Mixed Dark Matter in a Left-Right Extension of SM

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based on arXiv:1604.06100v1
with A. Berlin, P. Fox and D. Hooper.

Outline

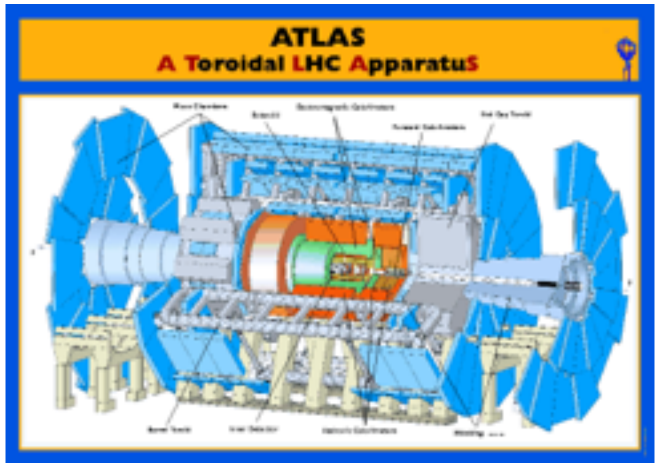
- Introduction
- Left-Right extension of SM
  - ✳ Higgs Sector
  - ✳ Gauge Boson Sector
  - ✳ Fermion Sector
- Dark Matter Phenomenology
  - ✳ Singlet Triplet
  - ✳ Singlet Bidoublet
  - ✳ Triplet Bidoublet
- Conclusions

Motivation

MAIN GOAL : Discuss new DM scenario in Left-right model.

Motivation 1: 8 TeV ATLAS & CMS diboson excess.

Motivation 2: Interesting Dark Matter phenomenology with detection prospects at future experiments.



Recap

Diboson excesses at LHC Run 1

1.8 - 2.0 TeV Range

ATLAS

$X \to V(J)V(J)$ Local: 3.4σ (WZ), 2.6σ (WW), 2.9σ (ZZ)

Global: 2.5σ (WZ)

arXiv:1506.00962

$X \to jj$ 1σ (jj)

arXiv:1407.1376

CMS

$X \to V(J)V(J)$ 1.4σ

arXiv:1405.1994

$X \to jj$ 2σ

$W' \to N_R\ e$ 2.2σ

arXiv:1407.3683

$W' \to Wh$ 2.8σ

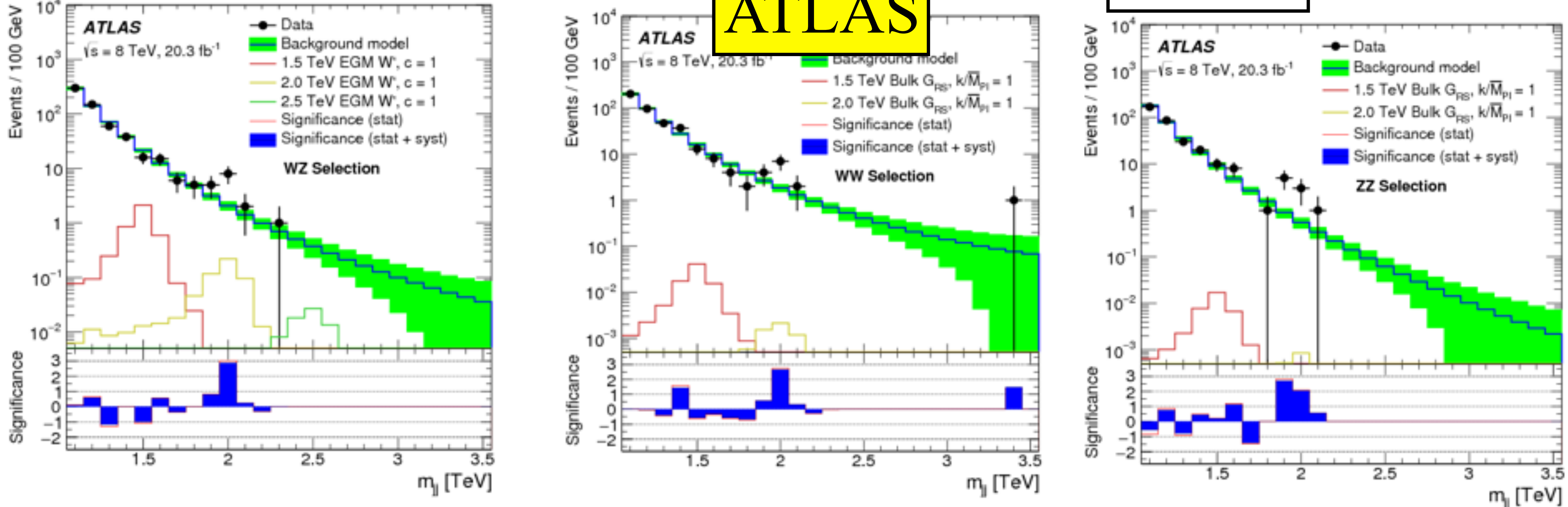
PAS-EXO-14-010

Diboson excesses at LHC Run 1

1.8 - 2.0 TeV Range

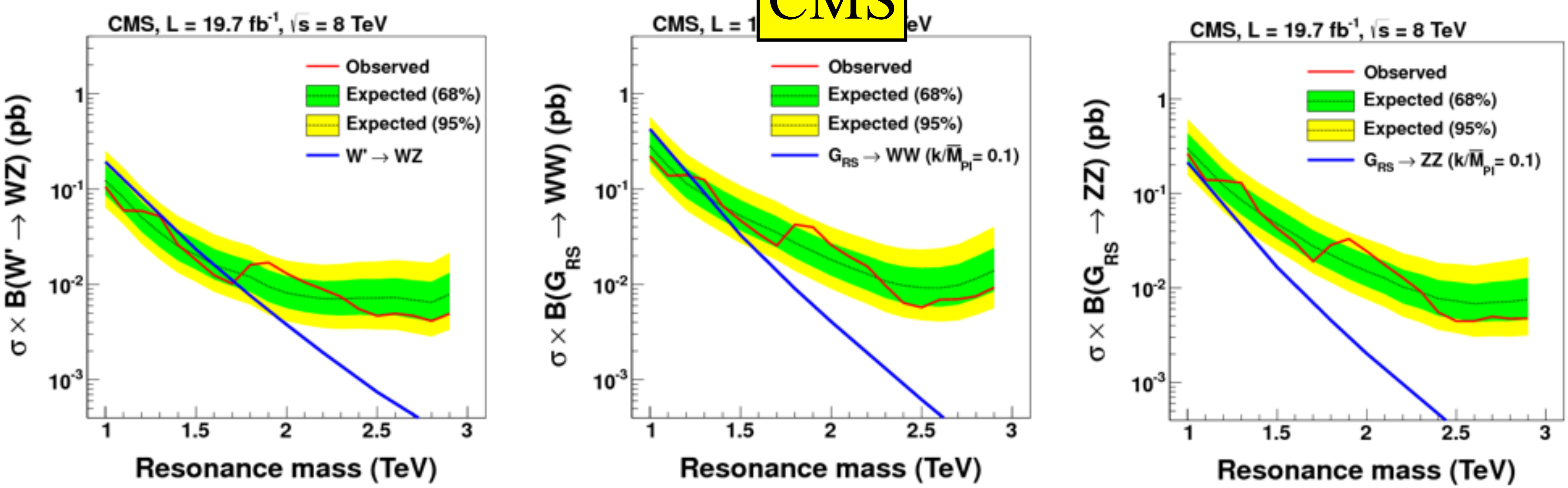
ATLAS

arXiv:1506.00962



arXiv:1405.1994

CMS



Has there been a 2 TeV resonance sighting?

I want to believe in 14 TeV

All 5/6 excesses consistent with massive W' boson connected to BSM theories

Left-Right Extension of SM

Introduced in 1974-75 to primarily Understand P-violation in SM.

At Lower Energies L-R models described by gauge group:

$$SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$$

Higgs Sector

Extended Higgs sector:

$$\Delta_L \in (3, 1, 2) \qquad \Delta_R \in (1, 3, 2) \qquad \phi \in (2, 2, 0)$$

Spontaneous Symmetry Breaking at TeV scale:

$$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \xrightarrow{\langle\Delta_R\rangle = v_R} SU(2)_L \otimes U(1)_Y$$

$$SU(2)_L \otimes U(1)_Y \xrightarrow{\langle\phi\rangle \sim v} U(1)_{EM}$$

Right Higgs Triplet is parametrized:

$$\Delta_R = \begin{pmatrix} \frac{g_R}{\sqrt{2}g_L}\frac{M_W}{M_{W'}}c_{2\beta}H^+ & \Delta^{++} \\ v_R + \frac{1}{\sqrt{2}}\Delta^0 & -\frac{g_R}{\sqrt{2}g_L}\frac{M_W}{M_{W'}}c_{2\beta}H^+ \end{pmatrix}$$

Higgs Bidoublet is parametrized

$$\phi = \begin{pmatrix} c_\beta v + \frac{1}{\sqrt{2}}(c_\beta h + s_\beta H + i s_\beta A) & c_\beta H^+ \\ s_\beta H^- & s_\beta v + \frac{1}{\sqrt{2}}(s_\beta h - c_\beta H + i c_\beta A) \end{pmatrix}$$

Gauge Boson Sector

After SSB Gauge Bosons get masses.

Compatible with 2 TeV excess

$$M_W = \frac{g_L v}{\sqrt{2}} \qquad M_{W'} = g_R v_R$$

$$M_A^2 = 0 \qquad M_Z^2 = (g_L^2 + g_Y^2)\frac{v^2}{2} \qquad M_{Z'}^2 = 2(g_R^2 + g_{B-L}^2)v_R^2$$

Fermion Sector

Parity is restored in LR model in Fermion sector:

$$Q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L \qquad Q_R = \begin{pmatrix} u \\ d \end{pmatrix}_R \qquad Q = T_{3L} + T_{3R} + \frac{Y_{B-L}}{2}$$

$$L_l = \begin{pmatrix} \nu \\ l \end{pmatrix}_L \qquad L_R = \begin{pmatrix} N \\ l \end{pmatrix}_R$$

Dark Matter Phenomenology

$SU(2)_R$ multiplets	Mixing?
Singlet-Doublet	No ✖
Singlet-Triplet	Yes ✓
Singlet-Bidoublet	Yes ✓
Doublet-Triplet	No ✖
Doublet-Bidoublet	No ✖
Triplet-Bidoublet	Yes ✓

mixing through renormalizable Yukawa Interactions with Triplet & Bidoublet Higgs

Similar studies in non LR models

C. Cheung & D. Sanford. (arXiv:1311.5896)

T. Tait & Z. Yu. (arXiv:1601.01354)

Singlet-Triplet

Fields	Charges	Spin
S	(1,1,0)	1/2
T_1	(1,3,2)	1/2
T_2	(1,3,-2)	1/2

Fermion Triplets parametrized as:

$$T_1 = \begin{pmatrix} t_1^{+}/\sqrt{2} & t_1^{++} \\ t_1^{0} & -t_1^{+}/\sqrt{2} \end{pmatrix} \qquad T_2 = \begin{pmatrix} t_2^{+}/\sqrt{2} & t_2^{++} \\ t_2^{0} & -t_2^{+}/\sqrt{2} \end{pmatrix}$$

Singlet-Triplet Lagrangian:

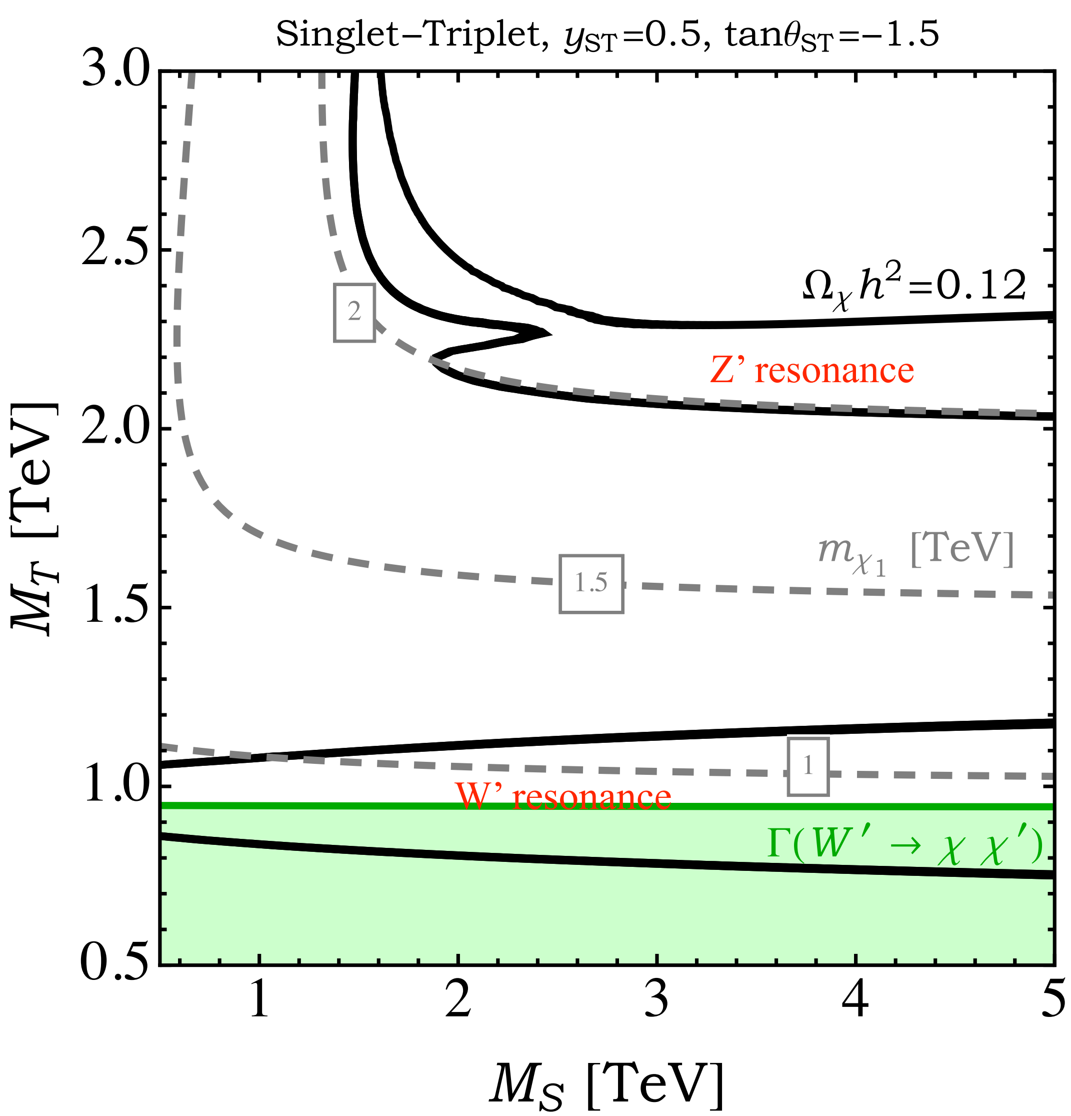
$$\mathcal{L} \supset S^\dagger i\bar{\sigma}^\mu \partial_\mu S + tr(T_1^\dagger i\bar{\sigma}^\mu D_\mu T_1) + tr(T_2^\dagger i\bar{\sigma}^\mu D_\mu T_2) - [\frac{1}{2} M_S S^2 + M_T tr(T_1 T_2)$$
$$+\lambda_1 \; S \; tr(T_1 \Delta_R^\dagger) + \lambda_2 \; S \; tr(T_2 \Delta_R) + \text{h.c.}]$$

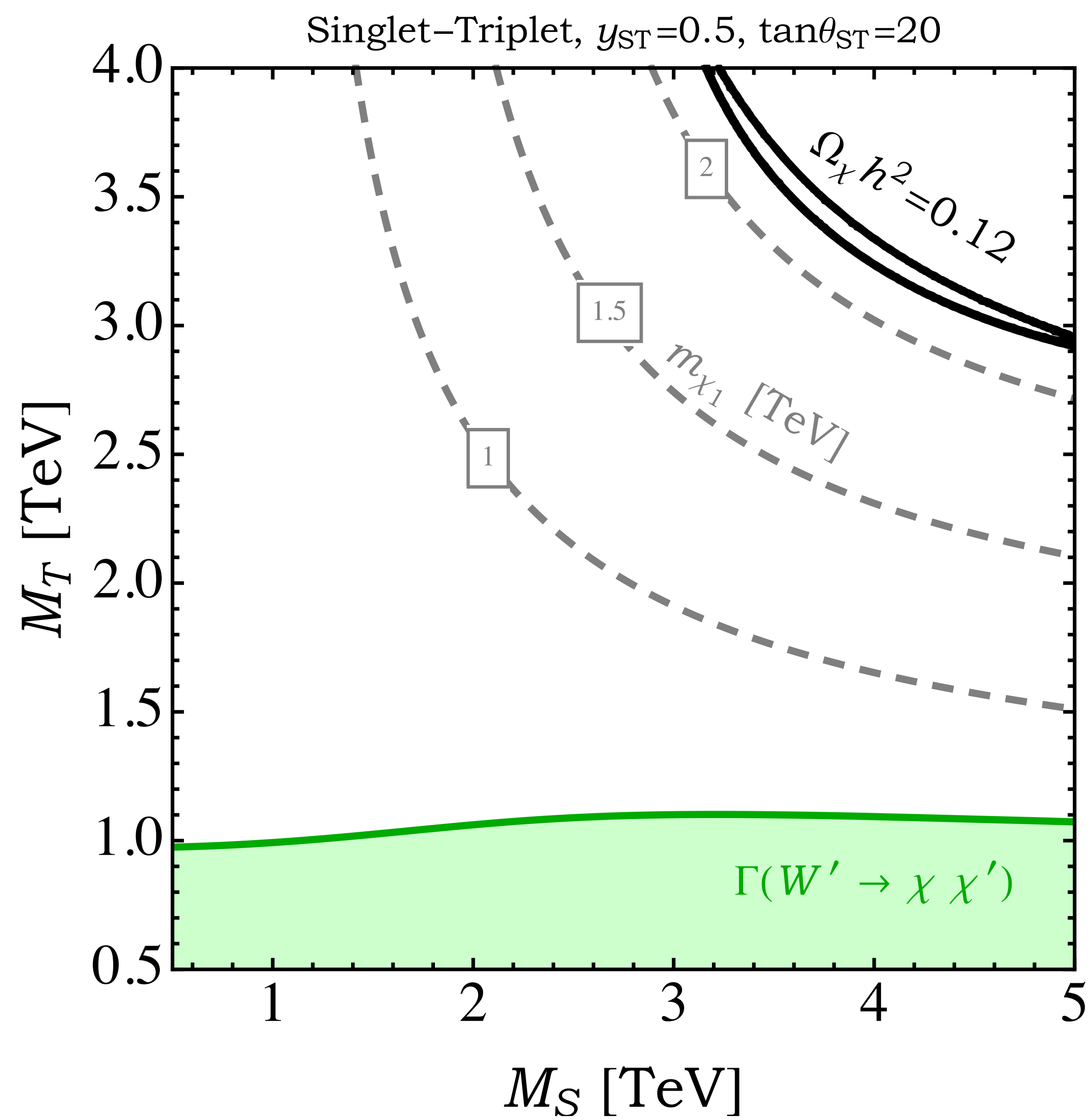
We use MicrOMEGAs and MadDM to compute relic density and direct detection.

$$y_{ST} = \sqrt{\lambda_1^2 + \lambda_2^2} \qquad tan\ \theta_{ST} = \lambda_1/\lambda_2$$

$M_{\chi_1^0}$ [TeV]

$\Omega_\chi h^2 = 0.12$





MicrOMEGAs.

Singlet-Bidoublet

Fields	Charges	Spin
S	(1,1,0)	1/2
B	(2,2,0)	1/2

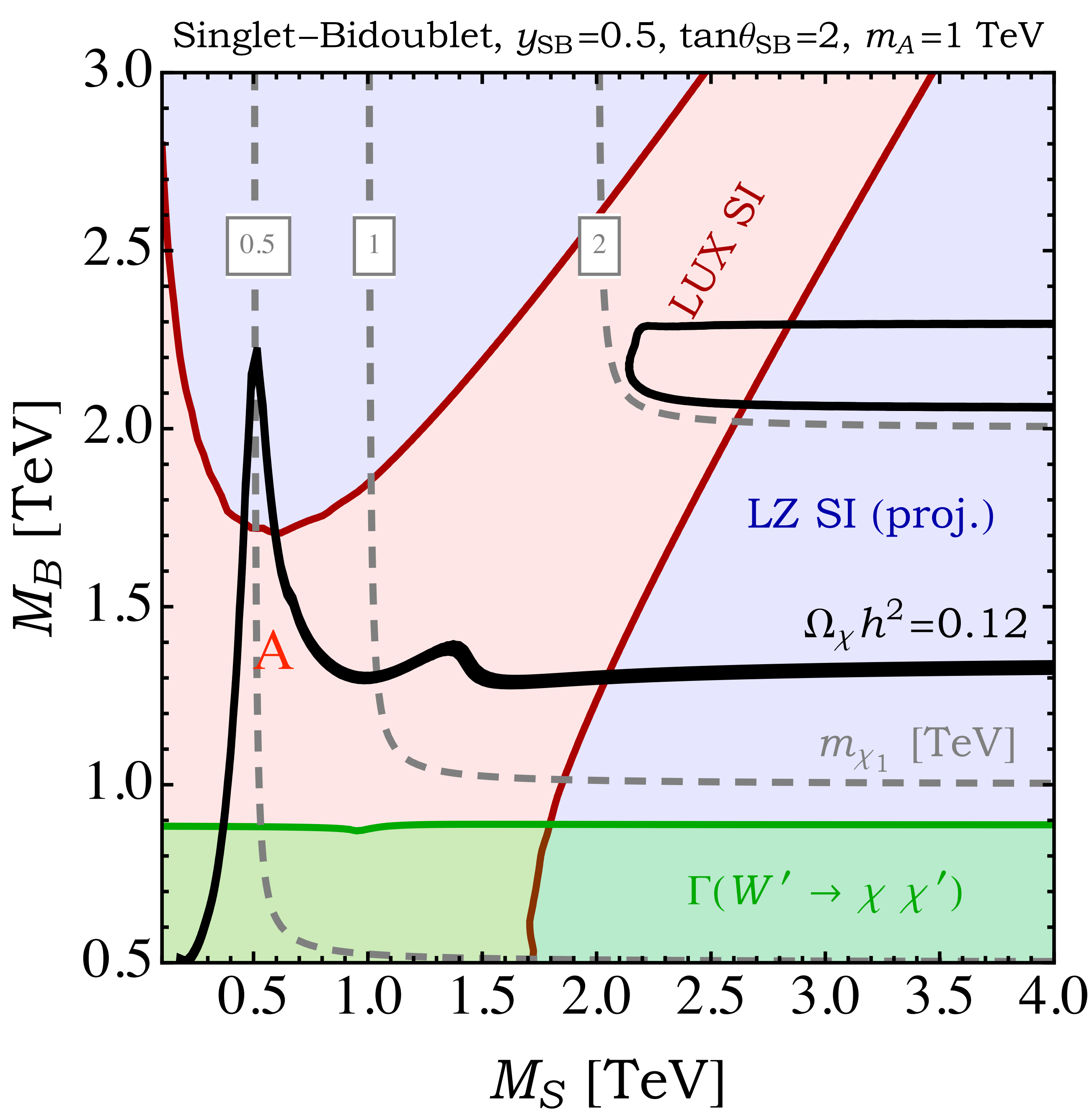
Fermion Bidoublet parametrized as:

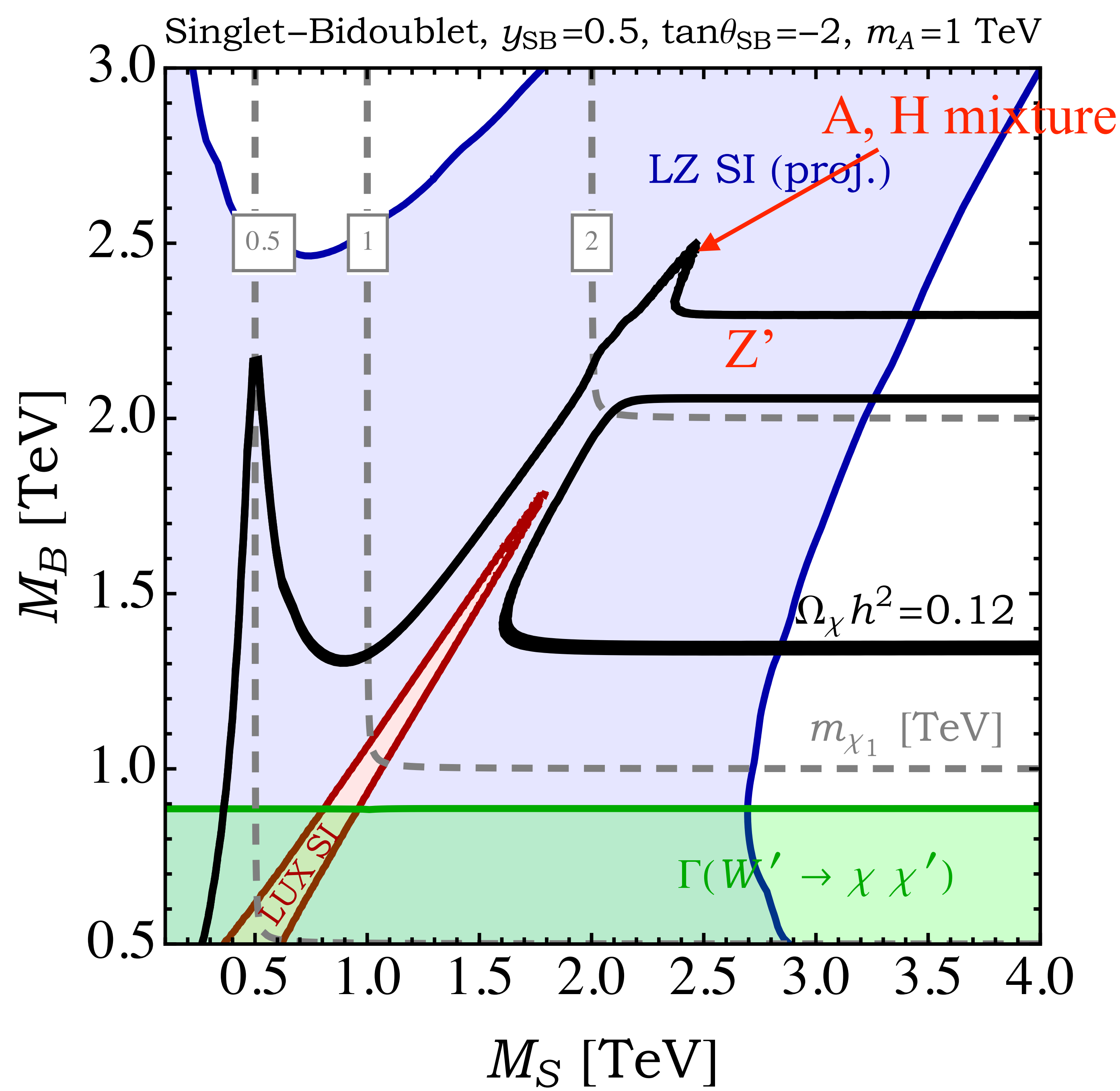
$$B = \begin{pmatrix} b_1^0 & -b_2^+ \\ b_1^- & b_2^0 \end{pmatrix}$$

Singlet-Bidoublet Lagrangian:

$$\mathcal{L} \supset S^\dagger i\bar{\sigma}^\mu \partial_\mu S + tr(B^\dagger i\bar{\sigma}^\mu D_\mu B) - [\frac{1}{2}M_s S^2 + \frac{1}{2}M_B tr(B\tilde{B}^\dagger)$$
$$+\lambda\ S\ tr(B\phi^\dagger) + \tilde{\lambda}\ S\ tr(B\tilde{\phi}^\dagger) + \text{h.c.}]$$

Parametrization $\quad y_{SB} = \sqrt{\lambda^2 + \tilde{\lambda}^2} \qquad \tan\theta_{SB} = \lambda/\tilde{\lambda}$ ← Yukawas





Triplet-Bidoublet

Fields	Charges	Spin
T	(1,3,0)	1/2
B	(2,2,0)	1/2

Fermion Bidoublet parametrized:

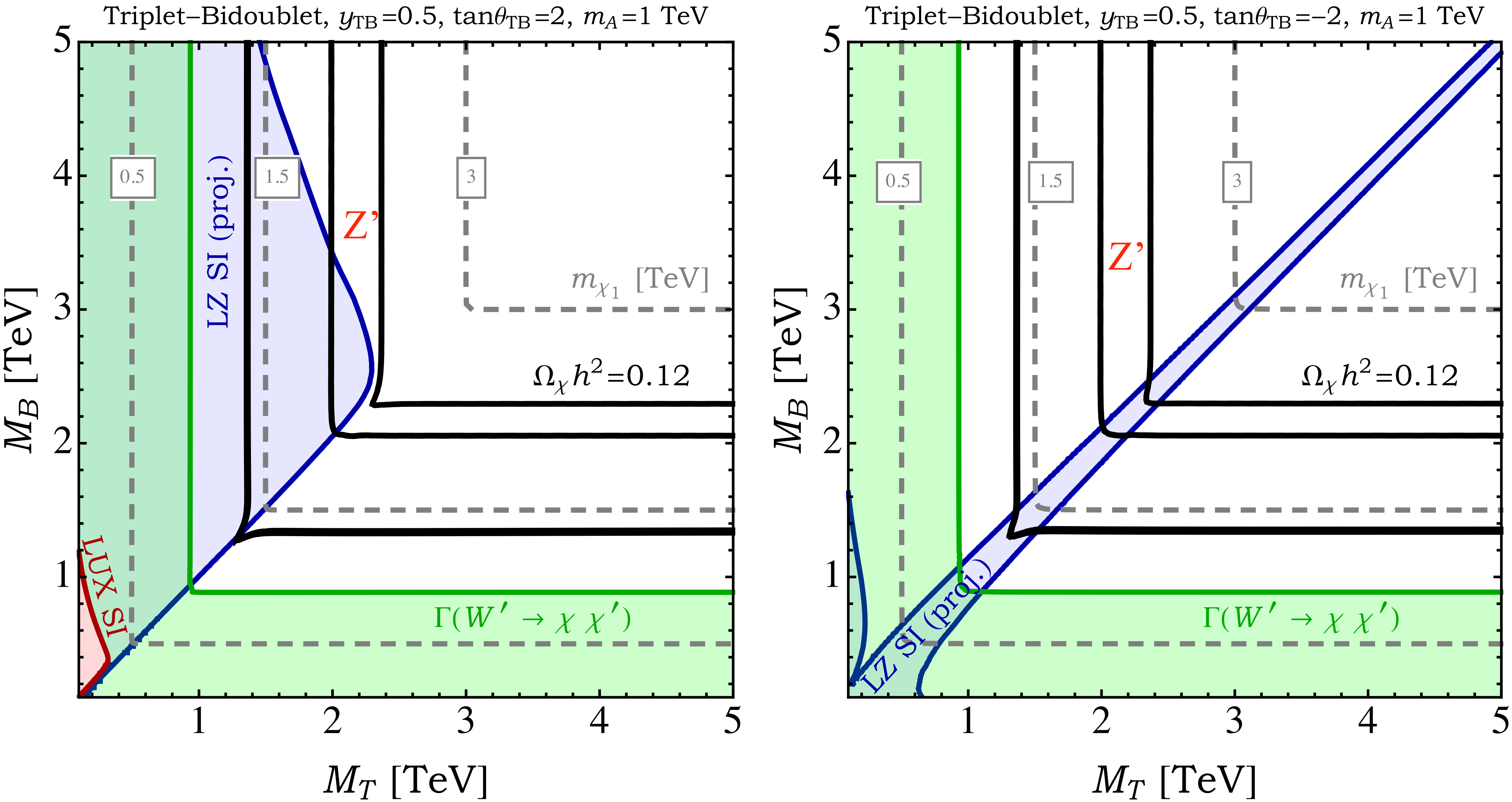
$$B = \begin{pmatrix} b_1^0 & -b_2^+ \\ b_1^- & b_2^0 \end{pmatrix}$$

Fermion Triplet parametrized:

$$T = \begin{pmatrix} t^0/\sqrt{2} & t_2^+ \\ t_1^- & -t^0/\sqrt{2} \end{pmatrix}$$

Triplet-Bidoublet Lagrangian:

$$\mathcal{L} \supset tr(T^\dagger i\bar{\sigma}^\mu D_\mu T) + tr(B^\dagger i\bar{\sigma}^\mu D_\mu B) - [\frac{1}{2}M_T tr(T^2) + \frac{1}{2}M_B tr(B\tilde{B}^\dagger)$$
$$+\lambda tr(BT\phi^\dagger) + \tilde{\lambda} tr(BT\tilde{\phi}^\dagger) + \text{h.c.}]$$

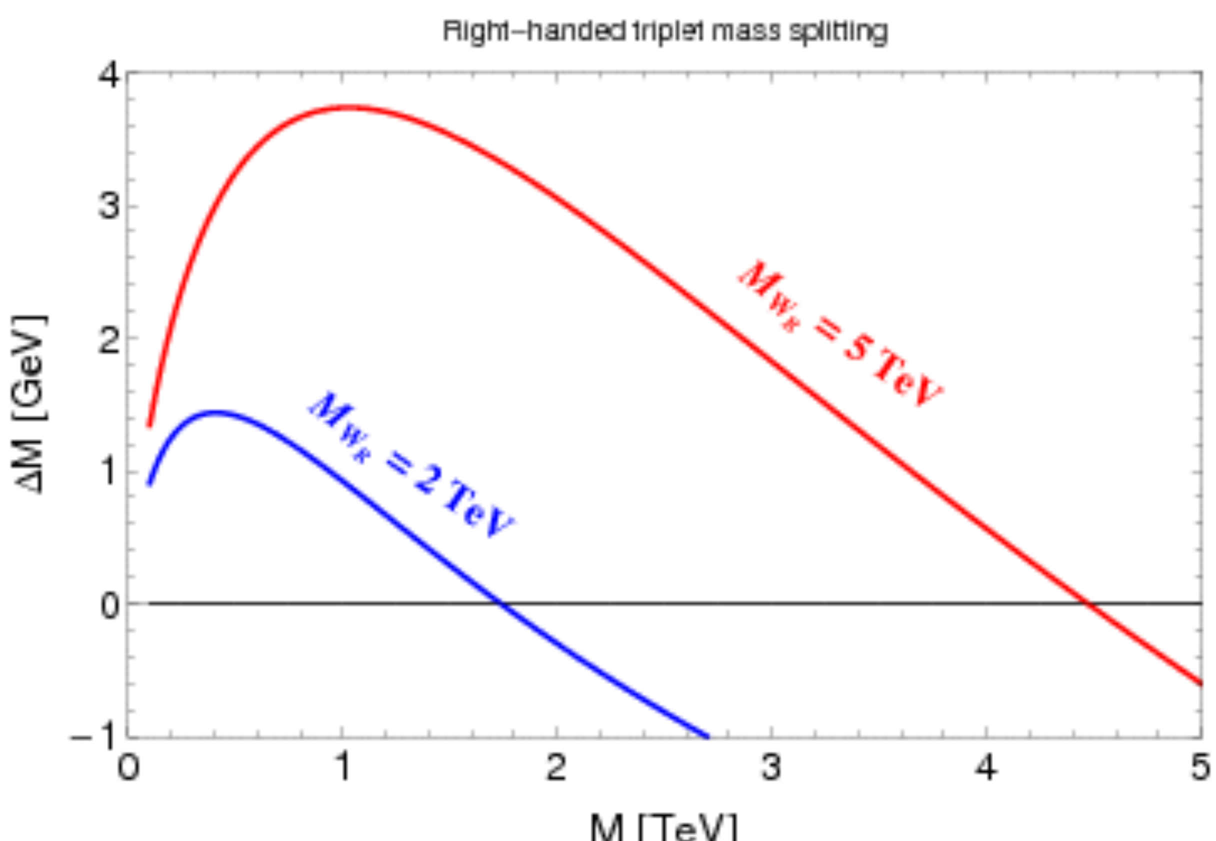

Triplet–Bidoublet, y_{TB}=0.5, tanθ_{TB}=2, m_A=1 TeV
LZ SI (proj.)
LUX SI
Z'
m_{χ_1} [TeV]
$\Omega_\chi h^2$=0.12
$\Gamma(W' \to \chi\, \chi')$
0.5
1.5
3
M_B [TeV]
M_T [TeV]
Triplet–Bidoublet, y_{TB}=0.5, tanθ_{TB}=−2, m_A=1 TeV
LZ SI (proj.)
Z'
m_{χ_1} [TeV]
$\Omega_\chi h^2$=0.12
$\Gamma(W' \to \chi\, \chi')$
0.5
1.5
3
M_B [TeV]
M_T [TeV]

Neutralness…

Point in parameter space where “chargino” lighter than lightest “neutralino”.

Then we would have charged DM

Loop corrections can provide large contributions to mass splitting, making “neutralino” heavier than “chargino”.



$$\Delta M = M_+ - M_0$$

Minimal Left-Right symmetric DM
Heeck & Patra
arXiv:1507.01584

DM mass

Dark Matter Stability

Stability - breaking of quantum numbers under unbroken Z_2 in $U(1)_{B-L}$

Z_2 subgroup remains when

$$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \xrightarrow{\Delta_R} SU(2)_L \otimes U(1)_Y \longrightarrow$$

Fermions odd under Z_2

Bosons even under Z_2

Lightest Fermion is stable if it carries even B-L charge.

$$O = X \times (\#\ of\ bosons) \times (odd\ \#\ of\ SM\ fermions)$$

Dark matter gauge eigenstate with lightest neutral component χ and B-L charge Q

- B-L gauge invariance
- Lorentz invariance

DM unstable only if $Q = \pm(1, 3, 5, ...)/3$

Conclusions

Why is this study important ???

LHC run 1 might have seen first hints of new physics.

Naturally incorporated in L-R models.

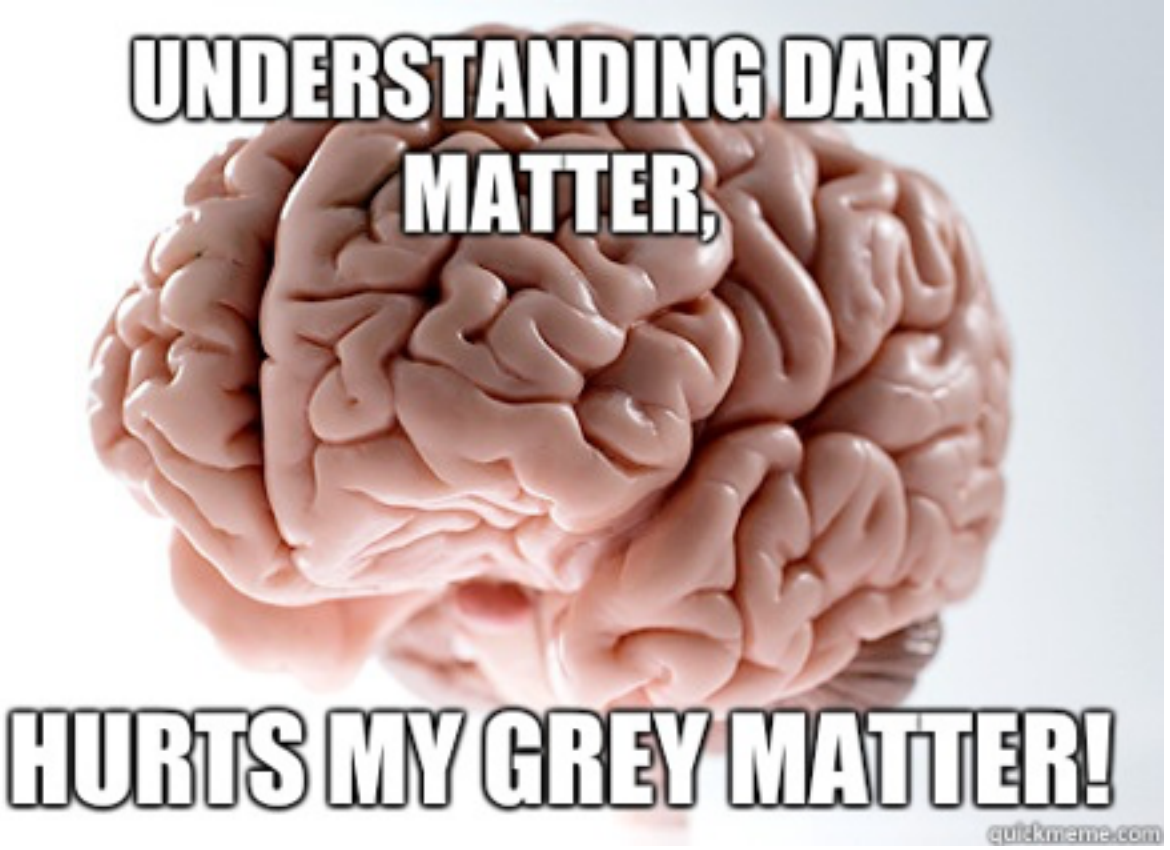
Naturally has DM, stability guaranteed by B-L gauge invariance.

Mixed DM mass splittings are not fixed unlike in pure DM.

Within reach of next generation DD experiments.

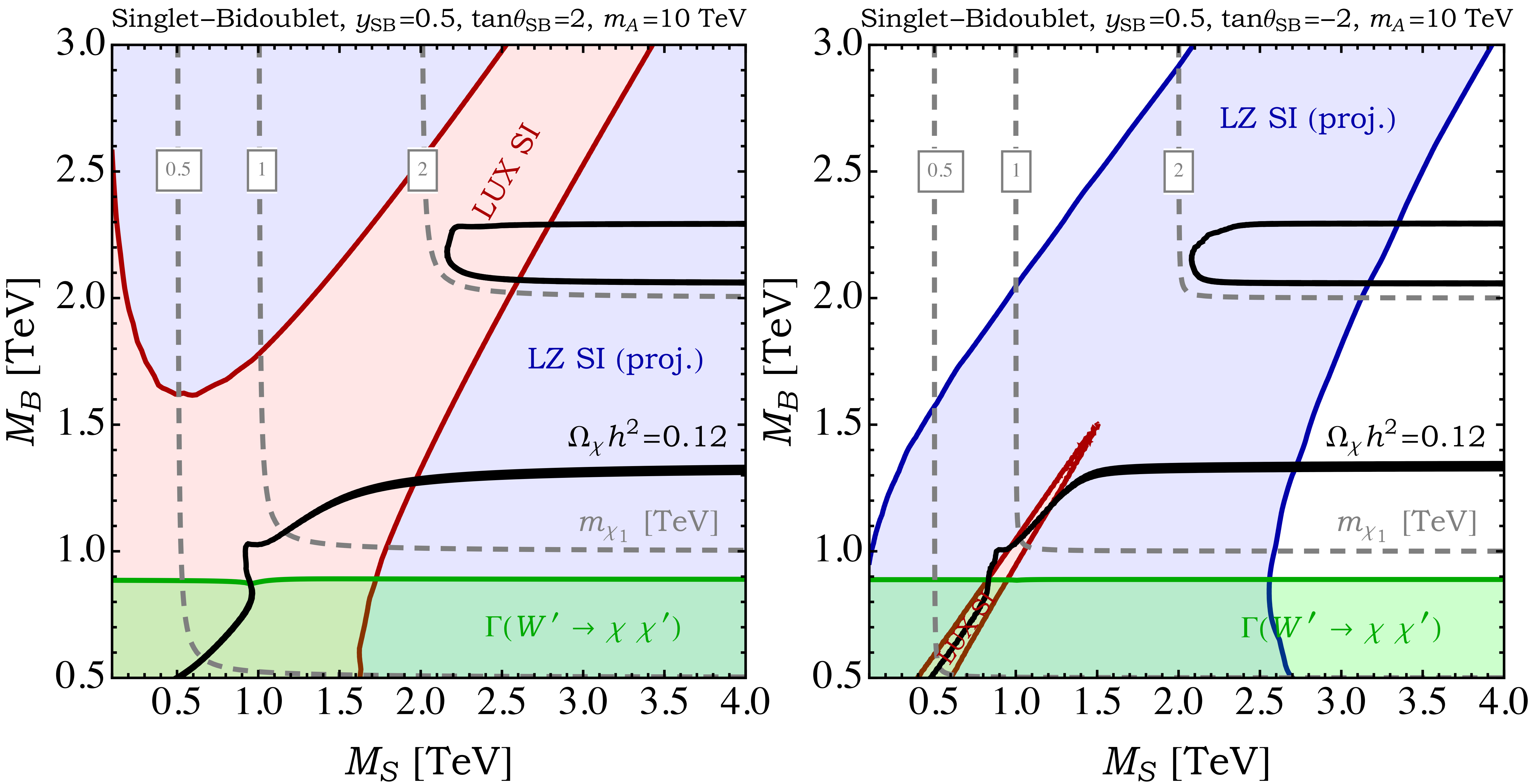
might be detected by LZ

Thank You

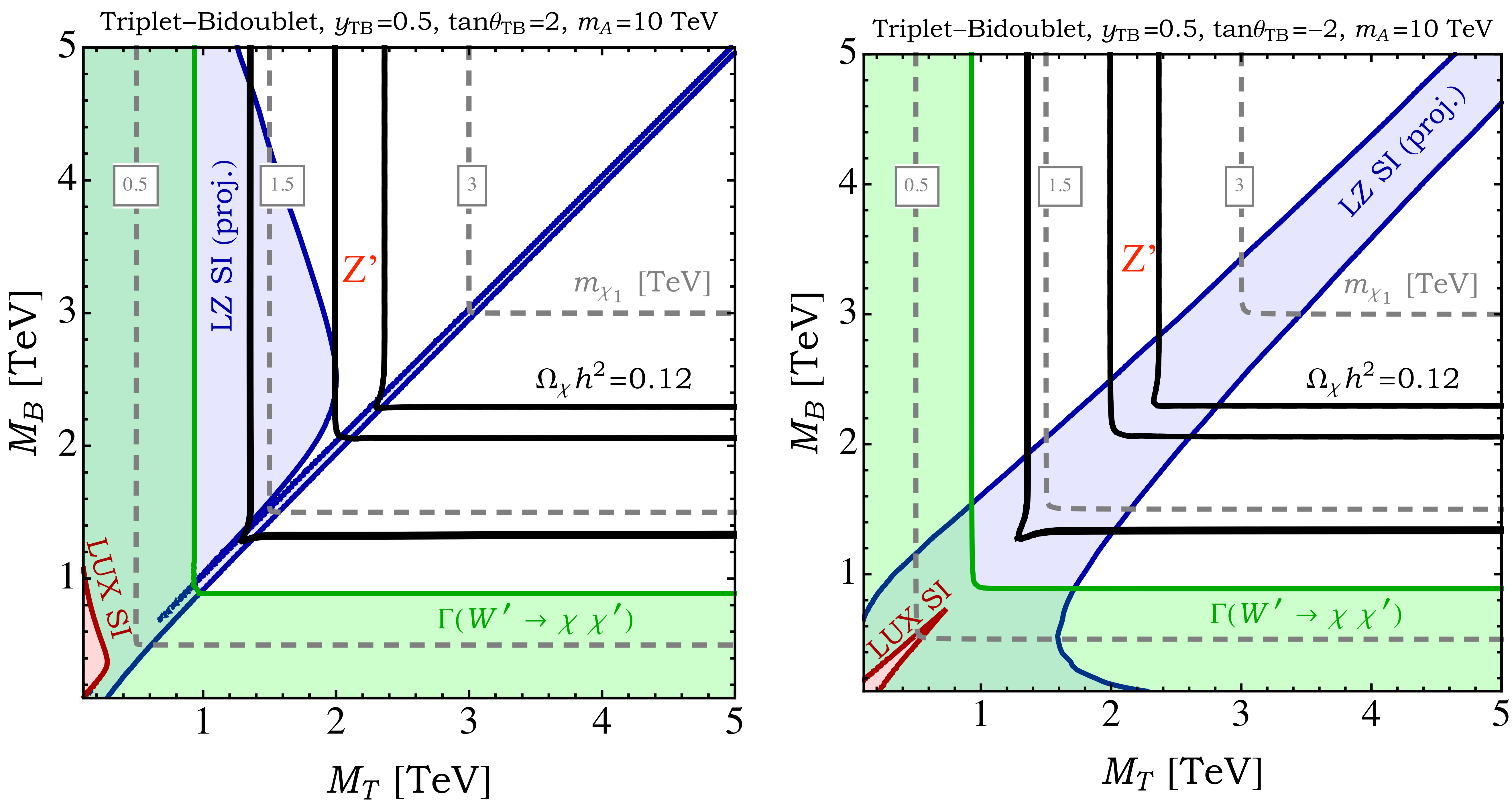


Questions? Comments?

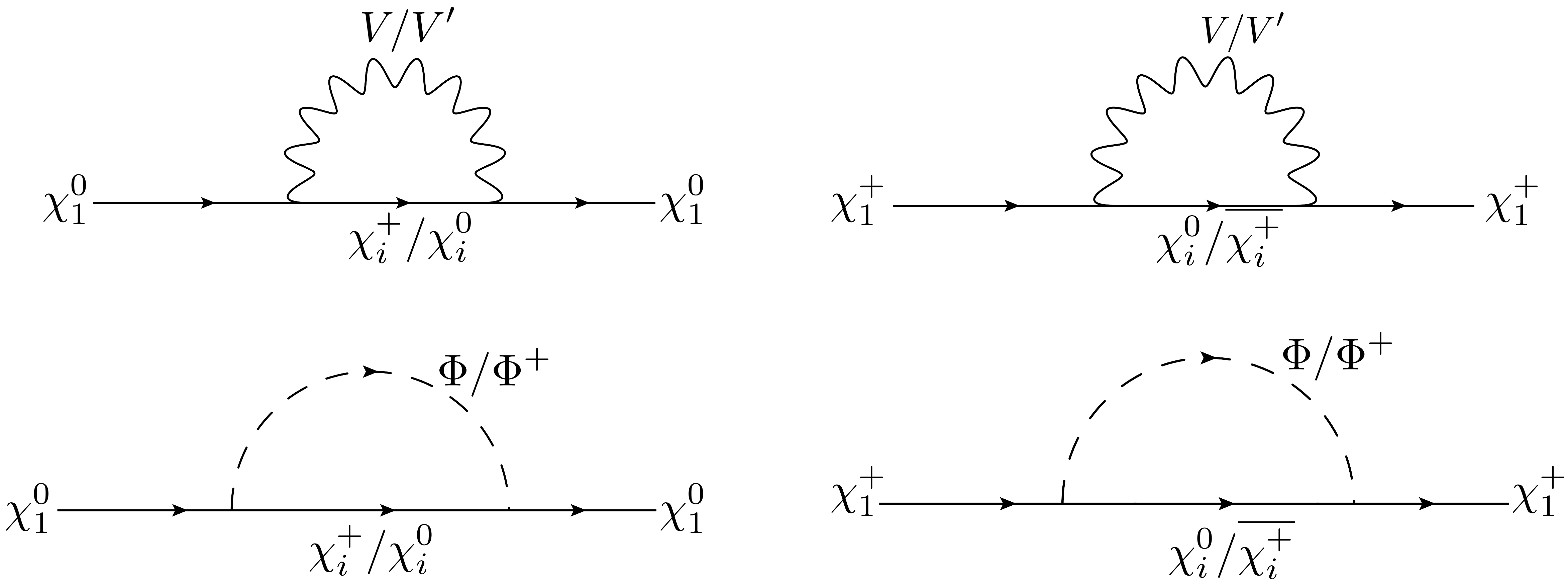
Back Up slides



Direct Detection dominated by SM higgs and heavy higgs interaction



Triplet–Bidoublet, $y_{\rm TB}$=0.5, tan$\theta_{\rm TB}$=2, m_A=10 TeV
M_B [TeV]
M_T [TeV]
0.5
1.5
3
LZ SI (proj.)
Z'
m_{χ_1} [TeV]
$\Omega_\chi h^2$=0.12
LUX SI
$\Gamma(W' \to \chi\,\chi')$
Triplet–Bidoublet, $y_{\rm TB}$=0.5, tan$\theta_{\rm TB}$=−2, m_A=10 TeV
M_B [TeV]
M_T [TeV]
0.5
1.5
3
LZ SI (proj.)
Z'
m_{χ_1} [TeV]
$\Omega_\chi h^2$=0.12
LUX SI
$\Gamma(W' \to \chi\,\chi')$



$V = Z/W^-$ $\quad V' = Z'/W'^-$ $\quad \Phi = h/A/H$ $\quad \Phi^+ = H^\pm$

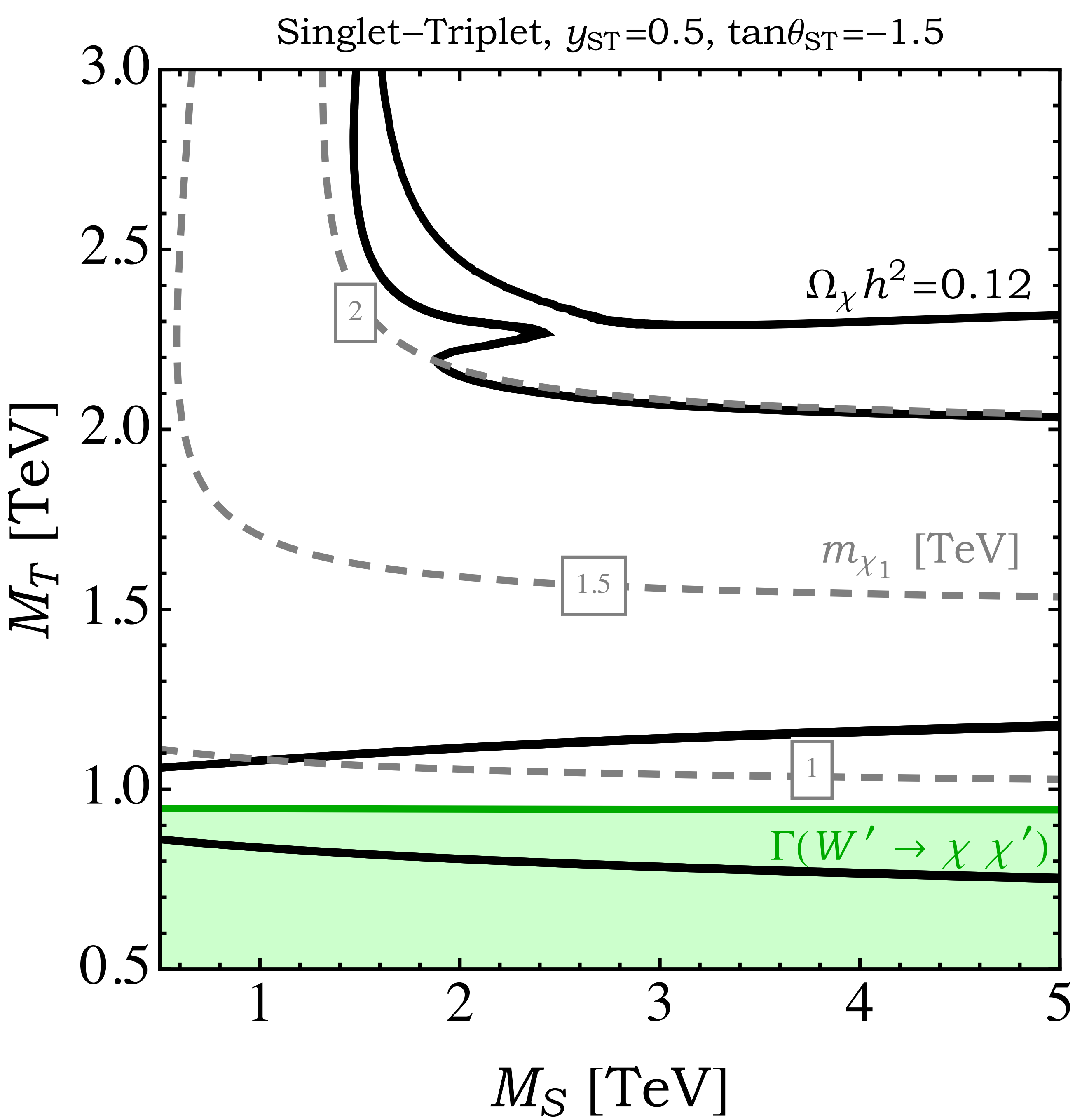
$\Delta M = M_{\chi^+} - M_{\chi^0}$ could help constrain parameter space further.

Please see appendix E

Berlin, Fox, Hooper & GM (arXiv:1604.06100)

Singlet-Triplet

$$M_{\chi^\pm} < M_{\chi_1} \qquad M_S \gtrsim 50 \text{ TeV} \gg M_T$$



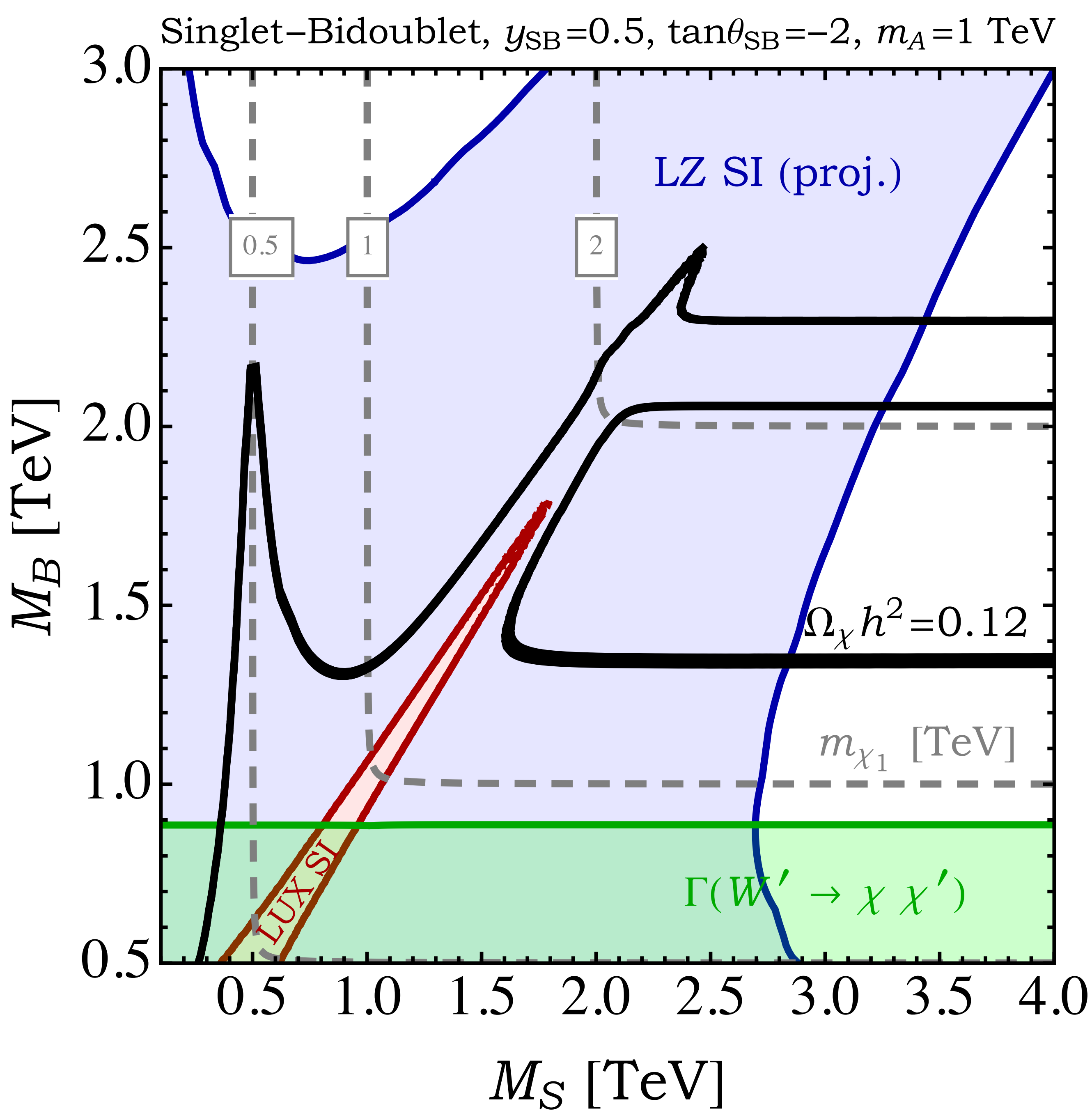
$$\tan\theta_{\rm ST} = -1.5$$

roughly here

Singlet-Bidoublet

$$M_{\chi^\pm} < M_{\chi_1} \qquad M_S \gtrsim 50 \text{ TeV} \gg M_B$$

$$\tan\theta_{\rm SB} = -2$$



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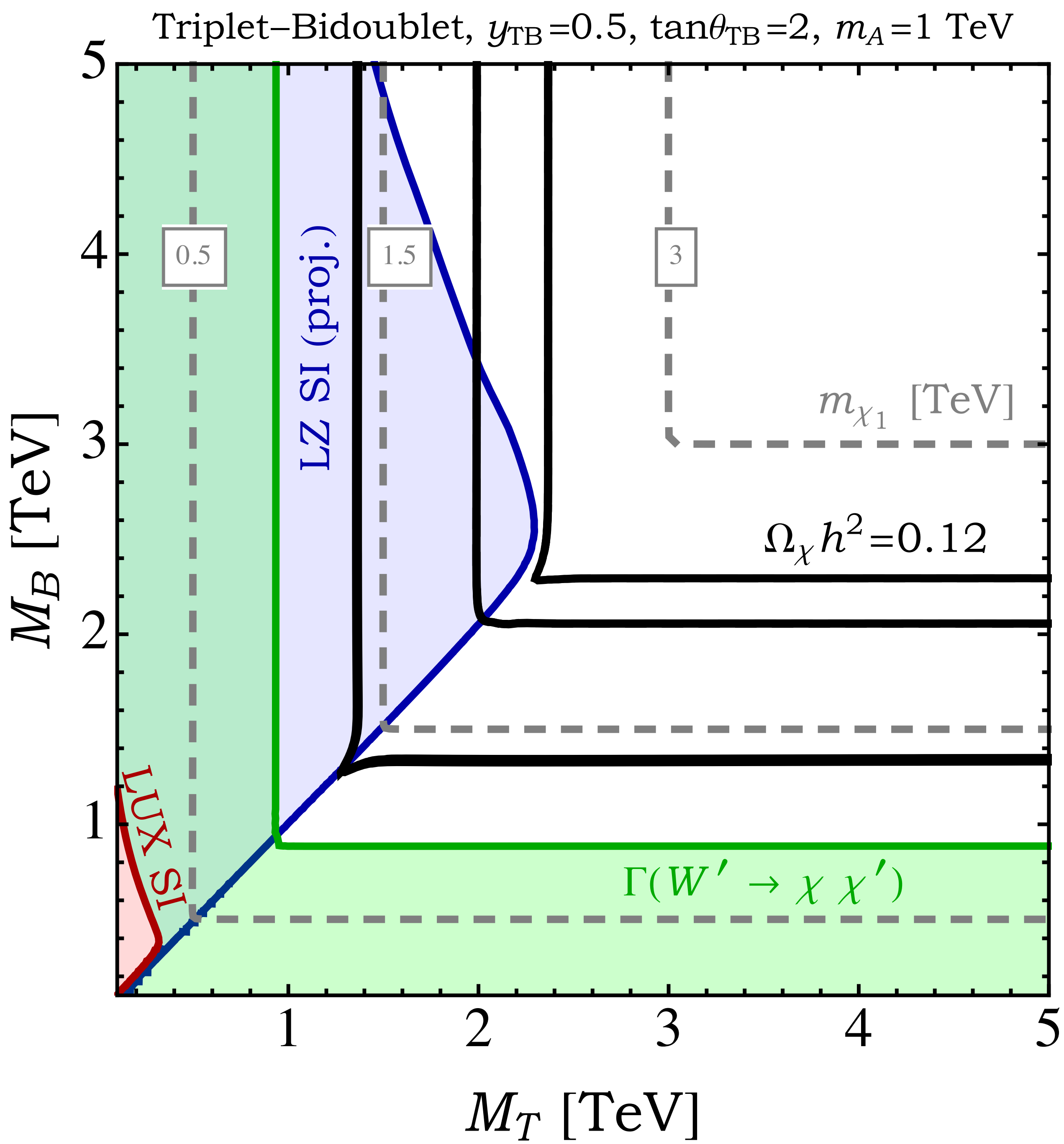
Triplet-Bidoublet

$$M_{\chi^\pm} < M_{\chi_1} \qquad M_B \ll M_T \gtrsim \mathcal{O}(10)TeV$$

$$M_T \ll M_B \gtrsim \mathcal{O}(10)TeV$$



roughly here

Gauge Boson Sector

After Symmetry breaking, Δ_R and ϕ get vevs, Gauge Boson mass term:

For the Charged Bosons, $W_L^{\pm}$ and $W_R^{\pm}$

$$\mathcal{L}_{W^\pm} = \begin{pmatrix} W_L^{+\mu} & W_R^{+\mu} \end{pmatrix} \begin{pmatrix} \frac{1}{2}g_L^2 v^2 & -\frac{1}{2}g_L g_R s_{2\beta} v^2 \\ -\frac{1}{2}g_L g_R s_{2\beta} v^2 & g_R^2(v_R^2 + \frac{1}{2}v^2) \end{pmatrix} \begin{pmatrix} W_L^{-\mu} \\ W_R^{-\mu} \end{pmatrix}$$

For the Neutral Bosons, W_L^3, W_R^3 and B

$$\mathcal{L}_{W^3,B} = \frac{1}{2} \begin{pmatrix} W_{L\mu}^3 & W_{R\mu}^3 & B_\mu \end{pmatrix} \begin{pmatrix} \frac{1}{2}g_L^2 v^2 & -\frac{1}{2}g_L g_R v^2 & 0 \\ -\frac{1}{2}g_L g_R v^2 & g_R^2(v_R^2 + \frac{1}{2}v^2) & -2g_{B-L}g_R v_R^2 \\ 0 & -2g_{B-L}g_R v_R^2 & 2g_{B-L}^2 v_R^2 \end{pmatrix} \begin{pmatrix} W_{L\mu}^3 \\ W_{R\mu}^3 \\ B_\mu \end{pmatrix}$$

Diagonalize both Charged and Neutral Gauge Boson Mass Matrices

Gives masses for γ, Z and Z', $W^{\pm}$ and $W'^{\pm}$

Important Model Parameters

Parameter space motivated by CMS & ATLAS 8 TeV Diboson excess

To match observed rates in diboson excess, we need:

$M_{W'} = 1.8 \text{ TeV} - 2.0 \text{ TeV}$ $\quad v_R = 3 \text{ TeV} - 4 \text{ TeV}$

$g_R = 0.4 - 0.6$ $\quad \tan\beta = 0.5 - 2$

We choose $M_{W'} = 1.9 \text{ TeV}$ and $g_R = 0.45$ such that $v_R = 4.2 \text{ TeV}$

and $M_{Z'} = 4.41 \text{ TeV}$

We also choose $\tan\beta = 2$

We choose to not deal with Higgs triplet and bidoublet potential terms since they add more parameters.

We work with $M_h = 125 \text{ GeV}$ and $M_{heavy} = 1 \text{ TeV}$

$|\tan\theta_{\mathrm{ST}}| \sim 1$ there is an enhanced parity symmetry acting on triplets

singlet mixes with only lin comb of neutral triplet parts

other lin comb of neutrals degenerate with charged states

$$\sigma_{\mathrm{SI}} \approx 2 \times 10^{-44}\,\mathrm{cm}^2 \times \left(\frac{\lambda_h^{(1)}}{0.1}\right)^2$$

Singlet-Bidoublet

$$\lambda_h^{(1)} \propto (1 + \sin 2\beta \sin 2\theta_{\mathrm{SB}}) m_{\chi_1} + (\sin 2\beta + \sin 2\theta_{\mathrm{SB}}) M_B$$

Triplet-Bidoublet

Destructive interference btw h and H DD diagrams

$$\lambda_h^{(1)} \propto (1 + \sin 2\beta \sin 2\theta_{\rm TB})m_{\chi_1} - (\sin 2\beta + \sin 2\theta_{\rm TB})M_B$$

Cancellations between higgs contributions happen $M_T \gg M_B \sim m_{\chi_1}$

$$\lambda_h^{(1)} \propto (1 - s_{2\beta})(1 - s_{2\theta_{\rm TB}})$$