W/Z+Jets Results Atlas Detector -LHC

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on behalf of the ATLAS Collaboration
QCD @ LHC 2011
St. Andrews, UK

Performed measurements

- $\sigma(W/Z+\geq N_{jets})$ – test of higher order calculations and pQCD
- $\sigma(W/Z+\geq N_{jets})/\sigma(W/Z+\geq N_{jets}\text{-}1)$ – test of pQCD, α_s constraint, ratio significantly reduces systematic uncertainties
- $d\sigma/dp^{N}_{T\text{-}jet}$ - test of higher order calculations and pQCD
- $d\sigma/dH^{N}_{T} = P_{T\text{-}l}+MET+\Sigma P_{T\text{-}jets}$- scale used in MCFM and BLACKHAT-SHERPA

$$\frac{d\sigma}{d\alpha} = \frac{N_{\mathrm{DATA}} - N_{\mathrm{BKG}}}{\int \mathscr{L}\, dt} * U(\alpha)$$

- Expanded set of distributions in the near future!

- **All cross section calculated within the fiducial region!**

Performed measurements II

- σ(W+1 jet)/σ(Z+1 jet) – reduced PDFs uncertainties, test for PDFs and pQCD
- σ(W+b jet) – test for PDFs
- Detector level results for Z+ b jets – test for PDFs

QCD – From data
Other BKG - MC

$$\frac{d\sigma}{d\alpha} = \frac{N_{DATA} - N_{BKG}}{\int \mathcal{L}\, dt} * U(\alpha)$$

Unfolding correction

- Expanded set of distributions in the near future!

- **All analyses performed on 33-35 pb^{-1} of 2010 data.**

Fiducial region

Lepton (e, μ)

- $p_T > 20$ GeV
- Muons: $|\eta| < 2.4$
- Electrons:
  $|\eta| < 2.47$,
  excluding $1.37 < \eta < 1.52$

Jets

- Anti-k_T algorithm, R=0.4
- $p_T > 20$ GeV (W), 30 GeV (Z)
- $|\eta| < 2.8$
- lepton-jet separation: $\Delta R_{lj} > 0.5$

W Selection

- Exactly one lepton
- Neutrino $p_T > 25$ GeV
- Transverse Mass: $M_T > 40$ GeV

Z Selection

- Exactly two opposite charge leptons
- Invariant Mass: $66 < M_{ll} < 116$ GeV

- Final state radiation photons within $\Delta R<0.1$ around the lepton added to lepton 4-momentum.

- **Note different definition of jets for W and Z analyses!**

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25GeV for heavy flavour results

W Selection

- Exactly one lepton
- Neutrino $p_T > 25$ GeV
- Transverse Mass: $M_T > 40$ GeV

- two opposite charge leptons
- Invariant Mass: $66 < M_{ll} < 116$ GeV

- Final state radiation photons within $\Delta R<0.1$ around the lepton added to lepton 4-momentum.

- **Note different definition of jets for W and Z analyses!**

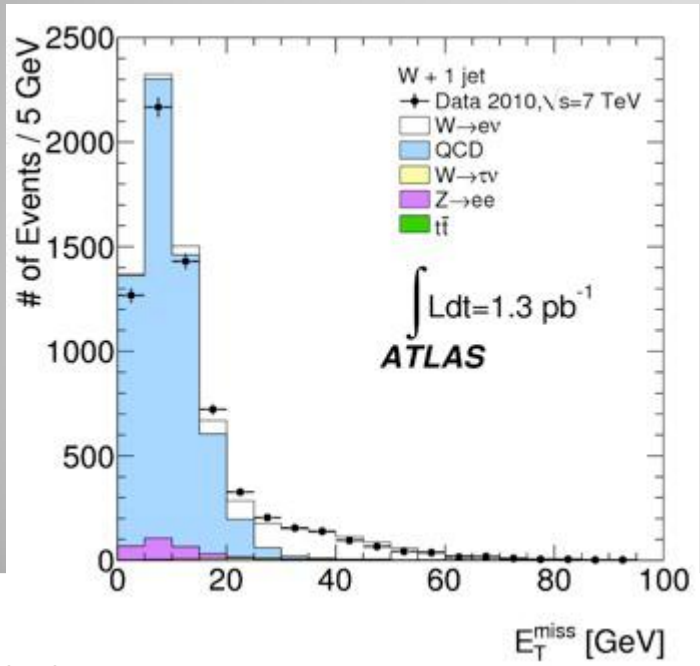
MC Datasets

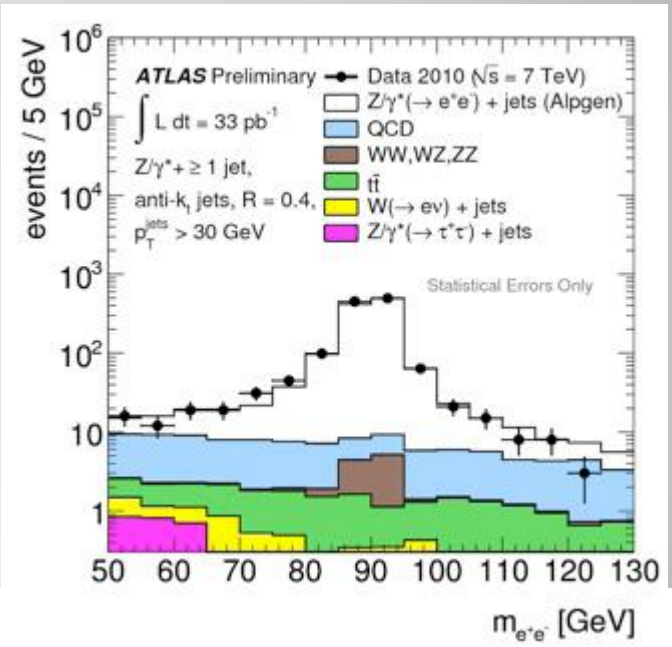
Generator	v.	Interfaces	Comments
ALPGEN	2.13	HERWIG, JIMMY, PHOTOS, CTEQ6L1, ATLAS MC09 tune	MLM matching pQCD normalized
SHERPA	1.13	CTEQ6L1, Default UE tune	CKKW matching pQCD normalized
PYTHIA	6.4.21	PHOTOS, MRST 2007 LO	LO Matrix Element + ISR, PS corrections pQCD normalized
MCFM	5.8	CTEQ6.6/CTEQ6L1	PYTHIA UE, fragmentation
SHERPA + BLACKHAT		CTEQ6.6M	PYTHIA UE, fragmentation

- pQCD normalized using FEWZ NNLO (MRST2007LO* PDF)

QCD estimation

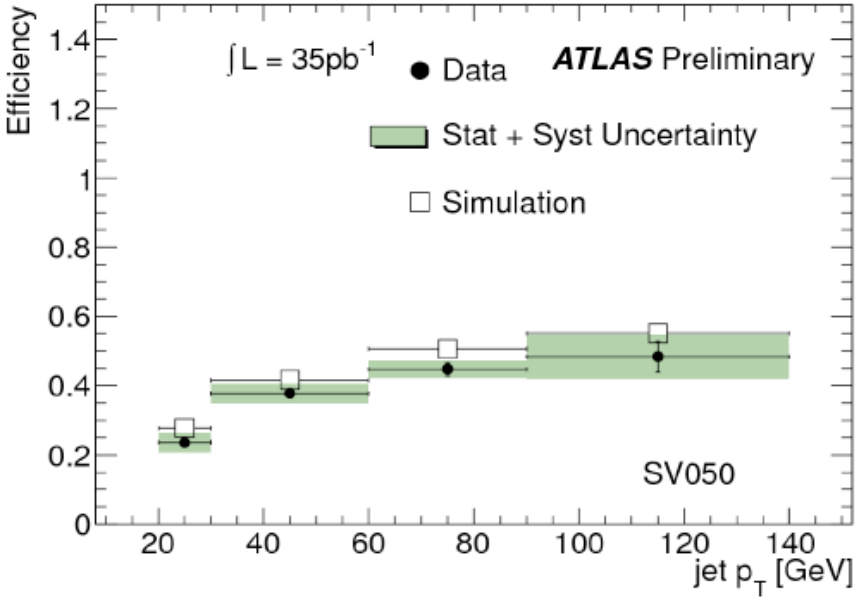
- W -ee: Fit data to MET distribution, QCD template by Electron ID reversal or electron selection replaced with photon
- W -μμ: Fit MET distribution, QCD template from MC
- Z -ee: Loosen electron ID, normalize with dilepton mass
- Z -μμ : directly from MC.

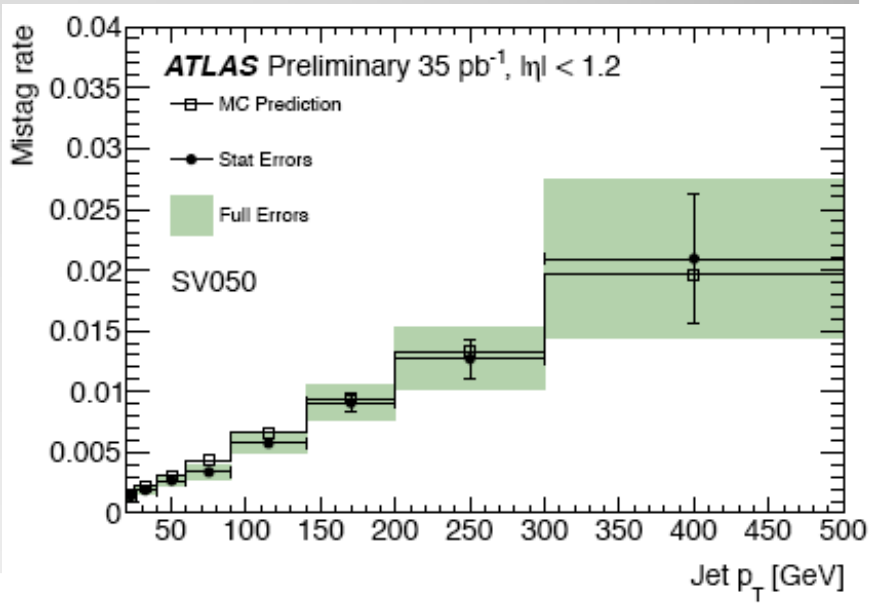




b tagging

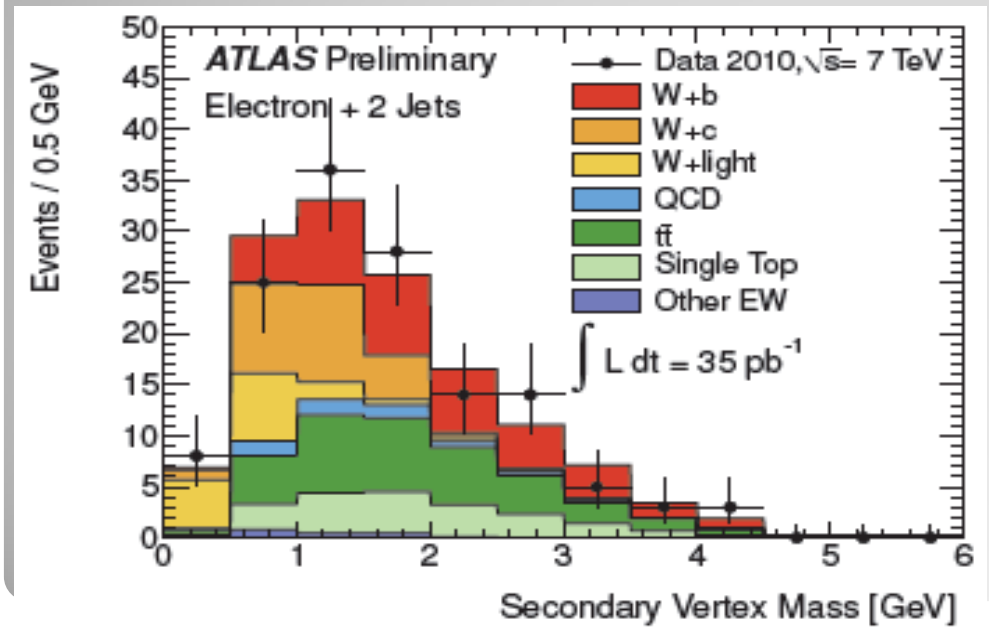
- Secondary vertex based b-tagging algorithm (SV0) used.
- Require a displaced vertex within a jet with a decay length significance > 5.85
- B tagging efficiency and systematic uncertainties estimated from semi-leptonic B decays in QCD and top events.

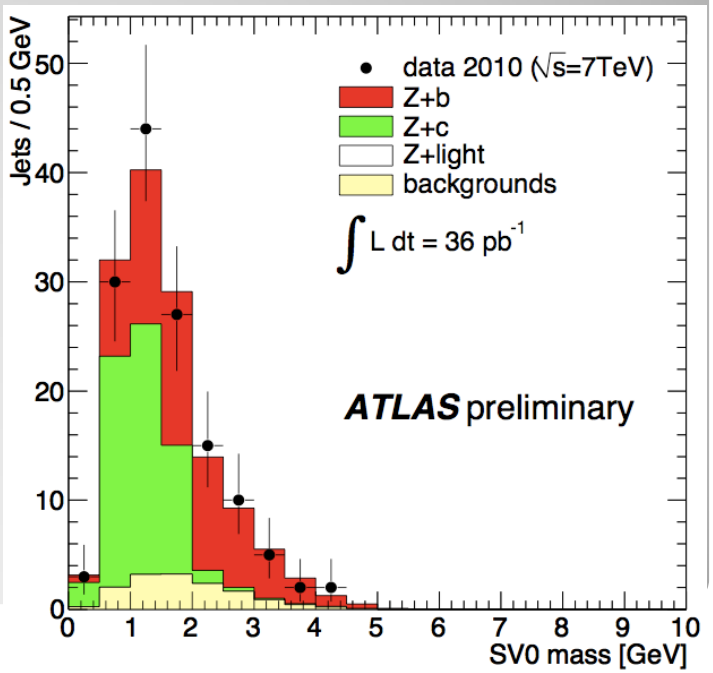




Extraction of b-jet fraction

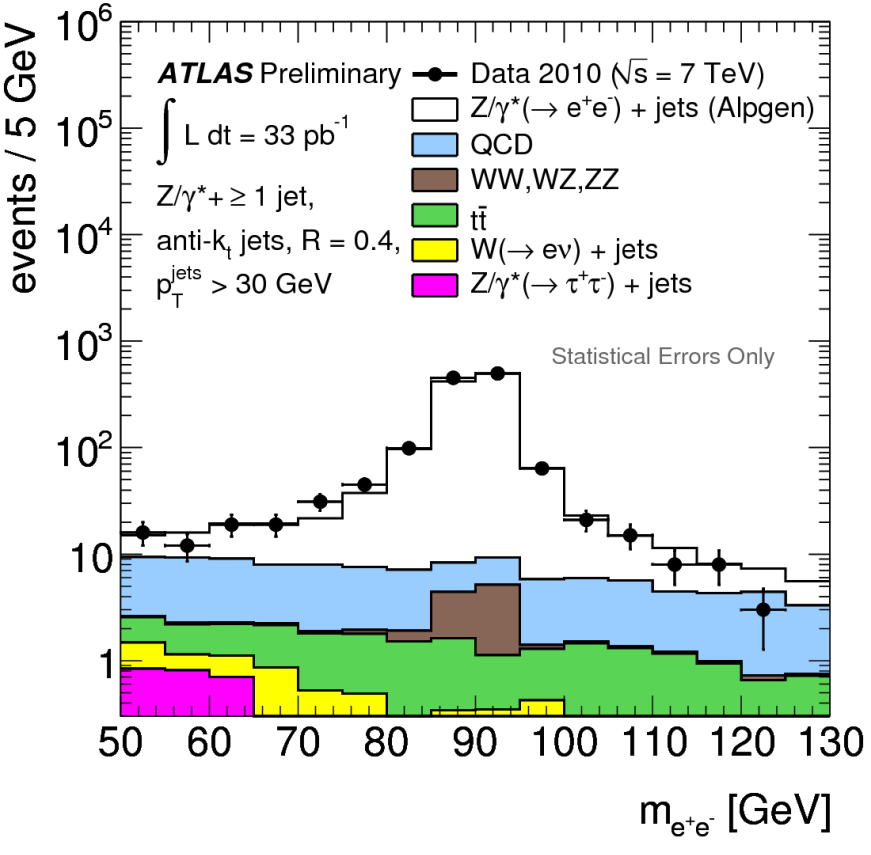
- Maximum likelihood fit to the SV0 mass distribution used to extract the flavour fraction.
- SV0 mass templates from MC
- Template systematic uncertainty: from data vs. MC

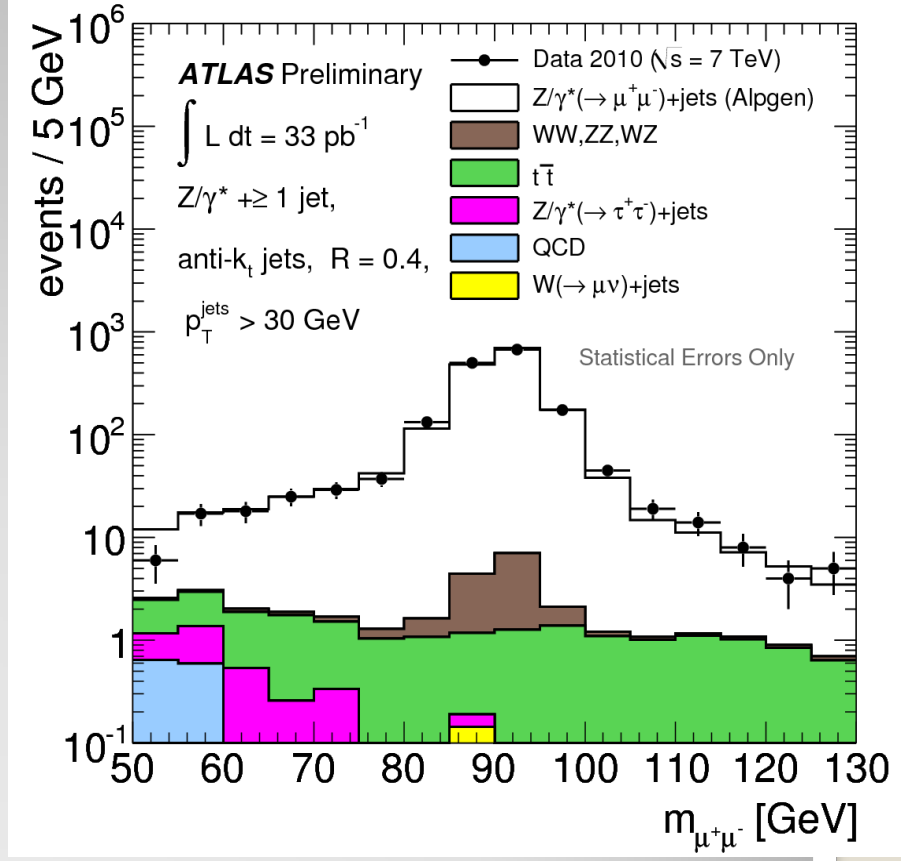




Detector Level Checks

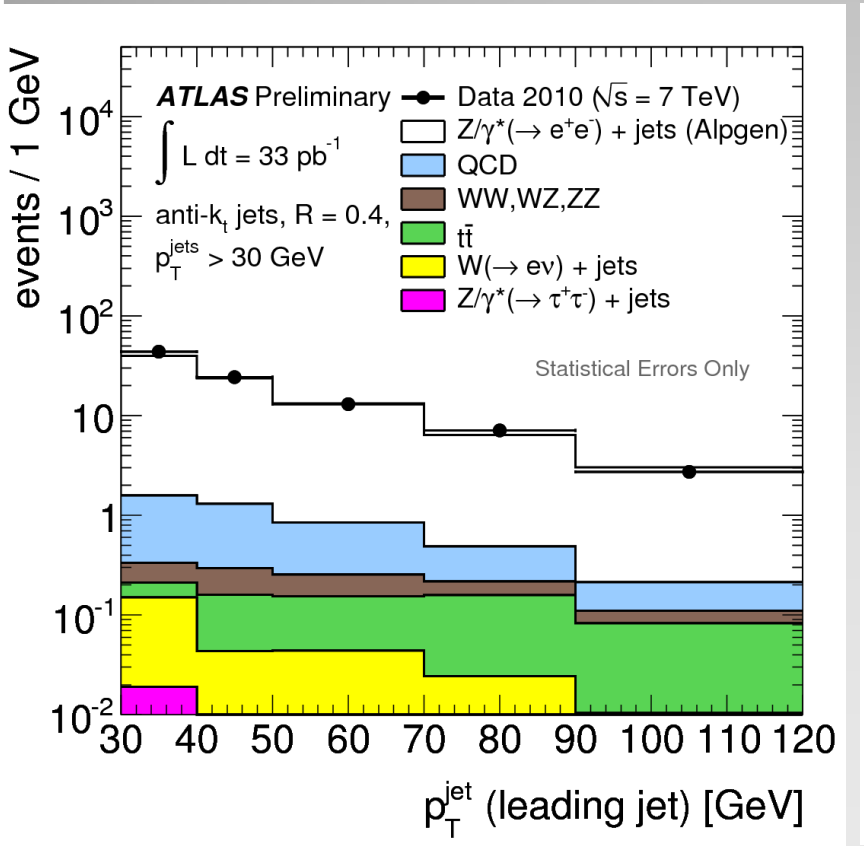
Z+jets sanity check

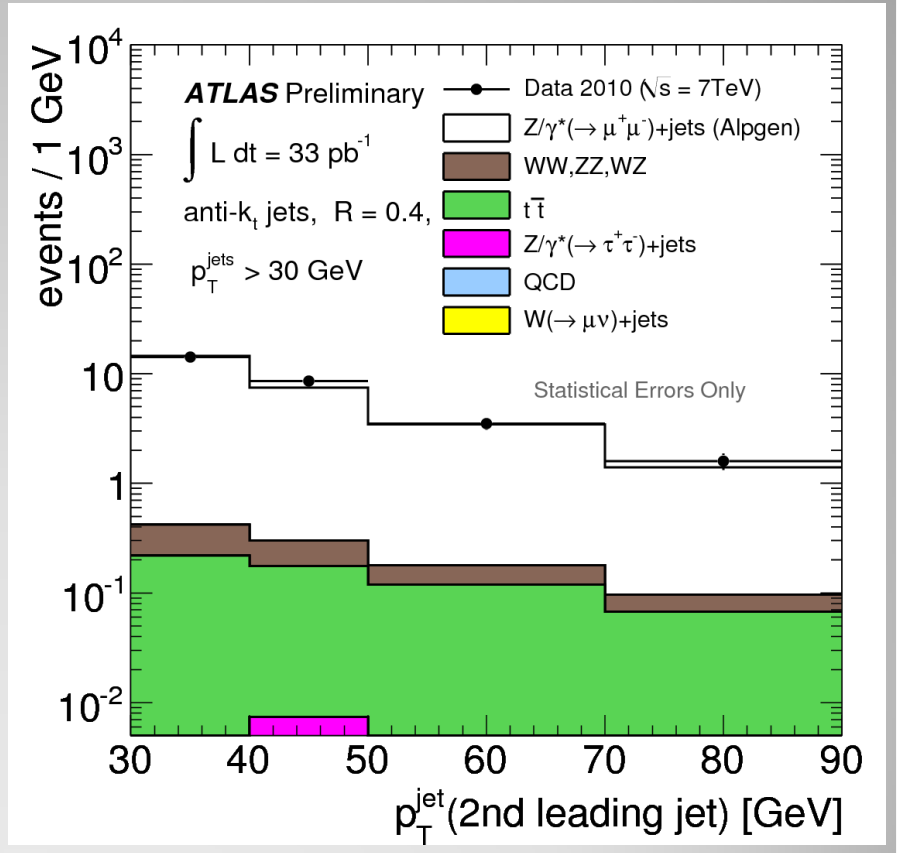




- Data compared to MC for signal (ALPGEN) +SM background
- **Overall good agreement!**

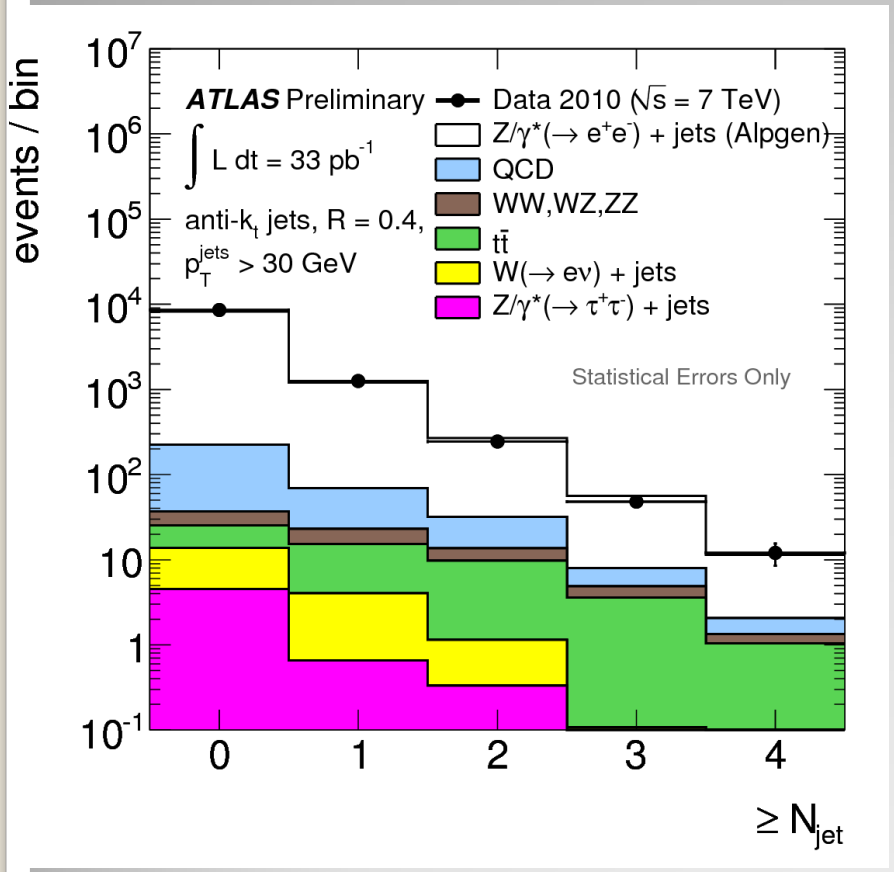
Detector Level (Z+Jets)

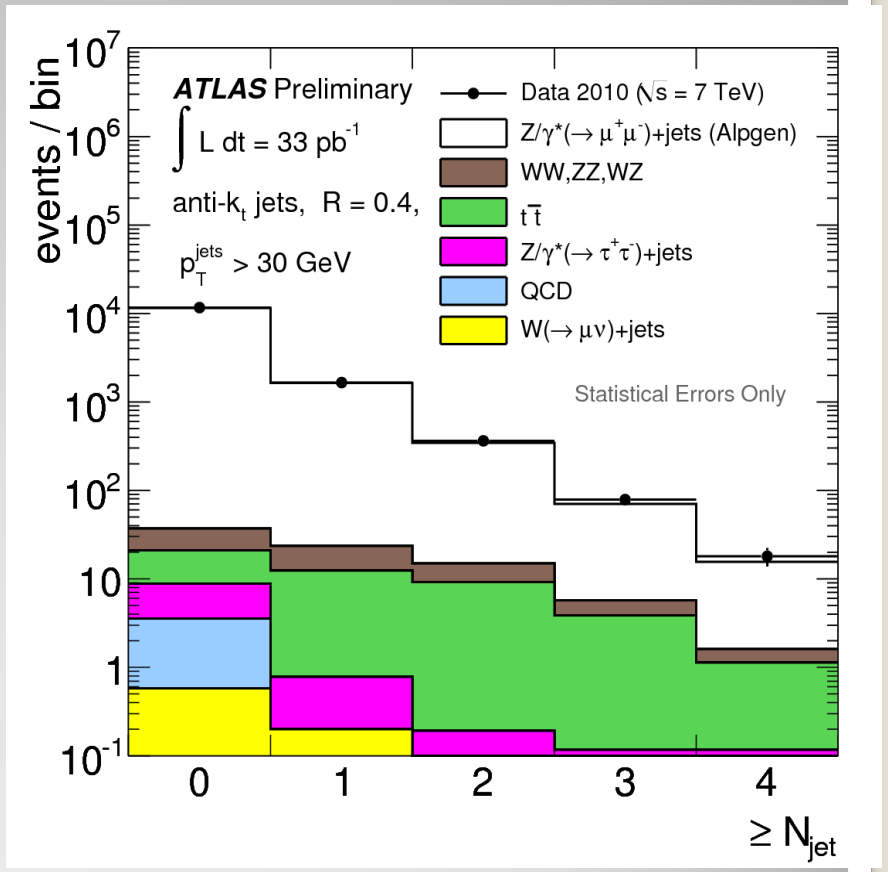




- Background of the order of ≈1-10% for both channels
- **Overall good agreement!**

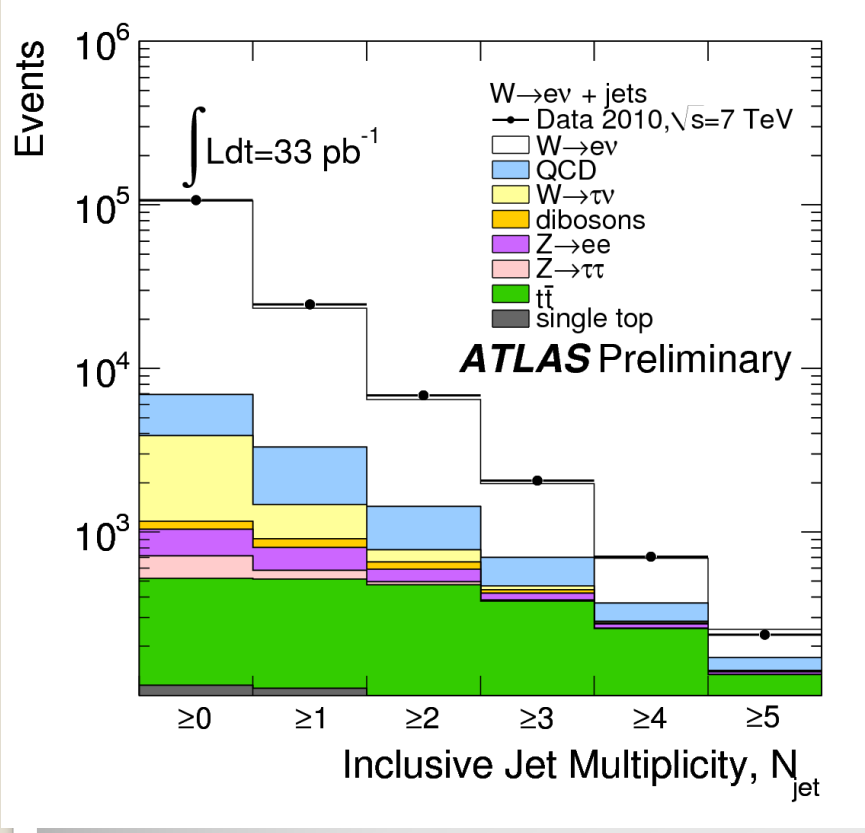
Jet Multiplicity (Z+jets)

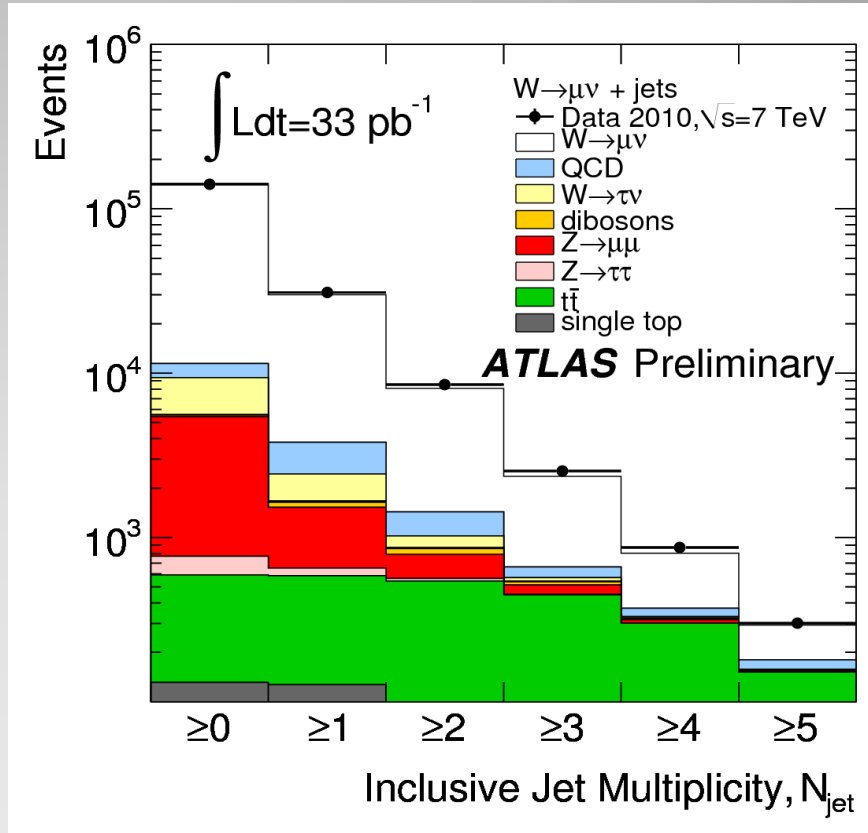




- Background increases with jet multiplicities.
- In particular dominated by top pairs at high multiplicities

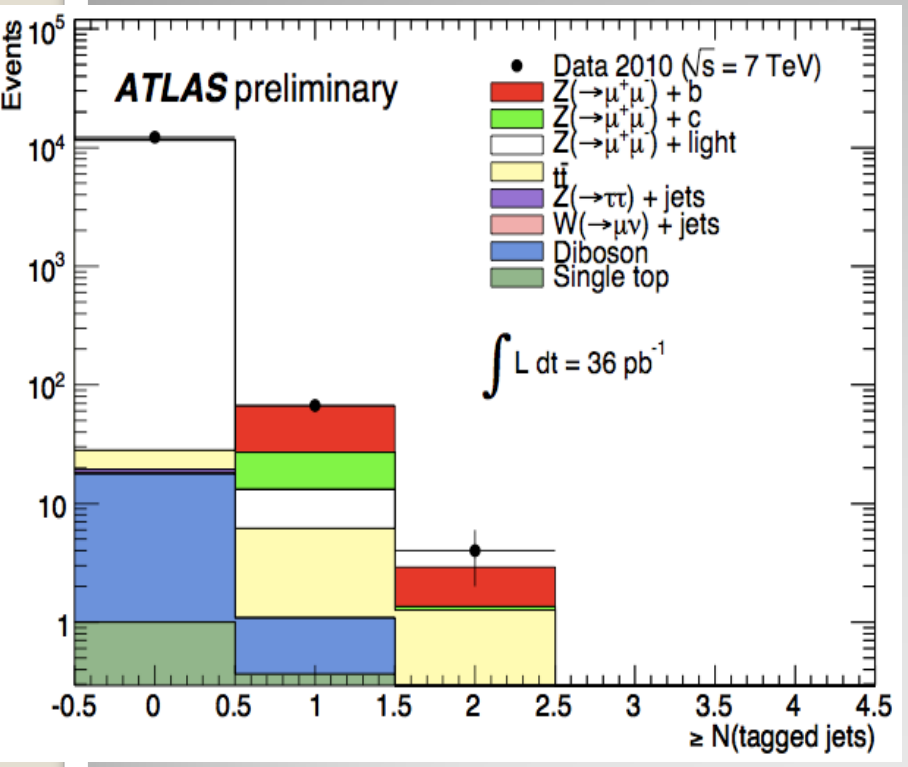
Jet Multiplicity (W+jets)

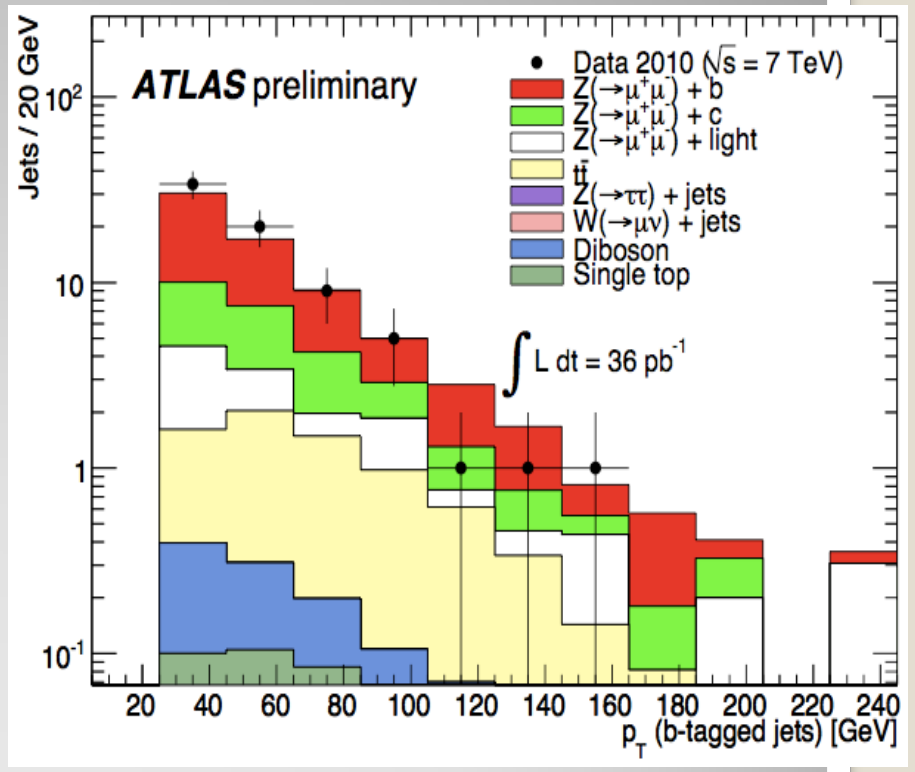




- Again - background increases with jet multiplicities.
- Also in this case top pair production major background
- At low multiplicities QCD significant (electron channel)

Z+b jets





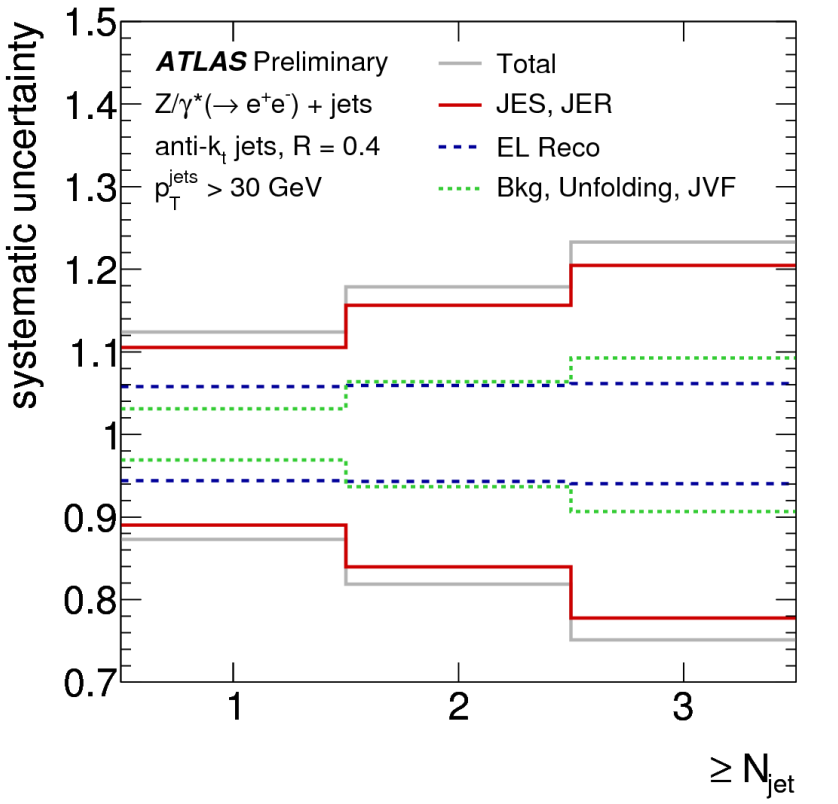
- **Results in good agreement with MCFM prediction**

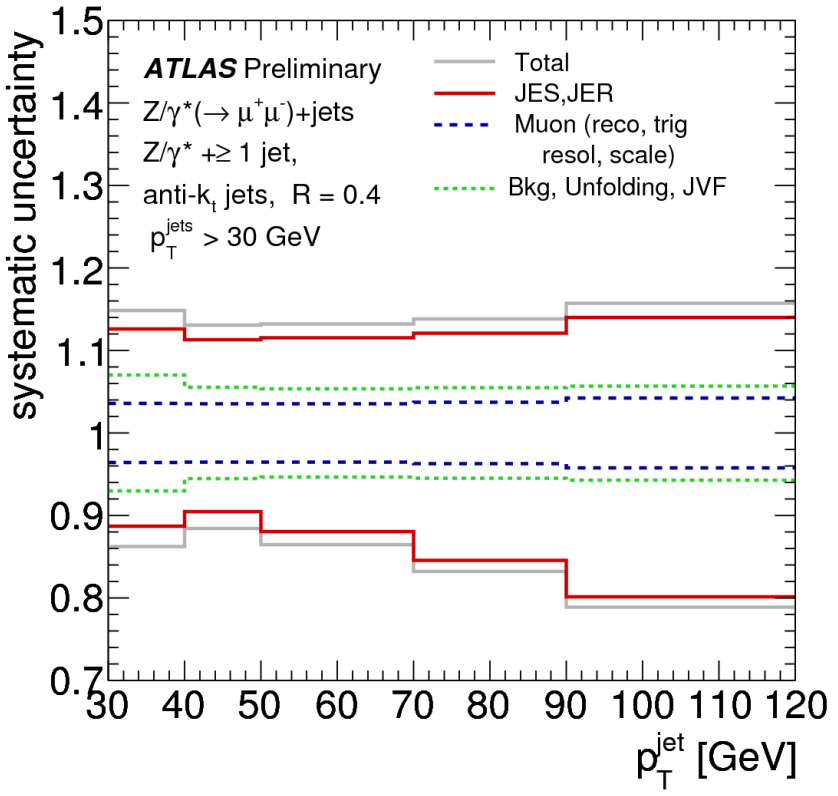
Unfolding

- Bin by Bin (method used):
  - Simple correction factor mechanism
  - Systematic uncertainty : difference ALPGEN and SHERPA derived corrections
- Bayesian (cross check + future use W+jets):
  - Lower MC dependence, better statistical treatment
  - More complex, need to pay attention to regularization
- Confident in Bin by bin results as:
  - Good agreement data-MC at Detector level
  - W/Z + jets measurements are systematically limited

- **Hence the two methods give very similar results!**

Systematic Uncertainties
Z+jets





- Measurement dominated by JES! ≈10% already in 1jet bin!
- Luminosity systematic 3.4%, pile-up jets ≈5% ....

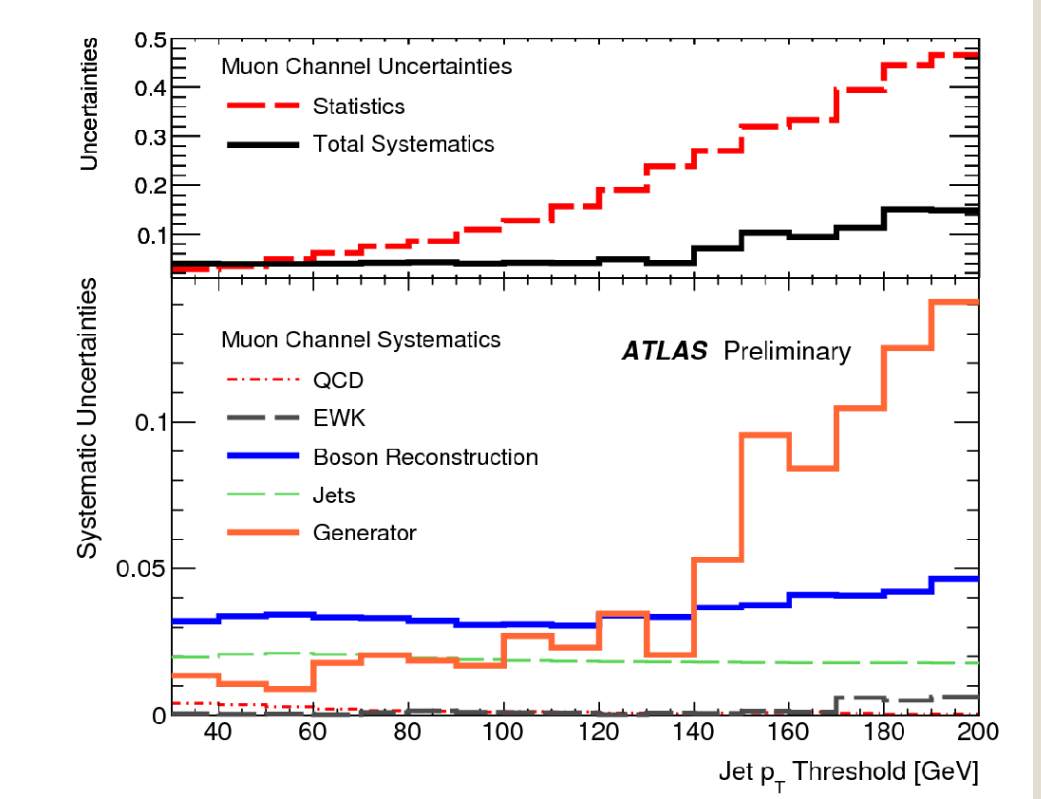
Systematics Detail
W+jets one jet bin

μ channel		
Effect	Range	Cross Section Uncertainty (%)
Jet energy scale and $E_{\mathrm{T}}^{\mathrm{miss}}$	$\approx 7\%$ (dependent on jet η and p_{T})	+10.3,-7.6
Jet energy resolution	10% on each jet	± 5.7
Muon trigger	±0.7% (±0.6%) in barrel (endcap)	± 0.5
Muon reconstruction	±1.1%	+1.1,-1.2
Muon momentum scale	±0.4%	± 0.7
Muon momentum resolution	±6%	± 0.1
Pile–up removal cut	4 – 7% in lowest jet p_{T} bin	+6.6
Residual pile-up effects	from simulation	+2.6
Unfolding	ALPGEN vs. SHERPA	±1.8
Luminosity	±3.4%	+3.5,-3.8

- Both measurements dominated by systematic uncertainties!
- In particular jet energy scale/resolution and pileup

(W+1jet)/(Z+1jet) - Systematics

- Systematic uncertainties substantially smaller than in the W and Z cases
- In particular reduction on the jet systematic uncertainties
- Systematic uncertainties of the order of less than 5%



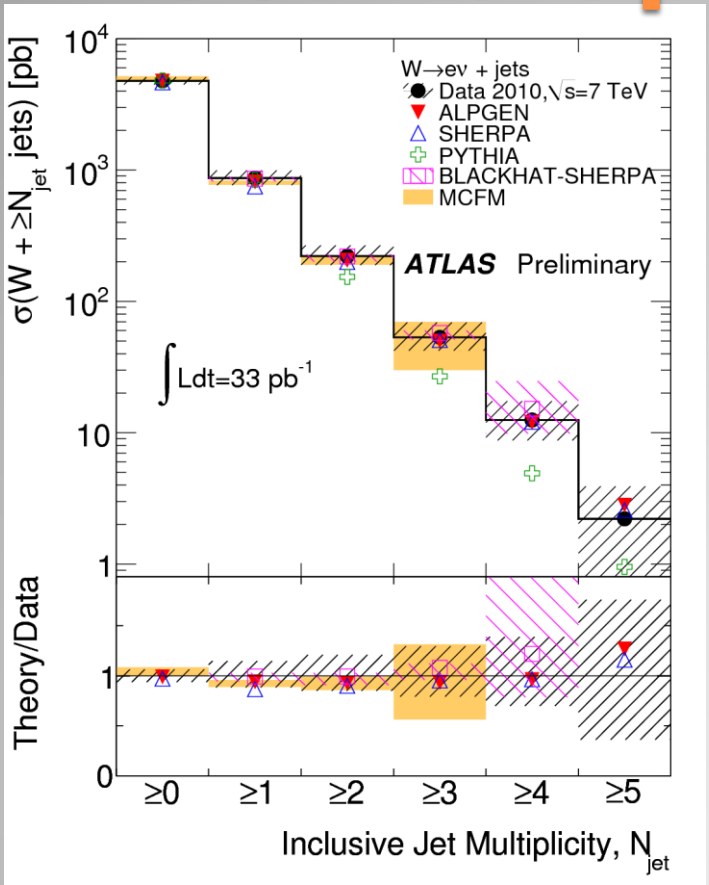
- **Precision still statistically limited.**

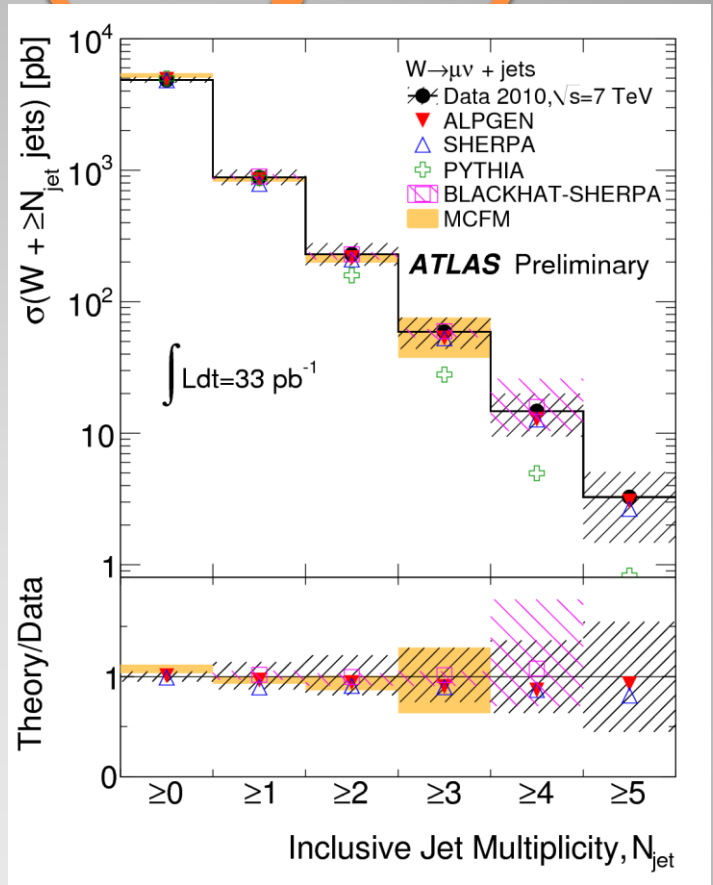
W/Z+Heavy Flavour- Systematics

- Systematic uncertainties of the order of 25%(W)-23%(Z)
- Systematic uncertainties dominated by:
  - B tagging uncertainties ≈ 16%(W)-10%(Z)
  - Modelling of the signal ≈ 10%(W)-10%(Z)
  - Jet + b jet energy scale ≈ 7%(W)-4%(Z)
- In the case of the W+b jet the QCD (7%) and the top background uncertainties (12%) are also significant

Results

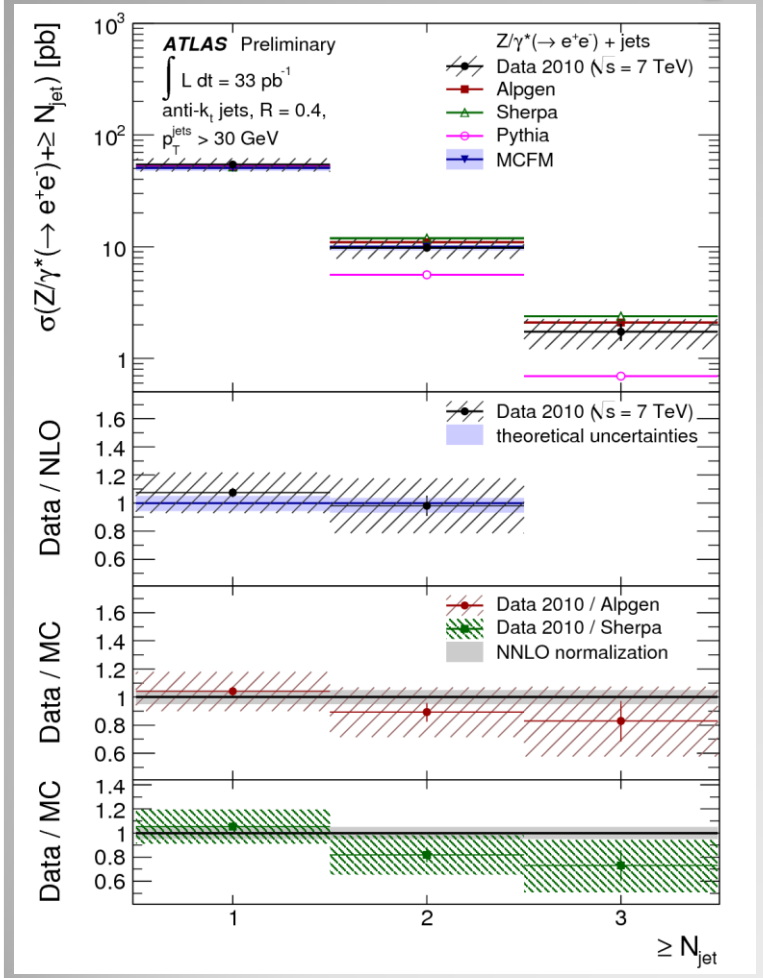
Jet Multiplicity (W+jets)

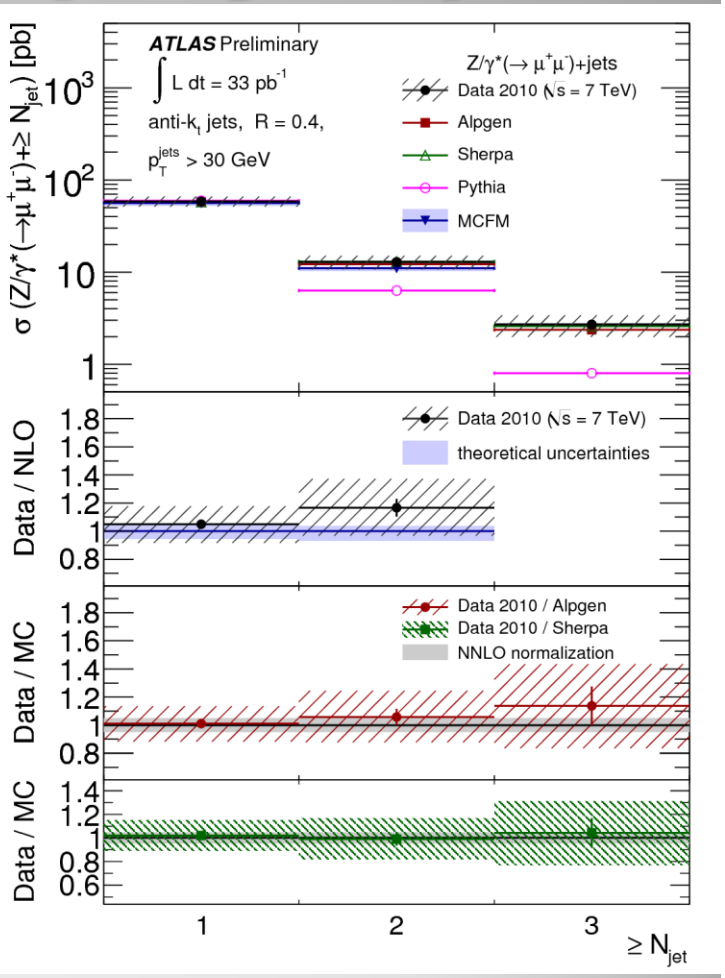




- Predictions from Blackhat-Sherpa are NLO for N jets ≤ 3, LO for N jets = 4. MCFM are NLO for N jets ≤ 3.
- As expected Pythia understimate rates of high multiplicites.

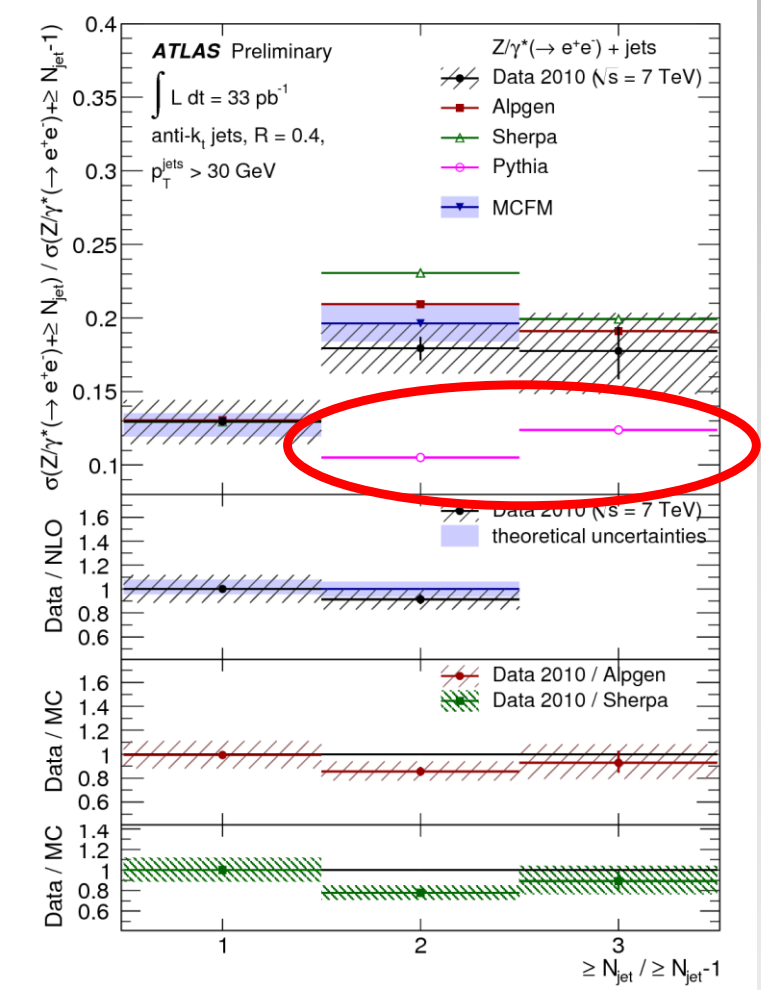
Jet Multiplicity (Z+jets)

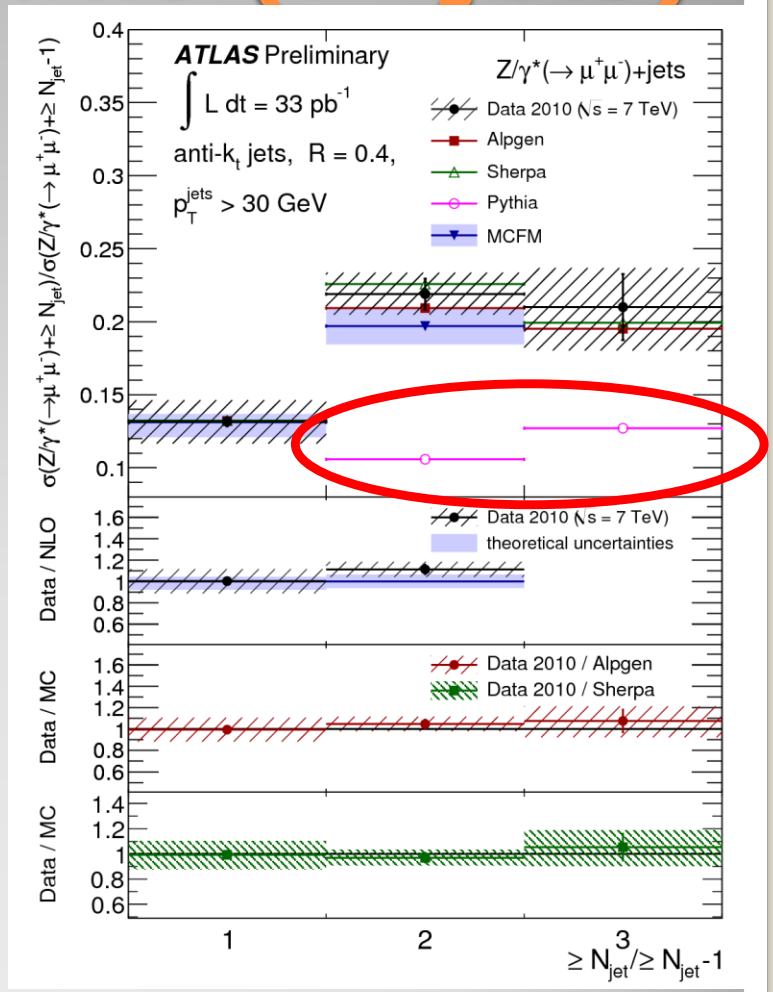




- All channels show very good agreement!

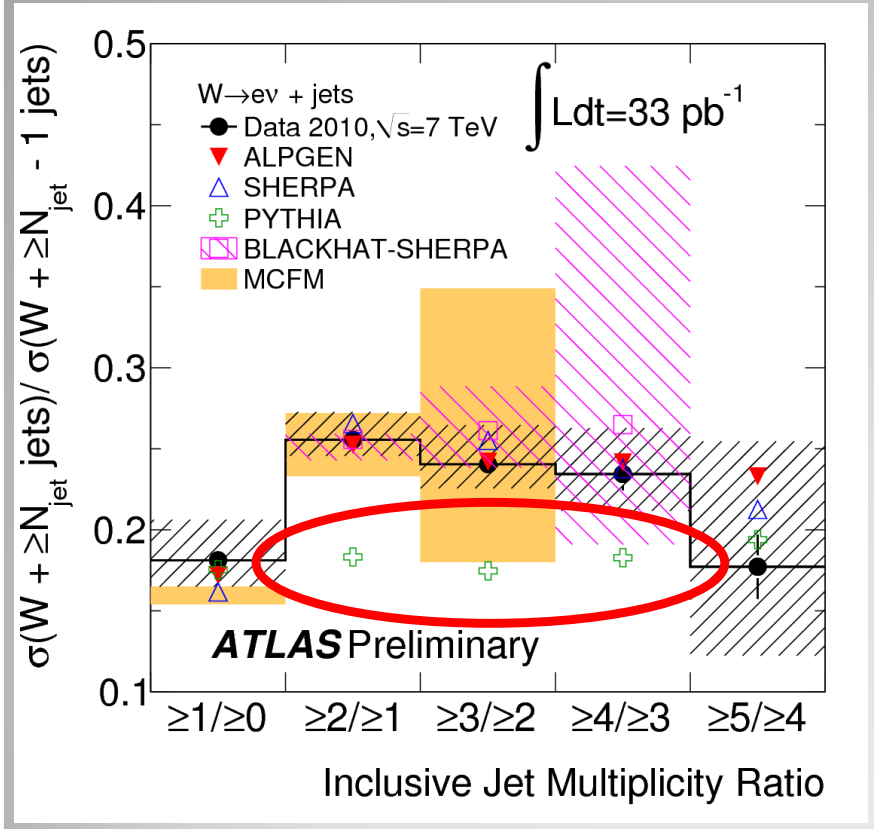
Jet Multiplicity Ratio (Z+jets)

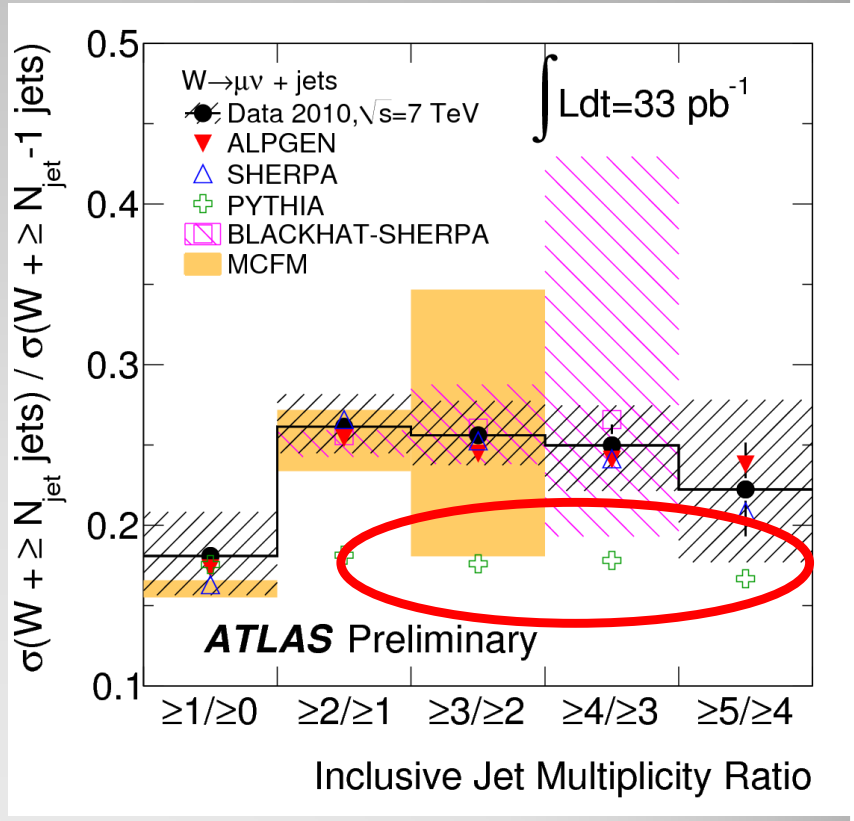




- Ratios eliminate systematic uncertainties
- Hence better constraint on physics

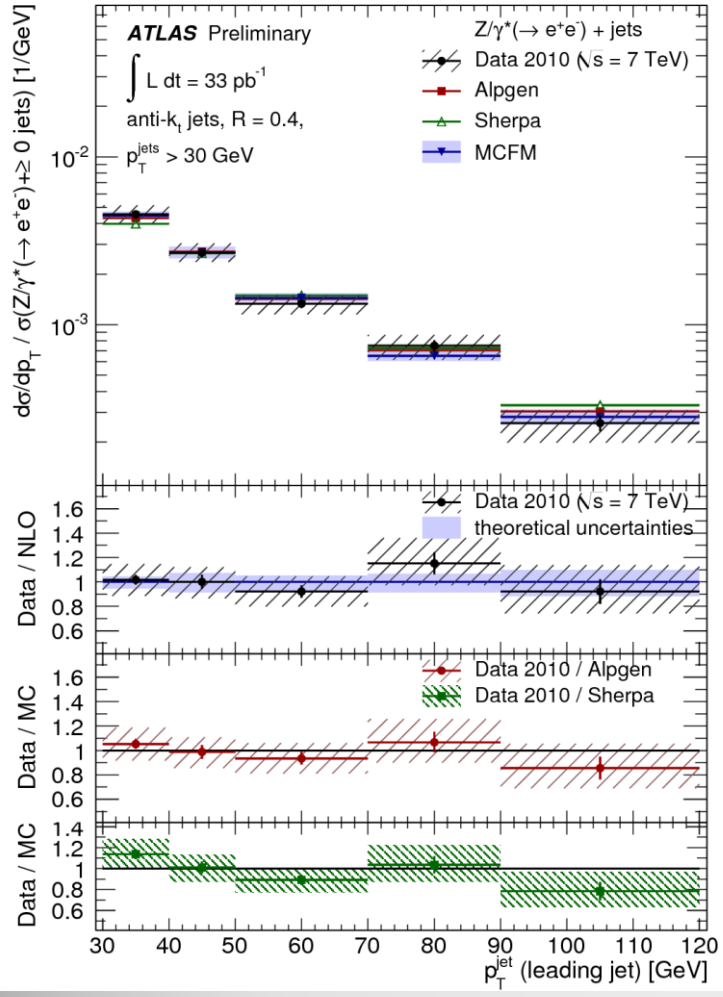
Jet Multiplicity Ratio (W+jets)

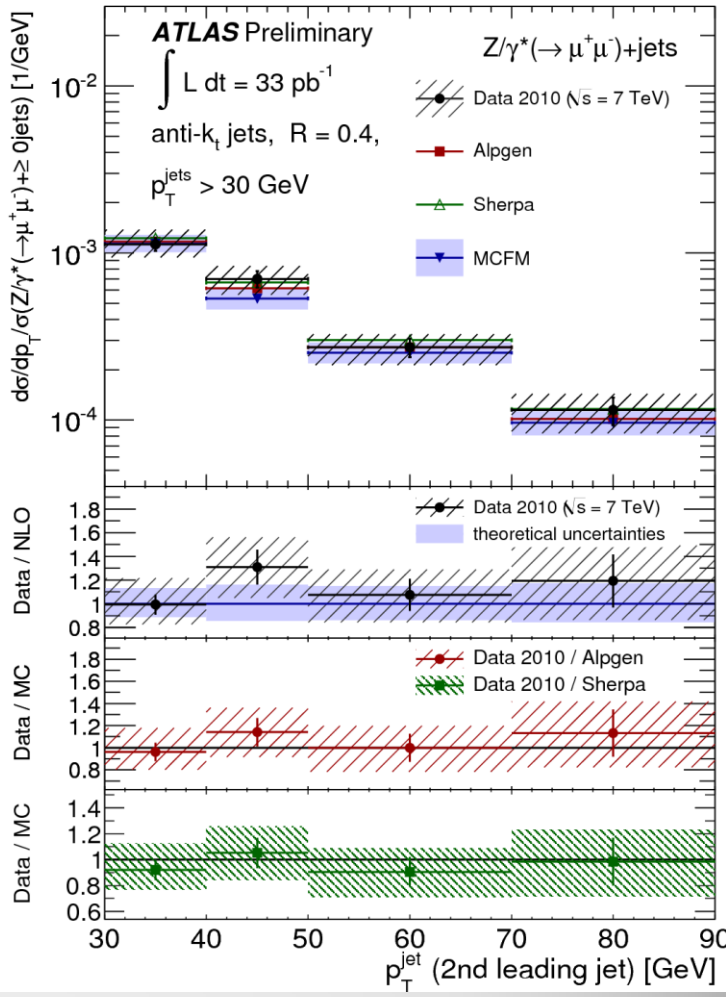




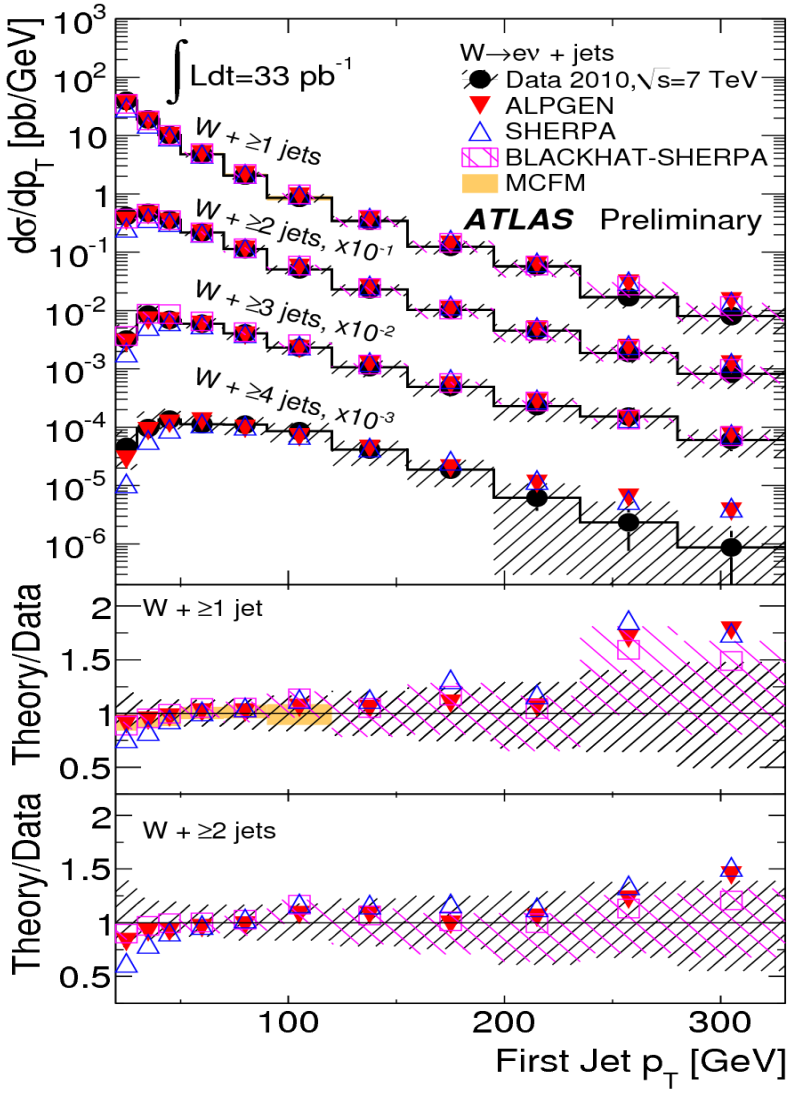
- Increased uncertainty on MCFM and Blackhat-Sherpa (in bin 3 and 4 respectively) due to LO prediction

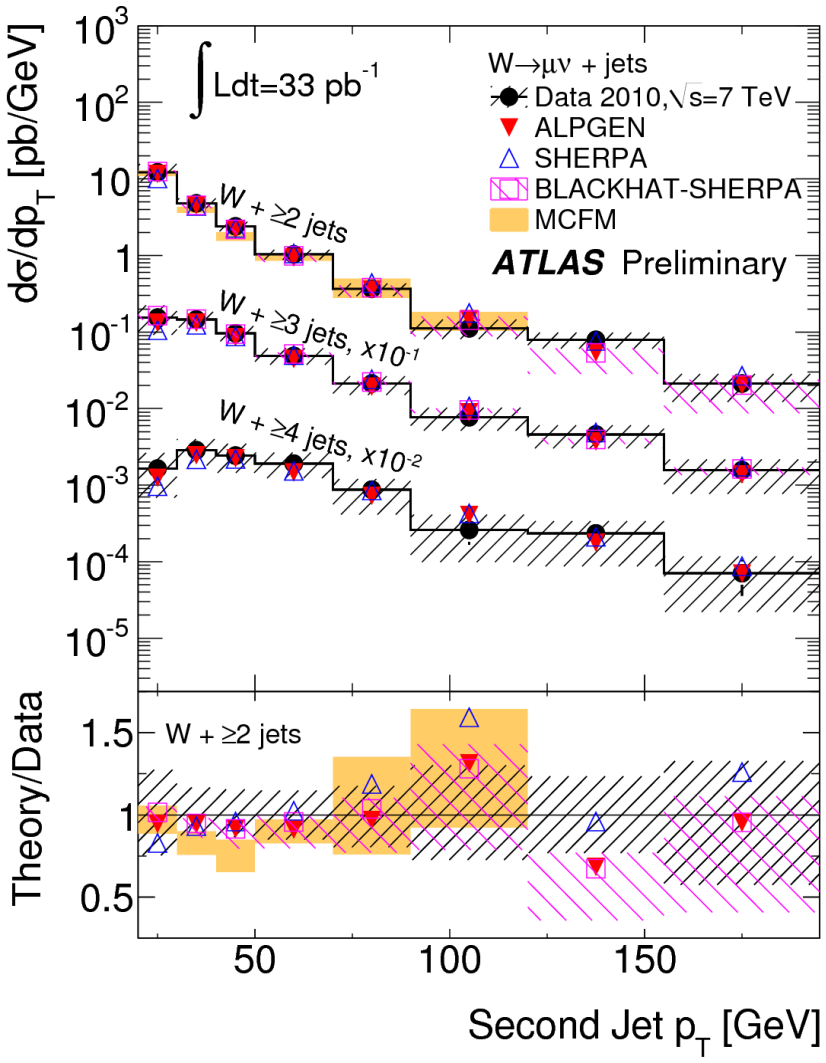
Jet P_T (Z+jets)


ATLAS Preliminary
∫ L dt = 33 pb-1
anti-kt jets, R = 0.4,
pTjets > 30 GeV
Z/γ*(→ e+e-) + jets
Data 2010 (√s = 7 TeV)
Alpgen
Sherpa
MCFM
dσ/dpT / σ(Z/γ*(→ e+e-)+≥ 0 jets) [1/GeV]
Data / NLO
theoretical uncertainties
Data / MC
Data 2010 / Alpgen
Data 2010 / Sherpa
pTjet (leading jet) [GeV]

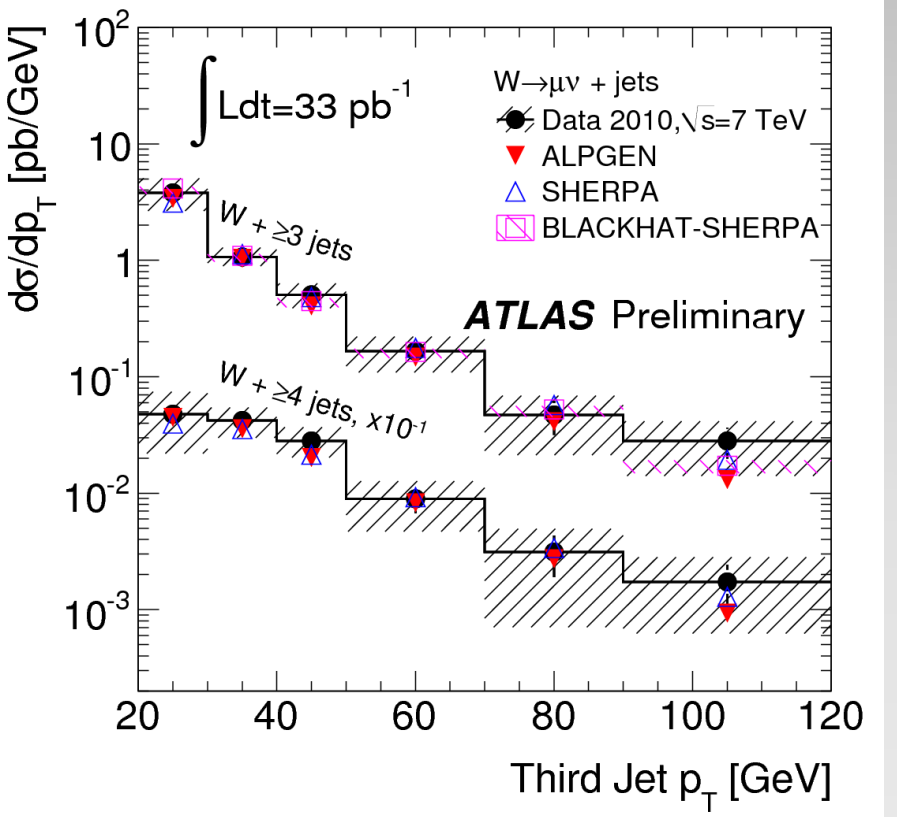

ATLAS Preliminary
∫ L dt = 33 pb-1
anti-kt jets, R = 0.4,
pTjets > 30 GeV
Z/γ*(→ μ+μ-)+jets
Data 2010 (√s = 7 TeV)
Alpgen
Sherpa
MCFM
dσ/dpT /σ(Z/γ*(→μ+μ-)+≥ 0jets) [1/GeV]
Data / NLO
theoretical uncertainties
Data / MC
Data 2010 / Alpgen
Data 2010 / Sherpa
pTjet (2nd leading jet) [GeV]

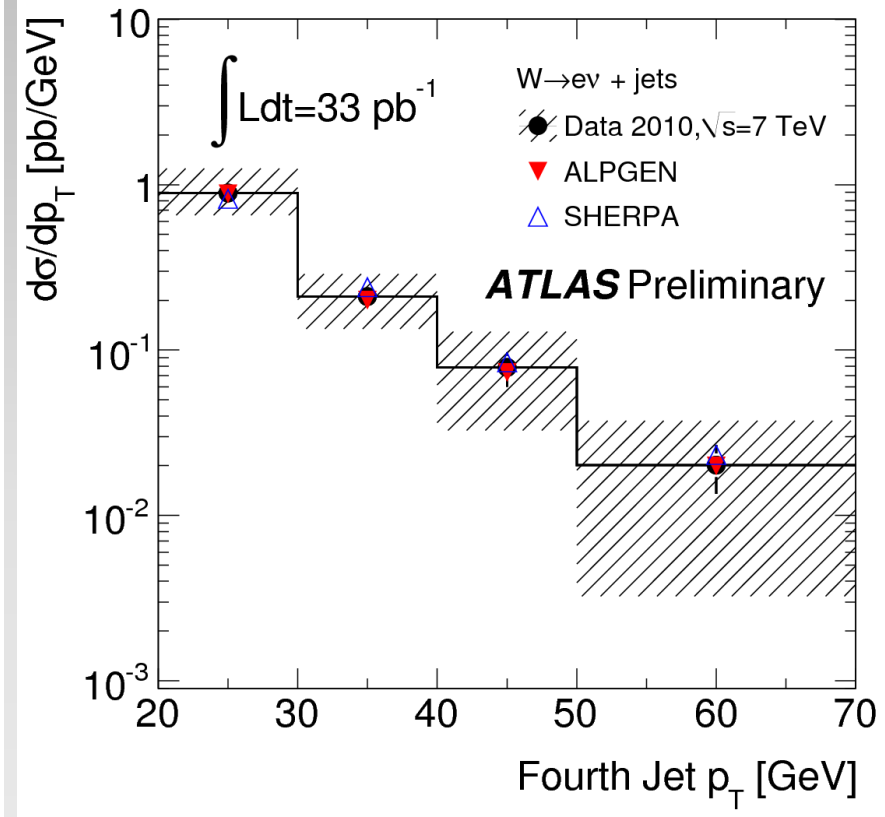
Jet P_T (W+jets)


∫Ldt=33 pb-1
W→eν + jets
Data 2010,√s=7 TeV
ALPGEN
SHERPA
BLACKHAT-SHERPA
MCFM
ATLAS Preliminary
W + ≥1 jets
W + ≥2 jets, x10-1
W + ≥3 jets, x10-2
W + ≥4 jets, x10-3
dσ/dpT [pb/GeV]
W + ≥1 jet
W + ≥2 jets
Theory/Data
First Jet pT [GeV]


∫Ldt=33 pb-1
W→μν + jets
Data 2010,√s=7 TeV
ALPGEN
SHERPA
BLACKHAT-SHERPA
MCFM
ATLAS Preliminary
W + ≥2 jets
W + ≥3 jets, x10-1
W + ≥4 jets, x10-2
dσ/dpT [pb/GeV]
W + ≥2 jets
Theory/Data
Second Jet pT [GeV]

More Jet P_T (W+jets)

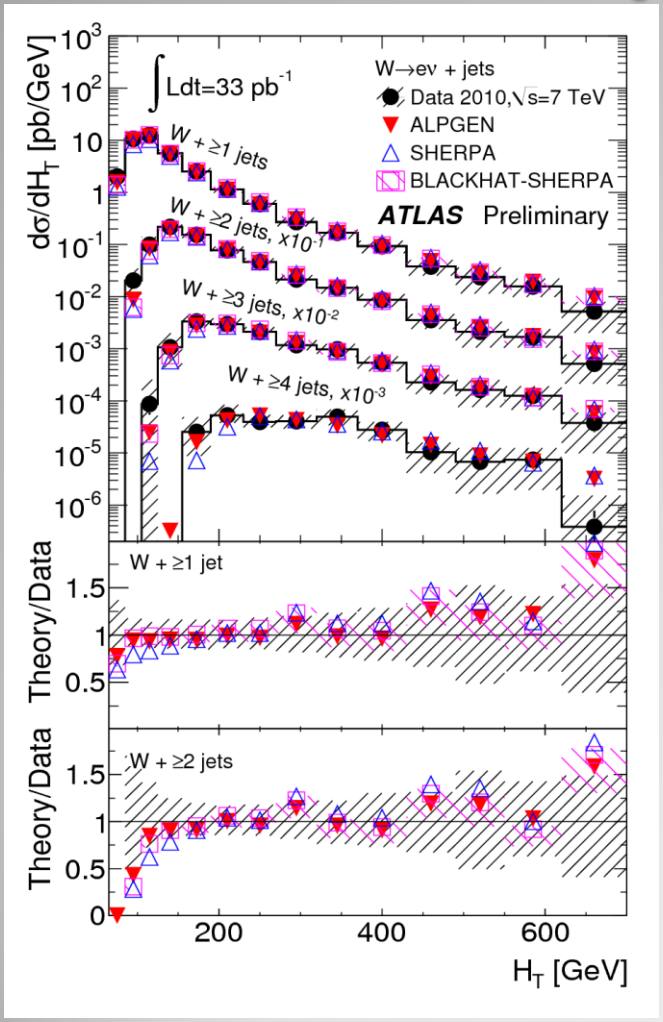


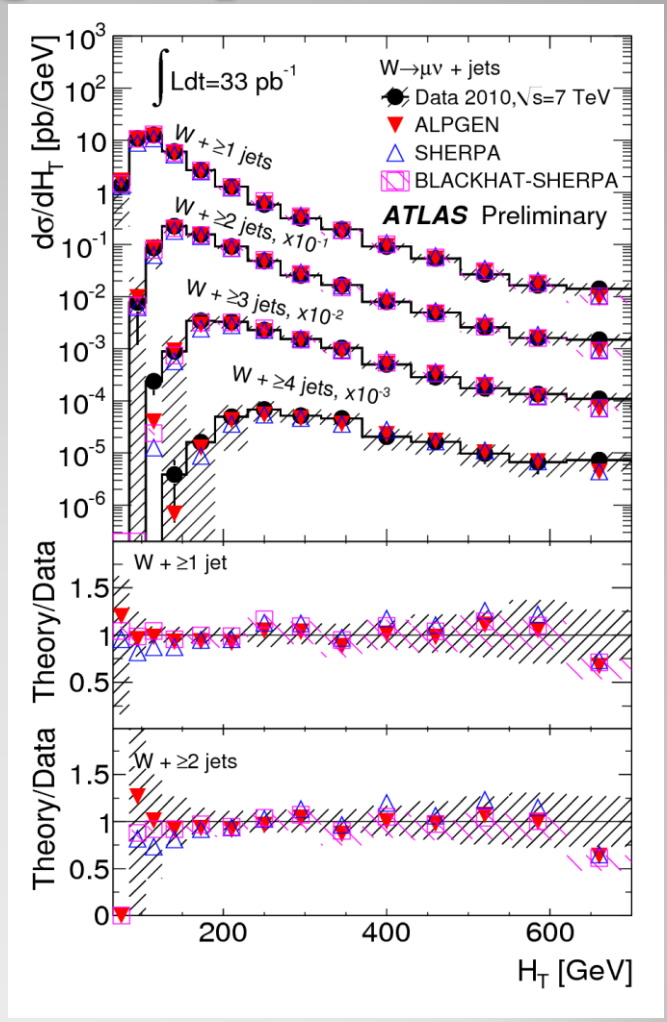


- Also 3/4 jet multiplicities are mainly systematics dominated.

- But statistics effect present and we had to limit pt range

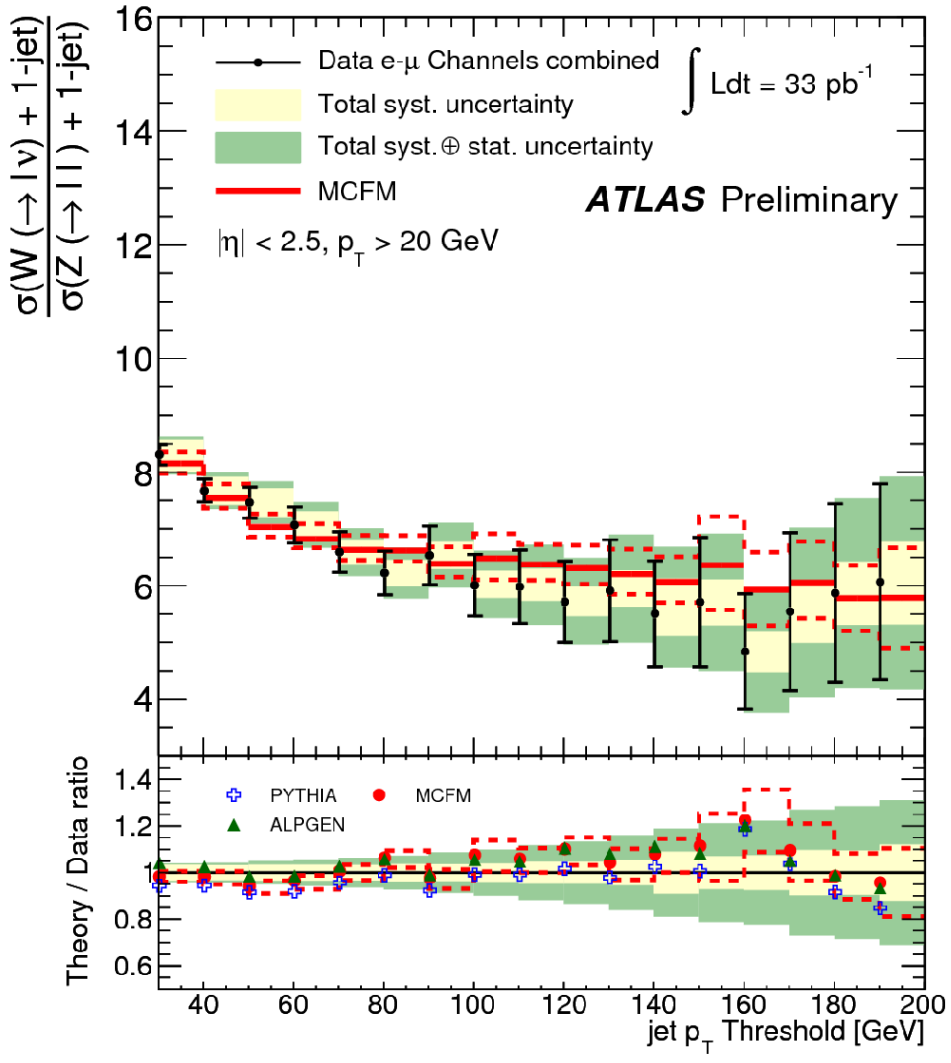
H_T (W+jets)


∫Ldt=33 pb-1
W→eν + jets
Data 2010,√s=7 TeV
ALPGEN
SHERPA
BLACKHAT-SHERPA
ATLAS Preliminary
W + ≥1 jets
W + ≥2 jets, x10-1
W + ≥3 jets, x10-2
W + ≥4 jets, x10-3
dσ/dHT [pb/GeV]
Theory/Data
W + ≥1 jet
W + ≥2 jets
HT [GeV]


∫Ldt=33 pb-1
W→μν + jets
Data 2010,√s=7 TeV
ALPGEN
SHERPA
BLACKHAT-SHERPA
ATLAS Preliminary
W + ≥1 jets
W + ≥2 jets, x10-1
W + ≥3 jets, x10-2
W + ≥4 jets, x10-3
dσ/dHT [pb/GeV]
Theory/Data
W + ≥1 jet
W + ≥2 jets
HT [GeV]

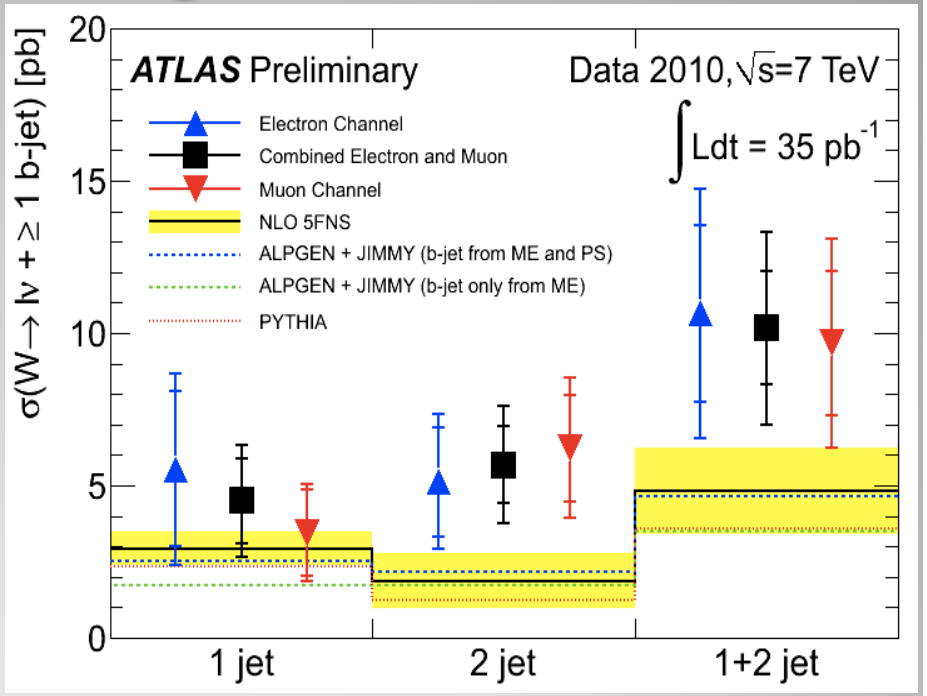
(W+1jet)/(Z+1jet) - Results

- Combined electron-muon results
- Very good agreement with MCFM NLO prediction
- Good agreement also with Pythia and Alpgen



W/Z+b jets

- Combined electron-muon results also provided
- NLO prediction obtained in the 5 flavour number scheme [F. Caola *et al.* *arXiv:1107.3714*]
- NLO agrees within 1.5σ with the measurements



Experiment	$3.55^{+0.82}_{-0.74}(\text{stat})^{+0.73}_{-0.55}(\text{syst}) \pm 0.12(\text{lumi})$ pb
MCFM	3.40 ± 0.44 pb
ALPGEN	2.23 ± 0.01(stat only)pb
SHERPA	3.33 ± 0.04(stat only) pb

- Z+b jets has a good agreement with NLO cross section

Conclusions

- Presented measurements of the production cross-section for W and Z bosons in association with jets, performed with data collected in 2010:
  - Inclusive cross-section as a function of jet multiplicity (up to 3 jets for Z, 5 jets for W)
  - Ratio of inclusive cross-sections
  - Differential cross-sections with respect to jet transverse momenta and H_T
  - Cross-sections corrected for all detector effects and quoted in the kinematic region of the detector acceptance.
  - Precision is mainly limited by systematic uncertainties!
  - Data compared to predictions at LO and NLO in QCD.
  - Good agreement between data and predictions from Alpgen, Sherpa, MCFM and Blackhat-Sherpa. Pythia disagrees with data when $N_{jet}>1$ (expected)

Conclusions II

- Presented preliminary measurements of the production cross-section for W and Z bosons in association with heavy flavour jets.
- Presented preliminary measurements of the production cross-section for W+1jet/Z+1jet
  - Differential cross-sections with respect to jet transverse momentum
  - Cross-sections corrected for all detector effects and quoted in the kinematic region of the detector acceptance
  - Measurement still statistically limited
- **All measurements in good agreement with NLO predictions. Event kinematics well modelled by matched LO generators**

References

ALL 2010 Data ($33pb^{-1}$):

- Measurement of the production cross section for W-bosons in association with jets in pp collisions using 33 pb-1 at sqrt(s) = 7 TeV with the ATLAS detector, ATLAS-CONF-2011-060
- Measurement of the production cross section for $Z/\gamma*$ in association with jets in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS Detector, ATLAS-CONF-2011-042

First Results ($1.3pb^{-1}$):

- Measurement of the production cross section for W bosons in association with jets in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS Detector, ATLAS Collaboration, Phys. Lett. B 698:325-345, 2001, DOI:10.1016/j.physletb.2011.03.012.
- Measurement of the production cross section for $Z/\gamma*$ in association with jets in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS Detector, ATLAS Collaboration, ATLASCONF-2011-001

Soon updates on all channels (in particular heavy flavour ones and W+jets), more info: https://twiki.cern.ch/twiki/bin/view/AtlasPublic