Multibosons @ ATLAS

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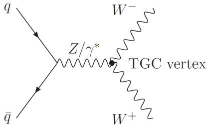
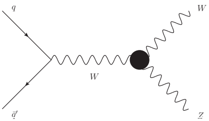
on behalf of the ATLAS Collaboration

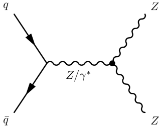
Standard Model @ LHC Conference
April 10-13, 2012

Outline

Why Multibosons Physics?







SM forbidden

SM Test: Measurement of the SM cross-sections and triple gauge couplings (TGC) tests the EW interactions structure

- ZWW and γWW fixed by SM
- ZZZ and γZZ SM forbidden

BSM Probe: Possible beyond SM physics interacting with gauge bosons could modify production cross-sections and final states kinematic.

Other Searches: Diboson production is one of the main backgrounds for many SM measurements and Higgs/BSM searches at LHC

In This Talk

- Diboson cross-sections measurements and limits on anomalous TGC in ATLAS are presented here, using 2011 data. Only leptonic channels considered, i.e. $l = e, \mu$: small branching ratio, but clean experimental signature
  - $WW \to l\nu l\nu$, $ZZ \to llll$ and $ZZ \to ll\nu\nu$ with 5 fb^{-1}
  - $WZ \to l\nu ll$, $W\gamma \to l\nu\gamma$ and $Z\gamma \to ll\gamma$ with 1 fb^{-1}

- Being as model independent as possible $\to$ test EW symmetry
- Minimize the impact of theoretical uncertainties on the experimental measurement $\to$ measuring fiducial cross-sections!
- Minimize the experimental uncertainties $\to$ take special care of object definition and background estimation

Main goal of this talk is to show both how we deal with these issues and results that we get.

Outline

Experimental Challenge

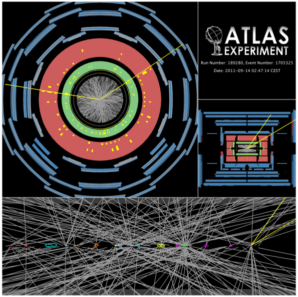
1. Collision events selection: single lepton triggers and good primary vertex

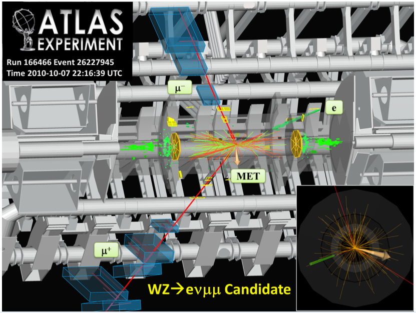
2. Good reconstructed objects selection: leptons, jets, photons and $E_{\mathrm{T}}^{\mathrm{miss}}$

3. Specific analysis event selection
   - Only focus on main analysis aspects
   - For all the details, click on the link on the references near the titles

4. Background estimation
   - Monte Carlo (MC) simulation for the others, corrected to match data conditions/performances (pile-up, lepton energy smearing and scale, JES...)
   - Data-driven methods for backgrounds with fake leptons or photons

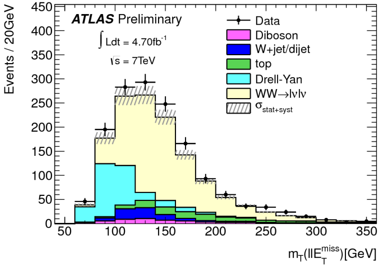
5. Cross-section and TGC limits extraction

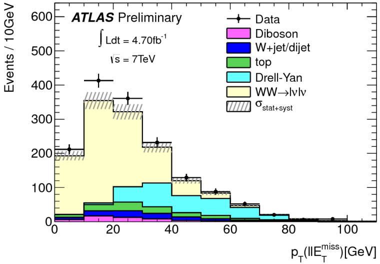




$WW \to l\nu l\nu$ Analysis [arXiv:1203.6232]

- Cross-section is sensitive to new physics
- Main background for $H \to WW$ search
- Event Selection:
  - Two high-p_{T} (> 20 GeV), opposite charged and isolated leptons (e, μ)
  - Veto events with $|m_{\ell\ell} - m_Z| < 10$ GeV
    $\to$ to reduce other diboson bkg
  - High $E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$, removing the events with fake $E_{\mathrm{T}}^{\mathrm{miss}}$ from lepton mis-id
    $\to$ to reduce Z/γ^* bkg
  - jet-veto
    $\to$ to reduce top background
- Data-driven background estimation from single bosons production in association with jets, where the jet "fakes" a lepton
- Observed events in 4.7 fb^{-1}: 1524
  Expected bkg: $531.1 \pm 13.7 \pm 48.7$

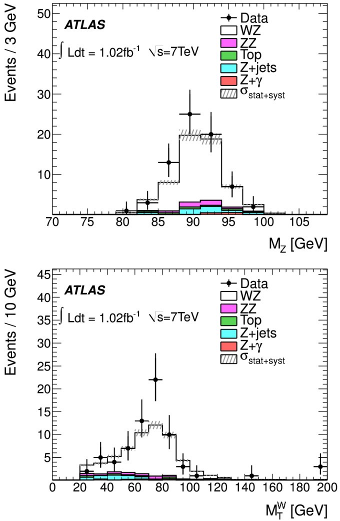




$$E_{\mathrm{T,\ Rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} \times \sin\left(\Delta\phi_{\ell,j}\right) & \text{if } \Delta\phi < \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2, \end{cases}$$

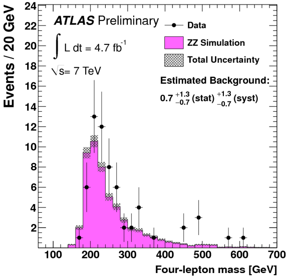
$WZ \rightarrow l\nu ll$ Analysis [CERN-PH-EP-2011-184, PLB paper]

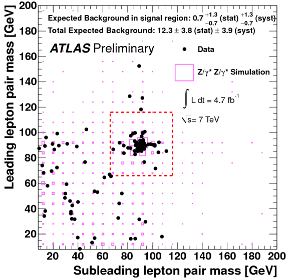
- Directly sensitive to aTGC
- Event Selection:
  - Two high-p_T (> 10 GeV), same-flavor and opposite-charge, isolated leptons (e, μ) within $|m_{\ell\ell} - m_Z| < 10$ GeV
  - third isolated lepton $p_T > 20$ GeV from W
    $\rightarrow$ to reduce other diboson bkg
  - High E_T^{miss} (> 25 GeV)
  - $m_T^W > 20$ GeV
    $\rightarrow$ to suppress Z and ZZ bkg
- Same fake background estimation as in WW
- Observed events in 1 fb^{-1}: 71
  Expected bkg: $12.1 \pm 1.4^{+4.1}_{-2.0}$



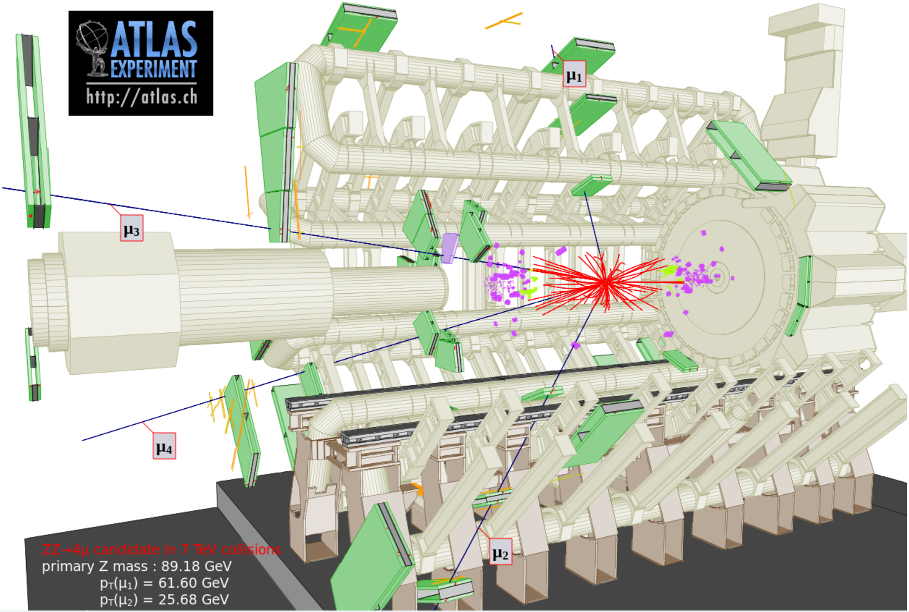
$ZZ \rightarrow llll$ Analysis [ATLAS-CONF-2012-026, PRL paper]

- Directly sensitive to the SM forbidden TGC
- Main background for $H \rightarrow ZZ$ search
- Low statistics but very clean channel
- Event Selection:
  - Two pairs of same-flavor and opposite-charge, isolated leptons (e, μ), with $p_T > 7$ GeV, within $|m_{\ell\ell} - m_Z| < 25$ GeV
  - forward muons (up to $|\eta| < 2.7$) are used, with $p_T > 10$ GeV, to increase the acceptance
  - in same flavor channels, pairs ambiguity resolved choosing pairs with lower sum of $|m_{\ell\ell} - m_Z|$ value
- Observed events in 4.7 fb^{-1}: 62
  Expected bkg: $0.7^{+1.3+1.3}_{-0.7-0.7}$



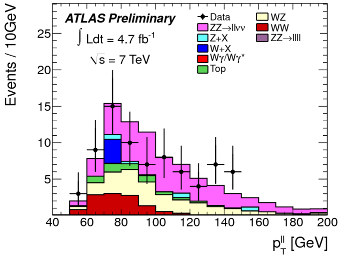


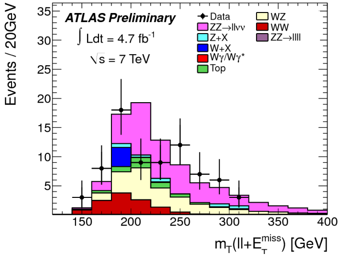
$ZZ \to llll$ Analysis [ATLAS-CONF-2012-026, PRL paper]



$ZZ \to ll\nu\nu$ Analysis [ATLAS-CONF-2012-027]

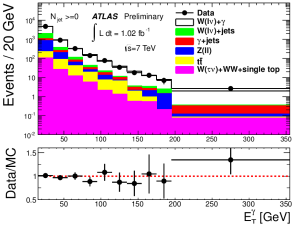
- First measurement!
- Directly sensitive to the SM forbidden TGC
- Event Selection:
  - A pair or high-p_{T} (> 20 GeV), same-flavor and opposite-charged, isolated leptons (e, μ) within $|m_{\ell\ell} - m_Z| < 15$ GeV
  - Axial-$E_{\mathrm{T}}^{\mathrm{miss}} > 80$ GeV
    $E_{\mathrm{T}}^{\mathrm{miss}} \times \cos\Delta\Phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,ll})$
    $\to$ to reject Z+jets bkg
  - Veto events with any jet with $p_{\mathrm{T}} > 25$ GeV in $|\eta| < 4.5$
    $\to$ to reject Z+jets and top bkg
  - Fractional p_{T} difference
    $|E_{\mathrm{T}}^{\mathrm{miss}} - p_{\mathrm{T}}^{Z}|/p_{\mathrm{T}}^{Z} < 0.6$
    $\to$ to reject WW bkg
- Observed events in 4.7 fb^{-1}: 78
  Expected bkg: $40.7 \pm 4.3 \pm 3.7$

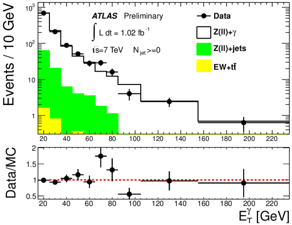




$W\gamma/Z\gamma$ Analysis [ATLAS-CONF-2011-013, to be updated soon]

- Background for many searches
- Directly sensitive to aTGC
- Event Selection:
  - One high-E_{T} isolated photon
  - $Z\gamma$: pair or high-p_{T} (> 25 GeV), same-flavor and opposite-charged, isolated leptons (e, μ) within $m_{\ell\ell} > 40$ GeV
  - $W\gamma$: one high-p_{T} (> 25 GeV), isolated lepton and $m_{\mathrm{T}}(l,\nu) > 40$ GeV
  - w/ and w/o vetoing events with any jet with $E_{\mathrm{T}} > 30$ GeV in $|\eta| < 4.4$ $\rightarrow$ w/ jet veto analysis used to extract TGC limits
  - ISR is included in the signal, FSR is bkg and suppressed by $\Delta R(l,\gamma) > 0.7$
- Data-driven background estimation from ingle bosons production in association with jets, producing non-prompt γ from meson decays from jet fragmentation





Outline

Cross-sections Summary

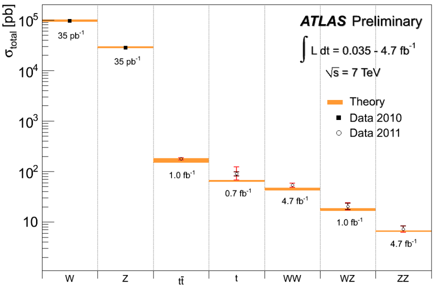
To minimize the effect of theoretical uncertainties on the measurement, mainly on the acceptance (kinematic distribution predictions, PDF..), fiducial cross-section is measured and total cross-section is extrapolated from it

- *C* is the ratio between reconstructed signal events over signal events in the defined fiducial volume

$$\sigma^{\text{fid}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{C \times \mathscr{L}}$$

- acceptance *A* is ratio between generated events in the fiducial volume and all generated events (comprehending the leptonic BR). It contains all the model assumptions and uncertainties

$$\sigma^{\text{fid}} = \sigma^{\text{tot}} \times A$$



Black bars: statistical uncertainties only.

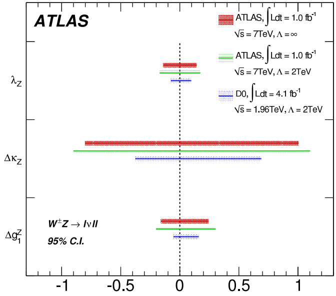
Red bars: full uncertainties.

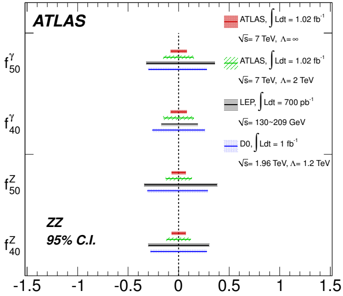
Limits on anomalous TGC

- The deviation of dimensionless parameters from the SM predicted ones, are used to explore the most general TGC vertex:
  - $g_1^Z = 1$, $k_Z = 1$ and $\lambda_Z = 0$ for $WWZ, WW\gamma$
  - $f_4^{Z,\gamma}$ (CP-violating) and $f_5^{Z,\gamma}$ (CP-conserving) for $ZZZ, ZZ\gamma$
  - h_i^V, $i = 1..4$, $V = Z, \gamma$ for $ZZ\gamma$ and $Z\gamma\gamma$ SM forbidden vertices
- to conserve the unitarity, a form factor is introduced which vanishes the couplings to high-energy, which depende on a cut off scale Λ
  - results are given for each parameter for different Λ assumptions, fixing the others to the SM values
- The most sensitive observable is chosen for each analysis to predict the effect of different aTGC, and compared to data
- 95% confidence intervals (C.I.) on the aTGC parameters are extracted for each analysis. Systematics uncertainties are included as nuisance parameters

Anomalous Triple Gauge Couplings Limits – from *WZ*, *ZZ*

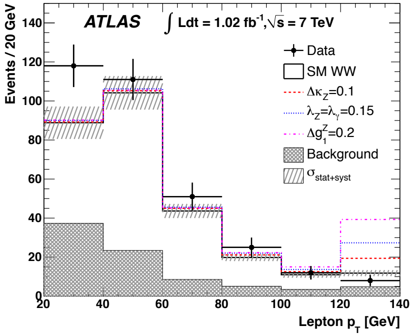
- Total number of observed events is used to determine aTGC limits from WZ, ZZ
- Re-weight procedure is used to predict the expected number of events using different TGC values assumptions
- Profile likelihood ratio test is used to determine the 95% C.I. for the anomalous couplings

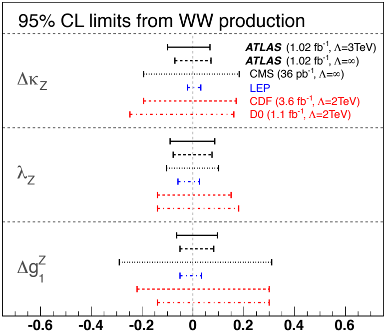




Anomalous Triple Gauge Couplings Limits – from *WW*

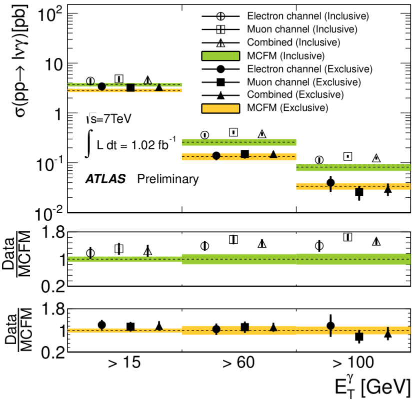
- Leading lepton p_T distribution is used in a binned likelihood fit to extract aTGC limits from *WW*
- Re-weight procedure is used to predict the leading lepton p_T distribution with different TGC values assumptions
- Better sensitivity than Tevatron, due to high statistics and center of mass energy!

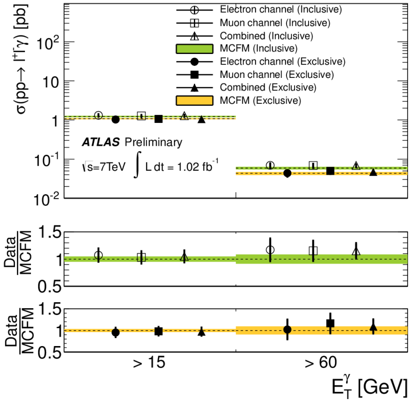




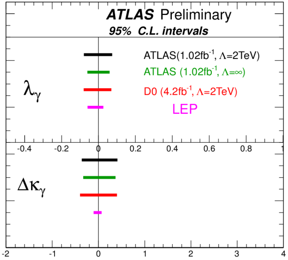
Anomalous Triple Gauge Couplings Limits – from $W\gamma, Z\gamma$

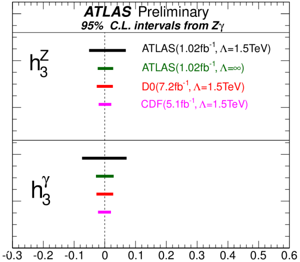
- Number of events with $N_{\mathrm{jet}} = 0$ and $p_{\mathrm{T}}^{\gamma} > 60(100)$ GeV are used to extract aTGC limits from $Z\gamma(W\gamma)$
- NLO predictions with different TGC assumptions are generated using MCFM
- Bayesian approach to set the limit

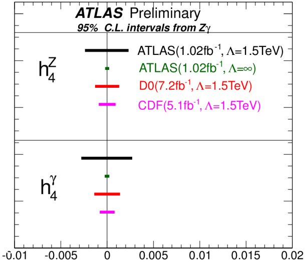




Anomalous Triple Gauge Couplings Limits – from $W\gamma, Z\gamma$







Summary

- Diboson production cross-sections have been measured in agreement with the SM predictions
- Both total and fiducial cross-sections are measured to provide theory-independent results
- Limits on aTGC have been set, competitive with LEP and Tevatron results
- Many new results to come this year:
  - Higher center of mass energy - 8 TeV - measurements
  - Aiming for 20 fb^{-1} dataset by the end of this year
- This is going to be an exciting year!

Thanks!

Backup

Inclusive vs fiducial cross-section

- To minimize the effect of theoretical uncertainties on the measurement, mainly on the acceptance (kinematic distribution predictions, PDF..), fiducial cross-section is measured
  - the fiducial volume is defined to match the experimentally accessible phase space, e.g. two high p_T leptons within some η region
  - C is the overall reconstruction efficiency/resolution/detector acceptance phase space correction factor, i.e. ratio between reconstructed signal events over signal events in the fiducial volume

$$\sigma^{\text{fid}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{C \times \mathscr{L}} \tag{1}$$

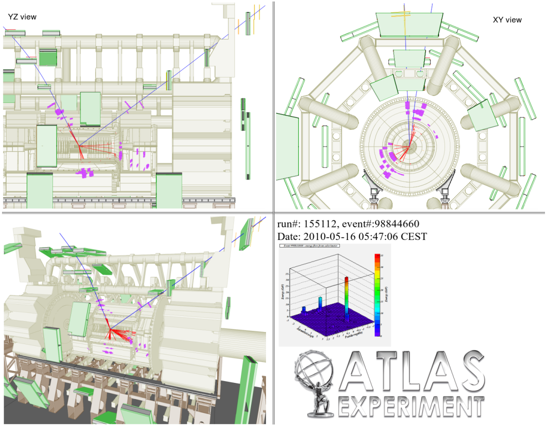
- σ^{fid} is extrapolated to the full production cross-section σ^{tot}, assuming predicted acceptance A from MC, i.e. ratio between generated events in the fiducial volume and all generated events (comprehending the leptonic BR)

$$\sigma^{\text{fid}} = \sigma^{\text{tot}} \times A \tag{2}$$

- The factor A contains all the model assumptions and uncertainties

Fake Leptons Background Data-Driven Estimation

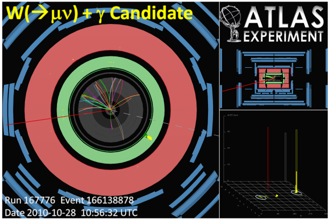
Single bosons production in association with jets, where the jet "fakes" a lepton
$\rightarrow$ difficult to accurately simulate in MC, data-driven method used

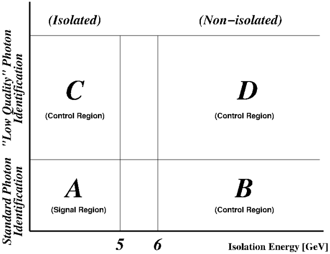


- A control region is defined, kinematically close to the signal region, containing one good lepton and one "lepton-like" jet, i.e. a jet passing loose lepton reconstruction criteria (no isolation cut)
- the probability for a lepton-like jet to be reconstructed as good lepton ($f(p_T)$) is measured from a di-jet independent sample
- Number of fake background events in signal region is determined opportunely scaling the control sample by $f(p_T)$

Fake Photons Background Data-Driven Estimation

Single bosons production in association with jets, producing non-prompt γ from meson decays from jet fragmentation $\rightarrow$ difficult to simulate in MC as well, data-driven method used





- Two dimensional side-band method is used to determine non-prompt photon background – photon identification and isolation are used to define signal and control regions

$$N_B / N_A = N_D / N_C$$

WW Event Yield

Final State	$e^+e^-E_T^{miss}$	$\mu^+\mu^-E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
Observed Events	196	287	1041	1524
Total expected events (S+B)	202.9±7.2±15.3	250.1±7.4±15.9	916.9±10.0±68.9	1370.1±14.3±96.5
MC WW Signal	88.5±1.3±10.1	137.0±1.6±14.4	613.6±3.6±59.8	839.0±4.2±83.3
Background estimations				
Top(data-driven)	14.0±2.0±2.9	25.2±2.9±5.1	70.8±5.2±14.4	110.0±6.2±22.4
W+jets (data-driven)	19.8±0.5±10.5	5.1±0.9±2.0	54.1±1.0±28.3	79.0±1.4±39.0
Drell-Yan (MC/data-driven)	72.0±6.7±3.2	70.0±6.5±3.5	142.2±7.1±12.5	284.2±11.7±17.2
Other dibosons (MC)	8.6±1.2±1.9	12.8±0.6±2.0	36.2±2.9±3.5	57.6±3.2±7.4
Total background	114.4±7.1±11.5	113.1±7.2±6.8	303.3±9.3±34.3	531.1±13.7±48.7
Significance (S / $\sqrt{B}$)	8.3	12.9	35.2	36.4

WZ Event Yield

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

$ZZ \to 4l$ Event Yield

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.)	$0.6^{+0.7+0.8}_{-0.6-0.6}$	$< 0.3^{+0.5}_{-0.2}$	$0.3^{+0.9+0.8}_{-0.3-0.3}$	$0.7^{+1.3+1.3}_{-0.7-0.7}$
Bkg(MC)	0.3 ± 0.3	< 0.8	0.6 ± 0.6	1.0 ± 0.6

$ZZ \to ll\nu\nu$ Event Yield

Final State	$e^+e^-\nu\bar{\nu}$	$\mu^+\mu^-\nu\bar{\nu}$	$\ell^+\ell^-\nu\bar{\nu}$
Observed	33	45	78
Expected ZZ	$19.3 \pm 0.5 \pm 1.2$	$23.0 \pm 0.6 \pm 0.9$	$42.3 \pm 0.8 \pm 1.8$
Background estimations:			
$W^\pm Z$ (MC)	$9.4 \pm 0.5 \pm 1.5$	$13.3 \pm 0.6 \pm 2.1$	$22.7 \pm 0.8 \pm 3.5$
$W^\pm$+γ (MC)	$0.20 \pm 0.10 \pm 0.01$	$0.09 \pm 0.06 \pm 0.01$	$0.29 \pm 0.12 \pm 0.01$
$t\bar{t}$, $W^\pm t$, W^+W^- and $Z \to \tau\tau$ (data-driven)	$6.5 \pm 1.8 \pm 0.3$	$8.2 \pm 2.3 \pm 0.3$	$14.7 \pm 4.1 \pm 0.6$
Z+jets (data-driven)	$0.8 \pm 0.4 \pm 0.4$	$0.9 \pm 0.3 \pm 0.4$	$1.7 \pm 0.5 \pm 0.8$
$W^\pm$+jets (data-driven)	$1.1 \pm 0.4 \pm 0.3$	$0.2 \pm 0.1 \pm 0.1$	$1.3 \pm 0.4 \pm 0.3$
Total Background	$18.0 \pm 2.0 \pm 1.6$	$22.7 \pm 2.4 \pm 2.1$	$40.7 \pm 4.3 \pm 3.7$

$W\gamma/Z\gamma$ Event Yield

	$\sigma^{ext-fid}[pb]$	$\sigma^{ext-fid}[pb]$
	Low p_T exclusive	**Low p_T inclusive**
$e\nu\gamma$	$3.42 \pm 0.14 \pm 0.50$	$4.35 \pm 0.16 \pm 0.64$
$\mu\nu\gamma$	$3.23 \pm 0.14 \pm 0.48$	$4.82 \pm 0.15 \pm 0.64$
$l\nu\gamma$	$3.32 \pm 0.10 \pm 0.48$	$4.60 \pm 0.11 \pm 0.64$
$e^+e^-\gamma$	$1.03 \pm 0.06 \pm 0.13$	$1.32 \pm 0.07 \pm 0.16$
$\mu^+\mu^-\gamma$	$1.06 \pm 0.05 \pm 0.12$	$1.27 \pm 0.06 \pm 0.15$
$l^+l^-\gamma$	$1.05 \pm 0.04 \pm 0.12$	$1.29 \pm 0.05 \pm 0.15$
	Medium p_T exclusive	**Medium p_T inclusive**
$e\nu\gamma$	$0.14 \pm 0.02 \pm 0.02$	$0.36 \pm 0.03 \pm 0.03$
$\mu\nu\gamma$	$0.15 \pm 0.02 \pm 0.02$	$0.41 \pm 0.03 \pm 0.03$
$l\nu\gamma$	$0.15 \pm 0.01 \pm 0.02$	$0.38 \pm 0.02 \pm 0.03$
$e^+e^-\gamma$	$0.044 \pm 0.010 \pm 0.004$	$0.069 \pm 0.012 \pm 0.006$
$\mu^+\mu^-\gamma$	$0.050 \pm 0.010 \pm 0.004$	$0.068 \pm 0.011 \pm 0.005$
$l^+l^-\gamma$	$0.047 \pm 0.007 \pm 0.004$	$0.068 \pm 0.008 \pm 0.005$
	High p_T exclusive	**High p_T inclusive**
$e\nu\gamma$	$0.040 \pm 0.011 \pm 0.009$	$0.114 \pm 0.018 \pm 0.010$
$\mu\nu\gamma$	$0.026 \pm 0.008 \pm 0.003$	$0.135 \pm 0.018 \pm 0.010$
$l\nu\gamma$	$0.030 \pm 0.006 \pm 0.006$	$0.125 \pm 0.013 \pm 0.010$