Dark Matter & Higgs bosons in MSSM

Higgs Signal Workshop

UC - Davis, April 23, 2013

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arXiv:1303.3040,
TH, Zhen Liu,
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SUSY Dark Matter:

One of the most appealing features for SUSY

Good News: Higgs boson discovered!

M_h = 125.7 ± 0.3 ± 0.3 GeV (CMS, Korytov)
= 125.5 ± 0.2 ± 0.6 GeV (ATLAS, Hays)

Weakly coupled theory, like SUSY:

$M_h \rightarrow \lambda \sim 1/8 \sim (g_1^2 + g_2^2)/8$

Its existence argues for new physics (naturalness)

Bad News: No clear sign for DM.

Direct searches: Xenon10,100 … (DAMA, CoGeNT, CRESST? CDMS2?)

Indirect searches: Pamela? Fermi/LAT, IceCube, AMS2

Collider searches: Tevatron, LHC (ILC?)

Assume MSSM

Scan over Parameters:

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

Lower bounds are typically from the collider searches.

Upper bounds are from "naturalness" argument

$\mu \sim 2$ TeV ➔ 0.04% fine tune.

* Higher values $M_2 \sim \mu$ change results: "well-tempered" OK

Arkani-Hamed, Delgado, Giudice, 2006.

* Signs of M_1, M_2, μ important – fine-tuned: "blind spots"

Cheung, Hall, Pinner, Ruderman, arXiv:1211.4873.

Constraints:

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

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).

Belle/BaBar:

$$2.31 \times 10^{-4} < \quad \text{BR}(b \to s\gamma) \quad < 4.51 \times 10^{-4},$$

LHCb: $\quad \text{BR}(B_s \to \mu^+\mu^-) \quad < 5.1 \times 10^{-9}.$

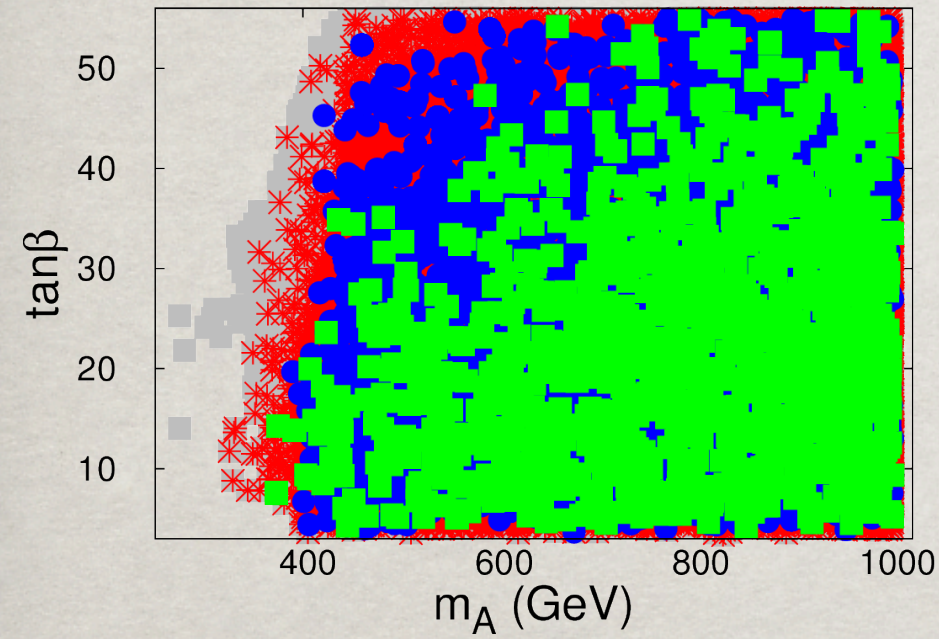
WMAP9/ACT/SPT/Planck…

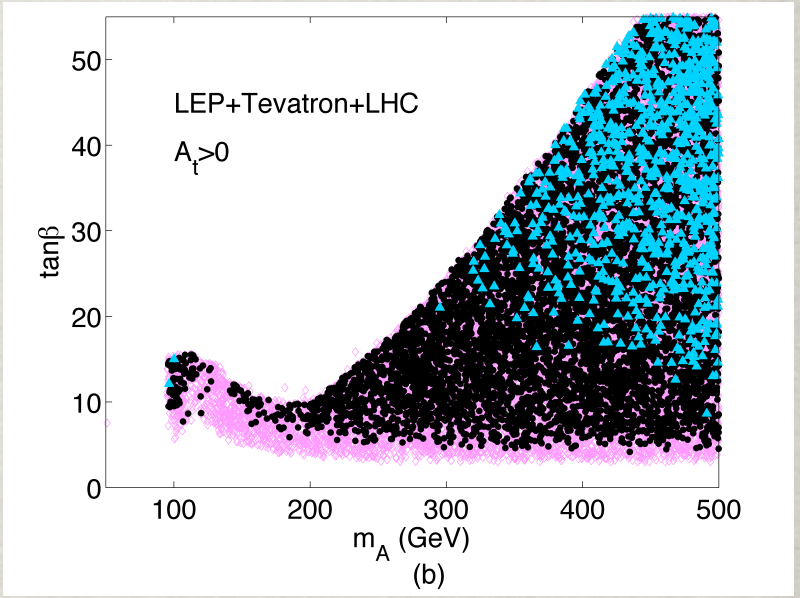
+ 10% theo. Uncertainty, 2σ window:

$$0.0947 < \Omega_{\chi_1^0} h^2 < 0.1427$$

Outputs versus M_A

FeynHiggs, HiggsBound, MicroOmega





TH, Su, Christensen, arXiv:1203.3207

Grey: Collider Higgs + not over-close the Universe

Red: + b-flavor constraints

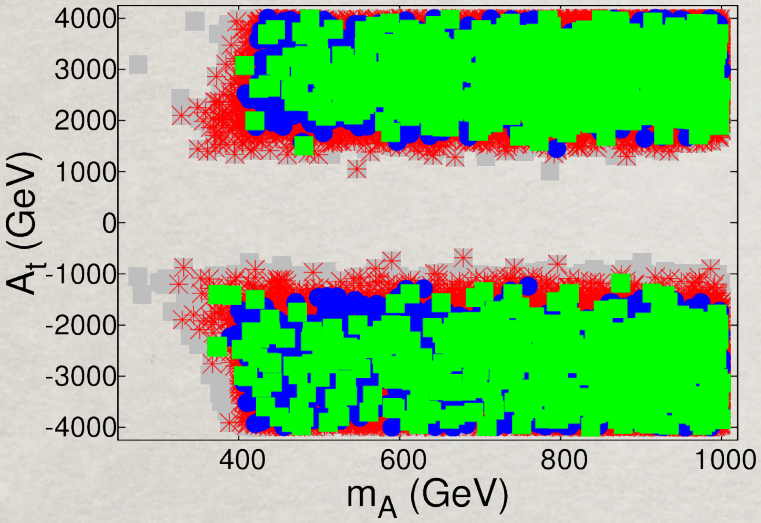
Blue: + correct relic density

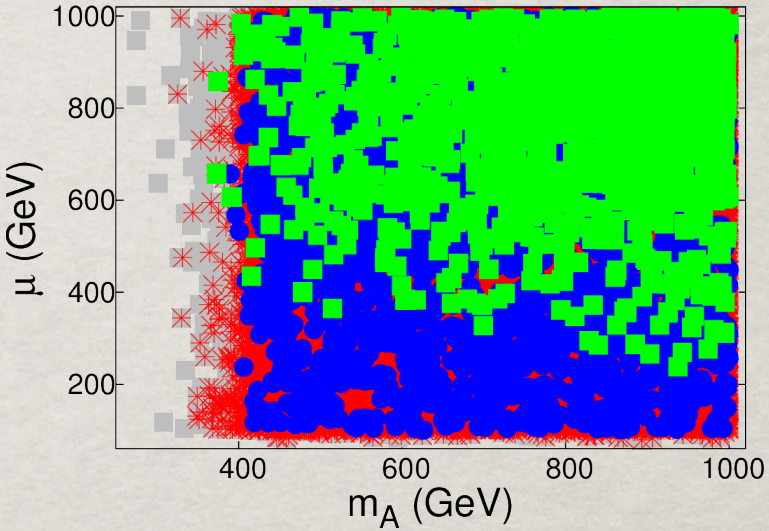
Green: + XENON 100 bound

More, versus M_A:

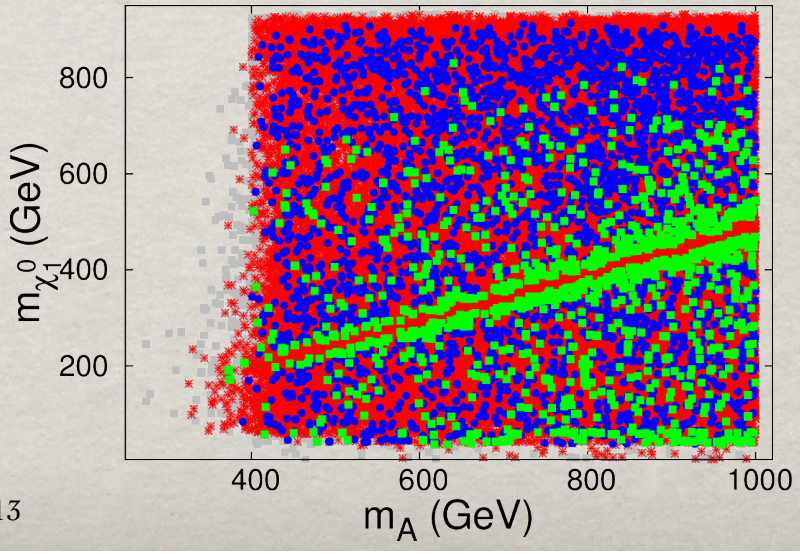
Blue: + correct relic density

Green: + XENON 100 bound



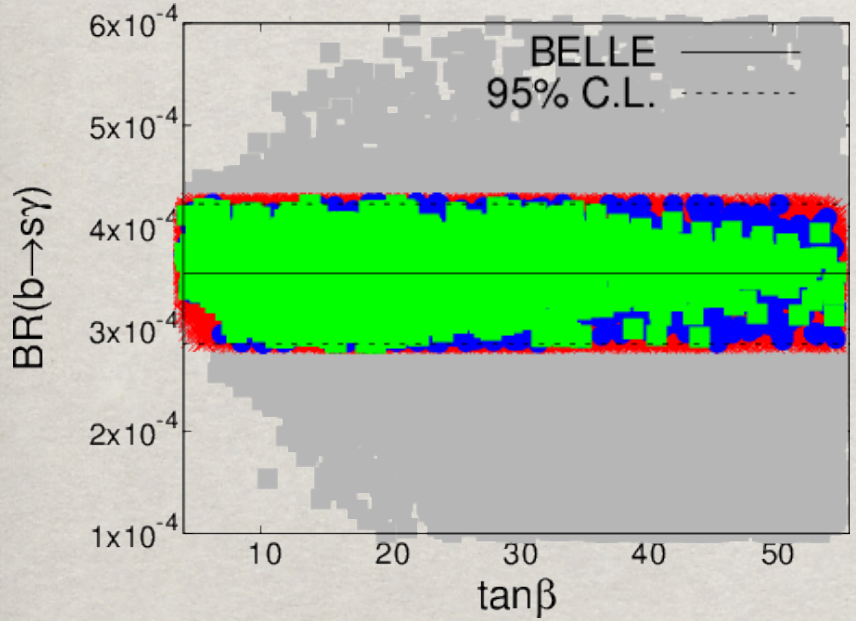


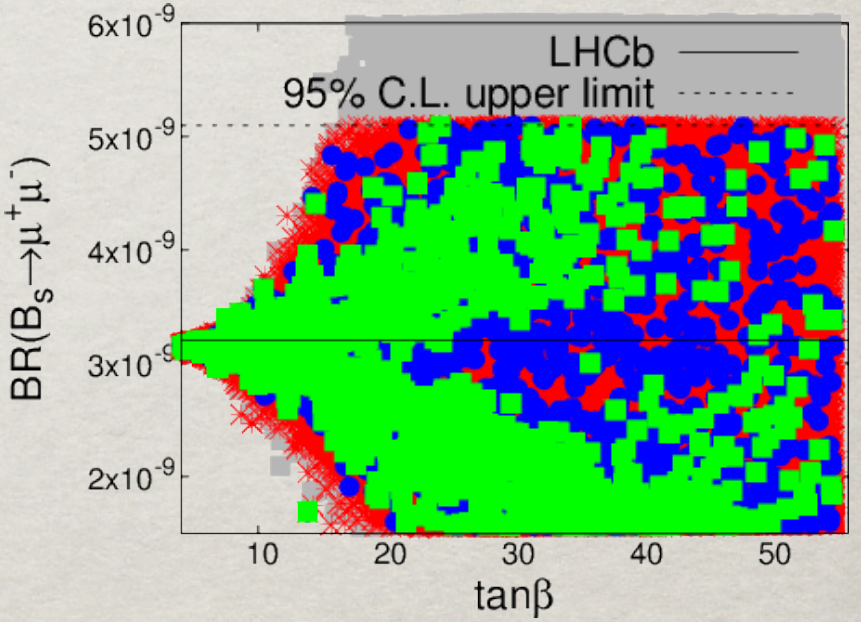
H/A-funnel & around:



B-FLAVOR CONSTRAINTS:

$b \rightarrow s\gamma$ and $B_s \rightarrow \mu^+\mu^-$ complementary.

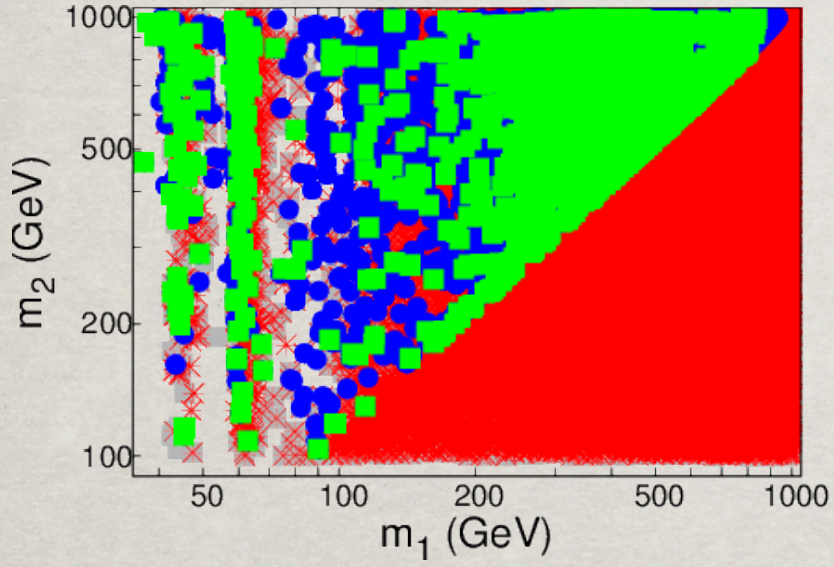




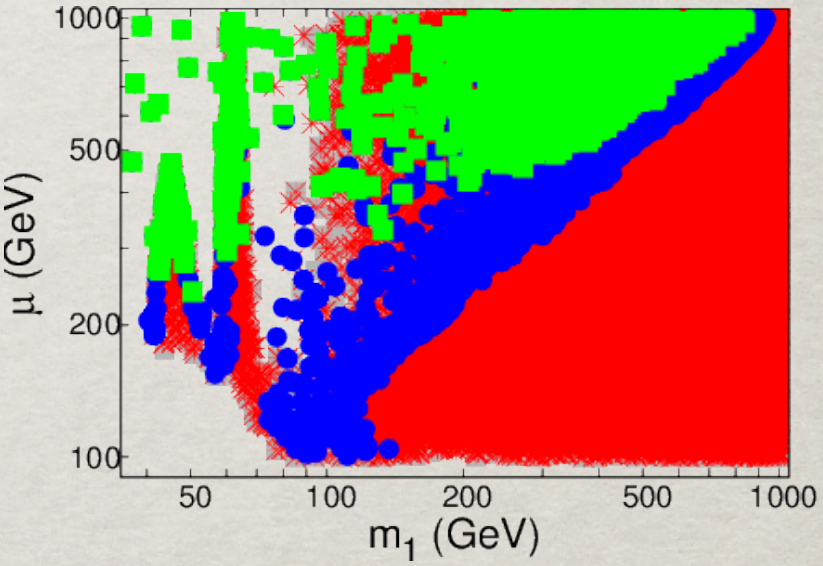
$\tan^6\beta \; / \; M^4_A$

SUSY PARAMETERS:

Wino mass parameter



Higgsino mass parameter

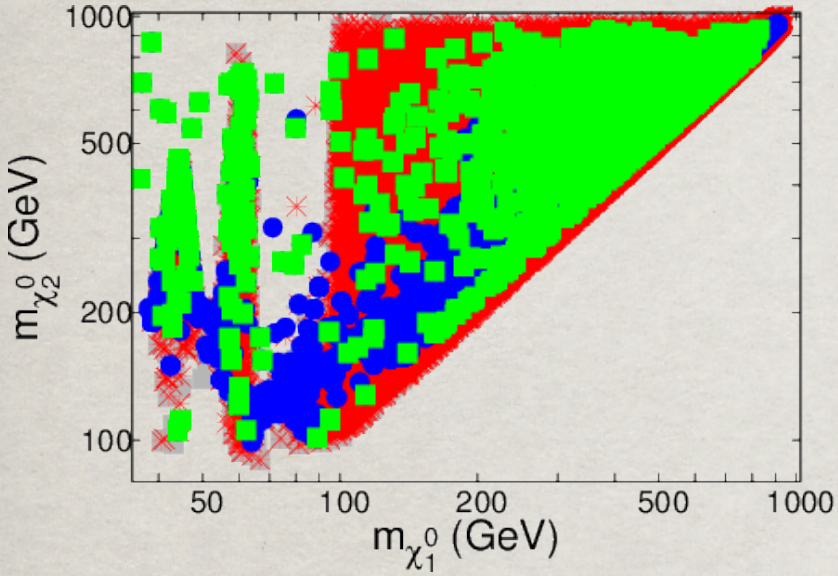


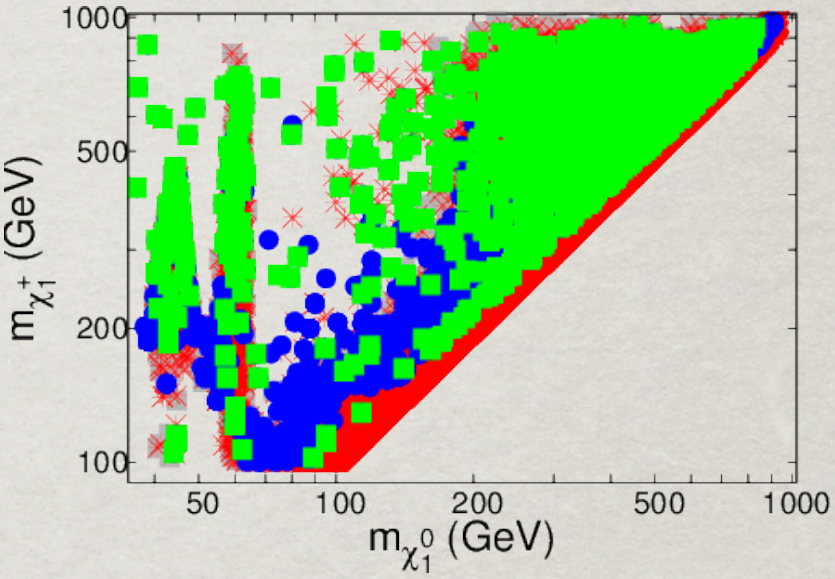
Features: Z, h → 2 "binos"

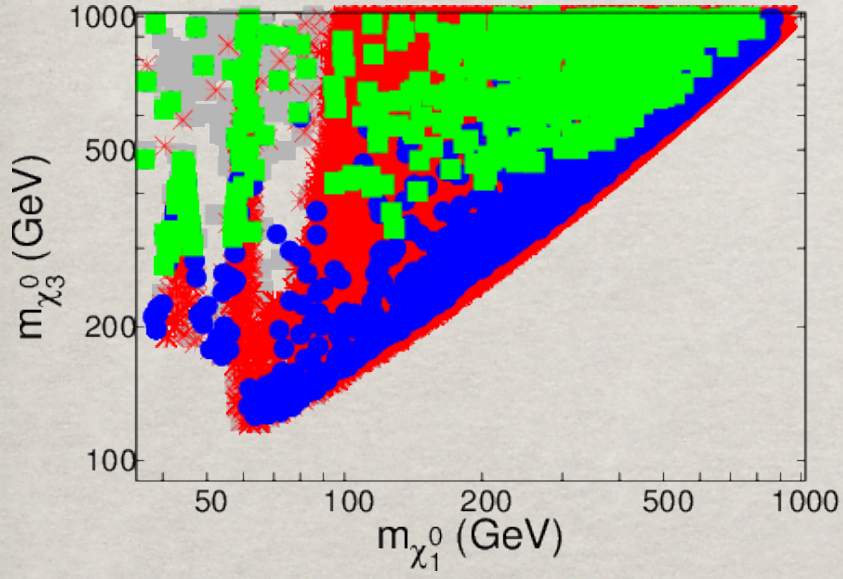
m1-m2 co-annihilations seen

μ-m2 co-annihilation limited by Xenon100

Neutralinos/charginos:







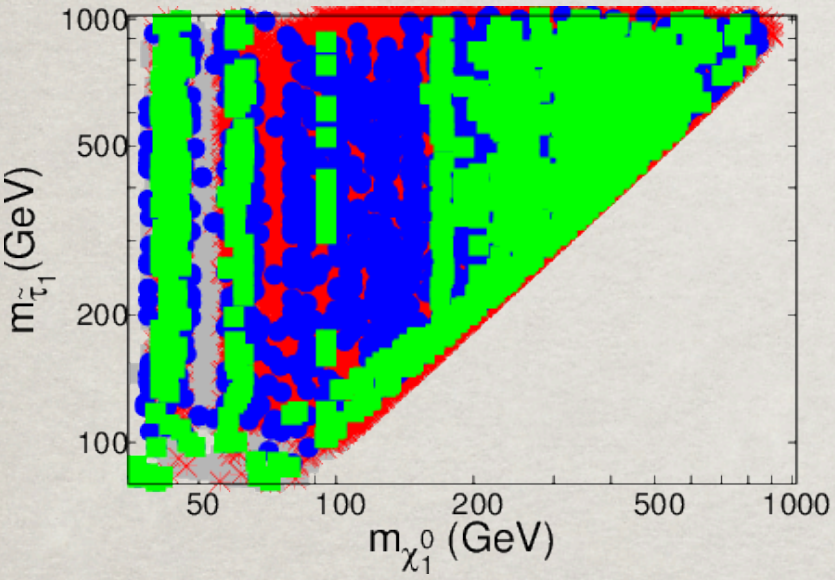
Features:

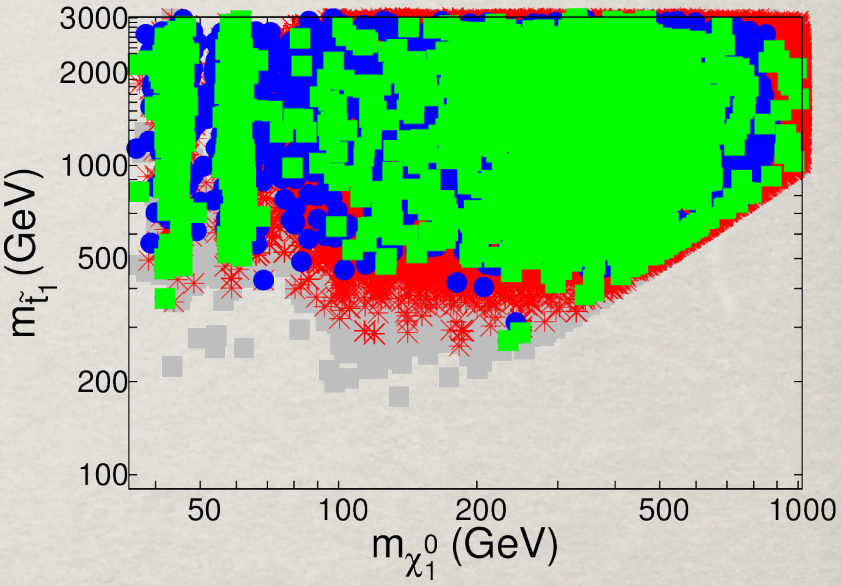
Z, h → 2 LSPs

Bino-wino co-annih. common;

Bino-Higgsino co-annih limited

Sfermion masses:





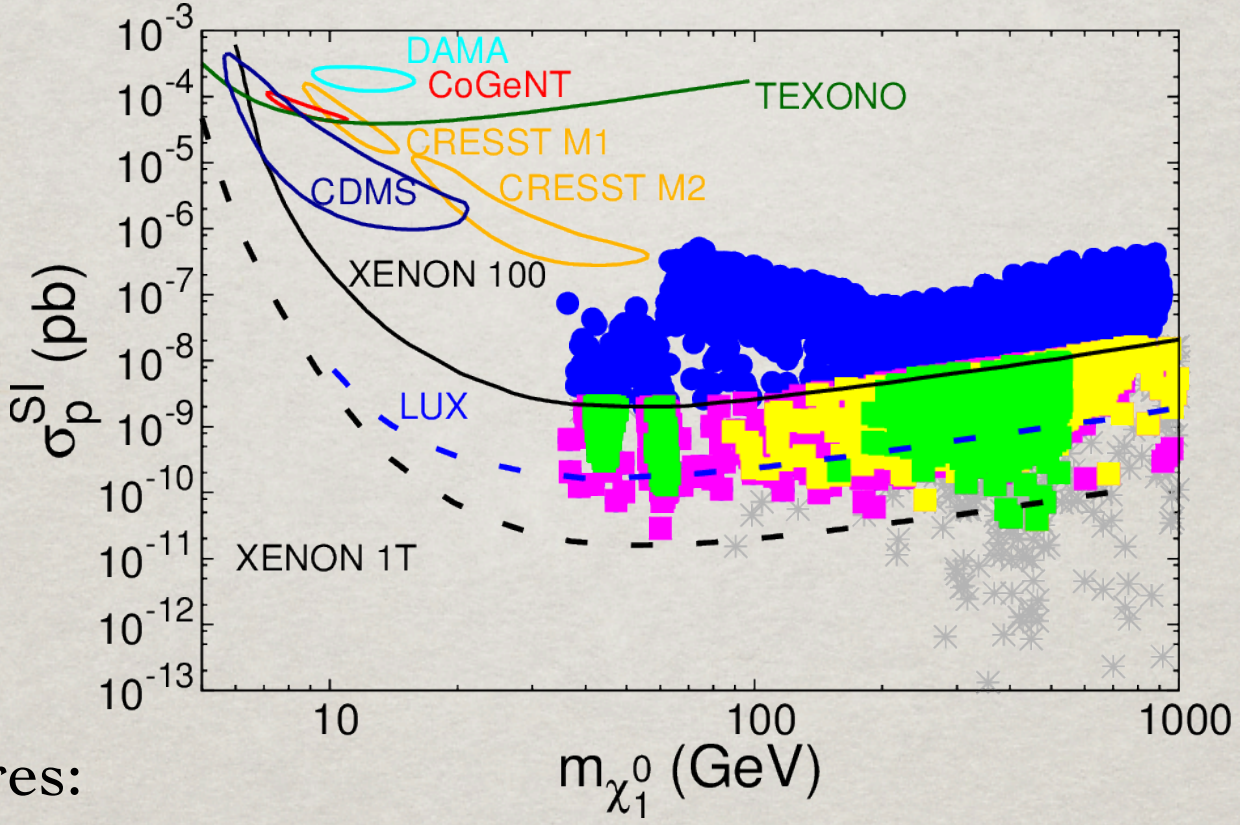
Features:

LSP-stau co-annihilation seen

LSP-stop co-annihilation seen

Light-stop removed by b-flavor bounds

Summary plot: Direct searches



Features:

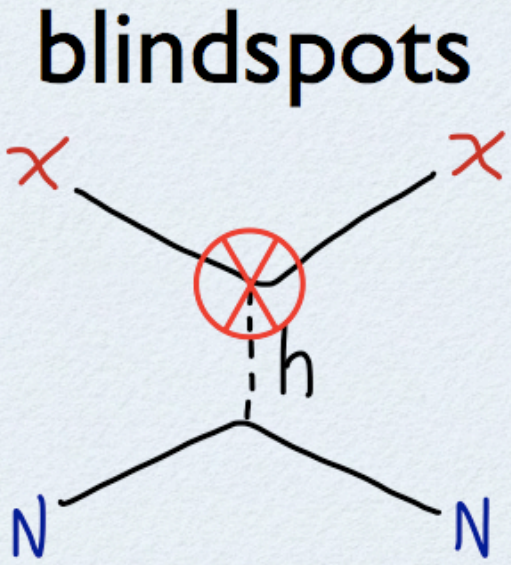
Z, h, H/A → 2 LSPs: green; Fully covered by Xenon1T

Co-annihilations: w/ NLSP yellow; w/ stau: magenta

Lower bound 10^{-46} cm^2 (M1, M2, $\mu > 0$)

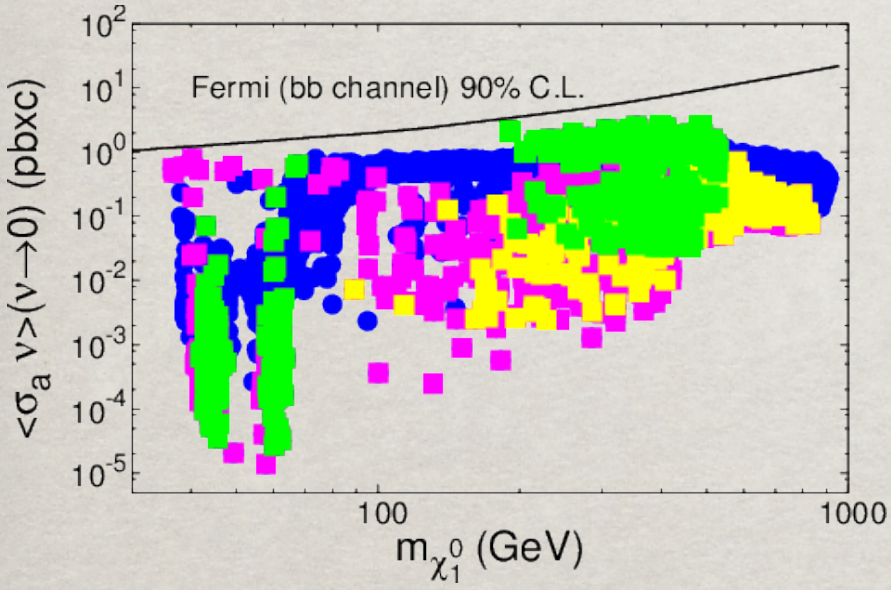
Except for the "blind spots" …

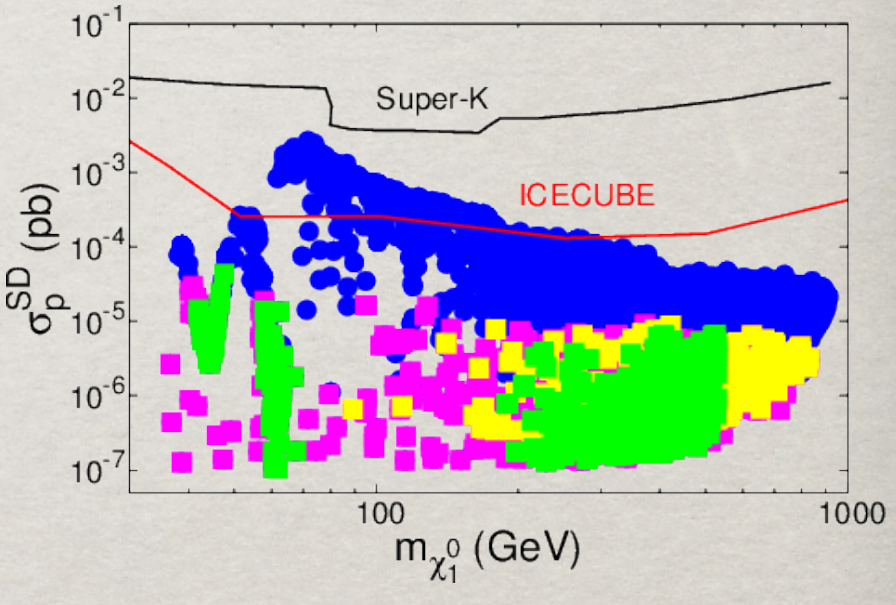
The blind spots:



$\mathbf{m_\chi}$	**condition**	**signs**
M_1	$M_1 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_1/\mu) = -1$
M_2	$M_2 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_2/\mu) = -1$
$-\mu$	$\tan\beta = 1$	$\mathrm{sign}(M_{1,2}/\mu) = -1$
M_2	$M_1 = M_2$	$\mathrm{sign}(M_{1,2}/\mu) = -1$

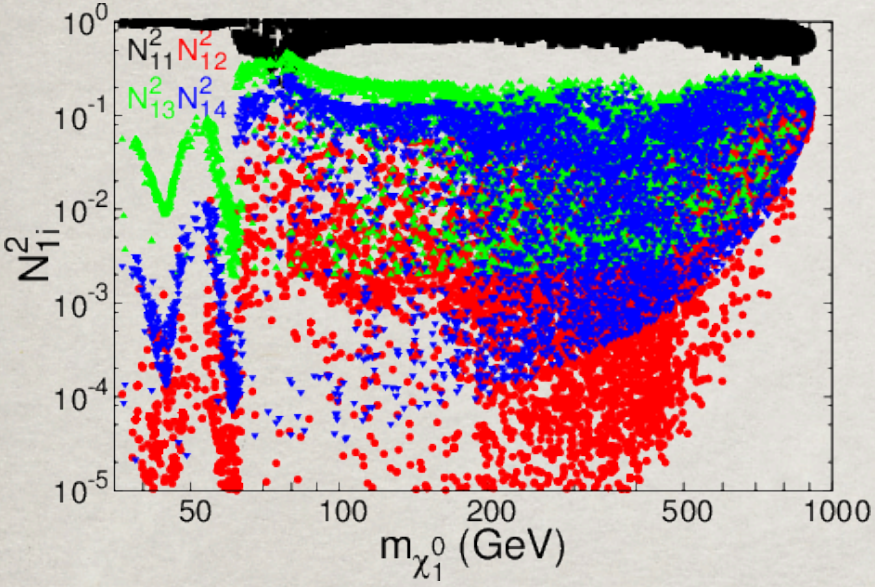
Indirect Searches:

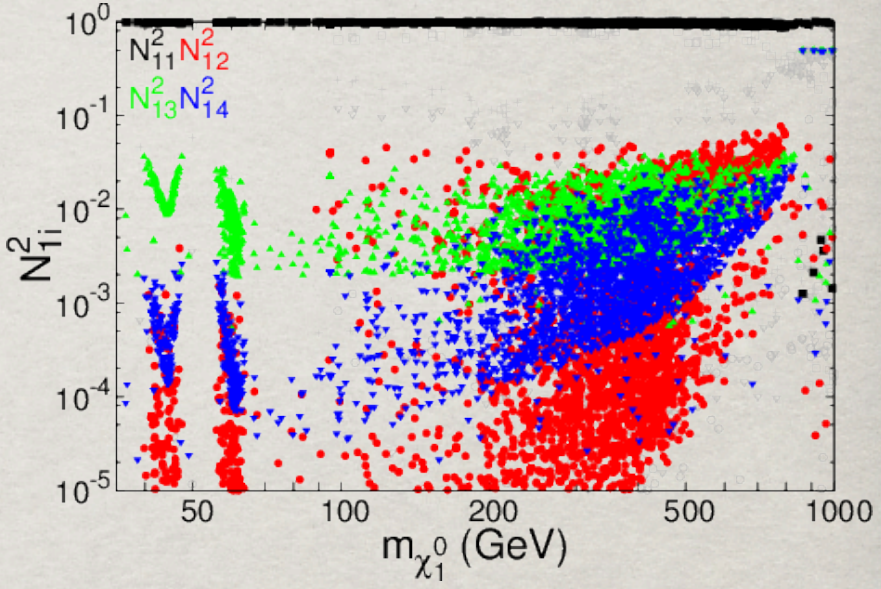




Nature of the LSP:

After Xenon 100:





Features:

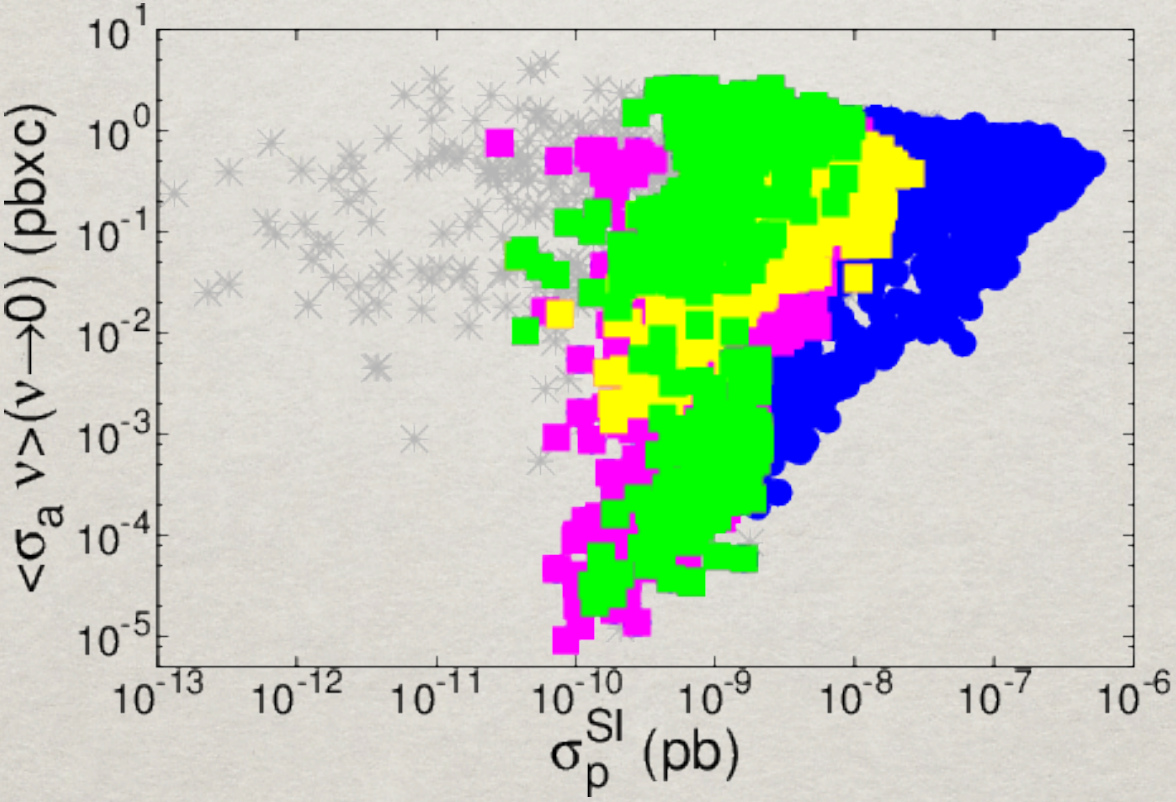
- Largely Bino, but with Wino/Higgsino
- Before Xenon: well-tempered scenario still valid
- After Xenon 100: Wino/Higgsino less than 20%

(depending on M2, mu ~ 1 TeV)

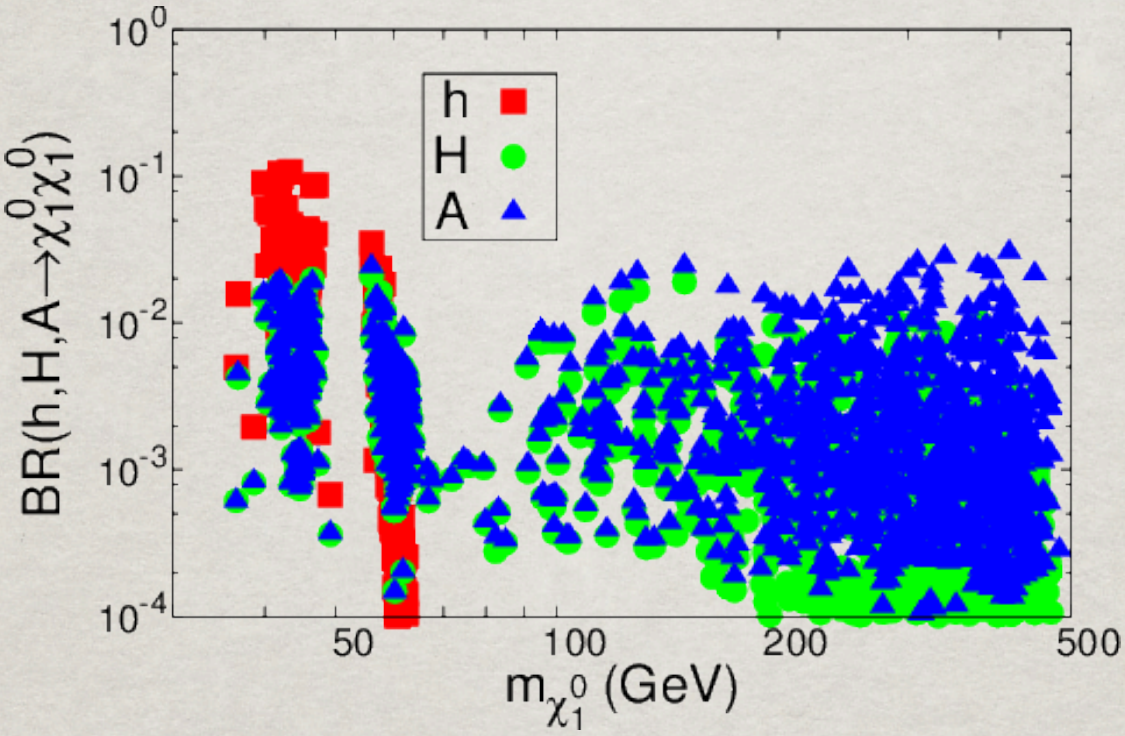
Summary Table:

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

Complementarity:
S-wave enhancement via A-funnel:
Velocity-independent s wave



Invisible Decays:



LHC insufficient.

ILC?

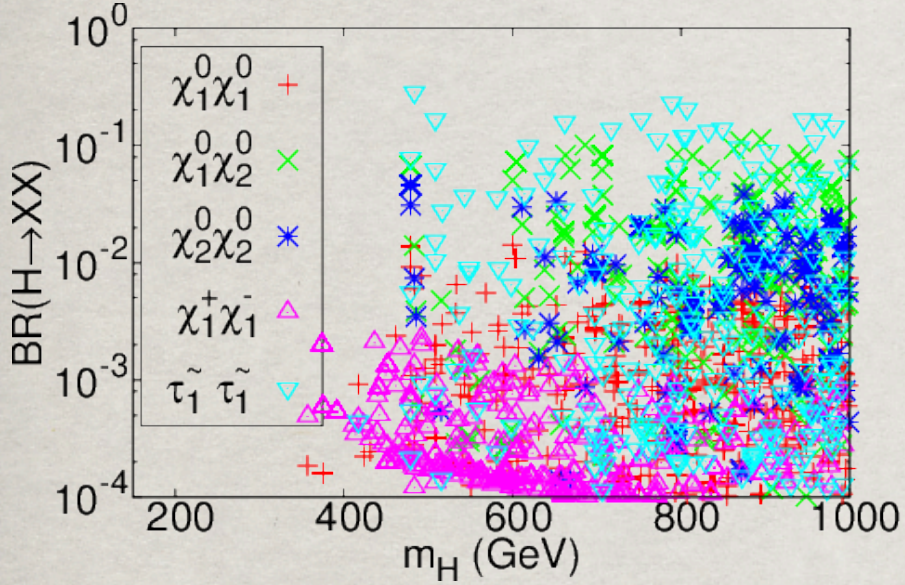
Features:

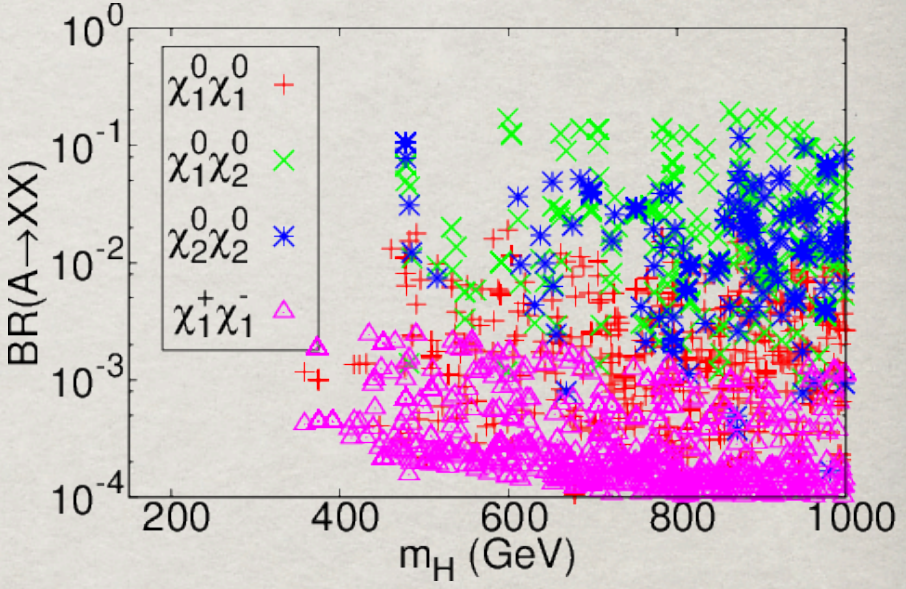
h → 2 LSP invisible as high as 10% at Z-funnel!

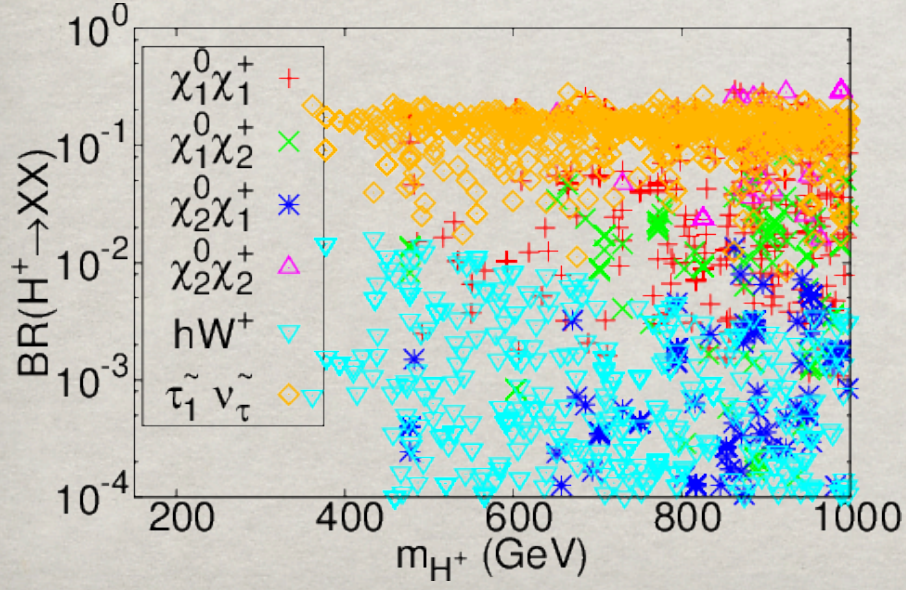
but, 5% at h-funnel, due to threshold suppression.

H,A → 2 LSP invisible 3-4%

More Invisible Decays:







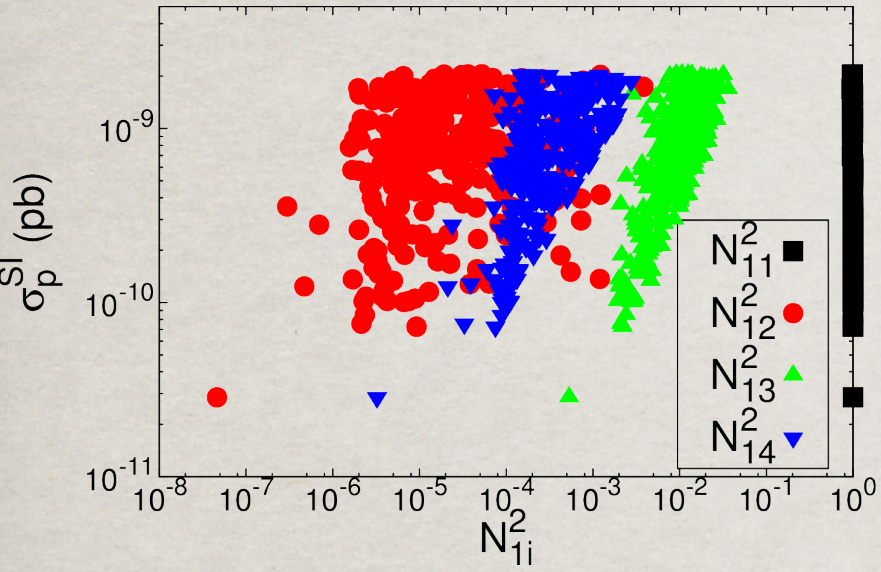
Features:

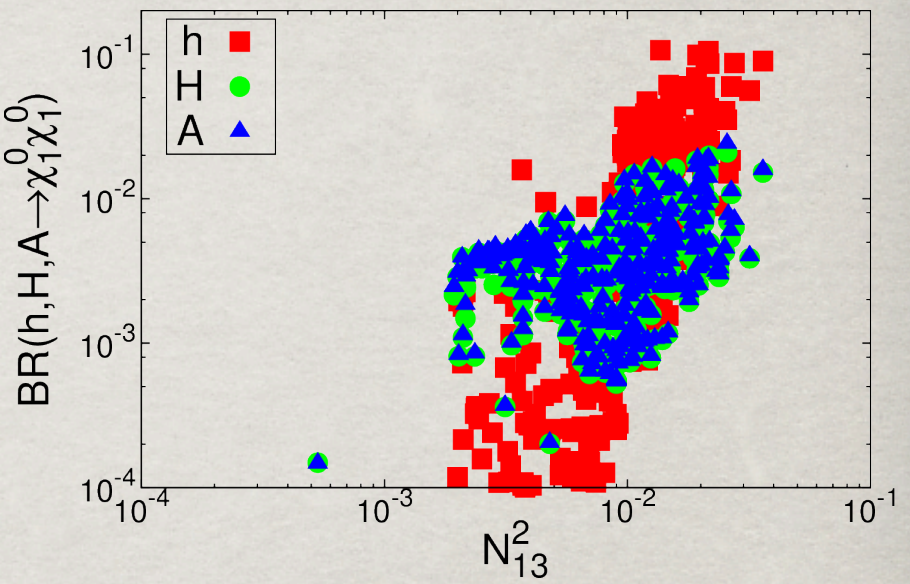
$H, A, H^{\pm} \rightarrow$ 2 LSP or NLSP

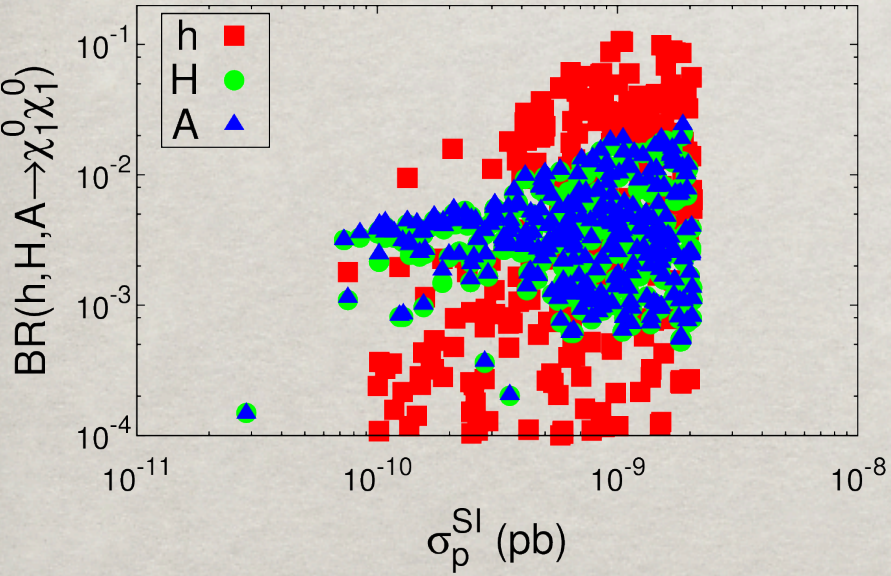
could be all invisible!

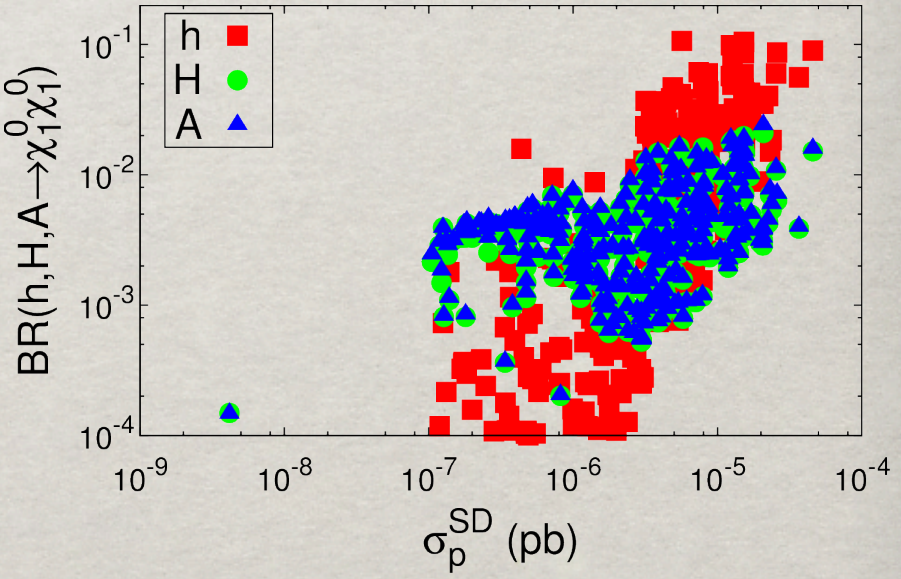
as high as 20%!

Correlations among observables:









Summary:

- The Higgs boson(s) could be the pivot:
  $\chi\chi \rightarrow$ h, H, A (Z) funnels for correct Ωh^2

- Direct search fully cover the funnels!

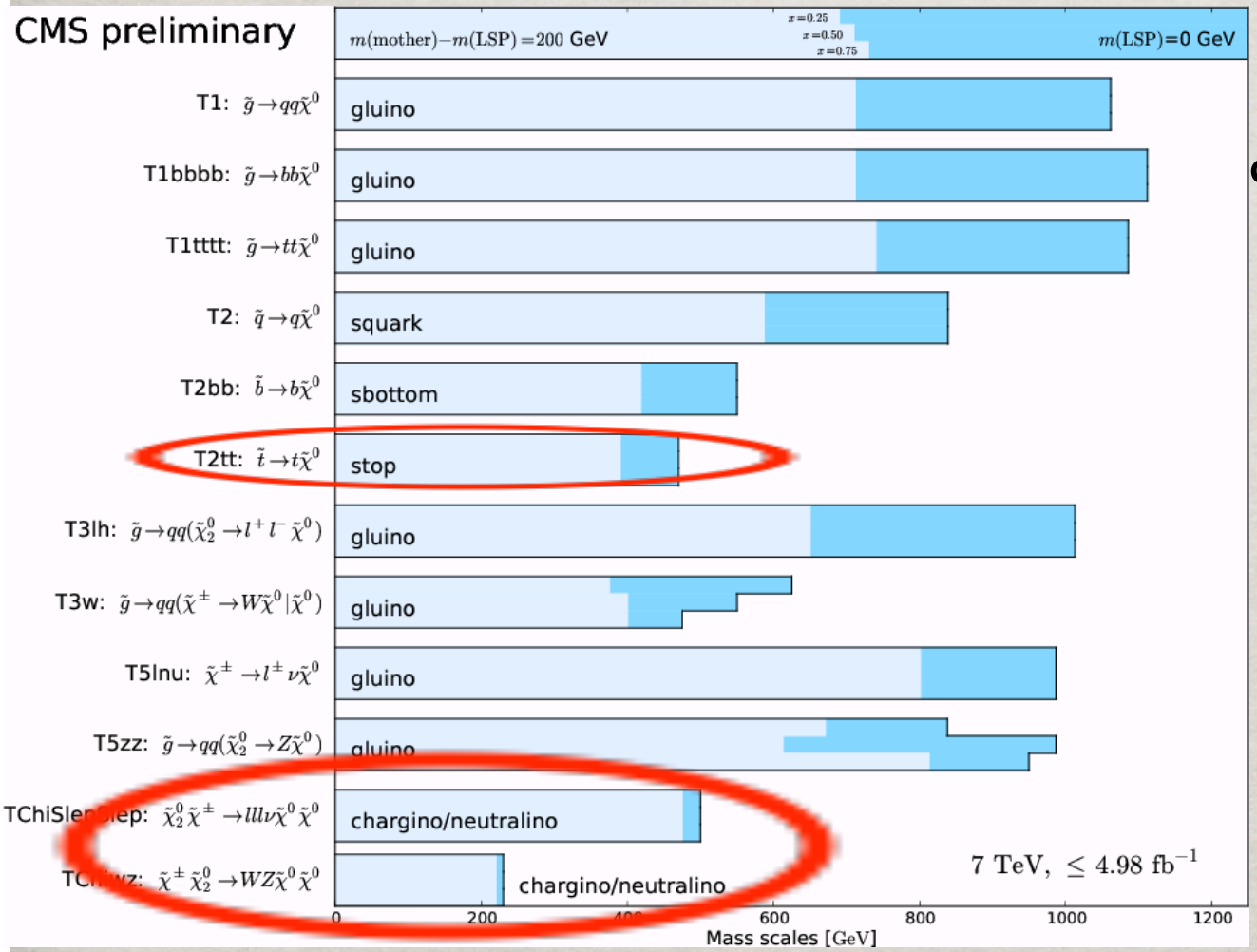
- Indirect detections complementary.

- LHC/ILC search for invisible modes
  crucial for confirmation.

An exciting journey ahead of us!

A Natural Higgs Sector at LHC

Supersymmetry:



Current bounds on the "most wanted" are still loose.

LHC will push stop to the extreme.

LHC may be limited to cover gauginos and Higgsinos.

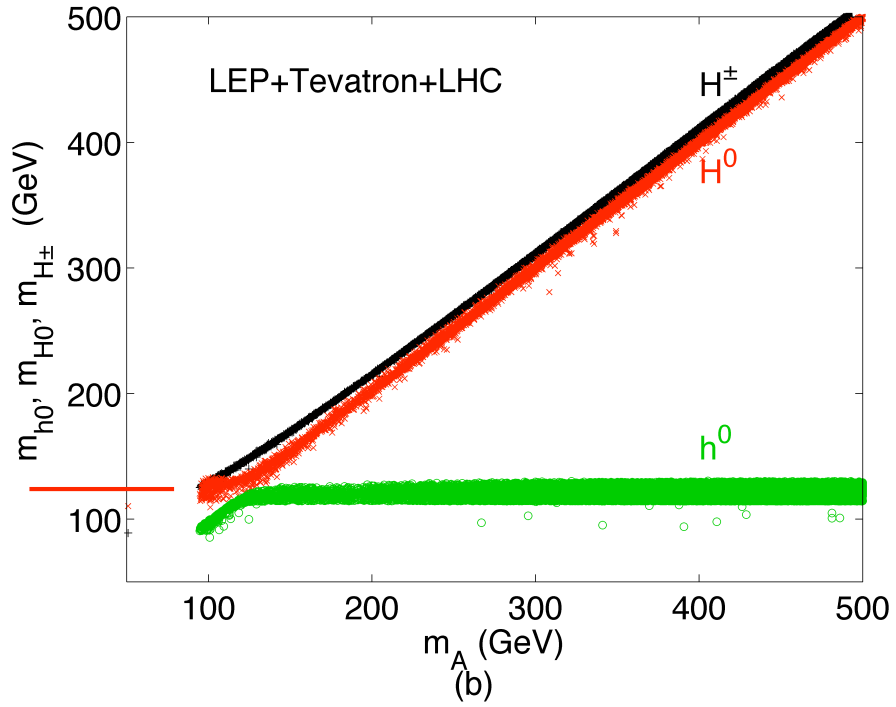
MSSM: Two Higgs-Doublet Model

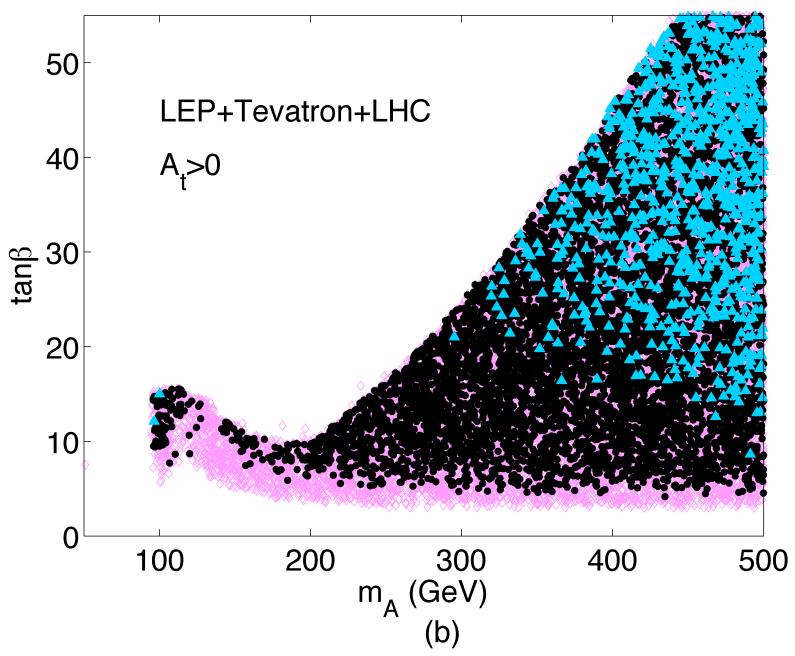
3 Goldstone bosons, 5 Higgs bosons:

$$h^0,\ H^0,\ A^0,\ H^\pm$$

Tree-level masses given by $M_A,\ \tan\beta$

Current LHC bounds:





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