Complementarity in the pMSSM

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Outline

- The phenomenological MSSM
- Individual searches for SUSY
- Comparison of different experiments
- Lessons learned

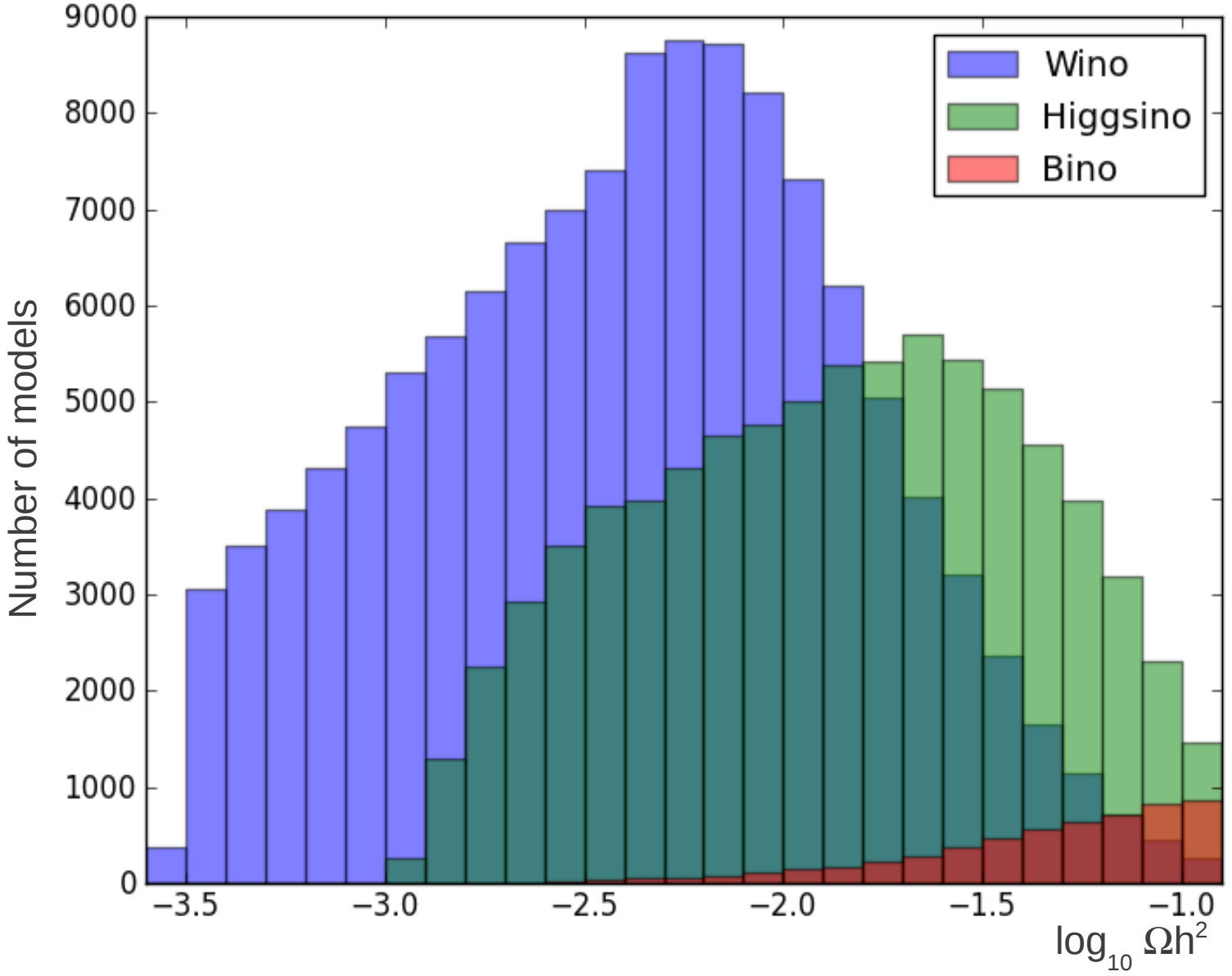
The phenomenological MSSM

- Start with the MSSM with R-parity
- Take minimal flavor violation, CP, diagonal sfermion masses with first two generations degenerate; motivated by experiment!
- Scan the resulting 19-dimensional space, searching for points consistent with all existing constraints: precision electroweak, flavor, colliders
- For more details of model generation, see talk by M. Cahill-Rowley, 1206.4321

The phenomenological MSSM

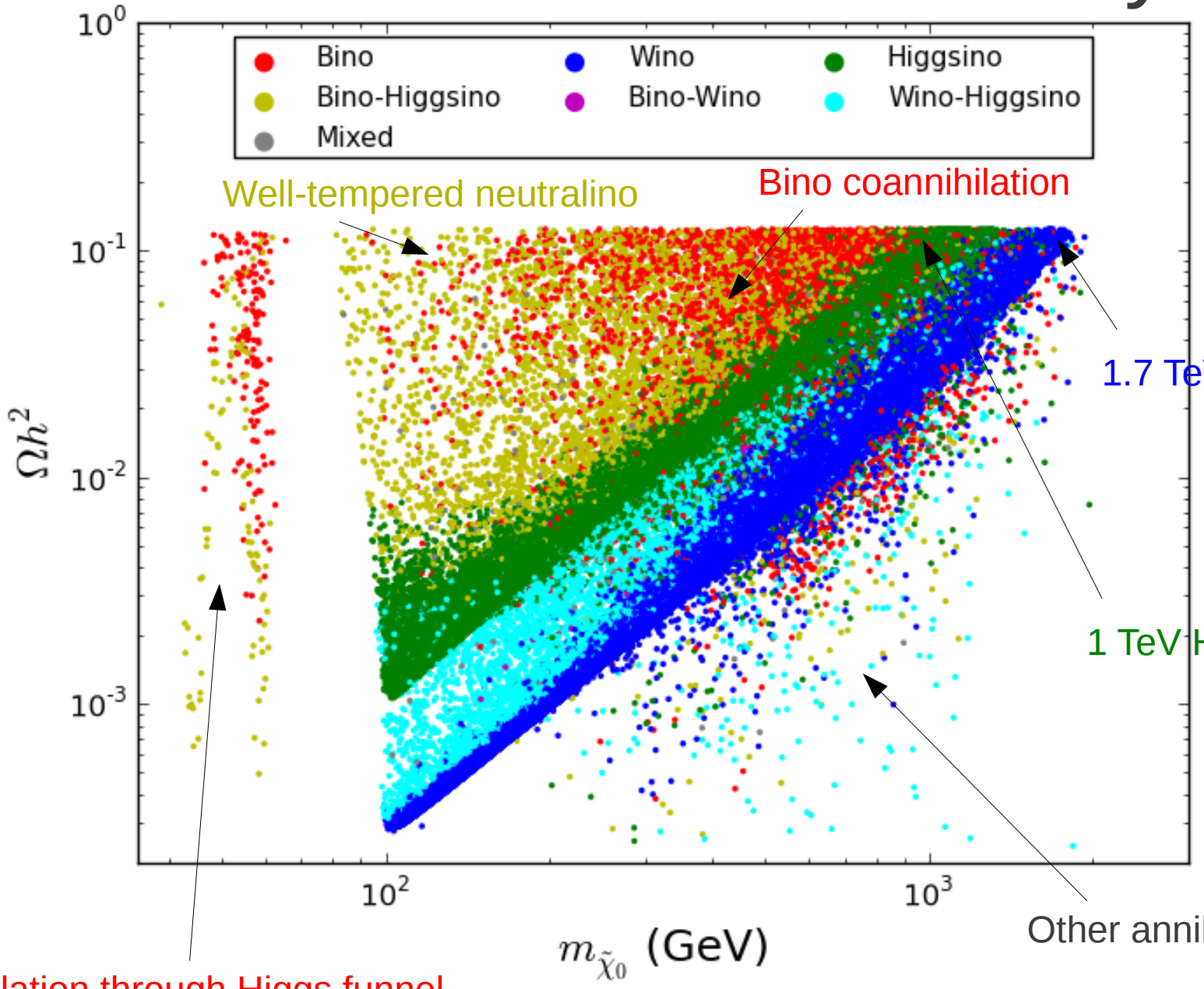
- Choose models where lightest neutralino is LSP
- Do not require LSP to saturate relic density
- Soft SUSY breaking masses are scanned up to 4 TeV, giving LSPs from 40 GeV to ~2 TeV
- Get resulting set of $2.2 \cdot 10^5$ models, which we can study at collider and dark matter experiments, both current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

Neutralino LSP relic density



Winos and higgsinos annihilate more (mixtures not shown)

Neutralino LSP relic density



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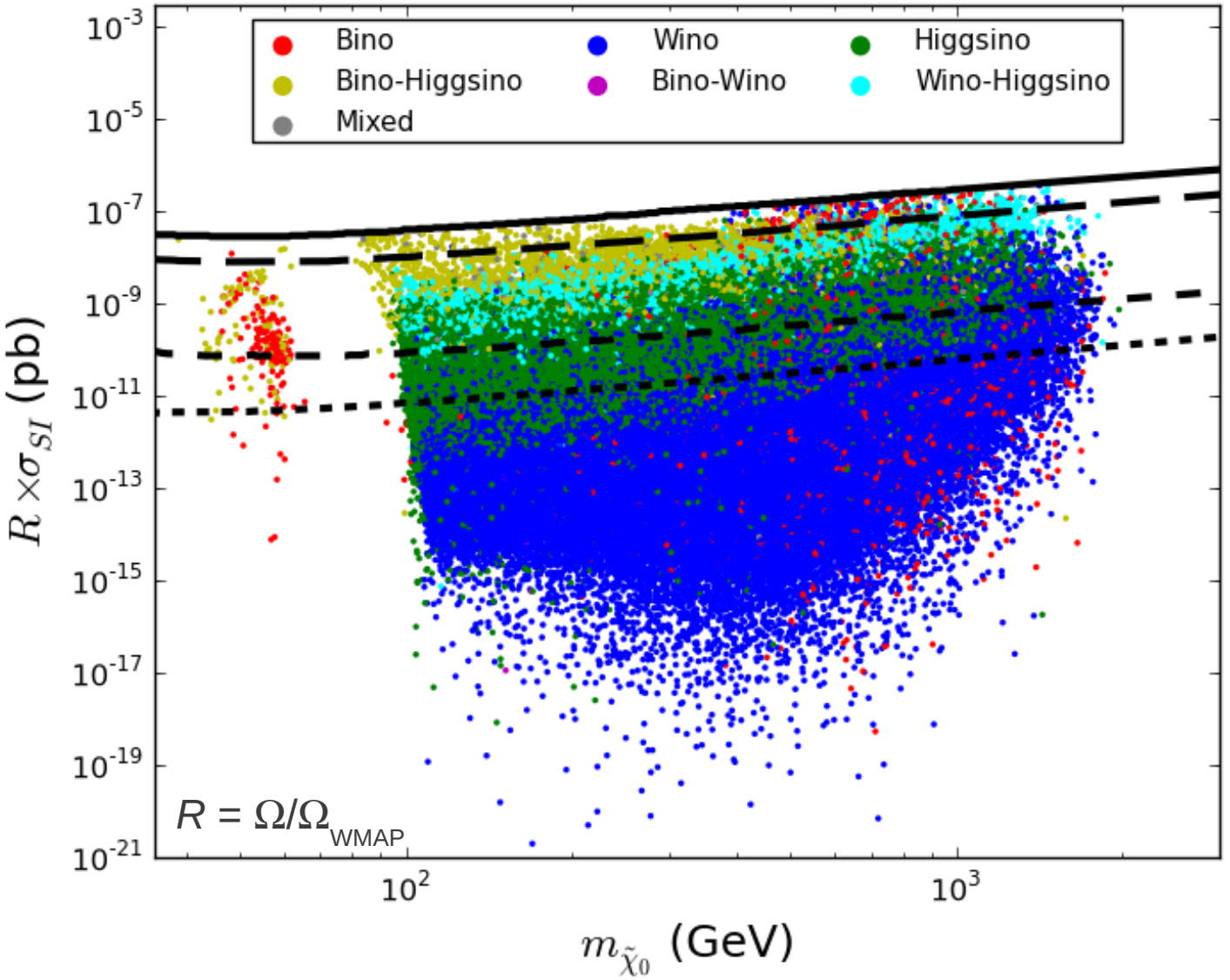
Direct detection



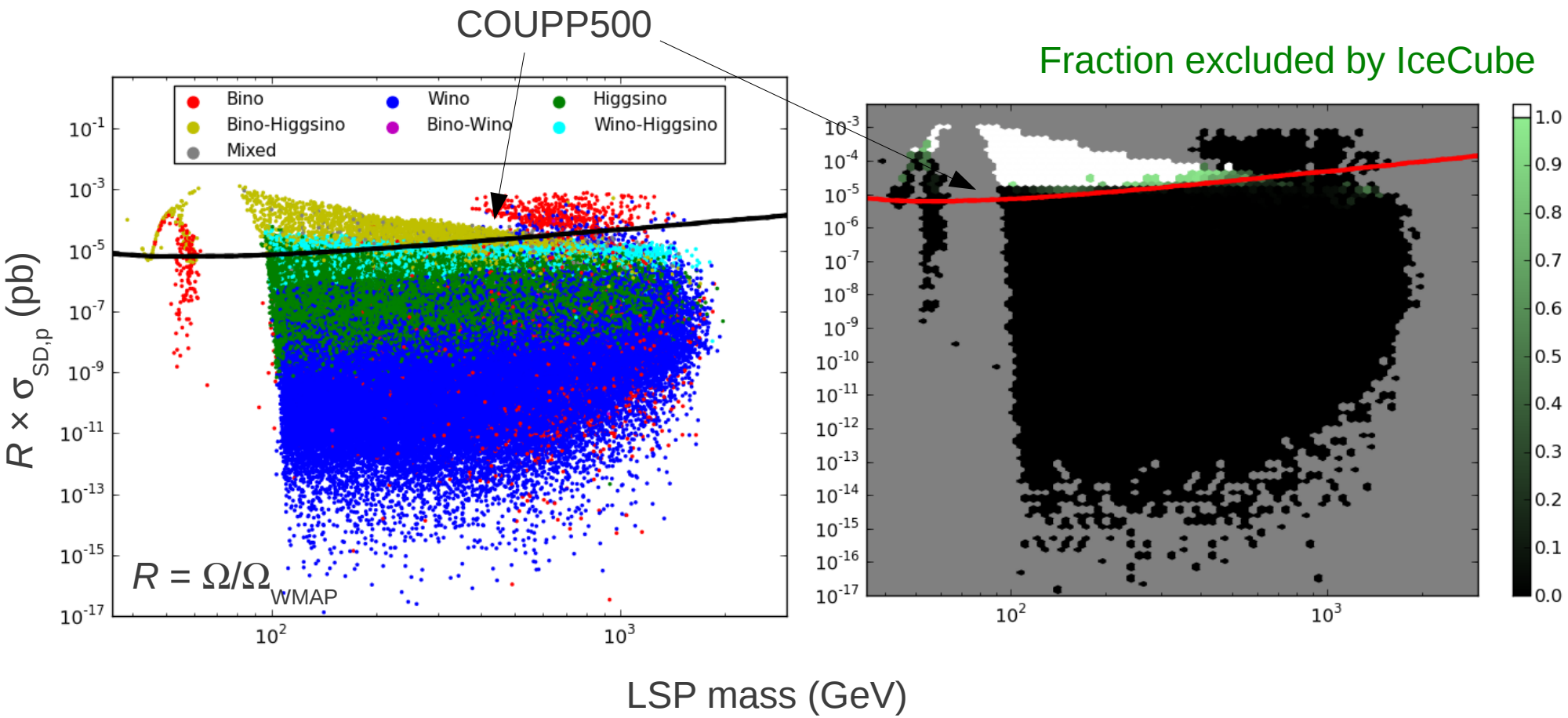
XENON100 (2011)
XENON100 (2012)
XENON1T (2017)
LZ (5M kg-days)

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 ν 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 ν flux!
- See talk by R. Cotta, 1105.1199 for more details

IceCube

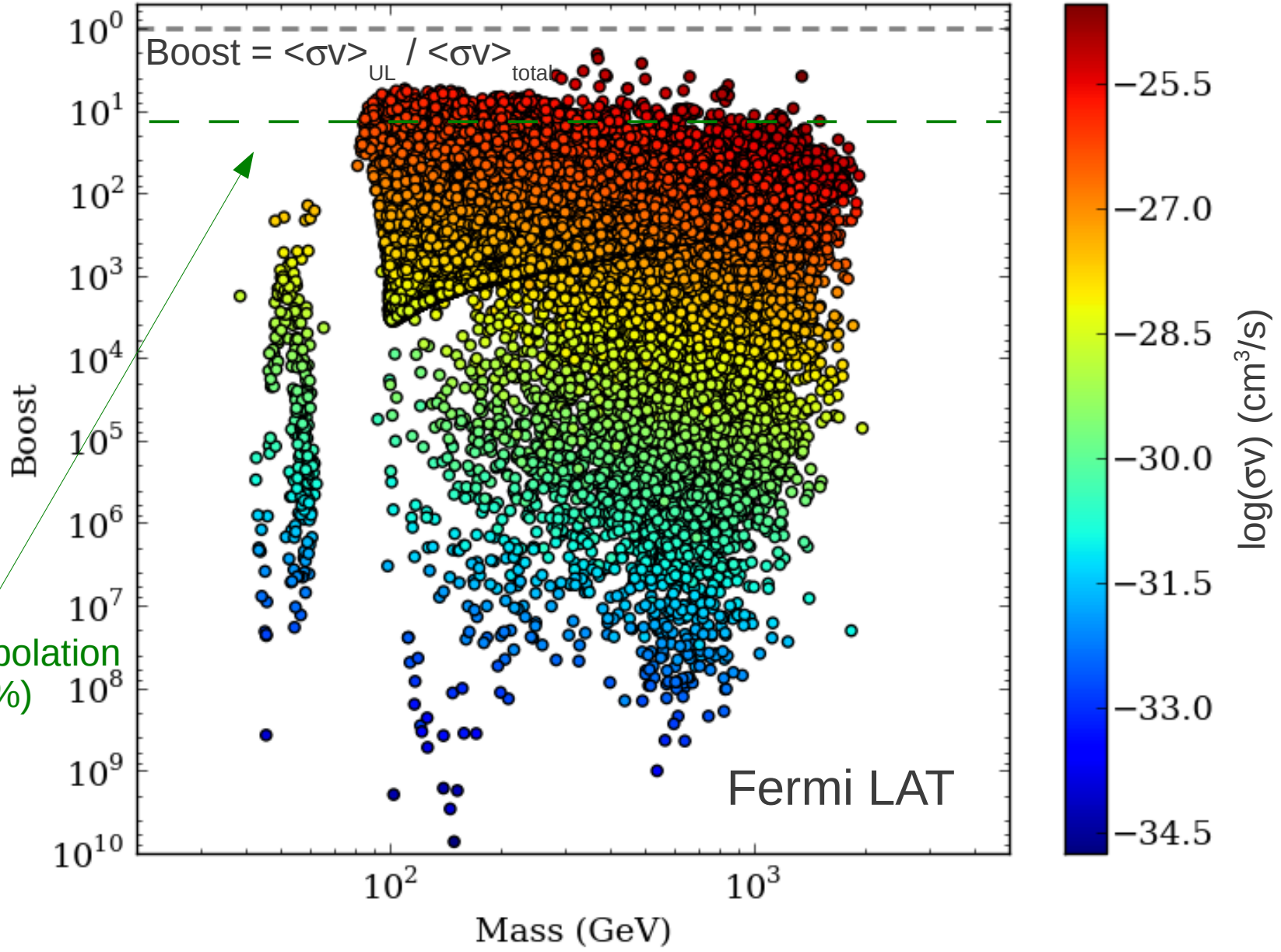


1.2% of models will be excluded by 5 years of IceCube data
Only sensitive to bino-Higgsino mixtures!
Pure eigenstate LSPs survive due to poor capture or annihilation

Indirect detection

- The LSP annihilates to some mixture of the standard decay modes bb, WW, $\tau\tau$, as well as others
- Calculate γ ray spectrum from annihilations for each model separately
- Fermi LAT two year dwarf analysis (1111.2604)
- Also consider CTA with 500 hours of exposure to galactic center SR
- See talks by A. Drlica-Wagner, M. Wood

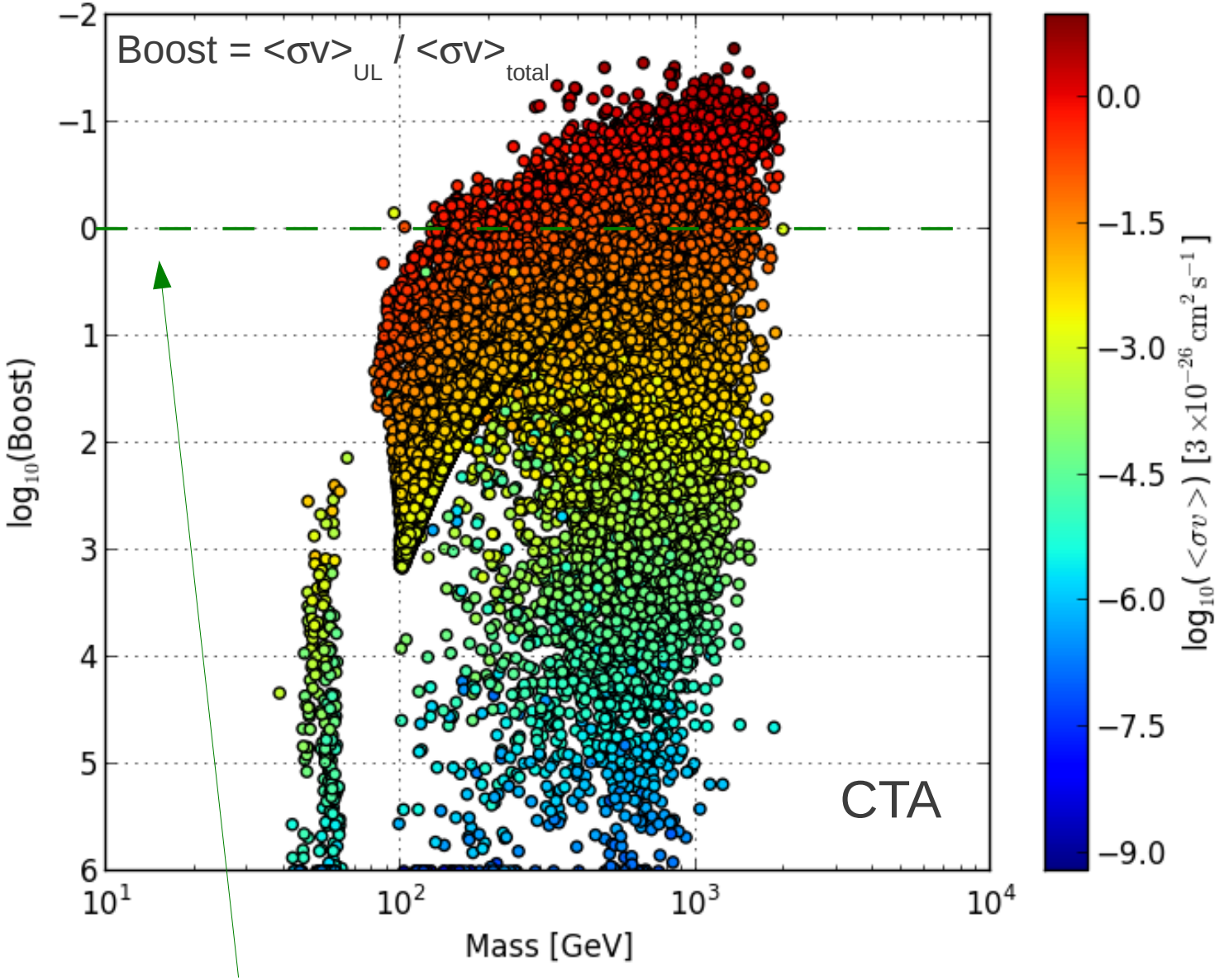
Indirect detection



Our extrapolation (0.1%)

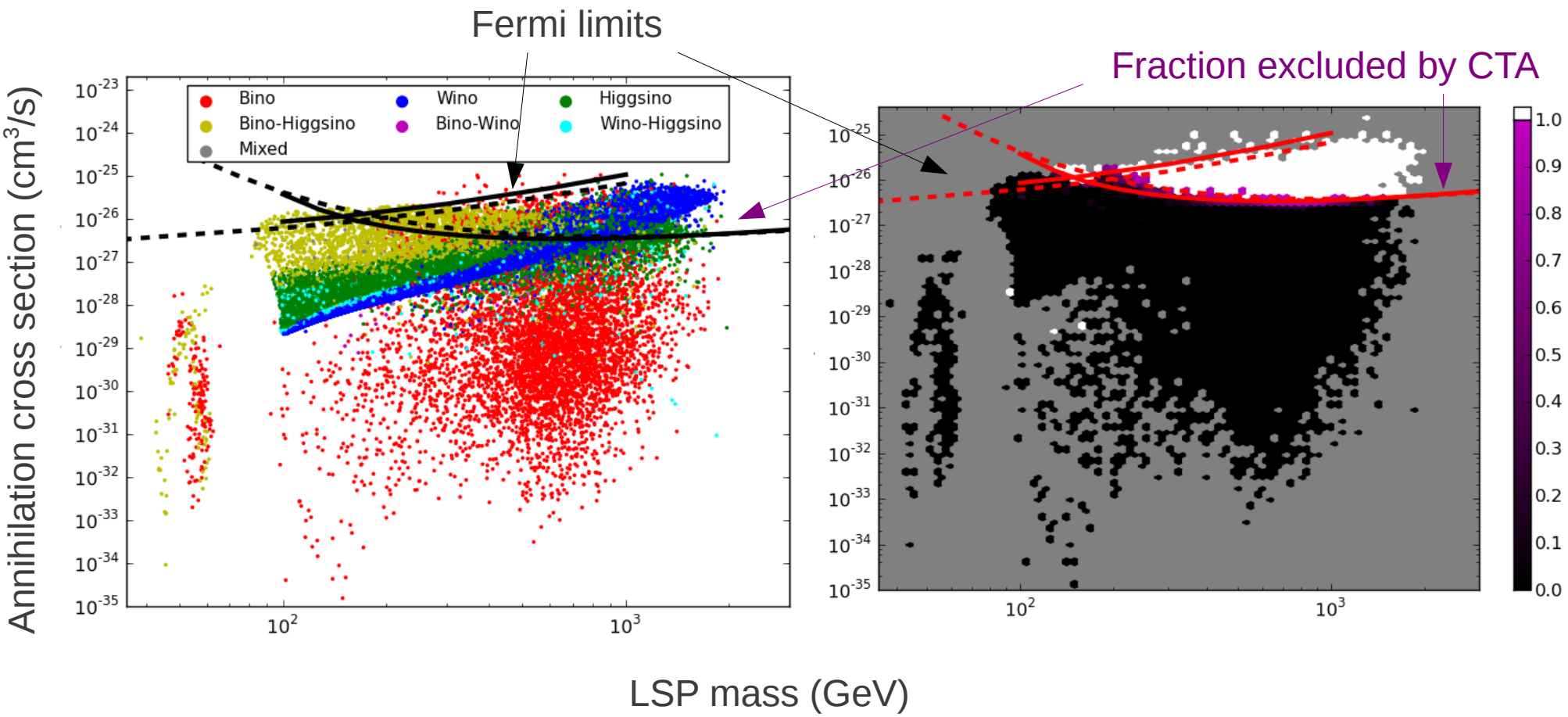
Two year LAT analysis doesn't exclude any models

Indirect detection



CTA is sensitive to 19% of models!

Indirect detection

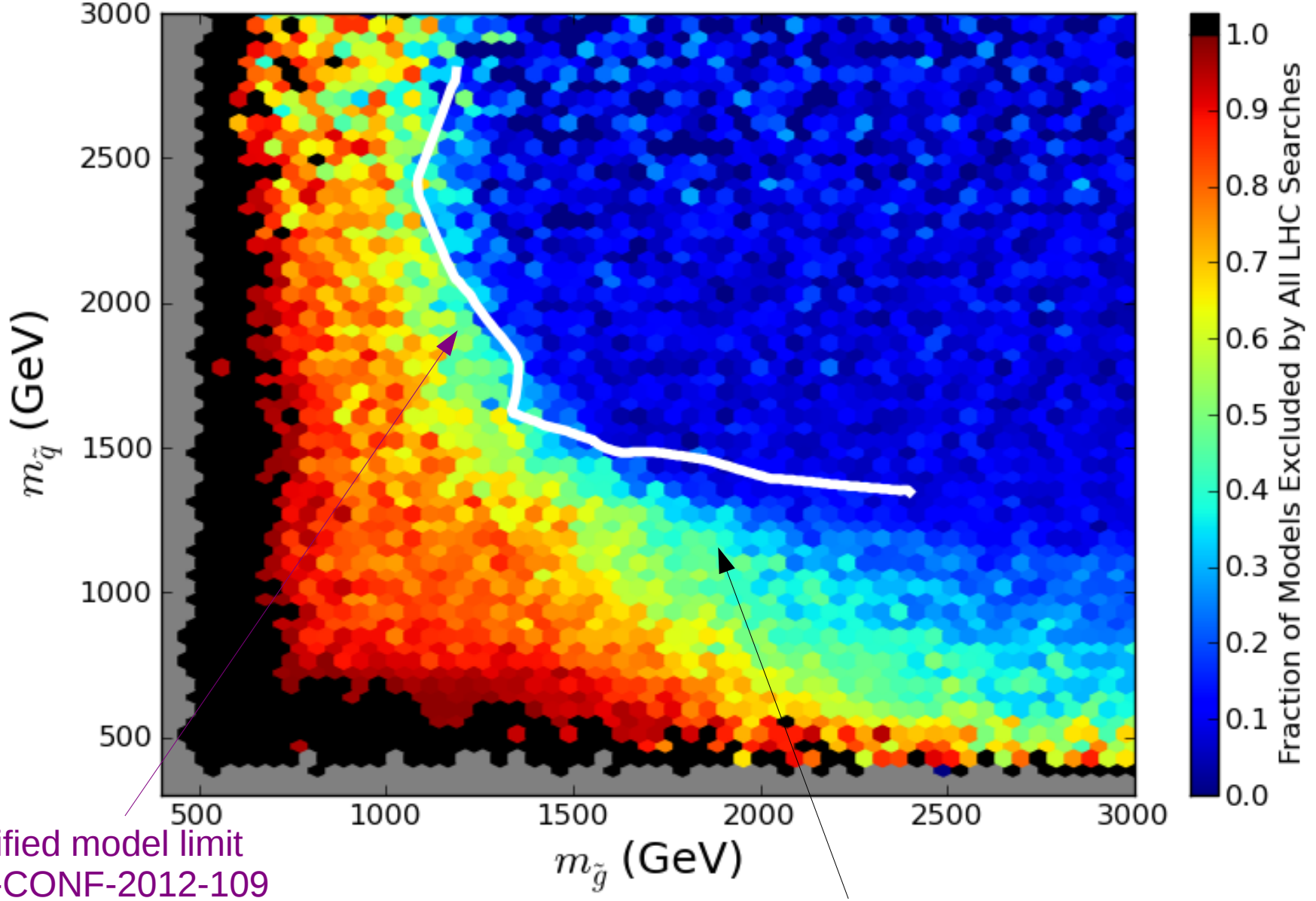


Fermi better at lower masses, CTA dominates for heavy LSP
Heavy coannihilating binos have very low annihilation cross sections, and won't be excluded by CTA (or LHC!)

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 talk by M. Cahill-Rowley, 1211.1981 for more details
- These searches probe more than just the LSP!

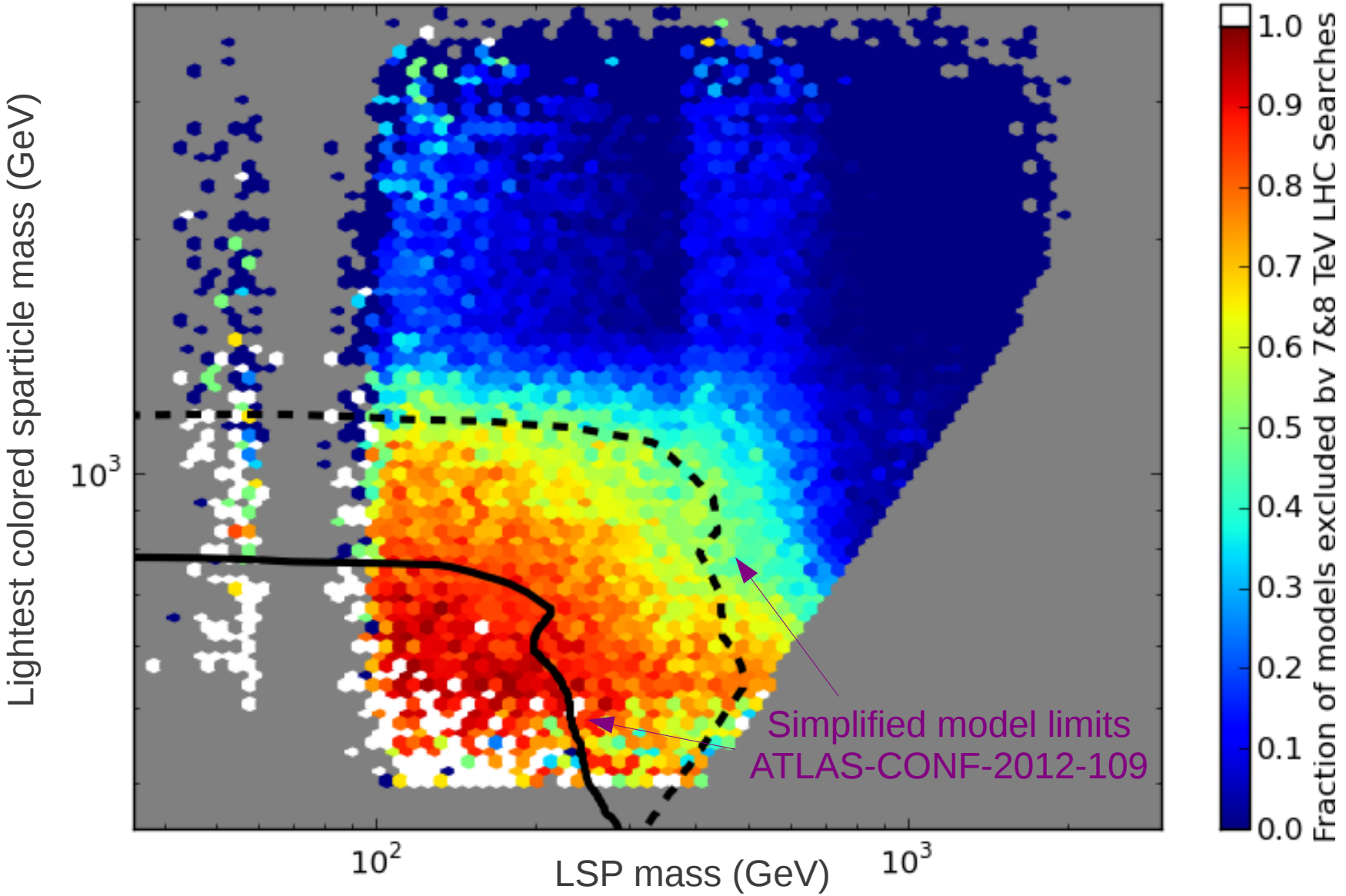
LHC



Simplified model limit
ATLAS-CONF-2012-109

Light non-degenerate squarks, compressed spectra can survive!

LHC



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

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 ± 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

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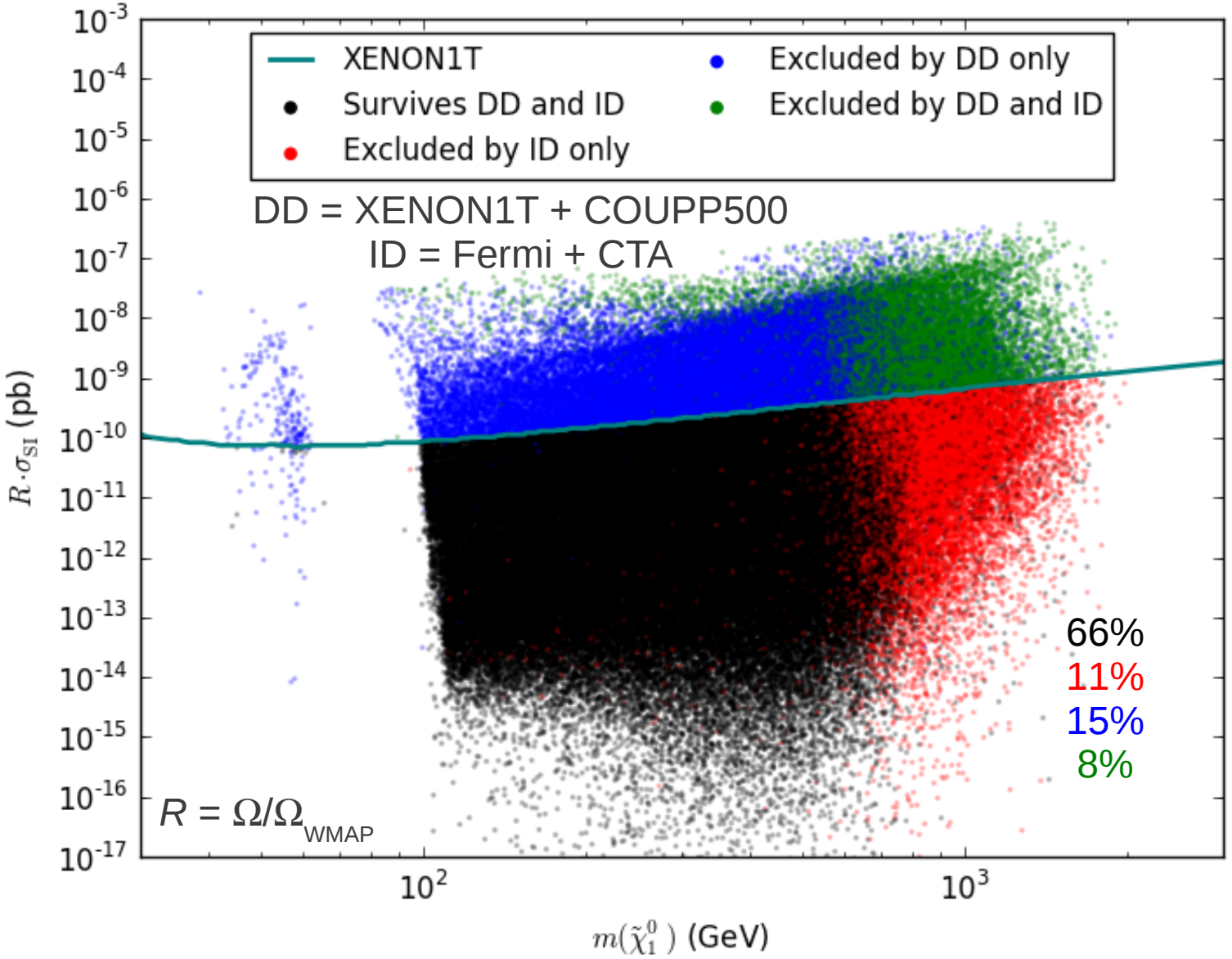
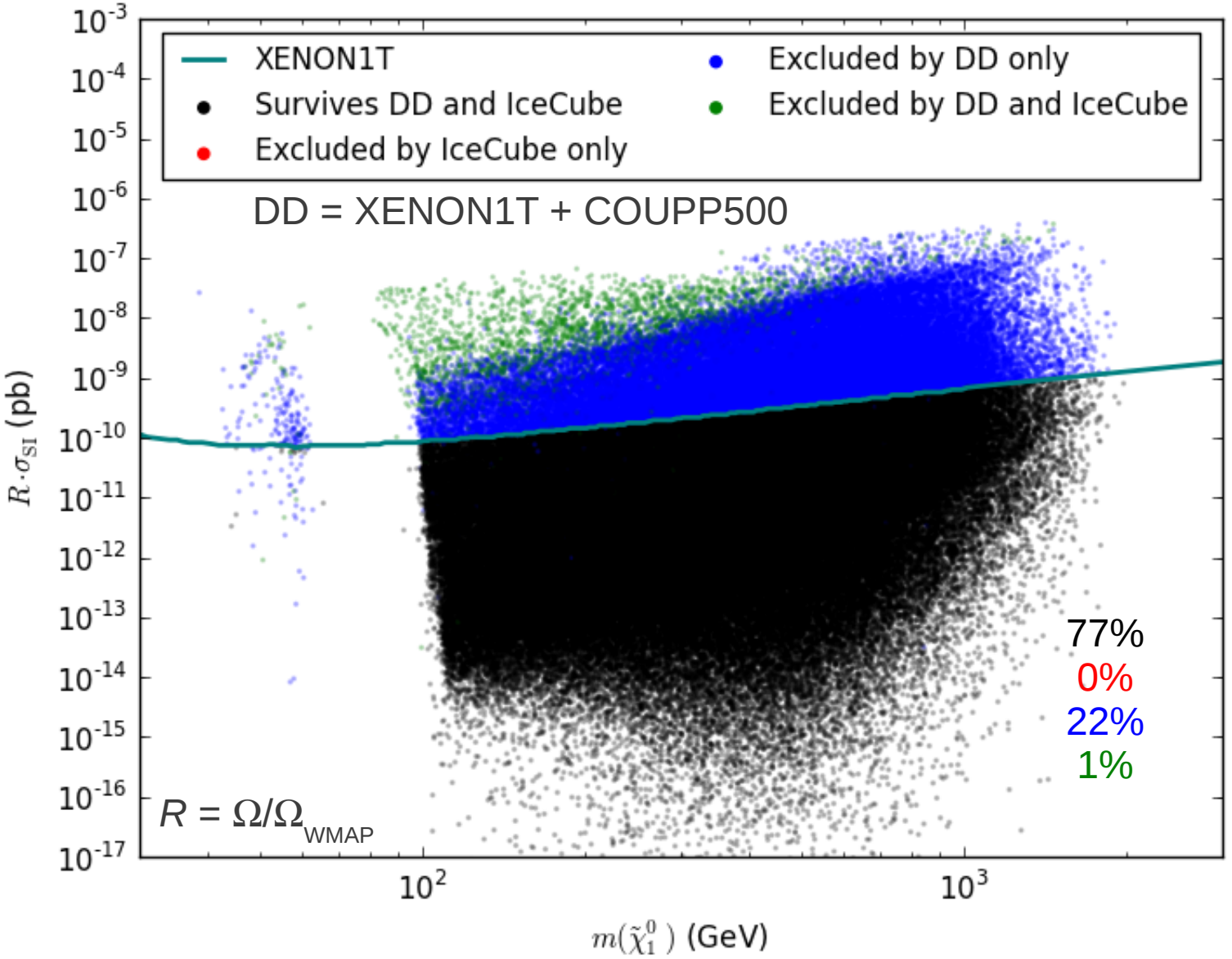
Search complementarity



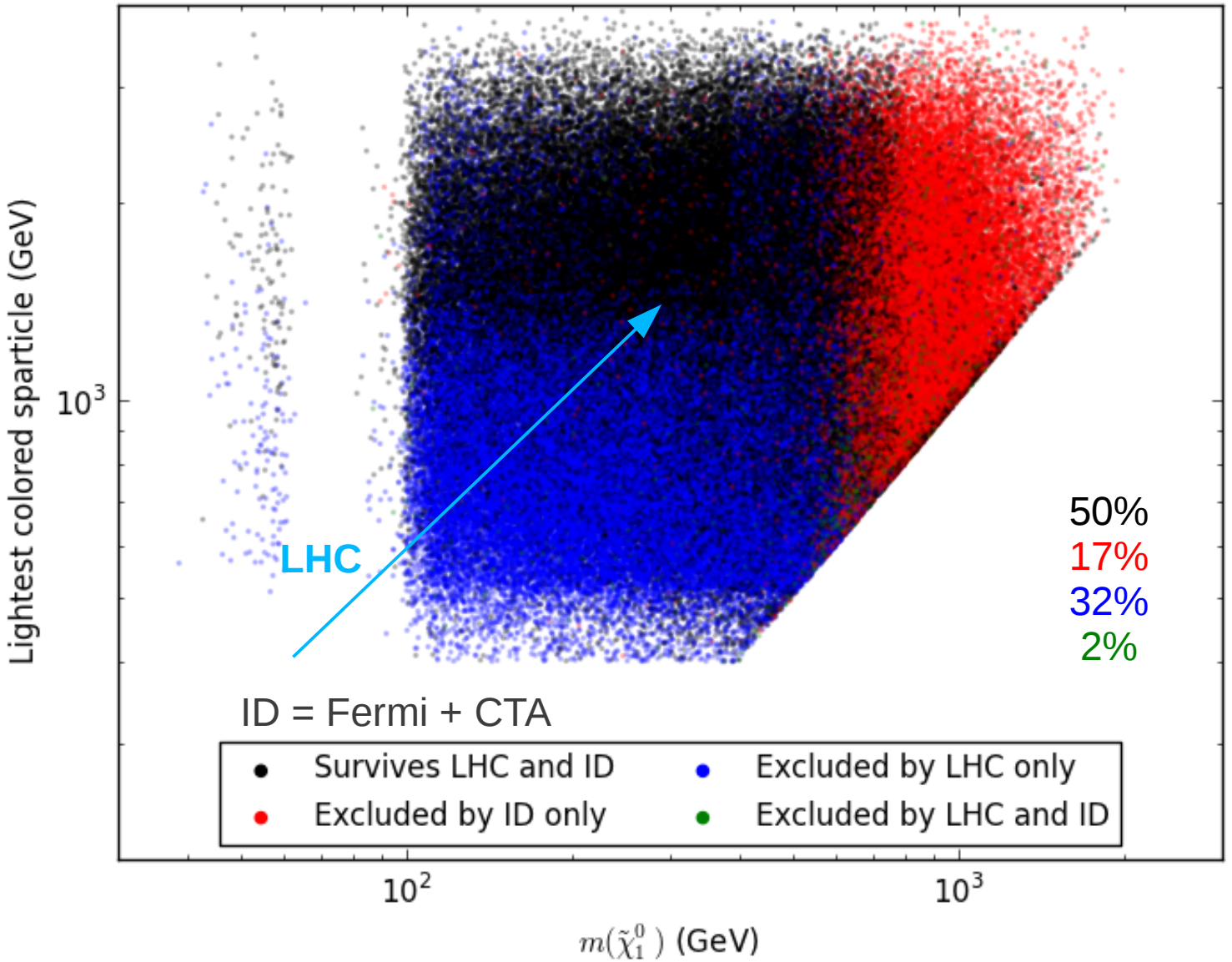
Direct and indirect detection probe distinct regions!

Search complementarity



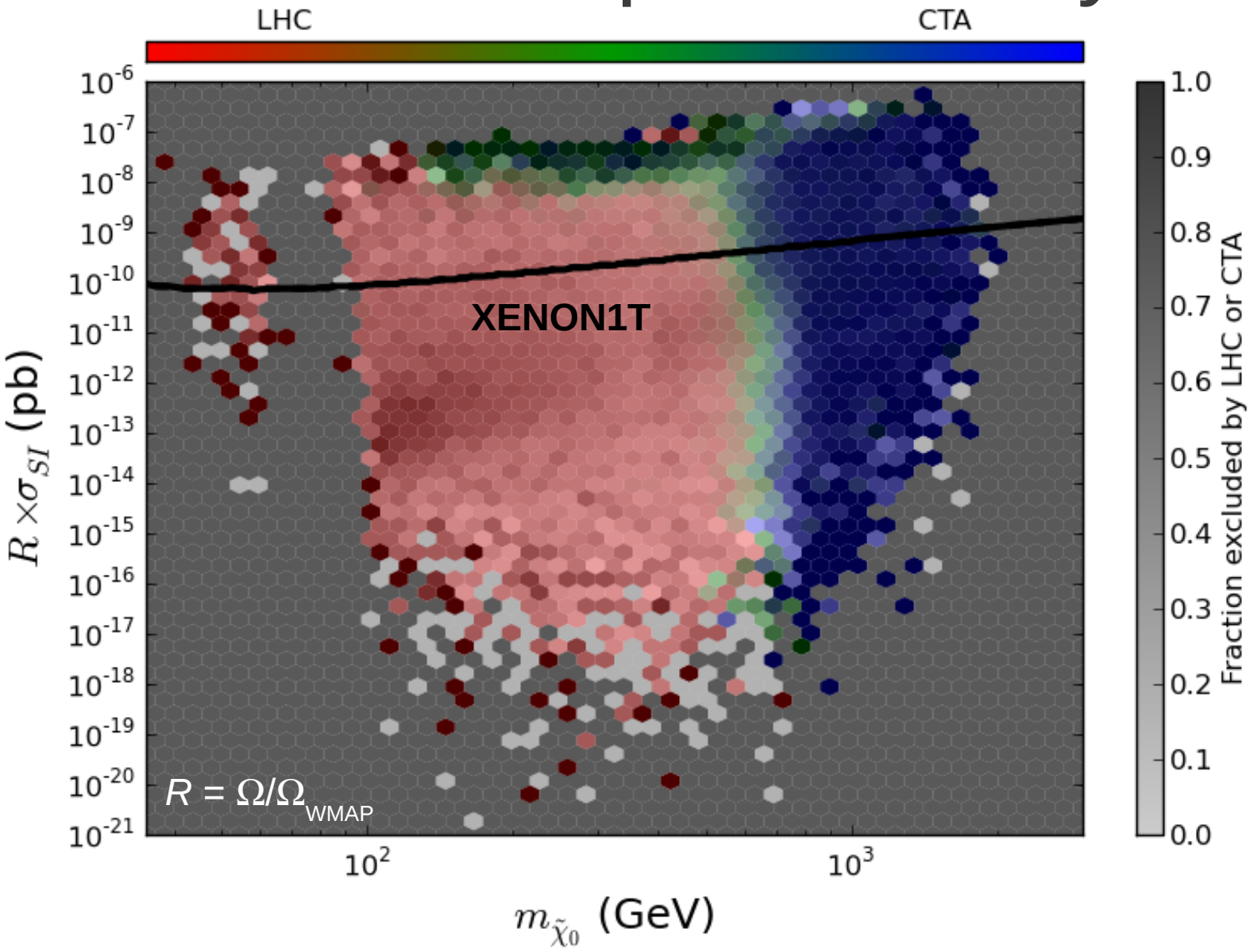
But IceCube won't see any new models beyond 1T direct detection....

Search complementarity



LHC will improve to complement CTA even better!

Search complementarity



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

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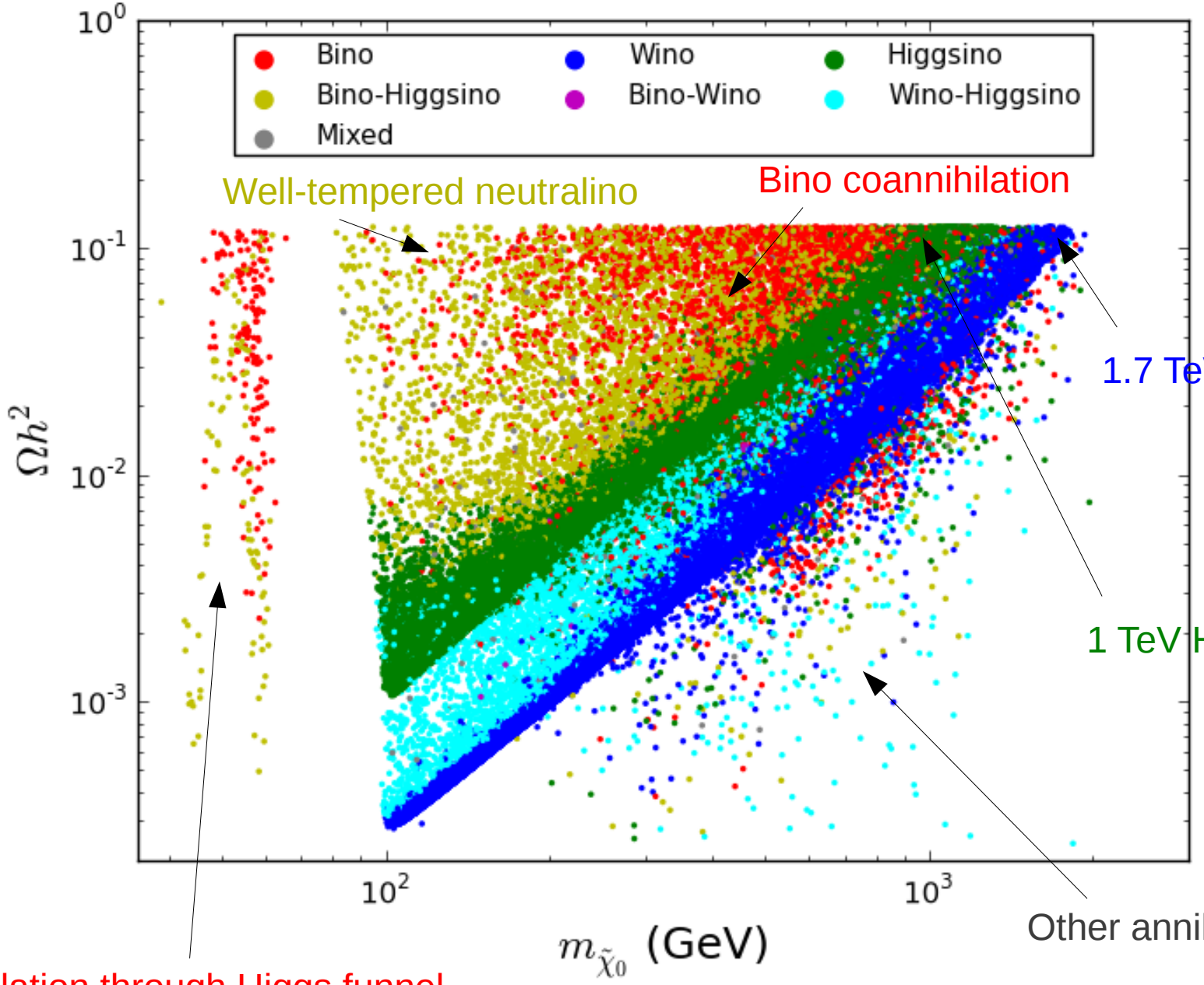
So what's left of this?



Well-tempered neutralino

Bino coannihilation

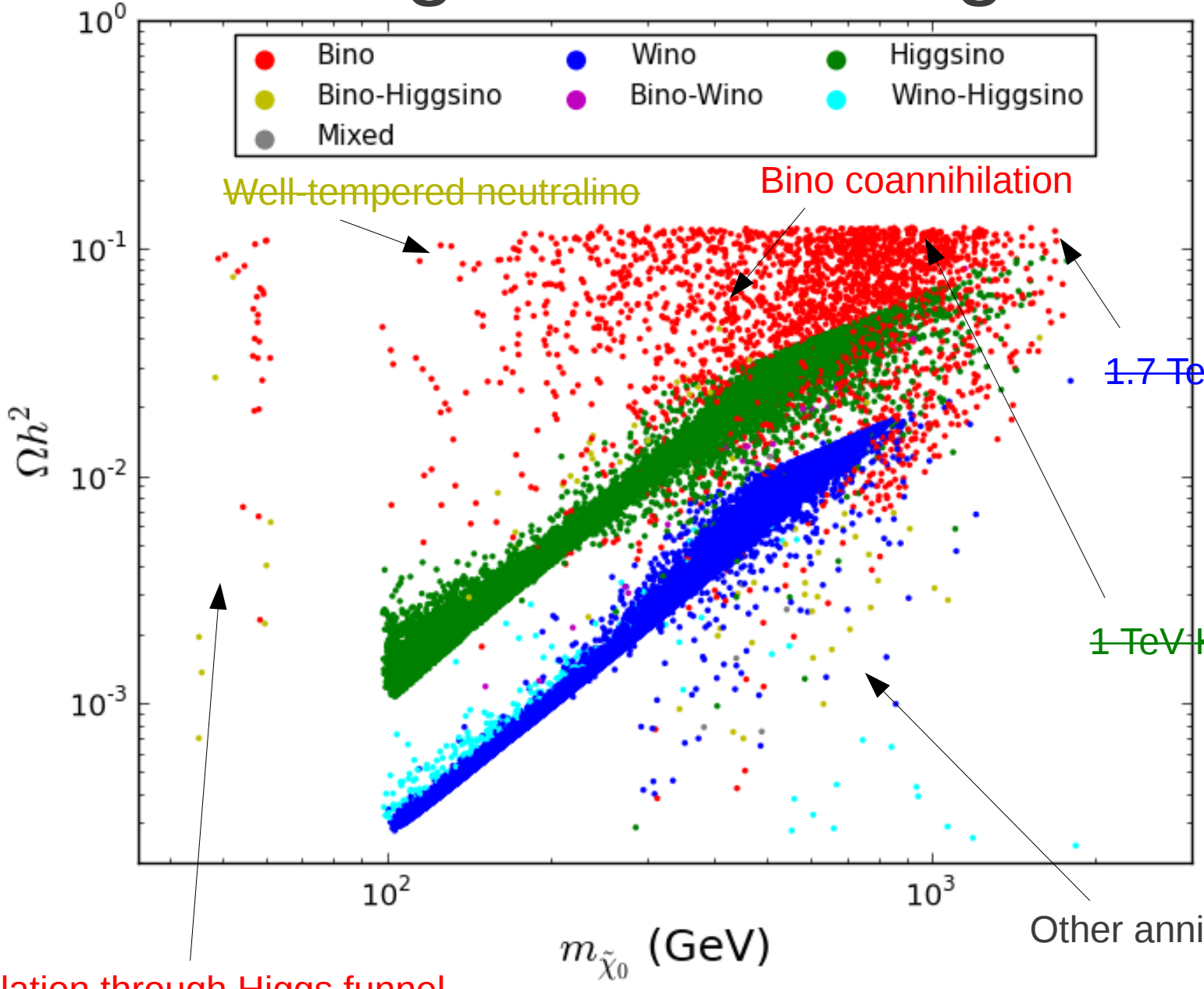
1.7 TeV wino

1 TeV Higgsino

Other annihilations

Bino annihilation through Higgs funnel

Most surviving LSPs are eigenstates



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