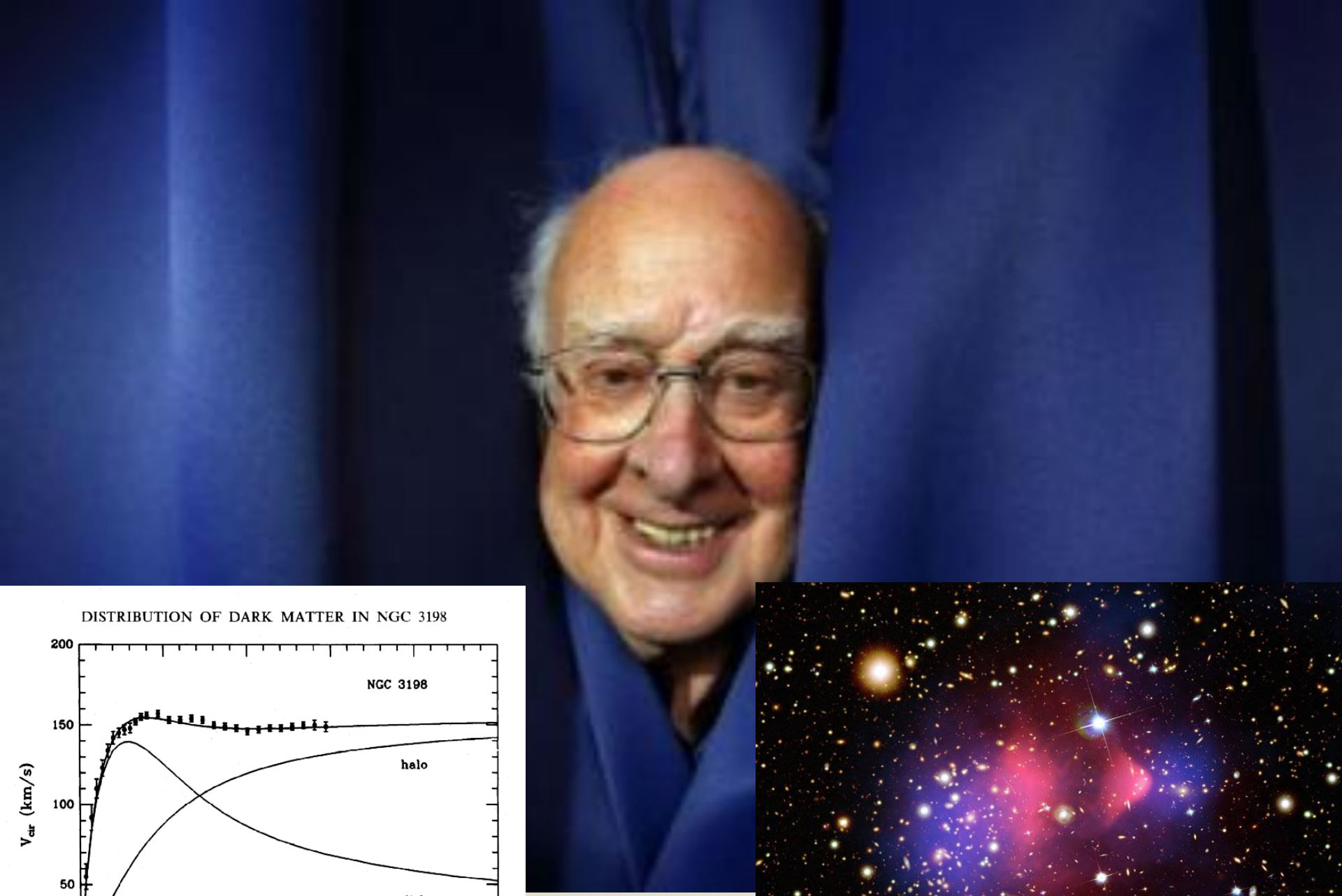
DARK MATTER AND HIGGS BOSONS IN THE MSSM

Zhen Liu

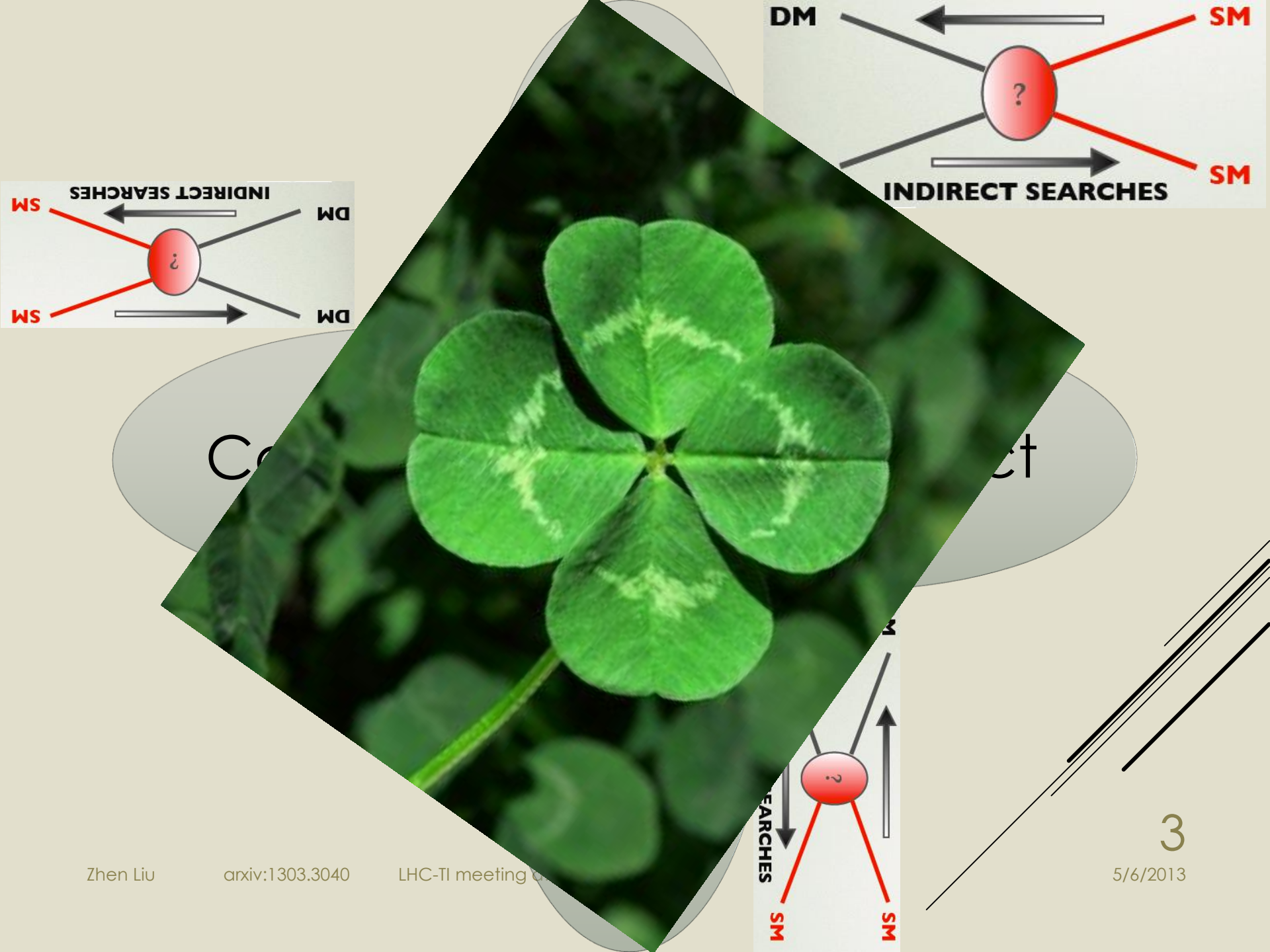
Based upon work with

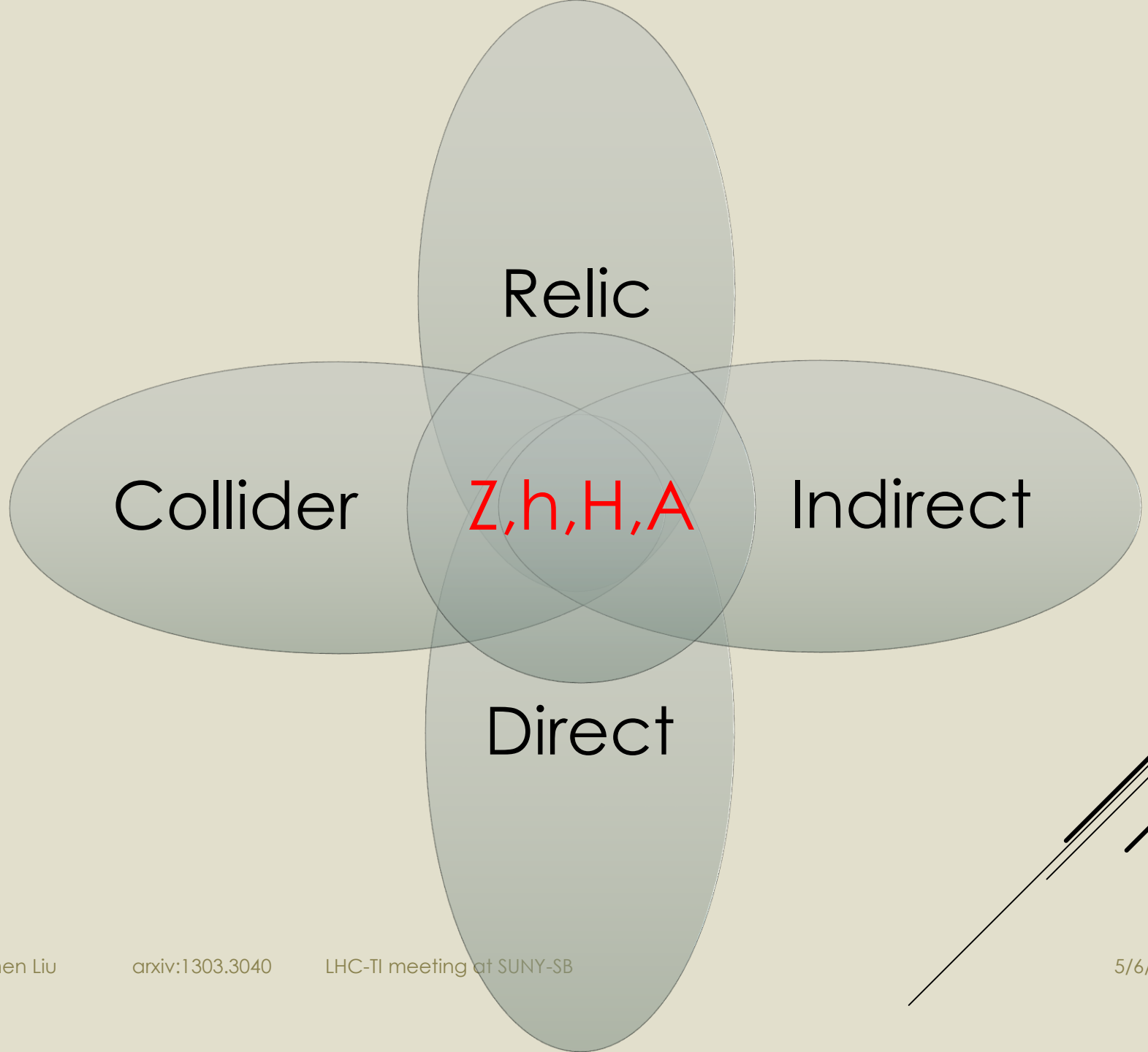
Tao Han and Aravind Natarajan, arxiv:1303.3040

Pheno 2013



ting at SUNY-SB


DM
SM
?
SM
INDIRECT SEARCHES


Relic
Collider
Z,h,H,A
Indirect
Direct

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

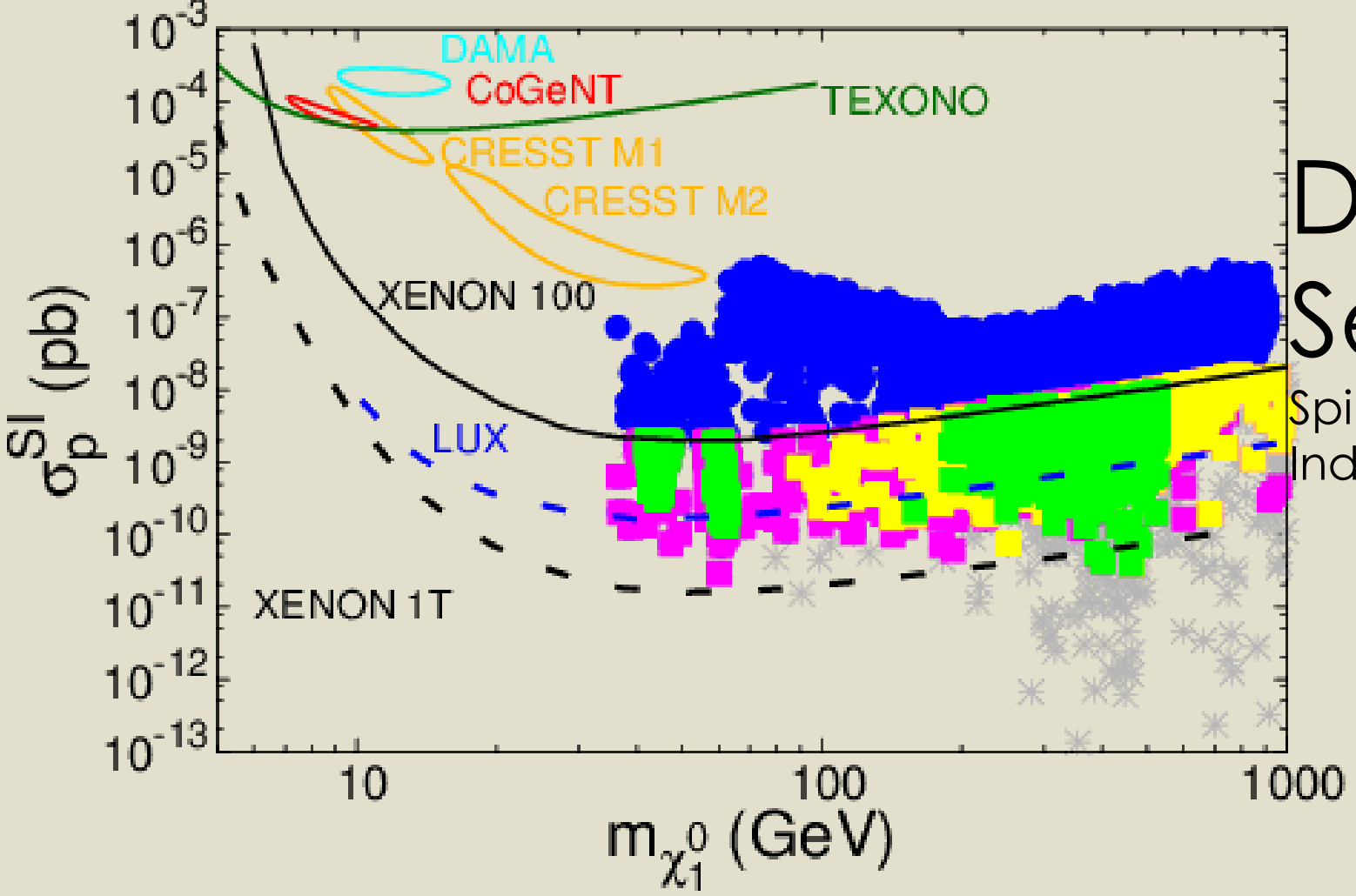
Parameters ranges:

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

SCAN SCHEME

Direct Search

Spin-Independent



Blue, excluded by XENON-100

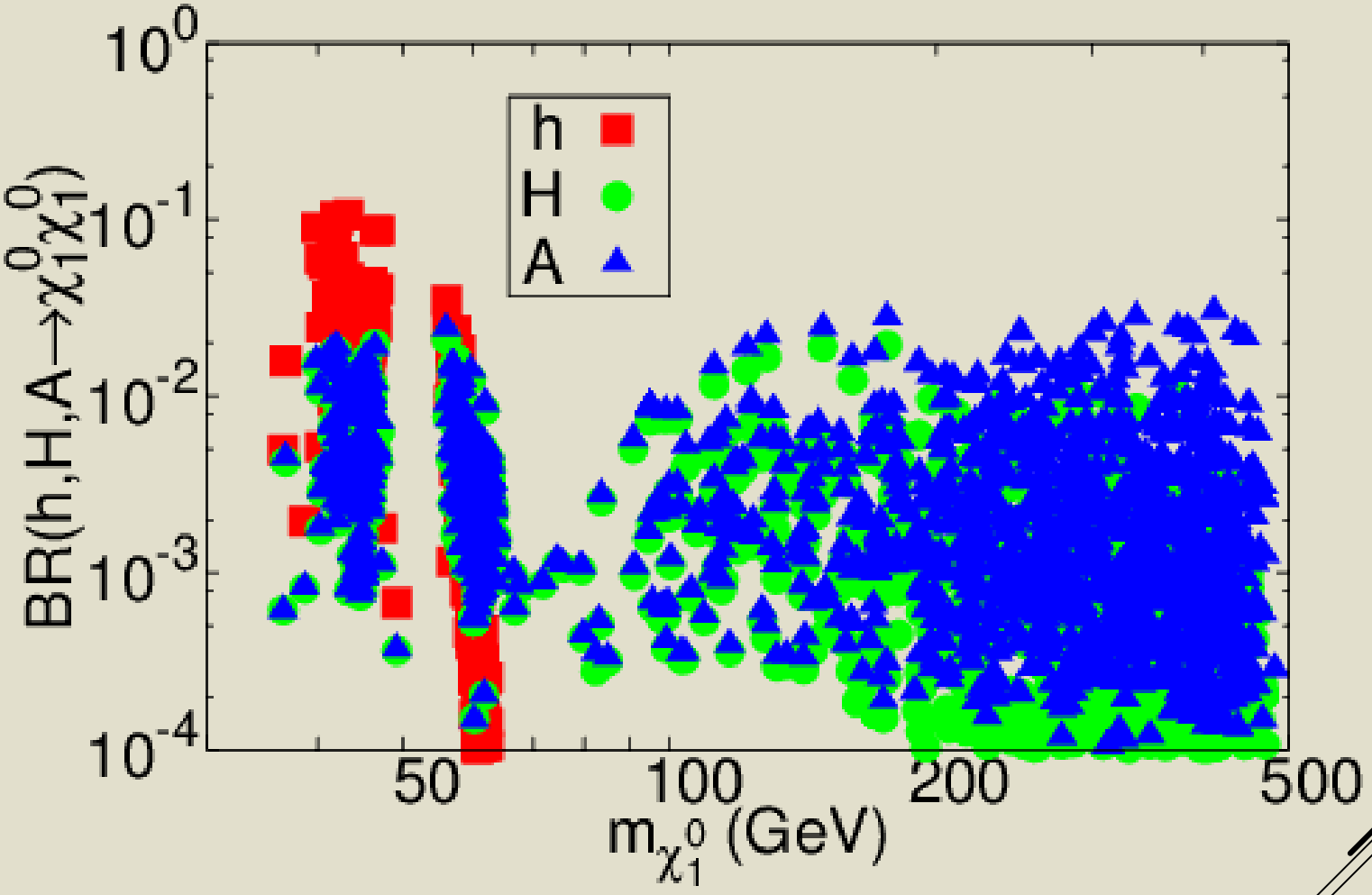
Green, Z-funnel, h-funnel, H/A-funnel

Yellow, neutralino/chargino coannihilation

Magenta, stermion assistance

—sfermion coannihilation, t-channel exchange

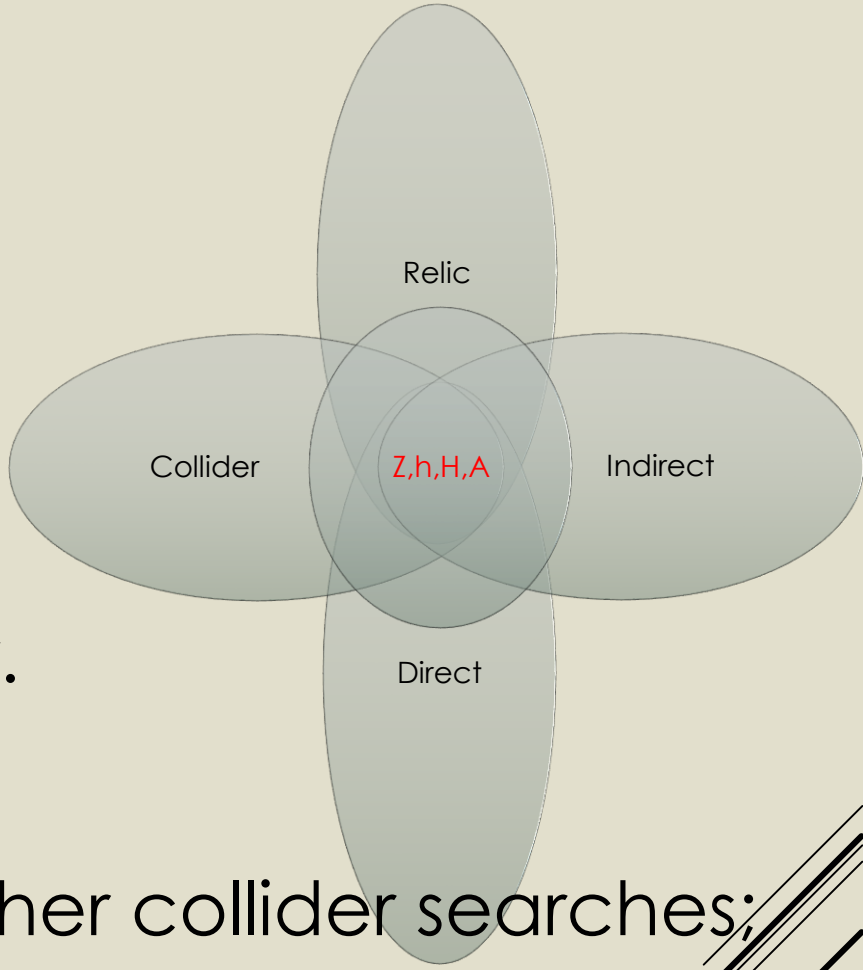
Gray, "blind spots"


h
H
A
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$BR(h,H,A\to\chi_1^0\chi_1^0)$
50
100
200
500
$m_{\chi_1^0}$ (GeV)

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	$h, H, A \to \chi_1^0\chi_1^0$
I-B	$\sim m_h/2$	$\chi_1^0\chi_1^0 \to h$	p	low	$H, A \to \chi_1^0\chi_1^0$
I-C	$\sim m_A/2$	$\chi_1^0\chi_1^0 \to A, H$	s, p	high	
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

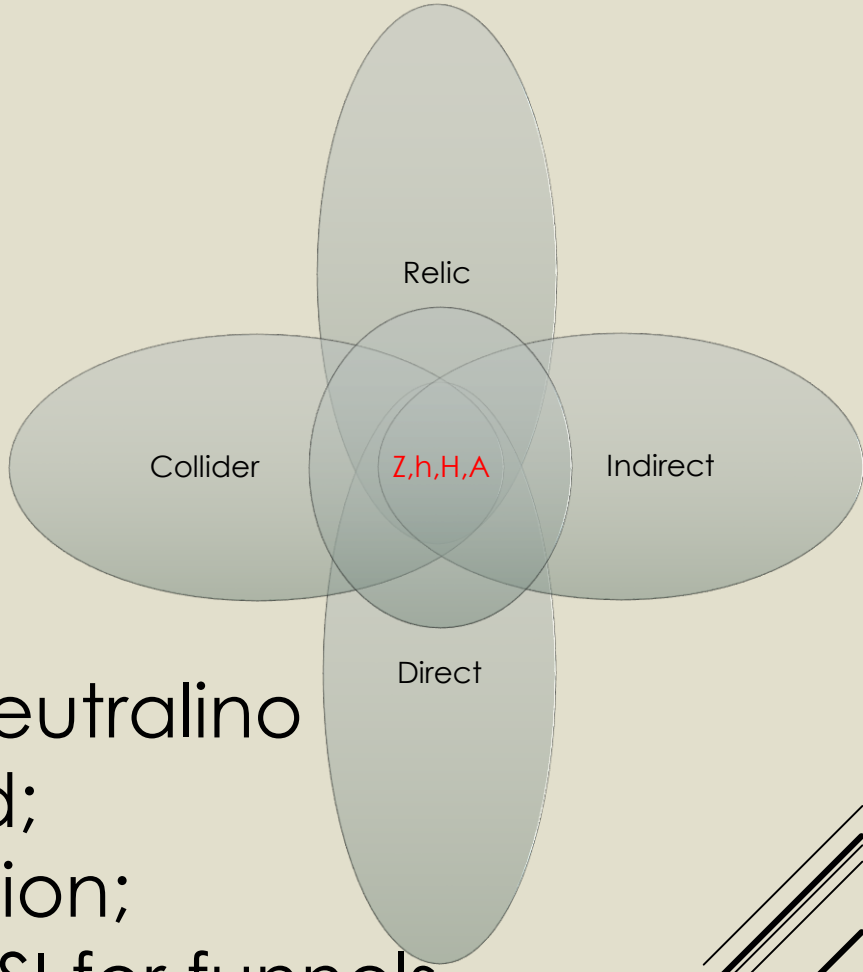
Summary



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

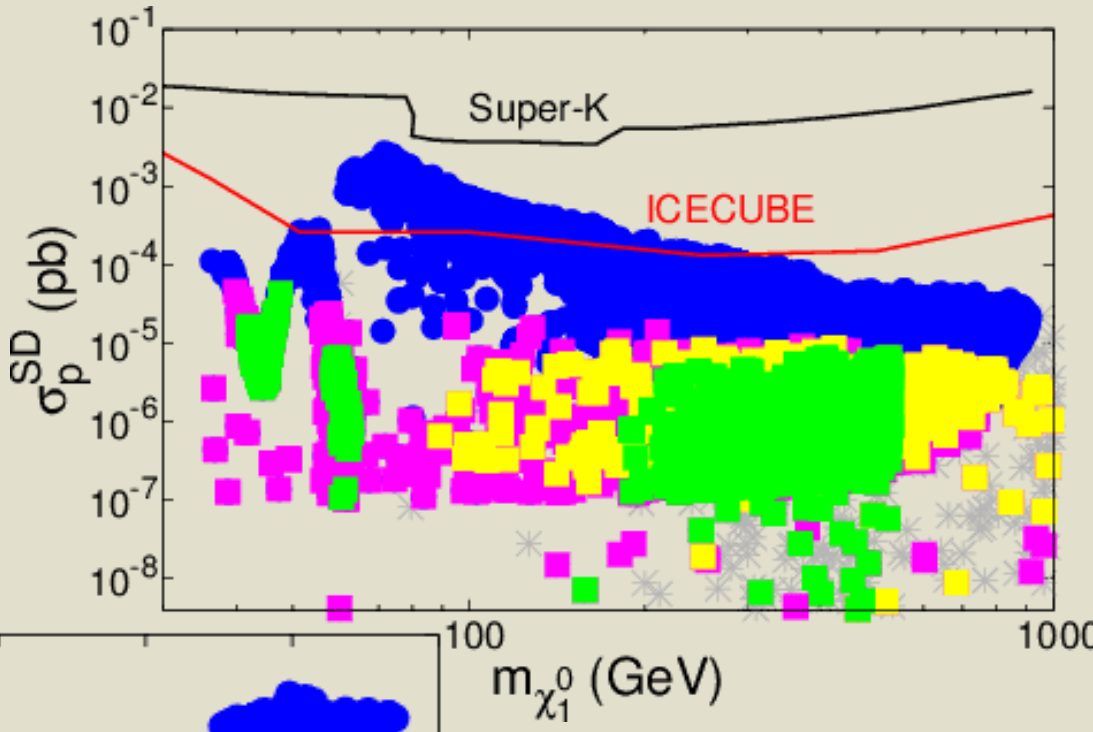


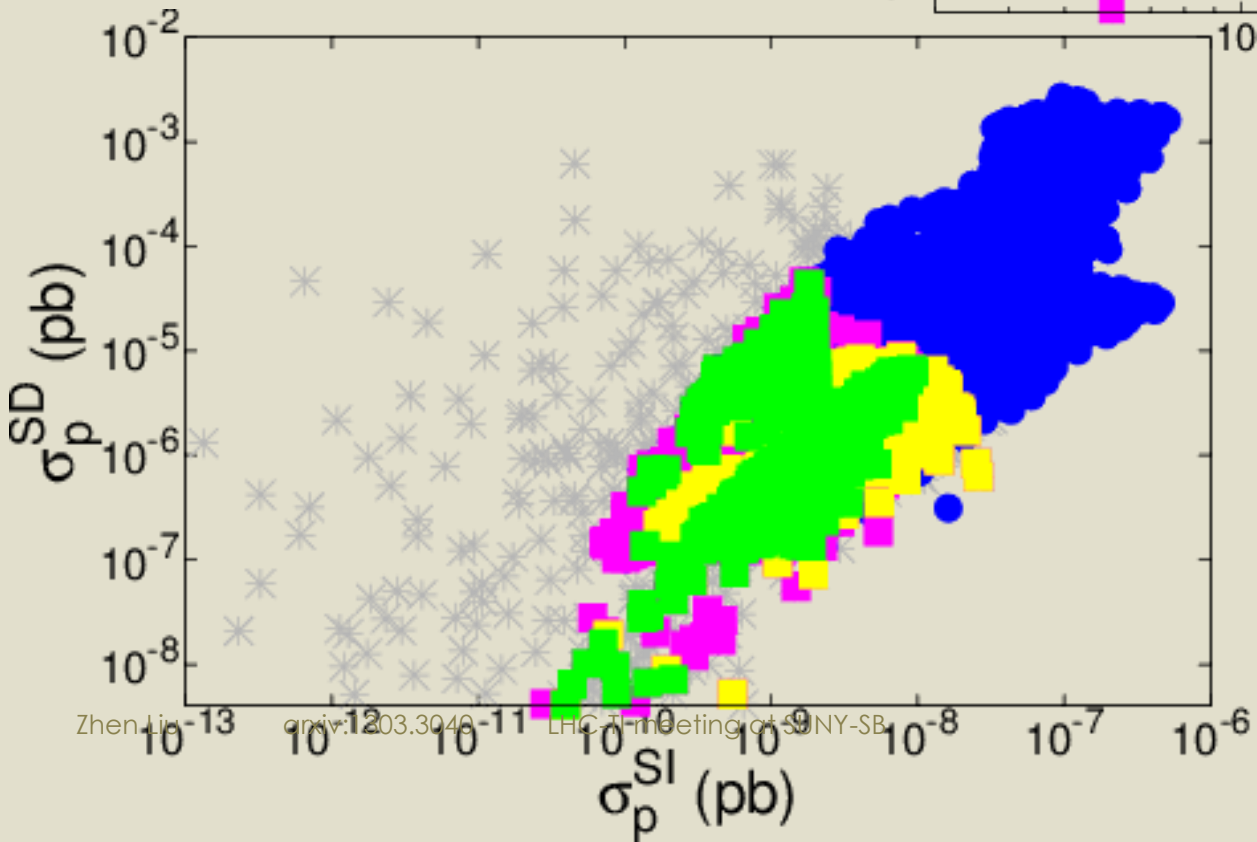
(1) DM Largely a Bino-like neutralino
(2) Low Mass DM disfavored;
(3) Funnels and Coannihilation;
(4) Lower bound on sigma_SI for funnels
(5) Indirect search will hit A-funnel
(6) Higgs decays to neutralino, chargino pairs.

BACKUP

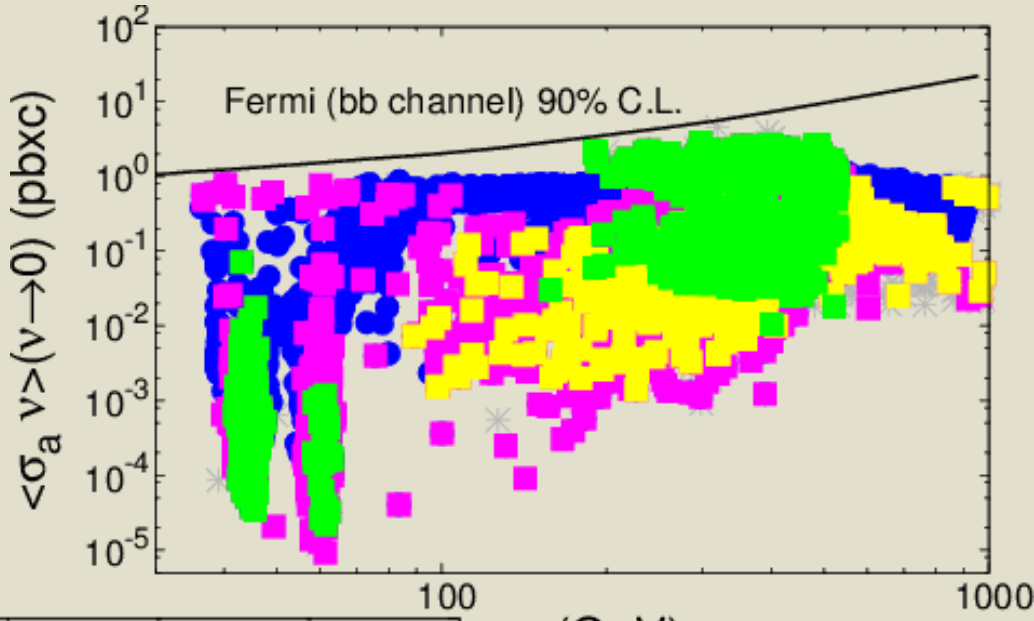
Direct Search

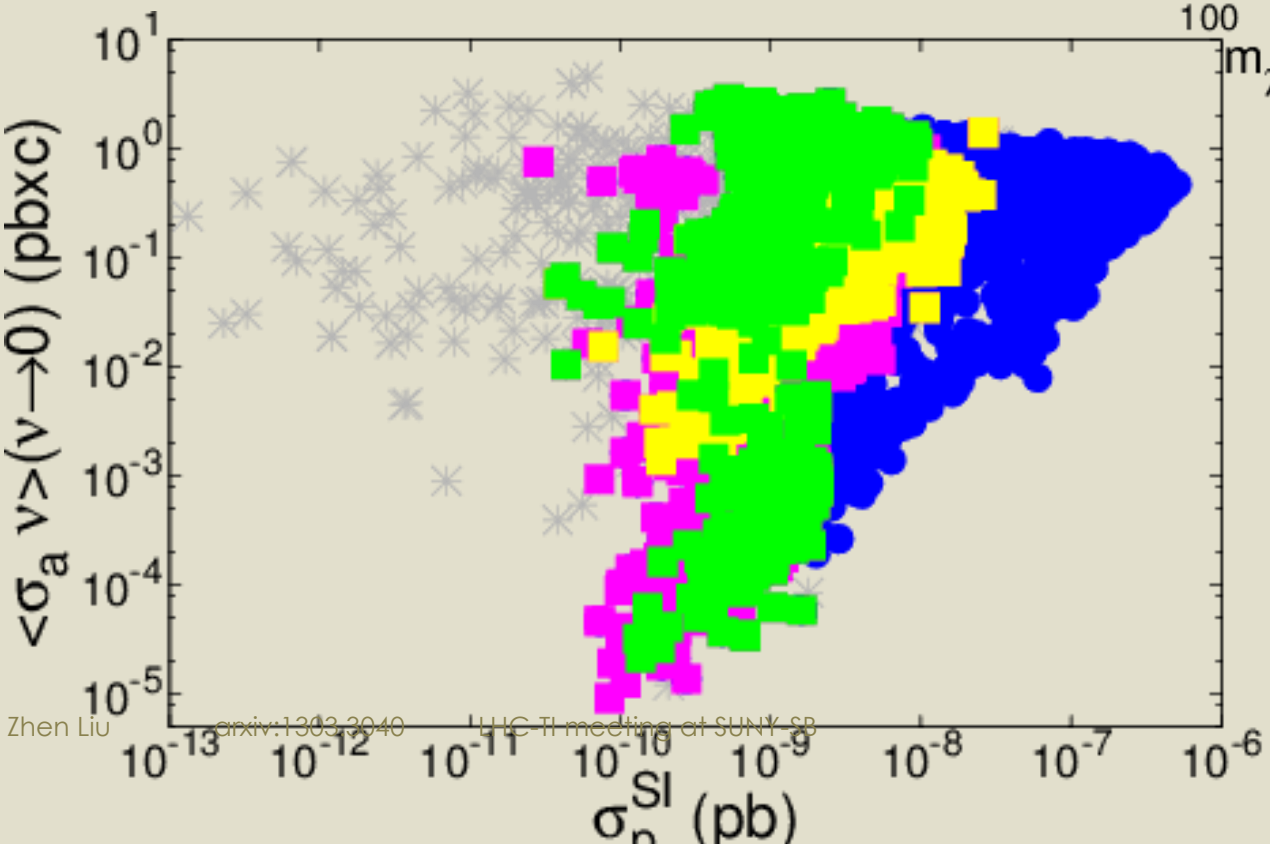
Spin-Dependent

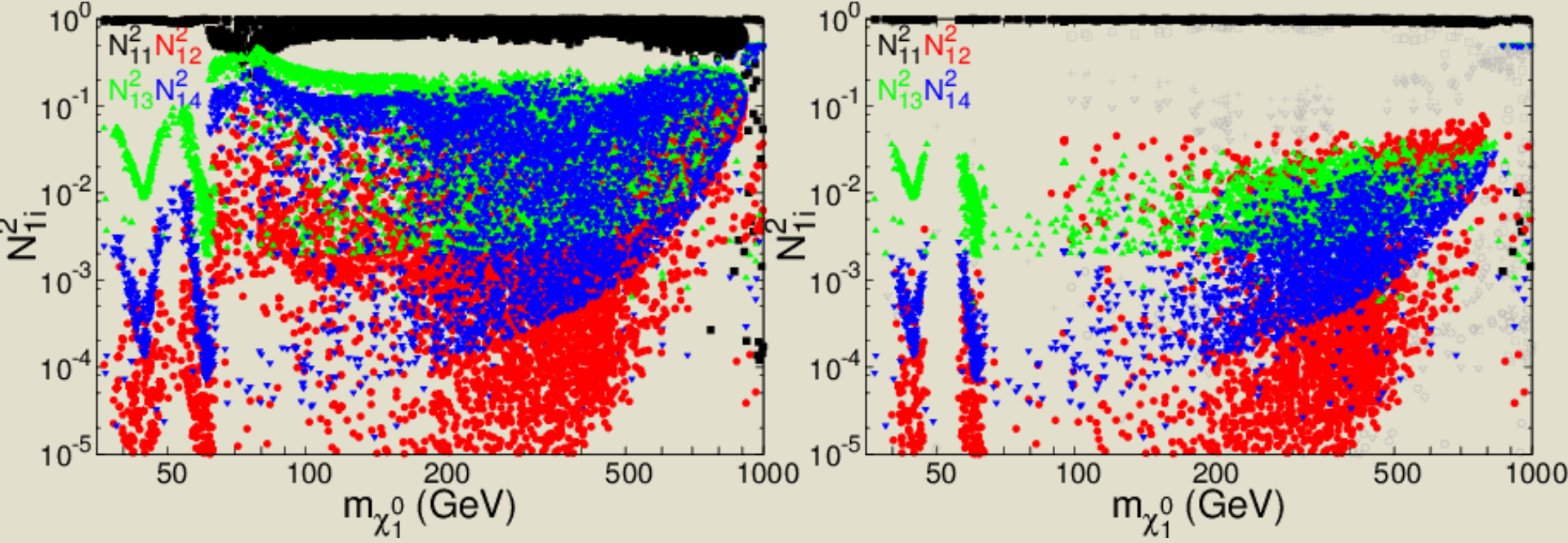




Indirect Search







Left: with right amount of relic density

Right: in addition safisfy XENON-100

Black, Bino fraction

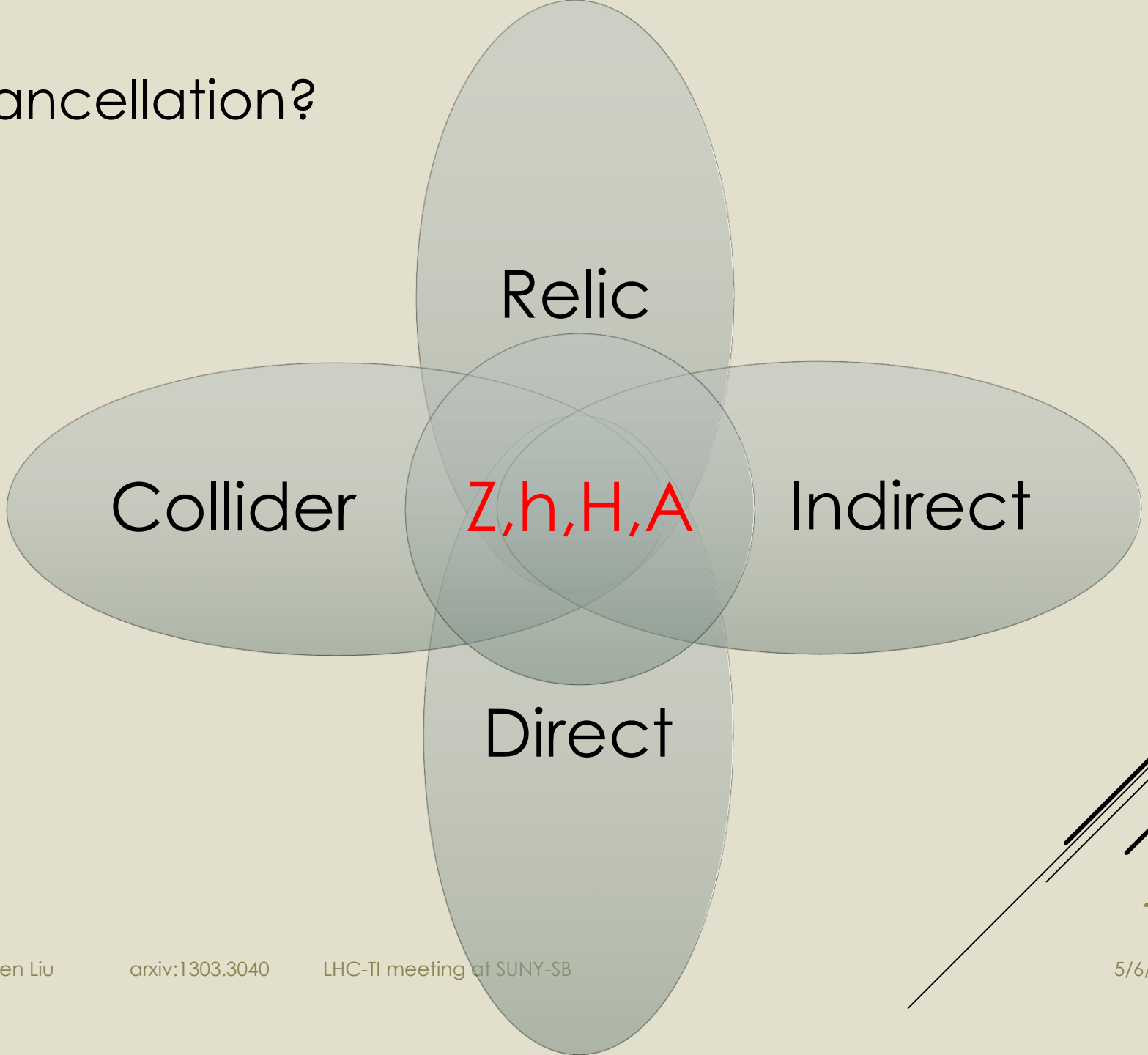
Red, Wino fraction

Green, Higgsino 1 (\tilde H_d) fraction

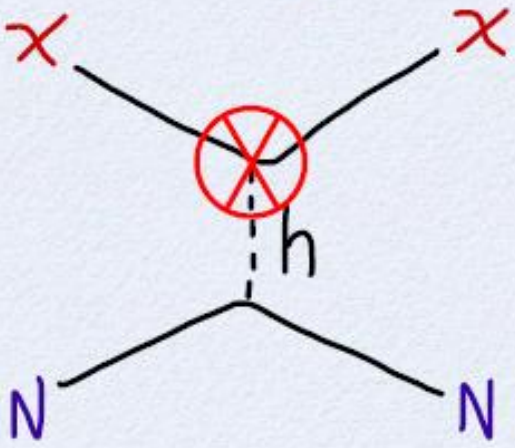
Blue, Higgsino 2 (\tidle H_u) fraction

Gaugino and Higgsino Fractions

Cancellation?

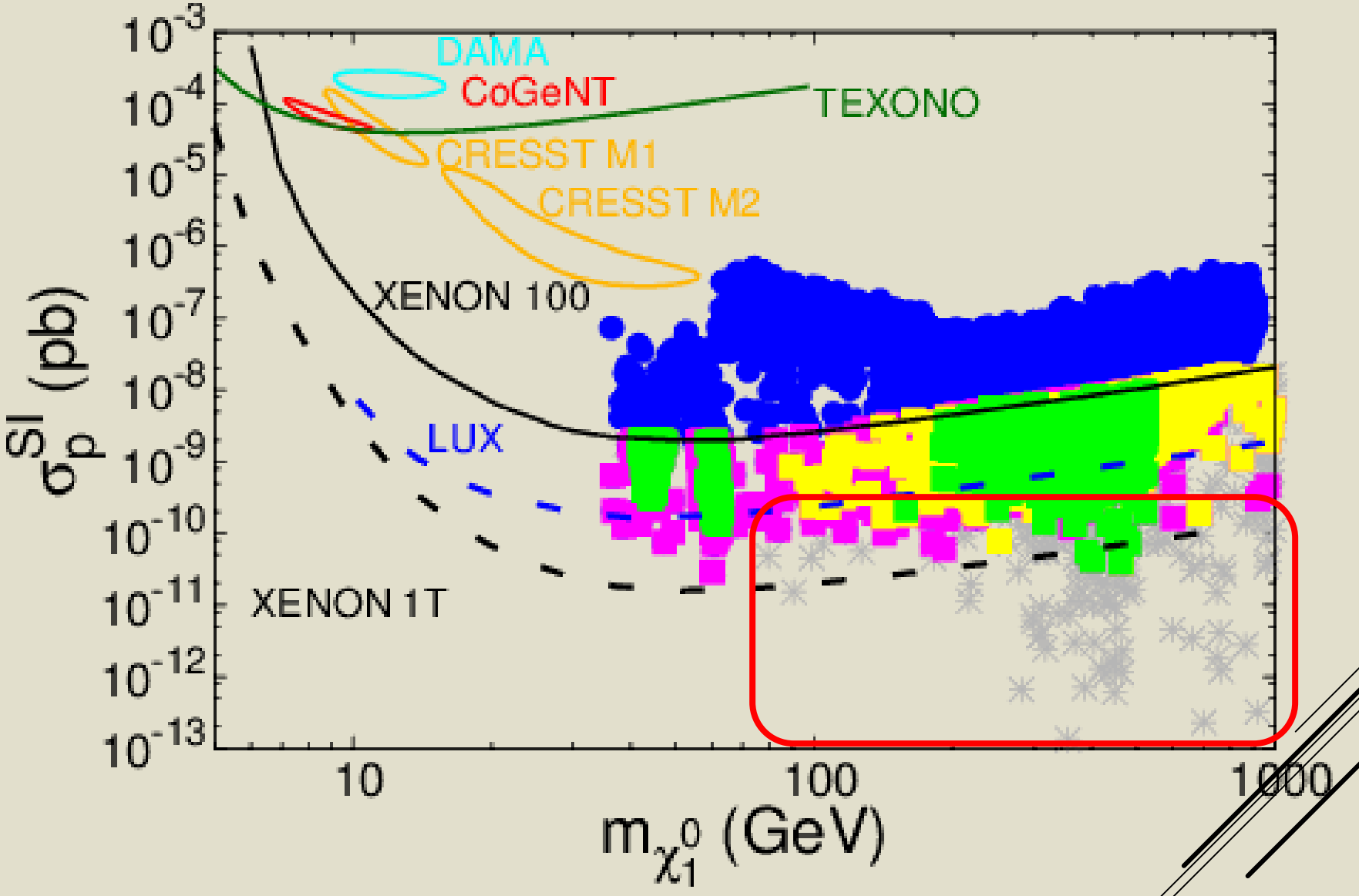


blindspots

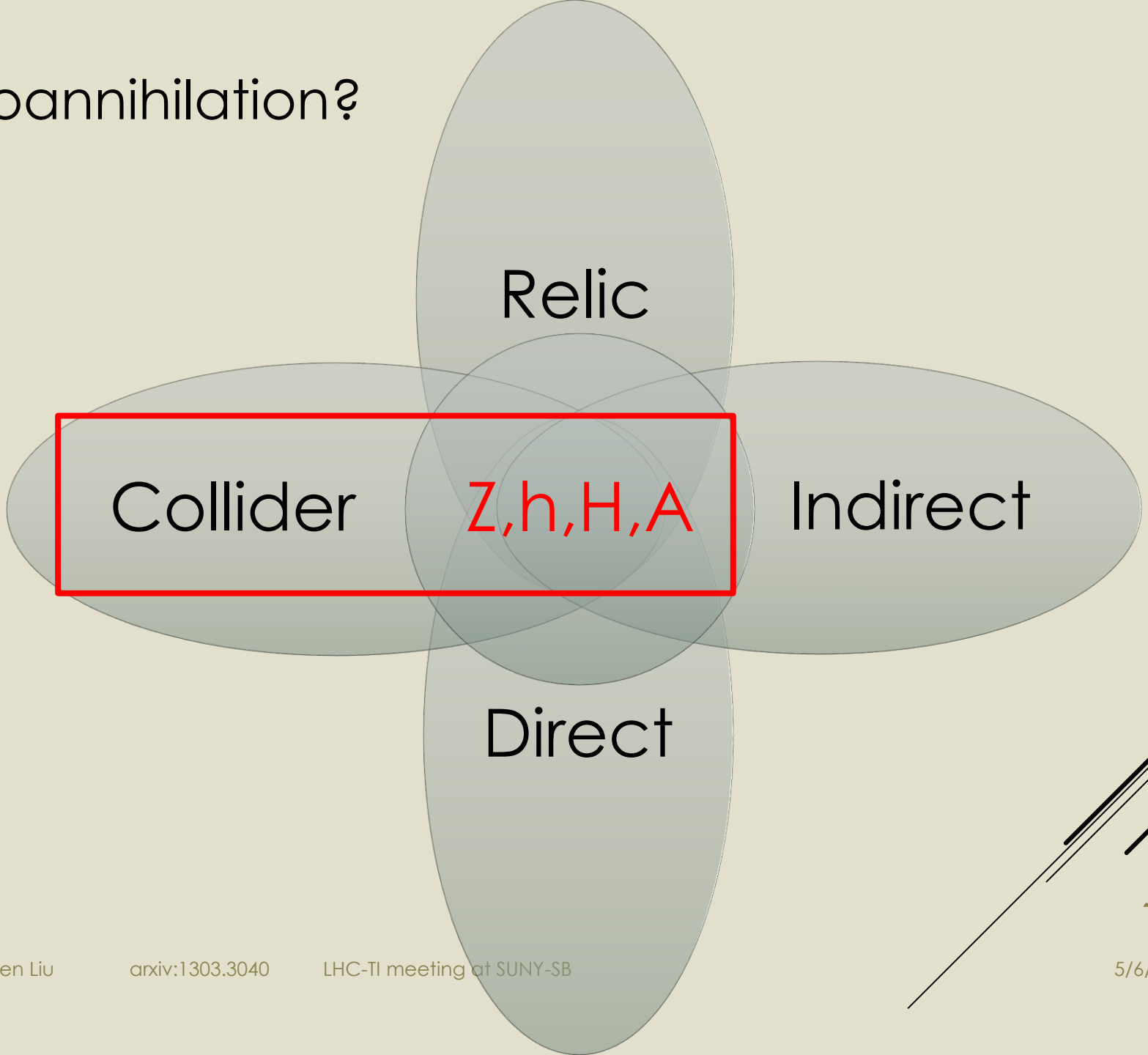


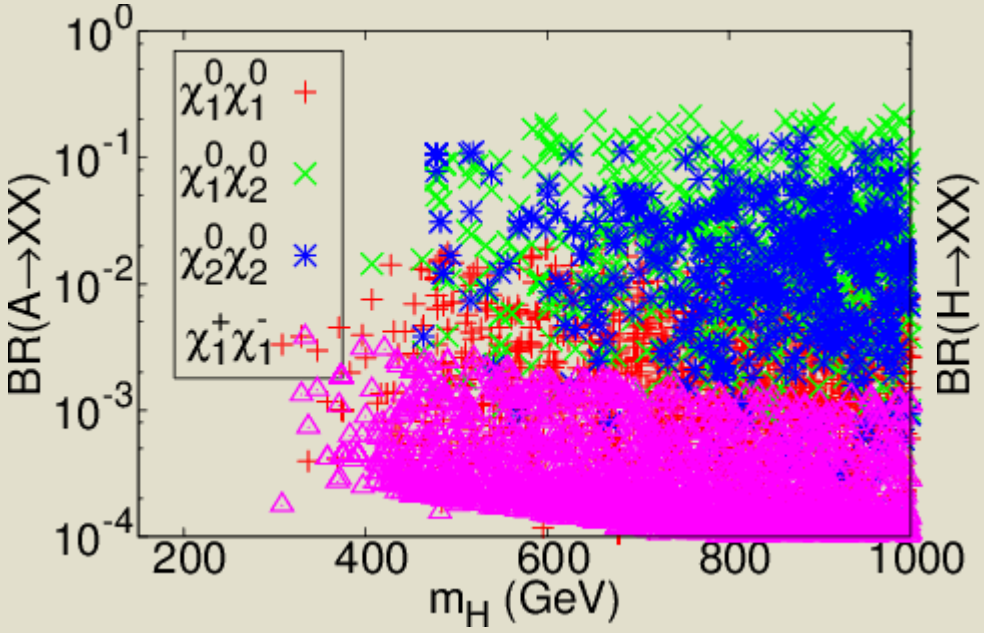
	m_χ	condition	signs
bino	M_1	$M_1 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_1/\mu) = -1$
wino	M_2	$M_2 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_2/\mu) = -1$
higgsino	$-\mu$	$\tan\beta = 1$	$\mathrm{sign}(M_{1,2}/\mu) = -1$
bino/wino	M_2	$M_1 = M_2$	$\mathrm{sign}(M_{1,2}/\mu) = -1$

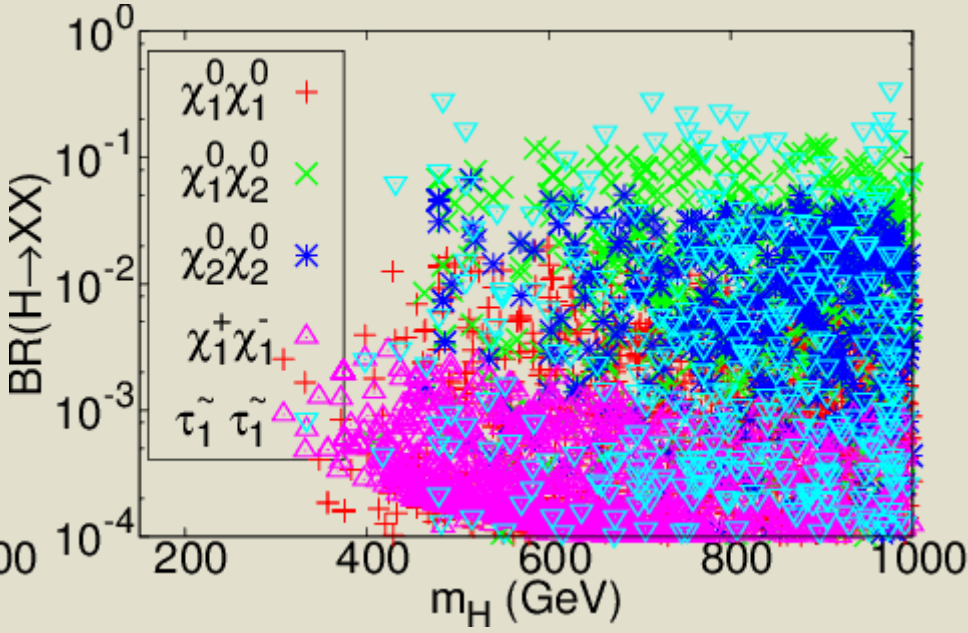
From Josh Runderman's talk at Texas A&M DM workshop, See more "blind spots" on Arxiv: 1211.4873

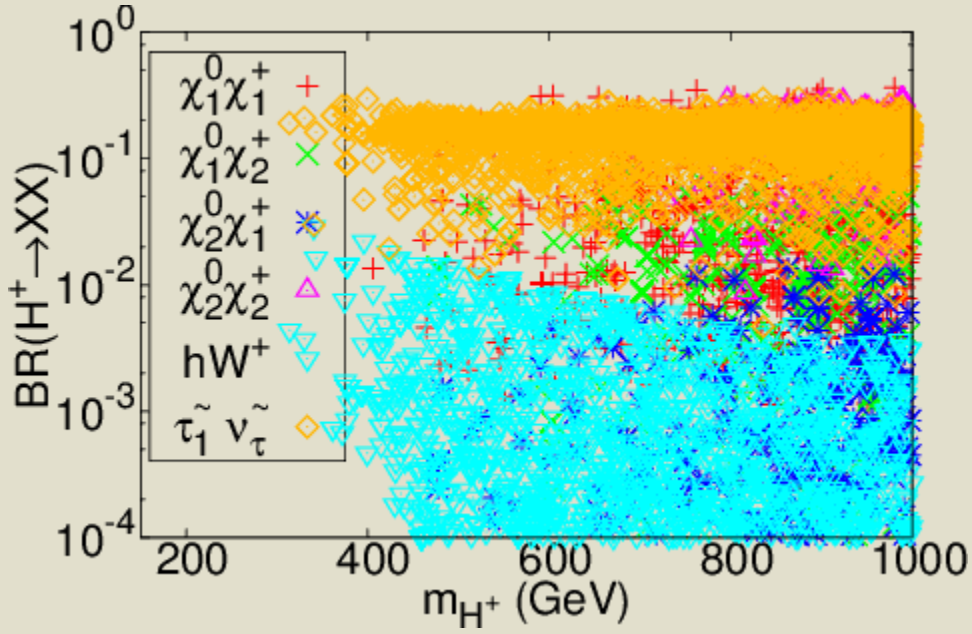

DAMA
CoGeNT
TEXONO
CRESST M1
CRESST M2
XENON 100
LUX
XENON 1T
σ_p^{SI} (pb)
$m_{\chi_1^0}$ (GeV)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10
100
1000

Coannihilation?









Higgs Decays

Collider Constraints

- Exclusions: LEP, Tevatron, LHC
- Higgs requirement

B rare decays

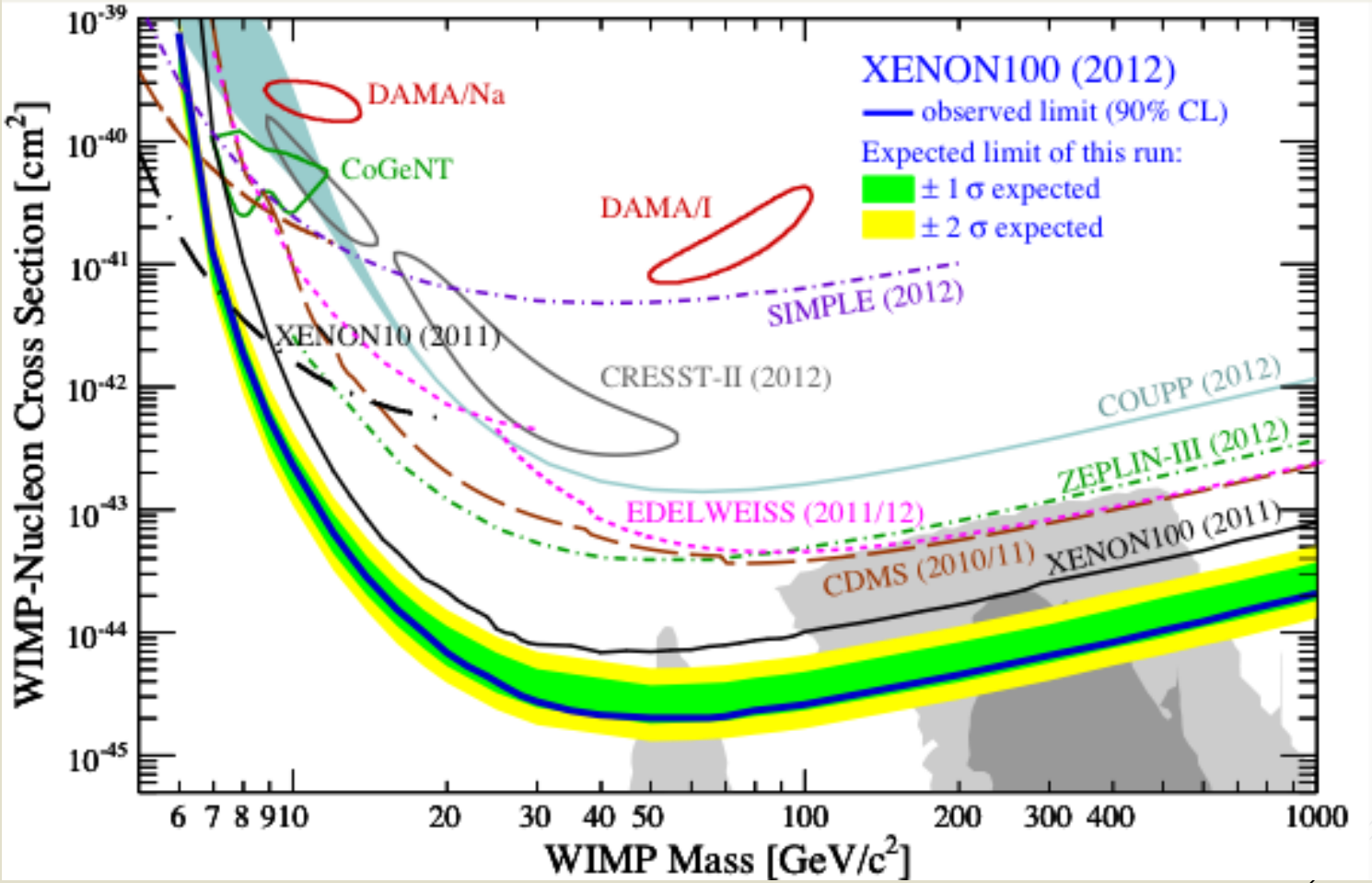
$$2.31 \times 10^{-4} < \quad \mathrm{BR}(b \to s\gamma) \quad < 4.51 \times 10^{-4},$$
$$\mathrm{BR}(B_\mathrm{s} \to \mu^+\mu^-) \quad < 5.1 \times 10^{-9}.$$

Relic Density

WMAP9/ACT/SPT…+10% theo. Uncertainty:

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

Direct DM Search



METHOD

SUSY? MSSM?

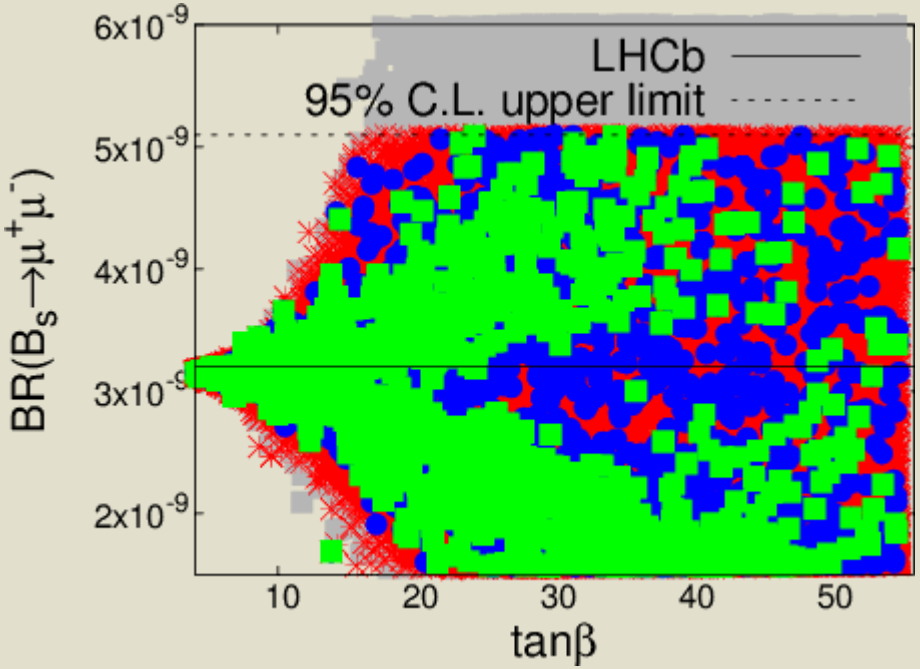
Simple
DM candidate

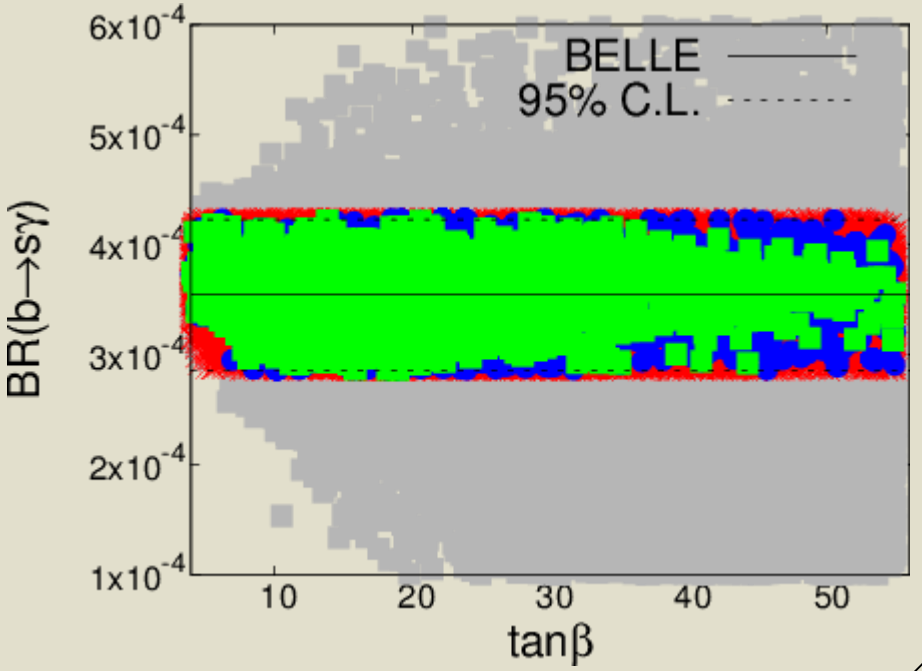
$$123\ \text{GeV} < m_h < 128\ \text{GeV}, \quad \sigma_{\gamma\gamma} > 0.8\ \sigma_{\gamma\gamma}(SM),$$

plus Higgs search bounds from LEP, Tevatron, LHC,

plus LEP bounds on the chargino mass ($\geq$ 100 GeV)

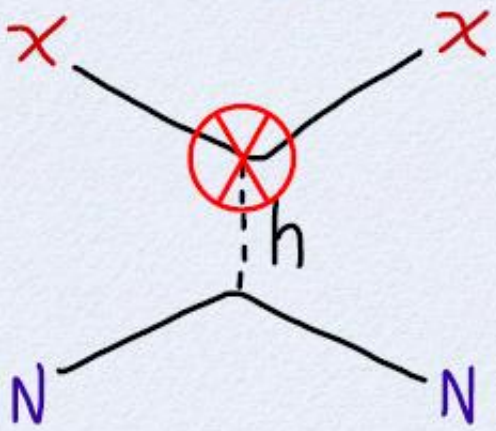
and the slepton mass ($\geq$ 80 GeV).


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

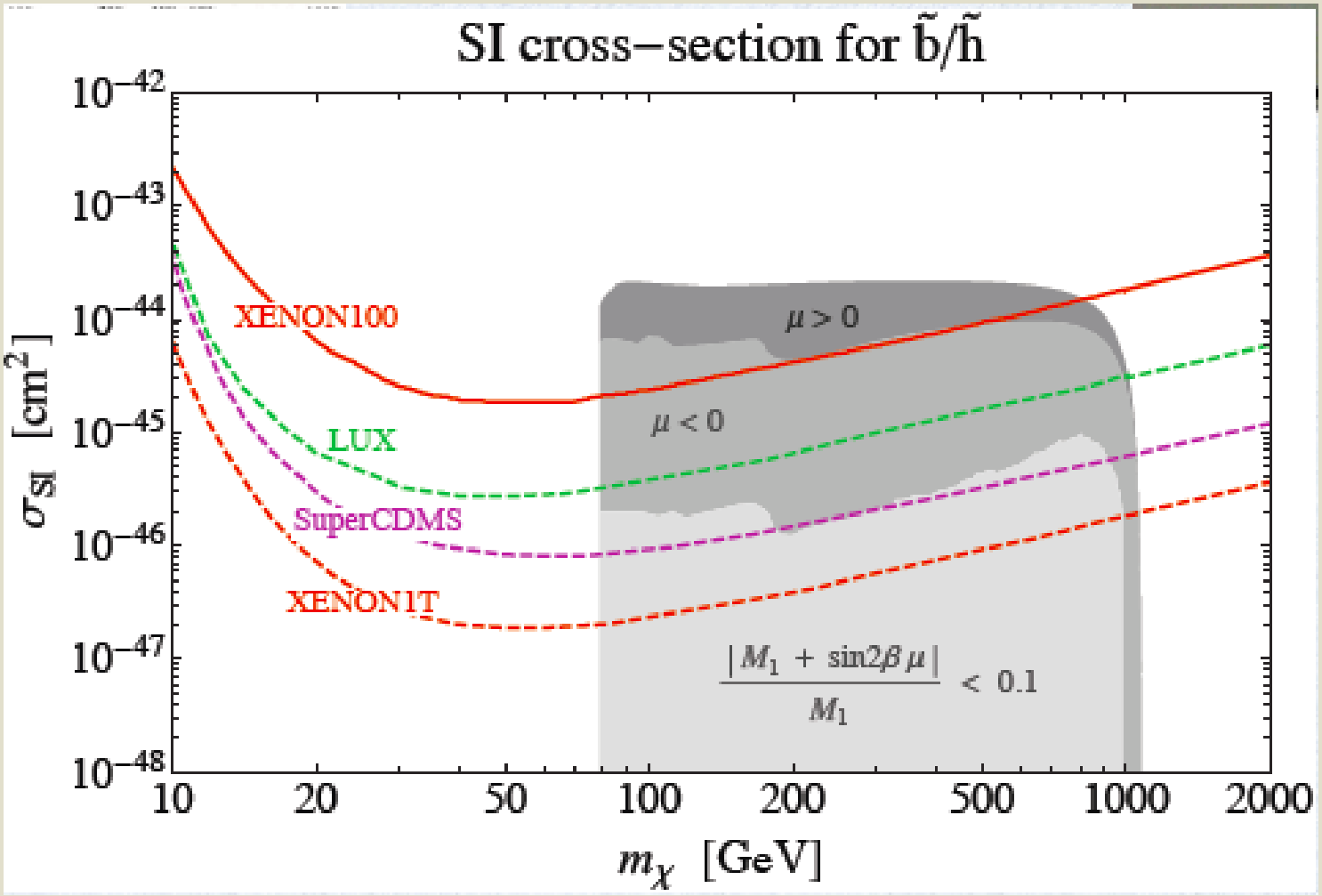

BELLE
95% C.L.
BR(b→sγ)
6x10^-4
5x10^-4
4x10^-4
3x10^-4
2x10^-4
1x10^-4
10
20
30
40
50
tanβ

DISCUSSION

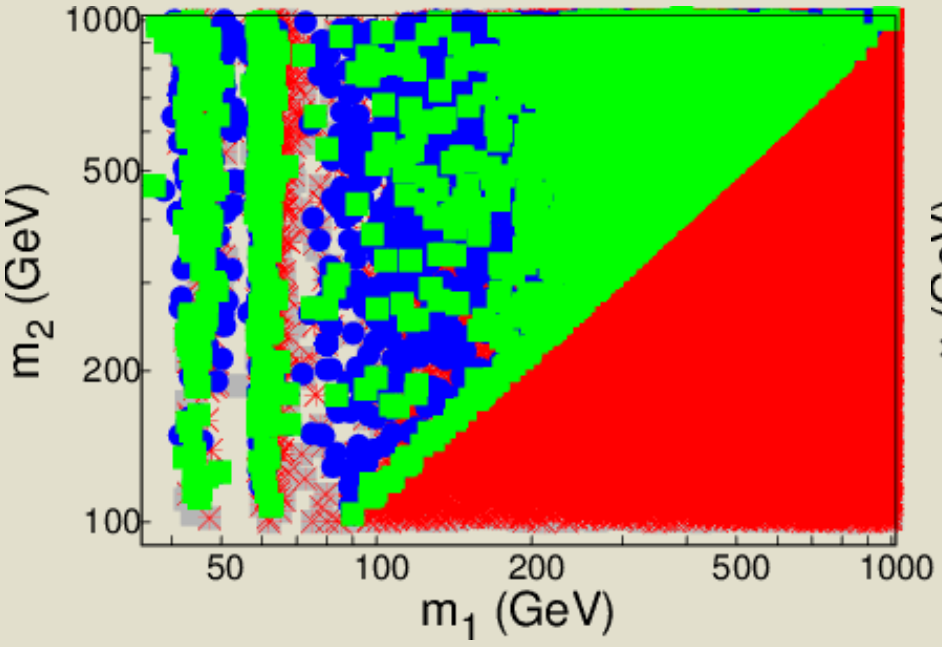
blindspots

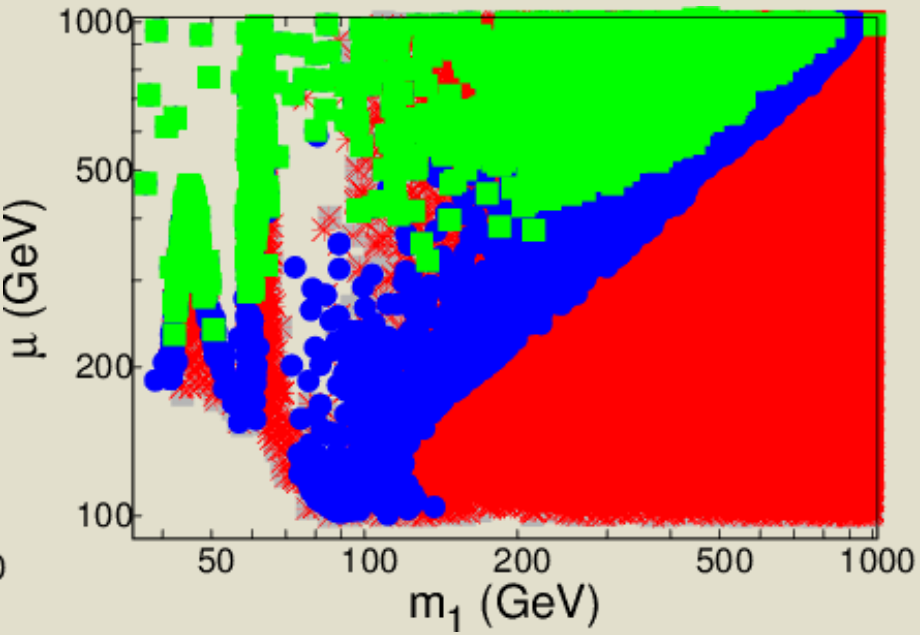


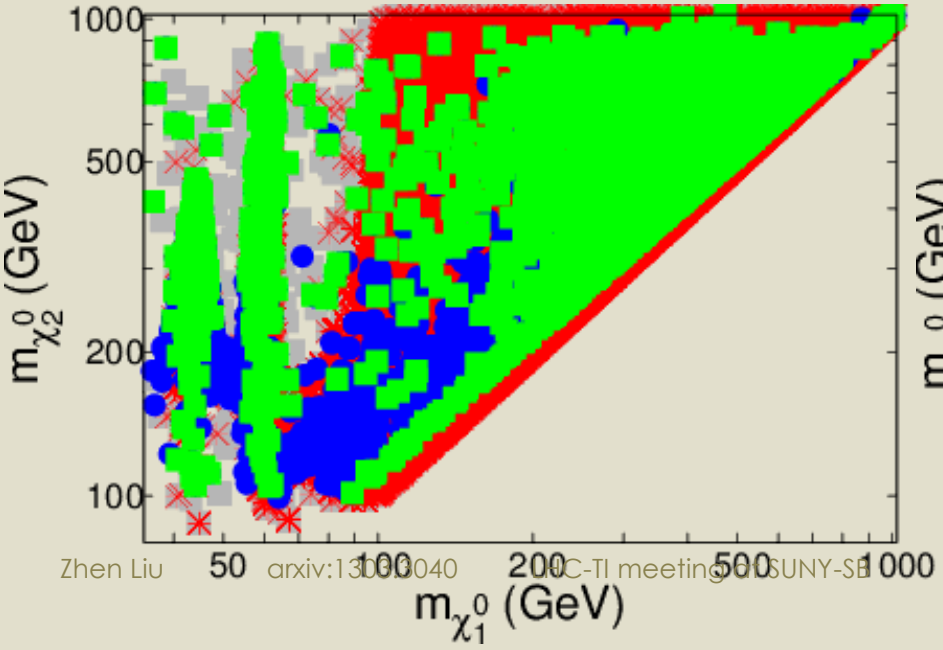
	m_χ	condition	signs
bino	M_1	$M_1 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_1/\mu) = -1$
wino	M_2	$M_2 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_2/\mu) = -1$
higgsino	$-\mu$	$\tan\beta = 1$	$\mathrm{sign}(M_{1,2}/\mu) = -1$
bino/wino	M_2	$M_1 = M_2$	$\mathrm{sign}(M_{1,2}/\mu) = -1$

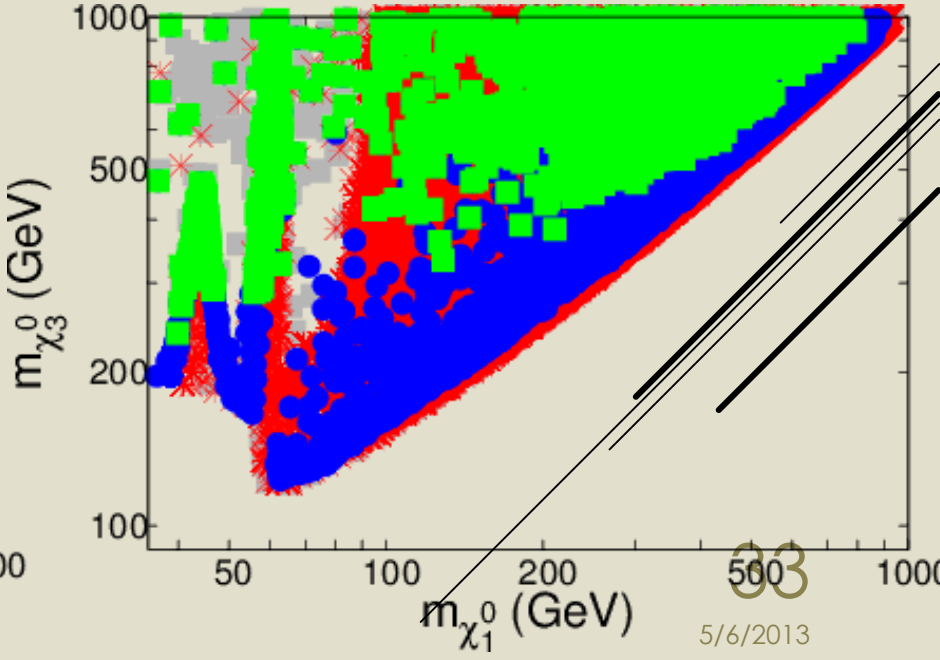

SI cross−section for b̃/h̃
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
σ_{SI} [cm^2]
XENON100
LUX
SuperCDMS
XENON1T
$\mu > 0$
$\mu < 0$
$\frac{|M_1 + \sin 2\beta\, \mu|}{M_1} < 0.1$
10
20
50
100
200
500
1000
2000
m_χ [GeV]

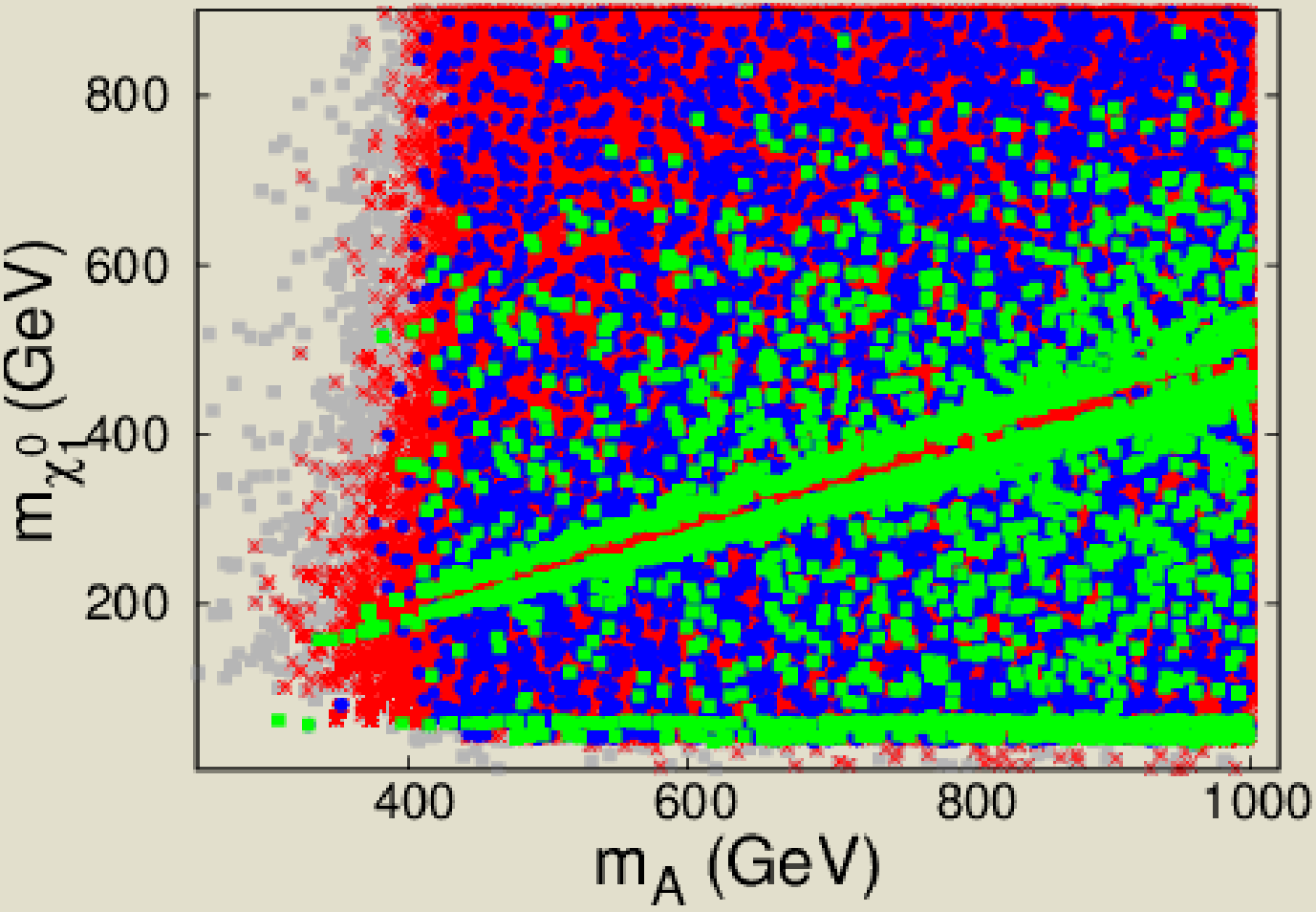
CONCLUSION

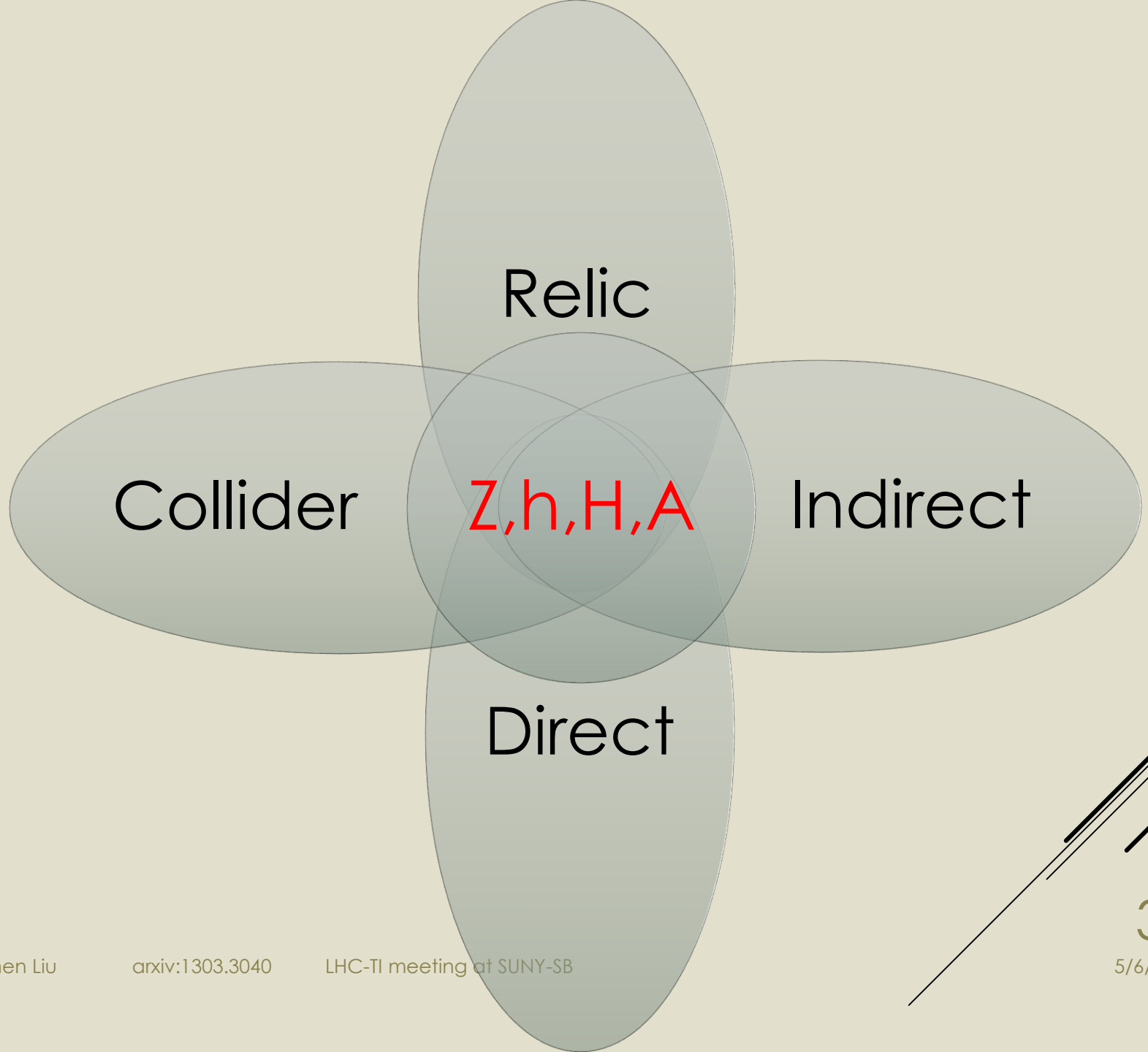

1000
500
200
100
50
100
200
500
1000
m_2 (GeV)
m_1 (GeV)


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)


Relic
Collider
Z,h,H,A
Indirect
Direct