ATLAS *R*-Parity Violating SUSY Searches

Dr. Daniel J. Pomeroy
Brandeis University

03-05-12

R-parity Violating (RPV) SUSY

- Most SUSY models assume R-parity ($=(-1)^{3(B-L)+2S}$) conservation
- There is no experimental evidence preventing an RPV superpotential:

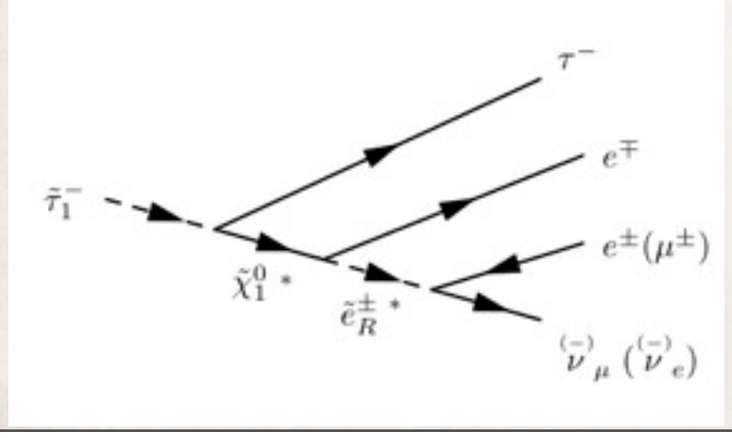
$$W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

- Proton decay experiments only forbids <u>simultaneous</u> violation of lepton flavor and baryon number
- RPV SUSY could explain neutrino flavor mixing

ATLAS RPV SUSY Searches

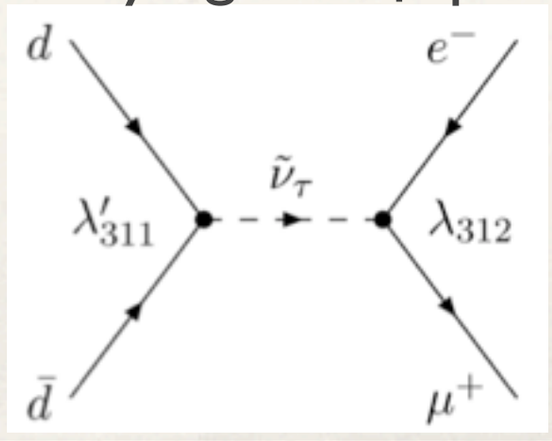
<u>Multilepton Search</u>

Generic analysis sensitive to many SUSY models



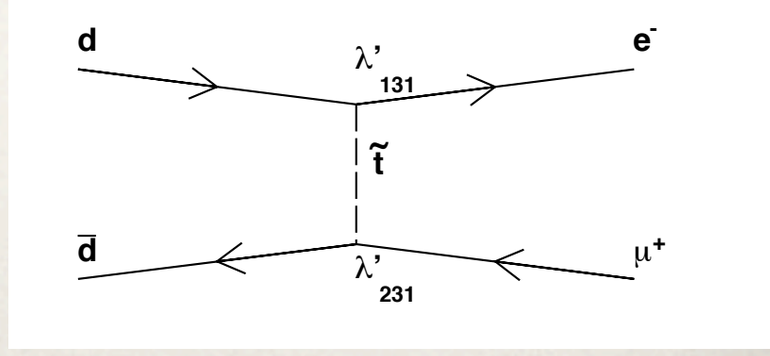
<u>e μ Resonance Search</u>

Neutral sneutrino decaying to e μ pair

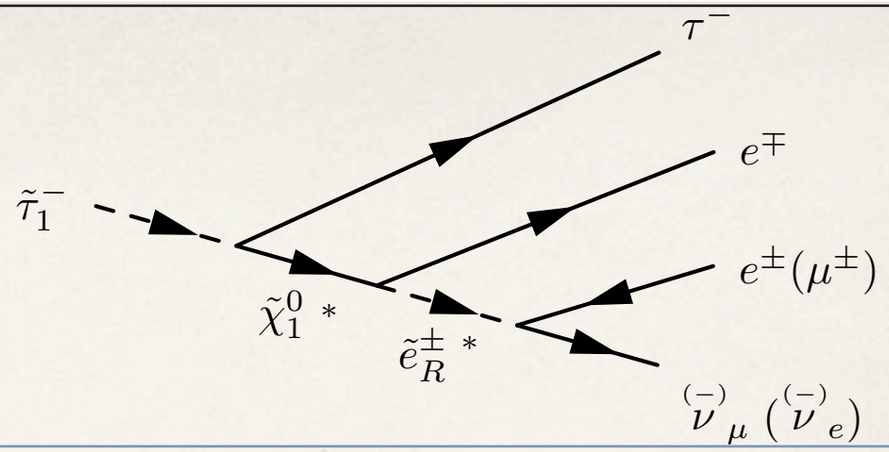


<u>e μ Continuum Search</u>

LFV t-channel exchange of scalar quark



Multilepton Search



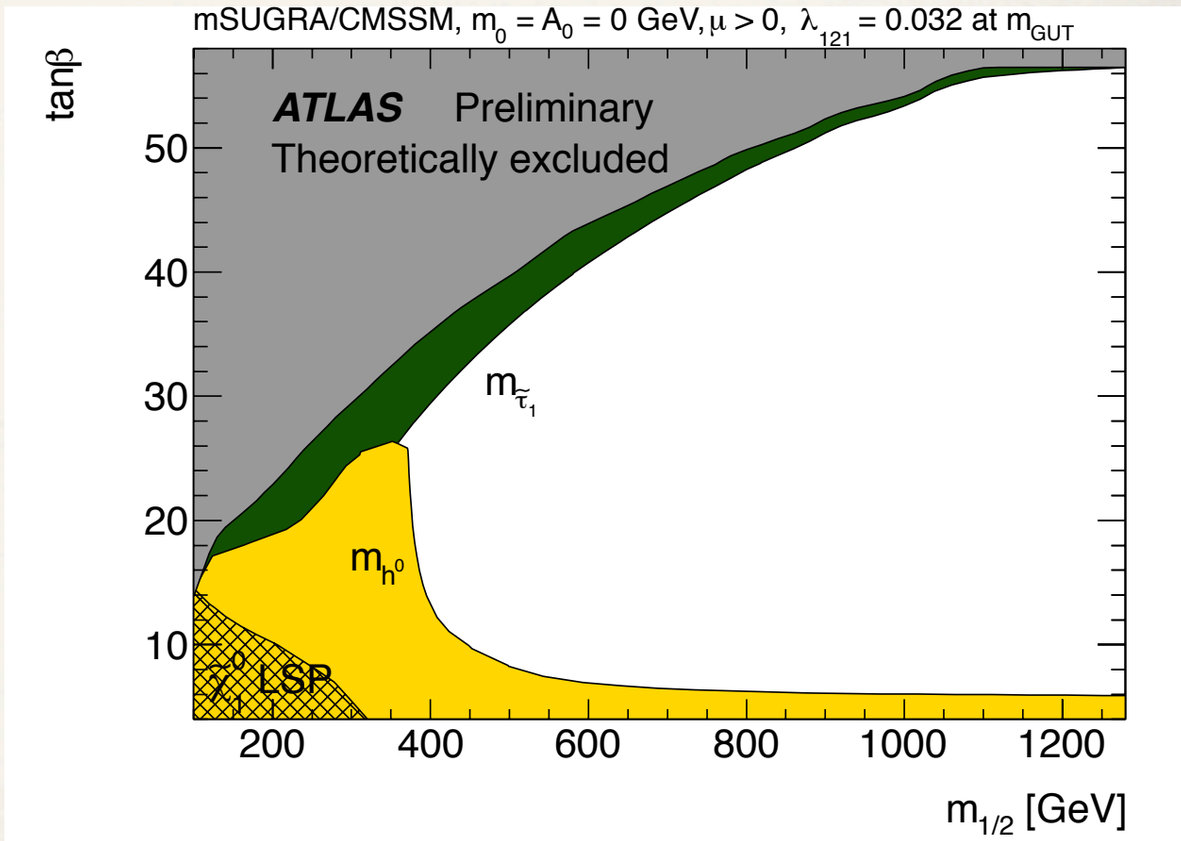
- "Constraining R-parity violating Minimal Supergravity with stau$_1$ LSP in a four lepton final state with missing transverse momentum."
  - ATLAS-CONF-2012-035
- mSUGRA/CMSSM model with R-parity violation described by 6 parameters
  - $m_0, m_{1/2}, A_0, \tan\beta$, sign($\mu$), λ_{121}

	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



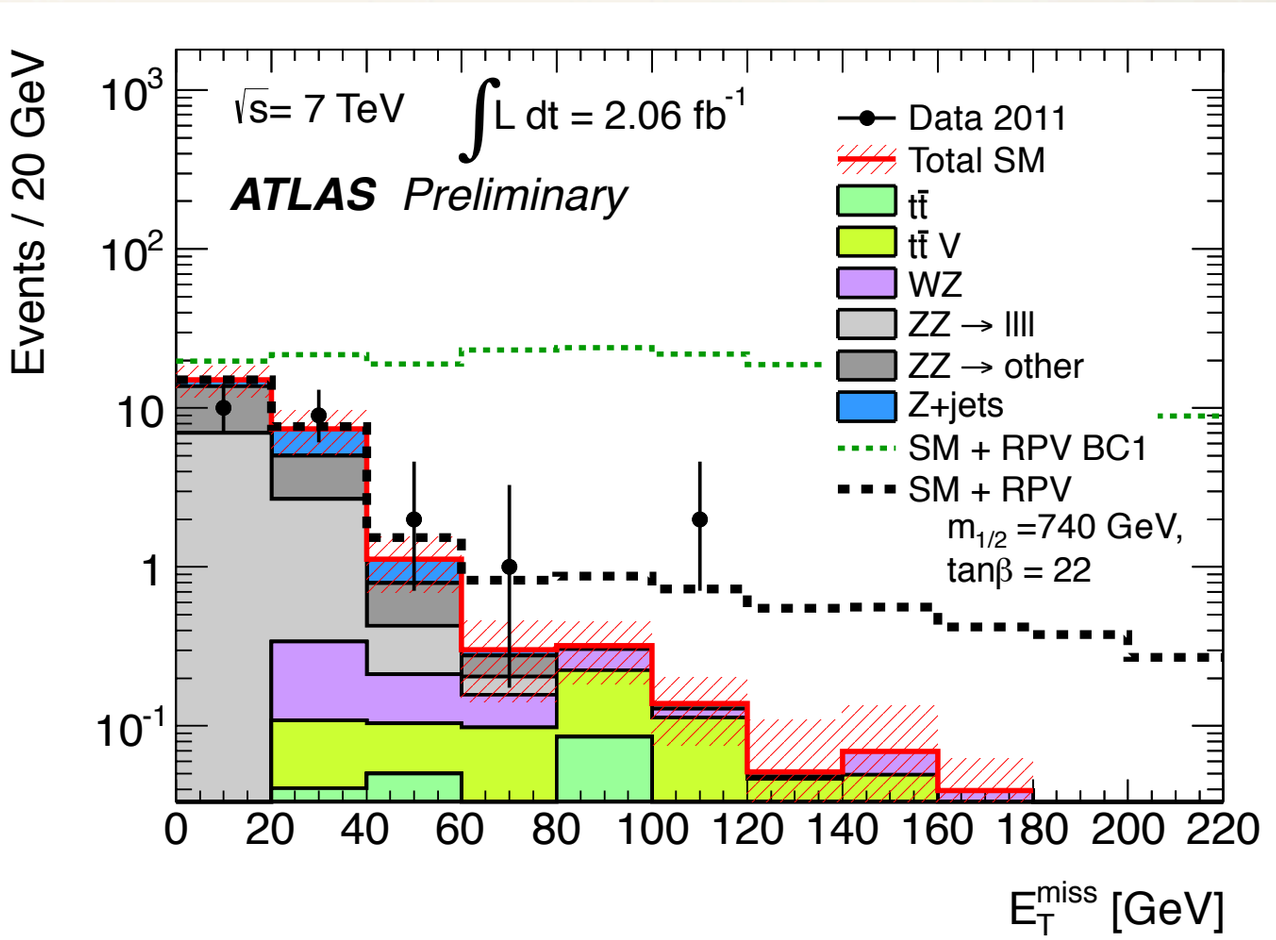
Previous excluded regions of phase space

Event Selection

- Analysis based on **2.06 fb^{-1}** of 2011 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



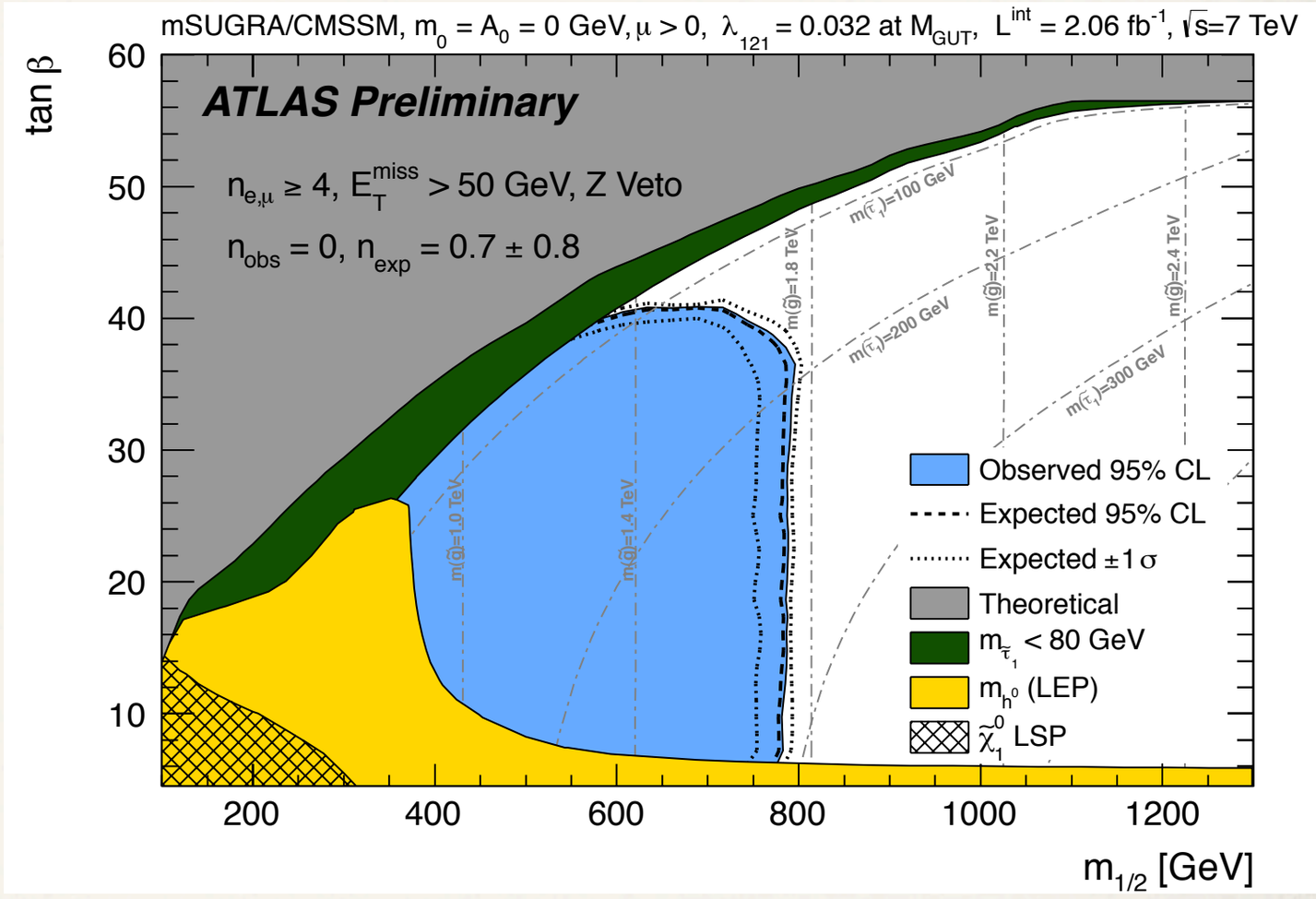
Signal Region 1: At least 4 leptons with E_T^{Miss} > 50 GeV

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

Results

- Backgrounds fully estimated with MC
  - Validated in control regions
  - Uncertainty dominated by low statistics in the Z+light flavor jets

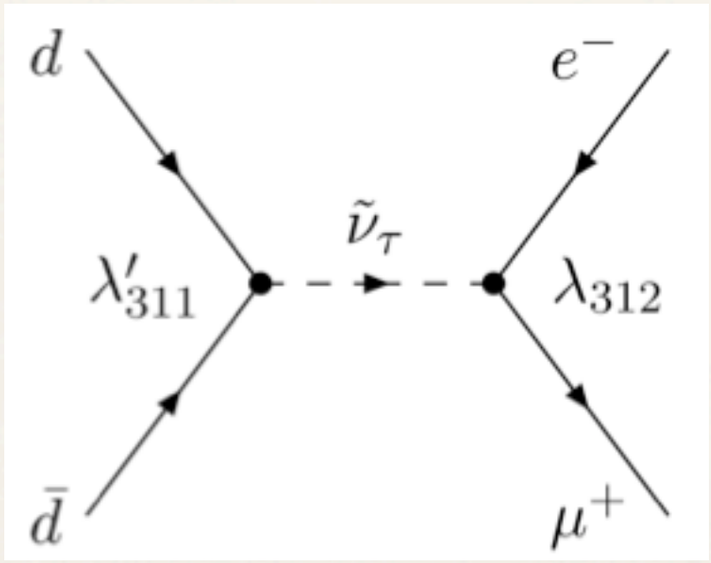
	≥4 leptons + Etmiss>50GeV	+ Z-veto
ttbar	0.17±0.14	0.13±0.11
single t	0±0.04	0±0.04
ttbar+V	0.48±0.21	0.07±0.04
ZZ	0.44±0.19	0.019±0.020
WZ	0.25±0.10	0.09±0.05
WW	0±0.015	0±0.015
Zγ	0±0.5	0±0.5
Z+LF-jets	0.33±0.67	0.33±0.67
Z+HFjets	0.024±0.035	0.024±0.035
Drell-Yan	0±0.05	0±0.05
BG Total	1.7±0.9	0.7±0.8
Data	4	0



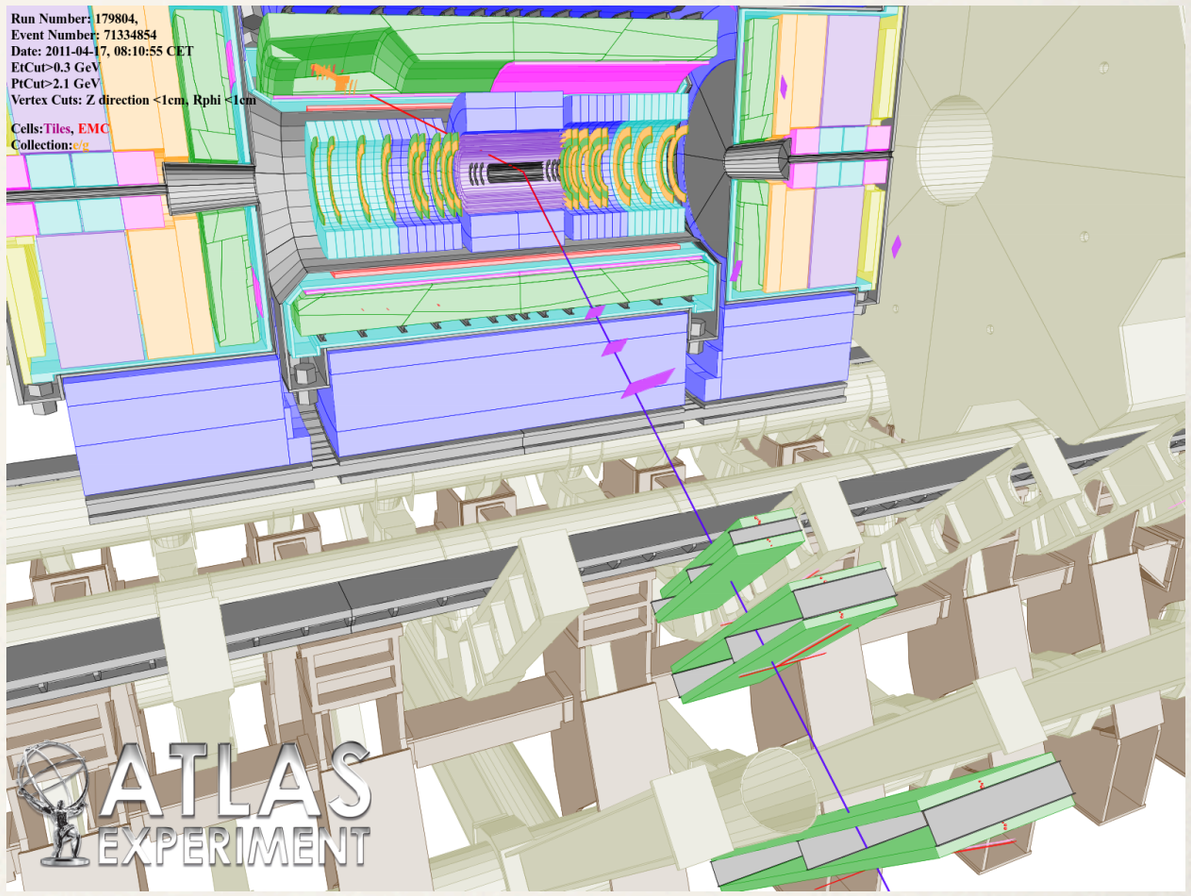
- No excess observed
- Use SR2 to set limits with profile likelihood procedure
- For tan β < 40, $m_{1/2}$ is excluded below 800 GeV ⇒ Gluino mass excluded below 1770 GeV

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'

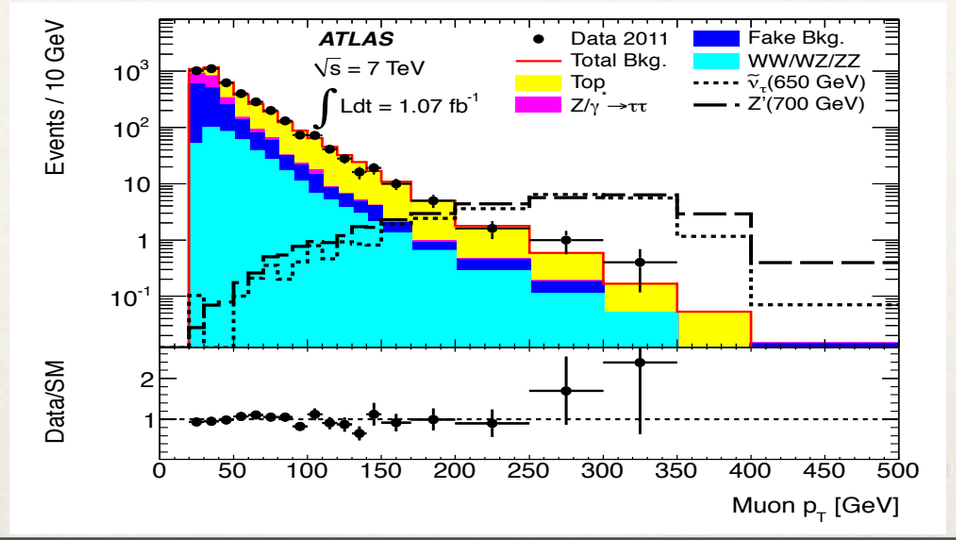


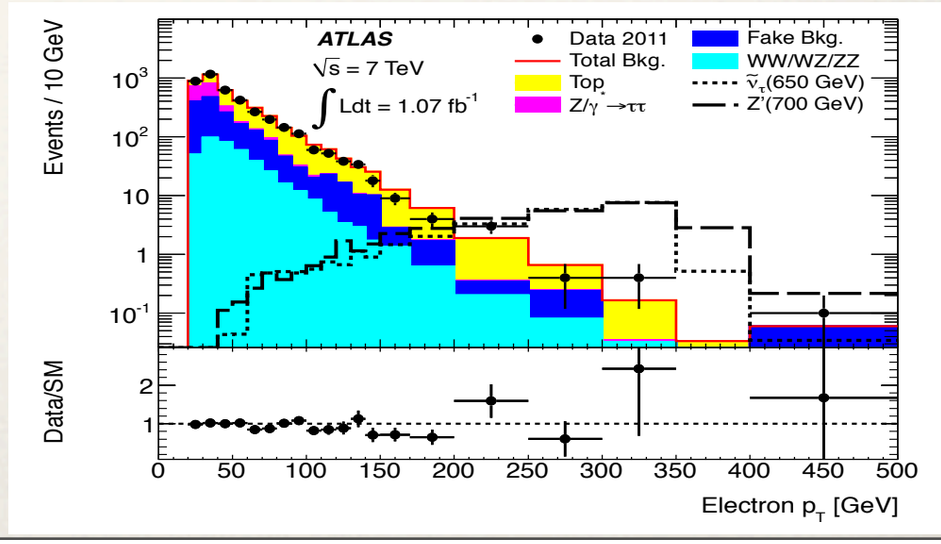
Event display of highest invariant mass e μ pair

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 p_T > 500 MeV
- Require exactly 1 e and 1 μ with:
  - Opposite charge
  - p_T > 25 GeV
  - η within fiducial region of the detector
  - Isolated

- Physics Backgrounds
  - $Z/\gamma^* \rightarrow \tau\tau$, top, diboson
- Fake Background
  - Multijet, W/Z + jets, W/Z + γ
- Multijet & W/Z + jets are estimated from data
- All others estimated from MC

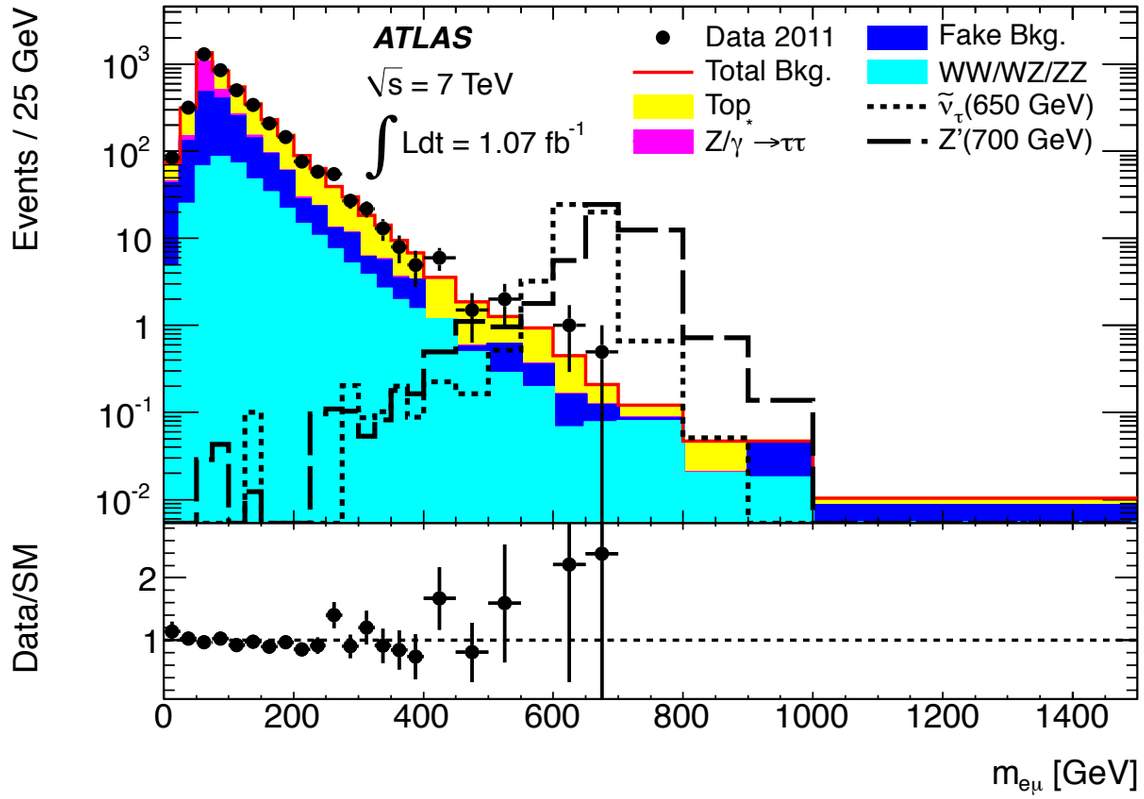


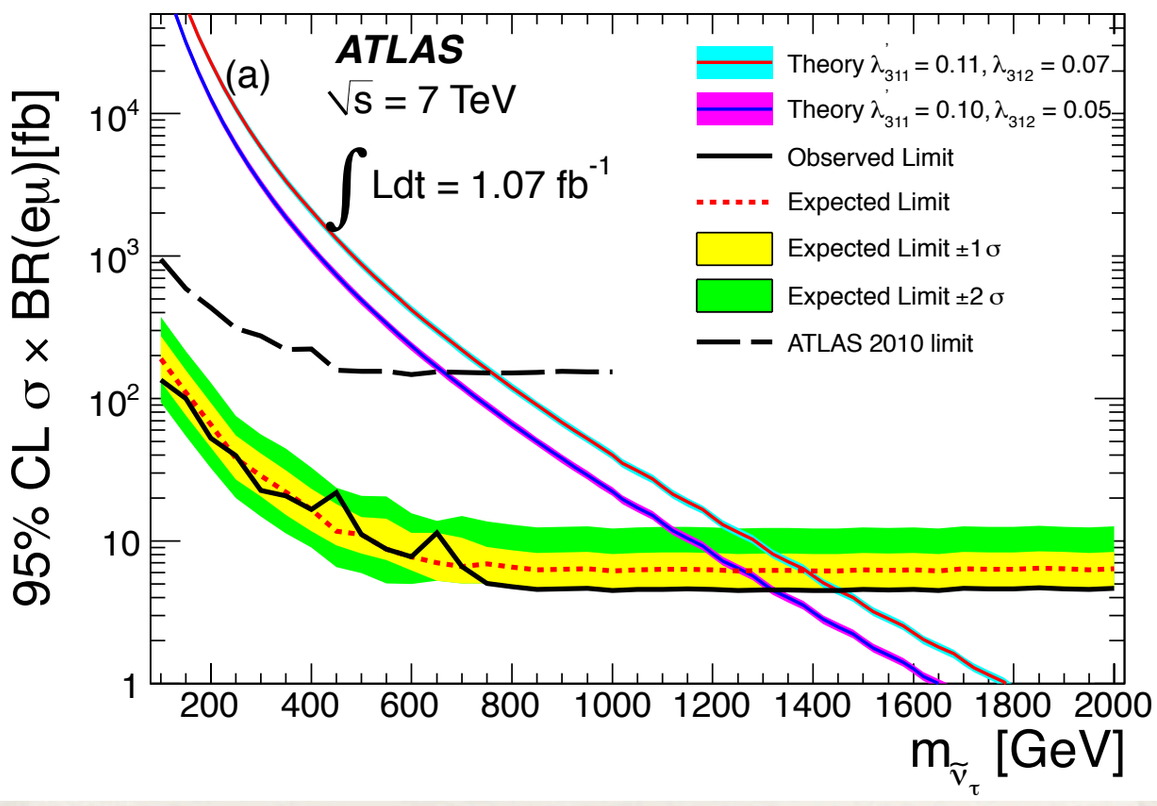


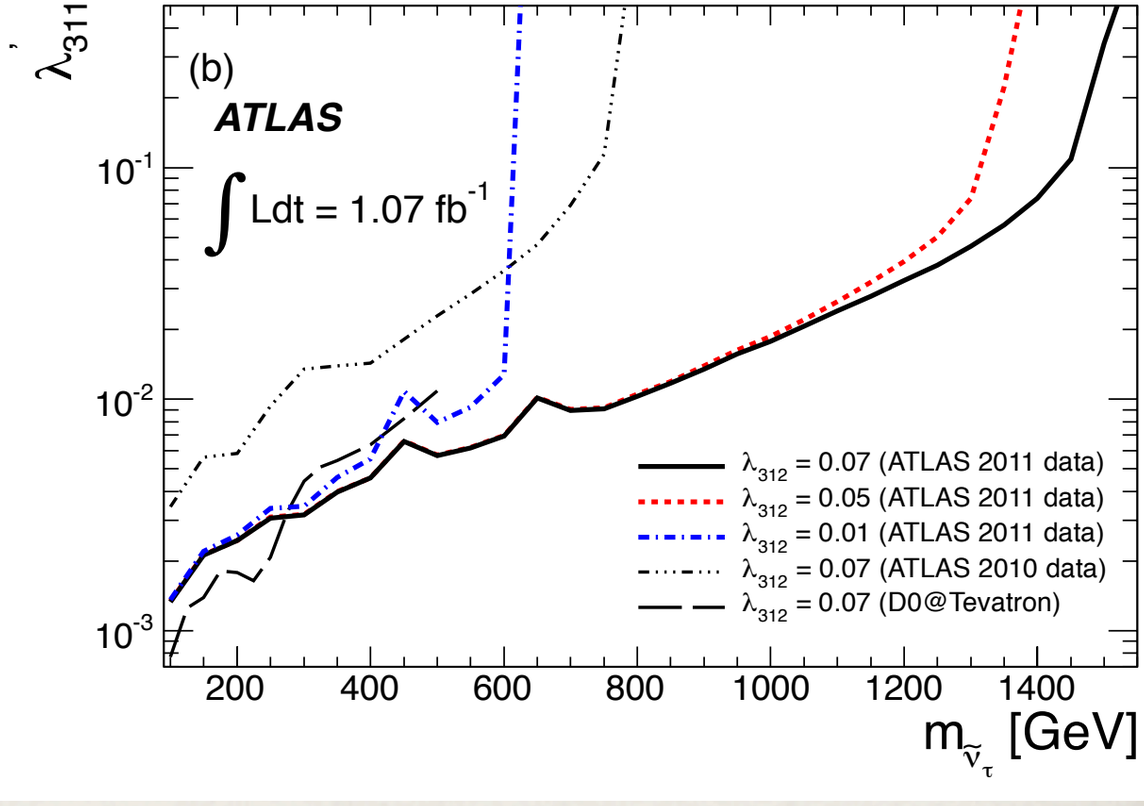
Results

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 sneutrino mass
- Using Bayesian analysis with flat prior

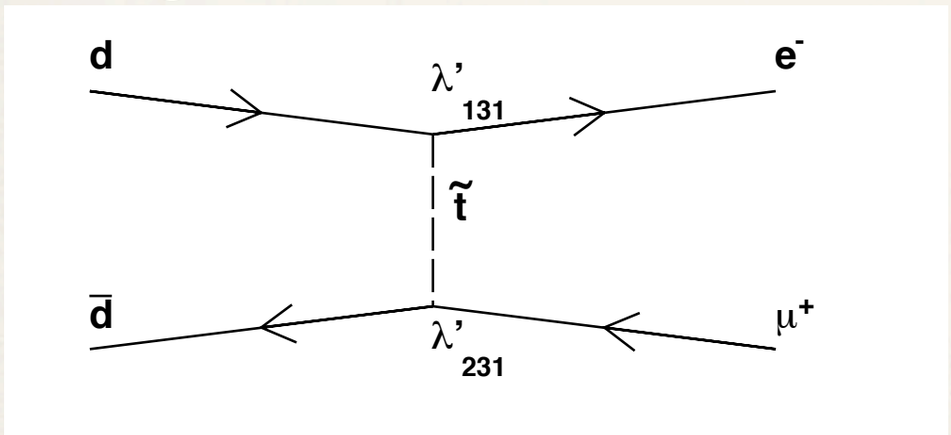






e μ Continuum Search

- "Search for lepton flavour violation in the eμ continuum with the ATLAS detector in sqrt(s) = 7 TeV pp collisions at the LHC"
  - Accepted for publication in EPJC
- RPV SUSY allows for LFV t-channel exchange



➡ **No peak in invariant mass spectrum**

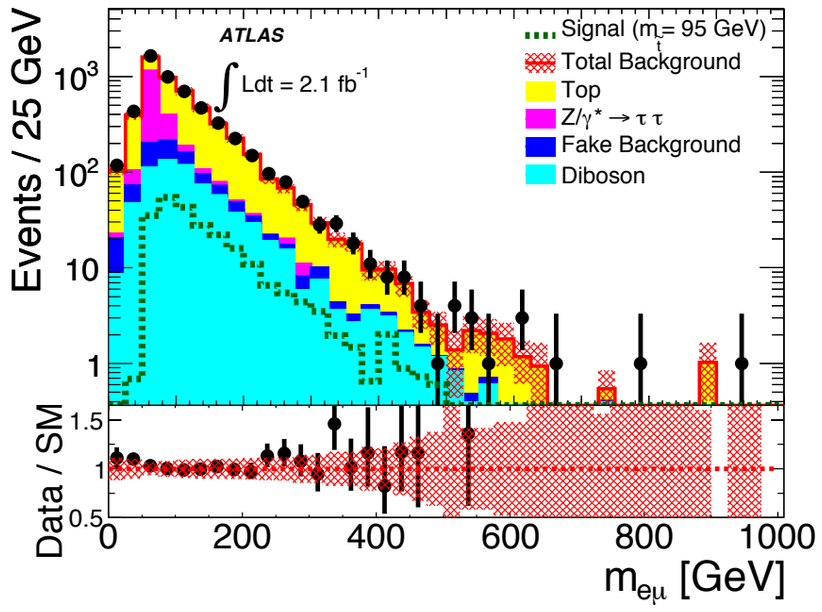
- Differential cross section:

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

- Also diagrams with the d/$\bar{d}$ independently replaced by s/$\bar{s}$
  - Cross section has same form but involves different couplings
- Analysis assumptions:
  - Cross section dominated by the lightest up-like squark (scalar top)
  - Scalar top mass limit ~95 GeV
  - $|\lambda'_{131}\lambda'_{231}| = |\lambda'_{132}\lambda'_{232}| = 0.05$
  - All other couplings negligible

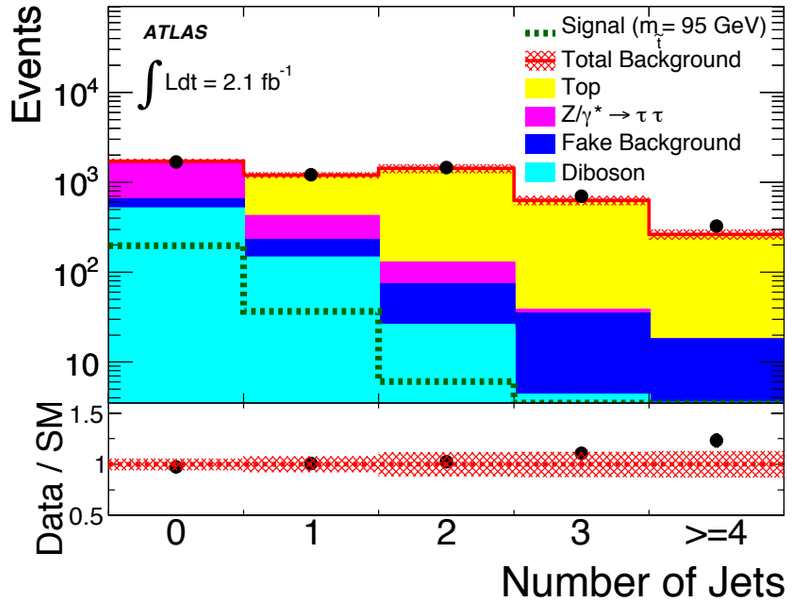
Event Preselection

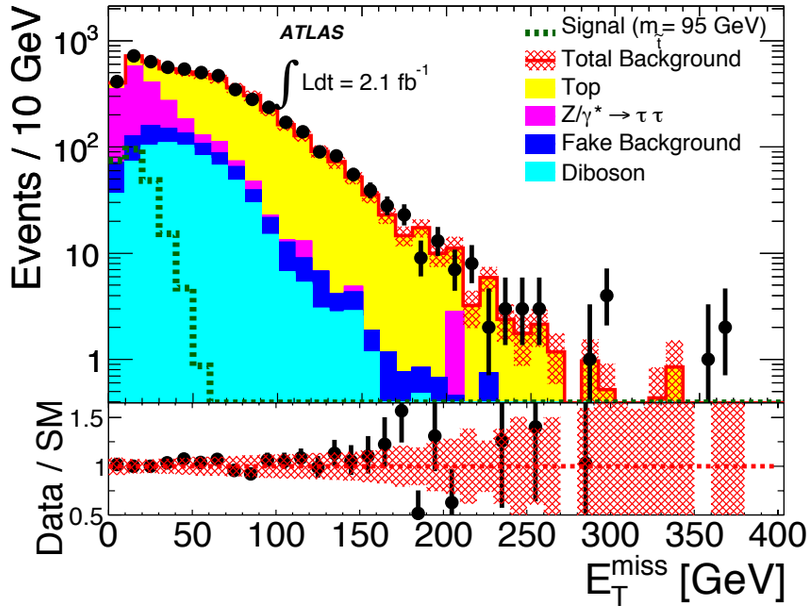
- Analysis based on 2.08 fb^{-1}
- Same e and μ definition as resonance search
  - Except tighter isolation requirements

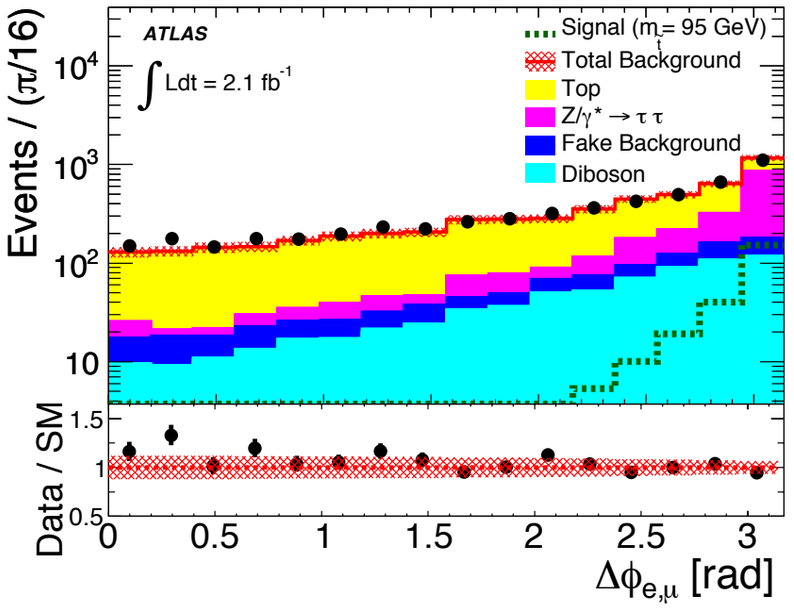


Process	Event Selection
$t\bar{t}$	2800 ± 400
$Z/\gamma^* \to \tau\tau$	1210 ± 110
WW	640 ± 50
Fake background	290 ± 40
Single top	270 ± 40
WZ	36 ± 4
$W/Z + \gamma$	20 ± 7
ZZ	4.0 ± 0.4
Total background	5300 ± 400
Data	5387
Signal ($m_{\tilde{t}} = 95$ GeV)	240 ± 15
Signal ($m_{\tilde{t}} = 500$ GeV)	3.05 ± 0.18
Signal ($m_{\tilde{t}} = 1000$ GeV)	0.305 ± 0.018

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



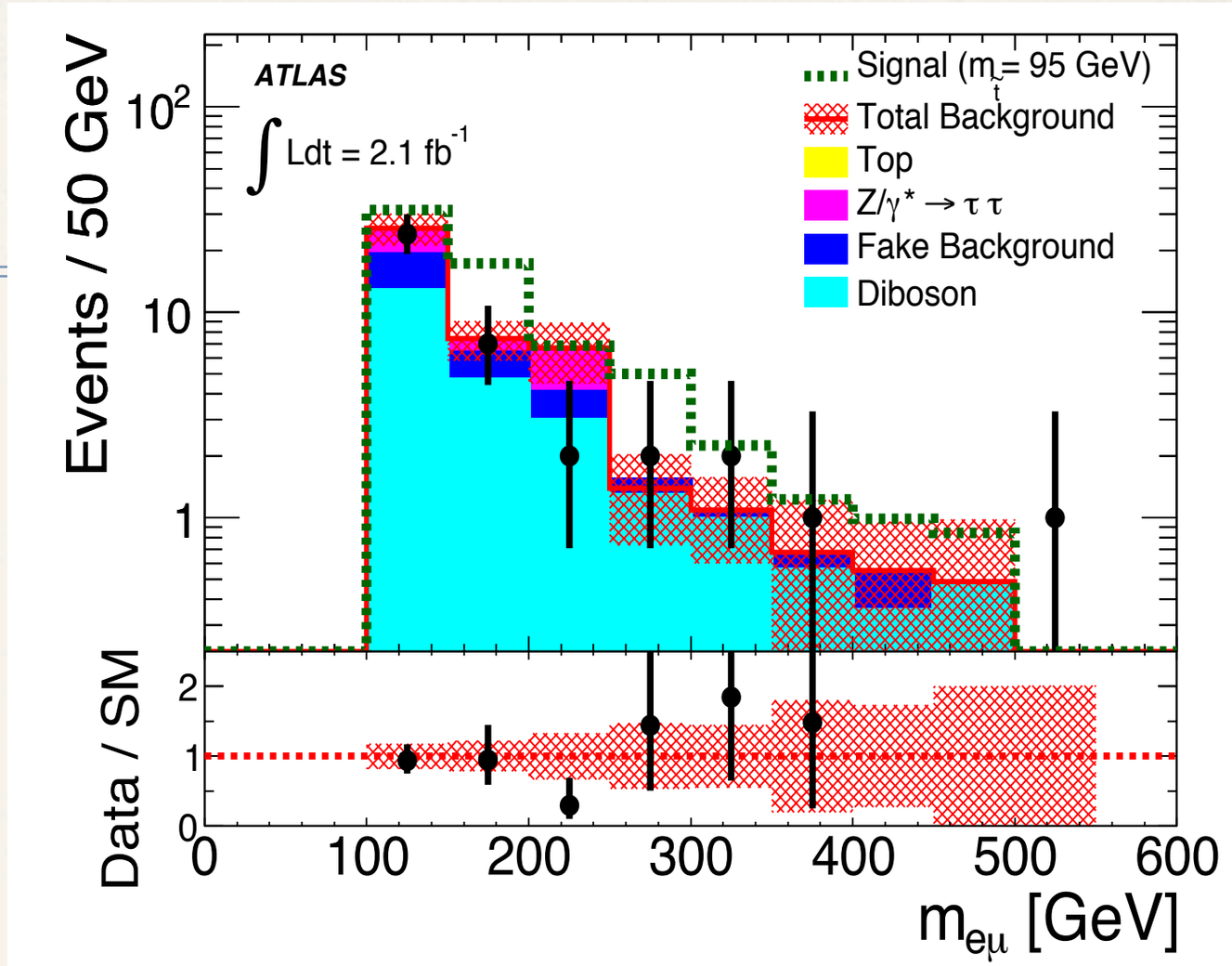




Final Selection

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

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

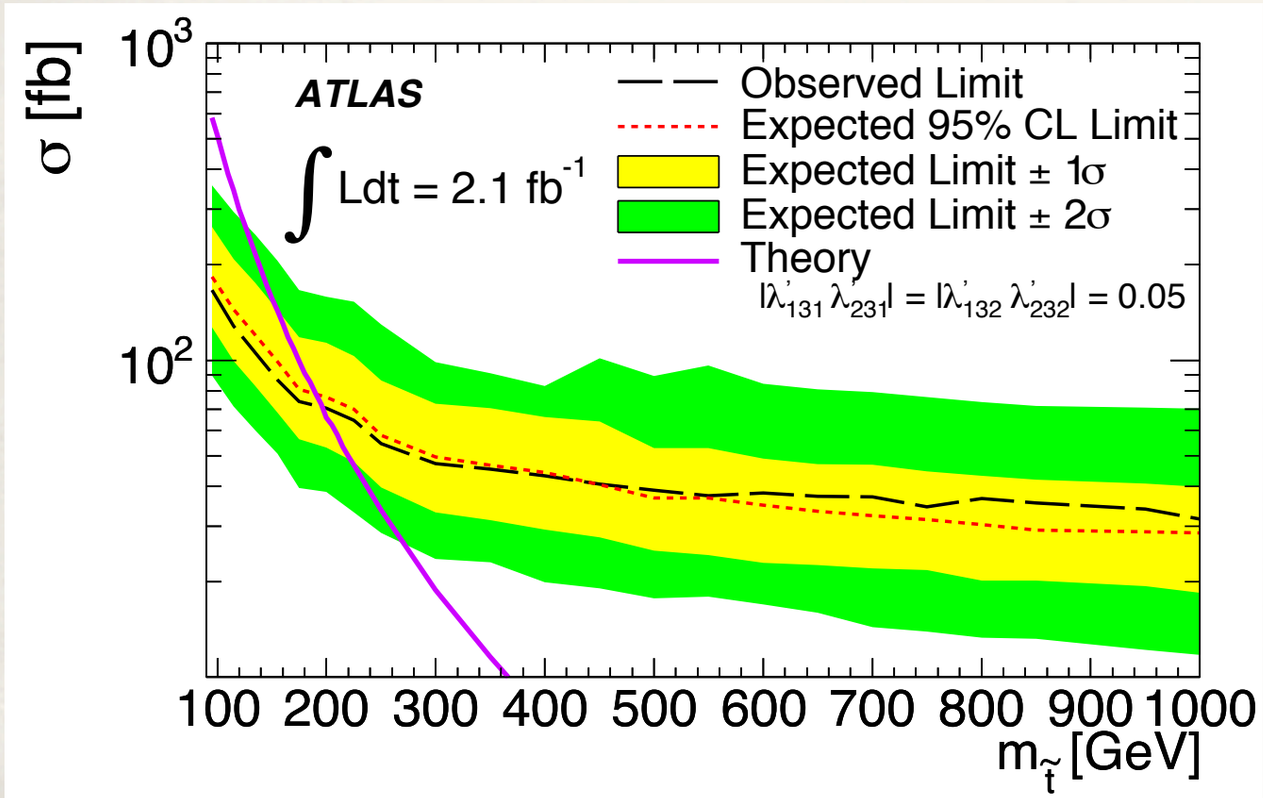


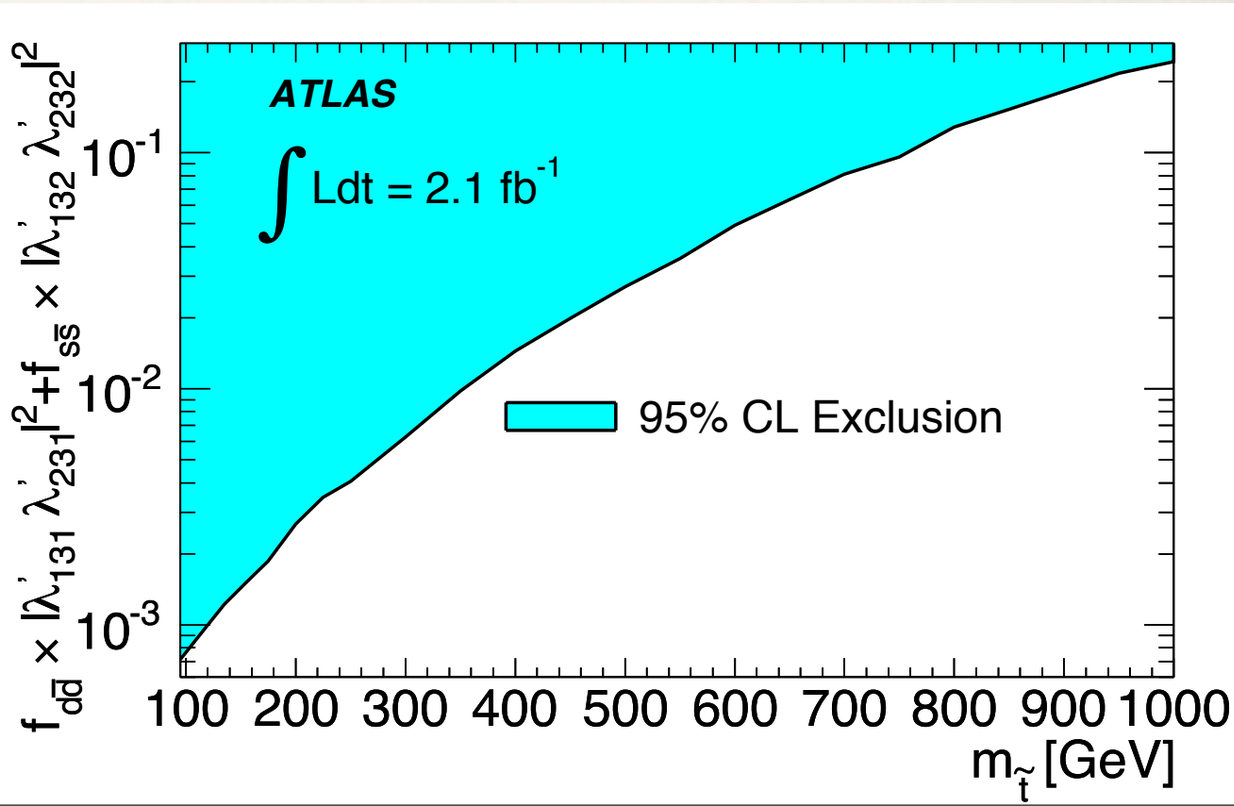
- No excess observed
  - Limits set with CLs method, using $m_{e\mu}$ distribution and a binned likelihood ratio test statistic to take shape into account

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





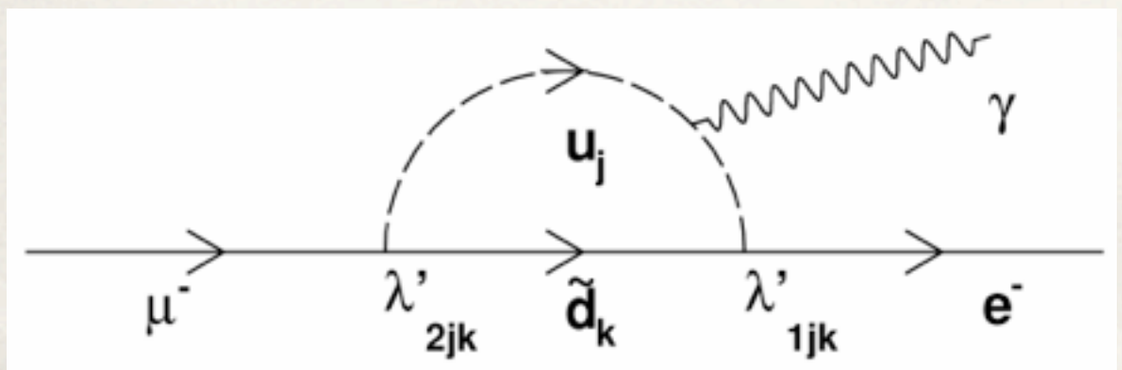
Summary and Conclusion

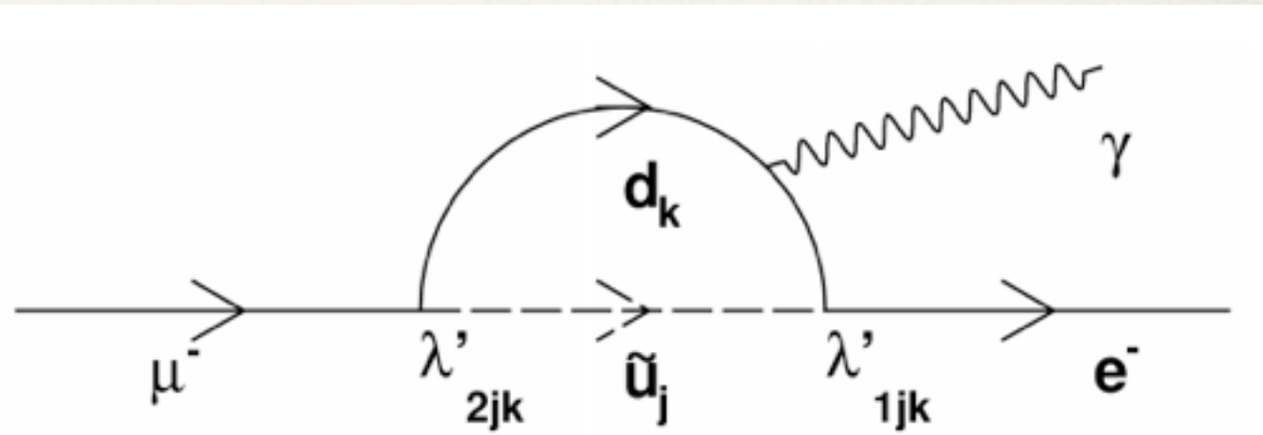
- **Three searches for R-parity violating SUSY with ATLAS presented in this talk**
  1. Searches for Stau LSP decays in the CMSSM in a four lepton analysis
  2. Searches for resonant production of a Sneutrino decaying into eμ pairs
  3. Searches for continuum production of eμ pairs through a t-channel 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 $\mu \rightarrow e\gamma$

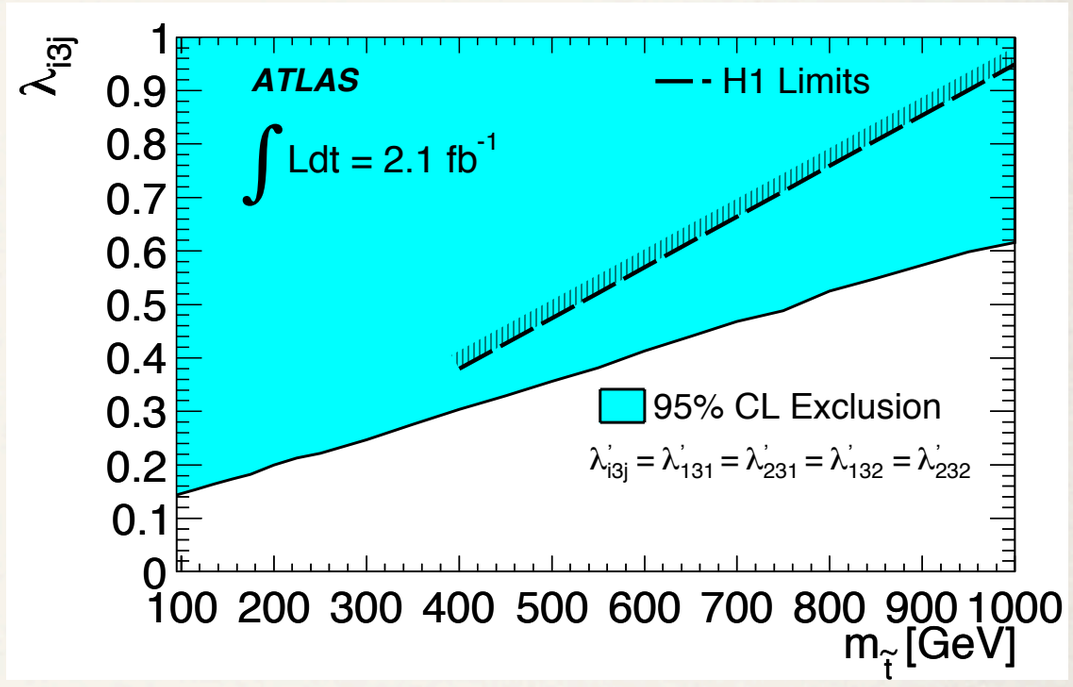
- To derive the limit $|\lambda'_{23k}\lambda^*_{13k}|<0.002$, the intermediate states are assumed to be d-scalar top and t-scalar down, and m_(scalar d)=300 GeV
- If SUSY is right, m(scalar d) are likely higher than 300 GeV
  - In general, once the squark mass > top mass, the limits weaken as the squark 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