Charged dark matter in supersymmetric Twin Higgs models

based on [2202.10488] by Marcin Badziak, Giovanni Grilli di Cortona, Keisuke Harigaya and MŁ

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Summary

1. Hierarchy problem
2. Twin Higgs
3. Twin stau as DM candidate

Hierarchy problem

In SM $m_h^2 = (m_h^0)^2 + \delta m_h^2$:

$$\delta m_h^2 = \frac{3}{4\pi^2}\left(-y_t^2 + \frac{g^2}{4} + \frac{g'^2}{8\cos^2\theta_W} + \lambda \right)\Lambda^2$$

Higgs mass in Standard Model (SM) is not natural, $m_h \ll \Lambda_{\text{cut-off}}$.

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Twin Higgs

1. double the particle content adding twin sector (in particular second higgs H')
2. impose Z_2 symmetry interchanging particles between sectors
3. the scalar potential is $SU(4)$ invariant due to Z_2 symmetry
$$V(\mathcal{H}) = -m_{\mathcal{H}}^2(H^2 + H'^2) + \lambda\left(H^2 + H'^2\right)^2 = -m_{\mathcal{H}}^2\mathcal{H}^\dagger\mathcal{H} + \lambda\left(\mathcal{H}^\dagger\mathcal{H}\right)^2$$
4. spontaneous symmetry breaking of $SU(4) \to SU(3)$ generates SM Higgs as one of Nambu-Goldstone bosons
5. Quadratically divergent gauge contributions to the potential
$$\delta V = \frac{9\Lambda^2 g^2}{64\pi^2}(H^\dagger H + H'^\dagger H') = \frac{9g^2\Lambda^2}{64\pi^2}\mathcal{H}^\dagger\mathcal{H}$$

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Twin Higgs models

General Twin Higgs potential could be written

$$V(H,H') = \lambda\big(H^2 + H'^2\big)^2 - m_{\mathcal{H}}^2\big(H^2 + H'^2\big) + \\ +\Delta\lambda\big(H^4 + H'^4\big) + \Delta m^2 H^2$$

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DM is TH models

- twin tau ($m_{\tau'} \approx 65 - 130$ GeV, [1505.07109])
- twin electrons ($m_{e'} \approx 2 - 5$ MeV [1908.03559])
- twin baryons ($m_{baryon} \approx 5$ GeV, [1506.03520])

Twin electromagnetism necessarily broken!

Self-interactions of DM are constrained and for self-coupling $g = g_{em}$ we have $m_{\mathrm{DM}} \gtrsim 200$ GeV. [1610.04611]

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Few remarks on SUSY TH

- In SUSY the potential is fixed by particle content, F-term, and gauge interactions, D-term.
- The $SU(4)$ invariant potential may be generated in two way, F-term SUSY TH [1611.08615] and D-term SUSY TH D-term [1703.02122]
- The main difference is captured by preferable values of $\tan\beta$, which are small (F-term) or large (D-term).
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Few remarks

1. assume Z_2 symmetric soft breaking terms and $\tan\beta$
2. lightest supersymmetric particle (LSP) is stable
3. **twin stau** is Z_2 partner of stau, supersymmetric partner of tau
4. The mass matrix of stau is given by

$$m^2_{\tilde{\tau}} = \begin{pmatrix} m^2_{L_3} + \Delta_{\tilde{\tau}_L} + m^2_\tau & -\mu v y_\tau \sin(\beta) \\ -\mu v y_\tau \sin(\beta)) & m^2_{\bar{e}_3} + \Delta_{\tilde{\tau}_R} + m^2_\tau \end{pmatrix}$$

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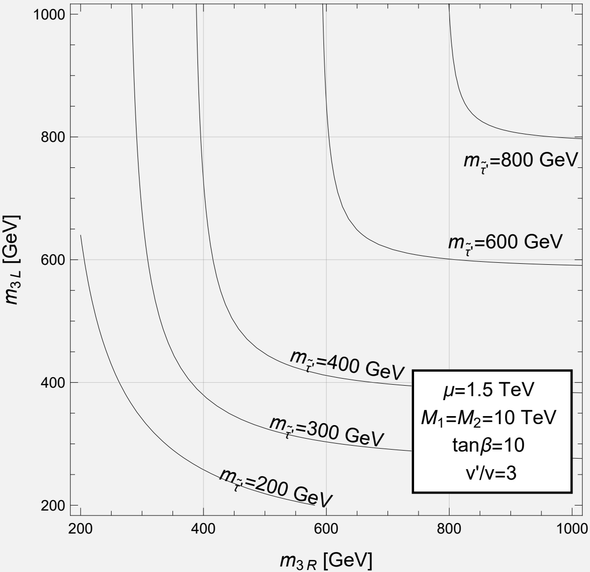
Decoupling limit



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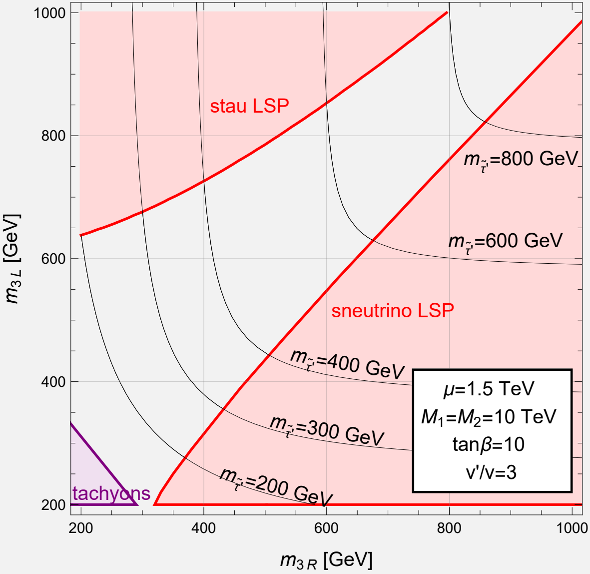

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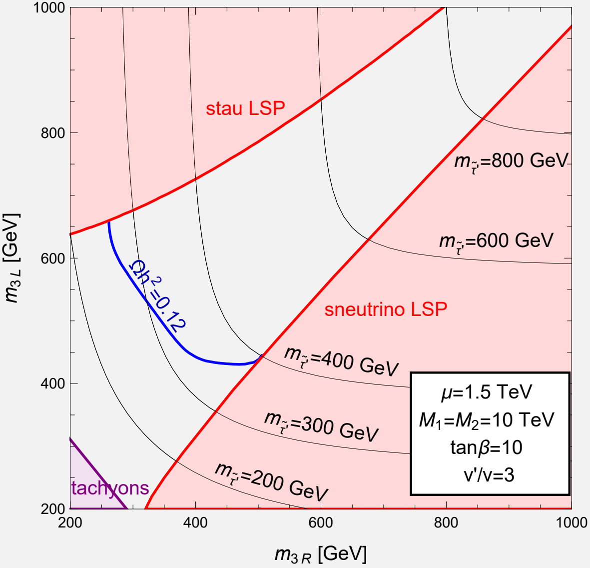

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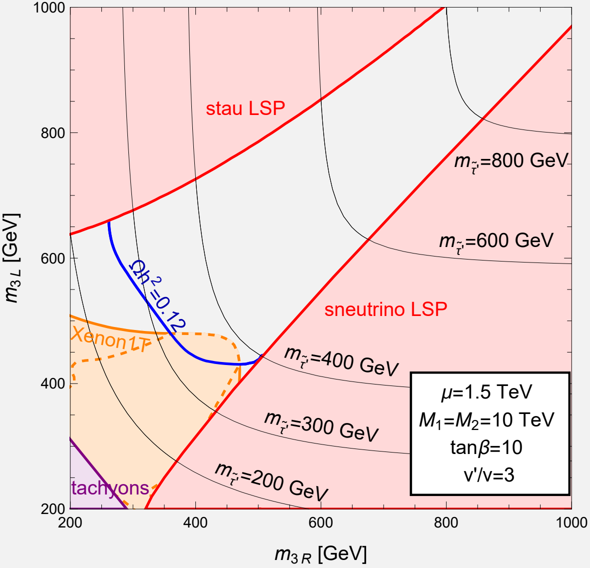

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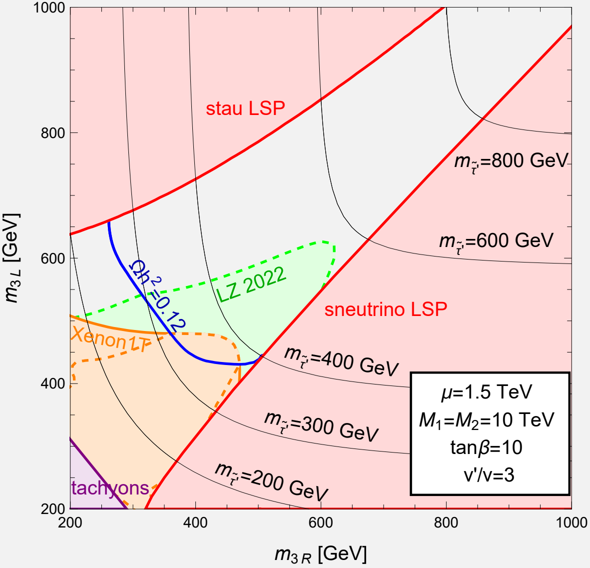

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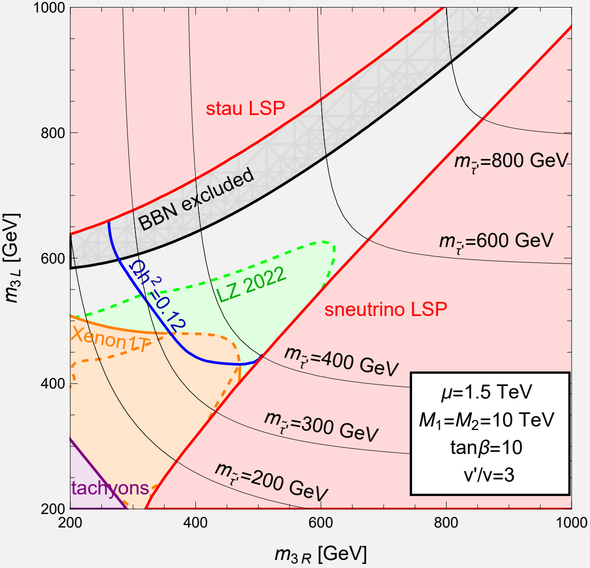

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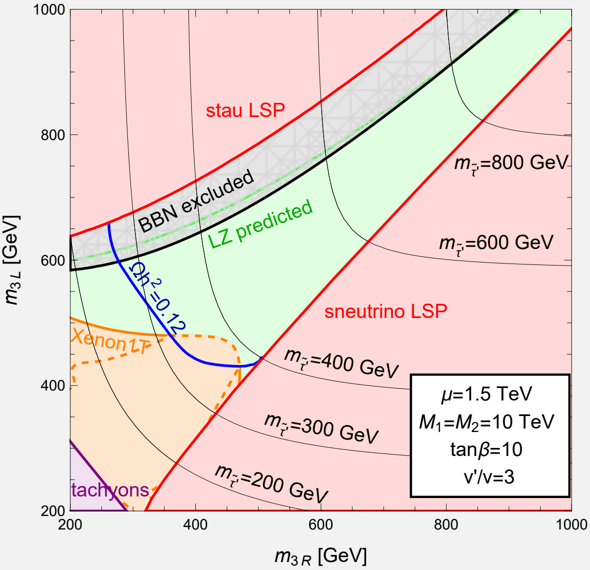

Conclusions

- Supersymmetric Twin Higgs models allow for naturally light Higgs boson, stable under quantum corrections
- in TH models usually one needs to break twin electromagnetism to obtain DM
- in SUSY completions large soft masses allow for LSP charged under twin EM
- twin stau DM will be probed by LZ experiment

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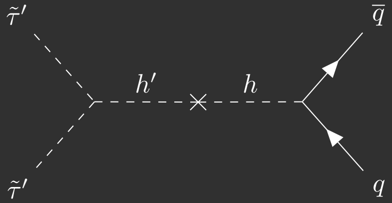
Thank you

Direct detection

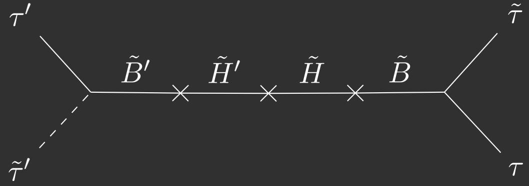
Twin stau can interact with nucleons from visible sector via Higgs portal. The relevant coupling in decoupling limit is

$$\lambda_{h\tilde{\tau}'\tilde{\tau}'} = \frac{g}{m_{W'}}\left[\left(\frac{1}{2}c^2_{\theta_{\tilde{\tau}'}} - s^2_W c_{2\theta_{\tilde{\tau}'}}\right)m^2_{Z'}c_{2\beta} - m^2_{\tau'} + \frac{m_{\tau'}}{2}\mu\tan\beta s_{2\theta_{\tilde{\tau}'}}\right]\frac{v}{v'}$$



Lifetime of stau

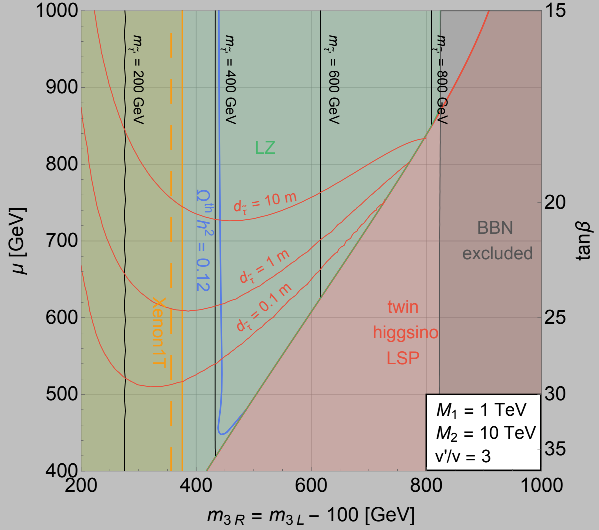
Effective $\tilde{\tau}\tilde{\tau}'^{\dagger}\tau\tau'$ operator from diagram:



$$\frac{1}{M}\tilde{\tau}\tilde{\tau}'^{\dagger}\tau\tau' = \frac{g'^4 v v' \varepsilon_{\tilde{H}} m_{\tilde{\tau}}^2 (M_1^2 + m_{\tilde{\tau}}^2)}{(M_1^2 - m_{\tilde{\tau}}^2)^2 (\mu^2 - m_{\tilde{\tau}}^2)^2}\tilde{\tau}\tilde{\tau}'^{\dagger}\tau\tau'$$

$$d_{\tilde{\tau}} \simeq 2.7\,\mathrm{m}\left(\frac{m_{\tilde{\tau}}}{300\ \mathrm{GeV}}\right)^2 \left(\frac{M}{10^6\ \mathrm{GeV}}\right)^2 \left(\frac{10\ \mathrm{GeV}}{m_{\tilde{\tau}} - m_{\tilde{\tau}'}}\right)^5 \tag{1}$$

Light Higgsino



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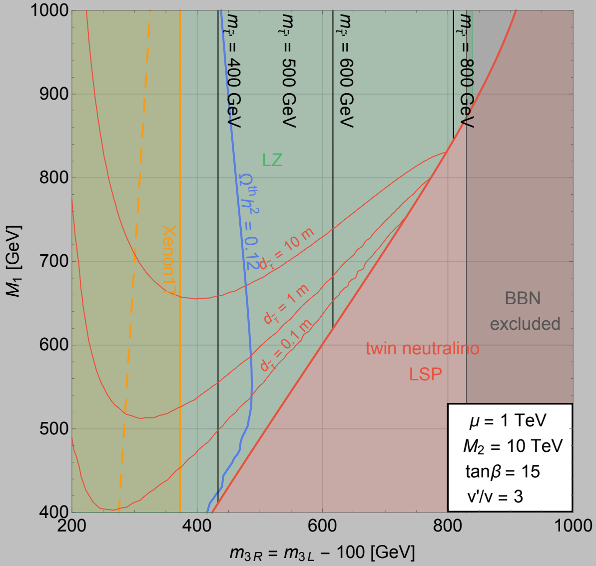
$m_{\tilde{\tau}}$ = 400 GeV
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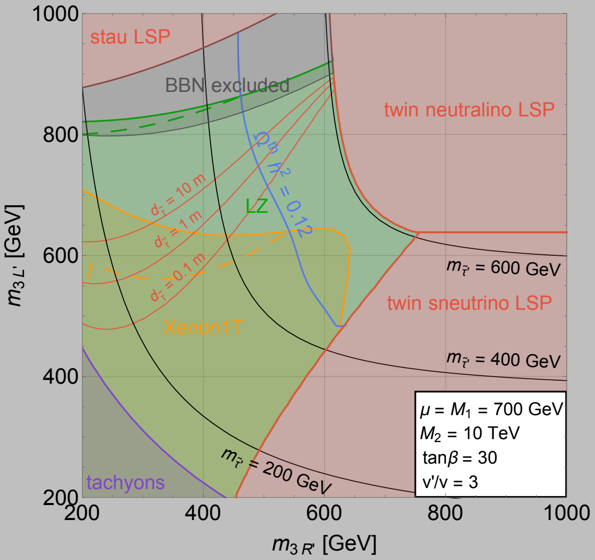
$m_{\tilde{\tau}}$ = 600 GeV
$m_{\tilde{\tau}}$ = 800 GeV
LZ
$\Omega^{th}h^2 = 0.12$
Xenon1T
$d_{\tilde{\tau}}$ = 10 m
$d_{\tilde{\tau}}$ = 1 m
$d_{\tilde{\tau}}$ = 0.1 m
twin neutralino LSP
BBN excluded
μ = 1 TeV
M_2 = 10 TeV
tanβ = 15
v'/v = 3
M_1 [GeV]
$m_{3R} = m_{3L} - 100$ [GeV]
1000
900
800
700
600
500
400
200
400
600
800
1000

Light higgsino and bino



Breaking Z_2 in Yukawa