Search for New Physics at $\sqrt{s}$ = 7 TeV in Hadronic Final States with $\not\!\!E_T$ and Heavy Flavor

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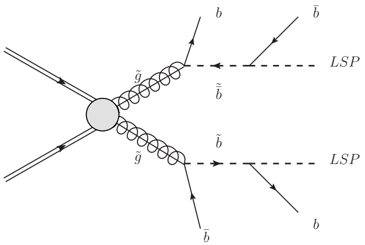
Introduction

- Supersymmetry (SUSY) is one of the most popular and compelling theoretical possibilities for physics beyond the standard model. In the R-parity conserving, minimal SUSY extension to the Standard Model, sparticles are produced in pairs and decay to Standard Model particles and the stable lightest supersymmetric particle ($\tilde{\chi}^0$).
- Mixing between left and right-handed squarks ($\tilde{q}$) can lead to heavy flavor squark mass eigenstates which are significantly lighter than the first and second-generation quark super-partners, thereby enhancing the gluino ($\tilde{g}$) decay branching ratio to heavy flavor.
- This analysis is an update and expansion of a previous ATLAS analysis done with 35 pb^{-1} of integrated luminosity.

The General Case: $\tilde{g} \rightarrow \tilde{b}, \tilde{b} \rightarrow b + \tilde{\chi}^0$

The general SUSY process we are looking for is gluino pair production and subsequent decay via sbottom to 4 b-jets and 2 $\tilde{\chi}^0$ (the LSP). The $\not{E}_T$ in these events arises from the momentum mismatch between the two outgoing $\tilde{\chi}^0$, resulting in a 4b + $\not{E}_T$ final state signature. In this phenomenological model, there are 3 parameters: $m_{\tilde{g}}$, $m_{\tilde{b}}$, and $m_{\tilde{\chi}^0}$.

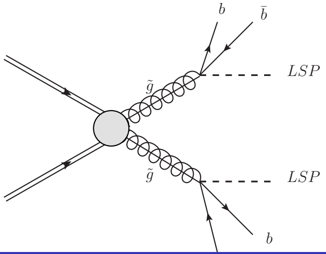


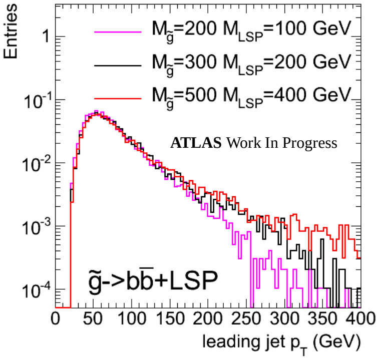
As we are in the 0 lepton (e, μ) channel, we are not very sensitive to $\tilde{t}$-mediated decays. These decays also tend to have lower $\not{E}_T$ due to the reduced phase space afforded the LSP.

Simplified Models: A Special Case

- $m_{\tilde{b}} >> m_{\tilde{g}} > m_{\tilde{\chi}^0}$
- $m_{\tilde{q}_{1,2}}, m_{\tilde{t}} >> m_{\tilde{b}}$
- $m_{\tilde{g}}$ and $m_{\tilde{\chi}^0}$ varied
- $\tilde{b}$ is off-shell, decay chain is effectively $\tilde{g} \rightarrow b\bar{b} + \tilde{\chi}^0$

In this limit, the squark mass spectrum is decoupled and the model kinematics are, to first order, determined by a single parameter: $m_{\tilde{g}} - m_{\tilde{\chi}^0}$.





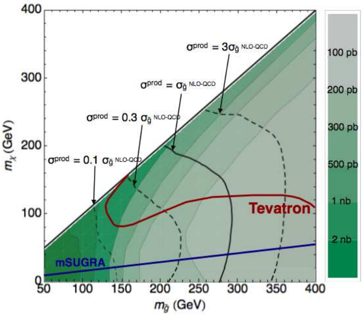
More on Simplified Models

Simplified models have many advantages as signal samples when attempting to design analyses sensitive to as broad a slice of phase space as is possible and practical.

- Well-motivated, SM-like production and decay processes common to many Beyond the Standard Model (BSM) scenarios
- Kinematics determined by few parameters ($m_{\tilde{g}} - m_{\tilde{\chi}^0}$)
- Single final state and final state signature

Moreover, final states are often insensitive to model details, so we pick the simplest to characterize.

These features together enable cross section-independent signal region optimization and results with broad applicability to BSM models with $\tilde{g}$-like decays to heavy flavor.



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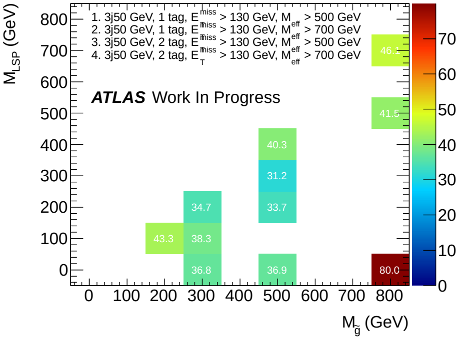
Baseline Selections

This search was conducted using 0.83 fb^{-1} of data collected with the ATLAS detector and a single jet + $\not\!\!E_T$ trigger. The baseline selections are driven by data quality, trigger requirements, QCD rejection, and heavy flavor signal enhancement.

Motivation	Cut	Details
Data quality	Detector flags and jet cleaning	Detector status, electronics noise
	At least 1 good vertex	Beam background/cosmic rejection
Trigger	1 jet with $p_{\mathrm{T}} > 130$ GeV	Turn-on plateau
	$\not\!\!E_T > 130$ GeV	Turn-on plateau
QCD rejection	$\Delta\phi(J1/2/3, \not\!\!E_T) > 0.4$	Fake $\not\!\!E_T$ due to mis-measured jets
	$\not\!\!E_T/M_{eff} > 0.25$	
Signal enhancement	Lepton vetos (e, μ)	No loose e or μ
	2 additional jets with $p_{\mathrm{T}} > 50$ GeV	
	1 or more SV0 b-tagged jets	Decay-length significance

Optimization procedure

1. Evaluate kinematic variables for signal/background separation power: $\not{E}_T$, H_T, M_{eff} ($\not{E}_T + H_T$), jet multiplicity, b-tagged jet multiplicity, etc.
2. Choose best variable set, create n-dimensional cut grid
3. Evaluate systematic-corrected significance at each cut grid point for each signal grid point to create a set of "optimal" kinematic cuts



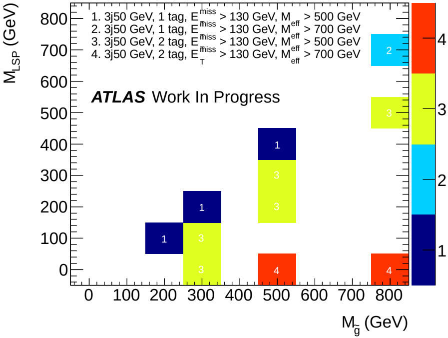
Sensitivity decrease (%) of final cuts relative to optimum

4. Reduce number of selections to a manageable number while ensuring each signal point retains a signal region reasonably (50% of optimum) sensitive to it.

Signal Regions

4 signal regions were chosen to represent good compromises among mass plane coverage, sensitivity, and practical concerns. These regions form a 2 by 2 grid in *b*-tagged jet multiplicity and M_{eff}.

Strong dependence on $m_{\tilde{g}} - m_{\tilde{\chi}^0}$, trends confirmed with full grid.



Most sensitive cut as a function of mass

	$M_{eff} > 500$ GeV	$M_{eff} > 700$ GeV
$\geq$1 *b*-tag	Region 1	Region 2
$\geq$2 *b*-tag	Region 3	Region 4

Monte Carlo Background Estimation

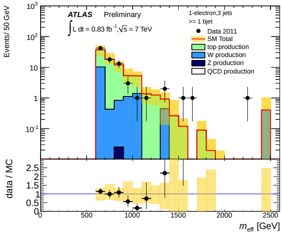
Non-QCD background estimates were taken from Monte Carlo simulation, and in the $t\bar{t}$ case validated using a 1-lepton (e or μ) control region. $t\bar{t}$ makes up the largest background component in all signal regions.

The 1-lepton control region uses the same kinematic cuts as the 0-lepton signal region except that 1 lepton with $p_T > 20$ GeV, $M_{eff} >$ 600 GeV and 40 GeV $< M_T <$ 100 GeV are required.

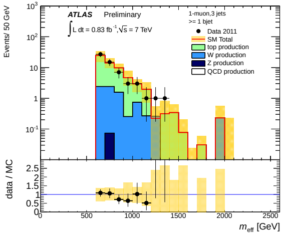
M_T = transverse mass of lepton and $\not{E}_T$

Physics process	$\sigma \cdot$ BR [nb]
$W \rightarrow \ell\nu$ (+jets)	31.4±1.6
$Z/\gamma^* \rightarrow \ell\ell$ (+jets)	3.20±0.16
$Z \rightarrow \nu\nu$ (+jets)	5.82±0.29
$t\bar{t}$	$0.165^{+0.011}_{-0.016}$
Single top	0.085±0.003

1e $t\bar{t}$ estimate validation



1μ $t\bar{t}$ estimate validation



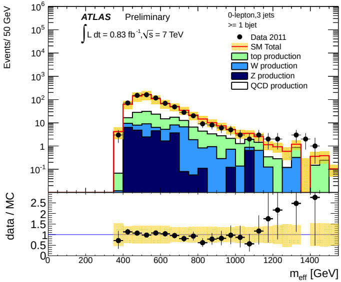
Data-driven QCD Estimation

The QCD background estimate in the signal region was estimated from data, as leading-order Monte Carlo was not sufficient to provide a reliable estimate.

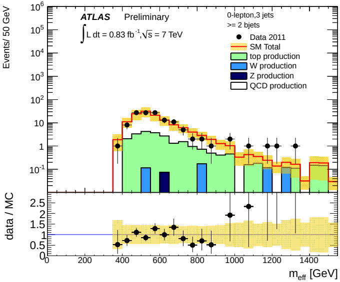
Fundamental Assumption: $\not{E}_T$ in QCD multi-jet background due to mis-measured jets

- Jet momenta in data events with low $\not{E}_T$ significance smeared with a jet response function to generate pseudoevents with large $\not{E}_T$.
- Validated by comparing data and pseudoevent distributions in QCD-enriched $(\Delta\phi(jet, \not{E}_T) < 0.4)$ control regions.

$\geq$1 *b*-tags



$\geq$2 *b*-tags



M_{eff} distributions in QCD control regions

Systematic Uncertainties

Non-QCD background - 30-35%

- Jet energy scale: 20-25%
- Theoretical: 25-30%
- W/Z + heavy flavor: 50-100%
- b-tagging efficiency: 10-30%
- Integrated luminosity: 4.5%

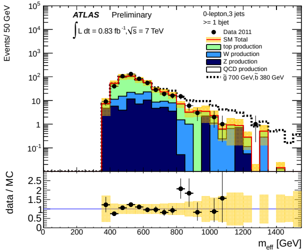
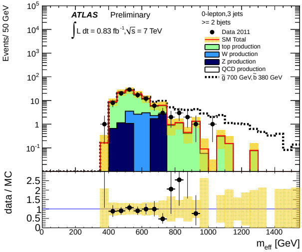
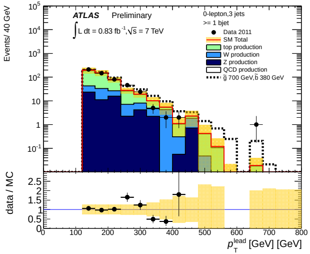
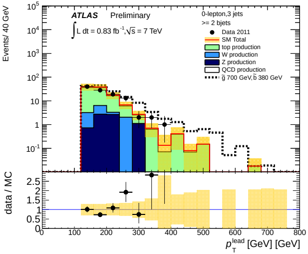
QCD background - 50%

- Smearing function dependency on flavor composition of the low-$\not{E}_T$ unsmeared sample

SUSY signal processes

- b-tagging and jet energy scale: 10-35%
- Renormalization/factorization scales: 16-30%
- PDF: 7-25%
- Integrated luminosity: 4.5%

Signal Region Data/MC Comparisons

	≥ 1 b-tag		≥ 2 b-tags
		M_{eff}	
		p_T^{lead}	

Signal Region Data/MC Comparisons

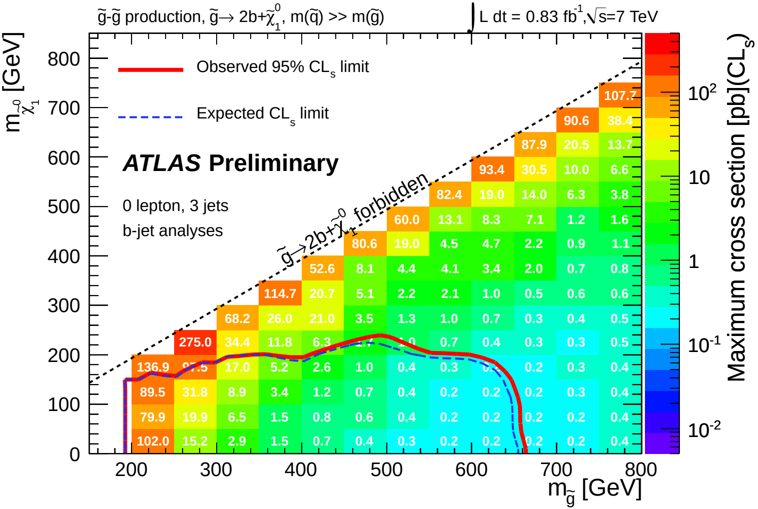
Good agreement is observed between the SM expectation and data for all signal regions.

Sig. Reg.	Data (0.83 fb^{-1})	Top	W/Z	QCD	Total
1 (1 b-tag $M_{eff} > 500$ GeV)	361	221^{+82}_{-68}	121 ± 61	15 ± 7	356^{+103}_{-92}
2 (1 b-tag $M_{eff} > 700$ GeV)	63	37^{+15}_{-12}	31 ± 19	1.9 ± 0.9	70^{+24}_{-22}
3 (2 b-tag $M_{eff} > 500$ GeV)	76	55^{+25}_{-22}	20 ± 12	3.6 ± 1.8	79^{+28}_{-25}
4 (2 b-tag $M_{eff} > 700$ GeV)	12	$7.8^{+3.5}_{-2.9}$	5 ± 4	0.5 ± 0.3	$13.0^{+5.6}_{-5.2}$

Signal-independent upper limits on the non-SM contributions to each signal region can be defined in terms of event yield and effective cross section ($\sigma_{eff} = \sigma \times BR \times \epsilon$).

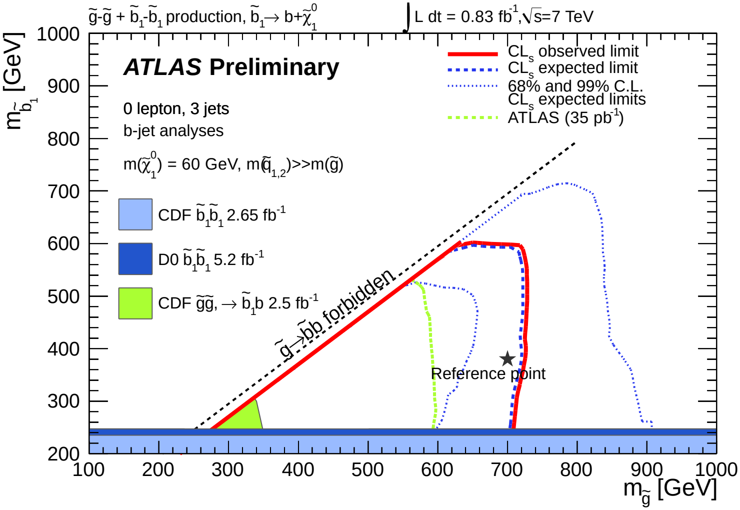
Sig. Reg.	95% C.L. N events CL_s (PCL)	95% C.L. σ_{eff} (pb) CL_s (PCL)
1(1 b-tag $M_{eff} > 500$ GeV)	240 (206)	0.288 (0.247)
1 (1 b-tag $M_{eff} > 700$ GeV)	51 (40)	0.061 (0.048)
2 (2 b-tag $M_{eff} > 500$ GeV)	65 (53)	0.078 (0.064)
3 (2 b-tag $M_{eff} > 700$ GeV)	14 (11)	0.017 (0.014)

Limits on $\tilde{g} \rightarrow b\bar{b} + \tilde{\chi}^0$ Simplified Models



LSP masses below 200-250 GeV are excluded for gluino masses in the range 200-660 GeV, if $m_{\tilde{g}} - m_{\tilde{\chi}^0} > 100$ GeV

Limits on $\tilde{g} \to \tilde{b}, \tilde{b} \to b + \tilde{\chi}^0$ Phenomenological Models



Gluino masses below 720 GeV are excluded for sbottom masses up to 600 GeV and $m_{\tilde{\chi}^0} = 60$ GeV.

Summary

A search for new physics with signatures characterized by heavy flavor, $\not{E}_T$, and no leptons was conducted on 0.83 fb^{-1} of data collected with the ATLAS detector at the LHC.

- For $\tilde{g} \rightarrow b\bar{b} + \tilde{\chi}^0$, LSP masses below 200-250 GeV are excluded for gluino masses in the range 200-660 GeV, if $m_{\tilde{g}} - m_{\tilde{\chi}^0} >$100 GeV
- For $\tilde{g} \rightarrow \tilde{b}$ general models, gluino masses below 720 GeV are excluded for sbottom masses up to 600 GeV and $m_{\tilde{\chi}^0}$ = 60 GeV. This extends the previous ATLAS limit by 130 GeV.
- Upper limits on the $\tilde{g} \rightarrow b\bar{b} + \tilde{\chi}^0$ cross section between 0.2 and 275 pb are set for gluino masses between 200 and 750 GeV and neutralino masses between 1 and 700 GeV. These limits apply to in some measure to any BSM model where gluino-like particles are pair-produced and decay to $b\bar{b} + \tilde{\chi}^0$.

Backup

Backup

SO10 Results

DR3

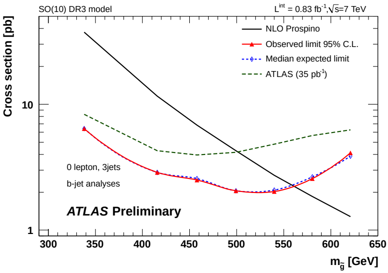
$m_{\tilde{g}} < 570$ GeV is excluded.

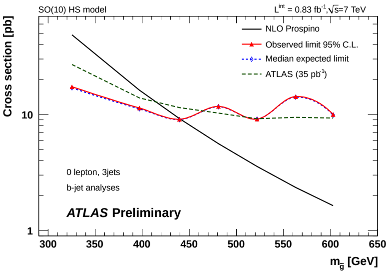
$\tilde{g} \longrightarrow b\bar{b} + \tilde{\chi}^0$ dominates up to $m_{\tilde{g}} =$ 550 GeV, above which other decay channels lower the sensitivity of this analysis.

HS

$m_{\tilde{g}} < 450$ GeV is excluded.

$\tilde{g} \longrightarrow b\bar{b} + \chi_0^2$ has a large branching ratio and $m_{\tilde{\chi}^0}$ is $\approx$2X higher than the DR3 case.





ATLAS Detector

The ATLAS detector is one of two general-purpose detectors built to collect pp collision data from the Large Hadron Collider at CERN. It consists of 4 major components: the inner detector (tracking), the calorimeters (energy measurements), the muon spectrometer, and the magnet and cooling systems.