W and Z measurements at the LHC

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Photon 2011

Outline

- Overview of the electroweak physics program at the LHC
- ATLAS and CMS detectors
  - Detection techniques for electrons, muons, jets and missing transverse energy (MET)
- Both ATLAS and CMS have produced a huge amount of precision electroweak measurements on the 2010 data sample
  - W and Z inclusive cross section measurements
  - W charge asymmetry and polarization
  - Drell-Yan rapidity and transverse momentum distributions
  - Associated production with jets and b-jets
  - Di-boson cross section measurements

W and Z at the LHC

- W and Z production at LHC is important for three broad classes of reasons
  - The distinctive signature of their final states make them an unique tool for detector calibration
  - They provide precision test of the Standard Model predictions
  - They are backgrounds to Higgs searches and to many beyond the Standard Model searches

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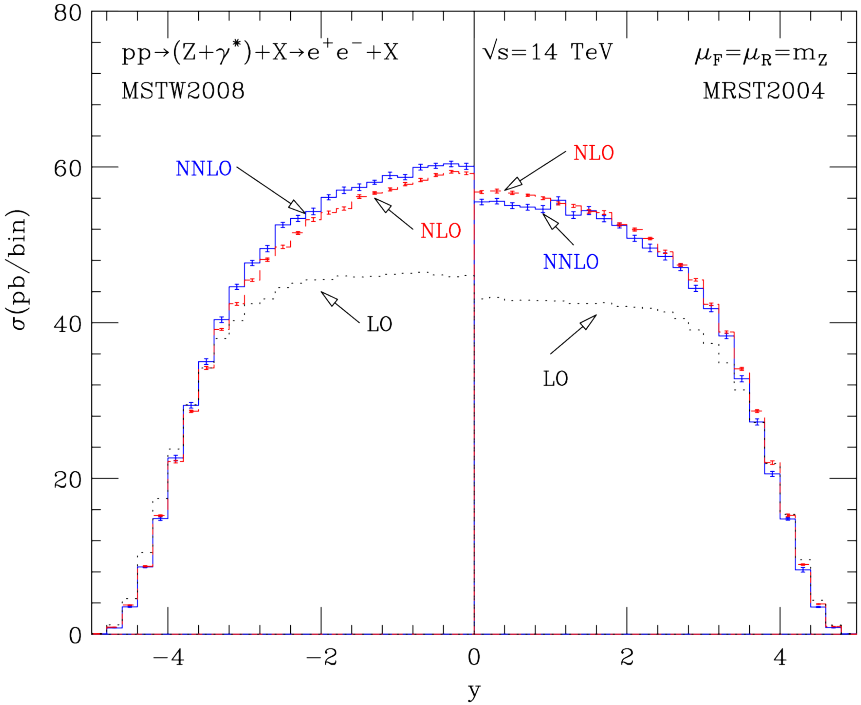
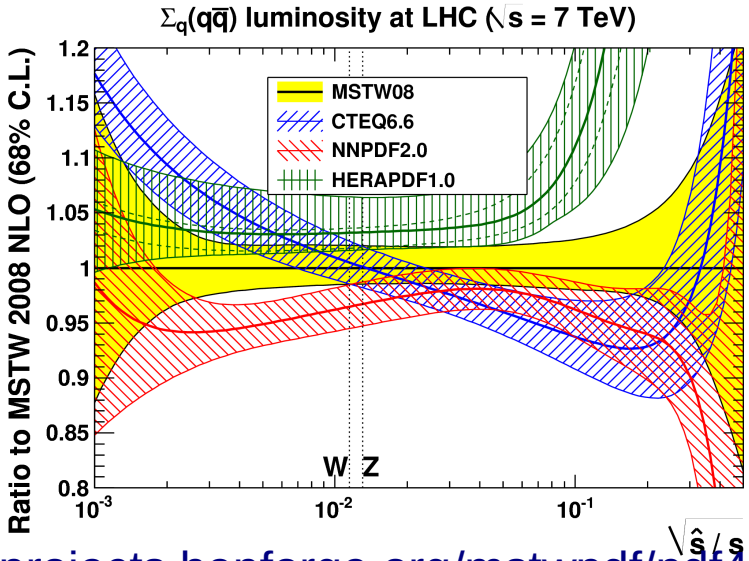
W and Z as a test ground for Standard Model

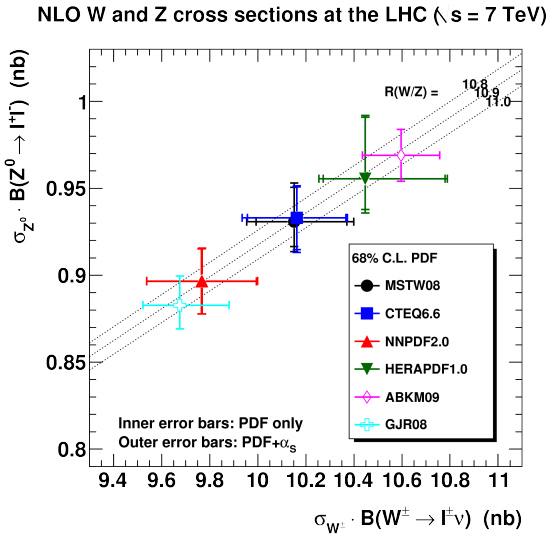
- Accurate predictions for W and Z production at the LHC are available
  - Monte Carlo event generators
    - NLO + parton shower (MC@NLO, POWHEG)
    - W and Z + multi-jet final states (Alpgen, MadGraph, Sherpa)
  - Parton level codes for distributions at NNLO



W and Z as a test ground for Standard Model

- W and Z production at the LHC probe parton density function with great precision
  - $>10^5$ W(→lν) and $>10^4$ Z(→ll) in 2010!
    - Cross sections factor ~3 with respect to the Tevatron
  - Main contribution from valence quark and sea anti-quark, with significant sea-sea contribution
  - Probes O~100 GeV and $10^{-3}<x<10^{-1}$



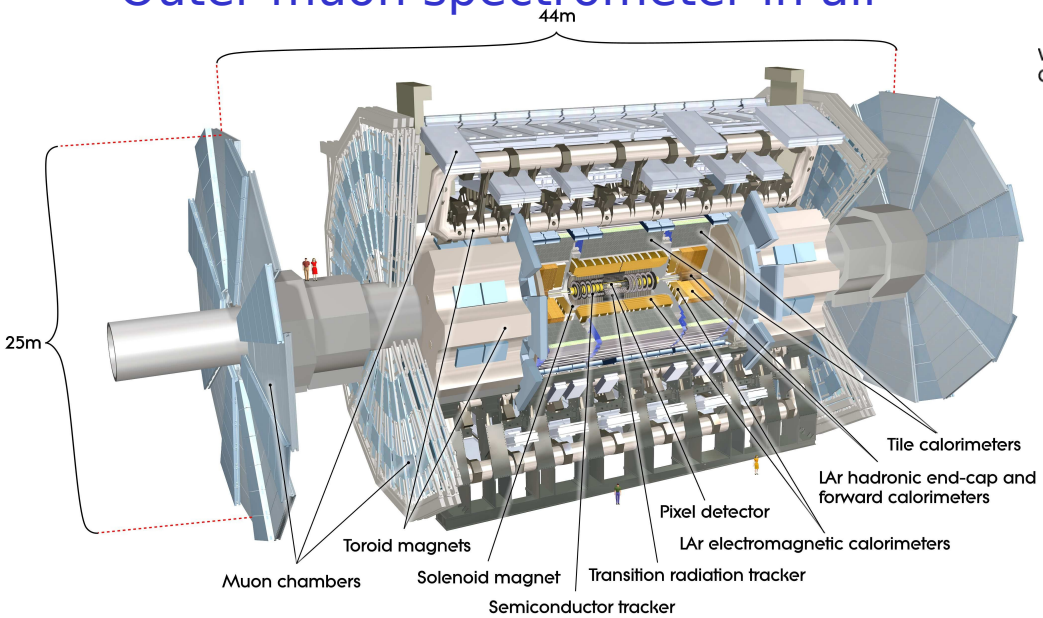


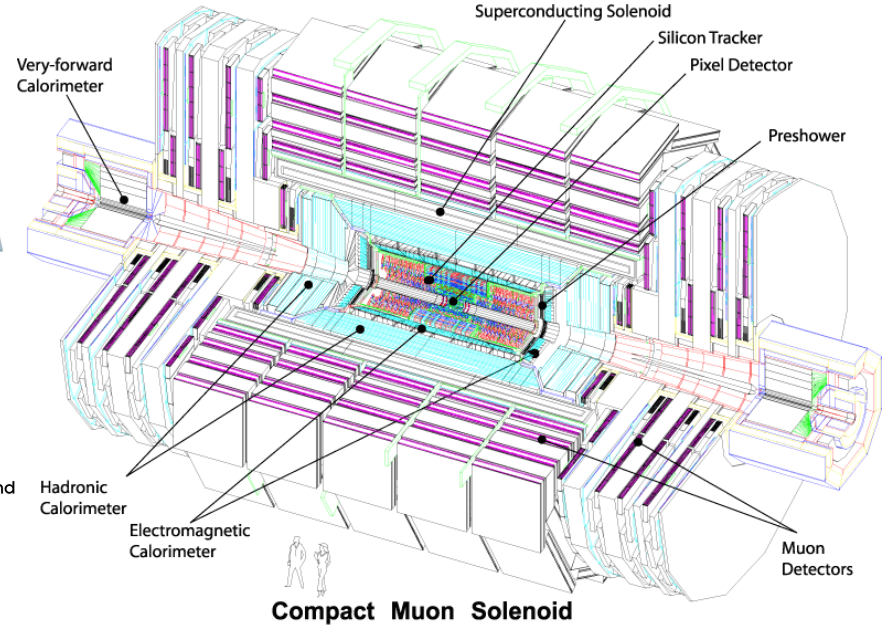
http://projects.hepforge.org/mstwpdf/pdf4lhc/partonlumi7TeV.html

ATLAS and CMS

- ATLAS
  - Toroidal outer magnet supplemented by a 2 T solenoid for inner tracking
  - Pixel/Strip + straw tube/transition radiation tracker
  - LAr electromagnetic calorimeter
  - Scintillator tile + LAr hadronic calorimeter
  - Outer muon spectrometer in air

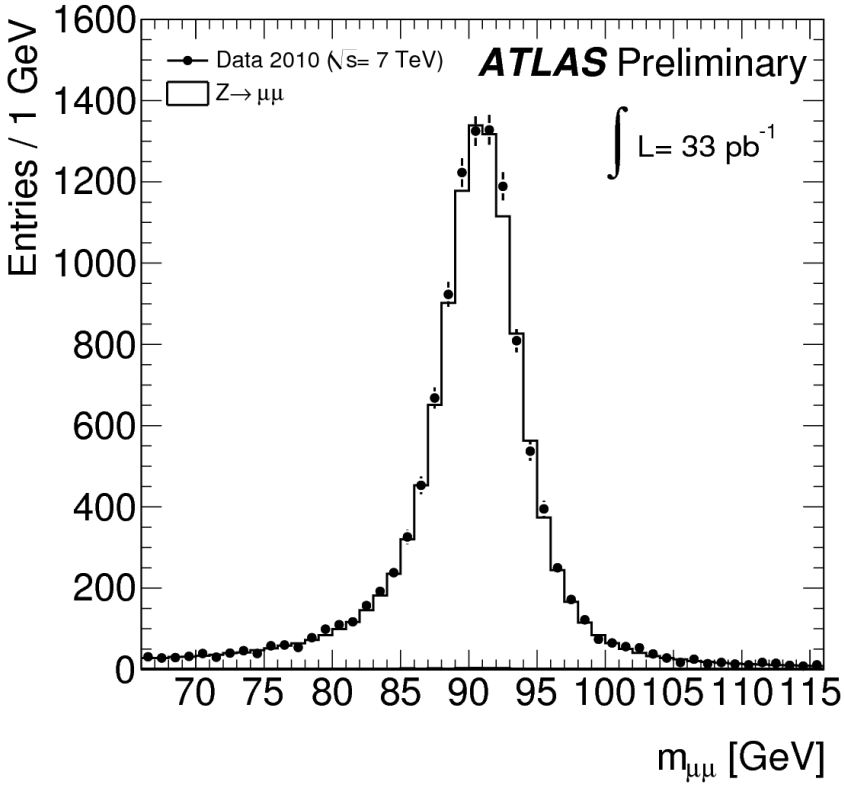
- CMS
  - 4 T solenoid
  - Pixel + SiStrip tracker
  - Scintillating crystals ($PbWO_4$) electromagnetic calorimeter
  - Brass/plastic hadron calorimeter
  - Muon spectrometer in the magnet iron return yoke

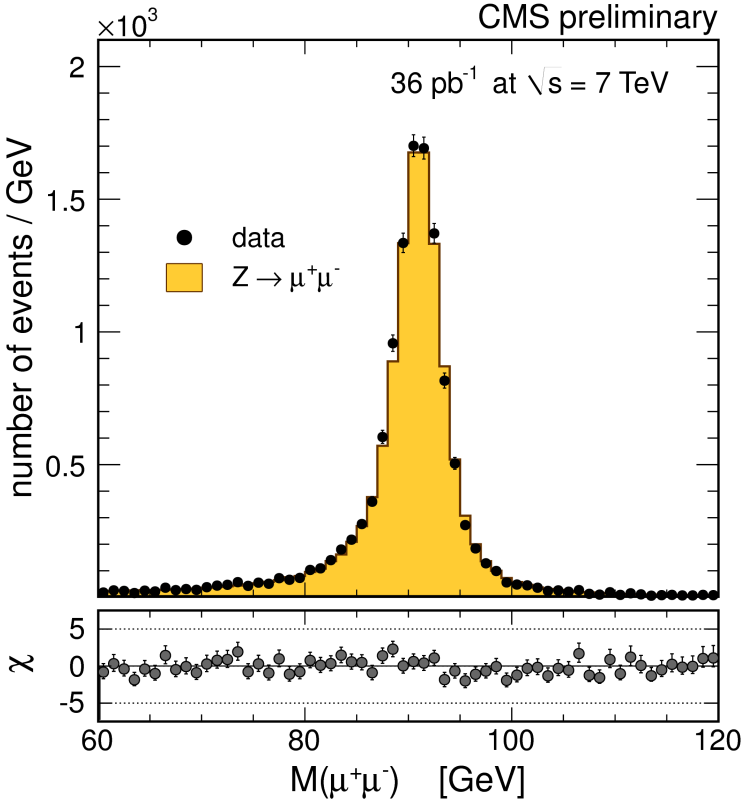




Muons

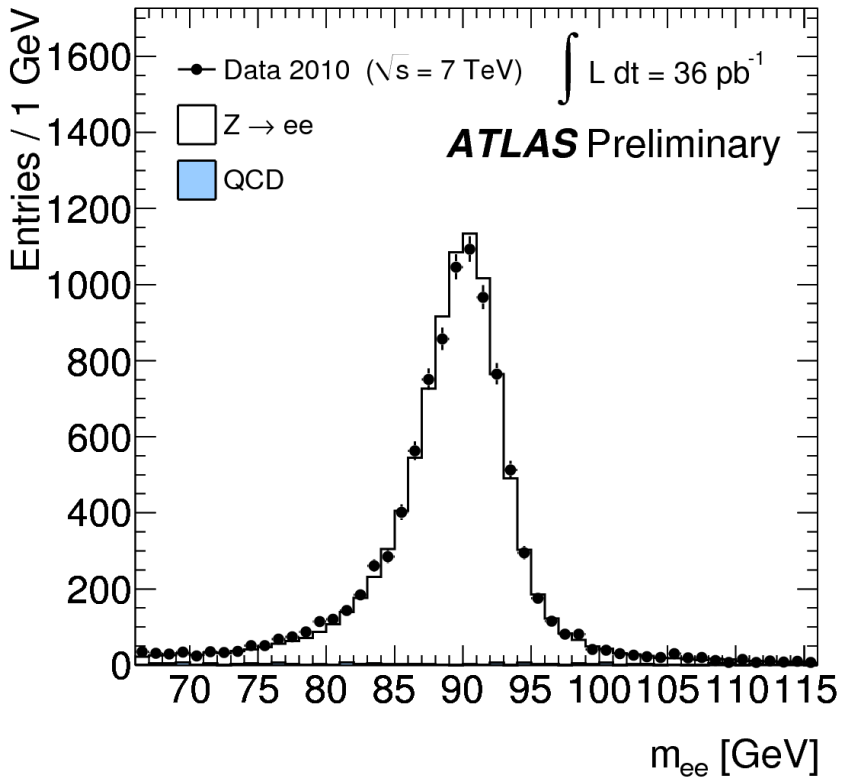
- Muons are reconstructed combining an inner tracker track and a track in the muon spectrometer
  - typical pT resolution for EWK processes
    - 2% in CMS, 4% in ATLAS
  - excellent agreement between data and simulation

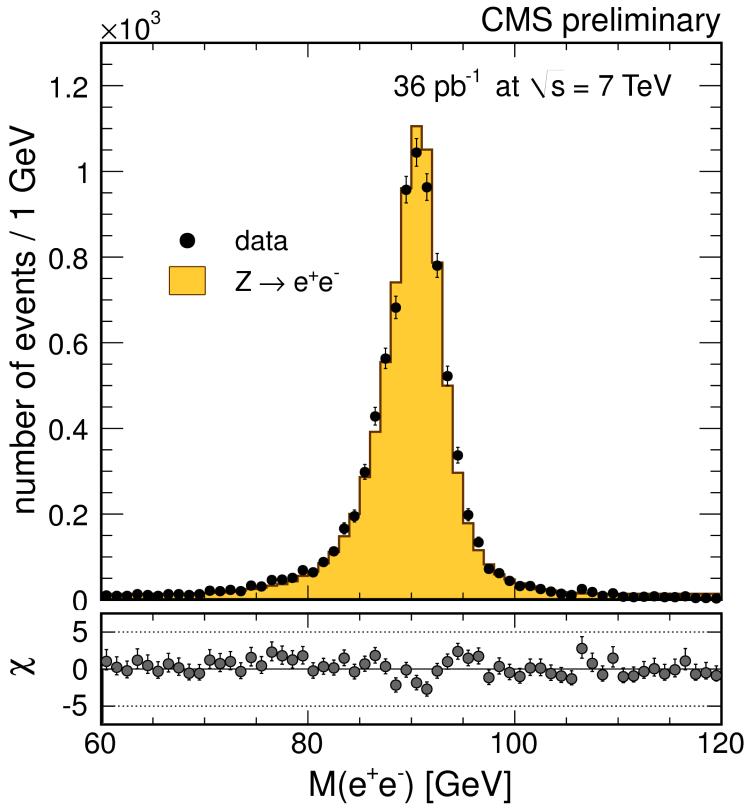




Electrons

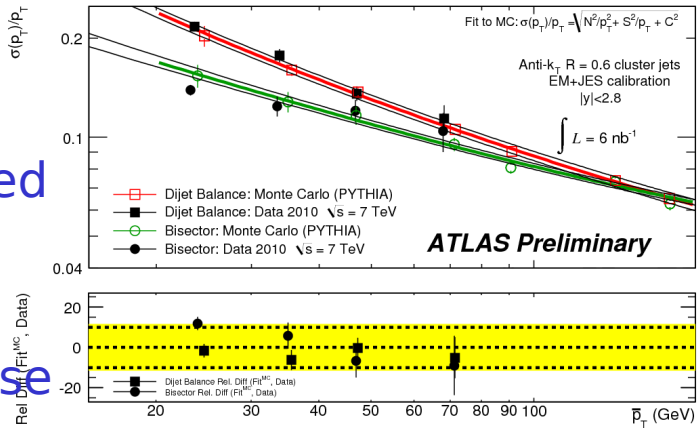
- Energy scale in the calorimeters is known at the 1% level in both ATLAS and CMS
- Energy resolution ~1%
- Good agreement between data and simulation

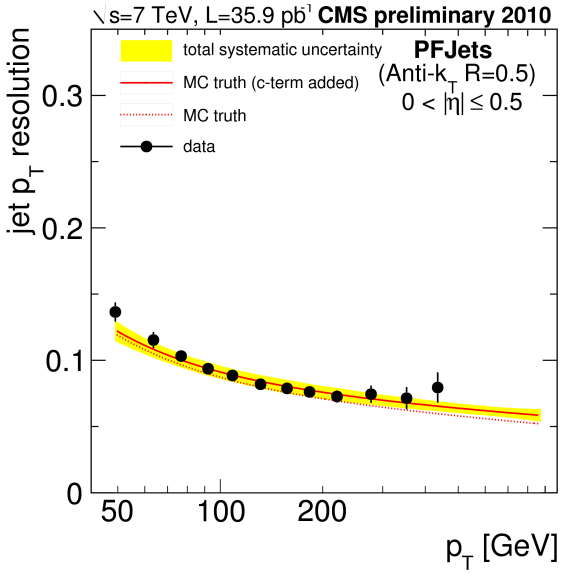


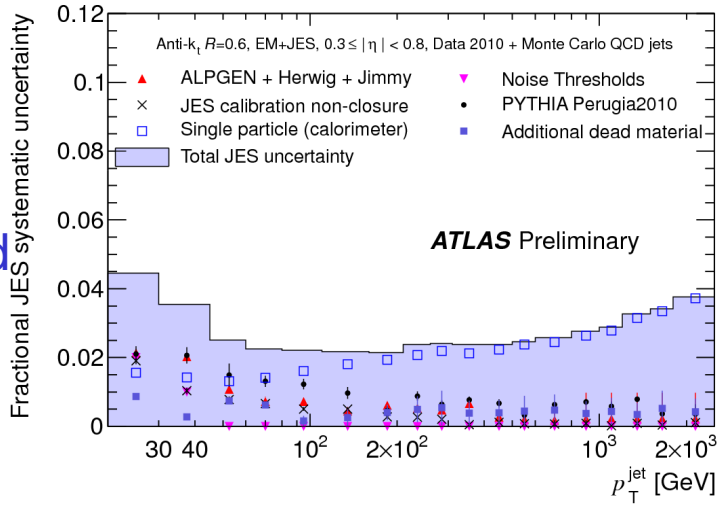


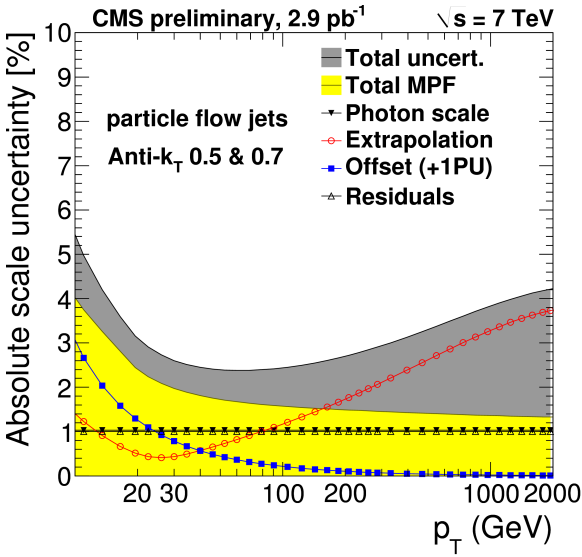
Jets

- ATLAS
  - Jets are made starting from calorimeter based "topo-cluster"
- CMS
  - Most analyses use particle flow techniques for jets
  - Individual charged hadrons, electrons, muons photons and neutral hadrons are reconstructed
  - Jets are made directly from particle-flow candidates



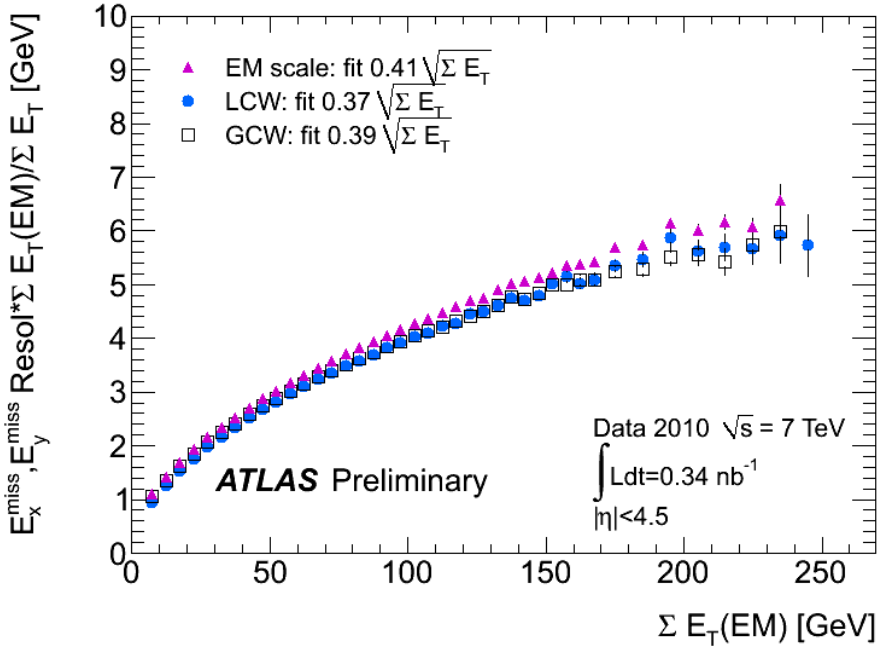


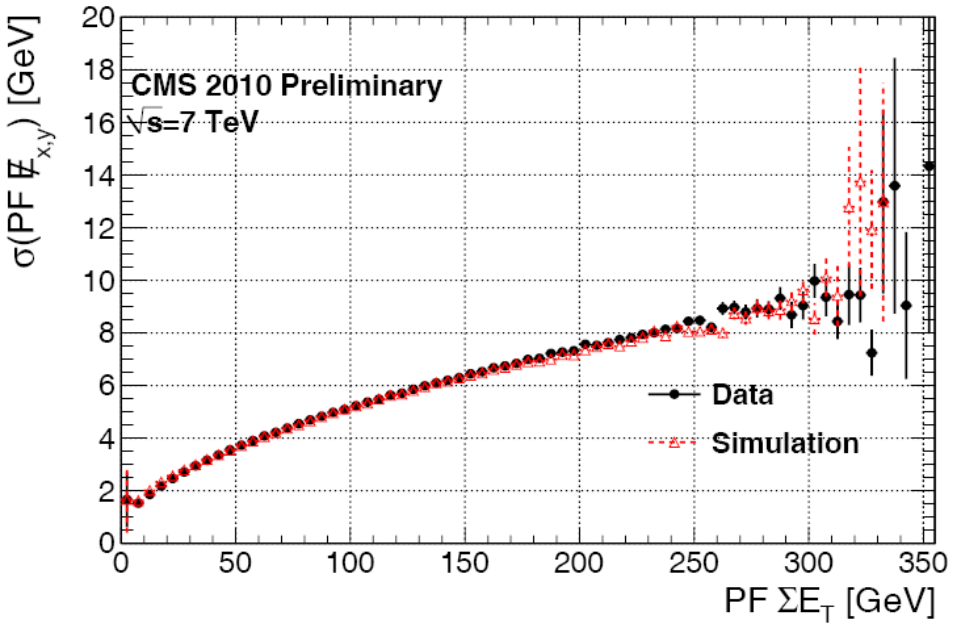




MET

- ATLAS
  - Mainly calorimeter-based MET, with jet energy corrections
- CMS
  - Best performances are obtained from particle-flow based MET

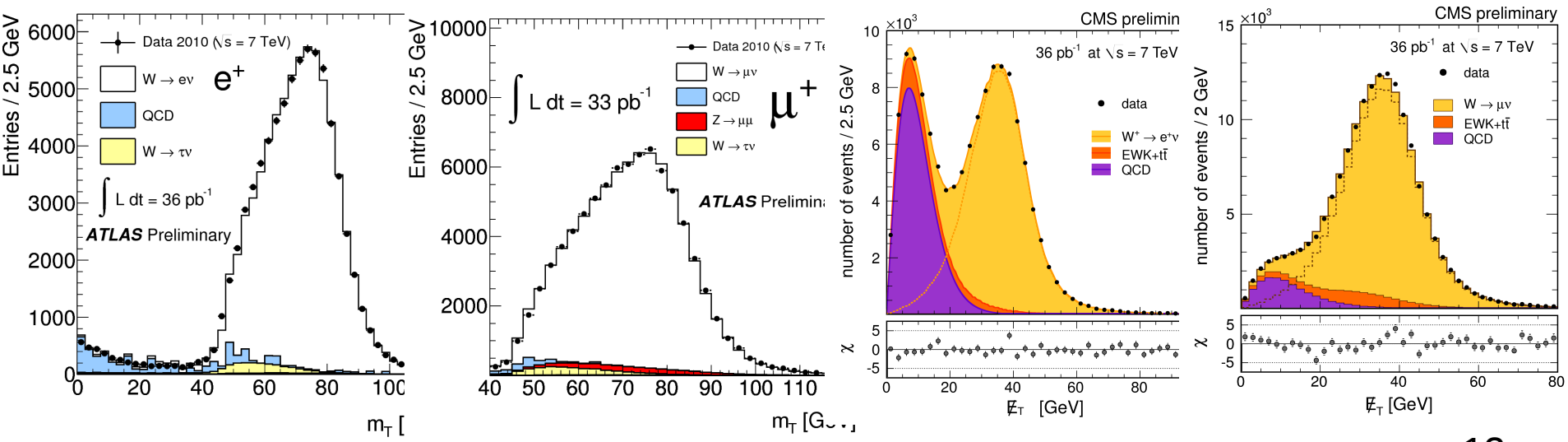




Inclusive W/Z cross sections

ATLAS-CONF-2011-041, CMS-EWK-10-005-pas

- Both ATLAS and CMS released preliminary results on the cross sections in the electron and muon channels, with full 2010 stat
  - Strategy:
    - Single un-prescaled lepton triggers
    - With kinematic cut (> 20 GeV) on leptons' transverse momentum (and MET for ATLAS) and isolation to reject QCD background
    - Data driven selection efficiency estimation is used
  - Main backgrounds are
    - Di-jet (muons from decays in flight, fake electrons)
    - EWK (Z→ττ, W→τυ, dibosons) and top



Inclusive W/Z cross sections

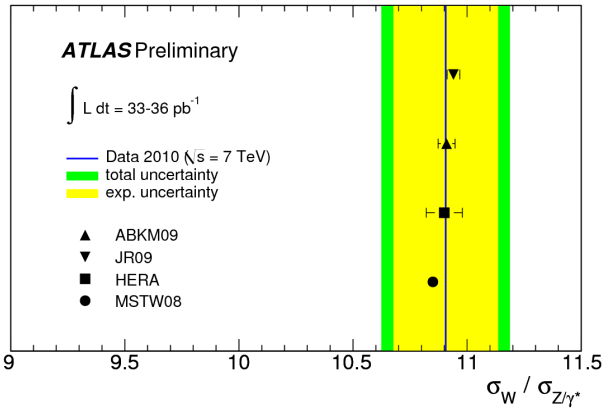
ATLAS-CONF-2011-041, CMS-EWK-10-005-pas

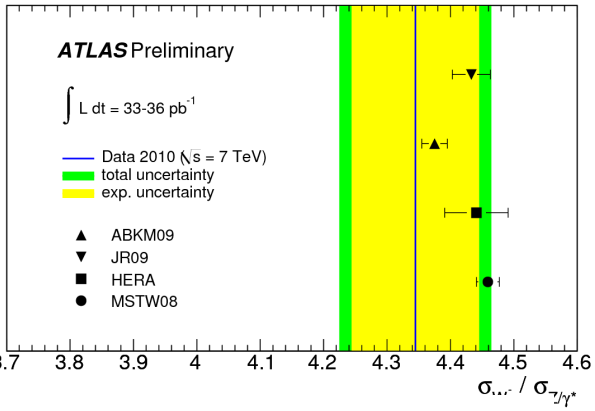
- Systematic uncertainties
  - Experimental:
    - ATLAS systematics dominated by MET (W) and reconstruction efficiency (Z)
    - CMS dominated by reconstruction efficiency
  - Theoretical:
    - Extrapolation to full phase space
    - ATLAS: difference between LO+shower and NLO+shower
    - CMS: pdf reweighting on NLO + shower

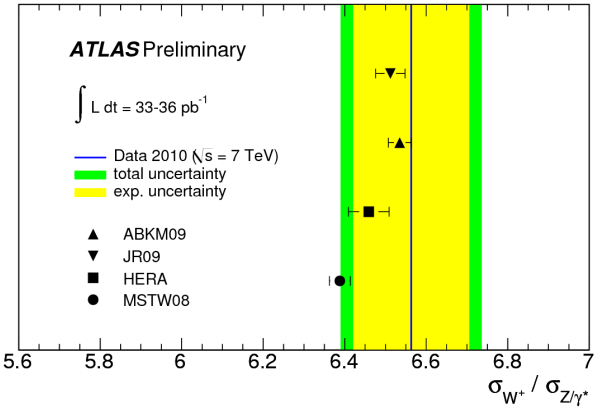
% on sig yield		$W \to e\nu$	$W \to \mu\nu$	$Z \to ee$	$Z \to \mu\mu$
ATLAS	experimental	2.8 (MET)	2.4 (MET)	3 (reco)	1.1 (reco)
Lumi: 3.4	theory	3	3	4	4
CMS	experimental	1.5(reco/ID)	1.1(reco/ID)	1.8(reco/ID)	0.7(trigger)
Lumi: 4	theory	0.9	1.1	1.7	2

Inclusive W/Z cross sections

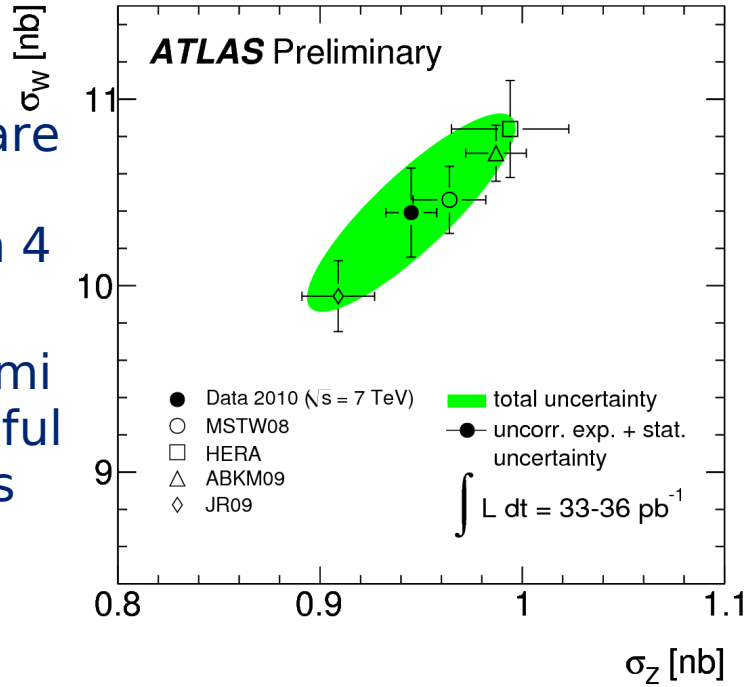
ATLAS-CONF-2011-041, CMS-EWK-10-005-pas

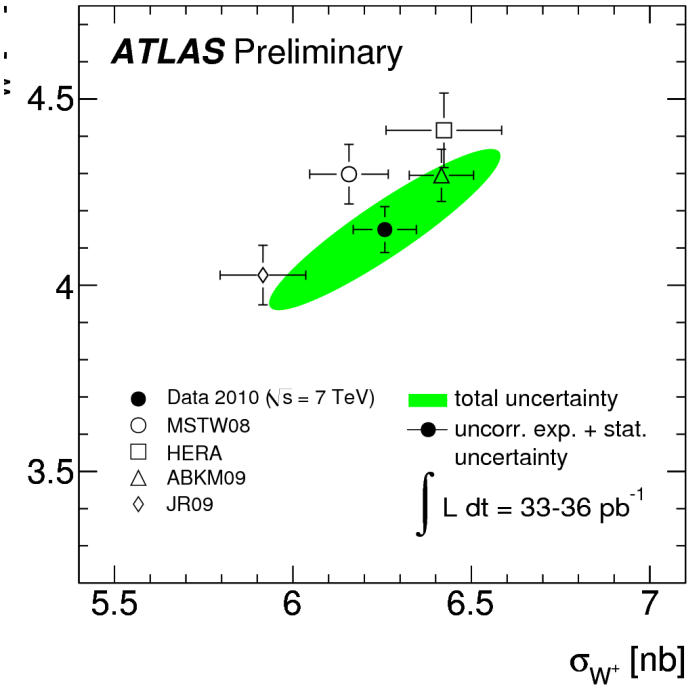






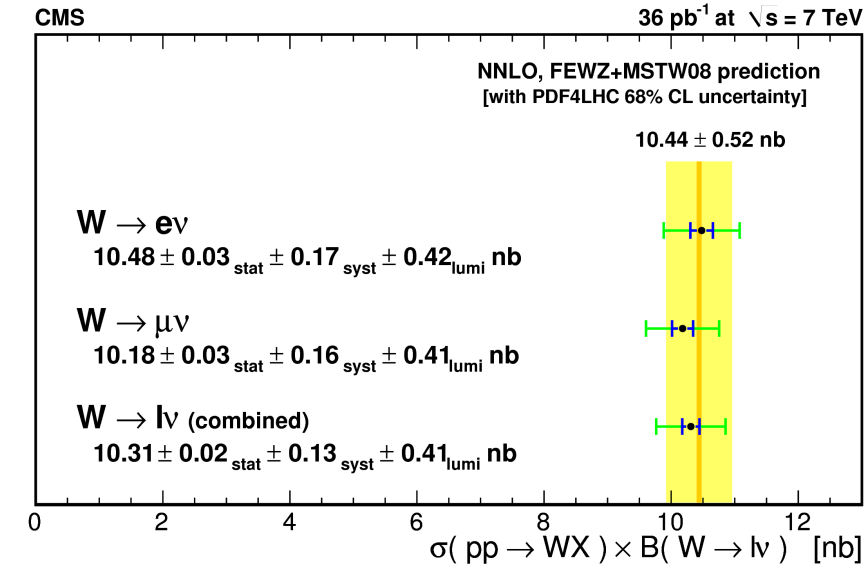
- Measurements are compared to predictions from 4 pdf sets
- Ratios free of lumi uncertainty, useful to constrain pdfs

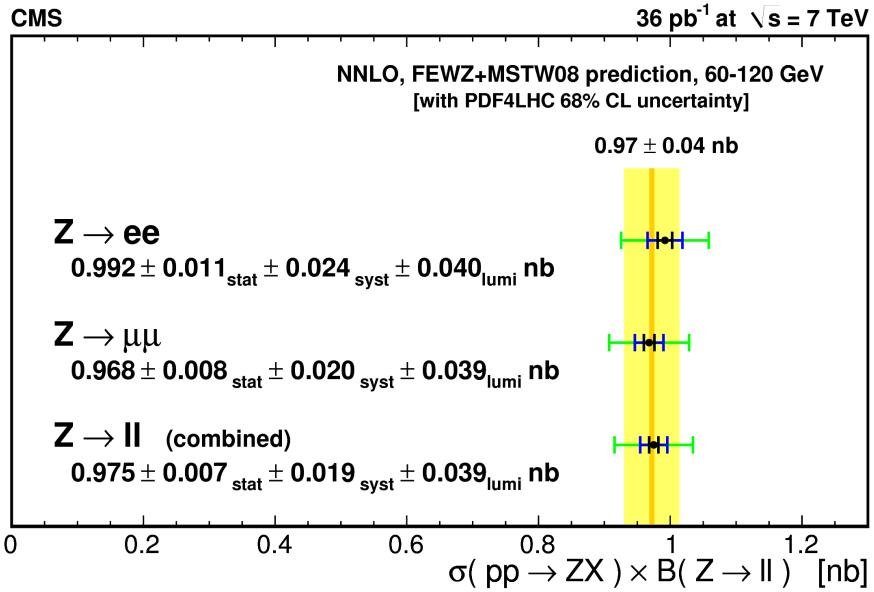


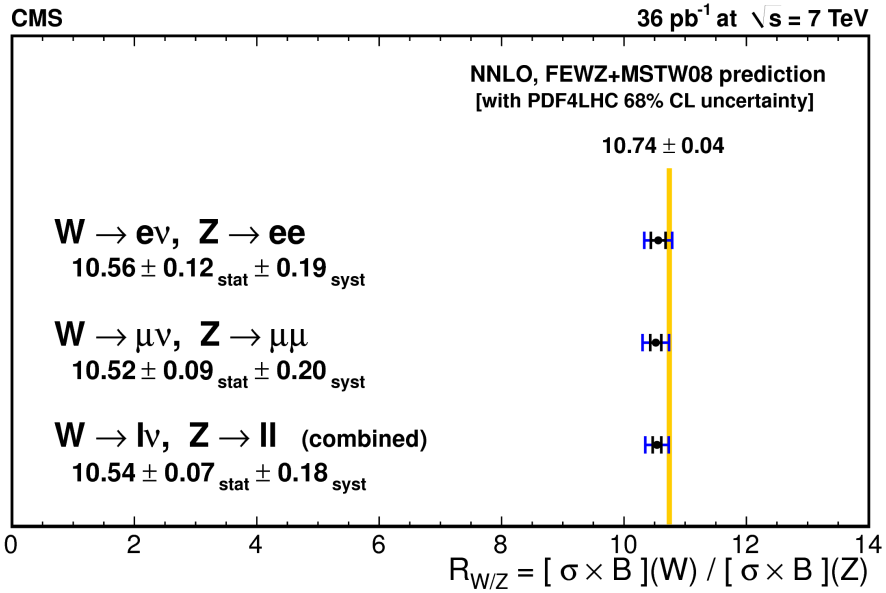


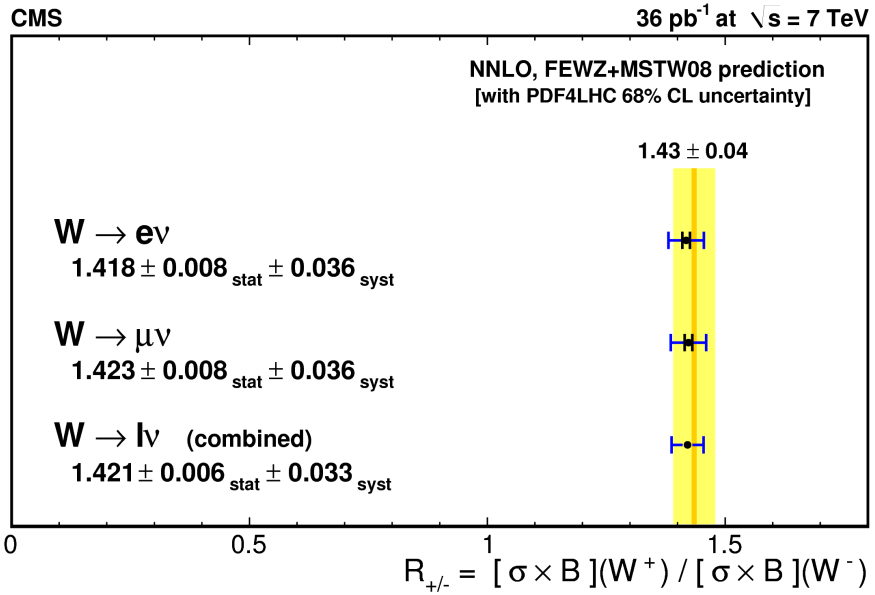
Inclusive W/Z cross sections

ATLAS-CONF-2011-041, CMS-EWK-10-005-pas







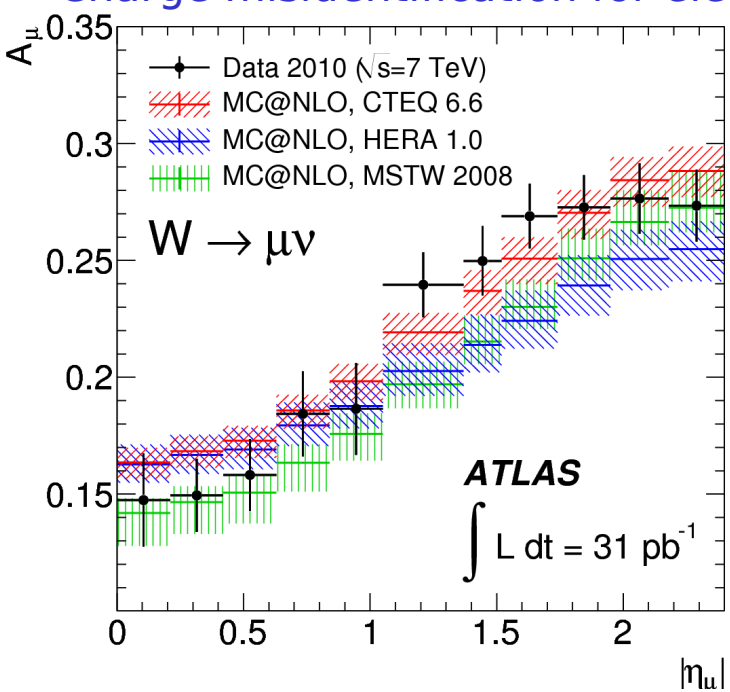


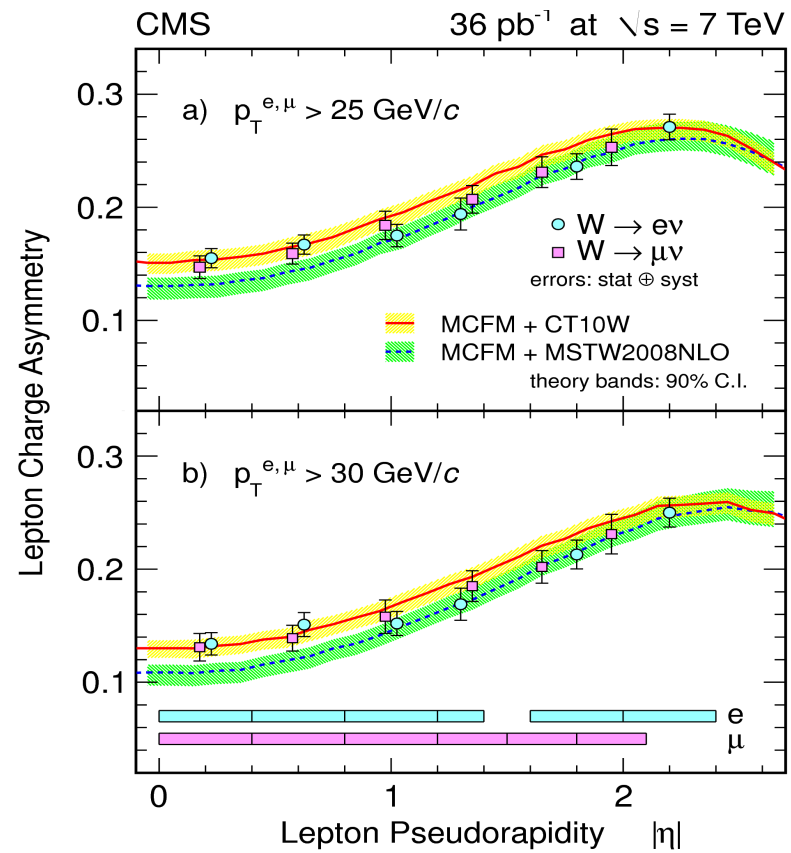
W charge asymmetry

arXiv:1103.2929v1, JHEP 1104:050,2011

- Powerful tool to constrain pdfs
  - Provides insight on the u/d ratio and sea antiquark densities
- ATLAS
  - Muon channel
- CMS
  - Muon and electron channels with 2transverse momentum selections
- Main systematics:
  - Different efficiency for the two charges
  - Charge misidentification for electrons

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$



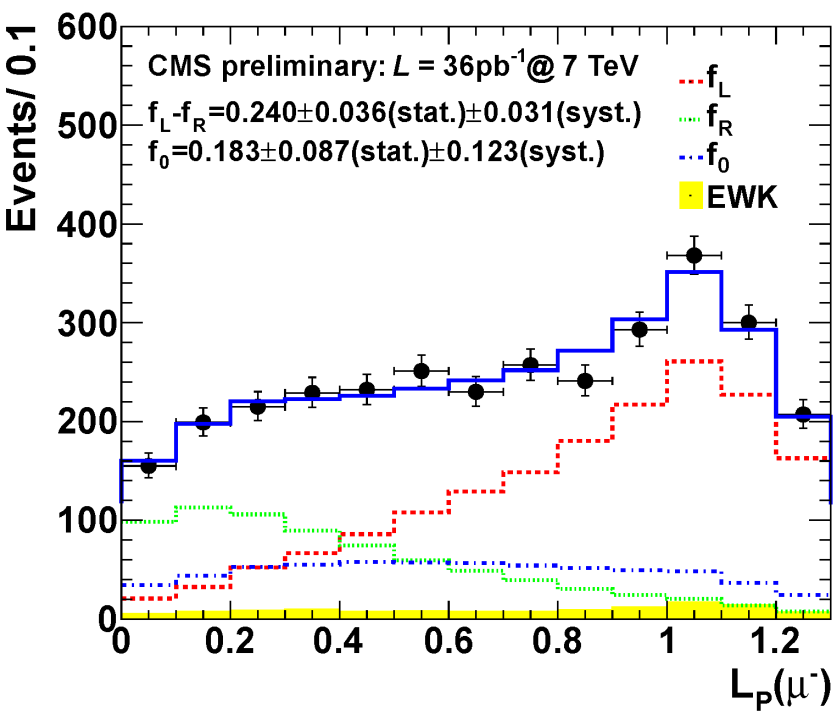


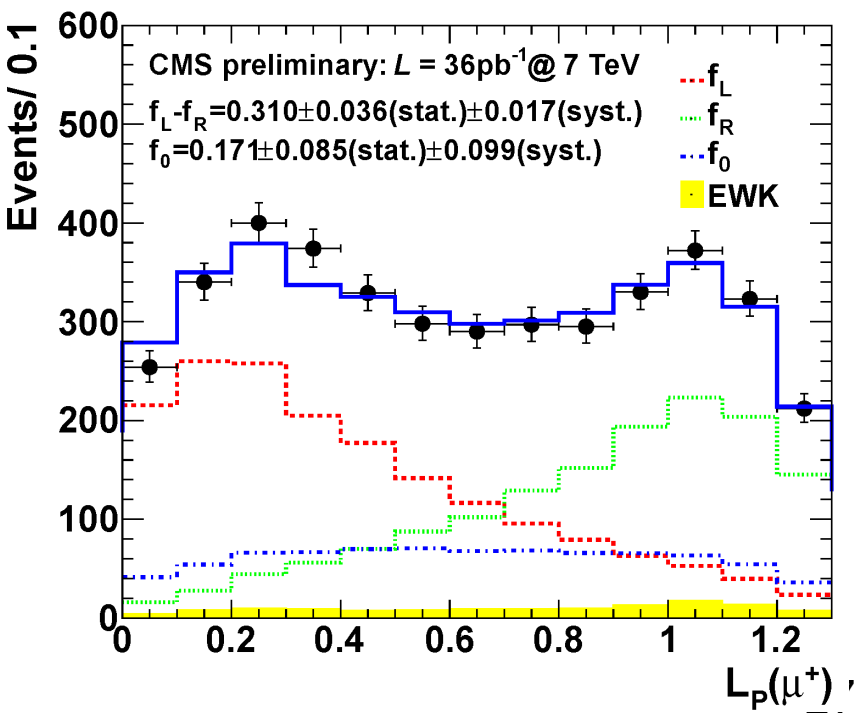
W polarization

arXiv:1104.3829

- W polarization for large transverse momentum
  - Effect unique to pp collisions!
  - CMS measured the effect for pT > 50 GeV and found that Ws are predominantly left-handed in pp collisions, as predicted by the SM
  - Since the kinematic is not closed, the lepton-projection (LP) variable was used and fitted to data

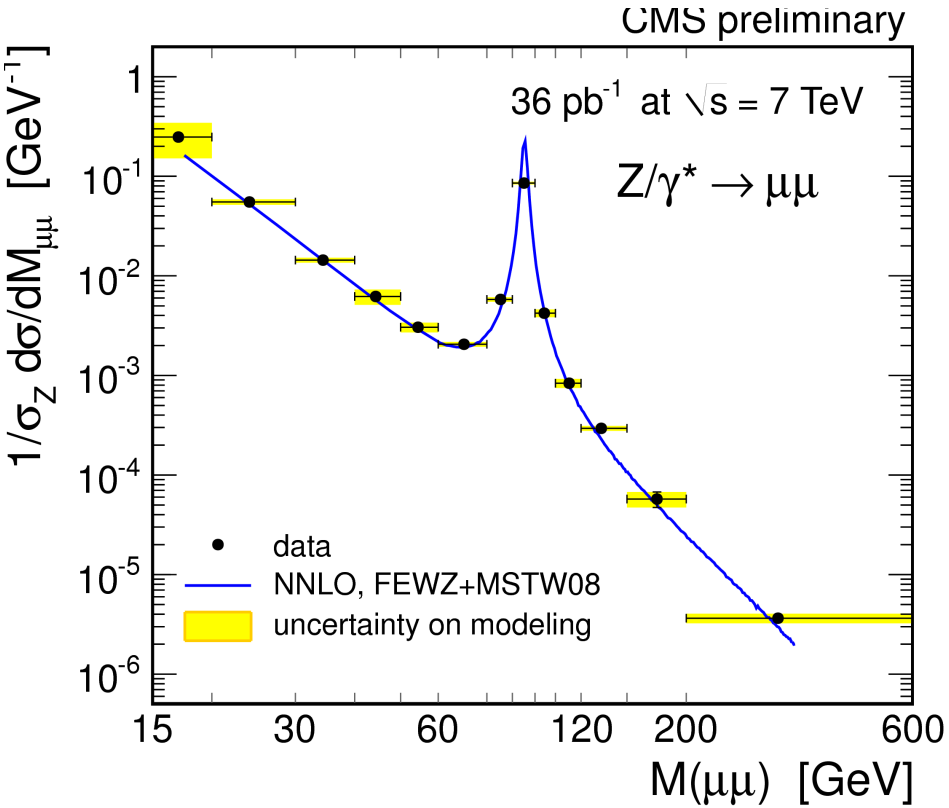
$$L_P = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(\mathrm{W})}{|\vec{p}_T(\mathrm{W})|^2}$$





Drell-Yan kinematic distributions

- DY mass spectrum
  - Sensitive to PDFs
  - Unfolded effect of final state radiation for comparison with parton level calculations
  - Good agreement with NNLO calculations plus modern NNLO PDFs

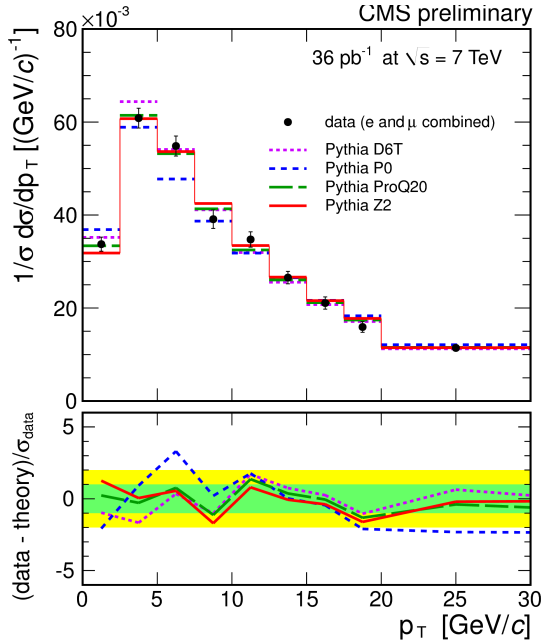


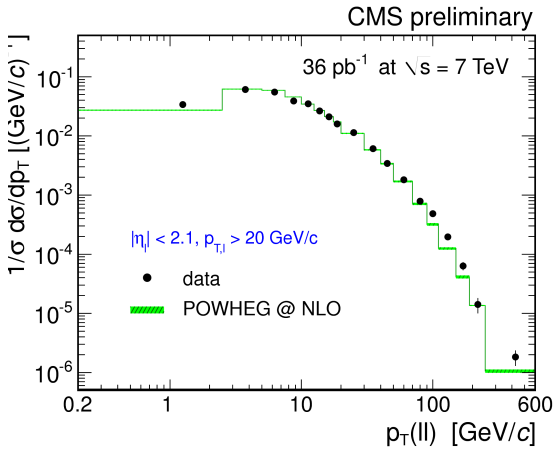
CMS-PAS-EWK-10-007

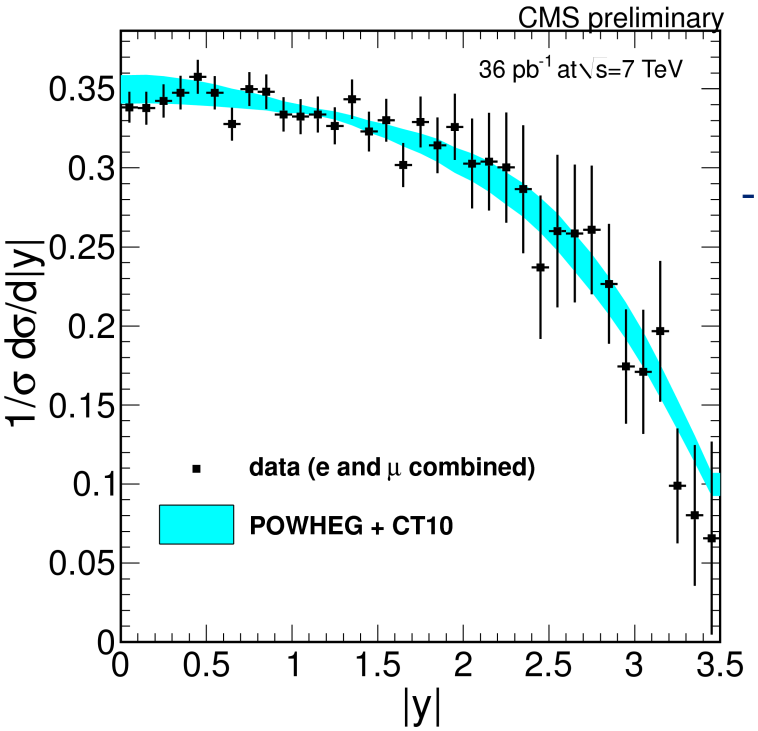
Drell-Yan kinematic distributions

CMS-PAS-EWK-10-010

- Drell-Yan pT distribution
  - Main systematics:
    - Theory related
    - Background estimation
  - Results were compared with both NLO + shower predictions and several Pythia underlying event tunes





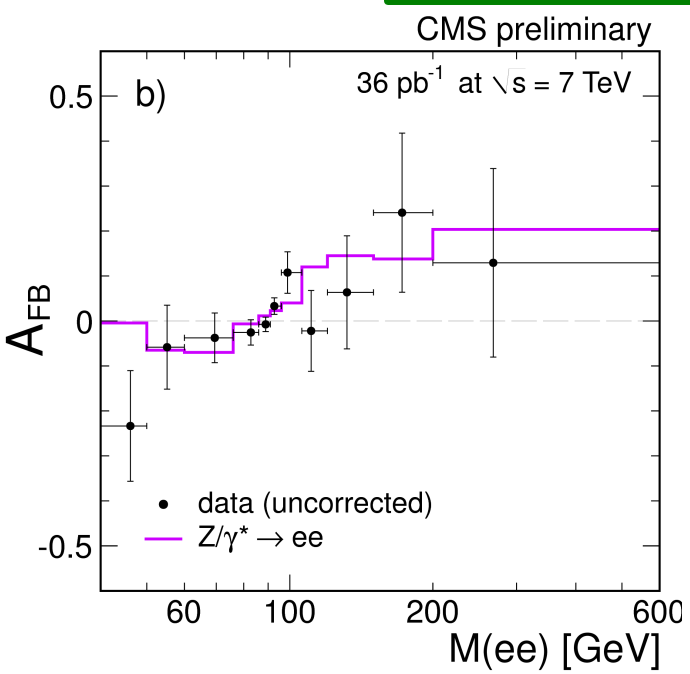


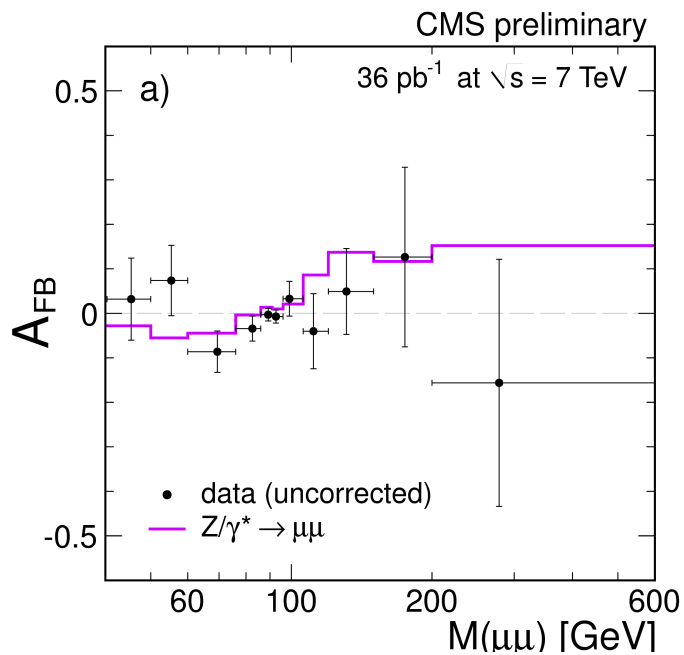
- Drell-Yan rapidity distribution
  - Both muons and electrons combined for central rapidity
  - Extended range for electrons thanks to electron identification in the forward calorimeter (beyond tracked acceptance)
  - This measurement will play a role in constraining future PDF fits

Drell-Yan kinematic distributions CMS-PAS-EWK-10-011

- Measurement of the forward-backward asymmetry and of the weak mixing angle
  - The asymmetry is measured in both electron and muon channels in bin of invariant mass
  - The mixing angle is obtained by a multi-dimensional fitting of the event yields as a function of mass, dilepton rapidity and decay angle in the Colin-Soper frame

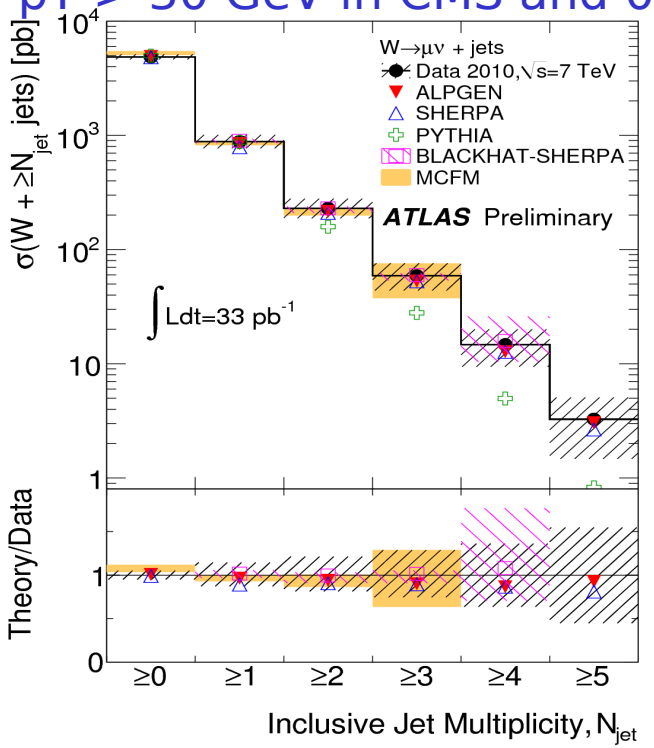
$$\sin^2\theta_{\text{eff}} = 0.2287 \pm 0.0077(\text{stat.}) \pm 0.0036(\text{syst.})$$

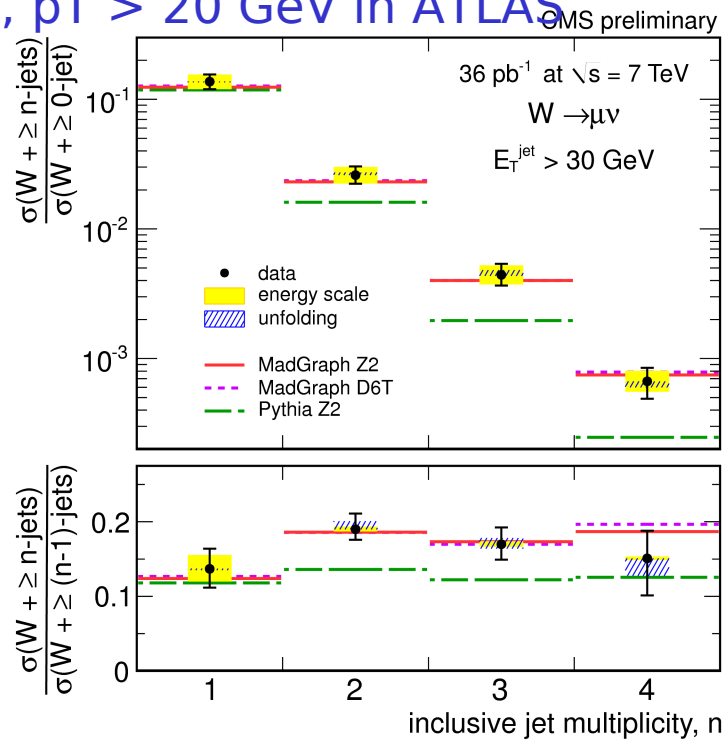




W/Z+jets

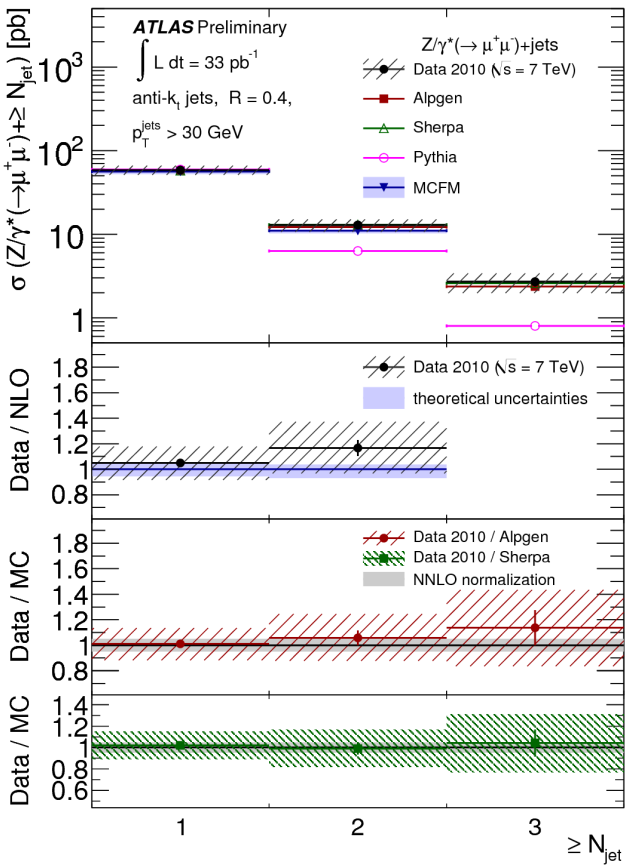
- Important as background for searches and as testing ground for higher order corrections in pQCD
- Detector's jet energy scale is the main systematic effect.
- Both ATLAS and CMS provided rates of events with jets
  - Results are given within the kinematic acceptance for leptons, unfolding detector effects
  - Jets are reconstructed with the anti-kT algorithm, with a radius of 0.5, pT > 30 GeV in CMS and 0.4, pT > 20 GeV in ATLAS

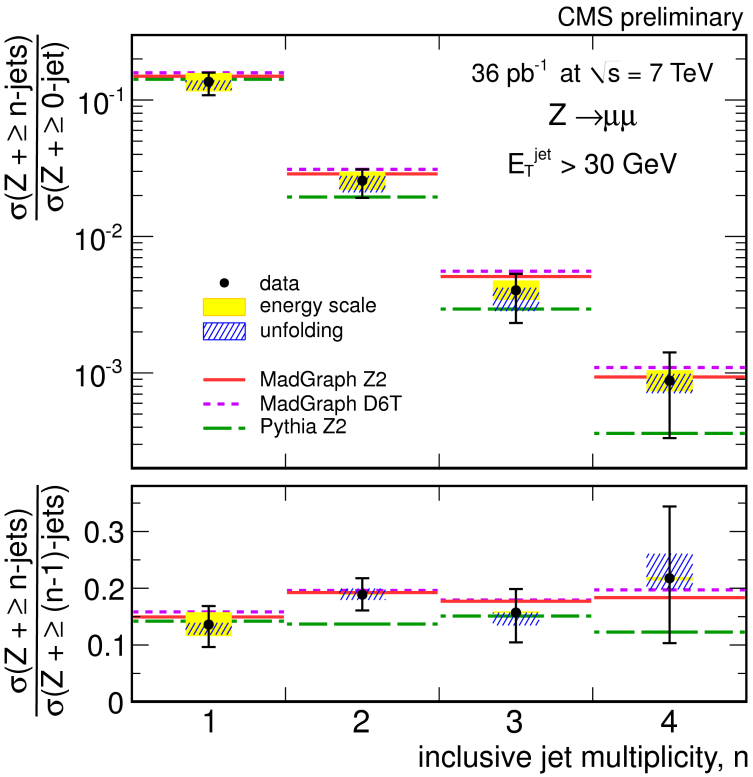




ATLAS-CONF-2011-042,
ATLAS-CONF-2011-060,
CMS-PAS-EWK-10-012

W/Z+jets

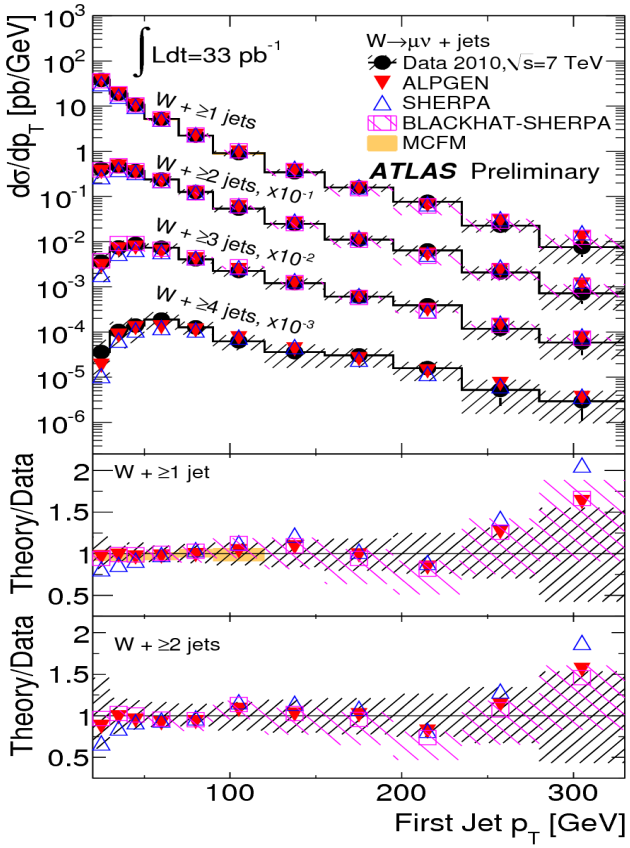


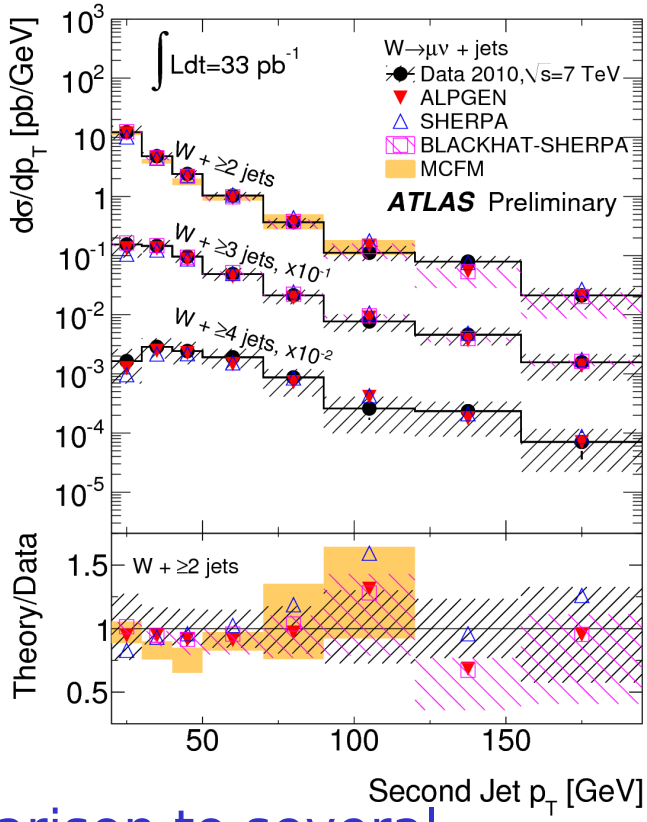


- Pure parton shower (Pythia) is not able to describe multi jet rates
- Several Matrix Element + shower predictions compared to data
  - General agreement with these predictions is found, as well as with rates obtained by pure parton level NLO calculations

W/Z+jets

- ATLAS also provided fully corrected jet spectra
  - Results up to 4 jets for W, 2 for Z
  - Resolution effect unfolded with bin-by-bin MC-based corrections



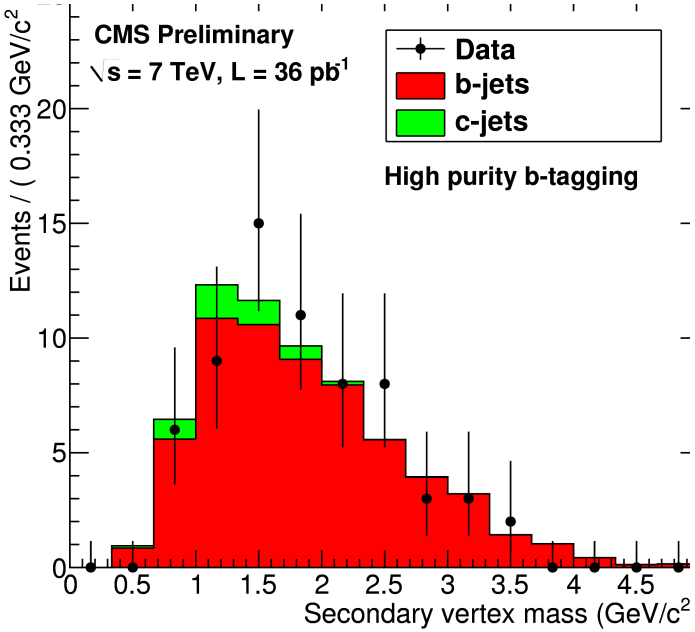


- Comparison to several predictions
  - Pure NLO parton level
  - Matched ME + shower
- Good agreement within uncertainties with predictions

W/Z+jets

CMS-PAS-EWK-10-015

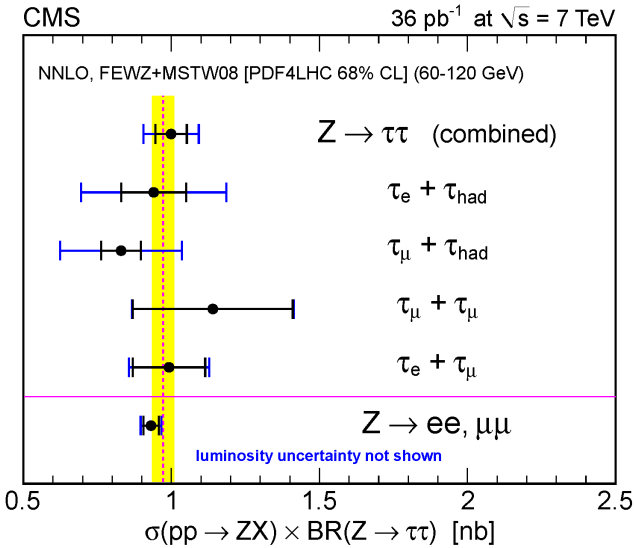
- CMS measured the associated production of Z + b-jets
  - Z selection plus high purity b-tagging
  - Main systematics: JES, b-tagging efficiency and mis-tag rate
  - The ratio between the Z+ b jets and Z + any jet has been measured for both electron and muon decay channels

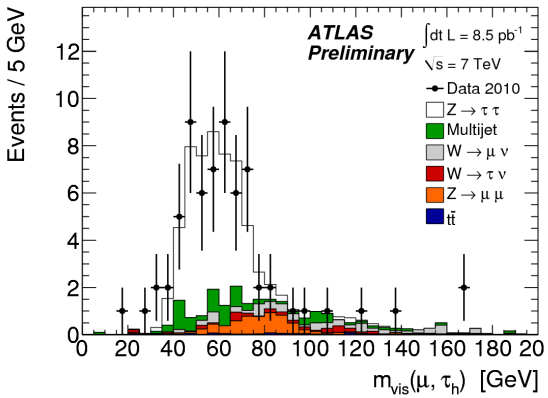


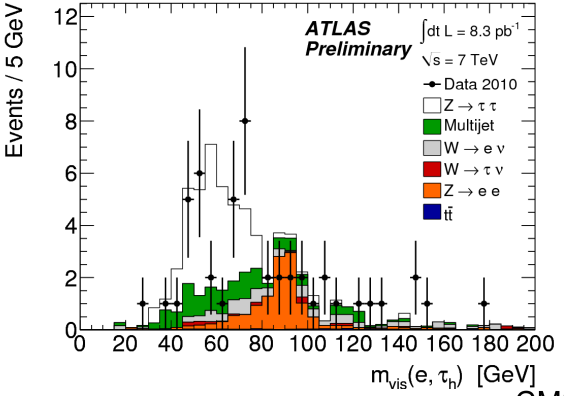
Sample	$\mathcal{R}(Z \to ee)$ (%), $p_T^e > 25$ GeV, $\lvert\eta^e\rvert < 2.5$	$\mathcal{R}(Z \to \mu\mu)$ (%), $p_T^\mu > 20$ GeV, $\lvert\eta^\mu\rvert < 2.1$
Data HE	$4.3 \pm 0.6(stat) \pm 1.1(syst)$	$5.1 \pm 0.6(stat) \pm 1.3(syst)$
Data HP	$5.4 \pm 1.0(stat) \pm 1.2(syst)$	$4.6 \pm 0.8(stat) \pm 1.1(syst)$
MADGRAPH	$5.1 \pm 0.2(stat) \pm 0.2(syst) \pm 0.6(theory)$	$5.3 \pm 0.1(stat) \pm 0.2(syst) \pm 0.6(theory)$
MCFM	$4.3 \pm 0.5(theory)$	$4.7 \pm 0.5(theory)$

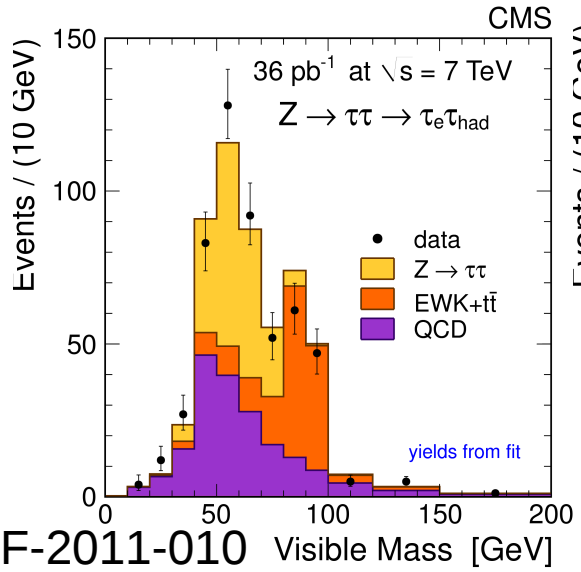
Z to ττ

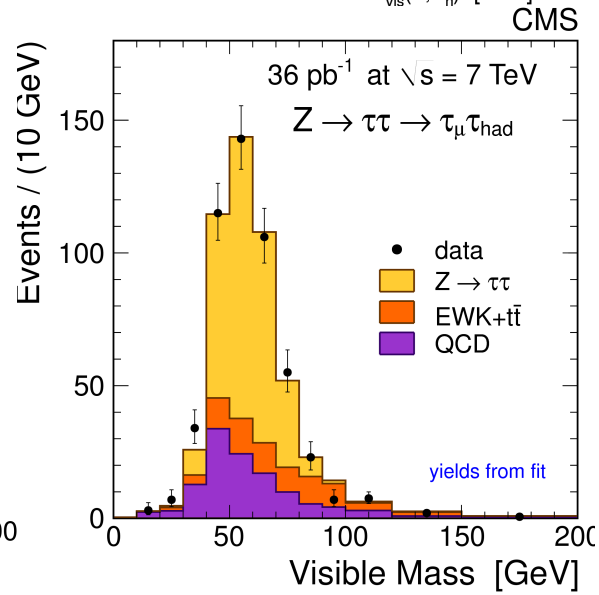
- Both ATLAS and CMS used Z to ττ events as a proof of principle of their hadronic τ reconstruction
  - For both experiments the main systematics is in the tau reconstruction and mis-tag rate











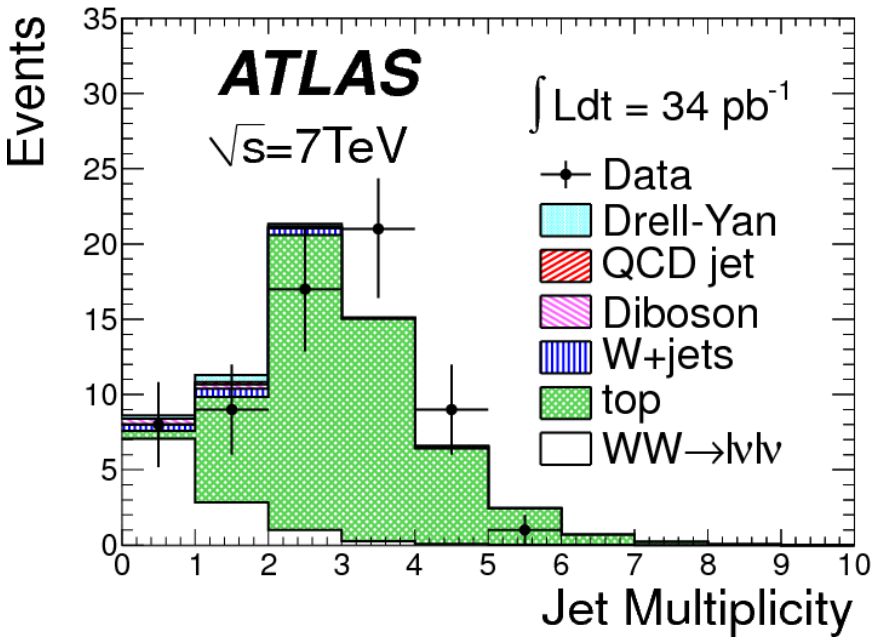
arXiv:1104.1617v1, ATLAS-CONF-2011-010

WW final state

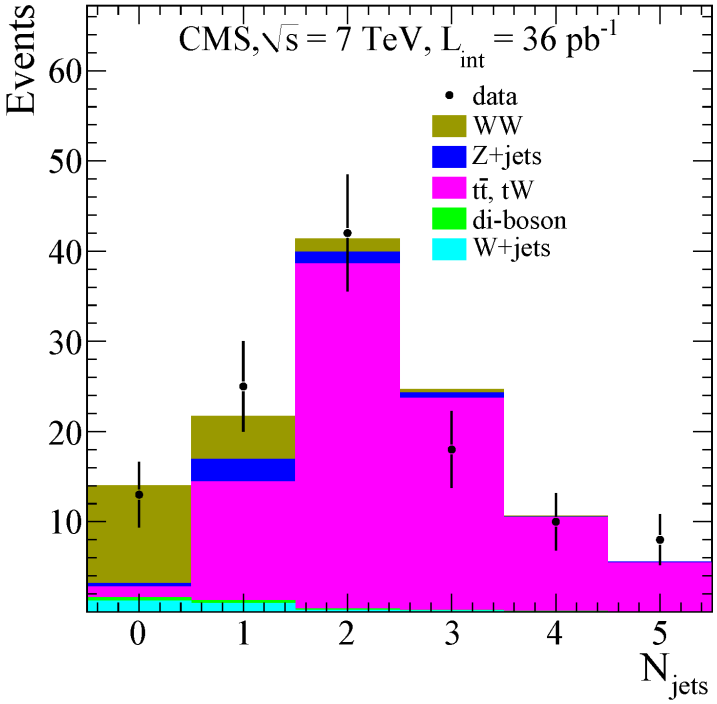
arXiv:1104.5225,Phys. Lett. B 699 (2011) 25-47

- Preliminary step towards H->WW
- Main backgrounds: W+jets, Drell-Yan, ttbar, tW
- Analysis strategy: require two leptons and veto Drell-Yan and extra jets
- Both analyses yielded cross section measurements with order of 10 candidates

$41^{+20}_{-16}(\text{stat.}) \pm 5(\text{syst.}) \pm 1(\text{lumi.})$ pb

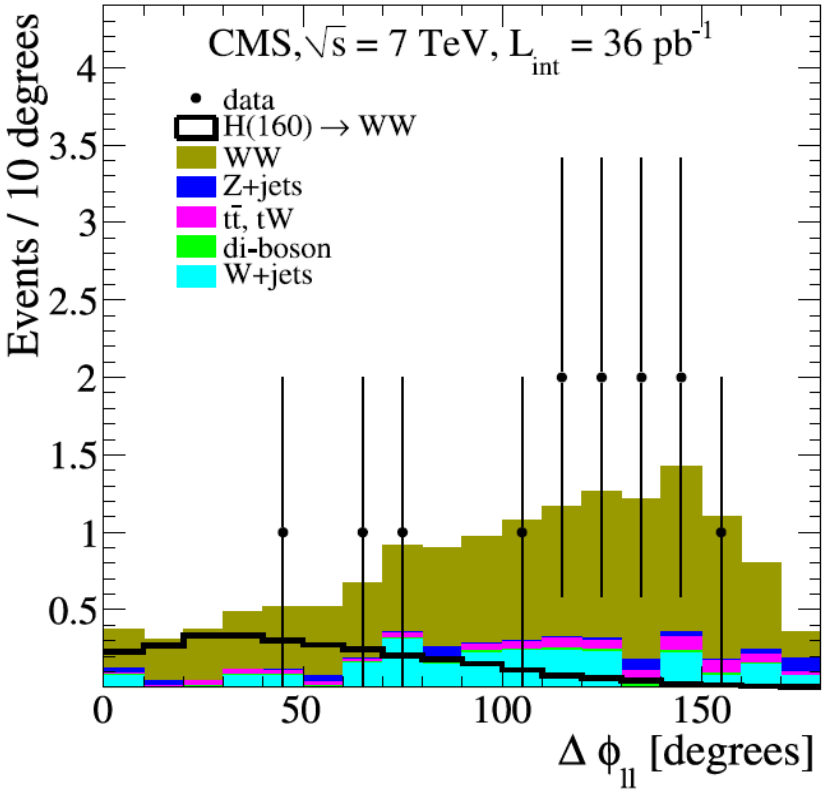


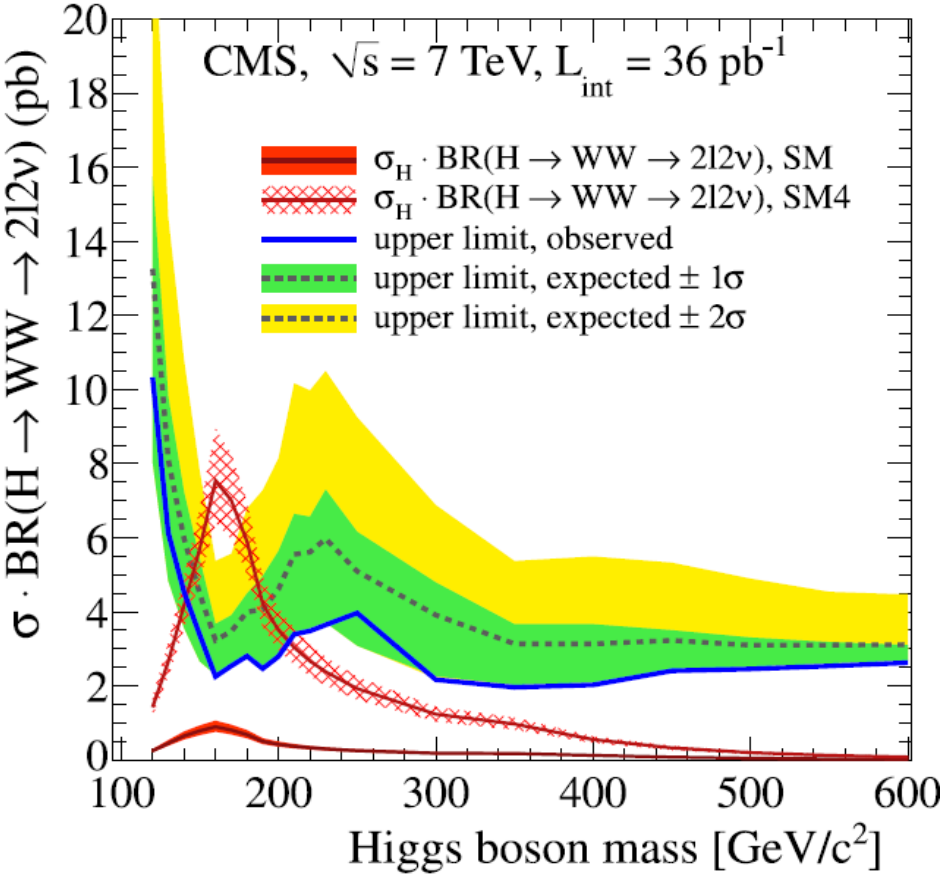
$41.1 \pm 15.3\ (\text{stat}) \pm 5.8\ (\text{syst}) \pm 4.5\ (\text{lumi})$ pb



WW final state

- Exploiting different spin correlations in Higgs decay CMS was able to exclude Higgs in 4 generation SM for masses between 144 and 207 GeV

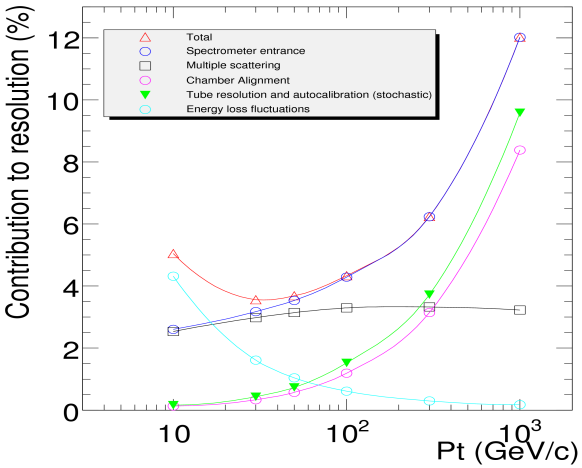




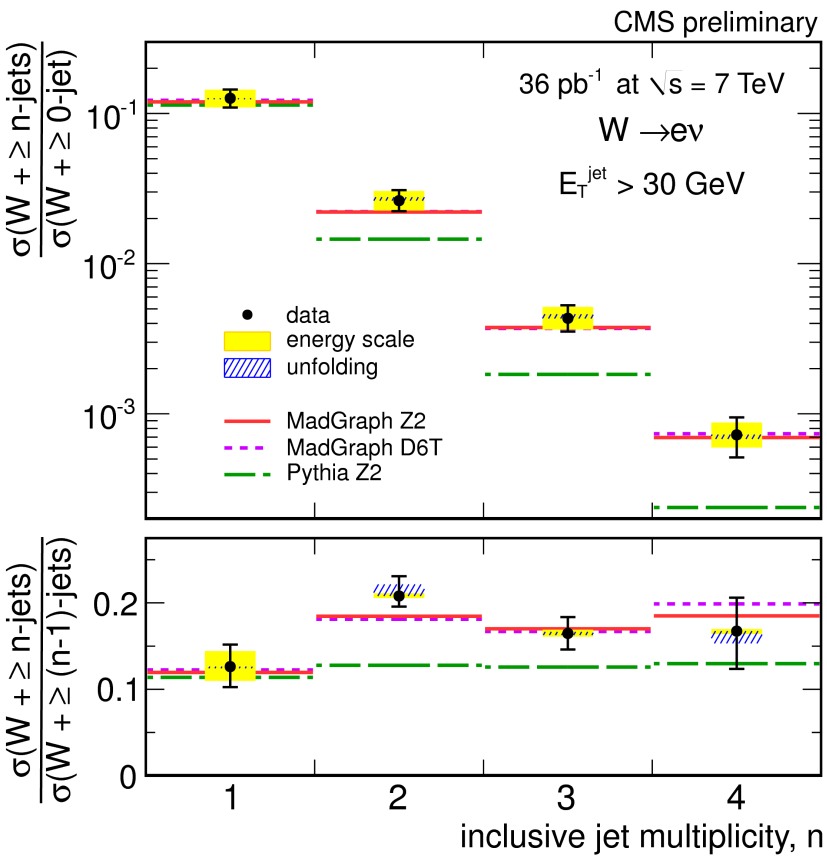
Conclusion

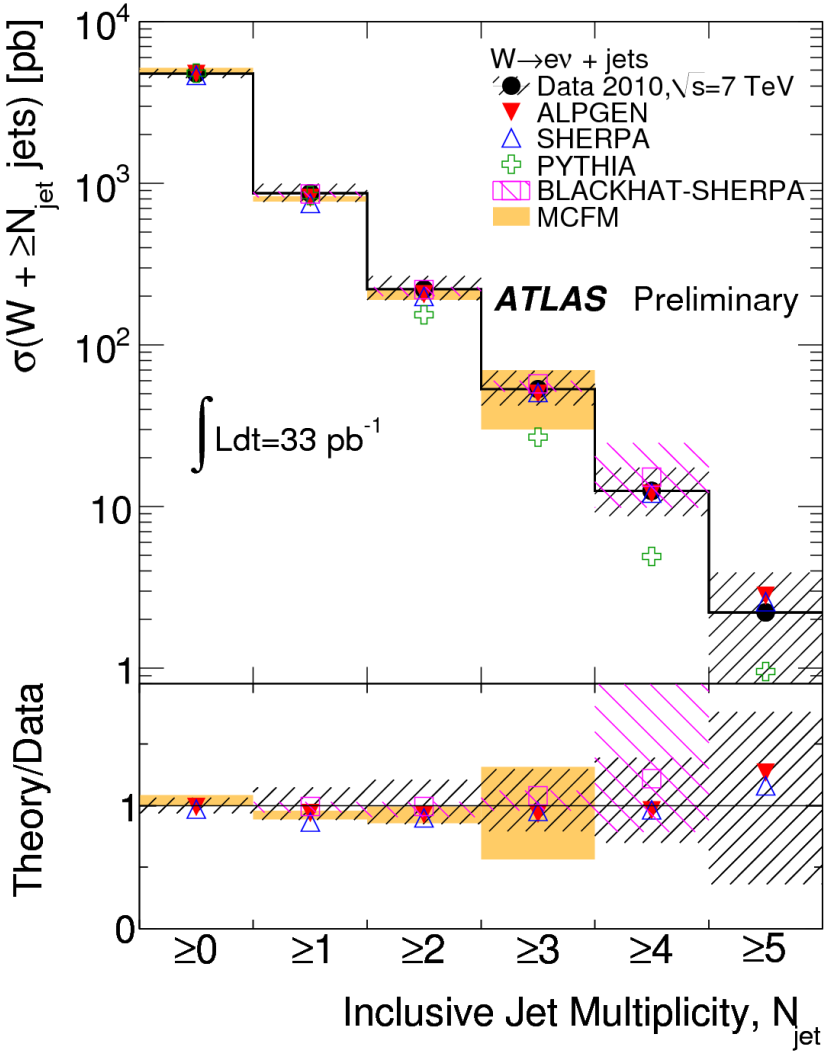
- The LHC electroweak program is progressing very well!
- Both ATLAS and CMS produced an enormous number of results with 2010 data
  - Cross sections
  - Asymmetries
  - Differential distributions
  - Associated production with jets
  - Final states with taus and b-jets
  - Di-bosons
- And more results are coming from the 2011 data!

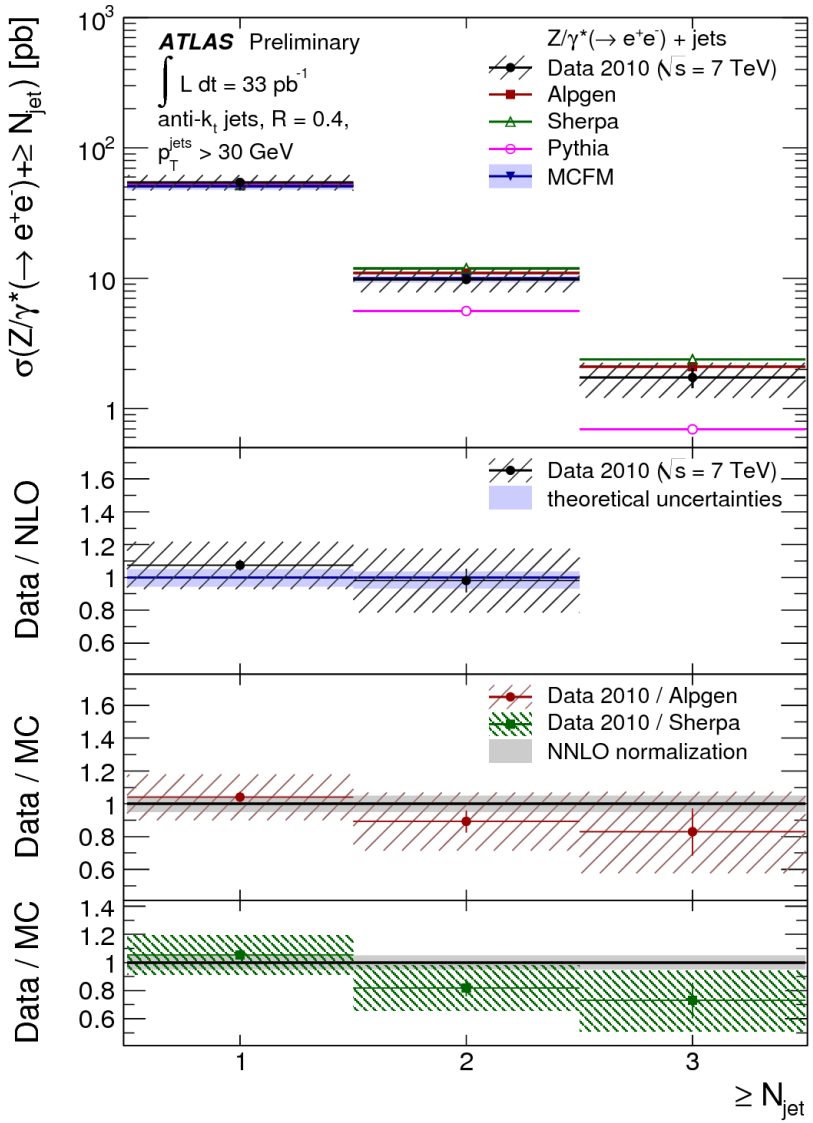
Backup

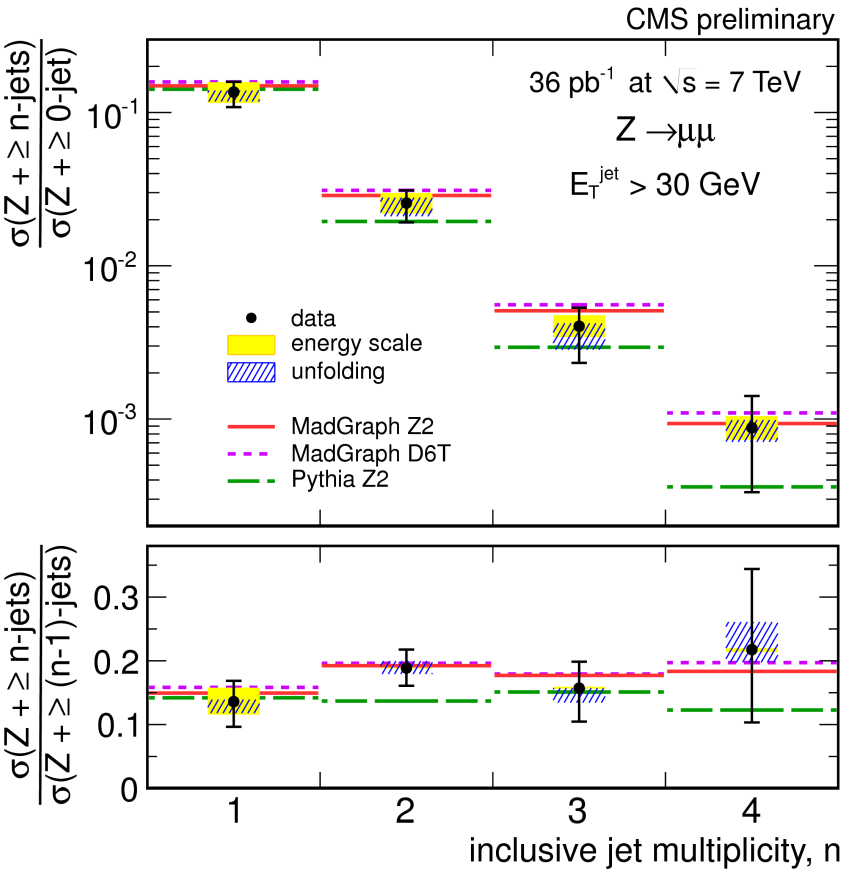

Contribution to resolution (%)
Pt (GeV/c)
Total
Spectrometer entrance
Multiple scattering
Chamber Alignment
Tube resolution and autocalibration (stochastic)
Energy loss fluctuations
0
2
4
6
8
10
12
10
10^2
10^3

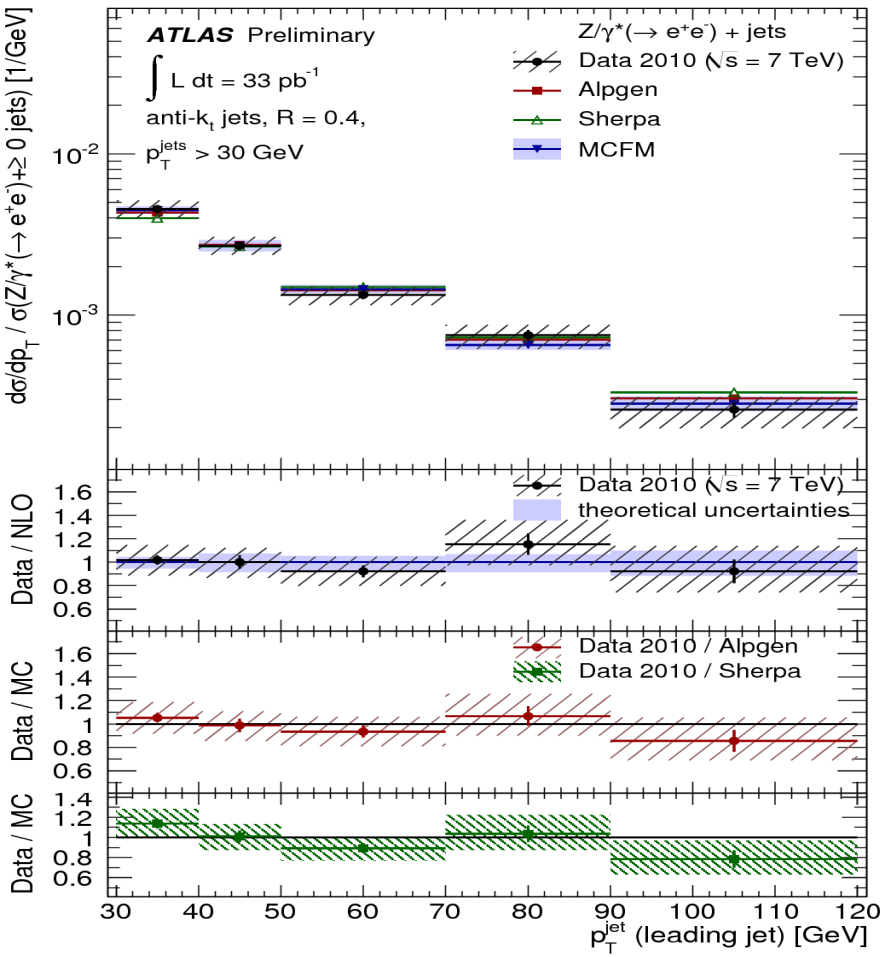
W/Z+jets

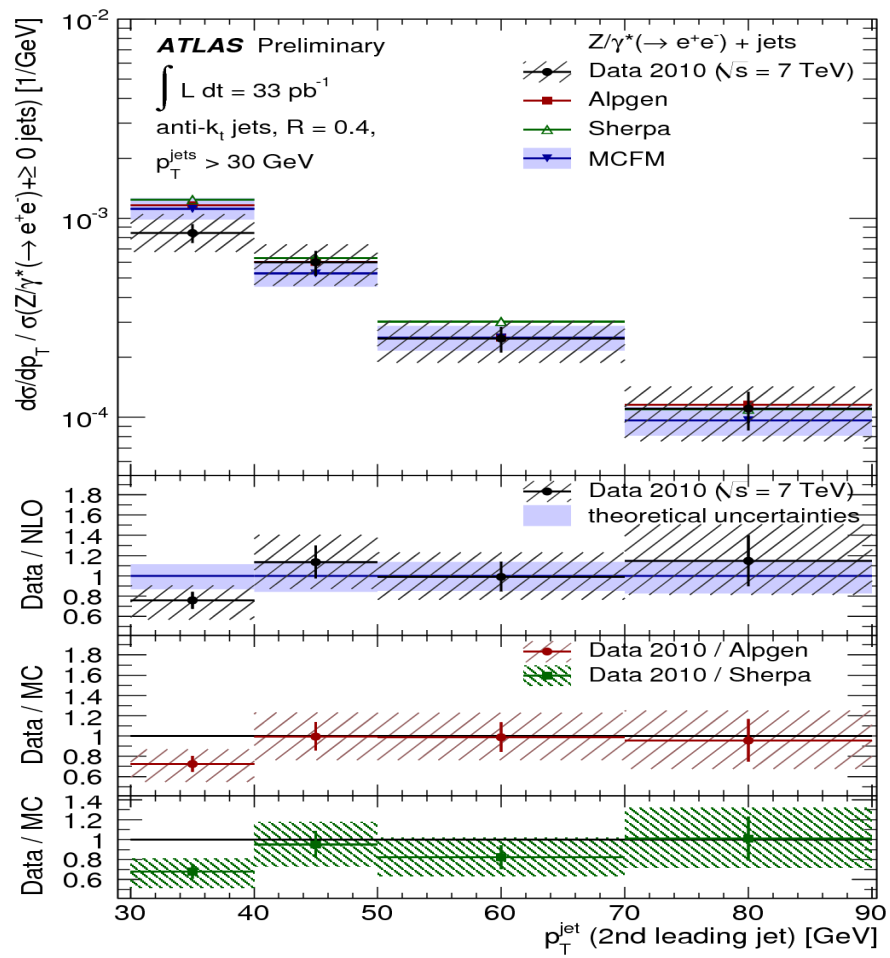

CMS preliminary
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
W →eν
E_T^{jet} > 30 GeV
data
energy scale
unfolding
MadGraph Z2
MadGraph D6T
Pythia Z2
σ(W + ≥ n-jets) / σ(W + ≥ 0-jet)
σ(W + ≥ n-jets) / σ(W + ≥ (n-1)-jets)
inclusive jet multiplicity, n


W→eν + jets
Data 2010, $\sqrt{s}$=7 TeV
ALPGEN
SHERPA
PYTHIA
BLACKHAT-SHERPA
MCFM
ATLAS Preliminary
$\int$ Ldt=33 pb^{-1}
σ(W + ≥N$_{jet}$ jets) [pb]
Theory/Data
Inclusive Jet Multiplicity, N$_{jet}$


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
Pythia
MCFM
σ(Z/γ*(→ e+e-)+≥ Njet) [pb]
Data 2010 (√s = 7 TeV)
theoretical uncertainties
Data / NLO
Data 2010 / Alpgen
Data 2010 / Sherpa
NNLO normalization
Data / MC
Data / MC
≥ Njet


CMS preliminary
36 pb-1 at √s = 7 TeV
Z →μμ
ETjet > 30 GeV
data
energy scale
unfolding
MadGraph Z2
MadGraph D6T
Pythia Z2
σ(Z + ≥ n-jets) / σ(Z + ≥ 0-jet)
σ(Z + ≥ n-jets) / σ(Z + ≥ (n-1)-jets)
inclusive jet multiplicity, n


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]


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 (2nd leading jet) [GeV]