GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

V+Jets production at LHC

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PHYSICS AT THE TERA SCALE Helmholtz Alliance

FSP 101 ATLAS

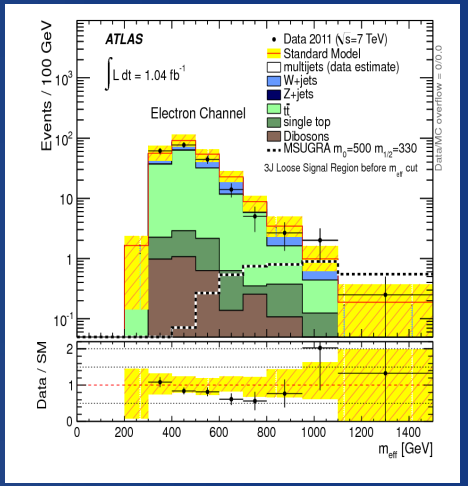
Bundesministerium für Bildung und Forschung

Motivation

- Many signals of new physics at the LHC characterized by leptons + 2,3 or more jets
- Similar: Top quark physics (2-4 jets)
  Higgs search: jet-binned results, jet vetos

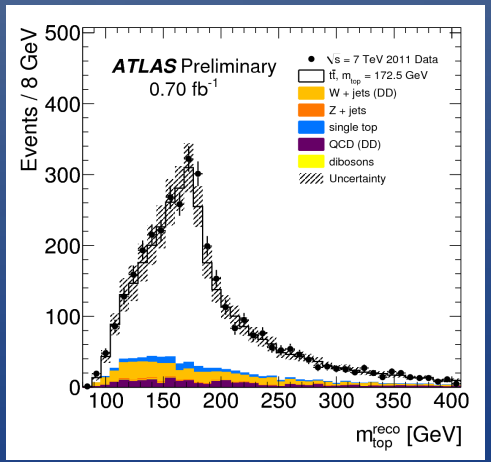
-> V+Jets important background

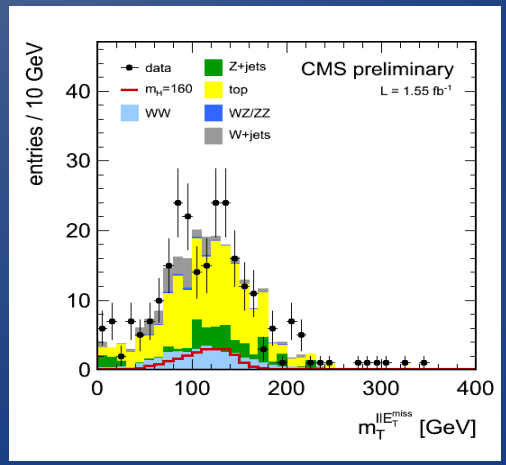
- LO ME+PS generators with large scale uncertainties
  -> to be tuend with data
- More precise descriptions at NLO (+NLL, nNLO)
  -> to be tested
- Heavy-flavour PDF not trivial: dependence on m_c, ,m_b
  → to be tuned with data



SUSY signal region: l+3jets (arXiv:1109.6606)

Top mass: l+4jets (1btag) (ATLAS-CONF-2011-120)



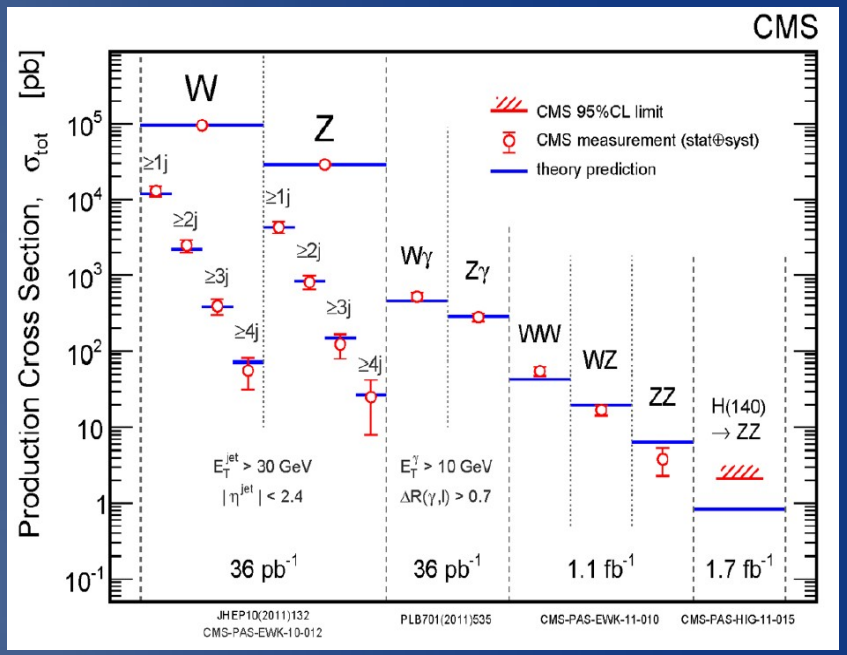


Search for VBF H-> WW: Higgs MT (CMS PAS HIG-11-01)

+V+jets at Tevatron and LHC

- LHC <-> Tevatron:
  - W,Z cross section 4x larger
  - Larger jet production (x2 per jet at medium pT(jet))
  - Background: top cross section: 100x larger

-> already in 2010 data comparable V+3/4jets rate !



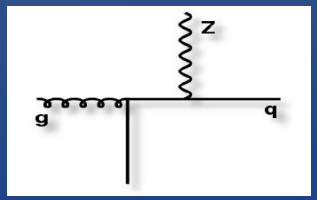
Tevatron: V +1,2 jets
medium energy ranges

LHC:
- high multiplicities
- large energies
- large scale differences

larger top background!

- Events per fb-1 at LHC:
  - W(->lν)+jets: 10e6, W+4jets: 10e4
  - Z(->ll)+jets: 10e5, Z+4jets: 10e3
  - W+HF: 10e3

- Jet composition:
  - Tevatron: Quark annihilation → gluon jets
  - LHC: Compton process → leading quark jet



LHC publications
2010 data set: 35-36 pb^{-1}

- WZ+Light jets
  - Atlas W+Jets: 1.3pb^{-1}: Phys.Lett.B 698(2011) 325-345 (1.3pb-1)
  - Atlas W+Jets: 33 pb^{-1}: ATLAS-CONF-2011-060, paper in preparation
  - Atlas Z+Jets: 35pb^{-1}: submitted to Phys.Rev.D, arXiv:1111.2690
  - CMS V+Jets: 36pb^{-1}: submitted to J. High Energy Phys. ArXiv:1110.3226
  - Atlas W+jets/Z+Jets: 35pb^{-1}: submitted to Phys.Lett.B, arXiv:1108.4908

- WZ+HF jets
  - Atlas W+b: 35 pb^{-1}, arXiv:1109.1470, submitted to Phys.Lett.B
  - Atlas Z+b: 35 pb^{-1}, arXiv:1109.1403, submitted to Phys.Lett.B
  - CMS W+c: 35pb^{-1}, CMS-PAS-EWK 11-013
  - CMS Z+b: 35pb^{-1}, CMS-PAS-EWK 10-015

Data-theory comparison

Measurement

Experiment

ATLAS & CMS

- Reco/ID Efficiencies
- resolution, calibration

Alpgen

Sherpa

Pythia

Particle Level

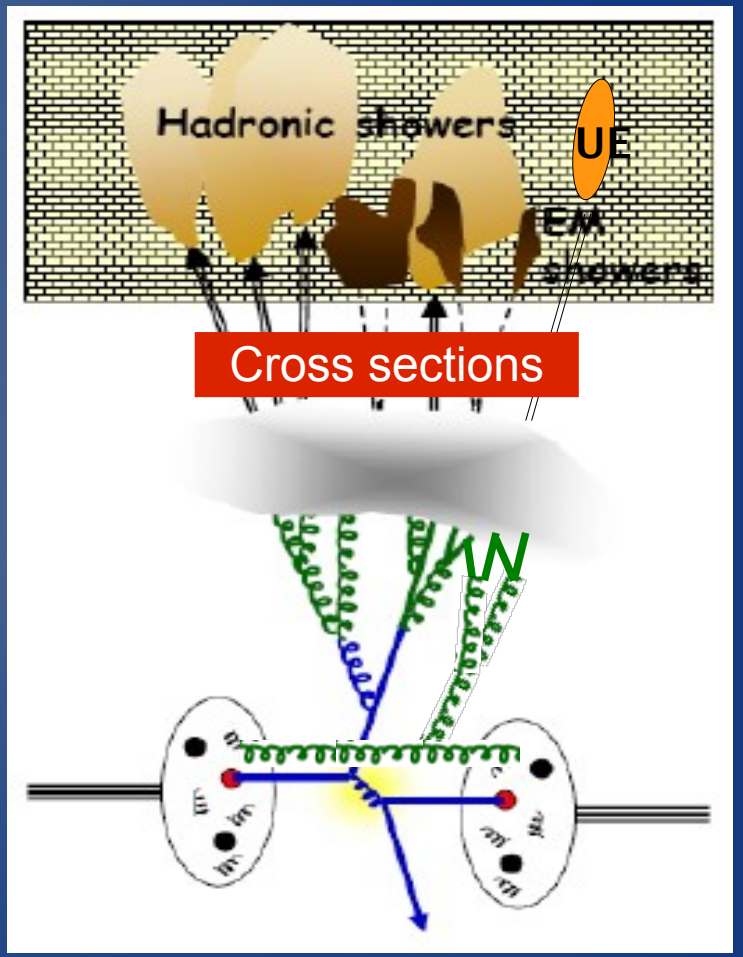
ATLAS

- Underlying Event
- Fragmentation
- QED FSR

MCFM

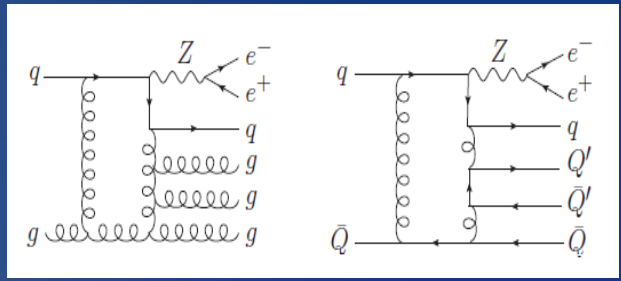
Blackhat +Sherpa

NLO theory



Theory predictions

NLO calculations: Blackhat+Sherpa

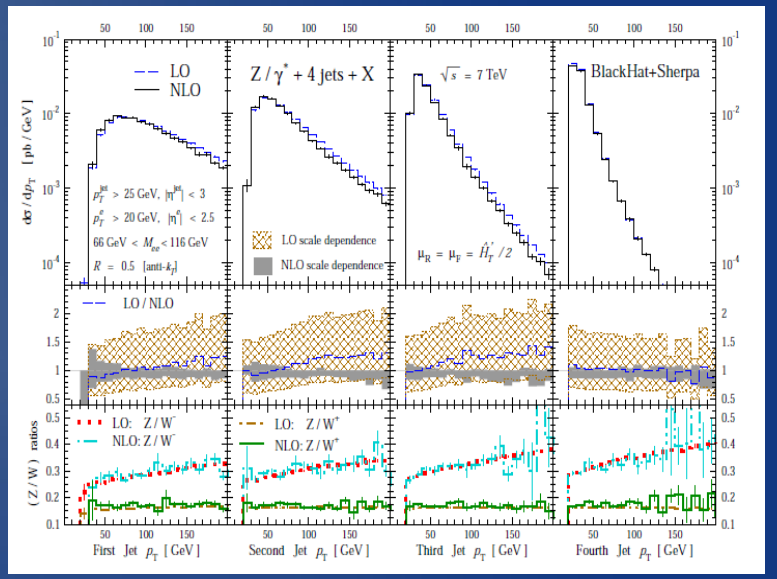


- W,Z/γ +3jets NLO:
  - W+3jets: C.F.Berger et al., Phys.Rev.D80:074036,2009
  - Z/γ+3jets: C.F.Berger et al., arXiv:1004.1659

- W,Z/γ +4jets NLO: **New!**
  - W+4jets: C.F. Berger et al. , Phys. Rev. Lett. 106,0 92001(2011)
  - Z/γ+4jets: H.Ita et.al., arXiv:1108.2229, 2011

Scale HT/2, PDF Cteq66,
Systematics (Z+1-4 Jets): Scale: 4-14%, PDF: 3-8%

- W +1bjet NLO:
  - J. M. Campbell, et al., Phys. Rev. D 79 (2009) 034023.



Blackhat+Sherpa Z+4jets
H.Ita et.al., arXiv:1108.2229, Sept '11

ME Generators:

- ATLAS: ALPGEN + HERWIG,Cteq6L1, 0p-5p
- ATLAS: SHERPA , MTscale, Cteq66 , 0p-5p
- CMS: MADGRAPH +Pythia, Cteq6L1 , 0p-4p

Parton to hadron correction

Account for UE and Fragmentation

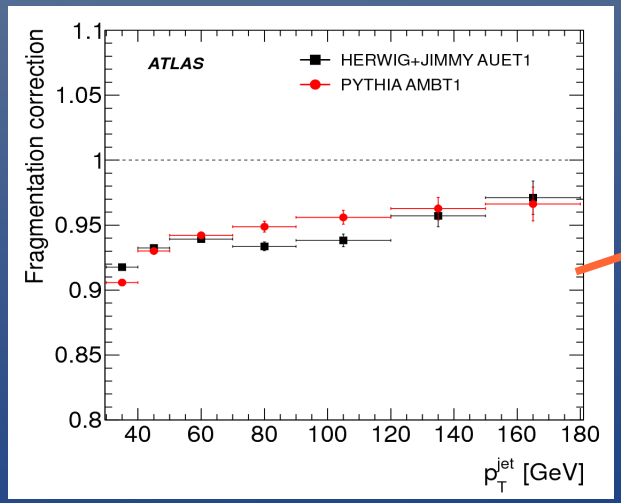
- Bin-by-Bin correction for each observable
- Modelled with MonteCarlo
- UE measurement in Z+Jets data soon

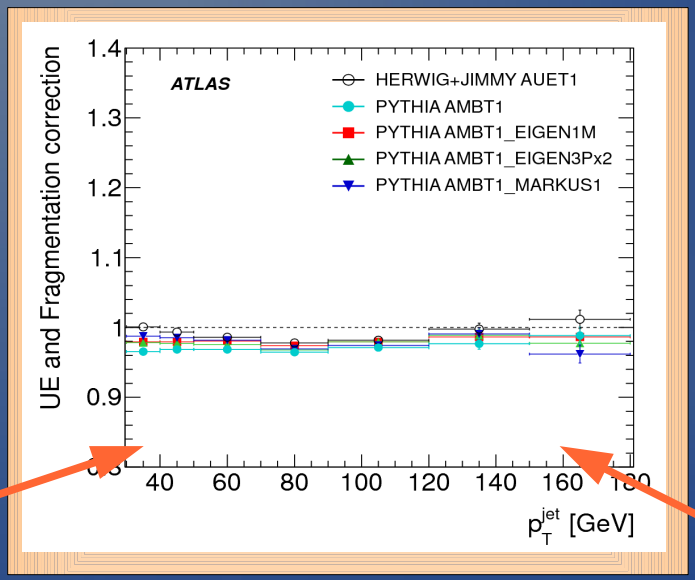
-> Fragmentation and UE effects cancel up to ~1-2%

Systematics: 2-5%
- fragmentation models
- different UE tunes
- iterative Bin-by-Bin

Fragmentation:

- Migration to lower jet-PT
- Lower multiplicity

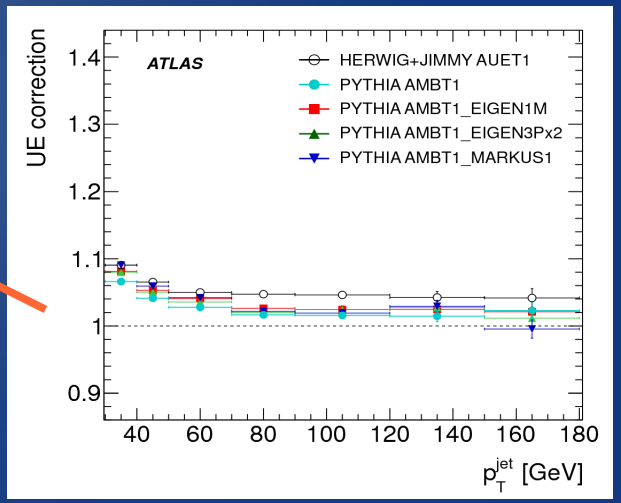




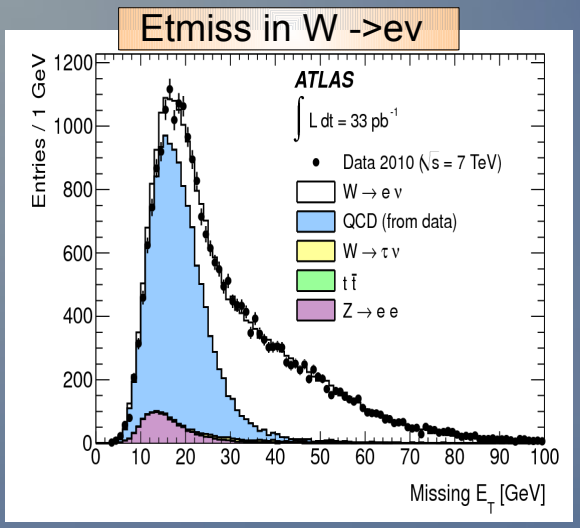
Jet PT=30GeV:
balancing corrections of +-10%

Underlying event:

- Migration to higher jet-PT
- Higher multiplicity



Signal selection W/Z+jets



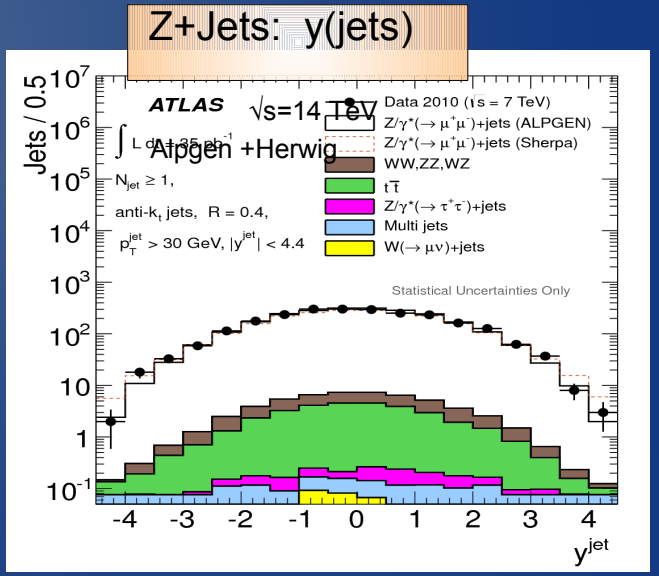
Z/γ+Jets: 2OS leptons, pT>20GeV, $|\eta| < \approx 2.5$
m(ll) = 91 ±25GeV, [91 ± 20GeV in Ratio W/Z]

W+Jets: 1 lepton, pT>20GeV, $|\eta| < \approx 2.5$
ETmiss>25GeV, mT>40GeV, veto 2nd lept.

-> Acceptance: ≈ 45% <-

Jet selection:

- AntiKt algorithm , R=0.4
- Calibration to hadronic scale based on MonteCarlo, offset corection for Pile-up
- PT>30 GeV: avoid UE and Pile-up dependence
- y<4.4 : probe large eta range and larger DY (jj) (y<2.8 for ratio Wjets/Zjets)
- Pile-up removal for W+jets, W/Z ratio

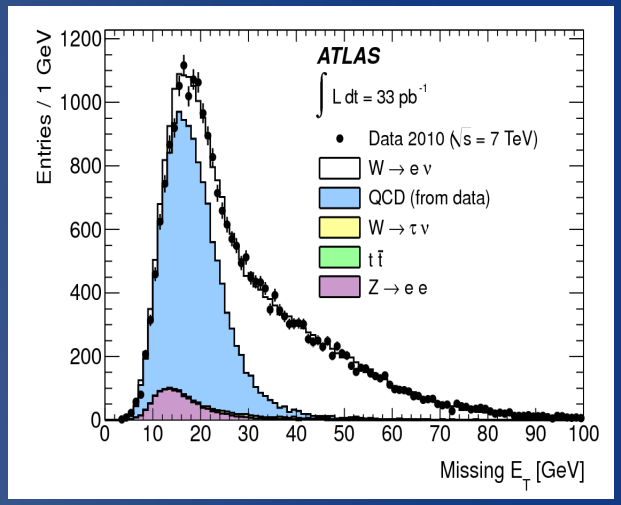


Challenge: backgrounds

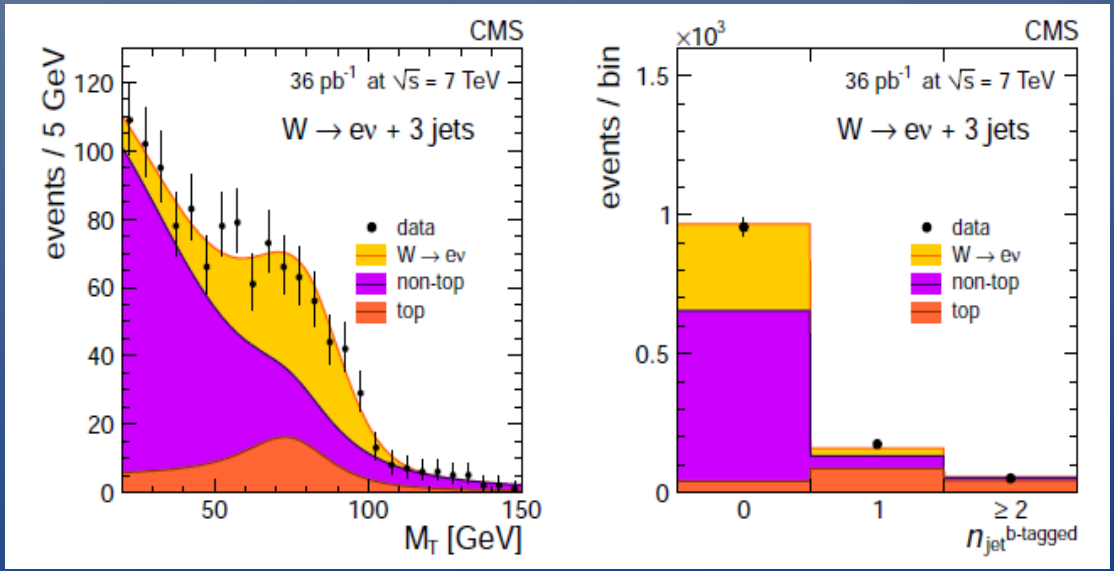
Z/γ+1-4Jets: QCD: <1%-5%, Top: 1-10%
W+1-4 Jets: QCD: 4-5%, Top: 4-60%

W+ 3/4 jets: dominated by top (30-60%)
Z+ 3/4jets: moderate 5-10% Top fraction

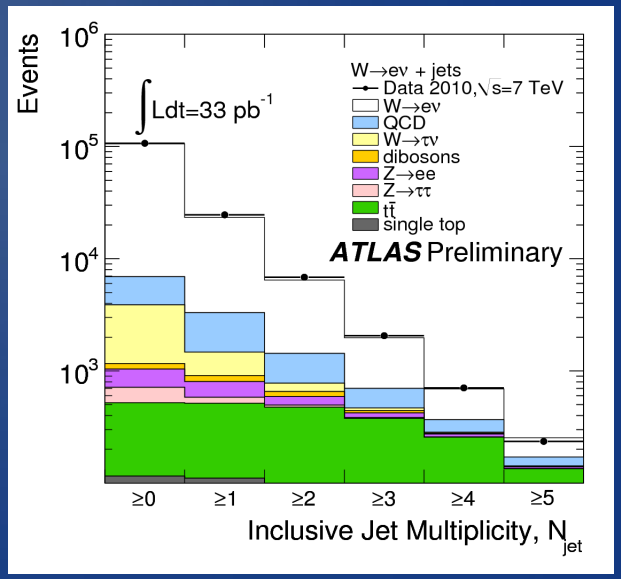
Top bkg fraction will further increase at √s=14TeV !



CMS: 2-dim template fit: - MT -> QCD
- number of b-jets -> top

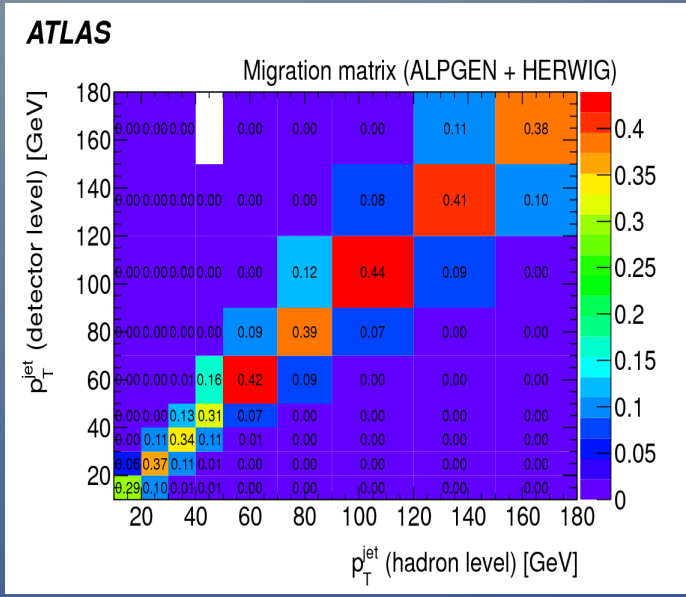


Atlas: QCD: template fit
top: in-situ validation



Challenge: Detector unfolding

ATLAS Zjets Migration matrix, pT(jets):



Rapidly falling jet pt spectrum
leads to sizable migration effects

Bin-by-Bin correction:

- Z+Jets: nominal
- Atlas W+Jets paper: systematics
- Atlas W+Jets/Z+Jets: nominal

Iterative unfolding:

- Atlas Z+Jets 2010: systematics, 2012: nominal
- Atlas W+Jets paper in preparation: nomina
- CMS: systematics

Singular Value Decomposition:

- CMS V+Jets: nominal,

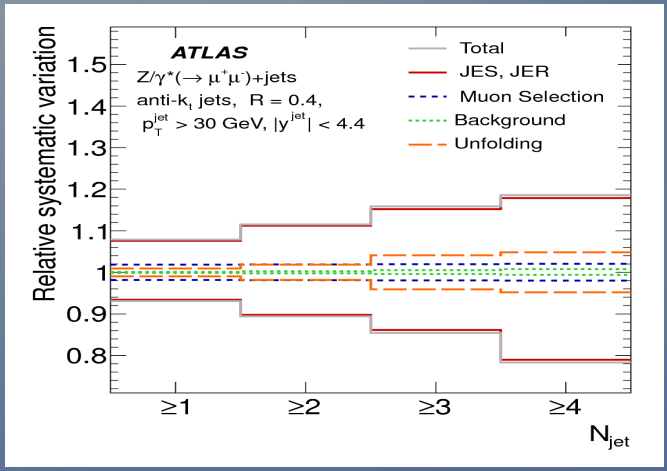
Choice of unfolding procedure

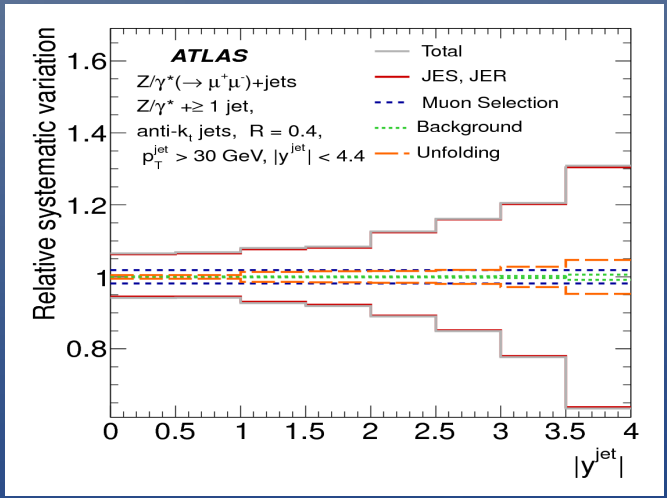
Minimize syst. and stat. uncertainty

- Performance of generator
- Bin size -> purity
- Background fraction
- Statistics in data and MC

Challenge: JES uncertainty

ATLAS: Zjets: systematic uncertainties vs N(jets), Y(jets)

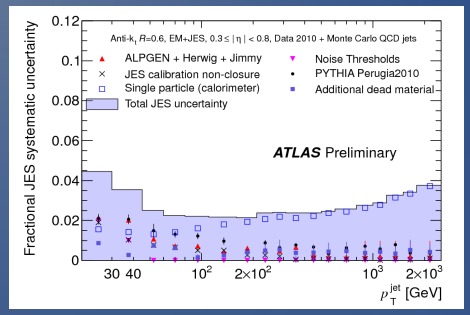


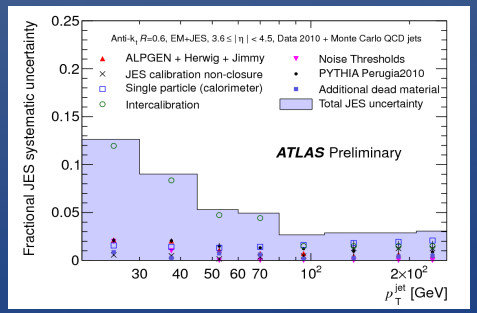


JES systematics:

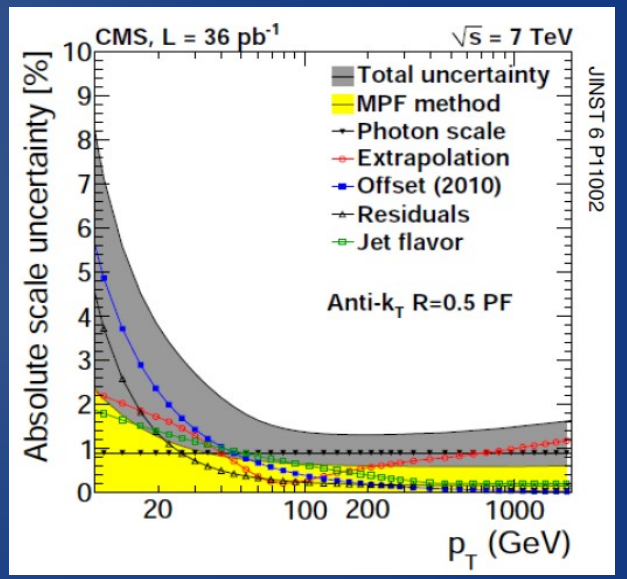
- ATLAS JES uncertainty 8-20% (Z+Jets)
- CMS JES uncertainty: 8-16%

  To be reduced for publication on 2011 data



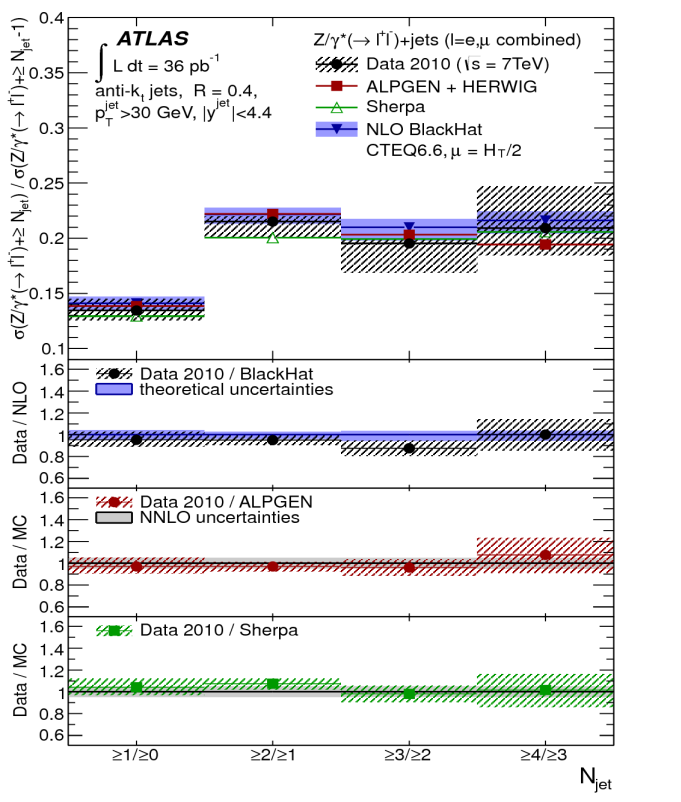


ATLAS, CMD JES uncertainty

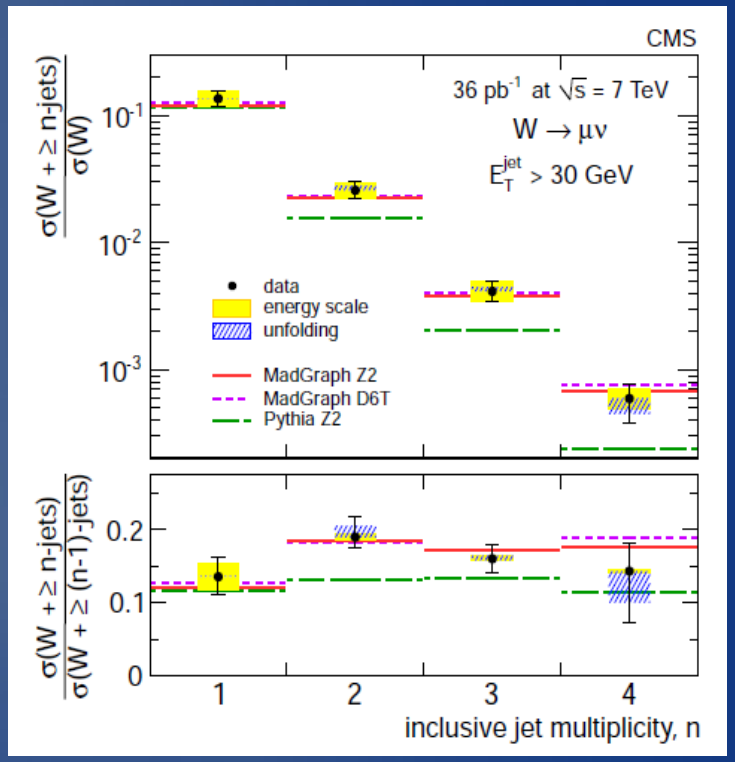


Cancellation of systematics: Multiplicity ratio

ATLAS: Z+Jets: multiplicity ratio



CMS: W+Jets: normalised multiplicity multiplicity ratio



Systematics cancellation

→ lumi
→ lepton ID
→ Z/W acceptance

Part of

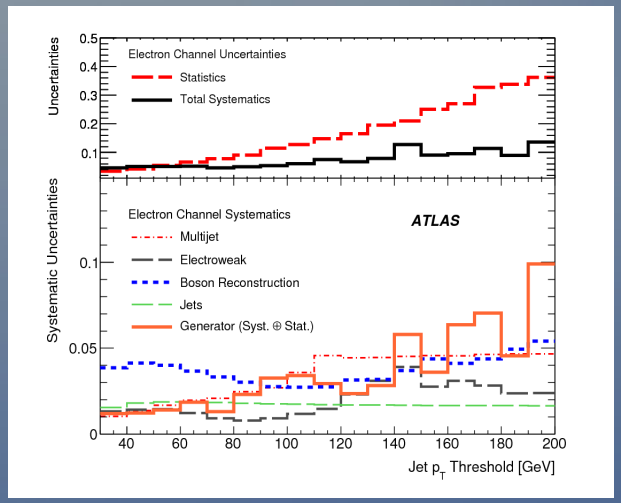
→ JES/JER
→ detector unfolding
→ correction parton-hadron

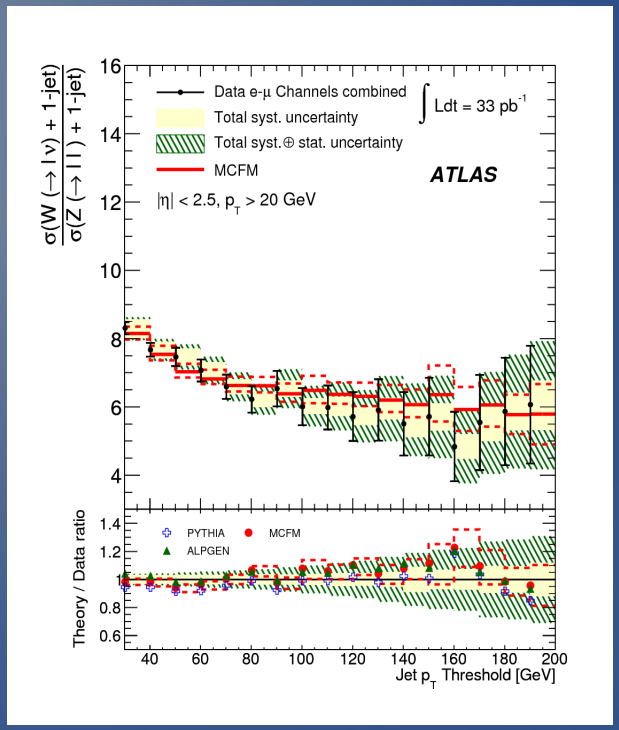
- Data consistent with N pQCD and ME generators
- Consistent with Behrends-Giehle scaling

$$\sigma(N)/\sigma(N+1) \sim 4.5 \pm 0.7$$

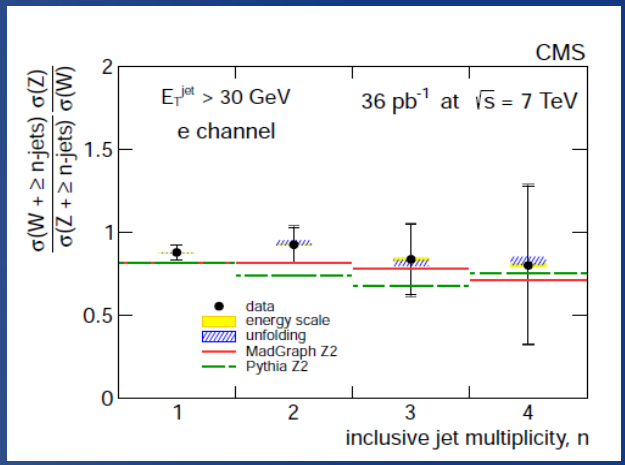
Cancellation of systematics: W+jets/Z+jets

ATLAS: Wjets/Zjets: jet pt ratio





CMS: Wjets/Zjets multiplicity ratio



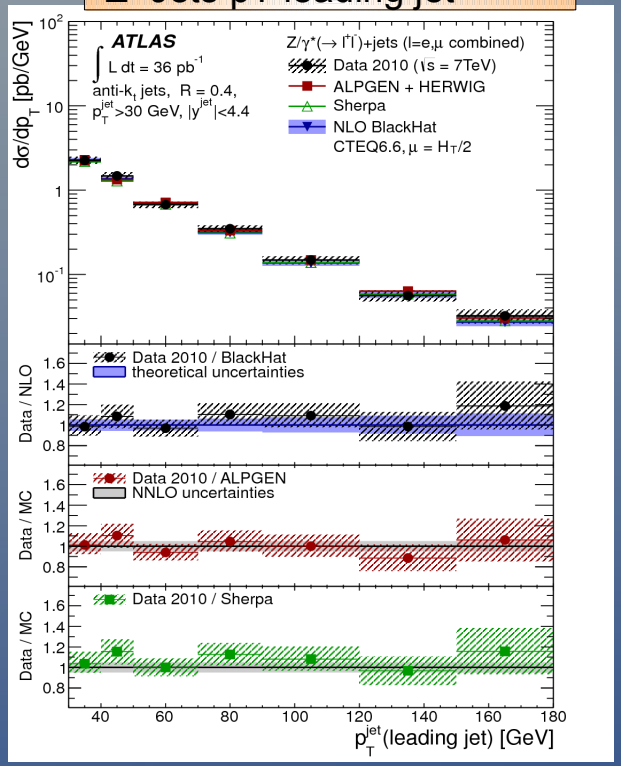
- Data consistent with NLO pQCD and ME generators

Cancellation of systematics
- -> lumi
- -> part of lepton ID
- -> large part of
  - JES/JER
  - detector unfolding
  - correction parton-hadron

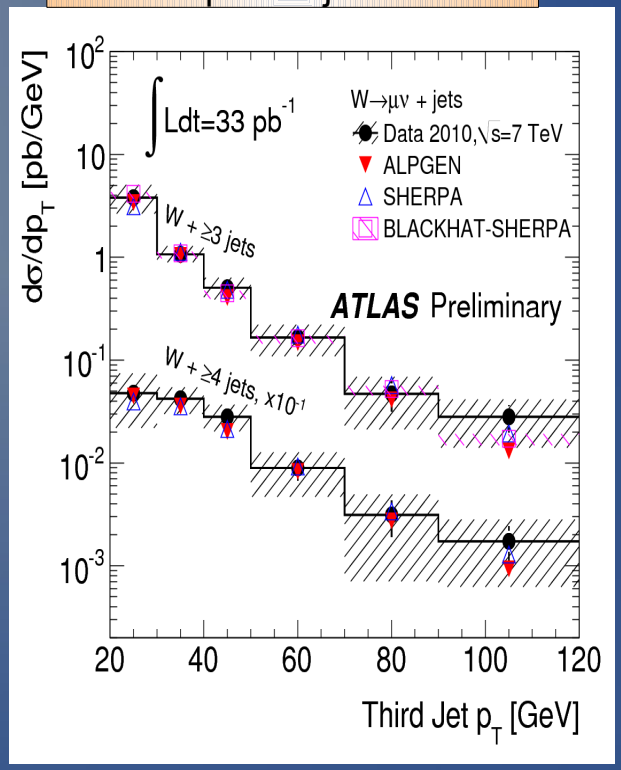
- Ratio decreases with increasing pT(jet): Effective scale of interaction becomes large compared to differences in Boson masses

Differential cross sections: pT(jet)/HT

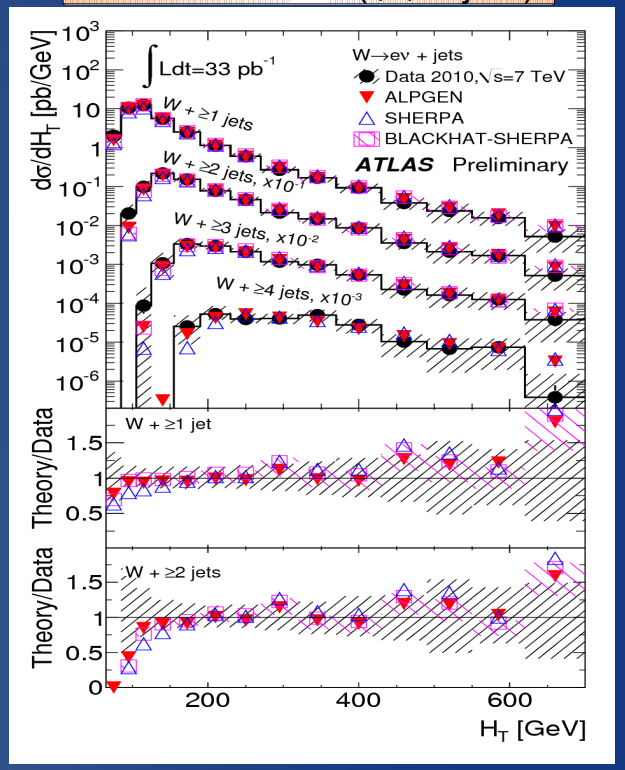
Z+Jets pT leading jet



W+Jets pT 3rd jet



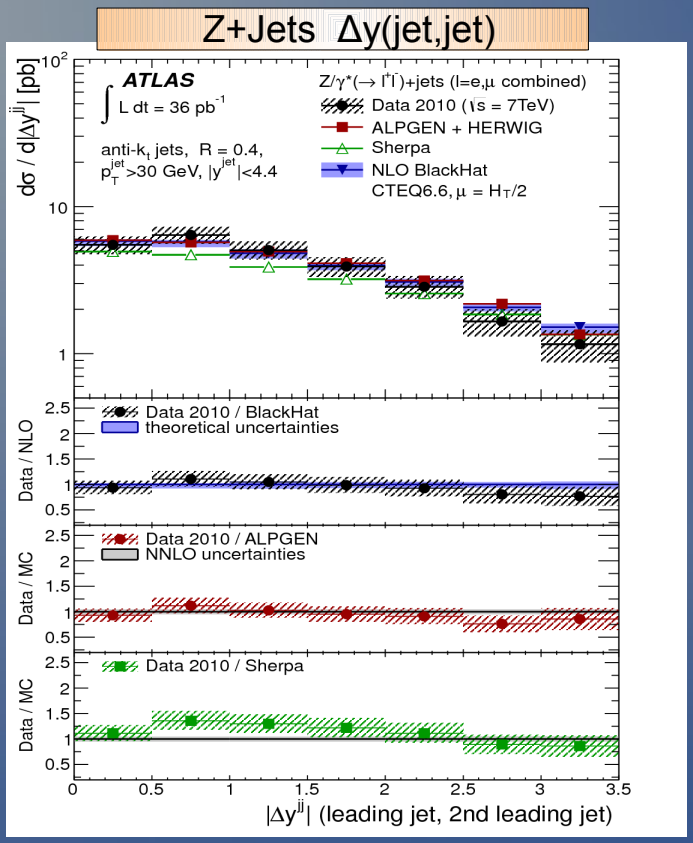
W+Jets HT(l,v,all jets)

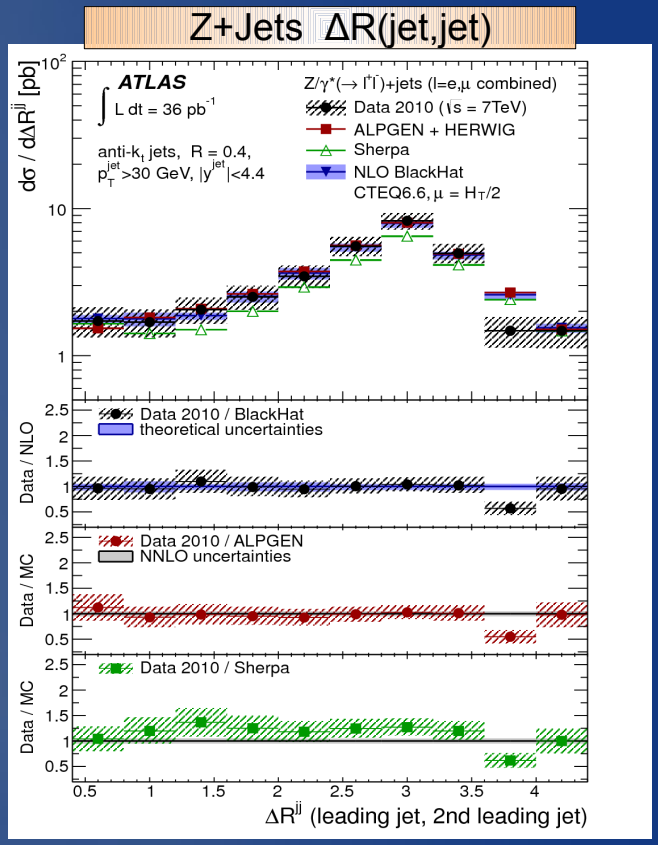


- Testing pQCD at various energy scales

- Data consistent with NLO pQCD prediction and with ME generators Sherpa and Alpgen.
- Not consistent with Pythia parton shower.
- Probe PT of 3rd jet (and 4th jet) in W+jets already in 2010 data

Angular distributions





- Hard parton emision at large angles, ME-PS matching
- Of interest for Higgs searches

- Data consistent with NLO pQCD prediction and with ME generators Sherpa and Alpgen.
- Some tension at rapidity, low ΔR → 2011 data

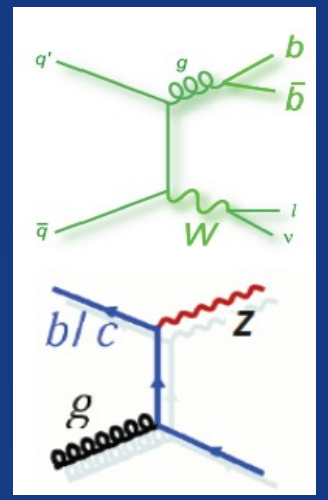
W+b jets

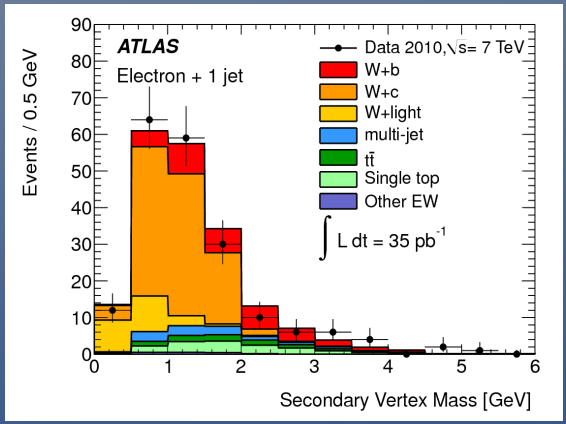
Require one b tag, 1or 2 jets
→ Top becomes the largest background
Estimated from W+4-jets bin

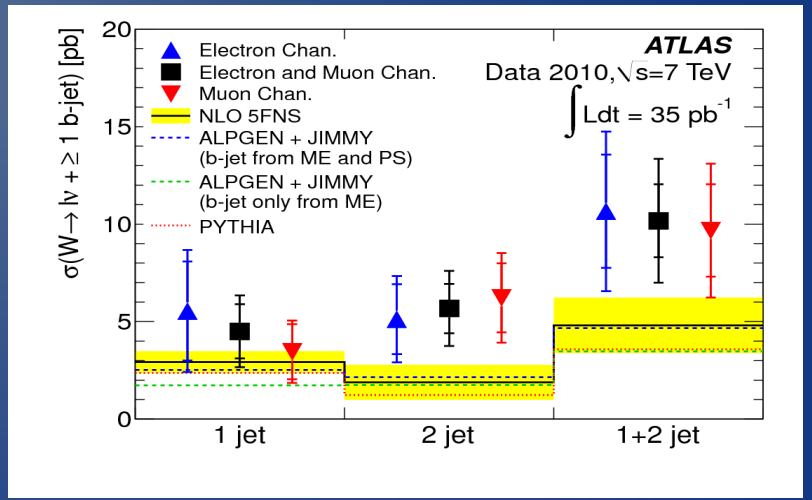
Signal extraction:
- Maximum likelihood fit to the SV0 mass distribution is used to
→ separate b-jets from c- and light-jets
• SV0 mass templates are modeled with MC
Systematics: vary HF and light jet fractions

phase space definition

- dressed lepton: combine QED rad. in a cone R<0.1
- p_T^l>20 GeV, $|\eta|$<2.5
- missing momentum: p_T^{nu}>25 GeV
- m^W_T >40 GeV
- jets anti-k_T R=0.4; p_T>25GeV $|y|$<2.1
- remove jets if ΔR(jet-lept.)<0.5
- b-jets: jet-B-hadron matching ΔR<0.3; pT(B)>5 GeV







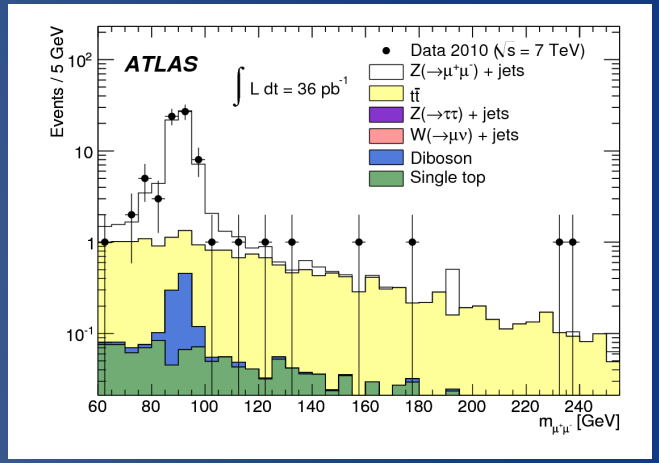
- dominant systematics:
  - b-tagging & SV mass template ≈16%
  - top background ≈12%
  - QCD background ≈7%
  - W+b-jet modeling ≈10%
  - Jet+b-jet energy scale ≈7%
- non perturbarive correction 0.93+-0.07

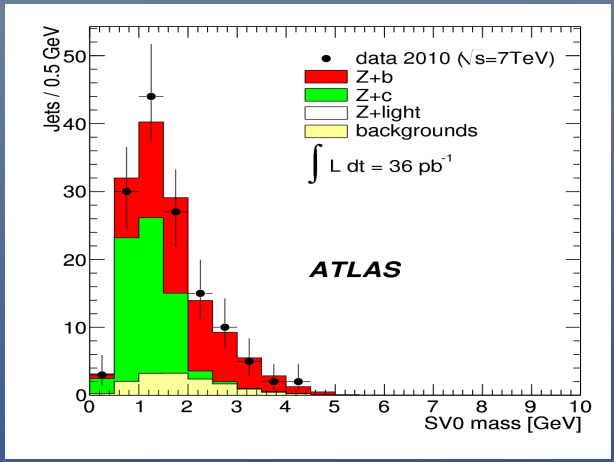
- Cross section measured in data is 1.5 σ above theory prediction

Z+b jets

- Require one b tag, 1or 2 jets
- Top becomes largest background

Signal extraction:
- Maximum likelihood fit to the SV0 mass distribution is used to
  → separate b-jets from c- and light-jets
• SV0 mass template are modeled with MC



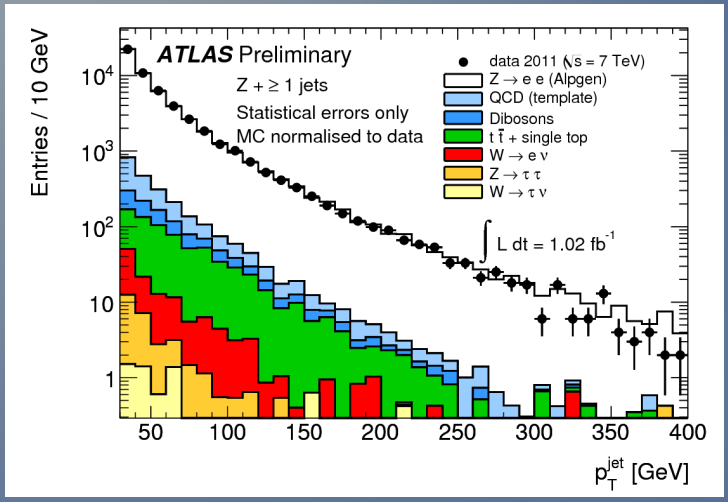


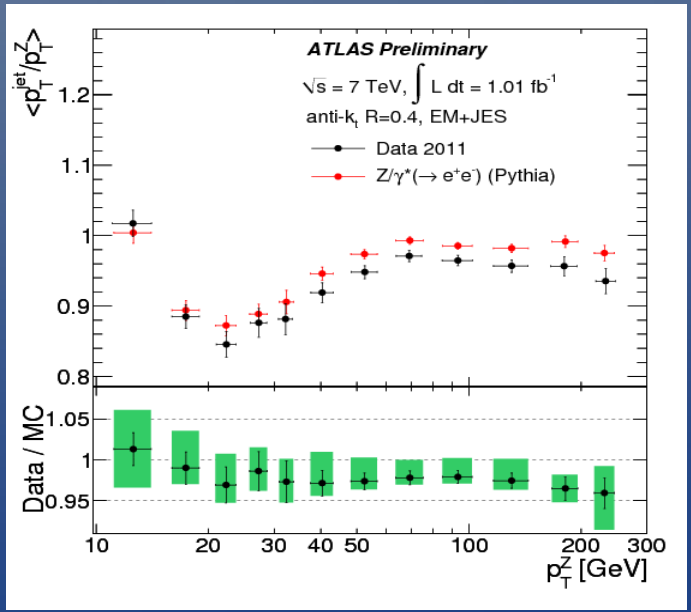
Experiment	$3.55^{+0.82}_{-0.74}(\text{stat})^{+0.73}_{-0.55}(\text{syst}) \pm 0.12(\text{lumi})$ pb
MCFM	3.88 ± 0.58 pb
ALPGEN	2.23 ± 0.01 (stat only) pb
SHERPA	3.29 ± 0.04 (stat only) pb

- uncertainty: ≈ 20% stat. and ≈23% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈10%
  - Z+b-jet modeling ≈10%
  - Jet + b-jet energy scale ≈4%

- Cross section measured in data is in agreement with theory prediction

Outlook 2011/12





Experimental progress:

- Collected >100 time the 2010 statistics
  -> PT(jets) up to TeV regime
  -> Jet multiplicities: up to 7/8 jets (@30GeV)

- JES: new in-situ measurements
  -> recalibrate jets -> lower JES uncertainty
- JER: lower systematics
- Pile-up -> beyond MC- based subtraction

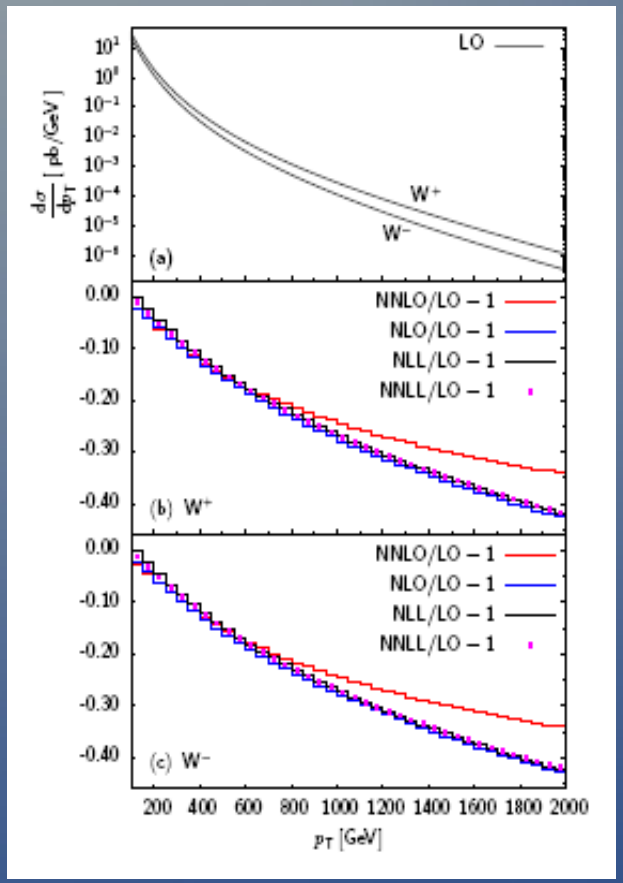
- Lower lepton lepton systematics ->1%
- Lower systematics on unfolding

- B-tagging: better performance
  - more advanced taggers
  - better control of performance (pT, eta)
  - improve MC gerenerationi

With 2011 data mainly systematically limited,
Particular challenge: JES/JER uncertainties

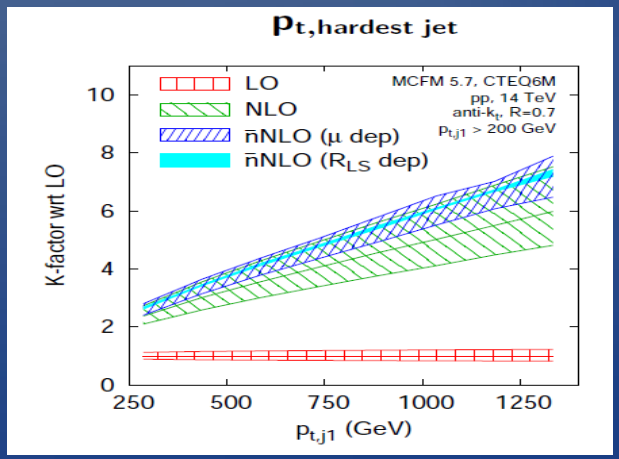
Outlook 2011/12

Plans with 2011 data:

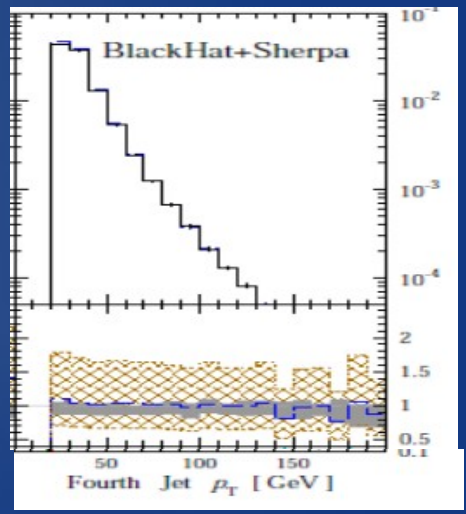


Kühn et al., arXiv:0708.0476

- WZ+light jets: Exploit kinematic coverage far beyond Tevatron reach: Large multiplicities, large PT, 3rd/4th jet
- Some examples :
  - Large scale differences: Large pT, large HT
  - Jet veto efficiencies, Large rapidity gaps
  - EW corrections at large PT(jet)
  - Charge asymmetry in W+jets
  - Cross section ratios in various kinematic regimes
- WZ+HV
  - W(Z)+b: confirm/exclude tension with theory
  - W+c: strange quark PDF
  - General: differential cross sections



Rubin et al.,arXiv:0708.0476



H.Ita et.al., arXiv:1108.2229