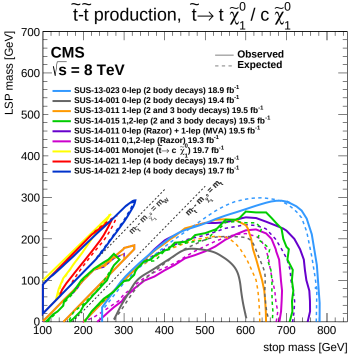
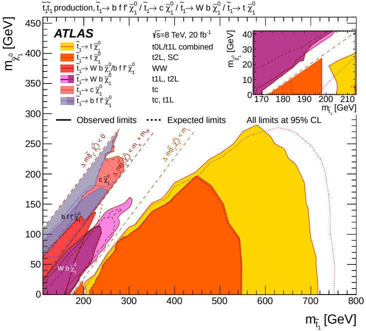
Stop Search in the Compressed Region via Semileptonic Decays





Based on arXiv:1604.00007

Collaborate with:

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Motivation

- A light Higgs boson puts tension on naturalness.
- A light stop is preferred to cancel the top loop contribution to m_H.
- Stop mass excluded upto $\sim$ 750 GeV on LHC.
- traditional search techniques using M_{T2}, H_T^{miss}... are not sensitive for stop in the compressed region. $(m_{\tilde{t}} \approx m_t + m_{\tilde{\chi}})$

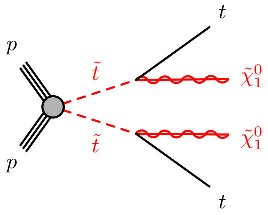
We need to fill the gap in the compressed region where a light stop is still possible.

Motivation (Continued)

Why do we prefer semileptonic decays ($WW \to \ell + \nu +$ jets)?

- Less SM background (e.g. QCD multi-jets, unidentified leptons)
- Considerable cross session (BR$\approx$ 44%)
  - Similar to fully hadronic decays (BR $\approx$ 46%)
  - Much bigger than dileptonic ones (BR $\approx$ 11%)

Stop Decay Chain



- We consider $\tilde{t} \to t\tilde{\chi}$ decay here.
- Other SUSY objects decoupled.

What happens when $m_{\tilde{t}} \approx m_t + m_{\tilde{\chi}}$?

Compressed Region

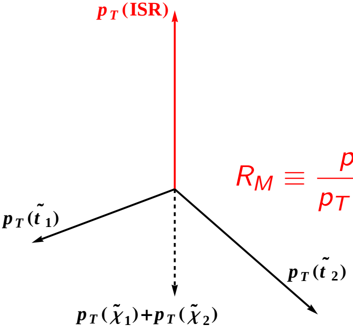
- In the compressed region, the decay products of stop decay (t and $\tilde{\chi}$) are both static in stop reference frame.
- When boosted, the two decay products becomes **comoving** in the lab frame. Therefore, their momentums would have the same ratio as their masses.

$$\frac{p_{\tilde{\chi}}}{p_{\tilde{t}}} \approx \frac{m_{\tilde{\chi}}}{m_{\tilde{t}}} \quad (1)$$

When the stop pair are produced nearly back-to-back, the event looks like a SM t pair production.

Compressed Region with a large ISR

New topology: stop pair produced with a hard initial state radiation(ISR) jet. $(p_{T_{\tilde{\chi}1}} + p_{T_{\tilde{\chi}2}} \approx \frac{m_{\tilde{\chi}}}{m_{\tilde{t}}}(p_{T_{\tilde{t}1}} + p_{T_{\tilde{t}2}}))$

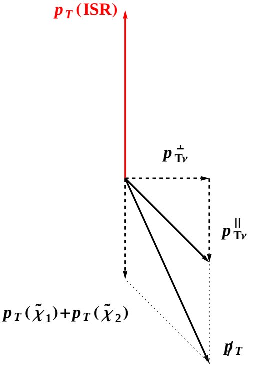


$$R_M \equiv \frac{p_T^{miss}}{p_T(ISR)} \approx \begin{cases} \frac{m_{\tilde{\chi}}}{m_{\tilde{t}}} & (stop) \\ 0 & (SM) \end{cases}$$

Hadronic Analysis (arXiv:1506.00653 [hep-ph]).

Semileptonic Case

- In order to recover the LSP momentum sum, need to solve for neutrino momentum (p_ν) and subtract it from the MET. ($R_M \to \bar{R}_M$)
- Requires 4 relations.



3 mass-shell relation

$$p_\nu^2 = 0$$

$$(p_\ell + p_\nu)^2 = m_{\mathrm{w}}^2$$

$$(p_\ell + p_\nu + p_b)^2 = m_t^2$$

perpendicular part:

$$p^{\perp}_{T\nu} = \not{p}^{\perp}_T$$

Cut Selection

- $p_T(ISR) \geq 475$ GeV
- MET ≥ 200 GeV.
- $|\phi_\ell - \phi_{MET}| > 0.9$.
- Others...

Background and Signal Simulation

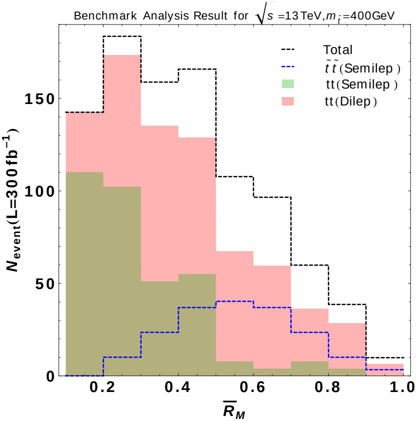
SM background

- $t\bar{t}$ (semileptonic)
- $t\bar{t}$ (dileptonic)
- single top production (small Xsec.)
- (Multi)vector boson with jets (small Xsec.)
- $t\bar{t}$ production with an extra vector boson. (low signal efficiency)

Compressed Region signal

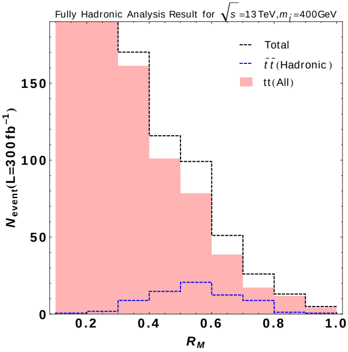
- Stop pair (semileptonic)

Result for case study



The significance is 8.4 for $m_{\tilde{t}} = 400$ GeV.

Compared with Fully Hadronic Analysis



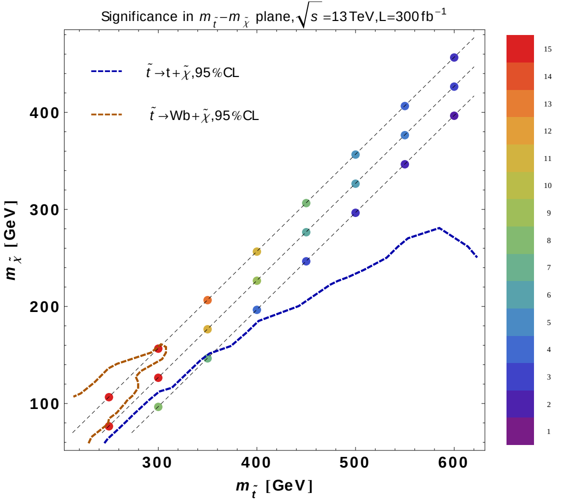
- $p_T(ISR) \geq 700$ GeV
- $p_T(J_2, J_3, J_4) \geq$ 60 GeV.
- $|\phi_{ISR} - \phi_{MET} - \pi| \leq$ 0.15.
- At least one b tag.
- $|\phi_{J_i} - \phi_{MET}| > 0.2$, $i = 2, 3, 4$

The significance is around 4 for $m_{\tilde{t}} = 400$ GeV.

Results

$m_{\tilde{t}}$ (GeV)	250	300	350	400	450	500	550	600
$\sigma_{m_{\tilde{t}}-(m_{\tilde{\chi}}+m_t)=0}$	19.7	15.8	11.0	8.4	5.8	5.1	3.8	2.1
$\sigma_{m_{\tilde{t}}-(m_{\tilde{\chi}}+m_t)=-30}$	22	19	13	11	7.2	4.7	3.1	1.7
$\sigma_{m_{\tilde{t}}-(m_{\tilde{\chi}}+m_t)=30}$	–	7.6	5.3	3.3	2.4	1.7	1.3	0.9

Results (Continued)

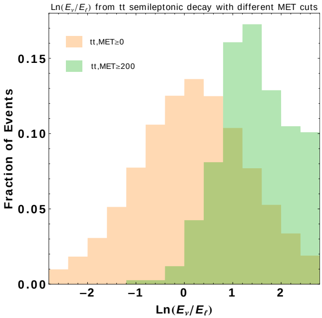


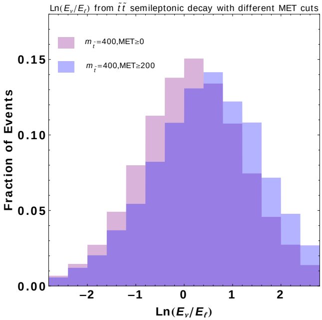
Conclusion

- We have studied the stop search from direct $\tilde{t}\tilde{t}j$ production in the compressed region, using the semileptonic decay mode.
- For 300 fb^{-1} integrated luminosity at LHC 13 TeV, the semileptonic channel can have a discovery reach for the stop mass up to about 500 GeV, in comparison to $\sim$ 400 GeV for the fully hadronic channel.

The End (Time For Questions)

Lepton Energy





- MET$\geq$ 200 GeV
- Choose the solution with bigger E_ν

Azimuthal Distribution

MET and $p_T(ISR)$ should be back-to-back without ν

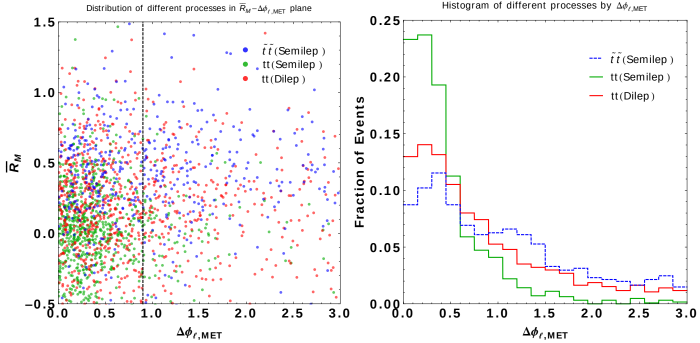
- $|\phi_{J_{ISR}} - \phi_{MET}| \geq 2$

What about the relation between the lepton and the MET?

- For SM, high MET indicates a highly boosted W, p_{T_ℓ} and p_T^{miss} tends to be collinear.
- For signal, p_T^{miss} could be separated from p_{T_ℓ}

Need to cut $\Delta\phi_{\ell,MET}$!

Azimuthal Distribution (Continued)



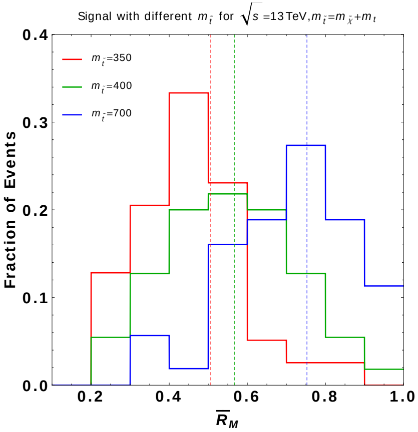
- Green points/curve: semileptonic $t\bar{t}$ background
- Red points/curve: dileptonic $t\bar{t}$ background

Cut Selection (details that nobody wants to know)

- At least 4 jets with non-zero b jets. Events with τ jets are vetoed.
- $p_{T\nu} < 180$ GeV, $p_{T\nu} < 6p_{T\ell}$.
- $p_T(J_2, J_3) \geq 60$ GeV.
- For more than 1 b jet that give solutions, choose the one with a smaller $\bar{R}_M$
- Pick the greater E_ν among two solutions.
- $|\phi_{ISR} - \phi_{MET}| \geq 2$.

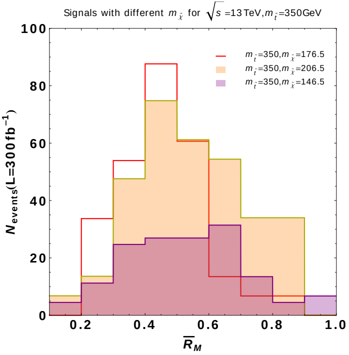
Moving along the Compressed Region

$\bar{R}_M$ expectation changes with $\frac{m_{\tilde{\chi}}}{m_{\tilde{t}}}$.



Moving away from the Compressed Region

If the spectrum deviates from $m_{\tilde{t}} \approx m_t + m_{\tilde{\chi}}$.



- If $m_{\tilde{\chi}} > m_{\tilde{t}} - m_t$, t becomes off-shell.
- If $m_{\tilde{\chi}} < m_{\tilde{t}} - m_t$, decay products will not be comoving.

Statistics

Criteria for signal region

- If $m_{\tilde{\chi}} \geq m_{\tilde{t}} - m_t$, choose $\frac{m_{\tilde{\chi}}}{m_{\tilde{t}}} - 0.15 < \bar{R}_M < 1$
- If $m_{\tilde{\chi}} < m_{\tilde{t}} - m_t$, choose $\frac{m_{\tilde{t}} - m_t}{m_{\tilde{t}}} - 0.15 < \bar{R}_M < 1$

The significance is given by

$$\sigma = \sqrt{2\left[(S+B)\log\left(\frac{S+B}{B}\right) - S\right]} \tag{2}$$

Statistics(Continued)

Significance as a function of the fractional background uncertainty for the case study.