Production of W and Z bosons and of W/Z+jets at ATLAS

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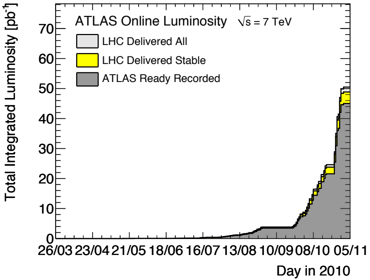
On behalf of the ATLAS Collaboration

Standard Model Benchmarks at High-Energy Hadron Colliders
15–17 June 2011, DESY (Zeuthen)

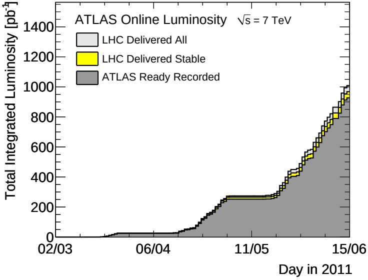
Outline



Most analyses presented use the full 2010 dataset: 31–35 pb^{-1}

Luminosity uncertainty: 3.4 %

Outline



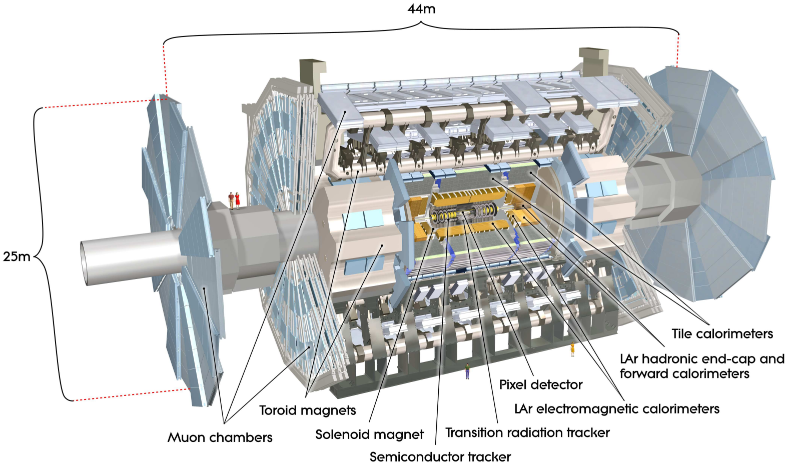
Until yesterday ATLAS recorded $933.8\,\mathrm{pb}^{-1}$ of data in 2011

Preliminary uncertainty: 4.5 %

Electroweak physics

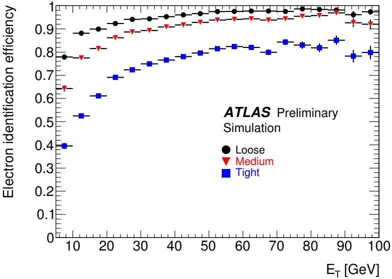
- Important ingredient in theoretical calculations is the parameterization of the momentum distribution of the partons in the proton
- Parton distribution functions (PDFs) have been determined up to NLO (CTEQ, NNPDF) and NNLO (MSTW, ABKM, HERA, JR)
- Production cross sections of W and Z bosons (+ jets) constrain the PDFs and provide an important test for QCD
- Leptonic decays of W and Z provide clear signatures, these *standard candles* are a valuable tool to understanding the detector
- Processes involving W/Z (+ jets) are important backgrounds to many new physics searches

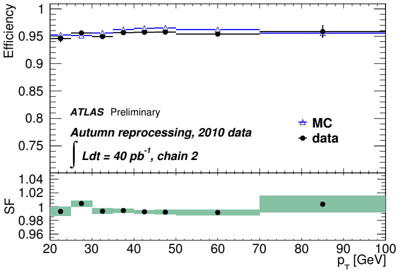
The ATLAS detector



Geometrical acceptance: inner tracker: $|\eta| < 2.5$, muon system: $|\eta| < 2.7$, calorimeter: $|\eta| < 4.9$

Electron/muon identification





Three classes of electrons:

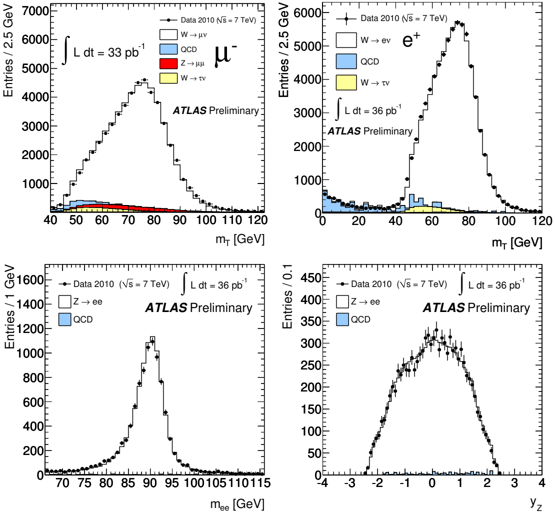
- loose
- medium
- tight

Efficiency and fake rate decrease going from loose to tight

Combined muons are used:

- reconstructed in the muon system
- corrected for the energy loss in the calorimeters
- combined with the inner detector momentum measurement

W/Z cross section



$W \to \ell\nu$

$p_T^\ell > 20$ GeV

$p_T^\nu > 25$ GeV

$m_T > 40$ GeV

$$m_T \equiv \sqrt{2 p_T^\ell p_T^\nu \left(1 - \cos\left(\Delta\phi_{\ell,\nu}\right)\right)}$$

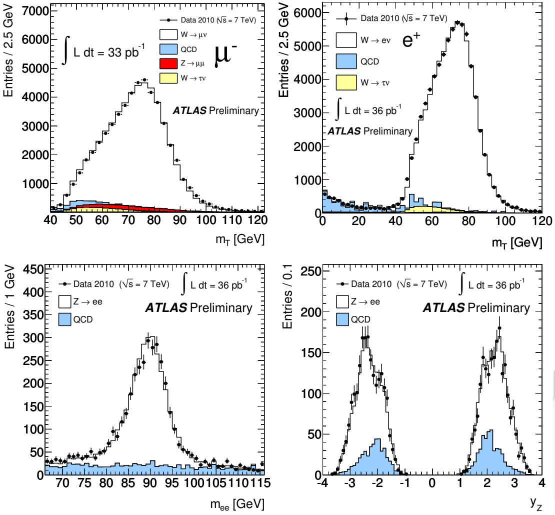
$Z \to \ell\ell$

$p_T^\ell > 20$ GeV

$66 < m_{\ell\ell} < 116$ GeV

ATLAS-CONF-2011-041

W/Z cross section



$W \to \ell\nu$

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$Z \to \ell\ell$

$p_T^\ell > 20$ GeV

$66 < m_{\ell\ell} < 116$ GeV

$Z \to ee$

Extended to one forward electron: $2.5 < |\eta_e| < 4.9$

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Results

	$\sigma_W^{tot} \times BR(W \to \ell\nu)$ [nb]
$W \to e\nu$	10.551 ± 0.032 (sta) ± 0.300 (sys) ± 0.359 (lum) ± 0.316 (acc)
$W \to \mu\nu$	10.322 ± 0.030 (sta) ± 0.249 (sys) ± 0.377 (lum) ± 0.310 (acc)

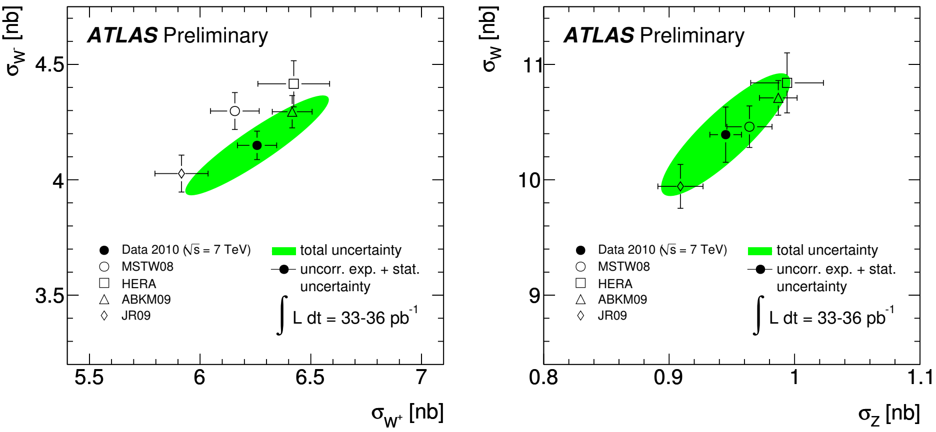
	$\sigma_{Z/\gamma^*}^{tot} \times BR(Z/\gamma^* \to \ell\ell)$ [nb]
$Z/\gamma^* \to ee$ (central)	0.972 ± 0.010 (sta) ± 0.034 (sys) ± 0.033 (lum) ± 0.038 (acc)
$Z/\gamma^* \to ee$ (forward)	0.903 ± 0.022 (sta) ± 0.087 (sys) ± 0.031 (lum) ± 0.035 (acc)
$Z/\gamma^* \to \mu\mu$	0.941 ± 0.008 (sta) ± 0.011 (sys) ± 0.032 (lum) ± 0.037 (acc)

- Fiducial cross section is extrapolated to the full phase space, acceptance uncertainty is the uncertainty in this extrapolation
- Good agreement with theory predictions:

Predictions

	MSTW08	ABKM09	HERA	JR09
$W \to \ell\nu$	10.46 ± 0.18	10.71 ± 0.15	10.84 ± 0.26	9.94 ± 0.19
$Z/\gamma^* \to \ell\ell$	0.964 ± 0.018	0.987 ± 0.015	0.994 ± 0.029	0.909 ± 0.018

Cross section ratios

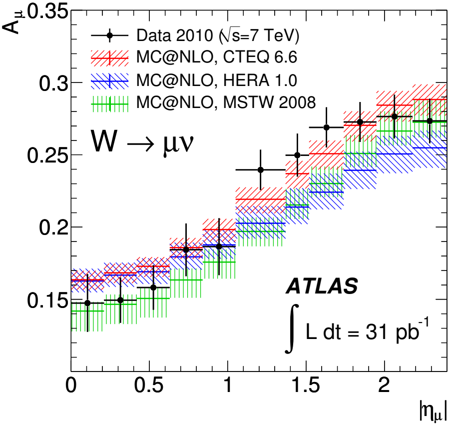


- Results (uncertainty $\sim 5\,\%$) agree with NNLO predictions

W charge asymmetry

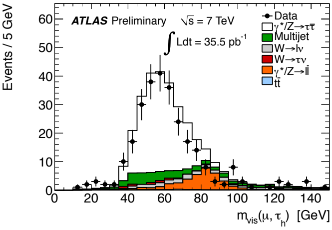
$$A_\mu = \frac{d\sigma_{W_{\mu^+}}/d\eta_\mu - d\sigma_{W_{\mu^-}}/d\eta_\mu}{d\sigma_{W_{\mu^+}}/d\eta_\mu + d\sigma_{W_{\mu^-}}/d\eta_\mu}$$

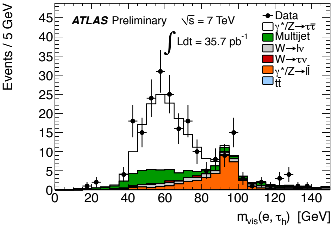
- $p_T^\mu > 20\,\mathrm{GeV}$
- More valence *u* in the proton: W^+ is favored over W^-
- Asymmetry measured versus muon rapidity
- Rapidity dependence probes *u* and *d* parton distribution functions



arXiv:1103.2929, submitted to Phys. Lett. B

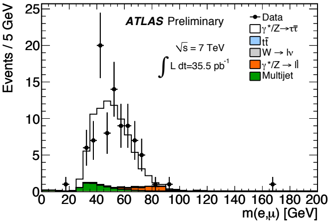
$Z \to \tau\tau$

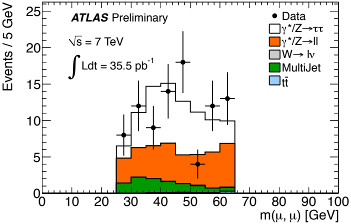




$Z \to \tau\tau$ cross section measured using four channels:

- $Z \to \tau_u \tau_h$
- $Z \to \tau_e \tau_h$
- $Z \to \tau_e \tau_u$
- $Z \to \tau_\mu \tau_\mu$





Main backgrounds:

- $Z \to \ell\ell$
- Multijet

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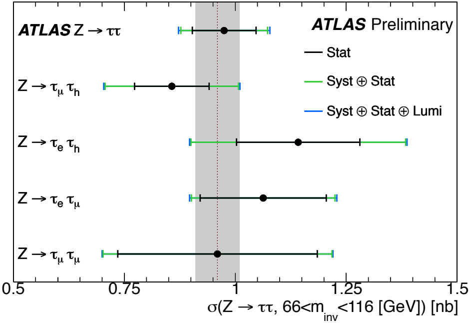
$Z \to \tau\tau$



- τ reconstruction is performing well
- Important step towards channels such as $H \to \tau\tau$
- Good agreement with Standard Model expectations

Combined result

	$\sigma_Z \times BR(Z \to \tau\tau)$ [nb]
Measured	0.97 $\pm$ 0.07 (stat) $\pm$ 0.07 (syst) $\pm$ 0.03 (lumi)
Predicted	0.96 $\pm$ 0.05 (syst)

W/Z + jets

- Jets reconstructed using the anti-k_T algorithm with $R = 0.4$
- $p_T^{jet} > 20\,\text{GeV}$ for W + jets and $p_T^{jet} > 30\,\text{GeV}$ for Z + jets analysis
- Jets within $\Delta R < 0.5$ of a selected lepton are rejected
- Pile-up jets are rejected by requiring the jet-vertex-fraction[1] (JVF) > 0.75

Z + jets

- Exactly two opposite sign
  - combined muons
  - medium electrons
- $66 < m_{\ell\ell} < 116\,\text{GeV}$

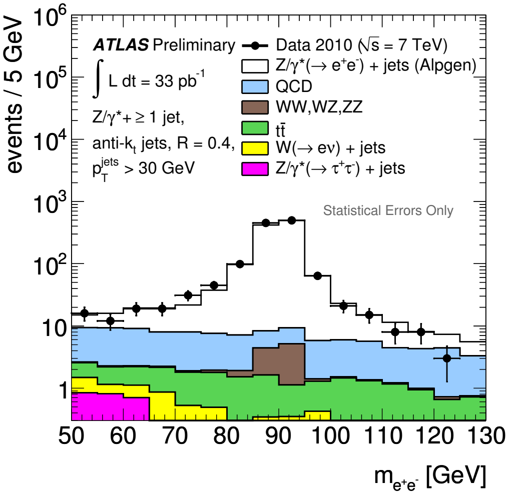
W + jets

- Exactly one
  - combined muon
  - tight electron
- No medium electrons present

- Main backgrounds: top and QCD (electron channel, estimated from data)
- Bin-by-bin unfolding correction is applied to correct back to parton level
- Dominant systematic uncertainty is the jet energy scale: 10-20%

[1] JVF = Scalar $\sum p_T$ of tracks in a jet pointing towards the primary vertex divided by the scalar $\sum p_T$ of all tracks in the jet

Z + jets



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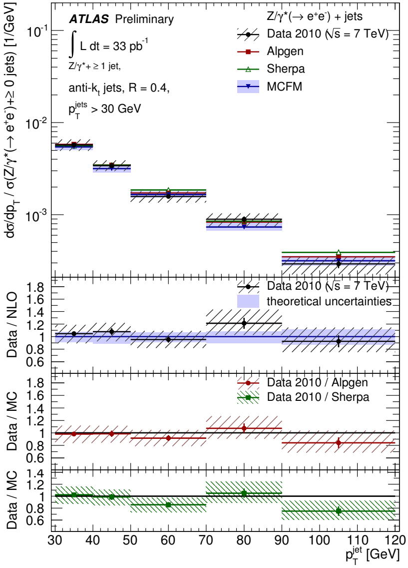
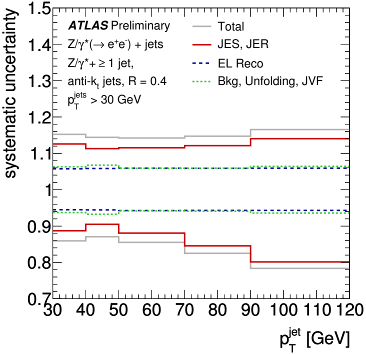
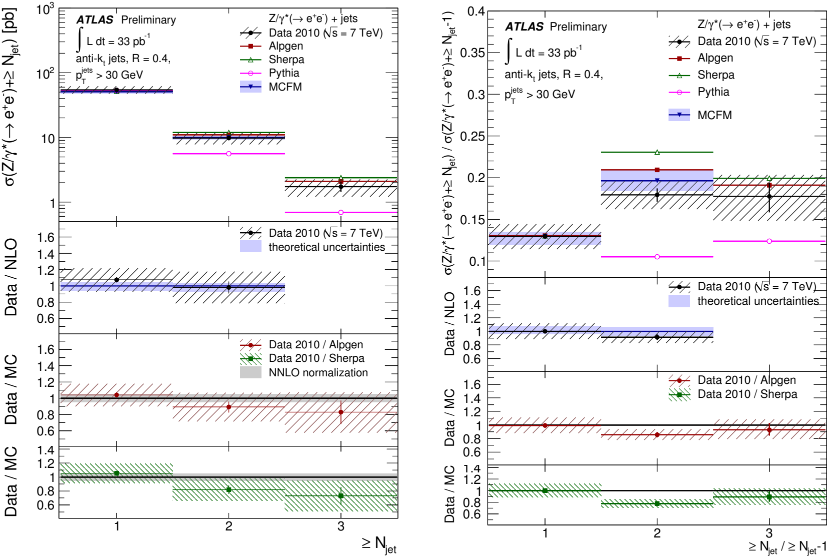
Dijet background for $Z \to ee$ is estimated from data:

- Orthogonal control sample containing two loose electrons
- Use this to determine the shape of the dijet background
- Fit the shape for each jet multiplicity separately

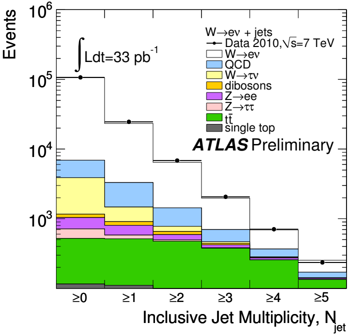


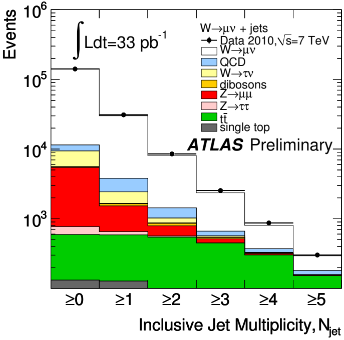


- Dominant systematic is the jet energy scale/resolution
- Described by NLO pQCD predictions, as well as LO + parton showers (ALPGEN, SHERPA)


ATLAS Preliminary
∫ L dt = 33 pb^-1
anti-kt jets, R = 0.4,
pT^jets > 30 GeV
Z/γ*(→ e+e-) + jets
Data 2010 (√s = 7 TeV)
Alpgen
Sherpa
Pythia
MCFM
σ(Z/γ*(→ e+e-)+≥ Njet) [pb]
Data / NLO
theoretical uncertainties
Data / MC
Data 2010 / Alpgen
Data 2010 / Sherpa
NNLO normalization
≥ Njet
σ(Z/γ*(→ e+e-)+≥ Njet) / σ(Z/γ*(→ e+e-)+≥ Njet-1)
≥ Njet / ≥ Njet-1

W + jets





- Measured as a function of p_T^{jet}, N_{jet} and $H_T \equiv \sum p_T^{jet} + p_T^{\ell} + E_T^{miss}$
- Main background for $W \to e\nu$ is QCD (data-driven determination)
- Main background for $W \to \mu\nu$ is $Z \to \mu\mu$ with one of the muons outside of the detector acceptance

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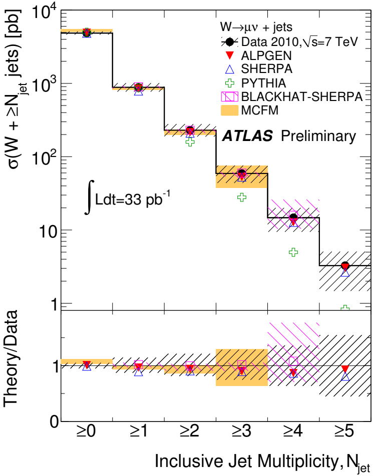
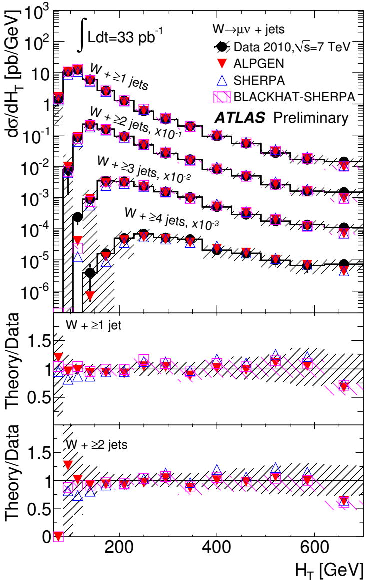
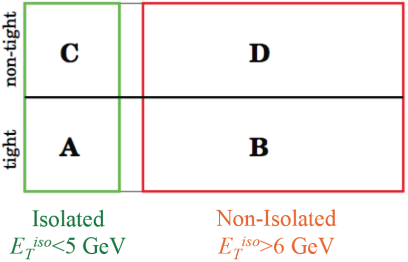




- Data agree well with predictions
- Pythia is LO, disagreement is expected for $N_{jet} > 1$

$W\gamma$ and $Z\gamma$

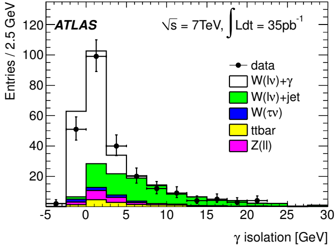
- Sensitive to triple gauge couplings
- Probe $ZZ\gamma$ and $Z\gamma\gamma$ vertices which vanish in the SM at tree level
- E_T^{iso}: excess transverse energy in a cone of $\Delta R < 0.4$ around the photon

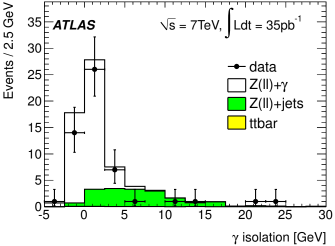


- W + jets background estimated from data
- Sidebands in two dimensions: photon quality and isolation
- Statistics currently insufficient to do the same for Z + jets
- Purity of the resulting $W\gamma$ ($Z\gamma$) sample is $\sim 80\,\%$ ($\sim 85\,\%$)

arXiv:1106.1592, submitted to JHEP

$W\gamma$ and $Z\gamma$

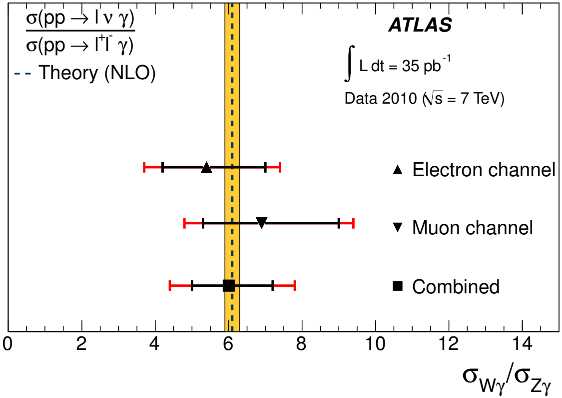




Results

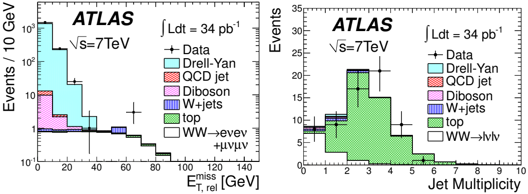
	σ^{tot} [pb] (measured)	σ [pb] (predicted)
$pp \to e^{\pm}\nu\gamma$	48.9 ± 6.6 (stat) ± 8.3 (syst) ± 1.7 (lumi)	42.1 ± 2.7 (syst)
$pp \to \mu^{\pm}\nu\gamma$	38.7 ± 5.3 (stat) ± 6.4 (syst) ± 1.3 (lumi)	42.1 ± 2.7 (syst)
$pp \to \ell^{\pm}\nu\gamma$	42.5 ± 4.2 (stat) ± 7.2 (syst) ± 1.4 (lumi)	42.1 ± 2.7 (syst)
$pp \to e^{+}e^{-}\gamma$	9.0 ± 2.5 (stat) ± 2.1 (syst) ± 0.3 (lumi)	6.9 ± 0.5 (syst)
$pp \to \mu^{+}\mu^{-}\gamma$	5.6 ± 1.4 (stat) ± 1.2 (syst) ± 0.2 (lumi)	6.9 ± 0.5 (syst)
$pp \to \ell^{+}\ell^{-}\gamma$	6.4 ± 1.2 (stat) ± 1.6 (syst) ± 0.2 (lumi)	6.9 ± 0.5 (syst)

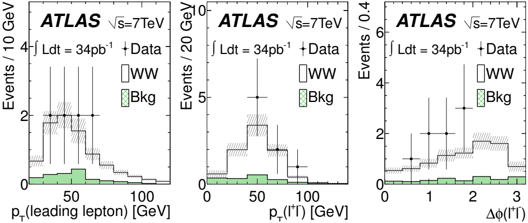
$W\gamma/Z\gamma$ cross section ratio



- Vertical band indicates $1\,\sigma$ uncertainty on the Standard Model prediction
- Cross section ratio is a direct test of the $WW\gamma$ triple gauge coupling
- Measured values are in good agreement with the SM prediction

WW





Select events with:

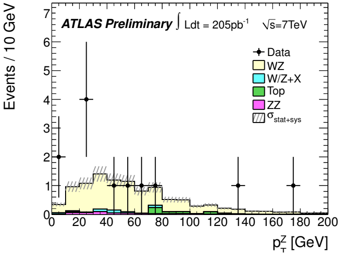
- Opposite sign leptons of $p_T^\ell > 20\,\text{GeV}$
- $E_{T,rel}^{miss} \begin{cases} > 40\,\text{GeV} & ee/\mu\mu \\ > 20\,\text{GeV} & e\mu \end{cases}$
- Veto $|m_{\ell\ell} - m_Z| < 10\,\text{GeV}$
- Veto jets with $p_T^{jet} > 20\,\text{GeV}$ and $|\eta| < 3$

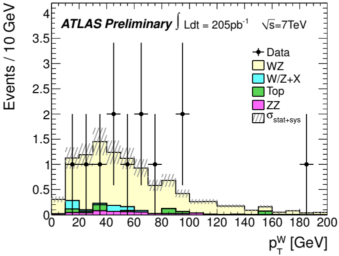
Results

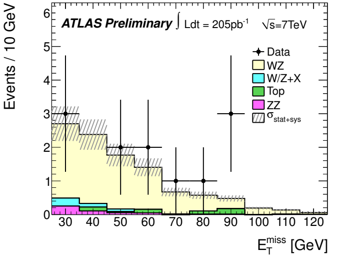
	$\sigma_{W^+W^-}$ [pb]
Meas.	$41\ ^{+20}_{-16}$ (stat) $\pm$ 5 (syst) $\pm$ 1 (lumi)
Pred.	44 $\pm$ 3 (syst)

arXiv:1104.5225, submitted to Phys. Rev. Lett.

WZ







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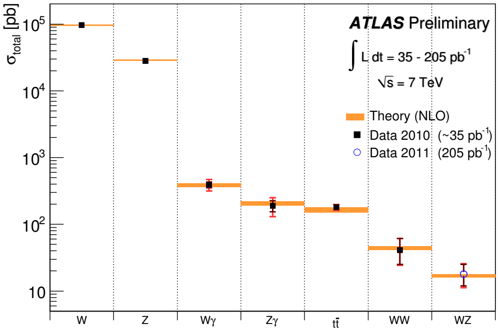
Results

	σ_{WZ}^{tot} [pb]
Measured	$18\,^{+7}_{-6}$ (stat) $\pm$ 3 (syst) $\pm$ 1 (lumi)
Predicted	$16.9\,^{+1.2}_{-0.8}$ (syst)

- Using 205 pb^{-1} of 2011 data!
- Good agreement with SM prediction

Conclusions and outlook

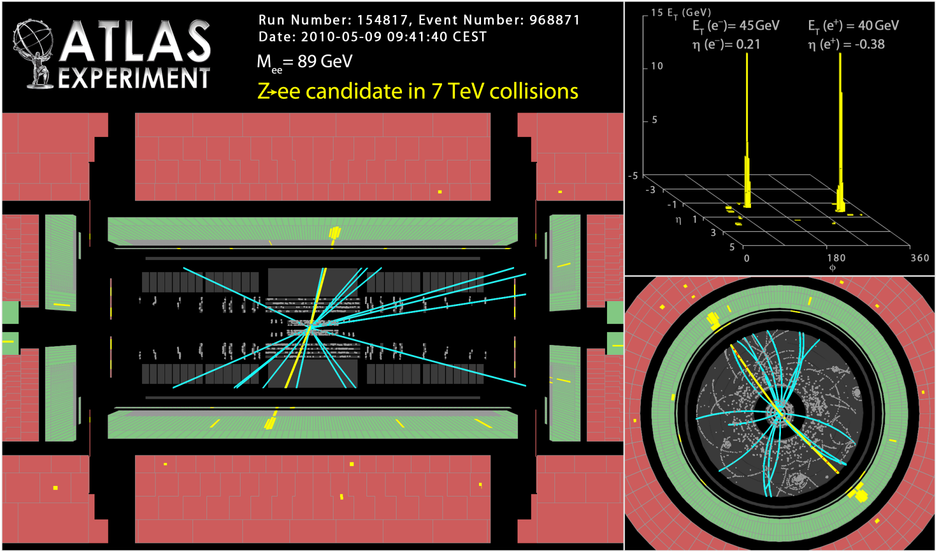
ATLAS W and Z results with the 2010 dataset (31–35 pb^{-1})

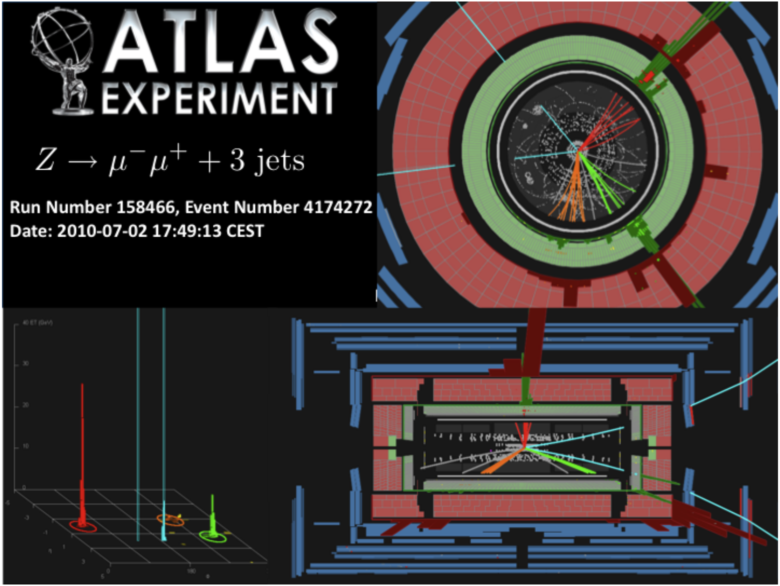


- Important tests of pQCD, constraints for PDFs
- W and Z bosons have been observed using electron, muon and tau channels
- Demonstrates good performance and understanding of detector
- Results show good agreement with Standard Model expectations

- The 2011 data will dramatically improve statistics, especially for channels such as WW and WZ

Backup slides


ATLAS EXPERIMENT
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST
M_ee = 89 GeV
Z→ee candidate in 7 TeV collisions
E_T (GeV)
E_T (e⁻)= 45 GeV
η (e⁻)= 0.21
E_T (e⁺) = 40 GeV
η (e⁺) = -0.38
η
φ


ATLAS
EXPERIMENT
$Z \to \mu^-\mu^+ + 3$ jets
Run Number 158466, Event Number 4174272
Date: 2010-07-02 17:49:13 CEST