ATLAS *R*-Parity Violating SUSY Searches

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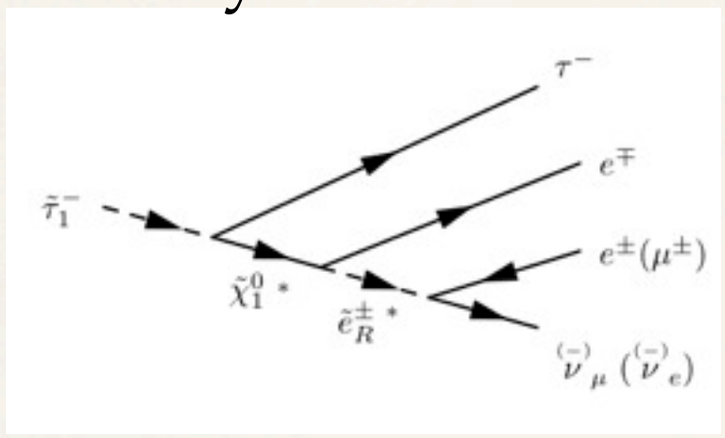
03-05-12

Outline

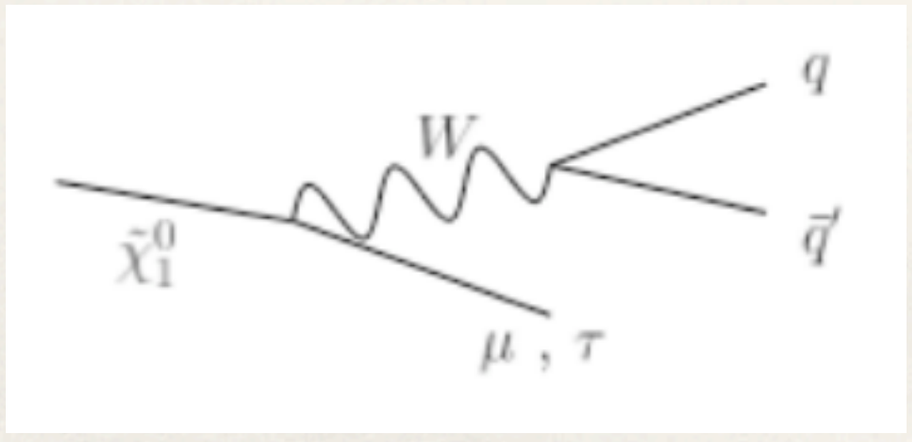
<u>Multilepton Search</u>

Generic analysis sensitive to many SUSY models



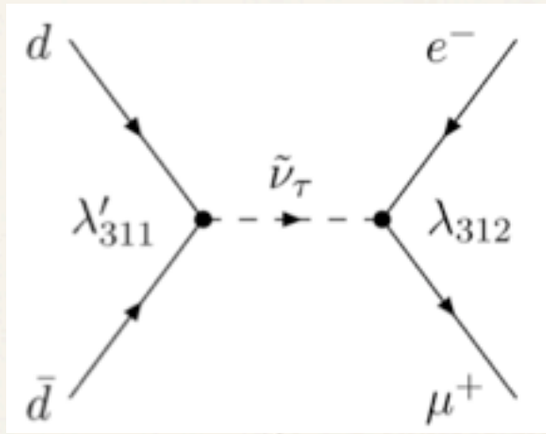
<u>Single Lepton Search</u>

Bi-linear RPV



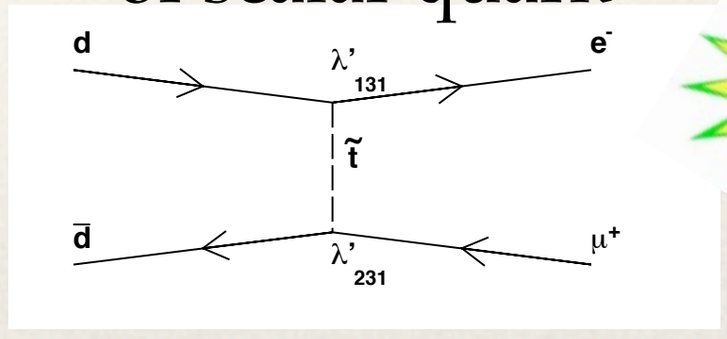
<u>e μ Resonance Search</u>

Neutral sneutrino decaying to e μ pair

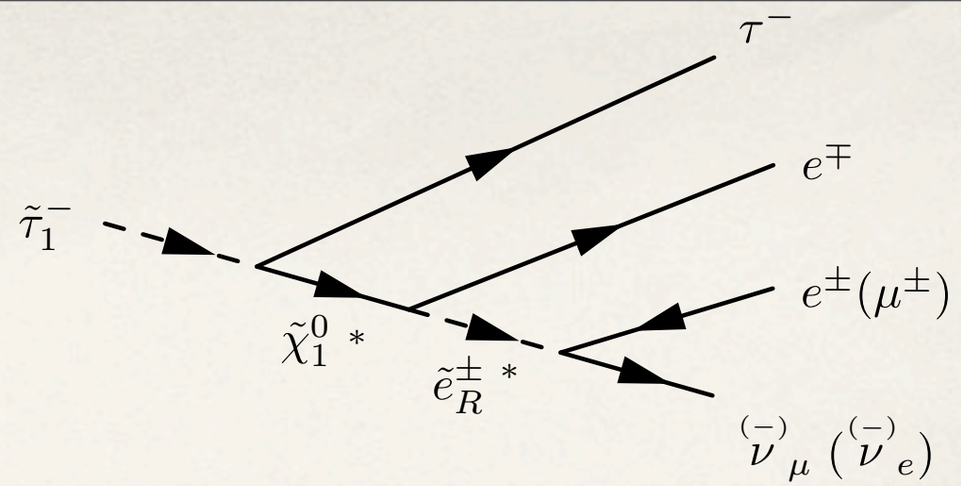


<u>e μ Continuum Search</u>

LFV t-channel exchange of scalar quark



Multilepton Search



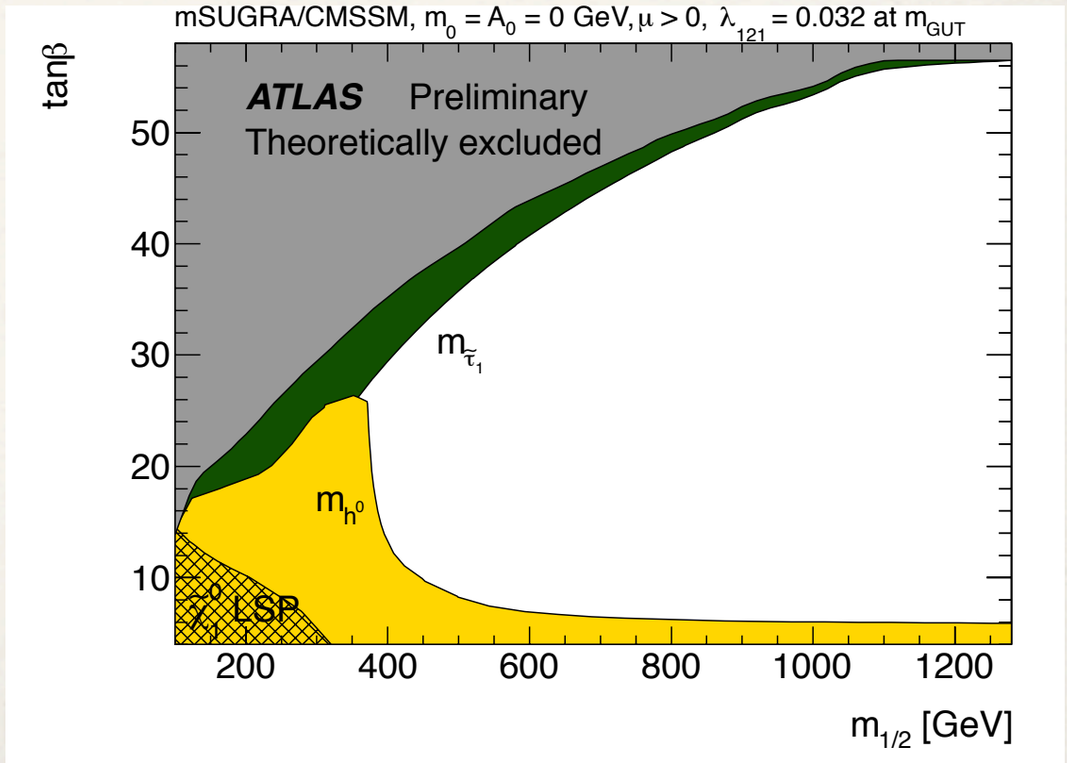
- "Constraining R-parity violating Minimal Supergravity with stau$_1$ LSP in a four lepton final state with missing transverse momentum."
  - ATLAS-CONF-2012-035
- mSUGRA/CMSSM model with R-parity violation described by 6 parameters
  - m_0, $m_{1/2}$, A_0, tan β, sign(μ), λ_{121}

	Mass [GeV]	Channel	BR	Channel	BR
$\tilde{\tau}_1^-$	148	$\tau^-\mu^\pm e^\mp \overset{(-)}{\nu}_e$	50.1%	$\tau^- e^\pm e^\mp \overset{(-)}{\nu}_\mu$	49.9%
$\tilde{e}_R^-$	161	$e^-\nu_\mu$	50.0%	$\mu^-\nu_e$	50.0%
$\tilde{\mu}_R^-$	161	$\tilde{\tau}_1^\pm\tau^\mp\mu^-$	99.9%		
$\tilde{\chi}_1^0$	162	$\tilde{\tau}_1^\pm\tau^\mp$	99.6%		

BC1 Scenario

$m_0 = A_0 = 0$, $\mu > 0$, $\lambda_{121} = 0.032$

Limits are set in tan β vs $m_{1/2}$ plane



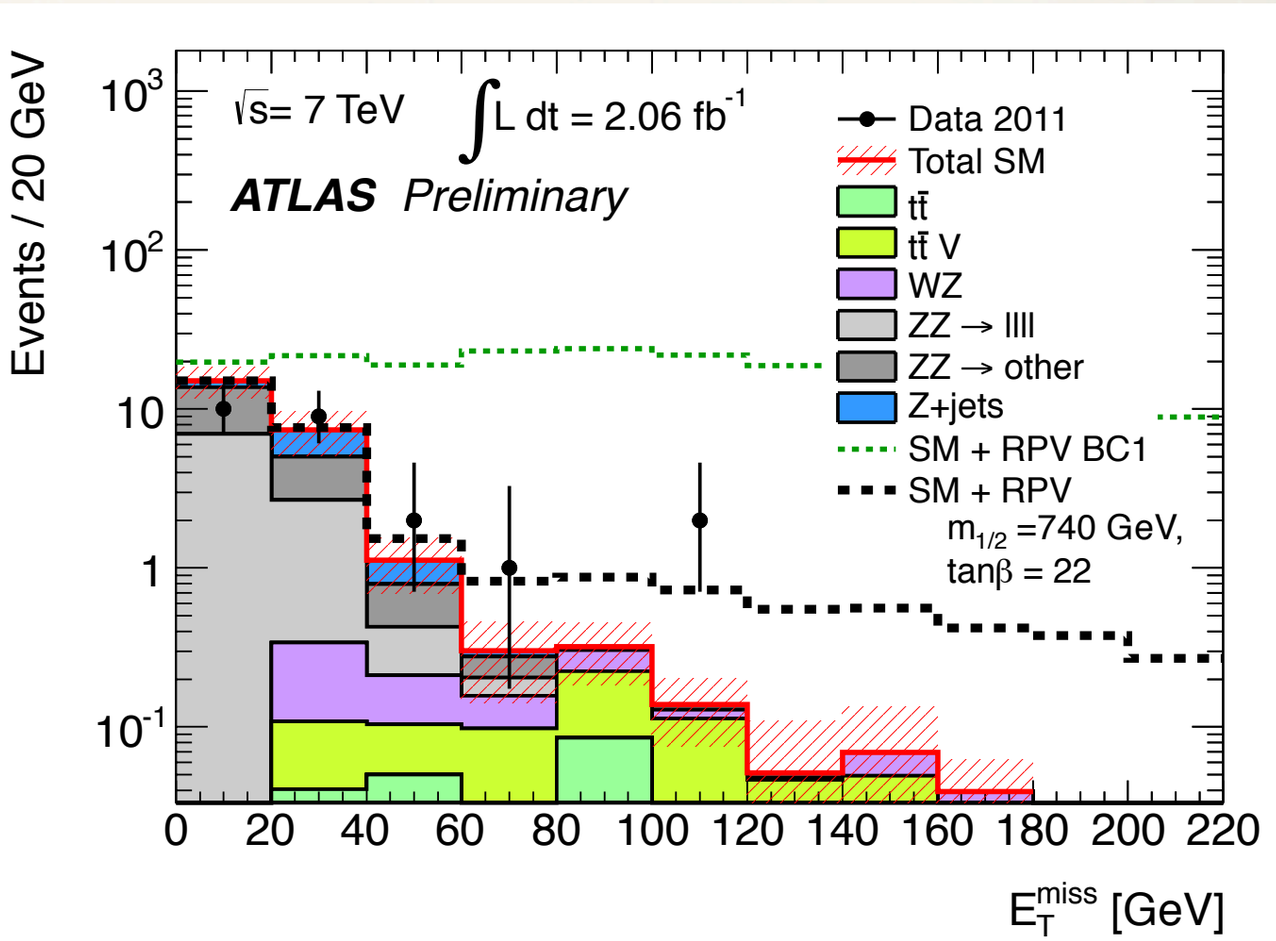
Previous excluded regions of phase space

Event Selection

- Analysis based on **2.06 fb^{-1}** of data using single lepton triggers

Object selection

- **Electrons**
  - E_T > 10 (15) GeV in central (barrel/endcap transition) region
  - Track isolation
- **Muons**
  - p_T > 10 GeV
  - Track and calorimeter isolation

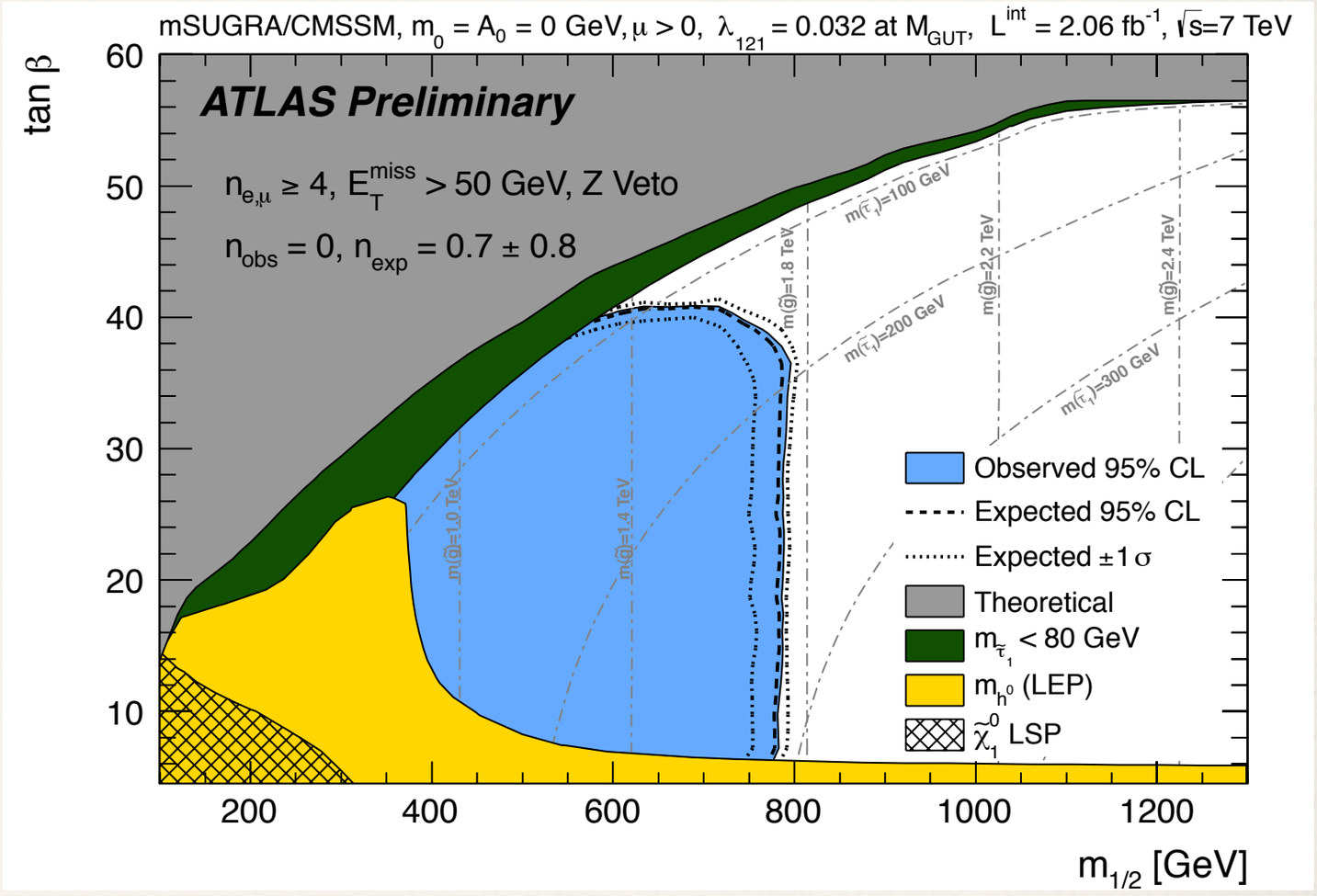


Signal Region 1: At least 4 leptons with $E_T^{Miss} > 50$ GeV

Signal Region 2: SR1 + $|m_{ll} - m_Z| < 10$ GeV for each l^+l^- pair

Results

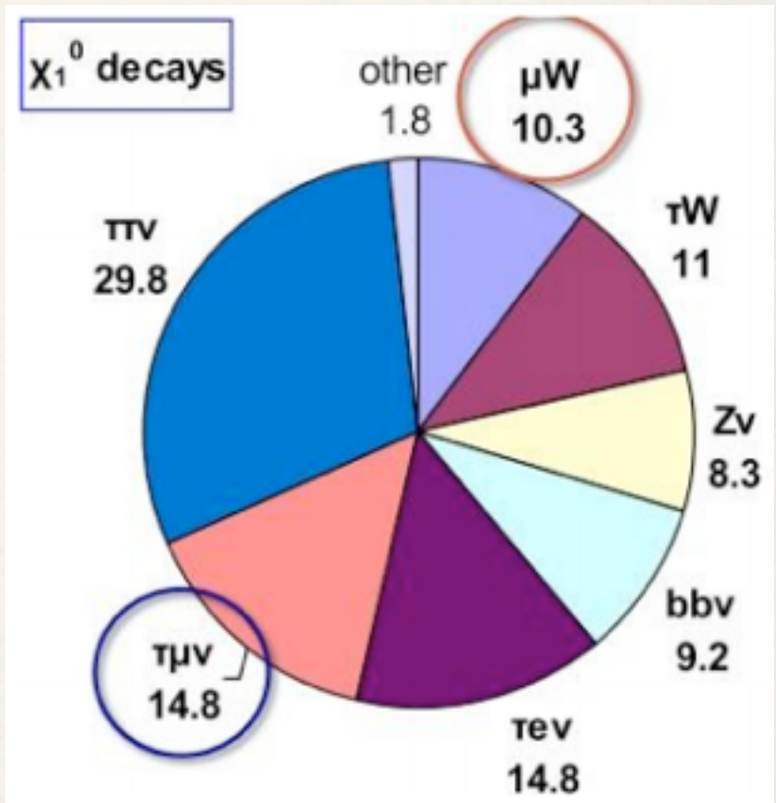
SR2	All
$t\bar{t}$	0.13±0.11
Single t	0±0.04
$t\bar{t}V$	0.07±0.04
ZZ	0.019±0.020
WZ	0.09±0.05
WW	0±0.015
$Z\gamma$	0±0.5
Z+(u, d, s jets)	0.33±0.67
Z+(c, b jets)	0.024±0.035
Drell-Yan	0±0.05
Σ SM	0.7±0.8
Data	0



- No excess observed
  - Use SR2 to set limits with profile likelihood procedure
  - For $\tan\beta < 40$, $m_{1/2}$ is excluded below 800 GeV ⇒ Gluino mass excluded below 1770 GeV

Single Lepton Search

- "Search for supersymmetry in final states with jets, missing transverse momentum and one isolated lepton in sqrt{s} = 7 TeV pp collisions using 1 fb^{-1} of ATLAS data."
  - Phys. Rev. D **85** 012006 (2012)
- mSUGRA/CMSSM with bilinear RPV
  - Non-vanishing vacuum expectation value for sneutrinos induces mixing between sneutrino and neutrino
    - ➡ Possible explanation for neutrino mass / mixing
  - Long cascade decay, but with neutralino decaying



Event Selection

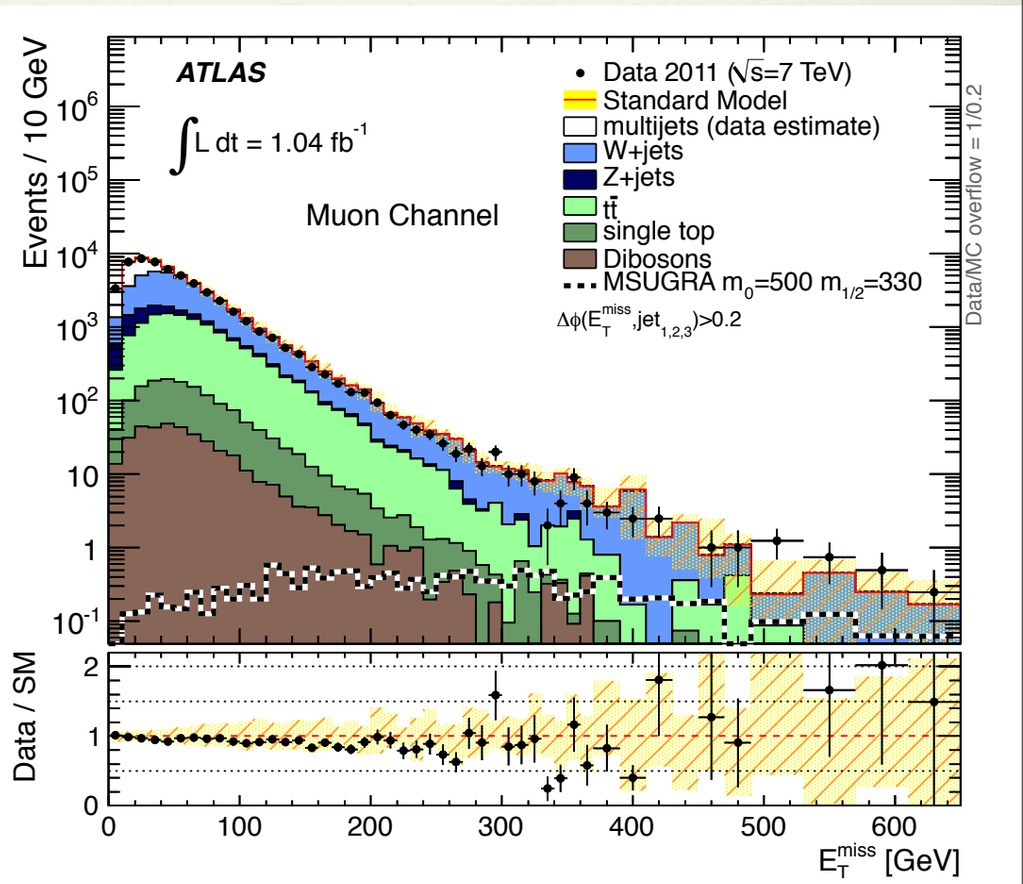
- Reinterprets single lepton analysis optimized for RPC using **1.04 fb^{-1}** of data
- Common event selection
  - Exactly 1 isolated muon with $p_T > 20$ GeV
  - Veto events with any electrons with $p_T > 20$ GeV to avoid overlap with other analyses
  - E_T^{Miss} separated from jets with $\Delta\phi > 0.2$

Four signal and two control regions are defined

Selection	Signal Regions				Control Regions	
	3JL	3JT	4JL	4JT	3J	4J
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		≥ 3	≥ 4
Leading jet p_T (GeV)	60	80	60	60	60	60
Subsequent jets p_T (GeV)	25	25	25	40	25	25
$\Delta\phi(\vec{jet}_i, \vec{E}_T^{miss})$	[> 0.2 (mod.π)] for all 3 (4) jets					
m_T (GeV)	> 100				40 < m_T < 80	
E_T^{miss} (GeV)	> 125	> 240	> 140	> 200	30 < E_T^{miss} < 80	
E_T^{miss}/m_{eff}	> 0.25	> 0.15	> 0.30	> 0.15	–	–
m_{eff} (GeV)	> 500	> 600	> 300	> 500	> 500	> 300

$$m_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{miss} \cdot (1 - \cos(\Delta\phi(\vec{\ell}, \vec{E}_T^{miss})))}$$

$$m_{eff} = p_T^{\ell} + \sum_{i=1}^{3(4)} p_T^{jet_i} + E_T^{miss}$$

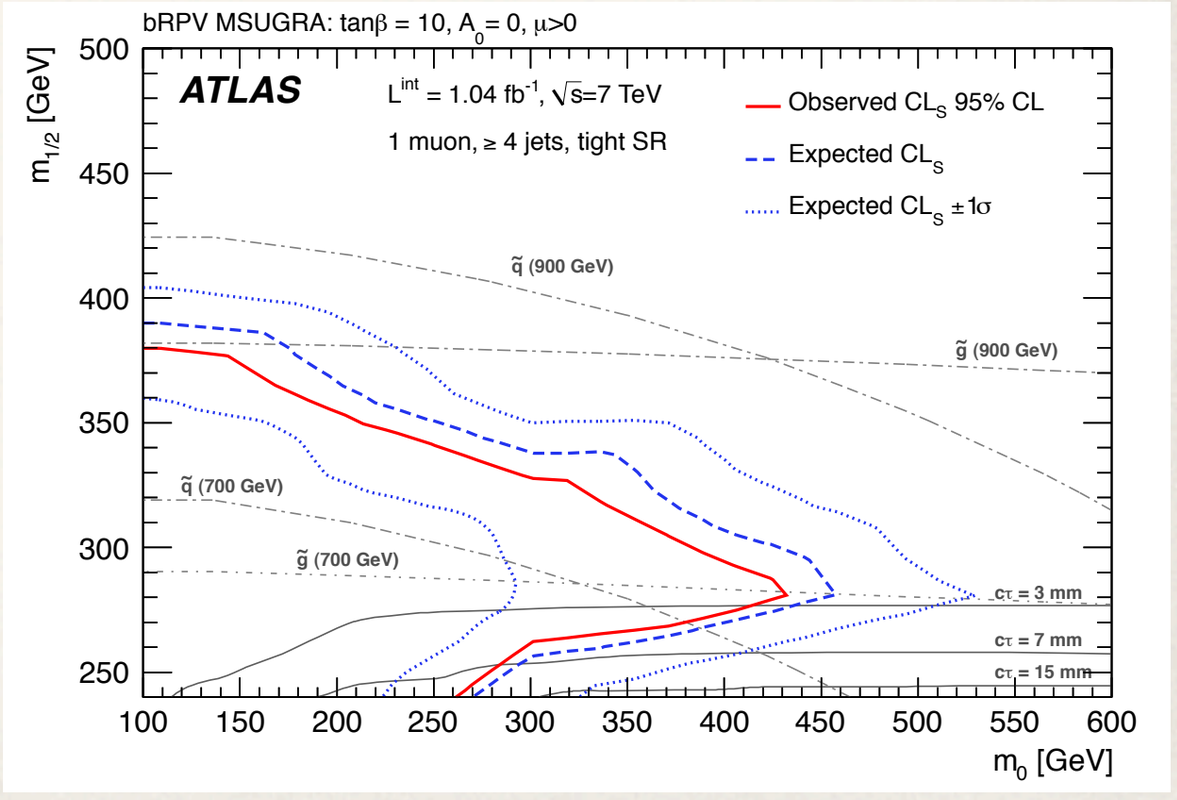


Background and Results

- MC simulation prediction of backgrounds in signal regions validated in control regions
- Multijet background estimated from data
- Final determination of background done through simultaneous likelihood fit of control regions to account for cross contamination
- Systematic uncertainties dominated by theoretical uncertainties (20 – 30%)

Muon channel		
Signal region	Observed	Fitted background
3JL	58	64 ± 19
3JT	11	13.9 ± 4.3
4JL	50	53 ± 16
4JT	7	6.0 ± 2.7

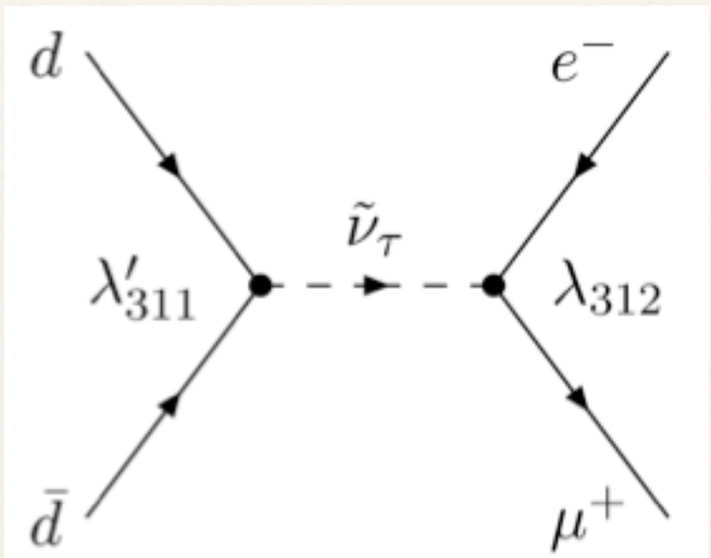
No excess observed ⇒ set limits in the 4JT SR for mSUGRA bRPV



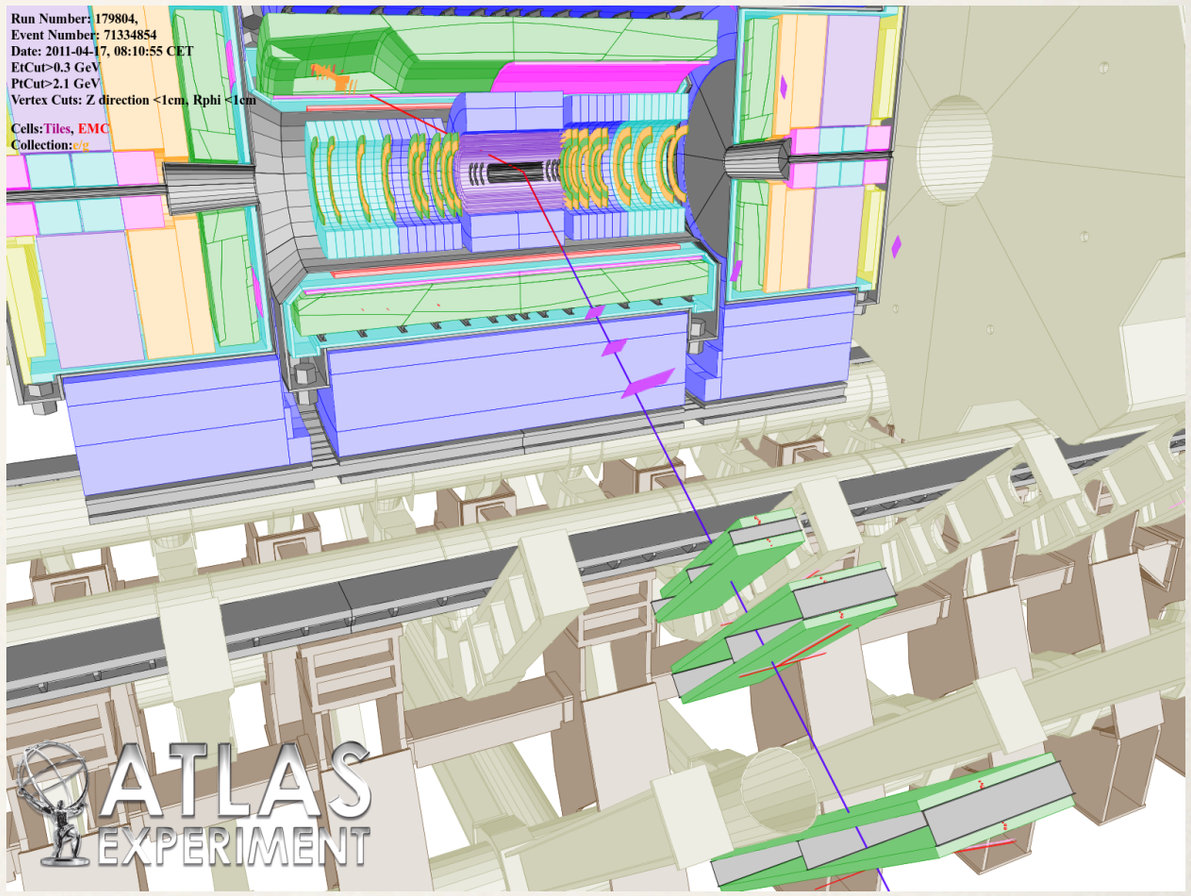
Limits not set for $m_{1/2} < 240$ GeV (ct of LSP > 15 mm)

e μ Resonance Search

- "Search for a heavy neutral particle decaying into an electron and a muon using 1 fb−1 of ATLAS data"
  - Eur. Phys. J. C **71**, 1809 (2011)
- Clean detector signature and small SM background



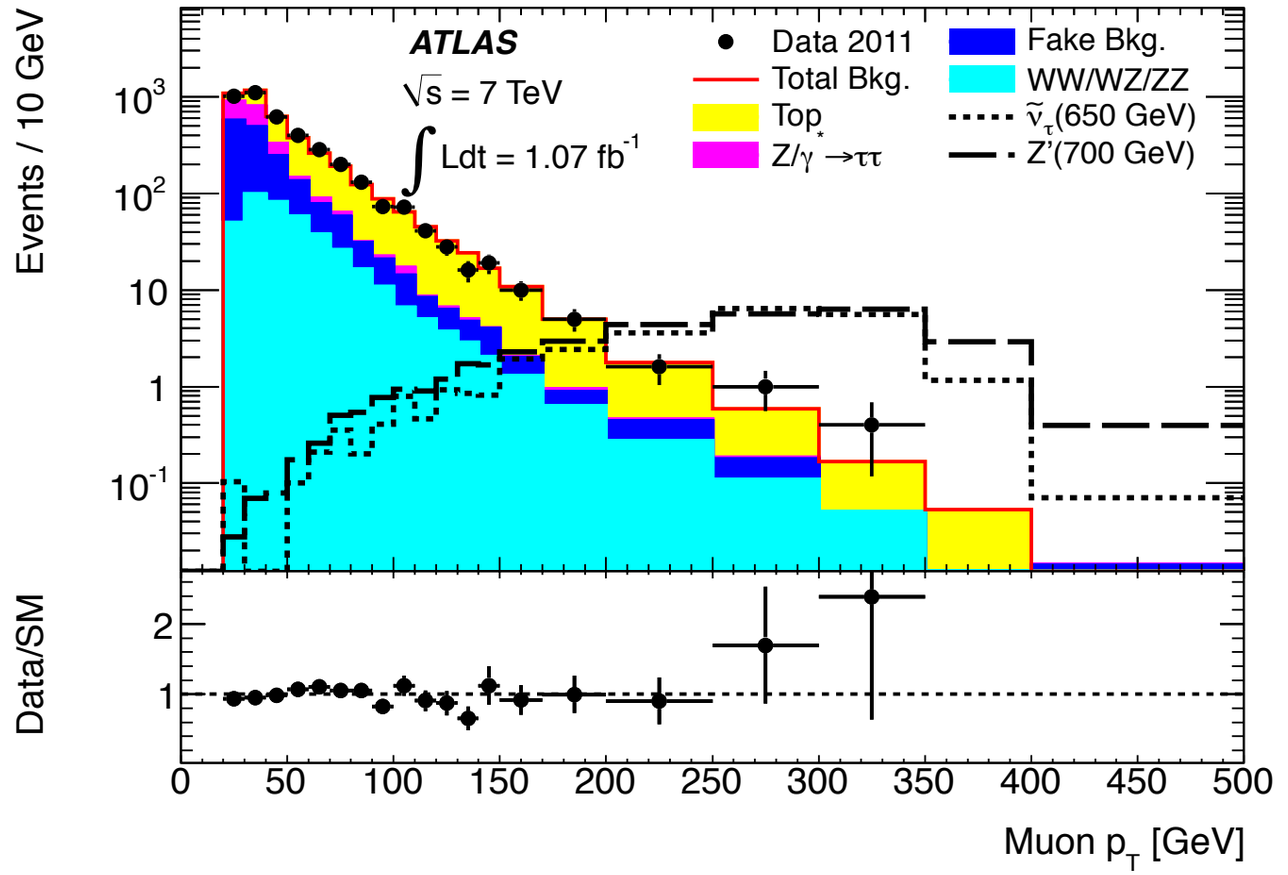
Search also sensitive to LFV Z′

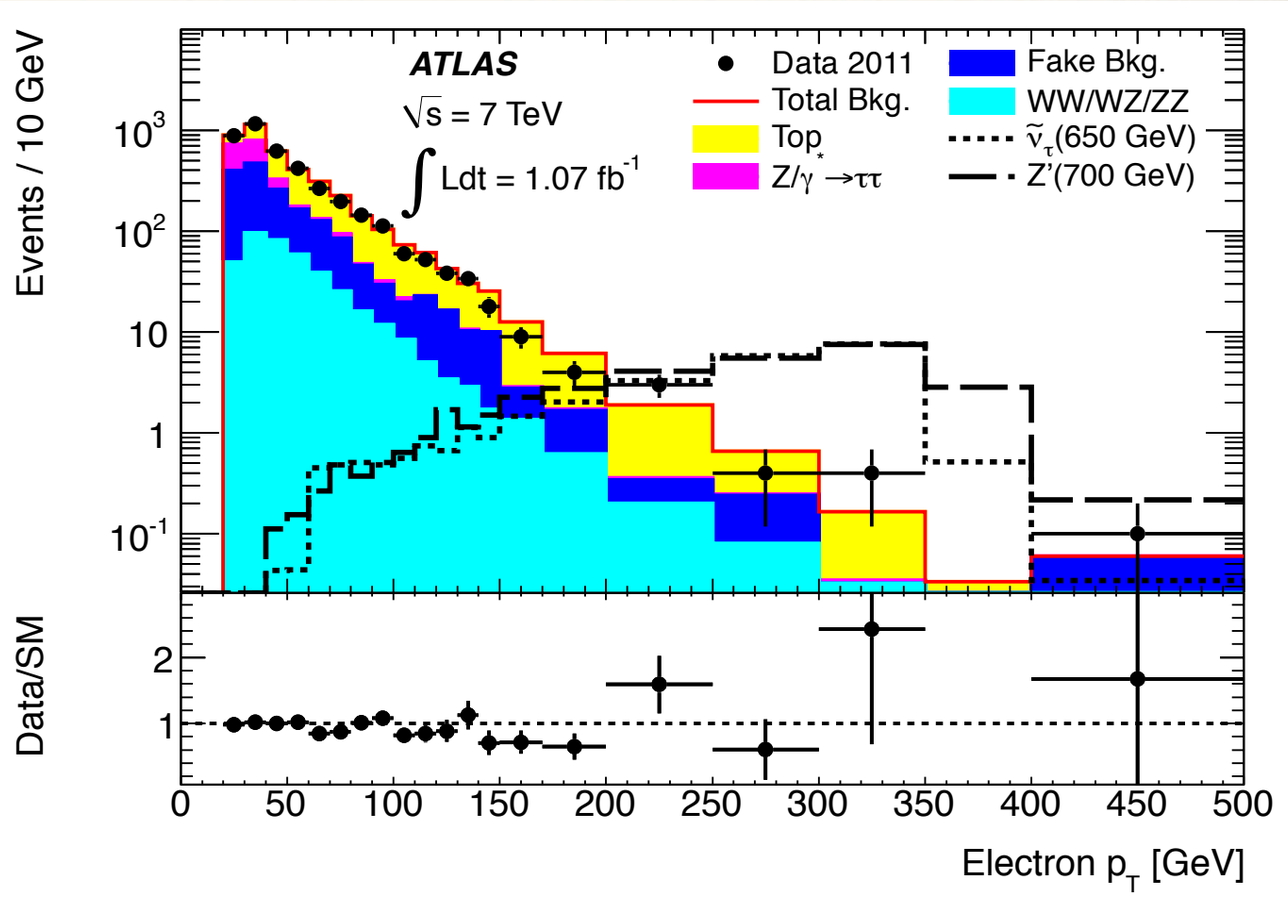


Event display of highest invariant mass e μ pair

Event Selection

- Analysis based on **1.04 fb^{-1}** of data
- Passes single lepton (e or μ) trigger
  - Efficiency 100%
- At least one primary vertex with at least 3 tracks whose pT > 500 MeV
- Require exactly 1 e and 1 μ with:
  - Opposite charge
  - pT > 25 GeV
  - η within fiducial region of the detector
  - Isolated





Backgrounds and Systematics

- Physics Backgrounds
  - Drell Yan ($Z/\gamma^* \rightarrow \tau\tau$)
  - $t\bar{t}$
  - Single Top (*Wt*)
  - Diboson (*WW, ZZ, WZ*)
- Fake Background
  - Multijet
  - W/Z + jets
  - W/Z + γ

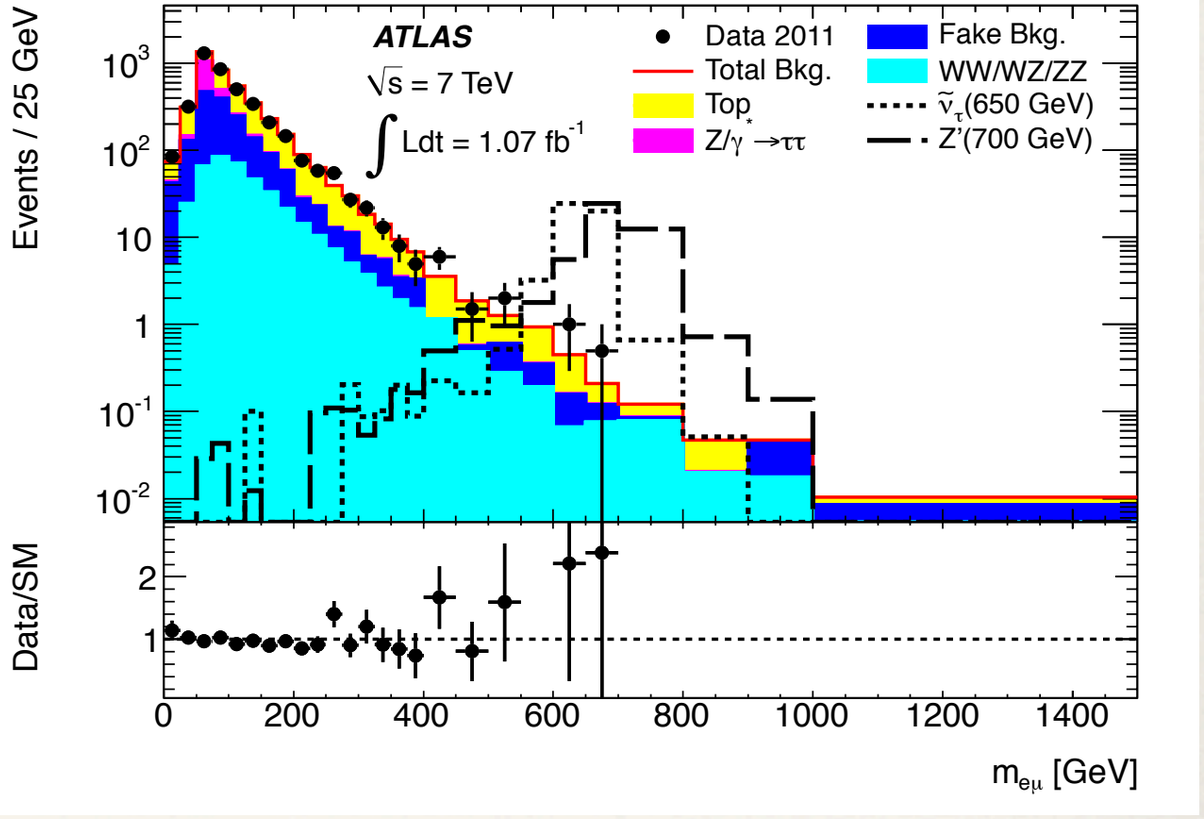
- All physics backgrounds modeled with Monte Carlo simulation
  - Lepton identification efficiencies, energy scales and resolutions are corrected to match data
- QCD and W/Z + jets are estimated using a data driven method
- W/Z + γ modeled with MC

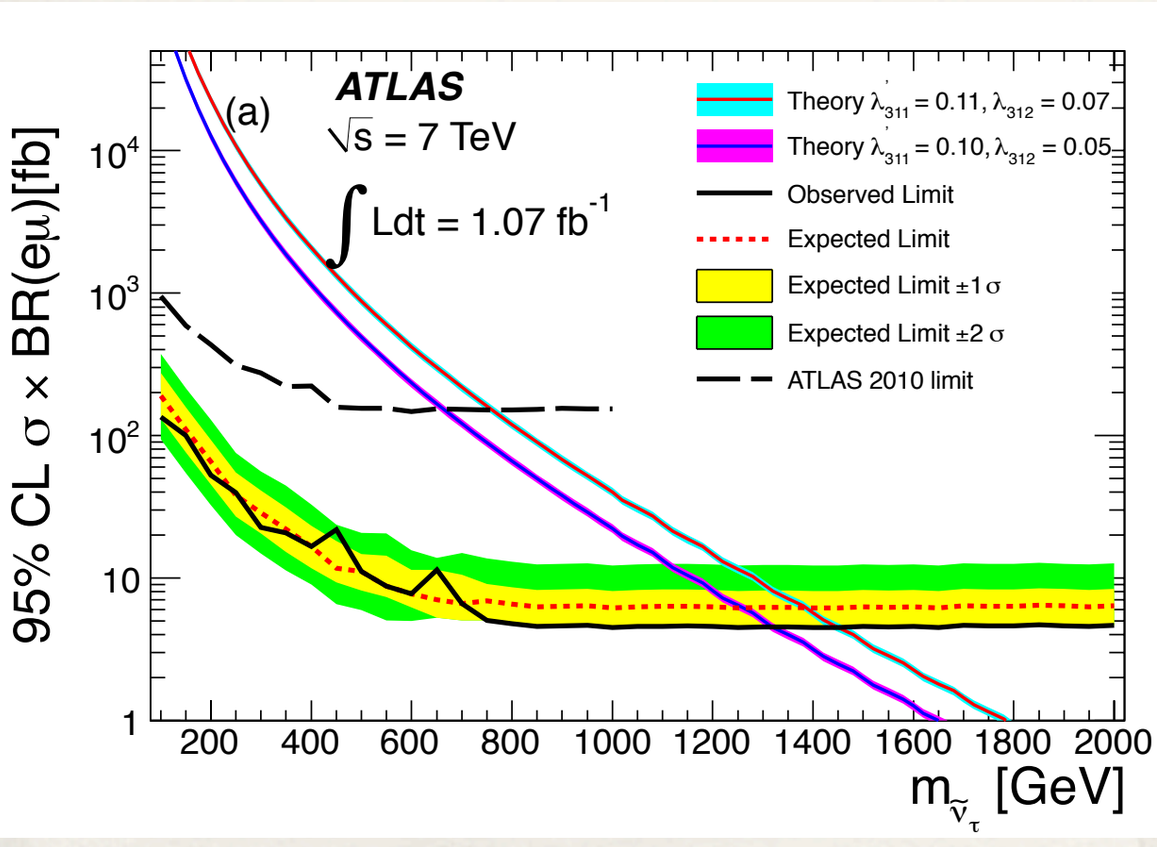
Source	Fractional uncertainty (%)	Relations with backgrounds	Relation with signal
Luminosity	3.7%	related to all bkg samples	related
Trigger efficiency	1%	related to all bkg samples	related
Electron reco and ID efficiency	2%	related to all bkg samples	related
Muon reco and ID efficiency	1%	related to all bkg samples	related
$Z/\gamma^* \rightarrow \tau\tau$ cross section	5%	related to $Z/\gamma^* \rightarrow \tau\tau$ sample	unrelated
ZZ cross section	5%	related to ZZ sample	unrelated
WW cross section	7%	related to WW sample	unrelated
WZ cross section	7%	related to WZ sample	unrelated
$t\bar{t}$ cross section	10%	related to $t\bar{t}$ sample	unrelated
Wt cross section	9%	related to Wt sample	unrelated
$W\gamma$ cross section	10%	related to $W\gamma$ sample	unrelated
$Z\gamma$ cross section	10%	related to $Z\gamma$ sample	unrelated

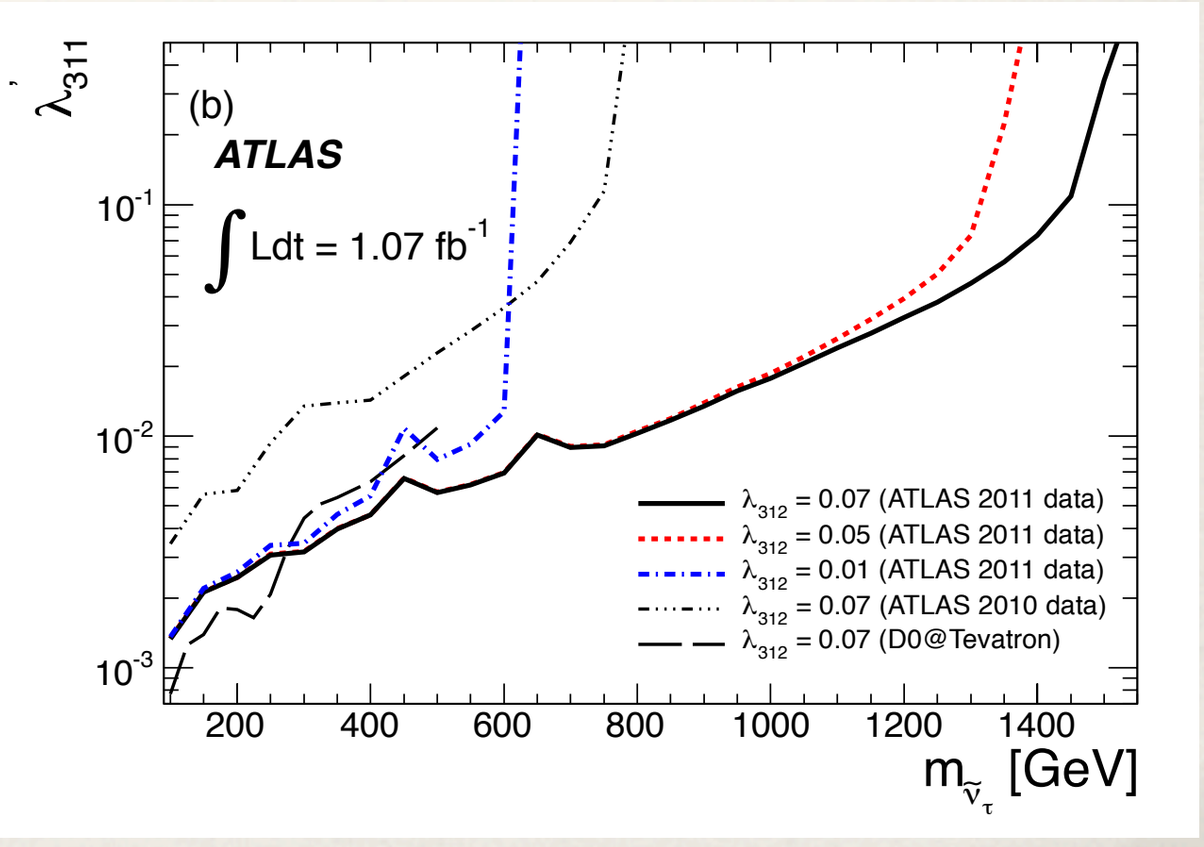
Results

Process	Number of events
$t\bar{t}$	1580 ± 170
Jet fake	1180 ± 120
$Z/\gamma^* \to \tau\tau$	750 ± 60
WW	380 ± 31
Single top	154 ± 16
$W/Z + \gamma$	82 ± 13
WZ	22.4 ± 2.3
ZZ	2.48 ± 0.26
Total background	4150 ± 250
Data	4053

- SM prediction agrees with data
- Limits are set on cross section times branching ratio and coupling as a function of snuetrino mass
- Using Bayesian analysis with flat prior

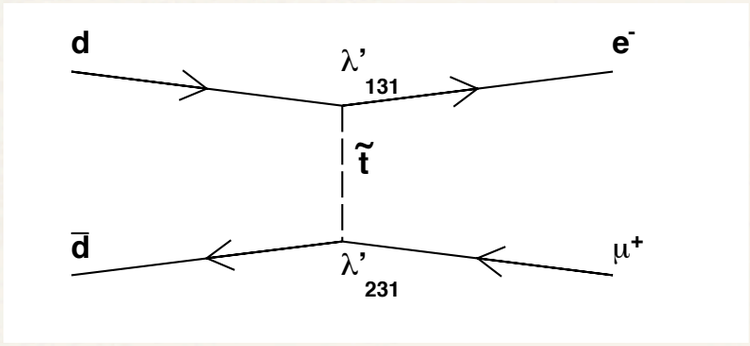






e μ Continuum Search

- An RPV Superpotential can also produce LFV t-channel exchange



- Differential cross section:

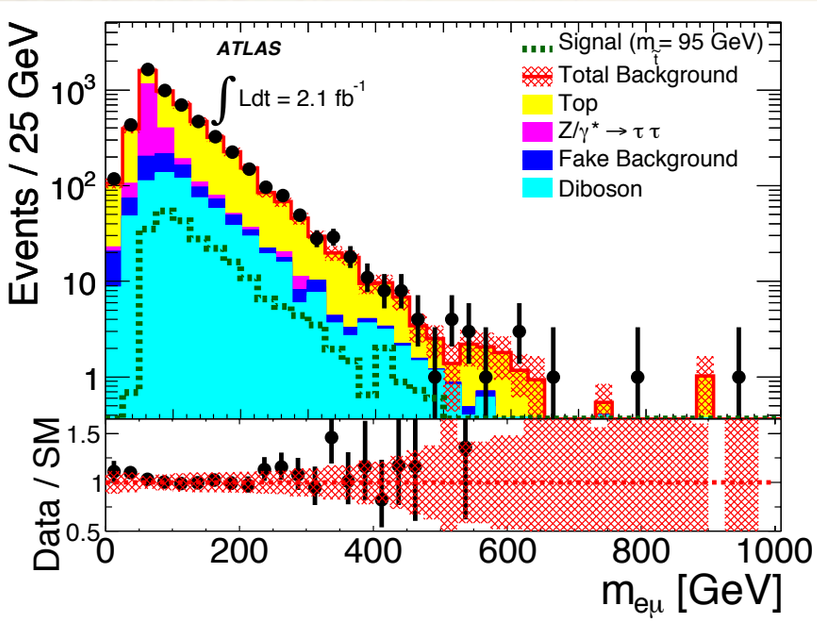
$$\frac{d\sigma}{dt} = \frac{|\lambda'_{131}\lambda'_{231}|^2 \hat{t}^2}{64 N_c \pi \hat{s}^2 \left(\hat{t} - m_{\tilde{t}}^2\right)^2}$$

- Dominated by the lightest up-like squark
- Also diagrams with the $d/\bar{d}$ independently replaced by $s/\bar{s}$
  - Cross section has same form but involves different couplings

- Analysis assumptions:
  - Scalar top is the lightest up-like squark
    - Current limit ~95 GeV
    - $|\lambda'_{131}\lambda'_{231}| = |\lambda'_{132}\lambda'_{232}| = 0.05$
    - All other couplings negligible
- **t-channel exchange**
  - ➡ **No peak in invariant mass spectrum**

Event Preselection

- Analysis based on **2.08 fb^{-1}**
- Same e and μ definition as resonance search
  - **Except tighter isolation requirements**



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Jet fake	1180 ± 120
$Z/\gamma^* \to \tau\tau$	750 ± 60
WW	380 ± 31
Single top	154 ± 16
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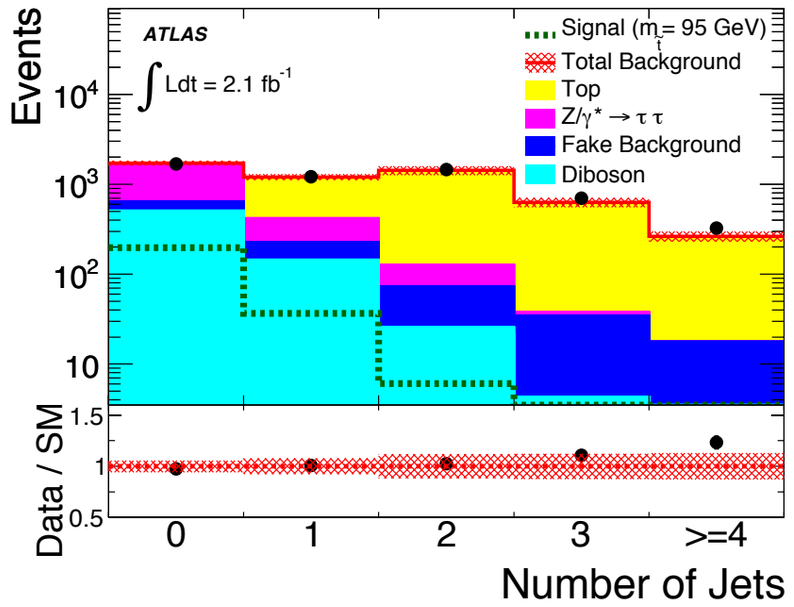
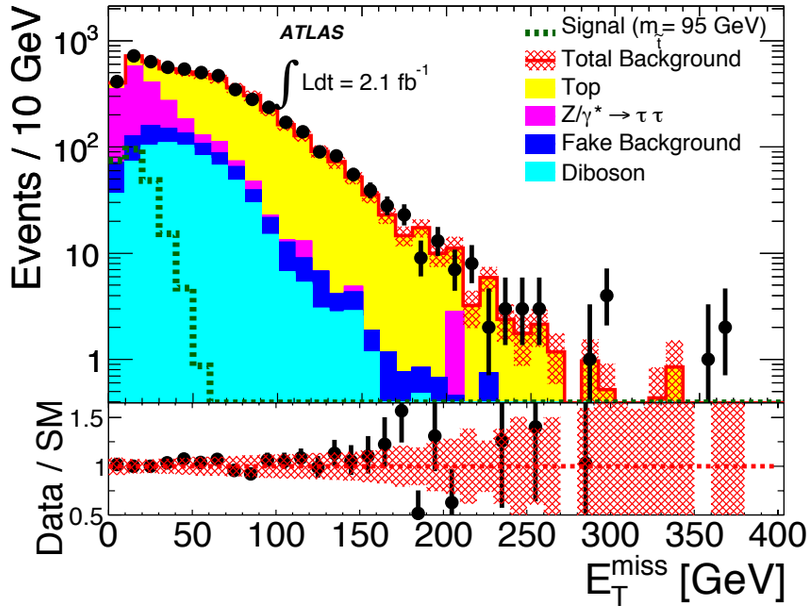
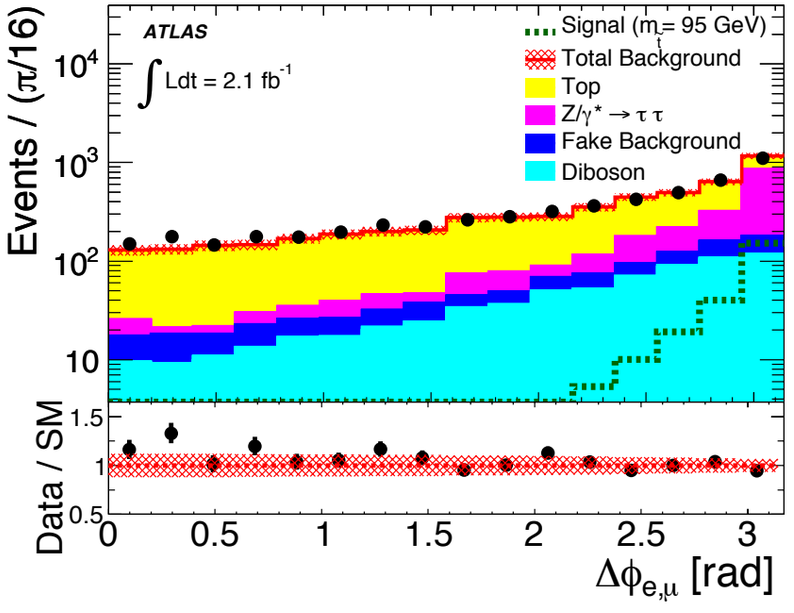
WZ	22.4 ± 2.3
ZZ	2.48 ± 0.26
Total background	4150 ± 250
Data	4053





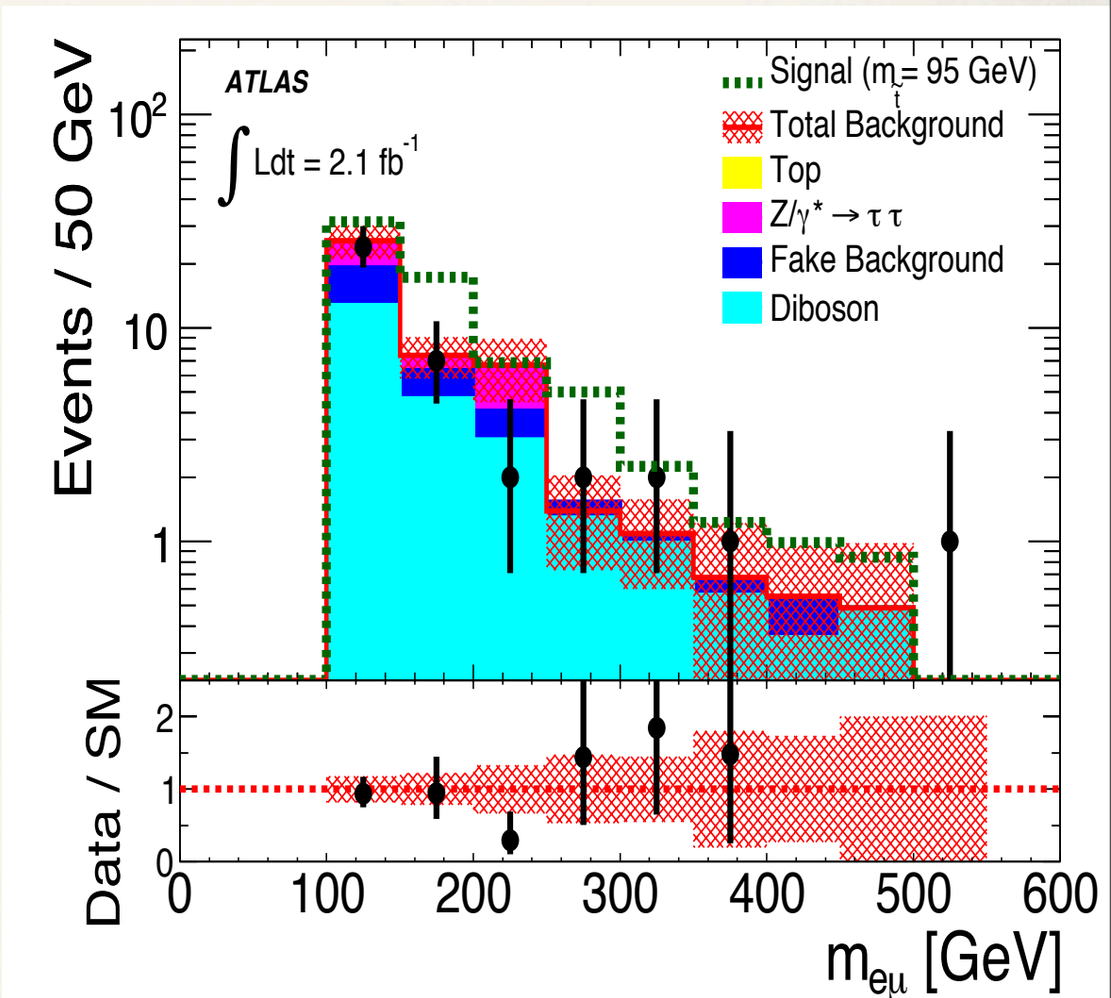


- Analysis uses 3 additional variables to separate signal from background:
  - Missing transverse energy, jet multiplicity, and angular separation

Final Selection

- Selection requirements:
  - No jets
  - $E_T^{miss} < 25$ GeV
  - $m_{e\mu} > 100$ GeV
  - $\Delta\phi_{e\mu} > 3.0$

Process	Final selection
WW	23.4 ± 3.3
$Z/\gamma^* \to \tau\tau$	10 ± 4
Fake background	9.6 ± 1.9
WZ	0.76 ± 0.31
$t\bar{t}$	0.25 ± 0.17
Single top	0.22 ± 0.20
$W/Z + \gamma$	0.04 ± 0.04
ZZ	0.042 ± 0.028
Total background	44 ± 6
Data	39
Signal ($m_{\tilde{t}} = 95$ GeV)	67 ± 5
Signal ($m_{\tilde{t}} = 500$ GeV)	1.28 ± 0.08
Signal ($m_{\tilde{t}} = 1000$ GeV)	0.124 ± 0.008

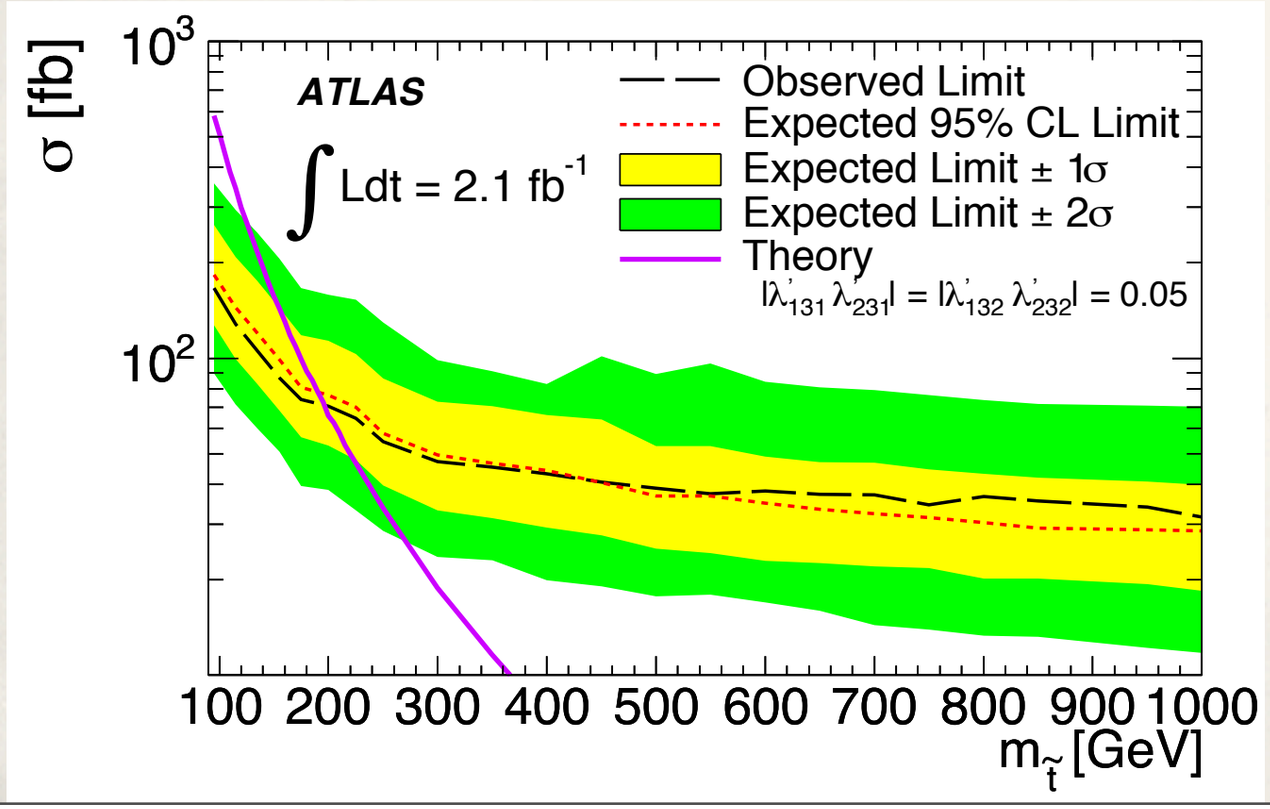


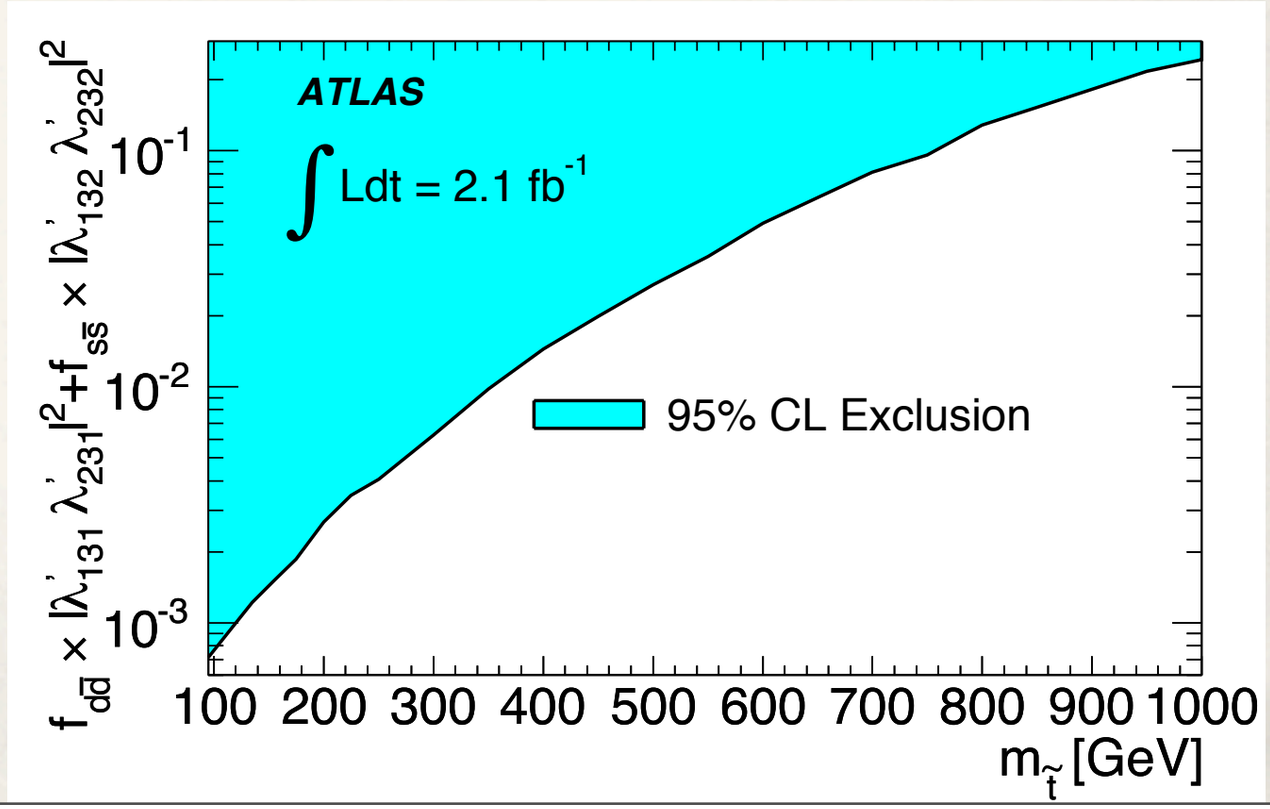
- No excess observed
  - Limits set with CLs method, using $m_{e\mu}$ distribution and a binned likelihood ratio test statistic to take shape into account

Limits and Systematics

- Limits set on production cross section as a function of scalar top mass
- Two-dimensional limits also placed in the plane of the PDF weighted sum of couplings vs scalar top mass

Source	Fractional Uncertainty	Applicable To
Luminosity	3.7%	Signal + All Background
Trigger	1%	Signal + All Background
Electron reco and ID efficiency	2%	Signal + MC Background
Muon reco and ID efficiency	1%	Signal + MC Background
Jet energy scale	3.6%	Signal + MC Background
Electron energy smearing	0.9%	Signal + MC Background
Muon momentum smearing	0.3%	Signal + MC Background
Theoretical cross section	5% - 10%	MC Background Only
MET Uncertainty	12.0%	MC Background Only
Data driven background	15.0%	Instrumental Only





Summary and Conclusion

- **Four searches for R-parity violating SUSY with ATLAS presented in this talk**

  1. Searches for bRPV in a one lepton analysis

  2. Searches for Stau LSP decays in the CMSSM in a four lepton analysis

  3. Searches for resonant production of a Sneutrino decaying into eμ pairs

  4. Searches for continuum production of eμ pairs through a t-channel exchange of a scalar quark

- **No deviations from SM expectations found**

  ➡ Limits set on a variety of SUSY parameter space

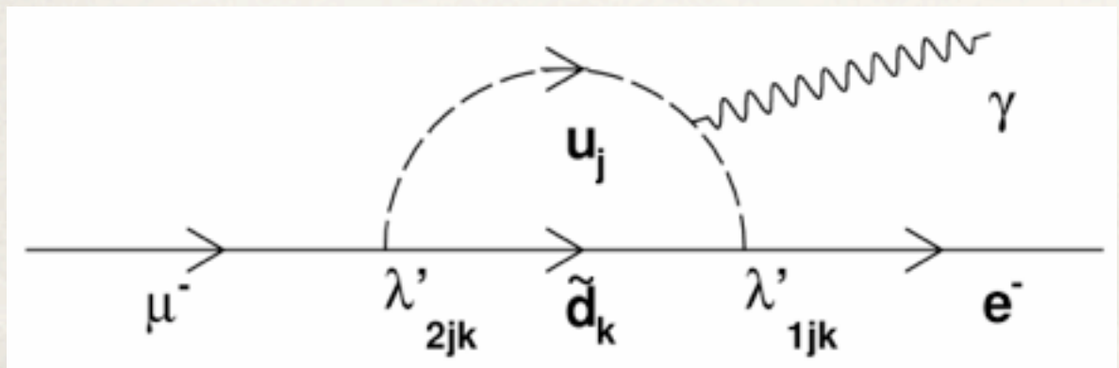
- **RPV Susy introduces 48 new terms in addition to MSSM**

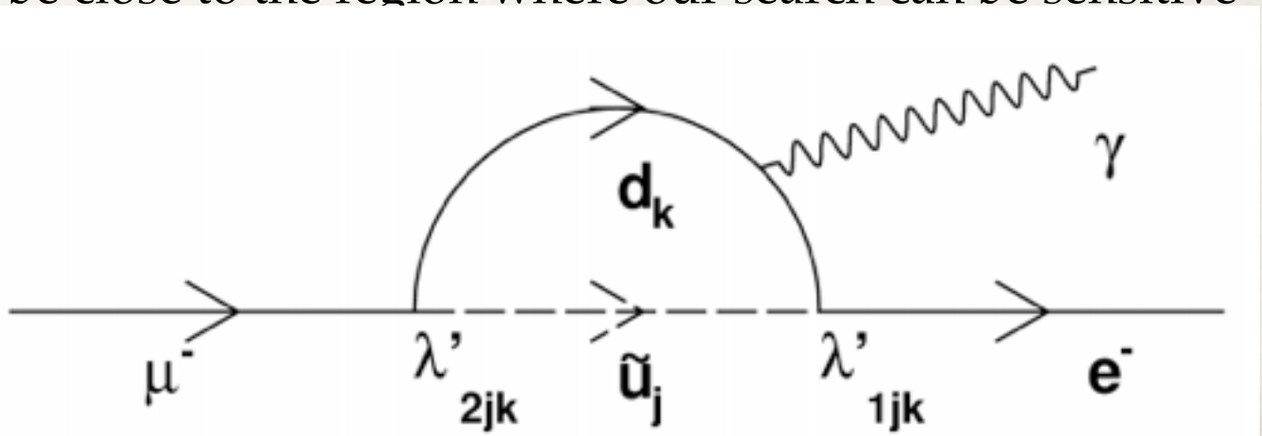
  ➡ Many more searches to be performed!

Backup Slides

Limits from $\mu \rightarrow e\,\gamma$

- To derive the limit $|\lambda'_{23k}\lambda^*_{13k}|<0.002$, the intermediate states are assumed to be d-scalar top and t-scalar down, and m_(scalar d)=300 GeV
- If SUSY is right, m(scalar d) are likely higher than 300 GeV
  - In general, once the squark mass > top mass, the limits weaken as the squark mass is increased
- Destructive interference between different quark-squark states are likely to exist given similar amplitude of masses and couplings which is ignored in the above limit setting
- Effects from other intermediate states are ignored
- These effects are not likely to reduce the limits by several orders of magnitude, but a reduction of one or two orders of magnitude is possible, which will be close to the region where our search can be sensitive





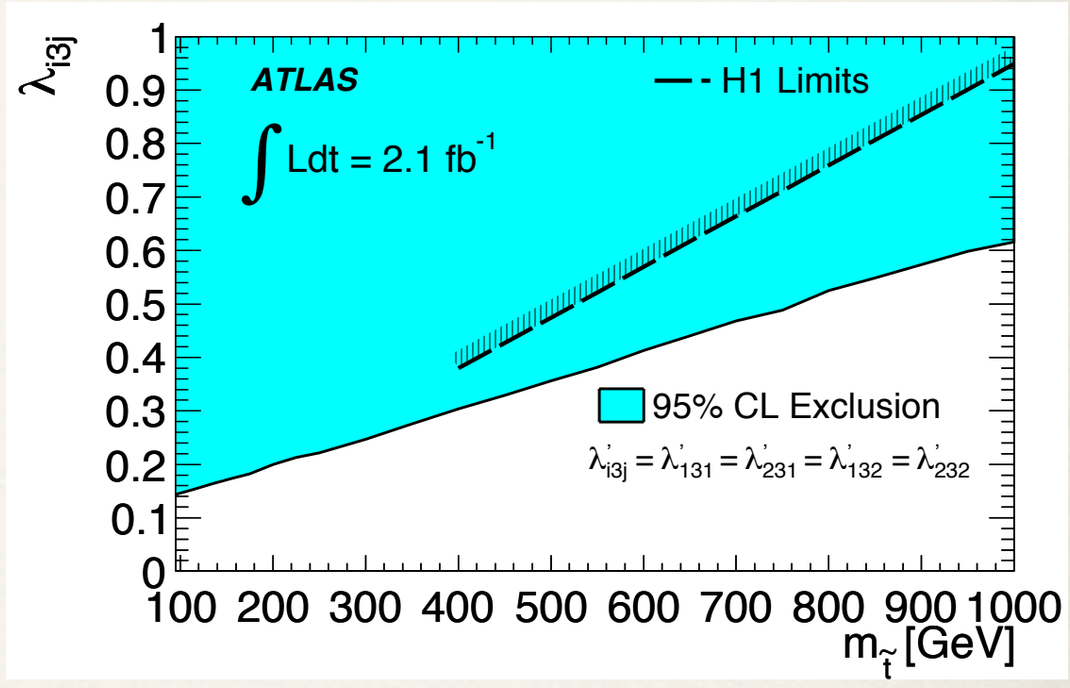
Limits from Leptoquarks

- Similar limits can be extracted from high energy searches at HERA

- The process ep → μX is assumed to be mediated by a LFV leptoquark

- Below HERA center of mass (~300 GeV), where s-channel production is allowed, stringent limits are placed

  - These limits depend on assumptions of branching ratios



- At high mass, where limits depend on u-channel exchange, limits are comparable to results achieved here

Limits from Z → eμ

- The limit from Z → eμ is $|\lambda'23k'\lambda^*13k|<0.065$ from table 2, R. Barbier et al. Phys. Rep. 420, 1 (2005)
- Some Feynman diagrams shown below
- Other Feynman diagrams exist with leptons and sleptons in the intermediate state
- Similar situations with e limits: assuming specific squark masses and couplings, dominance of one particular couplings and ignore destructive interference effects
- Limits obtained are close to our sensitivity