Light stops and deconstructed transverse mass variables

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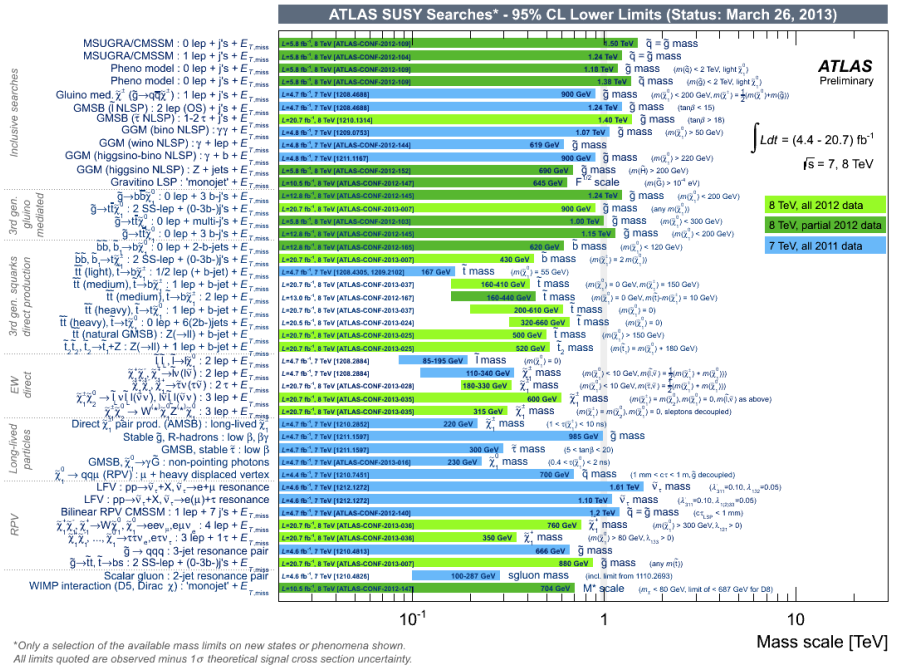
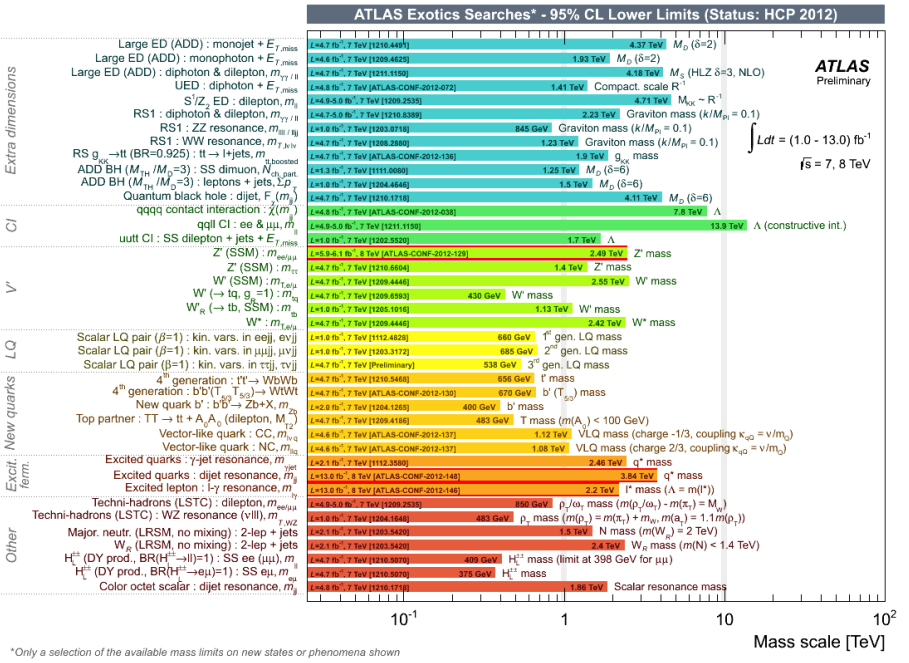
April 30, 2013

AI, Ariel Schwartzman, Reinhard Schwienhorst,
Joe Virzi, Devin Walker
1305.xxxx

Supersymmetry hasn't turned up yet...



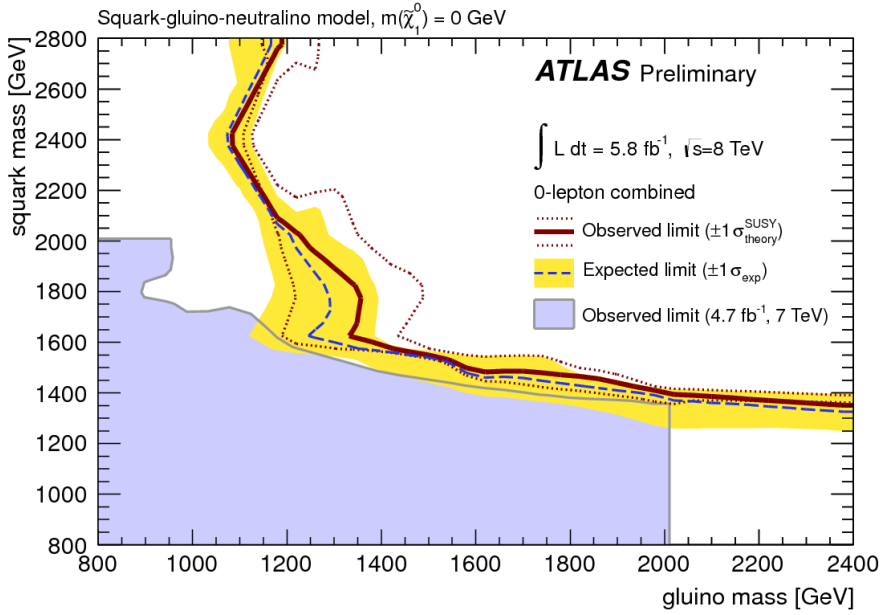
*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

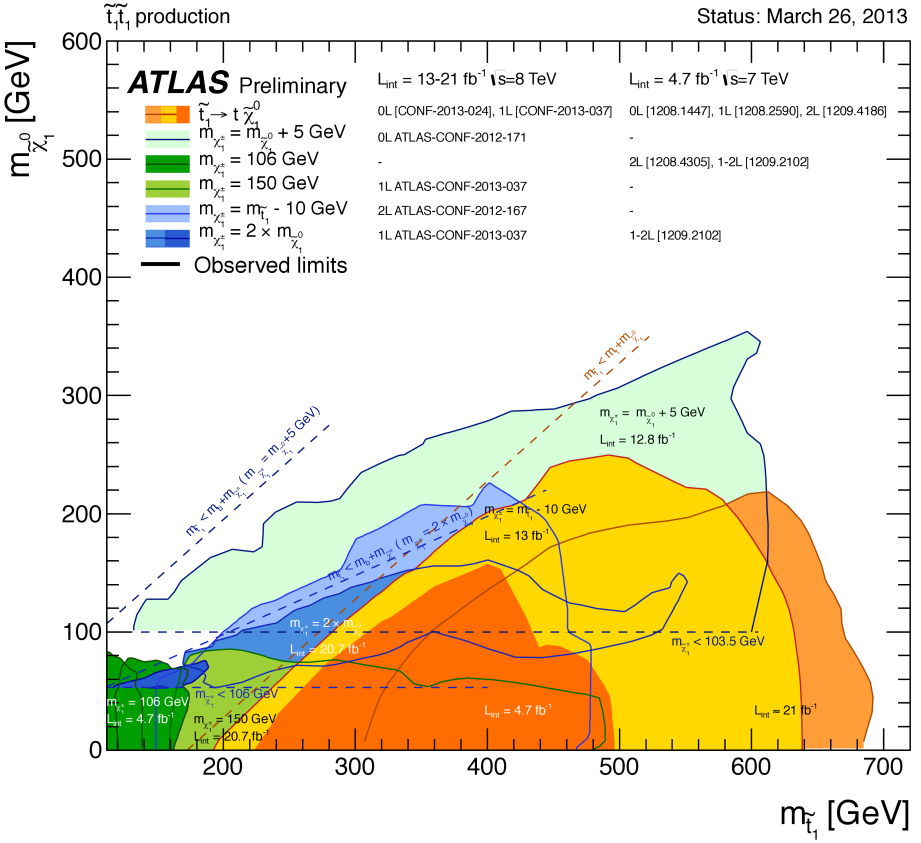


*Only a selection of the available mass limits on new states or phenomena shown

(though nor has anything else)

...and light-flavor squarks and gluinos are increasingly constrained!





Motivates development of searches for other sparticles

Searching for stops

- Low mass suggested by naturalness (see talk by T. Eifert)
- Colored production, unlike gauginos
- Usually assumed to decay to t + neutralino LSP, characterized by b-jets + MET; can require leptons in final state
- Can be produced either directly or through gluino decays

Challenges

- No MET in compressed region where stop is close in mass to top + LSP
- Often searches are geared towards decay mode stop → t + neutralino, but b + chargino decay may be quite common, particularly in natural scenarios
- Other possible decay modes, e.g. R-parity violating/extremely compressed stops
- Use all information about final states to construct signal regions

stop → b chargino

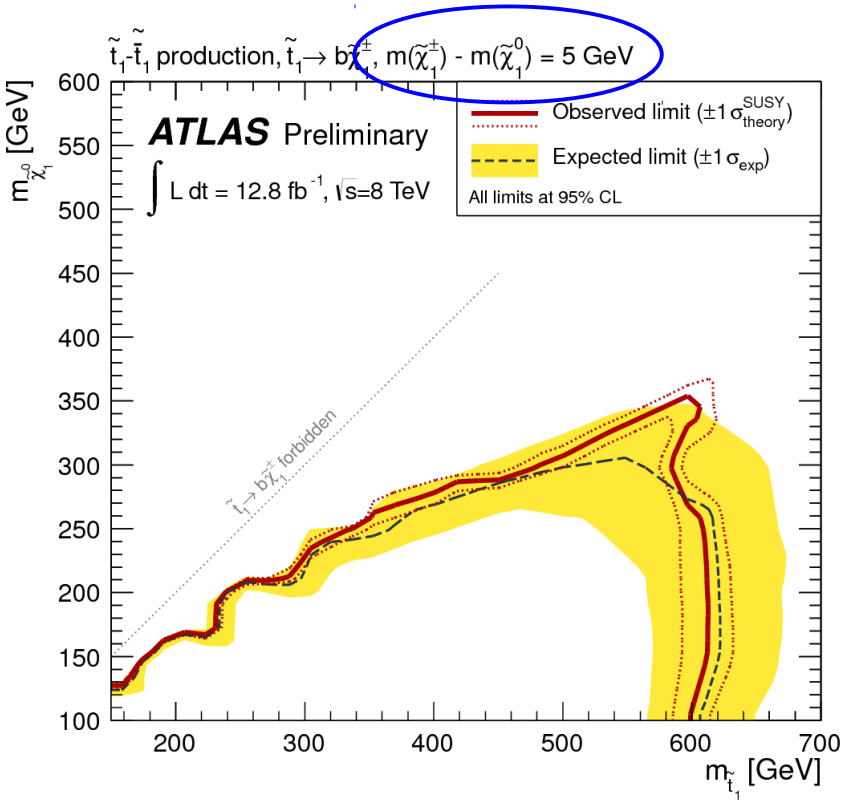
- Natural SUSY requires light higgsinos, but the MSSM higgsino multiplet contains two neutralinos and a chargino
- If the LSP is a neutral higgsino, there is likely to be a nearby charged higgsino with mass splitting < a few GeV
- So, in addition to the t + neutralino decay mode of light stops, should also consider b + chargino
- Such a chargino is effectively MET in the detector, as all decay products are soft

stop → b chargino

- If LSP is neutral wino, again the b + chargino mode is important because of the charged wino; here, the mass splitting can be < 1 GeV!
- b-jets + MET signature of stop pair production with this decay is probed by direct sbottom searches
- Stop search regions which rely on a top in the final state lose effectiveness
- Should no longer require leptons, additional jets, or try to reconstruct hadronic top

Some current ATLAS searches

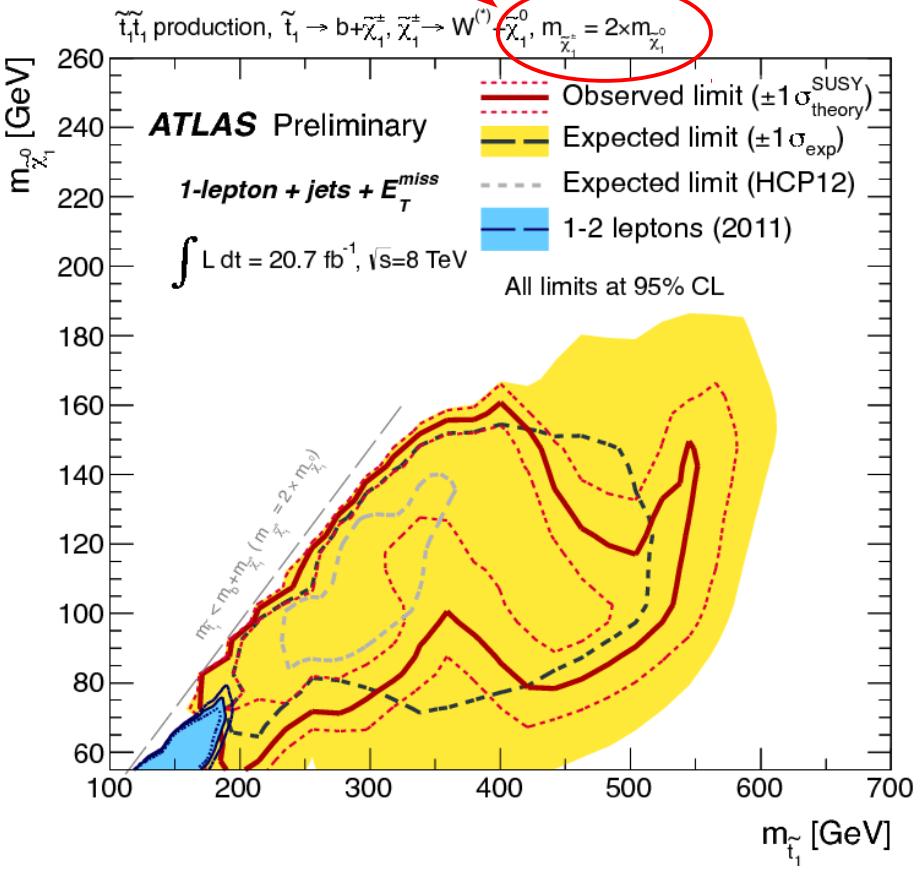
Small chargino-neutralino splitting assumed



ATLAS-CONF-2013-001

lepton veto

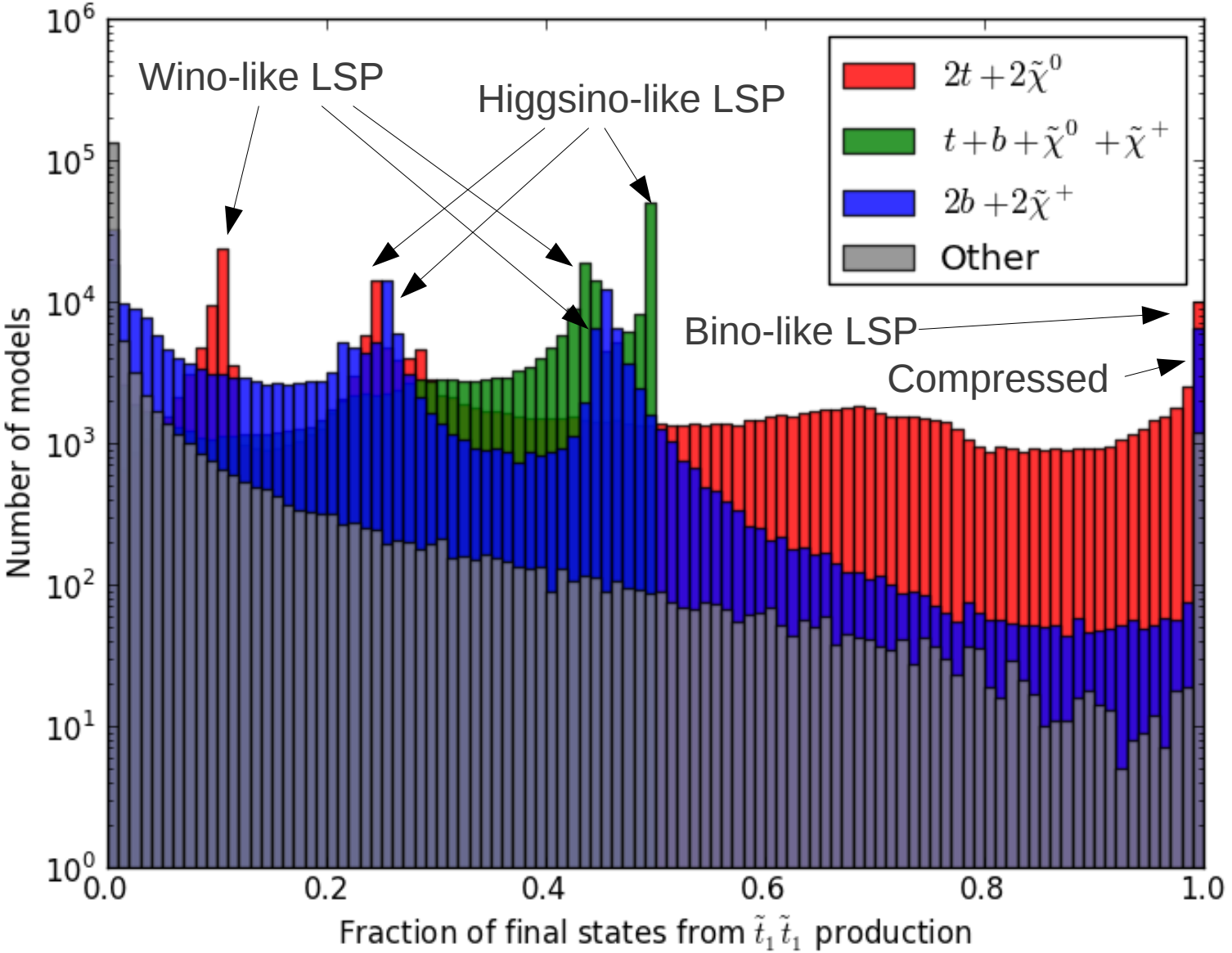
Chargino mass = 2 x neutralino mass assumed



ATLAS-CONF-2013-037

exactly one lepton required

Stops in the pMSSM

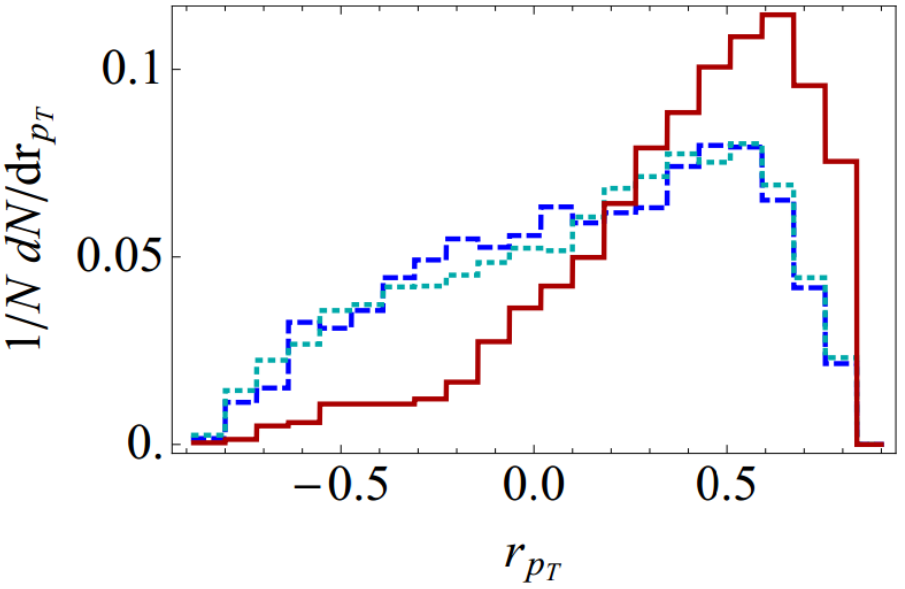


Matthew Cahill-Rowley, JoAnne Hewett, AI, Tom Rizzo

Mixed decays

- Pure b chargino decays are covered by direct sbottom searches
- What about mixed decays where stops are pair produced and decay to t b chargino neutralino?
- Hard b on chargino side, softer lepton on neutralino side

$$r_{p_T} = \frac{p_{Tb_1} - p_{T\ell}}{p_{Tb_1} + p_{T\ell}}$$



M.L. Graesser and J. Shelton
1212.4495

Rethinking transverse mass

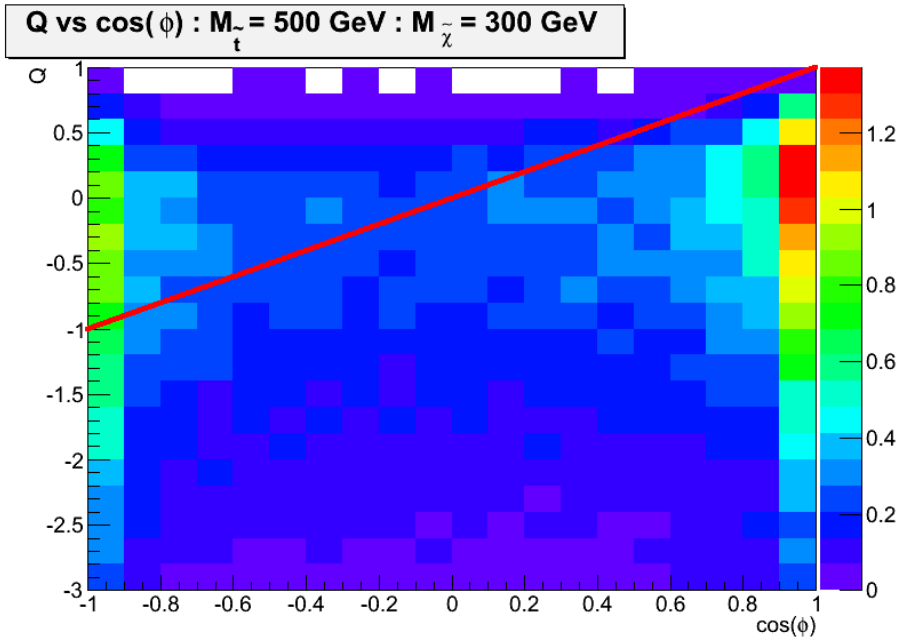
- One lepton stop searches typically cut on M_T, the transverse mass of the lepton
- $M_T^2 = 2\, p_T\, E_T^{miss} (1 - \cos\phi)$ combines information about the magnitudes of the lepton/missing momenta and their directions
- Compressed stops tend to decay to leptons that fail such a cut, as there's not much additional MET from the neutralino
- Goal: modify the traditional transverse mass cut to search for stops better

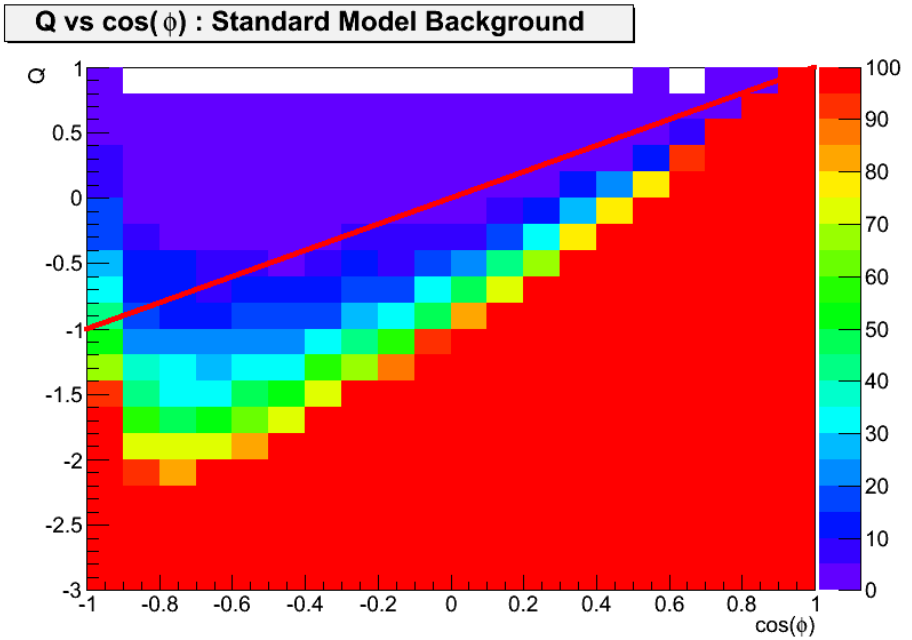
Deconstructed transverse mass variables

- $M_T^2 = 2\, p_T\, E_T^{miss}\, (1 - \cos\phi)$ combines information about the magnitudes of the lepton/missing momenta and their directions
- Introduce new variable $Q = 1 - M^2 / 2\, p_T\, E_t^{miss}$, where M is fixed
- $Q \rightarrow 1$ for large MET, and depends only on the magnitudes of the momenta
- Use $\cos\phi$, ϕ = angle between lepton and MET
- Aim to replace M_T cut with cut in Q–$\cos\phi$ plane

The Q–cos ϕ plane

Area above red line corresponds to traditional transverse mass cut of $M_T > M = 140$ GeV

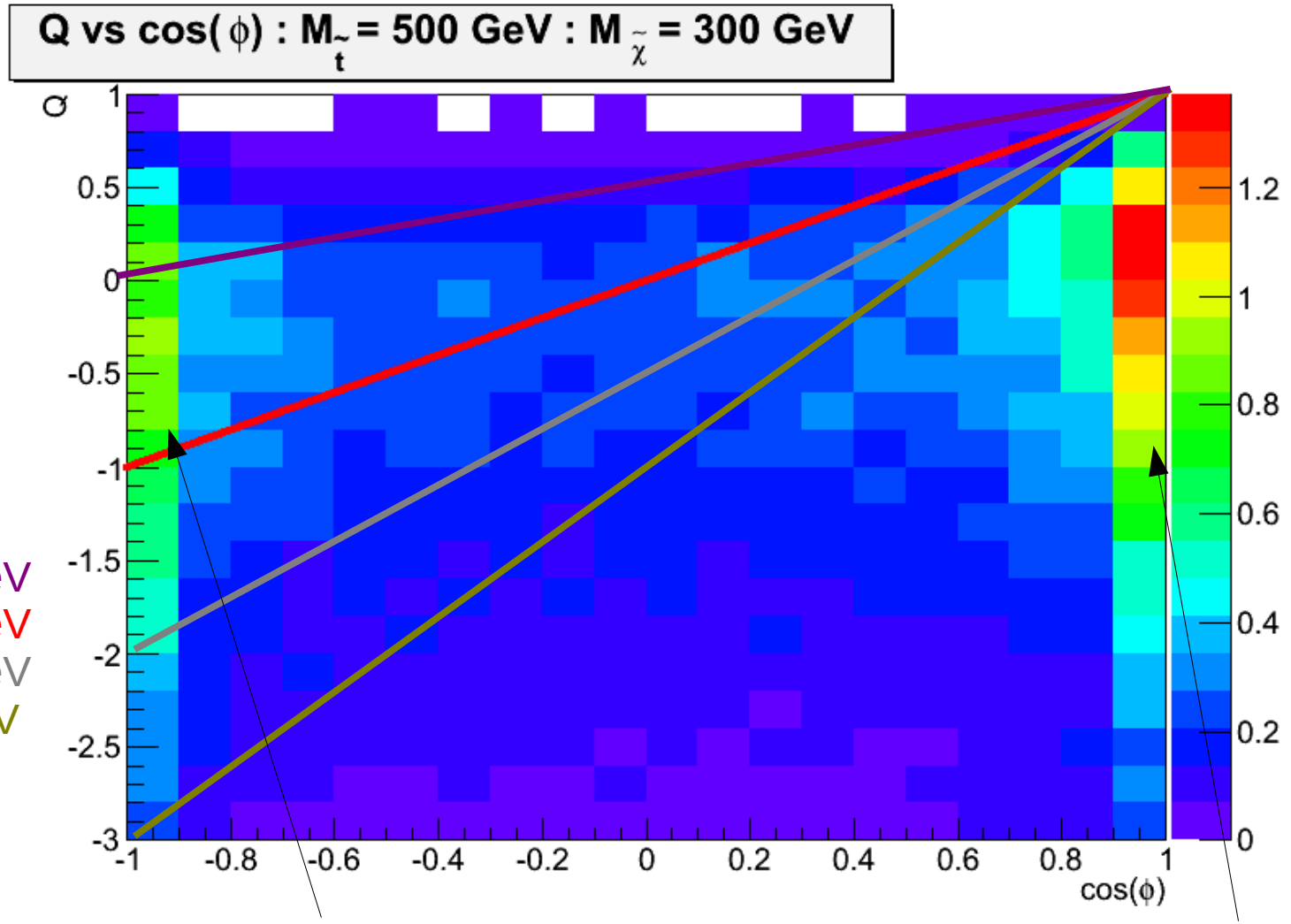




SM background dominated by tt

Can improve cut in this plane beyond a simple transverse mass cut! Use to construct stop analysis

The Q–cos ϕ plane



M_T
198 GeV
140 GeV
114 GeV
99 GeV

Boosted LSP gives MET
(clean signal)

Boosted neutrino gives MET
(lots of background)

Top reconstruction

- In semileptonic tt, the neutrino momentum can be reconstructed, up to a twofold ambiguity
- If we try to reconstruct the neutrino longitudinal momentum from a semileptonic stop pair event, assuming the event is tt, the reconstruction usually fails, i.e. we'll obtain a quadratic equation with no real solutions
- Introduce new variable that is the discriminant of this quadratic equation, so that the top reconstruction fails if and only if this variable is negative

Top reconstruction

$$\chi_t = p_{blL}^2 A'^2 + (E_{bl}^2 - p_{blL}^2)(A'^2 - 4E_{bl}^2 \not{E}_T^2)$$

$$A' = m_t^2 - M_{bl}^2 + 2\,\vec{p}_{blT} \cdot \vec{\not{E}}_T$$

- Get $\chi_t < 0$ for signal because neutralino is additional source of MET
- Get $\chi_t < 0$ for background from detector effects only
- Optimize exact position of χ_t cut

Constructing a stop search

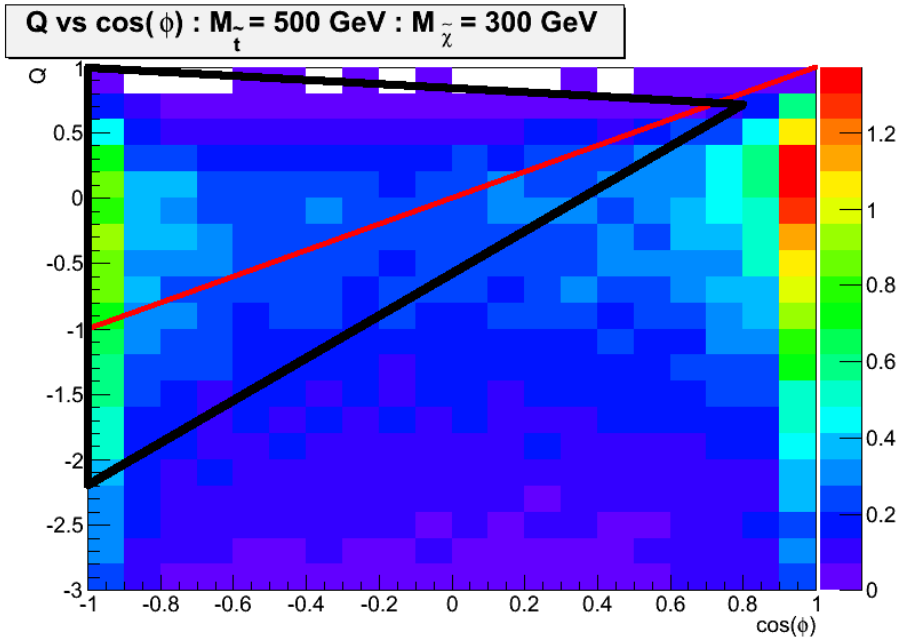
- Use 8 TeV 13 fb^{-1} ATLAS one lepton stop search as basis for our signal regions
- Four jets with $p_T > 25$ GeV and $|\eta| < 2.5$
- Exactly one lepton with $p_T > 25$ GeV and $|\eta| <$ 2.47/2.4 (electron/muon), no other leptons with p_T > 10 GeV
- Assume 75% b-tagging efficiency, and require at least one b-jet
- Require successful reconstruction of hadronic top with 130 GeV < m_{jjj} < 205 GeV

Constructing a stop search

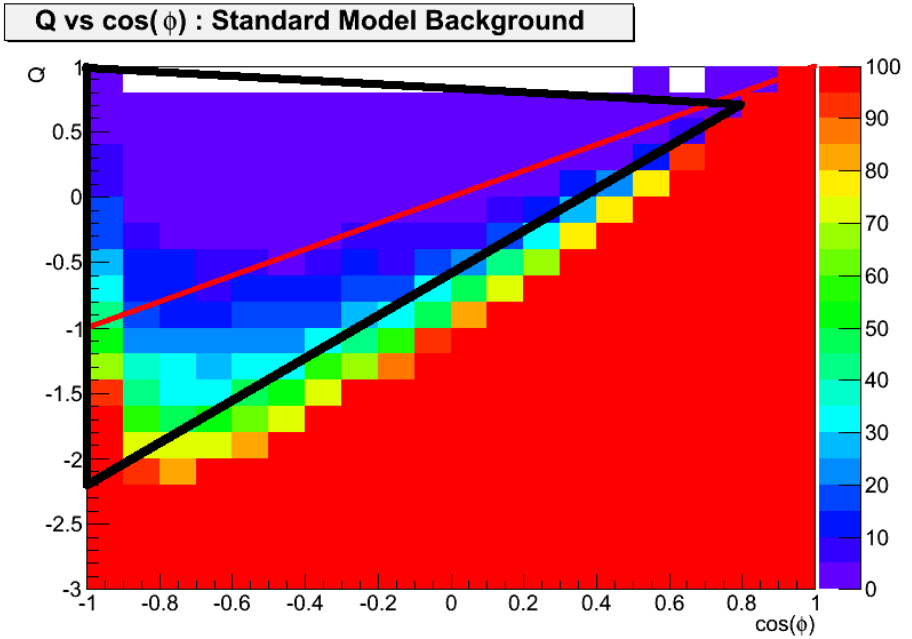
- After these common requirements, simultaneously optimize Q–cos ϕ plane, χ_t, and MET cuts for each of the three benchmark points (m_{stop}, m_{LSP}) = (500, 300), (700, 0), (700, 300) GeV to maximize signal significance
- Yields three different signal regions that should cover m_{stop}–m_{LSP} plane well

The Q–cos ϕ plane

Area below red line corresponds to traditional transverse mass cut of $M_T < M = 140$ GeV



500 GeV stop, 300 GeV neutralino

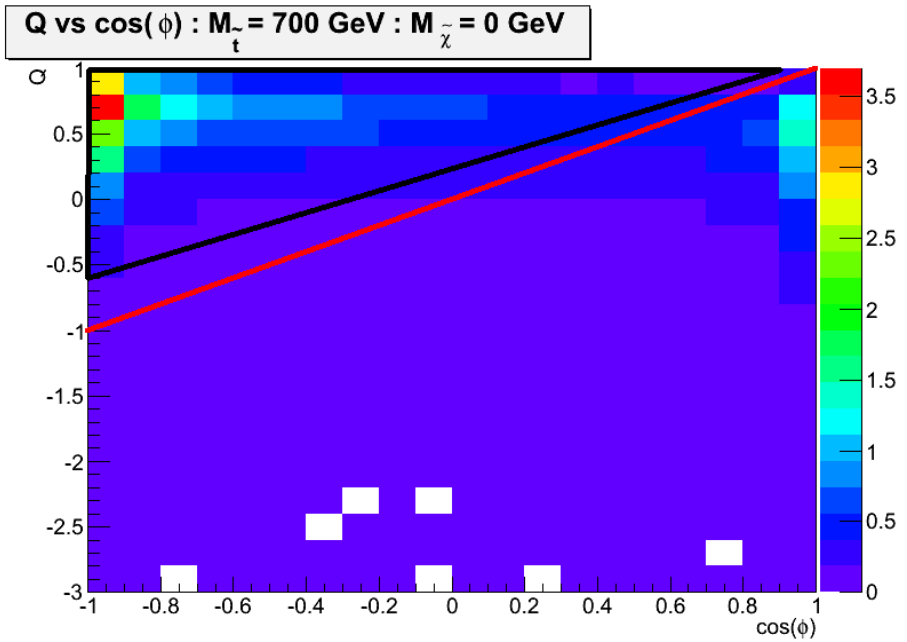


SM background dominated by tt

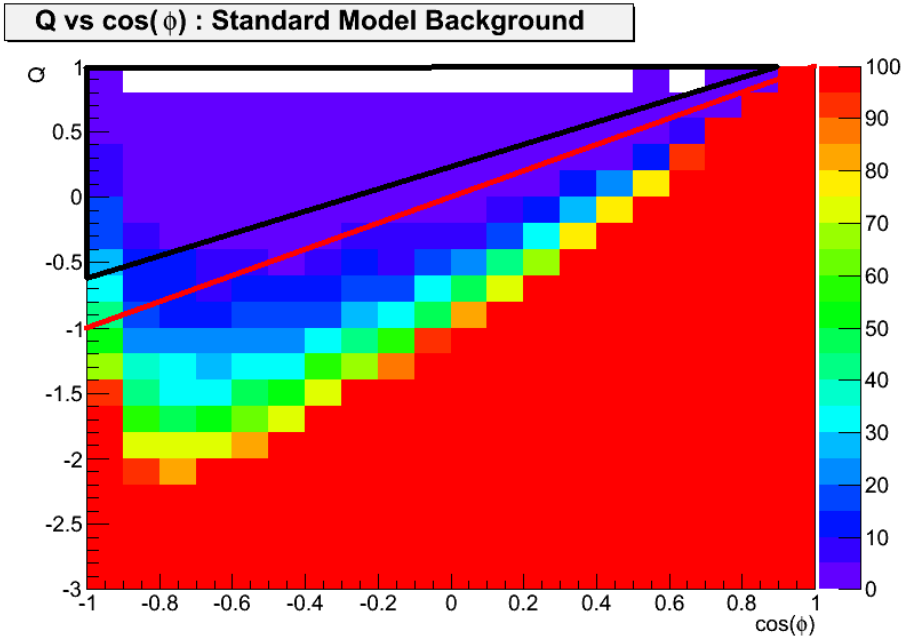
Selecting only events in this triangle optimizes the signal significance, after further cuts are applied

The Q–cos ϕ plane

Area below red line corresponds to traditional transverse mass cut of $M_T < M = 140$ GeV



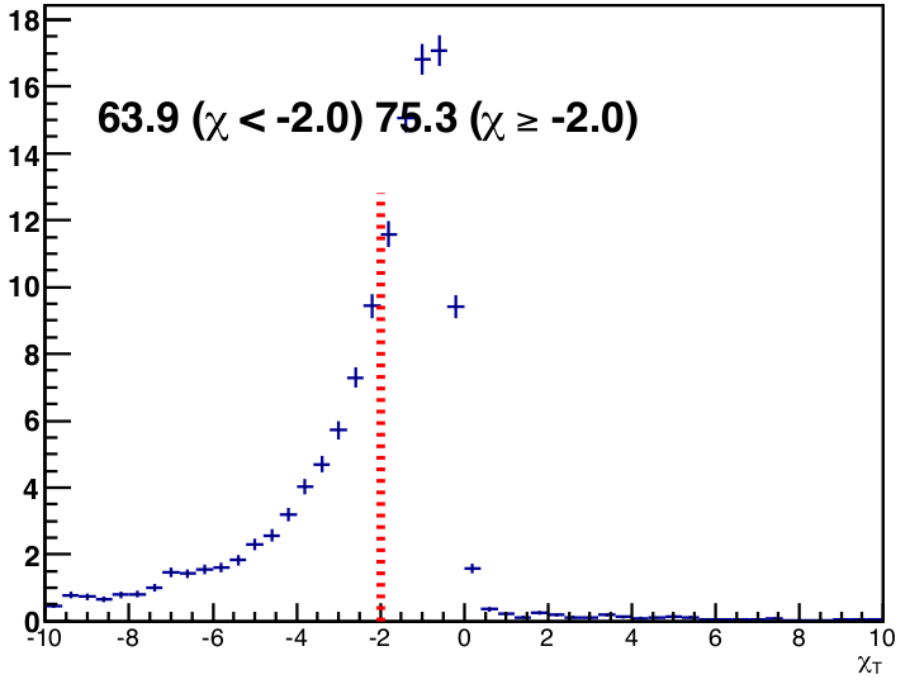
700 GeV stop, 0 GeV neutralino



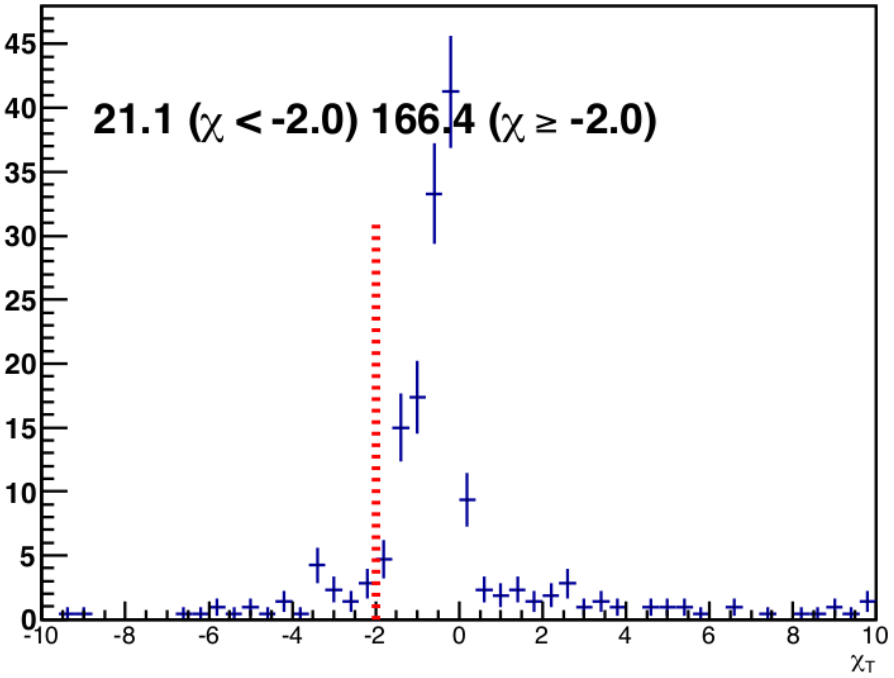
SM background dominated by tt

For large stop-neutralino mass splittings, the best region in the Q–cos ϕ plane approaches the standard M_T cut

Top reconstruction



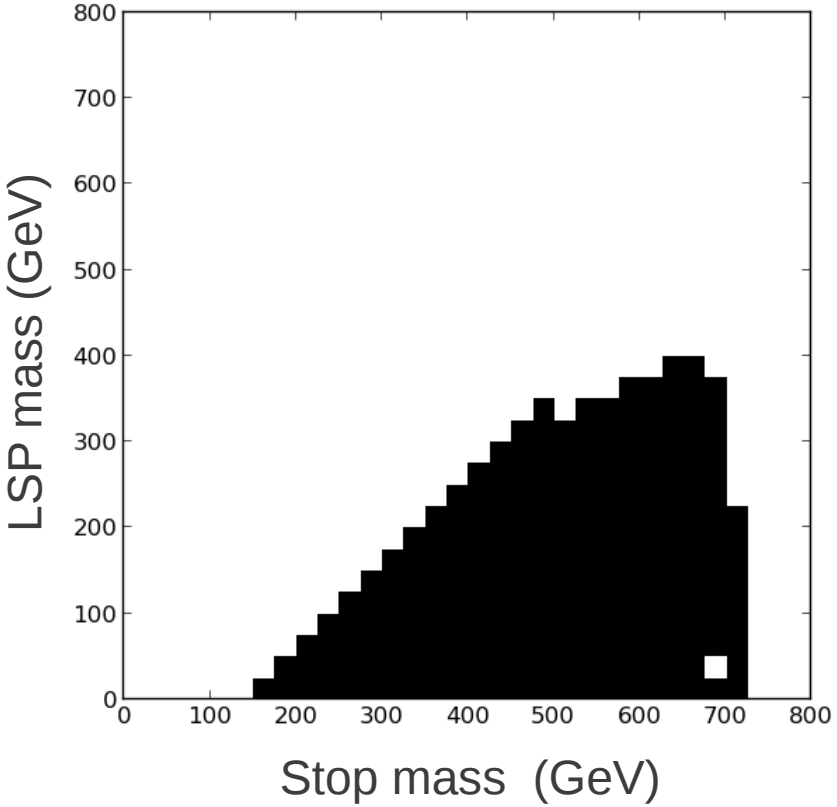
Signal

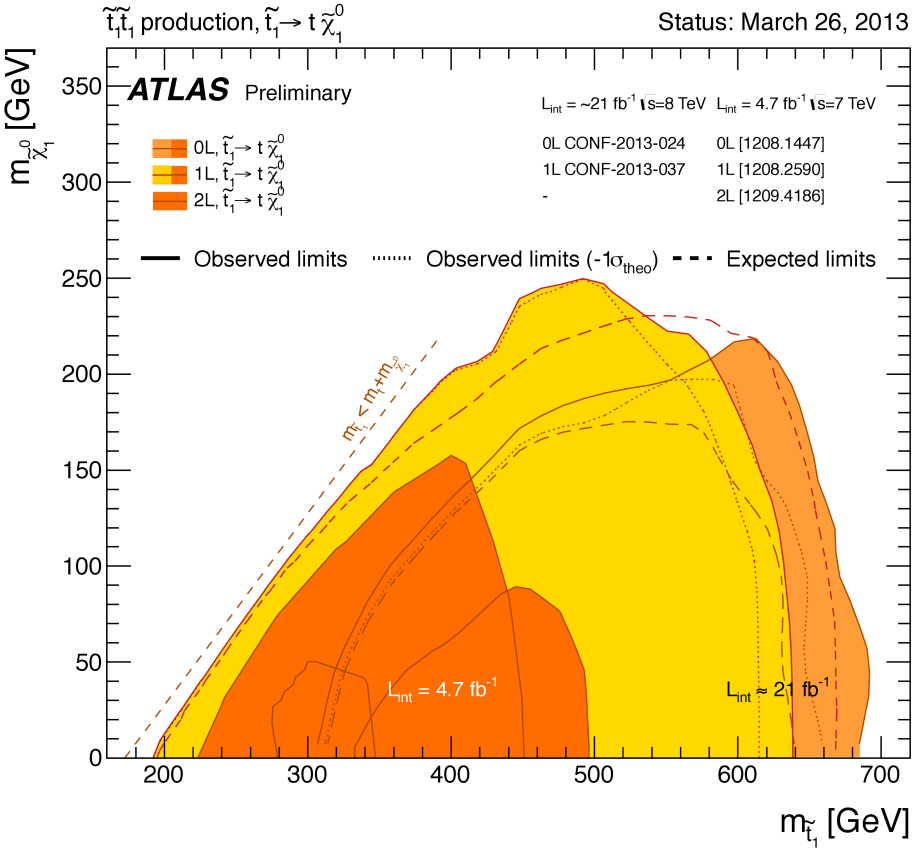


Background

Choose χ_t cut to get best separation between signal and background, given background smearing and stop, LSP masses

Preliminary exclusion





Can improve significantly over current ATLAS limits

Still to study: stops lighter than top + LSP

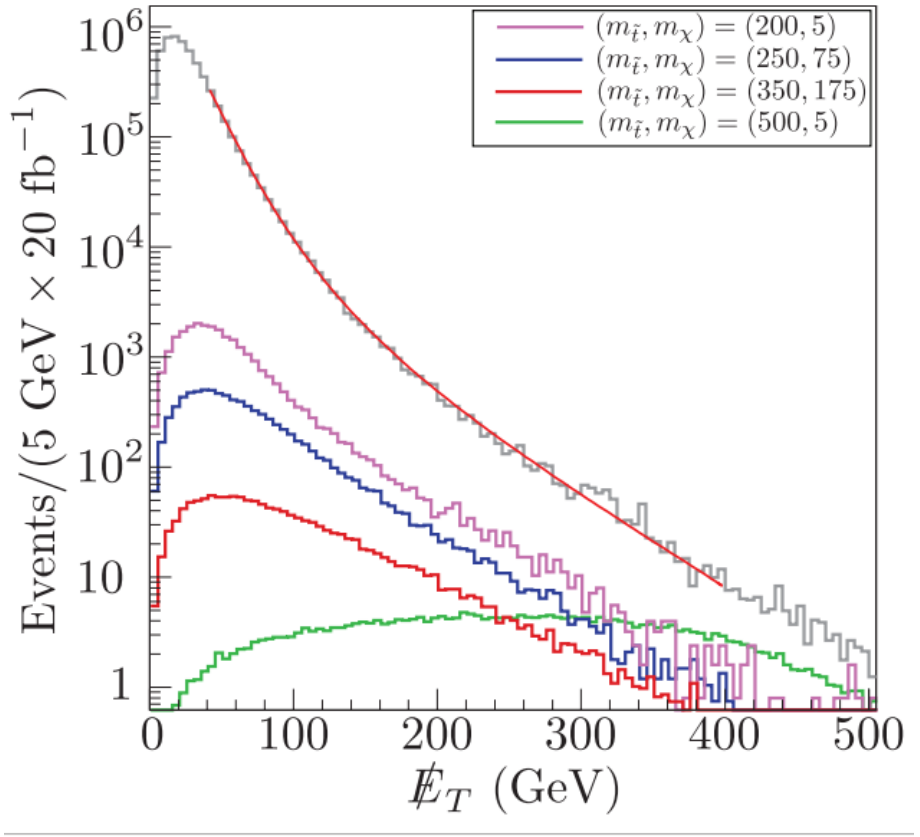
Summary

- Stop searches have received much interest, bolstered by natural SUSY
- Methods to see light stops include looking at alternate decay modes, and the development of new observables
- By deconstructing the typical transverse mass cut, we can improve the reach of the one lepton stop search considerably for compressed stops

Backup

Shape analysis

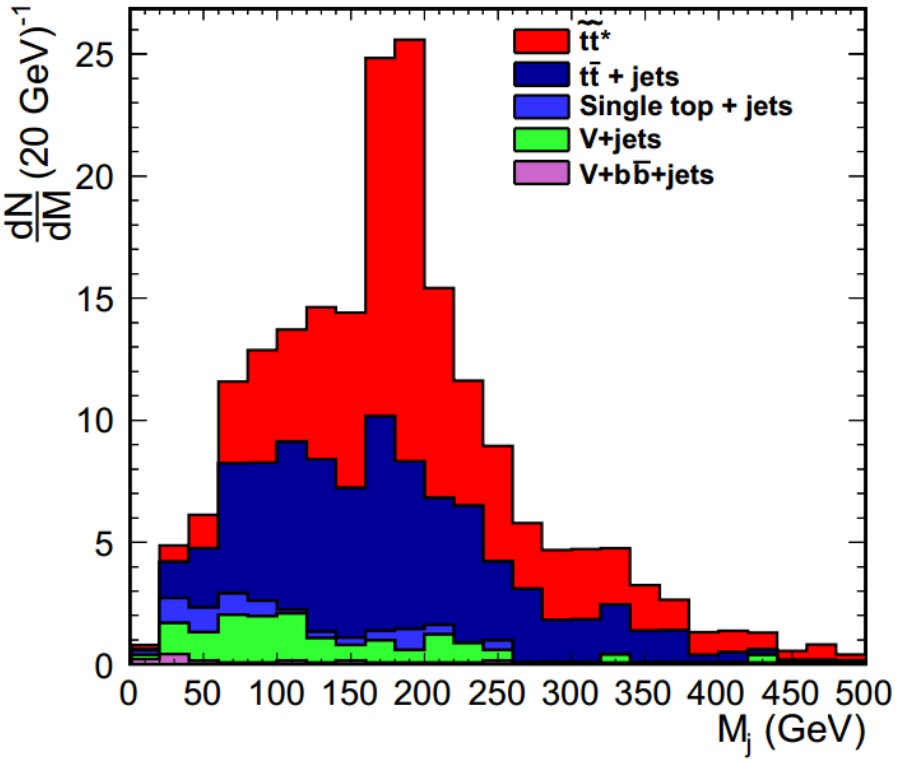
- MET distribution shape is different for hadronic stop production than for top background
- For semileptonic stop production, consider lepton transverse mass
- Now implemented in latest 1l stop search ATLAS-CONF-2013-037



D.S.M. Alves et al.
1205.5805

Jet substructure

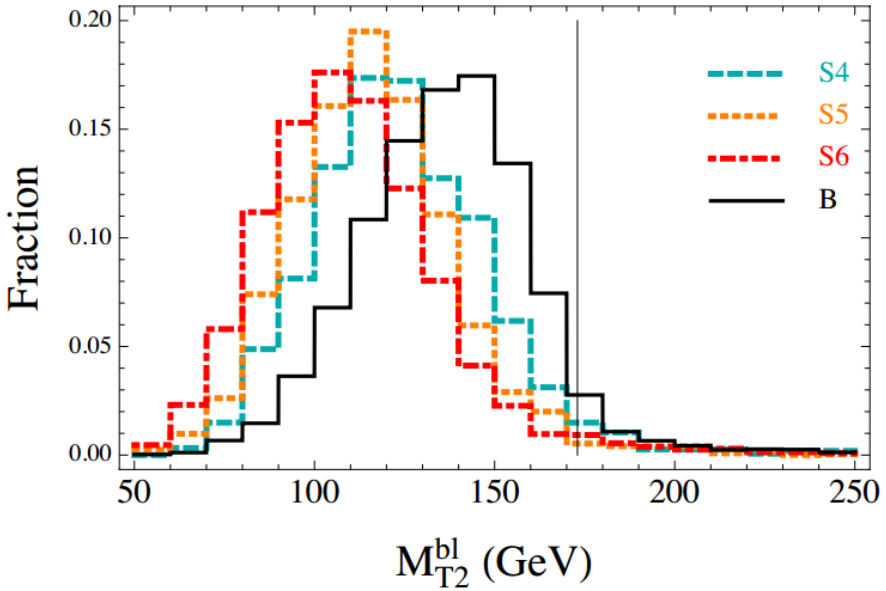
- Can tag hadronic tops by using fat jets and undoing clustering, looking for mass drop
- After lepton veto, largest remaining background is tt with one t going to a hadronic τ



D.E. Kaplan, K. Rehermann, D. Stolarski
1205.5816

Stransverse mass

- Two invisible particles in dileptonic stop pair production
- Powerful, but geared toward scenarios with hard leptons, and expensive to compute
- M_{T2} variants are now used in ATLAS stop searches



$$M_{T2}^{\ell} = \min \left\{ \bigcup_{\mathbf{p}_1+\mathbf{p}_2=\mathbf{p}_T^{\text{miss}}} \max \left[m_T(\mathbf{p}_T^{\ell_1}, \mathbf{p}_1), m_T(\mathbf{p}_T^{\ell_2}, \mathbf{p}_2) \right] \right\}$$

Y. Bai et al.
1304.3148