UNIVERSITY OF ALBERTA

DEPARTMENT OF PHYSICS

Search for Exotics Physics States Decaying to Leptonic Final states

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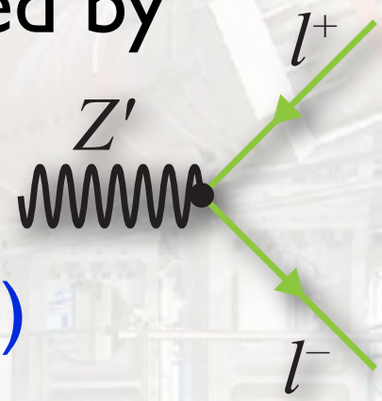
Introduction

- Here we will define "exotic" physics as
  - Beyond the Standard Model...but not SUSY!
- This talk will present the results from four recent "exotic" ATLAS search analyses
  - High mass dilepton resonances
    - ATLAS-CONF-2012-007
  - Excited electrons and muons
    - ATLAS-CONF-2012-008
  - Resonant WZ production
    - arXiv:1204:1648, submitted to Phys. Rev. D
  - Heavy neutrinos and right-handed W bosons
    - arXiv:1203:5420, submitted to Eur. Phys. J. C
- There are many more but no time to cover them!
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

Dilepton Resonances

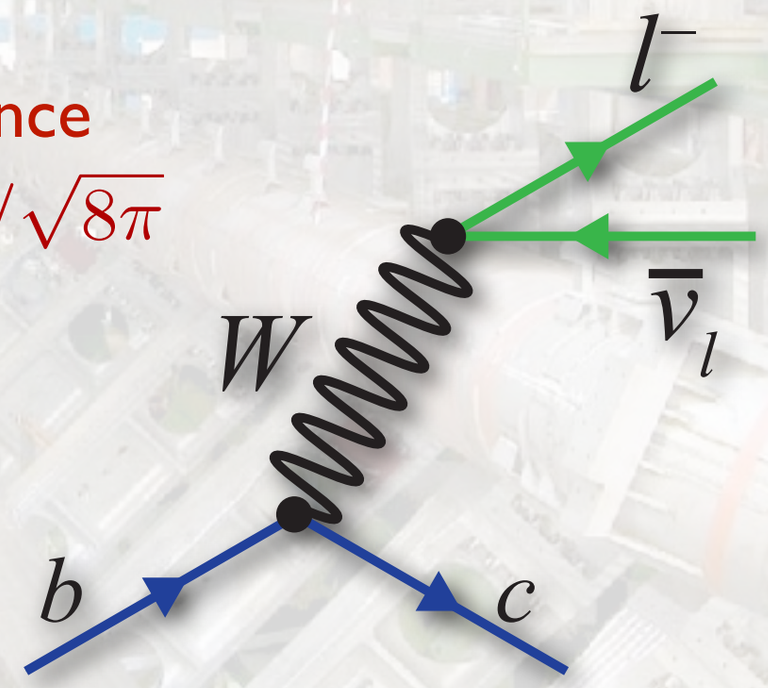
- High mass resonances decaying to ee or μμ suggested by several models
  - Sequential Standard Model: Z' with same couplings as Z
  - Grand Unified Symmetry breaking: E6->SU(5) and 2 U(1)
    - Z' formed from mixing gauge fields: couplings not same as Z
  - Randall-Sundrum spin-2 gravitons
    - Probe $0.01 < k/\overline{M}_{\rm Pl} < 0.1$ for narrow resonance



- Important Backgrounds

$\overline{M}_{\rm Pl} = M_{\rm Pl}/\sqrt{8\pi}$

  - Z/γ* (Drell-Yan) - dominant and irreducible
  - ttbar and diboson (WW,WZ, ZZ) - small
  - QCD and W+jets
    - μ channel: b and c quark semi-leptonic decays
    - e channel: mixture of hadronic mis-identification, semi-leptonic heavy quark decay and photon conversion



Event Selection

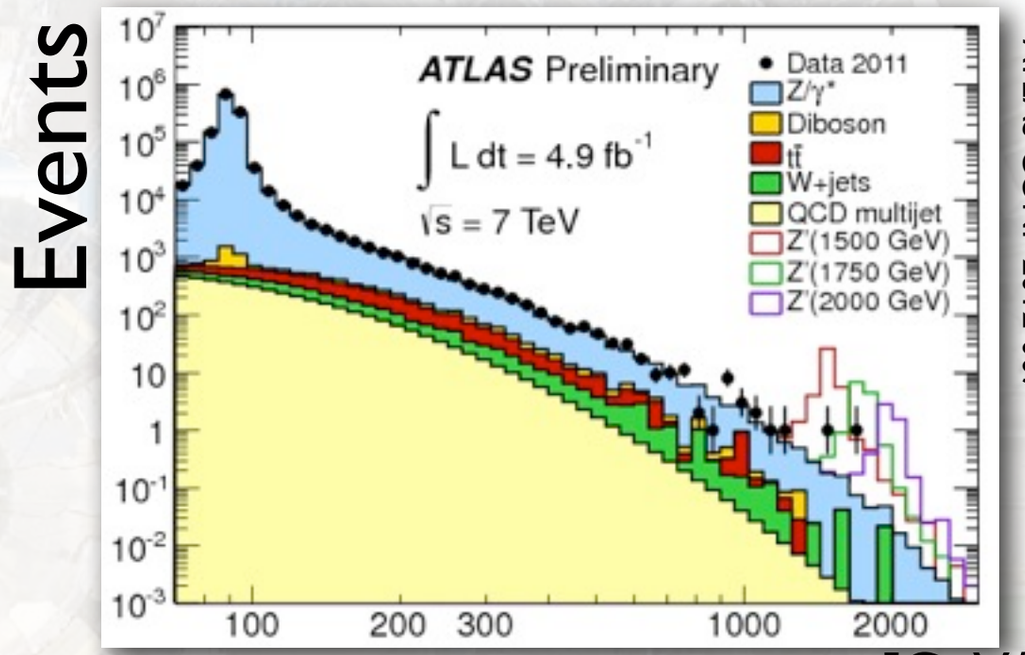
	e^+e^- Channel	$\mu^+\mu^-$ Channel
2011 Dataset	4.9 fb^{-1}	5.0 fb^{-1}
Trigger	2 e, $E_T \geq 20$ GeV	1 μ, $p_T \geq 22$ GeV/c
Trig. Efficiency	99%	85% barrel, 86% EC

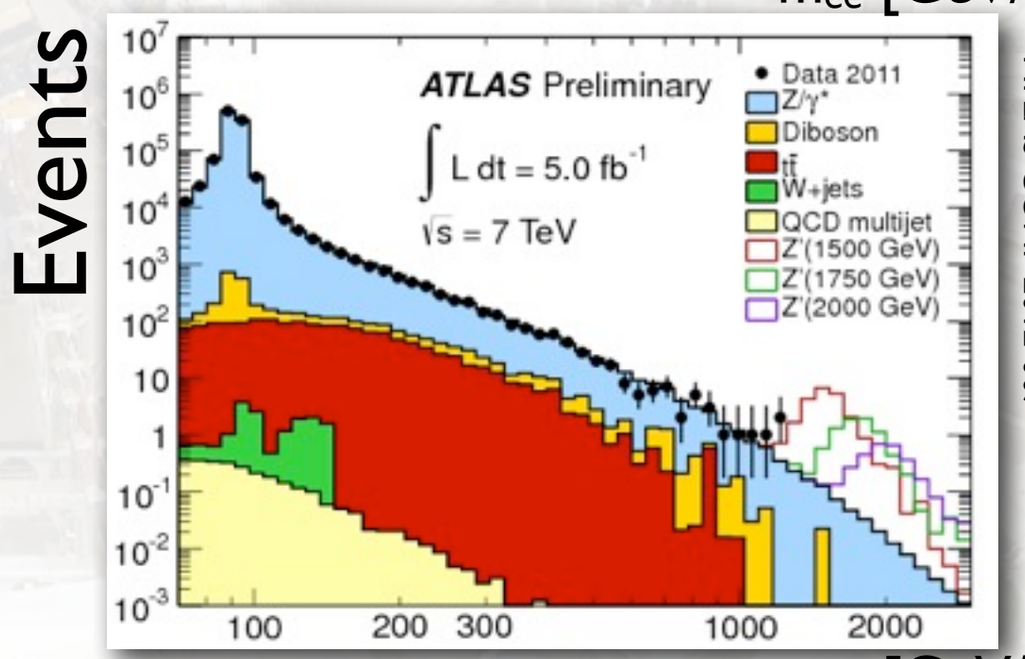
- e^+e^- Channel Analysis cuts
  - 2 e, $E_T \geq 25$GeV and $|\eta| < 2.47$, no charge requirements
  - Shower shape cuts corresponding to a "medium" electron
  - Hit in first active tracker pixel layer: remove γ conversion
  - Lead e isolated $\sum E_T(\Delta R < 0.2) < 7$ GeV: remove QCD
- $\mu^+\mu^-$ Channel Analysis cuts
  - 2 muons, $p_T \geq 25$ GeV/c, opposite sign [trigger out to $|\eta| < 2.4$]
  - Quality cuts: matched ID track, 3 hits in all three muon layers
    - 2 layers in strong B field/well aligned regions; μ dropped if barrel+EC hits
  - Cosmic removal: $PV_Z < 200$mm from centre, $|d_0| < 0.2$mm, beam-line to PV<1mm
  - QCD removal: both muons isolated $\sum p_T(\Delta R < 0.3)/p_T(\mu) < 0.05$

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

Backgrounds

- ee QCD estimated from data
  - Reverse subset of electron ID
  - Subtract non-QCD using MC
  - Fit function for m_{ee}=110-800 GeV/c^2
  - Use shape and normalize to observed m_{ee} in a control region
- μμ QCD estimation uses a similar approach but with isolation
  - Normalize QCD MC to data where $\sum p_T(\Delta R < 0.3)/p_T(\mu) > 0.1$
- MC samples generated at NLO (diboson LO)
  - Corrected to NNLO (diboson NLO) via mass dependent K-factor
- QCD (and Z') corrected by:
  $$\text{QCD K-factor} = \frac{\sigma_{NNLO}(Z/\gamma^*)}{\sigma_{LO}(Z/\gamma^*)}$$
- DY EW K-factor applied too





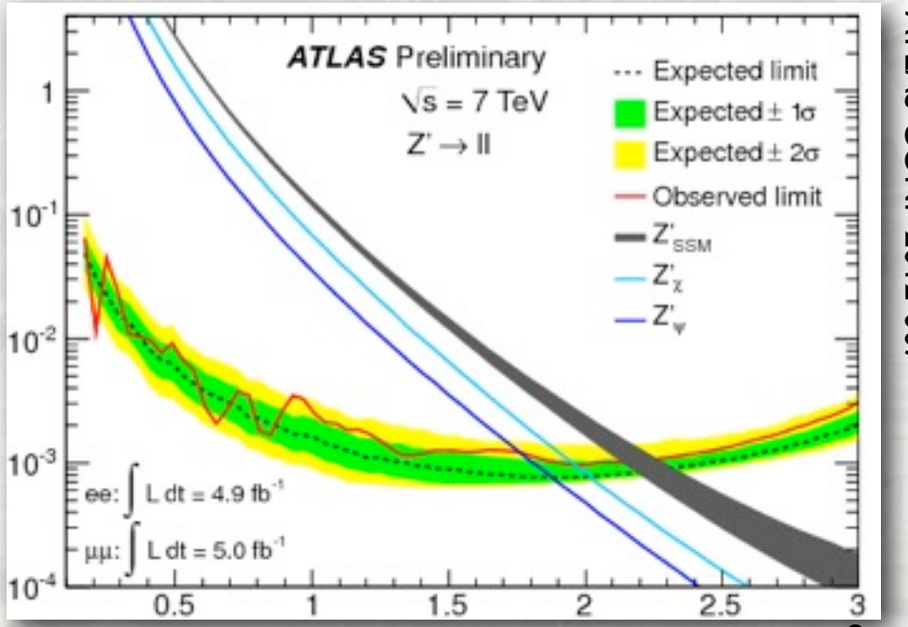
Dilepton Results

- Data consistent with SM backgrounds
- Systematic uncertainties considered
  - normalization to Z-peak, PDF choice and QCD corrections
- Set limits on σ×BR for Z' and G*
  - Combine muon and electron
  - Plots show the 95% CL limits

E_6 Z'	Limit [TeV/c^2]
Z'_ψ	1.76
Z'_N	1.78
Z'_η	1.84
Z'_I	1.84
Z'_S	1.90
Z'_χ	1.96

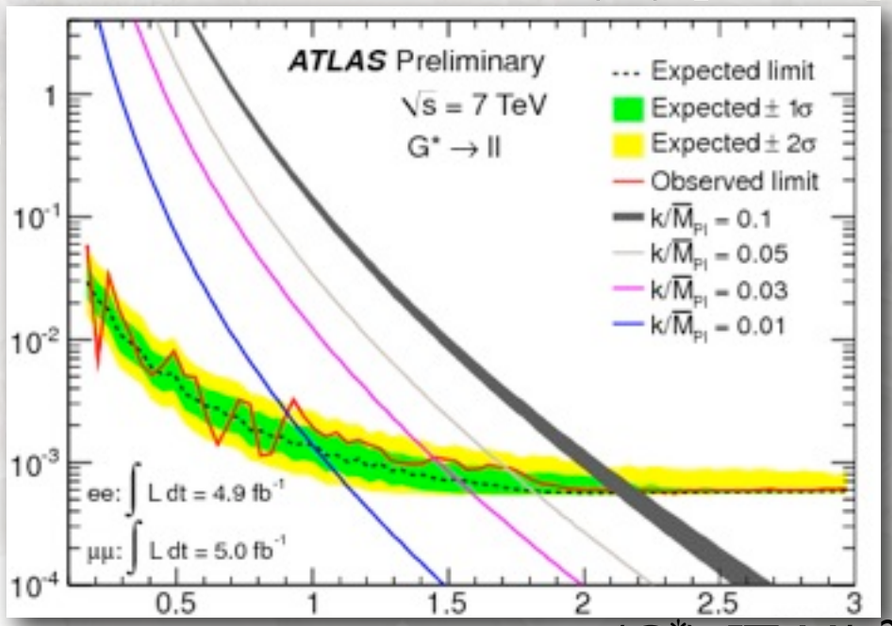
RS Graviton $k/\overline{M}_{\rm Pl}$	Limit [TeV/c^2]
0.01	0.91
0.03	1.45
0.05	1.71
0.1	2.16

σ×BR [pb]



ATLAS-CONF-2012-007

σ×BR [pb]

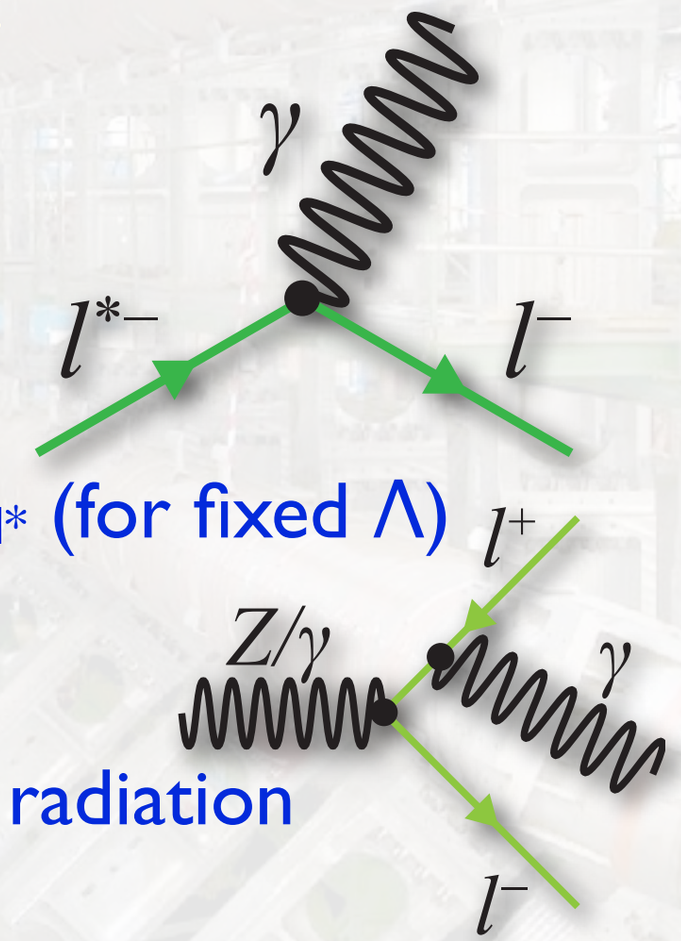


ATLAS-CONF-2012-007

Excited Leptons

- Extension to the SM: quarks, leptons composite particles
  - Each composed of "preons"
  - Excited lepton states may be produced at LHC:
- New parameters introduced
  - Λ compositeness scale
  - m_{l^*} mass of an excited lepton
- Excited states can decay by emitting photon
  - $\mathrm{BR}(\ell^{*\pm} \to \ell^{\pm}\gamma)$ decreases with increasing m_{l^*} (for fixed Λ)
    - Competing decay is $\ell^{*\pm} \to \ell^{\pm} f \bar{f}$
- Backgrounds
  - Drell-Yan + prompt photon or final/initial state radiation
  - Z+jets with jet mis-identified as a photon
  - Small contribution from ttbar and diboson (WW, WZ, ZZ)
  - W+jet and QCD negligible after lepton+photon isolation

$$q\bar{q} \to \ell^{*\pm}\ell^{\mp}$$



Analysis and Trigger

- Width of l^* predicted to be narrower that detector resolution for m_{l^*}<0.5Λ
  - Could use resonance search in $l+\gamma$ mass spectrum BUT ambiguity about which "l" is the decay product

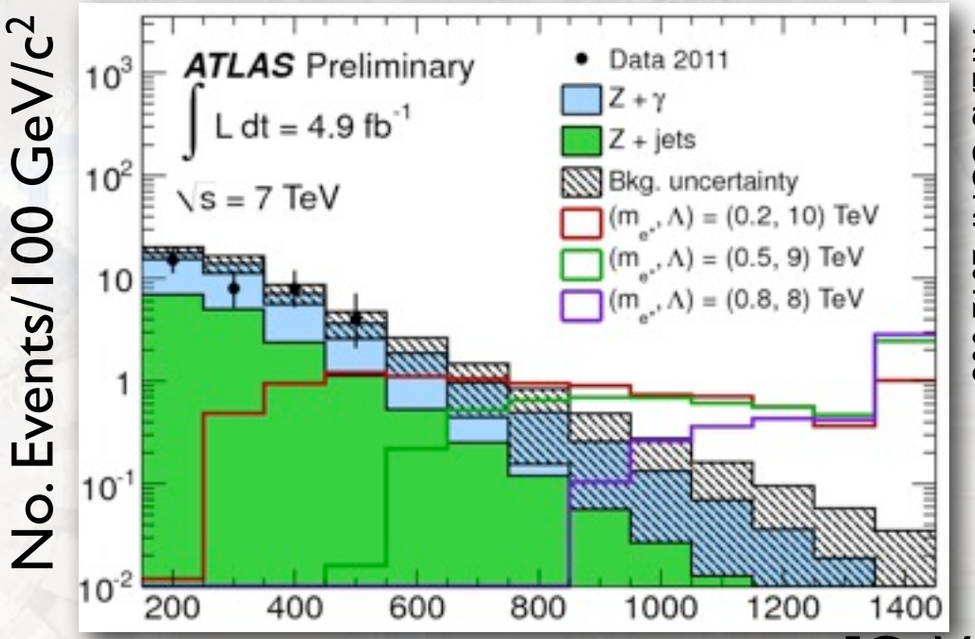
$$q\bar{q} \rightarrow \ell^{*\pm}\ell^{\mp}$$

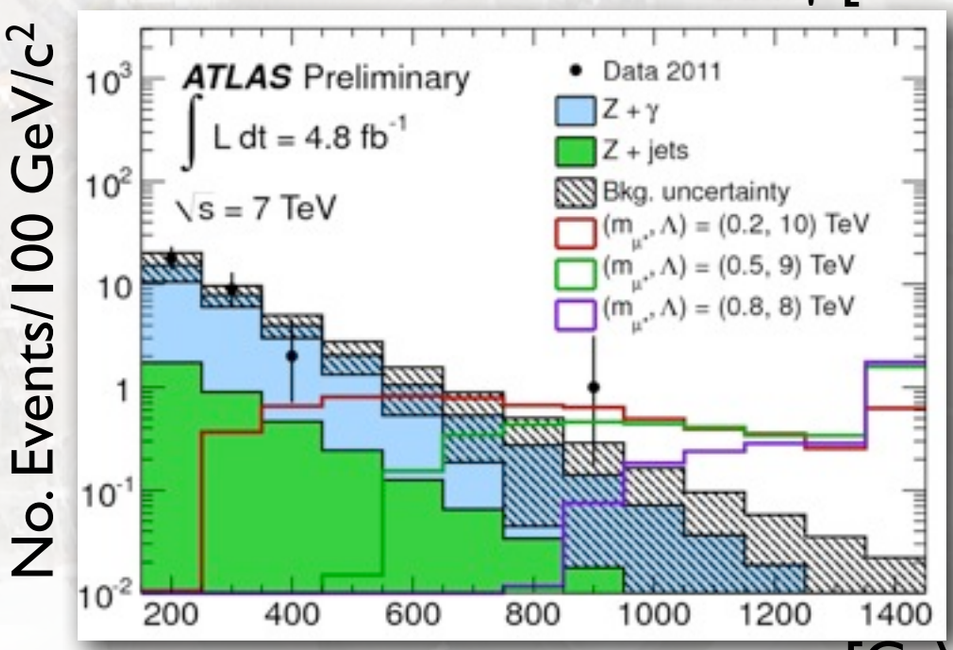
- Better strategy: look at $l^+ + l^- + \gamma$ mass spectrum
  - At high invariant mass (>~350GeV/c^2) almost no background
  - Covers whole m_{l^*}-Λ plane
- Consider only electron and muon channels

	eeγ Channel	**μμγ Channel**
Dataset	4.9 fb^{-1}	4.8 fb^{-1}
Trigger	2 e, $E_T \geq 20$ GeV	1 μ, $p_T \geq 22$ GeV/c or 1 μ, $p_T \geq 40$ GeV/c MSonly

Selection & Backgrounds

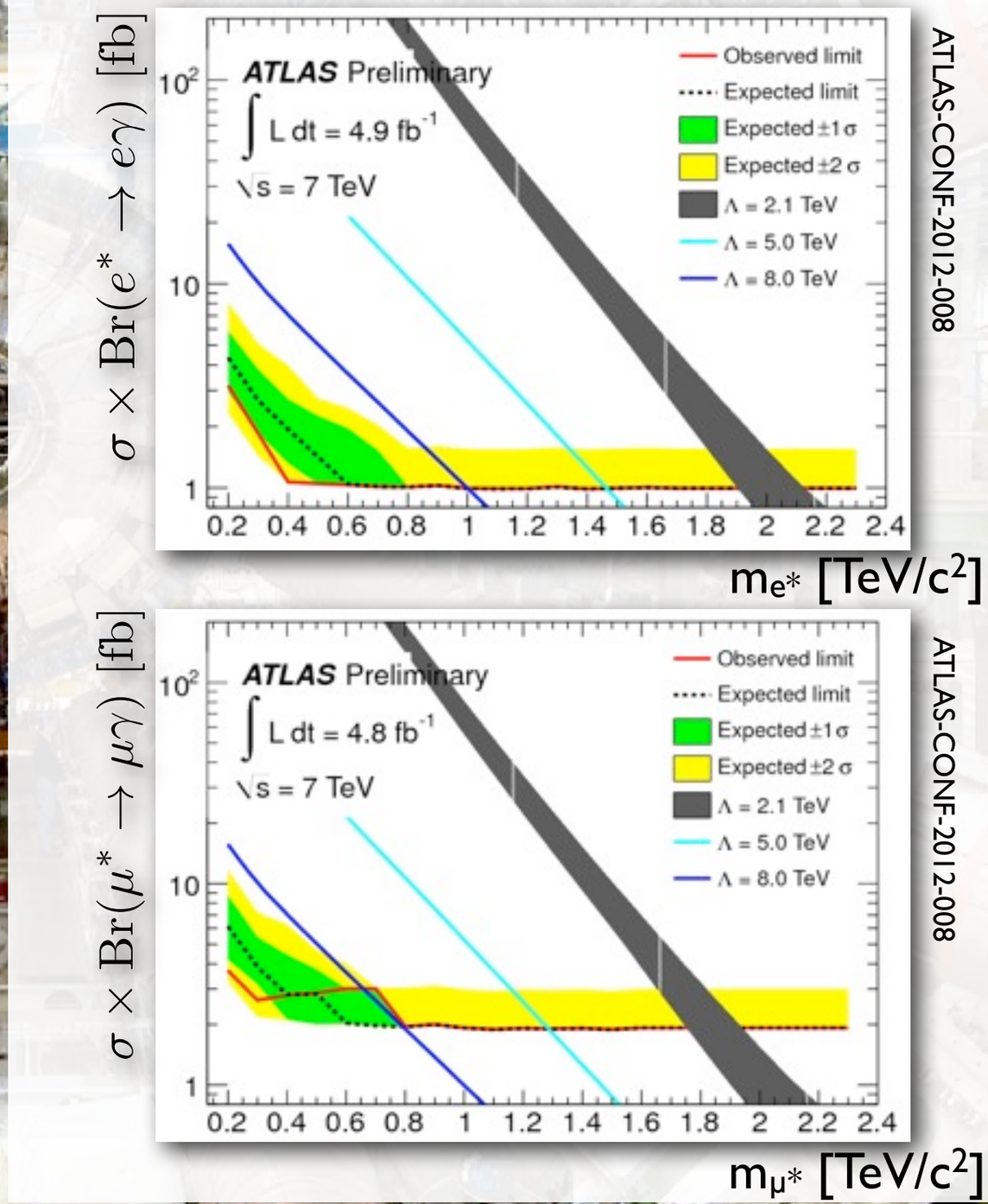
- Electron and μ selection as before
- Common, γ cuts
  - 1 "tight" γ, $E_T \geq 25$GeV and $|\eta| < 2.37$
  - Isolated: $\sum E_T(\Delta R < 0.4) < 10$ GeV
  - Separated from leptons to remove Z/γ* FSR: $\Delta R(\ell, \gamma) > 0.7$
- Background dominated by Z/γ*+γ and Z+jets
  - Monte-Carlo overestimates rate of jet faking γ
    - adjust Z+jets to fit data in signal depleted region where m_{ll}<110 GeV/c^2
  - Low MC background statistics for m_{ll}>110 GeV/c^2
    - Fit each over range 150 < m_{lly} < 950 GeV/c^2 and use projection where m_{lly} > 350 GeV/c^2



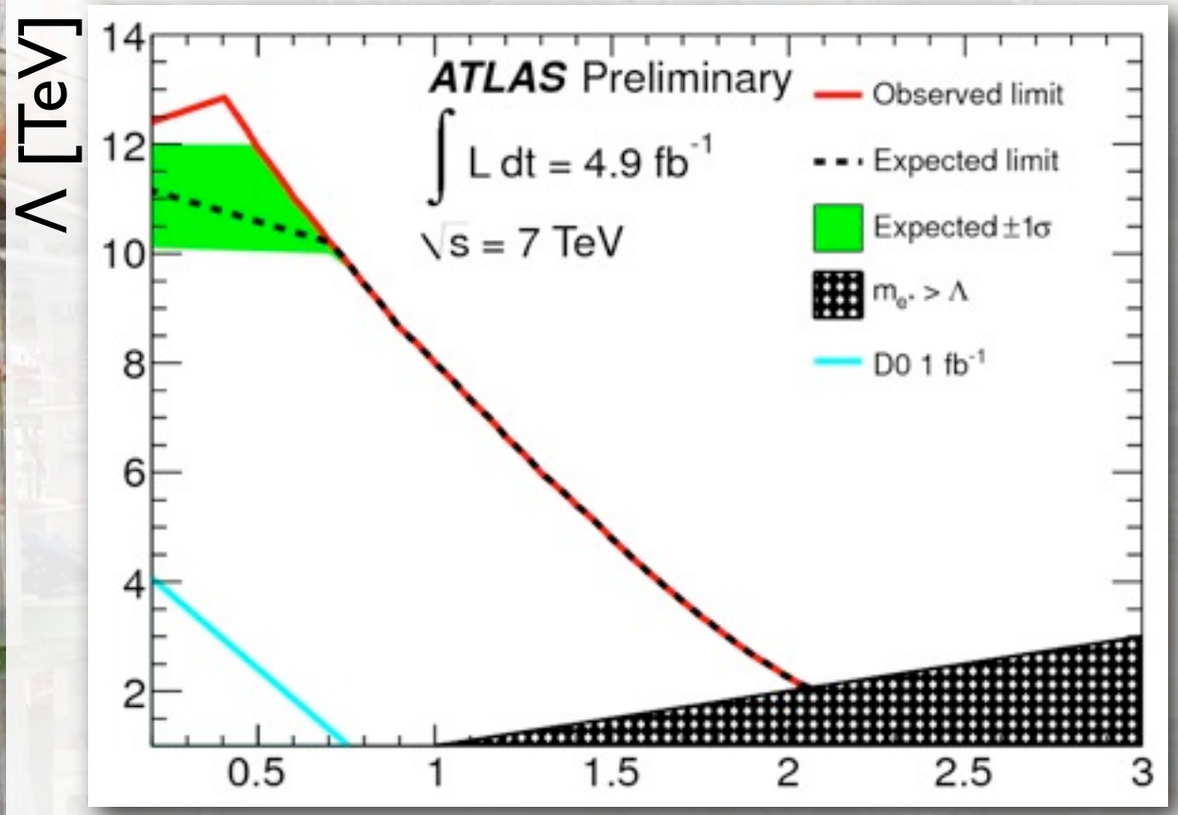


Excited Lepton Results

- Systematics
  - Z+γ background fit dominates due to low statistics with m_{ll}>110 GeV/c^2
    - 20-80% for m_{ll}>800 GeV/c^2
    - NLO+PDF theory (10%)
  - Z+jets normalization (10%)
  - Luminosity (3.9%)
  - Reconstruction and particle ID [see paper]
- Set limit using Bayesian approach with a flat, positive prior
  - On σ×BR as function of m_{l^*}
  - On m_{l^*}-Λ phase space
- For case where $m_{l^*}=\Lambda$
  - Limits are 2.0 and 1.9 TeV/c^2 on m_{e^*} and m_{μ^*} respectively @ 95% CL
  - CMS: 1.07(1.09) TeV/c^2 @ 95% CL for e*(μ*) with 36 pb^{-1} data

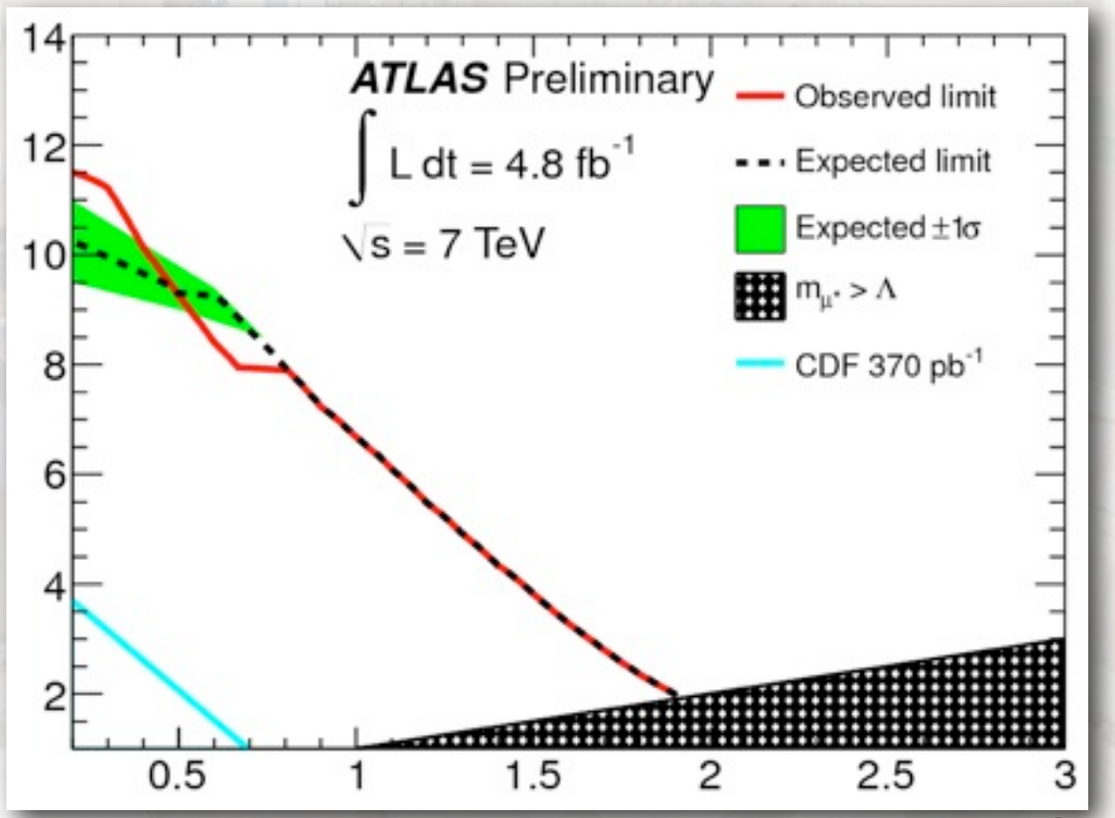


m_{l^*}-Λ Exclusion



$m_{e^*} > 2.0\ \mathrm{TeV/c^2}$ @ 95% CL
for $\Lambda = m_{\ell^*}$

$m_{\mu^*} > 1.9\ \mathrm{TeV/c^2}$ @ 95% CL
for $\Lambda = m_{\ell^*}$

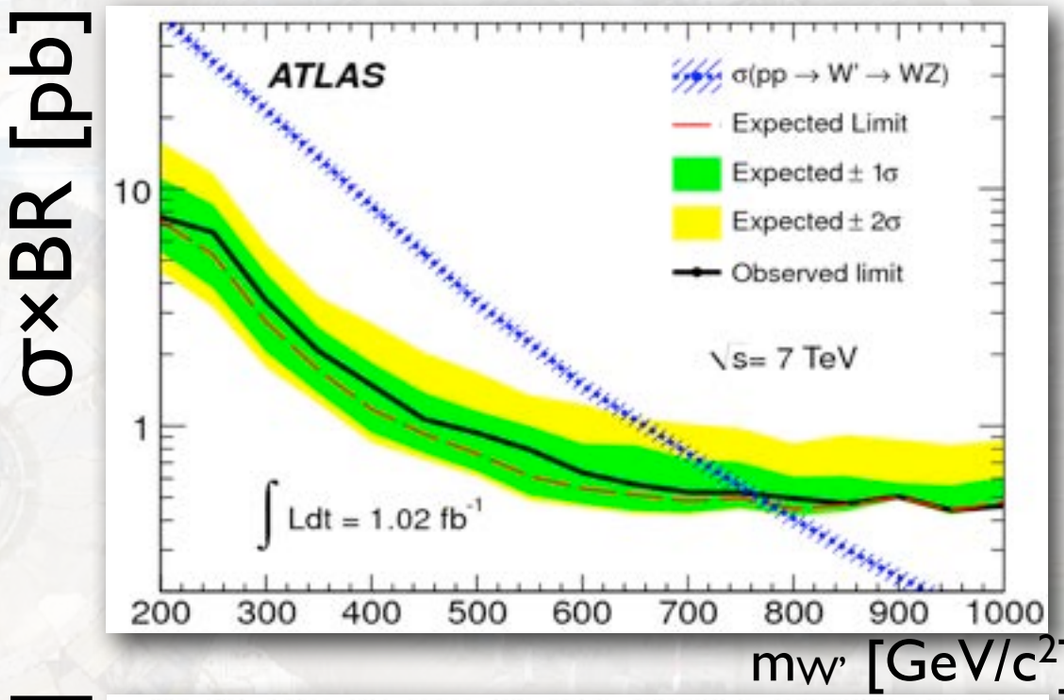


Resonant WZ Production

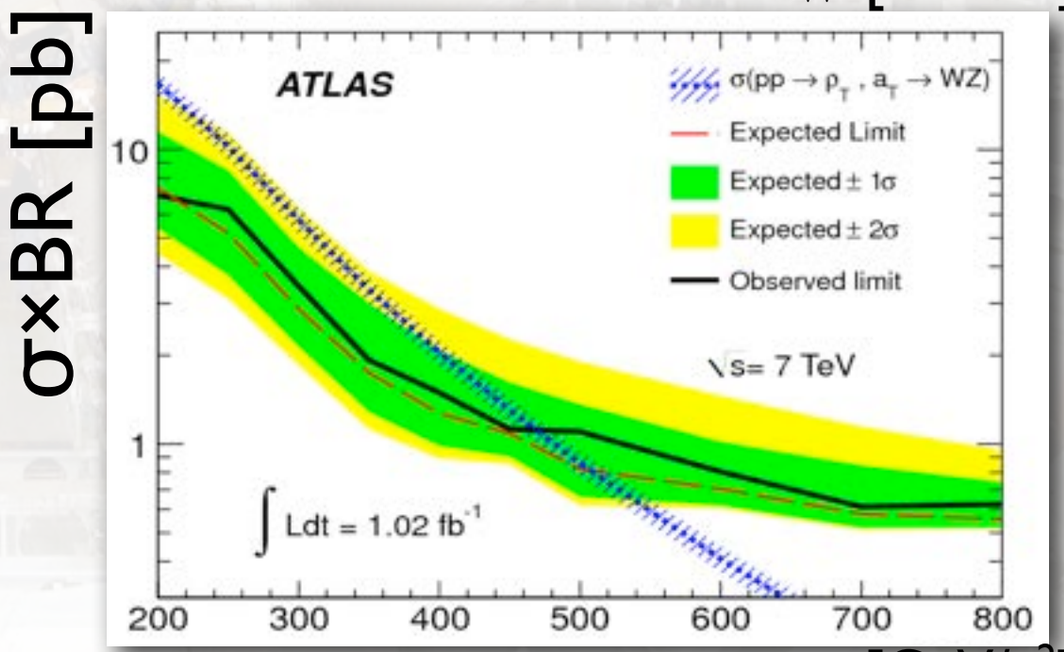
- Some models predict resonant structures in WZ production
  - Extended Gauge Model, Extra Dimensions and Technicolour

$$X \to WZ \to \ell\nu\ell'\bar{\ell}' \quad (\ell, \ell' = e, \mu)$$

- e,μ criteria similar to other analyses
  - 2 opposite sign leptons with m_{ll} within 20GeV of m_Z
  - 3 lepton and MET>25GeV
  - Only 3 leptons (ZZ background)
  - W transverse mass>15 GeV/c^2
- Backgrounds
  - SM WZ, ZZ, Zγ, *ll'*+jets
- No excess events in 1.02fb^{-1}
  - Set limits on σ×BR for EGM and Technicolour models



arXiv:1204.1648v1



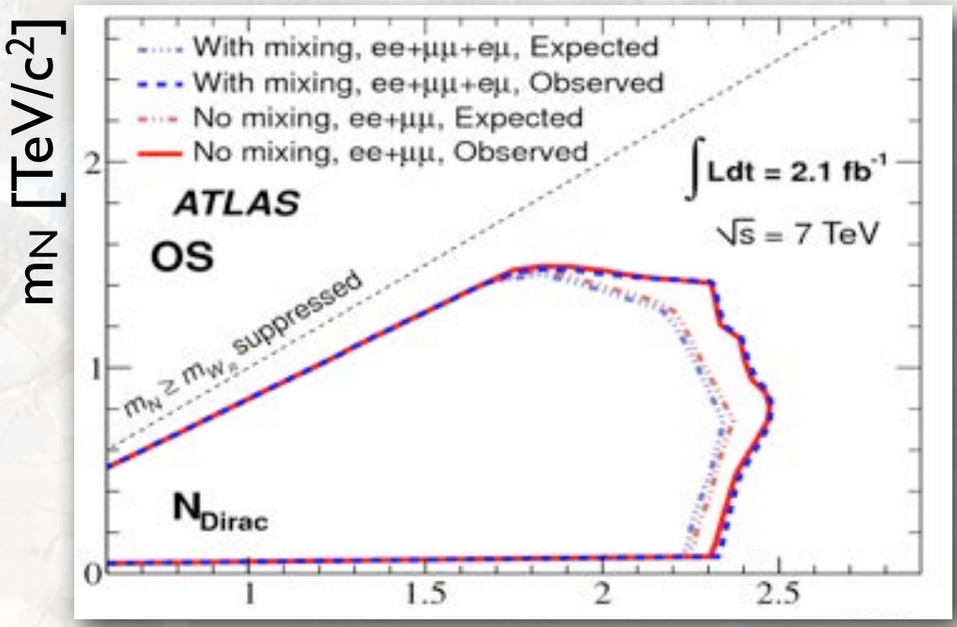
arXiv:1204.1648v1

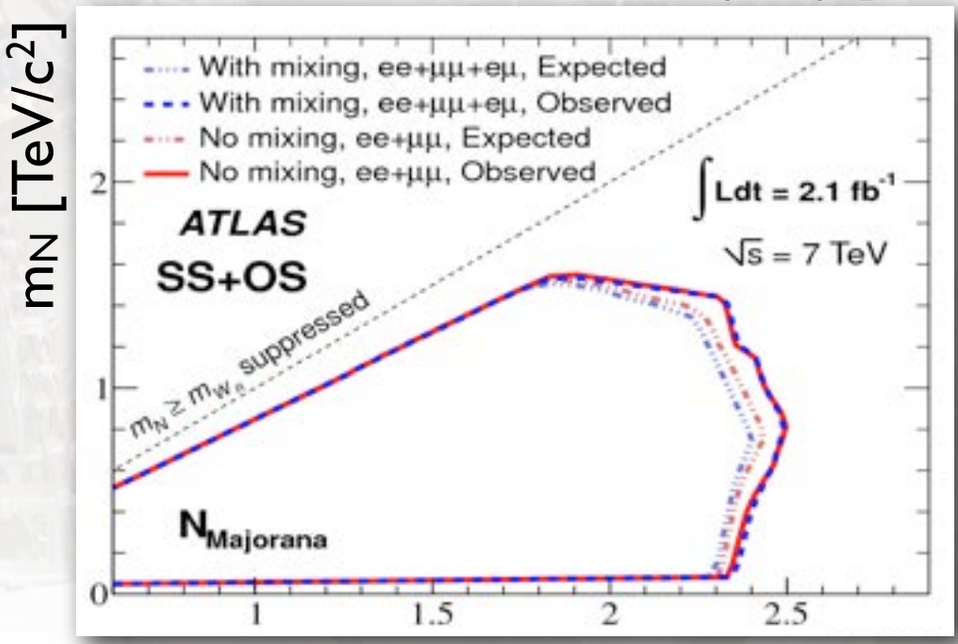
Heavy Neutrinos and W_R

- Search for right-handed extension to SM with associated heavy neutrino (N)

$$q\bar{q}' \to W_R \to \ell N$$
$$N \to \ell W_R^* \to \ell jj$$

- Only decays to e,μ considered
  - Event selection criteria very similar to previous analyses
  - N mixing: e+μ in event
  - Majorana: same sign leptons
- Major backgrounds
  - Z+jets, ttbar, diboson, single top
- First 2.1fb^{-1} of 2011 data analyzed
  - No events over background
  - Set limits in $m(W_R)$-$m(N)$ plane





Conclusions

- ATLAS is working on many analyses for beyond SM physics
  - ...this talk is just a taste of the most recent decaying to leptons
  - See the "Searches for Exotics physics states in jets and boosted objects final states" in ~1 hour for more searches like lepton-jets
- No signs of new, exciting physics so far but several searches yet to complete on 2011 data
  - 2011 dataset has taken us well beyond the reach of the Tevatron: we are far past the explored energy frontier
- 2012 dataset to look forward to!
  - Increased 8 TeV energy good for searches
  - ...and increased luminosity too
- Still plenty of opportunity to make some theorists' day....or to ruin it!

Backup Slides

For more information, conference notes, news and event pictures, videos etc. visit:

http://atlas.ch/

Dilepton Data Tables

$m_{e^+e^-}$ [GeV]	110 - 200	200 - 400	400 - 800	800 - 1200	1200 - 3000
Z/γ^*	26300 ± 800	3080 ± 120	265 ± 14	12.2 ± 0.9	1.46 ± 0.18
$t\bar{t}$	1300 ± 70	403 ± 26	28 ± 4	1.0 ± 0.8	0.021 ± 0.021
Diboson	440 ± 17	147 ± 8	14.7 ± 2.2	1.0 ± 0.4	0.06 ± 0.06
(W + jets) and QCD	2000 ± 400	420 ± 160	40 ± 40	1.8 ± 1.2	0.11 ± 0.08
Total	30000 ± 900	4050 ± 200	340 ± 40	16.0 ± 1.8	1.64 ± 0.21
Data	29993	4038	358	17	3

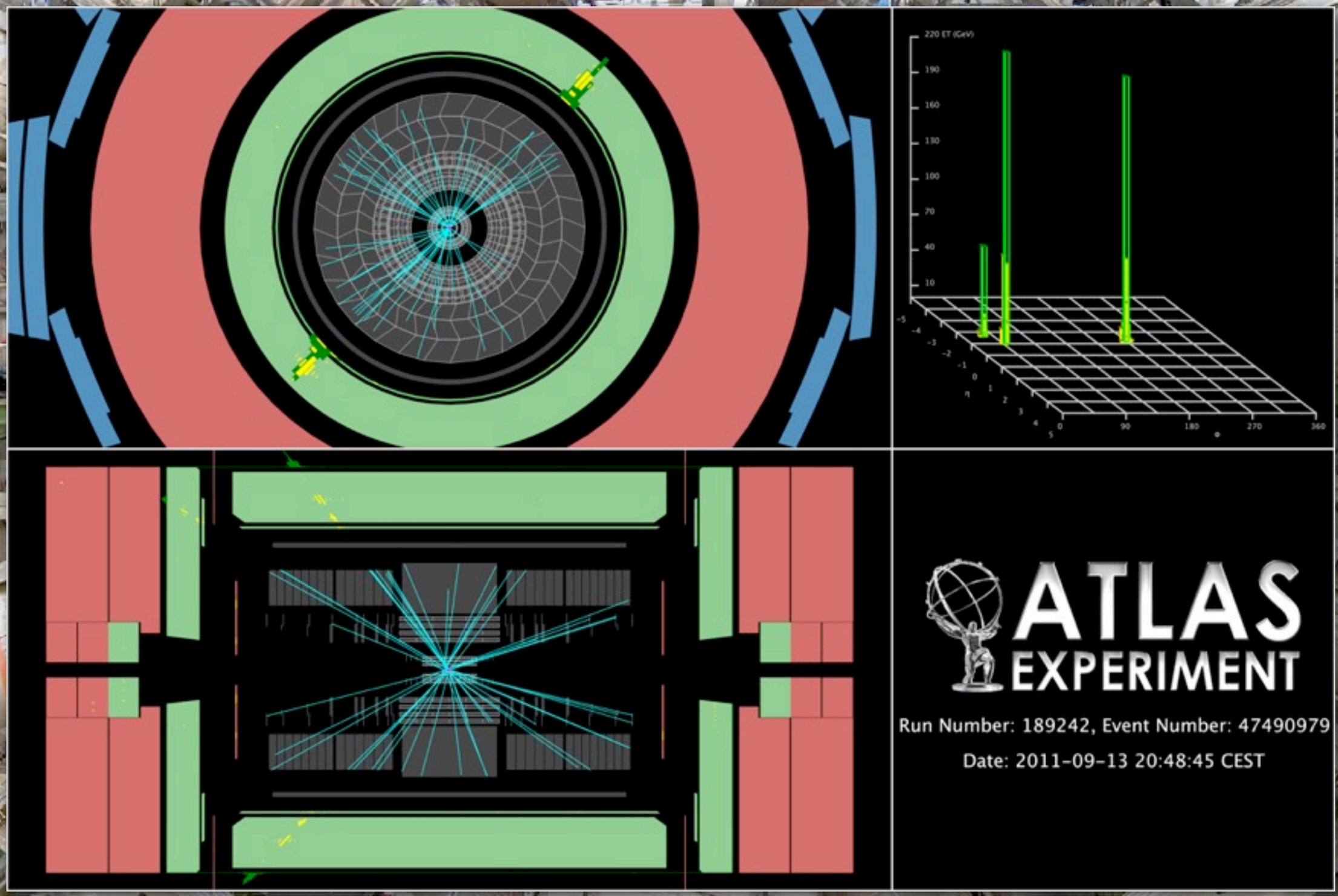
$m_{\mu^+\mu^-}$ [GeV]	110 - 200	200 - 400	400 - 800	800 - 1200	1200 - 3000
Z/γ^*	21000 ± 900	2040 ± 90	174 ± 9	7.3 ± 0.5	0.90 ± 0.11
$t\bar{t}$	830 ± 80	254 ± 24	20.0 ± 2.1	0.59 ± 0.15	< 0.005
Diboson	283 ± 15	98 ± 5	12.7 ± 1.0	0.83 ± 0.24	0.022 ± 0.028
(W + jets) and QCD	7 ± 4	< 0.5	< 0.5	< 0.05	< 0.005
Total	22100 ± 900	2400 ± 90	206 ± 9	8.7 ± 0.6	0.92 ± 0.11
Data	21941	2293	197	10	2

Excited Lepton Data Table

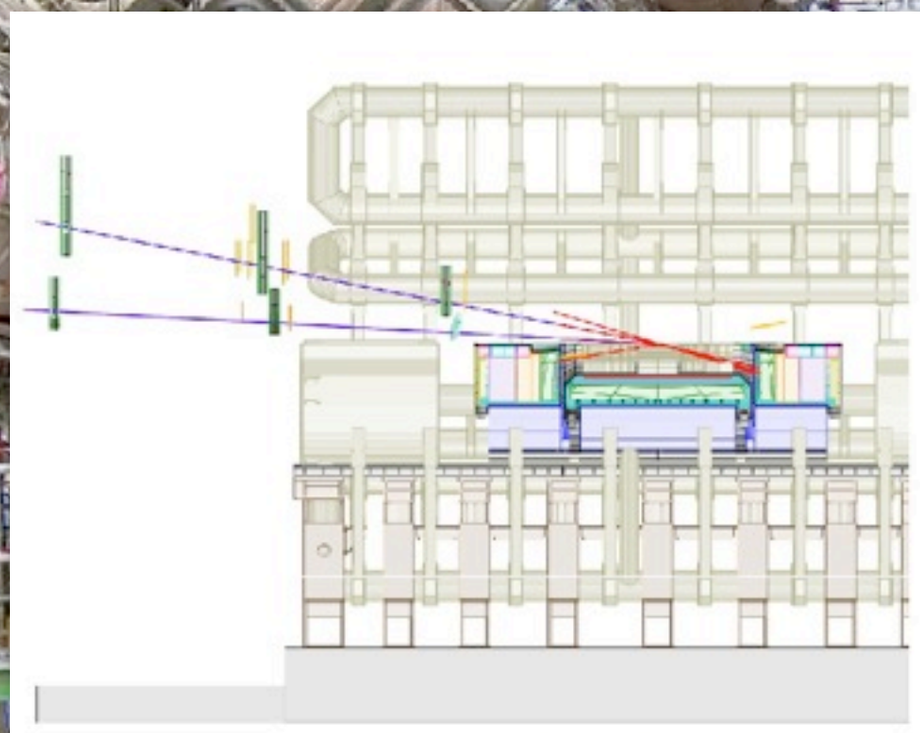
Region [GeV]	$Z+\gamma$	Z + jets	other	data
$m_{ee} < 110$	195 ± 2	115 ± 16	4.9 ± 0.6	315
$m_{ee} > 110$	32 ± 1	13 ± 3	4.5 ± 0.6	43
$m_{\mu\mu} < 110$	148 ± 2	101 ± 13	4.6 ± 0.6	254
$m_{\mu\mu} > 110$	20 ± 1	2.6 ± 0.9	0.4 ± 0.4	30

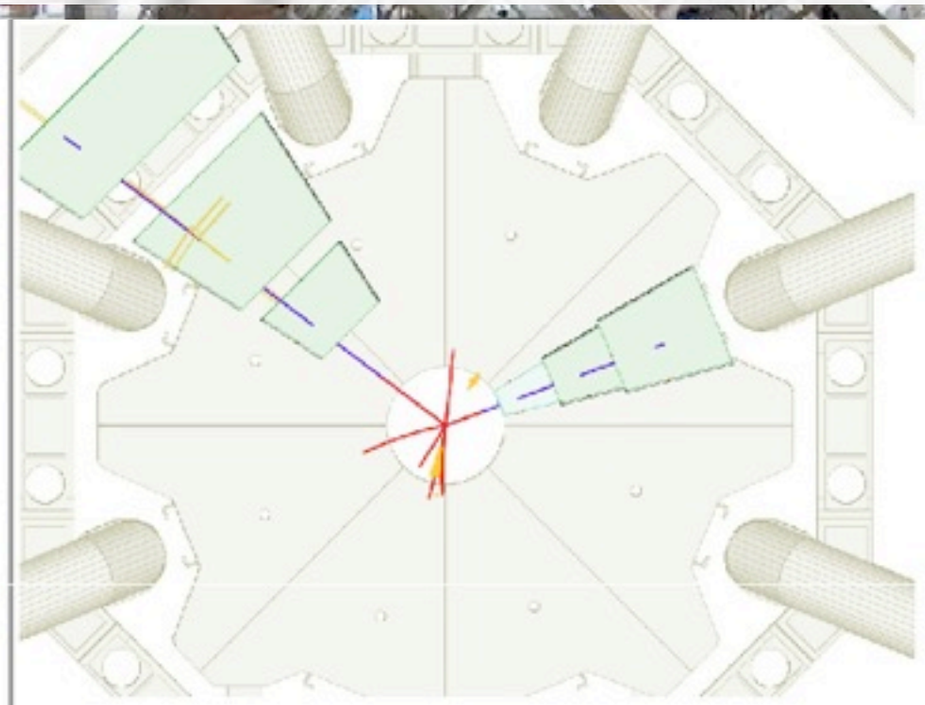
$m_{\ell\ell\gamma}$ region	e^* search			μ^* search		
[TeV]	$Z+\gamma$	total bkg	data	$Z+\gamma$	total bkg	data
> 0.35	12.4 ± 2.2	17.0 ± 2.8	12	7.2 ± 1.2	7.5 ± 1.3	3
> 0.45	5.9 ± 1.2	7.9 ± 1.6	4	3.6 ± 0.9	3.7 ± 1.0	1
> 0.55	2.8 ± 0.8	3.7 ± 1.1	0	1.9 ± 0.6	1.9 ± 0.6	1
> 0.65	1.35 ± 0.56	1.74 ± 0.73	0	0.95 ± 0.39	0.96 ± 0.42	1
> 0.75	0.64 ± 0.35	0.81 ± 0.46	0	0.49 ± 0.24	0.49 ± 0.27	1
> 0.85	0.31 ± 0.21	0.38 ± 0.28	0	0.25 ± 0.14	0.25 ± 0.16	1
> 0.95	0.15 ± 0.12	0.18 ± 0.17	0	0.13 ± 0.08	0.13 ± 0.10	0

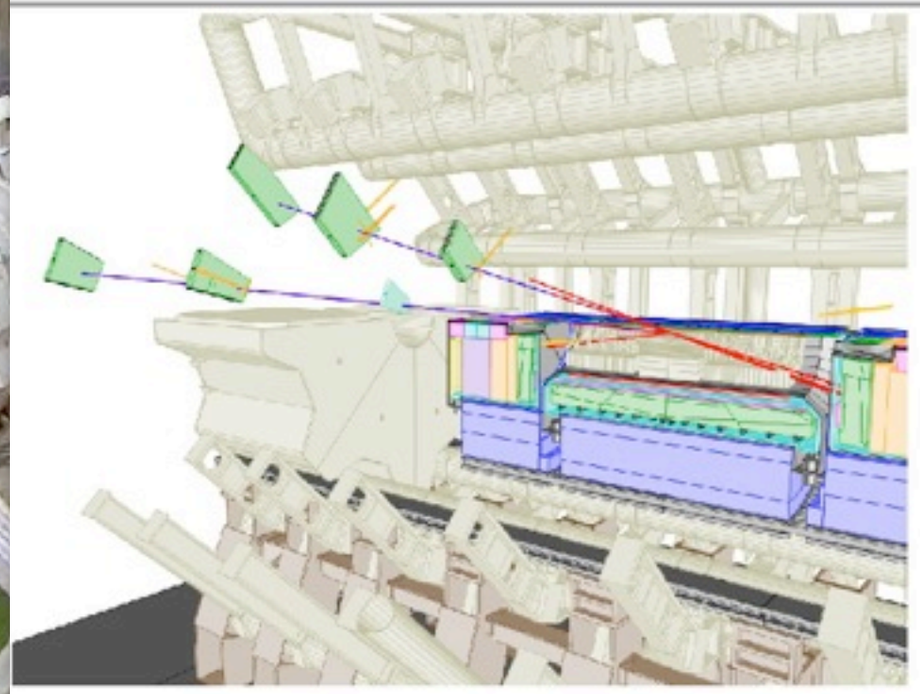
Highest m_{eey} Event



Highest $m_{\mu\mu\gamma}$ Event







ATLAS EXPERIMENT

Run Number: 186169,
Event Number: 33317424
Date: 2011-07-23, 03:55:27 CET

Cells: Tiles, EMC

Heavy Neutrino Tables

Physics Processes	$e^{\pm}e^{\mp}$	$\mu^{\pm}\mu^{\mp}$	$e^{\pm}\mu^{\mp}$	Total
Z/γ^*+jets	136.1 ± 12.5	173.2 ± 15.1	0.8 ± 0.8	310 ± 20
Diboson	4.3 ± 1.8	7.3 ± 1.9	5.9 ± 1.6	18 ± 3
Top	103.1 ± 12.3	100.9 ± 12.0	199.4 ± 23.3	403 ± 46
Fake lepton(s)	12.5 ± 8.1	-0.2 ± 0.7	6.1 ± 4.2	18 ± 9
Total Background	256.0 ± 26.2	281.2 ± 27.9	212.3 ± 33.8	750 ± 78
Observed events	248	245	247	740
	$m_{\ell\ell j(j)} \geq 400$ GeV			
Total Background	254.8 ± 25.8	279.7 ± 27.6	210.9 ± 33.4	745 ± 77
Observed events	246	241	244	731

Physics Processes	$e^{\pm}e^{\pm}$	$\mu^{\pm}\mu^{\pm}$	$e^{\pm}\mu^{\pm}$	Total
Z/γ^*+jets	26.1 ± 5.6	$0.0^{+1.6}_{-0}$	1.2 ± 0.7	27 ± 6
Diboson	12.7 ± 2.3	7.2 ± 1.7	18.8 ± 3.0	39 ± 6
Top	5.8 ± 1.3	0.7 ± 0.3	6.8 ± 1.6	13 ± 3
Fake lepton(s)	93.6 ± 35.7	3.1 ± 1.6	53.8 ± 20.3	151 ± 50
Total Background	138.3 ± 36.5	$11.0^{+2.9}_{-2.5}$	80.7 ± 20.8	230 ± 52
Observed events	155	14	99	268
	$m_{\ell\ell j(j)} \geq 400$ GeV			
Total Background	48.4 ± 16.1	$4.4^{+2.1}_{-1.3}$	24.6 ± 7.6	77 ± 21
Observed events	59	8	39	106

WZ Highest Mass Event