Di-boson results at ATLAS

Hadron Collider Physics Symposium
14-18 November 2011, Paris

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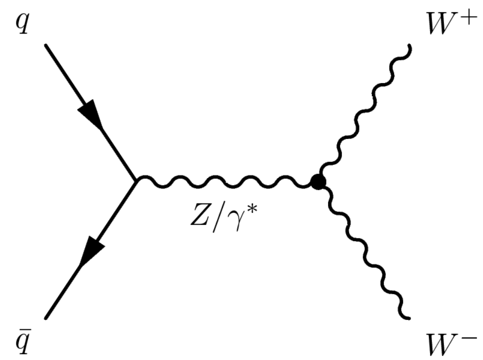
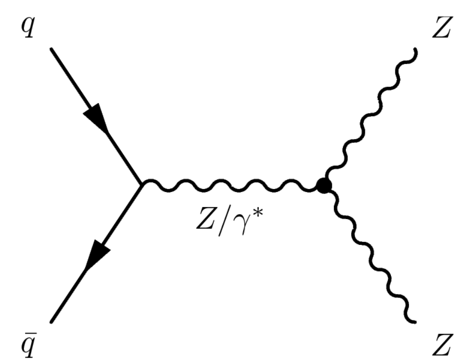
ATLAS

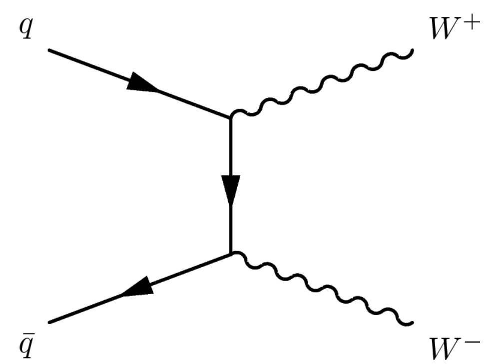
Introduction

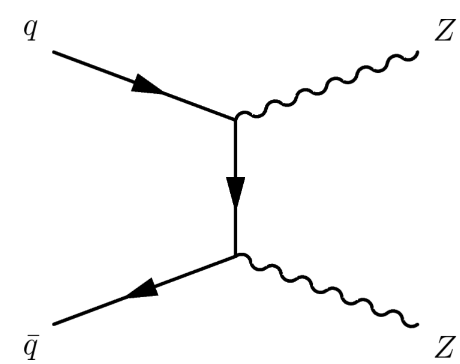
- Standard model predicts couplings with 3 gauge bosons (TGC), fully constraint by the electro-weak symmetry
  - WWγ and WWZ vertices are predicted, ZZγ and ZZZ are forbidden
  - Sector of the theory not fully covered by previous measurements
- Beyond standard model physics could modify the cross sections and final state kinematics
- At LHC, TGCs may be studied by looking at the production of di-boson final states
  - Final states also produced in the t channel at tree level
- Di-bosons are a background of other searches
  - Higgs

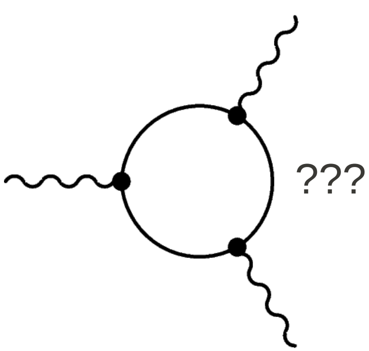




SM forbidden

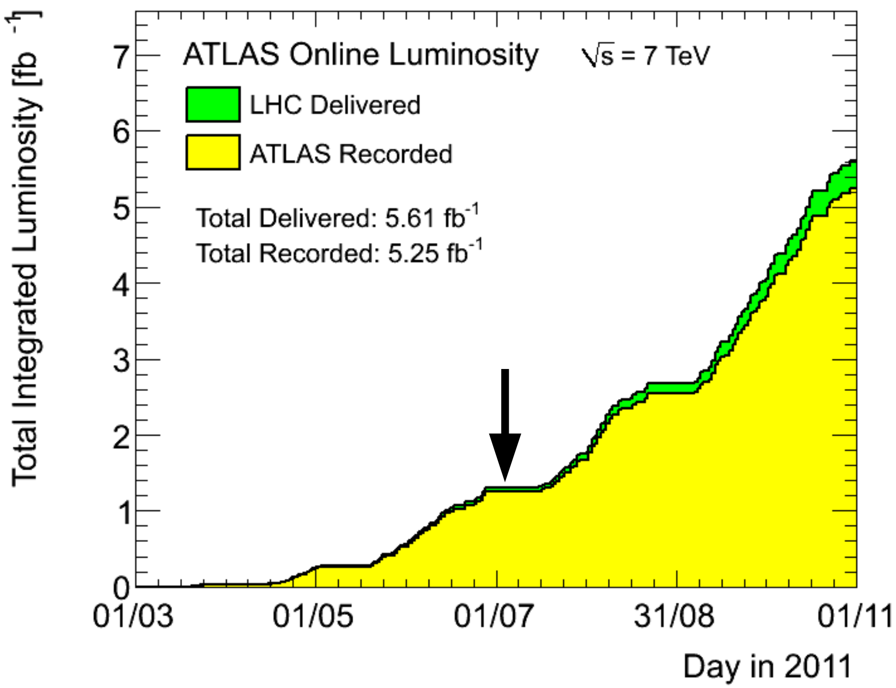






Di-boson production at ATLAS

- Di-boson cross sections measured with the ATLAS detector
- Analyses presented here:
  - WW, WZ, ZZ: 1.0 fb^{-1}, 2011 data
  - Wγ, Zγ: 35 pb^{-1}, 2010 data
- Predicted cross sections: O(10pb)
- Concentrate on leptonic (e and μ) final states: small branching fraction, but clean signal

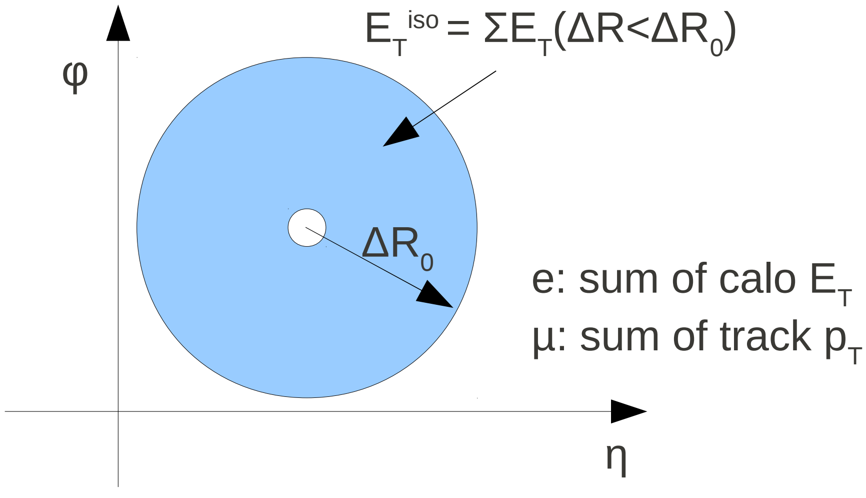


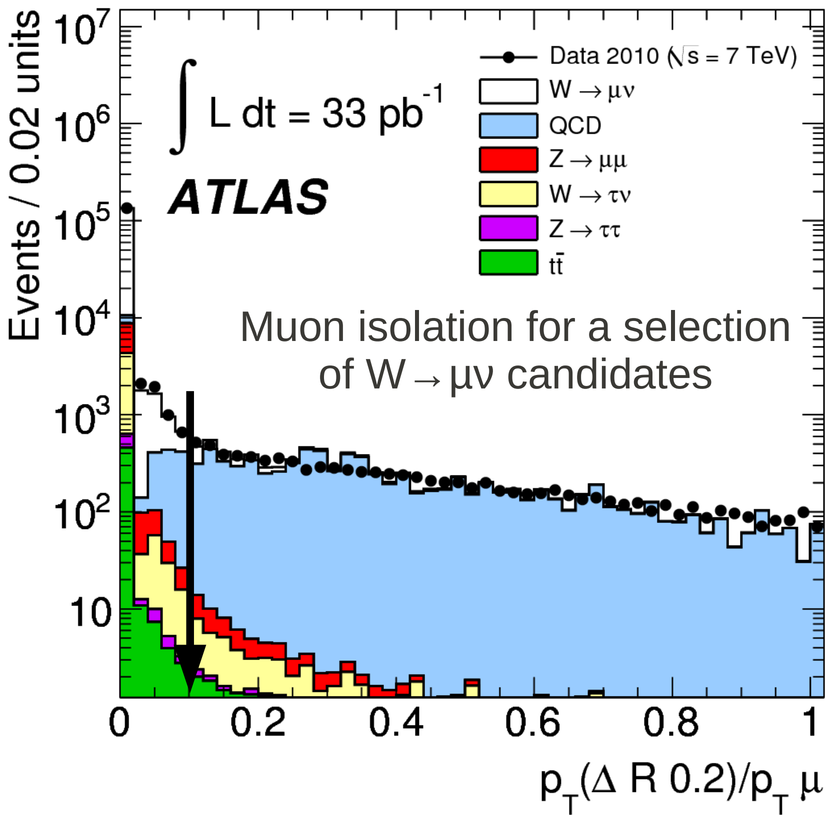
	σ_{NLO} (pb)	e/μ BF
WW	46	4.7%
WZ	17.2	1.5%
ZZ	6.5	0.5%
Wγ	333 (*)	22%
Zγ	205 (*)	6.7%

(*) includes phase space cuts for definition of prompt photon

Background estimation: data driven methods

- One of the important category of background: QCD generated background
- Example: W+jets, Z+jets
- A jet may produce a “fake” prompt lepton or photon
  - Real lepton from heavy flavor jet, reduced with isolation cuts
  - Pion mis-identified as electron or photon, reduced with tight identification cuts
- Decide not to trust Monte-Carlo to estimate these backgrounds
- Data driven method:
  - Control region built by reversing isolation cuts, or particle identification cuts
  - Event yield extrapolated to signal region by use of a fake factor
  - Fake factor estimated from independent control sample (di-jet sample, or sample obtained from reversing another analysis cut)





L = 1.0 fb^{-1}

WW → lνlν

ATLAS-CONF-2011-110

Signature: 2 leptons and E_T^{miss}

Backgrounds are challenging:

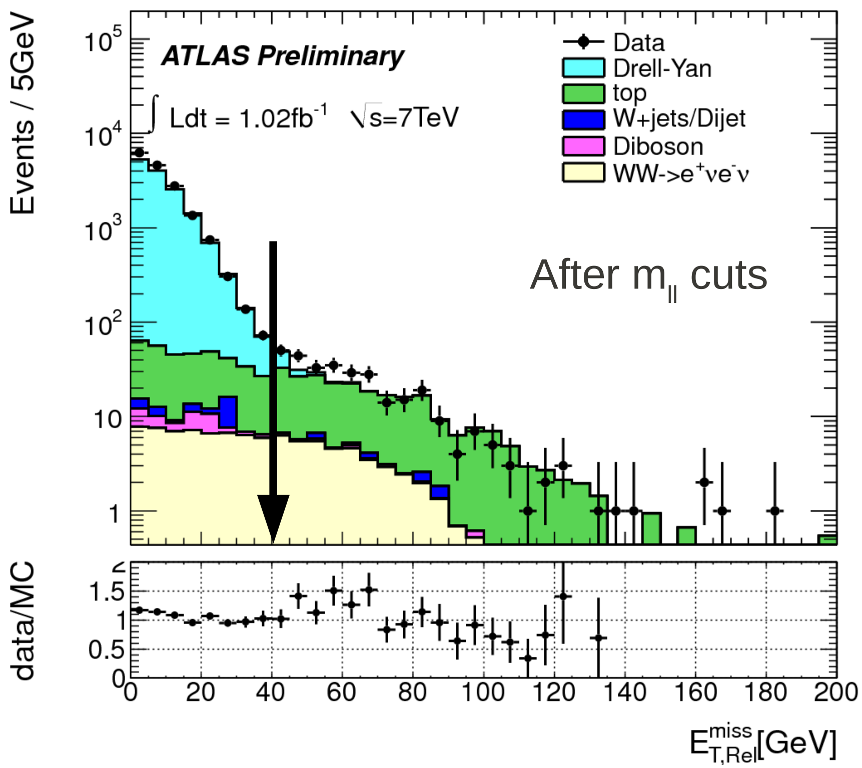
- Drell-Yan
- Top events
- W+jets
- Other diboson events

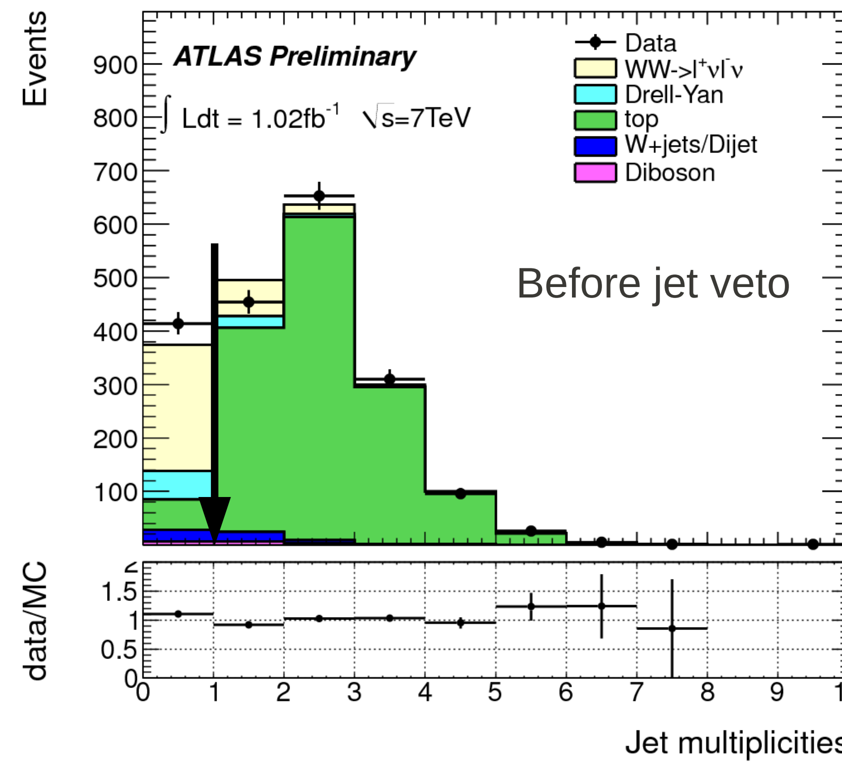
Selection:

- 2 leptons, p_T>20 GeV, p_T(leading e)>25 GeV, |η|<(2.4,2.47) (μ,e), isolation cuts, tight lepton ID
- m_{ll} > 15 GeV, $m_{e\mu}$ > 10 GeV, $|m_{ll}-m_Z|$>15 GeV
- $E_{T,Rel}^{miss}$ > (45,40,25) GeV (μμ,ee,eμ)
- Jet veto: p_T>30 GeV, |η|<4.5

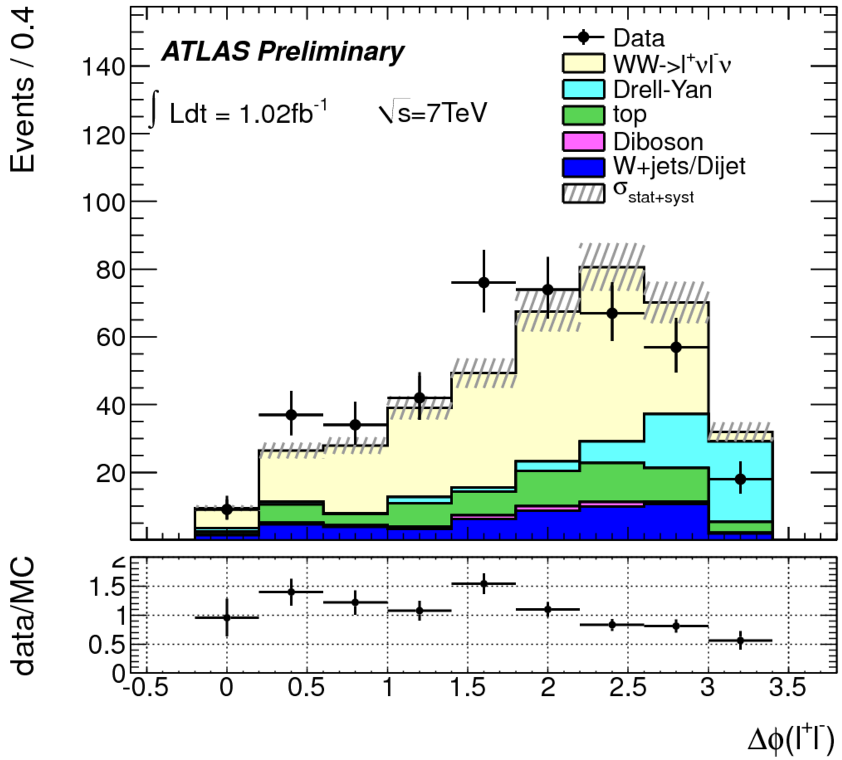
Definition to reduce impact of mis-measurements

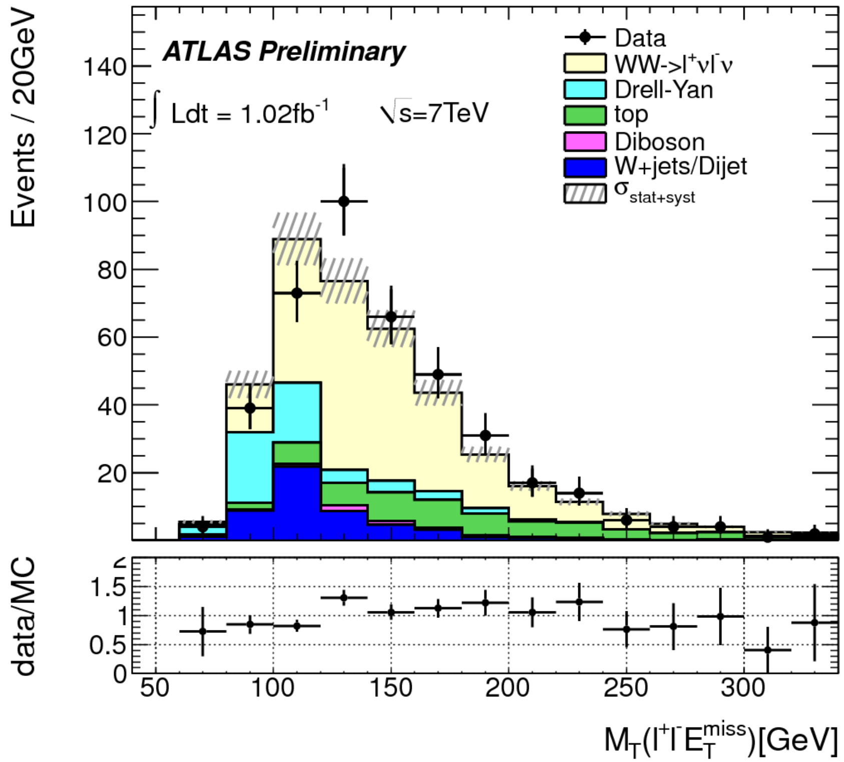
$E_{T,Rel}^{miss} = E_T^{miss} \sin \Delta\varphi(E_T^{miss}$,nearest lepton or jet), Δφ<90°





$WW \rightarrow l\nu l\nu$





Total selected events: 414
Background estimation: 169.8 ± 27.8

- W+jets: data driven, using fake lepton factors measured in a sample of di-jet events
- Top: semi-data driven, extrapolated from $N_{jet} \geq 2$ sample
- Drell-Yan: estimated with Monte-Carlo

Dominant systematics of background estimation:
 jet veto (jet energy scale)
 fake lepton factor measurement

Kinematic distributions are compatible with expectation from SM

WW → lνlν

Define fiducial cross section to reduce systematic uncertainty:
phase space cuts mimic analysis acceptance, different for the ee, μμ and eμ channels

Channels	expected σ^{fid} (fb)	measured σ^{fid}(fb)	$\Delta\sigma_{stat}$(fb)	$\Delta\sigma_{syst}$(fb)	$\Delta\sigma_{lumi}$(fb)
$e\nu e\nu$	66.8	90.1	$\pm$ 18.9	$\pm$ 11.3	$\pm$ 3.3
$\mu\nu\mu\nu$	63.8	62.0	$\pm$ 12.1	$\pm$ 10.7	$\pm$ 2.3
$e\nu\mu\nu$	245.1	252.0	$\pm$ 24.6	$\pm$ 29.4	$\pm$ 9.3

Total cross section extrapolated to complete phase space
assuming kinematic distributions predicted from SM:

Channels	Total cross-section (pb)	$\Delta\sigma_{stat}$(pb)	$\Delta\sigma_{syst}$(pb)	$\Delta\sigma_{lumi}$(pb)
$e\nu e\nu$	62.1	$\pm$ 13.5	$\pm$ 9.1	$\pm$ 2.3
$\mu\nu\mu\nu$	44.7	$\pm$ 8.7	$\pm$ 7.7	$\pm$ 1.7
$e\nu\mu\nu$	47.3	$\pm$ 4.8	$\pm$ 6.2	$\pm$ 1.8
Combined	48.2	$\pm$ 4.0	$\pm$ 6.4	$\pm$ 1.8

SM prediction (NLO): 46 ± 3 pb

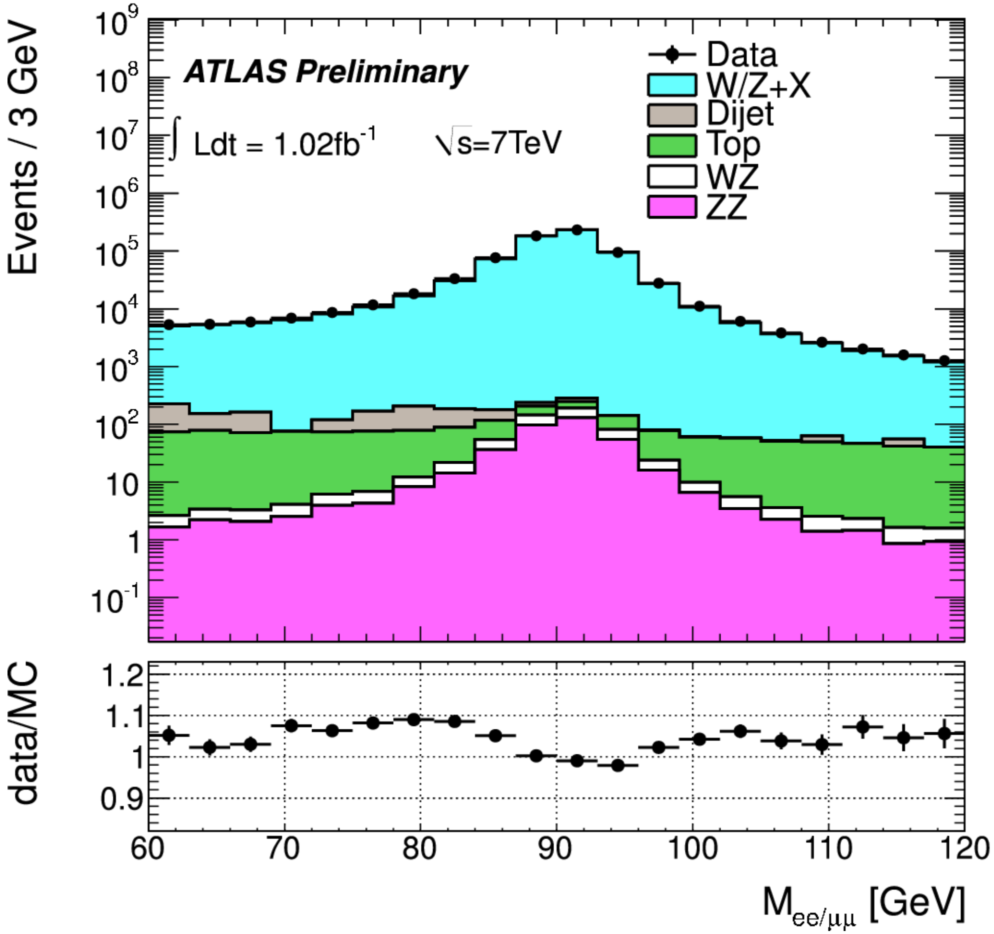
L = 1.0 fb^{-1}

WZ → lνll

ATLAS-CONF-2011-099

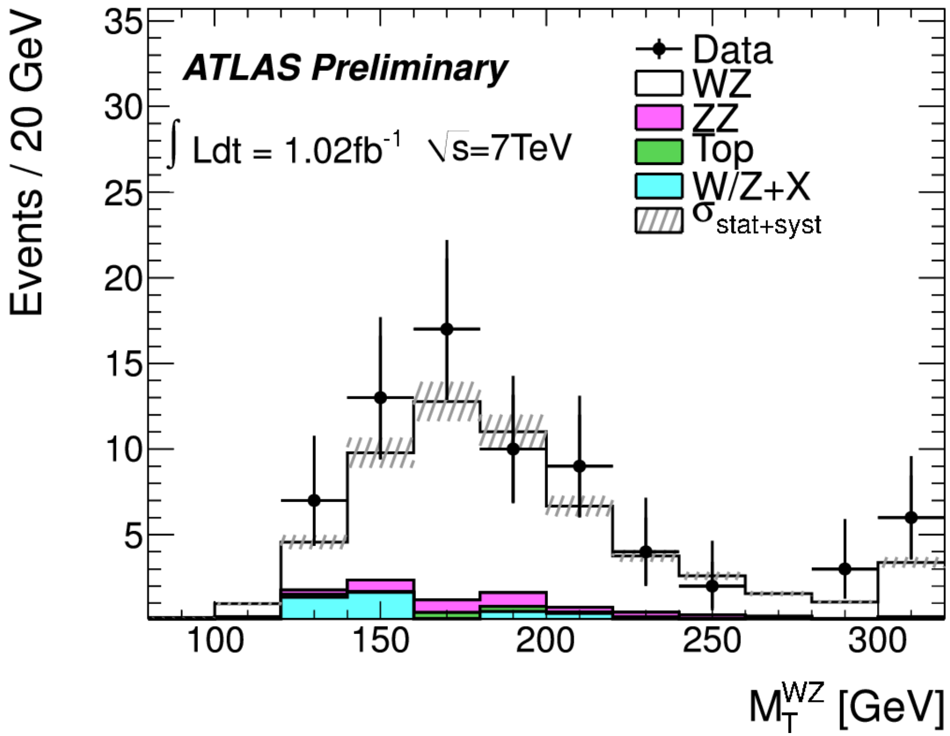
Signature: 3 leptons and E_T^{miss}
3 lepton requirement reduces most of background
Dominant background: W/Z+jets

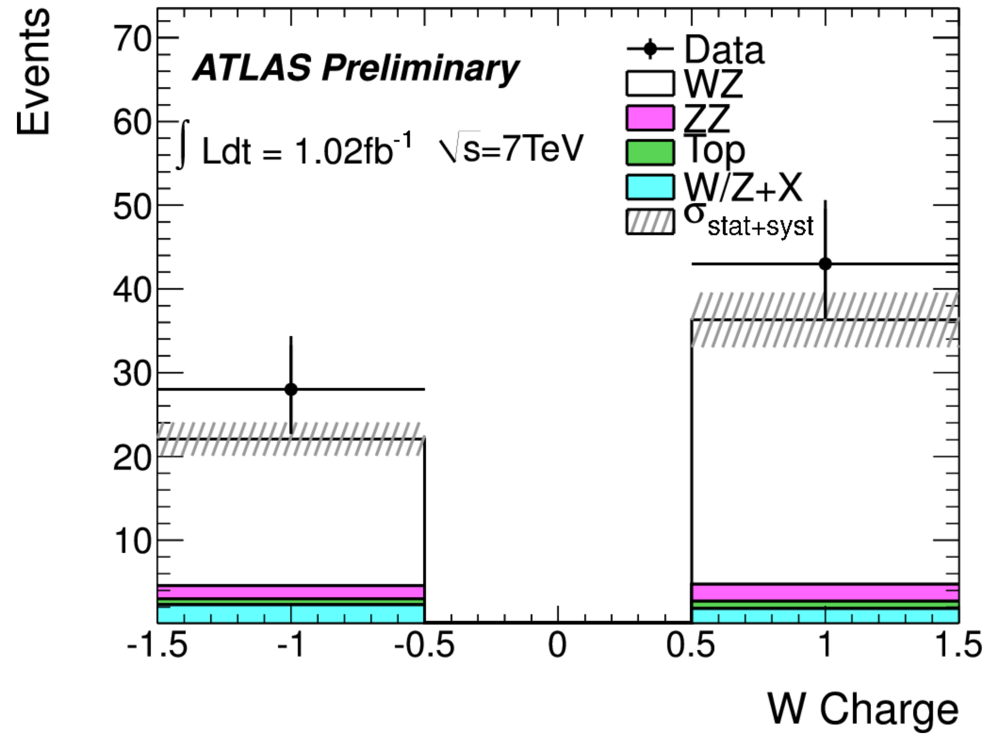
Selection:
- leptons, p_T>15 GeV, |η|<(2.5,2.47) (μ,e), isolation cuts, lepton ID
- $|m_{ll}-m_Z|$<10 GeV
- 3 leptons requirement
- lepton associated to W: p_T>20 GeV, tighter lepton ID
- E_T^{miss} > 25 GeV
- M_T^W > 20 GeV



Before 3 leptons requirement

WZ → lνll





Total selected events: 71
Estimated total background: $10.5^{+3.0}_{-2.2}$

- W/Z+jets: data driven, using fake lepton factors obtained from control sample with reversed E_T^{miss} cut
- ZZ di-boson production: estimated from Monte-Carlo

Dominant systematic: fake lepton factor determination

Kinematic distributions are compatible with expectation from SM

WZ→lνll

Fiducial cross section:

$$\sigma^{fid}_{WZ\to\ell\nu\ell\ell} = 118^{+18}_{-16}(\text{stat})\ ^{+6}_{-6}(\text{syst})\ ^{+5}_{-5}(\text{lumi})\ \text{fb}$$

Fiducial phase space defined with cuts that mimic analysis acceptance

Total cross section:

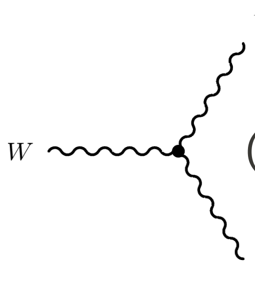
$$\sigma^{tot}_{WZ} = 21.1^{+3.1}_{-2.8}(\text{stat})\ ^{+1.2}_{-1.2}(\text{syst})\ ^{+0.9}_{-0.8}(\text{lumi})\ \text{pb}$$

Extrapolated to complete phase space using kinematic distributions predicted from SM

SM prediction (NLO): $17.2\ ^{+1.2}_{-0.8}$ pb

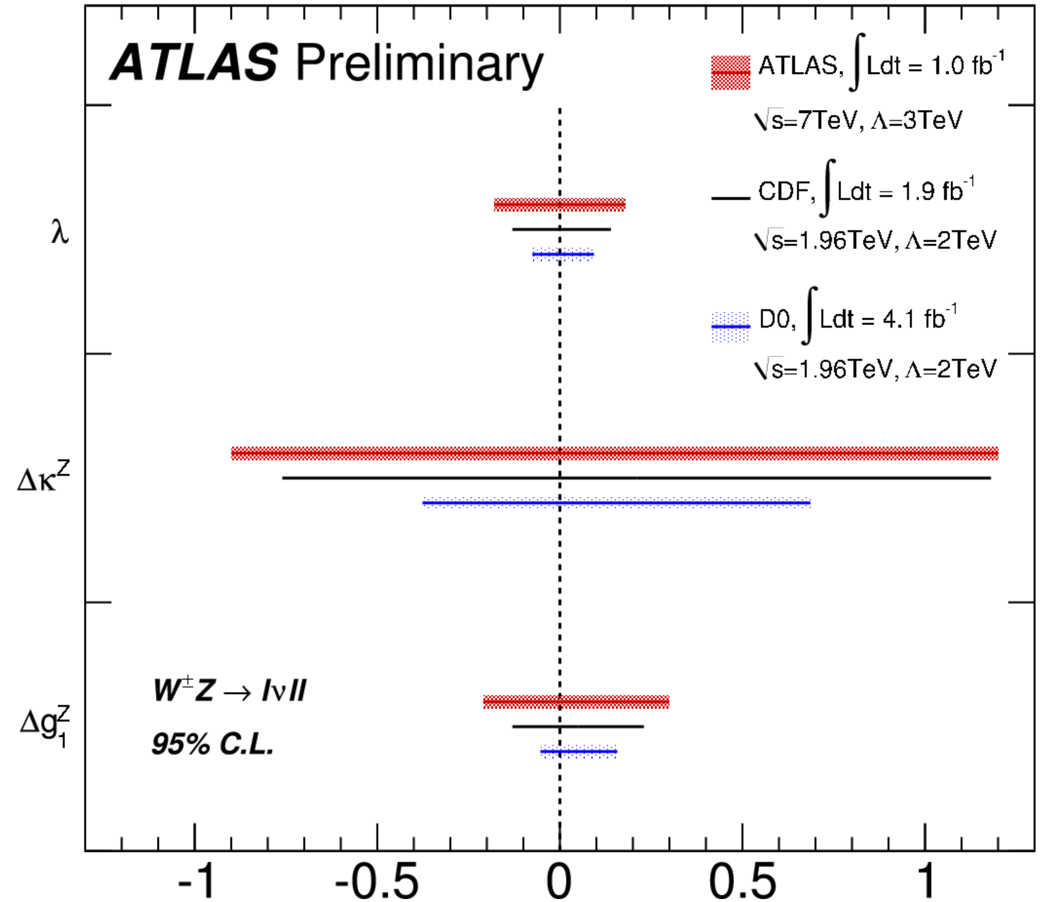
Triple gauge coupling:

Accessible TGC terms in effective Lagrangian:



$(g_1^Z,\kappa^Z,\lambda)=(1,1,0)_{SM}$

Arbitrary form factor with cut-off scale Λ=3 TeV: $\alpha(\hat{s}) = \dfrac{\alpha_0}{(1+\hat{s}/\Lambda^2)^2}$



Frequentist confidence intervals are set on anomalous TGC using the cross section measurement.

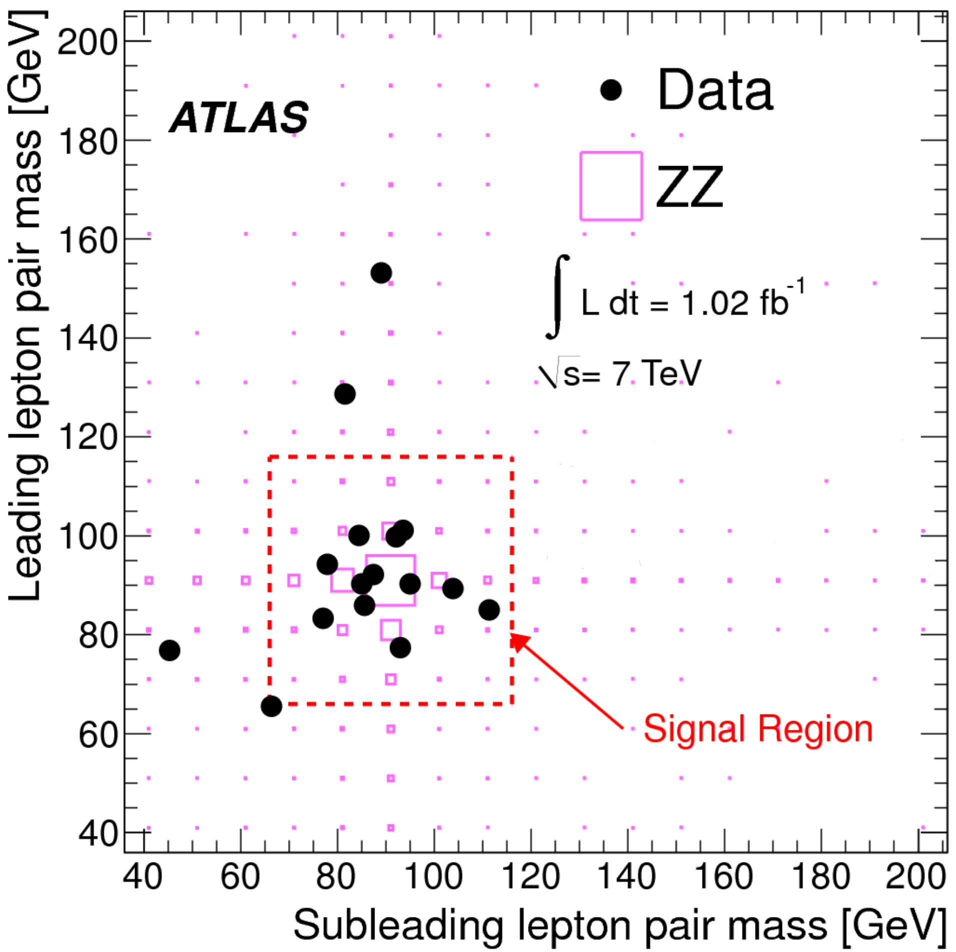
L = 1.0 fb^{-1}

$ZZ \rightarrow llll$

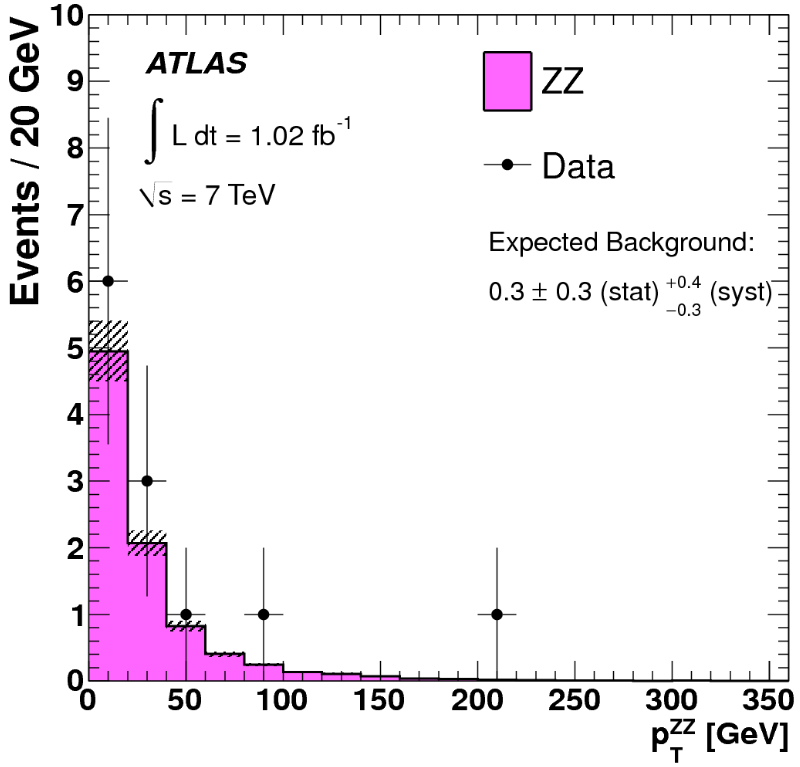
arXiv:1110.5016 [hep-ex]

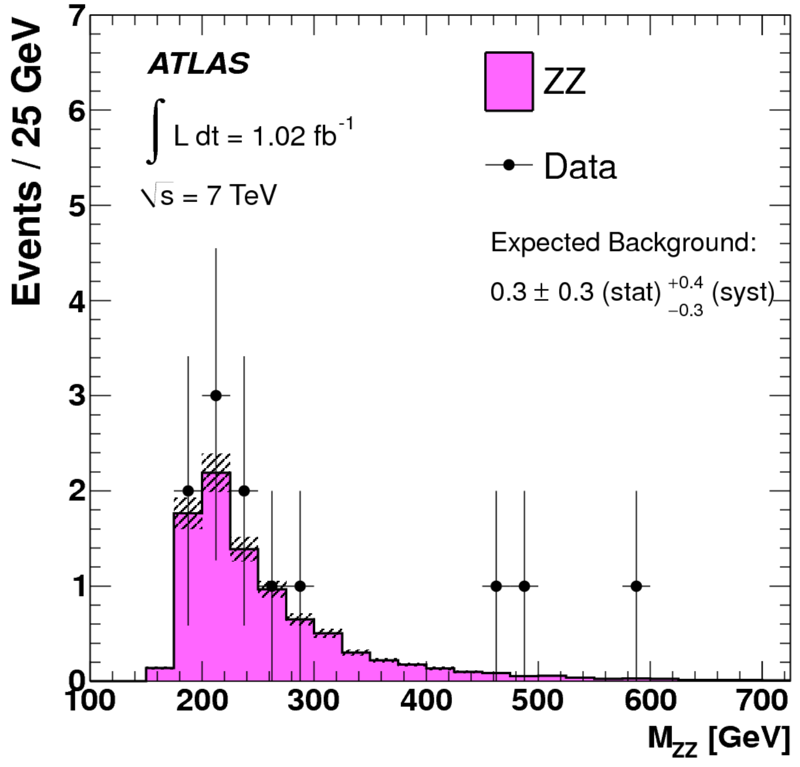
Signature: 4 leptons
Background with this signature is very reduced: Z+jets, top

Selection:
- 2 lepton pairs (eeee), (eeμμ), (μμμμ): p_T>15 GeV, |η|<(2.5,2.47) (μ,e), isolation cuts, lepton ID
- leading lepton p_T>(20,25) GeV (μ,e)
- 66 < m_{ll} < 116 GeV



ZZ→llll





Total selected events: 12
Estimated total background: $0.3\pm0.3^{+0.4}_{-0.3}$

- lllj events, the jet faking a prompt lepton
- estimated from data driven technique

Kinematic distributions are compatible with expectation from SM

$ZZ \to llll$

Fiducial cross section:

$$\sigma^{\rm fid}_{ZZ\to\ell^+\ell^-\ell^+\ell^-} = 19^{+6}_{-5}({\rm stat.}) \pm 1({\rm syst.}) \pm 1({\rm lumi.})\ {\rm fb}$$

Fiducial phase space defined with cuts that mimic analysis acceptance

Total cross section:

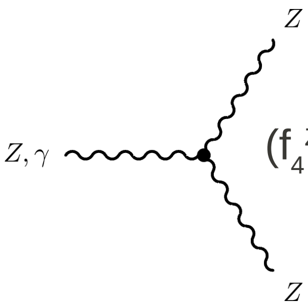
$$\sigma^{\rm tot}_{ZZ} = 8.5^{+2.7}_{-2.3}\ ({\rm stat.})\ {}^{+0.4}_{-0.3}\ ({\rm syst.})\ \pm 0.3\ ({\rm lumi.})\ {\rm pb}$$

Extrapolated to complete phase space using kinematic distributions predicted from SM

SM prediction (NLO): $6.5\ ^{+0.3}_{-0.2}$ pb

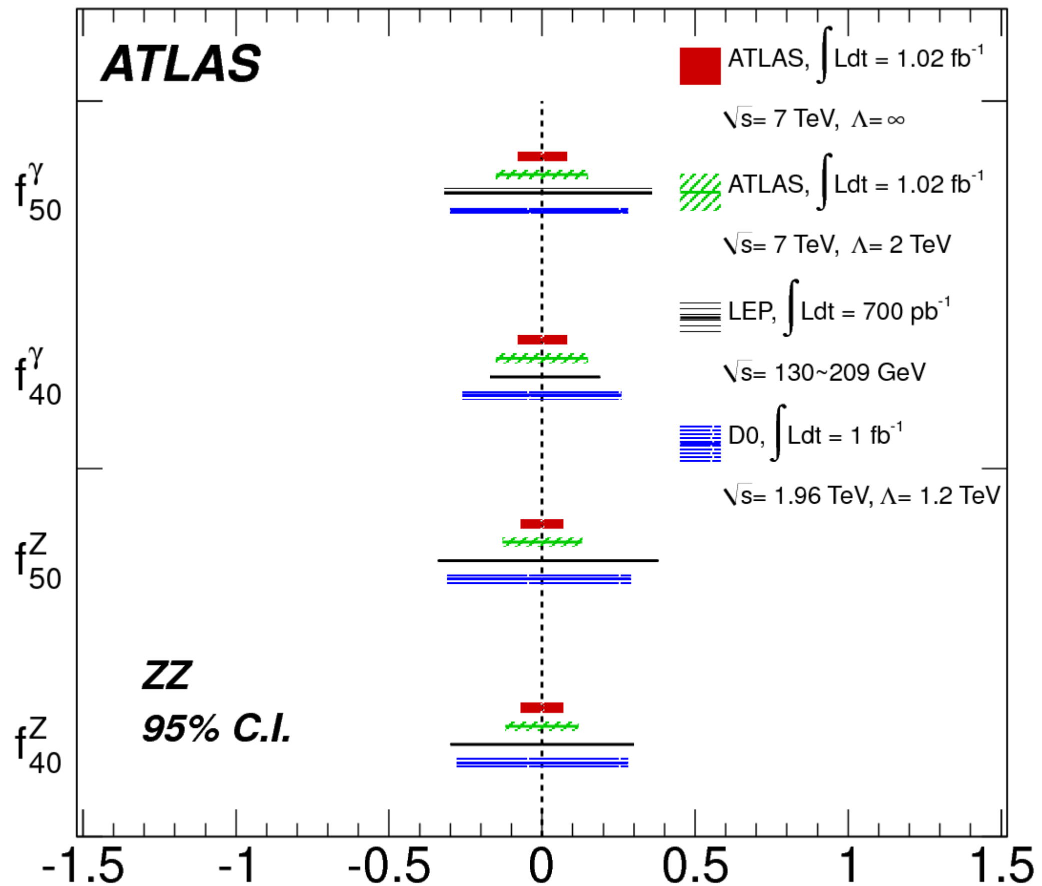
Triple gauge coupling:

Accessible TGC terms in effective Lagrangian:



$(f_4^Z, f_4^\gamma, f_5^Z, f_5^\gamma) = (0,0,0,0)_{SM}$

Optional form factor with cut-off scale Λ: $\alpha(\hat{s}) = \frac{\alpha_0}{(1+\hat{s}/\Lambda^2)^2}$



Frequentist confidence intervals are set on anomalous TGC using the cross section measurement

$W\gamma \rightarrow l\nu\gamma$ and $Z\gamma \rightarrow ll\gamma$

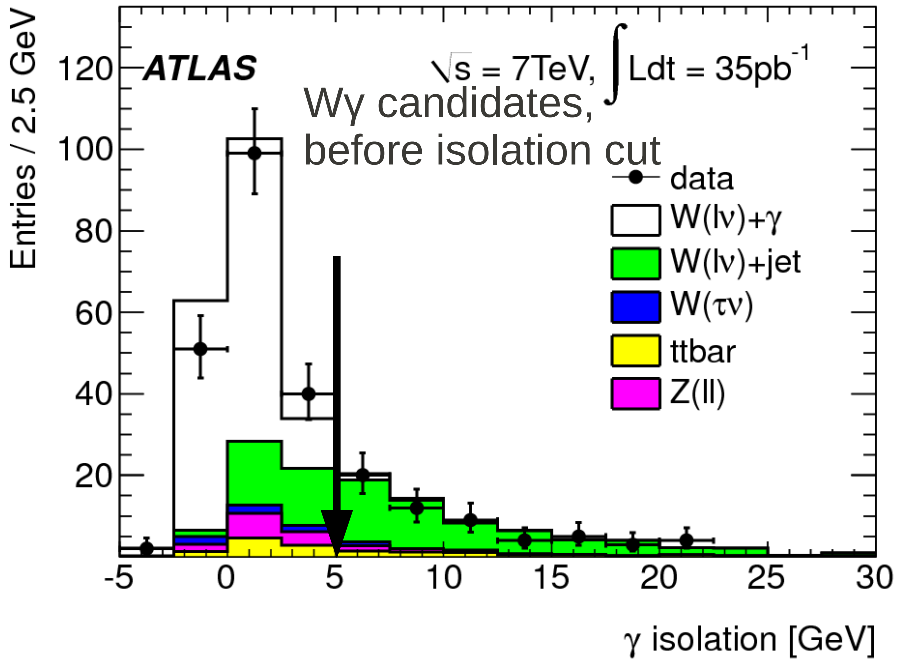
JHEP09(2011)072

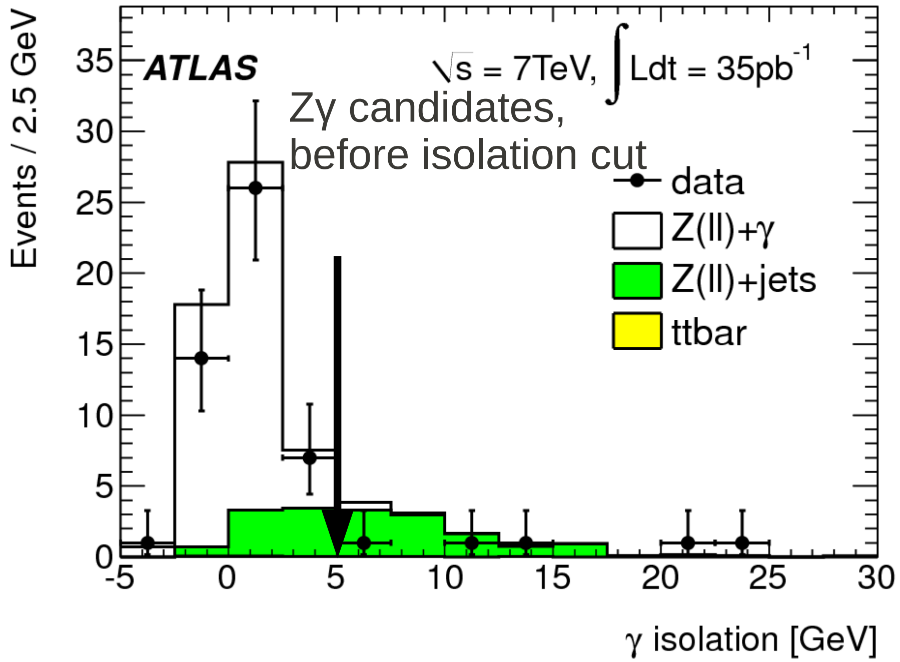
Definition of signal: W/Z + a photon with:
- $E_T^\gamma > 15$ GeV
- separation from closest lepton by $\Delta R > 0.7$
- isolation at parton level:

$$\varepsilon^h_p = \Sigma E_T(\Delta R<0.4)/E_T^\gamma < 0.5$$

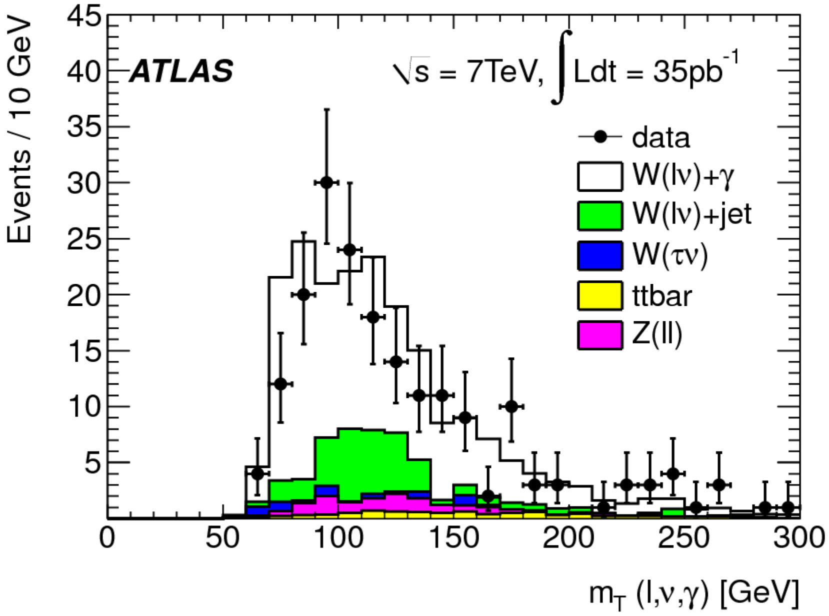
8% of signal comes from photons generated at fragmentation

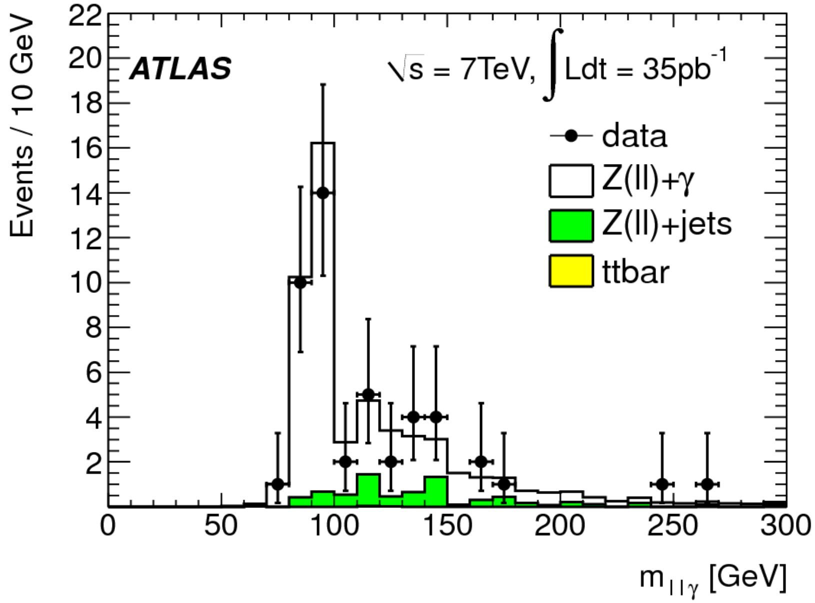
Selection:
- $Z \rightarrow ll$ or $W \rightarrow l\nu$ candidate
- photon: $E_T > 15$ GeV, $|\eta| < 2.37$, $\Delta R(\text{closest lepton}) > 0.7$
- photon isolation: $E_T^{iso} = \Sigma E_T(\Delta R<0.4) < 5$ GeV





Wγ → lνγ and Zγ → llγ





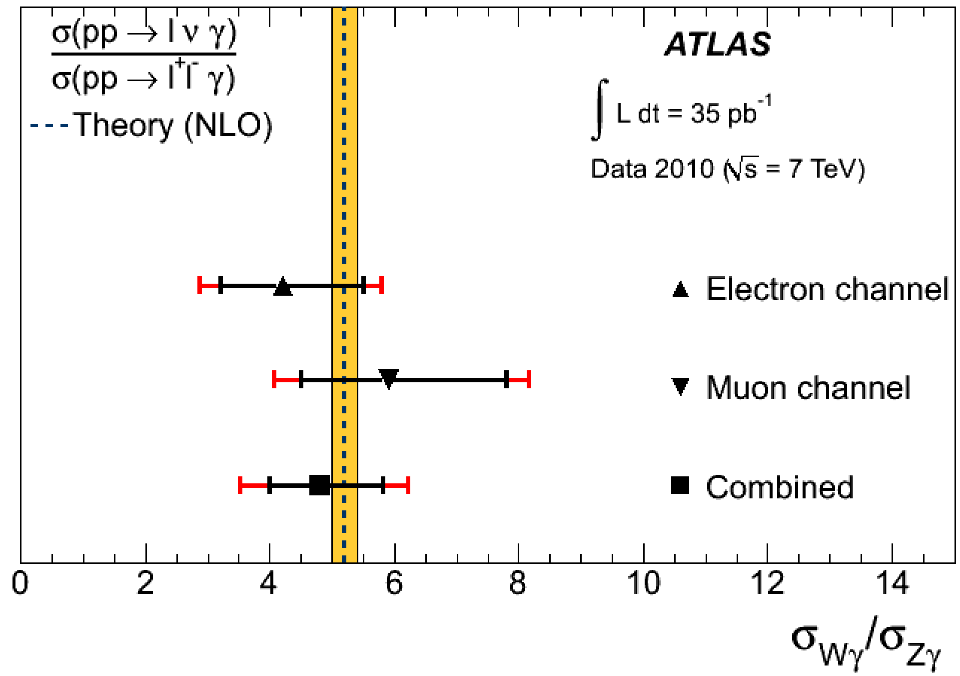
Total selected events: 192 Wγ and 48 Zγ candidates
Background estimated with data driven technique when statistics sufficient:

- ~29% of Wγ sample
- ~15% of Zγ sample

Kinematic distributions are compatible with expectation from SM

$W\gamma \rightarrow l\nu\gamma$ and $Z\gamma \rightarrow ll\gamma$

	Experimental measurement	SM prediction
	$\sigma^{\text{fid}}[\text{pb}]$	$\sigma^{\text{fid}}[\text{pb}]$
$pp \rightarrow e^{\pm}\nu\gamma$	$5.4 \pm 0.7 \pm 0.9 \pm 0.2$	4.7 ± 0.3
$pp \rightarrow \mu^{\pm}\nu\gamma$	$4.4 \pm 0.6 \pm 0.7 \pm 0.2$	4.9 ± 0.3
$pp \rightarrow e^{+}e^{-}\gamma$	$2.2 \pm 0.6 \pm 0.5 \pm 0.1$	1.5 ± 0.1
$pp \rightarrow \mu^{+}\mu^{-}\gamma$	$1.4 \pm 0.3 \pm 0.3 \pm 0.1$	1.7 ± 0.1
	$\sigma[\text{pb}]$	$\sigma[\text{pb}]$
$pp \rightarrow e^{\pm}\nu\gamma$	$41.1 \pm 5.7 \pm 7.1 \pm 1.4$	36.0 ± 2.3
$pp \rightarrow \mu^{\pm}\nu\gamma$	$33.0 \pm 4.6 \pm 5.5 \pm 1.1$	36.0 ± 2.3
$pp \rightarrow l^{\pm}\nu\gamma$	$36.0 \pm 3.6 \pm 6.2 \pm 1.2$	36.0 ± 2.3
$pp \rightarrow e^{+}e^{-}\gamma$	$9.9 \pm 2.7 \pm 2.3 \pm 0.3$	6.9 ± 0.5
$pp \rightarrow \mu^{+}\mu^{-}\gamma$	$5.6 \pm 1.4 \pm 1.2 \pm 0.2$	6.9 ± 0.5
$pp \rightarrow l^{+}l^{-}\gamma$	$6.5 \pm 1.2 \pm 1.7 \pm 0.2$	6.9 ± 0.5



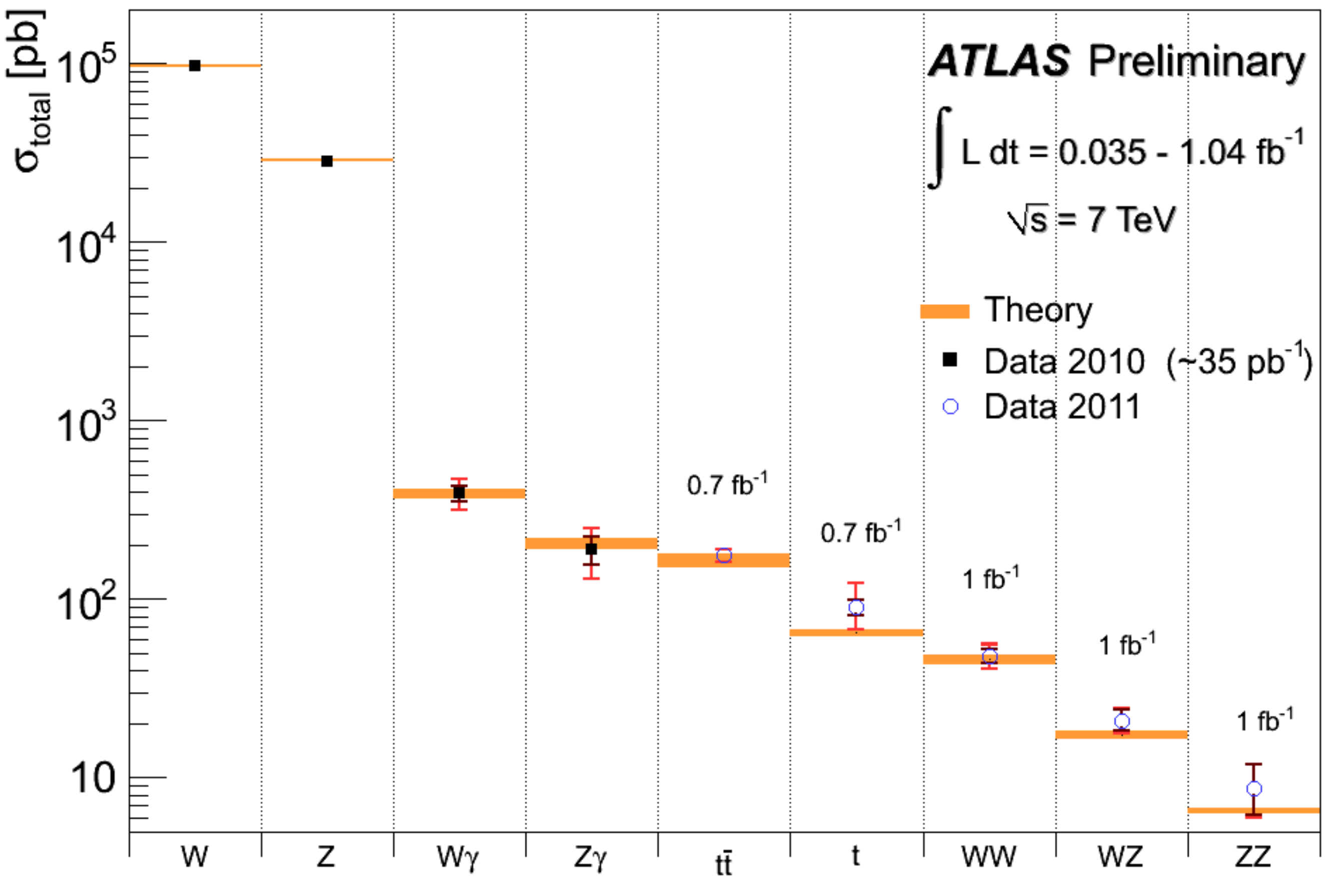
Fiducial cross section calculated with phase space cuts that mimic analysis acceptance

Total cross section extrapolated to complete phase space using kinematic distributions predicted from SM

Dominant systematic: photon reconstruction/ID efficiency

Ratio of cross sections used to minimize correlated systematic errors

Conclusion



- Di-boson final states have been observed and their cross-sections measured
- First limits on anomalous triple gauge couplings are derived

Backup

WW

Final State	$e^+e^-E_T^{miss}$	$\mu^+\mu^-E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
Observed Events	74	97	243	414
Background estimations				
Top(data-driven)	9.5±0.3±3.6	12.3 ±0.4±4.7	36.8±1.3±14.0	58.6±2.1±22.3
W+jets (data-driven)	5.3±0.4±1.7	12.4±2.9±5.2	32.9±3.8±9.2	50.5±4.8±14.7
Drell-Yan (MC/data-driven)	18.7±1.9±1.9	19.2±1.7±2.1	16.0±2.8±1.7	54.0±3.7± 4.5
Other dibosons (MC)	0.9±0.1±0.1	2.4±0.2±0.3	3.4±0.3±0.4	6.8±0.4±0.8
Total Background	34.4±2.0±4.4	46.3±3.4±7.3	89.1±4.9±16.8	169.8±6.4±27.1
Expected *WW* Signal	29.5±0.3±3.0	52.5±0.4±4.9	150.5±0.7±13.4	232.4±0.9±21.5
Significance ($S/\sqrt{B}$)	5.0	7.7	15.9	17.8

Table 6: Summary of observed events and expected signal and background contributions in the three di-lepton and combined channels. The first error is statistical, the second systematic. The central value and statistical uncertainty for the Drell-Yan process estimation is MC based while the systematic uncertainties are derived from a data-driven method.

WZ

Final State	$eee + E_T^{miss}$	$ee\mu + E_T^{miss}$	$e\mu\mu + E_T^{miss}$	$\mu\mu\mu + E_T^{miss}$	combined
Observed	11	9	22	29	71
ZZ	0.34±0.07	1.03±0.13	0.82±0.12	1.40±0.15	3.55±0.24±0.17
W/Z+jets	2.03±0.38	0.64±0.18	2.03±0.38	0.44±0.15	$5.14\pm0.59^{+2.97}_{-2.08}$
Top	0.26±0.10	0.31±0.09	0.41±0.12	0.60±0.15	1.58±0.23±0.10
$W/Z+\gamma$	0.49±0.28	–	0.56±0.39	–	1.05±0.48±0.08
Total Background	3.08±0.49	1.98±0.24	3.82±0.56	2.44±0.21	$10.5\pm0.8^{+2.9}_{-2.1}$
Expected Signal	7.55±0.17	11.27±0.20	12.12±0.22	18.16±0.27	49.1±0.4±3.02
Expected S/B	2.5	5.7	3.2	7.4	4.3

Details of the signal and background number of events

ZZ

Channel	Observed	BG(data-driven)	Expected ZZ
$e^+e^-e^+e^-$	2	$0.01^{+0.03+0.05}_{-0.01-0.01}$	$1.53\pm0.03\pm0.10$
$\mu^+\mu^-\mu^+\mu^-$	8	$0.3 \pm 0.3 \pm 0.3$	$3.03\pm0.04\pm0.06$
$e^+e^-\mu^+\mu^-$	2	$< 0.01^{+0.03}_{-0.01}$	$4.37\pm0.04\pm0.14$
$\ell^+\ell^-\ell^+\ell^-$	12	$0.3 \pm 0.3^{+0.4}_{-0.3}$	$8.9\pm0.1\pm0.3$

Details of the signal and background number of events