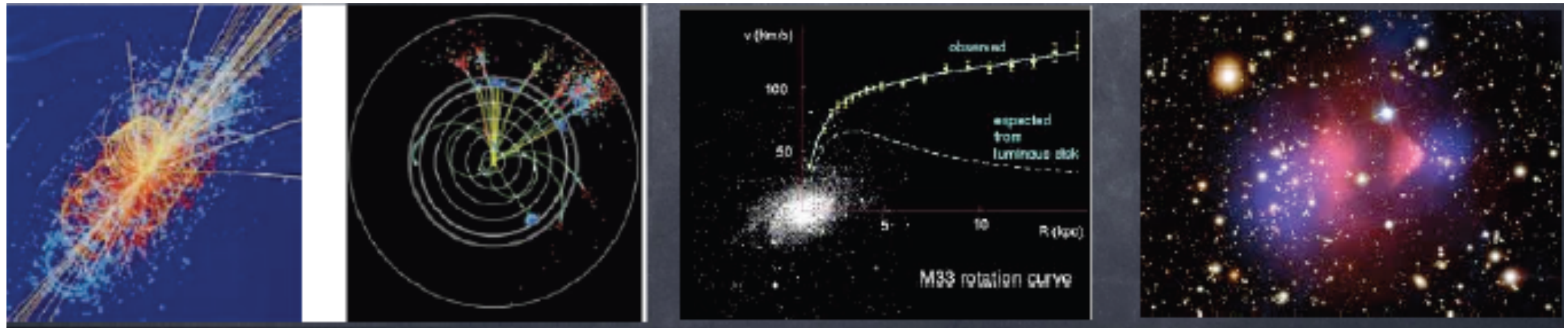


# Natural SUSY, mixed axion-higgsino dark matter and the gamma-ray sky

or

## What the Higgs discovery implies for WIMP detection

Howard Baer (University of Oklahoma)



# Discovery of Higgs at LHC vindicates SM!



but...

- Scalar particles contain quadratic divergences
- No dark matter candidates
- no valid baryogenesis mechanism

# SUSY extension of SM

- Tames quadratic divergences: stable hierarchies
- Supported by gauge coupling unification
- $m(t) \sim 173$  GeV needed to drive EWSB
- $m(h) \sim 126$  GeV falls within narrow predicted SUSY window
- a variety of DM candidates:  
neutralino (WIMP), axino, sneutrino\_R,  
gravitino...



# But where are the SUSY particles?

## ATLAS SUSY Searches\* - 95% CL Lower Limits

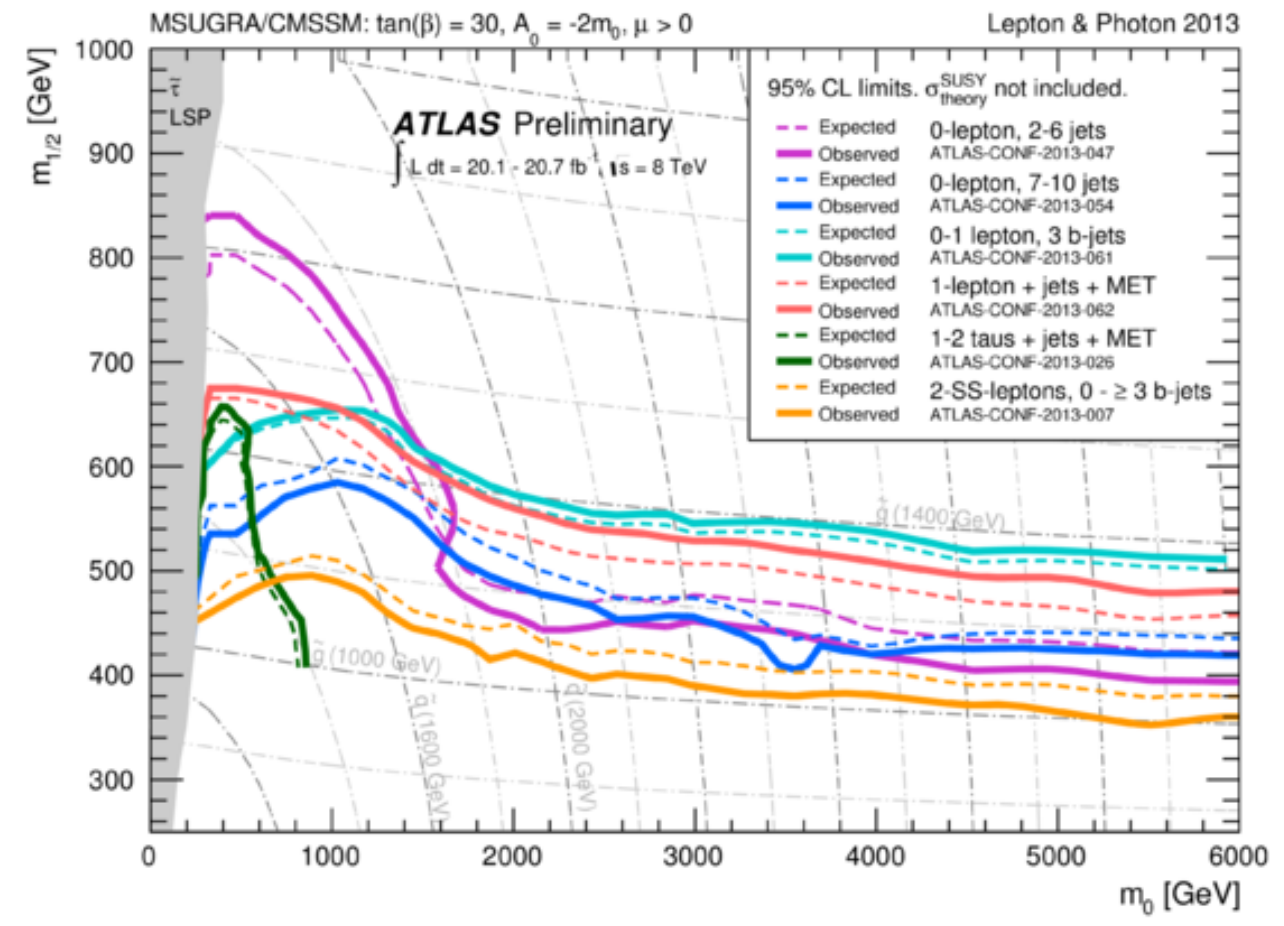
Status: SUSY 2013

ATLAS Preliminary

$\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1}$   $\sqrt{s} = 7, 8 \text{ TeV}$

Model	$e, \mu, \tau, \gamma$	Jets	$E_T^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$m(\tilde{g}) > 1.7 \text{ TeV}$
	MSUGRA/CMSSM	1 $e, \mu$	3-6 jets	Yes	20.3	$m(\tilde{g}) > 1.2 \text{ TeV}$
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$m(\tilde{g}) > 1.1 \text{ TeV}$
	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$m(\tilde{g}) > 740 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}$	0	2-6 jets	Yes	20.3	$m(\tilde{g}) > 1.3 \text{ TeV}$
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q} + \gamma$	1 $e, \mu$	3-6 jets	Yes	20.3	$m(\tilde{g}) > 1.16 \text{ TeV}$
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q} + \gamma + \gamma$	2 $e, \mu$	0-3 jets	-	20.3	$m(\tilde{g}) > 1.12 \text{ TeV}$
	GMSB (f NLSP)	2 $e, \mu$	2-4 jets	Yes	4.7	$m(\tilde{g}) > 1.24 \text{ TeV}$
	GMSB (f NLSP)	1-2 $e, \mu$	0-2 jets	Yes	20.7	$m(\tilde{g}) > 1.4 \text{ TeV}$
	GGM (bino NLSP)	2 $\gamma$	-	Yes	4.8	$m(\tilde{g}) > 1.87 \text{ TeV}$
3 <sup>rd</sup> gen squarks direct production	$\tilde{g}, \tilde{g} \rightarrow b\bar{b}$	0	3-6 jets	Yes	20.1	$m(\tilde{g}) > 1.2 \text{ TeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t}$	0	7-10 jets	Yes	20.3	$m(\tilde{g}) > 1.1 \text{ TeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma$	0-1 $e, \mu$	3-6 jets	Yes	20.1	$m(\tilde{g}) > 1.34 \text{ TeV}$
	$\tilde{g}, \tilde{g} \rightarrow b\bar{b} + \gamma$	0-1 $e, \mu$	3-6 jets	Yes	20.1	$m(\tilde{g}) > 1.3 \text{ TeV}$
	$\tilde{g}, \tilde{g} \rightarrow b\bar{b} + \gamma + \gamma$	0	2-6 jets	Yes	20.1	$m(\tilde{g}) > 1.00-620 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma$	2 $e, \mu$ (SS)	0-3 jets	Yes	20.7	$m(\tilde{g}) > 275-430 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma$	1-2 $e, \mu$	1-2 jets	Yes	4.7	$m(\tilde{g}) > 110-187 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma$	2 $e, \mu$	0-2 jets	Yes	20.3	$m(\tilde{g}) > 190-220 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma$	2 $e, \mu$	2 jets	Yes	20.3	$m(\tilde{g}) > 225-525 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma$	2 $e, \mu$	0 jets	Yes	20.1	$m(\tilde{g}) > 150-580 \text{ GeV}$
EW direct	$\tilde{g}, \tilde{g} \rightarrow b\bar{b} + \gamma$	1 $e, \mu$	1-6 jets	Yes	20.7	$m(\tilde{g}) > 200-610 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma$	0	2-6 jets	Yes	20.5	$m(\tilde{g}) > 320-580 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma$	0	mono-jet/c-tag	Yes	20.3	$m(\tilde{g}) > 90-200 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma$	2 $e, \mu$ (Z)	1-6 jets	Yes	20.7	$m(\tilde{g}) > 500 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma$	3 $e, \mu$ (Z)	1-6 jets	Yes	20.7	$m(\tilde{g}) > 271-520 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma$	2 $e, \mu$	0	Yes	20.3	$m(\tilde{g}) > 85-315 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	2 $e, \mu$	0	Yes	20.3	$m(\tilde{g}) > 125-450 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	2 $e, \mu$	0	Yes	20.7	$m(\tilde{g}) > 180-330 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	3 $e, \mu$	0	Yes	20.7	$m(\tilde{g}) > 315 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	3 $e, \mu$	0	Yes	20.7	$m(\tilde{g}) > 385 \text{ GeV}$
Long-lived particles	Direct $\tilde{g}, \tilde{g} \rightarrow t\bar{t}$ prod. long-lived $\tilde{t}$	Disapp. 9k	1 jet	Yes	20.3	$m(\tilde{g}) > 270 \text{ GeV}$
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$m(\tilde{g}) > 832 \text{ GeV}$
	GMSB, stable $\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	1-2 $\mu$	-	-	15.9	$m(\tilde{g}) > 475 \text{ GeV}$
	GMSB, $\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	2 $\gamma$	-	Yes	4.7	$m(\tilde{g}) > 230 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	1 $\mu$ , displ. vtx	-	-	20.3	$m(\tilde{g}) > 1.8 \text{ TeV}$
	LFV $\tilde{g}, \tilde{g} \rightarrow X, \tau, \nu \rightarrow e + \mu$	2 $e, \mu$	-	-	4.6	$m(\tilde{g}) > 1.81 \text{ TeV}$
	LFV $\tilde{g}, \tilde{g} \rightarrow X, \tau, \nu \rightarrow e + \mu + \tau$	1 $e, \mu + \tau$	-	-	4.6	$m(\tilde{g}) > 1.1 \text{ TeV}$
	Bilinear RPV CMSSM	1 $e, \mu$	7 jets	Yes	4.7	$m(\tilde{g}) > 1.2 \text{ TeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	4 $e, \mu$	-	Yes	20.7	$m(\tilde{g}) > 790 \text{ GeV}$
	$\tilde{g}, \tilde{g} \rightarrow t\bar{t} + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma + \gamma$	3 $e, \mu + \tau$	-	Yes	20.7	$m(\tilde{g}) > 350 \text{ GeV}$
Other	Scalar gluon pair, $\tilde{g}, \tilde{g} \rightarrow q\bar{q}$	0	4 jets	-	4.6	$m(\tilde{g}) > 100-287 \text{ GeV}$
	Scalar gluon pair, $\tilde{g}, \tilde{g} \rightarrow t\bar{t}$	2 $e, \mu$ (SS)	1-6 jets	Yes	14.3	$m(\tilde{g}) > 800 \text{ GeV}$
	WIMP interaction (DS, Dirac $\chi$ )	0	mono-jet	Yes	10.5	$m(\tilde{g}) > 704 \text{ GeV}$

\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1 $\sigma$  theoretical signal cross section uncertainty.



$$m_{\tilde{g}} > 1.4 \text{ TeV for } m_{\tilde{g}} \ll m_{\tilde{q}}$$

$$m_{\tilde{g}} > 1.8 \text{ TeV for } m_{\tilde{g}} \sim m_{\tilde{q}}$$

# Impression from past year and summer conferences: crisis of SUSY naturalness!

SM case:  $V = -\mu^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2$

$$m_h^2 = m_h^2|_{tree} + \delta m_h^2|_{rad}$$

$$m_h^2|_{tree} = \sqrt{2}\mu^2 \quad \delta m_h^2|_{rad} = \frac{c}{16\pi^2}\Lambda^2 \quad m_h^2|_{tree} \text{ and } \delta m_h^2|_{rad} \text{ are independent,}$$

$$\Delta_{SM} \equiv \delta m_h^2|_{rad}/(m_h^2/2) \quad \Delta_{SM} < 1 \Rightarrow \Lambda \sim 1 \text{ TeV}$$

MSSM case:  $m_h^2 \simeq \mu^2 + m_{H_u}^2 + \delta m_{H_u}^2|_{rad}$

$$\frac{dm_{H_u}^2}{dt} = \frac{1}{8\pi^2} \left( -\frac{3}{5}g_1^2 M_1^2 - 3g_2^2 M_2^2 + \frac{3}{10}g_1^2 S + 3f_t^2 X_t \right)$$

$$\delta m_{H_u}^2|_{rad} \sim -\frac{3f_t^2}{8\pi^2} (m_{Q_3}^2 + m_{U_3}^2 + A_t^2) \ln(\Lambda^2/m_{SUSY}^2)$$

$$\Delta \equiv \delta m_{H_u}^2/(m_h^2/2) \lesssim 10 \quad \text{then} \quad m_{\tilde{t}_{1,2}}, m_{\tilde{b}_1} \lesssim 200 \text{ GeV and } m_{\tilde{g}} \lesssim 600 \text{ GeV}$$

apparently in violation of LHC constraints!

In zeal for simplicity, have neglected that in SUSY

$m_{H_u}^2$  and  $\delta m_{H_u}^2|_{rad}$  are not independent

the larger the value of  $m_{H_u}^2(\Lambda)$ , then the larger is the cancelling correction  $\delta m_{H_u}^2|_{rad}$

This suggests a re-grouping

$$m_h^2|_{phys} = \mu^2 + (m_{H_u}^2(\Lambda) + \delta m_{H_u}^2)$$

where instead both  $\mu^2$  and  $(m_{H_u}^2 + \delta m_{H_u}^2)$  should be comparable to  $m_h^2|_{phys}$ .

Such a re-grouping is used in Barbieri-Giudice measure:

$$\Delta_{BG} \equiv \max_i [c_i] \quad \text{where} \quad c_i = \left| \frac{\partial \ln m_Z^2}{\partial \ln a_i} \right|$$

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2 \simeq -m_{H_u}^2 - \mu^2$$

↑  
express weak scale value in terms of high scale parameters

# Express $m(Z)$ in terms of high scale parameters:

$$m_Z^2 \simeq -2m_{H_u}^2 - 2\mu^2 \qquad -2\mu^2(m_{SUSY}) = -2.18\mu^2$$

$$\begin{aligned} -2m_{H_u}^2(m_{SUSY}) = & 3.84M_3^2 + 0.32M_3M_2 + 0.047M_1M_3 - 0.42M_2^2 \\ & + 0.011M_2M_1 - 0.012M_1^2 - 0.65M_3A_t - 0.15M_2A_t \\ & - 0.025M_1A_t + 0.22A_t^2 + 0.004m_3A_b \\ & - 1.27m_{H_u}^2 - 0.053m_{H_d}^2 \\ & + 0.73m_{Q_3}^2 + 0.57m_{U_3}^2 + 0.049m_{D_3}^2 - 0.052m_{L_3}^2 + 0.053m_{E_3}^2 \\ & + 0.051m_{Q_2}^2 - 0.11m_{U_2}^2 + 0.051m_{D_2}^2 - 0.052m_{L_2}^2 + 0.053m_{E_2}^2 \\ & + 0.051m_{Q_1}^2 - 0.11m_{U_1}^2 + 0.051m_{D_1}^2 - 0.052m_{L_1}^2 + 0.053m_{E_1}^2, \end{aligned}$$

For generic parameter choices,  $\Delta_{BG}$  is large

But if:  $m_{Q_{1,2}} = m_{U_{1,2}} = m_{D_{1,2}} = m_{L_{1,2}} = m_{E_{1,2}} \equiv m_{16}(1,2)$  then  $\sim 0.007m_{16}^2(1,2)$

Even better:  $m_{H_u}^2 = m_{H_d}^2 = m_{16}^2(3) \equiv m_0^2 \Rightarrow -0.017m_0^2$

**For correlated parameters, EWFT collapses in 3rd gen. sector!**

## Lessons:

- Large log finetuning selectively picks out one term to exclusion of others; gives gross overestimate by orders of magnitude
- $\Delta_{BG}$  properly uses  $m_h^2|_{phys} = \mu^2 + (m_{H_u}^2(\Lambda) + \delta m_{H_u}^2)$
- But  $\Delta_{BG}$  usually applied to general **effective** theories.
- The hope is that eff. theory contains the **ultimate theory** (UTH).
- Due to high scale parameter correlations, UTH can have far less EWFT than effective theories which may contain it.



What we really want to know is if nature is fine-tuned, (and by implication the UTH which describes it), and not whether-or-not the more general effective theories (which might contain the UTH) are fine-tuned

# Model-independent EWFT measure: $\Delta_{EW}$

No large uncorrelated cancellations in  $m(Z)$  or  $m(h)$

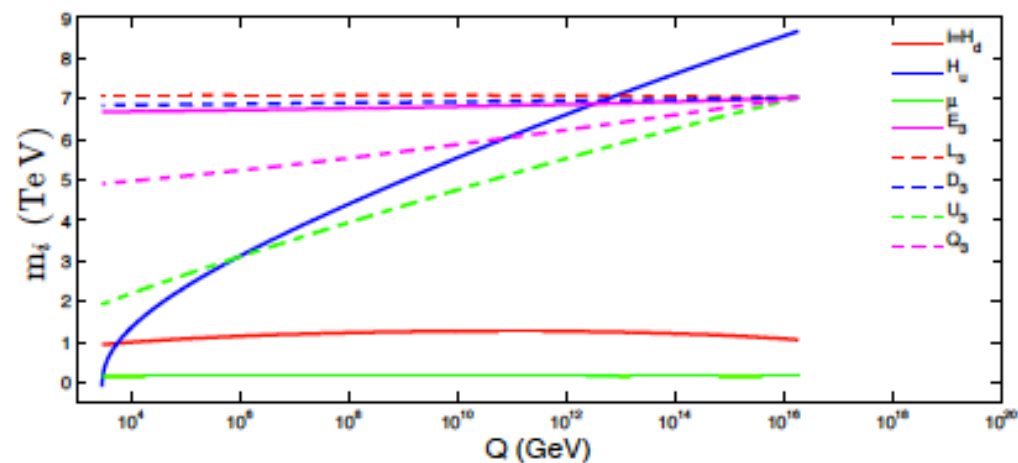
$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2$$

$$\Delta_{EW} \equiv \max_i |C_i| / (m_Z^2/2) \quad \text{with} \quad C_{H_u} = -m_{H_u}^2 \tan^2 \beta / (\tan^2 \beta - 1) \quad \text{etc.}$$

Since  $\Delta_{EW}$  model-independent (within MSSM),  
expect same value for Eff. theory as for UTH!

In order to achieve low  $\Delta_{EW}$ , it is necessary that  $-m_{H_u}^2$ ,  $\mu^2$  and  $-\Sigma_u^u$  all be nearby to  $m_Z^2/2$  to within a factor of a few[12, 13]:

1.  $\mu$  is required to lie in the 100 – 300 GeV range,
2. a value of  $m_{H_u}^2(m_{GUT}) \sim (1.3 - 2.5)m_0$  may be chosen so that  $m_{H_u}^2$  is driven radiatively to slightly negative at the weak scale, leading to  $m_{H_u}^2(weak) \sim -m_Z^2/2$ , and
3. with large stop mixing from  $A_0 \sim \pm 1.6m_0$ , the top-squark radiative corrections are softened while  $m_h$  is raised to the  $\sim 125$  GeV level.



Radiatively-driven natural SUSY

WIMP=mainly higgsino!

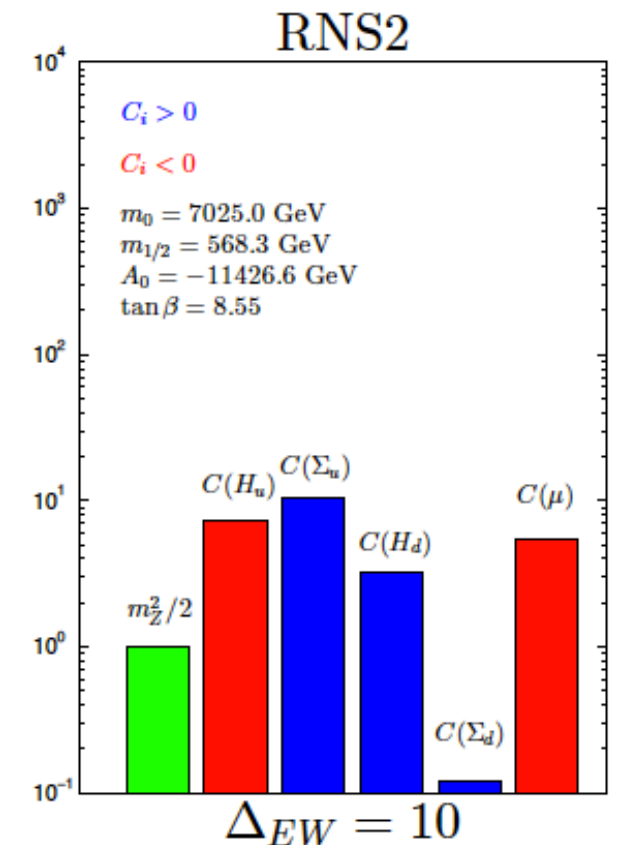
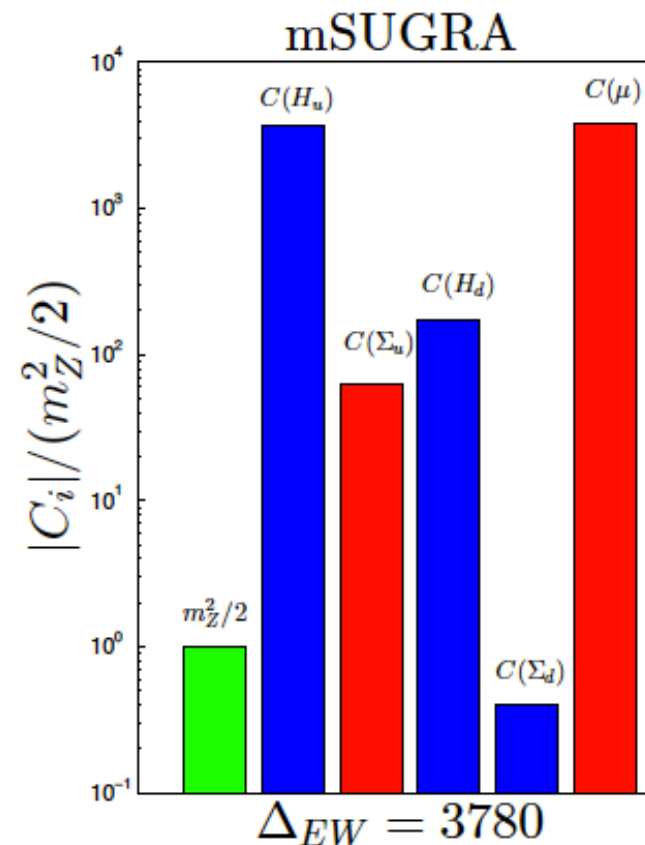
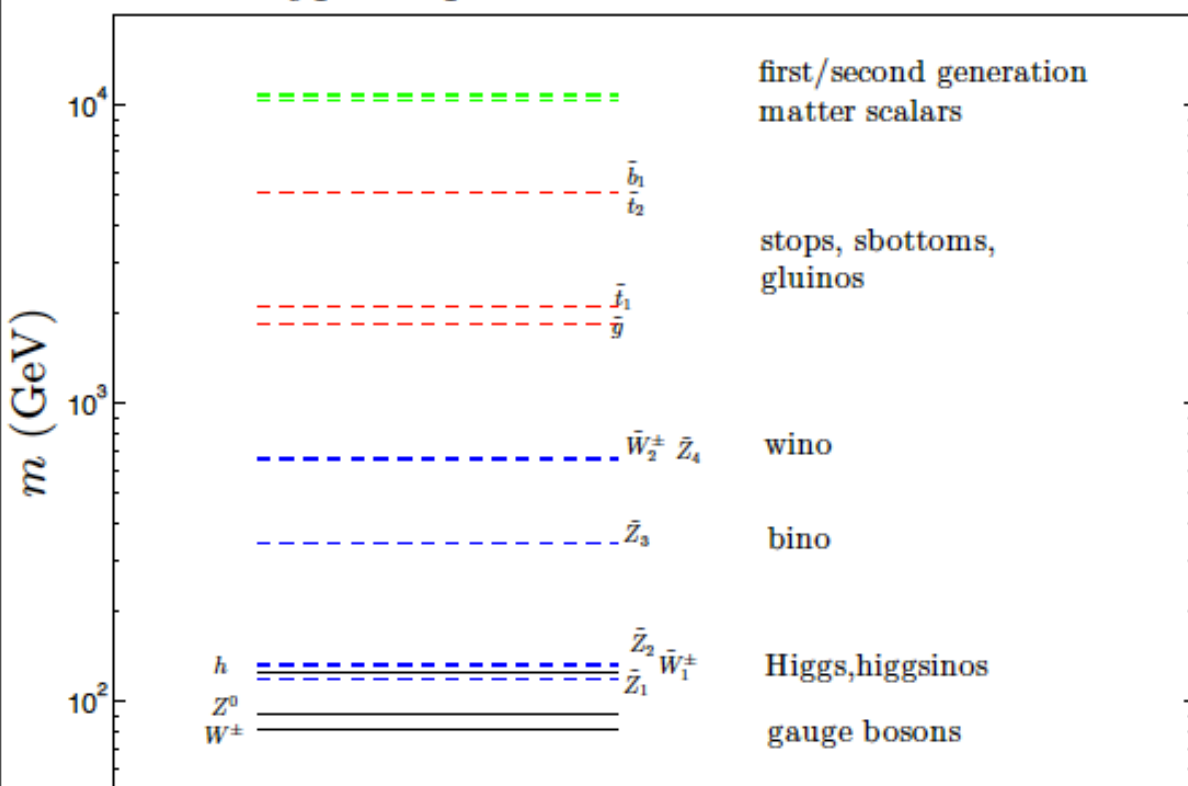
Models where  $m_{H_u}^2$  correlated with  $m_0$  (such as mSUGRA) are fine-tuned

Models such as NUHM2 can allow for low  $m_{\tilde{m}(Z)}$  while maintaining not-too-heavy but highly mixed stops

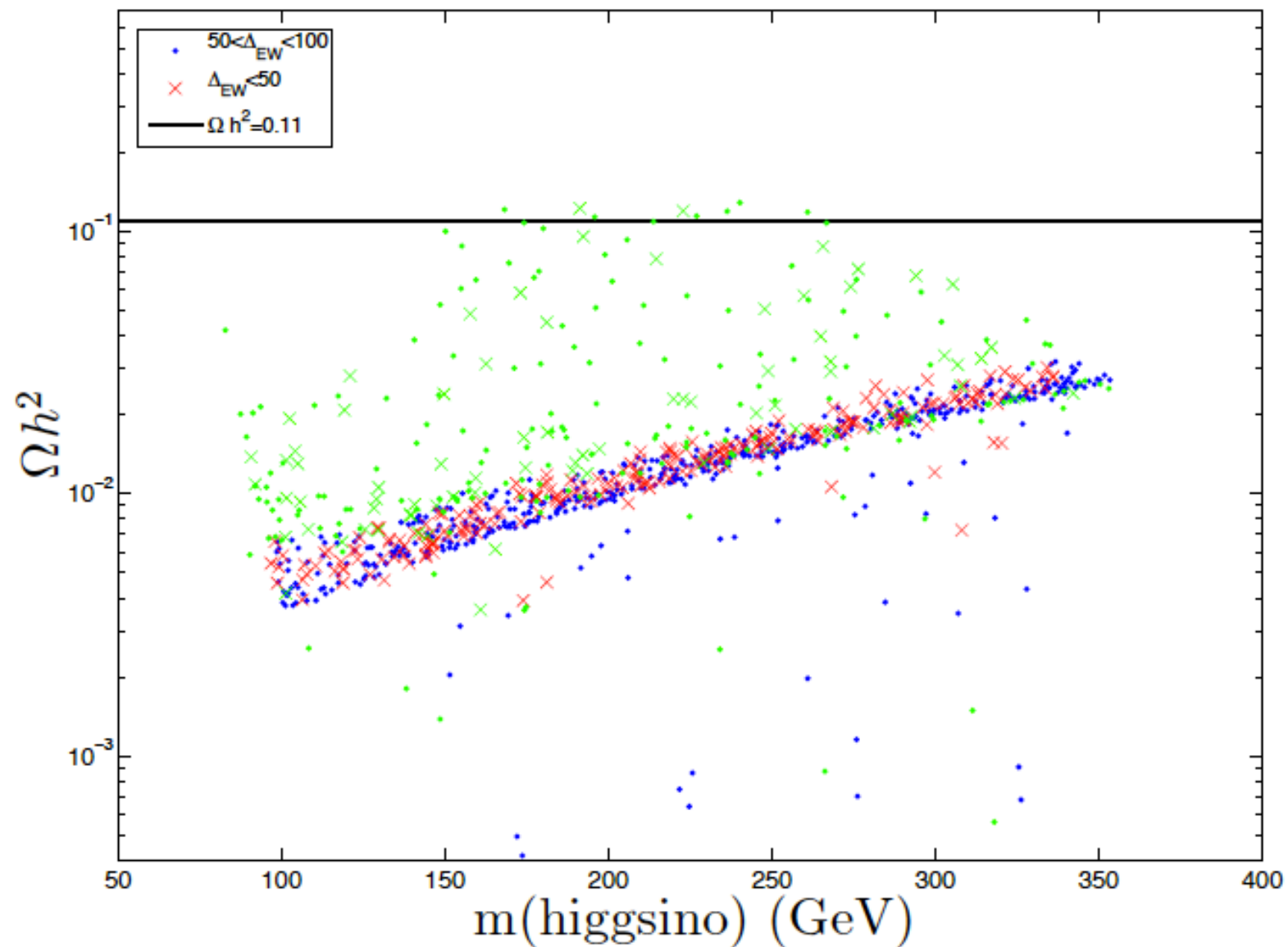
NUHM2 by

J. Ellis, K. Olive and Y. Santoso, *Phys. Lett. B* 539 (2002) 107; J. Ellis, T. Falk, K. Olive and Y. Santoso, *Nucl. Phys. B* 652 (2003) 259; H. Baer, A. Mustafayev, S. Profumo, A. Belyaev and X. Tata, *J. High Energy Phys.* 0507 (2005) 065.

Typical spectrum for low  $\Delta_{EW}$  models



# Mainly higgsino-like WIMPs underproduce DM



Factor of 10-15 too low



But so far we have addressed only Part I of finetuning problem:

In QCD sector, the term  $\frac{\bar{\theta}}{32\pi^2} F_{A\mu\nu} \tilde{F}_A^{\mu\nu}$  must occur

But neutron EDM says it is not there: strong CP problem  
(frequently ignored by SUSY types)

Best solution after 35 years: PQWW invisible axion

In SUSY, axion accompanied by axino and saxion

Changes DM calculus: expect mixed WIMP/axion DM  
(2 particles)

## Axion cosmology

★ Axion field eq'n of motion:  $\theta = a(x)/f_a$

–  $\ddot{\theta} + 3H(T)\dot{\theta} + \frac{1}{f_a^2} \frac{\partial V(\theta)}{\partial \theta} = 0$

–  $V(\theta) = m_a^2(T) f_a^2 (1 - \cos \theta)$

– Solution for  $T$  large,  $m_a(T) \sim 0$ :

$\theta = \text{const.}$

–  $m_a(T)$  turn-on  $\sim 1$  GeV

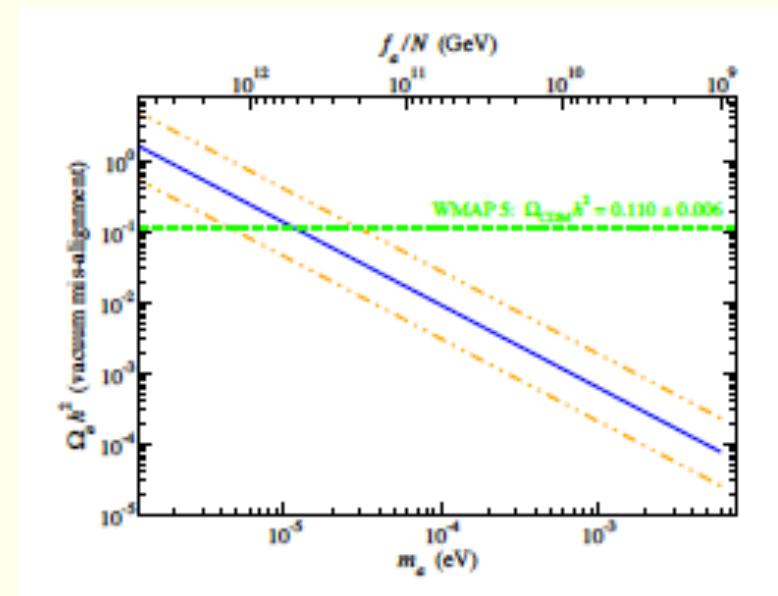
★  $a(x)$  oscillates,

creates axions with  $\vec{p} \sim 0$ :

production via vacuum mis-alignment

★  $\Omega_a h^2 \sim \frac{1}{2} \left[ \frac{6 \times 10^{-6} \text{ eV}}{m_a} \right]^{7/6} \theta_i^2 h^2$

★ astro bound: stellar cooling  $\Rightarrow f_a \gtrsim 10^9 \text{ GeV}$



# Axino/saxion decays

Decays very model-dependent;  
also depend on KSVZ or DFSZ model

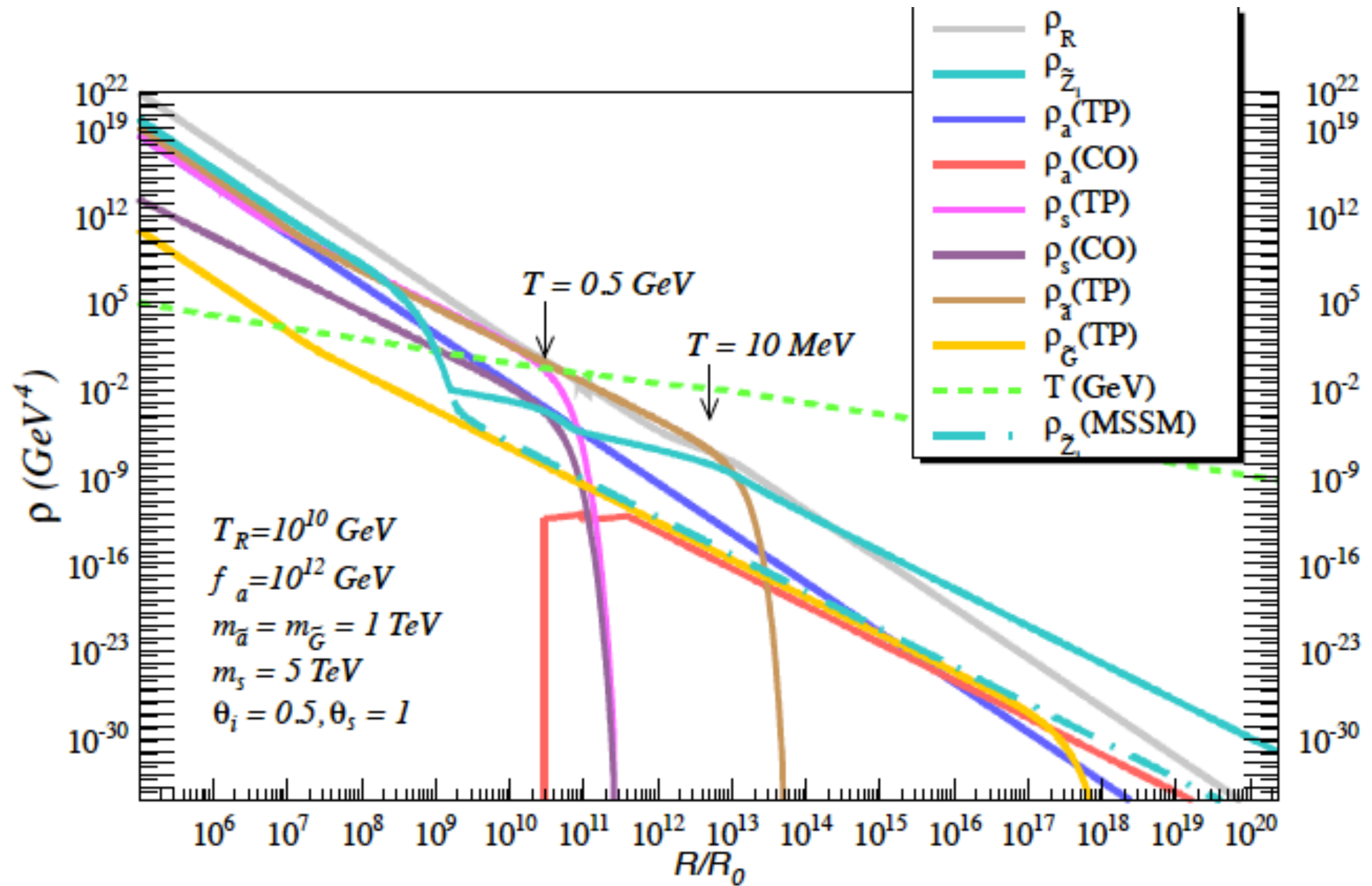
axino  $\rightarrow$  particle+sparticle: augment LSP abundance but  
also provide late-time entropy injection

saxion  $\rightarrow$  gg, hh, etc SM particles (entropy dilution)

saxion  $\rightarrow$  gl<sub>no</sub>+g<sub>no</sub>, hg<sub>no</sub>+hg<sub>no</sub>, etc (SUSY particles, augment)

saxion  $\rightarrow$  aa, dark radiation,  $\Delta N_{eff}$  bounds

# Coupled Boltzmann KSVZ $\xi = 0$



HB, Lessa, Sreethawong



mu problem: why is  $\mu \sim m(\text{weak})$  and not  $M_P$ ?

Kim-Nilles solution to SUSY mu problem

SUSY DFSZ model

(Dine-Fischler-Srednicki-Zhitnitsky, 1983)

Higgs fields  $H_u$  and  $H_d$  carry PQ charge:  $\mu$  term forbidden

Field  $S$  carries PQ charge and contains axion-axino-saxion

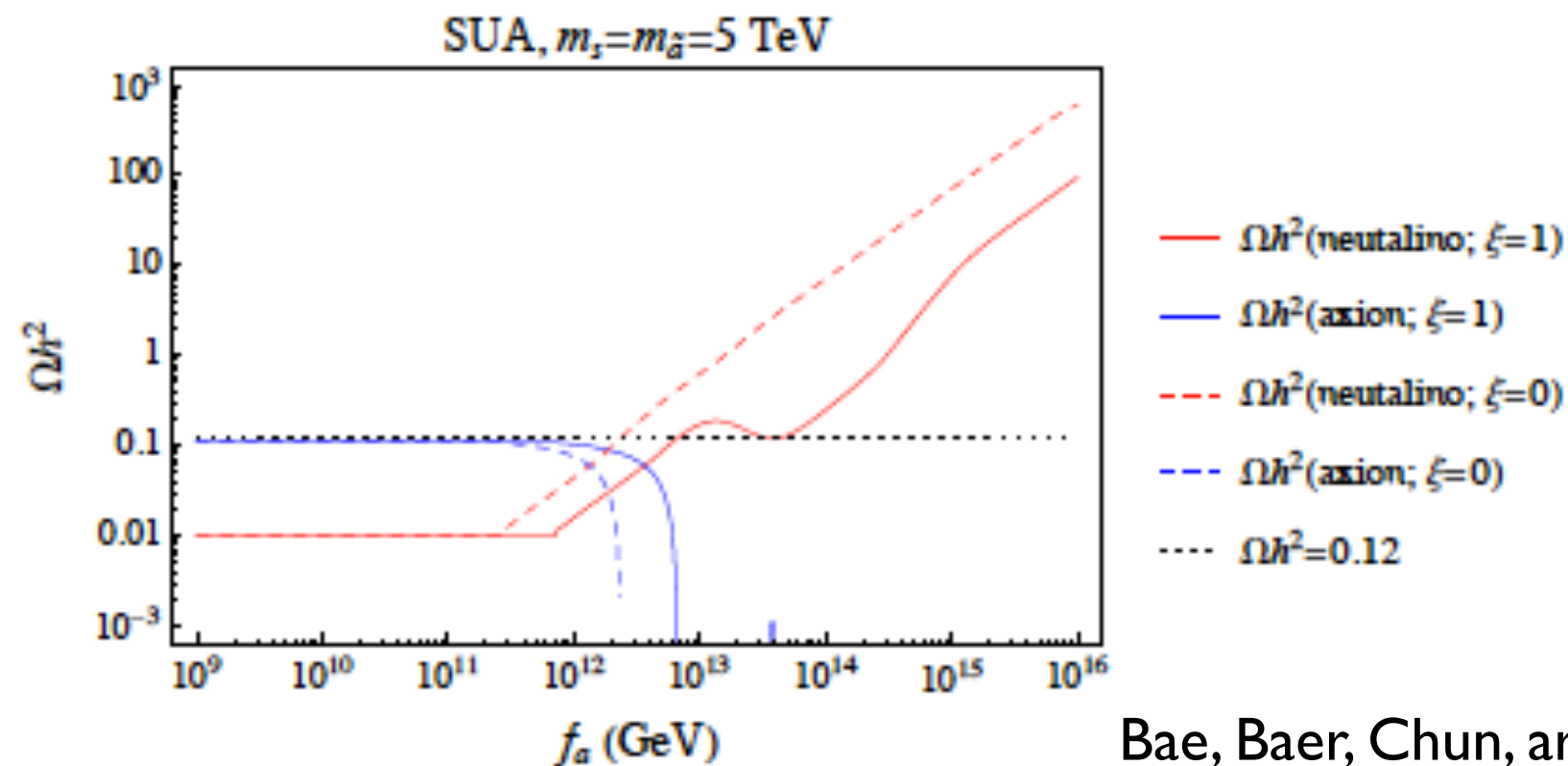
$$W_{\text{DFSZ}} \ni \lambda \frac{S^2}{M_P} H_u H_d$$

If  $S$  develops vev  $\sim f_a$ , then weak scale  $\mu$  generated!

$$\mu \sim \lambda f_a^2 / M_P \sim \lambda m_{3/2}$$

Tree level axion superfield couplings to higgs/higgsinos: axino/saxion decay before WIMP freezeout for  $f_a < 10^{12}$  GeV

Then usual WIMP abundance obtains but supplemented by axion CDM!



Bae, Baer, Chun, arXiv:1309.0519

Get 90-95% axion CDM plus 5-10% higgsino-like WIMPs

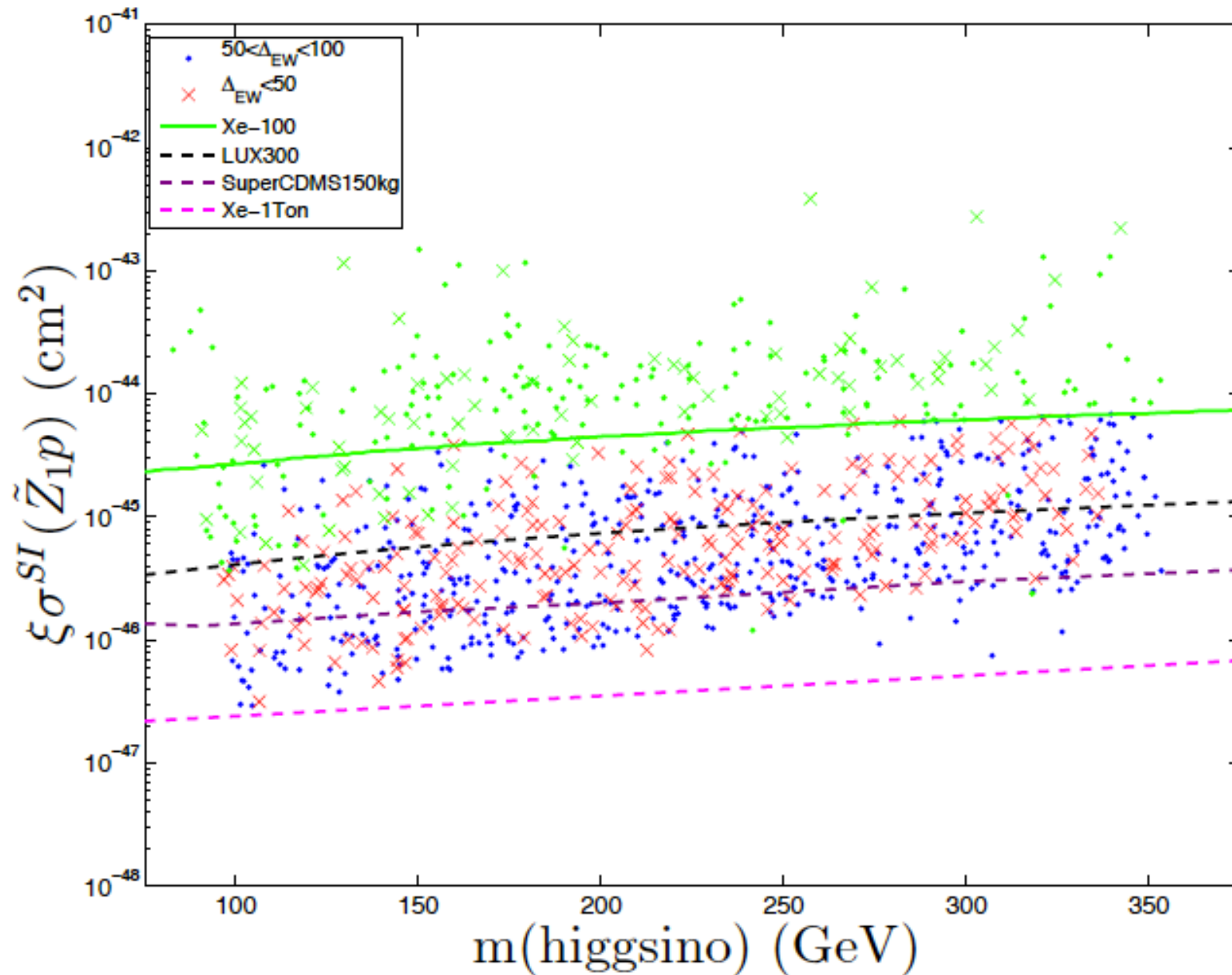
# Detection of mixed $a/Z_1$ DM in natural SUSY with DFSZ axion

detection of axion as usual: range of PQ scale  $f_a$ :  
 $10^9$ – $10^{12}$  favored in SUSY DFSZ

detection of WIMPs same as usual but theory projections should be scaled to account for WIMPs making only a fraction of total DM density

use Bottino, Fornengo et al.  $\xi \equiv \Omega_\chi h^2 / 0.12$       rescaling factor

# Direct higgsino detection rescaled for minimal local abundance



HB, Barger, Mickelson  
arXiv:1303.3816

$$\mathcal{L} \ni -X_{11}^h \bar{\tilde{Z}}_1 \tilde{Z}_1 h$$

$$X_{11}^h = -\frac{1}{2} (v_2^{(1)} \sin \alpha - v_1^{(1)} \cos \alpha) (g v_3^{(1)} - g' v_4^{(1)})$$

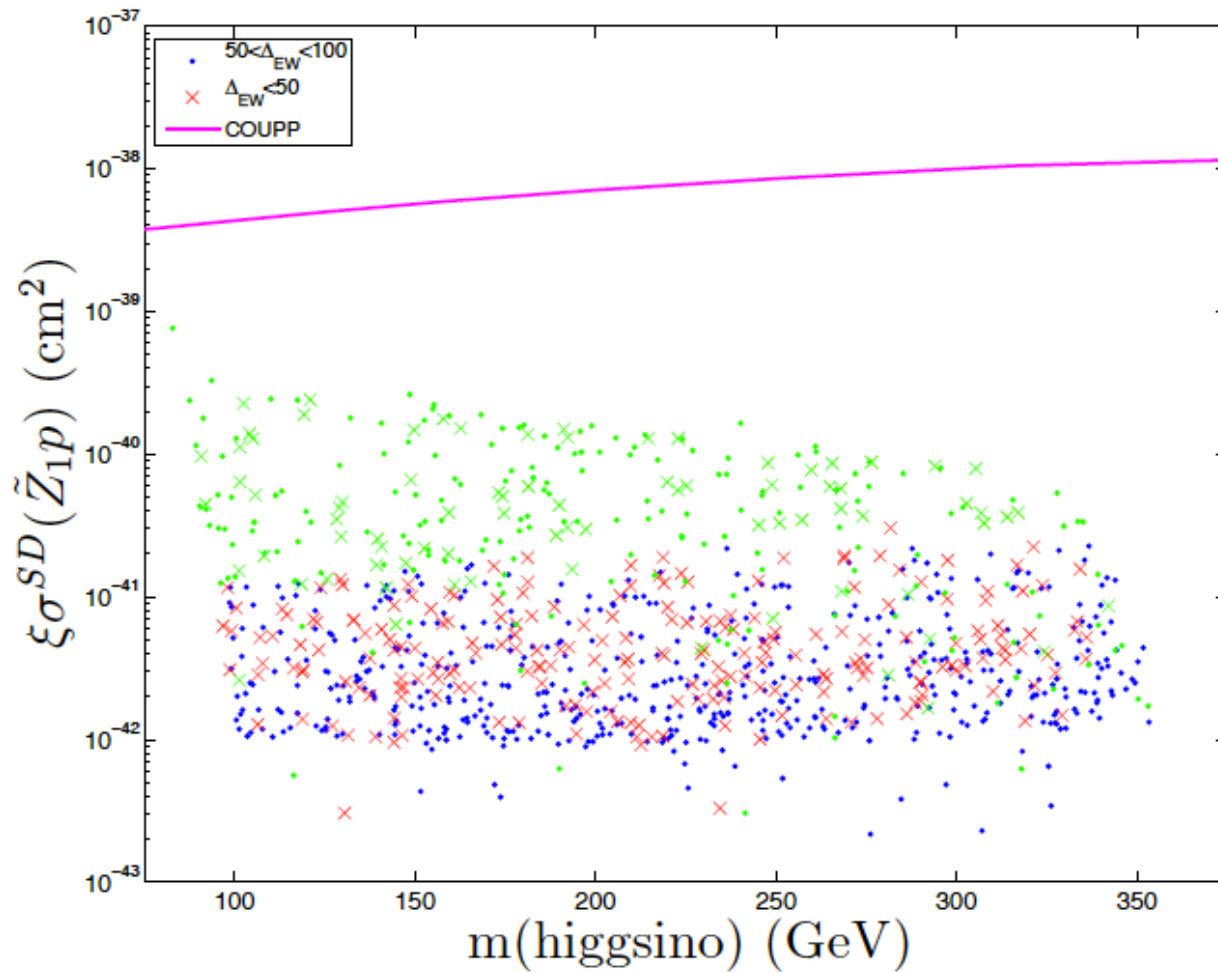
LUX has been deployed!

Deployment of Xe-1ton  
coming soon!

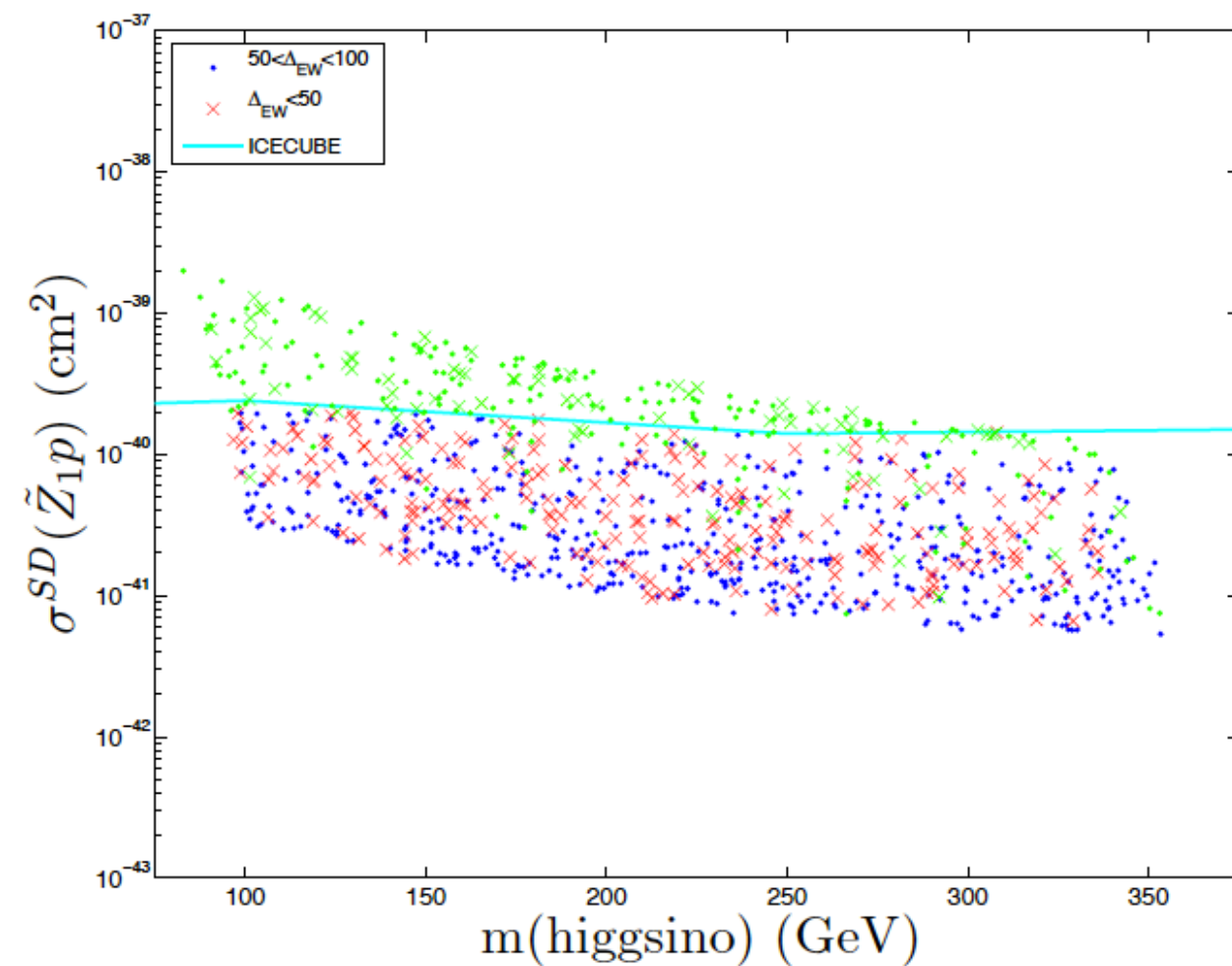
Can test completely with ton scale detector  
or equivalent (subject to minor caveats)



# Spin-dependent higgsino detection:

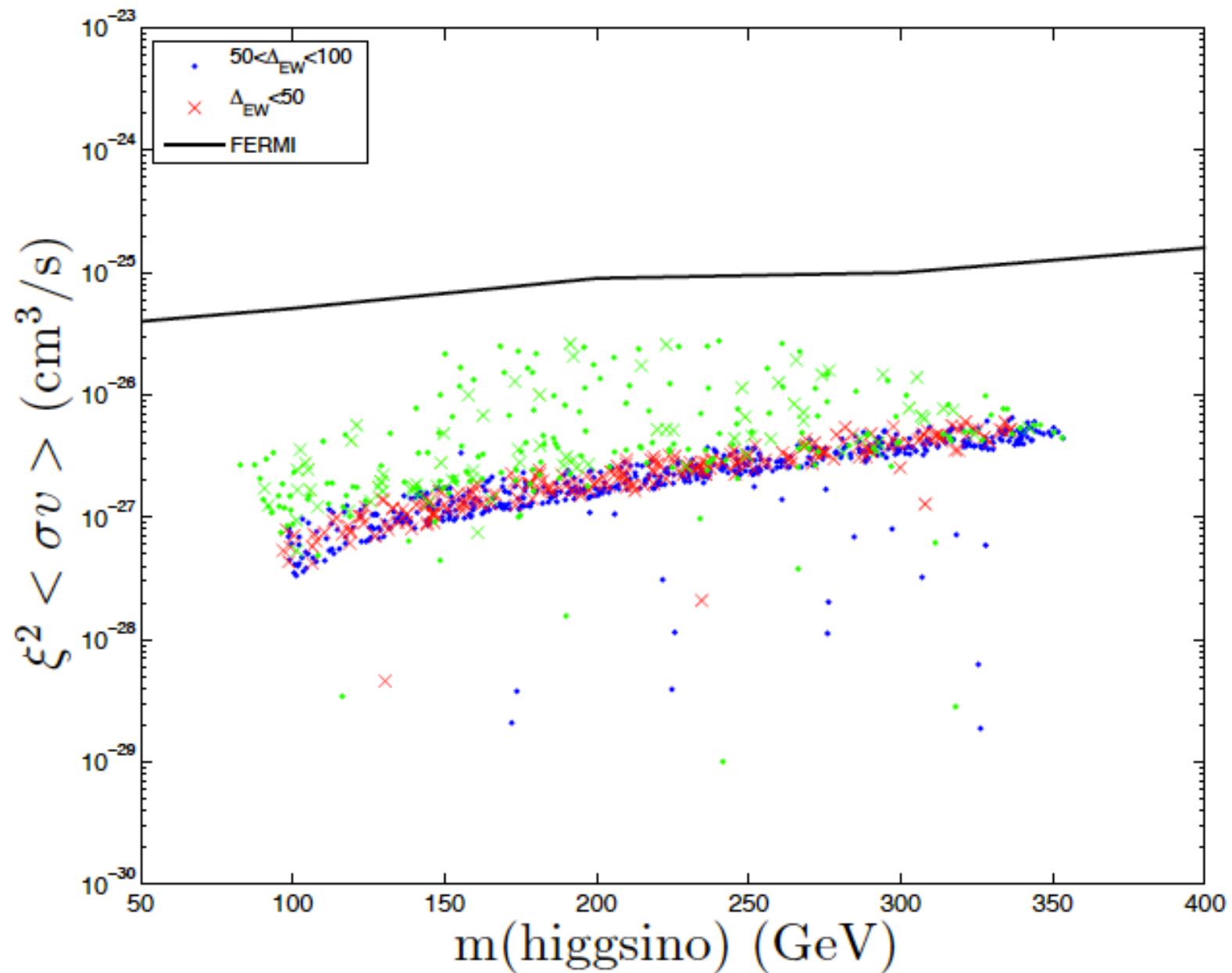


$10^2$  below current bounds



no rescaling for IceCube if equilibration between solar capture/annihilation has occurred

# Higgsino detection via halo annihilations:



green: excluded by Xe-100

annihilation rate is high but rescaling is **squared**

Gamma-ray sky signal is factor 10-20 below current limits

# Conclusions: SUSY dark matter post LHC8

- SUSY EWFT **non-crisis**: EWFT allowed at 10% level in radiatively-driven natural SUSY
- RNS spectra characterized by mainly higgsino-like WIMP: standard relic underabundance
- Also address strong CP problem via axion-axino-saxion
- DFSZ invisible axion model: solves  $\mu$  problem while allowing for  $\mu \sim m(Z)$
- Expect mainly axion CDM with 5-10% higgsino-like WIMPs over much of  $p$ -space
- Direct detect both axion and higgsino-like WIMP
- Gamma-ray signal below bounds by 10-20: ways to go...
- LHC14 w/  $300 \text{ fb}^{-1}$  can see about half of RNS parameter space
- $e^+e^-$  collider with  $\sqrt{s} \sim 500-600 \text{ GeV}$  needed to find predicted light higgsino states