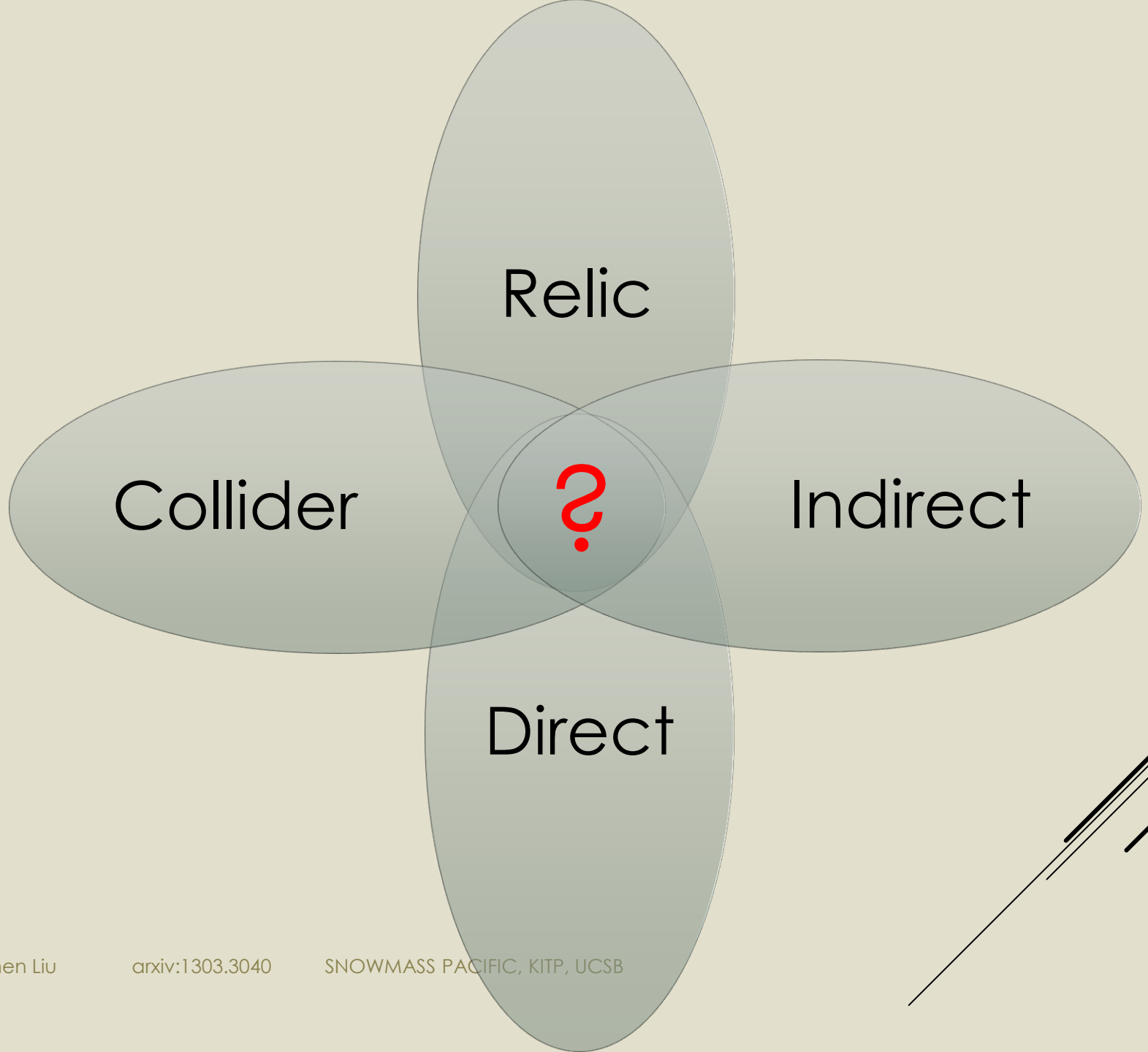
DARK MATTER AND HIGGS BOSONS IN THE MSSM

Zhen Liu

Based upon work with

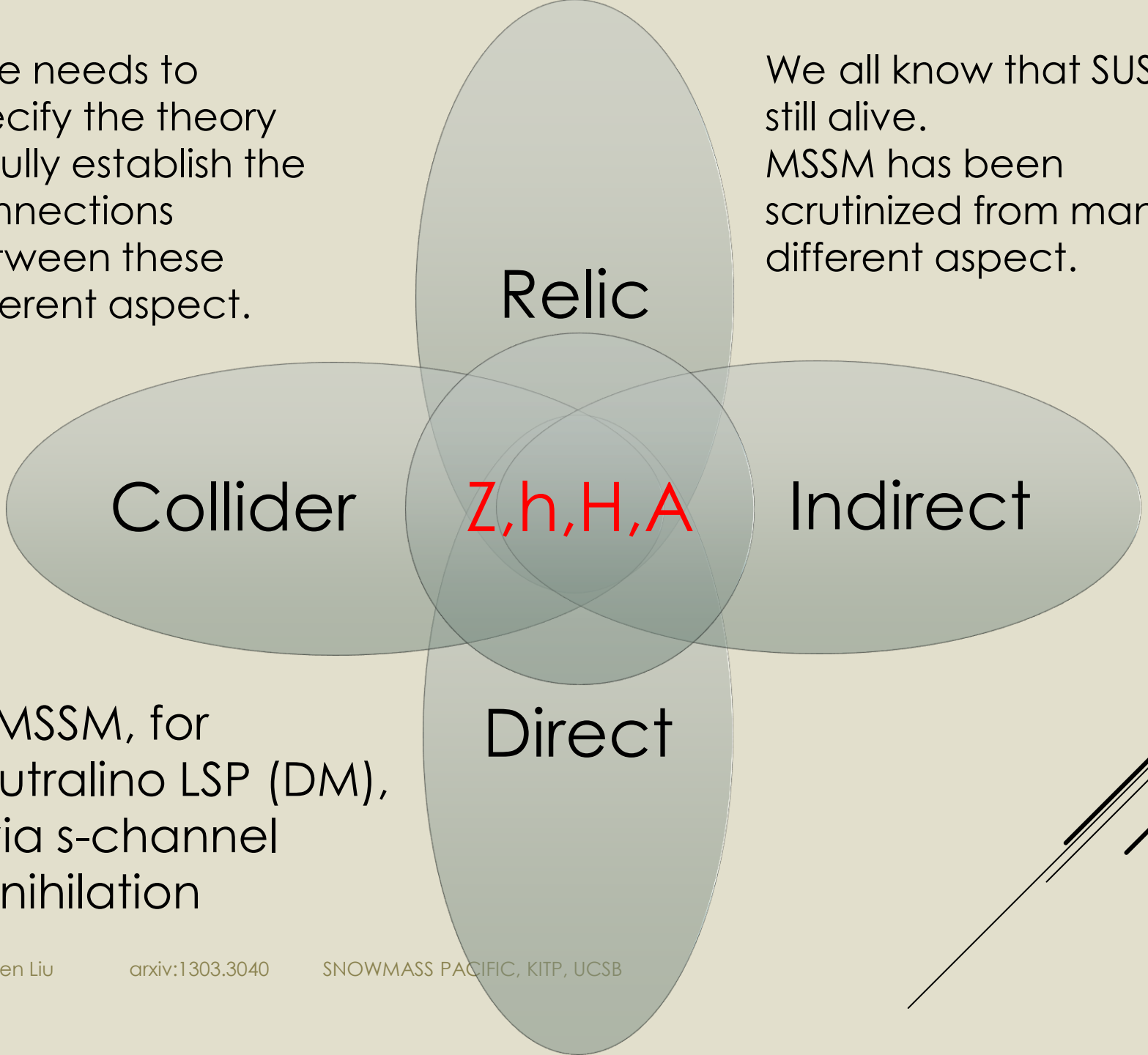
Tao Han and Aravind Natarajan, arxiv:1303.3040

SNOWMASS
PACIFIC
KITP,UCSB


Relic
Collider
?
Indirect
Direct

One needs to specify the theory to fully establish the connections between these different aspect.

We all know that SUSY is still alive.
MSSM has been scrutinized from many different aspect.



In MSSM, for neutralino LSP (DM), If via s-channel annihilation

Neutralino Lightest Supersymmetirc Particle (LSP)

$$\chi_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}_3 + N_{13}\tilde{H}_d + N_{14}\tilde{H}_u$$

$$\begin{bmatrix} M_1 & 0 & -m_z \cos\beta \sin\theta_w & m_z \sin\beta \sin\theta_w \\ 0 & M_2 & m_z \cos\beta \cos\theta_w & -m_z \sin\beta \cos\theta_w \\ -m_z \cos\beta \sin\theta_w & m_z \cos\beta \cos\theta_w & 0 & -\mu \\ m_z \sin\beta \sin\theta_w & -m_z \sin\beta \cos\theta_w & -\mu & 0 \end{bmatrix}$$

DM CANDIDATE

- Higgs discovery and other collider searches;

  Including LEP, Tevatron and LHC.

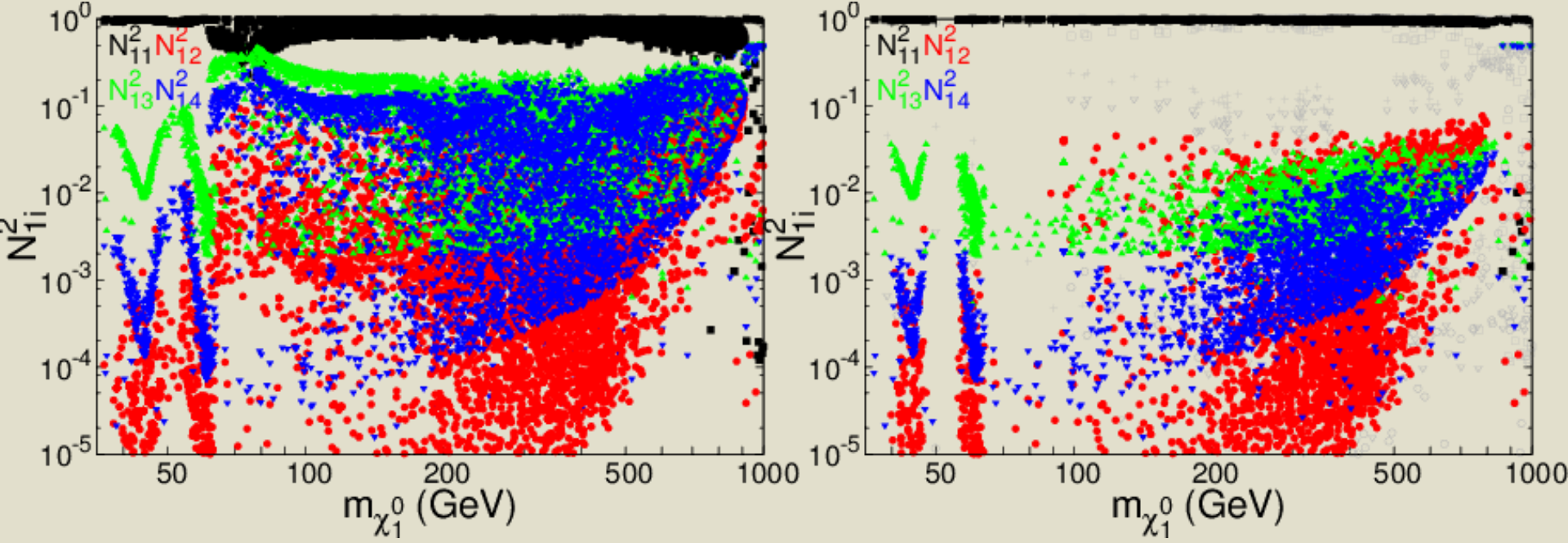
  Diphoton rate > 80% of SM value.
- B physics;
- The thermal relic density;
- DM direct detection.

CONSTRAINTS

Parameters ranges:

$$
\begin{aligned}
5\,\mathrm{GeV} < |M_1| < 2000\,\mathrm{GeV}, \quad & 100\,\mathrm{GeV} < |M_2,\ \mu| < 2000\,\mathrm{GeV}, \\
3 < \tan\beta < 55, \quad & 80\,\mathrm{GeV} < M_{\mathrm{A}} < 1000\,\mathrm{GeV}, \\
-4000\,\mathrm{GeV} < A_{\mathrm{t}} < 4000\,\mathrm{GeV}, \quad & 100\,\mathrm{GeV} < M_{\mathrm{Q3}},\ M_{\mathrm{U3}} < 3000\,\mathrm{GeV}, \\
-4000\,\mathrm{GeV} < A_{\mathrm{b}} < 4000\,\mathrm{GeV}, \quad & 100\,\mathrm{GeV} < M_{\mathrm{D3}} < 3000\,\mathrm{GeV}, \\
-4000\,\mathrm{GeV} < A_{\tau} < 4000\,\mathrm{GeV}, \quad & 100\,\mathrm{GeV} < M_{\mathrm{L3}},\ M_{\mathrm{E3}} < 3000\,\mathrm{GeV}.
\end{aligned}
$$

SCAN SCHEME



Left: before XENON-100

Right: after XENON-100

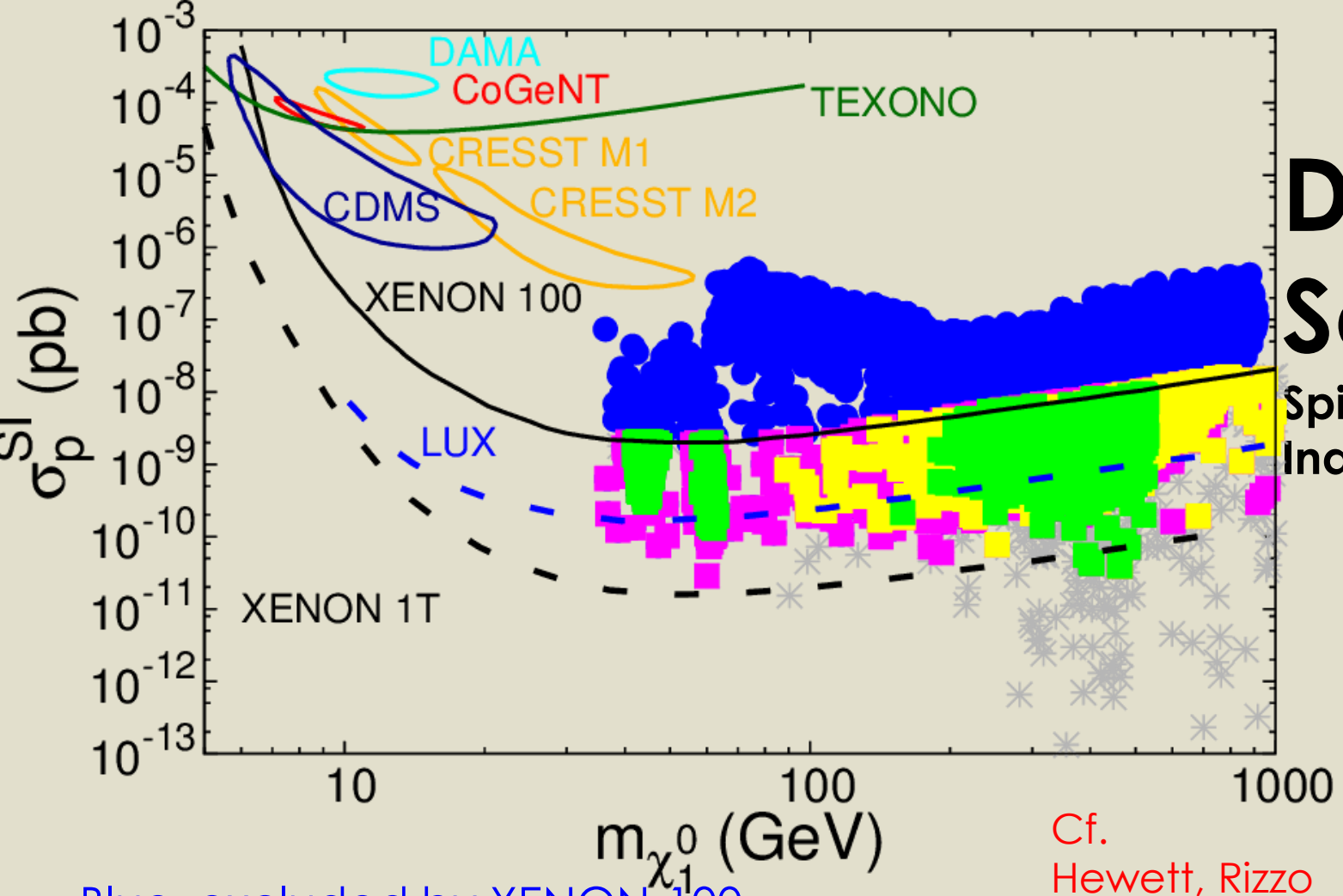
Black, **Bino** fraction

Red, **Wino** fraction

Green, Higgsino 1 (**tilde H_d**) fraction

Blue, Higgsino 2 (**tidle H_u**) fraction

Gaugino and Higgsino Fractions



Direct Search

Spin-Independent

Blue, excluded by XENON-100

Green, **Z-funnel, h-funnel, H/A-funnel**

Yellow, **neutralino/chargino** coannihilation

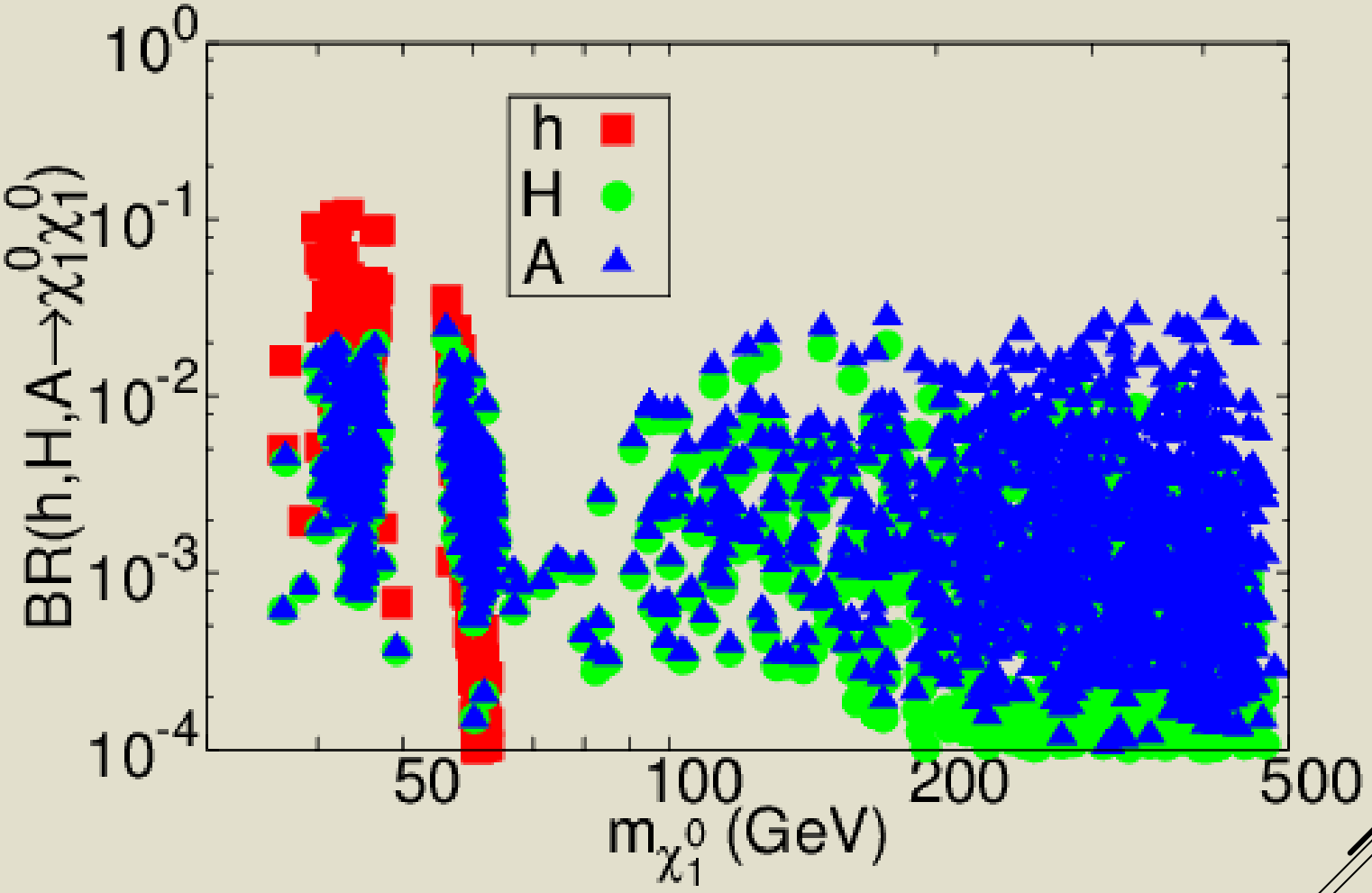
Magenta, stermion assistance

—sfermion coannihilation, t-channel exchange

Gray, "blind spots"

Cf.
Hewett, Rizzo
Arbey et al, 1205.2557
Hooper et al, 1304.2417
Baer et al, 1304.6732
Chueng et al, 1211.4873

Collider

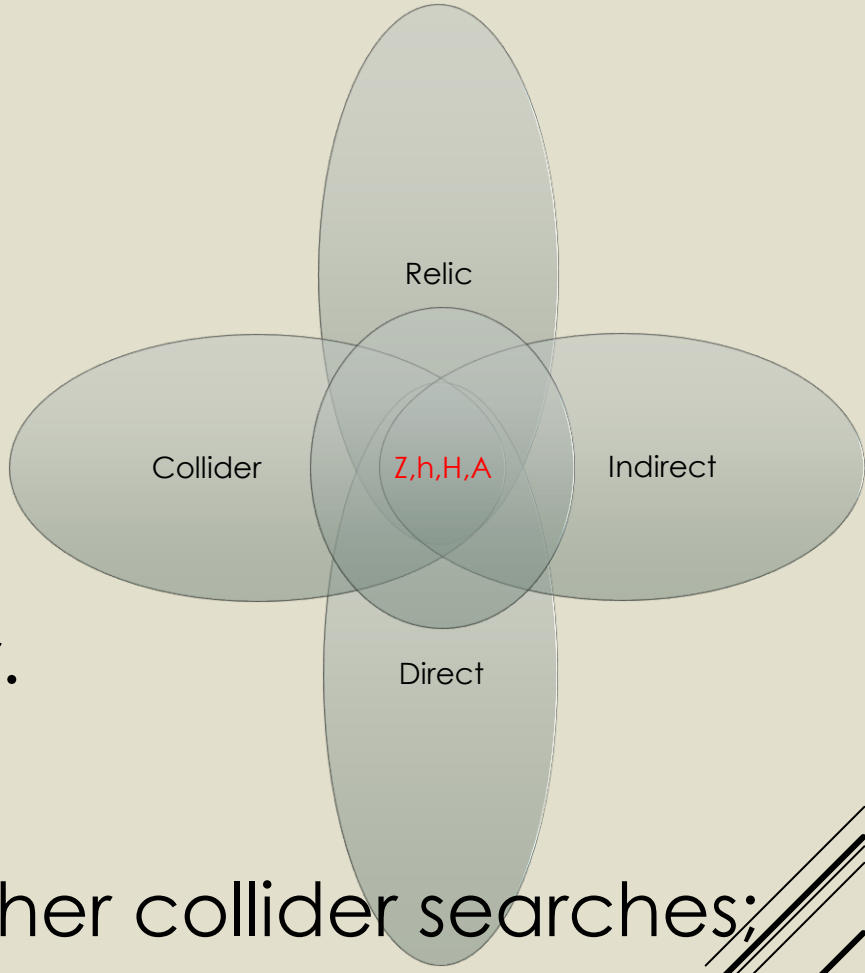


Needs Precise Higgs Invisible Width Measurement/Determination

Type labels	DM mass $m_{\chi_1^0}$	Annihilation channels	Partial waves	$\langle\sigma v\rangle(v \to 0)$	Collider searches
I-A	$\sim m_Z/2$	$\chi_1^0\chi_1^0 \to Z$	p	low	$Z, h, H, A \to \chi_1^0\chi_1^0$
I-B	$\sim m_h/2$	$\chi_1^0\chi_1^0 \to h$	p	low	$h, H, A \to \chi_1^0\chi_1^0$
I-C	$\sim m_A/2$	$\chi_1^0\chi_1^0 \to A$	s	high	$H, A \to \chi_1^0\chi_1^0$
II-A	$m_{\chi_1^0} \sim m_{\chi_1^\pm}$ $\sim m_{\chi_2^0}$	$\chi_1^0\chi_2^0, \chi_1^0\chi_1^\pm$ $\chi_2^0\chi_2^0, \chi_1^+\chi_1^-$ $\to SM$	s+p	medium	$H, A \to \chi_1^0\chi_2^0$ $H, A \to \chi_2^0\chi_2^0$ $H^\pm \to \chi_1^0\chi_1^\pm$
II-B	$m_{\chi_1^0} \sim m_{\tilde{\tau}_1}$ $\sim m_{\tilde{\nu}_\tau}$	$\tilde{\tau}_1^+\tilde{\tau}_1^-, \tilde{\nu}_\tau\tilde{\nu}_\tau,$ $\chi_0^1\tilde{\tau}_1^\pm \to SM$	s+p	medium	$H, A \to \tilde{\tau}_1^+\tilde{\tau}_1^-$ $H^\pm \to \tilde{\tau}_1^\pm\tilde{\nu}_\tau$

Simplified Summary Table

Summary



We performed a study on MSSM with a neutralino LSP as the full Dark Matter.

(a) Higgs discovery and other collider searches;
(b) B physics;
(c) The thermal relic density;
(d) DM direct detection.

Conclusion

(1) DM Largely a Bino-like neutralino
(2) Low Mass DM disfavored;
(3) Funnels and Coannihilation;
(4) Lower bound on sigma_SI for funnels
(5) Indirect search will hit A-funnel
(6) Higgs decays to neutralino, chargino pairs.

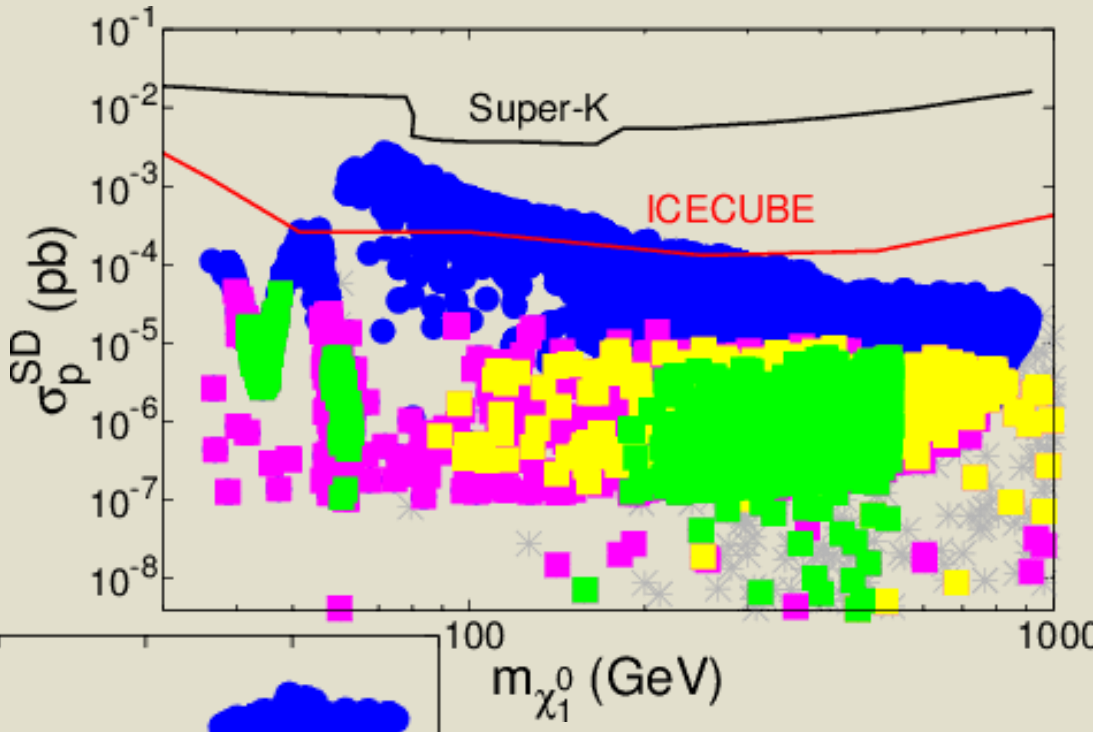
Limitations

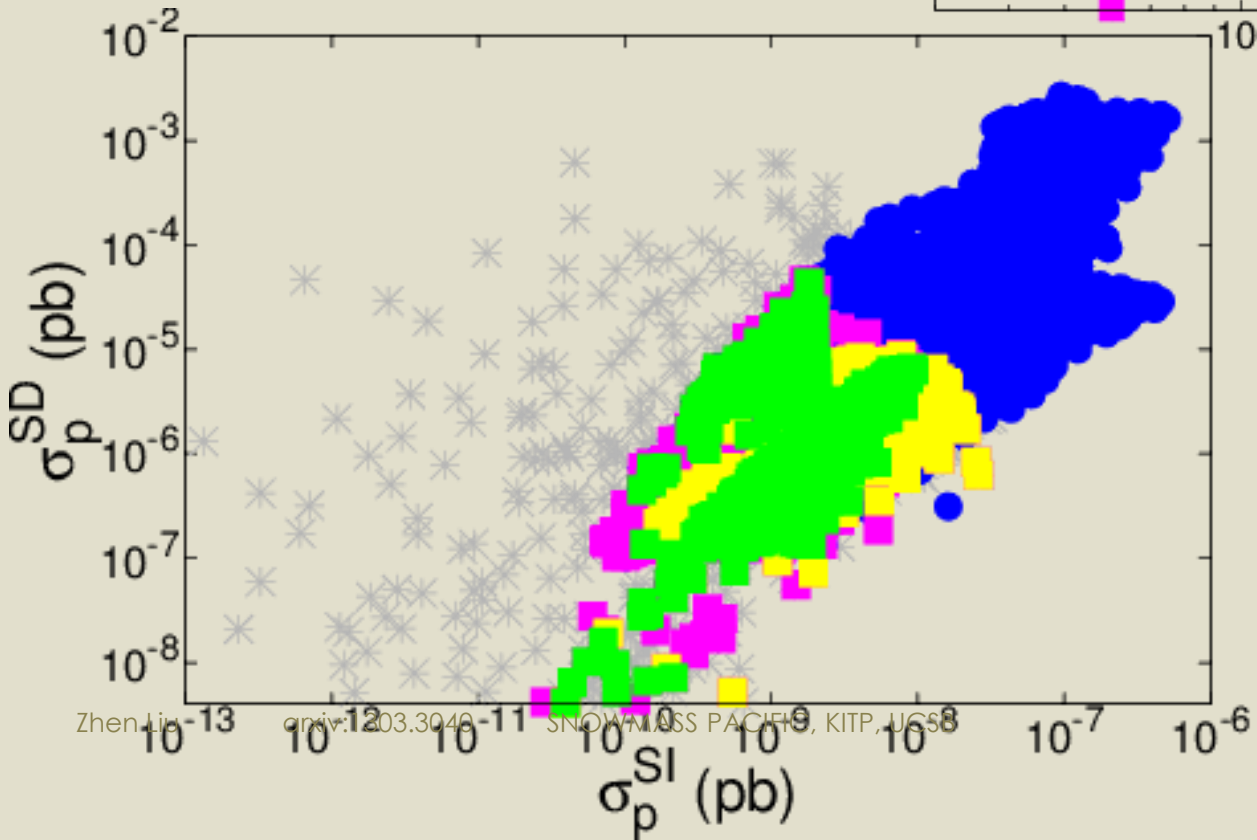
Thermal DM (no non-Thermal);
Neutralino DM (no gravitino DM);
Single DM (no multiple DM, dynamical DM, etc.);
Standard Cosmology/Astrophysics
(no special modes for the DM density profile—uncertainties, etc.)
…

BACKUP

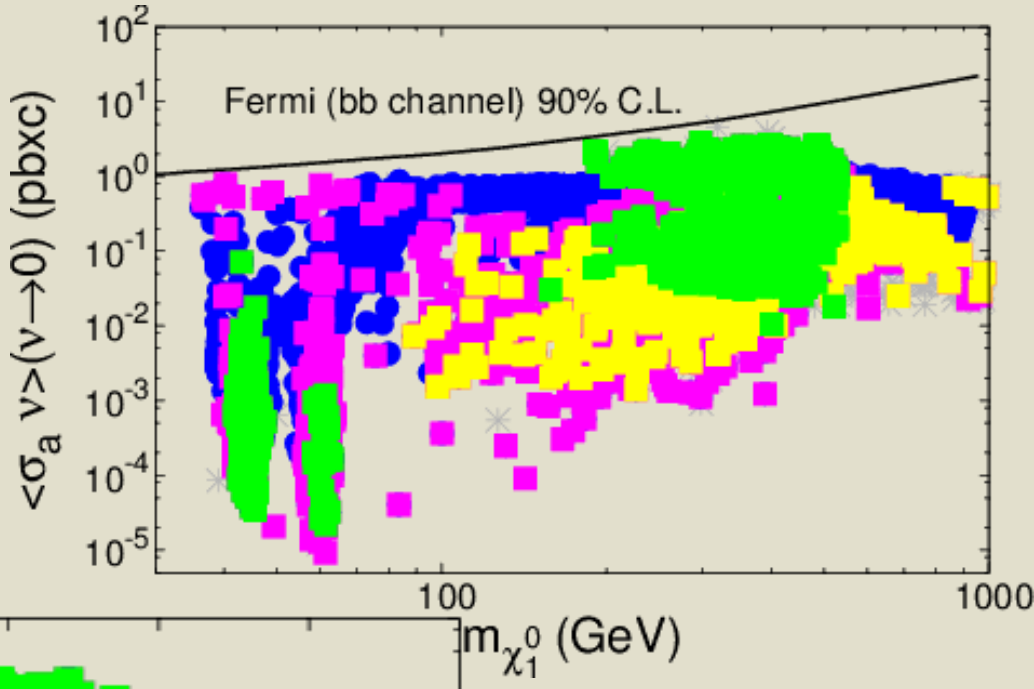
Direct Search

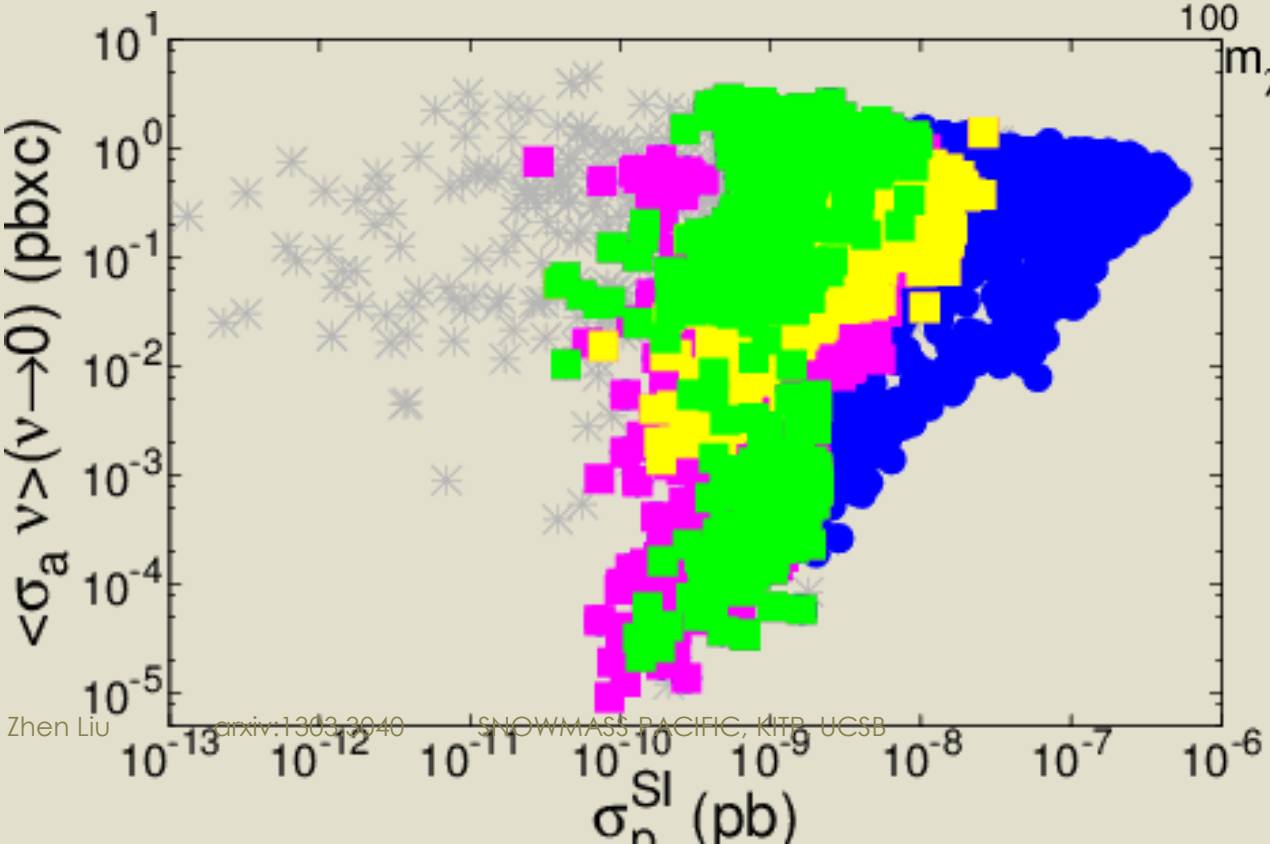
Spin-Dependent



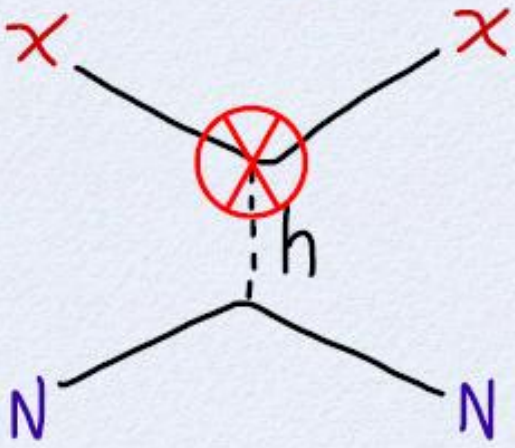


Indirect Search



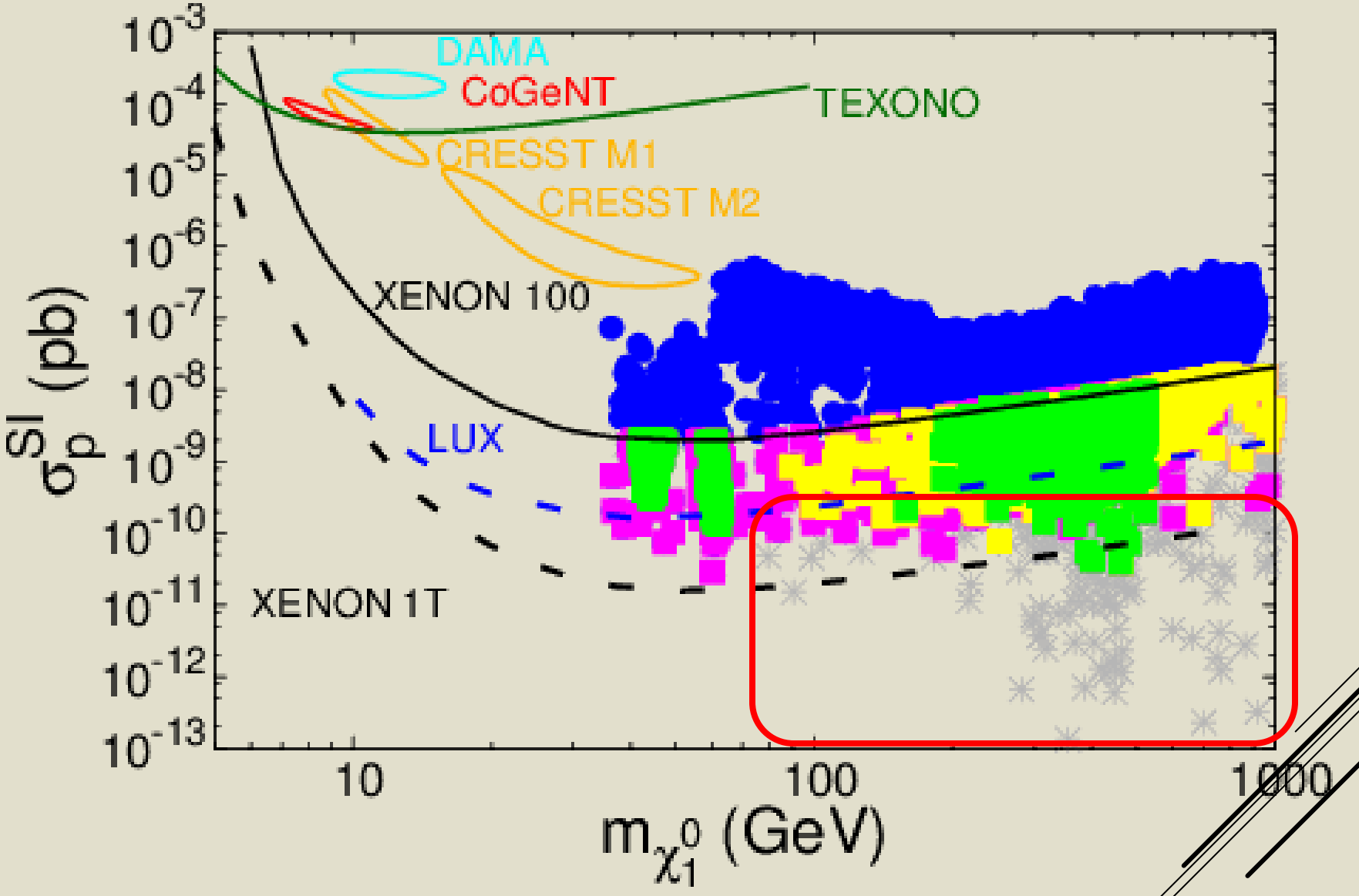


blindspots

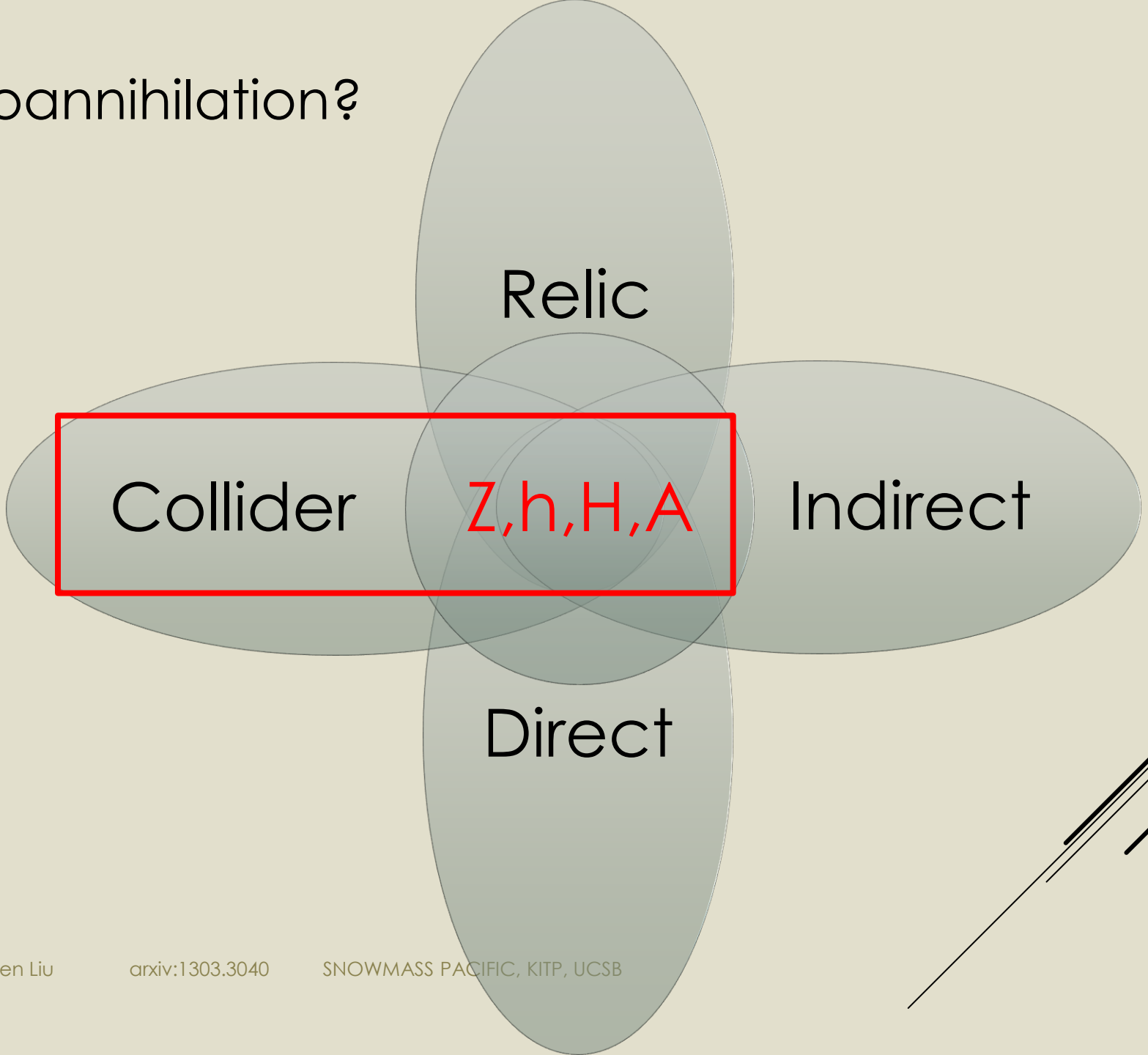


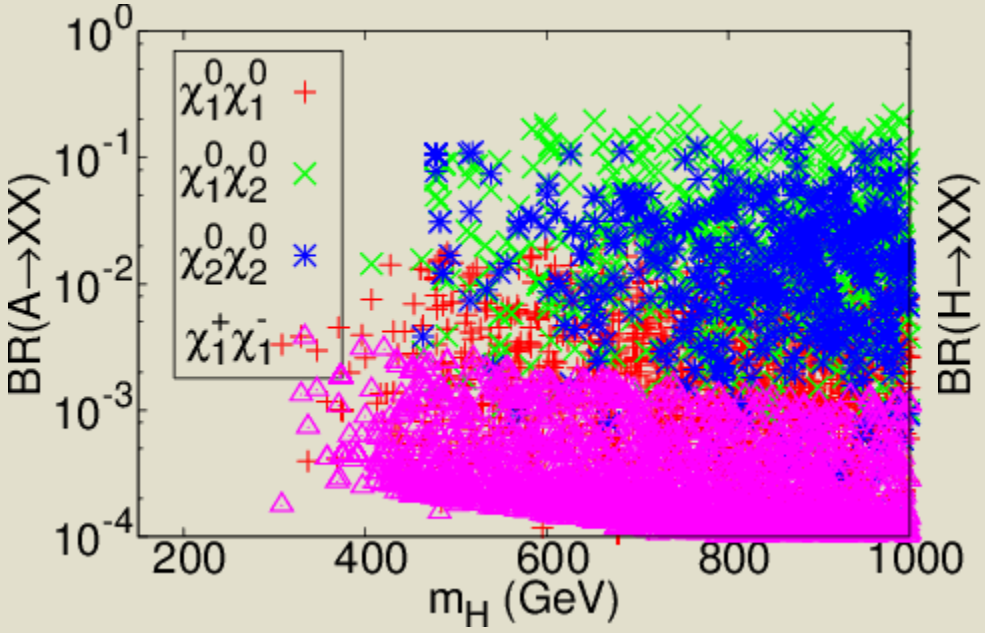
	m_χ	condition	signs
bino	M_1	$M_1 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_1/\mu) = -1$
wino	M_2	$M_2 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_2/\mu) = -1$
higgsino	$-\mu$	$\tan\beta = 1$	$\mathrm{sign}(M_{1,2}/\mu) = -1$
bino/wino	M_2	$M_1 = M_2$	$\mathrm{sign}(M_{1,2}/\mu) = -1$

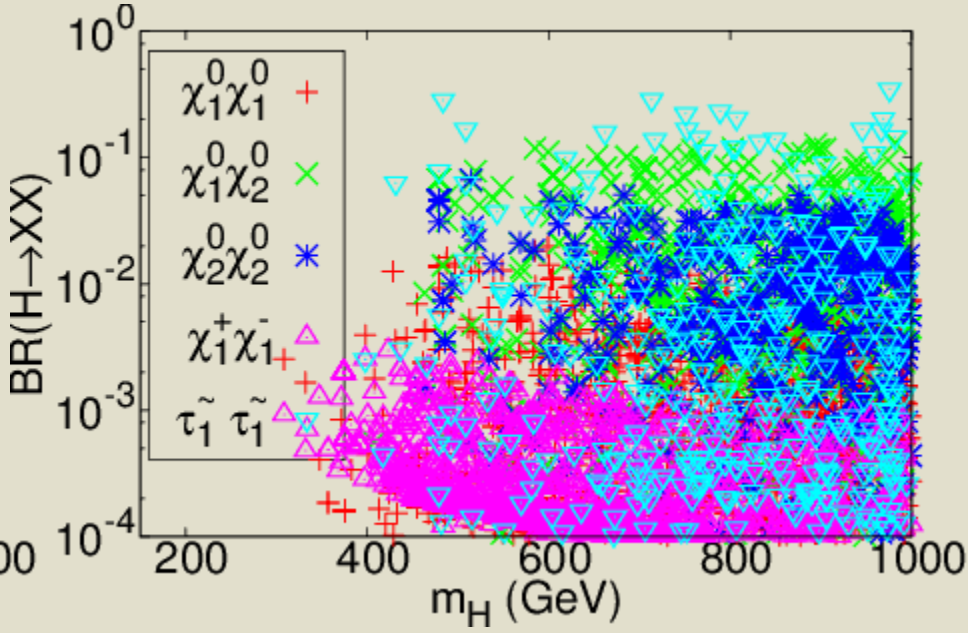
From Josh Runderman's talk at Texas A&M DM workshop, See more "blind spots" on Arxiv: 1211.4873

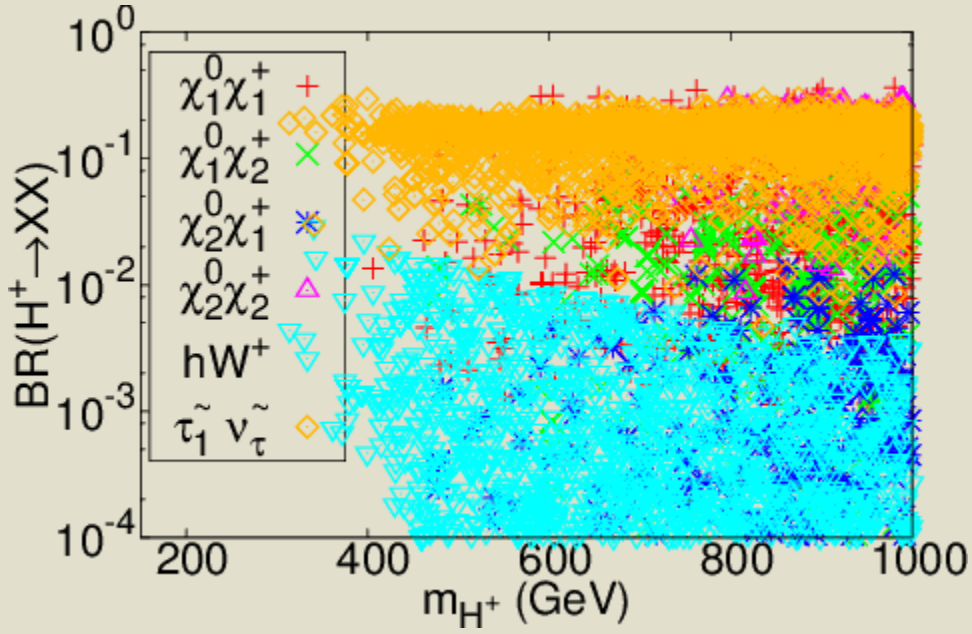

DAMA
CoGeNT
TEXONO
CRESST M1
CRESST M2
XENON 100
LUX
XENON 1T
σ_p^{SI} (pb)
$m_{\chi_1^0}$ (GeV)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10
100
1000

Coannihilation?









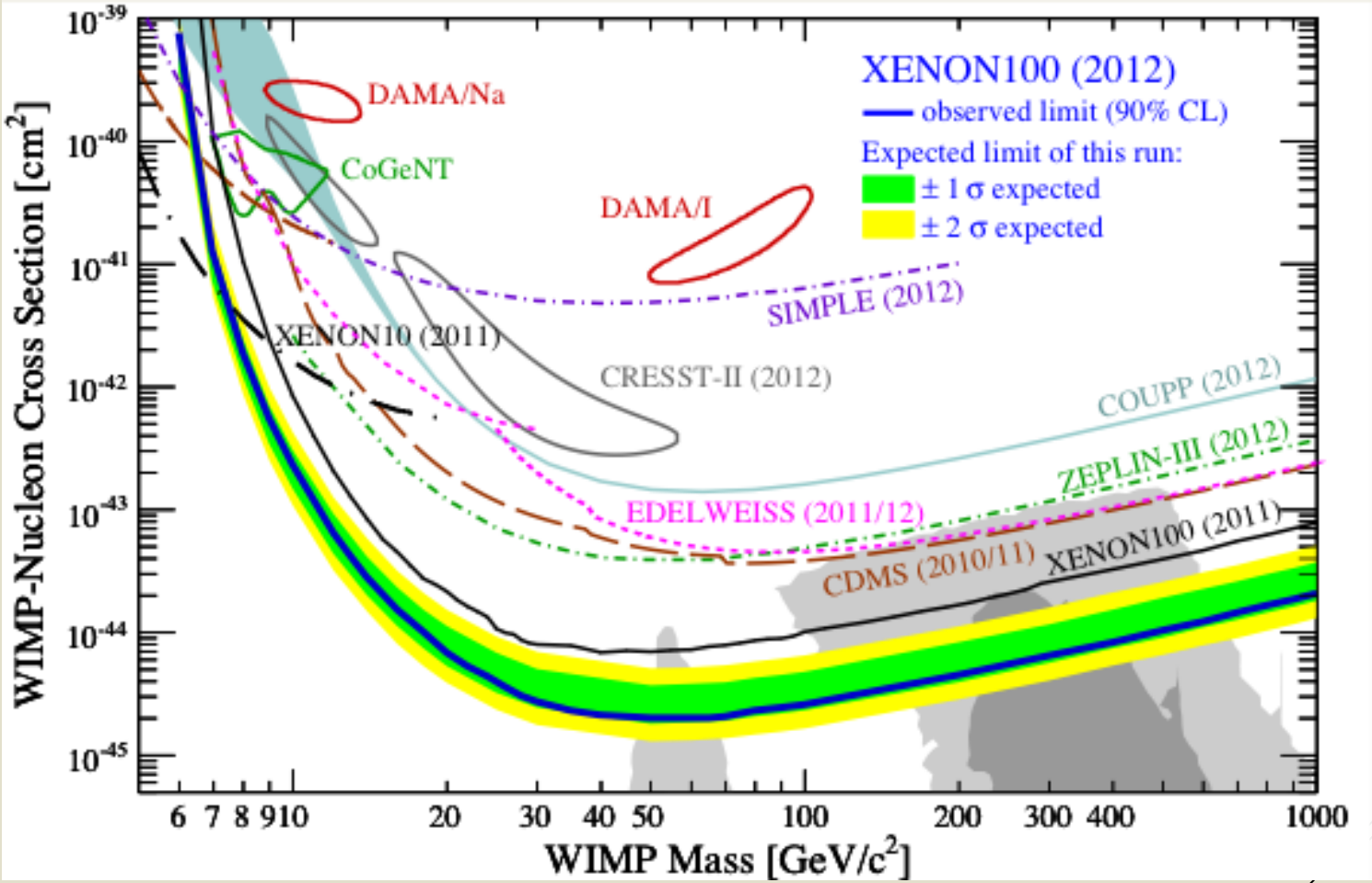
Higgs Decays

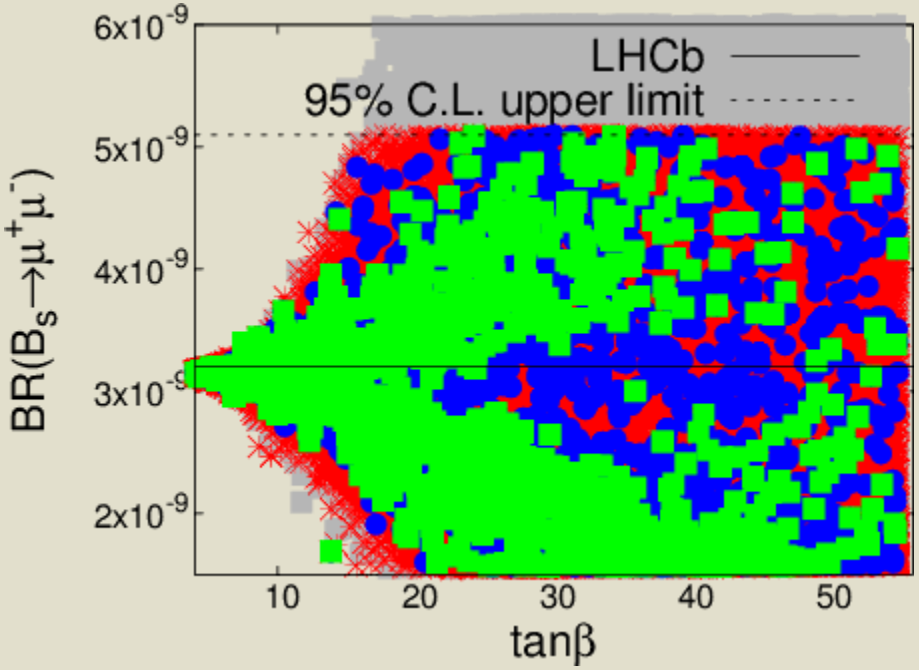
Relic Density

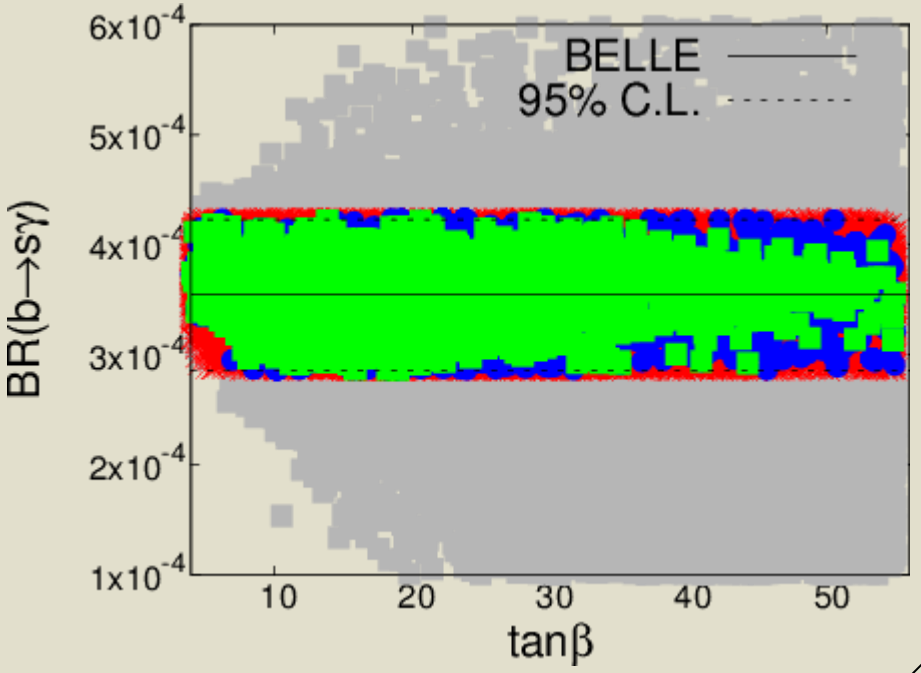
WMAP9/ACT/SPT…+10% theo. Uncertainty:

$$0.0915 < \Omega_{\chi_1^0} h^2 < 0.1381$$

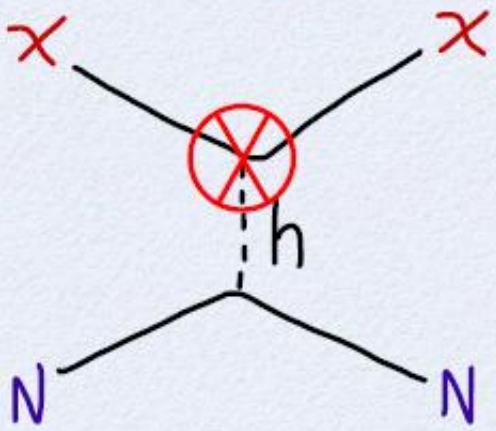
Direct DM Search




LHCb
95% C.L. upper limit
BR(B_s→μ^+μ^-)
6x10^-9
5x10^-9
4x10^-9
3x10^-9
2x10^-9
10
20
30
40
50
tanβ


BELLE
95% C.L.
BR(b→sγ)
6x10^-4
5x10^-4
4x10^-4
3x10^-4
2x10^-4
1x10^-4
10
20
30
40
50
tanβ

blindspots



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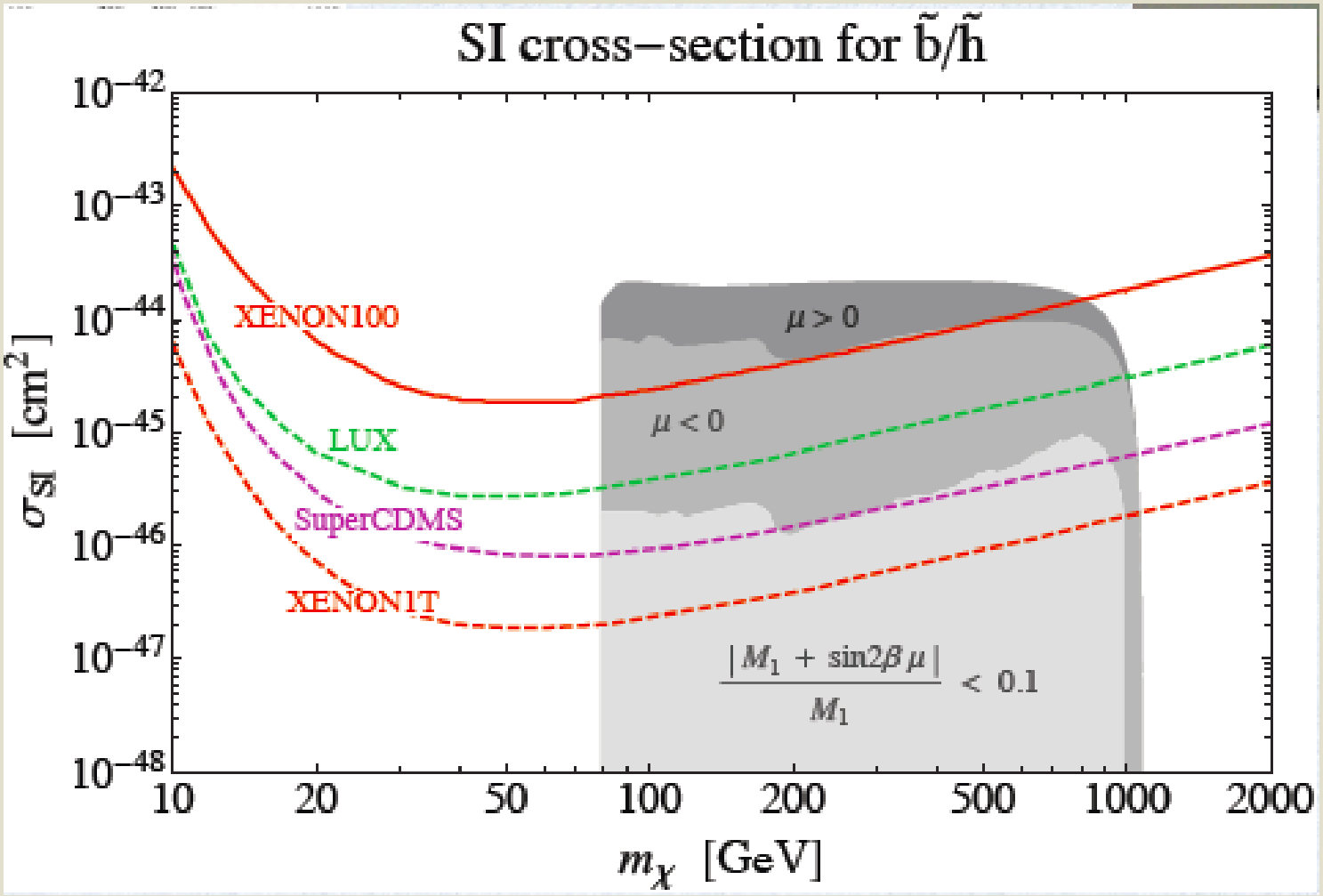
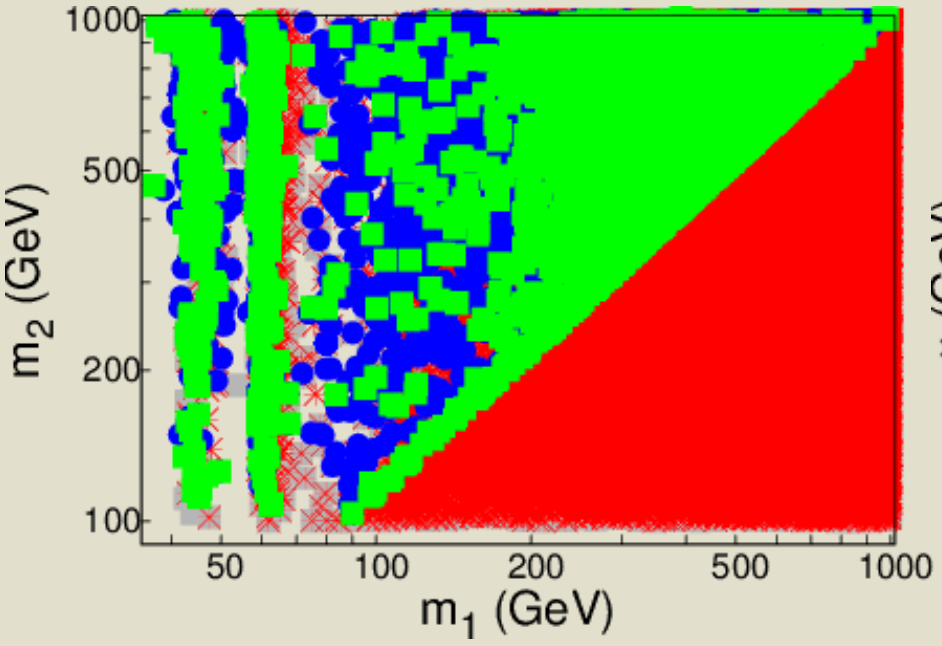
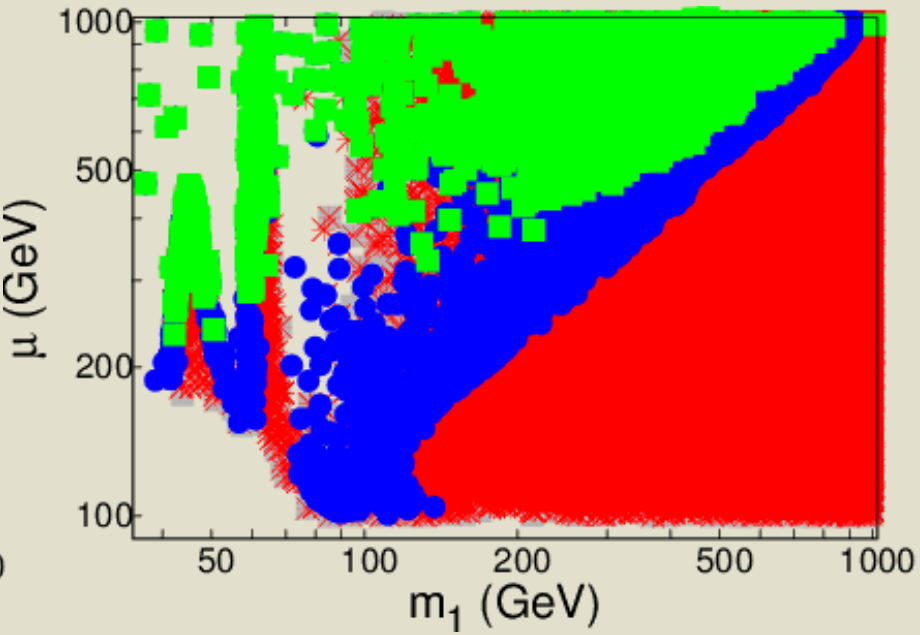
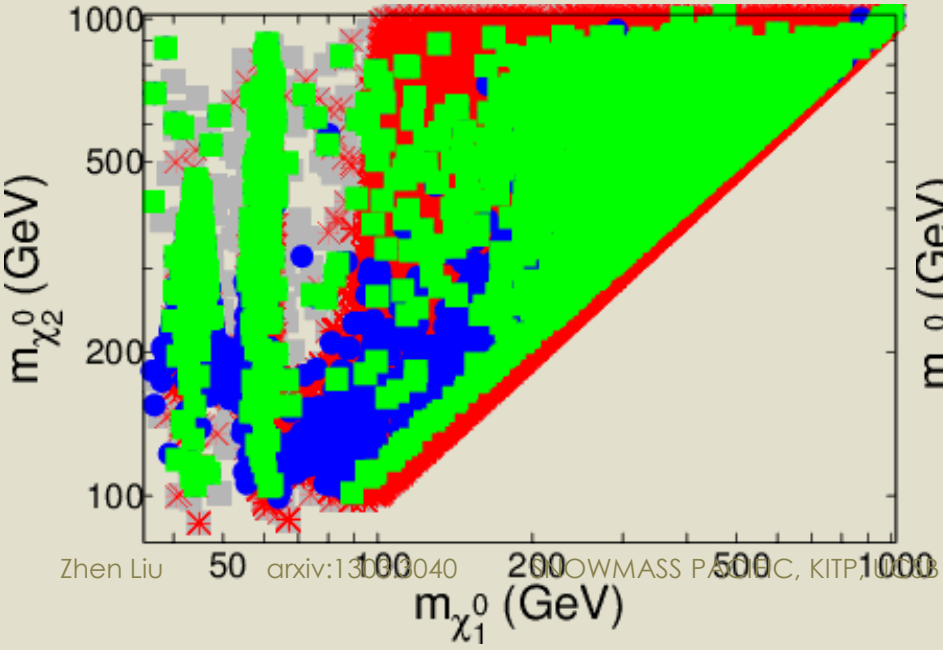
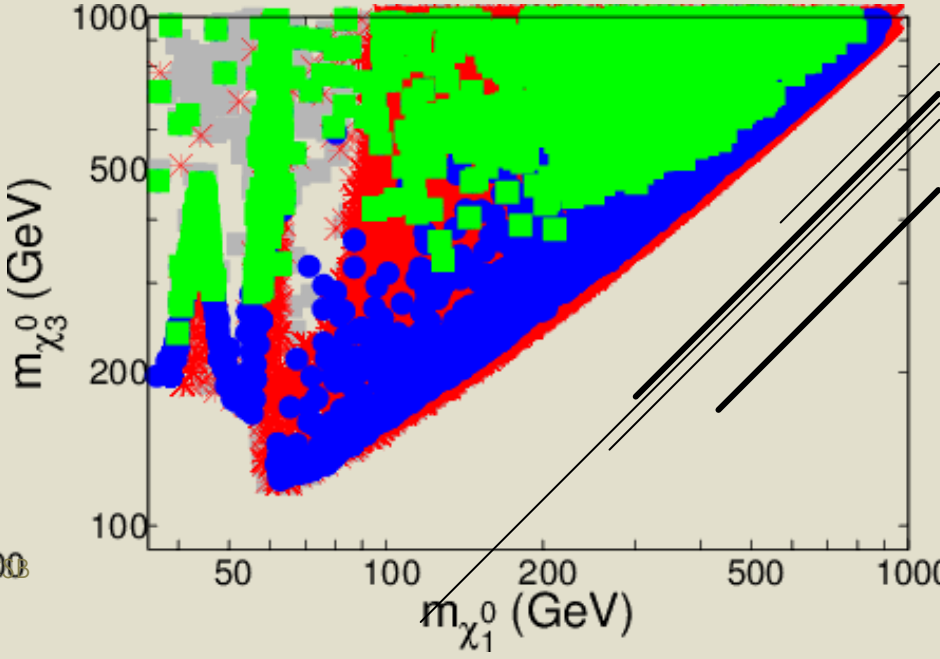
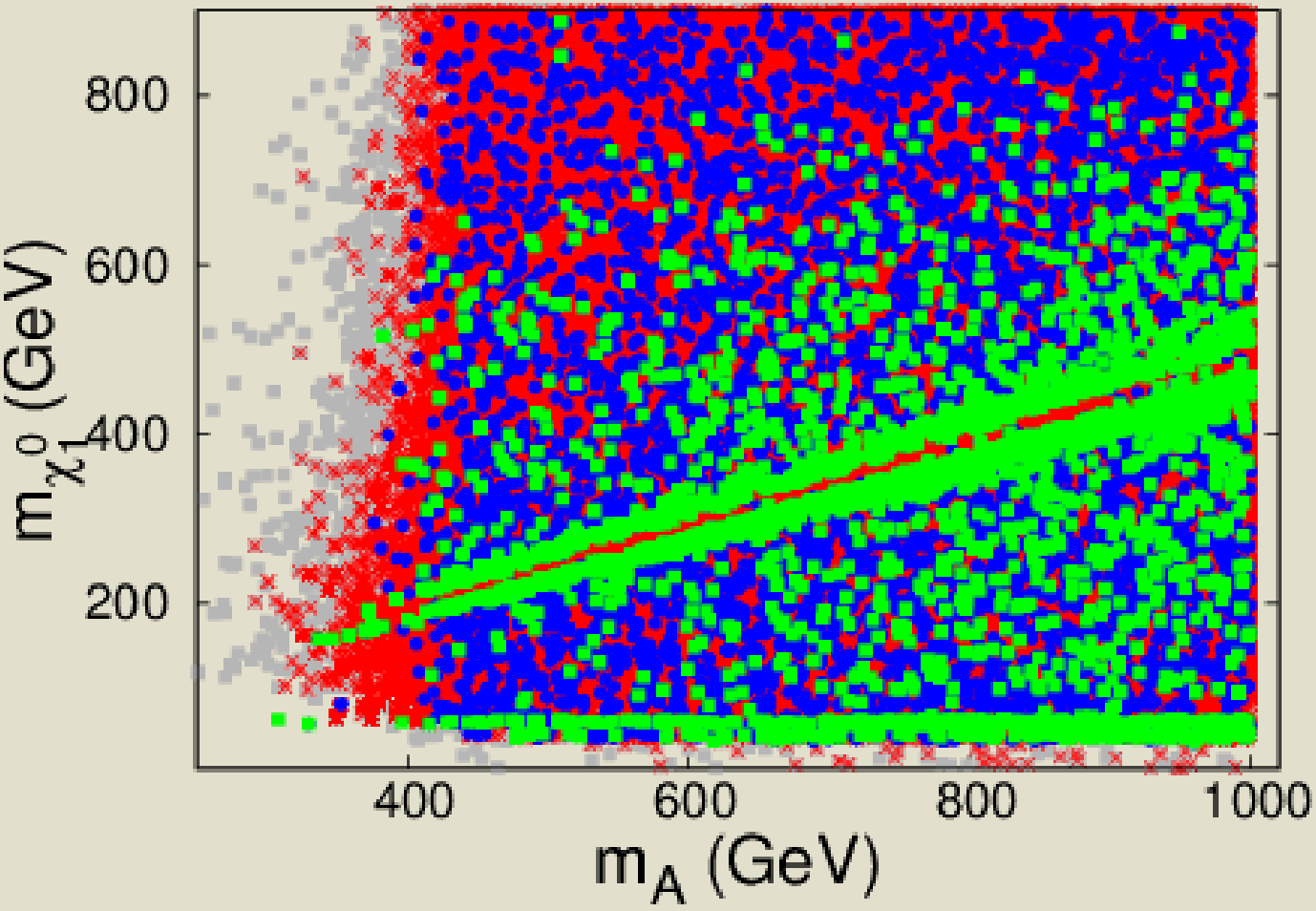

SI cross−section for b̃/h̃
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
σ_{SI} [cm^2]
XENON100
LUX
SuperCDMS
XENON1T
$\mu > 0$
$\mu < 0$
$\frac{|M_1 + \sin 2\beta\,\mu|}{M_1} < 0.1$
10
20
50
100
200
500
1000
2000
m_χ [GeV]


1000
500
200
100
50
100
200
500
1000
m_2 (GeV)
m_1 (GeV)


1000
500
200
100
50
100
200
500
1000
μ (GeV)
m_1 (GeV)


1000
500
200
100
50
100
200
500
1000
$m_{\chi_2^0}$ (GeV)
$m_{\chi_1^0}$ (GeV)


1000
500
200
100
50
100
200
500
1000
$m_{\chi_3^0}$ (GeV)
$m_{\chi_1^0}$ (GeV)


800
600
400
200
$m_{\chi_1^0}$ (GeV)
400
600
800
1000
m_A (GeV)