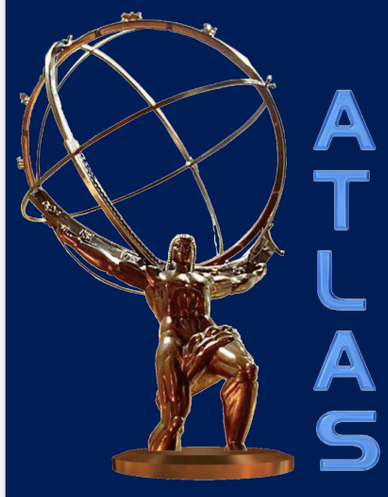

W and Z + jets physics in pp collisions at 7 TeV with the ATLAS detector

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CERN, Roma 1

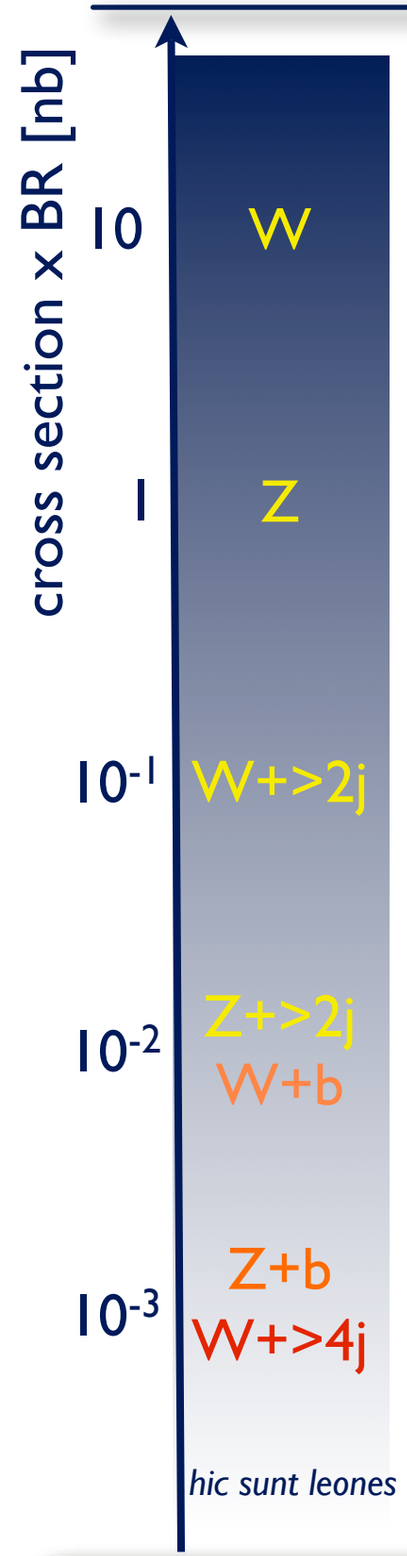
on behalf of the ATLAS collaboration

EPS HEP - Grenoble France - 20, 27 July 2011

Outline

- W/Z+jets production in pp collisions
  - ✓ the physics motivations
- The ATLAS experiment
- W/Z+jets including heavy flavour jets, a selection of latest results:
  - ✓ W/Z+jets differential cross sections (ATLAS-CONF-2011-042/060)
  - ✓ (Z+1 jet) / (W+1 jet) cross section ratio **new measurement** (paper in preparation)
  - ✓ W/Z+b-jets cross section **new measurement** (papers in preparation)
- conclusions

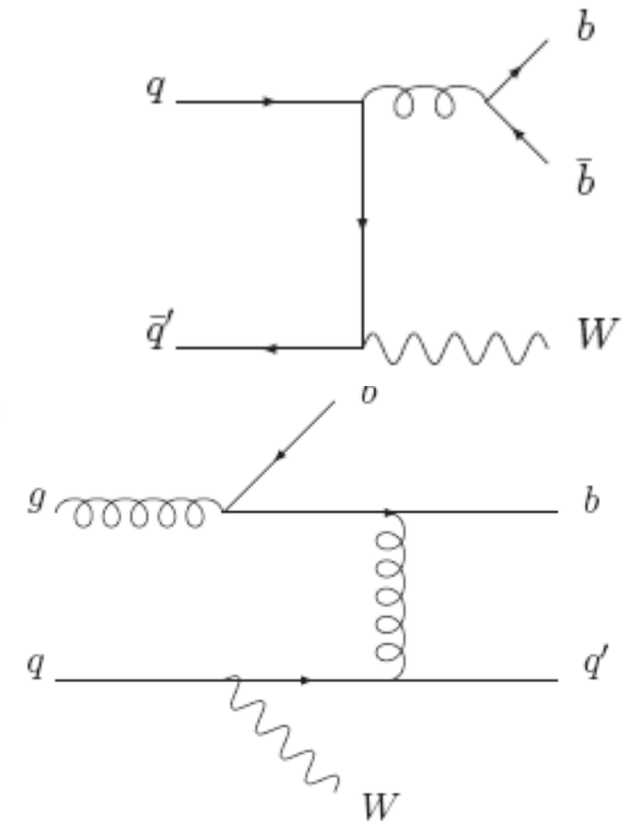
Motivations (I)

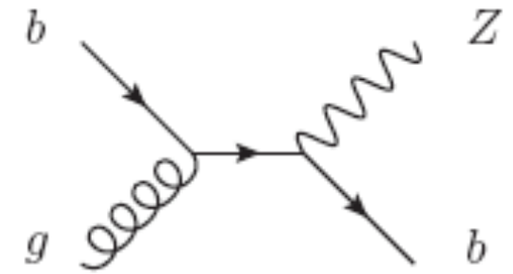


- W/Z+jets physics is a fundamental ingredient for reestablishing the Standard Model (SM) in pp collisions at 7 TeV

✓ larger available energy than at Tevatron:
=> more jets; larger kinematic reach
=> cross sections spanning several orders of magnitude

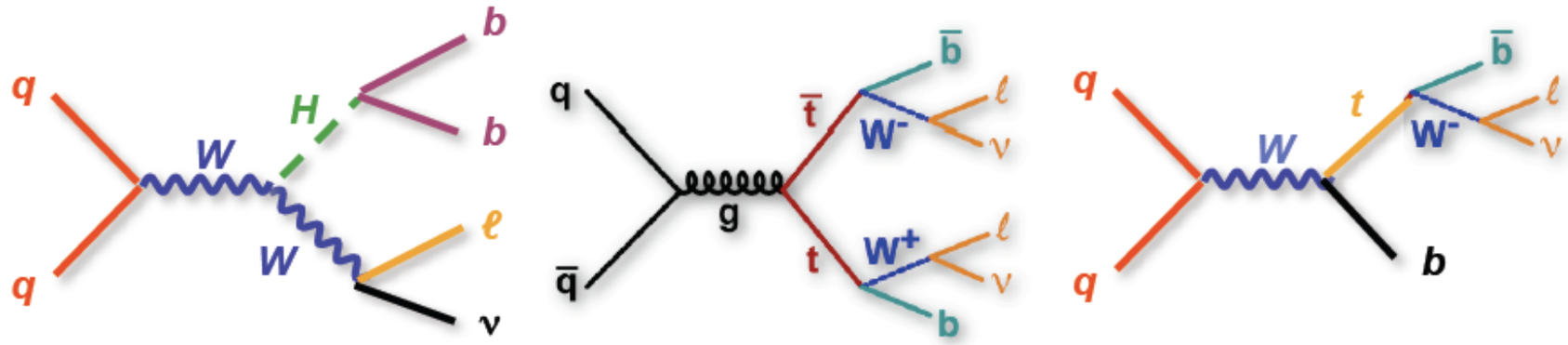
✓ higher relevance of processes initiated by qg and gg scattering
=> different contribution to the cross section compared to Tevatron
=> processes with heavy flavour in the initial state become important





- compelling test for the new NLO pQCD calculations of W/Z+(b)jets
(up to 4jet for light- and 2 for b-jets)

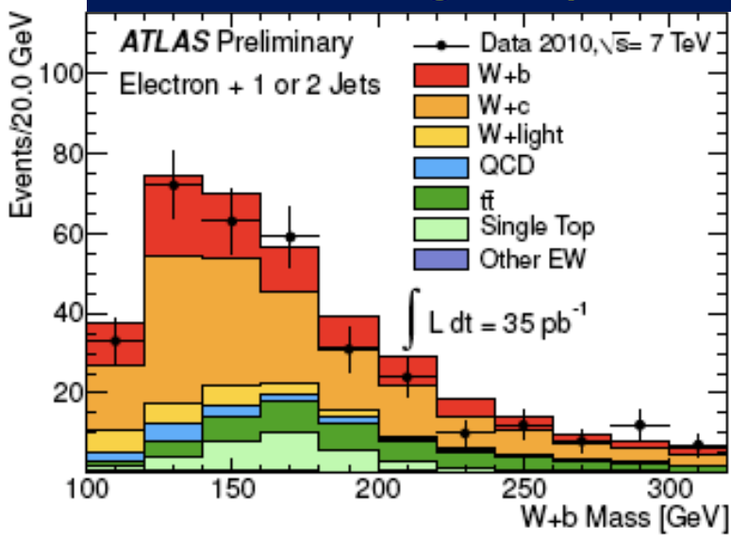
Motivations (II)



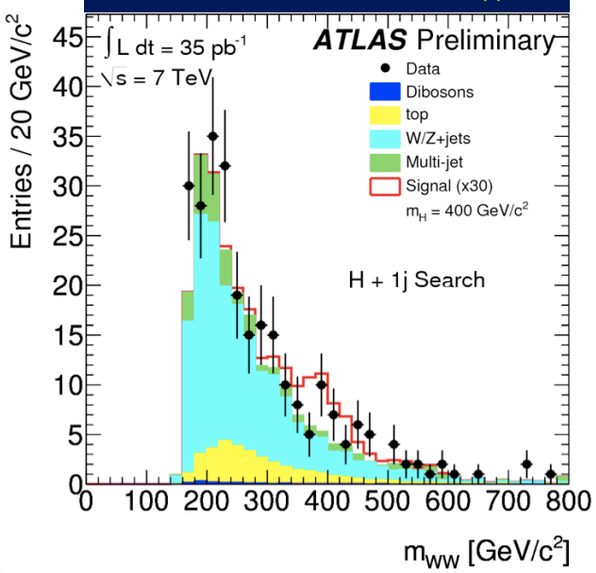
- W/Z+jets final states are the dominant signatures for the identification of a number of heavy particles produced at high energy, both in the SM and in theories beyond the SM

- the identification of these particles and the measurement of their properties requires an accurate description of the W/Z+jets SM production

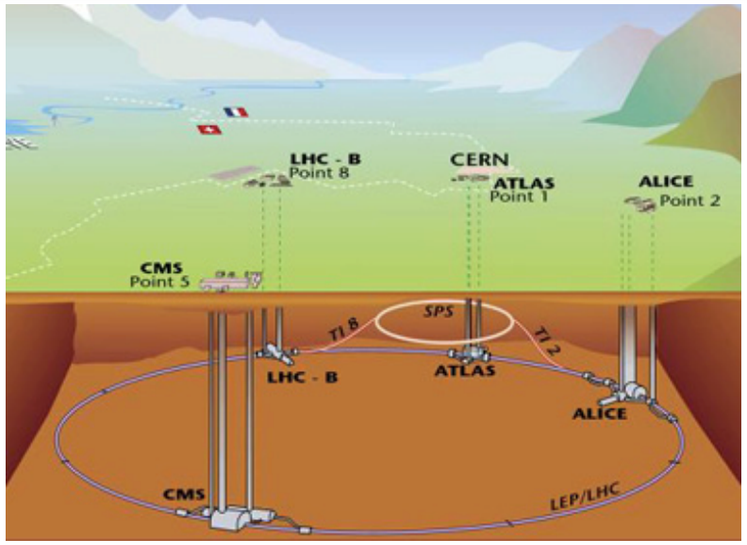
ttbar, single top



H⇒WW=>lνjj



ATLAS: experiment apparatus



2010 DATASET

pp collisions at $\sqrt{s}$ = 7 TeV

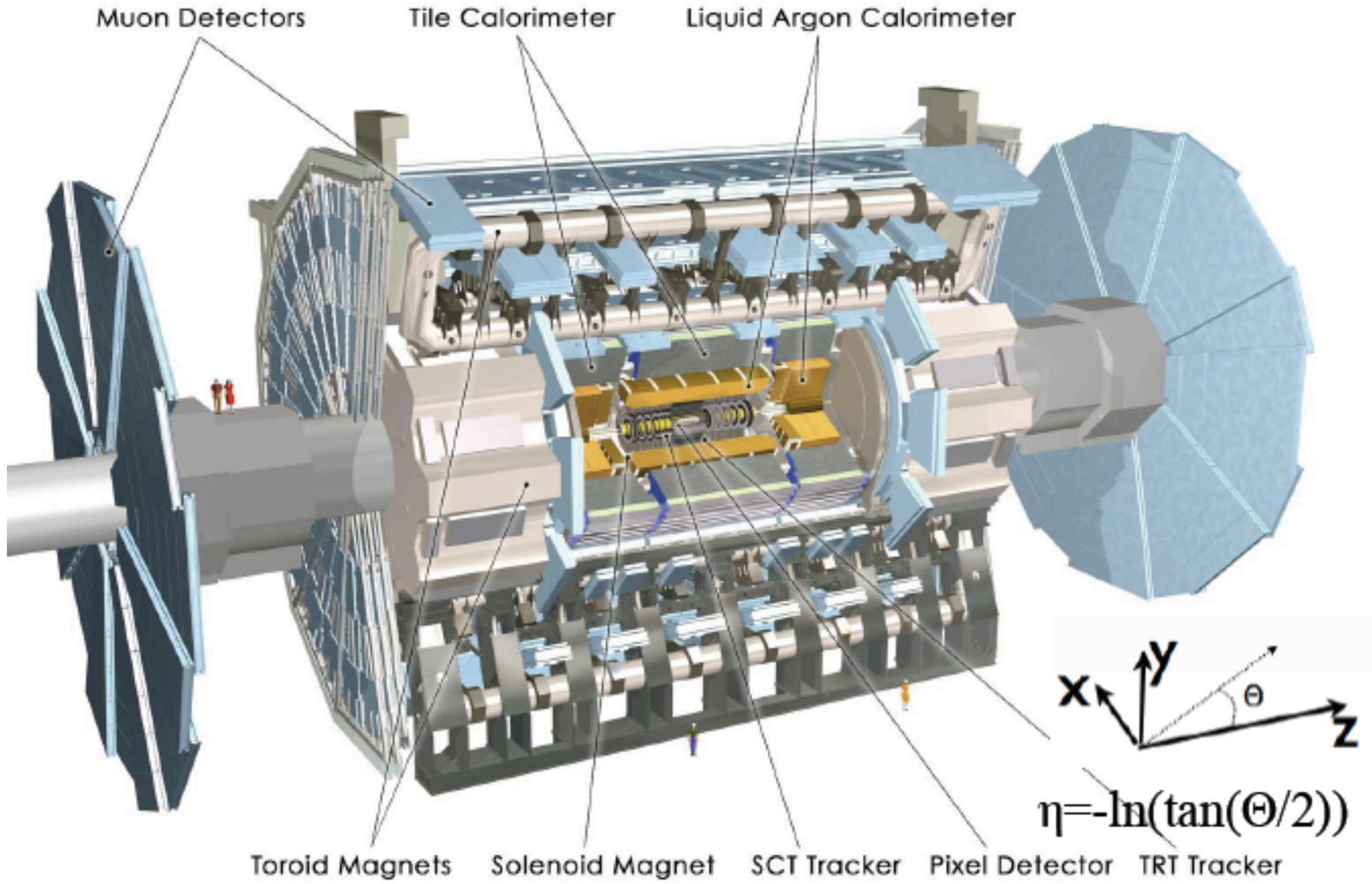
< interactions/BC > ≈ 2

≈35 pb^{-1} with single μ/e trigger

Luminosity uncertainty 3.4%

ATLAS Detector

- Inner detector:
  Pixel + SCT: |η|<2.5
  TRT: |η|<2
- Calorimetry:
  LAr + Tile: |η|<3.2
  FCAL: |η|<4.9
- Muons:
  RPC + TGC (trig.): |η|<2.4
  MDT + CSC: |η|<2.7



W/Z+jet analyses

Single lepton trigger
Offline selection: optimized to be on the trigger efficiency plateau

Electrons

- E_T>20 GeV
- |η|<2.47; excluding 1.37<|η|<1.52
- ID track point to EM cluster
- calorimeter (track) isolation

Muons

- E_T>20 GeV
- |η|<2.4
- combined ID+MS track
- track isolation

W boson

- one charged lepton
- Missing E_T>25 GeV
- $m_T(l\upsilon)$>40 GeV

Z boson

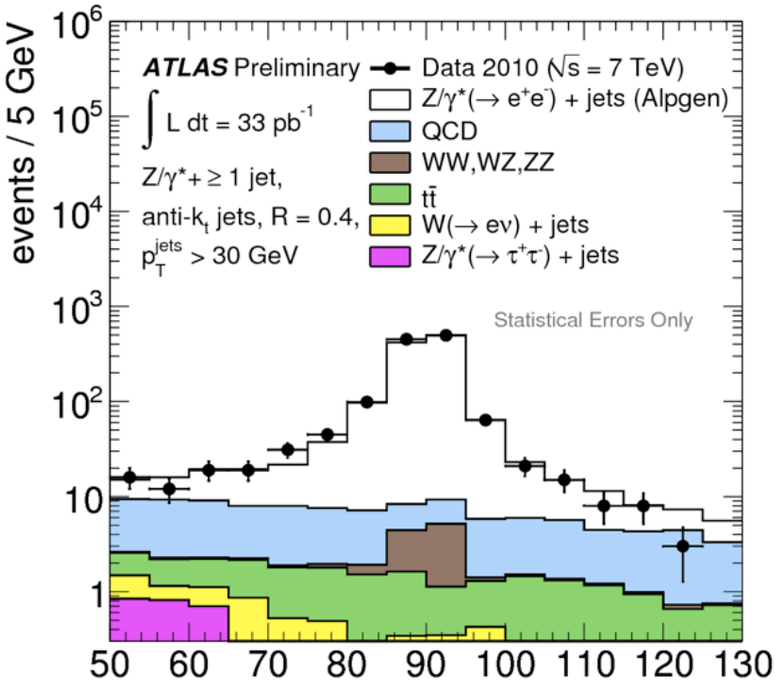
- two opposite charged lepton
- 66 GeV<m_{ll}<116 GeV

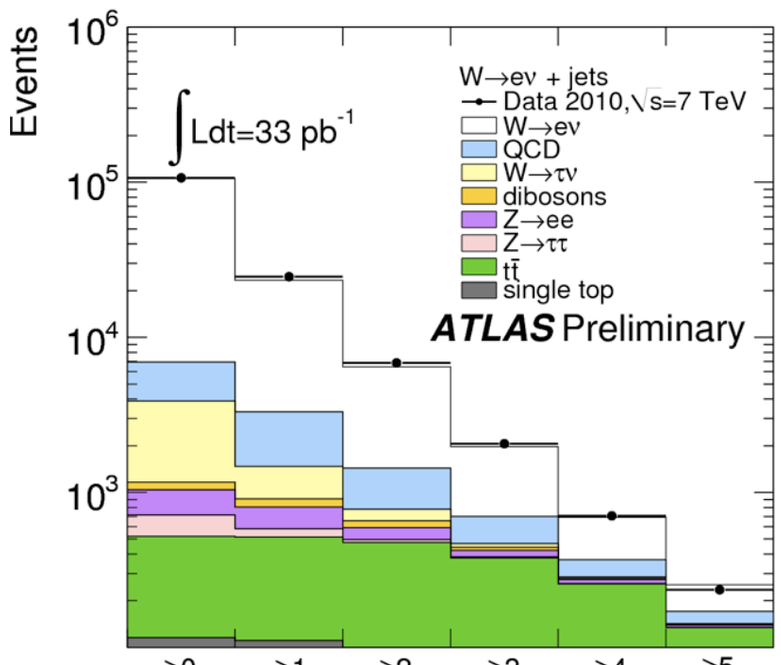
Jets:

- Anti-k_T algorithm (R=0.4); p_T>20 GeV; |y|<2.8; jets are considered if $\Delta R_{l\text{-}jet}$>0.5

- Detector effects corrected for using bin-by-bin unfolding:
  - lepton ID/trigger efficiency from data using Z⇒ll events
  - jet and missing E_T energy scale calibrated using simulation, single hadron, and γ-jets events
- Measurement presented in a kinematic phase space well covered by the detector acceptance
  - Jets: include all particles with τ>10 ps, except W/Z leptons
  - lepton momentum includes all photons radiated within ΔR<0.1

background for W/Z + jet





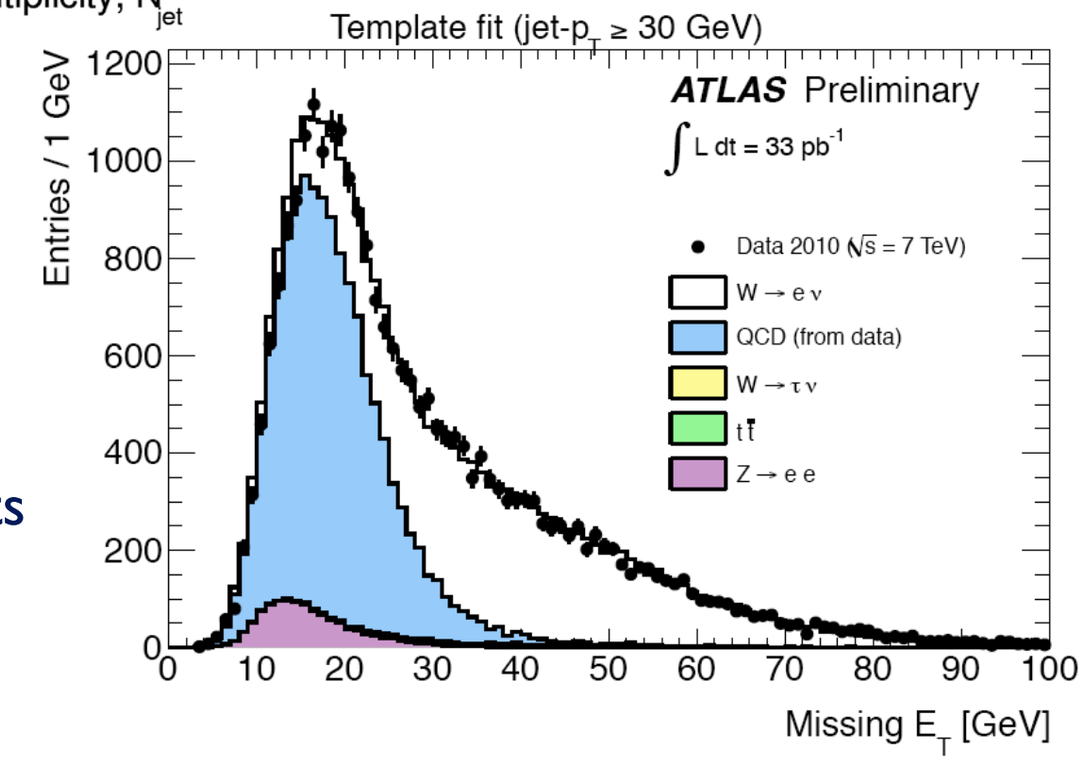
W+jets backgrounds

- 10-20% total background dominated by QCD at low and top at high p_T

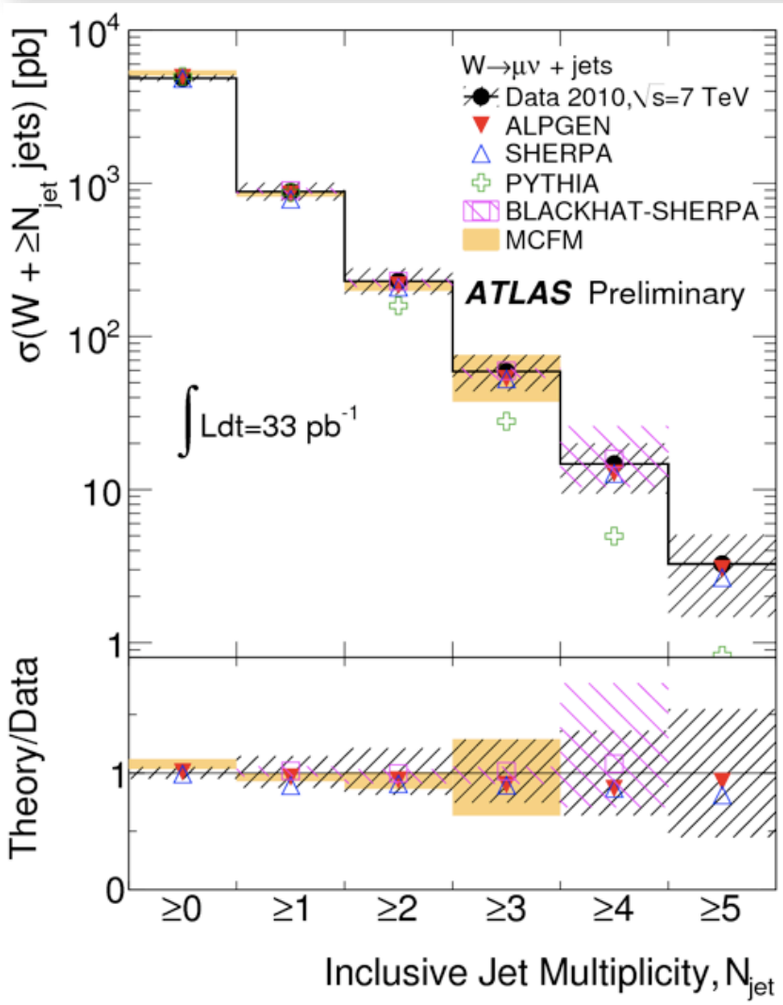
Z+jets backgrounds

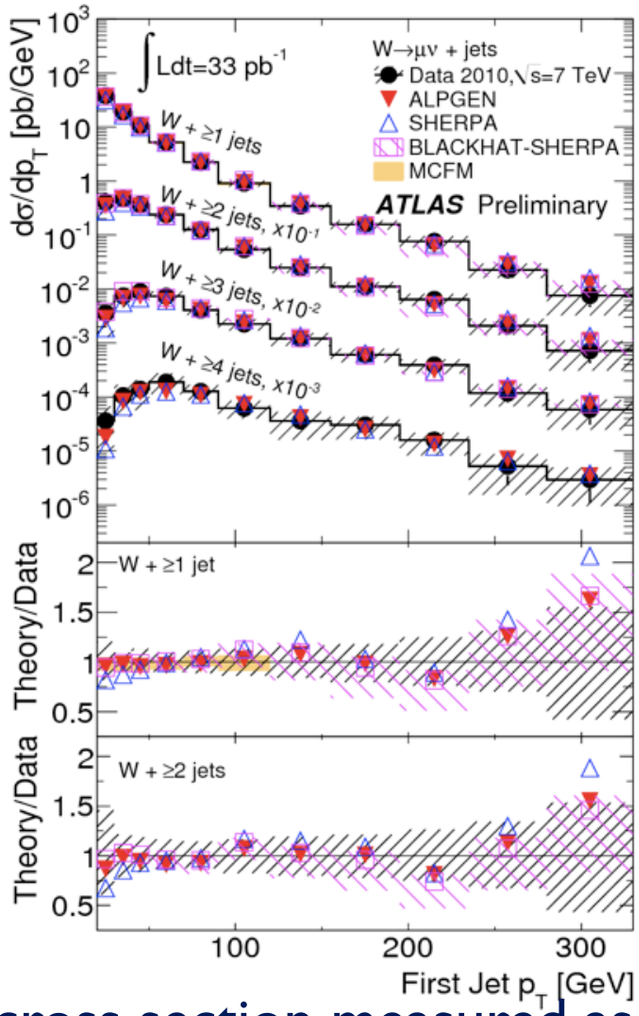
- O(5%) in electron and O(1%) in the muon channel

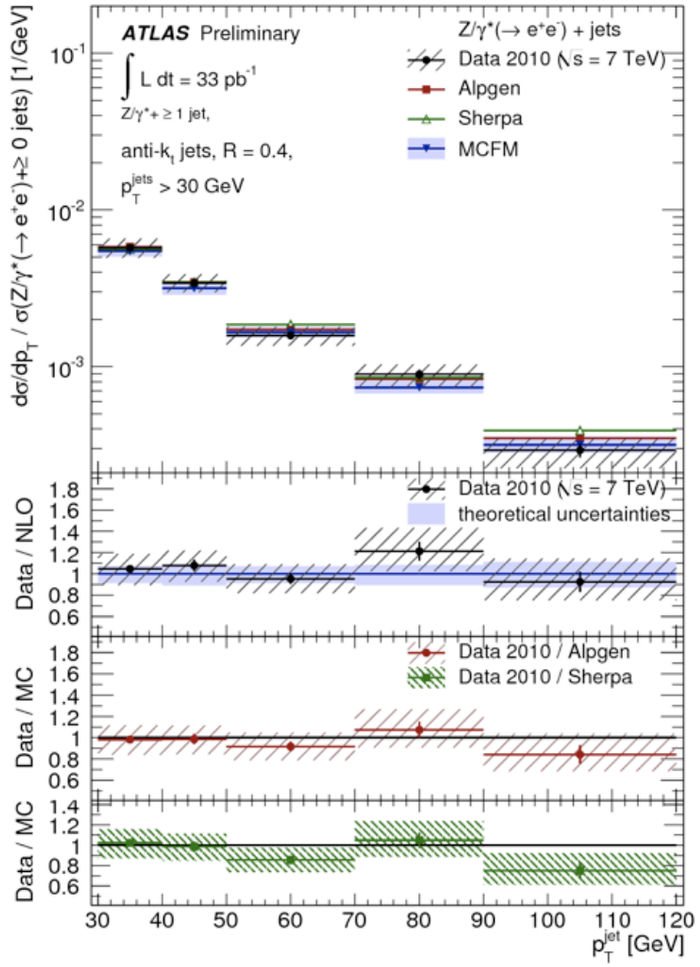
- Electroweak and top backgrounds from MC
- QCD background from data:
  - ✓ Template fit to the missing E_T distribution
  - ✓ QCD sample by inverting some lepton ID cuts



W/Z + jet results







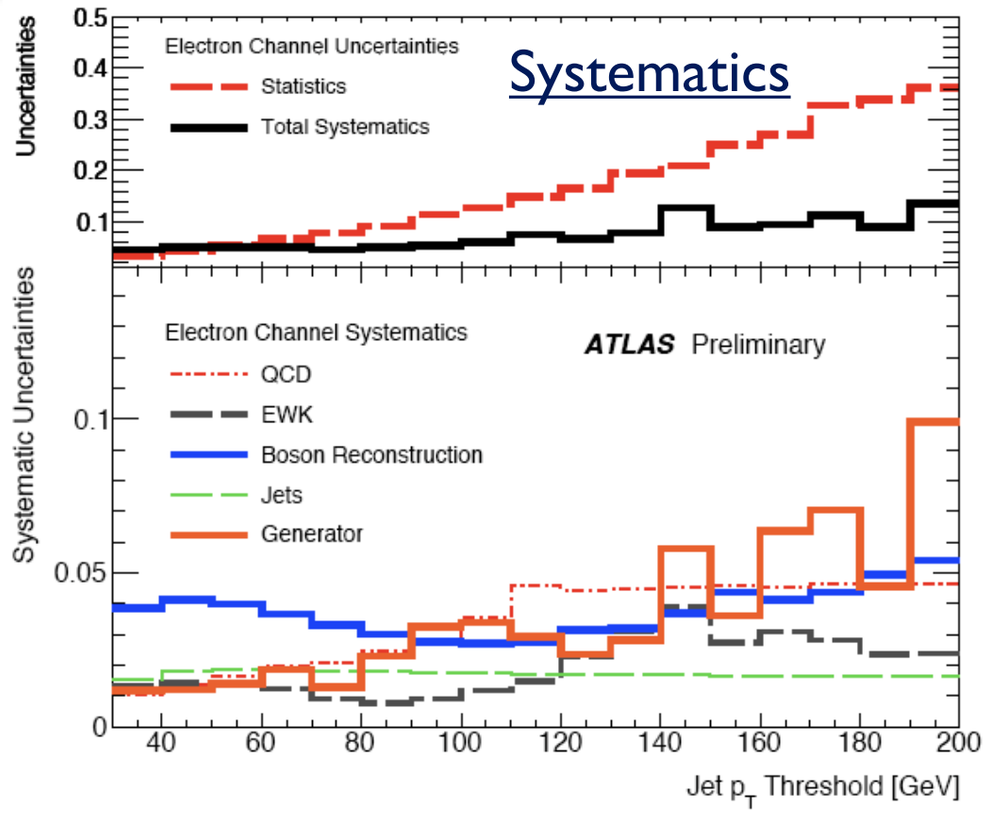
dominant systematics

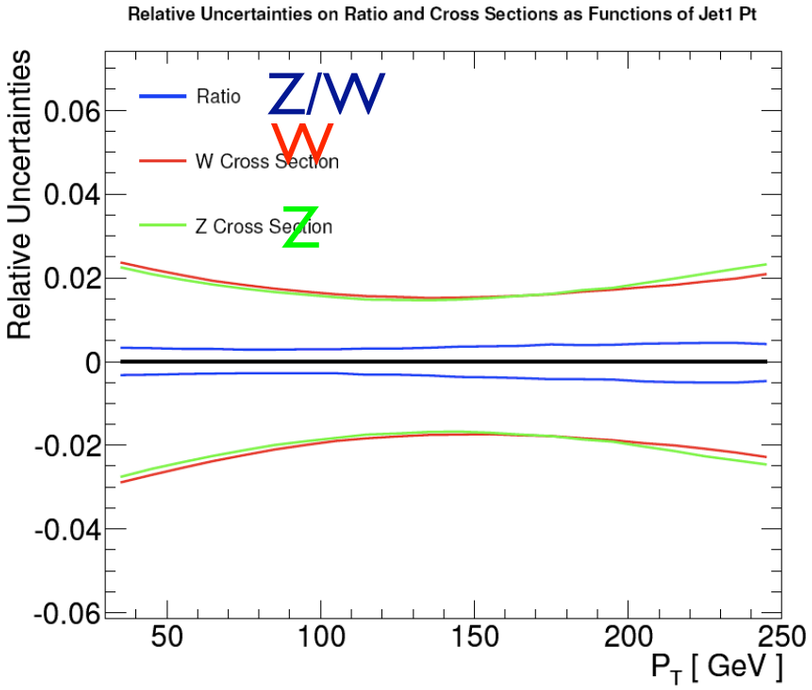
- JES: 8(26)% for $N_j \geq 1(4)$
- jets from pile-up ≈7%
- lep. reco. ≈ 2%
- QCD bkgd ≈ 2%
- unfolding ≈ 2%

- cross section measured as a function of several kinematic variables (see end of this talk)
- very good agreement with NLO predictions from MCFM and Blackhat-Sherpa in the total and differential cross sections
- good agreement with matched LO prediction from AlpGen and Sherpa once normalized to the NNLO prediction
- Poor agreement with LO PYTHIA in the high jet multiplicity

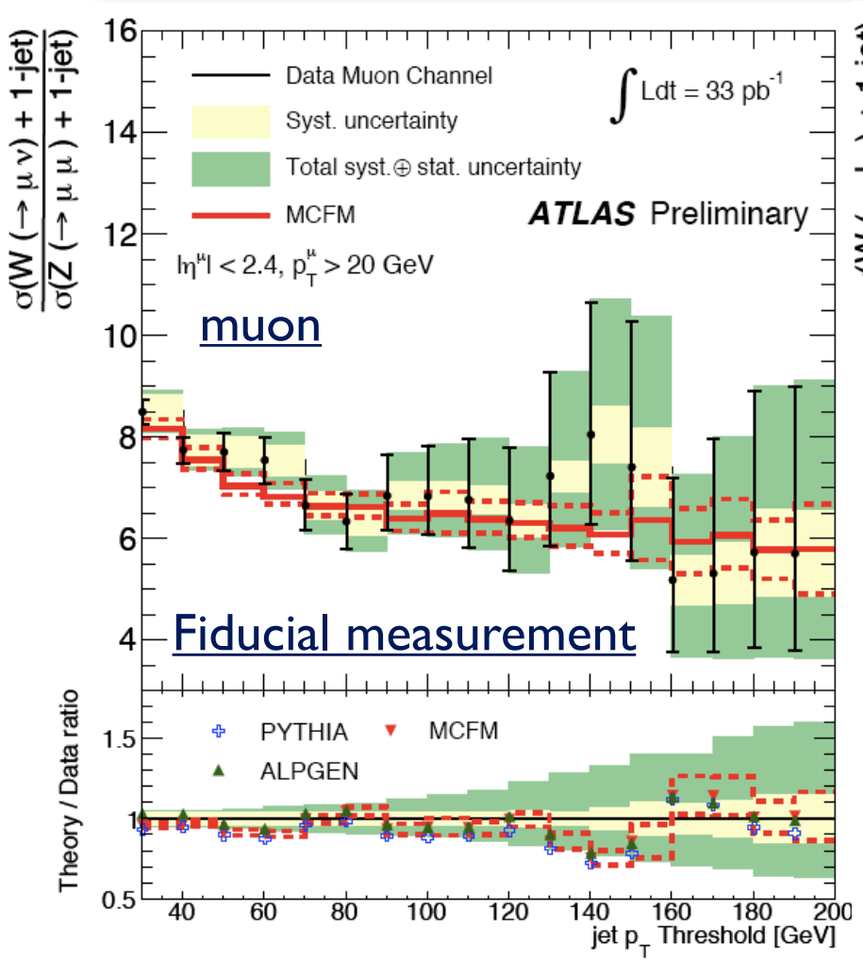
(Z+1 jet)/(W+1 jet) Rjet ratio

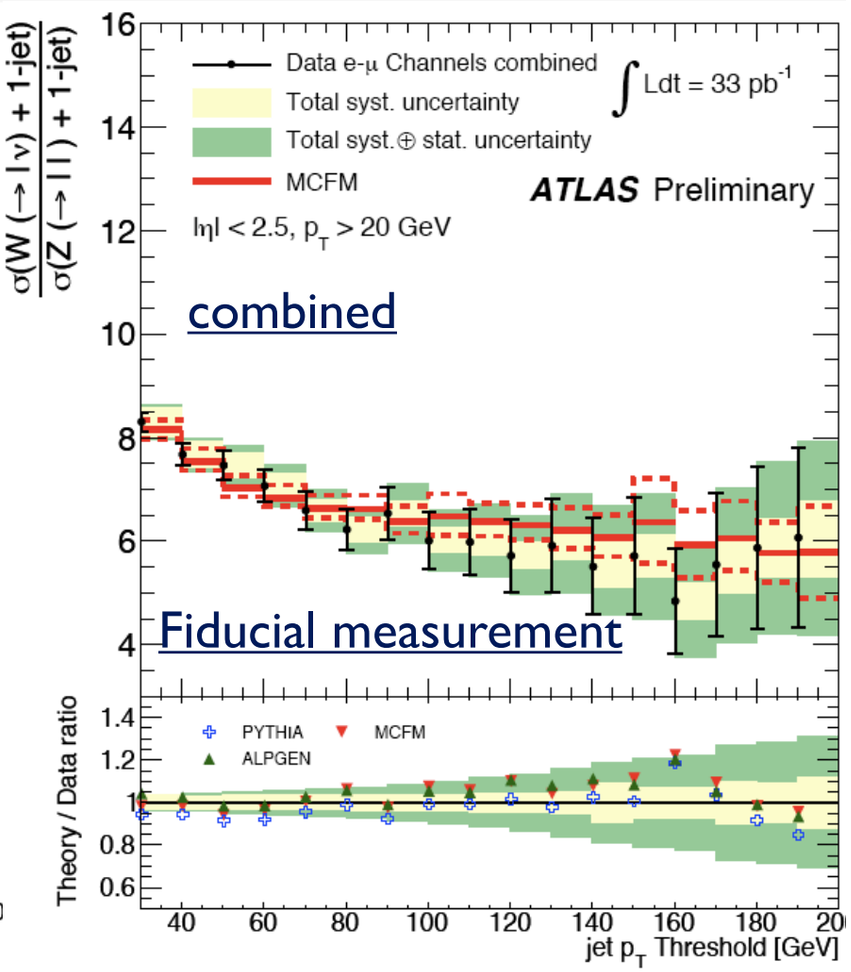
- Probe QCD dynamics without QCD uncertainties
- Theory uncertainty is reduced in the Rjet ratio: in particular there is significantly reduced dependence on the PDF
- First measurement of its kind, reached control on systematics at few precent level
- The Rjet is measured for events with only one jet with p_T>30 GeV and $|\eta|$<2.8 as a function of the minimum jet p_T
- Results are given for the electron and muon channel, both in the fiducial and total bosons phase space
  - the measurement can be mapped to different W/Z final states, and used to estimate SM bkgd to searches ($Z \Rightarrow \nu\nu$ in jet + missing E_T)

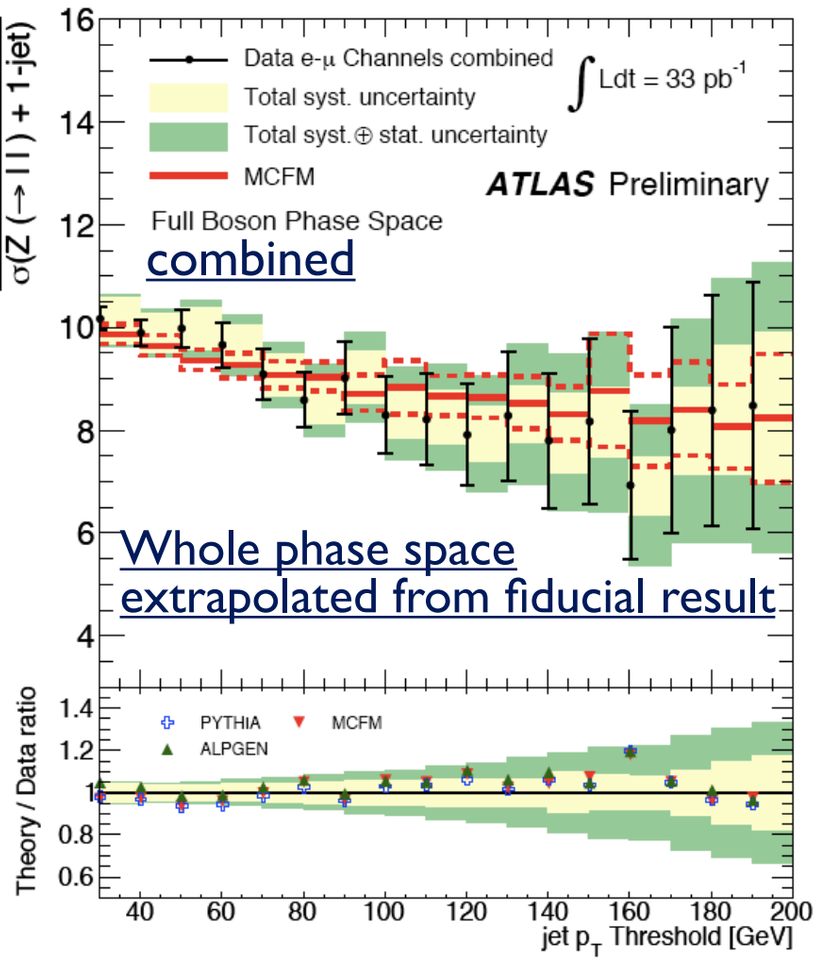




(Z+1 jet)/(W+1 jet) ratio results





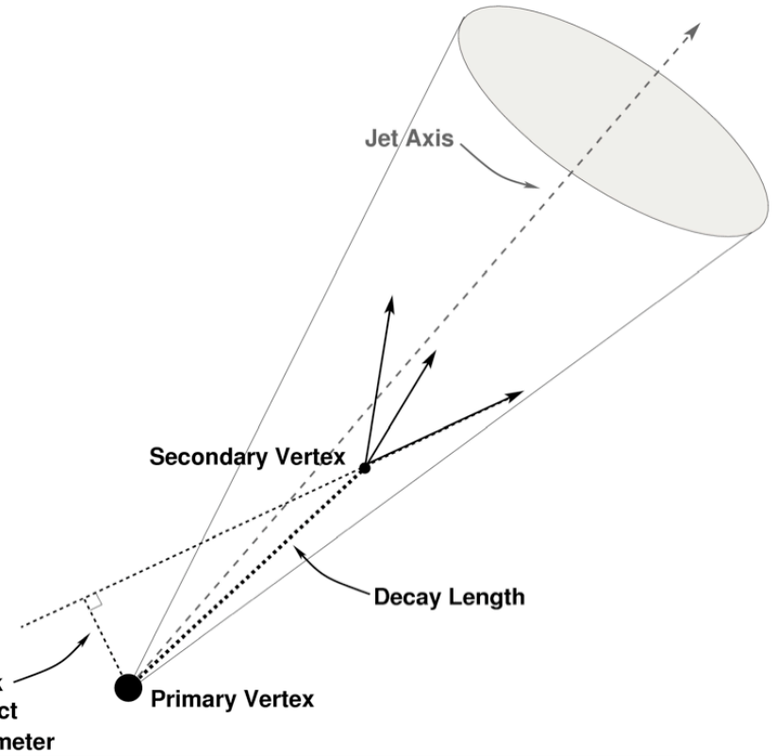


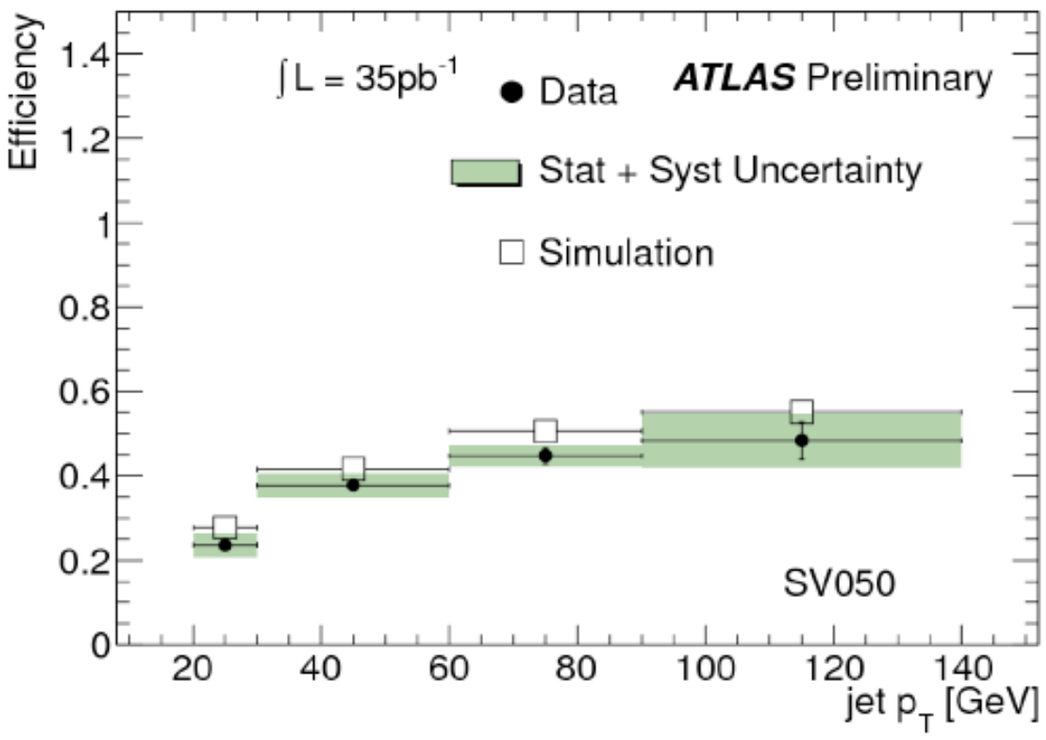
- Electron and muon results are compatible and are combined. For p_T>30 GeV:
  single channel: 5% stat. and 4% syst.
  combined: 3% stat and 2% syst.
- Very good agreement of NLO prediction from MCFM
- Very good agreement with matched LO prediction from AlpGen and PYTHIA (norm. to data)

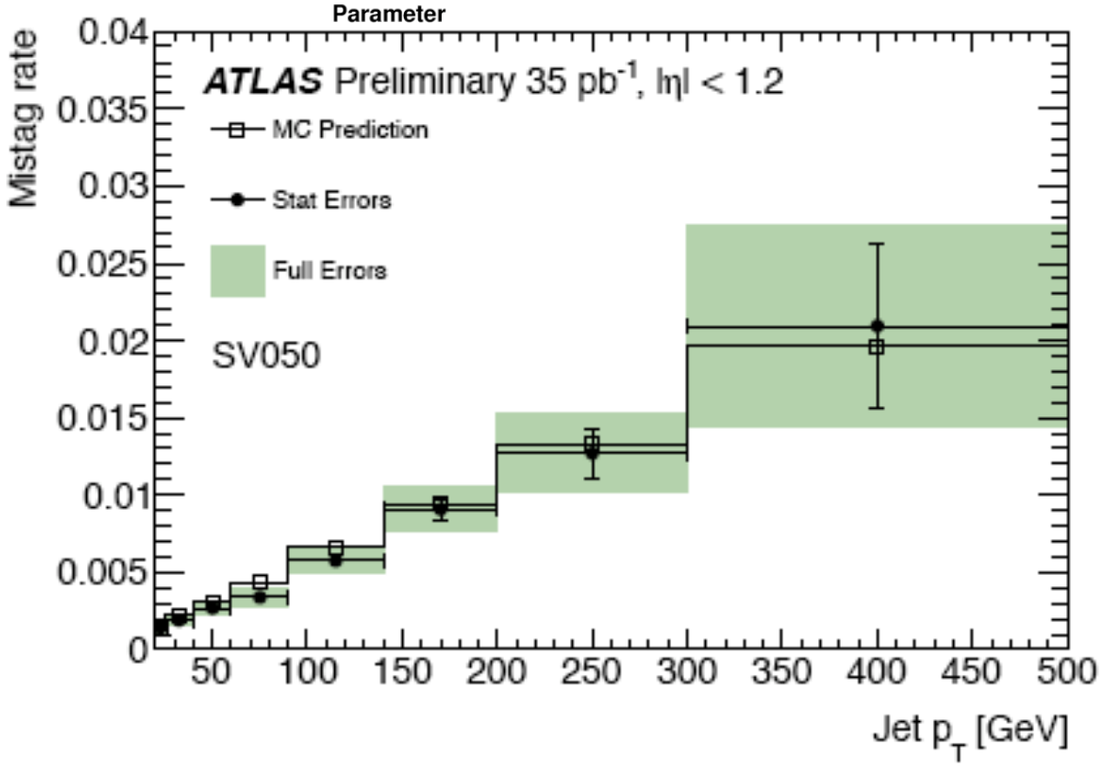
W/Z + b-jets measurements

W/Z + b-jets: b-tagging

- b-jets are selected exploiting the long lifetime (1.5 ps) and the large mass of B-hadrons
- The SV0 b-tagging algorithm is based on requiring a displaced secondary vertex reconstructed within a jet with a decay length significance > 5.85
- The b-tagging efficiency and its systematics is estimated by studying semi-leptonic B decays in QCD muti-jet events, and top events







W/Z+b-jets: backgrounds to W/Z

The b-tag changes the composition of backgrounds with respect to W/Z+jet measurements

Z+b-jet signal / background > 10

W+b-jet signal / background ≈ 0.5

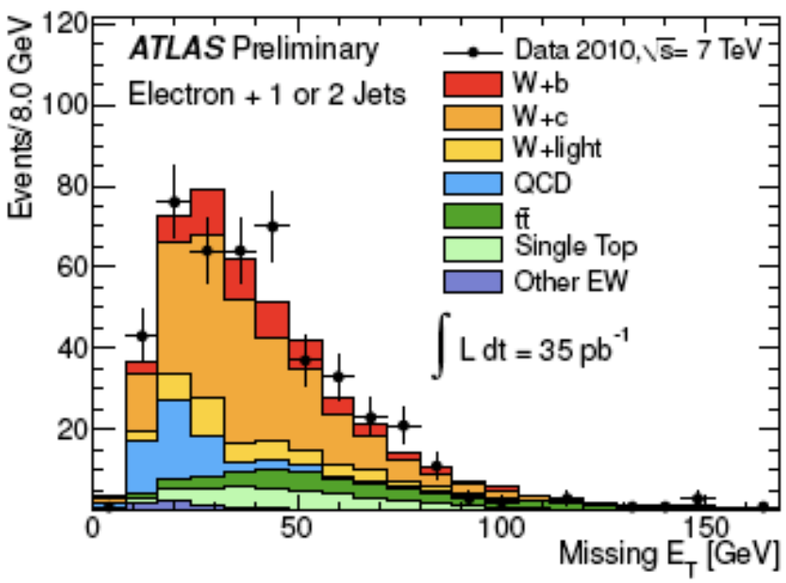
non-W background

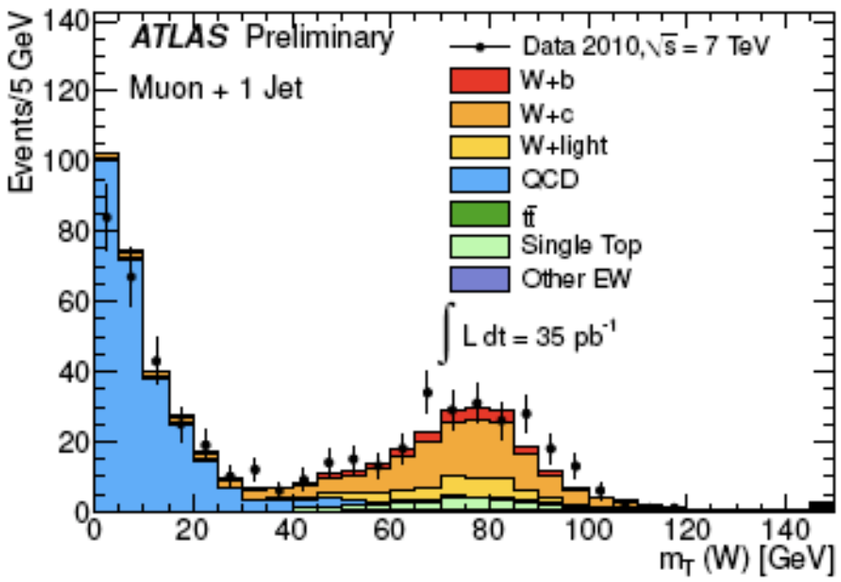
- comes from QCD multi-jet heavy flavour production.
- Tighten lep. ID to keep bkgd <30% with 50% uncertainty

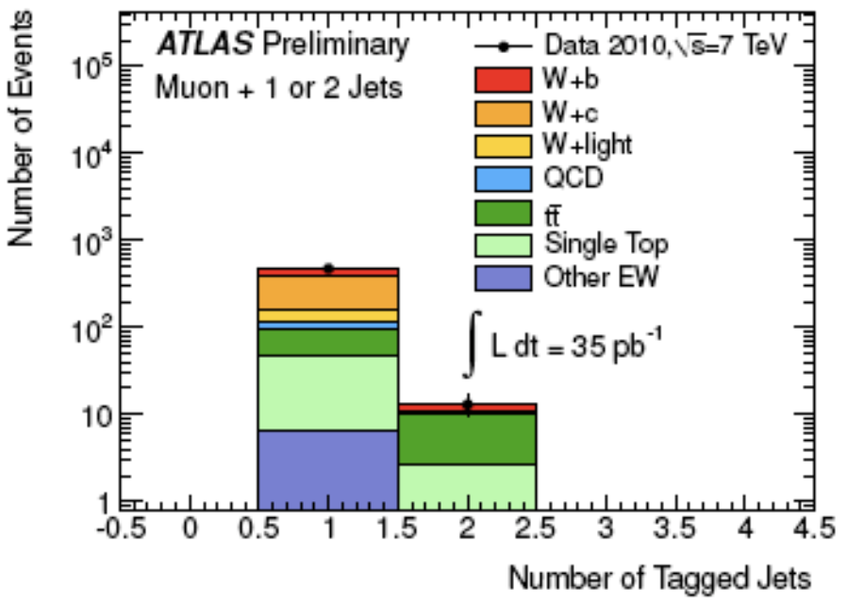
top background

(more at the end of this talk)

- t-tbar largest background (partially irreducible)
- single-top estimated with MC (partially irreducible)
- top yield measured in the ≥4 jet bin and extrapolated to 1, 2 jet wit MC
  - uncertainty ≈ 30% (JES)
  - b-tag uncertainty reduced to 2%







Extraction of b-jet fraction

A maximum likelihood fit to the SV0 mass distribution is used to separate b-jets from c- and light-jets, and extract the flavour fraction on a statistical basis.

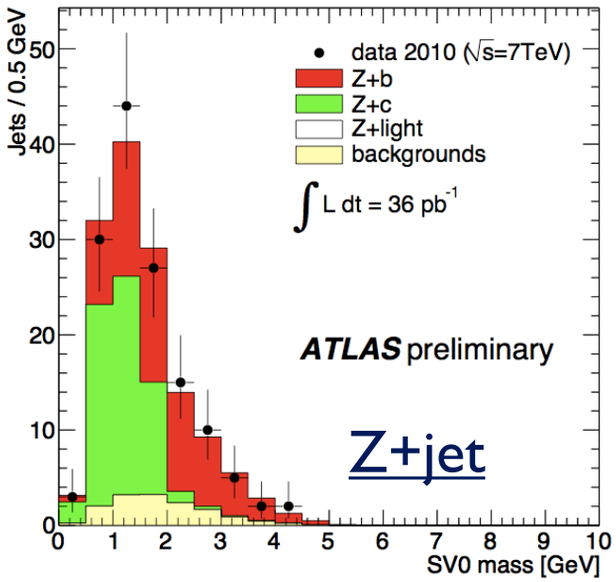
- SV0 mass template are modeled with MC
- template systematics: data vs. MC in multi-jet events enriched in light-, c-, and b-jets.

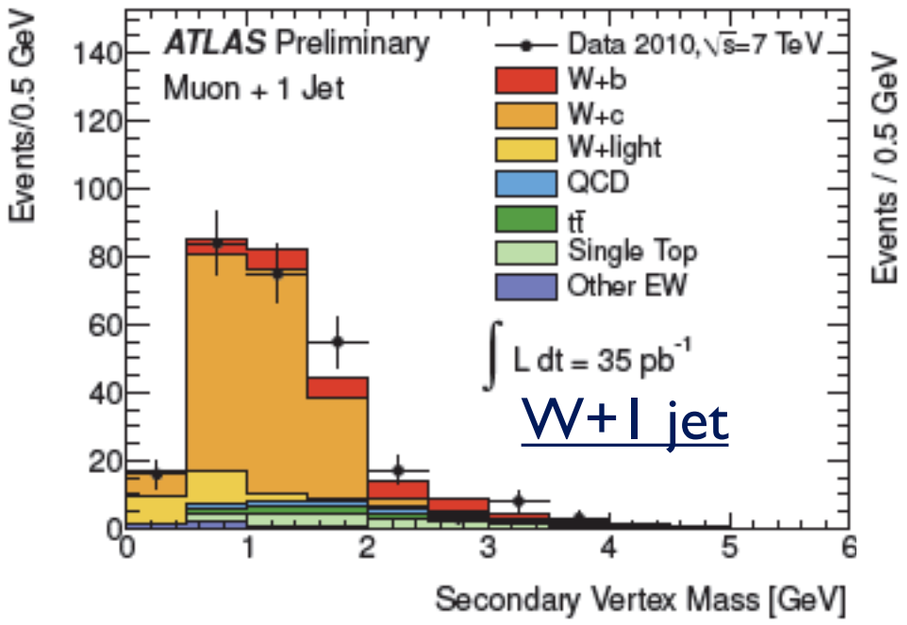
Z+bjet

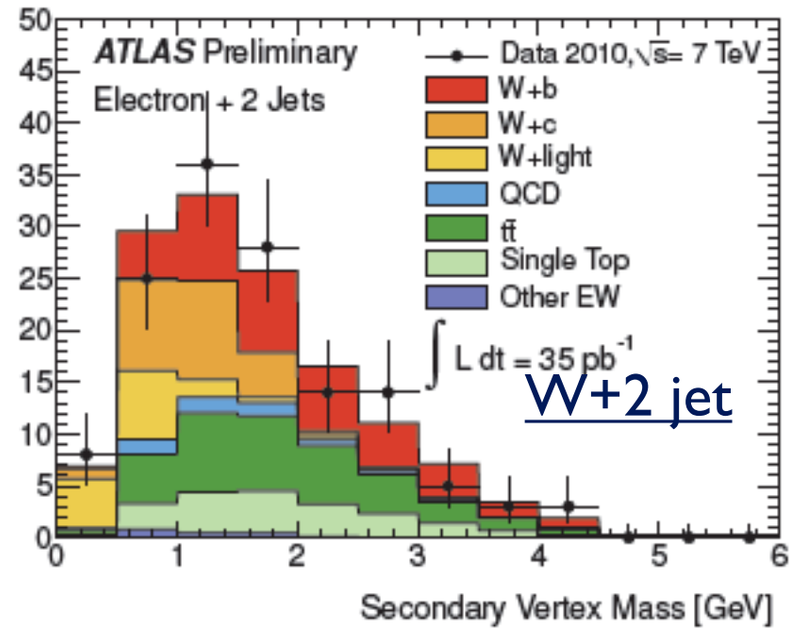
- Fit the combined e and μ samples and each b-tagged jet in the event
- At least 1 b-tagged jet

W+bjet

- 1 b-tagged jet
- about 10% of events have 2 b
- 1 or 2 jet
- fit each jet bin separately for e and μ





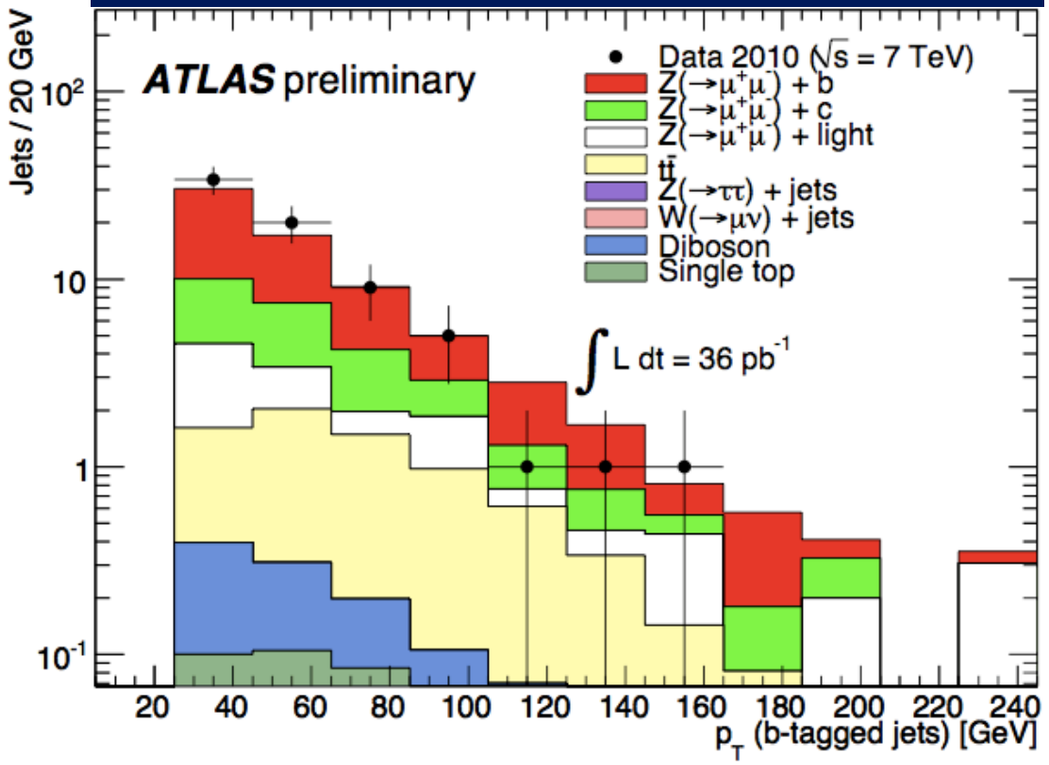


Z + b-jets results

$$\sigma = \frac{N_b}{C_e \times \mathcal{L}_e + C_\mu \times \mathcal{L}_\mu}$$

- Inclusive b-jet production cross section in association with a Z boson
- Jet fitted yield is corrected for all detector effects with MC LO matched prediction for Zjet (including heavy flavour) from ALPGEN and SHERPA
- uncertainty: ≈ 20% stat. and ≈23% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈10%
  - Z+b-jet modeling ≈10%
  - Jet + bjet energy scale ≈4%
- MCFM in good agreement with data within uncertainty

Z+b uncorrected b-jet spectrum

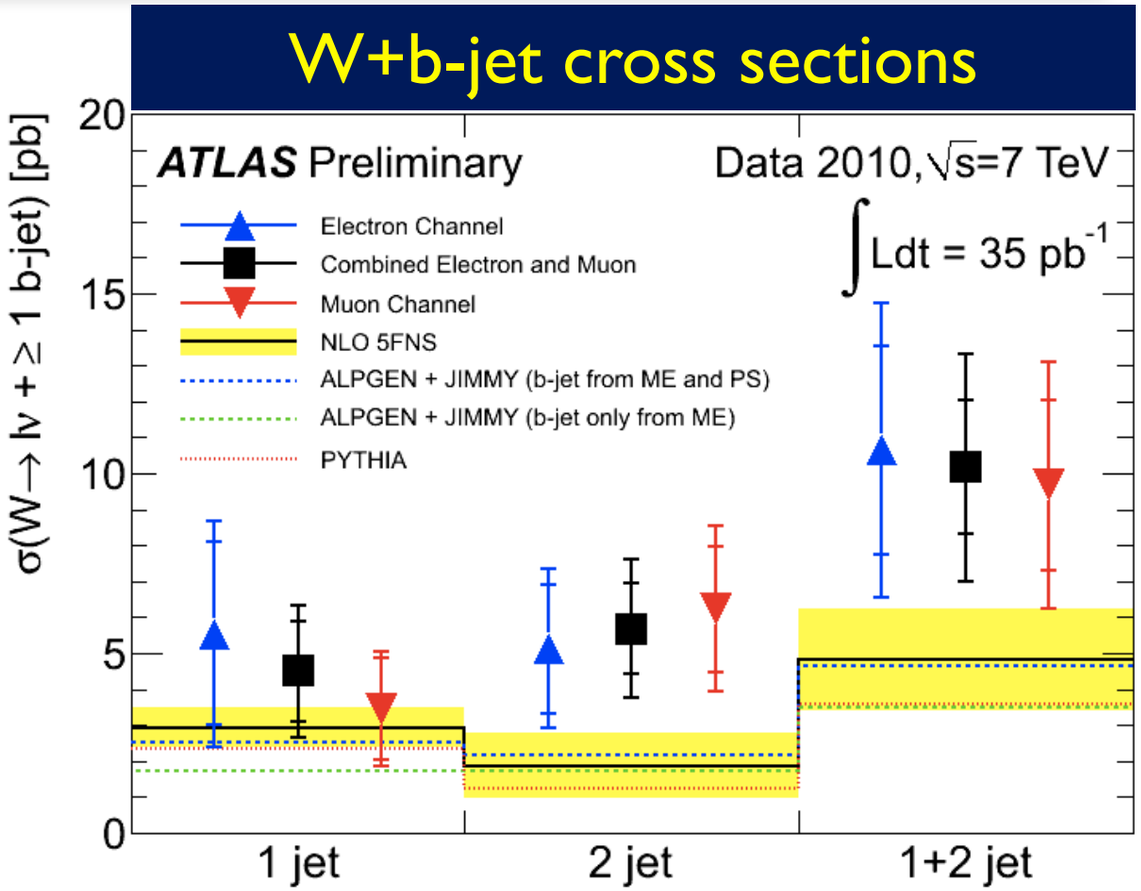


Experiment	$3.55^{+0.82}_{-0.74}(\text{stat})^{+0.73}_{-0.55}(\text{syst}) \pm 0.12(\text{lumi})$ pb
MCFM	3.40 ± 0.44 pb
ALPGEN	2.23 ± 0.01(stat only)pb
SHERPA	3.33 ± 0.04(stat only) pb

W + b-jets results

$$\sigma_{W+b-\text{jet}} \times \mathcal{B}(W \to \ell\nu) = \frac{n^{\text{tag}} \cdot f_{W+b-\text{jet}}}{\int Ldt \cdot \mathcal{U}}$$

- W+b-jet cross section (event level)
- First measurement in exclusive jet bins
- event fitted yield is corrected for all detector effects with MC LO matched prediction for Wjet (including heavy flavour) from ALPGEN
- uncertainty: ≈ 20% stat. and ≈25% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈16%
  - top background ≈12%
  - QCD background ≈7%
  - W+b-jet modeling ≈10%
  - Jet + bjet energy scale ≈7%



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

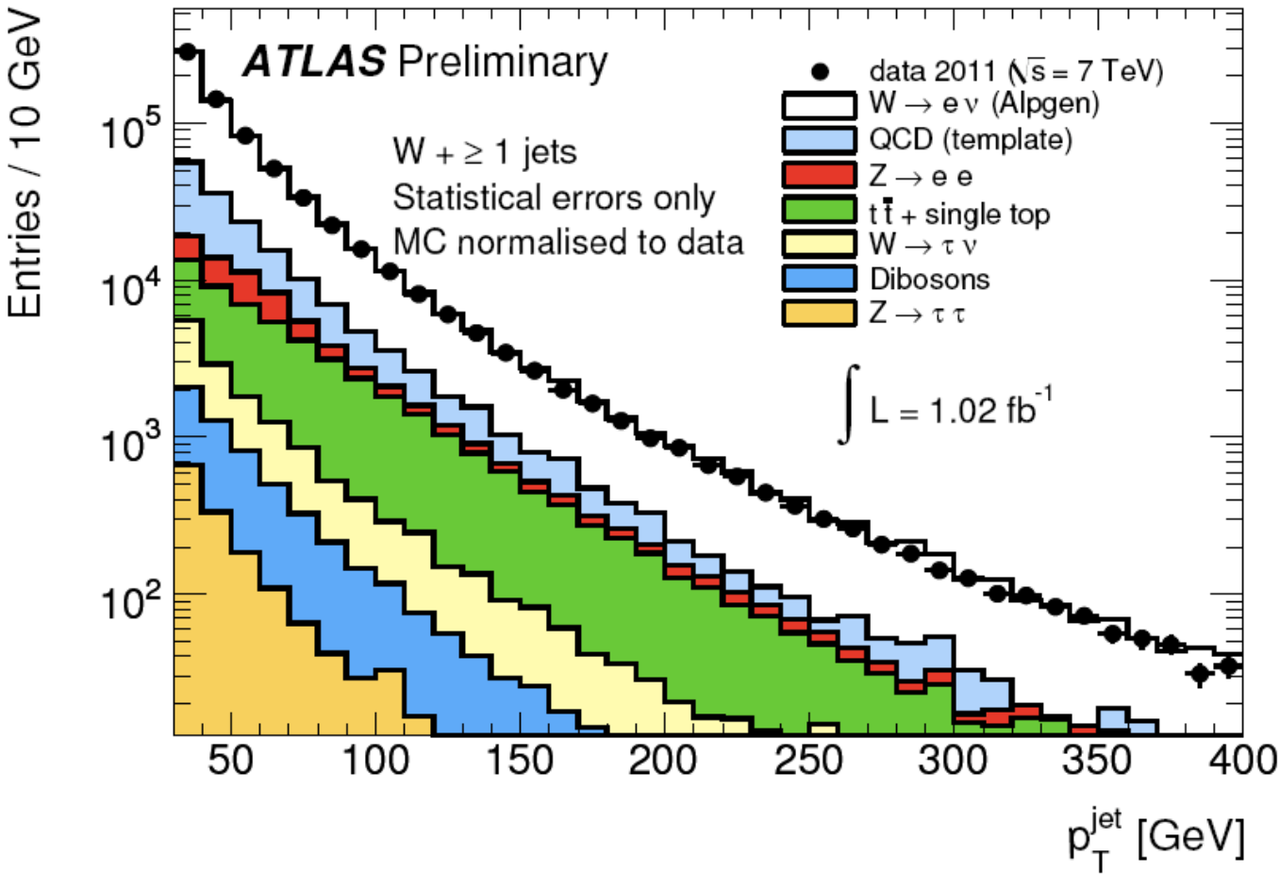
	σ_{vis} [pb]
1 jet	$2.9^{+0.40}_{-0.36}$ (scale) $^{+0.18}_{-0.02}$ (PDF) $^{+0.19}_{-0.10}$ $(m_b) \pm 0.20$ (non-pert)
2 jet	$1.9^{+0.81}_{-0.37}$ (scale) $^{+0.14}_{-0.02}$ (PDF) $^{+0.06}_{-0.05}$ $(m_b) \pm 0.13$ (non-pert.)
1+2 jet	$4.8^{+1.20}_{-0.73}$ (scale) $^{+0.32}_{-0.03}$ (PDF) $^{+0.25}_{-0.15}$ $(m_b) \pm 0.34$ (non-pert.)

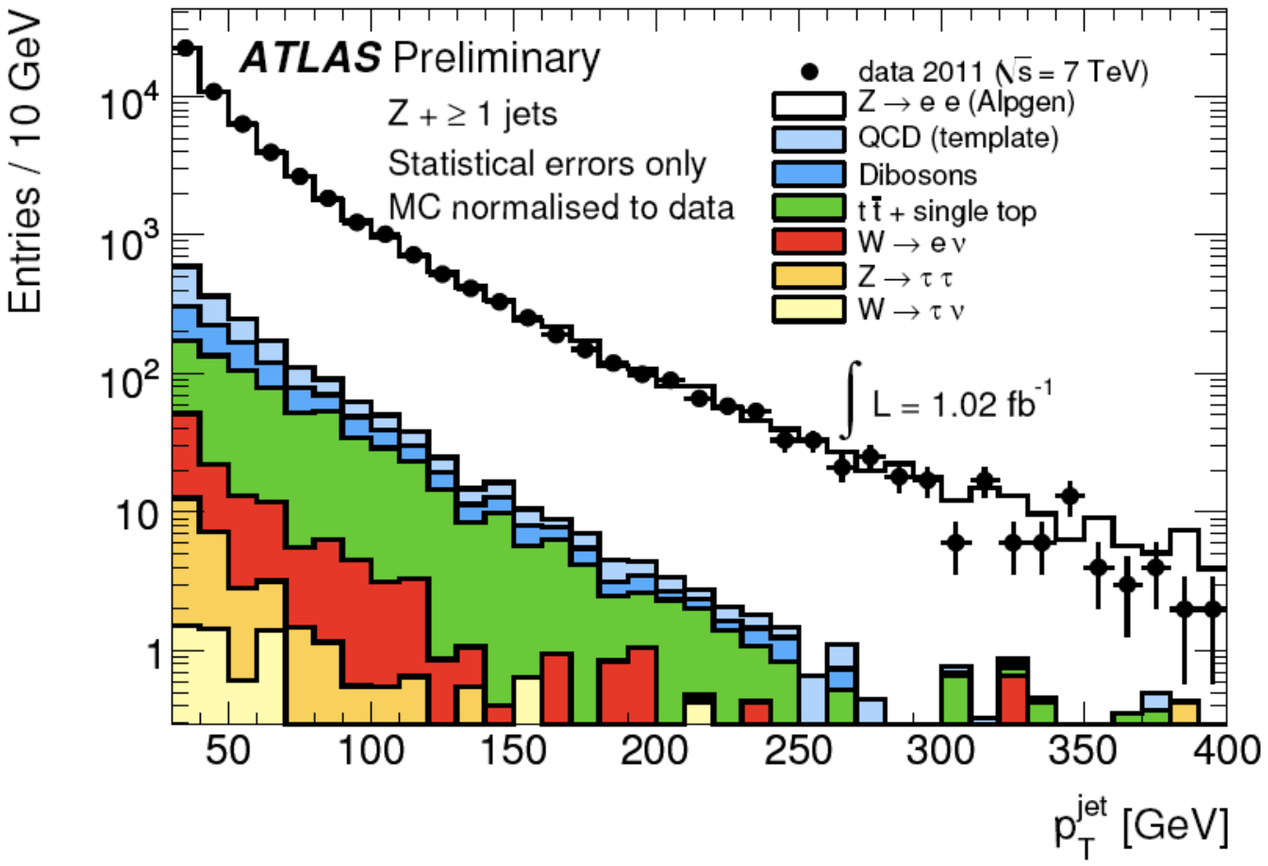
Conclusions

- With the first 35 pb^{-1} ATLAS has characterized the W/Z+jets physics at 7 TeV performing an extensive set of measurements:
  - ✓ differential W/Z+jet differential cross sections
  - ✓ (Z+1 jet) / (W+1 jet) cross section ratio
  - ✓ W/Z + b-jet cross section
- NLO predictions in good agreement with the measurements. The event kinematics is also well modeled by the matched LO event generators
- These measurements are a crucial input to searches for heavy particles decaying in W/Z+jet final states

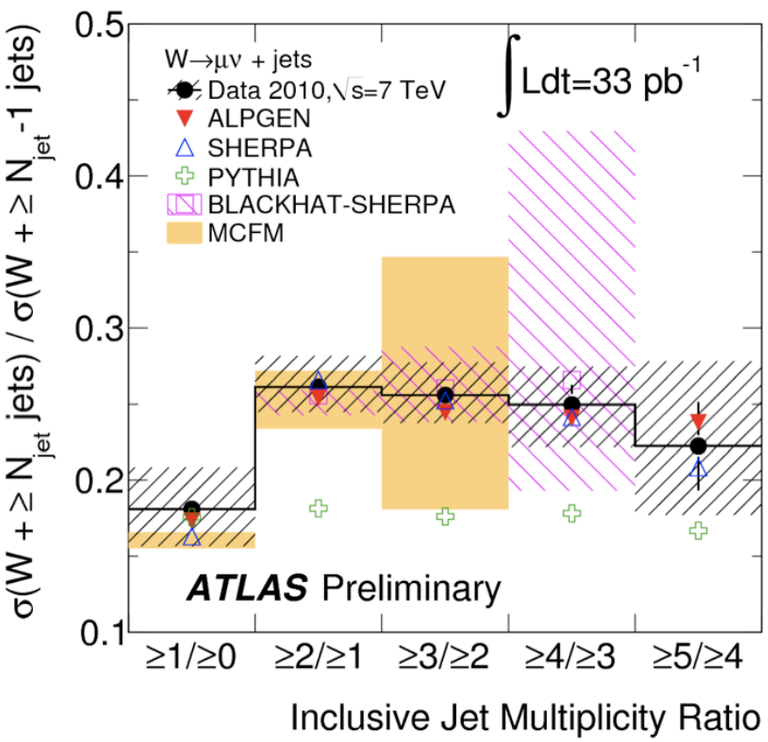
Additional material

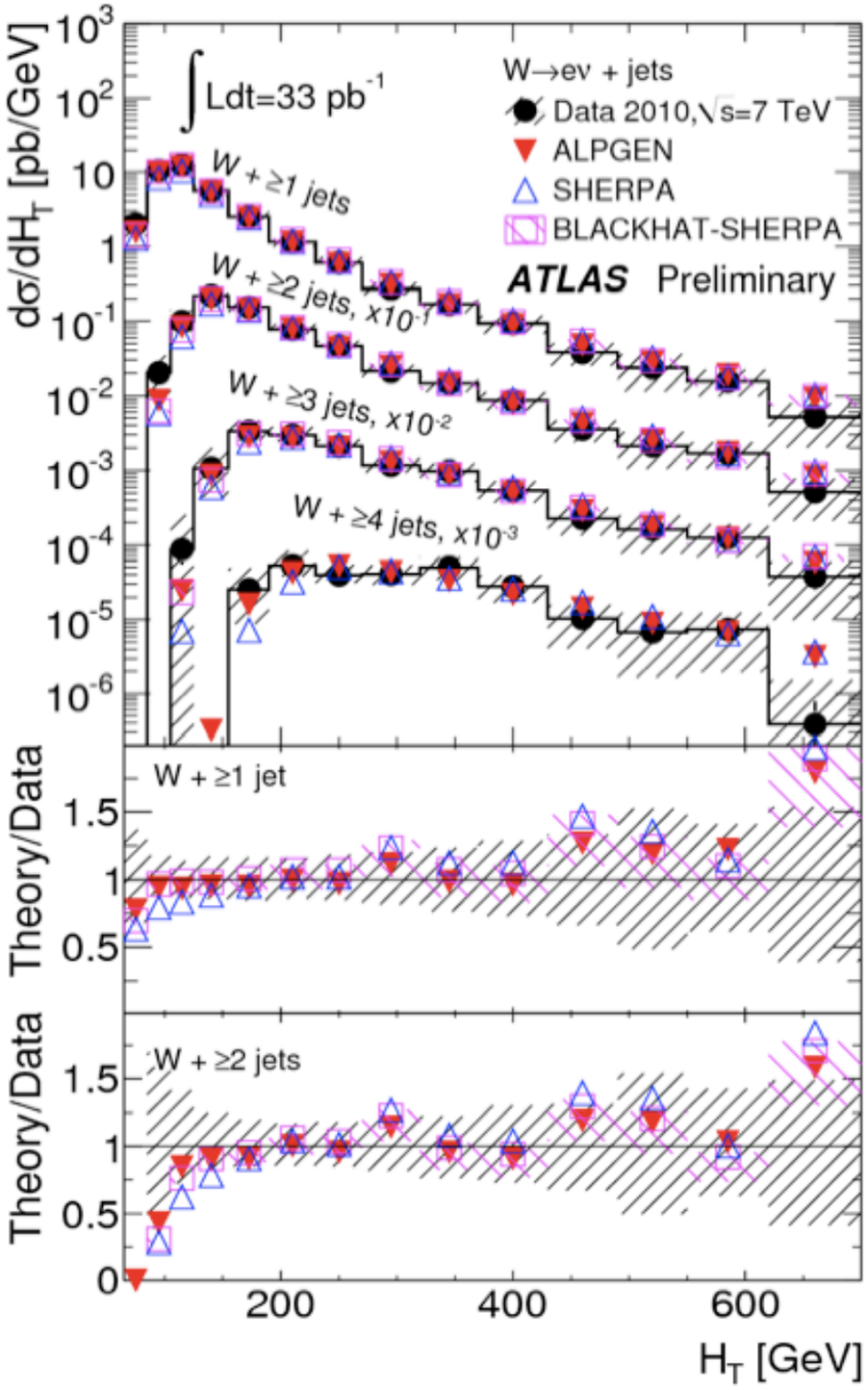
W/Z+jet with 1 fb^{-1}

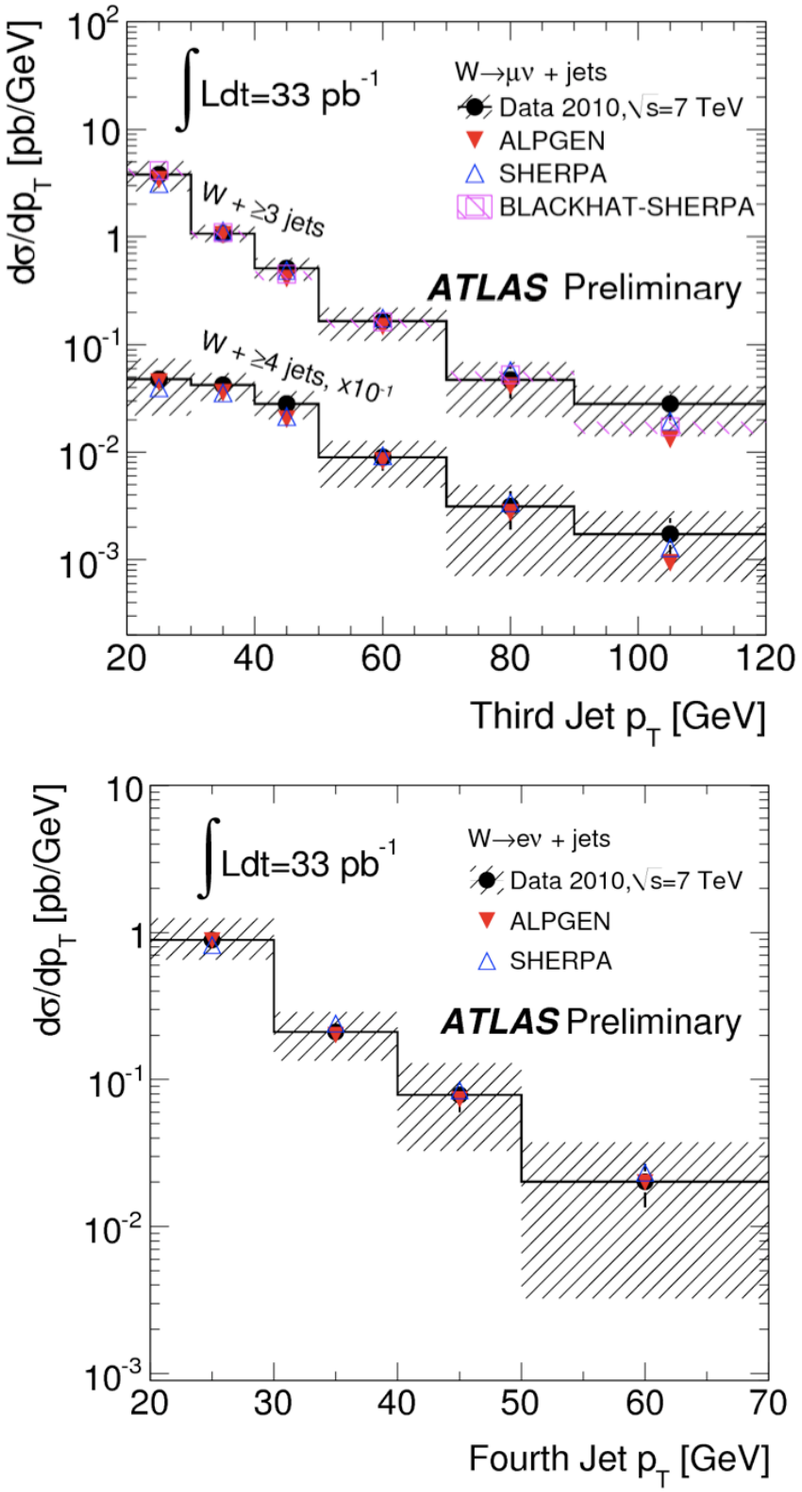




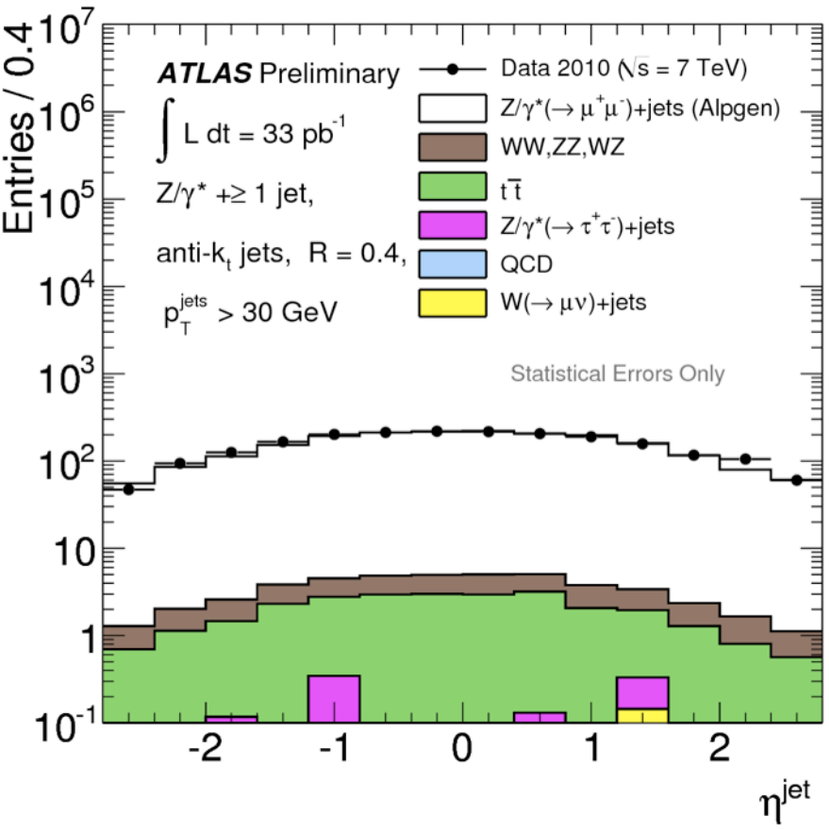
W+jet additional measurements

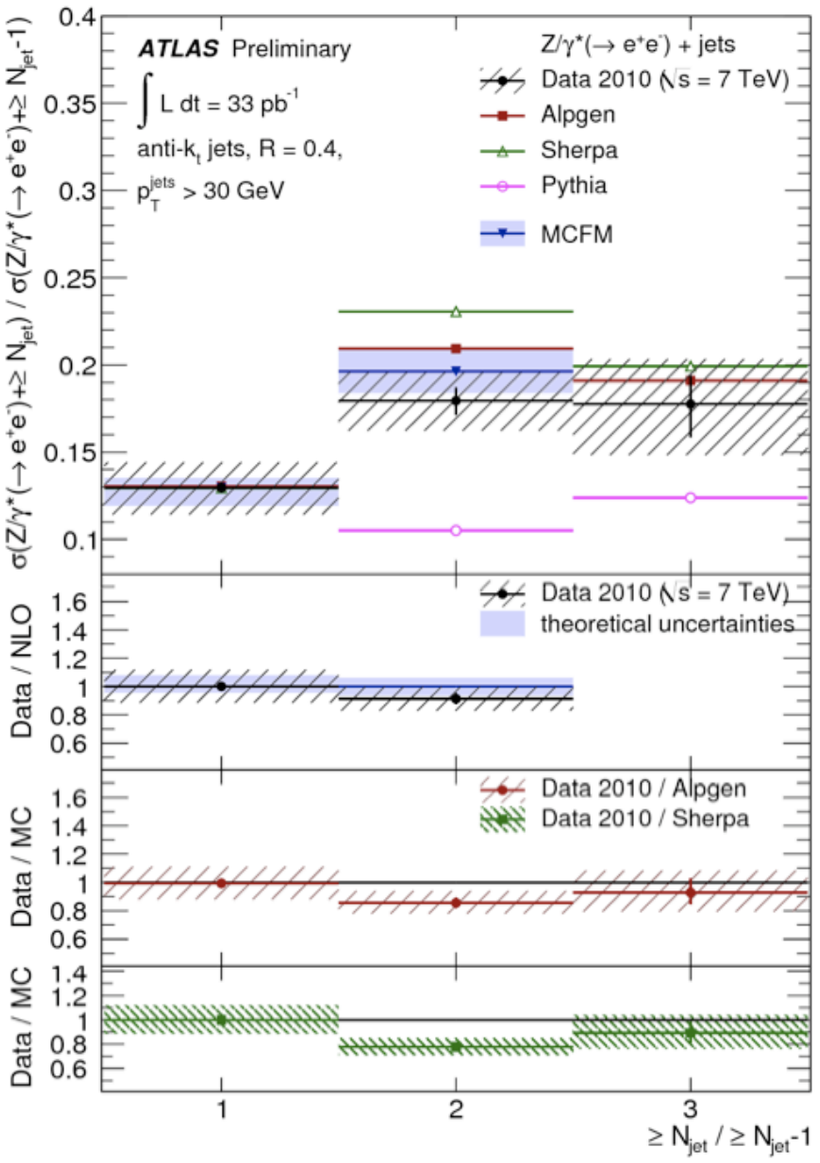


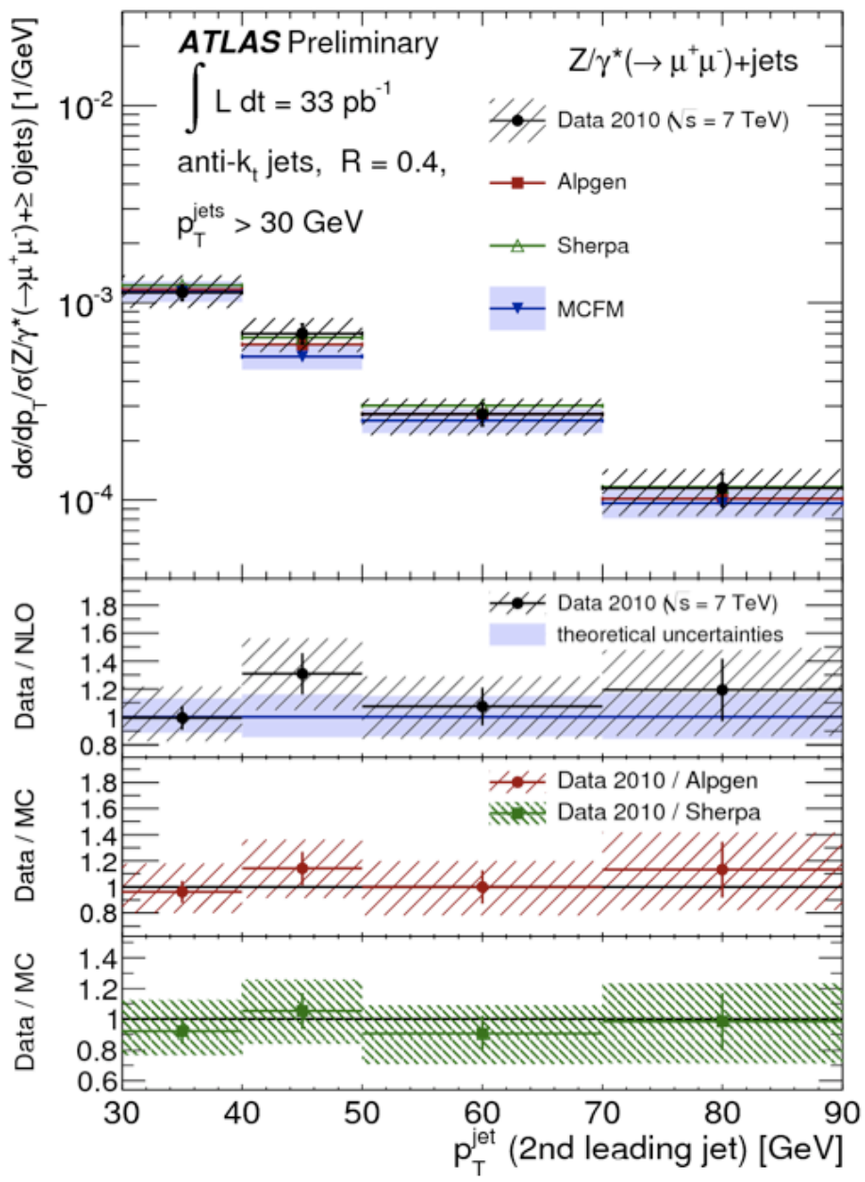




Z+jets additional measurements



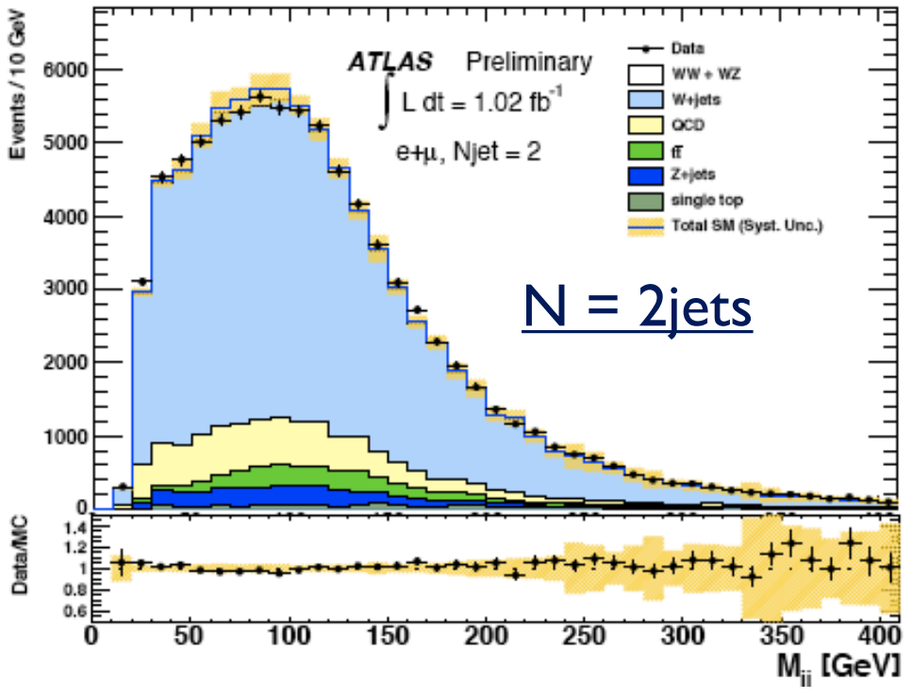


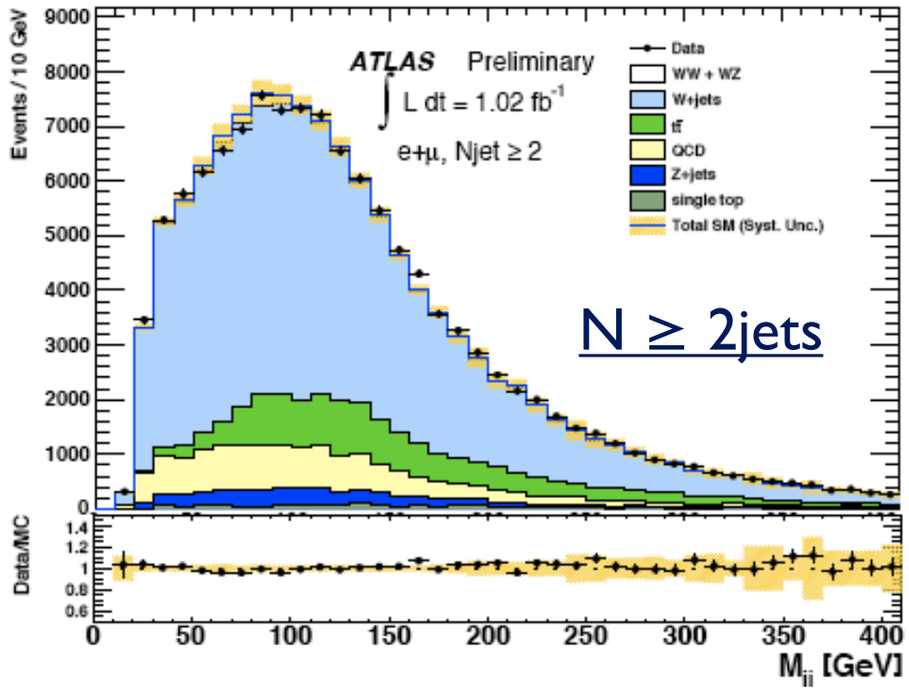


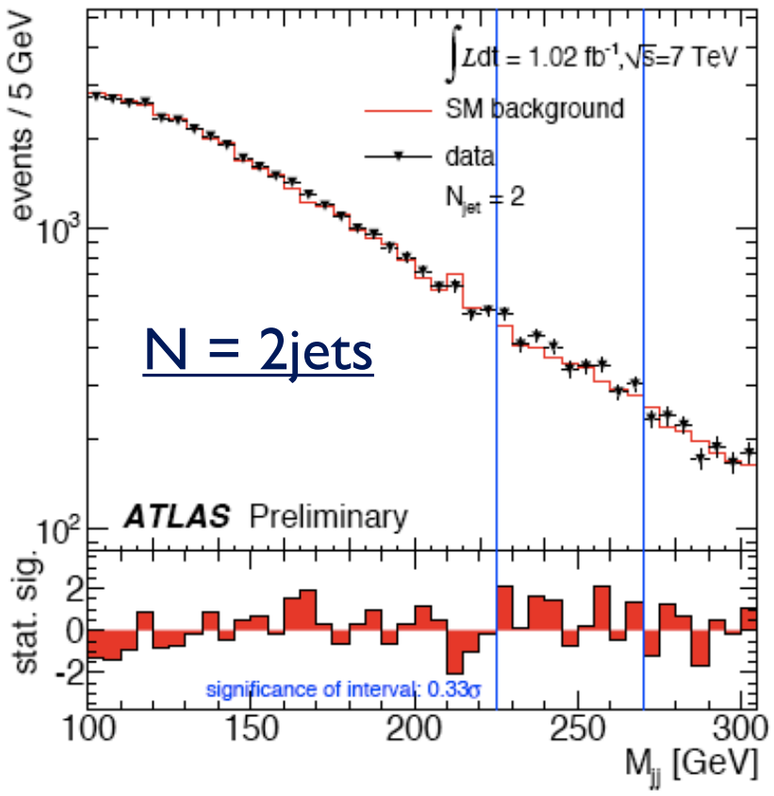
di-jet mass distribution for W+jets

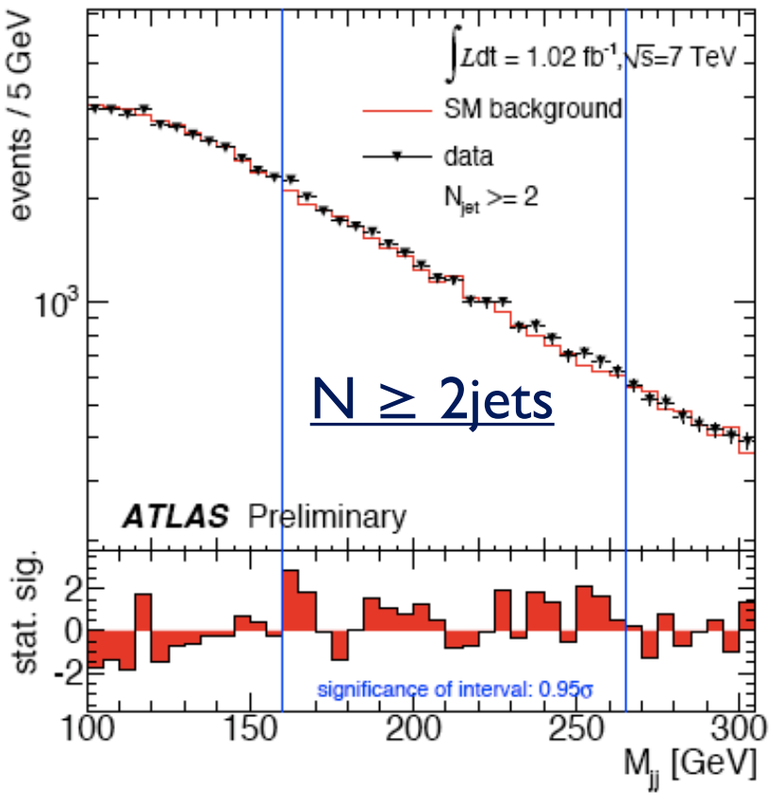
Using ≈ 1 fb^{-1} ATLAS sees no significant excess over the SM expectation in the di-jet invariant mass distribution for W+jets events

See Tetiana Hryn'ova's talk

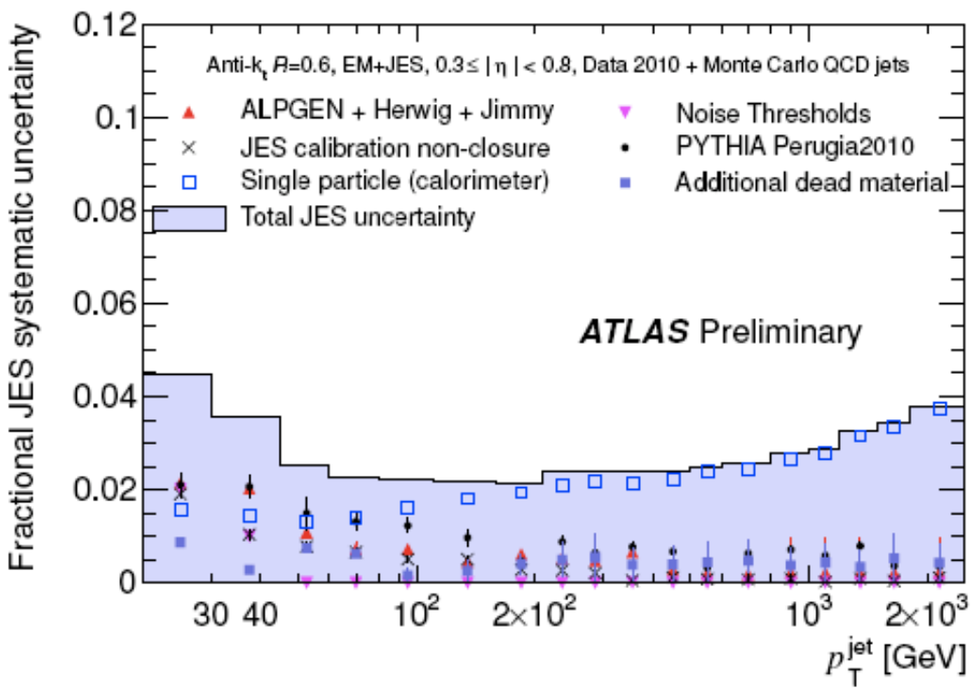


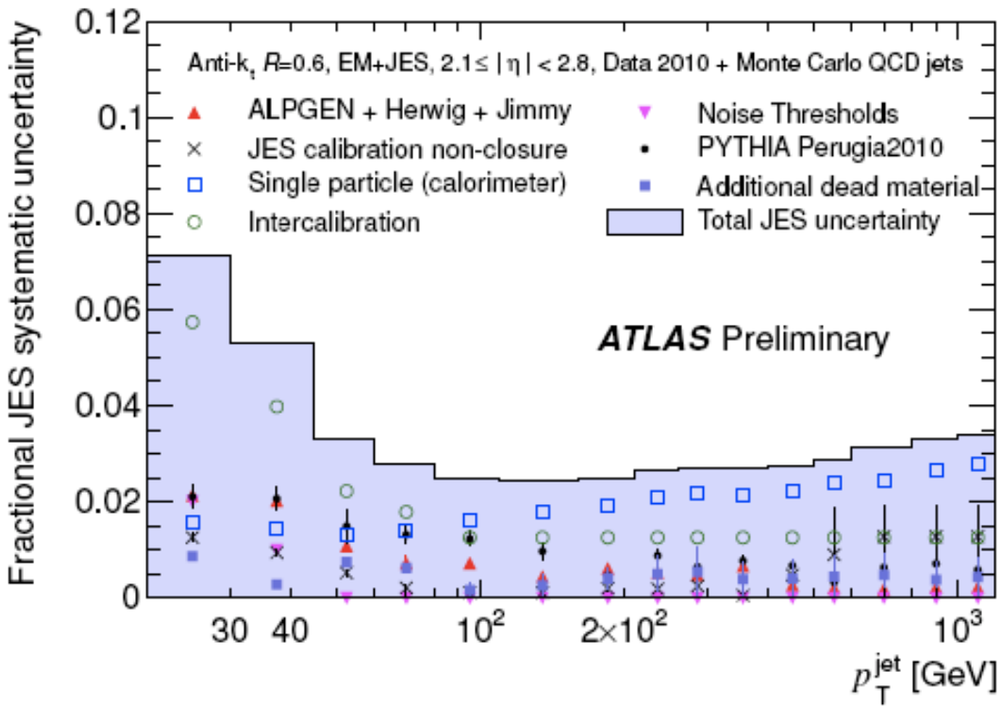






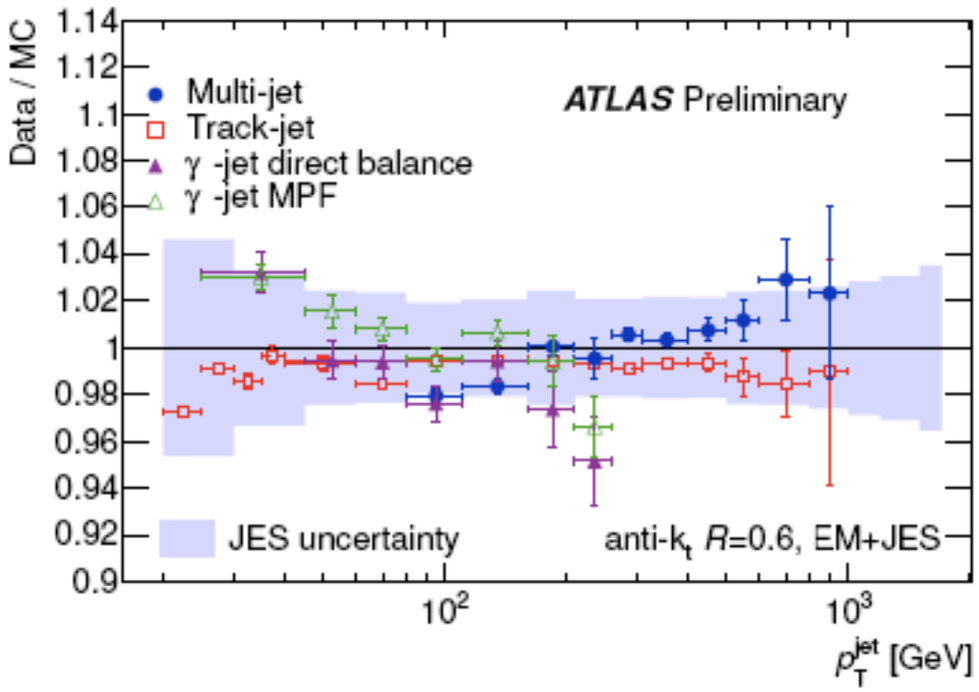
Jet energy scale systematics





More details in the presentation by Caterina Doglioni at this conference on:

"Jet energy scale uncertainty and resolution in the ATLAS Experiment"



W/Z + b-jets systematics

Z+b-jet cross sections systematics

Source	Templates (%)	Acceptance (%)
Both Electron and Muon		
b-tagging efficiency	1.7	9.1
SV0-mass templates	3.5	0.0
Model dependence	2.7	10.0
Jet Energy Scale	0.7	4.0
$t\bar{t}$ cross-section	2.0	0.0
MPI model	0.0	1.0
Electron only		
MC statistics	0.0	1.3
QCD	1.6	0.0
Electron efficiency	negl.	5.0
Total Electron	5.6	15.0
Muon only		
MC statistics	0.0	1.3
QCD	0.7	0.0
Muon efficiency	negl.	2.0
Total Muon	5.4	14.3
Total Systematic Uncertainty	+20.5% -15.6%	

W+b-jet cross sections systematics

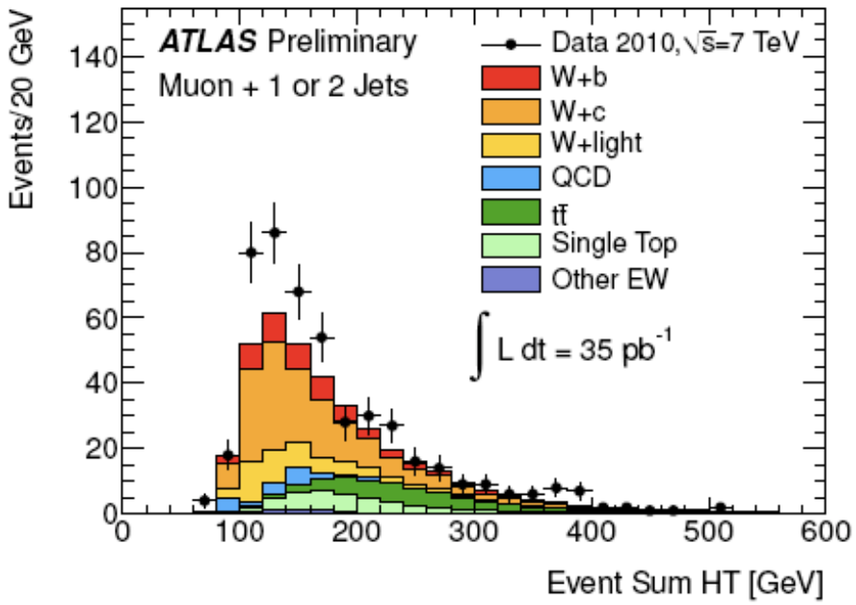
Cross Section [pb]									
	1 jet			2 jet			1+2 jet		
	μ	e	μ & e	μ	e	μ & e	μ	e	μ & e
Measured	3.5	5.5	4.5	6.2	5.1	5.7	9.7	10.7	10.2
Statistical	1.6	2.1	1.3	1.8	1.9	1.3	2.4	2.8	1.9
Systematic	1.1	1.7	1.3	1.5	1.5	1.4	2.4	3.0	2.6
Stat. ⊕ Syst.	1.9	2.7	1.8	2.3	2.4	1.9	3.4	4.1	3.2
Breakdown of total systematic uncertainty [%]									
b-tag efficiency	15	14	14	10	10	10	11	12	12
Template shapes	16	13	12	10	12	10	11	11	10
Jet uncertainties	9	6	7	7	10	8	7	7	7
QCD background	7	18	11	4	8	4	5	13	7
Missing Energy	1	1	1	2	2	1	1	1	1
$t\bar{t}$	9	6	7	12	16	13	11	11	11
single top	10	6	8	4	6	5	7	6	6
Lepton uncertainties	3	5	3	2	5	3	2	5	3
Model dependence	9	8	9	10	10	10	9	9	9
Pile-up	5	4	5	3	3	3	3	4	3
Luminosity	5	5	5	4	5	5	5	5	5

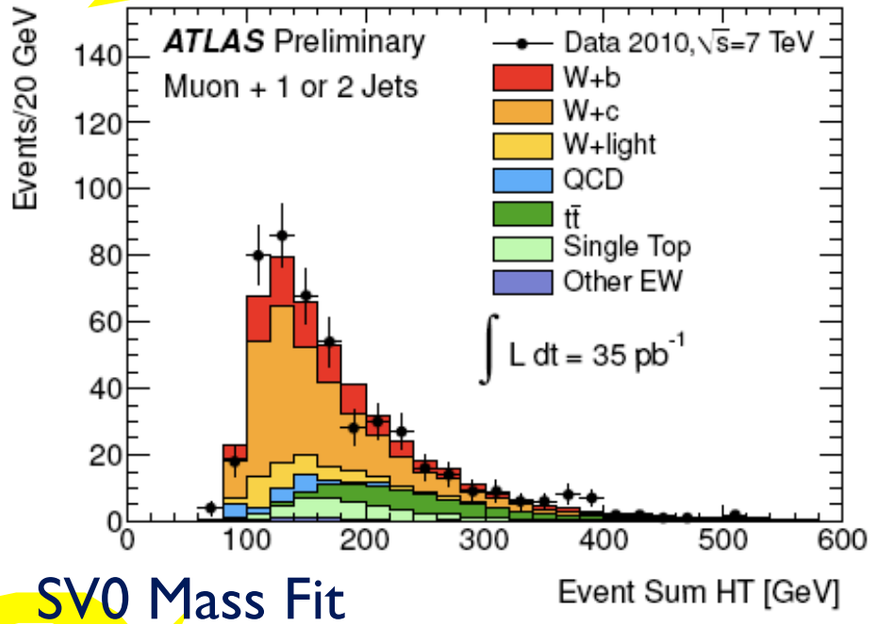
W + b-jets: is it really W+b?

- The top and single-top production represents a partially irreducible background as the final state has a W and a b-jet.
- The top background is estimated on data in the ≥4 jet bin, its contribution is projected to the lower jet multiplicity with MC. ISR/FSR varied to account for systematics in this extrapolation
- Single-top has a too small cross section to be estimated on data. However good agreement is found between data and predictions in the kinematic distribution where top and single-top have a a different shape than W+b-jets

Normalized to MC expectation

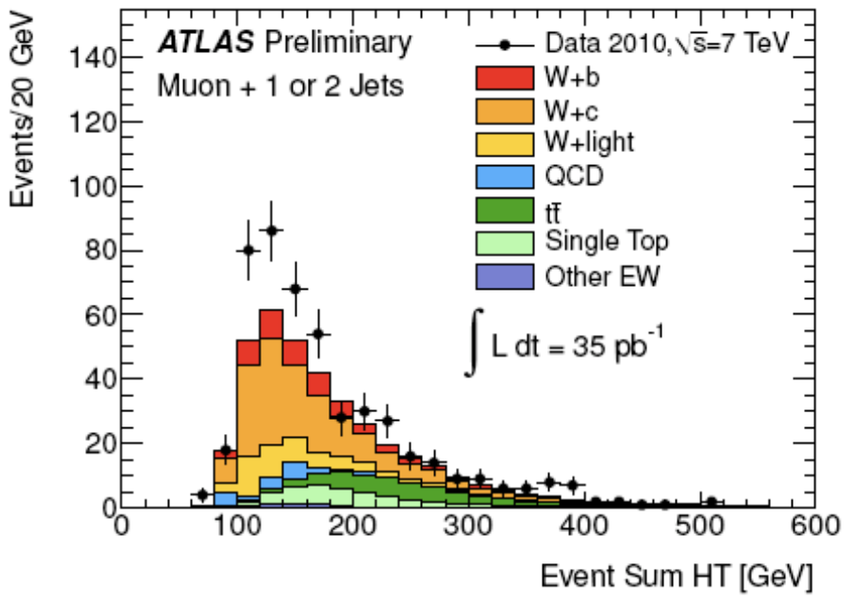
SV0 Mass Fit

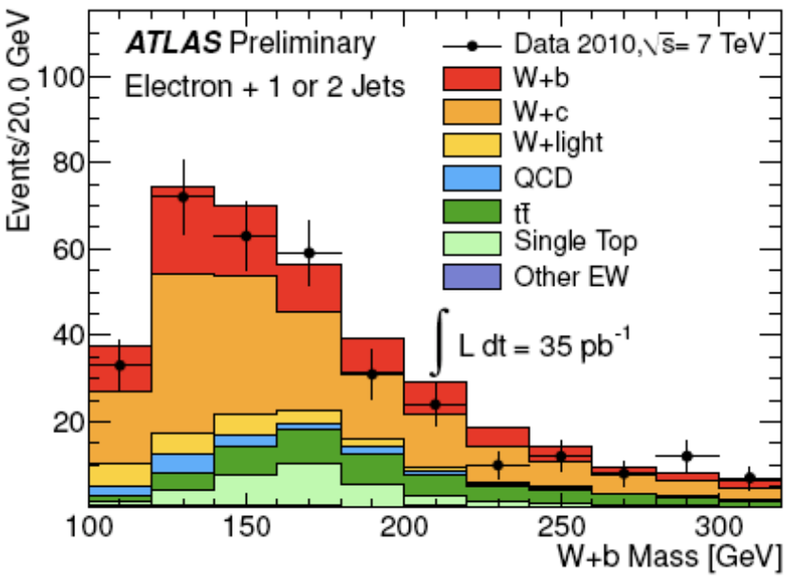




Normalized to MC expectation

SV0 Mass Fit





Z + b-jets: additional distributions