Charged dark matter in supersymmetric Twin Higgs models

based on JHEP 10 (2022) 057 by Marcin Badziak, Giovanni Grilli di Cortona, Keisuke Harigaya and MŁ [2202.10488]

Michał Łukawski

Faculty of Physics
University of Warsaw

8th Symposium on Prospects in the Physics of Discrete Symmetries

09.11.2022

Summary

1. Twin Higgs mechanism
2. Supersymmetric Twin Higgs
3. Twin stau as DM candidate

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
   $V(\mathcal{H}) = -m_{\mathcal{H}}^2(H^2 + H'^2) + \lambda(H^2 + H'^2)^2 = -m_{\mathcal{H}}^2\mathcal{H}^\dagger\mathcal{H} + \lambda(\mathcal{H}^\dagger\mathcal{H})^2$
   where $\mathcal{H} = (H, H')^T$
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

$$\delta V = \frac{9\Lambda^2 g^2}{64\pi^2}(H^\dagger H + H'^\dagger H') = \frac{9g^2\Lambda^2}{64\pi^2}\mathcal{H}^\dagger\mathcal{H}$$

$SU(4)$ symmetric!

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
   $V(\mathcal{H}) = -m_{\mathcal{H}}^2(H^2 + H'^2) + \lambda\left(H^2 + H'^2\right)^2 = -m_{\mathcal{H}}^2\mathcal{H}^\dagger\mathcal{H} + \lambda\left(\mathcal{H}^\dagger\mathcal{H}\right)^2$
   where $\mathcal{H} = (H, H')^T$
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

$$\delta V = \frac{9\Lambda^2 g^2}{64\pi^2}(H^\dagger H + H'^\dagger H') = \frac{9g^2\Lambda^2}{64\pi^2}\mathcal{H}^\dagger\mathcal{H}$$

$SU(4)$ symmetric!

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

   $V(\mathcal{H}) = -m_{\mathcal{H}}^2(H^2 + H'^2) + \lambda\left(H^2 + H'^2\right)^2 = -m_{\mathcal{H}}^2\mathcal{H}^\dagger\mathcal{H} + \lambda\left(\mathcal{H}^\dagger\mathcal{H}\right)^2$

   where $\mathcal{H} = (H, H')^T$
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

$$\delta V = \frac{9\Lambda^2 g^2}{64\pi^2}(H^\dagger H + H'^\dagger H') = \frac{9g^2\Lambda^2}{64\pi^2}\mathcal{H}^\dagger\mathcal{H}$$

$SU(4)$ symmetric!

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

   $V(\mathcal{H}) = -m_{\mathcal{H}}^2(H^2 + H'^2) + \lambda(H^2 + H'^2)^2 = -m_{\mathcal{H}}^2\mathcal{H}^\dagger\mathcal{H} + \lambda(\mathcal{H}^\dagger\mathcal{H})^2$

   where $\mathcal{H} = (H, H')^T$

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

$$\delta V = \frac{9\Lambda^2 g^2}{64\pi^2}(H^\dagger H + H'^\dagger H') = \frac{9g^2\Lambda^2}{64\pi^2}\mathcal{H}^\dagger\mathcal{H}$$

$SU(4)$ symmetric!

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

   $V(\mathcal{H}) = -m_{\mathcal{H}}^2(H^2 + H'^2) + \lambda\big(H^2 + H'^2\big)^2 = -m_{\mathcal{H}}^2 \mathcal{H}^\dagger\mathcal{H} + \lambda\big(\mathcal{H}^\dagger\mathcal{H}\big)^2$

   where $\mathcal{H} = (H, H')^T$
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

$$\delta V = \frac{9\Lambda^2 g^2}{64\pi^2}(H^\dagger H + H'^\dagger H') = \frac{9g^2\Lambda^2}{64\pi^2}\mathcal{H}^\dagger\mathcal{H}$$

$SU(4)$ symmetric!

Twin Higgs models

General Twin Higgs potential could be written

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

In minimal setting 4 parameters, but we know the mass of Higgs m_h and the EW vev v

We have only two parameters v'/v and the mass of the twin higgs $m_{h'}$.

Fine tuning due to Z_2 breaking $\Delta_{v'/v} = (v'^2/v^2 - 2)/2$,

for $v'/v = 3$ fine tuning is 29%
for $v'/v = 5$ fine tuning is 9%

Twin Higgs models

General Twin Higgs potential could be written

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

In minimal setting 4 parameters, but we know the mass of Higgs m_h and the EW vev v

We have only two parameters v'/v and the mass of the twin higgs $m_{h'}$.

Fine tuning due to Z_2 breaking $\Delta_{v'/v} = (v'^2/v^2 - 2)/2$,

for $v'/v = 3$ fine tuning is 29%
for $v'/v = 5$ fine tuning is 9%

Twin Higgs models

General Twin Higgs potential could be written

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

In minimal setting 4 parameters, but we know the mass of Higgs m_h and the EW vev v

We have only two parameters v'/v and the mass of the twin higgs $m_{h'}$.

Fine tuning due to Z_2 breaking $\Delta_{v'/v} = (v'^2/v^2 - 2)/2$,

for $v'/v = 3$ fine tuning is 29%
for $v'/v = 5$ fine tuning is 9%

Supersymmetric Twin Higgs models

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

In SUSY the potential is fixed by particle content (F-term), gauge interactions (D-term) and SUSY breaking.

The $SU(4)$ invariant λ-term may be generated in two ways, F-term [1611.08615] and D-term [1703.02122]

The $SU(4)$ breaking term generated by EW D-term $\Delta\lambda \simeq \frac{g^2+g'^2}{8}\cos(2\beta)$

Naturalness prefers large $\tan\beta$ and it is possible to have 10% FT for $m_{\tilde{t}} = 2$ TeV ($v'/v = 3$)

Supersymmetric Twin Higgs models

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

In SUSY the potential is fixed by particle content (F-term), gauge interactions (D-term) and SUSY breaking.

The $SU(4)$ invariant λ-term may be generated in two ways, F-term [1611.08615] and D-term [1703.02122]

The $SU(4)$ breaking term generated by EW D-term $\Delta\lambda \simeq \frac{g^2+g'^2}{8}\cos(2\beta)$

Naturalness prefers large $\tan\beta$ and it is possible to have 10% FT for $m_{\tilde{t}} = 2$ TeV ($v'/v = 3$)

Supersymmetric Twin Higgs models

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

In SUSY the potential is fixed by particle (F-term) content, gauge (D-term) interactions and SUSY breaking.

The $SU(4)$ invariant λ-term may be generated in two ways, F-term [1611.08615] and D-term [1703.02122]

The $SU(4)$ breaking term generated by EW D-term $\Delta\lambda \simeq \frac{g^2+g'^2}{8}\cos(2\beta)$

Naturalness prefers large $\tan\beta$ and it is possible to have 10% FT for $m_{\tilde{t}} = 2$ TeV $(v'/v = 3)$

Supersymmetric Twin Higgs models

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

In SUSY the potential is fixed by particle content (F-term), gauge interactions (D-term) and SUSY breaking.

The $SU(4)$ invariant λ-term may be generated in two ways, F-term [1611.08615] and D-term [1703.02122]

The $SU(4)$ breaking term generated by EW D-term $\Delta\lambda \simeq \frac{g^2+g'^2}{8}\cos(2\beta)$

Naturalness prefers large $\tan\beta$ and it is possible to have 10% FT for $m_{\tilde{t}} = 2$ TeV ($v'/v = 3$)

DM is TH models

Charged Twin DM candidates:

[1505.07109]
twin tau, $m_{\tau'} \approx 65 - 130$ GeV,

[1908.03559]
twin electrons, $m_{e'} \approx 2 - 5$ MeV,

[1506.03520]
twin baryons, $m_{\text{baryon}} \approx 5$ GeV,

Twin electromagnetism necessarily broken!

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

Observation:

SUSY partners with large soft masses and can escape that bound, while preserving unbroken $U'_{\text{em}}(1)$

DM is TH models

Charged Twin DM candidates:

[1505.07109]
twin tau, $m_{\tau'} \approx 65 - 130$ GeV,

[1908.03559]
twin electrons, $m_{e'} \approx 2 - 5$ MeV,

[1506.03520]
twin baryons, $m_{\text{baryon}} \approx 5$ GeV,

Twin electromagnetism necessarily broken!

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

Observation:

SUSY partners with large soft masses and can escape that bound, while preserving unbroken $U'_{\text{em}}(1)$

DM is TH models

Charged Twin DM candidates:

[1505.07109]
twin tau, $m_{\tau'} \approx 65 - 130$ GeV,

[1908.03559]
twin electrons, $m_{e'} \approx 2 - 5$ MeV,

[1506.03520]
twin baryons, $m_{\text{baryon}} \approx 5$ GeV,

Twin electromagnetism necessarily broken!

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

Observation:

SUSY partners with large soft masses and can escape that bound, while preserving unbroken $U'_{\mathsf{em}}(1)$

Mass matrix

We considered **twin stau** as DM candidate - Z_2 partner of stau.

- assume Z_2 symmetric soft SUSY breaking and $\tan\beta$
- R-parity is conserved: lightest supersymmetric particle (LSP) is stable
- The mass matrix of twin stau is given by

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

- for pure $\tilde{\tau}'_L$ $(m_{3L} \ll m_{3R})$ and $\tilde{\tau}'_R$ $(m_{3R} \ll m_{3L})$ visible stau is lighter
- off-diagonal term is larger in twin sector, for mixed state twin stau may be LSP

Mass matrix

We considered **twin stau** as DM candidate - Z_2 partner of stau.

- assume Z_2 symmetric soft SUSY breaking and $\tan\beta$
- R-parity is conserved: lightest supersymmetric particle (LSP) is stable
- The mass matrix of twin stau is given by

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

- for pure $\tilde{\tau}'_L$ ($m_{3L} \ll m_{3R}$) and $\tilde{\tau}'_R$ ($m_{3R} \ll m_{3L}$) visible stau is lighter
- off-diagonal term is larger in twin sector, for mixed state twin stau may be LSP

Mass matrix

We considered **twin stau** as DM candidate - Z_2 partner of stau.

- assume Z_2 symmetric soft SUSY breaking and $\tan\beta$
- R-parity is conserved: lightest supersymmetric particle (LSP) is stable
- The mass matrix of twin stau is given by

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

- for pure $\tilde{\tau}'_L$ $(m_{3L} \ll m_{3R})$ and $\tilde{\tau}'_R$ $(m_{3R} \ll m_{3L})$ visible stau is lighter
- off-diagonal term is larger in twin sector, for mixed state twin stau may be LSP

Mass matrix

We considered **twin stau** as DM candidate - Z_2 partner of stau.

- assume Z_2 symmetric soft SUSY breaking and $\tan\beta$
- R-parity is conserved: lightest supersymmetric particle (LSP) is stable
- The mass matrix of twin stau is given by

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

- for pure $\tilde{\tau}'_L$ ($m_{3L} \ll m_{3R}$) and $\tilde{\tau}'_R$ ($m_{3R} \ll m_{3L}$) visible stau is lighter
- off-diagonal term is larger in twin sector, for mixed state twin stau may be LSP

Mass matrix

We considered **twin stau** as DM candidate - Z_2 partner of stau.

- assume Z_2 symmetric soft SUSY breaking and $\tan\beta$
- R-parity is conserved: lightest supersymmetric particle (LSP) is stable
- The mass matrix of twin stau is given by

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

- for pure $\tilde{\tau}'_L$ $(m_{3L} \ll m_{3R})$ and $\tilde{\tau}'_R$ $(m_{3R} \ll m_{3L})$ visible stau is lighter
- off-diagonal term is larger in twin sector, for mixed state twin stau may be LSP

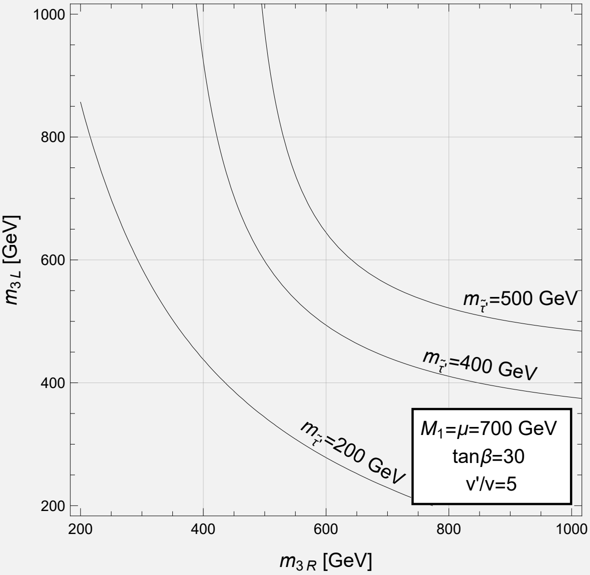
Mass matrix

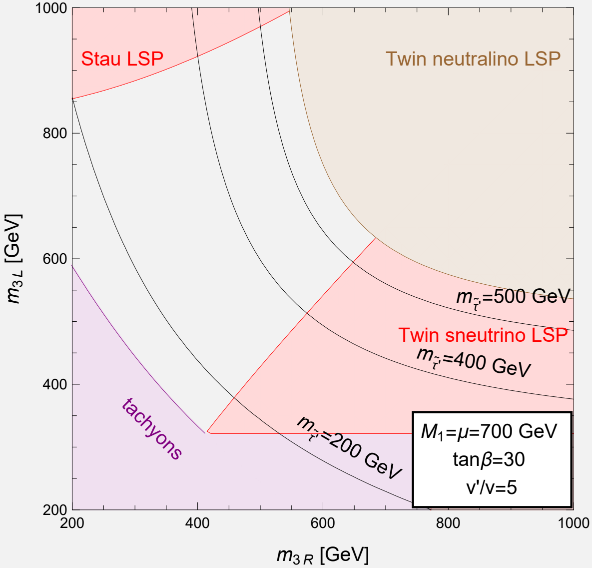
We considered **twin stau** as DM candidate - Z_2 partner of stau.

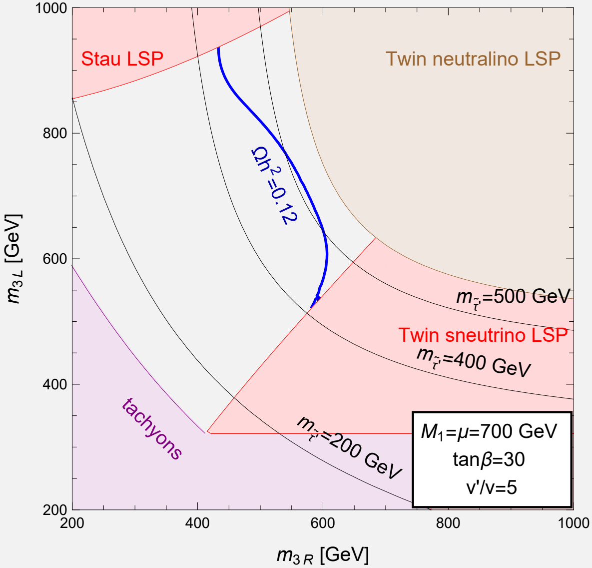
- assume Z_2 symmetric soft SUSY breaking and $\tan\beta$
- R-parity is conserved: lightest supersymmetric particle (LSP) is stable
- The mass matrix of twin stau is given by

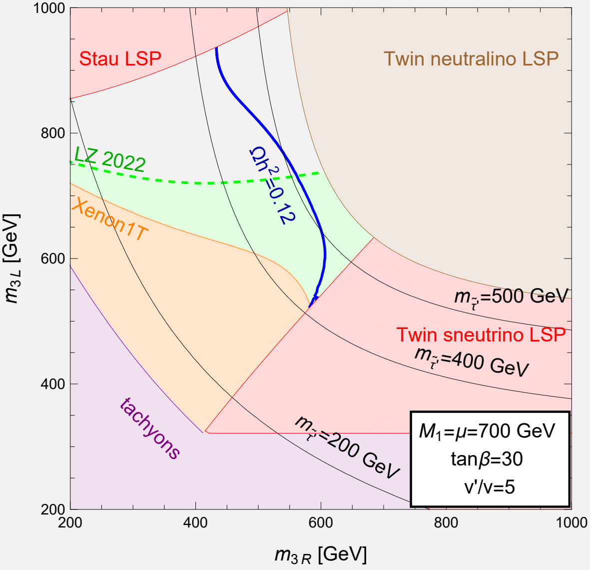
$$m^2_{\tilde{\tau}'} = \begin{pmatrix} m^2_{L_3} + \Delta_{\tilde{\tau}'_L} + m^2_{\tau'} & -\mu v' y_\tau \sin\beta \\ -\mu v' y_\tau \sin\beta & m^2_{\bar{e}_3} + \Delta_{\tilde{\tau}'_R} + m^2_{\tau'} \end{pmatrix}$$

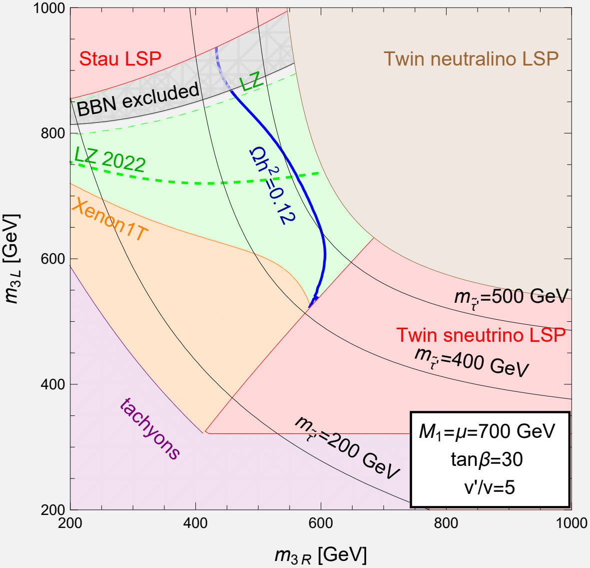
- for pure $\tilde{\tau}'_L$ $(m_{3L} \ll m_{3R})$ and $\tilde{\tau}'_R$ $(m_{3R} \ll m_{3L})$ visible stau is lighter
- off-diagonal term is larger in twin sector, for mixed state twin stau may be LSP

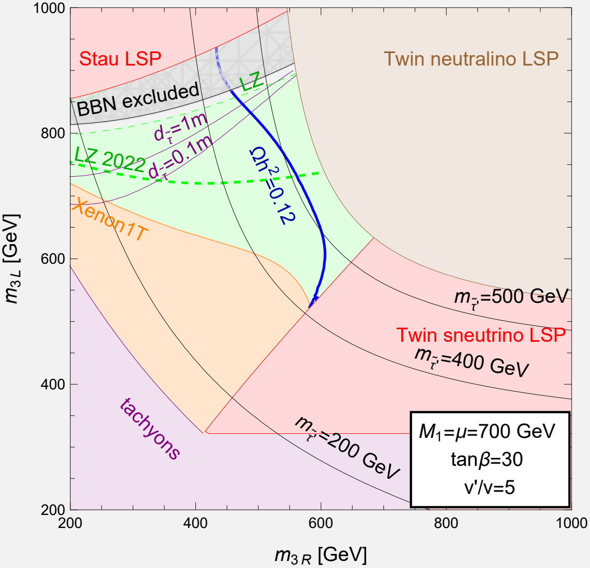

1000
800
600
400
200
200
400
600
800
1000
m_{3L} [GeV]
m_{3R} [GeV]
$m_{\tilde{\tau}'}$=500 GeV
$m_{\tilde{\tau}'}$=400 GeV
$m_{\tilde{\tau}'}$=200 GeV
M_1=μ=700 GeV
tanβ=30
v'/v=5


Stau LSP
Twin neutralino LSP
Twin sneutrino LSP
tachyons
$m_{\tilde{\tau}'}$=500 GeV
$m_{\tilde{\tau}'}$=400 GeV
$m_{\tilde{\tau}'}$=200 GeV
M_1=μ=700 GeV
tanβ=30
v'/v=5
m_{3L} [GeV]
m_{3R} [GeV]
200
400
600
800
1000

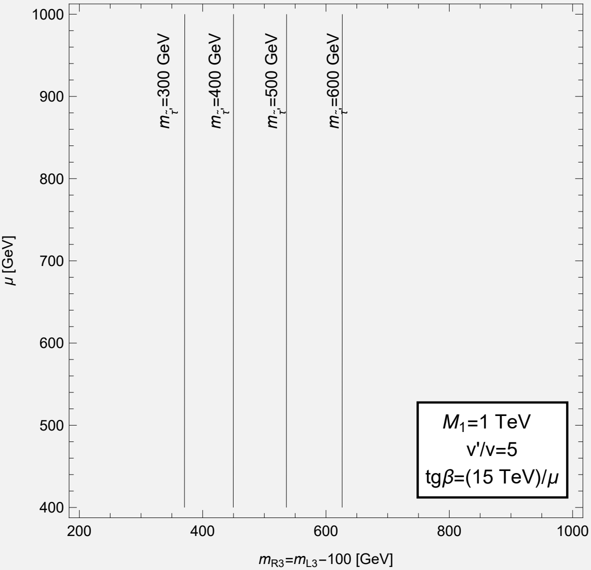

Stau LSP
Twin neutralino LSP
Ωh^2=0.12
$m_{\tilde{\tau}'}$=500 GeV
Twin sneutrino LSP
$m_{\tilde{\tau}'}$=400 GeV
tachyons
$m_{\tilde{\tau}'}$=200 GeV
M_1=μ=700 GeV
tanβ=30
v'/v=5
1000
800
600
400
200
m_{3L} [GeV]
m_{3R} [GeV]


Stau LSP
Twin neutralino LSP
LZ 2022
Ωh²=0.12
Xenon1T
Twin sneutrino LSP
tachyons
$m_{\tilde{\tau}'}$=500 GeV
$m_{\tilde{\tau}'}$=400 GeV
$m_{\tilde{\tau}'}$=200 GeV
M_1=μ=700 GeV
tanβ=30
v'/v=5
m_{3L} [GeV]
m_{3R} [GeV]
200
400
600
800
1000

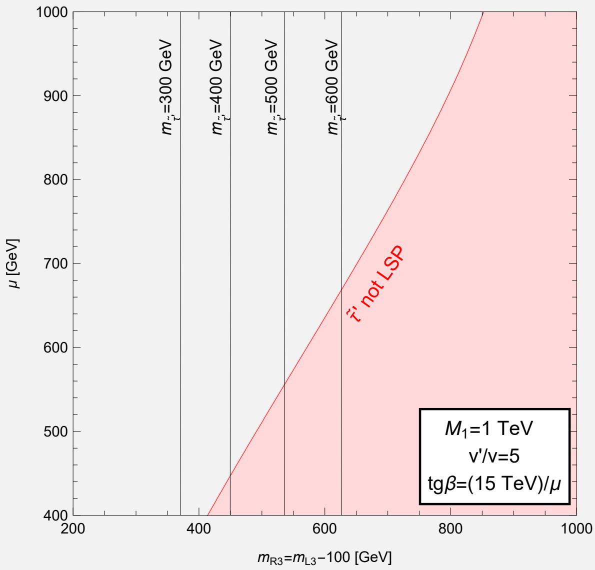

Stau LSP
Twin neutralino LSP
BBN excluded
LZ
LZ 2022
Ωh^2=0.12
Xenon1T
$m_{\tilde{\tau}'}$=500 GeV
Twin sneutrino LSP
$m_{\tilde{\tau}'}$=400 GeV
tachyons
$m_{\tilde{\tau}'}$=200 GeV
M_1=μ=700 GeV
tanβ=30
v'/v=5
m_{3L} [GeV]
m_{3R} [GeV]
200
400
600
800
1000


Stau LSP
BBN excluded
LZ
Twin neutralino LSP
$d_{\tilde{\tau}}$=1m
$d_{\tilde{\tau}}$=0.1m
LZ 2022
Ωh^2=0.12
Xenon1T
$m_{\tilde{\tau}'}$=500 GeV
Twin sneutrino LSP
$m_{\tilde{\tau}'}$=400 GeV
tachyons
$m_{\tilde{\tau}'}$=200 GeV
M_1=μ=700 GeV
tanβ=30
v'/v=5
m_{3L} [GeV]
m_{3R} [GeV]
200
400
600
800
1000

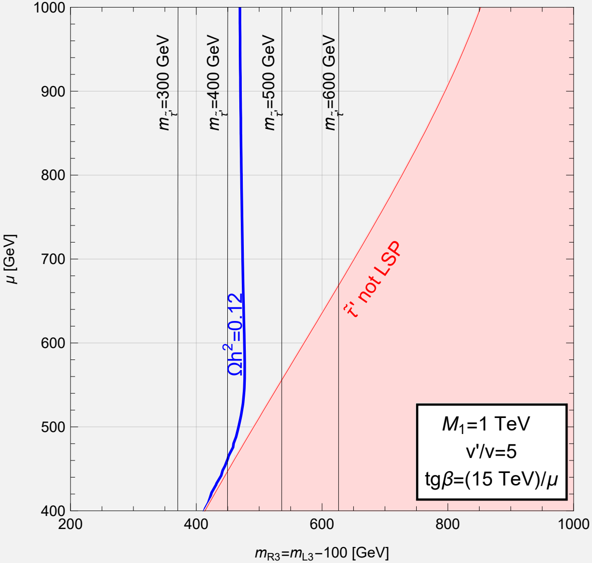
Light Higgsino



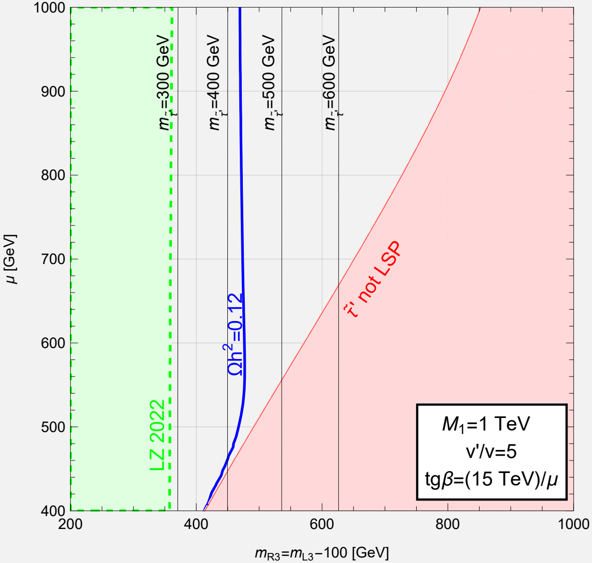
Light Higgsino



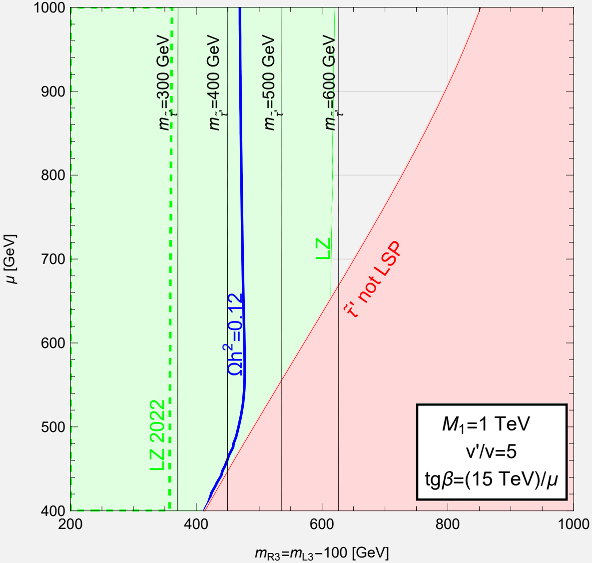
Light Higgsino



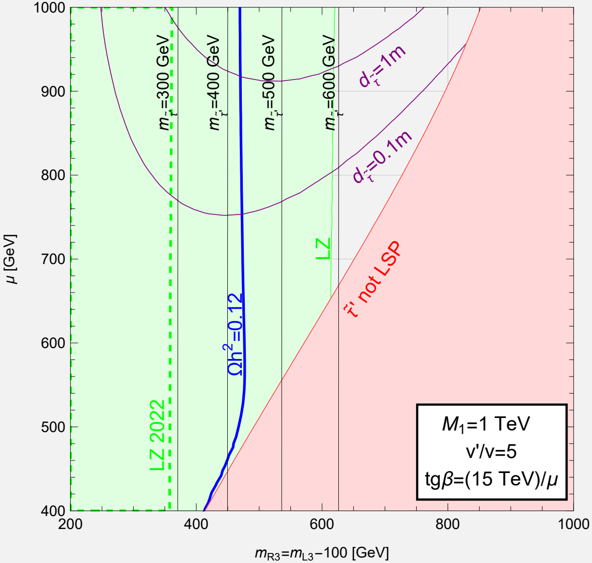
Light Higgsino



Light Higgsino



Light Higgsino



Conclusions

- Supersymmetric Twin Higgs models allow for naturally low EW scale, stable under the quantum corrections, FT$\approx 10\%$ with $m_{\tilde{t}} = 2$ TeV
- in TH models usually one needs to break the twin electromagnetism to obtain DM
- with SUSY completion, large soft masses allow for interacting DM charged under unbroken twin EM
- light stau may be observed at LHC as a long lived particle or a disappearing track
- twin stau DM will be probed by LZ experiment

Conclusions

- Supersymmetric Twin Higgs models allow for naturally low EW scale, stable under the quantum corrections, FT$\approx 10\%$ with $m_{\tilde{t}} = 2$ TeV
- in TH models usually one needs to break the twin electromagnetism to obtain DM
- with SUSY completion, large soft masses allow for interacting DM charged under unbroken twin EM
- light stau may be observed at LHC as a long lived particle or a disappearing track
- twin stau DM will be probed by LZ experiment

Conclusions

- Supersymmetric Twin Higgs models allow for naturally low EW scale, stable under the quantum corrections, FT$\approx 10\%$ with $m_{\tilde{t}} = 2$ TeV
- in TH models usually one needs to break the twin electromagnetism to obtain DM
- with SUSY completion, large soft masses allow for interacting DM charged under unbroken twin EM
- light stau may be observed at LHC as a long lived particle or a disappearing track
- twin stau DM will be probed by LZ experiment

Conclusions

- Supersymmetric Twin Higgs models allow for naturally low EW scale, stable under the quantum corrections, FT$\approx 10\%$ with $m_{\tilde{t}} = 2$ TeV
- in TH models usually one needs to break the twin electromagnetism to obtain DM
- with SUSY completion, large soft masses allow for interacting DM charged under unbroken twin EM
- light stau may be observed at LHC as a long lived particle or a disappearing track
- twin stau DM will be probed by LZ experiment

Conclusions

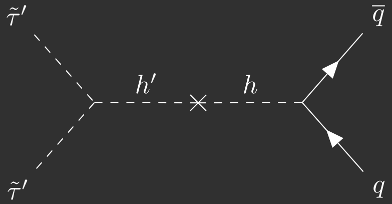
- Supersymmetric Twin Higgs models allow for naturally low EW scale, stable under the quantum corrections, FT$\approx 10\%$ with $m_{\tilde{t}} = 2$ TeV
- in TH models usually one needs to break the twin electromagnetism to obtain DM
- with SUSY completion, large soft masses allow for interacting DM charged under unbroken twin EM
- light stau may be observed at LHC as a long lived particle or a disappearing track
- twin stau DM will be probed by LZ experiment

Thank you

Direct detection

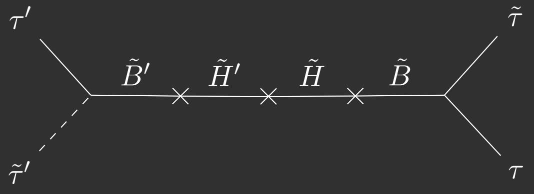
Twin stau can interact with nucleons from visible sector via Higgs portal. The relevant coupling in decoupling limit is

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



Lifetime of stau

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

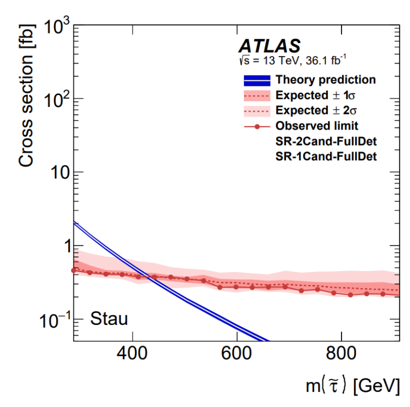


$$\frac{1}{M}\tilde{\tau}\tilde{\tau}'^{\dagger}\tau\tau' = \frac{g'^4 v v' \varepsilon_{\tilde{H}} m_{\tilde{\tau}}^2 (M_1^2 + m_{\tilde{\tau}}^2)}{(M_1^2 - m_{\tilde{\tau}}^2)^2(\mu^2 - m_{\tilde{\tau}}^2)^2}\tilde{\tau}\tilde{\tau}'^{\dagger}\tau\tau'$$

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

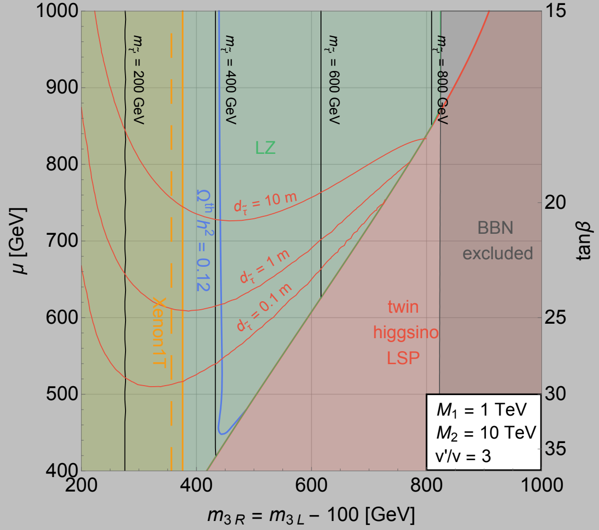
Collider

Due to Z_2, this scenario predicts light stau, which might be long-lived ($c\tau \simeq \mathcal{O}(1)$m) 1902.01636

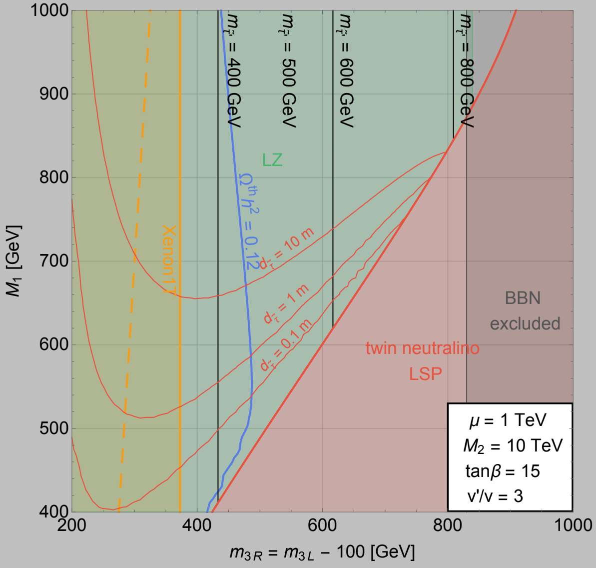


disappearing tracks ($c\tau \simeq 0.1 - 1$m) are poorly constrained

Light Higgsino

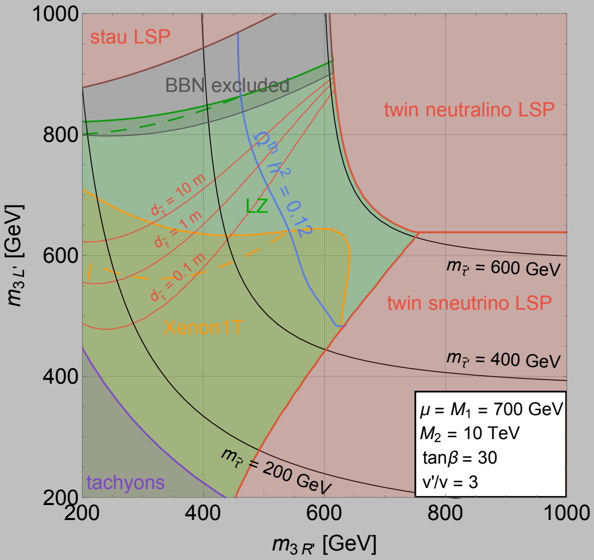


Light bino



1000
900
800
700
600
500
400
200
400
600
800
1000
M_1 [GeV]
$m_{3R} = m_{3L} - 100$ [GeV]
$m_{\tilde{\tau}'} = 400$ GeV
$m_{\tilde{\tau}'} = 500$ GeV
$m_{\tilde{\tau}'} = 600$ 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
BBN
excluded
twin neutralino
LSP
$\mu = 1$ TeV
$M_2 = 10$ TeV
$\tan\beta = 15$
v'/v = 3

Light higgsino and bino



Breaking Z_2 in Yukawa