Phenomenology of Natural Supersymmetry

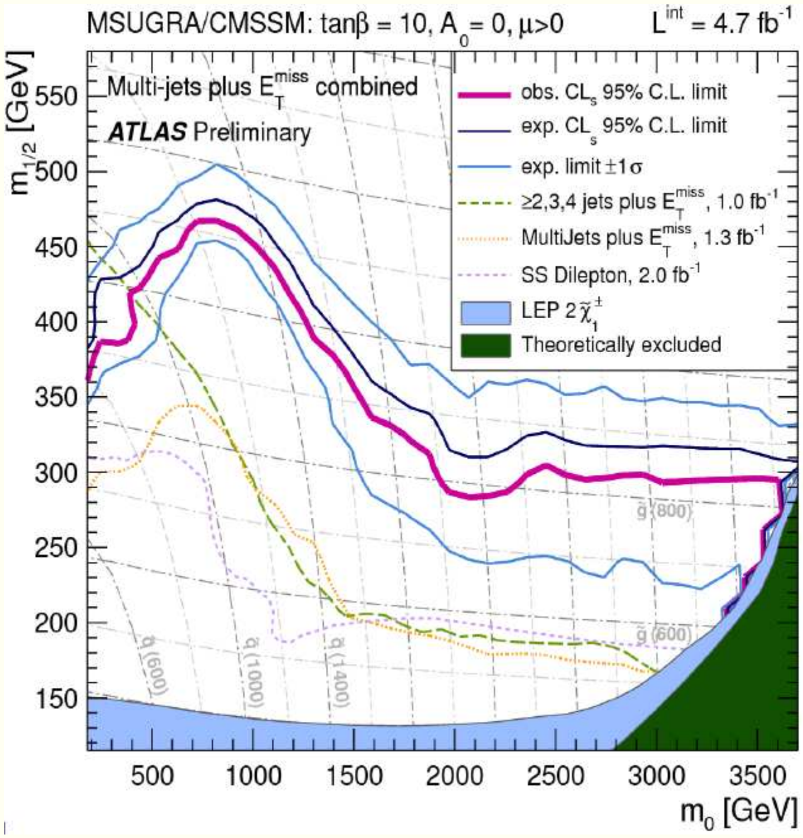
XERXES TATA
University of Hawaii

H. Baer, V. Barger, P. Huang, arXiv:1203.5539 plus A. Mustafayev

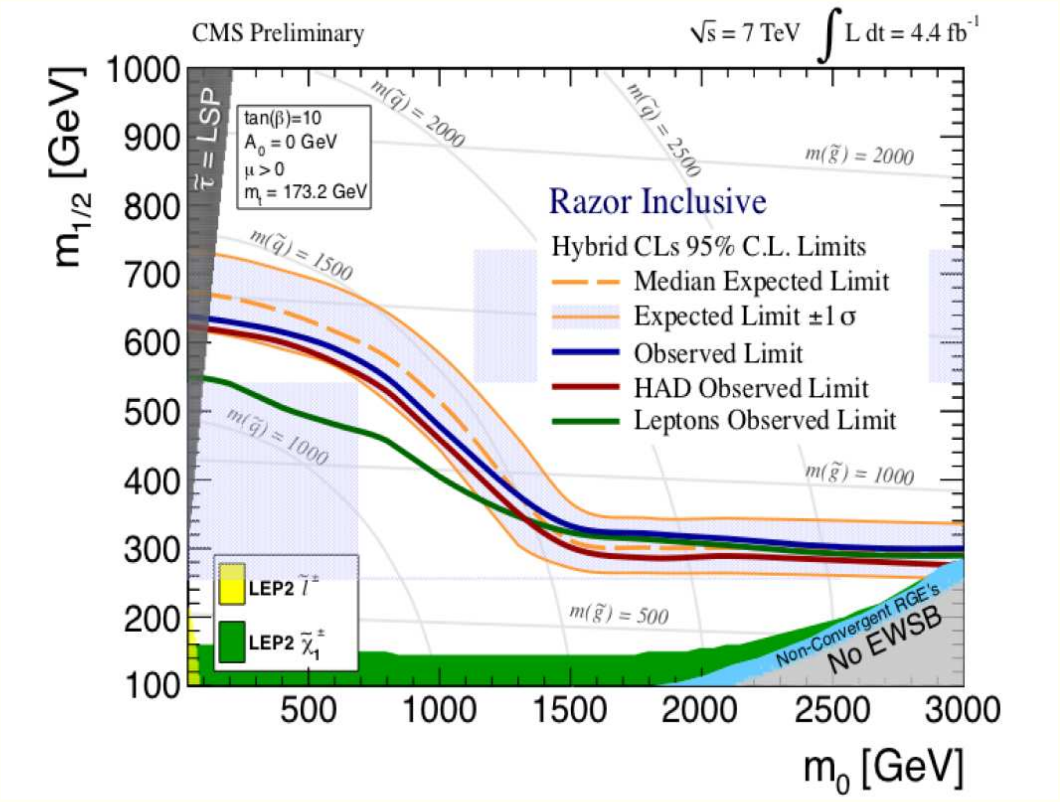
- ⋆ The LHC has been running fabulously.
- ⋆ We saw physics results that pushed probed superpartners beyond the reach of the Tevatron with just 35 pb^{-1} of integrated luminosity, a testimony to how well the detectors worked.
- ⋆ We have now seen results from Moriond with ~ 5 fb^{-1} of data. Lower 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.
- ⋆ The LHC has accumulated an integrated luminosity of ~ 5.6 fb^{-1} at 7 TeV, ~ 1 fb^{-1} at 8 TeV, and has the goal to accumulate 15 fb^{-1} at 8 TeV before the shutdown for the big energy upgrade

MORIOND 2012

ATLAS

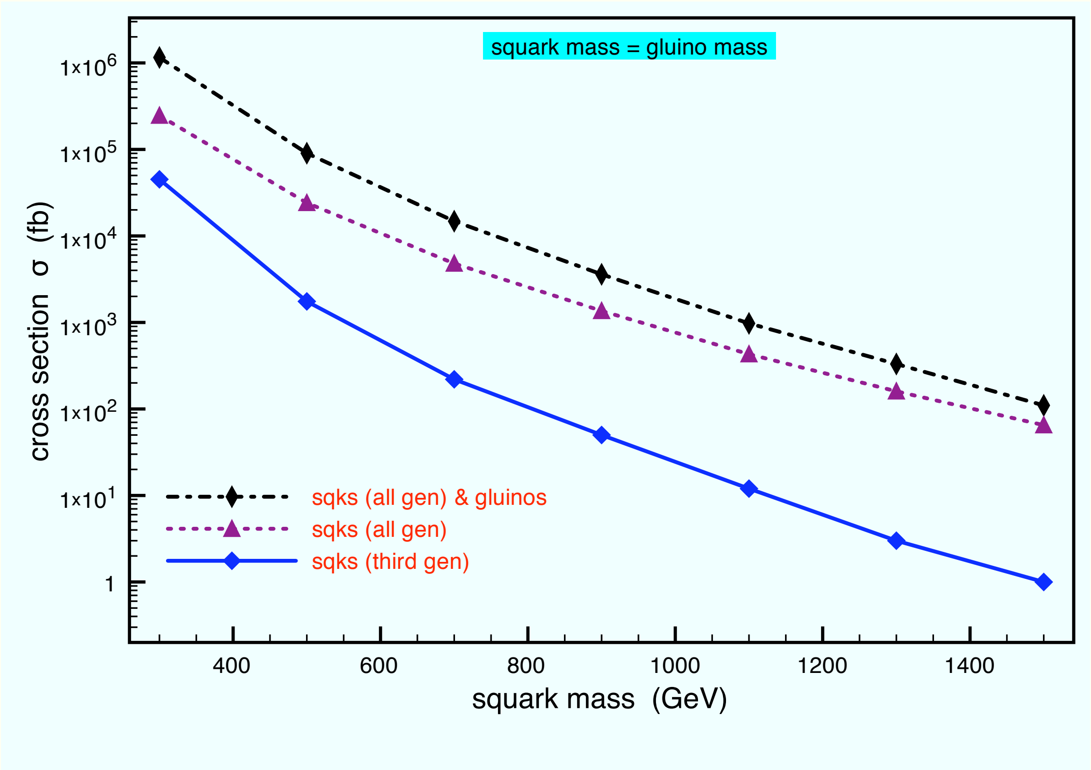


CMS



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 hierarchy 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.

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

All five terms should be of the same order, i.e. no "large cancellations". Call the maximum of these $C_5^{\rm max}$.

Less than 1 order of magnitude cancellation between terms implies $C_5^{\rm max}$ is smaller than $\sim (200\ {\rm GeV})^2$. (This is what Barbieri and Giudice called $\Delta = 10$.)

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

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

Estimate from King, Mulheitner and Nevzorov analysis hat $m_{\tilde{t}} \lesssim 1\ TeV[1.5$ TeV] if we require all terms smaller than $(150\ \text{GeV})^2$ $(200\ \text{GeV})^2$.

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

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

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

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

Multi-ten TeV first generation squarks and sleptons ameliorate the potential flavour and CP violations that are notorious to SUSY.

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.

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

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

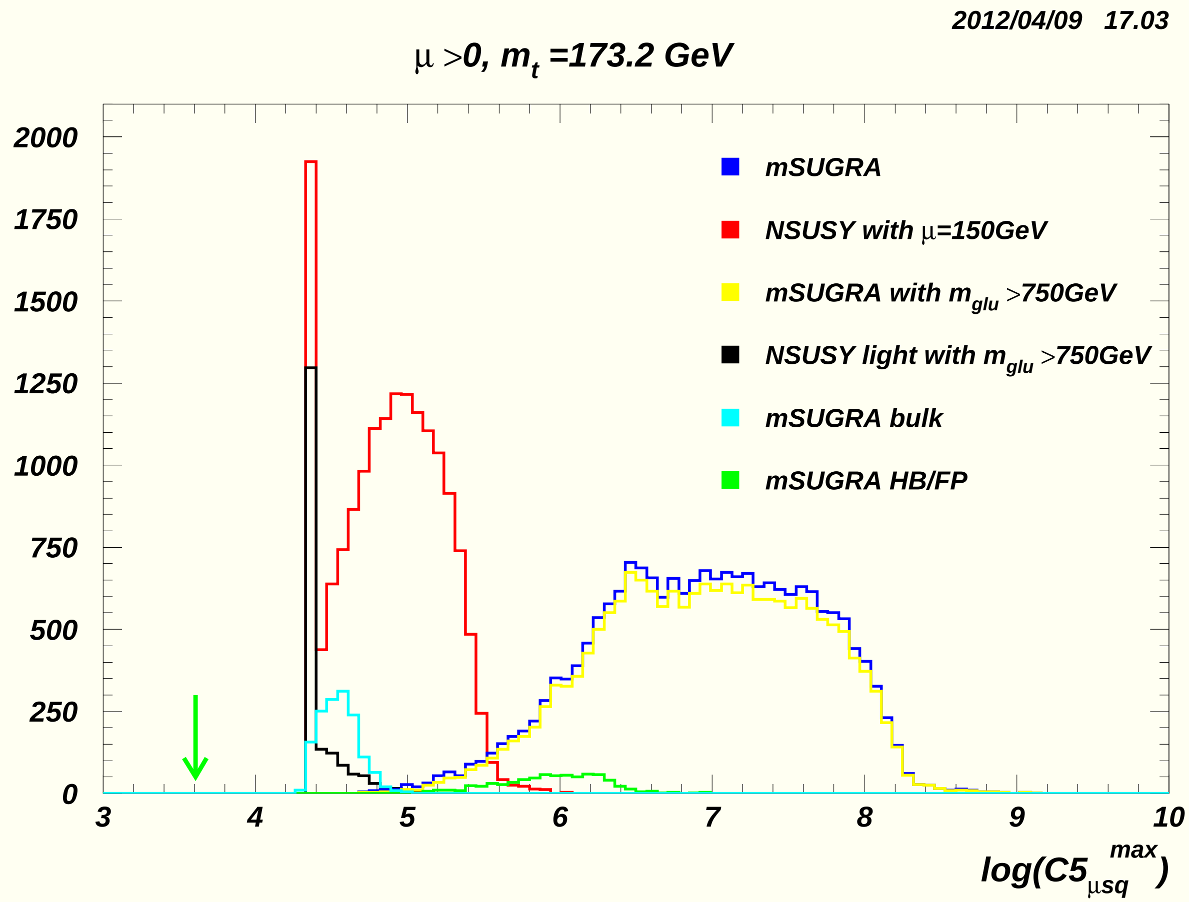
Consistent with Grand Unification symmetry.

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

What top down model gives such boundary conditions?

Let's see what happens in these scenarios.

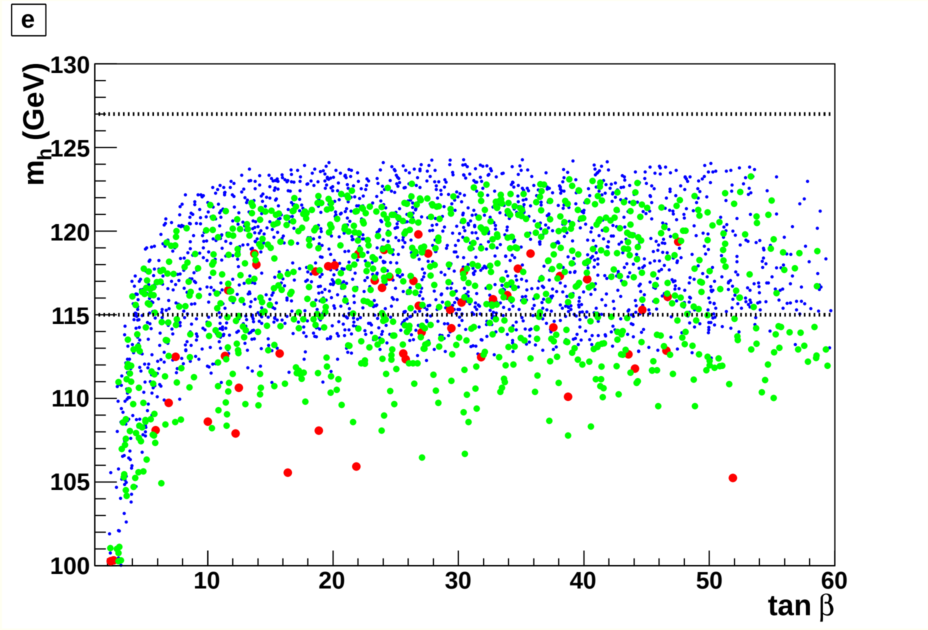
Fine-tuning in various models

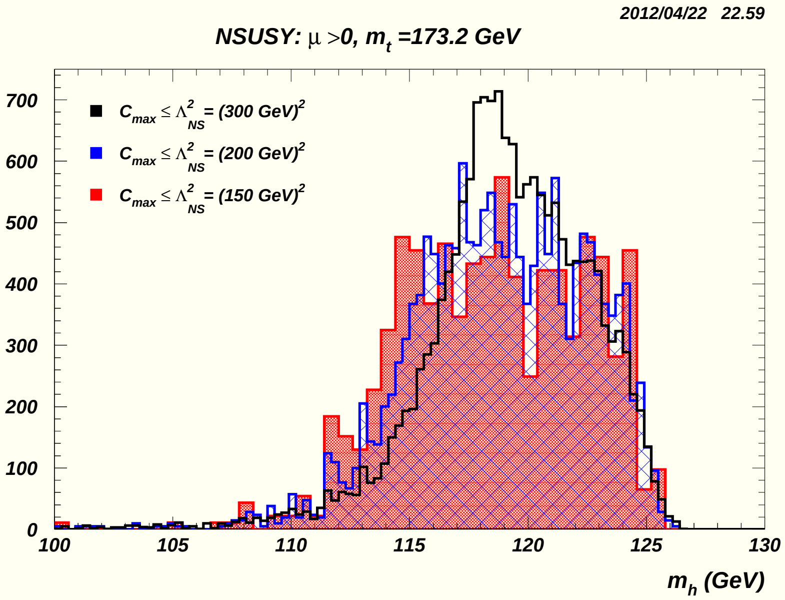


Slightly different scan here from that on previous page.

Peak at 150 GeV is an artifact of fixing $\mu = 150$ GeV.

The light Higgs scalar



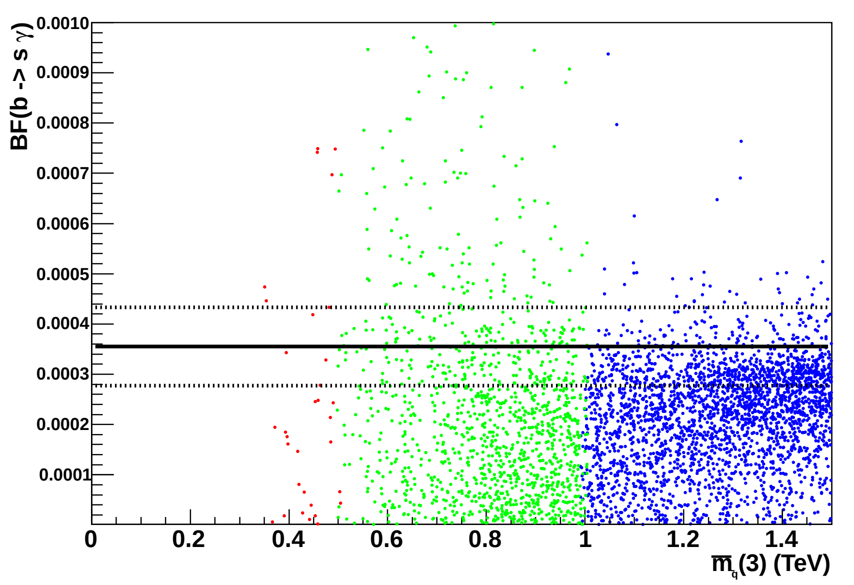


Slightly different scan in the right frame plot.

Maximum m_h in the vicnity of 126 GeV.

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

$B(b \to s\gamma)$



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

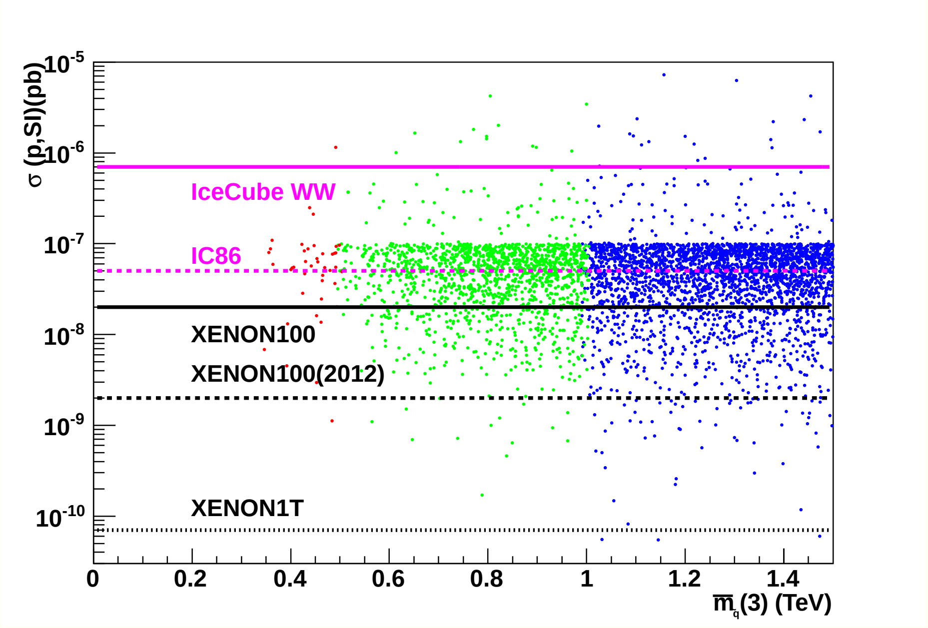
However, if there is another thermally produced late-decaying particle, it will contribute to the WIMP density.

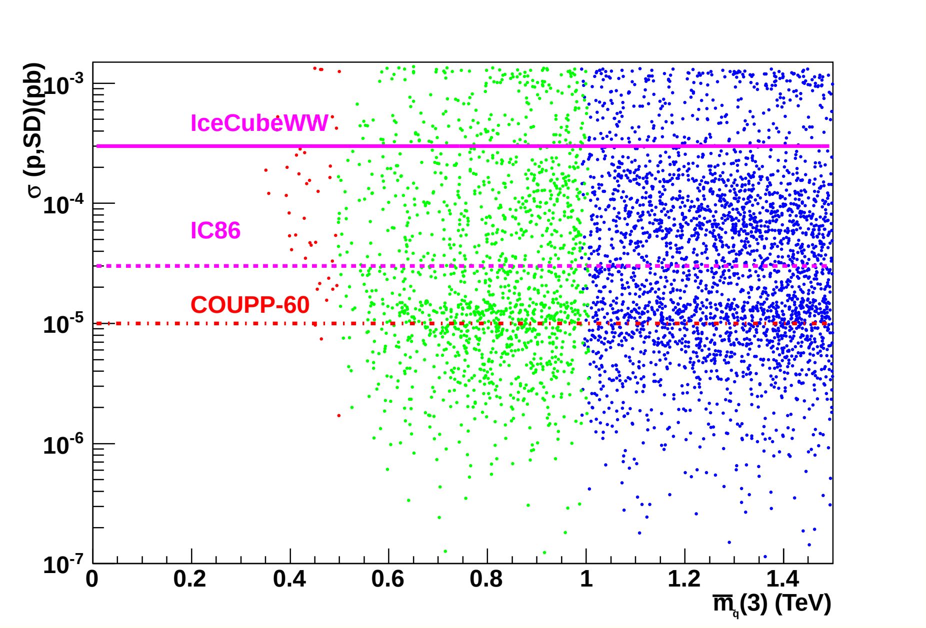
Thermally produced (heavy) axinos of an axion supermultiplet could provide an example.

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



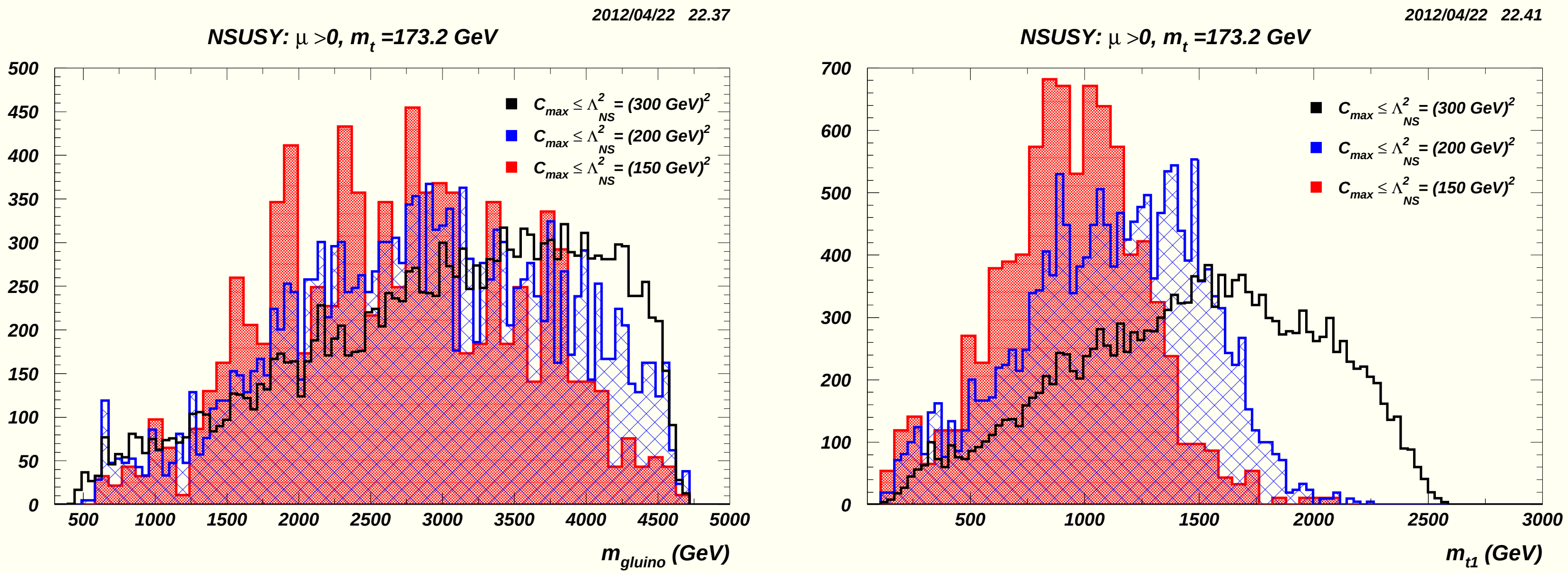


Assumes the WIMP neutralino saturates the DM density.

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

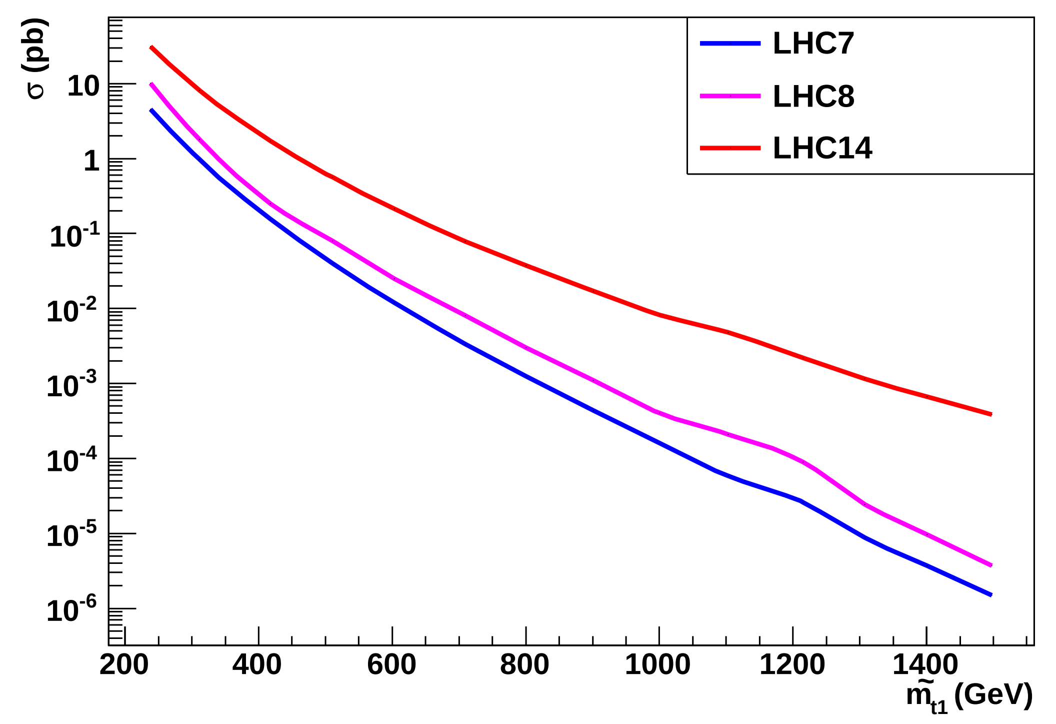
Also, implications from Fermi bounds on $\langle v\sigma \rangle$ from dwarf spheroidal satellites of the Milky Way

Squarks and gluinos at the LHC



The gluino cut-off is a scanning artifact. First generation squarks are way beyond LHC reach.

No guarantees at the LHC!*?!!

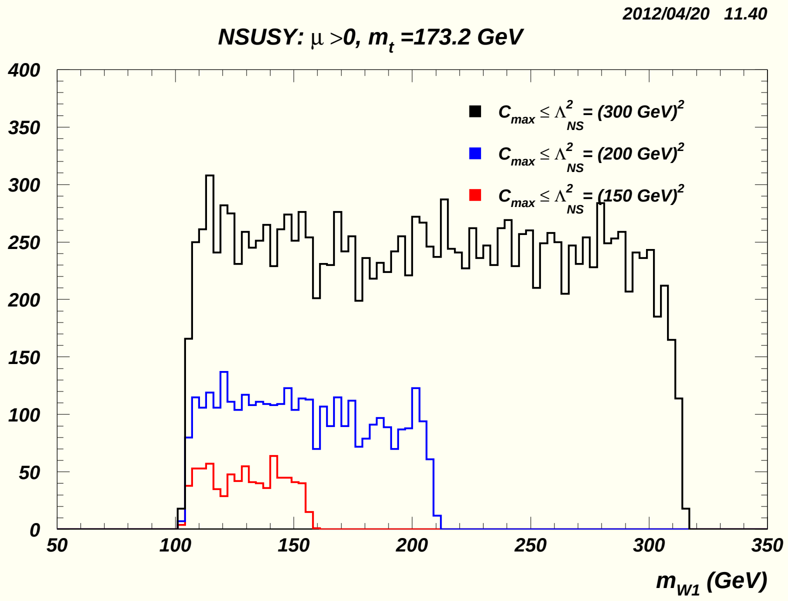


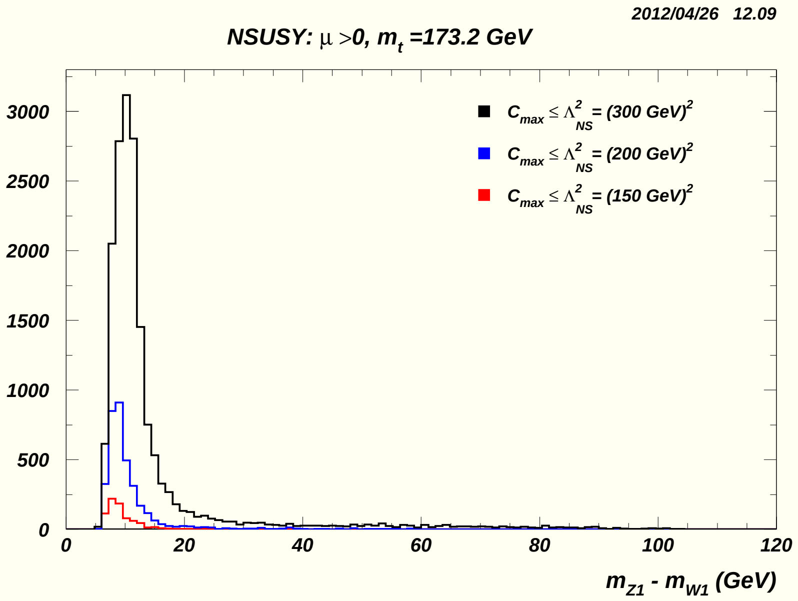
Cross section is 1 fb for $m_{\tilde{t}_1} \sim 1300$ GeV at LHC14!

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

IN SUMMARY

- ⋆ It appears that LHC data are suggesting heavy gluinos and first generation squarks
- ⋆ Not a problem for the stability of the Higgs sector.
- ⋆ The Natural Supersymmetry framework can accommodate this quite simply, and will be better suited than the much studied mSUGRA/CMSSM framework for future analysis if this trend persists.
- ⋆ Interesting signals possible, but perhaps not guaranteed at the LHC. Phenom consequences of Natural SUSY are just starting to be seriously examined.