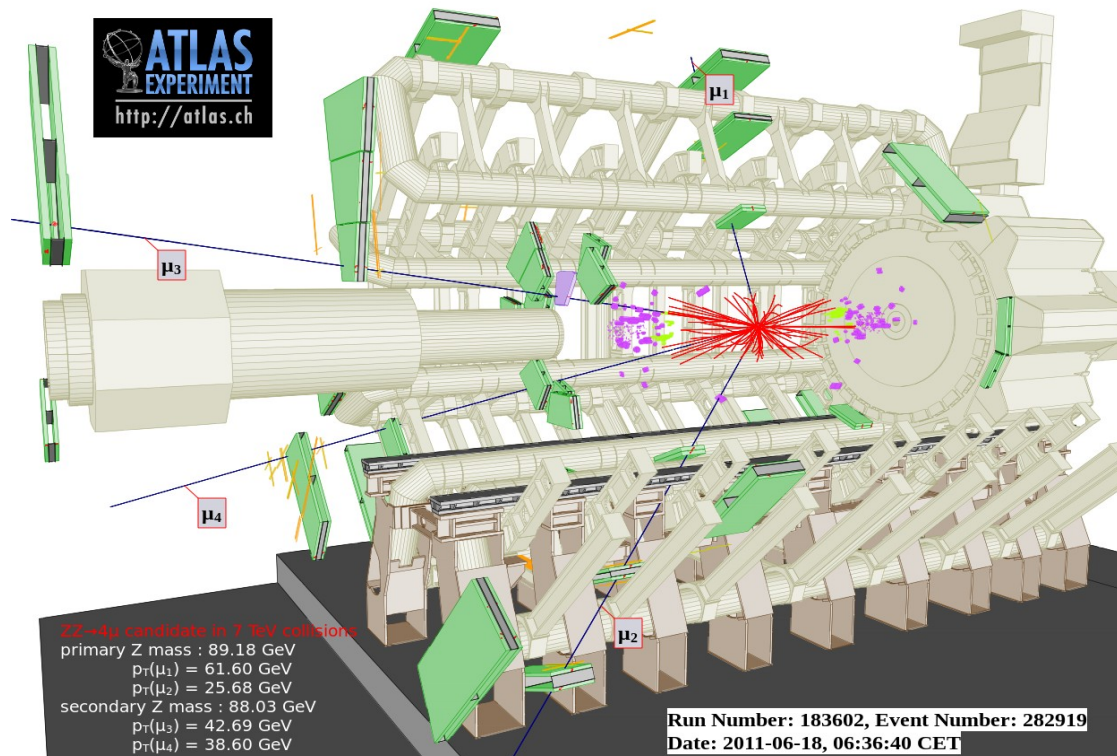


ATLAS measurements of WW, WZ, and ZZ production



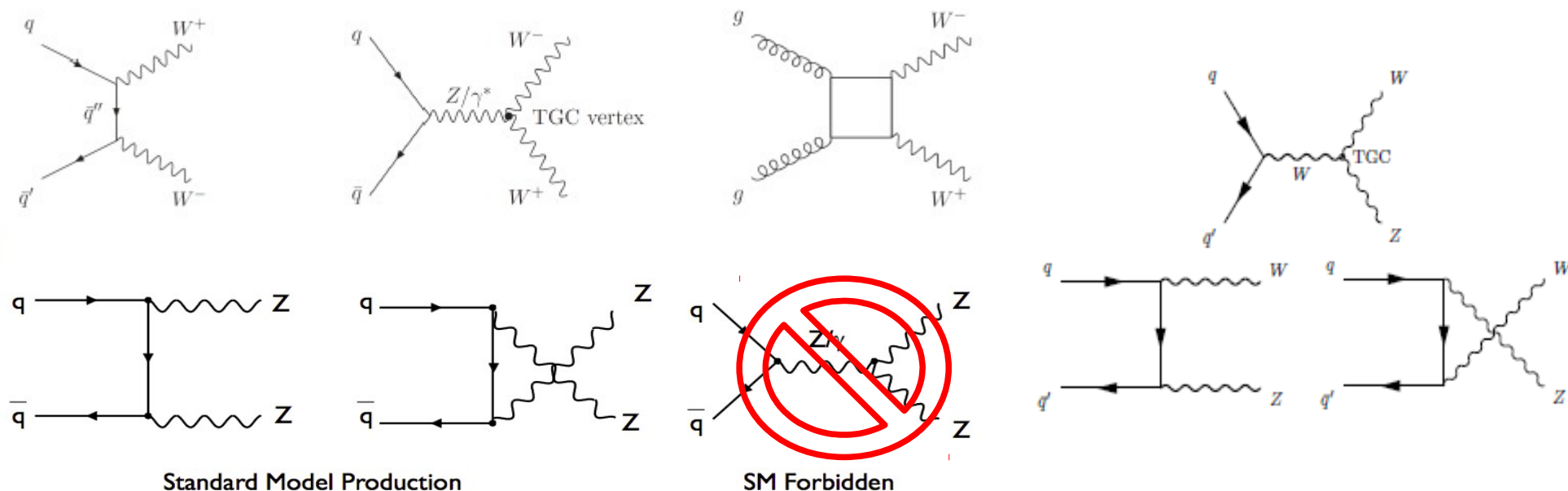
C. Hays, Oxford University
for the ATLAS Collaboration

6 July 2012



Diboson production at the LHC

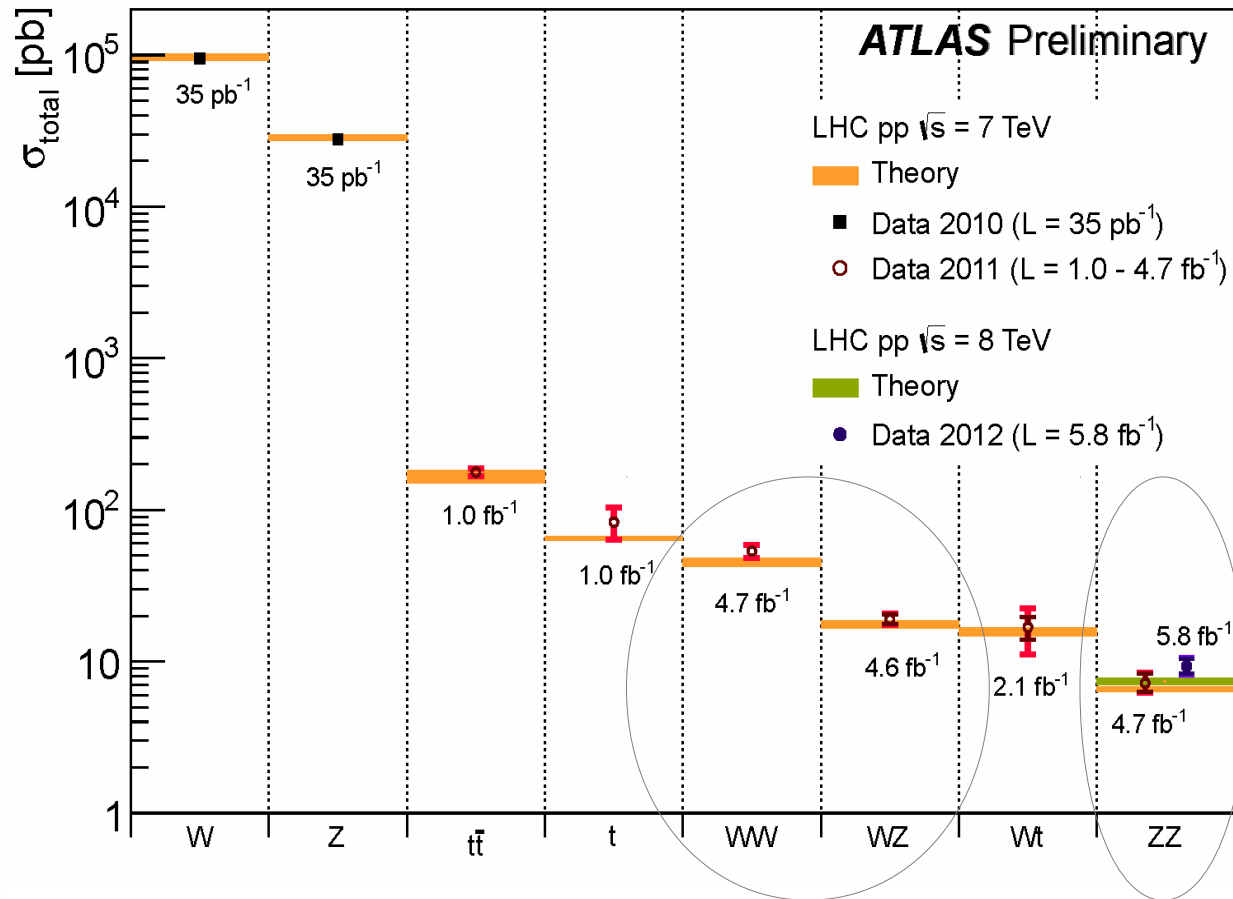
Probes gauge-boson self-couplings & interference in new energy regime



Measurements constrain modelling of backgrounds to Higgs (and other) searches

Can provide a calibration source for (boosted) dijet resonances

Diboson measurements at ATLAS



$WW \rightarrow l\nu l\nu : 4.7 \text{ fb}^{-1}$ at 7 TeV

$WZ \rightarrow l\nu ll : 4.6 \text{ fb}^{-1}$ at 7 TeV

$ZZ \rightarrow ll\nu\nu : 4.7 \text{ fb}^{-1}$ at 7 TeV

$ZZ \rightarrow llll : 4.7 \text{ fb}^{-1}$ at 7 TeV
 5.8 fb^{-1} at 8 TeV

ATLAS diboson measurement strategy

Measure cross section within a fiducial region

$$\sigma_{\text{fid}} = \frac{N_{\text{data}} - N_{\text{bg}}}{\mathcal{L} C_{WW}}$$

C_{WW} : ratio of measured to produced
WW events in fiducial region

Extrapolate to a total cross section

$$\sigma(pp \rightarrow WW) = \frac{N_{\text{data}} - N_{\text{bg}}}{A_{WW} C_{WW} \mathcal{L} \mathcal{B}}$$

A_{WW} : kinematic and
geometric acceptance

\mathcal{B} : branching ratio

Probe high- Q^2 events for anomalous triple-gauge couplings

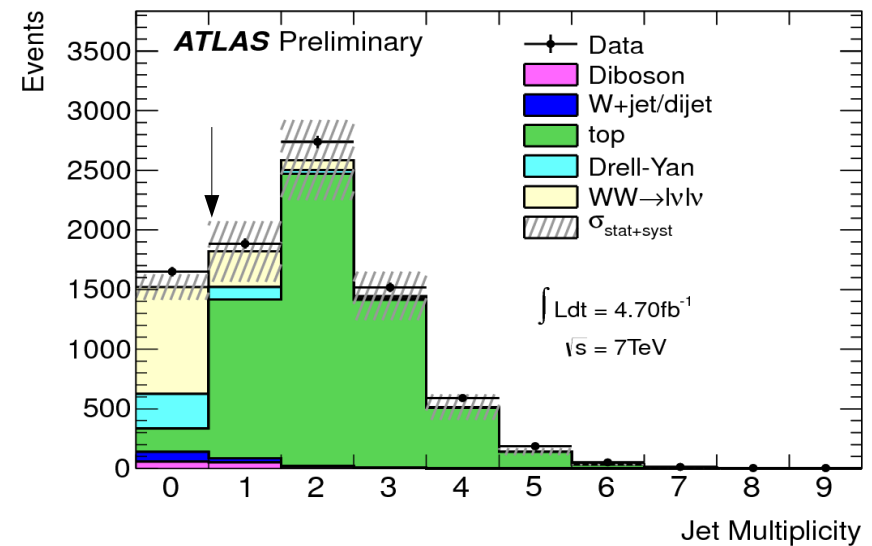
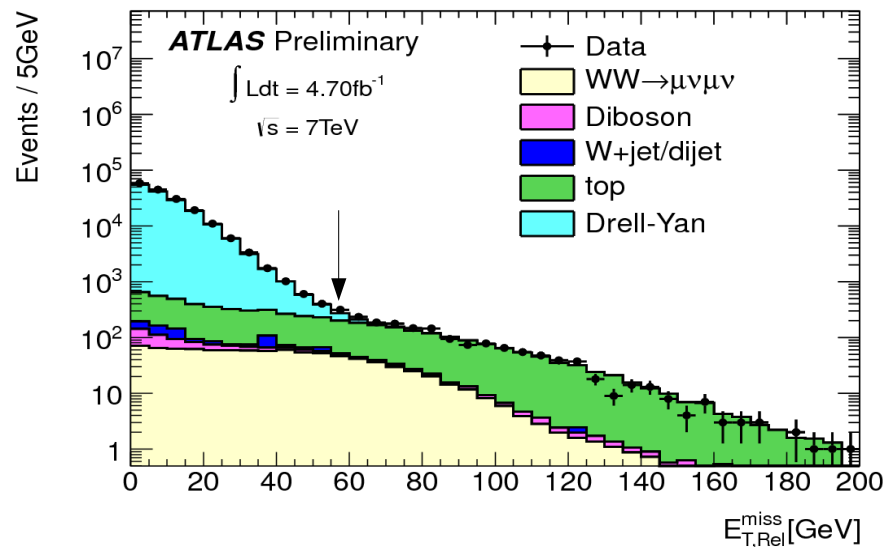
$$\begin{aligned} \mathcal{L}_{WWV} / g_{WWV} = & i g_1^V (W_{\mu\nu}^\dagger W^\mu V^\nu - W_\mu^\dagger V_\nu W^{\mu\nu}) \\ & + i \kappa_V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{i \lambda_V}{m_W^2} W_{\lambda\mu}^\dagger W_\nu^\mu V^{\nu\lambda} \end{aligned}$$

SM: $g_1^V = \kappa_V = 1$;
 $\lambda_V = 0$

WW cross section

Select dilepton events with $m_{ll} \neq m_Z$, large $E_{T,Rel}^{miss}$ and no jets

$$E_{T,Rel}^{miss} = \begin{cases} E_T^{miss} \times \sin(\Delta\phi_{\ell,j}) & \text{if } \Delta\phi < \pi/2 \\ E_T^{miss} & \text{if } \Delta\phi \geq \pi/2 \end{cases}$$



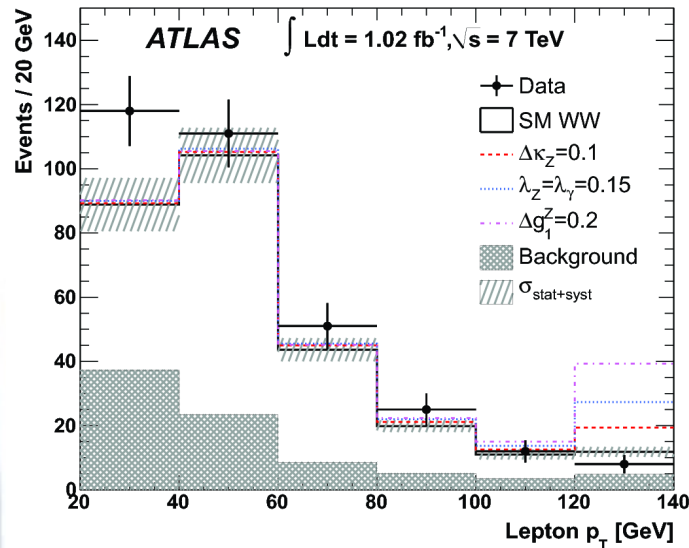
Fiducial cross sections

Channels	expected σ^{fid} (fb)	measured σ^{fid} (fb)	$\Delta\sigma_{stat}$ (fb)	$\Delta\sigma_{syst}$ (fb)	$\Delta\sigma_{lumi}$ (fb)
$e\nu e\nu$	44.9 ± 3.7	41.4	± 6.5	± 5.7	± 1.6
$\mu\nu\mu\nu$	38.0 ± 3.1	48.2	± 4.6	± 3.8	± 1.9
$e\nu\mu\nu$	237.4 ± 19.4	284.9	± 12.7	± 14.1	± 11.1

Total cross section consistent with MCFM prediction of 45.1 ± 2.8 pb

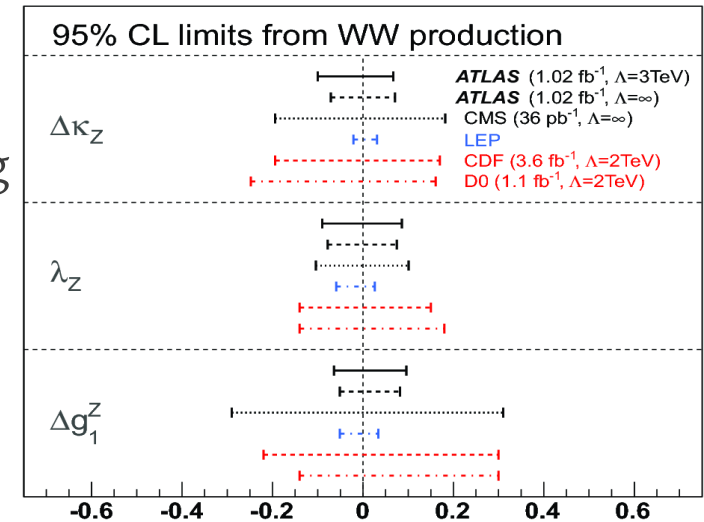
Channels	Total cross-section (pb)	$\Delta\sigma_{stat}$ (pb)	$\Delta\sigma_{syst}$ (pb)	$\Delta\sigma_{lumi}$ (pb)
$e\nu e\nu$	41.5	± 6.5	± 7.8	± 1.6
$\mu\nu\mu\nu$	57.3	± 5.5	± 5.4	± 2.2
$e\nu\mu\nu$	54.3	± 2.4	± 4.4	± 2.1
Combined	53.4	± 2.1	± 4.5	± 2.1

Anomalous couplings from WW events



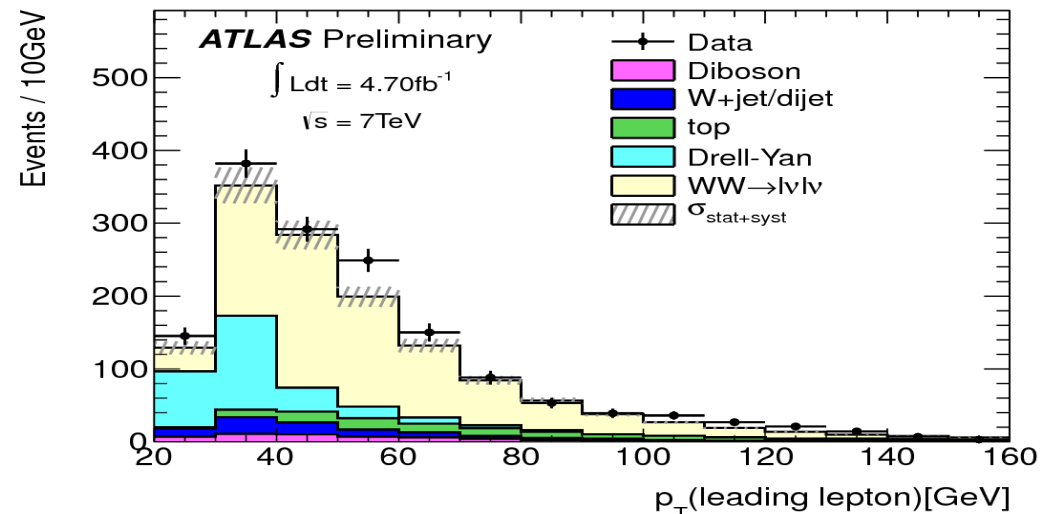
Fit for anomalous couplings using distribution of leading lepton p_T (1 fb^{-1})

$$\lambda(s) = \lambda / (1 + s/\Lambda^2)^2$$



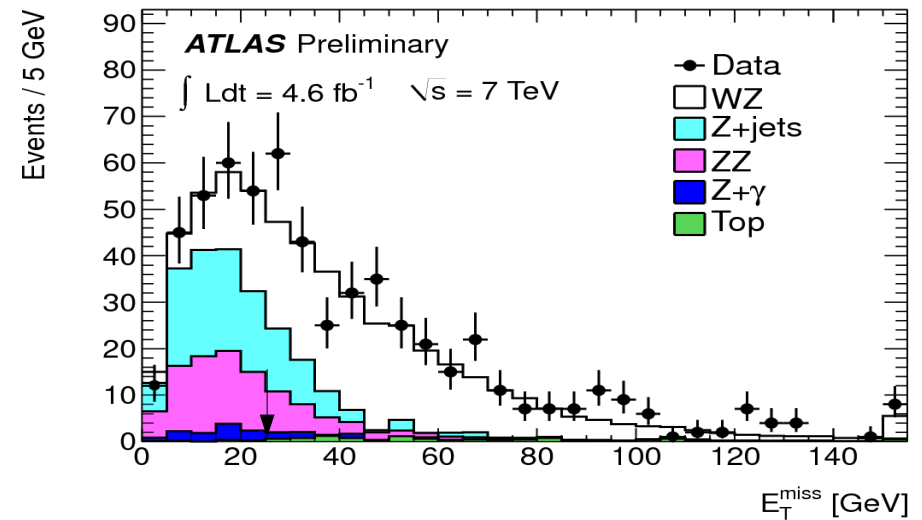
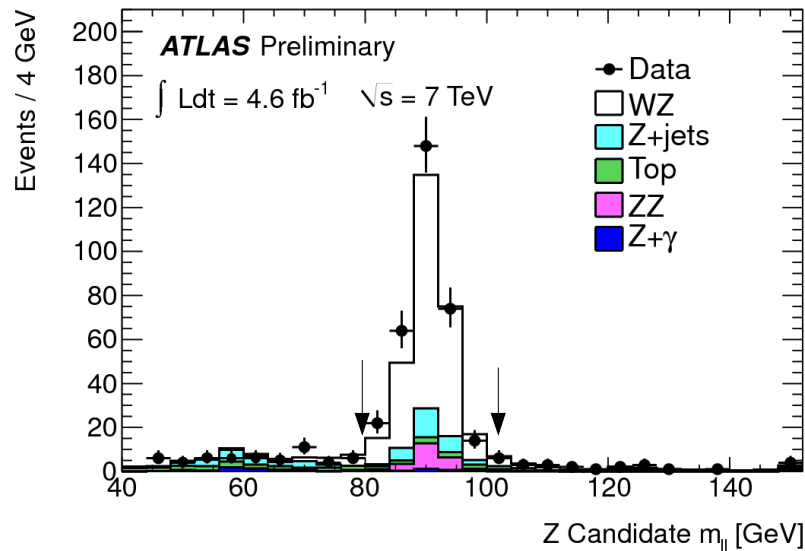
Anomalous couplings have largest effect at high p_T

Limits set in LEP, HISZ, and Equal Coupling scenarios



WZ total cross section

Select events with lepton pairs with mass $\sim m_Z$, an additional lepton, and large E_T^{miss}



317 candidates,
 68 ± 8 background

Total cross section
consistent with SM
prediction: $17.6^{+1.1}_{-1.0}$ pb

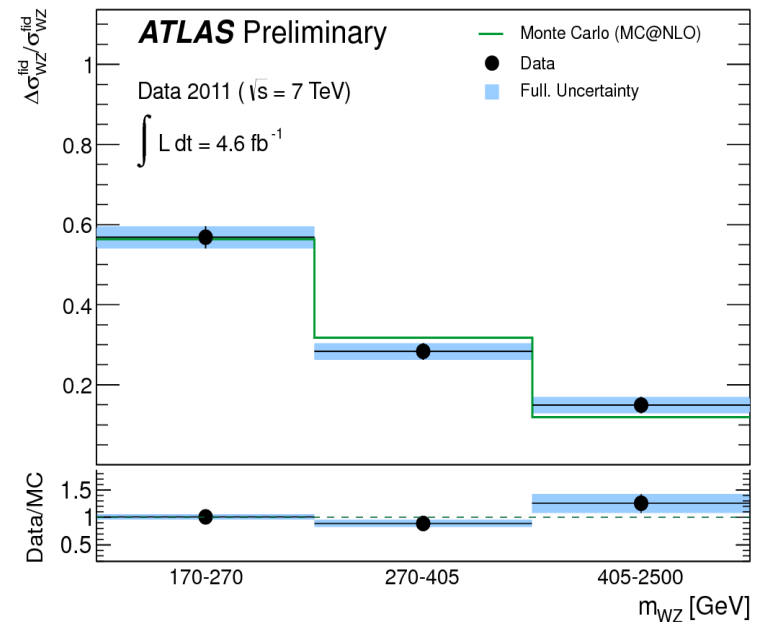
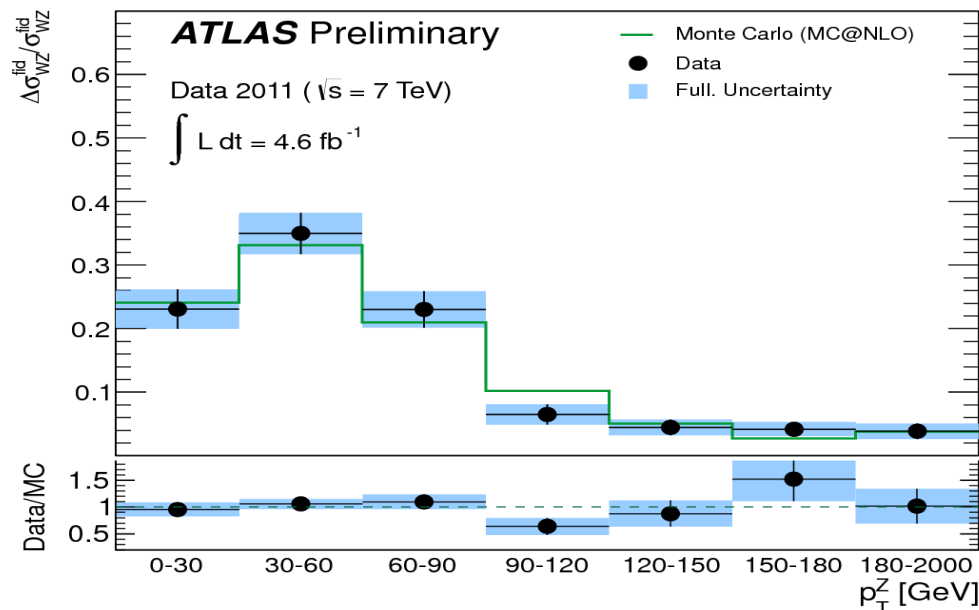
	<i>eee</i>	<i>μee</i>	<i>eμμ</i>	<i>μμμ</i>
N_{obs}	56	75	78	108
N_{sig}	38.9 ± 2.1	54.0 ± 2.2	56.6 ± 1.7	81.7 ± 2.1
N_{bkg}	14.5 ± 2.1	11.5 ± 1.9	21.0 ± 2.7	21.0 ± 4.2

$$\sigma_{WZ}^{\text{tot}} = 19.0^{+1.4}_{-1.3}(\text{stat}) \pm 0.8(\text{syst}) \pm 0.4(\text{lumi}) \text{ pb}$$

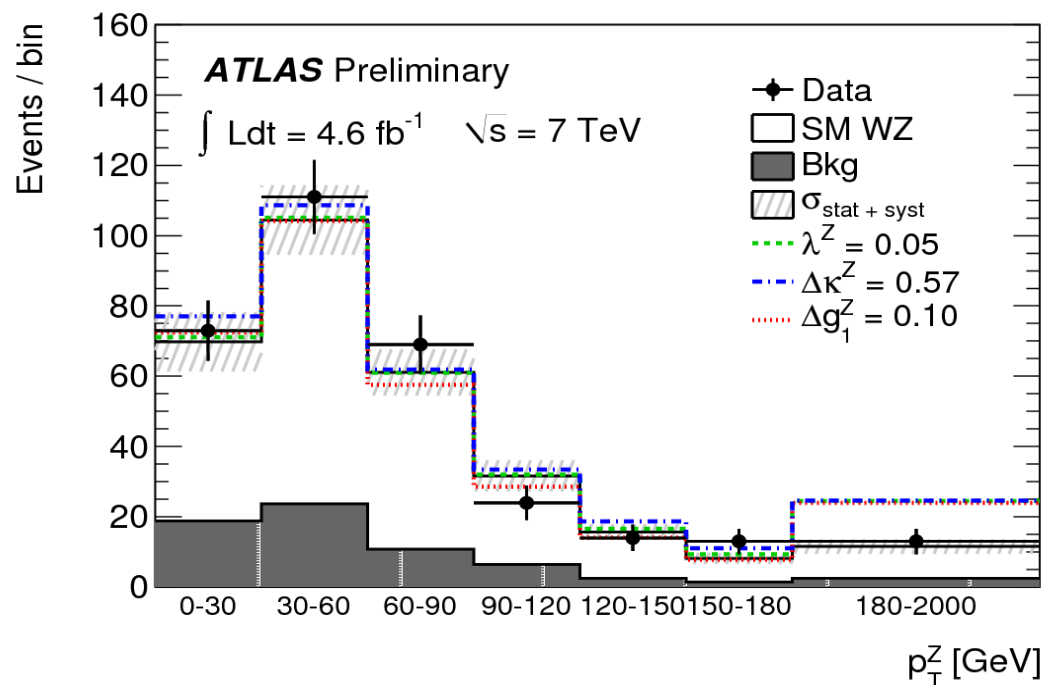
WZ fiducial cross section

Measure both inclusive fiducial cross section and unfolded differential cross sections:

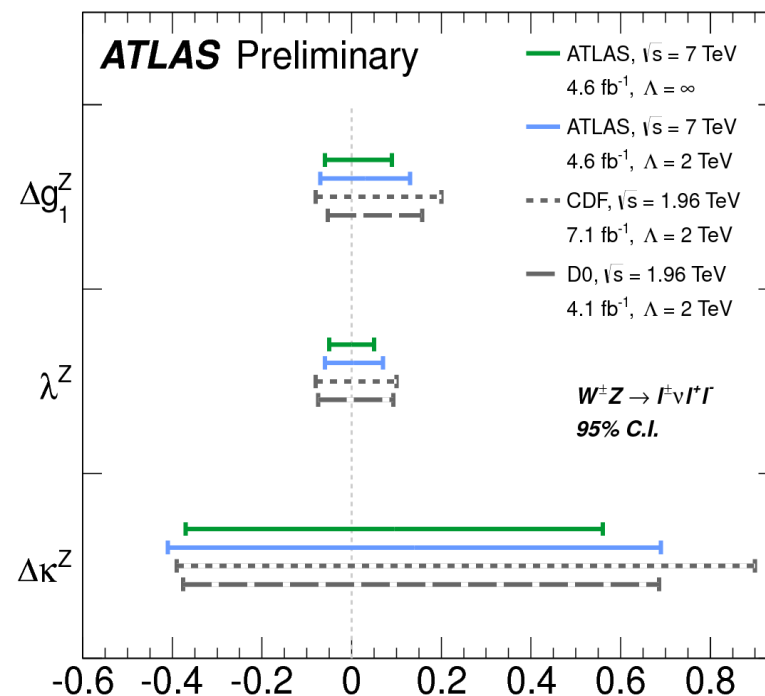
$$\sigma_{WZ}^{\text{fid}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\int \mathcal{L} dt \cdot C_{WZ}} \left(1 - \frac{N_{\tau}^{\text{MC}}}{N_{\text{sig}}^{\text{MC}}} \right) \quad \sigma_{WZ}^{\text{fid}} = 92_{-6}^{+7}(\text{stat}) \pm 4(\text{syst}) \pm 2(\text{lumi}) \text{ fb}$$



Anomalous couplings from WZ events



Fit Z p_T distribution for
anomalous couplings

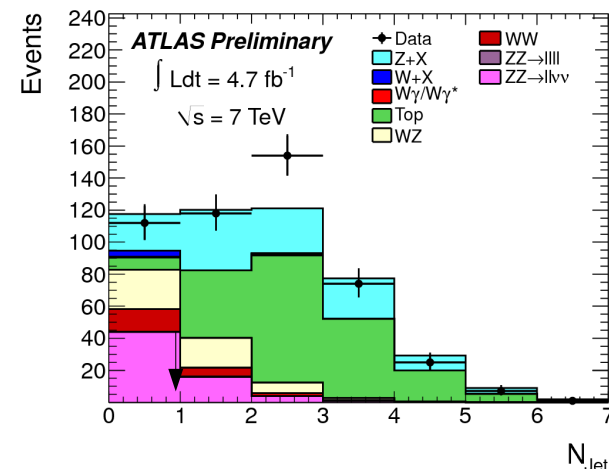
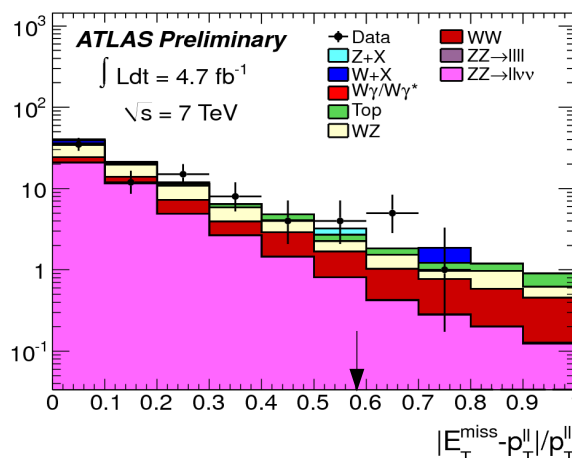
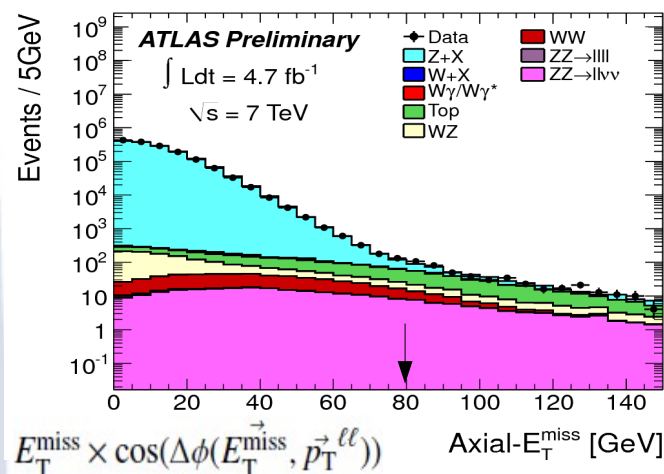


Probes anomalous WWZ
couplings specifically

ZZ cross section

llvv channel:

Select dilepton events with $m_{ll} \sim m_Z$, large axial E_T^{miss} , small $p_T^{\text{miss}} - E_T^{\text{miss}}$ difference, and no jets



Final State	$e^+e^- \nu\bar{\nu}$	$\mu^+\mu^- \nu\bar{\nu}$	$\ell^+ \ell^- \nu\bar{\nu}$
Observed	33	45	78
Expected ZZ	$19.3 \pm 0.5 \pm 1.2$	$23.0 \pm 0.6 \pm 0.9$	$42.3 \pm 0.8 \pm 1.8$
Total Background	$18.0 \pm 2.0 \pm 1.6$	$22.7 \pm 2.4 \pm 2.1$	$40.7 \pm 4.3 \pm 3.7$

$$\sigma_{ZZ \rightarrow \ell^+ \ell^- \nu\bar{\nu}}^{\text{fid}} = 12.2_{-2.8}^{+3.0}(\text{stat.}) \pm 1.9(\text{syst.}) \pm 0.5(\text{lumi.}) \text{ fb}$$

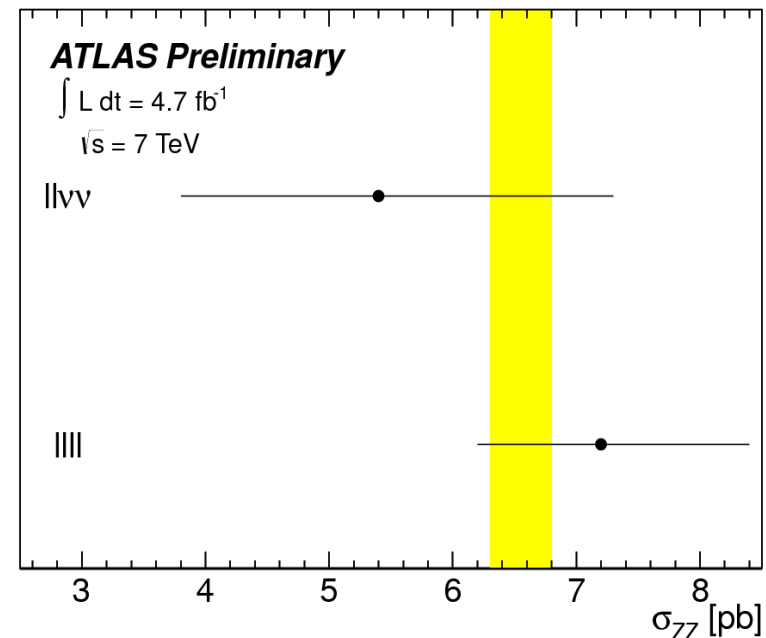
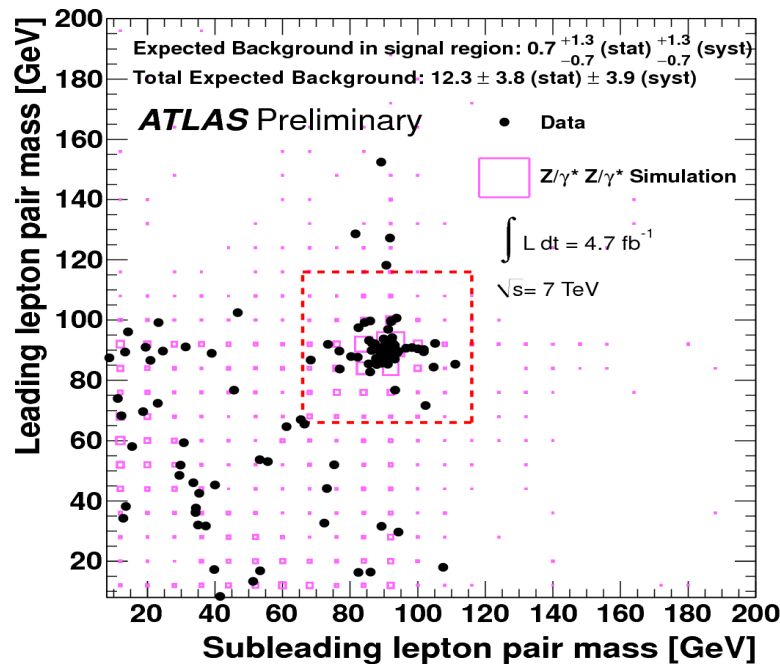
$$\sigma_{ZZ}^{\text{tot}} = 5.4_{-1.2}^{+1.3}(\text{stat.})_{-1.0}^{+1.4}(\text{syst.}) \pm 0.2(\text{lumi.}) \text{ pb}$$

$$\text{SM } \sigma_{ZZ} : 6.5_{-0.2}^{+0.3} \text{ pb}$$

ZZ cross section

llll channel: Select events with four leptons with two $m_{ll} \sim m_Z$

7 TeV



Final state	eeee	$\mu\mu\mu\mu$	$ee\mu\mu$	combined ($\ell\ell\ell\ell$)
Observed	15	21	26	62
Signal(MC)	$9.9 \pm 0.5 \pm 0.8$	$16.6 \pm 0.6 \pm 0.3$	$26.8 \pm 0.8 \pm 1.0$	$53.2 \pm 1.1 \pm 1.9$
Bkg(d.d.)	$0.6^{+0.7+0.8}_{-0.6-0.6}$	$< 0.3^{+0.5}_{-0.2}$	$0.3^{+0.9+0.8}_{-0.3-0.3}$	$0.7^{+1.3+1.3}_{-0.7-0.7}$

$$\sigma_{ZZ \rightarrow \ell^+ \ell^- \ell^+ \ell^-}^{\text{fid}} = 21.2^{+3.2}_{-2.7} (\text{stat}) ^{+1.0}_{-0.9} (\text{syst}) \pm 0.8 (\text{lumi}) \text{ fb}$$

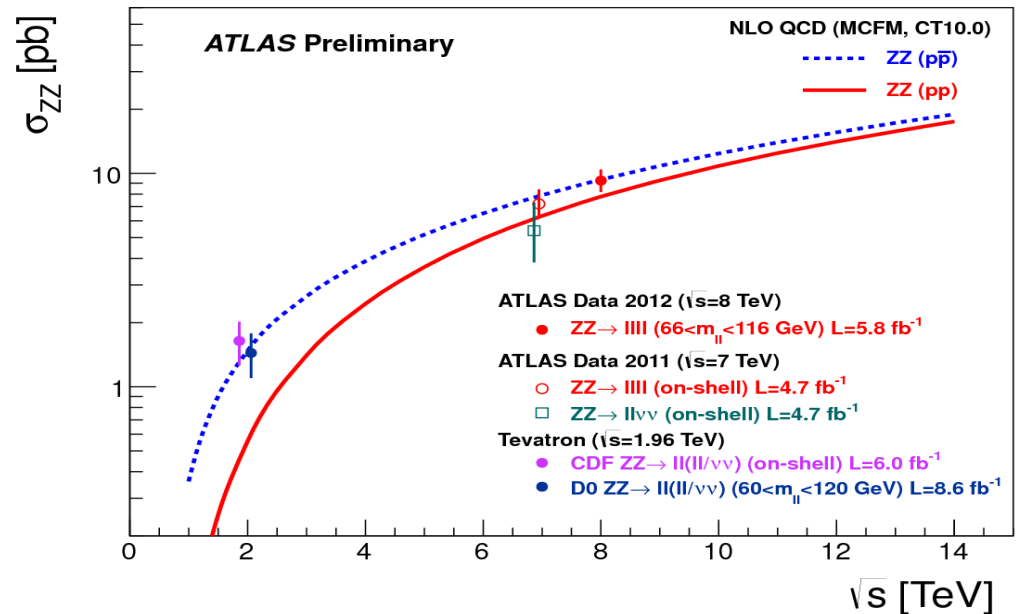
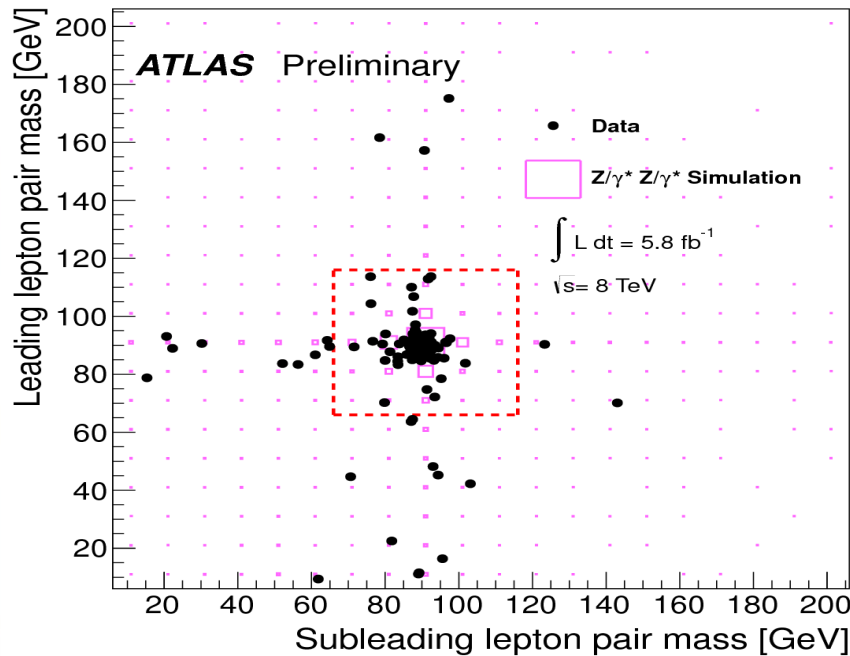
$$\sigma_{ZZ}^{\text{tot}} = 7.2^{+1.1}_{-0.9} (\text{stat}) ^{+0.4}_{-0.3} (\text{syst}) \pm 0.3 (\text{lumi}) \text{ pb}$$

$$\text{SM } \sigma_{ZZ} : 6.5^{+0.3}_{-0.2} \text{ pb}$$

ZZ cross section

llll channel: Select events with four leptons with two $m_{ll} \sim m_Z$

8 TeV



Final state	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell^+\ell^-$	$\sigma_{ZZ \rightarrow \ell^+\ell^-\ell^+\ell^-}^{\text{fid}} = 21.0^{+2.4}_{-2.2}(\text{stat.})^{+0.6}_{-0.5}(\text{syst.}) \pm 0.8(\text{lumi.}) \text{ fb}$
Observed	23	22	40	85	
Signal (MC)	16.5 ± 0.8	20.9 ± 0.4	33.2 ± 0.9	70.5 ± 1.7	$\sigma_{ZZ}^{\text{tot}} = 9.3^{+1.1}_{-1.0}(\text{stat.})^{+0.4}_{-0.3}(\text{syst.}) \pm 0.3(\text{lumi.}) \text{ pb.}$
Background (d.d.)	$0.6 \pm 0.4 \pm 0.2$	$0.1^{+0.6}_{-0.1} \pm 0.1$	$0.6^{+0.9}_{-0.6} \pm 0.3$	$1.3 \pm 1.2 \pm 0.5$	

Summary

Diboson cross sections measured using full 7 TeV data sets in leptonic decay channels

First unfolded differential cross sections in fiducial region measured in WZ production

Anomalous-coupling limits set with 7 TeV data

First ATLAS diboson measurement at
8 TeV in $ZZ \rightarrow llll$ production

New energy regime for probing
self-couplings of electroweak bosons

