Diboson Production and Anomalous Triple Gauge Couplings in ATLAS

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Brookhaven National Lab
Brookhaven Forum 2011: A First Glimpse of the Tera Scale

Outline

Motivations

Standard Model Diboson Cross-section

- Wγ/Zγ JHEP 09 (2011) 072
- WW ATLAS-CONF-2011-110
- WZ ATLAS-CONF-2011-099
- ZZ ATLAS-CONF-2011-107

2010 35 pb^{-1}

2011 1 fb^{-1}

Diboson searches

- ZZ ATLAS-CONF-2011-144

New

Summary

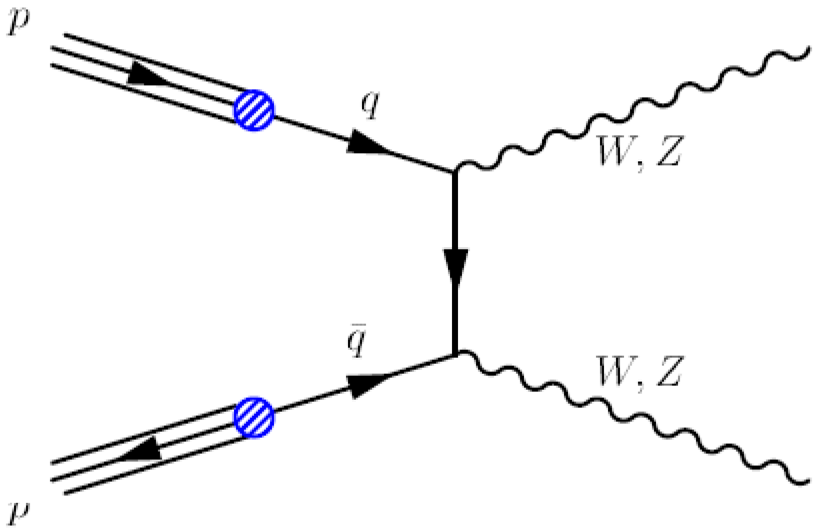
The Standard Model Diboson Production

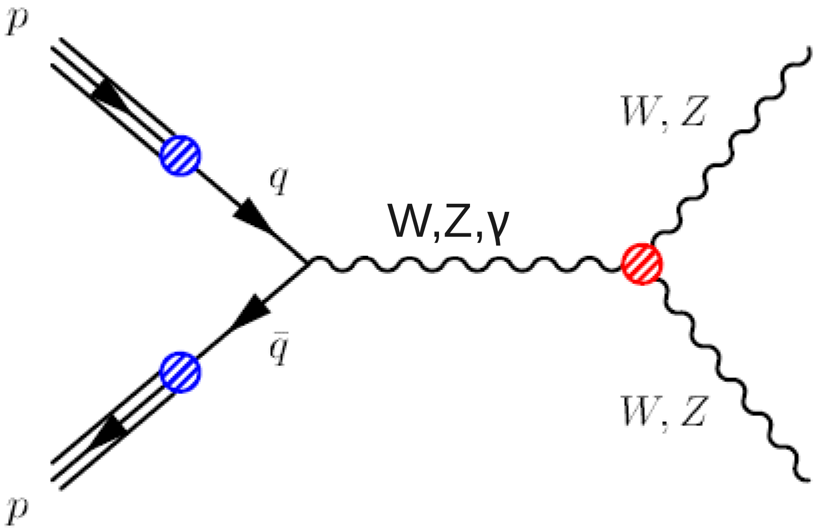
Signature

Associated production of two gauge bosons of electroweak interactions.

Foundation for later work

- Precision test of the standard model in self-coupling
- Charged Triple Gauge Couplings (TGC) in the W/Z sectors





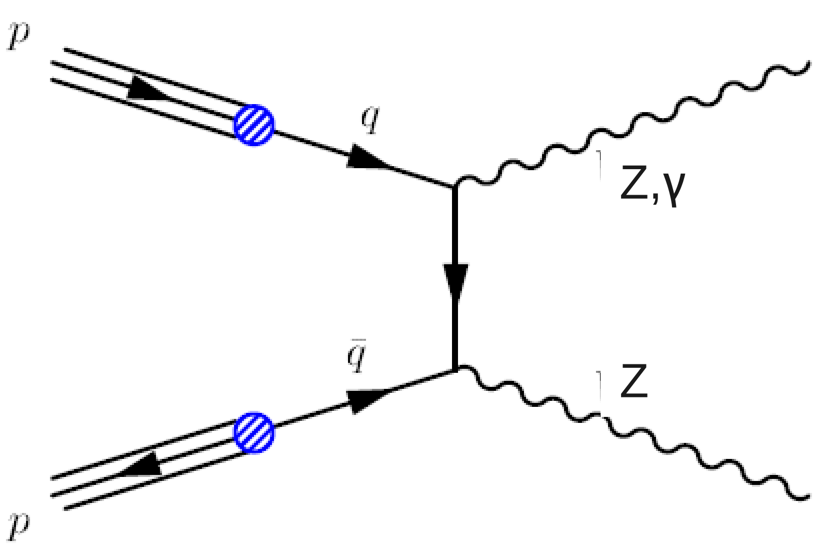
The Standard Model Diboson Production

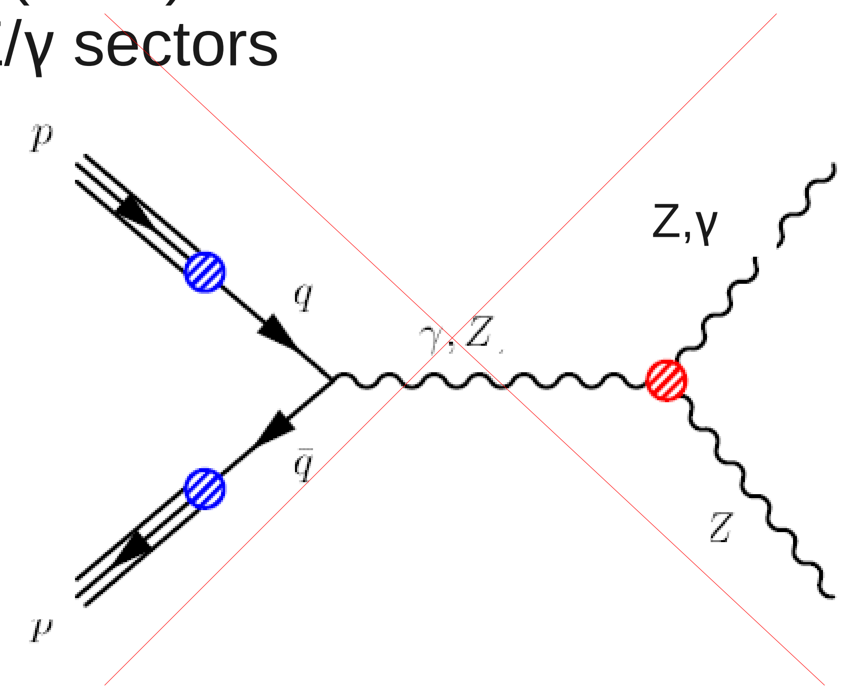
Signature

Associated production of two gauge bosons of electroweak interactions.

Foundation for later work

- Precision test of the standard model in self-coupling
- Charged Triple Gauge Couplings (TGC) in the W/Z sectors
- Anomalous Neutral TGC in the Z/γ sectors

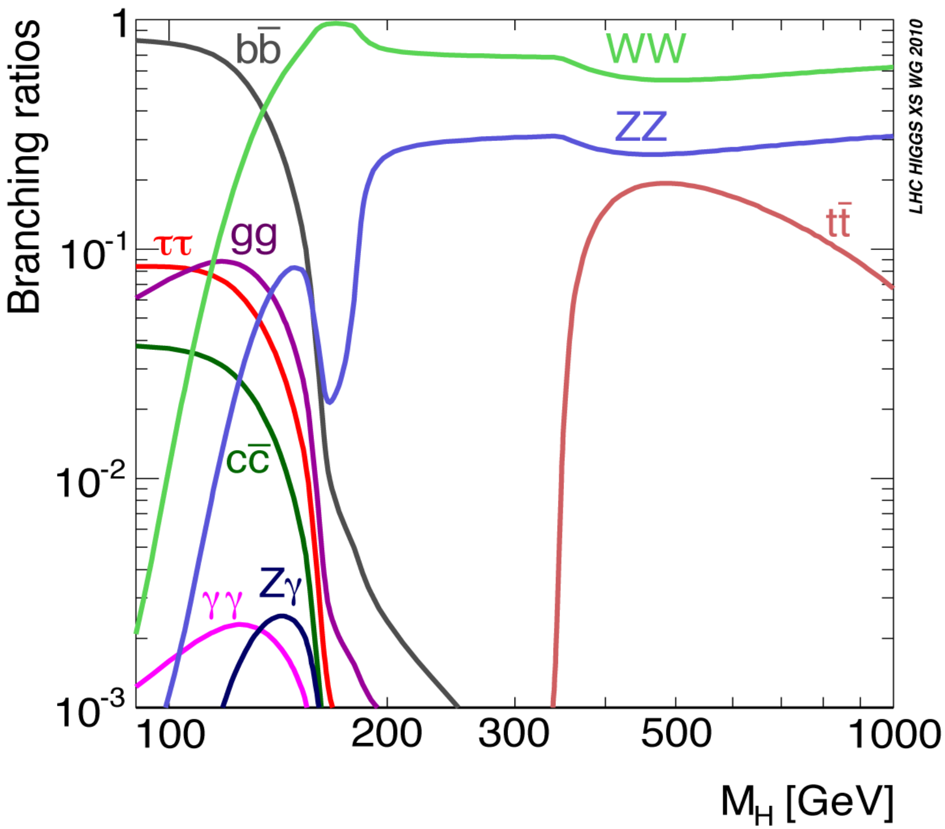


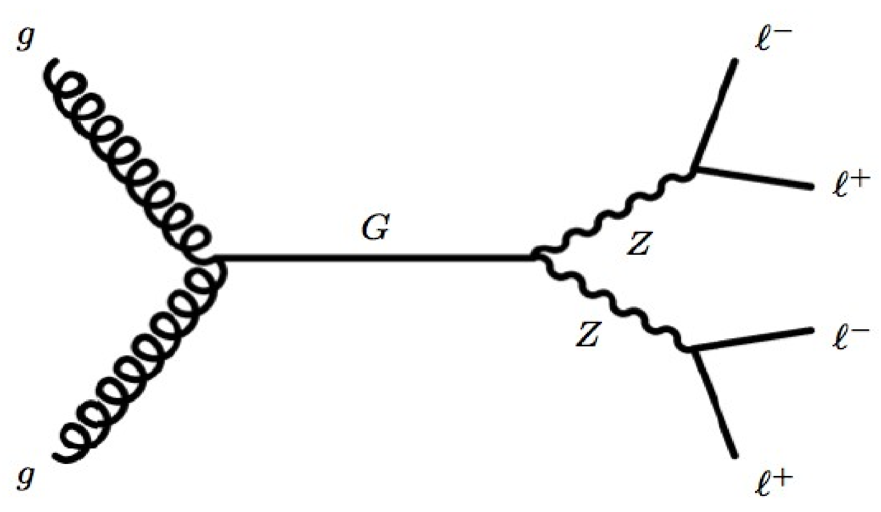


ZZZ/ZZγ are forbidden in the SM

Diboson is crucial for Higgs/BSM search

- **Primary search channel in a wide Higgs mass range**
  see Tae Ming Hong's talk on Oct 20
- **Unique signature/important background in Beyond the Standard Model search**
  Technicolor, Extra Dimension, SUSY





Fitzpatrick, et. al., JHEP0709, 013 (2007)
Agashe, et. al. PRD 76. 036006 (2007)

Cross-section Measurement

Fiducial cross-section:

Define efficiency in selected region

C_{ZZ}=N(reconstructed)/N(truth in fiducial)

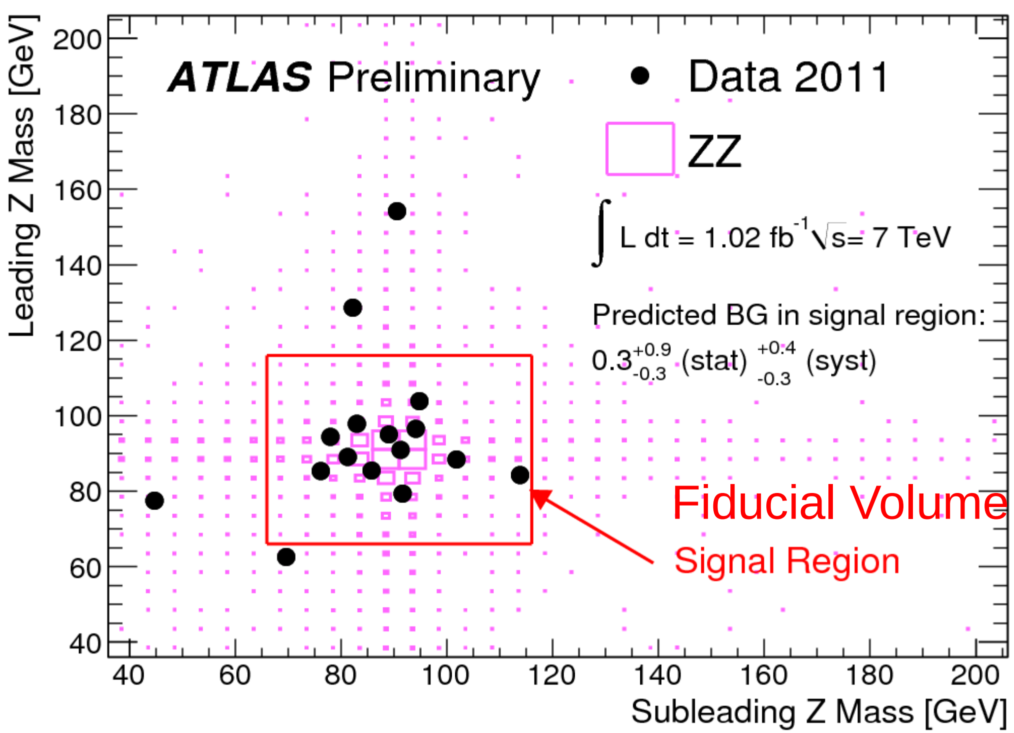
$$\frac{N_{obs} - N_{bkg}}{C_{ZZ} BR(ZZ \to e, \mu) L}$$

Total cross-section:

Extrapolation to full cross-section

A_{ZZ} = N(truth in fiducial)/ N(Total)

$$\frac{N_{obs} - N_{bkg}}{A_{ZZ} C_{ZZ} BR(ZZ \to e, \mu) L}$$

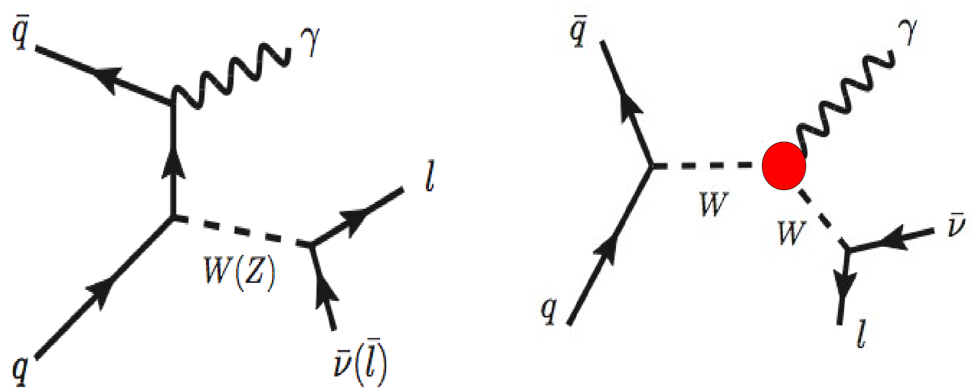


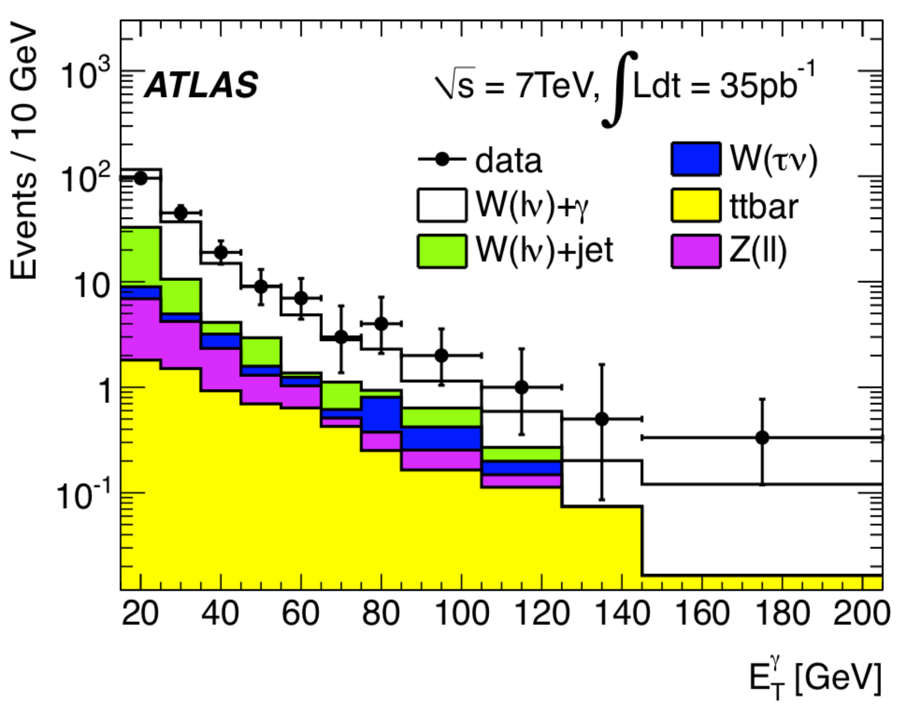
Wγ/Zγ Production

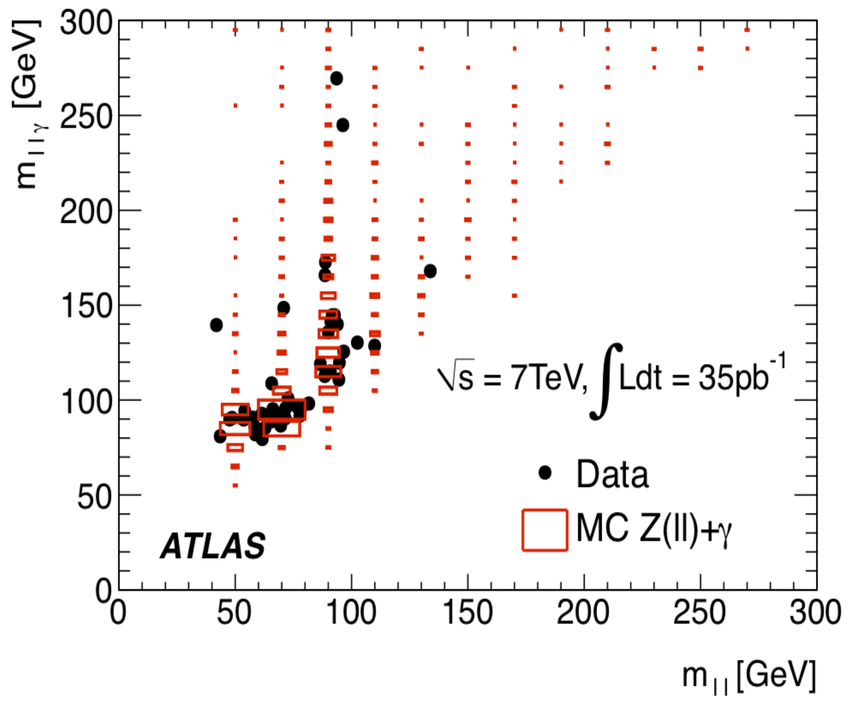
2010 35 pb^{-1}

Signature

Wγ: one lepton + one photon
and large Met
Zγ: two lepton + one photon
Lepton pT> 20 GeV
photon pT> 15 GeV
MET > 25 GeV
dR(l,photon) >0.7





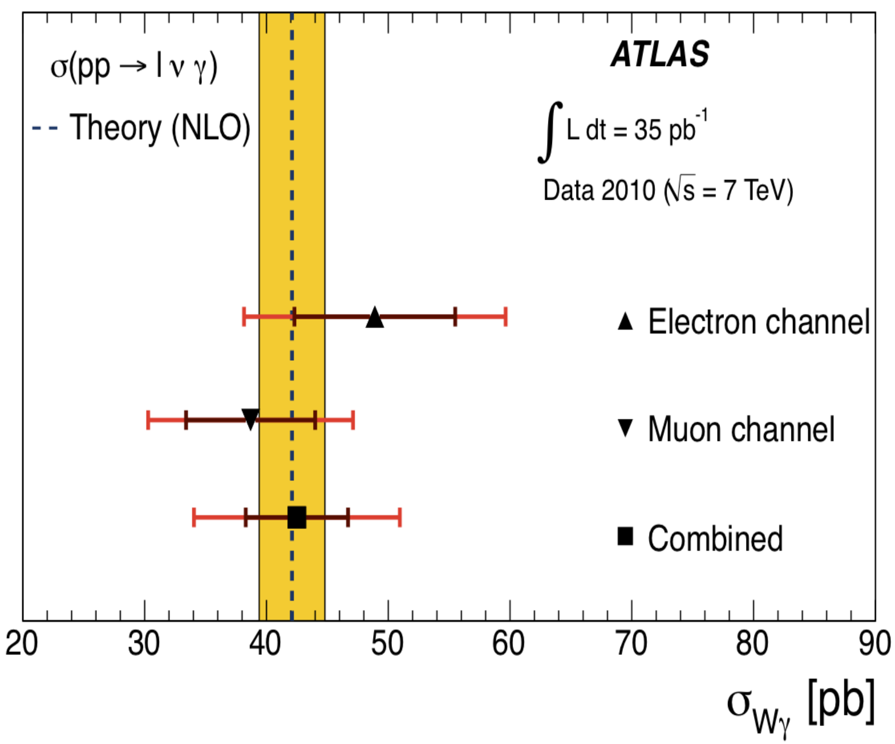


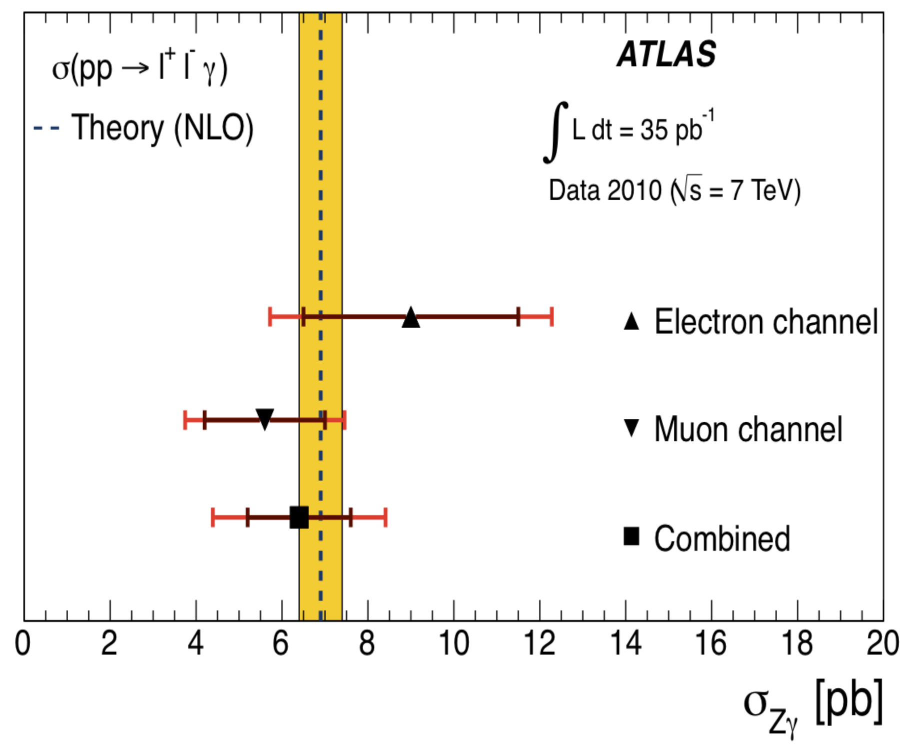
Wγ/Zγ Results Summary

2010 35 pb^{-1}

All measurements are consistent with SM expectations

Process	Observed events	EW+$t\bar{t}$ background	W+jets background	Extracted signal
$N_{obs}(W\gamma \rightarrow e^{\pm}\nu\gamma)$	95	$10.3 \pm 0.9 \pm 0.7$	$16.9 \pm 5.3 \pm 7.3$	$67.8 \pm 9.2 \pm 7.3$
$N_{obs}(W\gamma \rightarrow \mu^{\pm}\nu\gamma)$	97	$11.9 \pm 0.8 \pm 0.8$	$16.9 \pm 5.3 \pm 7.4$	$68.2 \pm 9.3 \pm 7.4$
Process	Observed events	EW+$t\bar{t}$ background		Extracted signal
$N_{obs}(Z\gamma \rightarrow e^{+}e^{-}\gamma)$	25	3.7 ± 3.7		$21.3 \pm 5.8 \pm 3.7$
$N_{obs}(Z\gamma \rightarrow \mu^{+}\mu^{-}\gamma)$	23	3.3 ± 3.3		$19.7 \pm 4.8 \pm 3.3$

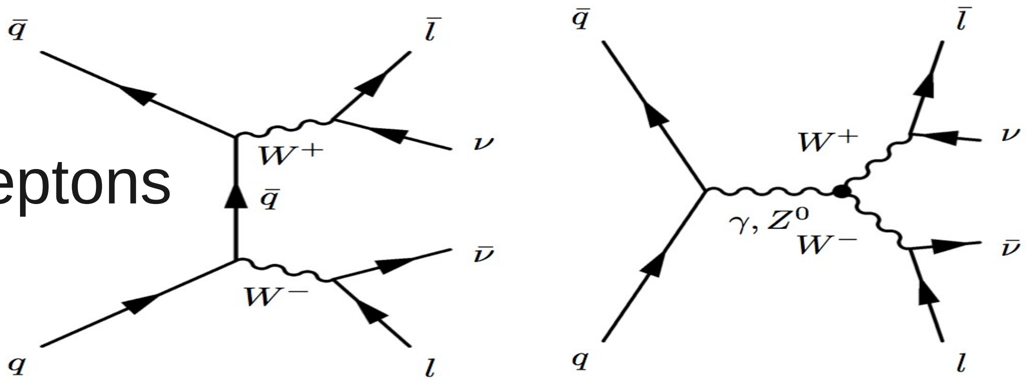


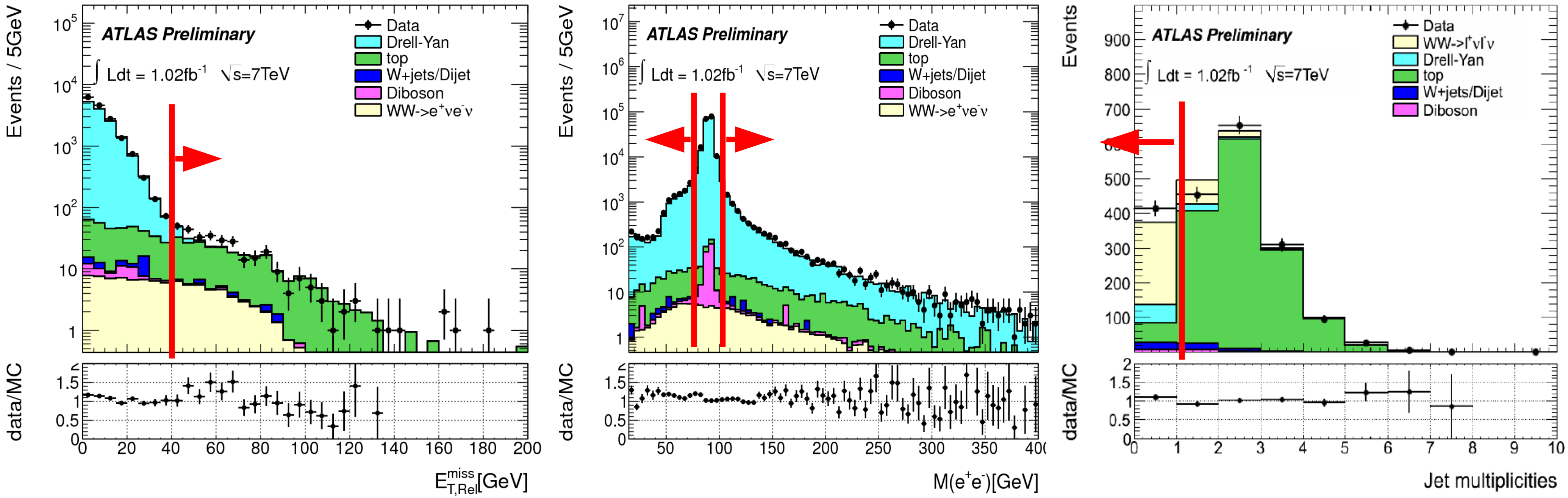


WW Production

Signature

- Two opposite signed isolated leptons (p_T threshold 25,20 GeV)
- large missing Et
- Z veto and 0 jet





WW Results

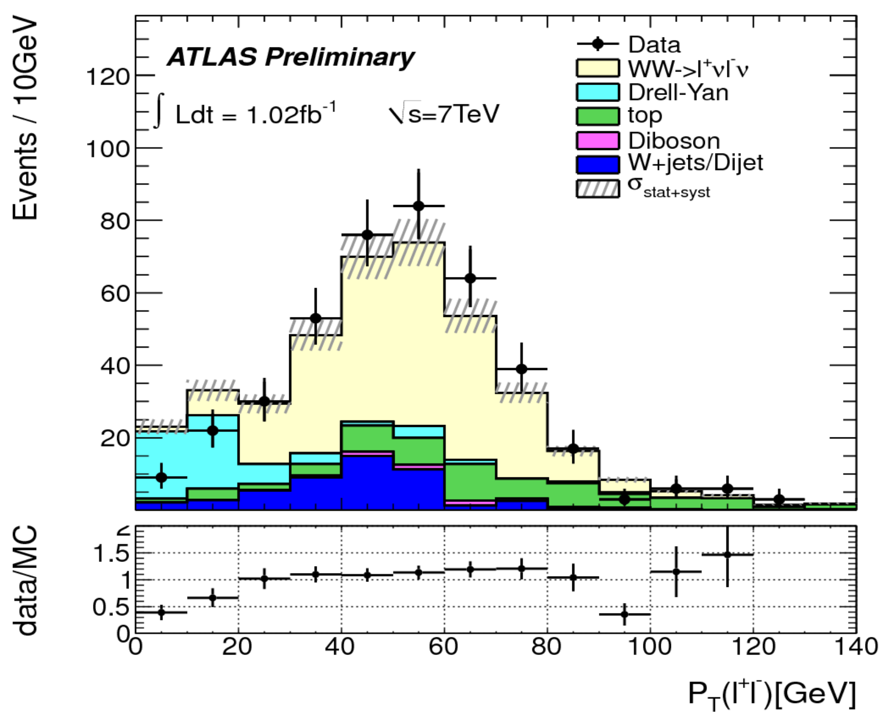
Observation: 414 candidates with background $169.8 \pm 6.4 \pm 27.1$

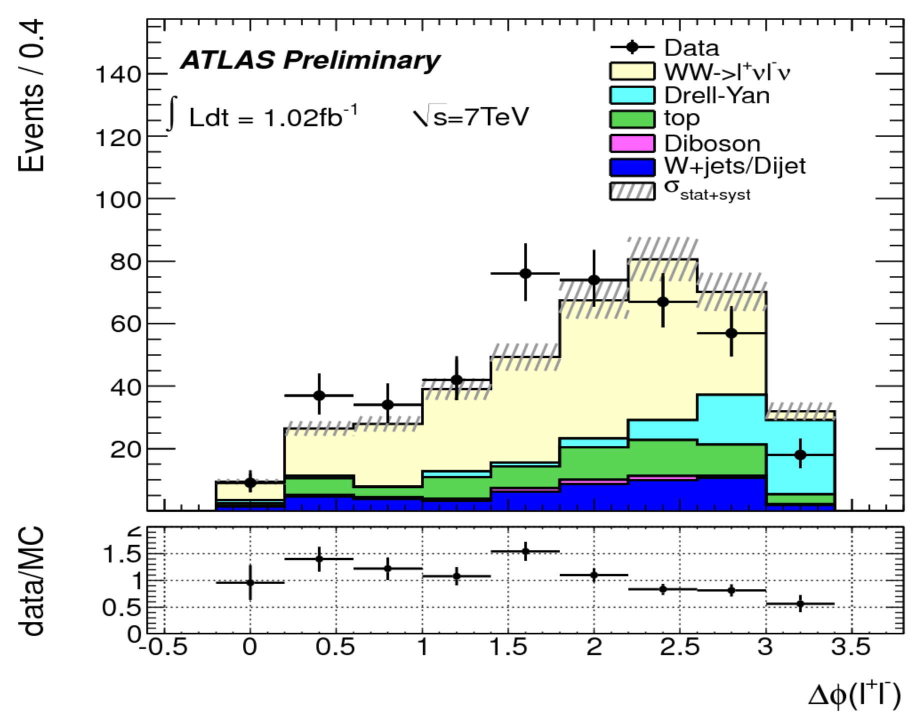
Fiducial Cross-section results

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 results consistent to NLO (46±3 pb)

$$\sigma_{total} = 48.2 \pm 4.0(\mathrm{stat}) \pm 6.4(\mathrm{sys}) \pm 1.8(\mathrm{lumi})\ \mathrm{pb}$$

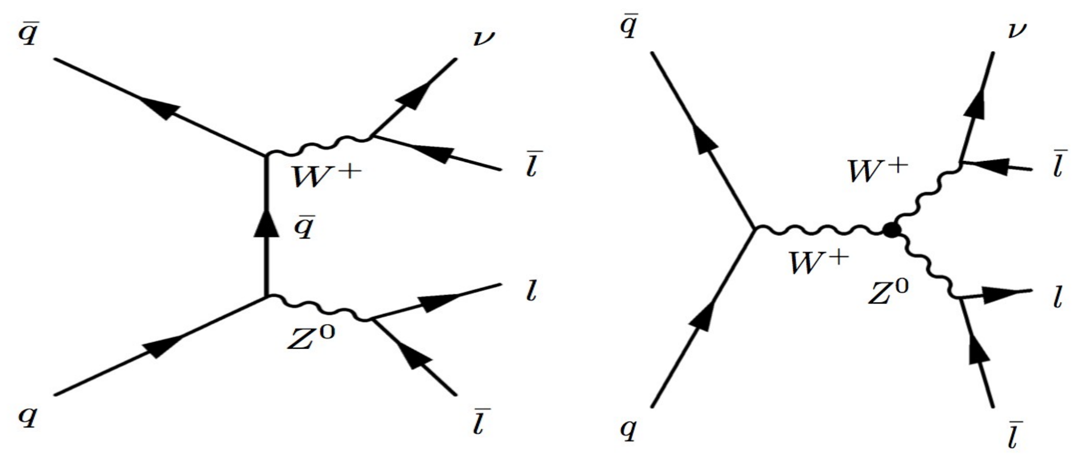


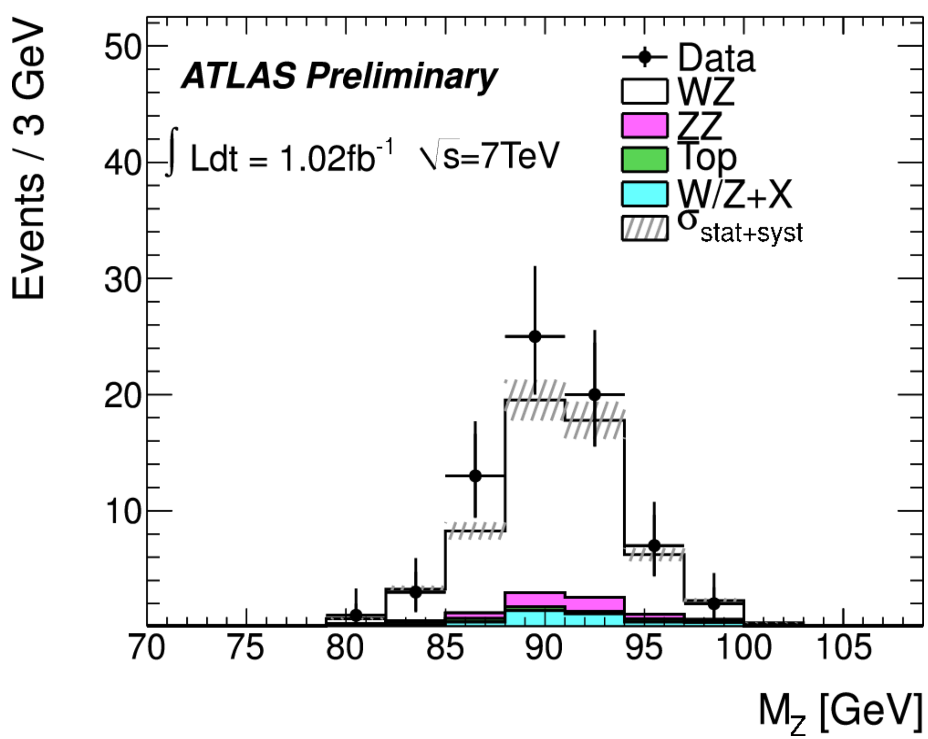


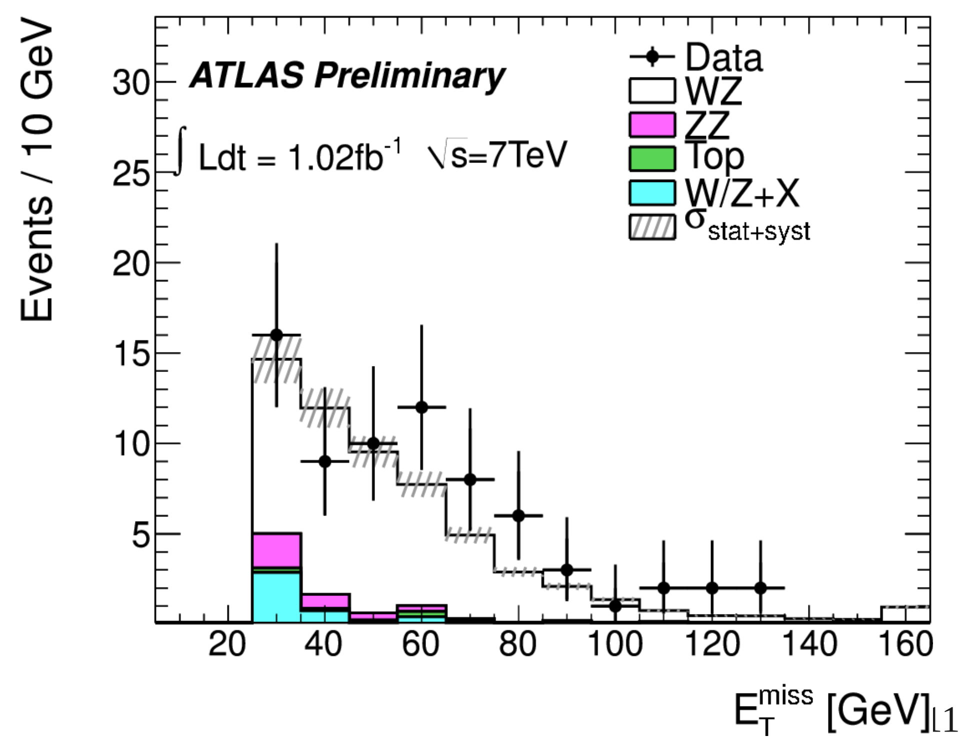
WZ Production

Signature

Three isolated leptons
(p_T threshold 20, 15 GeV)
One Opposite Signed Z pair
missing E_T > 25 GeV







WZ Results

Observation: 71 candidates with background $10.5 \pm 0.8^{+2.9}_{-2.1}$

Fiducial Cross-section

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

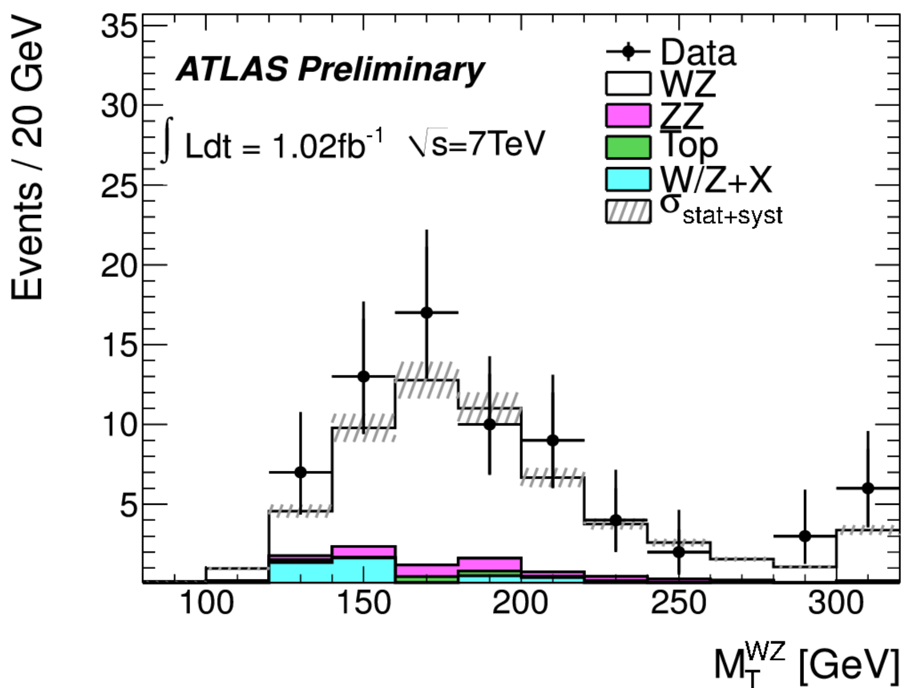
Fiducial Cross section:

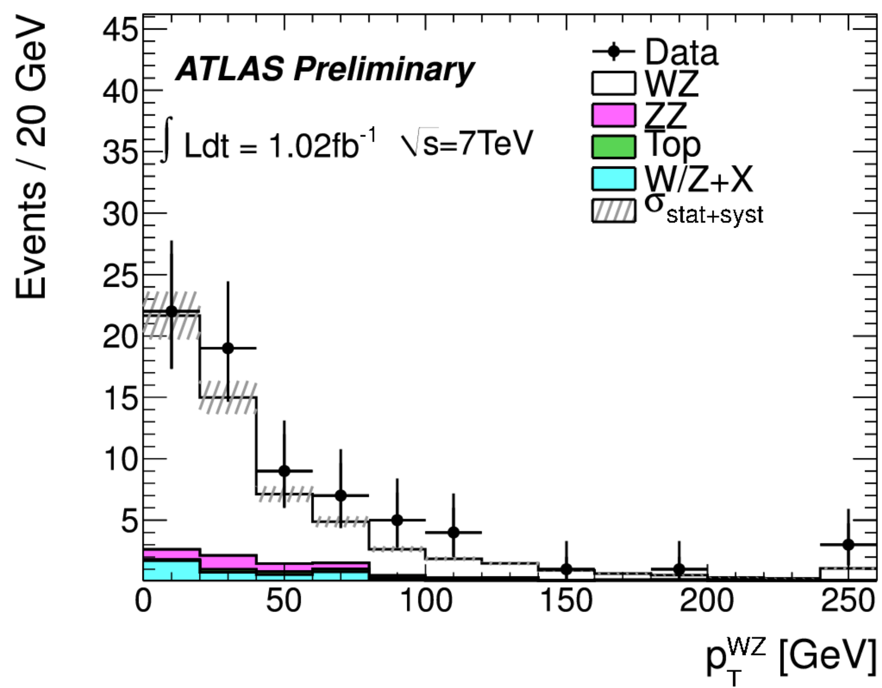
- $p_T(l) > 15$ GeV, $|\eta| < 2.5$, $pT(\nu) > 25$ GeV
- $M(ll) - M_Z < 10$ GeV
- $M_T(W) > 20$ GeV

Total Cross-section

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

Consistent to NLO 17.2 ± 1 pb

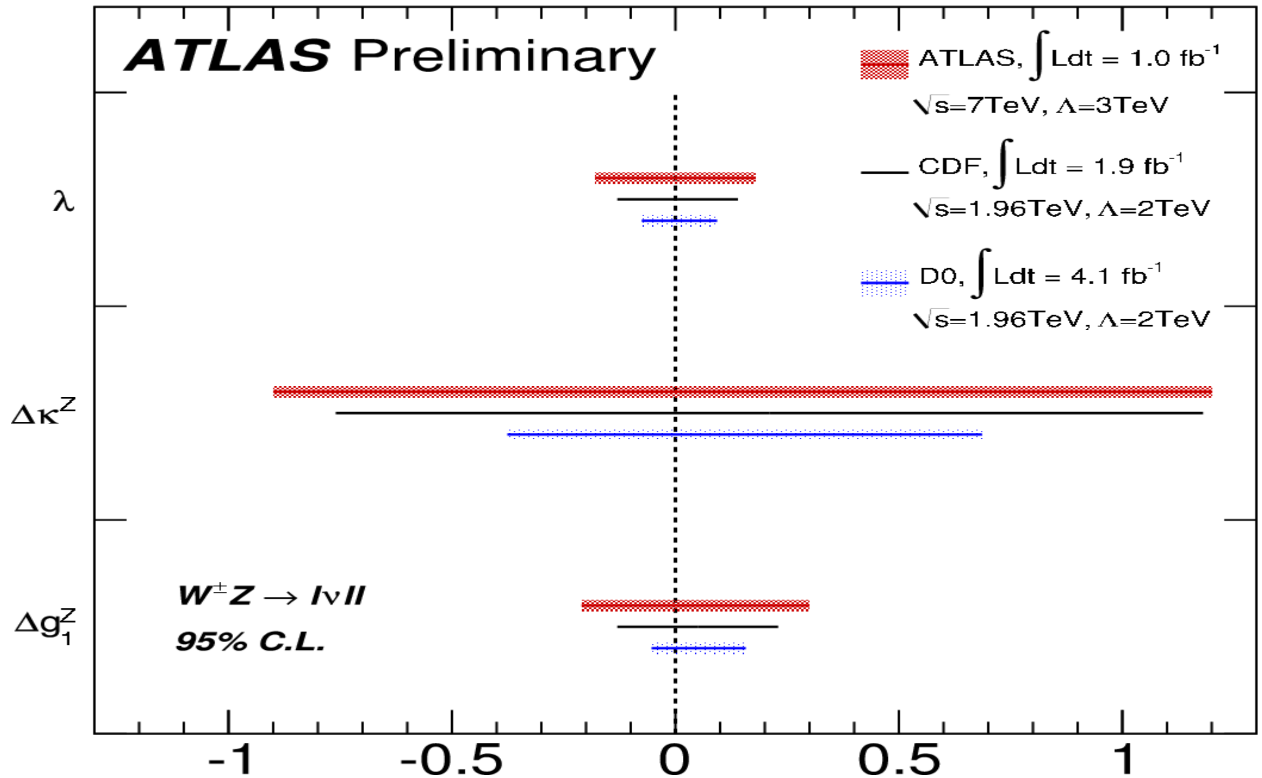




no

Anomalous Triple Gauge Coupling in WZ

The first aTGC results in WZ production at LHC
Results are competitive to previous experiments

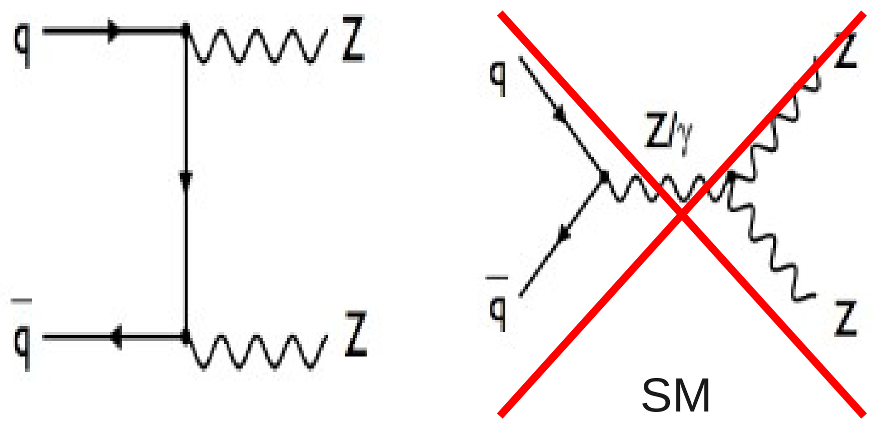


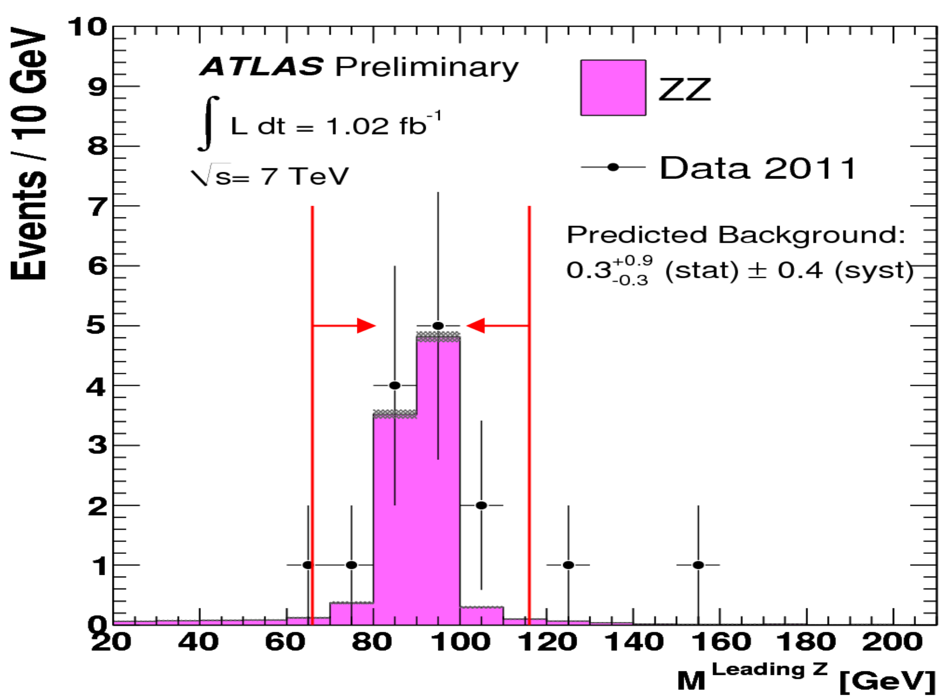
Anomalous Coupling	Limits of the 68% C.I.	Limits of the 95% C.I.
Δg_1^Z	$[-0.17, -0.05]$, $[0.13, 0.26]$	$[-0.21, 0.30]$
$\Delta\kappa^Z$	$[-0.8, -0.2]$, $[0.5, 1.0]$	$[-0.9, 1.2]$
λ	$[-0.15, -0.06]$, $[0.06, 0.15]$	$[-0.18, 0.18]$

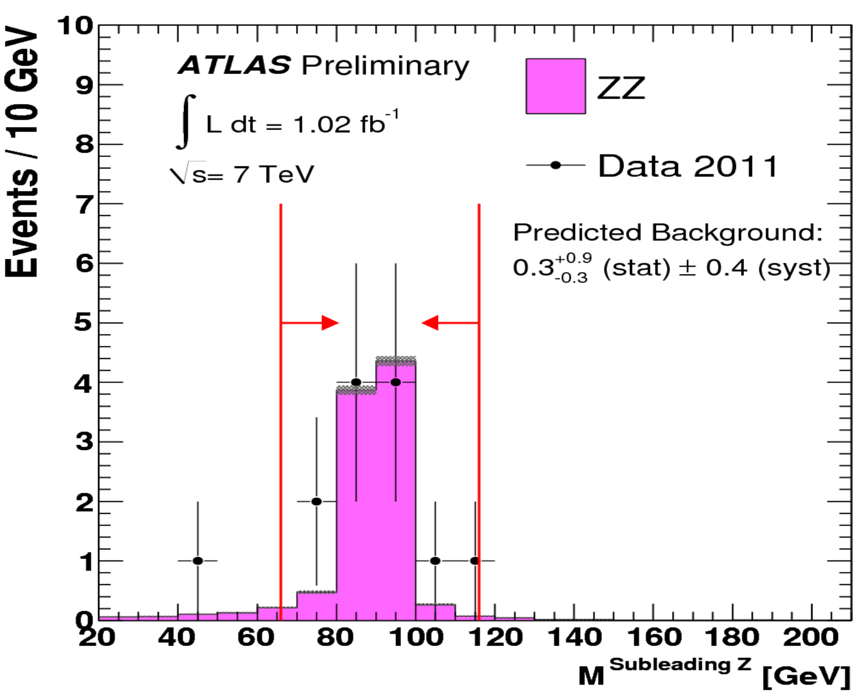
ZZ Production

Signature

Four isolated charged leptons
(p_T threshold 25, 15 GeV)
Z mass window requirement







Footnote: Z in this talk refers to Z/γ*

Cross-Section Results

Observation: 12 candidates with background $0.3^{+0.9+0.4}_{-0.3-0.3}$

Fiducial cross-section results

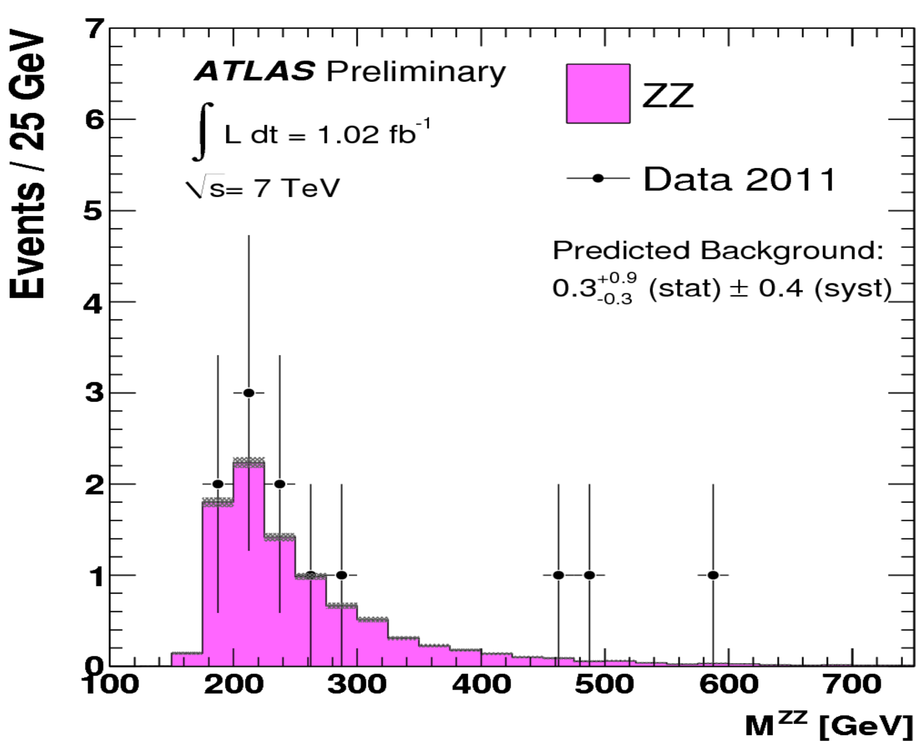
$$\sigma^{\mathrm{fid}}_{ZZ\to\ell^+\ell^-\ell^+\ell^-} = 19^{+6}_{-5}\,(\mathrm{stat})\,^{+1}_{-2}\,(\mathrm{syst})\ \pm 1\,(\mathrm{lumi})\ \mathrm{fb}$$

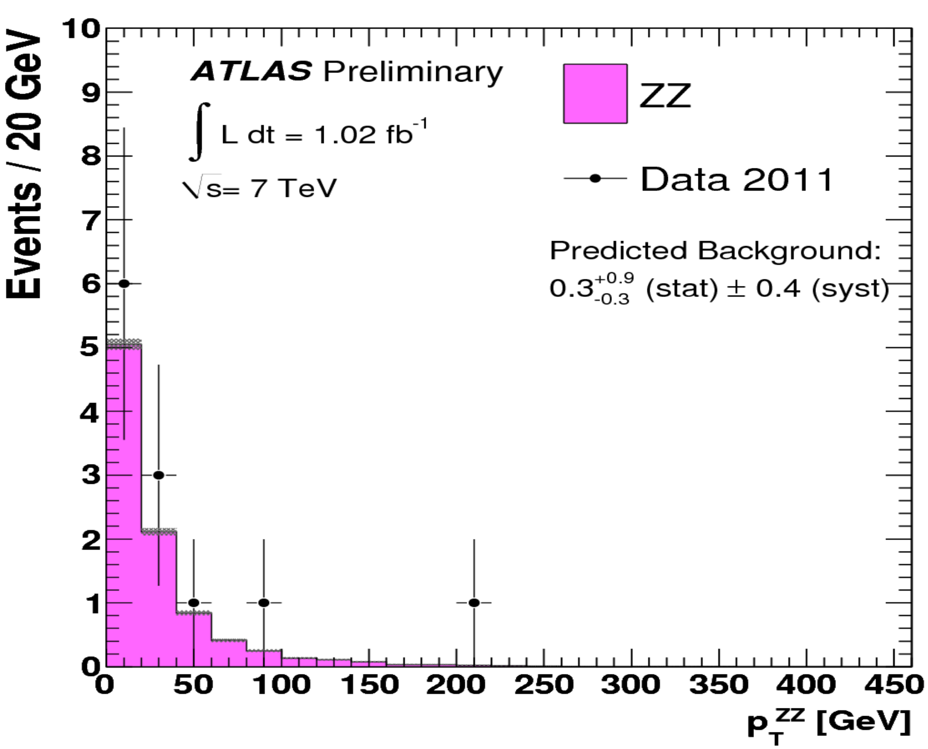
- $(Z/\gamma^*)(Z/\gamma^*)\to\ell^+\ell^-\ell^+\ell^-,\ \ell = e,\mu;$
- $|m(Z/\gamma*) - m_{\mathrm{PDG}}(Z)| < 25$ GeV;
- $p_T^\ell > 15$ GeV;

Total cross-section

$$\sigma^{\mathrm{tot}}_{ZZ} = 8.4^{+2.7}_{-2.3}\,(\mathrm{stat})\,^{+0.4}_{-0.7}\,(\mathrm{syst})\ \pm 0.3\,(\mathrm{lumi})\ \mathrm{pb}.$$

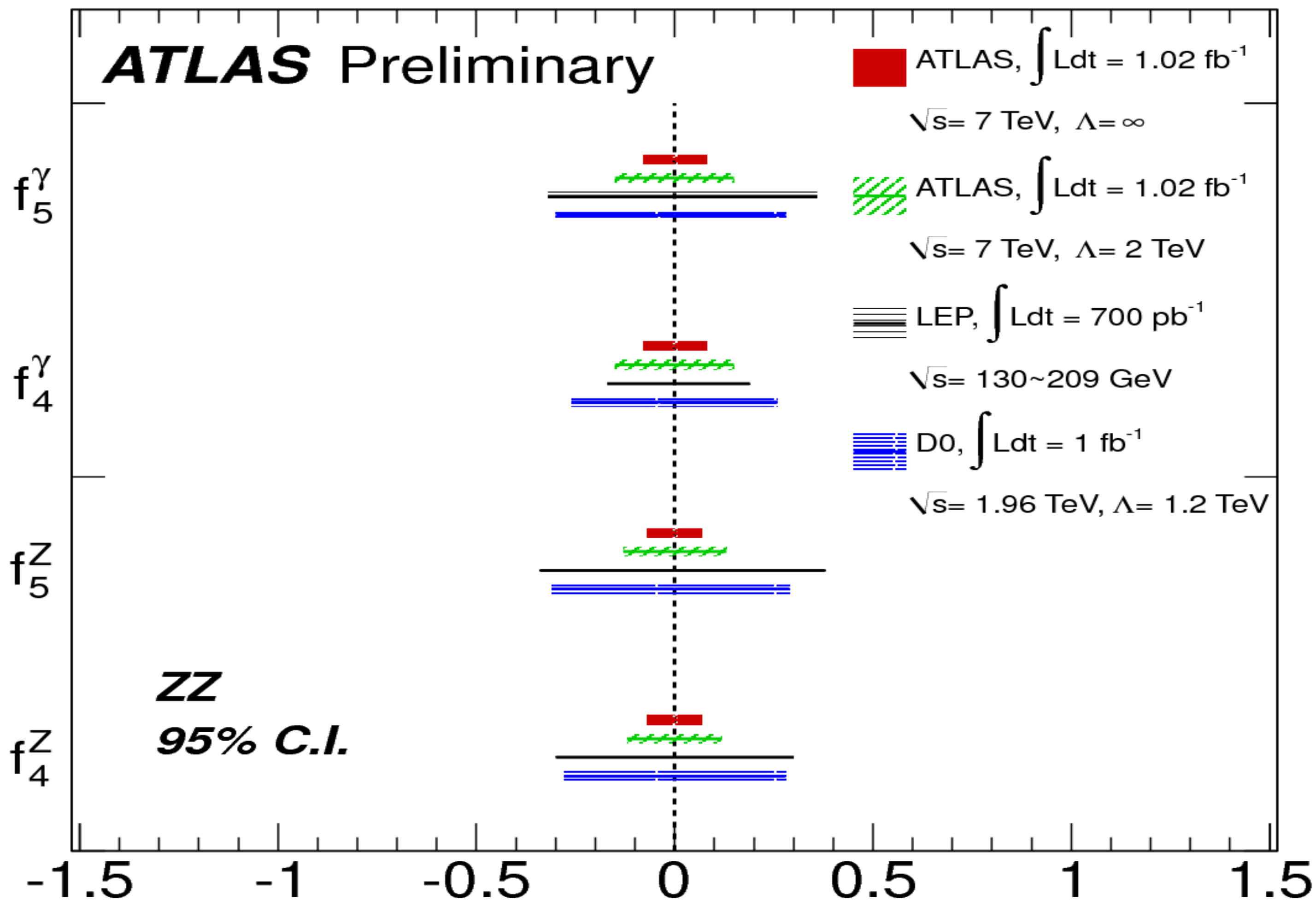
Consistent to NLO: Xsec (NLO) = $6.5^{+0.4}_{-0.3}$ pb





nTGC Results Comparisons

First neutral TGC results in 7 TeV pp collisions.
The best limits with higher energy cut-off Λ



ZZ Resonance Search

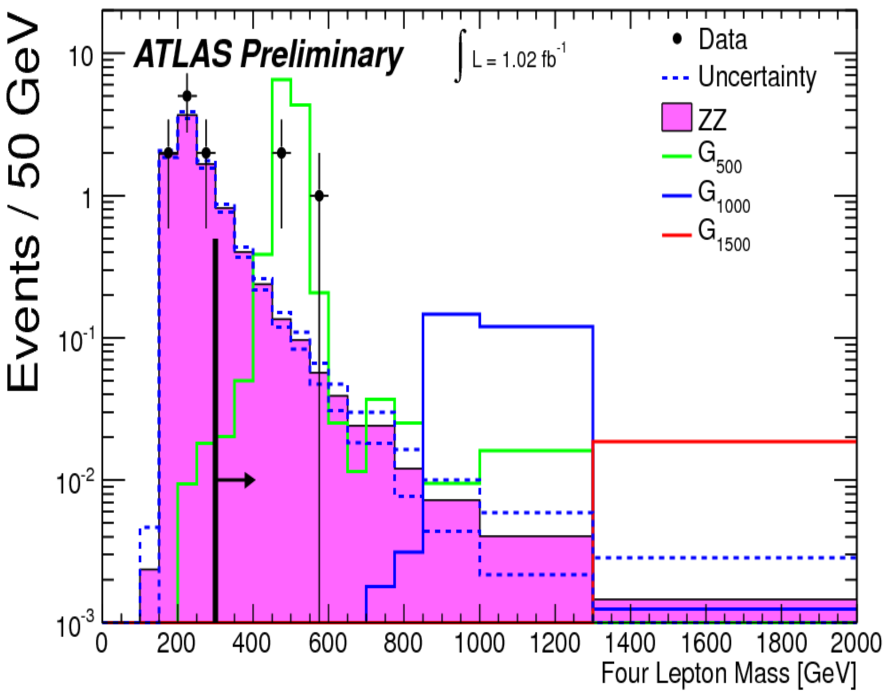
ZZ to four lepton Fiducial cross-section limit

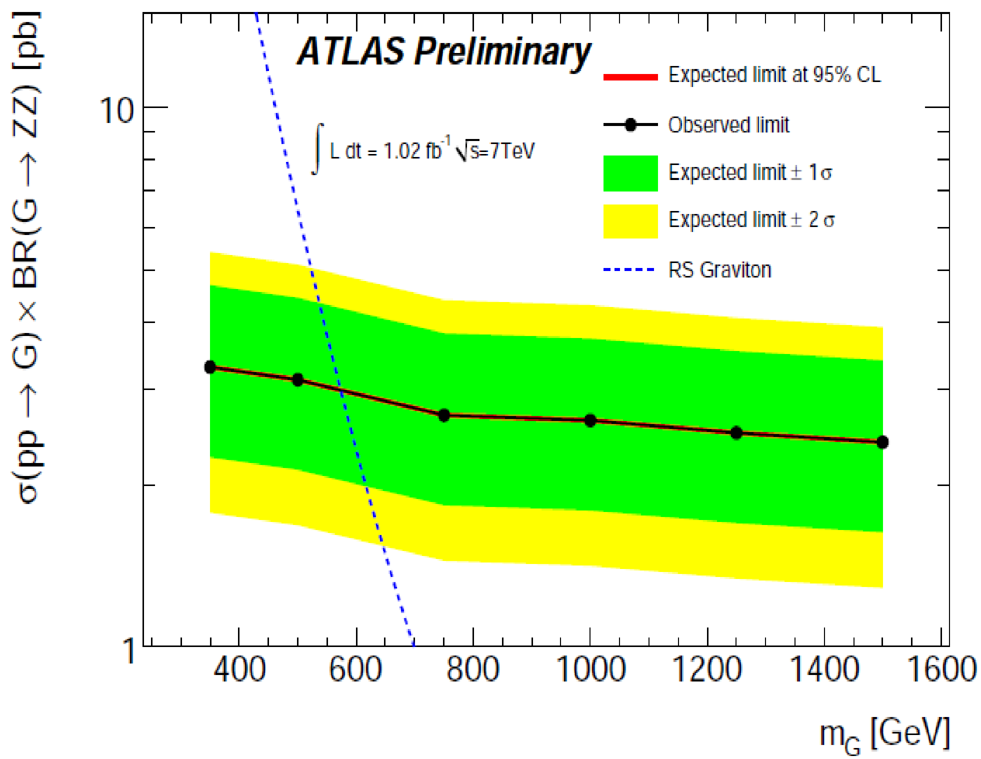
$$\sigma_{ZZ\ \mathrm{fid}} < \frac{N_{ZZ}}{\epsilon_{ZZ} \times BF(ZZ \to \ell\ell\ell\ell) \times \mathcal{L}} = \frac{5.7}{0.61 \times 0.010 \times 1.02\ \mathrm{fb}^{-1}} = 0.92\ \mathrm{pb}$$

Fiducial Cross section:

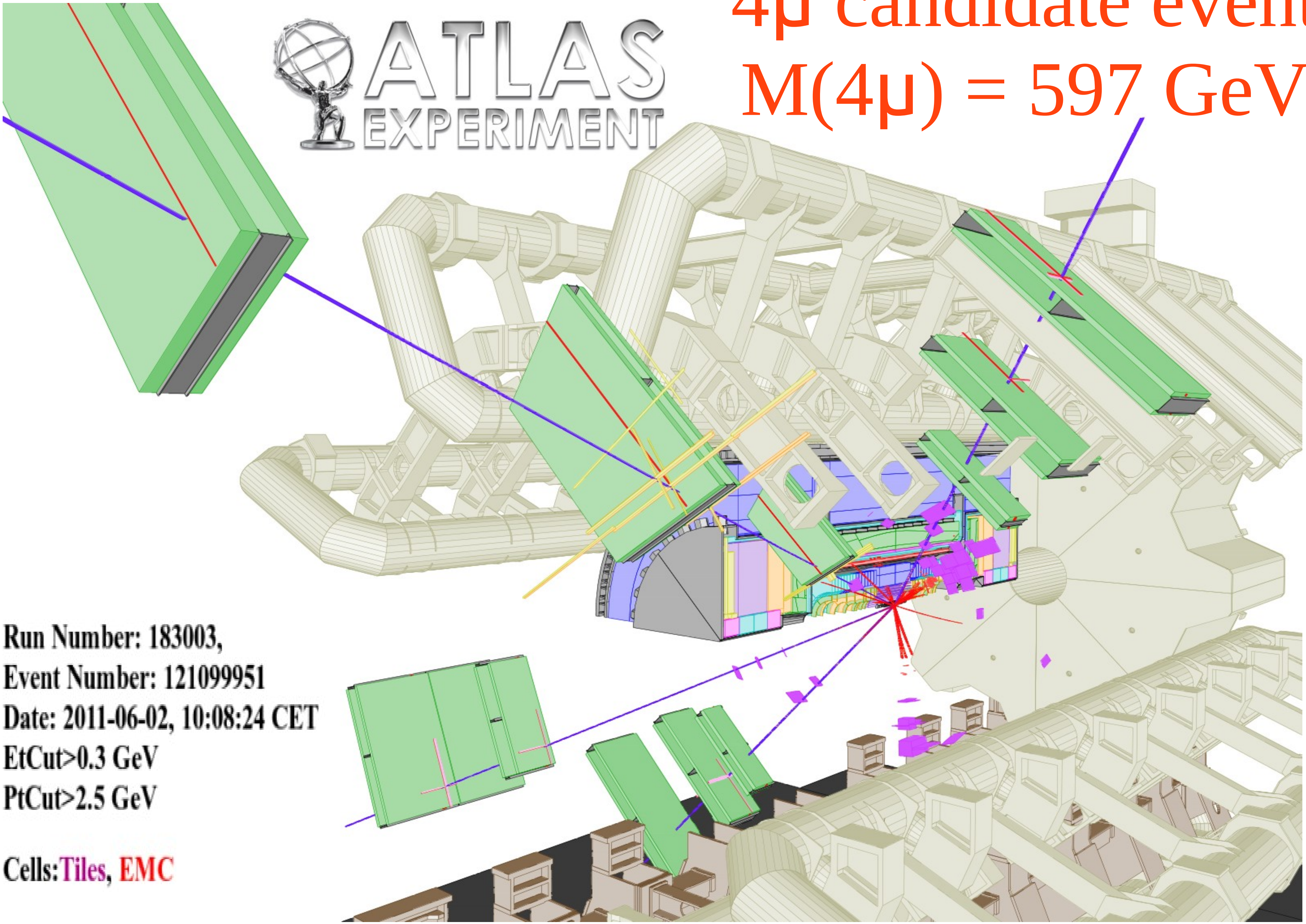
- $p_T(l) > 15$ GeV, $|\eta| < 2.5$, $pT(\nu) > 25$ GeV
- $M(ll)-M_Z < 10$ GeV
- $M_T(W) > 20$ GeV
- $M(4l) > 300$ GeV

Benchmark RS Graviton





4μ candidate event
M(4μ) = 597 GeV

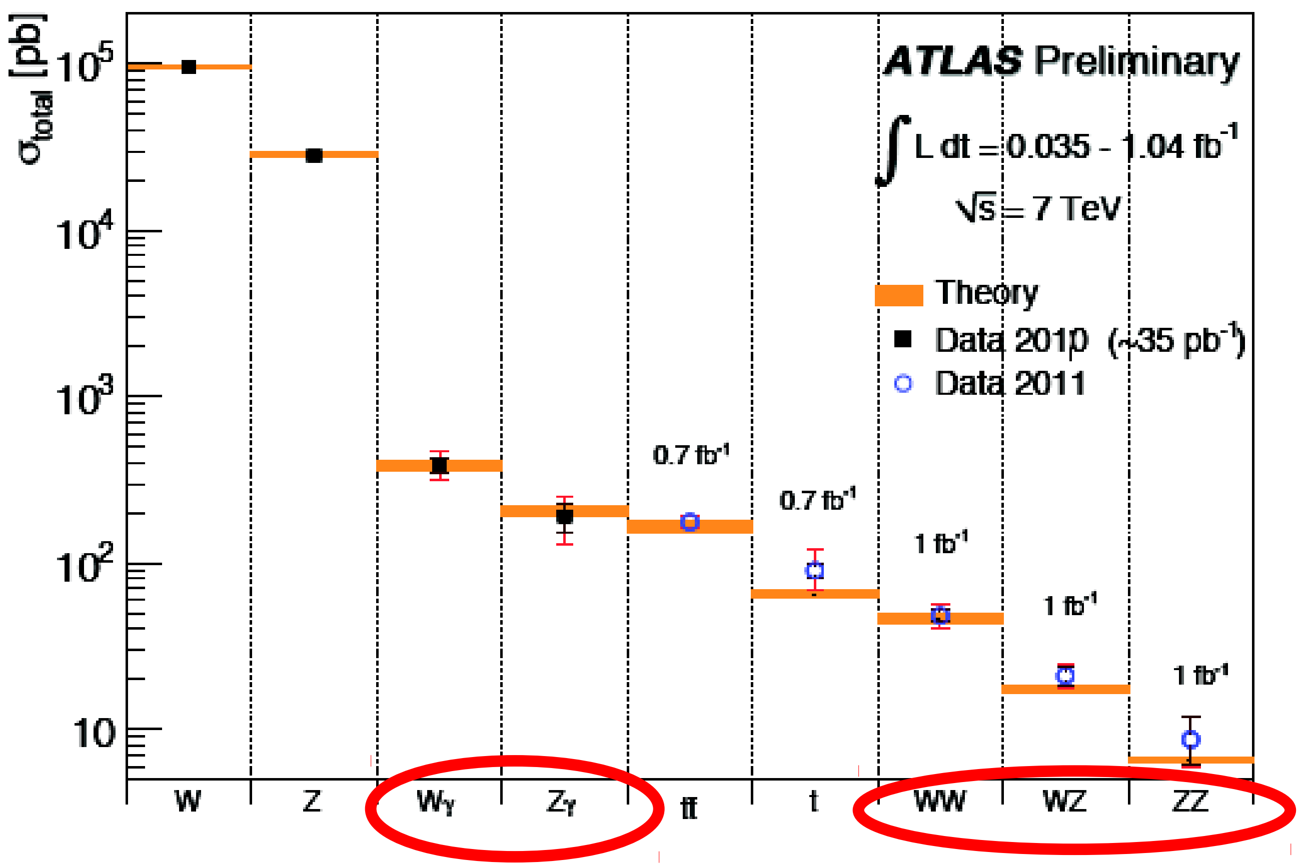


Run Number: 183003,
Event Number: 121099951
Date: 2011-06-02, 10:08:24 CET
EtCut>0.3 GeV
PtCut>2.5 GeV

Cells:Tiles, EMC

Summary and Outlook

- All leptonic diboson process is measured and consistent to the SM expectations
- The most competitive or strict TGC limits have been set
- The first 4 lepton ZZ resonance search is presented
- Looking forward to surprise: Higgs? BSM?



?
Higgs, BSM

Backup

Boosted Large Hadron Collider

LHC has performed extremely well in year 2011:

- Proton-proton collisions at $\sqrt{s}$ 7 TeV
- 50 ns bunch spacing with averaged 6 collisions/crossing
- 2.37 x 10^{33} /cm^2/s peak luminosity
- Delivered 2.68 fb^{-1} (Aug) with maximum ~80 pb^{-1} per day (36 pb^{-1} in 2010)

Geneva, Switzerland

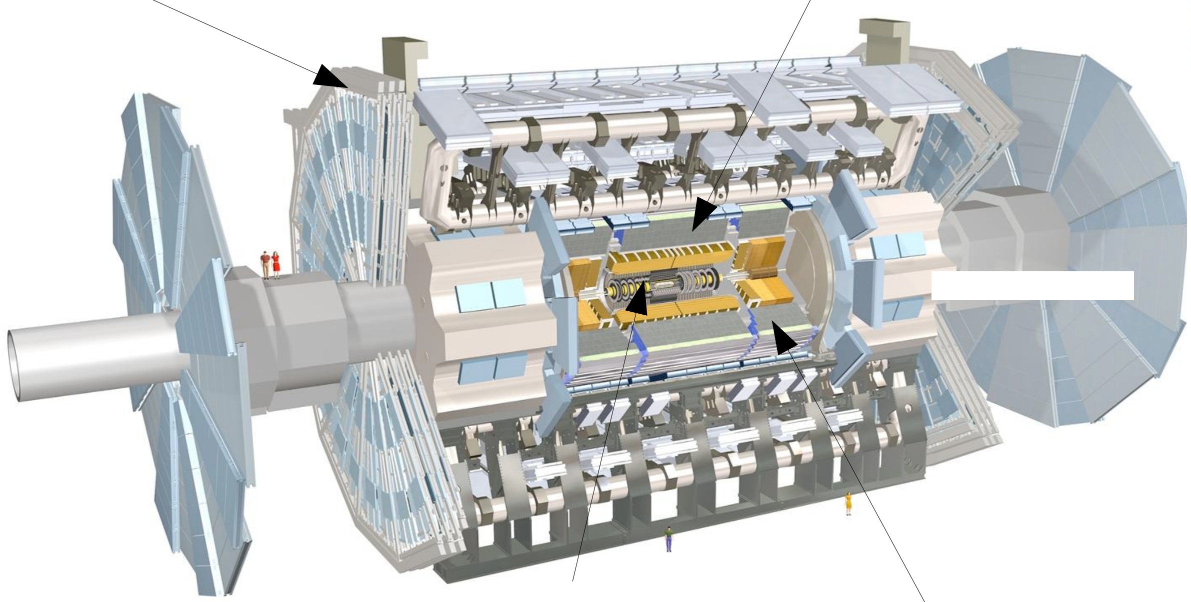
The ATLAS Detector

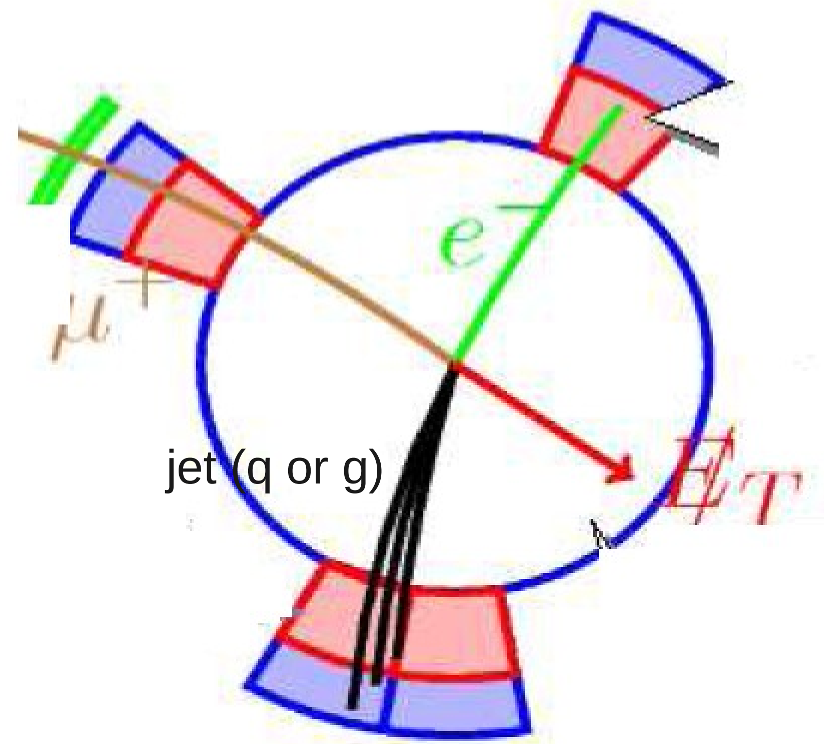
Muon Spectrometer

$|\eta|<2.7$
Air-core toroids and gas-based muon chambers
σ/pT = 2% @ 50GeV to 10% @ 1TeV

EM Calorimeter

$|\eta|<3.2$, Pb-Lar Accordion $\sigma/E=10\%\,\sqrt{E}\oplus 0.7\%$





Inner Detector

$|\eta|<2.5$, B=2T, Si pixels/strips and Trans. Rad. Det.;
$\sigma/p_T = 0.05\%\ p_T\ (\mathrm{GeV}) \oplus 1\%$

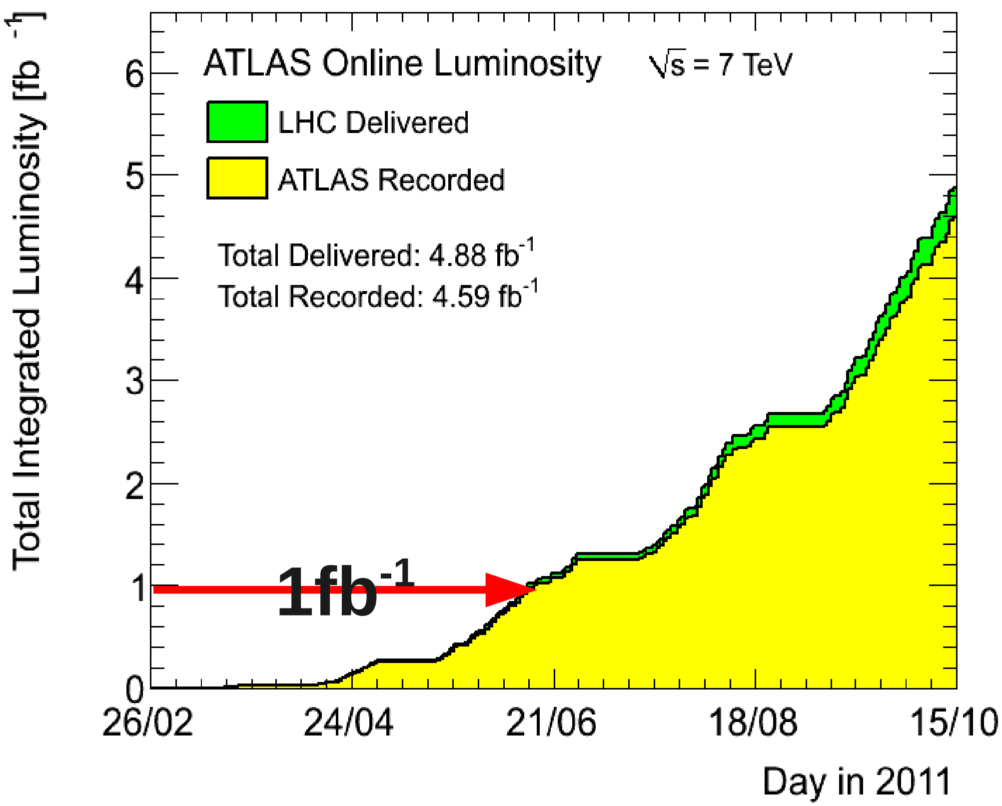
Hadronic Calorimeter

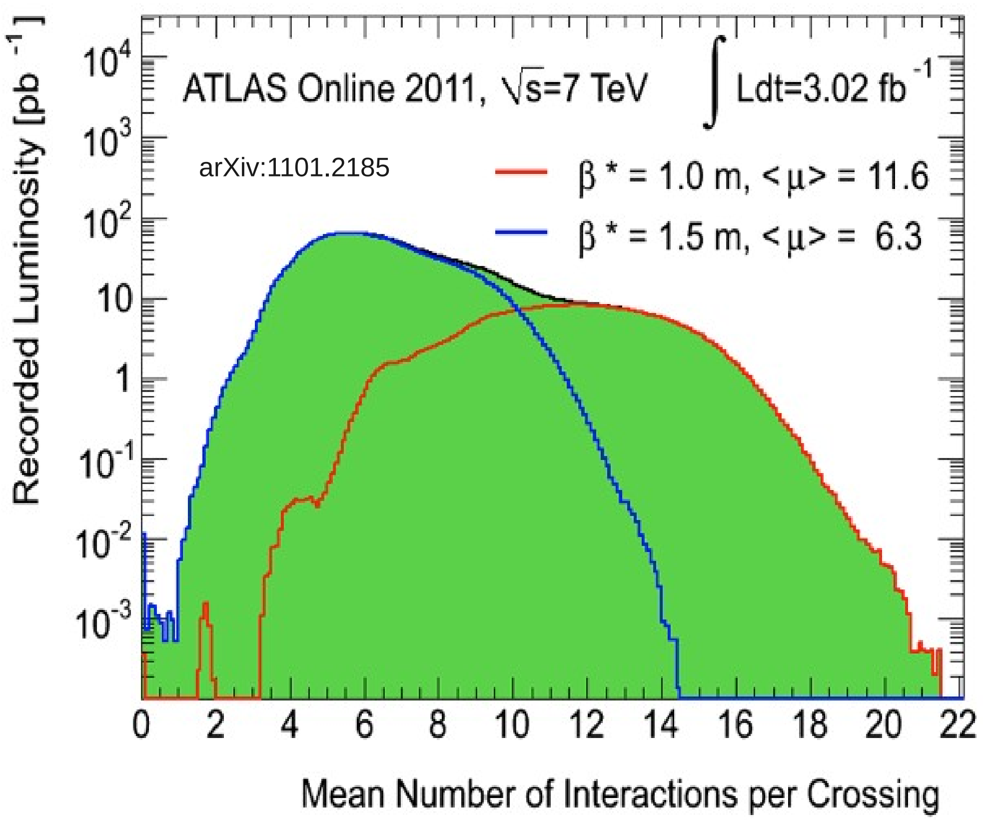
$|\eta|<1.7$ Fe/scintillator $1.3<|\eta|<4.9$ Cu/W-Lar;
$\sigma/E_{jet} = 50\%/\sqrt{E} \oplus 3\%$

The ATLAS Detector

- **Data taking efficiency ~ 95 %**
- **Pile-up challenging**

  substantial in- and out-of-time pile up with 6.3/11.6 interactions per bunch crossing before/after Sep Technical Stop

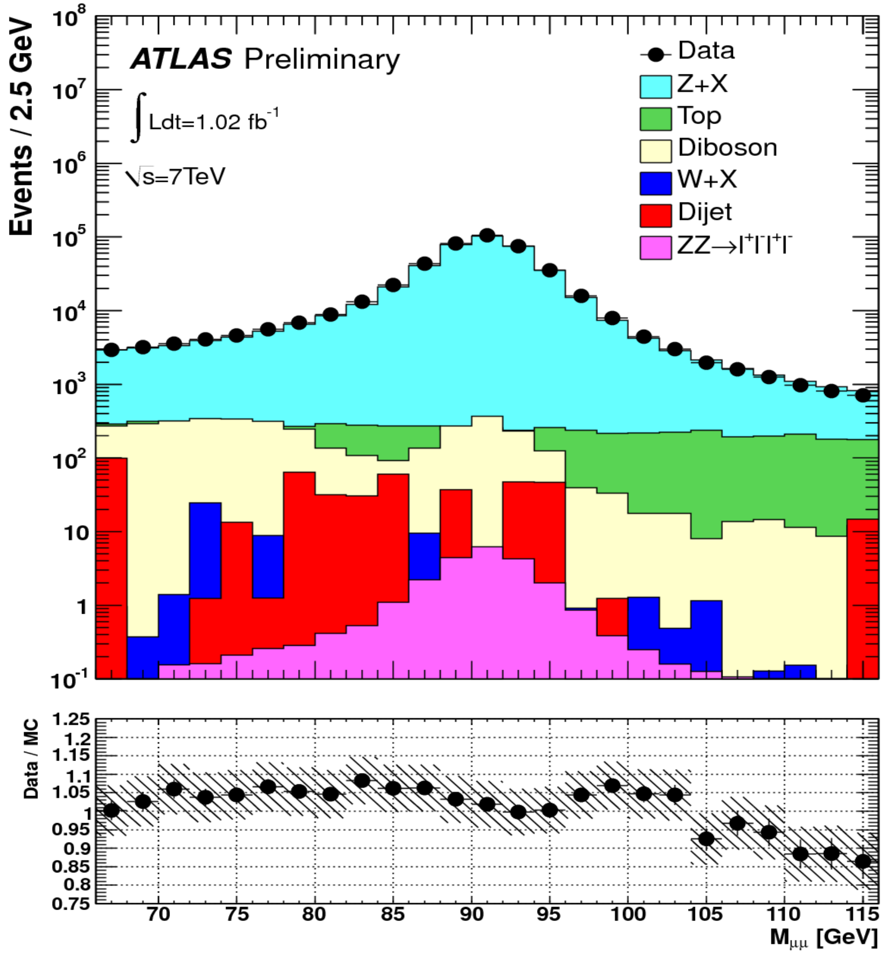


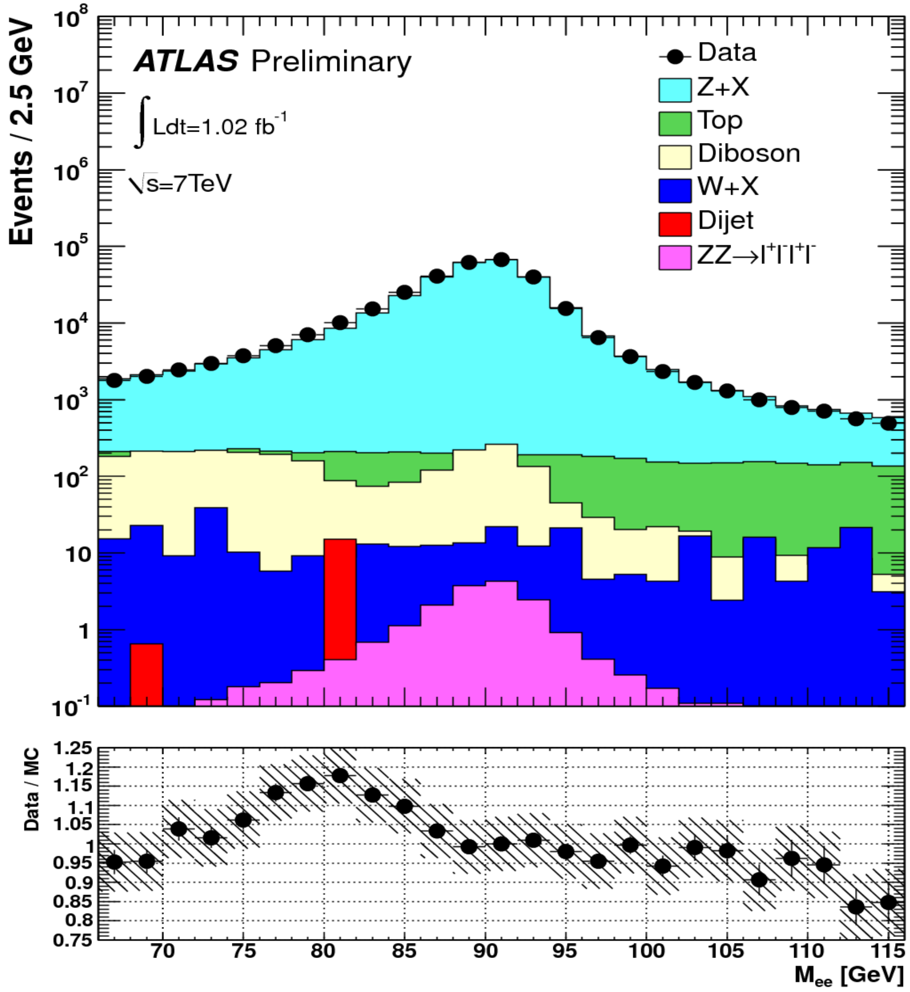


The results shown in this talk used data up to 1 fb^{-1}

Control Region Plots

Z performance shows reasonable agreement between MC and Data.

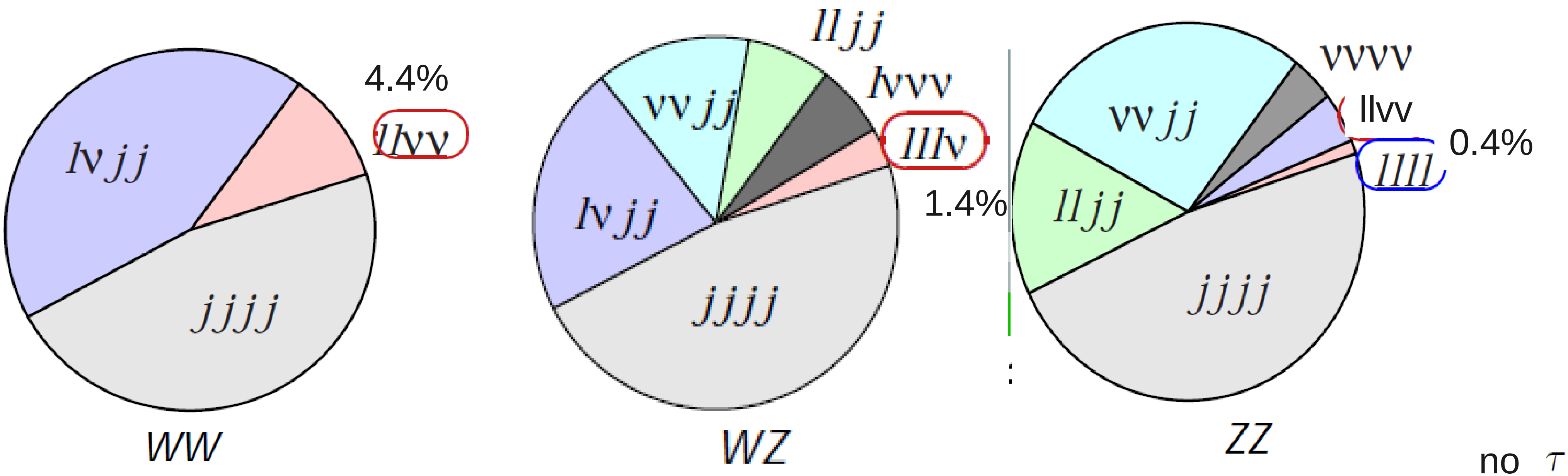




Heavy Diboson Production

Leptonic (e or μ) channels only for high sensitivity

	WW→llνν	WZ→lllν	ZZ→llll
Top	35%	12%	10%
W+X	30%	0%	-
Z+X	32%	52%	90%
VV	4%	36%	-
S/B	1.4	4	30
S/√B	18	12	17



Wγ/Zγ Cross-Section Results

Fiducial cross-section

$$\sigma^{fid}_{W\gamma(Z\gamma)} = \frac{N^{Sig}_{W\gamma(Z\gamma)}}{C_{W\gamma(Z\gamma)} \cdot L_{W\gamma(Z\gamma)}}$$

Total cross-section

$$\sigma^{prod}_{W\gamma(Z\gamma)} = \frac{\sigma^{fig}_{W\gamma(Z\gamma)}}{A_{W\gamma(Z\gamma)}}$$

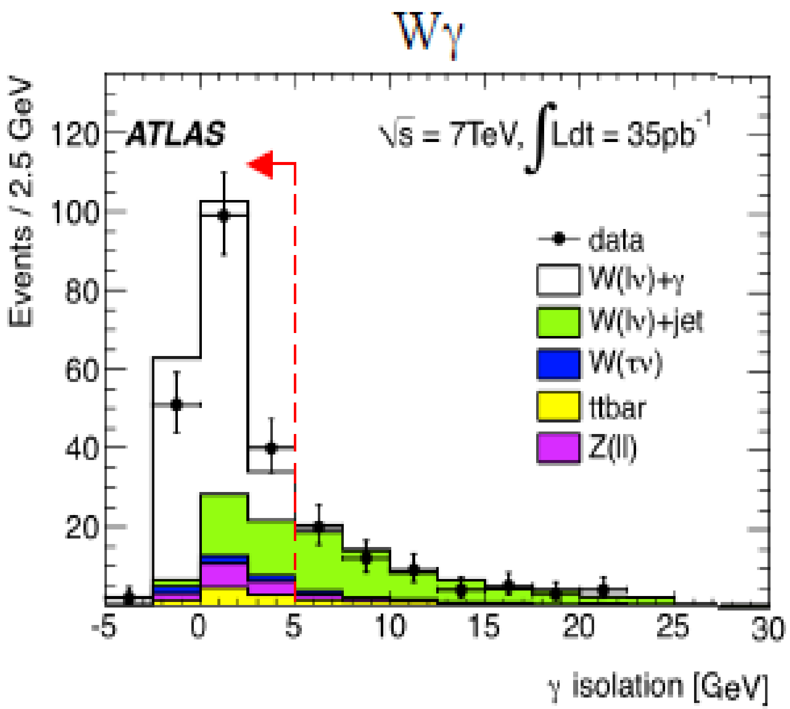
	Experimental measurement	SM prediction
	σ^{fid}[pb]	σ^{fid}[pb]
$pp \to e^{\pm}\nu\gamma$	$5.4 \pm 0.7 \pm 0.9 \pm 0.2$	4.7 ± 0.3
$pp \to \mu^{\pm}\nu\gamma$	$4.4 \pm 0.6 \pm 0.7 \pm 0.2$	4.9 ± 0.3
$pp \to e^{+}e^{-}\gamma$	$2.2 \pm 0.6 \pm 0.5 \pm 0.1$	1.7 ± 0.1
$pp \to \mu^{+}\mu^{-}\gamma$	$1.4 \pm 0.3 \pm 0.3 \pm 0.1$	1.7 ± 0.1
	σ[pb]	σ[pb]
$pp \to e^{\pm}\nu\gamma$	$48.9 \pm 6.6 \pm 8.3 \pm 1.7$	42.1 ± 2.7
$pp \to \mu^{\pm}\nu\gamma$	$38.7 \pm 5.3 \pm 6.4 \pm 1.3$	42.1 ± 2.7
$pp \to l^{\pm}\nu\gamma$	$42.5 \pm 4.2 \pm 7.2 \pm 1.4$	42.1 ± 2.7
$pp \to e^{+}e^{-}\gamma$	$9.0 \pm 2.5 \pm 2.1 \pm 0.3$	6.9 ± 0.5
$pp \to \mu^{+}\mu^{-}\gamma$	$5.6 \pm 1.4 \pm 1.2 \pm 0.2$	6.9 ± 0.5
$pp \to l^{+}l^{-}\gamma$	$6.4 \pm 1.2 \pm 1.6 \pm 0.2$	6.9 ± 0.5

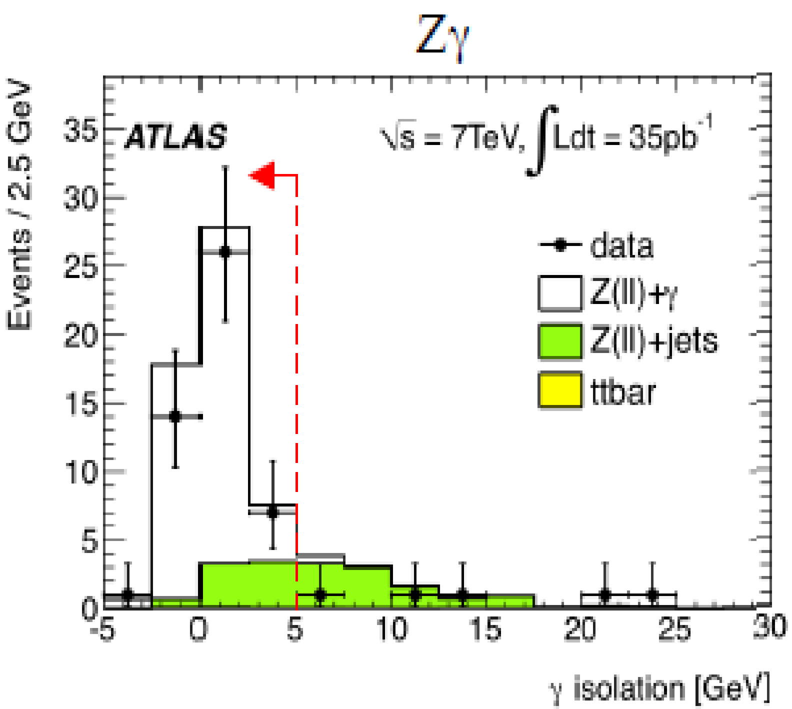
$N^{Sig}_{W\gamma(Z\gamma)}$: Number of measured signal events

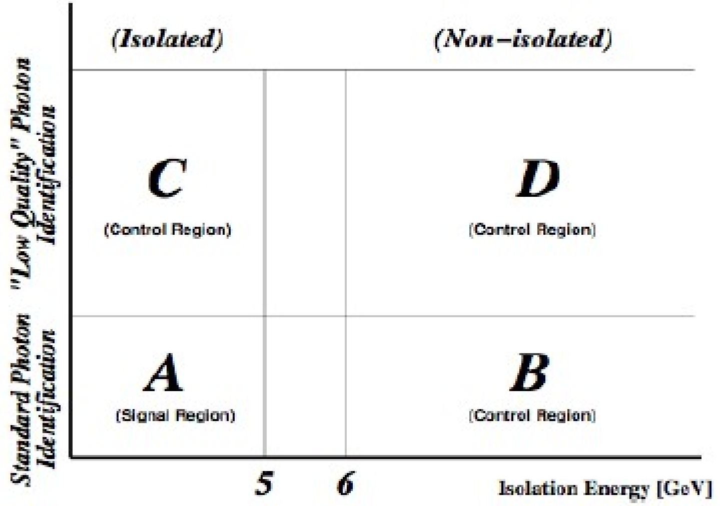
$C_{W\gamma(Z\gamma)}$: Reconstruction and identification efficiency

$A_{W\gamma(Z\gamma)}$: Acceptance of fiducial phase space with respect to total production phase space

Wγ/Zγ Background Estimate





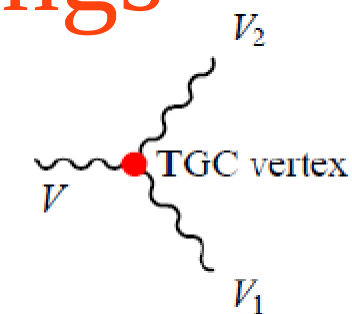


ABCD method for W+jet

$$N_A^{W+jets} = N_B \cdot \frac{N_C}{N_D}$$

MC based method for Z+jet

Anomalous Triple Gauge Couplings



Alternative way to probe new physics. Starting from a generalized Lagrangian:

$$L/g_{WWV} = ig_1^V(W^*_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{*\mu}V^\nu) + ik^V W^*_\mu W_\nu V^{\mu\nu} + \frac{i\lambda^V}{M_W^2} W^*_{\rho\mu}W^\mu_\nu V^{\nu\rho}$$

$$L = -\frac{e}{M_Z^2}[f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) + f_5^V(\partial^\sigma V_{\sigma\mu})\tilde{Z}^{\mu\beta}Z_\beta]$$

Reduced TGC parameters acquiring gauge invariance

- Charged aTGC: Δg_1^Z, $\Delta\kappa^z$,λ^z, $\Delta\kappa^\gamma$,λ^γ
- Neutral TGC: f_4^Z, f_5^Z, f_4^γ, f_5^γ , h_3^Z, h_4^Z, h_3^γ, h_4^γ (forbidden in SM)

Unitary conservation

Add form-factor constraint by the scale of new physics

$$f_i^V(s) = \frac{f_{i0}^V}{(1+s/\Lambda_{FF}^2)^n}$$

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Neutral Trilinear Gauge Coupling Measurement

Total expected yield is parametrized as function of TGC parameter

$$s(\sigma_{\text{fiducial}}, C_{ZZ}, f_i^V) = (C_{\text{Sm}} + C_{f_i^V} \cdot f_i^V + C_{f_i^V;f_i^V} \cdot (f_i^V)^2) \cdot \mathcal{L} \cdot C_{ZZ}.$$

Profiling likelihood is used to include systematics uncertainty

$$\begin{aligned} L(\sigma, C_{ZZ}, b; \Delta_b, \Delta_{C_{ZZ}}, N) &= P(\sigma, C'_{ZZ}, b'; N) \cdot G(C'_{ZZ}; C_{ZZ}, \Delta_{C_{ZZ}}) \cdot G(b'; b, \Delta_b) \\ &\cdot G(C'_{SM}; C_{SM}, \Delta_{C_{SM}}) \cdot G(C'_{f_i^V}; C_{f_i^V}, \Delta_{C_{f_i^V}}) \cdot G(C'_{f_i^V f_i^V}; C_{f_i^V f_i^V}, \Delta_{C_{f_i^V f_i^V}})(\end{aligned}$$

Infinite energy-cut off results are also included as a reference

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