LHC Signatures of Natural SUSY

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EW Fine-tuning

arXiv: 1207.3343, 1404.1386

- Minimization condition for higgs scalar potential (1-loop)

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

- Naturalness requires all terms on RHS comparable to LHS
  $\Rightarrow$ fine-tuning parameter

$$\Delta_{EW} \equiv max\left(\frac{m_{H_u}^2}{M_Z^2/2}\frac{\tan^2\beta}{\tan^2\beta-1}, \frac{\Sigma_u^u}{M_Z^2/2}\frac{\tan^2\beta}{\tan^2\beta-1}, \frac{\mu^2}{M_Z^2/2}, \ldots\right)$$

- Δ_{EW}=100 corresponds to 1% EWFT, Δ_{EW}=30 is ~3% EWFT
- Limited value of Δ_{EW} $\Rightarrow$ upper limit on $m_{H_u}^2$ and μ^2
- Δ_{EW} is a bound on FT, it measures minimal FT present in given spectrum (see X.Tata talk)

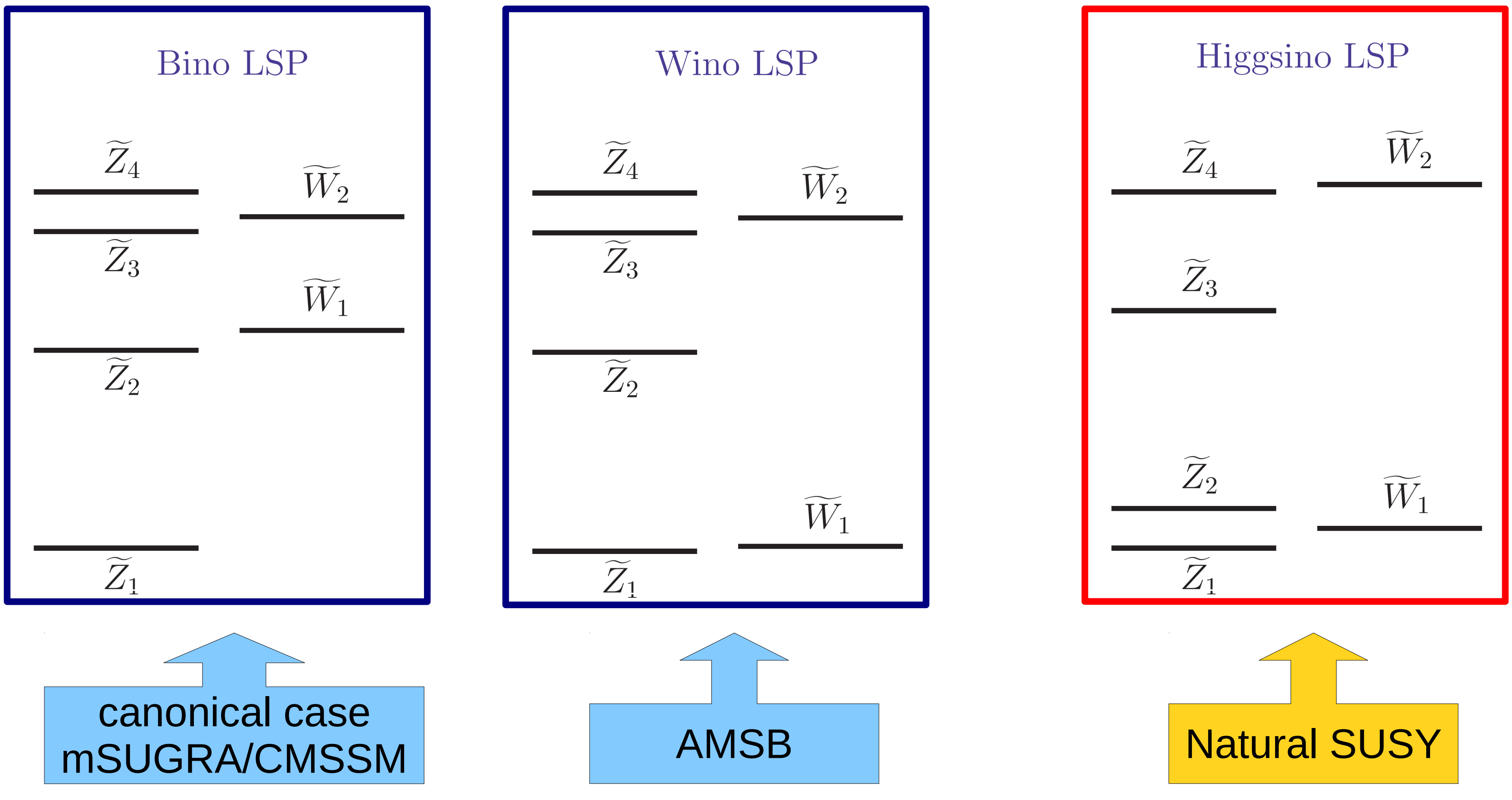
Summary of Natural spectrum

- For $m_h \sim 125$ GeV and $\Delta_{EW} < 30$:
    - $\mu \sim$ 100-300 GeV
    - stop_1 ~ 1-2 TeV, stop_2 = sbottom_1 ~ 2-4 TeV
    - gluino ~ 1-5 TeV
    - 1st/2nd generation squarks ~ 1-10 TeV
    - sleptons ~ 1-30 TeV
- This can be realized in a simple extension of mSUGRA, NUHM2

$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mu,\ m_A$$

- Here small $m_{H_u}^2 \simeq -M_Z^2$ and lighter stops are generated by RGE evolution, hence Radiatively-driven Natural SUSY (RNS) name

EW-ino spectrum



- Current ATLAS/CMS limits done in simplified models and not applicable to the light higgsino case

Hard trilepton signals

arXiv: 1310.4858

- Trileptons are golden channel for gaugino searches that relies on 3-body decay of neutralinos:
    - ATLAS/CMS exclude up to mass ~700GeV
    - or up to ~300GeV via WZ for 100% BF
- In RNS sleptons are heavy and the 3-body decays closed,

$$pp \to \widetilde{W}_2 \widetilde{Z}_4 \to (\widetilde{W}_1 Z) + (\widetilde{W}_1 W) \to WZ + E_T^{\rm miss} \to \ell^+ \ell^- \ell' + E_T^{\rm miss}$$

25%

- No reach at LHC8 beyond LEP2 bound
- At LHC14 the reach extends to $m_{1/2} = 500\ (630)\ \mathrm{GeV}$ for 300 (1000) fb^{-1}

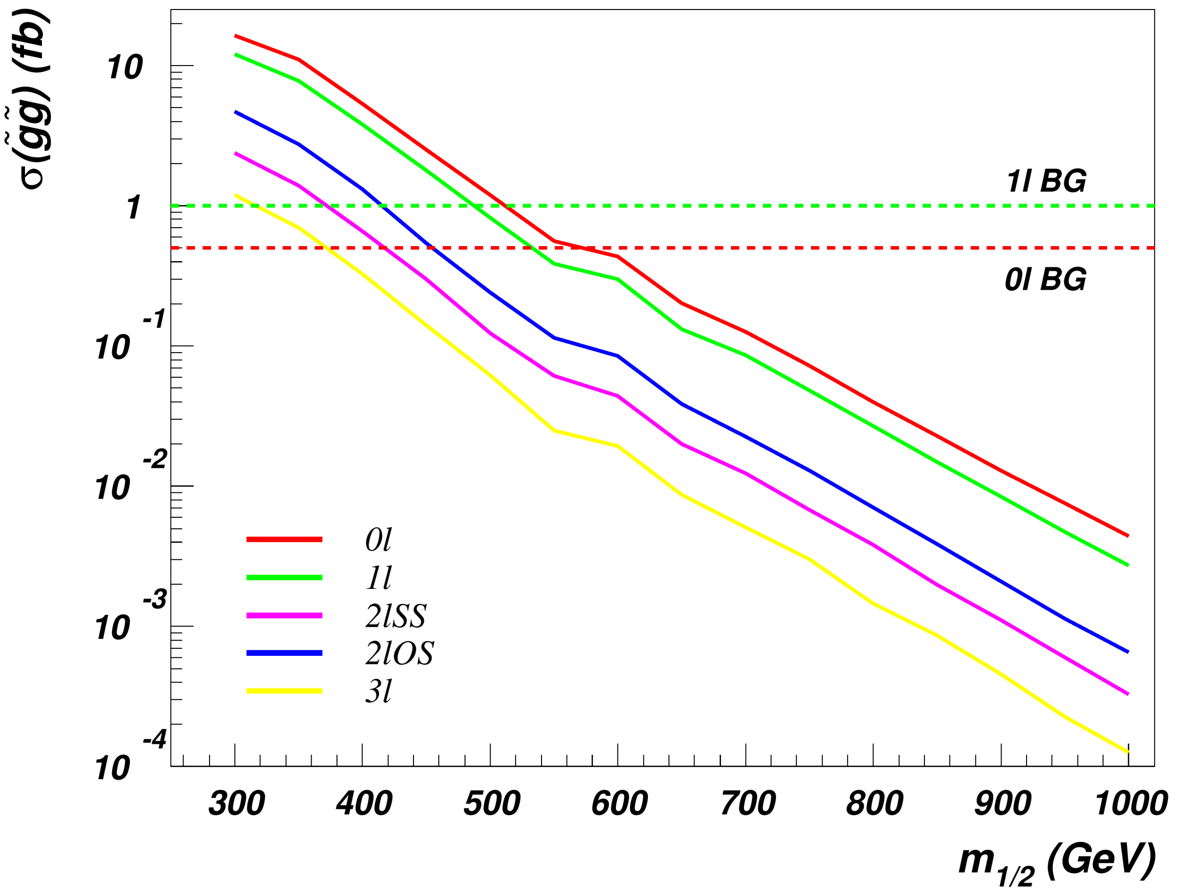
Gluino cascades

arXiv: 1310.4858

- $pp \to \tilde{g}\tilde{g}X$ followed by gluino cascades lead to multi-jets + multi-leptons + MET signature

NUHM2: m_0=5 TeV, A_0=-1.6m_0, tanβ=15, μ=150 GeV, m_A=1 TeV

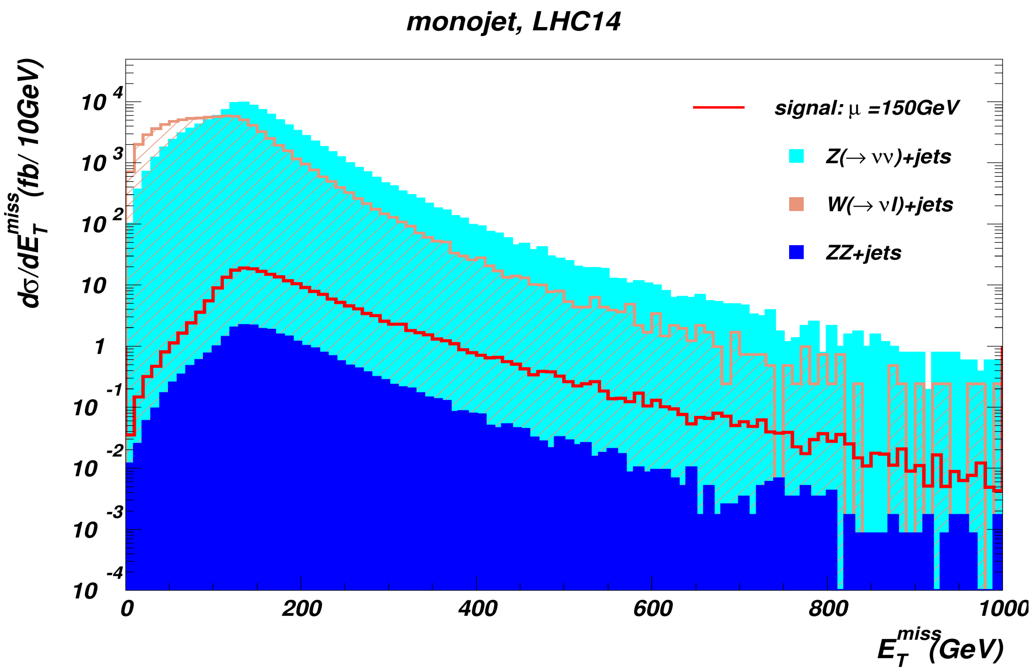
- LHC14 can only probe part of natural gluino mass range, up to 1700 GeV (1900 GeV) for 300 (1000)fb^{-1}
- $\widetilde{Z}_2 - \widetilde{Z}_1$ mass gap (if >25 GeV) can be measured from OS/SF dileptons



Mono-jets and mono-photons

arXiv: 1401.1162

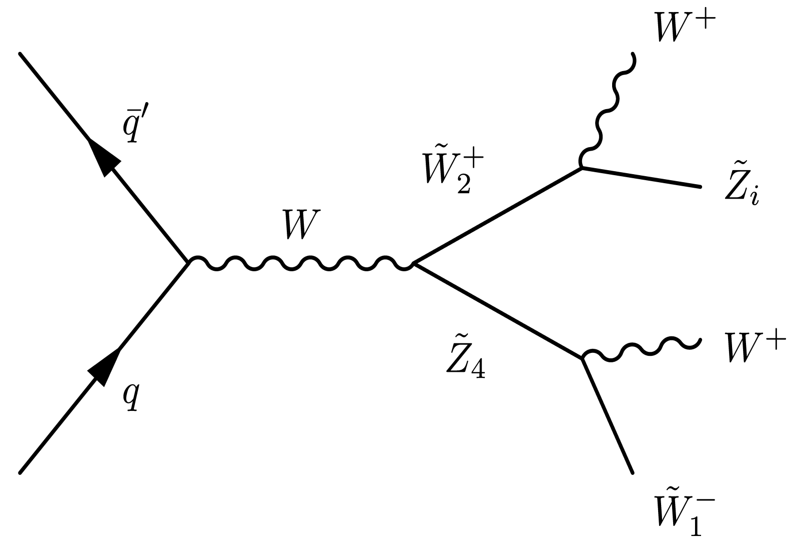
- Higgsinos have compressed spectrum with mass gap 10-30 GeV – only soft visible decay products
- $$pp \to \widetilde{Z}_{1,2}\widetilde{Z}_{1,2}/\widetilde{Z}_{1,2}\widetilde{W}_1/\widetilde{W}_1\widetilde{W}_1 + (j \text{ or } \gamma)$$
- Contact interaction, used in ATLAS/CMS search, not applicable: mediator mass $M_Z \ll \sqrt{\hat{s}} \sim p_T(jet) + E_T^{miss}$ leading to extra 1/s suppression for ME (see X.Tata talk)
- Signal has same shape as BG and S/B ≈1% detection is very challenging



Same-sign Dibosons

arXiv: 1302.5816

- Sizeable production cross section (~10-100 fb) for wino-like $\widetilde{Z}_4 \widetilde{W}_2$ and $\widetilde{W}_2 \widetilde{W}_2$
- Each decays into W about 50%
- Two W's are not charge correlated
- Same-sign WW is novel signature, charcteristic of light higgsinos
- No 2->2 SM production of ssWW
- BG from WZ and ttbar removed by mT>125 GeV cut



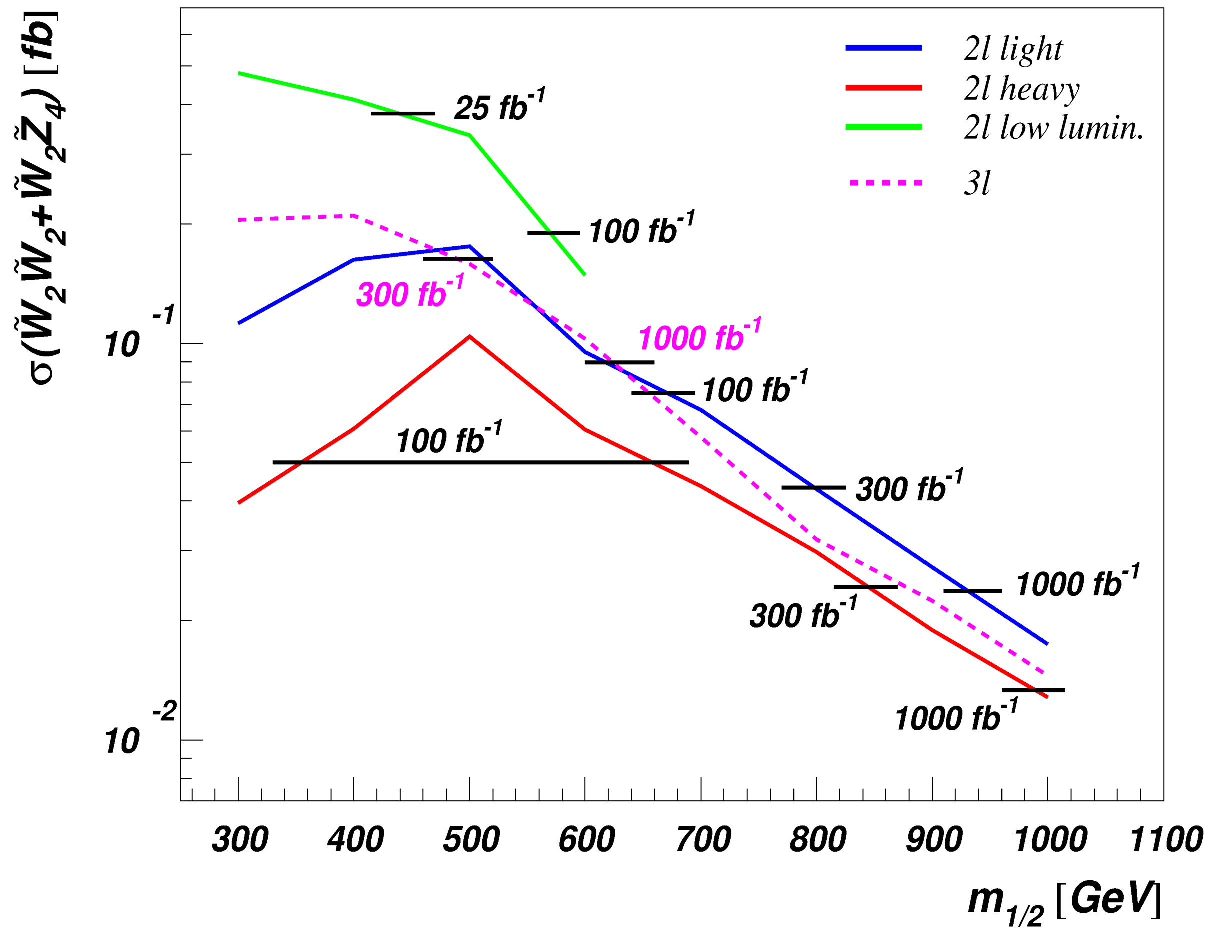
- 2lSS+MET is not probed by existing di-lepton searches that require significant hadronic activity

ssWW prospects

arXiv: 1302.5816,
1310.4858

- Reach for 100 (1000) fb^{-1} extends to $m_{1/2} \sim 680\ (1000)\ \mathrm{GeV}$
- Better than canonical 3-lepton reach
- Exceeds direct gluino production reach (if gaugino masses are unified)
- Independent of gluino search!

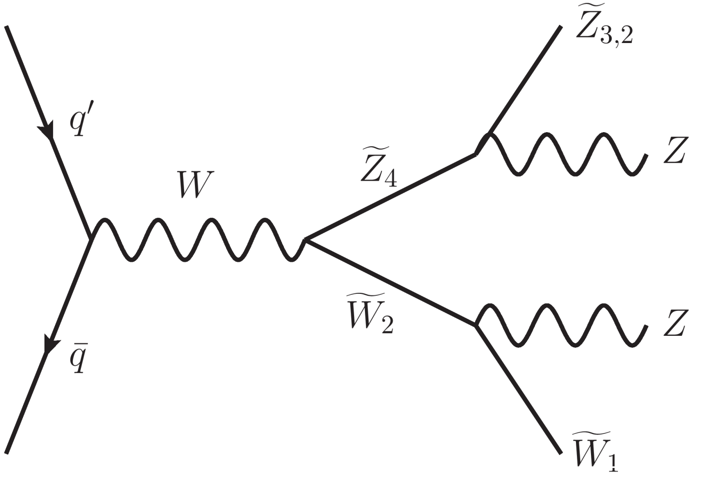
NUHM2: m_0=5 TeV, A_0=-1.6m_0, tanβ=15, μ=150 GeV, m_A=1 TeV



4-lepton signal

arXiv: 1310.4858

- Winos also have significant BF to Z, 25-50%
- Novel channel for low |μ| models: 4 isolated leptons + MET and no jets
- BGs controlled by MET > 200 GeV cut
- Reach for 300 (1000) fb^{-1} extends to $m_{1/2} \simeq 500\ (650)\ \mathrm{GeV}$
  - confirmatory channel for same-sign WW



- Current 4-lepton searches are optimized for glunio cascades in RPV with many leptons and jets

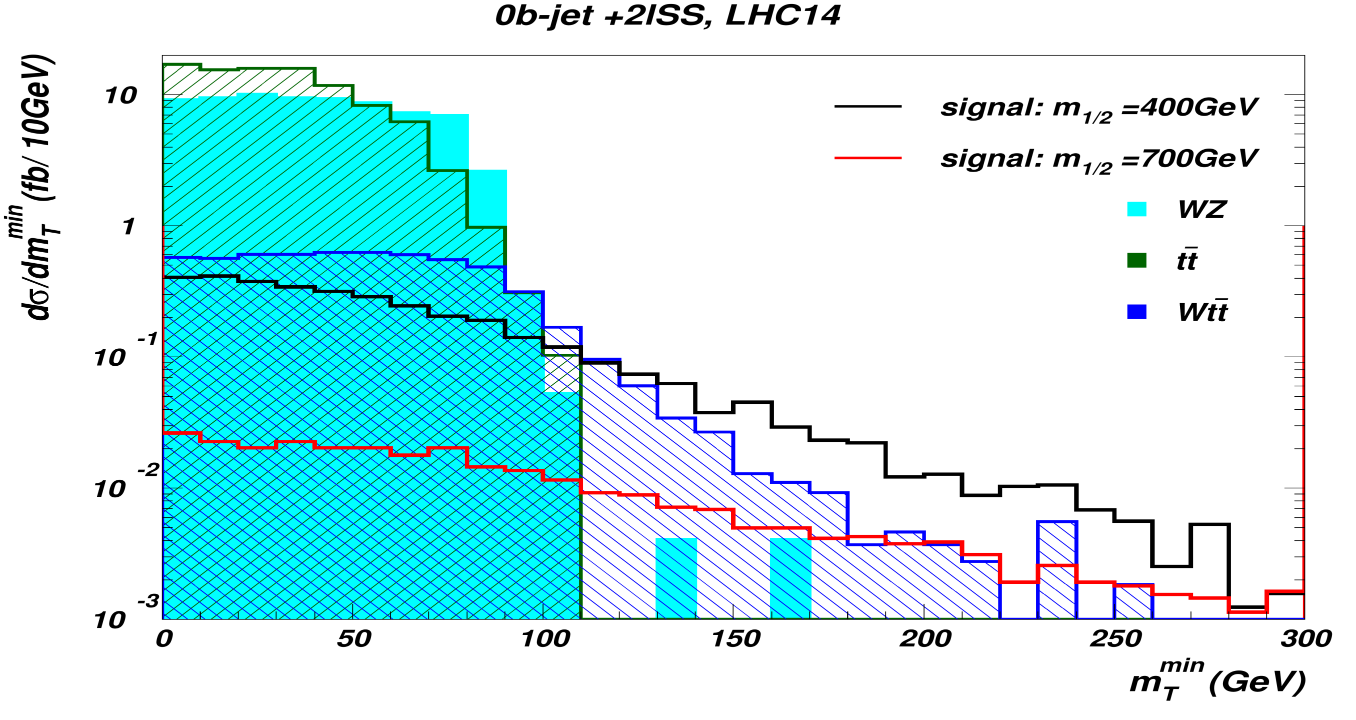
Conclusions

- Although FT is intrinsically model dependent, generic pheno studies of natural SUSY are possible with Δ_{EW} – lower bound on FT.
- Small μ is necessary (but not sufficient) condition for naturalness. It is more fundamental than light stops!
- Higgsino-like chargino and neutralinos are difficult to detect at LHC due to low visible energy release from their decays.
- Diboson productions are novel signatures characteristic of light higgsino scenario. They depend only on EW-ino spectrum.
- Same-sign WW can probe wino masses up to 550 (800) GeV, for 100 (1000) fb^{-1} at LHC14. Larger reach than in canonical trilepton channel.
- LHC can cover large portion of para space with FT >3% by ssWW, but ILC with ~600 GeV is necessary to complete the test of SUSY naturalness.

Cuts for ssWW

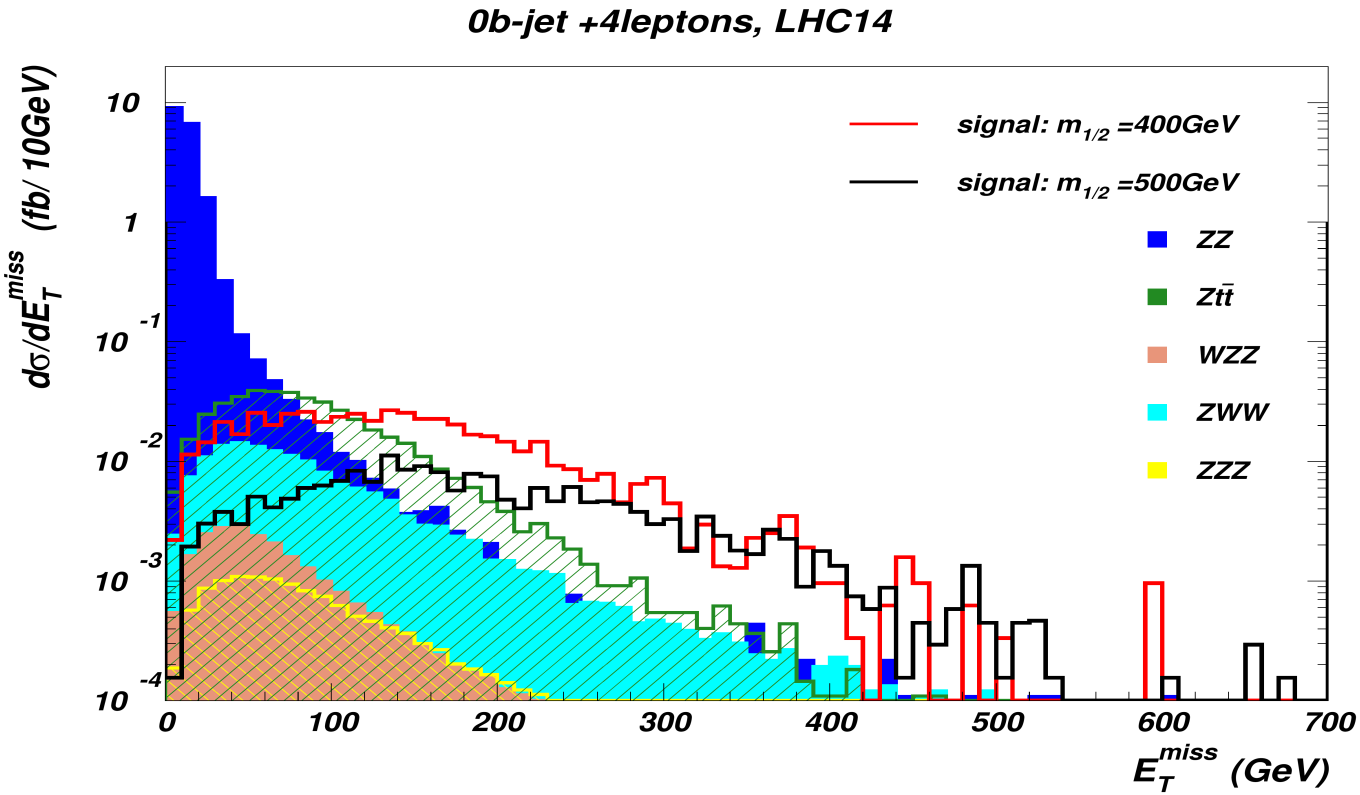
- b-jet veto (60% eff.)
- 2 isolated same-sign leptons $p_T(l_1) > 20GeV,\ p_T(l_2) > 10GeV$
- $m_T^{min} \equiv \min\left[m_T(l_1,\not{E}_T), m_T(l_2,\not{E}_T)\right] > 125GeV$

  removes WZ and ttbar due to kinematic cutoff for on-shell W
- MET>200GeV



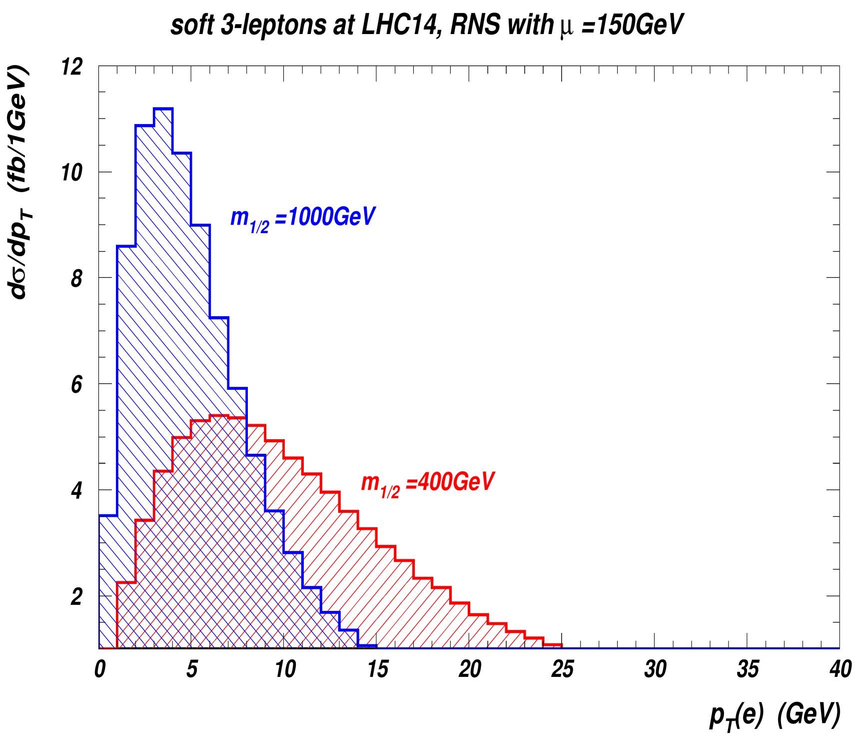
Cuts for ZZ

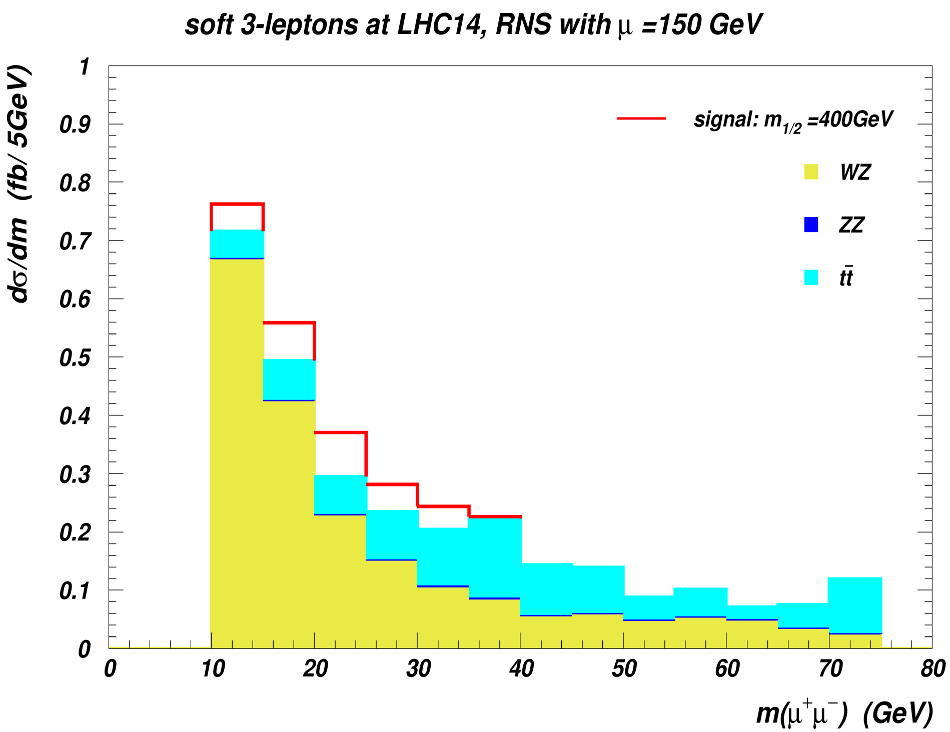
- b-jet veto (60% eff.)
- 4 isolated leptons with $p_T(l) > 10 \text{ GeV}, \ |\eta(l)| < 2.5$
- MET > 100 (200) GeV



Soft trileptons

- Mass gap between higgsinos is <30 GeV $\Rightarrow$ very soft leptons for higgsino pair production
- $pp \longrightarrow \widetilde{W}_1 \widetilde{Z}_2 \longrightarrow (e\nu_e \widetilde{Z}_1) + (\mu^+\mu^- \widetilde{Z}_1)$





- A shape analysis may allow to claim a signal with high luminocity