Measurements of the production of jets in association with a W or Z boson with the ATLAS detector

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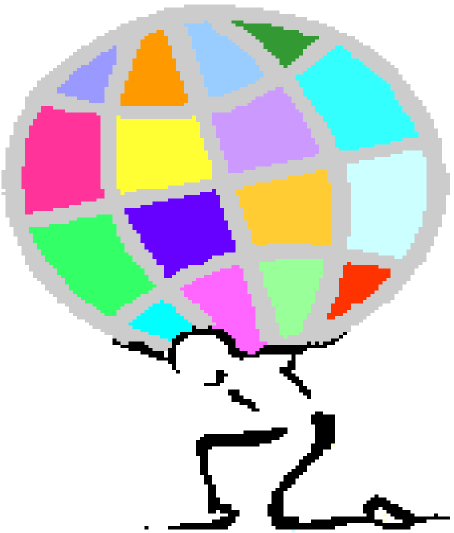


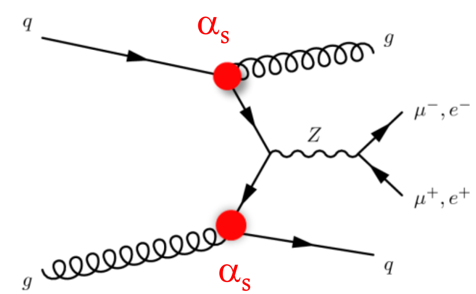
On behalf of the
ATLAS Collaboration

Motivations

Jet production in association with a W/Z boson dominated by **strong interactions:**

→ What do we learn from them?

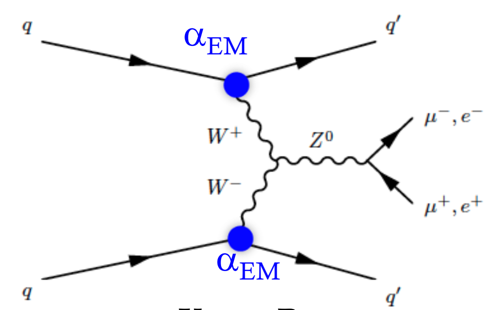
- Precision test of pQCD:
  → test state-of-the-art NLO pQCD calculations
- Background to SM measurements, Higgs and new Physics
  → important validation of the Matrix Element (ME) + Parton Shower (PS) MCs
- Impact on PDFs understanding



Production via purely **electroweak processes** rarer:

→ What do we learn from them?

- Probe triple gauge boson self-interactions
  → Model independent approach to explore new physics (anomalous couplings)
- Understand irreducible background to Higgs and beyond-SM searches
  → Constrain MCs in VBF-like regions (extreme phase spaces)



Vector Boson Fusion (VBF)

Outline

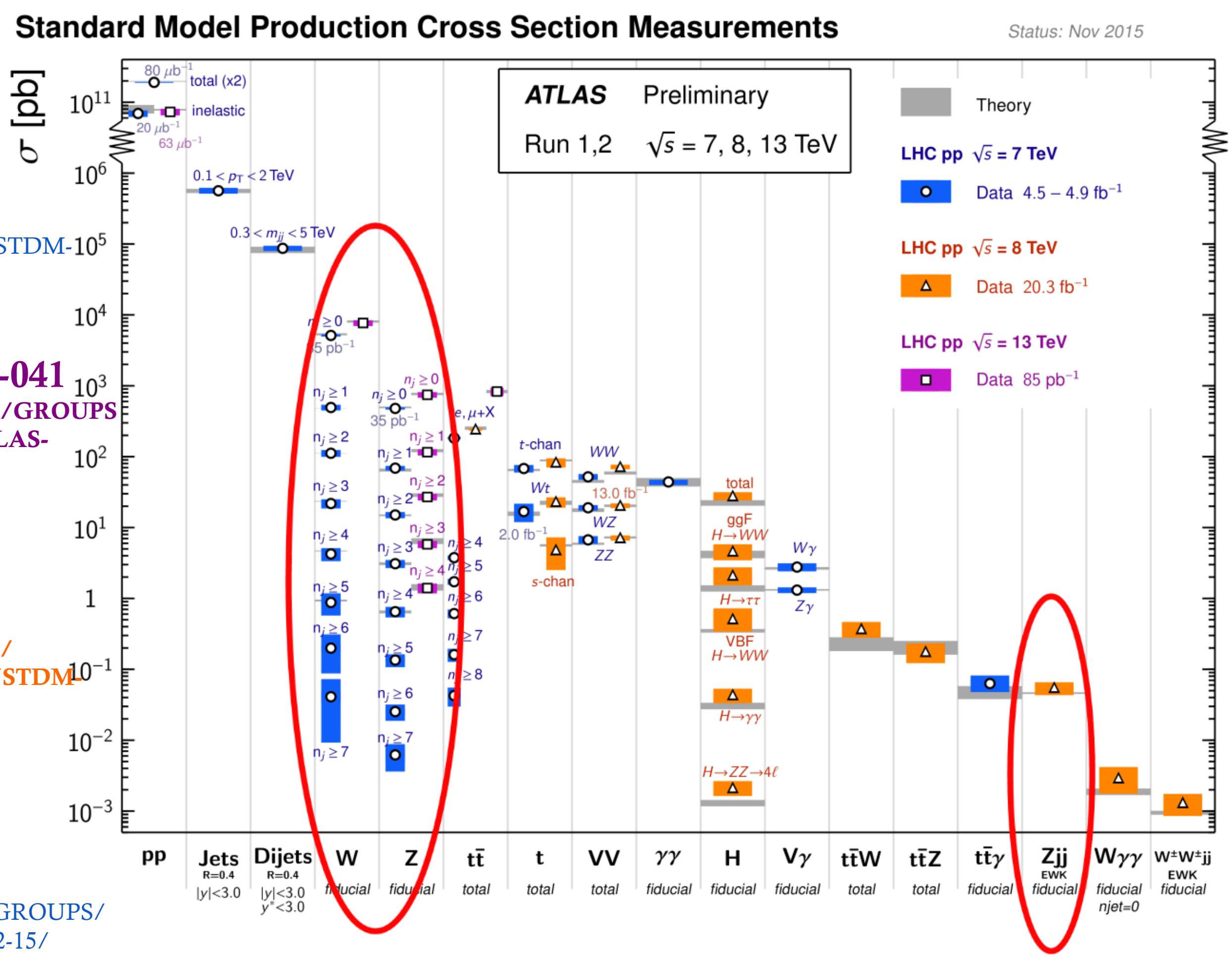
Measurements presented today:

QCD production:
W+jets@7TeV
EPJC(2015) 75:82
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2012-24/

Z+jets@13TeV
ATLAS-CONF-2015-041
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-041/

EW production:
VBF Z+jets@8TeV
JHEP04 (2014) 031
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2013-02/

QCD production:
Z+b-jets@7TeV
JHEP10(2014)141
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2012-15/



σ x BR (@13TeV) ~ 2 σ x BR(@7TeV)

σ x BR (@7-8TeV)

~ 1-10 nb (W/Z inclusive)

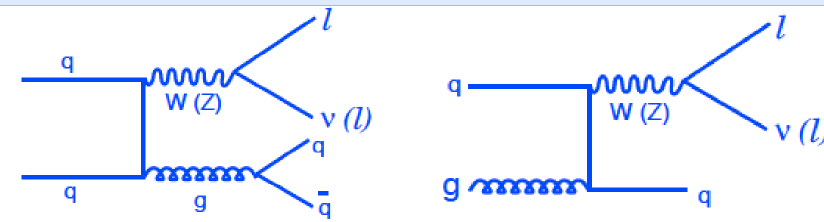
~ 1-10^{-5} nb (W/Z+1-7 jets)

~ 10^{-2}-10^{-3} nb (W/Z+ b-jets)

~ 10^{-4}-10^{-5} nb (EWK W/Z+ 2 jets)

V+jets: detector level

Look at leptonic decays Z→μμ/ee ; W→eν, μν



Kinematical region with high efficiencies, good detector performances and low backgrounds

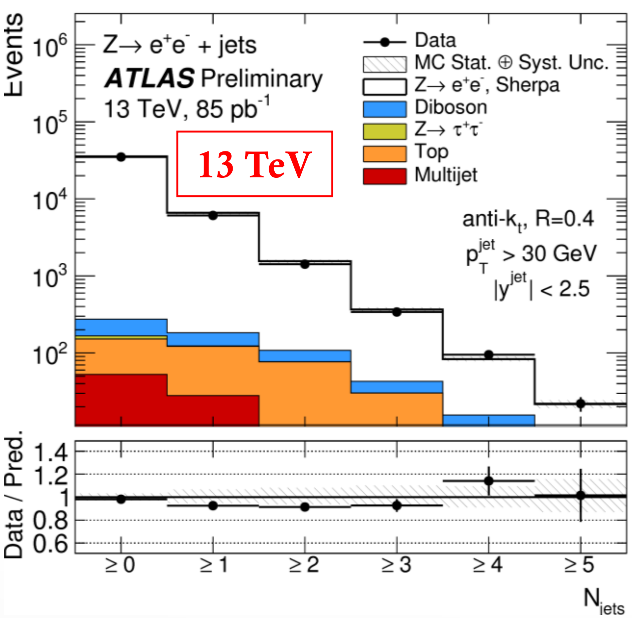
Leptons: p_T>25 GeV, |η|<2.4 (μ)- 2.47 (e)

Z: 66<m_{ll}<116 GeV

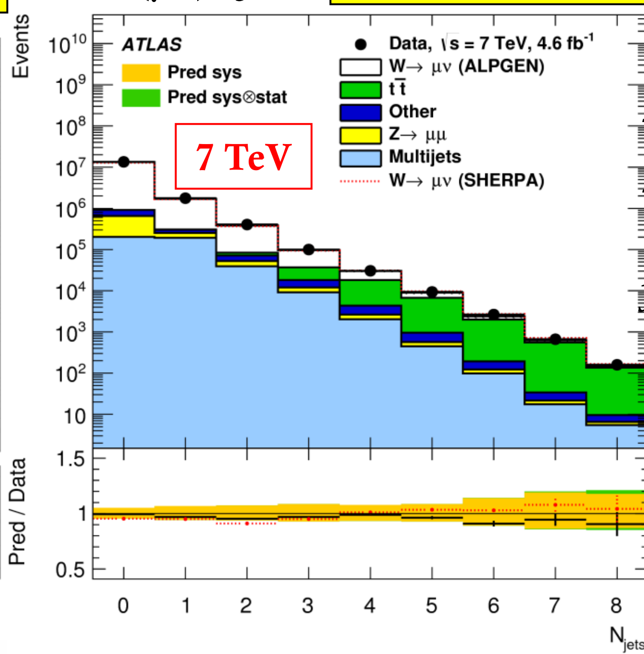
W: MET>25 GeV; m_T^W>40GeV

Jets: antiKt4, p_T>30 GeV, |y|<4.4 (7 TeV)- 2.5 (13 TeV), ΔR (l,j)>0.5

Z(ee)+jets **ATLAS-CONF-2015-041**



W(μν)+jets **Eur. Phys. J. C (2015) 75:82**



- **Z channel is a very clear probe**
- **W channel is more challenging**:
  multijet is ~10% of data up 3 jets
  top is >50% of data from 5 jets
  →detailed data driven estimation
  but $\boldsymbol{\sigma_{W+jets}}$ **~10** $\boldsymbol{\sigma_{Z+jets}}$
  → in W+jets larger kinematic ranges explored

V+jets : particle level

The Detector Level

Signal= Data –BKGs

UNFOLDING with MC

- Correct for detector effects (trigger and reconstruction efficiency, resolution, scales)
- Fiducial phase space close to the detector-level's one

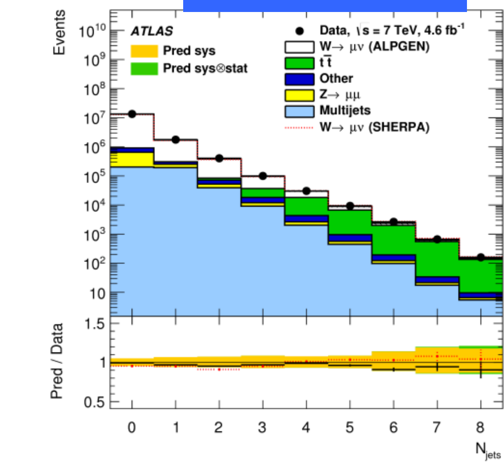
The Particle Level

Comparisons : Data unfolded – MCs

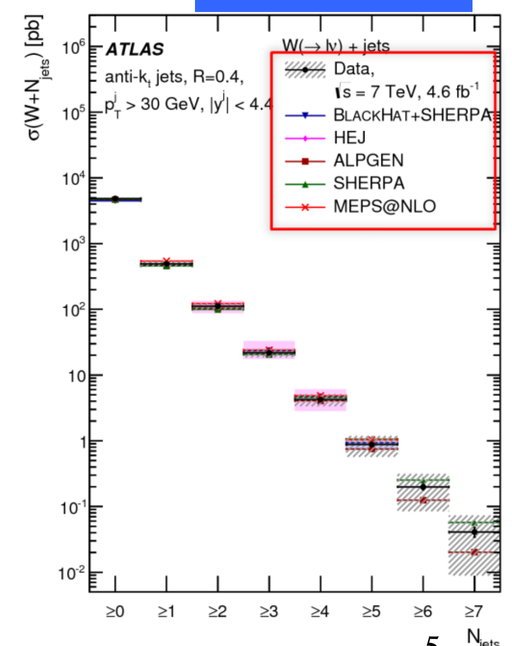
Data unfolded – Fixed order calculations corrected for non perturbative effect (Underlying event, fragmentation)

Features	MCs & Calculations	Comments
mP LO ME +PS MC	Alpgen (up to 5 partons) Sherpa 1.X (up to 4 partons)	Mainly in Run-1
	Madgraph (up to 4 partons)	New for Run-2
NLO ME+PS MC	MEPS@NLO (NLO up to 2 jets)	Run-1
	Sherpa 2.X (NLO up to 2 jets) aMC@NLO FxFx (NLO up to 2 jets)	New for Run-2
Fixed order NLO calc	BlackHat+Sherpa (NLO up 5 jets)	Run-1 and Run-2
Approx. NNLO	LoopSim (approx. NNLO for W+>=1 jets)	Run-1
Higher orders (with approx.)	HEJ (approx. to all orders for W+>=2 jets)	

Detector Level



Particle Level



V+jets: N_{jets}

Figure of merit of goodness of QCD predictions

Jet counting important discriminator with respect to the background in Higgs and searches

All predictions describe data up to 4/5 jets in 7 TeV analyses

Results confirmed at 13 TeV
Good agreement also looking at multiplicity ratio (high precision measurement)

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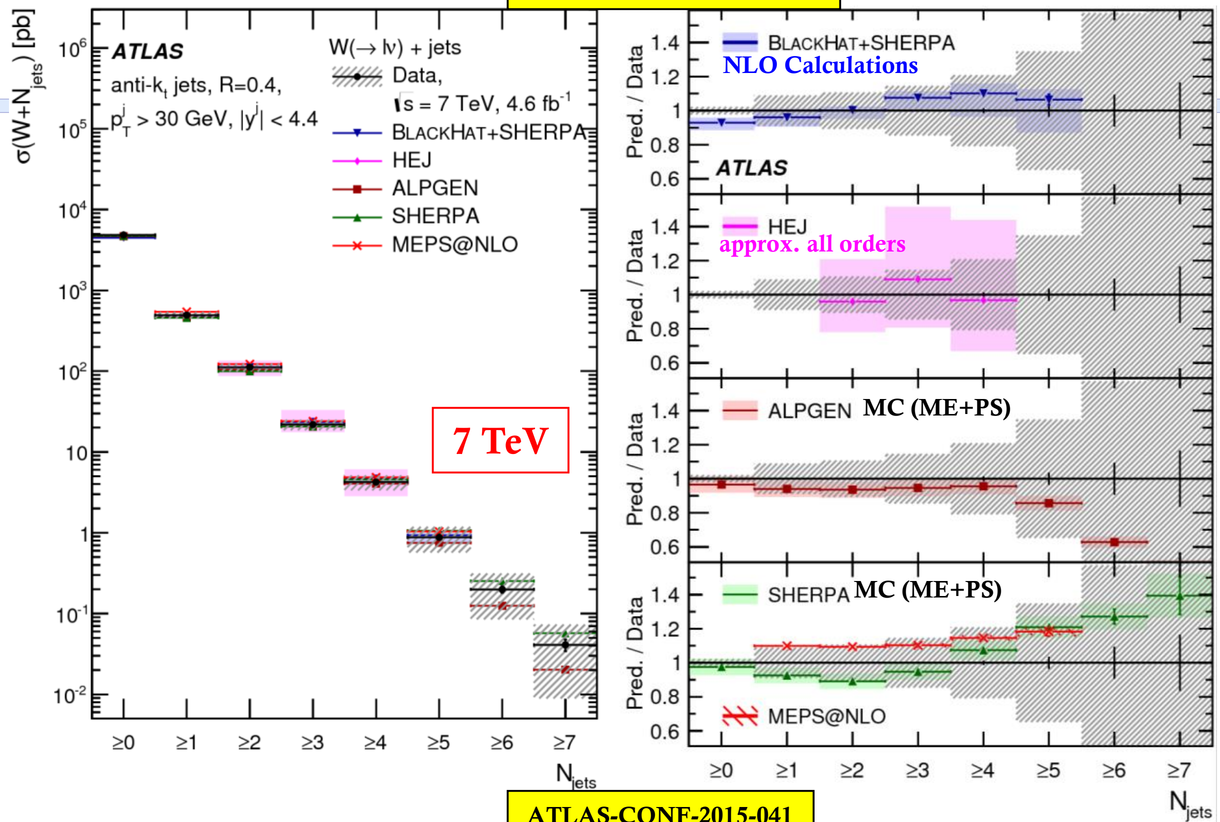

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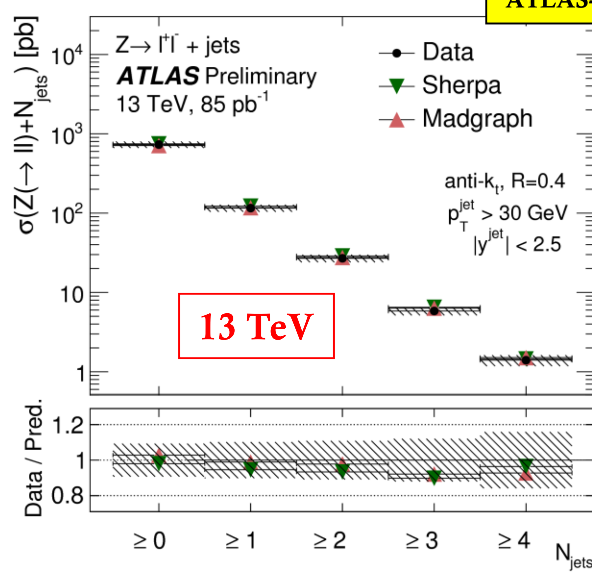
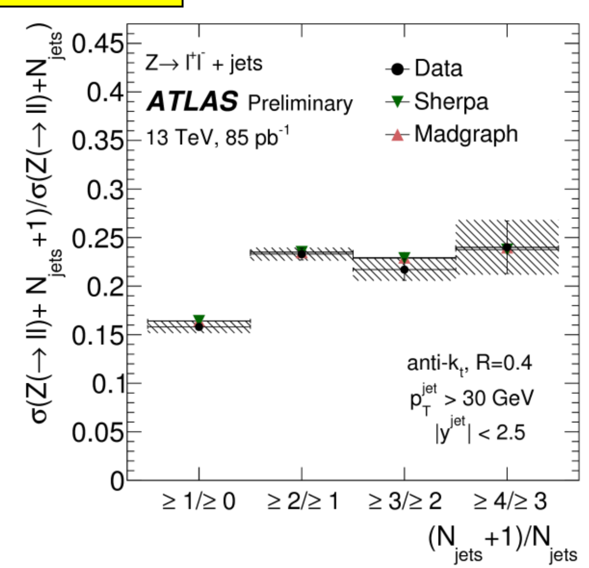
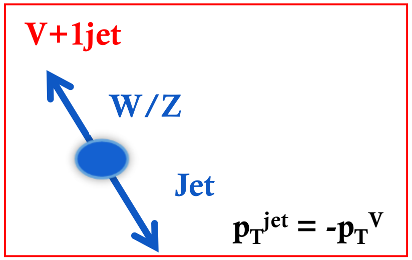
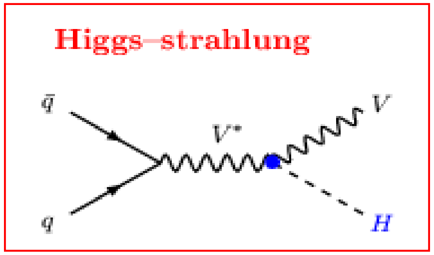




V+jets: Jet p_T

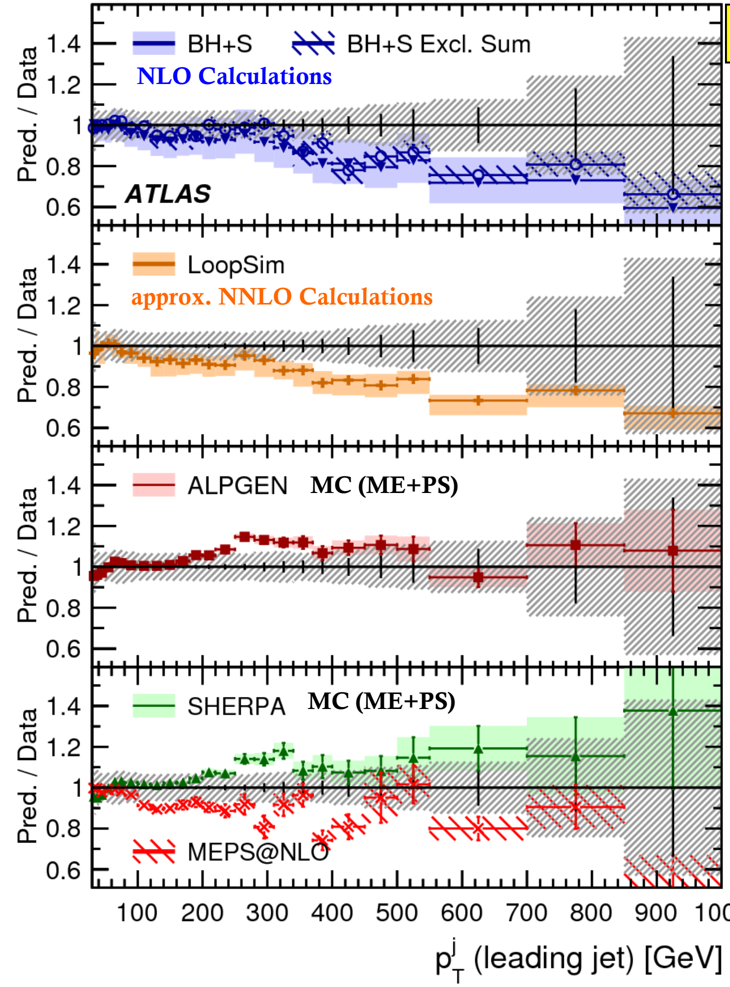
- Highly correlated to p_T of V boson
- Modeling important for VH and some BMS searches: analysis done in different p_T^V ranges
- Measured for the first time jet p_T up to 1 TeV in W+jets@7TeV analysis





At high p_T fixed order calculations (NLO and NNLO approx) underestimate data

ME+PS MCs provide a better description of data but agreement far to be perfect
→ further tuning needed



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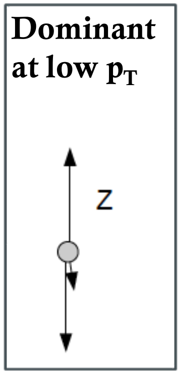
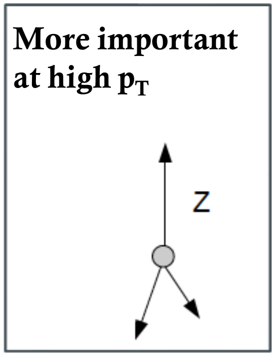
7 TeV





V+jets: H_T

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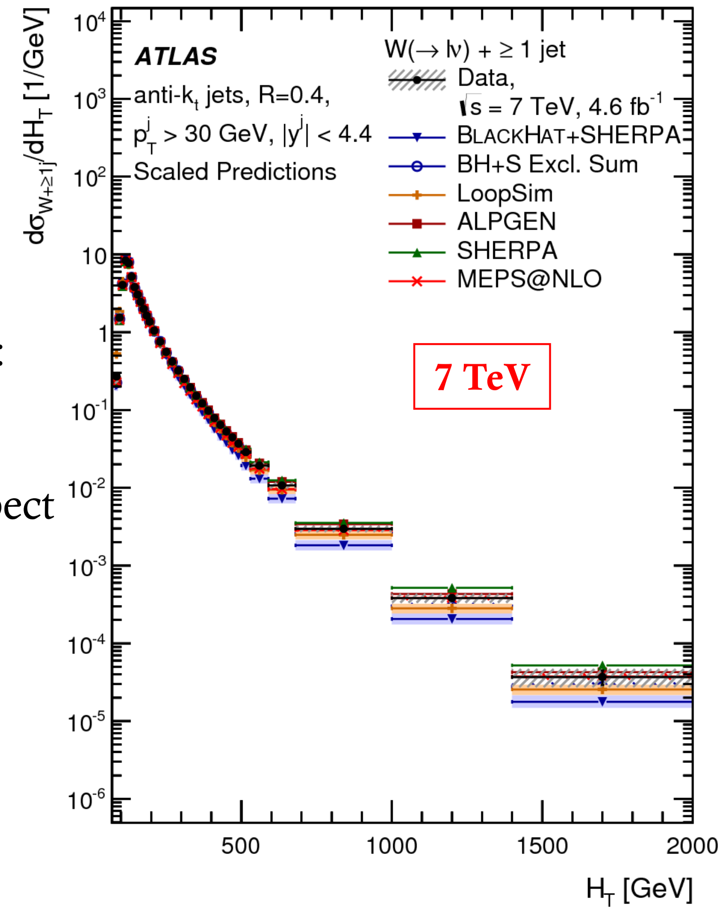
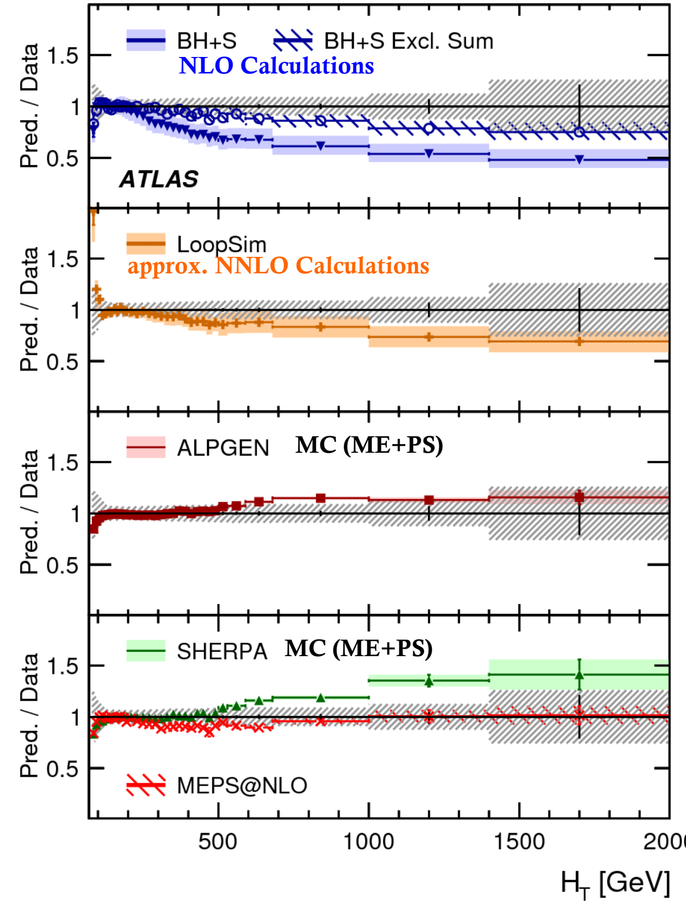
$$H_T = \sum_{leptons,jets} |p_T|$$

- Standard QCD scale
- Important for searches: signal topologies with large jet activity (discriminant with respect to SM background)

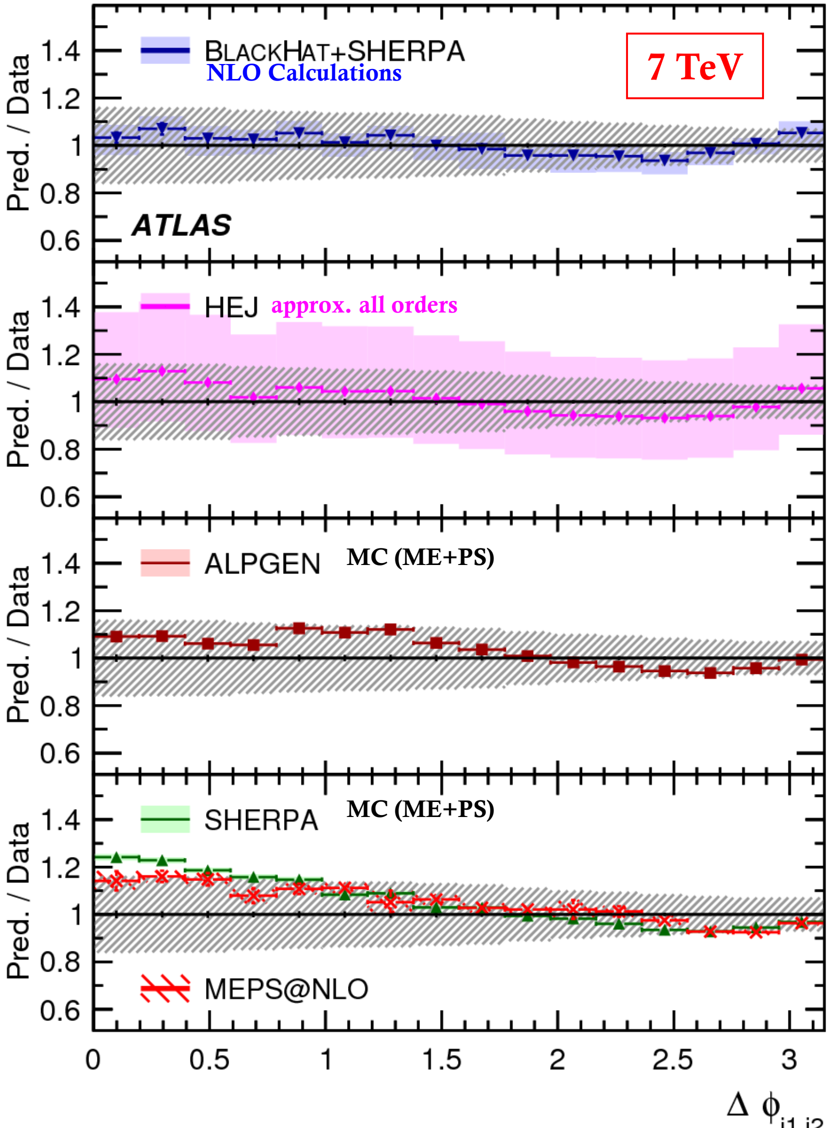




Fixed order calculations don't describe data in the high range as expected
Impressive improvement in MEPS@NLO (equivalent to Sherpa2.0) compared to Sherpa1

V+jets: $\Delta\phi_{jj}$

Important test of QCD and MC modeling: test hard radiation at large angles from matrix element and soft collinear radiation from PS



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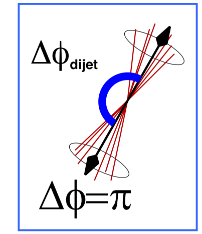
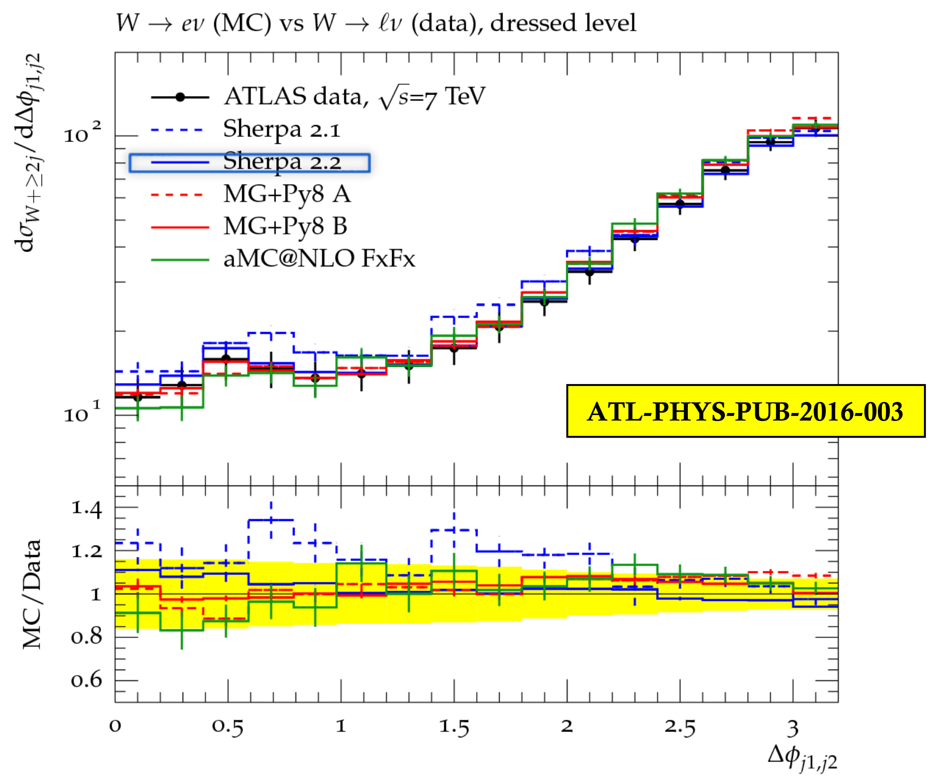
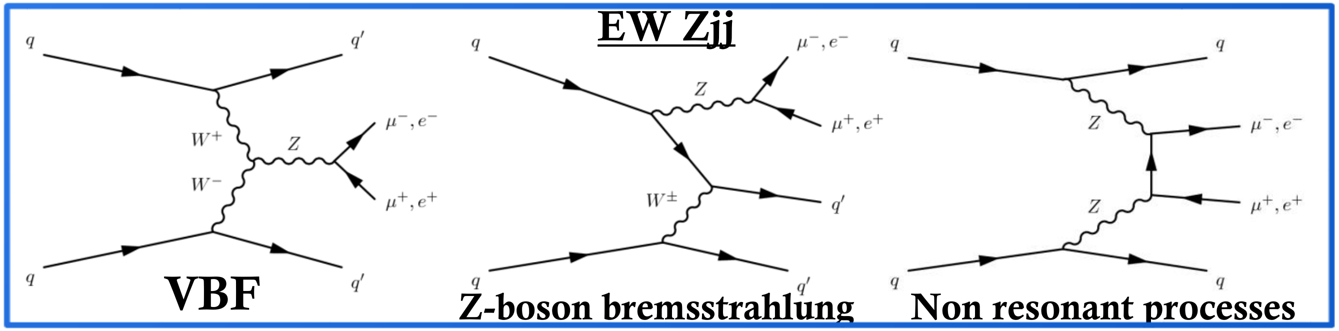


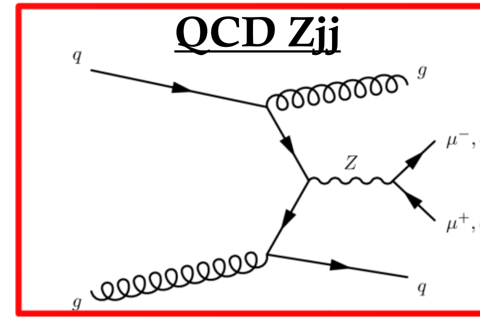


Sherpa1 showed evident mismodelling,
Sherpa 2.2 provides substantial improvement

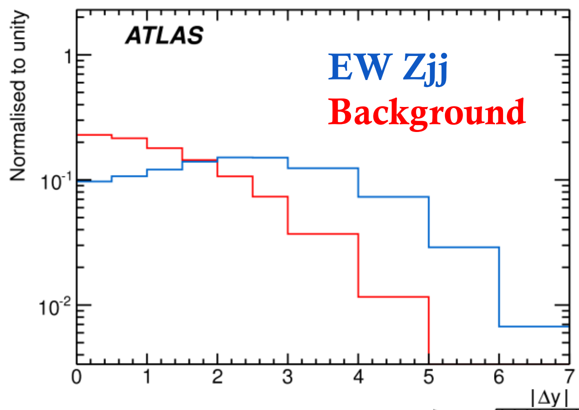
EW Zjj vs QCD Zjj

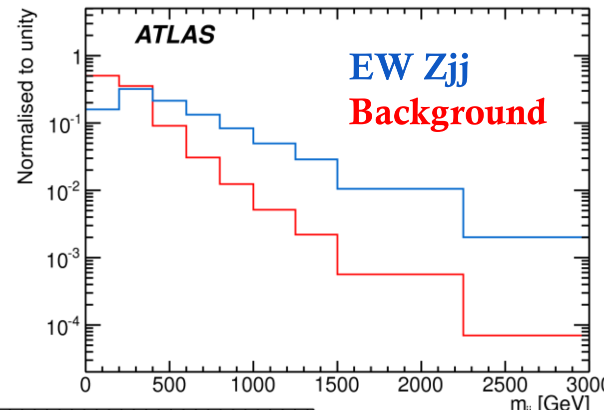
EW Z+2 jets production is ~1% of inclusive Z+2 jets cross section





How to disentangle
EW Zjj from QCD Zjj?





VBF selection:

-large Δy_{jj} and m_{jj}

-veto central jet activity

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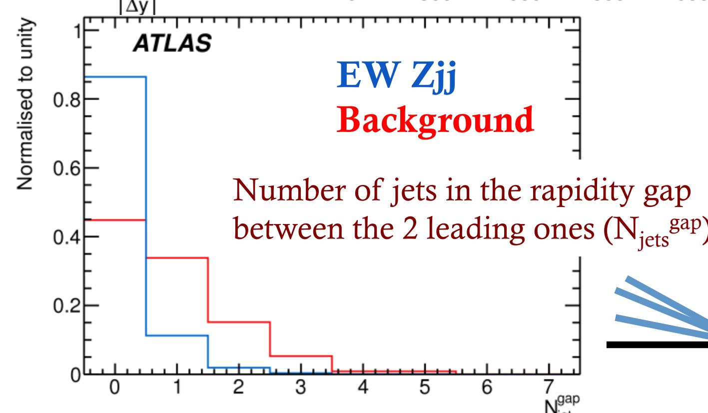
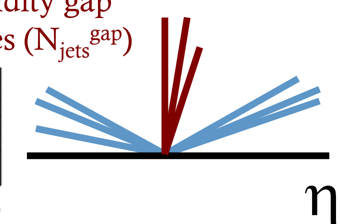
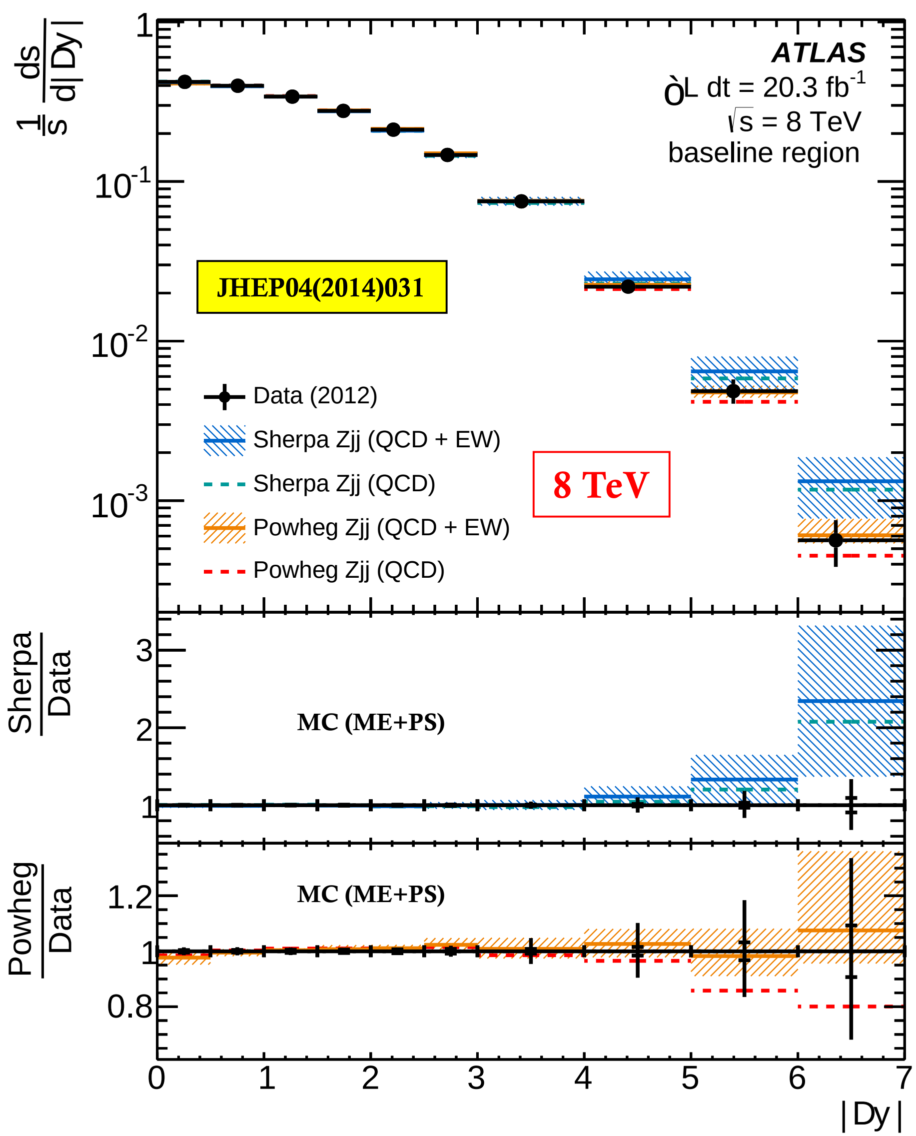
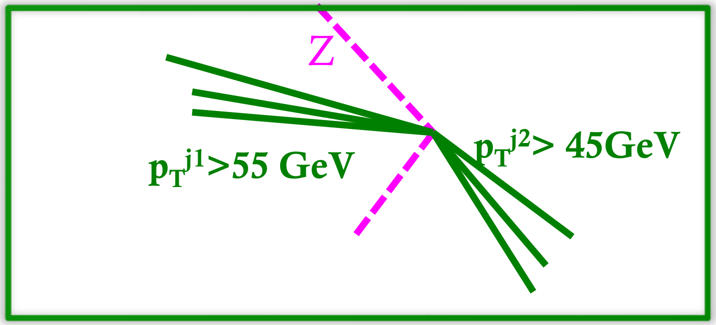




EW Zjj: Δy

Baseline region





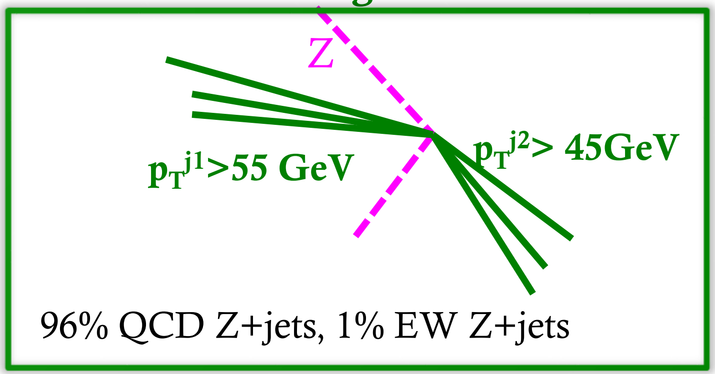
Explore higher p_T and large Δy
→ Include also EW component in MC to compare with data

Sherpa1 shows a large mismodelling

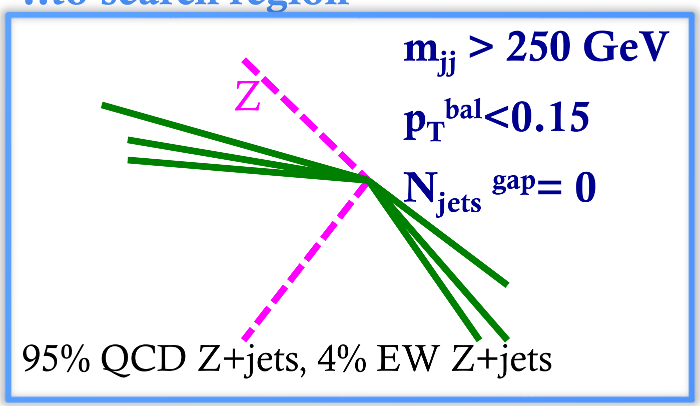
Powheg (NLO in pQCD) does a good job (typically used to describe VBF and ggF Higgs)

Search for EW Zjj signal

From baseline region..



..to search region



In search region both predictions give a satisfactory description of the data when QCD+EW processes are considered

8 TeV

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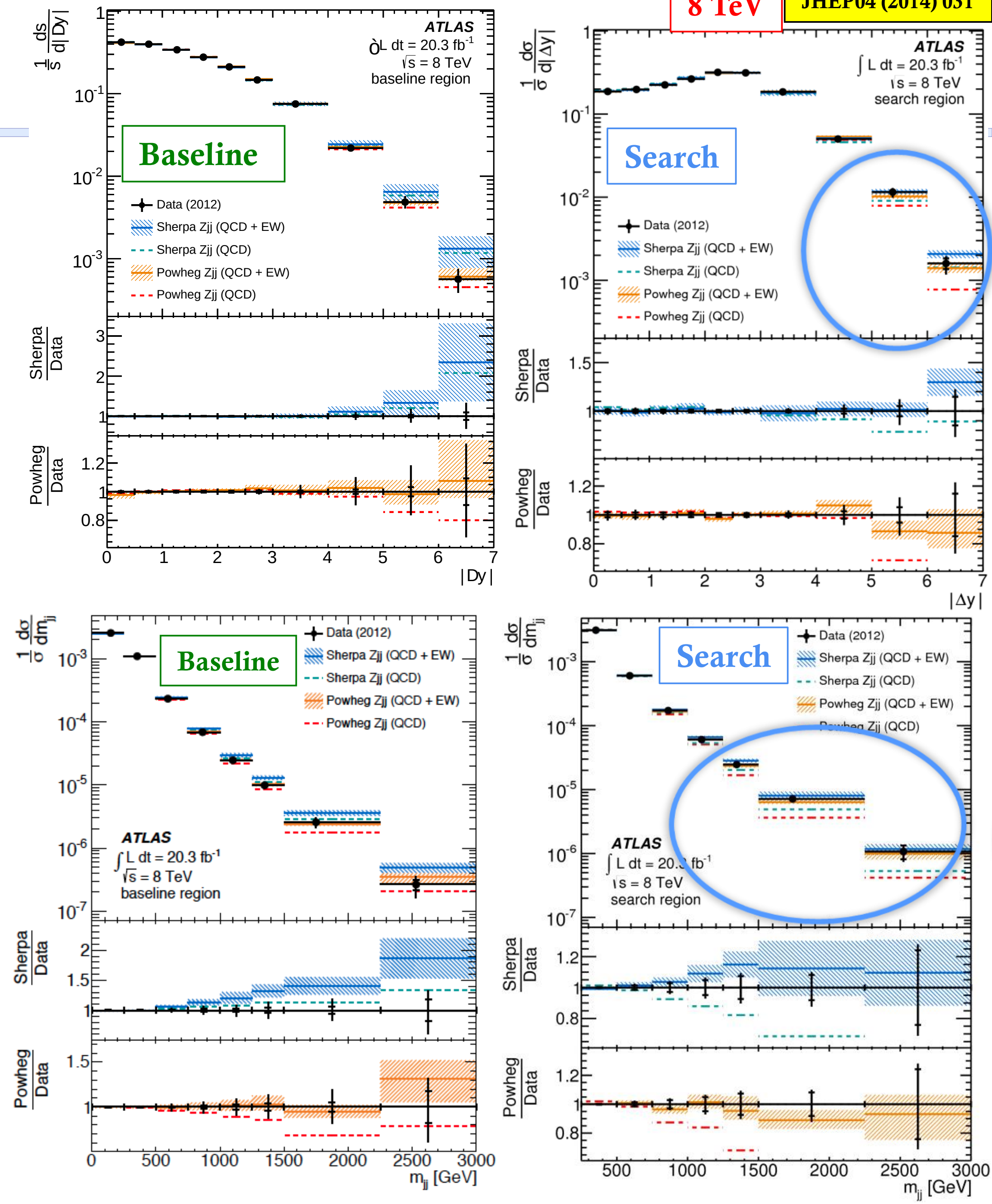

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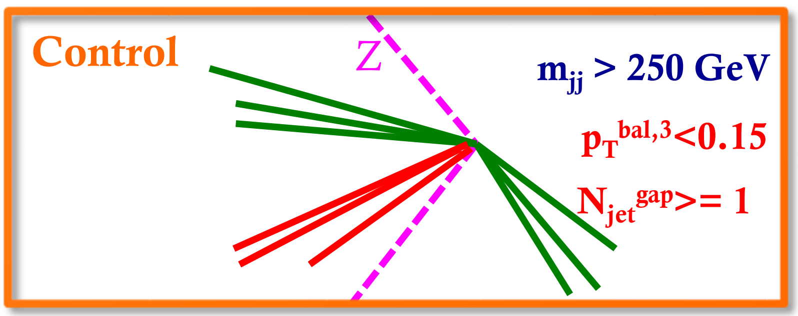
Extraction of EW signal

EW component extracted by a signal+background template fit of the dijet mass:

- Fit done in the search region (higher EW component)
- Background modelling (dominated by QCD Zjj) corrected using data/MC ratio in the **control region**



Background-only hypothesis rejected at greater than 5σ

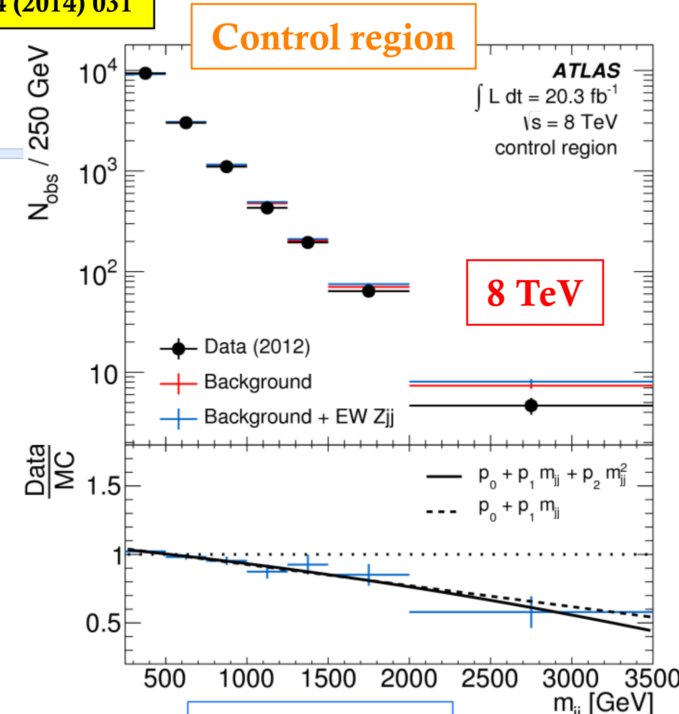
Extracted cross sections in 2 search fiducial regions:

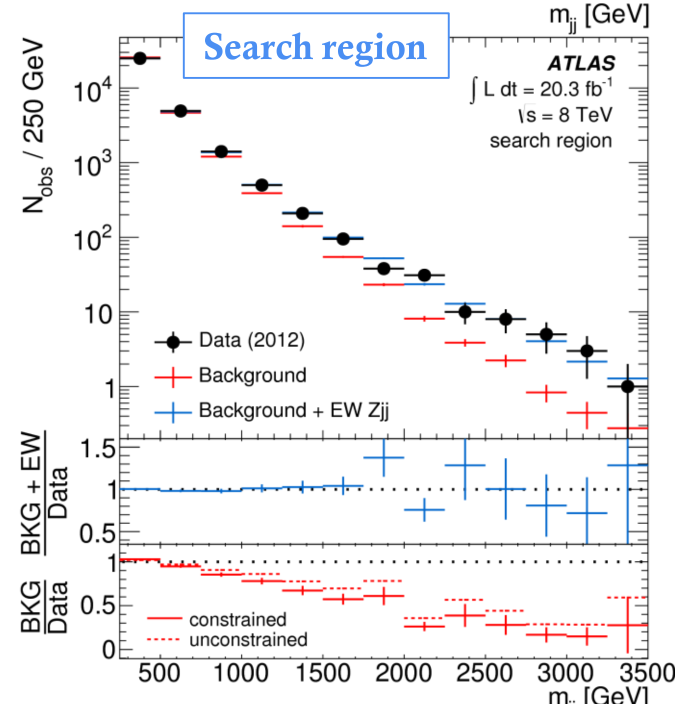
1) m_{jj}>250 GeV:

$$\sigma_{\text{EW,measured}} = 54.7 \pm 4.6(\text{stat}) \, ^{+9.8}_{-10.4}(\text{syst}) \pm 1.5(\text{lumi})\ \text{fb}$$
$$\sigma_{\text{theory}} = 46.1 \pm 0.2(\text{stat}) \, ^{+0.3}_{-0.2}(\text{scale}) \pm 0.8(\text{PDF}) \pm 0.5(\text{model})\ \text{fb}$$

2) m_{jj} > 1 TeV (most sensitive to EW Zjj component):

$$\sigma_{\text{EW,measured}} = 10.7 \pm 0.9(\text{stat}) \pm 1.9(\text{syst}) \pm 0.3(\text{lumi})\ \text{fb}$$
$$\sigma_{\text{theory}} = 9.38 \pm 0.05(\text{stat}) \, ^{+0.15}_{-0.24}(\text{scale}) \pm 0.24(\text{PDF}) \pm 0.09(\text{model})\ \text{fb}$$

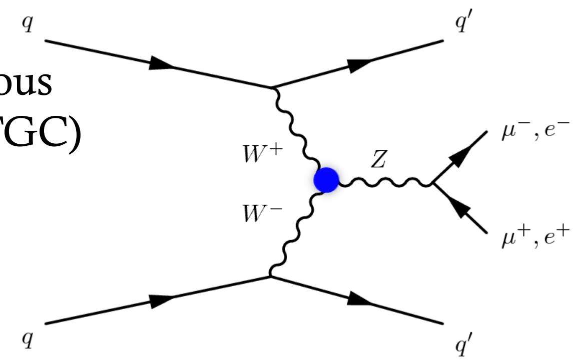




aTGC limits from EW Zjj

- Zjj sensitive to TGC
- New physics in EW sector modify gauge boson self-interactions

Zjj measurement used to place limits on the anomalous Triple Gauge Coupling (aTGC)



- In a generic aTGC model low energy effects from beyond SM physics can be parametrised by an effective Lagrangian (SM + higher-dimension operators):
  - 3 couplings describe the W,Z interaction strength:
    $g_{1,Z}$, λ_Z, κ_Z (in SM : $g_{1,Z}=1$, $\lambda_Z=0$, $\kappa_Z=0$)

Set 95% confidence intervals on $g_{1,Z}$, λ_Z from counting number of events in search region with $m_{jj}>1$TeV for 2 unitarization scales

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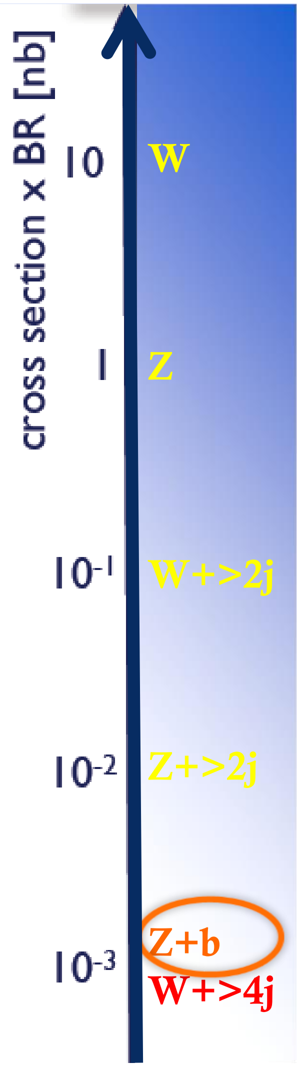
aTGC	$\Lambda = 6$ TeV (obs)	$\Lambda = 6$ TeV (exp)	$\Lambda = \infty$ (obs)	$\Lambda = \infty$ (exp)
$\Delta g_{1,Z}$	$[-0.65, 0.33]$	$[-0.58, 0.27]$	$[-0.50, 0.26]$	$[-0.45, 0.22]$
λ_Z	$[-0.22, 0.19]$	$[-0.19, 0.16]$	$[-0.15, 0.13]$	$[-0.14, 0.11]$

Not as stringent as limits set in diboson productions (~3 times smaller for λ_Z in WZ) but complementary (2 Ws have space-like momentum transfer, while in diboson processes all 3 bosons have time-like momentum)

V+b-jets

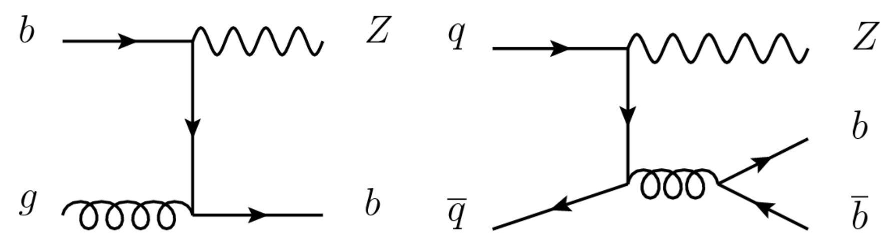


V+HF less understood than V+light jets and affected by larger theoretical uncertainties:

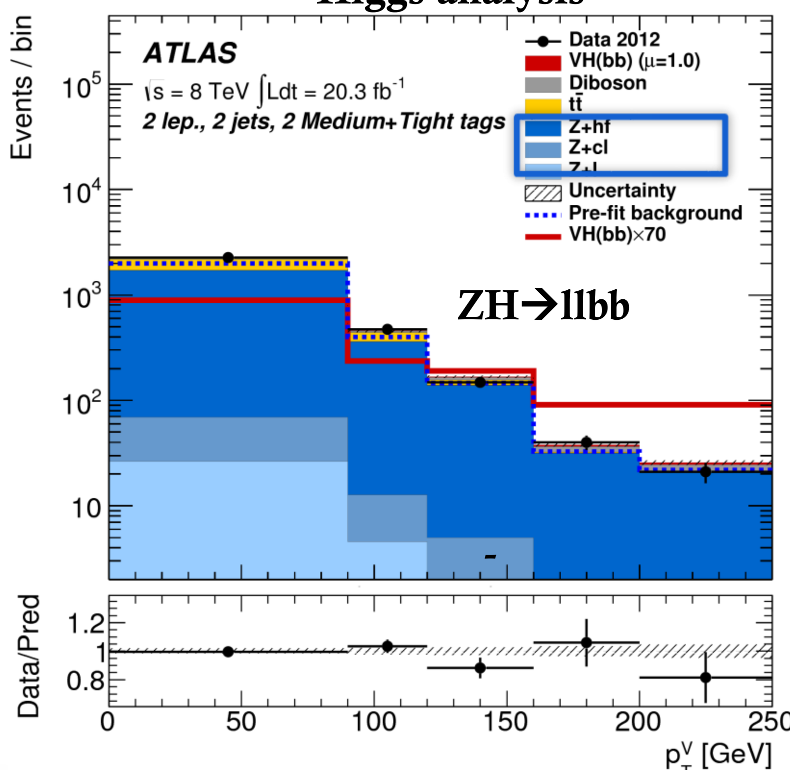
- heavy-quark content in the proton
- massive vs massless b-quark
- modeling of gluon splitting

- Important bkg for VH($b\bar{b}$) and some BSM searches

- SM measurements crucial for the understanding of these processes



Higgs analysis



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V+b-jets: strategy

Diversity to V+(inclusive) jets analysis

The Detector Level

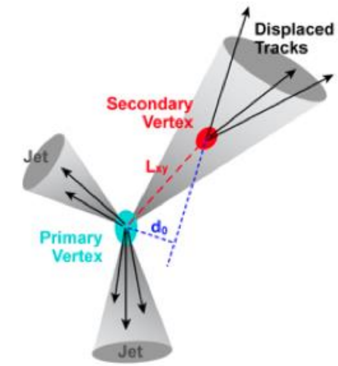
Signal= Data –BKGs

UNFOLDING

The Particle Level

Comparison data-MC/predictions

Select only b-tag jet:
Multivariate algorithms exploiting long life-time of b-hadrons (cτ 450 μm) (e.g. secondary vertex and large impact parameter) to tag b-jets



Signal extraction:
Fit to disentangle V+light-jets to V+b-jets to distributions sensitive to jet flavor

Z+b-jets analysis

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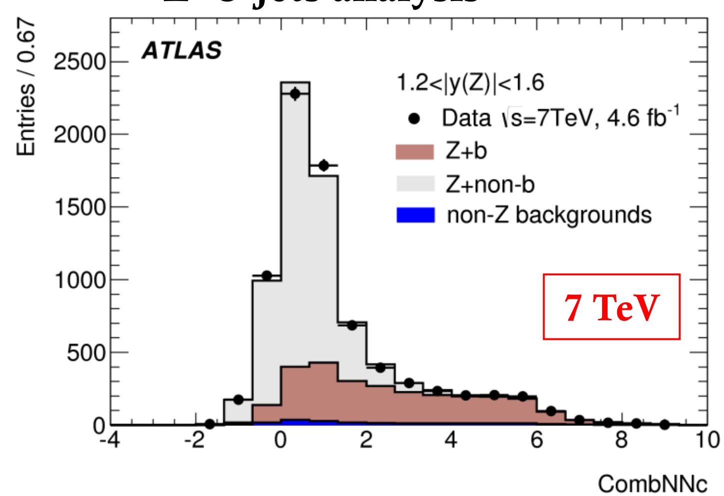

Z+b-jets

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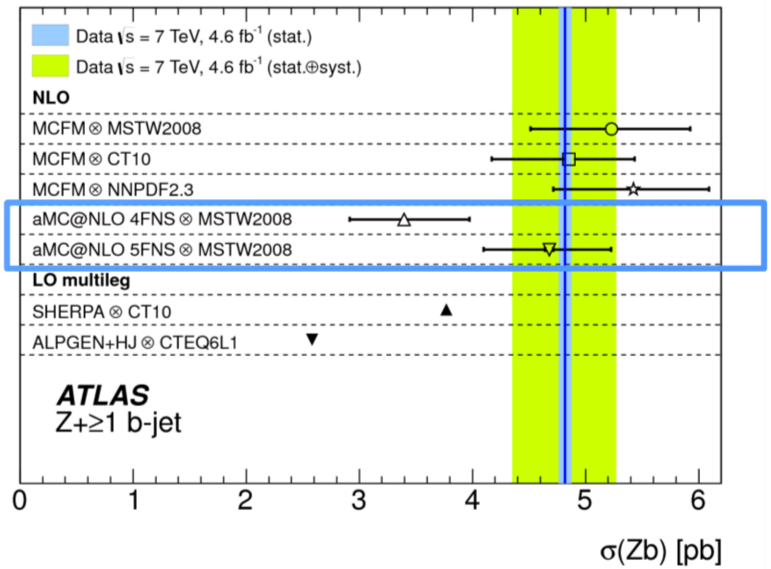
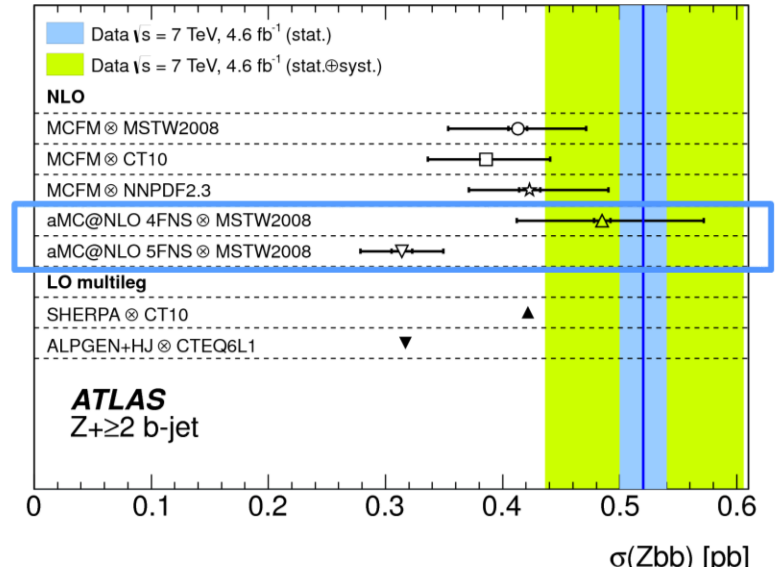


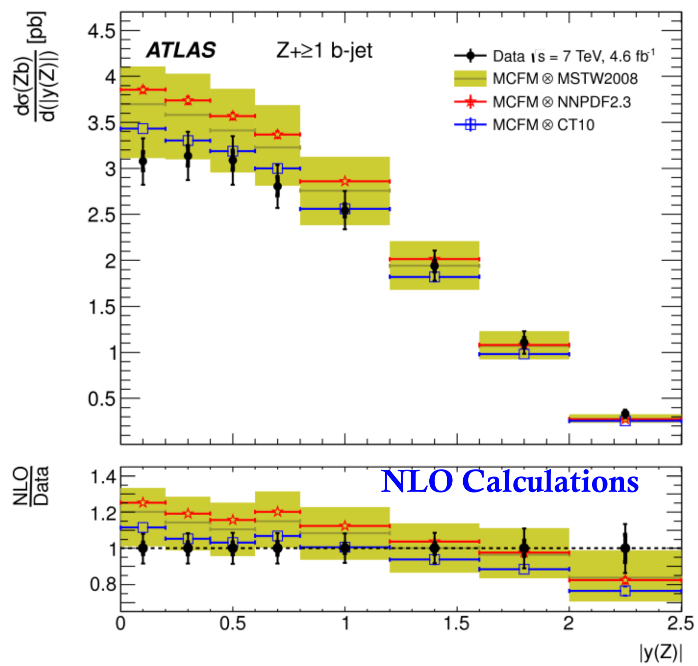


NLO agrees better with data than LO ME+PS MCs, but affected by large scale uncertainty

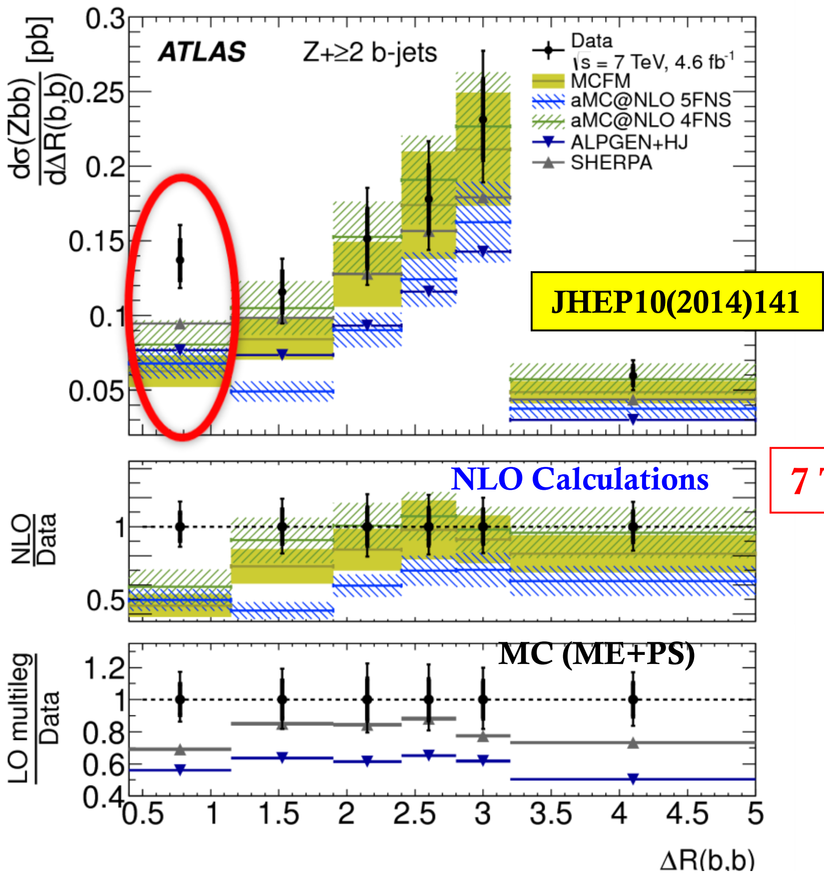
Z+1b data favour NLO 5FN, while Z+2b data agree better with NLO 4FN

Large scale uncertainty is a limit also for PDFs sensitivity:

A trend is visible in Z rapidity among different PDFs

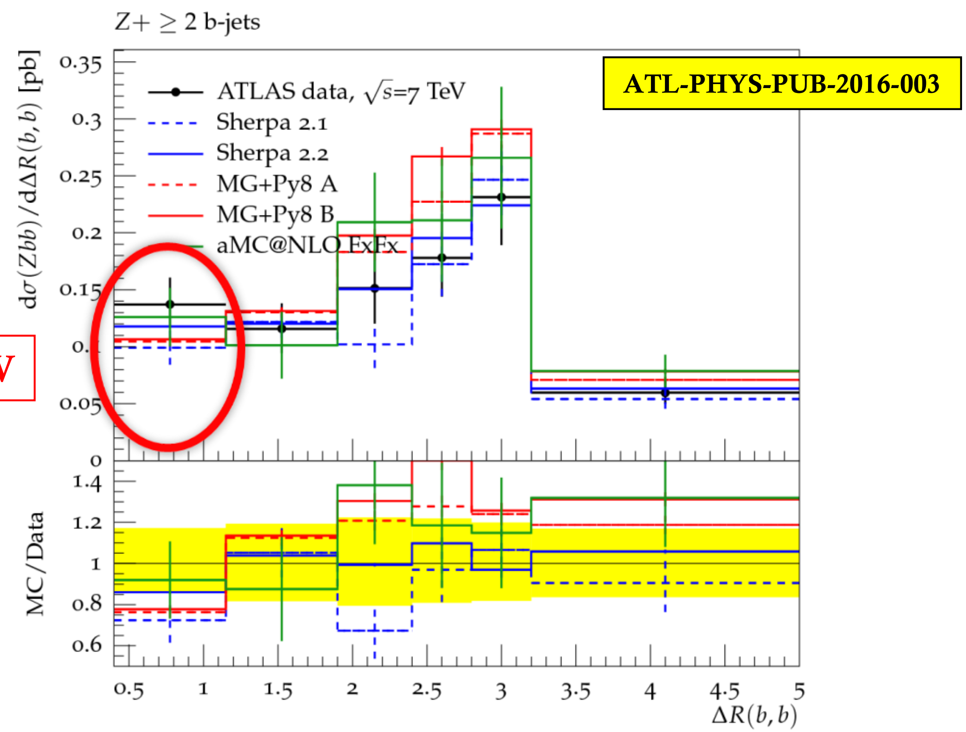


Z+b-jets

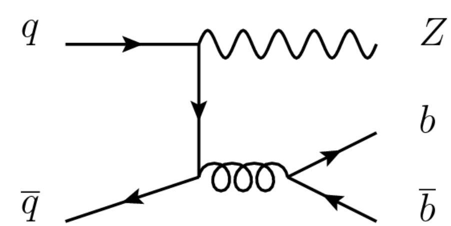


7 TeV

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$



Large mismodelling at small ΔR sensitive to gluon slitting
Description improved in the most recent generators



Conclusions

Measurements of jet production in association with a V boson allow us to:

- Improve understanding of pQCD
- Improve understanding of MCs modeling in different kinematical regions important for many measurements and for searches
- Explore triple gauge boson coupling sensitive to new physics

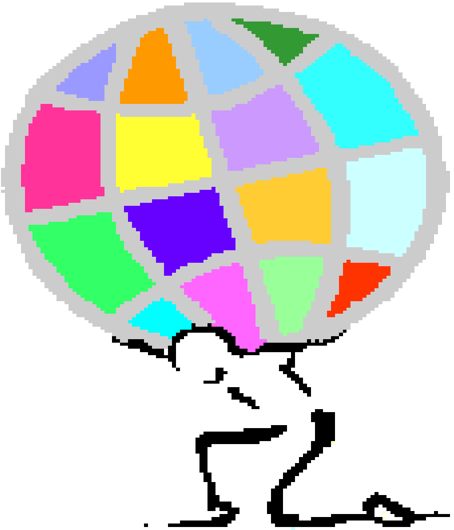
ATLAS published a vast set of results in this contest in Run1, just as reminder:

- Evidence of EW Z+jets production
- Measurement of W+jets up to 7 jets and up to 1 TeV in p_T
- Measurement of Z+2 b-jets differential distributions

and preliminary results with first Run-2 data @ 13 TeV also presented

A lot of new exiting results are coming soon with Run-1 and Run-2 data → **Stay tuned!**

BACKUP



W+jets: Background estimation

Eur. Phys. J. C (2015) 75:82

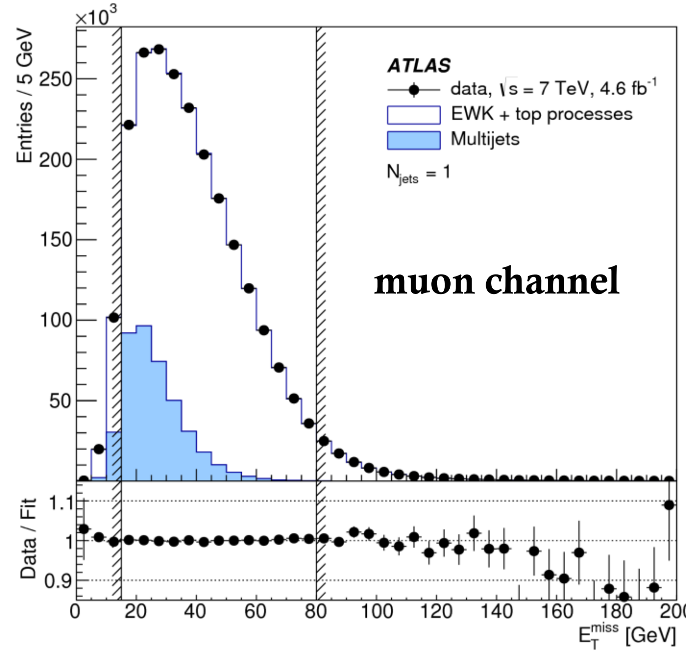
Multijet backgroup

Template from data:

Electron channel: Relaxed electron ID requirements and anti-isolated electrons

Muon channel: Anti-isolated muons

Fit on MET: on data with QCD template + signal and other bkgs from MCs



Top background

ttbar template from data:

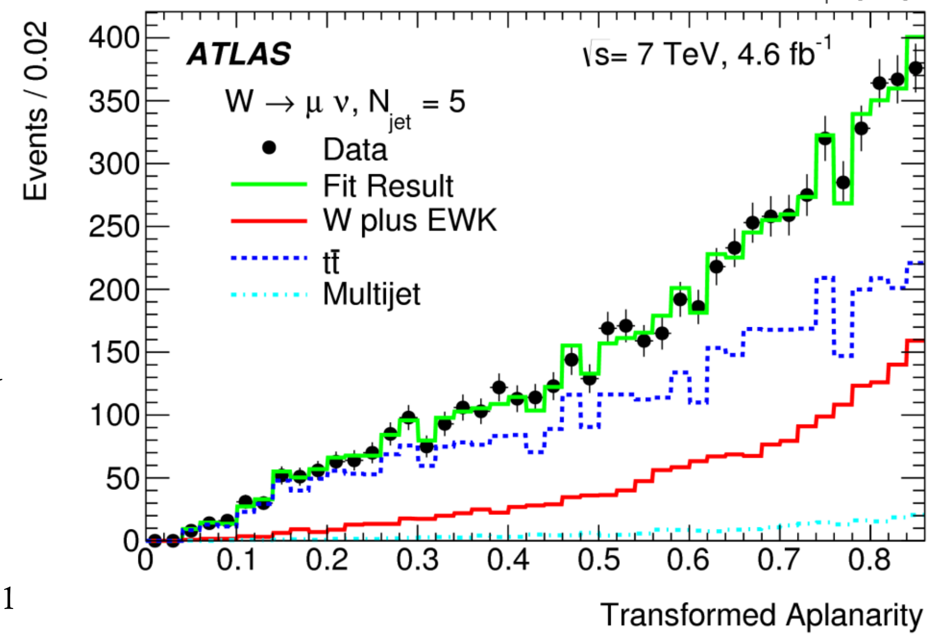
- Events with : >=3 jets, MET and MT cut and at least 1 b-jets
- Subtracted contamination from other processes (estimated with MC apart QCD estimated from data-driven)

Fit on transposed aplanarity

with ttbar template + other process estimated from MC (QDC from data-driven with norm fixed)

Tot uncertainty

~10%(3jets) – 20%(6jets)



W+jets: Signal and Background composition

Eur. Phys. J. C (2015) 75:82

N_{jet}	0	1	2	3	4	5	6	7
	$W \rightarrow e\nu$							
$W \rightarrow e\nu$	94 %	78 %	73 %	58 %	37 %	23 %	14 %	11 %
Multijet	4 %	11 %	12 %	11 %	7 %	6 %	5 %	4 %
$t\bar{t}$	<1 %	<1 %	3 %	18 %	46 %	62 %	76 %	80 %
Single top	<1 %	<1 %	2 %	3 %	4 %	3 %	2 %	2 %
$W \rightarrow \tau\nu$, diboson	2 %	3 %	3 %	3 %	2 %	1 %	1 %	1 %
$Z \rightarrow ee$	<1 %	8 %	7 %	7 %	5 %	4 %	3 %	3 %
Total predicted	11,100,000	1,510,000	354,000	89,500	28,200	8,550	2,530	572
	±640,000	± 99,000	±23,000	±5,600	±1,400	±440	±200	±61
Data observed	10,878,398	1,548,000	361,957	91,212	28,076	8,514	2,358	618
	$W \rightarrow \mu\nu$							
$W \rightarrow \mu\nu$	93 %	82 %	78 %	62 %	40 %	25 %	17 %	11 %
Multijet	2 %	11 %	10 %	9 %	7 %	5 %	4 %	3 %
$t\bar{t}$	<1 %	<1 %	3 %	19 %	46 %	64 %	75 %	83 %
Single top	<1 %	<1 %	2 %	3 %	4 %	3 %	2 %	2 %
$W \rightarrow \tau\nu$, diboson	2 %	3 %	3 %	3 %	2 %	1 %	1 %	<1 %
$Z \rightarrow \mu\mu$	3 %	4 %	3 %	3 %	2 %	1 %	1 %	1 %
Total predicted	13,300,000	1,710,000	384,000	96,700	30,100	8,990	2,400	627
	±770,000	±100,000	±24,000	±6,100	±1,600	±480	±180	±66
Data observed	13,414,400	1,758,239	403,146	99,749	30,400	9,325	2,637	663

W+jets: unfolding

Eur. Phys. J. C (2015) 75:82

Bayesian iterative unfolding:

- Response matrix to account for migrations with MC

$M_{ij}=M(R_i|T_j)$ = conditional probability that the effect R_i is produced by the cause T_j

-Goal: determine the probability $M(T_j|R_i)$

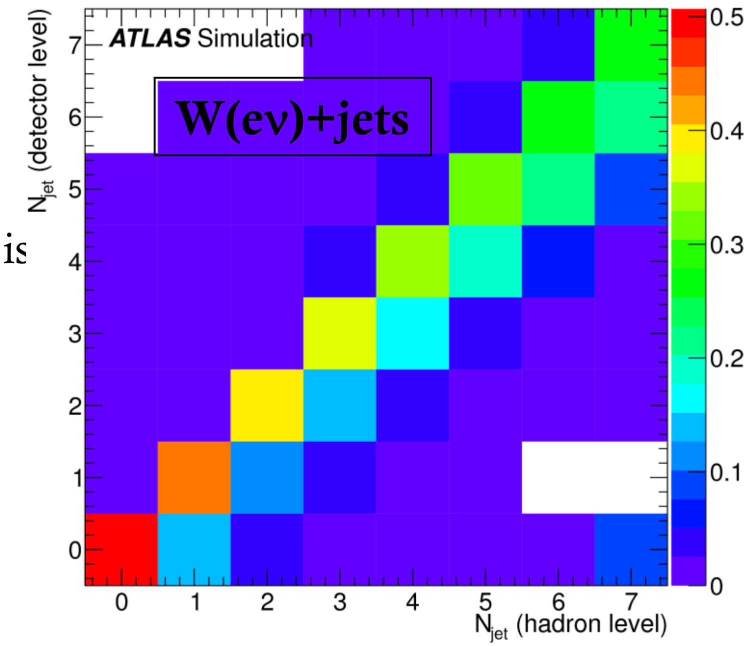
→Used Bayes' Theorem:

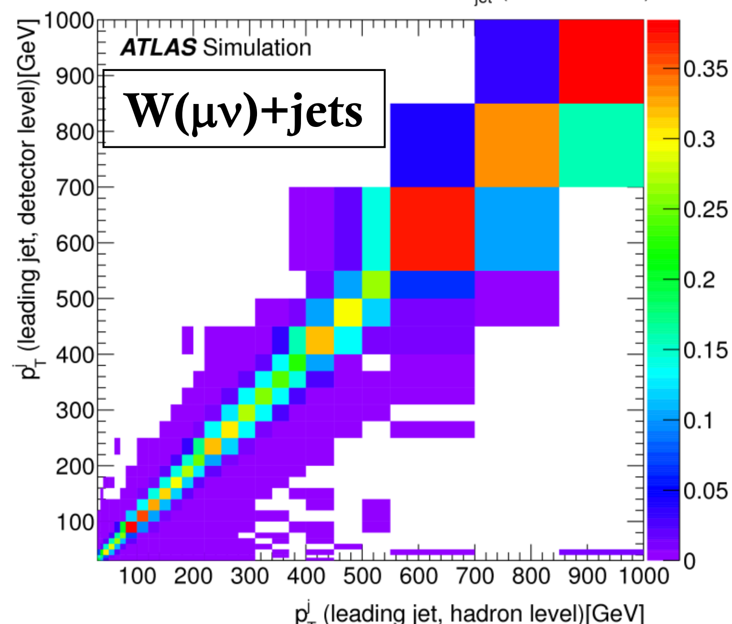
$$M(T_j|R_i) = \frac{M(R_i|T_j)\cdot P_0(T_j)}{\sum_{l=1}^{N_T} M(R_i|T_l)\cdot P_0(T_l)}$$

- Particle level MC used as an initial prior ($P_0(T_j)$) to determine a first estimate of the unfolded data distribution

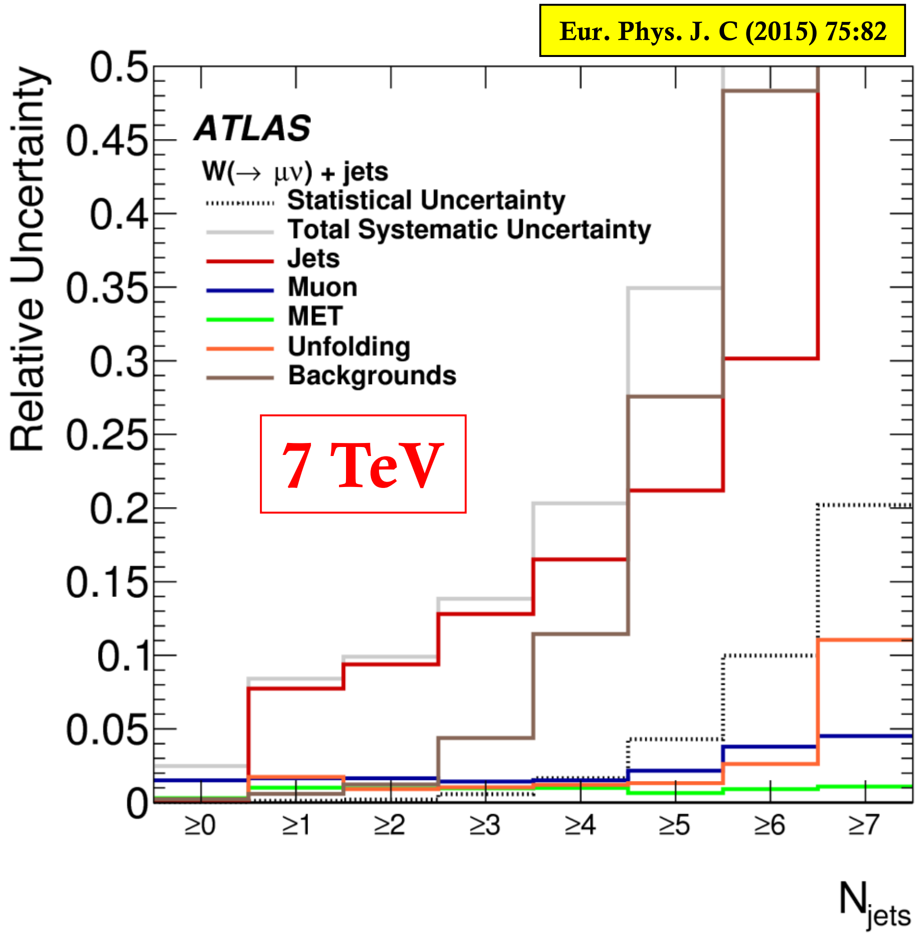
$$T_j = \sum_{i=1}^{N_R} M(T_j|R_i)R_i$$

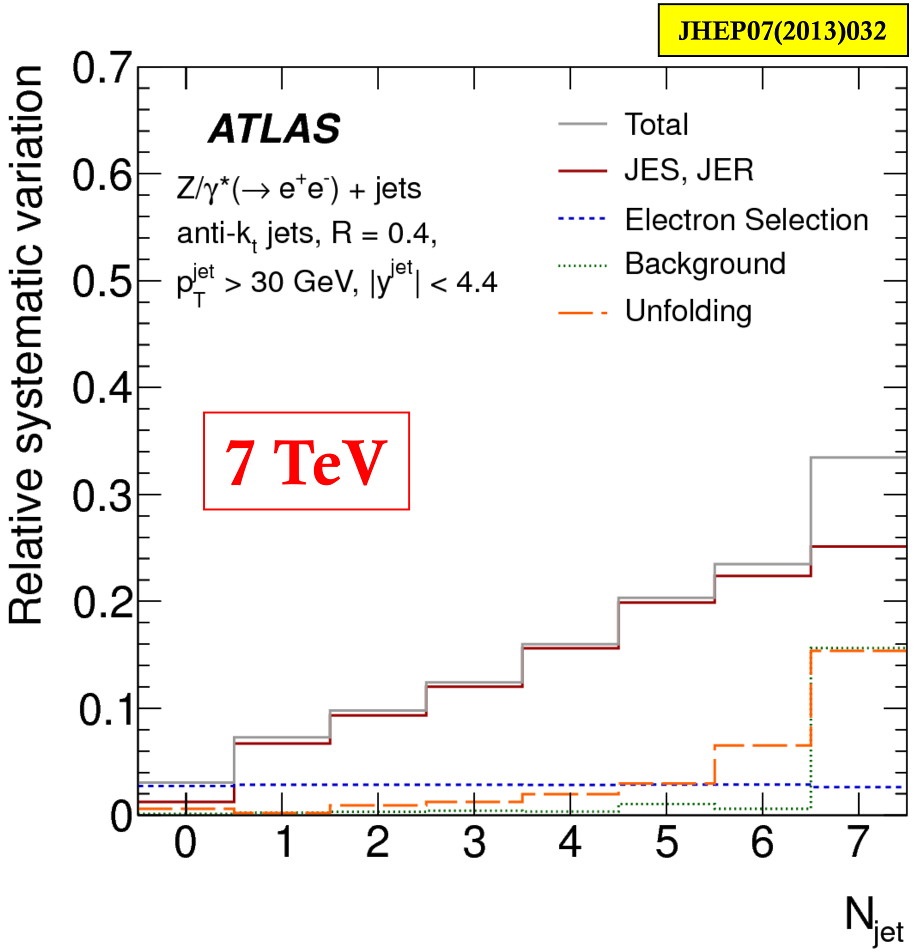
- For each further iteration the estimator for the unfolded distribution from the previous iteration is used as a new input prior





V+jets uncertainties (1/2)





V+jets uncertainties (2/2)

13 TeV

ATLAS-CONF-2015-041

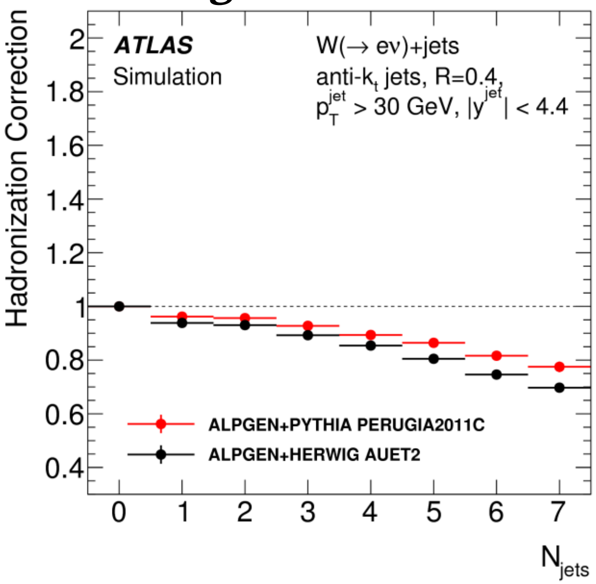
$\delta\sigma_{Z\to\ell^+\ell^-+\geq N_{\text{jets}}}/\sigma_{Z\to\ell^+\ell^-+\geq N_{\text{jets}}}$ (%)				
	$Z\to e^+e^-$			
Systematic source	$+\geq 1$ jet	$+\geq 2$ jets	$+\geq 3$ jets	$+\geq 4$ jets
Electron Trigger	0.5	0.5	0.5	0.5
Electron Reconstruction, Identification	5.2	6.0	6.8	7.8
Electron Isolation	1.2	1.4	1.6	1.8
Electron Scale and Resolution	0.4	0.5	0.4	0.7
JES and JER	4.4	5.9	8.5	7.7
Pileup	0.3	0.5	1.0	2.0
Backgrounds	0.2	0.5	1.0	1.2
Total	7.1	8.5	12.4	11.7
	$Z\to\mu^+\mu^-$			
Systematic source	$+\geq 1$ jet	$+\geq 2$ jets	$+\geq 3$ jets	$+\geq 4$ jets
Muon Trigger	1.0	1.0	1.1	1.2
Muon Reconstruction and Identification	0.9	1.0	1.0	1.2
Muon Isolation	0.7	0.9	1.3	1.8
Muon Scale and Resolution	0.2	0.2	0.3	0.6
JES and JER	4.9	6.5	8.4	10.5
Pileup	0.7	0.6	1.7	6.0
Backgrounds	0.2	0.5	1.1	1.9
Total	5.2	6.7	8.9	12.6

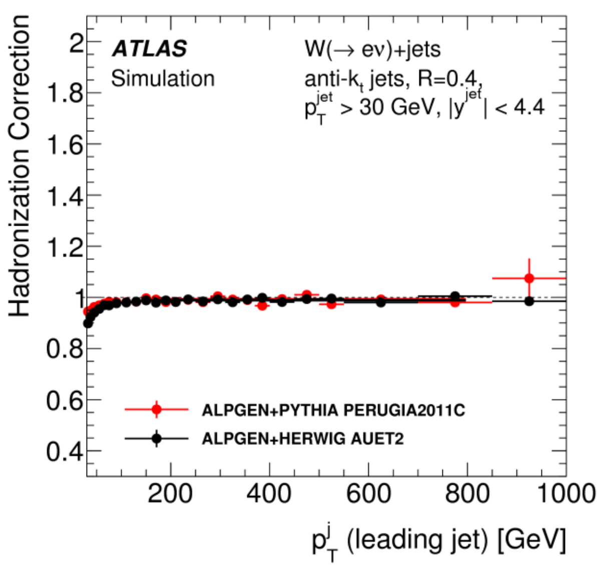
W+jets: MCs and Calculation

Features	MC&Calculation	Comments
mP LO ME +PS	Alpgen (up to 5p)	Herwig (for PS and hadronisation)+Jimmy (for UE) and Photon (for QED rad), MLM matching scheme. CTEQ6L1 PDFs
mP LO ME +PS	Sherpa 1.X (up to 4p)	Its own PS and CKKW matching scheme and internal QED rad model (YFS method). CT10 PDFs
NLO ME+PS	MEPS@NLO (NLO for 1&2 jets)	Virtual ME for W+1 and W+2jets from BlackHat; merged to LO ME up to 4p; Final state matched and hadronised with Sherpa. CT10 PDF.
NLO ME+PS	Powheg (NLO up to 2jets)	Pythia6 (for PS+hadronisation+MPI), Perugia2011tune NLO up to 2 jets (MiNLO), LO up to 1jets. CT10 PDFs
Fixed order NLO	BlackHat+Sherpa (NLO up 5 jets)	BH for the virtual element corrections and Sherpa for tree-level diagrams and for the phase-space integration. CT10 PDFs
Higher orders calc (with approx)	LoopSim (approx. NNLO)	-Approx. NNLO via merging of NLO samples with different multiplicity -It should provide predictions close to true NNLO when xs dominated by large contributions associated with new topologies appearing at NLO or beyond
Higher orders calc (with approx)	HEJ (approx. to all orders in α_s)	- Based on a perturbative calculation, approximation to the hard-scattering ME for Nj>=2 and to all orders in αs . Approximation exact in the limit of large rapidity separation between partons. - Results presented at the parton level (the relevant hadronisation corrections not available). CT10 PDF

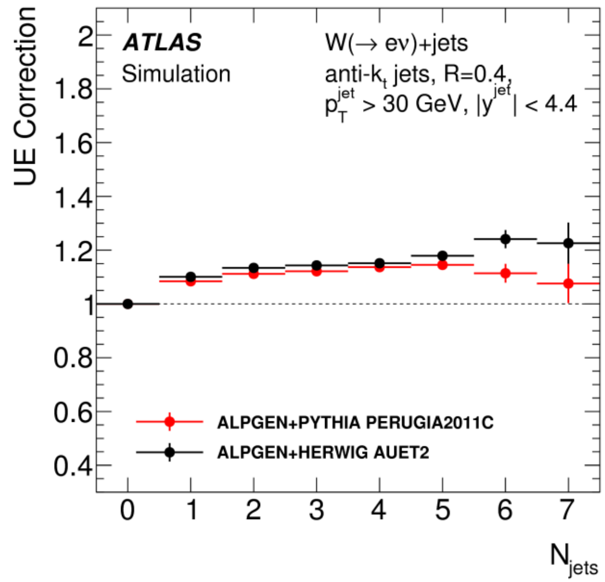
W+jets: Corrections to fixed order calculations

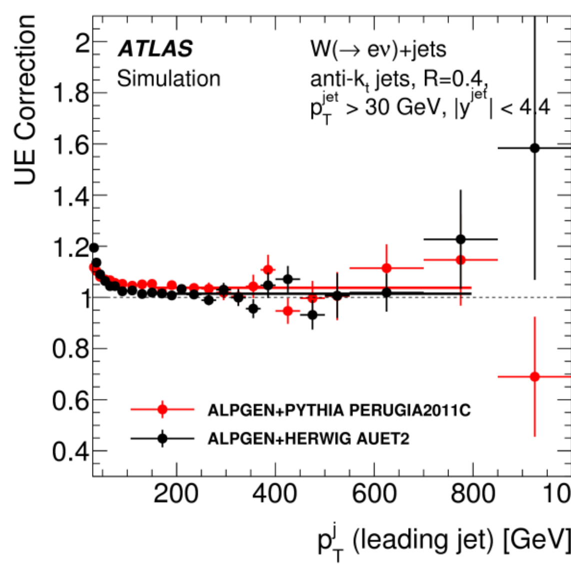
Fragmentation



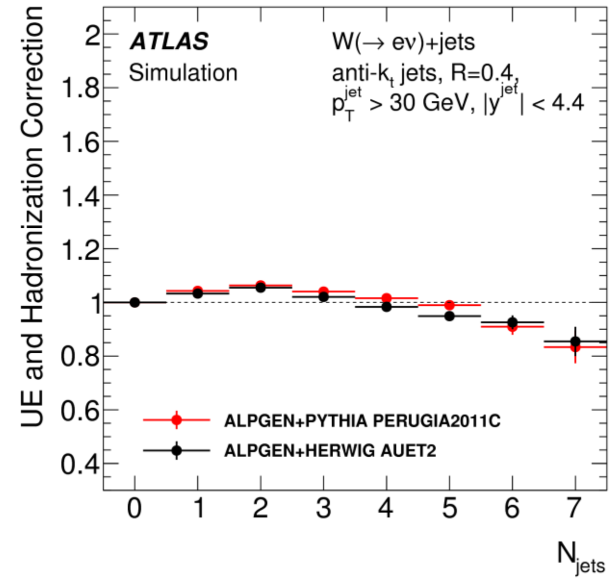


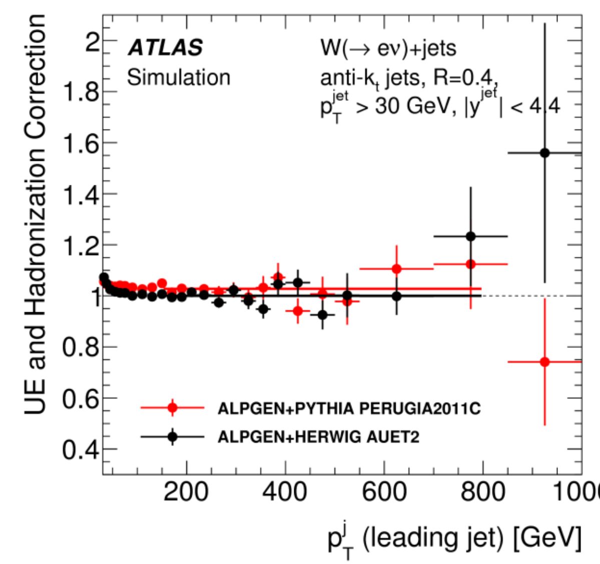
Underlying event





Total non perturbative correction





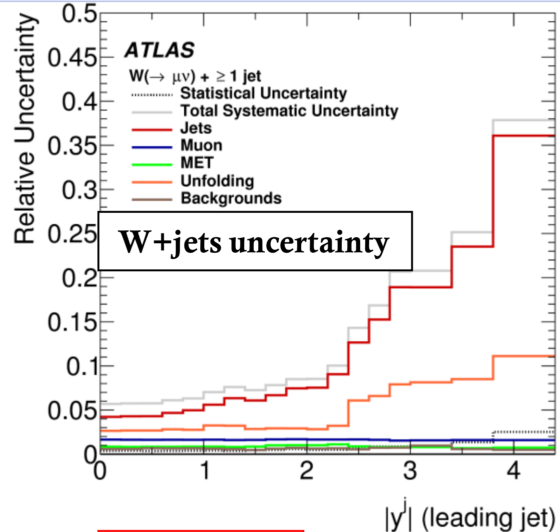
R_{jets}

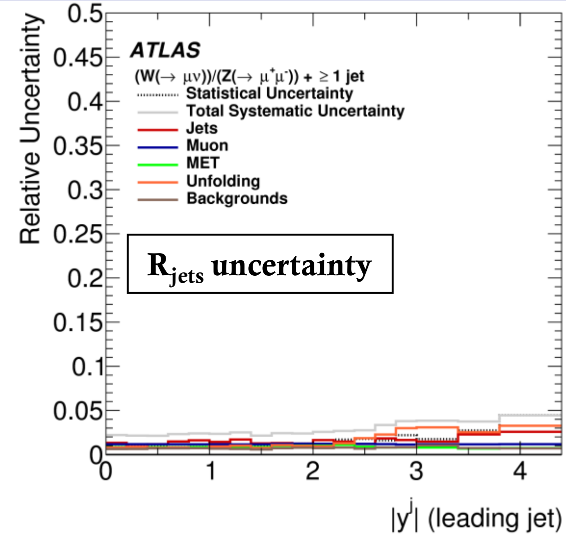
EPJC (2014) 74: 3168

High precision test of pQCD (cancellation of exp. and theoretical systematics)

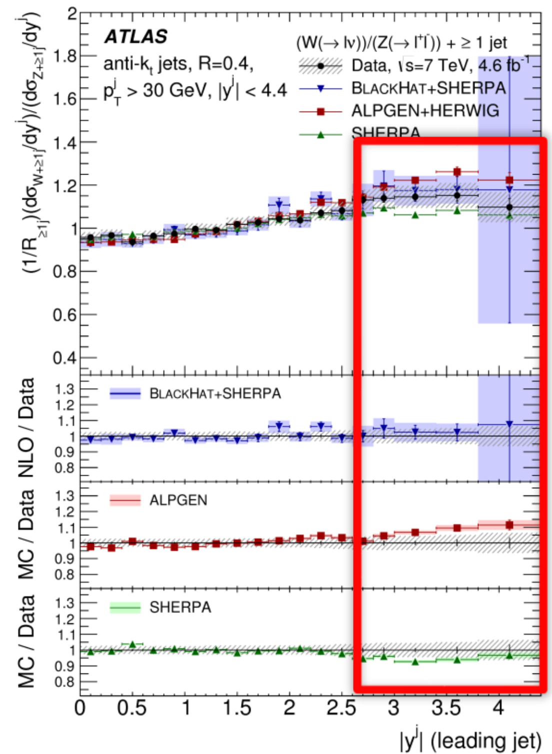
- Model independent sensitivity to new physics coupling with W or Z

-PDF sensitivity





7 TeV



CT10 PDFs

CTEQ6L1 PDFs

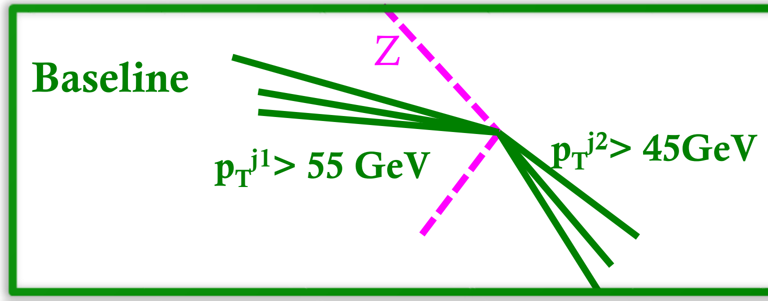
CT10 PDFs

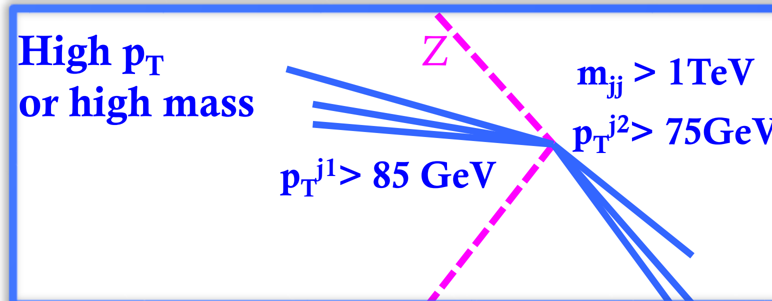
EW Zjj : strategy of the measurement

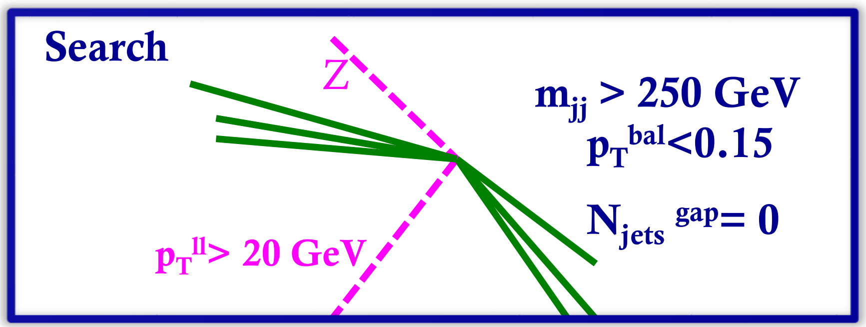
1) **Measure inclusive (QCD+EW) Zjj cross section and differential distributions in 5 fiducial regions with varying sensitivity to the EW component:**

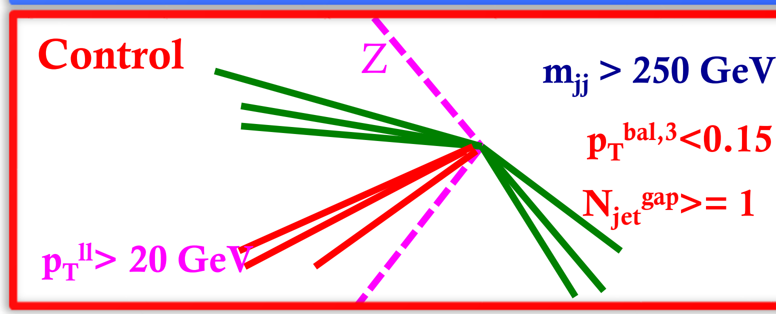
- 3 regions with simple topologies:
  - **"baseline"**
  - **"high p_T"** and **"high mass"**
    → probe impact of EW component
- 2 ad hoc selections**:**

  "search region" and **"control region"**







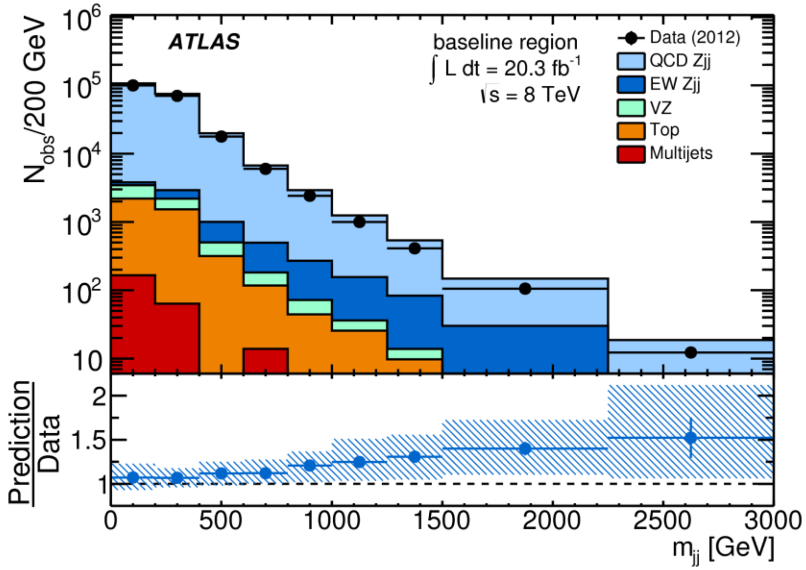


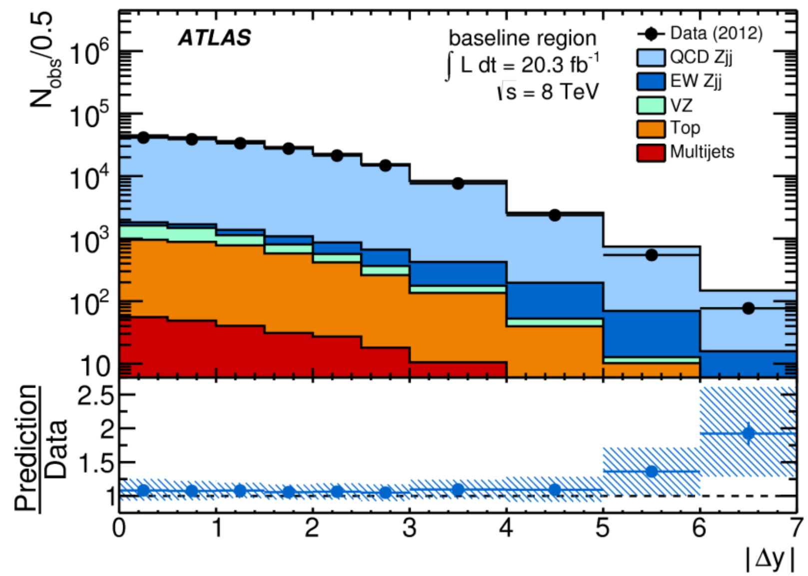
2) **Extract electroweak component** cross section from "search region", constraining the modeling on the background (QCD Zjj) from the "control region"

3) **Set limits on anomalous triple gauge couplings**

EW Zjj: Detector Level

JHEP04 (2014) 031





- QCD Zjj and EW Zjj with Sherpa (v1.4.3) normalized with Powheg
- WZ and ZZ with Sherpa
- ttbar and single top with MC@NLO+Herwig/Jimmy
- Multijets: data-driven

Sherpa describes adequately the data, apart some mismodelling at high m_{jj} and large angular separation

EW Zjj: fiducial regions and their composition

<table>
<tr><th>Object</th><th>baseline</th><th>high-mass</th><th>search</th><th>control</th><th>high-p_{T}</th></tr>
<tr><td>Leptons</td><td colspan="5">$|\eta^{\ell}| < 2.47$, $p_{\mathrm{T}}^{\ell} > 25$ GeV</td></tr>
<tr><td rowspan="2">Dilepton pair</td><td colspan="5">$81 \le m_{\ell\ell} \le 101$ GeV</td></tr>
<tr><td colspan="2">—</td><td colspan="2">$p_{\mathrm{T}}^{\ell\ell} > 20$ GeV</td><td>—</td></tr>
<tr><td rowspan="3">Jets</td><td colspan="5">$|y^{j}| < 4.4$, $\Delta R_{j,\ell} \ge 0.3$</td></tr>
<tr><td colspan="4">$p_{\mathrm{T}}^{j_1} > 55$ GeV</td><td>$p_{\mathrm{T}}^{j_1} > 85$ GeV</td></tr>
<tr><td colspan="4">$p_{\mathrm{T}}^{j_2} > 45$ GeV</td><td>$p_{\mathrm{T}}^{j_2} > 75$ GeV</td></tr>
<tr><td>Dijet system</td><td>—</td><td>$m_{jj} > 1$ TeV</td><td colspan="2">$m_{jj} > 250$ GeV</td><td>—</td></tr>
<tr><td>Interval jets</td><td colspan="2">—</td><td>$N_{\mathrm{jet}}^{\mathrm{gap}} = 0$</td><td>$N_{\mathrm{jet}}^{\mathrm{gap}} \ge 1$</td><td>—</td></tr>
<tr><td>Zjj system</td><td colspan="2">—</td><td>$p_{\mathrm{T}}^{\mathrm{balance}} < 0.15$</td><td>$p_{\mathrm{T}}^{\mathrm{balance,3}} < 0.15$</td><td>—</td></tr>
</table>

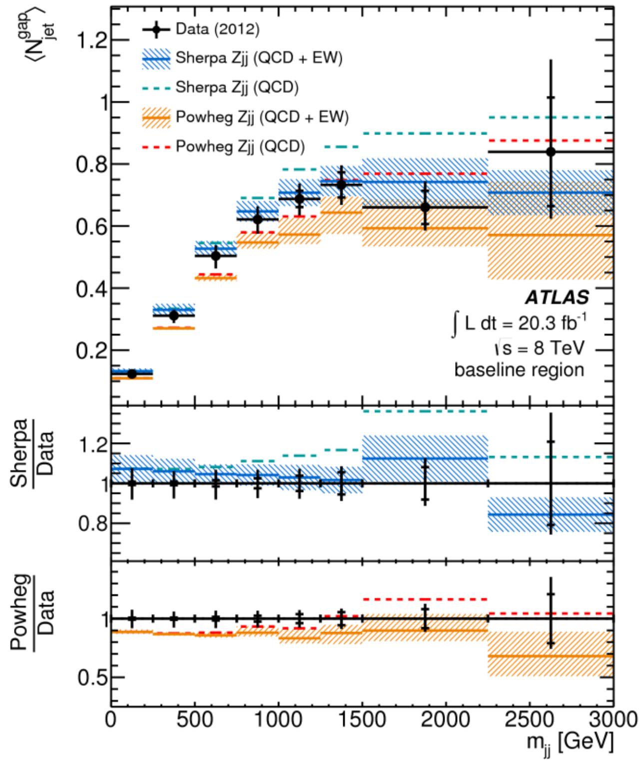
Jets in the gap counted if : p_{T}>25 GeV

$$p_{\mathrm{T}}^{\mathrm{balance}} = \frac{\left|\vec{p}_{\mathrm{T}}^{\,\ell_1} + \vec{p}_{\mathrm{T}}^{\,\ell_2} + \vec{p}_{\mathrm{T}}^{\,j_1} + \vec{p}_{\mathrm{T}}^{\,j_2}\right|}{\left|\vec{p}_{\mathrm{T}}^{\,\ell_1}\right| + \left|\vec{p}_{\mathrm{T}}^{\,\ell_2}\right| + \left|\vec{p}_{\mathrm{T}}^{\,j_1}\right| + \left|\vec{p}_{\mathrm{T}}^{\,j_2}\right|}$$

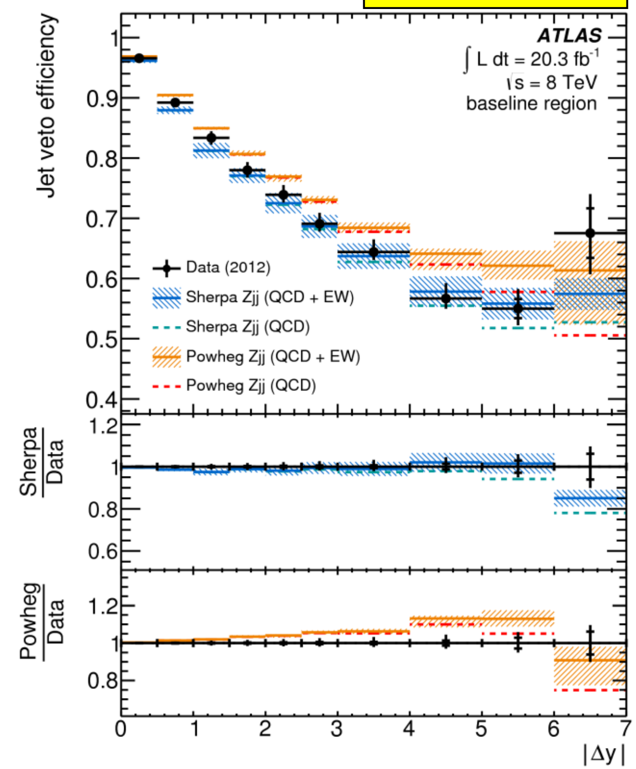
	Composition (%)				
Process	*baseline*	*high-*p_{T}	*search*	*control*	*high-mass*
Strong Zjj	95.8	94.0	94.7	96.0	85
Electroweak Zjj	1.1	2.1	4.0	1.4	12
WZ and ZZ	1.0	1.3	0.7	1.4	1
$t\bar{t}$	1.8	2.2	0.6	1.0	2
Single top	0.1	0.1	< 0.1	< 0.1	< 0.1
Multijet	0.1	0.2	< 0.1	0.2	< 0.1
WW, W+jets	< 0.1	< 0.1	< 0.1	< 1.1	< 0.1

EW Zjj: Jet Veto

JHEP04 (2014) 031



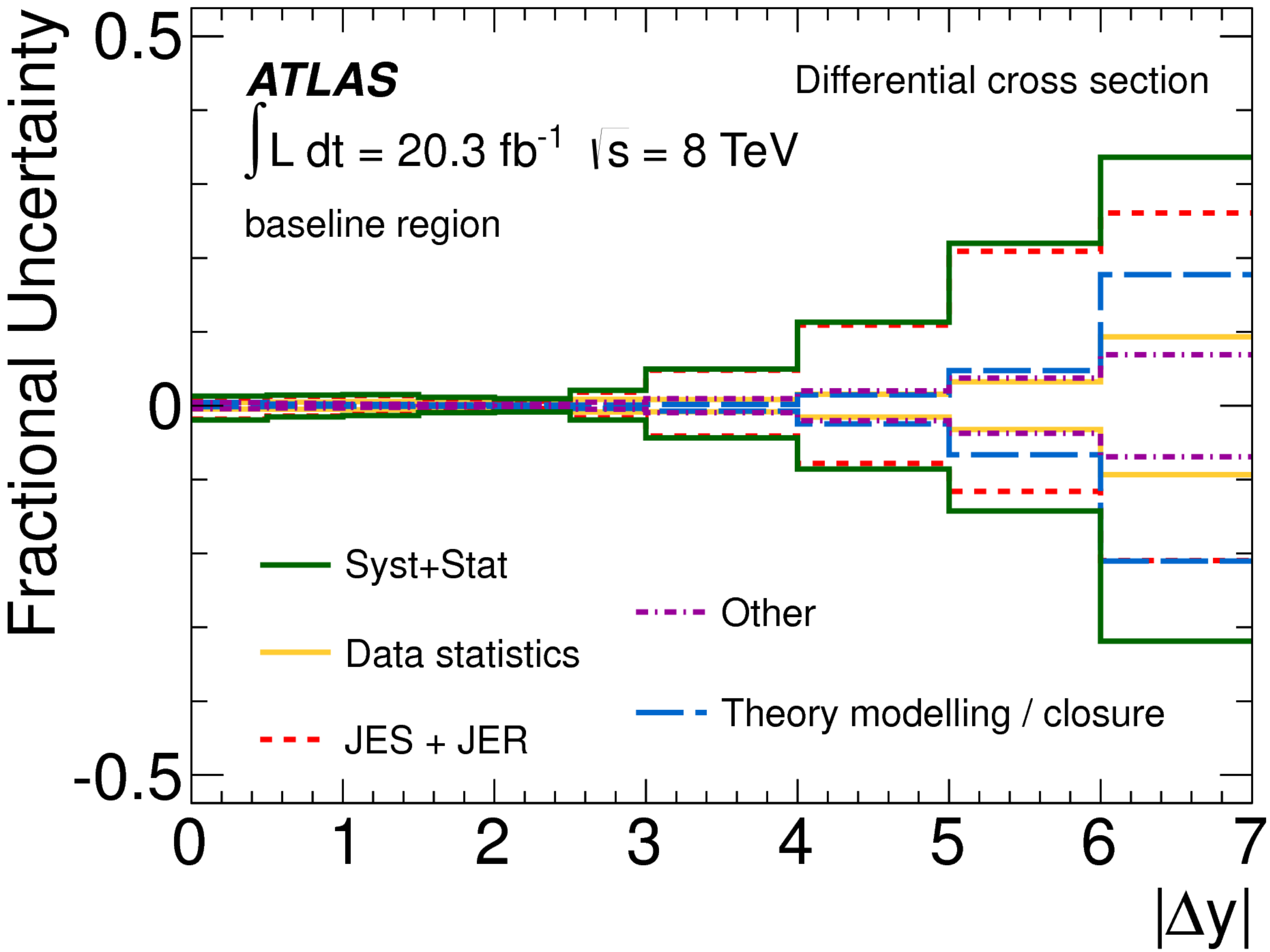
Jet veto efficiency defined as the fraction of events without additional jets with p_T>25 GeV in Δy



Probe wide-angle quark and gluon radiation in QCD Zjj as a function energy scale of dijet system, for EW processes little jet activity in the gap→ QCD Zjj has more activity (larger N_{jets}^{gap}, smaller fraction of events without additional jets)

Sherpa describes data quite better than Powheg for variable sensitive to additional jets

EW Zjj: uncertainties (1/2)



JHEP04 (2014) 031

EW Zjj: uncertainties (2/2)

JHEP04 (2014) 031

$$\sigma_{\mathrm{EW}} = \frac{N_{\mathrm{EW}}}{\int L\,\mathrm{d}t \cdot \mathcal{C}_{\mathrm{EW}}}$$

Source	ΔN_{EW}		$\Delta \mathcal{C}_{\mathrm{EW}}$	
	Electrons	Muons	Electrons	Muons
Lepton systematics	—	—	± 3.2 %	± 2.5%
Control region statistics	± 8.9 %	± 11.2 %	—	—
JES	± 5.6 %		$^{+2.7}_{-3.4}$ %	
JER	± 0.4 %		± 0.8 %	
Pileup jet modelling	± 0.3 %		± 0.3 %	
JVF	± 1.1 %		$^{+0.4}_{-1.0}$ %	
Signal modelling	± 8.9 %		$^{+0.6}_{-1.0}$ %	
Background modelling	± 7.5 %		—	
Signal/background interference	± 6.2 %		—	
PDF	$^{+1.5}_{-3.9}$ %		± 0.1 %	

EW Zjj: aTGC

JHEP04 (2014) 031

Effective Lagrangian:

$$\frac{\mathcal{L}}{g_{WWZ}} = i\left[g_{1,Z}\left(W^{\dagger}_{\mu\nu}W^{\mu}Z^{\nu} - W_{\mu\nu}W^{\dagger\mu}Z^{\nu}\right) + \kappa_Z W^{\dagger}_{\mu}W_{\nu}Z^{\mu\nu} + \frac{\lambda_Z}{m_W^2}W^{\dagger}_{\rho\mu}W^{\mu}_{\nu}Z^{\nu\rho}\right]$$

in SM : $g_{1,Z}=1$, $\lambda_Z=0$, $\kappa_Z=0$

To avoid tree-level unitarity violation, the anomalous couplings must vanish as the partonic centre-of-mass energy(s^) approaches infinity→ An arbitrary form factor may be introduced:

$$a(\hat{s}) = \frac{a_0}{(1+\hat{s}/\Lambda^2)^2}$$

a_0 is the anomalous coupling at low energy.
Λ is a unitarization scale

- Limits extracted in "search region" with m_{jj}>1 TeV to limit the effect of bkg modelling (900 events in data, 261 expected for EW Zjj and 592 for background estimated with the m_{jj} fit)

-aTGC and form factors varied with Sherpa

Z+b-jets: MCs & Calculations

MC&Calculation	Features	
MCFM	5FN NLO Z+b, Z+bb massless b-quarks	Run1
aMC@NLO 4FN	4FN NLO Z+bb, Z+b massive b-quark	Run1
aMC@NLO 5FN	NLO Z+b , LO Z+bb	Run1
Sherpa 1	5FN LO+PS, CT10 PDFs	Run1
Alpgen	4FN LO+PS, CTEQ6L1 PDFs	Run1
Madgraph	5FN LO+PS (A tuning uses NNPDF 2.3 B tuning uses NNPDF 3.0)	New for Run2
Sherpa 2	NLO up 2 jets, 5FN (Sherpa 2.1 uses NNPDF 2.3 Sherpa 2.2 uses NNPDF 3.0, improved tuning)	New for Run2
aMC@NLO FxFx	NLO up 2 jets, 5FN, NNPDF 2.3	New for Run2

Z+b-jets: uncertainties

JHEP10(2014)141

Source of uncertainty	$\sigma(Zb)$ [%]	$\sigma(Zbb)$ [%]
b-jet tagging efficiency	3.4	9.8
c-jet mistag rate	0.2	2.3
light-jet mistag rate	0.4	0.6
JES	2.9	4.7
JER	0.3	0.7
b-jet template shape	4.8	4.8
c-jet template shape	0.2	0.6
light-jet template shape	0.9	0.9
b-jet template scale factor	N/A	2.3
MPI	2.5	0.8
gluon splitting	1.2	1.5
background normalisation	1.1	3.6
$t\bar{t}$ modelling	0.0	2.9
MC sample size	1.0	1.4
lepton efficiency, scale and resolution	1.2	1.2
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.1	0.6
luminosity	1.8	1.8
total	7.7	14.0

W+b-jets

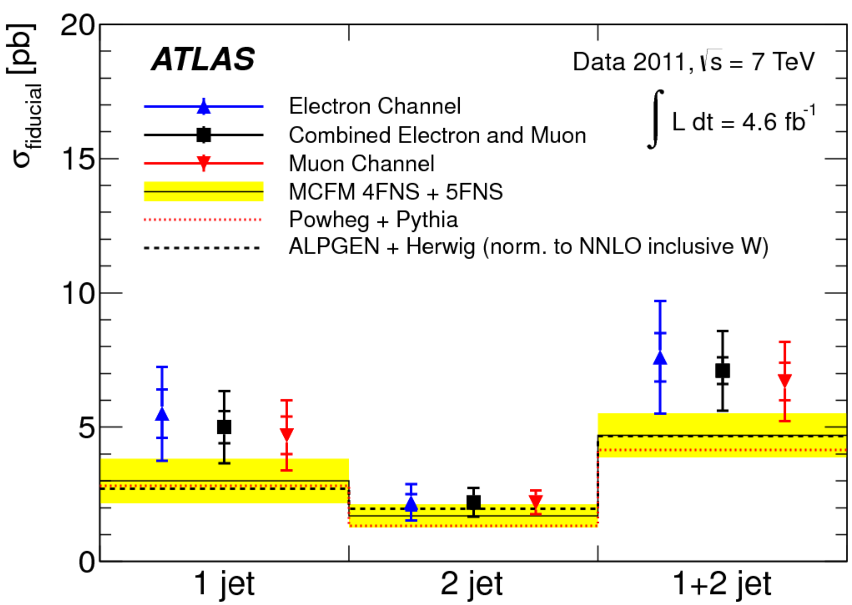
JHEP 06 (2013) 084

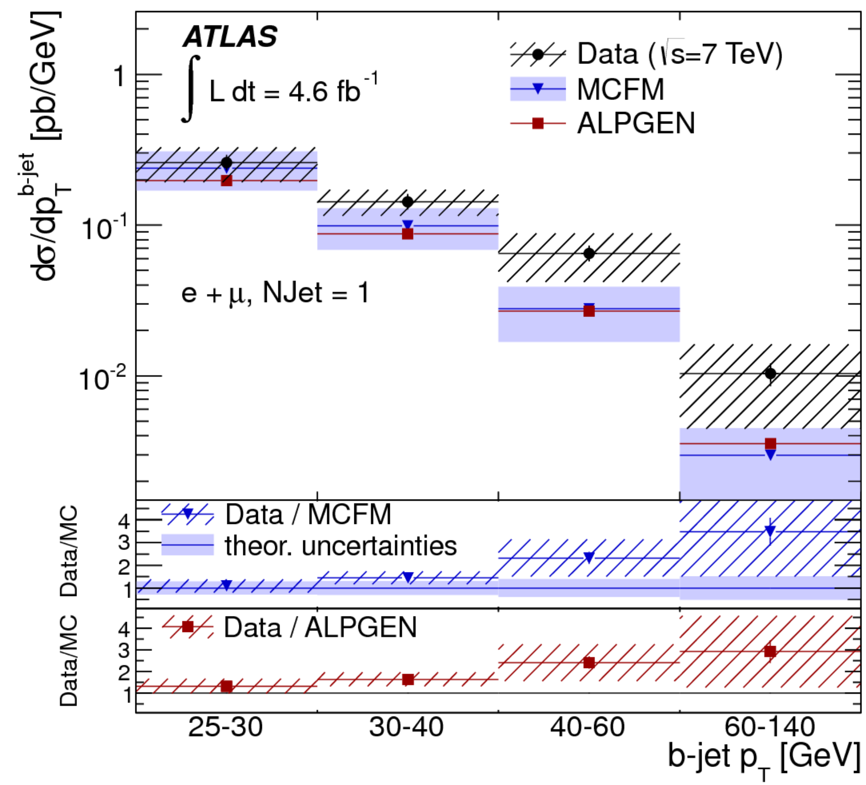
<u>W+b-jets cross-section:</u>

- 1 jet: "W+b"
- 2 jet: "W+b+j"

and differential in b-jet p_T

7 TeV



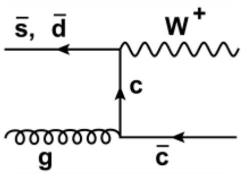


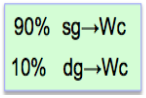
W+c: PDFs sensitivity

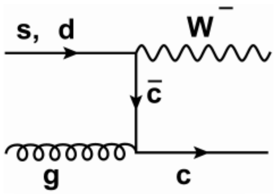
- Sensitive to **strange quark content in proton**

7 TeV

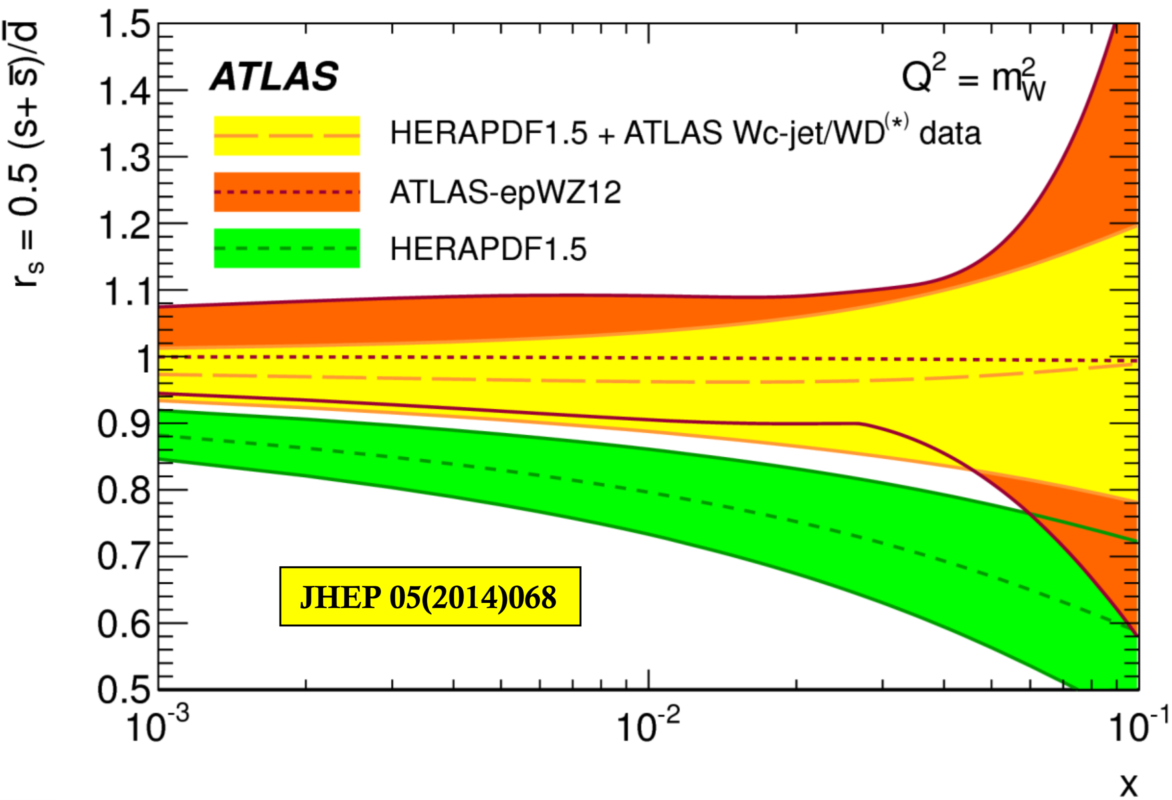
-**2 strategies**:
- W+c-jets (via soft muon tagged inside a jet)
- $W^{\pm}+D^{(*)}$







Ratio of strange-to-down sea-quark distributions



In HERAPDF1.5 s-quark sea density lower than the d-quark sea density

ATLAS W+c data favour a symmetric light-quark sea in good agreement with the results obtained in the ATLAS W/Z analysis with 2010 data