PRECISION MEASUREMENTS

WITH AN ELECTROWEAK BOSON IN THE FINAL STATE WITH THE ATLAS DETECTOR

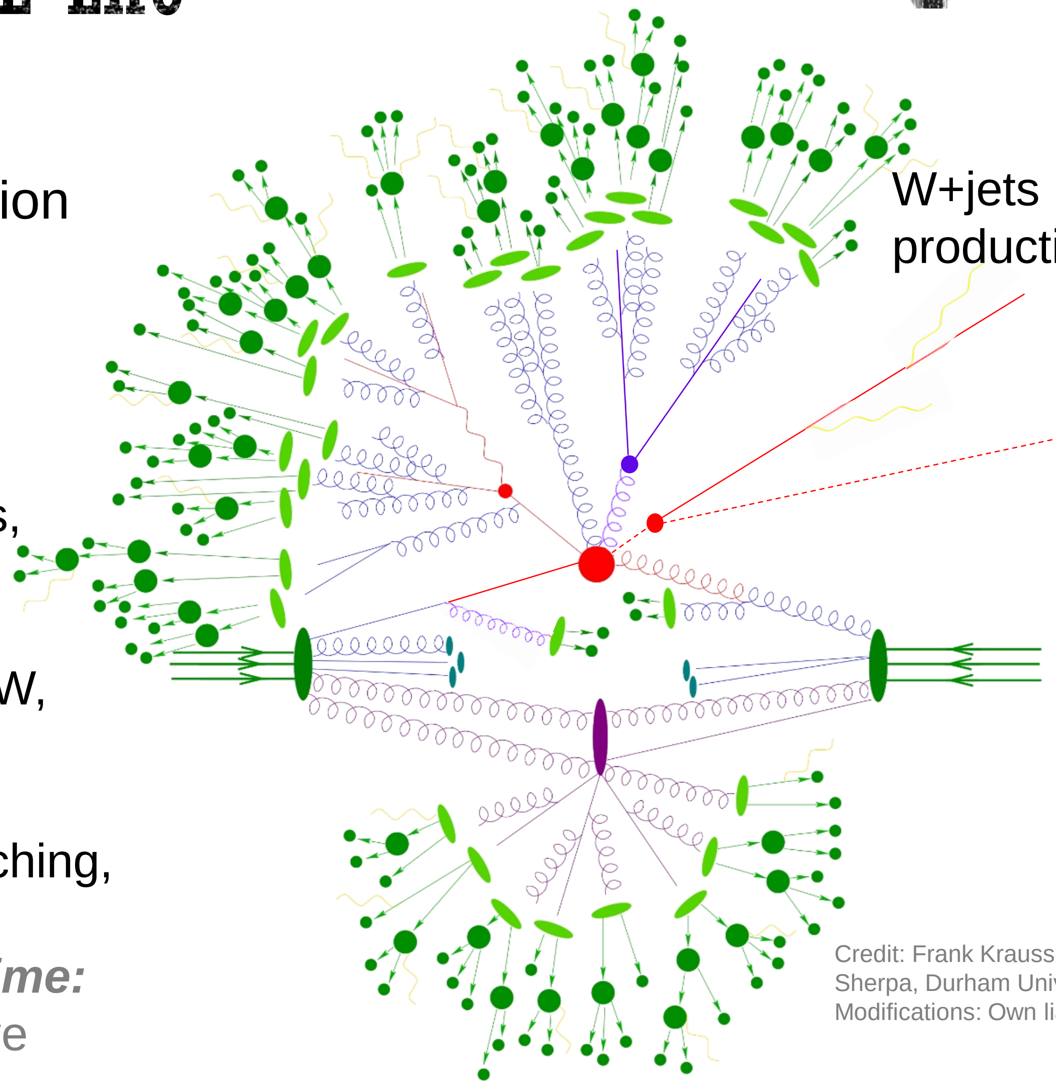
Valerie Lang
On behalf of the ATLAS Collaboration

PANIC 2017, Bejing, 1 Sep 2017

COLLISIONS AT THE LHC

- Our understanding
  as mapped into simulation

  We need to know
  - ***Electroweak sector:***
    m_W, lepton universality
  - ***Proton content:***
    Valence quarks, gluons, strange sea quarks
  - ***Hard interaction:***
    Higher order QCD & EW, hard parton emissions
  - ***Radiation:***
    Parton showers & matching, EW boson radiation
  - ***Non-perturbative regime:***
    Matching to perturbative



Credit: Frank Krauss, Sherpa, Durham University
Modifications: Own liability

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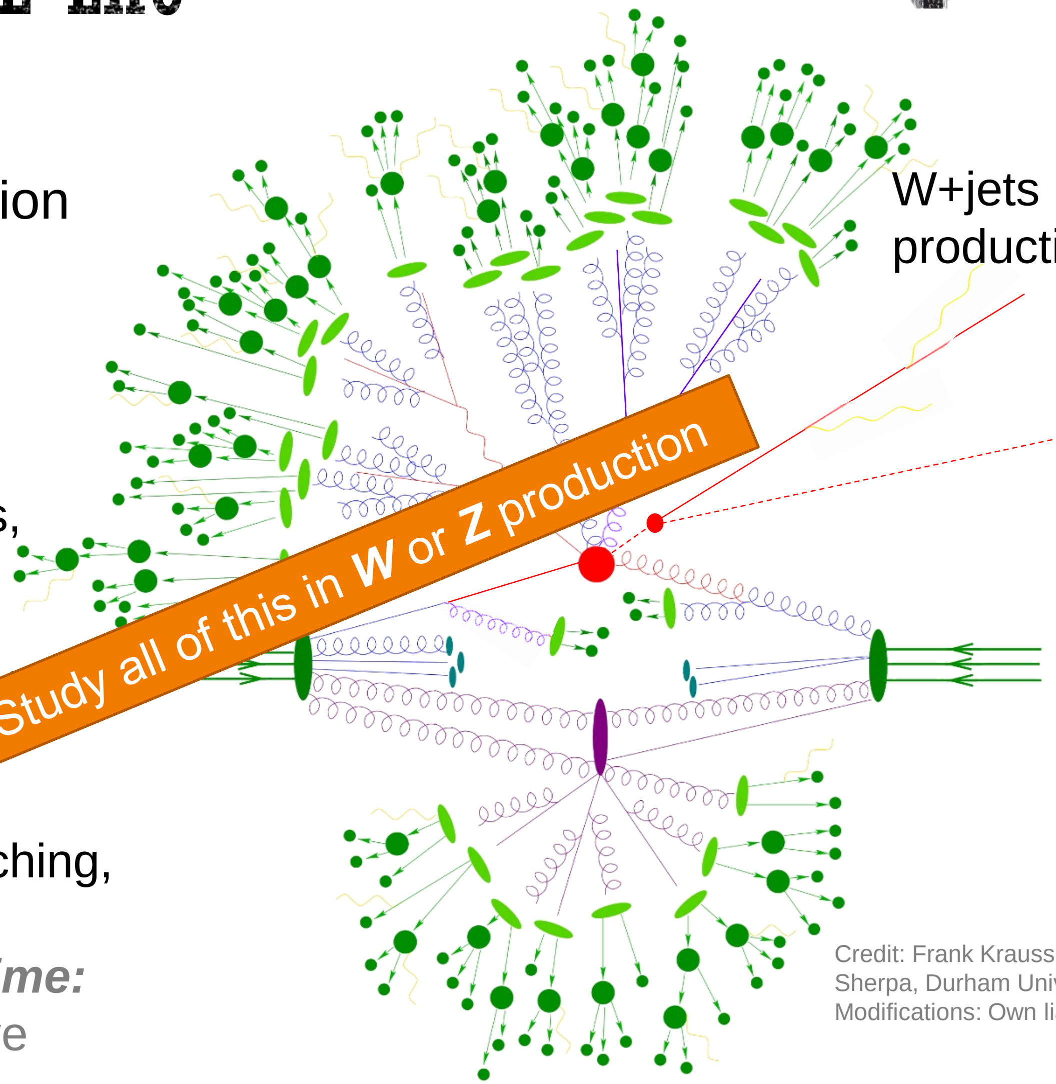


W+jets
production

→ Study all of this in ***W*** or ***Z*** production

Credit: Frank Krauss,
Sherpa, Durham University
Modifications: Own liability

W AND Z MEASUREMENTS
- A SELECTION -

- Recent ATLAS results → split into categories
  - Precision
    - W mass @ 7TeV (arXiv:1701.07240)
    - W, Z cross sections @ 7TeV (*Eur. Phys. J. C 77 (2017) 367*)
  - Jets
    - Z+jets @ 13TeV (*Eur. Phys. J. C77 (2017) 361*)
    - W+jets @ 8TeV – preliminary results for the first time

NEW

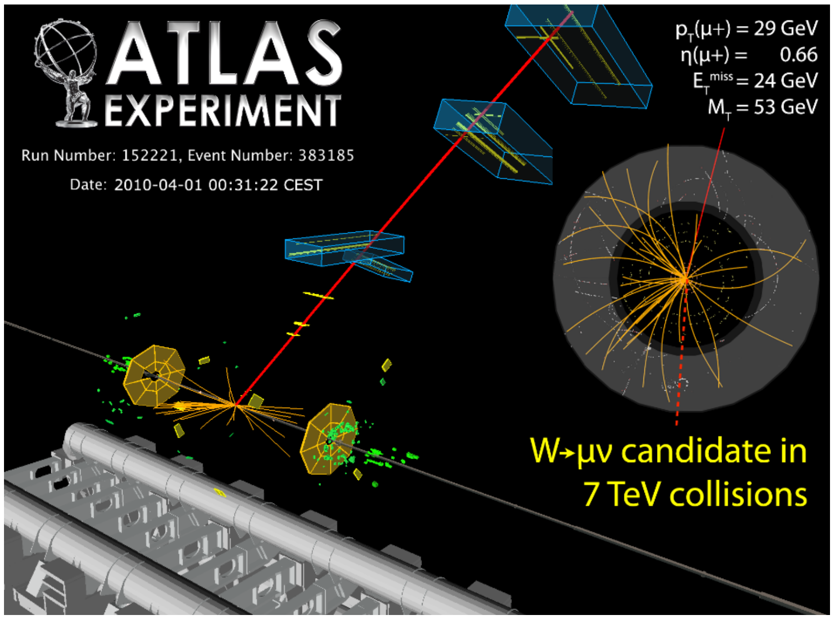
  - Specials
    - Collinear W @ 8TeV (*Phys. Lett. B 765 (2017) 132*)
    - k_t-splitting scales in Z production @ 8TeV (*JHEP08 (2017) 026*)
  - Comprehensive
    - Z 3D @ 8TeV (*Eur. Phys. J. C 76(5), 1-61 (2016)*)
      → skip in the interest of time

→ For full details, visit ATLAS public results page, W & Z

W BOSON MASS
- ARXIV:1701.07240 -

7TeV, 4.6fb-1

- W production in ATLAS



W mass

→ Need observables sensitive to m_W: p_T^{lep}, m_T

→ Challenge: High precision!

→ World average: $m_W = 80385 \pm 15 MeV$

→ 0.02% uncertainty

→ Electroweak fit: $m_W = 80356 \pm 8 MeV$

→ 0.01% uncertainty!

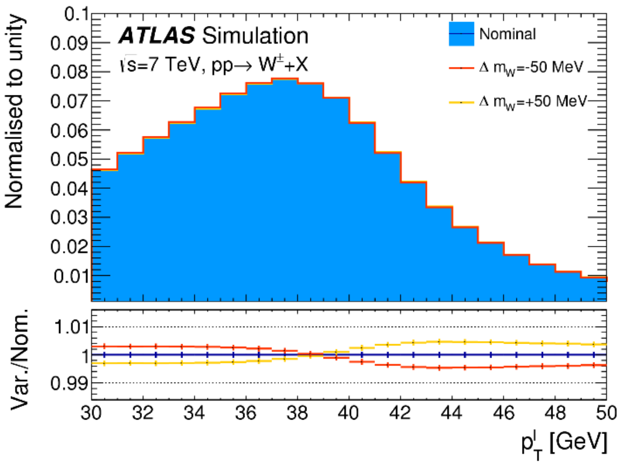
Typical selection in the presented analyses

- Exactly 1 isolated electron or muon with:
  - p_T > 20-30GeV, $|\eta|$ < 2.4-2.47
- Missing transverse momentum E_T^{miss} > 25-30GeV
- Transverse mass m_T > 40-60GeV

W BOSON MASS
- [ARXIV:1701.07240] -

7TeV, 4.6fb-1

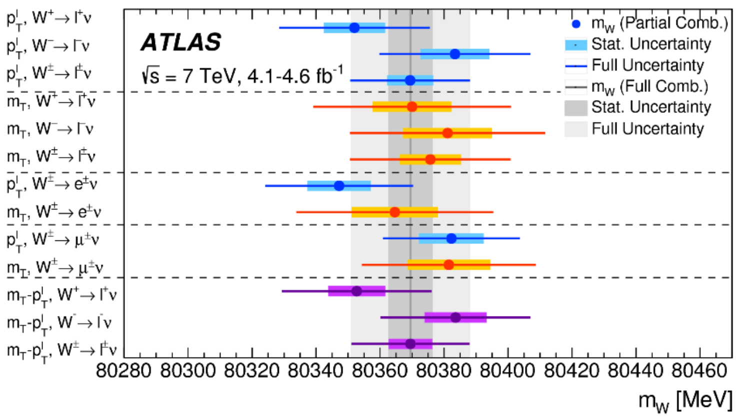
- Precision of m_W measurement
  - Extremely good understanding of lepton calibrations and hadronic recoil
  - Very detailed understanding of theoretical modelling
    - Default NLO *Powheg+Pythia8* MC simulation → reweighted to:
      - NNLO QCD as function of rapidity
      - At each rapidity: Vector boson p_T shape
      - At each rapidity & p_T: Angular coefficients describing decay in rest frame
- χ^2-Compatibility test for p_T^{lep} and m_T for different m_W
  - Minimum of interpolated χ^2-function → measured m_W

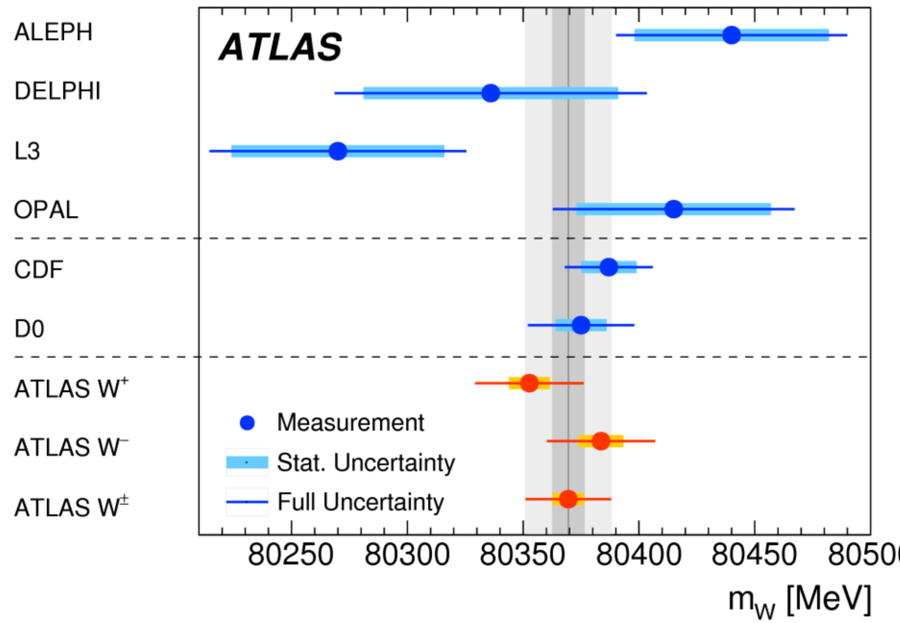


W BOSON MASS
- ARXIV:1701.07240 -

7TeV, 4.6fb-1

- Precision of m_W measurement
  - Separate results for W^+, W^-, electron, muon, p_T^{lep}, m_T, 3-4 $|\eta^{lep}|$ bins





→ Taking into account statistical and systematic uncertainties and their correlations

$$m_W = 80370 \pm 7\,(\text{stat.}) \pm 11\,(\text{exp. syst.}) \pm 14\,(\text{mod. syst.})\ \text{MeV}$$

→ Similar precision as currently leading measurements by CDF and D0

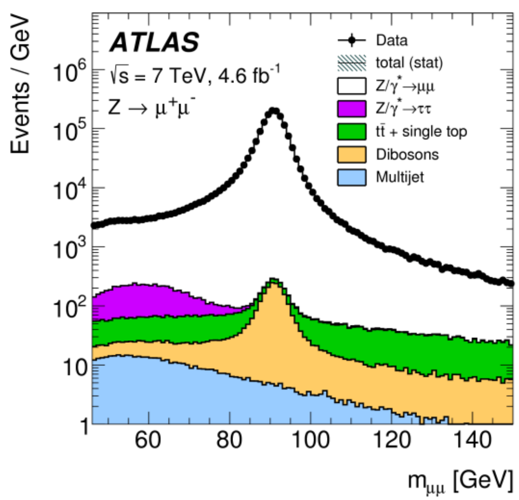
→ Dominating uncertainties: PDF (mod.), lepton-calibration (exp.)

W, Z CROSS SECTIONS
- EUR. PHYS. J. C 77 (2017) 367 -

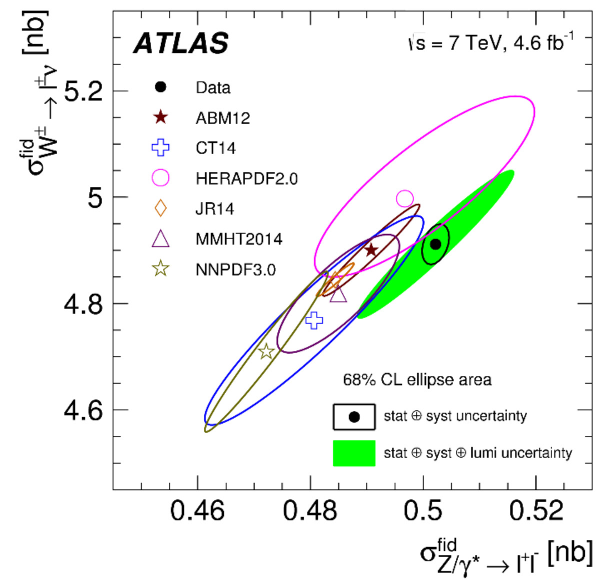
7TeV, 4.6fb^{-1}

- Precision total, fiducial and rapidity-related cross sections

Typical Z selection in the presented analyses



Fiducial cross sections



- Exactly two electrons or muons with:
  - p_T > 20-25GeV, $|\eta|$ < 2.4-2.47 (, opposite charge, here for 1 electron allowed: 2.5 < $|\eta^{el}|$ < 4.9)
- Invariant mass m_{ll} window around, below or above Z peak

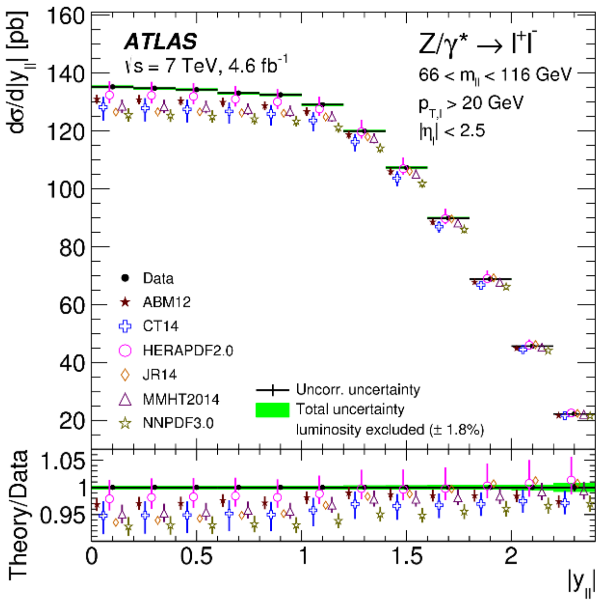
	W^+	W^-	Z
Exp. uncert. [%]	± 0.6	± 0.5	± 0.3
Diff. NNLO pred. [%]	+ 1.2	+ 0.7	+ 0.2

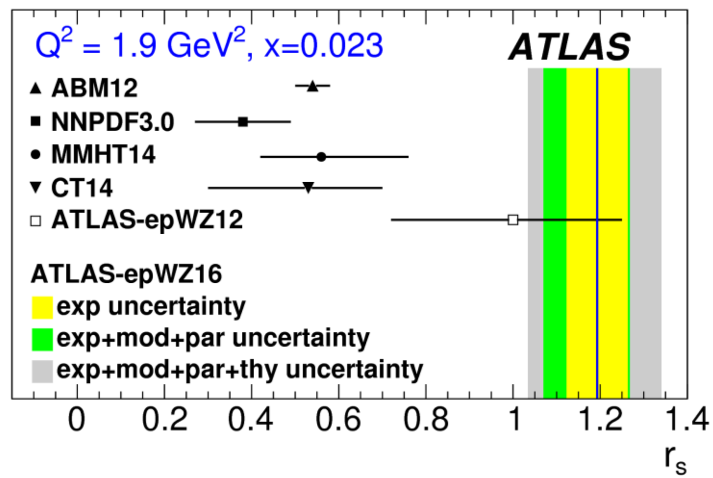
W, Z CROSS SECTIONS
- EUR. PHYS. J. C 77 (2017) 367 -

7TeV, 4.6fb^{-1}

→ Determine proton content
→ New PDF set ***ATLAS-epWZ16***

- Differential cross sections
  - For example for Z





→ Dominating uncertainties: Multijet bkg (W), lepton reconstruction & identification efficiencies (Z), signal modelling (both)

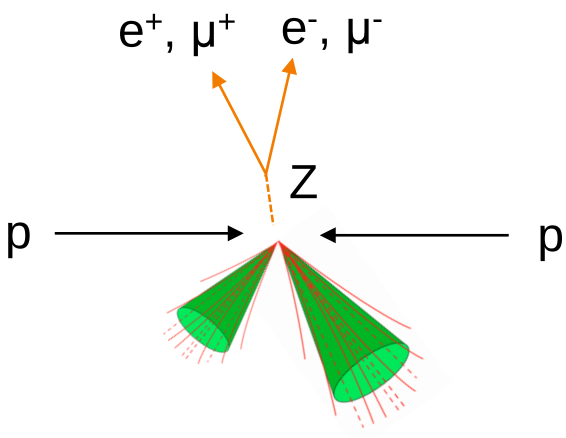
→ $r_s = \frac{s+\bar{s}}{2\bar{d}}$ → Supports unsurpressed strange sea

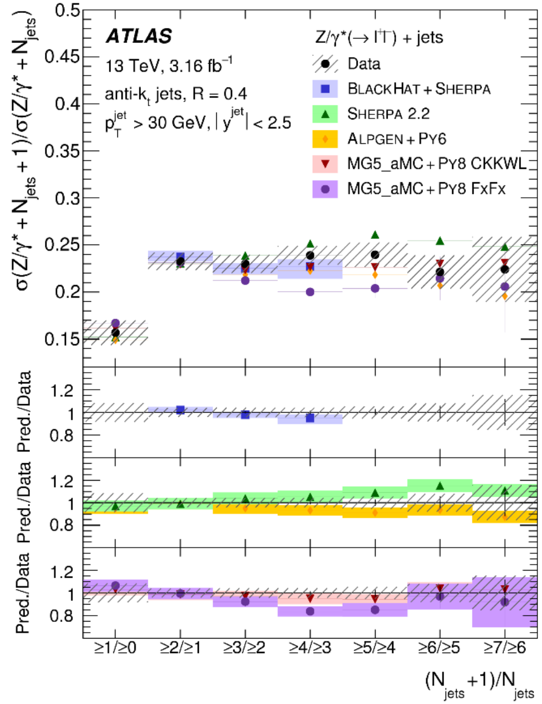
Z+JETS

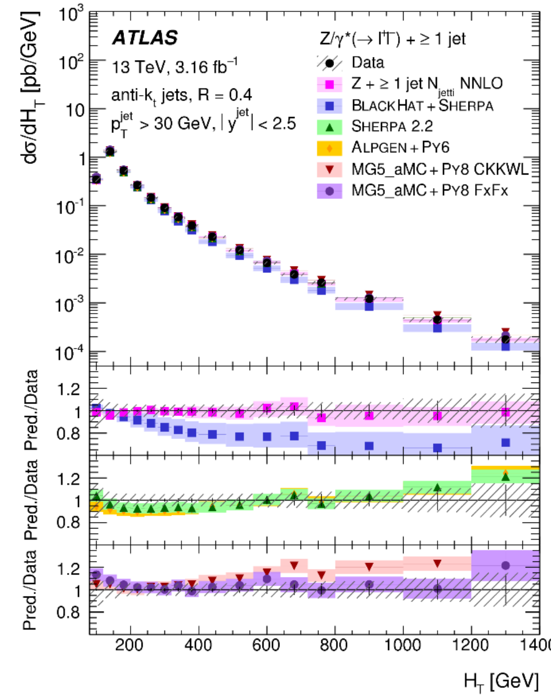
- EUR. PHYS. J. C77 (2017) 361 -

13TeV, 3.16fb^{-1}

- Production of jets in association with a Z boson







→ Count jets:
Anti-k_t R=0.4
p_T > 30GeV, |y| < 2.5

→ Measure jet (-related) properties like leading jet p_T, |y|, H_T (=Σp_T^{jet} +p_T^{lep1} +p_T^{lep2}), etc.

→ Constant (N_{jets}+1/N_{jets}) ratio as expected if dominated by gluon self-interaction

→ Large H_T: contributions from higher multiplicities essential → NNLO improves w.r.t. NLO

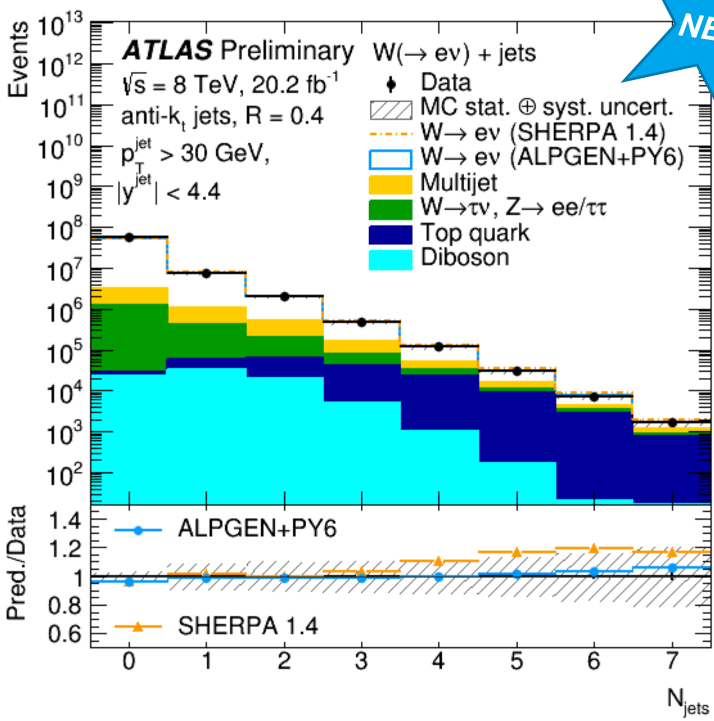
W+JETS

- FIRST PRELIMINARY RESULTS -

8TeV, $20.2fb^{-1}$

- W(→eν) production in association with jets
  - Include forward jets: |y| < 4.4

NEW



Challenge – Backgrounds

→ Multijet: Dominant at low N_{jets}
→ Suppress by electron isolation & low momentum contributions to E_T^{miss} from tracks, not calorimeter deposits

→ $t\bar{t}$: Dominant at high N_{jets}
→ Suppress by veto on events w/ b-tagged jets (MV1, 60% eff., p_T>20GeV, |η|<2.5)

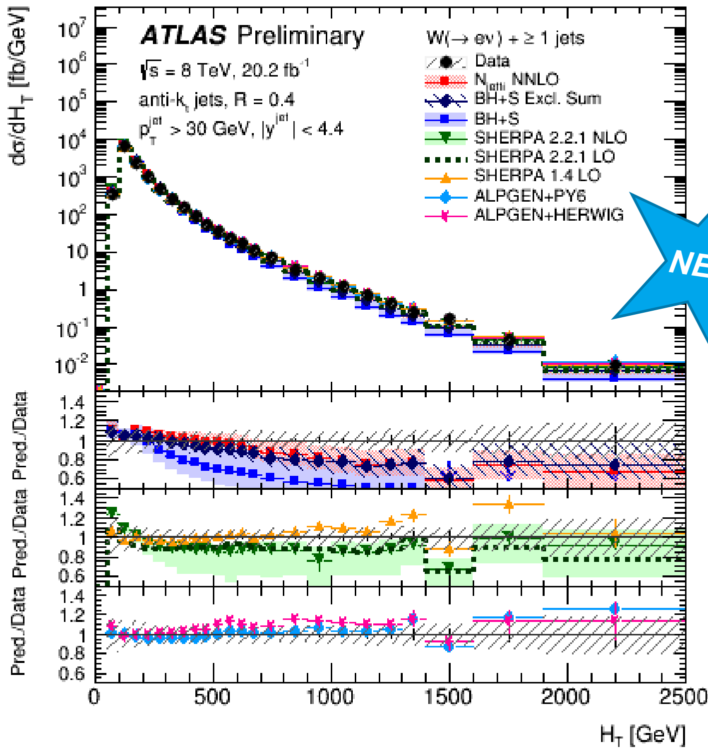
→ Measure fiducial and differential cross sections for W, W^+, W^- and W^+/W^-

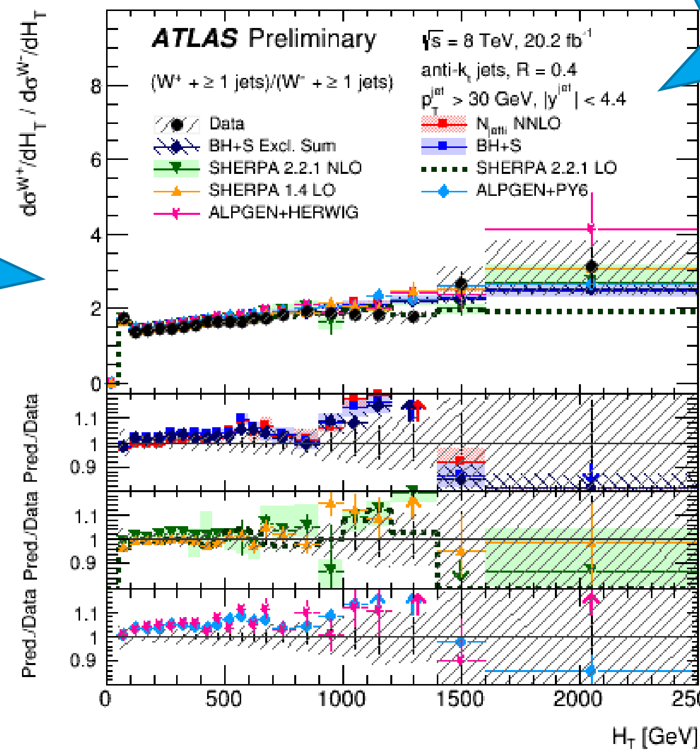
W+JETS
- FIRST PRELIMINARY RESULTS -

8TeV, $20.2fb^{-1}$

NEW

- Differential cross section and cross section ratio





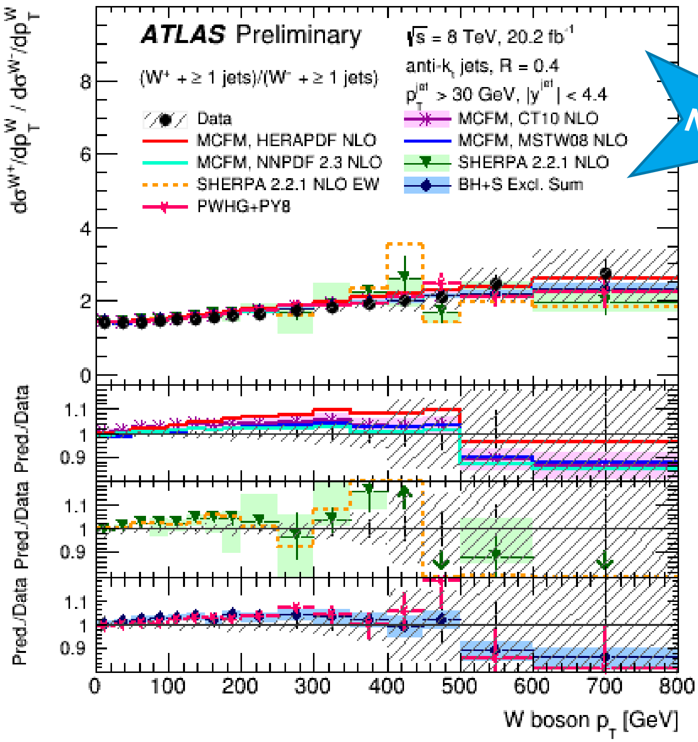
→ Similar to Z+jets, NNLO improves on NLO, though not as perfect w/ forward jets than with central jets only

→ W^+/W^- exposes different features in predictions → complementary

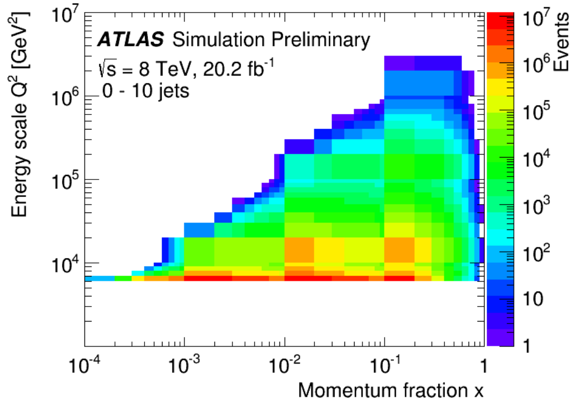
W+JETS
- FIRST PRELIMINARY RESULTS -

8TeV, 20.2fb-1

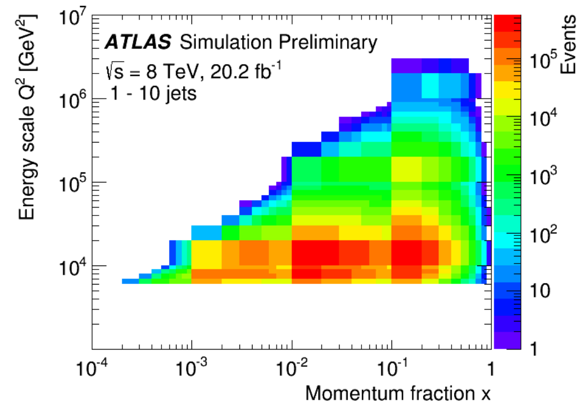
- Differential W^+/W^- cross section ratio



NEW



Very interesting input to PDF fits



→ Presence of at least one jet → Shifts x-Q^2 range of the collision higher

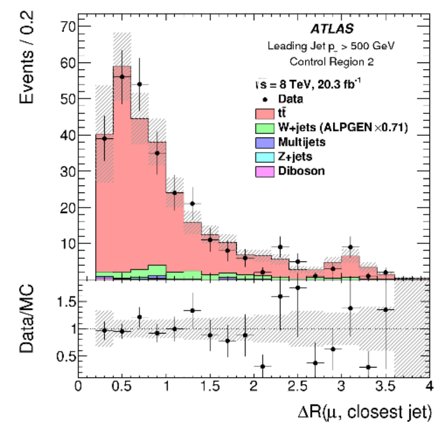
→ Information on proton content → Complementary to W asymmetry in ATLAS – probes similar x as W asymmetry @ Tevatron

COLLINEAR W EMISSION
- PHYS. LETT. B 765 (2017) 132 -

8TeV, 20.3fb[-1]

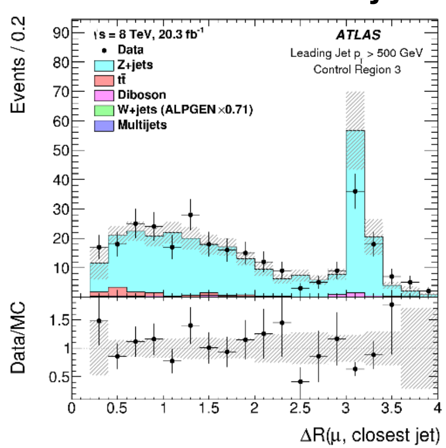
- Radiation of W bosons from light partons at high p_T
  - Measurement of angle of decay muon ($W \to \mu\nu$) to closest jet
  - Boosted topology, central ($|\eta^{jet}|<2.1$)
    - Leading jet p_T > 500GeV
    - Other jet p_T > 100GeV
    - Again no b-tagged jets (MV1, 70% eff., p_T>25GeV, $|\eta|<2.1$)

$t\bar{t}$



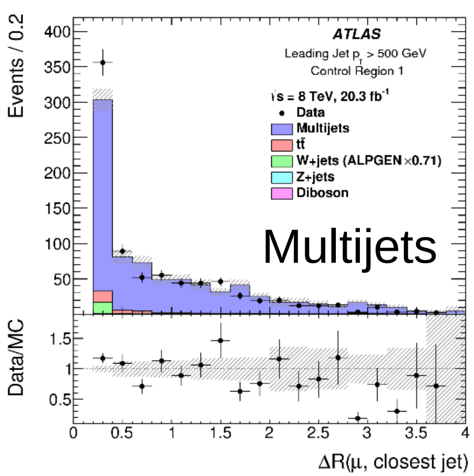
Control backgrounds

Z+jets



Composition

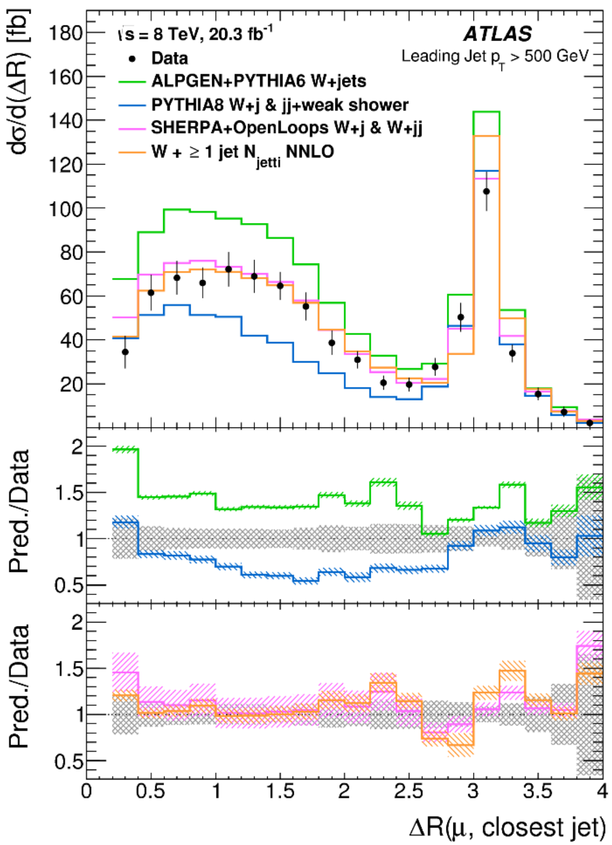
Process	$0.2 < \Delta R < 2.4$	$\Delta R > 2.4$
Dijets	5%	2%
$t\bar{t}$	7%	2%
$Z+$jets	6%	4%
Dibosons	2%	4%
$W+$jets	80%	88%
Data	1907	833

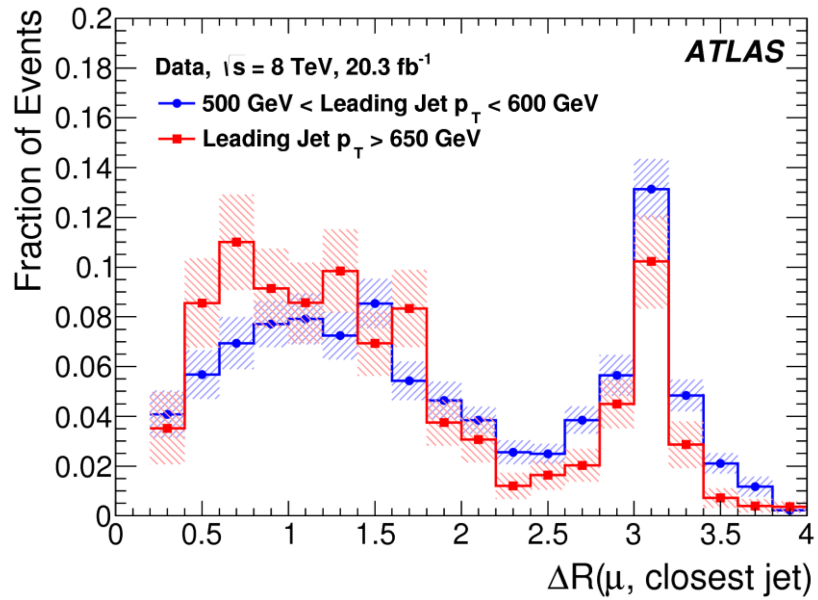


COLLINEAR W EMISSION
- PHYS. LETT. B 765 (2017) 132 -

8TeV, 20.3fb^{-1}

- Differential cross section as function of angular separation





→ NLO QCD+EW or NNLO calculations required for description of data

→ Amount of collinear W → increases with jet p_T

SUMMARY

- Many interesting measurements with W and Z bosons possible
  - Probing different aspects of our understanding of the Standard model
    - Proton structure functions, electroweak parameters, perturbative QCD, QCD radiation, electroweak radiation, etc.
  - Experimental challenges
    - Precision of calibrations, background suppression & estimation, large data and simulation samples required
  - Theoretical challenges
    - Meet experimental precision → higher order calculations in QCD and EW, higher number of hard parton emissions, radiations

→ Very interesting physics results obtained with W and Z bosons already
→ More data still to come ☺

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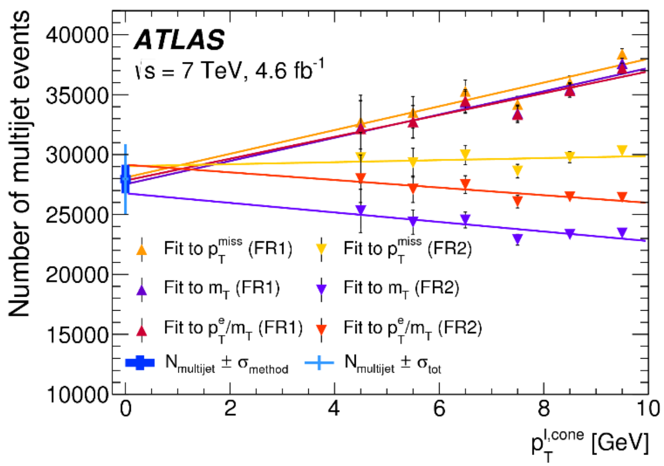
THANK YOU FOR YOUR ATTENTION

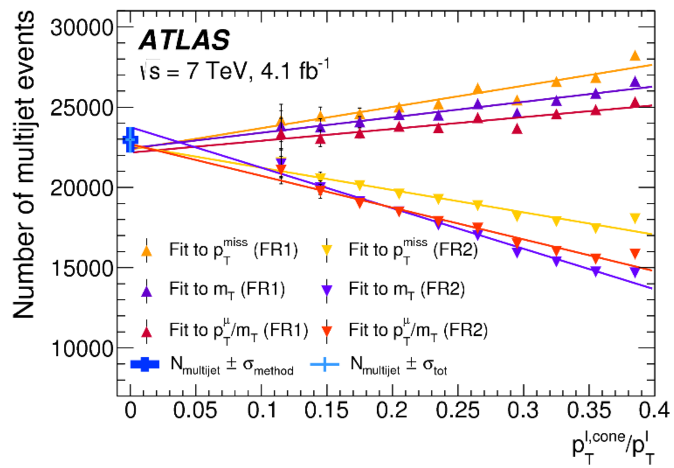
18 BACKUP

W BOSON MASS - [ARXIV:1701.07240] -

7TeV, $4.6 fb^{-1}$

- Multijet estimate
  - Template fits to p_T^{miss}, m_T and p_T^l/m_T in two jet-enriched regions
    - FR1: Remove SR-requirements on p_T^{miss} and m_T
    - FR2: In addition, remove SR-requirement on hadronic recoil u_T
  - Multijet template: From data w/ inverted lepton isolation requirement
    - Electron channel Muon channel





    - Extrapolation to SR-isolation requirement

W BOSON MASS - ARXIV:1701.07240 -

7TeV, $4.6 fb^{-1}$

- Systematic uncertainties

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T, W^+, e-μ	80370.0	12.3	8.3	6.7	14.5	9.7	9.4	3.4	16.9	30.9	2/6
m_T, W^-, e-μ	80381.1	13.9	8.8	6.6	11.8	10.2	9.7	3.4	16.2	30.5	7/6
m_T, $W^\pm$, e-μ	80375.7	9.6	7.8	5.5	13.0	8.3	9.6	3.4	10.2	25.1	11/13
p_T^ℓ, W^+, e-μ	80352.0	9.6	6.5	8.4	2.5	5.2	8.3	5.7	14.5	23.5	5/6
p_T^ℓ, W^-, e-μ	80383.4	10.8	7.0	8.1	2.5	6.1	8.1	5.7	13.5	23.6	10/6
p_T^ℓ, $W^\pm$, e-μ	80369.4	7.2	6.3	6.7	2.5	4.6	8.3	5.7	9.0	18.7	19/13
p_T^ℓ, $W^\pm$, e	80347.2	9.9	0.0	14.8	2.6	5.7	8.2	5.3	8.9	23.1	4/5
m_T, $W^\pm$, e	80364.6	13.5	0.0	14.4	13.2	12.8	9.5	3.4	10.2	30.8	8/5
m_T-p_T^ℓ, W^+, e	80345.4	11.7	0.0	16.0	3.8	7.4	8.3	5.0	13.7	27.4	1/5
m_T-p_T^ℓ, W^-, e	80359.4	12.9	0.0	15.1	3.9	8.5	8.4	4.9	13.4	27.6	8/5
m_T-p_T^ℓ, $W^\pm$, e	80349.8	9.0	0.0	14.7	3.3	6.1	8.3	5.1	9.0	22.9	12/11
p_T^ℓ, $W^\pm$, μ	80382.3	10.1	10.7	0.0	2.5	3.9	8.4	6.0	10.7	21.4	7/7
m_T, $W^\pm$, μ	80381.5	13.0	11.6	0.0	13.0	6.0	9.6	3.4	11.2	27.2	3/7
m_T-p_T^ℓ, W^+, μ	80364.1	11.4	12.4	0.0	4.0	4.7	8.8	5.4	17.6	27.2	5/7
m_T-p_T^ℓ, W^-, μ	80398.6	12.0	13.0	0.0	4.1	5.7	8.4	5.3	16.8	27.4	3/7
m_T-p_T^ℓ, $W^\pm$, μ	80382.0	8.6	10.7	0.0	3.7	4.3	8.6	5.4	10.9	21.0	10/15
m_T-p_T^ℓ, W^+, e-μ	80352.7	8.9	6.6	8.2	3.1	5.5	8.4	5.4	14.6	23.4	7/13
m_T-p_T^ℓ, W^-, e-μ	80383.6	9.7	7.2	7.8	3.3	6.6	8.3	5.3	13.6	23.4	15/13
m_T-p_T^ℓ, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

Table 11: Results of the m_W measurements for various combinations of categories. The table shows the statistical uncertainties, together with all experimental uncertainties, divided into muon-, electron-, recoil- and background-related uncertainties, and all modelling uncertainties, separately for QCD modelling including scale variations, parton shower and angular coefficients, electroweak corrections, and PDFs. All uncertainties are given in MeV.

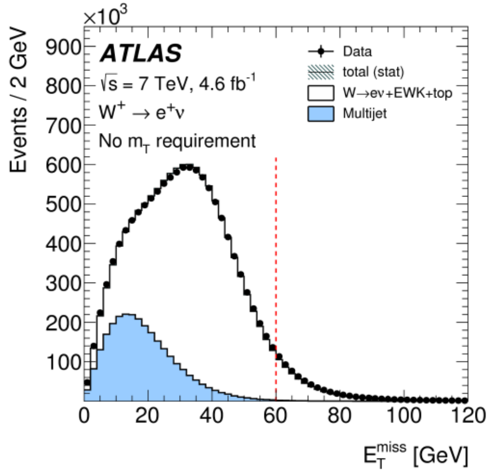
W, Z CROSS SECTIONS
- EUR. PHYS. J. C 77 (2017) 367 -

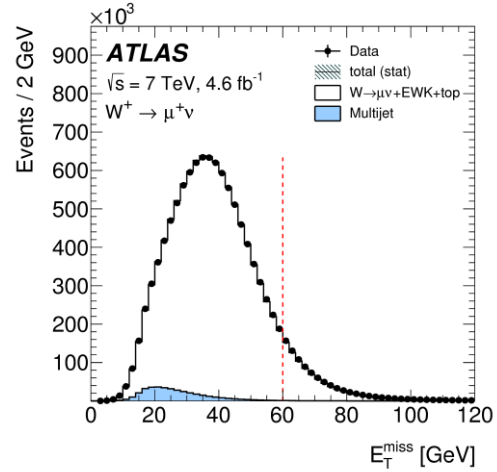
7TeV, 4.6fb-1

- Multijet estimate
  - Electron channel

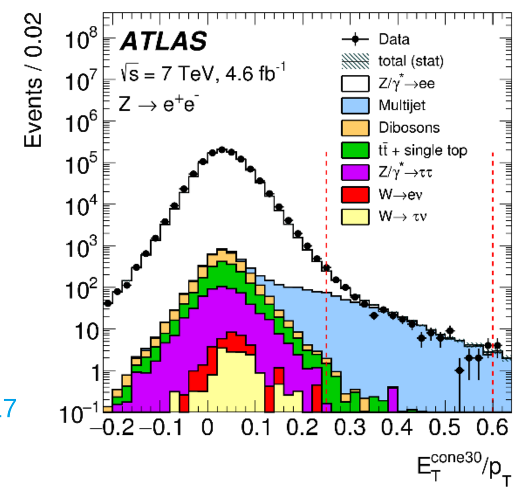
Muon channel

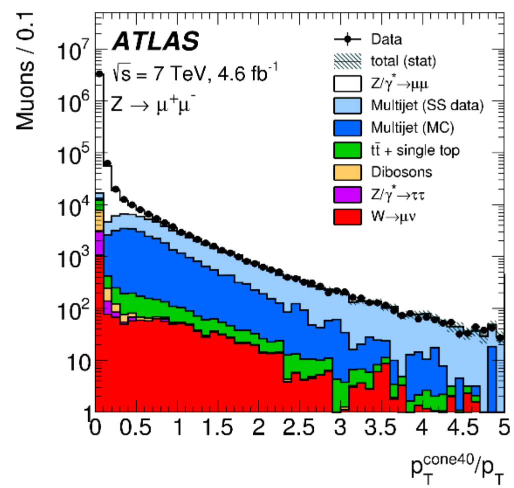
W: Fit E_T^{miss} → relaxing m_T and E_T^{miss} → Multijet tempalte from data w/ inverted (ID and) iso





Z: Fit isolation → Again MJ template from data





W, Z CROSS SECTIONS
- EUR. PHYS. J. C 77 (2017) 367 -

7TeV, 4.6fb^{-1}

- Systematic uncertainties
  - Electron channel

	$\delta\sigma_{W+}$ (%)	$\delta\sigma_{W-}$ (%)	$\delta\sigma_{Z}$ (%)	$\delta\sigma_{\text{forward } Z}$ (%)
Trigger efficiency	0.03	0.03	0.05	0.05
Reconstruction efficiency	0.12	0.12	0.20	0.13
Identification efficiency	0.09	0.09	0.16	0.12
Forward identification efficiency	–	–	–	1.51
Isolation efficiency	0.03	0.03	–	0.04
Charge misidentification	0.04	0.06	–	–
Electron p_T resolution	0.02	0.03	0.01	0.01
Electron p_T scale	0.22	0.18	0.08	0.12
Forward electron p_T scale + resolution	–	–	–	0.18
E_T^{miss} soft term scale	0.14	0.13	–	–
E_T^{miss} soft term resolution	0.06	0.04	–	–
Jet energy scale	0.04	0.02	–	–
Jet energy resolution	0.11	0.15	–	–
Signal modelling (matrix-element generator)	0.57	0.64	0.03	1.12
Signal modelling (parton shower and hadronization)	0.24	0.25	0.18	1.25
PDF	0.10	0.12	0.09	0.06
Boson p_T	0.22	0.19	0.01	0.04
Multijet background	0.55	0.72	0.03	0.05
Electroweak+top background	0.17	0.19	0.02	0.14
Background statistical uncertainty	0.02	0.03	<0.01	0.04
Unfolding statistical uncertainty	0.03	0.04	0.04	0.13
Data statistical uncertainty	0.04	0.05	0.10	0.18
Total experimental uncertainty	0.94	1.08	0.35	2.29
Luminosity	1.8	1.8	1.8	1.8

Muon channel

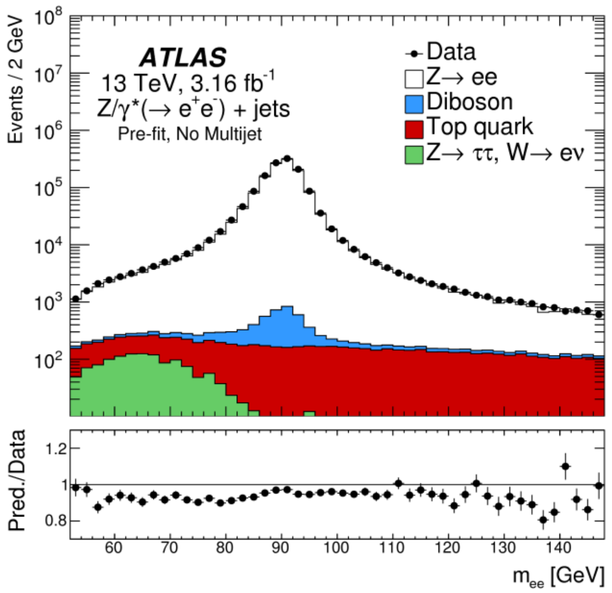
	$\delta\sigma_{W+}$ (%)	$\delta\sigma_{W-}$ (%)	$\delta\sigma_{Z}$ (%)
Trigger efficiency	0.08	0.07	0.05
Reconstruction efficiency	0.19	0.17	0.30
Isolation efficiency	0.10	0.09	0.15
Muon p_T resolution	0.01	0.01	<0.01
Muon p_T scale	0.18	0.17	0.03
E_T^{miss} soft term scale	0.19	0.19	–
E_T^{miss} soft term resolution	0.10	0.09	–
Jet energy scale	0.09	0.12	–
Jet energy resolution	0.11	0.16	–
Signal modelling (matrix-element generator)	0.12	0.06	0.04
Signal modelling (parton shower and hadronization)	0.14	0.17	0.22
PDF	0.09	0.12	0.07
Boson p_T	0.18	0.14	0.04
Multijet background	0.33	0.27	0.07
Electroweak+top background	0.19	0.24	0.02
Background statistical uncertainty	0.03	0.04	0.01
Unfolding statistical uncertainty	0.03	0.03	0.02
Data statistical uncertainty	0.04	0.04	0.08
Total experimental uncertainty	0.61	0.59	0.43
Luminosity	1.8	1.8	1.8

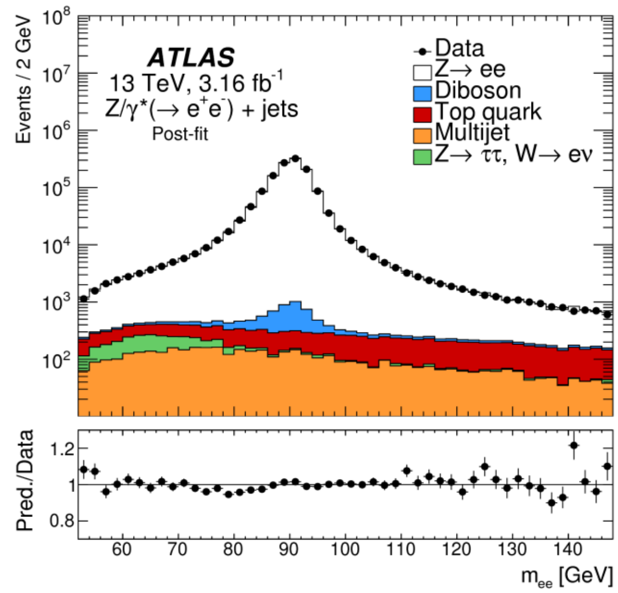
Z+JETS

- EUR. PHYS. J. C77 (2017) 361 -

13TeV, $3.16fb^{-1}$

- Multijet background → fit separately for each N_{jets}
  - Template fit of m_{ll} in range: 52-148GeV for electron, 40-80GeV for muon channel





  - Multjet templates from data with looser lepton ID and no/inverted isolation

Z+JETS
- EUR. PHYS. J. C77 (2017) 361 -

13TeV, 3.16fb^{-1}

- Systematic uncertainties

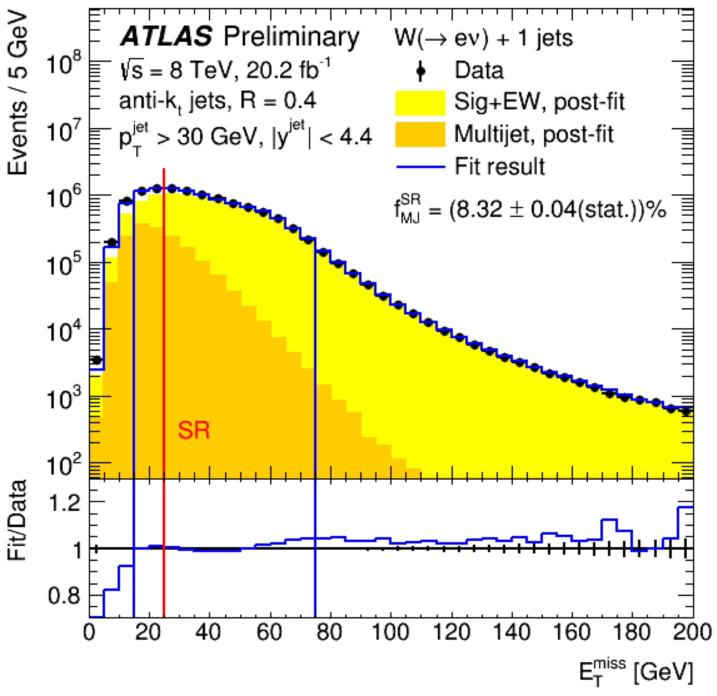
Table 4 Relative statistical and systematic uncertainties (in %) in the measured cross sections of Z + jets production for successive inclusive jet multiplicities in the electron (top) and muon (bottom) channels

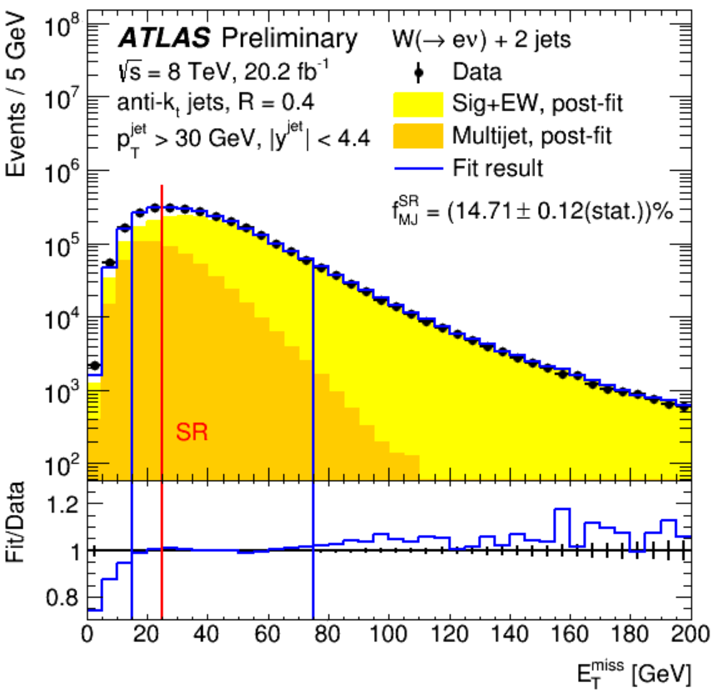
Systematic source	Relative uncertainty in $\sigma(Z(\rightarrow \ell^+\ell^-) + \geq N_{\text{jets}})$ (%)							
	$+ \geq 0$ jets	$+ \geq 1$ jets	$+ \geq 2$ jets	$+ \geq 3$ jets	$+ \geq 4$ jets	$+ \geq 5$ jets	$+ \geq 6$ jets	$+ \geq 7$ jets
$Z \rightarrow e^+e^-$								
Electron trigger	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3
Electron selection	1.2	1.6	1.8	1.9	2.3	2.7	2.9	3.8
Jet energy scale	<0.1	6.6	9.2	11.5	13.8	17.3	20.6	23.7
Jet energy resolution	<0.1	3.7	3.7	4.4	5.3	5.2	6.2	7.3
Jet vertex tagger	<0.1	1.3	2.1	2.8	3.6	4.5	5.5	6.3
Pile-up	0.4	0.2	0.1	0.2	0.2	0.1	0.4	0.8
Luminosity	2.1	2.1	2.2	2.3	2.4	2.5	2.6	2.8
Unfolding	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.2
Background	0.1	0.3	0.6	1.0	1.6	3.3	6.0	11.6
Total syst. Uncertainty	3.9	8.7	11.0	13.4	15.9	19.5	23.6	28.7
Stat. uncertainty	0.1	0.2	0.5	0.9	1.9	3.7	7.7	15.9
$Z \rightarrow \mu^+\mu^-$								
Muon trigger	0.4	0.5	0.4	0.5	0.4	0.5	0.9	0.6
Muon selection	0.8	0.9	1.0	1.0	1.0	1.5	4.2	16.6
Jet energy scale	<0.1	6.8	9.1	11.9	14.0	17.0	20.9	23.7
Jet energy resolution	<0.1	3.6	3.6	4.1	5.0	5.9	6.2	9.3
Jet vertex tagger	<0.1	1.3	2.1	3.1	3.6	4.4	5.6	6.6
Pile-up	0.4	0.1	<0.1	0.3	0.5	0.1	0.4	0.9
Luminosity	2.1	2.1	2.2	2.3	2.4	2.5	2.6	2.7
Unfolding	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.2
Background	0.2	0.4	0.6	0.9	1.7	4.0	7.4	12.9
Total syst. Uncertainty	3.8	8.7	10.8	13.6	16.0	19.4	24.6	36.3
Stat. uncertainty	0.1	0.2	0.4	0.8	1.7	3.4	7.2	16.3

W+JETS
- FIRST PRELIMINARY RESULTS -

8TeV, 20.2fb-1

- Multijet estimate
  - Fit of E_T^{miss} distribution in range 15-75GeV for each N_{jets} → removed E_T^{miss} requirement for the fit
  - Multijet template from data with inverted electron ID and isolation

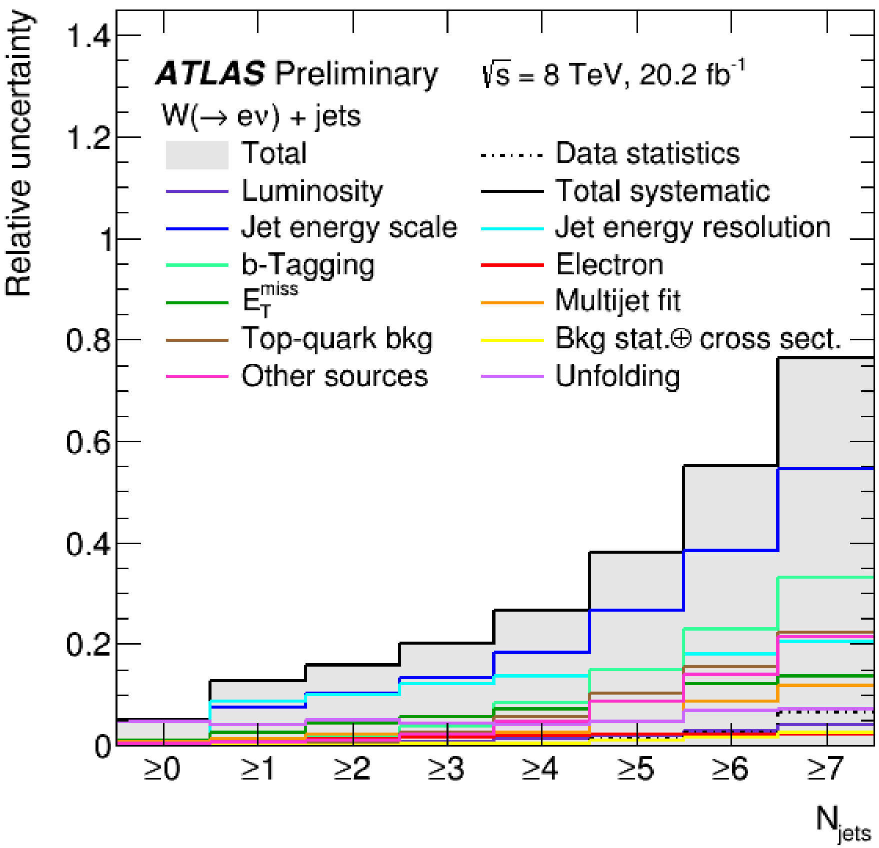


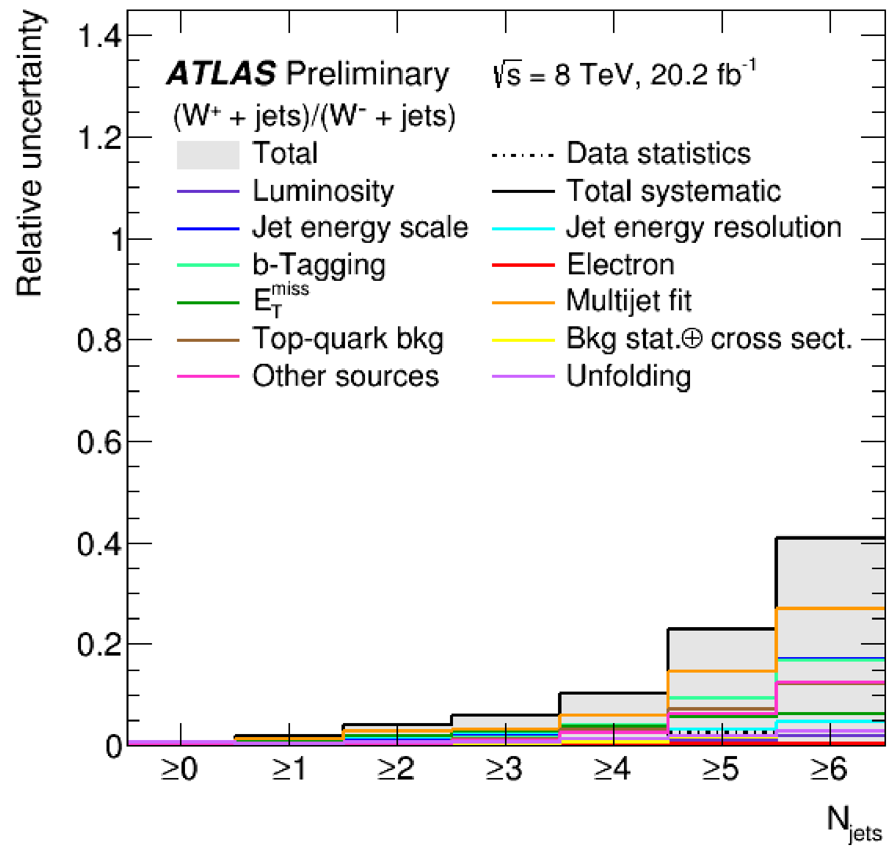


W+JETS
- FIRST PRELIMINARY RESULTS -

8TeV, $20.2 fb^{-1}$

- Systematic uncertainties

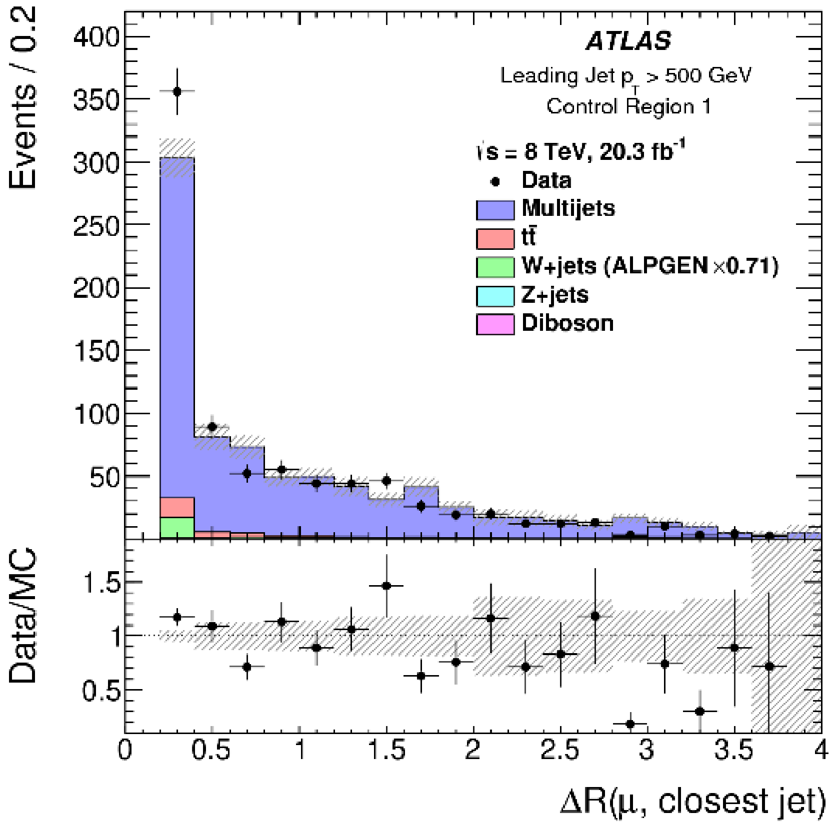




COLLINEAR W EMISSION
- PHYS. LETT. B 765 (2017) 132 -

8TeV, 20.3fb^{-1}

- Multijet estimate
  - Pythia 8 MC simulation → normalized to data in control region



Control region:

- 93% purity of multijet events
- Inverted SR isolation of the muon
- Normalization factor: 1.134 ± 0.054

COLLINEAR W EMISSION
- PHYS. LETT. B 765 (2017) 132 -

8TeV, 20.3fb^{-1}

- Systematic uncertainties

Table 1
The systematic uncertainties in the cross-section measurement. Multiple independent components have been combined into groups of systematic uncertainties.

Systematic Source	$0.2 < \Delta R < 2.4$	$\Delta R > 2.4$	Inclusive
Scaling of dijets to data	0.4%	0.1%	0.3%
Scaling of $t\bar{t}$ to data	0.6%	0.2%	0.5%
Scaling of $Z+$jets to data	0.6%	0.3%	0.5%
Jet energy scale	4.6%	5.8%	5.0%
b-tagging efficiency	3.7%	1.2%	2.9%
Data/MC disagreement for dijets	0.9%	0.6%	0.8%
Data/MC disagreement for $t\bar{t}$	1.2%	0.4%	1.0%
Data/MC disagreement for $Z+$jets	0.6%	1.5%	0.9%
Diboson background estimate	2.2%	0.1%	1.5%
Unfolding dependence on prior	1.1%	1.8%	1.3%
Muon momentum scale and resolution	0.0%	0.1%	0.1%
Muon reconstruction efficiency	0.4%	0.4%	0.4%
Muon trigger efficiency	2.0%	1.9%	1.9%
Jet energy resolution	0.6%	0.8%	0.6%
MC background statistical	2.4%	1.8%	2.3%
MC response statistical	1.7%	2.2%	1.9%
Total systematic (excluding luminosity)	7.6%	7.4%	7.3%
Luminosity	1.9%	2.0%	2.0%
Data statistical	2.7%	3.6%	2.2%

K_T-SPLITTING SCALES IN Z EVENTS
- JHEP08 (2017) 026 -

8TeV, $20.2fb^{-1}$

- Investigate transition from perturbative to non-perturbative regime
  - k_t-jets from charged-particle tracks in the ATLAS inner detector
    - Tracks with p_T > 400MeV, $|\eta| < 2.5$
    - Cluster to jets → combine track *i* with track *j*, if

$$d_{ij} = \min\left(p_{\mathrm{T},i}^2, p_{\mathrm{T},j}^2\right) \times \frac{\Delta R_{ij}^2}{R^2} < p_{\mathrm{T},i}^2$$

    - Splitting scale, when going from (k+1) to k objects: $d_k = \min_{i,j}(d_{ij}, d_{ib})$

k_T-SPLITTING SCALES IN Z EVENTS - JHEP08 (2017) 026 -

8TeV, 20.2fb^{-1}

- Investigate transition from perturbative to non-perturbative regime
  - k_t-jets from charged-particle tracks in the ATLAS inner detector
    - Tracks with $p_T > 400$MeV, $|\eta| < 2.5$
    - Cluster to jets → combine track *i* with track *j*, if

$$d_{ij} = \min\left(p^2_{\mathrm{T},i}, p^2_{\mathrm{T},j}\right) \times \frac{\Delta R^2_{ij}}{R^2} < p^2_{\mathrm{T},i}$$

    - Splitting scale, when going from (k+1) to k objects: $d_k = \min_{i,j}(d_{ij}, d_{ib})$

→ Let's do some numbers (R=0.4)

Track no.	p_T [GeV]	ΔR_{ij}	$\sqrt{d_{ij}}$ [GeV]
1	4	12: 0.2, 13: 0.5	***12: 2***, 13: 5
2	5	23: 0.3	23: 3.8
3	7		

Smallest
→ Combine 1 and 2

K_T-SPLITTING SCALES IN Z EVENTS
- JHEP08 (2017) 026 -

8TeV, 20.2fb-1

- Investigate transition from perturbative to non-perturbative regime
  - k_t-jets from charged-particle tracks in the ATLAS inner detector
    - Tracks with $p_T > 400$MeV, $|\eta| < 2.5$
    - Cluster to jets → combine track *i* with track *j*, if

$$d_{ij} = \min\left(p_{\mathrm{T},i}^2, p_{\mathrm{T},j}^2\right) \times \frac{\Delta R_{ij}^2}{R^2} < p_{\mathrm{T},i}^2$$

    - Splitting scale, when going from (k+1) to k objects: $d_k = \min_{i,j}(d_{ij}, d_{ib})$

→ Let's do some numbers (R=0.4)

Track no.	p_T [GeV]	ΔR_{ij}	$\sqrt{d_{ij}}$ [GeV]
(12)	~9	(12)3: 0.3	***(12)3: 5.3***
3	7		

Smallest
→ Combine (12) and 3

K_T-SPLITTING SCALES IN Z EVENTS

- JHEP08 (2017) 026 -

8TeV, 20.2fb-1

- Investigate transition from perturbative to non-perturbative regime
  - k_t-jets from charged-particle tracks in the ATLAS inner detector
    - Tracks with p_T > 400MeV, $|\eta| < 2.5$
    - Cluster to jets → combine track *i* with track *j*, if

$$d_{ij} = \min\left(p_{T,i}^2, p_{T,j}^2\right) \times \frac{\Delta R_{ij}^2}{R^2} < p_{T,i}^2$$

    - Splitting scale, when going from (k+1) to k objects: $d_k = \min_{i,j}(d_{ij}, d_{ib})$

→ Let's do some numbers (R=0.4)

Track no.	p_T [GeV]	ΔR_{ij}	$\sqrt{d_{ij}}$ [GeV]
(12)	~9	(12)3: 0.3	***(12)3: 5.3***
(123)	~***16***	No further track	-
3	7		

Smallest
→ Define jet

→ Now define splitting scales:
$\sqrt{d_0}$=16GeV, $\sqrt{d_1}$=5.3GeV, $\sqrt{d_2}$=2GeV

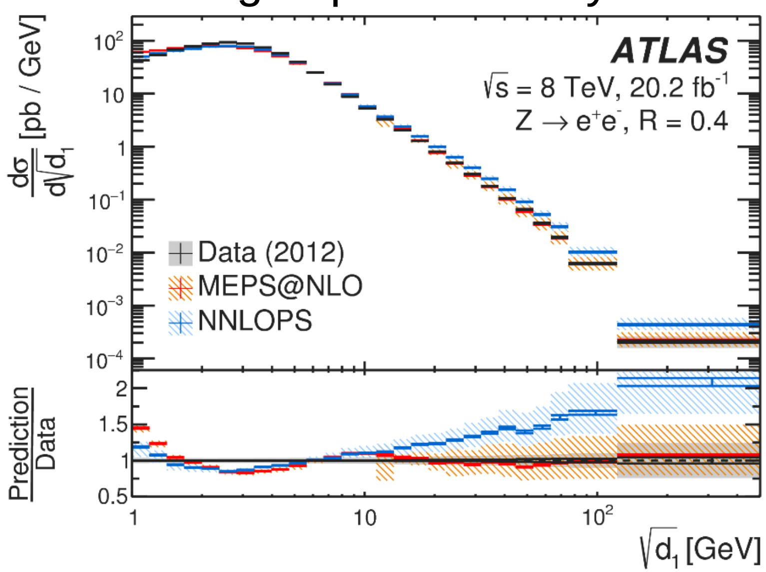
→ $\sqrt{d_0}$: measurement of leading track jet p_T

K_T-SPLITTING SCALES IN Z EVENTS - JHEP08 (2017) 026 -

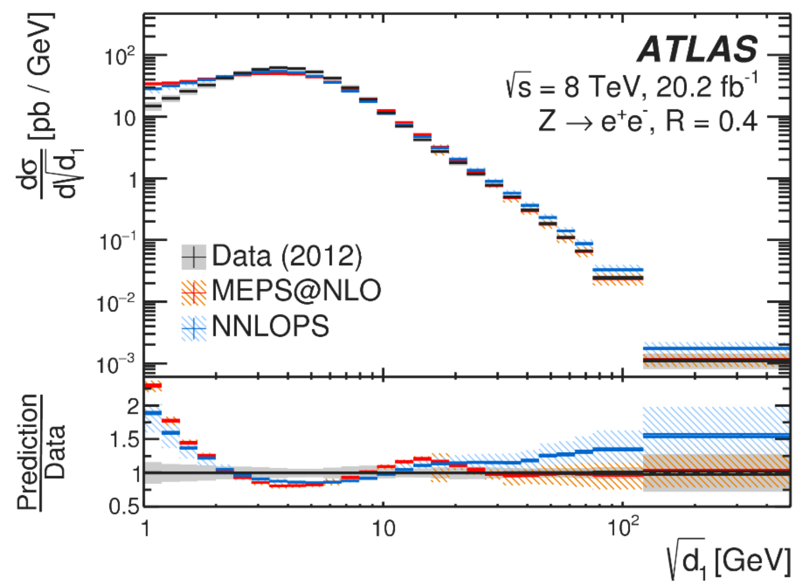
8TeV, 20.2fb^{-1}

- Cross section as function of splitting scale for R=0.4 and R=1.0 jets → w/ and w/o correction for neutral particles in jets

Charged particles only



Charged + neutral particles



→ New input for tuning of parameters in non-perturbative states of event generators

Z3D

- EUR. PHYS. J. C 76(5), 1-61 (2016) -

8TeV, 20.3fb-1

- Measurement of differential cross sections as function of p_T^{ll} and ϕ_η^* for bins in m_{ll} and $|y_{ll}|$

Table 1 Synopsis of the ϕ_η^* and $p_T^{\ell\ell}$ measurements, and of the fiducial region definitions used. Full details including the definition of the Born, bare and dressed particle levels are provided in the text. Unless otherwise stated criteria apply to both ϕ_η^* and $p_T^{\ell\ell}$ measurements

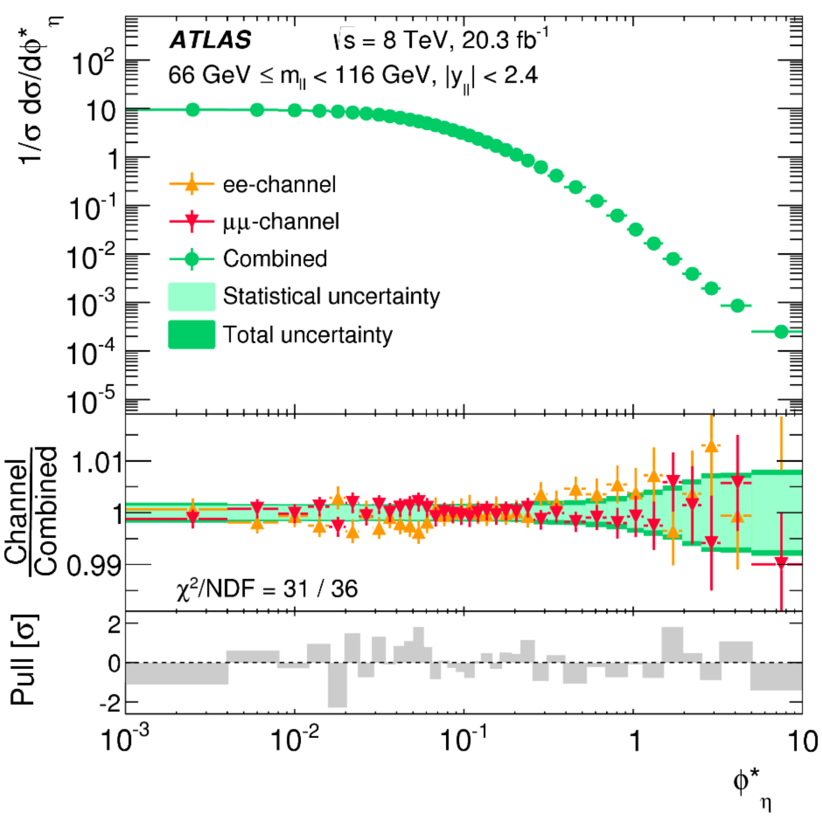
Particle-level definitions (treatment of final-state photon radiation)	
Electron pairs	Dressed; Born
Muon pairs	Bare; dressed; Born
Combined	Born
Fiducial region	
Leptons	$p_T > 20$ GeV and $\|\eta\| < 2.4$
Lepton pairs	$\|y_{\ell\ell}\| < 2.4$
Mass and rapidity regions	
46 GeV $< m_{\ell\ell} <$ 66 GeV	$\|y_{\ell\ell}\| < 0.8$; $0.8 < \|y_{\ell\ell}\| < 1.6$; $1.6 < \|y_{\ell\ell}\| < 2.4$ (ϕ_η^* measurements only)
	$\|y_{\ell\ell}\| < 2.4$
66 GeV $< m_{\ell\ell} <$ 116 GeV	$\|y_{\ell\ell}\| < 0.4$; $0.4 < \|y_{\ell\ell}\| < 0.8$; $0.8 < \|y_{\ell\ell}\| < 1.2$; $1.2 < \|y_{\ell\ell}\| < 1.6$; $1.6 < \|y_{\ell\ell}\| < 2.0$; $2.0 < \|y_{\ell\ell}\| < 2.4$; $\|y_{\ell\ell}\| < 2.4$
116 GeV $< m_{\ell\ell} <$ 150 GeV	$\|y_{\ell\ell}\| < 0.8$; $0.8 < \|y_{\ell\ell}\| < 1.6$; $1.6 < \|y_{\ell\ell}\| < 2.4$ (ϕ_η^* measurements only)
	$\|y_{\ell\ell}\| < 2.4$
Very-low mass regions	
12 GeV $< m_{\ell\ell} <$ 20 GeV 20 GeV $< m_{\ell\ell} <$ 30 GeV 30 GeV $< m_{\ell\ell} <$ 46 GeV	$\|y_{\ell\ell}\| < 2.4$, $p_T^{\ell\ell} > 45$ GeV, $p_T^{\ell\ell}$ measurements only

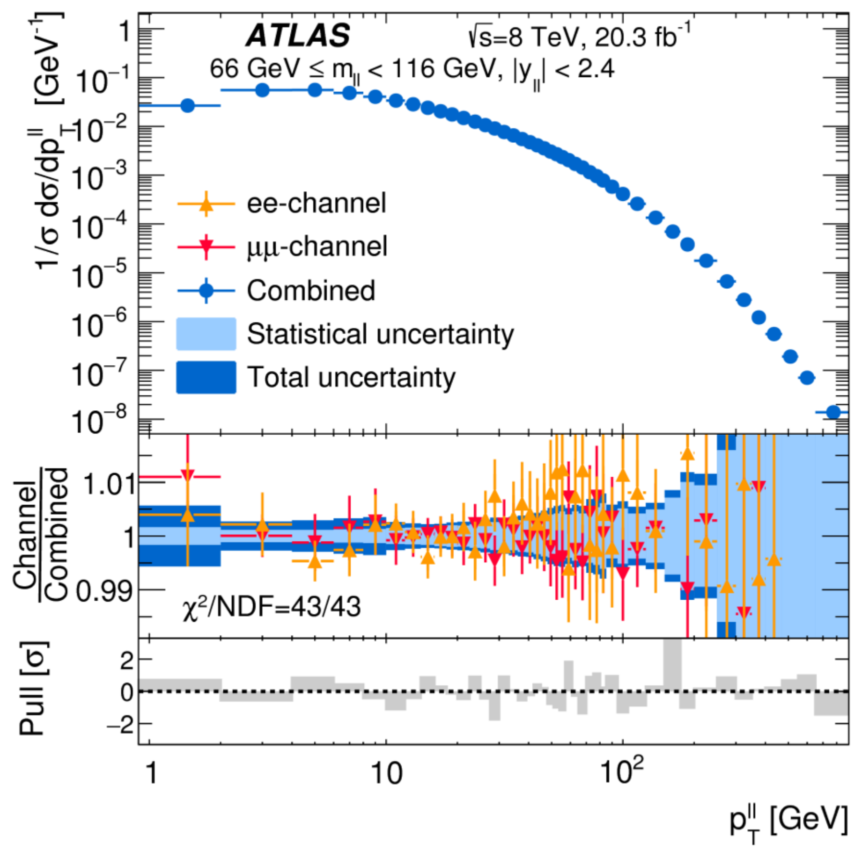
Z3D

- [EUR. PHYS. J. C 76(5), 1-61 (2016)] -

8TeV, 20.3fb^{-1}

- Differential cross sections in mass peak



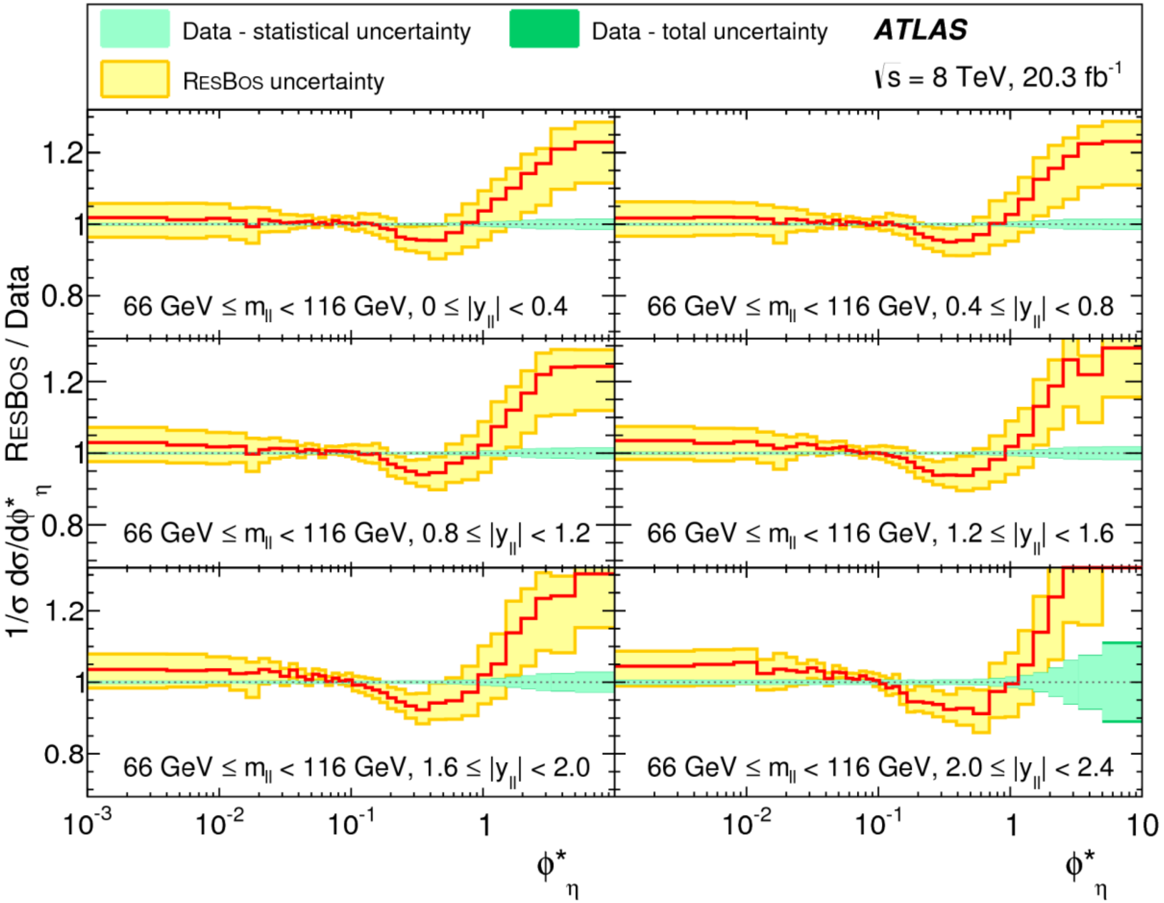


Z3D

\- [EUR. PHYS. J. C 76(5), 1-61 (2016)] -

8TeV, 20.3fb^{-1}

- Comparison to theory



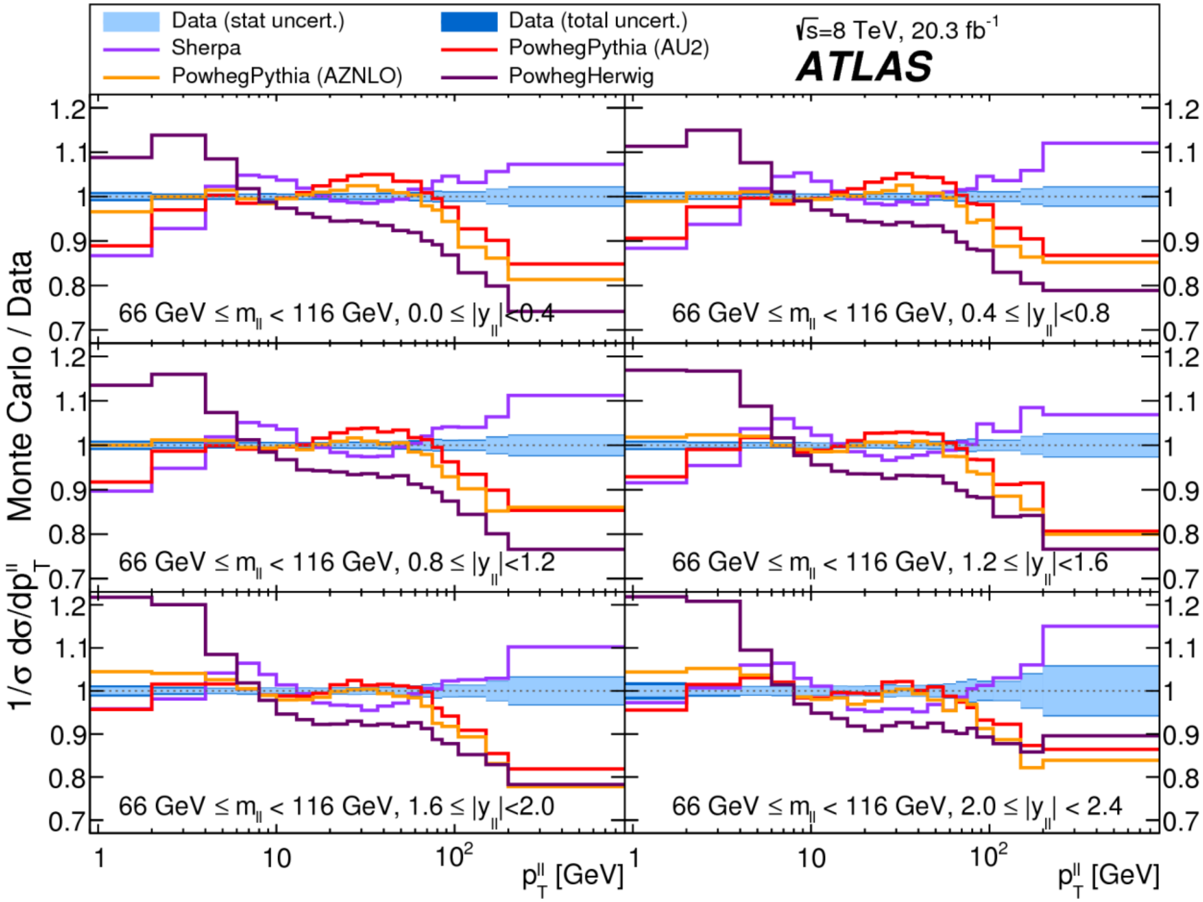
Resummed prediction ResBos describes well low ϕ_η^* , but not high ϕ_η^*

Z3D

- EUR. PHYS. J. C 76(5), 1-61 (2016) -

8TeV, 20.3fb-1

- Comparison to theory



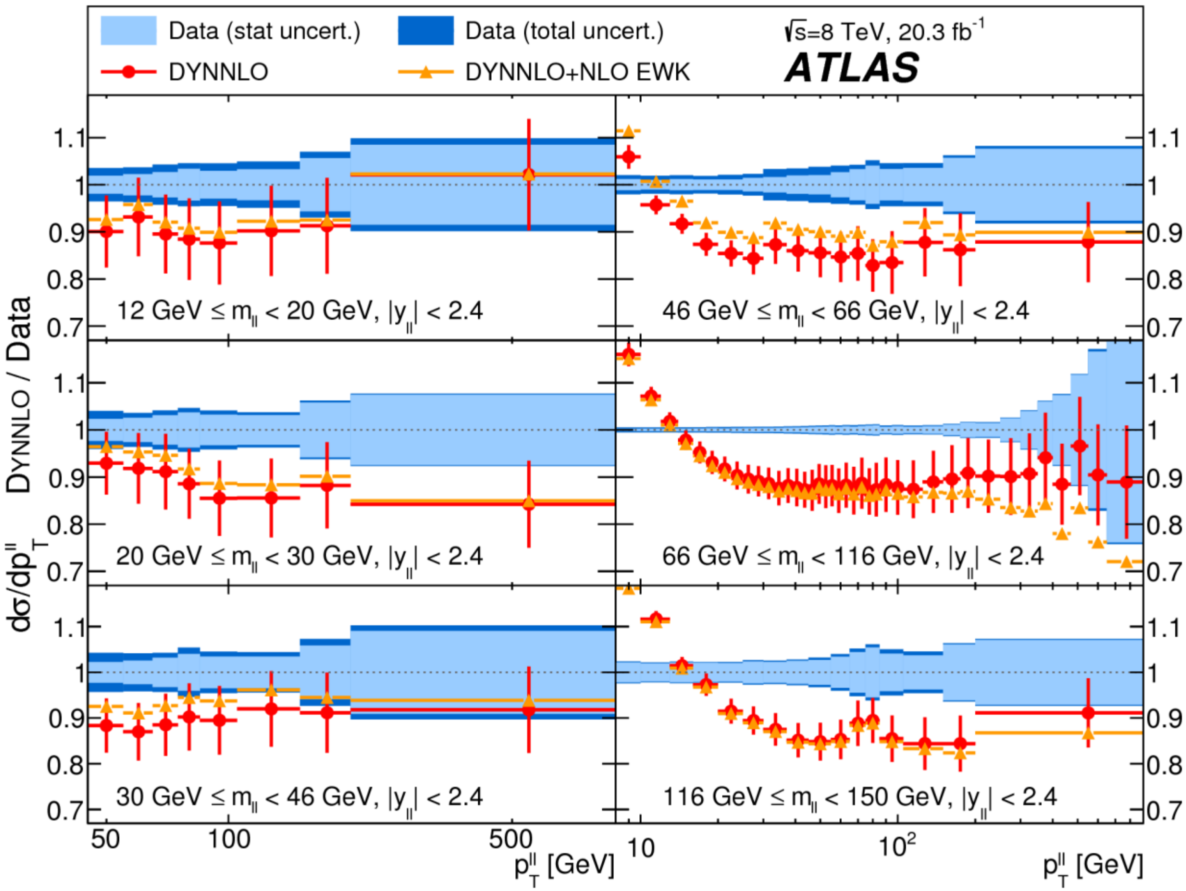
Generators interfaced to parton showers get the 5-100GeV part for p_T^{ll} roughly right, but neither the very low (non-perturbative) nor the high p_T (hard parton emission) part

Z3D

- [EUR. PHYS. J. C 76(5), 1-61 (2016)] -

8TeV, 20.3fb-1

- Comparison to theory



Fixed order NNLO prediction gets shape approximately right above 40GeV (flat ratio), but absolute cross section prediction is off by 15%, not covered by scale & PDF uncertainties