OVERVIEW OF SEARCHES FOR STOP & SBOTTOM IN ATLAS

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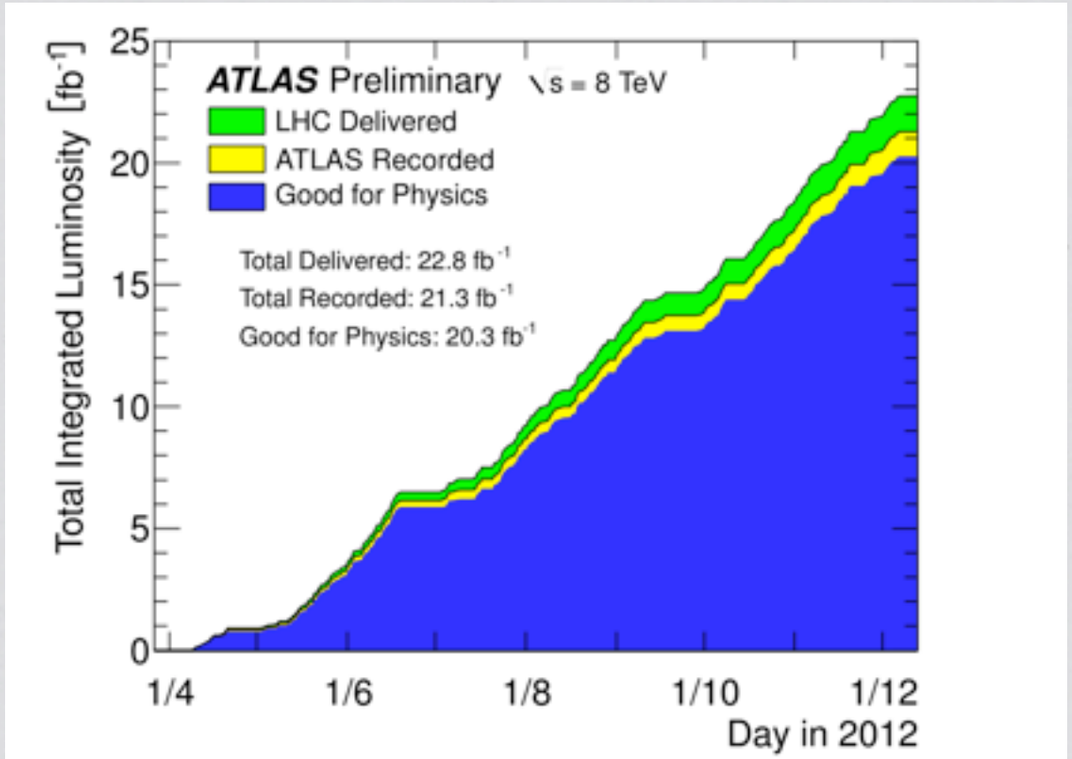
on behalf of the ATLAS collaboration

Content

* Introduction
* Sbottom searches
* Stop searches
* Long-lived R-hadrons
* Conclusion



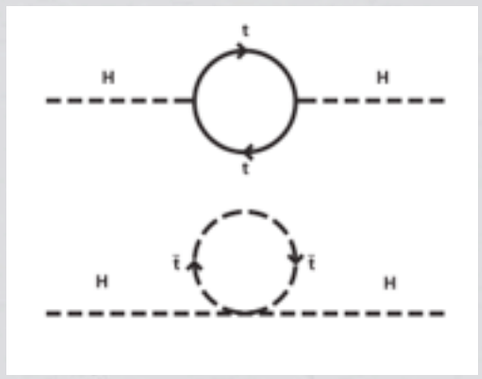
Results shown are all with full 2012 dataset (~20 fb^{-1} at $\sqrt{s}$=8 TeV)

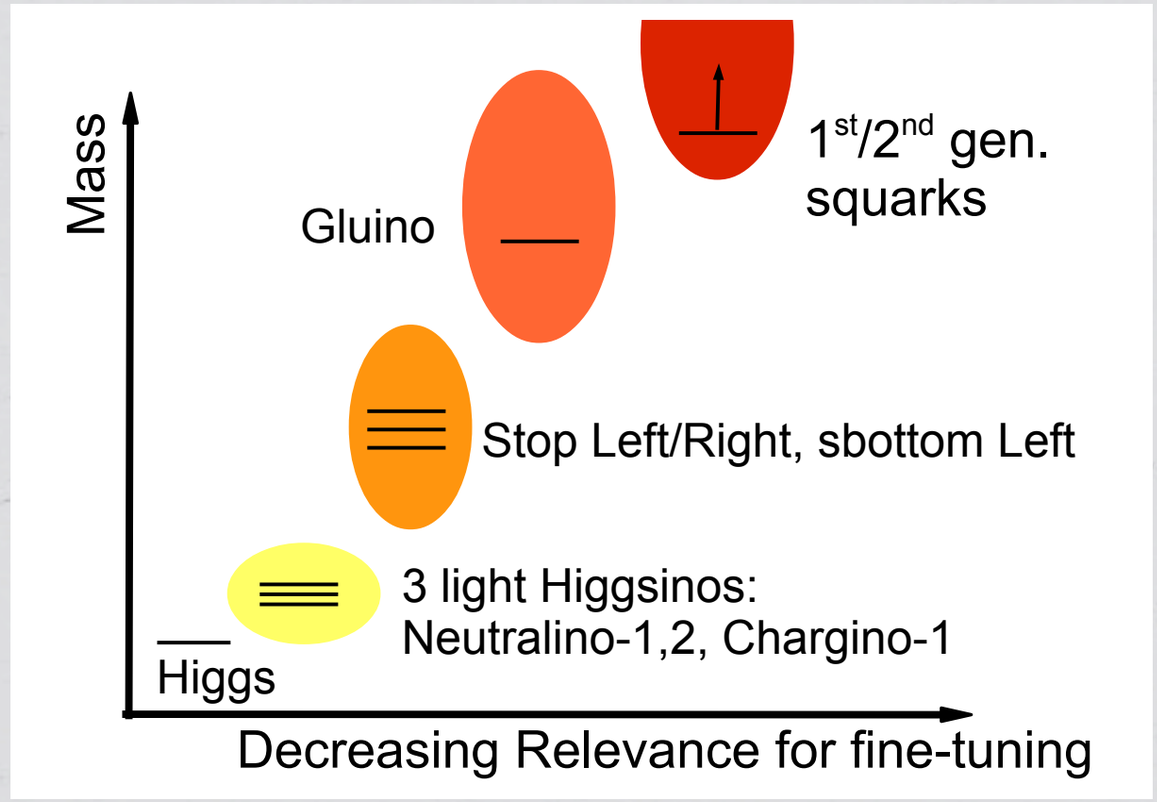
Introduction

SM - huge radiative corrections to Higgs mass ⇒ high-levels of fine tuning

SUSY - corrections to the Higgs (soft) mass are driven by the top/stops system,
Natural SUSY - low fine tuning:

- average mass of two Stops in the sub-TeV range
- at least one light Sbottom (part of the LH multiplet)



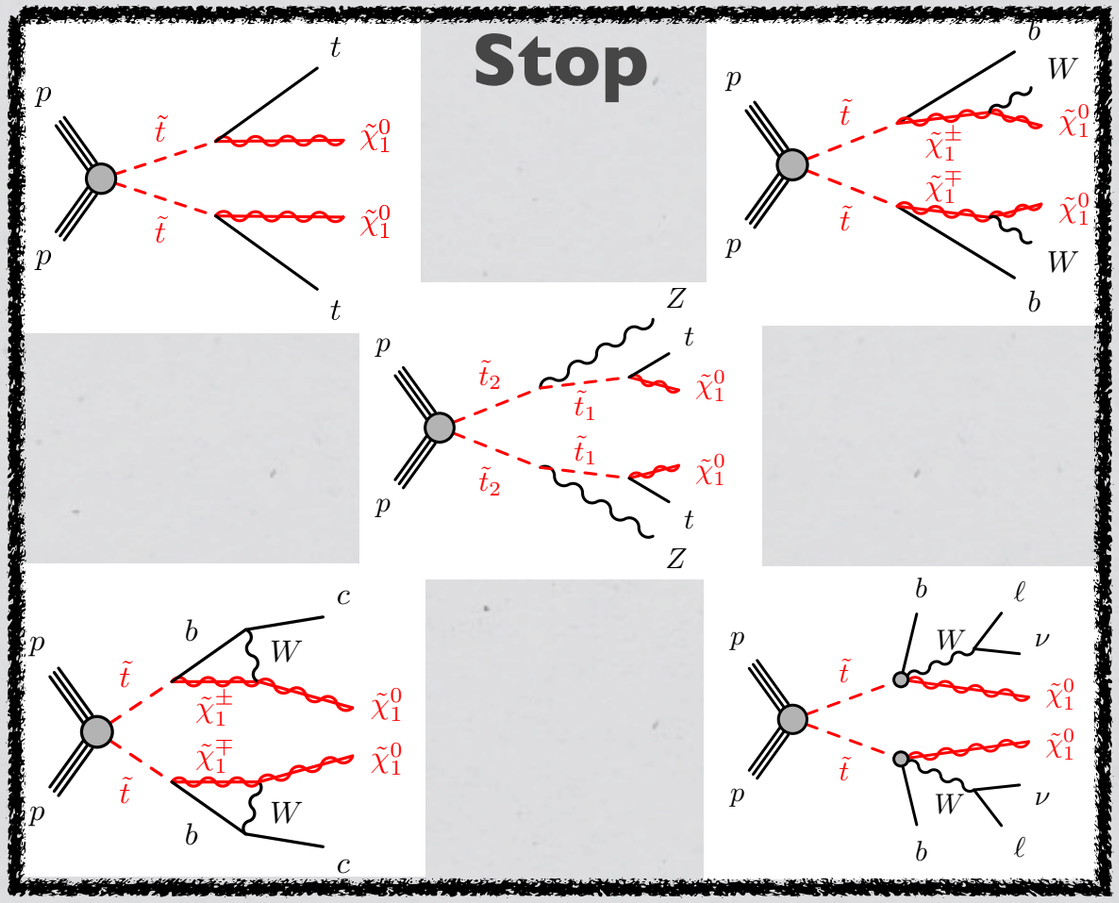


Plot from J.List talk on natural SUSY

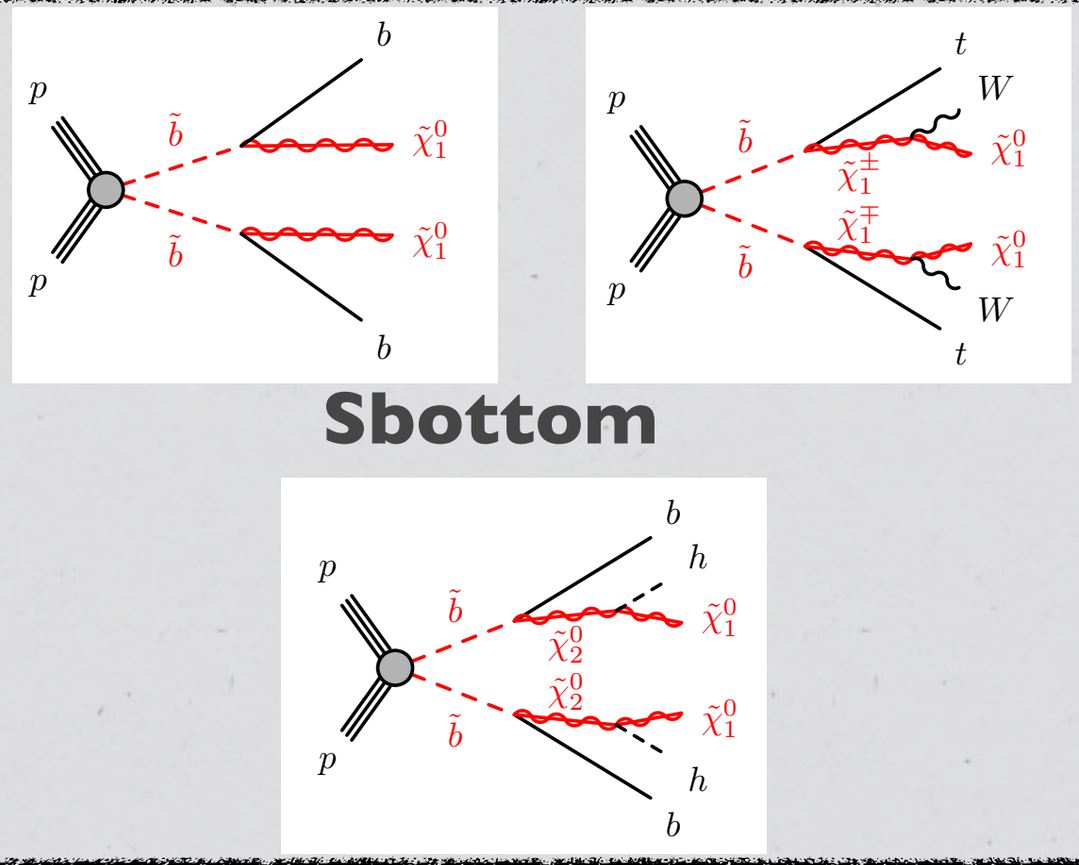
Light 3rd generation (≤ 1 TeV) preferred by naturalness.

3rd gen. squark searches

Stop



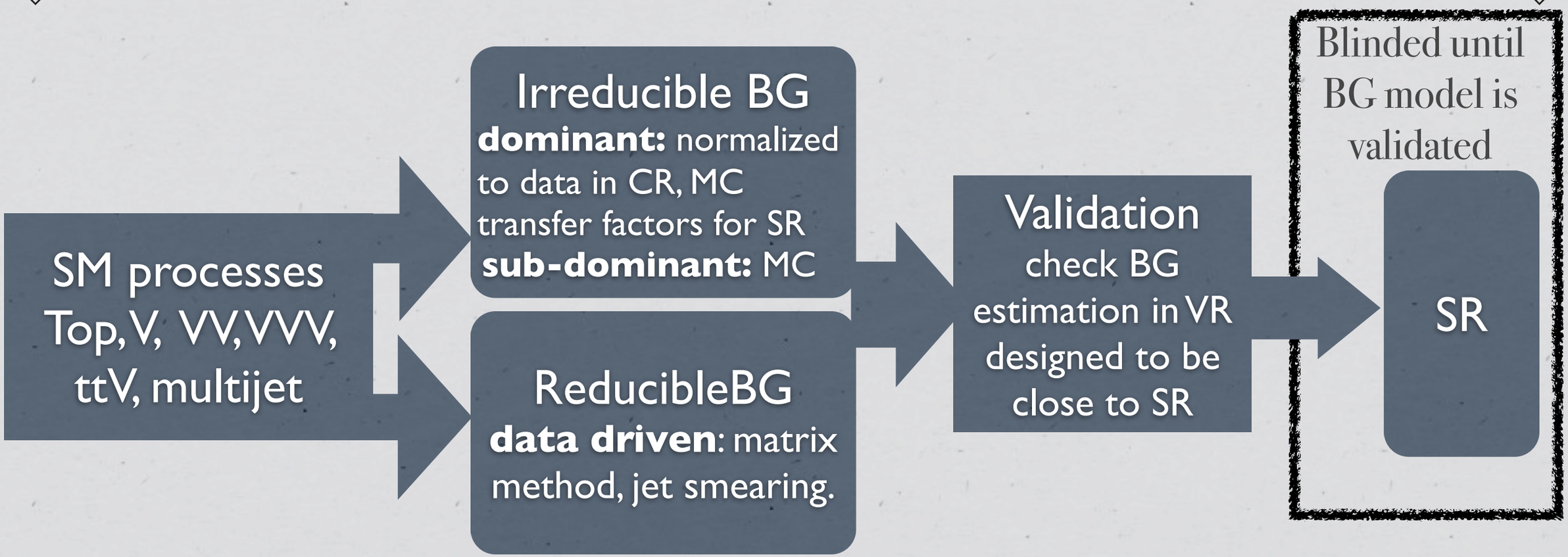
Sbottom



Simplified models:

- Decoupled sparticle spectra, particles of no interest considered very massive, isolated single production and decay mode
- Decay BR are assumed to be 100% into a selected mode

SM BG estimation



Light 3rd generation ⇒ very SM like

Direct production cross section small ⇒ need precise measurements of SM tails

Notations: Standard Model - SM, Background - BG, Monte Carlo - MC, Control Region - CR, Validation Region -VR, Signal Region - SR, Transfer Factor - TF.

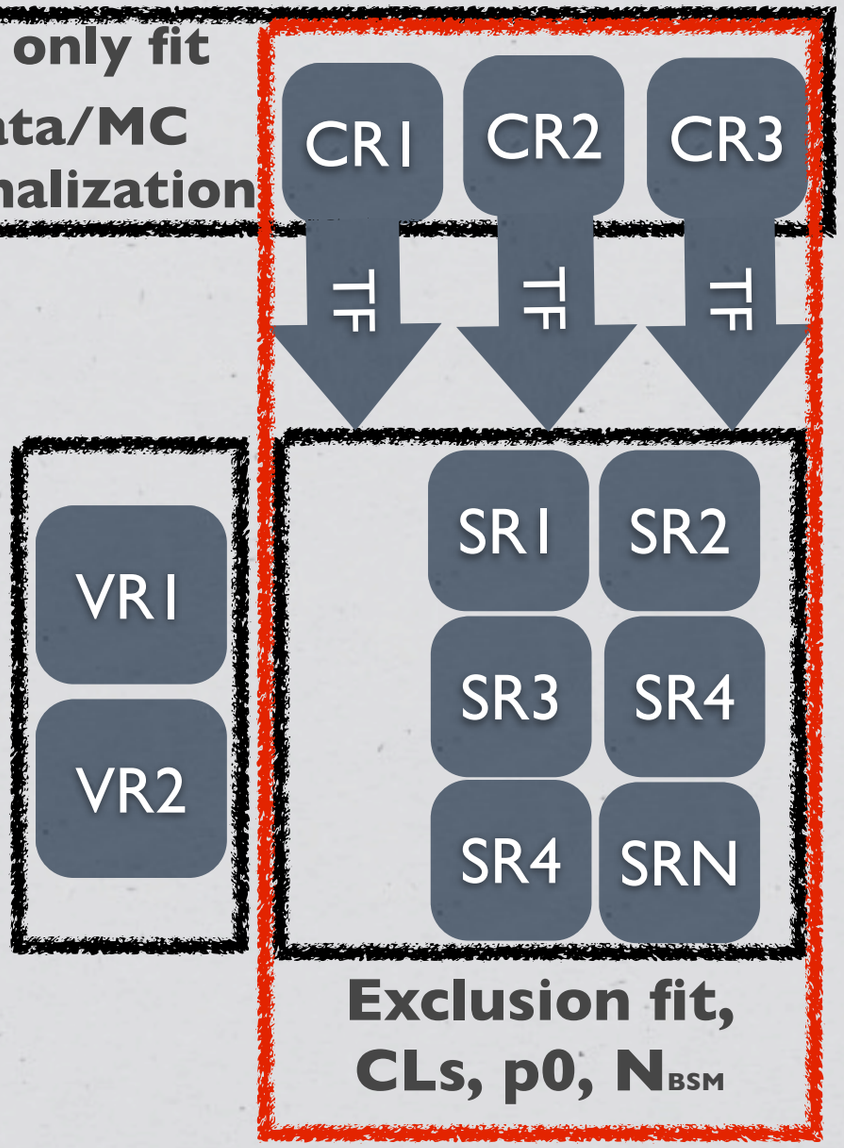
Systematics & Combined fit

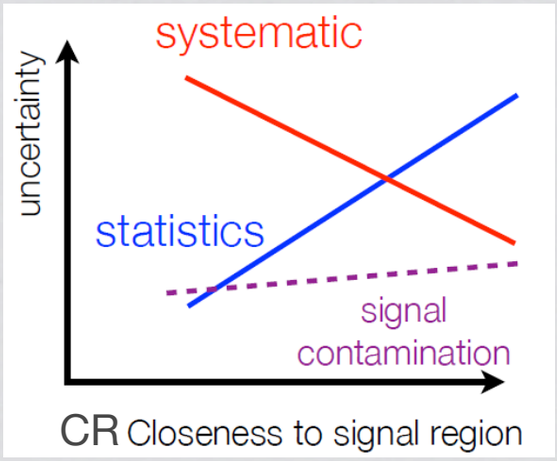
Detector systematics:

- Jet Energy Scale (JES)
- Jet Energy Resolution (JER)
- b-tagging uncertainties
- Lepton ID, energy scale & resolution
- Missing Transverse Energy soft component
- Trigger: scale factor uncertainties
- Luminosity uncertainty
- Pileup

BG MC modeling uncertainties:
generator choice, PDF, renormalisation and factorization scales, parton shower, ISR/FSR.

Signal systematics:
• ISR/FSR, parton shower, PDF, renormalisation and factorization scales and strong coupling (α_s) uncertainty.





multiple SRs per analysis

1. if SRs overlap use one with best expected sensitivity,
2. if SRs are orthogonal do statistical combination.

Sbottom searches

- *0 leptons + 2 b-jets + Etmiss - 1308.2631, JHEP*
- *0-1 leptons + >=3 b-jets + Etmiss - ATLAS-CONF-2013-061*
- *2 same-sign leptons + 0-3 b-jets + Etmiss - ATLAS-CONF-2013-007*

1308.2631, JHEP 10, 189

0L+2b+ Etmiss (I)

Selection: Etmiss, 2b jets, lepton veto.

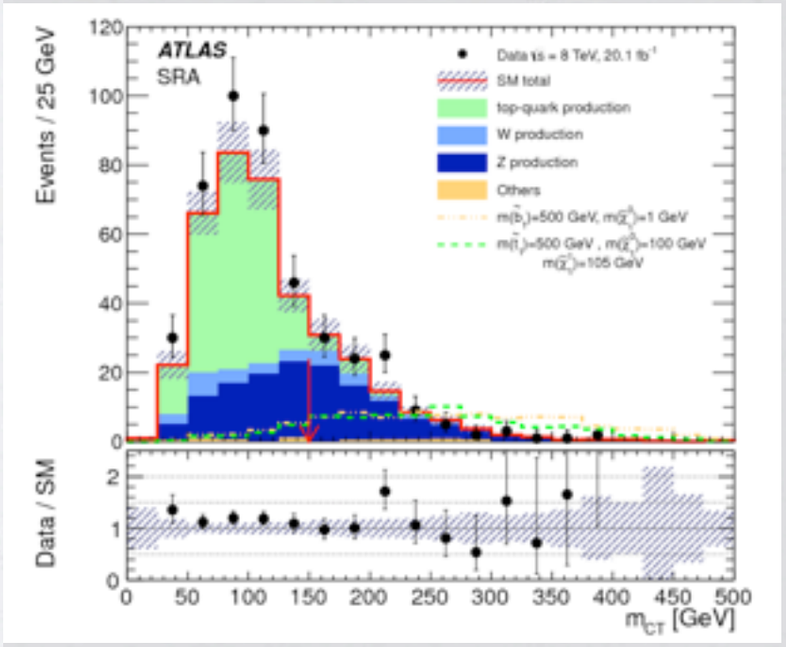
Main backgrounds: Z(vv)+b jets, W+b jets, tt.

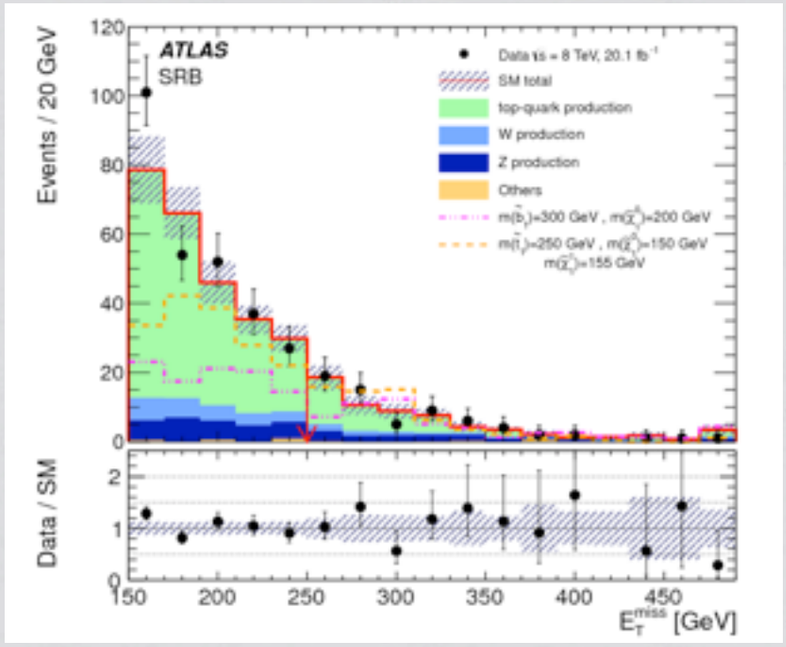
$$m^2_{CT}(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [p_T(v_1) - p_T(v_2)]^2$$

$$H_{T,3} = \sum_{i=4}^{n} (p_T^{\text{jet}})_i$$

Contransverse mass (m_{CT}) end point for tt ~135GeV

and for Signal $m_{\text{CT}}^{\text{max}} = \dfrac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$

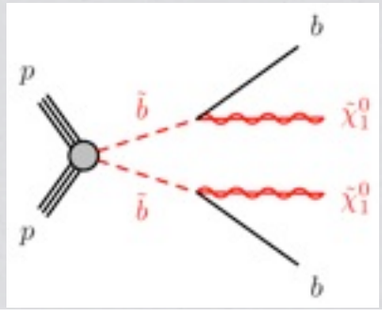


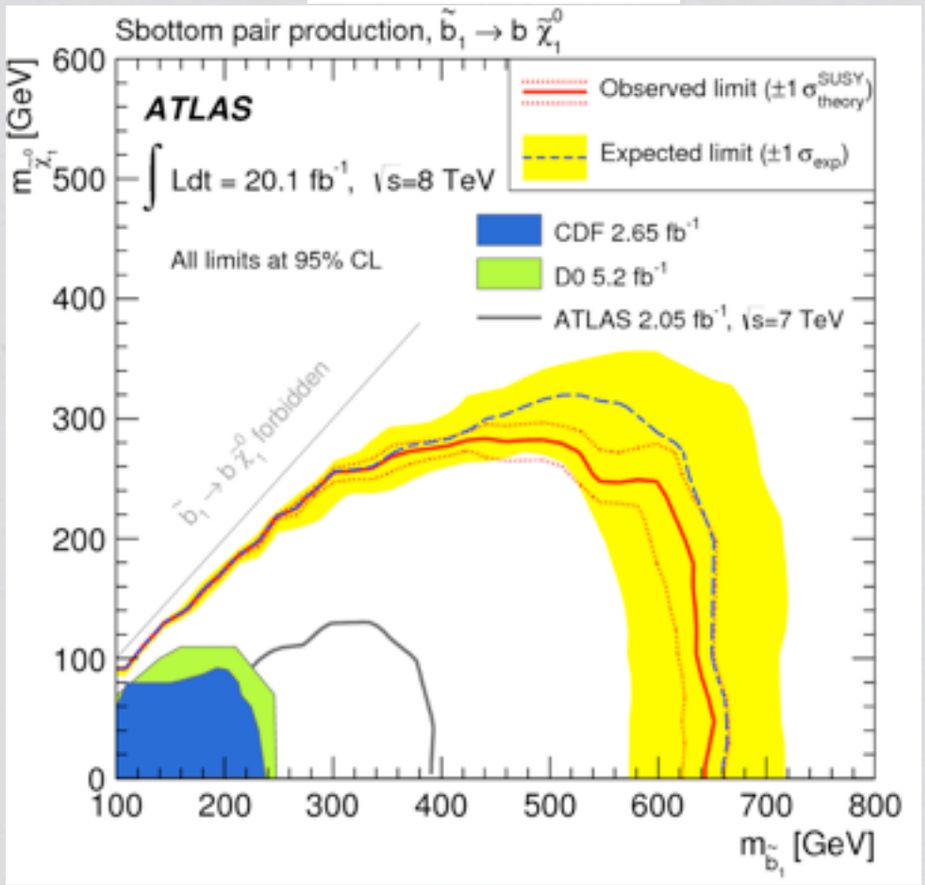


SRA - Large Δm($\tilde{b}_1, \tilde{\chi}_1^0$)
Etmiss > 150 GeV, mCT >150 to 350 GeV, mbb > 200GeV, 3rd jet veto.

SRB - small Δm ($\tilde{b}_1, \tilde{\chi}_1^0$)
anti-b tagged ISR jet, HT,3 < 50GeV, Etmiss > 250GeV.

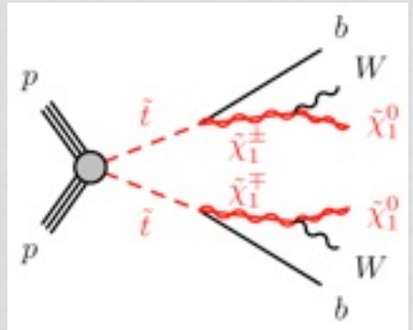
0L+2b+ Etmiss (II)





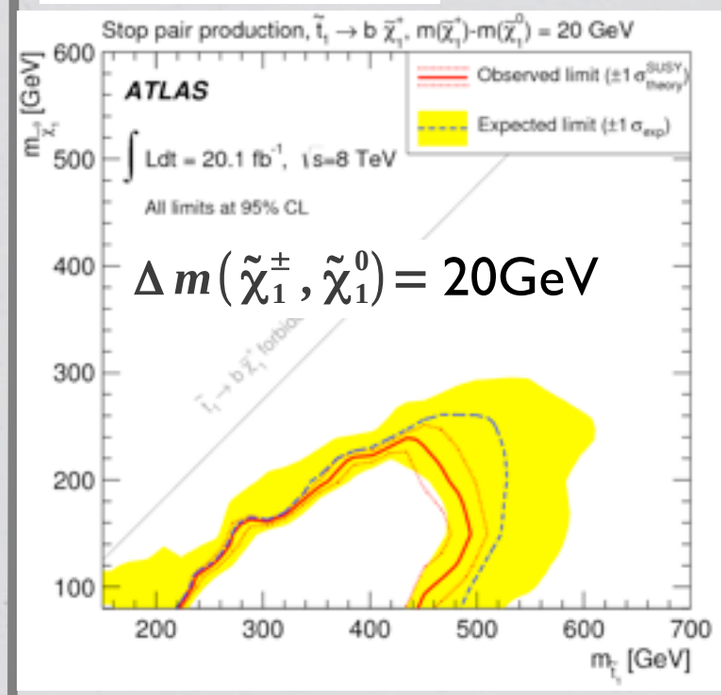
Sbottom masses up to 620 GeV are excluded at 95% CL for mLSP< 120 GeV.

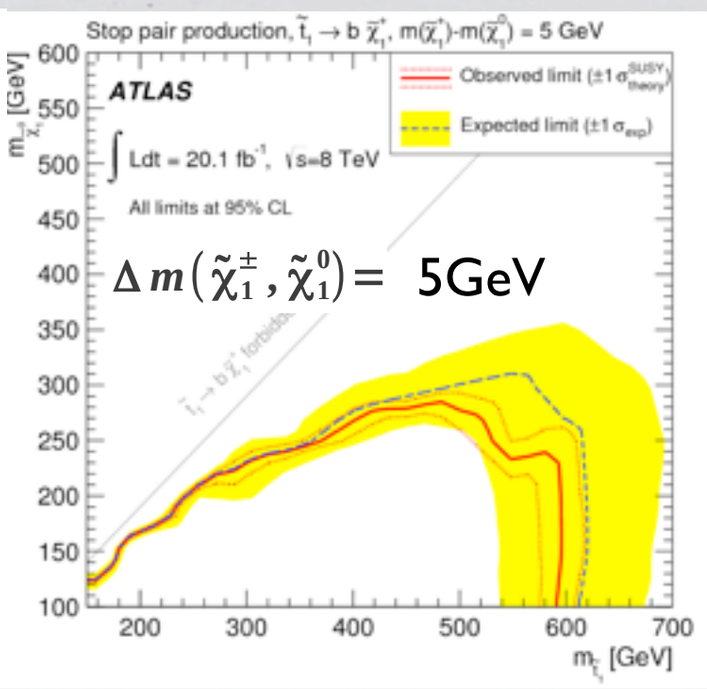
Bonus



Direct Stop sensitivity for small

$\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$, $\tilde{t}_1 \to b\,\tilde{\chi}_1^{\pm}$





stop masses up to 580 GeV (440 GeV) are excluded for $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$= 5 GeV (20 GeV) and for mLSP= 100 GeV.

ATLAS-CONF-2013-061

0-1L+>=3b+ Etmiss

1L Selection: >=6jets, Etmiss > 175 to 275GeV, mT (lepton, ETMiss)>140 to160GeV, meff>700 to 900GeV.
0L Selection: >=4/7jets, Etmiss > 200 to 350GeV, meff>1000 to 1500GeV.

Main Backgrounds: tt+HF(prompt/fake), fake HF estimated with matrix method.

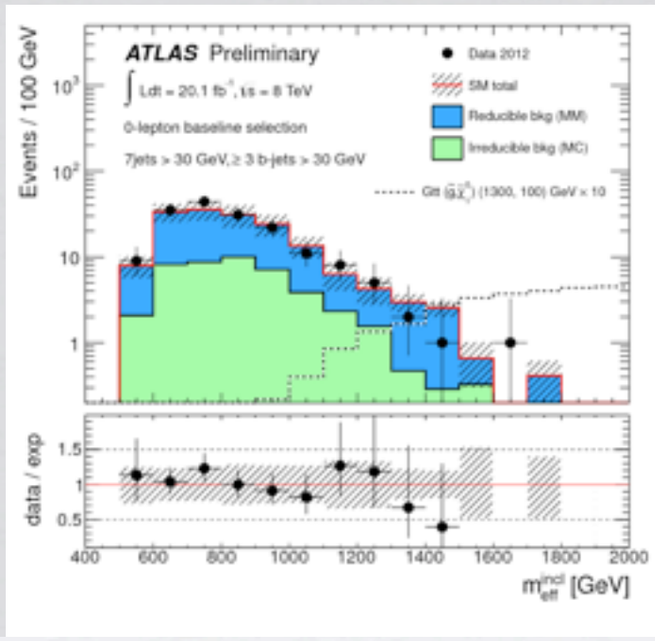
Multiple SRs - best expected limit is used per signal,
Statistical combination - 0 and 1 lepton SRs.

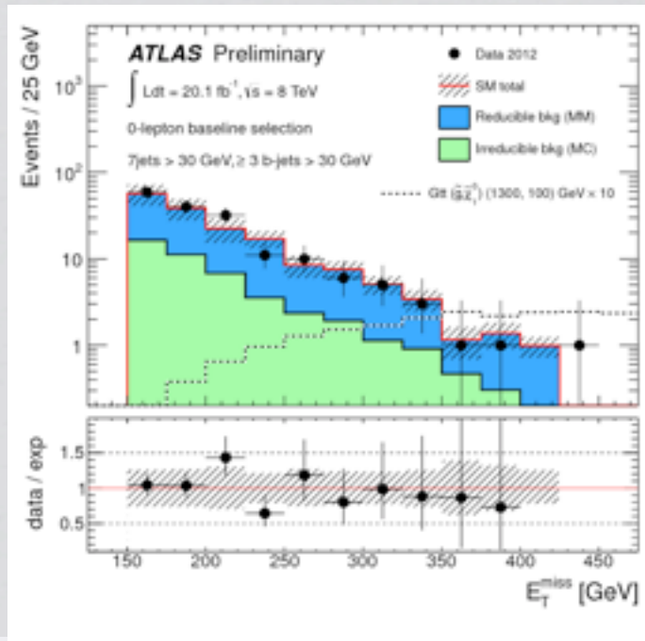
$$m_{\mathrm{eff}}(k) = \sum_{i=1}^{k} (p_{\mathrm{T}}^{\mathrm{jet}})_i + E_{\mathrm{T}}^{\mathrm{miss}} \text{ (+pT(lep))*}$$

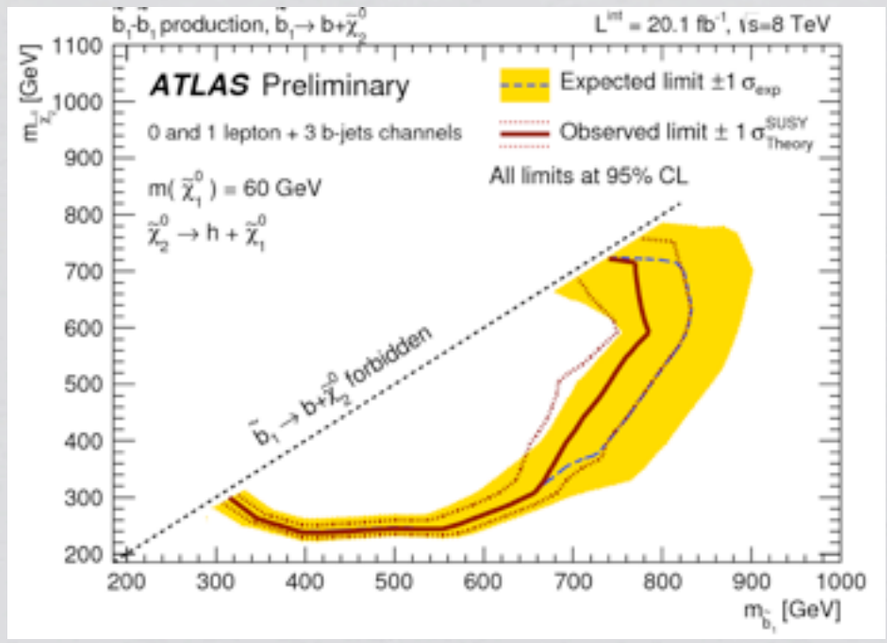
k=4 for $m_{\mathrm{eff}}^{4\mathrm{j}}$ * 1L SR

k=all jets for $m_{\mathrm{eff}}^{\mathrm{incl}}$

This analysis is driving the gluino-mediated stop/sbottom sensitivity, for more details see talk by J.Thompson.







Sbottom masses between 320 and 600 GeV are excluded for mLSP = 300 GeV.

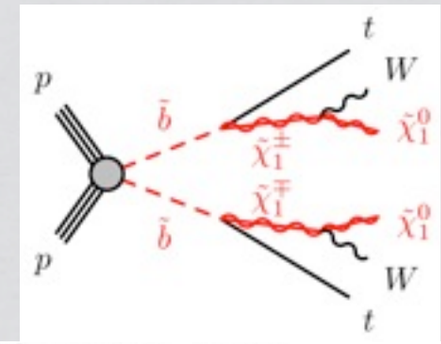
ATLAS-CONF-2013-007

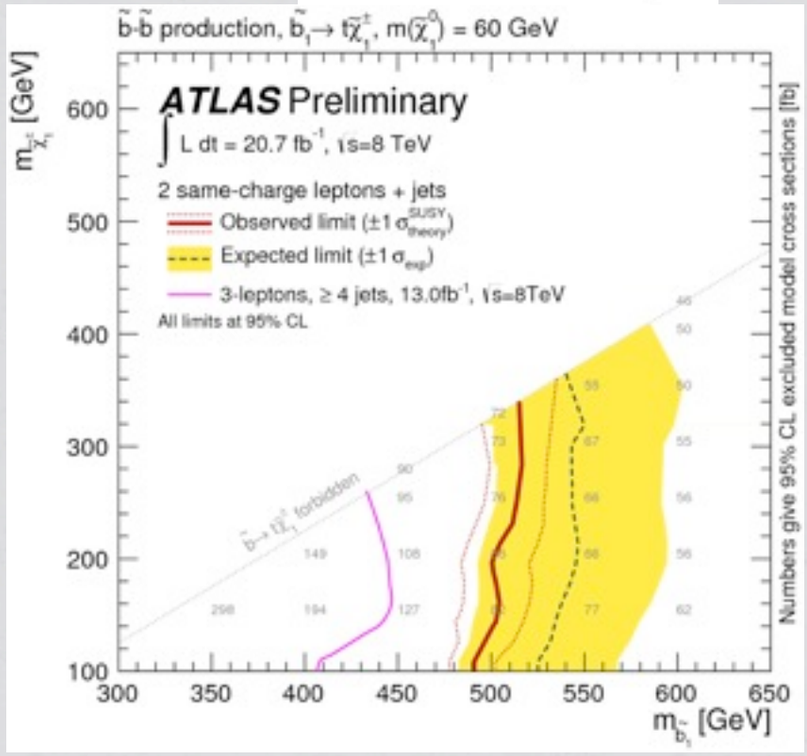
2(SS)L+0-3b+ Etmiss

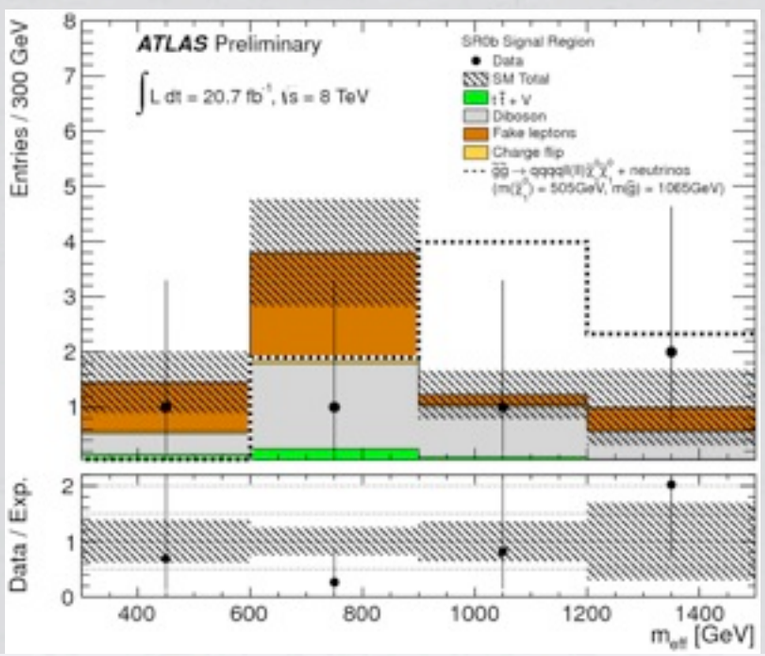
0b Selection: b-jet veto, >=3jets, Etmiss > 150GeV, mT>100GeV.
1b Selection: >= 1b-jet, >=3jets, Etmiss > 150GeV, mT>100GeV.
Binned shape fit in the meff(>300GeV) distribution for 0/1b selection.

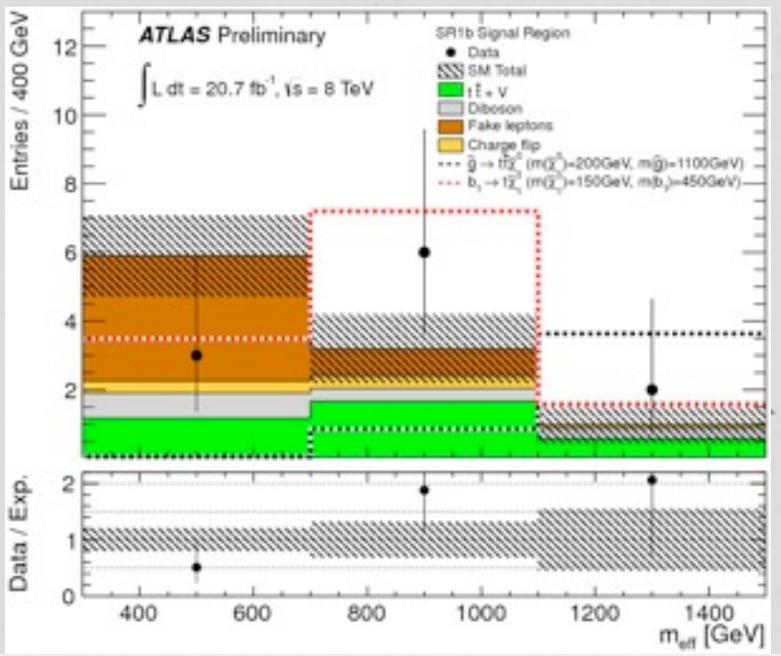
3b Selection: >=3 b-jets, >=5 jets, Etmiss< 150GeV or mT<100GeV orthogonal to 0/1b selection.

Main Backgrounds: ttV, VV+jets, BG with fake leptons estimated with fully data driven methods.





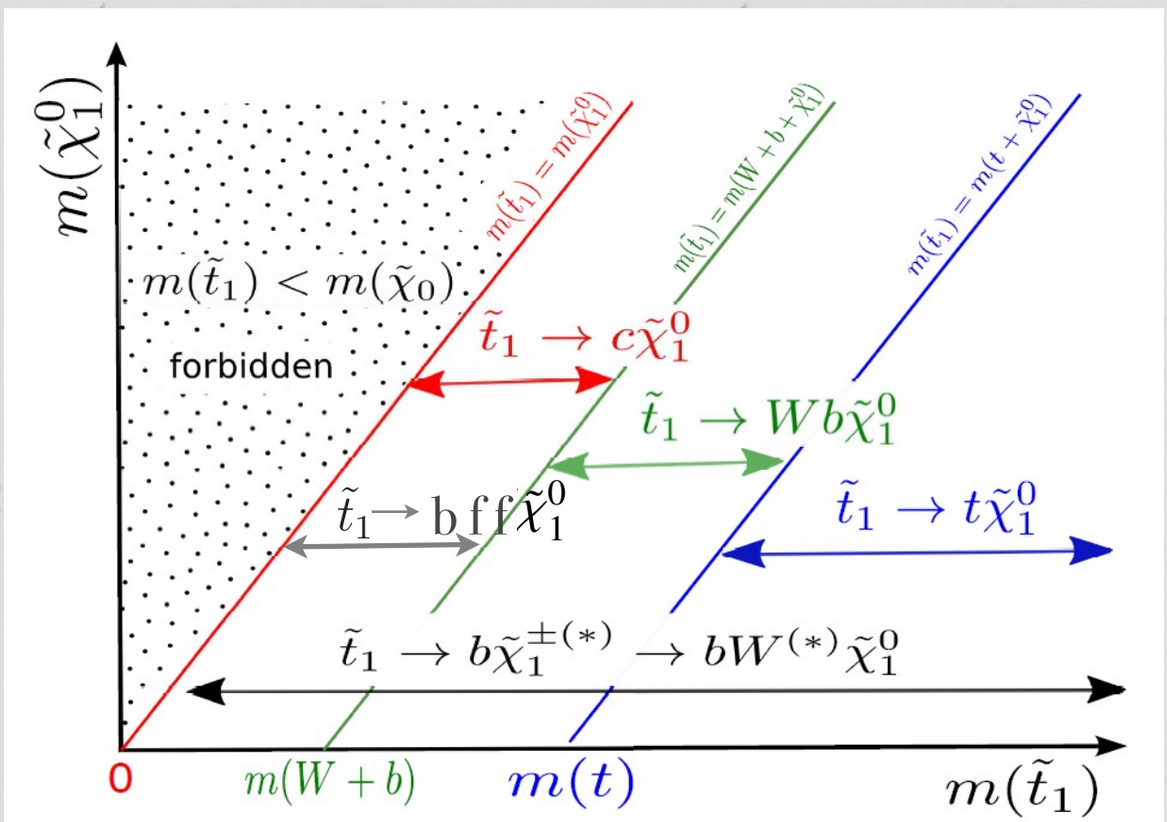


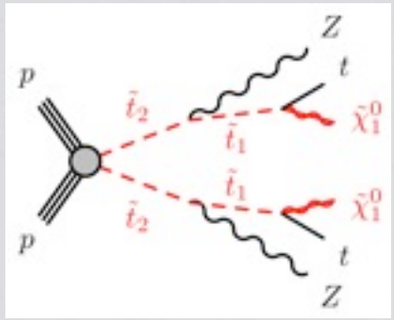


sbottom masses of 470-480 GeV are excluded with 95% CL for chargino masses below 280 GeV.

Stop searches

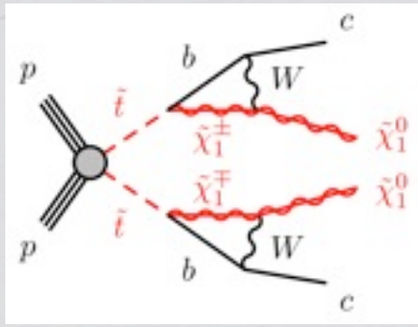
- *0 leptons + mono-jet/c-jets + Etmiss - ATLAS-CONF-2013-068*
- *0 lepton + 6 (2 b-)jets + Etmiss - ATLAS-CONF-2013-024*
- *1 lepton + 4(1b/2b)jets + Etmiss - ATLAS-CONF-2013-037*
- *2 leptons (+ jets) + Etmiss - ATLAS-CONF-2013-048*
- *2 leptons + (b)jets + Etmiss - ATLAS-CONF-2013-065*
- Z(ll)+l+bjets+Etmiss ATLAS-CONF-2013-025





ATLAS-CONF-2013-068

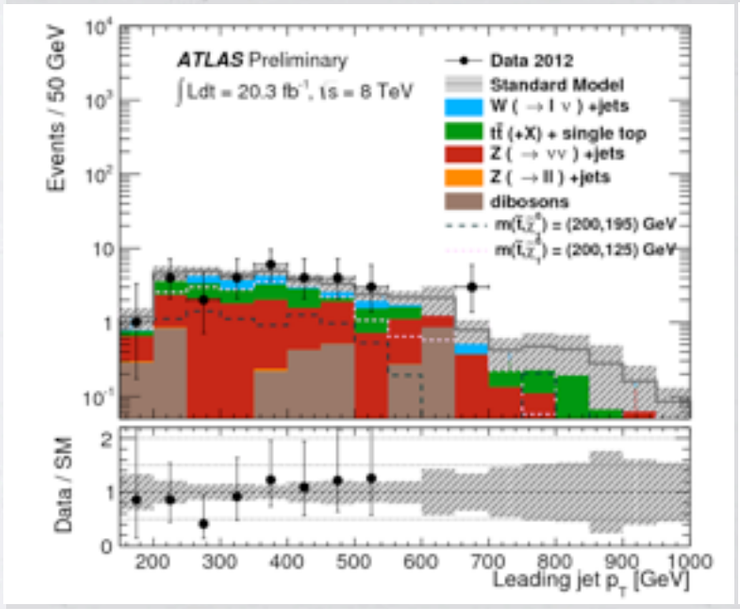
0L+c-jet/monojet like+ Etmiss

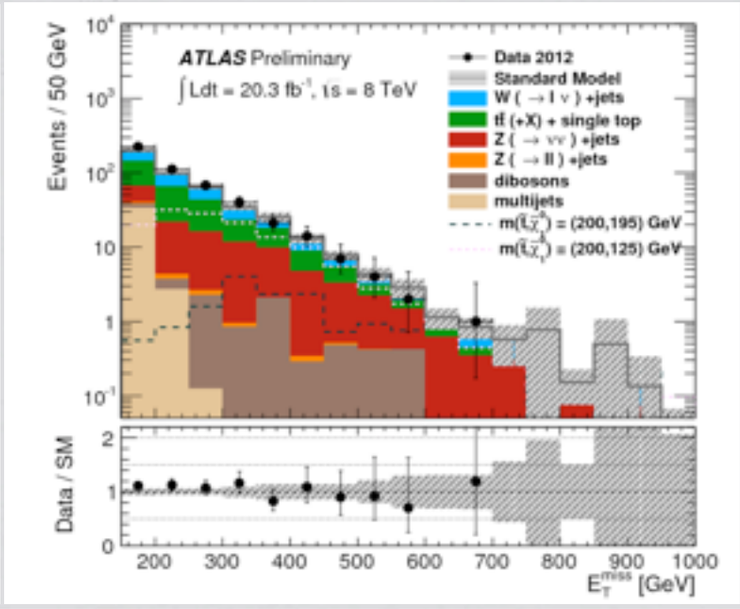


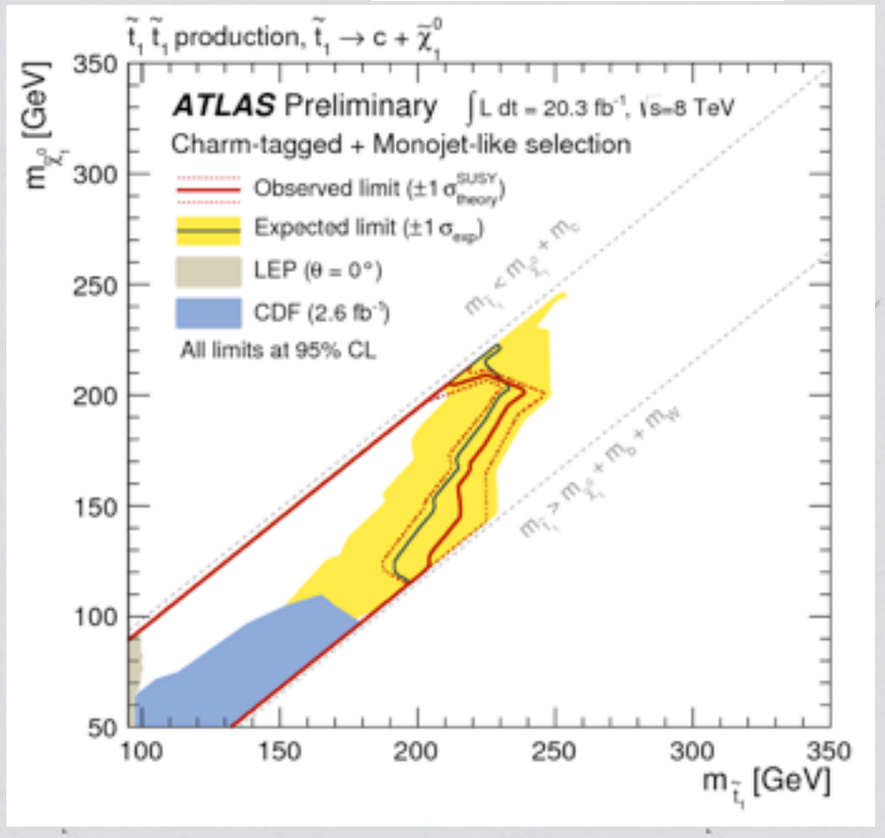
Monojet-like selection: <=3jets, 1st jet pT>280GeV, Etmiss>220GeV.

Charm-tag selection: >=4 jets, b veto for 2nd and 3rd jets, 4th jet c-tagged, 1st jet pT>270GeV (ISR), Etmiss > 410GeV.

Main Backgrounds: V+jets, VV.







Stop mass of 200 GeV is excluded at 95% CL for m(Stop)-m(LSP) < 85 GeV.
Stop masses up to 230 GeV are excluded for a LSP mass of 200 GeV.

ATLAS-CONF-2013-024

0L+6 (2b-)jets+ Etmiss

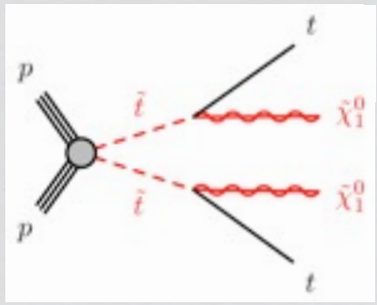
Selection: >=6jets, >=2b jets, Etmiss > 200 to 350GeV, mT(b-jet,Etmiss) >175GeV, tau veto.

Full reconstruction of hadronic tt system (3 closest jets in $\eta - \phi$ plane), 2 top candidates

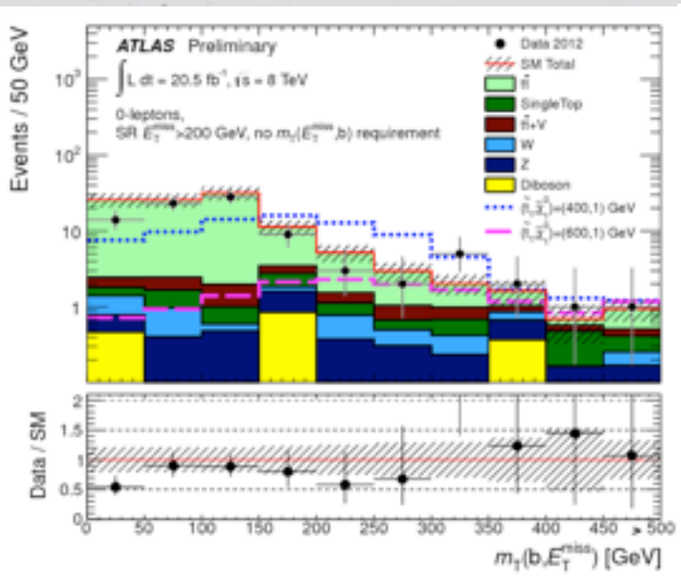
with 80 < m(jjj) < 270 GeV.

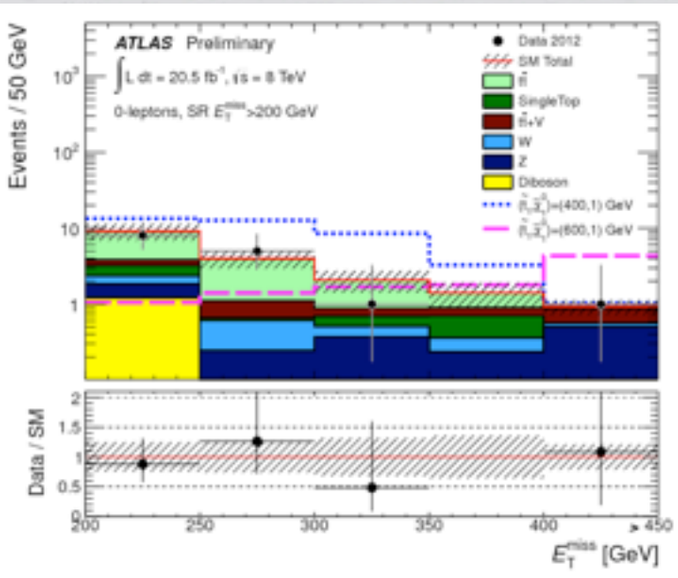
Analysis is insensitive to Stop polarization (L/R).

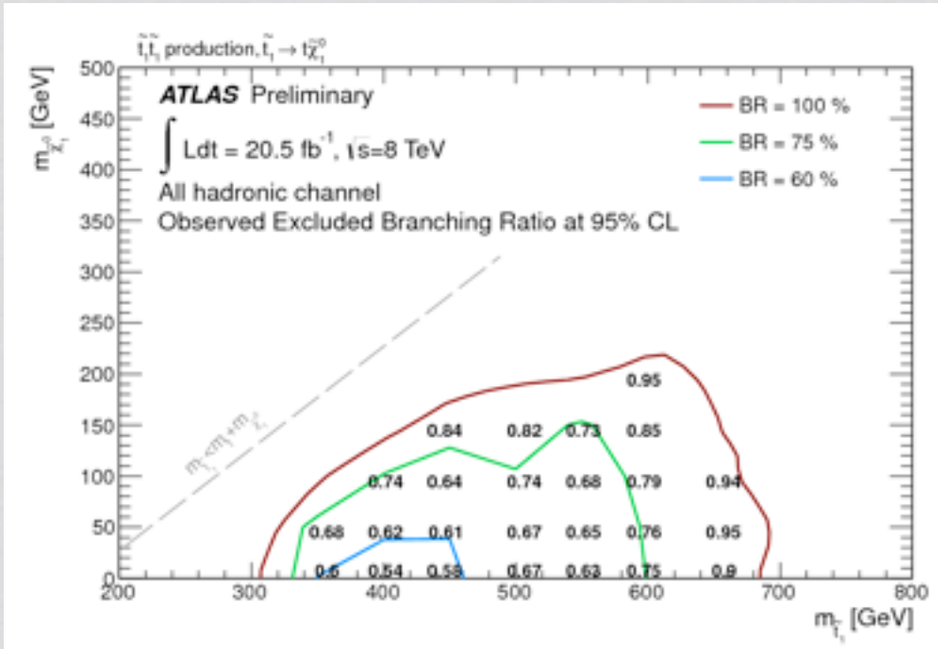
Main Backgrounds: tt, Z+jets, ttV.



The sensitivity as a function of the BR, assumes the other decay mode is invisible -> conservative.







Stop masses between 320 and 660 GeV are excluded at 95% CL for a nearly massless LSP (BR=100%).

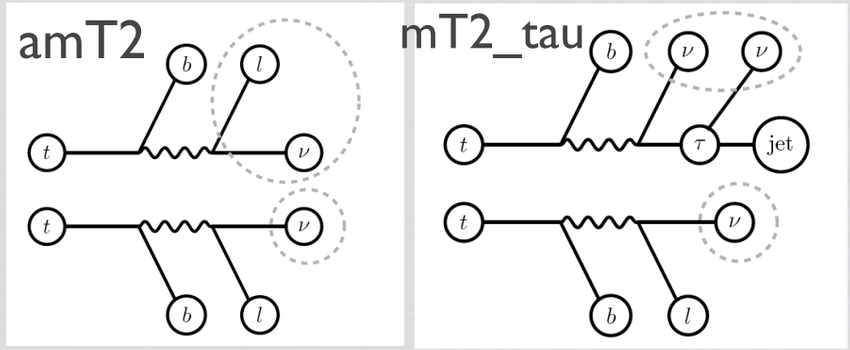
ATLAS-CONF-2013-037

1L+4(1b-)jets+ Etmiss (I)

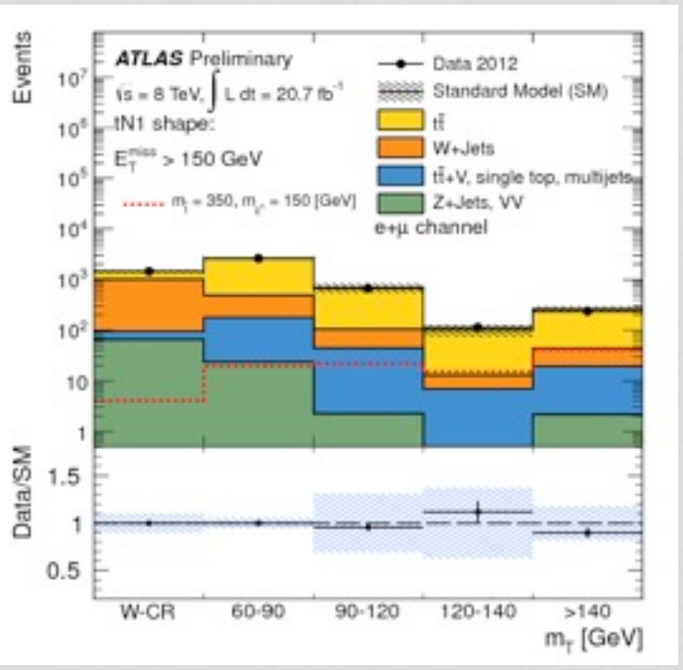
Selection: >= 4jets, >=1b/2b-jets, mT >120 to 200 GeV, 130 < m(jjj) < 205 GeV, Etmiss >100 to 275GeV, **amT2**>170 to 200 GeV, **mT2_tau**>80 GeV.

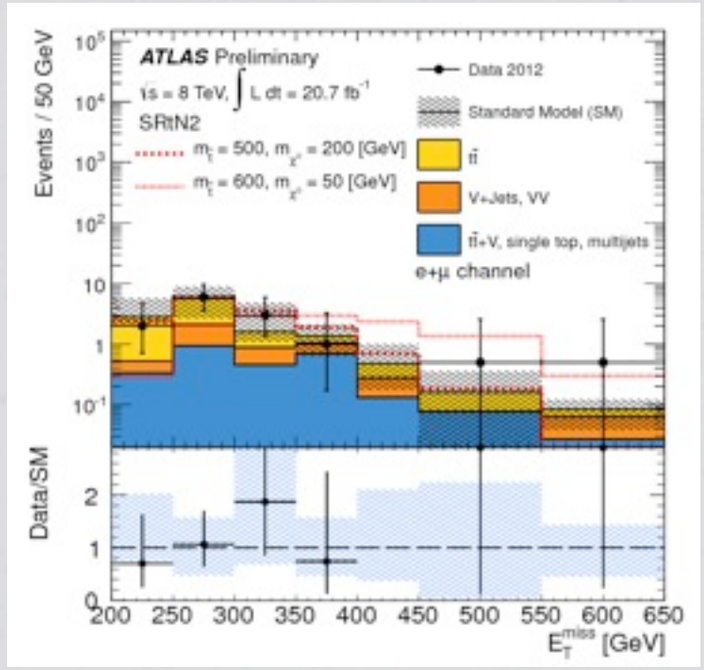
2D binned shape fit: mT [60-140-]GeV and Etmiss [100-150-] GeV.

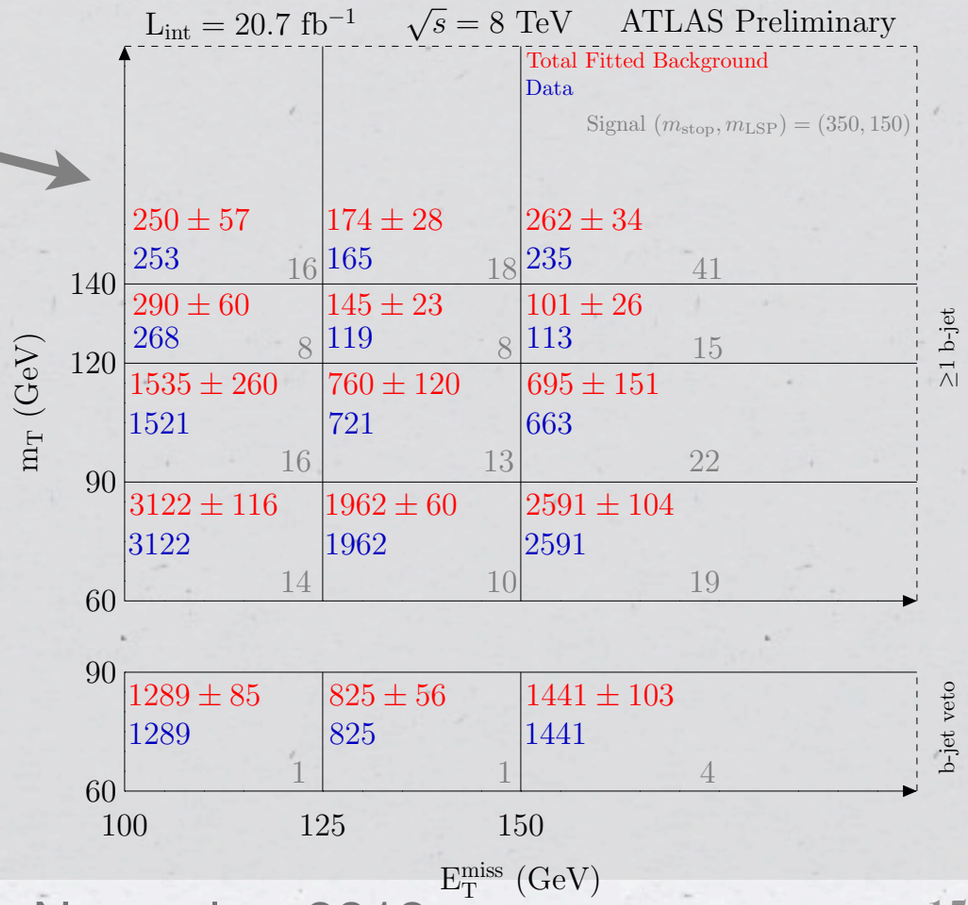
Main Backgrounds: tt, ttV, V+jets.



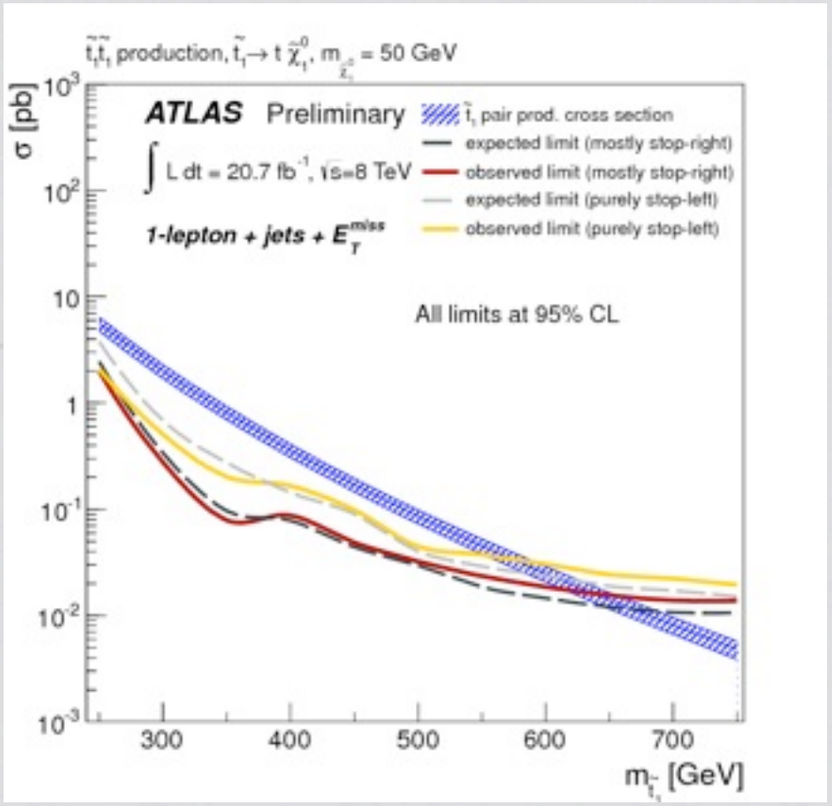
$$m_{T2} \equiv \min_{\vec{p}_{Ta}^{\,C}+\vec{p}_{Tb}^{\,C}=\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}} \{\max(m_{Ta}, m_{Tb})\}$$



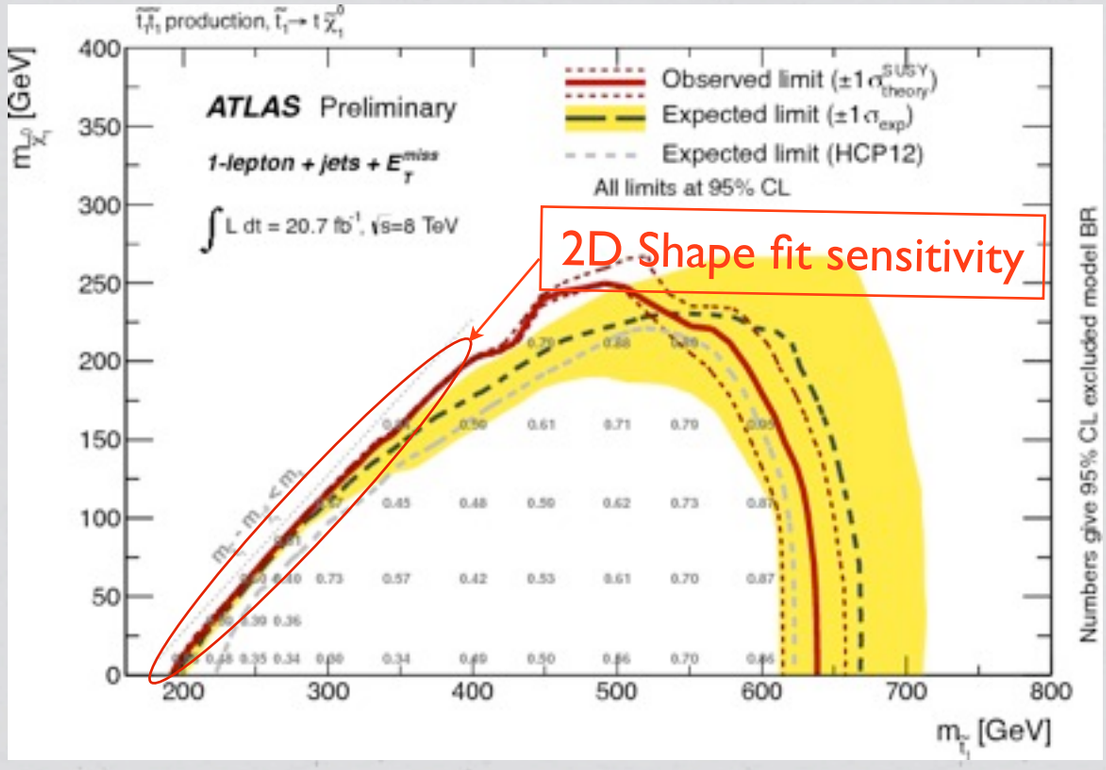




1L+4(1b-)jets+ Etmiss (II)



Baseline Stop signal model - mostly stop-right handed, comparing results with purely stop-left handed (LSP=50GeV) gives drop of the sensitivity (~75GeV).
⇒ lepton kinematics depends on Top polarization.



Stop masses are excluded between 200 GeV and 610 GeV for massless LSPs.

- The sensitivity as a function of the BR (grey numbers), assumes the other decay mode is invisible ⇒conservative.

ATLAS-CONF-2013-048/065

2L+(b)jets+ Etmiss (I)

lepton mT2 selection:

mT2(*l*,*l*,*Etmiss*)>90 to120 GeV, 0/>=2jets,

Main Backgrounds: tt, Wt, Z+jets.

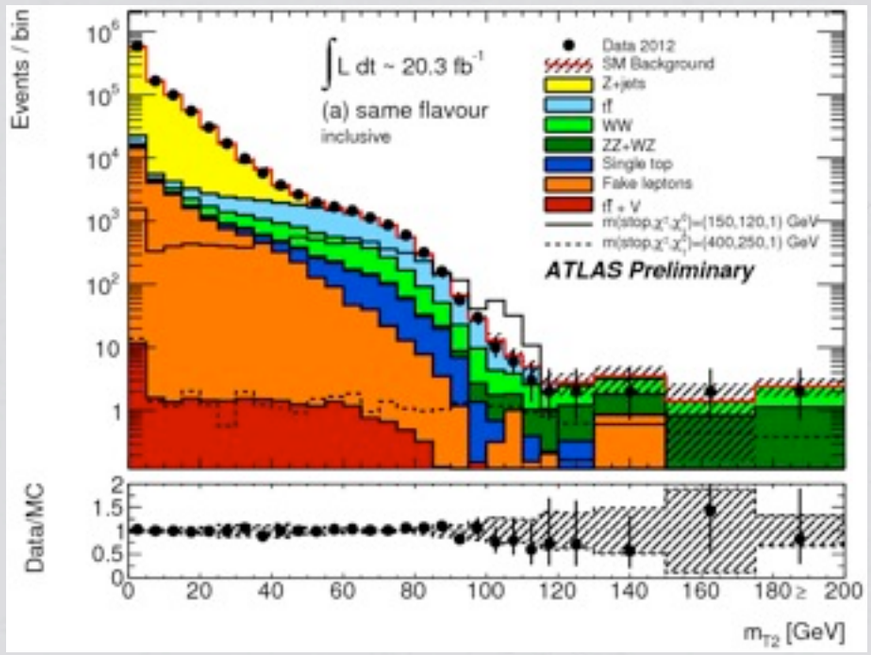
hadronic mT2 selection:

==2b jets, *mT2*(*l*,*l*,*Etmiss*)<90 GeV,

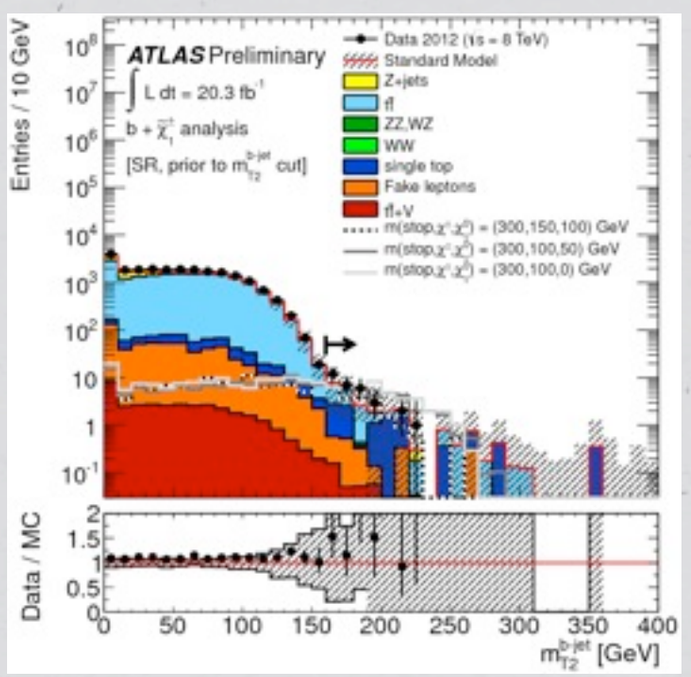
mT2(*b*,*b*,l+l+*Etmiss*)>160GeV.

Main Backgrounds: tt.

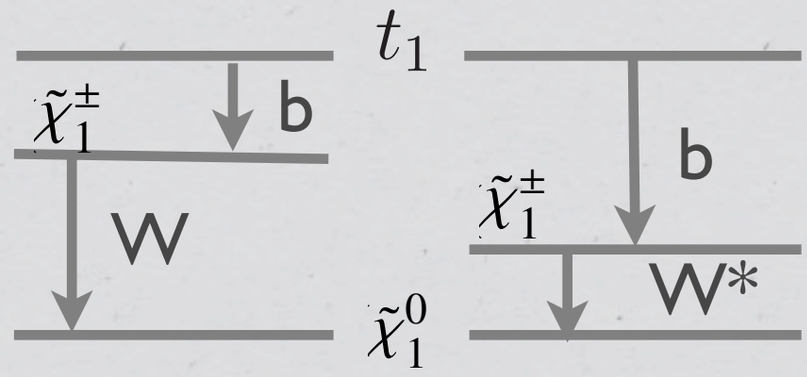
$$m_{T2}(\mathbf{p}_T^1, \mathbf{p}_T^2, \mathbf{q}_T) = \min_{\mathbf{q}_T^1+\mathbf{q}_T^2=\mathbf{q}_T} \left\{ \max[\, m_T(\mathbf{p}_T^1, \mathbf{q}_T^1), m_T(\mathbf{p}_T^2, \mathbf{q}_T^2) \,] \right\}$$



mT2(*l*,*l*,*EtMiss*) bounded by W mass for WW, Wt, tt



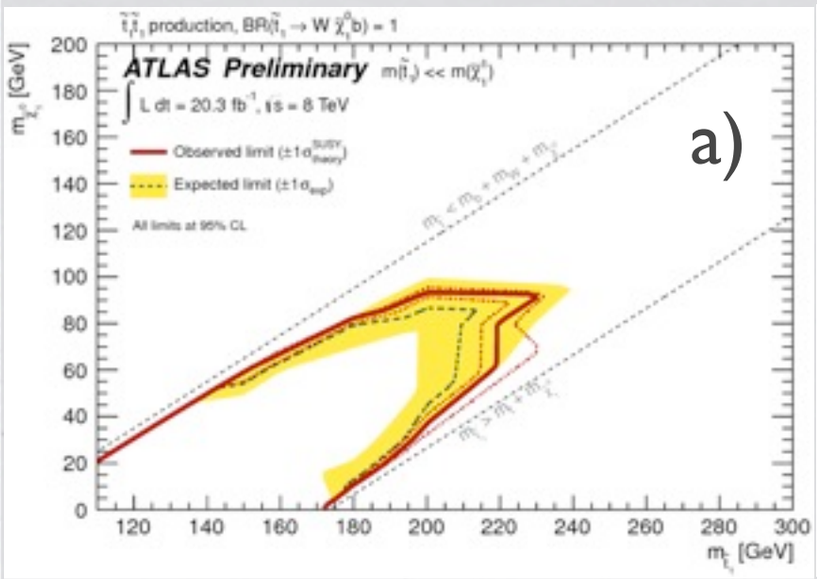
mT2(b,b,l+l+Etmiss) bounded by top mass for tt

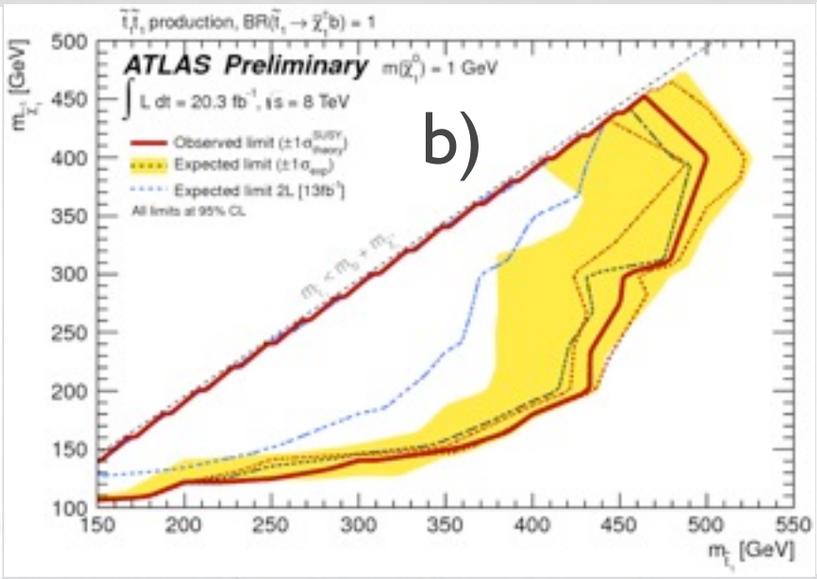


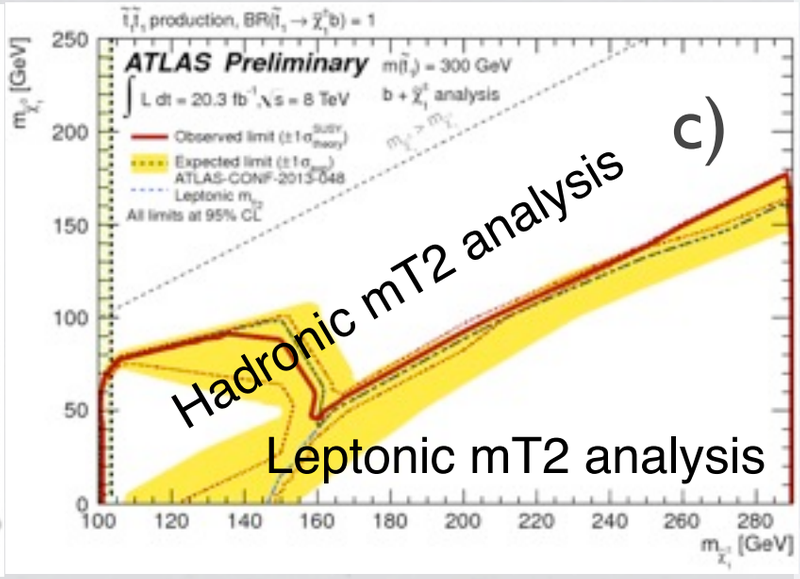
Leptonic mT2 analysis targeting large chargino neutralino mass splitting.

Hadronic mT2 analysis targeting large stop chargino mass splitting.

2L+(b)jets+ Etmiss (II)







a) For m(Stop) – m(LSP) = 90/130/160 GeV Stop mass lower than 155/220/200 GeV are excluded.

b) Stop mass between 150 and 442 GeV is excluded at 95% CL for a neutralino with a mass of 1 GeV and and approximately degenerate chargino and stop masses.

c) Chargino masses between 100 and 150 GeV are excluded for a 50 GeV neutralino and 300 GeV stop.

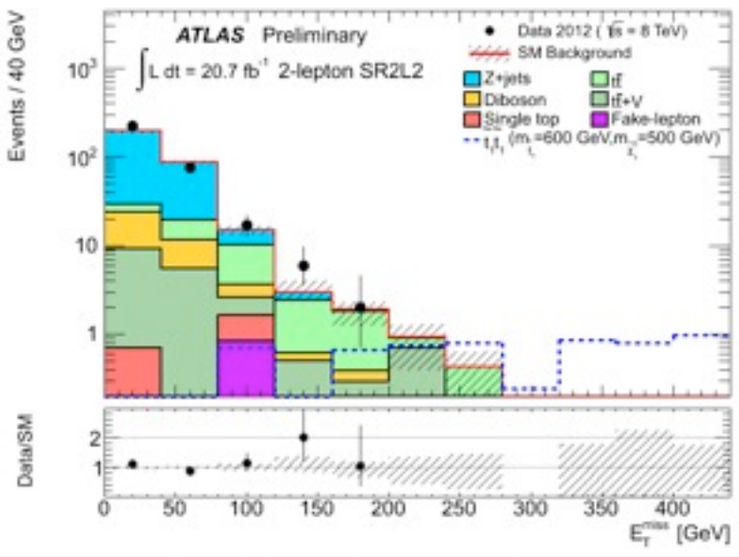
ATLAS-CONF-2013-025

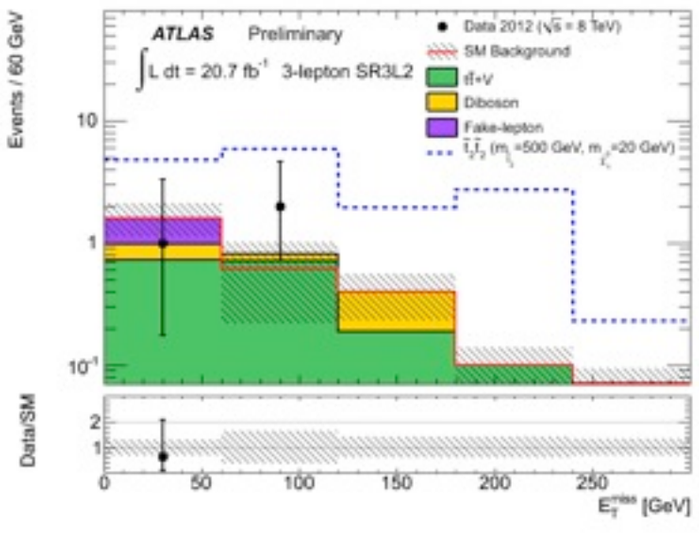
Z+(1b-)jets+Etmiss

2L Selection: ==2L (SFOS), Z reconstruction, (3,4,>5) jets, 1b jet, Etmiss >160 GeV to 200 GeV.

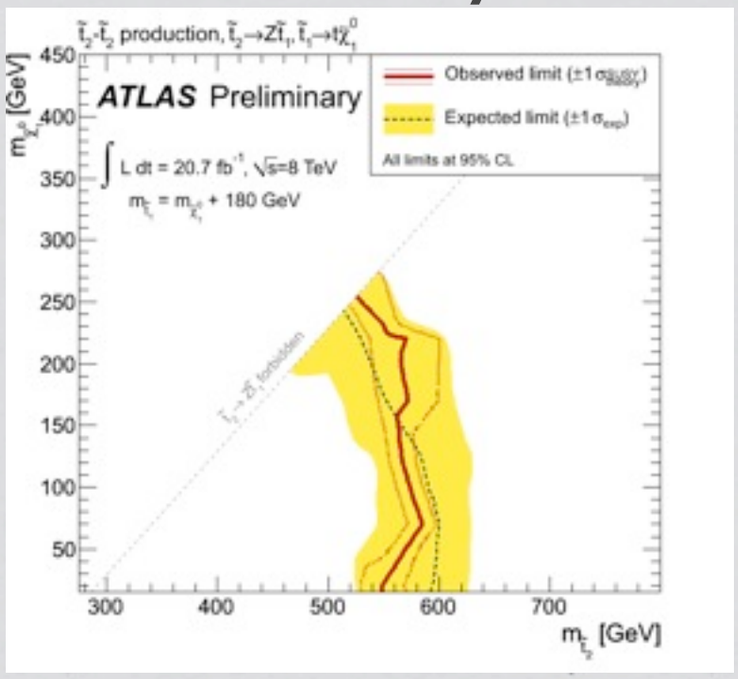
3L Selection: >=3L, Z reconstruction, >= 5jets, 1b jet, Etmiss > 60 GeV.

Main Backgrounds: 2L SR - tt, 3L SR- ttV, VV, fake lepton - estimated with matrix method.





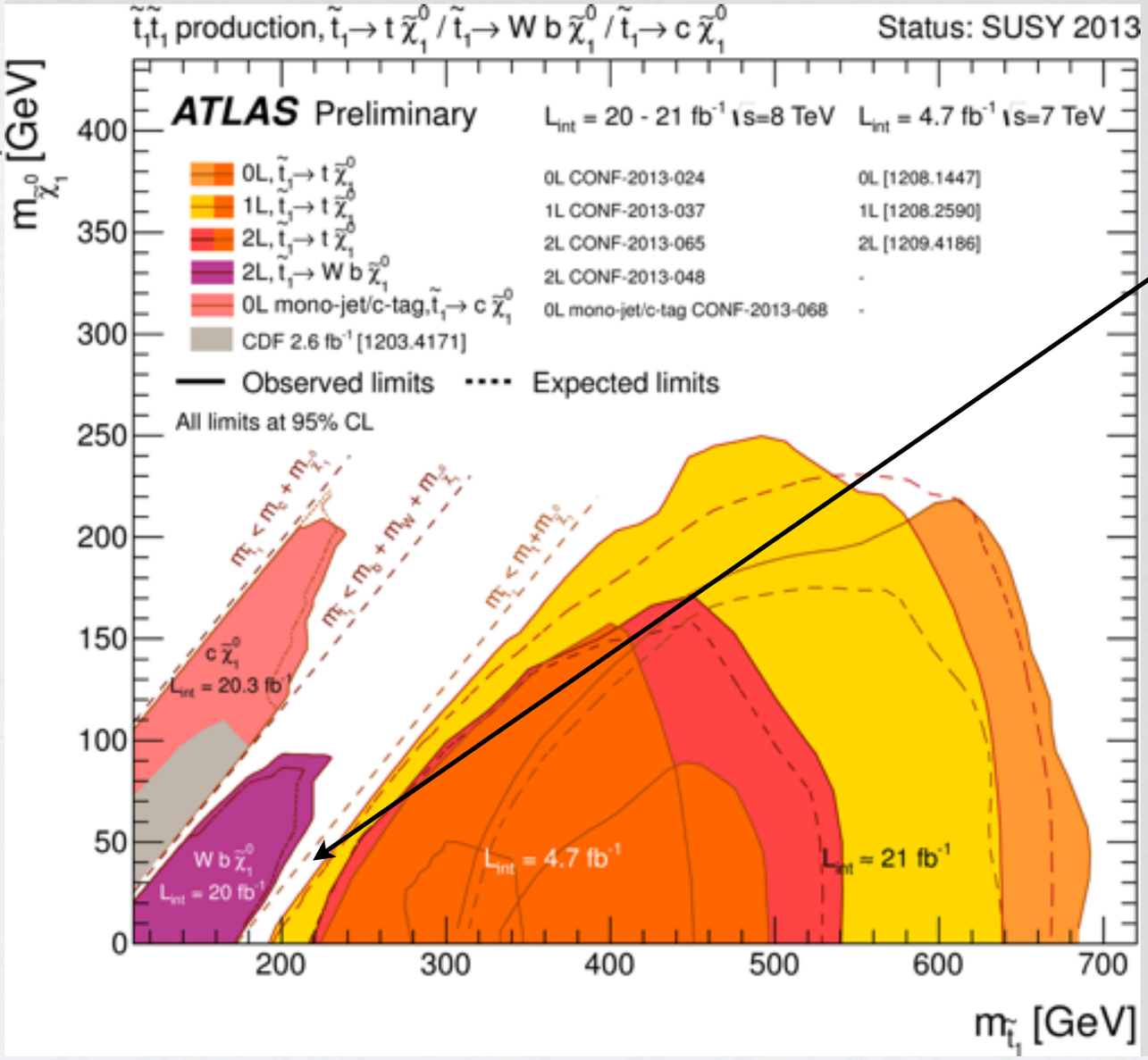
Stop2 interpretation done with 3L analysis.

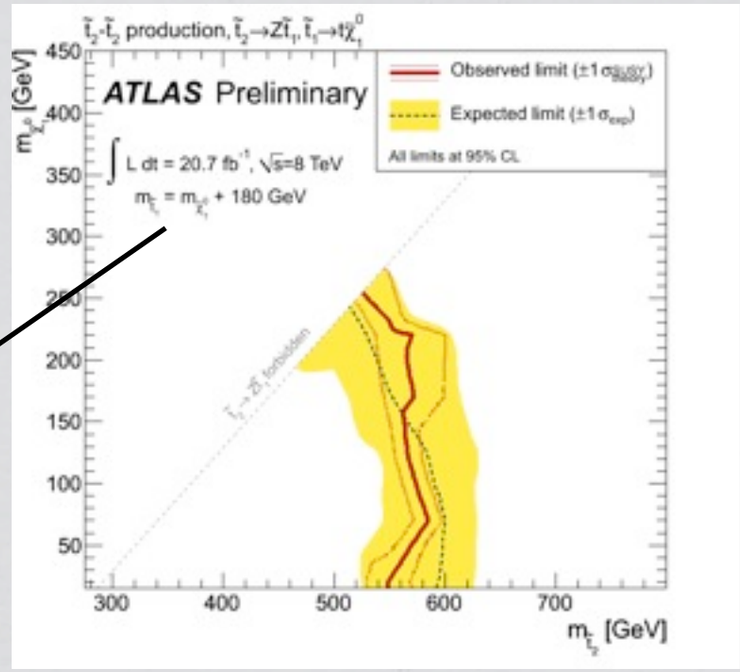


Stop2 mass 530 GeV and neutralino mass 245 GeV are excluded with 95% CL.

This analysis provides Stop1 interpretations in natural GMSB, for more details see talk by Andy Haas.

Summary: Stop ⇒top+LSP





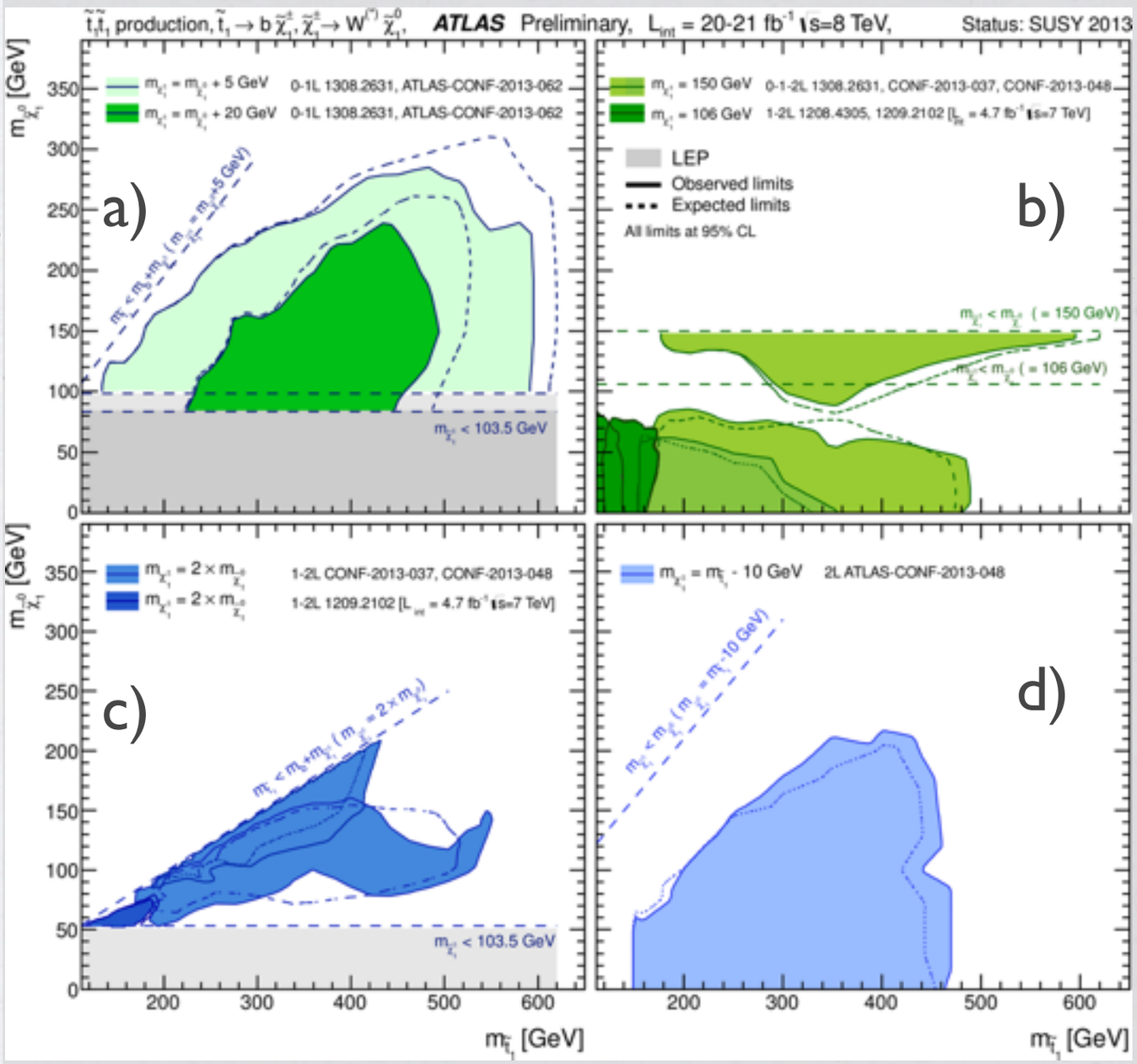
Many Signatures considered ⇒

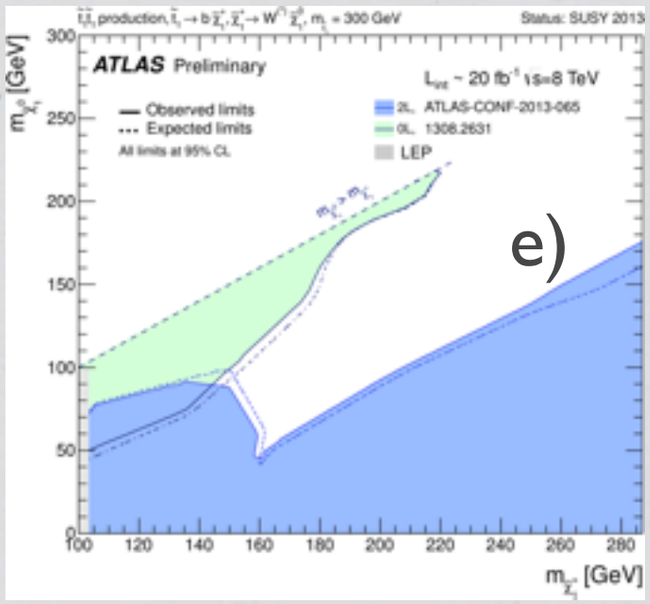
addressing all corners of Stop LSP plane.

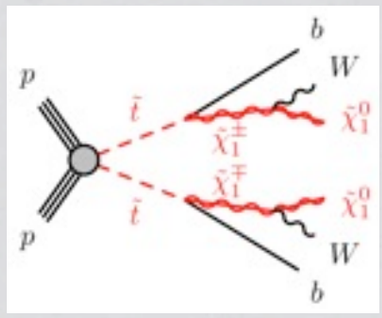
Stop up to 660 GeV for massless LSP and LSP up to 250 GeV for Stop around 500 GeV are excluded.

Warning: simplified models with 100% BR.

Summary: Stop⇒b+Chargino







3 mass parameters: Stop, lightest chargino and neutralino masses.

2 dimensional slices to quantify the exclusion limits on these parameters:

a) small $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 5, 20$ GeV

b) fixed Chargino mass, 106, 150 GeV

c) $m(\tilde{\chi}_1^{\pm}) = 2m(\tilde{\chi}_1^0)$

d) small $\Delta m(\tilde{t}_1, \tilde{\chi}_1^{\pm}) = 10$ GeV

e) fixed Stop mass 300 GeV.

1310.6584, PRD

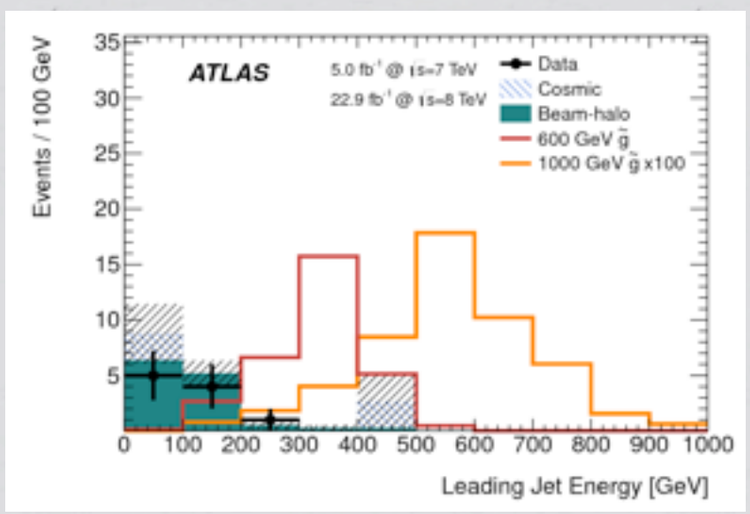
Long-lived R-hadrons (I)

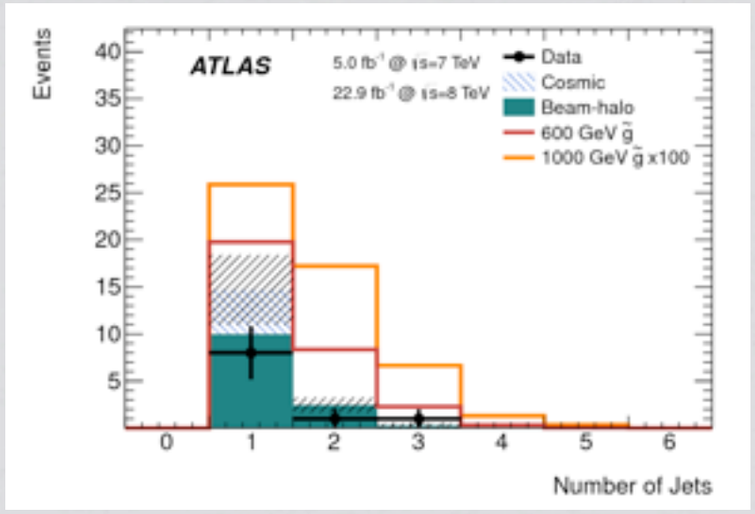
long-lived squarks forming R-hadrons with sizable lifetime ⇒ large out-of-time energy deposits in the calorimeter with minimal additional detector activity.

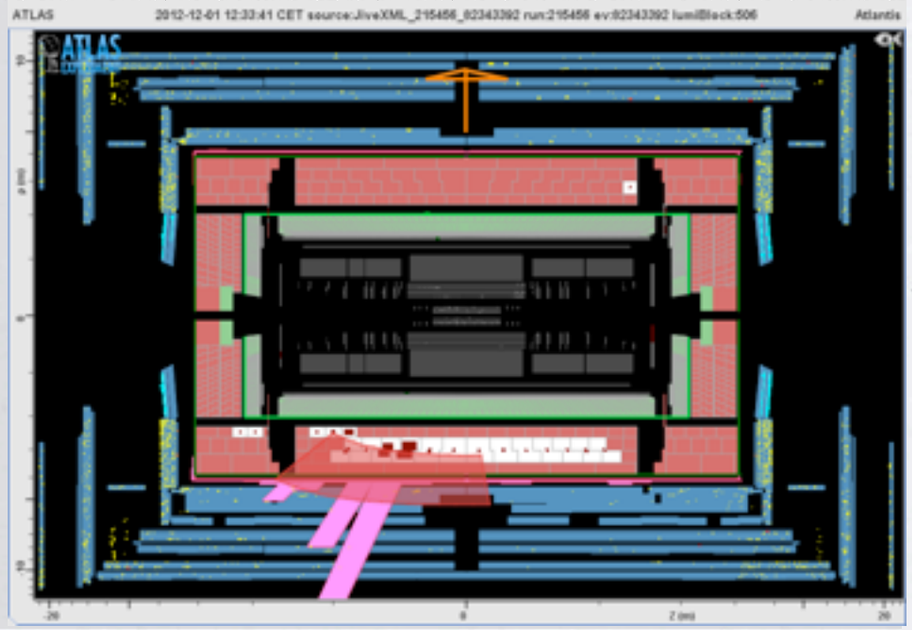
Selection: < 6 jets, 1st jet |η| < 1.2, 1st jet p_T > 100 to 300 GeV, Etmiss/p_T(Jet1) > 0.5.

Main Background: cosmic and beam-halo muon - fully data driven estimation.

- R-hadrons produced in filled LHC bunch slots and decay randomly, select decays in empty bunches
- Special low threshold calorimeter triggers (low BG).
- Tight detector noise cleaning cuts



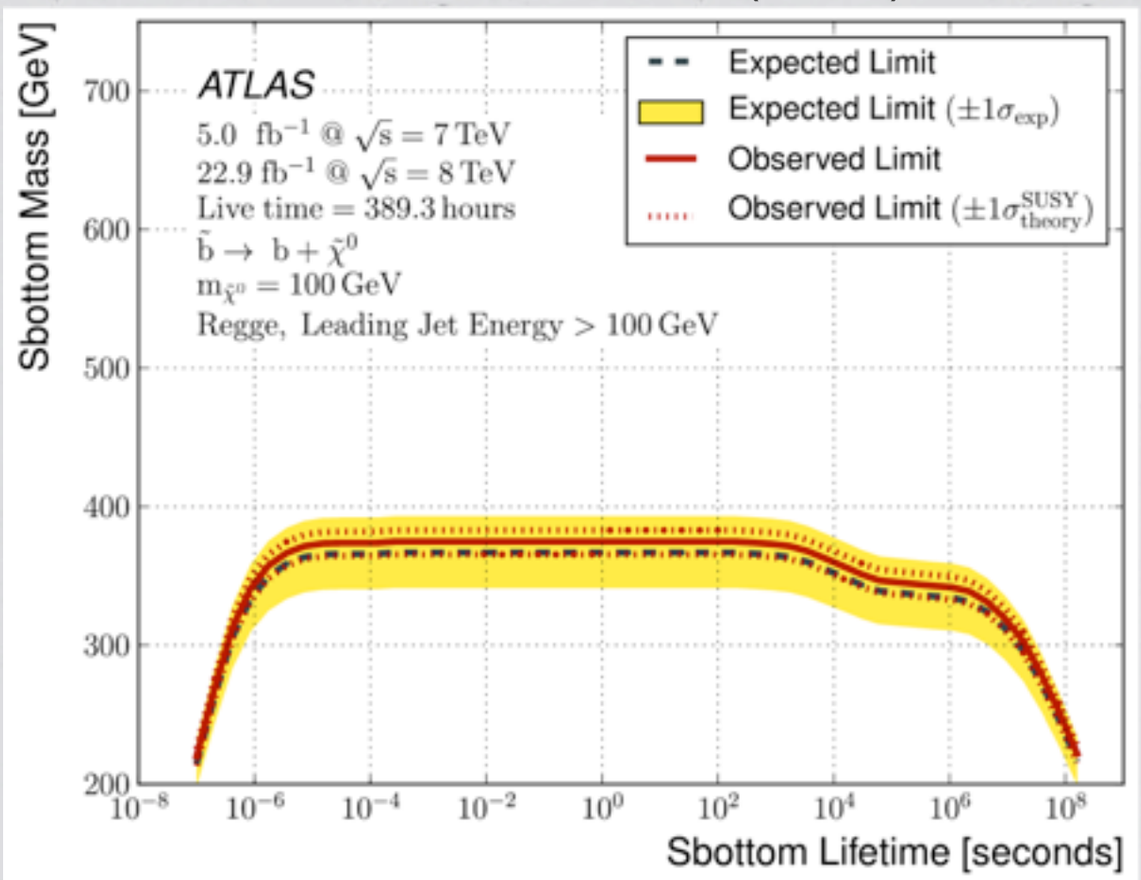


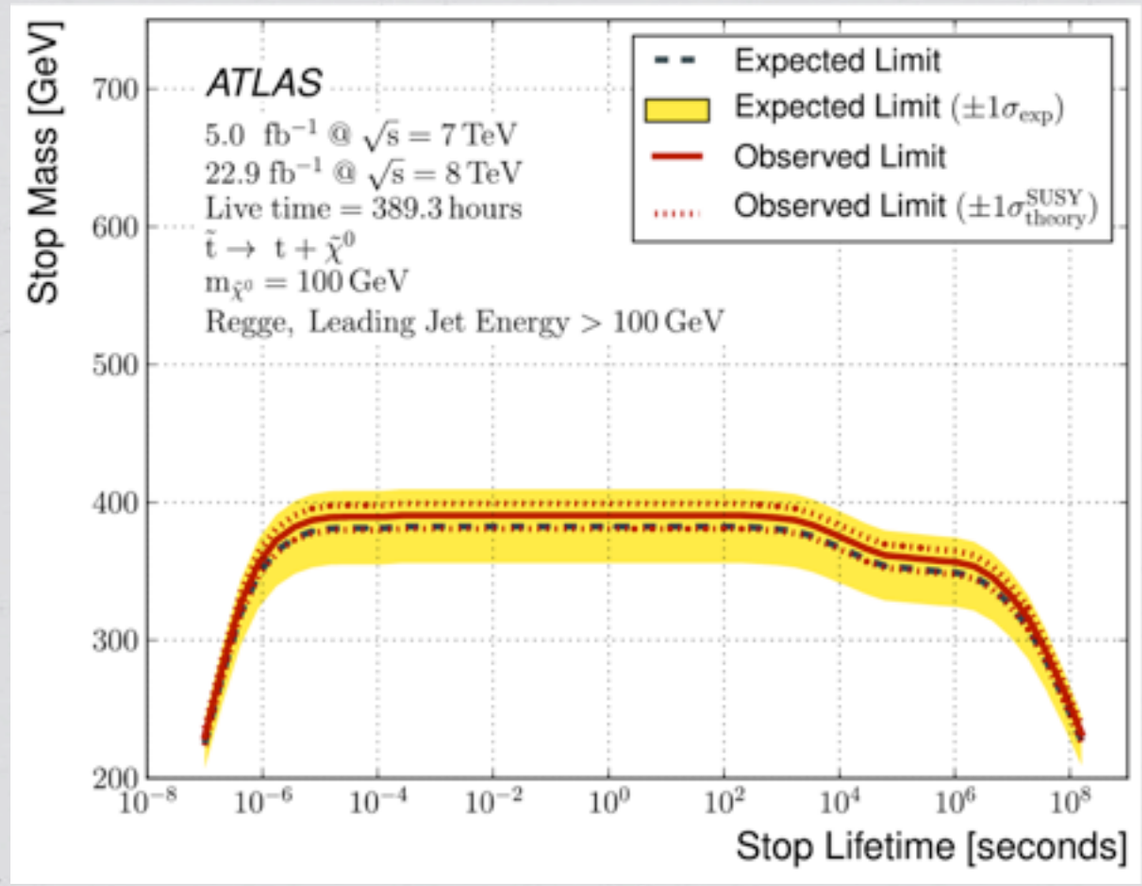


Long-lived R-hadrons (II)

Combined data set:
22.9 fb^{-1} collected at $\sqrt{s}$= 8 TeV (2012)
and ~5.0 fb^{-1} at $\sqrt{s}$= 7 TeV (2011)

Analysis provides limits in terms of the gluino, stop, or sbottom masses.





800 GeV stop or sbottom, in the generic (Regge) R-hadron model is used as a reference for the stopping fraction and reconstruction efficiency.

Conclusion

- ATLAS has very intensive Stop and Sbottom search program,
- Significant reach with LHC run-I data,
- Long shutdown -> time for the R&D,
- More dedicated analyses to cover challenging kinematics,
- Increasing number of simplified and full models -> only discovery can stop us.

Backup

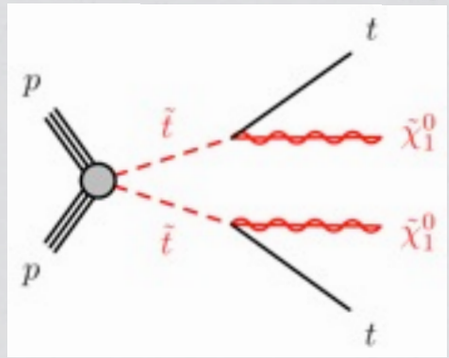
ATLAS-CONF-2013-065

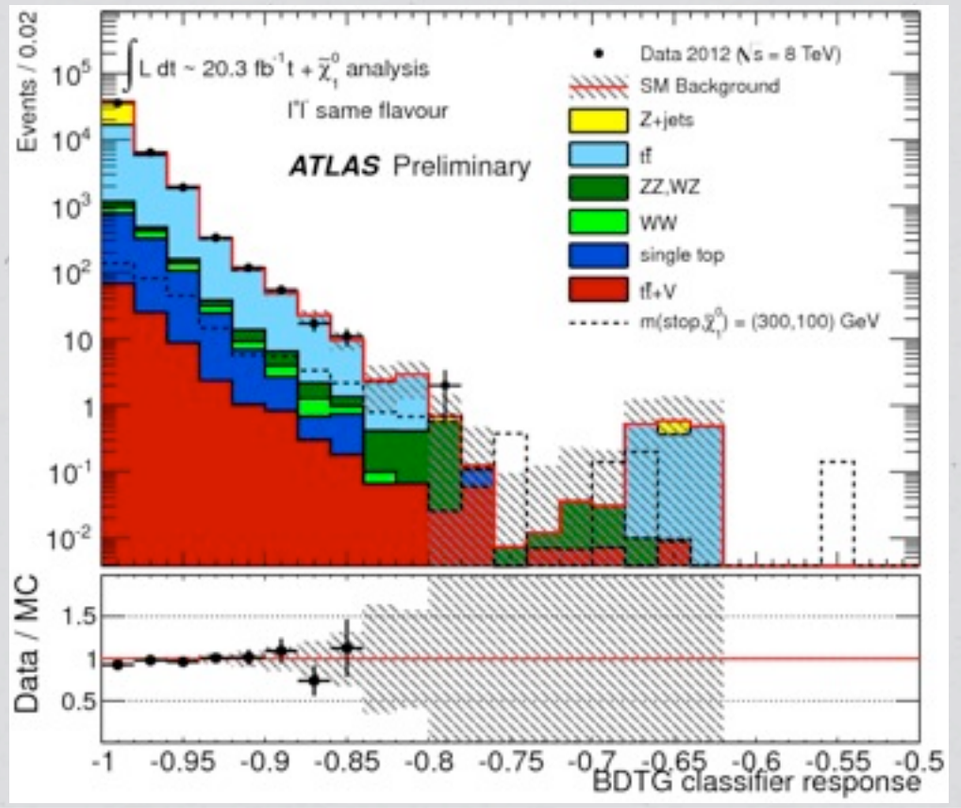
2L +(b)jets+ Etmiss (MVA)

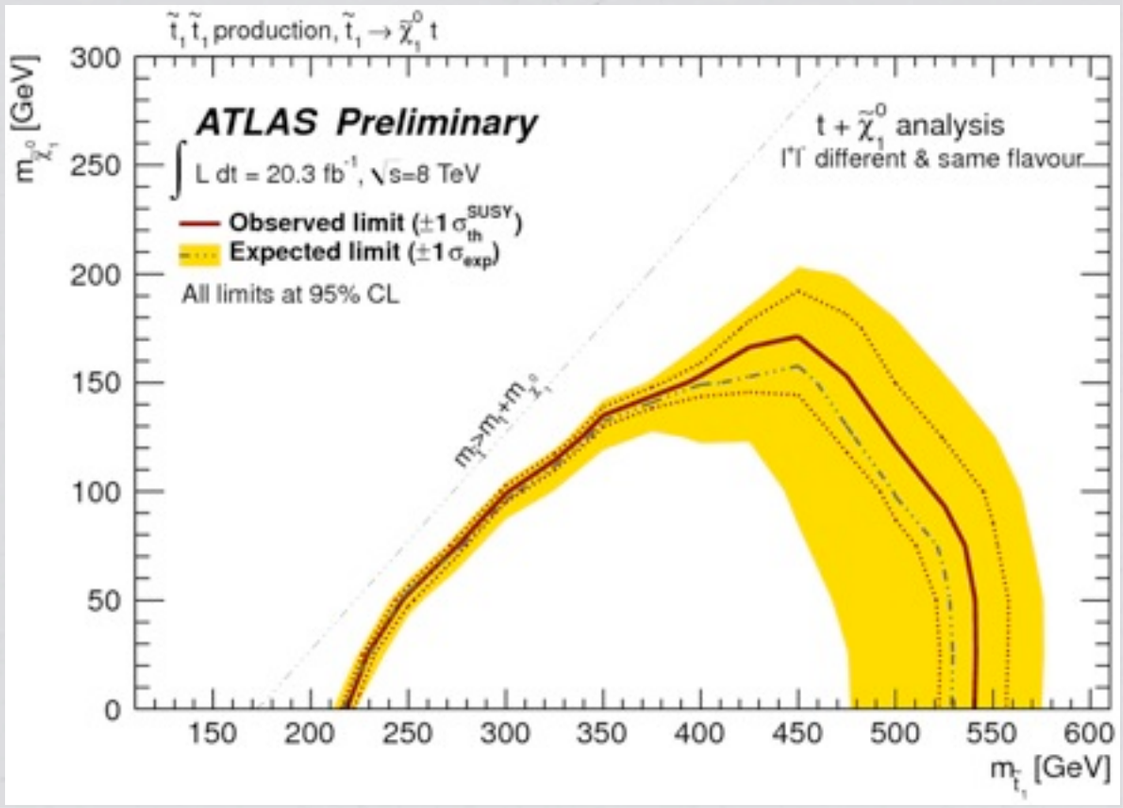
Selection: == 2 jets, meff > 300GeV.

Multivariate analysis, 7 variables: Etmiss, m(ll), mT2(l,l,Etmiss), Δϕ(ll), Δθ(ll), Δϕ(Etmiss,lep1), Δϕ(jet1,lep1).

Main Backgrounds: tt, VV.







Matrix method

fake lepton, or fake HF estimation

Define loose and tight (signal) object selections,

$$N(\text{loose}) = N(\text{loose})_{\text{real}} + N(\text{loose})_{\text{fake}}$$

$$N(\text{tight}) = N(\text{tight})_{\text{real}} + N(\text{tight})_{\text{fake}} = \varepsilon_{\text{real}}\, N(\text{loose})_{\text{real}} + \varepsilon_{\text{fake}} N(\text{loose})_{\text{fake}}$$

$$\varepsilon_{\text{real}} = N(\text{tight})_{\text{real}} / N(\text{loose})_{\text{real}} \quad \text{and} \quad \varepsilon_{\text{fake}} = N(\text{tight})_{\text{fake}} / N(\text{loose})_{\text{fake}}$$

$$N(\text{tight})_{\text{fake}} = (\varepsilon_{\text{fake}} / (\varepsilon_{\text{real}} - \varepsilon_{\text{fake}})) * (\varepsilon_{\text{real}}\, N(\text{loose}) - N(\text{tight}))$$

Fake lepton:
Semi-leptonic decay of a b jet.
Mis-reconstructed jets.
Photon conversions.
Fake b jet:
c, tau (hadronic decay), light jets - mis-tagged as b jet.

jet smearing

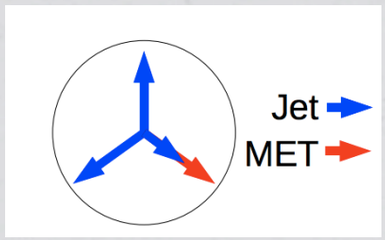
Large fake Etmiss - jet mis-measurement

Select enriched multi jet events with low Etmiss,

Smear jet with response function - account both the effects of jet mis-measurement and contributions from neutrinos and muons in jets from heavy flavor decays.

Initial smearing function derived from MC, 2 data driven methods to modify smearing function for the detector effects:

1) pT balance in di-jet events,
2) 3 jet events with Etmiss originating from one of the jet.



Charm tagging

Multivariate algorithm provides 3 weights per jet:

Pu - light flavour and gluon jet, Pc - charm jet, Pb - b-jet,

Medium cuts on log(Pc/Pu) and log(Pc/Pb):

20% charm tag efficiency, b-jet/light-jet rejection factor 5/140.

Loose cuts on log(Pc/Pu) and log(Pc/Pb):

95% charm tag efficiency, b-jet rejection 1/2.