MANCHESTER 1824

The University of Manchester

Measurement of the WW, WZ and ZZ production cross sections and TGC's in collisions at 7 TeV with the ATLAS detector

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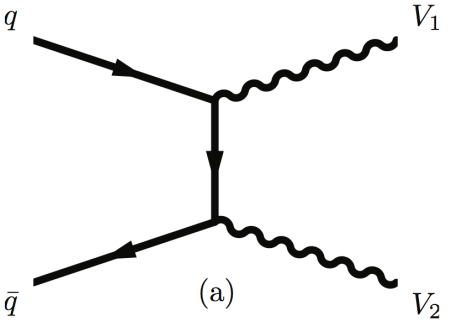
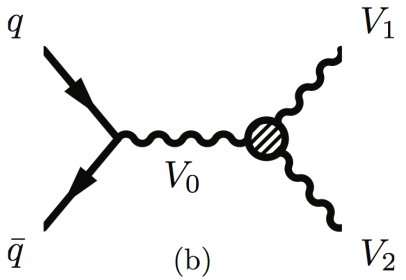
on behalf of the ATLAS Collaboration

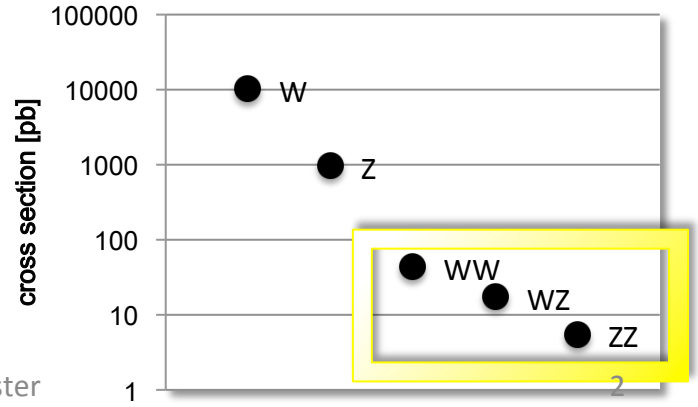
Introduction

Di-boson production is a O(1-10)pb process.

- **Probes the electro-weak gauge symmetry of the SM.**
  - Determination of Triple Gauge Boson Couplings provide a model independent test for "new" physics.
  - Measure "fiducial" cross sections to minimize the dependence on theoretical predictions.
  - Sensitivity increases with energy reach.
- **Background to many searches.**
  - Higgs production
  - SUSY
  - Technicolor

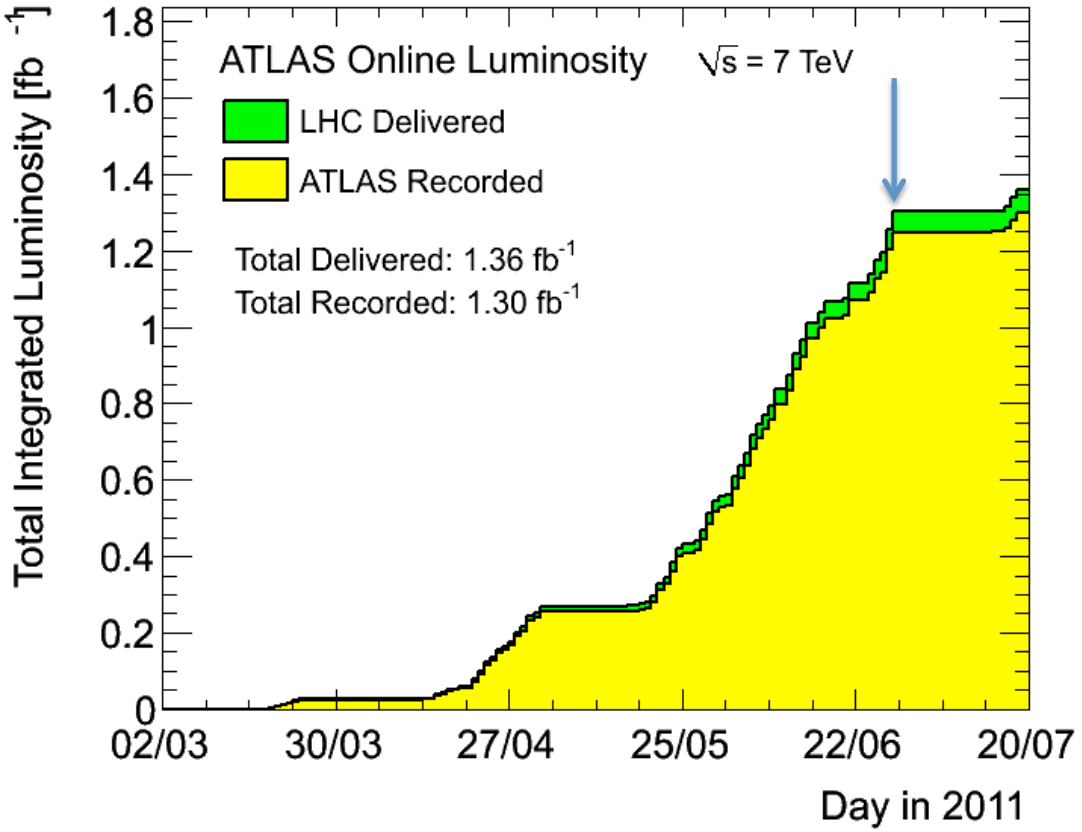






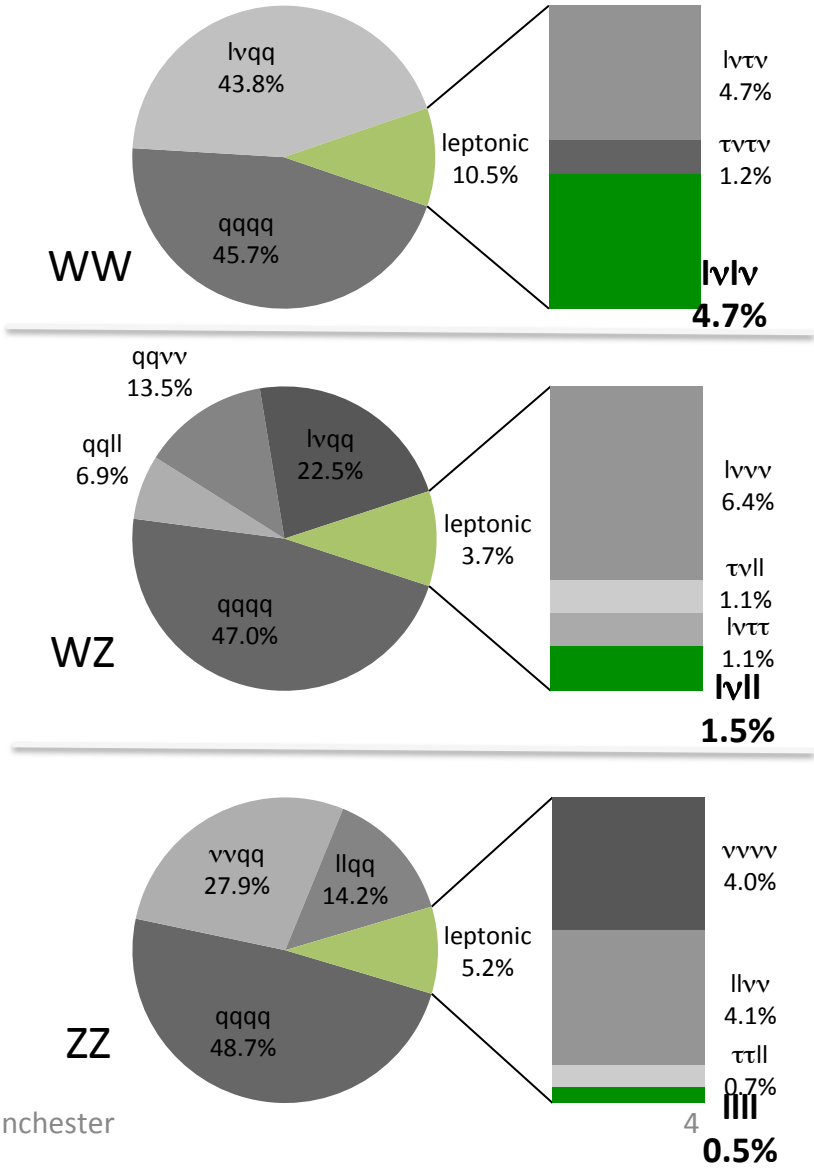
LHC & ATLAS 2011

- Integrated luminosity reached 1.2 fb^{-1}!
  - $\Delta L/L = 3.7\%$
- Di-bosons analysis no longer a finger counting exercise…
- **Challenges in 2011:**
  - Higher pile-up.
  - Decreasing of statistical error needs better understanding of systematics uncertainties.
  - Background studies cannot rely only on MC anymore.



Heavy Di-Boson Production at LHC

- Use leptonic decays:
  - Small Branching Ratios
  - Low background
- Tau decays contribute to e/μ channels
  - Accounted for in cross section extraction.
- Clean but small signal.



Backgrounds

Multi-lepton finals states from top-quark decays.

Use data driven techniques.

Fake leptons from jets associated with Z/W. Use data driven techniques.

Di-Boson is signal and background for other VV channels.

2l+MET | 3l+M_Z+MET | 2M_Z

Bckgnd	WW	WZ	ZZ
top	35%	12%	incl. DD
W+jets	30%	0%	incl. DD
Z+jets	32%	52%	incl. DD
VV	4%	28%	incl. DD
Z+gamma	incl. in VV	8%	incl. DD
S/B	**1.4**	**4**	**30**
S/sqrt(B)	**18**	**12**	**17**

WW-> lνlν

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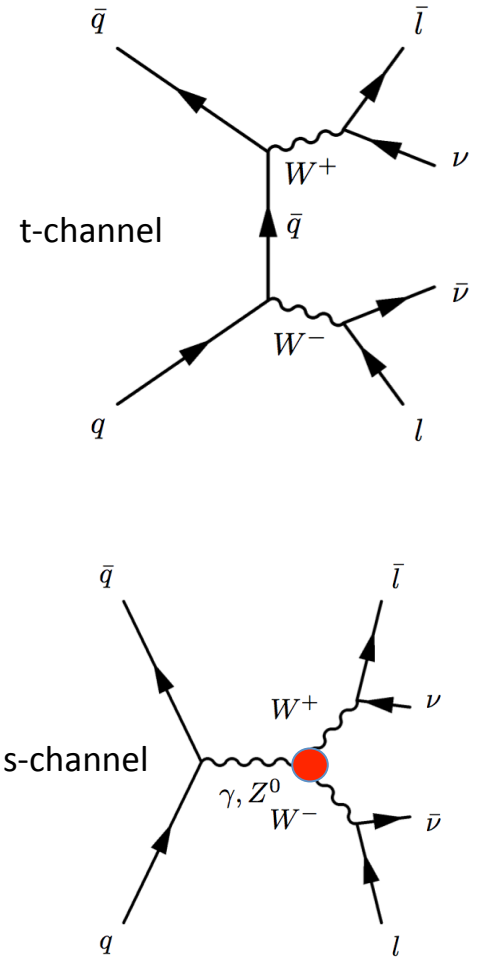
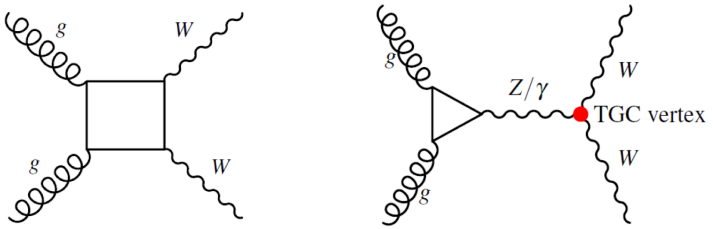


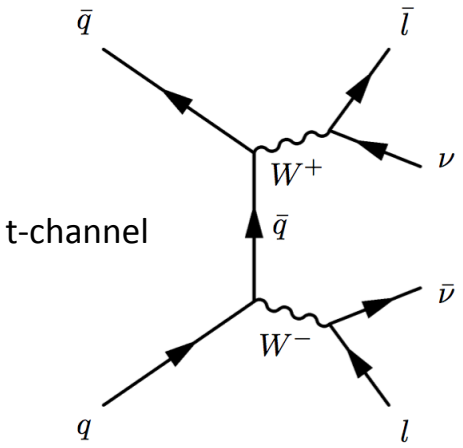
- Signature two leptons and MET.
- Small contribution (3%) from gg:

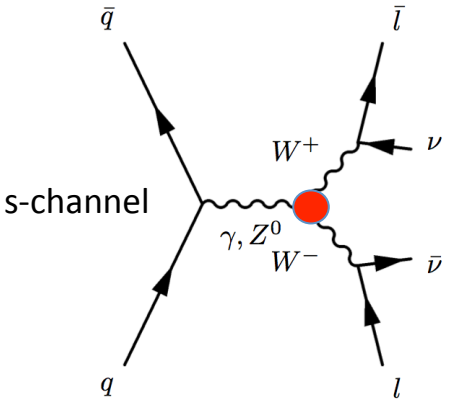


- Important background to H->WW studies!

  (see “Search for Higgs to WW”,ID297)

WW-> lνlν





Selection

- Exactly 2 leptons opposite signs, p_T > 20GeV
- Leading electron p_T > 25 GeV
- m_{ll} > 15GeV, $m_{e\mu}$ > 10GeV
- Z veto ($|m_{ll}-m_Z|$ < 15GeV
- MET (rel) > (45,40,25) GeV, (μμ,ee,eμ)
- Jet veto (pT>30GeV, |eta|<4.5,anti-kt,DR=0.4)

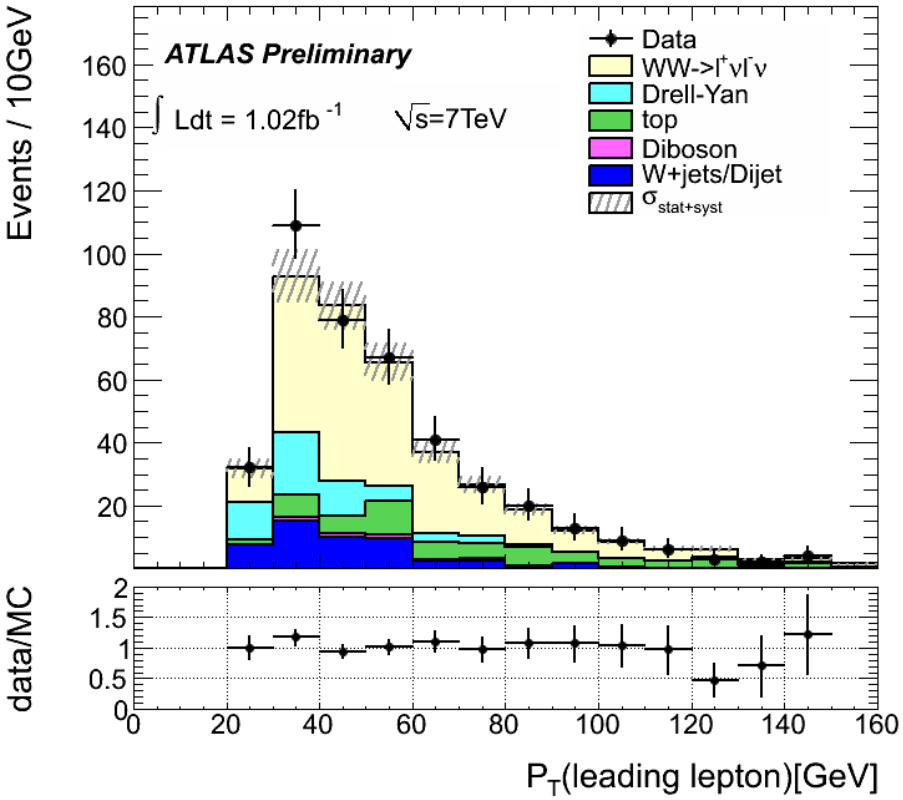
- MET:
  - Use MET relative to nearest lepton: $MET_{rel}=\sin(\Delta\phi)*MET$ for $\phi < 90°$
  - Reduces DY contribution for miss-measured jets/leptons and Z->ττ.
- Backgrounds:
  - Use DD backgrounds for W+jets and ttbar.
  - Use MC for DY and Di-Boson.

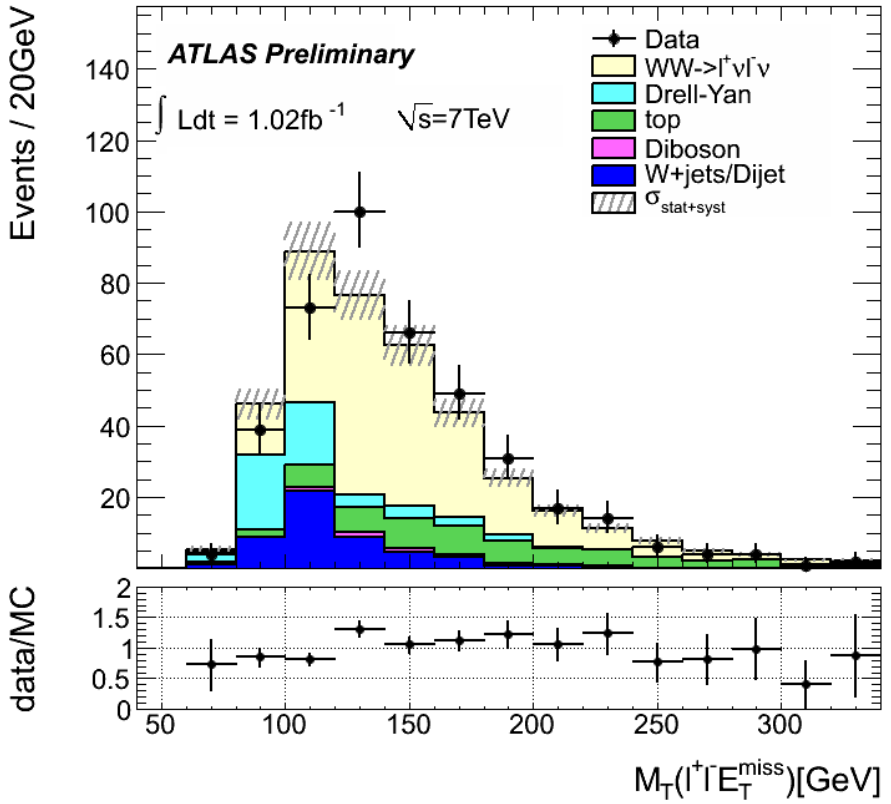
WW-> lνlν

L=1.0 fb^{-1}

Kinematic Distribution after all selection cuts

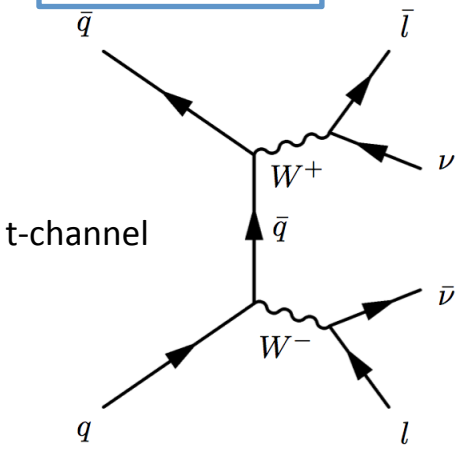
N(cand) = 414 , N(bckgnd) = 170±28

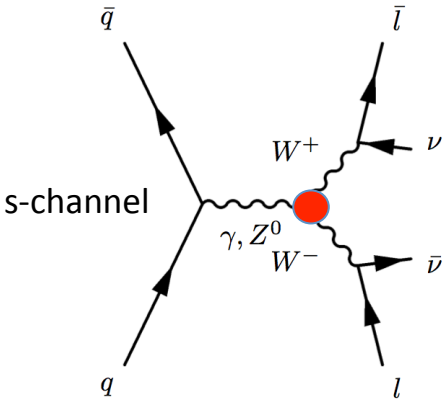




WW-> lνlν

L=1.0 fb^{-1}





Total production cross section result

σ_{total}=48.2± 4.0(stat)± 6.4(sys) ± 1.8(lumi) pb

Fiducial production cross section result

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

Phase space mimics selection cuts, different for ee,eμ,μμ.

- NLO SM expectation:
  σ_{total}=46±3 pb
- Limited by systematic
  - Dominated by Data Driven background estimation.

WZ-> lllν

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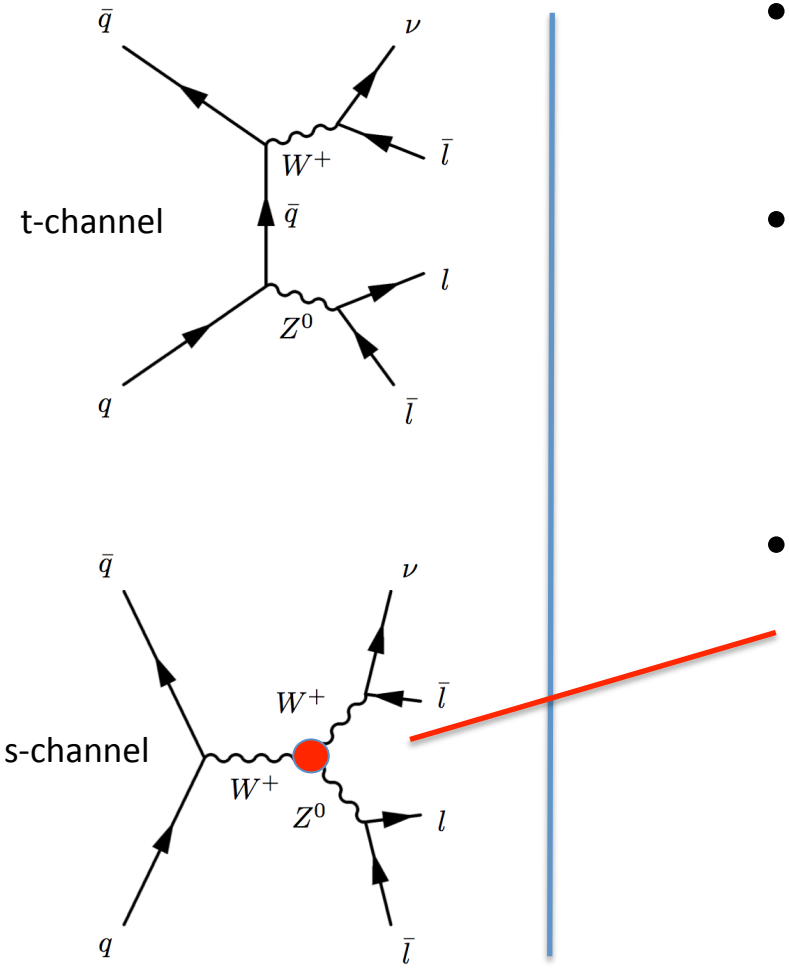
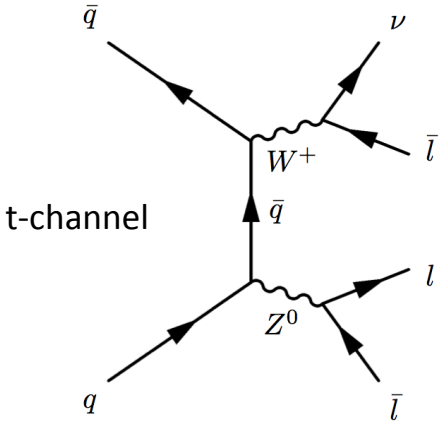
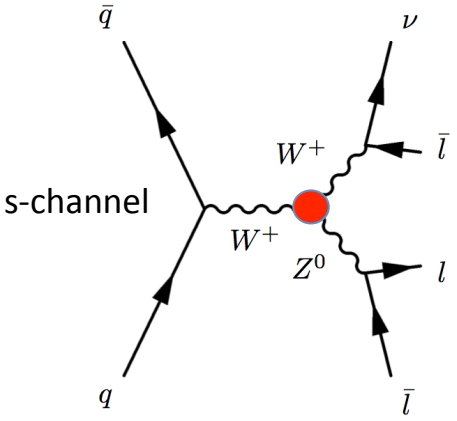


- Signature:
  Three leptons and MET.
- Presence of Z allows effective suppression of ttbar backgrounds.
  - Dominant background source Z +jets.
- Cross section and anomalous **triple gauge couplings** determined.

WZ-> lllν

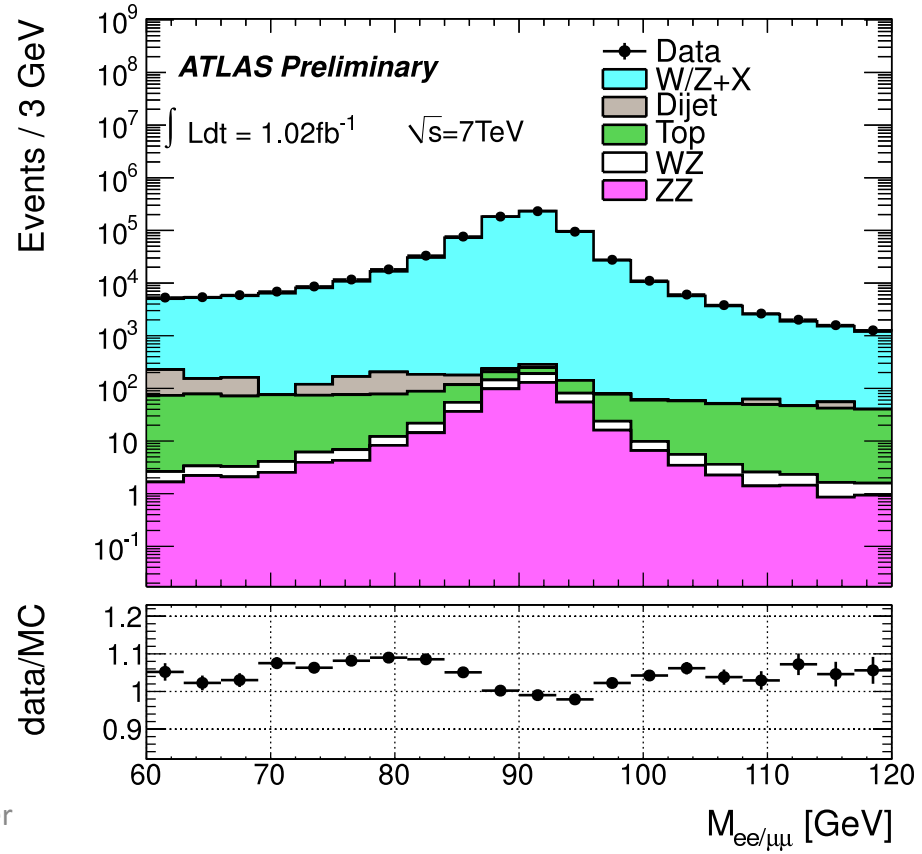
L=1.0 fb^{-1}





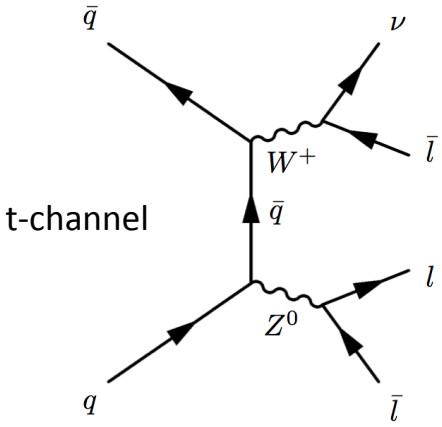
Selection

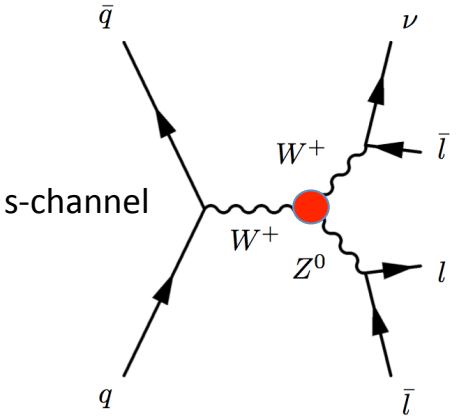
- Z $|m_{ll}-m_Z| < 10$ GeV
- 3 leptons, $p_T > 15$ GeV
- MET > 25GeV
- W MT > 20 GeV
- Trigger Match with $p_T(e,\mu) > (25,20)$ GeV



WZ-> lllν

L=1.0 fb^{-1}

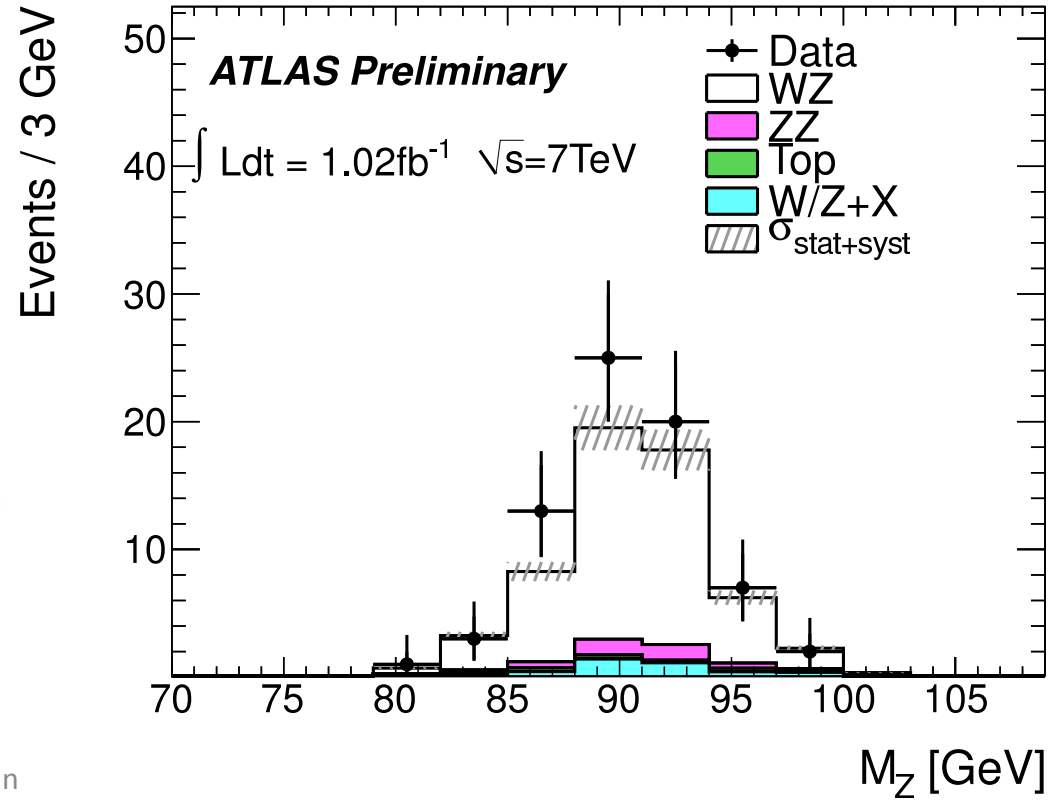




Selection

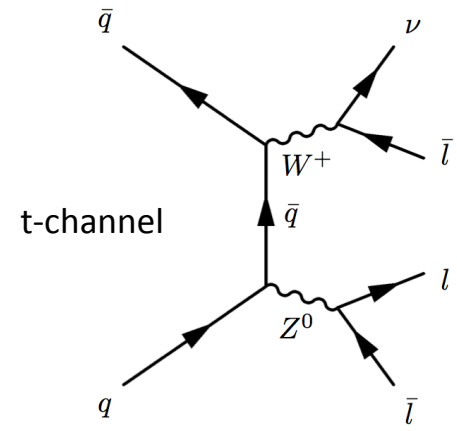
- Z $|m_{ll}-m_Z| < 10$ GeV
- MET > 25GeV
- W MT > 20 GeV
- Trigger Match with $p_T(e,\mu) > (25,20)$ GeV

N(Data) = 71 , N(bkg MC) = 10.5



WZ-> lllν

L=1.0 fb^{-1}



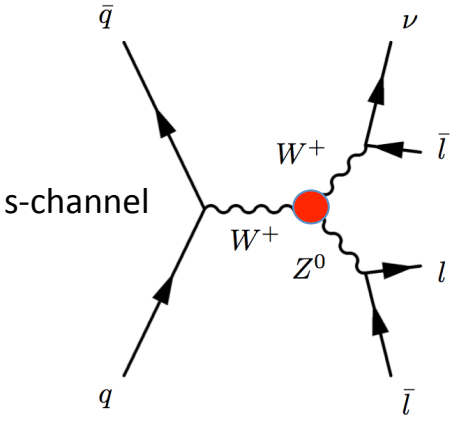
t-channel

Total cross section:

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

SM NLO expectation 17.2±1pb

Good agreement with the Standard Model.



s-channel

Fiducial Cross section:

- $p_T(l) > 15$ GeV, $|\eta| < 2.5$, $pT(\nu) > 25$ GeV
- $M(ll)-M_Z < 10$ GeV
- $M_T(W) > 20$ GeV

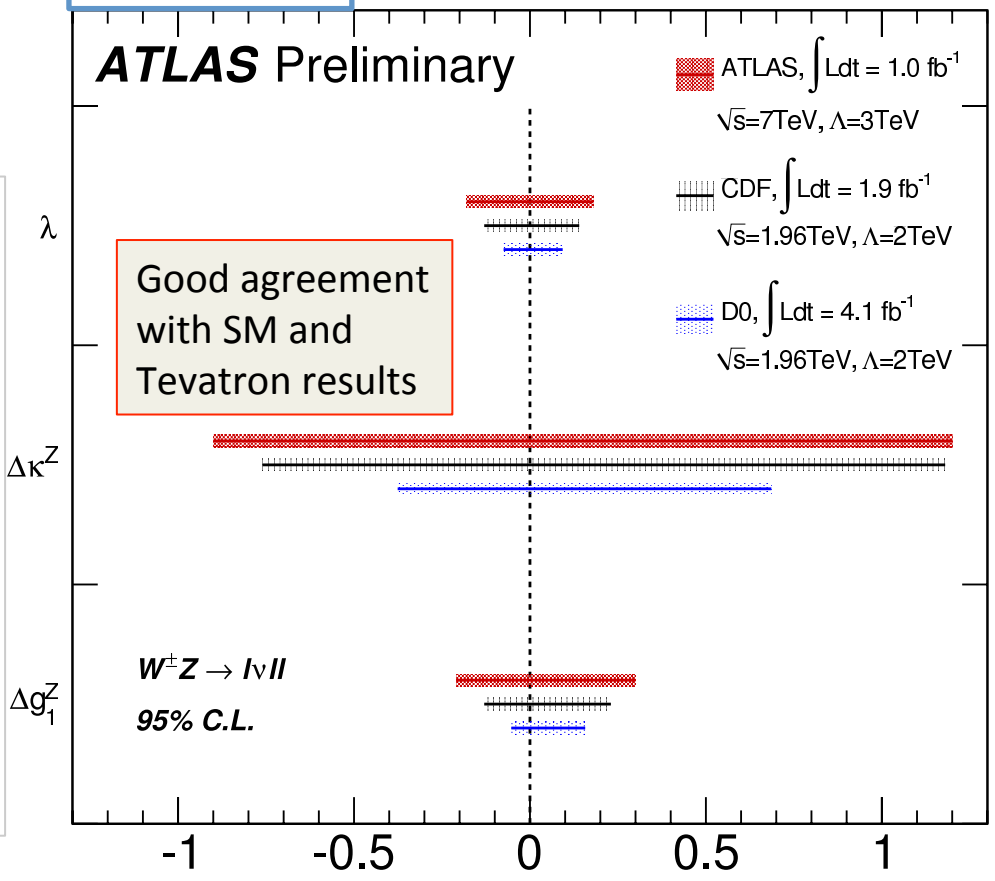
$$\sigma^{fid}_{WZ\to\ell\nu\ell\ell} = 118^{+18}_{-16}(\text{stat})\ ^{+6}_{-6}(\text{syst})\ ^{+5}_{-5}(\text{lumi})\ \text{fb}$$

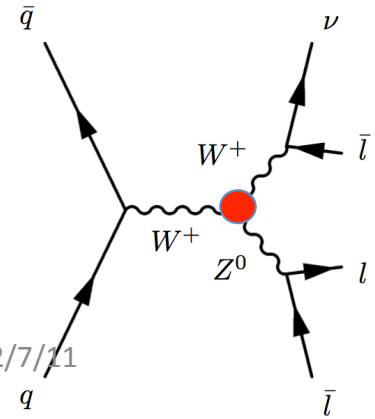
WZ-> lllν

L=1.0 fb^{-1}

<u>Extraction of anomalous triple gauge boson couplings</u>

- Use total cross section to fit TGC.
- NLO MC with reweighting technique.
- Use cut-off of Λ=3TeV
- Profile likelihood ratio, including systematics as nuisance parameters.
- Confidence Intervals obtained by Neyman construction based on cross section.





Anomalous Coupling	Limits of the 68% C.I.	Limits of the 95% C.I.
Δg_1^Z	$[-0.17, -0.05], [0.13, 0.26]$	$[-0.21, 0.30]$
$\Delta\kappa^Z$	$[-0.8, -0.2], [0.5, 1.0]$	$[-0.9, 1.2]$
λ	$[-0.15, -0.06], [0.06, 0.15]$	$[-0.18, 0.18]$

ZZ-> llll

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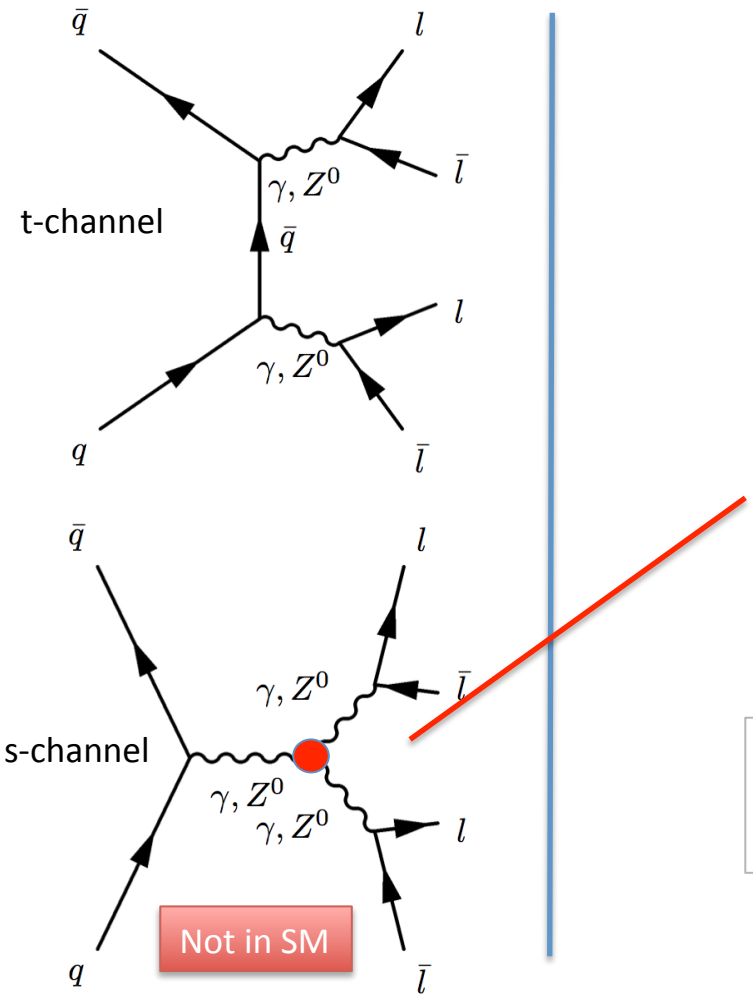
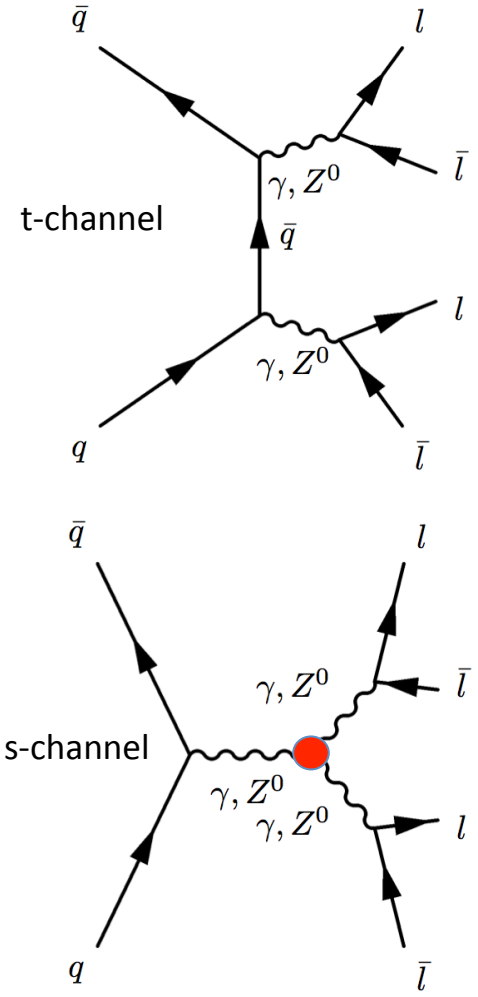


- Signature:
  Four leptons.
- Presence of two Z make this channel effectively background free.
  - Enhanced acceptance by loosened object definitions.
- Cross section and **anomalous triple gauge couplings** determined.

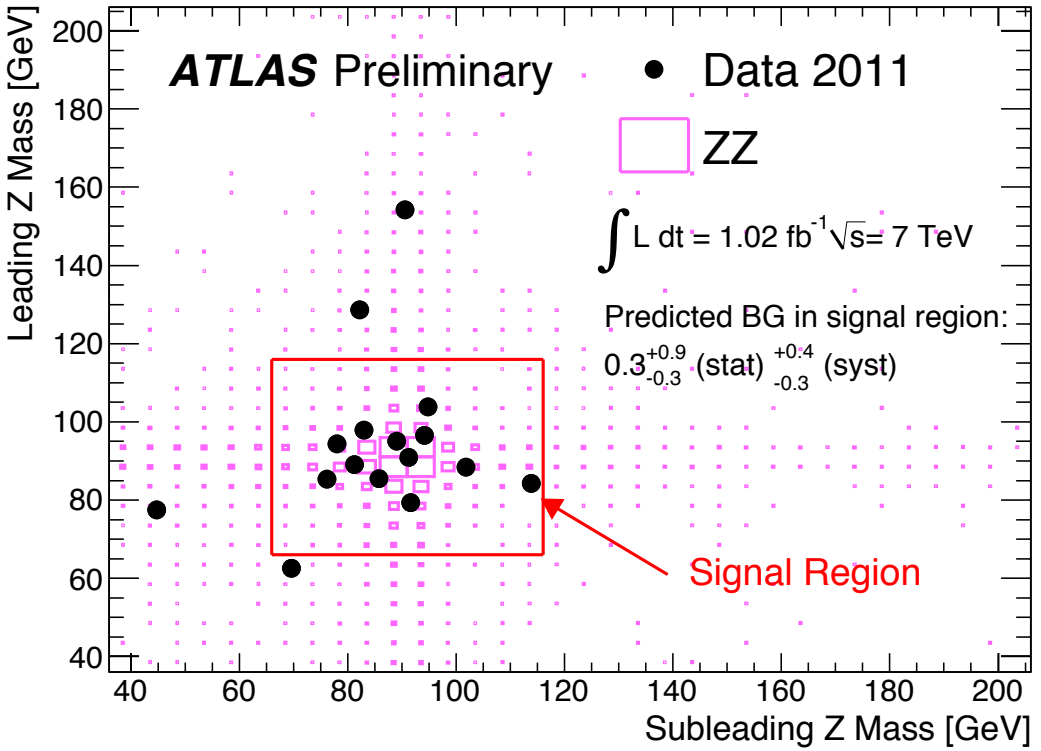
See also poster
"Measurement of the ZZ production cross section with ATLAS"
by Andreas Petridis.

ZZ-> llll

L=1.0 fb^{-1}



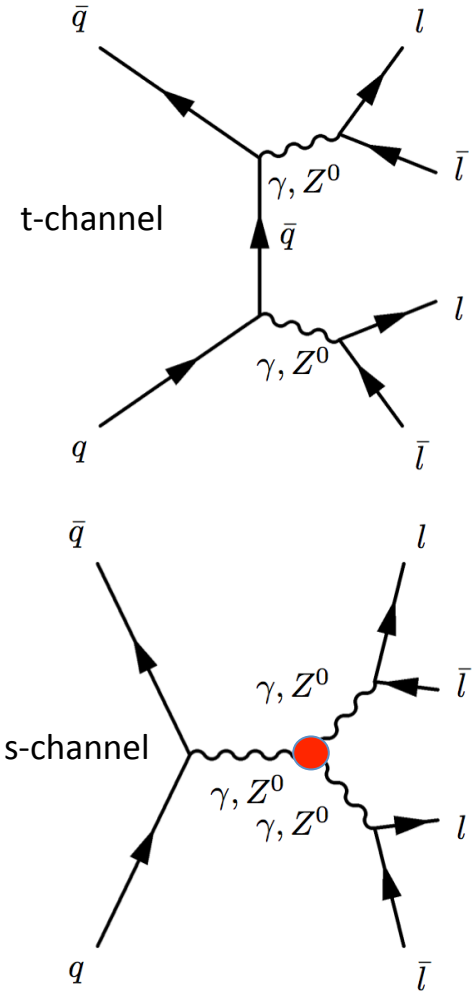
- Background for H->ZZ
  (see “Search for Higgs to ZZ”, ID298)
- Anomalous coupling vertex in s-channel (forbidden in SM).
- Selection:
  - 4 leptons, pT>15GeV, $|\eta|$<2.5, leading μ(e) pT>20 (25) GeV
  - 2 Z candidates with $|M_{ll}-M_z| < 25$GeV.
- Background estimate from Data driven methods.



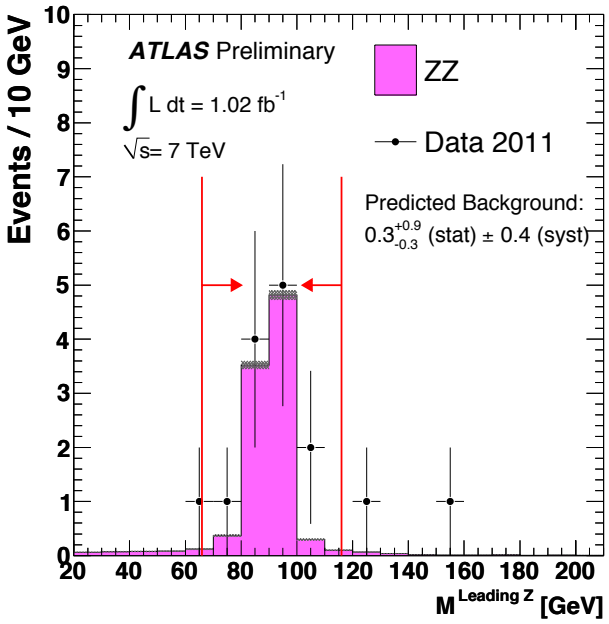
ZZ-> llll

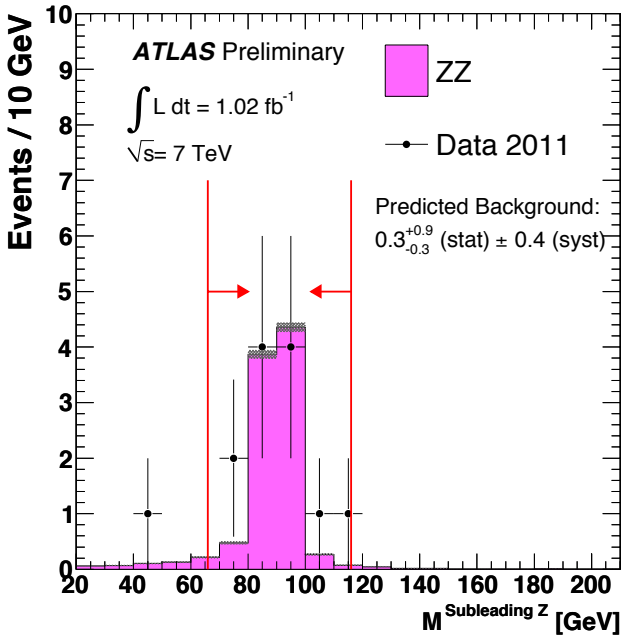
L=1.0 fb^{-1}

- Found 12 candidate events.



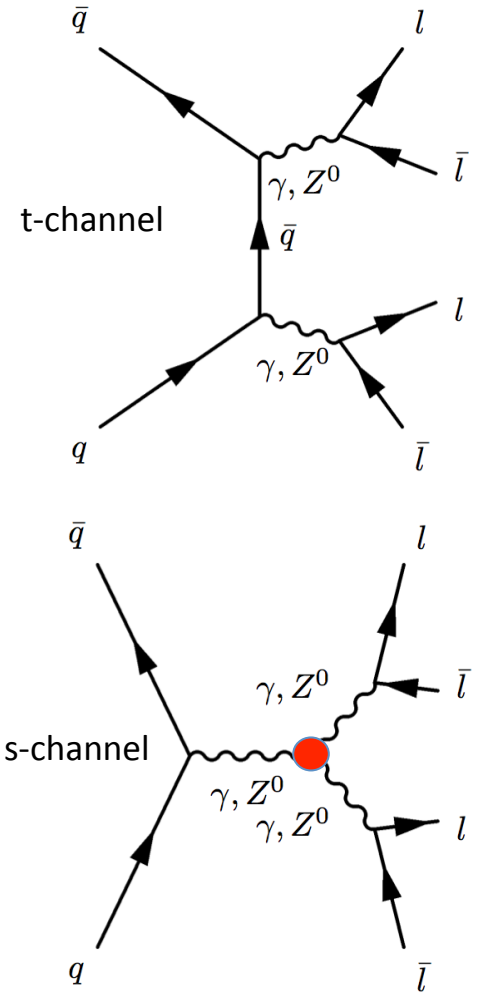
Final State	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell^+\ell^-$
Observed	2	8	2	12
Bkg(data-driven)	$0.01^{+0.03+0.05}_{-0.01-0.01}$	$0.3^{+0.9}_{-0.3} \pm 0.3$	$< 0.01^{+0.03}_{-0.01}$	$0.3^{+0.9+0.4}_{-0.3-0.3}$
Expected ZZ	1.57±0.03±0.11	3.09±0.04±0.06	4.5±0.1±0.2	9.1±0.1±0.3



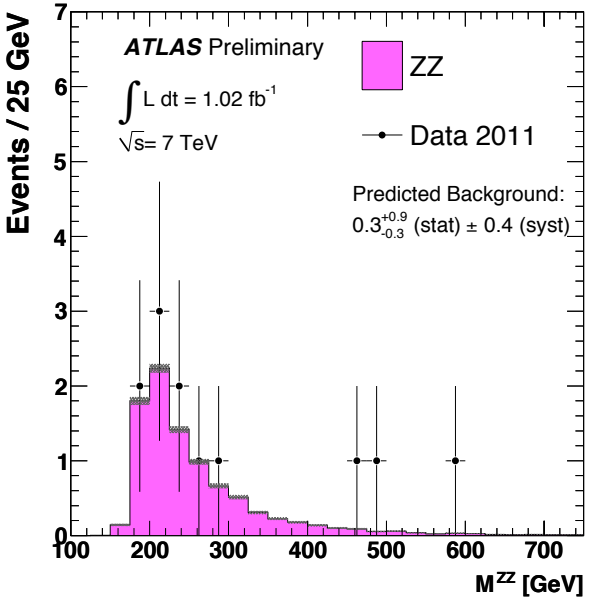


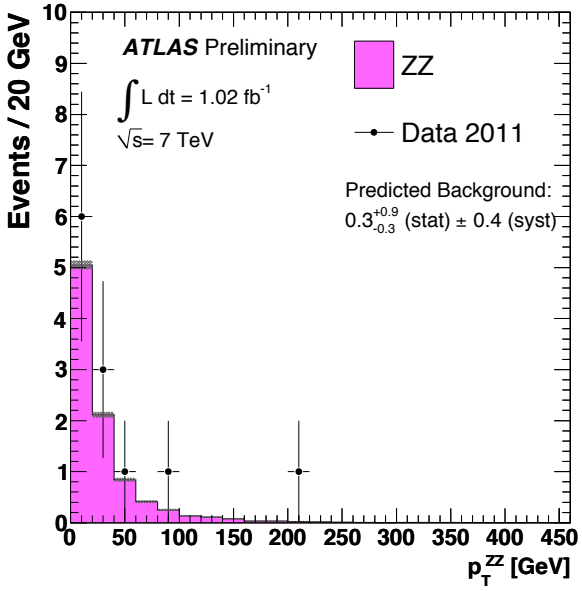
ZZ-> llll

L=1.0 fb^{-1}



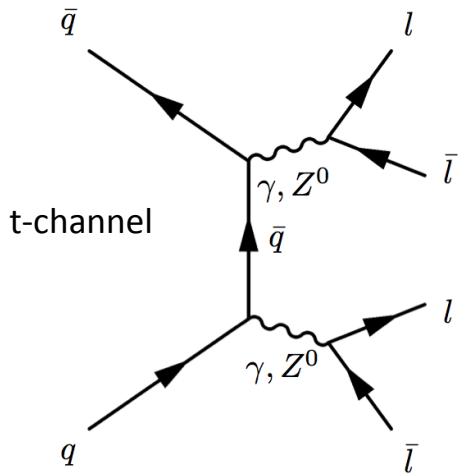
- Kinematic distributions pT(ZZ), M(ZZ)
- Agreement with SM expectations.

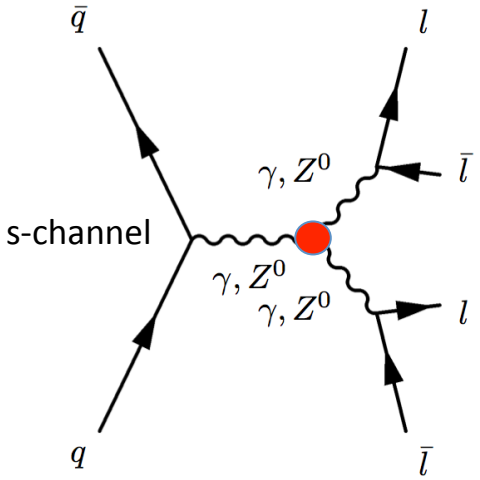




ZZ-> llll

L=1.0 fb^{-1}





Total cross section:

$$\sigma^{tot}_{ZZ} = 8.7^{+3.1}_{-2.5}\ (stat)\ ^{+0.5}_{-0.9}\ (syst)\ \pm 0.4\ (lumi)\ pb$$

SM NLO expectation 6.5±0.3pb

Good agreement with the Standard Model.

Fiducial Cross section:

- $p_T(l) > 15$ GeV, $|\eta| < 2.5$
- $|M(ll)-M_Z| < 25$ GeV

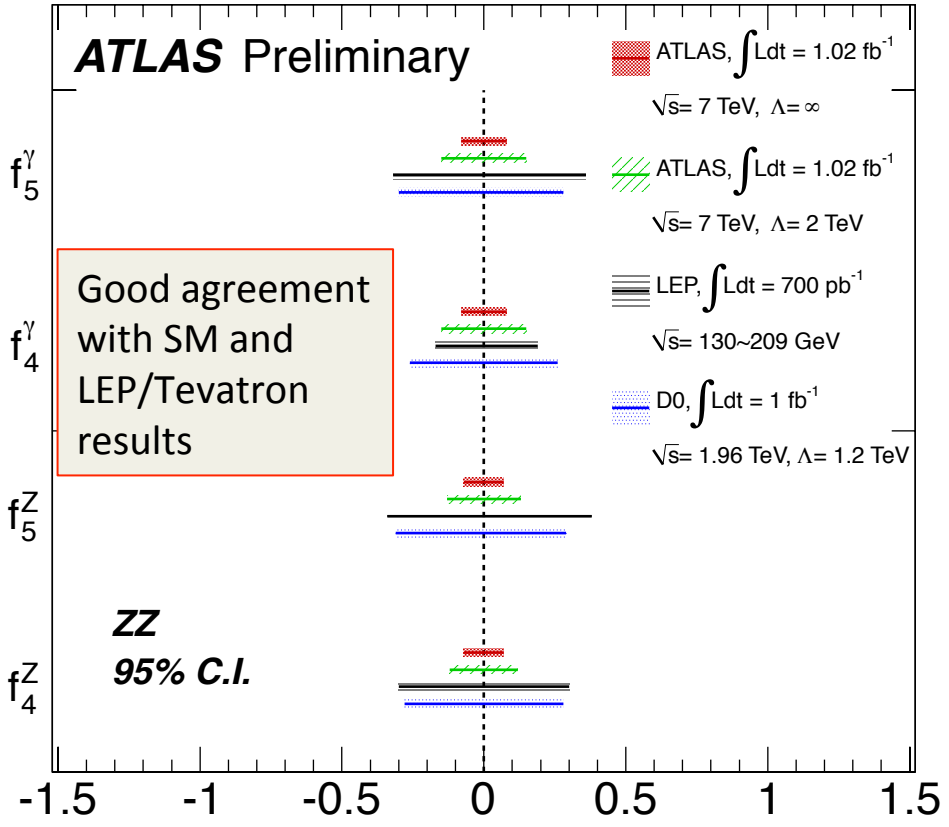
$$\sigma^{fid}_{ZZ\to\ell^+\ell^-\ell^+\ell^-} = 5.0^{+1.8}_{-1.5}\ (stat)\ ^{+0.3}_{-0.5}\ (syst)\ \pm 0.2\ (lumi)\ fb$$

ZZ-> llll

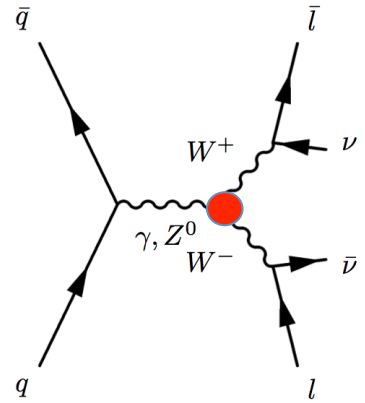
L=1.0 fb^{-1}

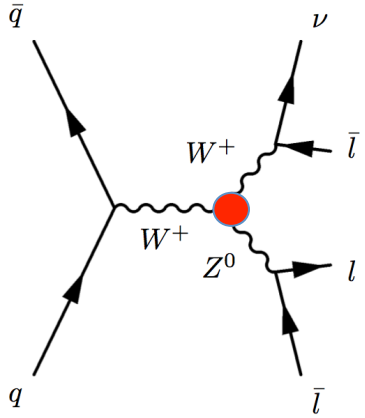
Extraction of anomalous triple gauge boson couplings

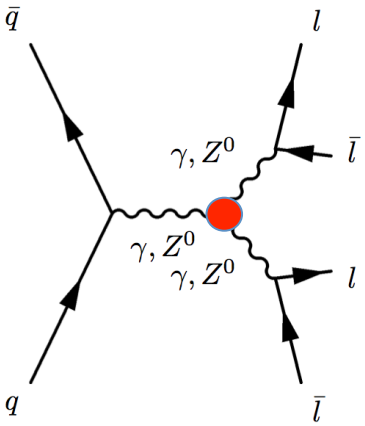
- Use total cross section to fit TGC.
- LO reweighting technique with NLO correction (Baur-Rainwater + Sherpa)
- Use cut-off of Λ=2TeV, ∞
- Profile likelihood ratio, including systematics as nuisance parameters.
- 95% Confidence Intervals obtained by ΔL=1.92



Coupling 95% CI	f_4^γ	f_4^Z	f_5^γ	f_5^Z
$\Lambda = 2$ TeV	$[-0.15, 0.15]$	$[-0.12, 0.12]$	$[-0.15, 0.15]$	$[-0.13, 0.13]$
$\Lambda = \infty$	$[-0.08, 0.08]$	$[-0.07, 0.07]$	$[-0.08, 0.08]$	$[-0.07, 0.07]$





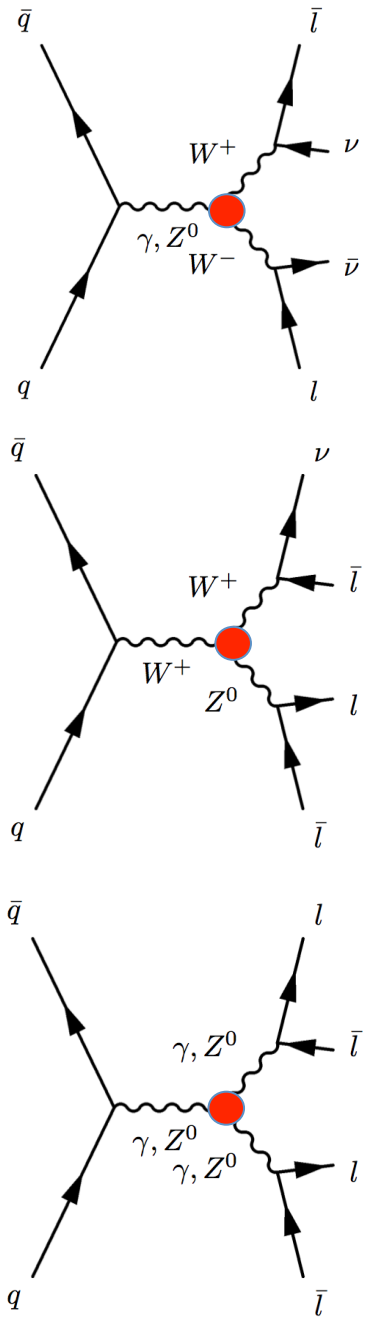


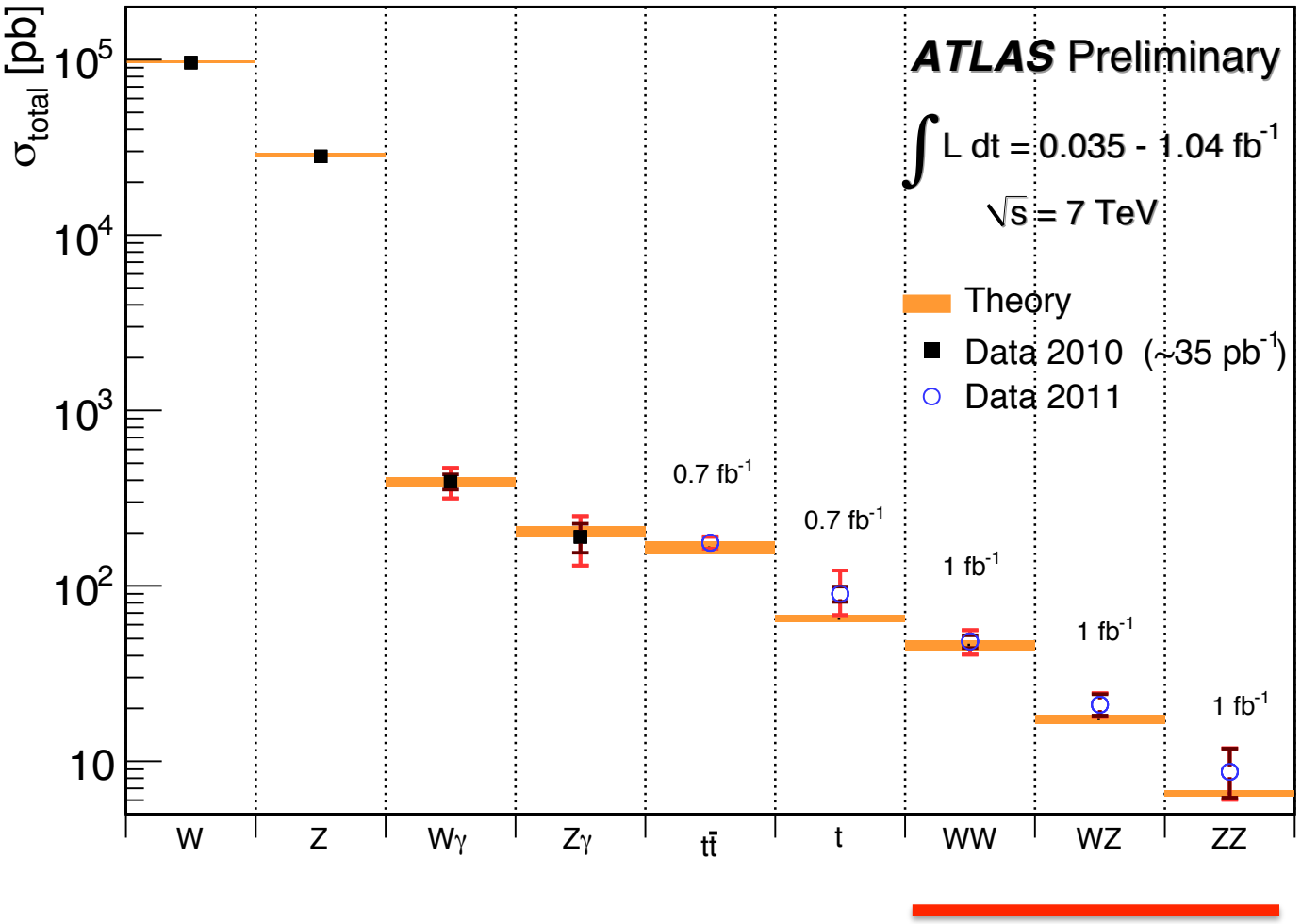
Summary

- Observed and measured cross sections of all heavy di-boson states WW, WZ, ZZ
- Set first limits on anomalous triple gauge boson couplings.
- With rapidly increasing luminosity expect tighter limits soon!

Cross Section [pb]	WW	WZ	ZZ
Expected total	46	17.2	6.5
Measured total	**48.2**	**21.1**	**8.4**
Stat err	4	2.95	2.5
Syst err	6.4	1.2	0.55
Lumi err	1.8	0.85	0.3

Summary


$\bar{q}$
$\bar{l}$
W^+
ν
γ, Z^0
W^-
$\bar{\nu}$
q
l
$\bar{q}$
ν
W^+
$\bar{l}$
W^+
Z^0
l
q
$\bar{l}$
$\bar{q}$
l
γ, Z^0
$\bar{l}$
γ, Z^0
γ, Z^0
l
q
$\bar{l}$


σ_{total} [pb]
10^5
10^4
10^3
10^2
10
ATLAS Preliminary
$\int$ L dt = 0.035 - 1.04 fb^{-1}
$\sqrt{s}$ = 7 TeV
Theory
Data 2010 (~35 pb^{-1})
Data 2011
0.7 fb^{-1}
0.7 fb^{-1}
1 fb^{-1}
1 fb^{-1}
1 fb^{-1}
W
Z
Wγ
Zγ
tt̄
t
WW
WZ
ZZ

BACKUP

WW

- Acceptance

Cuts	ee Channel		$\mu\mu$ Channel		$e\mu$ Channel	
	$e\nu e\nu$	$\tau\nu\ell\nu$	$\mu\nu\mu\nu$	$\tau\nu\ell\nu$	$e\nu\mu\nu$	$\tau\nu\ell\nu$
Total Events	552.3	211.4	552.3	211.4	1104.5	423.1
2 leptons (SS+OS)	116.6	11.8	229.0	25.5	332.7	35.5
2 leptons (OS)	115.7	11.6	229.0	25.5	331.3	35.3
leading electron Pt $>$ 25GeV	114.4	11.4	-	-	305.5	30.2
trigger matching	114.2	11.4	231.9	25.8	305.3	30.2
$M_{\ell\ell} > 15$ GeV, $M_{e\mu} > 10$ GeV	113.5	11.3	229.7	25.6	304.5	30.1
Z mass veto	88.2	8.4	176.6	19.0	-	-
$E^{\text{miss}}_{\text{T, Rel}}$ cut	38.6	2.9	69.7	5.2	193.2	16.1
Jet veto (No. of Jet=0)	27.8	1.7	49.4	3.1	139.6	10.9
W^+W^- Acceptance	5.0%	0.8%	8.9%	1.5%	12.6%	2.6%

Table 2: W^+W^- MC event selection cut flow and overall acceptance. The MC W^+W^- signal expectations are normalized to 1.02 fb^{-1} integrated luminosity, using the NLO SM cross sections. ℓ refers to e, μ and τ in this table.

WW

- Total xsec by channel

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

Table 7: The measured total W^+W^- production cross sections in the three dilepton channels and in the combined channel.

WW

- Details on backgrounds

Final State	$e^+e^-E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu^+\mu^-E_{\mathrm{T}}^{\mathrm{miss}}$	$e^\pm\mu^\mp E_{\mathrm{T}}^{\mathrm{miss}}$	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

WW

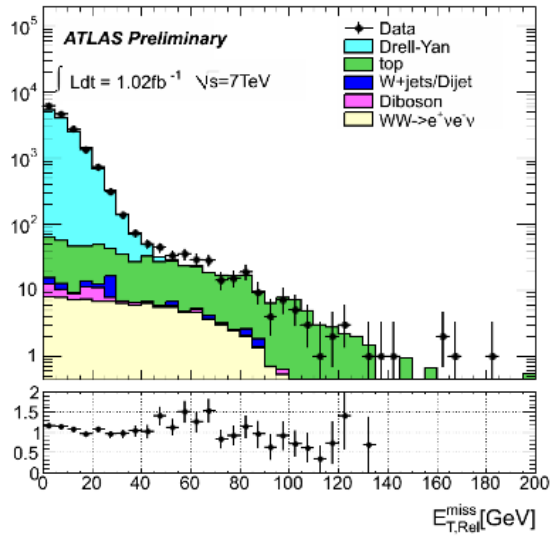
- Details on systematics

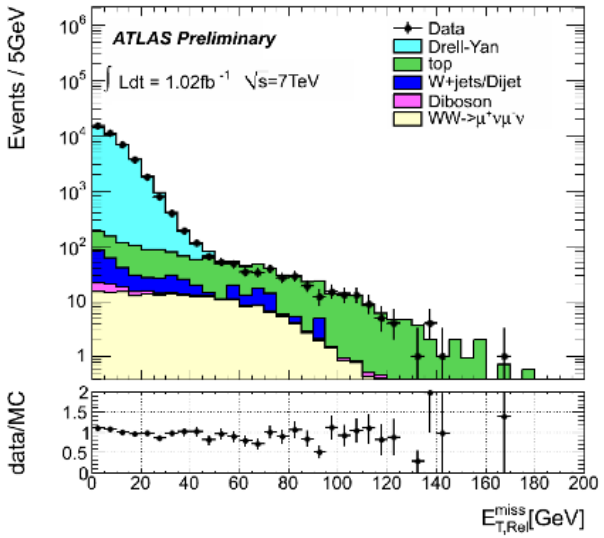
Sources	$e^+e^-E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu^+\mu^-E_{\mathrm{T}}^{\mathrm{miss}}$	$e^{\pm}\mu^{\mp}E_{\mathrm{T}}^{\mathrm{miss}}$
Luminosity	3.7%	3.7%	3.7%
Cross-section (theory)	5%	5%	5%
PDF	1.2%	1.4%	1.4%
Trigger	1.0%	1.0%	1.0%
Lepton p_T smearing	0.2%	0.1%	0.1%
Reco eff. scale factors	1.4%	0.0%	0.7%
E_T/p_T scale correction	0.9%	0.0%	0.4%
Particle ID eff. scale factors	3.3%	1.4%	1.6%
Isolation	4.0%	2.0%	3.0%
E_T^{miss} in-time contribution	3.5%	3.9%	1.4%
E_T^{miss} out-of-time contribution	0.5%	0.5%	0.3%
Jet-veto	4.8%	4.8%	4.8%
Total experimental uncertainty	8.1%	6.7%	6.2%
Overall uncertainty for WW signal estimation	10.3%	9.2%	8.9%

Table 3: Uncertainty sources and associated relative uncertainties for WW signal for the ee, $e\mu$ and $\mu\mu$ channels.

WW

- MET rel





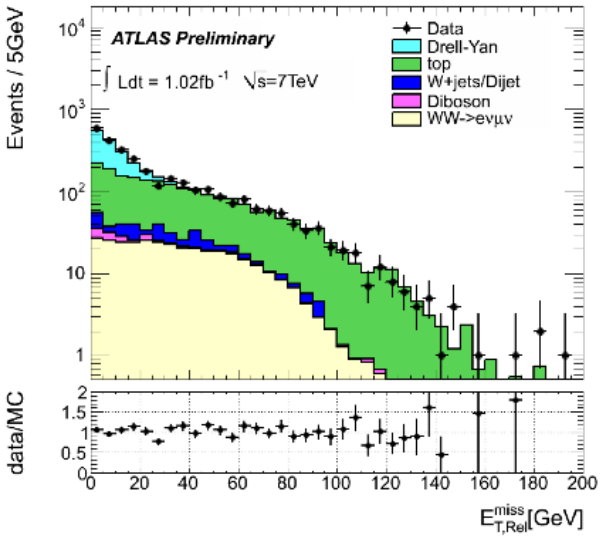


Figure 3: $E_{\mathrm{T,\,Rel}}^{\mathrm{miss}}$ distributions for the selected ee, $\mu\mu$ and $e\mu$ samples after the Z mass veto cut.

WZ

- Acceptance (incl taus)

Cut Sequence	Acceptance [%]
Muon or electron trigger	78.9 (78.9)
Primary Vertex	78.7 (99.8)
$\lvert m_{ll} - m_Z \rvert < 10$ GeV	28.2 (35.8)
Three leptons	12.3 (43.7)
$E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV	10.0 (81.2)
$M_{\mathrm{T}}^{W} > 20$ GeV	8.5 (84.9)
Trigger Match	8.4 (99.5)

WZ

- Details on backgrounds

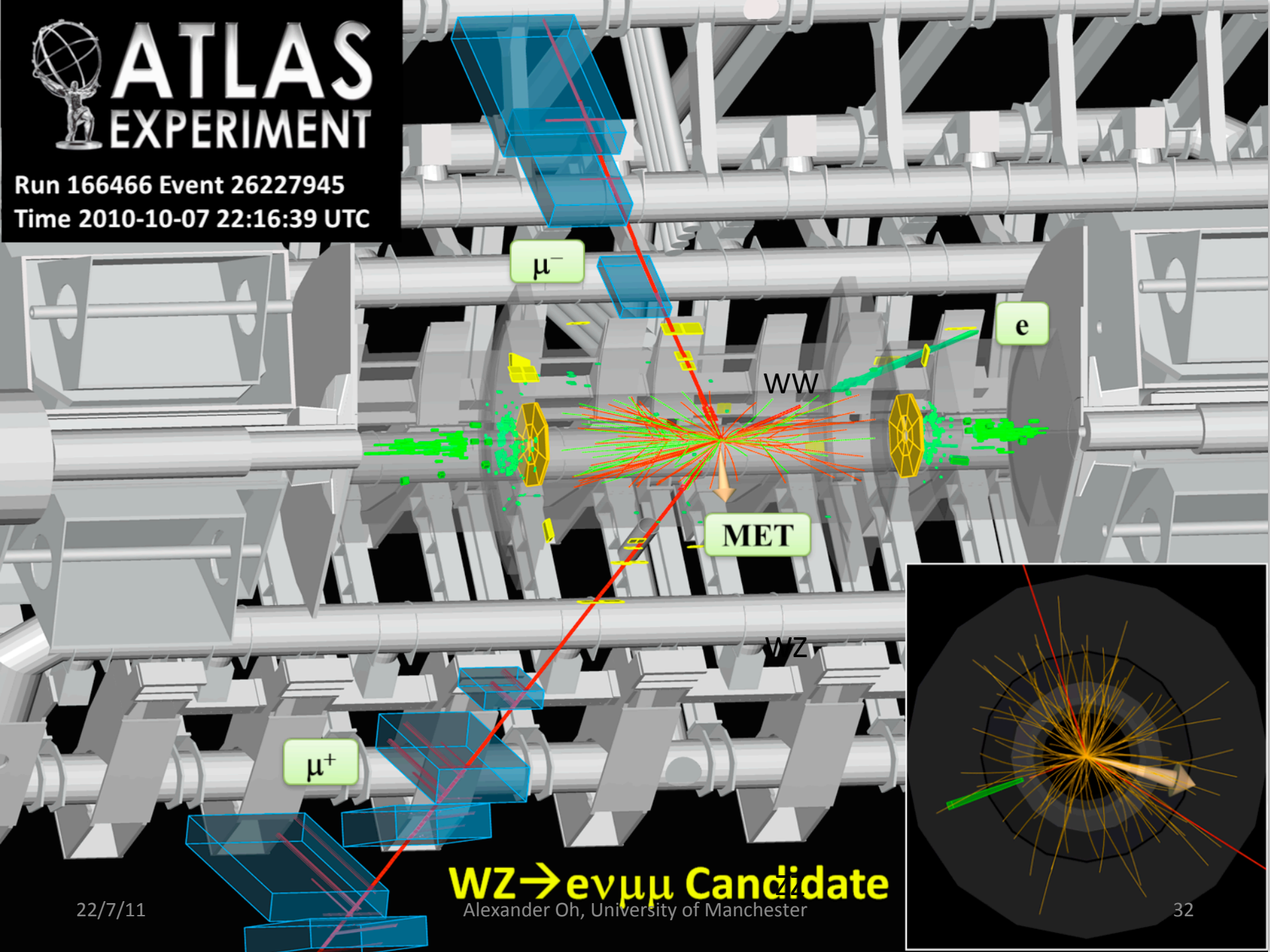
Final State	$eee + E_{\mathrm{T}}^{\mathrm{miss}}$	$ee\mu + E_{\mathrm{T}}^{\mathrm{miss}}$	$e\mu\mu + E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu\mu\mu + E_{\mathrm{T}}^{\mathrm{miss}}$	combined
Observed	11	9	22	29	71
ZZ	0.34±0.07	1.03±0.13	0.82±0.12	1.40±0.15	3.55±0.24±0.17
W/Z+jets	2.03±0.38	0.64±0.18	2.03±0.38	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

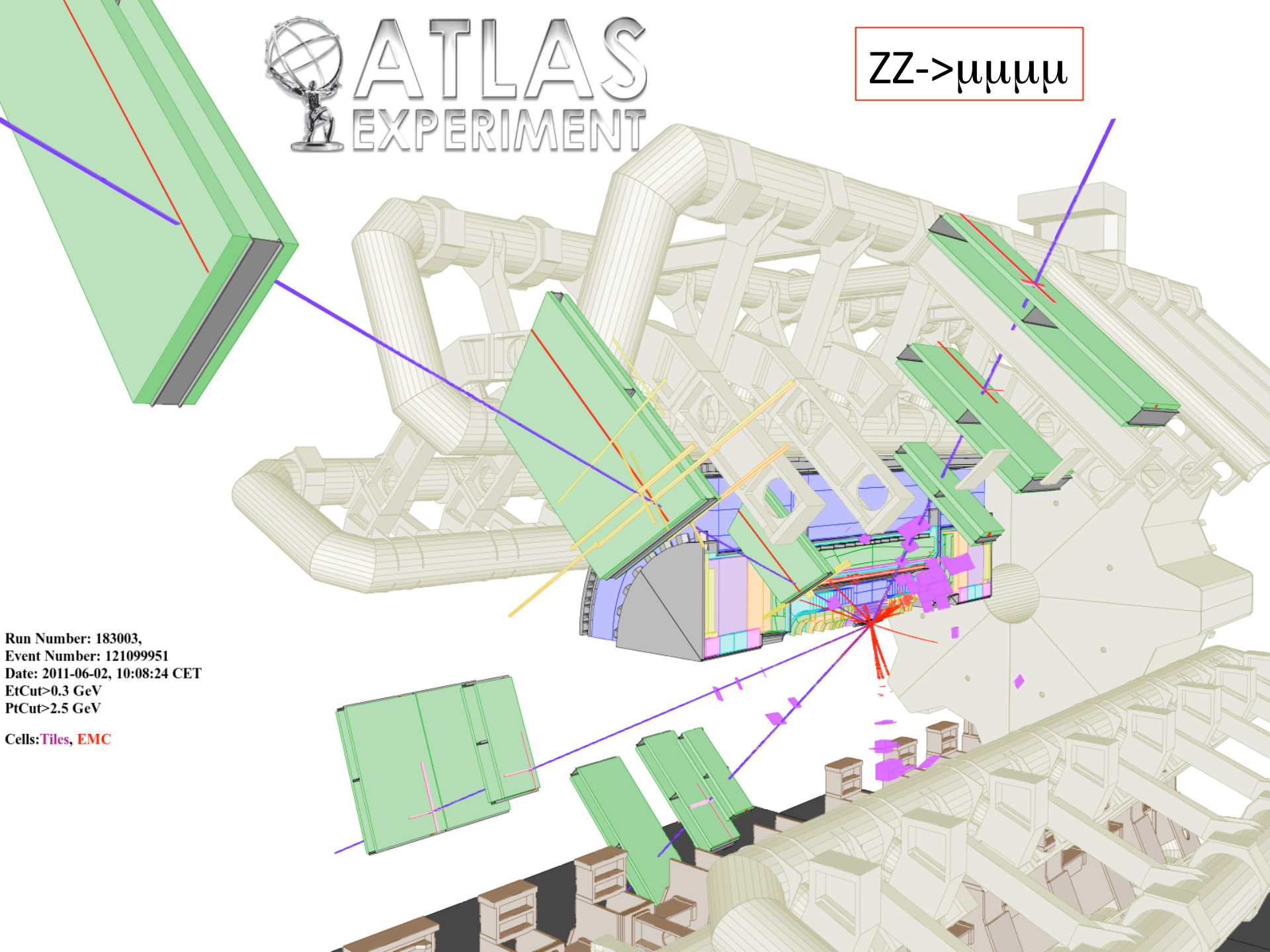
ZZ

- Acceptance (within fiducial volume)

Channels	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell^+\ell^-$
Cuts	$N_{ZZ}/C_{ZZ}(\%)$	$N_{ZZ}/C_{ZZ}(\%)$	$N_{ZZ}/C_{ZZ}(\%)$	$N_{ZZ}/C_{ZZ}(\%)$
Four leptons	1.84 / 49	3.61 / 94	5.3 / 67	11 / 69
Trigger Match	1.83 / 49	3.60 / 94	5.3 / 67	11 / 69
Two pairs	1.78 / 47	3.60 / 94	5.1 / 66	11/ 68
Mass cut on leading Z	1.68 / 45	3.33 / 87	4.8 / 61	9.8 / 64
Mass cut on subleading Z	1.57 / 41	3.09 / 81	4.5 / 57	9.1 / 59

Table 1: Expected number of events N_{ZZ} and reconstruction efficiency $C_{ZZ}(\%)$ after different selection steps for $ZZ \rightarrow \ell^+\ell^-\ell^+\ell^-$ normalized to $\mathcal{L}$=1.02 fb^{-1}. The lower signal expectation in the $e^+e^-e^+e^-$channel compared with the $\mu^+\mu^-\mu^+\mu^-$ channel reflects the lower electron identification efficiency.


ATLAS
EXPERIMENT
Run 166466 Event 26227945
Time 2010-10-07 22:16:39 UTC
μ⁻
e
WW
MET
WZ
μ⁺
WZ→eνμμ Candidate


ATLAS
EXPERIMENT
ZZ->μμμμ
Run Number: 183003,
Event Number: 121099951
Date: 2011-06-02, 10:08:24 CET
EtCut>0.3 GeV
PtCut>2.5 GeV
Cells:Tiles, EMC