

Searches for Jets and Missing Transverse Energy with Leptons at ATLAS

Timo Müller (Johannes Gutenberg-Universität Mainz)

on behalf of the ATLAS Collaboration

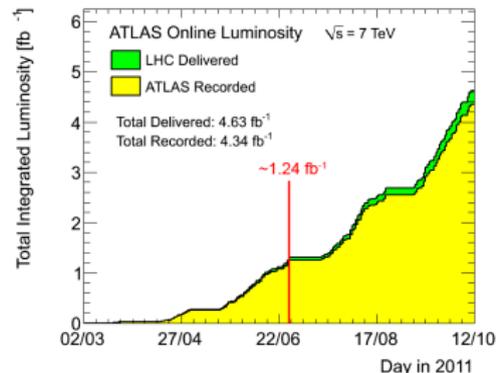
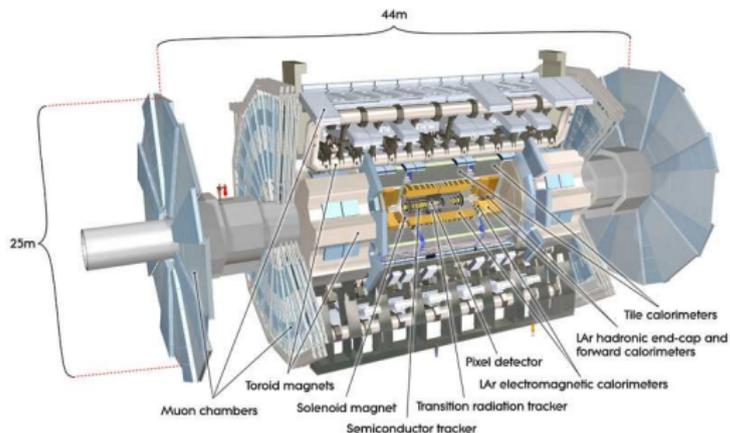
October 19th 2011,
Berkeley Workshop on Searches for Supersymmetry at the LHC



JOHANNES GUTENBERG
UNIVERSITÄT MAINZ



ATLAS and 2011 Data



2011 ATLAS Data

- ▶ So far more than 4 fb^{-1} recorded by ATLAS in 2011
- ▶ Instantaneous luminosity up to $3.4 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- ▶ Results in this talk based on $\sim 1.24 \text{ fb}^{-1}$ ($\sim 1.04 \text{ fb}^{-1}$ after basic Data Quality requirements)

Covered SUSY Signatures

SUSY Signature

Pairs of squarks and/or gluinos decay via long cascades resulting in

- ▶ **Hard jets** from decays of gluinos and squarks
- ▶ **Missing transverse energy** due to LSPs escaping detector
- ▶ Possibly **leptons** from chargino, neutralino and slepton decays

⇒

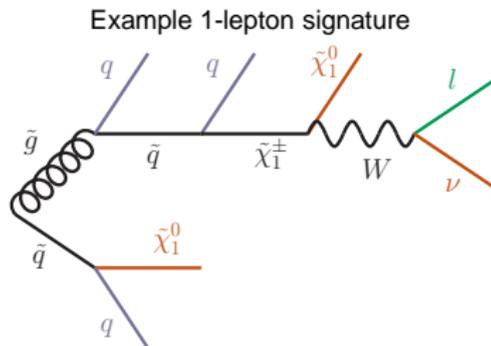
leptons + jets + \cancel{E}_T

This talk:

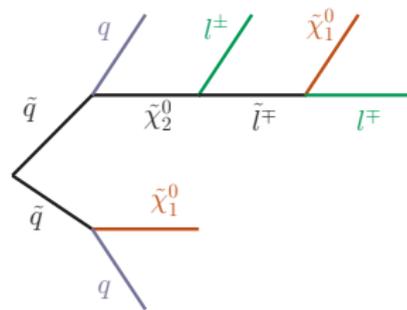
- ▶ Single lepton final state
- ▶ Dilepton final state:
 - ▶ Opposite sign (incl. "flavour subtraction")
 - ▶ Same sign

... For all ATLAS SUSY results see:

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults>



Example 2-lepton signature (OS)



1-Lepton Analysis*

*([arXiv:1109.6606v1](https://arxiv.org/abs/1109.6606v1) [[hep-ex](#)], Paper submitted to PRD)

Event Selection

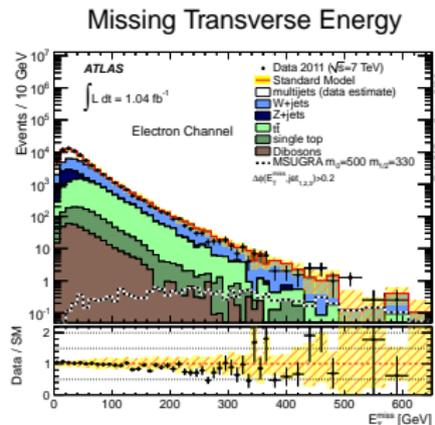
Search Channel

- ▶ Exactly 1 isolated lepton (e or μ) + at least 3/4 jets + Missing Transverse Energy

Event Selection

- ▶ Analysis unspecific preselection (Data Quality, Trigger, Primary vertex)
- ▶ **4 Signal Regions** aiming at different kinematic regions / SUSY models:
 - ▶ Loose (Tight) selection: Compressed spectra (mSUGRA/CMSSM)
 - ▶ 3 (4) jet selection: $\tilde{q}\tilde{q}$ -production ($\tilde{q}\tilde{q}/\tilde{g}\tilde{g}$ -production)

Selection	3JL	3JT	4JL	4JT
Number of Leptons	= 1			
Lepton p_T (GeV)	> 25(20) for electrons (muons)			
Veto lepton p_T (GeV)	> 20(10) for electrons (muons)			
Number of jets	≥ 3		≥ 4	
Lead. jet p_T (GeV)	60	80	60	60
Sub-lead. jet p_T (GeV)	25	25	25	40
$\Delta\phi(\text{jet}_i, \vec{E}_T)$	[> 0.2 (mod. π)] for all 3 (4) jets			
m_T (GeV)	> 100			
\cancel{E}_T (GeV)	> 125	> 240	> 140	> 200
$\cancel{E}_T/m_{\text{eff}}$	> 0.25	> 0.15	> 0.30	> 0.15
m_{eff} (GeV)	> 500	> 600	> 300	> 500



$$m_T = \sqrt{2 \cdot p_T^l \cdot \cancel{E}_T \cdot (1 - \cos(\Delta\phi(l, \vec{E}_T)))}, \quad m_{\text{eff}} = p_T^l + \sum_{i=1}^3 p_T^{\text{jet}_i} + \cancel{E}_T$$

Event Selection

Search Channel

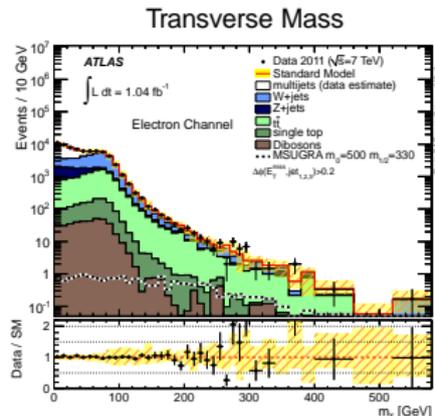
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m_T (GeV)	> 100			
\cancel{E}_T (GeV)	> 125	> 240	> 140	> 200
$\cancel{E}_T/m_{\text{eff}}$	> 0.25	> 0.15	> 0.30	> 0.15
m_{eff} (GeV)	> 500	> 600	> 300	> 500

$$m_T = \sqrt{2 \cdot p_T^l \cdot \cancel{E}_T \cdot (1 - \cos(\Delta\phi(l, \vec{E}_T)))}, \quad m_{\text{eff}} = p_T^l + \sum_{i=1}^3 p_T^{\text{jet}_i} + \cancel{E}_T$$



Background Strategy

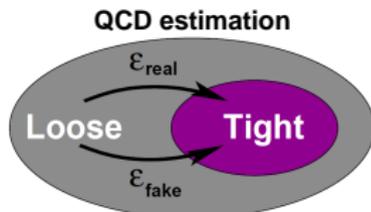
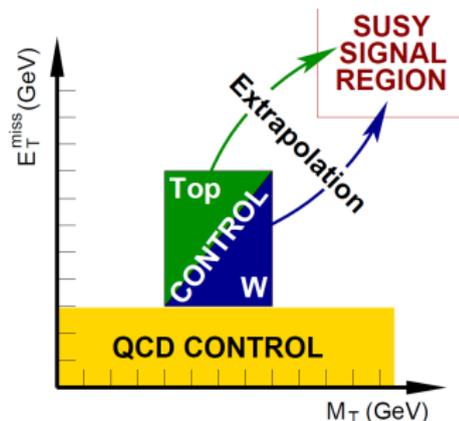
Dominant backgrounds in Signal Regions: $t\bar{t}$ and W + jets

$t\bar{t}$ and W + jets: Semi data-driven approach

- ▶ Normalize MC to data in background specific Control Regions
- ▶ Extrapolate to Signal Regions using MC shapes (Transfer Functions)
- ▶ Final determination of backgrounds by simultaneous likelihood fit of the different Control Regions (cross-contaminations)

QCD: Fully data-driven

- ▶ Measure real and fake lepton efficiencies in Control Region
- ▶ Estimate QCD in Signal Region via Matrix Method

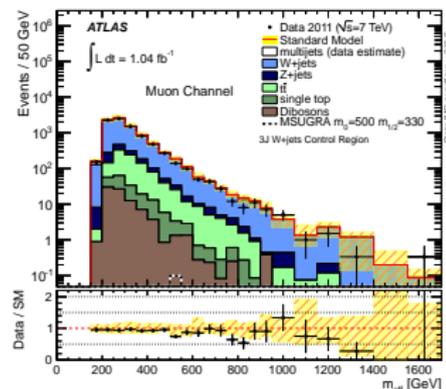


Details: $t\bar{t}$ and $W + \text{jets}$ Backgrounds

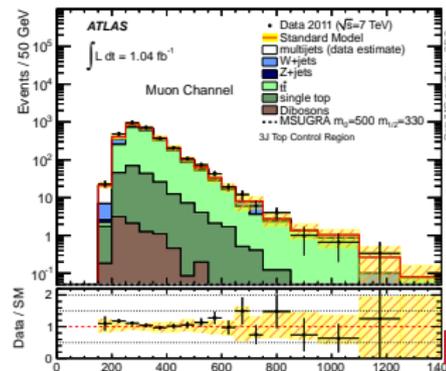
$t\bar{t}$ and $W + \text{jets}$ Control Regions

- ▶ Separate Control Regions for 3J and 4J selections
- ▶ Lepton and jet selection as before
- ▶ Box cuts in (\cancel{E}_T, m_T) -plane:
 - ▶ $40 \text{ GeV} < \cancel{E}_T < 80 \text{ GeV}$
 - ▶ $30 \text{ GeV} < m_T < 80 \text{ GeV}$
- ▶ Cut on m_{eff} to get closer to the Signal Regions / reduce extrapolation uncertainties:
 - ▶ 3J regions: $m_{\text{eff}} > 500 \text{ GeV}$
 - ▶ 3J regions: $m_{\text{eff}} > 300 \text{ GeV}$
- ▶ b -tagging requirements to separate $t\bar{t}$ and W :
 - ▶ $W + \text{jets}$ CR: No b -tagged jet amongst 3/4 leading jets
 - ▶ $t\bar{t}$ CR: At least one b -tagged jet amongst 3/4 leading jets
- ▶ Main uncertainties: Jet Energy Scale (2–20%), generator/theory uncertainties (2–20%)

m_{eff} in 3J $W + \text{jets}$ CR



m_{eff} in 3J $t\bar{t}$ CR



The QCD Matrix Method

Basic system of equations

- ▶ $N_{\text{pass}} = \epsilon_{\text{fake}} \cdot N_{\text{fake}} + \epsilon_{\text{real}} \cdot N_{\text{real}}$,
- ▶ $N_{\text{fail}} = (1 - \epsilon_{\text{fake}}) \cdot N_{\text{fake}} + (1 - \epsilon_{\text{real}}) \cdot N_{\text{real}}$
- ... with
- ▶ $N_{\text{fake/real}}$: total number of fake/real lepton events
- ▶ $N_{\text{pass/fail}}$: number of events with lepton passing/failing tight lepton criteria
- ▶ $\epsilon_{\text{fake/real}}$: probability for fake/real lepton to pass tight lepton criteria

Estimated number of QCD events in the Signal Region

$$\text{▶ } N_{\text{fake}}^{\text{pass}} = \epsilon_{\text{fake}} \cdot N_{\text{fake}} = \frac{N_{\text{fail}} - (1/\epsilon_{\text{real}} - 1) \cdot N_{\text{pass}}}{1/\epsilon_{\text{fake}} - 1/\epsilon_{\text{real}}}$$

- ▶ Efficiency ϵ_{fake} is measured in QCD Control Region (exactly 1 “loose” lepton (no isolation), $\cancel{E}_T < 30 \text{ GeV}$, at least 1 jet with $p_T > 30 \text{ GeV}$)
- ▶ Efficiency ϵ_{real} is measured via $Z \rightarrow ee$ T&P (electrons) / taken from MC in W +jets enriched region (muons)
- ▶ Efficiencies are binned in p_T and η

Results

- ▶ Final event numbers in Signal and Control Regions from combined likelihood fit

$$L(\mathbf{n}|\mu, \mathbf{b}, \theta) = P_S \times P_W \times P_T \times C_{\text{sys}}$$

- ▶ Poisson probability functions P for event counts in Signal S and Control Regions (W , T) and C_{sys} constraining systematics
- ... with number of observed events in data \mathbf{n} , signal strength μ , background \mathbf{b} and nuisance parameters θ

Fit Results

Electron channel	3JL SR	3JT SR	4JL SR	4JT SR
Observed events	71	14	41	9
Fitted background events	98 ± 28	18.5 ± 7.4	48 ± 18	8.0 ± 3.7
Muon channel	3JL SR	3JT SR	4JL SR	4JT SR
Observed events	58	11	50	7
Fitted background events	64 ± 19	13.9 ± 4.3	53 ± 16	6.0 ± 2.7

*more details in backup

- ▶ Fit results validated in 28 additional Control Regions
- ▶ **No significant excess over Standard Model expectation observed**
- ⇒ **Can go ahead and set Limits**

Model Independent Limits and Limits on mSUGRA

- Exclusion Limits with CL_S method using profile likelihood ratio test statistics

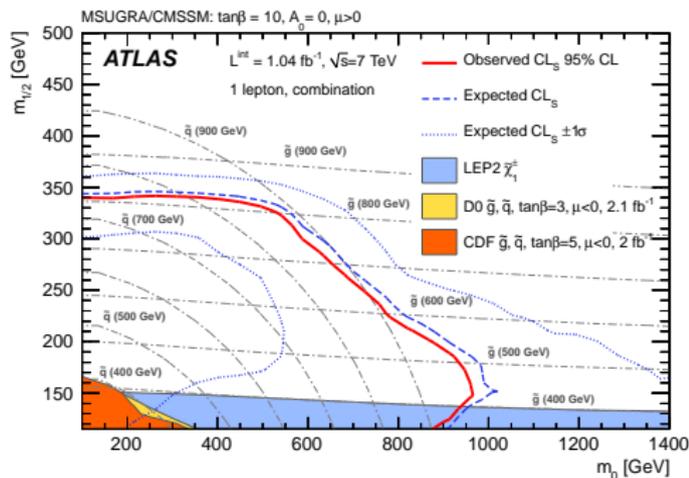
Upper Limit on the visible cross-section

Electron channel	$\langle \epsilon\sigma \rangle_{obs}^{95}$ [fb]
3JL	50
3JT	14
4JL	33
4JT	10

Muon channel	$\langle \epsilon\sigma \rangle_{obs}^{95}$ [fb]
3JL	36
3JT	10
4JL	31
4JT	9

- Model independent

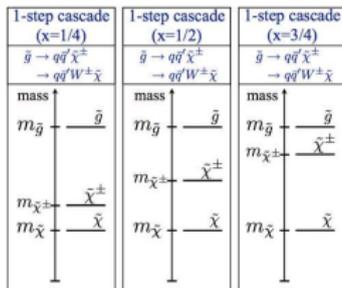
Limit on the mSUGRA/CMSSM model



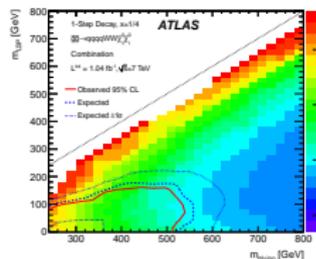
- New Limit: $m_{\tilde{g}} = m_{\tilde{q}} < 820 \text{ GeV}$ excluded at 95% CL

Simplified Models

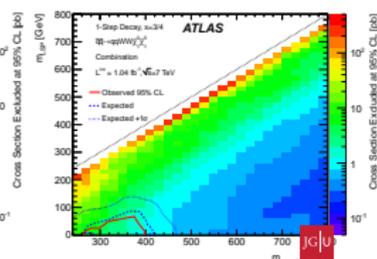
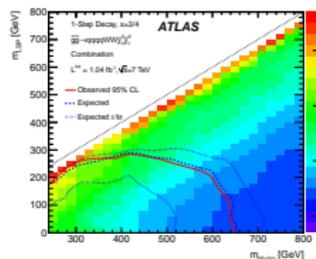
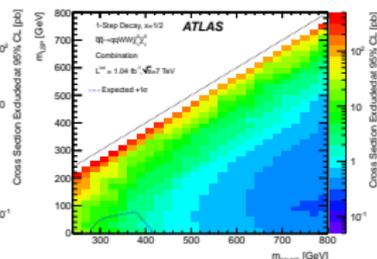
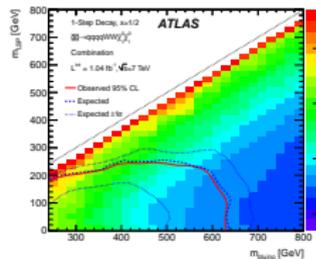
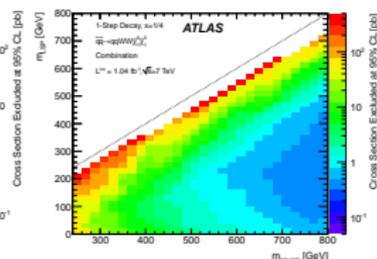
- ▶ **Simplified Models:** Single production mode and decay chain isolated
- ▶ Considered models: $\tilde{g}\tilde{g}$ and $\tilde{q}_L\tilde{q}_L$ production with subsequent decays to LSP via chargino (one-step decays)
- ▶ 3 parameters:
 1. Mass of the heavy sparticles
 2. Mass of the LSP
 3. Chargino-LSP mass difference rel. to heavy sparticles-LSP mass difference $x = \frac{m_{\text{heavy}} - m_{\text{chargino}}}{m_{\text{heavy}} - m_{\text{LSP}}}$
- ▶ Results presented in the $m_{\text{heavy}} - m_{\text{LSP}}$ plane for $x = 1/4, 1/2$ and $3/4$



gluino production



squark production



2-Lepton Analysis*

*(Paper coming soon)

Overview

3 analyses are performed:

SS Same Sign:

- ▶ Production of gluinos or SS-squarks with decay (a) or (b) on both legs
- ▶ Very small Standard Model event rate
- ▶ Main backgrounds from fake leptons, charge misidentification, dibosons

OS Opposite Sign:

- ▶ Decays (a) or (b) on both legs, (c) or (d) on a single leg
- ▶ $t\bar{t}$ is the dominant background

FS Flavour Subtraction:

- ▶ Decays (c) or (d) on a single leg
- ▶ Use OS events to search for excess of same flavour over different flavour
- ▶ Exploits cancellation of Standard Model flavour-symmetric processes like $t\bar{t}$
- ▶ Main backgrounds from flavour-asymmetric processes like Z and dibosons
- ▶ Offers route to measurement of SUSY masses via edges in flavour subtracted m_{ll} distribution

- * All analyses share common object definitions and event selections

Main processes

$$(a) \quad \tilde{\chi}_i^0 \rightarrow l^\pm \nu \tilde{\chi}_j^\mp$$

$$(b) \quad \tilde{\chi}_i^\pm \rightarrow l^\pm \nu \tilde{\chi}_j^0$$

$$(c) \quad \tilde{\chi}_i^0 \rightarrow l^\pm l^\mp \tilde{\chi}_j^0$$

$$(d) \quad \tilde{\chi}_i^\pm \rightarrow l^\pm l^\mp \tilde{\chi}_j^\pm$$

Signal Regions

Common cuts

- ▶ Preselection (Data Quality, Trigger, Primary Vertex)
- ▶ 2 leptons: electron $p_T > 25/20$ GeV, muon $p_T > 20/10$ GeV, $m_{ll} > 12$ GeV

Opposite Sign

- SR1** $\cancel{E}_T > 250$ GeV
- SR2** 3 jets $p_T > 80, 40, 40$ GeV,
 $\cancel{E}_T > 220$ GeV (gluino 2-body decays)
- SR3** 4 jets $p_T > 100, 70, 70, 70$ GeV,
 $\cancel{E}_T > 100$ GeV (gluino 3-body decays)

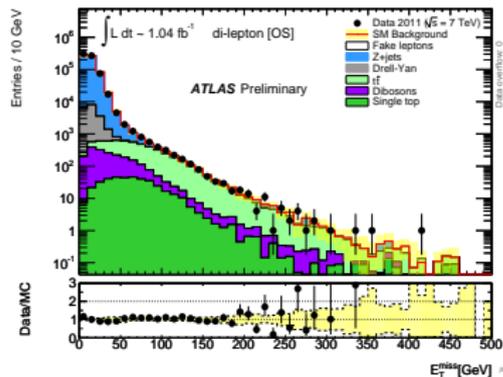
Same Sign

- SR1** $\cancel{E}_T > 100$ GeV (weak gaugino production)
- SR2** 2 jets $p_T > 50, 50$ GeV, $\cancel{E}_T > 80$ GeV (mSUGRA/CMSSM)

Flavour Subtraction

- SR1** $\cancel{E}_T > 80$ GeV
Z veto: $80 > m_{ll} \parallel m_{ll} > 100$ GeV
- SR2** 2 jets $p_T > 20, 20$ GeV, $\cancel{E}_T > 80$ GeV
- SR3** $\cancel{E}_T > 250$ GeV

Missing Transverse Energy OS



Signal Regions

Common cuts

- ▶ Preselection (Data Quality, Trigger, Primary Vertex)
- ▶ 2 leptons: electron $p_T > 25/20$ GeV, muon $p_T > 20/10$ GeV, $m_{ll} > 12$ GeV

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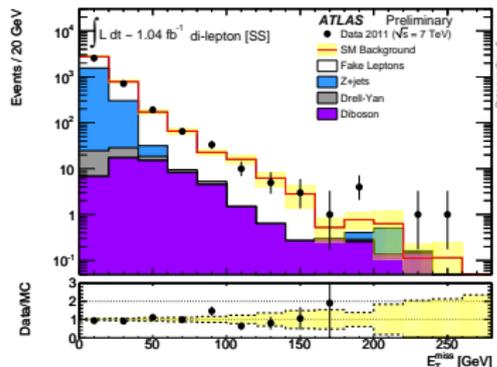
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- SR3** $\cancel{E}_T > 250$ GeV

Missing Transverse Energy SS



Fake Leptons and Charge Misidentification (mainly SS)

Background from fake leptons

- ▶ From light or heavy flavour jets (2 fakes), semileptonic $t\bar{t}$ and $W + \text{jets}$ (1 fake)
- ▶ Measure fake lepton efficiency in appropriate Control Regions (binned in p_T):
 - ▶ μ : 2 “loose” muons (no isolation), $\cancel{E}_T < 30 \text{ GeV}$
 - ▶ e : 1 “loose” electron (looser ID, no isolation), $\cancel{E}_T < 30 \text{ GeV}$, $\Delta\phi(\cancel{E}_T, l) < 0.5$, at least 1 jet
- ▶ Extract real lepton efficiency from Z events
- ▶ Apply Matrix Method similar to 1-lepton analysis

Background from charge misidentification

- ▶ Charge flip after hard brem: $e_{\text{hard}}^{\mp} \rightarrow \gamma_{\text{hard}} e_{\text{soft}}^{\mp} \rightarrow e_{\text{soft}}^{\mp} e_{\text{soft}}^{\mp} e_{\text{hard}}^{\pm}$
- ▶ Flip rates estimated in MC with $Z \rightarrow ee$ events
- ▶ Apply misidentification probabilities to $t\bar{t}$ MC events

Leptonic $t\bar{t}$ and $Z + \text{jets}$ Backgrounds (only OS)

Semi data-driven strategy

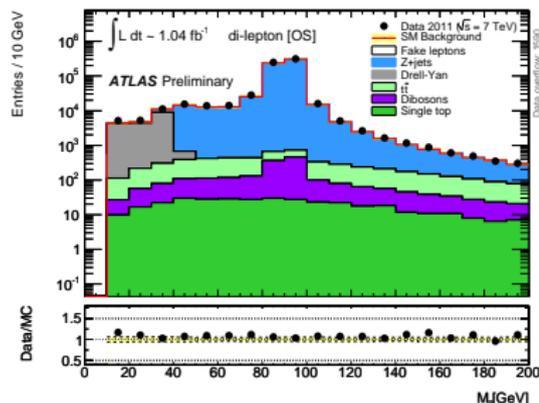
- ▶ Normalize MC to data in specific Control Region
- ▶ Extrapolate to Signal Region using a MC ratio
- ▶ Contaminations from other background processes subtracted based on MC
- ▶ Define Control Regions that are similar to corresponding Signal Region to reduce extrapolation uncertainty

Leptonic $t\bar{t}$

- ▶ Define Control Region with \cancel{E}_T window cut $60 < \cancel{E}_T < 80$ GeV and jet cuts depending on Signal Region
- ▶ Tag $t\bar{t}$ events using cotransverse mass m_{CT} (see [JHEP 0804 \(2008\) 034](#) for details)

$Z + \text{jets}$

- ▶ Control Region with $\cancel{E}_T < 20$ GeV and $81 < m_{\parallel} < 101$ GeV
- ▶ Different jet requirements depending on Signal Region



Results OS and SS

Event yields and Limits on $A \times \epsilon \times \sigma$

- ▶ No significant excess observed \Rightarrow set Limits using CL_S technique

	Background	Obs.	95% CL
OS-SR1	$15.5 \pm 1.2 \pm 3.8$	13	9.9 fb
OS-SR2	$13.0 \pm 1.8 \pm 3.6$	17	14.4 fb
OS-SR3	$5.7 \pm 1.1 \pm 3.4$	2	6.4 fb
SS-SR1	$32.6 \pm 4.4 \pm 6.0$	25	14.8 fb
SS-SR2	$24.9 \pm 4.1 \pm 4.2$	28	17.7 fb

Results FS

Quantify the same flavour excess in OS events using the variable S

$$S = \underbrace{\frac{N(e^\pm e^\mp)}{\beta(1 - (1 - \tau_e)^2)} + \frac{\beta N(\mu^\pm \mu^\mp)}{(1 - (1 - \tau_\mu)^2)}}_{\text{same flavour}} - \underbrace{\frac{N(e^\pm \mu^\mp)}{1 - (1 - \tau_e)(1 - \tau_\mu)}}_{\text{different flavour}}$$

- ... τ_μ, τ_e : Trigger efficiencies
- ... β : Ratio of electron to muon reconstruction efficiencies and acceptances
- ▶ Consistency of observation in data S_{obs} with SM expectation \bar{S}_b is checked using pseudo experiments
- ▶ 95% CL Limits on contributions from new phenomena \bar{S}_s by comparing S_{obs} with signal-plus-background pseudo-experiments: $\%S < S_{\text{obs}}$ is 5%
- ▶ Assumption: $\text{BR}(l'l') = 0$

	S_{obs}	\bar{S}_b	RMS
FS-SR1	$131.6 \pm 2.5(\text{sys})$	$118.7 \pm 23.6 \pm 13.1$	48.6
FS-SR2	$142.2 \pm 1.0(\text{sys})$	$67.1 \pm 23.2 \pm 16.7$	49.0
FS-SR3	$-3.06 \pm 0.04(\text{sys})$	$0.7 \pm 1.1 \pm 1.1$	4.5

	$S > S_{\text{obs}}$ (%)	Limit \bar{S}_s (95% CL)
FS-SR1	39	94
FS-SR2	6	158
FS-SR3	79	4.5

Summary and Outlook

Summary

- ▶ Presented update of ATLAS searches for SUSY with Jets, Missing Transverse Energy and Leptons to $\sim 1 \text{ fb}^{-1}$
- ▶ No significant excess observed
- ▶ Limits have been set for various models

Outlook

- ▶ Updates with more luminosity in progress
- ▶ Shape fits being studied to improve systematics on background estimation
- ▶ New Signal Regions being explored (soft leptons, multijets)
- ▶ Looking into ways to improve MC statistics situation



Backup

Object Definitions

Muons

- ▶ Quality: Loose
- ▶ $p_T > 10$, GeV, $|\eta| < 2.4$
- ▶ STACO combined or segment tagged muon
- ▶ $\Delta R(\mu, \text{jet}) > 0.4$
- ▶ Cosmics: $|z_0| < 5$ mm, $|d_0| < 2$ mm
- ▶ Additional cuts for **signal muons**:
- ▶ $p_T > 20$, GeV
- ▶ Track isolation: $\sum p_T$ in 0.2 cone < 1.8 GeV

Missing Transverse Energy

- ▶ Jets with $p_T > 20$ GeV at EM+JES scale
- ▶ Signal lepton
- ▶ Additional non-isolated muons
- ▶ TopoClusters not associated to objects (CellOut) at EM scale

Electrons

- ▶ Quality: Medium
- ▶ $p_T > 20$ GeV, $|\eta^{\text{clus}}| < 2.47$
- ▶ not $0.2 < \Delta R(e, \text{jet}) < 0.4$
- ▶ Additional cuts for **signal electrons**:
- ▶ Quality: Tight
- ▶ $p_T > 25$ GeV
- ▶ Track isolation:
 $\sum p_T$ in 0.2 cone / $p_T < 0.1$

Jets

- ▶ AntiKt4Topo
- ▶ $p_T > 20$, GeV, $|\eta| < 2.8$
- ▶ $\Delta R(\text{jet}, e) > 0.2$
- ▶ Reject events with loose bad jets
- ▶ **Signal jets**: $p_T > 25$ GeV, $|\text{JVF}| > 0.75$
- ▶ **b-jets**: JetFitterCombNN > 2.0

Fit Results 3J

- ▶ Fit results in the 3J Signal Regions
- ▶ Nominal MC expectations are given in parentheses for comparison

Electron channel	3JL Signal region	3JT Signal region	Top region	W region
Observed events	71	14	162	565
Fitted top events	57 ± 19 (51)	7.6 ± 3.0 (6.8)	125 ± 16 (112)	64 ± 15 (58)
Fitted W/Z events	35 ± 19 (34)	10.5 ± 6.5 (10.1)	30.1 ± 9.1 (29.3)	425 ± 38 (413)
Fitted QCD events	$6.0^{+2.3}_{-1.4}$	$0.46^{+0.37}_{-0.22}$	7.2 ± 2.6	76 ± 24
Fitted sum of background events	98 ± 28	18.5 ± 7.4	162 ± 13	565 ± 24

Muon channel	3JL Signal region	3JT Signal region	Top region	W region
Observed events	58	11	166	413
Fitted top events	47 ± 16 (38)	8.9 ± 3.2 (7.3)	142 ± 15 (115)	70 ± 15 (57)
Fitted W/Z events	16.6 ± 9.4 (20.1)	5.0 ± 3.2 (6.1)	19.0 ± 5.1 (23.2)	322 ± 27 (393)
Fitted QCD events	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.6}_{-0.0}$	5.4 ± 2.2	21.6 ± 5.7
Fitted sum of background events	64 ± 19	13.9 ± 4.3	166 ± 13	413 ± 20

Fit Results 4J

- Fit results in the 4J Signal Regions
- Nominal MC expectations are given in parentheses for comparison

Electron channel	4JL Signal region	4JT Signal region	Top region	W region
Observed events	41	9	1382	1872
Fitted top events	38 ± 15 (34)	4.5 ± 2.6 (4.1)	1258 ± 44 (1138)	391 ± 14 (354)
Fitted W/Z events	9.5 ± 7.5 (9.2)	3.5 ± 2.2 (3.4)	88 ± 21 (86)	1242 ± 89 (1202)
Fitted QCD events	$0.90^{+0.54}_{-0.37}$	$0.00^{+0.02}_{-0.00}$	35 ± 13	239 ± 78
Fitted sum of background events	48 ± 18	8.0 ± 3.7	1382 ± 37	1872 ± 43

Muon channel	4JL Signal region	4JT Signal region	Top region	W region
Observed events	50	7	1448	1623
Fitted top events	39 ± 13 (36)	4.7 ± 2.2 (4.3)	1319 ± 45 (1231)	382 ± 13 (357)
Fitted W/Z events	14.1 ± 8.5 (14.2)	1.4 ± 1.1 (1.4)	91 ± 19 (92)	1169 ± 46 (1185)
Fitted QCD events	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.6}_{-0.0}$	38 ± 10	71 ± 16
Fitted sum of background events	53 ± 16	6.0 ± 2.7	1448 ± 38	1623 ± 40

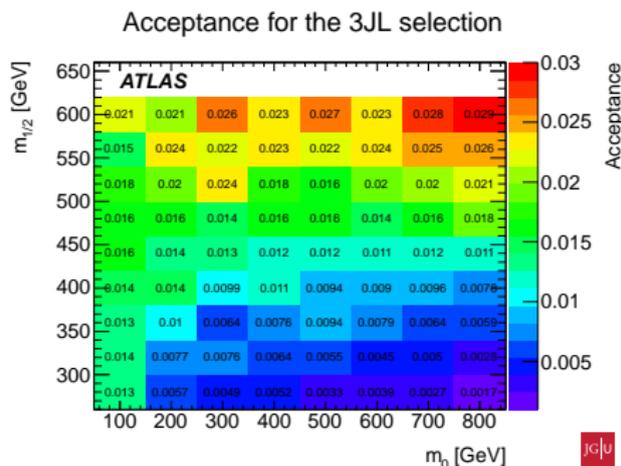
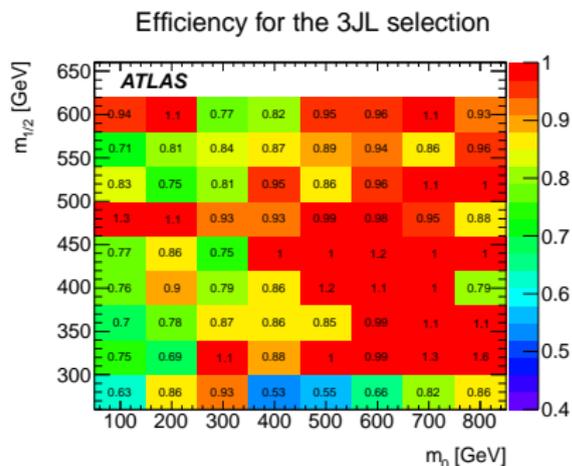
Breakdown of Systematic Uncertainties

Electron channel	3JL	3JT	4JL	4JT
Total statistical ($\sqrt{N_{\text{obs}}}$)	± 8.4	± 3.7	± 6.4	± 3.0
Total background systematic	± 30.2	± 7.4	± 17.9	± 3.7
Jet/ E_T energy resolution	± 5.9	± 0.5	± 4.2	± 0.8
Jet/ E_T energy scale	± 18.6	± 4.1	± 13.6	± 2.4
Lepton energy resolution	± 0.5	± 0.3	± 0.1	± 0.3
Lepton energy scale	± 1.1	± 0.3	± 0.4	± 0.5
b-tagging	< 0.1	< 0.1	< 0.1	< 0.1
MC stat. top	± 5.8	± 2.0	± 3.8	± 1.4
MC stat. W	± 4.4	± 2.3	± 2.2	± 1.3
QCD fake rate	< 0.1	< 0.1	< 0.1	< 0.1
QCD real rate	< 0.1	< 0.1	< 0.1	< 0.1
Theory top	± 15.9	± 2.1	± 9.8	± 1.2
Theory W	± 19.0	± 5.6	± 5.1	± 1.9
Pile-up	± 5.1	± 1.0	± 2.5	± 0.4
Muon channel	3JL	3JT	4JL	4JT
Total statistical ($\sqrt{N_{\text{obs}}}$)	± 7.6	± 3.3	± 7.1	± 2.7
Total background systematic	± 19.3	± 4.3	± 15.8	± 2.7
Jet/ E_T energy resolution	± 9.0	± 1.1	± 0.9	± 0.5
Jet/ E_T energy scale	± 7.0	± 0.2	± 9.1	± 1.6
Lepton energy resolution	< 0.1	< 0.1	< 0.1	< 0.1
Lepton energy scale	± 0.8	± 0.3	± 1.4	± 0.5
b-tagging	< 0.1	< 0.1	< 0.1	< 0.1
MC stat. top	± 5.4	± 2.1	± 4.0	± 1.4
MC stat. W	± 2.5	± 1.4	± 2.6	± 0.7
QCD fake rate	< 0.1	< 0.1	< 0.1	< 0.1
QCD real rate	< 0.1	< 0.1	< 0.1	< 0.1
Theory top	± 12.9	± 2.4	± 10.0	± 1.2
Theory W	± 8.8	± 2.7	± 7.3	± 0.7
Pile-up	± 3.5	± 0.8	± 2.7	± 0.3

R-parity violating SUSY

Bilinear R-parity violating model

- ▶ Bilinear R -parity violating terms in the superpotential introduce neutrino masses in an intrinsically supersymmetric way
- ▶ Phenomenological consequence: LSP is unstable and decays within the detector (e.g. $\tilde{\chi}_1^0 \rightarrow \ell^\pm W^\mp \rightarrow \ell^\pm q\bar{q}'$)
- ▶ Theoretical framework: mSUGRA + bRPV
 - ▶ $m_0 = 100, \dots, 800$, $m_{1/2} = 200, \dots, 600$
 - ▶ Fixed parameters: $\tan\beta = 10$, $A_0 = 0$, $\mu > 0$
- ▶ Limits only for $c\tau$ of LSP < 15 mm



Limits on bilinear R-Parity violating Model

- Observed and expected 95% CL exclusion limits in mSUGRA + bRPV parameter space

