A light singlino in the NMSSM: Challenges for SUSY searches at the LHC

Ulrich Ellwanger
LPT Orsay, Univ. Paris-Sud XI and
University of Southampton
(with A. M. Teixeira)

24/7/2015

Shortcomings of the SM — Solved by SUSY?

- What is Dark Matter? ✓
- Hierarchy Problem ✓
- Grand Unification
  (Quarks, leptons fill complete SU(5) representations,
  but gauge couplings do not quite unify) ✓
- Matter-Antimatter Asymmetry ✓
- Origin of the tiny Neutrino Masses –
- Hierarchy/Mixing of Quark/Lepton Masses –

– means "can be implemented", but not automatically

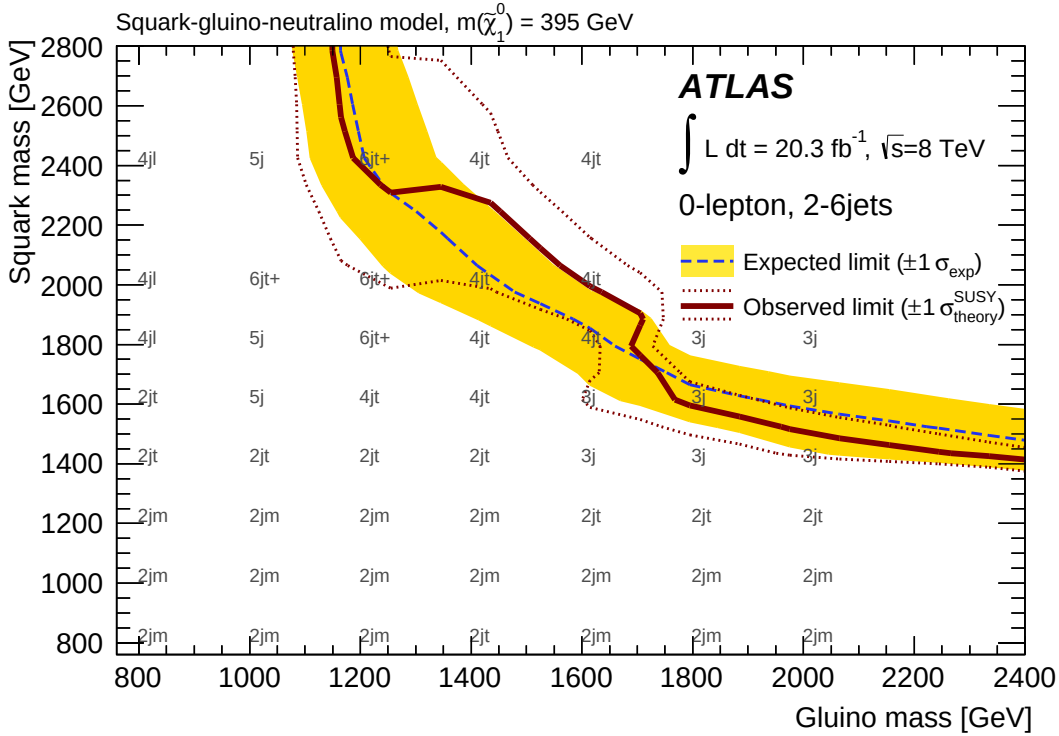
→ Hard to give up, despite the absence of "sparticles" at the LHC:

Lower bounds on sparticle masses after the LHC run I:

If $M_{squark} \sim M_{gluino}$:

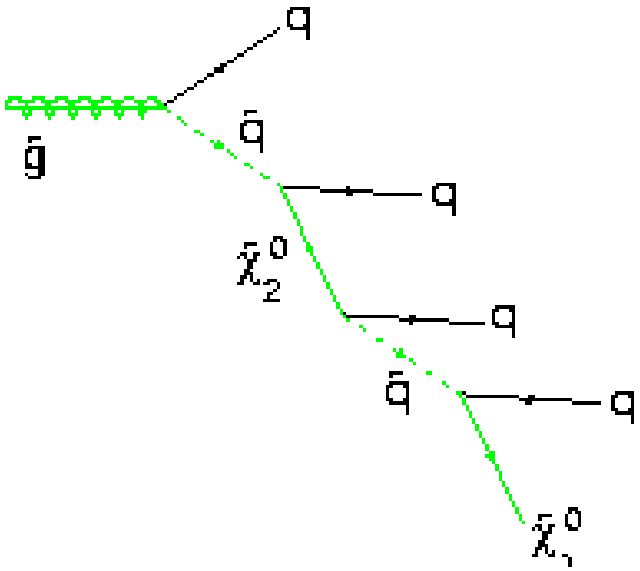
$M_{squark} \sim M_{gluino} \gtrsim 1.7$ TeV

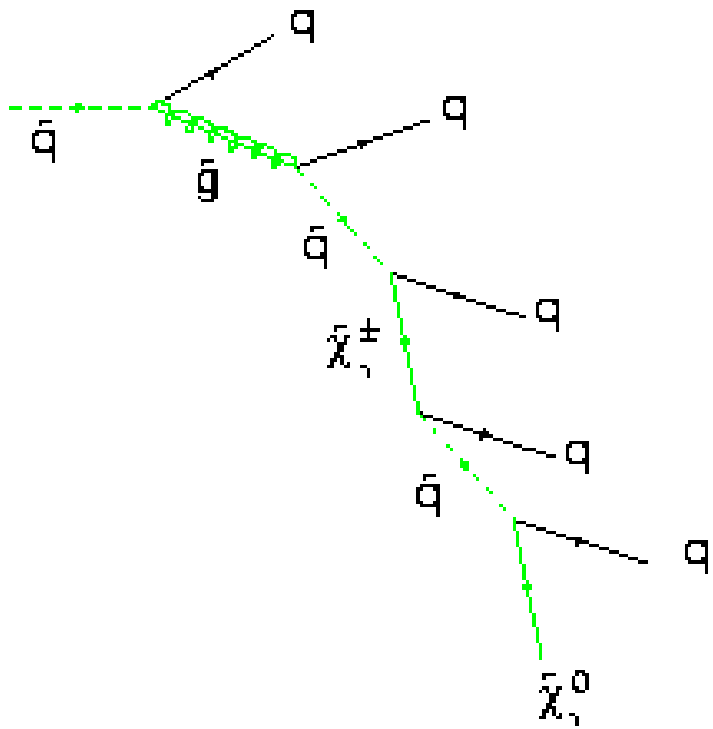
(CMS/MSUGRA bounds are similar)



Limits depend on the assumed decay cascades:

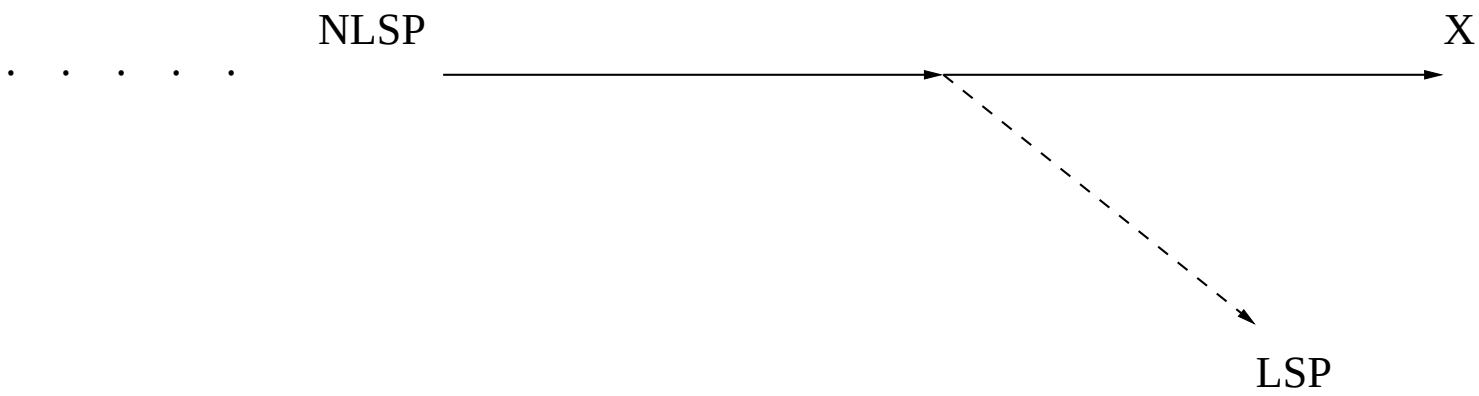
Once sparticles are produced (in pairs), they decay into other sparticles, but the lightest neutralino escapes undetected and gives rise to E^T_{miss}:





The NMSSM:

– An additional singlet scalar in the Higgs sector helps to understand the mass of 125 GeV of the SM-like Higgs boson
(MSSM: large rad. corrections from unnaturally heavy stops are required)
$\longrightarrow$ Its fermionic partner, the singlino, can well be the lightest neutralino (LSP) and a good dark matter candidate
$\longrightarrow$ The singlino has small couplings to squarks, sleptons, charginos and the other neutralinos
$\longrightarrow$ Nobody wants to decay into the singlino, only the NLSP which has no other choice (assuming R-parity):



Possible (natural) configuration:

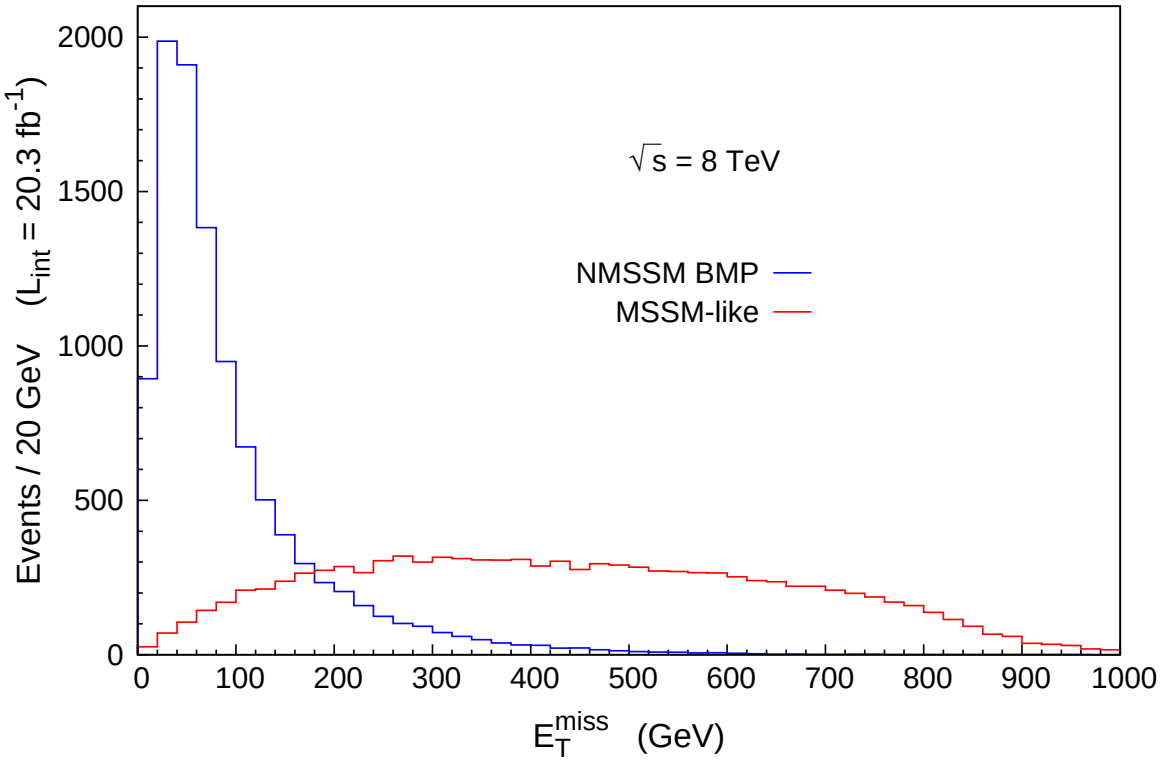
- The singlino LSP is light (a few GeV), X is a Higgs boson (H_{SM}, or an additional NMSSM-specific scalar H_S)
- The mass of the NLSP is not far above $M_{singlino} + M_H$
- Then: little (missing transverse) energy is transferred from the NLSP to the singlino; the transverse energy is carried away by the Higgs boson
- If Higgs decays do not give rise to E_T^{miss}, the E_T^{miss} signature is dramatically reduced!
- Note: NMSSM-specific Higgses H_S with masses below 125 GeV are not ruled out (by LEP) if their couplings to Z-bosons are sufficiently small;
  these can also play the rôle of "X" in NLSP $\rightarrow X+$ singlino cascades

Impact of a NLSP $\to H_S+$ singlino cascade (LHC run I):

Compare the spectrum of E_T^{miss} from ≈ 1 TeV squark/gluino production:

— MSSM with a 89 GeV bino as LSP

— NMSSM with an additional bino $\to H_S+$ singlino cascade,
$M_{H_S} \sim 83$ GeV, $M_{singlino} \sim 5$ GeV:



Where does the remaining E_T^{miss} come from?

H_S has branching fractions similar to H_{SM} of the same mass:
$\sim 8\%$ into $\tau^+\tau^-$ leading to neutrinos in the final state;
$\sim 85\%$ into $b\bar{b}$ with partially leptonic decays

Still: The example with $M_{squarks} \sim 830$ GeV, $M_{gluino} \sim 860$ GeV, $M_{stops,sbottoms} \sim 810 - 1060$, $M_{charginos} \sim 830 - 950$ GeV passes all LHC constraints

The only LHC allowed scenario with all sparticle masses below ~ 1 TeV!

Why not in the MSSM?

A light bino of a few GeV is possible, in principle (although difficult to get the correct dark matter relic density)

Then however, squarks and sleptons (all of which have hypercharge, i.e. couple to the bino) would prefer to decay directly into the bino-like LSP, without a cascade via the NLSP

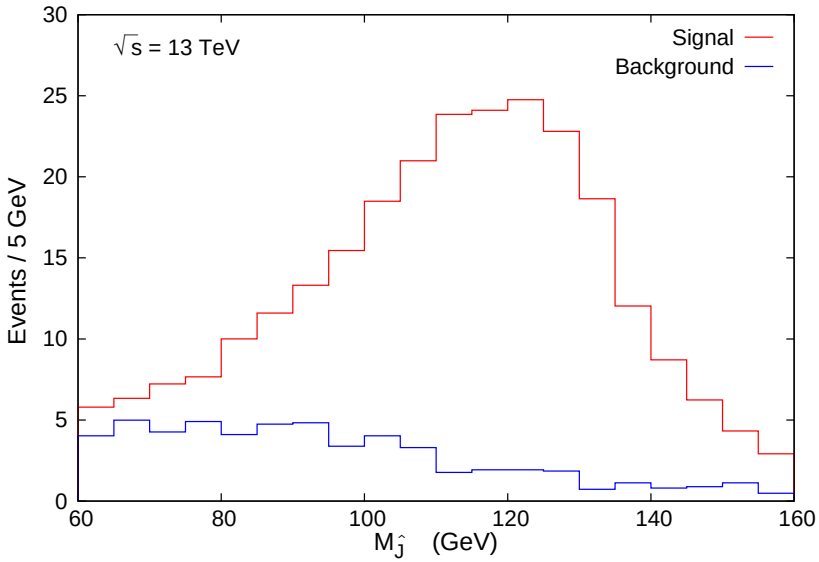
$\longrightarrow$ The effect disappears!

What would be the signature of squark/gluino production at the LHC run II in the case bino $\rightarrow H+$ singlino?

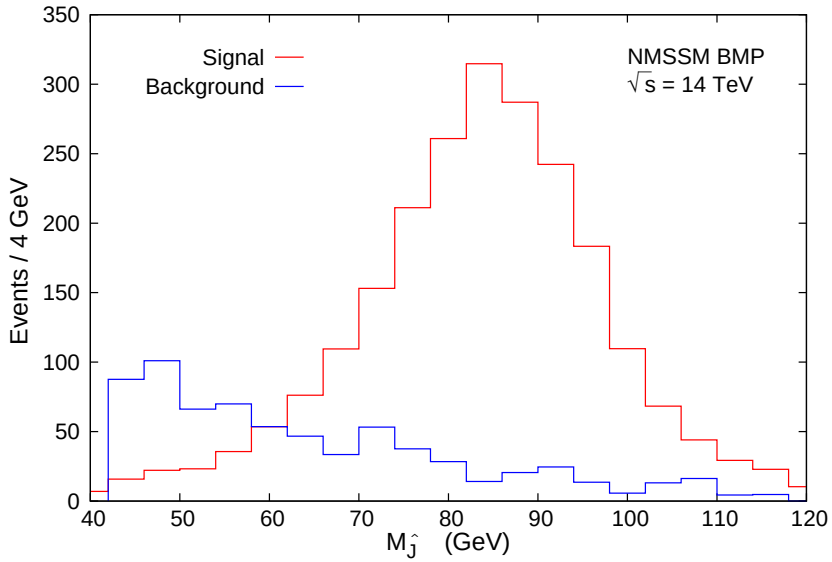
Jets + the remnants of two Higgs states (instead of E_T^{miss}) , but M_H not known, e.g. $M_{H_{SM}} = 125$ GeV, or $M_{H_S} \sim ...50 - 100...$ GeV

$\longrightarrow$ Look for, e.g., one $b\bar{b}$ pair and one $\tau^+\tau^-$ pair (+ cuts on p_T of jets), and a bump at the $b\bar{b}$ invariant mass:

(Different scenarios are possible)



bino $\to H_{SM}$ + singlino



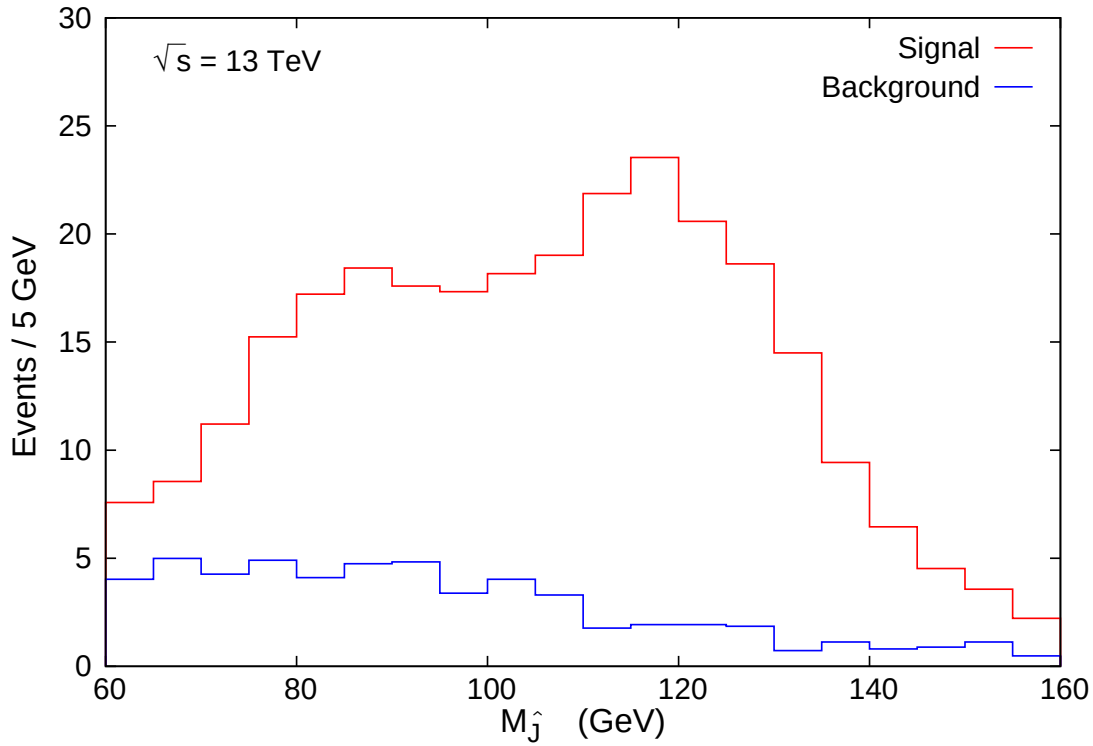
bino $\to H_S$ + singlino

$\hat{J}$: A "fat" jet constructed out of two b-jets, $M_{\hat{J}} = m_{b\bar{b}}$

Background suppression: Require 2 τ_h
(allow for $\Delta R_{\tau\tau} < 0.5 \to 2\,\tau$ fake rate larger than $(1\,\tau$ fake rate$)^2$!)
Cuts on 4 jets with
$p_T > 400, 300, 200, 100$ GeV (left) $\quad p_T > 200, 100, 80, 80$ GeV (right)

(Simulation with A.M. Teixeira, 1406.7221 and 1412.6394)

Another possibility:
50% BR(bino $\rightarrow H_{SM}$ + singlino), 50% BR(bino $\rightarrow H_S$ + singlino):



$\rightarrow$ Double peaks are possible and visible

Conclusions

- In the presence of a light singlino in the NMSSM the standard E_T^{miss} signature for sparticle production can be strongly suppressed
- Re-interpreting the absence of excesses at the LHC run I leads to lower lower bounds on sparticle masses
- Instead, a Higgs boson is produced in each sparticle cascade; possibly H_{SM}, or a new (lighter) H_S, or both
- Dedicated searches at the run II are necessary in this case, not relying on E_T^{miss}, but sensitive to Higgs decay products! Our simulations indicate that

  SUSY may be discovered together with an additional Higgs boson!