W/Z + jets production at the LHC

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Particle Physics and Cosmology

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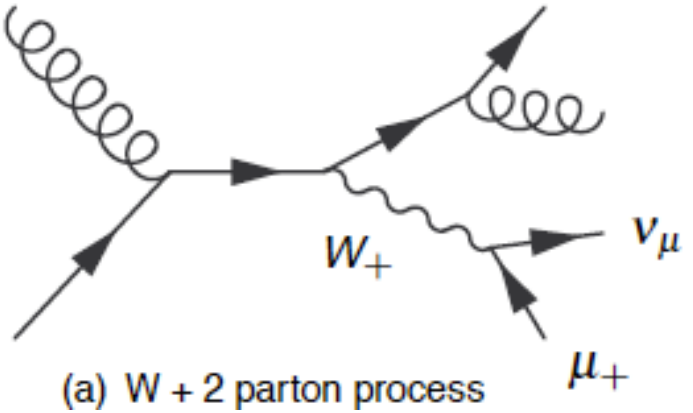
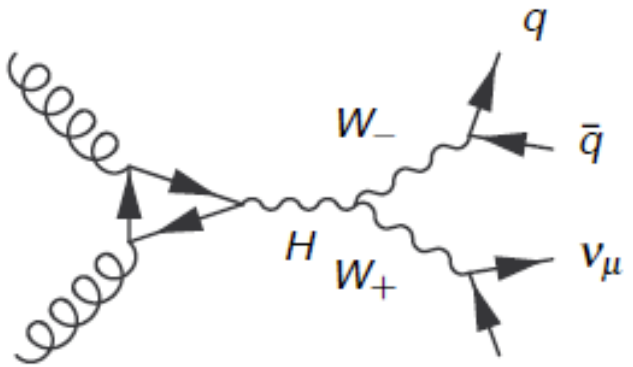
(On behalf of the ATLAS and CMS collaboration)

Motivation

- Test of perturbative QCD
  - comparison with Parton Shower (PS) Monte Carlo (Pythia)
  - comparison with matrix element + PS MC (Alpgen, Sherpa, MadGraph)
  - Comparison with NLO predictions (MCFM, Blackhat-Sherpa)
- W/Z + jet is an important background
  - for top
  - for Higgs searches
  - for beyond Standard Model (SUSY) signals



(a) W + 2 parton process

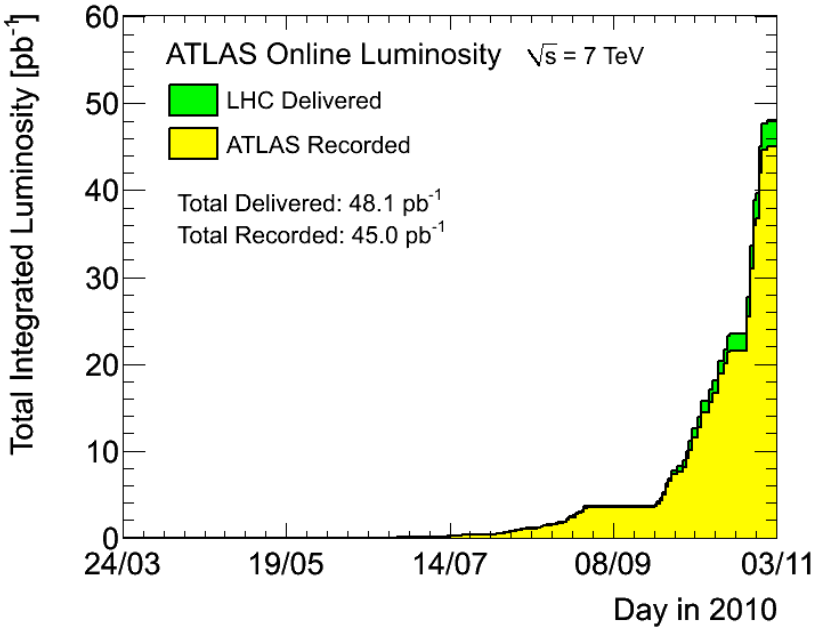


(b) SM Higgs production, where $H \to WW \to l\nu q\bar{q}$

2010 dataset

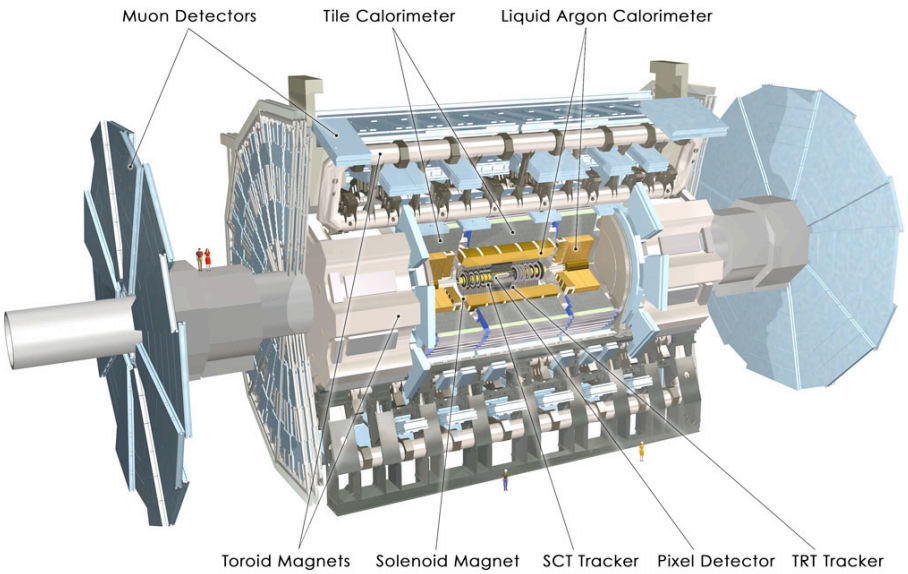
- LHC proton-proton collider:
  - E_{cm} = 7 TeV
  - Peak luminosity: 2.1 x 10^{32} $cm^{-2}s^{-1}$
  - LHC delivered data in 2010: 48 pb^{-1}
  - Data used for the analysis:

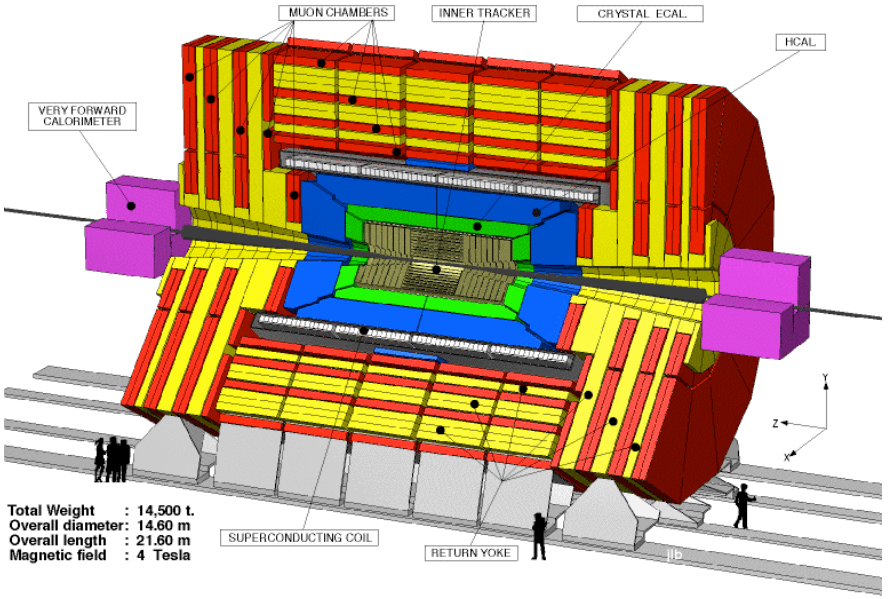
    ATLAS: 33 pb^{-1} CMS: 36 pb^{-1}



- Measurement: (V=W,Z)
  - Cross section ratios: $\sigma(V+ \geq (N+1)\ jets)/\sigma(V+ \geq N\ jets)$ N = 0,…,4
  - Differential cross section: $d\sigma(V+ \geq (N+1)\ jets)/dp_T(N^{th}\ jet)$

ATLAS and CMS detector

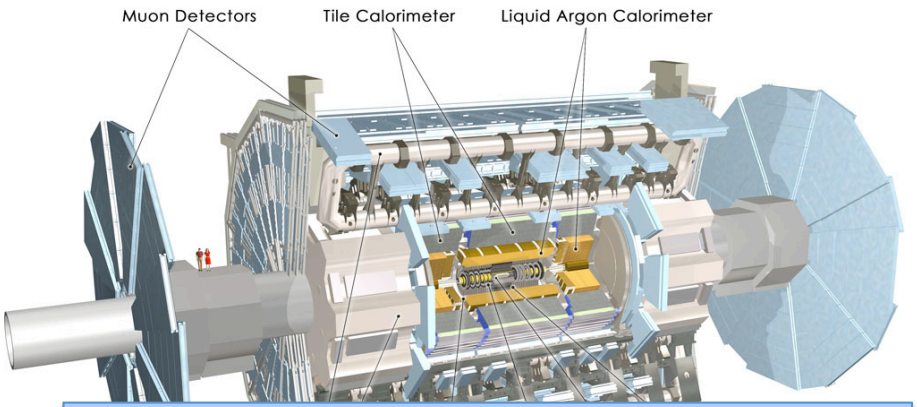


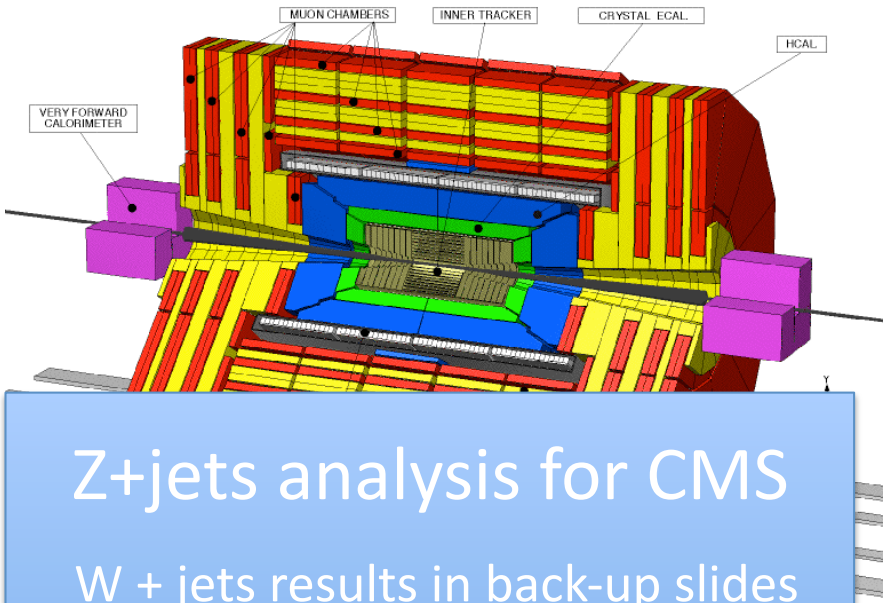


- Inner detector:
  - Pixel and SCT $|\eta| < 2.4$
  - TRT $|\eta| < 2.0$
- Calorimeter:
  - Lar + Tile $|\eta| < 3.2$, FCAL $|\eta| < 4.9$
- Muon spectrometer:
  - MDT + CSC $|\eta| < 2.7$
  - RPC+TGC $|\eta| < 2.4$ (trigger chambers)

- Inner tracker:
  - Si Pixel, Si strip $|\eta| < 2.5$
- Calorimeter:
  - Tg crystals $|\eta| < 3.0$
  - brass/scintillator $|\eta| < 3.0$
- Muon system:
  - DT+CSC + RPC $|\eta| < 2.4$

ATLAS and CMS detector





W+jets analysis for ATLAS

Z + jets results in back-up slides

ATLAS-CONF-2011-042

ATLAS-CONF-2011-060

ATLAS public results:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

Z+jets analysis for CMS

W + jets results in back-up slides

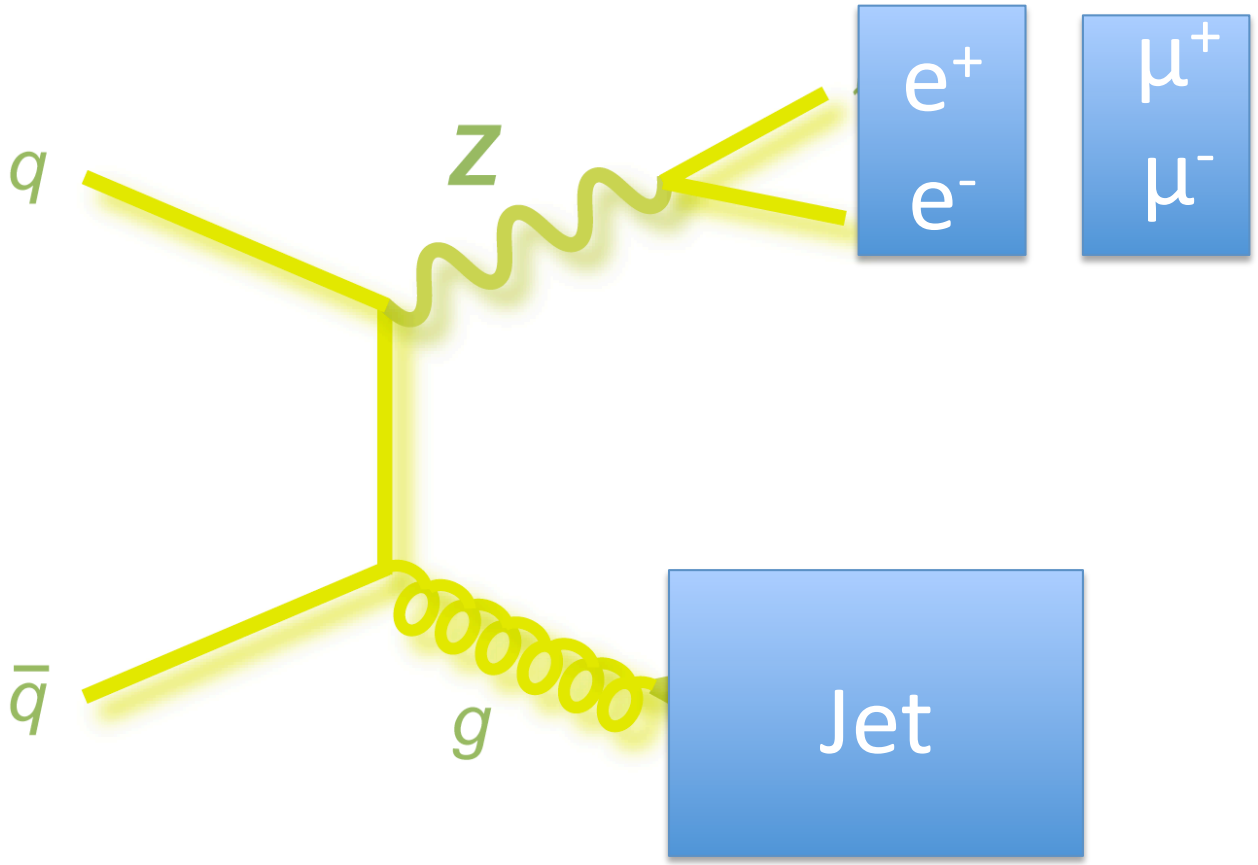
CMS PAS-EWK 10-012

CMS PAS-EWK 10-015

CMS public results:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Z + jets



Z + jets event selection

First electron:
- $p_T > 20$ GeV
- $|\eta| < 2.5$ (No: $1.44<|\eta|<1.57$)
- Matches lepton in the trigger
- Isolation

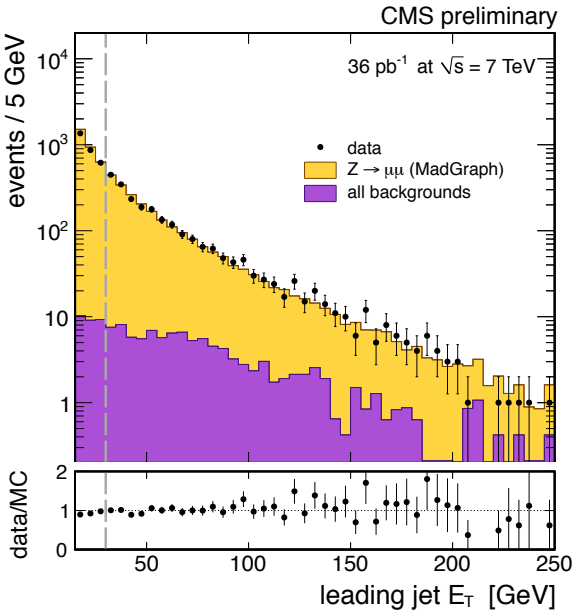
First muon:
- $p_T > 20$ GeV
- $|\eta| < 2.1$
- Matches lepton in the trigger
- Isolation

Z event

-> search second lepton with:
- $p_T > 10$ GeV
- $|\eta_e|$ as 1.st e , μ: $|\eta_\mu|<2.4$
- 60 GeV < M_{l+l-} < 120 GeV

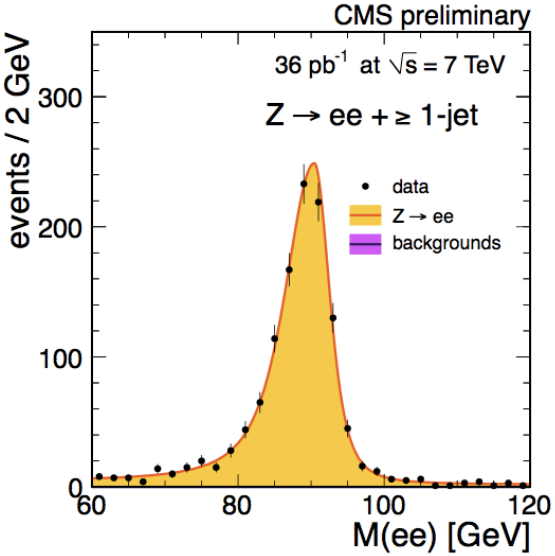
• Jet selection:
- Anti-k_t jet algorithm with R = 0.5
  (using ''Particle Flow'' objects, no muons)
- $E_T > 30$ GeV , $|\eta| < 2.4$ (tracker acceptance)

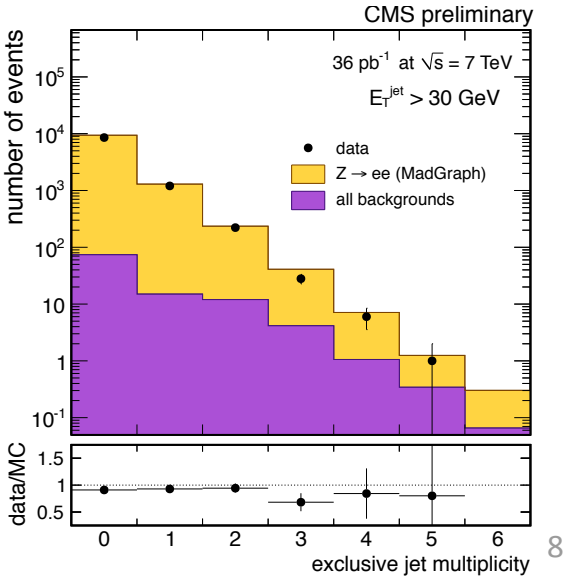
• Pile-up jets and overlap removal:
- remove off-set energy from underlying event
- ΔR(ele,jet) > 0.3



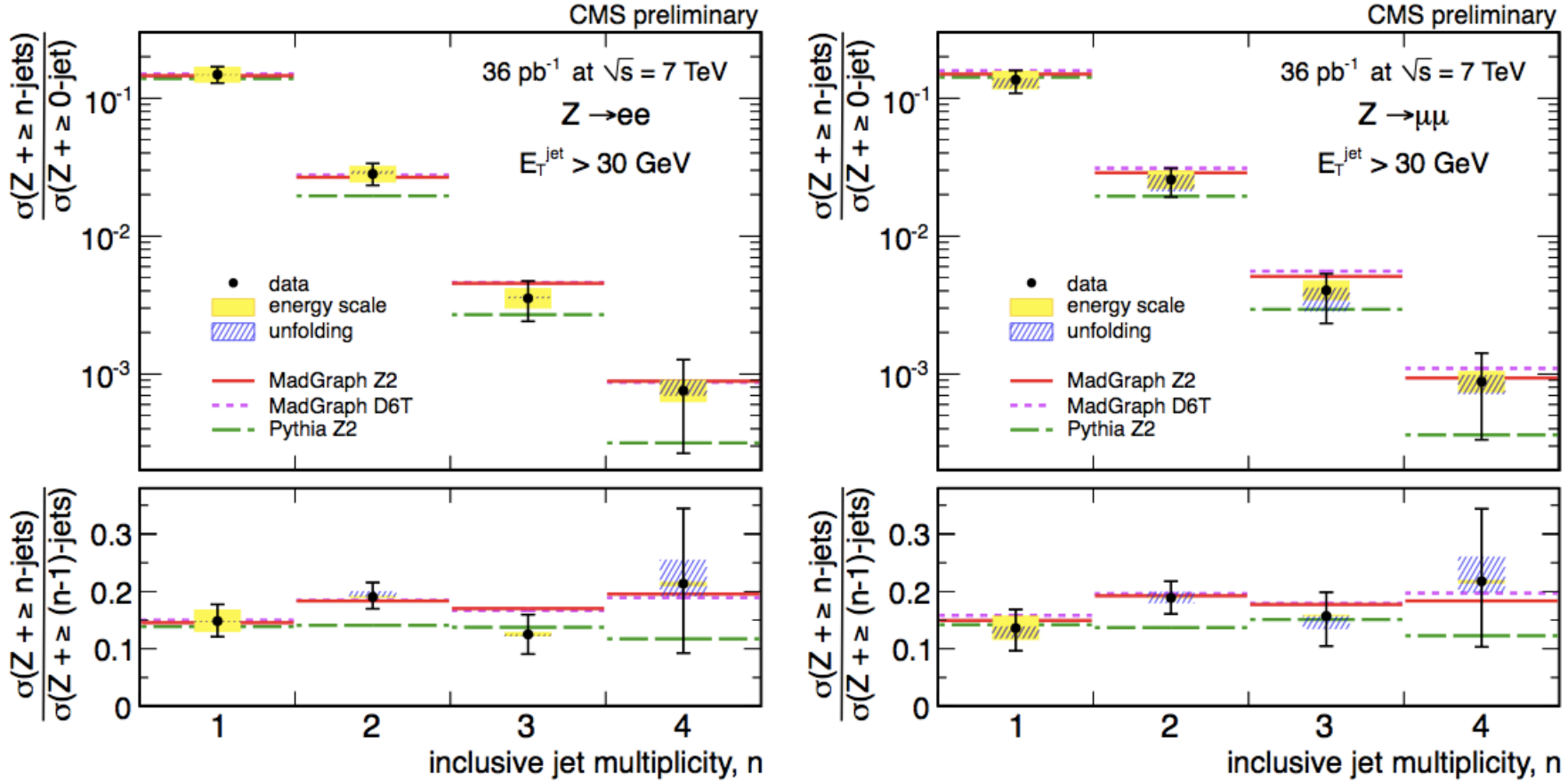
Z + jets analysis

- Signal extraction:
  - unbinned maximum likelihood fit in M_{ll}
- Efficiency corrections:
  - tag and probe from Z/γ* + jets data sample
  - factorized as:
    - Reconstruction
    - Identification (N_{jet} dependence due to isolat. cut)
    - Trigger
- Migration among jet bin:
  - Migration matrix R(n_{Reco},n_{truth}) from MC simulation
  - Single Value Decomposition (SVD) for ''unsmearing'' N_{jet} distribution





Z + jets cross section ratio

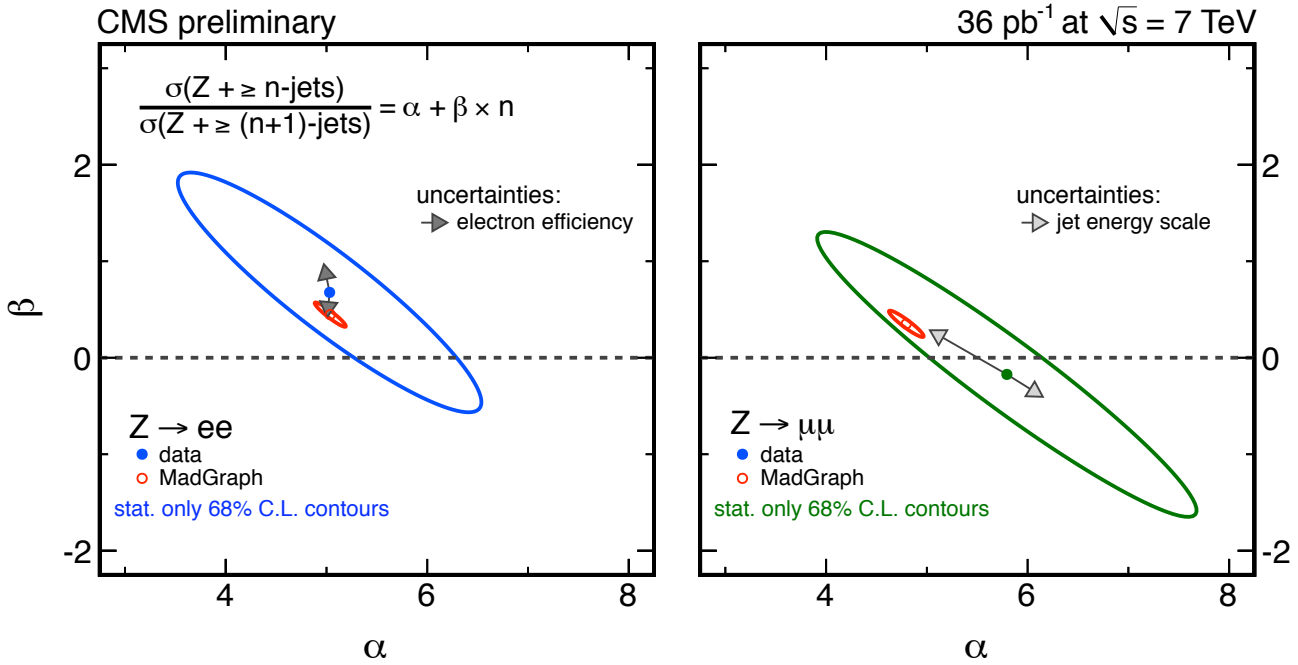


Excellent agreement for matrix element plus parton shower MC (MadGraph) and compatible with parton shower alone (Pythia)

Berends-Giele scaling

Berends-Giele scaling: $C_n = \frac{\sigma_n}{\sigma_{n+1}}$ ≈ constant for n ≥ 1

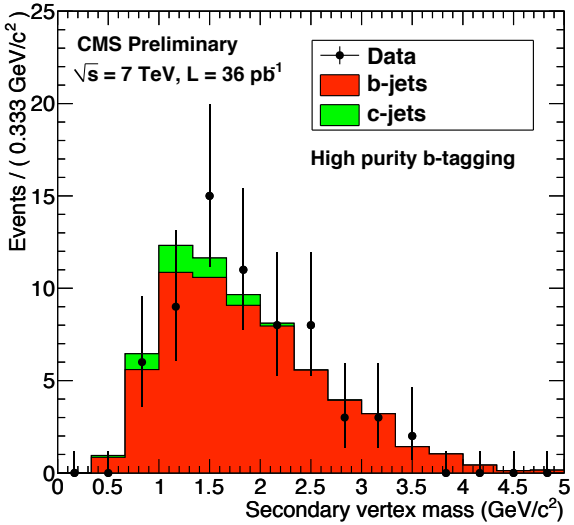
- Test scaling by fitting: $C_n = \alpha + \beta n$
- Taking into account correlation between σ_n and migrations between jet bins



Z + b jets

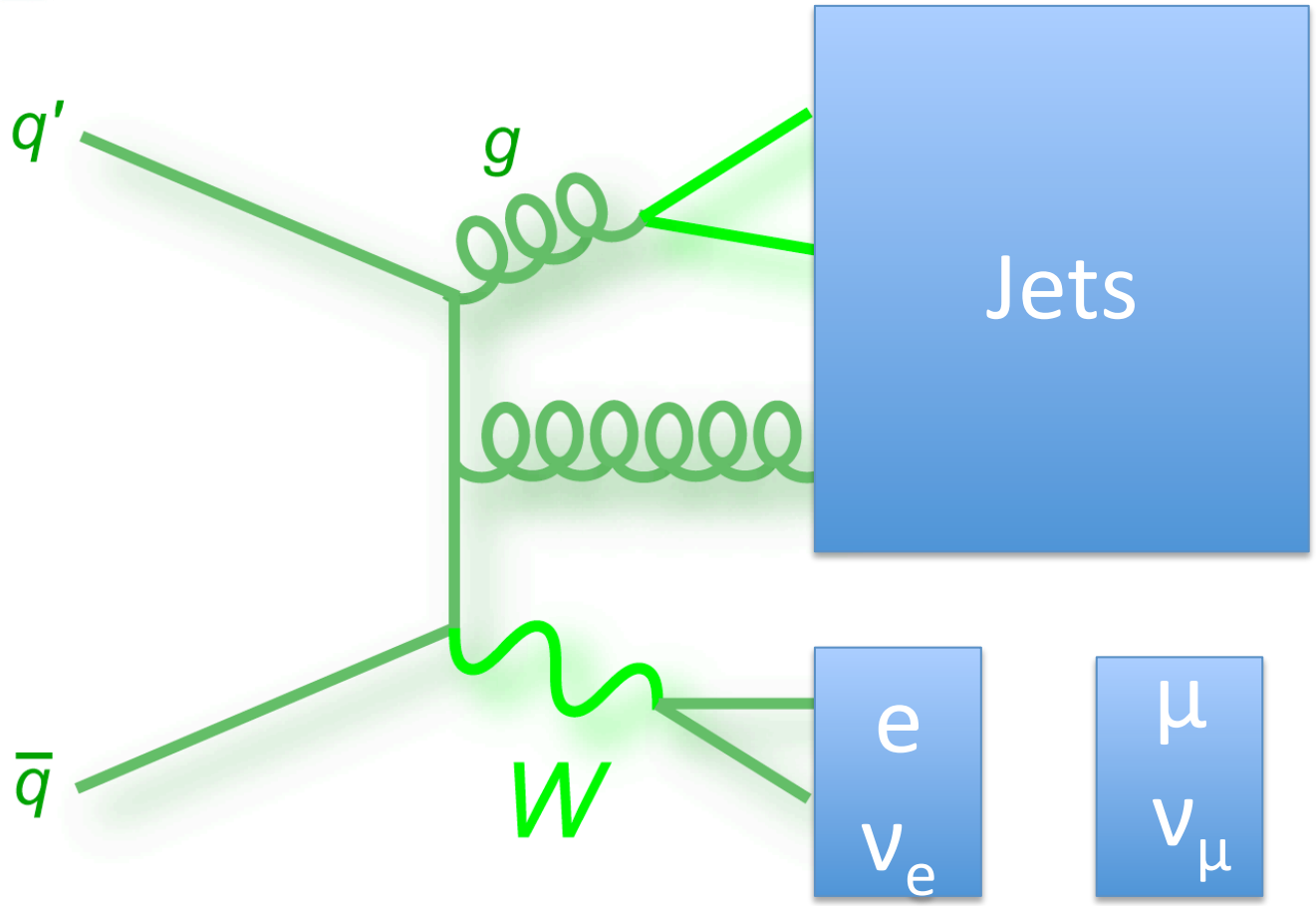
- Event selection:
  - at least one Z (p_T^e> 25 GeV , p_T^μ >20 GeV)
  - at least one jet with E_T > 25 GeV, $|\eta|$< 2.1, $\Delta R(l,jet) > 0.5$
  - E_T^{miss} < 40 GeV (tt-bar rejection)
  - b-jet tagging algorithm (secondary vertex)

- Z + b purity: 88% ± 11% (data), 82% ± 4% (MC)
  - extracted from binned likelihood fit to secondary vertex mass in data events



σ(Z + b)/σ(Z + j)	Z -> ee (±stat±syst) [%]	Z -> μμ (±stat±syst) [%]
data	5.4 ±1.0 ±1.2	4.6 ±0.8 ±1.1
MadGraph	5.1 ±0.2 ±0.2 ±0.6 (theory)	5.3 ±0.1 ±0.2 ±0.6 (theory)
MCFM	4.3 ±0.5 (theory)	4.7 ±0.5 (theory)

W + jets



W + jets event selection

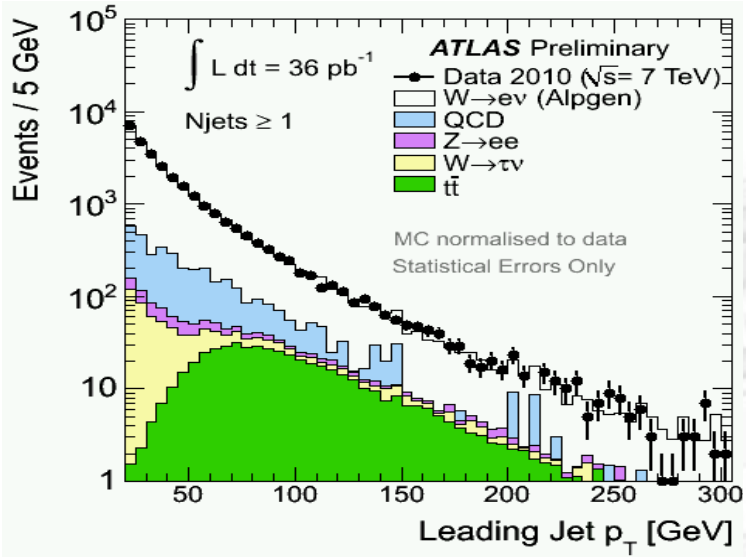
Electron:
- $E_T > 20$ GeV
- $|\eta| < 2.47$ (No: $1.37<|\eta|<1.52$)
- Isolation

Muon:
- $p_T > 20$ GeV
- $|\eta| < 2.4$
- Isolation

W event:
- exactly one lepton
- $E_T^{miss} > 25$ GeV
- $m_T > 40$ GeV

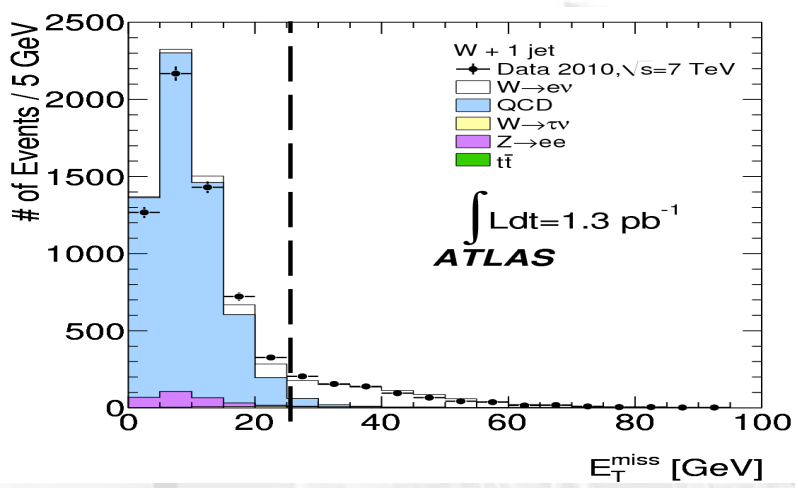
• Jet selection:
- Anti-k_t jet algorithm with R = 0.4
  (all particles with τ>10 ps, no W/Z leptons)
- $p_T > 20$ GeV , $|y| < 2.8$

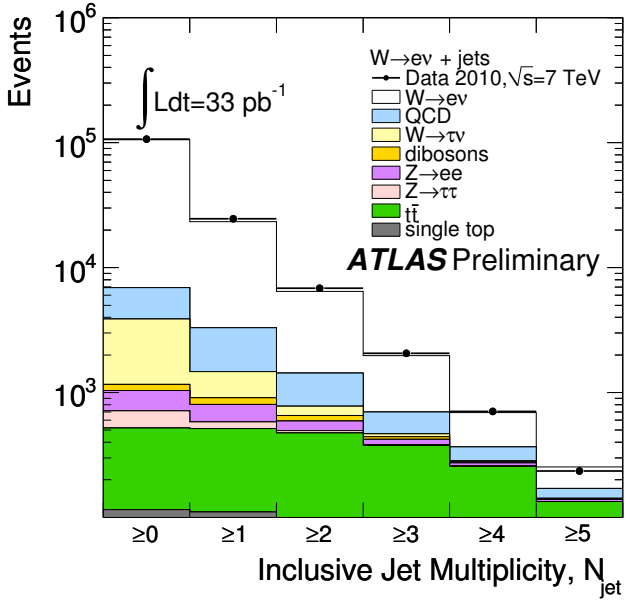
• Pile-up jets and overlap removal:
- use percent of tracks belonging to primary vertex
- ΔR(l,jet) > 0.5 (l=e, μ)



W + jets analysis

- Signal extraction:
  - multi-jet (QCD) with data-driven method (template fit in control region)
  - electroweak and tt-bar background from MC
- Background:
  - low N_{jet}: multi-jet (e), Z->μμ, W->τν (μ)
  - high N_{jet} : tt-bar (e and μ)
- Correction for detector effect:
  - Bin-by-bin correction method
- Systematic uncertainty:
  - jet energy scale (≈10%)
  - luminosity (≈4 %)
  - Pile-up removal (≈5%)





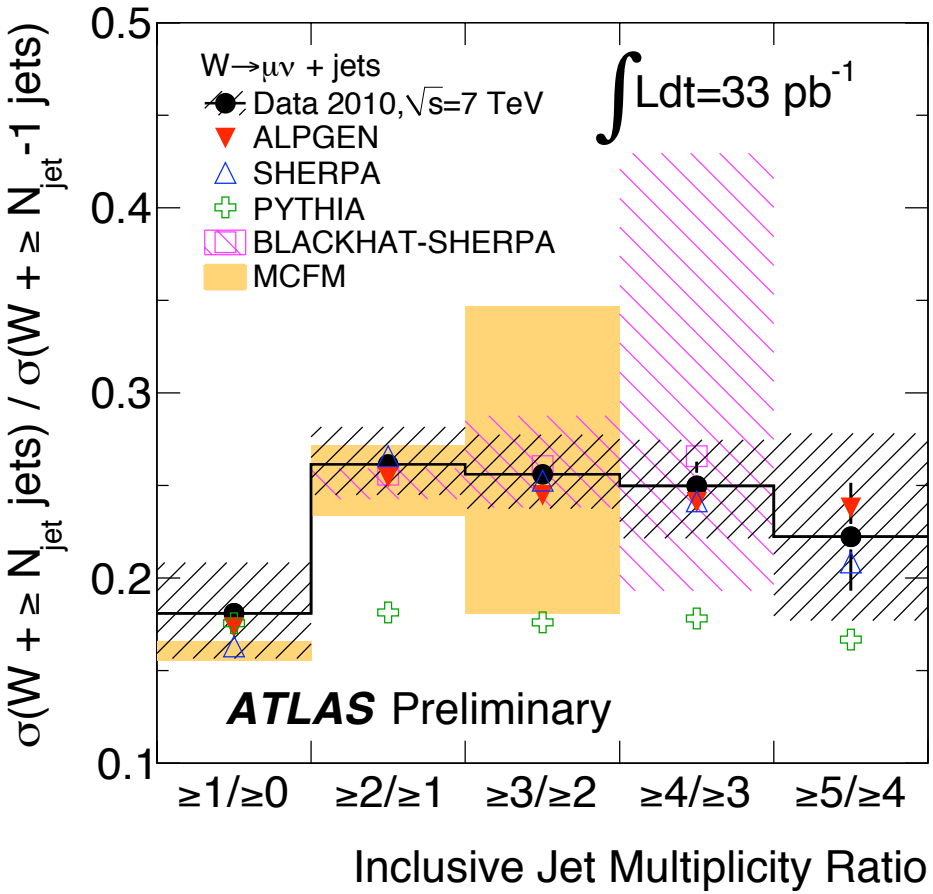
W + jets cross section ratio

- Ratio more robust against systematic uncertainties (lumi, JES)
- Good agreement with predictions at NLO from MCFM (up to W+ 2 jet)
- Good agreement with predictions at NLO (up to W+ 3 jet) from Blackhat-Sherpa

(NLO predictions corrected to particle level)

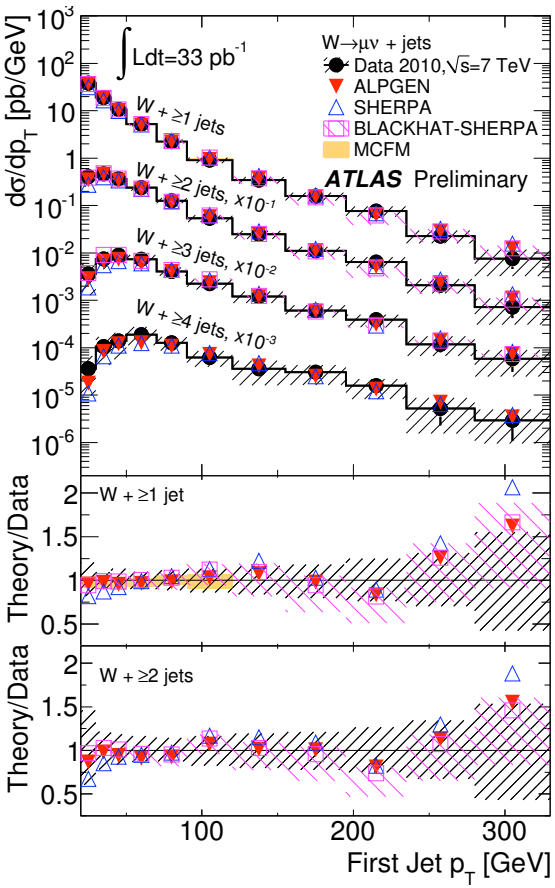
-> first time W + 3 jets NLO vs LHC data

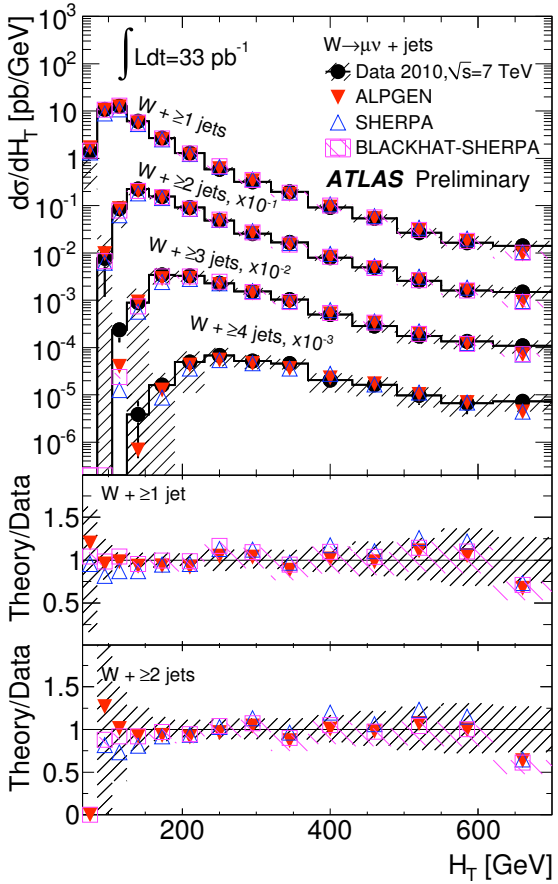
- Good agreement with predictions from multi-parton ME +PS (Alpgen, Sherpa)



- Poor agreement with Pythia (LO + PS) for events with more than 1 jet

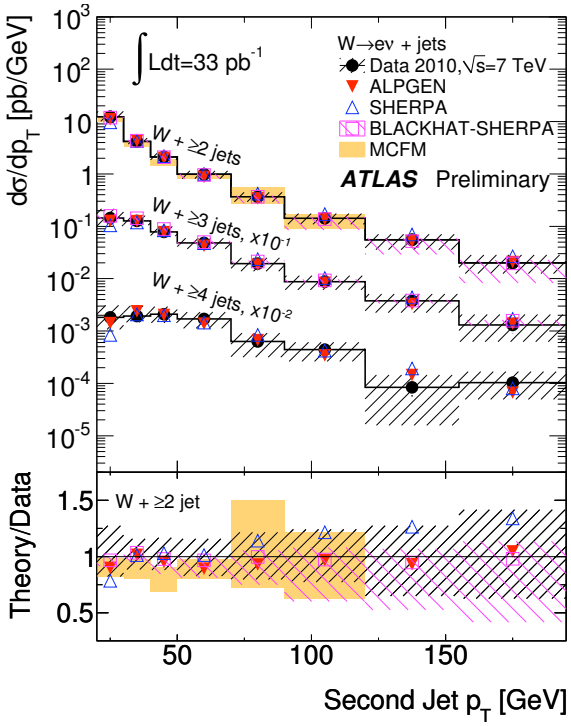
W + jets differential cross sections

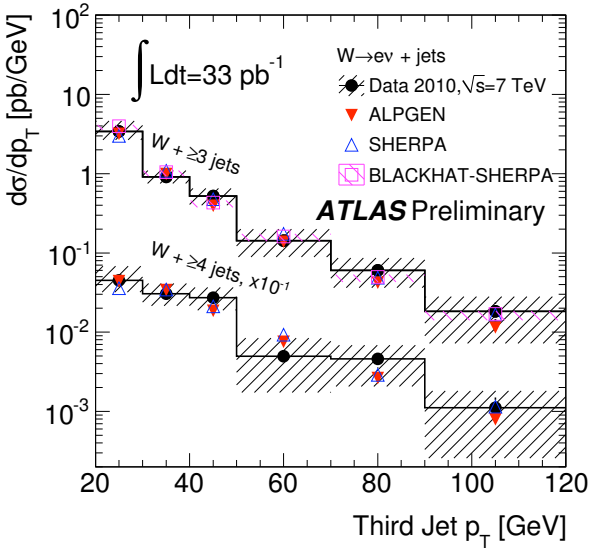


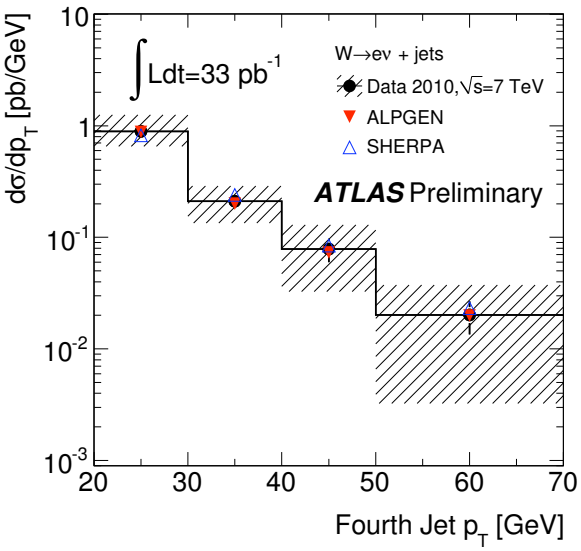


- Differential cross section measured for each jet multiplicity separately wrt to jet p_T and $H_T = \Sigma_i\, p_T^{jet,i} + p_T^{l} + p_T^{\nu}$ (characteristic scale of ME+PS MCs)
- Good agreement with NLO MC (MCFM and Blackhat-Sherpa) predictions and ME +PS MC predicitions (Alpgen, Sherpa)

W + jets differential cross sections







Good agreement with MC ME+PS predictions
and with NLO (Blackhat-Sherpa)

Conclusion

- W/Z + jet cross section ratios and differential cross sections measured with the full 2010 data set with the ATLAS and CMS detector
- Cross sections given in restricted kinematical region covered by the detector acceptance and corrected for all detector effects
- Direct measurement of the Berends-Giele scaling, observation of Z+b jet and calculation of the ratio σ(Z+ b jet)/σ(Z + jet)
- Good agreement with NLO predictions and with matrix element plus parton shower, poor agreement with parton shower alone for more than 1 jet

ATLAS public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic
CMS public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

ATLAS: W + jets: ATLAS-CONF-2011-060 Z + jets : ATLAS-CONF-2011-042

CMS: W/Z + jets: CMS PAS-EWK-10-012 Z + b jets : CMS PAS EWK-10-015

BACK UP

W + jets results (CMS)

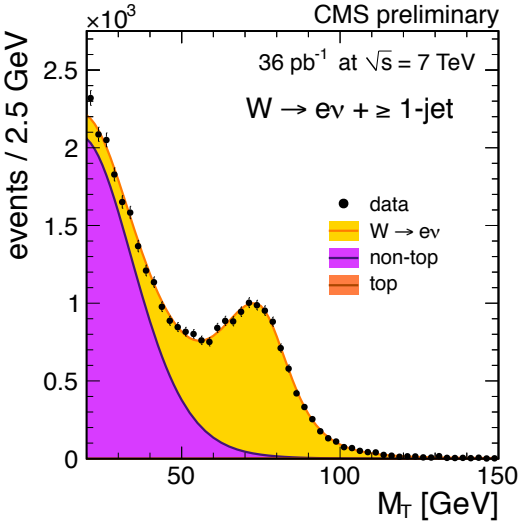
W + jets background estimation

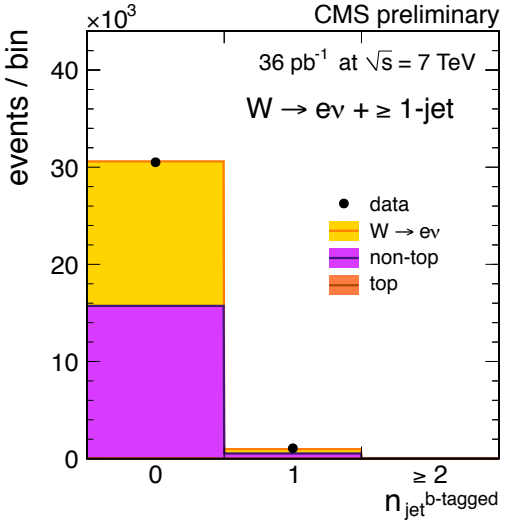
Electron and muon selection like for the Z+ jets analysis

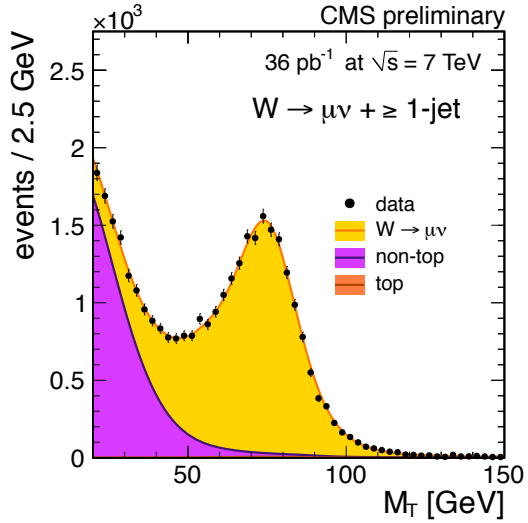
Jet selection:
same as for the Z + jets analysis

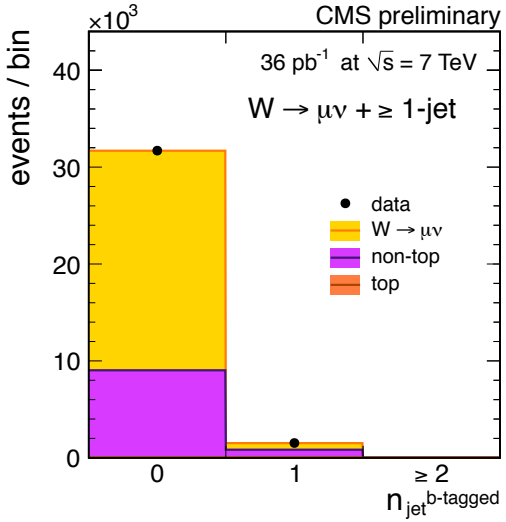
W selection:
- No second lepton
- $M_T > 20$ GeV

Signal extraction:
- Unbinned maximum likelihood fit in M_T and n-b tag (to control top)

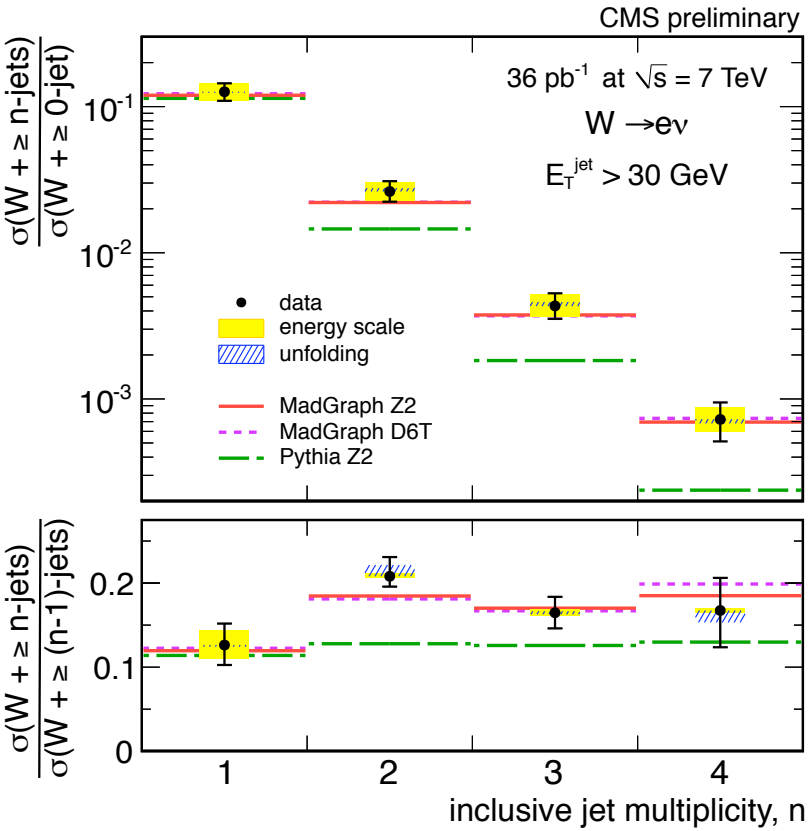


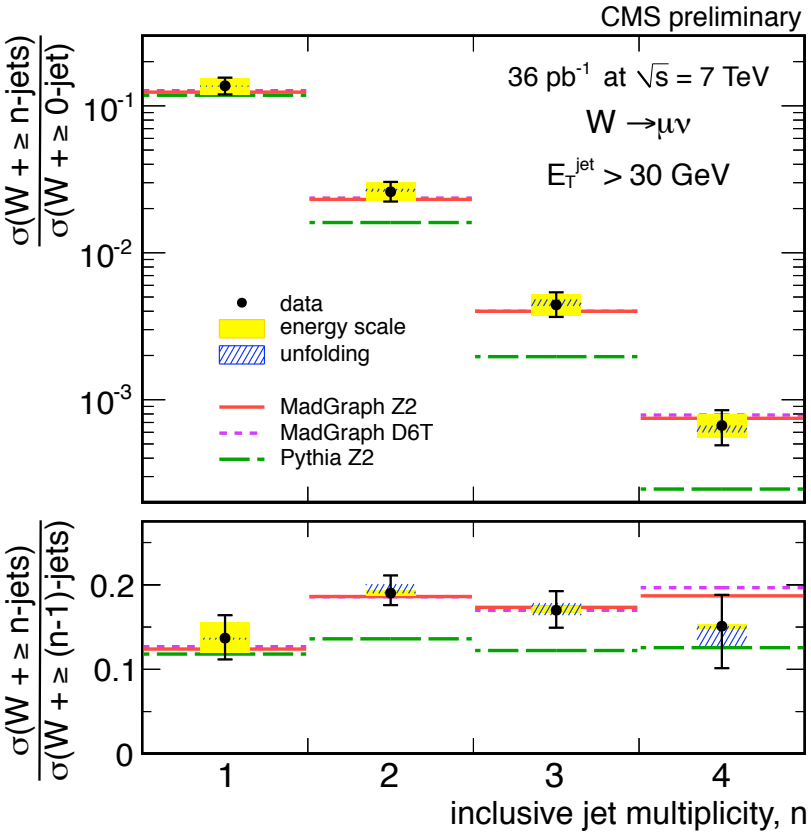




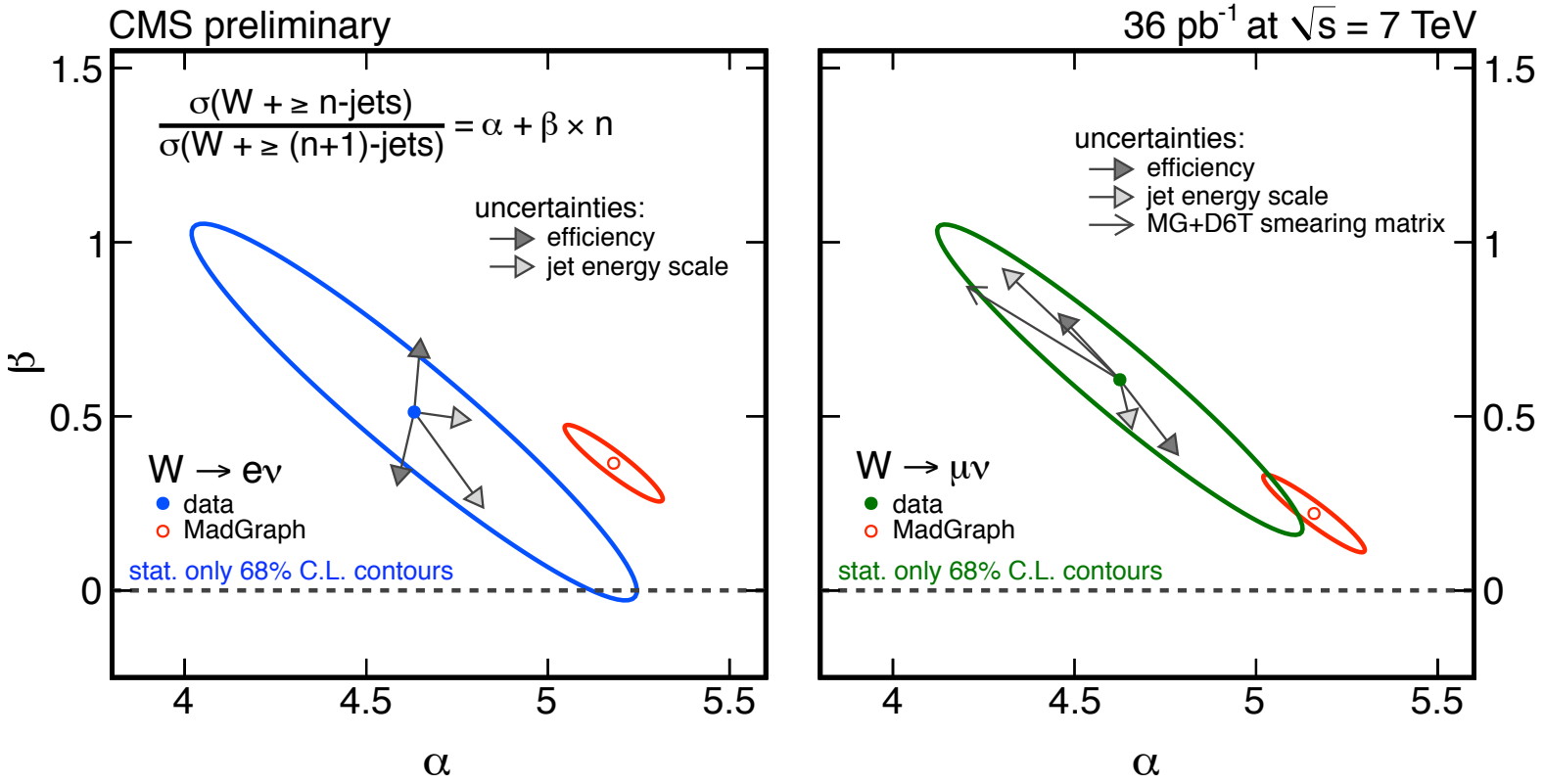


W + jets cross section ratio





Berends-Giele scaling (CMS)



Z + jets results (ATLAS)

Z + jets background estimation

Muon and electron selection
as for the W selection

Jets:

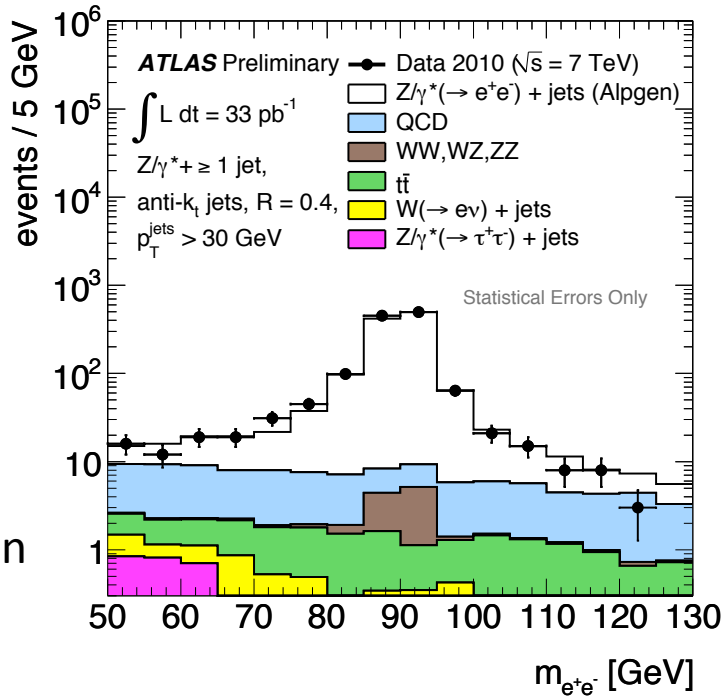
$p_T > 30$ GeV

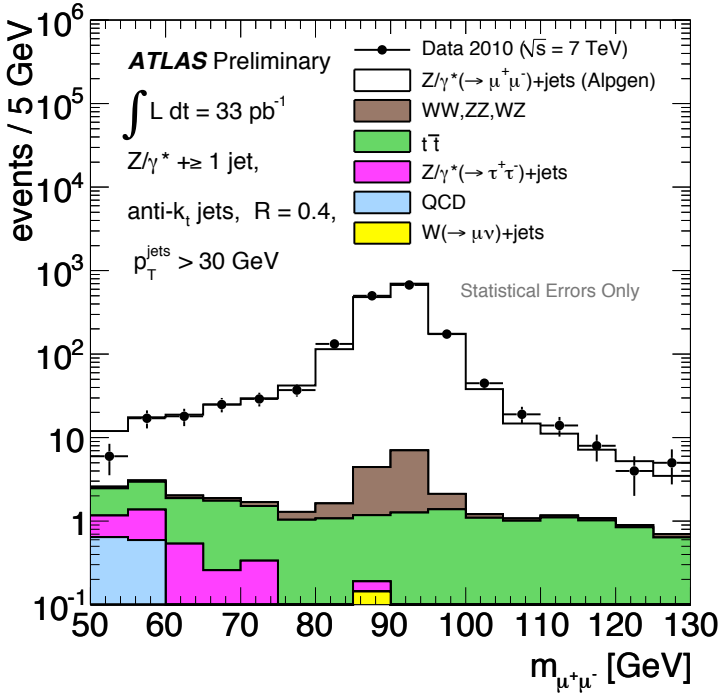
$|\eta| < 2.8$

Z event:

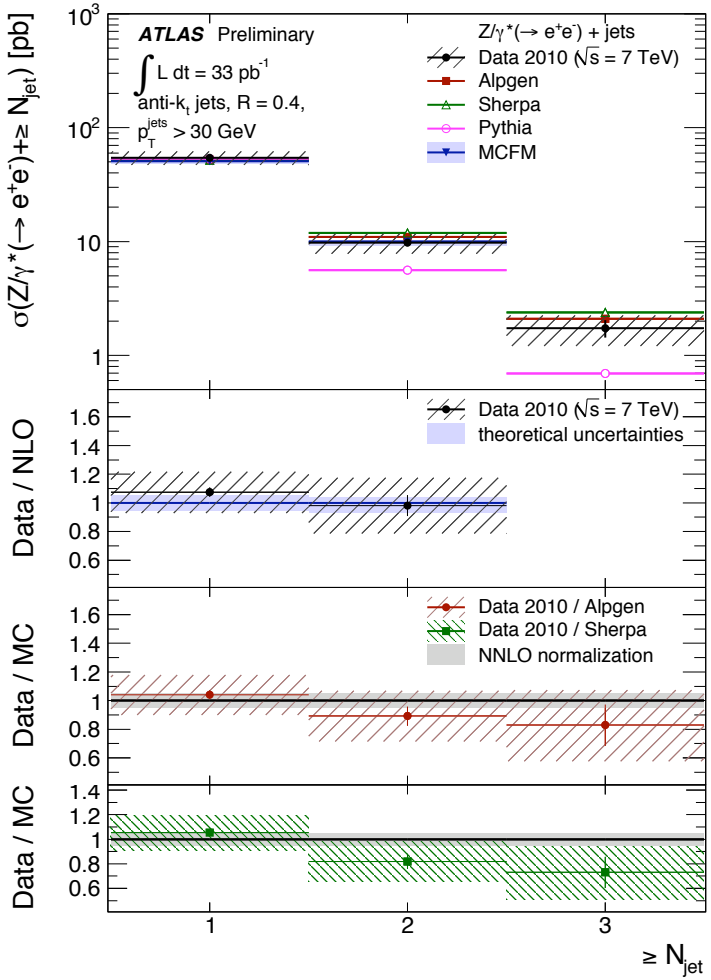
Exactly two opposite sign leptons

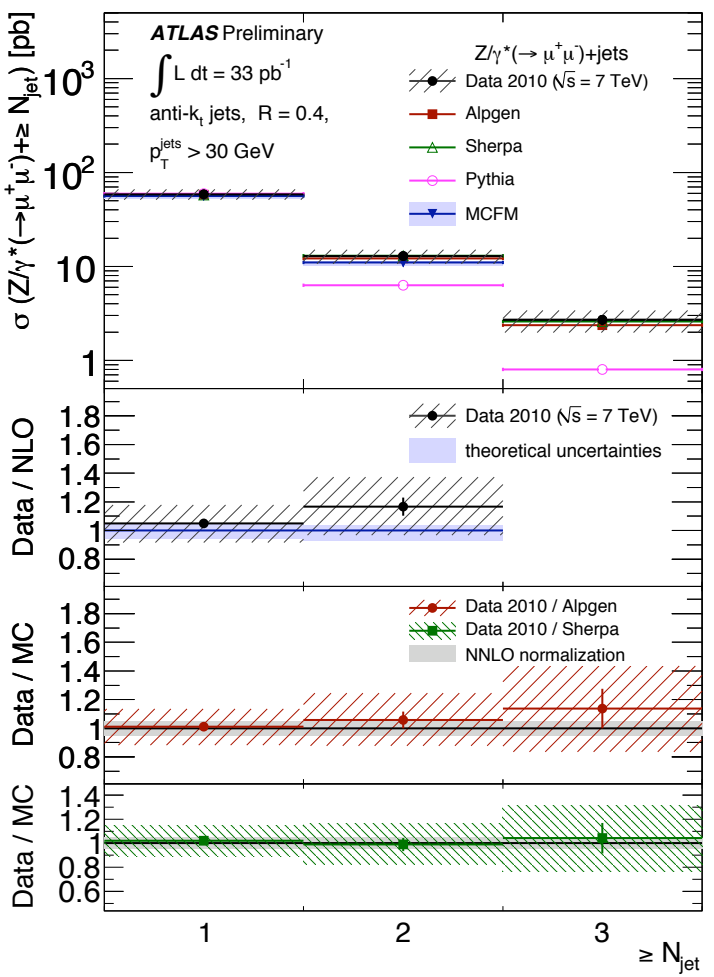
66 GeV < M_{ll} < 116 GeV



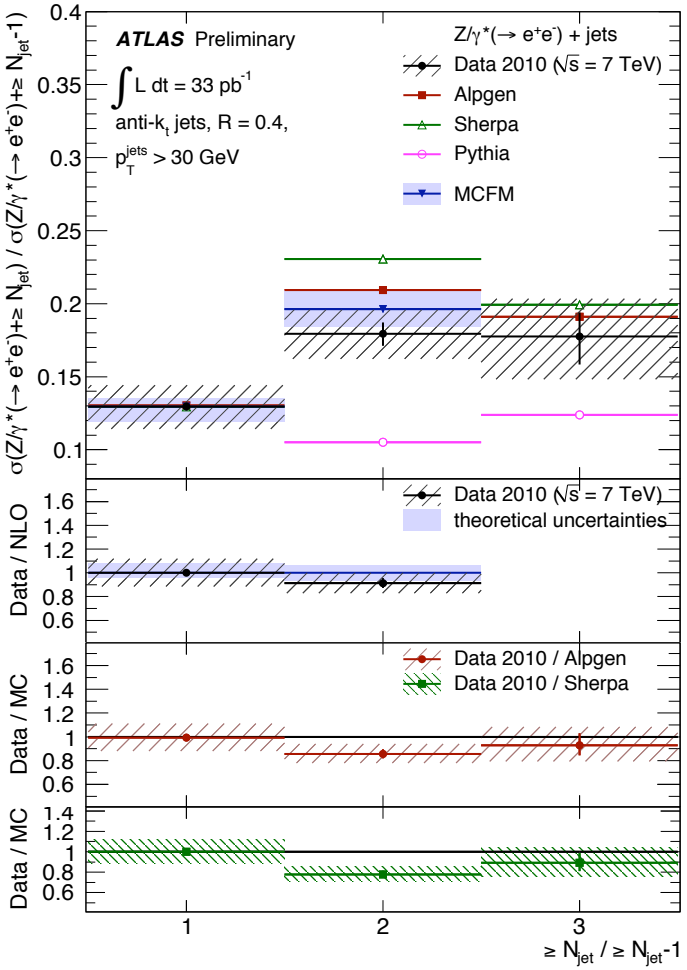


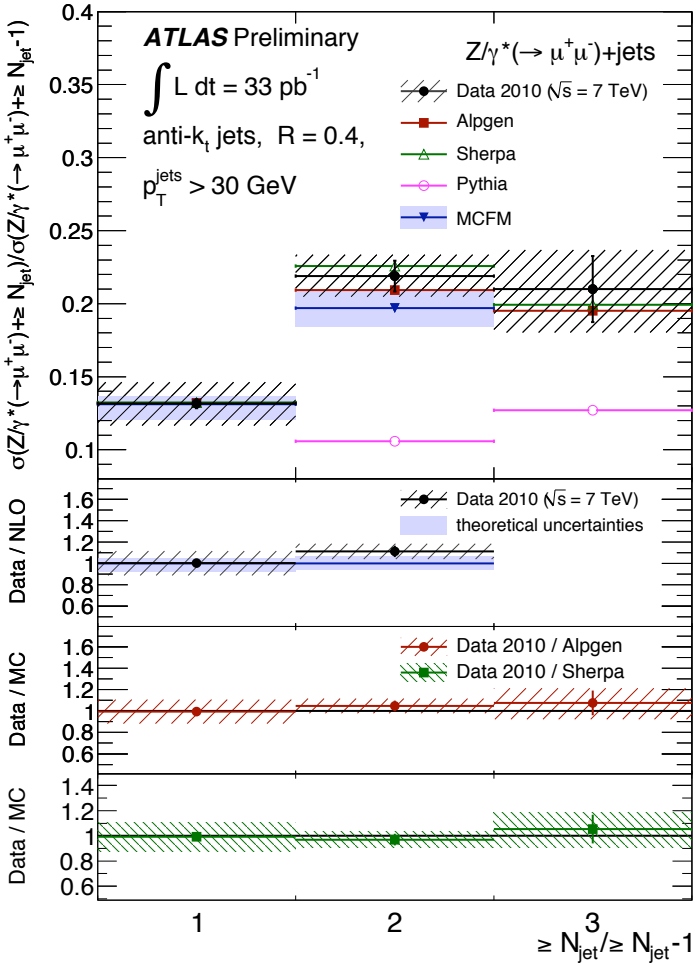
Z + jets inclusive cross section



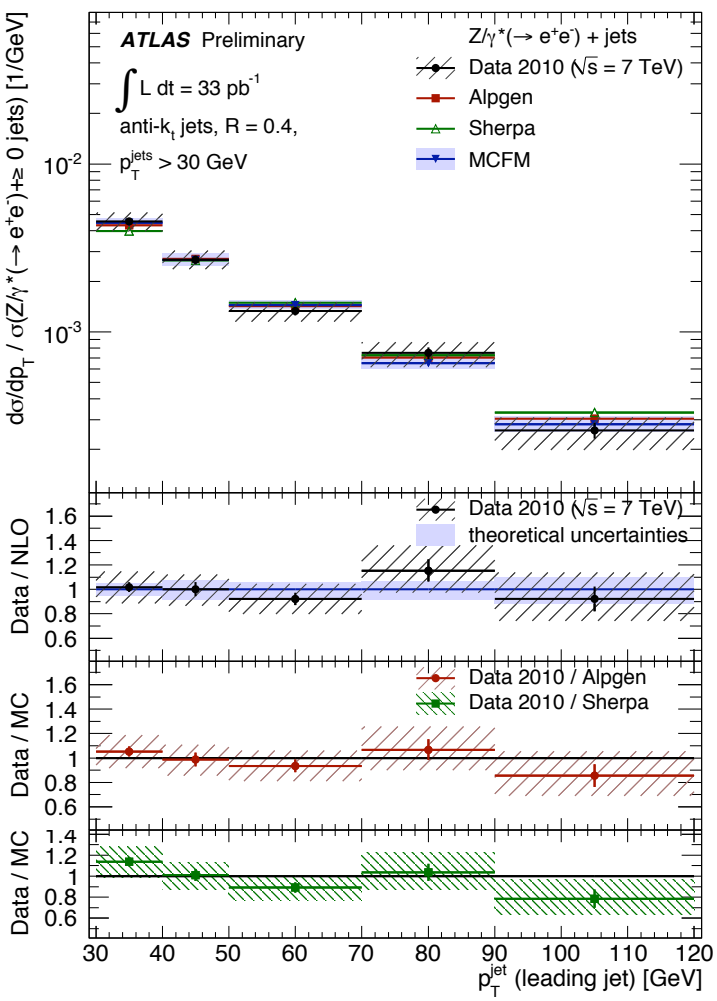


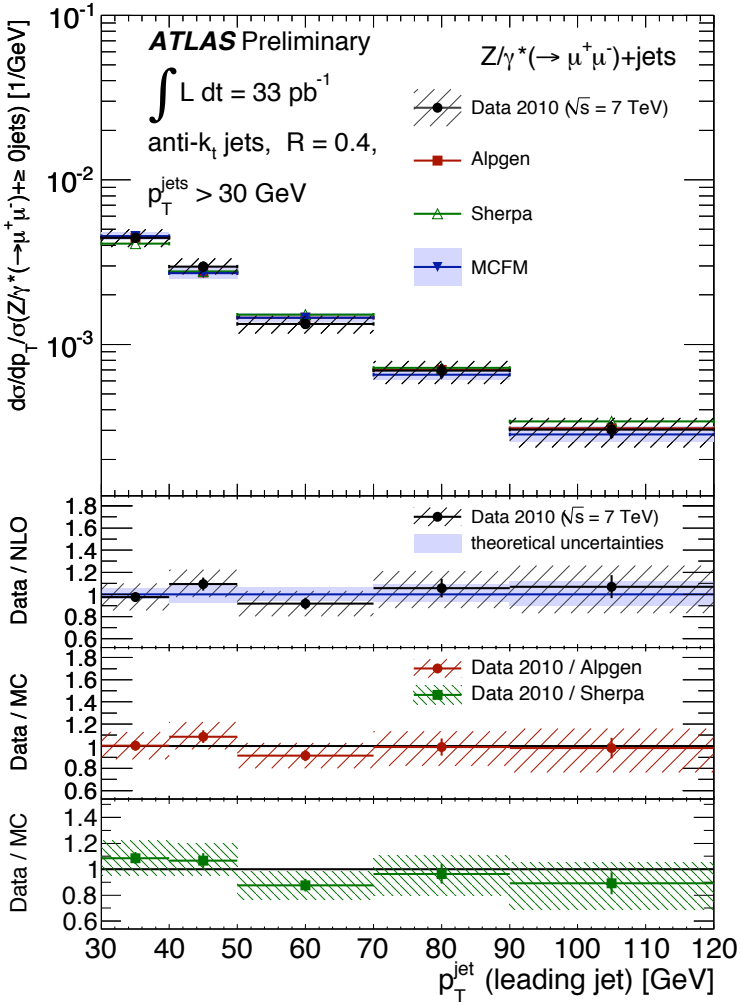
Z + jets cross section ratio



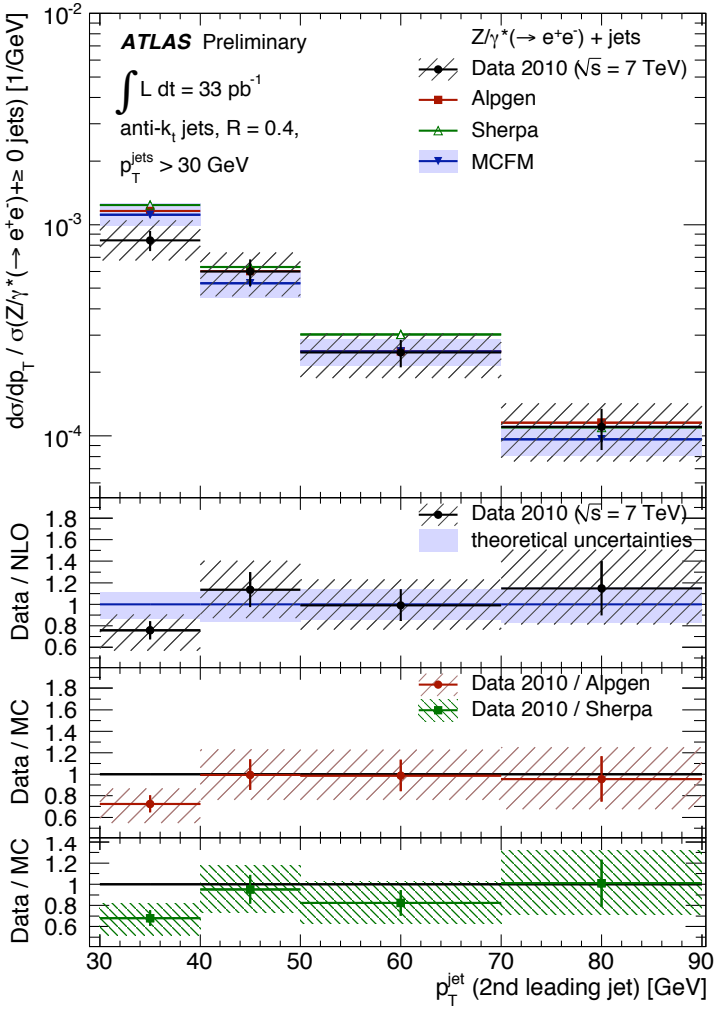


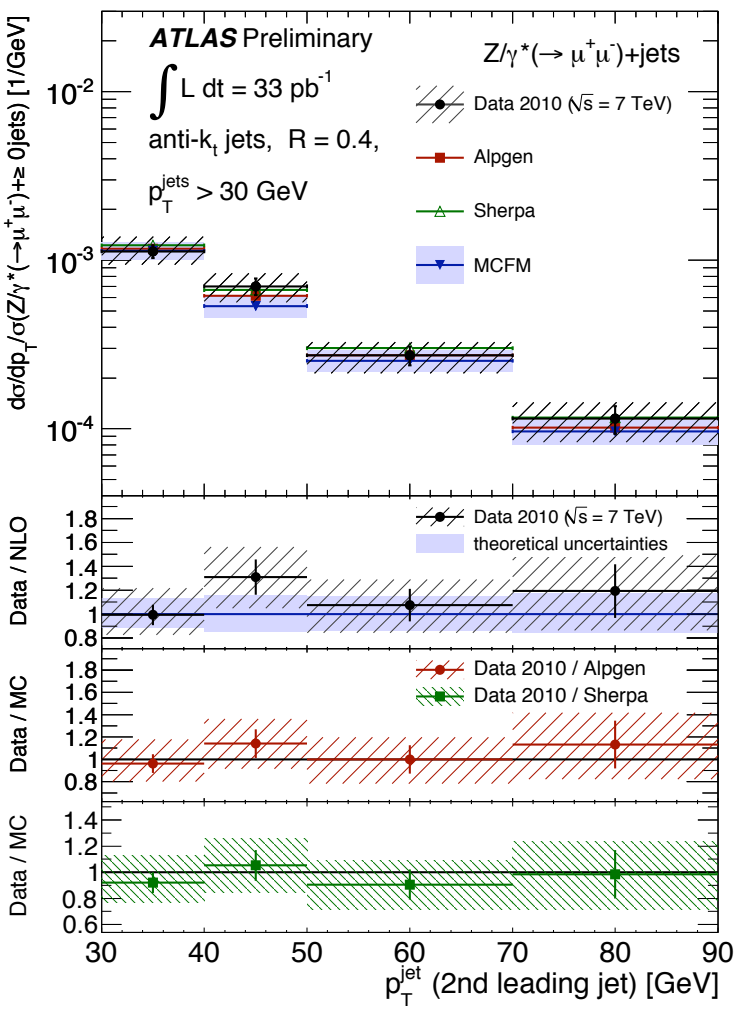
Z + jets differential cross section





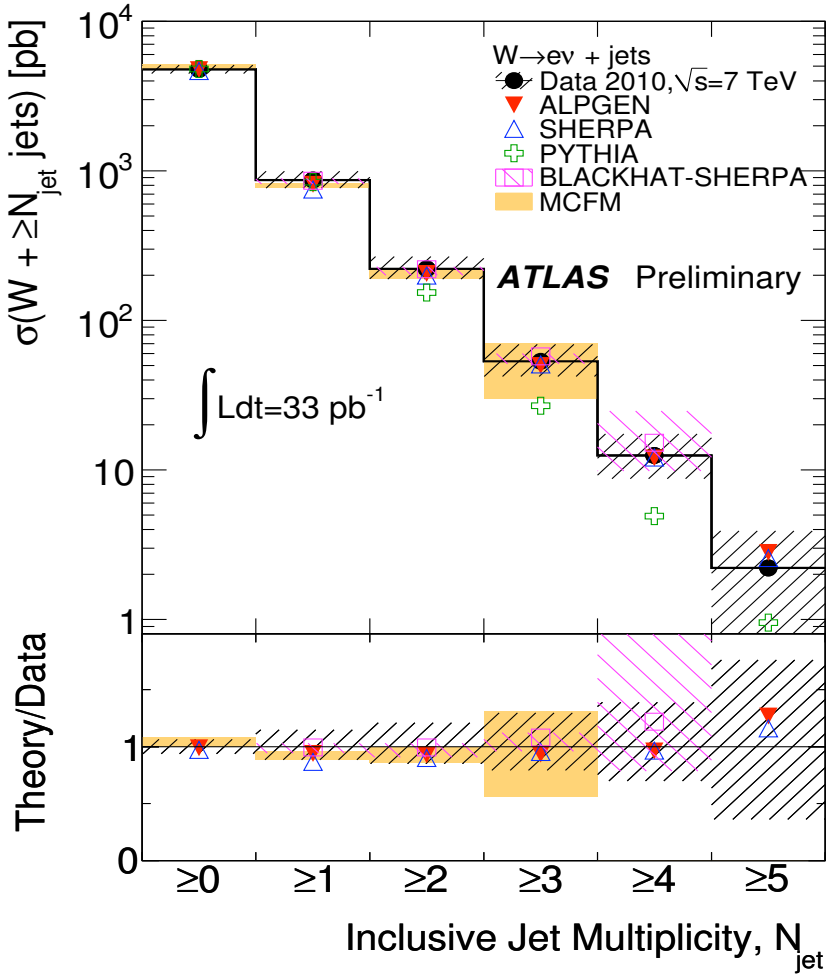
Z + jets differential cross section

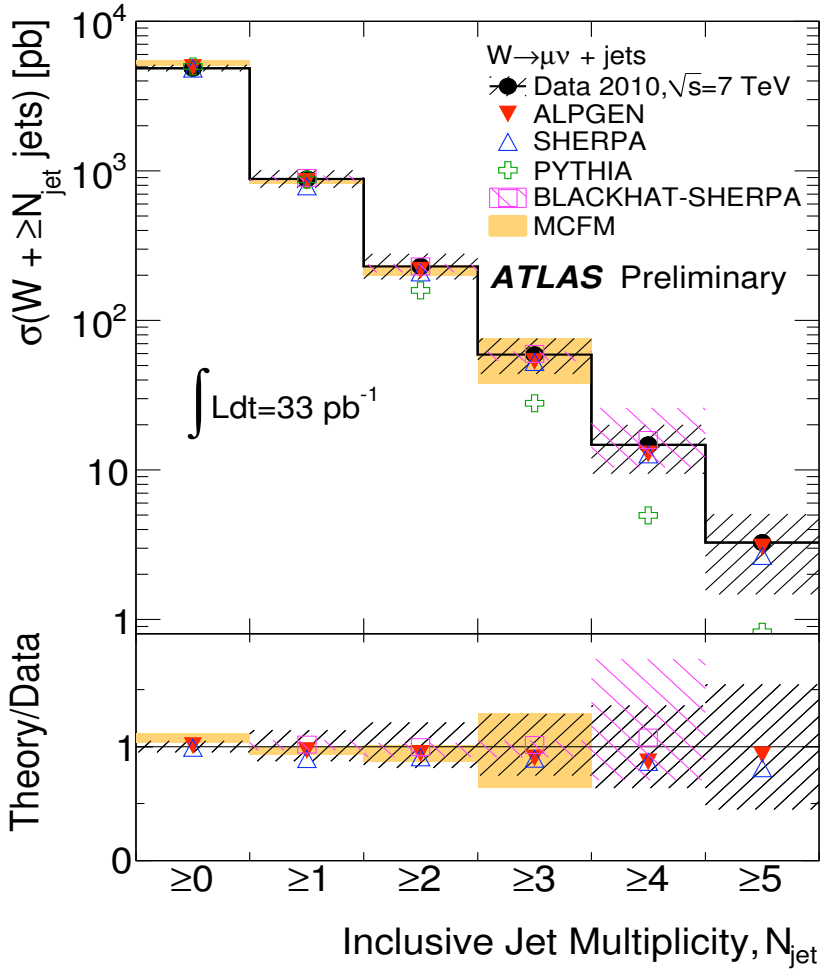




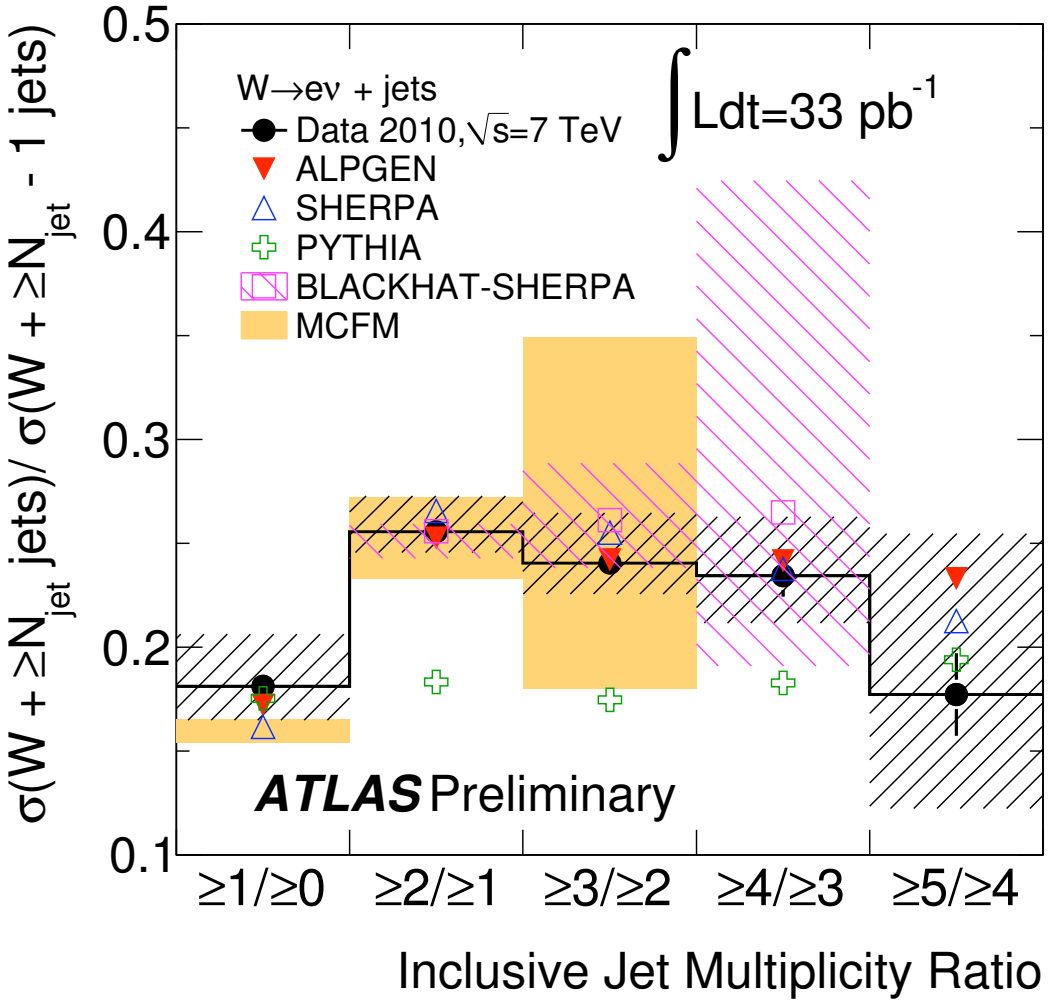
W + jets results (ATLAS)

W + jets inclusive cross section

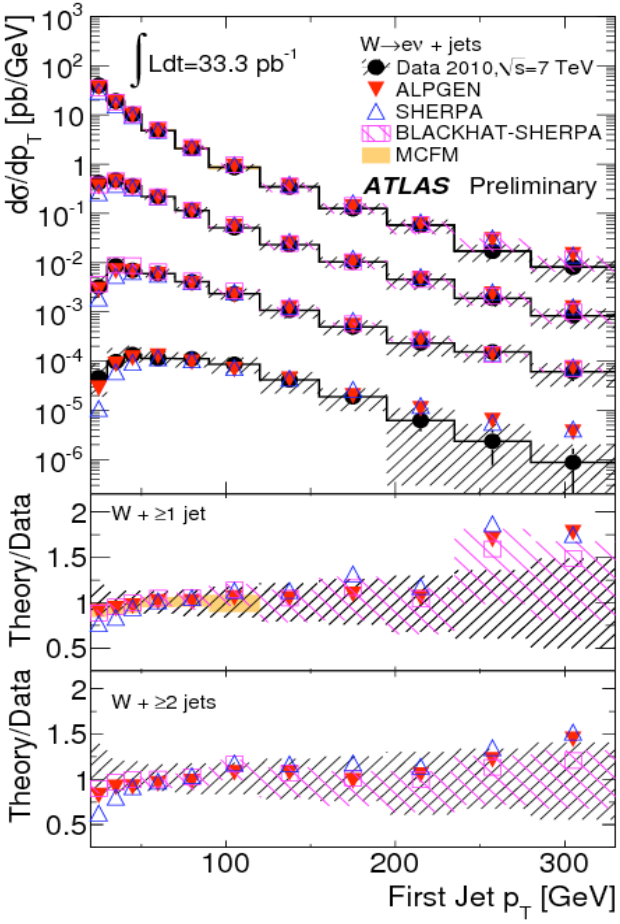


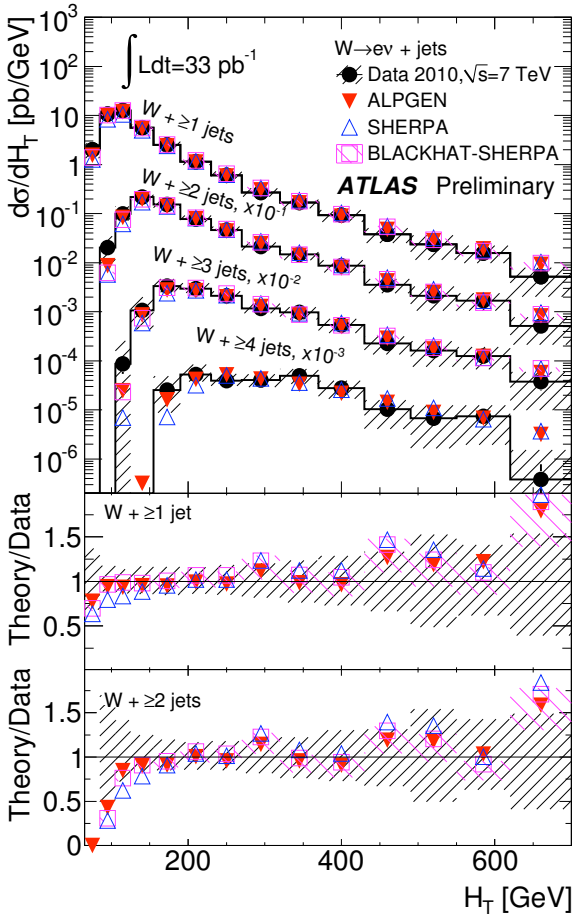


W + jets cross section ratio



W + jets differential cross sections





W + jets differential cross sections