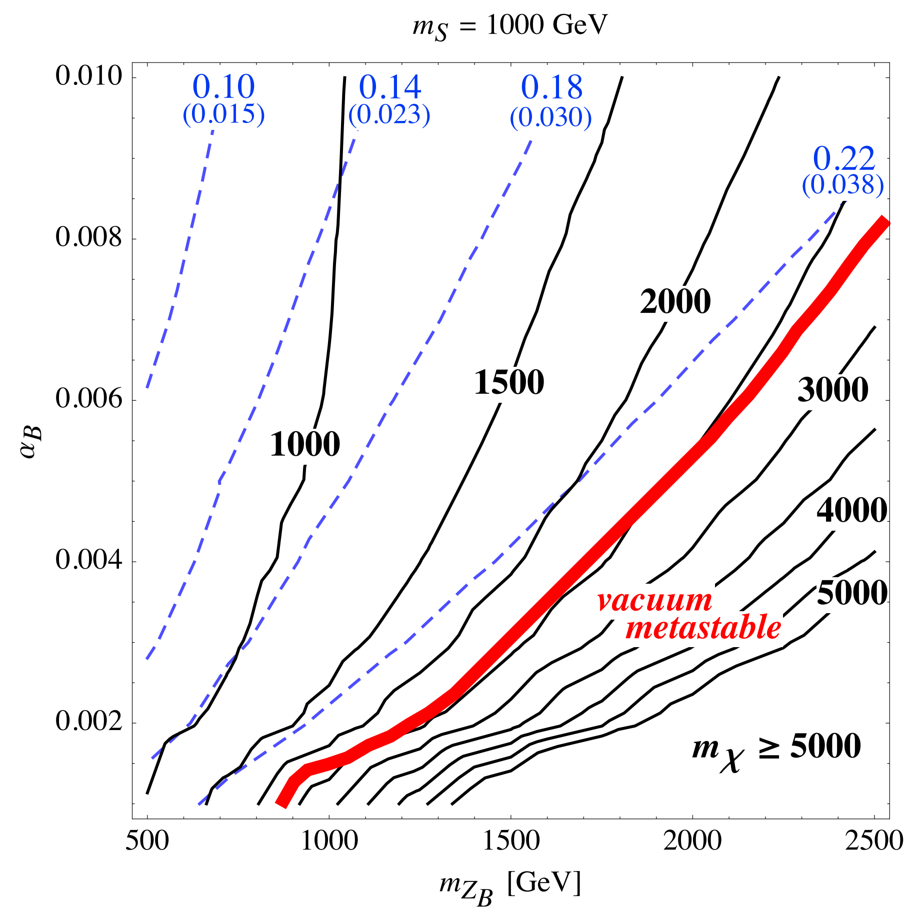
Backup: Resonant annihilation

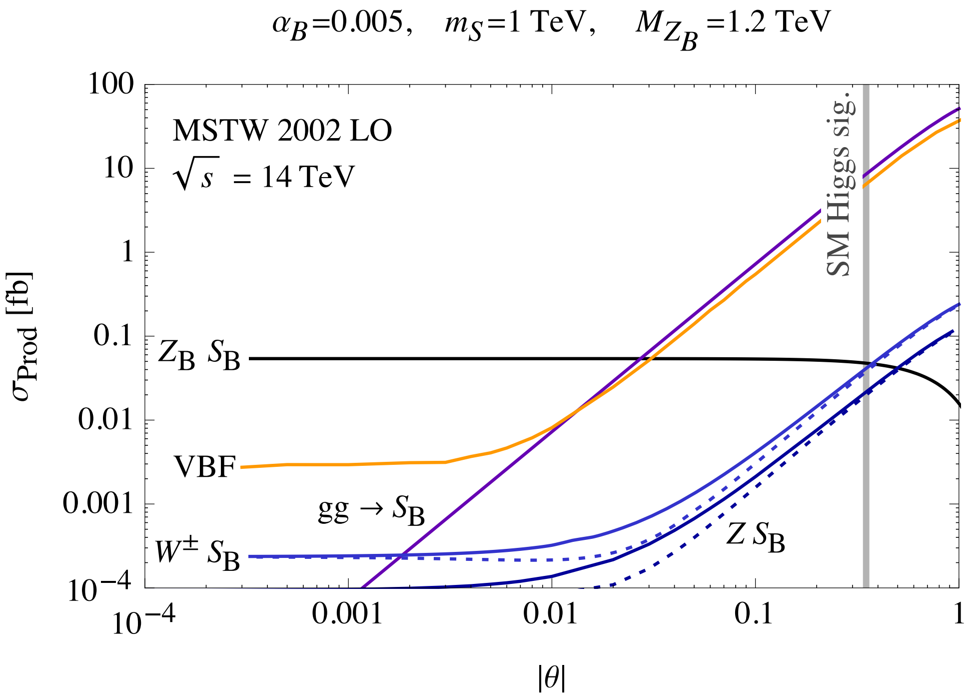


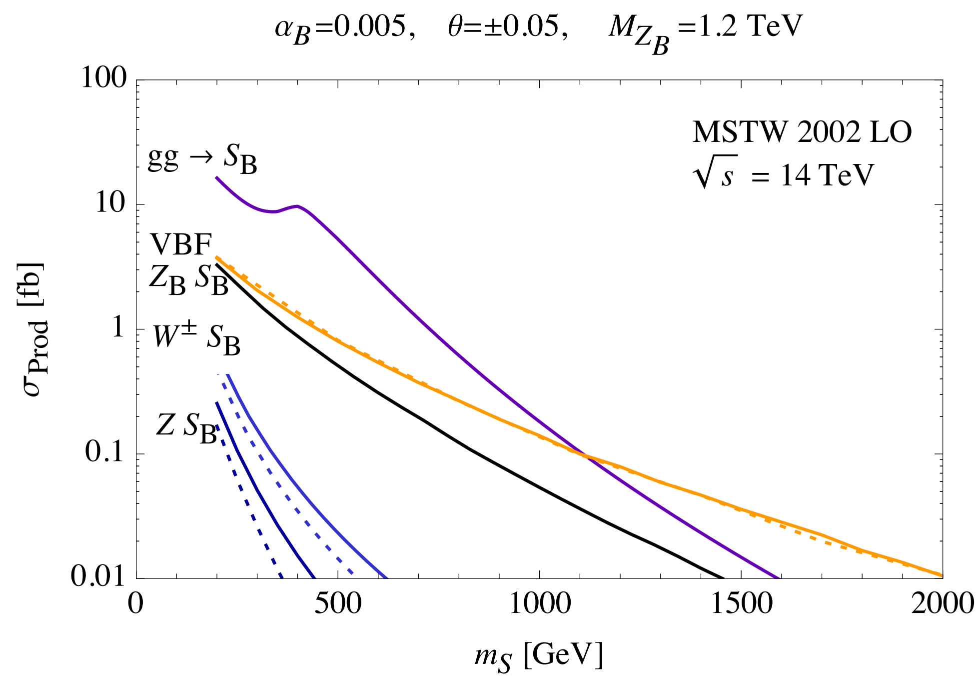
Backup: non-resonant annihilation





Backup: Higgs production





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