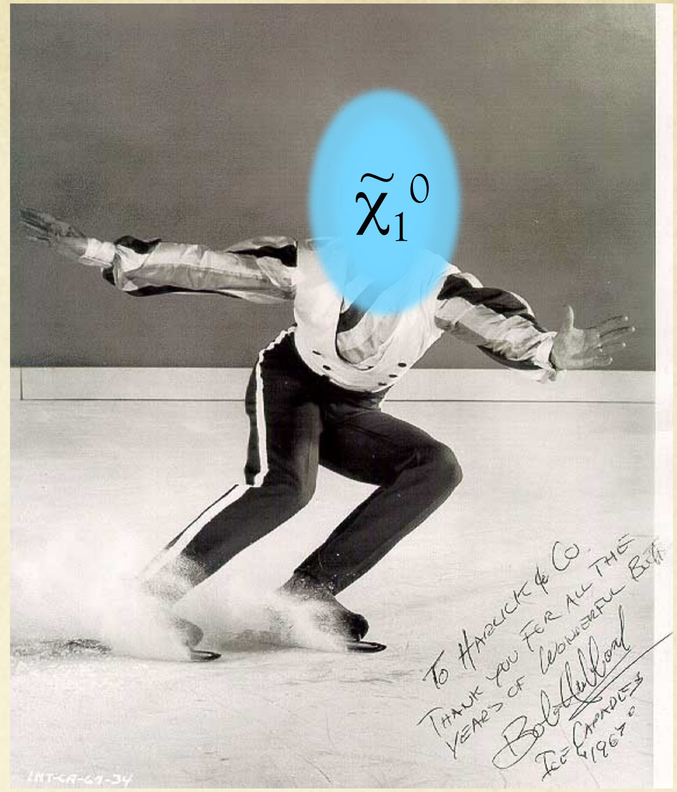
pMSSM Dark Matter Searches

…

On Ice!



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Based on:
1104.XXXX
(next week or bust.)

In case the title slide wasn't self-explanatory…

- We'll recall the solar WIMP idea, and the IceCube/DeepCore (IC/DC) search for energetic ν's produced in solar WIMP annihilation.

- Investigate supersymmetry predictions for signal using tens of thousands of SUSY models from the p(henomenological)MSSM.

- Prospects for IC/DC to constrain/discover pMSSM dark matter,

- Compare the performance of the IC/DC search with Direct Detection experiments and LHC analyses.

The Solar DM Search…

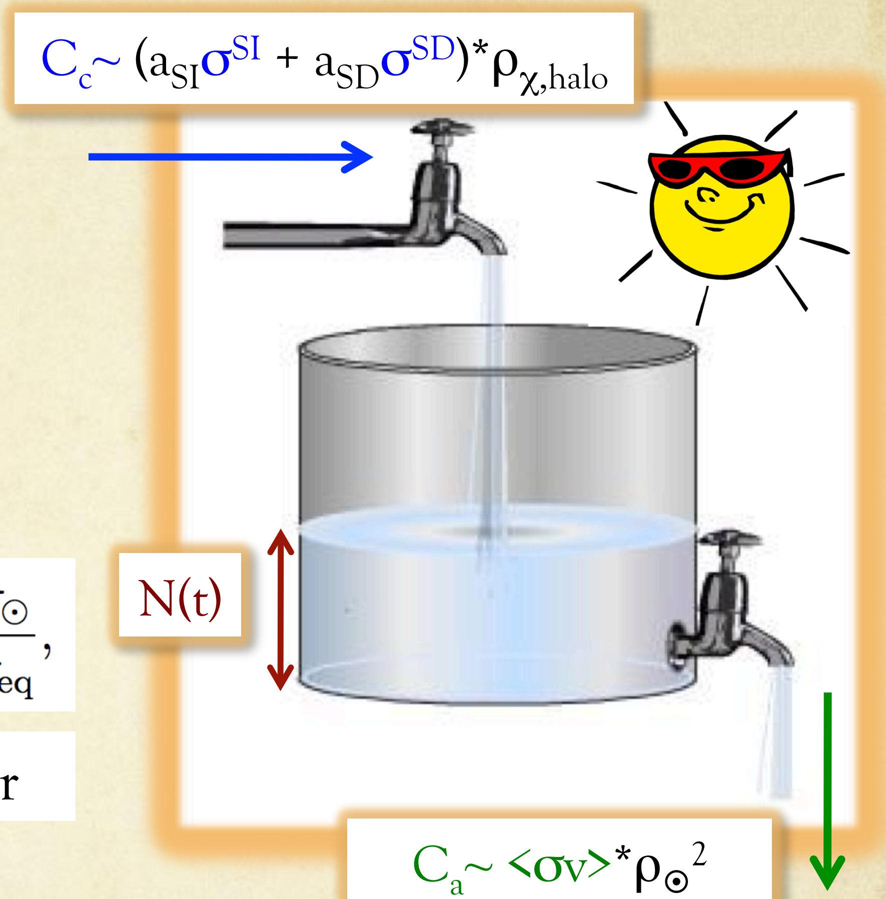
Annihilations from Captured WIMPs*

WIMPs in Milky Way DM halo scatter off of nuclei in the sun, become trapped in bound orbits and sink to the solar core. This population of WIMPs is also depleted by annihilation:

Solar WIMPs: $$\frac{dN}{dt} = C_c - C_a N(t)^2,$$

Solution: $$\Gamma_a \equiv \frac{1}{2} C_a N^2(\tau_\odot) = \frac{C_c}{2} \tanh^2 \frac{\tau_\odot}{\tau_{\rm eq}},$$

with: $\tau_{eq} = (C_a C_c)^{-1/2}$, $\tau_\odot \sim 4*10^9$ yr



In Equilibrium: $\Gamma_a \sim C_c/2 \sim \sigma_{elastic}$

Depends only on elastic cross-section, not $\langle\sigma v\rangle$.

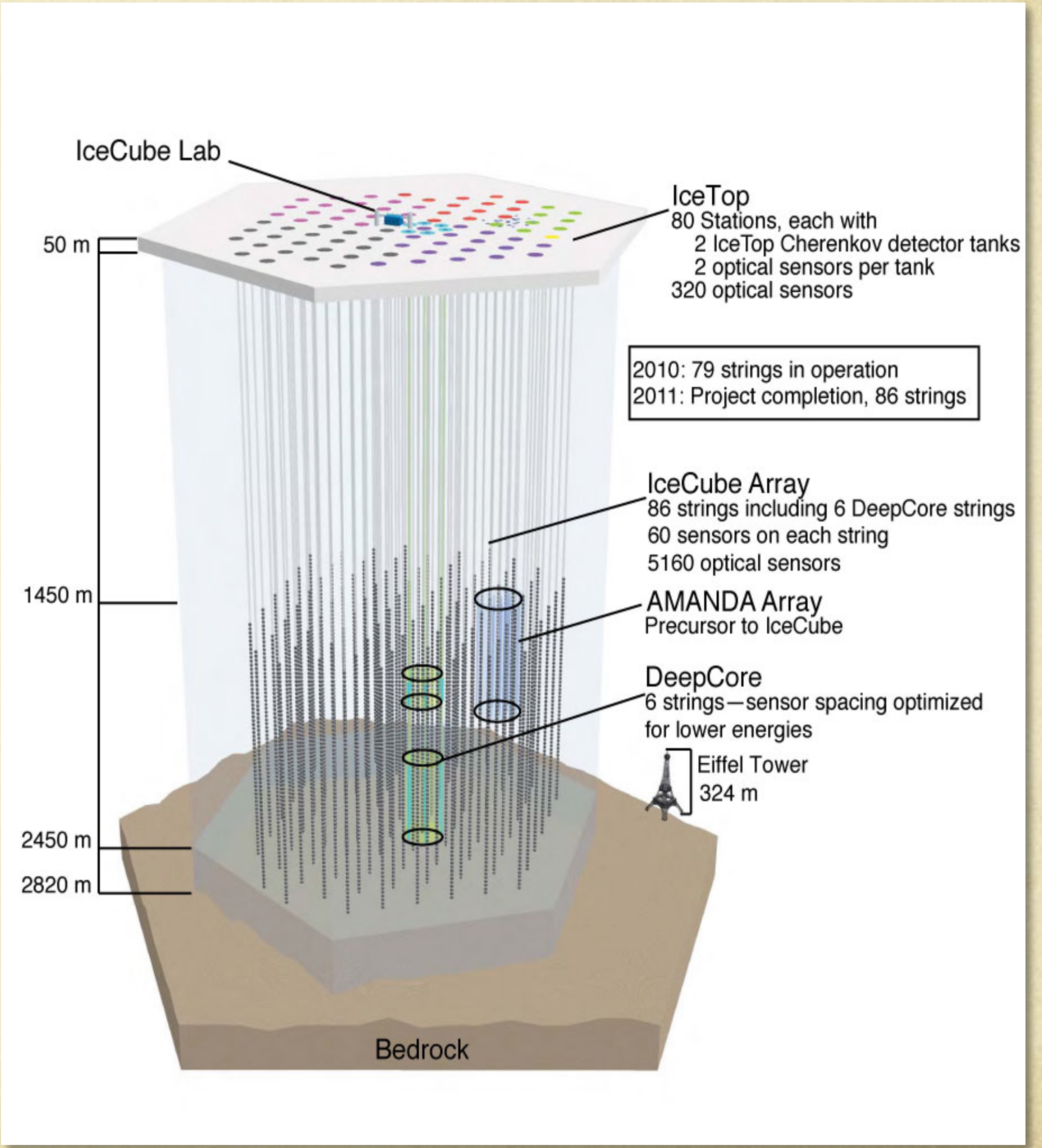
* Press, Spergel (1985); Silk, Olive, Srednicki (1986)

The IceCube-DeepCore Solar DM Search...

Annihilations of these solar WIMPs inject >1 GeV ν's that propagate out of the sun to neutrino detectors on earth.

IceCube+DeepCore (IC/DC) observes >10 GeV ν's with spatial resolution necessary to observe an excess of <~100 events/yr correlated with the sun.

The search we discuss here requires ~5 years of useable data, taken over ~10 years. The full IC/DC detector is currently being commissioned



IC/DC description: see e.g., 0907.2263

SUSY Without Prejudice

C.F. Berger, J.S. Gainer, J.L. Hewett, T.G. Rizzo

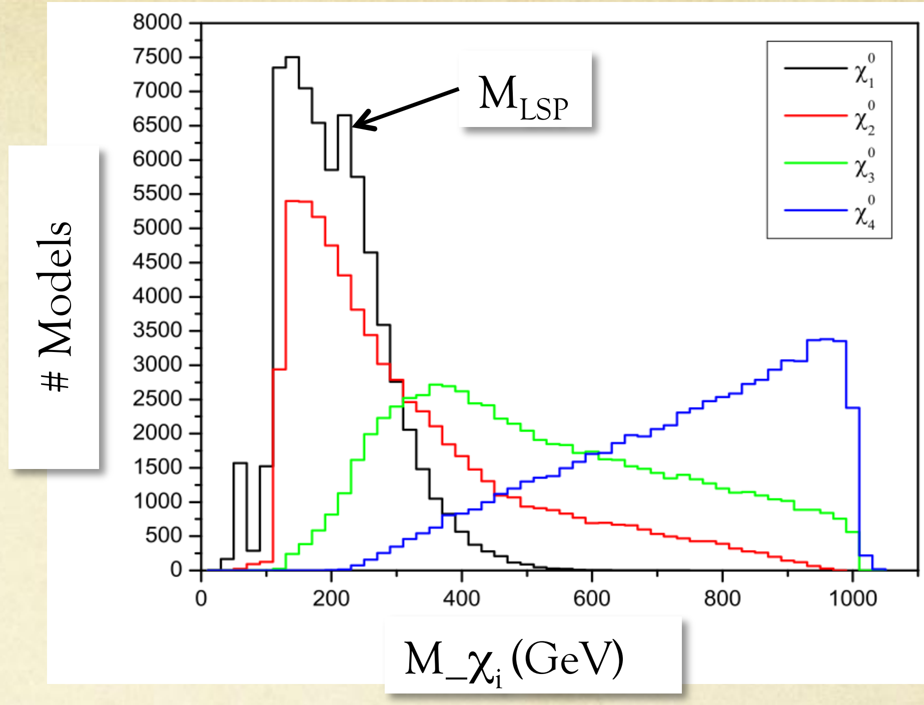
0812.0980

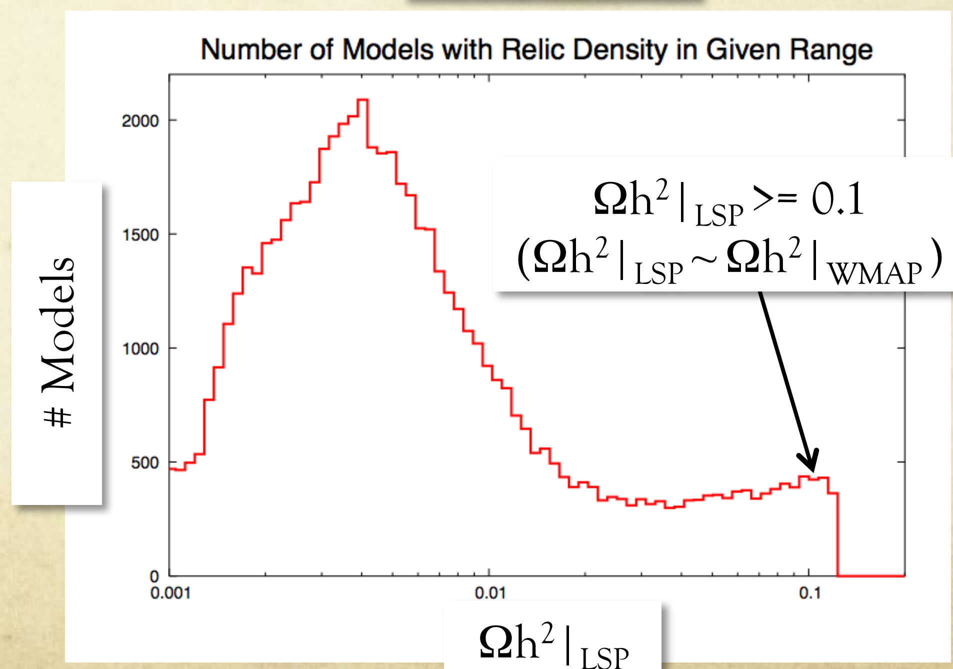
Scan Ranges:

$$100\,\text{GeV} \leq m_{\tilde{f}} \leq 1\,\text{TeV}\,,$$
$$50\,\text{GeV} \leq |M_{1,2}, \mu| \leq 1\,\text{TeV}\,,$$
$$100\,\text{GeV} \leq M_3 \leq 1\,\text{TeV}\,,$$
$$|A_{b,t,\tau}| \leq 1\,\text{TeV}\,,$$
$$1 \leq \tan\beta \leq 50\,,$$
$$43.5\,\text{GeV} \leq m_A \leq 1\,\text{TeV}\,.$$

LSP Composition

LSP Type	Definition	Fraction of Models
Bino	$\|Z_{11}\|^2 > 0.95$	0.14
Mostly Bino	$0.8 < \|Z_{11}\|^2 \leq 0.95$	0.03
Wino	$\|Z_{12}\|^2 > 0.95$	0.14
Mostly Wino	$0.8 < \|Z_{12}\|^2 \leq 0.95$	0.09
Higgsino	$\|Z_{13}\|^2 + \|Z_{14}\|^2 > 0.95$	0.32
Mostly Higgsino	$0.8 < \|Z_{13}\|^2 + \|Z_{14}\|^2 \leq 0.95$	0.12
All other models		0.15





LSP Relic Density...

We always assume thermal WIMP freeze-out. Many of the LSPs in our set have depleted DM abundance $(\Omega h^2|_{LSP} < \Omega h^2|_{WMAP})$ so we must be careful to scale observables by the appropriate power of $R = (\Omega h^2|_{LSP} / \Omega h^2|_{WMAP})$, i.e.,

In Equilibrium:

$$\Gamma_a \sim C_c/2 = (1/2)^*(a_{SI}\sigma^{SI} + a_{SD}\sigma^{SD})^*\rho_{\chi,halo}$$

with $\rho_{\chi,halo} = R^*\rho_0$ and $\rho_0 \sim 0.3$ GeV/cm^3

Although IceCube observes annihilating WIMPs, the signals scale as $\sigma_{elastic}{}^*R$ like terrestrial direct detection experiments (CDMS, COUPP, etc.)...

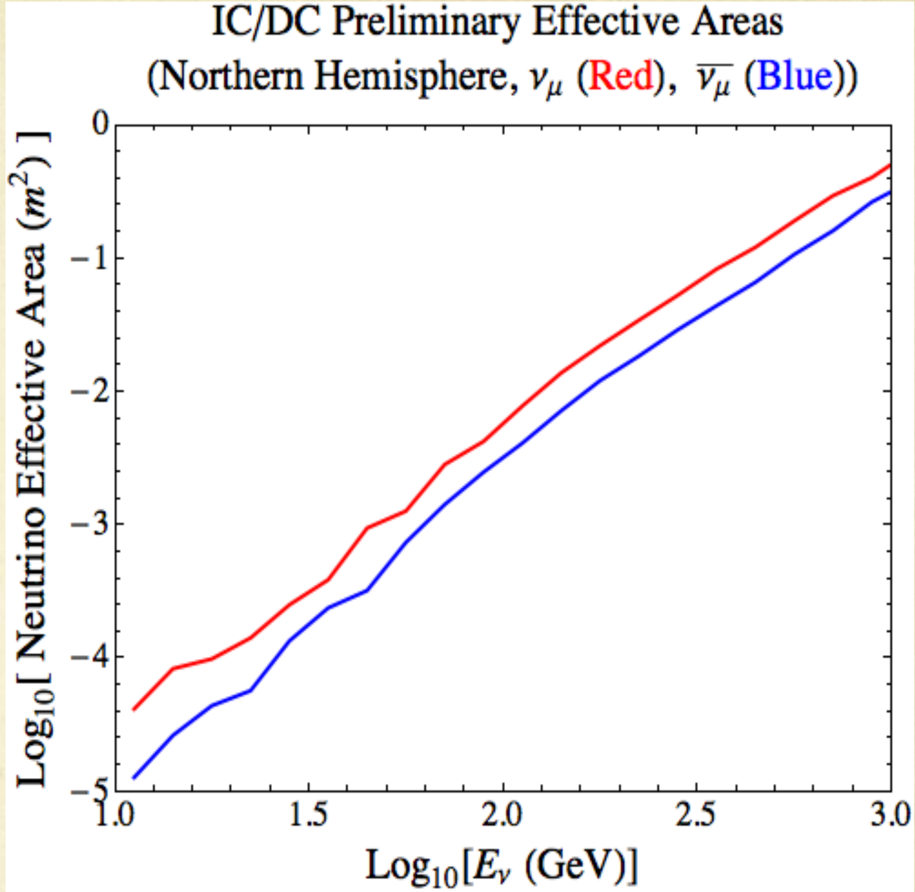
...and NOT as $<\sigma v>^*R^2$ like other searches for DM annihilation (FERMI, HESS, PAMELA, etc.).

Calculating IC/DC ν rates from the pMSSM

- Raw ν spectra calculated for each pMSSM model using DarkSUSY 5.0.5.

- Raw spectra are convolved with preliminary detector effective areas:

•Accurate estimates for discovery/exclusion significance are difficult. Detected rates $\Phi^D_\nu \sim \{10\text{-}100\}$ events/yr are plausible.

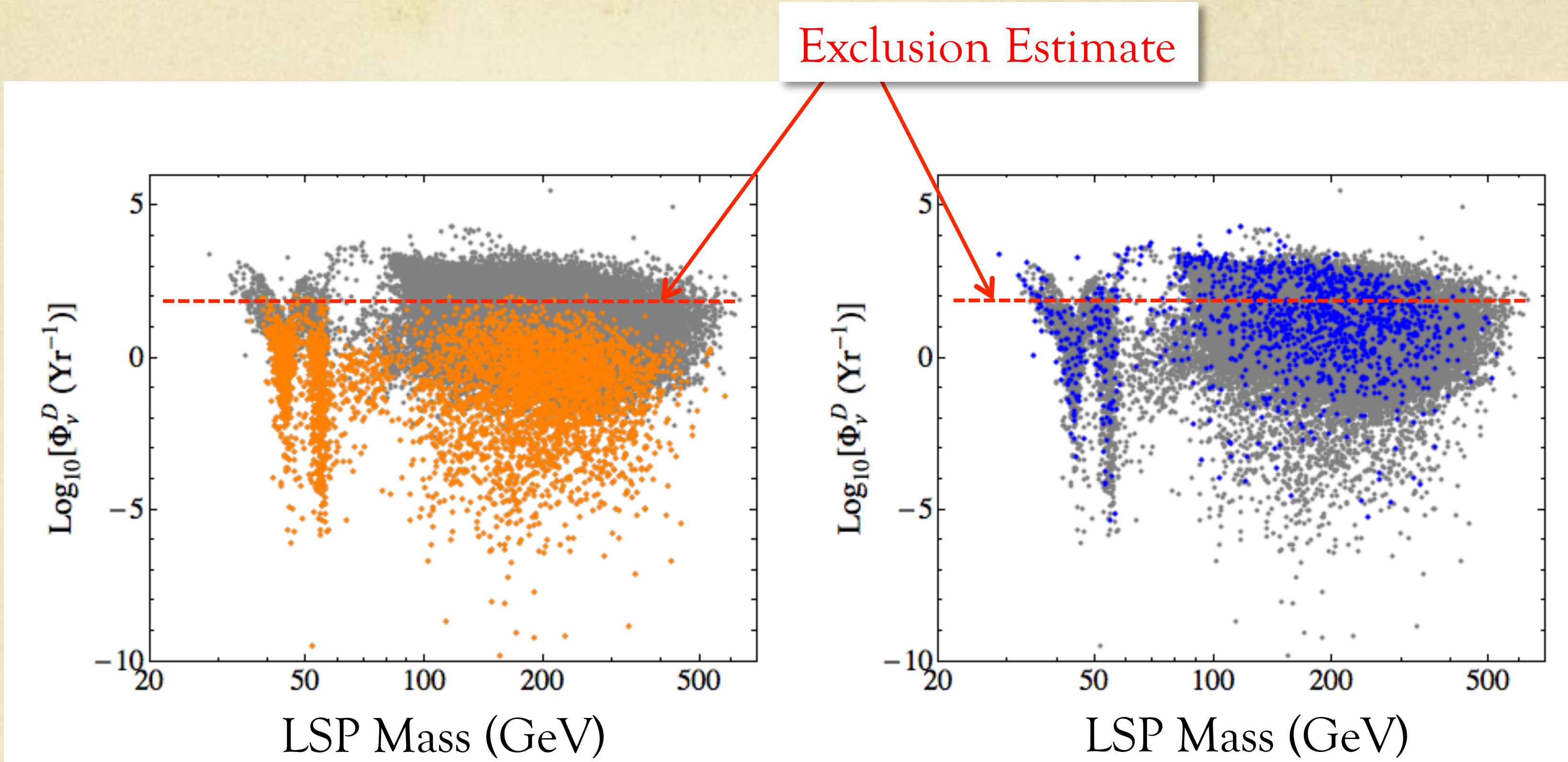


We take $\Phi^D_\nu > 40$ events/yr as a criterion for *exclusion* and $\Phi^D_\nu > 100$ events/yr as a criterion for *discovery*.

Basic Results...

Signal Rate vs. LSP Mass:

Log_{10}[Detected Signal Rate /yr]

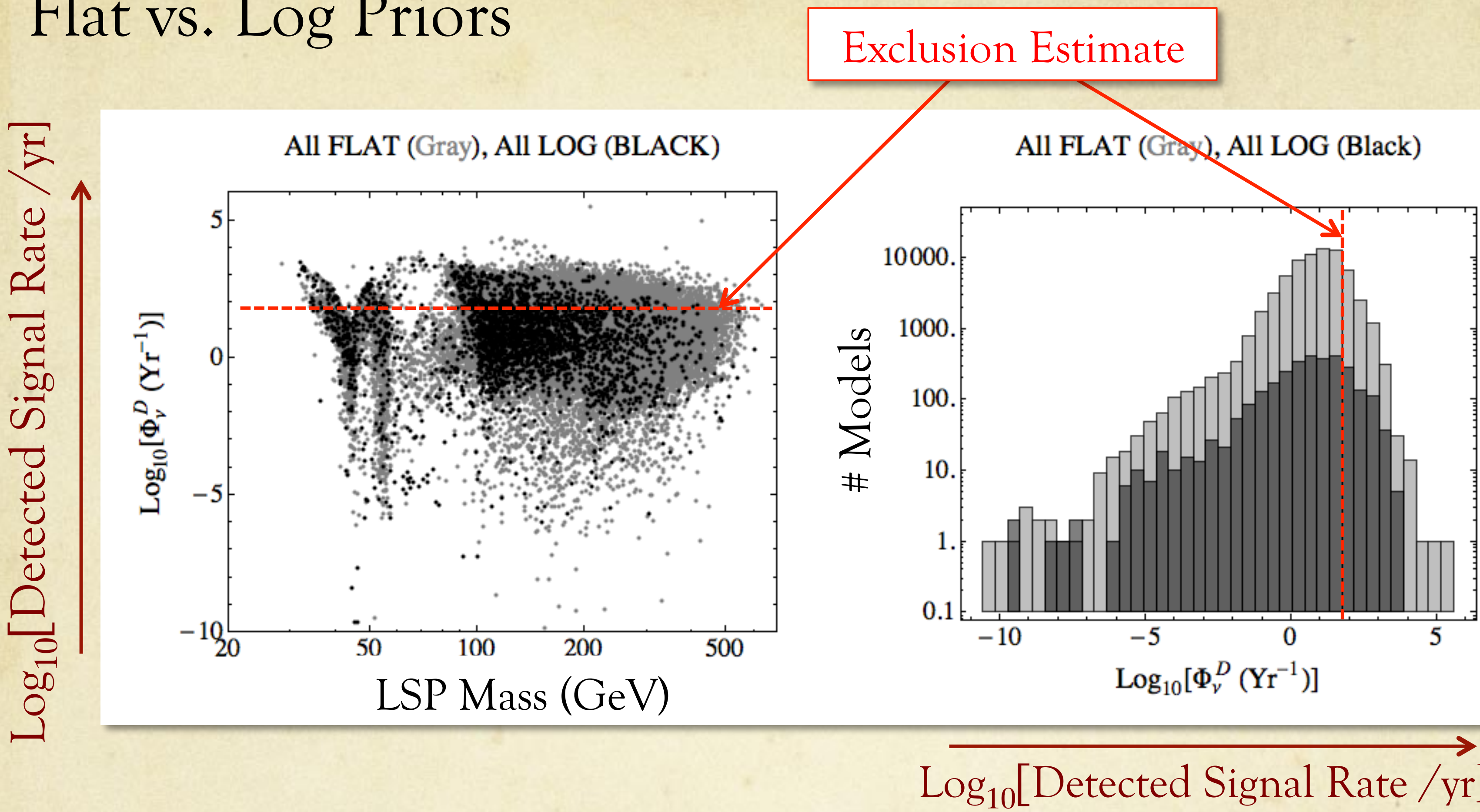


Grey Points: All flat-prior pMSSM models. (~ 63.4k models)

Blue Points: $\Omega h^2|_{LSP}$ >= 0.1 models (1240 models)

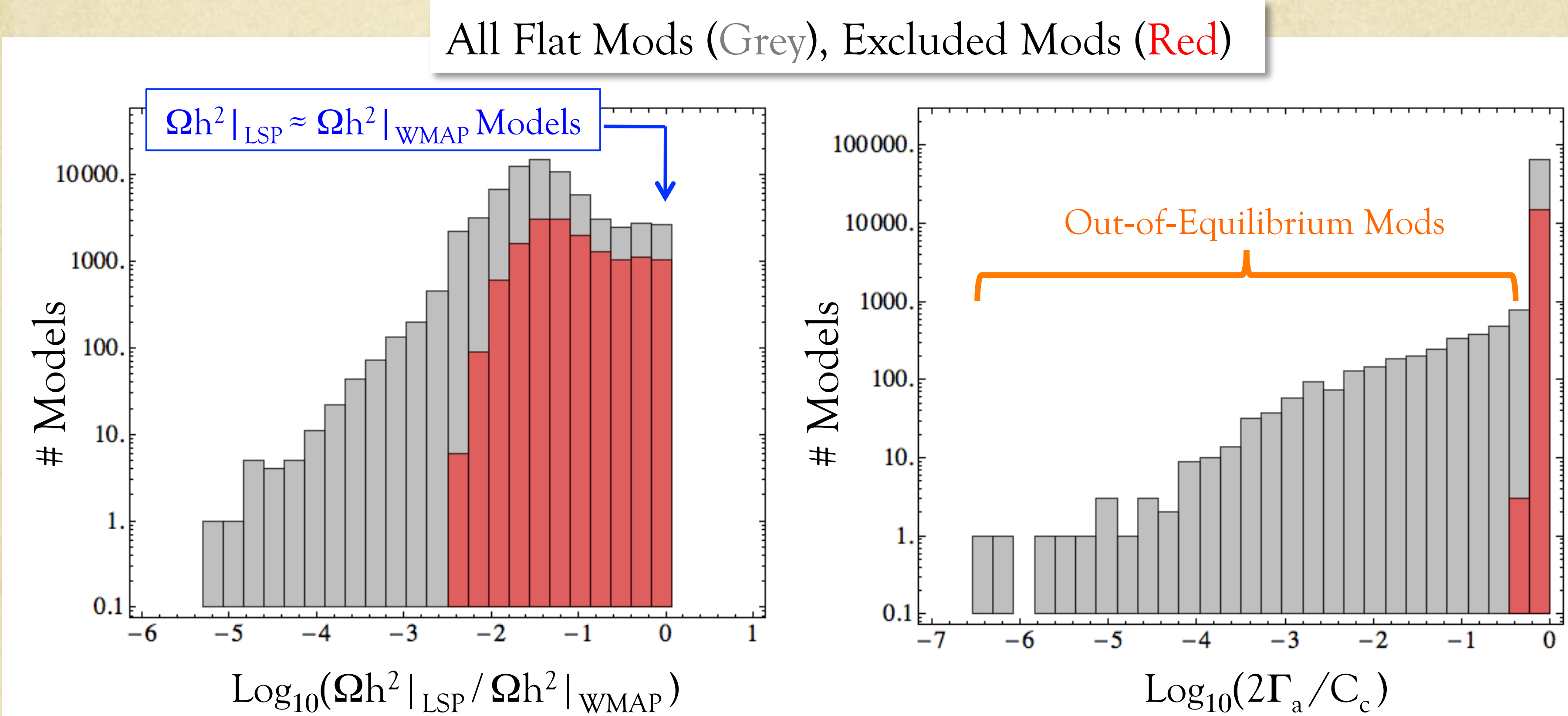
Orange Points: $2\Gamma_a/C_c < 0.9$ (Out-of-Equilbrium models ~ 4500)

Flat vs. Log Priors



- Grey points: all flat-prior mods. Black points: all log-prior mods.
- Flat- and log-prior predictions are similar.
- 22% of flat-prior mods and 25% of log-prior mods would be excluded.

Low Relic Density and Out-of-Eq. Models...



- IC/DC search is able to exclude DM, even with very low relic density.
- Out-of-Equilibrium Models are hard to exclude.

SUSY Model Dependence...

The *Magnitude* of the Signal ν Spectra...

Determined by the capture rate (C_c), and thus by the thermal elastic scattering cross sections ($\sigma^{SI}*R$, $\sigma^{SD}*R$):

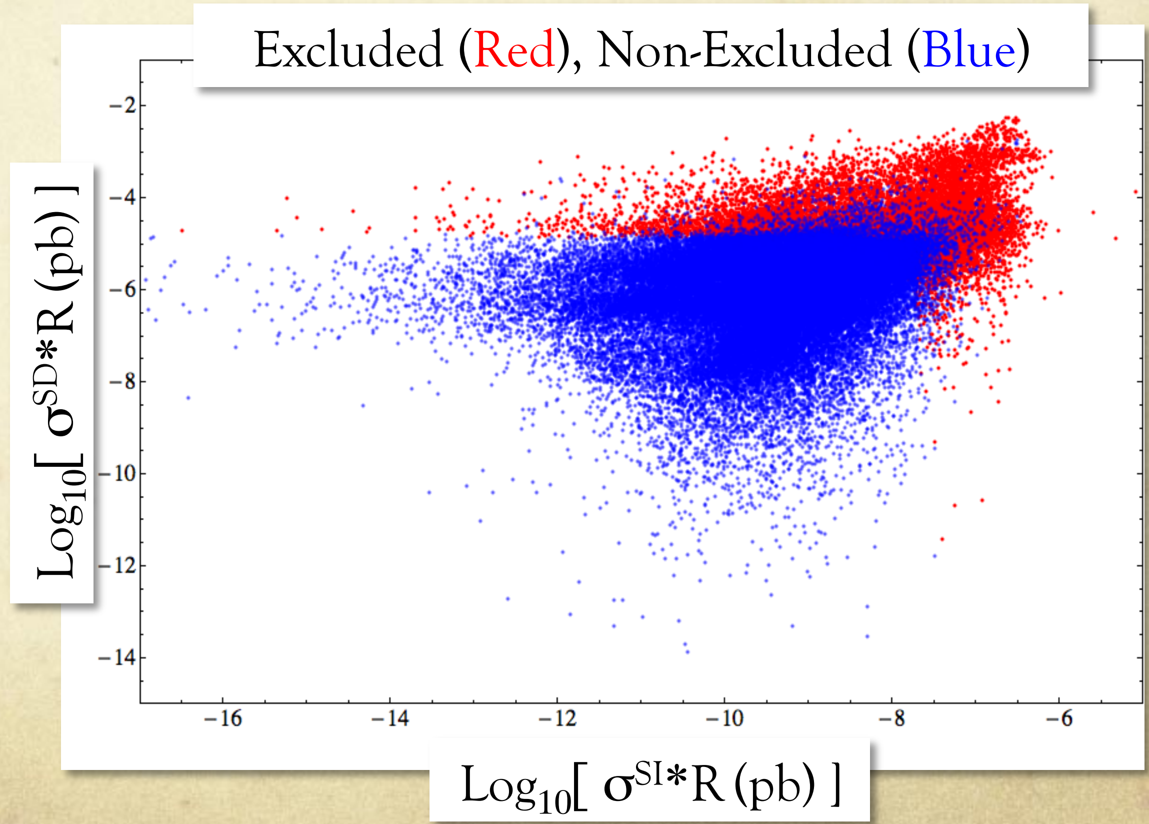
$$C_c = (a_{SI}\sigma^{SI} + a_{SD}\sigma^{SD})^{*}R^{*}\rho_0$$

$$R = (\Omega h^2|_{LSP} / \Omega h^2|_{WMAP}),$$

$$\rho_0 \sim 0.3\ \mathrm{GeV/cm^3}$$

Although spin-independent χ-N_A scattering is coherent ($\sigma_{\chi\text{-}N_A} \sim A^2$), heavy elements are rare compared to H nuclei in the sun. When it comes to C_c we see:

$$a_{SD} \approx (10^{2\text{-}3})^{*}a_{SI}$$

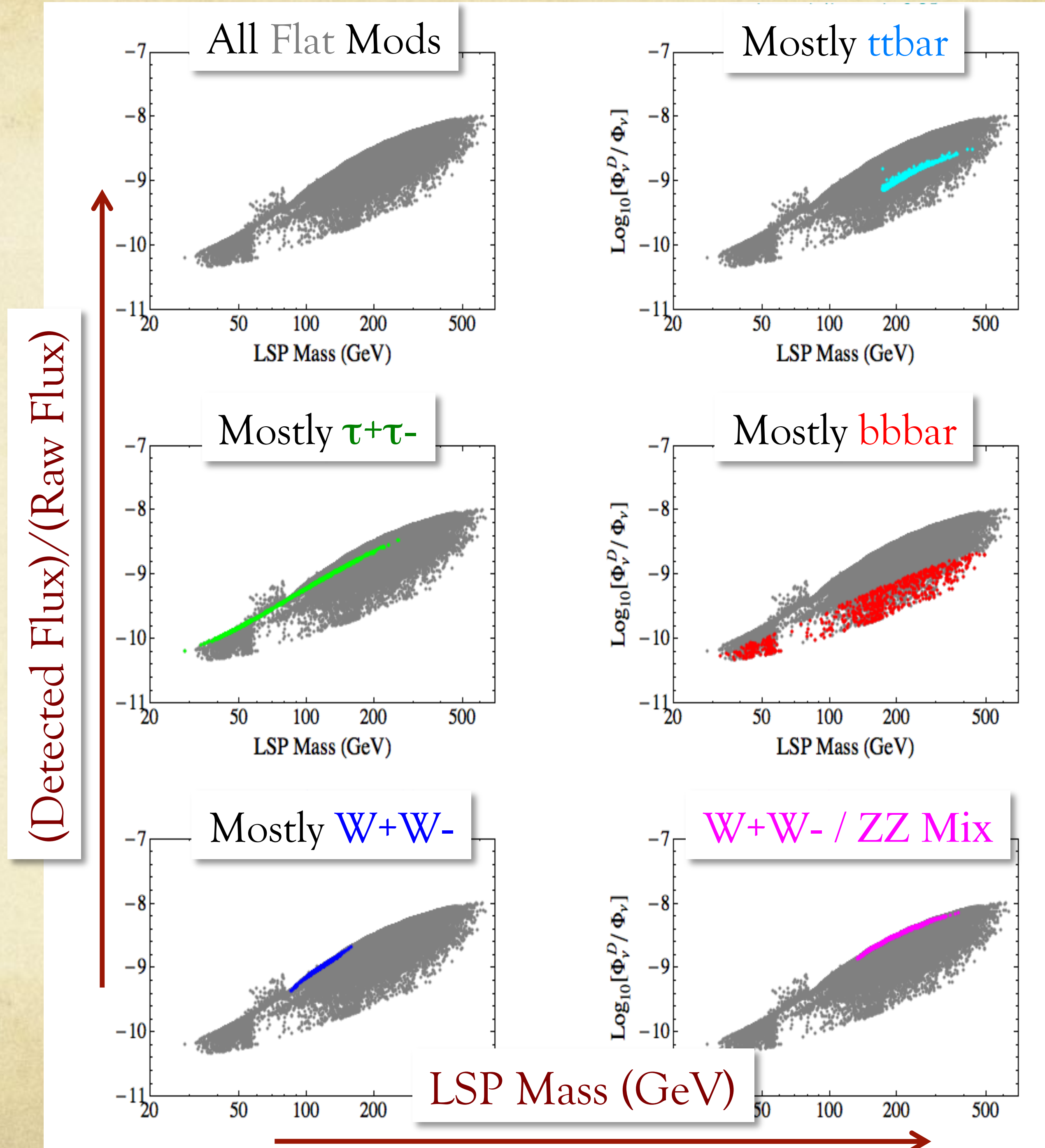


The *Shape* of the Signal ν Spectra...

The IC/DC effective area is sharply dependent on the rigidity of the spectra.

Spectral *Shape* is determined by the annihilation rates into various Standard Model final states.

Different final states can see very different effective areas.



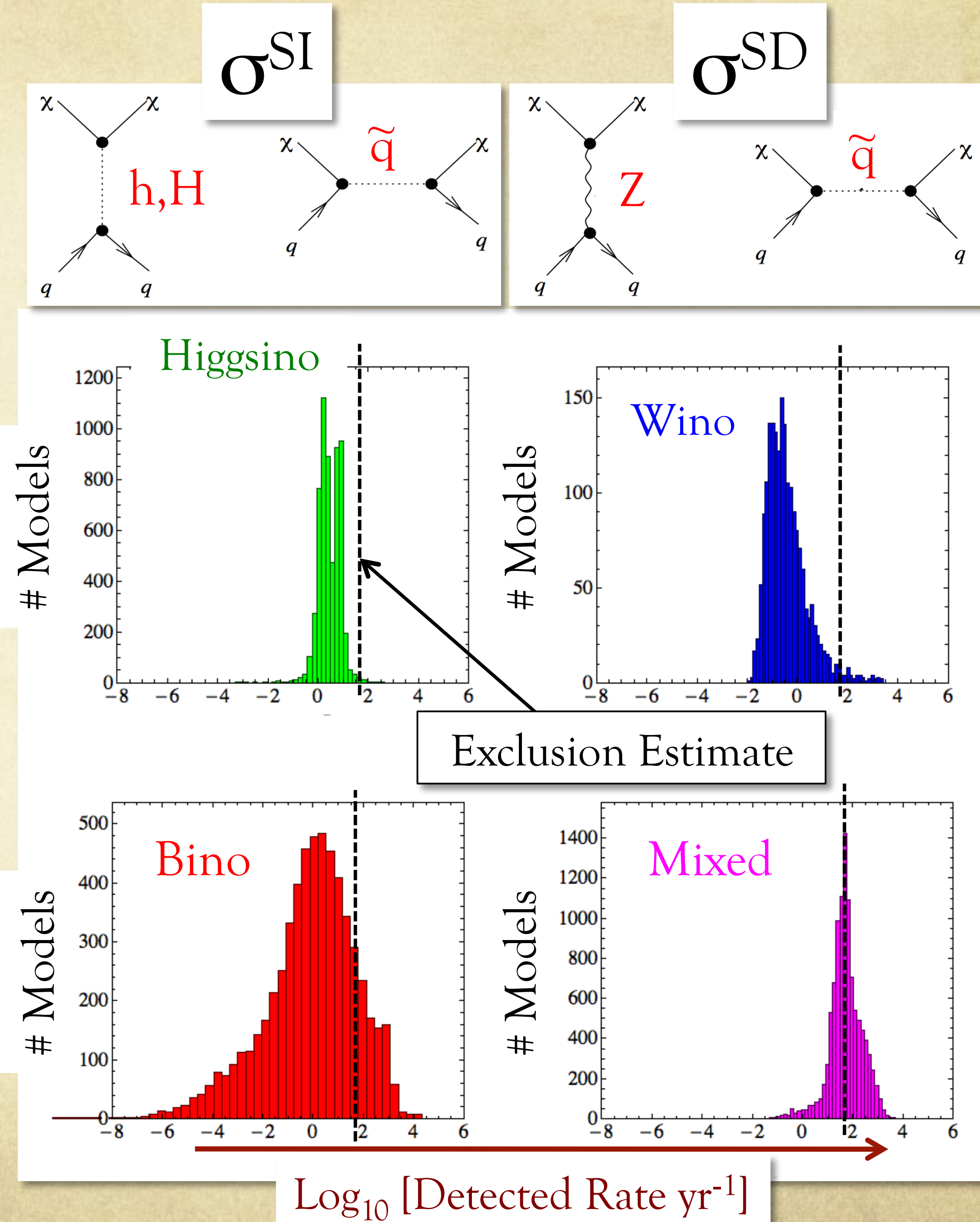
LSP Composition...

Since *overall* signal rates depend on σ^{SI}, σ^{SD}, R and the annihilation rates into SM final states it is useful to classify our models by LSP composition. We see:

- Pure Winos/Higgsinos are hard to see (relic density)

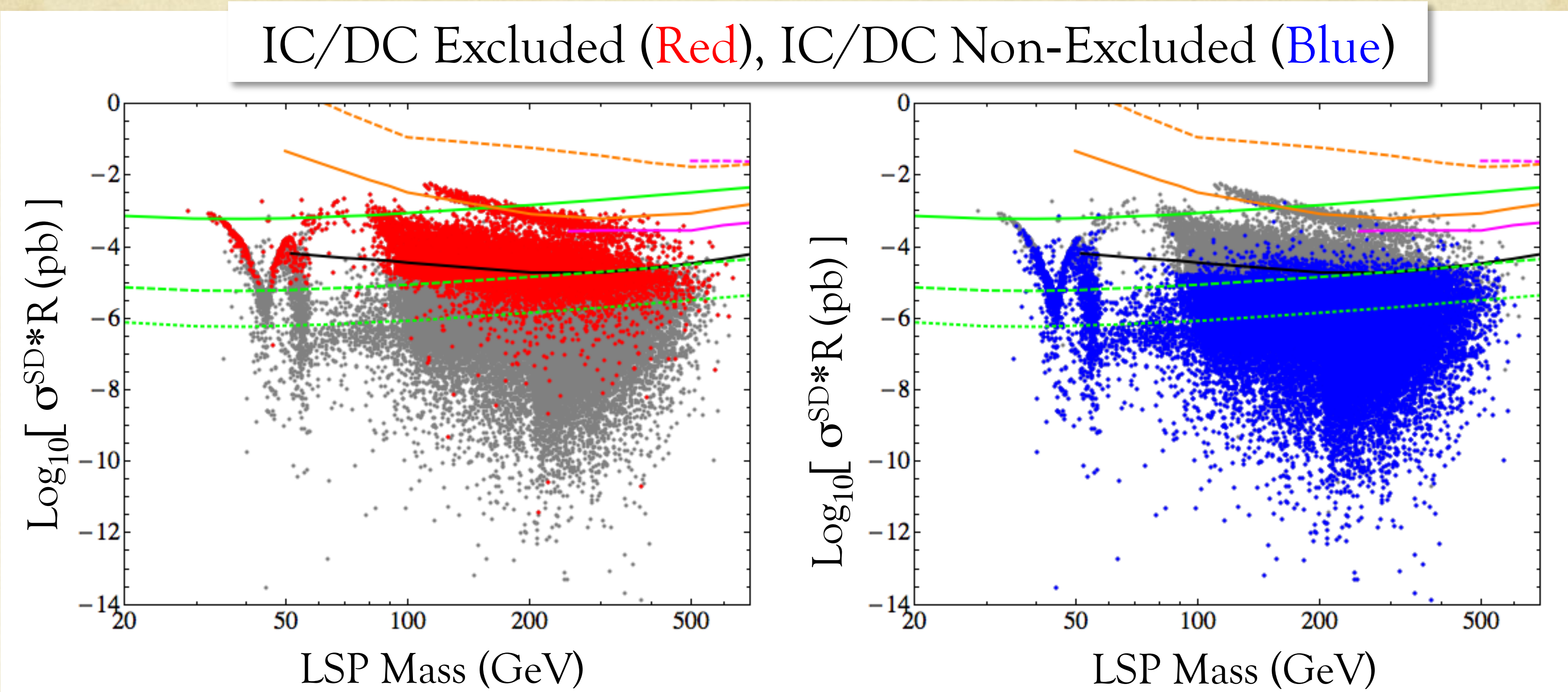
- Bino predictions vary a lot b/c they depend on (scanned) sfermion masses

- Mixed LSPs (often B-H) typically have large rates (high relic density + hard f.s. channels).



Comparing With Other Experiments...

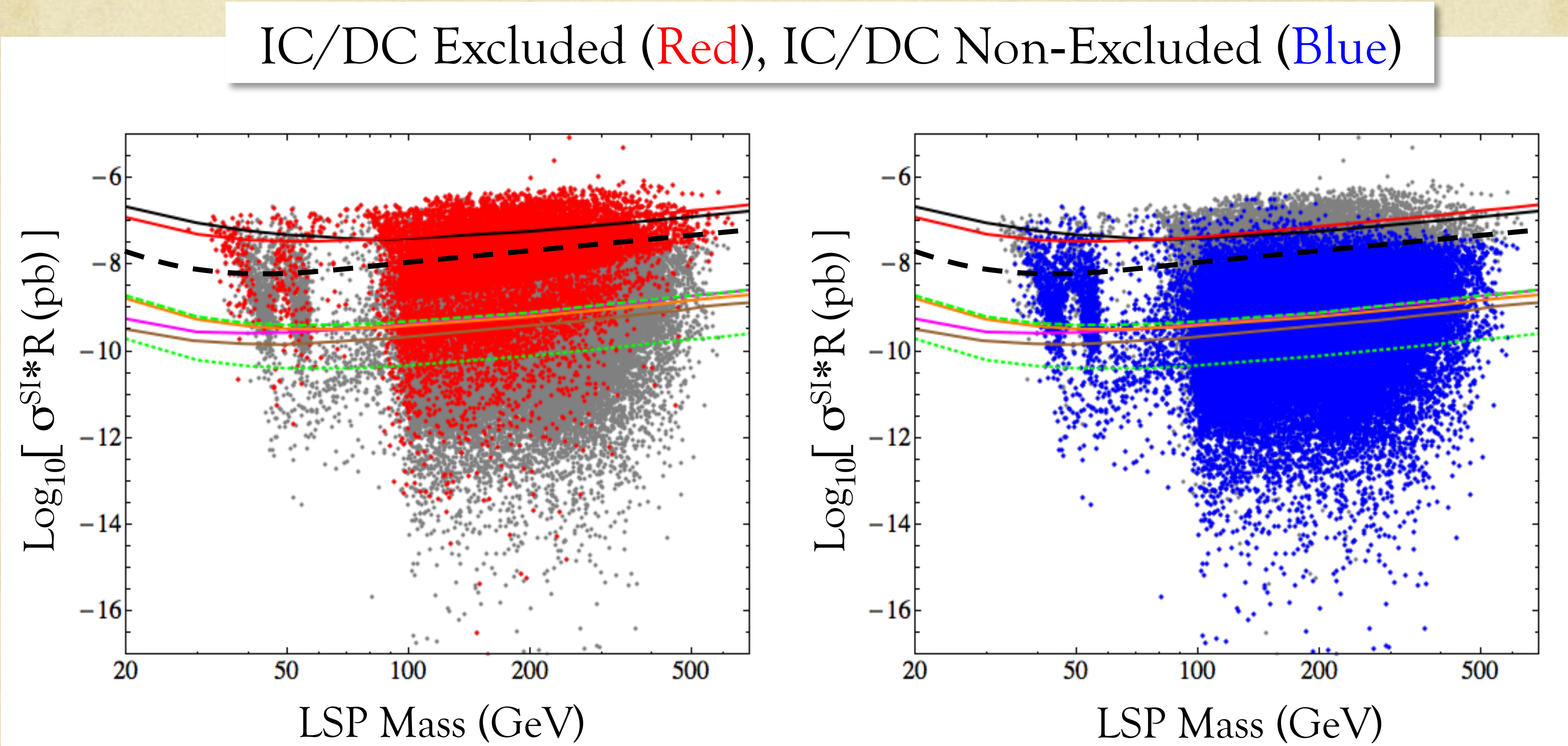
Direct Detection, σ^{SD}:



* ν telescope limits assume *(i)* Equilibrium, *(ii)* $\Omega h^2|_{LSP} = \Omega h^2|_{WMAP}$ and *(iii)* annihilations into hard (WW, ZZ, ττ) or soft (qq) SM channels, as noted.

- AMANDA* (Hard, Current)
- AMANDA* (Soft, Current)
- IceCube-22* (Hard, Current)
- IceCube-22* (Soft, Current)
- IceCube/**DeepCore*** (Hard, Future)
- COUPP 4kg (Current)
- COUPP 60kg 1yr (Future)
- COUPP 500kg 1yr (Future)

Direct Detection, σ^{SI}:

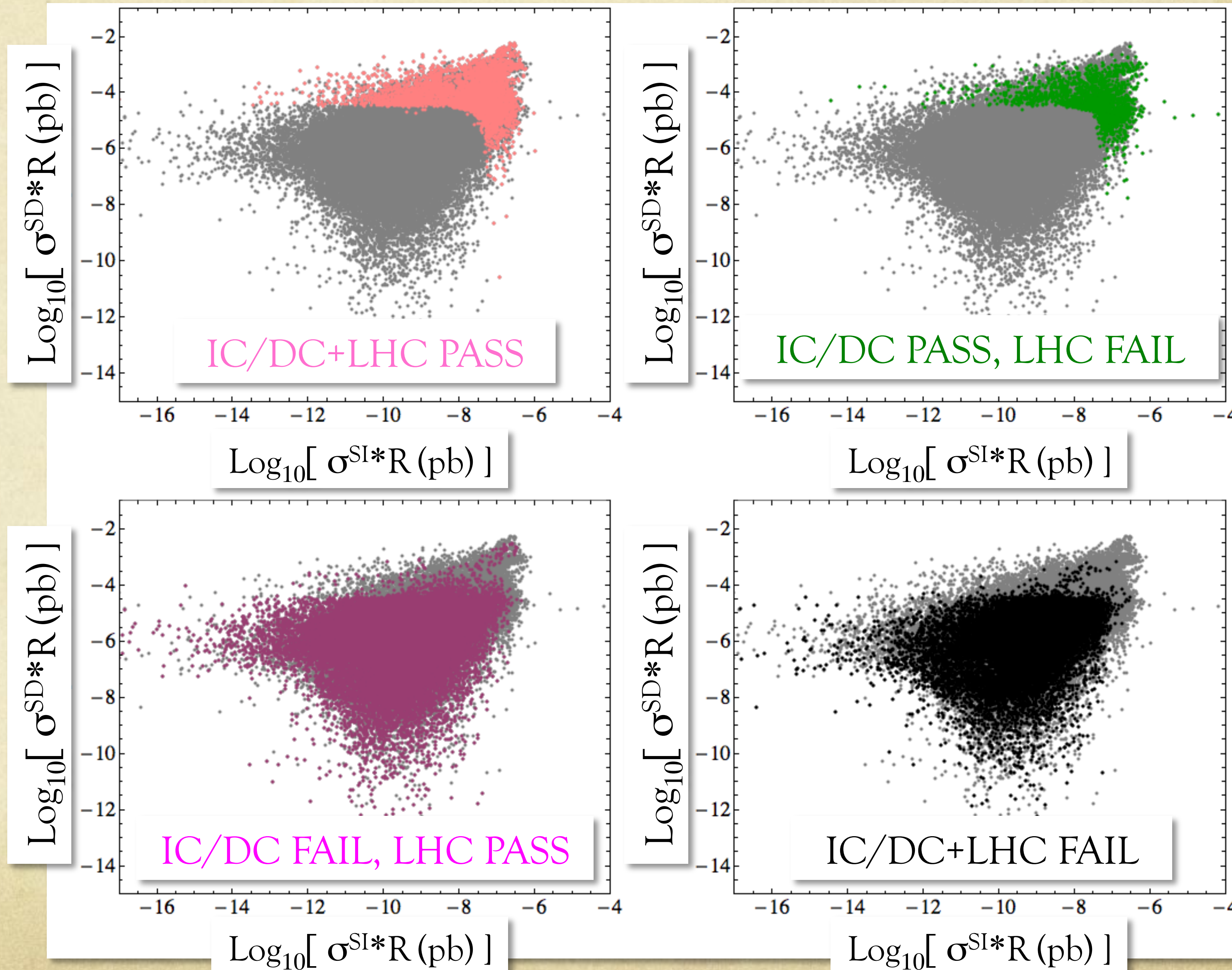


	CDMS (Current)
	XENON 100 (Current 2010)
Forget this projection >>>>>	XENON 100 (Future)
	LUX (Future)
	SuperCDMS (Future)
This is (roughly) the new limit >>>>>	XENON 100 (Current 2011)
	COUPP 60kg 1yr (Future)
	COUPP 500kg 1yr (Future)

LHC Searches (ATLAS 7TeV 1fb^{-1} 4jet-0lepton):

"PASS"= $S/\sqrt{B}>5$ (ATLAS), or $\Phi^D_\nu<100$ events/yr (IC/DC)

"FAIL"= $S/\sqrt{B}<5$ (ATLAS), or $\Phi^D_\nu<100$ events/yr (IC/DC)

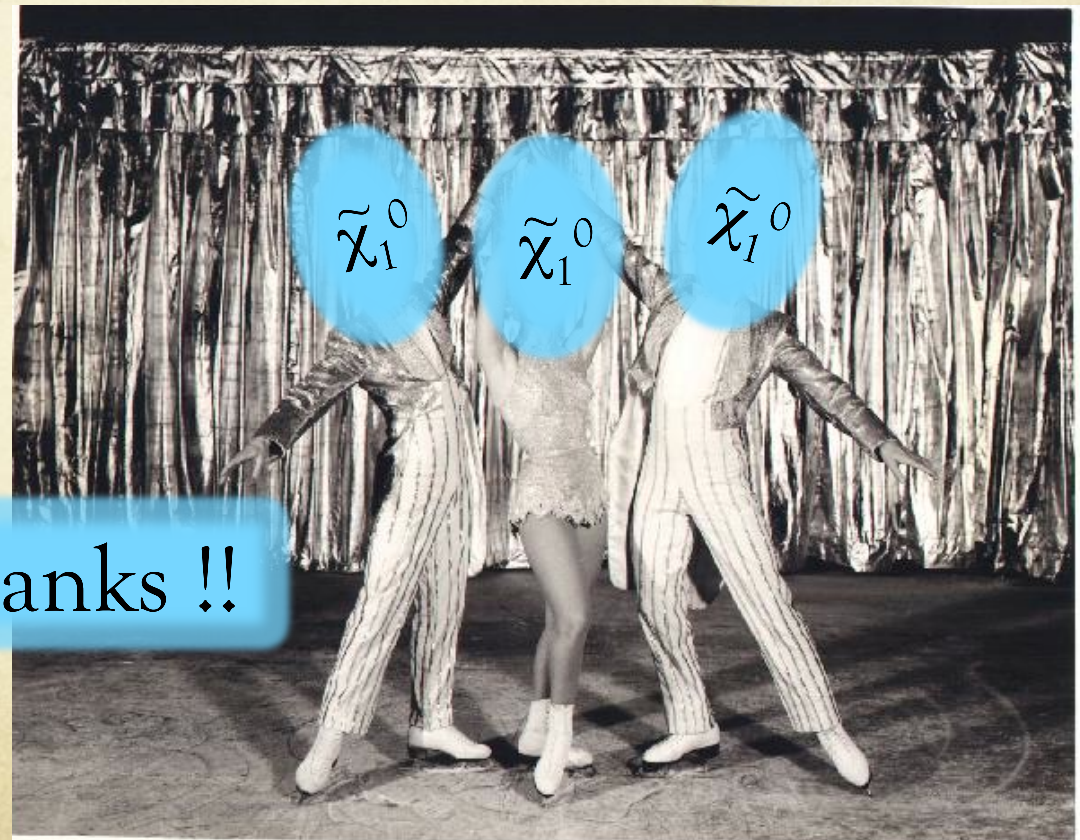


Conclusions...

• The IC/DC solar WIMP search can constrain/discover a large fraction of the SUSY DM models in our pMSSM set.

• IC/DC appears competitive with near future SD-DD experiments (COUPP) in probing the pMSSM.

•The IC/DC and SD-DD searches will have different signal and background systematics, providing a non-trivial cross-check.

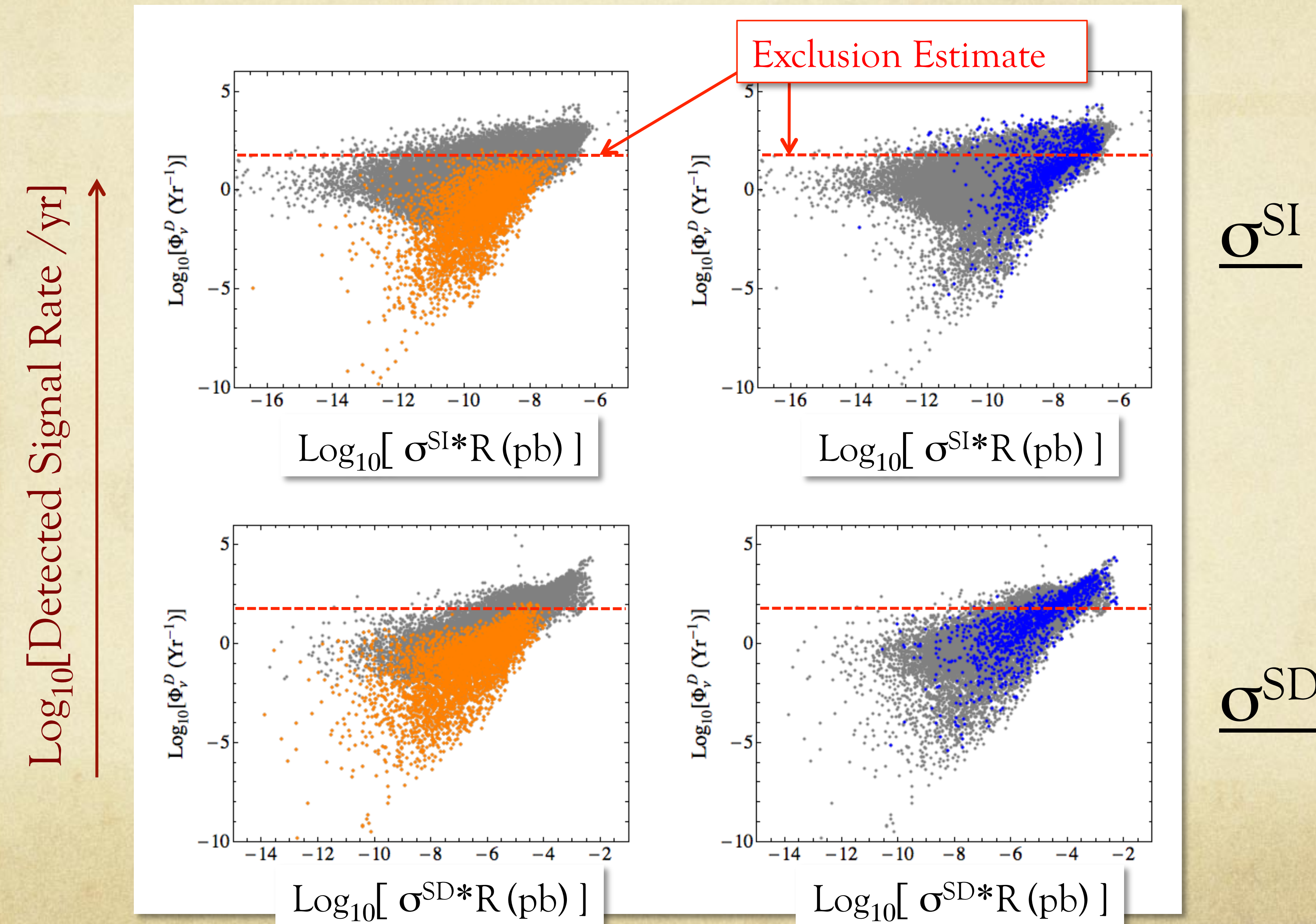


Thanks !!

Backup Slides…

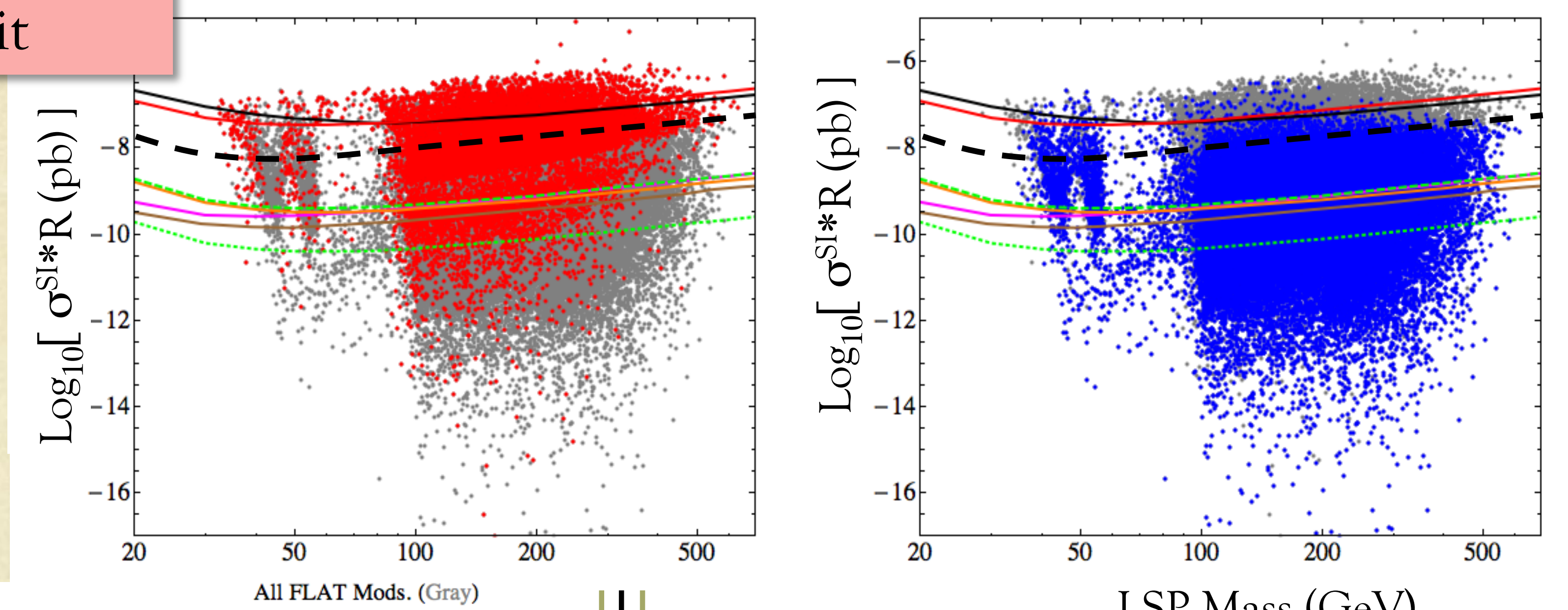
Elastic Cross-Sections...

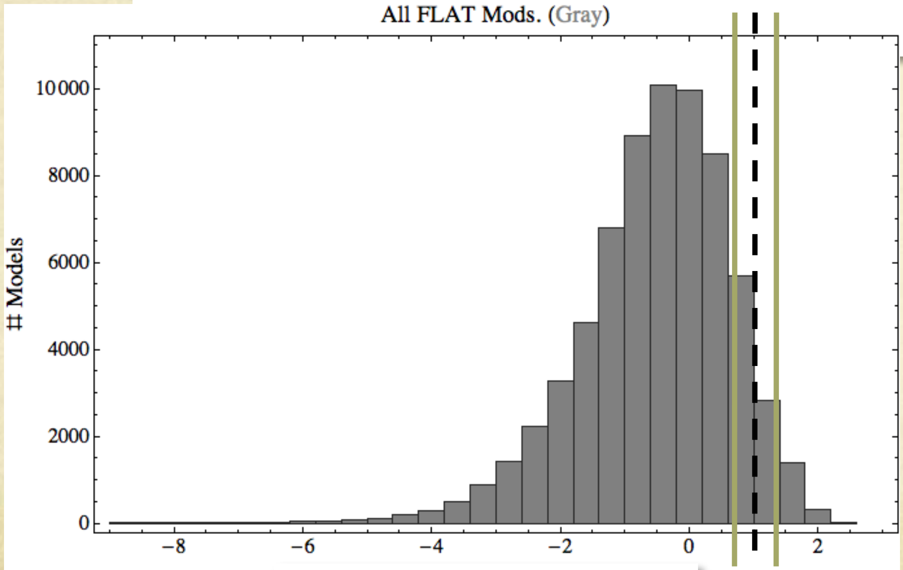
Grey Points: All flat-prior pMSSM models.
Blue Points: $\Omega h^2|_{LSP}$ >= 0.1 models
Orange Points: $2\Gamma_a/C_c$< 0.9 (Out-of-Equilbrium Models)



XENON 100 2011 limit

IC/DC Excluded (Red), IC/DC Non-Excluded (Blue)





$Log_{10}[\ \sigma^{SI}*R\ (zb)\ ]$

$1\ zb = 10^{-9}\ pb$

XENON limit is ~10^{-8} pb for most of our LSPs. This excludes ~16% of our Flat-prior models (~42% of WMAP saturating flat models). For illustration, if nuclear form factor uncertainties allow a factor of 2 in either direction, ~10% or ~25% of flat models would be excluded. Log performance is similar.

Coverage by Experiment.

SI DD:

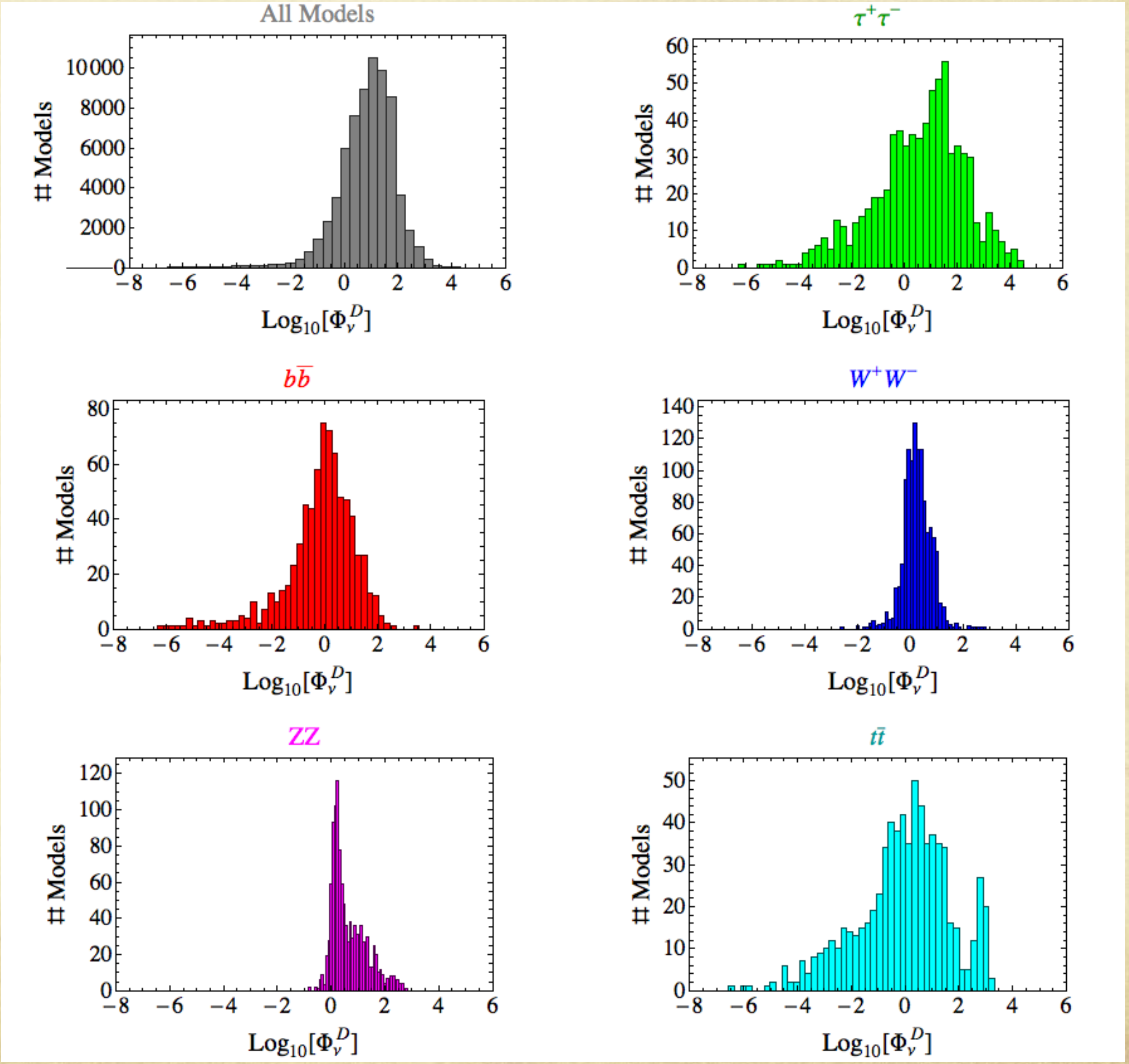
$\sigma_{SD,p} \times R > 10^{-4}$ pb would be excluded by the IC/DC search. If we assume, as a rough estimate, that all models with $\sigma_{SI,p} \times R > 10^{-9}$ pb will be excluded in the near-future ton-scale spin-independent scattering searches we estimate that, in our flat-prior model set, ~18% of the models will be excluded by both the IC/DC search and the SI DD searches, while ~4% will be excluded by IC/DC and not by SI DD searches, ~31% will be excluded by SI DD searches but not by IC/DC and ~47% of these models would not be excluded by either IC/DC or SI DD searches.

SD DD: IceCube/DeepCore and COUPP 60kg are similarly capable.

LHC:

the fact that the solar WIMP signal is very strongly correlated with the elastic scattering cross-sections while the rate of 4j0l events in ATLAS is only very indirectly so. We find that ~6% of the models in our flat-prior set are expected to be discovered by both experiments, ~2.6% of the models should be seen in IC/DC and missed in the 4j0l data, ~62% of models should be missed by IC/DC but seen in the 4j0l data and ~30% of these models would be missed in both data sets. Including estimates for near-future SI DD experiments, we expect that ~5% of our flat prior model set would be seen in all three classes of experiment while ~15% of models would be missed by all three classes of experiment.

Pure Final State Histograms



LSP Composition & Effective Area