Probing natural susy: from stop to higgsino

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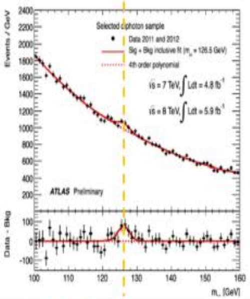
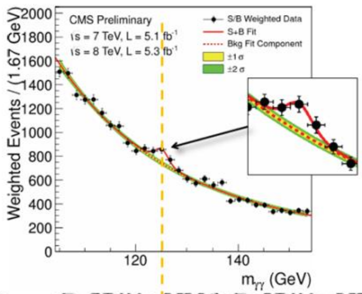
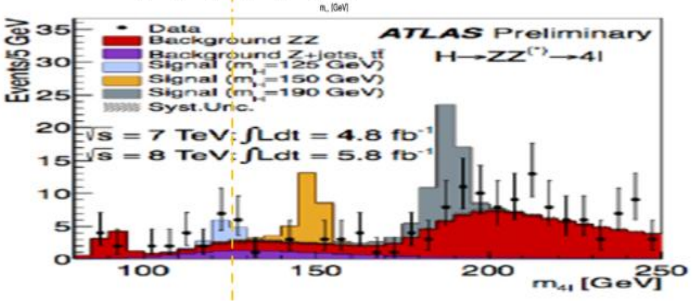
Outline

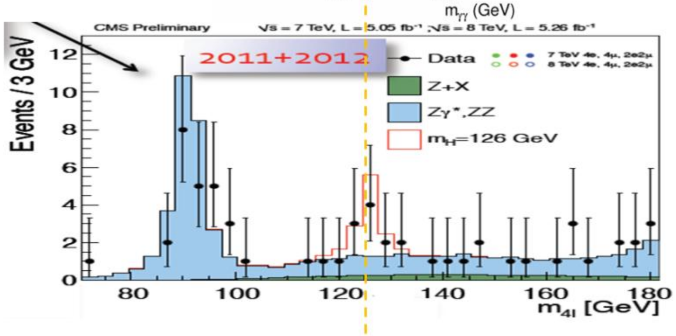
- Higgs boson, Naturalness and SUSY;
- Stop mass limit in Natural MSSM;
- Monojet signal of higgsinos in Natural MSSM.

Higgs boson, SUSY searches-Naturalness



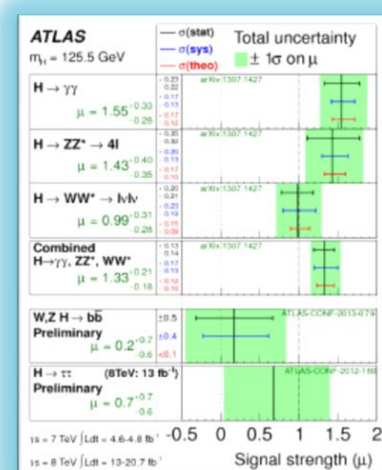


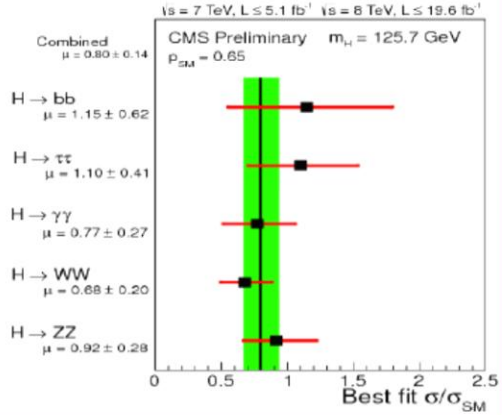




- The **ATLAS** and **CMS** experiments have unequivocally discovered a **new neutral boson** of **mass ~ 125 GeV;**
- Measuring its **properties** is a fundamental step to determine its **nature:**
  - Signal strengths;
  - Couplings (to fermions and bosons);
  - Quantum numbers (spin and parity);
  - Exotic Higgs decays.

Signal strengths:





- **ATLAS** (γγ, WW* and ZZ*) $\mu = 1.33^{+0.21}_{-0.18}$ ($\mu = 1.23^{+0.18}_{-0.18}$ including bb and ττ)
- **CMS** (γγ,bb, ττ, WW* and ZZ*) $\mu = 0.80^{+0.14}_{-0.14}$

Compatible with the SM Higgs boson expectation at 15% level

Spin & CP:

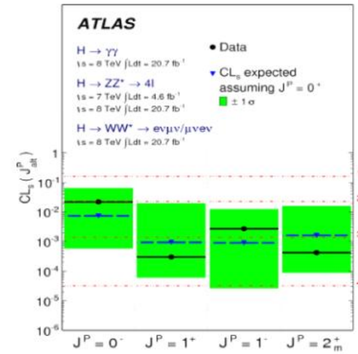
CMS

CL_s	ZZ → 4l	WW→2l2ν	Comb ZZ-WW	γγ
0^-	0.16 %	-	-	-
1^-	< 0.1%			
1^+	< 0.1%			
$2_m^+(gg)$	1.5%	14%	0.6%	60.9%
$2_m^+(q\bar{q})$	0.1%	-	-	16.9%

Spin-parity tested in bosonic modes

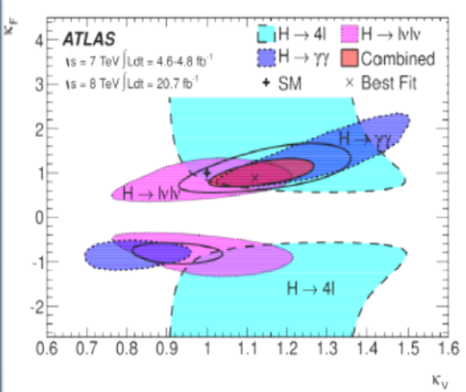
Strongly favored SM 0^+ hypothesis

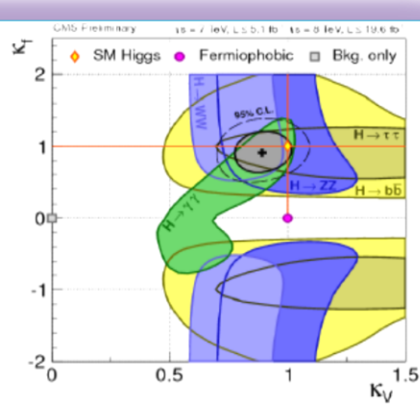
Many alternative models tested:
Excluded at > 95% CL



But CP mixing state not excluded

Couplings:



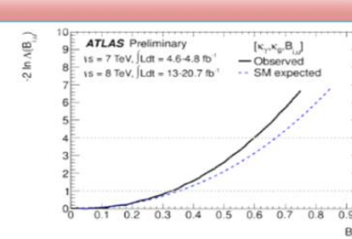


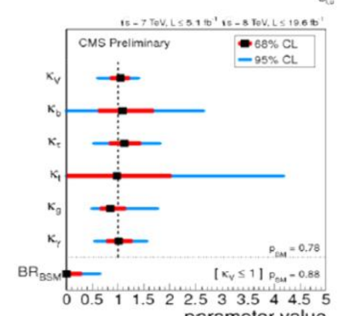
All experiments compatible with SM predictions at ~10-20%

- **ATLAS**: κ_V [1.05,1.22] at 68% CL - κ_F [0.76,1.18] at 68% CL
- **CMS** : κ_V [0.74,1.06] at 95% CL - κ_F [0.61,1.33] at 95% CL

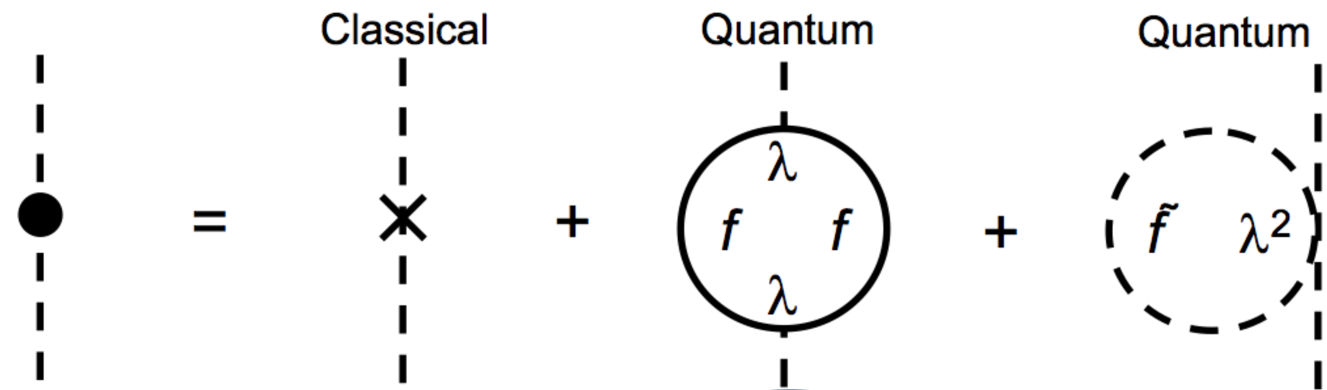
Exotic Higgs decays:

- Limits from direct searches (ZH → ll – invisible)
  ATLAS: BR_{inv} < 0.65 @ 95% CL
  CMS : BR_{inv} < 0.75 @ 95% CL
- $\Gamma_H = \Gamma_{SM} + \Gamma_{BSM} \rightarrow BR_{BSM} = \Gamma_{BSM} / \Gamma_H$
- BR_{BSM} is sensitive to invisible and undetectable decay modes (H → light hadrons)
- **ATLAS**
  Assume tree level couplings: $\kappa_b = \kappa_W ... = 1$
  $\Gamma_{SM} \sim 0.9 + 0.1\ \kappa_g$
  3 fitted parameters: κ_γ , κ_g and BR_{BSM}
  - BR_{BSM} < 0.6 @ 95% C.L.
- **CMS**
  Assume $\kappa_V \leq 1$ (motivated by EWSB)
  7 fitted parameters: $\kappa_V, \kappa_t, \kappa_b, \kappa_\tau, \kappa_\gamma, \kappa_g$ and BR_{BSM}
  - BR_{BSM} < 0.64 @ 95% C.L.





Naturalness, MSSM



$$m_h^2 = (m_h^2)_0 - \underbrace{\frac{1}{16\pi^2}\lambda^2\Lambda^2 + \frac{1}{16\pi^2}\lambda^2\Lambda^2} + \frac{1}{16\pi^2}\lambda^2(m_{\tilde{f}}^2 - m_f^2)\ln(\Lambda/m_h)$$

Quadratic divergence

Supersymmetry can stabilize the Higgs mass by introducing the symmetry between fermions and bosons

- In MSSM, we usually start to discuss the fine tuning from the minimization of scalar potential of the MSSM leads to the well-known relation：

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

$m_{H_{u,d}}$ is the soft mass;

$\Sigma_{u,d}$ is the radiative correction;

μ is higgsino mass.

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

- In large tanb approximation,

Tree level

1 loop level

$$m_Z^2 = -2(m_{H_u}^2 + |\mu|^2) + \dots$$

$$\delta m_{H_u}^2 \approx -\frac{3y_t^2 m_{\tilde{t}}^2}{4\pi^2}(1 + a^2/2)\log\frac{\Lambda}{m_{\tilde{t}}}$$

$$\delta m_{\tilde{t}}^2 = \frac{8\alpha_s}{3\pi} M_3^2 \log\frac{\Lambda}{M_3}$$

2 loop level

arxiv:1112.2703

- So, if low fine tuning, spectrum of sparticles should be:

$$|\mu| \sim 100 - 200\text{GeV};$$

$$m_{\tilde{t}_1} < 1 \text{ TeV};$$

$$m_{\tilde{g}} < 3 \text{ TeV};$$

$$m_{\tilde{q}_{1,2}} \sim 10 - 30 \text{ TeV};$$

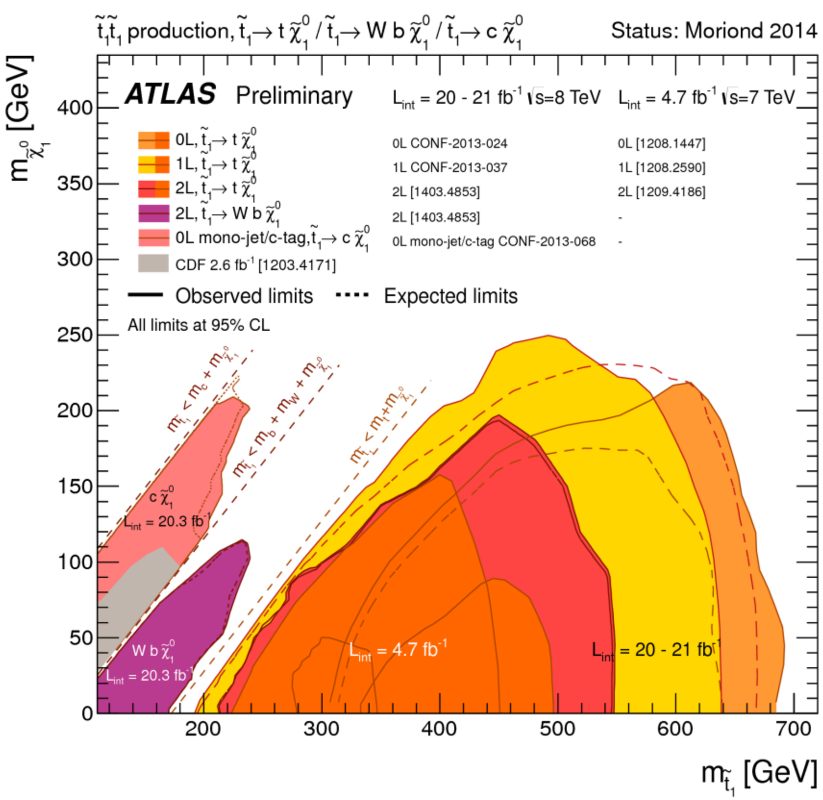
$$m_h \sim 125 \text{ GeV}.$$

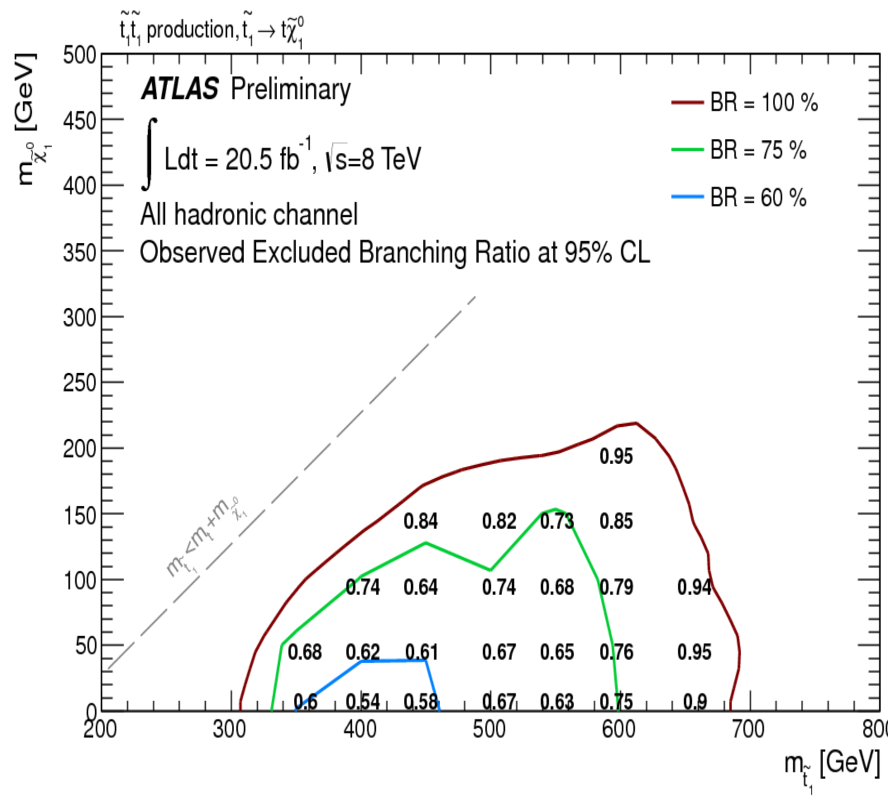
10 % Fine tuning

If you believe naturalness principle, the target of SUSY searches would be:

light stop and light Higgsinos!

- The limit on the stop mass at LHC





- What is stop mass limit in natural susy?

Since the component of the lighter stop will affect its decay modes, we class it into two scenarios:

Scenario I the stop is left-hand like $m_{\tilde{t}_L} < m_{\tilde{t}_R}$

Scenario II the stop is right-hand like $m_{\tilde{t}_L} > m_{\tilde{t}_R}$

I. Constraints on stop in natural MSSM

Scan of the following parameter space

$m_{\tilde{q}_3} < 2 \text{ TeV}$

$m_{\tilde{u}_3} = m_{\tilde{d}_3} < 2 \text{ TeV}$

$m_1 = m_2 = m_3 = 2 \text{ TeV}$

$m_{\tilde{l}_{1,2,3}} = m_{\tilde{q}_{1,2}} = m_{\tilde{e}_{1,2,3}} = 5 \text{ TeV}$

$-3 \text{ TeV} < A_t = A_b < 3 \text{ TeV}$

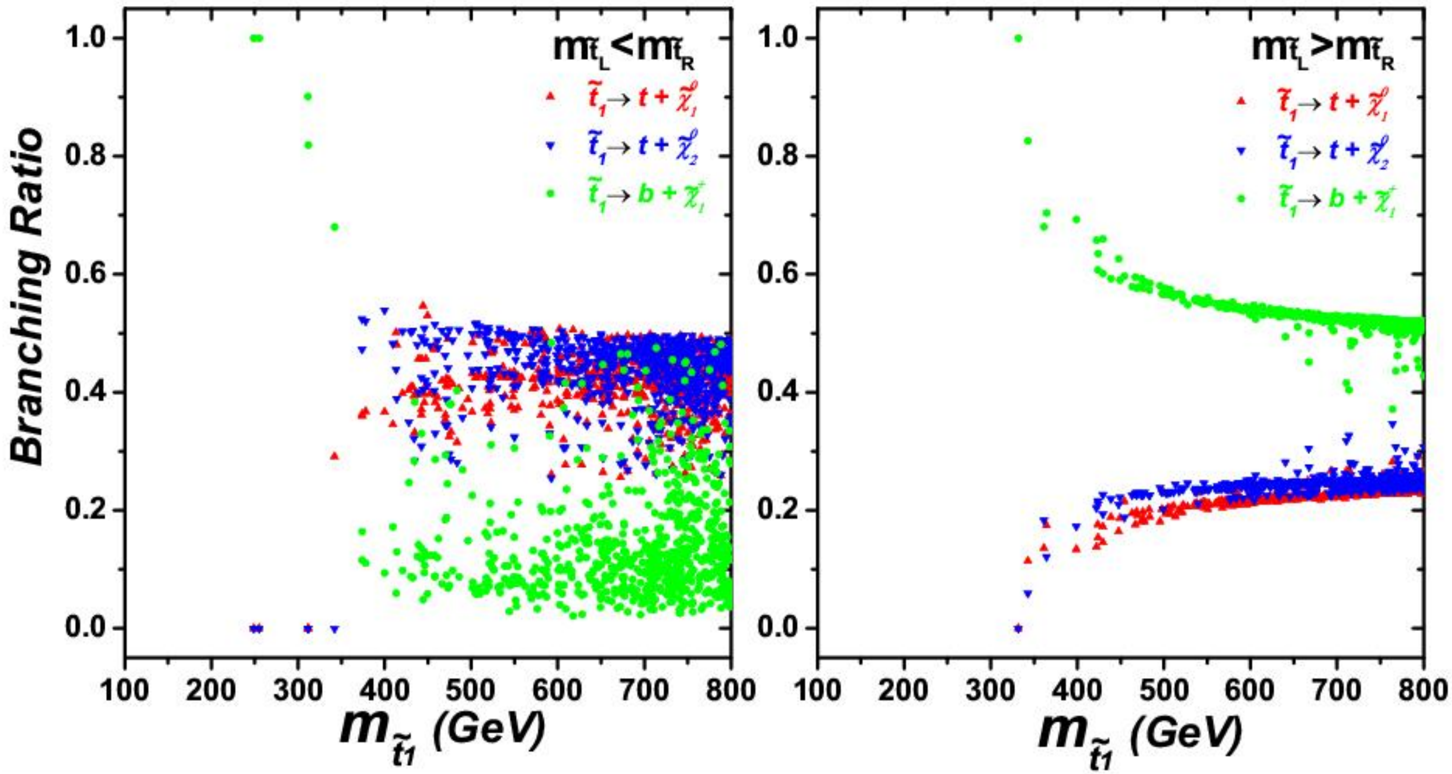
$100 \text{ GeV} < \mu < 200 \text{ GeV}$

$1 < \tan\beta < 60$

$100 \text{ GeV} < m_A < 2000 \text{ GeV}$

We also require $m_{\tilde{t}_1} < 1.5 \text{ TeV}$, $m_{\tilde{t}_2} < 2 \text{ TeV}$

I. Constraints on stop in natural MSSM



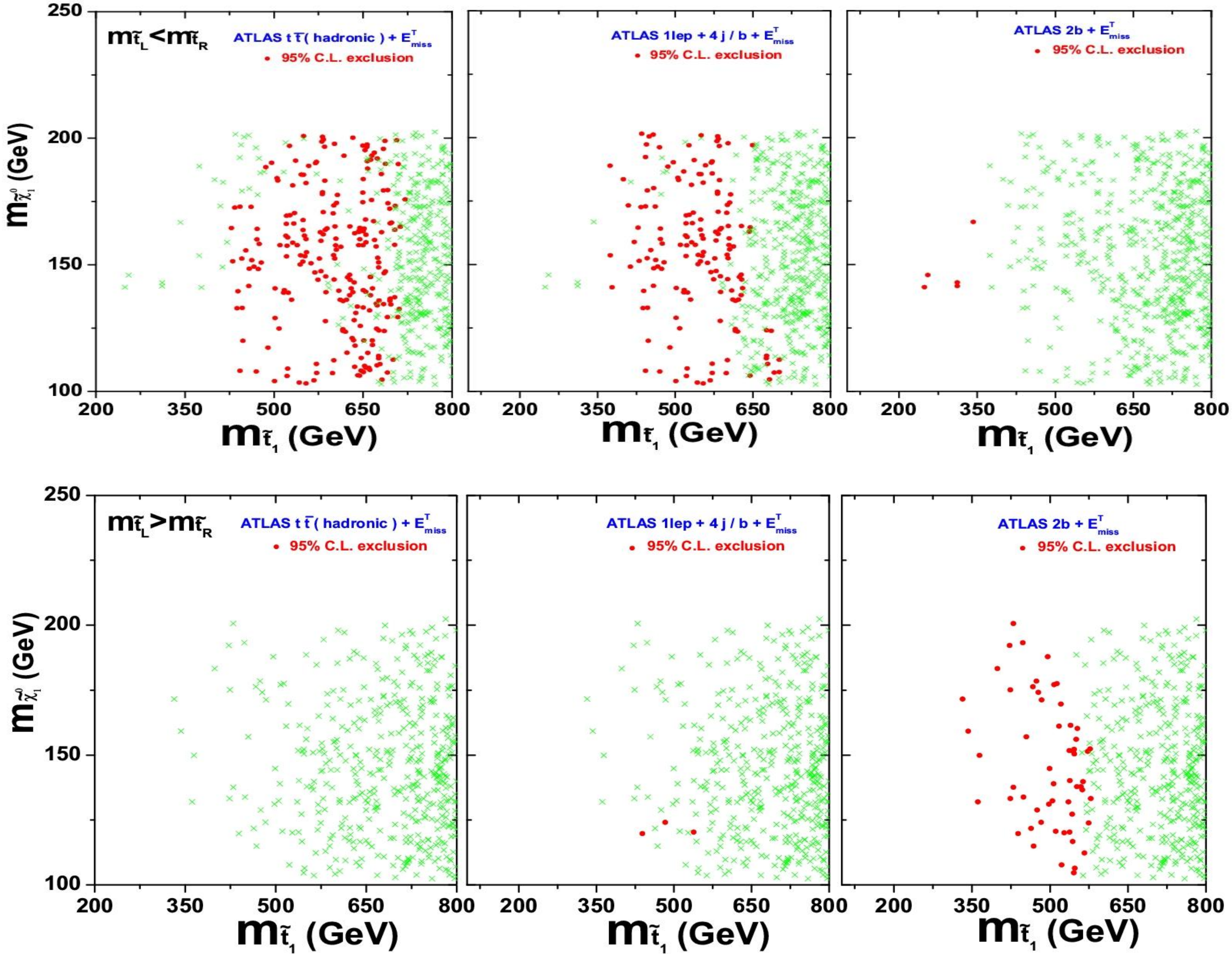
I. Constraints on stop in natural MSSM

- **Attention:**

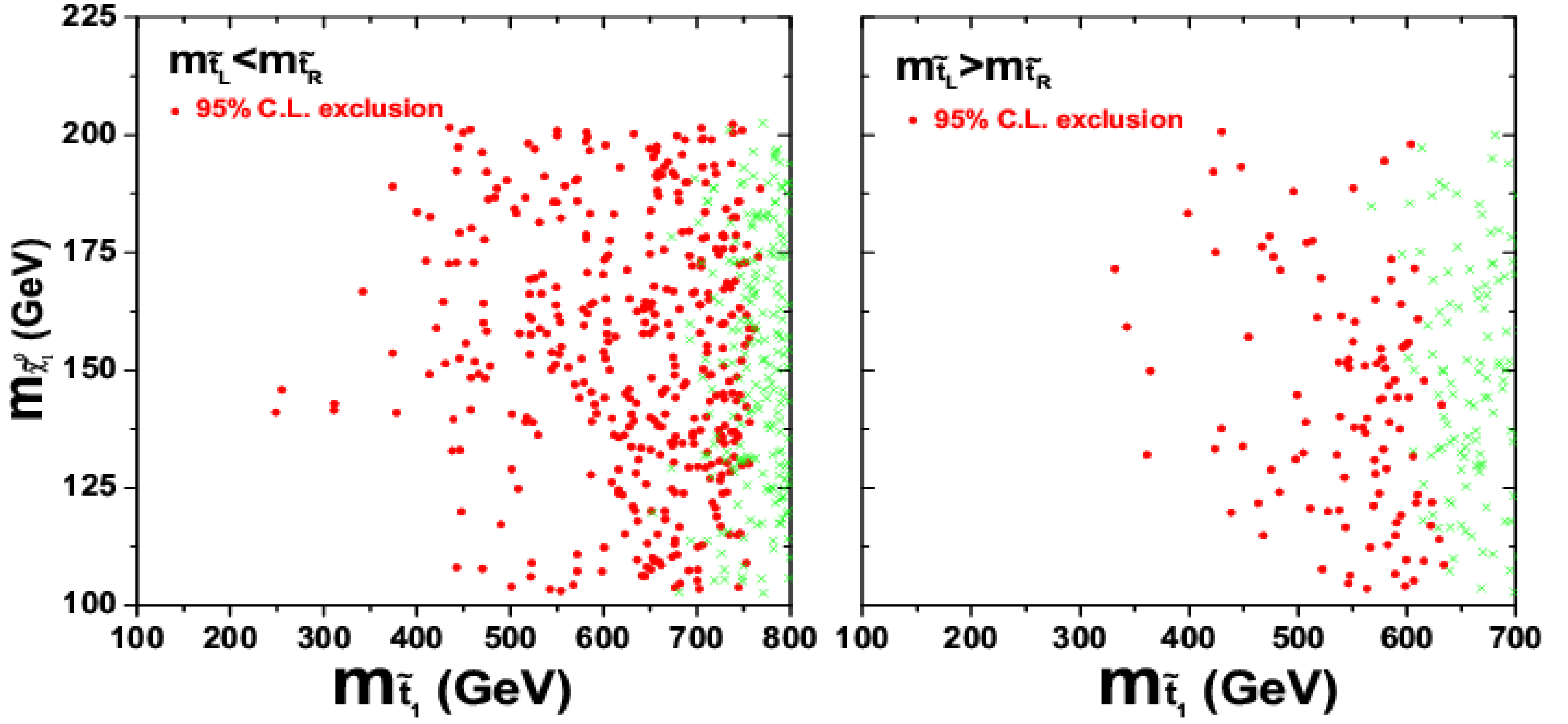
  Degenerate Higgsinos !

ATLAS stop/sbottom direct searches	natural MSSM stop/sbottom decays
$\ell + jets + \not{E}_T$	$\tilde{t} \to t\tilde{\chi}^0_{1,2}$, $\tilde{b} \to t\tilde{\chi}^-_1$
$t\bar{t}$(hadronic)$+\not{E}_T$	$\tilde{t} \to t\tilde{\chi}^0_{1,2}$, $\tilde{b} \to t\tilde{\chi}^-_1$
$2b + \not{E}_T$	$\tilde{b} \to b\tilde{\chi}^0_{1,2}$, $\tilde{t} \to b\tilde{\chi}^+_1$

I. Constraints on stop in natural MSSM



I. Constraints on stop in natural MSSM



A stop lighter than 600 GeV can be excluded at 95% CL.

II. Monojet signal of higgsinos in Natural MSSM

1. Feature of light higgsinos at collider

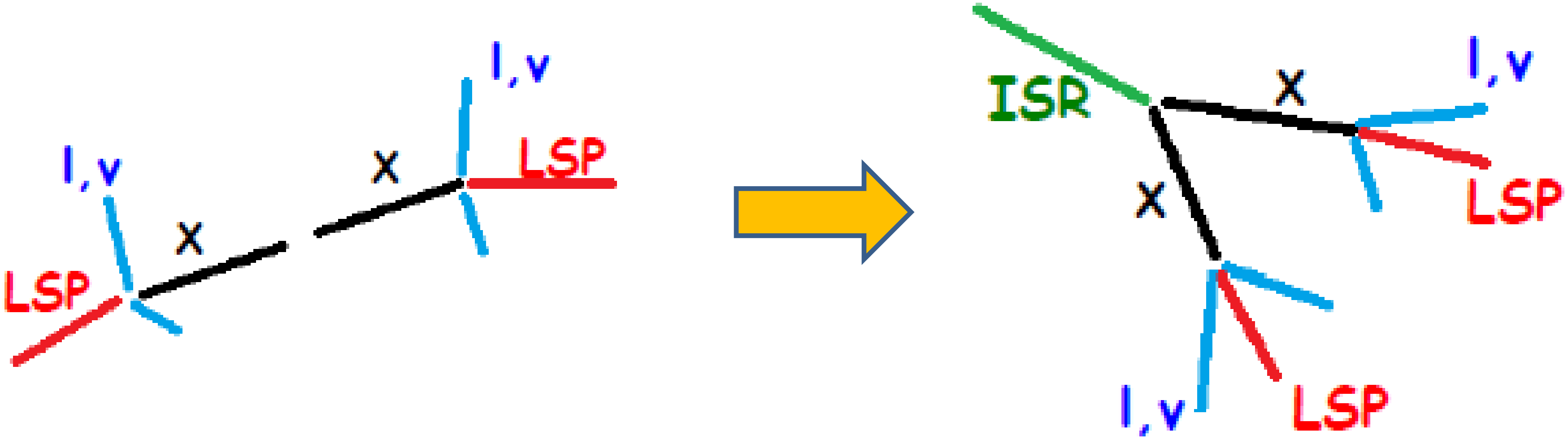
$$
\begin{aligned}
m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} &= \frac{M_W^2}{2M_2}\left(1 - \sin 2\beta - \frac{2\mu}{M_2}\right) \\
&+ \frac{M_W^2}{2M_1}\tan^2\theta_W(1 + \sin 2\beta), \\
m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} &= \frac{M_W^2}{2M_2}\left(1 - \sin 2\beta + \frac{2\mu}{M_2}\right) \\
&+ \frac{M_W^2}{2M_1}\tan^2\theta_W(1 - \sin 2\beta)\ .
\end{aligned}
$$

$M_{1,2} >> \mu$ → $\chi_1^\pm \approx \chi_{1,2}^0$

II. Monojet signal of higgsinos in Natural MSSM

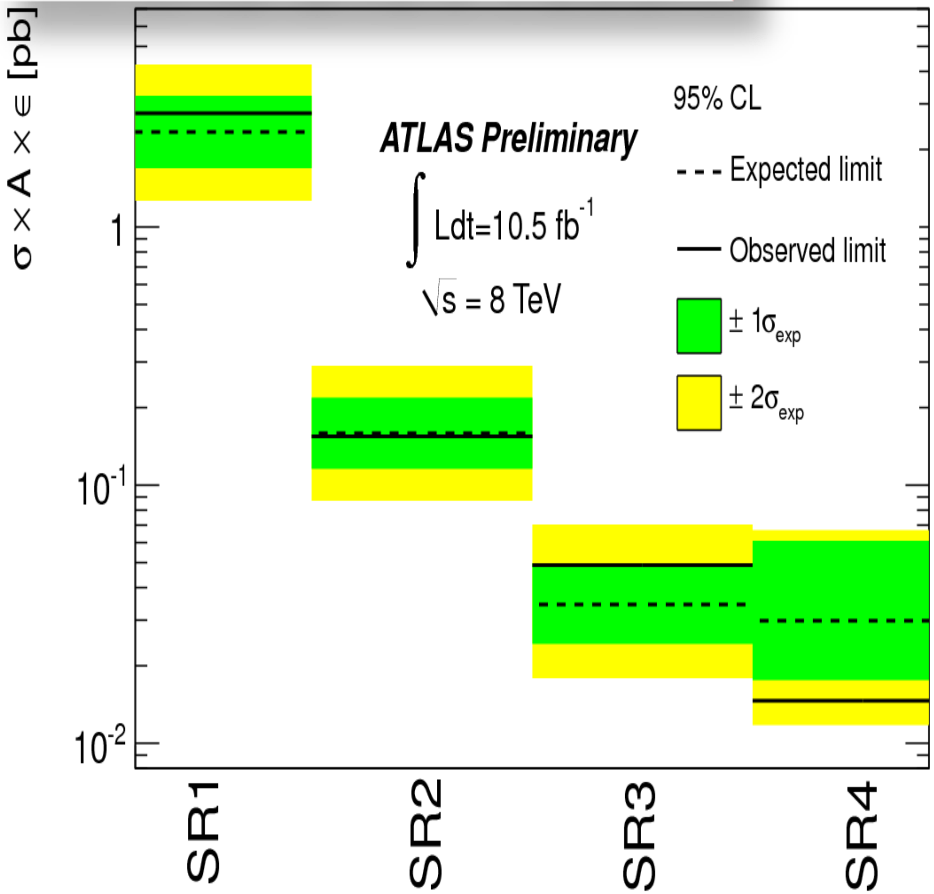
2. Monojet for light higgsinos

- Small-splitting region is generally less sensitive because visible particles are soft
- To improve, ISR jets or photons will be very helpful.



II. Monojet signal of higgsinos in Natural MSSM

ATLAS 8TeV result:



2.8 pb, 0.16 pb, 0.05 pb, and 0.02 pb

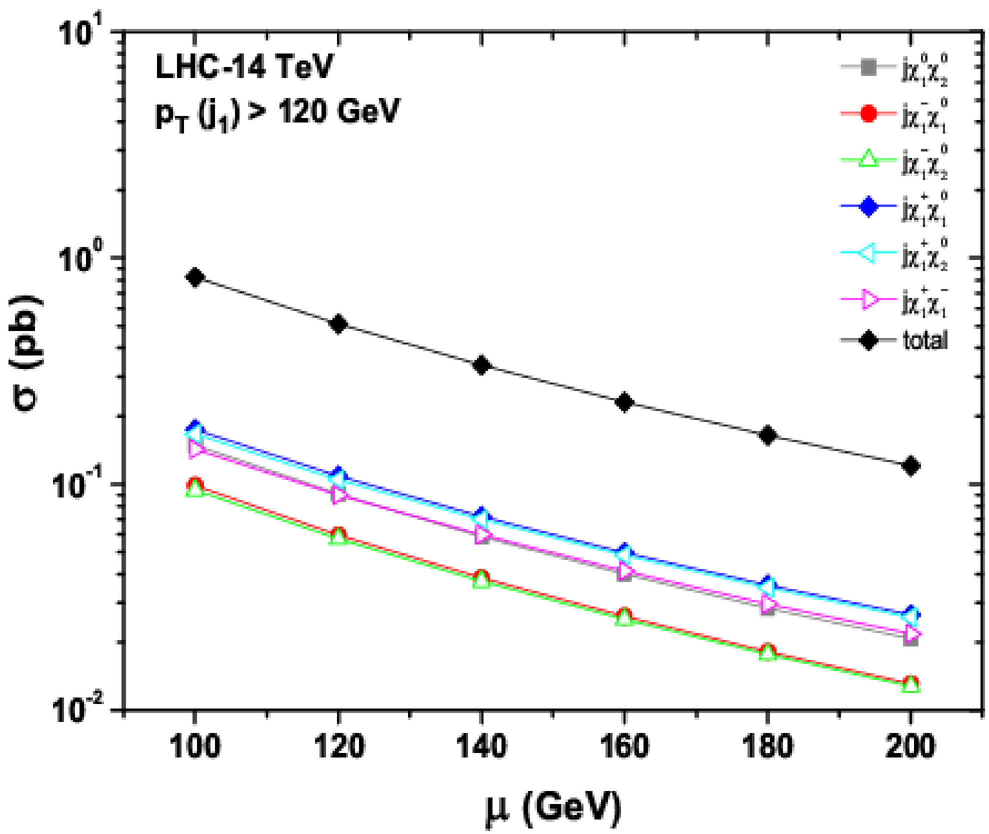
ATLAS-CONF-2012-147

Selection criteria				
Primary vertex				
$E_T^{miss} > 120$ GeV				
Jet cleanup requirements				
Leading jet with $p_T > 120$ GeV and $\|\eta\| < 2.0$				
At most two jets with $p_T > 30$ GeV and $\|\eta\| < 4.5$				
$\Delta\phi(\text{jet}, E_T^{miss}) > 0.5$ (second-leading jet)				
Lepton vetoes				
signal region	SR1	SR2	SR3	SR4
minimum leading jet p_T (GeV)	120	220	350	500
minimum E_T^{miss} (GeV)	120	220	350	500
Events in data (10.5 fb^{-1})	350932	25515	2353	268

II. Monojet signal of higgsinos in Natural MSSM

The Signals are:

$$pp \to j + (\tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\chi}_2^0\tilde{\chi}_2^0, \tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^0\tilde{\chi}_2^0, \tilde{\chi}_1^\pm\tilde{\chi}_{1,2}^0)$$



Signal is enhanced by the sum of all the higgsinos final states **!**

II. Monojet signal of higgsinos in Natural MSSM

The backgrounds are:

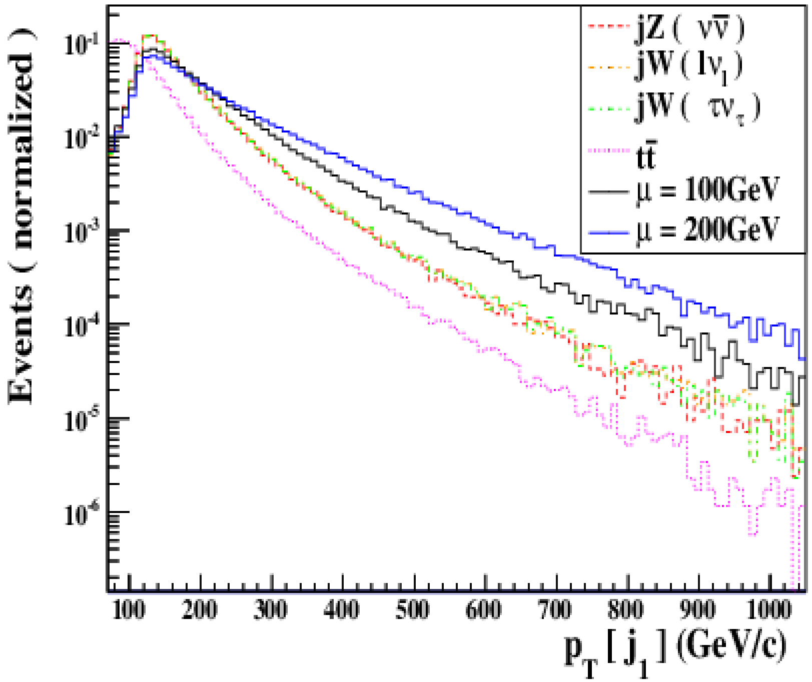
$Z(\to \nu\bar{\nu}) + j$, irreducible background;

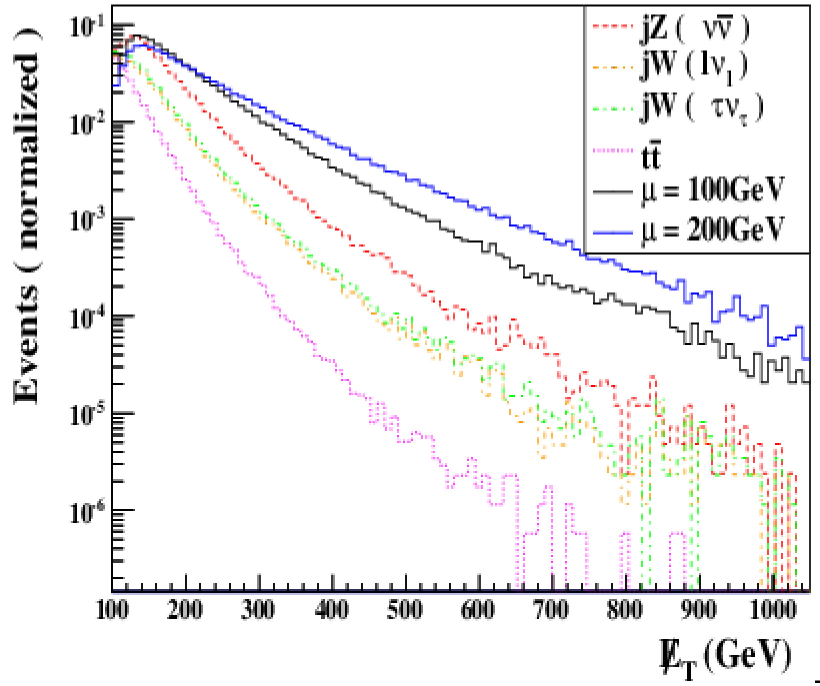
$W(\to \ell\nu_\ell) + j$, when lepton missing or close to jet

$W(\to \tau\nu_\tau) + j$, since 2nd jet from tau tends to E_T^{miss} side

$t\bar{t}$, dileptonic and semileptonic decay.

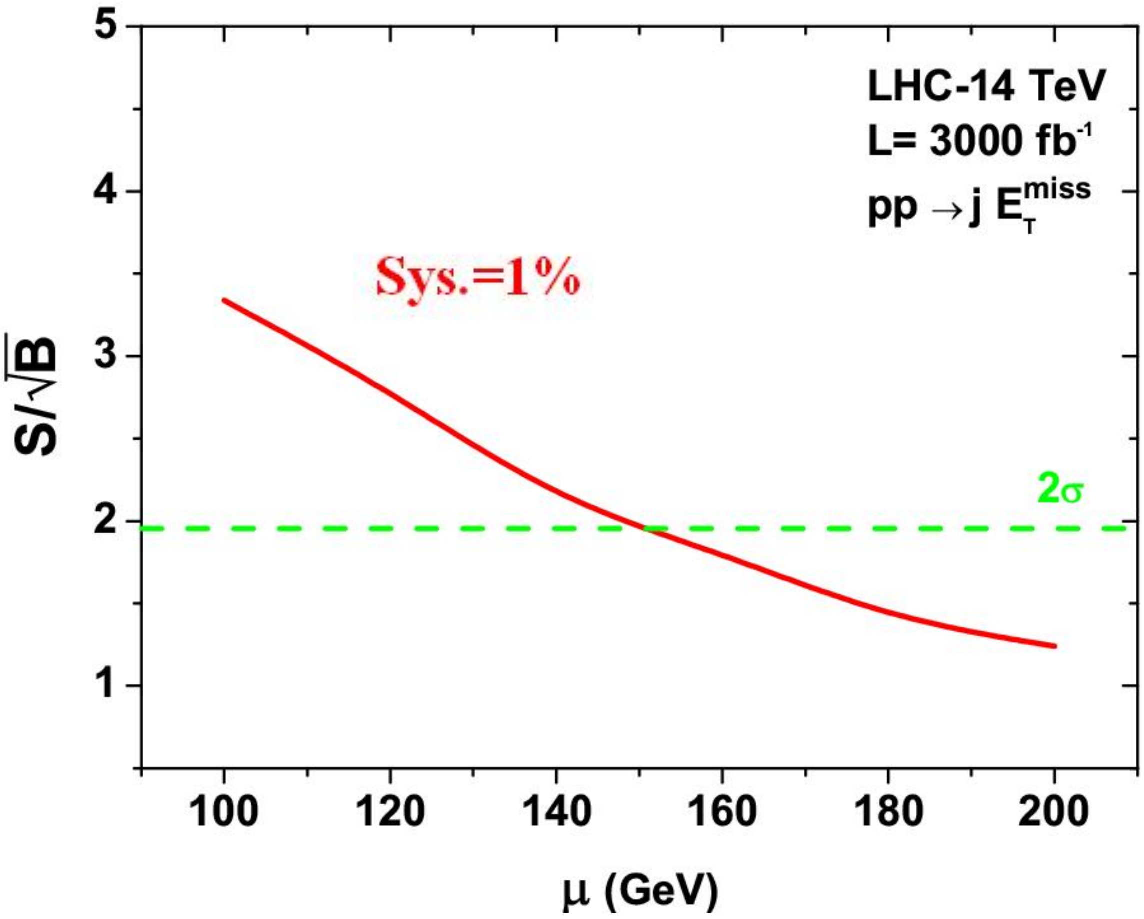
II. Monojet signal of higgsinos in Natural MSSM





cut	$Z(\nu\bar{\nu})+j$	$W(\ell\nu_\ell)+j$	$W(\tau\nu_\tau)+j$	$t\bar{t}$	Signal ($\mu = 100$ GeV)	Signal ($\mu = 200$ GeV)
$p_T(j_1) > 500$GeV	69322	241740	119078	210943	1242	415
$\not{E}_T > 500$GeV	26304	28209	16513	2786	950	335
veto on $p_T(j_2) > 100$, $p_T(j_3) > 30$	16988	12194	7577	306	602	223
veto on e, μ, τ	16557	3963	3088	102	597	220
veto on $b-$jets	16303	3867	3046	56	576	214

II. Monojet signal of higgsinos in Natural MSSM



No matter discovery or exclusion, the low fine tuning region can be touched by the LHC!

Conclusions

Conclusions:

- Natural SUSY is the most promising scenario of SUSY;
- Stop sector has been tightly constraints by the LHC data;
- Electroweakinos sector can be a feasible way to probe Natural SUSY;


STEPHEN COVEY:
Begin with the end in mind.