New physics searches with dileptons and diphotons at ATLAS

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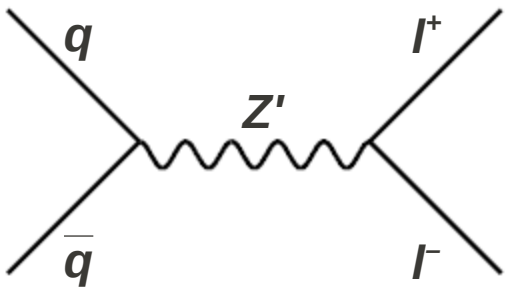
Introduction

- Will go through several recent results
  - Searches in dilepton mass spectrum
    - Search for high-mass dilepton resonances: 5 fb^{-1}
    - Search for techni-hadrons: 1 fb^{-1}
    - Search for contact interactions: 1 fb^{-1}
  - Search for excited leptons in llγ: 5 fb^{-1}
  - Searches for anomalous like-sign lepton production
    - Inclusive search: 1 fb^{-1}
    - Search for like-sign top quark production: 1 fb^{-1}
    - Search for strong gravity signatures: 1 fb^{-1}
  - Search for extra dimensions in diphoton events: 2 fb^{-1}

- ATLAS has many other related results which are covered by other speakers here

High-mass dilepton resonances: introduction



- Several models predict new resonances decaying to pairs of charged leptons
  - Spin-1 benchmarks: Z' in Sequential Standard Model or E_6 grand unified symmetry group
  - Spin-2 benchmark: Graviton in Randall-Sundrum models
  - For both, width is narrow w.r.t. detector resolution
- Searches at ATLAS in ee and μμ final states updated with 5 fb^{-1}
  - ATLAS-CONF-2012-007
- Expect very high-p_T leptons from this signal
  - No SM process with which to calibrate these
  - Need to understand detector and simulation
  - Impose tight selection cuts to assure optimal resolution
    - For muons, require hits in three stations of Muon Spectrometer in most of detector region
    - Reduces muon acceptance
    - New in 5 fb^{-1}: some two-station tracks allowed in well-understood detector regions

High-mass dilepton resonances: selection

Muons

- Trigger: one muon with p_T>22 GeV
- $p_T(\mu)$ > 25 GeV, $|\eta(\mu)|$ < 2.5
- Muons with combined ID and MS tracks, plus extra hit requirements in MS
- Both muons isolated:
  $\Sigma p_T(\Delta R < 0.3)/p_T(\mu) < 0.05$
- Muons must have opposite charges
- Acceptance * efficiency
  - Z' (2 TeV) → μμ: 43%
  - G* (2 TeV) → μμ: 47%

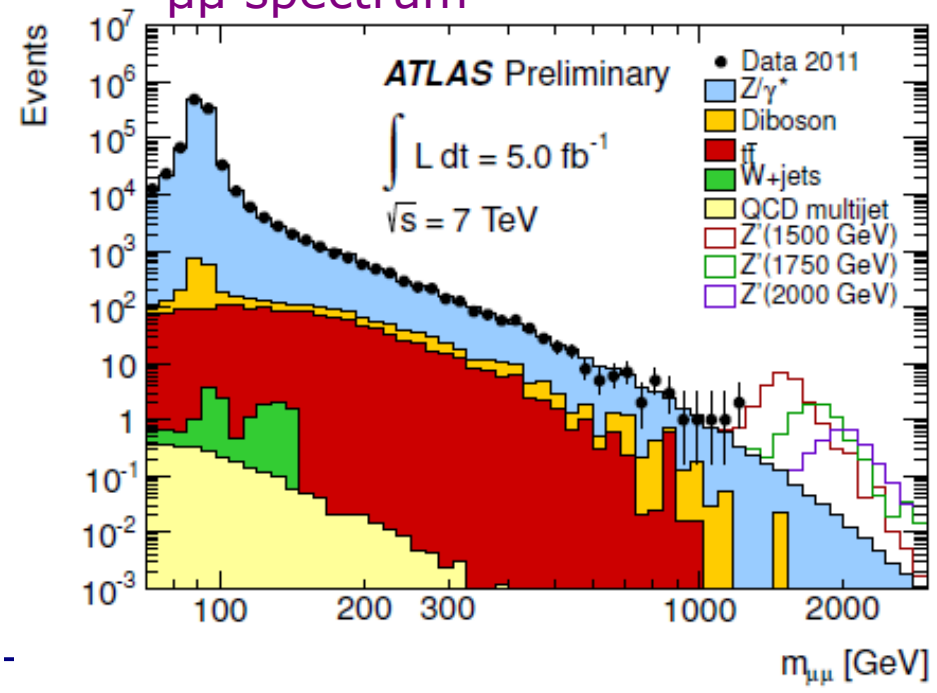
Electrons

- Trigger: two EM clusters with E_T > 20 GeV
- $E_T(e)$ > 25 GeV, $|\eta(e)|$ < 2.47
  - Excluding crack $1.37<|\eta(e)|<1.52$
- "Medium" electrons (shower shape and track matching cuts)
- Higher-p_T electron isolated:
  $\Sigma E_T(\Delta R < 0.2) < 7$ GeV
- No charge requirement
- Acceptance * efficiency
  - Z' (2 TeV) → ee: 71%
  - G* (2 TeV) → ee: 72%

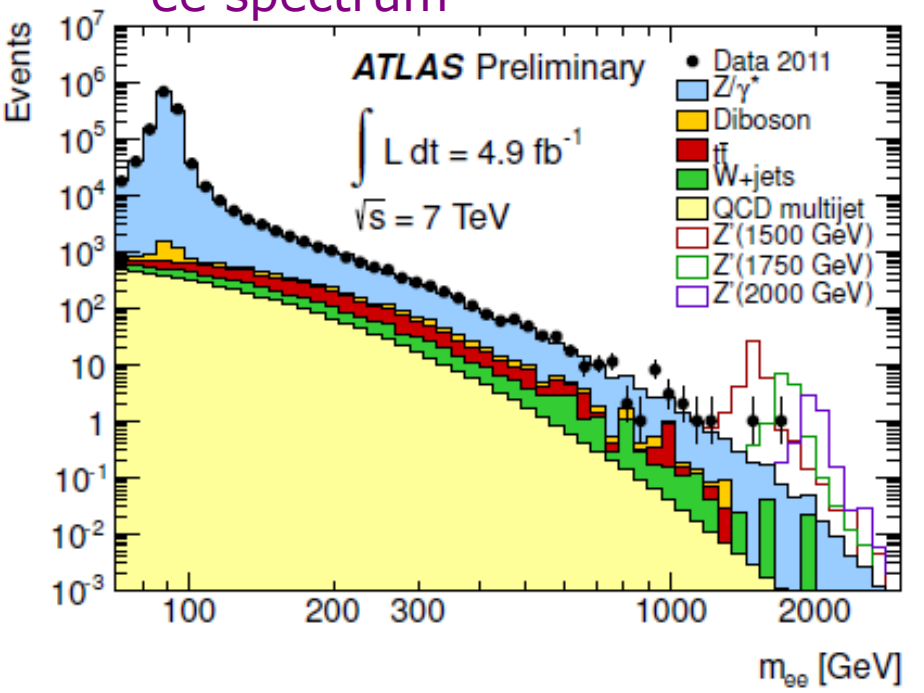
High-mass dilepton resonances: backgrounds

- Dominant background: Z/γ*: estimated from LO Monte Carlo with mass-dependent NNLO/LO K-factors applied
  - Total background normalized to data in Z peak
- Dominant systematic uncertainty: PDF and scale uncertainties on background shape: ~20% at 2 TeV
- Search strategy: compare dilepton mass to background and signal templates

μμ spectrum



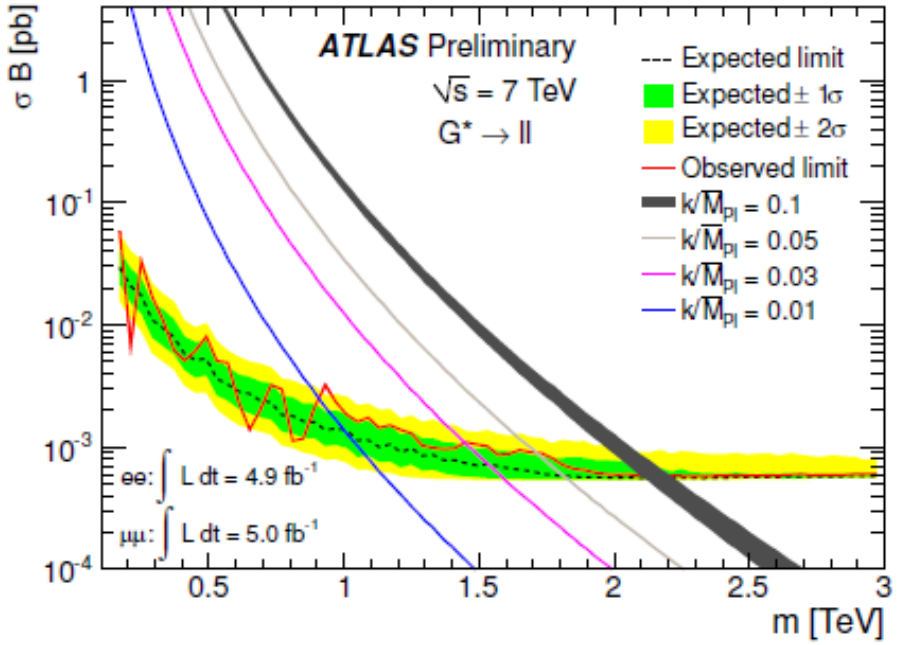
ee spectrum



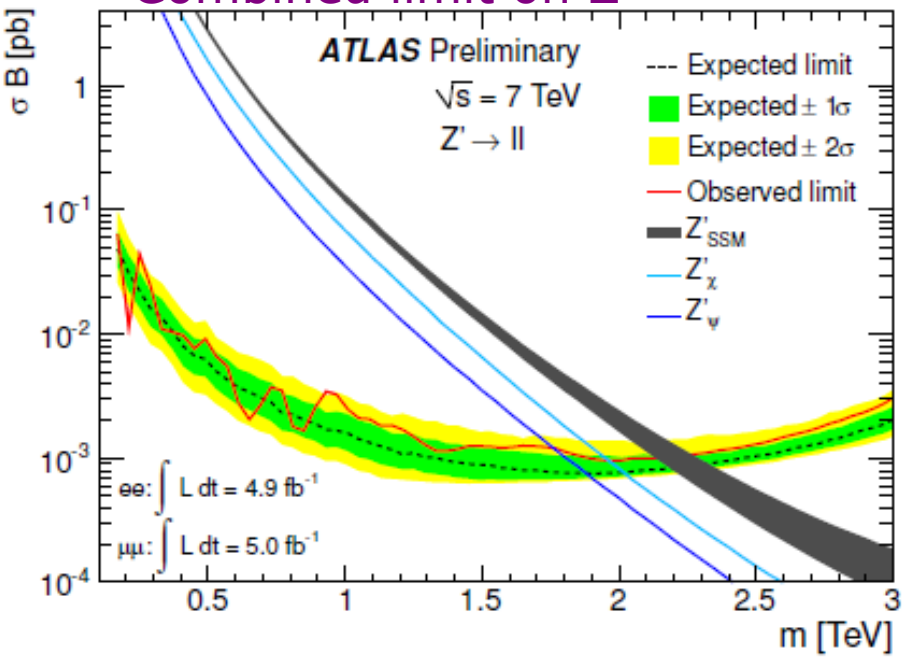
High-mass dilepton resonances: interpretation

- Derive upper limits on σ*B.R. in each channel and combined
  - Translate to lower mass limit for benchmark models

Combined limit on G*

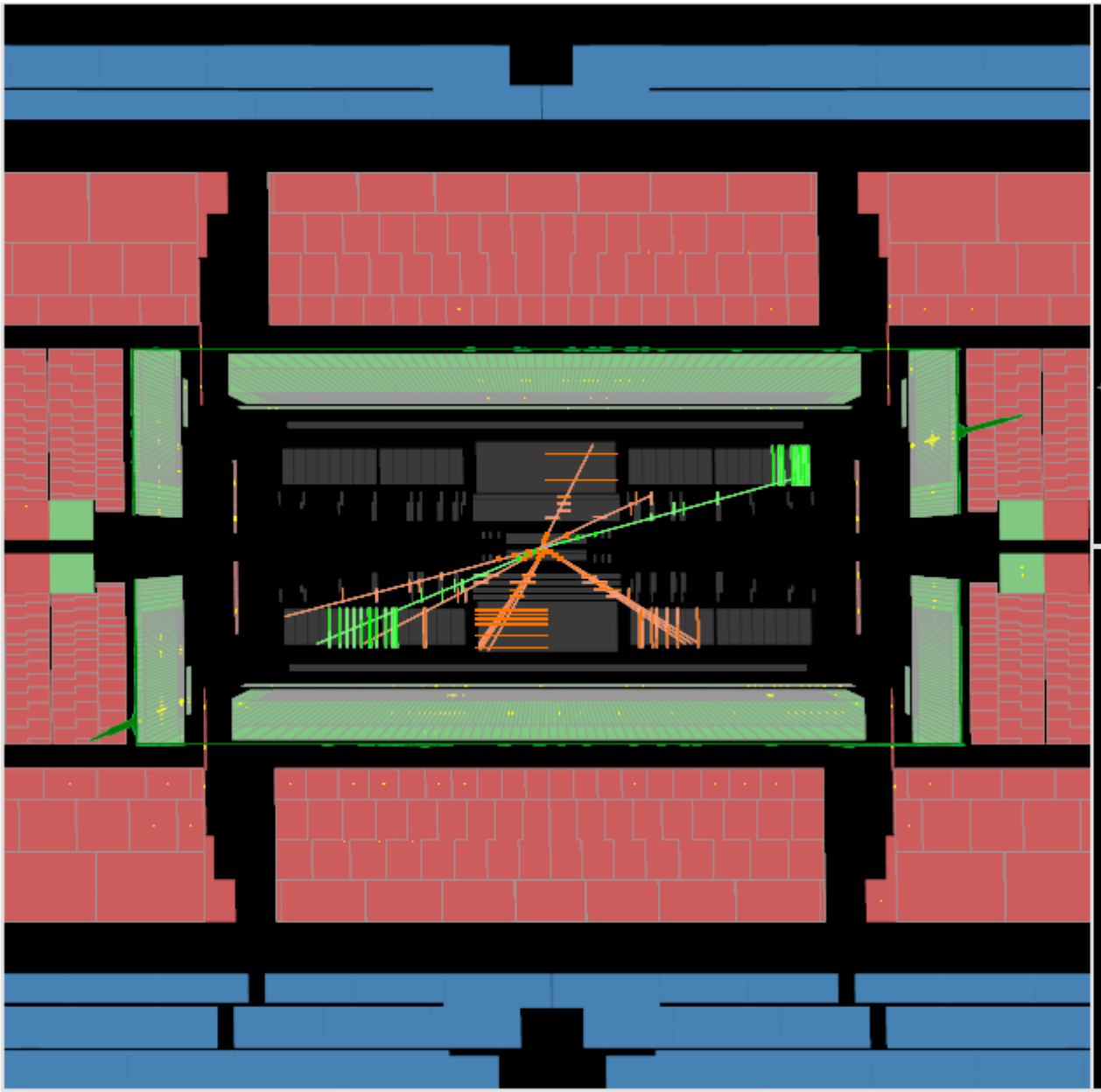


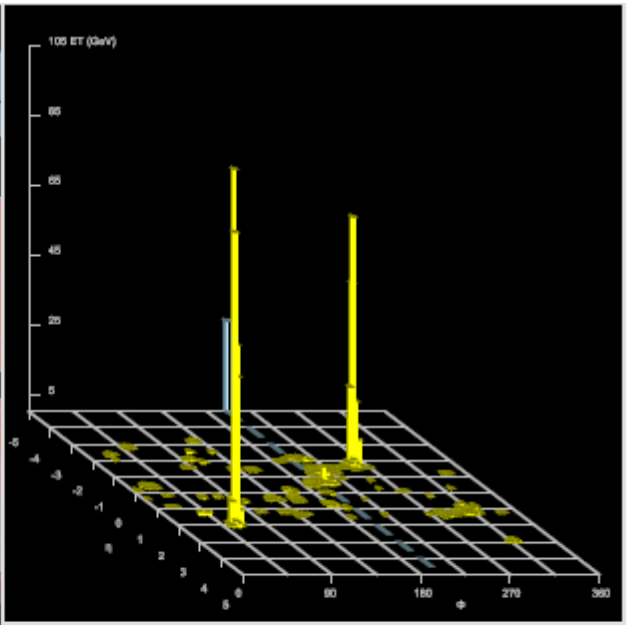
Combined limit on Z'



	Observed (Expected) mass limit [TeV]		
	ee	μμ	Combination
Z' (SSM)	2.07 (2.14)	1.99 (2.01)	2.21 (2.26)
G*	2.03 (2.05)	1.90 (1.92)	2.16 (2.17)

Highest-mass dilepton event





$m(ee) = 1.7$ TeV

$E_T(e_1) = 329$ GeV

$\eta(e_1) = 2.0$

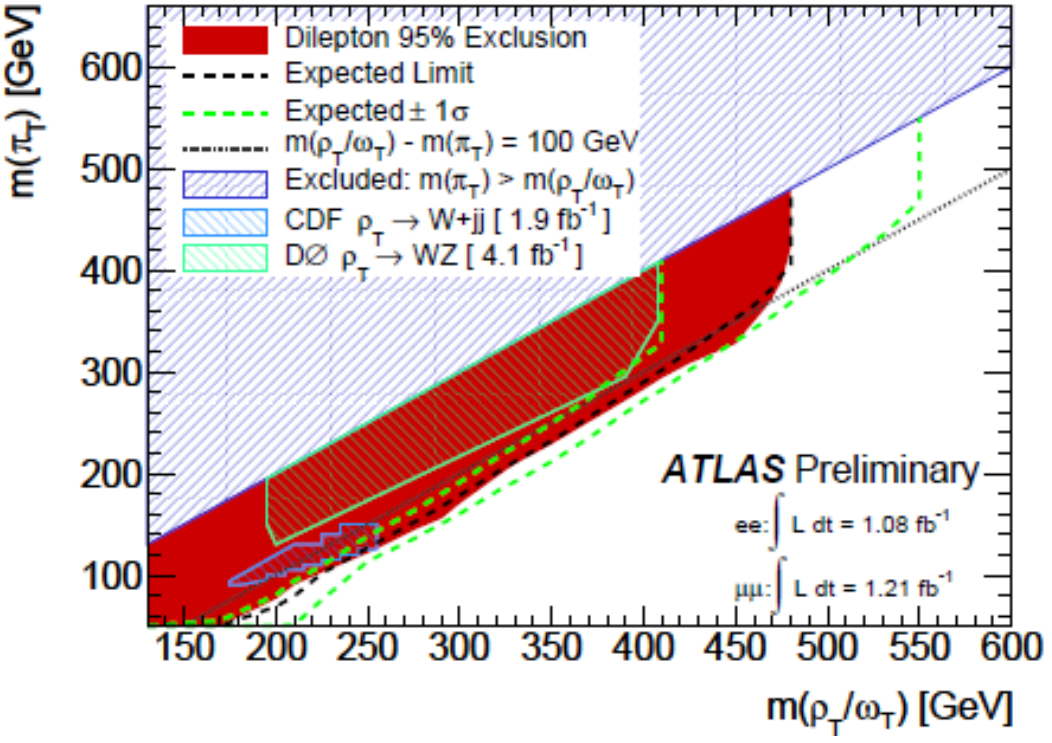
$E_T(e_2) = 217$ GeV

$\eta(e_2) = -1.6$

$\Delta\varphi(ee) = 2.9$

Techni-hadrons

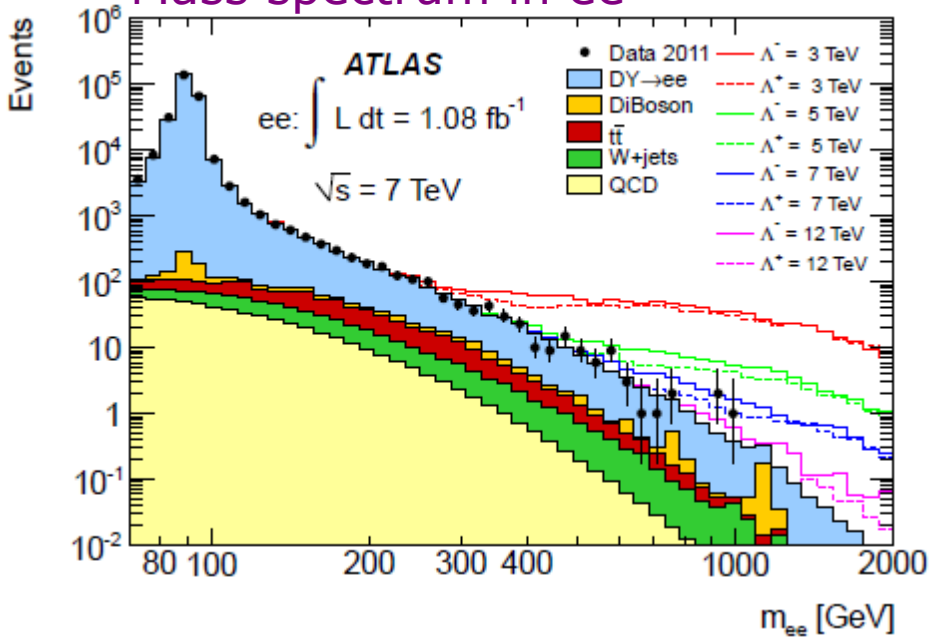
- Apply limits from Z' to another spin-1 resonance
  - Low-scale technicolor model: degenerate techni-ρ and techni-ω decaying to charged lepton pairs
  - A*ε are shown to be the same as for the Z'
- Result for ee and μμ channels in ~1 fb^{-1}: ATLAS-CONF-2011-125



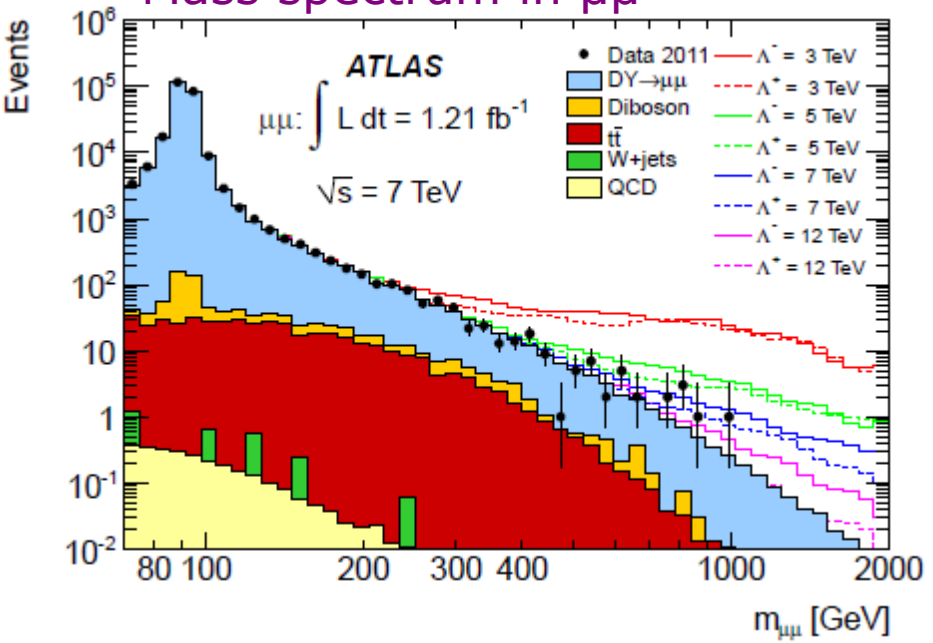
Contact interaction

- Same data sample as Z' search
- Result for ee and μμ channels in ~1 fb^{-1}: arXiv:1112.4462

Mass spectrum in ee



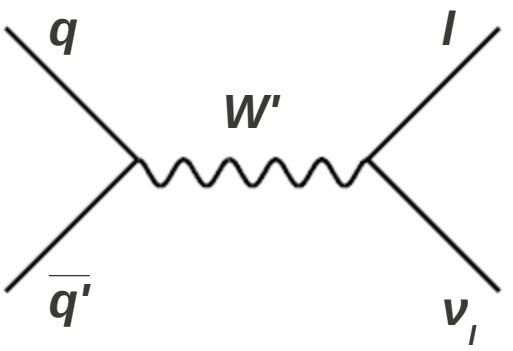
Mass spectrum in μμ



	Observed (Expected) limit on Λ[TeV]	
	Constructive	Destructive
e^+e^-	10.1 (9.6)	9.4 (9.3)
$\mu^+\mu^-$	8.0 (8.9)	7.0 (8.6)
Combined	10.2 (10.4)	8.8 (10.1)

Heavy gauge boson decaying to lν

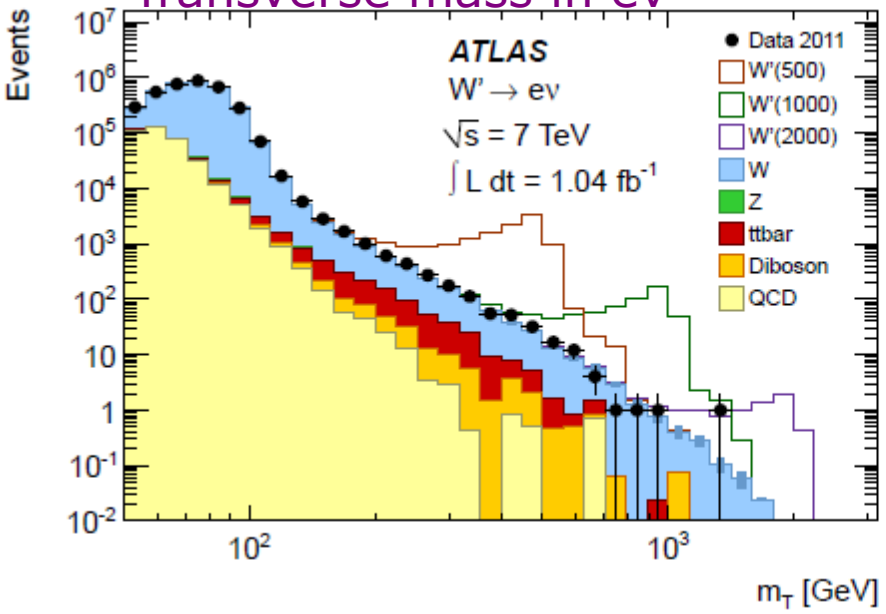
- Various extensions of SM predict heavy charged boson decaying to charged lepton and neutrino (W')
- ATLAS searched for W'→eν and W'→μν
  - Most recent result from ~1 fb^{-1}: arXiv:1108.1316



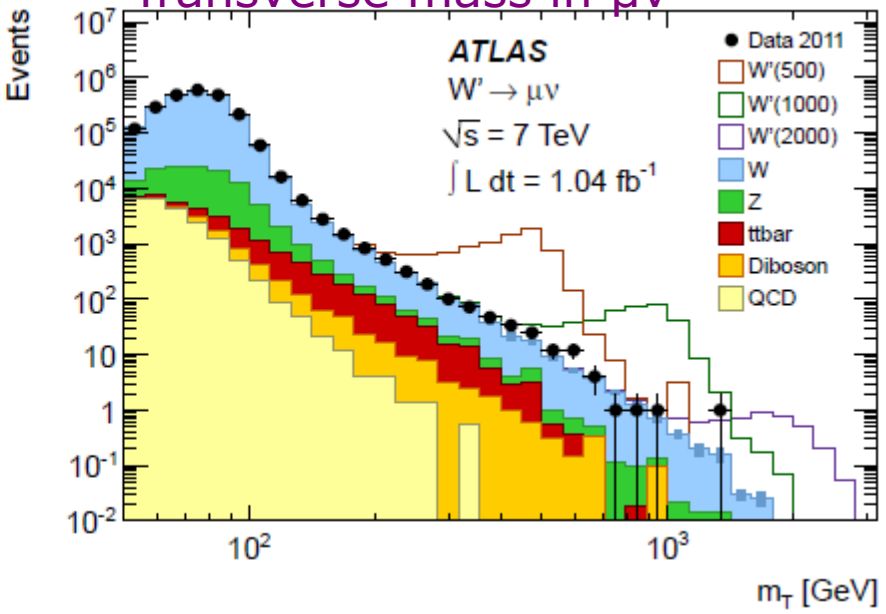
- Event selection: electron or muon plus missing transverse energy
  - $p_T(\mu) > 25$ GeV, $E_T(e) > 25$ GeV, MET > 25 GeV
  - Leptons must be isolated
  - As in Z' search, strict muon hit requirements
  - For electrons, MET > $0.6*E_T(e)$
  - Lower threshold on $m_T(W)$ dependent on mass of W'
- A*ε depends on mass of W'
  - Between 33% and 54% for electron channel
  - Between 22% and 37% for muon channel

W': results

Transverse mass in eν



Transverse mass in μν

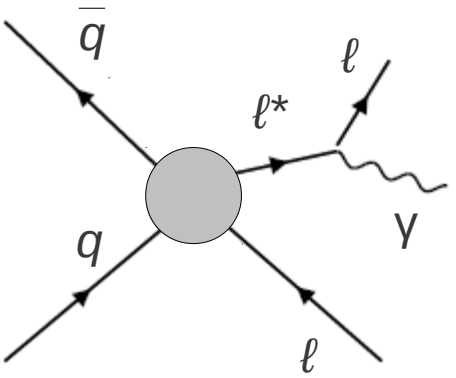


- No significant deviation from SM expectations
- Limit based on counting events above certain m_T threshold
  - Threshold optimized for each W' mass
  - e.g. for m(W') = 2 TeV, threshold = 1.122 TeV
- Set limits on W' in Sequential Standard Model

	$m_{W'}$ [TeV] Exp.	Obs.
$e\nu$	2.17	2.08
$\mu\nu$	2.08	1.98
both	2.23	2.15

Excited leptons: motivation and selection

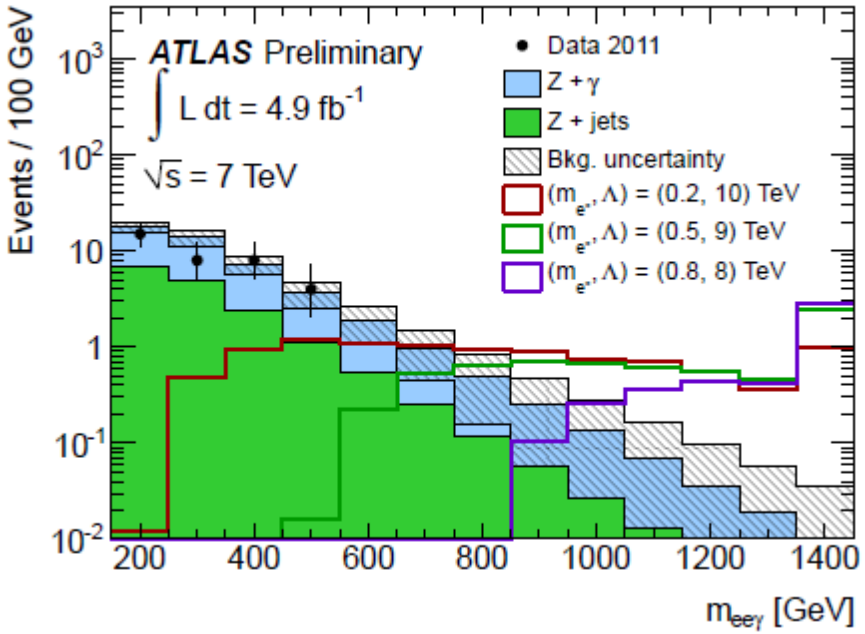
- Excited leptons occur if leptons are composite objects
  - Produced via qql*l contact interactions
  - Can decay l* → lγ, B.R. decreases with m(l*)
- Search at ATLAS for ee*→eeγ and μμ*→μμγ
  - Result with 5 fb^{-1}: ATLAS-CONF-2012-008

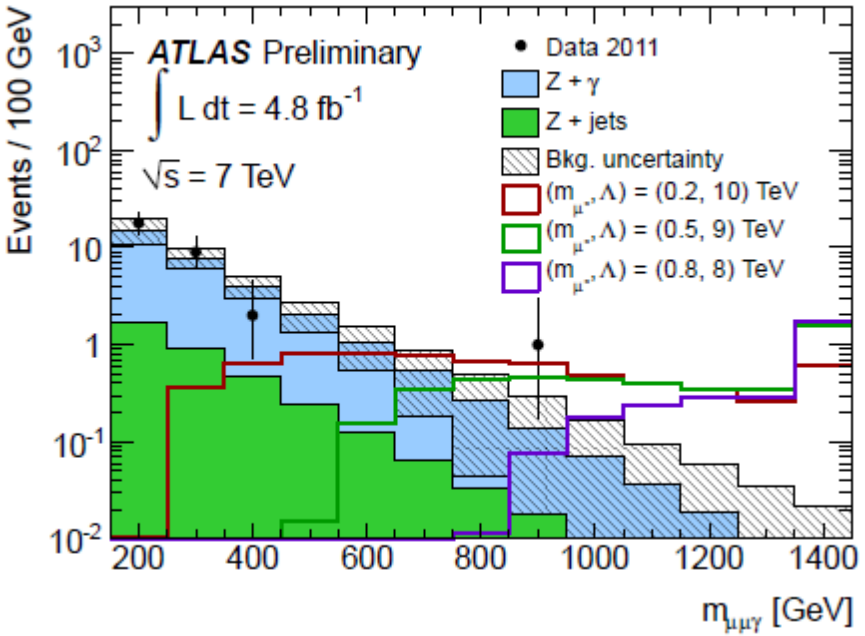


- Event selection: two electrons or muons and a photon
  - $p_T(\mu) > 25$ GeV, $E_T(e) > 25$ GeV, $p_T(\gamma) > 40$ GeV
  - Leptons and photons must be isolated and separated from each other
  - m(ll) > 110 GeV
- Acceptance times efficiency
  - ~55% in eeγ channel for m(l*) > 800 GeV
  - ~30% in μμγ channel for m(l*) > 800 GeV

Excited leptons: backgrounds

- Dominant background: Zγ
  - Simulated with Sherpa
  - m(llγ)-dependent NLO / LO K-factor applied
- Dominant uncertainty is on background shape prediction
  - Parameterization based on limited MC statistics
- Strategy: counting experiment in m(llγ) > m(l*)+150 GeV

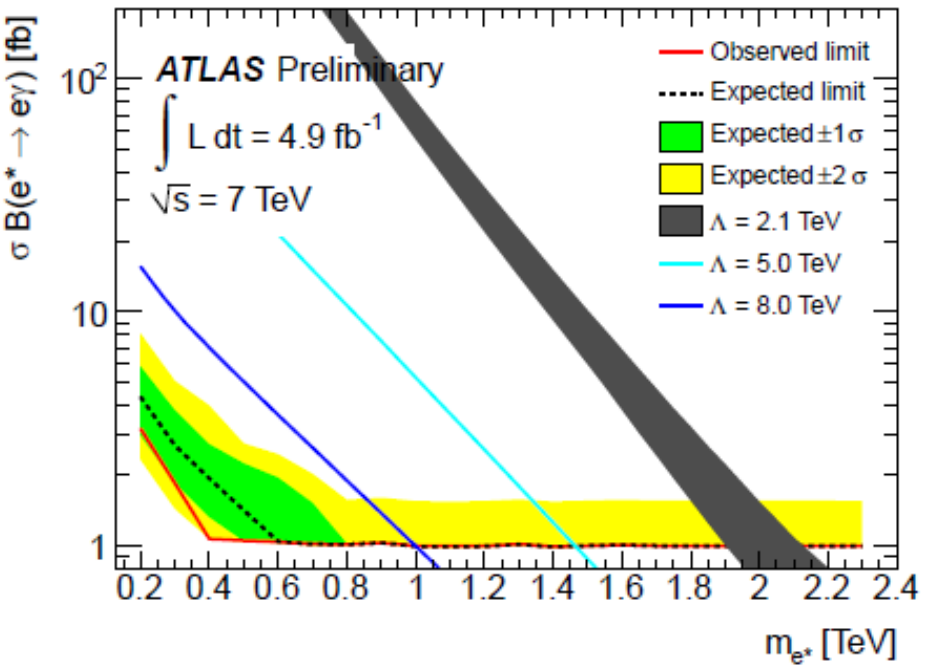




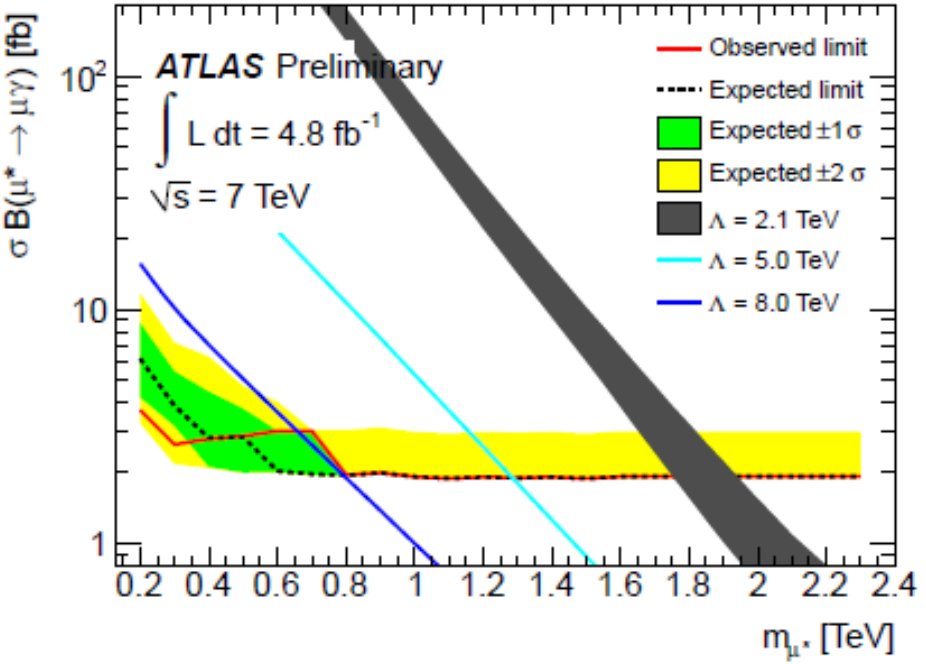
Excited leptons: limits

- Set upper limit on cross-section times branching ratio of excited leptons
  - For m(l*)>0.9 TeV, σB(e*) < 1.0 fb, σB(μ*) < 1.9 fb
- Can also interpret this as exclusion region in m(l*)-Λ plane
  - For m(l*) = Λ, m(e*) > 2.0 TeV, m(μ*) > 1.9 TeV

Limits for e*



Limits for μ*



Inclusive like-sign dimuons: introduction

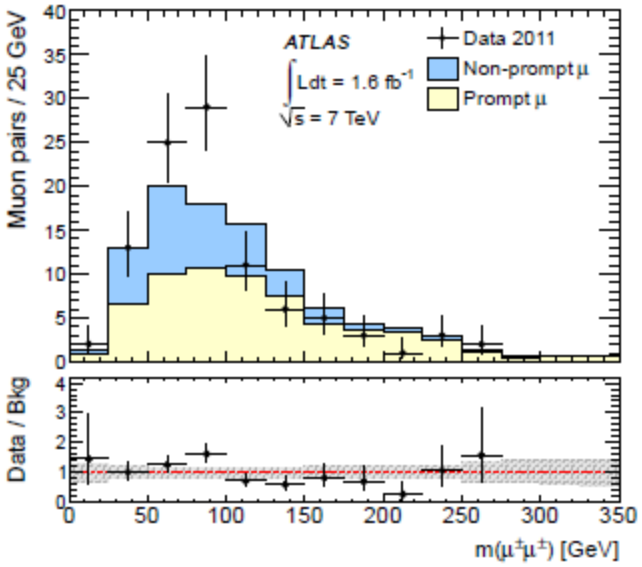
- Search for anomalous production of like-sign muon pairs
  - No optimization for specific model
  - Like-sign muons are clean final state without further selections
- 1.6 fb^{-1} result: arXiv:1201.1091

- Event selection: two like-sign muons
  - $p_T(\mu) > 20$ GeV, $|\eta(\mu)| < 2.5$
  - Search focused on lower-p_T muons than previous searches → don't have stringent hit requirements in MS
  - Both muons required to be isolated and have low impact parameter signficance
    - $\Sigma p_T(\Delta R<0.4) / p_T(\mu) < 0.08$ and $\Sigma p_T(\Delta R<0.4) < 5$ GeV
    - Very tight requirements because muons from b/c-hadron decay are large background

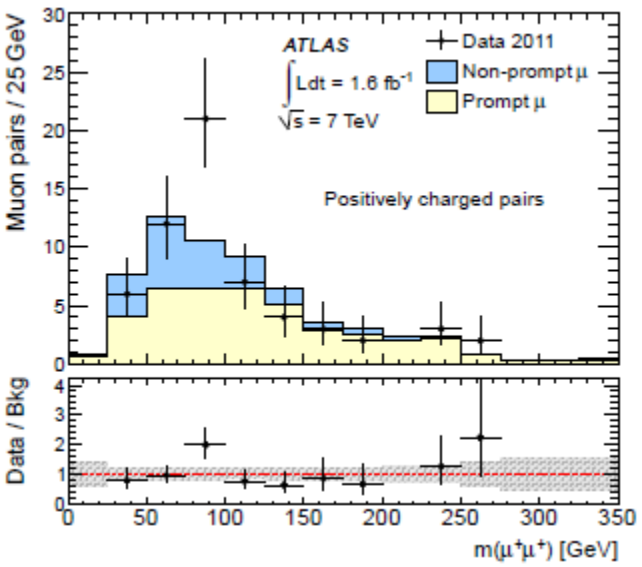
Inclusive like-sign dimuons: backgrounds

- "Prompt" SM production: mostly WZ → lvll
  - Herwig with mass-dependent NLO / LO K-factors
- "Non-prompt" production: events where one or more muons from b/c or pi/K decay
  - Shape and normalization derived in data-driven way by loosening isolation requirements

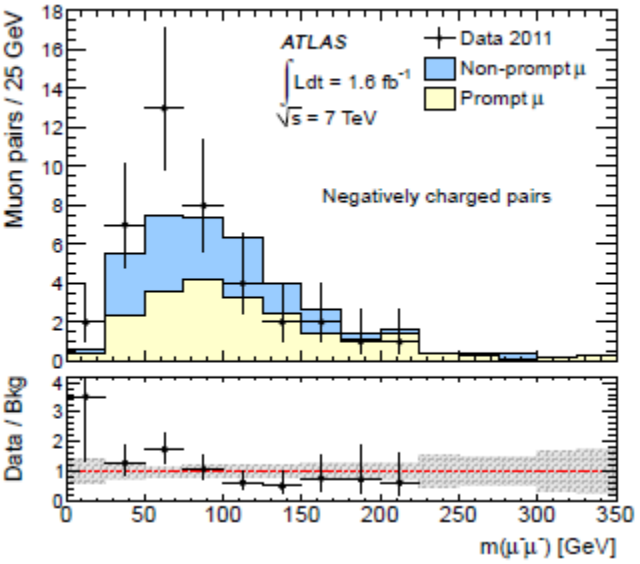
All same-sign muon pairs



Positively charged pairs



Negatively charged pairs



Inclusive like-sign dimuons: interpretation

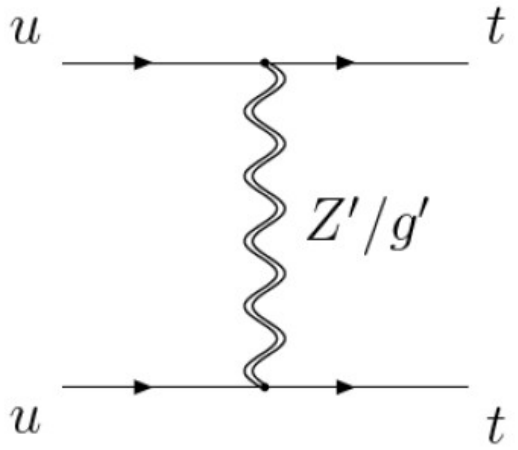
- Fiducial cross-section limit
  - Define fiducial region at particle level
  - Limit on cross section for new physics contributing to that region
- There is a model-dependent reconstruction efficiency for muon pairs in true fiducial region
  - Mostly due to p_T-dependent isolation efficiency
  - Derive efficiency for several different models
    - Clean, high-pT models, e.g. doubly charged Higgs or right-handed W decaying to heavy Majorana neutrino: ε>70%
    - Busy, low-pT model, e.g. like-sign top quark production: ε ~ 44%
  - Conservative fiducial limit is derived from lowest efficiency

Mass range [GeV]	σ_{95}^{fid} [fb]	
	expected	observed
All muon pairs		
$m(\mu^{\pm}\mu^{\pm}) > 15$	58^{+19}_{-17}	58
$m(\mu^{\pm}\mu^{\pm}) > 100$	30^{+11}_{-9}	16
$m(\mu^{\pm}\mu^{\pm}) > 200$	$13.7^{+5.7}_{-4.4}$	8.4
$m(\mu^{\pm}\mu^{\pm}) > 300$	$8.0^{+3.3}_{-2.6}$	5.3

- Limits derived for all like-sign muon pairs and separately for ++ and -- pairs in four invariant mass ranges
- Limits can be applied to other models
  - Just need to derive acceptance for true fiducial region

Inclusive like-sign dimuons: limits on same-sign top

- Use previous fiducial cross-section limit to determine limit on same-sign top quark production
  - Example of using fiducial limits; dedicated analysis (next slides) has stronger limit
- Same-sign top quarks could be produced via flavor-changing Z'
  - Possible explanation of A_{FB} in $t\bar{t}$ at Tevatron



- Use particle-level simulation to determine acceptance for this model within true fiducial region

$$\sigma_{95} = \frac{\sigma_{95}^{fid}(\mu\mu)}{A_{fid}}$$

$m(Z')$	$\sigma_{95}(t_R t_R)$ [pb]	
	expected	observed
100 GeV	$4.2^{+2.3}_{-0.9}$	3.7
150 GeV	$3.3^{+1.9}_{-0.7}$	3.0
200 GeV	$2.9^{+1.6}_{-0.6}$	2.6
$\gg 1$ TeV	$2.5^{+1.4}_{-0.5}$	2.2

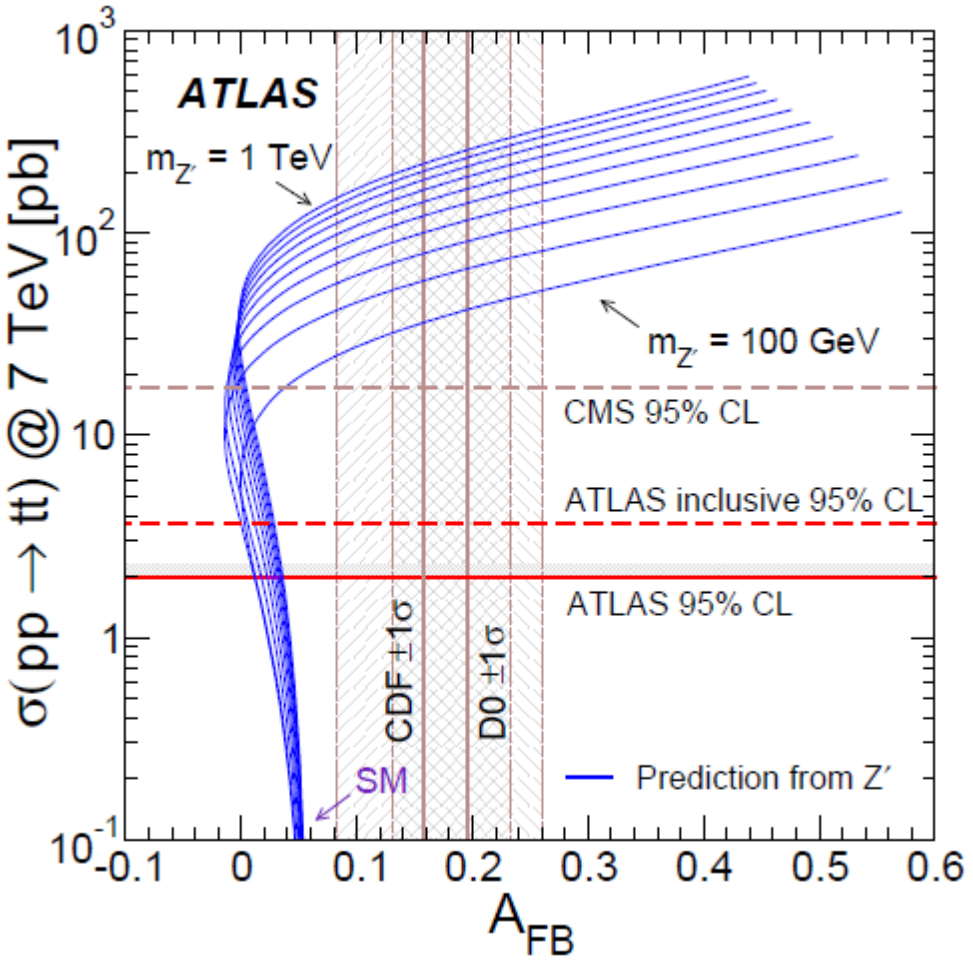
Like-sign top quarks: dedicated search

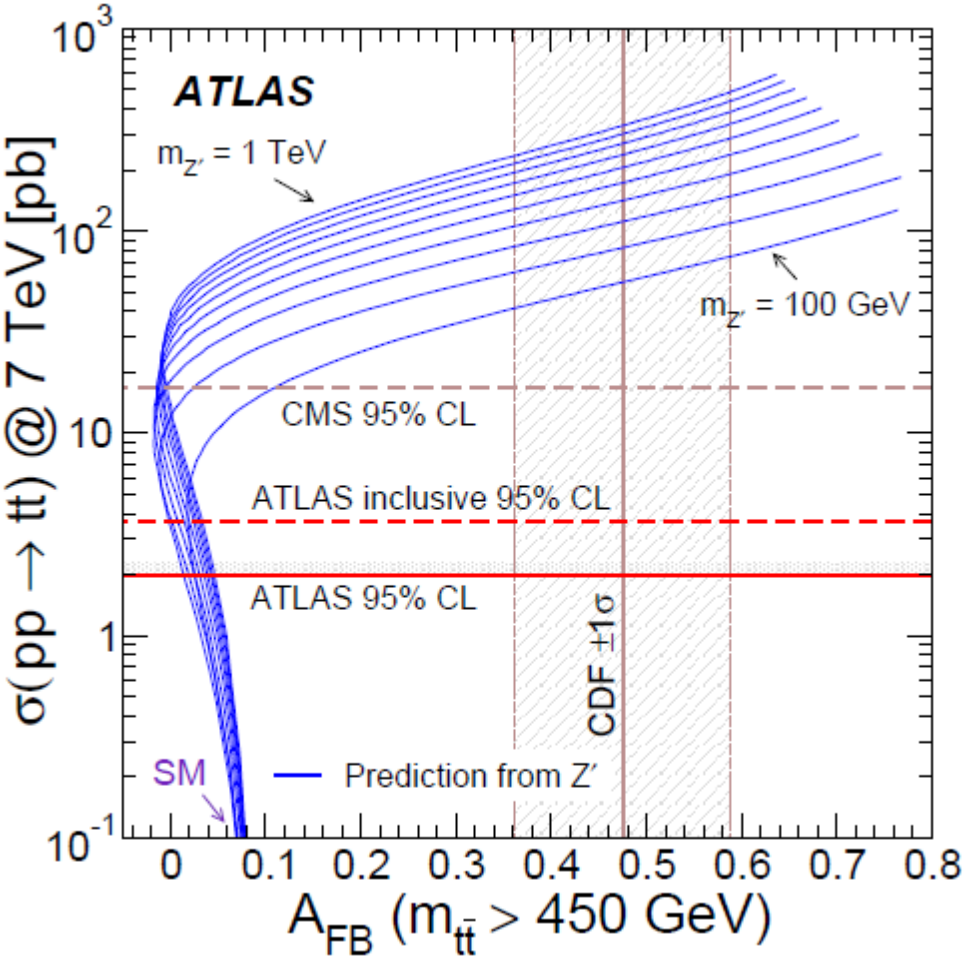
- Event selection: same-sign leptons plus ≥2 jets plus MET
  - Presented yesterday in search for heavy quarks
  - e^+e^+, $e^+\mu^+$, $\mu^+\mu^+$ channels
  - $E_T(e) > 25$ GeV, $p_T(\mu) > 20$ GeV, $p_T(\text{jet})>20$ GeV, MET>40
  - In ee and μμ channels, |m(Z)-m(ll)|>10 GeV
  - Low-mass Z' signal region: $H_T>150$ GeV and m(ll) > 100 GeV

    High-mass Z' signal region: $H_T>350$ GeV
- A*ε*B.R. ~ 0.8%

	e^+e^+	$e^+\mu^+$	$\mu^+\mu^+$
	$m(ll) > 100$ GeV, $H_T > 150$ GeV		
Total BG	$3.0^{+1.3}_{-1.0}$	$9.6^{+3.0}_{-3.9}$	$3.7^{+1.6}_{-1.6}$
Data	3	8	4
	$H_T > 300$ GeV		
Total BG	$3.0^{+1.0}_{-1.6}$	$8.1^{+2.5}_{-3.6}$	$2.6^{+0.9}_{-1.1}$
Data	2	10	1

Like-sign top quarks: limit





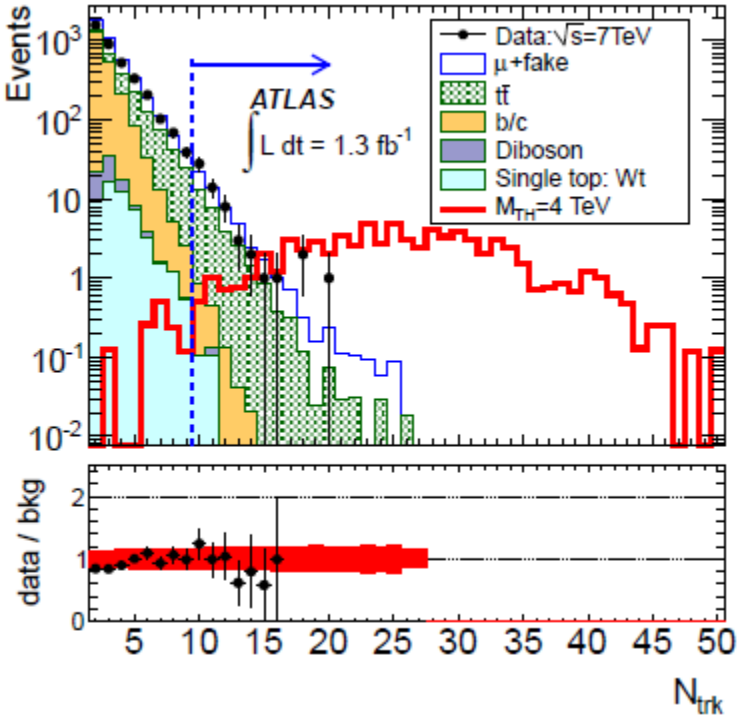
Strong gravity in same-sign dimuons

- Some models of extra dimensions result in microscopic black holes at the LHC
  - Decay into large numbers of high-p_T particles
- 1.3 fb^{-1} result: arXiv:1111.0080

- Event selection: two same-sign muons and ten or more tracks
  - $p_T(\mu_1) > 25$ GeV, $|\eta(\mu_1)| < 2.4$
  - $p_T(\mu_2) > 15$ GeV, $|\eta(\mu_2)| < 2.4$
  - Only higher-p_T muon is required to be isolated and have small impact parameter significance
    - $\Sigma p_T(\Delta R<0.2) / p_T(\mu_1) < 0.2$
    - No requirement on second muon increases signal acceptance due to large number of muons from hadronic decay in signal
  - $p_T(\text{track}) > 10$ GeV, $|\eta(\text{track})| < 2.4$
    - Ten or more tracks, including the two muon candidates

Strong gravity in same-sign dimuons: backgrounds

- Two dominant backgrounds in signal region: $t\bar{t}$ and μ+fake
- $t\bar{t}$ determined from NLO MC
- μ+fake dominated by W plus heavy flavor production
  - Estimated in data-driven way
  - Select W+track sample, estimate probability for track to fake μ



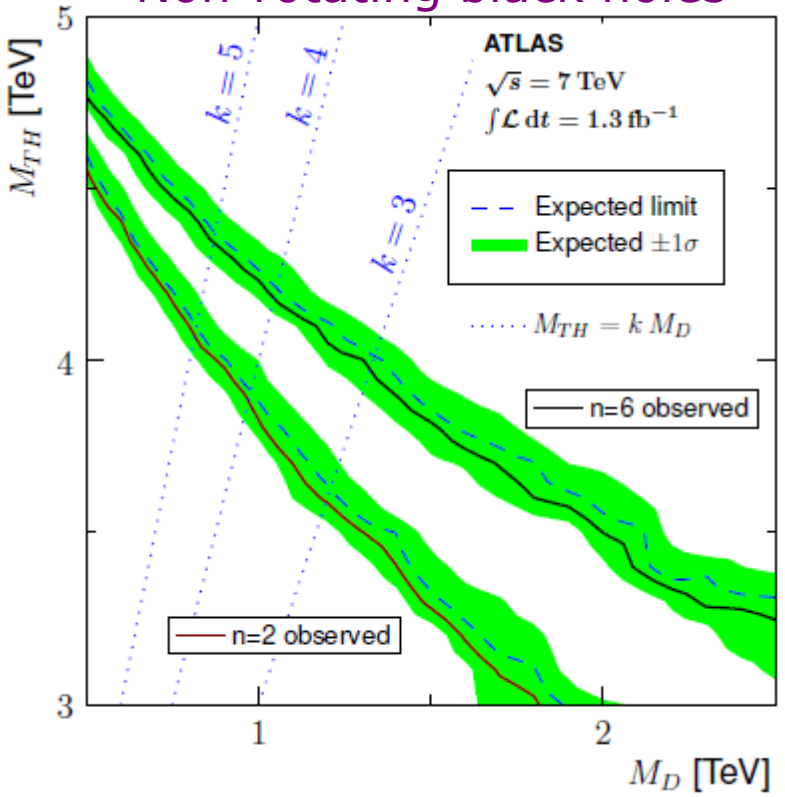
- Uncertainty on $t\bar{t}$: ISR/FSR, top quark mass, $t\bar{t}$ cross section, and generator used
- Uncertainty on μ+fake: subtraction of correlated backgrounds from region where fake rate is estimated

Process	Events
$t\bar{t}$	29.2 ± 4.2
μ+fake	25.6 ± 5.2
Other	1.0 ± 0.8
Total prediction	55.8 ± 6.8
Data	60

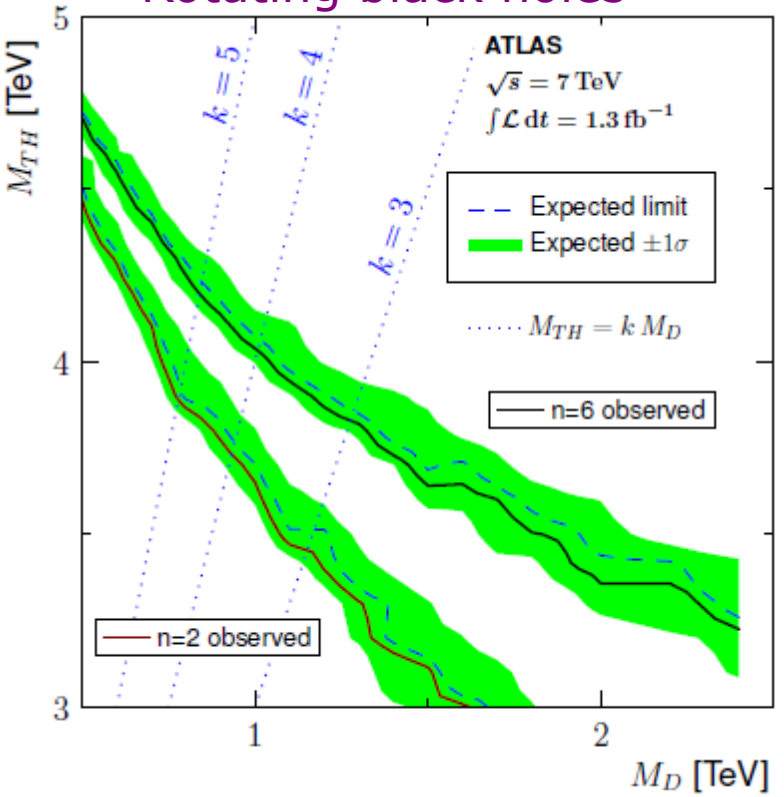
Strong gravity in same-sign dimuons: limits

- 60 events observed in signal region, 56 predicted
  - Upper limit on σ * B.R. * A is 0.018 pb
- Interpreted as exclusion contours in M_D-M_{TH} plane
  - M_D is Planck scale in n+4 dimensions
  - M_{TH} is lower limit on black hole mass

Non-rotating black holes

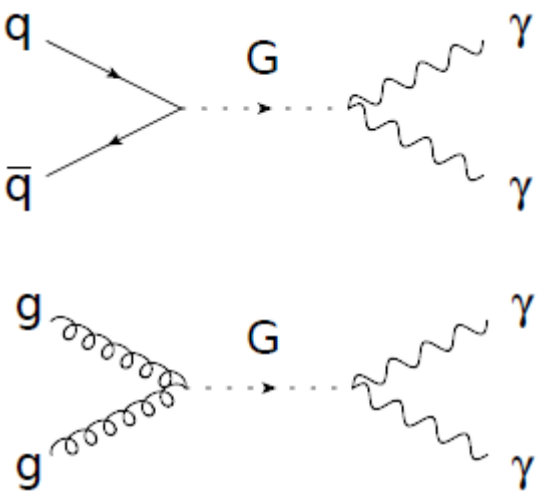


Rotating black holes



Extra dimensions in diphotons: introduction

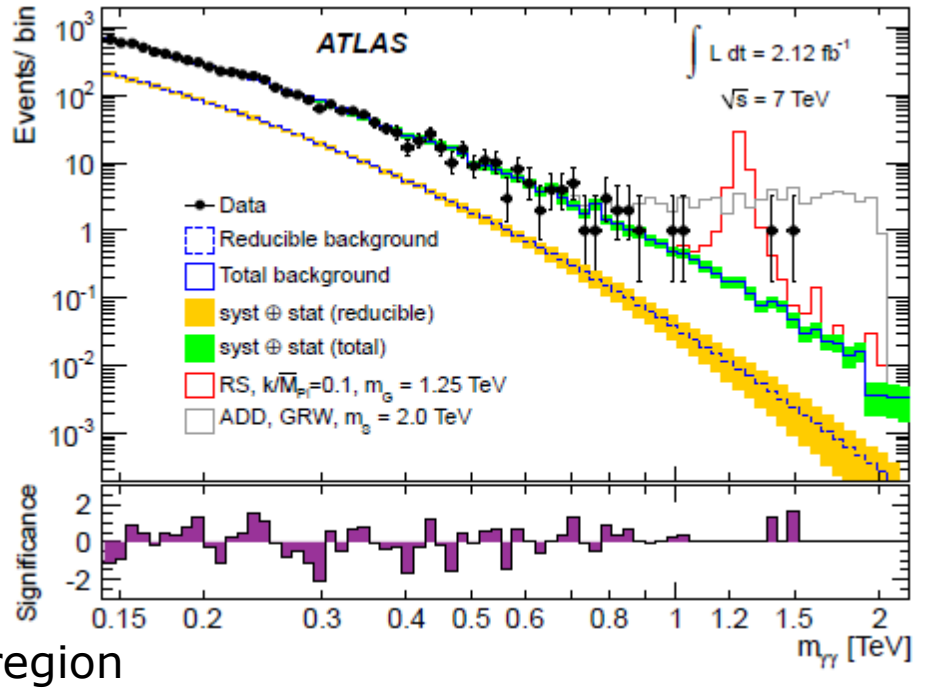
- Search for Gravitons decaying to photon pairs in ADD and RS models of extra dimensions
- Recent result from ATLAS with 2 fb^{-1}: arXiv:1112.2194



- Event selection: two photons
  - Trigger on two photons with E_T>20 GeV
  - $E_T(\gamma)$ > 25 GeV, $|\eta(\gamma)|$<2.37
  - Photons must be isolated: $\Sigma E_T(\Delta R<0.4)$ < 5 GeV
  - $m(\gamma\gamma)$ > 140

Extra dimensions in diphotons: backgrounds

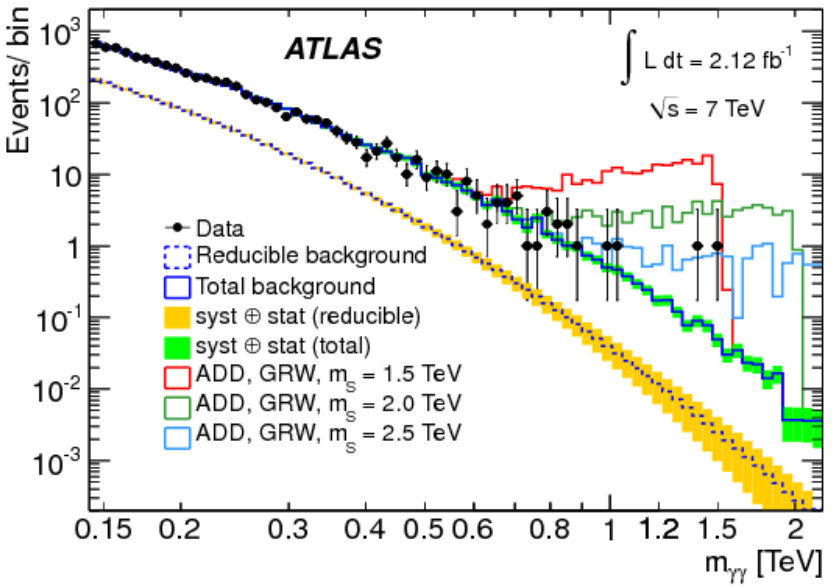
- Dominant background: SM γγ
  - Estimated from MC, reweighting Pythia to NLO cross sections from DIPHOX
- Second background: γ+jet
  - Shape taken from data samples where one or both photons fail some identification criteria
    - Shape extrapolated to high-mass region



- Total background normalized to data in 140<m(γγ)<400 GeV region
- Systematic uncertainty on background shape
  - Variation of scale and PDFs in γγ prediction
  - Use of different control samples for γ+jet shape
  - Fraction of γ+jet contribution
  - Total uncertainty: ~2% at 140 GeV up to ~20% above 2 TeV

Extra dimensions in diphotons: ADD limits

- Expect nearly continuous spectrum of KK Gravitons
  - Search for general excess rather than resonance
  - Acceptance: 15-20%, ε ~70%
- Count events with m(γγ)>1.1 TeV
  - Two events observed, 1.33±0.26 background events expected
  - Upper limit on σ*A*ε = 2.49 fb



- Limit on effective scale in ADD depends on model convention

$$\frac{d^2\sigma}{dM\,d\cos\theta^*} = f_{\rm SM} + f_{\rm int}\eta_G + f_{\rm KK}\eta_G^2$$

$$\mathcal{F} = 1, \text{ (GRW)}$$

$$\mathcal{F} = \begin{cases} \log\left(\frac{M_S^2}{\hat{s}}\right) & n = 2 \\ \frac{2}{n-2} & n > 2 \end{cases}, \text{ (HLZ)}$$

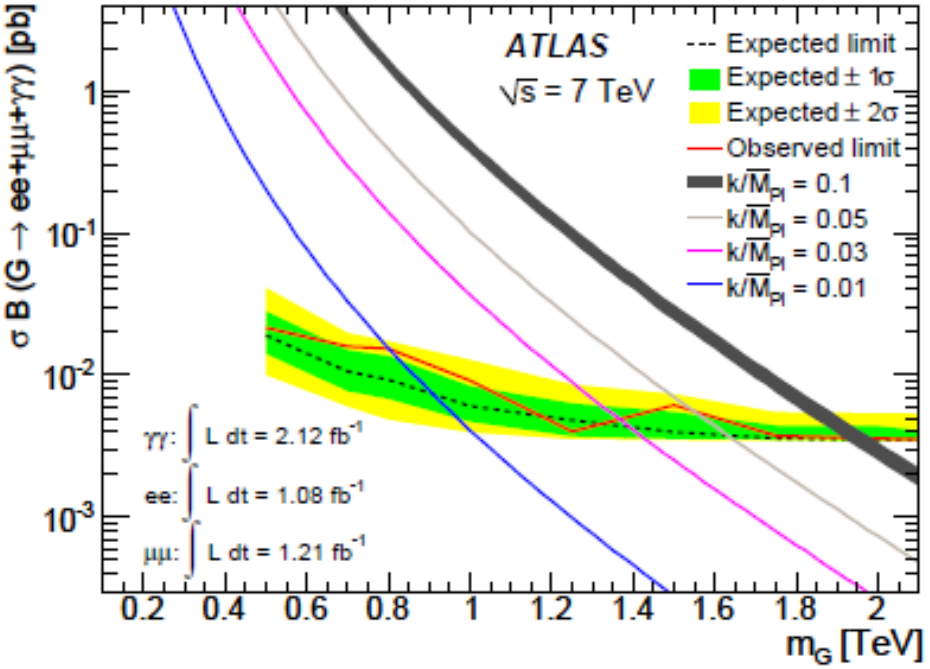
$$\mathcal{F} = \pm\frac{2}{\pi}, \text{ (Hewett)}$$

Limits on M_S (in TeV):

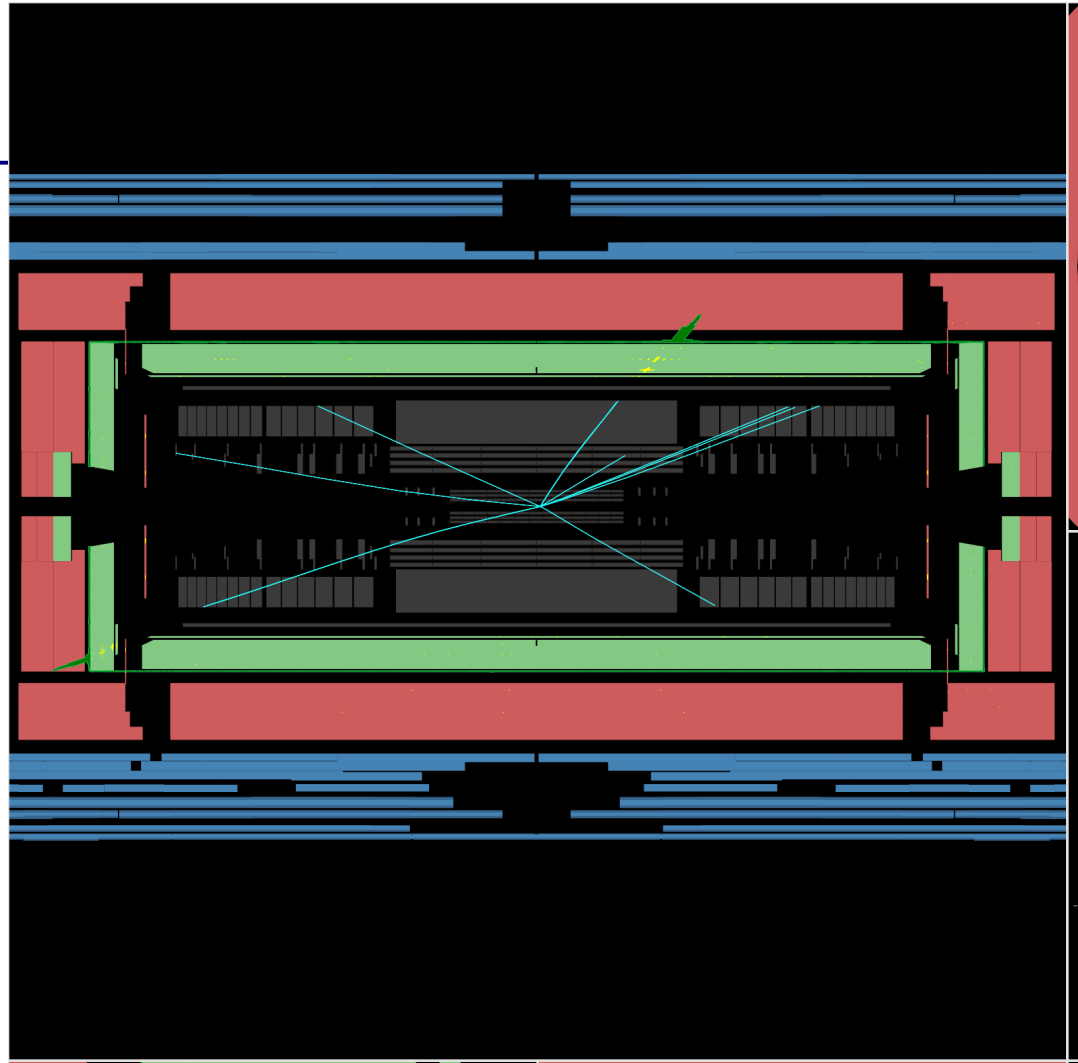
k-factor Value	GRW	Hewett Pos	Hewett Neg	HLZ $n=3$	HLZ $n=4$	HLZ $n=5$	HLZ $n=6$	HLZ $n=7$
1	2.73	2.44	2.16	3.25	2.73	2.47	2.30	2.17
1.70	2.97	2.66	2.27	3.53	2.97	2.69	2.50	2.36

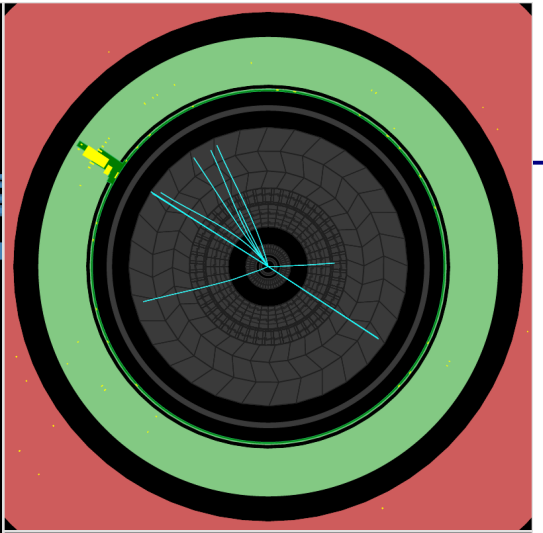
Extra dimensions in diphotons: RS limits

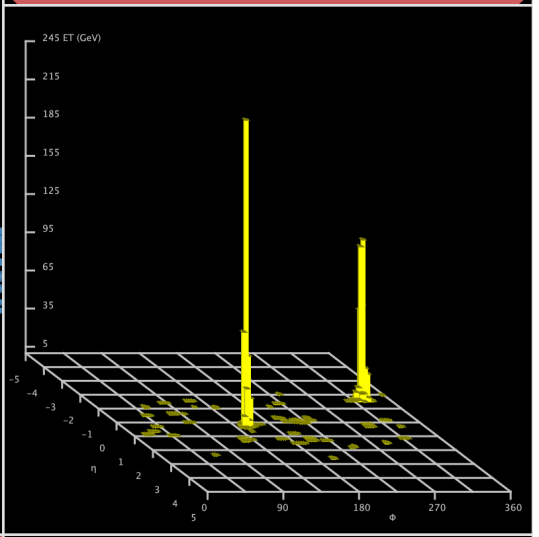
- Resonance: A * ε = 53-60%
- Derive limit by doing template fit in m(γγ) > 500 GeV to expected background plus signal
- Combine these results with resonance search in ee and μμ channels
  - 1 fb^{-1} version of dilepton analysis shown earlier in talk

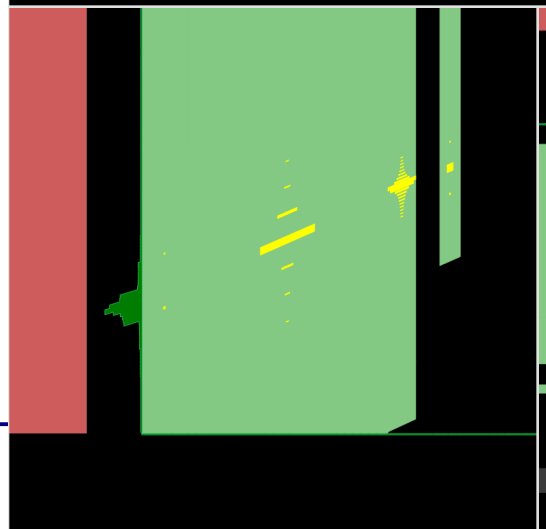


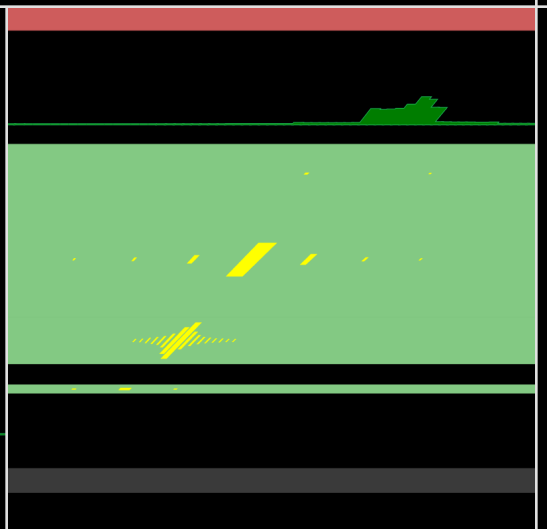
	Mass limit [TeV]			
	k/M_{Pl} value			
	0.01	0.03	0.05	0.10
G → γγ	0.74	1.26	1.41	1.79
G → γγ/ee/μμ	0.76	1.32	1.47	1.90











$m(\gamma\gamma) = 1.5$ TeV
$E_T(\gamma 1) = 520$ GeV
$\eta(\gamma 1) = -1.6$
$E_T(\gamma 2) = 470$ GeV
$\eta(\gamma 2) = 0.3$
$\Delta\varphi = 3.0$

Conclusions

- ATLAS is searching for new physics in final states with charged lepton pairs or photon pairs
  - Z' and excited lepton searches have been updated with 5 fb^{-1}
  - Several other results with smaller data samples have been released in recent months

- No deviation from Standard Model predictions has been observed yet

- The search continues
  - Many channels working toward result with full 7 TeV data sample
  - Looking forward to higher energy and larger sample this year!

Backup

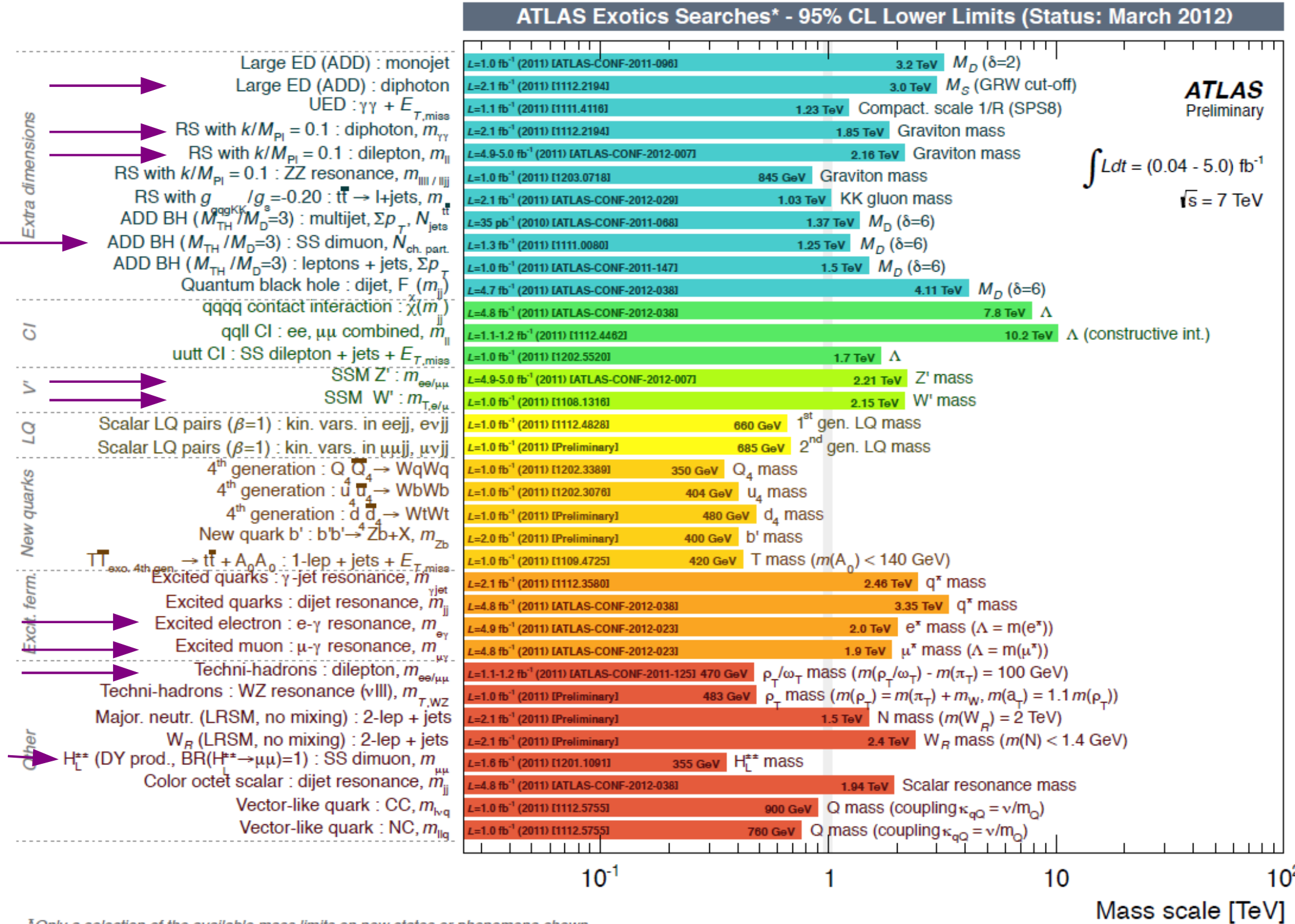
Contact interaction in dileptons

- General contact interaction: $\mathcal{L} = \frac{g^2}{2\Lambda^2}\,[\;\; \eta_{LL}\;\overline{\psi}_L\gamma_\mu\psi_L\,\overline{\psi}_L\gamma^\mu\psi_L + \eta_{RR}\;\overline{\psi}_R\gamma_\mu\psi_R\,\overline{\psi}_R\gamma^\mu\psi_R + 2\eta_{LR}\,\overline{\psi}_L\gamma_\mu\psi_L\,\overline{\psi}_R\gamma^\mu\psi_R\;]$

- "LLIM": $\eta_{LL} = \pm 1$, $\eta_{RR} = \eta_{LR} = 0$
  - Differential cross section: $\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{DY}}{dm_{\ell\ell}} - \eta_{LL}\frac{F_I(m_{\ell\ell})}{\Lambda^2} + \frac{F_C(m_{\ell\ell})}{\Lambda^4}$

Interference term:
important at high Λ

  - Destructive interference: $\eta_{LL} = +1$, limit on Λ^+
  - Destructive interference: $\eta_{LL} = -1$, limit on Λ^-
- Allowing all quark flavors to contribute to contact interaction
- Strong limits on qqee from LEP; only LHC can constrain qqμμ
  - qqee from LEP: $\Lambda^+ > 12.9$ TeV, $\Lambda^- > 7.2$ TeV

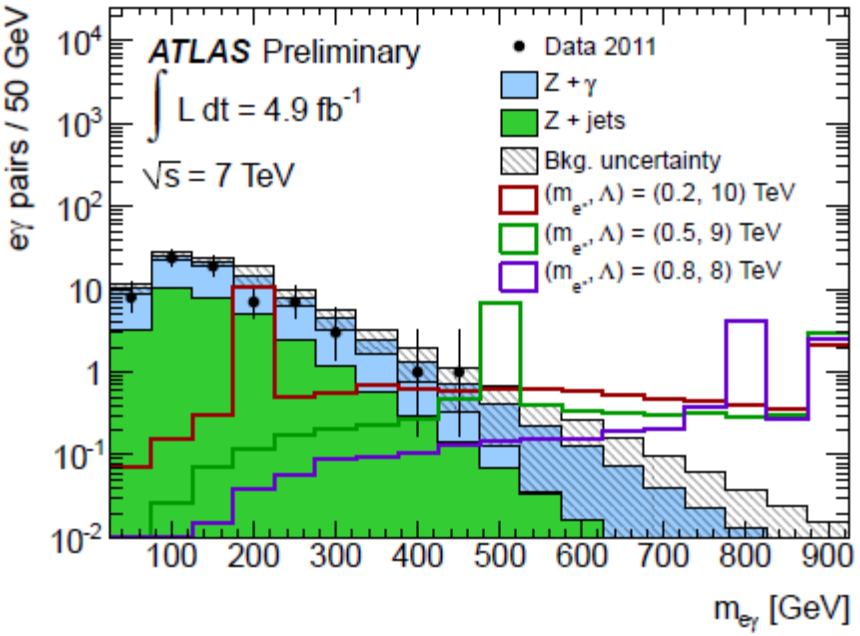


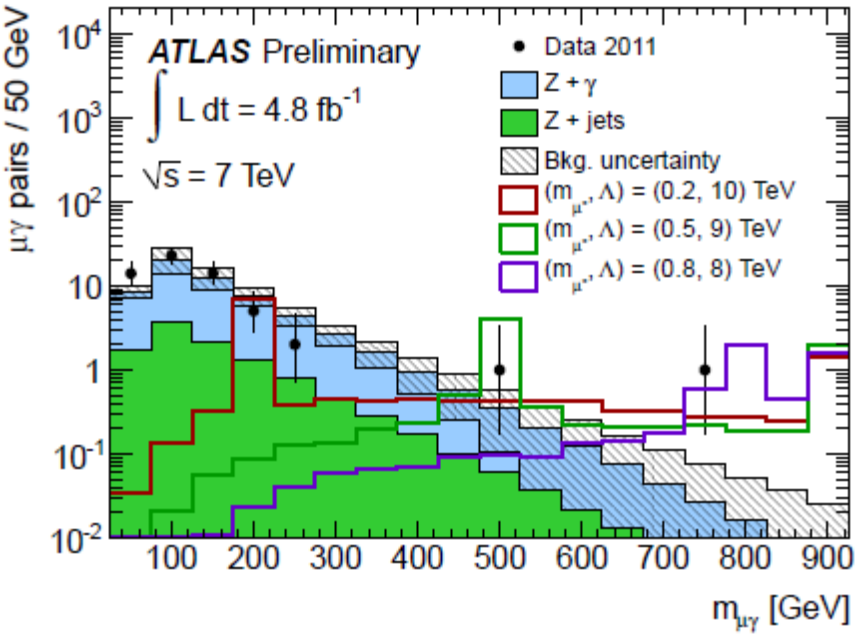
*Only a selection of the available mass limits on new states or phenomena shown

Dilepton resonance search, more limits

	E_6 Z' models						RS graviton			
Model/Coupling	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ	0.01	0.03	0.05	0.1
Mass limit [TeV]	1.76	1.78	1.84	1.84	1.90	1.96	0.91	1.45	1.71	2.16

m(lγ) mass spectrum for excited leptons





Inclusive like-sign dimuons: limits on $H^{\pm\pm}$

- In same data sample with same background estimate, search in narrow mass bins for resonance
  - Benchmark model is pair production of doubly charged Higgs bosons
- Lower mass limits:
  - 355 GeV for $H_L^{\pm\pm}$ with 100% B.R. to μμ
  - 251 GeV for $H_R^{\pm\pm}$ with 100% B.R. to μμ