Электрослабая физика в эксперименте АТЛАС

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Протвино

Overview

Large **H**adron **C**ollider provides pp collisions at unprecedented energies

Before search for new physics we need to check that the standard physics is well under control with Standard Model measurements which allow to:

- **validate** SM in **new energy** regime
- **constrain new physics** contributions (like anomalous couplings)
- **improve precision** of known SM parameters
- **understand** processes which are **backgrounds** for other studies

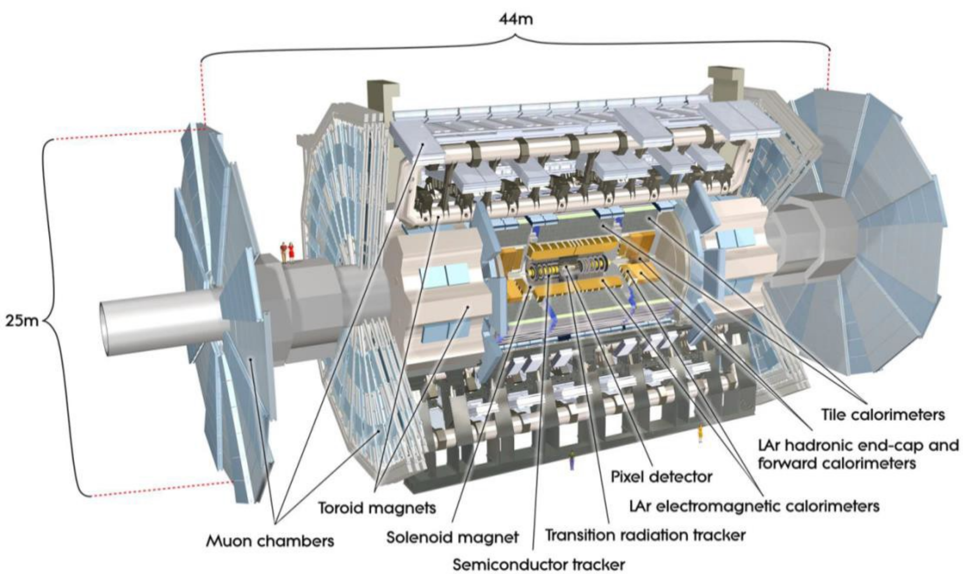
This talk is a selection of recent *electroweak* results in ATLAS:

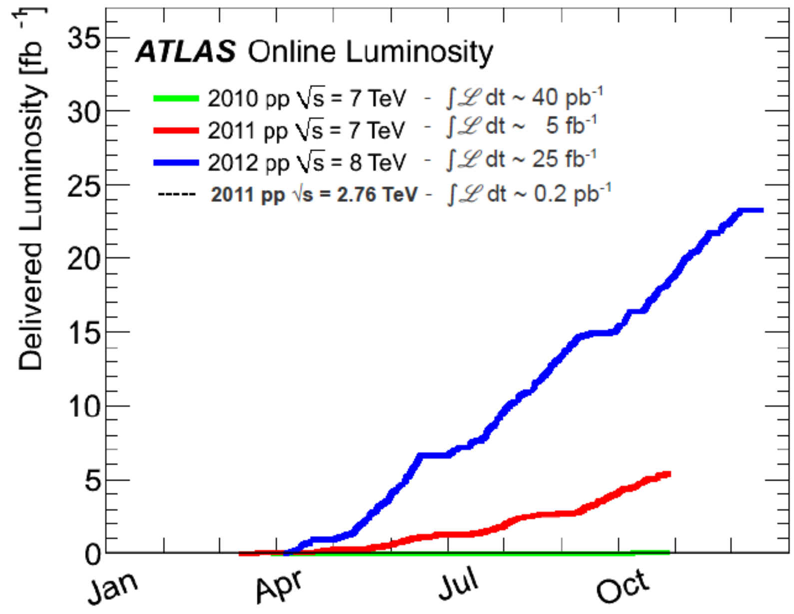
- W/Z cross section, High-mass Drell-Yan differential cross section
- Forward-backward asymmetry of Z/γ^* and $\sin^2\theta_W$
- Z + jet, W + c, W + b-jet
- $W\gamma$, $Z\gamma$, ZZ, WZ WW production and Triple Gauge Couplings

Theory predictions available:

- Multileg LO: Alpgen, Madgraph, Sherpa
- NLO: MC@NLO, MCFM, Powgeg, BlackHat
- NNLO, parton level calculations: FEWZ
- Parton level generators are interfaced to general purpose MC for showering and hadronization

The ATLAS detector

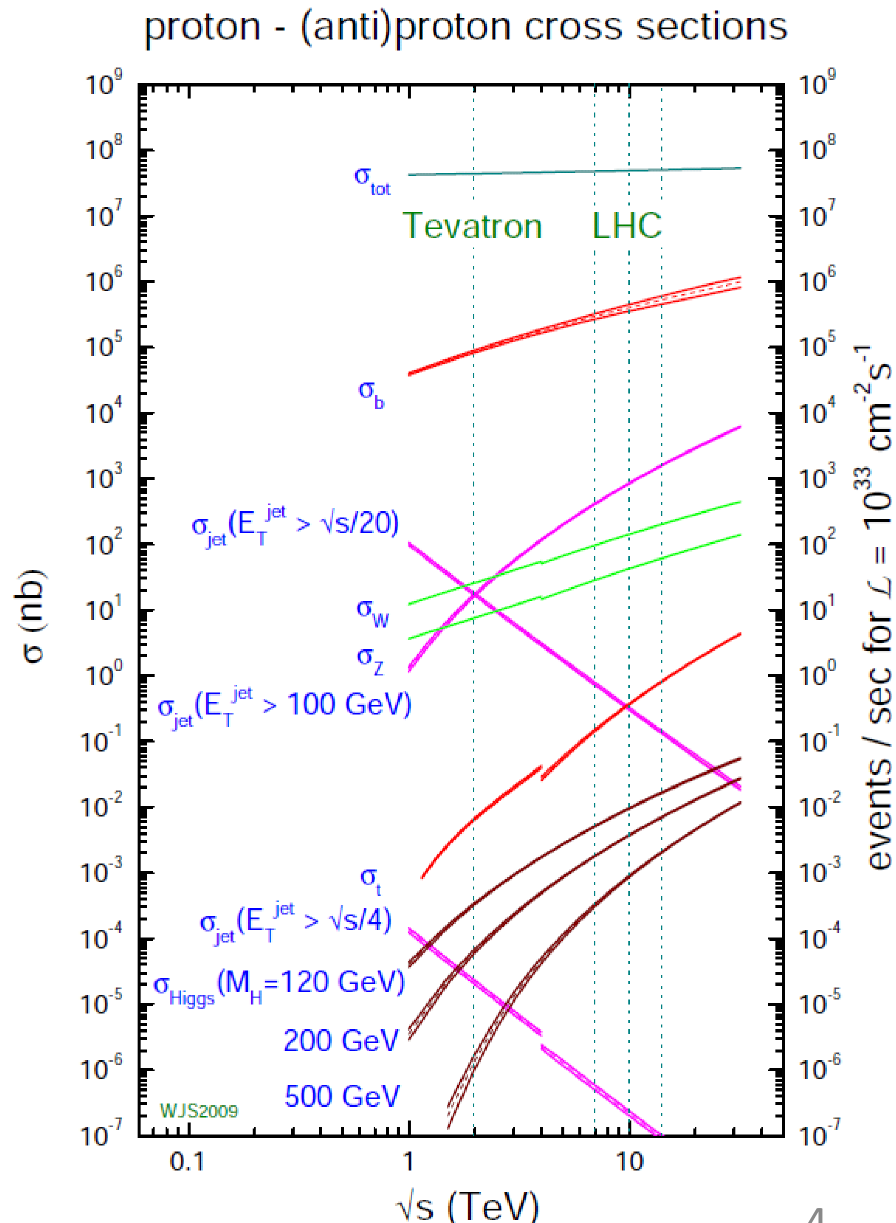




- Very successful running in 2010-2011 (7 TeV) and 2012 (8 TeV)
- Data taking efficiency in 2012: 93%, 96% of which is used for physics
- Bunch spacing 50 ns, peak luminosity ~ $8 \times 10^{33} cm^{-2} s^{-1}$
- Total data set (after data quality selections): 7 TeV: 4.8 fb^{-1}, 8 TeV: 20.7 fb^{-1}
- Main issue: high pileup. ATLAS has been able to handle this challenge thanks to fast triggers, optimized reconstruction of objects, precise modelling of pile up in MC and improvement in computing models to handle the rate

Cross sections and production rates

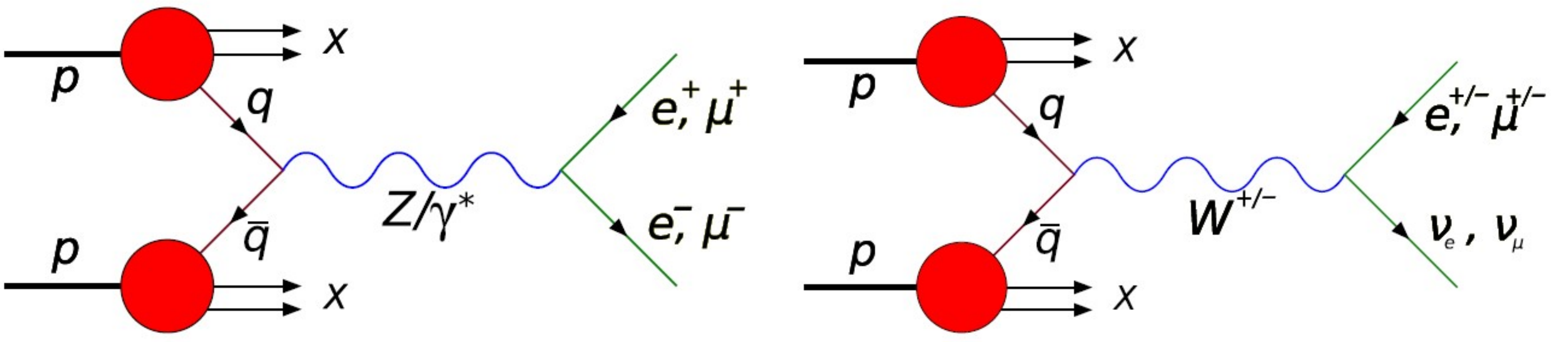
Process	Events / 1 fb $^{-1}$
W → eν / μν	~ 10^7
Z → ee /μμ	~ 10^6
tt → lν jj	~ 3×10^5
WW	~ 5×10^4
ZZ	~ 5×10^3



- LHC - W/Z and t factory
- rare EW final states produced abundantly
- testing SM up to O(TeV) scales

W/Z production at LHC

Drell-Yan production of W and Z calculable to high orders in pQCD (diagramm only LO)

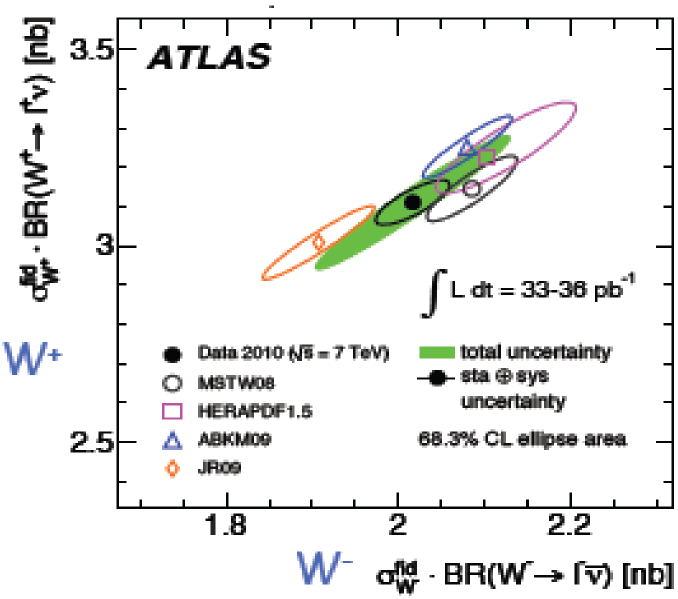


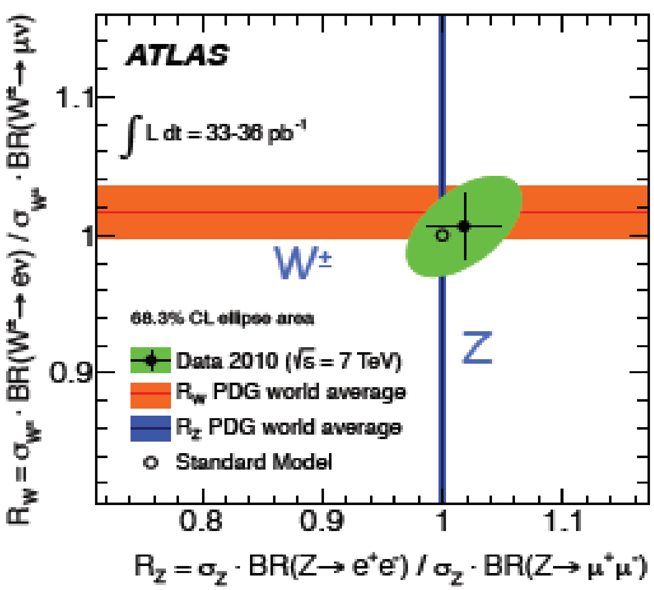
ATLAS performs measurements

- With any X (jets) or with selected flavor (c or b-hadrons)
- With or without cuts on jet multiplicity

W/Z cross section

Phys. Rev. D85 (2012) 072004





Process: pp → W/Z + X $\sqrt{s}$ = 7 TeV L=36 pb^{-1}

Result: $\sigma^{W/Z}_{tot}$ measured with ~4% accuracy

σ_{tot} (pp → $W^{\pm}$X) × B(W → lν) [nb] =

$10.207 \pm 0.021_{sta} \pm 0.121_{sys} \pm 0.347_{lum} \pm 0.164_{acc}$

σ_{tot} (pp → ZX) × B(Z → $l^+ l^-$) [nb] =

$0.937 \pm 0.006_{sta} \pm 0.009_{sys} \pm 0.032_{lum} \pm 0.016_{acc}$

The sample is so large that one can perform rare/precision measurement

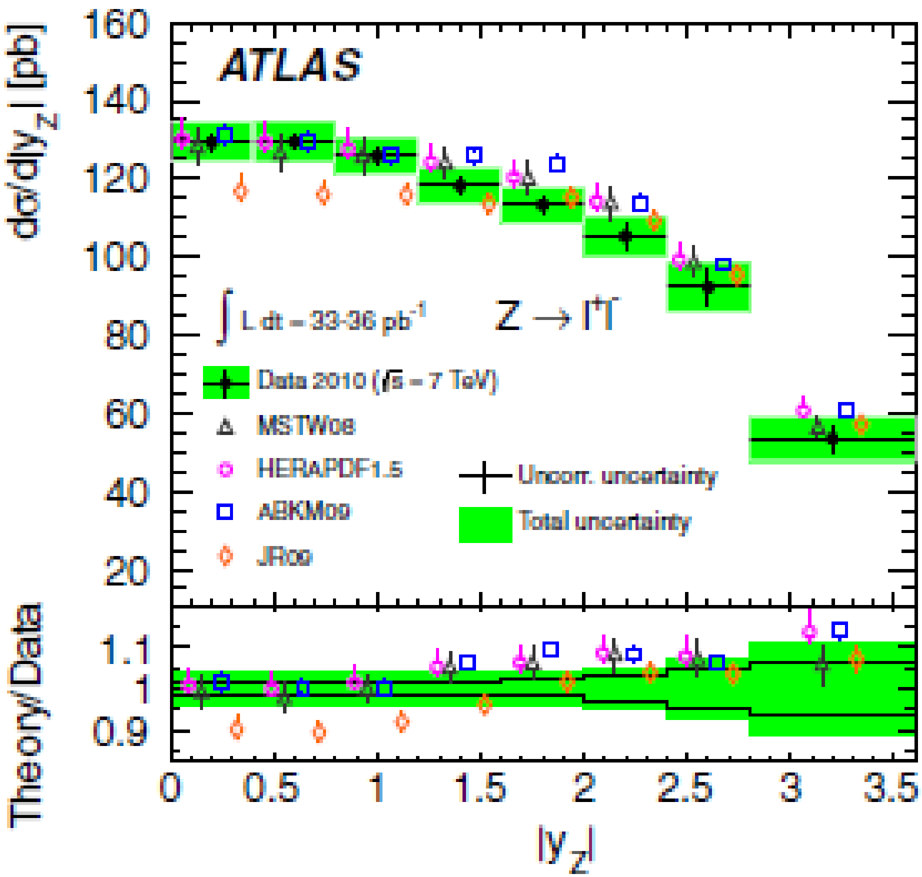
- Sensitivity to PDFs
- Demonstration of the lepton universality
- Agreement with theory predictions based on different PDFs sets

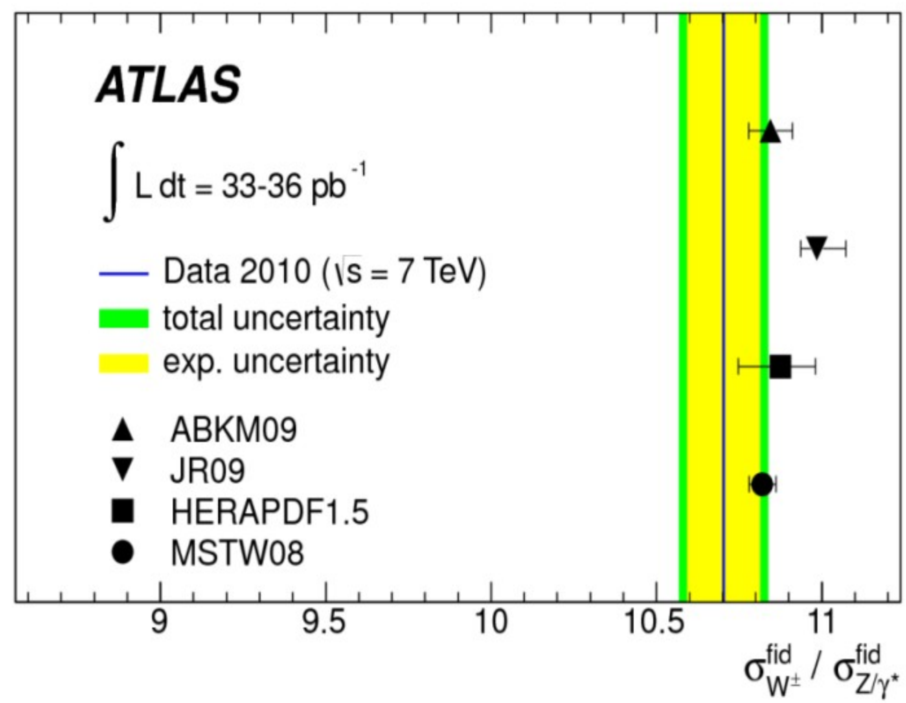
W/Z cross section (continued)

Phys. Rev. D85 (2012) 072004

Good agreement with NNLO calculations

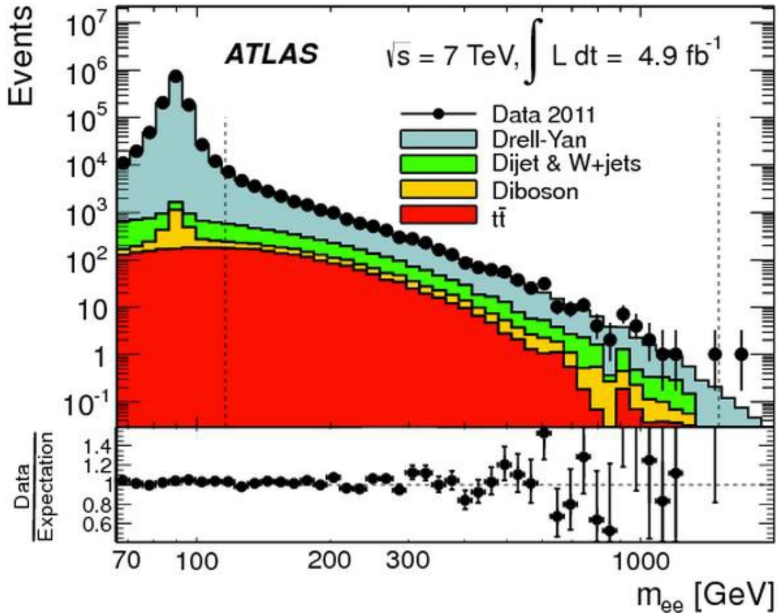
Systematic uncertainties reduced for ratio $\sigma^{Z}_{fid} / \sigma^{W}_{fid}$ ➔ possible to constrain PDFs





High Mass Drell – Yan

Phys. Lett. B725 (2013) 223-242



- Process: pp → Z/γ^* → $e^+ e^-$ $\sqrt{s}$ = 7 TeV L=4.6 fb^{-1}
- Measurement: differential cross section as a function of m_{ee} in the range 116 < m_{ee} < 1500 GeV
- Clean signal, low backgrounds → precision test of pQCD

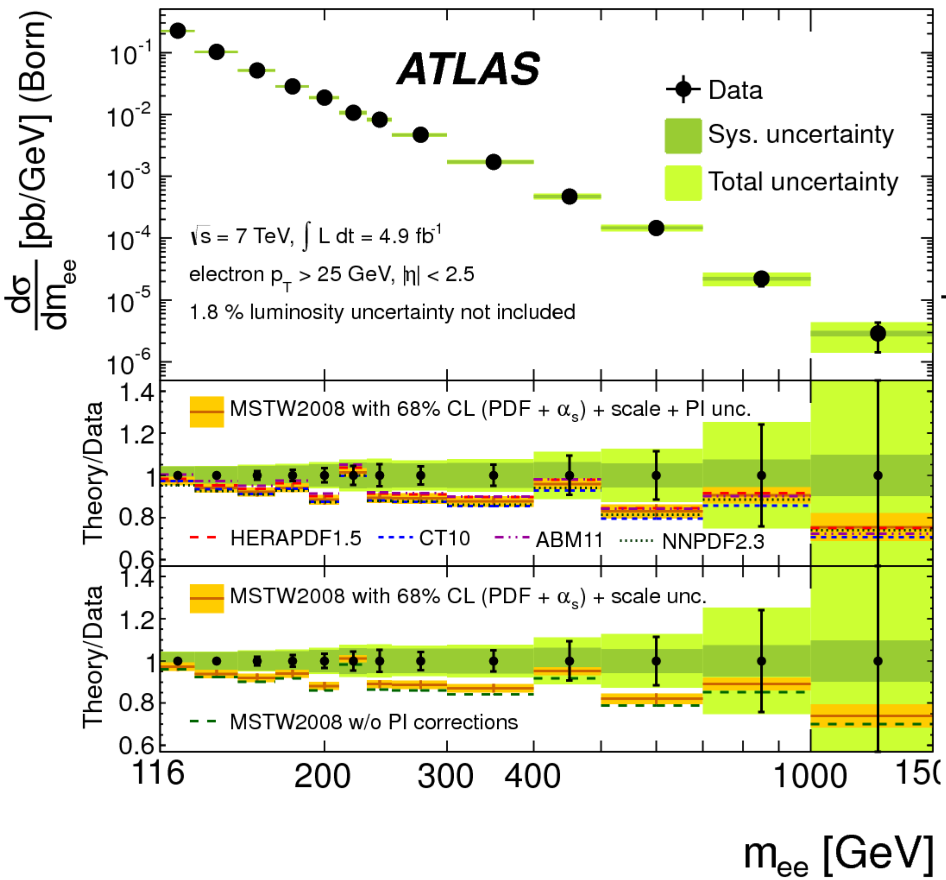
Source of uncertainty	Uncertainty [%] in m_{ee} bin 116–130 GeV	1000–1500 GeV
Total background estimate (Stat.)	0.1	7.6
Total background estimate (Syst.)	1.3	3.1
Electron energy scale & resolution	2.1	3.3
Electron identification	2.3	2.5
Electron reconstruction	1.6	1.7
Bin-by-bin correction	1.5	1.5
Trigger efficiency	0.8	0.8
MC statistics (C_{DY} stat.)	0.7	0.4
MC modelling	0.2	0.3
Theoretical uncertainty	0.3	0.4
Total systematic uncertainty	4.2	9.8
Luminosity uncertainty	1.8	1.8
Data statistical uncertainty	1.1	50

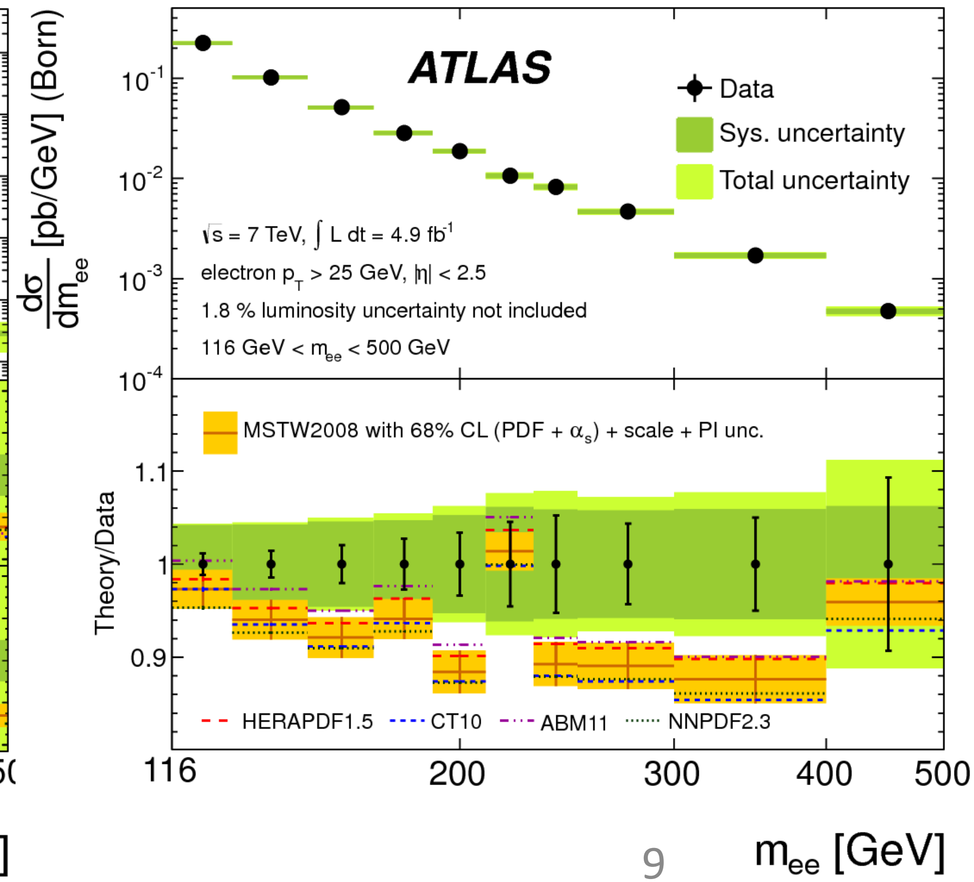
- Dominant background (6-16%) from particles misidentified as electrons (DiJet (QCD) and jet+real electron (e.g. pp → W(eν)+jets))
- Smaller irreducible background (5% -9%) from other processes with two real electrons in the final state
- Measurement dominated by systematic uncertainty up to m_{ee} ~400 GeV

High Mass Drell – Yan (continued)

Phys. Lett. B725 (2013) 223-242

- Predictions based on NNLO QCD FEWZ calculations + NLO EW corrections (becoming important at high energies)
- 5 different NLO PDF sets compatible with data, but data generally lies above predictions
- X^2 fits over the full mass yield, taking all uncertainties into account gives values between 13.5 (HERAPDF) and 18.9 (CT10) for 13 data points
- Potential to constrain large antiquark PDFs at large x.

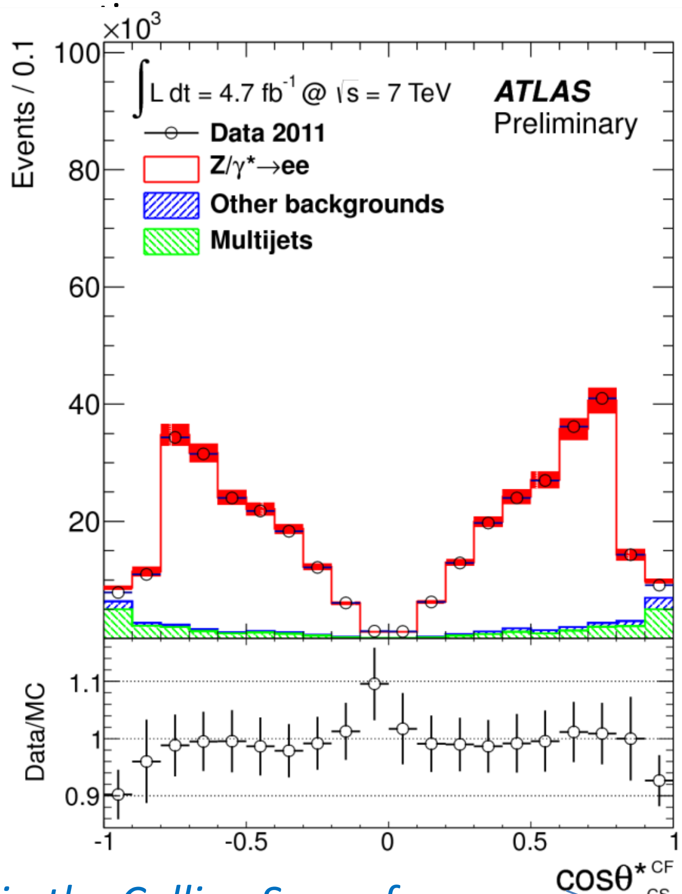




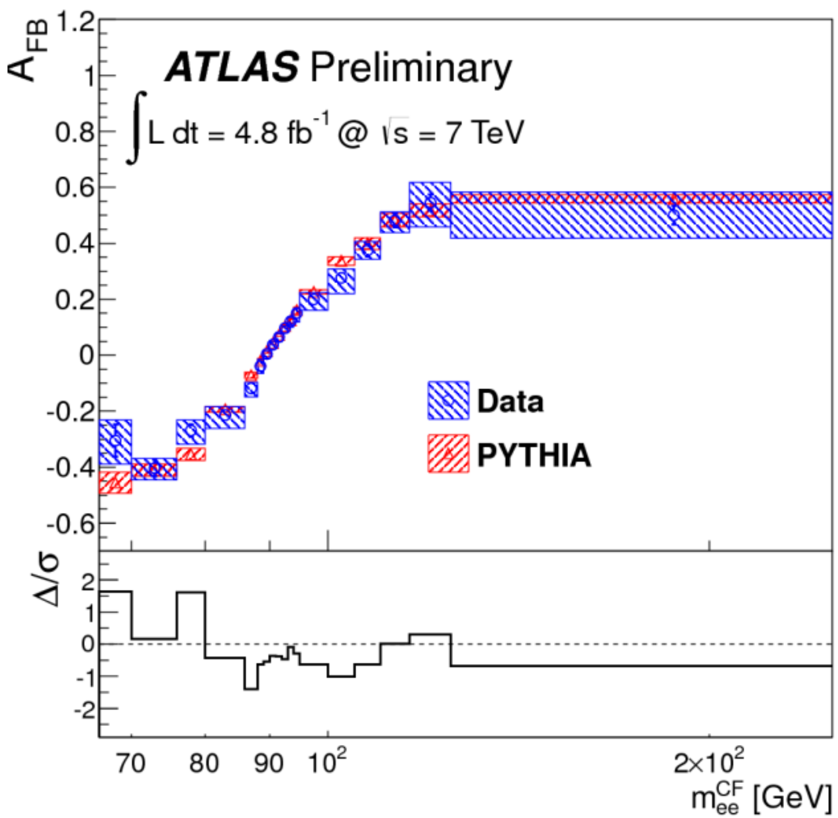
For/back asymmetry Z/γ* and $\sin^2\Theta_W$

ATLAS-CONF-2013-043

- Measurement: lepton pairs from Z/γ* decays. $\sqrt{s}$ = 7 TeV L=4.7 fb^{-1}
- Asymmetry ($A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$) sensitive to effective weak mixing angle $\sin^2\theta_W$
- Very important to include forward electrons. For CF (one central, one forward electron) A_{FB} is already visible from reco-level distribution
- A_{FB} unfolded to Born-level is compared to PYTHIA predictions including QED FSR NLO QCD



in the Collins-Soper frame

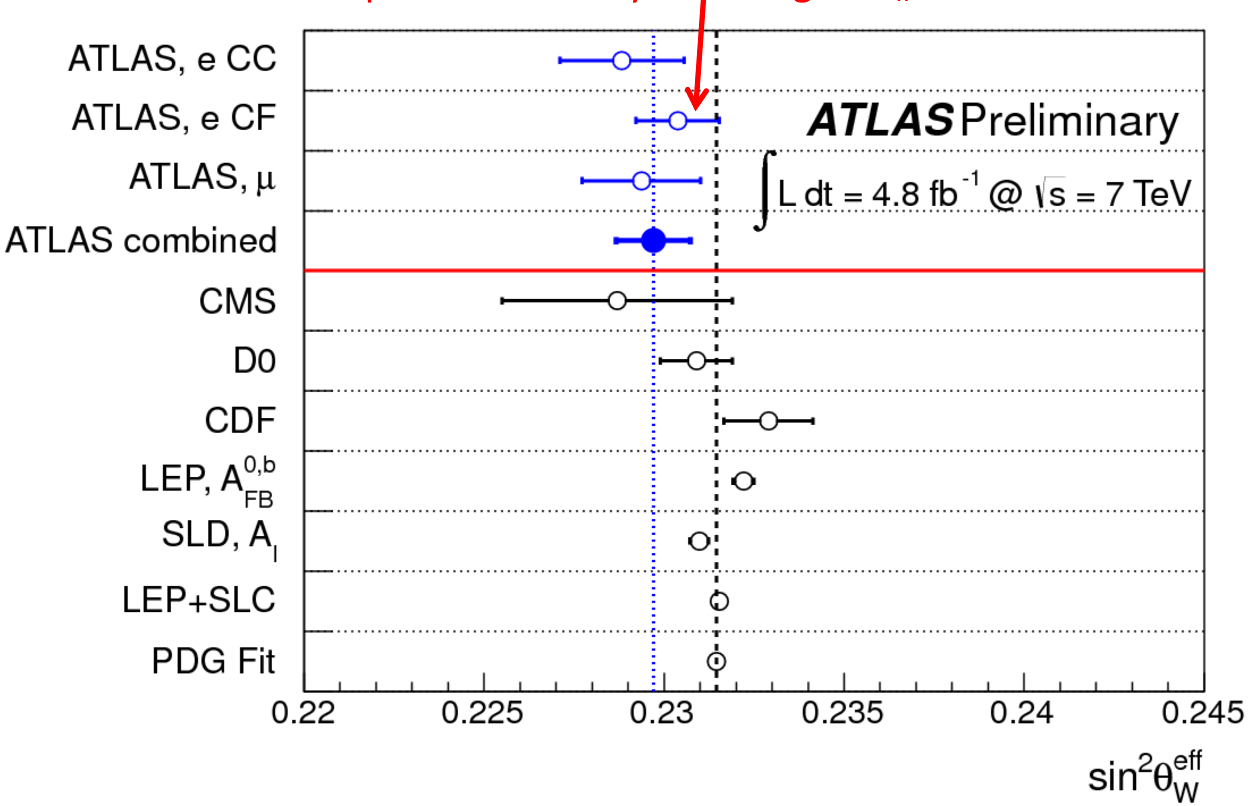


For/back asymmetry Z/γ^* and $\sin^2\Theta_W$ (continued)

ATLAS-CONF-2013-043

- Value of $\sin^2\Theta_W$ is extracted from the raw A_{FB} spectra by comparing it to MC predictions produced with varying initial values of the weak mixing angle
- Combined result: $\sin^2\theta_W^{eff} = 0.2297 \pm 0.0004(stat) \pm 0.0009(syst)$

Most precise result by including one „forward“ electron

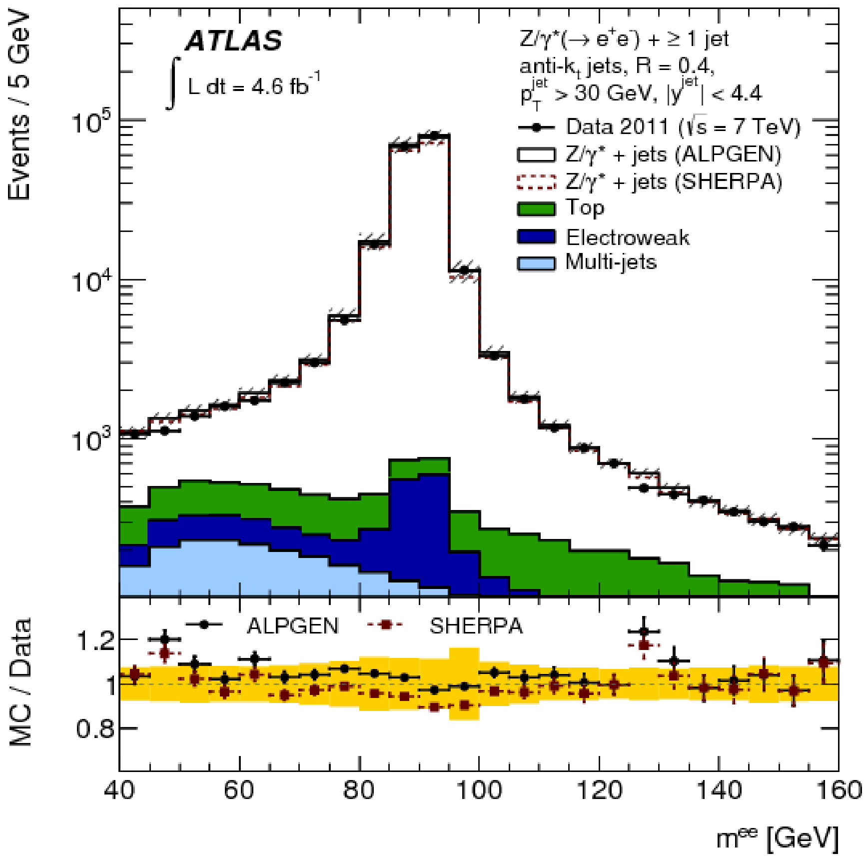


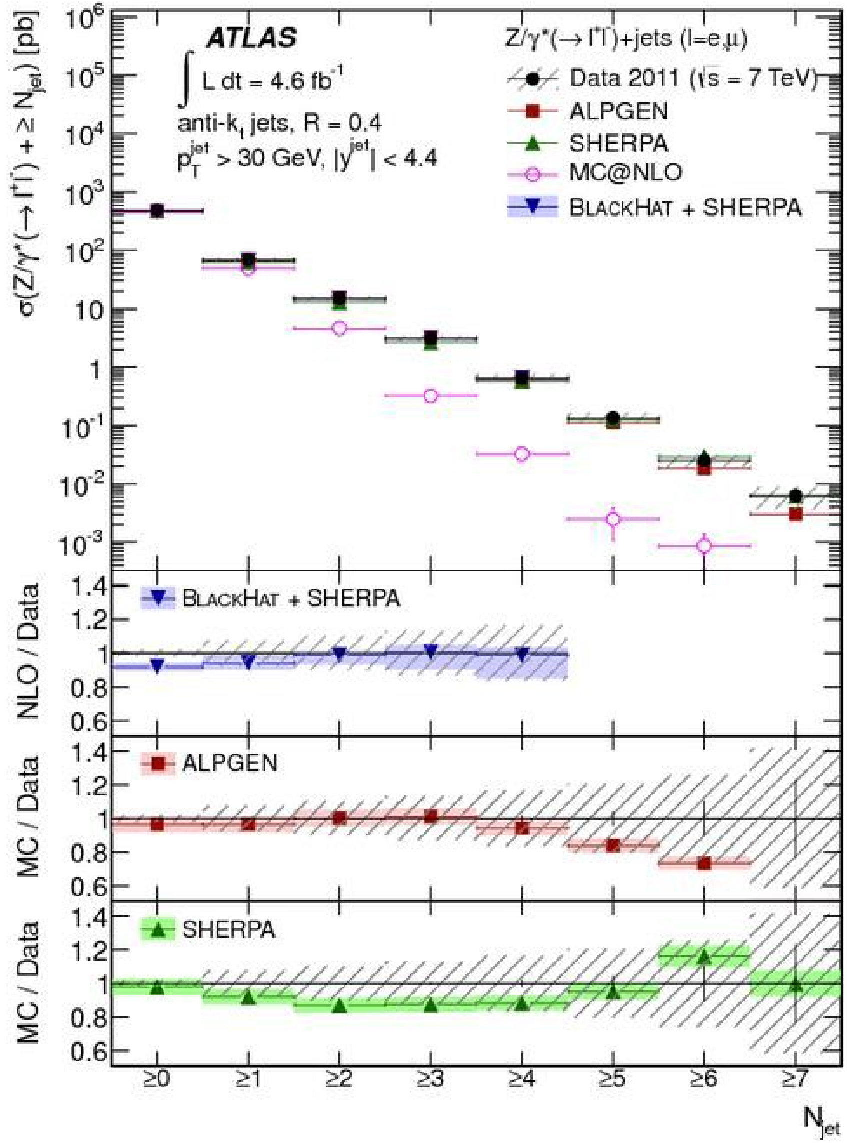
- Systematic uncertainty is dominated by the PDF uncertainty and MC statistics
- Result is consistent with previous measurements (1.8 σ from the PDG global fit)
- Precision is comparable with Tevatron results

Z + Jets

JHEP 07(2013) 032

- Inclusive and differential cross section in
  pp → Z(→ l^+l^-) + jets $\sqrt{s}$ = 7 TeV L=4.6 fb^{-1}
- Test new NLO predictions of jet multiplicity and momentum
- Systematic uncertainties are dominant
  - Largest uncertainty is JER/JES

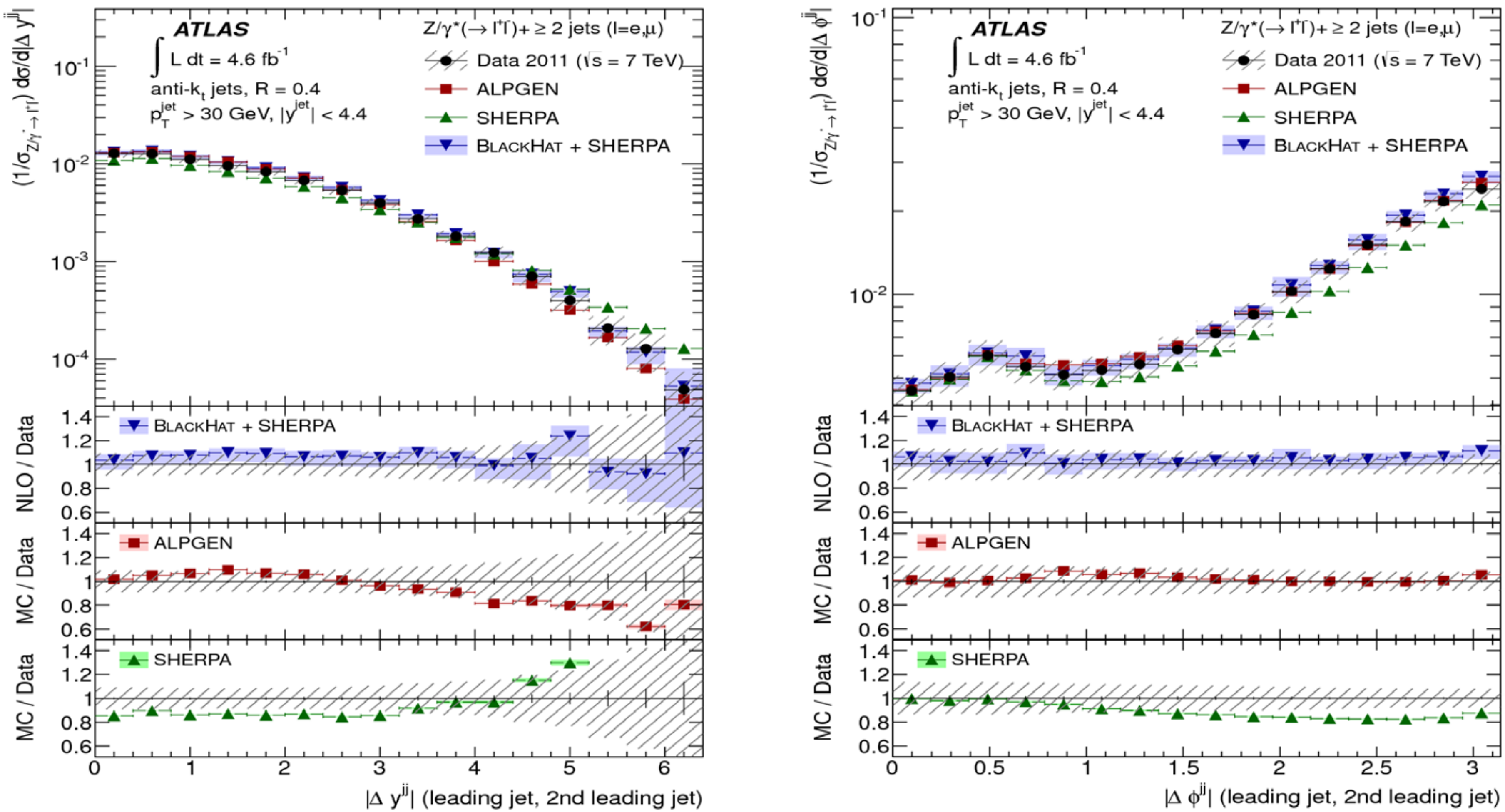




Z + Jets (continued)

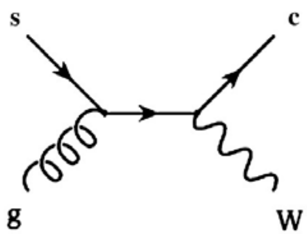
JHEP 07(2013) 032

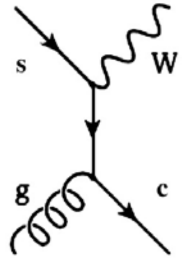
- Predictions:
  - BlackHat + SHERPA: NLO of up to Z + 4 partons
  - ALPGEN/SHERPA: LO of up to Z + 5 partons
  - MC@NLO: NLO of Z + 1 parton (previous slide only – mis-modelling for $N^j > 1$)

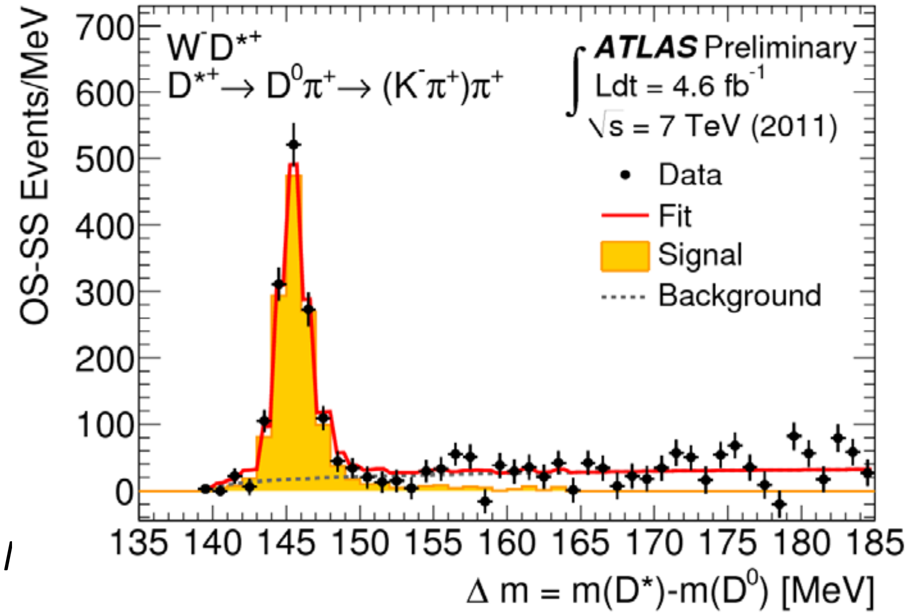


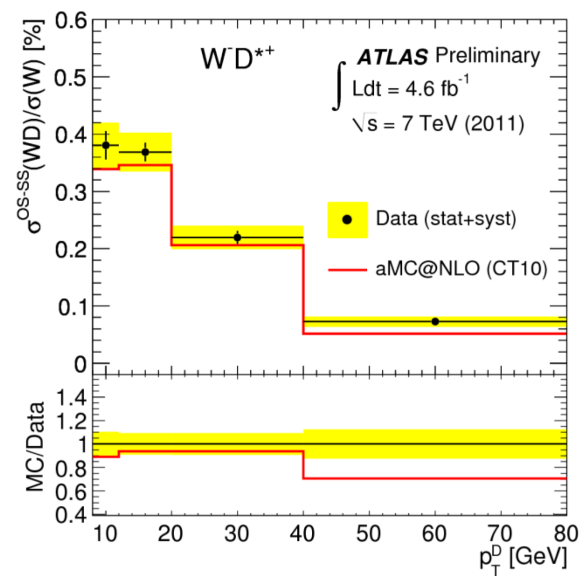
W + c

ATLAS-CONF-2013-045





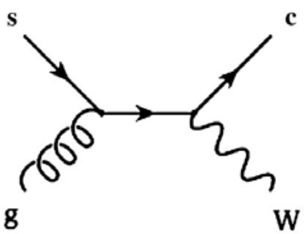


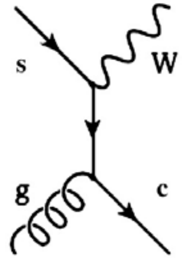


- Process: pp → W (→ $\mu\nu_\mu$/e ν_e) + c
  $\sqrt{s}$ = 7 TeV L=4.6 fb^{-1}
- Measurement: cross section for the production of a single charm hadron in association with a W boson and ratio $\sigma(W^\pm D^{(*)\pm})/\sigma(W^\pm)$ as a function of p_t^D and ηl
- Decay modes:
  - $D^+ \to K^-\pi^+\pi^+$
  - $D^{*+} \to D^0\pi^+$,
    - $D^0 \to K^-\pi^+$
    - $D^0 \to K^-\pi^+\pi^0$
    - $D^0 \to K^-\pi^+\pi^-\pi^+$
- Obtain D decay candidates from tracks
  - Exploit opposite charge of W and D by binning in opposite sign (OS) – same sign (SS) events to help remove backgrounds
  - W+D yield obtained by fitting $m(D^\pm)$ or $m(D^*)$-$m(D^0)$

W + c (continued)

ATLAS-CONF-2013-045



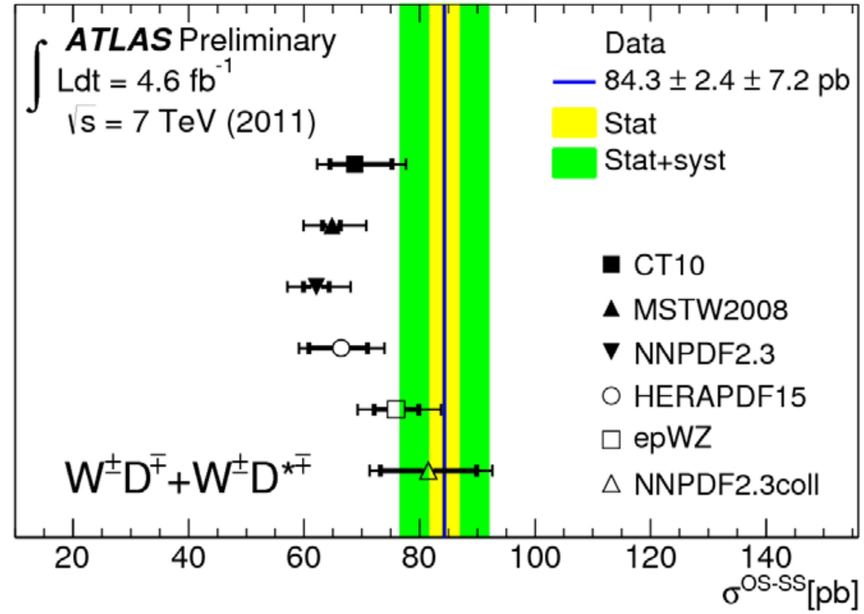


- $\sigma(W^{\pm}D^{(*)\pm})$ is directly sensitive to s-quark PDF
- Results are compared with MC@NLO NLO calculations

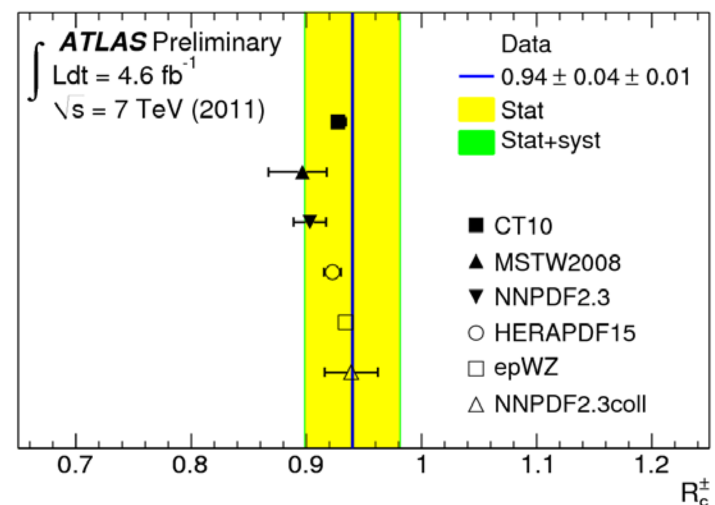
Good agreement with two out of five PDFs:

- ❑ epWZ (PR109 (2012) 012001) ,
- ❑ NNPDF2.3coll

Both of them assume symmetric s and anti-d quark distributions



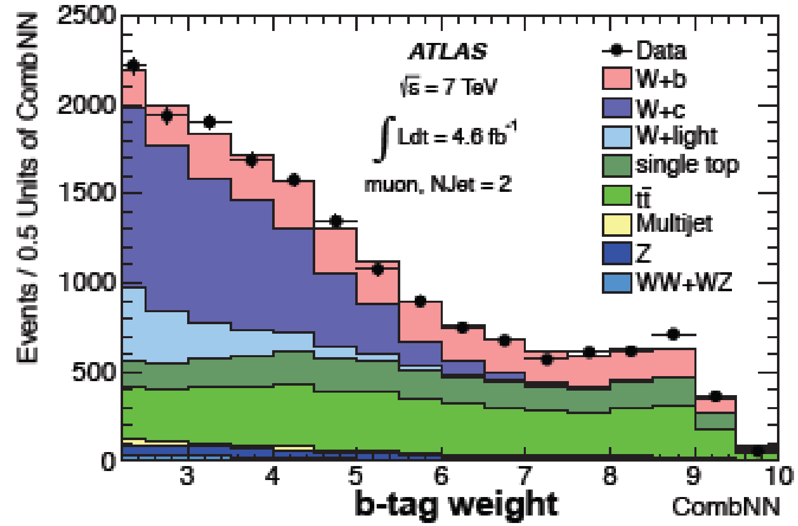
$R_c^{\pm} = \sigma(W^+D^{(*)-})/\sigma(W^-D^{(*)+})$ →



W + b-jets

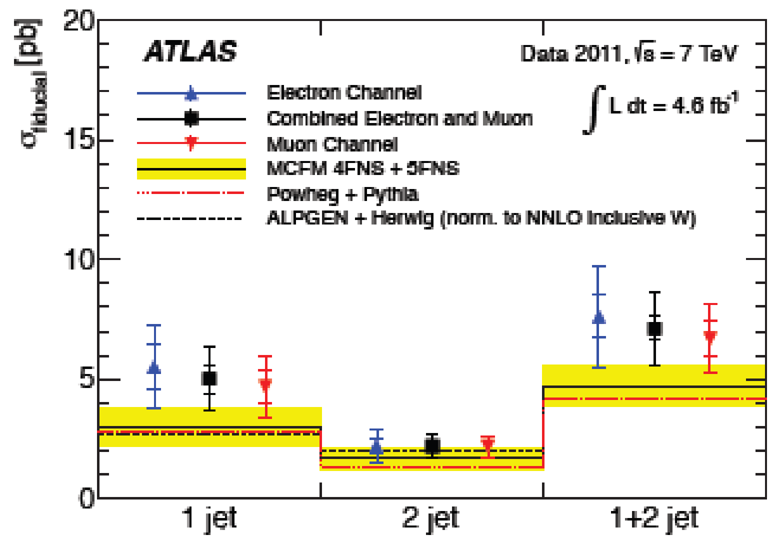
JHEP 06 (2013) 084

- Process: pp → W (→ $\mu\nu_\mu$/e ν_e) + b-jets
  $\sqrt{s}$ = 7 TeV L=4.6 fb^{-1}
- Measurement: σ as a function of p_T for 1 and 2 bjets
- *W*(→*lv*) + *bb* is a key background to Higgs search
- *W*(→*lv*) *H*(→*bb*)
- Testing pQCD with a heavy quark final state



$\sigma_{fiducial}$ = 7.1 ± 0.5 (stat) ± 1.4 (syst) pb

- ➢ Consistent within 1.5σ to MCFM NLO prediction
- ➢ Jet energy measurement is the dominant systematics

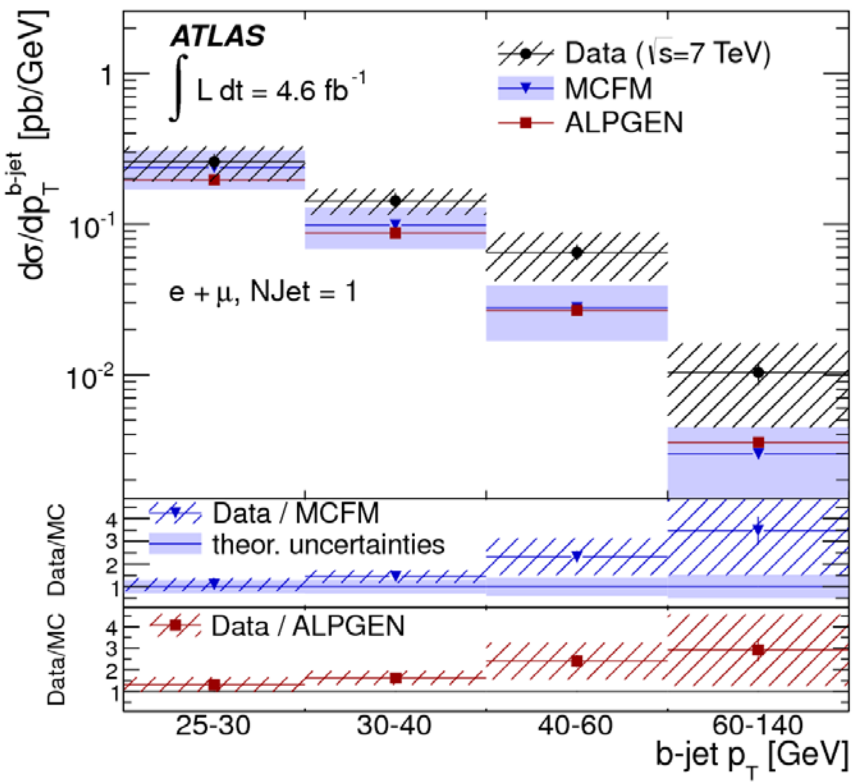


W + b-jets (continued)

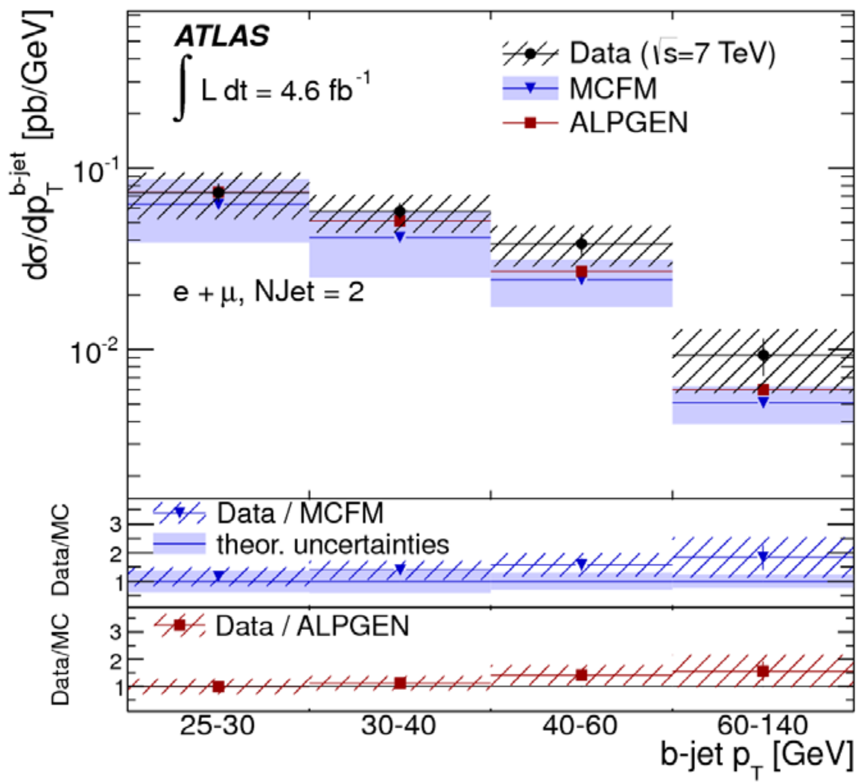
JHEP 06 (2013) 084

b-jet p_t spectrum

_W + b_



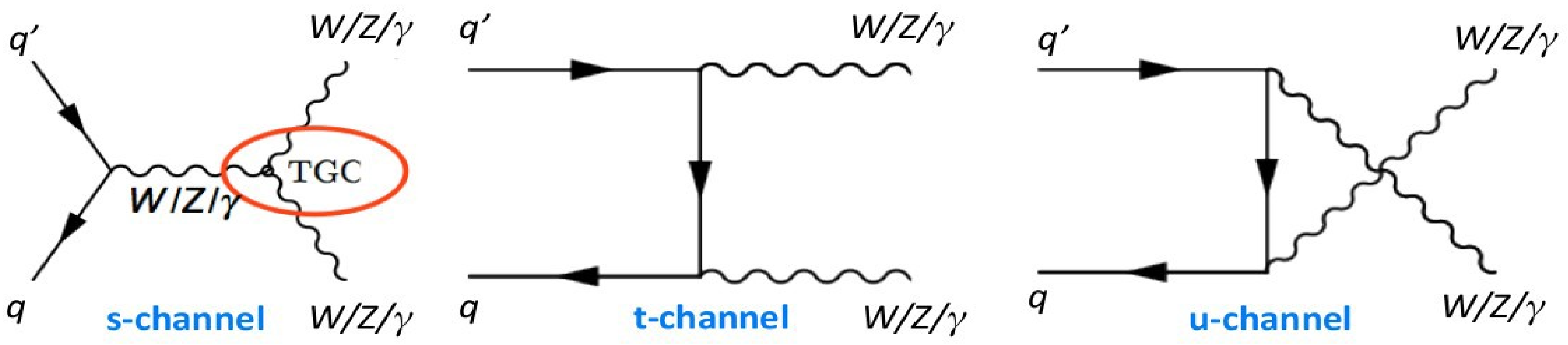
_W + bb_



Diboson

Importance of di-boson production:

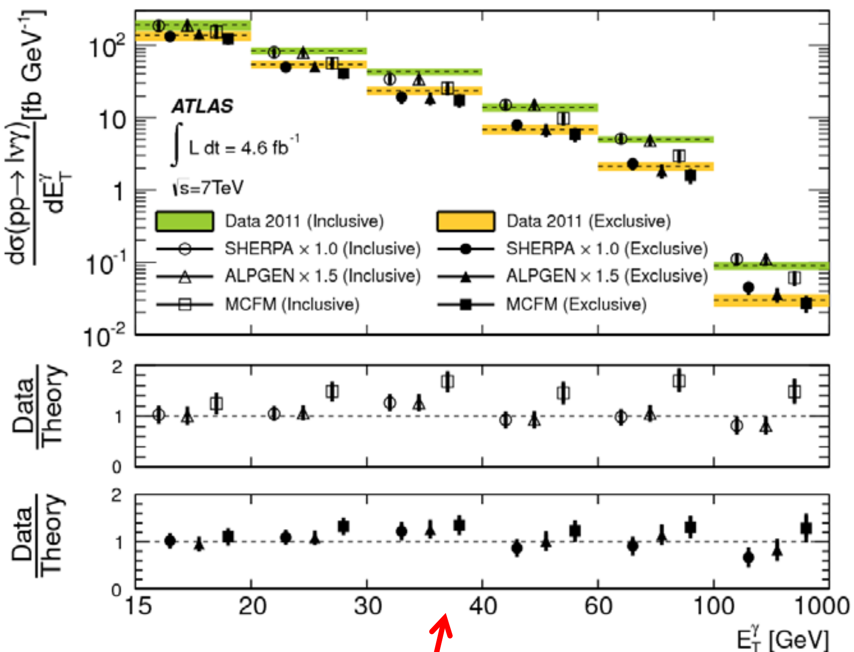
- significant and irreducible background for Higgs and exotica searches (for m_H = 125 GeV, H → VV is 25%)
- dibosons sensitive to Triple Gauge Couplings (TGC).
- deviations could indicate physics beyond SM, such as neutral TGC.
  - WWγ and WWZ are allowed
  - ZZγ, Z$\gamma\gamma$ and ZZZ are forbidden

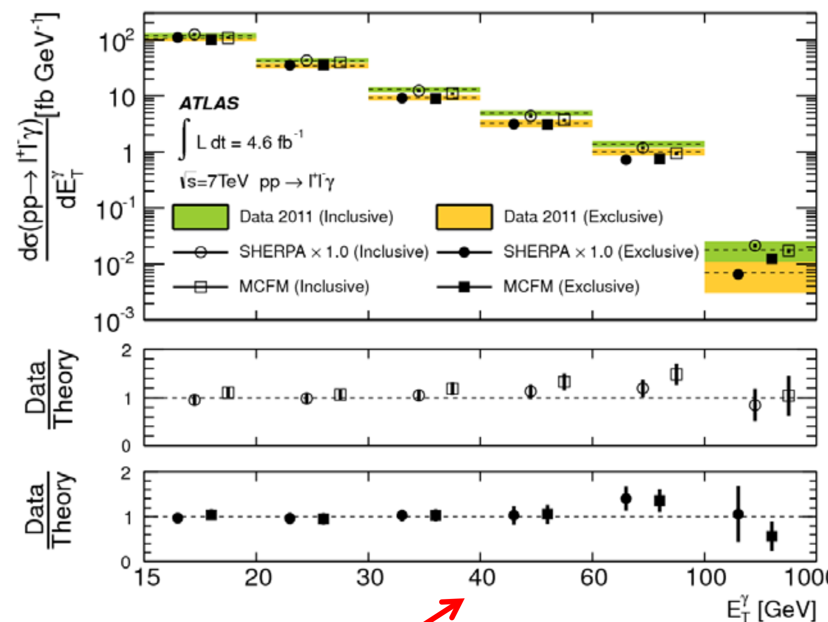


In this talk only final states with e and mu are considered

Wγ and Zγ cross section

Phys. Rev. D87 (2013) 112003





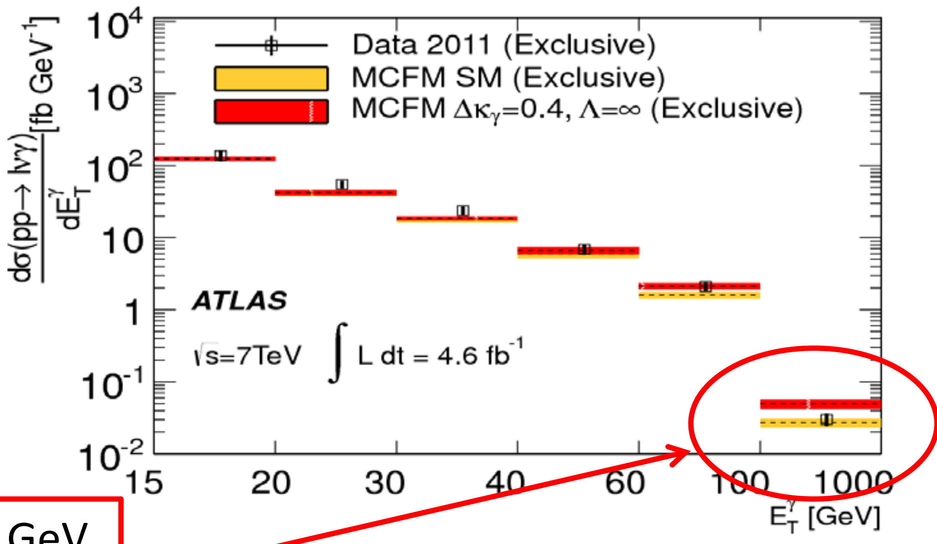
- Process: pp → W (→ $\mu\nu_\mu$/e ν_e) + γ, pp → Z(→ $\mu^+\mu^-$ / $e^+ e^-$) + γ
  $\sqrt{s}$ = 7 TeV L=4.6 fb^{-1}
- Wγ/Zγ kinematic distribution well described by ALPGEN/SHERPA
- Wγ measurement disagrees with MCFM NLO theoretical prediction at high E_T^{γ} with $N_{jet} \geq 0$. Agreement improved for N_{jet} =0
- Fair agreement with MCFM for Zγ.
- Dominant systematic uncertainties : photon ID, background normalization, jet energy scale

Wγ and Zγ aTGC

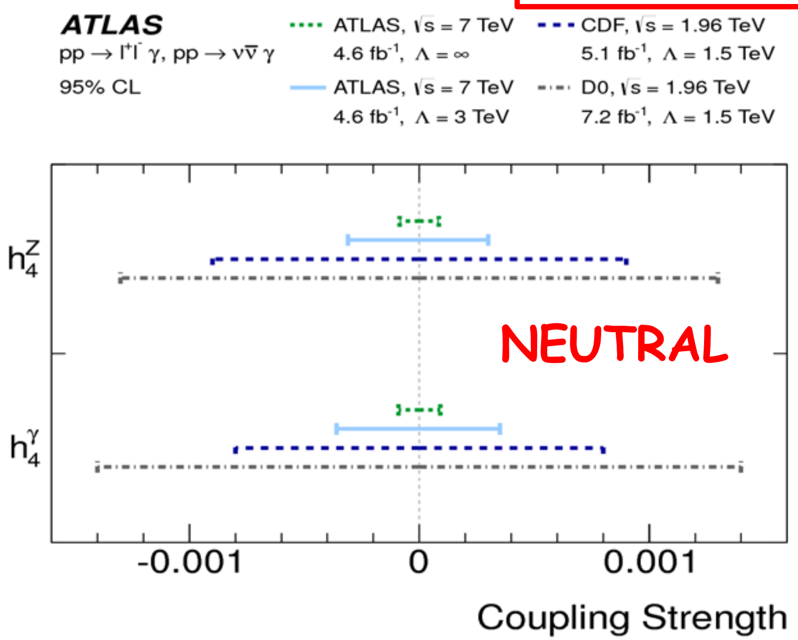
Phys. Rev. D87 (2013) 112003

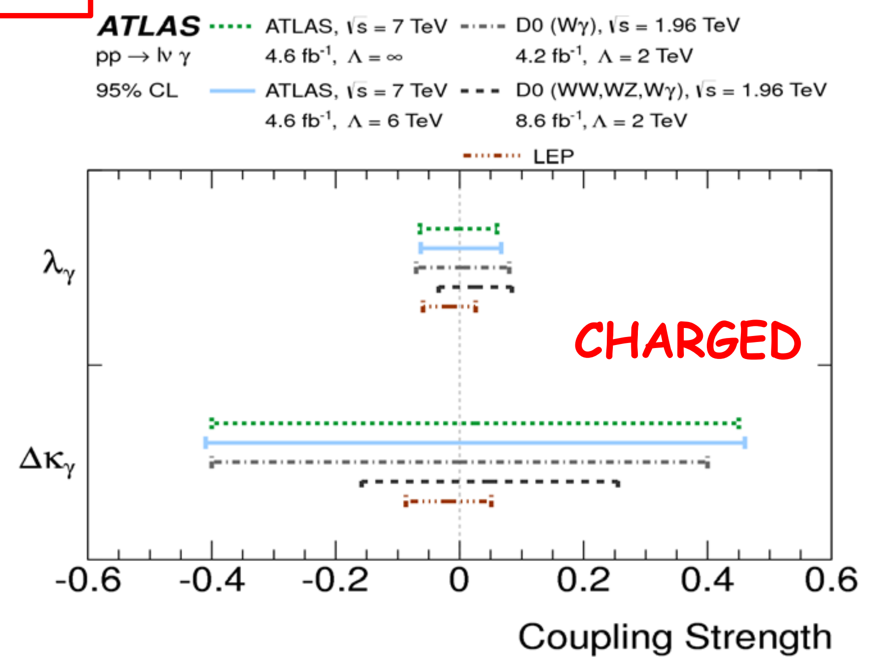
- aTGC search, using exclusive (Njet=0) photon E_T in all final states.
- \- Limits comparable or better to that obtained from Tevatron and LEP

- ***No deviation from the SM observed***



Only last bin E_T >100 GeV used to extract limits





WW cross section

Phys. Rev. D87 (2013) 112003

Calculation using MCFM with CT10 with gluon-gluon fusion contribution gives from theory:

Combined total cross-section @7 TeV

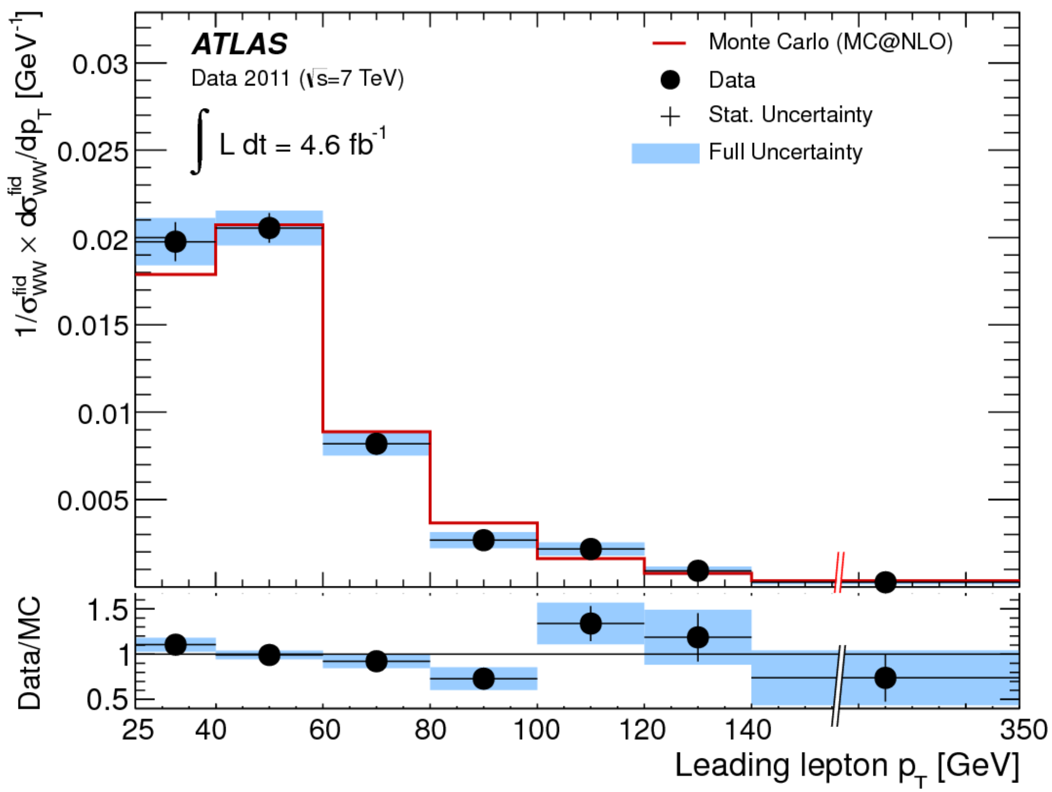
σ_{meas} = 51.9 ± 2.0(stat) ± 3.9(syst) ± 2.0 (lumi) pb

agreement

$\sigma_{NLO} = 44.7\ ^{+2.1}_{-1.9}$ pb

Normalized differential cross section as a function of the leading lepton transverse momentum

In agreement with MC@NLO SM prediction

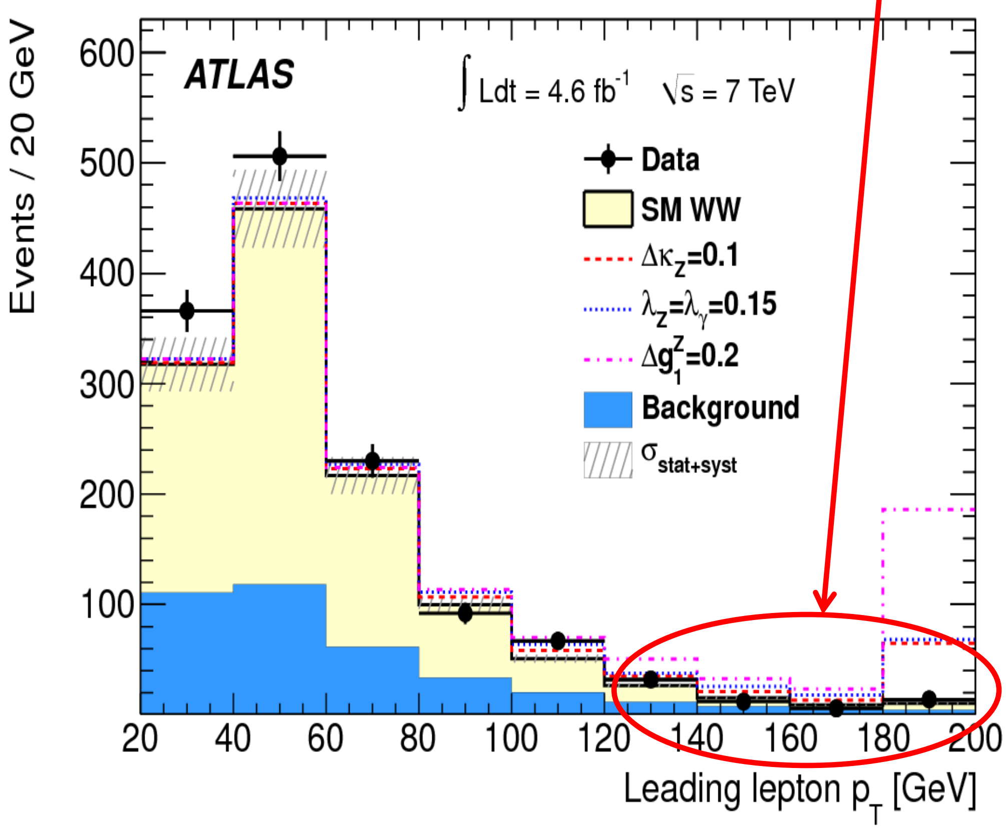


WWV aTGC from WW

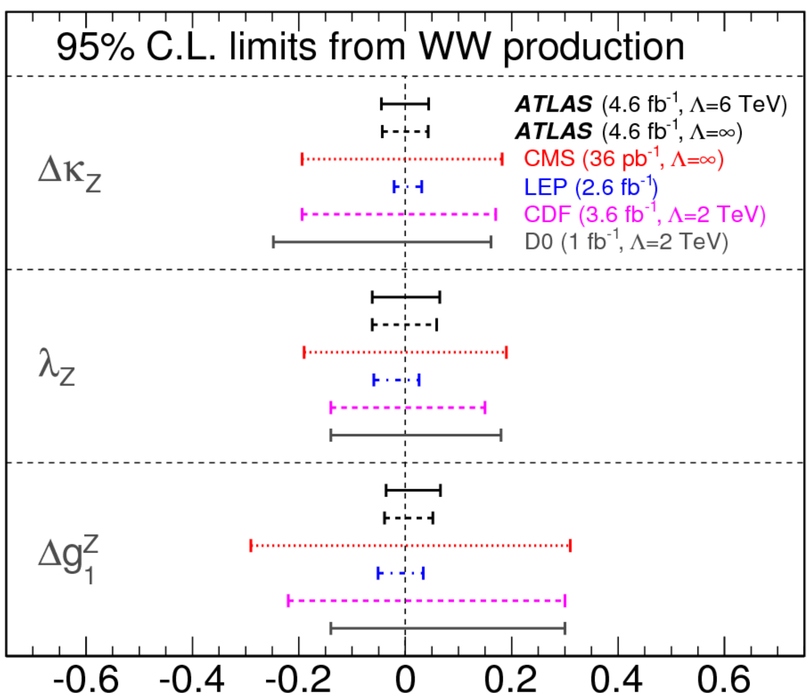
Phys. Rev. D87 (2013) 112003

Leading lepton p_T distribution is used to extract aTGC limits

Region more sensitive to aTGC (leading lepton p_T >120GeV)



No deviation from the SM observed



WZ cross section

7 TeV EPJC 72 (2012) 2173
8 TeV ATLAS-CONF 2013-021

Total cross-sections measured @ 7 TeV

σ_{Meas}= 19.0$^{+1.4}_{-1.3}$(stat) ± 0.9(syst) ± 0.4 (lumi) pb

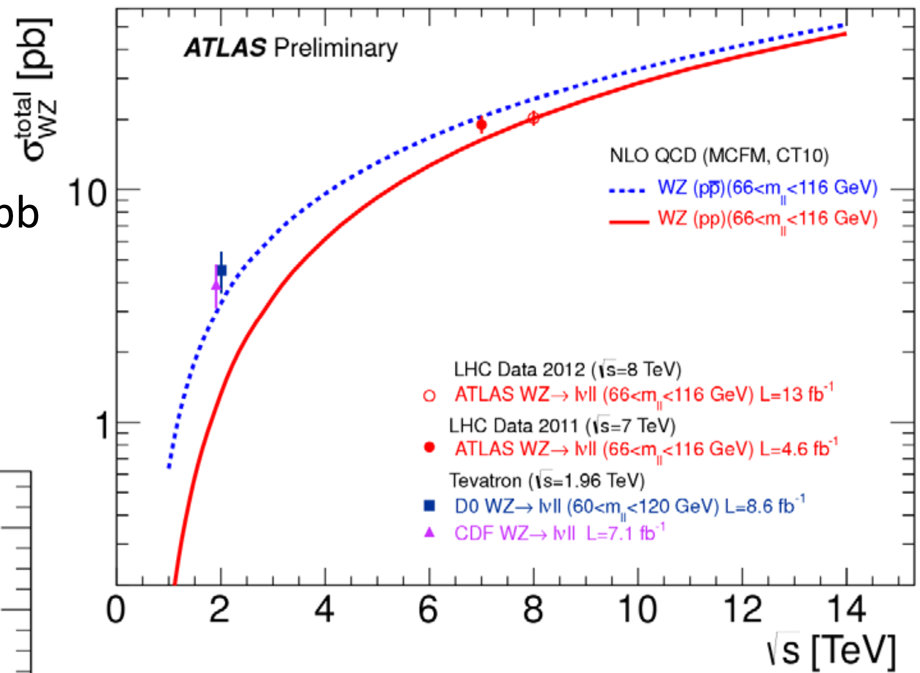
σ_{NLO} = 17.6 $^{+1.1}_{-1.0}$ pb

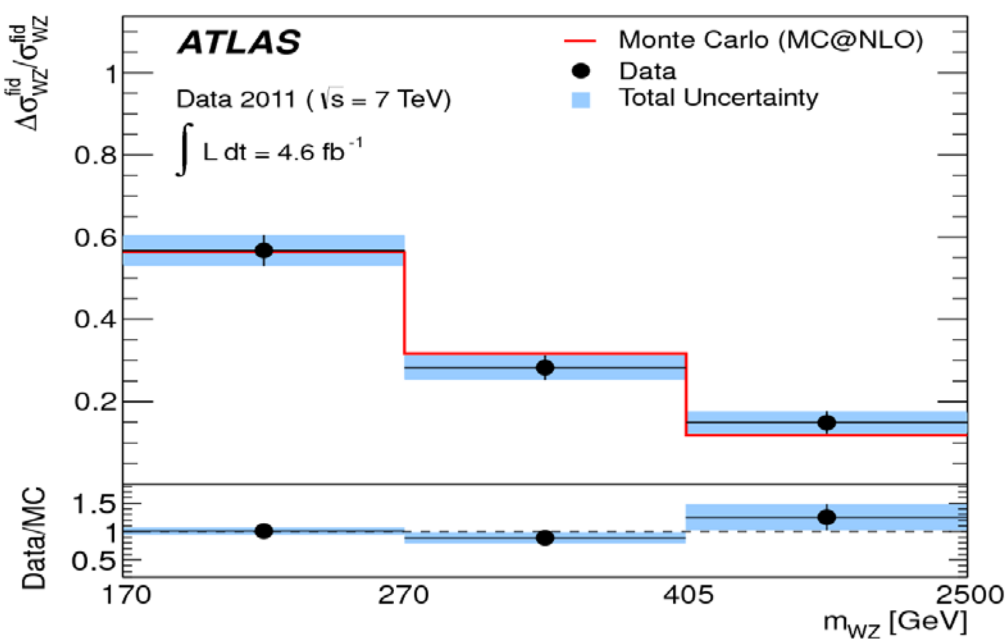
Total cross-sections measured @ 8 TeV

σ_{Meas}= 20.3$^{+0.8}_{-0.7}$(stat) $^{+1.2}_{-1.1}$ (syst)$^{+0.7}_{-0.6}$ (lumi) pb

σ_{NLO} = 20.3 ± 0.8 pb

Theory predictions using MCFM with CT10 pdf

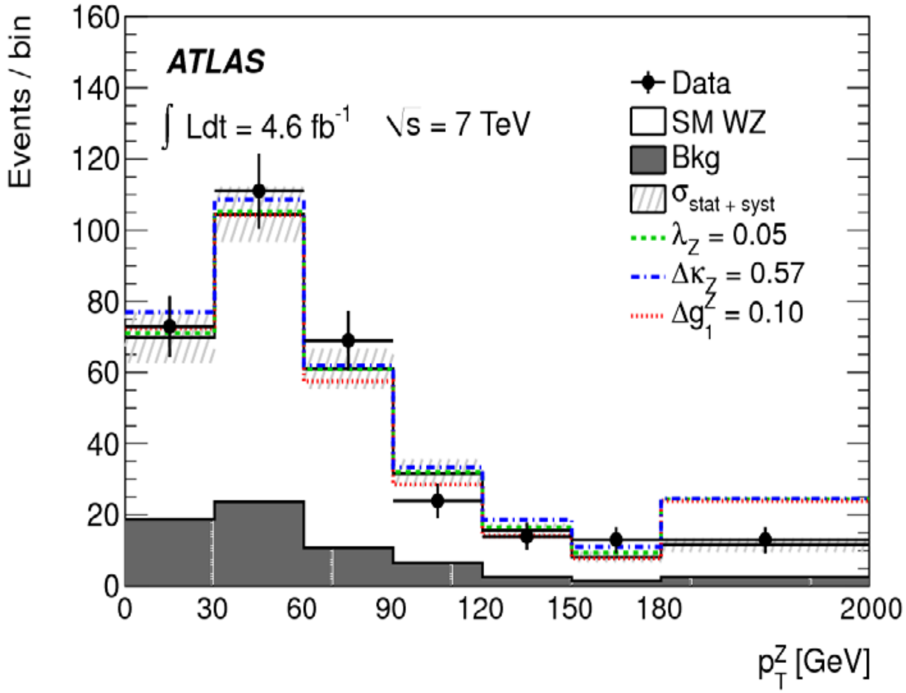




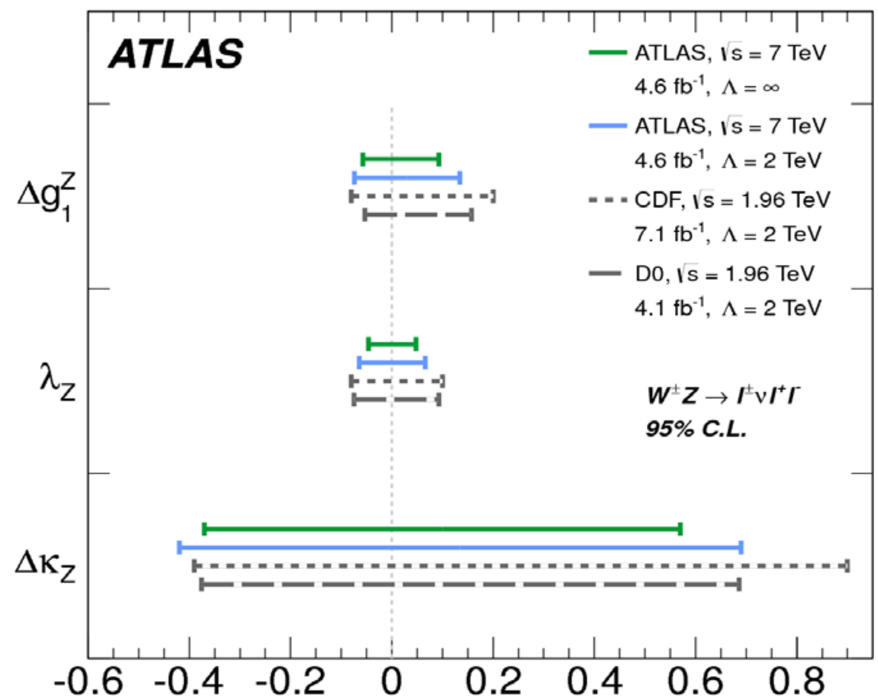
Differential cross-section is in agreement with MC@NLO SM prediction

WWZ aTGC from WZ

7 TeV EPJC 72 (2012) 2173



aTGC limits extraction using Z p_T distribution



No deviation from SM predictions observed using 4.6 fb^{-1} of 2011 dataset

ZZ cross section

7 TeV JHEP03 (2013) 128
8 TeV ATLAS-CONF 2013-020

Total cross-sections measured @ 7 TeV

σ_{Meas}= 6.7± 0.7(stat) $^{+0.4}_{-0.3}$ (syst) ± 0.3 (lumi) pb

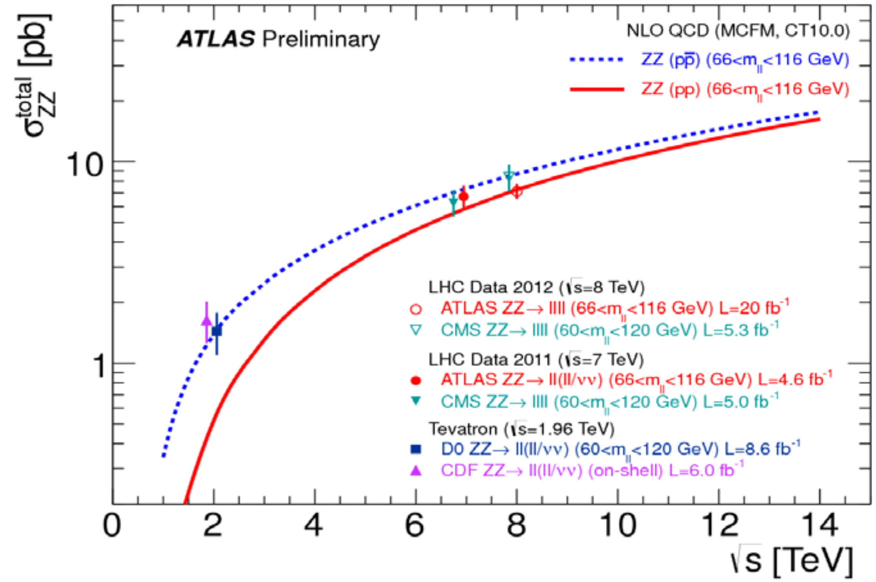
σ_{NLO} = 5.89 $^{+0.22}_{-0.18}$ pb

Total cross-sections measured @ 8 TeV

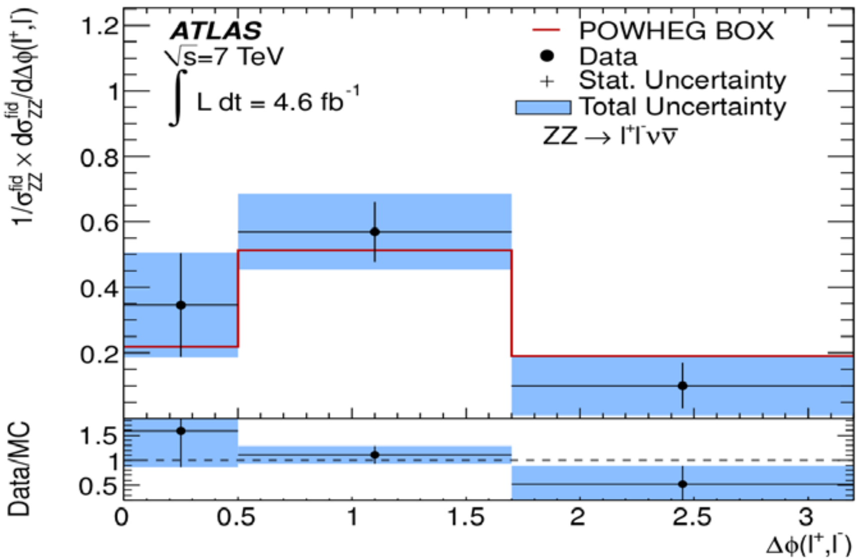
σ_{Meas}= 7.1$^{+0.5}_{-0.4}$(stat) ± 0.3(syst) ± 0.3 (lumi) pb

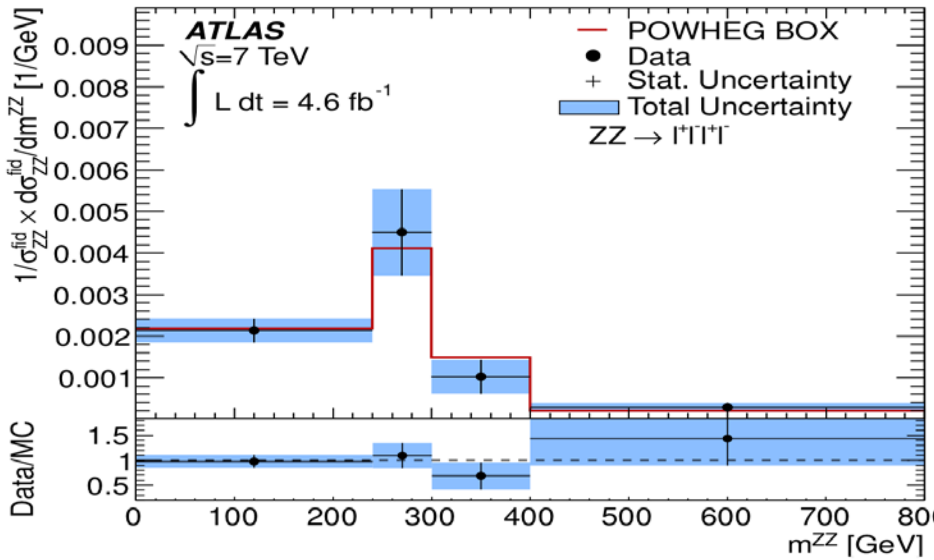
σ_{NLO} = 7.2 $^{+0.3}_{-0.1}$ pb

Theory predictions using MCFM with CT10 pdf



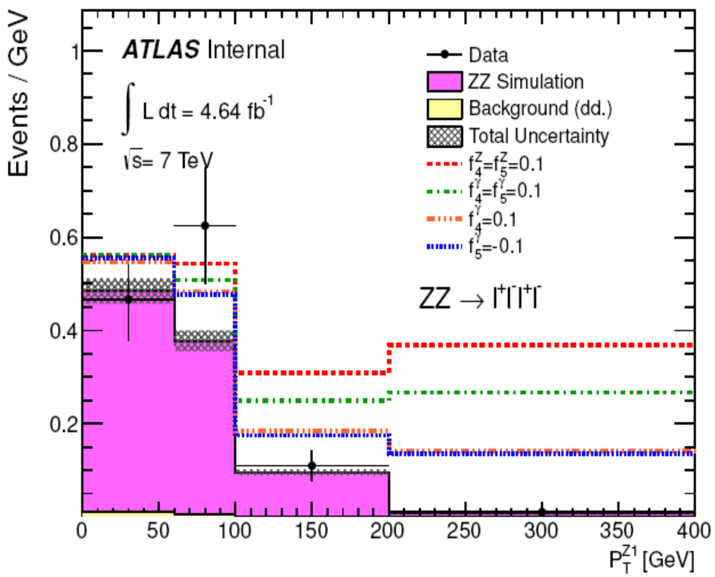
Differential cross-section is in agreement with MC@NLO SM prediction

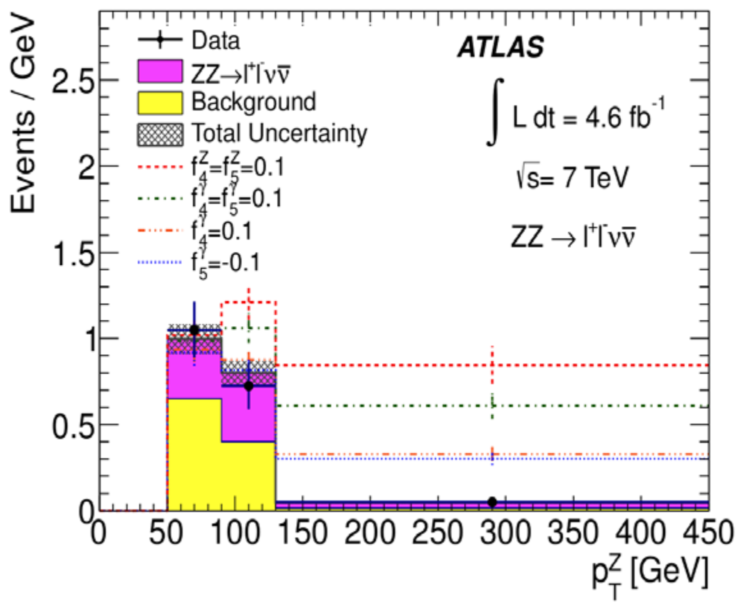




ZZV aTGC from ZZ

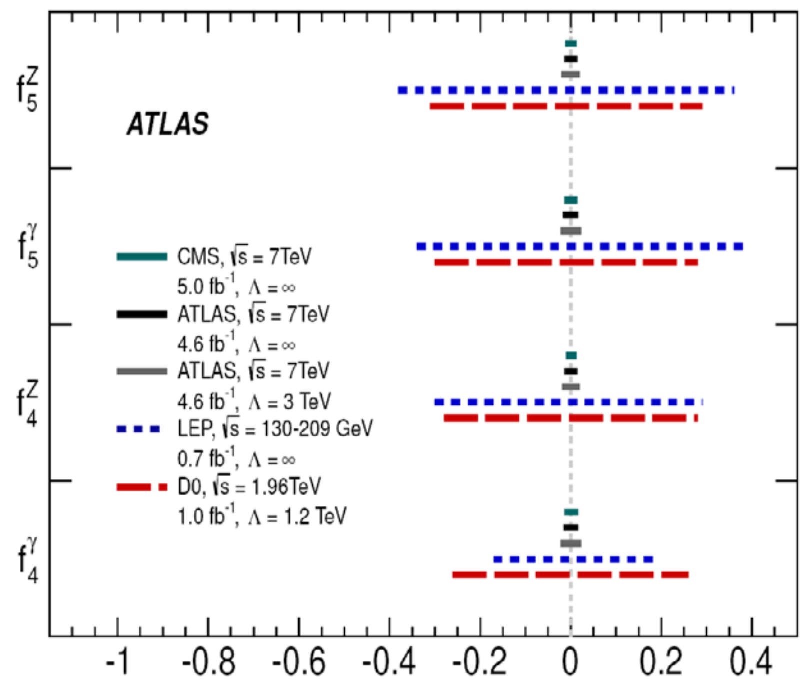
7 TeV JHEP03 (2013) 128





Enhanced yields at high p_T^Z predicted if any neutral aTGC, notobserved in data

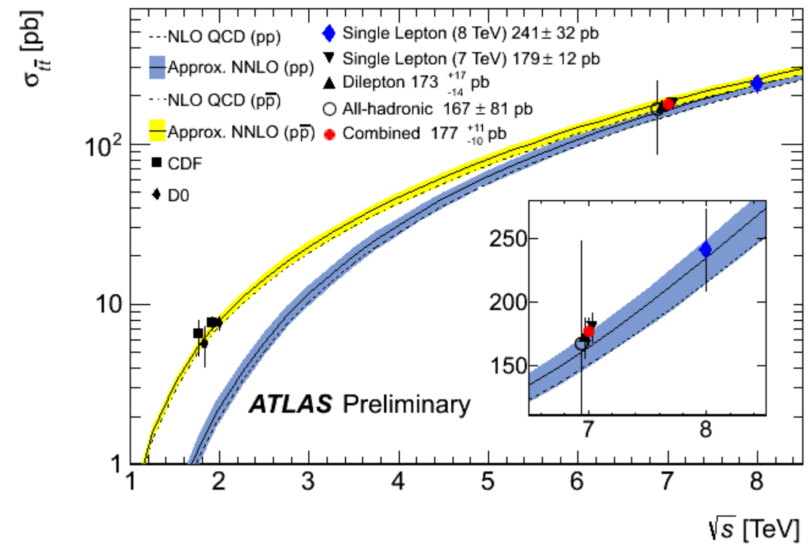
No deviation from the SM is observed

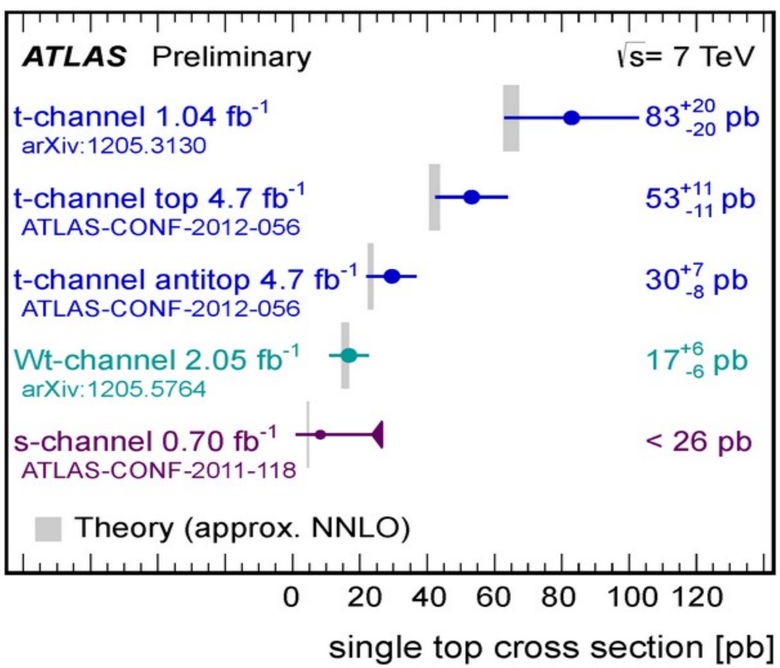


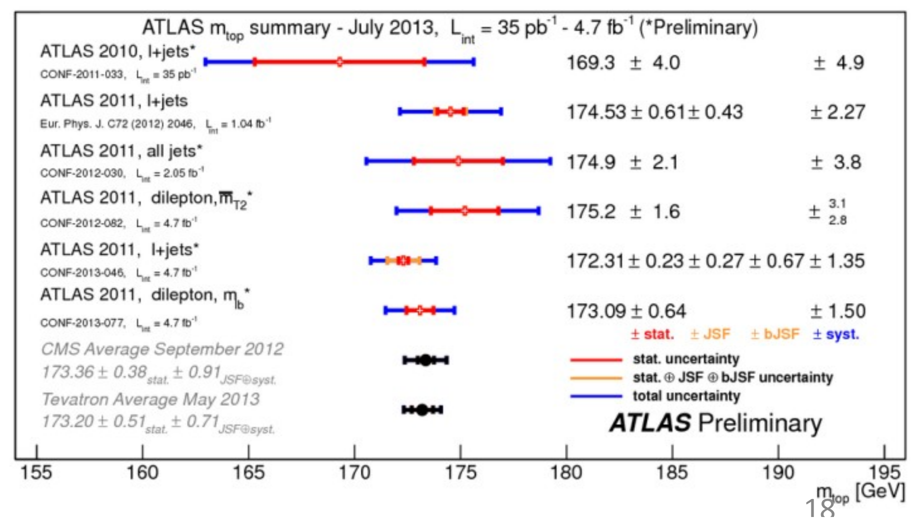
LHC limits on the ZZ anomalous triple gauge couplings are the most stringent ones

Top physics *(very briefly)*

- Heaviest particle in the SM: special role in EW symmetry breaking; large coupling to Higgs
- Top production to be well understood as it is the most important background to many New Physics signatures and Higgs.
- LHC gives an unprecedented sample of top quarks: ~6M top pairs and ~3M single top
- Tool for precise test of SM (NLO, NNLO QCD) and search for new physics
- Enough statistics to measure differential cross sections as a function of observables sensitive to QCD predictions







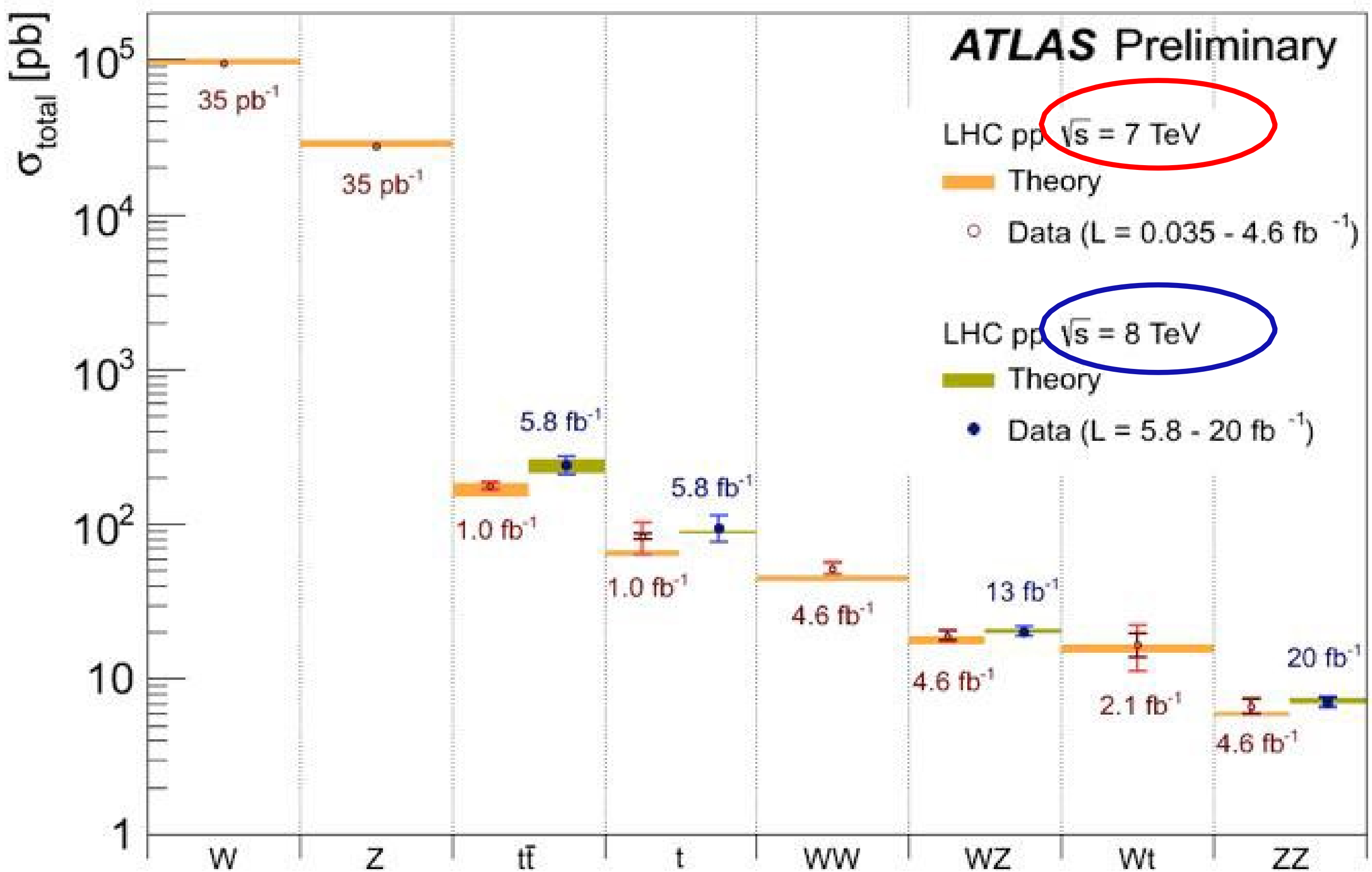
$$m_{top} = 172.31 \pm 0.75 \text{ (stat + JSF + bJSF)} \pm 1.35 \text{ (syst) GeV,}$$

S. Franchino, SM measurements with the ATLAS detector

Cross section summary plot

- SM processes well understood

  found impressive agreement with theory across orders of magnitude
- Experimental precision in data starts to challenge theoretical uncertainty.



Summary

- Very good ATLAS detector performance in RUN-I at 7 TeV and 8 TeV: high efficiency of data taking, computing and physics analysis.

- Large statistics of the LHC sample allows to perform more detailed SM measurements and already new measurements are probing observables at unprecedented level of accuracy and in never before exploited phase space regions.

- Agreement between data and SM predictions is observed for all SM processes

- Cross section measurements are in very good agreement with NNLO calculations and in many cases the systematics are becoming limiting: we are entering the era of precision measurements at the LHC.

- No sign of deviations due to possible aTGC contributions is observed. New limits are set that improve previous LEP and Tevatron results.

- Only a subset of ATLAS results have been shown here, please have a look at the experiment public page for a full list of publications.

- LHC and ATLAS are taking a short break until 2015 to come back at 14TeV at the new energy frontier giving new results and hopefully surprises.

Backup slides

Anomalous Triple Gauge Couplings

Effect of aTGCs are modelled using an effective Lagrangian which depends on few parameters

Anomalous TGC signatures:

- Enhancement of cross-section at high p_T distributions
- Change in angular distributions

SM predictions: $\lambda_\gamma = \lambda_Z = 0$; $g_1^Z = K_\gamma = K_Z = 1$

$$a = a_0 / (1 + \frac{\hat{s}}{\Lambda_{FF}^2})^n$$

- n = form factor power
- Λ_{FF} is the scale for new physics
  - Λ_{FF} = few TeV preserves unitarity, less general
  - No Form Factor violates unitarity at high energy, no model assumptions

Charged TGC

coupling	parameters	channel
$WW\gamma$	λ_γ, $\Delta\kappa_\gamma$	WW, Wγ
WWZ	λ_Z, $\Delta\kappa_Z$, Δg_1^Z	WW, WZ
$ZZ\gamma$	h_3^Z, h_4^Z	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma Z$	f_{40}^Z, f_{50}^Z	ZZ
ZZZ	f_{40}^γ, f_{50}^γ	ZZ

Neutral TGC