A Search for Heavy Resonances in the Dilepton Channel

by Daniel Hayden, on behalf of the ATLAS Collaboration

Theory

Z′

Many extensions to the Standard Model (SM) predict extra U(1) symmetries. Currently the SM gauge symmetries can be described using group theory as such:

$SU(3)\times SU(2)\times U(1)$

SU(3) ⇒ Strong Force (8 Gluons)
SU(2) ⇒ Weak Force ($W^{\pm}$,Z^0), U(1) ⇒ E/M Force (γ)

Several Grand Unified Theories (GUTs) allow this scheme to be extended, such as the Sequential Standard Model (SSM) where the Z′ has the same couplings as the Z.

$SU(3)\times SU(2)\times U(1)\times U(1)'$ ⇒ U(1)′ ⇒ Extra Symmetry (Z′)

A more theoretically motivated model involves the decomposition of the E_6 GUT:

$$E_6 \rightarrow SO(10)\times U(1)_\psi \rightarrow SU(5)\times U(1)_\chi \times U(1)_\psi$$

$$Z'(\theta) = Z'_\chi \cos\theta + Z'_\psi \sin\theta$$

where the mixing angle θ determines the coupling to fermions.

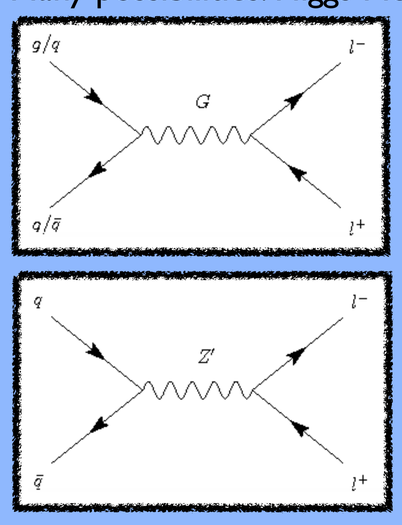
This leads to six different possible models with specific Z′ states named:
Z'_ψ Z'_N Z'_η Z'_I Z'_S Z'_χ

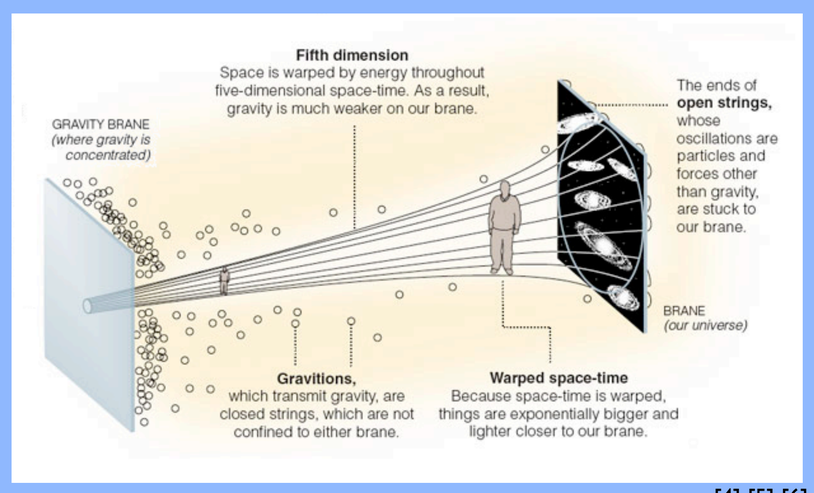
G*

One of the questions in Physics today is, why is Gravity so weak? (Hierarchy Problem).

Interaction	Strong	E/M	Weak	Gravity
Coupling	1	1×10^{-2}	1×10^{-6}	1×10^{-39}

Many possibilities: Higgs Mechanism, Super Symmetry, Extra Dimensions, and so on!





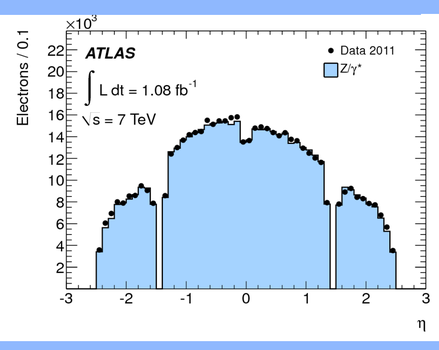
[4] [5] [6]

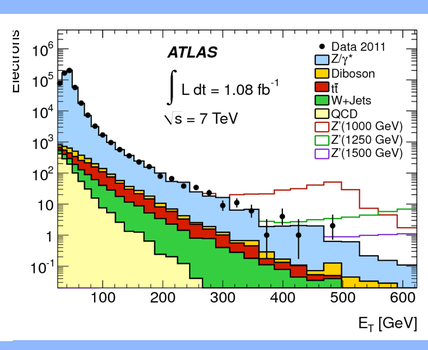
Dilepton Analysis

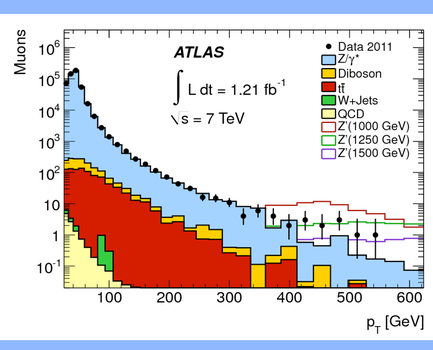
To select candidate events from data, each channel performs a cut flow analysis requiring at least 2 e / μ to pass.
The main backgrounds to a Z′/G* search come from: Drell-Yan, $t\bar{t}$, W+Jets, Di-Bosons, and QCD.
The SM background contributions are estimated using Monte Carlo (MC) simulation, except for QCD which uses a data-driven method: reverse ID sample for electrons, and a non-isolated sample for muons [1] [2].

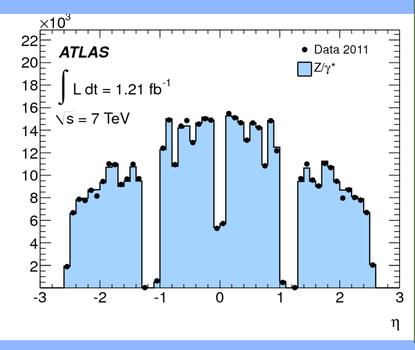
Electron Cut Flow

- e/γ Good Runs List (GRL)
- Primary Vertex (>2 Tracks)
- Trigger (e20_medium)
- Reconstruction Algorithm
- $|\eta| < 2.47$
- $E_T > 25$ GeV
- Object Quality
- isEM Identification
- B-Layer requirement
- Isolation < 7 GeV
- $M_{ee} \geq 70$ GeV



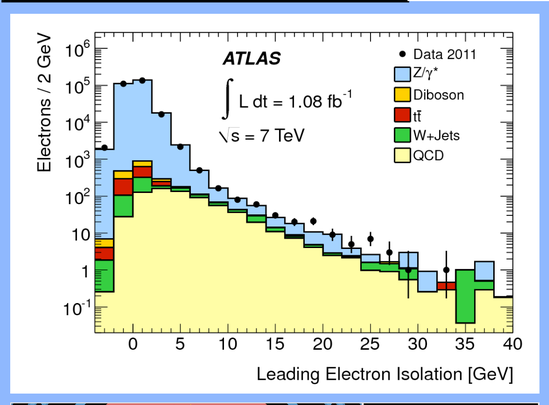


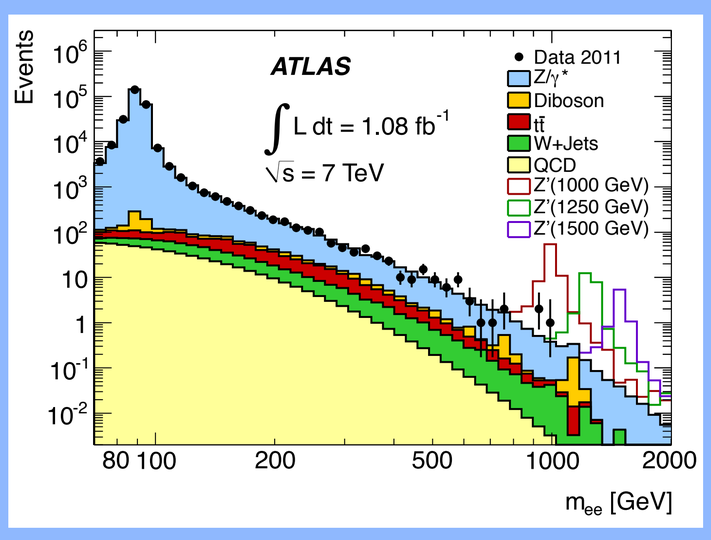


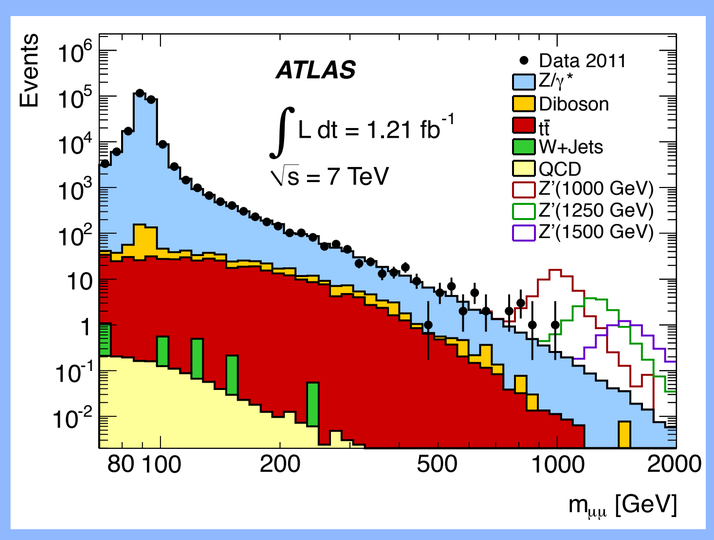


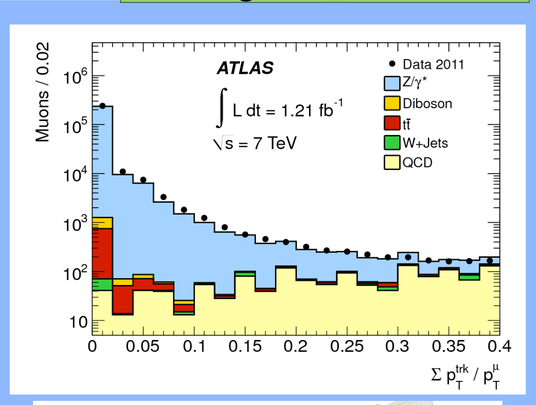
Muon Cut Flow

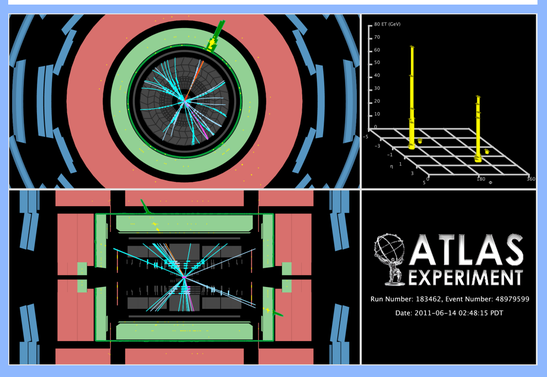
- Muon CP GRL
- Trigger (mu22 or mu40)
- PV > 2 Tracks, $|z_{PV}|$>200mm
- 2 combined MuID muons
- $p_T > 25$ GeV
- Pixel, SCT, and TRT req
- ≥3 hits in all MS layers
- d_0<0.2mm, z_0<1.0mm
- $\sum P_T(\text{cone30})/P_T < 0.05$
- Opposite Sign Muons
- Highest $\sum P_T$ Pair

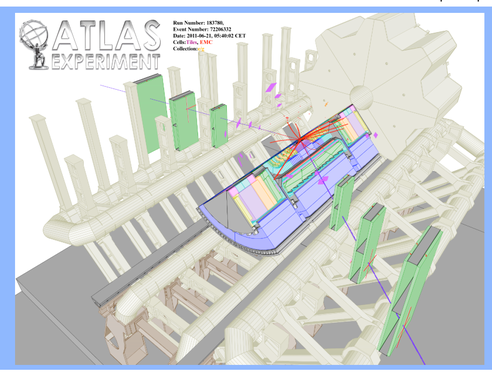












Limit Setting

Any excess in data is quantified using a log-likelihood-ratio test. In this dataset the greatest excesses gave p-values of 54% and 24% for the e^+e^- and $\mu^+\mu^-$ channel respectively.

$$LLR = -2\ln\frac{\mathcal{L}(data|\hat{N}_{Z'}, \hat{M}_{Z'}, \hat{\theta}_i)}{\mathcal{L}(data|(N_{Z'}=0), \hat{\hat{\theta}}_i)}$$

$$p = p(LLR > LLR_{obs}|SM\ only)$$

In the absence of any signal, limits are set on the σB of the process at 95% CL, using the Bayesian Analysis Toolkit (BAT) [3].

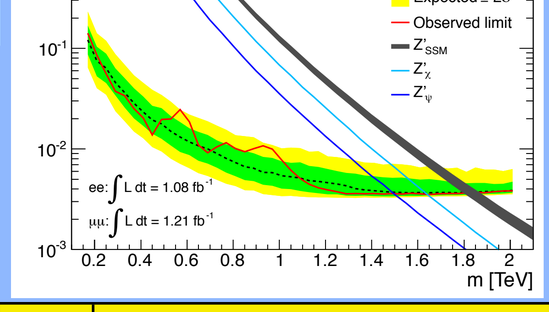
BAT is based on template shape fitting, and is essentially a Poisson counting experiment in many bins, constructing the likelihood as follows:

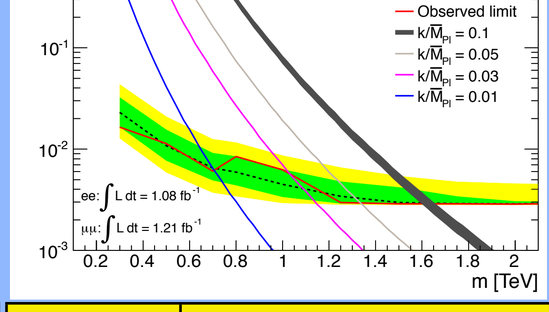
$$\mathcal{L}(data|\sigma B, \theta_i) = \prod_{l=1}^{N_{channel}} \prod_{k=1}^{N_{bin}} \frac{\mu_{lk}^{n_{lk}} e^{-\mu_{lk}}}{n_{lk}!} \prod_{i=1}^{N_{sys}} G(\theta_i, 0, 1)$$

Combination of channels is achieved by taking the product of poisson probabilities per bin. Nuisance parameters are then integrated out using Markov Chain Monte Carlo (MCMC).

$$\mathcal{L}'(data|\sigma B) = \int \mathcal{L}(\sigma B, \theta_1, ..., \theta_N) d\theta_1, ..., d\theta_N$$

$$0.95 = \frac{\int_0^{(\sigma B)_{95}} \mathcal{L}'(\sigma B)\pi(\sigma B)d(\sigma B)}{\int_0^{\infty} \mathcal{L}'(\sigma B)\pi(\sigma B)d(\sigma B)}.$$





Model	Z'_{SSM} | Z'_{E6}						
	Z'_{SSM}	$Z'_{(\Psi)}$	$Z'_{(N)}$	$Z'_{(\eta)}$	$Z'_{(I)}$	$Z'_{(S)}$	$Z'_{(\chi)}$
Mass Limit [TeV]	1.83	1.50	1.52	1.54	1.56	1.60	1.64

	RS Graviton			
Coupling [k/M_{Pl}]	0.01	0.03	0.05	0.10
Mass Limit [TeV]	0.70	1.03	1.33	1.63

Supervisor:
Dr Tracey Berry

References:
[1] The ATLAS Collaboration, Search for dilepton resonances in pp collisions at √s = 7 TeV with the ATLAS detector, arXiv:1108.1582v1 (Accepted by PRL).
[2] The ATLAS Collaboration, Search for high-mass dilepton resonances in pp collisions at √s = 7 TeV (Support Note), ATL-COM-PHYS-2011-770.
[3] Limit Setting and Signal Extraction Procedures in the Search for Narrow Resonances Decaying into Leptons at ATLAS, ATL-COM-PHYS-2011-085.
[4] D. London and J. L. Rosner, Phys. Rev. D34, 1530 (1986).
[5] L. Randall and R. Sundrum, Phys. Rev. Lett. 83, 3370 (1999).
[6] P. Langacker, Rev. Mod. Phys. 81, 1199 (2009).

E-mail:
daniel.hayden@cern.ch

Royal Holloway
University of London