ATLAS Searches for New Physics with an *eμ* Final State

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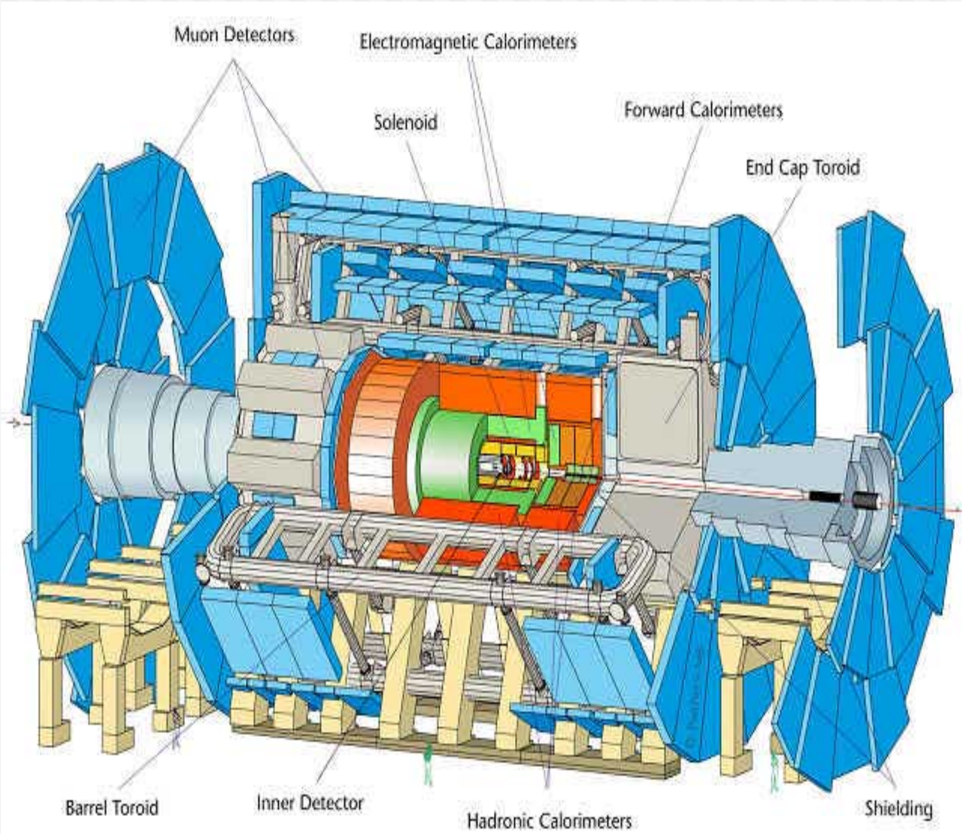
Motivation for *eμ* Searches

- Historically important in discoveries:
  - Tau lepton at SPEAR
  - Top quark at Tevatron
- Final state has a clean detector signature and low backgrounds
- Neutrino oscillations show that lepton flavor conservation is not absolute
- *eμ* final states are predicted by a number of extensions to the standard model
  - R-parity violating supersymmetry (RPV SUSY)
  - Extra gauge boson (Z') with lepton flavor violating interactions

ATLAS Detector

- A multi-purpose particle physics apparatus with a forward-backward symmetric cylindrical geometry
- Near 4π coverage in solid angle
- Inner detector
  - Surrounded by a superconducting solenoid providing a 2 T magnetic field
- Electromagnetic Calorimeter
  - Reconstructs electrons with $|\eta| < 2.5$
- Muon spectrometer



Event Selection

- Total integrated luminosity: 1.07 $\pm$ 0.04 fb
- Passes a single lepton (e or μ) trigger
  - Trigger efficiency 100%
- At least 1 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 the fiducial region of the detector
  - Isolated

Backgrounds

- Physics
  - Drell Yan (Z/γ^* -> $\tau\,\tau$)
  - $t\bar{t}$
  - Single Top (*W t*)
  - Diboson (*WW, WZ, ZZ*)
- "Instrumental"
  - QCD (dijets)
  - W/Z + jets
  - W/Z + γ

- All physics backgrounds modeled with Monte Carlo simulation
  - Detector response simulated with GEANT4
  - Lepton identification efficiencies, energy scales and resolutions are corrected to match data
- QCD and W/Z + jets are estimated from data using a data driven method
- W/Z + γ modeled with MC

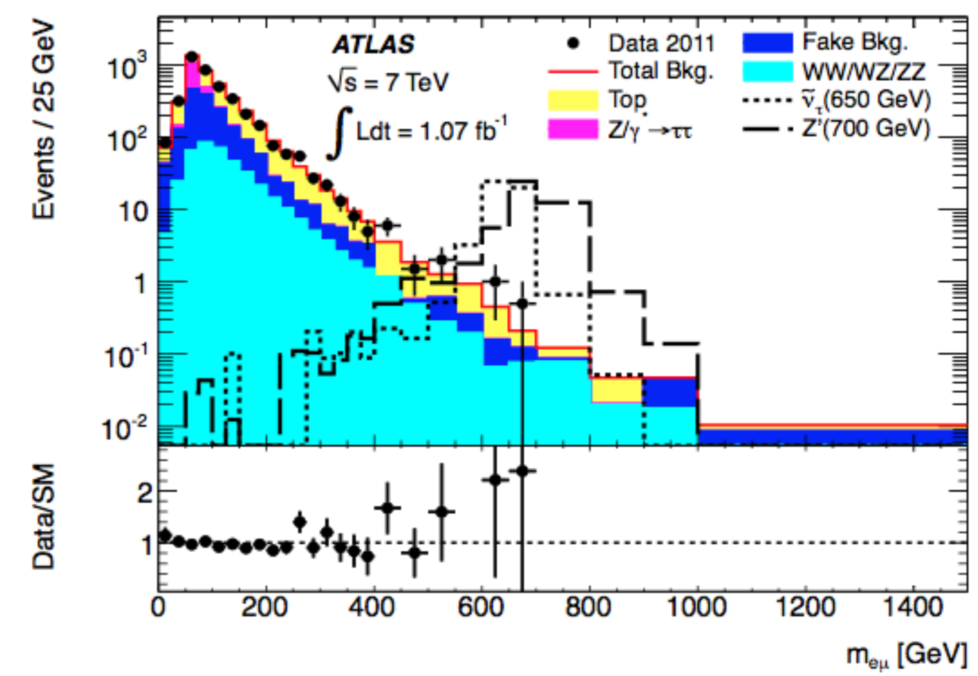
Systematics

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
$Z/\gamma^* \to \tau\tau$ cross section	5%	related to $Z/\gamma^* \to \tau\tau$ 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

- Also studied and found to be negligible:
  - Electron energy scale and resolution
  - Muon momentum scale and resolution

Results after Event Selection

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



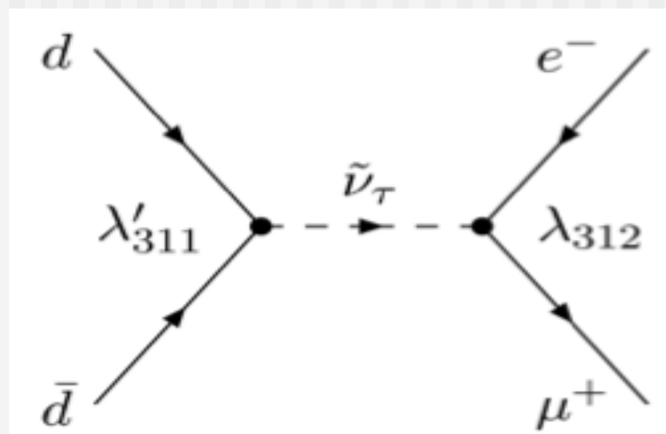
- Data is consistent with expected standard model background
- Results used to set limits on two possible new physics signals
  - Sneutrino production in R-parity violating SUSY
  - Lepton flavor violating vector particles (Z′)

R-parity Violating (RPV) SUSY

- $R = (-1)^{3B+L+2S}$
  - B is Baryon Number
  - L is Lepton Number
  - S is Spin Number
- No reason to assume R is conserved
- General RPV Superpotential:

$$\mathcal{W}_{\not{R}_p} = \frac{1}{2}\varepsilon_{ab}\lambda_{ijk}\hat{L}_i^a\hat{L}_j^b\hat{E}_k + \varepsilon_{ab}\lambda'_{ijk}\hat{L}_i^a\hat{Q}_j^b\hat{D}_k + \frac{1}{2}\varepsilon_{\alpha\beta\gamma}\lambda''_{ijk}\hat{U}_i^\alpha\hat{D}_j^\beta\hat{D}_k^\gamma + \varepsilon_{ab}\mu_i\hat{L}_i^a\hat{H}_2^b$$

- LLE and LQD lead to:



RPV SUSY

- Search is performed under the following assumptions:
  - $\tilde{\nu}_\tau$ is the LSP
  - All RPV couplings except λ'_{311} and $\lambda_{312} = \lambda_{321}$ are zero
- Cross section depends only on snuetrino mass (M) and couplings:

$$\hat{\sigma}_{e\mu} \propto (\lambda'_{311})^2 \times (\lambda_{312})^2 \cdot \frac{1}{|\hat{s} - M^2 + i\Gamma M|^2}$$

- For this analysis couplings are set to current limits:
  - $\lambda'_{311} = 0.11$
  - $\lambda_{312} = \lambda_{321} = 0.07$
- Current limits obtained from measurements of tau lepton branching ratios at low energy

Lepton Flavor Violating Z′

- One well motivated extension to the SM is the addition of an extra *U*(1) gauge symmetry leading to a neutral gauge boson (Z′)
- We use a Sequential Standard Model Z′
  - Assumes Z′ to have the same couplings as Z
  - Add a coupling (Q^l_{12}) which couples Z′ to eμ
- Z′ cross section: $$\sigma(Z' \to l_i^- l_j^+) = \frac{g_z^2}{4\pi} \frac{(Q^l_{ij})^2}{144} \frac{M^2}{(M^2 - M_{Z'}^2)^2 + M_{Z'}^2 \Gamma_{Z'}^2}$$
- μ -> eee experiments have set stringent limits on Q^l_{12}
- We use Z′ as benchmark to place limits on a spin-1 particle which can decay to eμ

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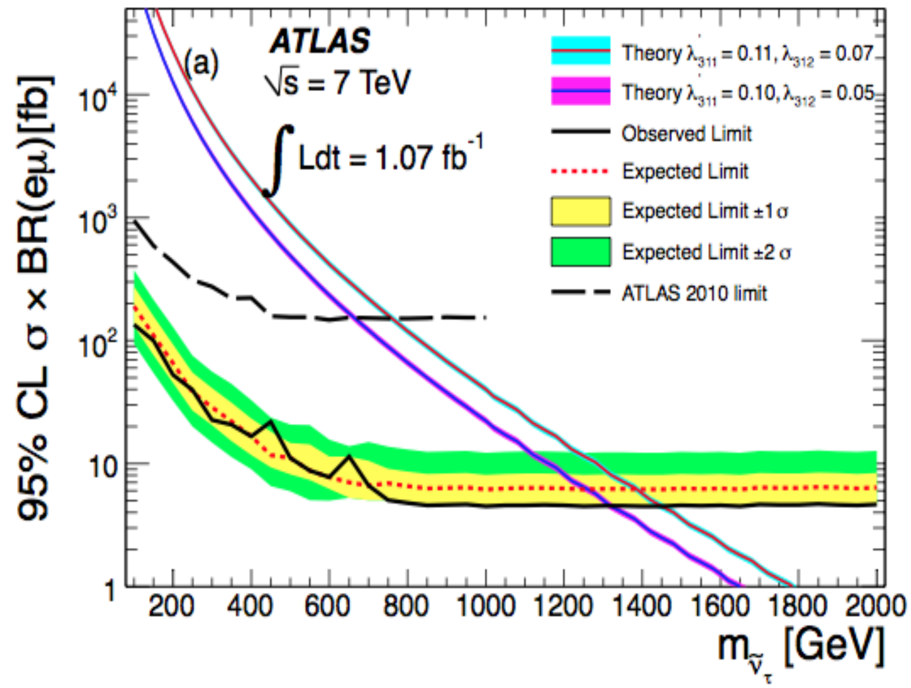
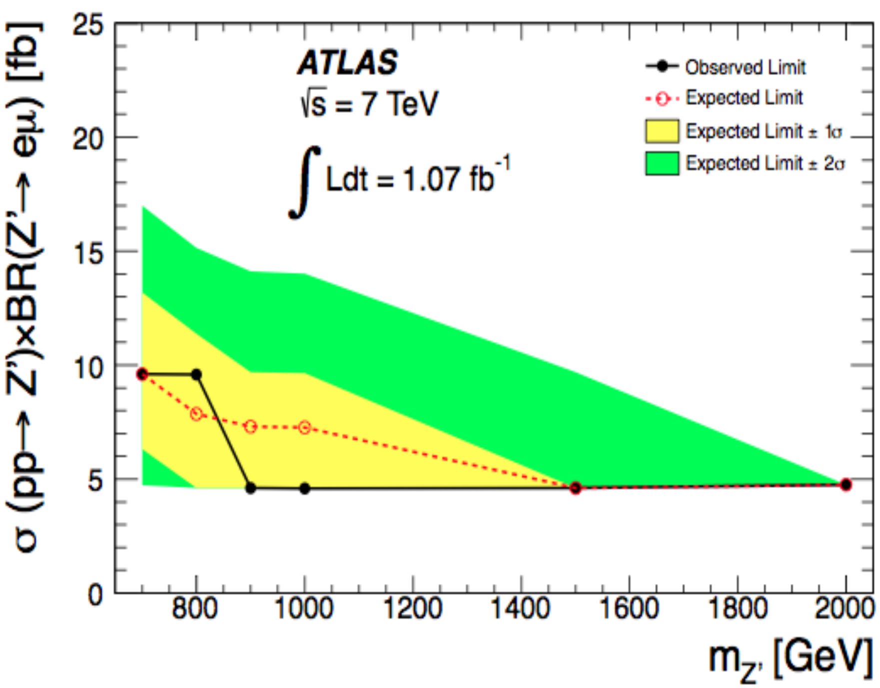
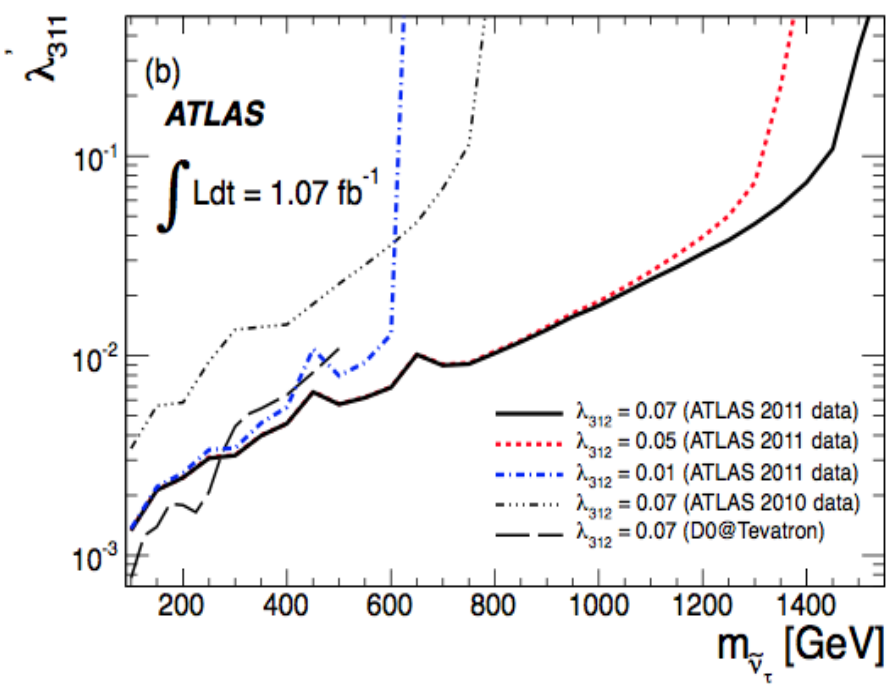
Limits

- We perform a simple counting experiment using Bayesian analysis and a flat prior.







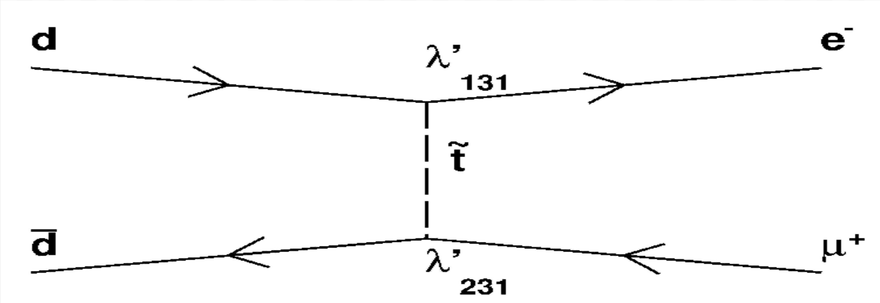
http://arxiv.org/pdf/1109.3089v1

Conclusion

- A search has been performed for high mass $e\mu$ events using the ATLAS detector.
- The observed $m_{e\mu}$ distribution is consistent with standard model predictions
- 95% C.L exclusions are placed on:
  - RPV coupling values of the tau sneutrino
  - Tau sneutrino mass below 1.32 (1.45) TeV assuming $\lambda'_{311} = 0.10$ and $\lambda_{312} = \lambda_{321} = 0.05$ ($\lambda'_{311} = 0.11$ and $\lambda_{312} = \lambda_{321} = 0.07$)
  - Production cross section of lepton flavor violating spin-1 particle

Current and Future Work

- RPV SUSY can also lead to the production of *eμ* pairs through t-channel exchange:



- Non-resonant production leads to a continuum distribution in the invariant mass distribution
- A simple invariant mass cut does not separate signal from background
- A multivariate technique is being developed to provide better separation power

Backup Slides

Matrix Method

- Define a “loose” and “tight” selection for both electrons and muons.
- “Loose” electron sample:
  - Require only isEM_loose
  - Do not require isolation (EtCone40 < 10 GeV)
- “Loose” muon sample:
  - Do not require isolation (PtCone40 < 10 GeV)
- Measure efficiencies of real muons (electrons) to pass tight selection using Z-> $\mu\mu$ (ee) data samples.
- In dijet samples look for jets which pass loose lepton selection, measure efficiency of tight selection.

Matrix Method

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} r_e r_\mu & r_e f_\mu & f_e r_\mu & f_e f_\mu \\ r_e(1-r_\mu) & r_e(1-f_\mu) & f_e(1-r_\mu) & f_e(1-f_\mu) \\ (1-r_e)r_\mu & (1-r_e)f_\mu & (1-f_e)r_\mu & (1-f_e)f_\mu \\ (1-r_e)(1-r_\mu) & (1-r_e)(1-f_\mu) & (1-f_e)(1-r_\mu) & (1-f_e)(1-f_\mu) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

- r_e (r_μ) - efficiency of tight selection for real electrons (muons)
- f_e (f_μ) - efficiency of tight selection for jets faking electrons (muons)
- N_{TT} - Number of events in final selection passing tight electron and muon requirements
- N_{TL} (N_{LT}) - Number of events in loose selection passing tight electron (muon) selection but failing tight muon (electron) selection.
- N_{LL} - Number of events passing the loose electron and muon selection and failing tight selection.
- N_{RR} - Number of events with a real electron and real muon
- N_{RF} (N_{FR}) - Number of events with a real electron (muon) and fake muon (electron)
- N_{FF} - Number of events with a fake electron and fake muon.

Matrix Method

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} r_e r_\mu & r_e f_\mu & f_e r_\mu & f_e f_\mu \\ r_e(1-r_\mu) & r_e(1-f_\mu) & f_e(1-r_\mu) & f_e(1-f_\mu) \\ (1-r_e)r_\mu & (1-r_e)f_\mu & (1-f_e)r_\mu & (1-f_e)f_\mu \\ (1-r_e)(1-r_\mu) & (1-r_e)(1-f_\mu) & (1-f_e)(1-r_\mu) & (1-f_e)(1-f_\mu) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

- Invert the matrix and solve for the number of fake events in data.
- Use this to determine the probability that a data event is fake.
- Make a new “instrumental” background which is the data weighted event by event with the probability that it is fake.
- Do this all in bins of muon p_T because f_μ varies significantly with p_T. All other efficiencies mostly flat in p_T.