Probing “hidden” MSSM neutralino DM

武雷

南京师范大学

arXiv:1804.05238 [PRD]
arXiv:1711.03893 [PLB]
arXiv:1705.09164 [EPJC]

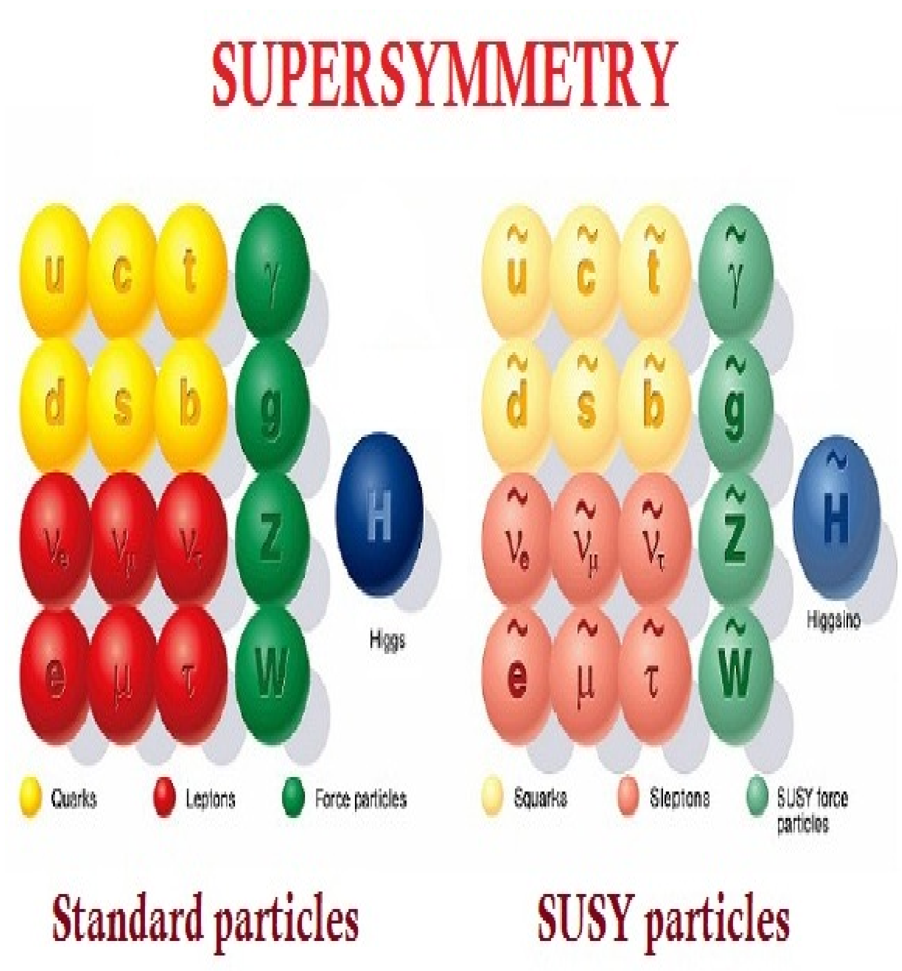
Outline

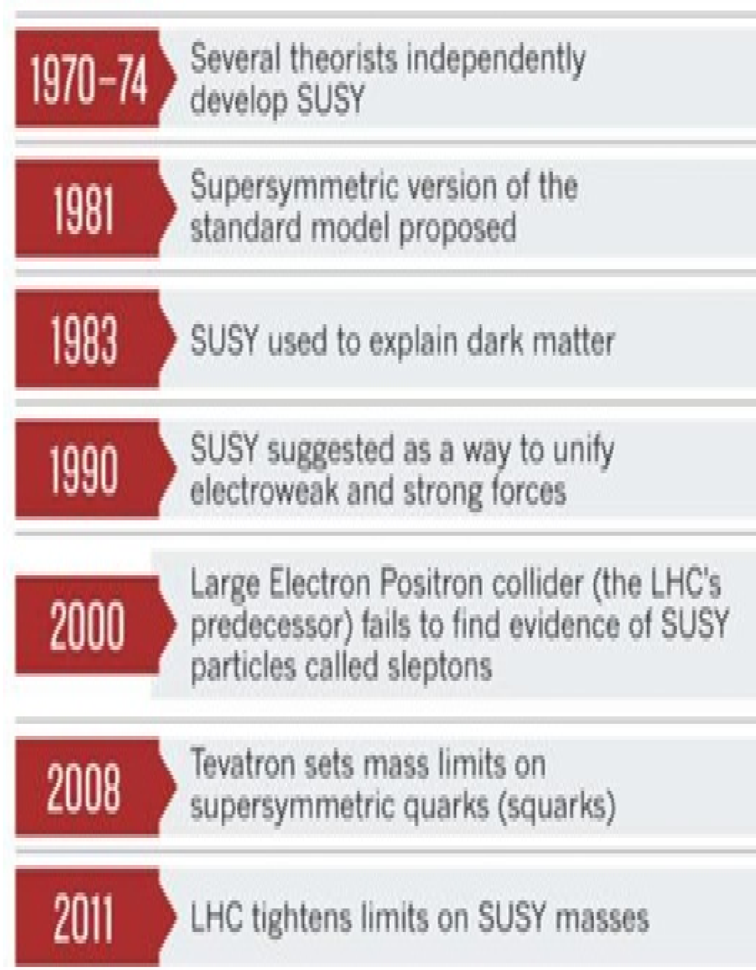
- MSSM “hidden” neutralino DM

- (1) Bino-Wino coannihilation — arXiv:1804.05238 [PRD]
- (2) Bino-Higgsino blind spot — arXiv:1705.09164 [EPJC]
- (3) Dark Higgs in alignment limit — arXiv:1711.03893 [PLB]

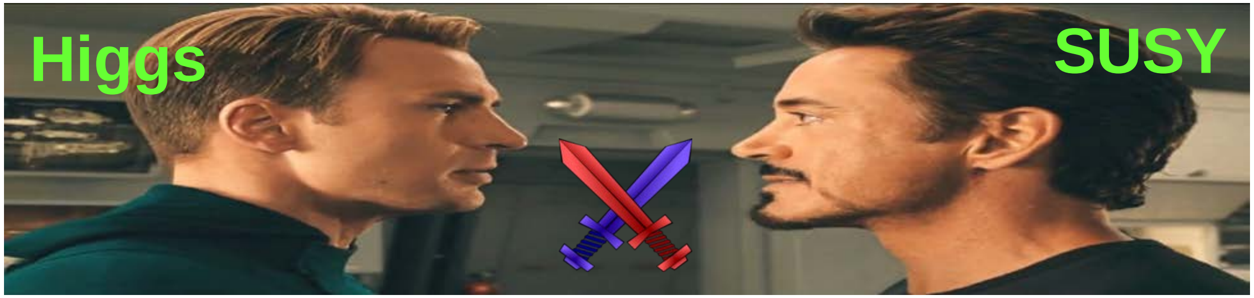
- Conclusions

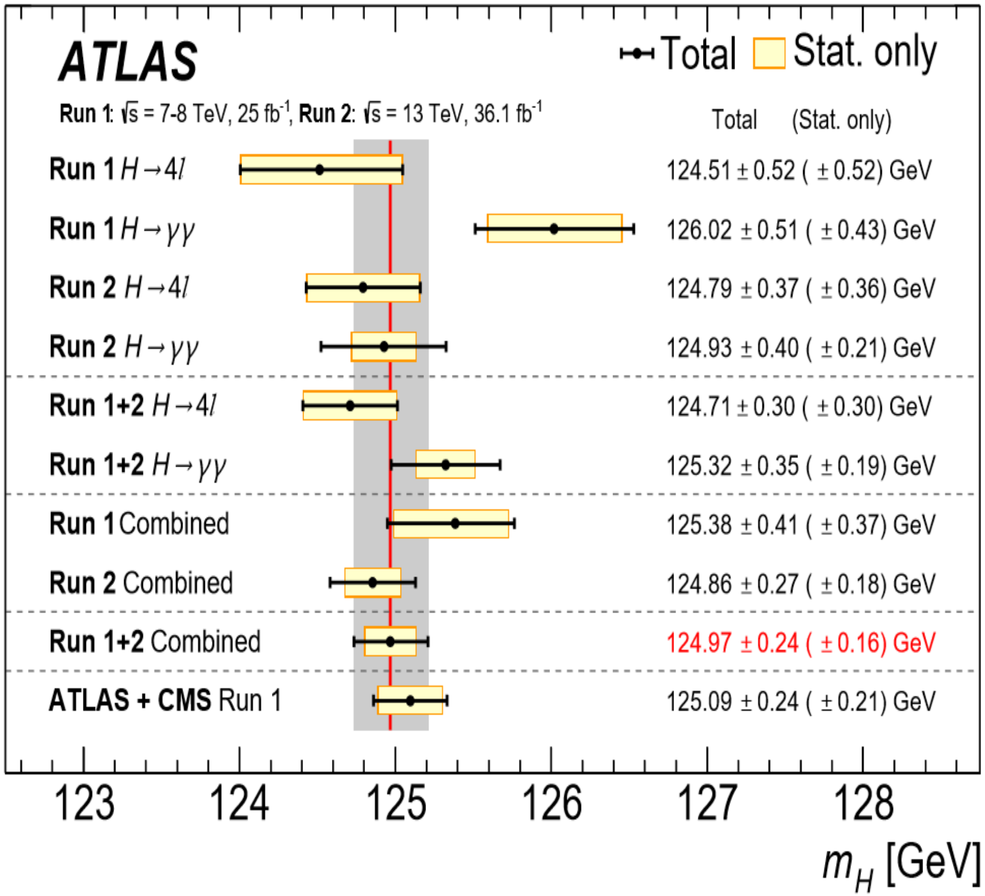
MSSM neutralino DM





爱恨交织





$$M_h \leq \min(M_A, M_Z)\cdot|\cos 2\beta| \leq M_Z$$

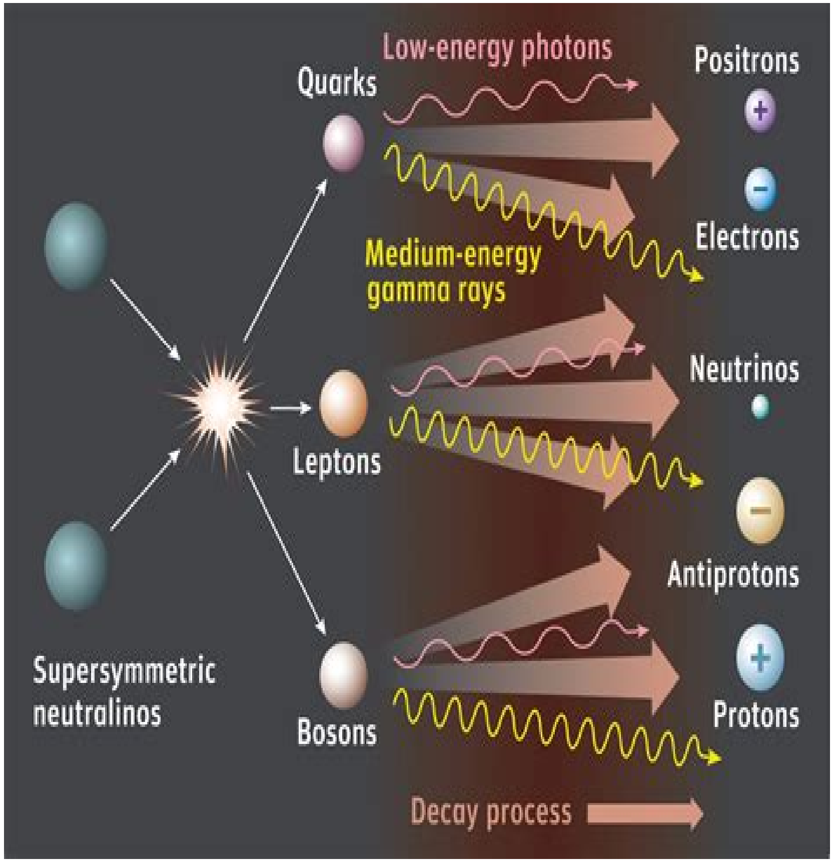
(tree level)

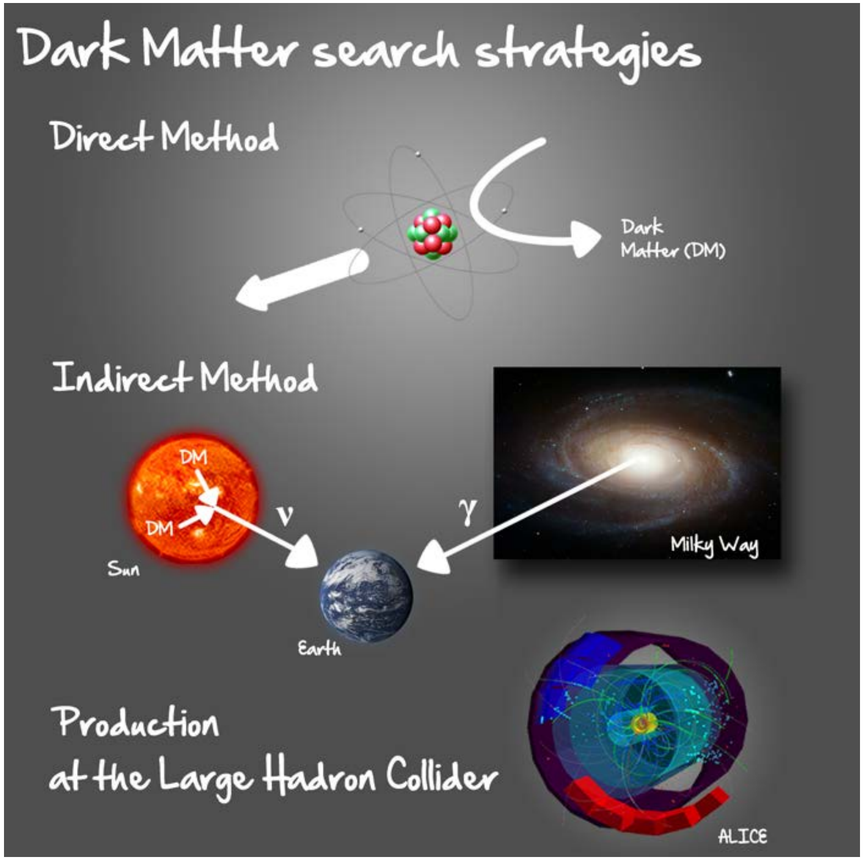
$$\Delta M_h^2 = \frac{3G_\mu}{\sqrt{2}\pi^2} m_t^4 \log\frac{M_S^2}{m_t^2}$$

(loop level)

$$M_h^{\max} \sim 140 \text{ GeV}$$

Dark Matter--- WIMP miracle





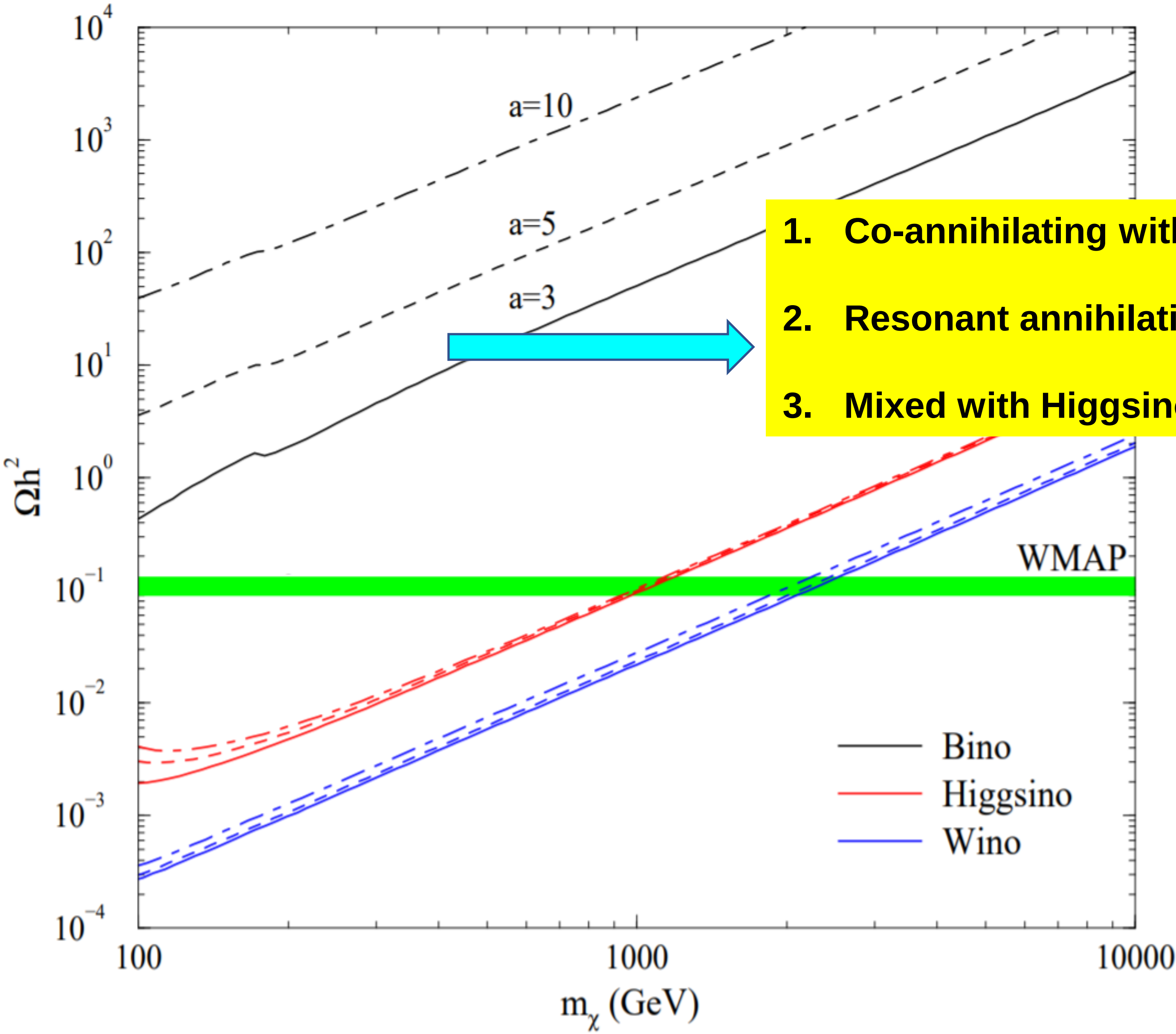
In the R-parity conserving MSSM, the lightest neutralino can play the role of DM,

$$\mathcal{M}_{\chi^0} = \begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ 0 & M_2 & m_Z c_W c_\beta & -m_Z c_W s_\beta \\ -m_Z s_W c_\beta & m_Z c_W c_\beta & 0 & -\mu \\ m_Z s_W s_\beta & -m_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

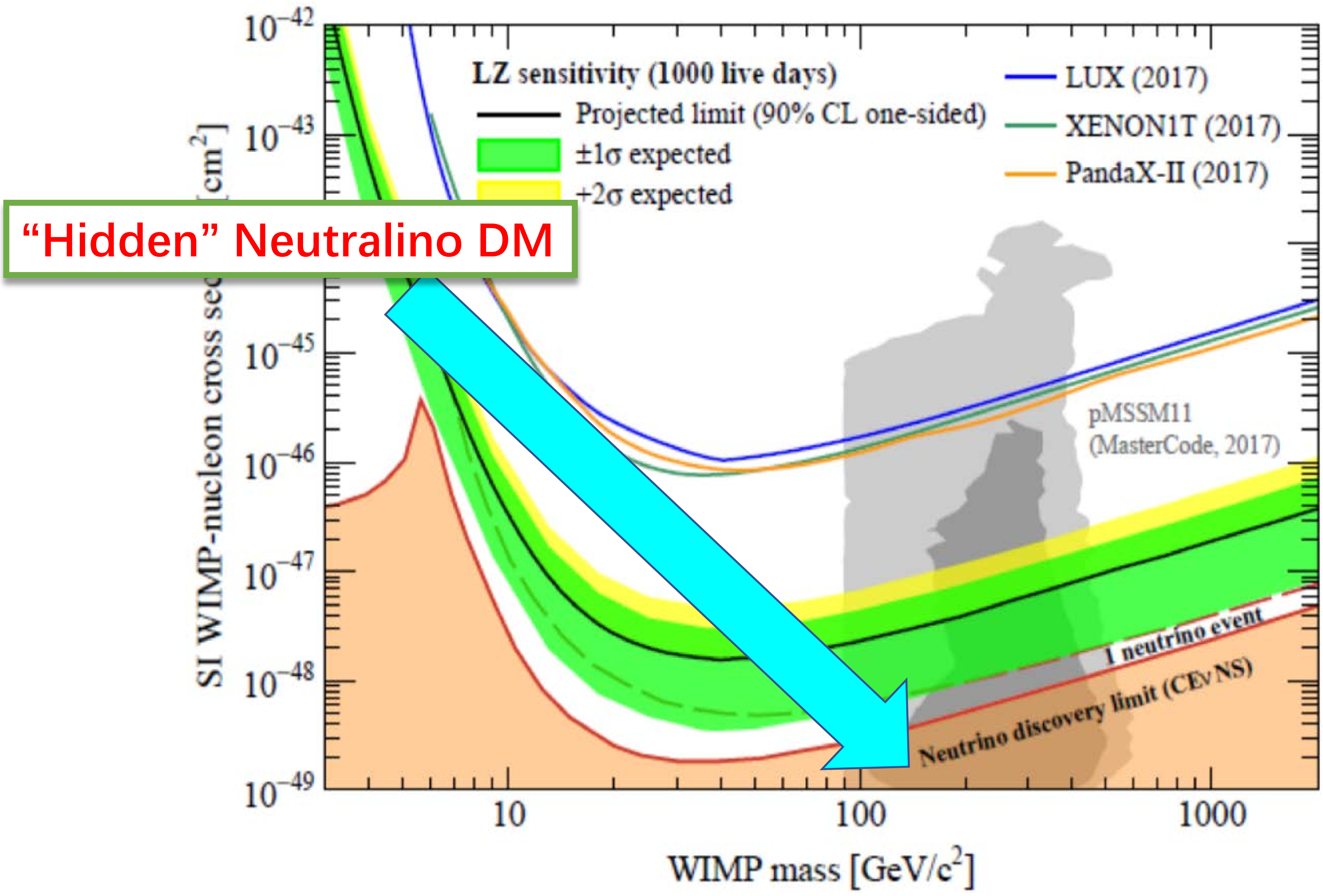
This mass matrix can be diagonalized by a unitary 4 × 4 matrices *N*,

$$\chi = N_{11}\tilde{B}^0 + N_{12}\tilde{W}^0 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

Bino-like	Wino-like	Higgsino-like	Mixed
$N_{11}^2 > \max\{N_{12}^2, N_{13}^2 + N_{14}^2\}$	$N_{12}^2 > \max\{N_{11}^2, N_{13}^2 + N_{14}^2\}$	$N_{13}^2 + N_{14}^2 > \max\{N_{11}^2, N_{12}^2\}$	$N_{11} \sim N_{12} \sim N_{13} \sim N_{14}$



1. **Co-annihilating with stop/stau/wino…**
2. **Resonant annihilation via Z, h, A, H**
3. **Mixed with Higgsinos(+Wino)**

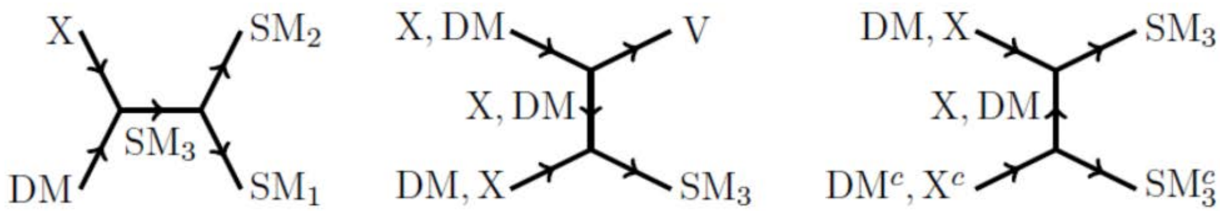


“Hidden” Neutralino DM
LZ sensitivity (1000 live days)
Projected limit (90% CL one-sided)
±1σ expected
+2σ expected
LUX (2017)
XENON1T (2017)
PandaX-II (2017)
pMSSM11
(MasterCode, 2017)
1 neutrino event
Neutrino discovery limit (CEνNS)
SI WIMP-nucleon cross section [cm²]
WIMP mass [GeV/c²]
10
100
1000

Can we escape direct detection bound?

1. Coannihilation,

[1804.05238, Duan, Ren, Hikasa, Wu, Yang]

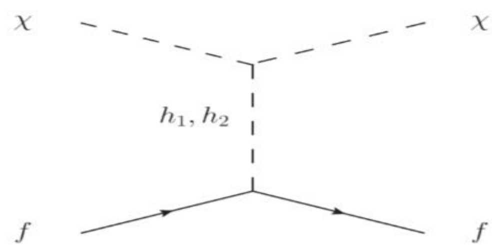


2. Cancelation (blind spot),

[1705.09164, Abdughani, Wu, Yang]

$$C_{h\tilde{\chi}_1^0\tilde{\chi}_1^0} \approx -\sqrt{2}g_1 N_{11}^2 \frac{M_Z s_W}{\mu} \frac{M_1/\mu + \sin 2\beta}{1-(M_1/\mu)^2}$$

or

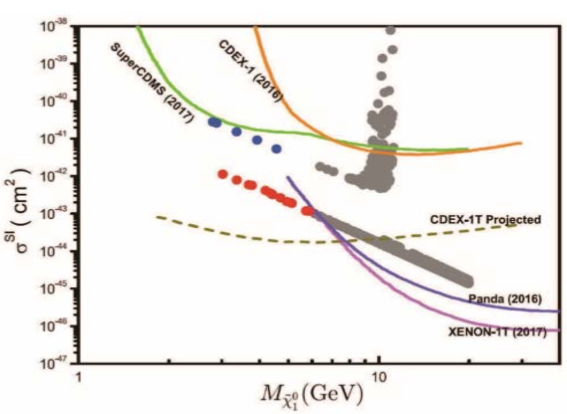


3. Light DM Limit (dark Higgs),

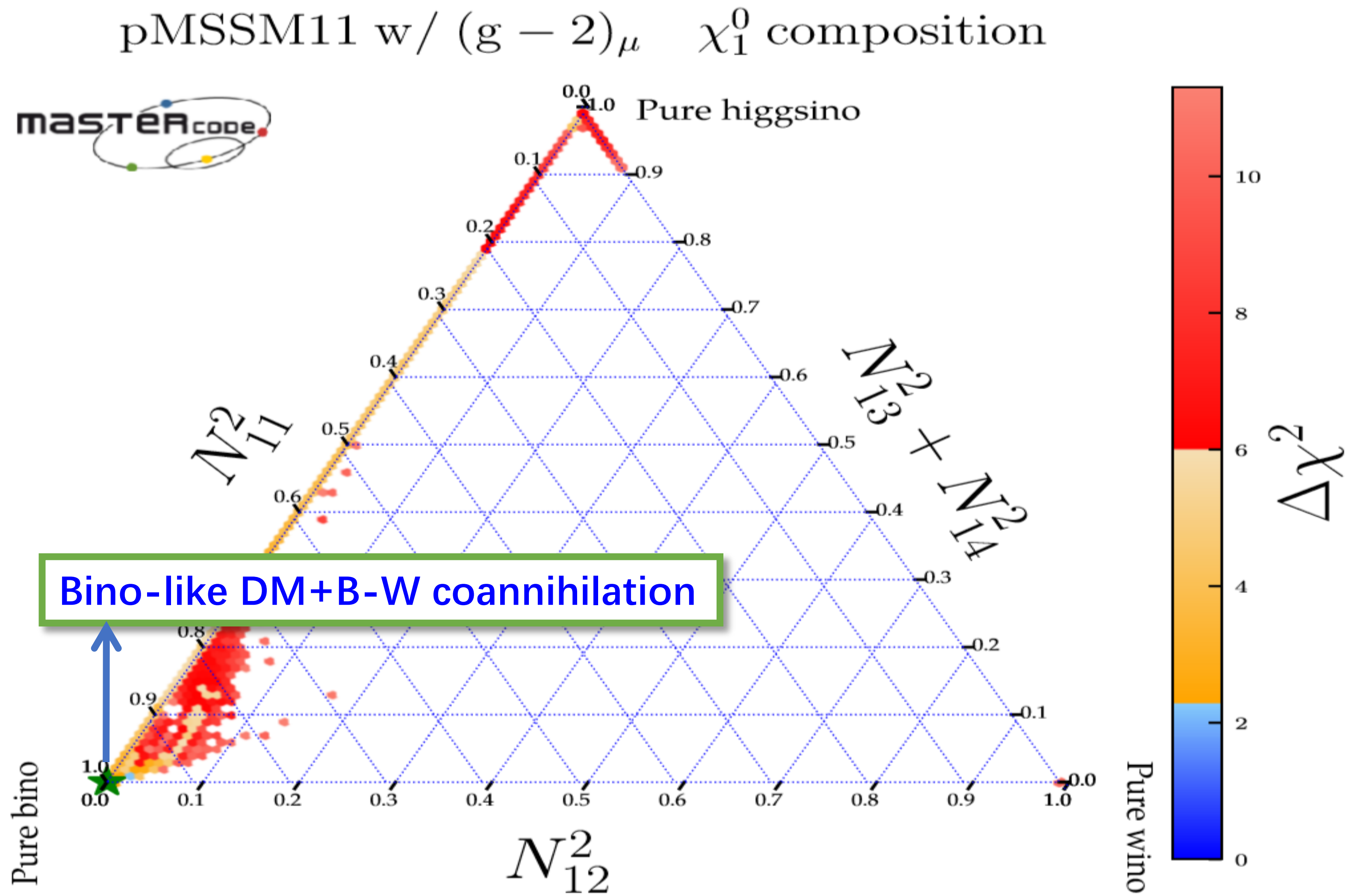
[1711.03893, Duan, Wang, Wu, Yang, Zhao]

$$\mathcal{M}^2 = \begin{pmatrix} Z_1 v^2 & Z_6 v^2 \\ Z_6 v^2 & M_A^2 + Z_5 v^2 \end{pmatrix}$$

Alignment limit without decoupling, $|Z_6| \ll 1$



(1). Bino-Wino coannihilation



B-W coannihilation can appear in e.g. Split SUSY, SUSY GUT models with NUGM, pMSSM11 w g-2.

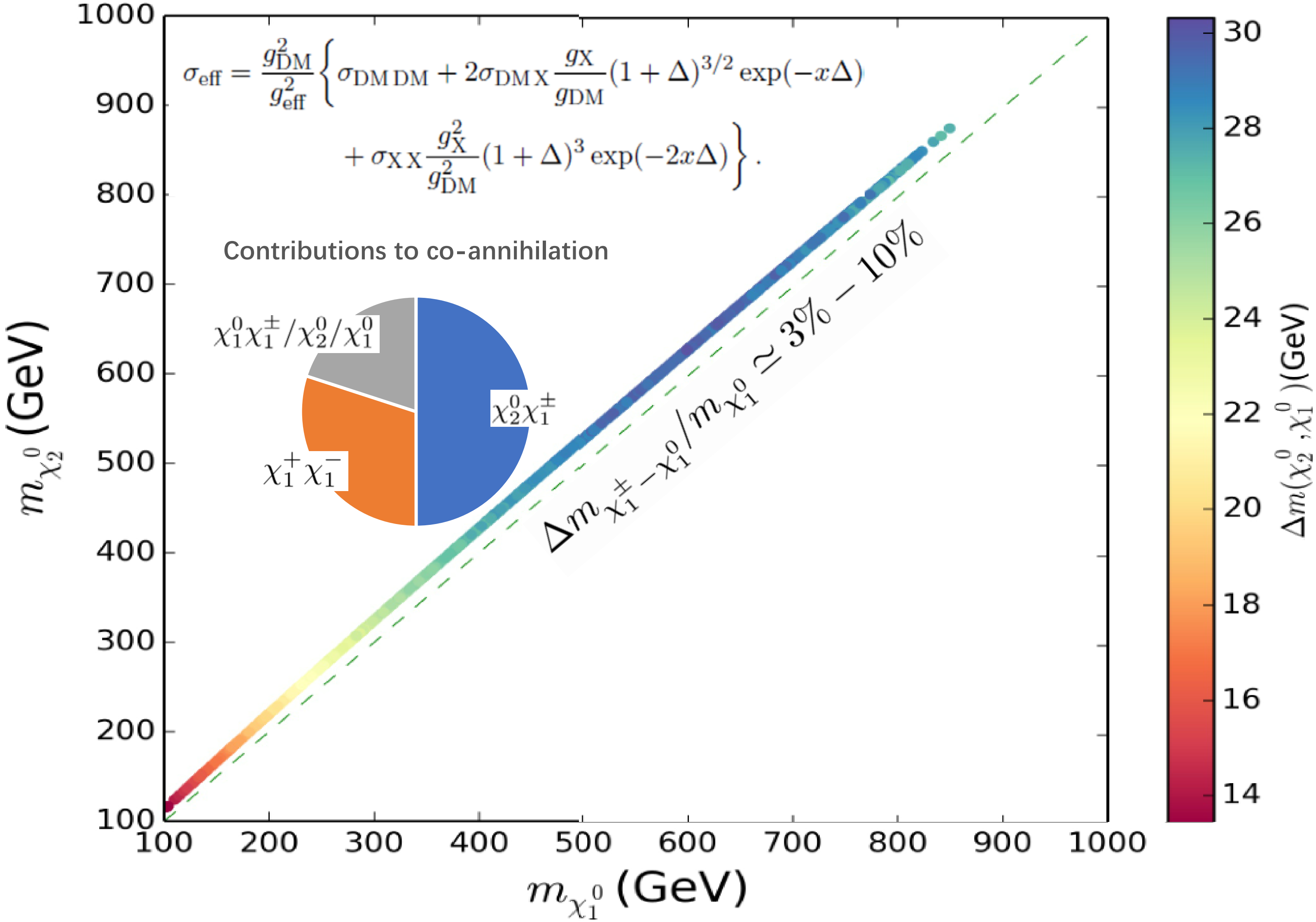
We scan over the relevant parameter space for the B-W coannihilation:

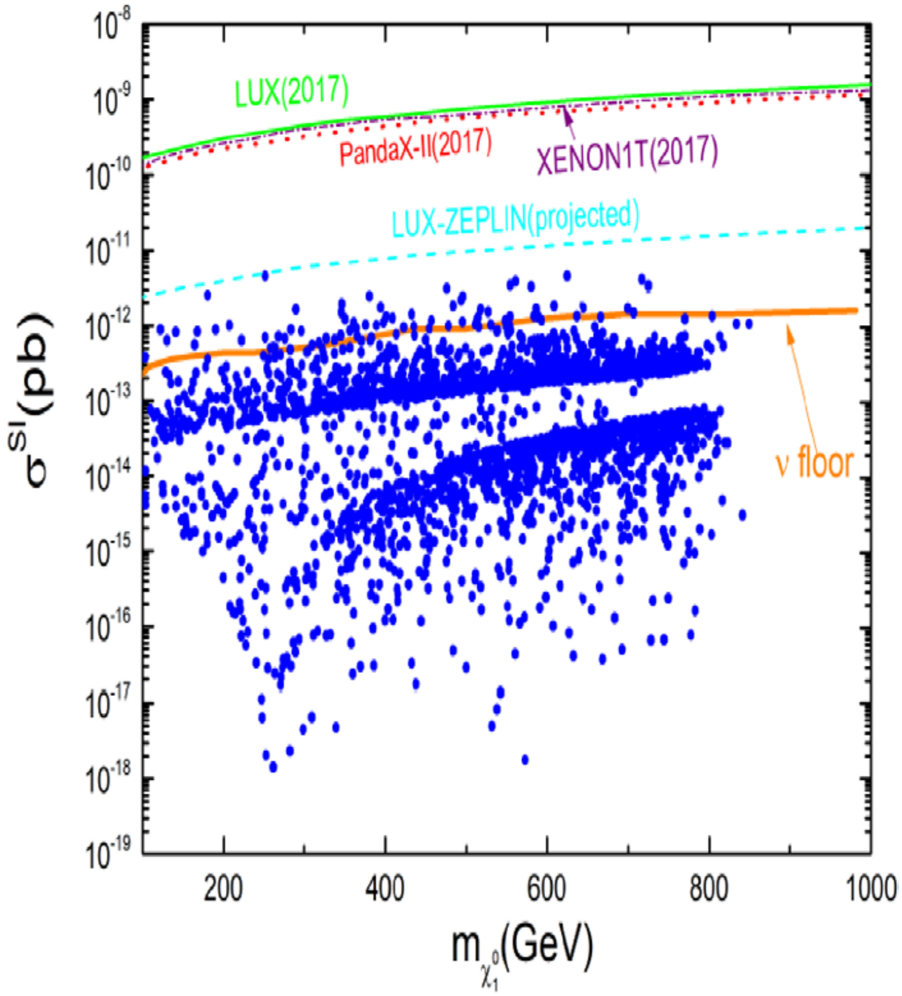
$$100 \text{ GeV} < |M_{1,2}| < 1 \text{ TeV}, \quad 1 < \tan\beta < 60.$$

and impose the constraints:

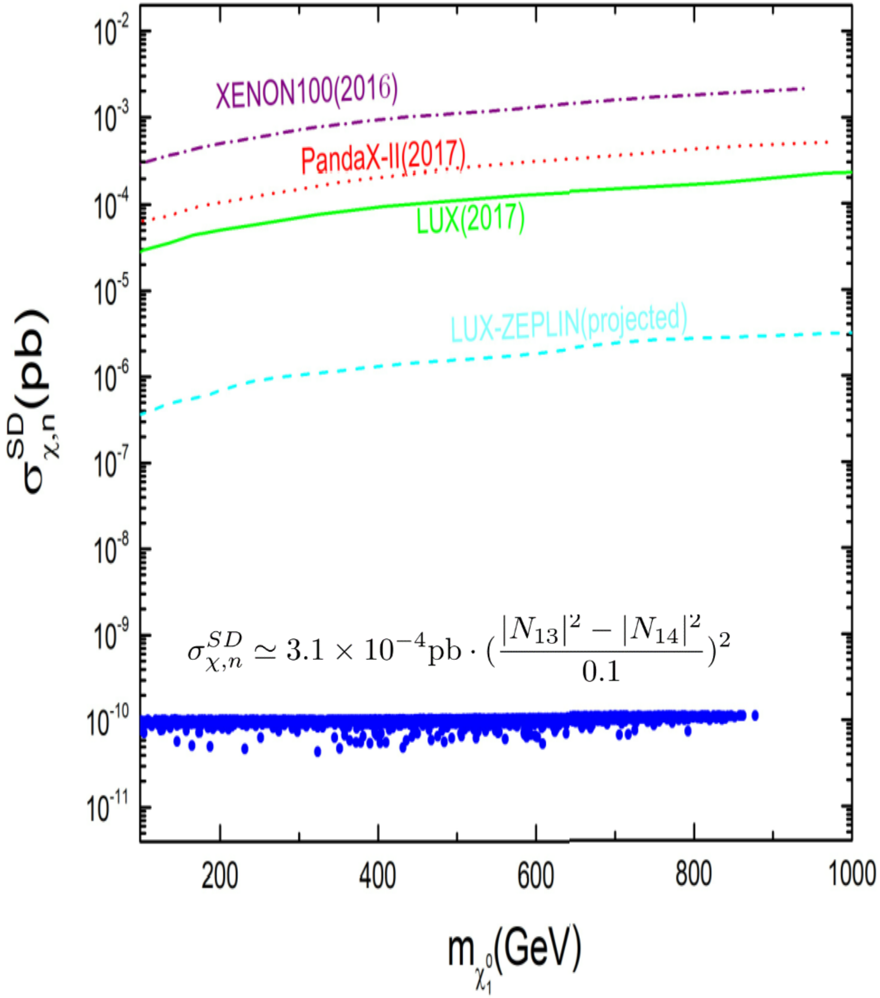
(1) The light CP-even Higgs boson mass should be within the range of 125 ± 3 GeV.

(2) The DM relic density should satisfy the observed value 0.1186 ± 0.0020 within 2σ range.

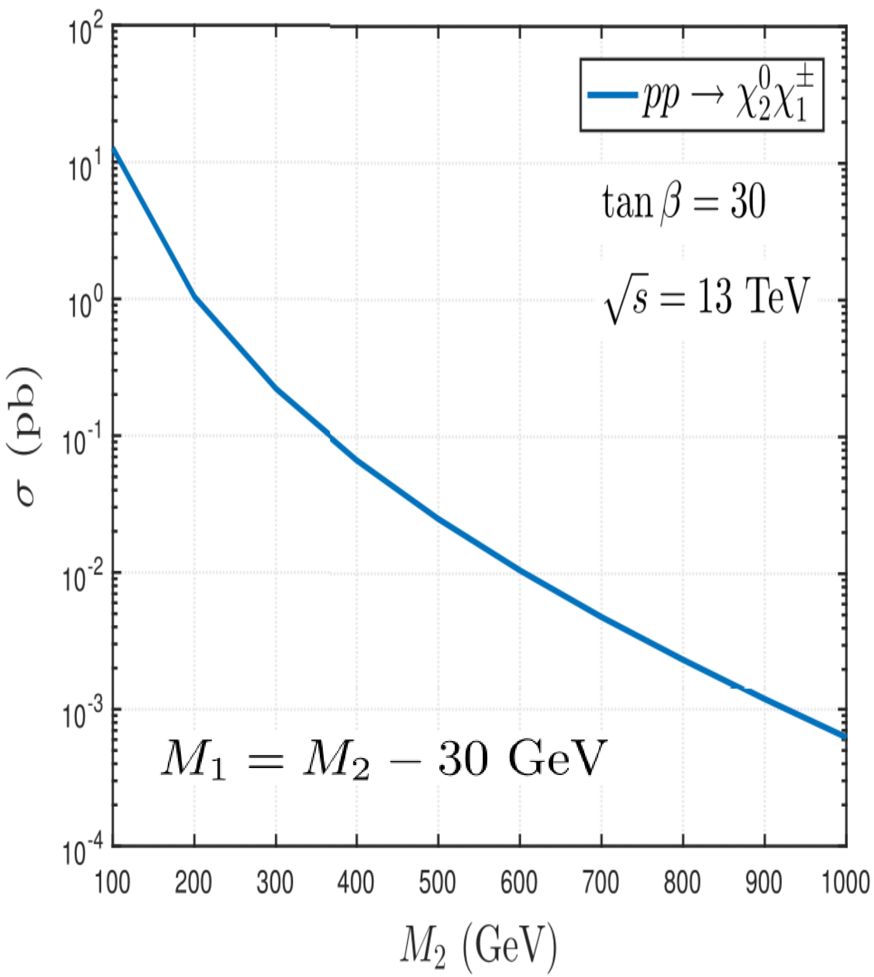

$\sigma_{\rm eff} = \frac{g_{\rm DM}^2}{g_{\rm eff}^2}\left\{\sigma_{\rm DM\,DM} + 2\sigma_{\rm DM\,X}\frac{g_{\rm X}}{g_{\rm DM}}(1+\Delta)^{3/2}\exp(-x\Delta) + \sigma_{\rm X\,X}\frac{g_{\rm X}^2}{g_{\rm DM}^2}(1+\Delta)^3\exp(-2x\Delta)\right\}.$
Contributions to co-annihilation
$\chi_1^0\chi_1^\pm/\chi_2^0/\chi_1^0$
$\chi_1^+\chi_1^-$
$\chi_2^0\chi_1^\pm$
$\Delta m_{\chi_1^\pm-\chi_1^0}/m_{\chi_1^0} \simeq 3\% - 10\%$
$m_{\chi_2^0}$ (GeV)
$m_{\chi_1^0}$ (GeV)
$\Delta m(\chi_2^0,\chi_1^0)$(GeV)
100
200
300
400
500
600
700
800
900
1000
14
16
18
20
22
24
26
28
30

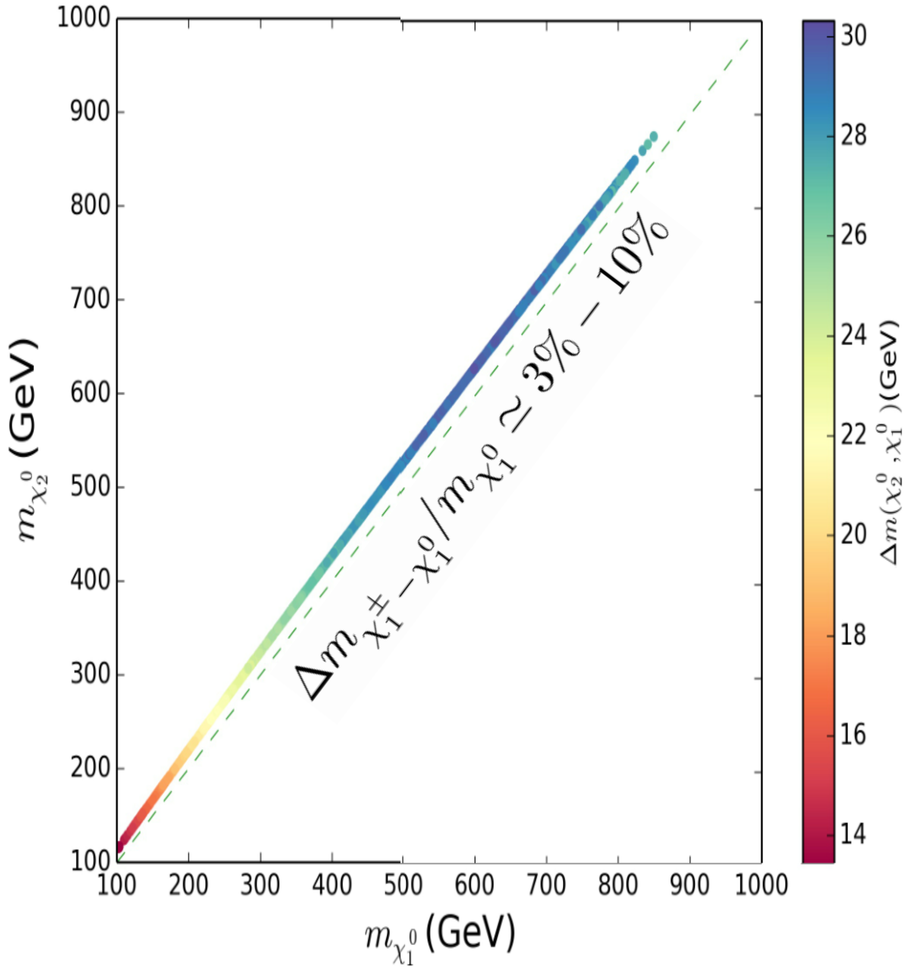


LUX(2017)
PandaX-II(2017)
XENON1T(2017)
LUX-ZEPLIN(projected)
ν floor
σ^{SI}(pb)
$m_{\chi_1^0}$(GeV)



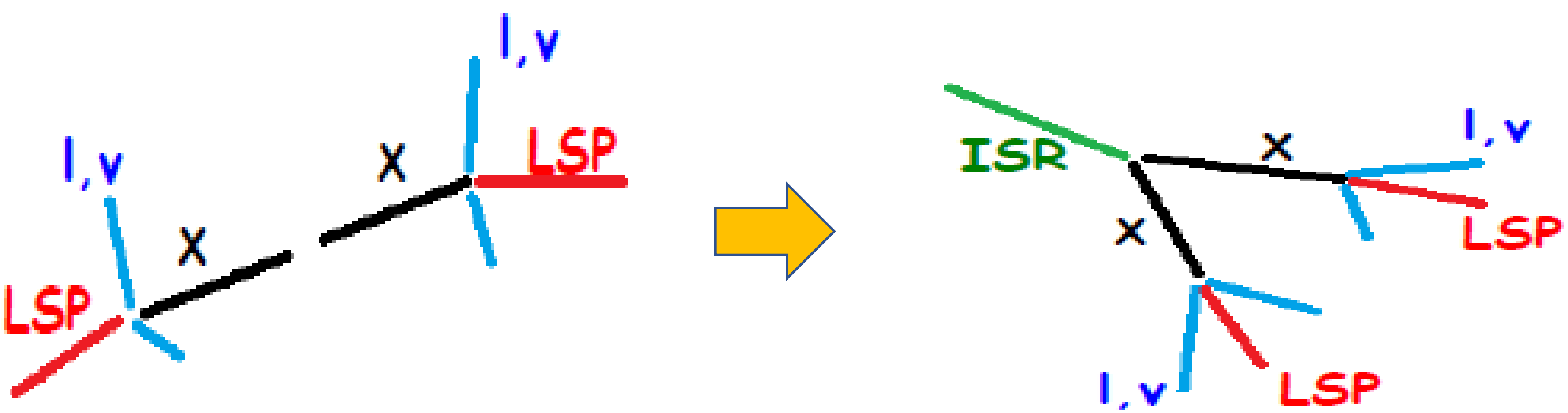
XENON100(2016)
PandaX-II(2017)
LUX(2017)
LUX-ZEPLIN(projected)
$\sigma^{SD}_{\chi,n} \simeq 3.1 \times 10^{-4}\text{pb} \cdot (\frac{|N_{13}|^2 - |N_{14}|^2}{0.1})^2$
$\sigma^{SD}_{\chi,n}$(pb)
$m_{\chi_1^0}$(GeV)


10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
σ (pb)
$pp \to \chi_2^0 \chi_1^\pm$
$\tan\beta = 30$
$\sqrt{s} = 13$ TeV
$M_1 = M_2 - 30$ GeV
100 200 300 400 500 600 700 800 900 1000
M_2 (GeV)


1000
900
800
700
600
500
400
300
200
100
$m_{\chi_2^0}$ (GeV)
$\Delta m_{\chi_1^\pm - \chi_1^0}/m_{\chi_1^0} \simeq 3\% - 10\%$
100 200 300 400 500 600 700 800 900 1000
$m_{\chi_1^0}$ (GeV)
30
28
26
24
22
20
18
16
14
$\Delta m(\chi_2^0, \chi_1^0)$(GeV)

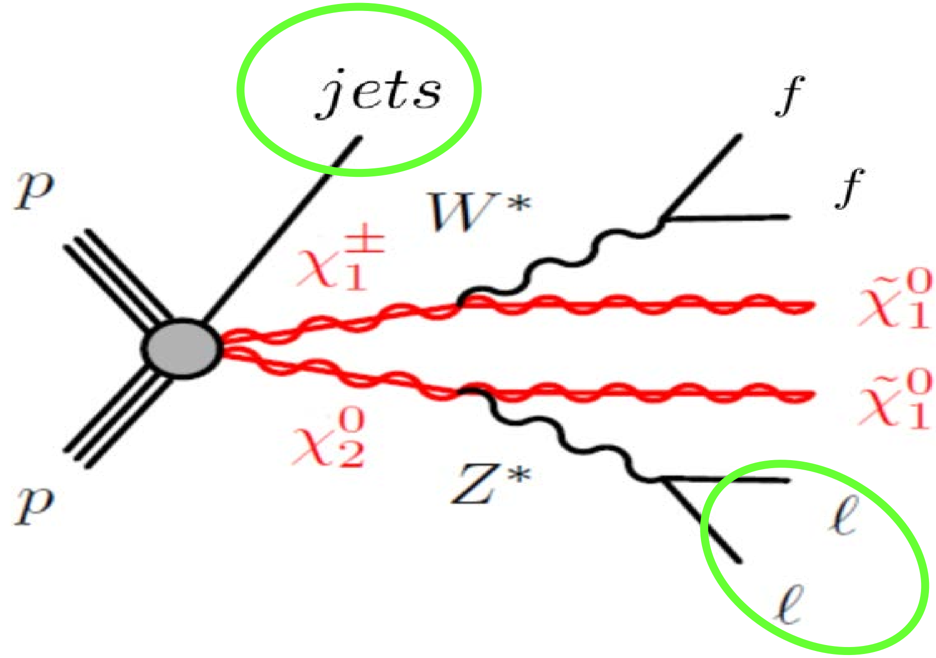
For small-splitting region, visible particles are soft and LSPs are back-to-back causing small MET.

ISR jet can boost the electrowinos X, making MET become larger as LSPs align.



Mono-jet

Monojet-like



1. There is no upper limit on the number of jets in our analysis. Instead jet veto, a cut on $m_T(\ell_i, \not{E}_T) < 70$ GeV can also remove $t\bar{t}$ background events efficiently but do not hurt the signal too much.

2. A soft lepton pair in the final states can help to suppress Dell-Yan and V+jets backgrounds.

The main SM backgrounds for our signal are events from,

- Drell-Yan (DY) processes with subsequent decays $\gamma/Z^* \to \tau^+\tau^- \to \ell^+\ell^-\nu_\ell\bar{\nu}_\ell\nu_\tau\bar{\nu}_\tau$;
- Leptonic $t\bar{t}$ decays;
- Diboson (VV) processes like W^+W^- and single top production like tW;
- Non-prompt leptons can also mimic our signal, which mainly arise from $W+j$ events.

  fake rate is quoted as $\mathcal{O}((0.6\text{–}3)\times 10^{-5})$

The following cuts are applied to differentiate signal from backgrounds:

- A large missing transverse energy $\not{E}_T > 125$ GeV is required.
- At least one jet but a veto on events with $p_T(b) > 25$ GeV is imposed to reduce the $t\bar{t}$ background.
- A pair of opposite-sign same-flavor (OSSF) leptons are required. Two leptons should have a small transverse momentum 5 GeV $< p_T(\ell_{1,2}) <$ 30 GeV.
- The invariant mass of the two leptons is required in the range 4 GeV $< m_{\ell\ell} <$ 50 GeV but $m_{\ell\ell} \notin [9, 10.5]$ GeV, which can reduce the diboson background and the potential soft lepton events from Drell-Yan and J/ψ and Υ decays.
- The transverse mass $m_T(\ell_i, \not{E}_T) < 70$ GeV is used to further suppress $t\bar{t}$ backgrounds.

- The invariant mass $m_{\tau\tau} \notin [0, 160]$ GeV. The $\gamma^*/Z \to \tau^+\tau^-$ backgrounds will have a narrow peak around m_Z in $m_{\tau\tau}$ distribution, while the signal will be featureless.

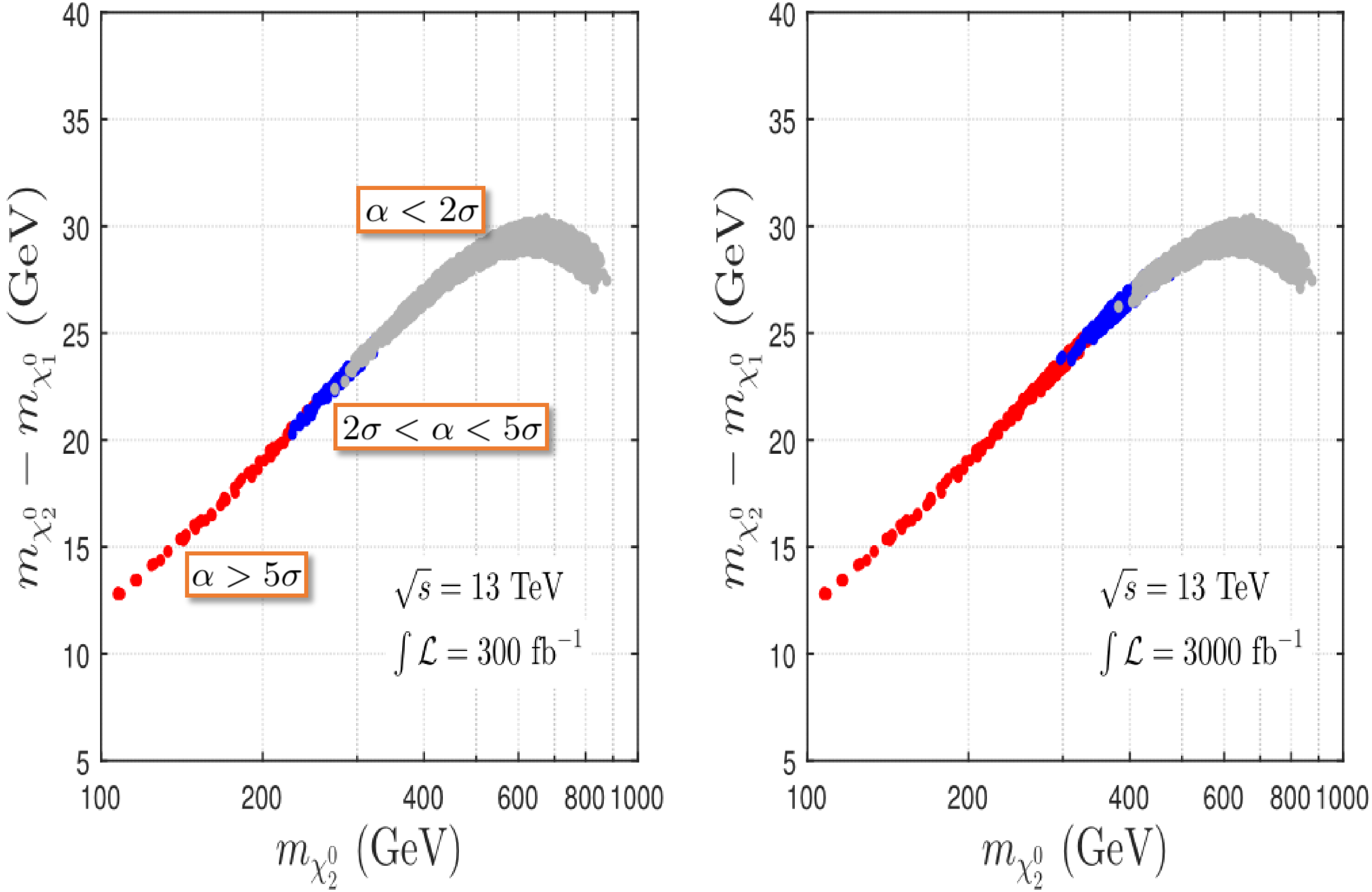
- The transverse hadronic energy $H_T > 100$ GeV, which is defined as the scalar sum of the transverse momenta of the selected jets.

- The QCD multijet background can be efficiently suppressed by the requirement of large $\not{E}_T$ and two leptons. Besides, we apply a cut $0.6 < \not{E}_T/H_T < 1.4$ to reject the residual QCD multijet events.

TABLE I. The cut flow for the cross sections of the signal and backgrounds at the 13 TeV LHC before using the signal regions. The benchmark point is $m_{\chi_1^0} = 137.1$ GeV, $m_{\chi_2^0} = m_{\chi_1^\pm} = 153.3$ GeV, $\tan\beta = 34$. The cross sections are in unit of fb.

	Backgrounds			Signal
Cuts	$t\bar{t}$	Drell-Yan	diboson	$\chi_2^0\chi_1^\pm$
$\not{E}_T > 125$ GeV	45108.12	1636.39	2664.94	662.84
$N(j) > 0$, $N(b) = 0$	8776.16	1309.35	1903.41	528.24
$N(\ell) = 2$, OSSF, $p_T(\ell_{1,2}) \in [5, 30]$ GeV	57.45	31.45	5.77	5.45
$m_{\ell\ell} \in [4, 50]$ GeV, $m_{\ell\ell} \notin [9, 10.5]$ GeV	44.62	29.34	4.43	4.35
$H_T > 100$ GeV, $\not{E}_T/H_T \in [0.6, 1.4]$	28.14	23.47	3.32	3.59
$M_T(l, \not{E}_T) < 70$ GeV	8.83	21.57	0.98	2.77
$M_{\tau\tau} \notin [0, 160]$ GeV	6.12	7.21	0.75	2.123

After the above selections, we seperate the signal events into three regions: $\not{E}_T \in [125, 200]$ GeV, $\not{E}_T \in [200, 250]$ GeV, $\not{E}_T > 250$ GeV. In each $\not{E}_T$ bin, we further define four signal regions $m_{\ell\ell} = [4, 10], [10, 20], [20, 30], [30, 50]$ GeV to enhance the sensitivity.



$\alpha < 2\sigma$
$2\sigma < \alpha < 5\sigma$
$\alpha > 5\sigma$
$\sqrt{s} = 13$ TeV
$\int \mathcal{L} = 300\ \mathrm{fb}^{-1}$
$\sqrt{s} = 13$ TeV
$\int \mathcal{L} = 3000\ \mathrm{fb}^{-1}$
$m_{\chi_2^0} - m_{\chi_1^0}$ (GeV)
$m_{\chi_2^0}$ (GeV)

(2). Bino-Higgsino blind spot

- Naturalness: minimization condition from Higgs scalar potential, which determines the **Z-boson mass**. (Alternatively, one may examine **Higgs boson mass** and arrive at similar conclusions.)

$$\frac{M_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

To obtain a natural value of M_Z on the left-hand side, one would like each term C_i (with $i = H_u, H_d, \mu, \Sigma_u^u(k), \Sigma_d^d(k)$) on the right-hand side to have an absolute value of order $M_Z^2/2$.

Tree level

1 loop level

$$m_Z^2 = -2(m_{H_u}^2 + |\mu|^2) + \dots$$

$$\delta m_{H_u}^2 \approx -\frac{3y_t^2 m_{\tilde{t}}^2}{4\pi^2}(1 + a^2/2)\log\frac{\Lambda}{m_{\tilde{t}}}$$

$$\delta m_{\tilde{t}}^2 = \frac{8\alpha_s}{3\pi} M_3^2 \log\frac{\Lambda}{M_3}$$

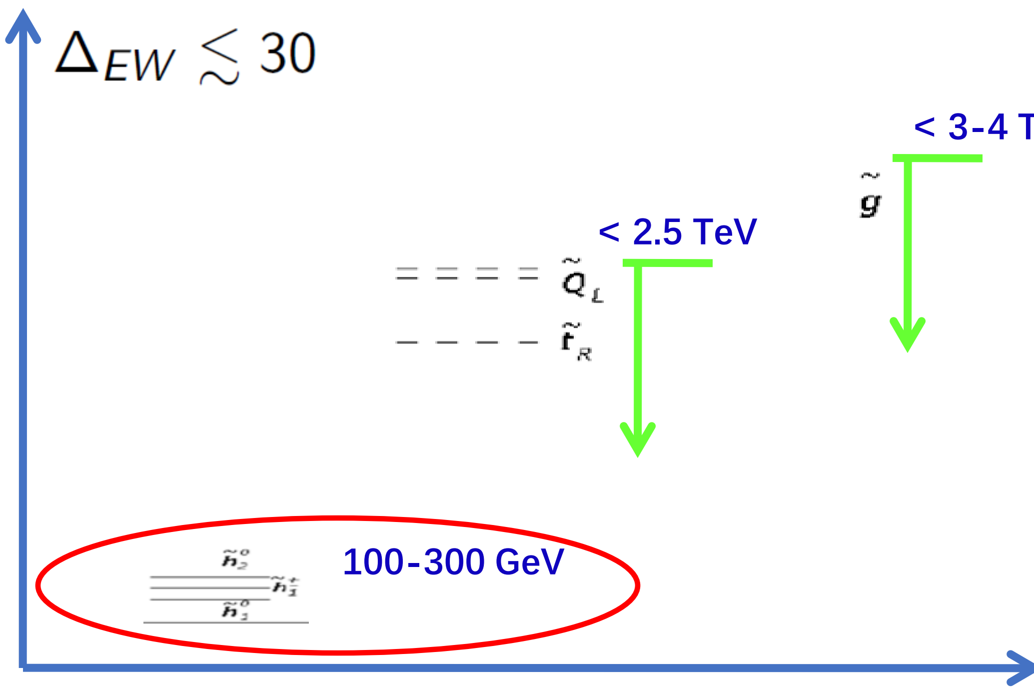
2 loop level

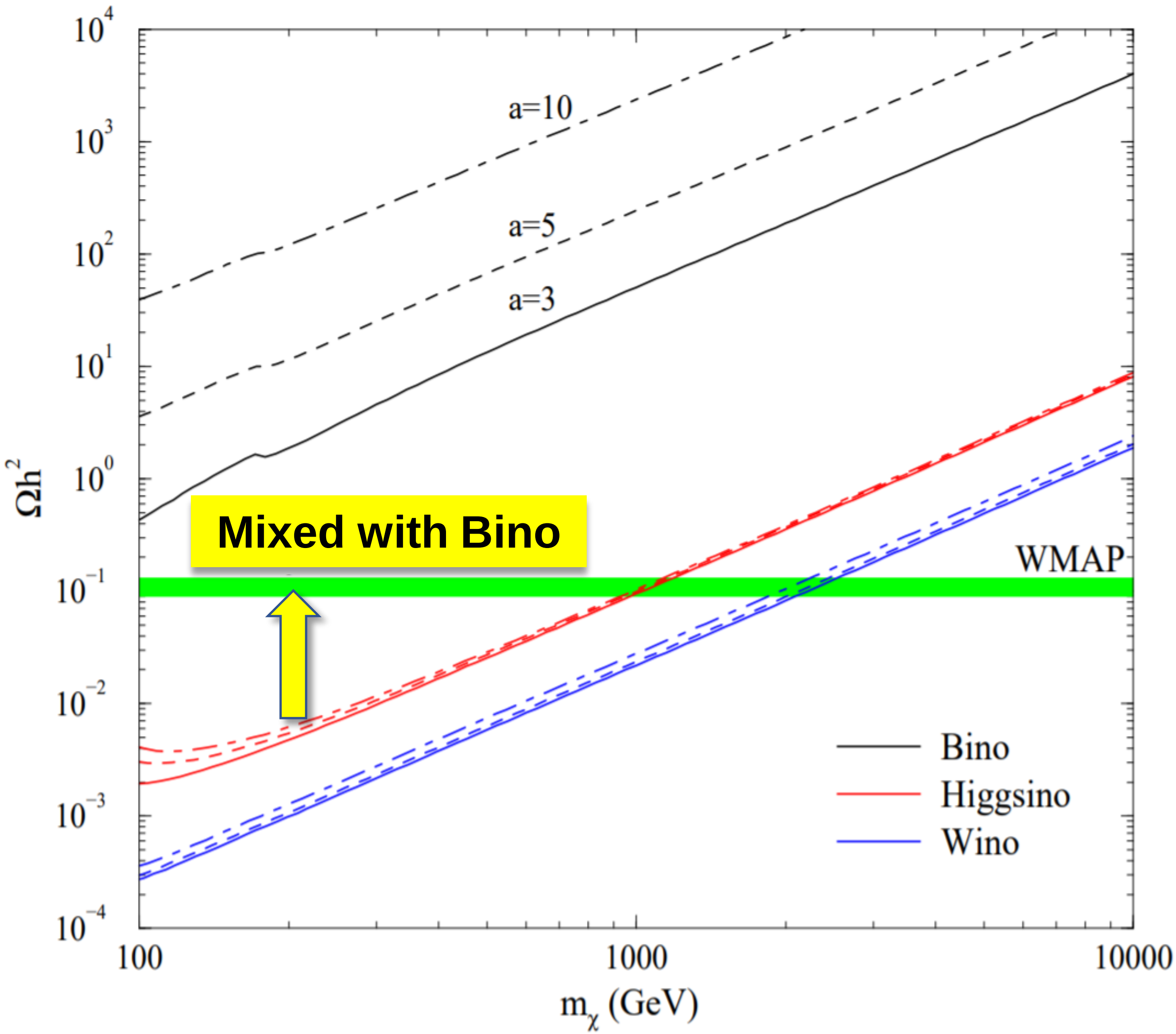
Note: a heavy stop and gluino, can still produce an acceptable finetuning in minimal framework, such as Focus Point, RNS and NUGM…

The most robust test of naturalness is to search for light Higgsinos!

$$\Delta_{EW} \equiv max(C_i)/(M_Z^2/2).$$

Note that Δ_{EW} depends only on the weak scale parameters of the theory and hence is essentially fixed by the particle spectrum, independent of how superpartner masses arise[5].



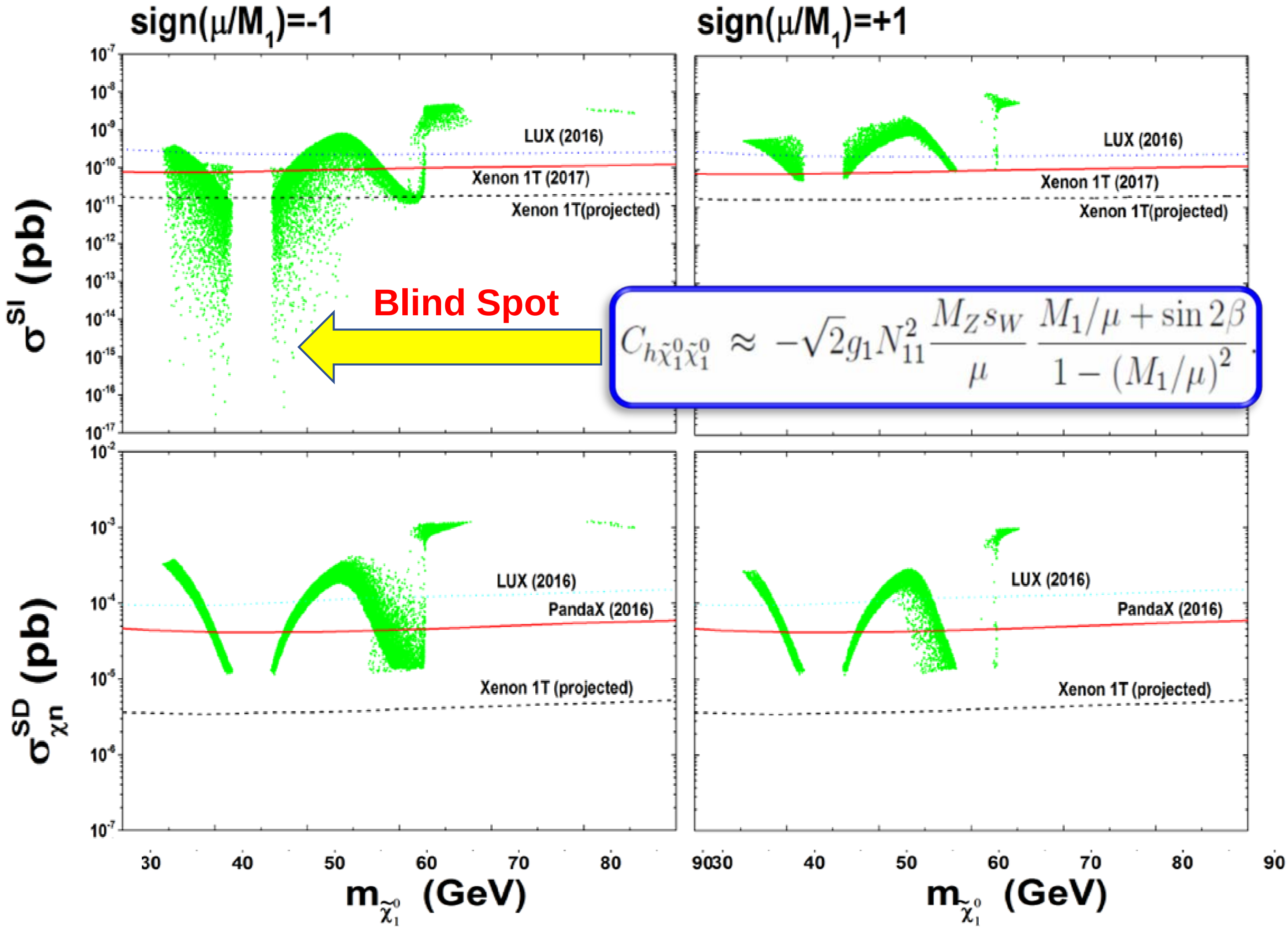

a=10
a=5
a=3
Mixed with Bino
WMAP
Bino
Higgsino
Wino
Ωh^2
m_χ (GeV)
100
1000
10000
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}

Scan ranges of Bino-Higgsino:

$$100\ \text{GeV} \leq |\mu| \leq 300\ \text{GeV},\ \ 30\ \text{GeV} \leq |M_1| \leq 100\ \text{GeV},\ \ 10 \leq tan\beta \leq 50.$$

Constraints:

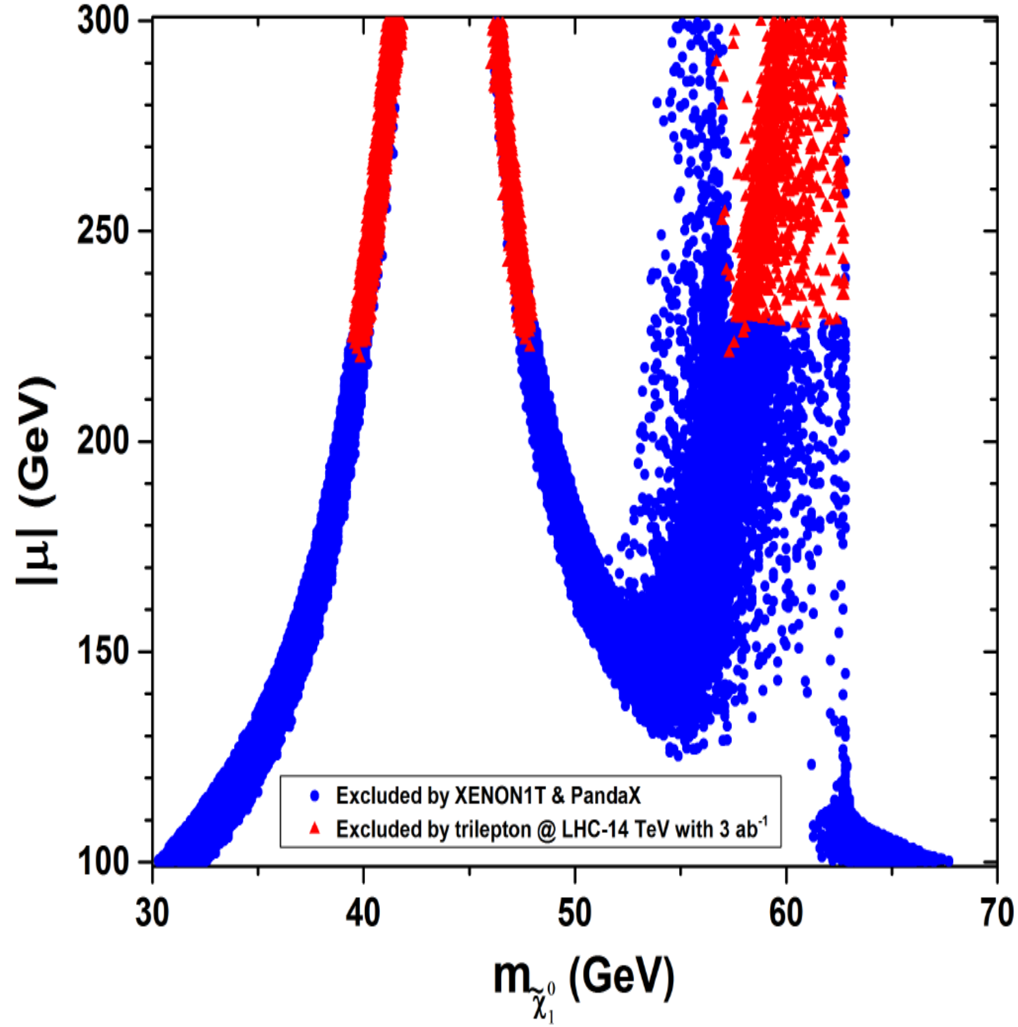
- Light CP-even Higgs boson masses should be within the range of 122–128 GeV.
- Samples have to be consistent with the Higgs data from LEP, Tevatron and LHC.
- Relic density of neutralino dark matter $\Omega_{\tilde{\chi}} h^2$ within 2σ range of 0.1186 ± 0.0020.
- Higgs invisible decay $Br(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) < 24\%$
- Invisible width of the Z boson is required less than 0.5 MeV to satisfy LEP limit.
- LEP upper limit, $\sigma(e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_{2,3}^0 \times Br(\tilde{\chi}_{2,3}^0 \to \tilde{\chi}_1^0 Z^*) < 100$ fb.



$$C_{h\tilde{\chi}_1^0\tilde{\chi}_1^0} \approx -\sqrt{2} g_1 N_{11}^2 \frac{M_Z s_W}{\mu} \frac{M_1/\mu + \sin 2\beta}{1-(M_1/\mu)^2}$$

exclude the higgsino mass $|\mu|$ and the LSP mass $m_{\tilde{\chi}_1^0}$ up to about 230 GeV and 37 GeV

Final states	Source of signal in our scenario
$3\text{lepton} + \not{E}_T$ [74]	$pp \to \tilde{\chi}_1^{\pm}(\to W^{\pm}\tilde{\chi}_1^0)\tilde{\chi}_{2,3}^0(\to Z\tilde{\chi}_1^0)$
$1\text{lepton} + h + \not{E}_T$ [75]	$pp \to \tilde{\chi}_1^{\pm}(\to W^{\pm}\tilde{\chi}_1^0)\tilde{\chi}_{2,3}^0(\to h\tilde{\chi}_1^0)$
$\ell^+\ell^- + \not{E}_T$ [76]	$pp \to \tilde{\chi}_1^+\tilde{\chi}_1^-$

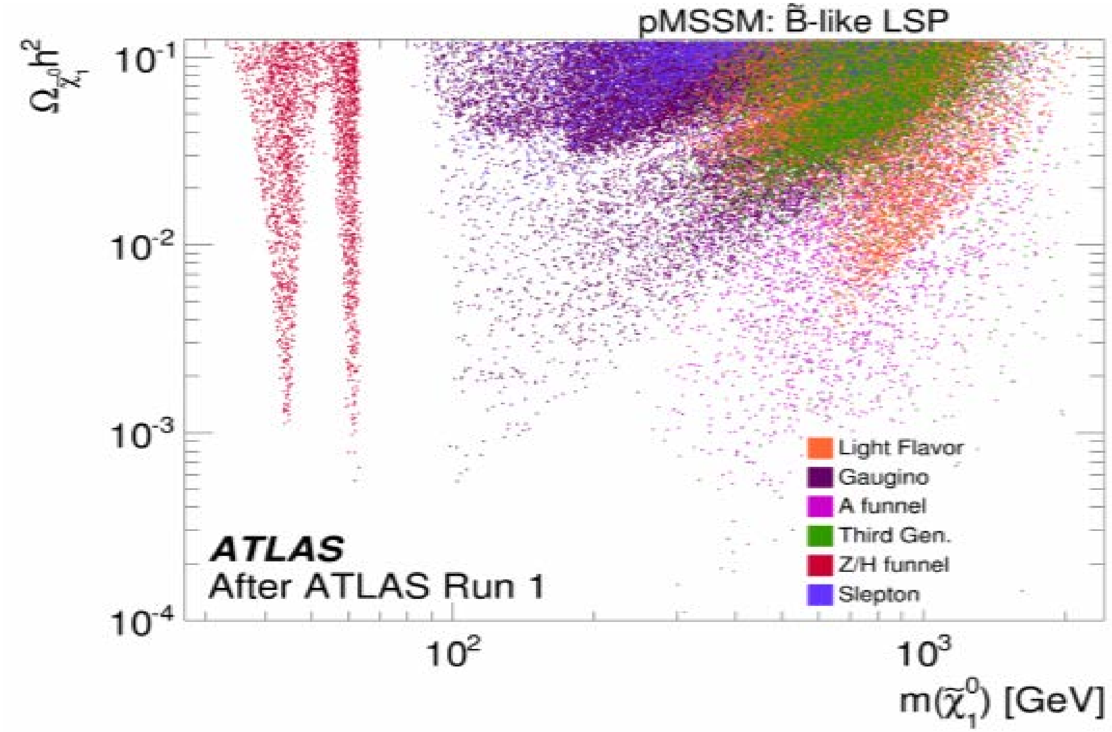


Current surviving parameter space will be fully covered by projected XENON1T experiment or the future trilepton searches at the HL-LHC.

(3). Dark Higgs in alignment limit

- Can Heavy CP-even Higgs (H) be SM-like?

- Can DM be light? — LHC and direct detection data (>30 GeV, h~125 GeV)
  — Relic density



Higgs basis

The tree-level Higgs potential is given by

$$V = (|\mu|^2 + m_{H_u}^2)|H_u|^2 + (|\mu|^2 + m_{H_d}^2)|H_d|^2 - B\mu(\epsilon_{\alpha\beta} H_u^\alpha H_d^\beta + h.c.) + \frac{g^2 + g'^2}{8}(|H_u|^2 - |H_d|^2)^2 + \frac{g^2}{2}|H_u^\dagger H_d|^2 \,,$$

we use the Higgs basis (H_1, H_2) defined as

$$H_1 = \begin{pmatrix} H_1^+ \\ H_1^0 \end{pmatrix} \equiv \frac{v_1\Phi_1 + v_2\Phi_2}{v}, \qquad H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} \equiv \frac{-v_2\Phi_1 + v_1\Phi_2}{v}$$

with

$$(\Phi_1)^i = \epsilon_{ij}(H_d^*)^j \,, \qquad (\Phi_2)^i = (H_u)^i \,,$$

It can be seen that $\langle H_1^0 \rangle = v/\sqrt{2}$ and $\langle H_2^0 \rangle = 0$.

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} c_{\beta-\alpha} & -s_{\beta-\alpha} \\ s_{\beta-\alpha} & c_{\beta-\alpha} \end{pmatrix} \begin{pmatrix} \sqrt{2}\,\mathrm{Re}\, H_1^0 - v \\ \sqrt{2}\,\mathrm{Re}\, H_2^0 \end{pmatrix}$$

SM-like Higgs should align with $\sqrt{2}\,\mathrm{Re}\, H_1^0 - v$

Alignment limit

In terms of the Higgs basis fields, we can rewrite the Higgs potential ,

$$V = \ldots + \frac{1}{2} Z_1 (H_1^\dagger H_1)^2 + \ldots + [\frac{1}{2} Z_5 (H_1^\dagger H_2)^2 + Z_6 (H_1^\dagger H_1)(H_1^\dagger H_2) + \text{h.c.}] + \ldots ,$$

At tree-level, the above quartic couplings Z_1, Z_5 and Z_6 are given by,

$$Z_1 = \tfrac{1}{4}(g^2 + g'^2) c_{2\beta}^2 , \qquad Z_5 = \tfrac{1}{4}(g^2 + g'^2) s_{2\beta}^2 , \qquad Z_6 = -\tfrac{1}{4}(g^2 + g'^2) s_{2\beta} c_{2\beta} .$$

where $c_{2\beta} \equiv \cos 2\beta$ and $s_{2\beta} \equiv \sin 2\beta$. Then, we can compute the squared-mass matrix of the neutral CP-even Higgs bosons, with respect to the neutral Higgs states, $\{\sqrt{2}\,\text{Re}\, H_1^0 - v\, , \sqrt{2}\,\text{Re}\, H_2^0\}$

$$\mathcal{M}^2 = \begin{pmatrix} Z_1 v^2 & Z_6 v^2 \\ Z_6 v^2 & M_A^2 + Z_5 v^2 \end{pmatrix} .$$

1. *Decoupling limit*, $M_A^2 + Z_5 v^2 \gg Z_1 v^2$. In this case h is SM-like and $M_A \sim M_H \sim M_{H^\pm} \gg M_h$.

2. *Alignment limit without decoupling*, $|Z_6| \ll 1$. In this case h is SM-like if $(M_A^2 + Z_5 v^2) > Z_1 v^2$ and H is SM-like if $M_A^2 + Z_5 v^2 < Z_1 v^2$. The latter case necessarily corresponds to this alignment limit.

Condition: accidental cancellation

It should be noted that the exact alignment without decoupling, $Z_6 = 0$, trivially occurs when $\beta = 0$ or $\pi/2$ (corresponding to the vanishing of either v_1 or v_2). However, this will lead to a massless b quark ($m_b = y_b v c_\beta/\sqrt{2}$) or t quark ($m_t = y_t v s_\beta/\sqrt{2}$), respectively, at tree-level. Therefore, the MSSM Higgs alignment $Z_6 = 0$ can only happen through an accidental cancellation of the tree-level terms with contributions arising at the one-loop level (or higher). In the limit $M_{Z,A} \ll M_S$, the leading one-loop correction to Z_6 is given by:

$$Z_6 v^2 = -s_{2\beta}\left\{M_Z^2 c_{2\beta} - \frac{3m_t^4}{4\pi^2 v^2 s_\beta^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t(X_t+Y_t)}{2M_S^2} - \frac{X_t^3 Y_t}{12 M_S^4}\right]\right\},$$

Since the Higgs alignment is independent of M_A^2, Z_1 and Z_5, the lighter CP-even Higgs boson h can be light if the heavy Higgs boson H is interpreted as the SM-like Higgs boson. The appearance of light Higgs boson h will enrich MSSM dark matter phenomenology.

Scan ranges and Constraints:

$$2\ \mathrm{GeV} \leq M_1 \leq 20\ \mathrm{GeV}, \quad 2\ \mathrm{TeV} \leq \mu \leq 10\ \mathrm{TeV}, \quad -3\ \mathrm{TeV} \leq A_{t=b} \leq 3\ \mathrm{TeV}$$

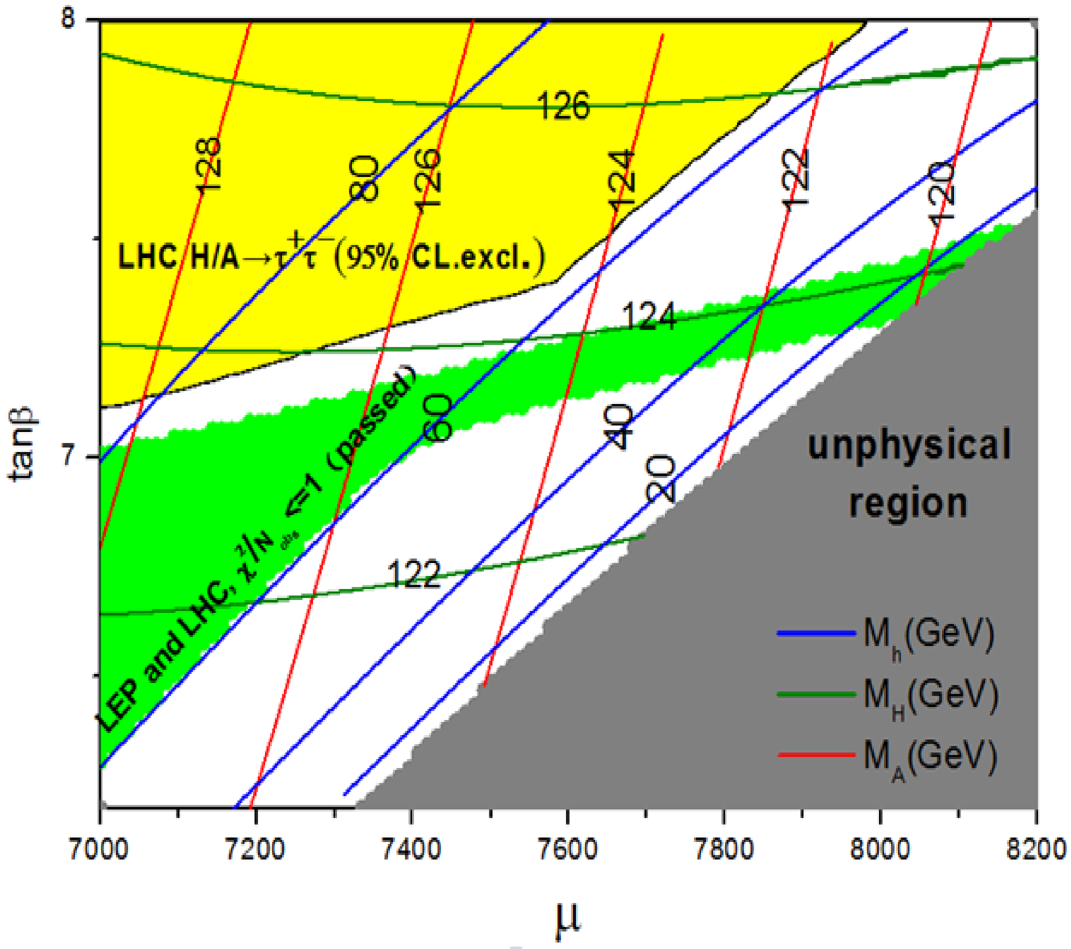
$$1 \leq \tan\beta \leq 50, \quad 1\ \mathrm{TeV} \leq M_{Q_3=U_3=D_3} \leq 5\ \mathrm{TeV}, \quad 100\mathrm{GeV} < M_A < 200\mathrm{GeV}.$$

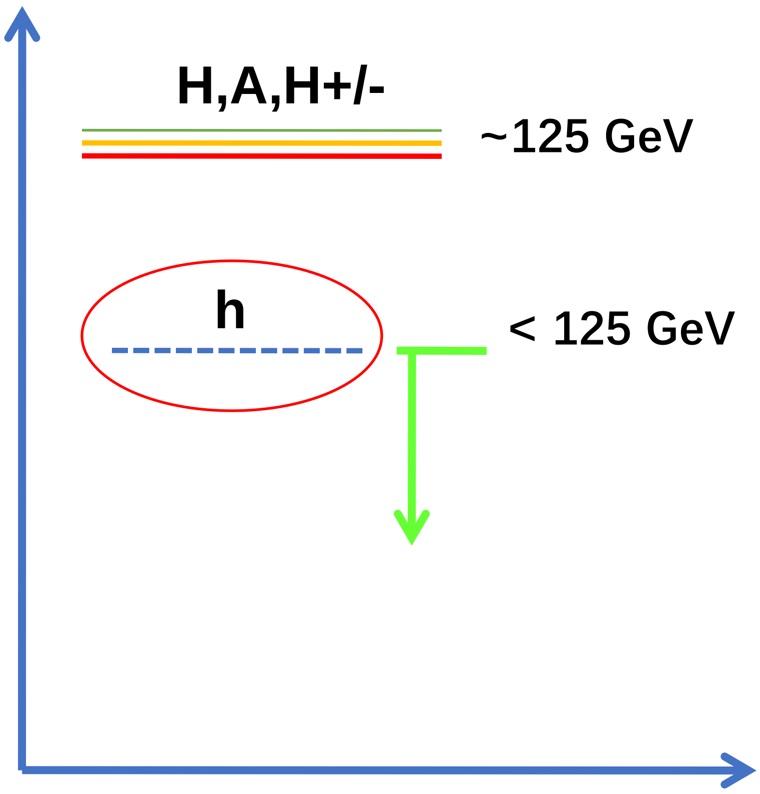
1. 122<mH<129 GeV, including 2-loop corrections and NNLL resummation contributions;

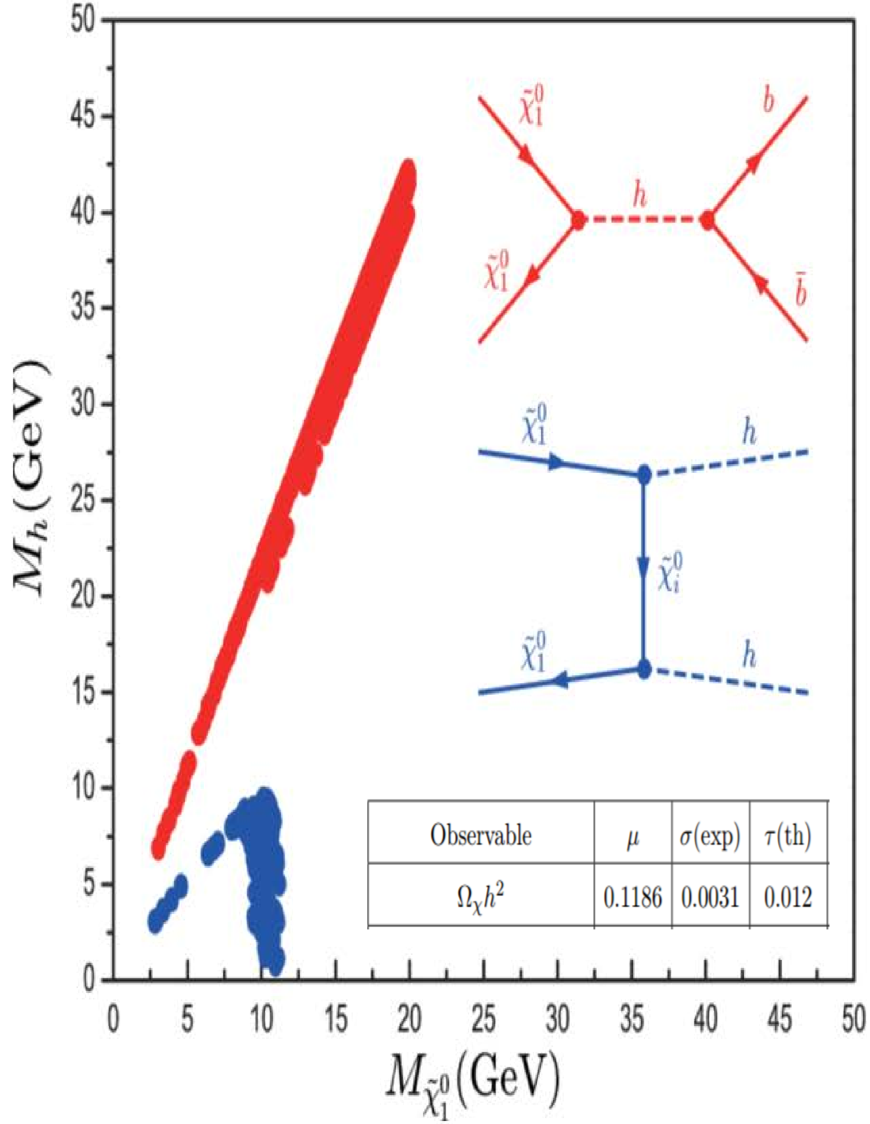
2. 95% C. L. exclusion limits from LEP, Tevatron and LHC in Higgs searches and Higgs data fit;

3. Approximate vacuum meta-stability.

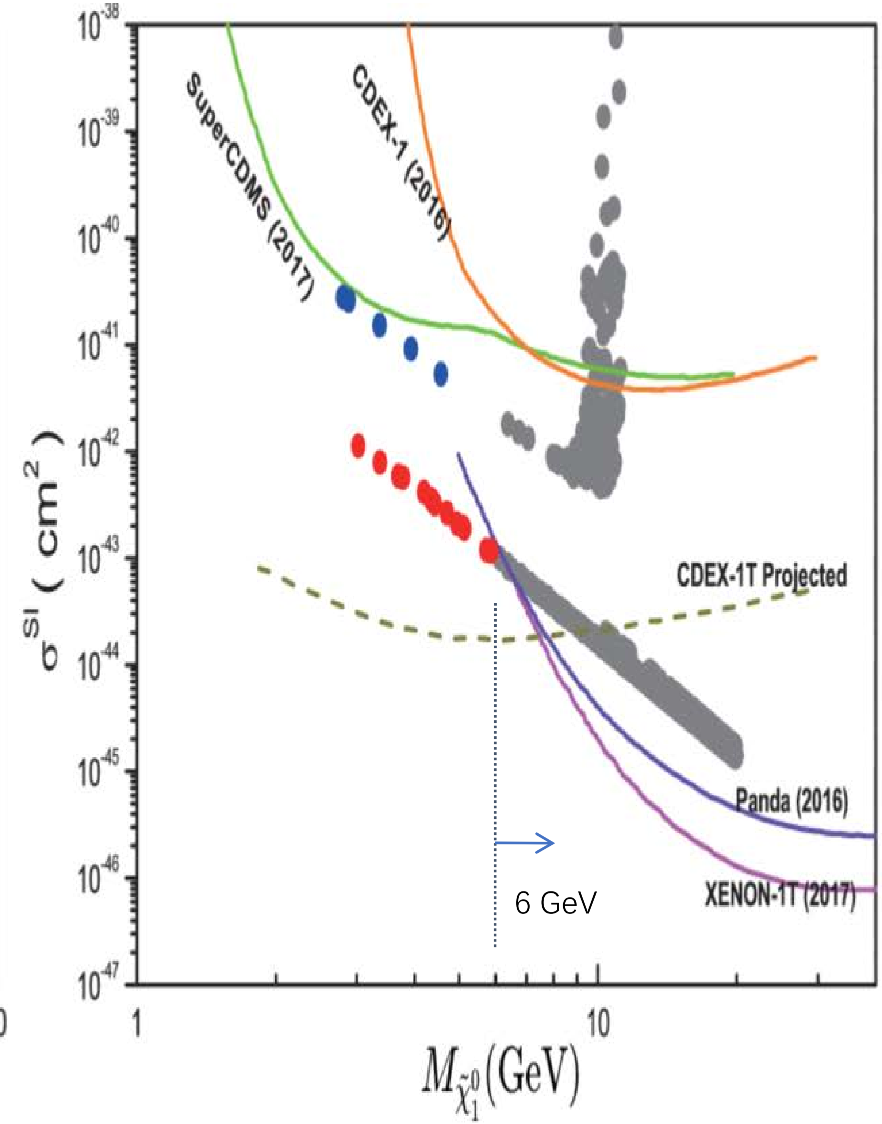
Dark Higgs boson: h

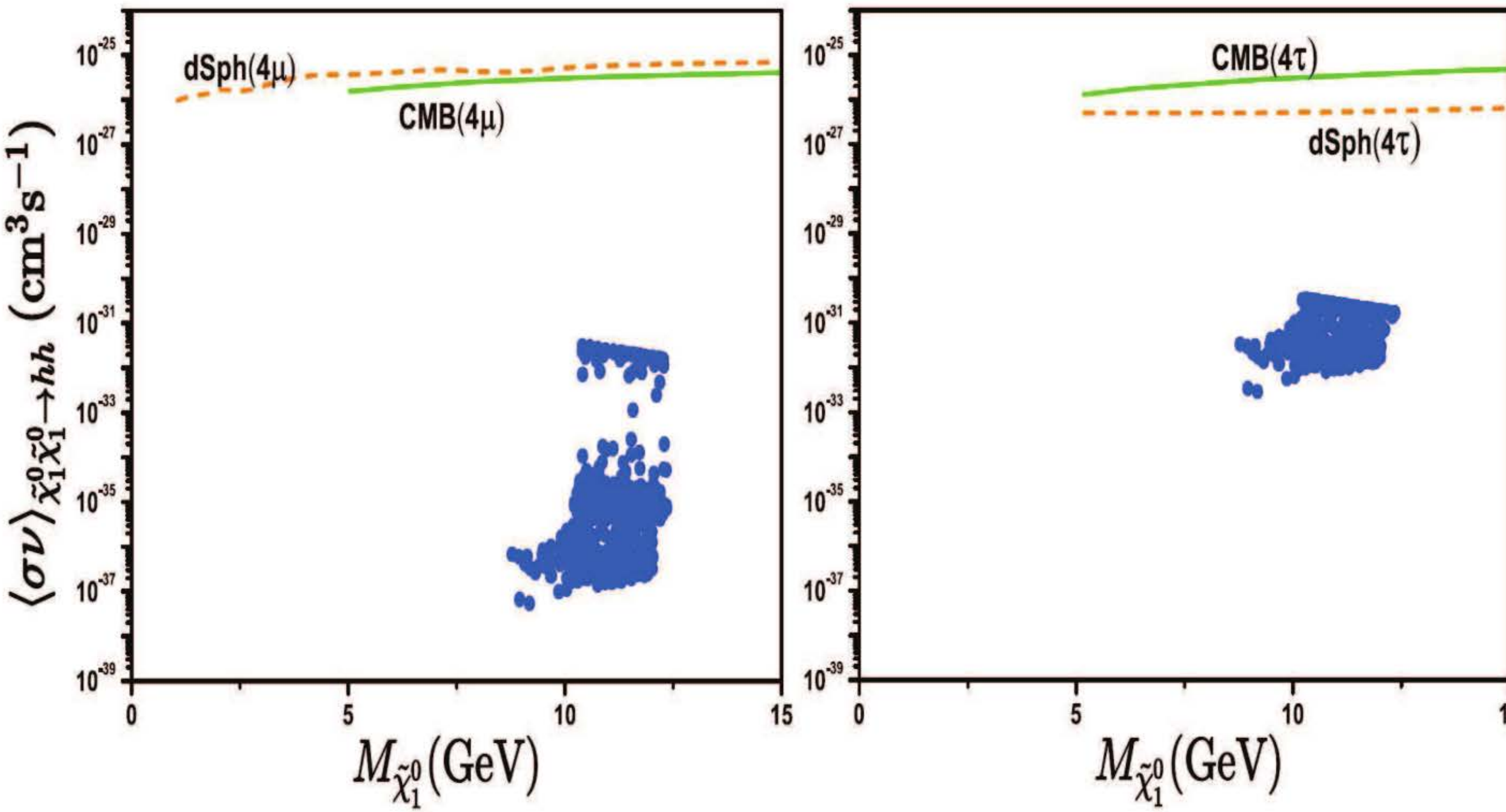




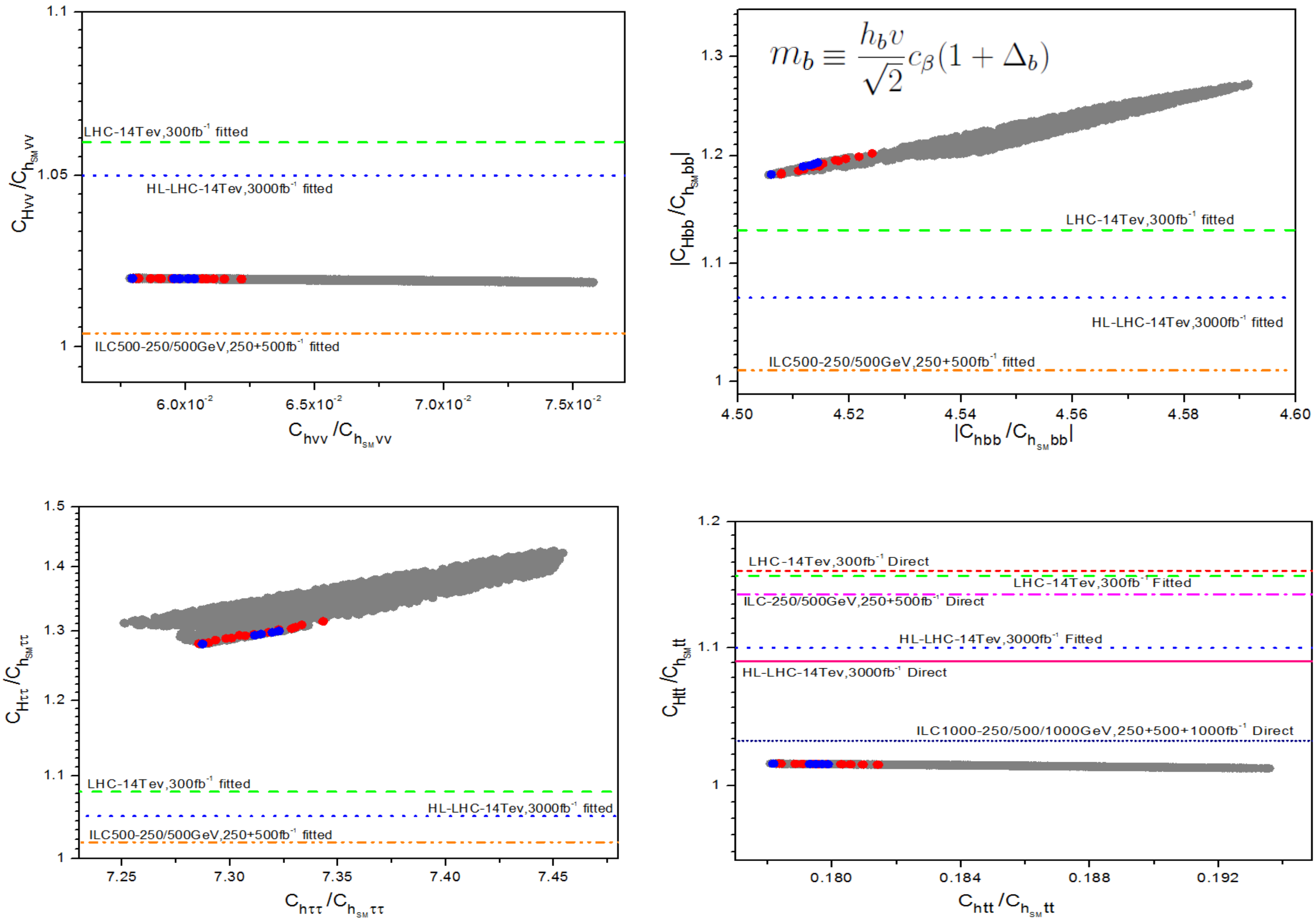


Observable	μ	σ(exp)	τ(th)
$\Omega_\chi h^2$	0.1186	0.0031	0.012





dSph(4μ)
CMB(4μ)
CMB(4τ)
dSph(4τ)
$\langle\sigma\nu\rangle_{\tilde{\chi}_1^0\tilde{\chi}_1^0\to hh}$ (cm^{3}s^{-1})
$M_{\tilde{\chi}_1^0}$(GeV)
$M_{\tilde{\chi}_1^0}$(GeV)



LHC-14Tev,300fb-1 fitted
HL-LHC-14Tev,3000fb-1 fitted
ILC500-250/500GeV,250+500fb-1 fitted
$m_b \equiv \frac{h_b v}{\sqrt{2}} c_\beta (1+\Delta_b)$
LHC-14Tev,300fb-1 Direct
LHC-14Tev,300fb-1 Fitted
ILC-250/500GeV,250+500fb-1 Direct
HL-LHC-14Tev,3000fb-1 Fitted
HL-LHC-14Tev,3000fb-1 Direct
ILC1000-250/500/1000GeV,250+500+1000fb-1 Direct

Conclusions

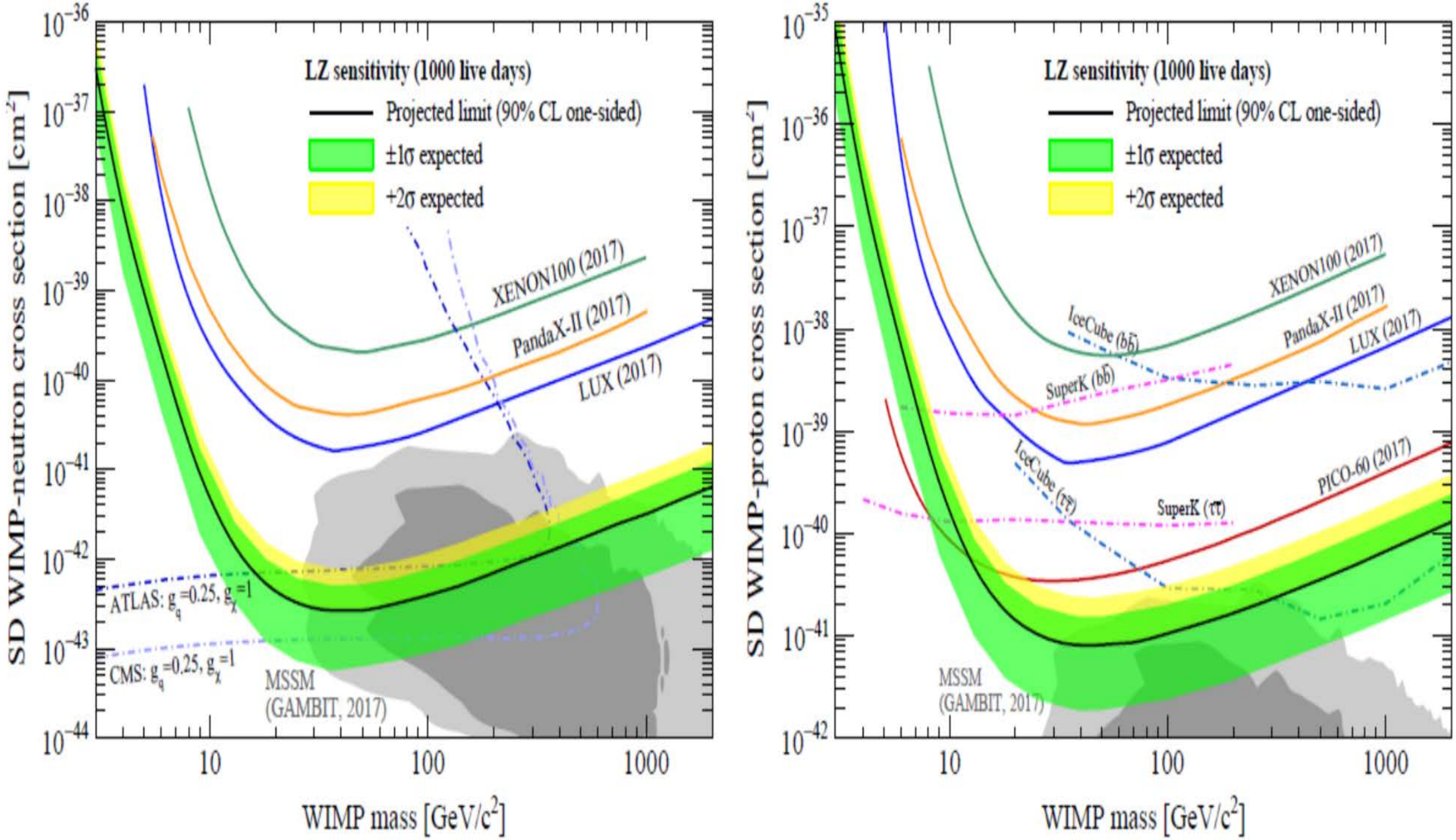
1. MSSM Neutralino DM is under siege from direct detection, but still alive.

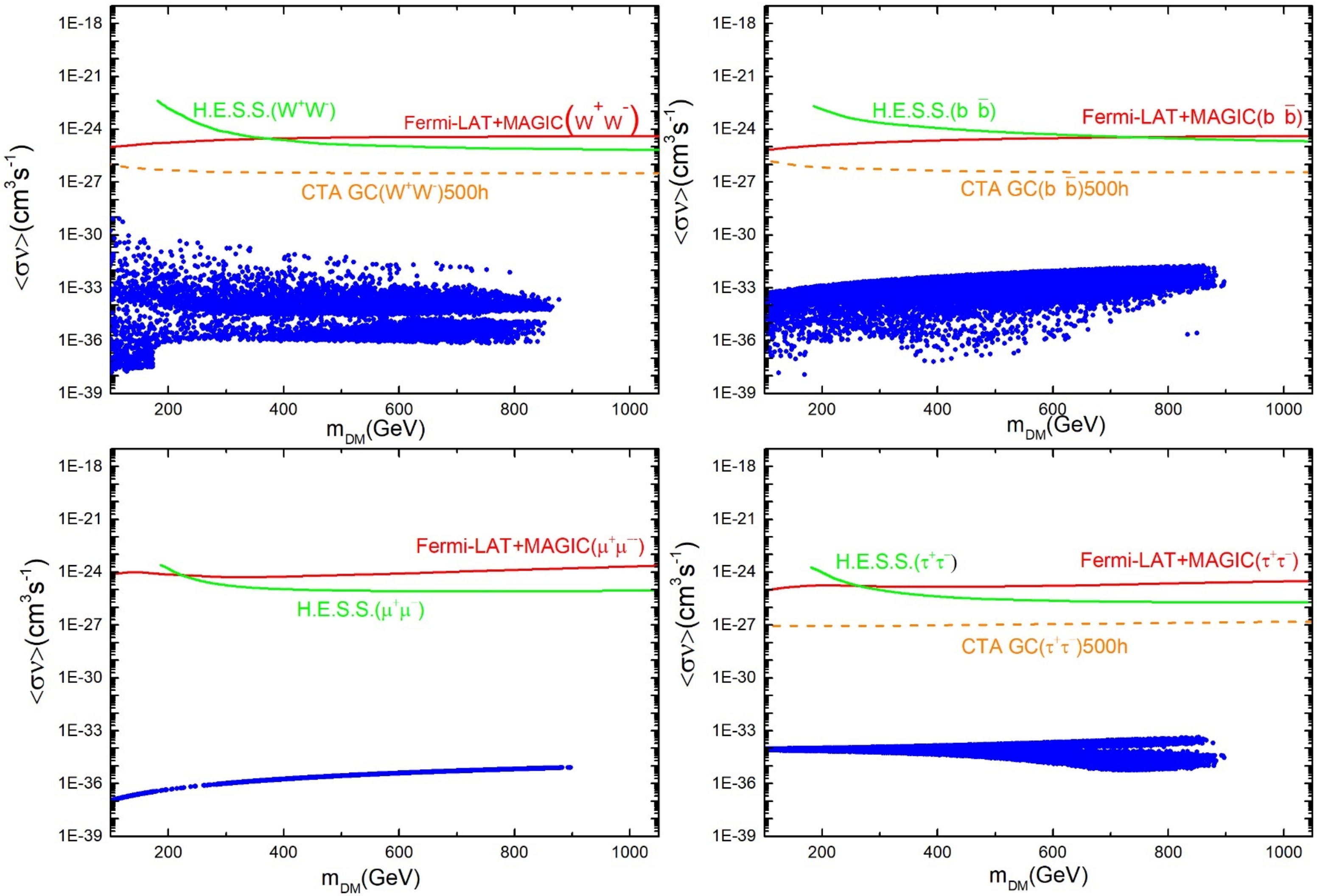
2. It can satisfy the DM relic density and escape direct detection bounds, such as (1-3).

3. Digging out neutralino DM under neutrino floor needs the help of colliders.

Thanks！

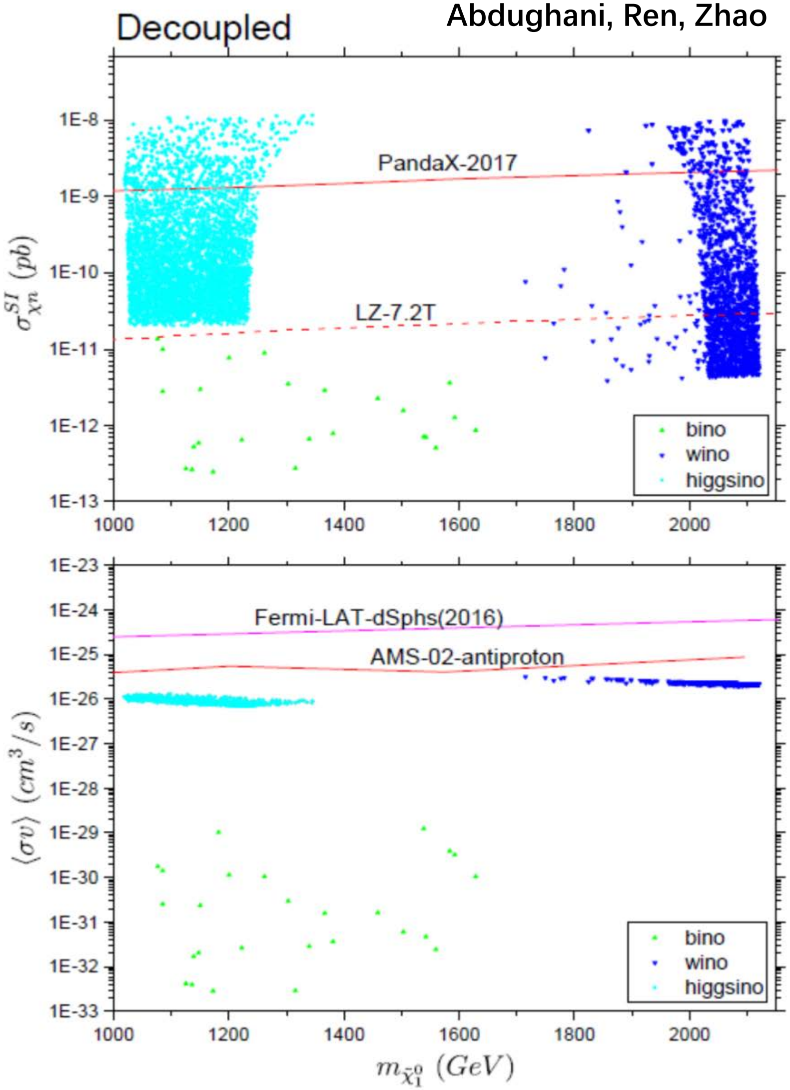
Backup


LZ sensitivity (1000 live days)
Projected limit (90% CL one-sided)
±1σ expected
+2σ expected
XENON100 (2017)
PandaX-II (2017)
LUX (2017)
ATLAS: g_q=0.25, g_χ=1
CMS: g_q=0.25, g_χ=1
MSSM (GAMBIT, 2017)
SD WIMP-neutron cross section [cm^-2]
WIMP mass [GeV/c^2]
IceCube (bb̄)
SuperK (bb̄)
IceCube (ττ̄)
SuperK (ττ̄)
PICO-60 (2017)
SD WIMP-proton cross section [cm^-2]

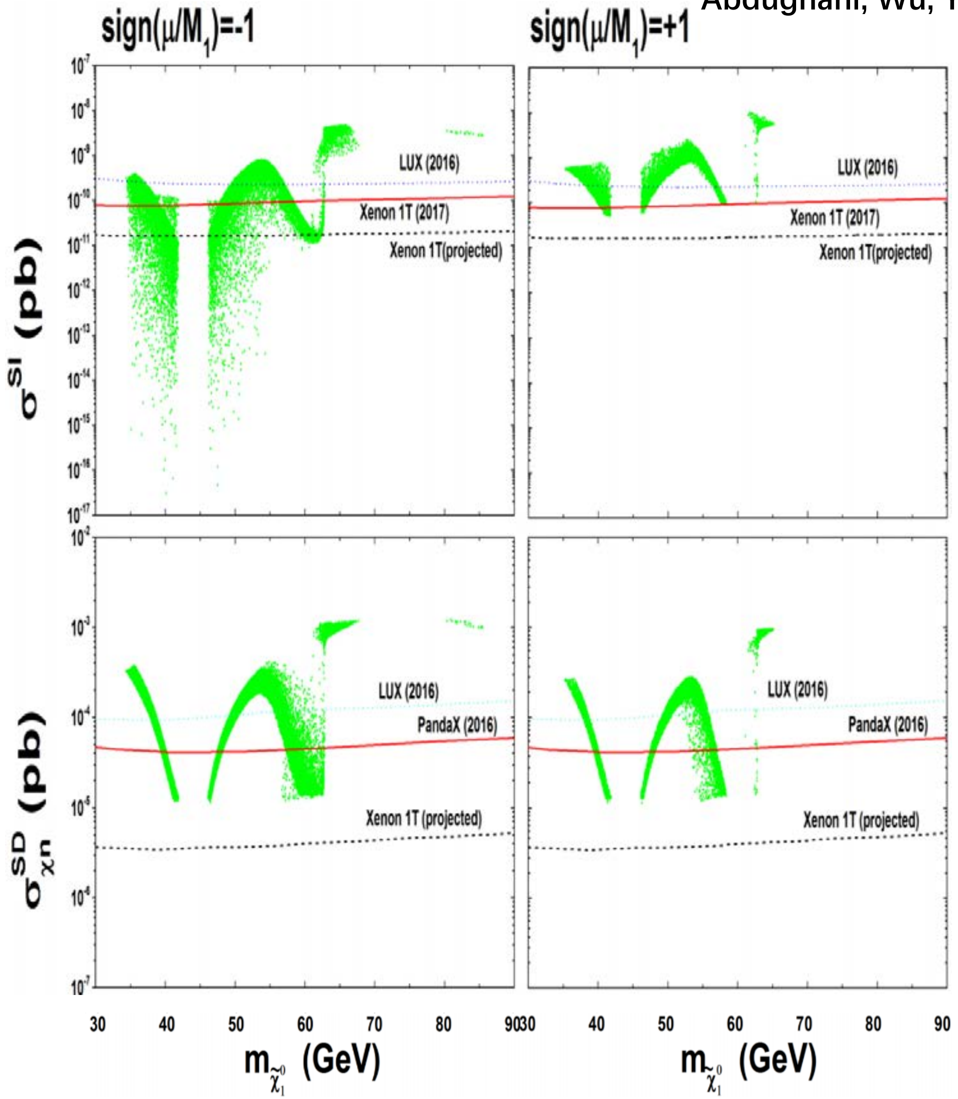


H.E.S.S.(W⁺W⁻)
Fermi-LAT+MAGIC(W⁺W⁻)
CTA GC(W⁺W⁻)500h
H.E.S.S.(b b̄)
Fermi-LAT+MAGIC(b b̄)
CTA GC(b b̄)500h
Fermi-LAT+MAGIC(μ⁺μ⁻)
H.E.S.S.(μ⁺μ⁻)
H.E.S.S.(τ⁺τ⁻)
Fermi-LAT+MAGIC(τ⁺τ⁻)
CTA GC(τ⁺τ⁻)500h
<σv>(cm³s⁻¹)
m_DM(GeV)

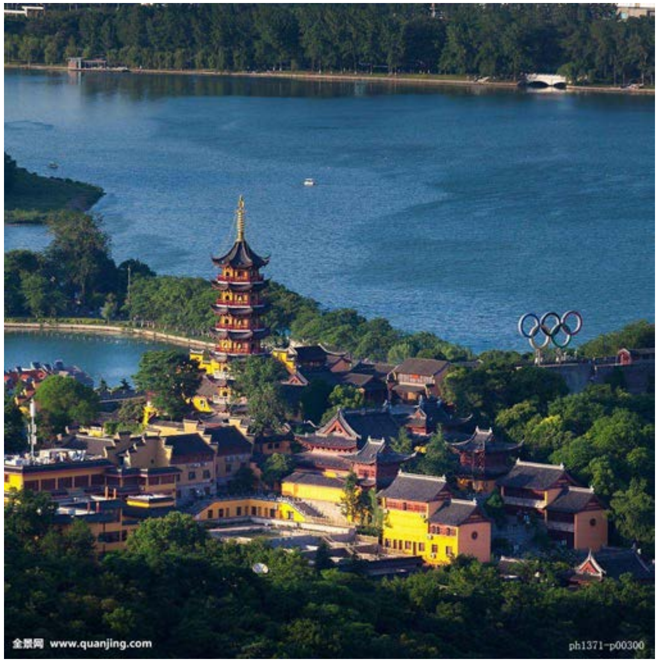
arXiv:1805.06206
Abdughani, Ren, Zhao



arXiv:1705.09164
Abdughani, Wu, Yang



Wino, Higgsino DM and Bino DM mixed with Higgsino (well-tempered) has been tightly constrained by direct detections and will be largely, even completed covered.


全景网 www.quanjing.com
ph1371-p00300