QCD and Electroweak Measurements with the ATLAS detector

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on behalf of ATLAS Collaboration

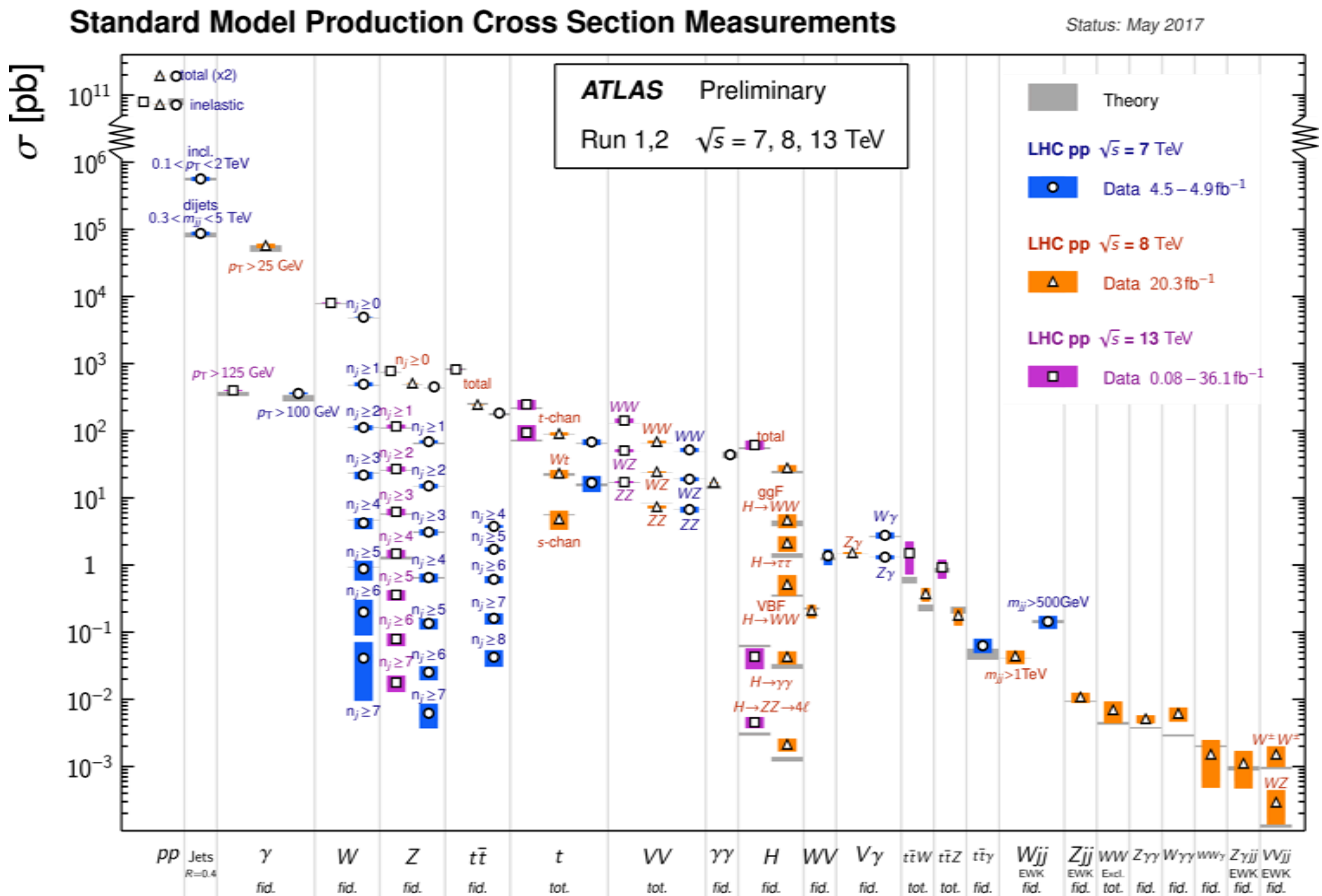
Motivation

Why Standard Model physics?

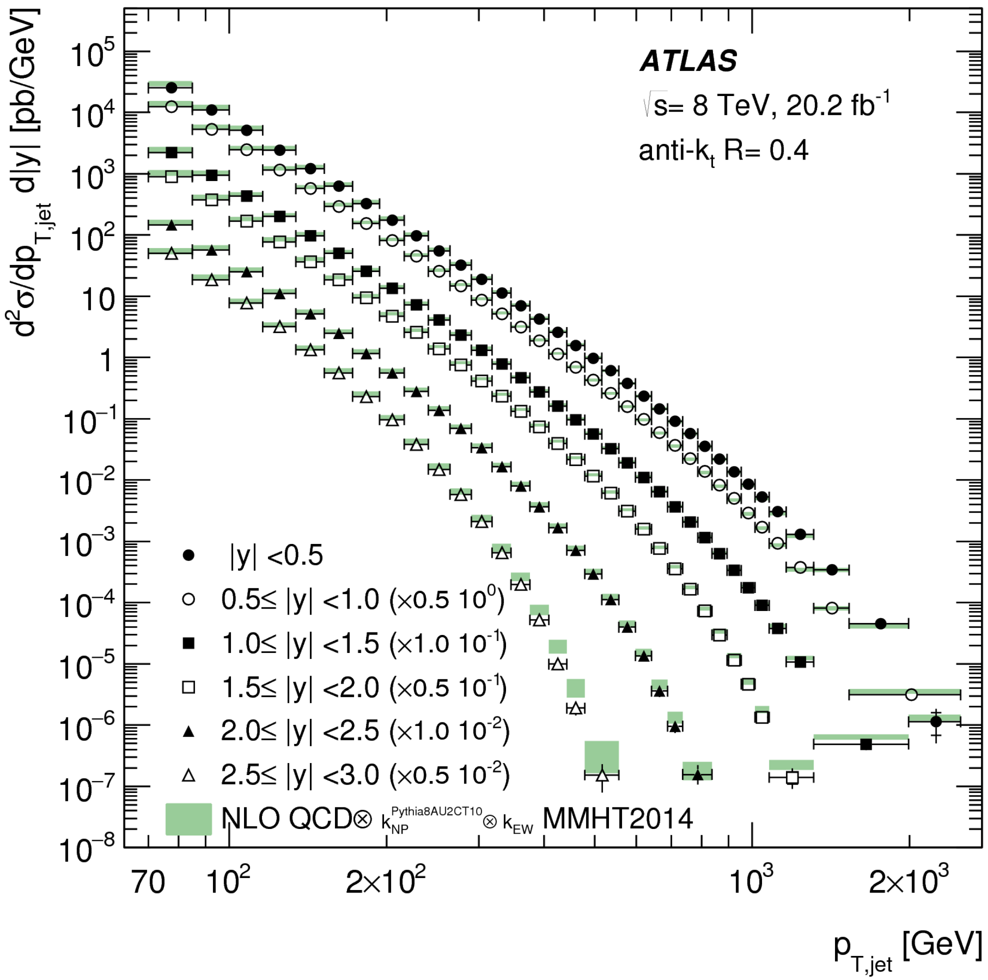
- Test predictions of perturbative QCD
- Understanding of backgrounds to new physics searches
- Precision measurements of observables to test the consistency of the Electroweak Sector

Physics	Probes
Different qcd order predictions	Jets W,Z bosons
EWK corrections	Photons Dibosons
EWK parameters	Top -> yersterday talk by Kevin Black

Summary of SM cross section measurement



Inclusive jet cross sections



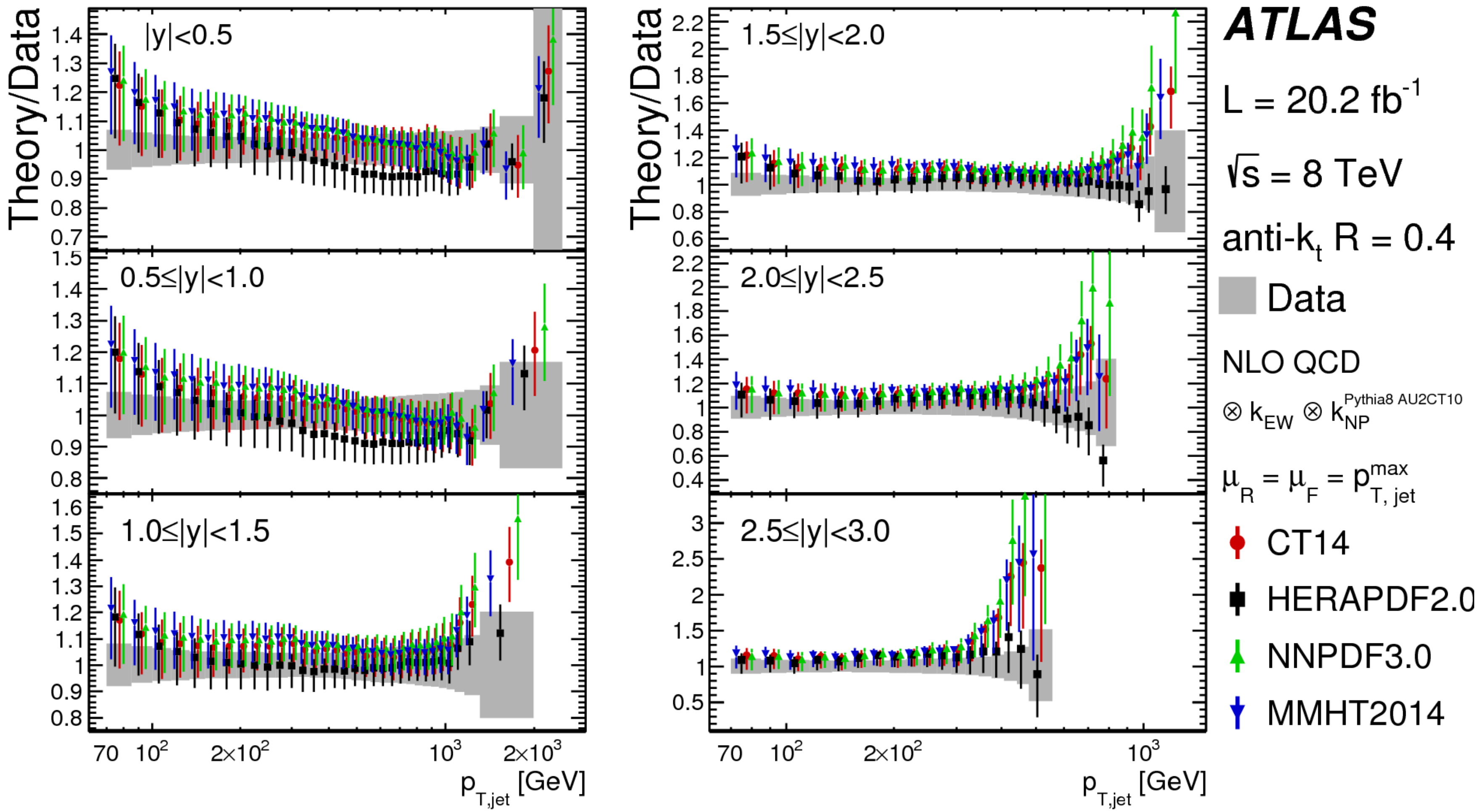
arxiv:1706.03192

- The anti-k_t jet clustering algorithm: R=0.4 and R=0.6
- The dominant systematic uncertainty: from the jet energy calibration.
- Significant reduction of the uncertainties (compared to previous jet cross-section measurements)

- The data are compared to the NLO QCD prediction with the MMHT2014 PDF set corrected for non-perturbative and electroweak effects.
- The theory prediction describes the gross features in the data.

Inclusive jet cross sections

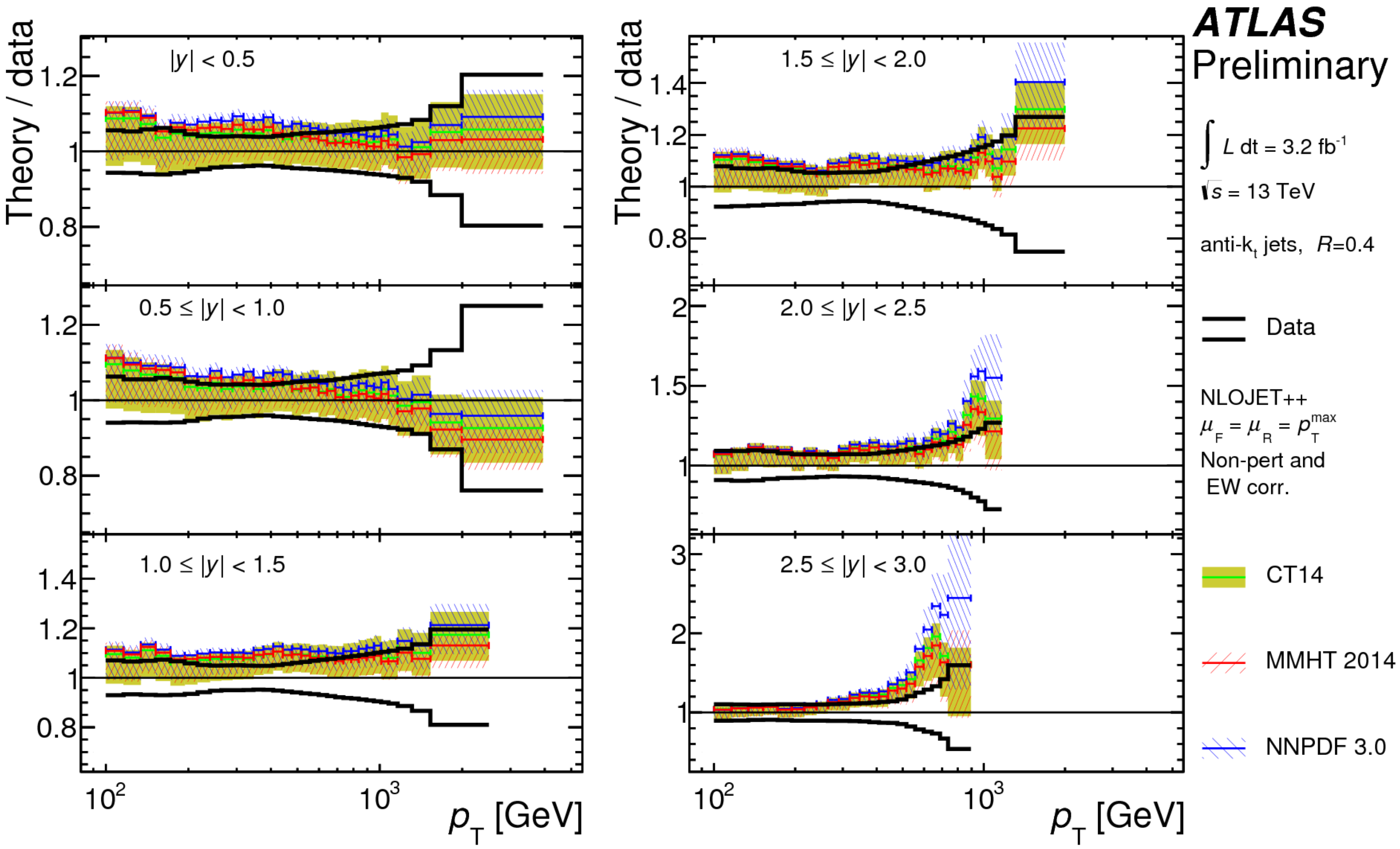
arxiv:1706.03192



- low p_T the level of agreement is very sensitive to non-perturbative effects (10-20%)
- the highest p_T at central rapidities they are typically up to 10–20%
- similar behavior: CT14, NNPDF3.0 and MMHT2014 PDF sets
- HERAPDF2.0 lower than data (300 < p_T < 1000 GeV)

Inclusive jet cross sections

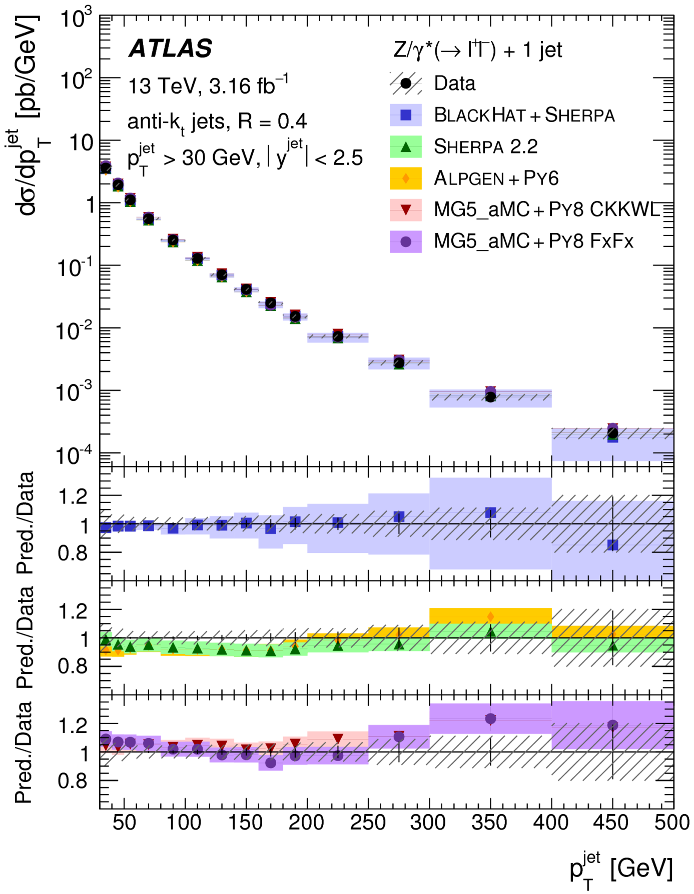
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-092/

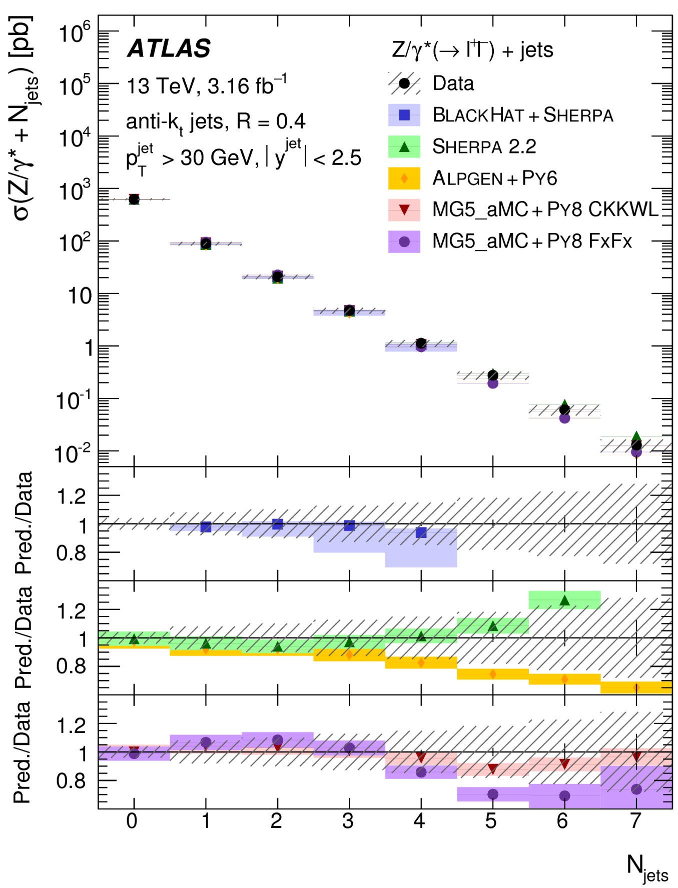


- The behaviour is similar to previous results

Measurements of the production cross section of a *Z* boson + jets

Eur. Phys. J. C77 (2017) 361





- Leptons:

  p_T>25 GeV

  Medium idetintification

  $|\eta|_{electrons}$<2.47

  $|\eta|_{muos}$<2.4

- Jets:

  p_T>30 GeV

  $|y|$<2.5

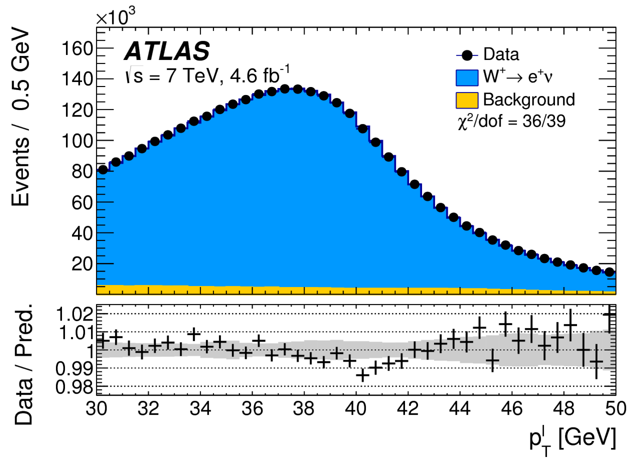
- Agreement with data in range up to p_T=500 GeV within systematic uncertainties
- Measured cross section as a function of the exclusive jet multiplicity shows disagreement for Sherpa,Alpgen+Py6 and MG5_aMC+Py8 FxFx in high jet multiplicity region (where jets are produced by the parton shower are non-negligible)

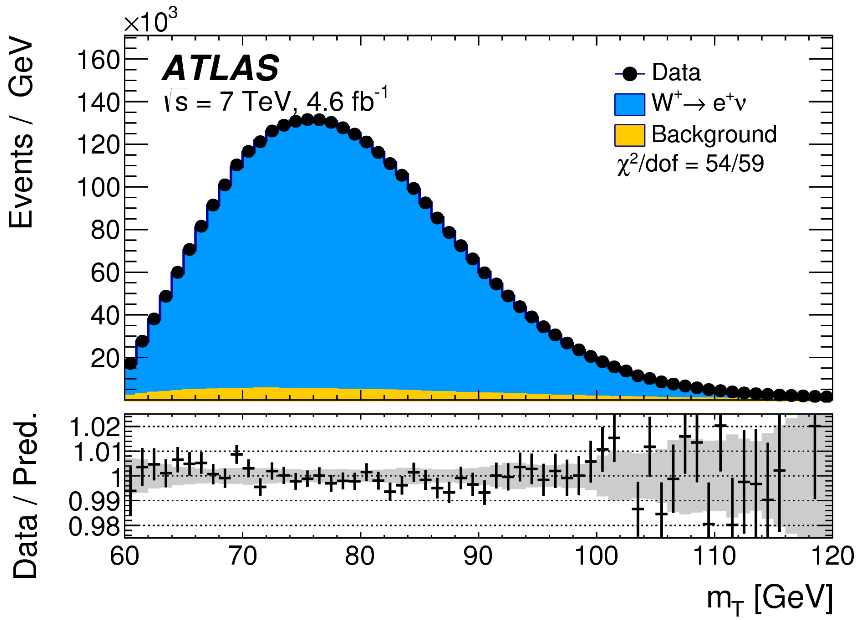
Measurements of W mass

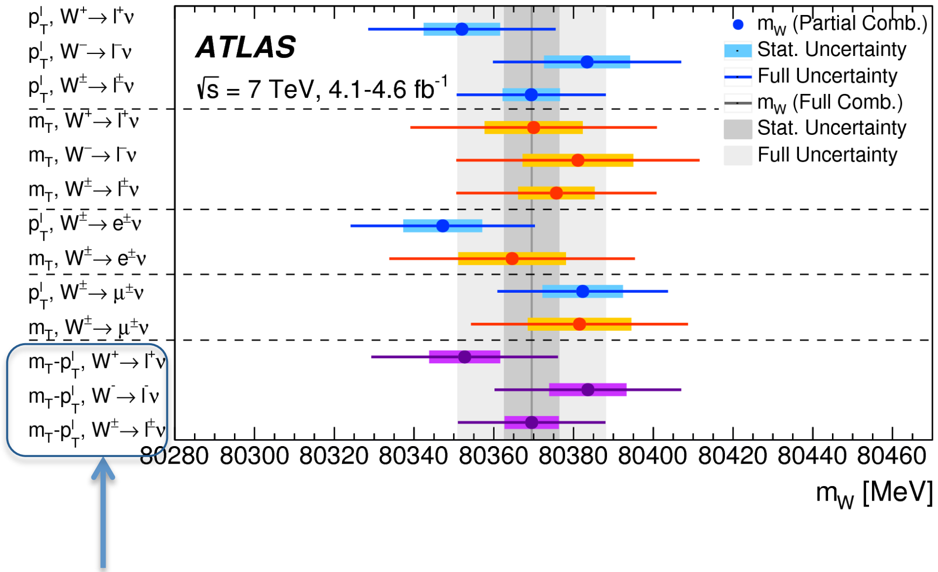
Overview of m_W measurements at ATLAS

arxiv:1701.07240

- The mass of the W boson is determined from fits to the transverse momentum of the charged lepton and to the transverse mass of the W-boson.
- Detector modeling and physics modeling have to be corrected to achieve a precision of 0.01%, which is required by the global electroweak fit.







$$m_W = 80370 \pm 7\,(\text{stat.}) \pm 11\,(\text{exp. syst.}) \pm 14\,(\text{mod. syst.})\ \text{MeV}$$
$$= 80370 \pm 19\ \text{MeV},$$

Measurements of W mass

Overview of systematic uncertainties of the m_W measurements at ATLAS

arxiv:1701.07240

- The systematic uncertainties are estimated separately for each source.
- The fit ranges ($32 < p_T^l < 45$ GeV and $66 < m_T < 99$ GeV) minimise the total expected measurement uncertainty.
- 4 sources:
  - electroweak and QCD corrections
  - calibration of electrons and muons
  - calibration of recoil
  - electroweak, top-quark and multijet background estimation

Decay channel	$W \to e\nu$		$W \to \mu\nu$	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]				
FSR (real)	< 0.1	< 0.1	< 0.1	< 0.1
Pure weak and IFI corrections	3.3	2.5	3.5	2.5
FSR (pair production)	3.6	0.8	4.4	0.8
Total	4.9	2.6	5.6	2.6

W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]						
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_F with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

$\lvert\eta_\ell\rvert$ range	[0.0, 0.6]		[0.6, 1.2]		[1.82, 2.4]		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]								
Energy scale	10.4	10.3	10.8	10.1	16.1	17.1	8.1	8.0
Energy resolution	5.0	6.0	7.3	6.7	10.4	15.5	3.5	5.5
Energy linearity	2.2	4.2	5.8	8.9	8.6	10.6	3.4	5.5
Energy tails	2.3	3.3	2.3	3.3	2.3	3.3	2.3	3.3
Reconstruction efficiency	10.5	8.8	9.9	7.8	14.5	11.0	7.2	6.0
Identification efficiency	10.4	7.7	11.7	8.8	16.7	12.1	7.3	5.6
Trigger and isolation efficiencies	0.2	0.5	0.3	0.5	2.0	2.2	0.8	0.9
Charge mismeasurement	0.2	0.2	0.2	0.2	1.5	1.5	0.1	0.1
Total	19.0	17.5	21.1	19.4	30.7	30.5	14.2	14.3

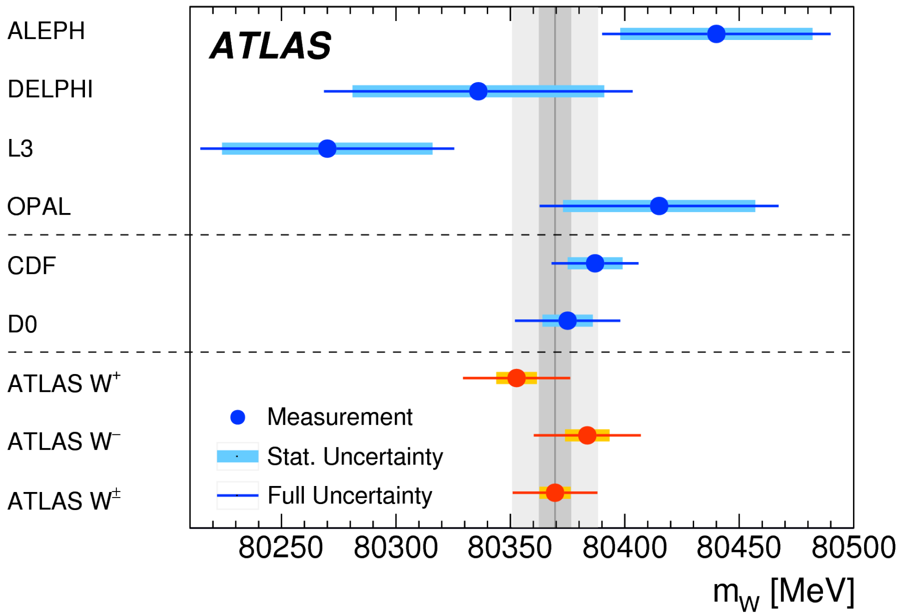
W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]						
$\langle\mu\rangle$ scale factor	0.2	1.0	0.2	1.0	0.2	1.0
$\Sigma\bar{E}_T$ correction	0.9	12.2	1.1	10.2	1.0	11.2
Residual corrections (statistics)	2.0	2.7	2.0	2.7	2.0	2.7
Residual corrections (interpolation)	1.4	3.1	1.4	3.1	1.4	3.1
Residual corrections ($Z \to W$ extrapolation)	0.2	5.8	0.2	4.3	0.2	5.1
Total	2.6	14.2	2.7	11.8	2.6	13.0

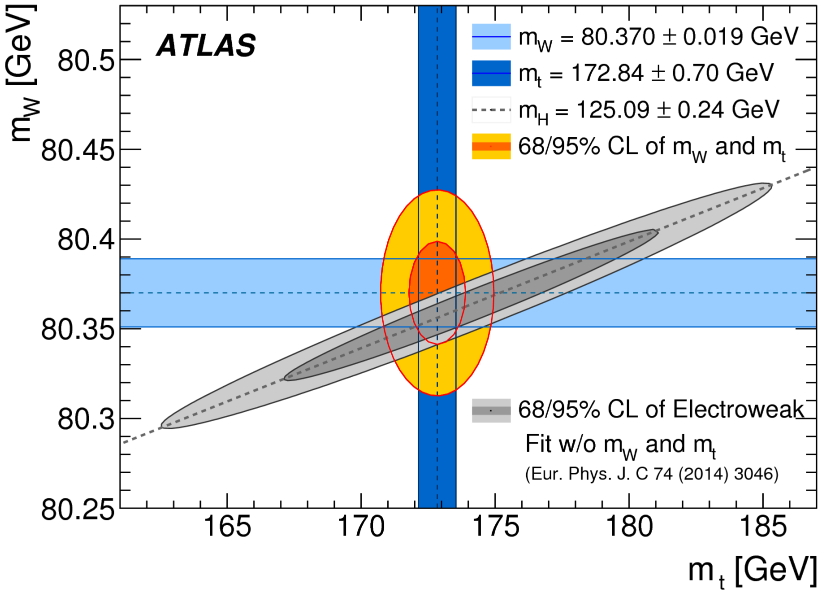
Kinematic distribution	p_T^ℓ				m_T			
Decay channel	$W \to e\nu$		$W \to \mu\nu$		$W \to e\nu$		$W \to \mu\nu$	
W-boson charge	W^+	W^-	W^+	W^-	W^+	W^-	W^+	W^-
δm_W [MeV]								
$W \to \tau\nu$ (fraction, shape)	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.3
$Z \to ee$ (fraction, shape)	3.3	4.8	–	–	4.3	6.4	–	–
$Z \to \mu\mu$ (fraction, shape)	–	–	3.5	4.5	–	–	4.3	5.2
$Z \to \tau\tau$ (fraction, shape)	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.3
WW, WZ, ZZ (fraction)	0.1	0.1	0.1	0.1	0.4	0.4	0.3	0.4
Top (fraction)	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
Multijet (fraction)	3.2	3.6	1.8	2.4	8.1	8.6	3.7	4.6
Multijet (shape)	3.8	3.1	1.6	1.5	8.6	8.0	2.5	2.4
Total	6.0	6.8	4.3	5.3	12.6	13.4	6.2	7.4

Measurements of W mass

M_W = 80370 ± 19 MeV

arxiv:1701.07240





- close to current world average and compatible to current best ones.
- consistent with other results and SM electroweak fit

Z pT mesurement

arxiv:1701.07240

General approach of W boson mass measurement:
Precise measurement of the Z boson production and testing the MC event generators there.
One more important aspect: modeling of the angular coefficients.

The correction procedure is based on the factorisation of the fully differential leptonic Drell-Yan cross-section:

$$\frac{d\sigma}{dp_1\,dp_2} = \left[\frac{d\sigma(m)}{dm}\right]\left[\frac{d\sigma(y)}{dy}\right]\left[\frac{d\sigma(p_T,y)}{dp_T\,dy}\left(\frac{d\sigma(y)}{dy}\right)^{-1}\right]\left[(1+\cos^2\theta)+\sum_{i=0}^{7}A_i(p_T,y)P_i(\cos\theta,\phi)\right]$$

Breit-Wigner

Fixed-order perturbative QCD predictions

Parton Showers

Perturbative QCD

where A_i – angular coefficients (A_i are the ratios of the helicity cross-sections for Z/γ* relative to unpolarized productions):

$$\left\langle \frac{1}{2}(1-3\cos^2\theta) \right\rangle = \frac{3}{20}\left(A_0 - \frac{2}{3}\right)$$

$$\langle \sin 2\theta \, \cos\phi \rangle = \frac{1}{5} A_1$$

$$\langle \sin^2\theta \, \cos 2\phi \rangle = \frac{1}{10} A_2$$

$$\langle \sin\theta \, \cos\phi \rangle = \frac{1}{4} A_3$$

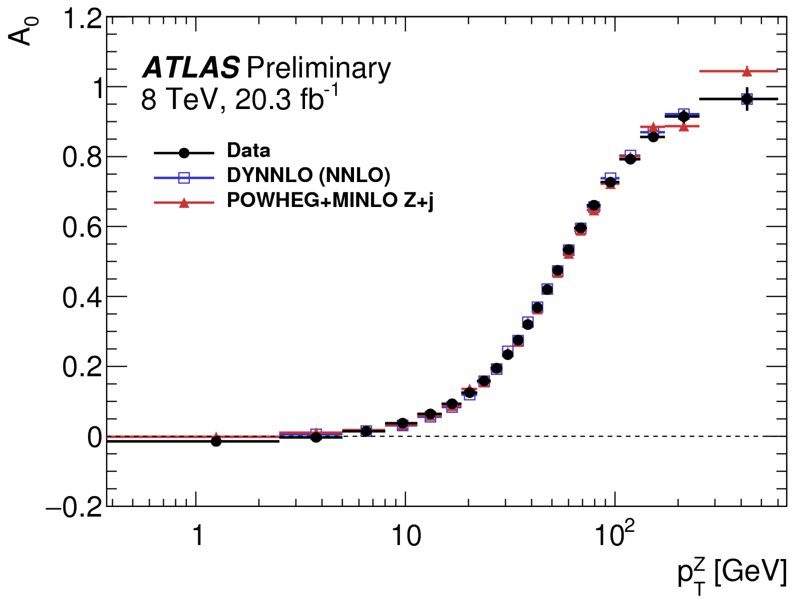
$$\langle \cos\theta \rangle = \frac{1}{4} A_4$$

$$\langle \sin^2\theta \, \sin 2\phi \rangle = \frac{1}{5} A_5$$

$$\langle \sin 2\theta \, \sin\phi \rangle = \frac{1}{5} A_6$$

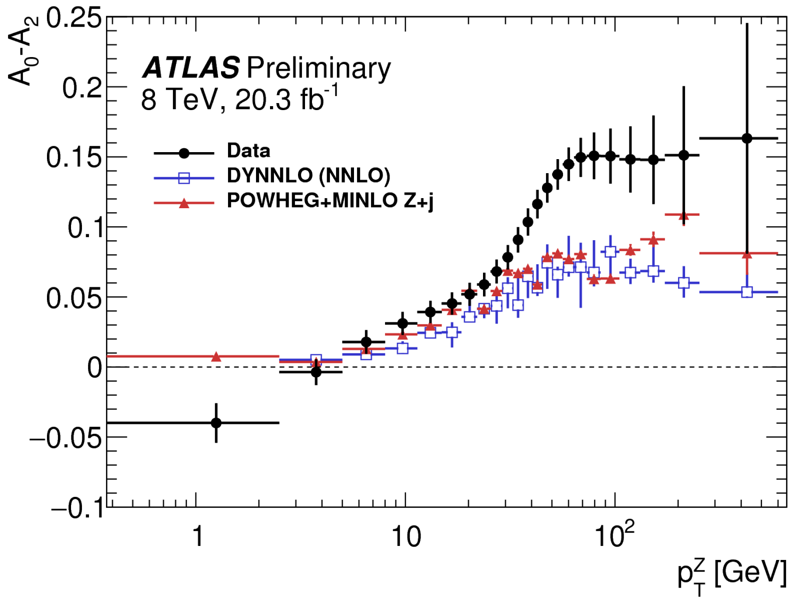
$$\langle \sin\theta \, \sin\phi \rangle = \frac{1}{4} A_7$$

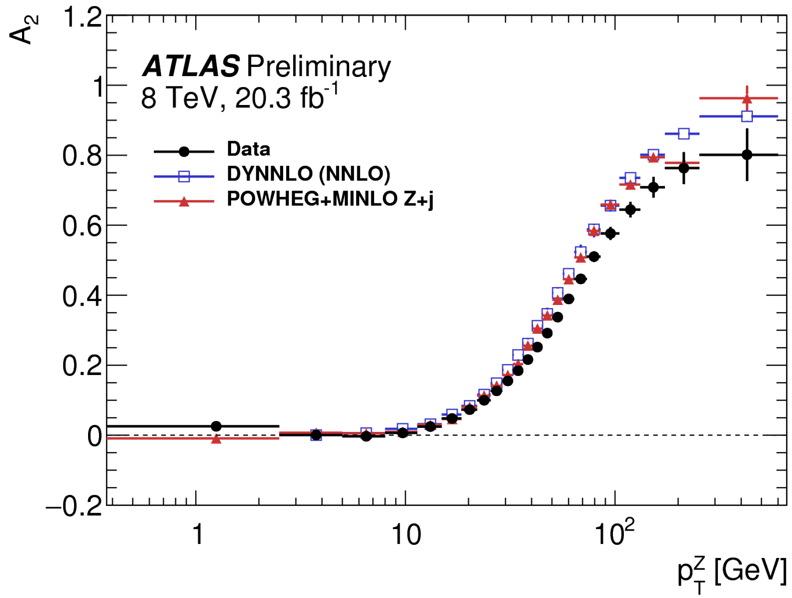
Measurement of angular coefficients



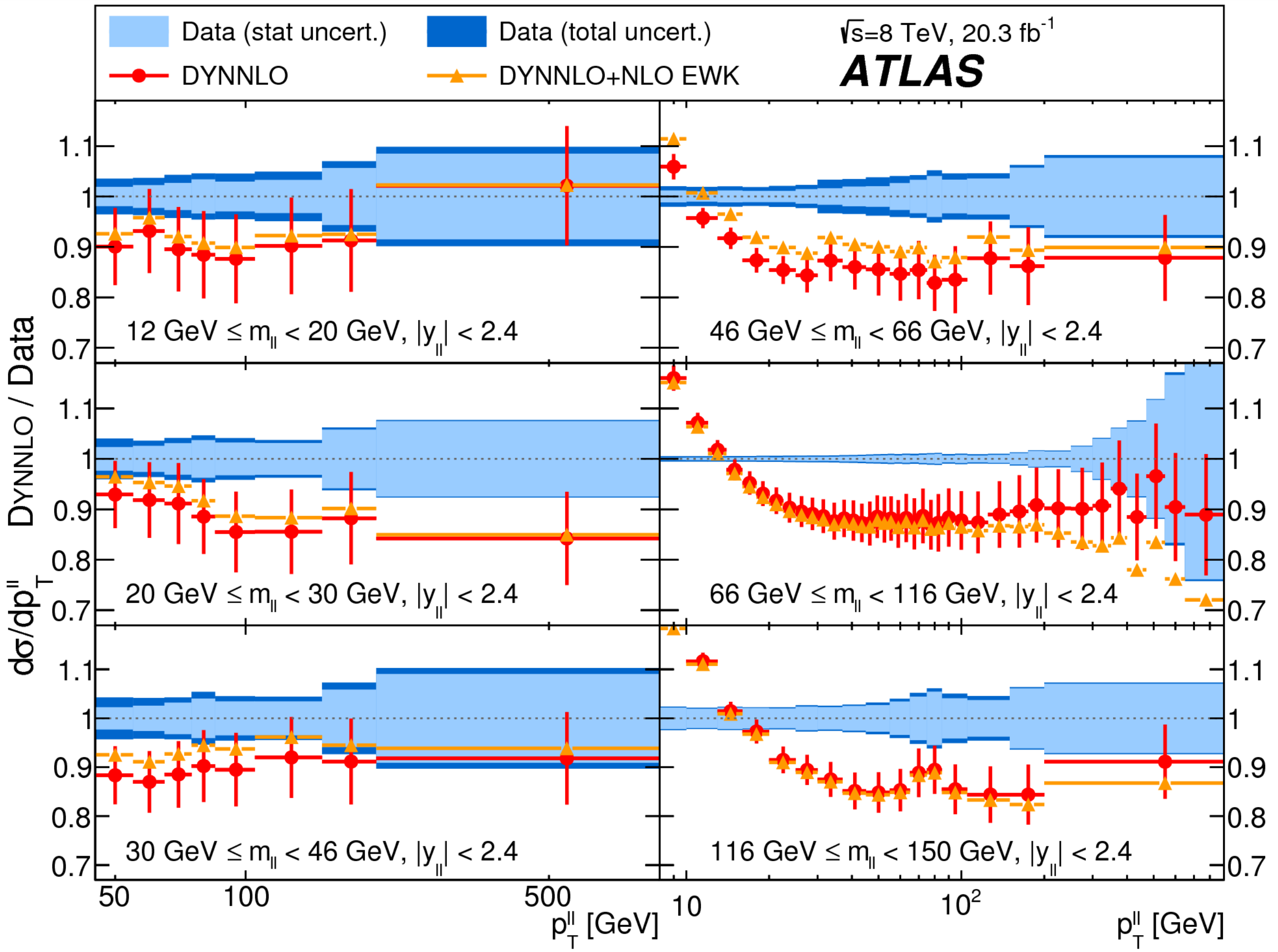
JHEP08(2016)159

- A_0-A_2 (Lam-Tung) sensitive to higher order corrections (significant deviation from NNLO predictions)





Precision p_T Z-boson measurement

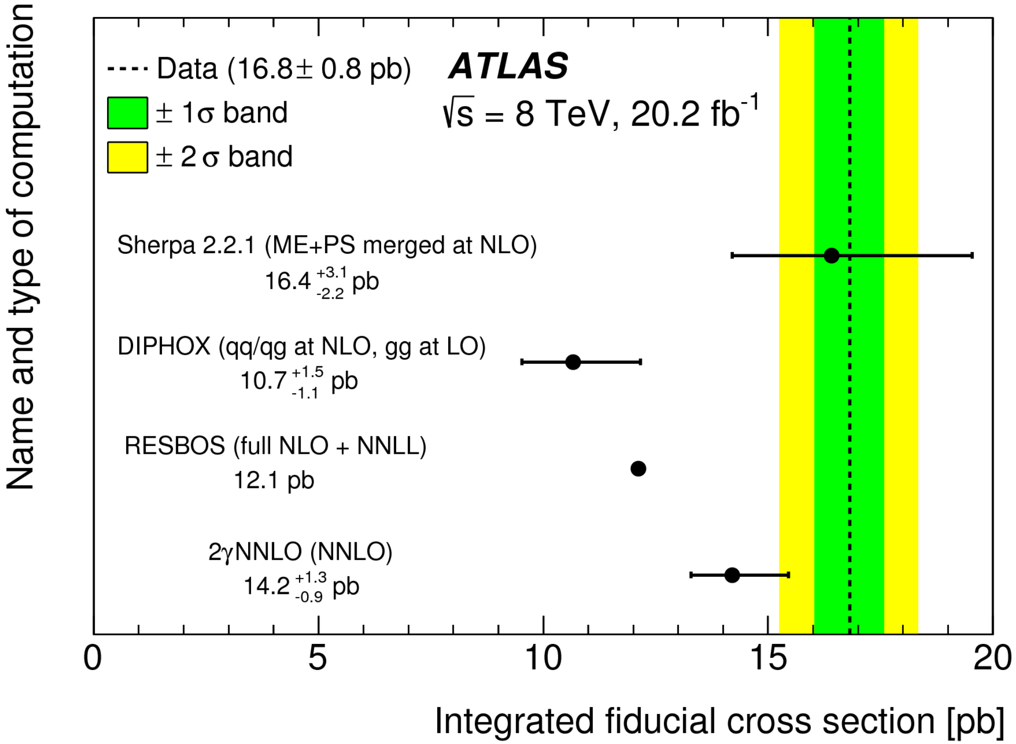


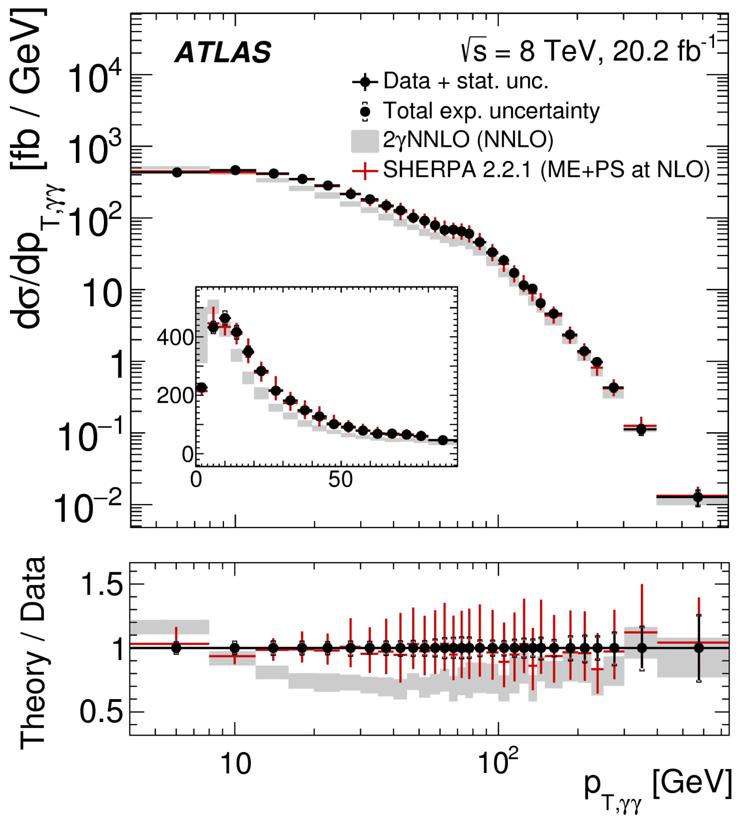
arxiv:1512.02192

- predictions are not expected to describe the shape of the data for low values of p^{ll}_T due to effect soft-gluon emissions
- no significant changes due to NLO EWK correction vs the difference between the predictions and the data

Isolated photon pair production

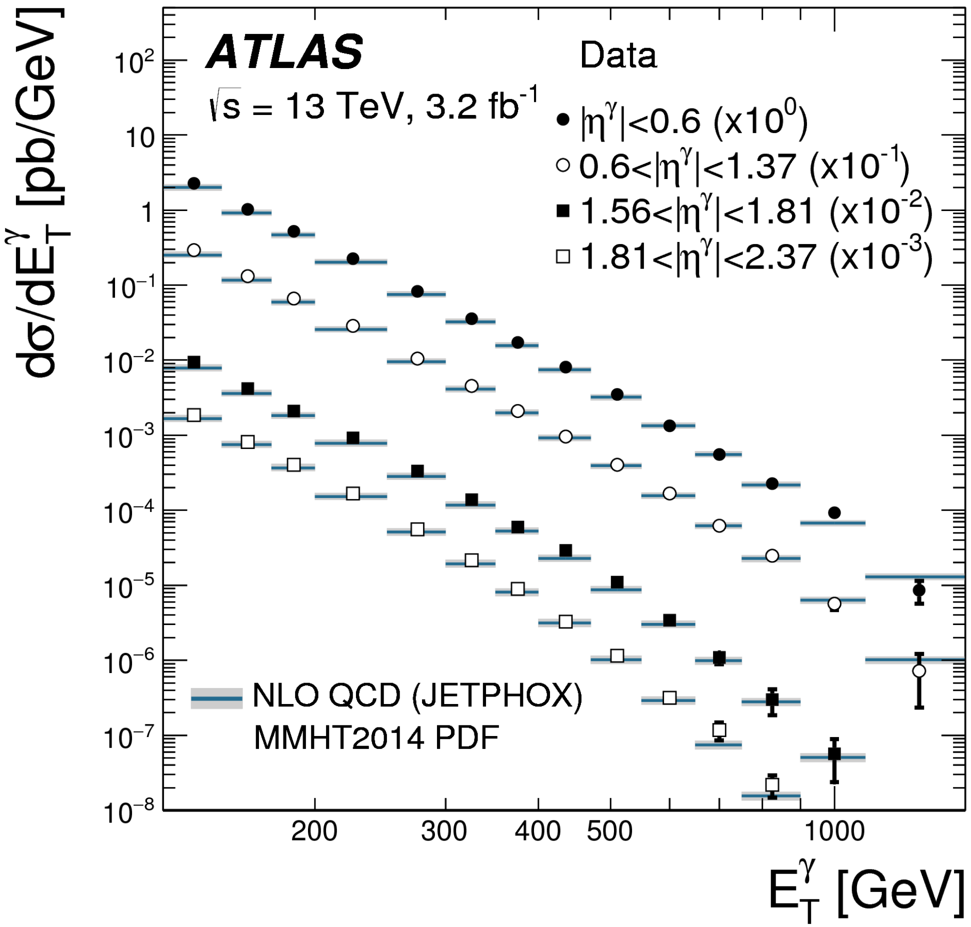
arxiv:1704.03839



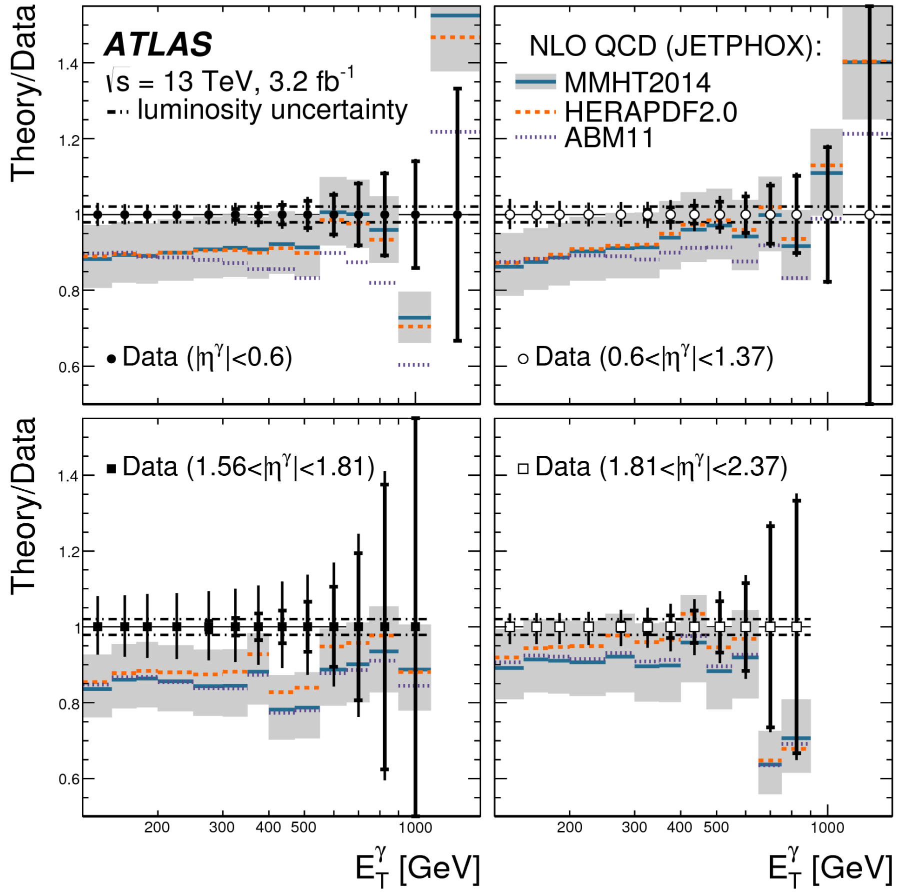


- The prediction from Diphox (NLO) - 36% lower (>2 standard deviations)
- The prediction from Resbos (NLO + NNLO) -28%
- The prediction from 2γNNLO (NNLO) – 16%
- The prediction from Sherpa 2.2.1 (ME+PS at NLO) is in agreement with the data.

Inclusive isolated-photon production

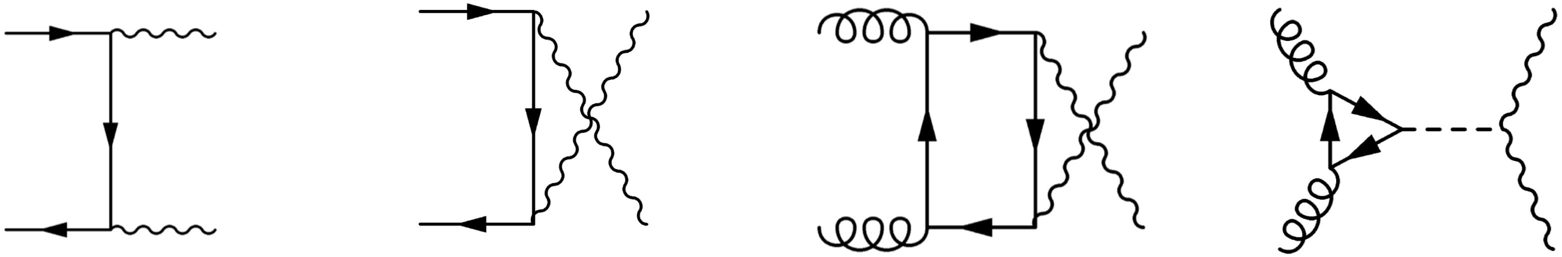


[arxiv:1701.06882](https://arxiv.org/abs/1701.06882)



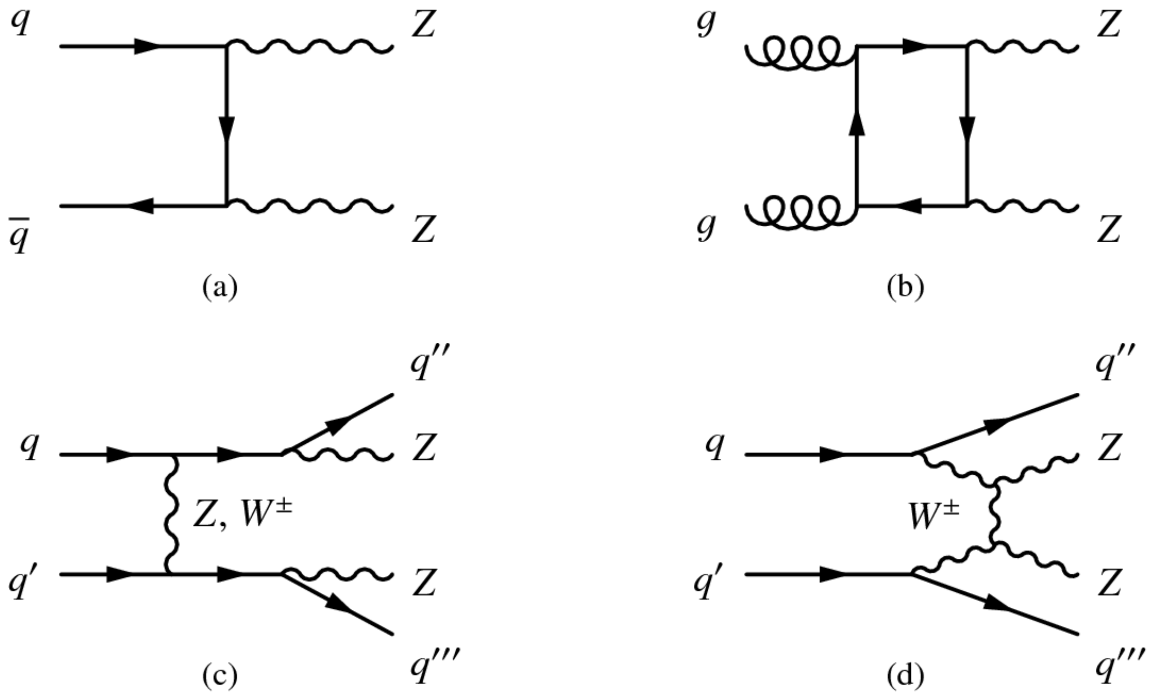
- NLO perturbative QCD and Monte Carlo event-generator predictions provide an adequate description of the data

Dibosons production



(a) t-channel (b) u-channel (e) (f)

Lowest-order Feynman diagrams for *ZZ* production:
(a) and (b) - contribute to ZZ producton cross-sections
(e) and (f) - one-loop contributions to *ZZ* production via gluon pairs

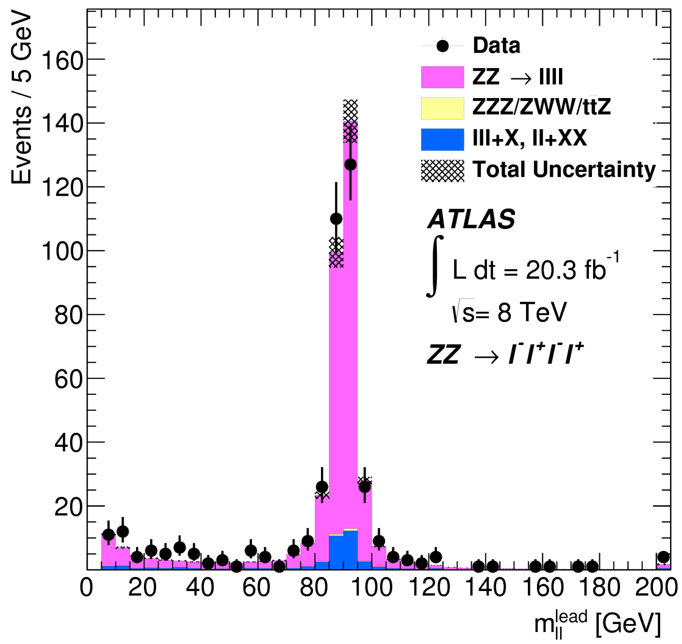


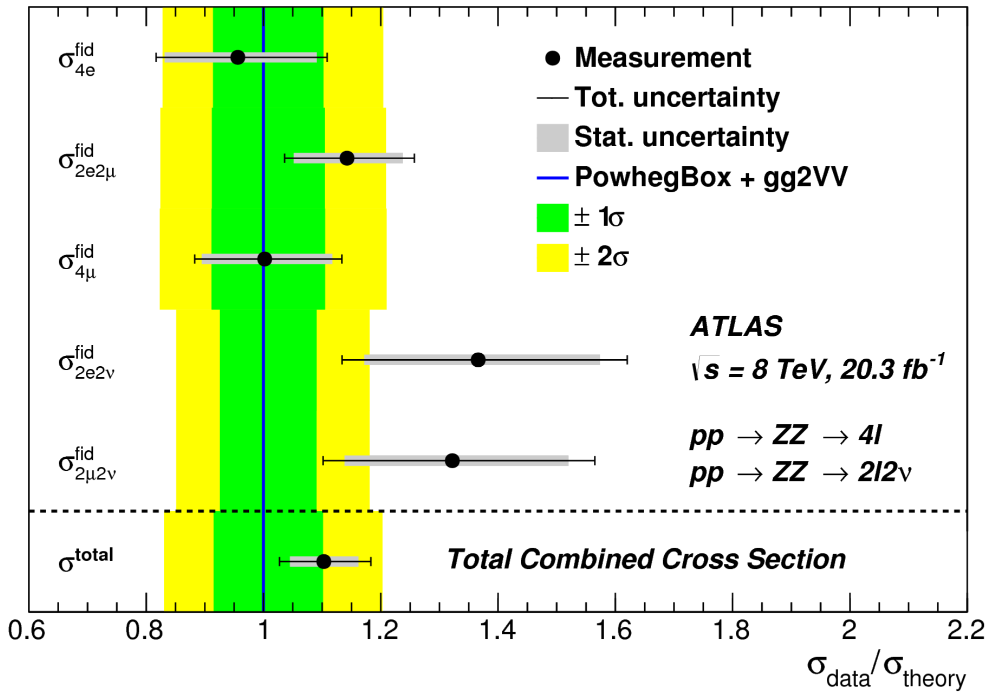
Leading-order SM Feynman diagramsfor ZZ production:

(a) qq-initiated
(b) gg-initiated
(c) electroweak *ZZ j j* production
(d) electroweak *ZZ j j* production
via weak-boson scattering

Measurement of the ZZ production cross section

arXiv:1610.07585

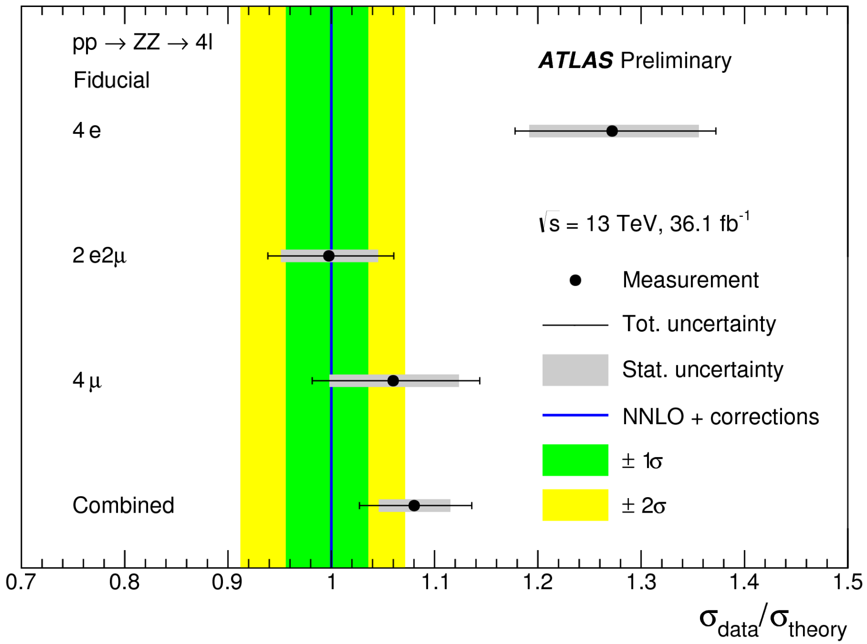


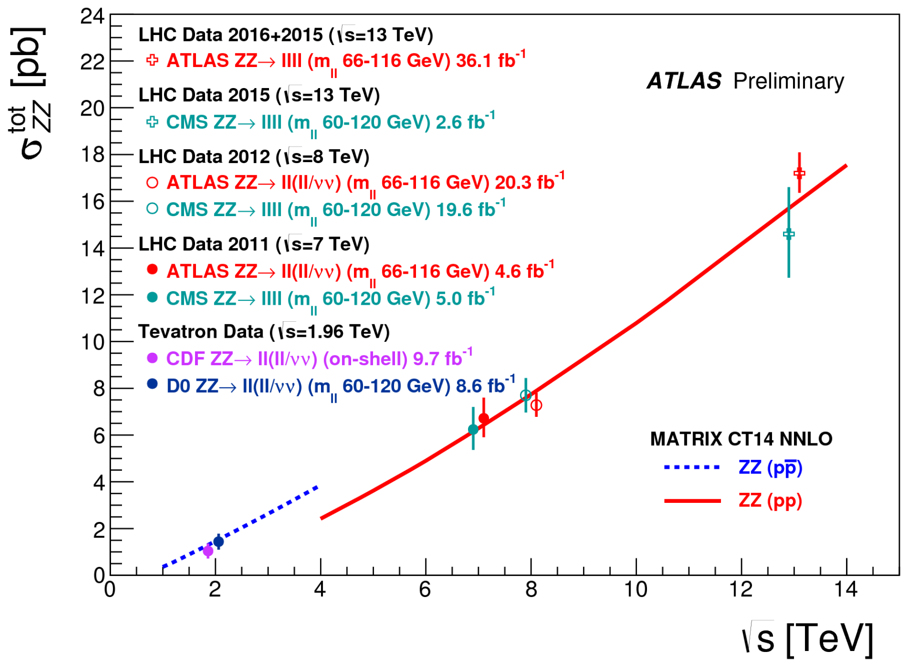


- The cross section: 7.3±0.4(stat.) ±0.3(syst.) ±0.2(lumi) pb
- The result is consistent with latest SM predictions (that include high-order QCD effects)

Measurement of the *ZZ* production cross section

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-031/





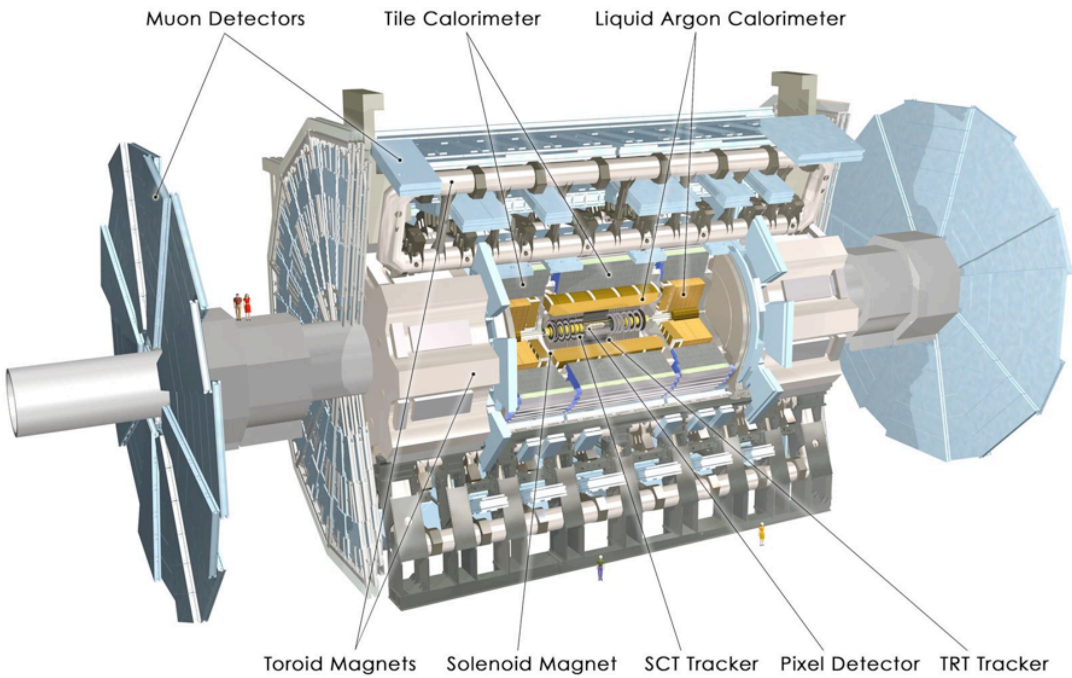
- The cross section: $46.4 \pm 1.5\ (\text{stat.}) \pm 1.0\ (\text{syst.})^{+1.5}_{-1.4}\ (\text{lumi})$ pb
- The result is consistent with latest SM predictions

Conclusions

- A lot of QCD and electroweak measurement were done by ATLAS collaboration.
- Only small part shown today (the latest results)!
- The presented results are consistent with theoretical predictions
- A lot of analysis are ongoing using lager statistic available (@13 TeV)

BACKUP

The ATLAS detector



- Multi-purpose particle detector at the LHC
- High-efficiency particle reconstruction and identification

Recorded data with ATLAS detector:

- 7 TeV – 4.6 fb^{-1}
- 8 TeV – 20.2 fb^{-1}
- 13 TeV – 36.1 fb^{-1}