Natural Supersymmetry

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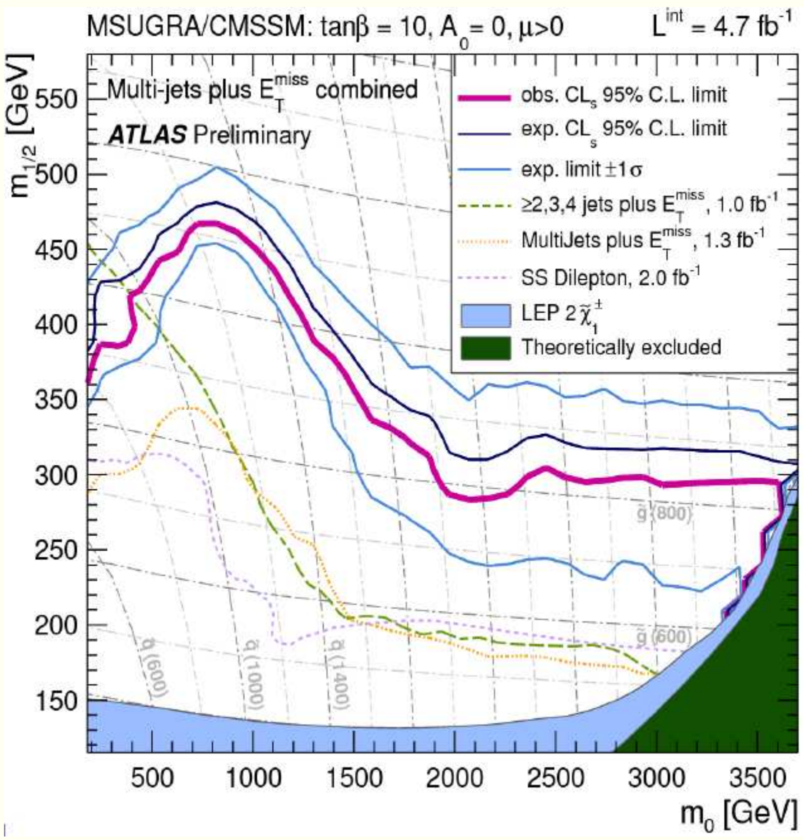
H. Baer, V. Barger, P. Huang, JHEP 1205 (2012) 109
plus Work in progress with A. Mustafayev

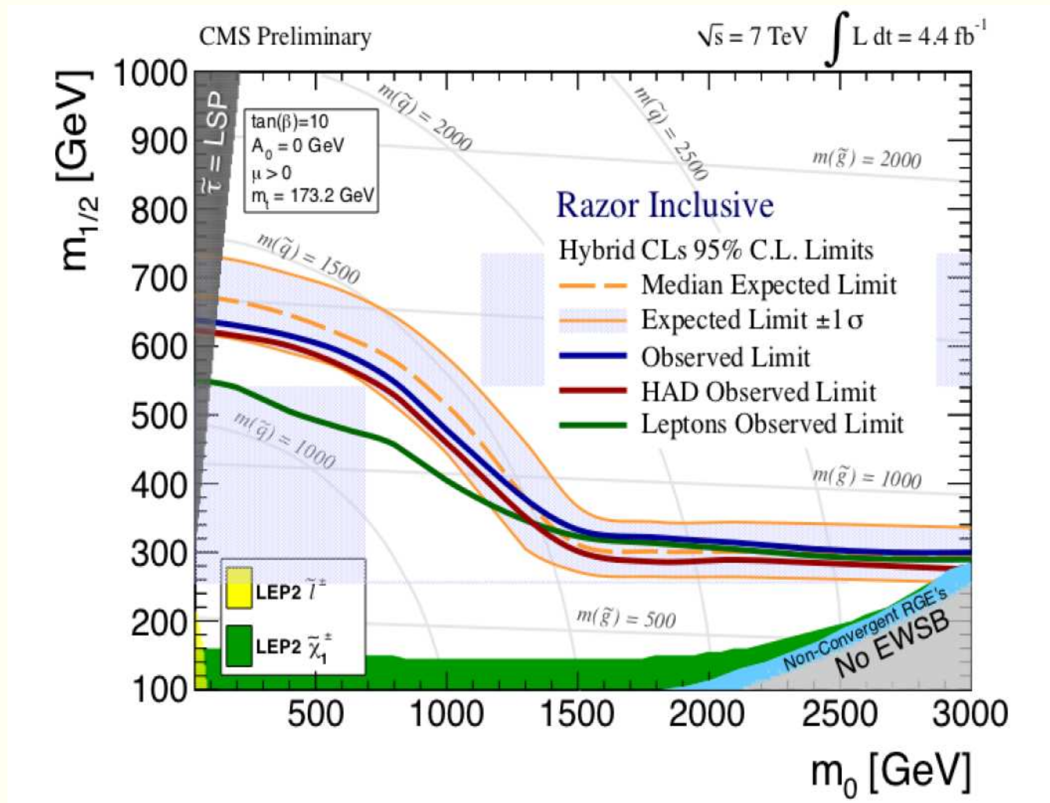
- ⋆ The LHC has been running fabulously.
- ⋆ The LHC has accumulated an integrated luminosity of ~ 5.6 fb^{-1} at 7 TeV. This year, we already have ~ 6 fb^{-1} (and counting) at 8 TeV, and has the goal to accumulate 15 fb^{-1} at 8 TeV before the shutdown for the big energy upgrade
- ⋆ We have now seen results from Moriond with ~ 5 fb^{-1} of data. Lower limits of 1.2-1.4 TeV if $m_{\tilde{q}} \sim m_{\tilde{g}}$, or $m_{\tilde{g}} \gtrsim 700 - 800$ GeV if squarks are much heavier.
- ⋆ We will see updates of analyses of Higgs and SUSY searches at this meeting.

MORIOND 2012

ATLAS

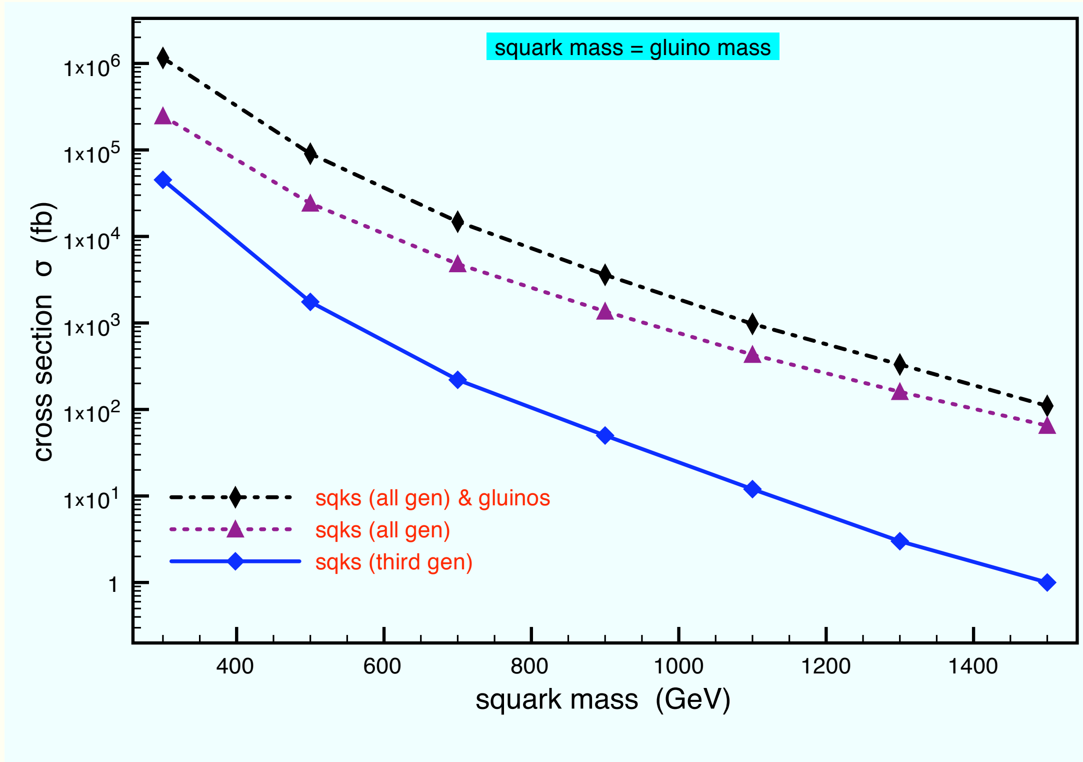


CMS



SHOULD WE DESPAIR THAT SUSY HAS NOT BEEN FOUND AT THE TEV SCALE?

LHC14



Mainly first generation squarks are produced at the LHC for $m_{\tilde{q}} \gtrsim 1.2$ TeV. Second/third generation squark production is subdominant (accentuated even more at LHC8). Should view LHC squark bound as a limit on first generation squarks.

On the other hand

Supersymmetry stabilizes the weak scale as long as sparticles that couple significantly to the Higgs boson – these are the the EW-inos and 3rd generation sfermions – are close to, or below, the TeV scale.

The LHC, however, mainly produces first generation squarks and gluinos. These 1.2-1.4 TeV limits, therefore apply to gluinos and first generation squarks that do not couple directly to the Higgs sector!. The EW scale would be stable even if these guys were at multi-TeV scales!!!!!!

Indeed such scenarios have been proposed to ameliorate the flavour constraints.

Dine,Kagan,Samuel; Arkani-Hamed,Murayama; Dimopoulos,Giudice; Pomarol,Tomassini; Cohen,Kaplan,Nelson; Baer,Kraml,Lessa,Sekmen,XT

But there is more to the stability story than just squark masses.

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

Σ_u and Σ_d are radiative corrections to the tree level potential and get contributions from loops various SM particles and superpartners; *e.g.*

$\Sigma_u = \sum_i \Sigma_u(i),\ i = t, \tilde{t}_{1,2}, b, \tilde{b}_{1,2}, \tau, \tilde{\tau}_{1,2}, W, Z, h, H, A, \widetilde{W}_i, \widetilde{Z}_i$, where

$$\Sigma_u(\tilde{t}) \sim \frac{3f_t^2}{16\pi^2} \times m_{\tilde{t}_i}^2 \left(\ln(m_{\tilde{t}_i}^2/Q^2) - 1\right)$$

All terms in the red equation should be of the same order, i.e. no "large cancellations". Call the maximum of these $C_{\rm max}$.

Less than 1 order of magnitude cancellation between terms implies $C_{\rm max}$ is smaller than $\sim (200\ {\rm GeV})^2$. (This is what Barbieri and Giudice called $\Delta = 10$, or 10% fine tuning.)

Notice the corrections grow quadratically with the top squark mass so, for instance, these cannot be too heavy.

The most vanilla fine-tuning constraint!!!

For the published study, we had used an estimate from King, Mulheitner and Nevzorov analysis that $m_{\tilde{t}} \lesssim$ 1 TeV [1.5 TeV] if we require all terms smaller than (150 GeV)^2 (200 GeV)^2. Show you the results of more honest calculation with contributions to Σs separated shortly.

It would seem then that gluinos and first generation squarks can be very heavy without jeopardizing the Higgs scale.

Recall, however, that gluino top loops give corections to the top squark mass!

$$\delta m^2_{\tilde{t}_i} \sim \frac{2g_s^2}{3\pi^2} m^2_{\tilde{g}} \times \text{ logarithms}$$

$$m_{\tilde{g}} \lesssim 3m_{\tilde{q}} \sim 4.5 \text{ TeV}$$

Multi-ten TeV first/second generation squarks and sleptons ameliorate unwanted potential flavour and CP violations generic to SUSY models.

Heavier Higgs scalar could be in the multi-TeV range because $m^2_{H_d}$ is large.

Heavy gravitino – whose mass scale is likely set by heaviest superpartners – solves the cosmological gravitino problem.

Posit a high scale set of boundary conditions that will yield such a spectrum.

$$m_0(1,2),\ m_0(3),\ m_{1/2},\ A_0,\ \tan\beta,\ \mu,\ m_A.$$

Consistent with Grand Unification symmetry.

Fix μ (or scan in small range) and scan in the ranges:

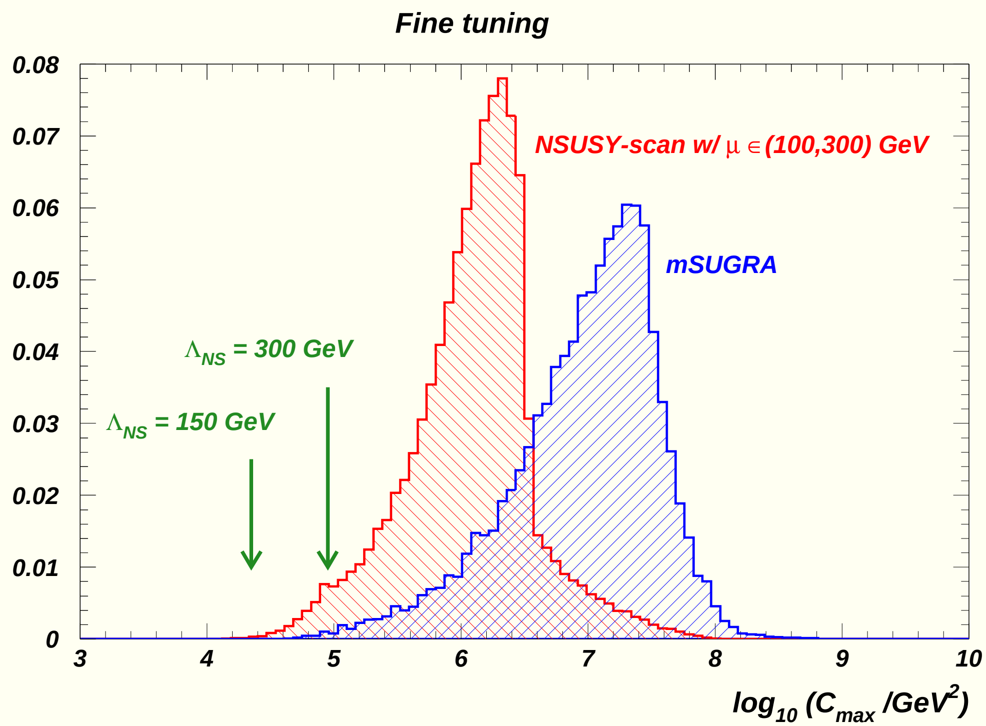
$$\begin{aligned} m_0(1,2):&\ 5-50\ \mathrm{TeV},\\ m_0(3):&\ 0-5\ \mathrm{TeV},\\ m_{1/2}:&\ 0-5\ \mathrm{TeV},\\ -4<\ A_0/m_0(3)&\ <4,\\ m_A:&\ 0.15-2\ \mathrm{TeV},\\ \tan\beta:&\ 1-60. \end{aligned}$$

Then require $C_{\max} < \Lambda^2_{\rm NS}$ for pre-assigned $\Lambda_{\rm NS} = 150, 200, 300$ GeV.

What top down model gives such boundary conditions?

Let's see what happens in these scenarios.

Fine-tuning in Natural SUSY versus mSUGRA

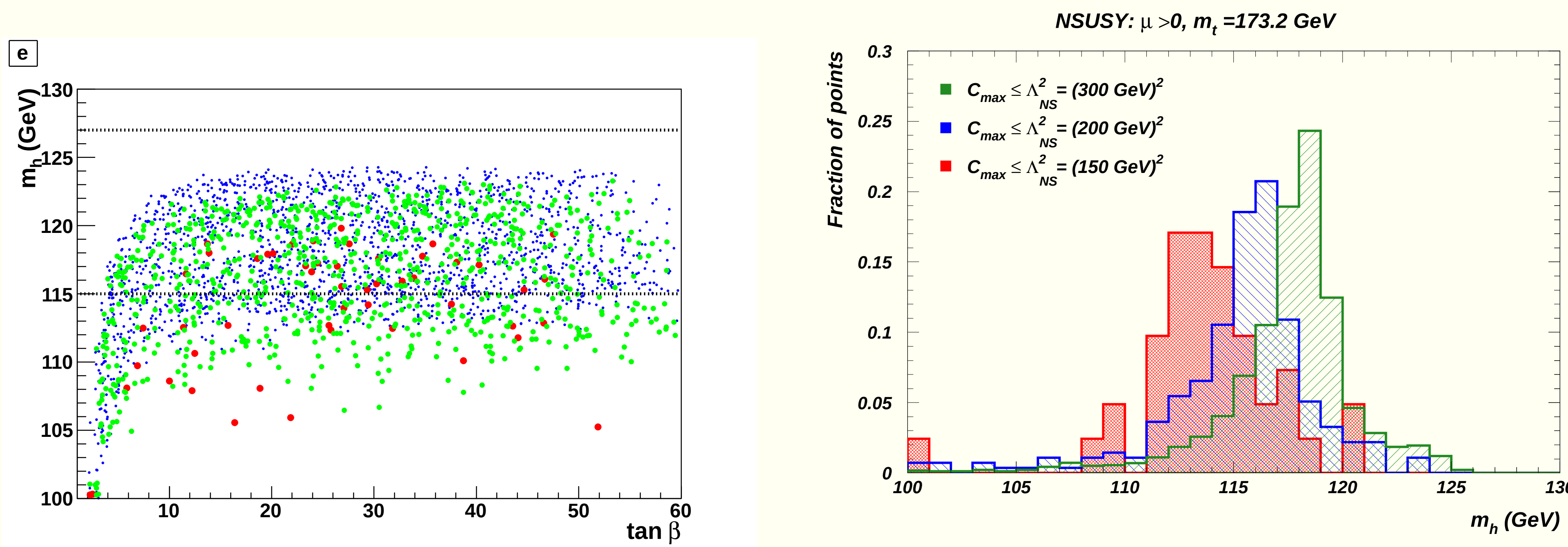


Slightly different scan in the red histogram from that on previous page.

Natural SUSY lives in the teeny corner on the left of red histogram.

Same range of $m_{1/2}$, A_0 while m_0 and $m_0(3)$ have the same range in the red and blue scans.

The light Higgs scalar



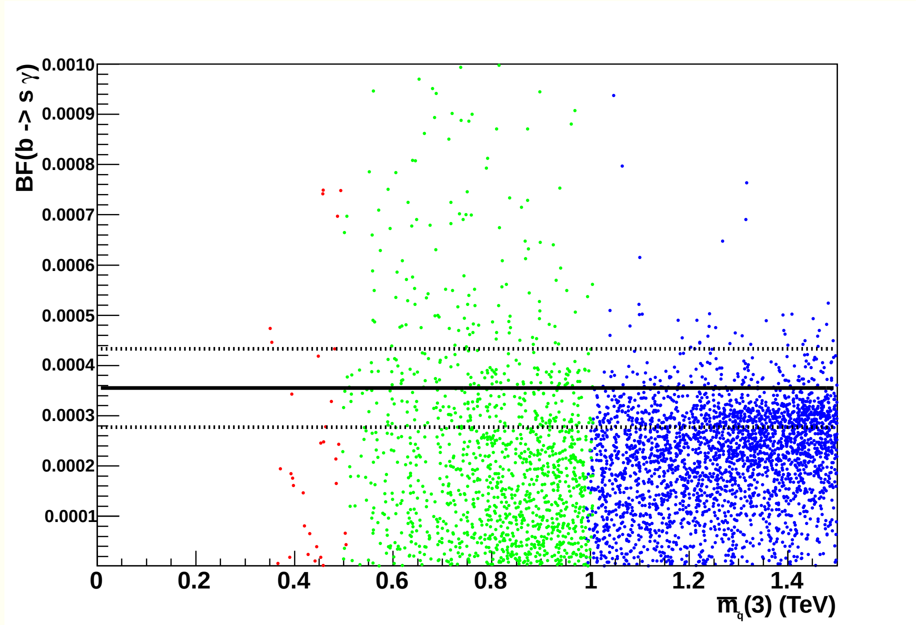
Slightly different scan in the right frame plot (with $\Sigma_{u,d}(i)$ broken up.)

Maximum m_h in the vicinity of 126 GeV for 5% fine tuning.

(Remember there is also some intrinsic error in the evaluation of m_h.)

m_h cut off artifact of $m_0(3)$ range.

$B(b \to s\gamma)$



Here, $m_q(3)$ is average of $m_{\tilde{t}_1}$, $m_{\tilde{t}_2}$ and $m_{\tilde{b}_1}$.

$B(b \to s\gamma)$ can be readily accommodated, and shows no preference for the 3rd generation mass.

The dark matter story is different

Because $|\mu|$ is small, lightest neutralino is higgsino-like.

Typically, the thermal higgsino-wimps annihilate very efficiently resulting in too little thermal DM (unless the WIMP is itself beyond 1 TeV).

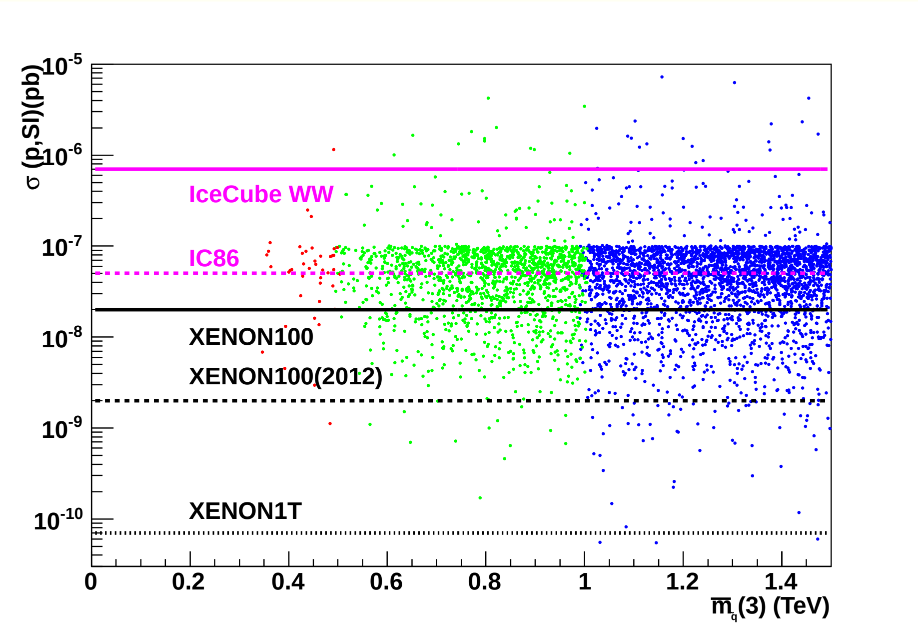
However, if there is another thermally produced late-decaying particle, it will contribute to the WIMP density.

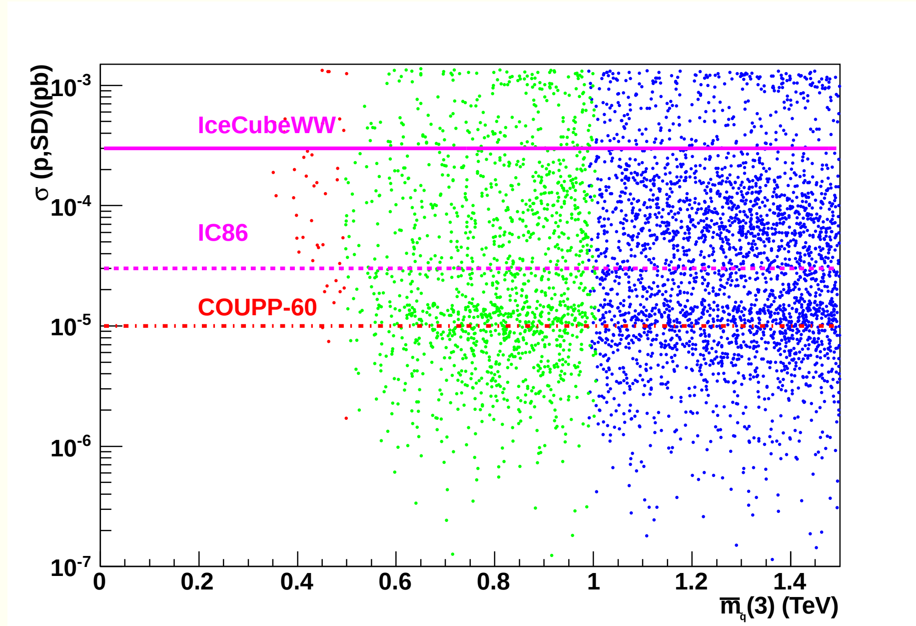
Thermally produced (heavy) axinos of an axion supermultiplet could provide an example.

In such a scenario, the DM would be a combination of higgsino WIMPS and axions

Championed by Choi, Kim, Lee and Seto; Baer, Lessa, Rajagopalan and Sreethawong

Dark Matter Detection



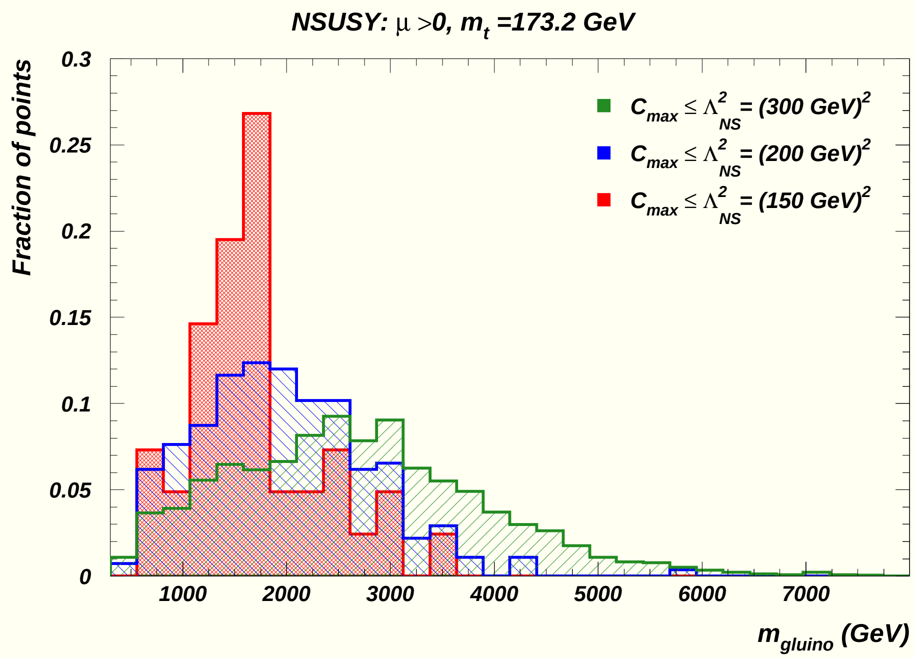


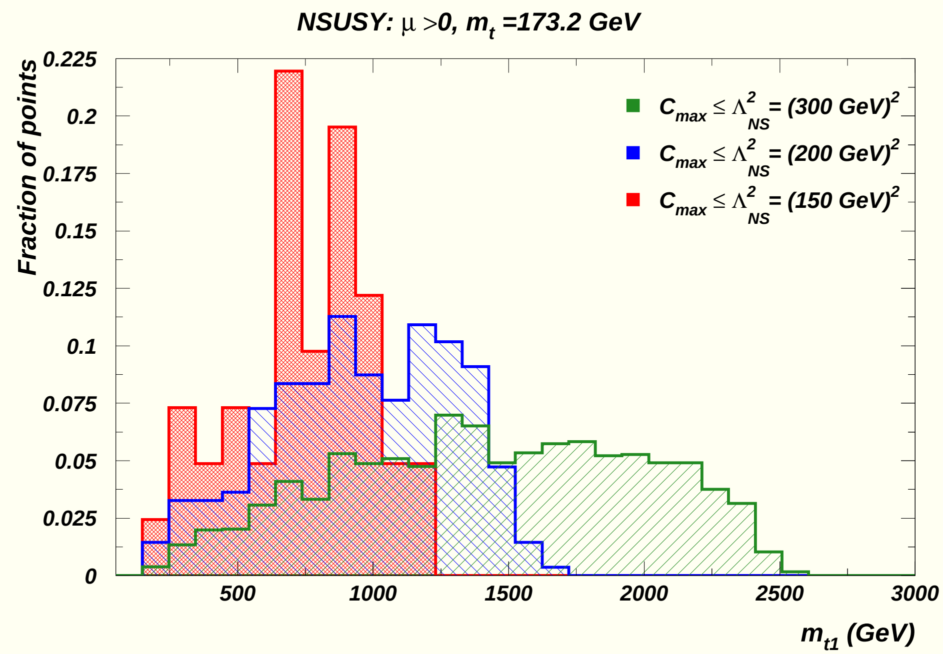
Assumes the WIMP neutralino saturates the DM density.

Remember though that the DM may only be part higgsino-like-WIMP.

Also, implications from Fermi bounds on $\langle v\sigma\rangle$ from dwarf spheroidal satellites of the Milky Way

Squarks and gluinos at the LHC

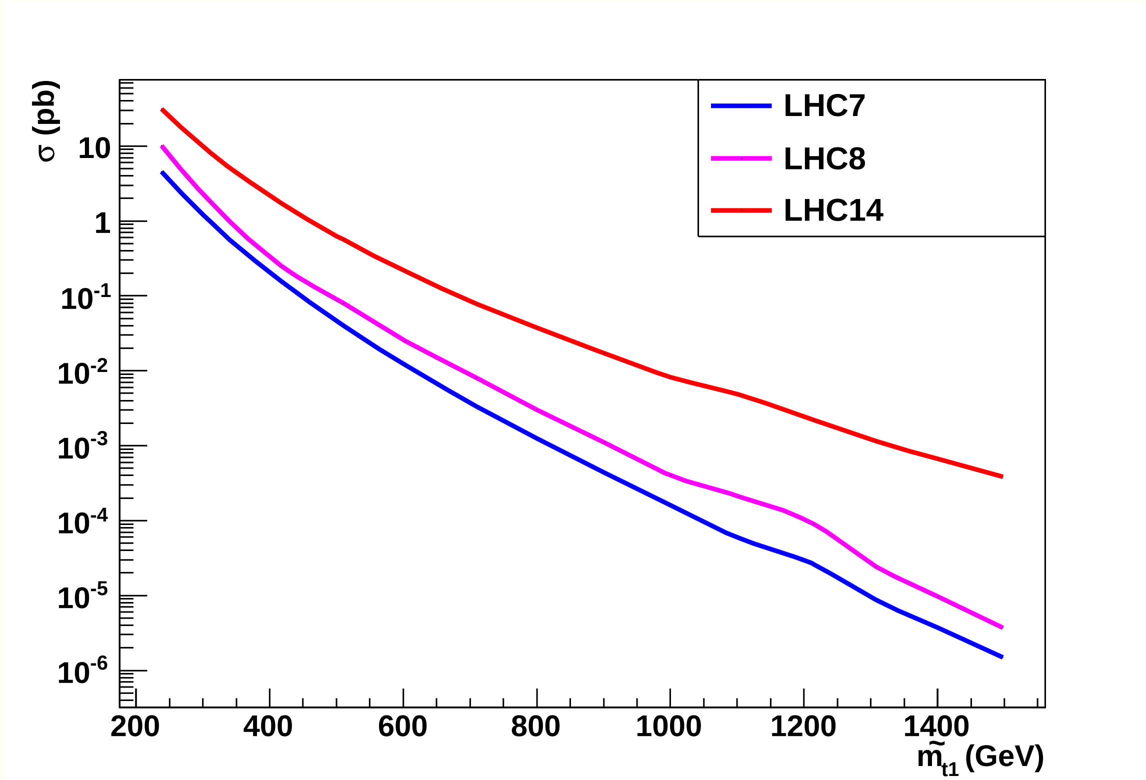




First generation squarks are way beyond LHC reach.

No guarantees at the LHC!*?!!

Similarly, $m_{b_1} \lesssim 2.5/3.5/4.5$ TeV

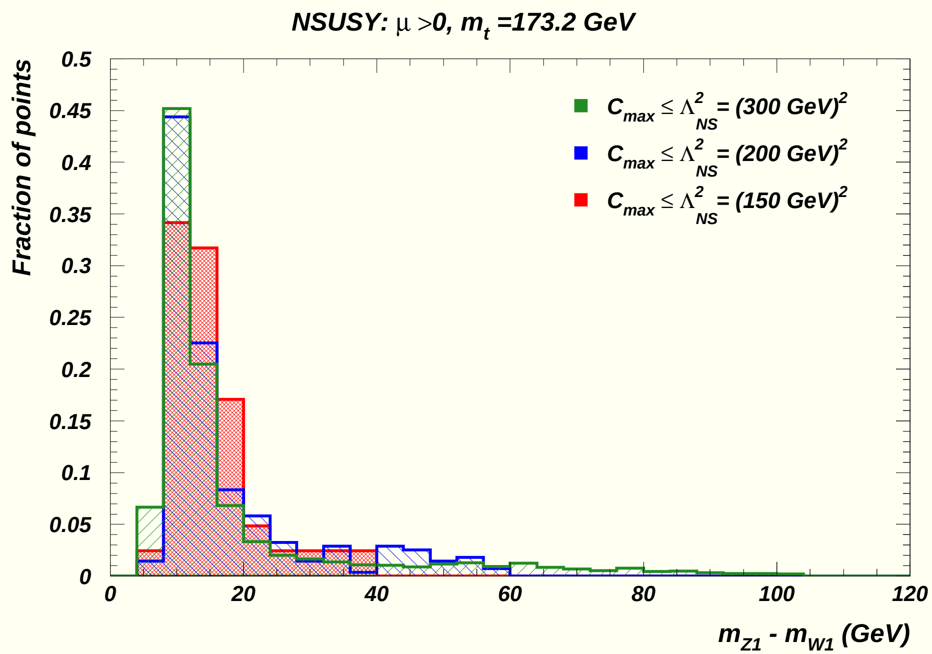


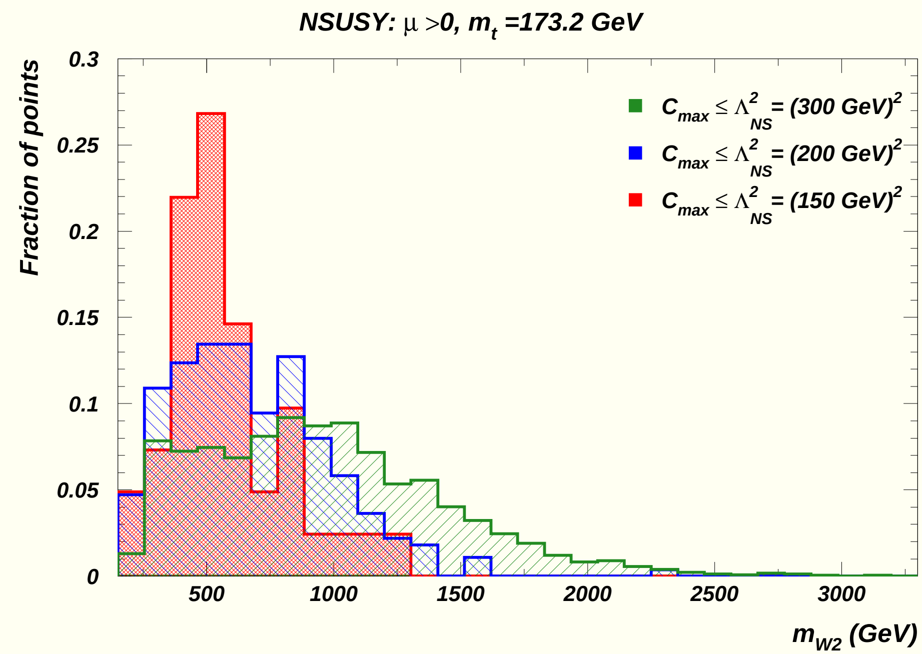
Cross section is 1 fb for $m_{\tilde{t}_1} \sim 1300$ GeV at LHC14!

Of course, we need not be gloomy since the $\tilde{t}_1$ may be lighter! Perhaps also $\tilde{t}_2$ and $\tilde{b}_1$. Also, revisit $\tilde{g}$ search.

$b\bar{b}+ \not{E}_T$, $t\bar{t}+ \not{E}_T$ and in favourable cases, also more complex topologies – $b\bar{b}W^+W^-+ \not{E}_T$ and $ZZb\bar{b}+ \not{E}_T$ to search for a signal

Unusual search strategies may be needed.





$\widetilde{W}_1$ and $\widetilde{Z}_2$ very difficult to see at LHC because of small mass gap.

An e^+e^- collider could be a discovery machine! Special search strategies will be needed to beat two-photon backgounds. Baer, Belyaev, Krupovnickas and XT

Are there observable signals from EW production of $\widetilde{W}_2$, $\widetilde{Z}_3$ and $\widetilde{Z}_4$? After all, $\widetilde{W}_2 \to W, Z, h$ and also perhaps $\tilde{t}_1$ and $\tilde{b}_1$. (Under investigation).

In this connection, please see Phys. Rev. **D85** (2012) 055022 and JHEP **1203** (2012) 092

IN SUMMARY

- ⋆ It appears that LHC data are suggesting heavy gluinos and first/second generation squarks
- ⋆ Not a problem for the stability of the Higgs sector.
- ⋆ The Natural Supersymmetry framework can accommodate this, and will be better suited than the much studied mSUGRA/CMSSM framework for future analysis if this trend persists.
- ⋆ The SUSY WIMP, in this case, is higgsino-like, and may constitute only a (small) fraction of the dark matter.
- ⋆ Interesting signals possible, but not guaranteed at the LHC. A 0.5 – 1 TeV e^+e^- linear can decisively probe Natural SUSY if the light chargino signal (despite its small energy release) is observable above two-photon backgrounds.
- ⋆ Phenomenological consequences of Natural SUSY are just starting to be seriously examined.