Measurement of the production cross section for Z/γ* and W in association with jets in pp collisions at √s=7 TeV with the ATLAS Detector

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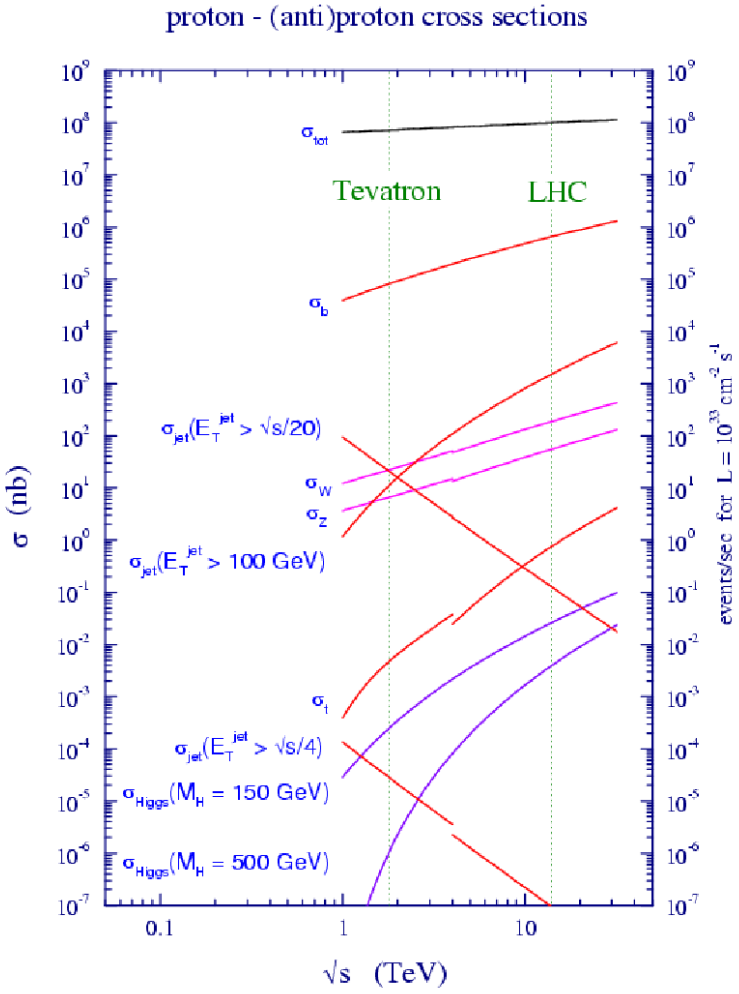
PHYSICS AT THE TERA SCALE
Helmholtz Alliance

FSP 101 ATLAS

Bundesministerium für Bildung und Forschung

Introduction

- Analysis:
  - Measurement of the inclusive and differential Z + jets and W + jets cross section on hadron level in the electron and muon channel and their ratio
- Motivation:
  - Test of pertubative QCD predictions at the Z scale
  - Background for searches of the Higgs Boson and new physics



Introduction

- Public results
  - Z/γ*+jets: arXiv:1111.2690v1; CERN-PH-EP-2011-162 (36 pb^{-1})
  - W+jets: ATLAS-CONF-2011-060 (33 pb^{-1})
  - R jets: arXiv:1108.4908; CERN-PH-EP-2011-126 (33 pb^{-1})
- German contributions from: Berlin, Bonn, Freiburg, Göttingen, Munich, Wuppertal
- Data sample:
  - Using 2010 data
    - Well understood electron, muon and jet performace
    - Relatively low collision rates and low pile-up rates
    - Allow cross section measurement at low jet transverse momentum
- Large measurement menu:
  - Total inclusive cross section as a function of jet multiplicity
  - Inclusive jet p_T and |y| differential cross sections
  - Differential dijet cross sections: m^{jj}, $|\Delta y^{jj}|$, $|\Delta\phi^{jj}|$, ΔR^{jj}
  - Ratio of the W and Z cross sections with exactly one associated jet

V+jets cross section measurement

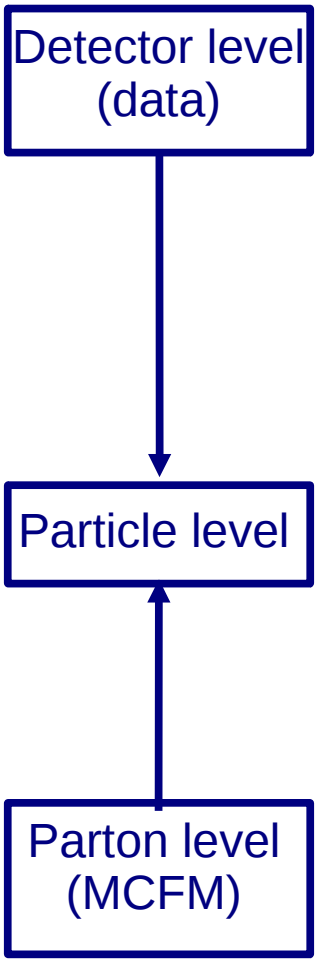
Uncertanties

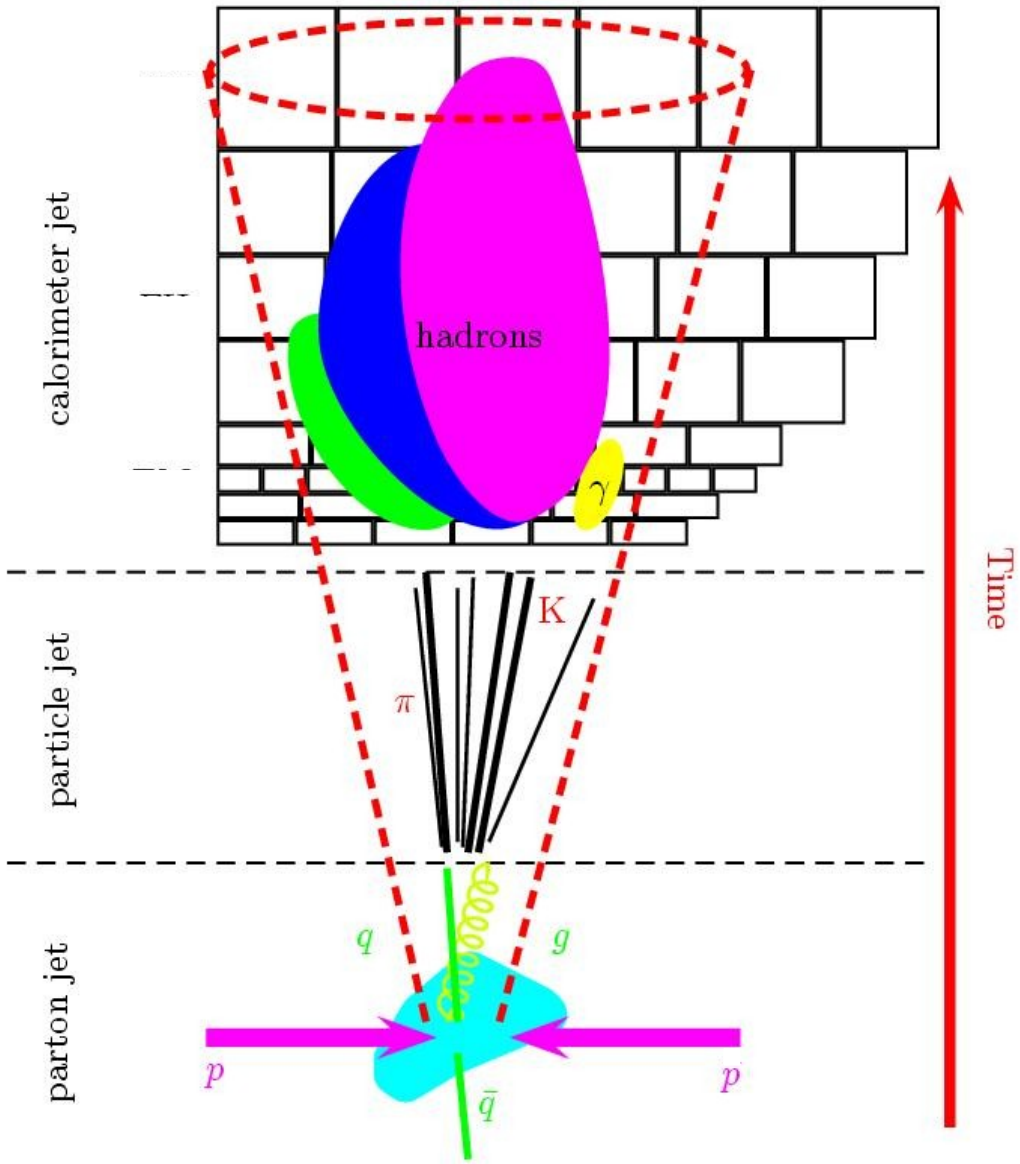
Statistics

JES, JER,
lepton reco & ID + triger

Non-perturbative effects
(UE, fragmentation)

PDF, α_s





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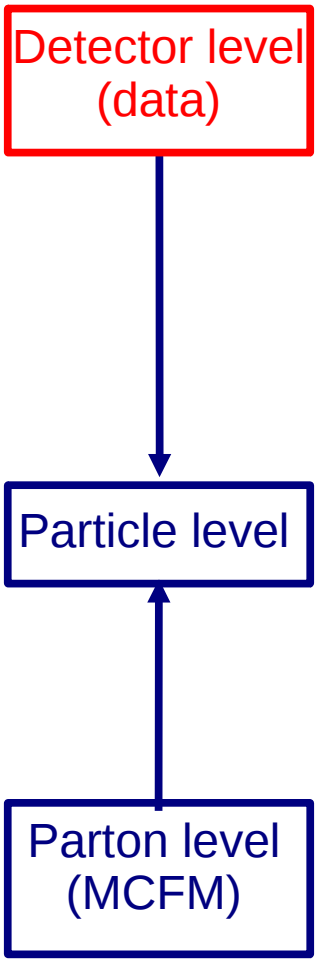
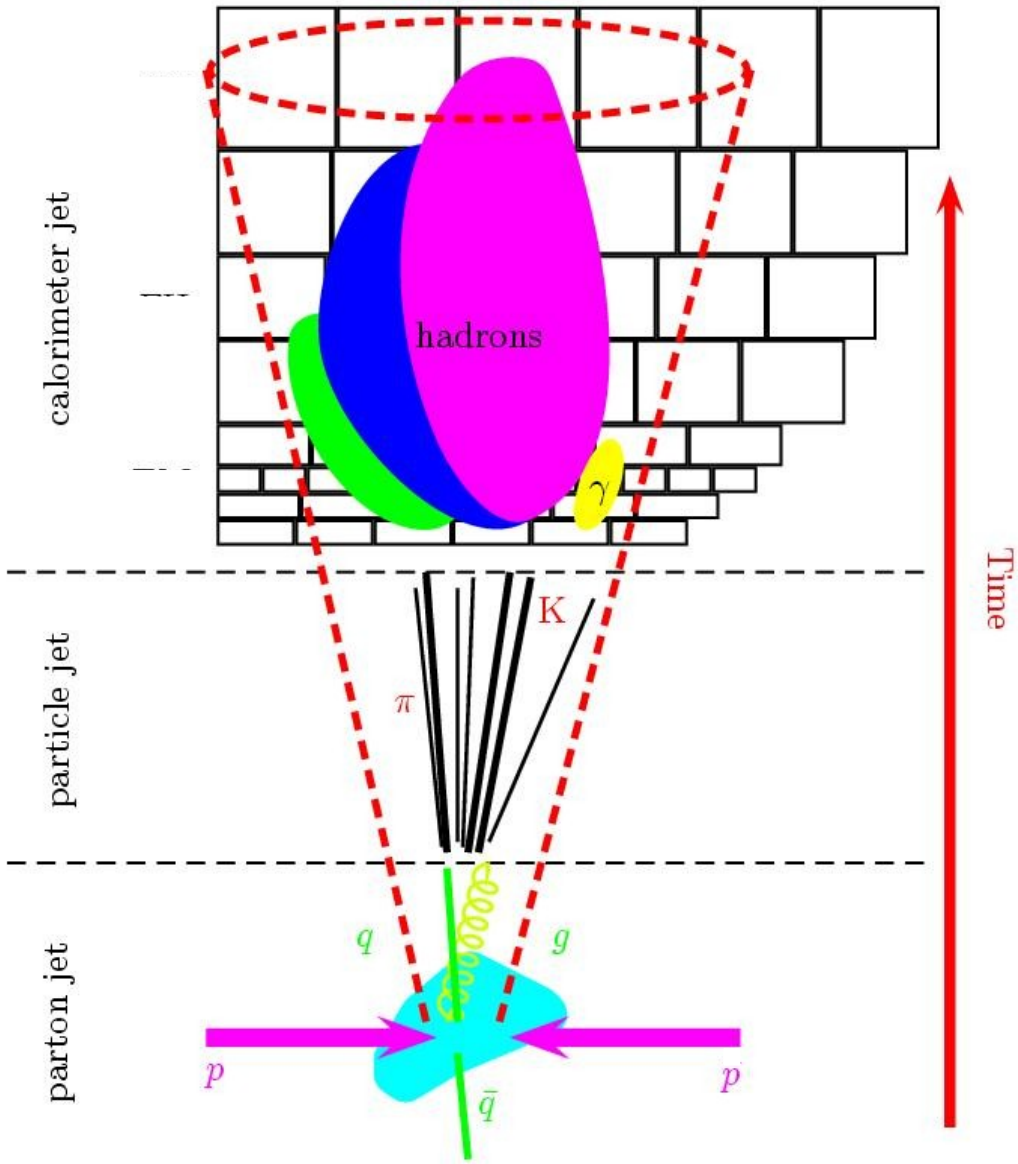
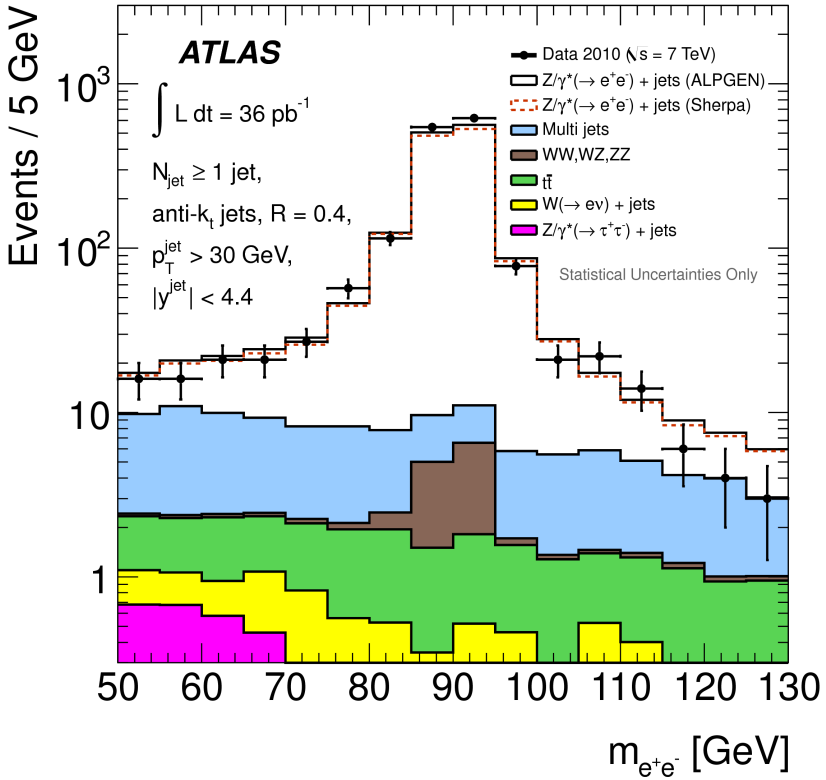
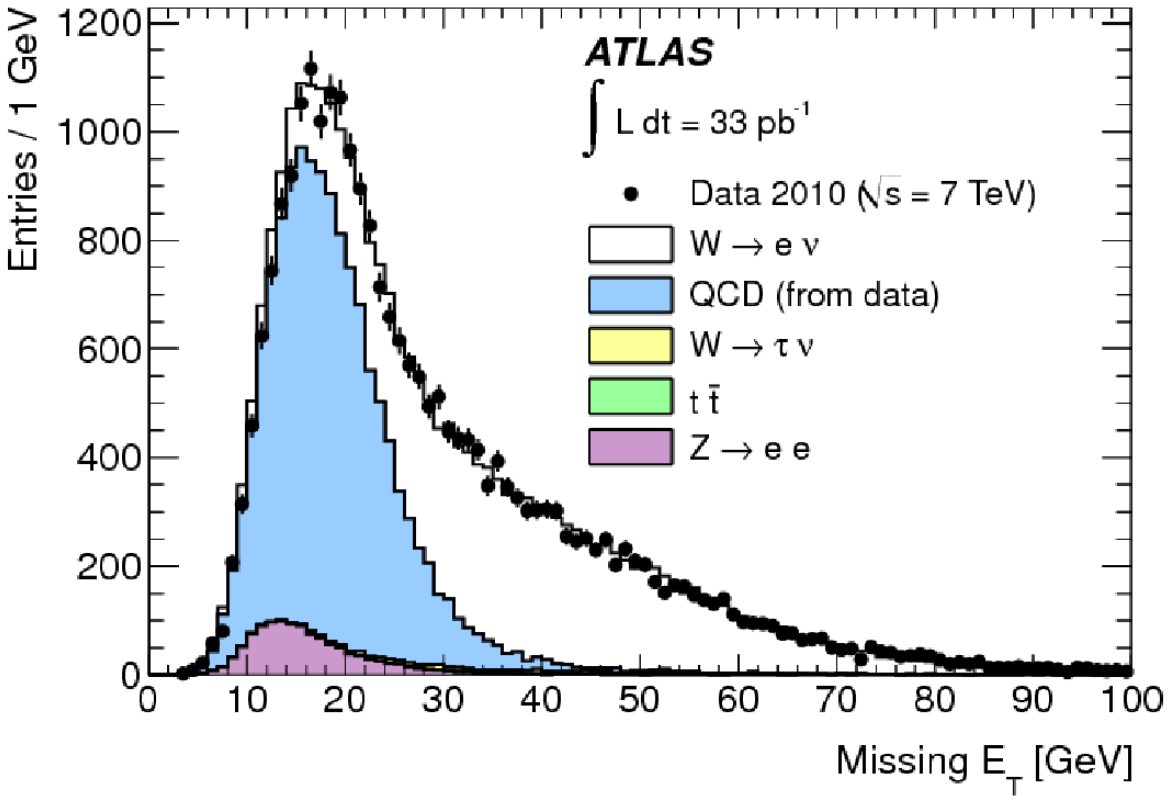




W, Z selection

- Z selection: 2 opposite sign leptons, p_T>20GeV, 66<M(ll)<116GeV
- W selection: 1 lepton, p_T>20GeV, MET>25GeV, M_T>40GeV

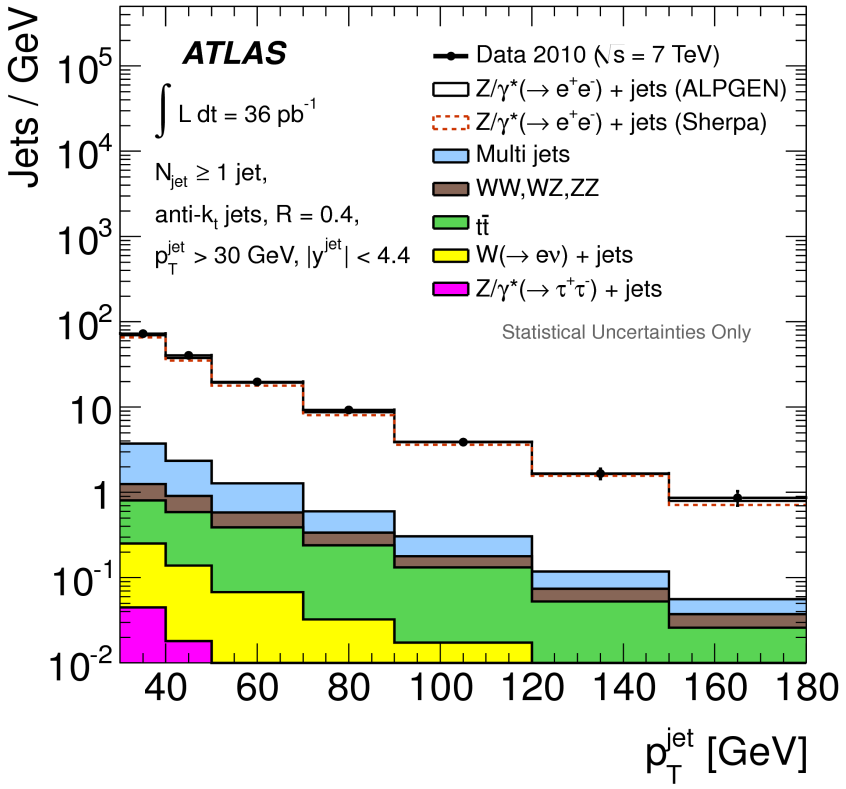


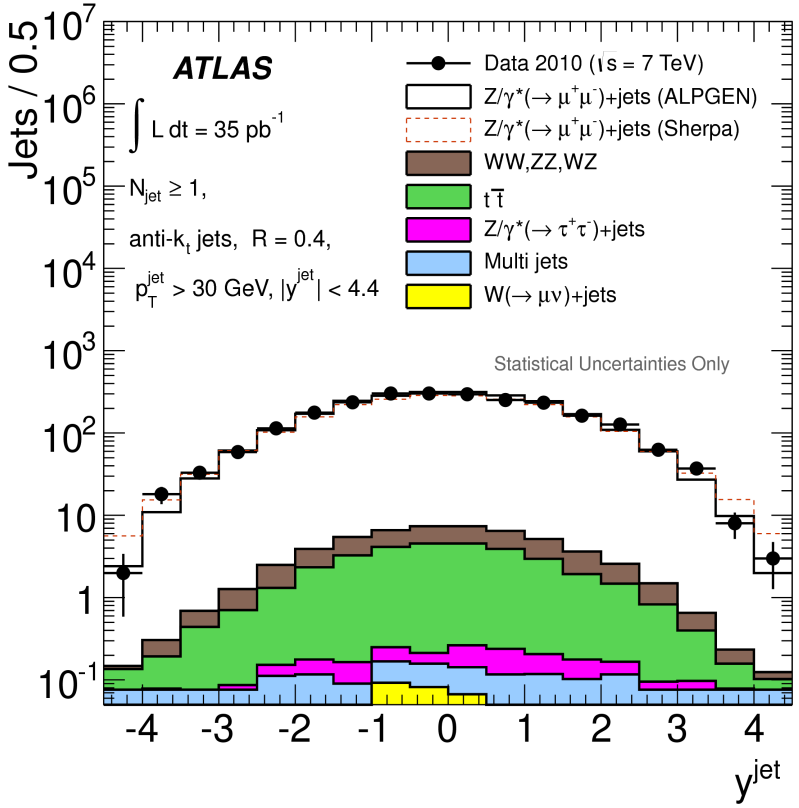


- Signal MC: Alpgen+Herwig (Z+jets, W+jets, R jets) and Sherpa (Z+jets)
- MC: scaled to integrated luminosity in data

Jet selection

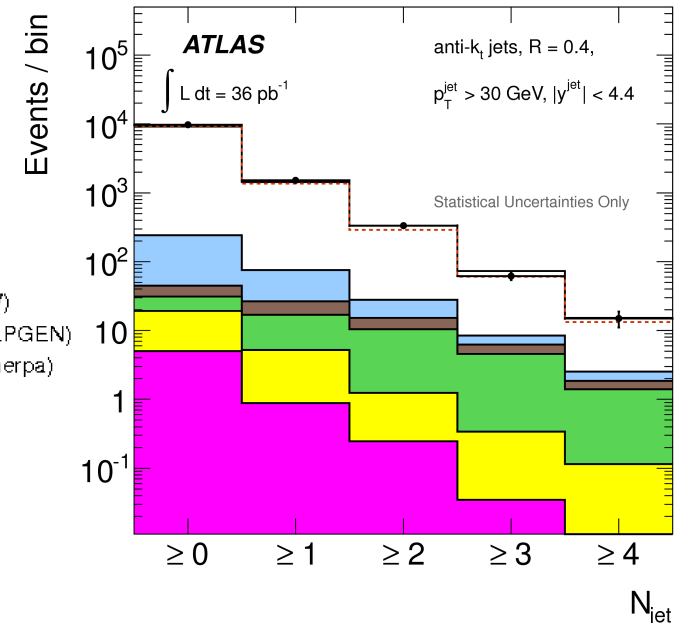
- Antikt jets, R=0.4, build from calorimter clusters
- EM+JES calibration with offset and beamspot correction
- p_T>30 GeV (Z+jets, R jets), p_T>20 GeV (W+jets)
- |y|<4.4 (Z+jets), |y|<2.8 (W+jets), |η|<2.8 (R jets)
- Jet isolation: ΔR(lepton,jet)>0.5

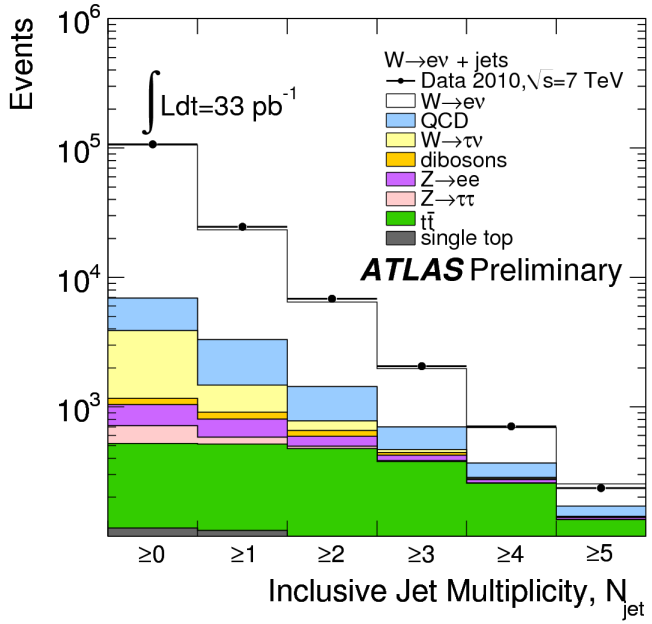




Backgrounds

- Z/γ*+jets:
  - Main backgrounds:
    - QCD multijet (3%-5%, electron channel)
    - Ttbar (1%-9%, both channels)
    - Diboson (0.7%-3%, both channels)
- W+jets:
  - Main backgrounds:
    - QCD multijet (4%-36%, electron channel)
    - Ttbar (0.4%-49%, both channels)
    - W→τν, Diboson, Z→ττ (both channels)
- QCD multijet is estimated from data
  - Electron channel:
    - Template fits (Z+jets,W+jets, R jets)
  - Muon channel:
    - ABCD method (Z+jets)
    - Template fits (R jets)





V+jets cross section measurement

Uncertanties

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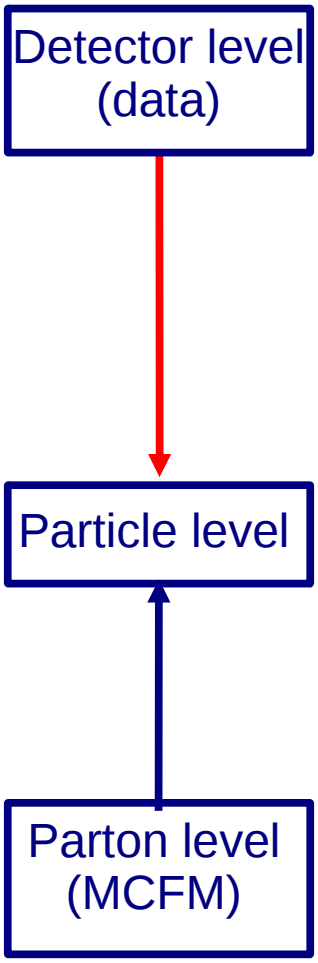
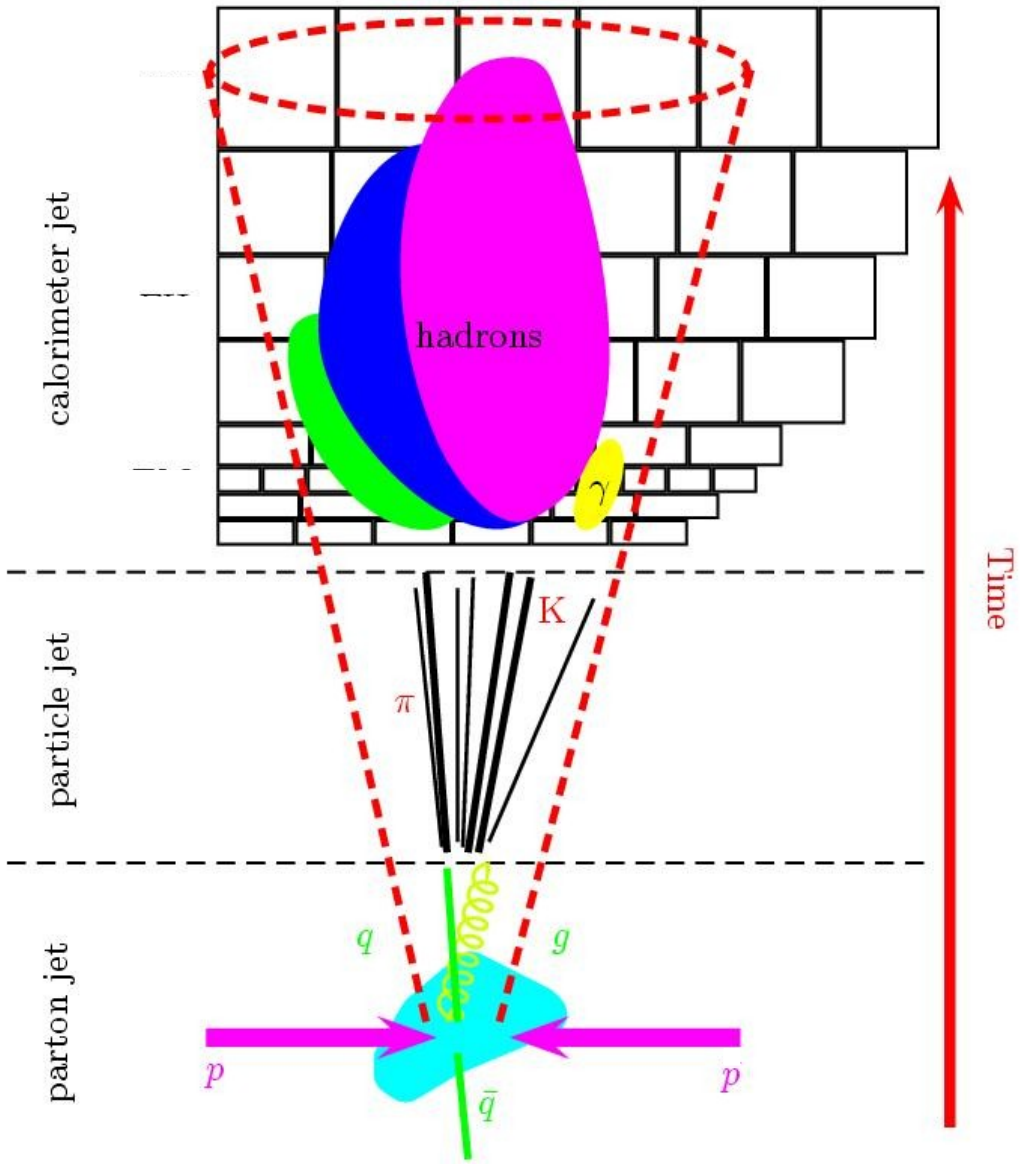
PDF, α_s



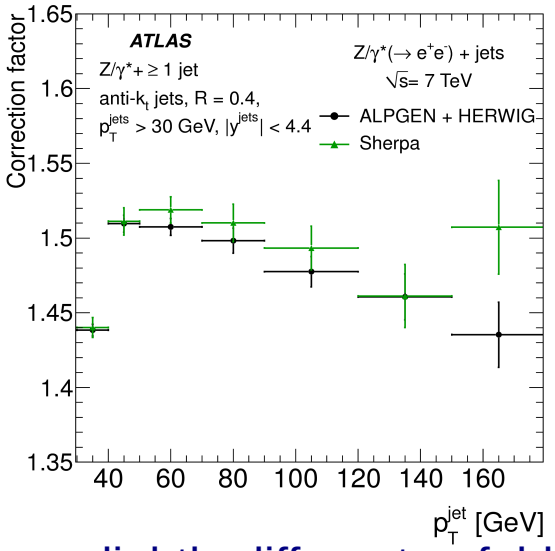


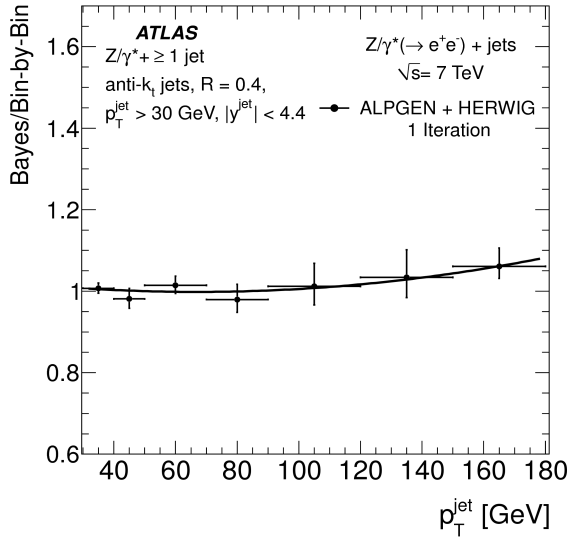
Unfolding for detector effects

- Differential cross sections: defined as function of a variable ξ in a given fiducial region

$$\frac{d\sigma}{d\xi} = \frac{1}{L}\,\frac{1}{\Delta\xi}(N_{\mathrm{data}} - N_{\mathrm{backg}}) \times U(\xi)$$

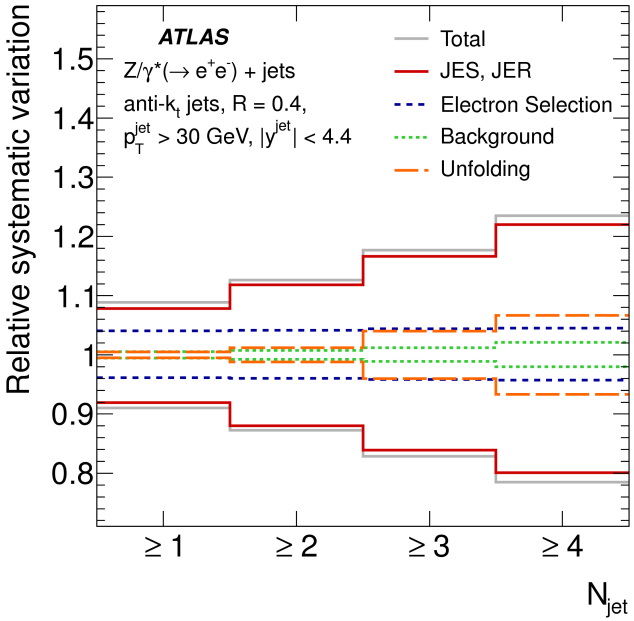
- For combination differential measurements are corrected to Born-Level and extrapolated to common phase space regions (p_T>20 GeV and η<2.5 for the leptons)
- The unfolding factor U(ξ) back to the particle level is determined using the bin-by-bin method
- Lepton kinematics on particle level in the MC generated samples are defined to include the contributions within a cone of 0.1 around the lepton direction

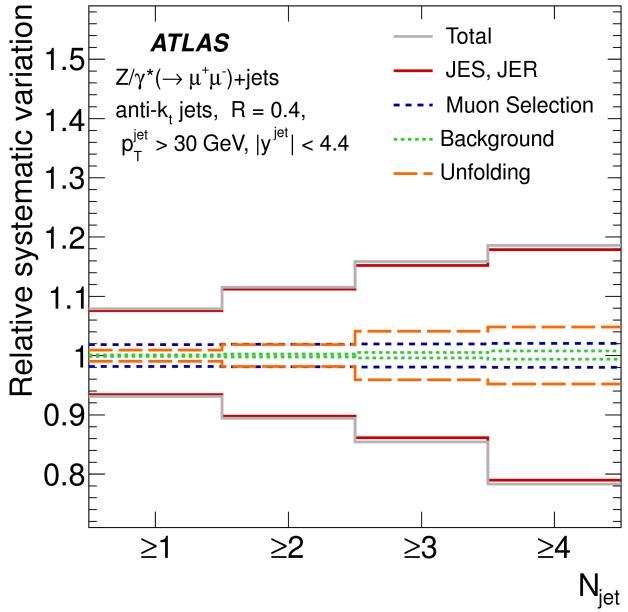




- Sherpa/Alpgen: slightly different unfolding factor
  - ➔ Jet kinematics and composition (parton shower, fragmentation, ...) dependence
- For the final results Alpgen is used for unfolding and Sherpa for systematics
- Systematic: Comparison Bin-by-Bin method with Alpgen and Sherpa and with the iterative (Bayes) method

Systematic uncertainties





- Systematic uncertainties for Z+jets:
  - JES uncertainty dominant contribution (7% -22%)
  - JER estimated using the official tool (~1%)
  - Lepton uncertainty
    - 2% muon channel
    - 4% electron channel
  - Unfolding from difference between Alpgen and Sherpa (0.4% - 4.5%) and Bayes instead of bin-by-bin (< 1%)
- Similar systematics for W+jets, but larger contribution from QCD background and from ttbar for large jet multiplicities

Z+jets cross section measurement

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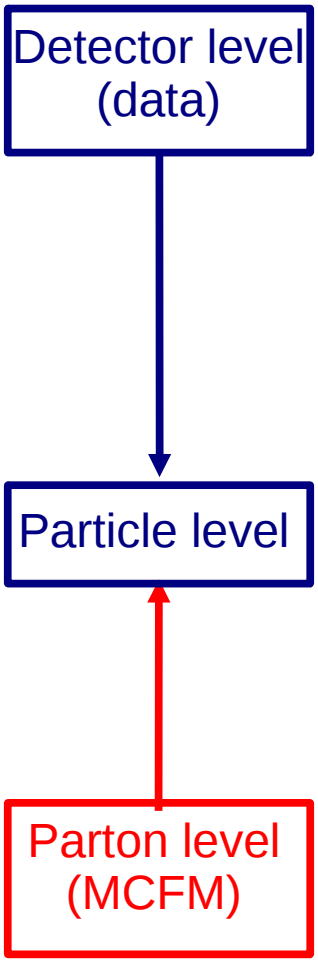

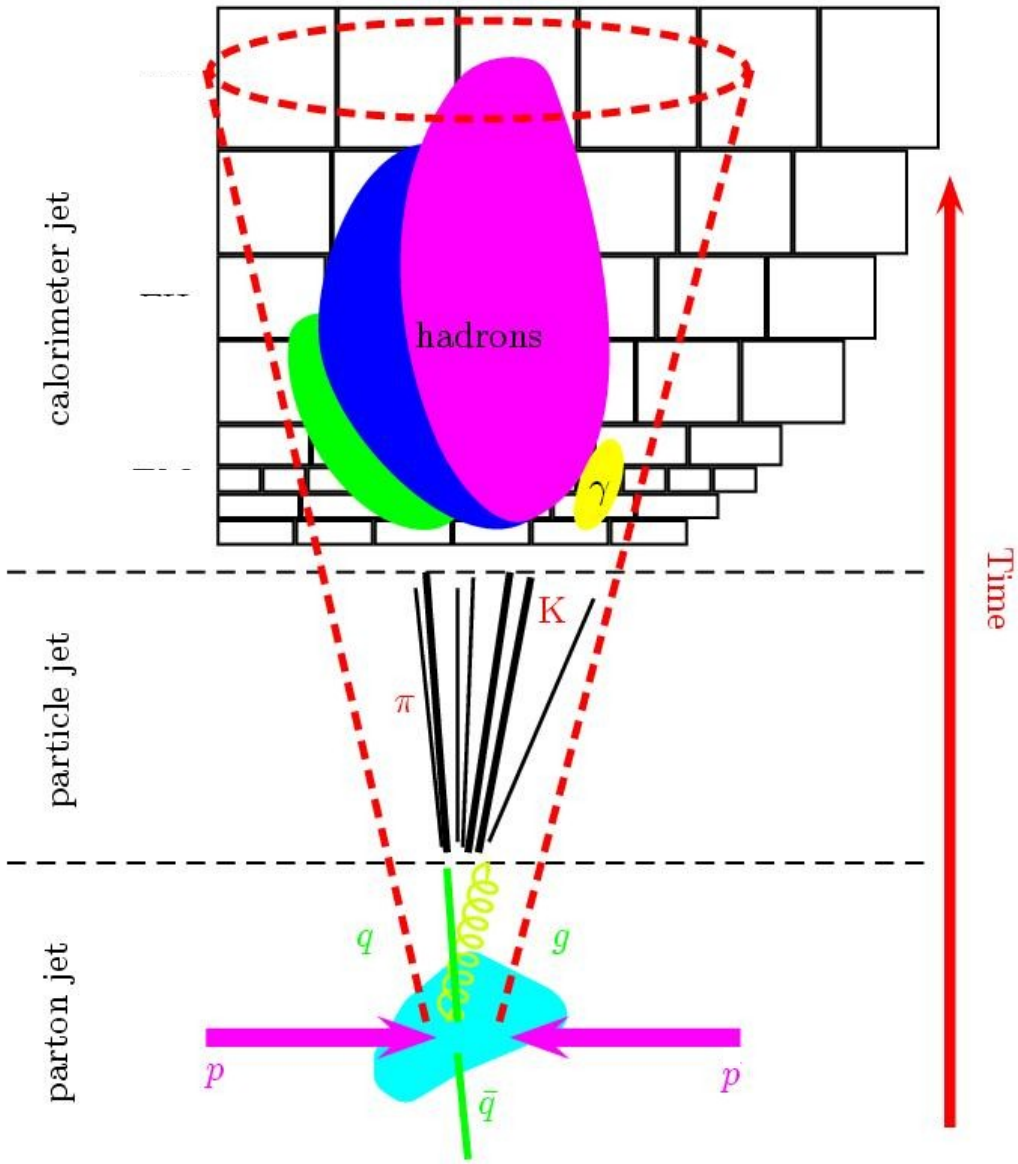

NLO pQCD Predictions

- Blackhat (arXiv:hep-ph/1004.1659, arXiv:hep-ph/1108.2229), Z+0,1,2,3,4 jets NL0
- Scale:
  - Hadronization and factorization scale: $H_T/2$
  - Systematic uncertainty is calculated by varying both scales simultaniously by factor of 2 (4% - 14%)
- PDF:
  - CTEQ6.6
  - Systematic uncertainty: complete PDF CTEQ6.6 error set (2% - 5%)
  - Use Hessian Method, 90%CL
- α_s uncertainty:
  - varying the input α_s at the Z scale by +/- 0.002 (2% - 7%)
- Theoretical prediction are corrected for
  - QED radiation effects (~2%)
  - non-perturbative contributions (UE, fragmentation):
    - Nominal correction: Herwig+Jimmy (1%-10%)
    - Systematics: Pythia + various AMBT tunes

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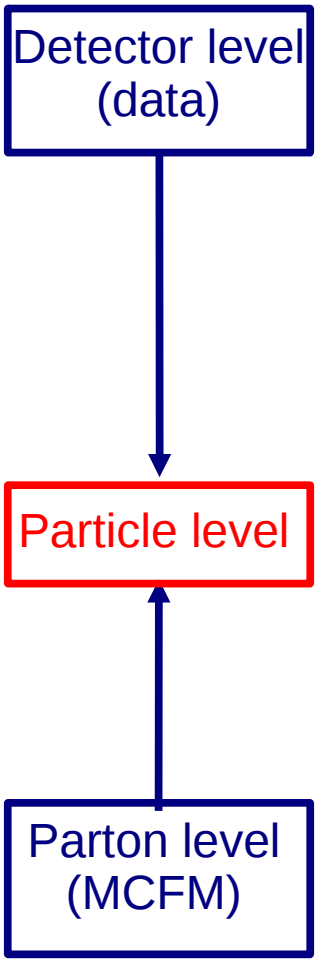
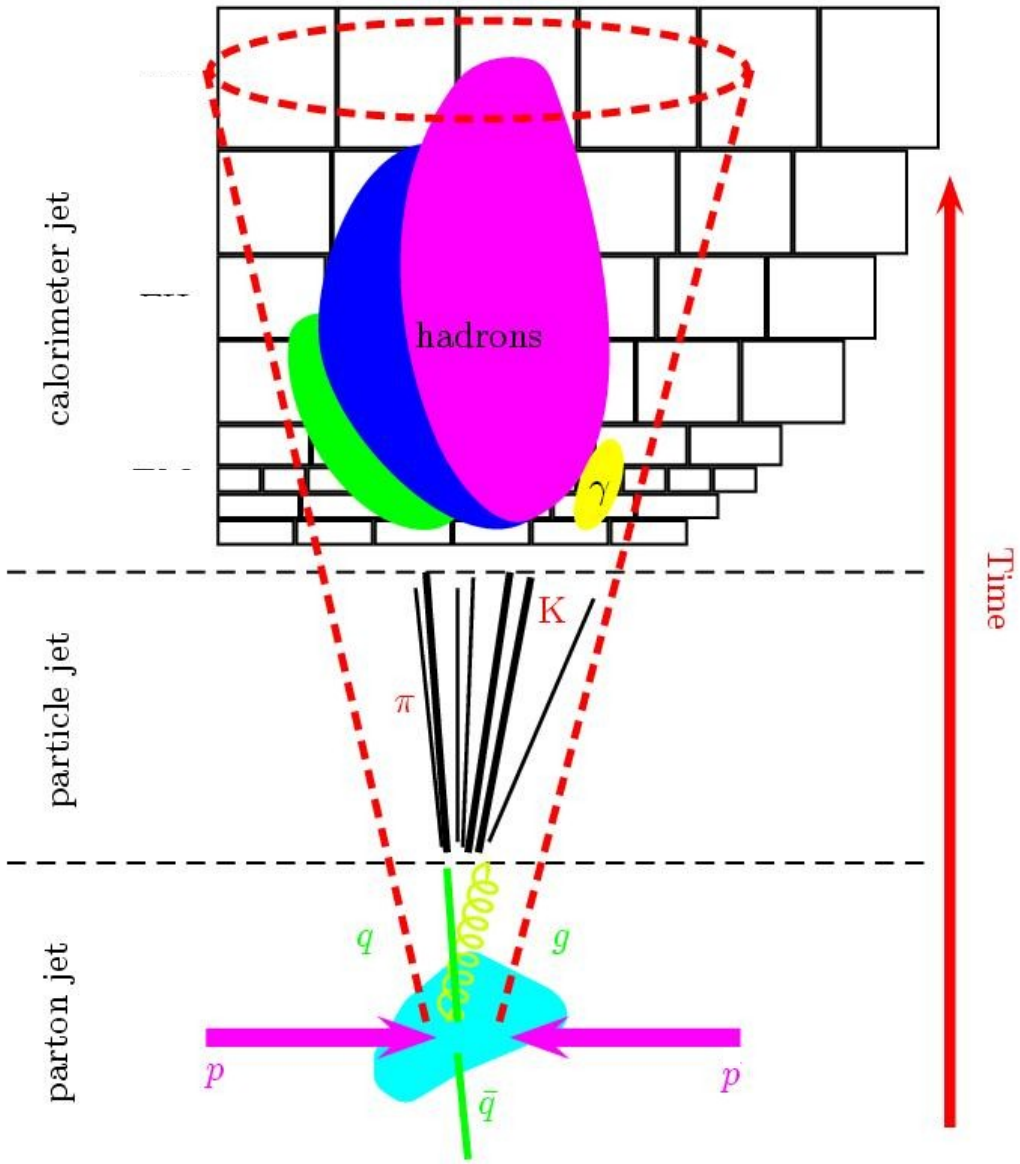
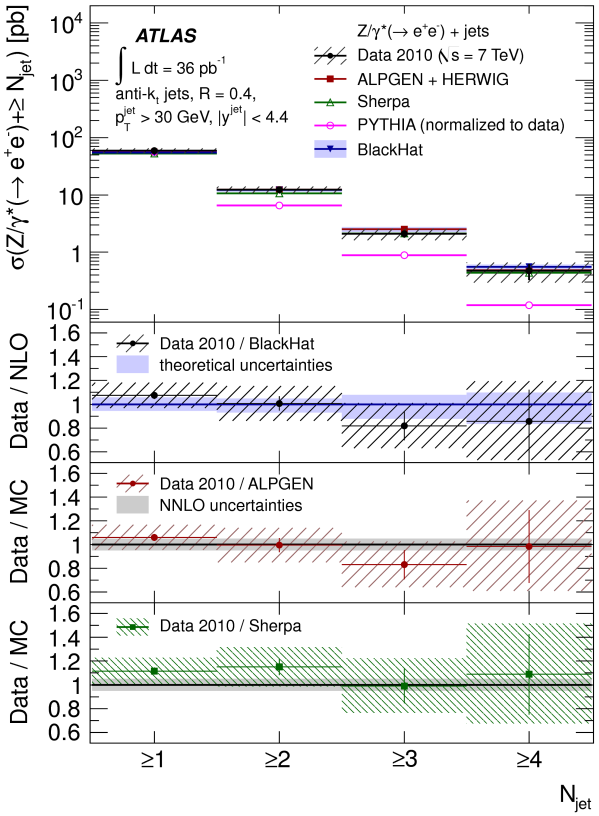
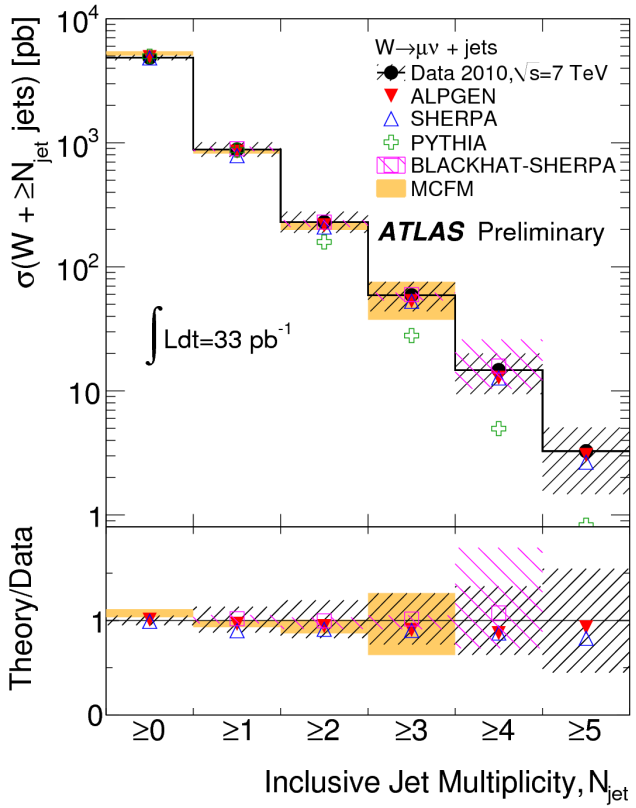




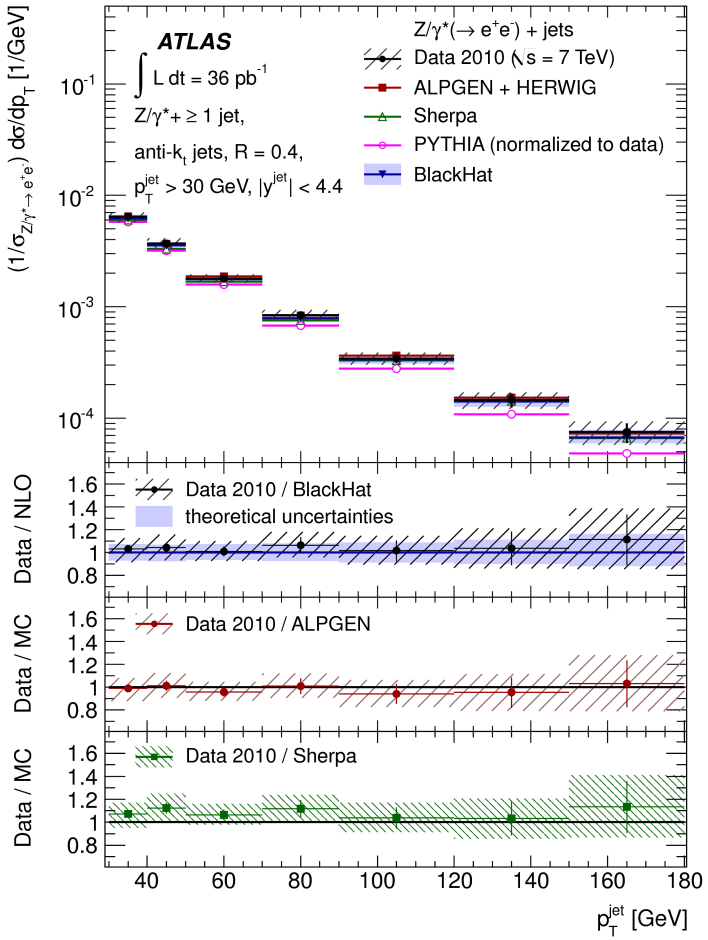
Results – inclusive jet multiplicity

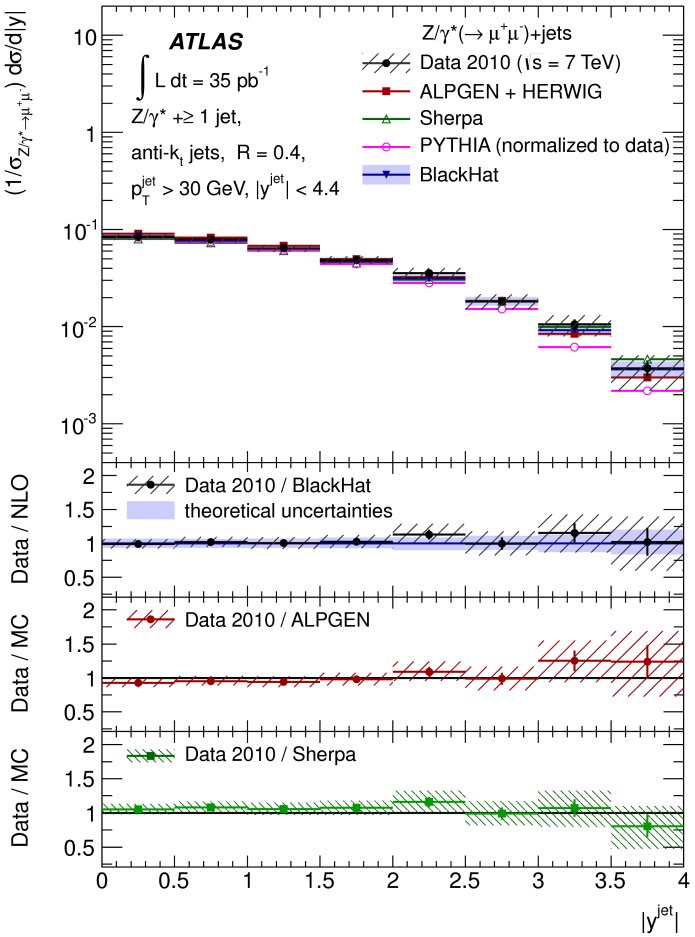




- Cross section: up to 4 jets (Z+jets), up to 5 jets (W+jets)
- As expected the measured cross section decreases with increasing jet multiplicity
- Alpgen/Sherpa normalized to the inclusive NNLO cross section, Pythia (2→2 process) normalized to inclusive 1 jet cross section in data
- Alpgen, Sherpa and NLO pQCD / data: good agreement in the fiducial region
- Pythia predictions underestimate the measured cross section for larger jet multiplicities

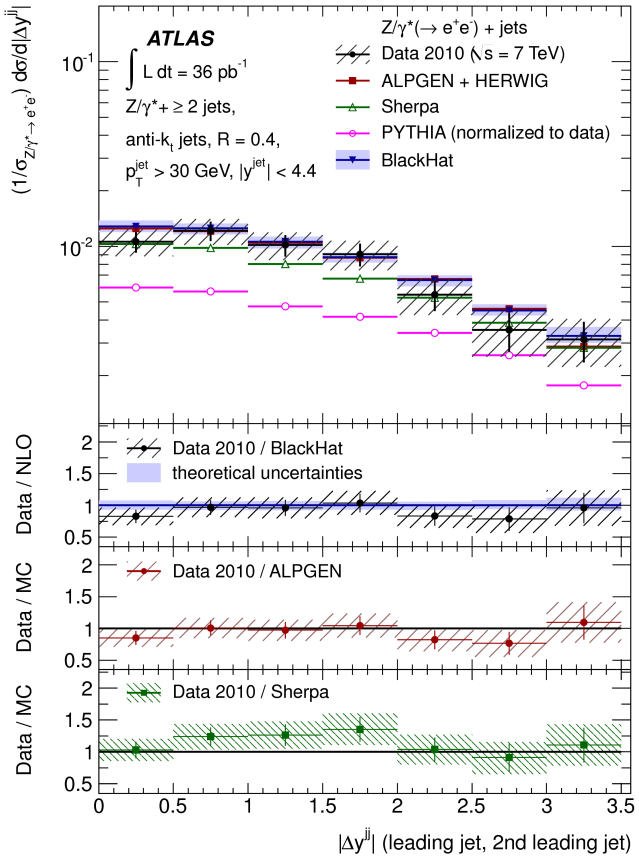
Results - $d\sigma/dp_T$ and $d\sigma/d|y|$

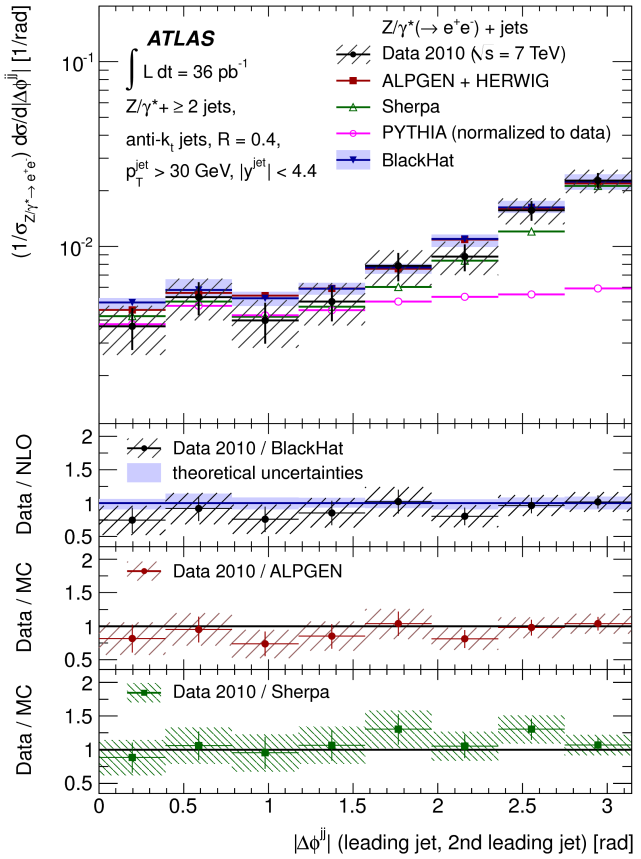


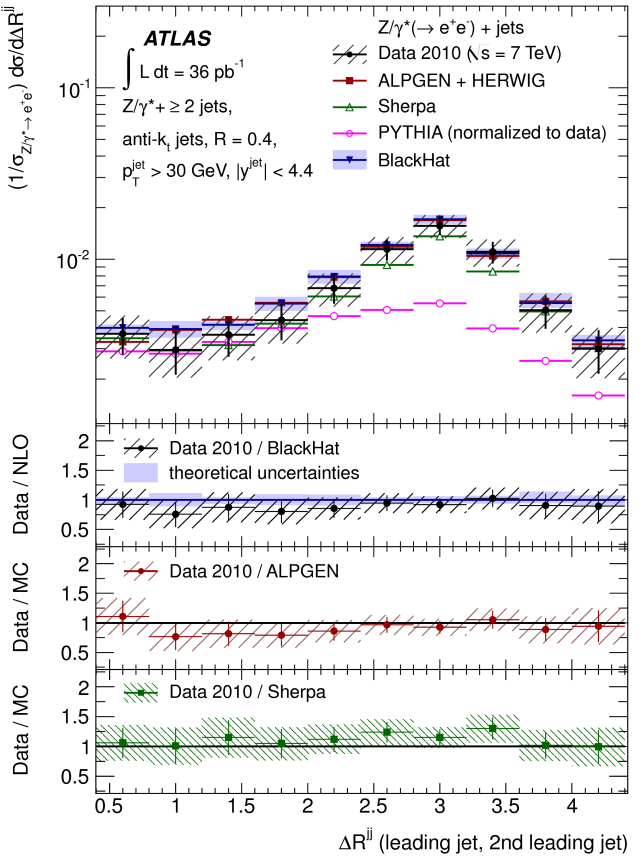


- Differential cross section as a function of p_T(jet) and |y(jet)|
  - Cross section is normalized to the inclusive DY cross section
  - ➔ Some systematics cancel out
  - Measured cross section decreases with increasing p_T and increasing |y|
  - Alpgen, Sherpa and NLO pQCD / Data: within uncertainties good agreement in the fiducial region

Results - dσ/d|y^{jj}|, dσ/d|ϕ^{jj}| and dσ/dR^{jj}

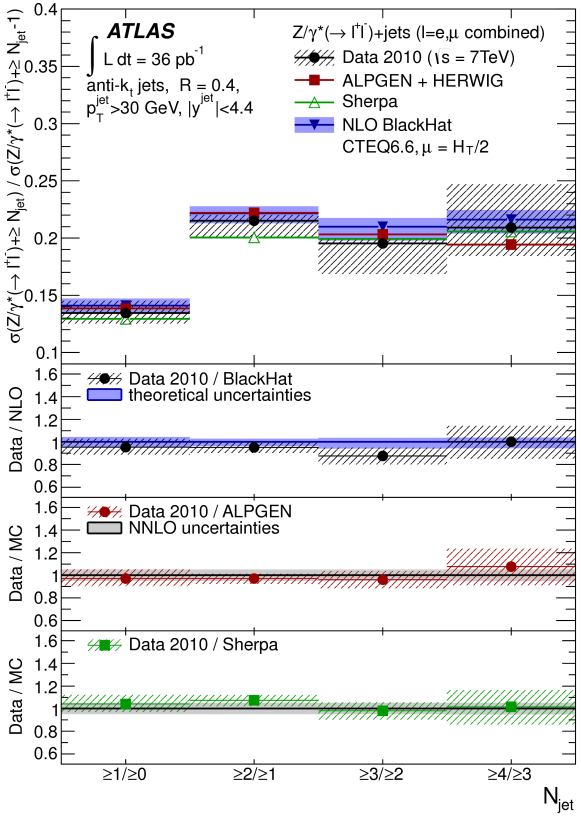


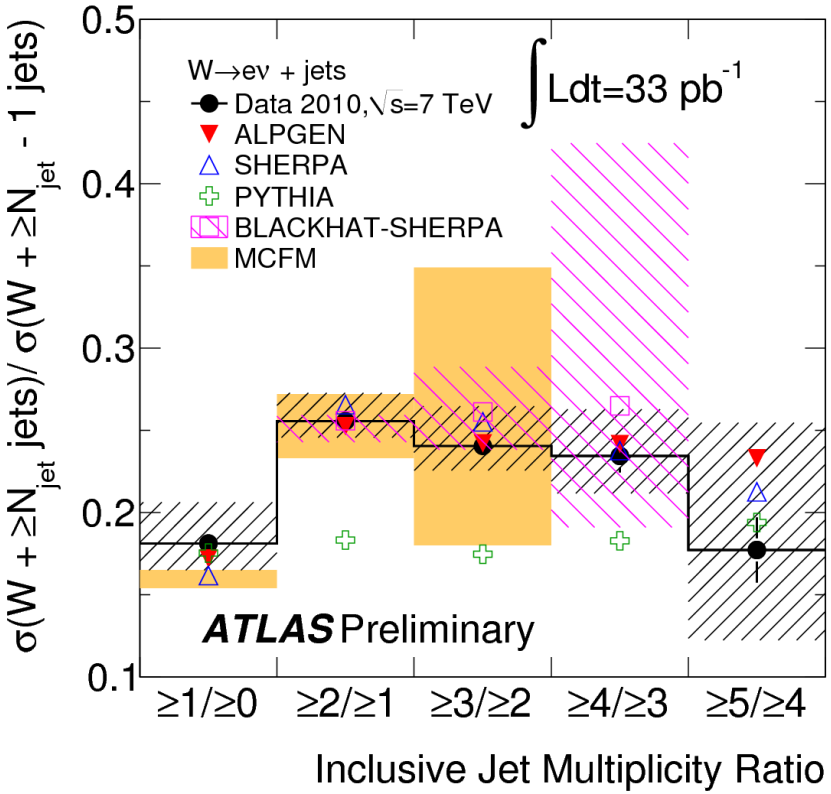




- Differential dijet cross sections as a function of the spatial seperation of the two leading jets
  - Cross section is normalized to the inclusive DY cross section
  - ➔ Some systematics cancel out
  - Measurements are well described by Alpgen, Sherpa and NLO pQCD predictions
  - Pythia underestimates the measured cross sections for |Δy^{jj}|, large |$\Delta\phi^{jj}$| and large R^{jj}

Results - inclusive jet multiplicity

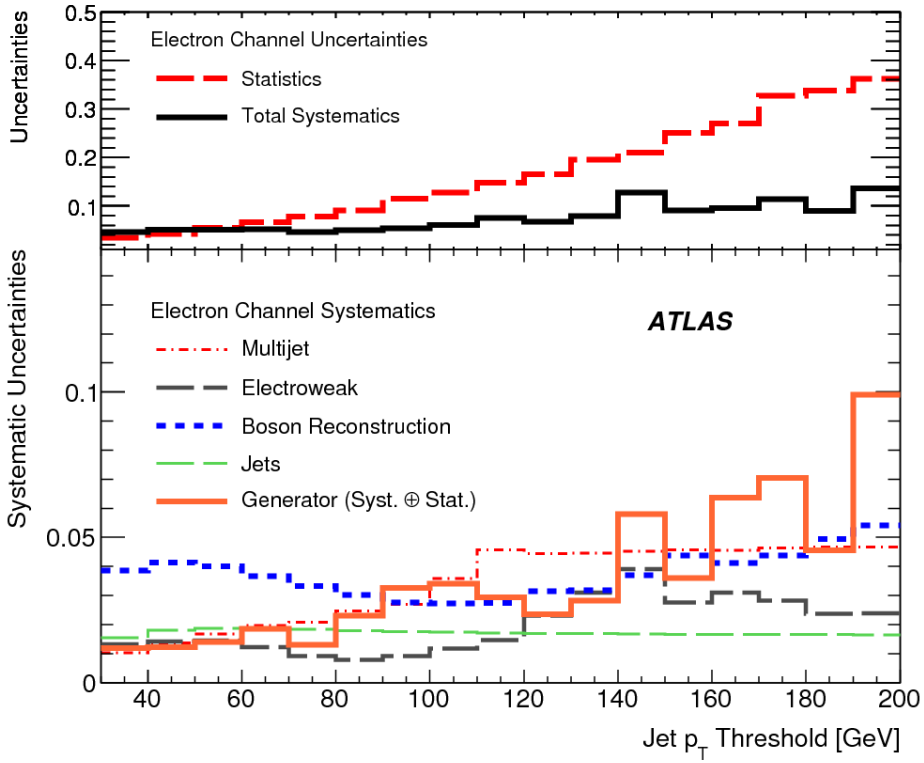


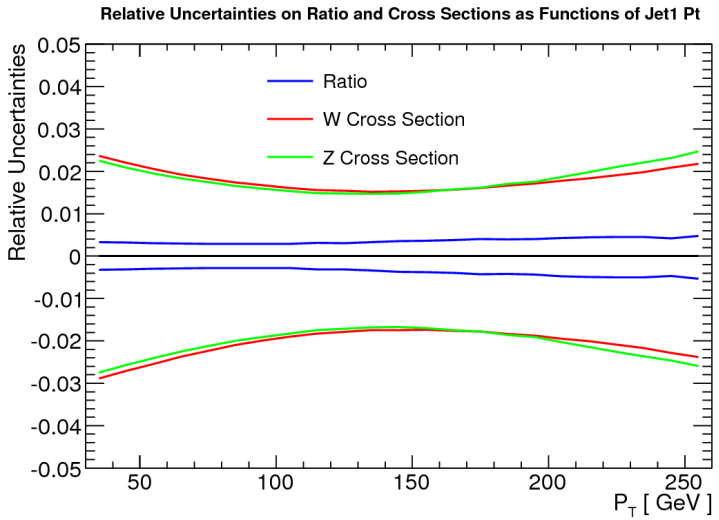


- Ratios of inclusive jet cross section:
  - Some systematics cancel out again
  - Sensitive to value of the strong coupling, the implementation of higher order matrix elements and soft gluon contributions in the theoratical predictions
  - Cross section decreases by a factor of 4-5 with increasing jet multiplicity
    - Alpgen, Sherpa and NLO pQCD / data: good agreement
    - Pythia fails to describe the cross section ratio

Ratio of W and Z cross sections with $N_{jet}=1$

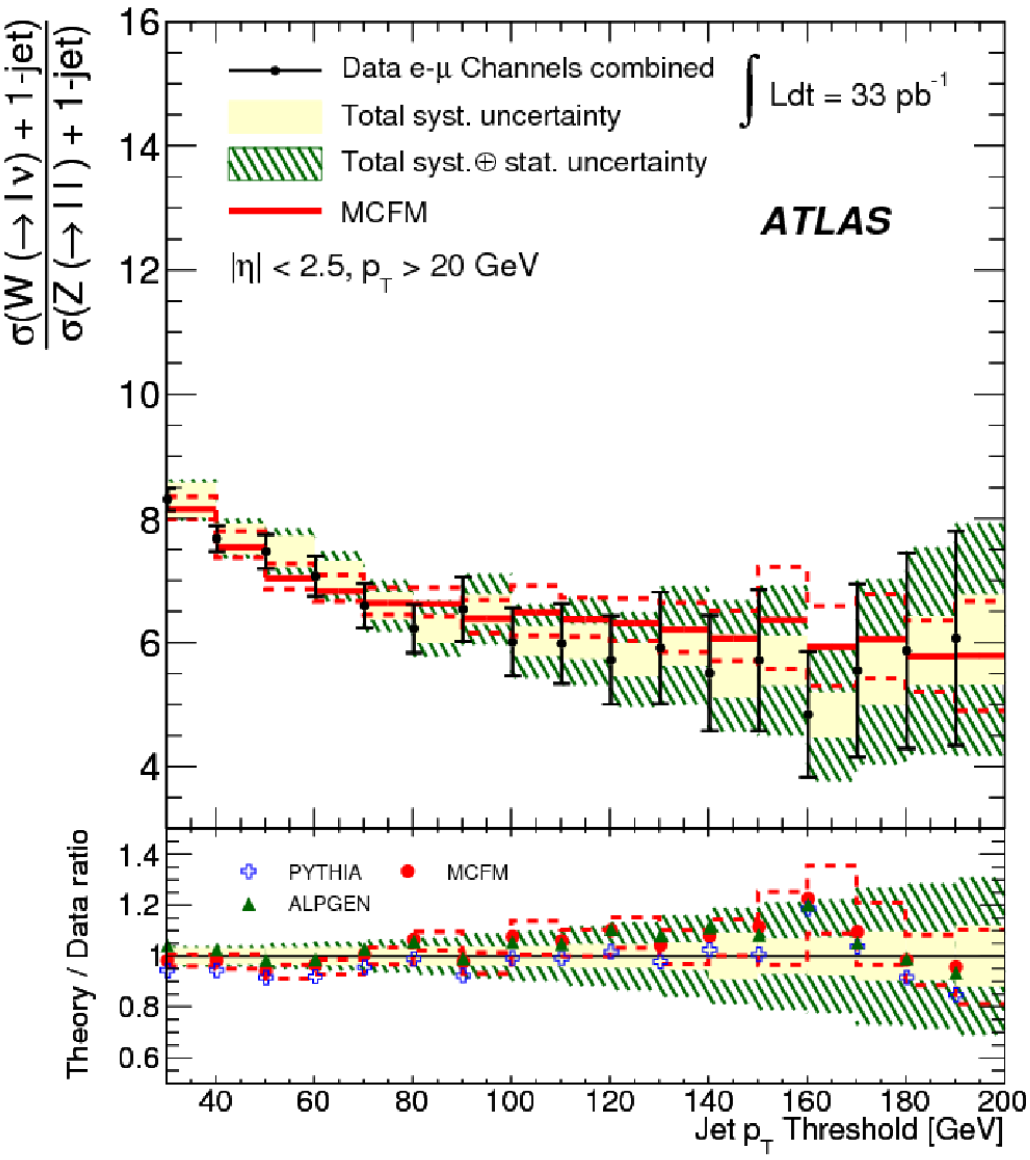
- Ratio of W and Z cross sections with $N_{jet}=1$ as a function of p_T(jet) threshold
- Performed to maximise the cancellation of experimental and theoretical uncertainties
  - Especially Jet uncertainties and PDF uncertainties are significantly reduced
  - ➔ High precision test of SM
- First measurement of its kind
- Provides model-independent sensitivity to new physics coupling to leptons and jets





Ratio of W and Z cross sections with $N_{jet}=1$

- Measurement is performed in electron and muon channel, both in fiducial and extrapolated phase space
- As expected measured ratio decreases with increasing p_T(jet) threshold
  - effective scale of the interaction becomes large compared to the difference in boson masses
- ALPGEN, PYTHIA and NLO pQCD / data: good agreement

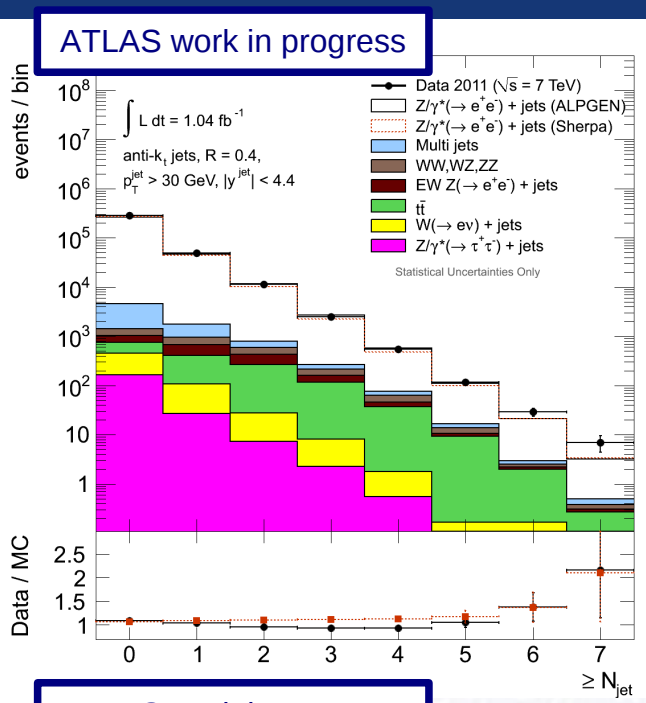


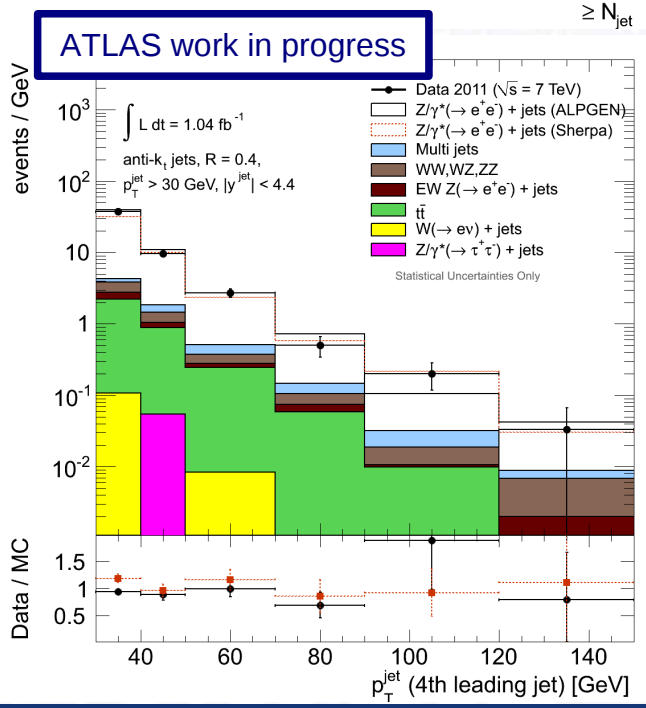
Summary

- Inclusive and differential V + jets cross section measurement with the full 2010 dataset
  - Total inclusive cross section as a function of jet multiplicity
  - Inclusive jet p_T and |y| differential cross sections
  - Differential dijet cross sections: m^{jj}, $|\Delta y^{jj}|$, $|\Delta\phi^{jj}|$, ΔR^{jj}
  - Ratio of the W and Z cross sections with exactly one associated jet
- NLO pQCD calculations and predictions from matrix element generators (ALPGEN, Sherpa) agree well within uncertainties with the data
- Some phase space regions are statistically limited
- Dominant systematic uncertainty for V+jets: JES uncertainty

Outlook

- Currently working on updated results with 2011 data
- 2011 data allows to expand the measurement menu further more
  - Higher jet multiplicity
  - New phase space regions
  - Kinematics for 3rd and 4th jet
- No longer limited by statistics
- Currently limited by JES uncertainty

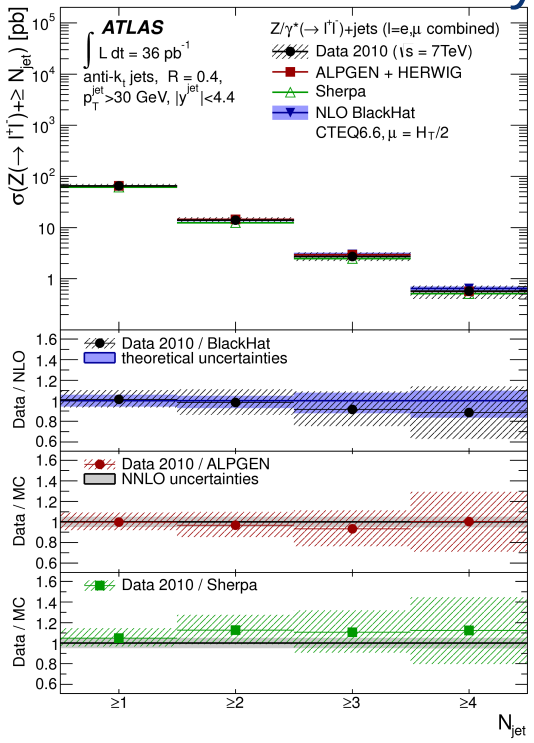


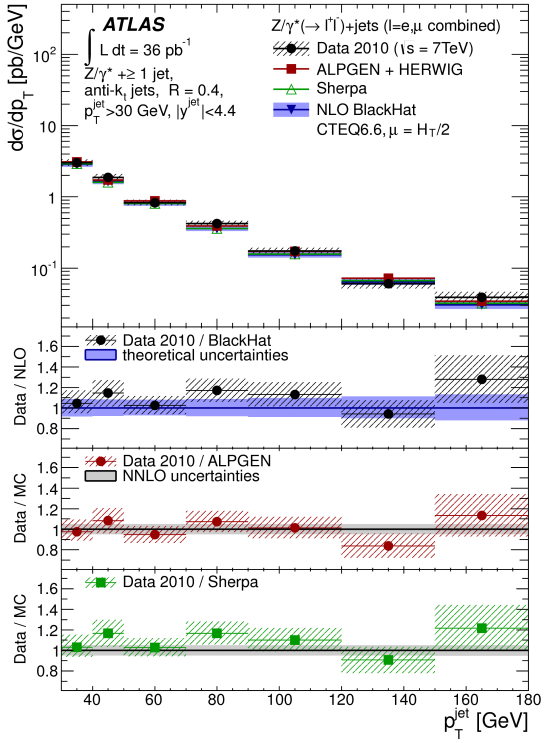


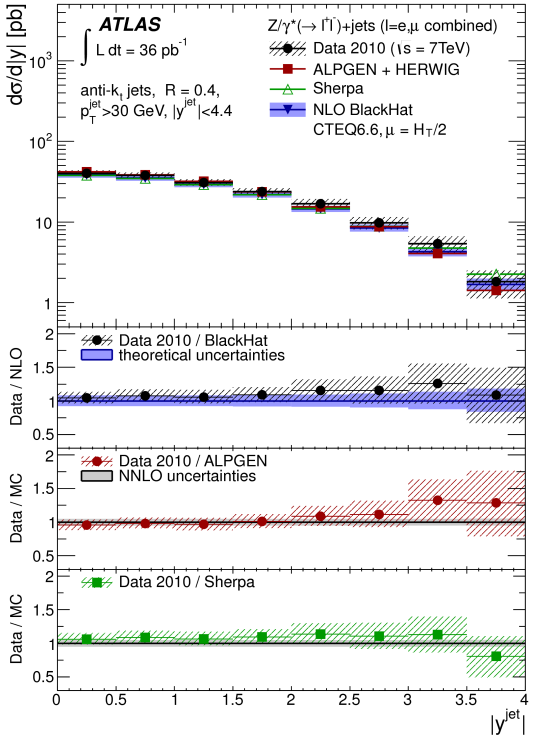
Back-Up

Combination of electron and muon results

- Differential measurements are corrected to Born-Level and extrapolated to common phase space regions (p_T>20 GeV and η<2.5 for the leptons)
- The results are not normalized to the inclusive DY cross section for the combination
- A χ^2 test is performed for each observable between both results before the combination (probabilities larger than 60%)
- The combination is done using the BLUE method, which takes into account the correlation of the systematic uncertainties in both channels







Assymetric iterative BLUE method

- The BLUE method assumes Gaussian χ^2 distributions
- ➔ Not directly possible to treat assymetric uncertainties present in the measured cross section
- ➔ Modified assymetric iterative BLUE method is employed
- ➔ For each bin in a given observable ξ, three separate BLUE combinations are computed using the upper, the lower and the average of the upper and lower uncertainties in both channels
- ➔ The central value with its upper and lower uncertainties are given by

$$\sigma_\xi = \sigma_\xi^{\text{ave}},$$
$$\sigma_{\xi+} = 2 \times R \times \sigma_\xi^{\text{ave}}, \text{ and}$$
$$\sigma_{\xi-} = 2 \times (1-R) \times \sigma_\xi^{\text{ave}},$$

with

$$R = \frac{\sigma_\xi^{\text{up}}}{\sigma_\xi^{\text{up}} + \sigma_\xi^{\text{low}}}.$$

Note on Chi2 test

- The Chi2 tests are now performed in the electron and muon measurements separately (before combination) with respect of the NLO pQCD predictions.

  (in the previous version an attempt was made to use the combined results for which a complete treatment of correlations is not possible in the chi2 formula since BLUE mixes statistical and systematic uncertainties from the different channels)

- Now the correlation of systematic uncertainties across points can be properly taken into account in the Chi2 test

$$\chi^2 = \sum_{j=1}^{bins} \frac{[d_j - th_j(\bar{s})]^2}{[\delta d_j]^2 + [\delta th_j(\bar{s})]^2} + \sum_{i=1}^{7} [s_i]^2$$

- 7 sources of systematic uncertainty: JES/JER, Lepton ID, Background-QCD, EWKBackground,Unfolding, Luminosity, and MCFM

- Chi2 minimized with respect to the “s” (vector of standard deviations of the different sources of uncertainty) and the correlations enter into th(s).