Recent results on associated vector boson (W, Z) production with the ATLAS experiment

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Outline - References

Results at √s = 7 TeV and √s = 8 TeV

- Motivation
- **W + jets NEW!**
  - arXiv:1409.8639, Eur. Phys. J. C (2015) **75**:82
- **Z + jets**
  - arXiv:1304.7098, JHEP07 (2013) 032
- **Rjets = (W + jets) / (Z + jets) NEW!**
  - arXiv:1408.6510, Eur. Phys. J. C (2014) **74**:3168
- **Zb, Zbb**
  - arXiv:1407.3643, JHEP10 (2014) 141
- **Wb**
  - arXiv:1302.2929, JHEP06 (2013) 084
- **Wc**
  - arXiv:1402.6263, JHEP05 (2014) 068
- **ttbarW, ttbarZ**
  - ATLAS-CONF-2014-038
- Summary and Outlook

Motivation

- Precision measurements of **associated vector boson production** at the LHC are crucial
  - Vector boson leptonic decays (**electrons, muons**) are studied (**clean signatures**)
- **Test and validate** the perturbative QCD (**pQCD**) calculations
- Constrain the parton proton structure (**PDFs**)
- Provide important experimental constraints **to improve the theoretical uncertainties** on existing predictions
- Important background for numerous **Standard Model (SM) processes**
  - ttbar, single top
  - Higgs boson production

  and for **physics beyond SM**
  - Supersymmetry

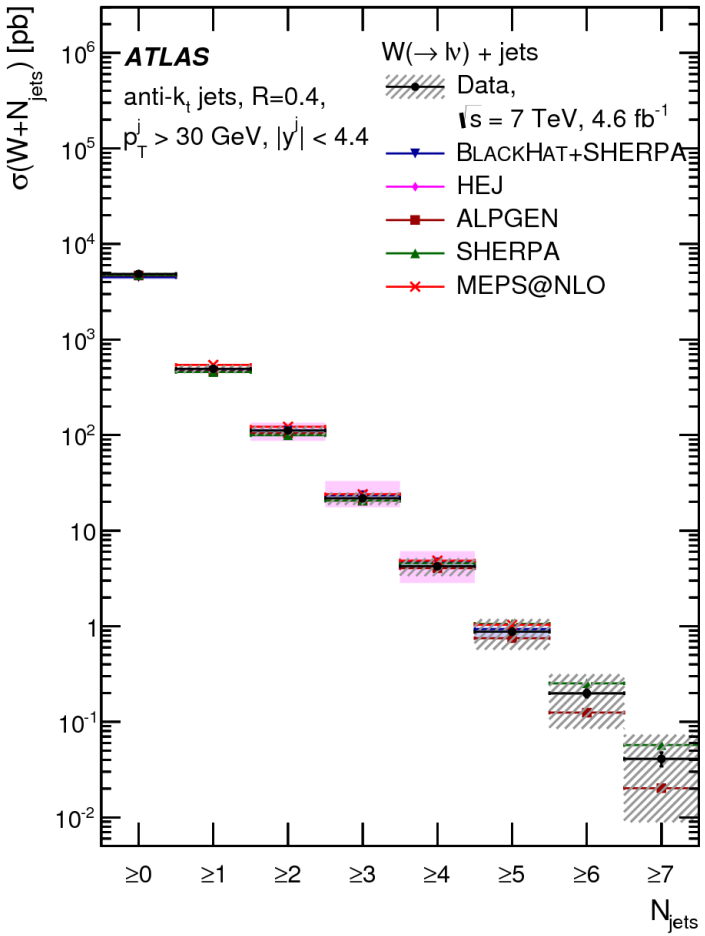
W + jets (7 TeV)

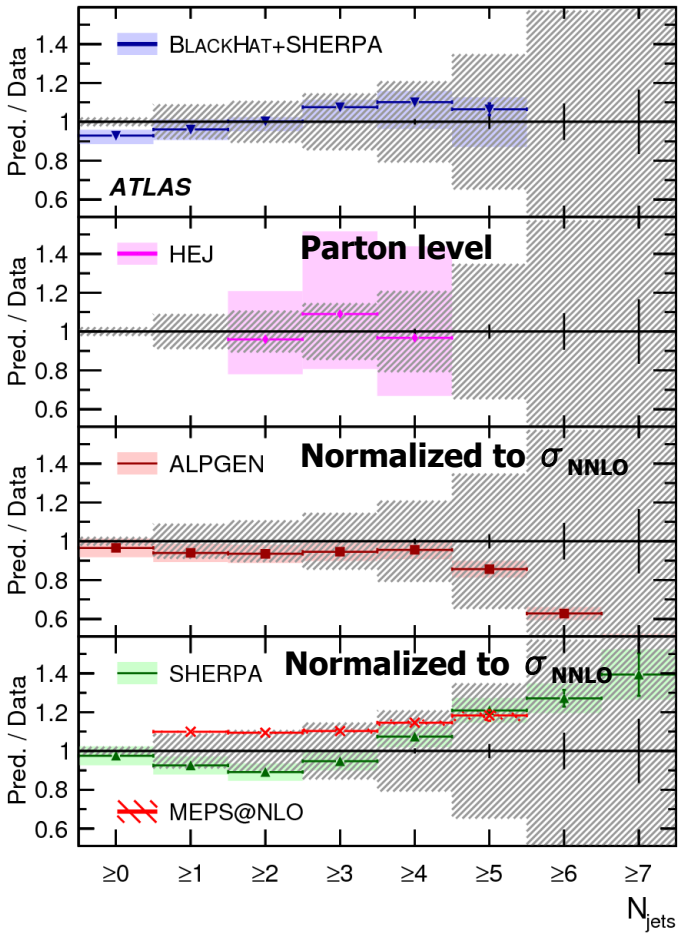
- **$p_{T\,\mu}$, $p_{T\,e}$ > 25 GeV**
- $|\eta|$ < 2.47 (e), 2.4 (μ)
- **AntikT4 (R=0.4), Jet p_T > 30 GeV, |y| < 4.4**
- **E_{Tmiss} > 40 GeV, m_T > 40 GeV**

- **Unfolded** results (i.e. corrected for detector effects) compared at **particle level** with **LO** and **NLO** theory predictions
  - Bayesian Iterative Unfolding
- **Parton-level predictions (e.g. BLACKHAT+SHERPA)** corrected for hadronization, UE, QED FSR
- Theory systematic uncertainties: PDF, scale(μ_R, μ_F), α_s
- Dominant systematic uncertainties
  - Jet energy scale (JES)
  - Data driven ttbar background estimation (high jet multiplicities)

W + jets (7 TeV)

- **Inclusive jet multiplicity** for up to **7** jets

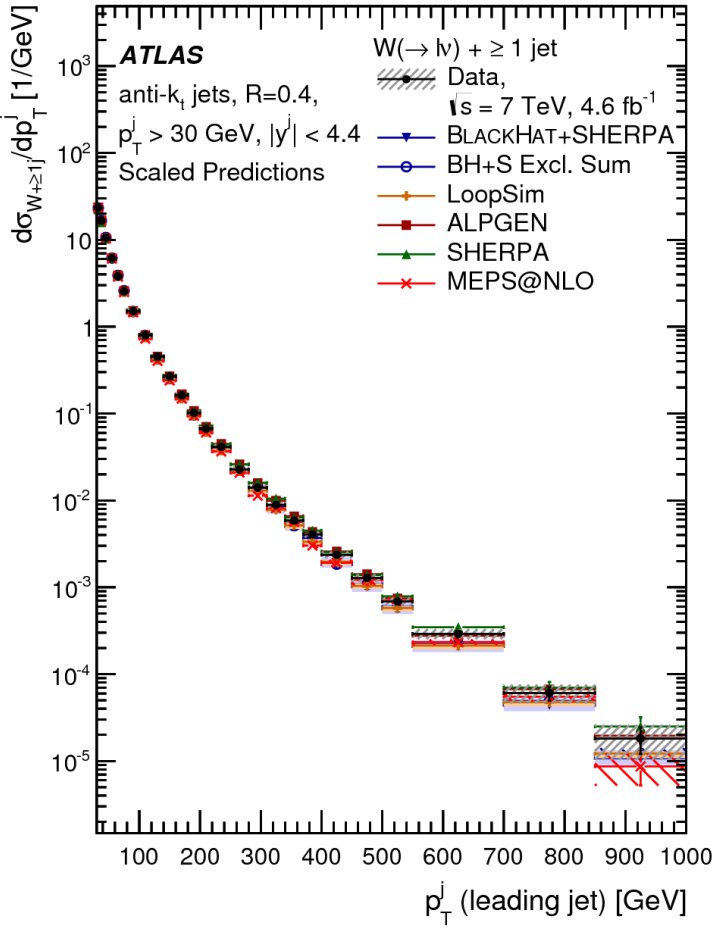


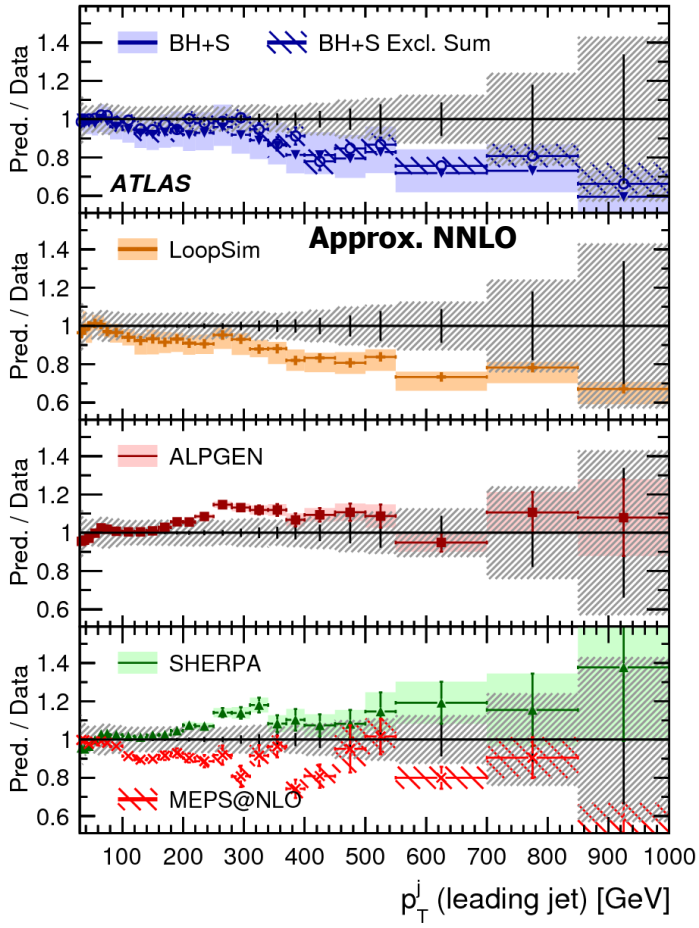


Measurements in agreement within uncertainties with theoretical predictions

W + jets (7 TeV)

- **Leading jet p_T** up to **1 TeV**!
  - Up to 5th leading jet

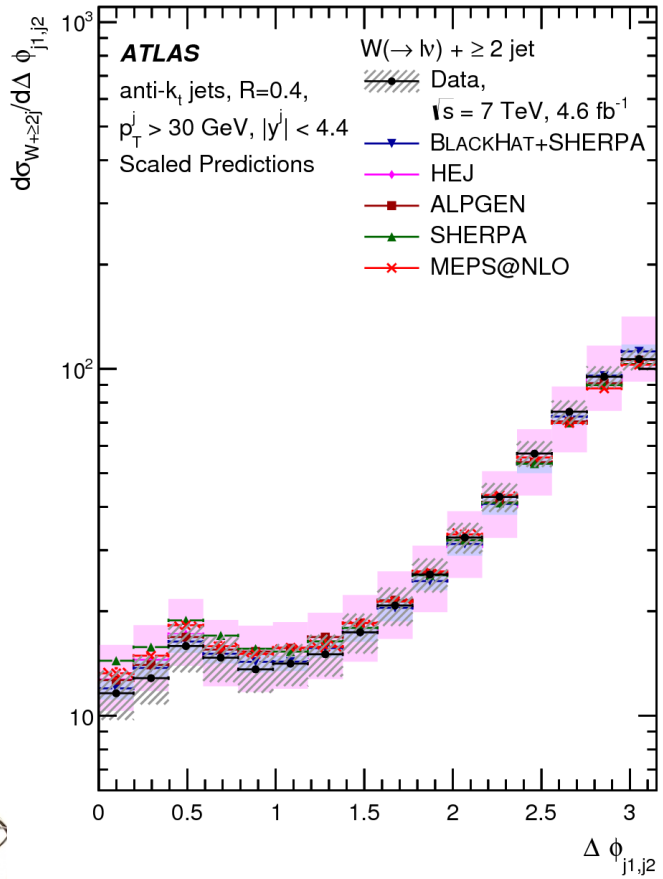


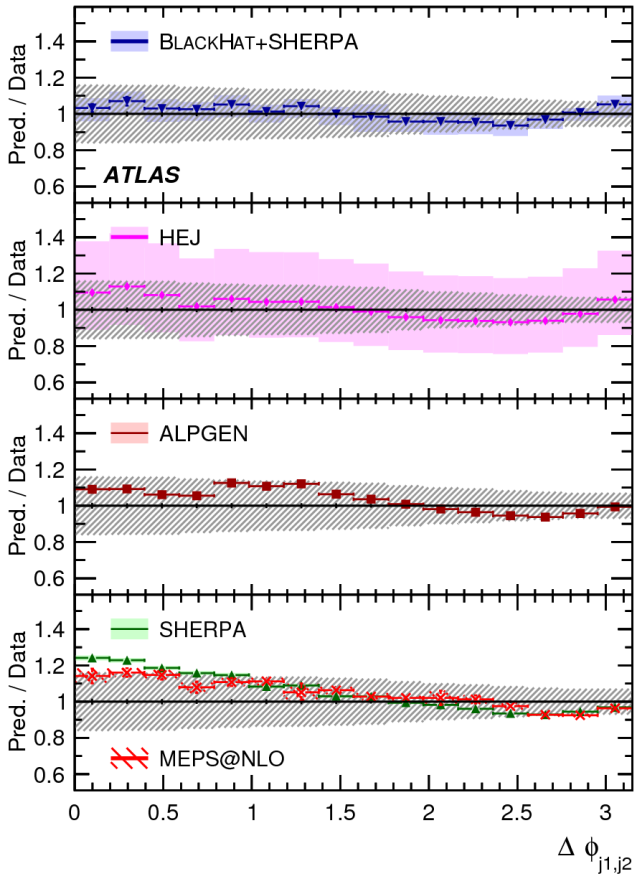


BLACKHAT+SHERPA, LoopSim underestimate the data at high p_T

W + jets (7 TeV)

- **Δ Φ(j1,j2)**
- Many other variables measured
  - **Exclusive jet multiplicity** up to 7 jets
  - **jets y**, **H_T**: scalar sum of jets p_Ts, lepton p_Ts, E_{tmiss}
  - Δ Y (j1,j2), Δ R(j1,j2), m(j1,j2)





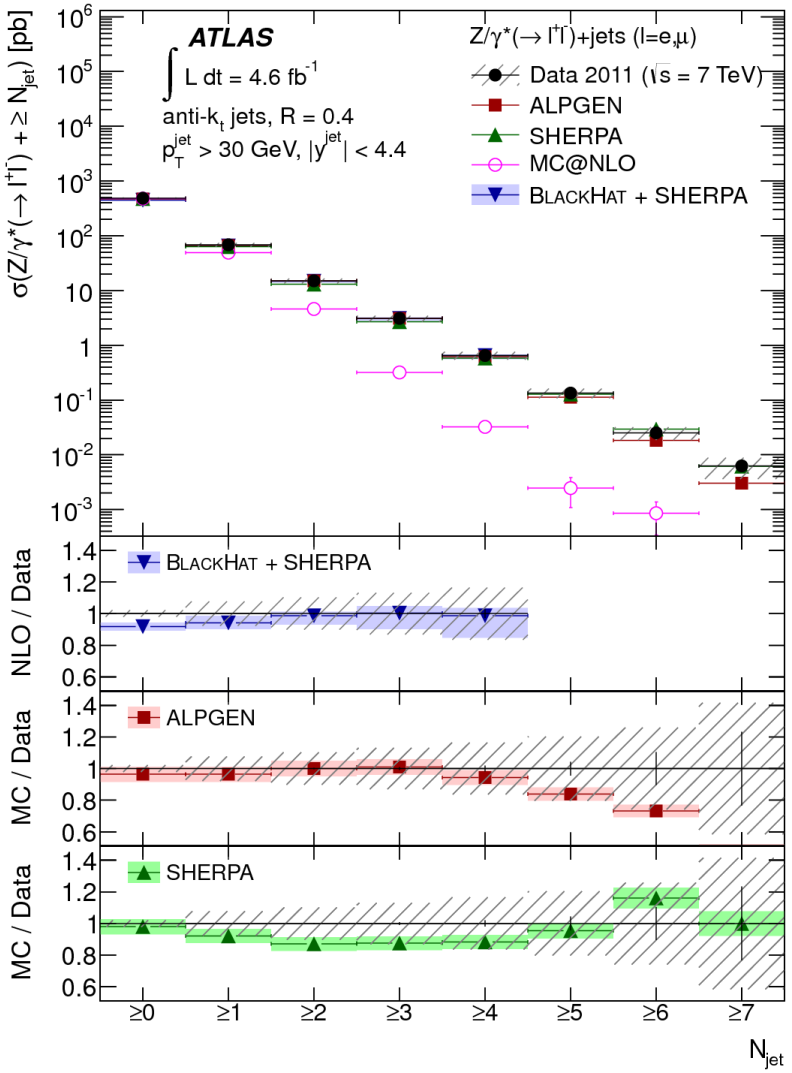
Small shape differences with **SHERPA**

Z + jets (7 TeV)

- $p_{T\,\mu}$, $p_{T\,e}$ > 20 GeV
- $|\eta|$ < 2.47 (e), 2.4 (μ)
- AntikT4, **Jet p_T > 30 GeV, $|y|$ < 4.4**
- Two OSSF **66 < m_{ll} < 116 GeV**

- **Inclusive jet multiplicity** up to **7** jets

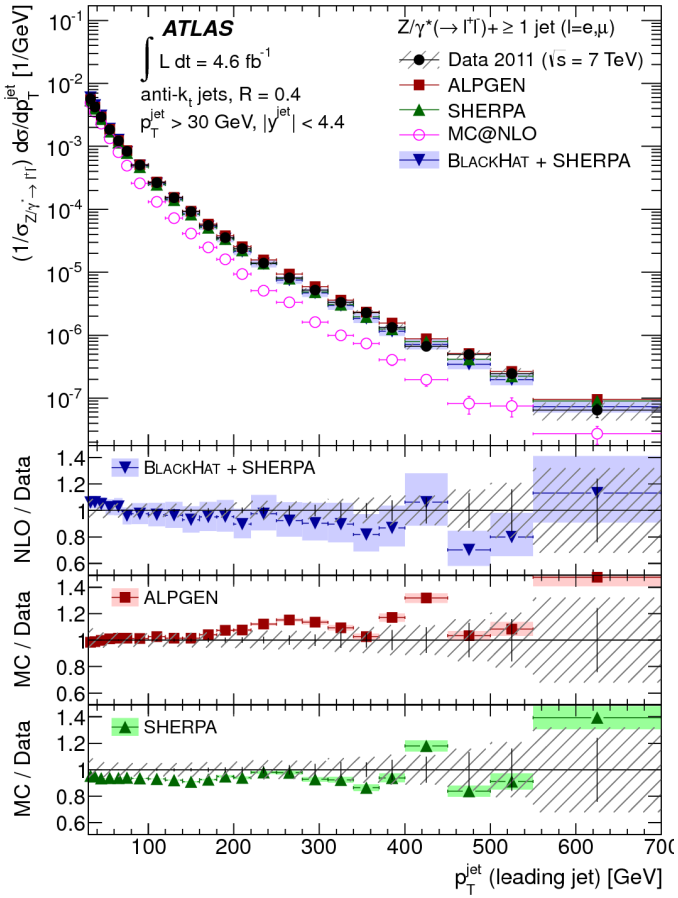
MC@NLO parton shower underestimates the observed rate

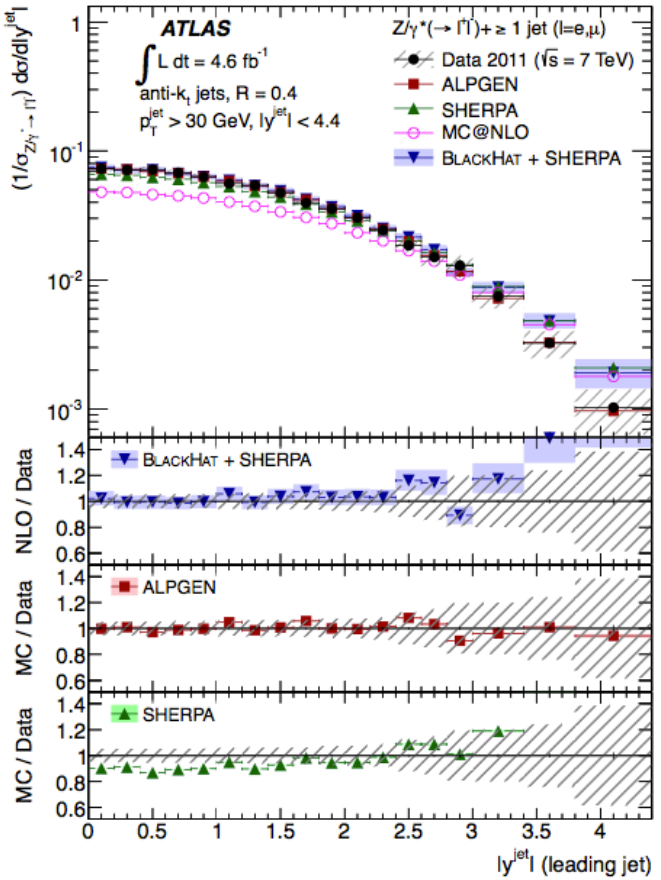


Z + jets (7 TeV)

- **Leading jet p_T** up to 700 GeV and **leading jet y**
  - Up to 4th leading jet
- Also measured:
  - **Exclusive jet multiplicity, H_T, S_T:** scalar sum of all jets p_T
  - $N_{jet}+1/ N_{jet}$
  - $\Delta\Phi(j1,j2)$
  - $\Delta Y(j1,j2)$
  - $\Delta R(j1,j2)$
  - $m(j1,j2)$

ALPGEN spectrum harder at higher p_T
SHERPA small offset to data

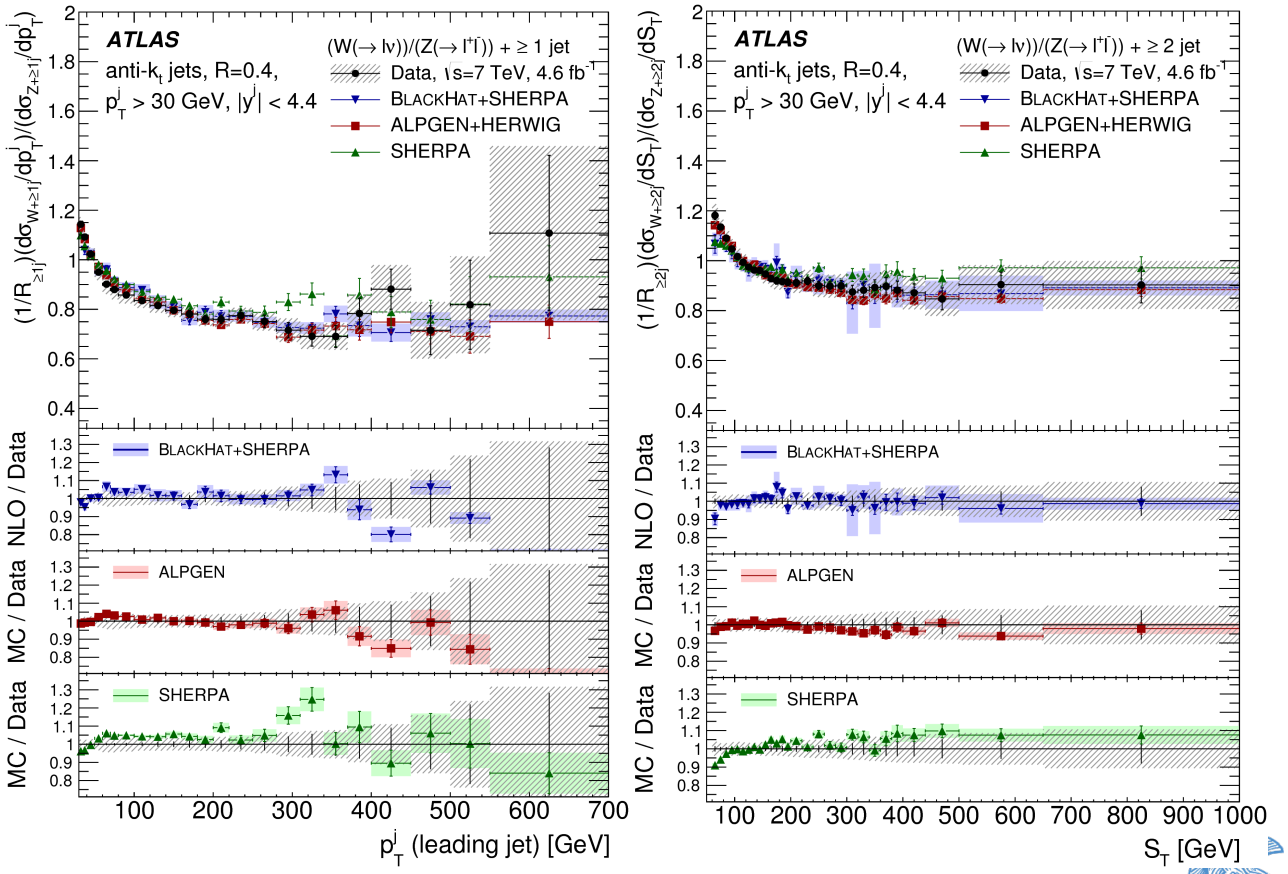




Rjets (7 TeV)

- Some experimental uncertainties and non-perturbative effects are greatly reduced
- **Sensitive to new physics** at high energies
- Measured versus many more variables for up to **4** jets

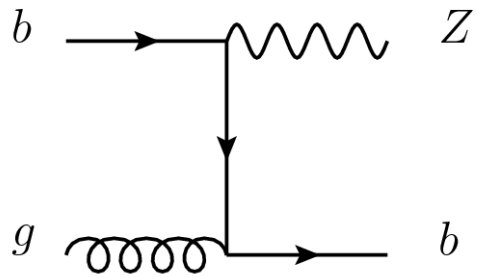
- **$p_{T\,\mu}$, p_{Te} > 25 GeV**
- $|\eta|$ < 2.47 (e), 2.4 (μ)
- AntikT4, **Jet p_T > 30 GeV, $|y|$ < 4.4**
- **W:** E_{Tmiss} > 25 GeV, m_T > 40 GeV
- **Z:** Two OSSF 66 < m_{ll} < 116 GeV



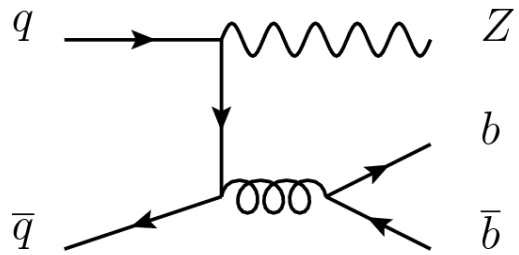
SHERPA: discrepancies at the lowest values

Zb, Zbb (7 TeV)

- **$p_{T\,\mu}$, p_{Te} > 20 GeV**
- $|\eta|$ < 2.47 (e), 2.4 (μ)
- AntikT4, **Jet p_T > 20 GeV, |y| < 2.4**
- Two OSSF 76 < m_{ll} < 106 GeV
- **At least one or two b-jets**



- Jets originating from b quarks are tagged by the advanced multivariate **MV1** algorithm



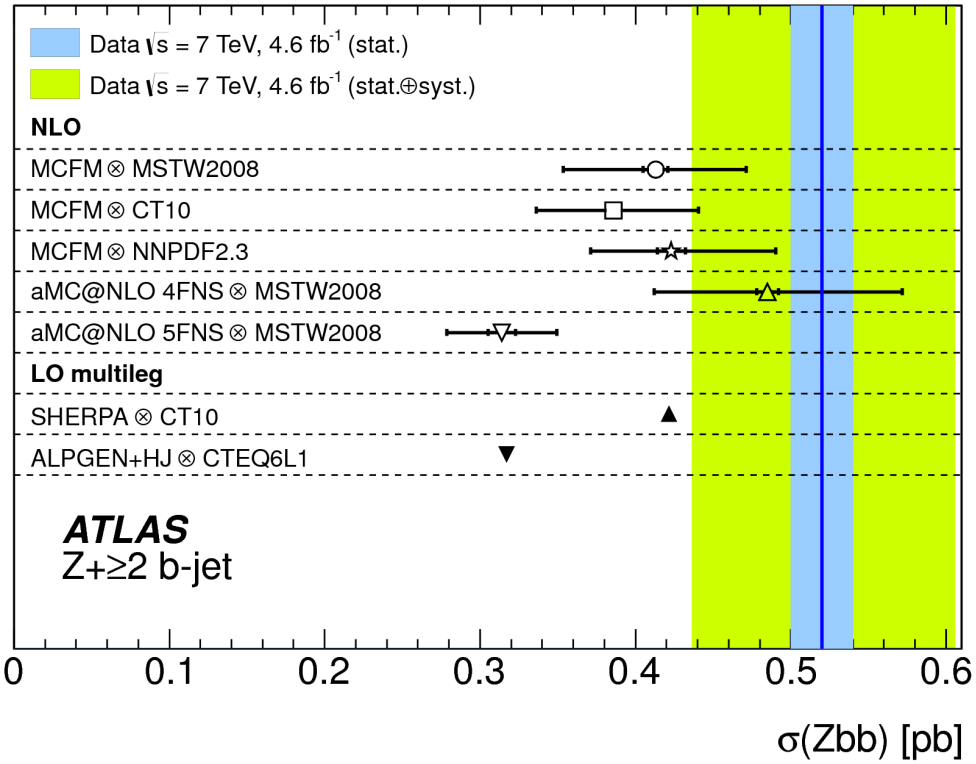
- **Also measured:**
  - **Z + ≥ 1 b-jet, Z + ≥ 2 b-jet**
  - b-jet p_T and rapidity, Zp_T and rapidity
  - $\Delta\Phi$(Z,b), ΔY(Z,b), ΔR(Z,b)
  - m(b,b), ΔR(b,b)

For W/Z + heavy flavour jets, see also Nicolas' Orlando talk

Zb, Zbb (7 TeV)

- Z production with **at least two b-jets**

- Two schemes in pQCD calculations containing heavy flavour quarks
  - **4FNS**: no b quarks at initial state
  - **5FNS**: b quarks considered at initial state

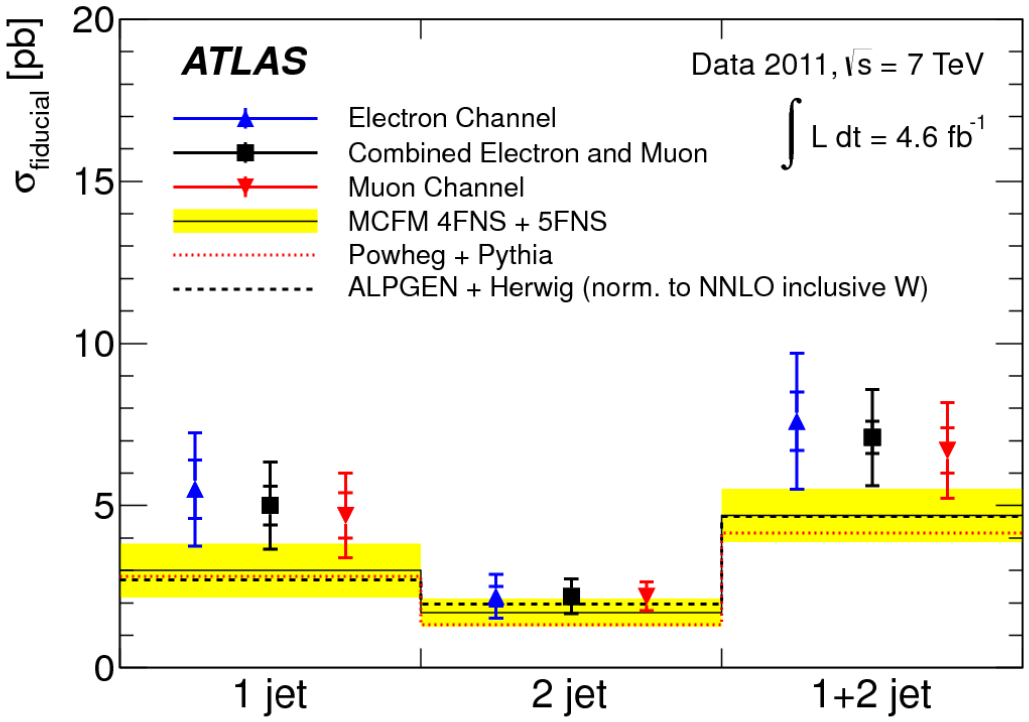


aMC@NLO (5FNS), ALPGEN (4FNS), SHERPA (5FNS): largest discrepancies

Wb (7 TeV)

- **$p_{T\,\mu}$, p_{Te} > 25 GeV**, $|\eta| < 2.47$ (e), 2.4 (μ)
- AntikT4, **Jet p_T > 25 GeV, $|y| < 2.1$**
- E_{Tmiss} > 25 GeV, m_T > 60 GeV

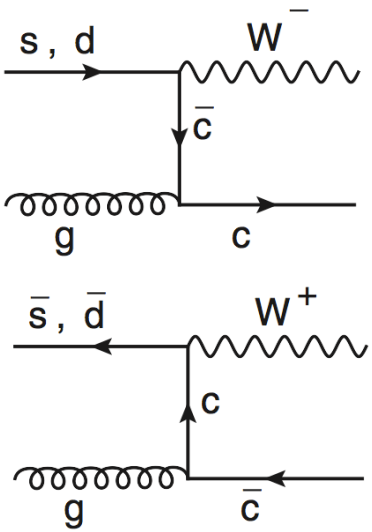
- W production with **only one b-jet or at least two jets** (only one of the two is a b-jet)

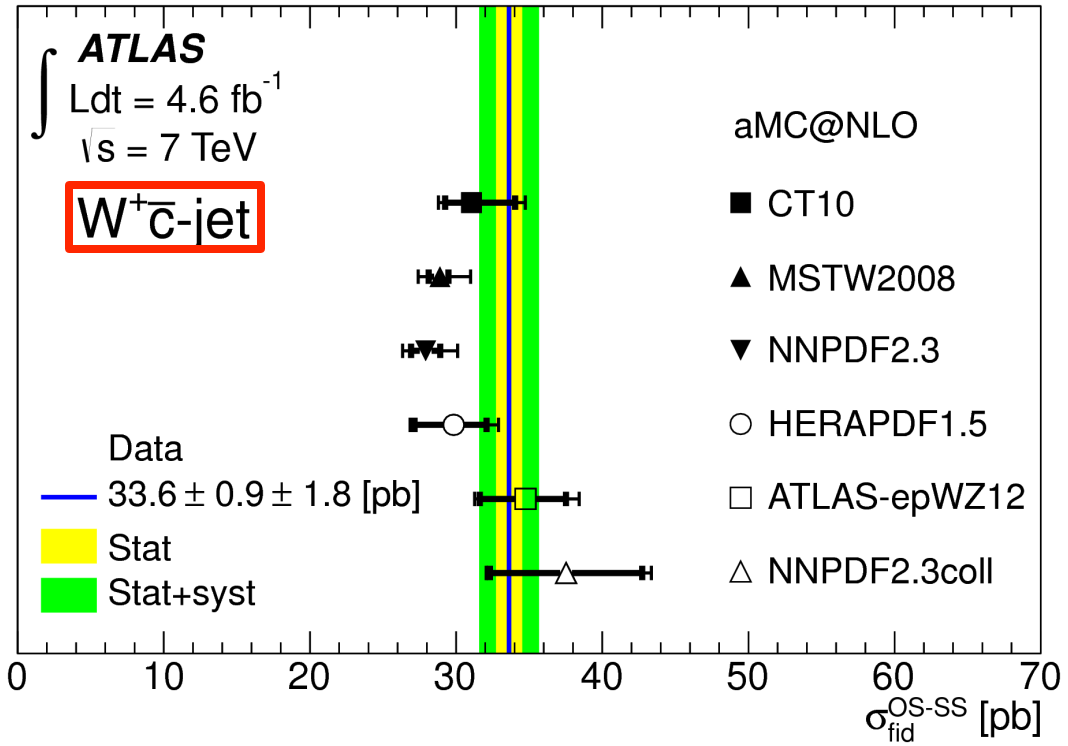


Measurements in agreement with theoretical predictions
- consistent with NLO within 1.5 σ

Wc (7 TeV)

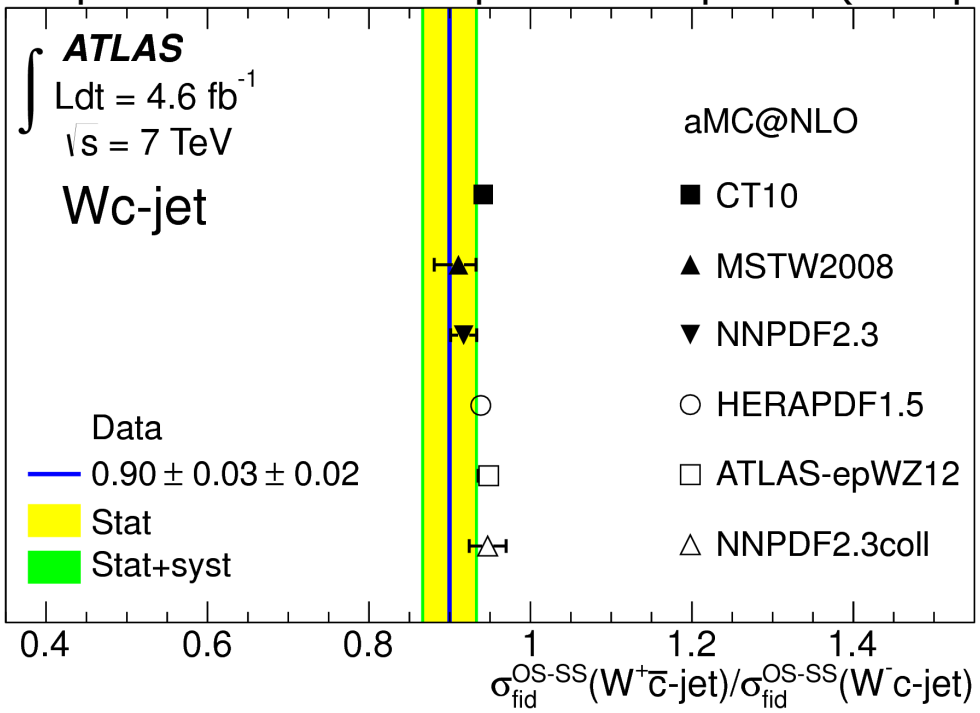
- Sensitive to the **s-quark PDF** at momentum transfer ~M_W
- Six measurements:
  - **$W^{\pm}$ + c-jet, $W^{\pm}$ + D, $W^{\pm}$ + D***
- **Important strategy:**
  - Charge correlation between W and c => μ in c-jet and D/D* has a charge opposite (OS) to the W boson
  - **W + c yields = OS events — SS events (backgrounds)**





Wc (7 TeV)

- **Cross section ratio (W^+ + cbar) / (W^- + c)**
- The observed **W^- + c** yield slightly larger than the **W^+ + cbar**
  - dominance of the d-quark over the d-antiquark in the proton (as expected)



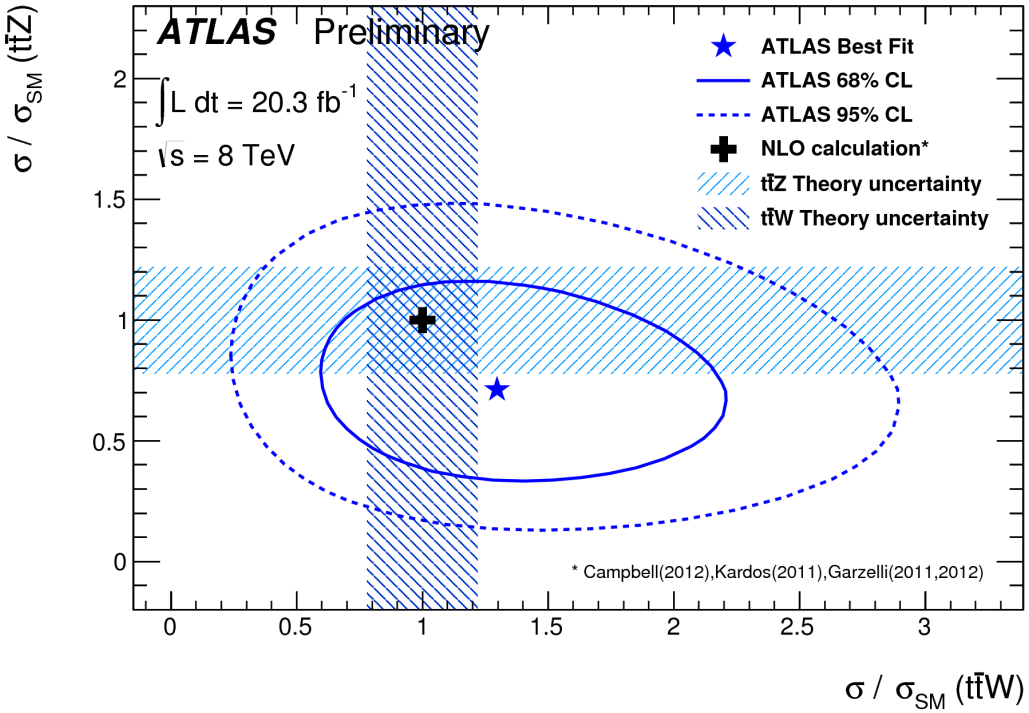
- Also measured:
  - **Differential cross section** (W + c) vs. lepton | η |
  - **The ratio (r_s)** of the strange-to-down sea-quark distributions:

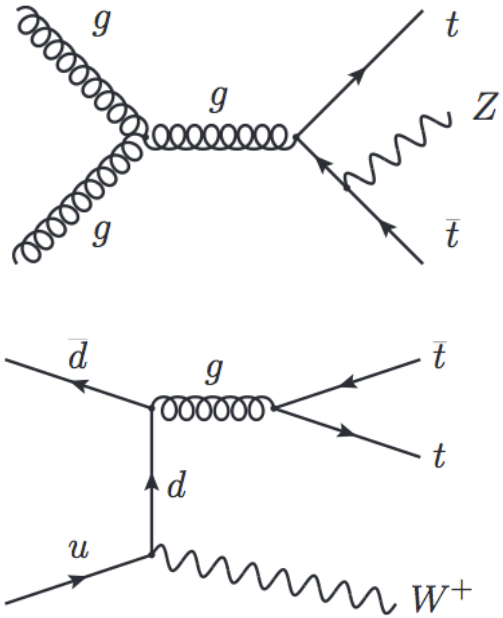
$$r_s \equiv 0.5(s+\bar{s})/\bar{d} = 0.96^{+0.26}_{-0.30}$$

  - Supports the hypothesis of a symmetric light-quark sea

ttbarW, ttbarZ (8 TeV)

- **Three channels** considered:
  - Same-sign **dimuon** (ttbarW)
  - Trilepton (ttbarZ)
  - Opp. Sign dilepton (ttbarW, ttbarZ)





The result of the **combined 2D simultaneous fit** for ttbarW and ttbarZ cross sections is **in agreement** with **NLO QCD predictions**:

- Campbell (2012), Kardos (2011) and Garzelli (2011,2012)

Summary and Outlook

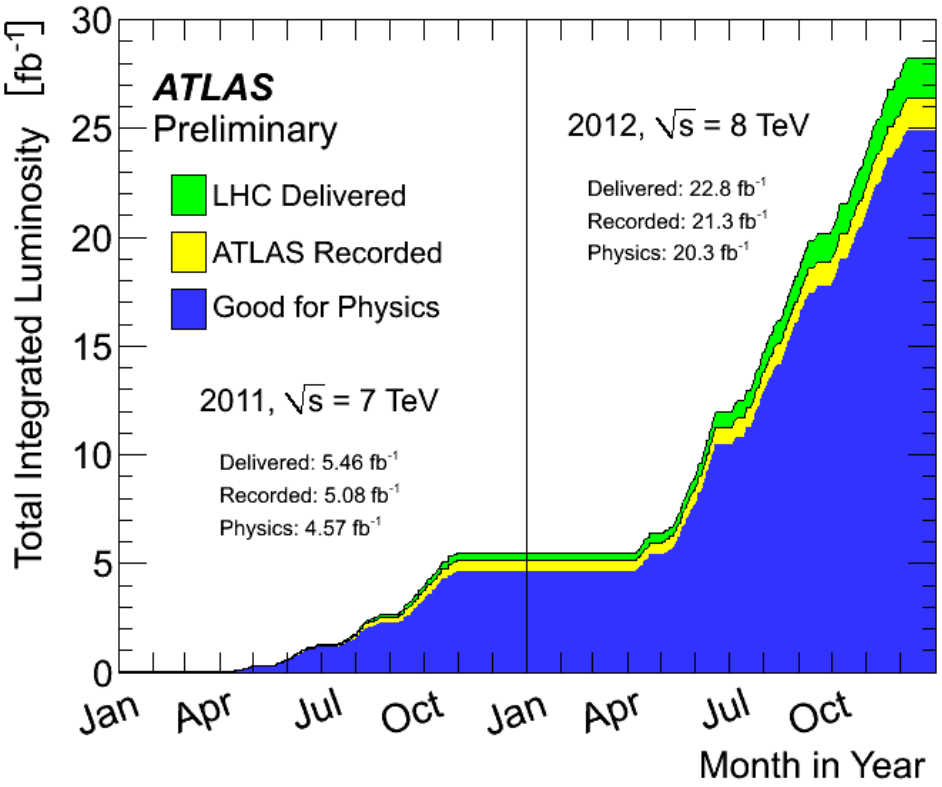
- **ATLAS excellent performance** allows the precise study of associated vector boson production
- A **hot topic** for theoretical studies for several years can be finally exploited with high precision experimental measurements!
- Several results for **7 TeV (2011)** and **8 TeV (2012)** were presented
  - Overall good agreement with theory predictions; some discrepancies exist
- Many **8 TeV (2012)** measurements are in progress
- **Important feedback** to theorists and our understanding of QCD and electroweak processes in the high energy LHC regime

Looking forward for more precise measurements this year at 13 TeV!

BACKUP

Total Integrated Luminosity in 2011 and 2012

- Excellent performance
- Utilize most of the LHC delivered luminosity



ATLAS Standard Model Cross Sections