Production of W and Z bosons in association with light and heavy flavour jets at the LHC

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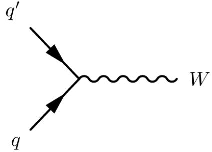
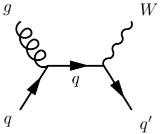
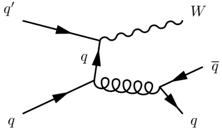
Max-Planck-Institut für Physik

29$^{\mathrm{th}}$ May 2013 - 25$^{\mathrm{th}}$ Rencontres de Blois

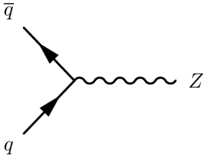
Measurement of W/Z+jets production in proton-proton collisions

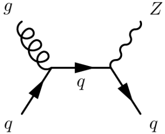


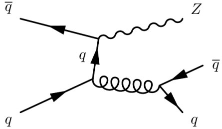




- High energies, high statistics at the LHC
- Backgrounds for many SM and beyond SM processes
- Test of perturbative QCD predictions
  - e.g. 4-flavour number scheme vs 5-flavour number scheme
  - probing regions of the phase space where large higher order corrections are expected
- Test of Monte Carlo generators
  - MadGraph(LO Matrix Element) + Pythia(Parton Shower)
  - Alpgen(LO) + Pythia(PS) or Herwig(PS)
  - Sherpa(LO+PS)
    - Blackhat (NLO cross section calculations)
  - Powheg(NLO)+ Pythia(PS) or Herwig(PS)
  - MCFM parton level NLO cross section predictions
- Input to Parton Density Functions

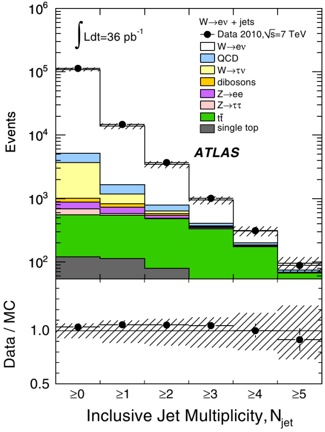




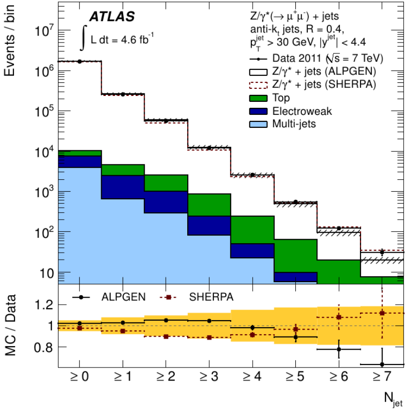


- $W \to l\nu$ and $Z \to ll$ decays. High p_T isolated $l = e, \mu$ selected.
- W selection: missing transverse energy and m_T^W jacobian peak
- Z selection: dilepton invariant mass
- Jets reconstructed with $anti - k_T$ algorithm
  Jet Energy Scale and Resolution are dominant sources of uncertainty
- Highest background uncertainties: QCD multi-jet at low n_{jets}, $t\bar{t}$ at high n_{jets}

ATLAS, W+jets



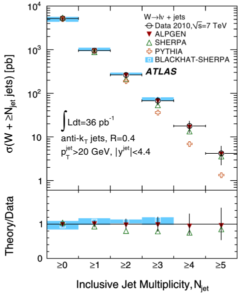
ATLAS, Z+jets

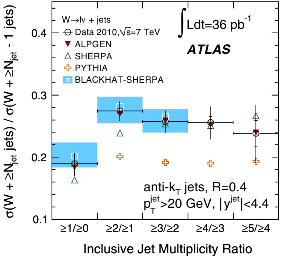


n_{jets} in W+jets events

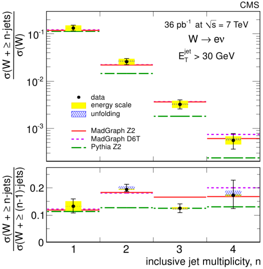
ATLAS measurement with 36 pb^{-1} at $\sqrt{s} = 7$ TeV; Phys. Rev. D85 (2012) 092002;
CMS measurement with 36 pb^{-1} at $\sqrt{s} = 7$ TeV; J. High Energy Phys. 01 (2012) 010

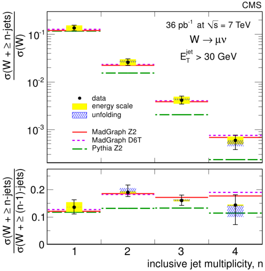
ATLAS





CMS





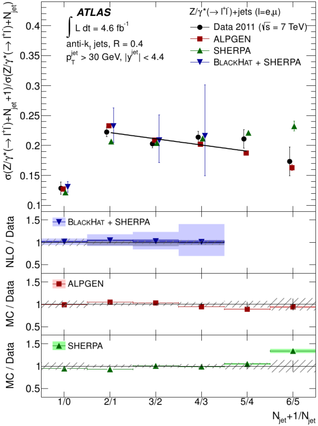
- Simulations normalised to NNLO W inclusive cross section
- ALPGEN+HERWIG(PS) and BLACKHAT-SHERPA correctly describe ATLAS data
- MADGRAPH+PYTHIA(PS) correctly describes CMS data
- Results in agreement with scaling hypothesis

Blackhat predictions
Phys. Rev. Lett. 106, 092001 (2011)

Scaling of $(n_{jets}+1)/n_{jets}$ in Z+jets events

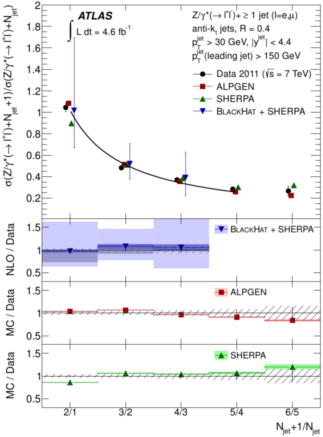
ATLAS measurement with 4.6 fb^{-1} at $\sqrt{s} = 7$ TeV; arXiv:1304.7098v1;

leading jet with $p_T > 30$ GeV

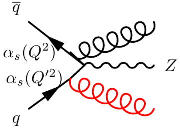


Linear fit

leading jet with $p_T > 150$ GeV



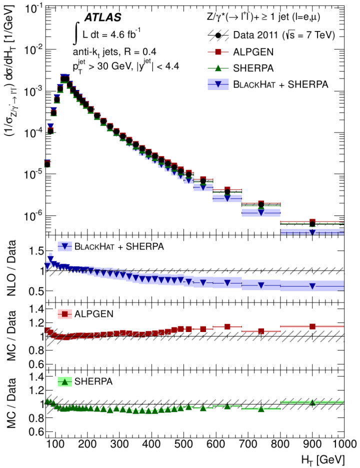
Poisson fit



- $R_n = \sigma^{n+1\ jets}/\sigma^n$
- R_n at LHC between two patterns: $R_{(n+1)/n} \approx$ constant and $R_{(n+1)/n} \propto (1/n)$
- Second behaviour expected to emerge when introducing large scale differences

For scaling patterns see arXiv:1208.3676 [hep-ph]

Blackhat predictions Phys. Rev. D 82 (2010) 074002 and Phys. Rev. D 85 (2012) 031501

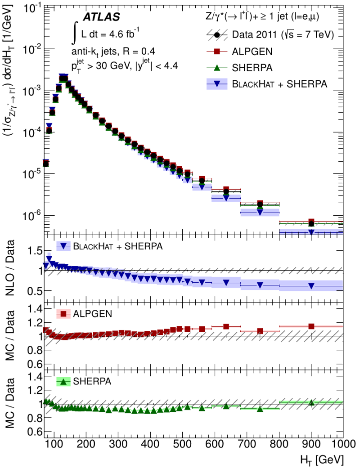


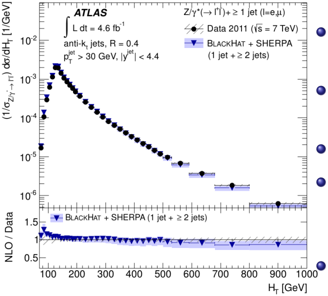
- Discrepancies in H_T already found in W+jets
- Significative discrepancies for high H_T in Z+jets
- ALPGEN too hard
- BLACKHAT-SHERPA Z+≥1 jet fixed order NLO too soft
- SHERPA has ≈constant offset

$$H_T = \sum_{leptons,jets} |p_T|$$

Kinematics of Z+jets events

ATLAS measurement with 4.6 fb^{-1} at $\sqrt{s} = 7$ TeV; arXiv:1304.7098v1;





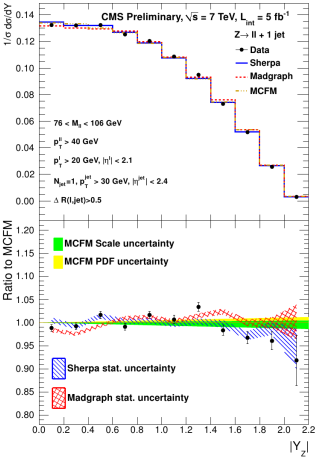
Exclusive sum of Z+1 jet and Z+≥2 jets predictions

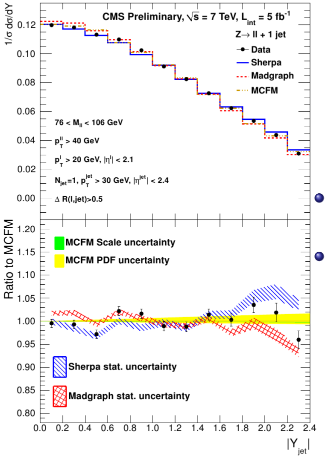
- Discrepancies in H_T already found in W+jets
- Significative discrepancies for high H_T in Z+jets
- ALPGEN too hard
- BLACKHAT-SHERPA Z+≥1 jet fixed order NLO too soft
- SHERPA has ≈constant offset
- BLACKHAT-SHERPA sum of Z+1 jet and Z+≥2 jets describe data

$$H_T = \sum_{leptons,jets} |p_T|$$

Topology of Z+1-jet production

CMS preliminary measurement with 5.0 fb^{-1} at $\sqrt{s} = 7$ TeV; CMS-PAS-SMP-12-004

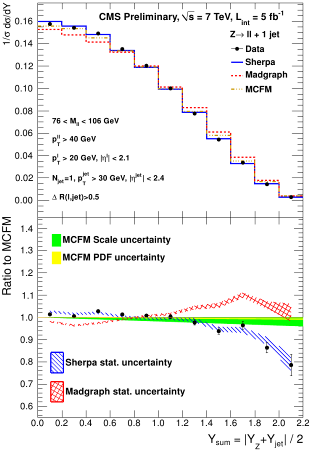


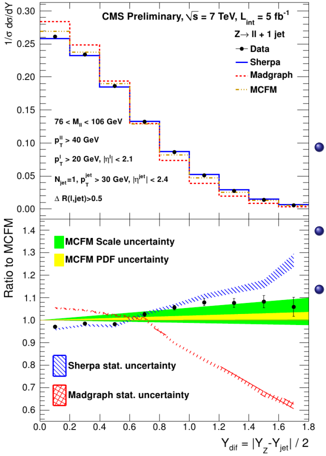


- Rapidity Y_Z and Y_{jet} correlated
- Good data/MC agreement

Topology of Z+1-jet production

CMS preliminary measurement with 5.0 fb^{-1} at $\sqrt{s} = 7$ TeV; CMS-PAS-SMP-12-004

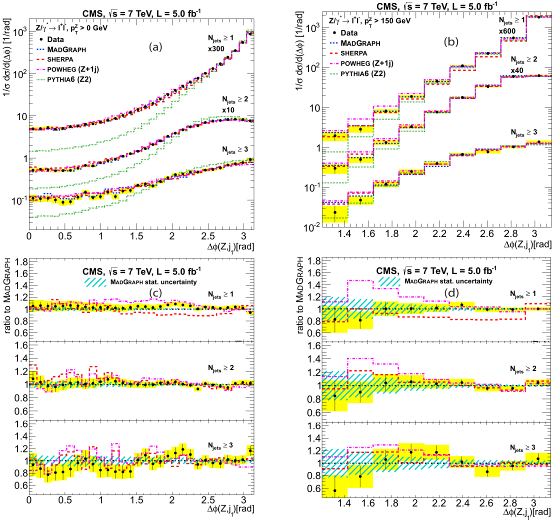




- Rapidity sum $|Y_Z + Y_{jet}|/2$ and difference $|Y_Z - Y_{jet}|/2$ approximatively uncorrelated
- MadGraph+Pythia(PS):
  MLM scheme
- Sherpa:
  CKKW scheme

CMS measurement with 5.0 fb^{-1} at $\sqrt{s} = 7$ TeV; Phys. Lett. B722 (2013) 238

$p_T^Z > 0$ GeV $\qquad$ $p_T^Z > 150$ GeV

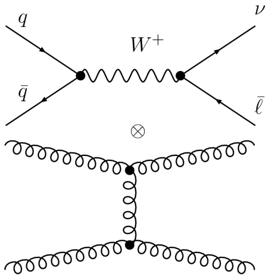


- MadGraph(LO) +Pythia in agreement with measurement
- Powheg+Pythia within 10%

  only evaluates Z+1-jet at fixed order NLO
- Sherpa (up to 4 partons) within 10%
- Discrepancies less relevant at higher n_{jets}
- Pythia stand-alone performs better for $p_T^Z > 150$ GeV

Double Parton Interactions in W ($\rightarrow$lnu) + 2 jet events

ATLAS measurement with 36 pb^{-1} at $\sqrt{s} = 7$ TeV; New J. Phys. 15 (2013) 033038
CMS measurement with 5 fb^{-1} at $\sqrt{s} = 7$ TeV;
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ12028



W+2-jets production via DPI

Given two processes X and Y:

$$\sigma^{tot}_{X+Y}(s) = \sigma^{SPI}_{X+Y}(s) + \sigma^{DPI}_{X+Y}(s)$$
$$\sigma^{DPI}_{X+Y}(s) = \frac{\sigma_X(s)+\sigma_Y(s)}{\sigma_{eff}(s)}$$

- $\sigma_{eff}(s)$ appr. independent from phase space
  $\rightarrow$ results can be compared to other experiments
- W+2 jets kinematics is different for SPI and DPI
- f^{DPI}: fit to jets momentum unbalance
- SPI template from simulations
- DPI template from dijet data

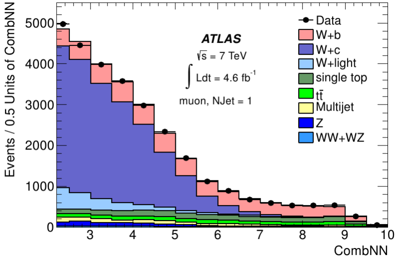
Result

- $\sigma_{eff}(7\mathrm{TeV}) = 15 \pm 3(\mathrm{stat})^{+5}_{-3}(\mathrm{syst})$ mb
- Consistent with measurements in other experiments
- Good agreement with Alpgen+Herwig+Jimmy and Sherpa
- DPI important for many measurements (see ATLAS Wbb)
- Recent preliminary study at high statistics by CMS find good agreement with the MadGraph+Pythia predictions

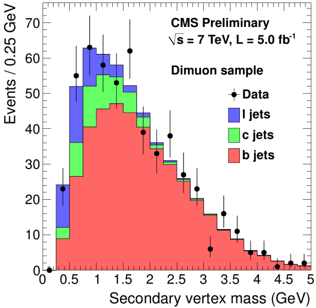
W/Z+heavy-flavour jets

- b-jets tagged using long life-time, high mass of b-hadrons
  $\rightarrow$ secondary vertex (SV) decay lenght, SV mass, impact parameters of tracks, semi-leptonic decays, jet kinematics
- neural network taggers combine all information
- light, *c*, *b* jets contributions estimated with fits to discriminating variables

ATLAS W+b-jets



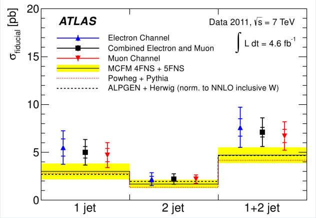
CMS Z+b-jets



W+b-jets fiducial cross section measurements

ATLAS measurement of $W+$ at least one b-jet with 4.6 fb^{-1} at 7 TeV; arXiv:1302.2929
CMS preliminary measurement of W+2 b-jets with 5.0 fb^{-1} at 7 TeV; CMS-PAS-SMP-12-026

ATLAS: W+1 b-jet + 0-1 additional jet of any flavour



- $\sigma^{fiducial}(W+1\ b\text{−jet}) =$
  5.0±0.5(stat)±1.2(syst) pb vs pred. $3.01^{+0.83}_{-0.62}$
- $\sigma^{fiducial}(W+1\ b\text{−jet}+1\text{−jet}) =$
  2.2±0.2(stat)±0.5(syst) pb vs pred. $1.69^{+0.43}_{-0.27}$
- Good agreement with MCFM (5FNS) NLO prediction (Phys. Rev. D 86 (2012) 034021)
- Predictions corrected for DPI with uncertainty assessed from ATLAS measurement
- Measurement differential in b-jet p_T provided

CMS: W + exactly 2 b-jets

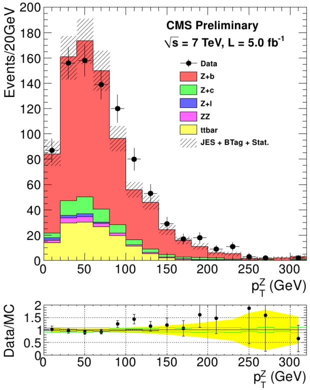
- $t\bar{t}$ is dominant background
- $\sigma^{fiducial}(W+2b\text{−jets}) =$0.53±0.05(stat)±0.09(syst)±0.06(th.)±0.01(lumi) pb
- Perfect agreement with MCFM NLO prediction 0.52±0.03 pb (JHEP 03 (2011) 027)

Z+b-jets cross section measurement

CMS preliminary measurement with 5.0 fb^{-1} at 7 TeV; CMS-PAS-SMP-13-004

Results

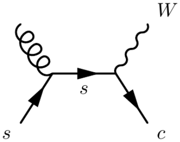
- Z+b-jets:
  3.88±0.02(stat)±0.22(syst) pb
- In agreement with predictions from MadGraph:
  - 3.49±0.03 pb in 4FNS
  - 4.03±0.02 pb in 5FNS
- Z+b-jets/Z also measured
- Dominating uncertainties:
  - b-tagging
  - JES
  - $t\bar{t}$
  - MC modelling and scales



Potential limitations of simulations with massless b-quarks which predict p_T spectra softer than data

W+c fiducial cross section measurement

ATLAS preliminary measurement with 4.6 fb^{-1} at 7 TeV; ATLAS-CONF-2013-045
CMS preliminary measurement with 5.0 fb^{-1} at 7 TeV; CMS-PAS-SMP-12-002



- sensitive to s-quark PDF
- *Wc* charge anti-correlation
  $\rightarrow$ very pure sample

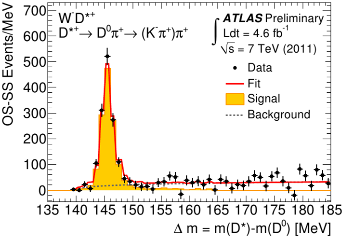
Analysis selection

- Reconstruction of $D^{\pm}/D^{*\pm}$ decays in Inner Detectors
  - ATLAS measurement not requiring a reconstructed jet
  - CMS measurement in events with at least one jet
- Selection of $c \rightarrow \mu + X$ decays (CMS only)
- *Wc* charge anti-correlation

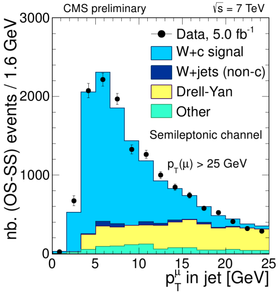
  $\rightarrow$ Opposite Sign - Same Sign (OS-SS)

  Signal is only in OS
- Important unc. from c-hadron modelling
- $W^{+} + \bar{c}/W^{-} + c$ and differential measurements provided

ATLAS



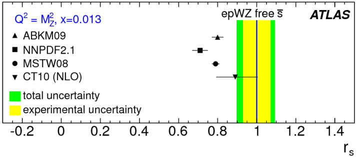
CMS



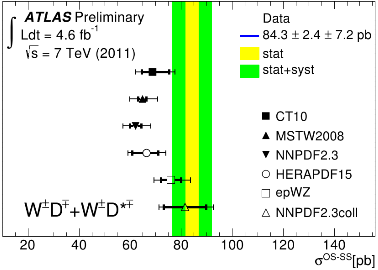
ATLAS preliminary measurement with 4.6 fb^{-1} at 7 TeV; ATLAS-CONF-2013-045
CMS preliminary measurement with 5.0 fb^{-1} at 7 TeV; CMS-PAS-SMP-12-002

- Comparison with PDF predictions
  $\rightarrow$ different level of $s/\bar{d}$ suppression
- Previous ATLAS measurement from W and Z inclusive cross sections measure no $s/\bar{d}$ suppression

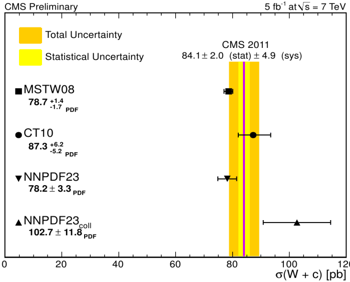
$s/\bar{d}$ from W and Z inclusive
Phys. Rev. Lett. 109 (2012) 012001



ATLAS (compared with aMC@NLO)



CMS (compared with MCFM)



The W+c measurements cannot be directly compared due to different phase space

Conclusions

- High statistics $\rightarrow$ test for theoretical predictions and Monte Carlo simulations
- In general good agreement found with data
- Some discrepancies are found especially in phase space regions with large higher order corrections
- Experimental results are reaching the sensitivity to NNLO effects
- Measurements are providing input for the PDF fits

List of references - ATLAS

W,Z + heavy-flavour jets

- Measurement of the production of a W boson in association with a charm hadron in pp collisions at $\sqrt{s} = 7\ \mathrm{TeV}$; ATLAS-CONF-2013-045
- Measurement of the cross-section for W boson production in association with b-jets in pp collisions at $\sqrt{s} = 7\ \mathrm{TeV}$ with the ATLAS detector; arXiv:1302.2929
  - Previous measurement: Phys.Lett. B707 (2012) 418-437
- Measurement of the cross-section for b-jets produced in association with a Z boson at $\sqrt{s} =$ 7 TeV with the ATLAS detector; Phys.Lett. B706 (2012) 295-313

W,Z + jets

- Measurement of the production cross section of jets in association with a Z boson in pp collisions at $\sqrt{s}$ =7 TeV with the ATLAS detector; arXiv:1304.7098v1
  - Previous measurement: Phys. Rev. D85 (2012) 032009
- Measurement of kt splitting scales in W→lnu events at $\sqrt{s} =$ 7 TeV with the ATLAS detector; arXiv:1302.1415
- Measurement of hard double-parton interactions in W (→lnu) + 2 jet events at $\sqrt{s} =$ 7 TeV with the ATLAS detector; New J. Phys. 15 (2013) 033038
- Study of jets produced in association with a W boson in pp collisions at $\sqrt{s} =$ 7 TeV with the ATLAS detector; Phys. Rev. D85 (2012) 092002
  - Previous measurement: Phys.Lett. B698 (2011) 325-345
- A measurement of the ratio of the W and Z cross sections with exactly one associated jet in pp collisions at $\sqrt{s} =$ 7 TeV with ATLAS; Phys. Lett. B708 (2012) 221-240

List of references - CMS

W,Z + heavy-flavour jets

- Measurement of the Z/γ+b-jet cross section in pp collisions at $\sqrt{s}$ =7 TeV; J. High Energy Phys. 06 (2012) 126
  - update in CMS-PAS-SMP-13-004
- Measurement of the production cross section of W bosons in association with two b jets in pp collisions at $\sqrt{s} = 7$ TeV; CMS-PAS-SMP-12-026
- Measurement of associated charm production in W final states at $\sqrt{s} = 7$ TeV; CMS-PAS-SMP-12-002

W,Z + jets

- Measurement of Rapidity Distributions for a Z Boson or a Photon in Association with a Single Jet in pp Collisions at $\sqrt{s} = 7$ TeV; CMS-PAS-SMP-12-004
- Event shapes and azimuthal correlations in Z + jets events in pp collisions at $\sqrt{s}$ =7 TeV; Phys. Lett. B722 (2013) 238
- Study of the Dijet Mass Spectrum in pp$\rightarrow$W+jets Events at $\sqrt{s}$ =7 TeV; Phys. Rev. Lett. 109, 251801 (2012)
- Jet production rates in association with W and Z bosons in pp collisions at $\sqrt{s}$ =7TeV; J. High Energy Phys. 01 (2012) 010
- Measurement of the Polarization of W Bosons with Large Transverse Momenta in W+jets Events at the LHC; Phys. Rev. Lett. 107, 021802 (2011)

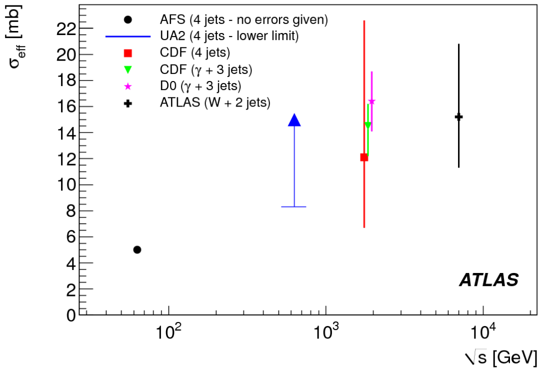
BACKUP

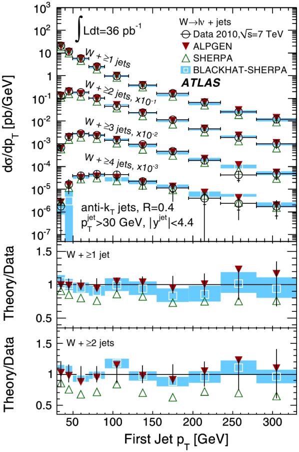
$$d\sigma^{tot}_{X+Y}(s) = d\sigma^{SPI}_{X+Y}(s) + d\sigma^{DPI}_{X+Y}(s)$$
$$d\sigma^{DPI}_{X+Y}(s) = \frac{d\sigma_X(s) + d\sigma_Y(s)}{\sigma_{eff}(s)}$$

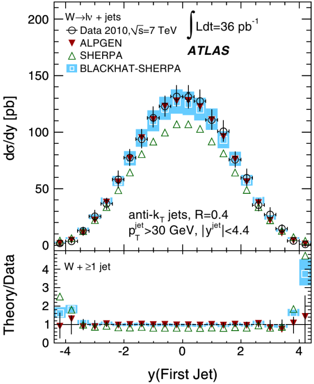
Factorization of W and 2j system selection efficiencies is assumed:

$$\sigma_{eff}(s) = \frac{\sigma_{W0j}\sigma_{2j}}{\sigma_{W+2j^{DPI}}} = \frac{N_{W0j}N_{2j}}{f^{DPI}N_{W+2j}} \frac{1}{\epsilon^{trig}_{2j}\mathcal{L}^{int}_{2j}}$$

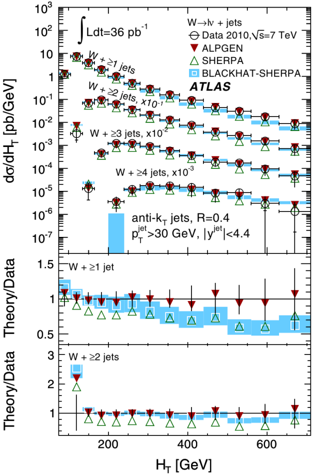
The fraction of DPI events is extracted with a fit to: $|\vec{p}_{T,j1} + \vec{p}_{T,j2}|/(|\vec{p}_{T,j1}| + |\vec{p}_{T,j2}|)$







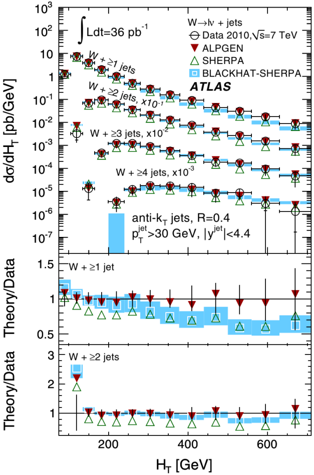
- jet p_T, y well described by Alpgen+Herwig(PS) and BlackHat-Sherpa
- Sherpa standalone uses different scales and PDFs

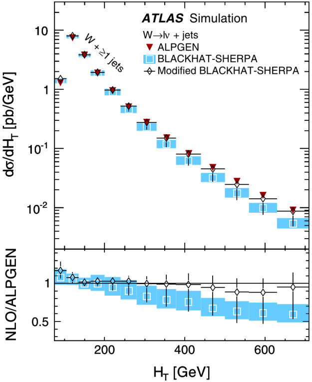


- BLACKHAT-SHERPA disagreement in H_T due to missing ME $N_p \geq 3$

Kinematics and topology of W+jets production

ATLAS measurement with 36 pb^{-1} at $\sqrt{s} = 7$ TeV; Phys. Rev. D85 (2012) 092002;



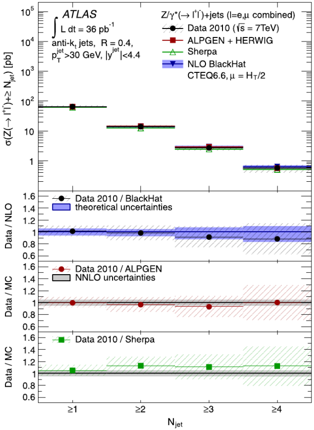


- BLACKHAT-SHERPA disagreement in H_T due to missing ME $N_p \geq 3$
- A modified treatment including higher-order terms is shown to better reproduce data

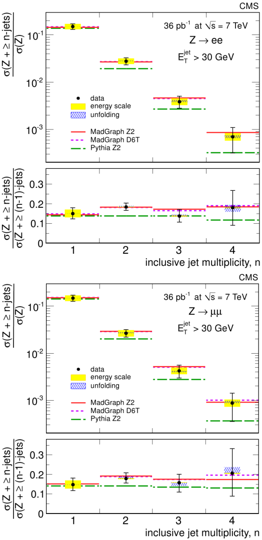
n_{jets} in Z+jets events

ATLAS measurements with 36 pb^{-1} at $\sqrt{s} = 7$ TeV;
CMS measurement with 36 pb^{-1} at $\sqrt{s} = 7$ TeV; J. High Energy Phys. 01 (2012) 010

ATLAS



CMS

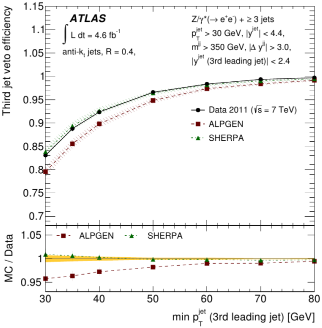


- Ratio measurements reduce uncertainty
- Simulations provide correct description
- In agreement with scaling hypothesis

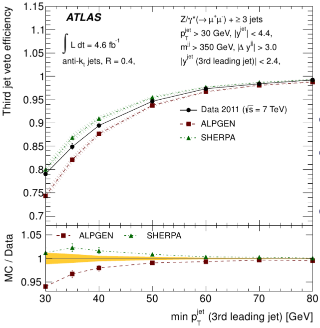
Vector Boson Fusion (VBF) veto for Z+jets events

ATLAS measurement with 4.6 fb^{-1} at $\sqrt{s} = 7$ TeV; arXiv:1304.7098v1;

VBF events selected requiring m^{jj} >350 GeV and $|\Delta y^{jj}|$ >3.0
In Higgs searches veto on third central jet to reject Z+jets background

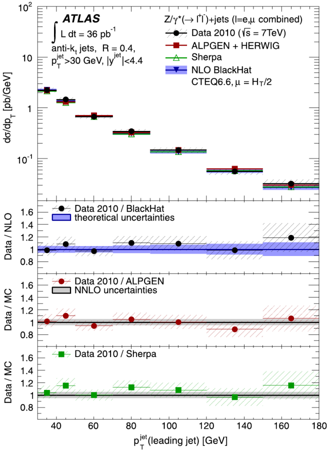


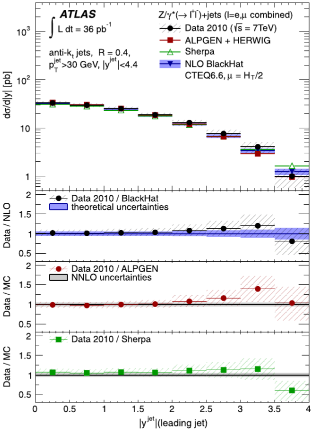
electron channel



muon channel

- Veto is tested in Z+jets
- Small discrepancy with ALPGEN
- Better agreement with SHERPA





- Very good agreement with predictions

TABLE V. Summary of systematic uncertainties on the cross sections. The uncertainties are shown for $N_{\rm jet} \geq 1$ and $N_{\rm jet} \geq 4$. The sign convention for the JES and lepton energy scale uncertainties is such that a positive change in the energy scale results in an increase in the jet or lepton energy observed in the data.

$W \to e\nu$ channel

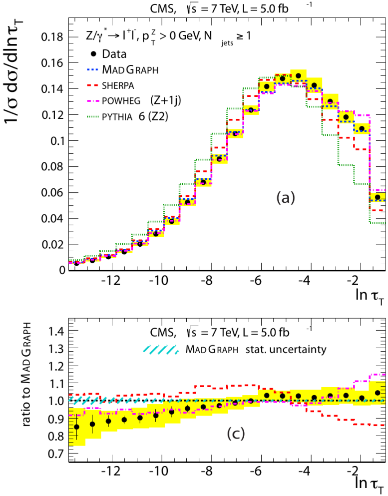
Effect	Range	Cross-section uncertainty (%) $N_{\rm jet} \geq 1$	Cross-section uncertainty (%) $N_{\rm jet} \geq 4$
Jet and cluster energy scales	2.5–14% (dependent on jet η and $p_{\rm T}$)	$+9.0, -6.6$	$+37, -35$
Jet energy resolution	$\sim$10% on each jet (dependent on jet η and $p_{\rm T}$)	± 1.6	± 6
Electron trigger	$\pm 0.5\%$	$+0.6, -0.5$	± 1
Electron reconstruction	$\pm 1.5\%$	$+1.7, -1.6$	± 4
Electron identification	$\pm$2–8% (dependent on electron η and $p_{\rm T}$)	$+4.3, -4.0$	$+10, -9$
Electron energy scale	$\pm$0.3–1.6% (dependent on η and $p_{\rm T}$)	± 0.6	$+1, -3$
Electron energy resolution	$<$0.6% of the energy	± 0.0	<1
Pileup removal requirement	$\sim$1.5% in lowest jet $p_{\rm T}$ bin	± 1.1	± 3
Multijet QCD background shape	from template variation	± 0.7	± 11
Unfolding	ALPGEN vs SHERPA	± 1.5	± 6
Luminosity	$\pm 3.4\%$	$+3.8, -3.6$	$+9, -8$
NNLO cross section for W/Z	$\pm 5\%$	± 0.2	<1
NLO cross section for $t\bar{t}$	$+7 - 10\%$	± 0.3	± 10
Simulated $t\bar{t}$ shape	from samples with more or less ISR	± 0.1	$+12, -21$

Example of the systematics uncertainties: ATLAS Z+jets

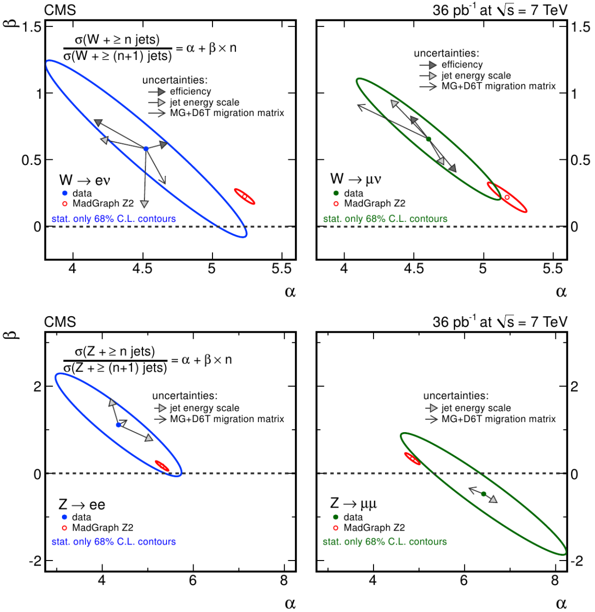
$Z(\rightarrow ee)$	≥ 1 jet	≥ 2 jets	≥ 3 jets	≥ 4 jets	p_T^{jet} in [30–500 GeV]
electron reconstruction	2.8%	2.8%	2.8%	2.8%	2.6–2.9%
jet energy scale, resol.	7.4%	10.1%	13%	17%	4.3–9.0%
backgrounds	0.26%	0.34%	0.44%	0.50%	0.2–3.2%
unfolding	0.22%	0.94%	1.2%	1.9%	1.4–6.8%
total	7.9%	10.5%	13%	17%	5.5–12.0%
$Z(\rightarrow \mu\mu)$	≥ 1 jet	≥ 2 jets	≥ 3 jets	≥ 4 jets	p_T^{jet} in [30–500 GeV]
muon reconstruction	0.86%	0.87%	0.87%	0.88%	0.8–1.0%
jet energy scale, resol.	7.5%	9.9%	13%	16%	3.2–8.7%
backgrounds	0.093%	0.20%	0.41%	0.66%	0.1–1.9%
unfolding	0.30%	0.68%	0.52%	1.3%	0.5–6.2%
total	7.6%	10.0%	13%	16%	4.4–10.2%

$$\tau = 1 - max_{\vec{n}_\tau} \frac{\sum_i |\vec{p}_T^{\,i} \vec{n}_\tau|}{\sum_i p_T^i}$$

- $\vec{n}_\tau$ is the unit vector that maximizes the sum
- i are the Z boson and the jets
- τ is 0 in the limit of Z+1-jet back-to-back production
- $\ln \tau$ is a convenient quantity
- $\ln \tau \approx 0$ for spherically isotropic events
- $\ln \tau \to -\infty$ for maximum anisotropy



CMS W/Z+jets scaling



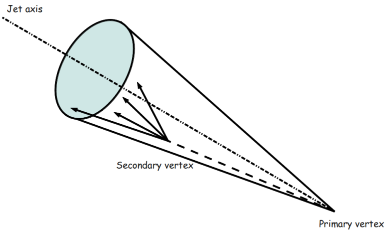
b-jets tagging

b-hadrons have long life-time, high mass, can decay via semi-leptonical modes

Tagging techniques

- Identification of secondary decay-vertices

  $\rightarrow$ decay lenght or high mass of the vertex
- high impact parameter of tracks in the jet
- muonic decays have low BR but clean signature



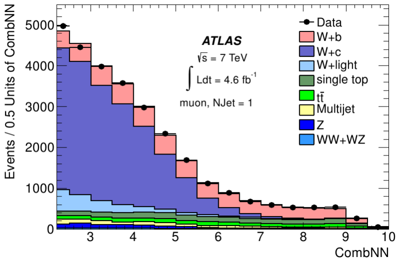
- Most advanced taggers combine several quantities (including jet kinematics) in a likelihood or with a neural network
- A discrimant variable is built to statistically separate b-jets from c-jets and light-jets
- Different working points, standard $\approx$50% efficiency
- Misedintification rates are at 0.1% level for light-jets, 10% level for c-jets

W+b-jets measurement

ATLAS measurement of $W+$ at least one b-jet with 4.6 fb^{-1} at 7 TeV arXiv:1302.2929

Previous measurement on 35 pb^{-1} Phys.Lett. B707 (2012) 418-437

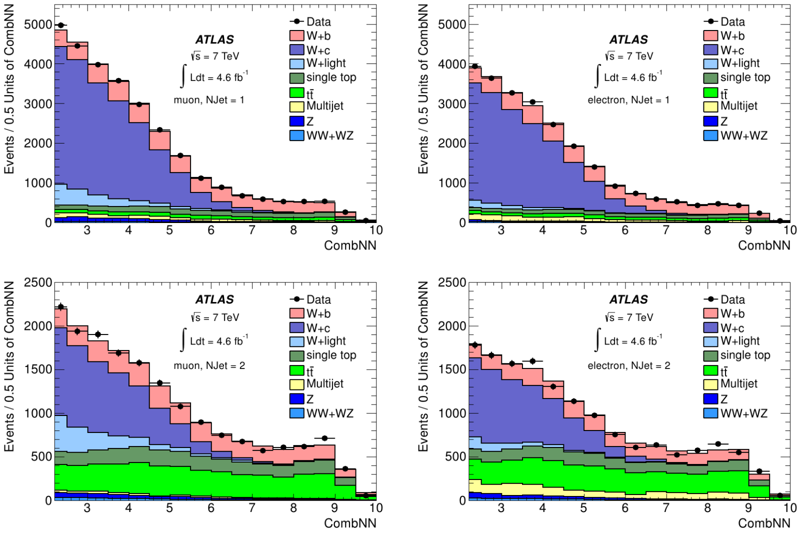
- W+1,2 jets selected
- CombNN neural network b-tagger
- n_{b-jets} =1
- CombNN shapes different for:
  - b-jets
  - c-jets
  - light jets
- W+b-jets fraction extracted from fit



W+b-jets, W+c-jets, W+light-jets shapes are fitted, other bkg fixed to data-driven predictions

- Dominating uncertainties: JES and JER.
- b-jet efficiency and MC modelling (PDF, scales, p_T^{b-jet}) are relevant
- DPI important effect, mostly 1-jet bin, low p_T^{b-jet} region

ATLAS W+bb fits and background



ATLAS W+bb systematics

Fiducial cross-section [pb]			
	1 jet	2 jet	1+2 jet
σ_{fid}	5.0	2.2	7.1
Statistical uncertainty	0.5	0.2	0.5
Systematic uncertainty	1.2	0.5	1.4
Breakdown of systematic uncertainty [%]			
Jet energy scale	15	15	15
Jet energy resolution	14	4	8
b-jet efficiency	6	4	5
c-jet efficiency	1	1	0
light-jet efficiency	1	3	2
ISR/FSR	4	8	3
MC modelling	8	4	6
Lepton resolution	1	1	0
Trigger efficiency	1	2	2
Lepton efficiency	1	2	1
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale	3	6	2
$E_{\mathrm{T}}^{\mathrm{miss}}$ pile-up	2	2	2
b-jet template	3	5	4
c-jet template	4	2	3
light-jet template	0	0	0
Multijet template	2	2	2
Total syst. uncertainty	24	23	20

ATLAS measurement of $W+$ at least one b-jet with 4.6 fb^{-1} at 7 TeV arXiv:1302.2929

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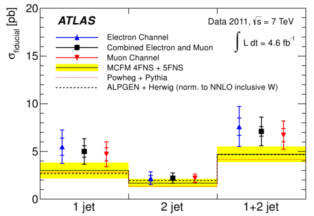
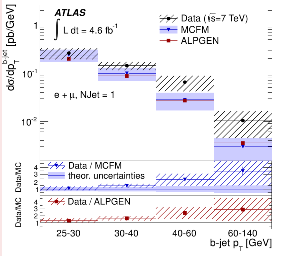
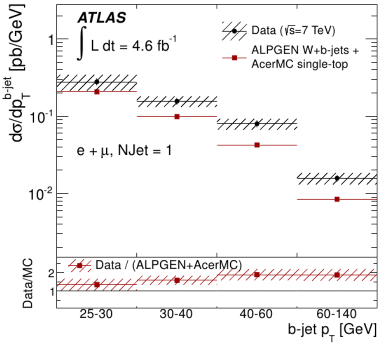
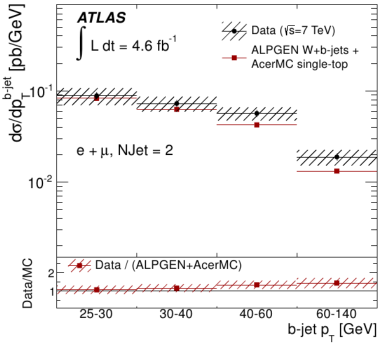


- cross section 7.1±0.5(stat)±1.4(syst) pb
- MCFM (5FNS) NLO prediction: $4.70^{+0.82}_{-0.65}$ (highest uncertainties scale and DPI)
- Agreement measured-predicted within 1.5 σ
- Alpgen and Powheg predictions (4FNS), scaled to NNLO W inclusive, in good agreement

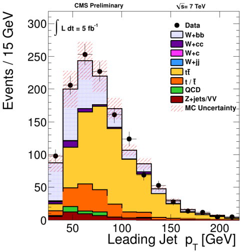
- Differential measurement vs p_T^{b-jet} (4 bins)
- In the 1-jet bin hints of tension wrt predictions at high p_T^{b-jet}
- Still compatible within uncertainties
- 2-jets bin results in agreement with predicitons

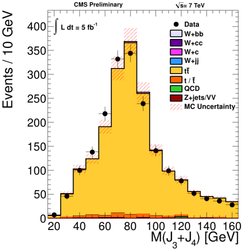



ATLAS
$\int$ L dt = 4.6 fb^{-1}
Data ($\sqrt{s}$=7 TeV)
ALPGEN W+b-jets + AcerMC single-top
e + μ, NJet = 1
Data / (ALPGEN+AcerMC)
$d\sigma/dp_T^{b\text{-jet}}$ [pb/GeV]
Data/MC
25-30
30-40
40-60
60-140
b-jet p_T [GeV]


ATLAS
$\int$ L dt = 4.6 fb^{-1}
Data ($\sqrt{s}$=7 TeV)
ALPGEN W+b-jets + AcerMC single-top
e + μ, NJet = 2
Data / (ALPGEN+AcerMC)
$d\sigma/dp_T^{b\text{-jet}}$ [pb/GeV]
Data/MC
25-30
30-40
40-60
60-140
b-jet p_T [GeV]

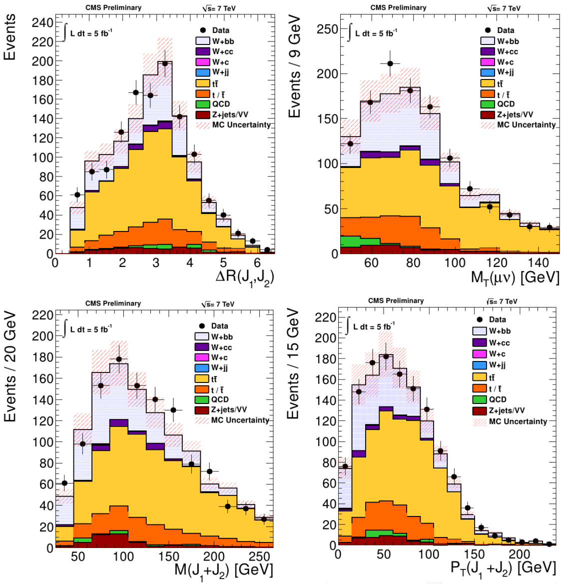
- muon channel only
- Secondary vertex tagger
- n_{b-jets} =2
- Signal and bkg kinematics different
- Simultaneous fit to
  - Leading jet p_T in SR
  - $M(J_3 + J_4)$ in 4-jets CR





- fiducial cross section 0.53±0.05(stat)±0.09(syst)±0.06(theory)±0.01(lumi) pb
- dominant uncertainties are b-tagging efficiency, mistag rates, JES
- theoretical uncertainties from PDF and scales; no DPI yet
- result in perfect agreement with MCFM NLO prediction of 0.52±0.03 pb

CMS W+2 b-jets kinematics



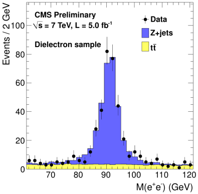
Z+b-jets measurement

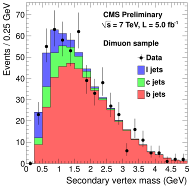
ATLAS measurement of Z+b-jets with 36 pb^{-1} at 7 TeVPhys.Lett. B706 (2012) 295-313
CMS measurement of Z+b-jets with 2.2 fb^{-1} at 7 TeV J. High Energy Phys. 06 (2012) 126
CMS measurement with 5.0 fb^{-1} at 7 TeV CMS-PAS-SMP-13-004

- Result from ATLAS with technique similar to the W+bb one (fit to secondary vertex mass)
- In good agreement with predictions, but statistically limited
- CMS result with 2.2 fb^{-1} show possible tension with predictions at 1.8σ level

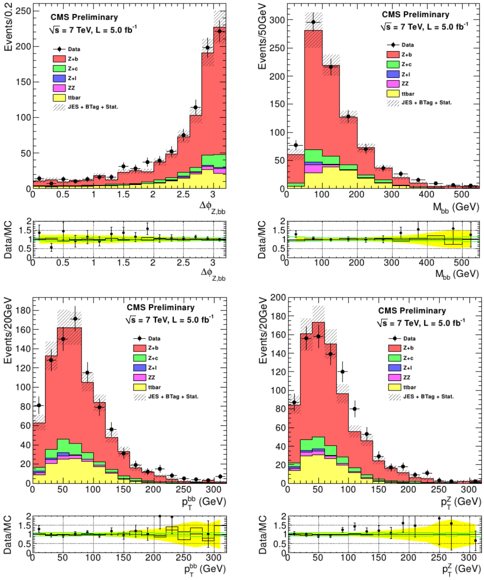
CMS results with 5 fb^{-1}

- SSV secondary vertex tagger
  $\rightarrow$ uses decay lenght significance
- Separately selected Z+1 b-jet, Z+2 b-jets samples
- Z+jets background for Z+1 b-jet
- $t\bar{t}$ relevant in Z+2 b-jets, small ZZ contribution
- $t\bar{t}$ extracted from fit to dilepton mass
- Z+b-jets purity among Z+jets through fit to SVmass



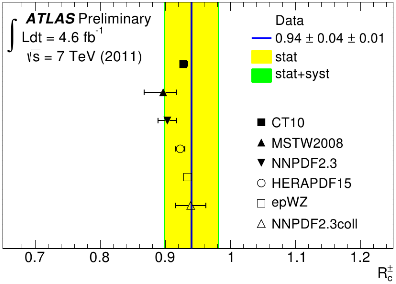


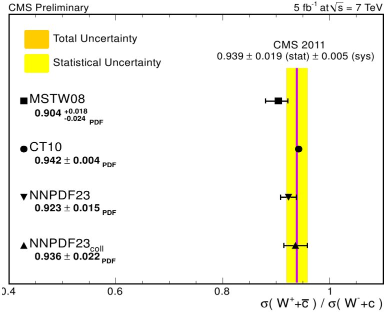
CMS Z+bb kinematics



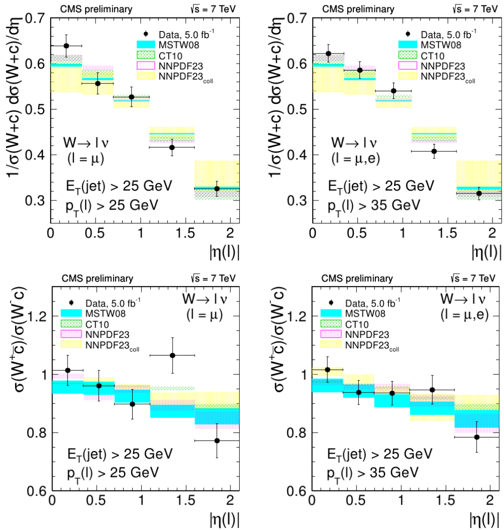
	$\mu\mu$ (%)		ee (%)	
	Z+1b	Z+2b	Z+1b	Z+2b
Uncorrelated				
b-purity	3.0	12.7	3.3	15.1
$t\bar{t}$	1.7	3.8	1.7	4.8
Dilepton selection	1.0	1.0	2.0	2.0
MC statistics	0.9	4.2	1.2	5.1
Correlated				
b-tag efficiency SFs	3.6	9.0	3.6	9.0
JES	2.0	3.6	2.0	3.6
Theory	1.8	3.0	1.8	3.0
Luminosity	2.2	2.2	2.2	2.2
ZZ	0.4	1.2	0.5	1.4
JER	0.6	0.7	0.6	0.7
Pile-up	0.3	0.3	0.3	0.3
Mistag	0.0	0.1	0.0	0.1
Tot. Stat. unc.	0.9	4.5	1.0	5.4
Tot. Syst. unc.	6.3	17.4	6.7	19.8

W+c ratio measurements

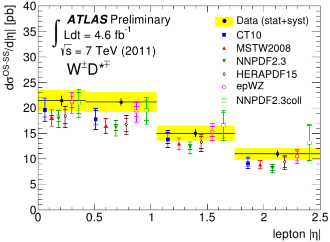




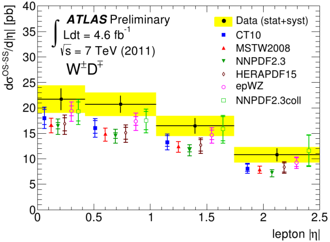
CMS W+c differential measurement



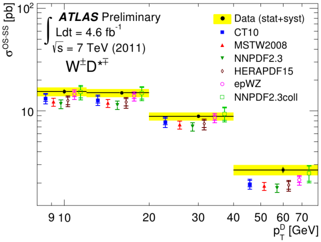
ATLAS W+c differential measurement



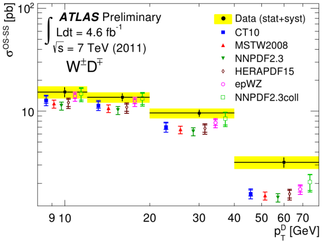
(e) $W^{\pm}D^{*\mp}$



(f) $W^{\pm}D^{\mp}$



(e) $W^{\pm}D^{*\mp}$



(f) $W^{\pm}D^{\mp}$