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Constraints on Supersymmetry from Collider Searches and Other Experiments

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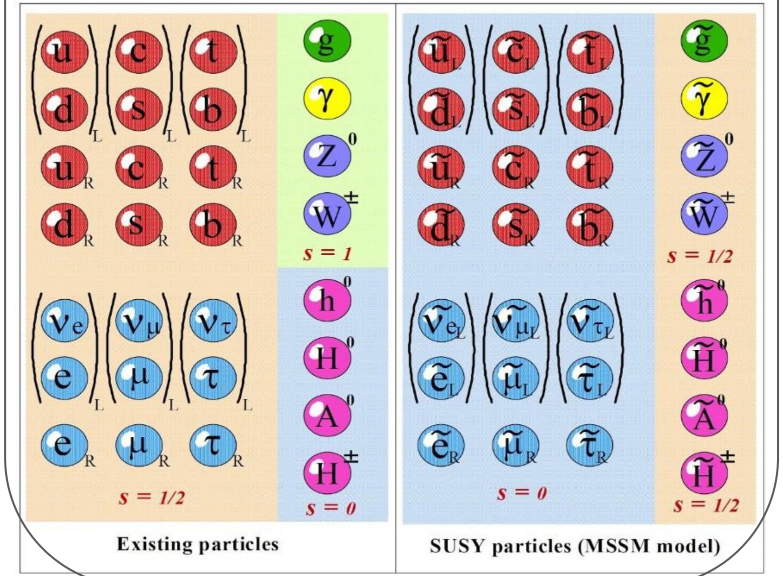
the (phenomenological) MSSM

complete SUSY model: MSSM

2HDM model

copied SM particle content with different spin

>100 new parameters
→ **impractical to interpret analyses in**



compromise:
MSSM with few general assumptions

minimal impact on phenomenology

pMSSM-19

JHEP 0902:023,2009

1. no tree-level *Flavor Changing Neutral Currents*
2. no CP violation
3. mass-degenerate 1st, 2nd generation
4. only 3rd generation trilinear couplings
5. the lightest supersymmetric particle (LSP) is the lightest neutralino and stable

→ **19 new parameters, defined at the TeV scale**:

- 10 sfermion masses
- 3 gaugino parameters
- 3 third generation trilinear couplings
- 3 Higgs parameters

study MSSM using pMSSM as proxy

How to: pMSSM Interpretation

generate pMSSM points with McMC.
Implements flavor constraints

Prior: flat in 19 pMSSM parameters

flavor posterior = CMS prior

scan of parameter space

covered parameter space

squarks up to 10 TeV

gluino up to 10 TeV

sleptons up to 4 TeV

heavy Higgs up to 4 TeV

electroweakinos up to 4 TeV

trilinear couplings up to 7 TeV

tan β from 2 to 60

Markov chain Monte Carlo (McMC)

BR($b \to s\,\gamma$)*

BR($b \to s\,\mu\mu$)*

BR($b \to s\,ee$)*

BR($B_s \to \mu\mu$)*

BR($B_d \to \mu\mu$)*

BR($B_u \to \tau\nu$)*

BR($D_s \to \tau\nu$)**

BR($D_s \to \mu\nu$)**

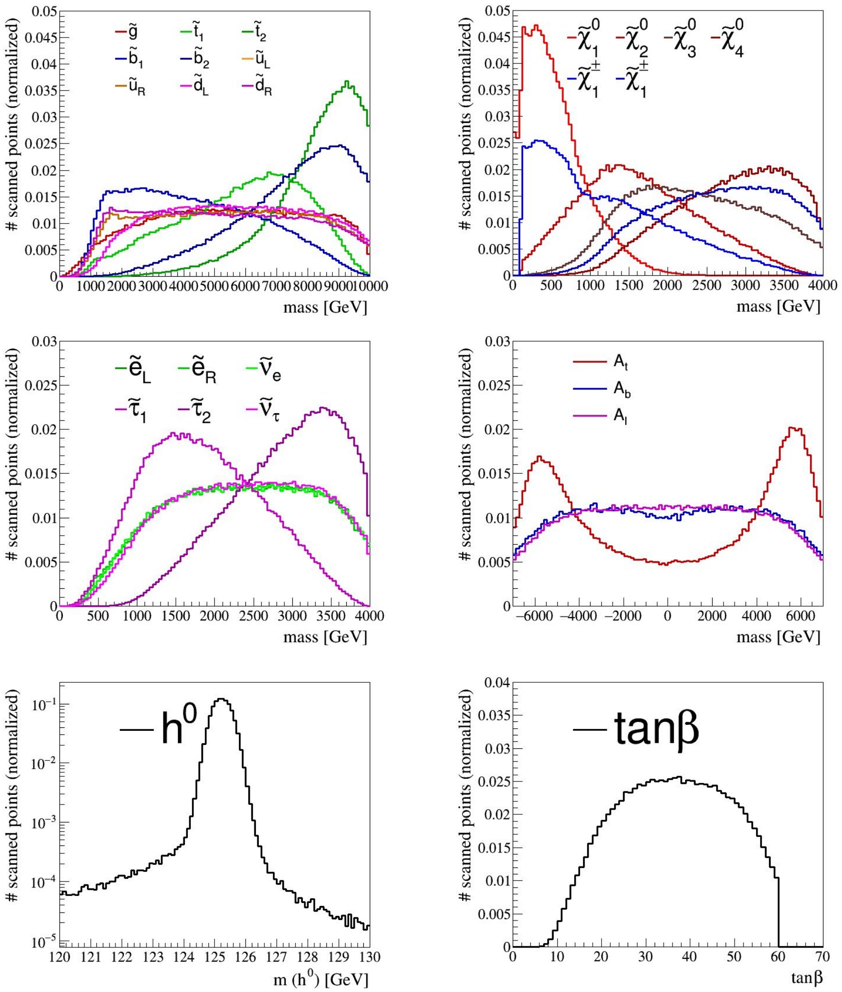
BR($B^0 \to K^{*0}\,\gamma$)*

Δ_0 ($B \to K^*\,\gamma$) **

$\Delta\rho$

m(h^0)***

LEP constraints



* with superiso v4.0 (30. June 2018) ** with SPheno v 4.0.4 (3 Oct. 2019) *** with FeynHiggs 2.16.1

How to: pMSSM Interpretation

generate pMSSM points with McMC.
Implements flavor constraints

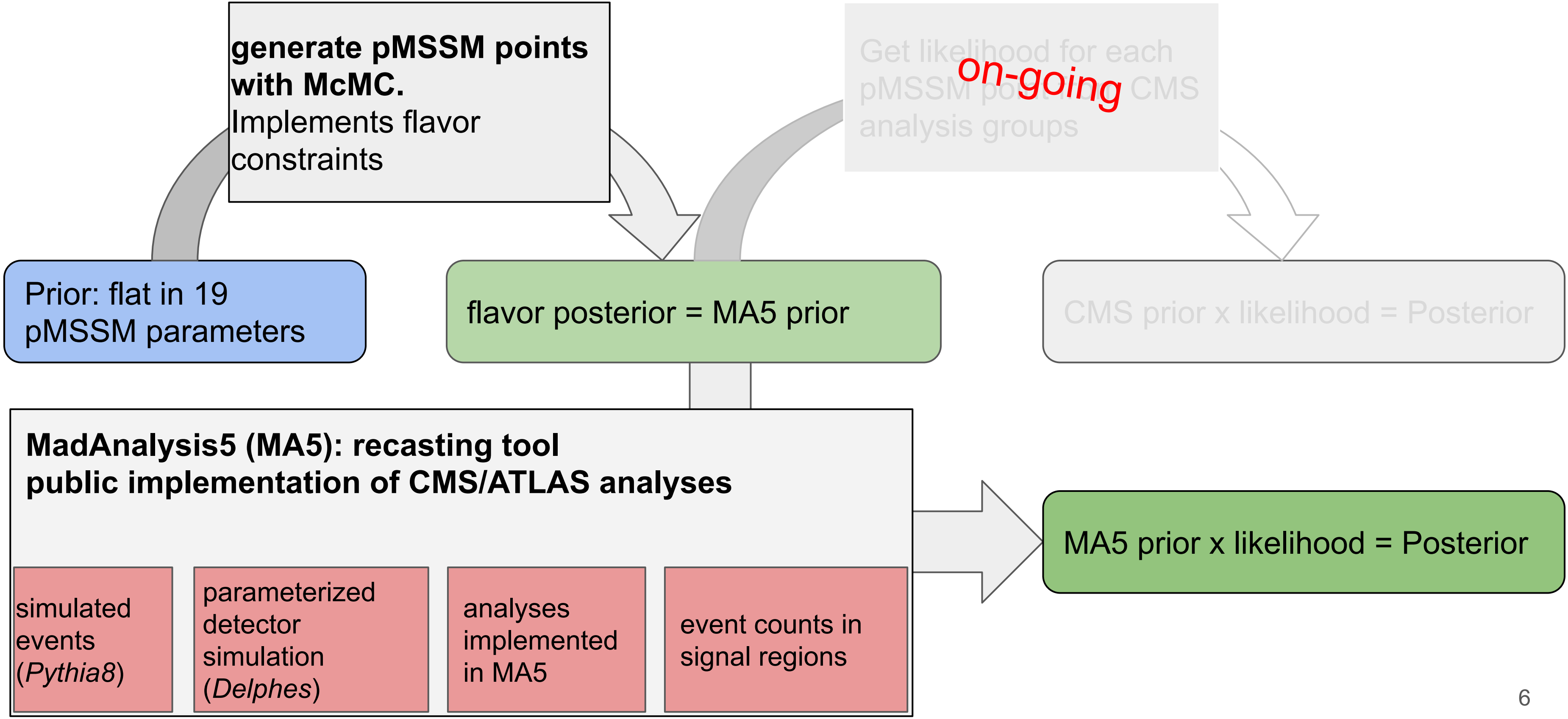
Get likelihood for each pMSSM point from CMS analysis groups

Prior: flat in 19 pMSSM parameters

flavor posterior = CMS prior

CMS prior x likelihood = Posterior

How to: pMSSM Interpretation

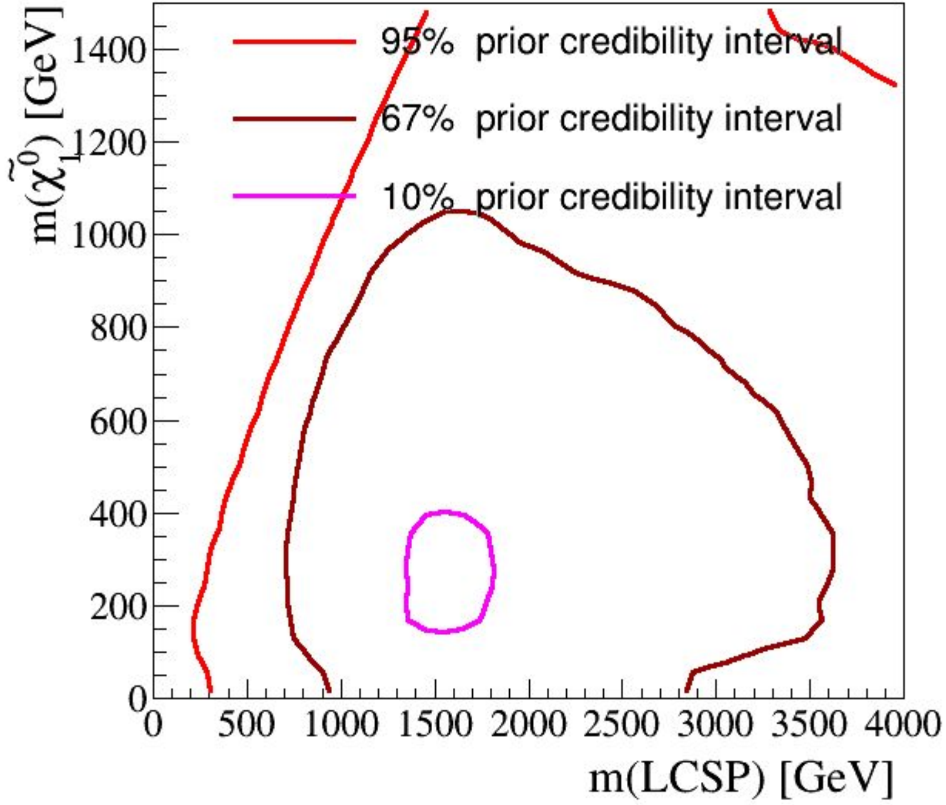


pMSSM interpretation with MadAnalysis5

- private simulation of 500,000 chosen points
- $N_{events} = 5 \times \sigma L \rightarrow$ **10^9 events** simulated with *Pythia8*
- MA5 with three analyses (1 CMS, 2 ATLAS):
    - *J. High Energ. Phys.* **2019,** 244 (2019) (CMS):
      jets+missing transverse momentum → strongly interacting SUSY
    - *Eur. Phys. J. C 80 (2020) 123* : (ATLAS)
      2 leptons + missing transverse momentum → electroweakinos, slepton
    - Phys. Rev. D 101, 072001: (ATLAS)
      3 leptons → electroweakinos

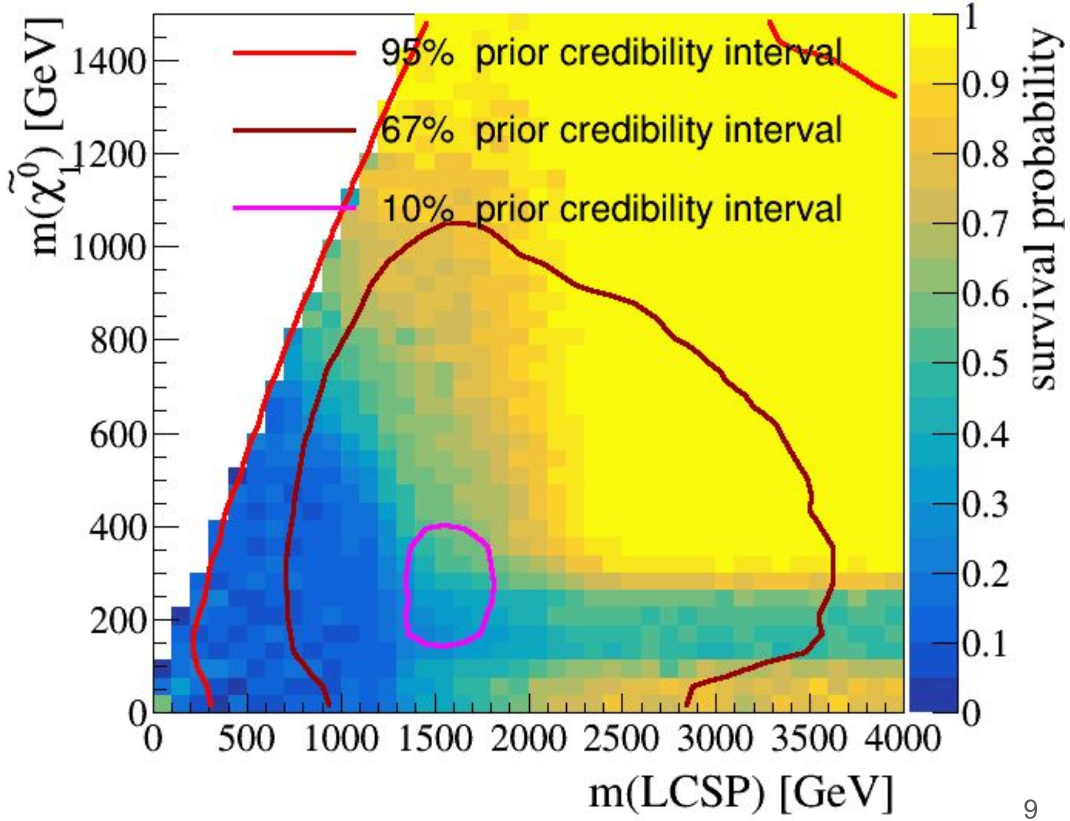
LHC and strong SUSY

- **credibility interval (CI)**: probability of finding nature in interval **IF ASSUMPTIONS ABOUT PRIOR CORRECT**
- prior peaks at
  - m(LCSP) ~1.5 TeV
  - m(LSP) ~300 GeV



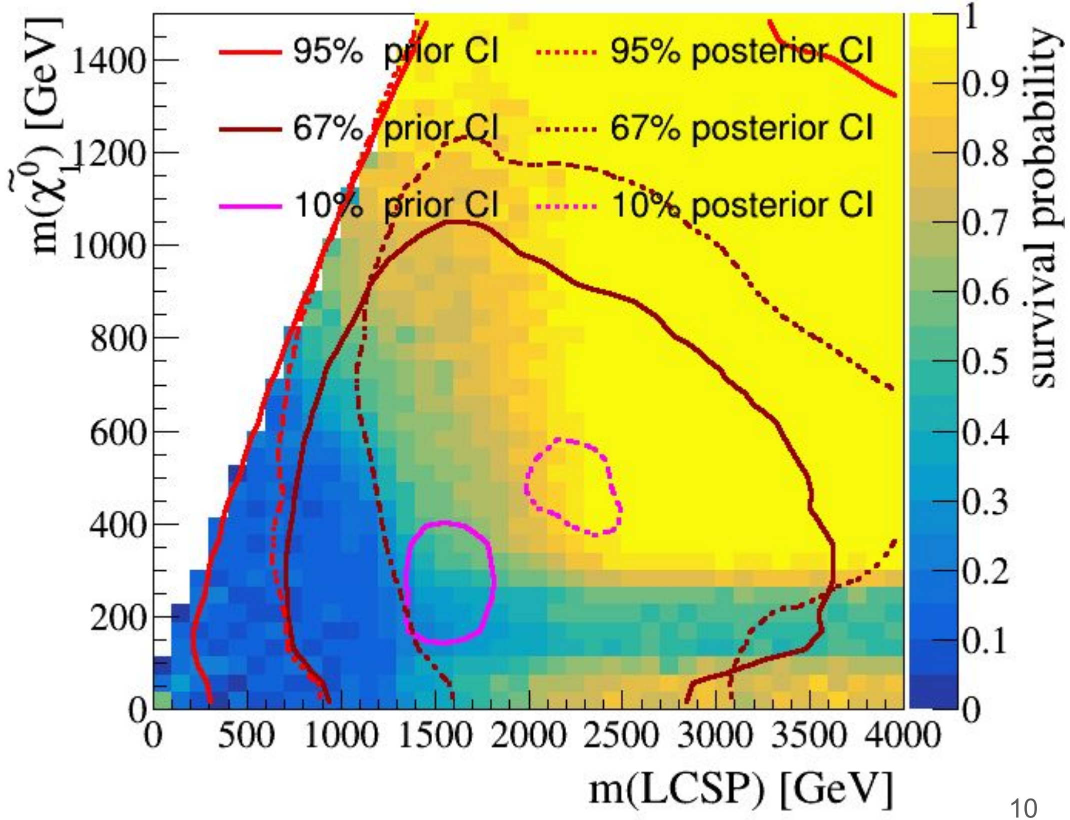
LHC and strong SUSY

- LHC sensitive to pMSSM up to m(LCSP) ~ 2 TeV
- higher fraction of models survive in compressed region
- LHC sensitive to direct LSP production up to m(LSP) ~ 300 GeV



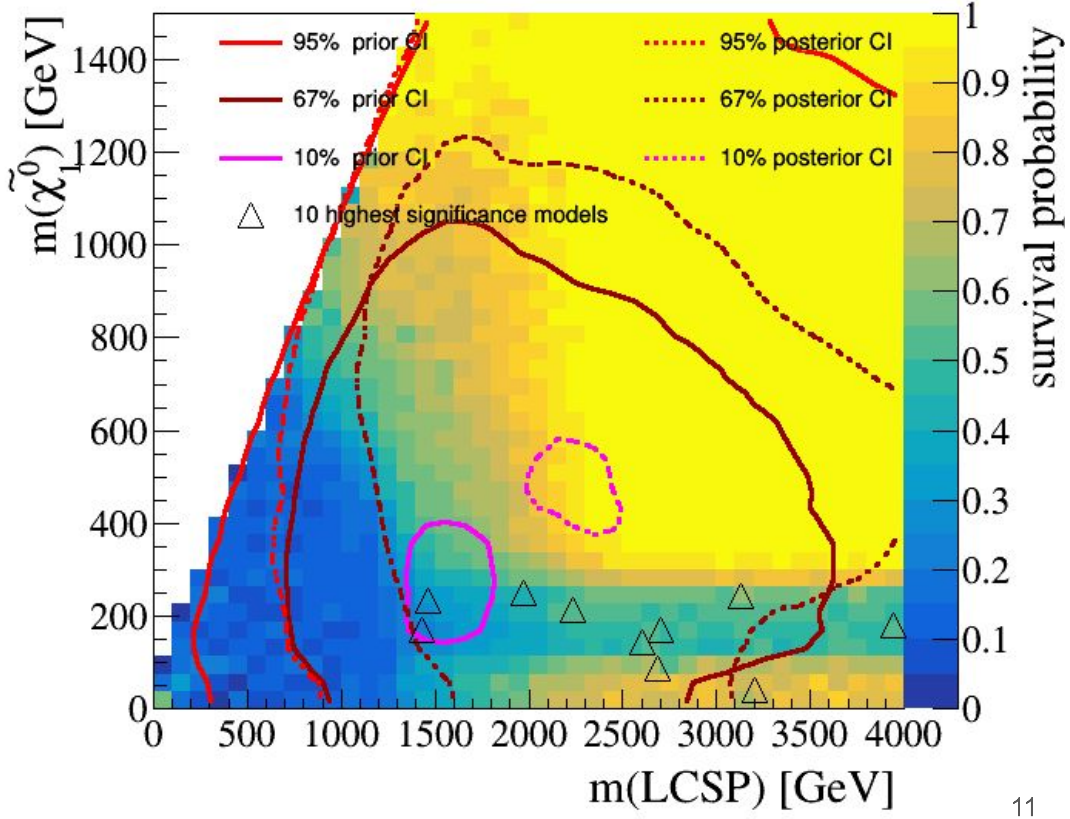
LHC and strong SUSY

- LHC shifts posterior density w.r.t. prior density
- posterior peaks at
  - m(LCSP) ~2.3 TeV
  - m(LSP) ~450 GeV
- >5% of posterior density has m(LCSP)<1 TeV



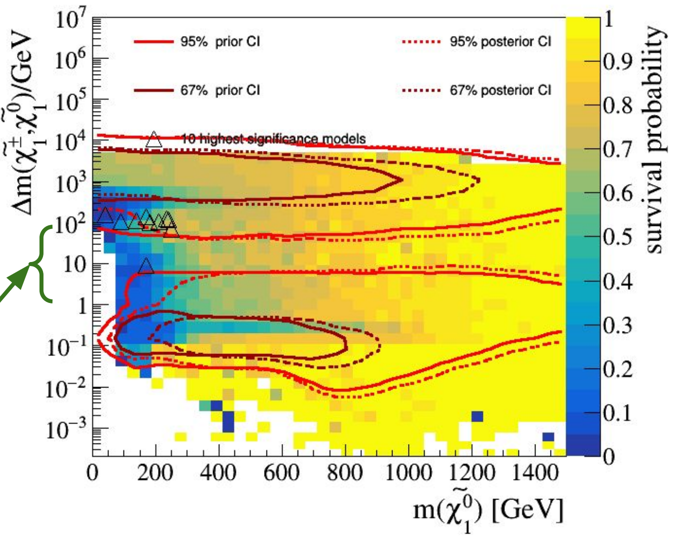
LHC and strong SUSY

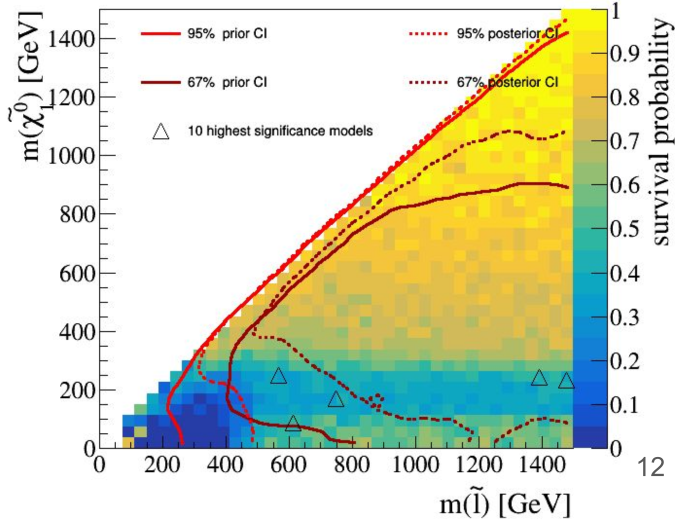
- LHC shifts posterior density w.r.t. prior density
- posterior peaks at
  - m(LCSP) ~2.3 TeV
  - m(LSP) ~450 GeV
- >5% of posterior density has m(LCSP)<1 TeV
- 10 highest significance models:
  - LSP mass below 300 GeV
  - otherwise, no strong correlation to LCSP mass or LSP mass



LHC and electroweak SUSY

- LHC sensitive to electroweak models with LSP masses up to ~300 GeV
- most points with high significance have a chargino-neutralino mass difference of ~100 GeV
- inclusion of search targeting soft leptons expected to improve sensitivity at intermediate mass differences
- most models with a light slepton below 500 GeV excluded





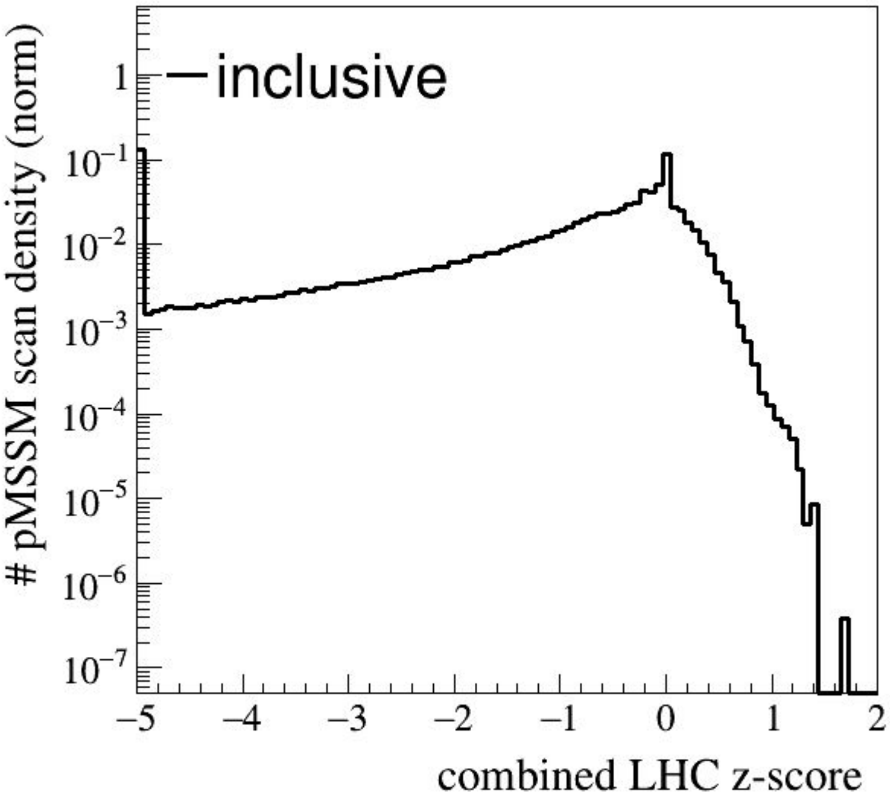
LHC and other experiments

- signed sensitivity measure: z-score

$$Z = sign(lnB_{10})\sqrt{2|lnB_{10}|}$$

$$B_{10} = \frac{L(SUSY)}{L(SM)}$$

- Z < -1.64 →excluded at 95% CL



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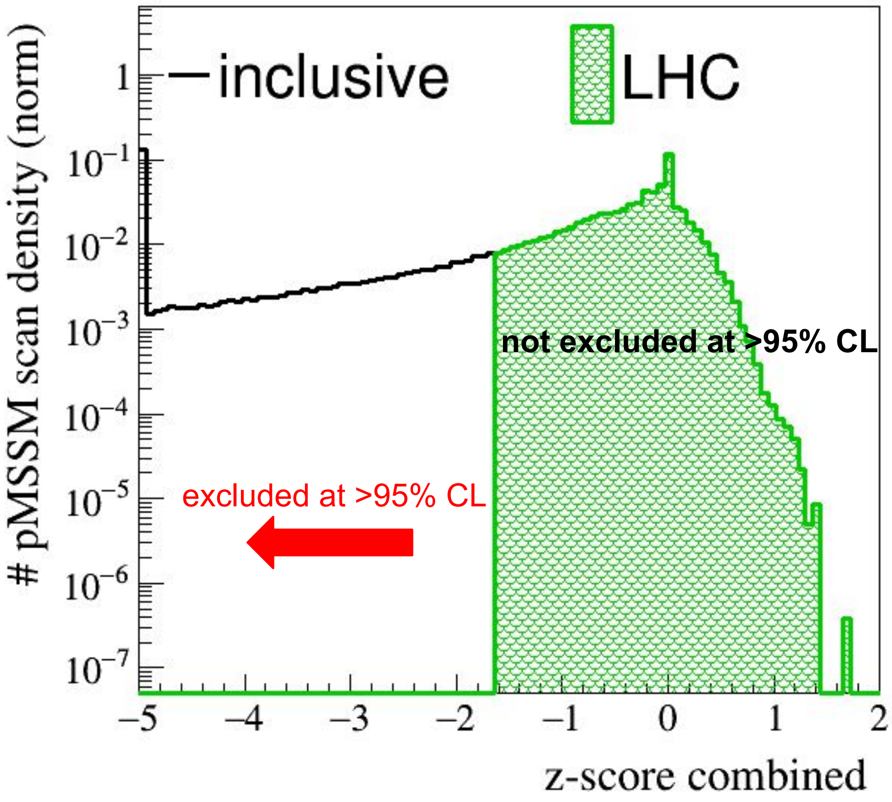

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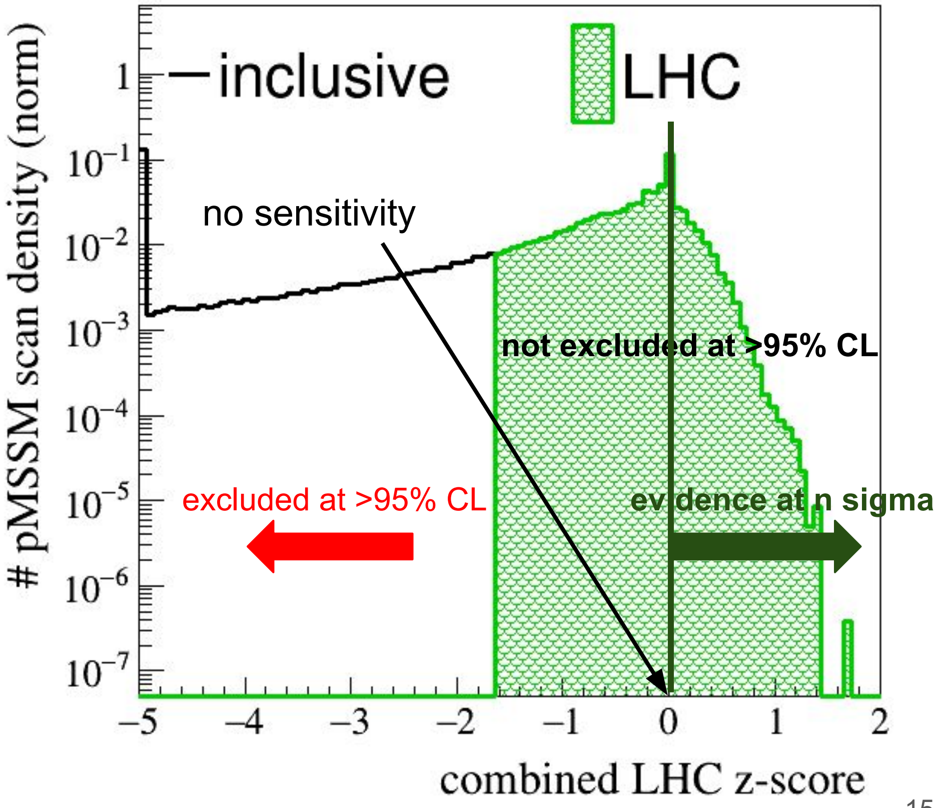

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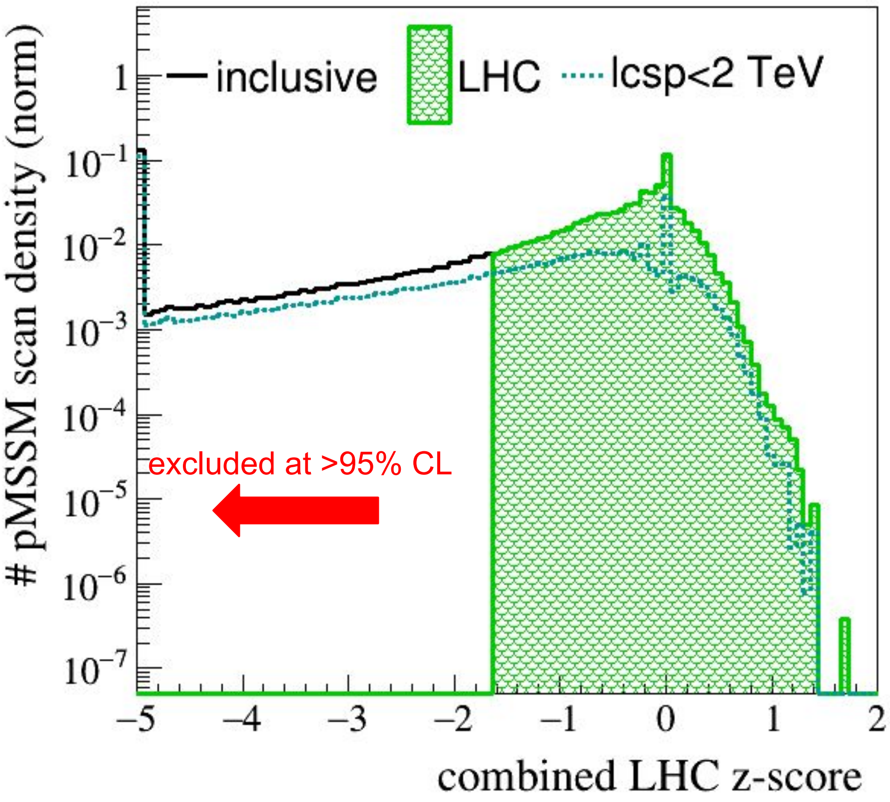
- LHC most sensitive to models with light LCSP



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- Z < -1.64 →excluded at 95% CL
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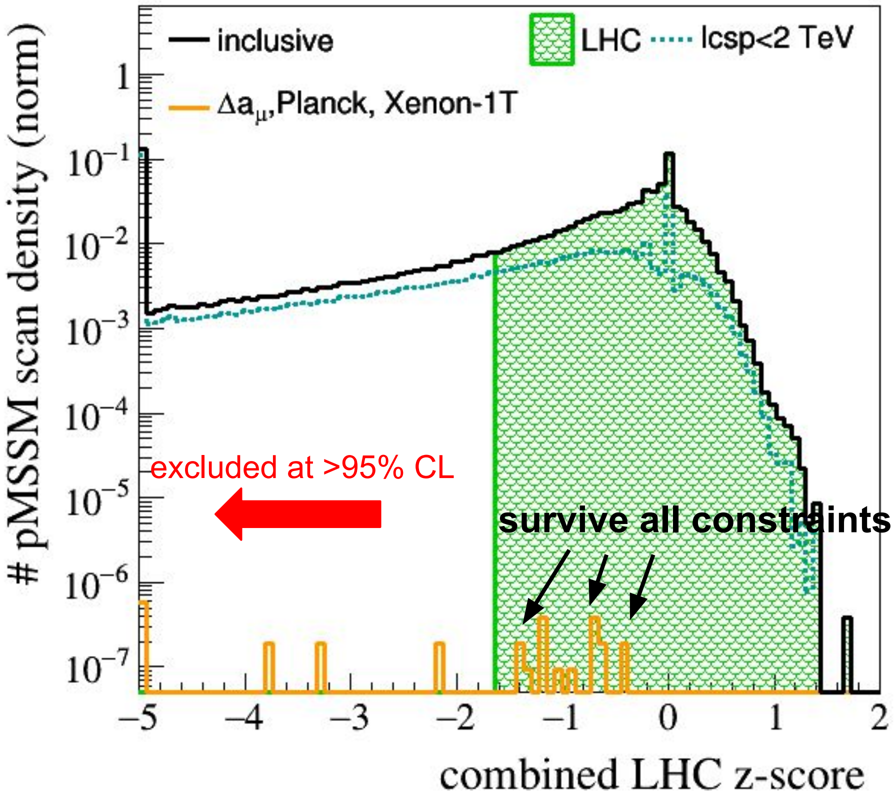
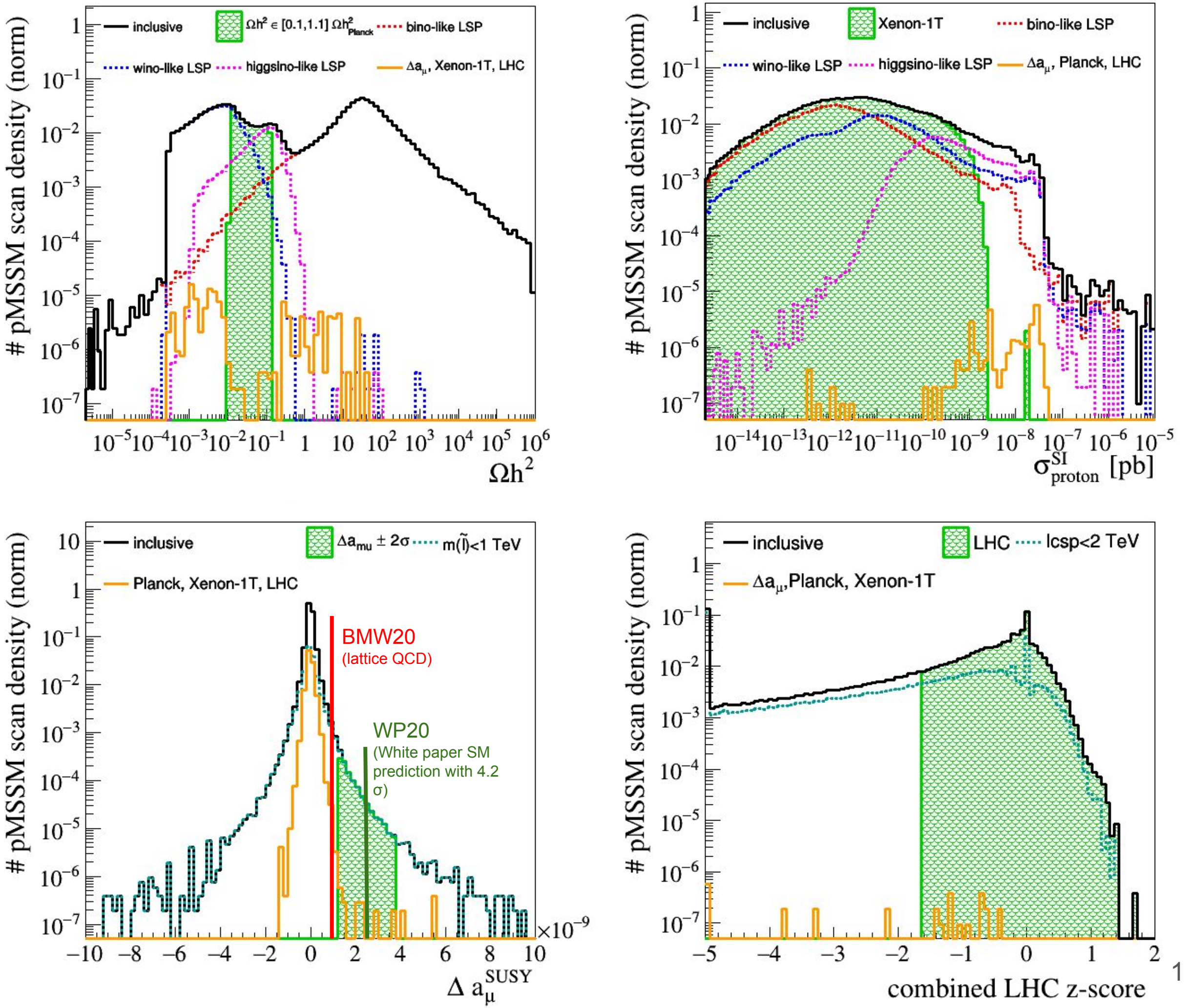
- LHC most sensitive to models with light LCSP
- g-2, relic density, direct detection constraints severely constrain space



LHC and other experiments

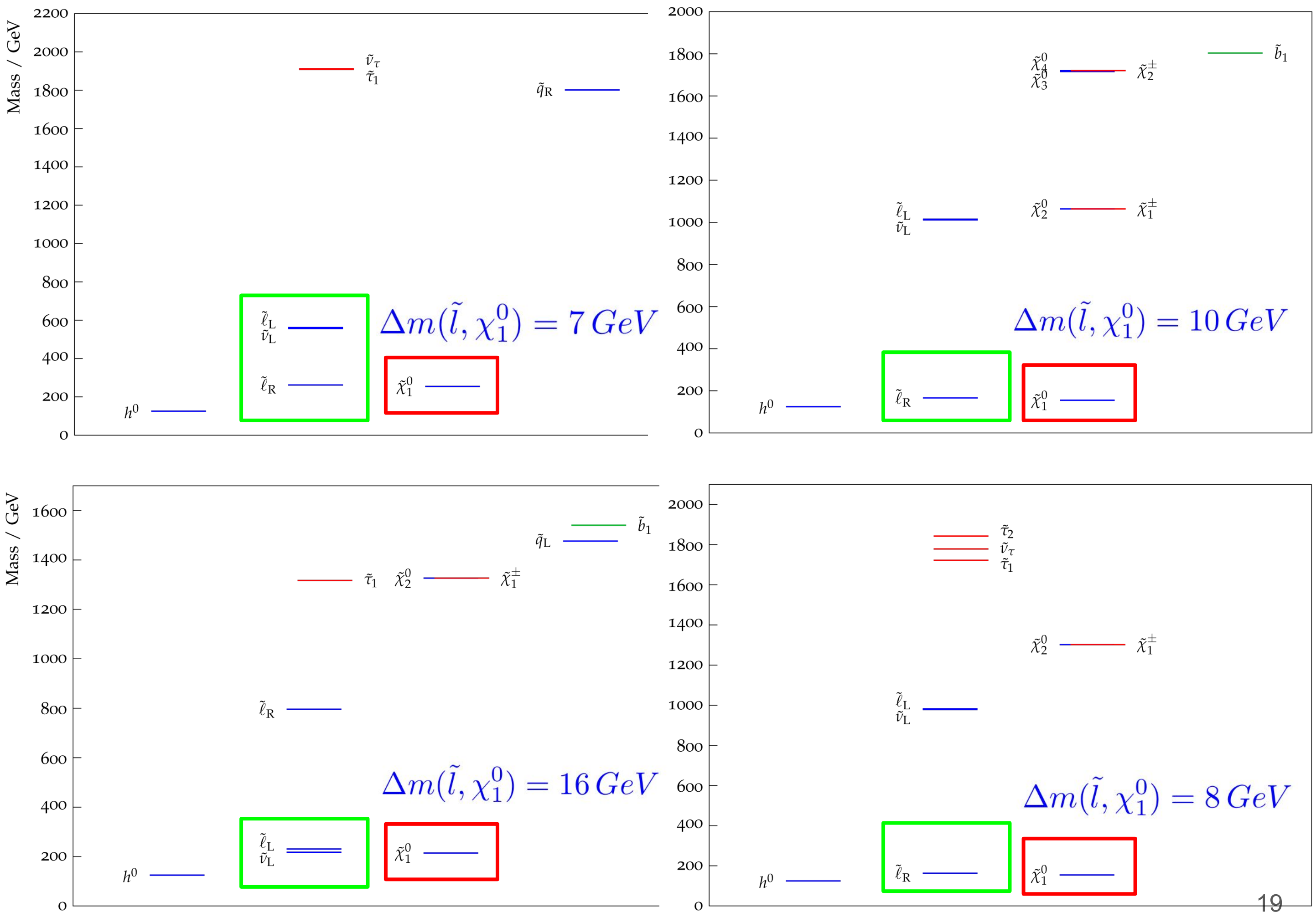
- Planck* A&A 641, A6 (2020)
  - disfavors binos, light winos, light higgsinos
- Xenon-1T* Phys. Rev. Lett. 121, 111302 (2018)
  - most sensitive to higgsinos
- g-2** Phys. Rev. Lett. 126, 141801 (2021)
  - strongly favors light sleptons
- ATLAS+CMS***
  - strongly disfavors light squarks, gluinos
  - disfavors light higgsinos, winos



* with micromegas ** with gm2calc *** with MA5

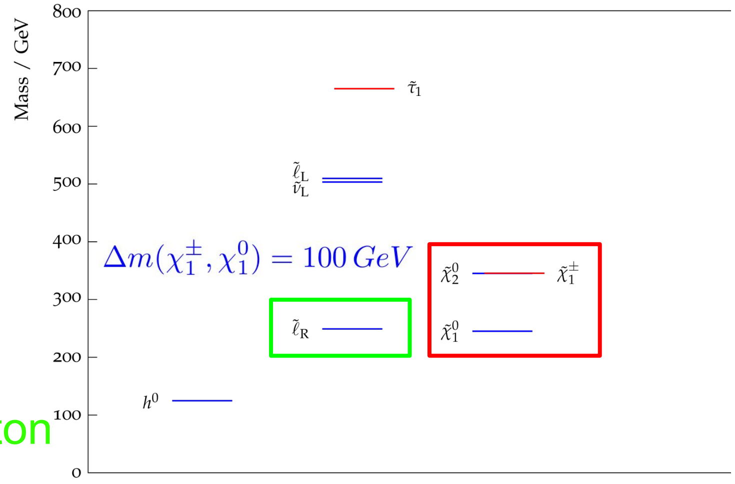
surviving pMSSM models

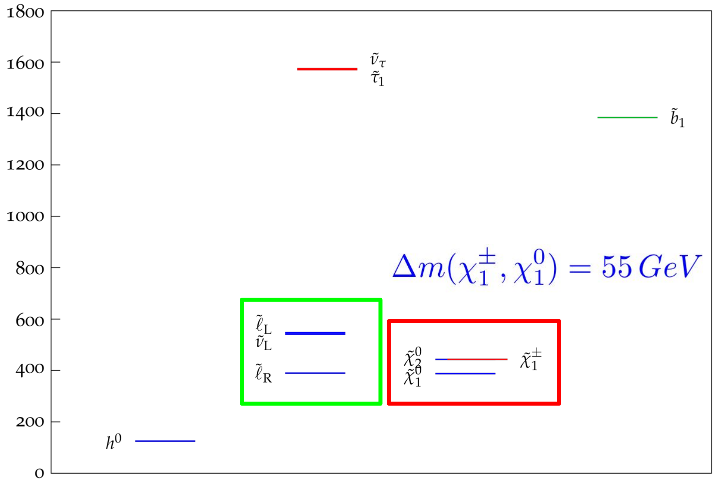
- all surviving points contain a light slepton (g-2)
- in bino-like scenarios:
  - sensitivity given by slepton production cross section
  - soft leptons in final state

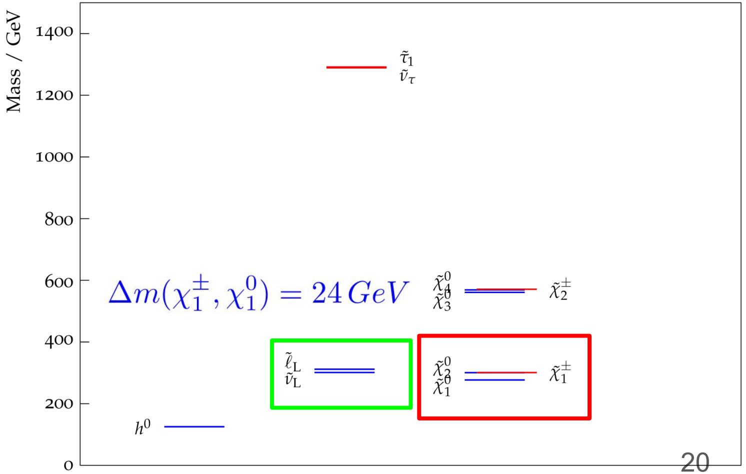


surviving pMSSM models

- all surviving points contain a light slepton (g-2)
- bino-wino mixed scenarios:
  - sensitivity given by wino production cross section
  - enhancement of soft leptons in final state
  - both low-pt and high-pt leptons in final state?

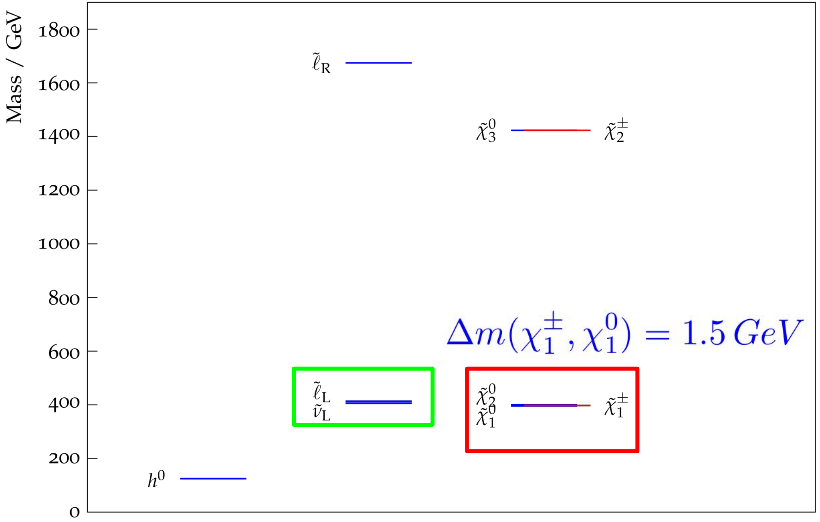


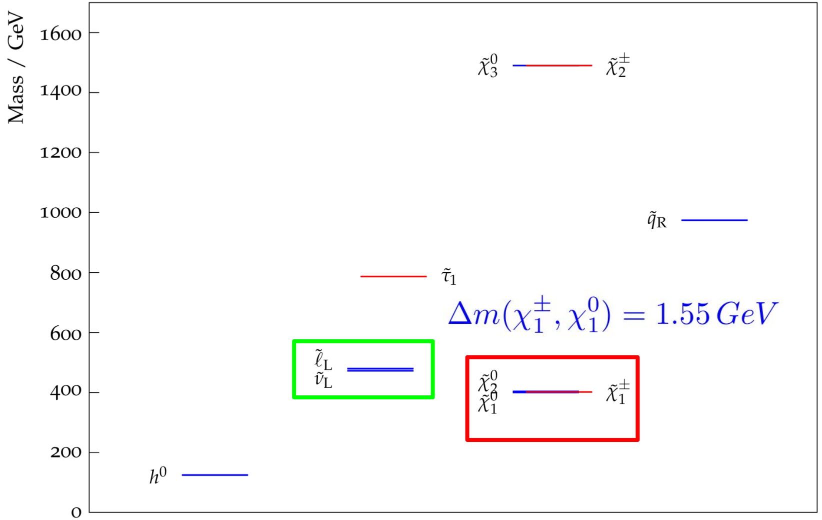




surviving pMSSM models

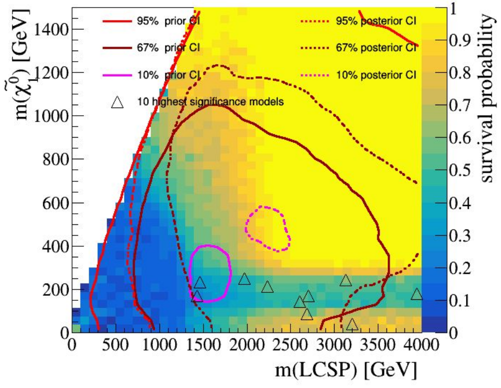
- all surviving points contain a light slepton (g-2)
- in higgsino-like scenarios:
  - sensitivity given by higgsino production cross section
  - enhancement of soft leptons in final state
  - both low-pt and high-pt leptons in final state?

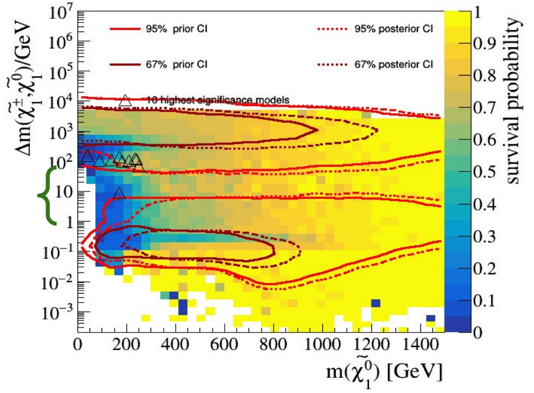


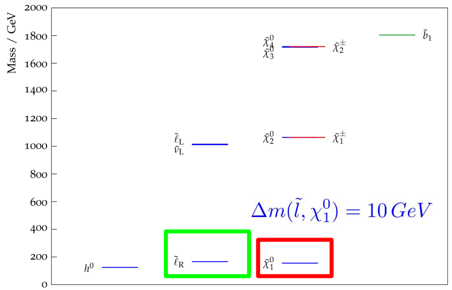


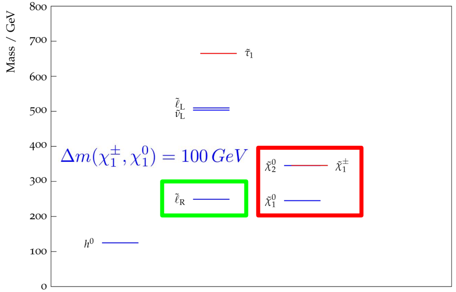
Closing remarks

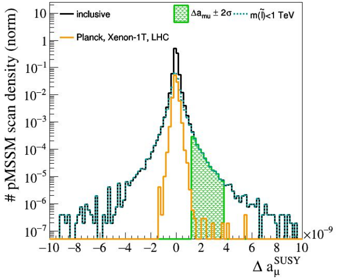
- considered MSSM space highly constrained by considered results
- a number of models with light squarks and gluinos evade exclusion - under investigation
- some few models survive relic density, direct detection, g-2, and LHC constraints

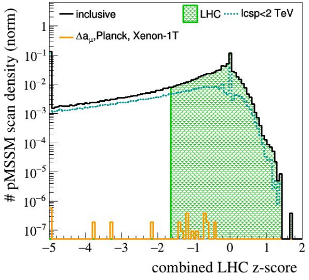


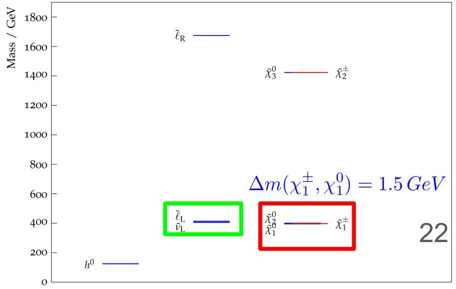












Backup

LHC and strong SUSY

- sensitivity depends on nature of LCSP
- gluinos up to ~2.2 TeV, squarks up to 1.2 TeV strongly constrained
- survival probability lower if both light squark and gluino present
- >5% of posterior with m(gluino)<1.5 TeV or m(squark)<800 GeV