Search for direct production of the top squark with the ATLAS detector

IoP HEPP & APP Meeting 2013, Liverpool

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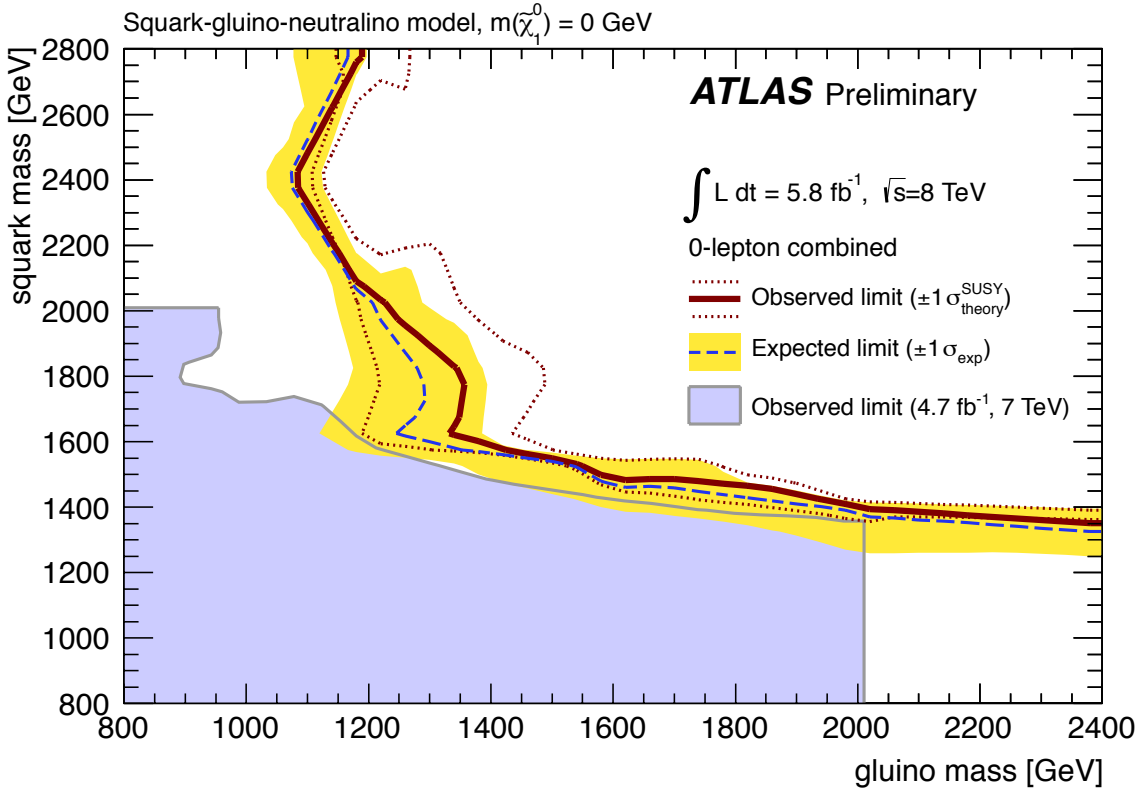
Overview

- Motivation for top squark searches
- Top squark signal
- All-hadronic top squark search
  - Selection
  - Background estimation
    - lepton+jets $t\bar{t}$
    - $Z \rightarrow \nu\nu$
    - Multijets
  - Results and interpretation

Motivation

- Searches for **3rd generation squarks** at the LHC are well motivated by **naturalness** arguments.
- The **exclusion of ~TeV scale first and second generation squarks and gluinos** by previous LHC searches make these searches particularly interesting.



ATLAS-CONF-2012-109

Motivation

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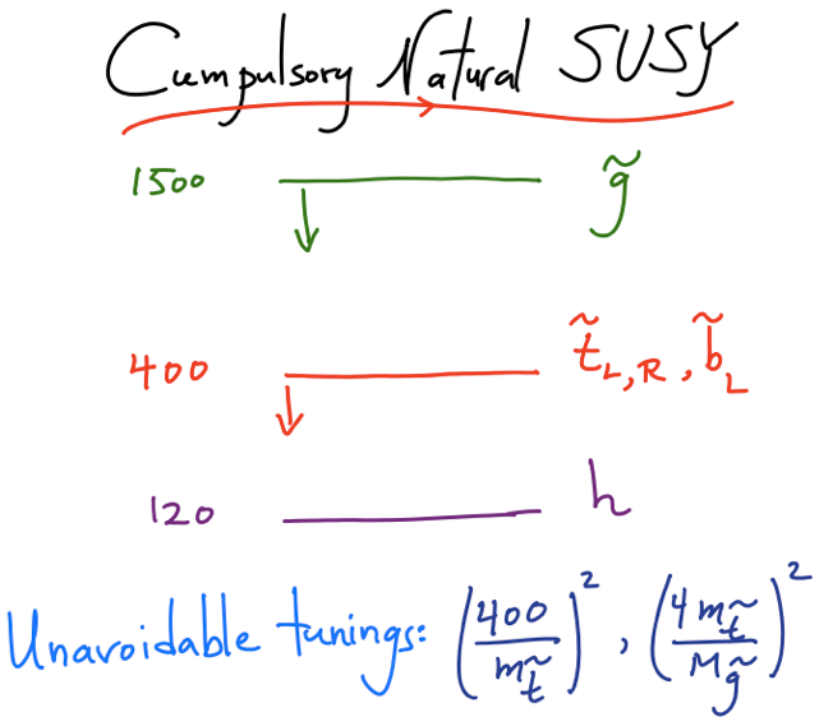
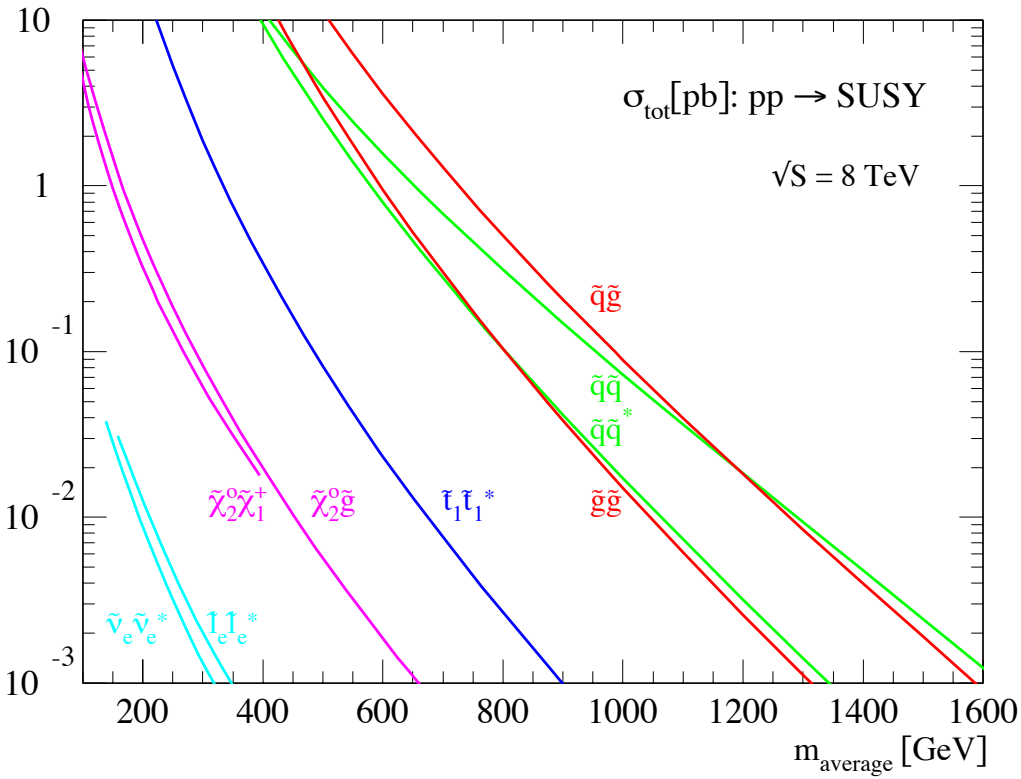
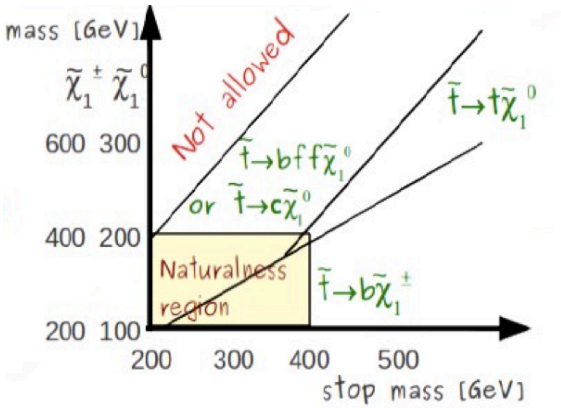
- The **exclusion of ~TeV scale first and second generation squarks and gluinos** by previous LHC searches makes these searches particularly interesting.
- Several **"natural"** SUSY scenarios rely on **"light"** third generation squarks and gauginos.



Which top squark?

- Production
  - Gluino mediated stop
  - Direct stop production





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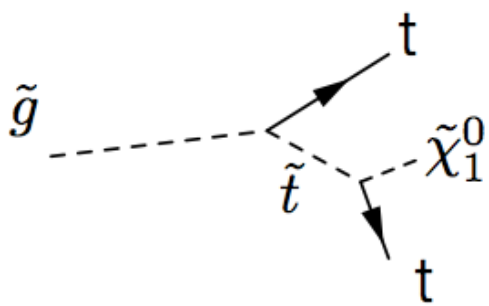

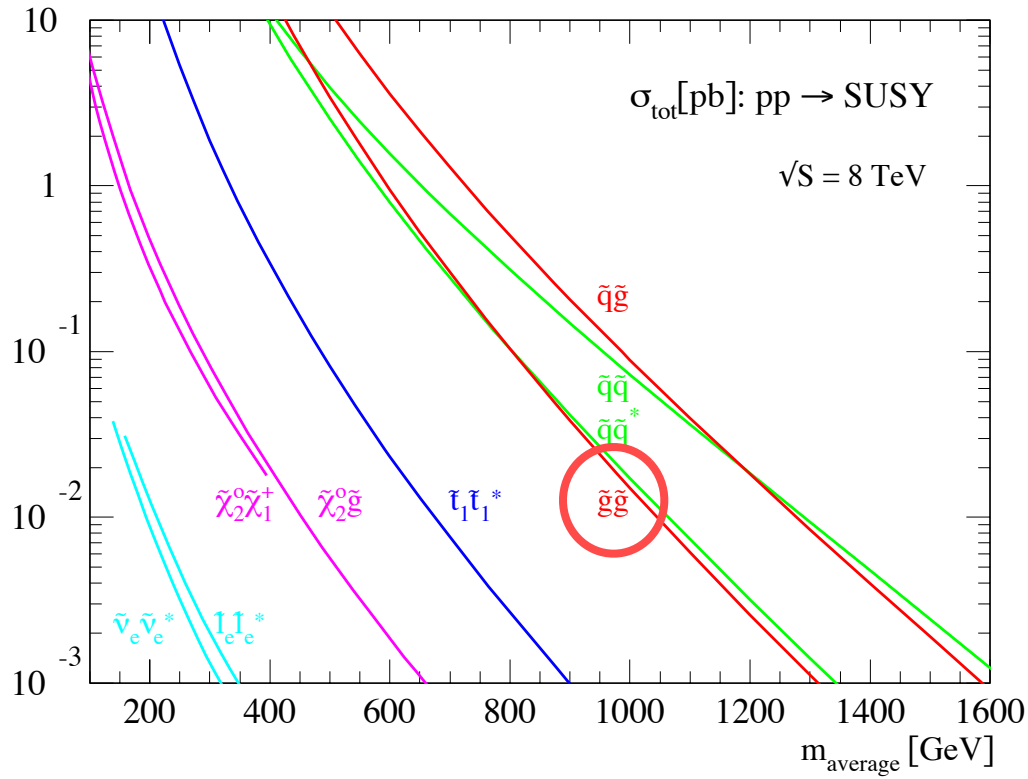

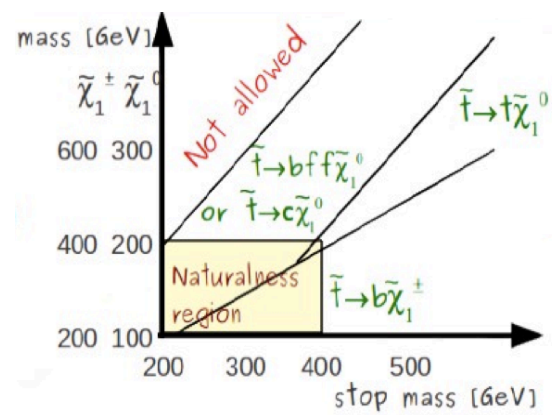

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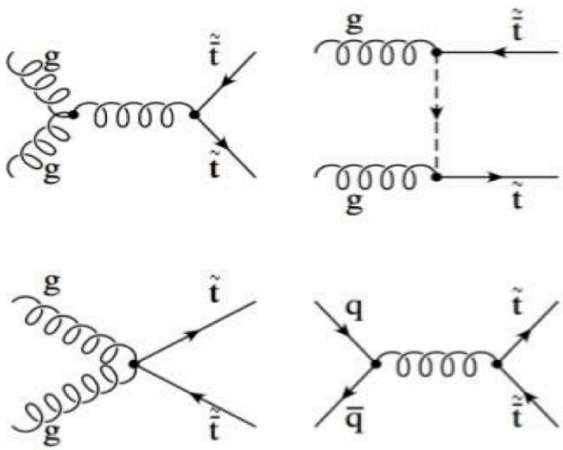

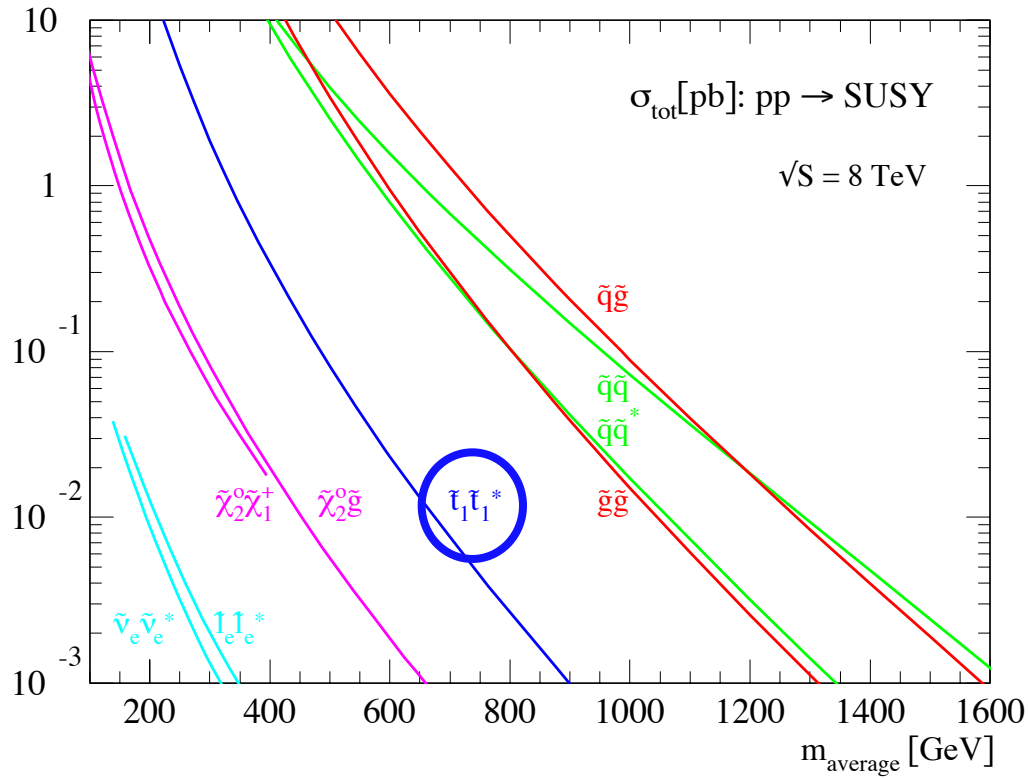

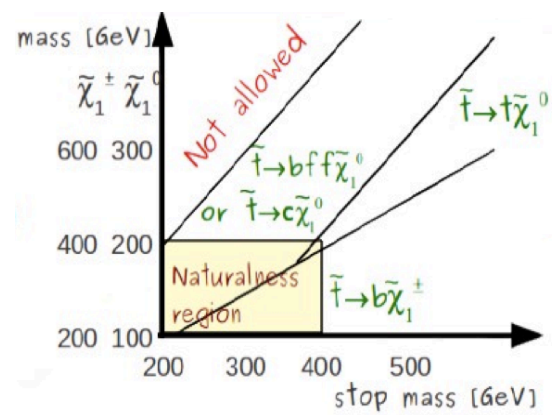

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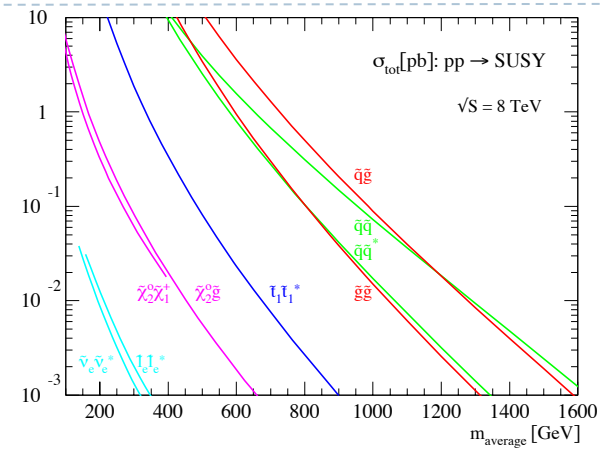
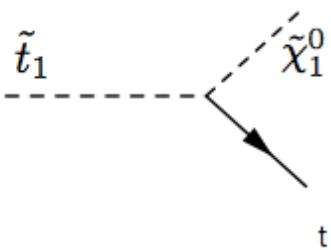
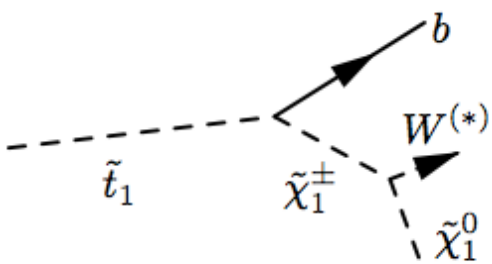


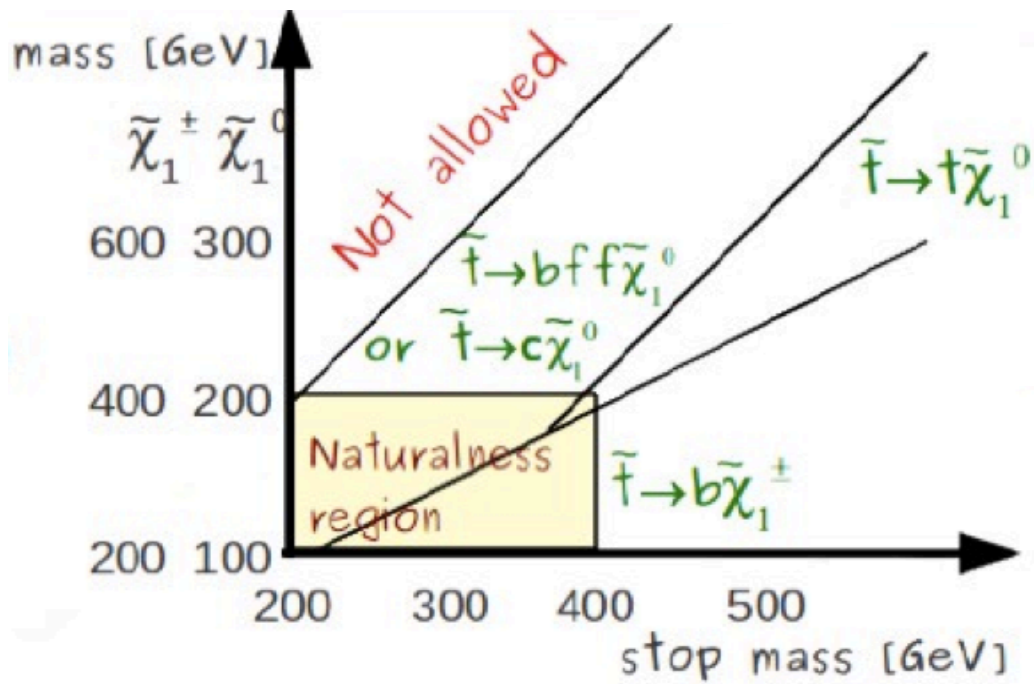
- Decay mode
  - $\tilde{t} \rightarrow t + LSP$



  - $\tilde{t} \rightarrow b + Chargino$



  - and others...



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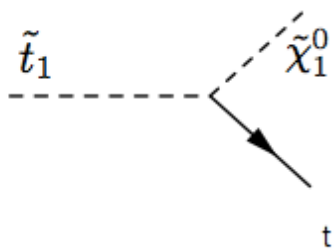

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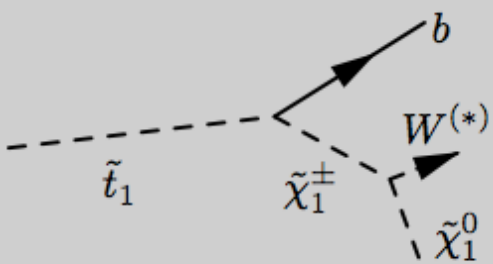

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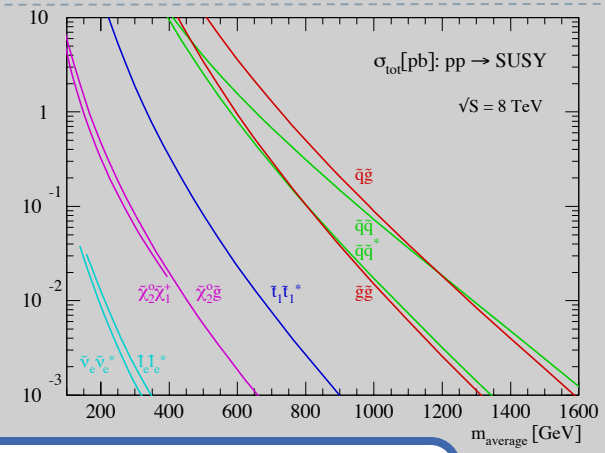
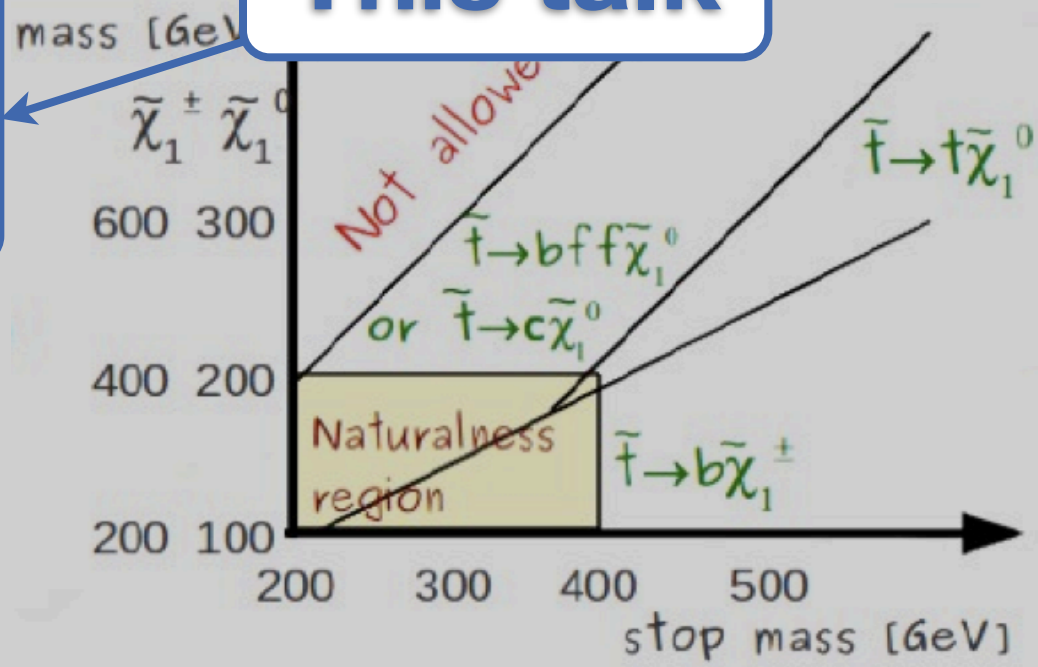
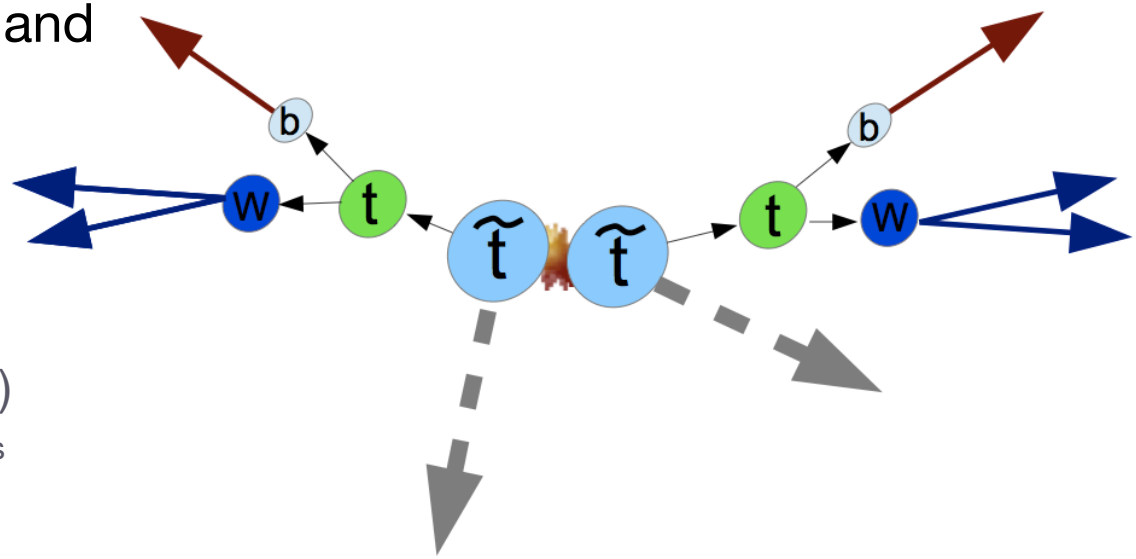


This talk



All-hadronic direct stop analysis

- Focus of this talk is on all-hadronic direct top squark search in ATLAS with full 2012 8 TeV dataset: **ATLAS-CONF-2013-024**
  - The analysis searches for **pair produced** top squarks.
  - Assume decay **$\tilde{t} \rightarrow t + LSP$** with BR=100%.
  - Consider final state where both top quarks decay **hadronically**.
- Signature is **6 jets**, **2 b-jets** and **significant E_T^{miss}**.



- **Signal selection**
  - Trigger on E_T^{miss}
  - Veto events with leptons (e,μ)
  - Reject events with fake E_T^{miss}
  - Require 6 jets and 2 b-jets
  - Reconstruct two top quarks
  - Veto events if E_T^{miss} and b-jet are consistent with semi-leptonic $t\bar{t}$
  - Veto events if a jet close to E_T^{miss} is consistent with hadronic τ

Selection | Overview

- **Preselection:**
  - E_T^{miss} trigger, standard event cleaning
  - **6 jets p_T > 80,80,35,...,35 GeV**

- **Signal region selection:**

Selection Criteria		
2 loose b-tagged jets		
$E_T^{miss,track} > 30$ GeV and $\left\lvert \Delta\phi\left(E_T^{miss}, E_T^{miss,track}\right)\right\rvert < \frac{\pi}{3}$		
$\min \left\lvert \Delta\phi\left(\text{jet}^{0-2}, E_T^{miss}\right)\right\rvert > 0.2\,\pi$		
$m_T\left(b_{\min[\Delta\phi(b,E_T^{miss})]}, E_T^{miss}\right) > 175$ GeV		
Veto events with a τ candidate		
80 GeV $< m^0_{jjj}, m^1_{jjj} <$ 270 GeV		
Signal Region I	Signal Region II	Signal Region III
$E_T^{miss} > 200$ GeV	$E_T^{miss} > 300$ GeV	$E_T^{miss} > 350$ GeV

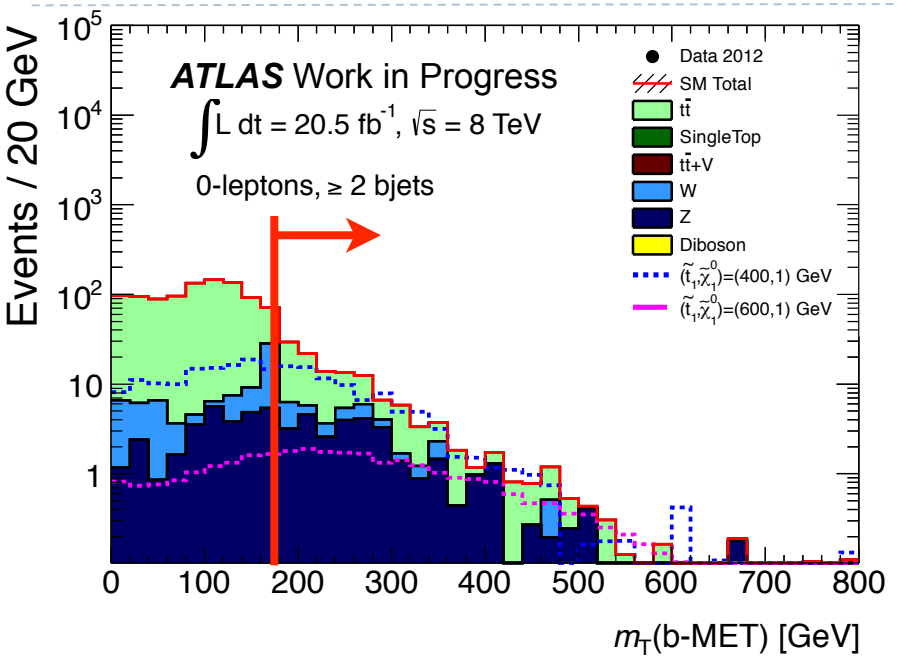
QCD and EW rejection

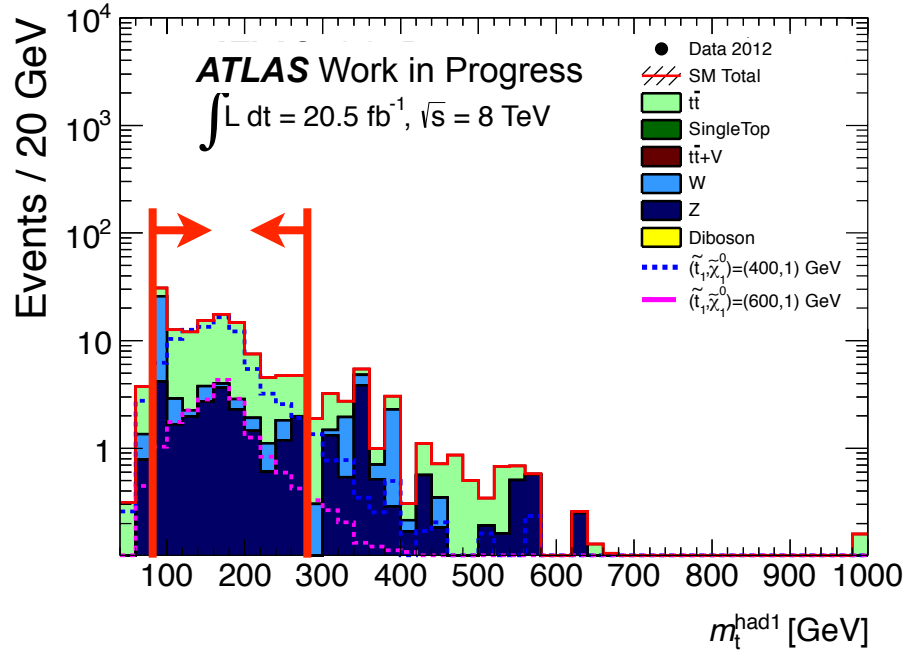
QCD rejection

Semileptonic $t\bar{t}$ and EW rejection

Signal regions

Selection | $t\bar{t}$ & EW rejection





$$m_{\mathrm{T}}\left(b_{\min[\Delta\phi(b,E_{\mathrm{T}}^{\mathrm{miss}})]}, E_{\mathrm{T}}^{\mathrm{miss}}\right) > 175\ \mathrm{GeV}$$

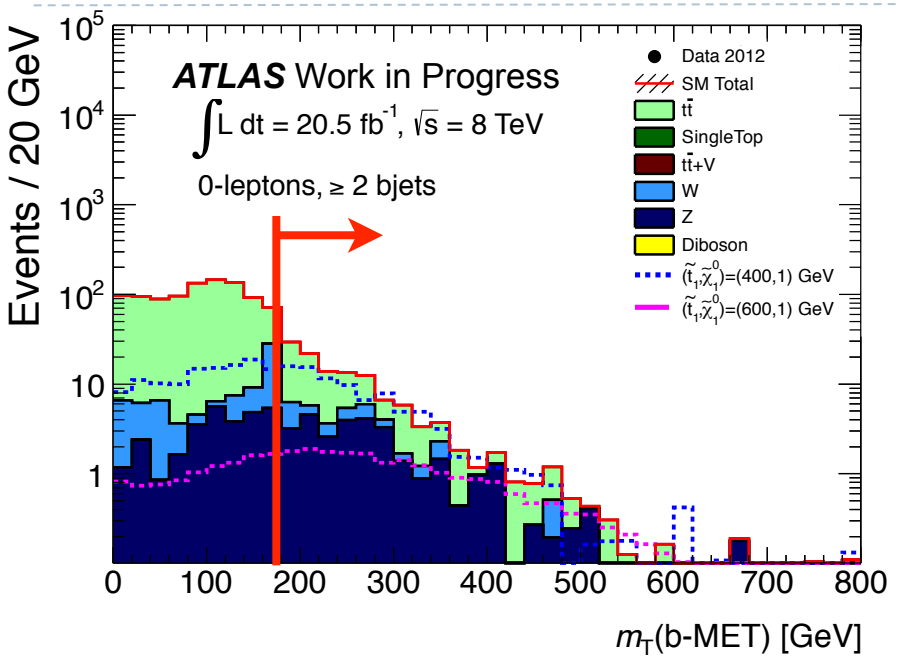
Veto events with a τ candidate

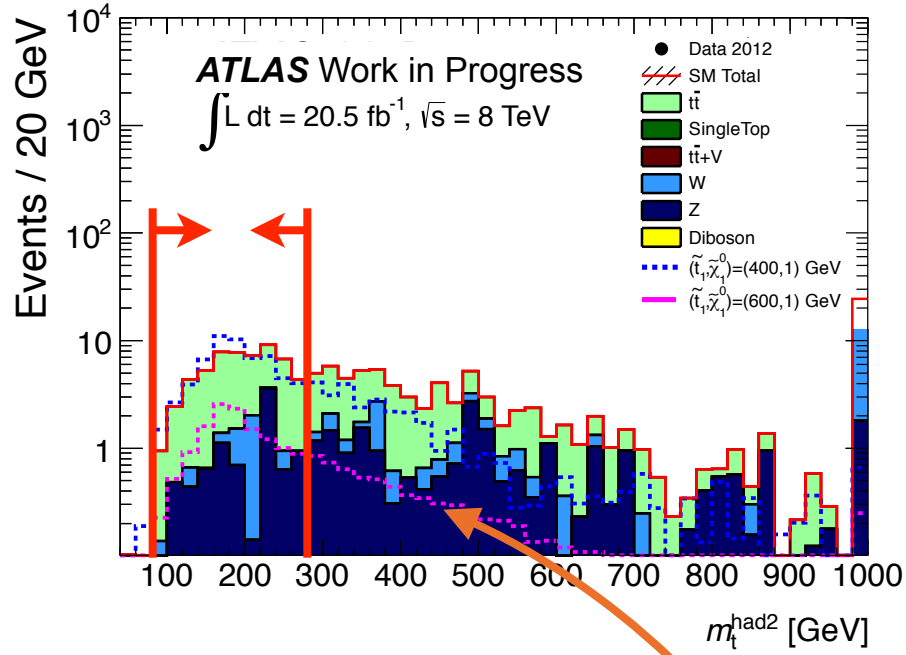
$$80\ \mathrm{GeV} < m_{jjj}^{0},\ m_{jjj}^{1} < 270\ \mathrm{GeV}$$

Semileptonic $t\bar{t}$ and EW rejection

- $m_T(b\text{-}E_T^{miss})$ has an endpoint at ~m_t for $t\bar{t}$
  - Cutting above 175 GeV removes a huge amount of the semileptonic $t\bar{t}$ background.
- Reconstruct two hadronic tops from the ≥6 jets
  - Top mass window cut removes a large amount of remaining $t\bar{t}$ and W/Z+jets backgrounds.

Selection | $t\bar{t}$ & EW rejection





$$m_T\left(b_{\min[\Delta\phi(b,E_T^{miss})]}, E_T^{miss}\right) > 175 \text{ GeV}$$

Veto events with a τ candidate

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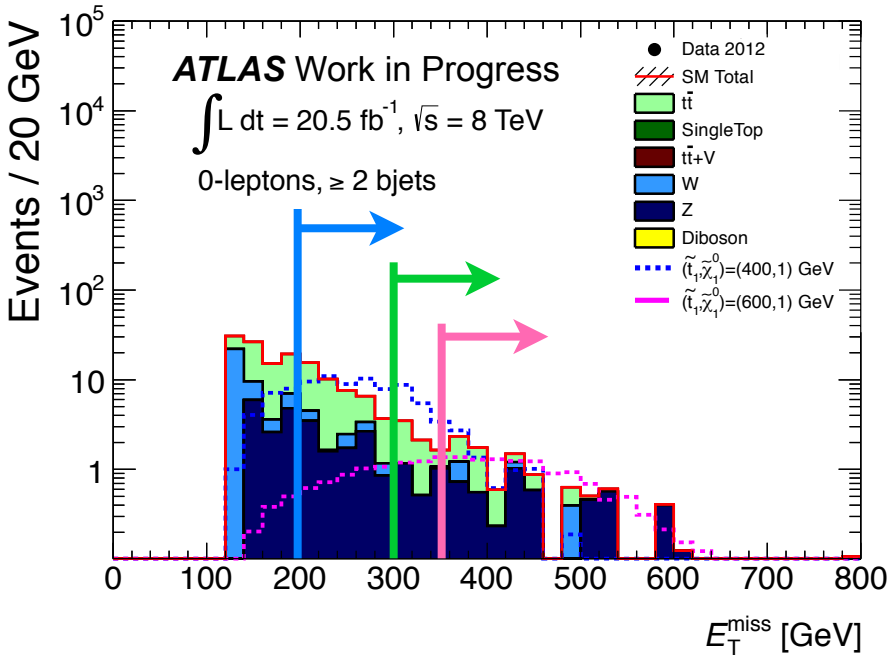
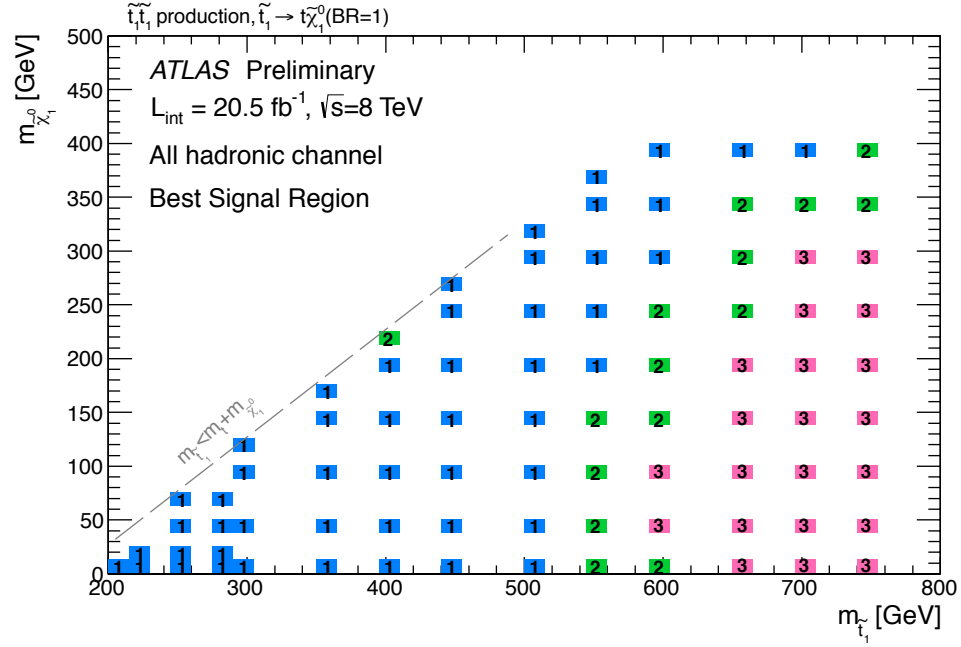
- Reconstruct two hadronic tops from the ≥6 jets
  - Top mass window cut removes a large amount of remaining $t\bar{t}$ and W/Z+jets backgrounds - **especially on the least well reconstructed hadronic top.**

Selection | Discrimination with E_T^{miss}





Signal Region I	Signal Region II	Signal Region III
$E_T^{miss} > 200$ GeV	$E_T^{miss} > 300$ GeV	$E_T^{miss} > 350$ GeV

Signal regions

- After extensive optimisation E_T^{miss} provides the best discrimination between the signal and remaining backgrounds.
- Incremental E_T^{miss} thresholds define the signal regions.

Analysis strategy

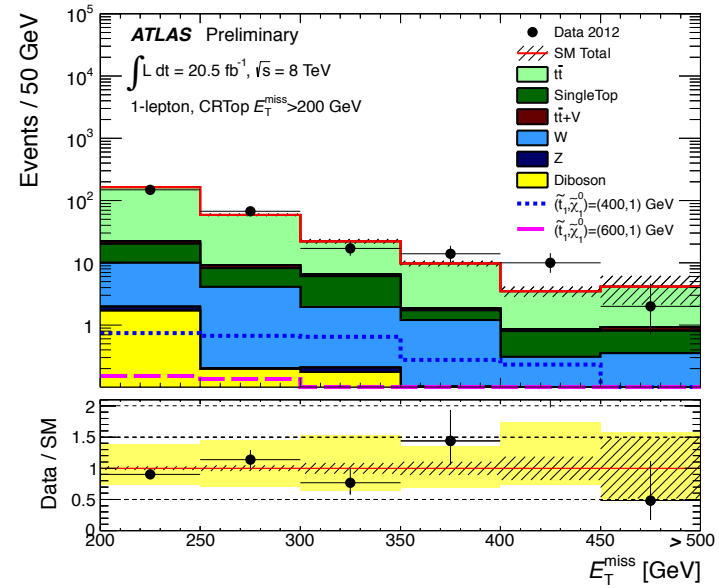
- Control regions defined for important backgrounds:
  - Semileptonic $t\bar{t}$ + jets (hadronic τ or low p_T e/μ)
  - $Z \rightarrow \nu\nu$ + jets (including heavy flavour jets)
  - Multijets (E_T^{miss} coming from mis-measured jets)

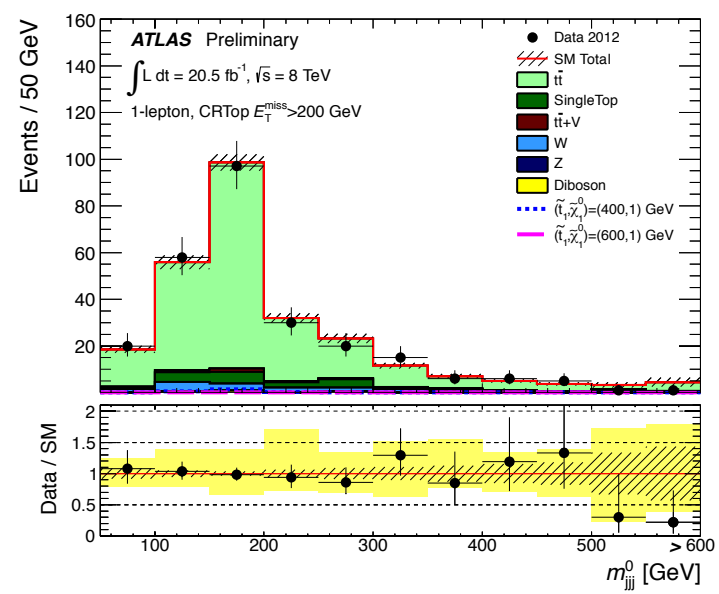
- Single top, $t\bar{t}$+V and diboson estimated from Monte Carlo.

- A simultaneous fit to each of the signal and $t\bar{t}$ control regions is performed to extract the final limit.
  - The $t\bar{t}$ normalisation is allowed to float in the fit.
  - QCD and Z backgrounds have fixed contributions and uncertainties.

Background estimation | Top

- Background comes from semileptonic $t\bar{t}$
  - Mostly composed of events with hadronic tau leptons
  - Large uncertainties on normalisation
- Use **1-lepton control region**
- Select events with:
  - Exactly 1 good e/μ
  - 5 (other) jets, 2 b-tagged
  - Large E_T^{miss}
  - At least 1 well reconstructed top
  - Passes cuts to remove fake E_T^{miss}
  - $40 < m_T(l,E_T^{miss}) < 120$ GeV
  - Consider the lepton to be a jet
    - Mimics the hadronic tau in the signal region
- Uncertainties
  - JES and theory (generator and parton shower) uncertainties are dominant.





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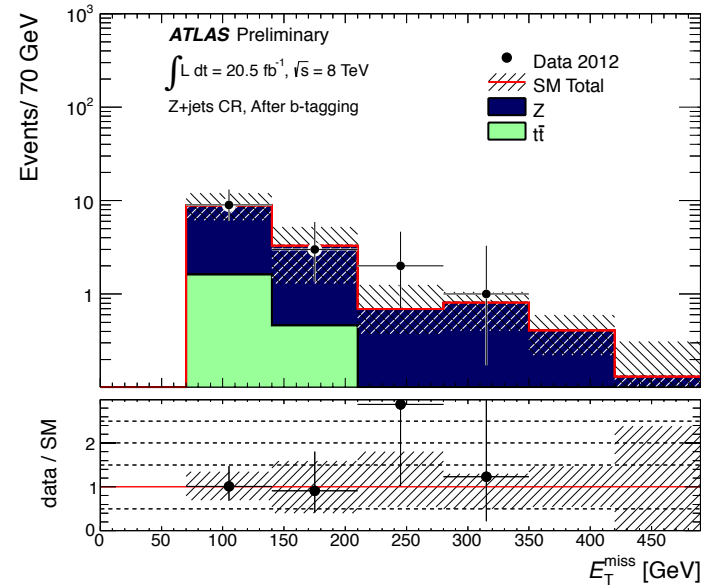
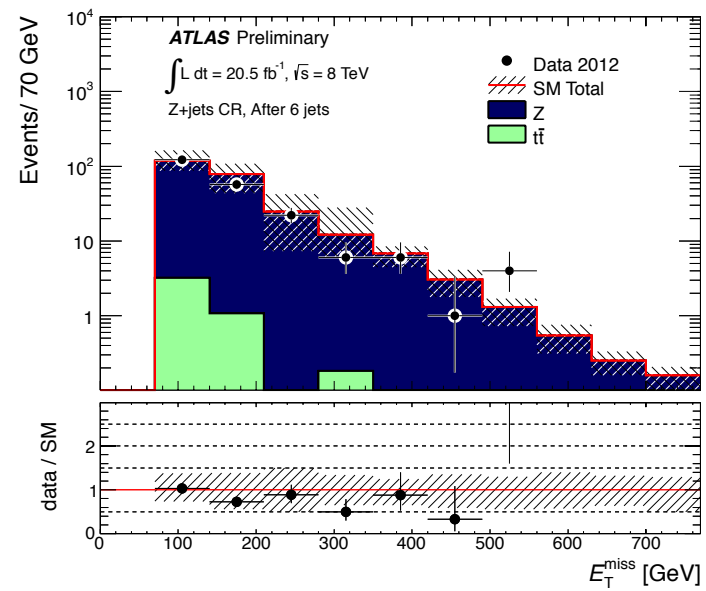
Background estimation | Z→νν

- Irreducible background from Z→νν + (HF) jets
- Use **2-lepton control region**
  - Mimic Z→νν with Z→ll events by subtracting the lepton p_T from E_T^{miss}.
- Select events with:
  - Opposite sign ee or μμ pair
  - Require E_T^{miss} < 50 GeV (removes $t\bar{t}$)
  - Subtract the lepton p_T from E_T^{miss}
  - 81 < m_{ll} < 101 GeV
  - Same jet selection as SR
  - **Modified** E_T^{miss} > 70 GeV
  - b-tagging
- Uncertainties
  - Detector, theory and scale variations are considered, uncertainties of 31-35% are assigned for each SR.





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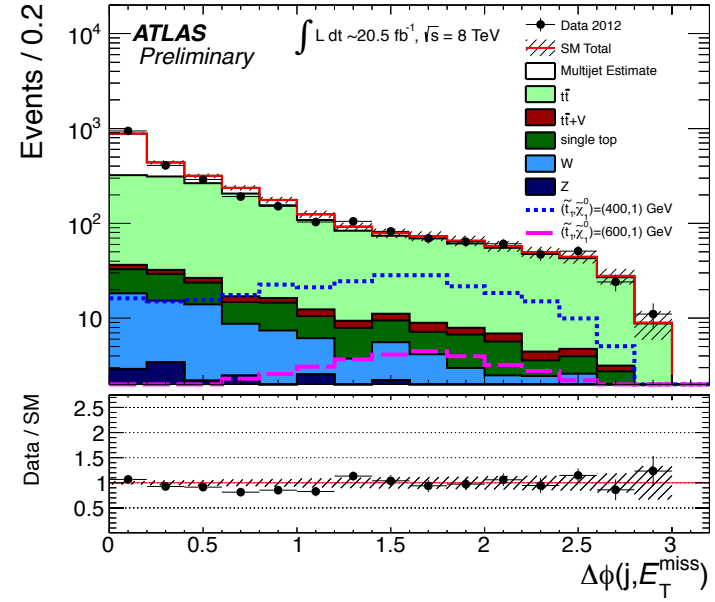
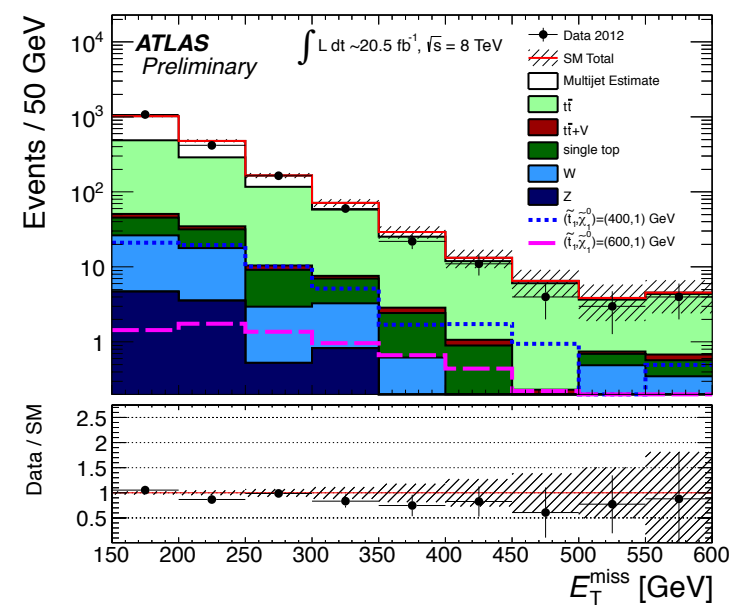
Background estimation | Multijets

- Estimate multijet (and all-hadronic top) background with jet smearing method.
  - Select clean multijet events from data.
  - Smear jets, sampling from a MC derived response function, to form "pseudo data" that can acquire large E_T^{miss} from fluctuating jets.
  - Pass "pseudo data" through SR selection.

- Normalisation is taken from a QCD enriched CR:
  - Same jet and E_T^{miss} selection as SR.
  - Logical or of reversed $\Delta\Phi(j,E_T^{miss})$ and reversed $\Delta\Phi(E_T^{miss},E_T^{miss,track})$ regions.

- Uncertainties
  - 100% uncertainty from variations to the response function Gaussian core and tail shape.





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Systematic uncertainties

- Dominant systematic uncertainties come from control region sample size, jet energy scale and $t\bar{t}$ theoretical uncertainties.

Uncertainty	SR1	SR2	SR3
Total	18%	33%	45%
Background sample sizes (data and simulation)	10%	17%	21%
Jet energy scale and resolution	10%	10%	25%
$t\bar{t}$ theory	10%	19%	22%
Z+jets theory	4%	8%	8%
$t\bar{t} + W/Z$ theory	5%	8%	10%

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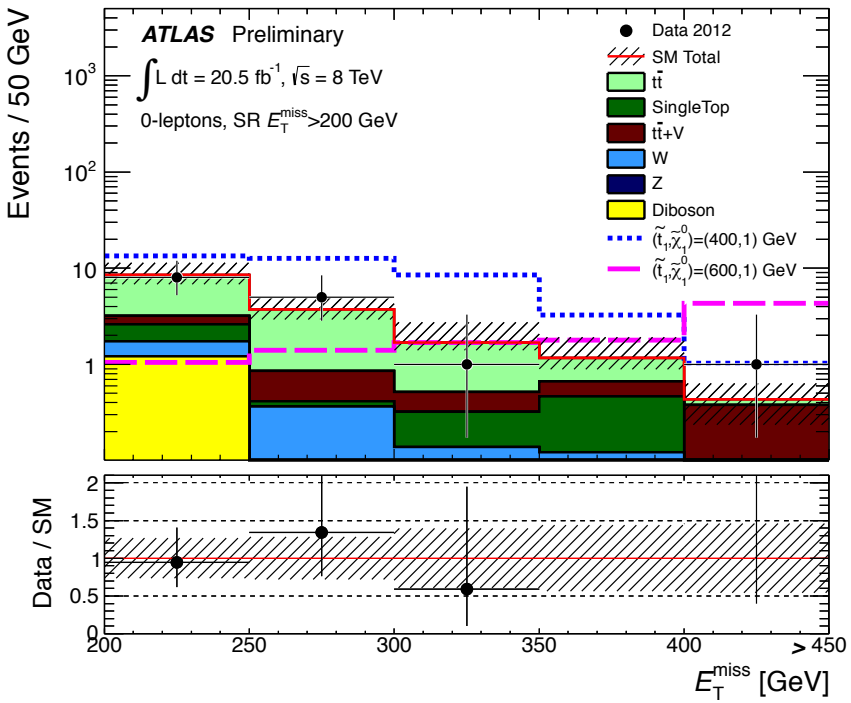
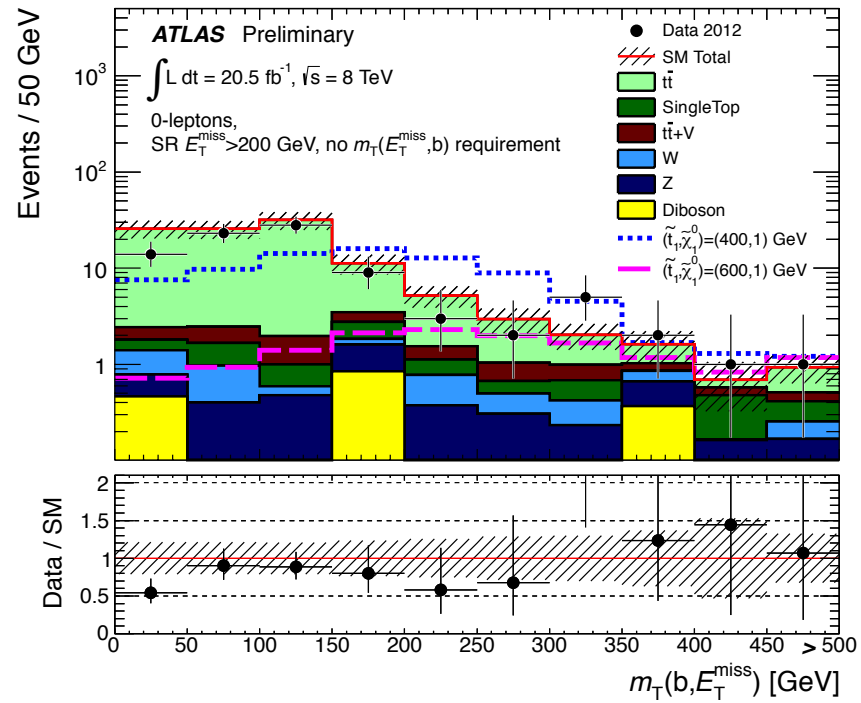
Results

- Observations are consistent with SM expectations.

Number of events	SR1	SR2	SR3
Observed	15	2	1
Expected background	17.5 ± 3.2	4.7 ± 1.5	2.7 ± 1.2
Expected $t\bar{t}$	9.8 ± 2.6	1.9 ± 1.3	0.9 ± 0.7
Expected $t\bar{t} + W/Z$	1.7 ± 1.0	0.7 ± 0.4	0.51 ± 0.30
Expected Z+jets	2.1 ± 1.0	1.2 ± 0.5	0.8 ± 0.4
Expected W+jets	1.2 ± 0.8	0.32 ± 0.29	$0.19^{+0.23}_{-0.19}$
Expected single-top	1.5 ± 0.9	0.5 ± 0.4	$0.3^{+0.5}_{-0.3}$
Expected multijet	0.12 ± 0.12	0.01 ± 0.01	< 0.01
Expected diboson	1.2 ± 1.2	< 0.22	< 0.22
Fit input expectation $t\bar{t}$	9.9	1.7	0.6





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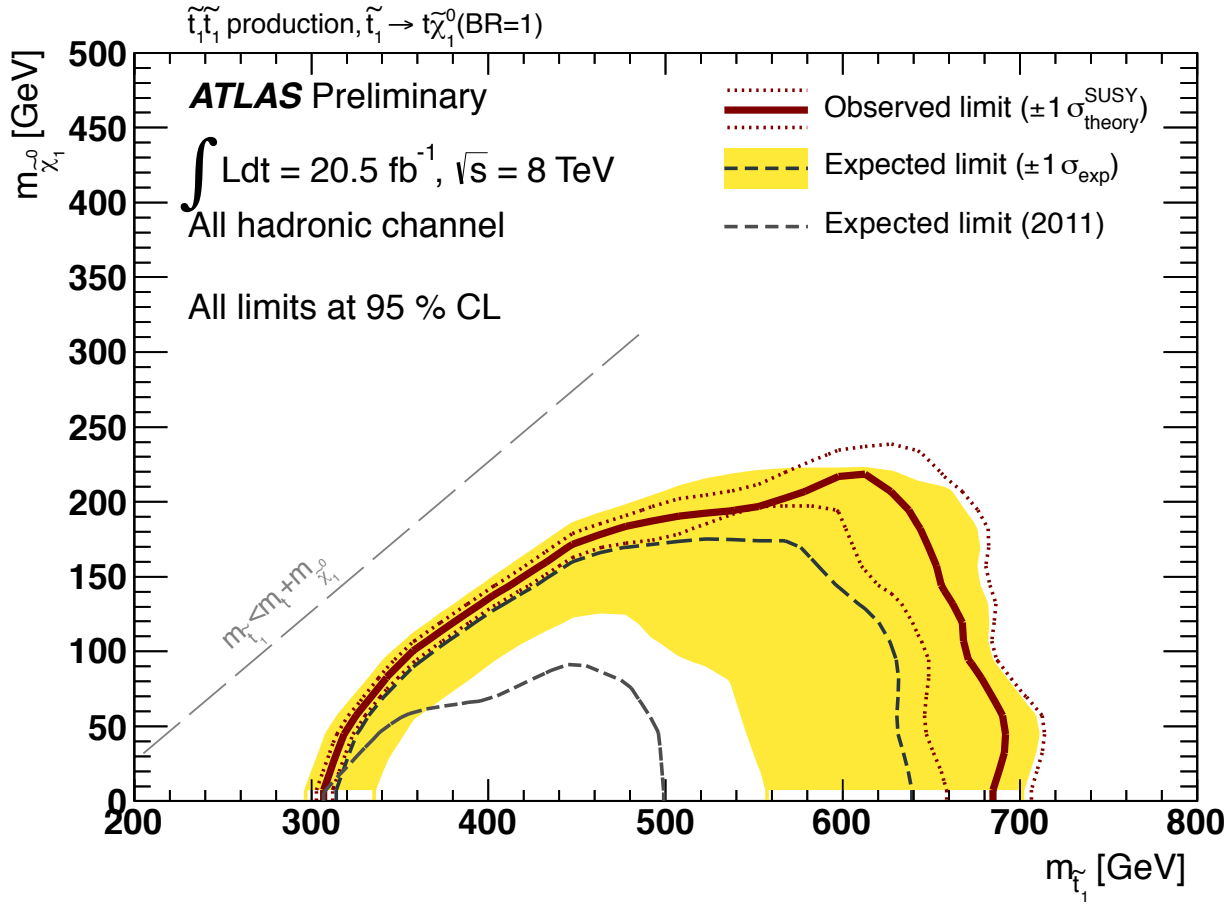
Interpretation | $m_{\tilde{t}}$ - m_{LSP} limits

- Exclusion limits at 95% CL have been set.
  - Stop masses between **320 and 660 GeV** are excluded for a nearly massless LSP.
  - For a LSP mass of **150 GeV** stop masses are excluded between **400 and 620 GeV**.



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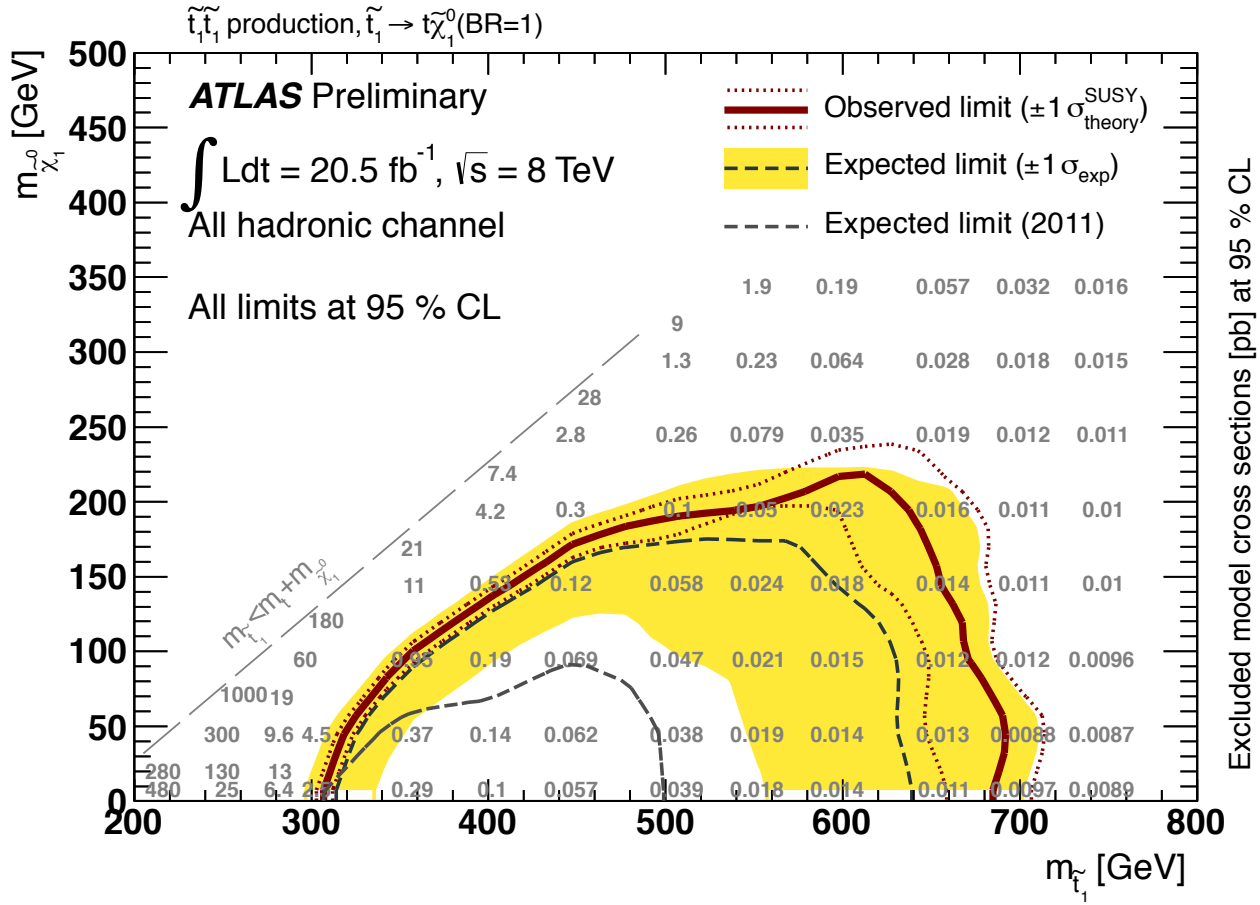

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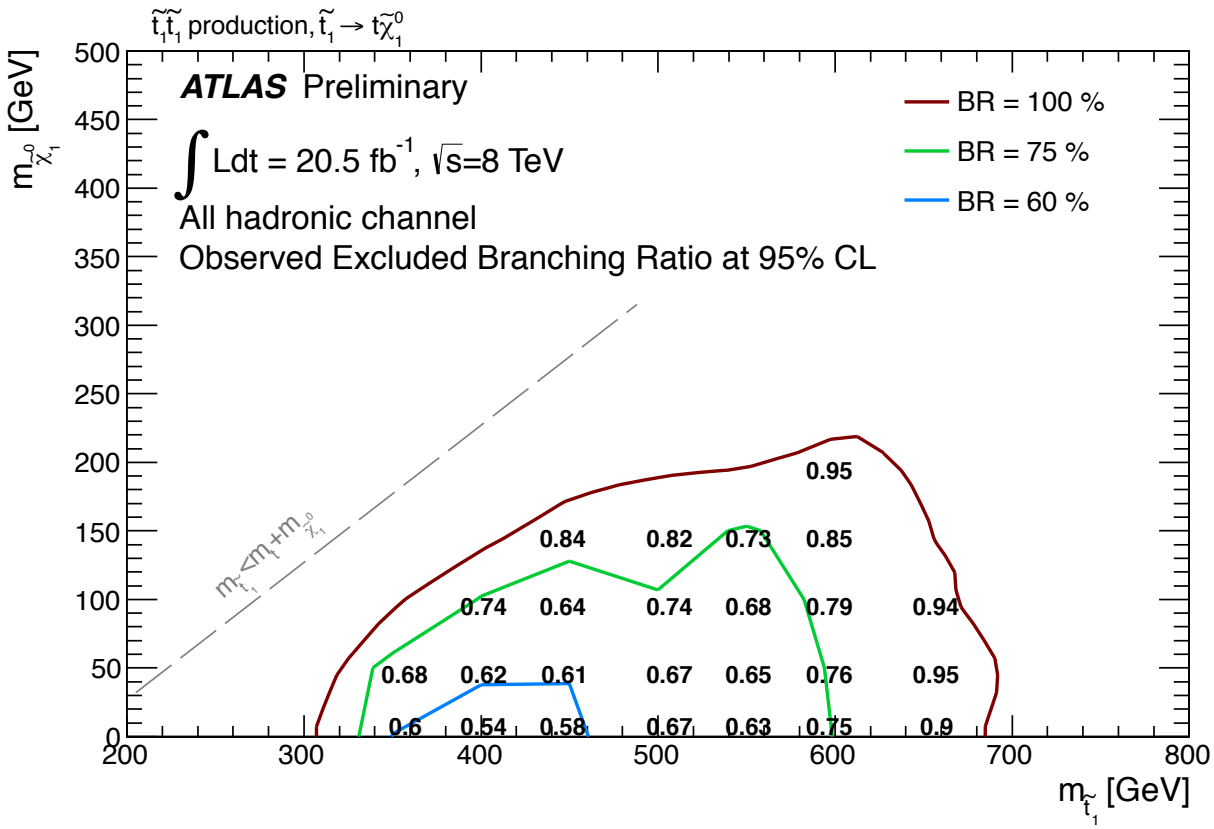
Interpretation | $m_{\tilde{t}}$ - m_{LSP} BR limits

- It is possible to interpret the model cross section upper limits in terms of **branching ratio** (BR) limits.

- We are able to exclude **BR > 54%** for **m_{stop}=400 GeV, m_{LSP}=1 GeV**.



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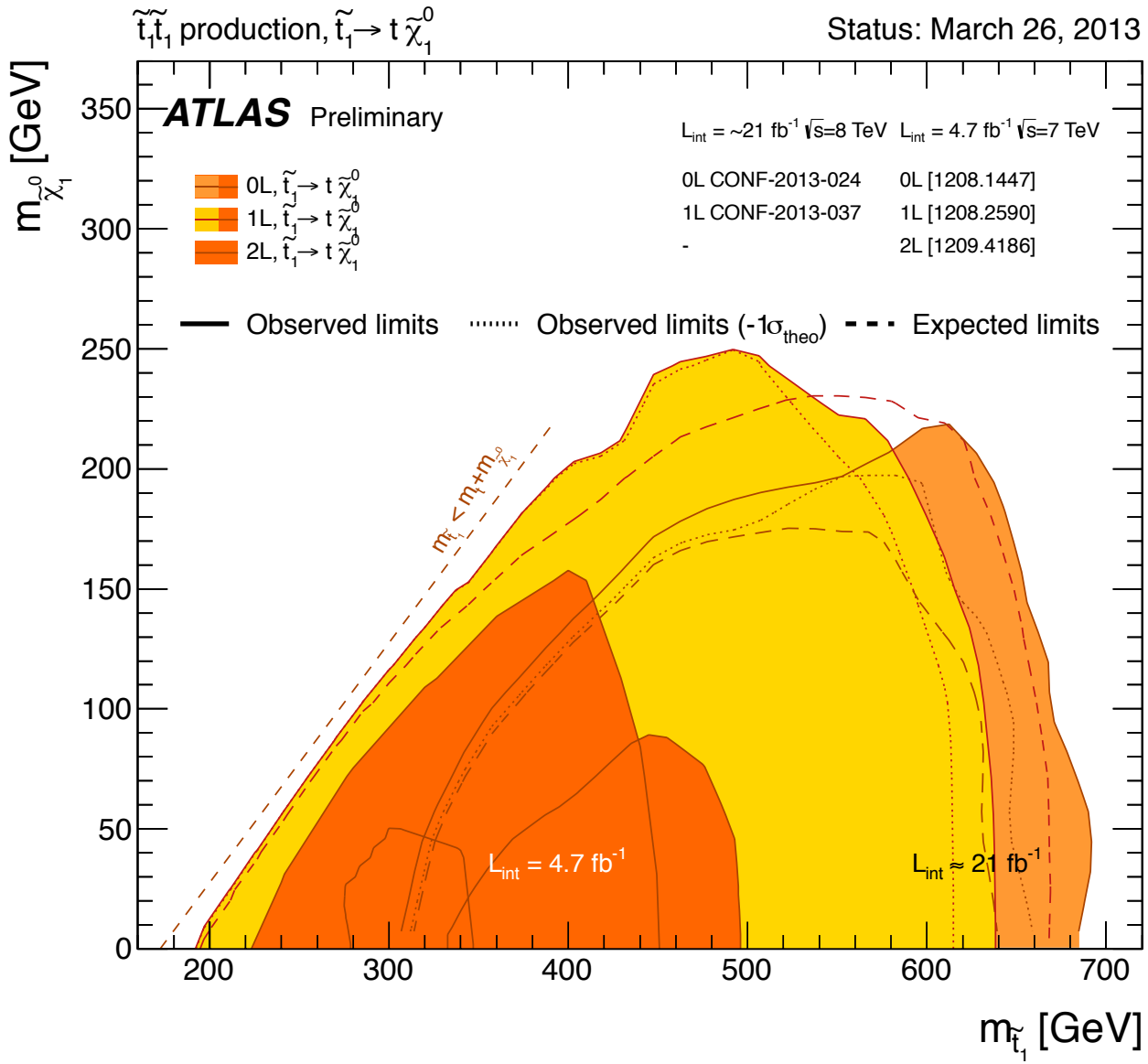
ATLAS $\tilde{t} \rightarrow t + LSP$ exclusion limits

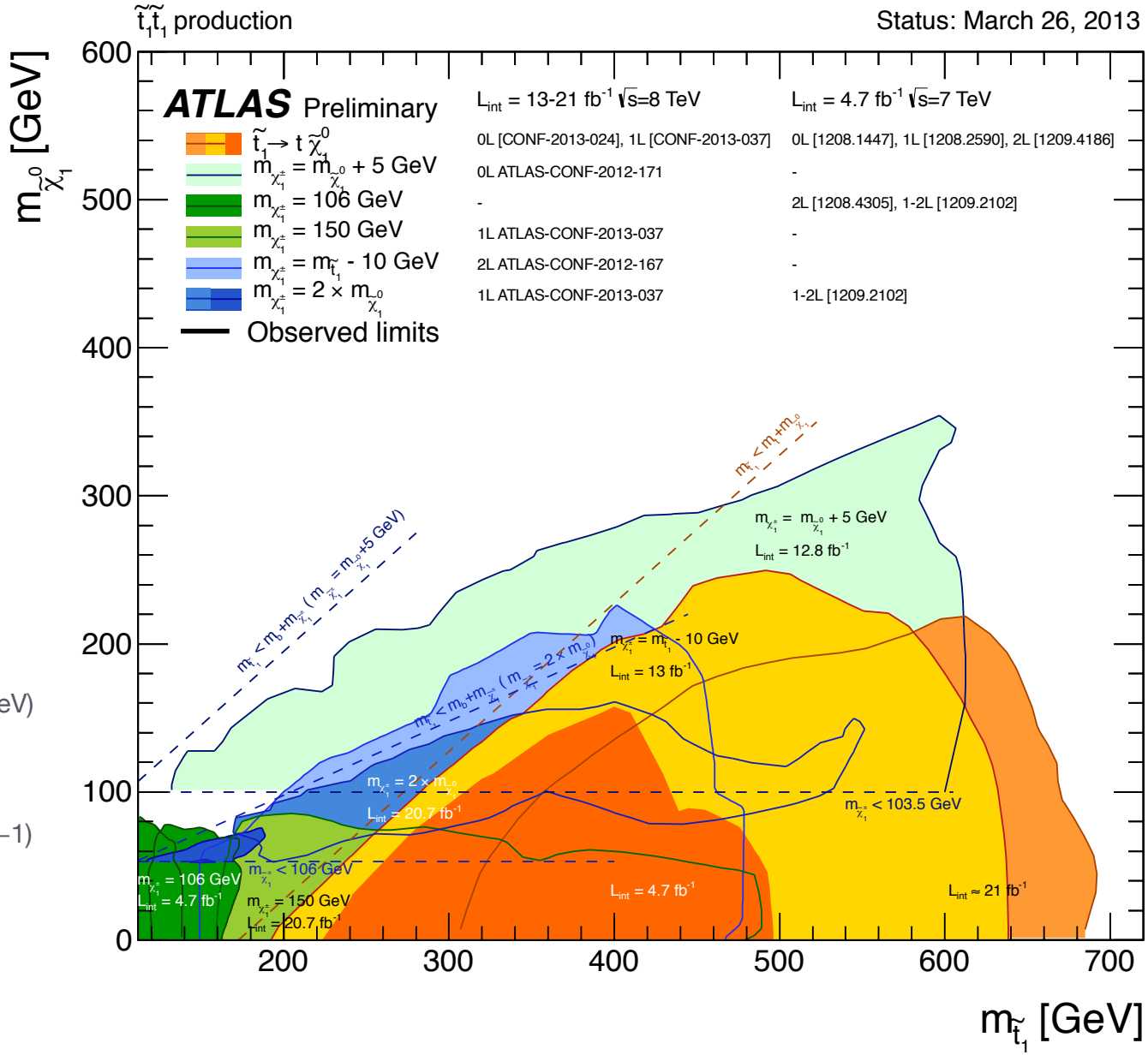
- A summary of all the ATLAS stop searches where $\tilde{t} \rightarrow t + LSP$
- This result:
- Extends previous ATLAS limits.



ATLAS stop exclusion limits | Combined

- *Note that these plots overlay contours belonging to different stop decay channels, different sparticle mass hierarchies, and simplified decay scenarios.*

- References
  - [1] arxiv:1208.1447 (0-lepton 7 TeV)
  - [2] arxiv:1208.2590 (1-lepton 7 TeV)
  - [3] arxiv:1209.4186 (2-lepton 7 TeV)
  - [4] ATLAS-CONF-2013-037 (1-lepton 8 TeV, 21 fb−1)
  - [5] ATLAS-CONF-2013-024 (0-lepton 8 TeV, 21 fb−1)
  - [6] arxiv:1208.4305 (very light stop: 2-lepton 7 TeV)
  - [7] arxiv:1209.2102 (light stop: 1/2-lepton, bjets 7 TeV)
  - [8] ATLAS-CONF-2012-167 (2-lepton 8 TeV, 13 fb−1)
  - [9] ATLAS-CONF-2013-001 (0-lepton, bb+MET 8 TeV, 13 fb−1)



Summary

- A search for direct pair production of top squarks in final states containing six or more jets and E_T^{miss} was performed with 20.5 fb^{-1} of $\sqrt{s}$ = 8 TeV 2012 data.

- Observations are consistent with SM expectations.

- The result significantly extends previous limits in the all-hadronic final state and excludes top squarks up to higher masses than in previous searches.

- We eagerly await the LHC running with higher $\sqrt{s}$ which will present a thorough test for natural SUSY.

Back-ups

Stop mixing | left/right-handed table

- Cutflow table shows the yields for the T600, L1 signal point with both the right and left-handed stops.
- Note the slight increase in acceptance for the left-handed stop after the b-jet cut.

Selection	Right-handed	Left-handed
No selection	507.3	507.3
Trigger	468.0	467.8
Primary Vertex	467.8	467.4
Event cleaning	459.0	459.6
Muon veto	381.2	382.5
Electron veto	284.4	292.3
$E_T^{miss} > 130$ GeV	263.1	270.1
Jet multiplicity and p_T	97.7	92.2
$E_T^{miss,track} > 30$ GeV	96.3	90.5
$\Delta\phi(E_T^{miss}, E_T^{miss,track}) < \pi/3$	90.3	84.3
$\Delta\phi(\text{jet}, E_T^{miss}) > \pi/5$	77.1	72.0
Tau veto	67.4	61.9
$\geq 2b$-tagged jets	29.5	31.5
$m_T(b\text{-jet}, E_T^{miss}) > 175$ GeV	20.2	23.6
80 GeV$< m_{jjj}^0 <$ 270 GeV	17.8	20.4
80 GeV$< m_{jjj}^1 <$ 270 GeV	10.9	11.9
$E_T^{miss} > 150$ GeV	10.8	11.8
$E_T^{miss} > 200$ GeV	10.3	11.2
$E_T^{miss} > 250$ GeV	9.2	10.0
$E_T^{miss} > 300$ GeV	7.8	8.3
$E_T^{miss} > 350$ GeV	6.1	6.6

ATLAS-CONF-2013-024

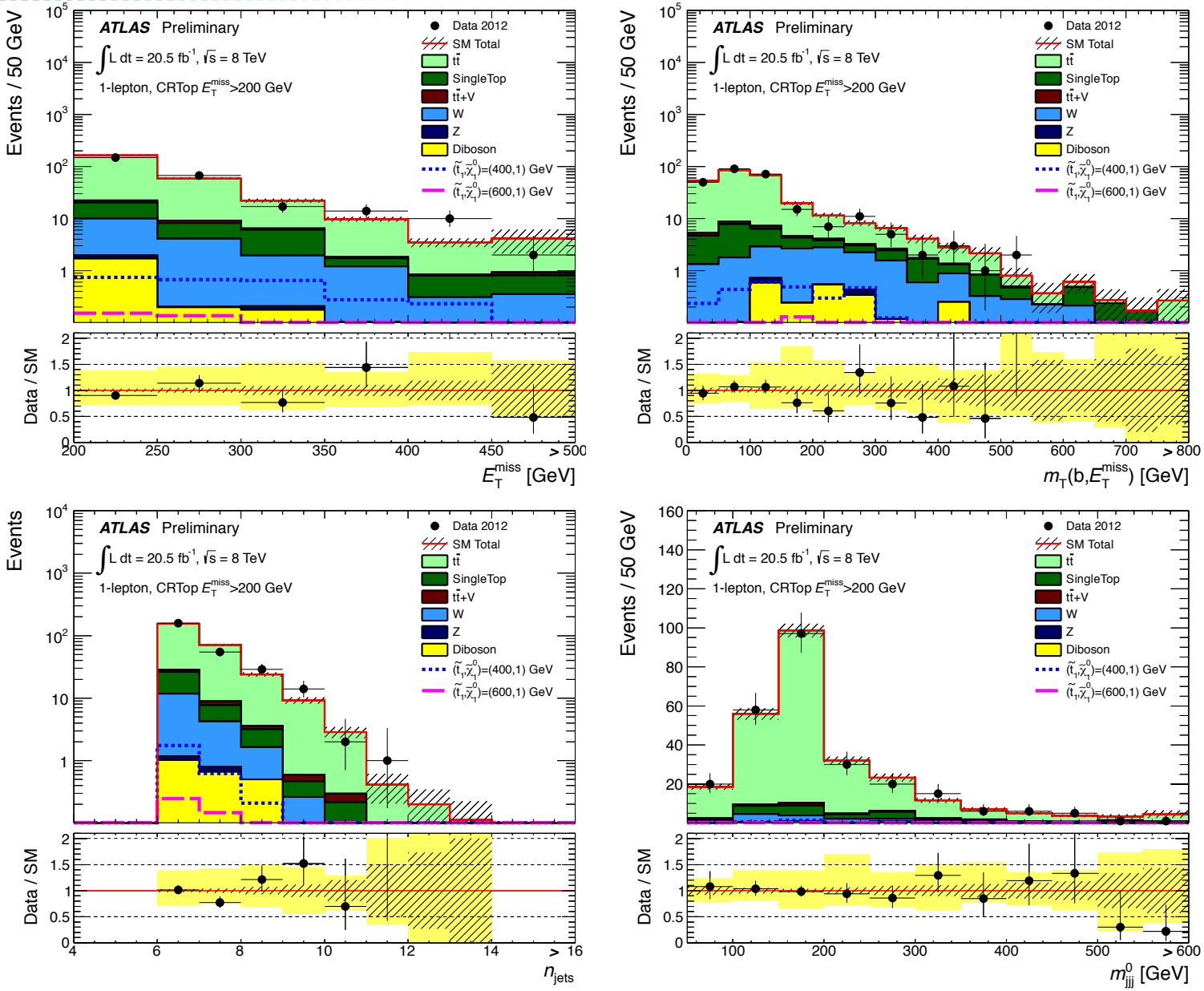
Results | Model independent limits table

Signal region	$\langle\varepsilon\sigma\rangle^{95}_{\text{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B
SR1	0.49	10.0	$10.6^{+5.5}_{-1.7}$	0.39
SR2	0.17	3.6	$5.3^{+3.2}_{-1.7}$	0.20
SR3	0.19	3.9	$4.5^{+1.9}_{-0.7}$	0.27

ATLAS-CONF-2013-024

Top CR | Figures

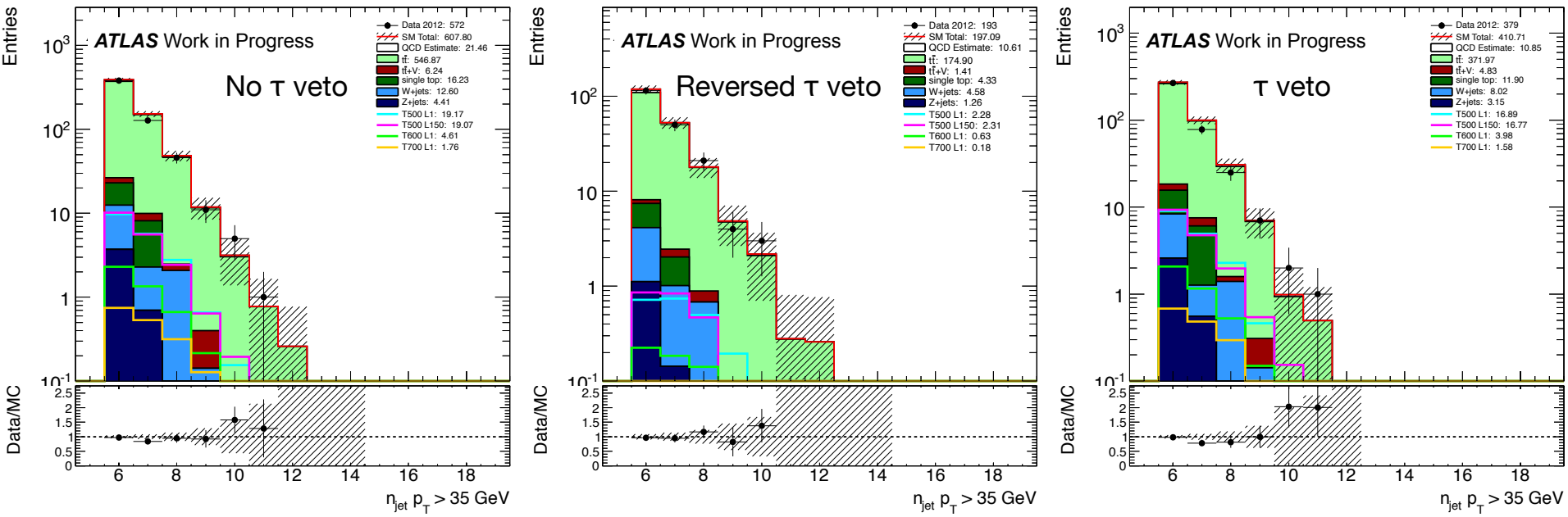
- Top control region figures.
- The hashed band represents the statistical uncertainty and the yellow represents to systematic uncertainty.



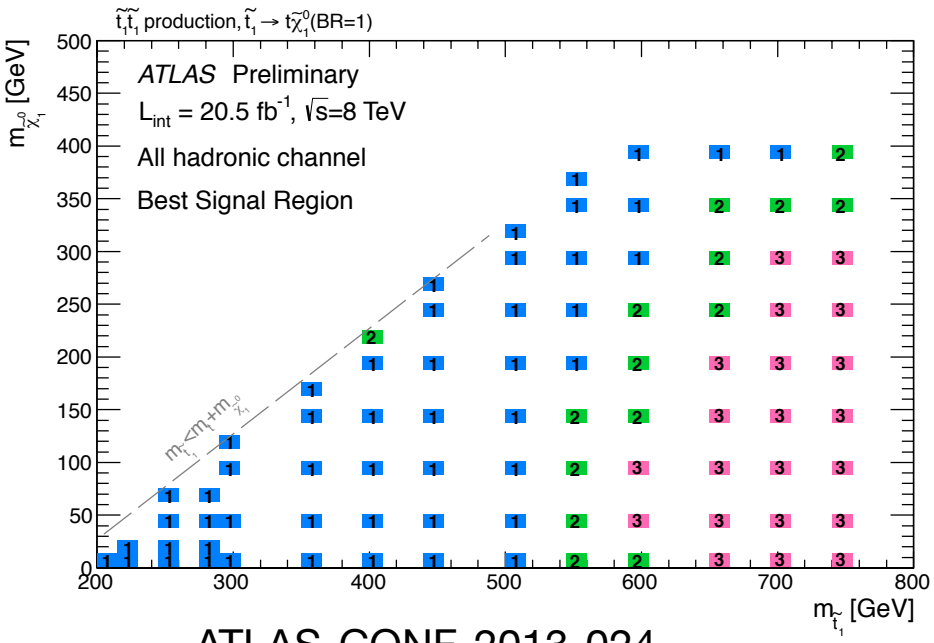
ATLAS-CONF-2013-024

Top | 0-lepton validation region

- These plots show a **0-lepton validation region** for the Top background.
- Events are selected in **$50 < m_T(b,E_T^{miss}) < 150$ GeV** window.
- The plots show the number of jets with **no tau veto** at all (left), the **tau veto reversed** (middle) and the **tau veto applied** (right).
- The good data/MC agreement gives us faith in the MC modelling.



Selection | Optimisation



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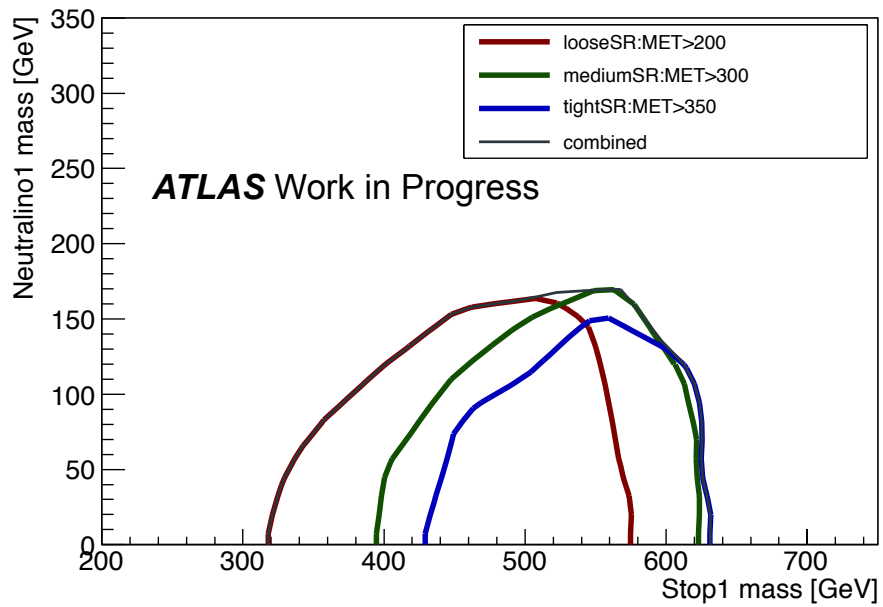
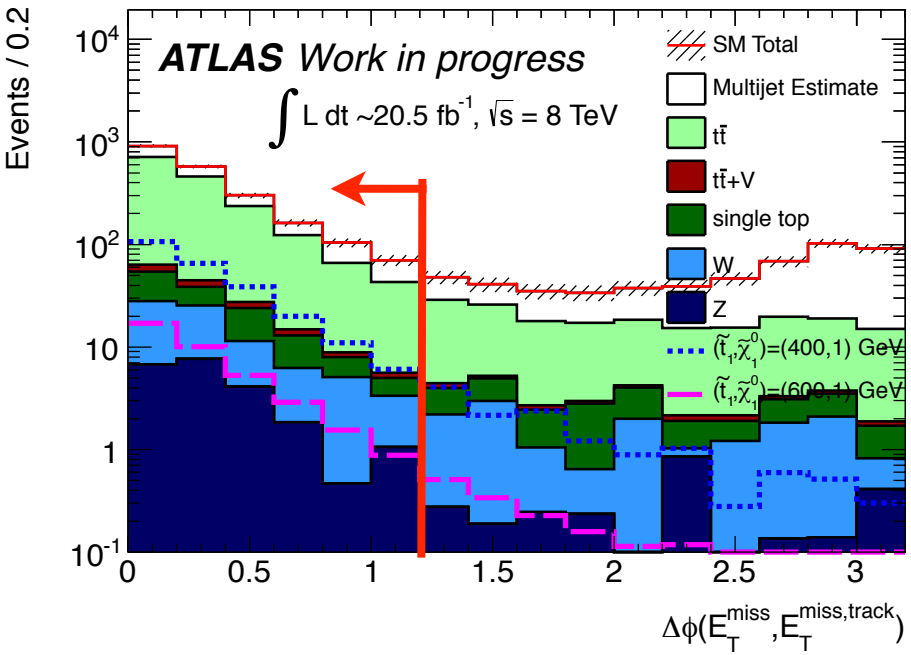
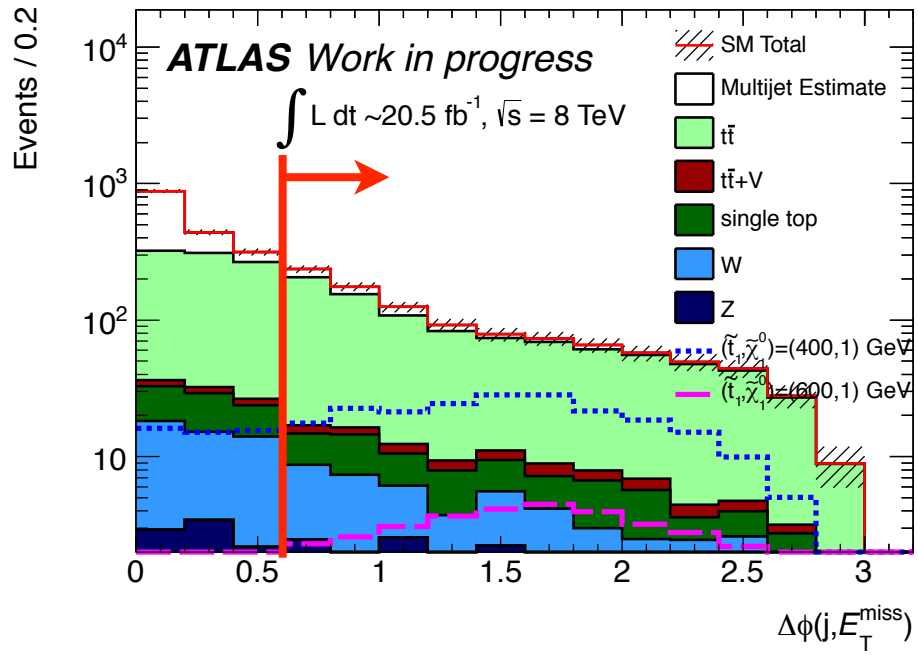


Selection | QCD rejection





$E_{\mathrm{T}}^{\mathrm{miss,track}} > 30$ GeV and $\left\lvert\Delta\phi\left(E_{\mathrm{T}}^{\mathrm{miss}}, E_{\mathrm{T}}^{\mathrm{miss,track}}\right)\right\rvert < \frac{\pi}{3}$
$\min\left\lvert\Delta\phi\left(\mathrm{jet}^{0-2}, E_{\mathrm{T}}^{\mathrm{miss}}\right)\right\rvert > 0.2\,\pi$

QCD rejection

- Cuts on the angle between the track and calorimeter based E_T^{miss} and the angle between the leading 3 jets and E_T^{miss} reject events with fake E_T^{miss}.

$t\bar{t}$+V | Systematics

- $t\bar{t}$+Z kinematic distributions sensitive to uncertainties.