Light Dark Matter in the NMSSM after CDMS-II, LUX and Higgs Discovery

based on 1311.0678

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Outline

- Motivation
- Introduction of NMSSM
- Numerical scan and experimental constraints
- Results and discussion
- Conclusion

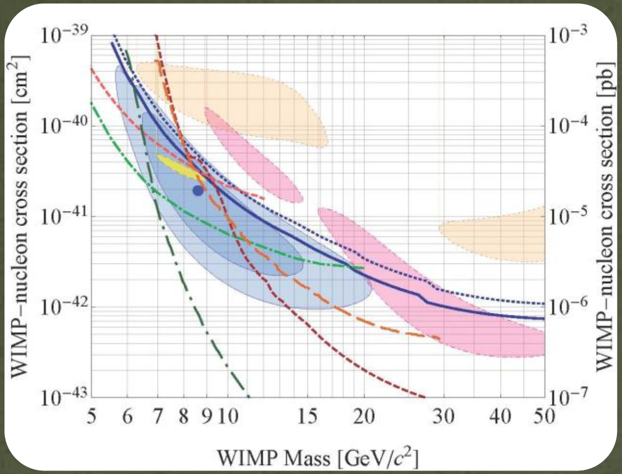
Why a light DM?

- Direct detection (incompatible results)
- Indirect detection (peaks in X-ray spectrum)
- $h_{SM} \to$ DM pair ⟷ Higgs data
- Annihilation mechanism is simple

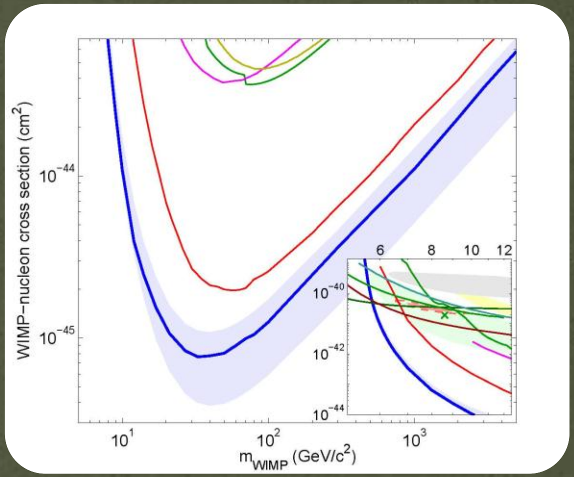
Why a light DM?

- Direct detection (incompatible results)

CDMS, 1304.4279



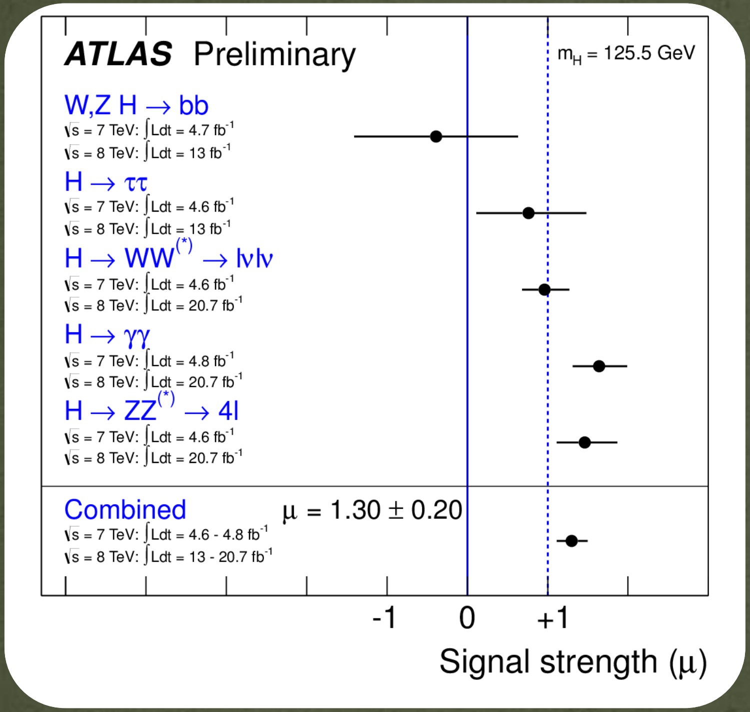
LUX, 1310.8214

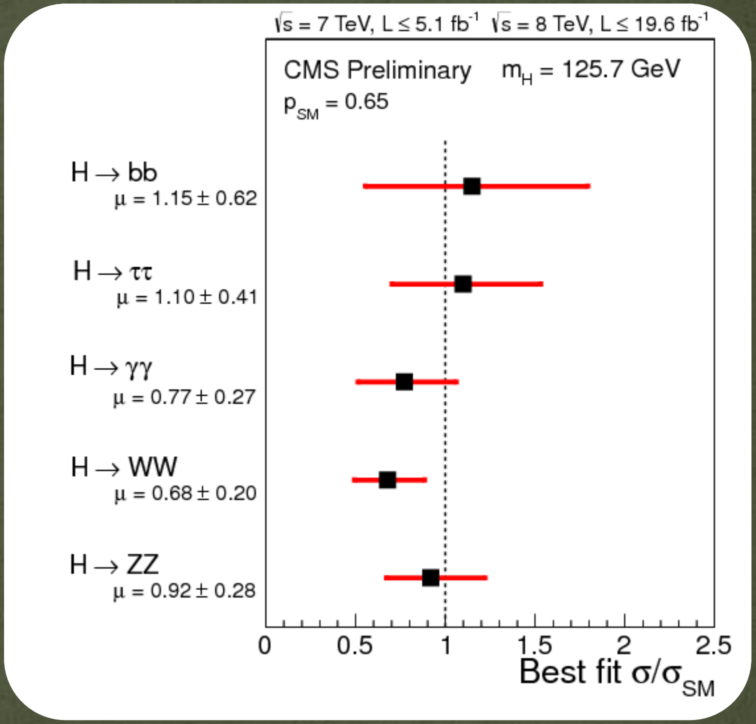


- Indirect detection
  - Fermi-LAT, X-ray peaks around **1-10** GeV

Why a light DM?

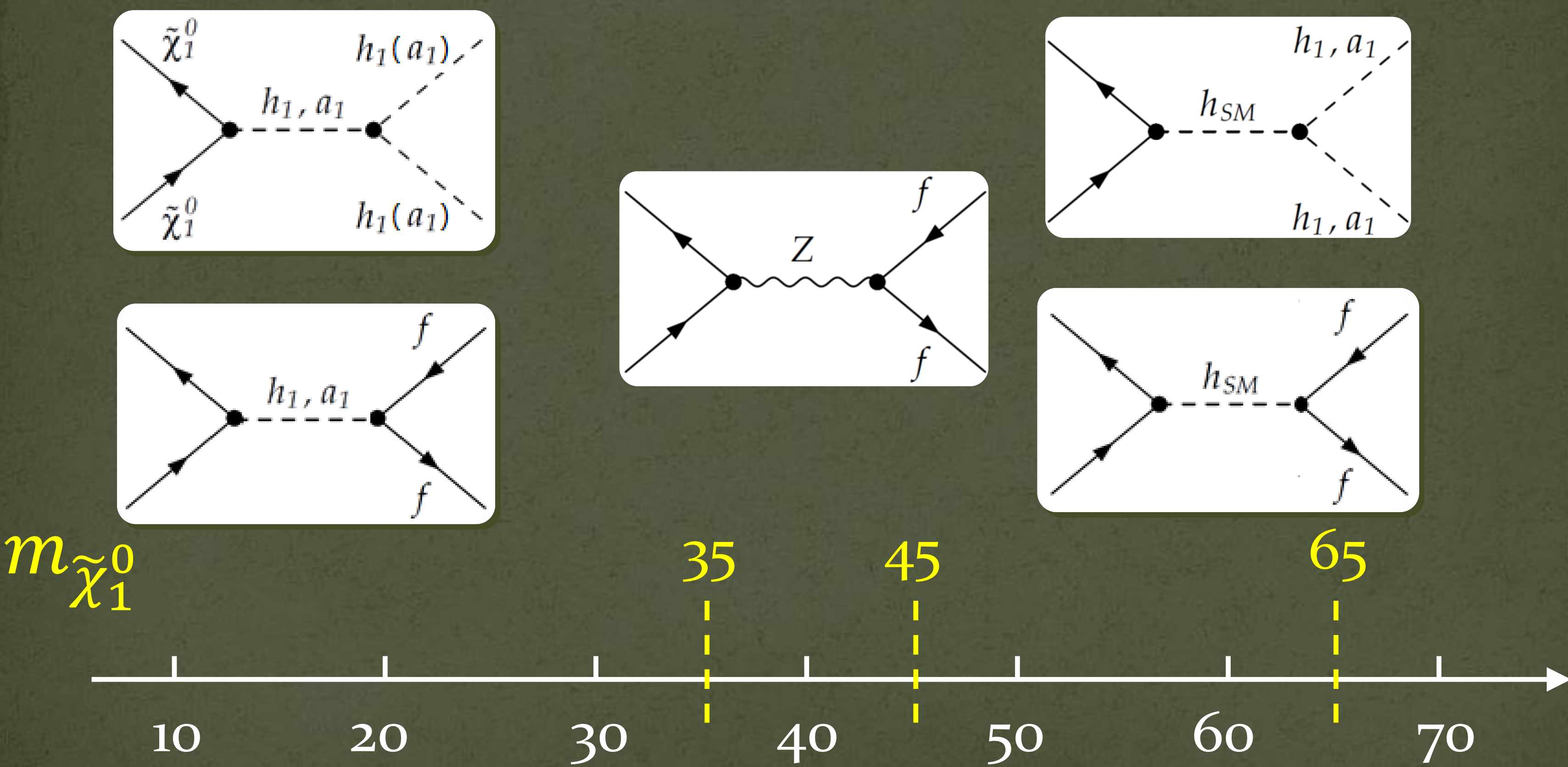
- $h_{SM} \rightarrow$ DM pair ⟷ Higgs data





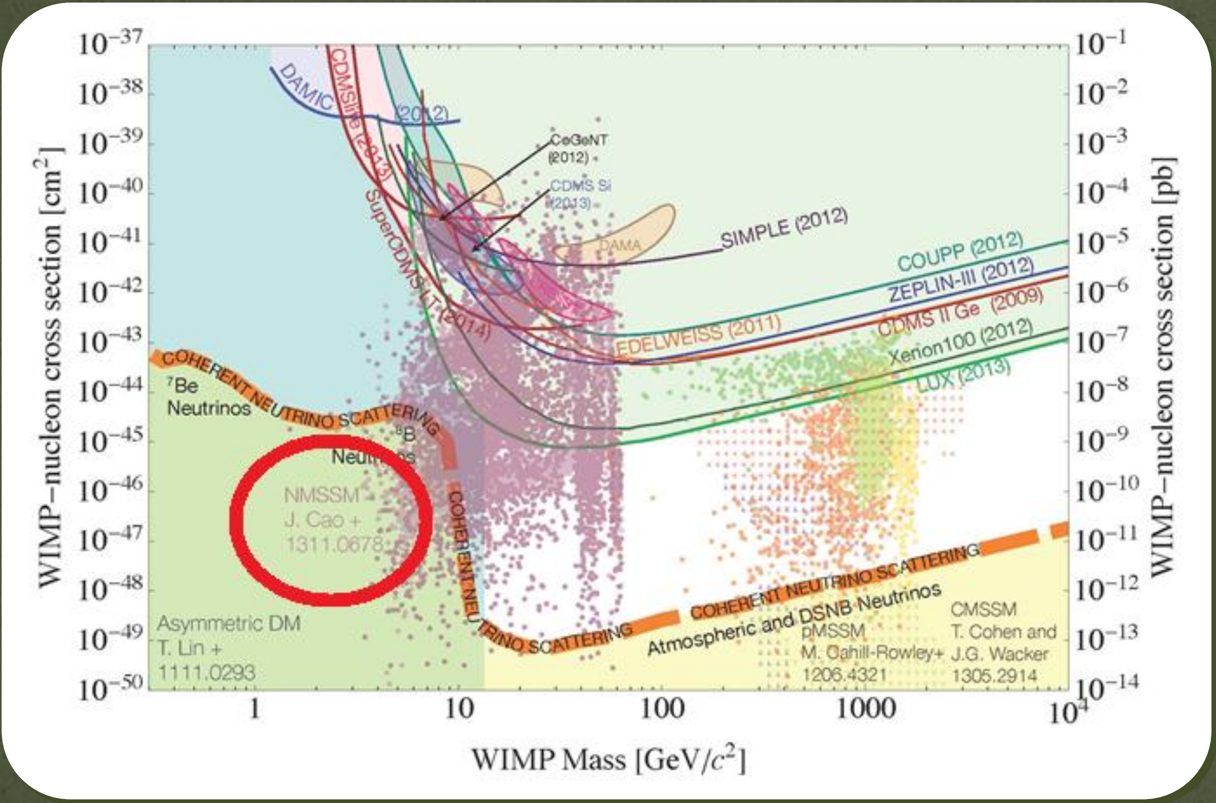
Why a light DM?

- Annihilation mechanism is simple



Light DM: unresolved

- Interesting both experimentally and theoretically



from E. Figueroa-Feliciano
CDMS collaboration

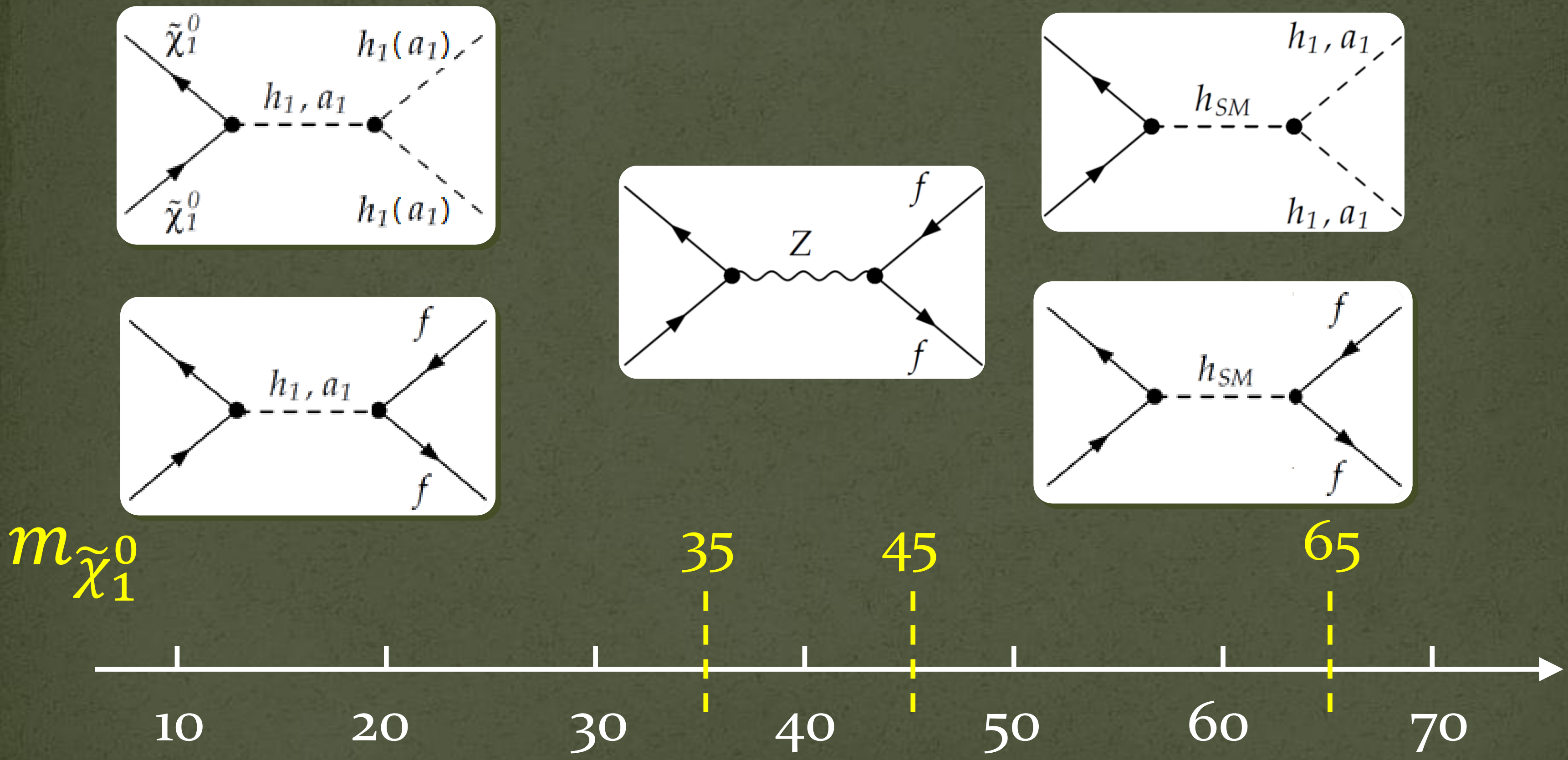
Next-to-MSSM

- Higgs sector
  - CP-even: $\boldsymbol{h_1}, h_2, h_3$
  - CP-odd: $\boldsymbol{a_1}, a_2$
  - Charged: $H^{\pm}$

- Neutralino sector
  - $\tilde{\chi}_i^0, \; i = \mathbf{1}, 2,3,4,5$

$h_1, a_1 \;\; (\tilde{\chi}_1^0)$
can be
singlet (singlino)-like
and *light*

Light DM annihilation



Numerical scan (MCMC)

- Simplifications
  - $\tilde{q}$ = 2 TeV
    - $A_t = A_b$ to tune $m_{h_{\rm SM}}$
  - $\tilde{l}$ = 300 GeV
    - muon g-2
  - $\tilde{g}$ = 2 TeV
  - vary M_1, M_2 independently
- Mass requirement:
  - $m_{h_{\rm SM}} \sim 125$ GeV, $m_{\tilde{\chi}_1^0} < m_{h_{\rm SM}}/2$

Numerical scan (MCMC)

- Experimental constraints
  - B-physics
    - $\Upsilon \to h_1(a_1)\gamma, B \to X_s\gamma, B_s \to \mu^+\mu^-$ at 2σ level
  - DM relic density
    - $0.091 < \Omega h^2 < 0.138$
  - LEP bounds from SUSY searches
    - $m_{\chi_1^\pm} > 103$ GeV, $\Gamma_{inv.}^{\mathrm{non-SM}} < 2.0$ MeV
  - Muon g-2
    - $\Delta a_\mu = (26.1 \pm 8.0) \times 10^{-10}$ at 2σ level

Numerical scan (MCMC)

- Experimental constraints
  - Higgs search from LEP, Tevatron, LHC
    - HiggsBounds-4.0.0
    - $pp \to H \to h_1 h_1 (a_1 a_1) \to 4l$ (CMS-PAS-HIG-13-010)
  - LHC searches for $\tilde{\chi}_i^{\pm} \tilde{\chi}_j^0$ associated production
    - $pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^{\pm} \to 3l + E_T^{miss}$ (ATLAS-CONF-2013-035)
- A global fit
  - HiggsSignals-1.0.0, keep 2σ samples

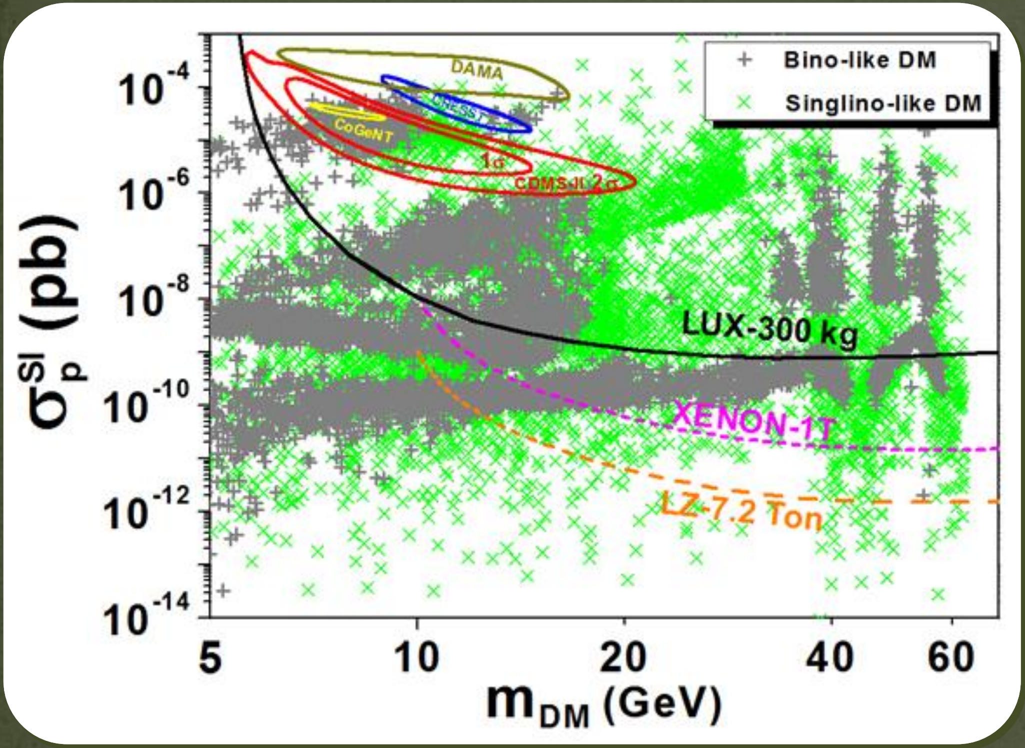
Numerical scan (MCMC)

- Scan range ([mass] in **TeV**)
  - $1 < tan\beta < 40,\ 0 < \lambda < 0.7,\ 0 < |\kappa| < 0.7,$
  - $0 < |A_\kappa| < 2,\ 0 < A_\lambda < 5,\ |A_t| < 5,$
  - $0 < |M_1| < 0.6,\ 0.3 < M_2 < 0.6,\ 0.1 < \mu < 0.6$

- Markov Chain Monte Carlo (MCMC) scan
  - **Much** more efficient
  - Including preference

Results

- $m_{\tilde{\chi}_1^0}$ vs $\sigma_p^{\rm SI}$

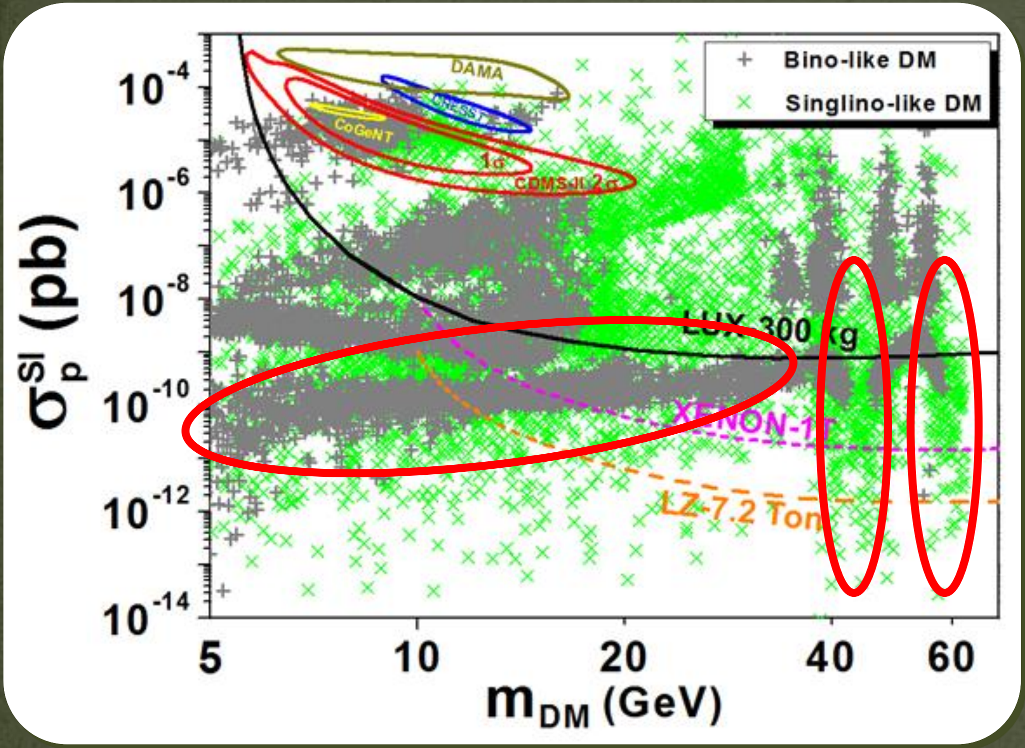


Parameter space is *cut* by

- $0.091 < \Omega h^2 < 0.138$
- $m_{h_{\rm SM}} \sim 125$ GeV
- $Br(h_{SM} \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$
- $Br(h_{SM} \to h_1 h_1, a_1 a_1)$
- $\Upsilon \to h_1(a_1)\gamma$
- $B \to X_s\gamma,\ \ B_s \to \mu^+\mu^-$
- …

Results

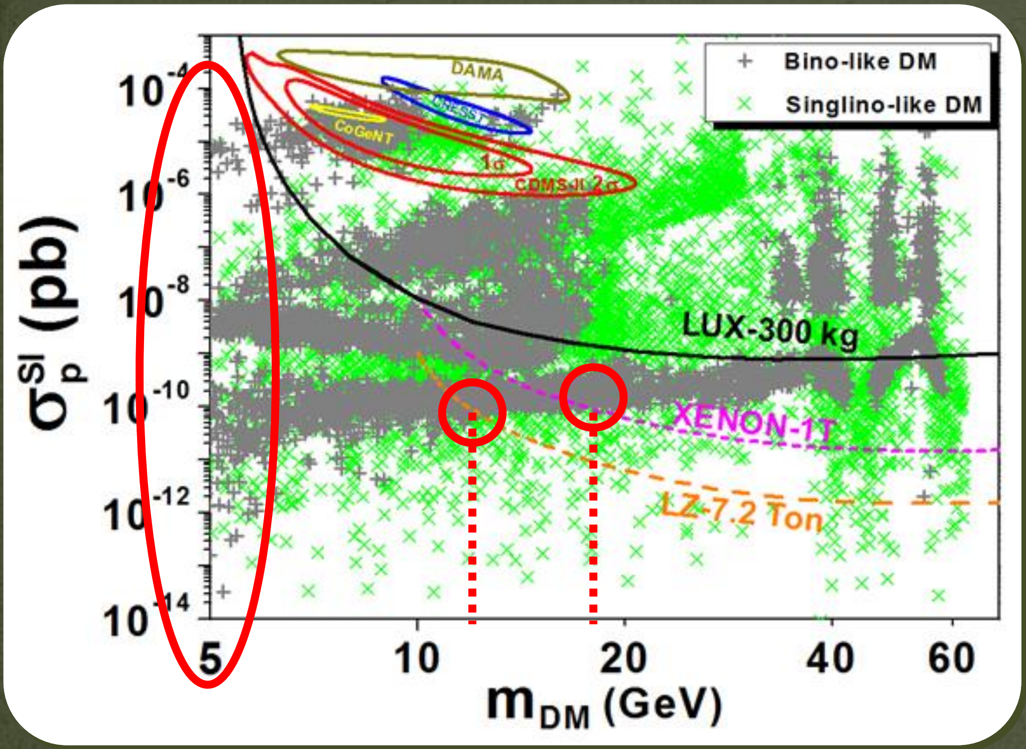
- $m_{\tilde{\chi}_1^0}$ vs σ_p^{SI}



- Z resonance
- h_{SM} resonance
- h_1, a_1 resonance

Results

- $m_{\tilde{\chi}_1^0}$ vs σ_p^{SI}



- $m_{\tilde{\chi}_1^0}$~5 GeV is still allowed
- Bino-like:
  - XENON-1T: $m_{\tilde{\chi}_1^0} < 17$ GeV
  - LZ-7.2 Ton: $m_{\tilde{\chi}_1^0} < 12$ GeV
- Singlino-like:
  - not affected much

Results

- Survived parameter range

	bino-like		singlino-like	
	CDMS-II	LUX	CDMS-II	LUX
M_1	(8 , 22)	(4 , 39)	(-600 , -110)	(-600 , -80)
M_2	(300 , 600)	(300 , 600)	(300 , 600)	(300 , 600)
μ	(160 , 225)	(157 , 320)	(115 , 220)	(119 , 320)
$\tan\beta$	(14 , 28)	(6 , 40)	(7 , 29)	(7 , 37)
λ	(0.28 , 0.49)	(0.015 , 0.59)	(0.08 , 0.25)	(0.06 , 0.3)
κ	(0.29 , 0.57)	(0 , 0.6)	(-0.01 , 0.02)	(-0.03 , 0.02)
A_λ	(2400 , 4800)	(1050 , 5000)	(1070 , 4990)	(1200 , 5000)
A_κ	(-1100 , -630)	(-1300 , 0)	(-80 , 60)	(-120 , 110)

How to have $m_{\tilde{\chi}_1^0} < 35$ GeV ?

- Bino-like: $M_1 \in (4{,}40)$
- Singlino-like: $|\kappa| \ll \lambda$

$$
\begin{pmatrix}
M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\
 & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\
 & & 0 & -\mu & -\lambda v_u \\
 & & & 0 & -\lambda v_d \\
 & & & & \frac{2\kappa}{\lambda}\mu
\end{pmatrix}
$$

Results

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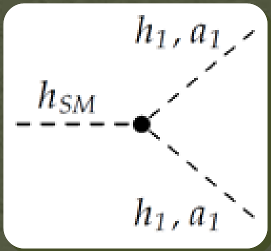
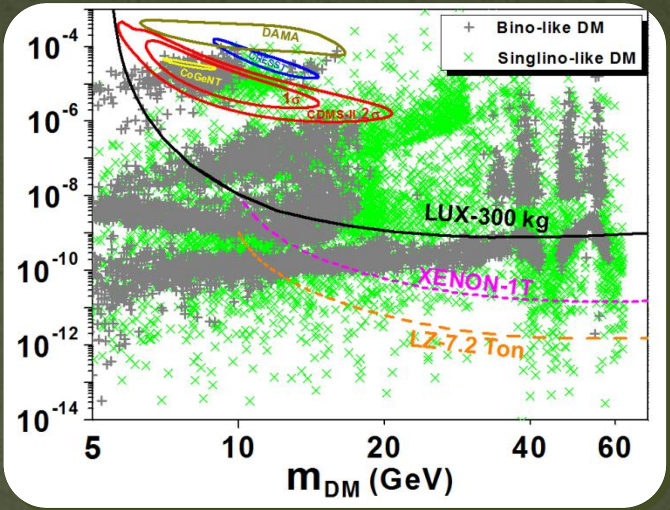


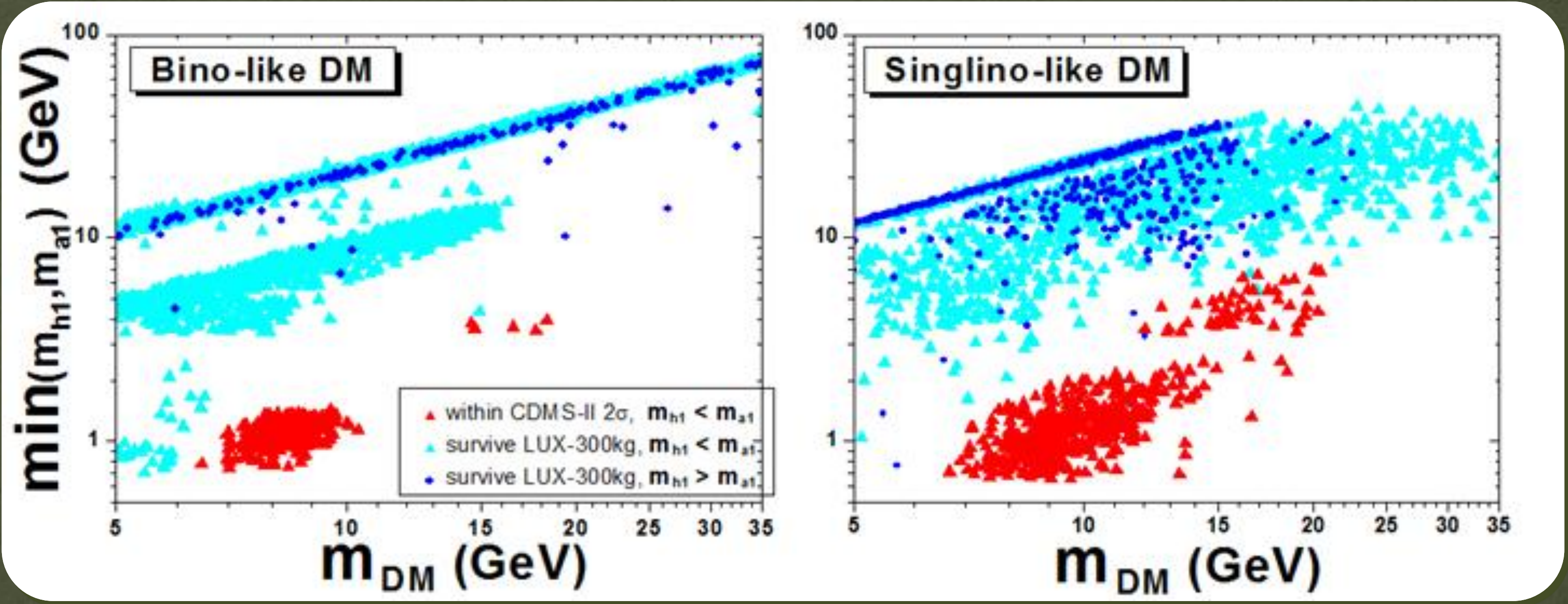
- Bino-like: moderate λ, κ
  - accidental cancellation
- Singlino-like: small λ
  - $W \ni \lambda H_u H_d S + \frac{\kappa}{3} S^3$
  - small λ, κ to suppress $h_{SM} \to h_1 h_1, a_1 a_1$

Results

- h_1, a_1 as resonance/final states

Red: CDMS-II 2σ, $m_{h_1} < m_{a_1}$
Cyan: LUX-300kg, $m_{h_1} < m_{a_1}$
Blue: LUX-300kg, $m_{h_1} > m_{a_1}$





Results

- light h_1, large σ_p^{SI}

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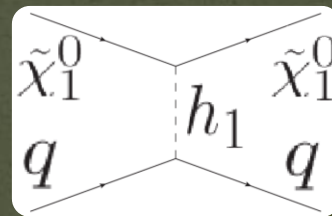

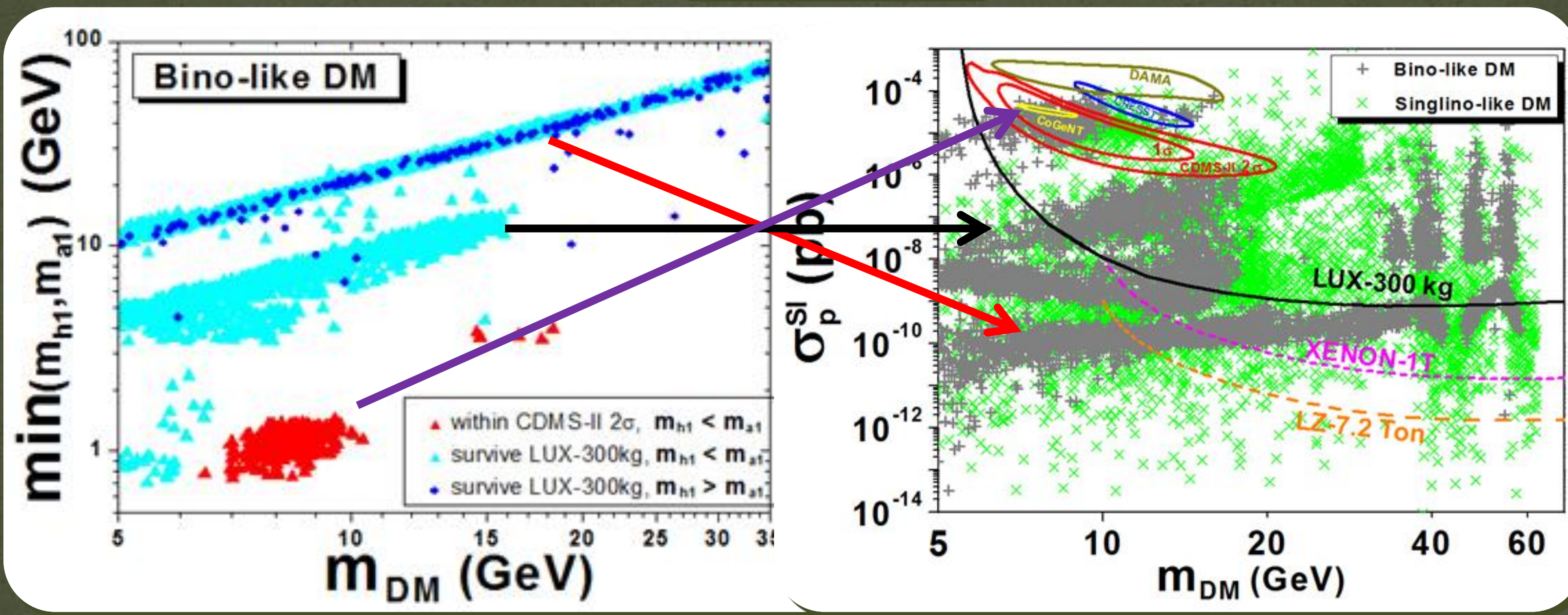

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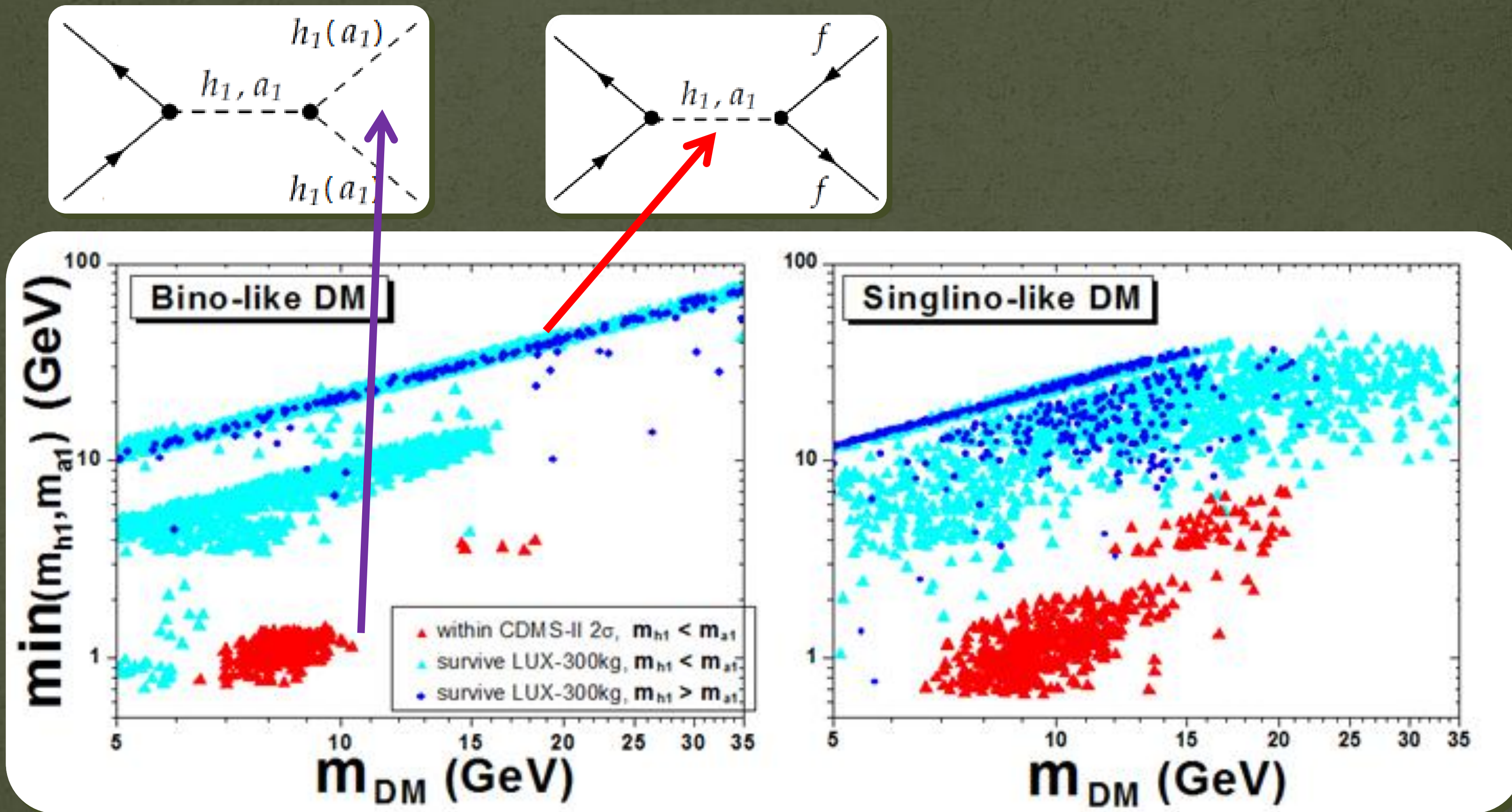
- h_1, a_1 as resonance/final states



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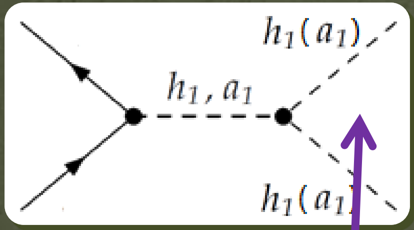

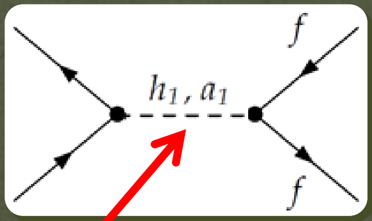

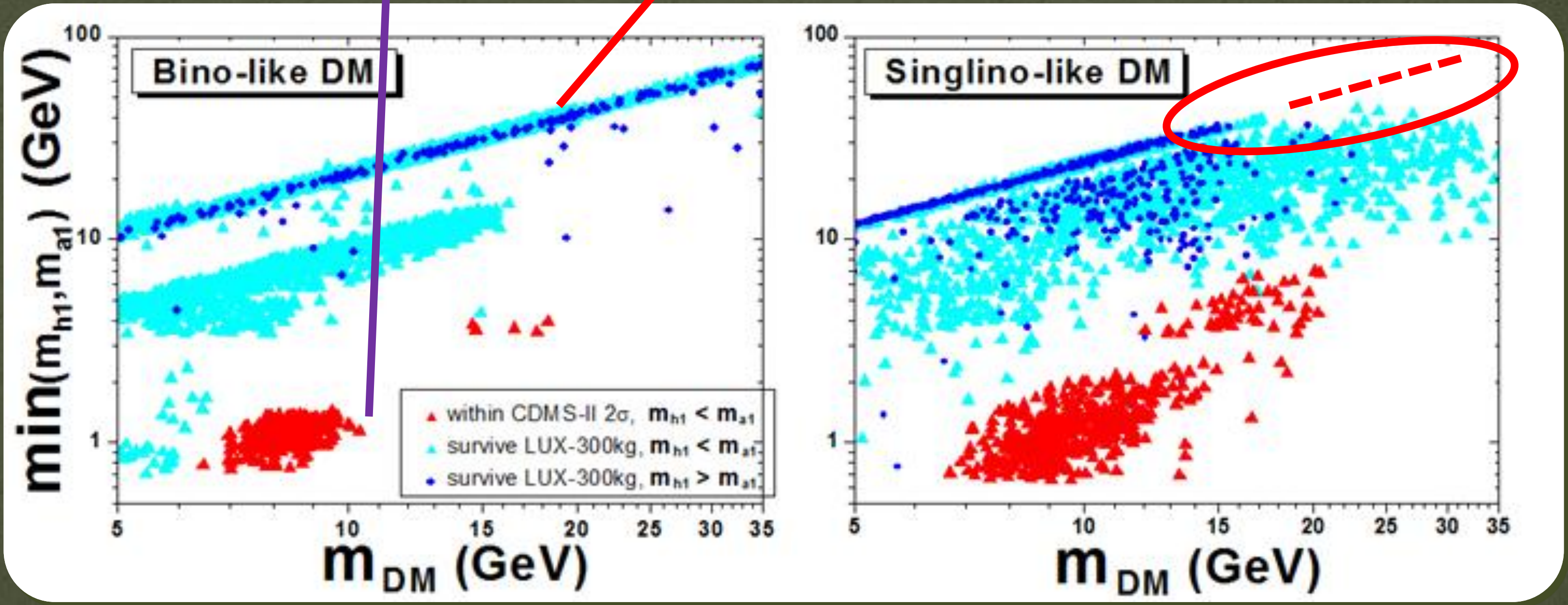

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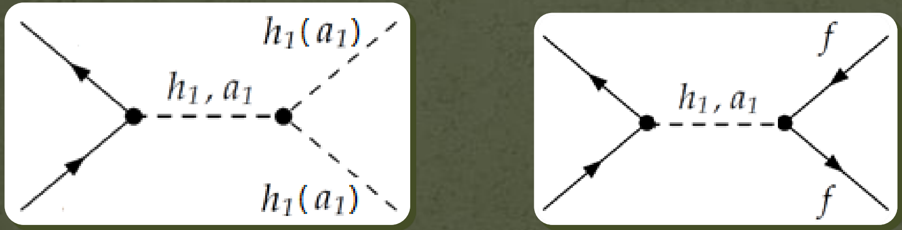

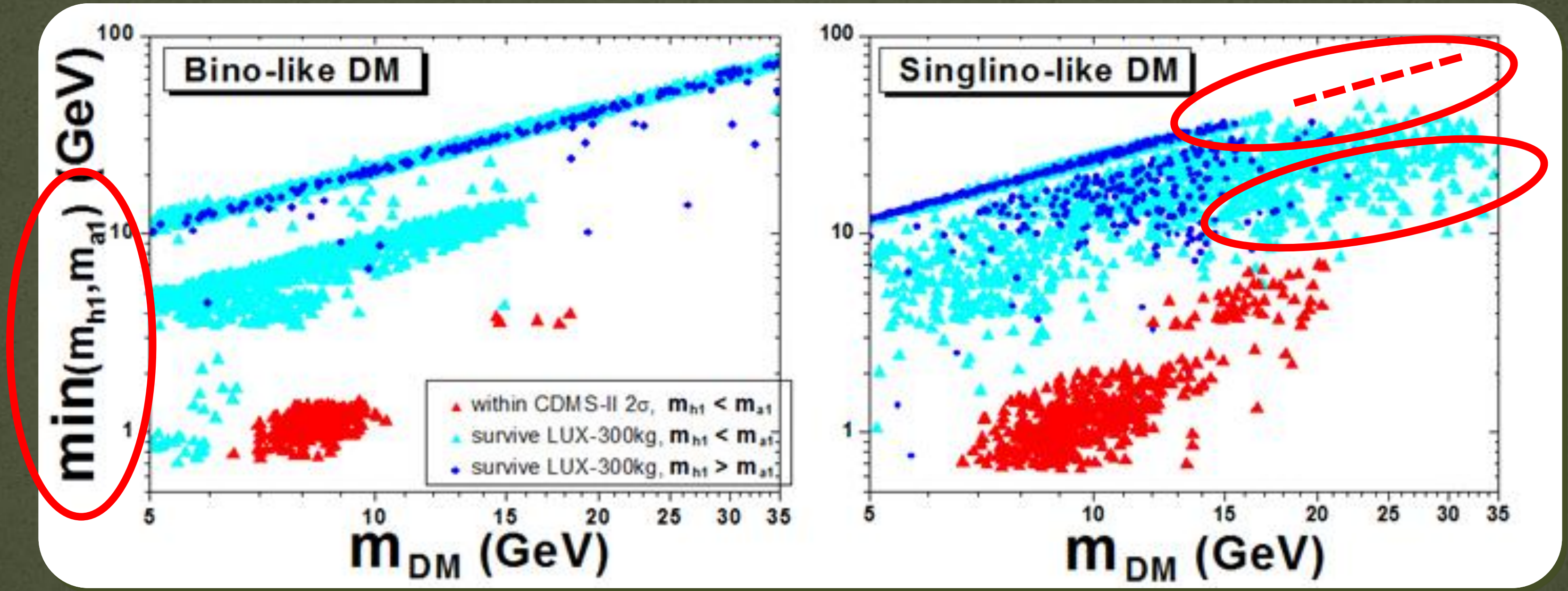

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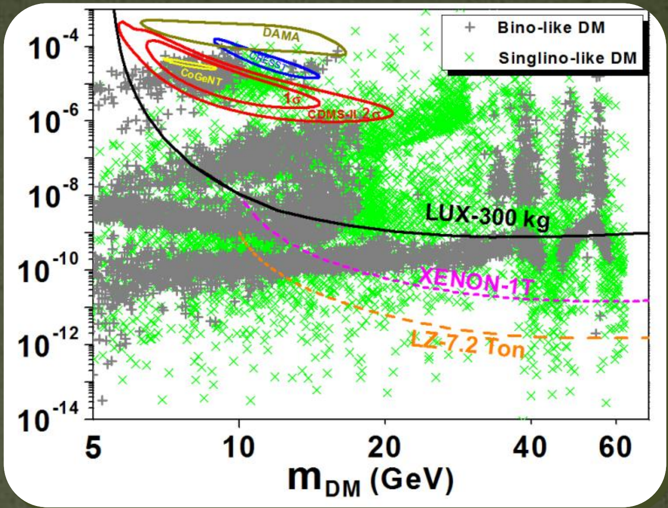
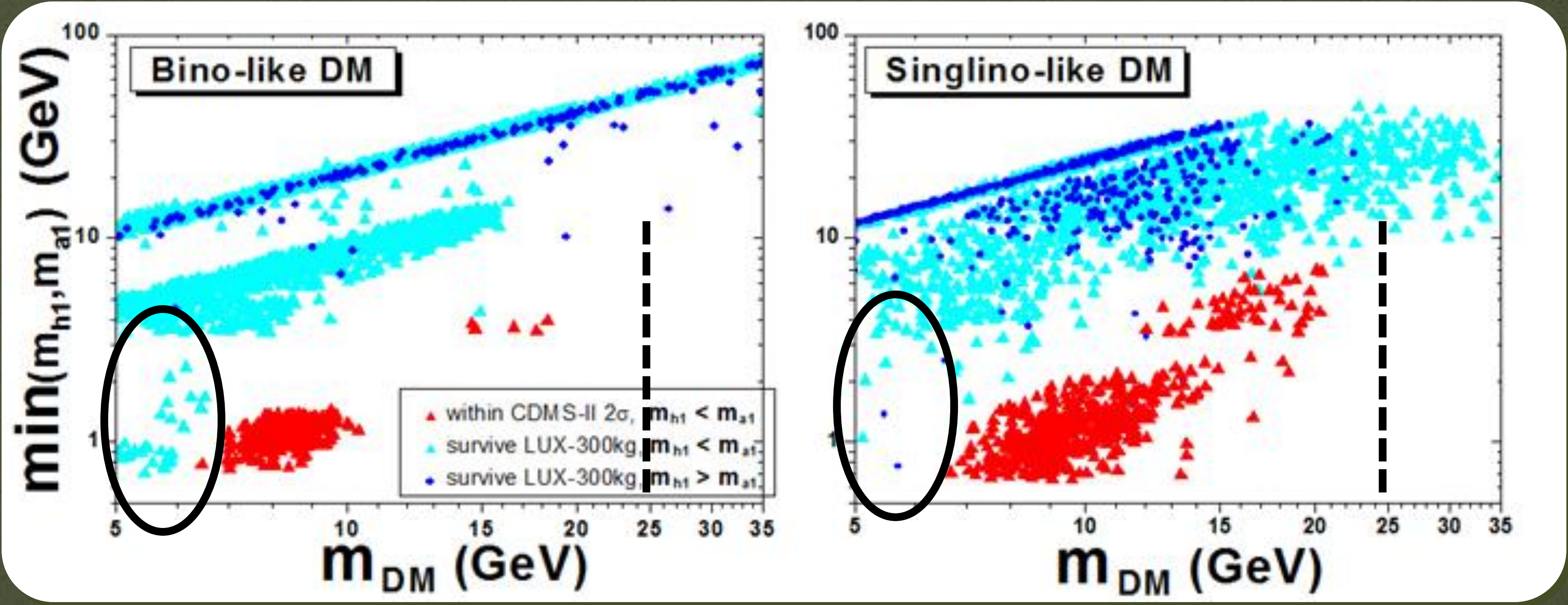


- h_1, a_1 as resonance/final states
  - $m_{\tilde{\chi}_1^0} < 7$ GeV, $m_{h_1} \sim 1$ GeV
  - $m_{\tilde{\chi}_1^0} > 25$ GeV, $m_{h_1} \gtrsim 10$ GeV



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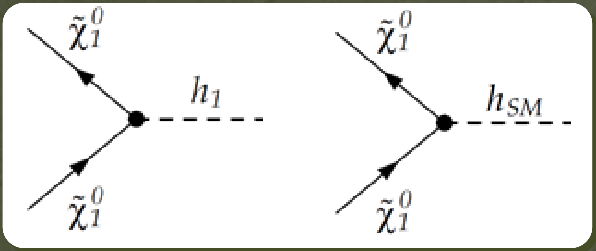
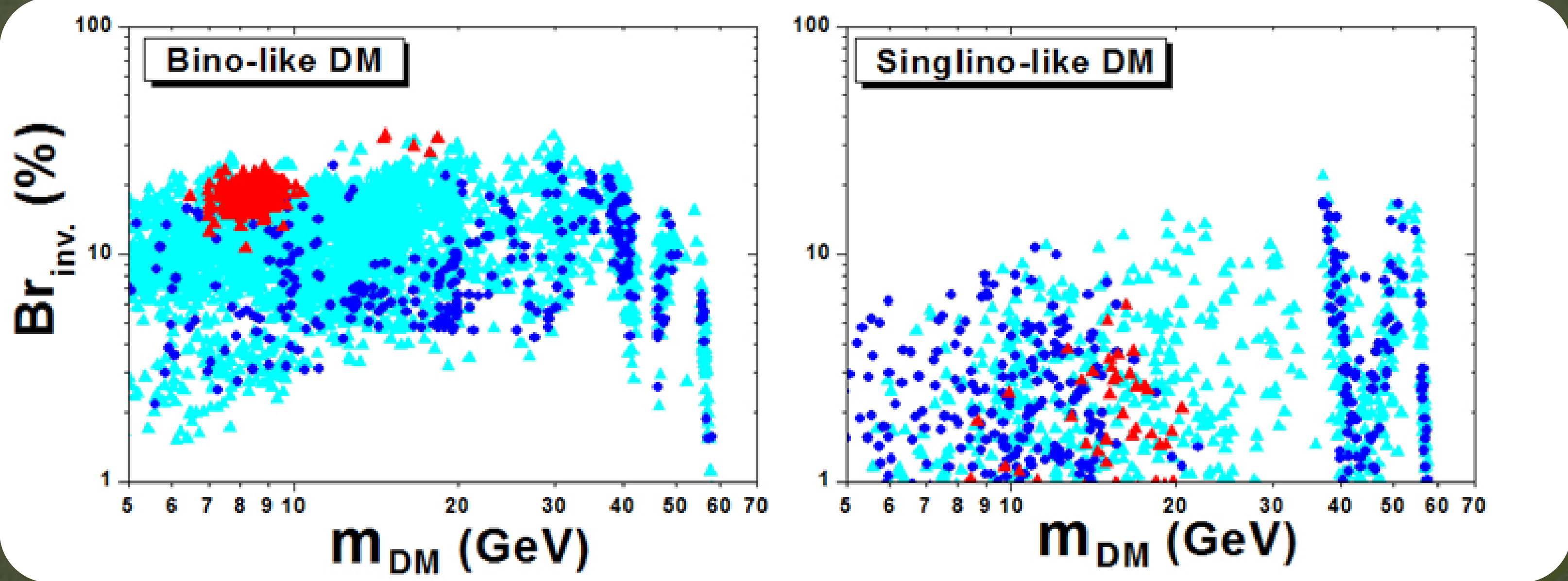
- $Br(h_{SM} \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$





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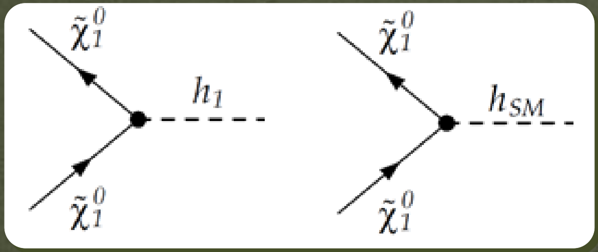
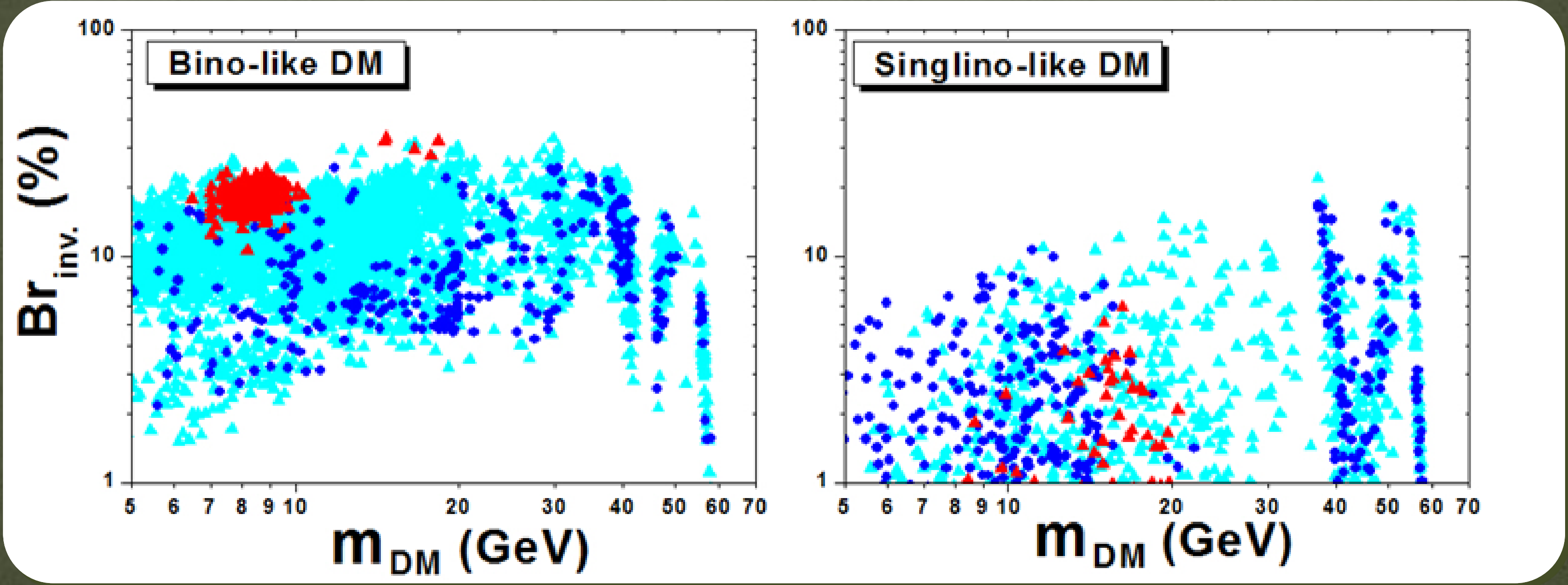


- Bino-like DM:
  - $\tilde{H}_u^0, \tilde{H}_d^0$ in $\tilde{\chi}_1^0$ to enhance $C_{h_1 \tilde{\chi}_1^0 \tilde{\chi}_1^0}$
    → not too small $C_{h_{SM} \tilde{\chi}_1^0 \tilde{\chi}_1^0}$
  - generically moderate



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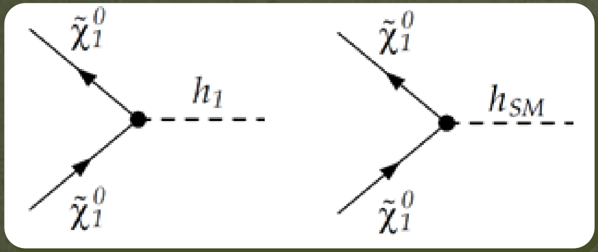
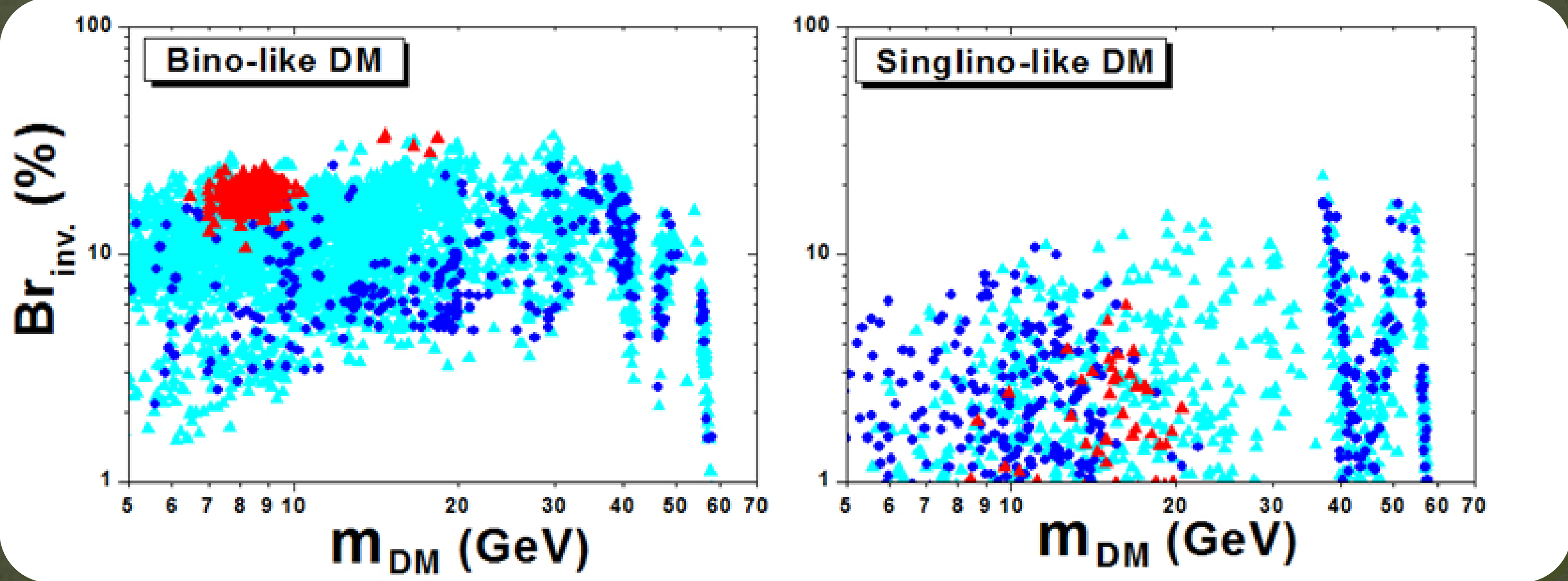
- $Br(h_{SM} \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$



- Singlino-like DM:
  - small λ, κ → small $C_{h_{SM}\tilde{\chi}_1^0\tilde{\chi}_1^0}$
  - at most 20%



Results

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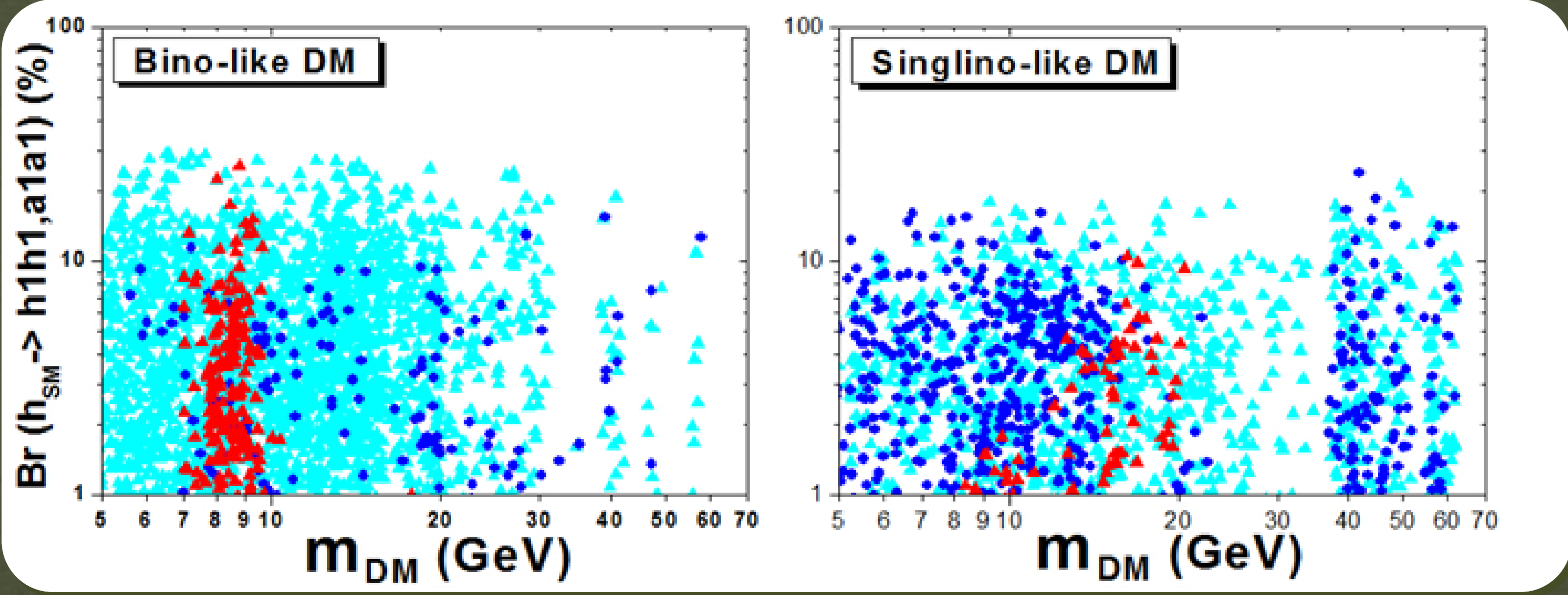
Cyan: LUX-300kg, $m_{h_1} < m_{a_1}$
Blue: LUX-300kg, $m_{h_1} > m_{a_1}$

- $h_{\mathrm{SM}} \to h_1 h_1, a_1 a_1$
  - Bino-like: moderate λ, κ
    - accidental cancellation
    - about 30%
  - Singlino-like: small λ, $|\kappa| \ll \lambda$
    - reduce $C_{h_{\mathrm{SM}} h_1 h_1}, C_{h_{\mathrm{SM}} a_1 a_1}$
    - about 20%



Conclusion

- $m_{\tilde{\chi}_1^0}$ ~8 GeV is still allowed, σ_p^{SI} can reach GoGeNT/CDMS-II region
- LUX cuts deeply into parameter space, but still leave a light DM viable
- Under current LHC data, $Br_{inv.}$ can reach 30%, which may be covered by 14 TeV LHC