Search for direct pair production of the top squark in all-hadronic final states

LHCP Poster Session – Columbia University, 6 June 2014

Direct Stop Search

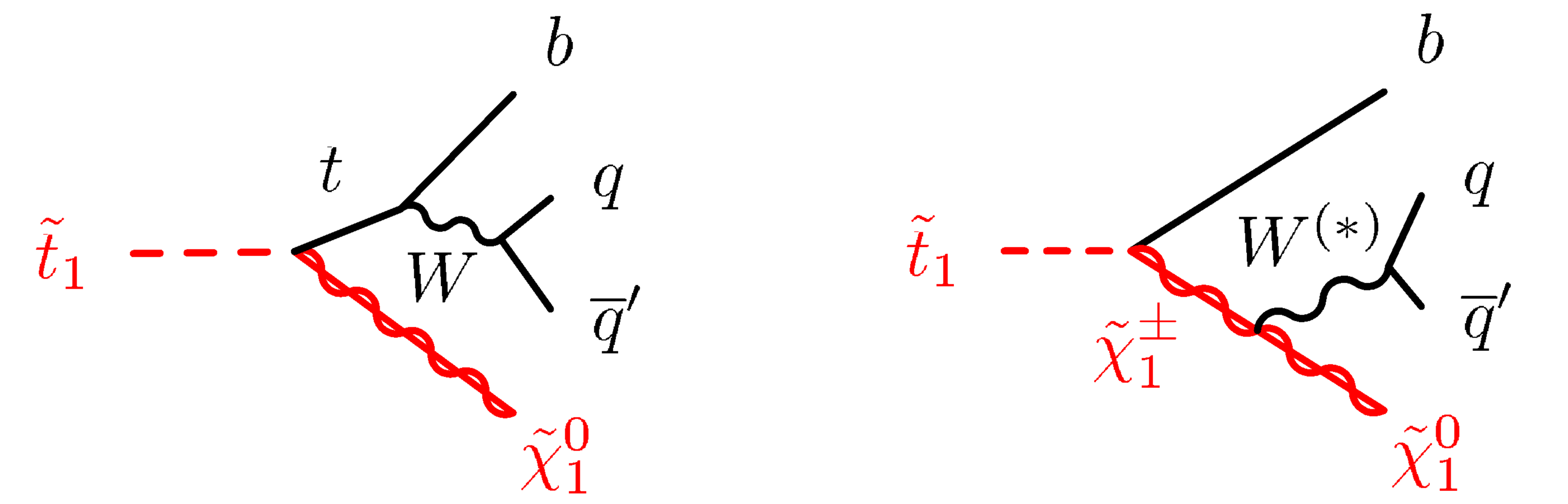
- Search for decays of pair produced top squarks to all-hadronic decays of top plus neutralino ($\tilde{\chi}_1^0$) or bottom plus chargino ($\tilde{\chi}_1^\pm$).
- Neutralinos appear as missing transverse energy (E_T^{miss}).
- The signal signatures are multiple jets (≥4) and high E_T^{miss}.

Advantages:
- All-hadronic decays of top provide the largest branching ratios.
- Absence of leptonic decay avoids neutrino contribution to E_T^{miss}.
- Mostly insensitive to the mixing of $\tilde{t}_L$ and $\tilde{t}_R$

Challenges:
- Jet kinematics are generally harder to measure than electrons or muons.
- Associating jets from each top in the all-hadronic decays is difficult.

The motivation for looking for direct pair production is that stop has the highest production cross section next to gluinos and light squarks, but both might be out of reach at the LHC. Also, due to large Yukawa coupling, stop can be much lighter than the light flavor partners. Finally, to resolve the hierarchy problem, stop mass should be below ~1 TeV.

Stop Decay Modes Considered



Signal Regions

All-hadronic Stop Search

$\tilde{t}_1 \to t\tilde{\chi}_1^0, \tilde{t}_1 \to t\tilde{\chi}_1^0$ | $\tilde{t}_1 \to t\tilde{\chi}_1^0, \tilde{t}_1 \to b\tilde{\chi}_1^\pm$

SRA: Fully resolved top decays anti $- k_t$, R = 0.4 jets ≥ 6

SRB: Partially resolved top decays 4 ≤ anti $- k_t$, R = 0.4 jets < 6

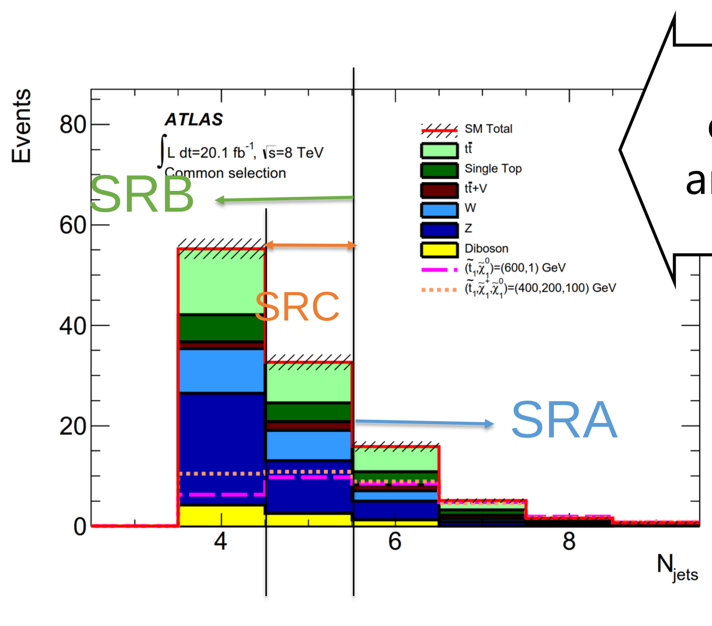
SRC: anti $- k_t$, R = 0.4 jets = 5

SRA1-4: Optimized for different stop masses

SRB1, $\mathcal{A}_{m_{top}}$ < 0.5: Two tops balanced

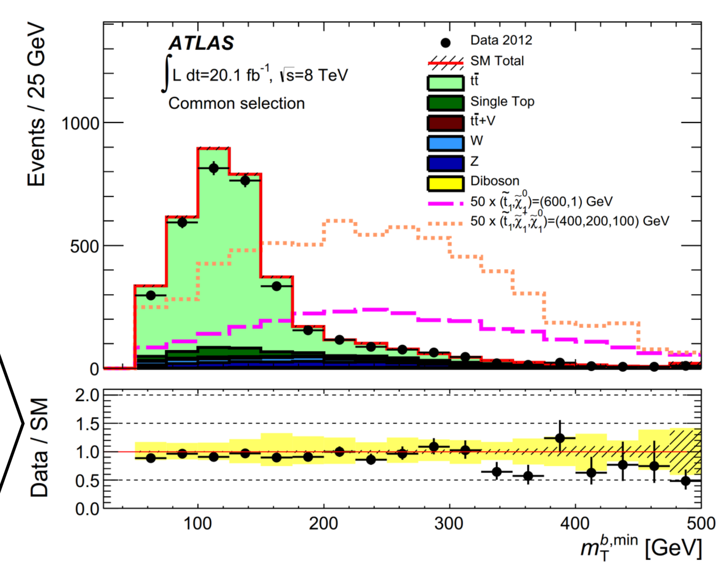
SRB2, $\mathcal{A}_{m_{top}}$ > 0.5: Two tops overlapped

SRC1-3: Optimized for different stop masses



Background compositions are different for each SR

$m_T^{b\,min}$ > 175 GeV is very powerful at rejecting semi-leptonic $t\bar{t}$ background



Histograms showing the jet multiplicities (left) with common selections and E_T^{miss} > 300 GeV cut, and transverse mass between E_T^{miss} and the closest b-jets (right). The simulated signals are shown as dashed and dotted lines and the backgrounds are shaded histograms (stacked).

Background Estimation

$t\bar{t}$	Main background in SRA and SRC
	ν from W decays create E_T^{miss}, extra jets from τ or ISR/FSR
	CR: Similar to SR but require 1 lepton, treat it as a jet.
Z+jets	Main background in SRB, important for SRC
	$Z \to \nu\nu$ making large E_T^{miss}, jets from QCD
	CR: Take $Z \to \ell\ell$ then treat the leptons as E_T^{miss}
W+jets	Important background for SRB
	Missing lepton from W decays
	CR: Similar to $t\bar{t}$, but optimized to enhanced the heavy flavor jets

These backgrounds are estimated by normalizing MC to data in Control Region (CR)

Top Reconstruction

For the **SRA**, the top quark decays are fully resolved, thus the top reconstruction are optimized for efficiency while retaining some background rejection power. A simple but effective method (ΔR_{min}) is used in which the two closest light jets are combined with the closest b-jet. The exact steps are shown below

1. Pick the two highest b-tagging weight jets.
2. For the rest of the jets, combine the two that are the closest in $\eta - \phi$ plane to form a W candidate.
3. Combine the W candidate with the closest b-jet from the first step to form the first top candidate.
4. Repeat the process with the rest of the jets to form the second top candidate.

To enhance the sensitivity for this all-hadronic signature, the **SRB** is designed to target the cases where the top candidate daughters cannot be resolved fully. This is especially important for the heavier stop because the top decay products can be more boosted.

New Technique needed
- ΔR_{min} method will not work out of the box.
- A top reconstruction algorithm that can extend naturally to 4-5 jet bins.
- More efficient way to select events.

Jet Reclustering
- Use anti-k_t with $R = 1.2$ to recluster the anti-k_t $R = 0.4$ jets.
- The method is most effective for separating top candidates; overlapping top candidates are challenging

Mass Asymmetry

$$\mathcal{A}_{m_t} = \frac{|m^0_{\text{jet},R=1.2} - m^1_{\text{jet},R=1.2}|}{m^0_{\text{jet},R=1.2} + m^1_{\text{jet},R=1.2}}.$$

- Separate the events with two tops balanced (SRB1) from the two tops overlapping topology (SRB2).

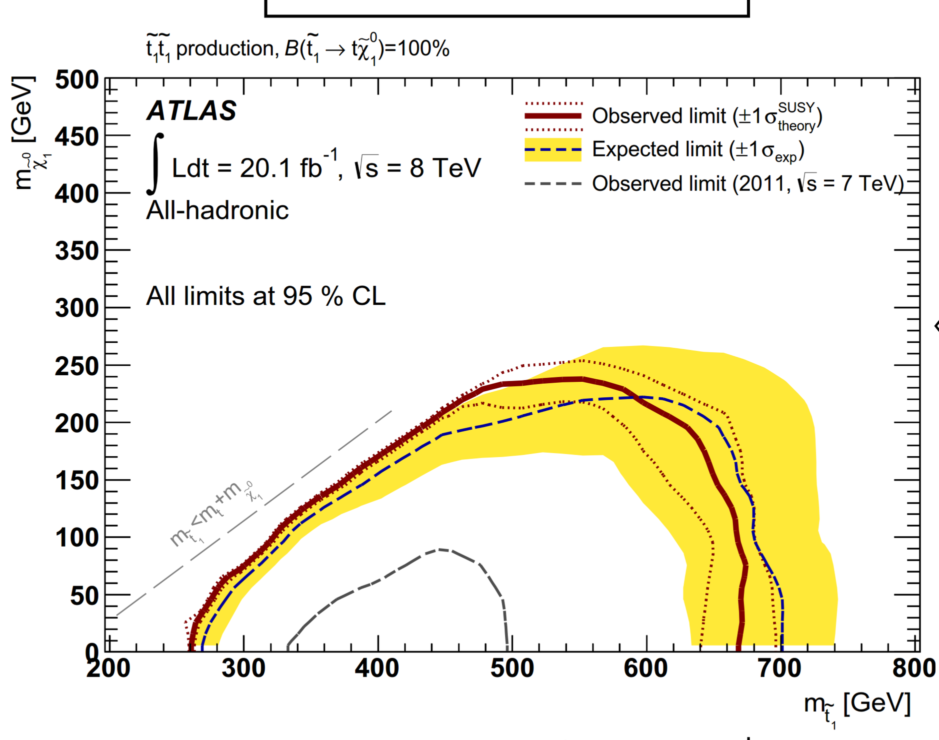
Optimizing
- By categorizing the event using $\mathcal{A}_{m_t}$ into two categories, the selection can be optimized based on the topology to maximize the efficiency.

Results & Interpretation

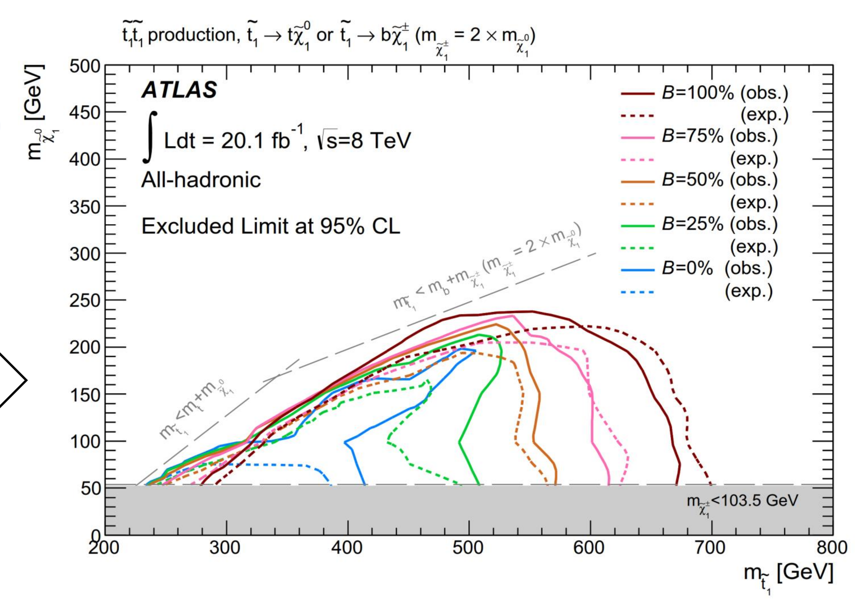
	SRA1	SRA2	SRA3	SRA4	SRB	SRC1	SRC2	SRC3
Observed events	11	4	5	4	2	59	30	15
Total SM	15.8 ± 1.9	4.1 ± 0.8	4.1 ± 0.9	2.4 ± 0.7	2.4 ± 0.7	68 ± 7	34 ± 5	20.3 ± 3.0
$t\bar{t}$	10.6 ± 1.9	1.8 ± 0.5	1.1 ± 0.6	0.49 ± 0.34	$0.10^{+0.14}_{-0.10}$	32 ± 4	12.9 ± 2.0	6.7 ± 1.2
$t\bar{t} + W/Z$	1.8 ± 0.6	0.85 ± 0.29	0.82 ± 0.29	0.50 ± 0.17	0.47 ± 0.17	3.2 ± 0.8	1.9 ± 0.5	1.3 ± 0.4
Z + jets	1.4 ± 0.5	0.63 ± 0.22	1.2 ± 0.4	0.68 ± 0.27	1.23 ± 0.31	15.7 ± 3.5	9.0 ± 1.9	6.1 ± 1.3
W + jets	1.0 ± 0.5	0.46 ± 0.21	0.21 ± 0.19	$0.06^{+0.10}_{-0.06}$	0.49 ± 0.33	8 ± 4	4.8 ± 2.2	2.8 ± 1.2
single top	1.0 ± 0.4	0.30 ± 0.17	0.44 ± 0.14	0.31 ± 0.16	0.08 ± 0.06	7.2 ± 2.9	4.5 ± 1.8	2.9 ± 1.4
diboson	< 0.4	< 0.13	0.32 ± 0.17	0.32 ± 0.18	0.02 ± 0.01	1.1 ± 0.8	$0.6^{+0.7}_{-0.6}$	$0.6^{+0.7}_{-0.6}$
multijets	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.24 ± 0.24	0.06 ± 0.06	0.01 ± 0.01

No significant excess observed

SRA1-4 are orthogonal to SRB/SRC, therefore SRA is statistically combined both with SRB (SRA+SRB) and with each of SRC1-3 (SRA+SRC), then choose the best (smallest) 95% CL$_s$ value for each $\tilde{t}_1$ and $\tilde{\chi}_1^0$ mass. The expected and observed exclusion curves for exclusive $\tilde{t}_1 \to t\tilde{\chi}_1^0$ decays is shown on the left.



Also considered the $\tilde{t}_1 \to b\tilde{\chi}_1^\pm$ decay mode of the stop, assuming $m_{\tilde{\chi}_1^\pm} = 2 \times m_{\tilde{\chi}_1^0}$. The exclusion curves for a range of branching ratios are shown here on the right.



Reference

Search for direct pair production of the top squark in all-hadronic final states in proton-proton collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector. ATLAS-SUSY-2013-16-002. (To be updated to arXiv reference)

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ATLAS EXPERIMENT