LHC days in Split, October 1-6, 2012

W and Z physics in ATLAS

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on behalf of the ATLAS Collaboration

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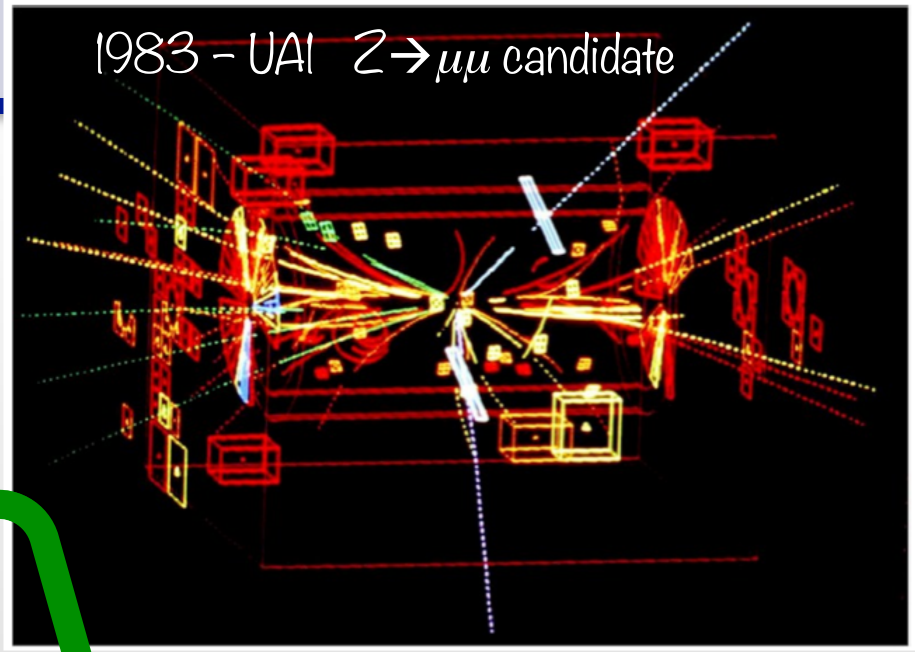
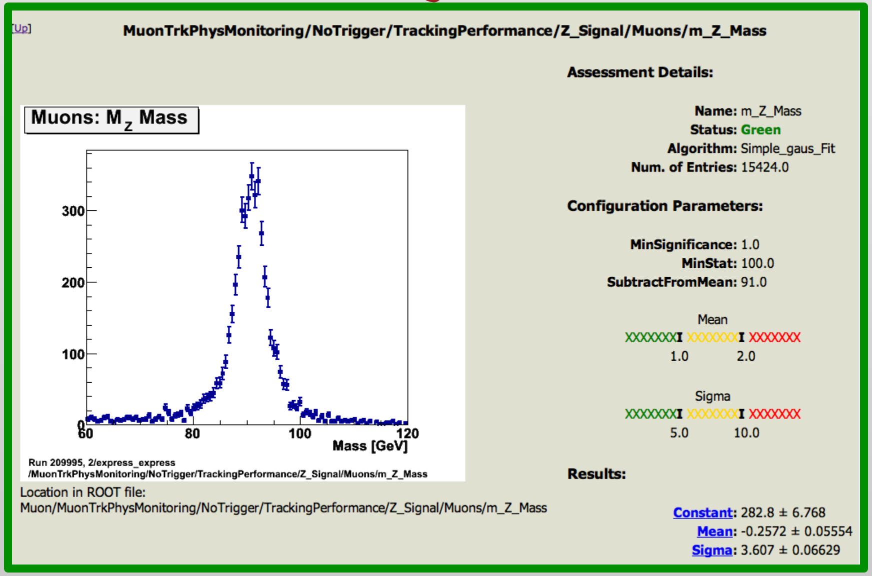
INTRODUCTION

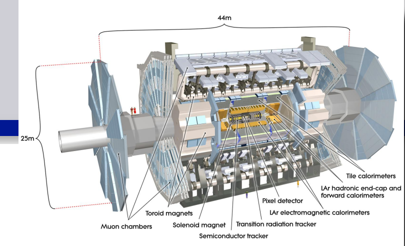
- After 30 years from their discovery … why we still measure W and Z bosons production at LHC ?
  - LHC is a W/Z factory → produced at high rates
  - clean signatures: isolated leptons, missing energy
  - A stringent test ground of pQCD; LO, NLO, NNLO at a new energy scale
  - Constraints on Structure Functions of the Proton
  - W/Z (+jets) are dominant signal and/or background in many other analyses and searches



ATLAS Run Monitoring

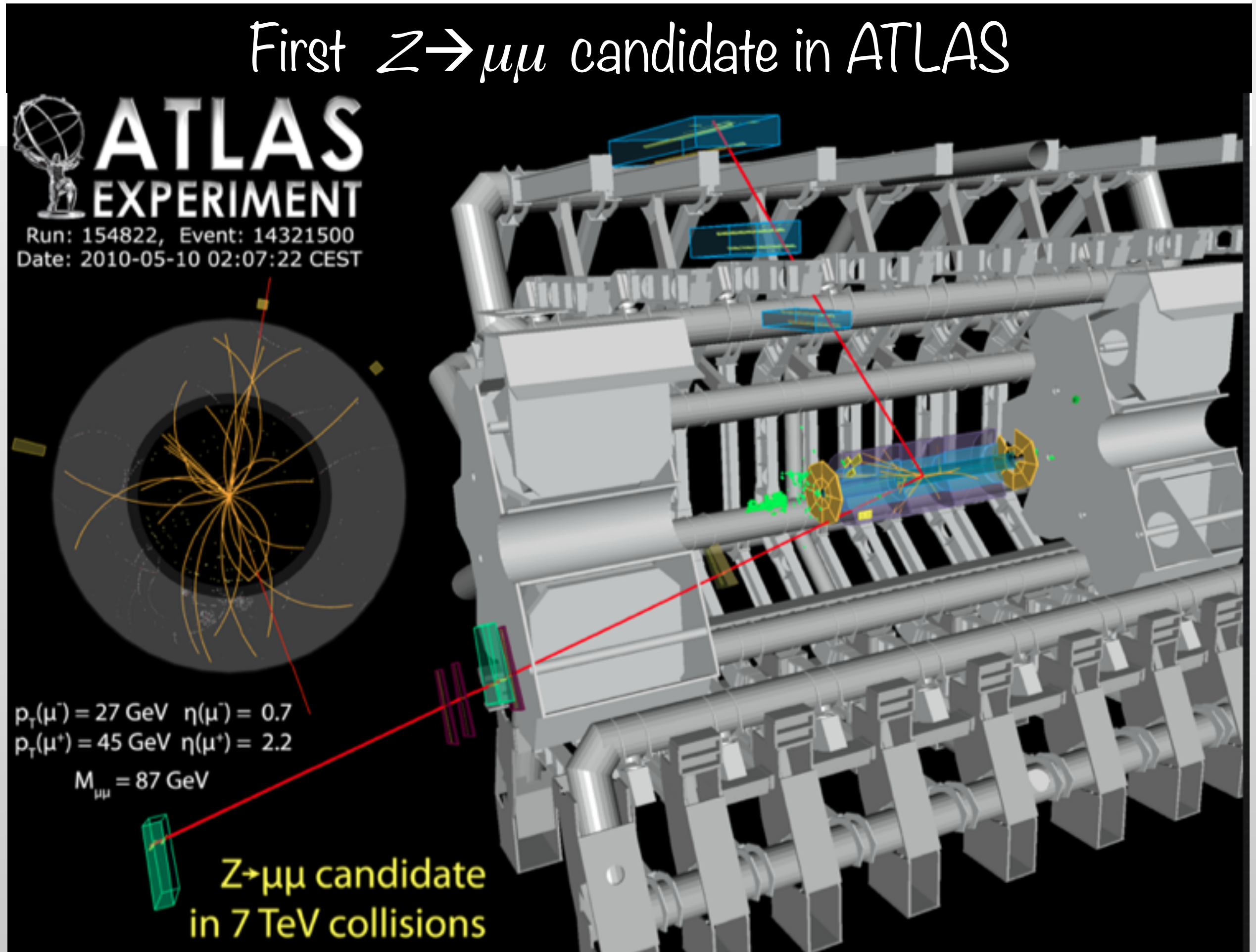


DATA AND LEPTON SELECTION

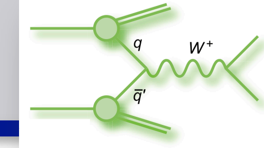


- For the analysis presented here: data from 2010 at √7 TeV
- W, Z measured in the *e*, μ channels using $36.2pb^{-1}$, $32.6\ pb^{-1}$ respectively
  - $W^{\pm} \to e^{\pm}\nu$, $W^{\pm} \to \mu^{\pm}\nu$
  - $Z \to e^{+}e^{-}$, $Z \to \mu^{+}\mu^{-}$

- Trigger
  - Muons: $|\eta_{\mu}|<2.4$
  - Electrons: $|\eta_{e}|<2.5$
- μ selection
  - $p_T>20$ GeV
  - $|\eta_{\mu}|<2.4$
- *e* selection
  - $p_T>20$ GeV
  - $|\eta_{e}|<2.47$ excluding $1.37<|\eta_{e}|<1.52$

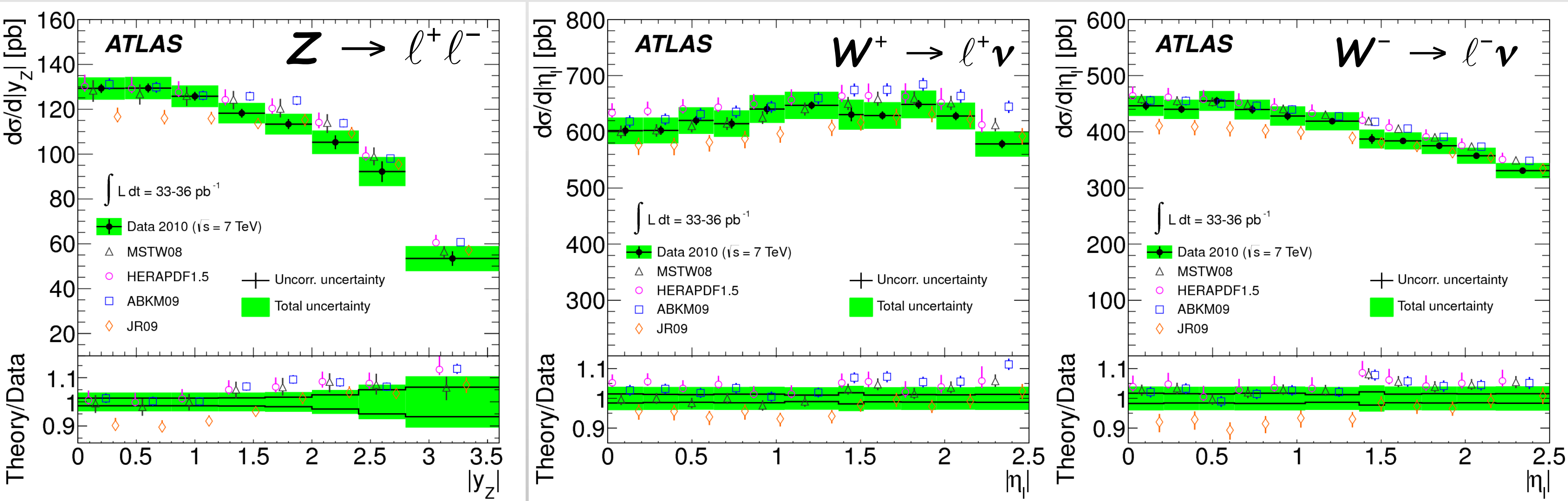


DIFFERENTIAL CROSS SECTIONS



- Differential cross sections measured in the *e, μ* channels and combined in the common fiducial volume:
  - As a function of $|Y_Z|$ for $Z \rightarrow \ell^+\ell^-$ with 2-3% accuracy in the central region
  - As a function of η_l for $W^\pm \rightarrow \ell^\pm\nu$ with 2% accuracy in the full range
- Comparison with NNLO calculations show an overall agreement with the considered PDF – some deviation observed (e.g. for JR09)

☞ *These Measurements can reduce the uncertainties on PDF and influence central values*



W Charge Asymmetry

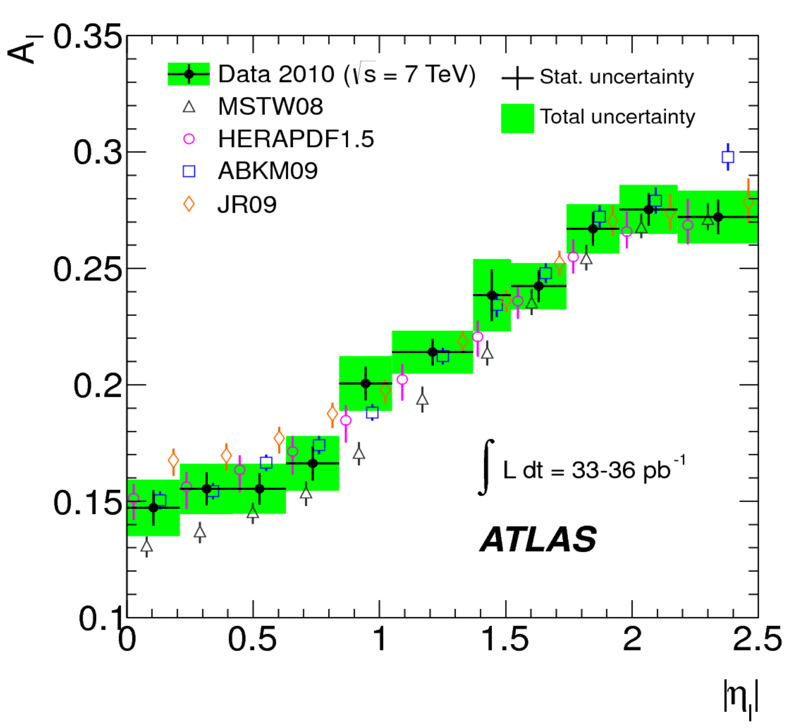
- In *pp* scattering, W^+ (W^-) bosons are mainly produced by the annihilation of a *u* (*d*) quark (valence+sea) in one proton with the $\bar{d}$ ($\bar{u}$) anti-quark (sea) in the other.

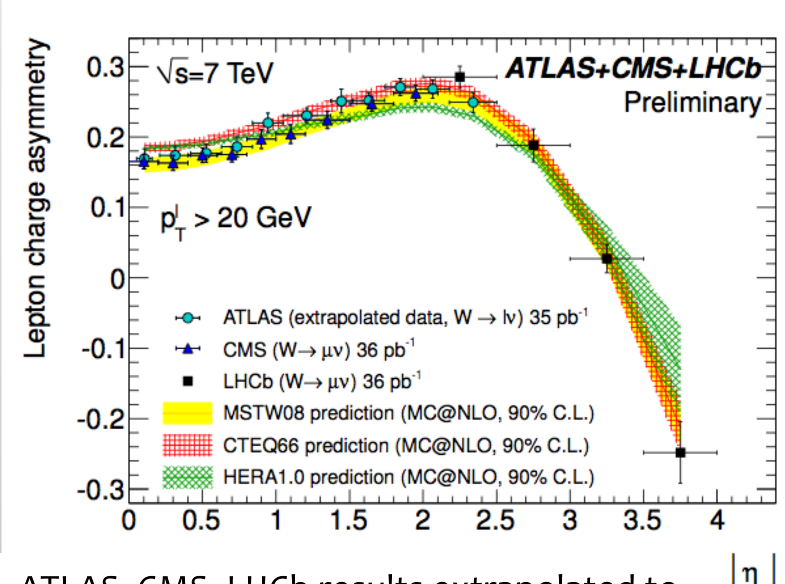
- Asymmetry in the W^+ and W^- rapidity distributions sensitive to u_v/d_v distributions

- Constrains on u_v/d_v distributions (PDF) can be obtained by measuring the W-charge asymmetry Vs η_l

$$A_\ell(\eta_\ell) = \frac{d\sigma_{W^+}/d\eta_\ell - d\sigma_{W^-}/d\eta_\ell}{d\sigma_{W^+}/d\eta_\ell + d\sigma_{W^-}/d\eta_\ell}$$

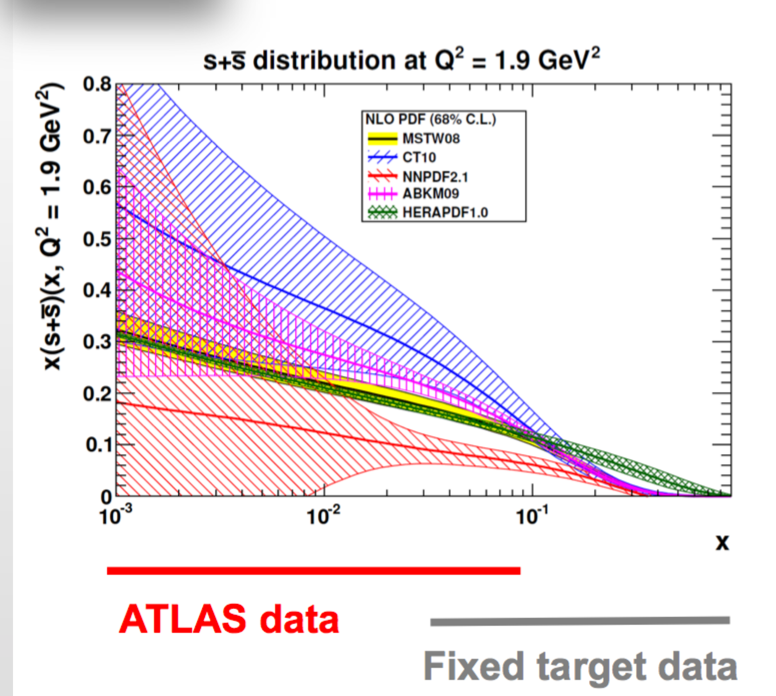
- Combined *e*, μ charge asymm. measured with accuracy 4-8% and compared with NNLO theoretical predictions





ATLAS, CMS, LHCb results extrapolated to a common region

STRANGE-QUARK DENSITY OF THE PROTON



- FLAVOR SU(3) SYMMETRY SUGGESTS THAT THE THREE LIGHT SEA QUARKS DISTRIBUTION ARE EQUAL.
- HOWEVER STRANGE QUARKS MAY BE SUPPRESSED DUE TO THEIR LARGER MASS

- THE COMPOSITION OF THE TOTAL LIGHT SEA $x\Sigma = 2x(\bar{u} + \bar{d} + \bar{s})$ IS NOT MEASURED AT 0.001<X<0.1
  - LOW X: CONSTRAINTS FROM HERA RESULTS
  - ATLAS W AND Z MEASUREMENTS PUT CONSTRAINTS AT $x\sim0.01$ AND HIGH $Q^2\sim M_{Z,W}^2$ → PROPAGATED AT LOW Q^2 THROUGH PQCD EVOLUTION

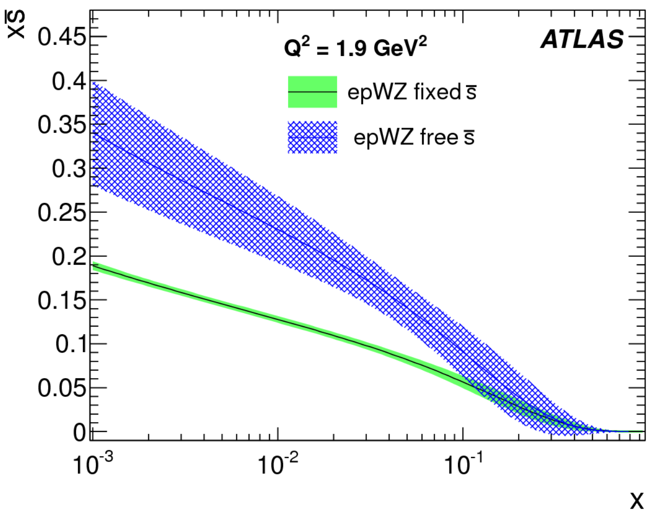
- Two types of NNLO fit, "epWZ" performed in the HERAFitter framework to
  - ATLAS differential σ(W) and σ(Z) data (Phys. Rev. D85 (2012) 072004)
  - HERA ep DIS data (JHEP 1001:109(2010))

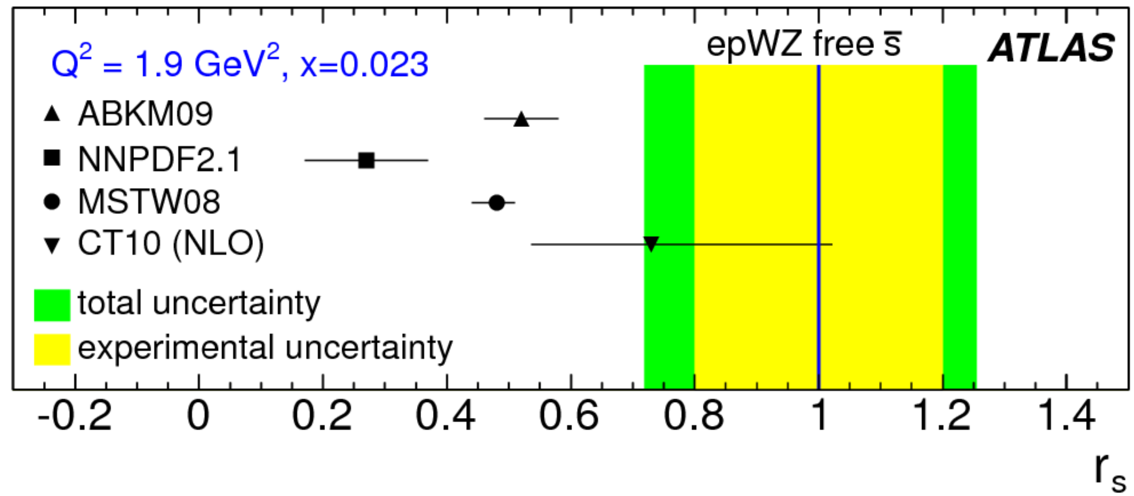
1) "Fixed strange fit" : s-quark distribution fully coupled to *d-sea-quark* and suppressed:
$\bar{s}/\bar{d} = 0.5 \ at \ Q_0^2 = 1.9 \ GeV^2$

2) "Free strange fit" : Parametrized *s-quark* distribution (assuming $x\bar{s} = xs$)

Result of the fit at Q^2=1.9 GeV^2, x=0.023

Comparison of the epWZ fixed strange and free strange NNLO fits





$$r_s = \frac{s(x)+\bar{s}(x)}{2\bar{d}(x)} = 1.00 \pm 0.20(exp) \pm 0.07(mod)\ ^{+0.10}_{-0.15}(par)\ ^{+0.06}_{-0.07}\alpha_s \pm 0.08(th)$$

More strange sea quarks than expected:

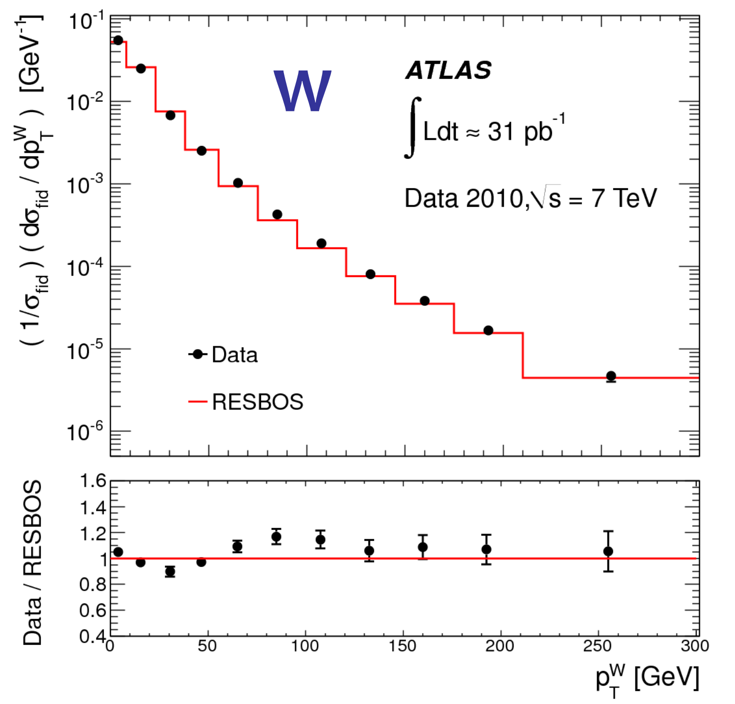
as much strange as down sea quarks

- Exp uncert. (both stat and syst) dominate
- Model uncert. from variation of charm mass, Q^2 cut and starting scale values
- Parametrization uncert. by additional parameters in the distributions
- Variation of α_s and theor. uncert. on different predictions of W,Z production

p_T DISTRIBUTIONS OF W / Z

- At lowest order W and Z $p_T \approx 0$
- Initial State Radiation will cause the bosons to have a finite transverse momentum:
  - AT LOW P_T DOMINATED BY MULTIPLE SOFT PARTONS
  - AT HIGH P_T DOMINATED BY EMISSION OF ONE OR MORE HARD PARTONS

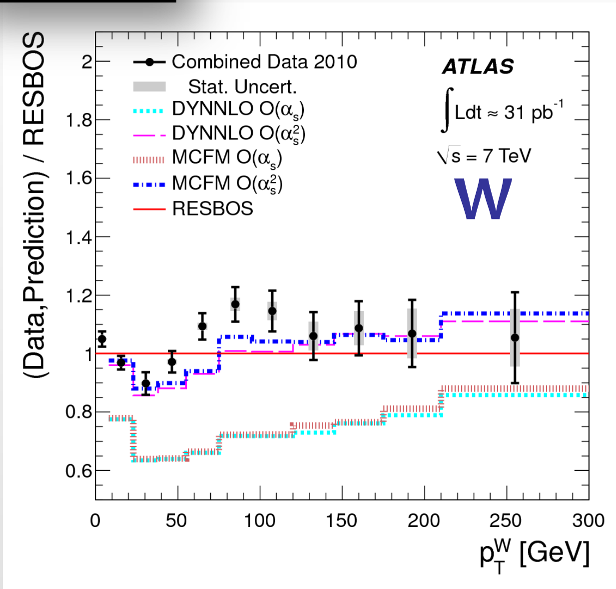
- p_T distributions of W and Z provides a useful test of QCD calculations:
  - different types of calculations are expected to provide the most accurate predictions for the low-pT and high-pT part of the spectrum

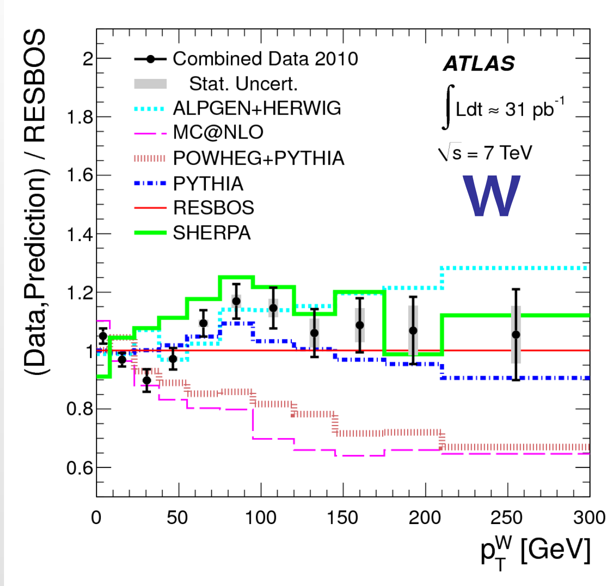


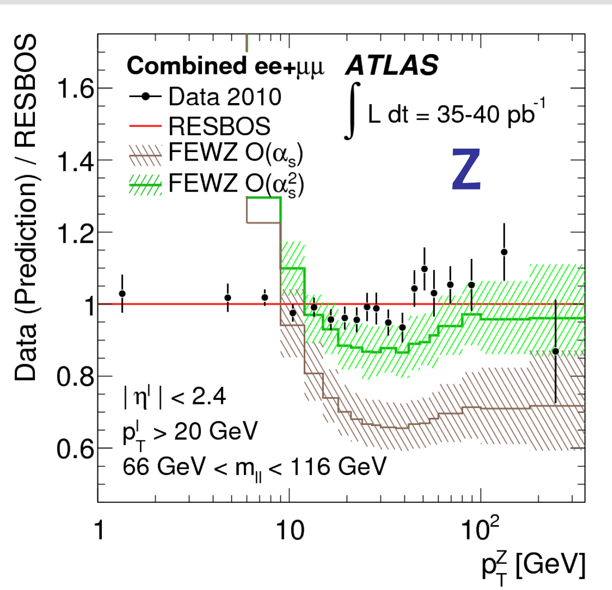
Normalized differential cross section Vs p_T compared to RESBOS

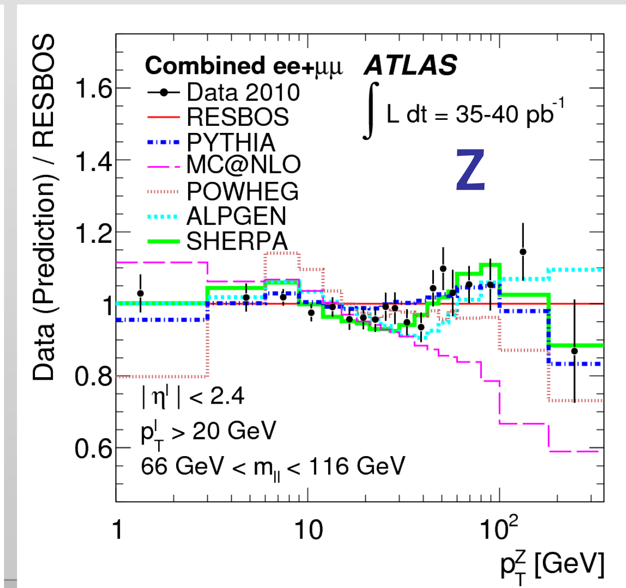
RESBOS: resum logarithmically divergent terms to all orders in α_s and use pT-dependent k-factors to extend to large pT - also tuned to Tevatron data - not yet to LHC)

p_T DISTRIBUTIONS OF W / Z









RESBOS: GOOD AGREEMENT WITH MEASUREMENTS OVER THE ENTIRE RANGE (IMPORTANCE OF RESUMMATION EVEN AT LARGE PT).
HIGHER THEN DATA IN RANGE 10-40 GEV AND LOWER FOR PT>40 GEV

NLO PREDICTIONS UNDERSHOOT DATA AT HIGH PT
NNLO OR HIGHER-ORDER ME PREDICTIONS RESTORE AGREEMENT

PYTHIA, ALPGEN, SHERPA GOOD OVER ALL P_T RANGE

- Z AND W MEASUREMENTS SHOW SIMILAR TRENDS
- DATA ALLOW TO REFINE PARTON SHOWER / RESUMMATION MODELS

POLARIZATION OF W BOSONS

- W are produced in three helicity states: f_L, f_R, f_0

- At small p_T : $u\bar{d} \rightarrow W^+$ and $d\bar{u} \rightarrow W^-$

→ Predominantly left-handed in pp at LHC

- At large p_T : $gu \rightarrow W^+ d$, $g\bar{d} \rightarrow W^+ \bar{u}$ and $\bar{u}d \rightarrow W^+ g$

Given the vector nature of gluons, more complex production mechanism contribute.
Also longitudinal state (with fraction f_0) allowed.
→detailed helicity state calculations are required

Define the "transverse helicity angle" :

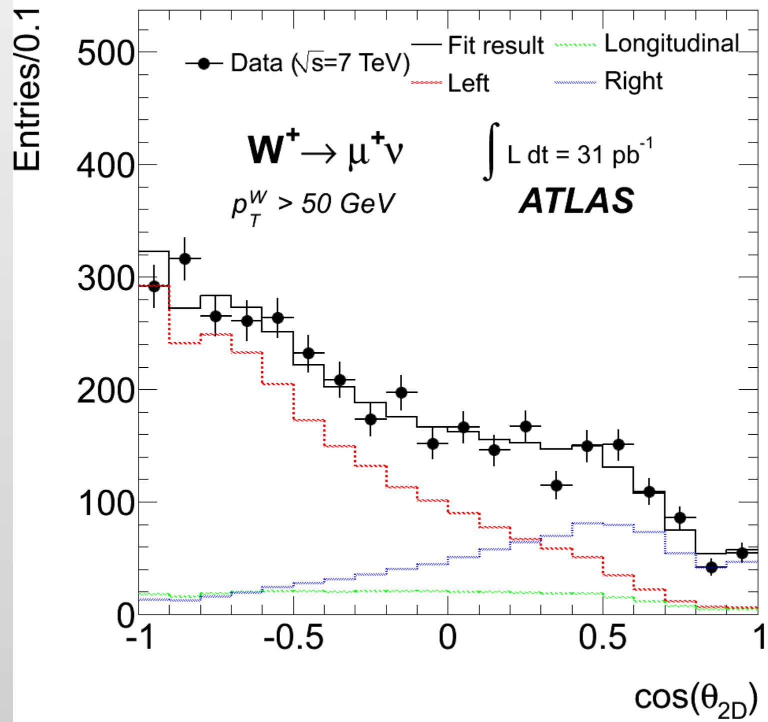
$$\cos\theta_{2D} = \frac{\vec{p}_T^{\,l*} \cdot \vec{p}_T^{\,W}}{\left|\vec{p}_T^{\,l*}\right|\left|\vec{p}_T^{\,W}\right|}$$

$\vec{p}_T^{\,l*}$ Lepton p_T in the tranverse W rest frame

$\vec{p}_T^{\,W}$ W pT in the Lab

(Θ_{2D} is the 2D projection of the "helicity angle" onto the transv. plane)

HELICITY FRACTIONS ARE MEASURED BY FITTING $\cos(\Theta_{2D})$ DISTRIBUTIONS WITH WEIGHTED SUM OF TEMPLATES FOR LONGITUDINAL, LEFT-HANDED AND RIGHT-HANDED STATES.



Results of the fit for $W^+ \rightarrow \mu^+ \nu$ using helicity templates of $\cos(\Theta_{2D})$ (built from MC@NLO)

Polarization of W Bosons

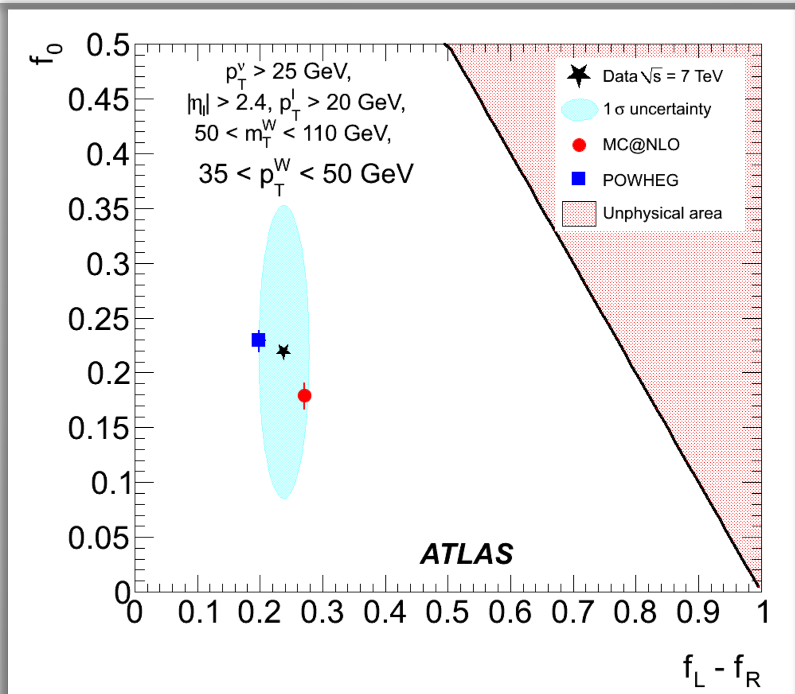
- Measurements performed in two pT regions $35 < p_T^W < 50\ GeV$, $p_T^W > 50\ GeV$
- Fit results averaged over charge and lepton flavors and compared to NLO calculations (MC@NLO and POWHEG)
- Uncertainties on f_L-f_R reduced (partially cancel in W^+ and W^- average)
- Large uncertainties on the longitudinal fraction f_o

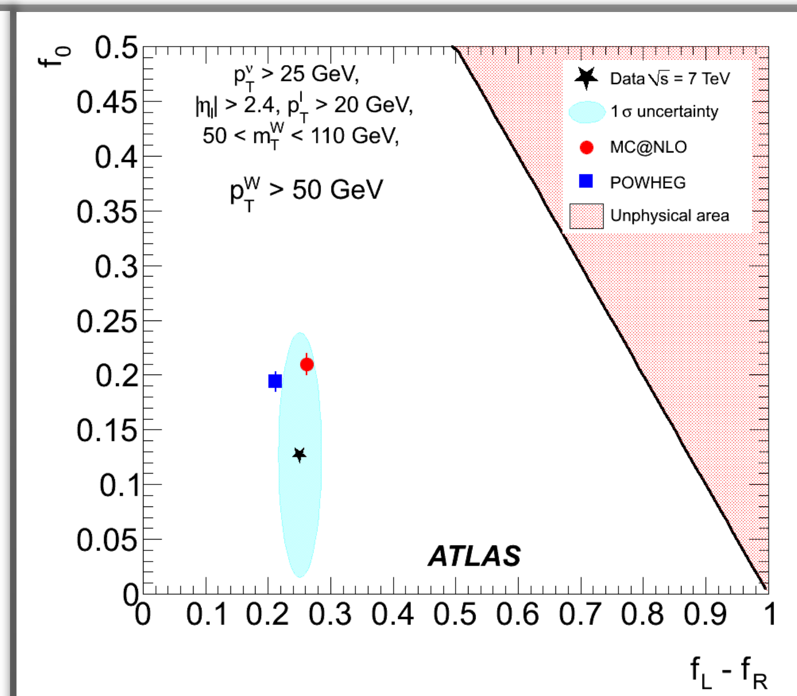
☞ *f_L-f_R consistent with predictions*

☞ *f_o lower than predictions at high p_T*

Unphysical area

Due to $f_L+f_R+f_o=1$





SUMMARY AND OUTLOOK

- ATLAS precision measurements for W and Z bosons at percent level using 36 pb^{-1} of data at 7 TeV have been presented
  - provide a significant contribution to the reduction of PDF uncertainties
  - Constrain the strange content of the proton
  - Test of different aspects of QCD at high and low pT (hard Vs soft processes)

✧ Apologies for not being able to present more W, Z analyses – due to time constraints

- 2011 data analyses being finalized:

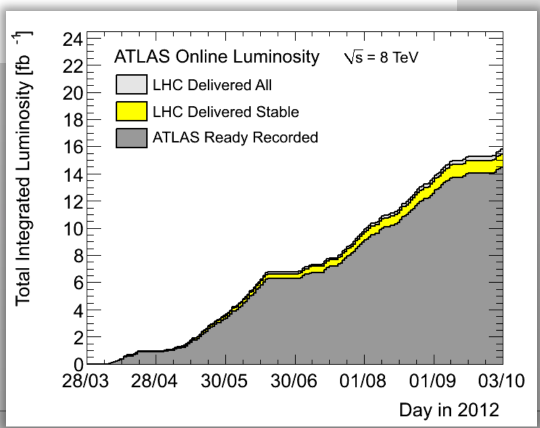
  $\sqrt{s}$ = 7 TeV $\mathcal{L}=5\ fb^{-1}$

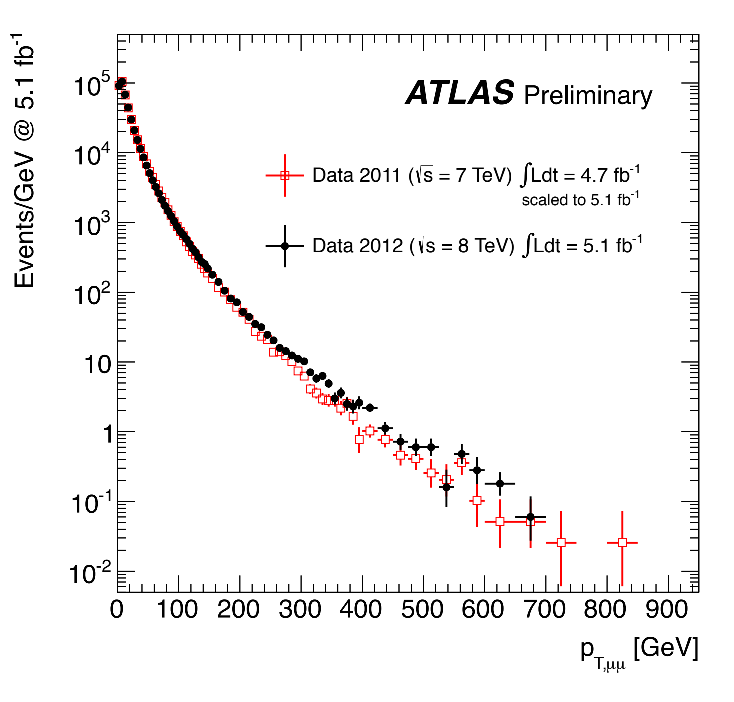
  - Target precision ≤1%, tightening the 2010 constraints

- 2012 data:

  $\sqrt{s}$ = 8 TeV

  $\mathcal{L} > 14\ fb^{-1}$ (to date)





BACKUP SLIDES

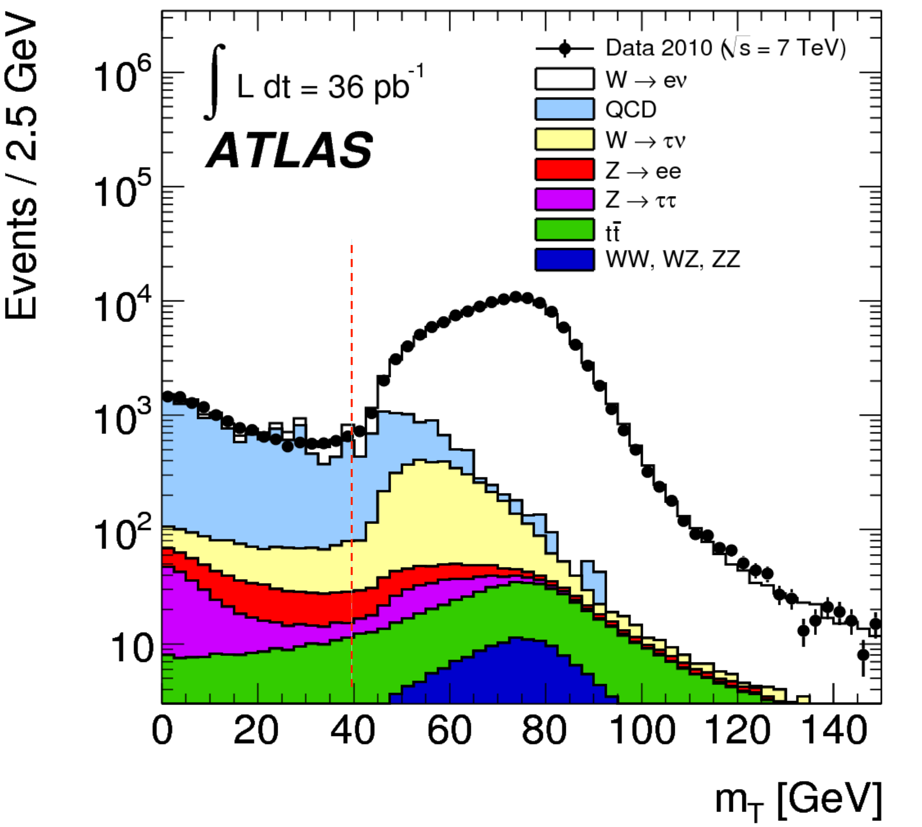
W, Z Bosons Selection

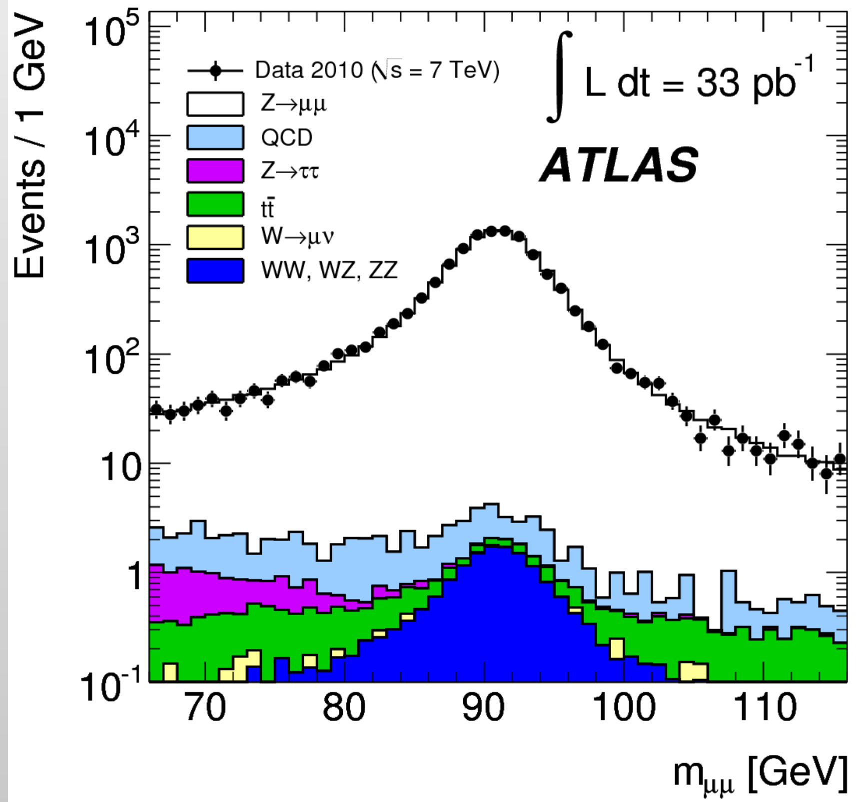
W

- *Single lepton trigger*
- *Calorimeter Isolation*
- *ETMiss > 25 GeV*
- $M_T = \sqrt{2p_T^{\ell}E_T^{Miss}(1-\cos(\Phi^{\ell}-\Phi^{\nu})} > 40\ GeV$

Z

- *Single lepton trigger*
- *Calorimeter Isolation*
- *Same flavor, opposite charge leptons*
- $66 < M_{\ell\ell} < 116\ GeV$





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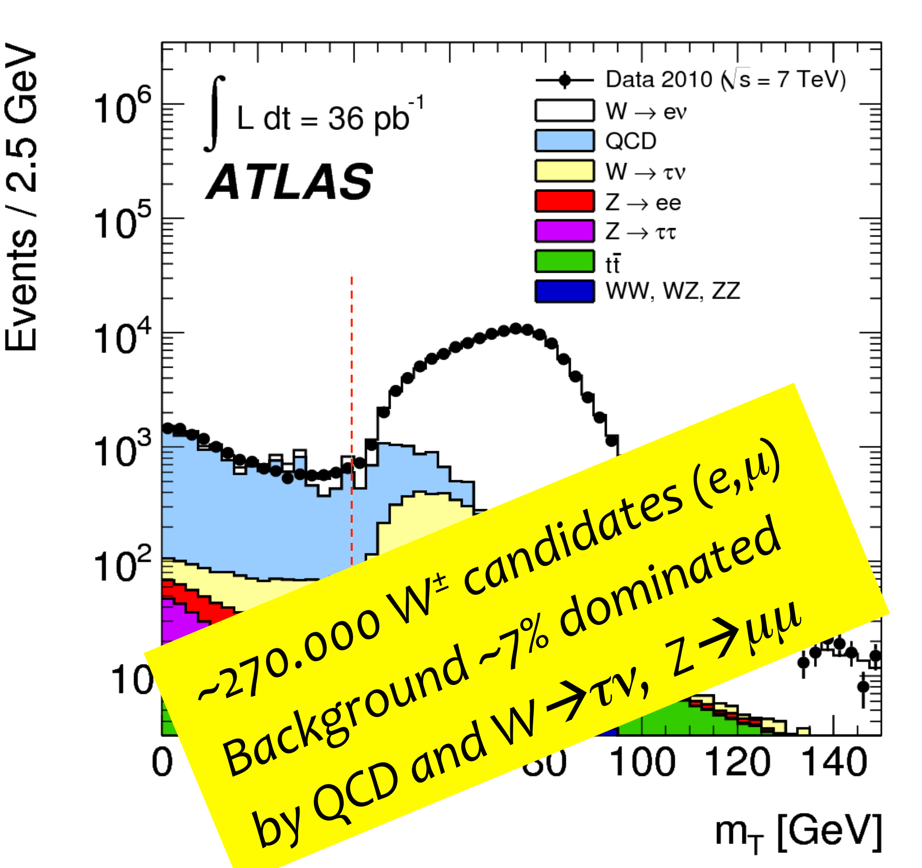
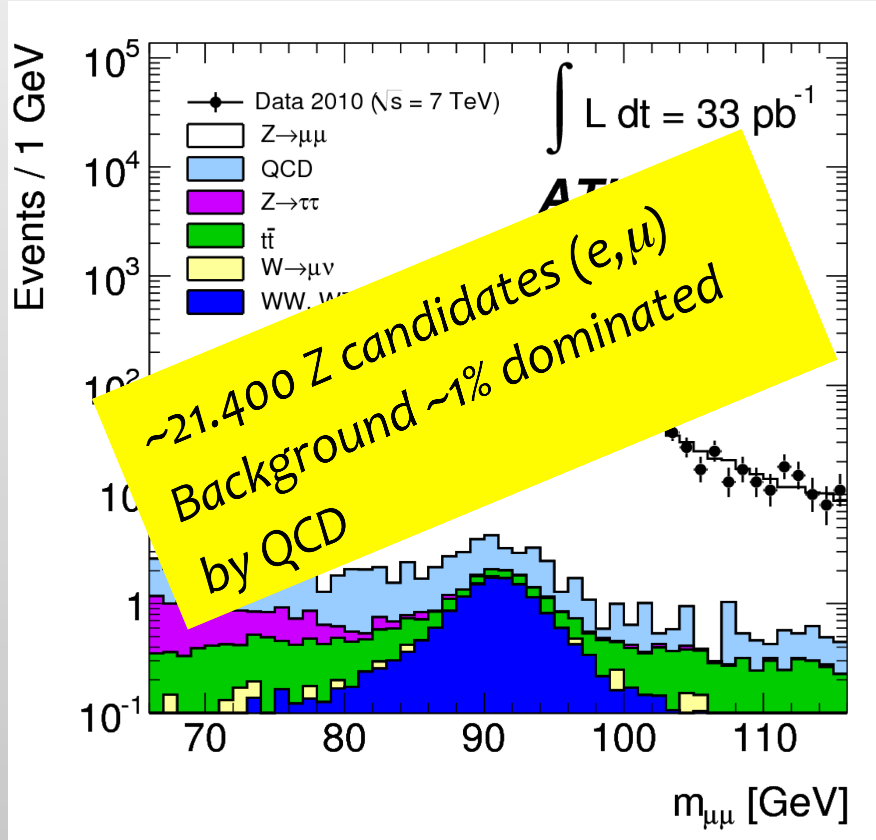




INTEGRATED CROSS SECTIONS

- Integrated W^+, W^-, $W^\pm$, Z cross sections measured in the e, μ channels

Combined to a common fiducial volume *(negligible uncert. in the extrapolation)*

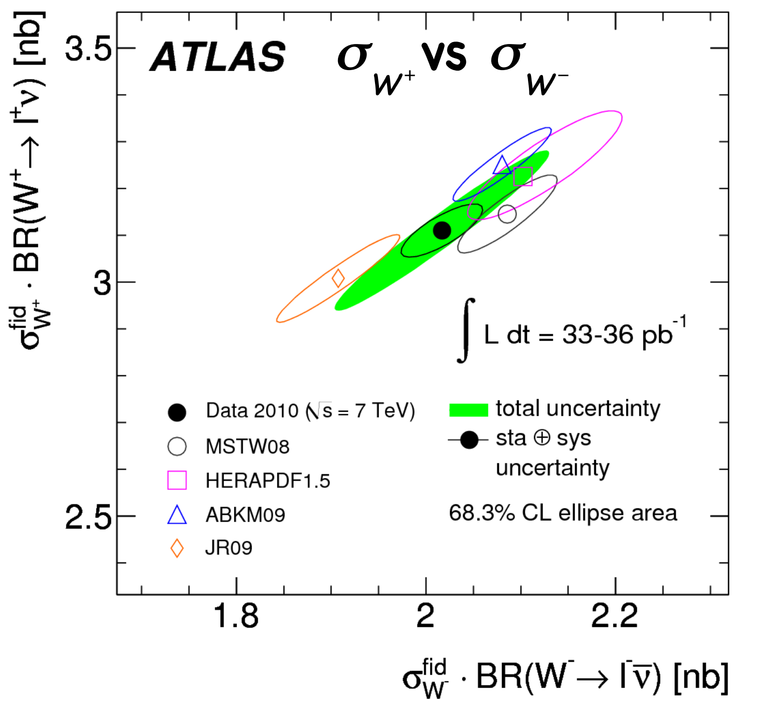
  - All measured to ~ 1% systematic uncertainty (small stat. uncert.)
  - Luminosity uncert. of 3.4% fully correlated between the measurements

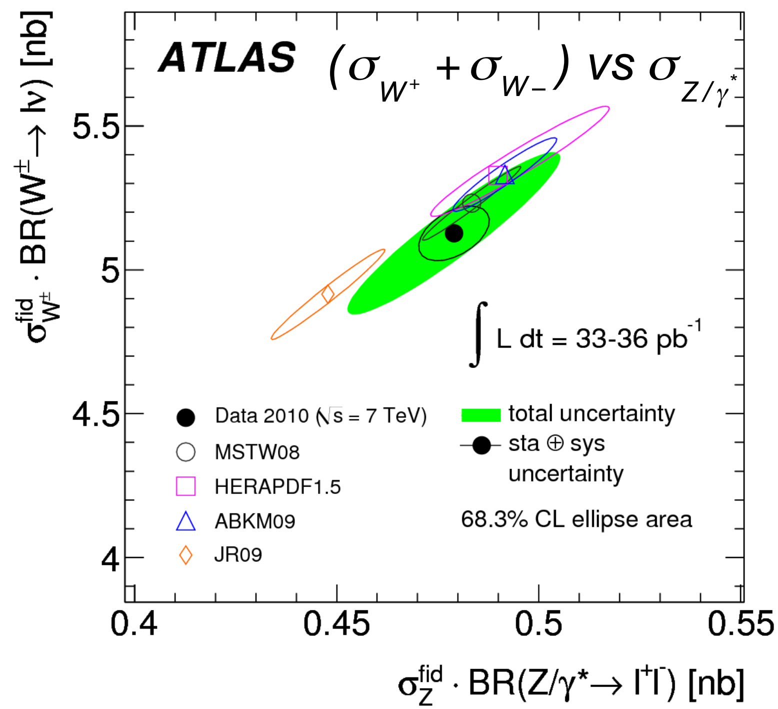
- Comparison with NNLO calculations using FEWZ and four set of NNLO PDF

☞ *Sensitivity to different predictions, though hindered by luminosity uncert.*

☞ *Overall agreement with predictions → validity of PDF evolution from low to W,Z mass scale*

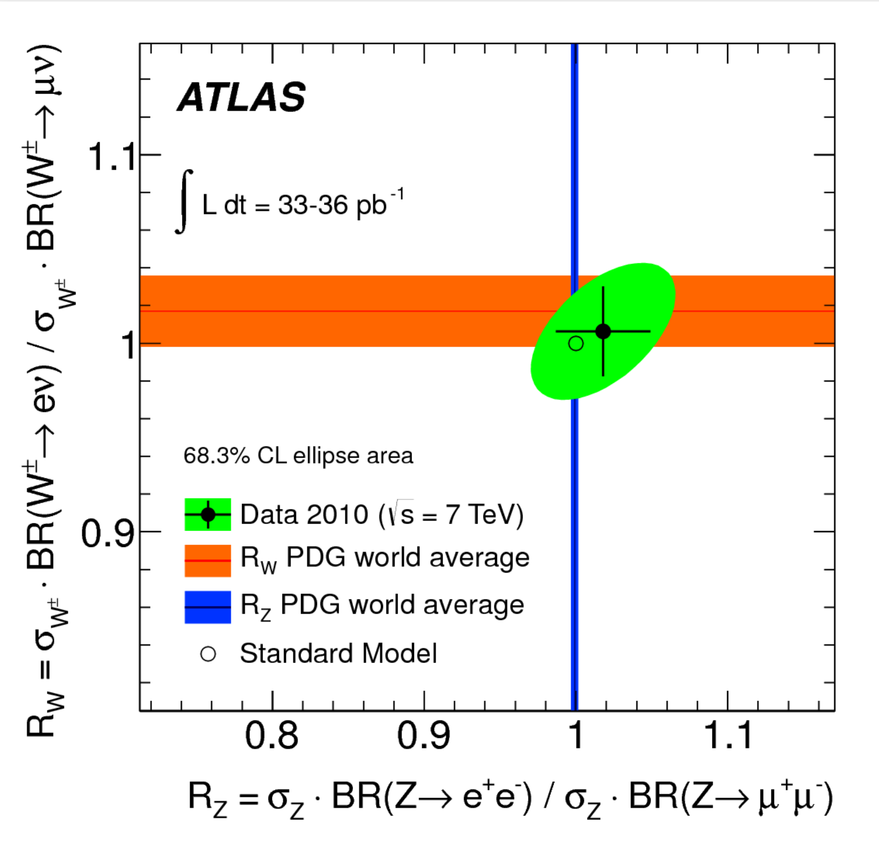
Common Fiducial volume:
pT>20 GeV $|\eta_l|<2.5$





Ratios of Cross Sections – Lepton Universality

- Ratio of electron and muon cross sections measured in the common fiducial region
- W and Z productions are independent of the flavor of the decay lepton
  - ➥ New measurement of ratios of *e* and μ branching fractions:



$$R_Z = \frac{\sigma_Z^e}{\sigma_Z^\mu} = \frac{Br(Z \to ee)}{Br(Z \to \mu\mu)} = 1.018 \pm 0.031$$

World average: 0.9991±0.0024

$$R_W = \frac{\sigma_W^e}{\sigma_W^\mu} = \frac{Br(W \to e\nu)}{Br(W \to \mu\nu)} = 1.006 \pm 0.024$$

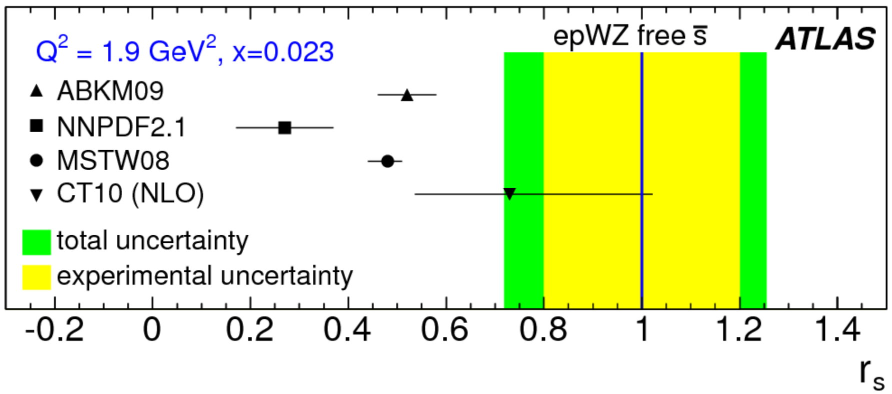
World average: 1.017±0.019

- Experimental accuracy at few % level: Close to world average for R_W, still much less accurate for R_Z
- RESULTS confirm *e* - *μ* universality in W and Z decays

Result of the Fit at $Q^2=1.9$ GeV^2, $x=0.023$

$$r_s = \frac{s(x)+\bar{s}(x)}{2\bar{d}(x)} = 1.00 \pm 0.20(exp) \pm 0.07(mod)\ ^{+0.10}_{-0.15}(par)\ ^{+0.06}_{-0.07}\alpha_s \pm 0.08(th)$$

More strange sea quarks than expected: as much strange as down sea quarks



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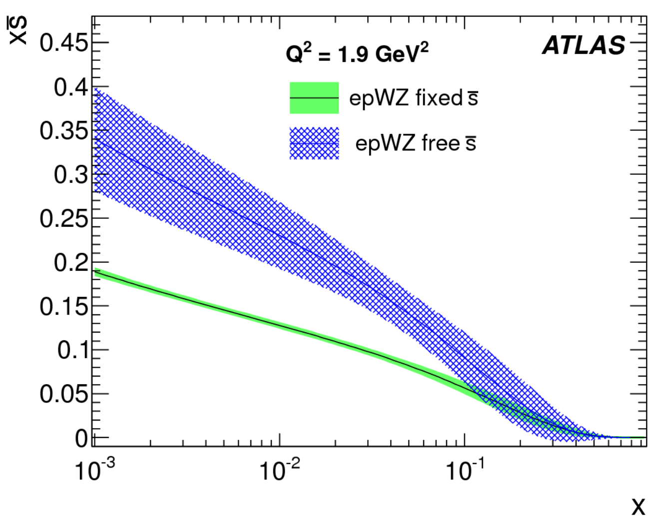
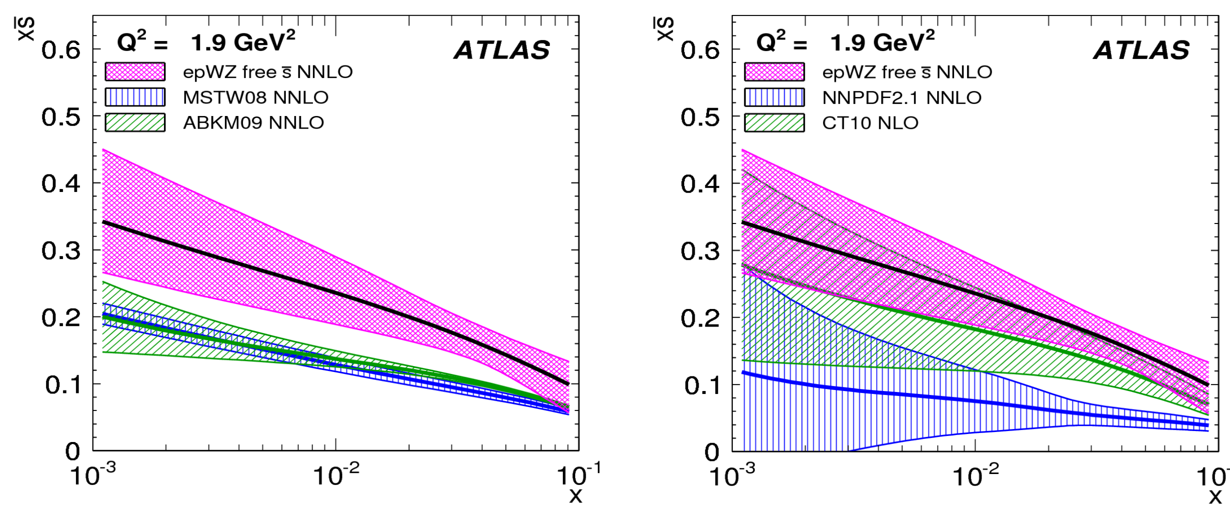
- Variation of α_s and theor. uncert. on different predictions of W,Z production

Comparison the epWZ fixed strange and free strange NNLO fits

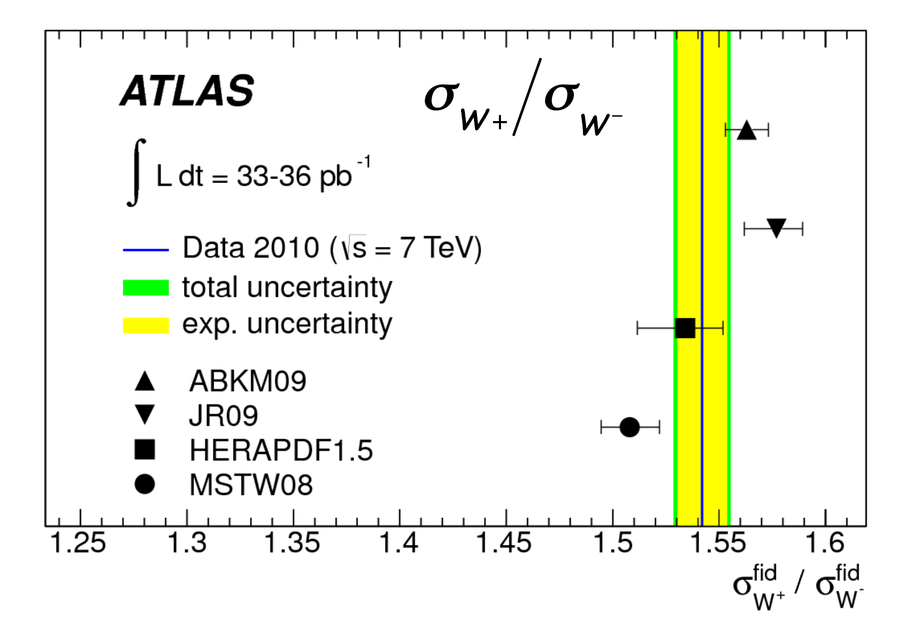


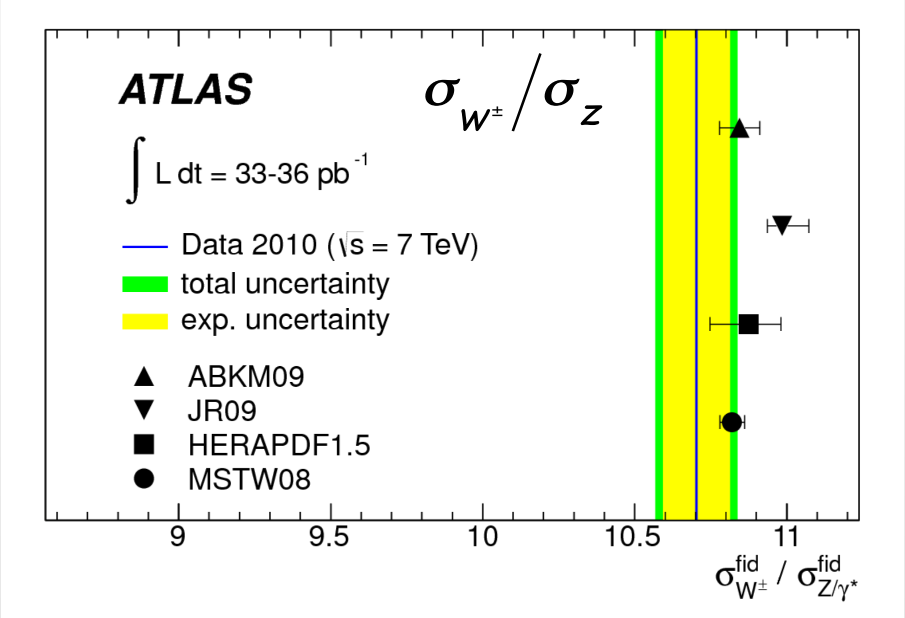
Comparison the epWZ free sbar fit with predictions from MSTW08, ABKM09, NNPDF2.1 and CT10



Ratios of Cross Sections

- Ratios of Cross Sections measured with high precision
  - benefit from experimental and theoretical systematic cancellations
  - W^+/W^- : sensitive to ratio of u/d valence quarks
  - $W^{\pm}/Z$: sensitive to flavor composition of quark sea





Measurement of Tau Polarization in $W \rightarrow \tau\nu$ events

- In $W \rightarrow \tau\nu$ decays, W^- expected to couple to left-handed τ^-; W^+ to right-handed τ^+

  ➡ $P_\tau = -1$

- First measurement of Tau Polarization at hadron colliders

$$P_\tau = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

- The measured process:

$W^- \rightarrow \tau^- \nu$

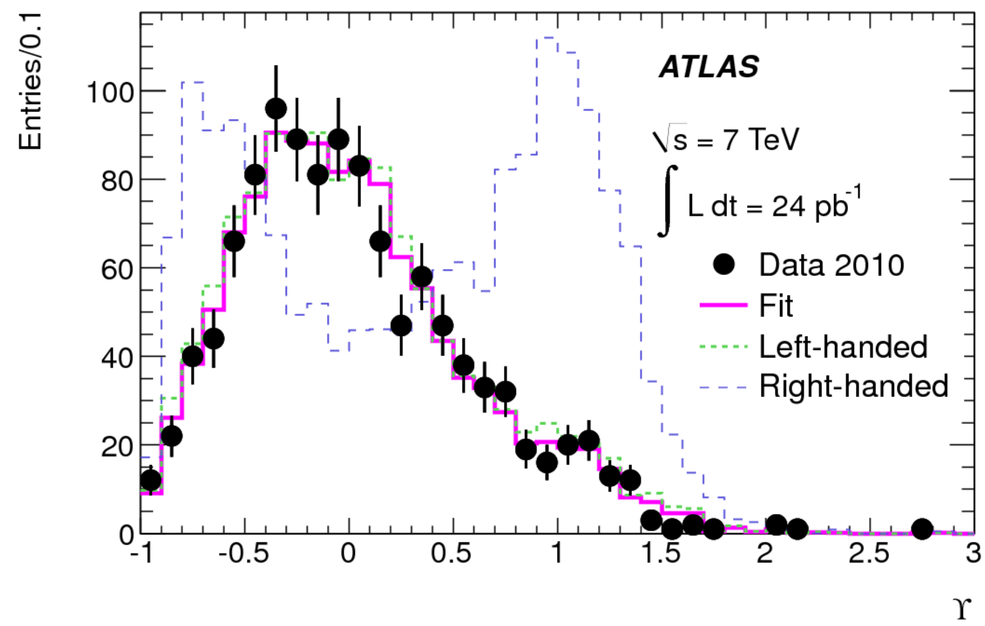
$\quad \hookrightarrow \rho^- \nu_\tau \rightarrow \pi^- \pi^0 \nu_\tau$

- The "charge asymmetry":

$$\Upsilon = 2\frac{p_T^{trk}}{P_T^\tau} - 1$$

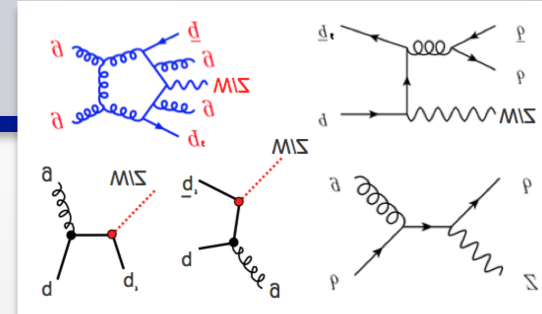
Measured in all decay modes to a single charged meson inclusively

- Results by a fit of the Υ distribution to a linear combination of left-handed and right-handed templates



$$P_\tau = -1.06 \pm 0.04(stat)\ ^{+0.05}_{-0.07}(syst)$$

W,Z Production in association with Jets

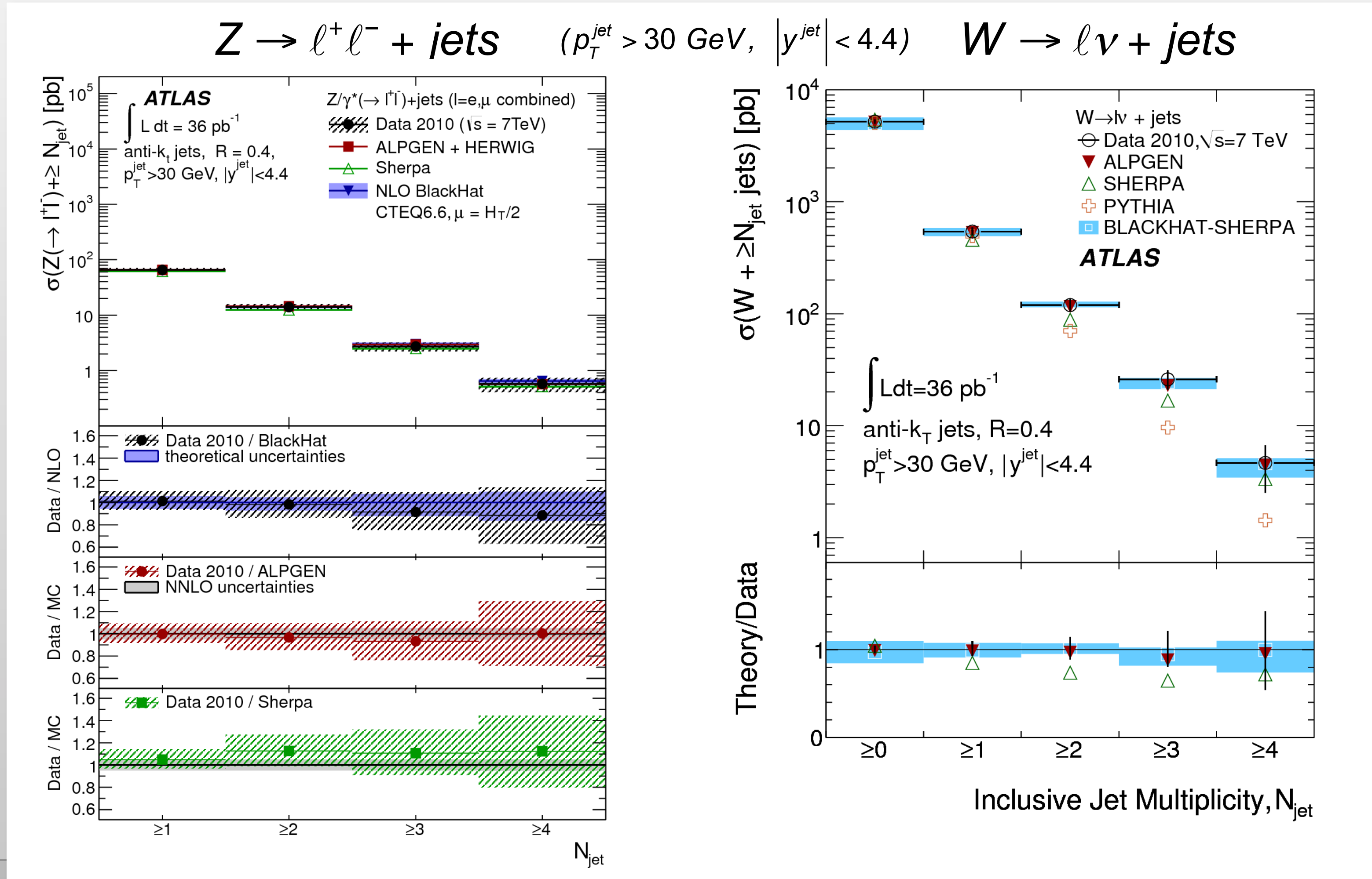


- W/Z+jets cross section provide tests of pQCD at LHC energy scale
- Processes with high cross-sections and important backgrounds for many other measurements/searches

σ_{njets} as a function of jet multiplicity compared to predictions:

- NLO BlackHat
- NLO Alpgen and Sherpa normalized to NNLO tot cross section
- As expected PYTHIA fails to reproduce data for njet>1

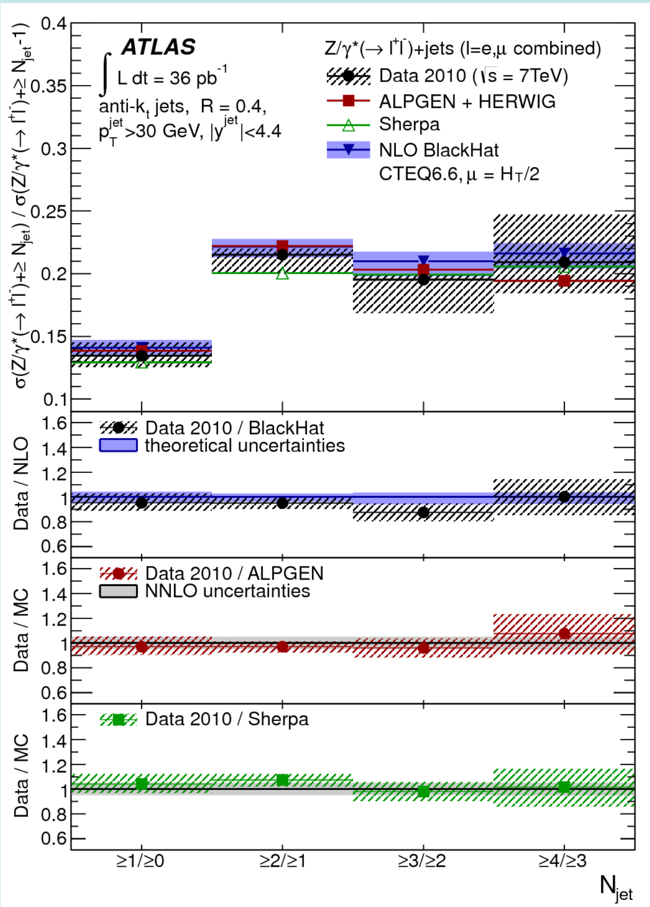
- Multiplicities generally in good agreement with NLO predictions



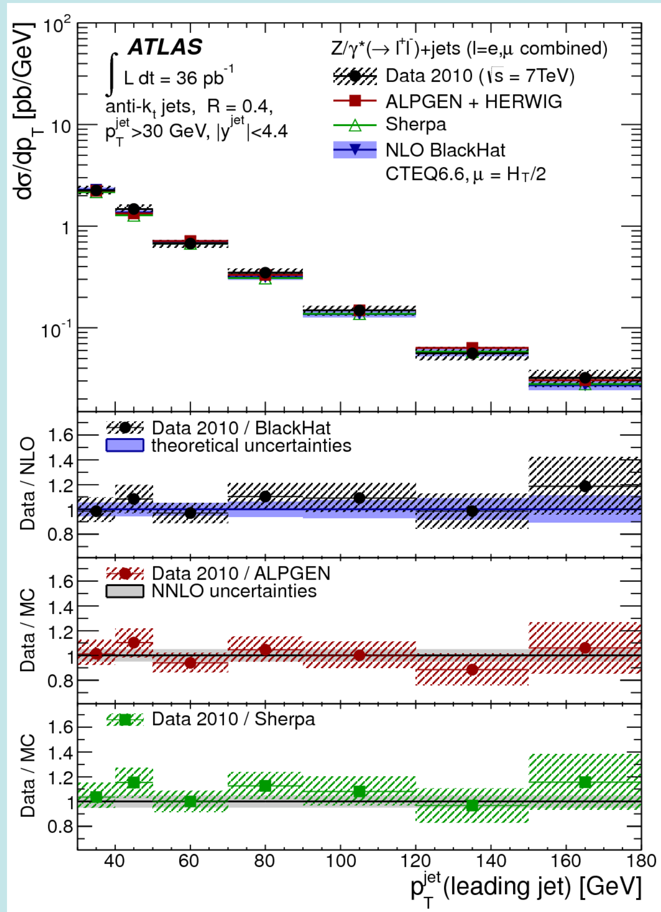
Z Production in association with Jets

$\sigma_{Njet} / \sigma_{Njet-1}$

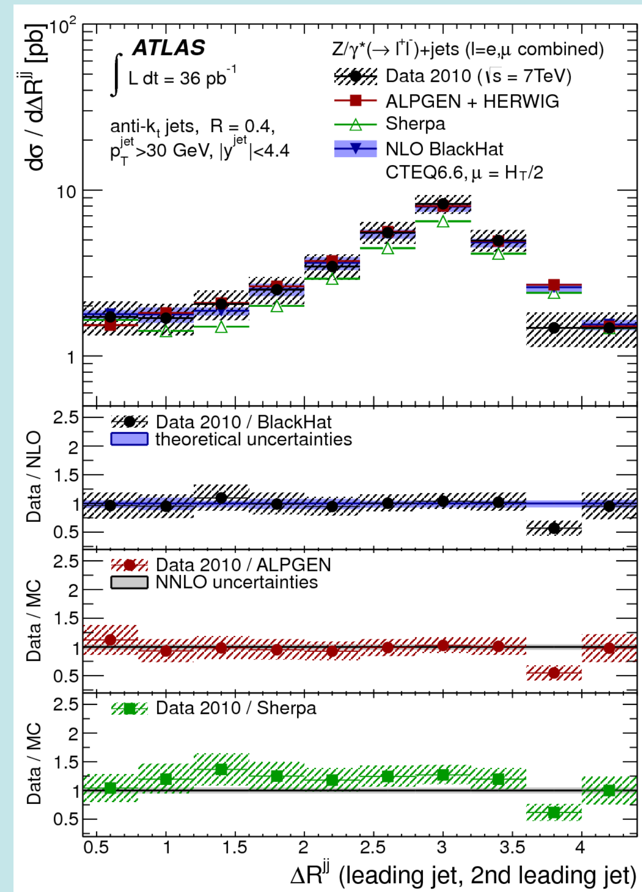
(drop in the cross section by about a factor 5 for each additional jet)



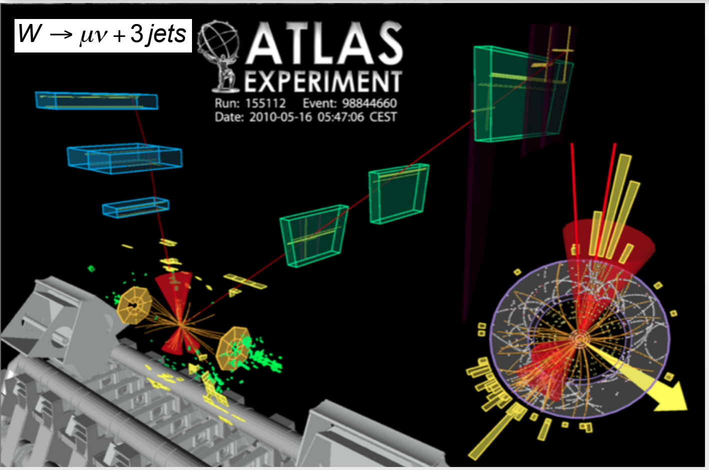
$d\sigma / dp_T$ as a function of the leading jet p_T



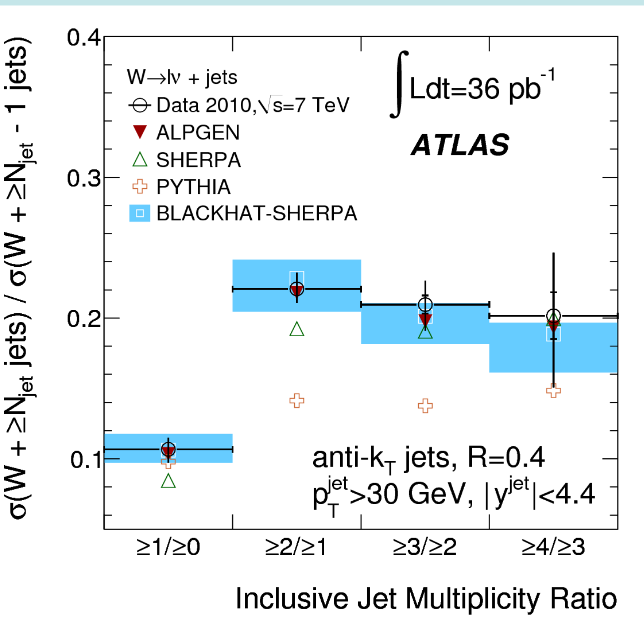
$d\sigma / d\Delta R^{jj}$ as a function of the angular separation of the two leading jet



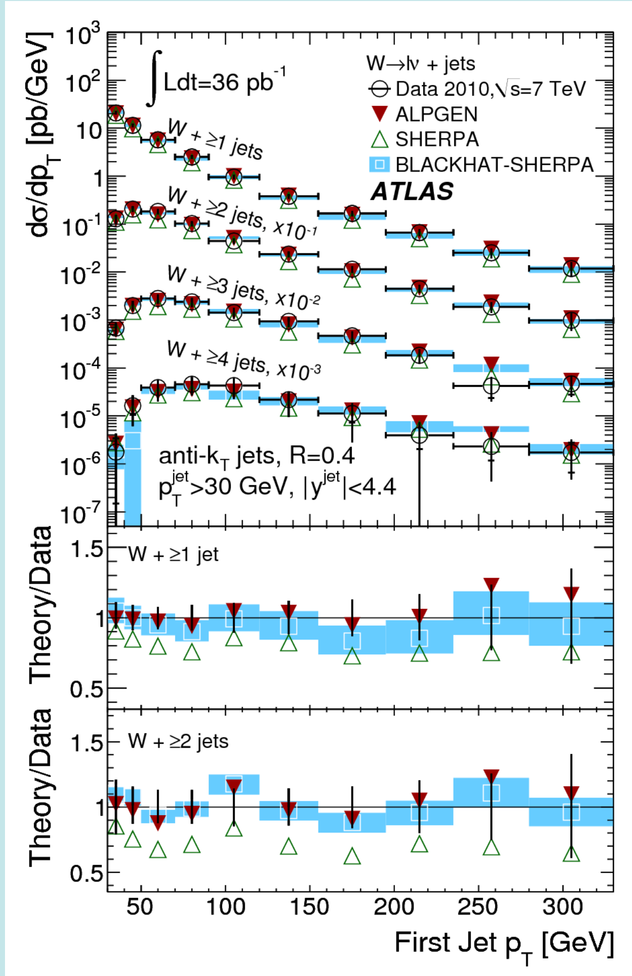
W Production in association with Jets



$\sigma_{Njet} / \sigma_{Njet-1}$



$d\sigma/dp_T$ as a function of the first jet p_T



Cross section as a function of *y(l)-y(first jet)* for events with njets≥1

Sensitivity to PDF