The Abdus Salam
International Centre for Theoretical Physics

United Nations
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2263-3

Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

19 - 23 September 2011

Search for Di-Lepton Resonances at ATLAS

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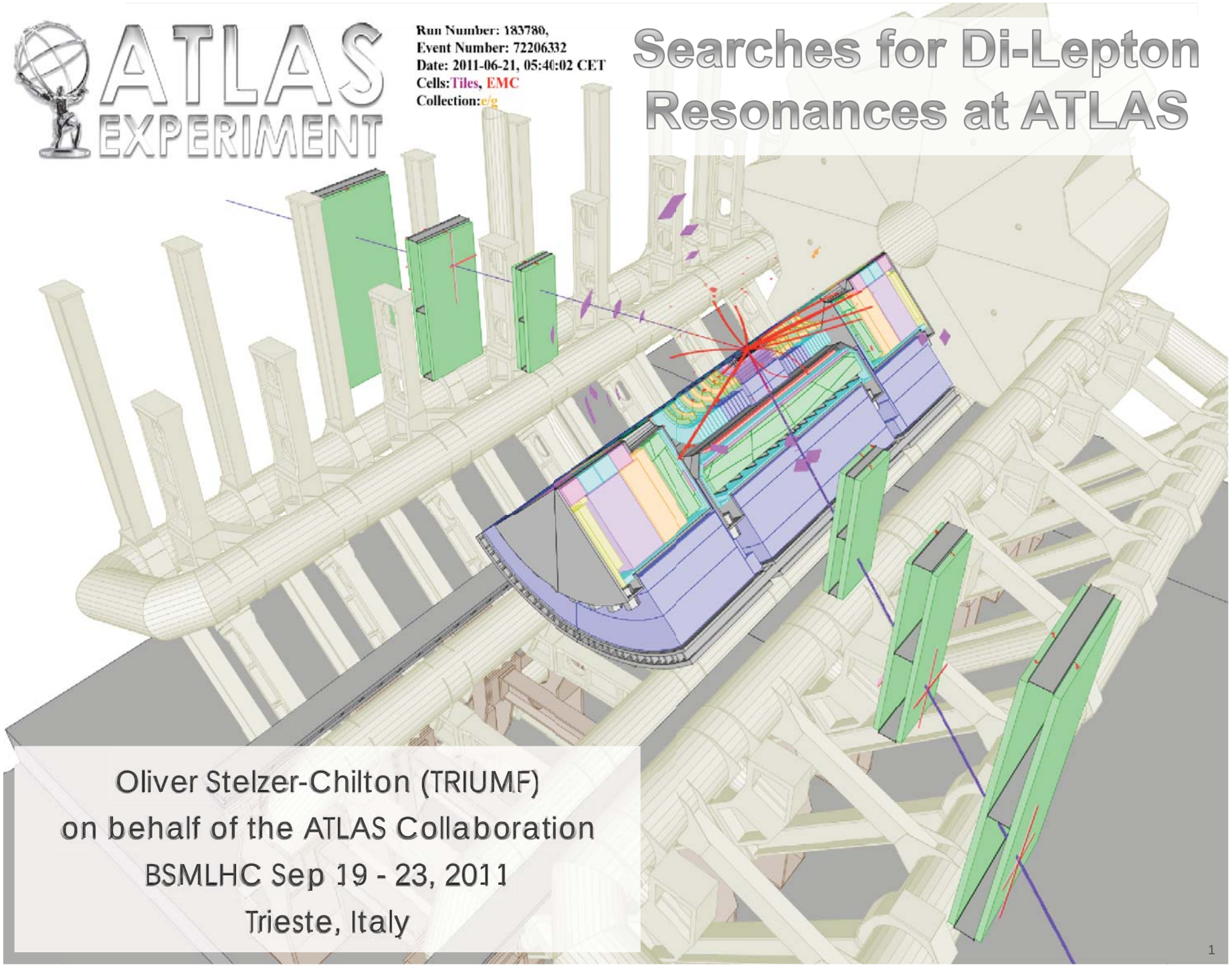
Searches for Di-Lepton Resonances at ATLAS



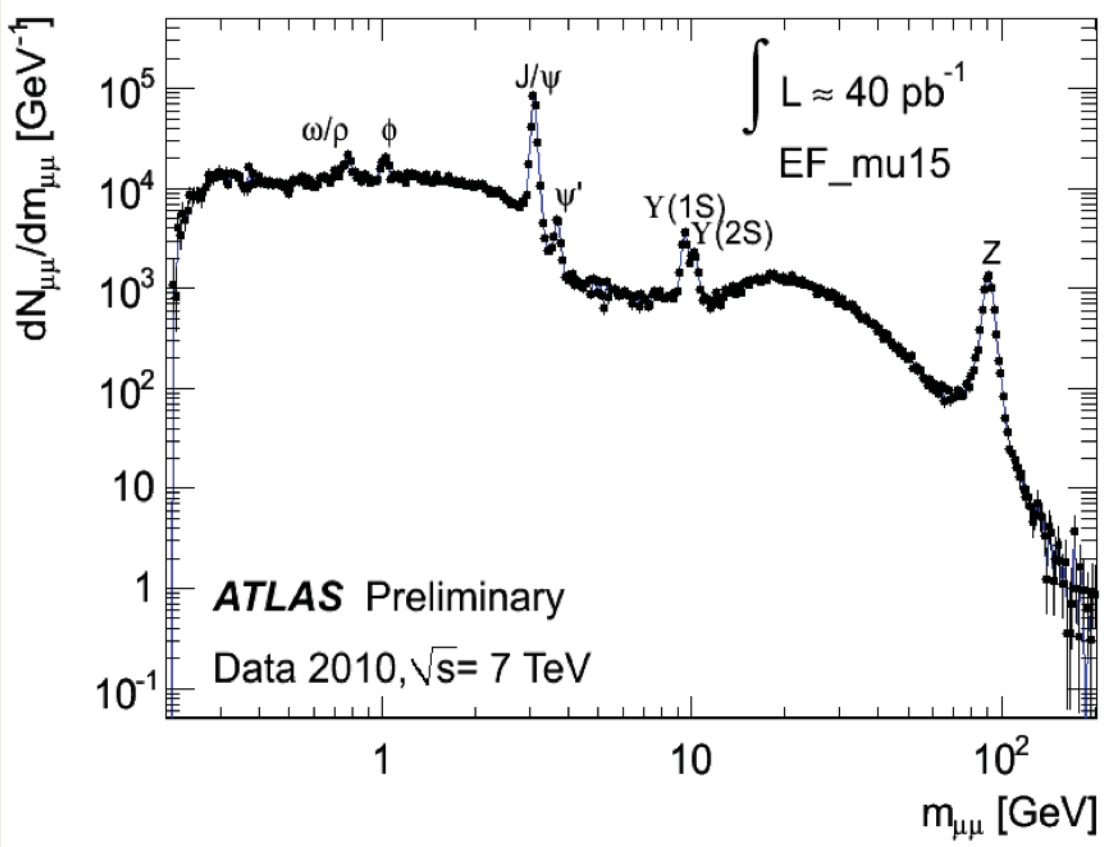
Oliver Stelzer-Chilton (TRIUMF)
on behalf of the ATLAS Collaboration

BSMLHC Sep 19 - 23, 2011

Trieste, Italy

Outline

- Motivation
- High-p_T Leptons
- Selection
- Backgrounds
- Fitting Strategy
- Systematics
- Discovery Statistics
- Limits
- Outlook



Search for Narrow Resonances

A resonance decaying to dileptons can have spin 0, 1, or 2

- **Spin 0**
  - No fundamental scalar particle yet observed
  - Higgs branching ratio to dileptons $O(10^{-4})$
  - Sneutrino resonance possible if R-parity violated
- **Spin 1**
  - Many models predict new U(1) with neutral gauge boson Z'
- **Spin 2**
  - Excited graviton resonances G^* predicted by Randall-Sundrum model of warped extra dimensions

Z' Production (spin 1)

- Benchmark model: Sequential Standard Model
  - But not motivated

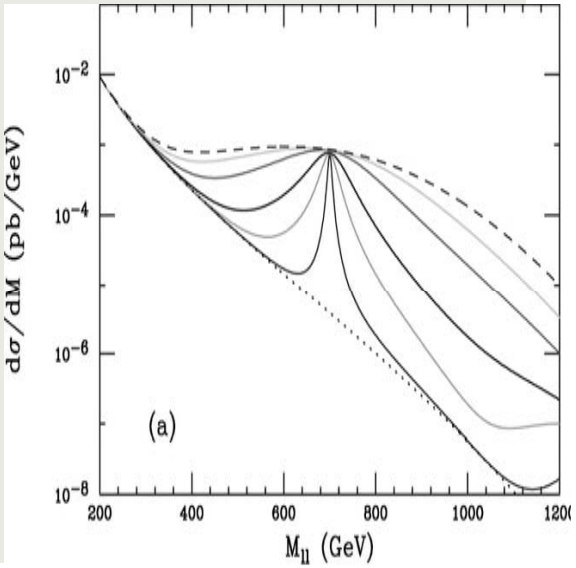
- GUT inspired E6 model

$$E_6 \rightarrow SO(10) \times U(1)_\psi$$
$$\rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi$$
$$\rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_\chi \times U(1)_\psi$$
$$\rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)'$$
$$\rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y$$

- Assume EWK-scale U(1)' is a linear combination of $U(1)_\chi \times U(1)_\psi$
  - Generic U(1)' can be expressed in terms of θ
  - $Z'(\theta) = Z_\psi' \cos(\theta) + Z_\chi' \sin(\theta)$
  - Z_ψ', Z_N', Z_χ' Z_η', Z_I', Z_S'

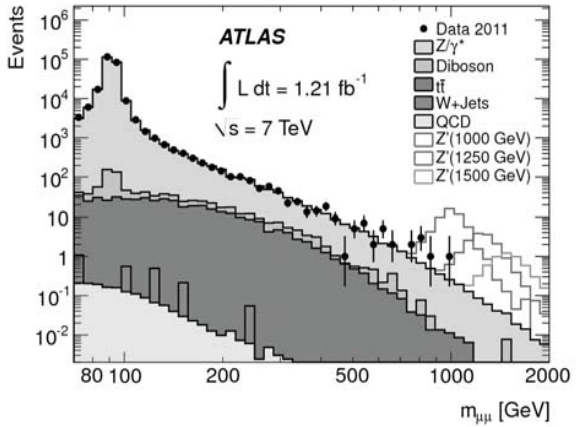
Graviton G* Production (spin 2)

- Randall-Sundrum
  - Warped extra dimension, exponential warp factor solves hierarchy problem
  - Two branes, TeV and Planck
  - Gravitons live everywhere
  - SM confined to TeV brane
- Excited states of graviton wave function has big overlaps
  - Massive gravitons with EWK-strength couplings to SM particles on our brane
- Expect first excitation to be TeV scale
  - Width proportional to $(k / M_{Pl})^2$
  - Narrow resonance for $k / M_{Pl} \lesssim 0.1$

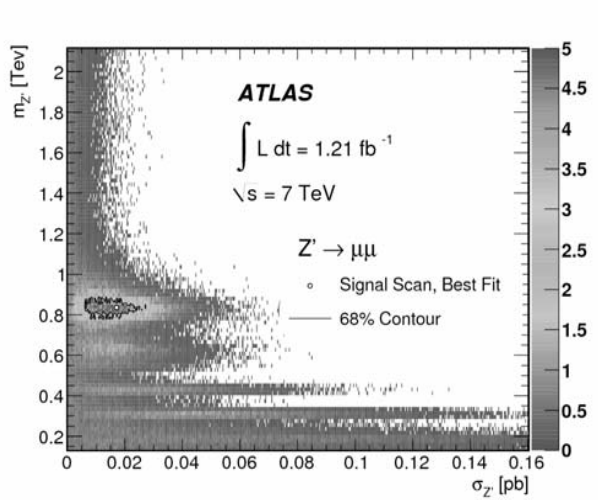


General Strategy

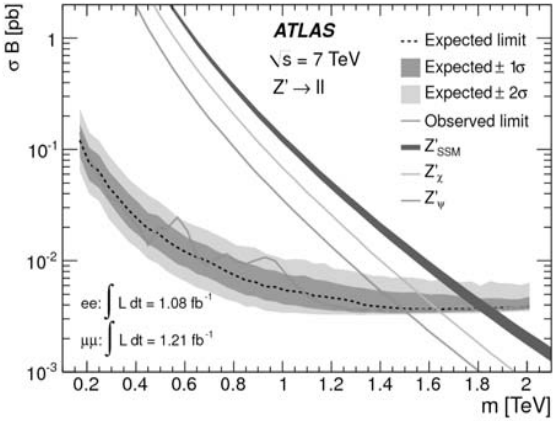
Calibrate detector resolution and scale



Understand background evaluate systematics



Determine scanning procedure, evaluate p-value



Interpret results from data

High p_T Lepton Resolutions

Electrons:

- Isolated energy deposition in the EM calorimeter

$$\frac{\sigma(E)}{E} = \frac{k_1}{\sqrt{E}} + k_2$$

- For high energy electrons, resolution dominated by constant term k_2 which is 1.2% in the barrel and 1.8% in the endcap

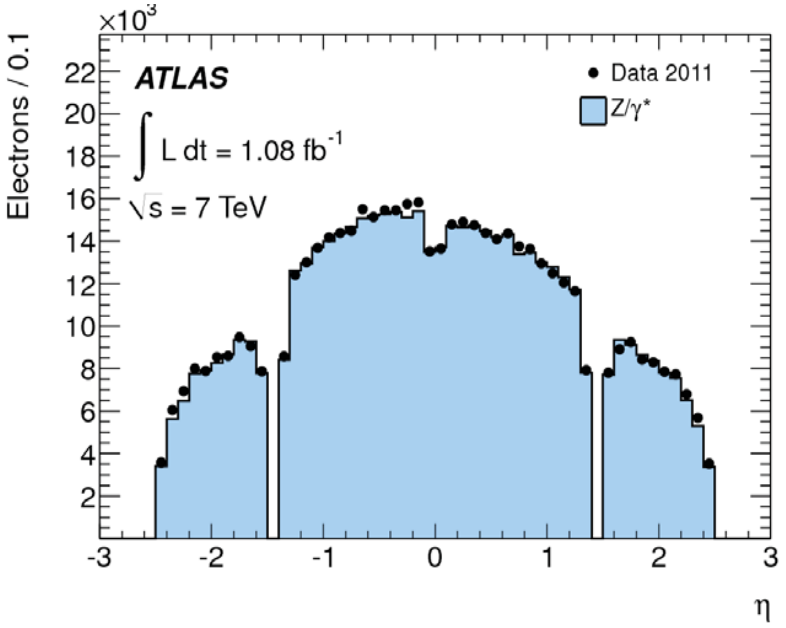
Muons:

- Use combined tracks from Inner Detector and Muon Spectrometer
- At high p_T, curvature resolution dominated by intrinsic/misalignment term S_2 which ranges from 0.15 TeV^{-1} to 0.44 TeV^{-1} (for η >2)

$$q/p_T \rightarrow (q/p_T)_{ini} + S_1 (q/p_T)_{ini} + S_2$$

Electron Selection

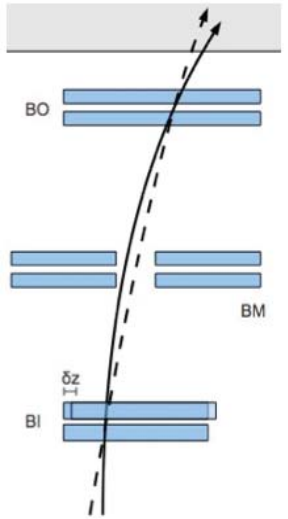
- EM clusters with $E_T > 25$ GeV, $|\eta| < 2.47$
- Criteria on the transverse shower shape, the longitudinal leakage into the hadronic calorimeter
- Removal of transition region between barrel and endcap $1.37 < |\eta| < 1.52$
- Association to an inner detector track
- Calorimeter isolation for leading electron < 0.2 in cone ΔR of 0.2

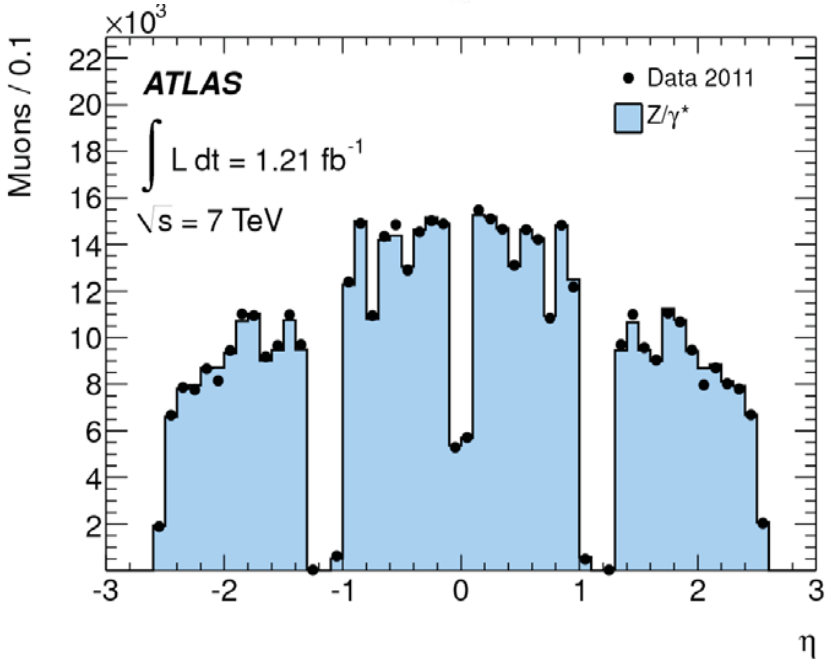


Signal efficiency for 1.5 TeV
Z' (Randall-Sundrum G*) 65% (69%)

Muon Selection

- Hit requirements in ID and MS
  Require 3 hits in all 3 muon stations to ensure optimal momentum resolution
- Combined muons with $p_T > 25$ GeV
- Impact parameter cus: $|d0| < 0.2$ mm and z0 wrt PV < 1.0 mm
- Relative track isolation < 0.05 in cone ΔR of 0.3
- Muons of opposite charge





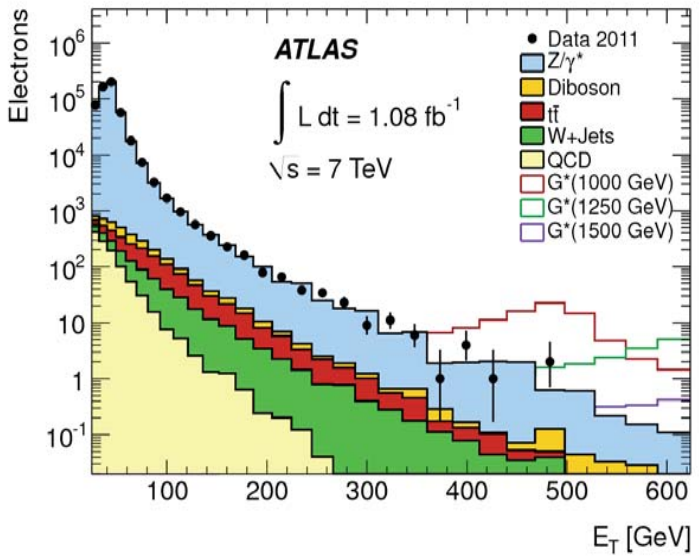
Signal efficiency for 1.5 TeV
Z' (Randall-Sundrum G*) 40% (44%)

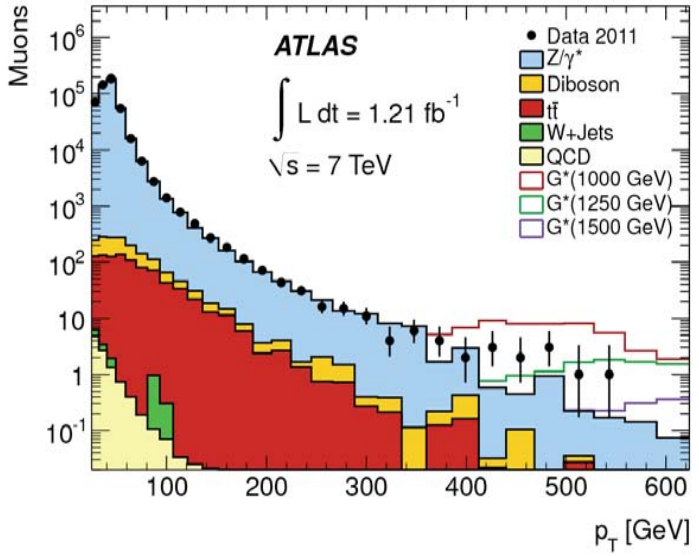
Signal and Backgrounds

- Z' and G* signal simulated using Pythia
- Backgrounds simulated using:
  - Pythia (Z/γ*)
  - Alpgen (W+Jets)
  - Herwig (WW, WZ, ZZ)
  - MC@NLO (ttbar)
- Apply k-factors to MC cross-sections
- Data-driven backgrounds for QCD

$m_{e^+e^-}$ [GeV]	70-110	110-200	200-400	400-800	800-3000
DY	258482 ± 410	5449 ± 180	613 ± 26	53.8 ± 3.1	2.8 ± 0.1
$t\bar{t}$	218 ± 36	253 ± 10	82 ± 3	5.4 ± 0.3	0.1 ± 0.0
Diboson	368 ± 19	85 ± 5	29 ± 2	3.1 ± 0.5	0.3 ± 0.1
W+jets	150 ± 100	150 ± 26	43 ± 10	4.6 ± 1.8	0.2 ± 0.4
QCD	332 ± 59	191 ± 75	36 ± 29	1.8 ± 1.4	< 0.05
Total	259550 ± 510	6128 ± 200	803 ± 40	68.8 ± 3.9	3.4 ± 0.4
Data	259550	6117	808	65	3

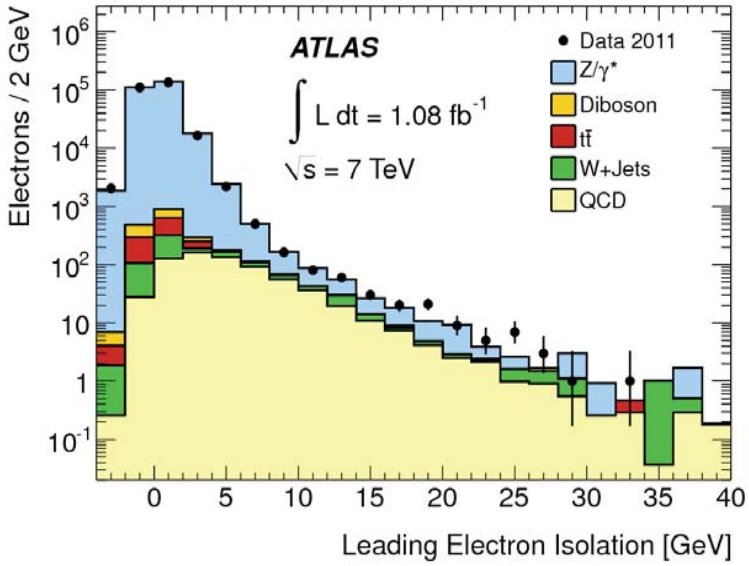
$m_{\mu^+\mu^-}$ [GeV]	70-110	110-200	200-400	400-800	800-3000
DY	236319 ± 320	5171 ± 150	483 ± 22	40.3 ± 2.5	2.0 ± 0.3
$t\bar{t}$	193 ± 21	193 ± 20	63 ± 6	4.2 ± 0.4	0.1 ± 0.0
Diboson	307 ± 16	69 ± 5	25 ± 2	1.7 ± 0.5	< 0.05
W+jets	1 ± 1	1 ± 1	< 0.5	< 0.05	< 0.05
QCD	1 ± 1	< 0.5	< 0.5	< 0.05	< 0.05
Total	236821 ± 487	5434 ± 150	571 ± 23	46.1 ± 2.6	2.1 ± 0.3
Data	236821	5406	557	51	5

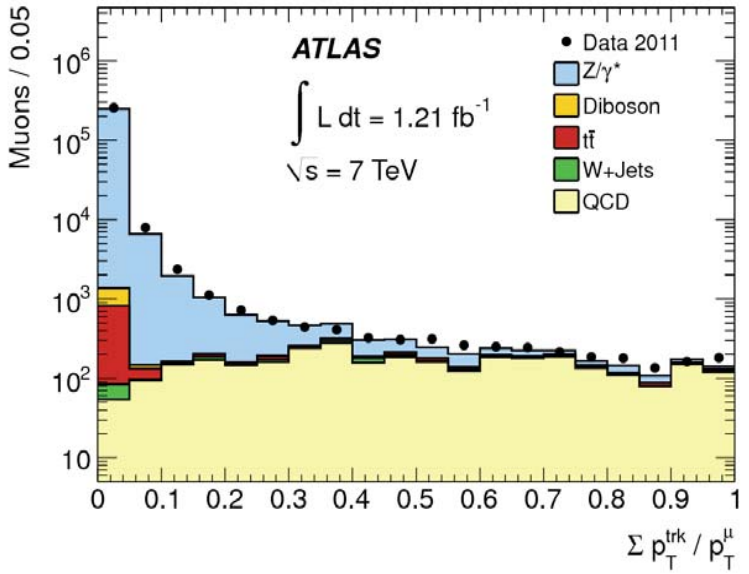




QCD Background

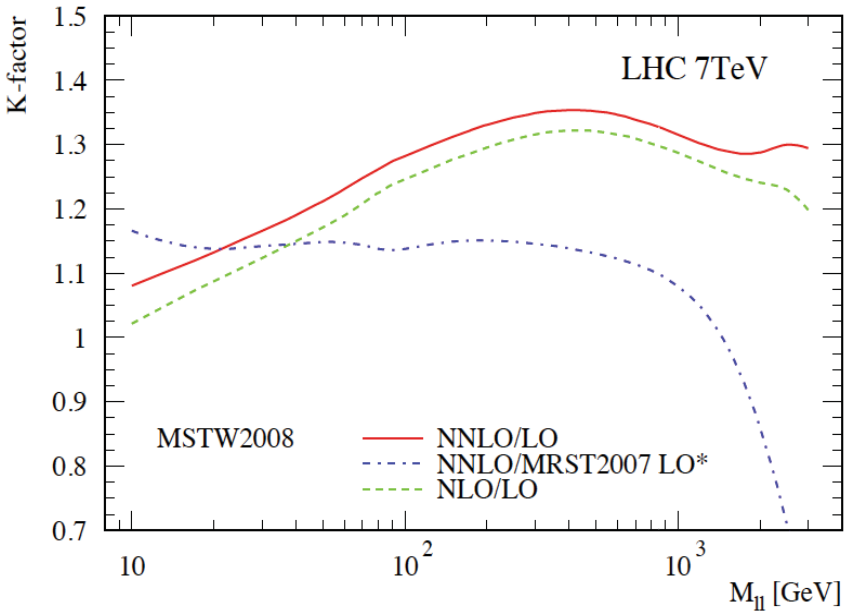
- Sources for electron channel
  - Photon conversions
  - Semi-leptonic heavy quark decays
  - Hadrons faking electrons
- Estimates from three methods
  - Reversed electron identification
  - Isolation fit techniques
  - Fake rates from jet samples
- Source for muon channel
  - Semi-leptonic decays of b and c quarks
  - Kaons and Pions decays In flight
- Estimate from muon isolation variable
  - Found to be negligible





Drell-Yan Background

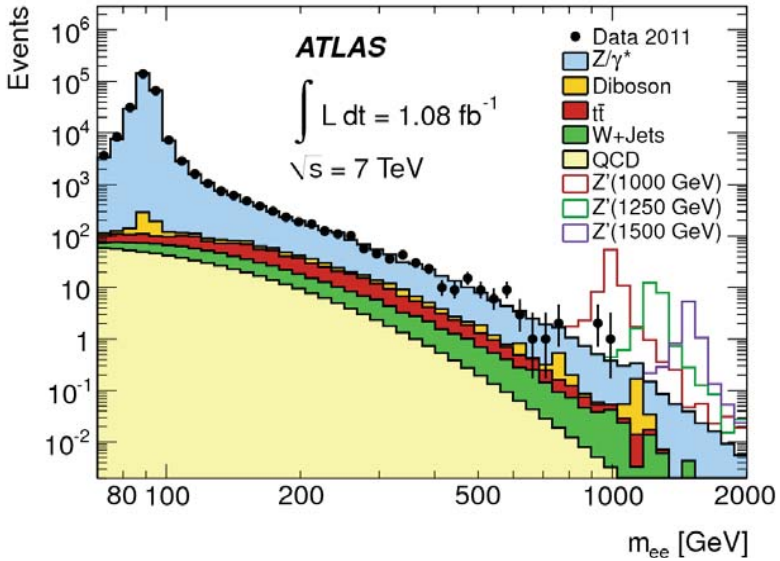
- Cut on reducible backgrounds so that Z/γ^* dominates SM expectation in entire search region
  - Predicted using PYTHIA with a mass dependent NNLO multiplicative k-factor correction from PHOZPR
  - Apply same k-factor Z' signal

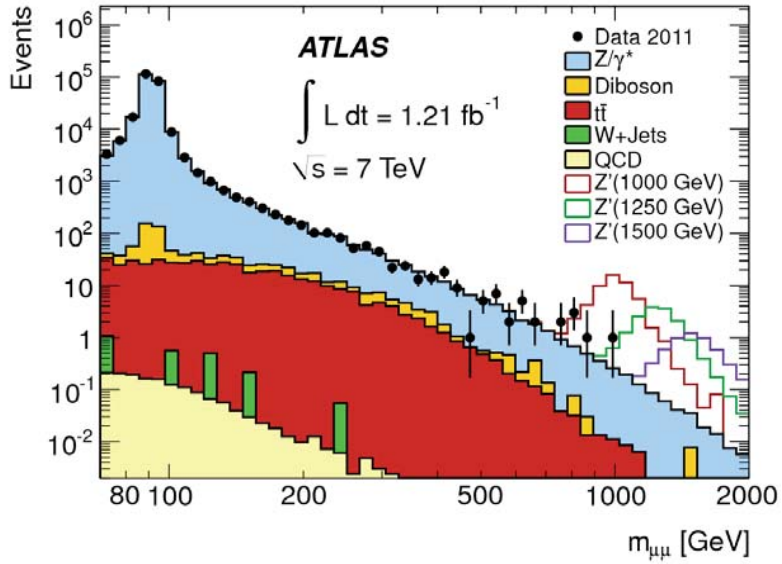


Smooth background shape

Dominant uncertainties due to PDFs and higher-order corrections

Fitting Strategy





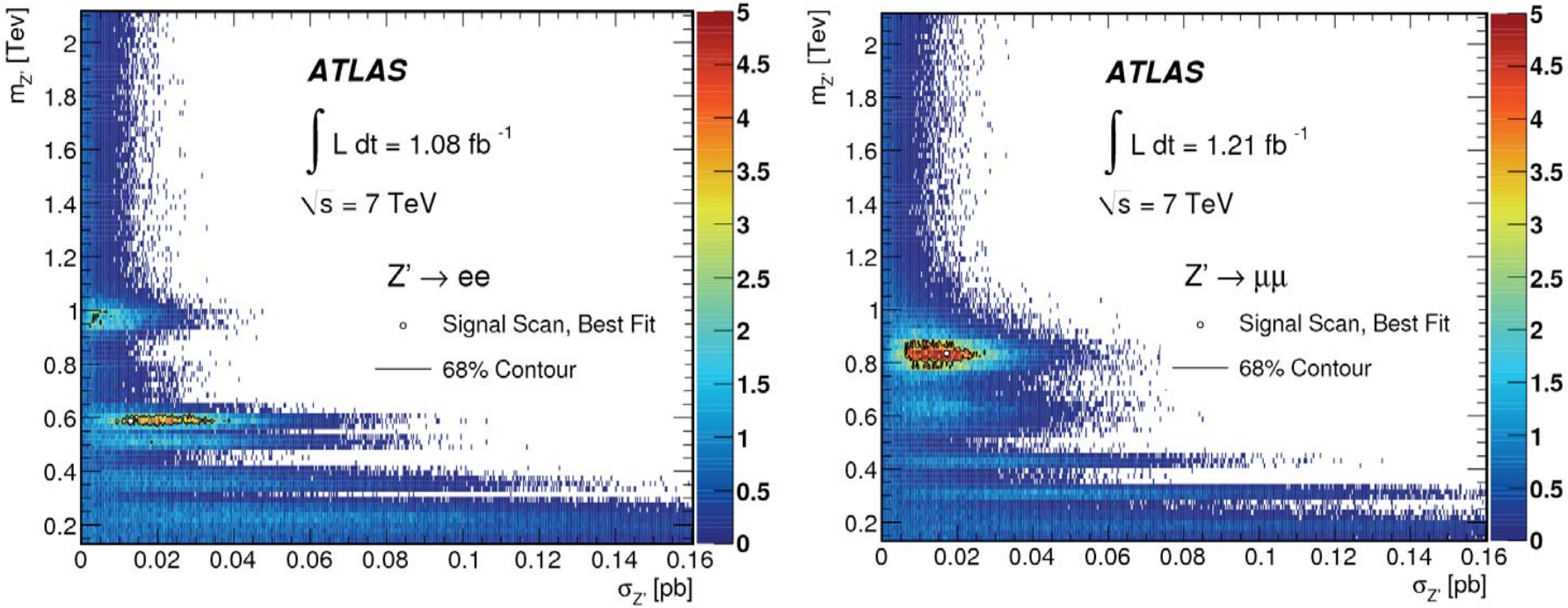
- Normalization to the Z peak
  $\sigma_{Z'} = \sigma_Z * N_{Z'}/N_Z * A_Z/A_{Z'}$
- Removes mass-independent systematics
- Remaining dominant systematics

Source	dielectrons		dimuons	
	signal	background	signal	background
Normalization	5%	NA	5%	NA
PDFs/α_S	NA	10%	NA	10%
QCD K-factor	NA	3%	NA	3%
Weak K-factor	NA	4.5%	NA	4.5%
Trigger/Reconstruction	negligible	negligible	4.5%	4.5%
Total	5%	11%	7%	12%

- No systematics applied to signal

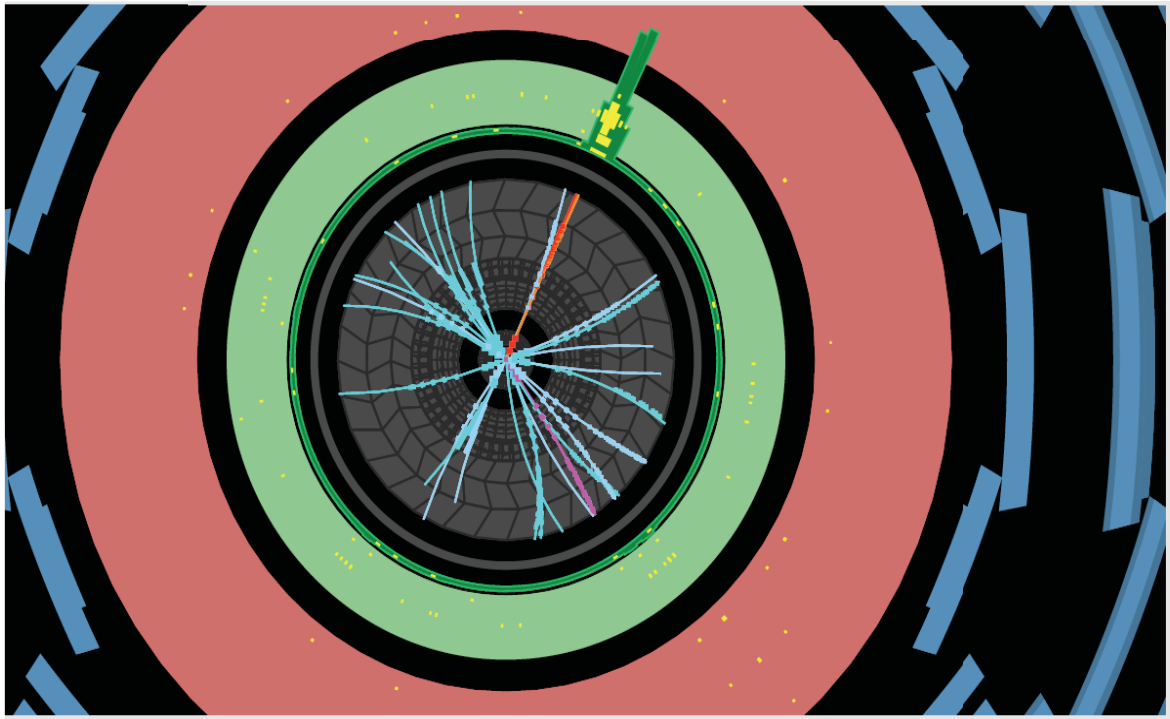
Discovery Statistics

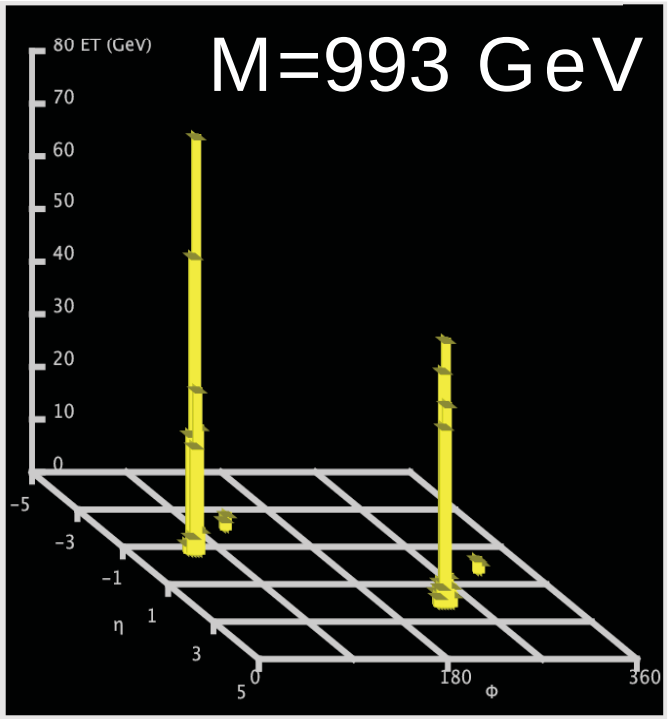
- 2D fit for $M_{Z'}$ and $\sigma_{Z'}$ using finely binned fully simulated signal lineshapes and naturally includes trials factor

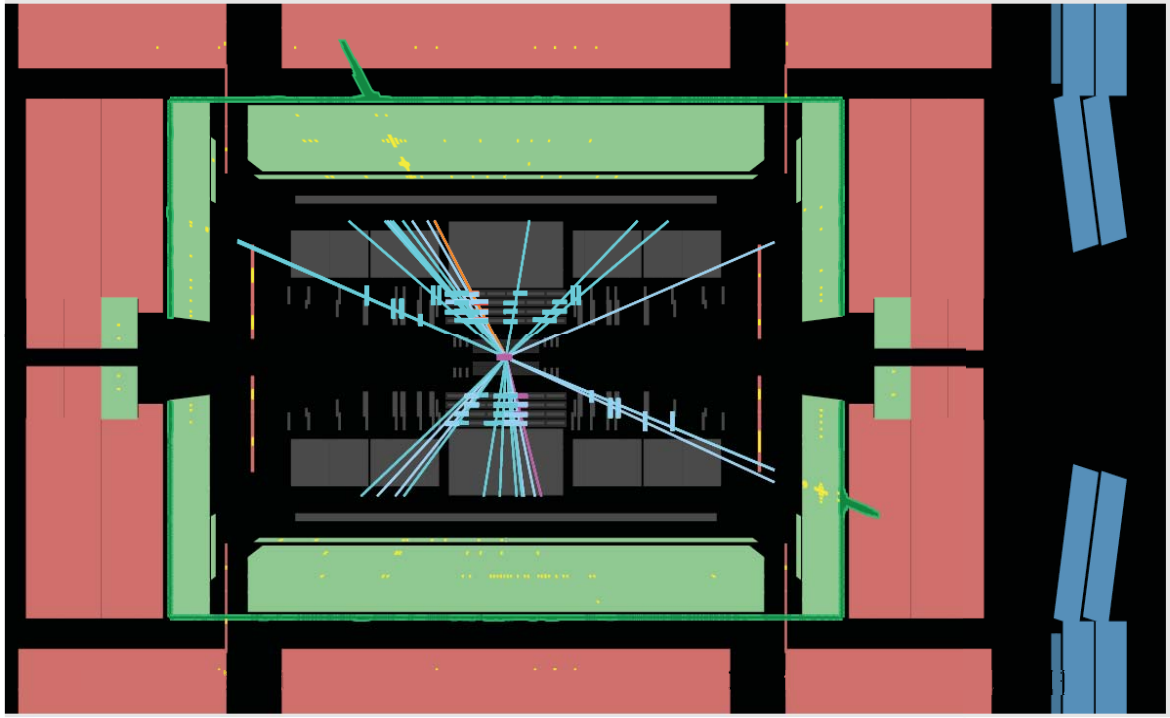


- Outcome is ranked using a likelihood ratio

- Resulting p-values: 54% (ee) and 24% ($\mu\ \mu$)







ATLAS EXPERIMENT

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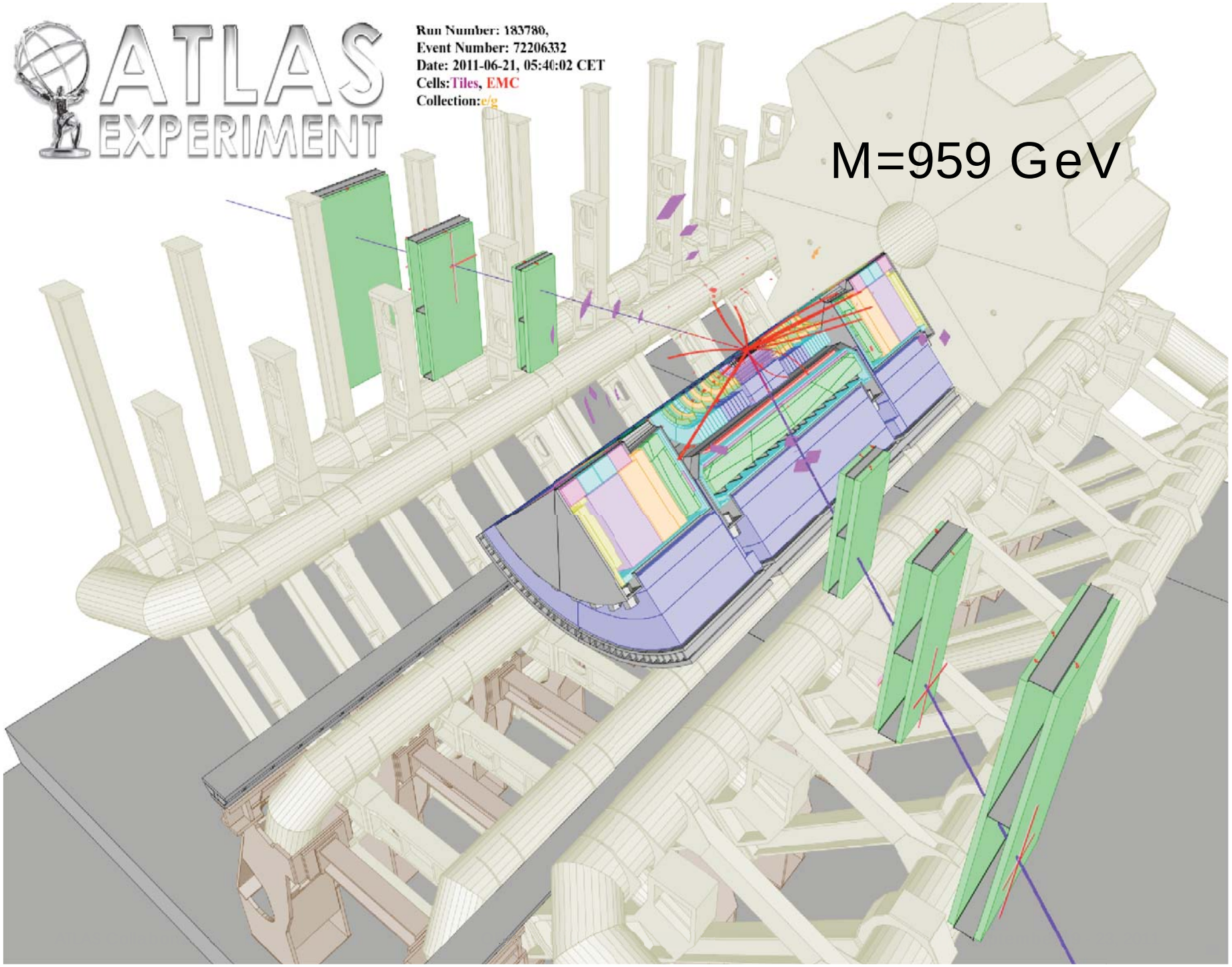
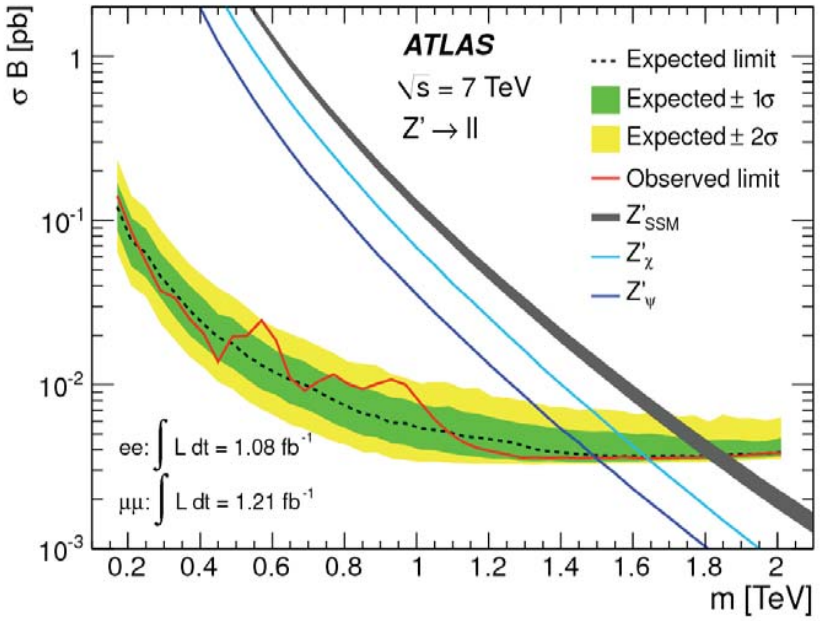
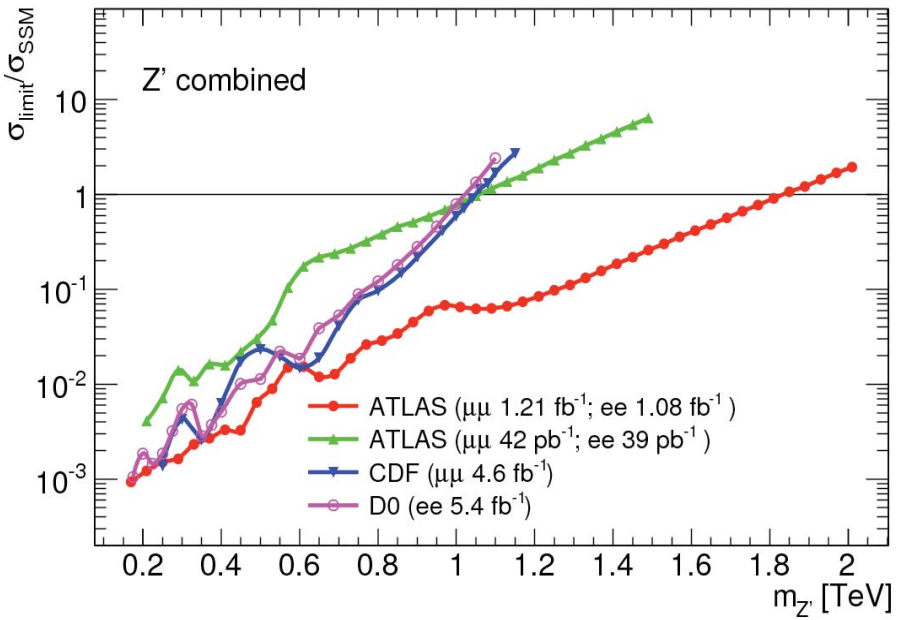
Date: 2011-06-14 02:48:15 PDT


ATLAS
EXPERIMENT
Run Number: 183780,
Event Number: 72206332
Date: 2011-06-21, 05:40:02 CET
Cells:Tiles, EMC
Collection:e/g
M=959 GeV

Z' Limits

- 95% CL intervals on fitted $\sigma(Z')$ converted into limits on $\sigma \cdot B(Z' \rightarrow ll)$ using the cross-section ratio between Z/Z'





- Resulting mass limits

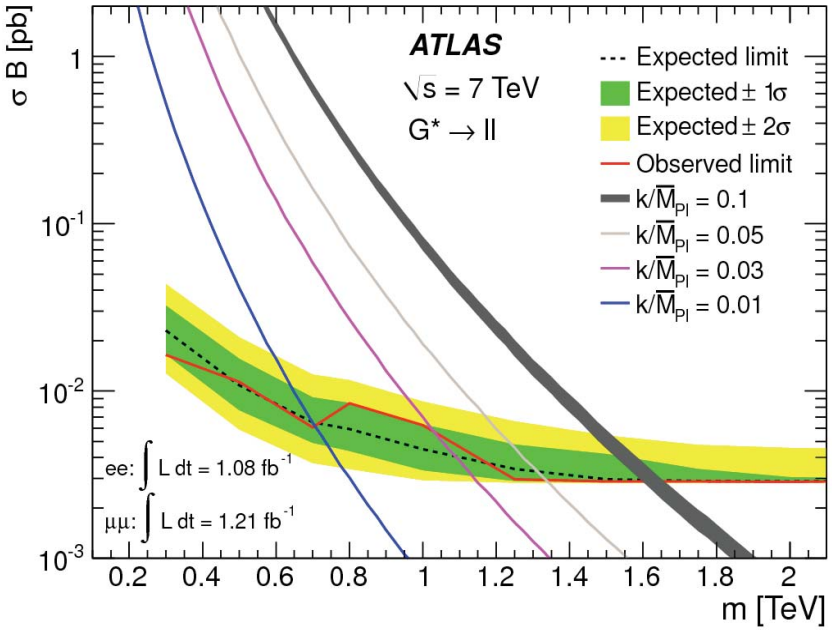
	E_6 Z' Models					
Model/Coupling	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
Mass limit [TeV]	1.49	1.52	1.54	1.56	1.60	1.64

Model	e^+e^-	$\mu^+\mu^-$	$\ell^+\ell^-$
Z'_{SSM}	1.70 (1.70)	1.61 (1.61)	1.83 (1.83)

values in brackets indicated the expects limits

Randall-Sundrum Graviton Limits

- Signal acceptance is larger for spin-2 RS Graviton, also parton luminosity effect is slightly smaller



- Resulting mass limits

	RS Graviton			
Model/Coupling	0.01	0.03	0.05	0.1
Mass limit [TeV]	0.71	1.03	1.33	1.63

Model	e^+e^-	$\mu^+\mu^-$	$\ell^+\ell^-$
G^*	1.51 (1.50)	1.45 (1.44)	1.63 (1.63)

values in brackets indicated the expects limits

Outlook

- Motivation to search for high mass resonances continues
  - Field changing discoveries in the past
- During first year, LHC has entered new territory in resonance search
- Cross section limits at 95% C.L. are converted into mass limits
  - $M_{Z'SSM} > 1.83$ TeV
  - $M_{Z'\chi} > 1.64$ TeV
  - $M_{G^*(k/Mpl=0.1)} > 1.63$ TeV
  - $M_{G^*(k/Mpl=0.01)} > 0.71$ TeV

arXiv:1108.1582 submitted to PRL

- Will double dataset at least four more times before shutdown
  - Discovery might be around the corner!