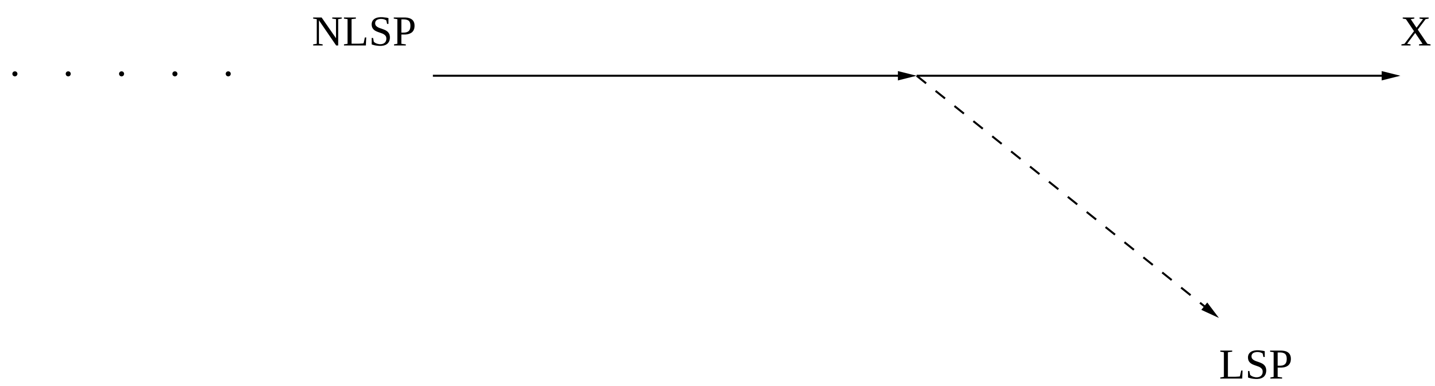
Light Singlinos in the NMSSM:
Challenges for Susy Searches at the LHC

U. Ellwanger, LPT Orsay, with A. M. Teixeira (1406.7221)

"Missing" missing transverse energy:

Consider a (possible) last step in a Susy particle decay cascade from a next-to-lightest Susy particle (NLSP) into the LSP + X,



where "X" decays into SM particles (X = Higgs boson, Z,...)
Usually χ_1^0 leads to missing transverse energy

If the available phase space is narrow, $M_{NLSP} - (M_{LSP} + M_X) \ll M_{NLSP}$, the energy (momentum) E_{LSP} transferred from the NLSP to the LSP is proportional to the ratio of masses:

$$\frac{E_{LSP}}{E_{NLSP}} \simeq \frac{M_{LSP}}{M_{NLSP}}$$

$\longrightarrow$ If the LSP is light and $M_X \sim M_{NLSP} - M_{LSP}$, little (missing transverse) energy is transferred to the LSP; the transverse energy is carried away by X

$\longrightarrow$ If X decays do not give rise to E_T^{miss}, the E_T^{miss} signature disappears!

Possible in the MSSM? A light ($\sim$ few GeV) LSP has to be bino-like (higgsinos/winos have charged SU(2) partners)
$\longrightarrow$ Squarks (with hypercharge!) etc. would prefer to decay directly into the LSP, without the NLSP in the decay cascade
$\longrightarrow$ The effect would be rare

In the NMSSM, the neutralino$_1$ can be mostly "singlet-like" with small couplings to all sparticles; then

— all sparticle decay cascades end up "provisionally" in the (bino-like) NLSP; only subsequently the NLSP decays into the LSP+Higgs (H_{125}, or a lighter NMSSM-Higgs)

— Then: all sparticle decay cascades contain a Higgs boson

— the missing energy in sparticle decay cascades is strongly reduced

$\longrightarrow$ lower bounds on squark/gluino masses from run 1 at the LHC are considerably alleviated

— searches for Higgs pairs (+ jets) at 13/14 TeV are the relevant search channels for Supersymmetry

Which Higgs?

H_{SM}: Has leptonic decays $H_{SM} \to WW^*/ZZ^* \to$ ... which lead to some E_T^{miss}

Worst case with little E_T^{miss}: H_1, a NMSSM specific light Higgs boson with $M_{H_1} < M_Z$ (Just occasionnaly: $H_1 \to \tau^+\tau^- \to \ldots +$ neutrinos)

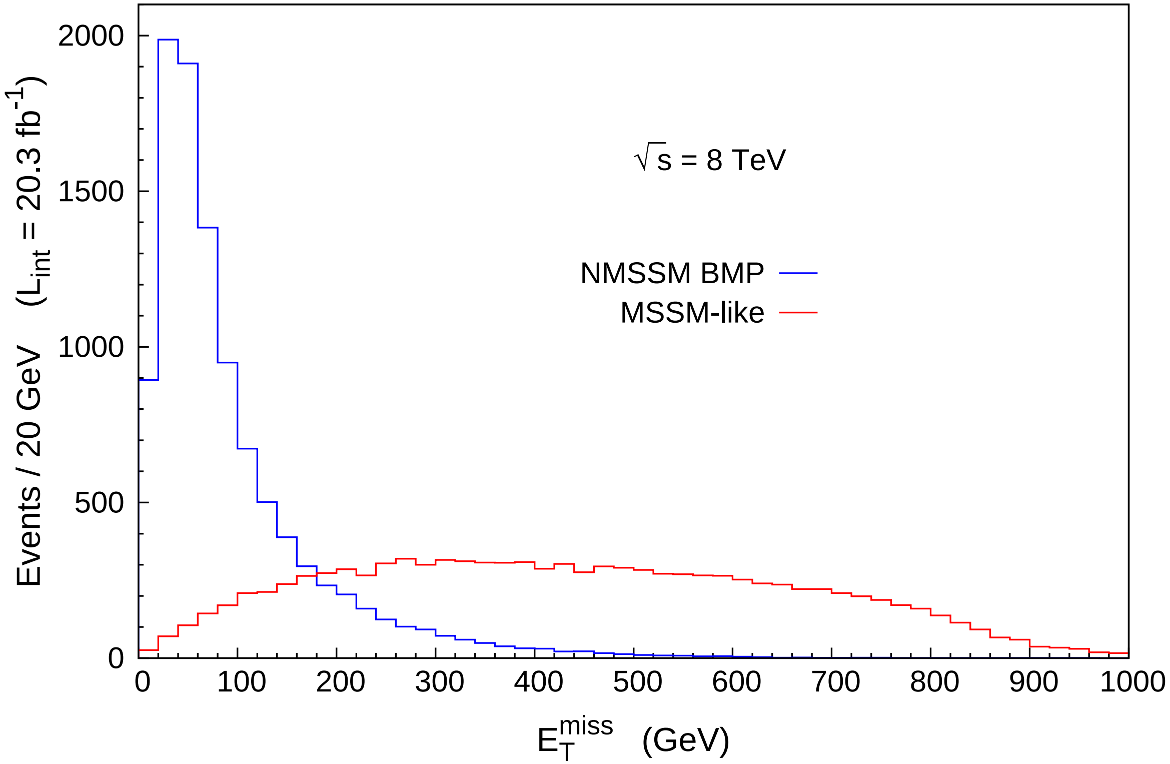
If squarks decay directly into the bino (no Zs/Ws in the cascades, which decay possibly into neutrinos):

A benchmark point with
$M_{NLSP\equiv bino} \sim$ 89 GeV, $M_{H_1} \sim$ 83 GeV, $M_{LSP\equiv singlino} \sim$ 5 GeV, $M_{squarks} \sim$ 860 GeV, $M_{gluino} \sim$ 890 GeV, $M_{stops,sbottoms} \sim 810-1060$, passes all LHC constraints

Strongest constraints come from searches for multijets incl. multi-b-jets (searches for RPV), not from standard SUSY searches incl. E_T^{miss}

Cross section possibly much larger than SM Higgs pair production;
here: $\sim$ 5.2 pb

Spectrum of E_T^{miss} from squark/gluino production at 8 TeV:



— in the MSSM with a 89 GeV bino as LSP, would be ruled out!

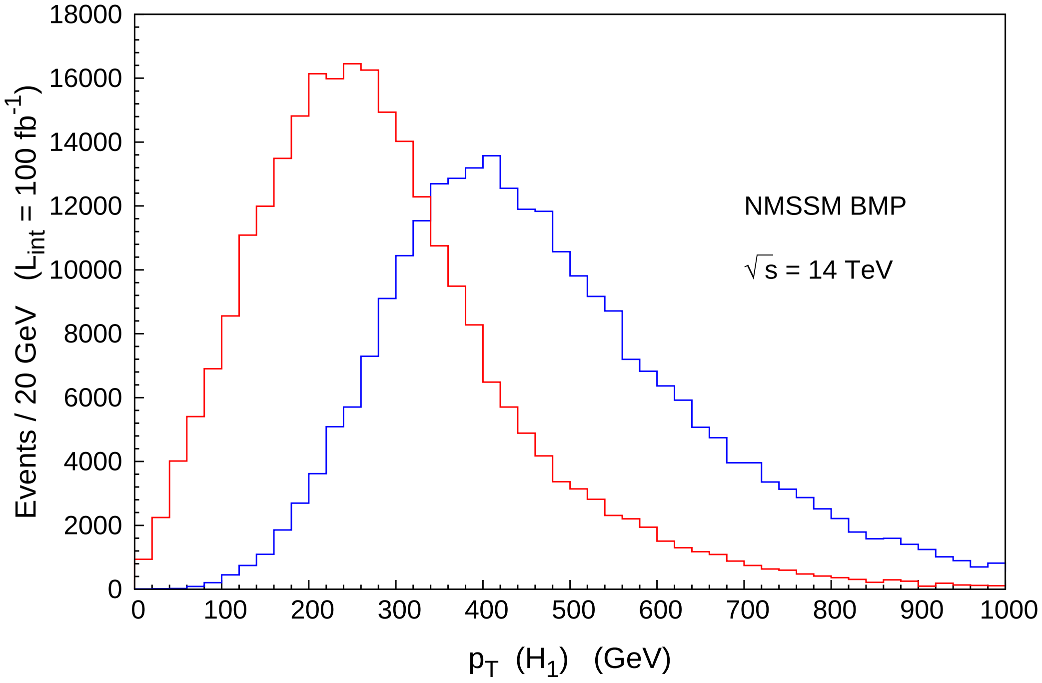
— in the NMSSM with the additional bino $\to H_1 +$ singlino cascade

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

Simple squark→quark+bino cascade:

Properties of the final state:

Hard jets + two (boosted) Higgs states with large p_T:



(Blue: leading Higgs; red: Next-to-leading Higgs boson)

Possible search strategy at the LHC at 13/14 TeV:

— Require four hard jets, e.g. with $P_T \geq 400,\ 200,\ 80,\ 80$ GeV (from, e.g., $2 \times (\tilde{q} \to q + bino \to q + singlino + H_1$ and/or $\tilde{g} \to q + \tilde{q} \to ...)$

— Instead of E_T^{miss}, look for remnants of two H_1 Higgs bosons: These decay with slightly larger BRs than H_{SM} into $b\bar{b}$ ($\sim 85\%$) and into $\tau^+\tau^-$ ($\sim 8\%$)

— Ask for two b-jets and two τ_h ($M_{2\tau} < 120$ GeV); try to reconstruct the a priori unknown Higgs (H_1) mass from two b-jets

(The results below are based on simulations with MadGraph5+1j, Pythia, Delphes)

Case of boosted Higgses: Analyse the final state twice

First:

— since the H_1 decay products are boosted, look for two "slim" b-jets and two τ_h using anti-k_T jet-finding algorithm with small cone size $R = 0.15$ (simulation assumes calorimeter cells with $\Delta\varphi,\ \Delta\eta \simeq 0.1$)

Define a $2b$ pseudo-jet $2bPJ$ as the sum of both b-tagged jets (assumed: 70% b-tag efficiency)

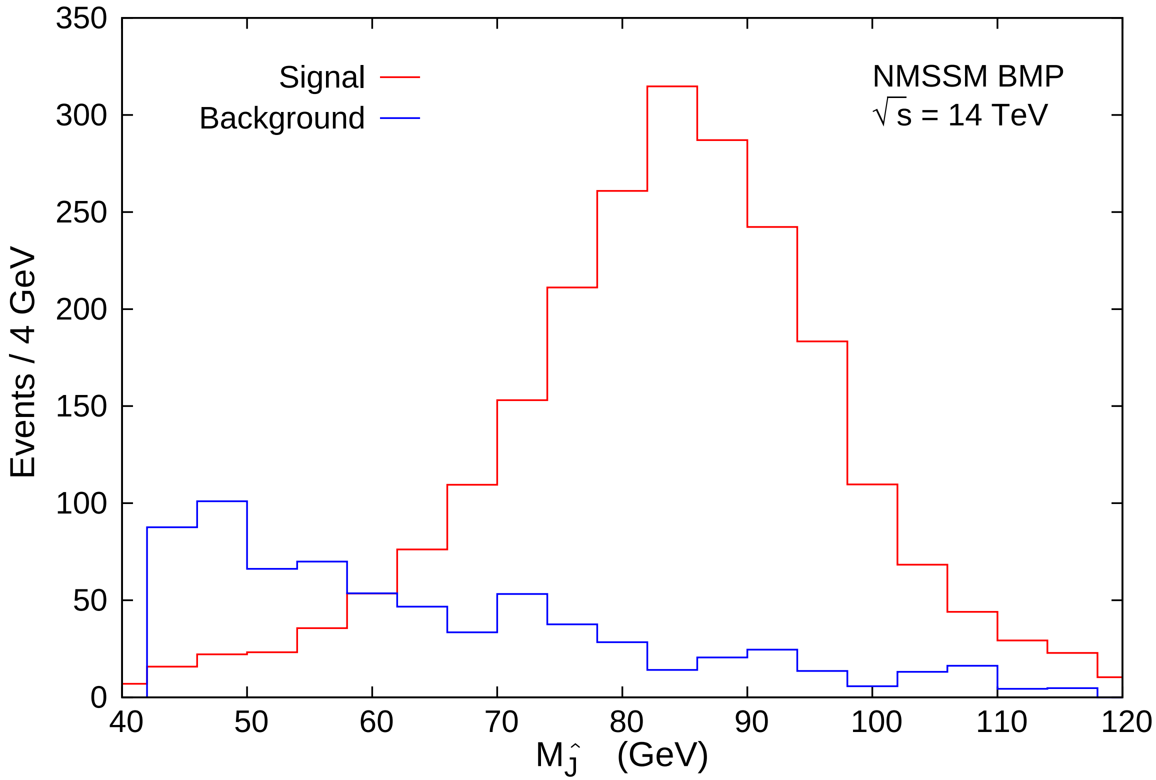
Second:

— Apply the anti-k_T jet-finding algorithm again, with $R = 0.5$

$\longrightarrow$ The two boosted b-jets tend to merge into a single fatter jet $\hat{J}$;

Look for the jet $\hat{J}$ with $p_T > 400$ GeV closest in ΔR to the previously found $2bPJ$

Invariant mass of $\hat{J}$ (event numbers after $100 fb^{-1}$ at 14 TeV):

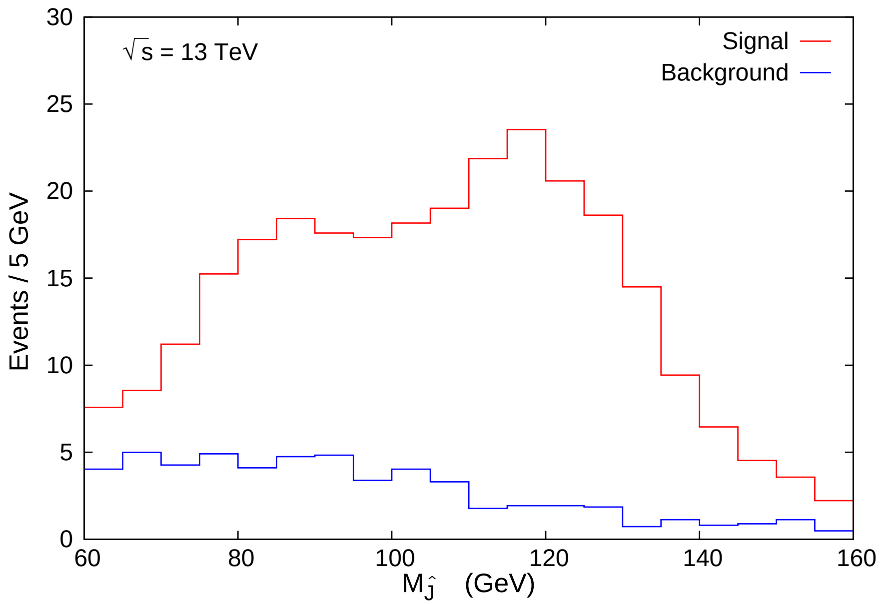


→ The signal is there! Recall: $M_{H1} = 83$ GeV

Of course: for heavier squarks/gluinos the H_1 production cross section (here: ~ 5.2 pb) would go down; for different M_{H_1} the height of the peak remains the same.

Dominant background from QCD: 2 jets + $b\bar{b}$ + 2 fake τ's

Case of a 130 GeV bino with branching fractions both into H_1 with $M_{H_1} = 83$ GeV, and H_{125}:



→ "Twin peaks" are possible
(Here: ~ 1 TeV squarks/gluinos, harder cuts to suppress background)

Longer squark decay cascades, and $M_{\text{bino}} \gtrsim H_{125}$:

$\tilde{q} \to q + \tilde{g}$, $\tilde{g} \to q + \bar{q}$ + bino,
or $\tilde{g} \to t + \tilde{t}$, $\tilde{t} \to t$ + bino, bino $\to H_{125}+$ singlino:

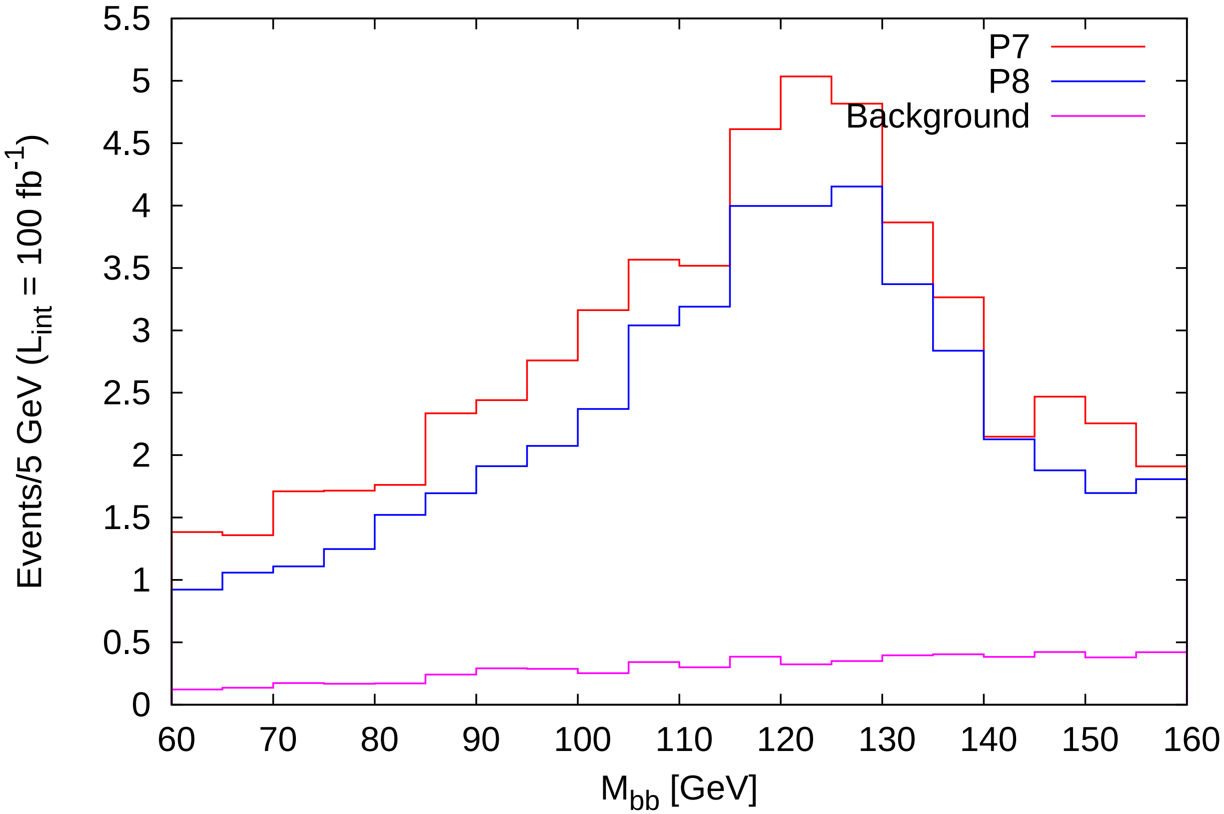
Higgses are less boosted, $H \to b\bar{b}$ gives two separate jets visible with $R = 0.4$ jet algorithms; their invariant mass M_{bb} should peak at M_{Higgs}

Examples (from "to appear"):

Benchmark point P7:
$\tilde{q}_{1.5\,TeV} \to q + \tilde{g}_{1.3\,TeV} \to q + t + \tilde{t}_{750\,GeV} \to q + t + \bar{t}$+bino,
bino $\to H_{125}$+singlino

Benchmarkpoint P8: same with $t \leftrightarrow b$

$\longrightarrow$ Many jets, many b-quarks (some E_T^{miss} from leptonic t-decays)



M_{bb} for the benchmark points P7 and P8

After cuts on four hard jets with $P_T \geq 400,\ 300,\ 200,\ 100$ GeV and requiring two hadronic τ-leptons with combined $P_T \geq 100$ GeV

$\rightarrow$ Visible after a few 100 fb^{-1} luminosity

Conclusions:

The NMSSM with a light singlino LSP can lead to blind spots in standard SUSY search channels, due to "missing" E_T^{miss}

$\longrightarrow$ The present scenario is consistent with constraints from run I with both squark and gluino masses of ~ 900 GeV

$\longrightarrow$ Production cross sections up to ~ 5 pb at 13/14 TeV are possible (compared to ~ 30 fb for Standard Model Higgs pair production)

Dedicated search strategies for Higgs pairs plus many jets are required

$\rightarrow$ may lead to a discovery of both Supersymmetry and, possibly, additional NMSSM specific Higgs bosons