



# Light Top Squark in Precise Top Quark Sample

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# LHC is a QCD machine!

Find signals in the strong interacting background: 1 out of  $10^8$ .  
Only final states with certain distinguished features can be triggered:

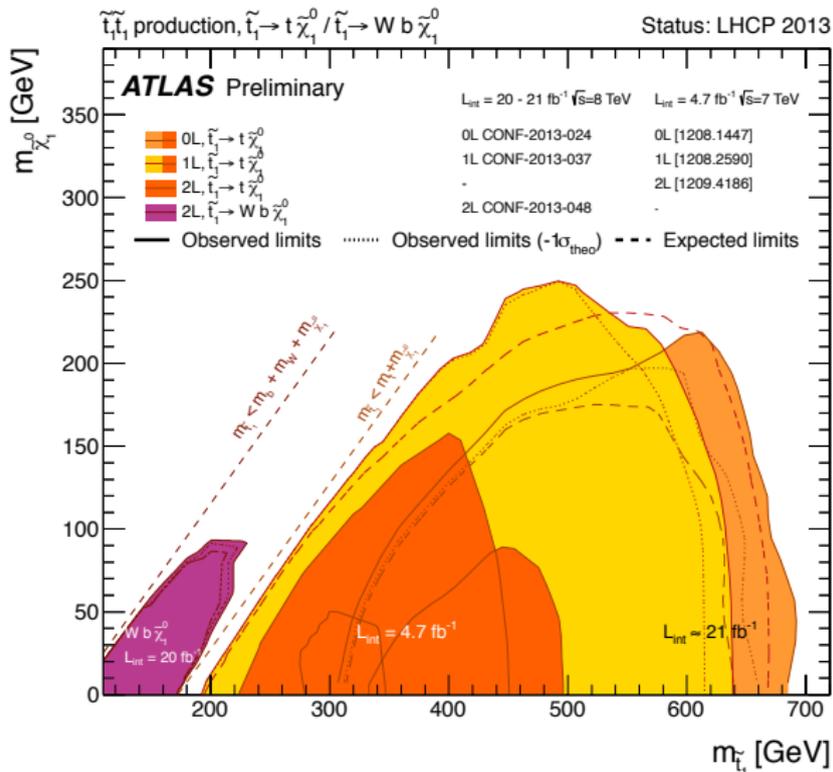
- ① Hard jet: **large mass difference**
- ② Large missing transverse energy: dark matter and its kinematics
- ③ Isolated leptons ( $e^\pm, \mu^\pm$ ) or photon  $\gamma$  passing basic cuts:  
 $\Delta R$
- ④ Secondary vertex:  $b$ -tagging

**Scenarios with compressed spectrum?** (light top squark?)

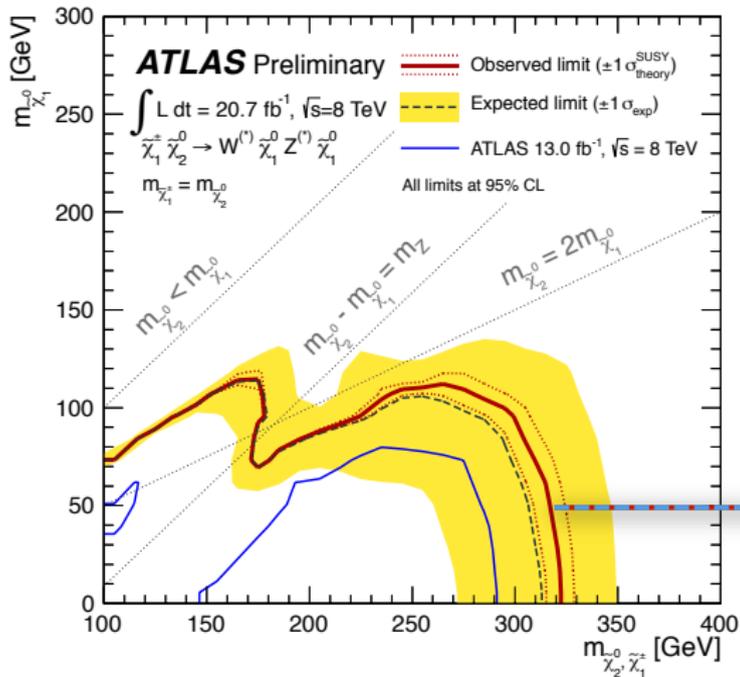
We study whether precision measurement of  $W$ -polarization in top sample can help to distinguish the light stop from the SM top.



# Constraints on light Stop



# Constraints on $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ from Tri-lepton final states



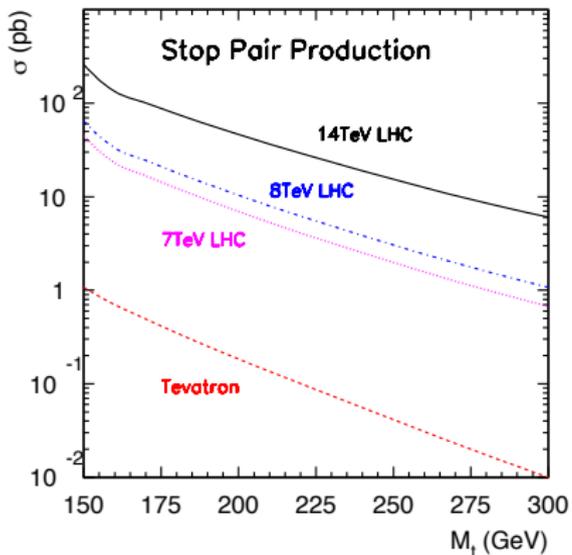
$M_{\tilde{t}_1} \simeq 190 \text{ GeV}$  with  $M_{\tilde{\chi}_1^\pm} \simeq 150 \text{ GeV}, M_{\tilde{\chi}_1^0} \simeq 100 \text{ GeV}$





## Stop pair cross section

$$\sigma_{t\bar{t}}^{(7 \text{ TeV})} = 162 \text{ pb} \pm 4\%$$



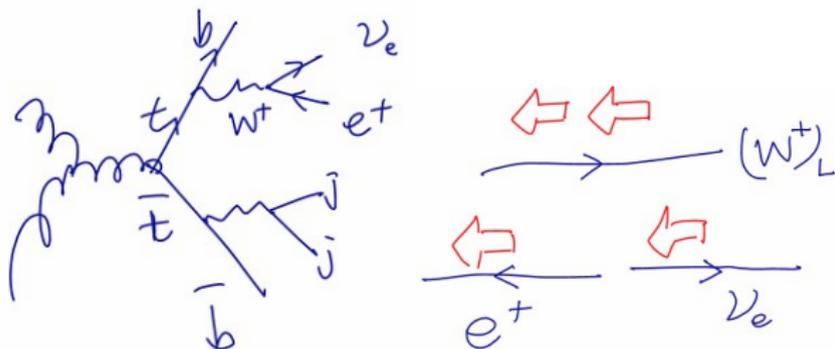
$$\sigma_{t\bar{t}^*}^{(7 \text{ TeV})}(M_{\tilde{t}} = 200) \simeq 6 \text{ pb}$$

$$\sigma_{t\bar{t}^*}^{(\text{Tevatron})}(M_{\tilde{t}} = 200) \simeq 0.2 \text{ pb}$$



## $W$ -boson polarization in top-quark decay

We study whether precision measurement of  $W$ -polarization in top sample can help to distinguish the light stop from top.



$t \rightarrow bW_L^+ \Rightarrow e^+$  is moving in the opposite direction of  $W$  boson

$$\Rightarrow (1 - \cos \theta)^2$$

$$t \rightarrow bW_0^+ \Rightarrow \sin^2 \theta$$

$$t \rightarrow bW_R^+ \Rightarrow (1 + \cos \theta)^2$$

$$\frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta} = \frac{3}{8} F_L (1 - \cos \theta)^2 + \frac{3}{4} F_0 \sin^2 \theta + \frac{3}{8} F_R (1 + \cos \theta)^2$$



# W-boson polarization in top-quark decay

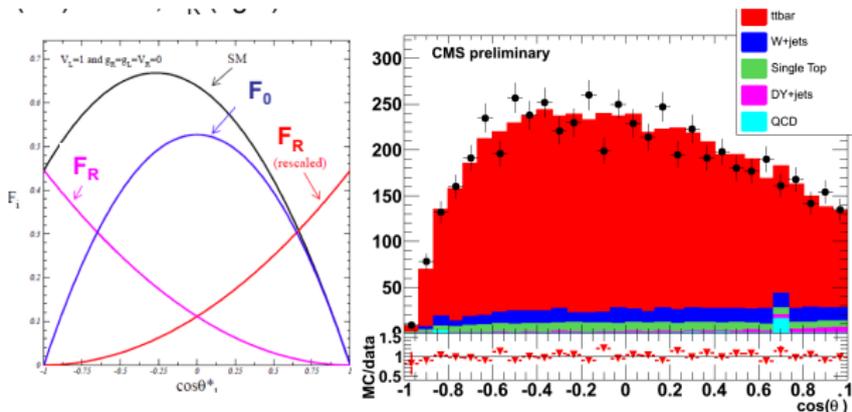
The ATLAS and CMS combined helicity fractions are

$$F_L = 0.359 \pm 0.021(\text{stat.}) \pm 0.028(\text{syst.}),$$

$$F_0 = 0.626 \pm 0.034(\text{stat.}) \pm 0.048(\text{syst.}),$$

which are in agreement with predictions from NNLO QCD.

[ATLAS-CONF-2013-033, CMS-PAS-TOP-12-025]



In the left figure, the purple line is actually left-handed (typo by CMS).





## Events selection and reconstruction ( $\chi^2$ -method)

Experimentally, we don't even know there exists chargino. Stop events may fake the top events. For reconstruction, we use the  $\chi^2$  method given by the ATLAS Collaboration.

[ATLAS-CONF-2011-037]

- No  $b$ -tagging
- $\vec{p}_T^\nu = \vec{p}_T^*$
- Scan  $p_z^\nu$ : -3.5 TeV –3.5 TeV and make all possible combinations of four jets.

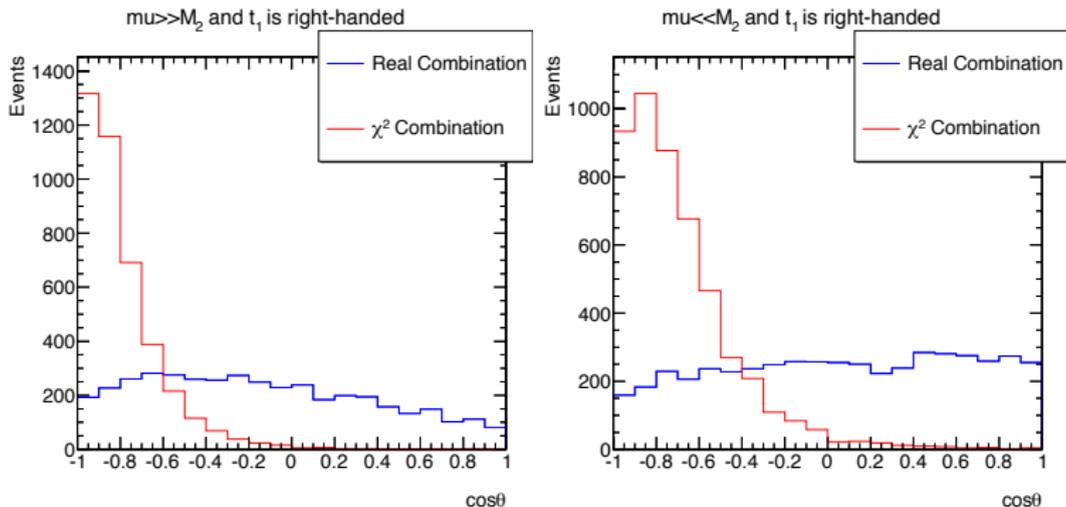
$$\chi^2 = \frac{(M_{\ell\nu j_a} - m_t)^2}{\sigma_t^2} + \frac{(M_{j_b j_c j_d} - m_t)^2}{\sigma_t^2} + \frac{(M_{\ell\nu} - m_W)^2}{\sigma_W^2} + \frac{(M_{j_c j_d} - m_W)^2}{\sigma_W^2}$$

$m_t = 172.5$  GeV,  $m_W = 80.4$  GeV,  $\sigma_t = 14$  GeV,  $\sigma_W = 10$  GeV

- By minimizing the  $\chi^2$ , we obtain the  $p_z^\nu$  and distinguish one b-jet, which accompanies with a leptonic W boson, from other jets.
- $\cos \theta$  is measured in the reconstructed W boson rest frame.



# $\cos\theta$ : Correct vs. Fake



Why  $\tilde{t}_1\tilde{t}_1^*$  events are left-handed like after  $\chi^2$  reconstruction?



$$\cos \theta$$

$\vec{p}_\ell$  and  $\vec{p}_b$  are the three momentum of lepton and bottom quark.

$$\cos \theta = -\frac{\vec{p}_\ell \cdot \vec{p}_b}{|\vec{p}_\ell| |\vec{p}_b|}$$

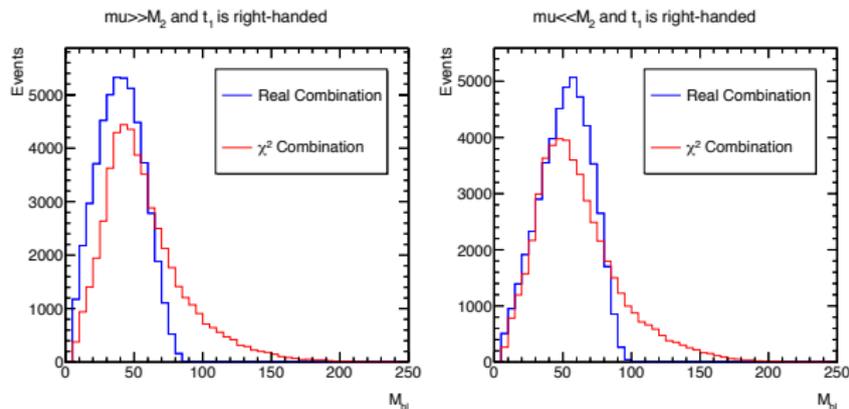
In the  $m_b = 0$  and  $m_\ell = 0$  limit,  $|\vec{p}_\ell| = E_\ell$ ,  $|\vec{p}_b| = E_b$

$$\cos \theta = -\frac{\vec{p}_\ell \cdot \vec{p}_b}{|\vec{p}_\ell| |\vec{p}_b|} = \frac{p_l \cdot p_b - E_l \cdot E_b}{|\vec{p}_\ell| |\vec{p}_b|} = \frac{M_{\ell b}^2}{2E_\ell E_b} - 1$$

$M_{\ell b}$  is Lorentz invariant mass of  $\ell$  and  $b$  and is determined by the interaction Lagrangians.  $E_b$  and  $E_\ell$  depends on the chosen frame.



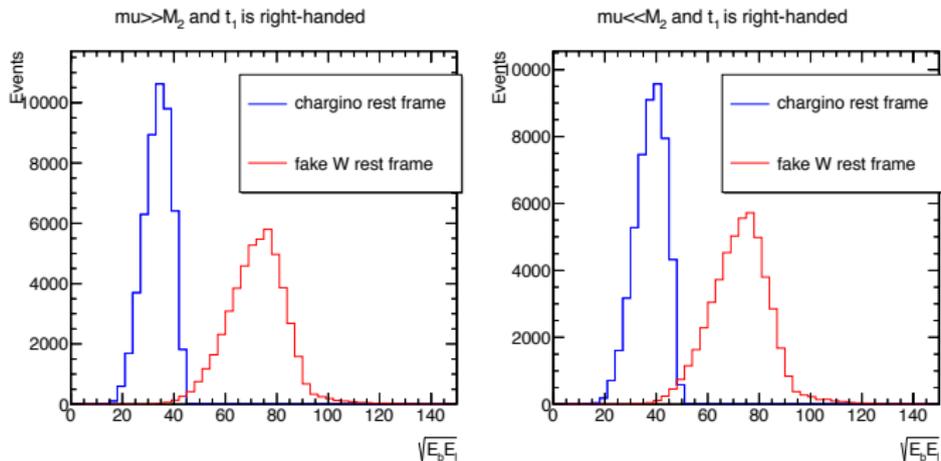
# $M_{\ell b}$ : Correct vs. Fake



- The difference between two combinations originates from the wrong combination. By using  $\chi^2$  method, a fake leptonic-branch b-jet may be picked out of the four jets to get  $M_{\ell b}$ .
- The fake and real  $M_{\ell b}$  are similar, which is not the main reason leading to different  $\cos \theta$  distributions.



# $\sqrt{E_b E_\ell}$ : Correct vs. Fake



- The fake  $\sqrt{E_b E_\ell}$  in the fake W boson rest frame is much larger than the real  $\sqrt{E_b E_\ell}$  in the real chargino rest frame.



$$\cos \theta = \frac{M_{lb}^2}{2E_\ell E_b} - 1$$

$\sqrt{E_b E_\ell} \uparrow \Rightarrow \cos \theta \text{ tends to } -1 \Rightarrow \text{more left-handed}$



## $\chi^2$ method applied to top squark events

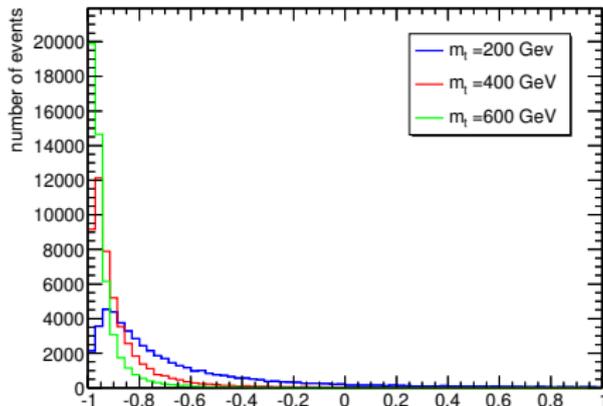
The fake  $\sqrt{E_b E_\ell}$  of stop evens peak at 77 GeV, just  $t\bar{t}$  events.

$$\sqrt{E_b E_\ell} = \sqrt{\frac{m_t^2 - m_W^2}{4}} \sim 77 \text{ GeV}$$

$\chi^2$  reconstruction will make  $\tilde{t}_1 \tilde{t}_1^*$  events similar as  $t\bar{t}$  events:

$$\cos \theta = \frac{2M_{\ell b}^2}{m_t^2 - m_W^2} - 1$$

If  $m_t$  becomes larger in  $\chi^2$  method,  $\cos \theta$  tends to -1.



## Conclusion

- We study whether precision measurement of  $W$ -polarization in top sample can help to distinguish the light stop from the SM top.
- After  $\chi^2$  reconstruction, charigno from stop decay behaves like a left-handed  $W$  boson.
- $F_L/F_R/F_0$  contribution from benchmark point which only changes  $F_L$  by 1%:

$$\text{SM} : F_L = 0.303, F_R = 0.0493, F_0 = 0.647,$$

$$\text{SM+stop} : F_L = 0.313, F_R = 0.0497, F_0 = 0.638.$$

$W$ -polarization cannot exclude the light stop scenario with stop mass around top-quark mass.

Thank you !

