

# Complementarity in the pMSSM

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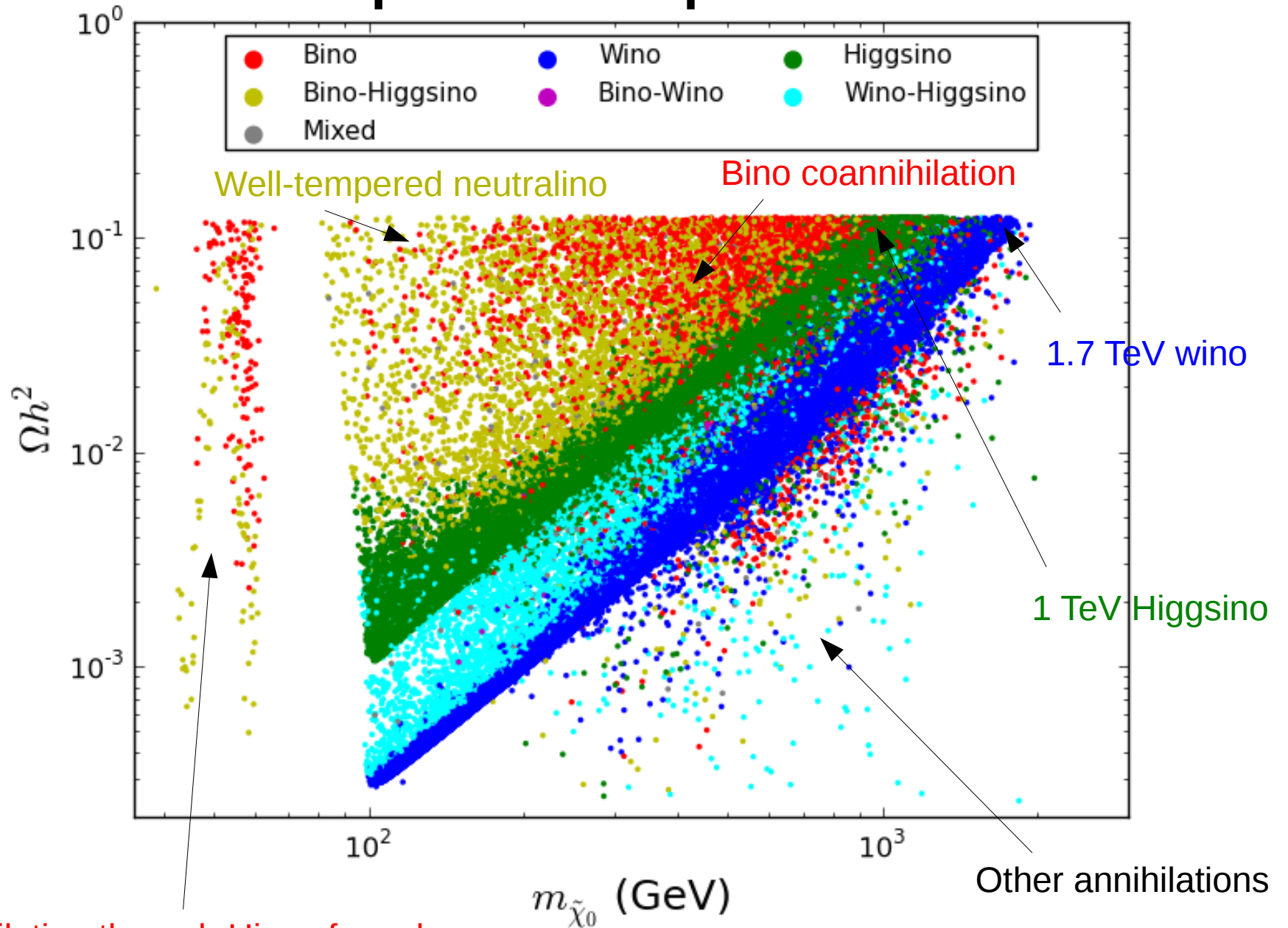
Matthew Cahill-Rowley, Randy Cotta, Alex  
Drlica-Wagner, Stefan Funk, JoAnne Hewett, AI,  
Tom Rizzo, Matthew Wood

1305.6921, 1305.1605

# The phenomenological MSSM

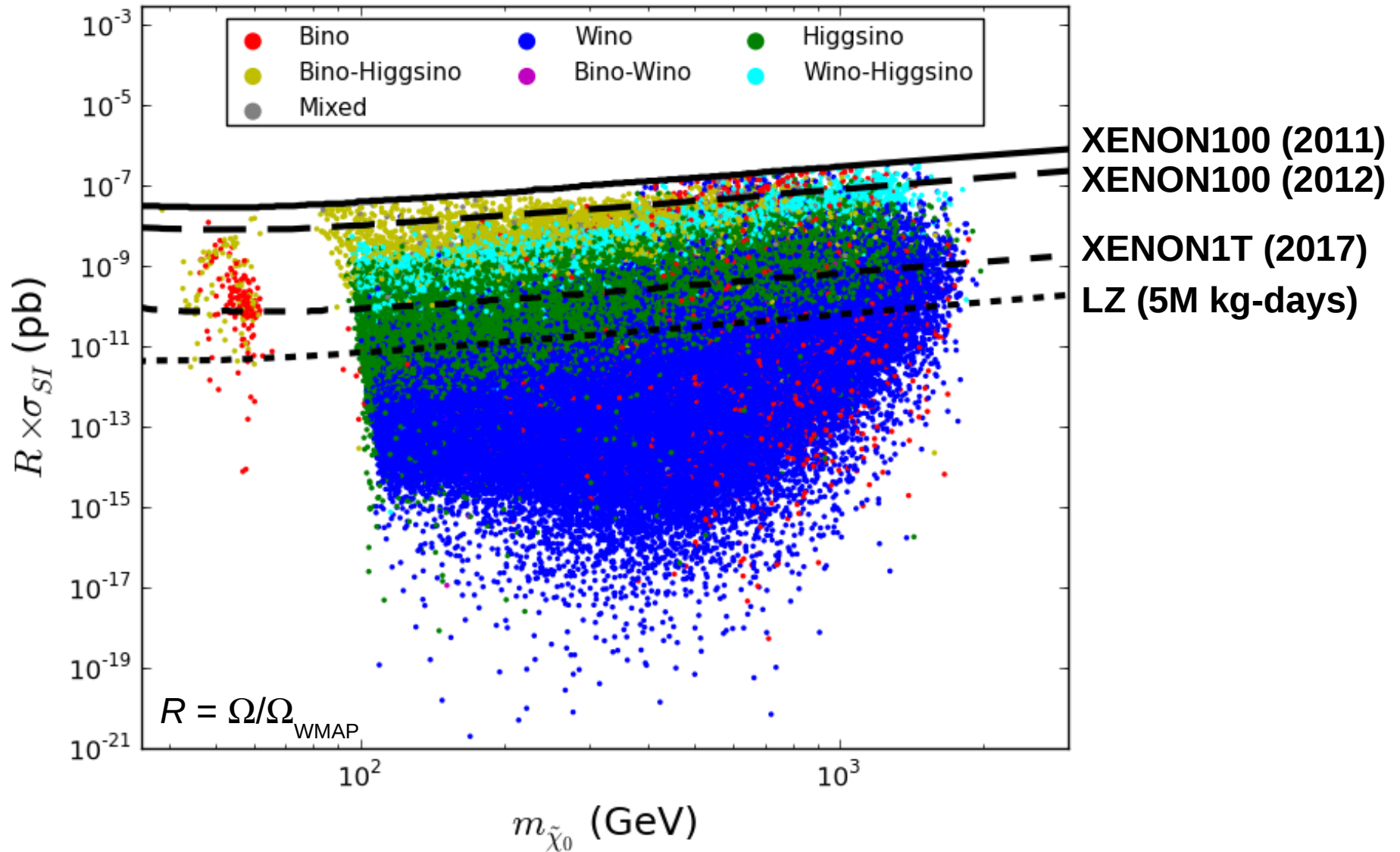
- Choose models where **lightest neutralino is LSP**
- Do **not** require LSP to saturate relic density
- Soft SUSY breaking masses are scanned up to 4 TeV, giving LSPs from 40 GeV to  $\sim 2$  TeV
- Get resulting set of  $2.2 \cdot 10^5$  models, which we can study at dark matter and collider experiments, both current and future
- Today: examine **complementarity** of various searches in constraining our set of pMSSM models; see also talk by **T. Rizzo**

# A map of the pMSSM



Bino annihilation through Higgs funnel

# Direct detection



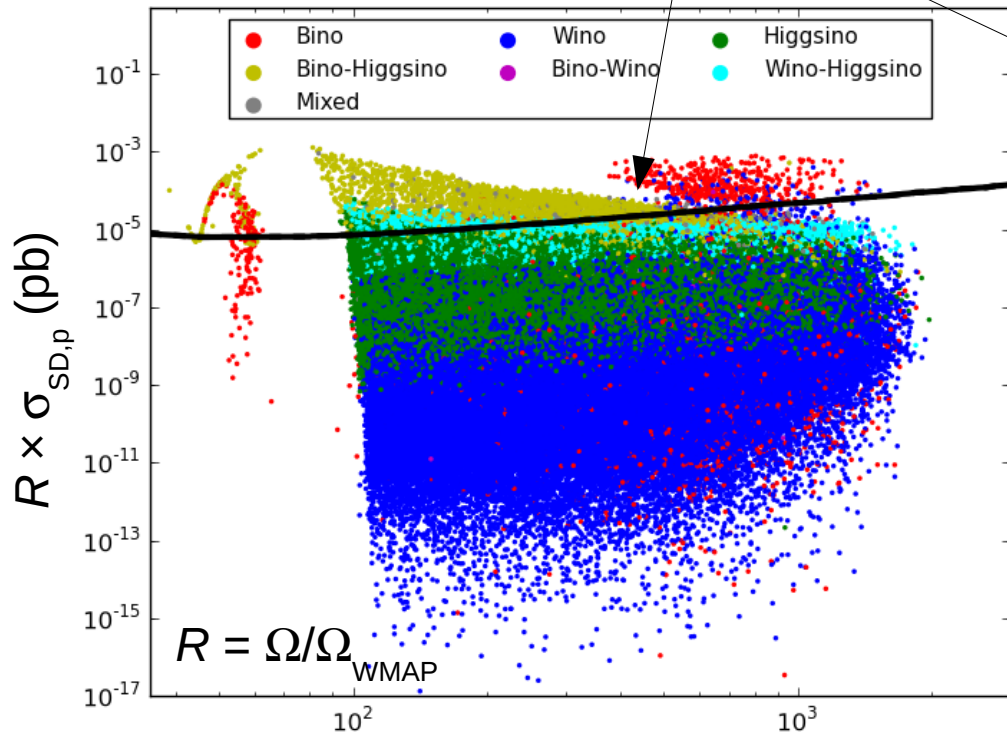
XENON1T (LUX + ZEPLIN) can exclude 23% (50%) of models  
 COUPP500 can exclude 2% through SD detection

# IceCube

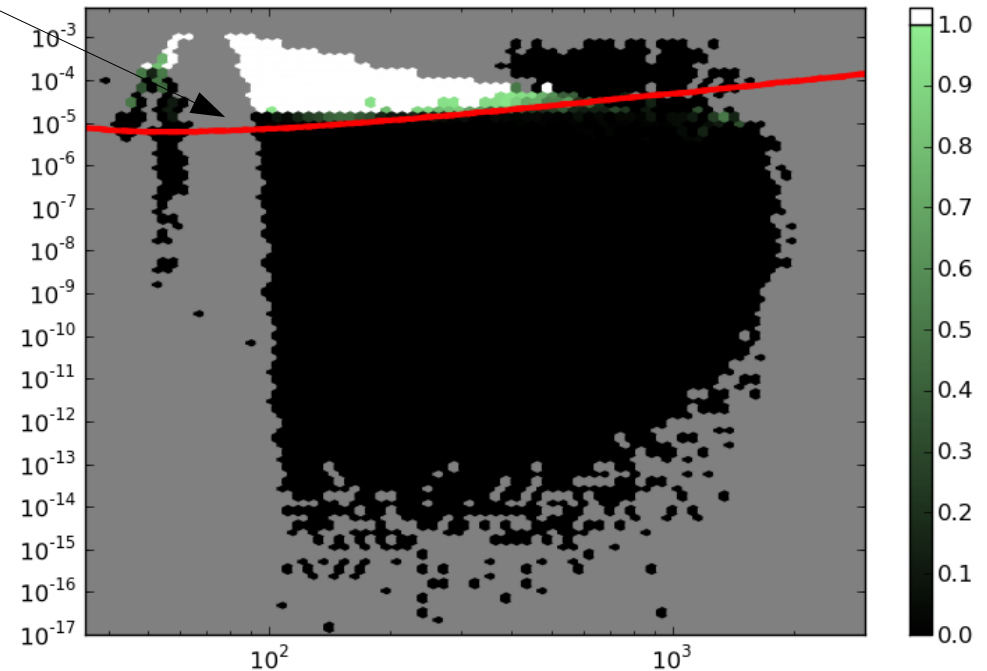
- LSP capture in the sun and subsequent annihilation produces high energy neutrinos
- Calculate  $\nu$  flux for each model, because annihilations go to **different final states**
- Also need to check **capture-annihilation equilibrium**; 48% of our models do not have these processes balanced in the sun, typically giving a low  $\nu$  flux!
- See **1105.1199** for more details

# IceCube

COUPP500



Fraction excluded by IceCube



LSP mass (GeV)

1.2% of models will be excluded by 5 years of IceCube data

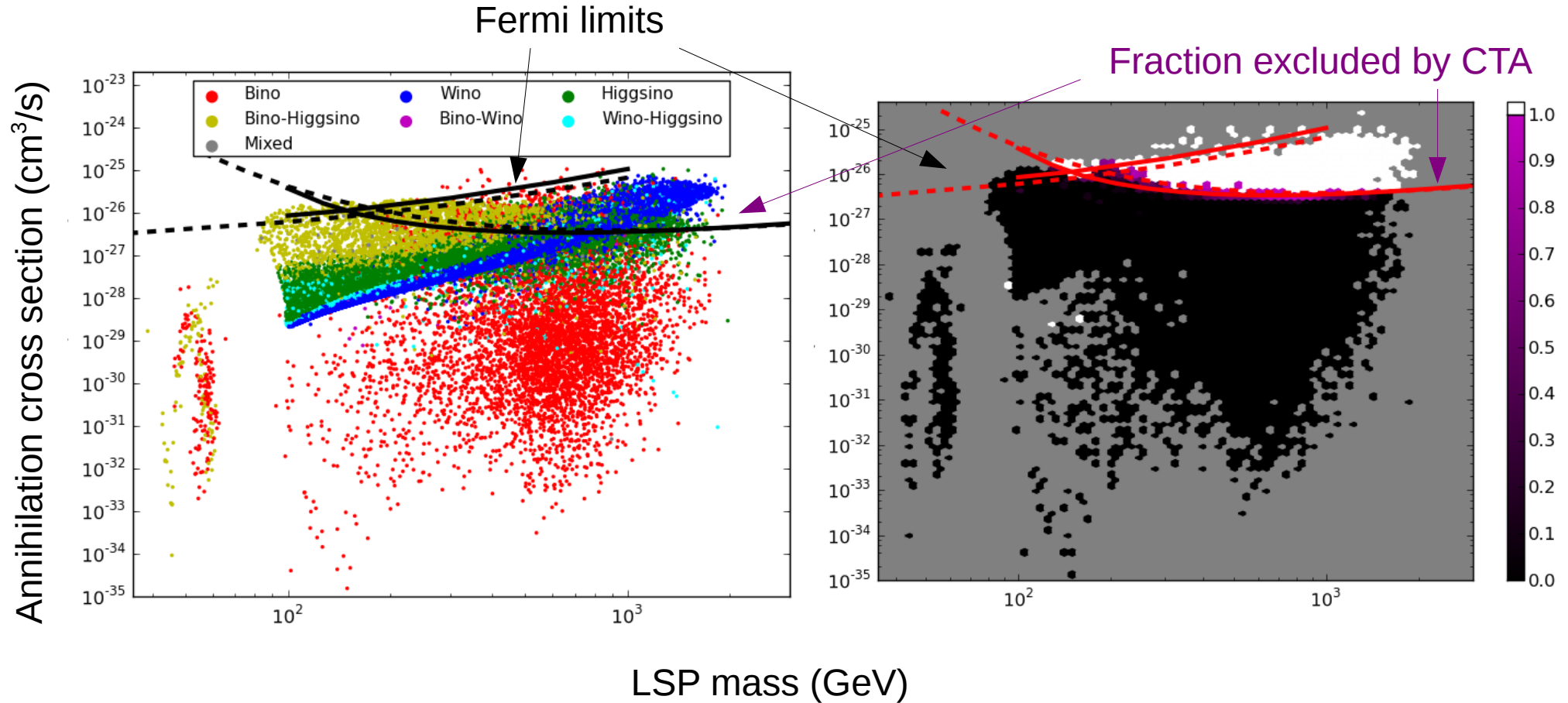
Only sensitive to bino-Higgsino mixtures!

Pure eigenstate LSPs survive due to poor capture or annihilation

# Indirect detection

- The LSP annihilates to some mixture of the standard decay modes  $bb$ ,  $WW$ ,  $\tau\tau$ , as well as others
- Calculate  $\gamma$  ray spectrum from annihilations for each model *separately*
- Fermi LAT two year dwarf analysis (1111.2604) + 10x improvement (0.1%)
- CTA with US contribution with 500 hours of exposure to galactic center SR (19%)

# Indirect detection



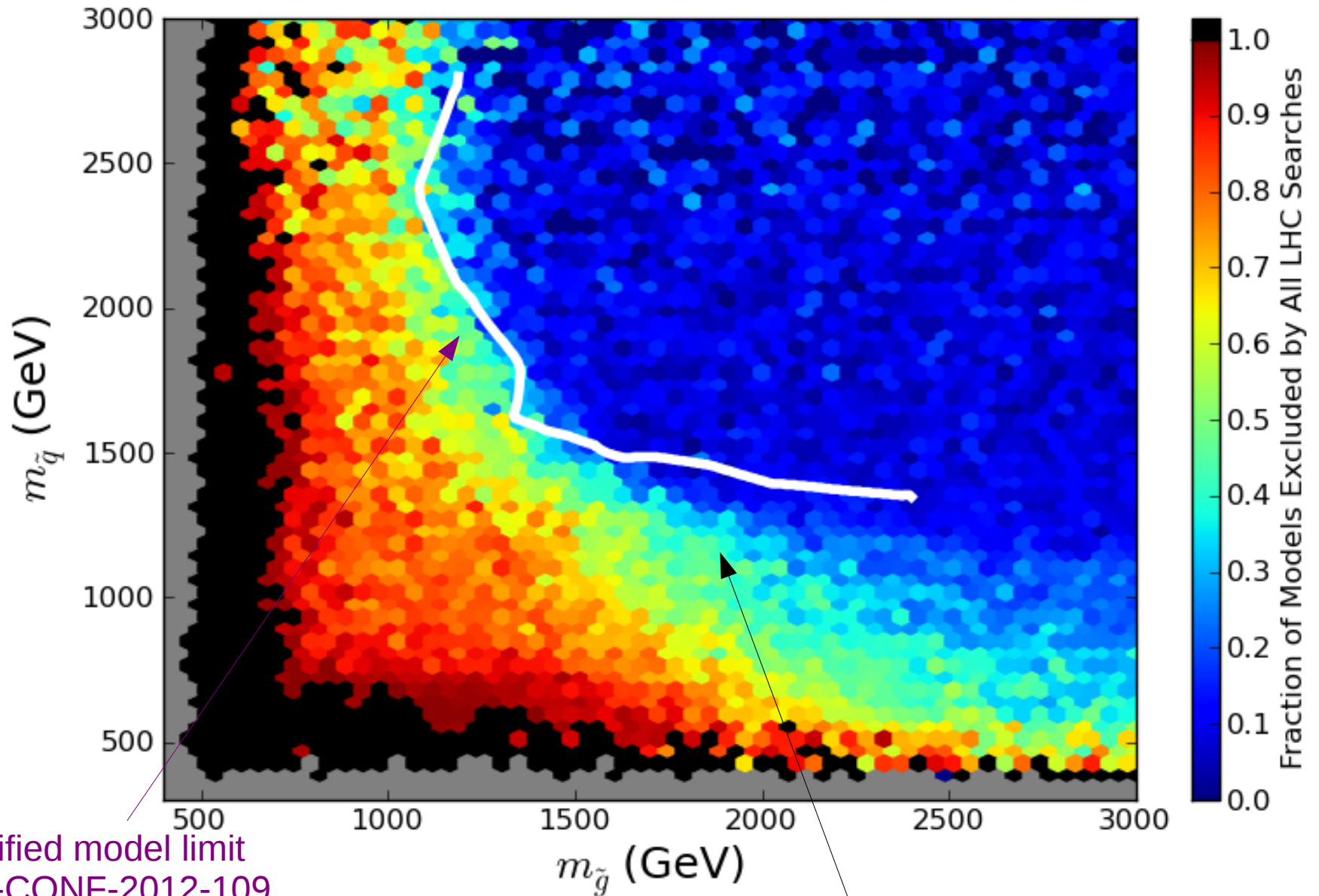
Fermi better at lower masses, CTA dominates for heavy LSP  
Heavy coannihilating binos have very low annihilation cross sections, and **won't be excluded by CTA (or LHC!)**



# LHC

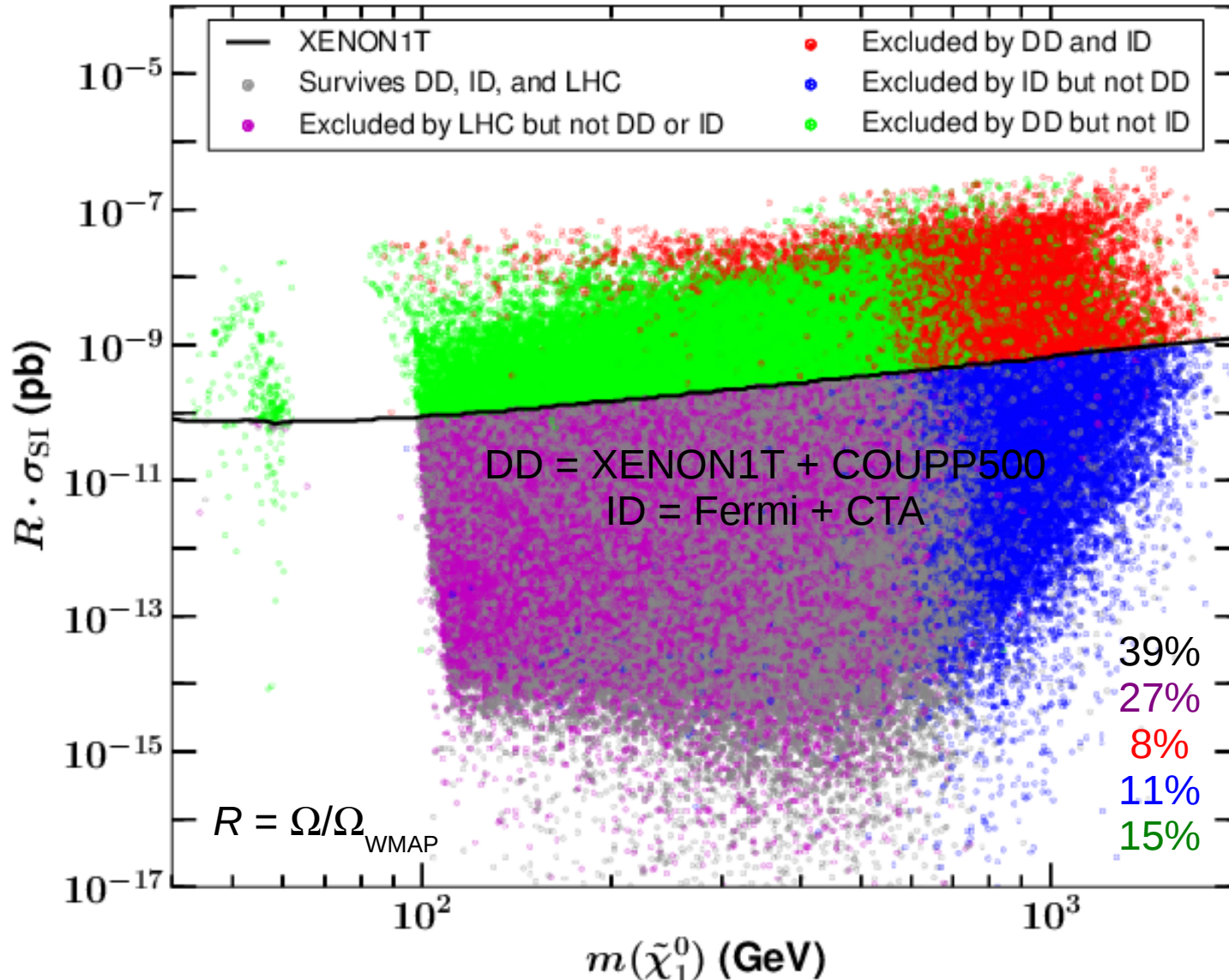
- Searches through 09/2012 are considered, both standard ATLAS SUSY and other limits like  $B_s \rightarrow \mu\mu$
- Currently expanding analysis suite for recent 8 TeV searches, with 14 TeV projections to come
- See [1211.1981](#) for more details
- These searches probe **more** than just the LSP!

# LHC



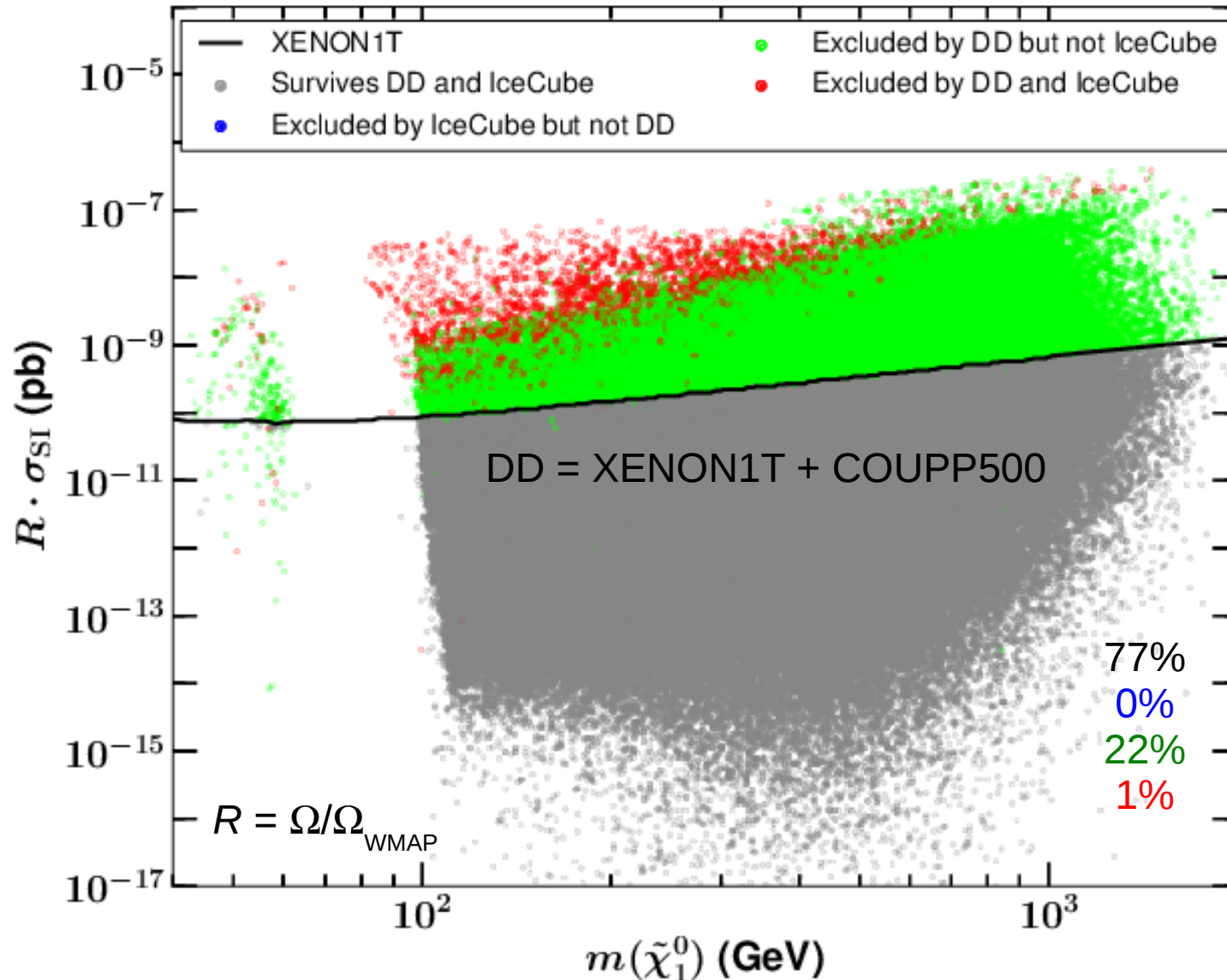
Light non-degenerate squarks, compressed spectra can survive!

# Search complementarity



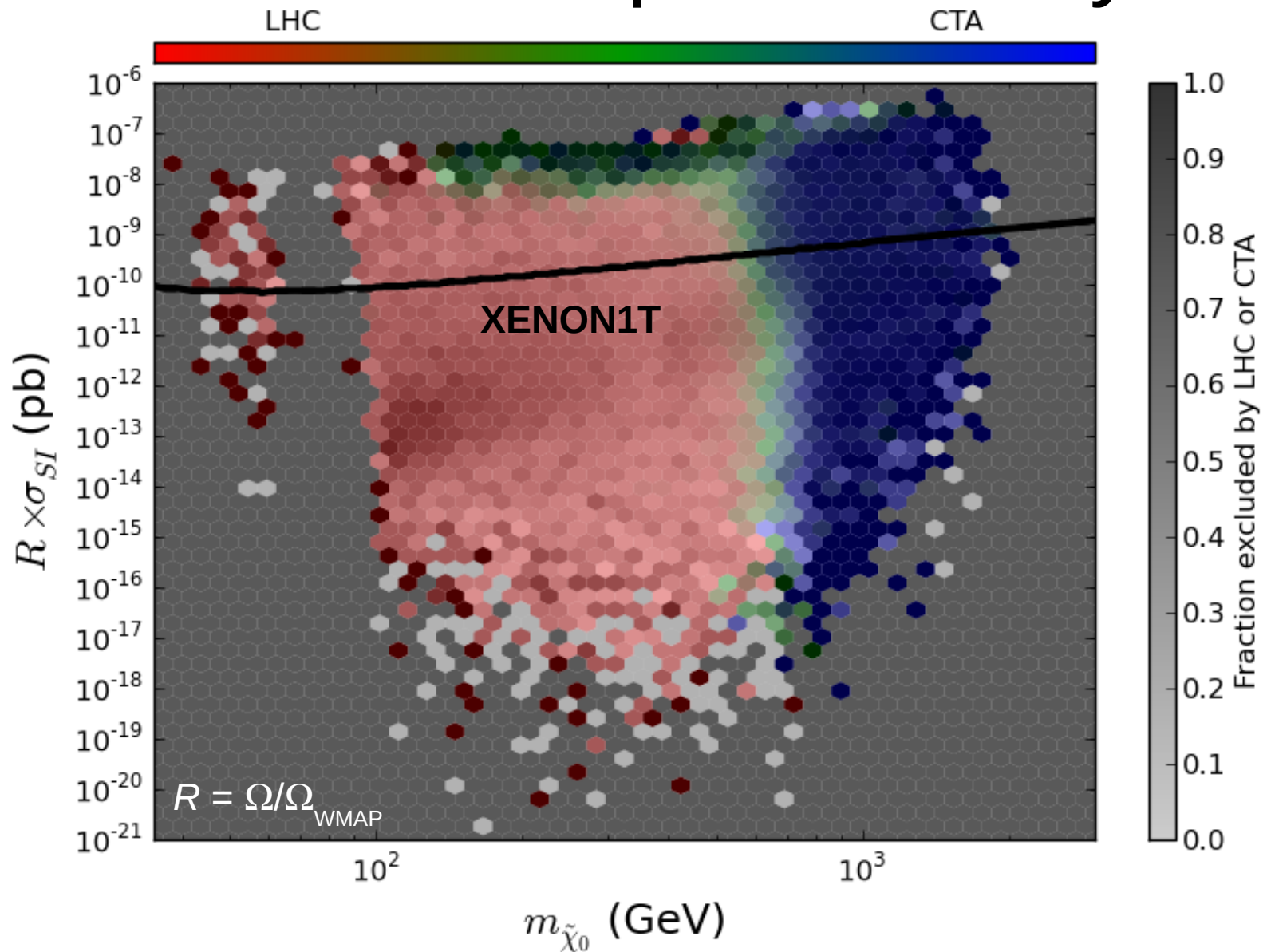
Direct and indirect detection probe distinct regions!

# Search complementarity



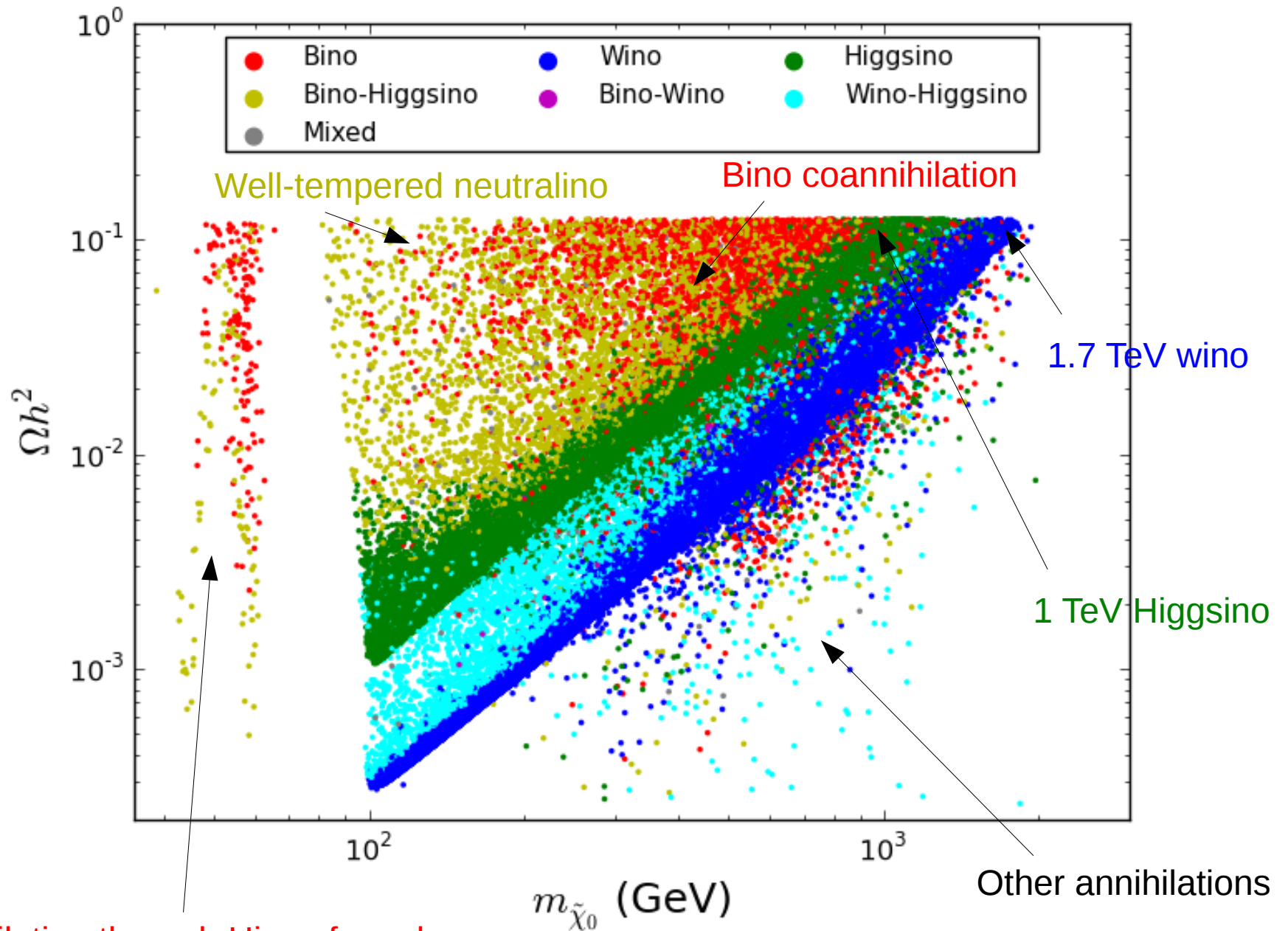
But IceCube won't see any new models beyond 1T direct detection....

# Search complementarity



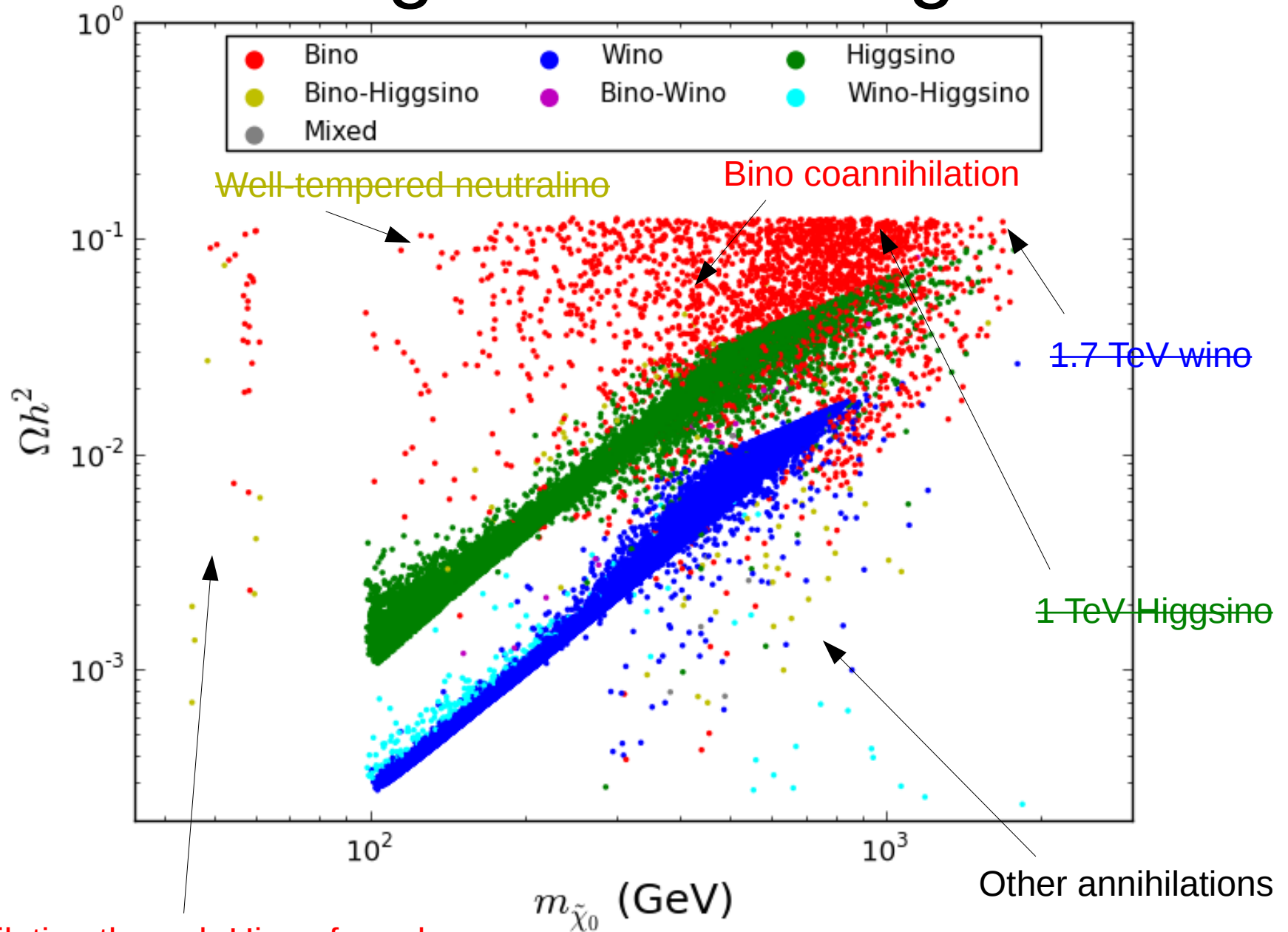
LHC, CTA, and XENON1T act orthogonally and exclude many models

# So what's left of this?



Bino annihilation through Higgs funnel

# Most surviving LSPs are eigenstates



Bino annihilation through Higgs funnel

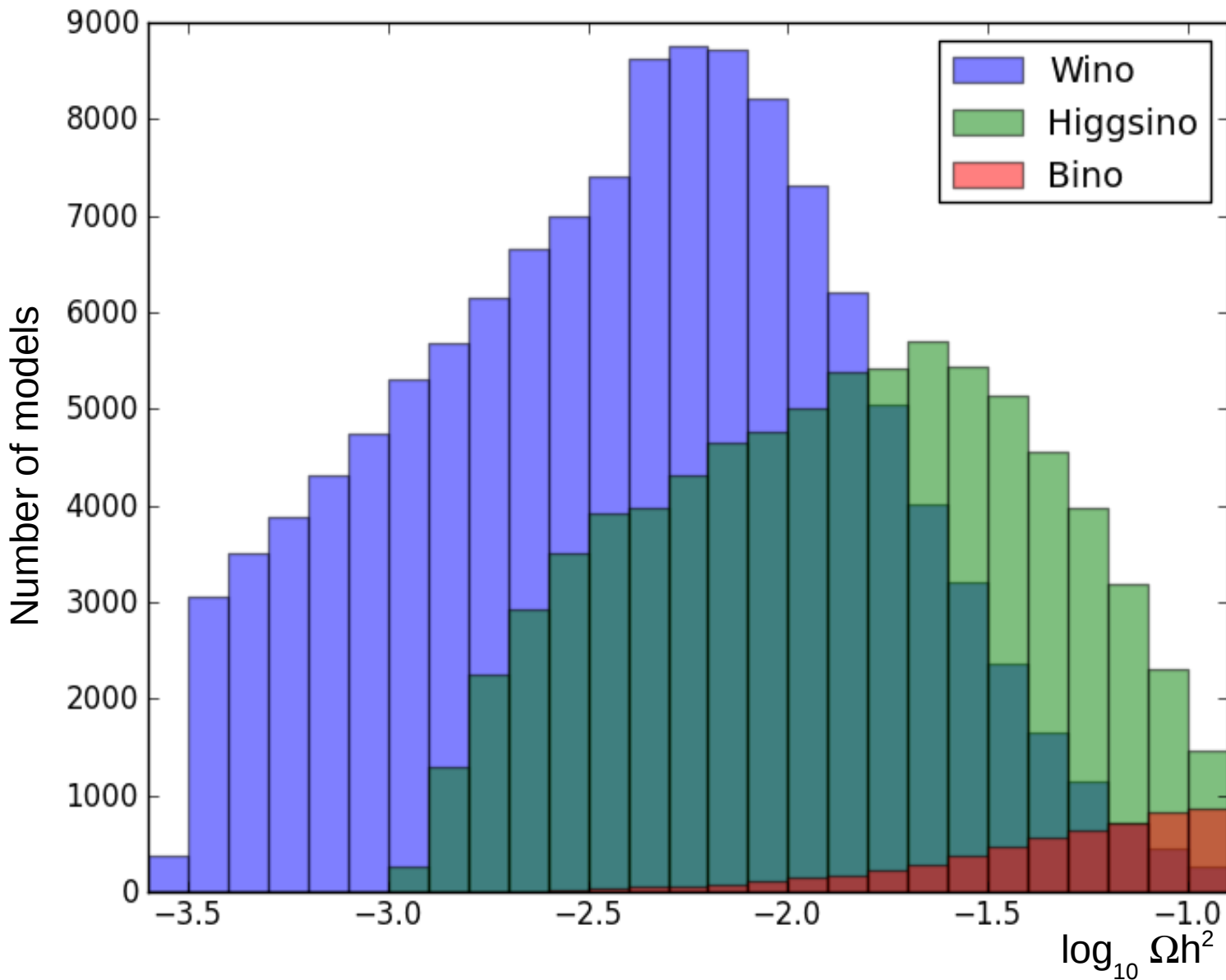
# Lessons learned

- Even if the LSP **doesn't** make up all the dark matter, it can often produce enough signal in direct detection, indirect detection, or neutrino experiments
- Remaining models that *do* have right relic density have **(co)annihilating bino LSPs**
- Spin-independent direct detection, CTA, and the LHC are expected to be the most powerful searches for the pMSSM in the near future
- Most experiments provide **complementary** probes of SUSY



Backup

# Neutralino LSP relic density

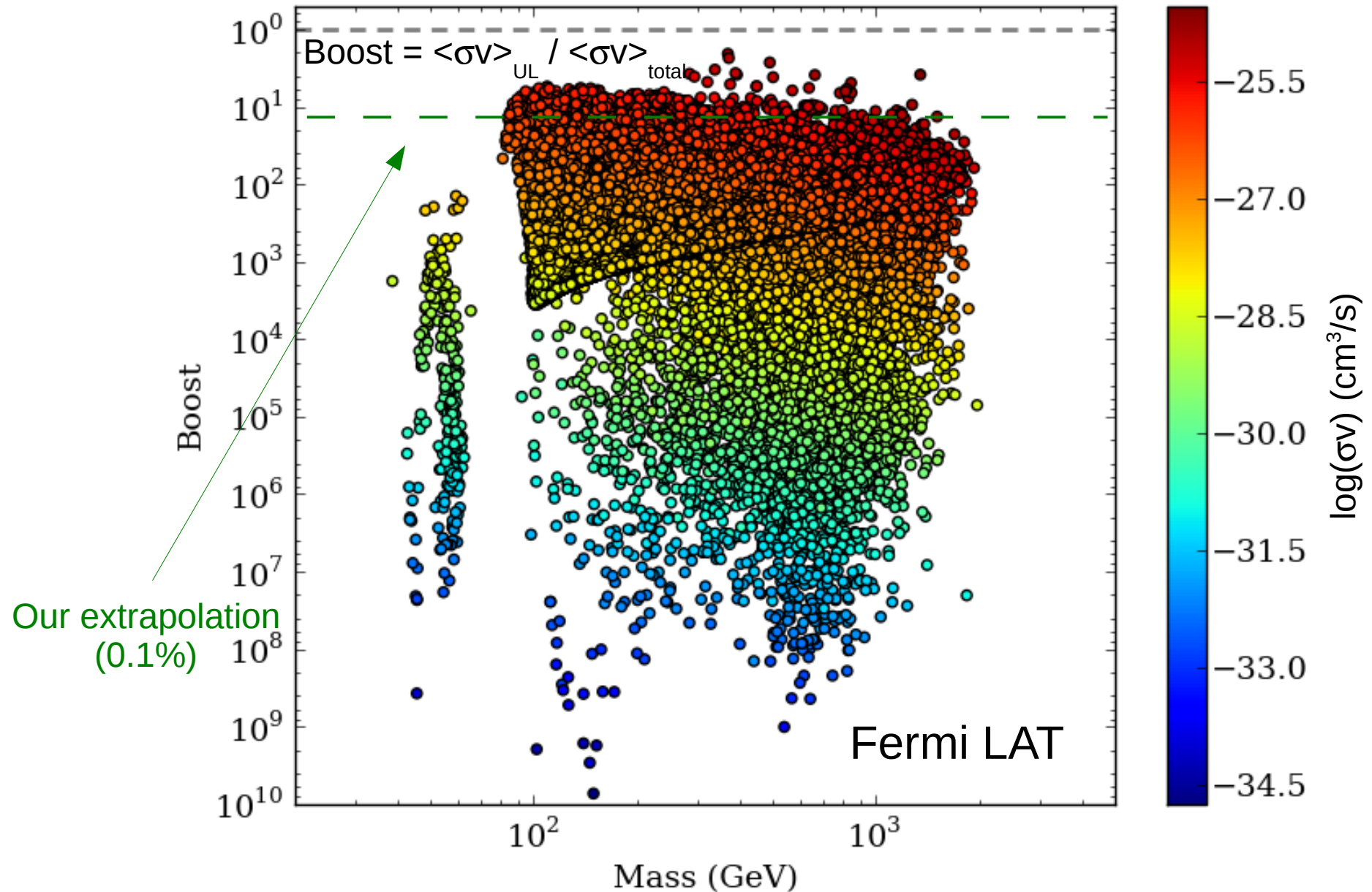


Winos and higgsinos annihilate more (mixtures not shown)

# An aside: the Higgs mass

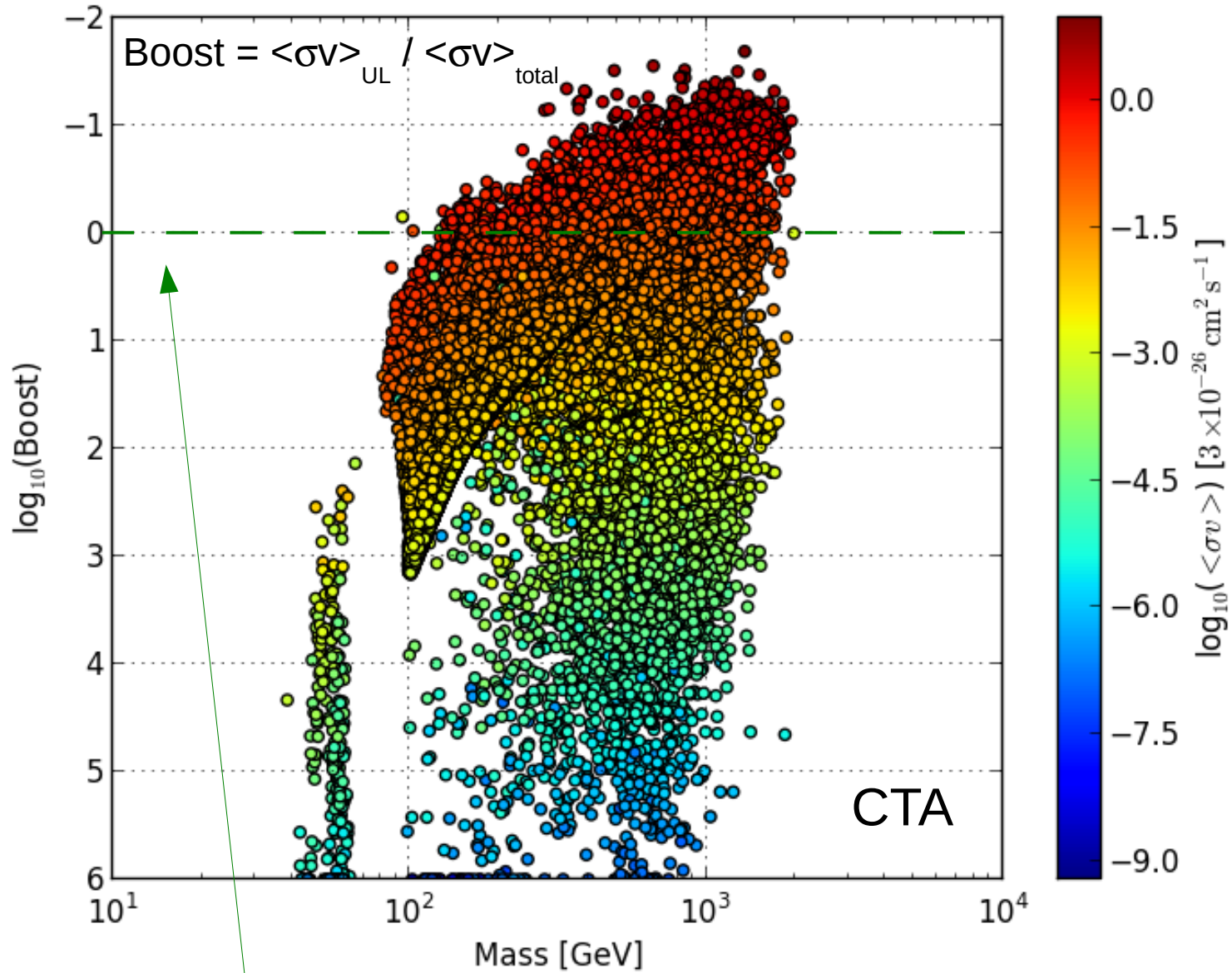
- This model set was generated *before* the Higgs discovery
- 20% of our models have the lighter CP-even Higgs weighing  $126 \pm 3$  GeV (**1206.5800**)
- Generally, an MSSM Higgs this heavy requires either heavy stops or large stop mixing
- The LHC results for the subset of our models with a Higgs near 126 GeV are **very similar** to those for the full model set (**1211.1981**)
- All other results are completely **unaffected**

# Indirect detection



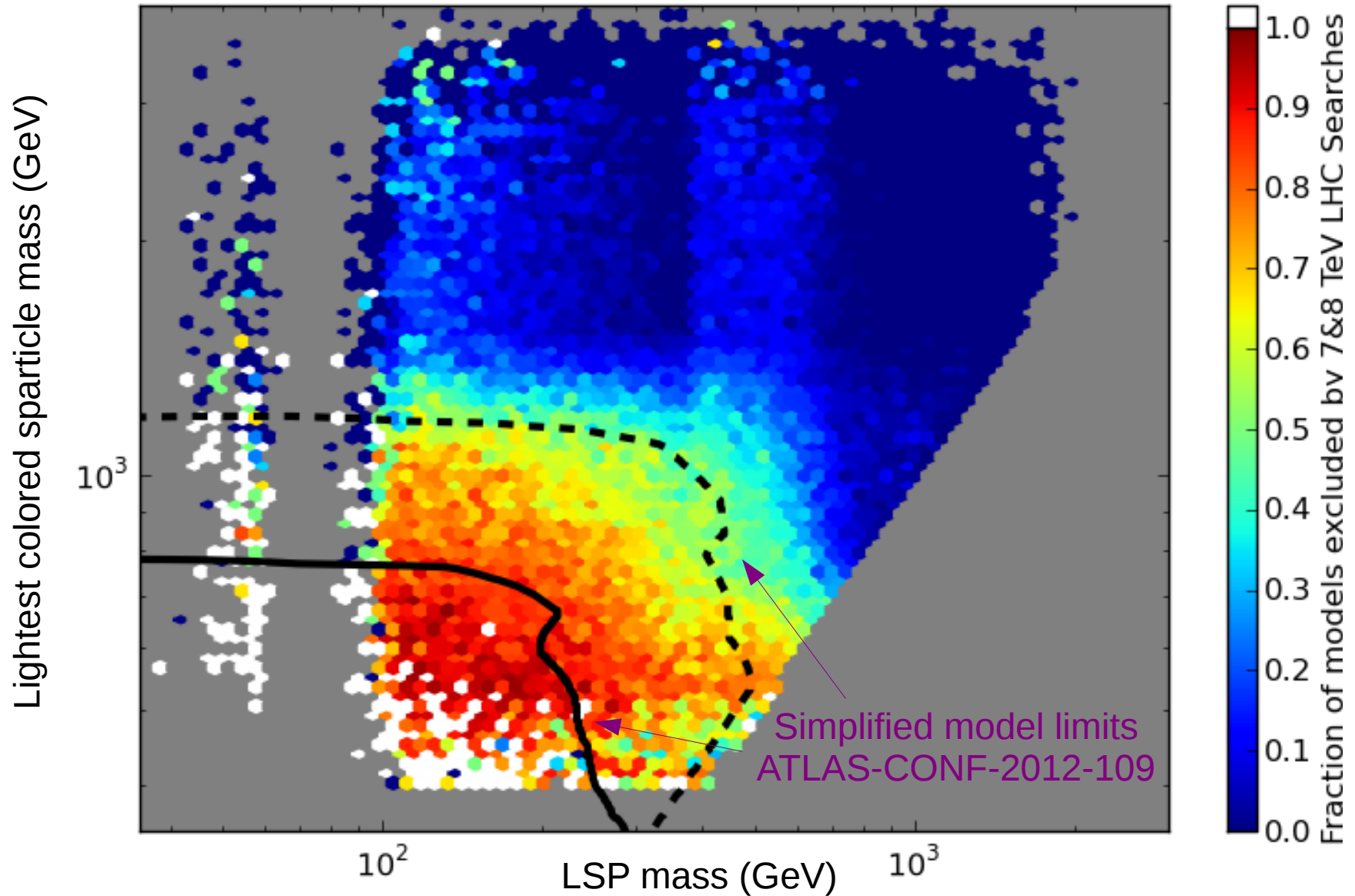
Two year LAT analysis doesn't exclude any models

# Indirect detection



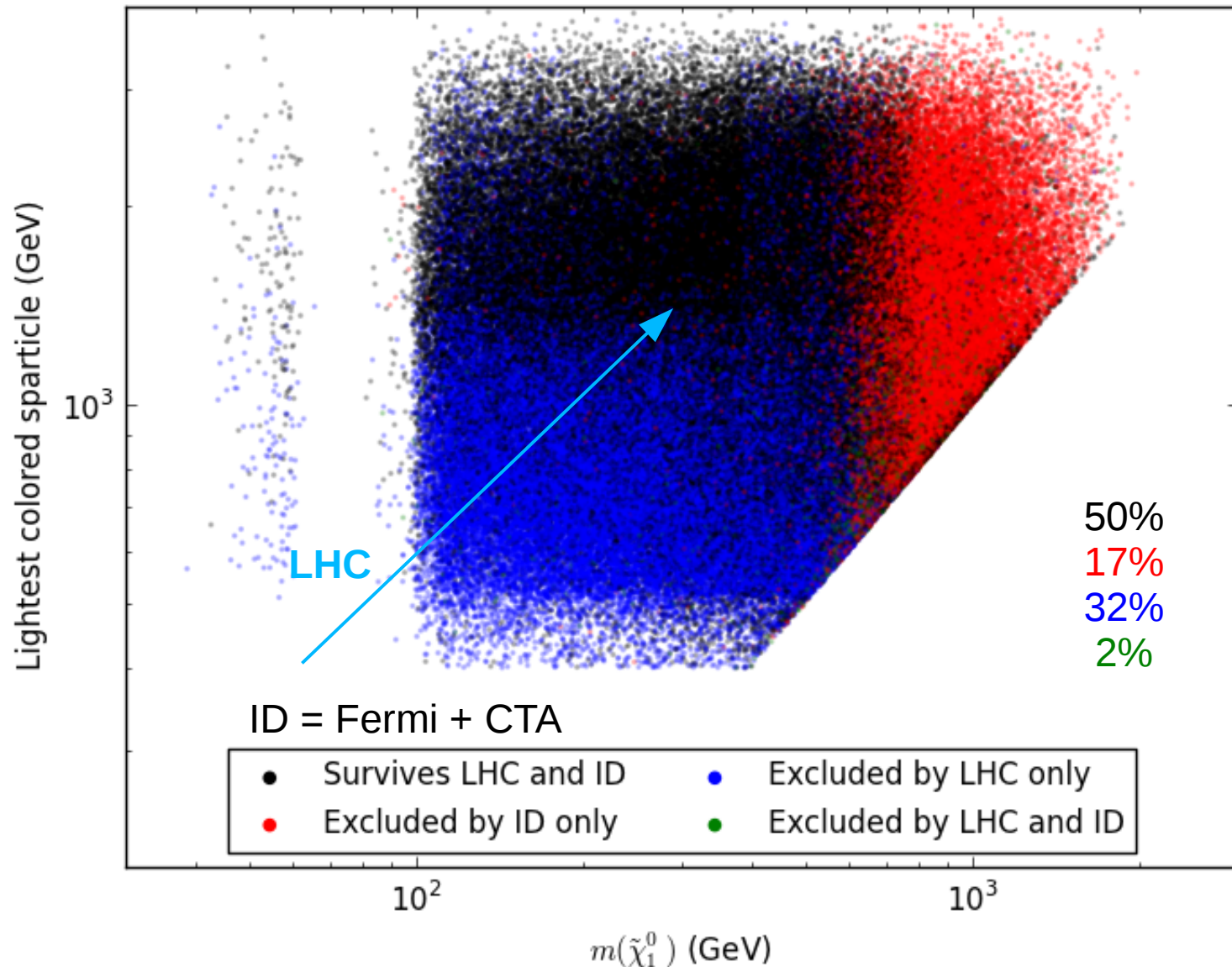
CTA is sensitive to 19% of models!

# LHC



Strong production *and* phase space between LCP and LSP matters

# Search complementarity



LHC will improve to complement CTA even better!