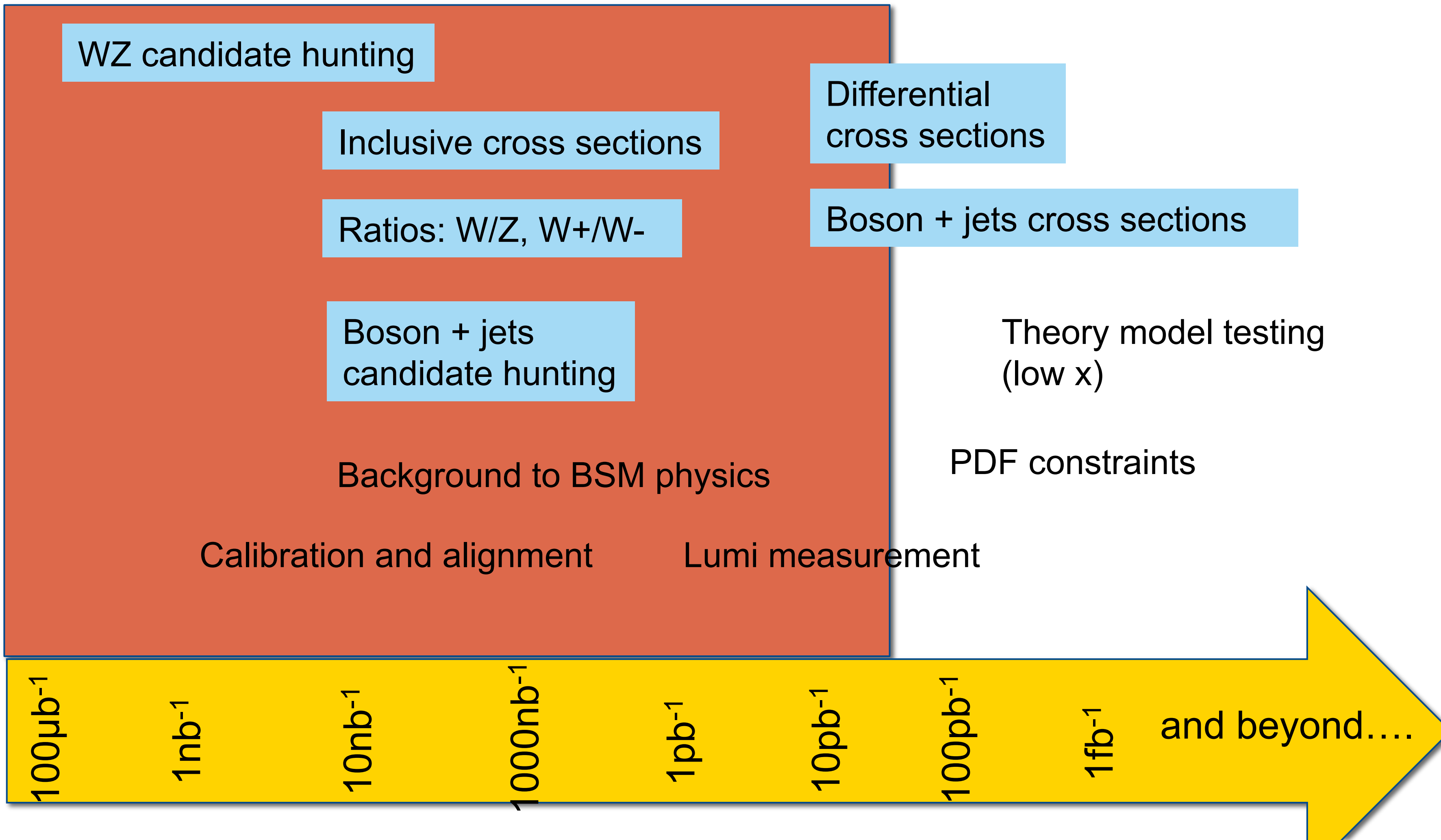
V+JETS IN ATLAS

Ellie Dobson (CERN)

On behalf of the ATLAS Collaboration

35 pb^{-1} Data taking

- Full 2010 dataset (periods A-I)
- Preselection
  - All relevant subdetectors in stable operation
  - Event cleaning
  - At least one good primary vertex
  - Single electron or muon trigger



What we are measuring

Answer: cross sections*!

Quantity	Motivation
$\sigma(V+\geq N_{jets}) \bullet BR(V)$	Test of higher order calculations and pQCD Choice of jet-parton matching and parton showering
$\sigma(V+\geq N_{jets}) / \sigma(V+\geq N_{jets}-1)$	Constraining α_s and PDFs Many uncertainties cancel out in the ratio Background to top (extrapolate to higher jet multiplicity)
$d\sigma/dP^{N}_{T\ jet}$	Test of higher order calculations and pQCD Understand background to new physics
$d\sigma/dHT$	$HT=P_T^{l}+MET+\Sigma P_T^{jets}$ - scale used in MCFM and BLACKHAT-SHERPA

Different production mechanism and energy regime to Tevatron

Plus comparison to ALPGEN, SHERPA, PYTHIA, MCFM, BLACKHAT+SHERPA

***within defined phase space for η_l, P_T^l, M^Z, M_T^W, MET**

* Just for signal samples

MC Datasets and settings*

Generator	v.	Interfaced with	Comments
ALPGEN	2.13	HERWIG 6.510 JIMMY 4.31 PHOTOS 2.15.4 CTEQ6L1 ATLAS MC09 tune	MLM matching
SHERPA	1.1.3	CTEQ6L1 Default UE tune	CKKW matching
PYTHIA	6.4.21	PHOTOS 2.15.4 MRST 2007 LO∗ ATLAS MC09 tune	LO ME with corrections to ISR PS emission
MCFM		CTEQ6.6/CTEQ6L1	NLO for <=2jets, LO for 3 jets
SHERPA +BLACKHAT		CTEQ6.6M	NLO for <=3jets

ALPGEN, SHERPA, PYTHIA: Normalised to FEWZ NNLO pQCD prediction (MRST2007LO∗ PDFs)

MCFM, SHERPA+BLACKHAT: + Pythia UE and fragmentation corrections + recombination of FSR photons

Event selection

Compare with 30000 Z+≥1jet events currently analysed at the Tevatron

Electrons
- P_T > 20 GeV
- |η| >2.47
- |η| < 1.37 || >1.52
- Identification criteria
- Removal in bad calorimeter regions
- Isolation

Jets
- AntiKt4 jets
- P_T > 20(30) GeV in W (Z)
- y (η in W analysis) < 2.8
- ΔR (lepton-jet) >0.5
- Pileup removal cuts

Muons
- P_T > 20 GeV
- |η| > 2.4
- Quality requirements
- Isolation

# jets	W	Z
No req	106831	8651
≥ 1	24589	1249
≥ 2	6846	244
≥ 3	2059	48
≥ 4	705	12

Event
- Preselection

- MET > 25 GeV (W)
- M_W^T > 40 GeV (W)
- Second lepton veto (W)
- 66 GeV < M_Z < 116 GeV (Z)
- Opposite sign leptons (Z)

# jets	W	Z
No req	140966	11665
≥ 1	30937	1648
≥ 2	8505	364
≥ 3	2544	79
≥ 4	870	18

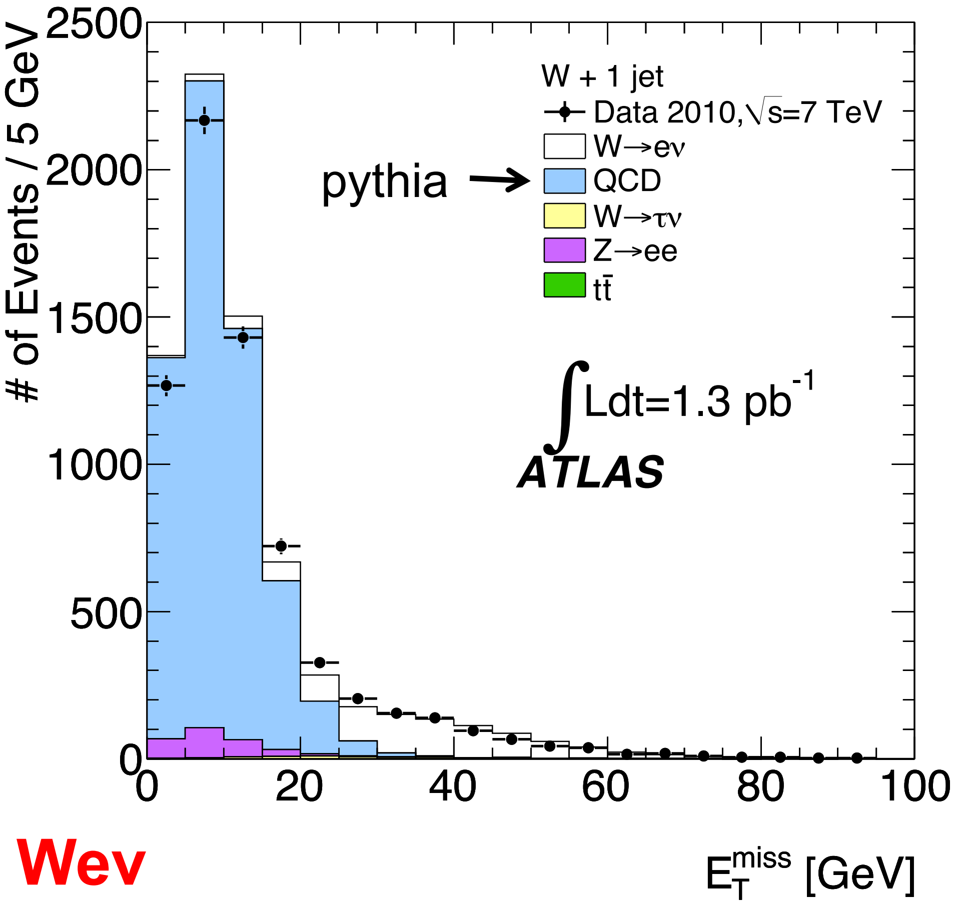
QCD background estimation techniques

	Wlnu	Zll
e	Fit data MET distribution - QCD and leptonic template QCD template obtained by 1) Electron ID reversal 2) Replace electron by photon selection	Loosen electron ID criteria - scale to data
mu	Fit MET and M_W data distribution - QCD and leptonic template	Monte Carlo

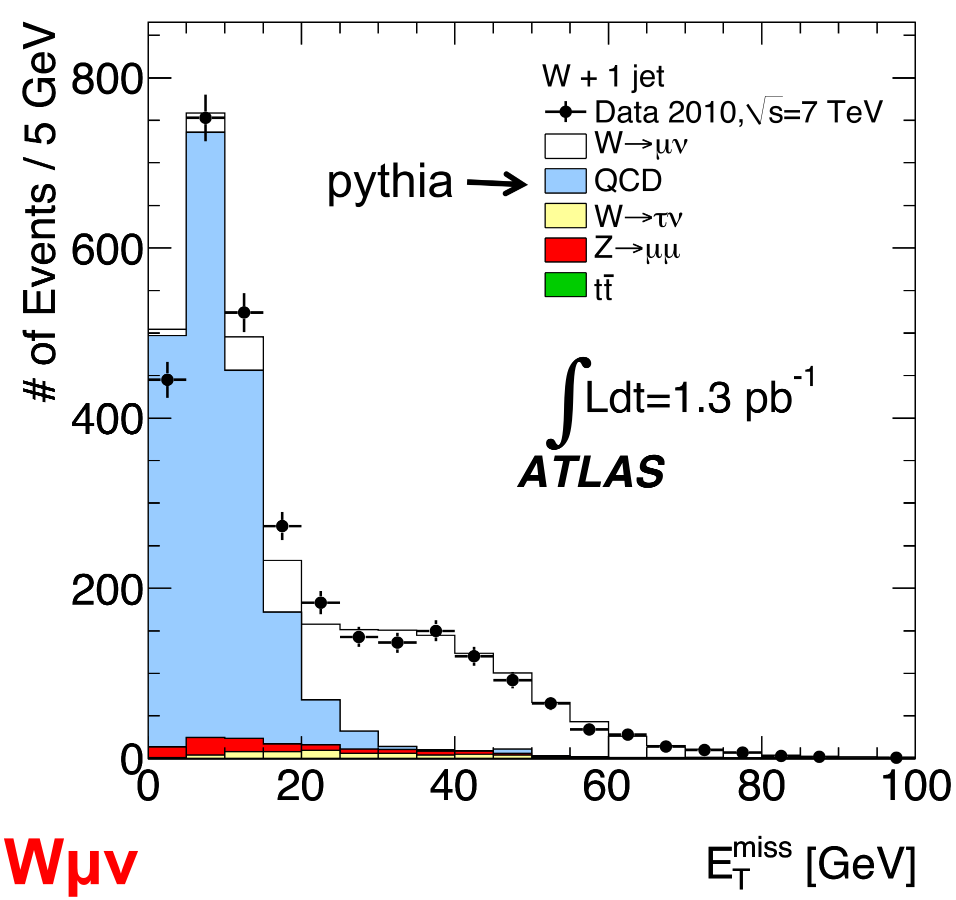
- Leptonic backgrounds taken from MC: Wτν, Zee, Zμμ, Zττ, top, tt, VV
- Total background O(10%)/O(1-5%) for W/Z analysis

QCD background estimation techniques

In future hope to play a similar game with ttbar



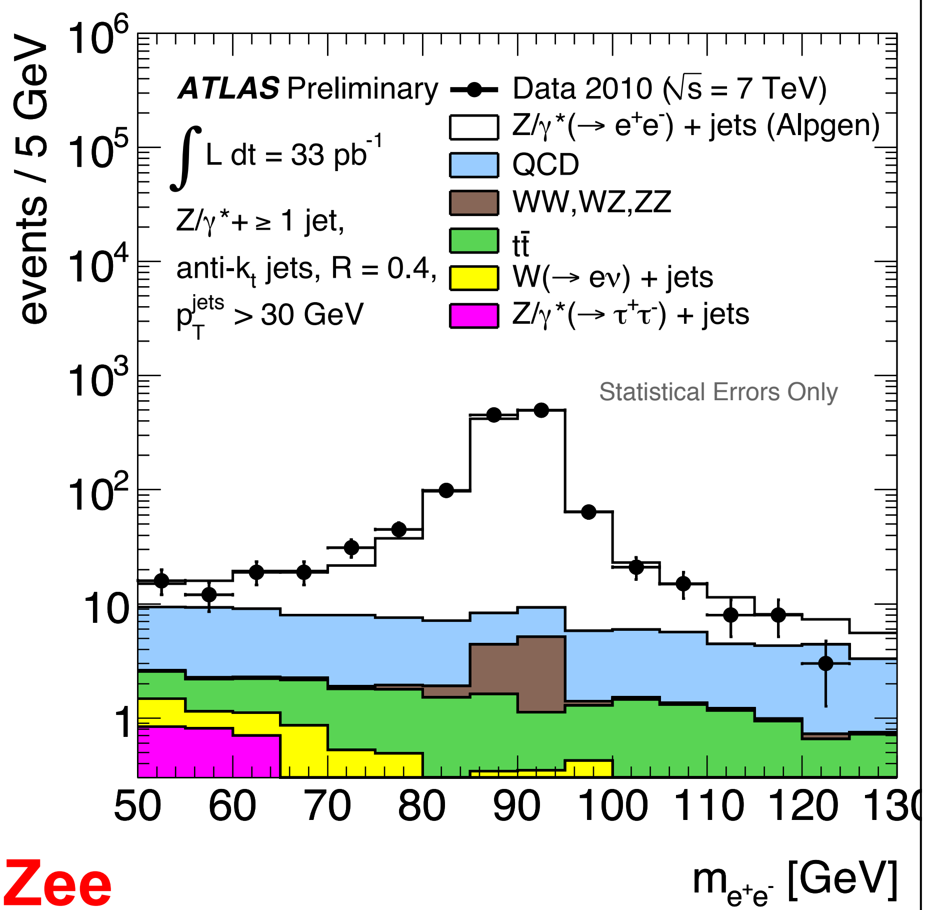
Wev



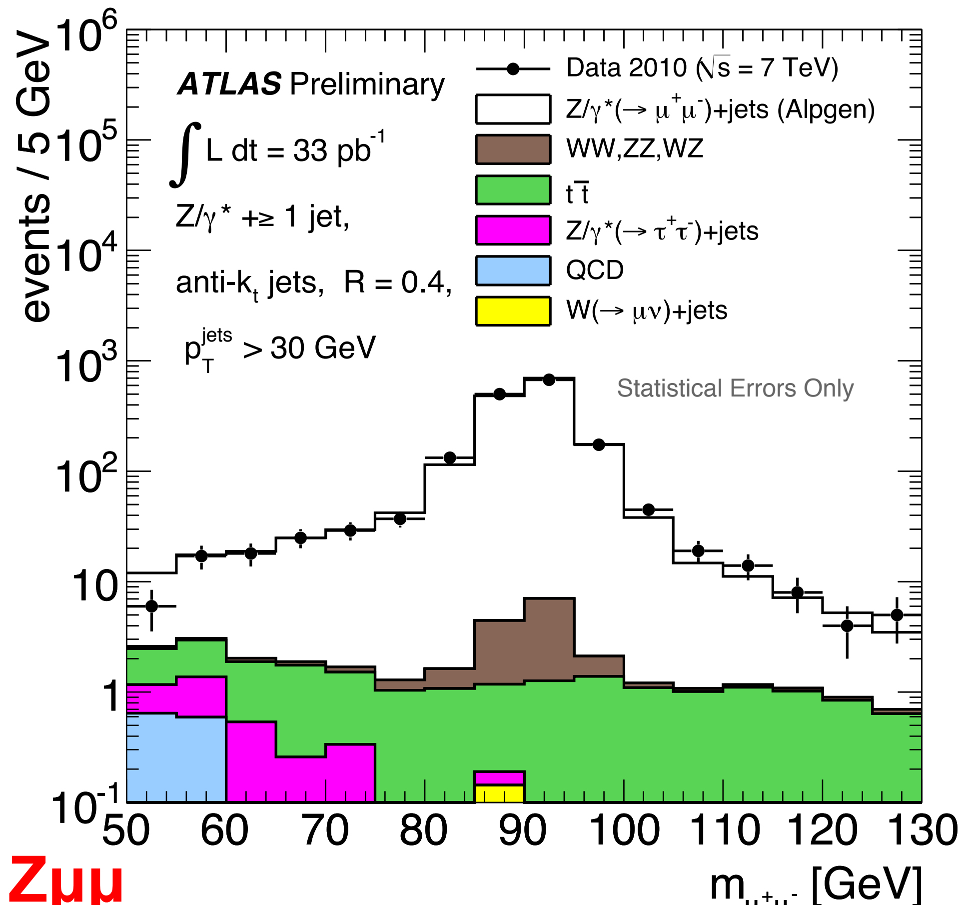
Wμv

Sanity checks : Z mass

Presence of jets does not affect lepton reconstruction



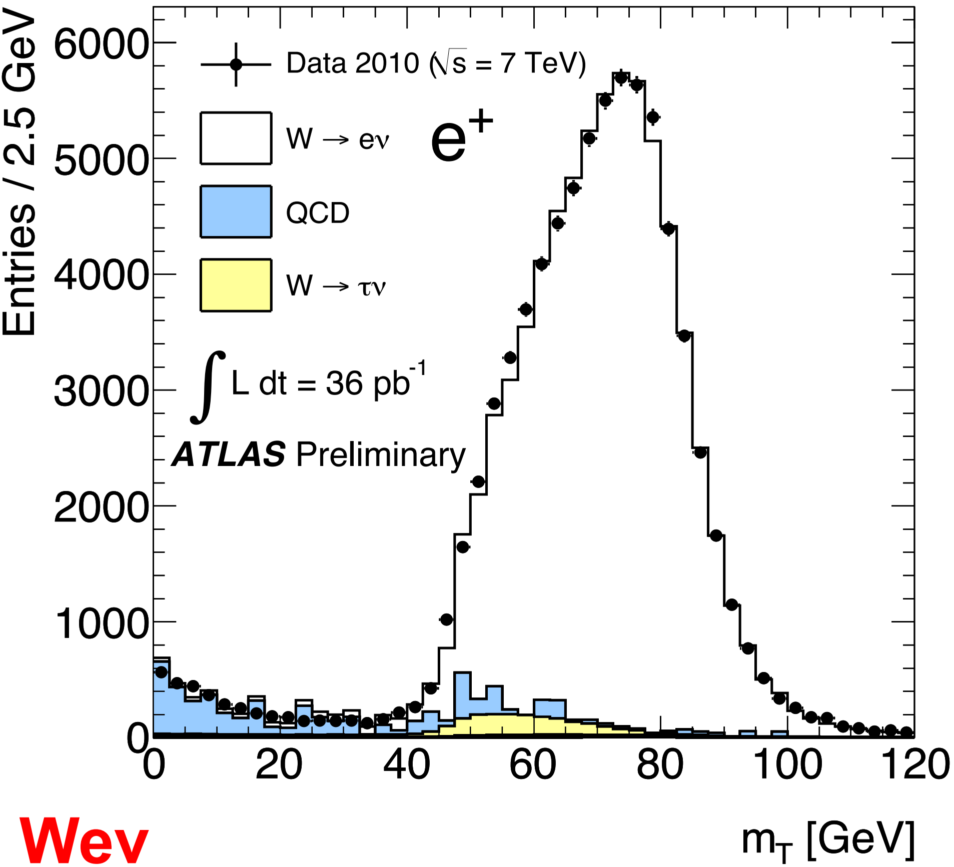
Zee



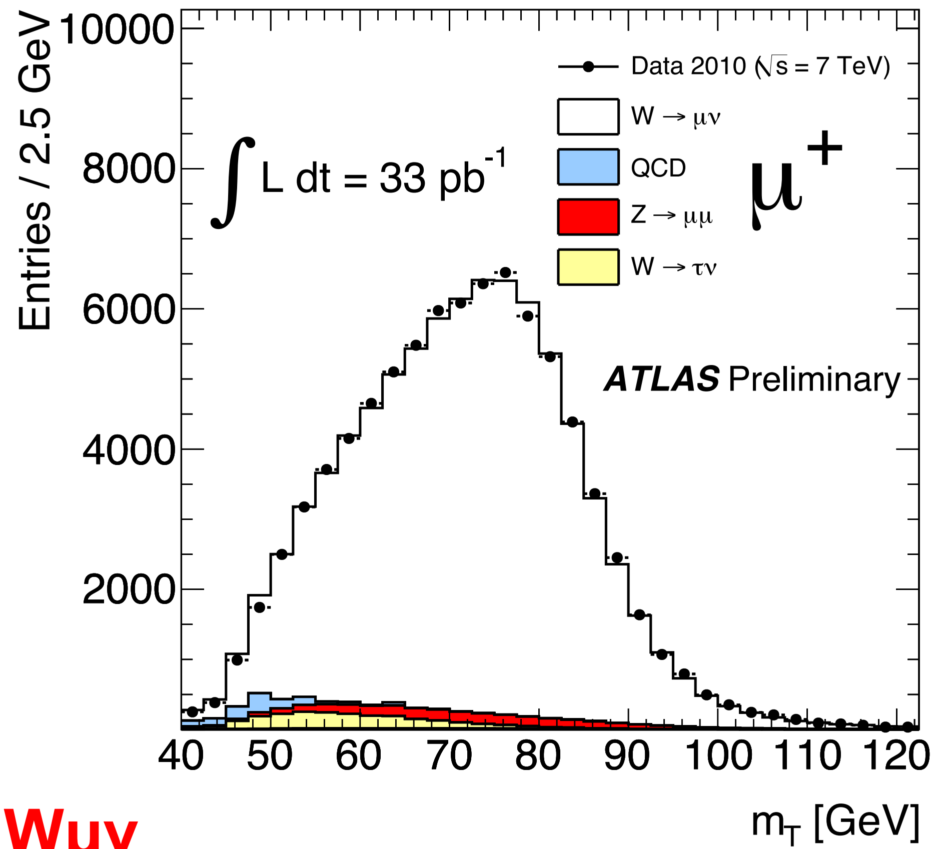
Zμμ

Sanity checks: W transverse mass

Presence of jets does not affect MET reconstruction



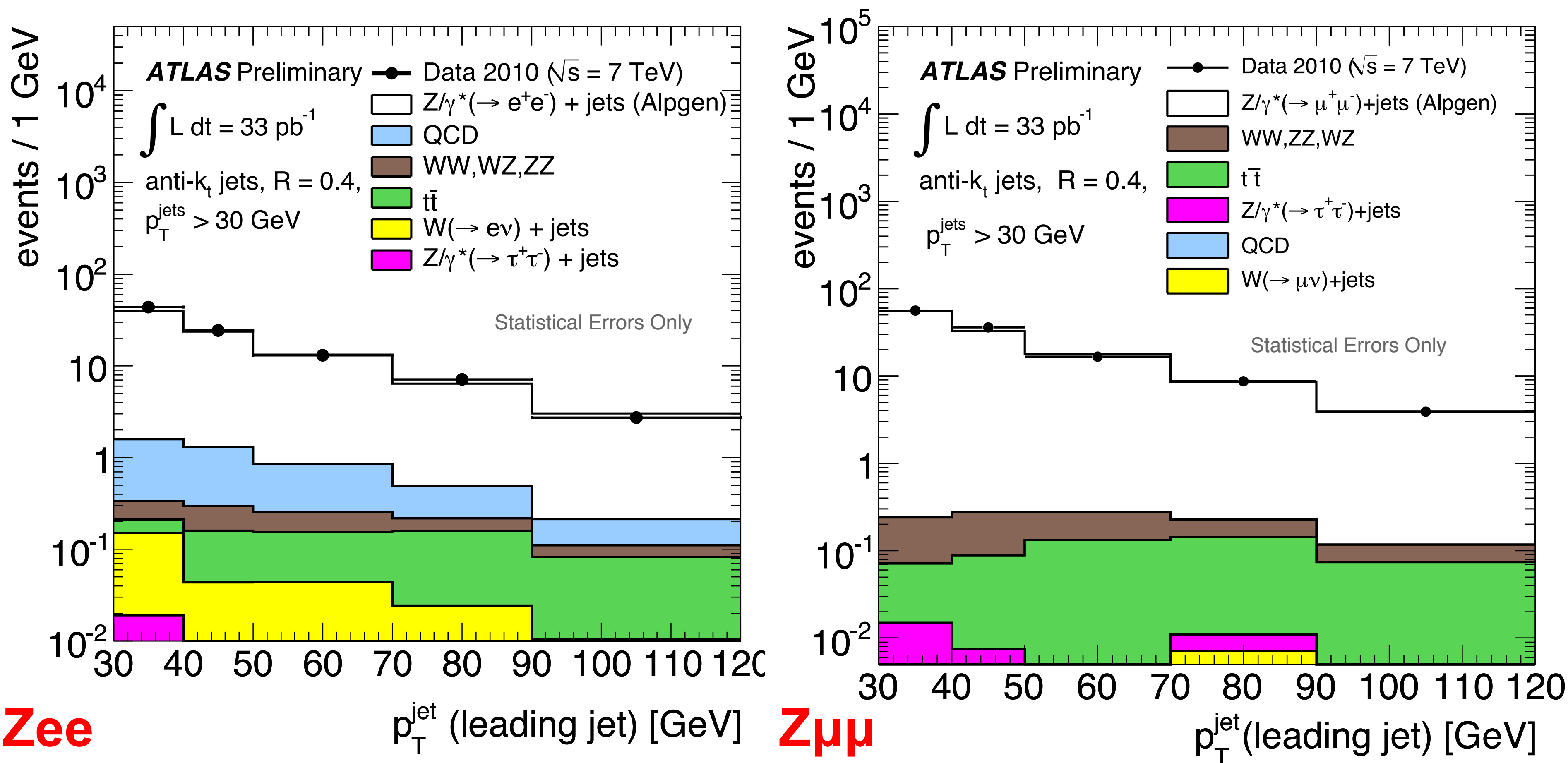
Wev



Wμv

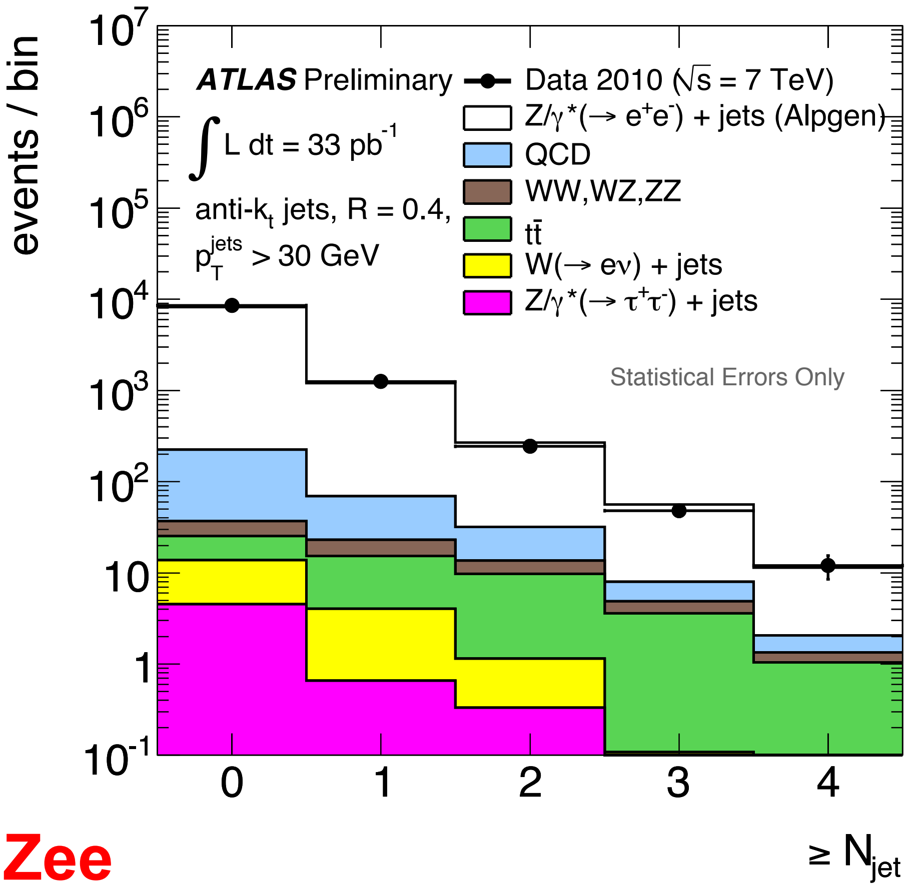
Sanity checks: jet P_T

Jet response consistently good over whole P_T range

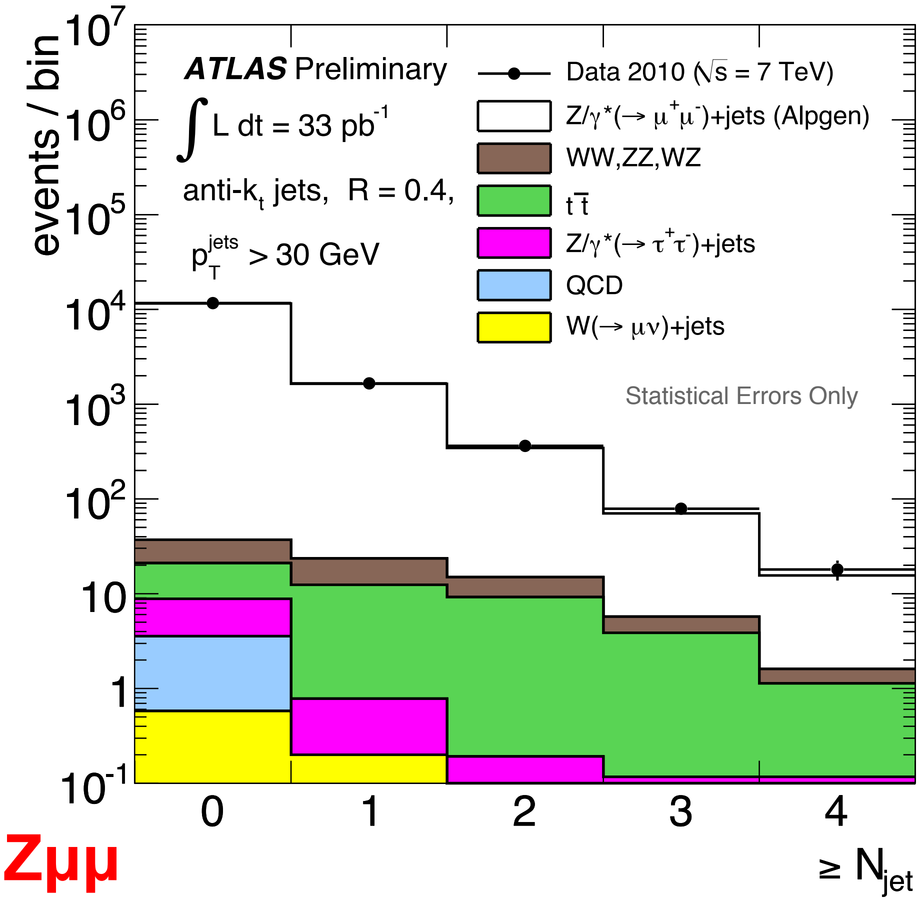


Sanity checks: jet multiplicity

ttbar background more problematic at higher jet multiplicity



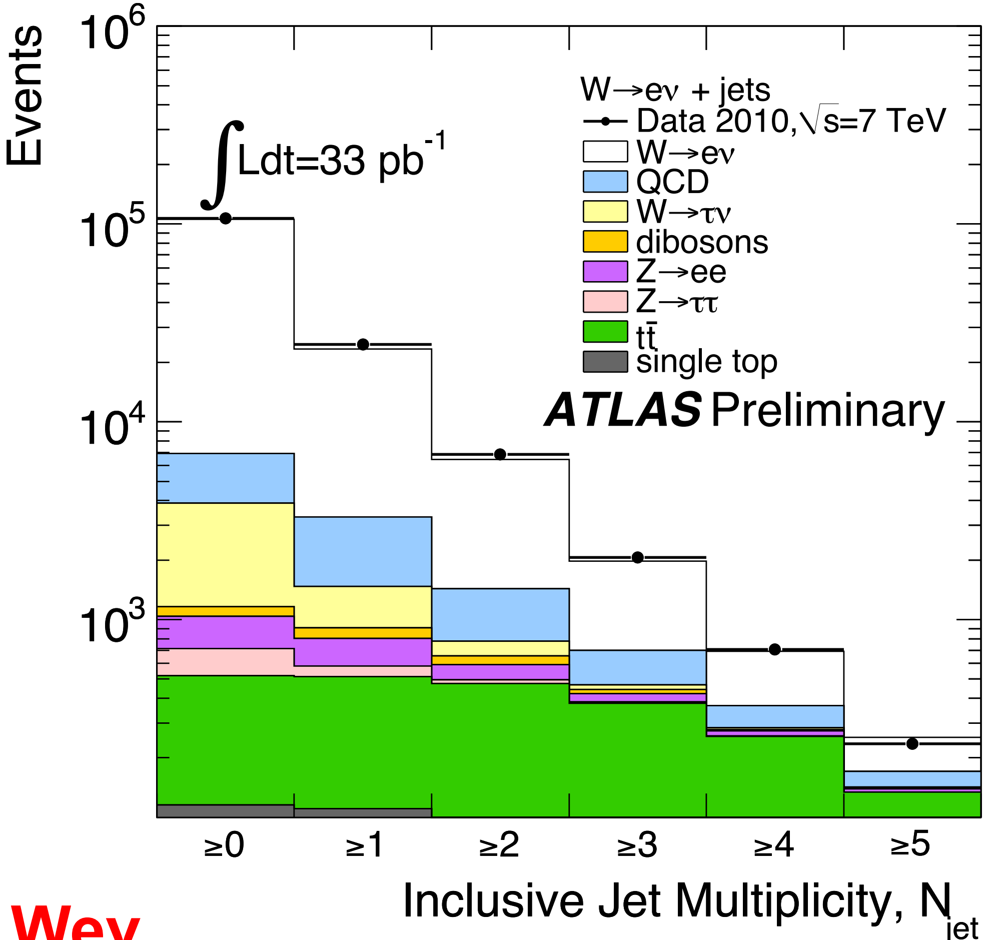
Zee



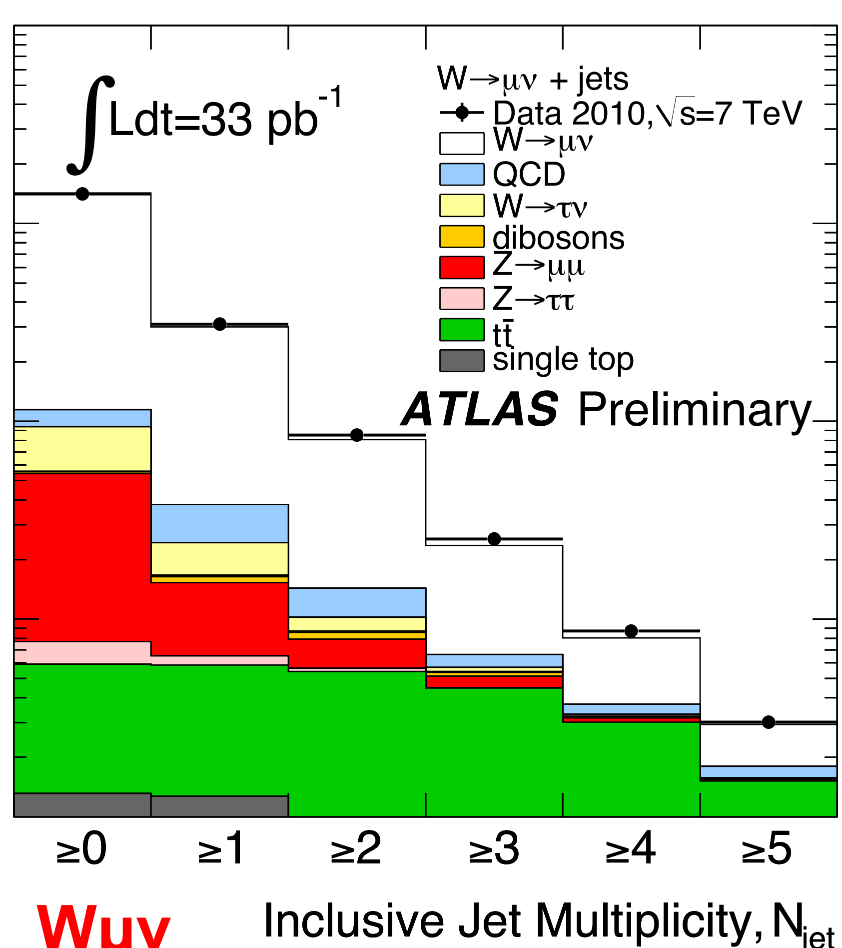
Zμμ

Sanity checks: jet multiplicity

Backgrounds more problematic in W analysis



Weν



Wμν

Analysis strategy

Detector level

Data distributions (as already seen)

Unfolding: Efficiencies, response, trigger, acceptance

Particle level (public results)

Non pQCD effects: Hadronisation, underlying event, QED FSR + phase space

Parton level

BLACKHAT+SHERPA+≤3jets (W analysis only)
MCFM NLO for W+<=3 jets; LO for W+4jets
ALPGEN, SHERPA normalised to FEWZ NNLO

Unfolding from detector to particle level

Bin by bin unfolding

- Simple correction factor mechanism.
- Systematics uncertainty : difference ALPGEN and SHERPA derived corrections

Bayesian unfolding

- Lower MC dependence, better statistical treatment
- Results in large fluctuations when computing systematics in bins with low statistics

Agreement of results between the two methods and highly diagonal conditional migration matrices give us confidence in the bin by bin method

Systematic uncertainties: W summary

e channel		
Effect	Range	Cross Section Uncertainty (%)
Jet energy scale and E_T^{miss}	$\approx$ 7% (dependent on jet η and p_T)	+9.8,-7.6
Jet energy resolution	10% on each jet	± 3.3
Electron trigger	±0.5%	± 0.5
Electron reconstruction	±1.5%	± 1.6
Electron correction factors	±3 – 5% (dependent on electron η)	+3.3,-3.5
Electron energy scale	±3%	+4.7,-5.2
Electron energy resolution	20% on sampling term 100% (400%) on constant term in barrel (endcap)	±0.1
Pile–up removal cut	4 – 7% in lowest jet p_T bin	+6.6
Residual pile-up effects	from simulation	+3.6
QCD background shape	from template variation	± 1.9
Unfolding	ALPGEN vs. SHERPA	+2.0
Luminosity	±3.4%	± 3.5

μ channel		
Effect	Range	Cross Section Uncertainty (%)
Jet energy scale and E_T^{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

Dominant uncertainty

Subdominant uncertainty

Subsubdominant uncertainty

Lepton uncertainties slightly larger in electron channel

Systematic uncertainties: Z summary

e channel		
Source	range	uncertainty on cross section (%)
Jet energy scale	4% to 8%, depending on p_T^{jet} and η^{jet} $\oplus$ pile-up contribution $\oplus$ 5%	10% to 20%
Jet energy resolution	10% uncertainty	$< 1\%$
Pile-up jet removal	difference of JVF impact in data and MC	4% at $p_T^{jet} < 50$ GeV
QCD background	from data using control samples	2% to 2.4%
$t\bar{t}, Z/W$+jets, dibosons	6%, 5%, 5% on normalization	1%
Lepton selection	1% to 3% e-scale uncertainty, resolution, reconstruction efficiency	5% to 6%
Unfolding	using SHERPA instead of ALPGEN and re-weighted ALPGEN	5% to 7%

μ channel		
Source	range	uncertainty on cross section (%)
Jet energy scale	4% to 8%, depending on p_T^{jet} and η^{jet} $\oplus$ pile-up contribution $\oplus$ 5%	10% to 20%
Jet energy resolution	10% uncertainty	$< 1\%$
Pile-up jet removal	difference of JVF impact in data and MC	4% at $p_T^{jet} < 50$ GeV
QCD background	100% uncertainty	$< 1\%$
$t\bar{t}, Z/W$+jets, dibosons	6%, 5%, 5% on normalization	$< 1\%$
Lepton selection	with/without applying the correction factors in the simulation	4%
Unfolding	using SHERPA instead of ALPGEN and re-weighted ALPGEN	5% to 7%

Dominant uncertainty

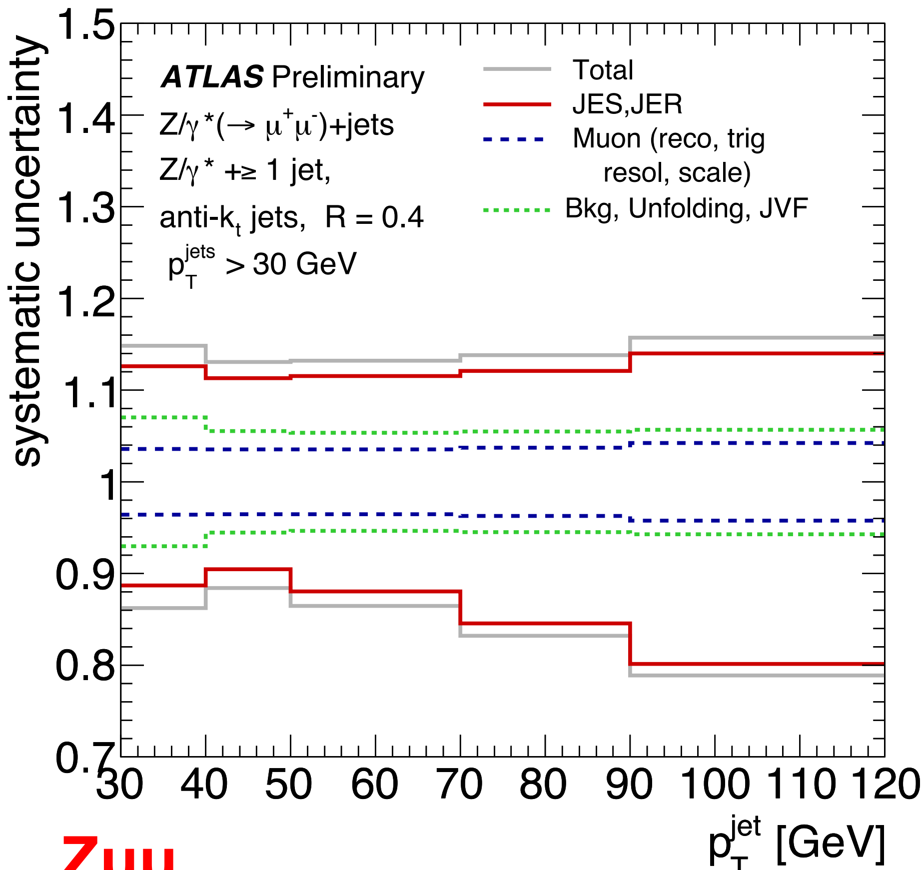
Uncertainty conclusions comparable to W channel

Subdominant uncertainty

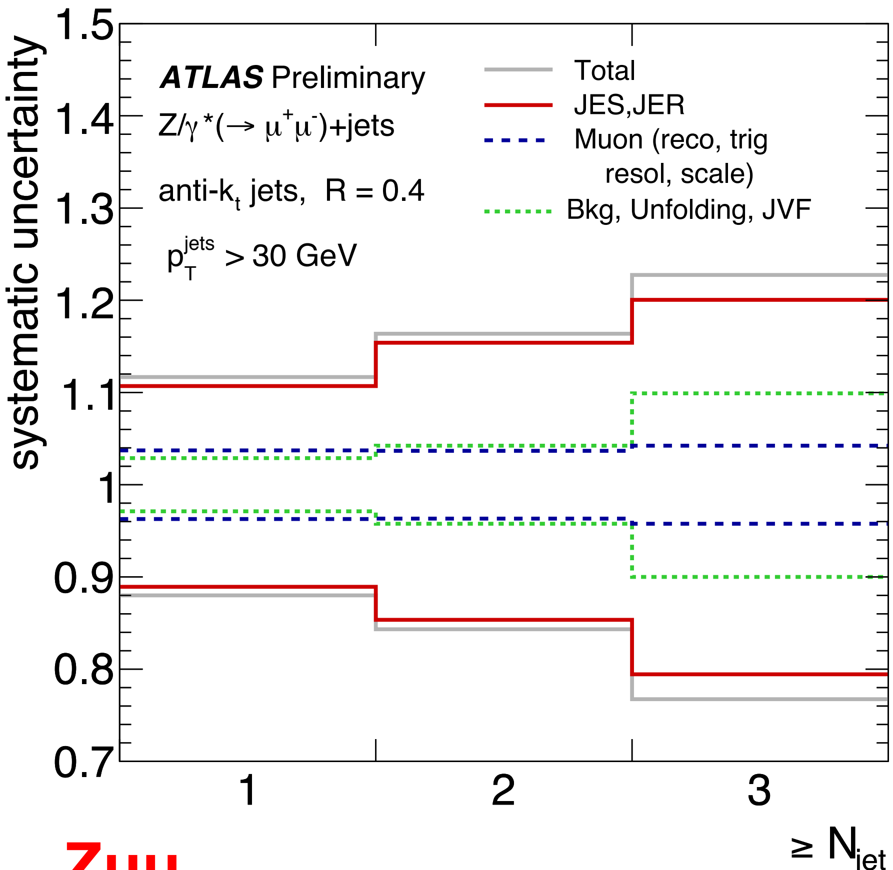
Subsubdominant uncertainty

Systematic uncertainty dependence

Uncertainties increase with Njets: due to JES and BG
More or less flat wrt jet P_T



Zμμ



Zμμ

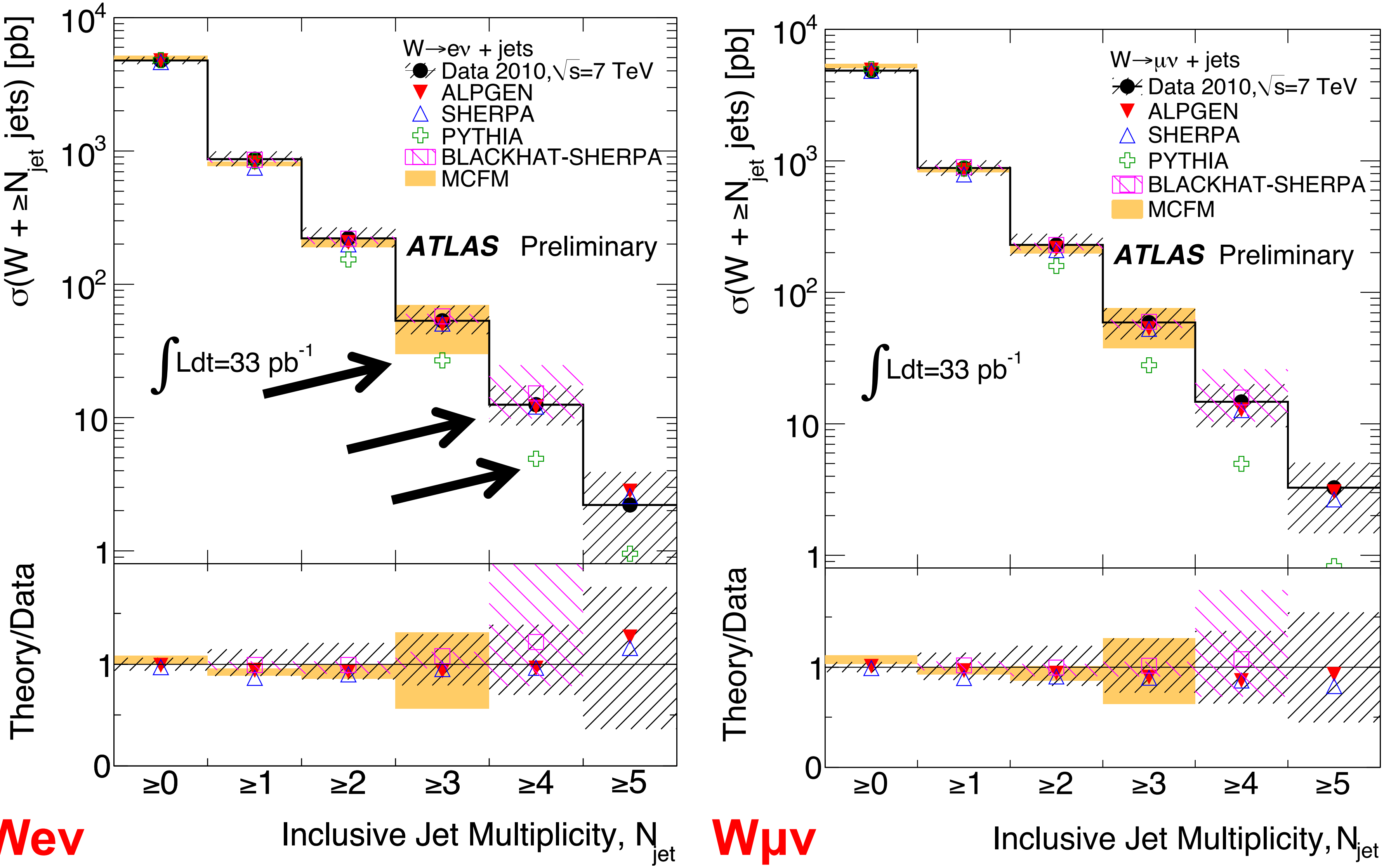
Systematic uncertainties on NLO predictions

Uncertainty	Evaluation	Impact
Scale	• Vary nominal HT/2 up and down by factor 2	2-9%
PDF	• Hessian method with CTEQ6.6 • Comparison with MSTW2008 • variation around nominal α_s	1-3%
UE+Frag	• AMBT1 vs JIMMY • Varying AMBT1 to increase UE by 10% • PYTHIA vs HERWIG+JIMMY	4-8%
QED FSR	• ALPGEN vs SHERPA and PYTHIA	1%

particle->parton level

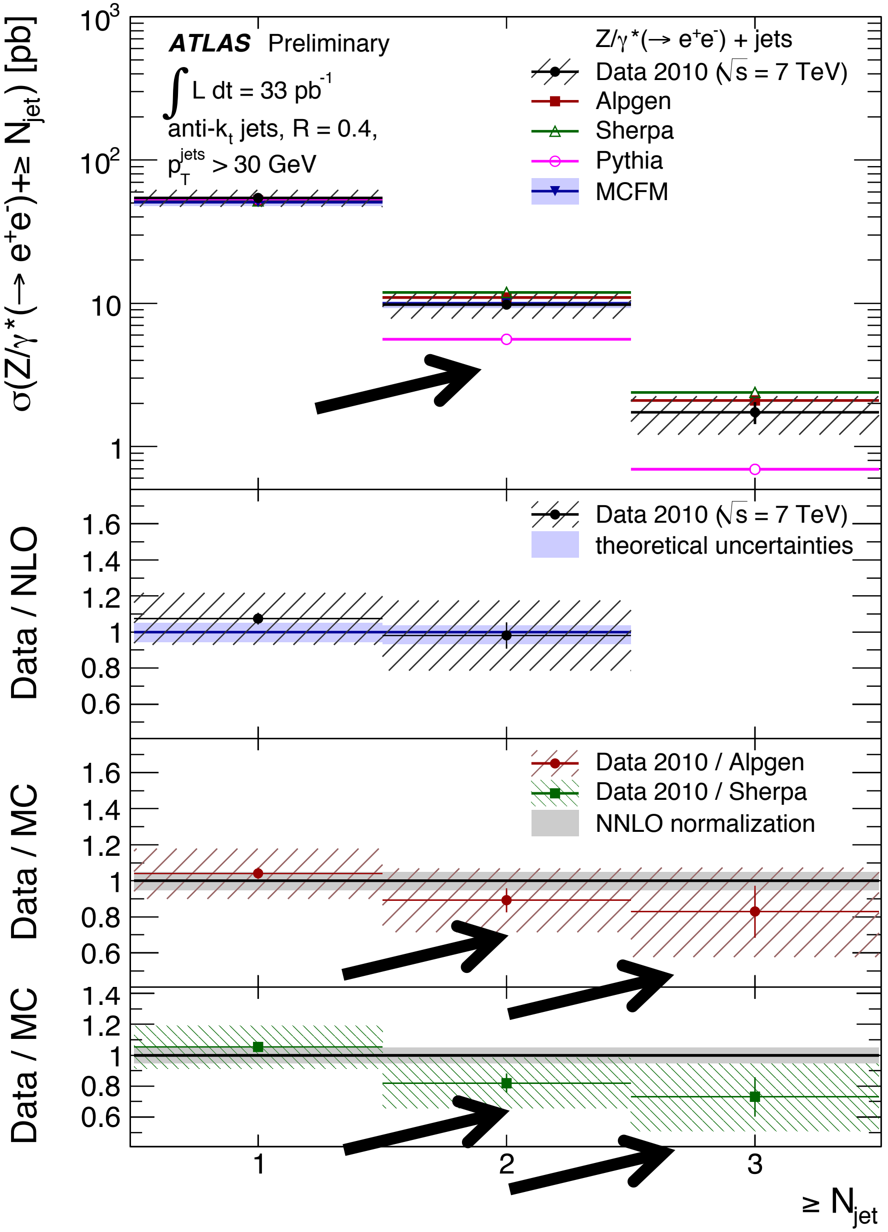
Parton level cross section

$d\sigma/dN_{jet}$

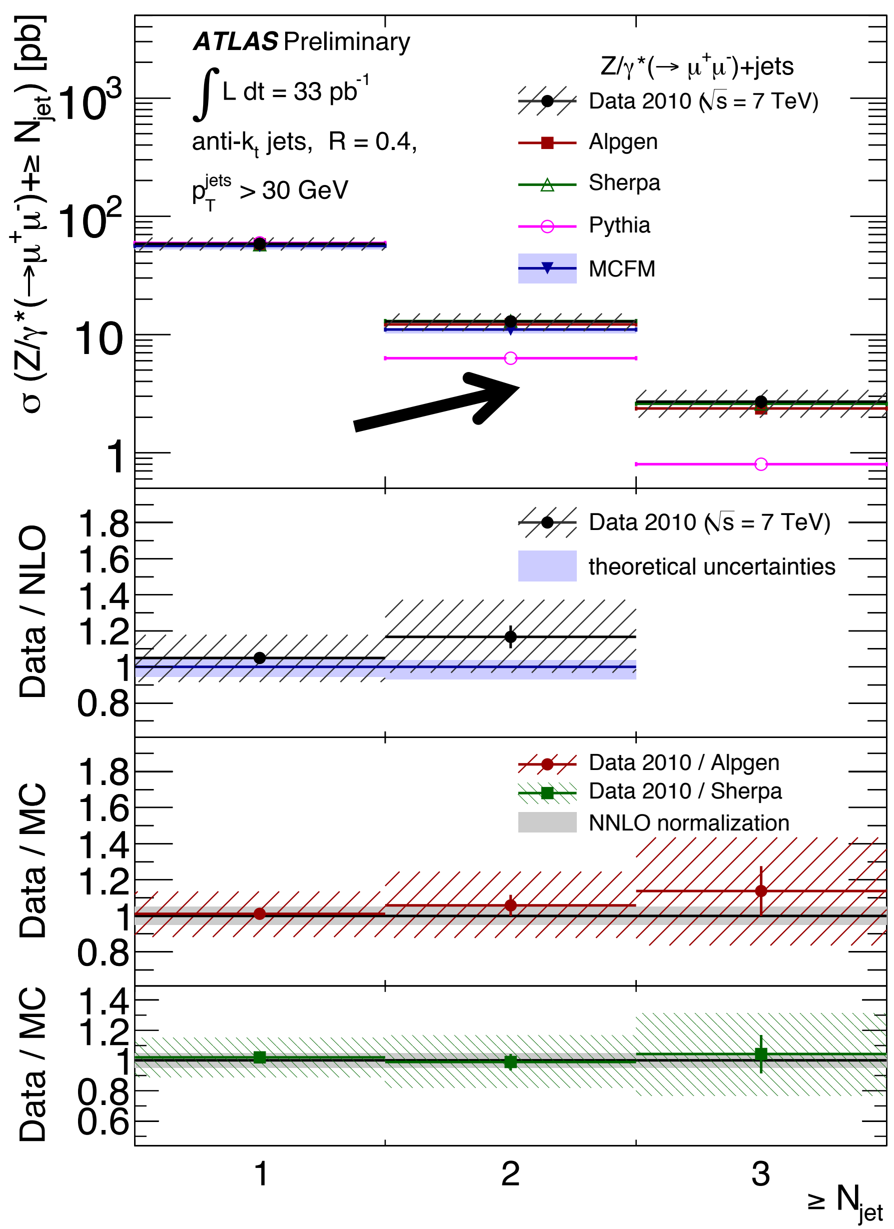


Wev **Wμν**

Zee


ATLAS Preliminary
∫L dt = 33 pb⁻¹
anti-k_t jets, R = 0.4,
p_T^jets > 30 GeV
Z/γ*(→ e⁺e⁻) + jets
Data 2010 (√s = 7 TeV)
Alpgen
Sherpa
Pythia
MCFM
σ(Z/γ*(→ e⁺e⁻)+≥ N_jet) [pb]
Data / NLO
theoretical uncertainties
Data / MC
Data 2010 / Alpgen
Data 2010 / Sherpa
NNLO normalization
≥ N_jet

Zμμ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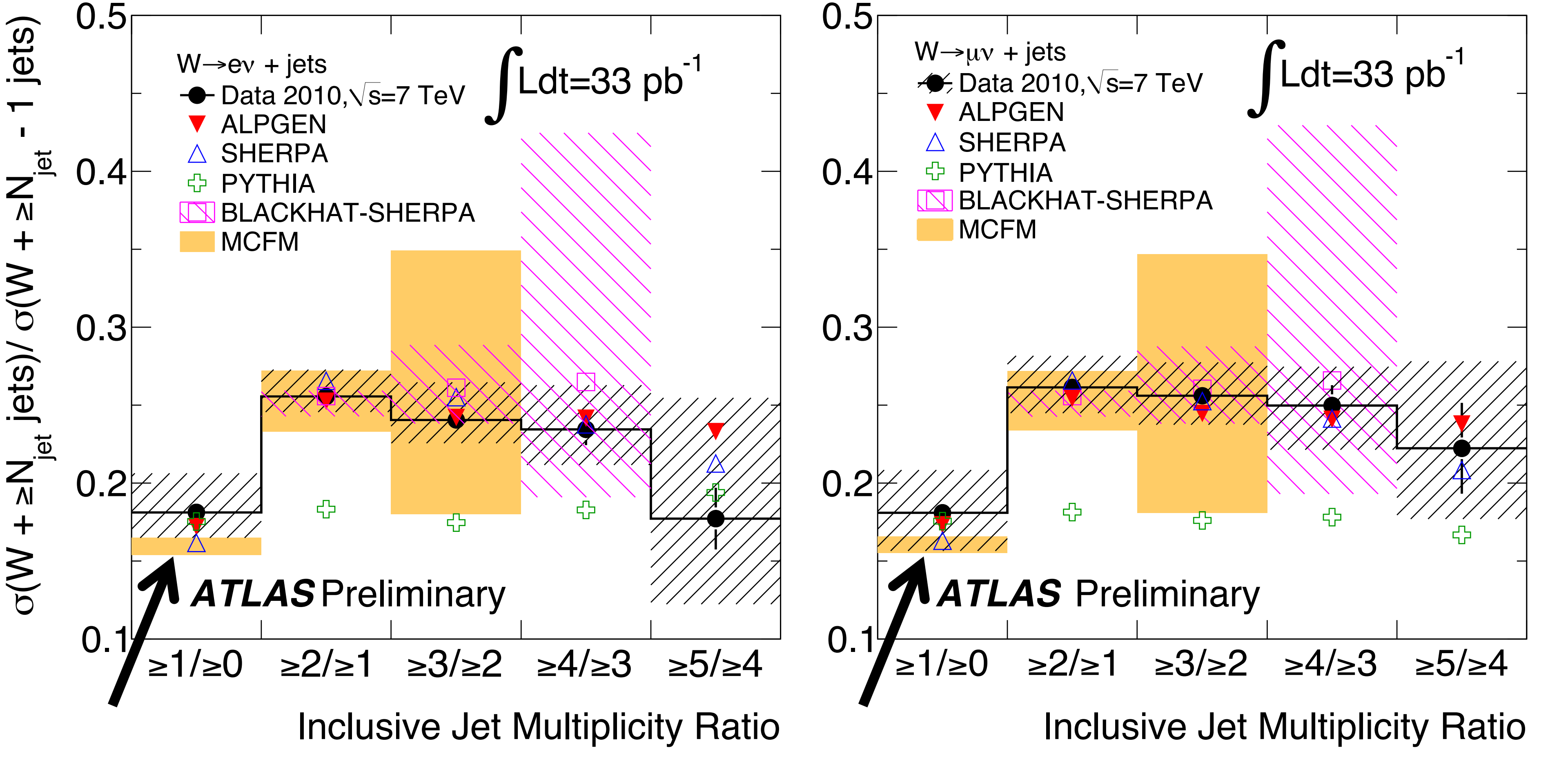
Data / NLO
theoretical uncertainties
Data / MC
Data 2010 / Alpgen
Data 2010 / Sherpa
NNLO normalization
≥ N_jet

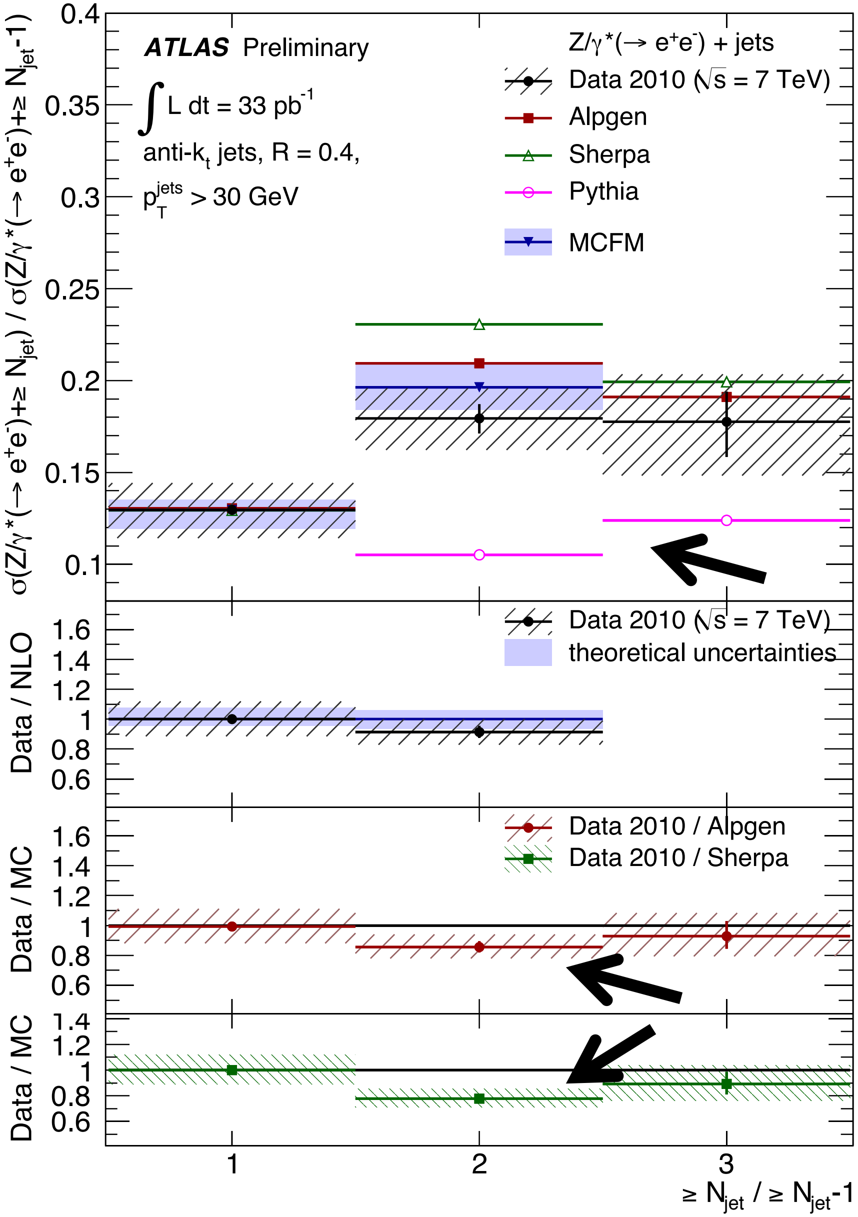
σ(N)/σ(N-1)



Wev

Wμv

Zee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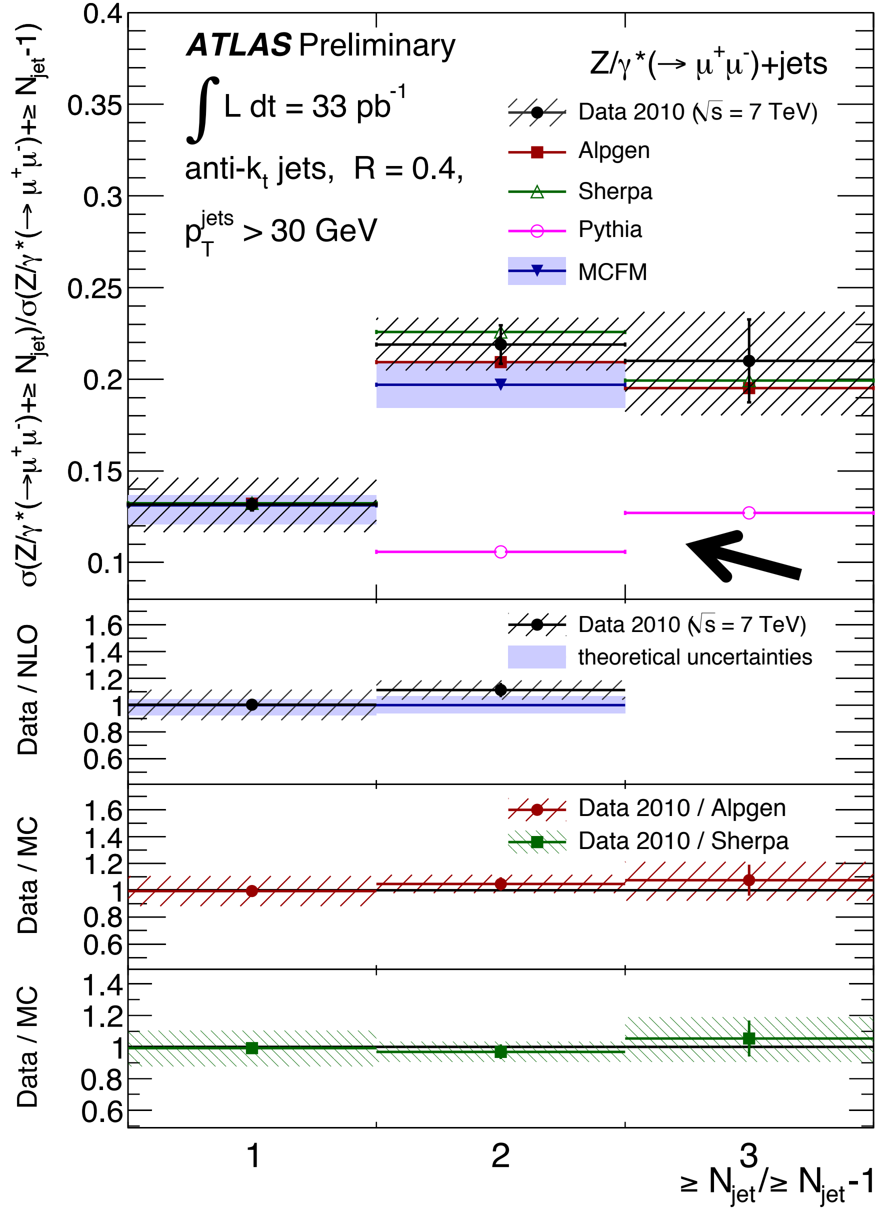
Z/γ*(→ e⁺e⁻) + jets
Data 2010 (√s = 7 TeV)
Alpgen
Sherpa
Pythia
MCFM
σ(Z/γ*(→ e⁺e⁻)+≥ N_jet) / σ(Z/γ*(→ e⁺e⁻)+≥ N_jet-1)
Data / NLO
theoretical uncertainties
Data / MC
Data 2010 / Alpgen
Data 2010 / Sherpa
≥ N_jet / ≥ N_jet-1

Zμμ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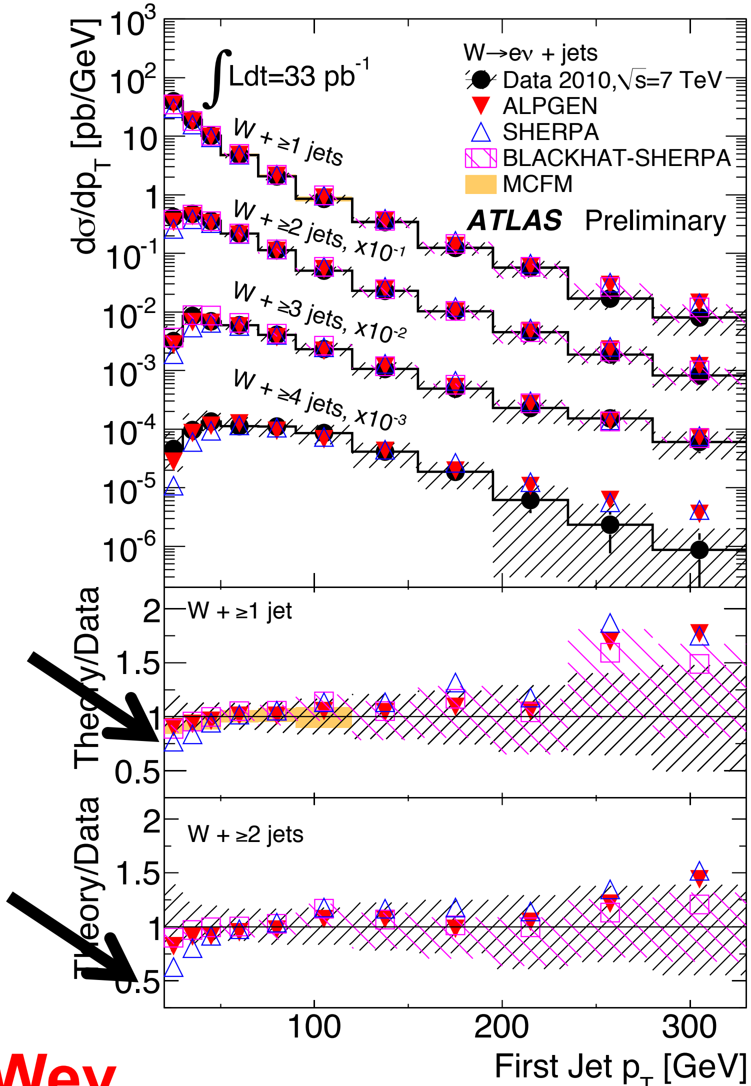
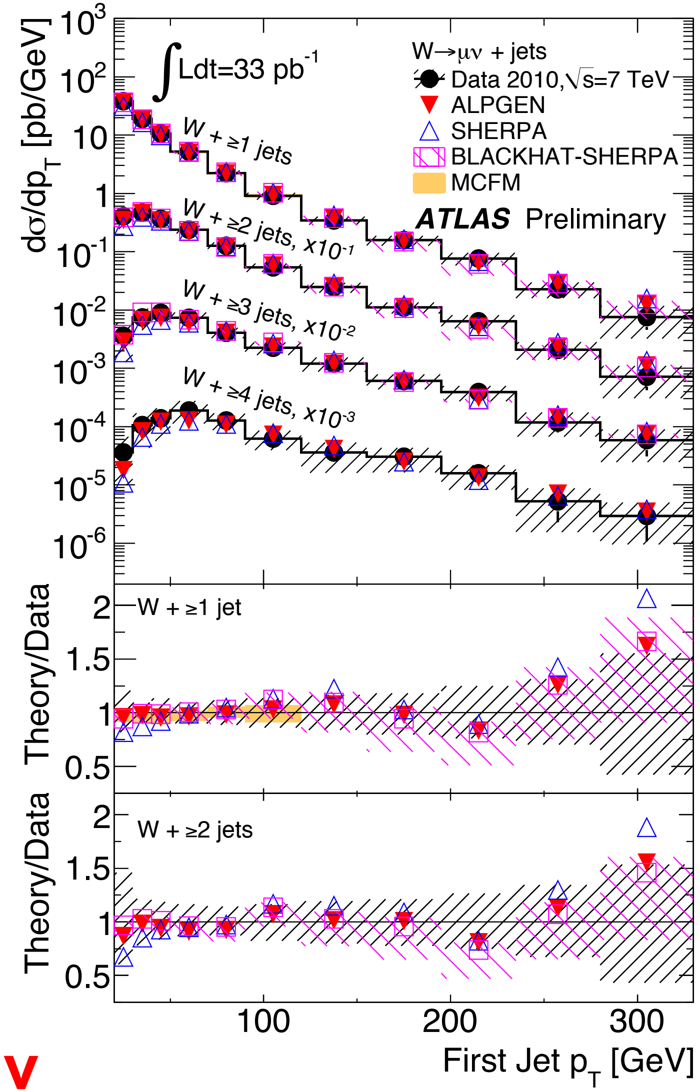
Z/γ*(→ μ⁺μ⁻)+jets
Data 2010 (√s = 7 TeV)
Alpgen
Sherpa
Pythia
MCFM
σ(Z/γ*(→μ⁺μ⁻)+≥ N_jet)/σ(Z/γ*(→ μ⁺μ⁻)+≥ N_jet-1)
Data / NLO
theoretical uncertainties
Data / MC
Data 2010 / Alpgen
Data 2010 / Sherpa
≥ N_jet/≥ N_jet-1

dσ/dP$_T$^{1}

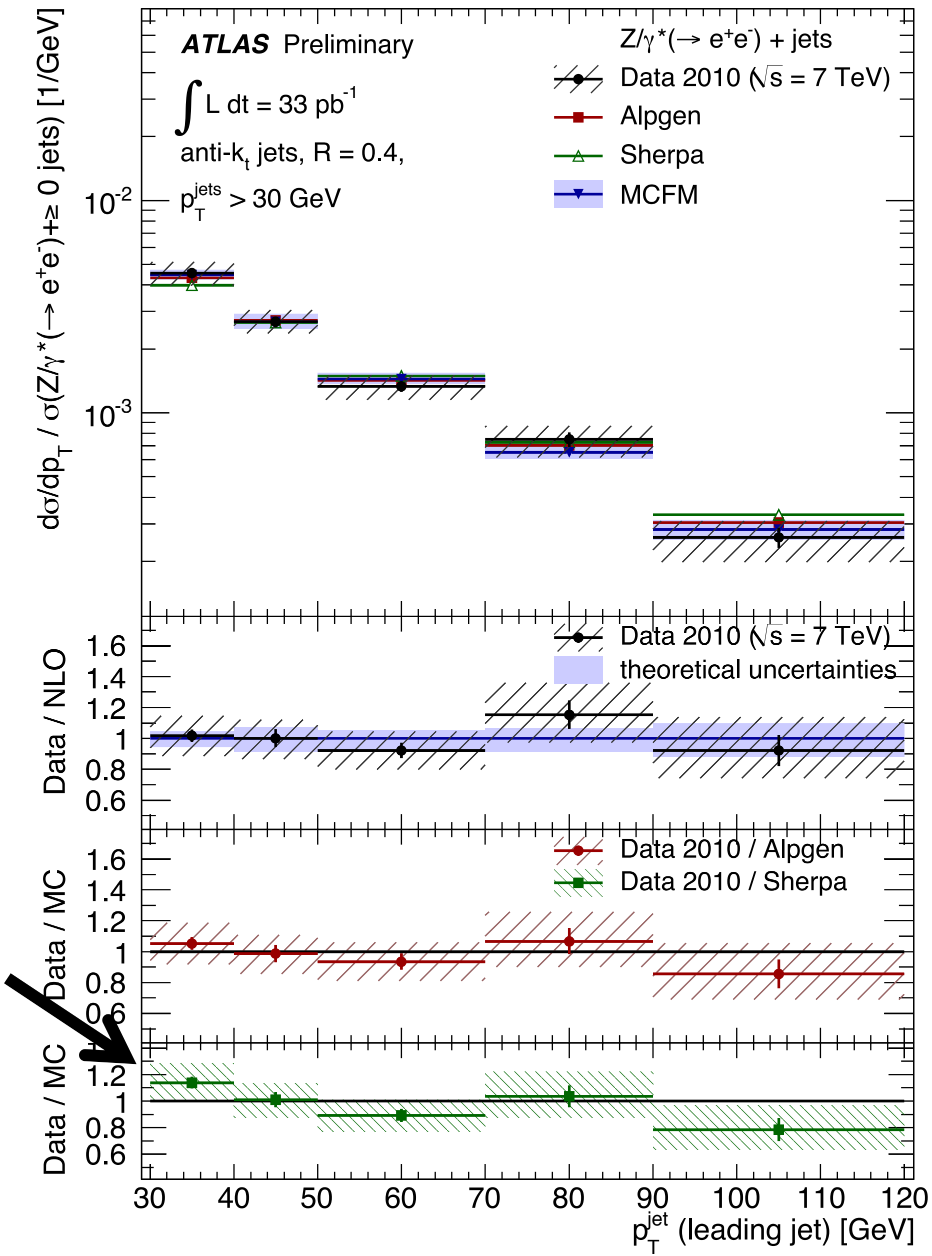


Wev

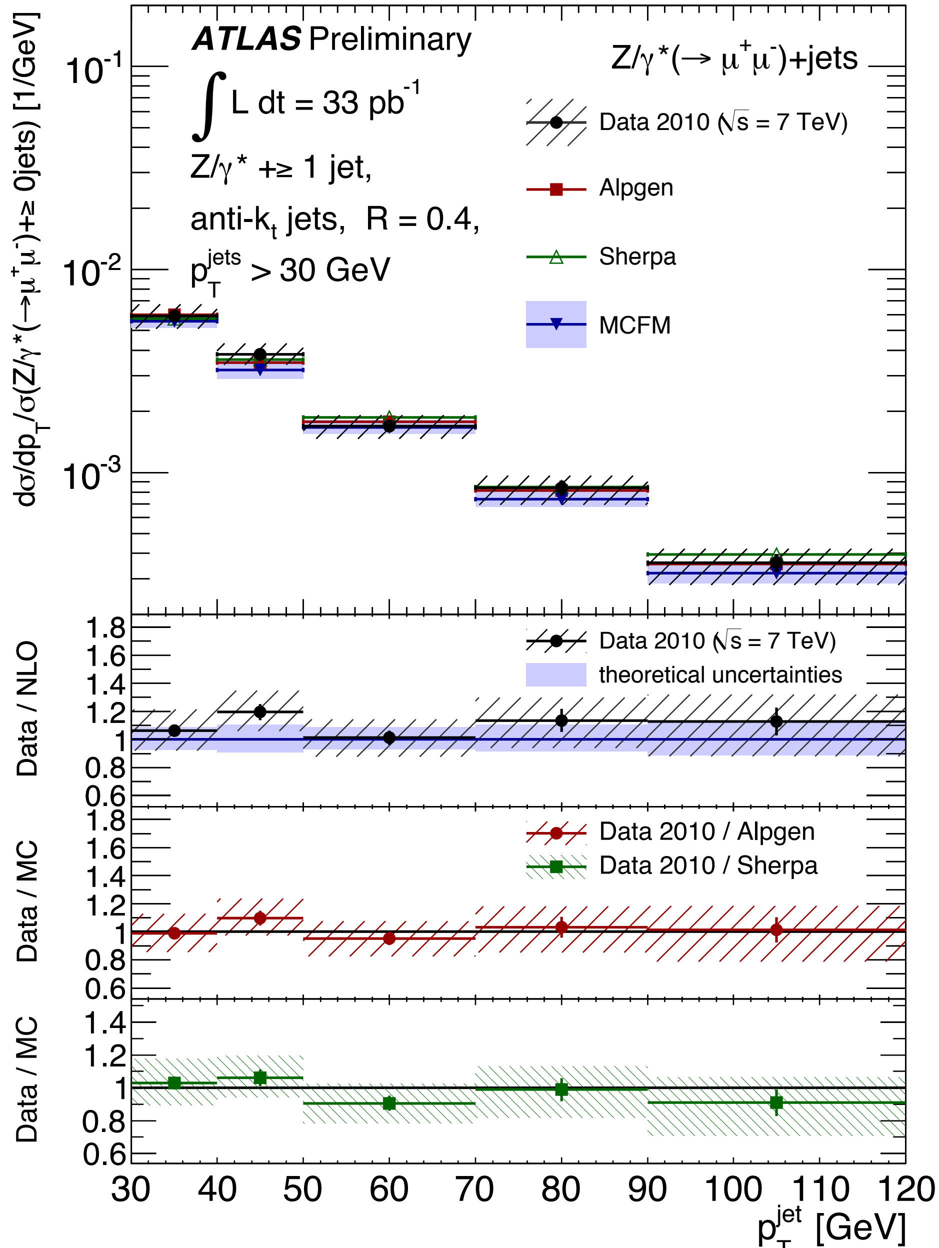


Wμν

Zee


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

Zμμ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Z/γ* +≥ 1 jet,
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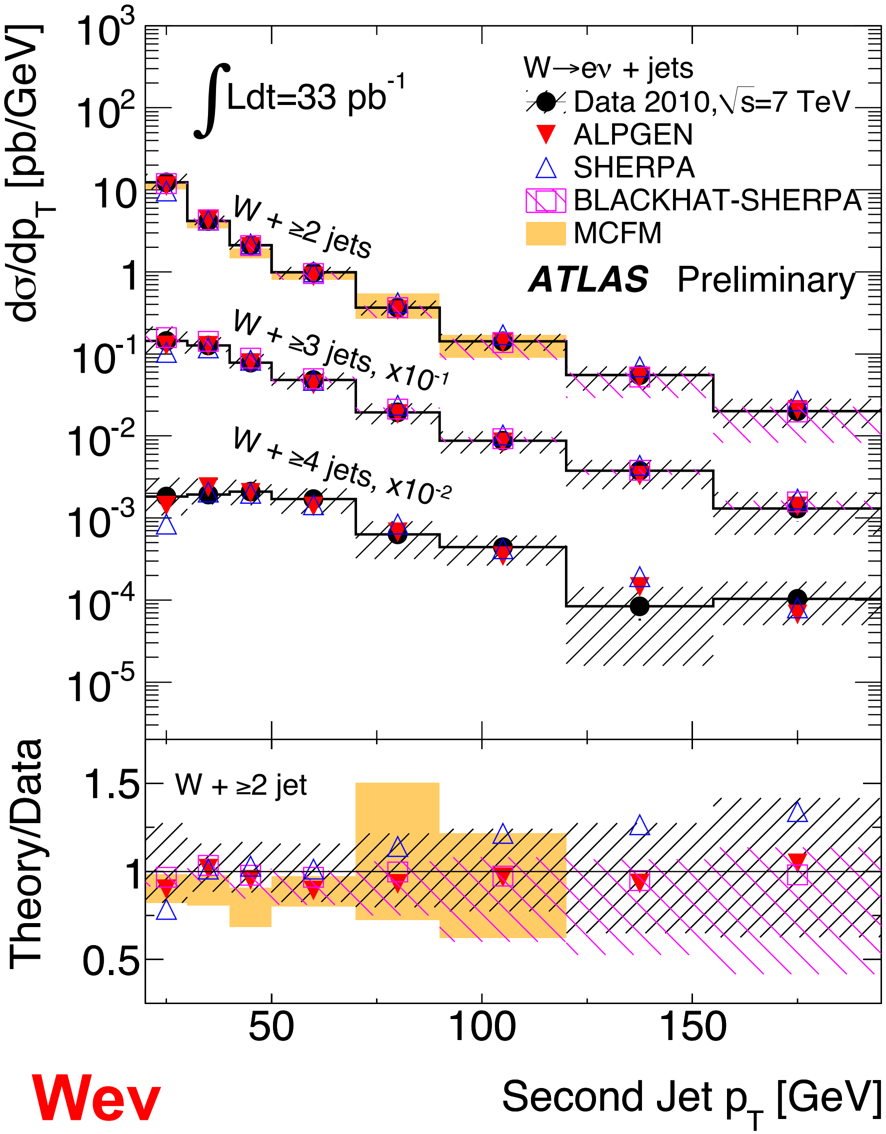
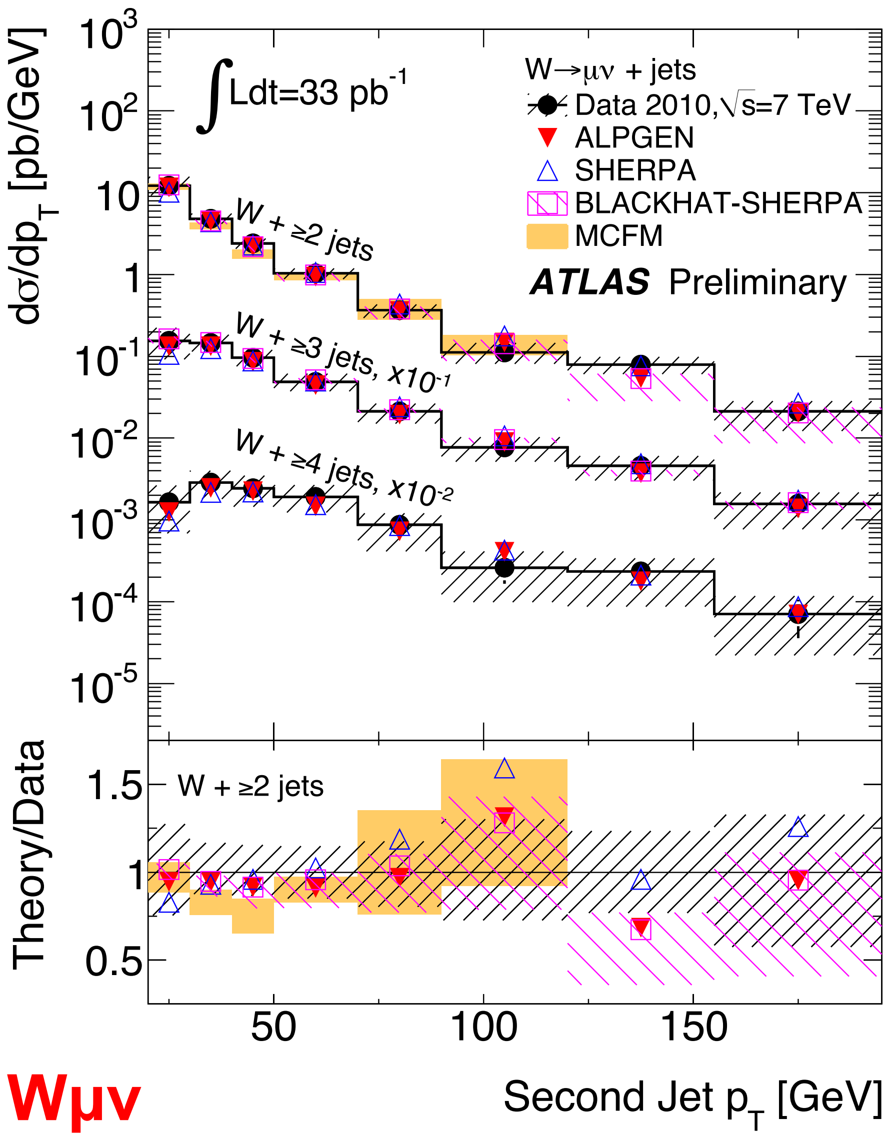
p_T^jets > 30 GeV
Z/γ*(→ μ+μ-)+jets
Data 2010 (√s = 7 TeV)
Alpgen
Sherpa
MCFM
dσ/dp_T/σ(Z/γ*(→μ+μ-)+≥ 0jets) [1/GeV]
Data 2010 (√s = 7 TeV)
theoretical uncertainties
Data / NLO
Data 2010 / Alpgen
Data 2010 / Sherpa
Data / MC
Data / MC
p_T^jet [GeV]

dσ/dP$_T^2$

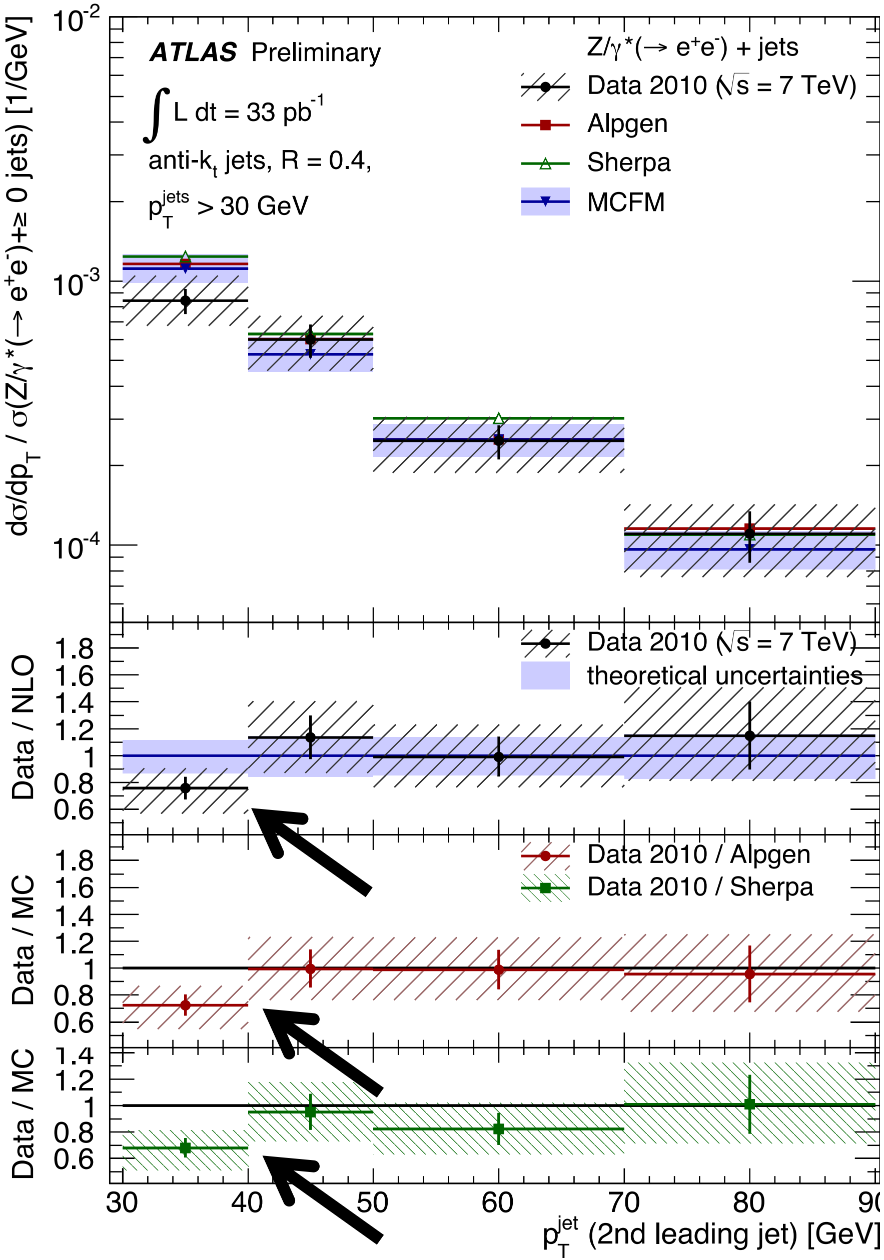


Wev



Wμv

Zee



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Data 2010 (√s = 7 TeV)
Alpgen
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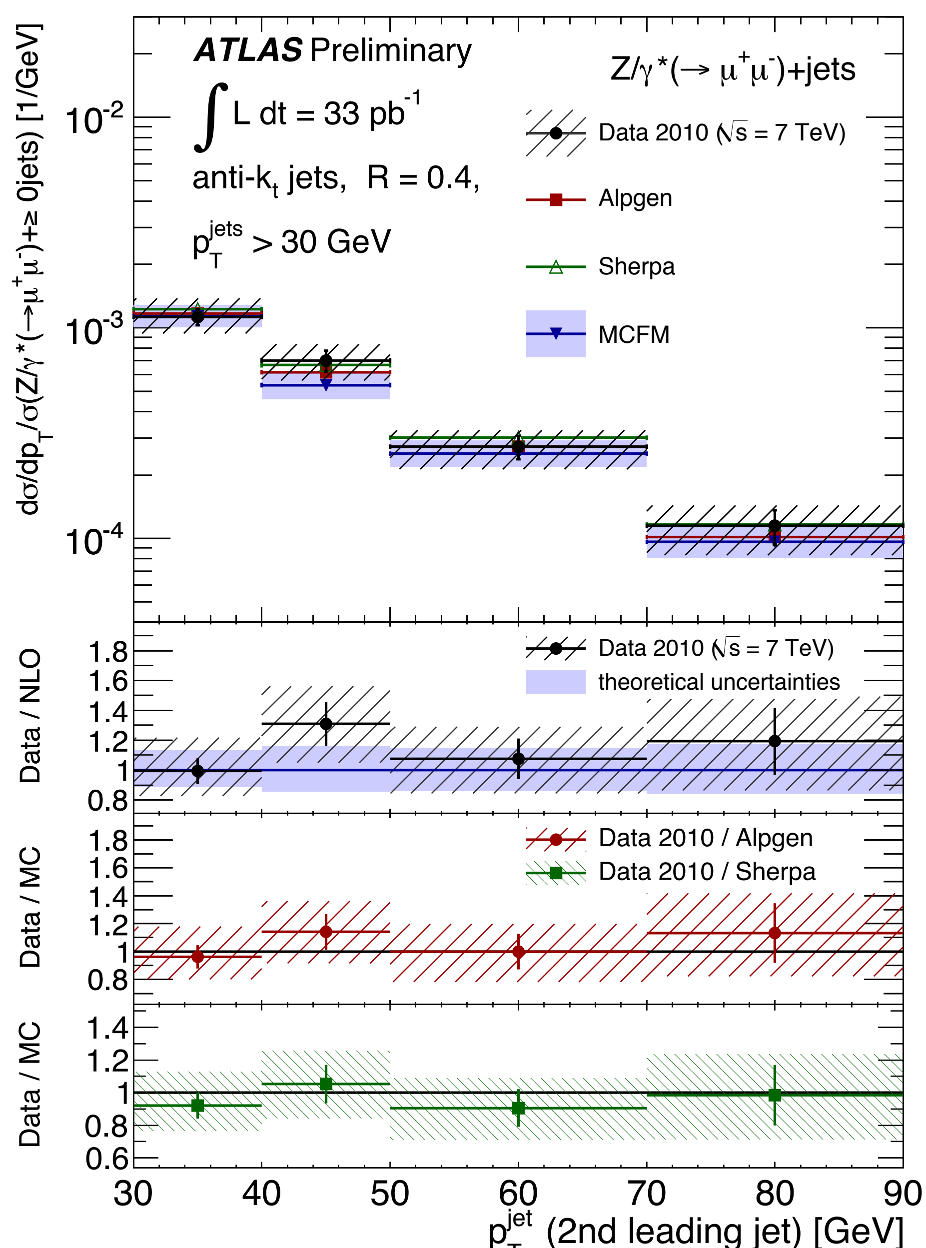
theoretical uncertainties
Data 2010 / Alpgen
Data 2010 / Sherpa
dσ/dp$_T$ / σ(Z/γ*(→ e⁺e⁻)+≥ 0 jets) [1/GeV]
Data / NLO
Data / MC
Data / MC
p_T^{jet} (2nd leading jet) [GeV]

Zμμ



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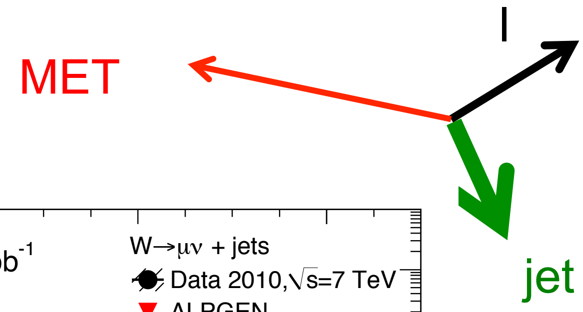
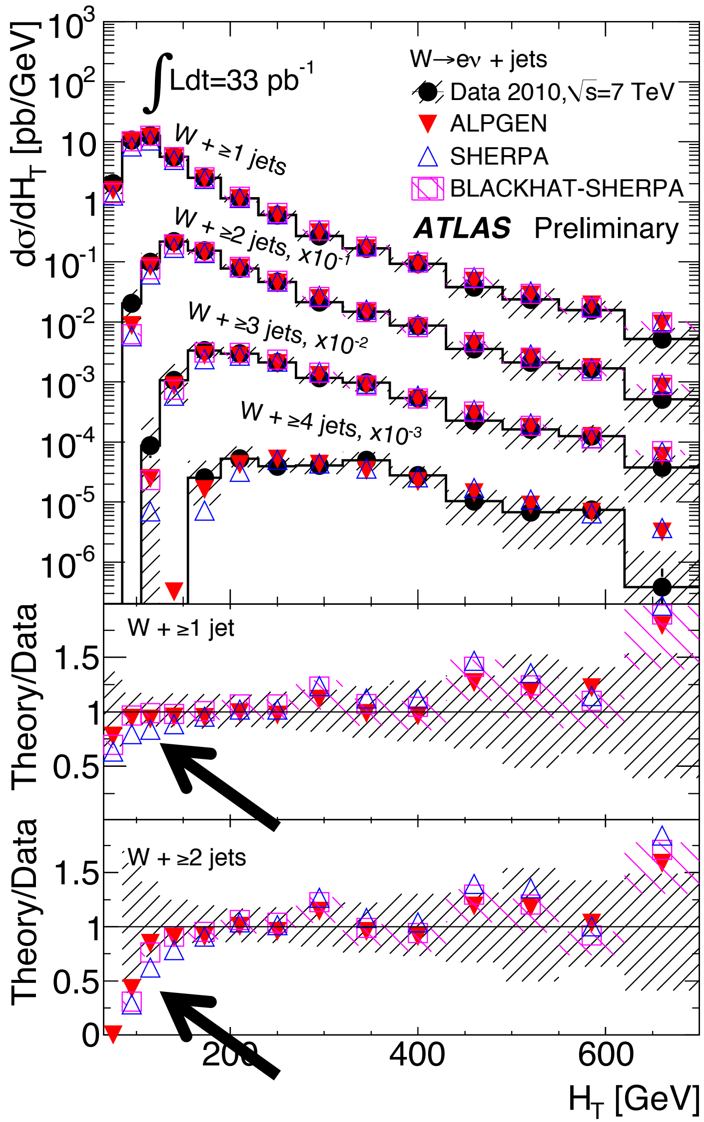
Data 2010 / Alpgen
Data 2010 / Sherpa
dσ/dp$_T$/σ(Z/γ*(→μ⁺μ⁻)+≥ 0jets) [1/GeV]
Data / NLO
Data / MC
Data / MC
p_T^{jet} (2nd leading jet) [GeV]

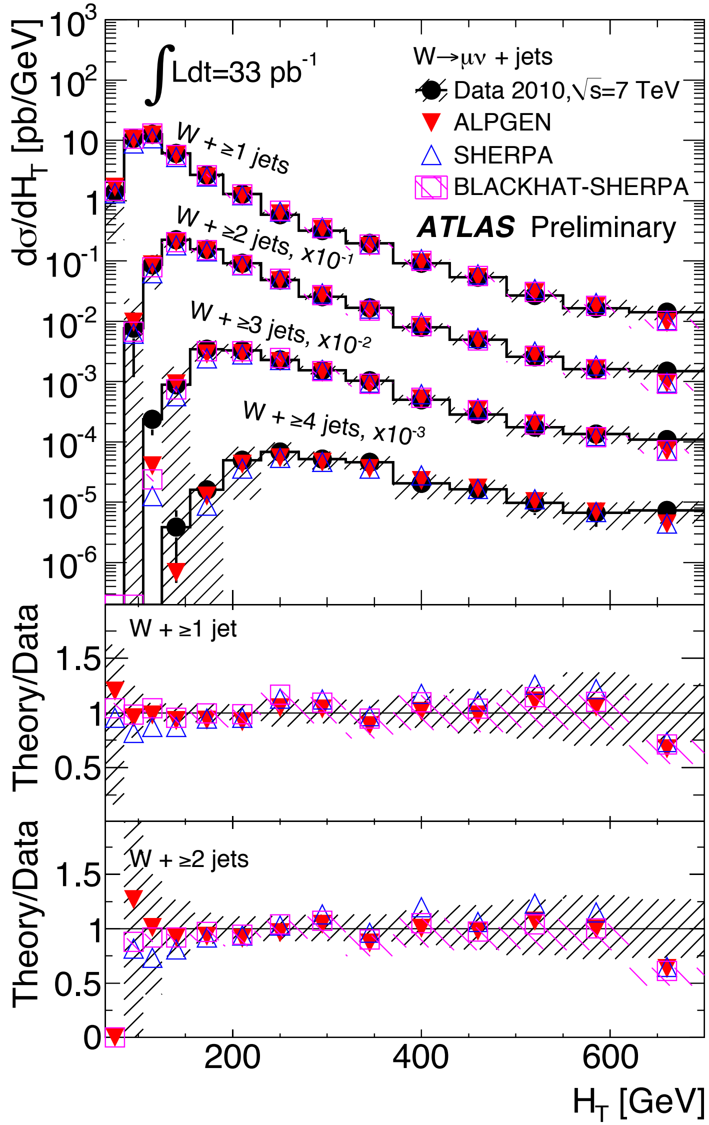
dσ/dHT



MET
l
jet



∫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]

Systematics: how can we do better

- We are already dominated by systematic and not statistical uncertainty….and no longer can hide behind the luminosity systematic (<4%)

- jet energy scale
- pileup
- unfolding
- background estimation
- new NLO predictions

Conclusions

- Detailed study at W+jets and Z+jets associated production
  - Inclusive and differential cross sections
  - Ratios of cross sections
- First comparison with W+3jets at NLO (Blackhat + Sherpa)
- Data unfolded to particle level agrees well with NLO and LO ME+PS predictions from MCFM, Alpgen, and Sherpa
  - Pythia is not expected to be accurate for events with more than one jet by construction
- Accuracy of the measurement is already systematically limited by uncertainties on jet energy scale

Backup

Background samples to W

Physics process	Generator	$\sigma \cdot$ BR (nb)		
$Z \to \ell\ell$ + jets ($m_{\ell\ell} > 40$ GeV, $0 \leq N_{parton} \leq 5$)	ALPGEN 2.13 [22]	1.07	NNLO	[14]
$Z \to \tau\tau$ ($m_{\ell\ell} > 60$ GeV)	PYTHIA 6.4.21 [21]	0.85	NNLO	[14]
$t\bar{t}$	POWHEG-HVQ			
	v1.01 patch 4 [25]	0.16	NLO+NNLL	[26]
Single-top (s-channel)	MC@NLO 3.3.1 [24]	4.3×10^{-4}	NLO	[27]
Single-top (t-channel)	MC@NLO 3.3.1 [24]	6.34×10^{-3}	NLO	[27]
Single-top (Wt)	MC@NLO 3.3.1 [24]	13.1×10^{-3}	NLO	[27]
WW	HERWIG 6.510 [28]	44.9×10^{-3}	NLO	[27]
WZ	HERWIG 6.510 [28]	18.5×10^{-3}	NLO	[27]
ZZ	HERWIG 6.510 [28]	5.7×10^{-3}	NLO	[27]
Dijet (e channel, $\hat{p}_T > 15$ GeV)	PYTHIA 6.4.21 [21]	1.2×10^{6}	LO	[21]
Dijet (μ channel, $\hat{p}_T > 8$ GeV, $p_T^{\mu} > 8$ GeV)	PYTHIA 6.4.21 [21]	10.6×10^{6}	LO	[21]

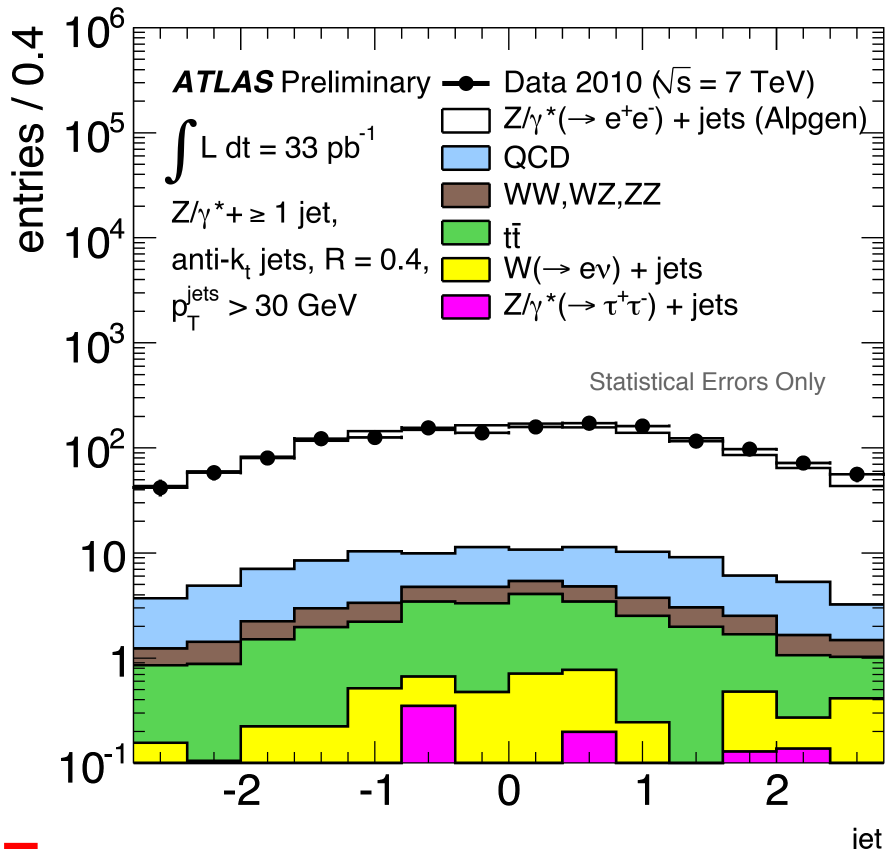
$W(\to l\nu_l)$+jets, $l = e, \mu$	ALPGEN	10.46 (NNLO)
$t\bar{t}$ (lepton + X final state)	MC@NLO	0.16 (NLO+NLL)
$WW + WZ + ZZ$ (2 leptons + X final state, $0 \leq N_{parton} \leq 3$)	ALPGEN	0.007 (NLO)
Dijets ($b\bar{b} + c\bar{c}$, muon filter $p_T > 15$ GeV)	PYTHIA	102.3 (LO)

MC datasets

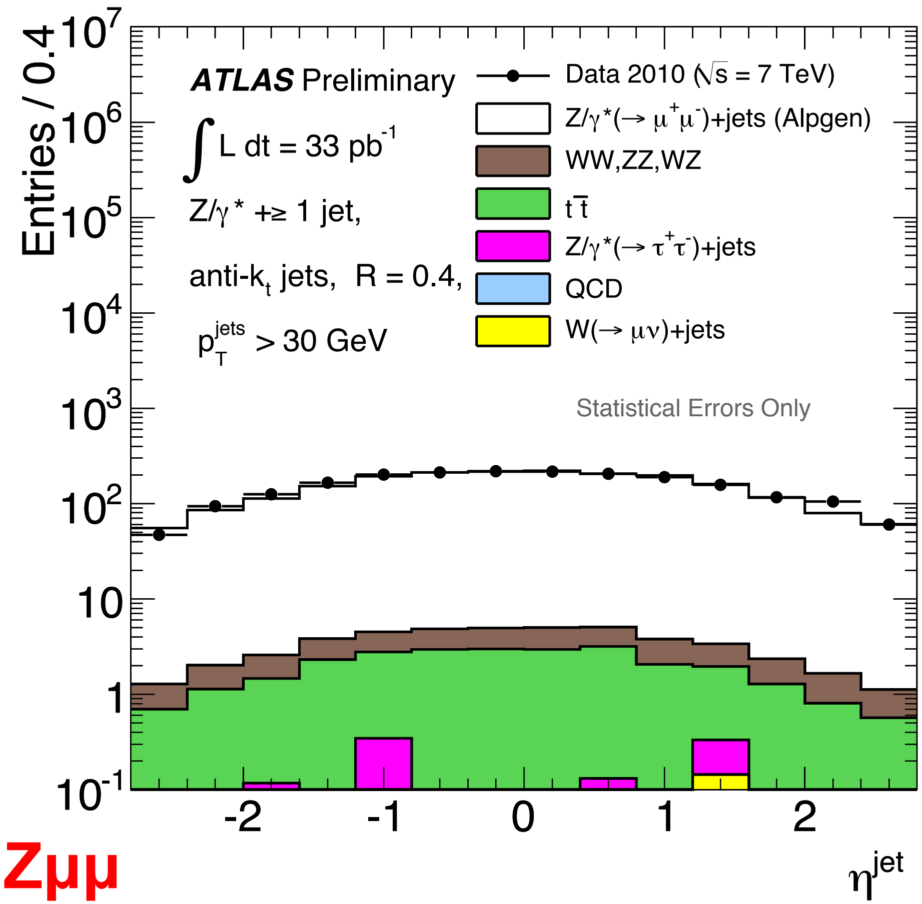
Physics process	Generator	$\sigma \times$ Br (nb)
$Z/\gamma^*(\rightarrow ll)$+jets, $l = e, \mu, \tau$ ($m_{ll} > 40$ GeV, $0 \leq N_{parton} \leq 5$)	ALPGEN	1.07 (NNLO)
$Z/\gamma^*(\rightarrow ll)$+jets, $l = e, \mu$ ($m_{ll} > 60$ GeV, $0 \leq N_{parton} \leq 4$)	SHERPA	0.99 (NNLO)
$Z/\gamma^*(\rightarrow ll)$+jets, $l = e, \mu$ ($m_{ll} > 40$ GeV, $\hat{p}_t > 10$ GeV)	PYTHIA	0.47 (LO)
$Z/\gamma^*(\rightarrow ll)$+jets, $l = e, \mu$ ($m_{ll} > 40$ GeV, $\hat{p}_t > 10$ GeV)	HERWIG+JIMMY	0.37 (LO)
$W \rightarrow \ell\nu$ inclusive ($\ell = e, \mu, \tau$)	PYTHIA 6.4.21 [21]	1.17
$W \rightarrow \ell\nu$ + jets ($\ell = e, \mu$, $0 \leq N_{parton} \leq 5$)	ALPGEN 2.13 [22]	1.21
$W \rightarrow \ell\nu$ + jets ($\ell = e, \mu$, $0 \leq N_{parton} \leq 4$)	SHERPA 1.1.3 [23]	1.19
$W \rightarrow \ell\nu$ + jets ($\ell = e, \mu$)	PYTHIA 6.4.21 [21]	—
$W \rightarrow \ell\nu$ + jets ($\ell = e, \mu$)	MC@NLO 3.3.1 [24]	—

Detector level sanity checks

Jet response: pseudorapidity



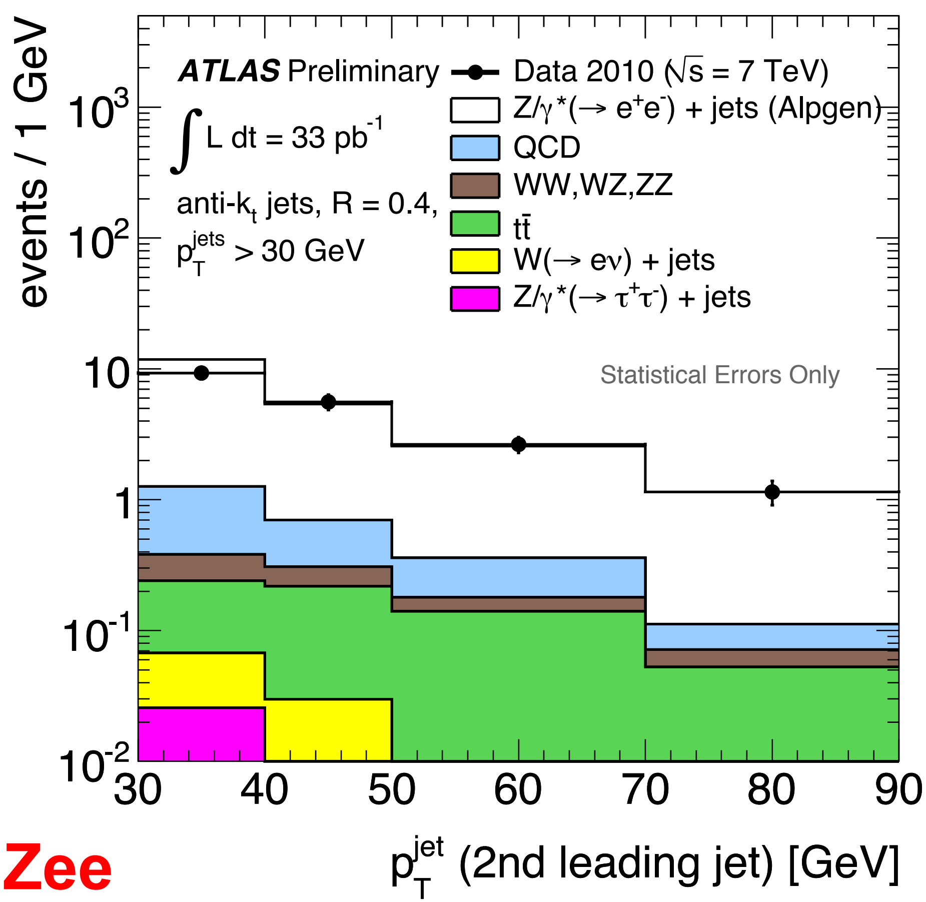
Zee



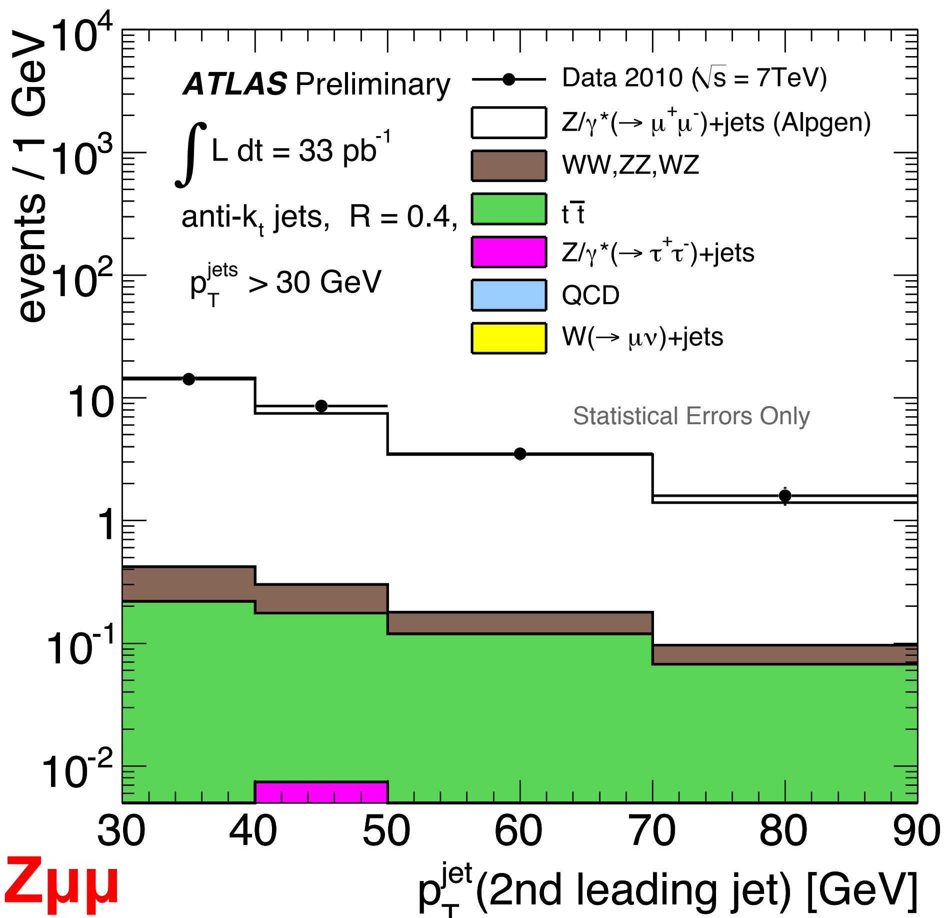
Zμμ

Detector level sanity checks

Secondary jet pt



Zee



Zμμ