Results on EW gauge boson and jet production

Elzbieta Richter-Was

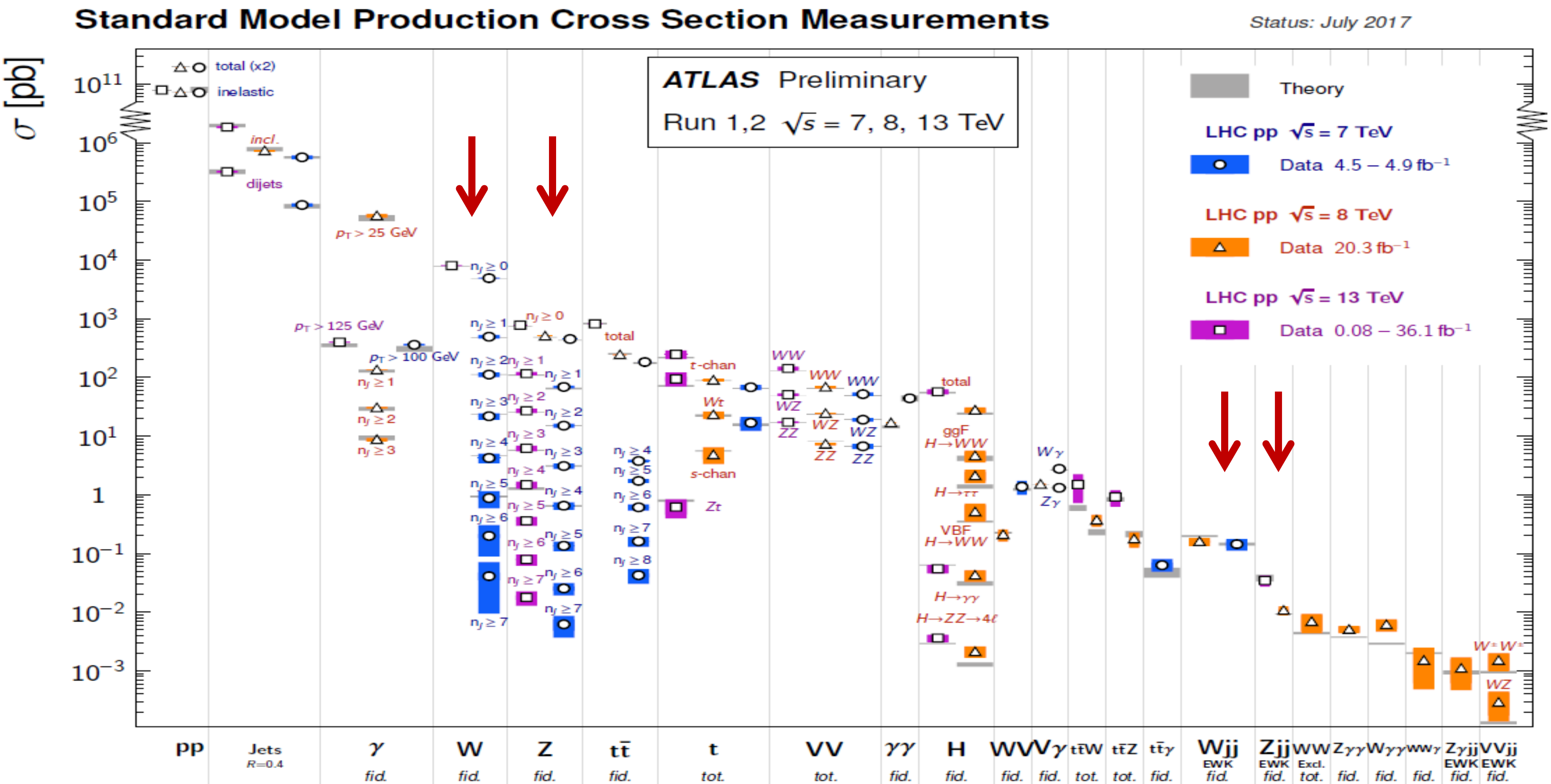
Jagiellonian University, Cracow, Poland

- „Classic" V+jets measurements (V = W, Z)
- Exploring phase-space: VBF-like, V+j collinear
- V+HF jets
- Learning QCD dynamics from angular coefficients
- Impact on PDFs

Disclaimers: I show mostly ATLAS results and it is only selection of what was published during spring/summer 2017!!

Landscape: Measurements and Predictions

Impressive data-theory agreement.



Measurements: probe different aspects of pQCD calculations, crucial for understanding backgrounds to Higgs and New Physics searches.

Landscape: Theory predictions

Monte Carlo's (+different PS matching schemes: MLM, CKKWL, FxFx)

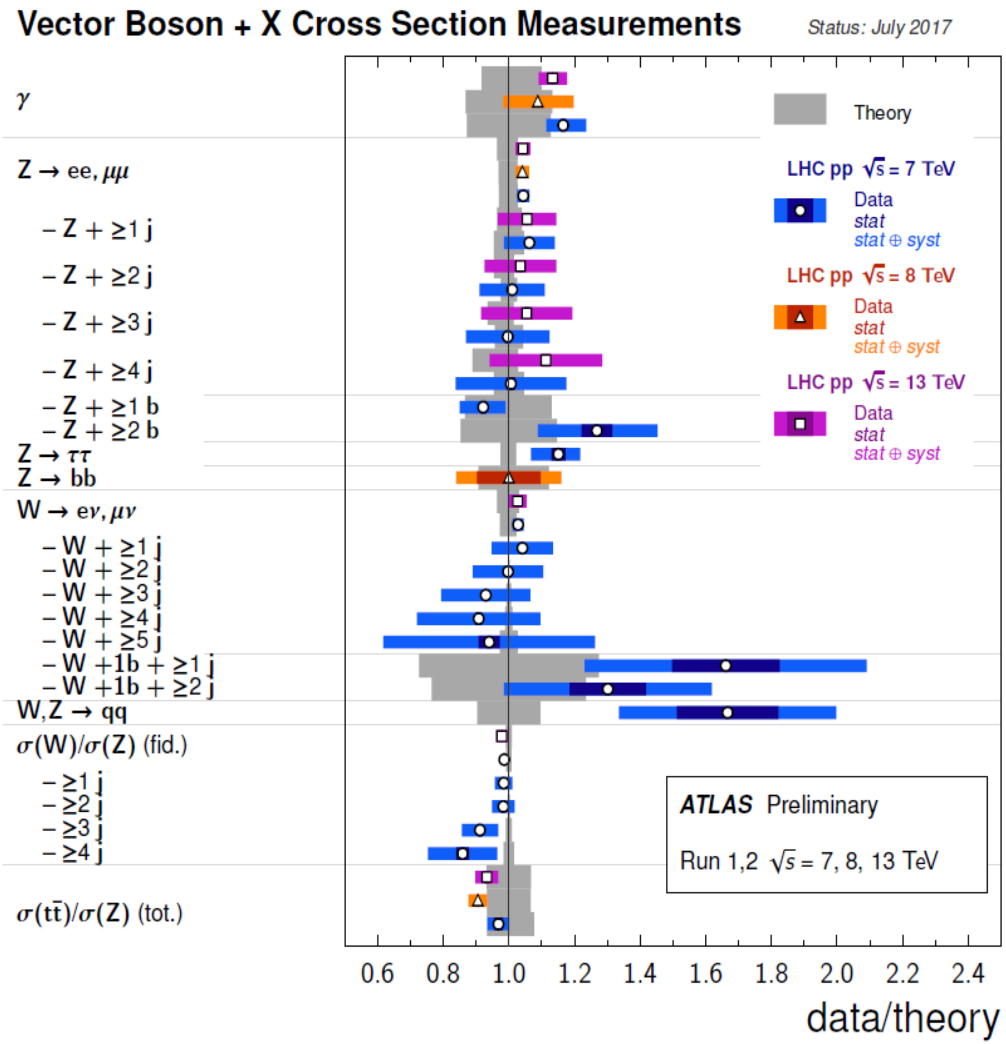
pQCD accuracy	MC versions
LO Matrix Element (M.E.) + Parton Shower (P.S.)	Pythia6, Pythia8, Herwig
Multi-parton (Np) LO + P.S.	Alpgen (Np $\leq$ 5), Sherpa 1.4 (Np $\leq$ 4), MadGraph (Np $\leq$ 4)
[N]NLO for lowest multiplicity M.E. + P.S.	aMC@NLO, Powheg [NNLOPS], Herwig++ , Herwig7
NLO for lowest multiplicity M.E., LO for other multiplicities + P.S.	Sherpa 1.4 MEnloPS, Powheg MiNLO MadGraph5_aMC@NLO (NLO Np $\leq$ 2)
NLO for higher parton multiplicity M.E. + P.S	aMC@NLO, Sherpa 2.x (NLO Np $\leq$2, LO ME Np $\leq$3,4) MEPS@NLO
NNLO for Z+1j	NNLOjet

Fixed Order Calculations

pQCD accuracy	Program
NLO for Z+1j	DYNNLO (LO EW), FEWZ (NLO EW), Black-Hat (Np $\leq$ 4)
NNLO	(NLO) MCFM+N-jetti , HEJ (HO Resum)

N(N)LO QCD is slowly emerging as a standard. Higher order EW corrections not yet included in the main-stream MC's.

„Classic" V+jets measurements



Production dominated by strong interactions:

- **Precision tests of pQCD**
- **Validation of matrix element (ME) and parton shower (PS) MCs**
- **Impacts understanding of PDFs**
- **Also probes regions relevant to BSM searches.**

„Classic" V+jets measurements mostly done @7 TeV and now being redone @13TeV (not full lumi yet, larger uncertainties). V+ heavy-flavour jets ongoing @8TeV.

„Classic" V+jets measurement

Detector level:

- W/Z clean signatures in leptonic decay chanels
  - Trigger events on charged leptons
  - Often both e, μ channels, useful for cross-check and constraining uncertainties
  - Selection by cuts on inv. Mass(Z) or m_T (W), missing E_T(W)
- Background contamination: small for Z+jets; larger (could be overhelming) for W+jets
  - multi-jet: 5-15% (W+jets), extracted with data-driven techniques
  - ttbar: ~0% (1 jet) – 20%(Z+6 jets) – 80% (W+ 6jets) Estimated by MC or in data-driven way, suppressed by b-jet veto

Particle Level:

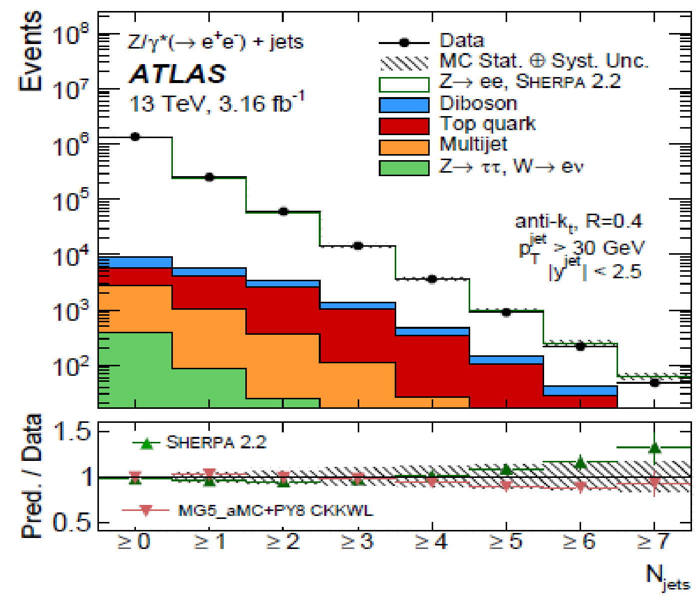
unfolding with MC corrects for detector effects; leptons „dressed" with QED FSR

Systematic uncertainties:

dominated by jet energy scale and background (on W)

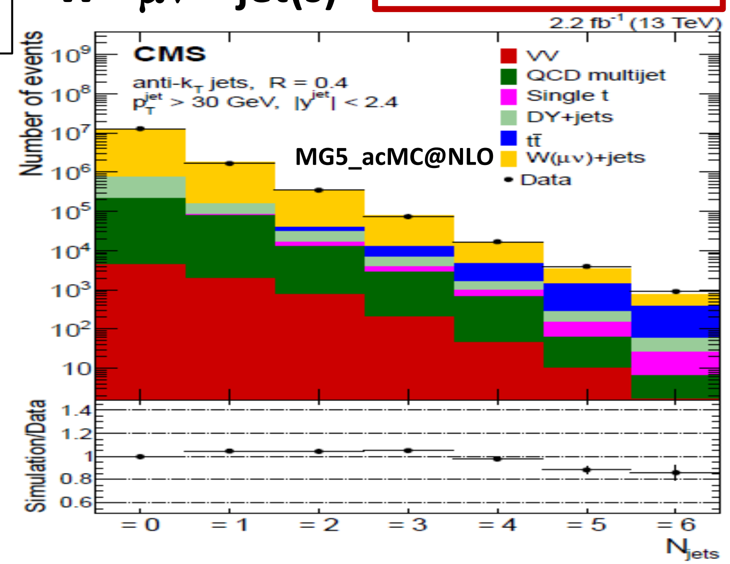
Z->ee + jet(s)

EPJ C77 (2017) 361



W->$\mu\nu$ + jet(s)

arXiv:1707.05979



EPJC77 (2017) 361
ATLAS

	Relative uncertainty in $\sigma(Z(\to \ell^+\ell^-) + \geq N_{jets})$ [%]							
	$Z \to e^+e^-$							
Systematic source	$+\geq 0$ jets	$+\geq 1$ jets	$+\geq 2$ jets	$+\geq 3$ jets	$+\geq 4$ jets	$+\geq 5$ jets	$+\geq 6$ jets	$+\geq 7$ jets
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

ATLAS: Z+jets@13 TeV (3.2 fb^{-1})

Theory predictions:

- **Different MC's (LO, NLO) and maching schemes (CKKW-L, FxFx)**
- **Mixture of MC and Fixed Order: BlackHat+Sherpa**

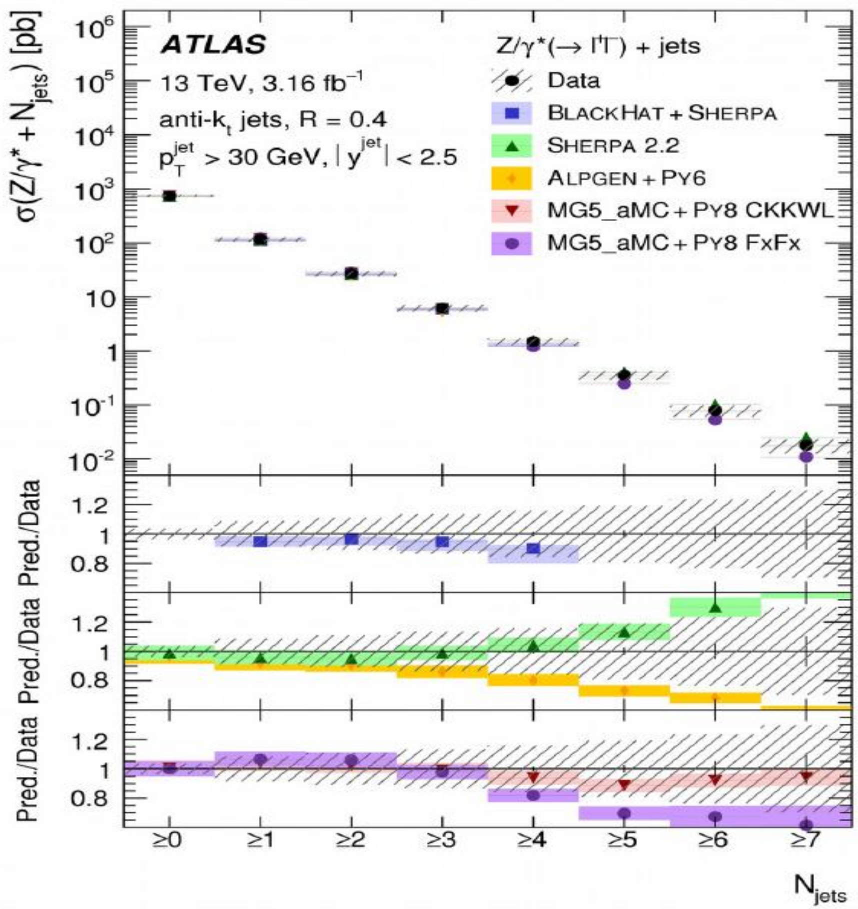
Uncertainties on predictions:

- **5% uncertainty on all**
- **PDFs and scale variations for BlackHat+Sherpa**

N_{jets}:
LO MG5_aMC+Py8 CKKWL shows good agreement
LO Alpgen+Py6, NLO Sherpa 2.2, NLO MG5_aMC+Py8 FxFx systematic trend deviating from data. Agreement reasonable up to 3 jets.

Njetti *(NNLO@1j)*
BlackHat+Sherpa *(FO NLO@4j)*
Sherpa2.2 (*NLO@2j LO@4j)*
Alpgen+Pythia8 *(LO@5j)*
MG5_aMC+Py8 CKKW-L *(LO@4j)*
MG5_aMC+Py8 FxFx *(NLO@2j)*

EPJ C77 (2017) 361

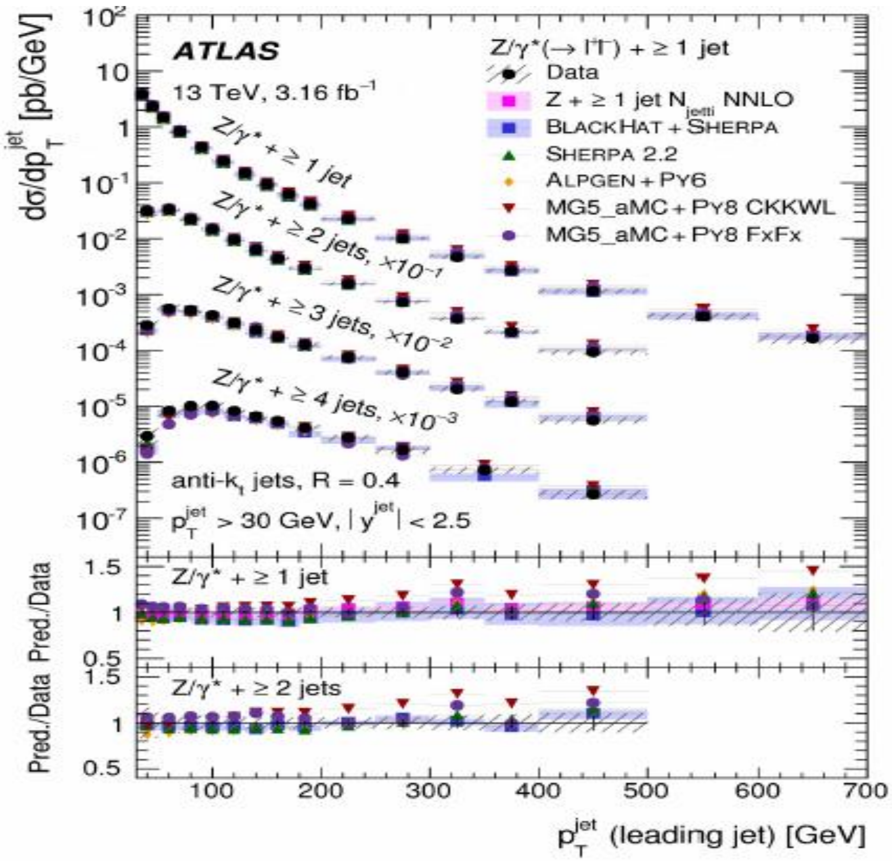


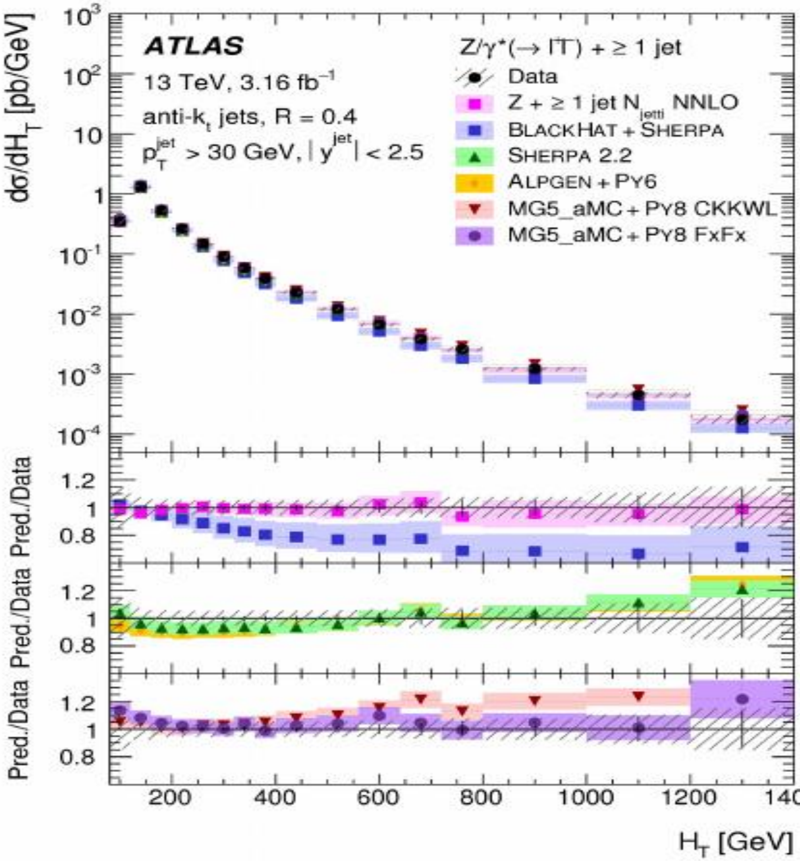
ATLAS: Z+jets@13 TeV

EPJ C77 (2017) 361

pT_{jet}:
LO MG5_aMC+Py8 CKKWL too hard jet pT spectrum (dynamic scale used)
LO Alpgen+Py6, NLO Sherpa 2.2, NLO BlackHat+Sherpa, Njetti NNLO shows good agreement

H_T = sum pT leptons and jets
LO MG5_aMC+Py8 CKKWL overpredicts at large H_T
LO Alpgen+Py6, NLO Sherpa 2.2 agree
NLO BlackHat+Sherpa underpredicts while Njetti NNLO recovers agreement.





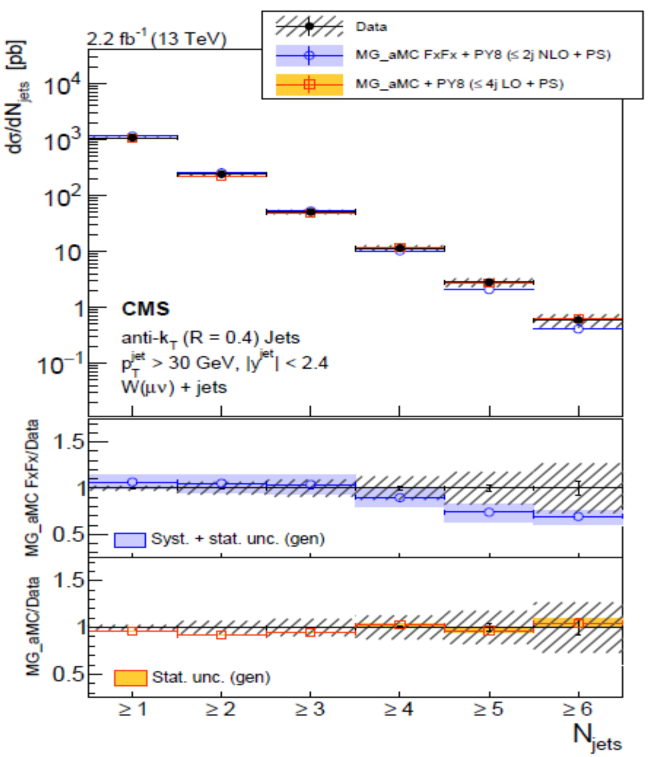
CMS: W+jets@13 TeV (2.2 fb^{-1})

arXiv:1707.05979

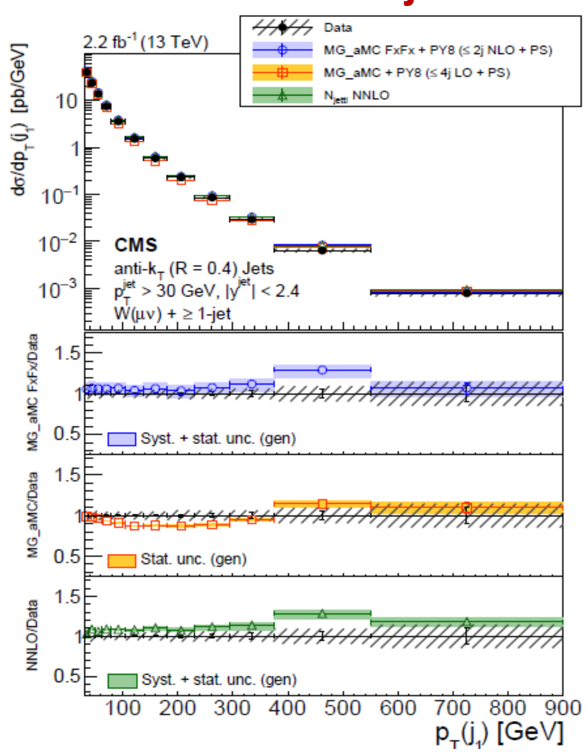
Measurements using W->$\mu\nu$ decay mode. Background-subtracted data unfolded and compared with MC predictions on several kinematical variables.

Dominant syst from jet energy-scale: 1-25% for jet multiplicity 1-6.

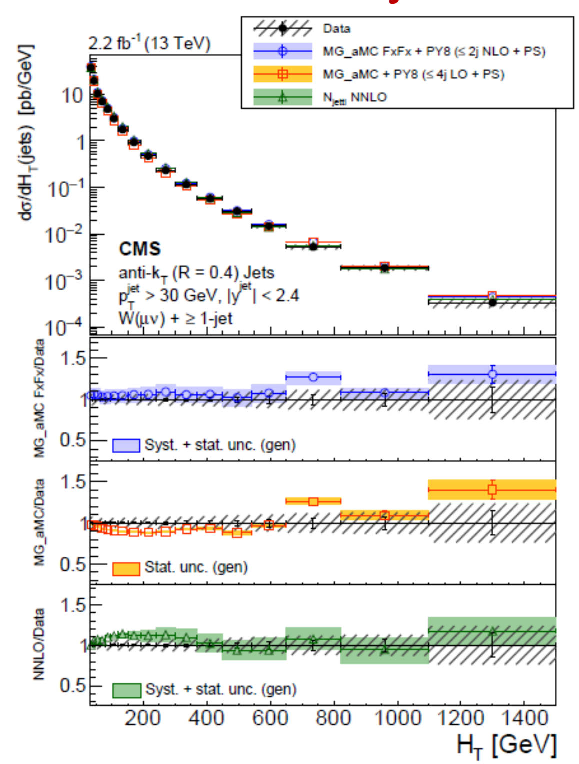
MG_aMC (LO) underestimates data at low and moderate p_T of leading jet and H_T.
MG_aMC FxFx NLO and Njetti NNLO performs better for leading jet p_T and H_T.



W + >= 1 j



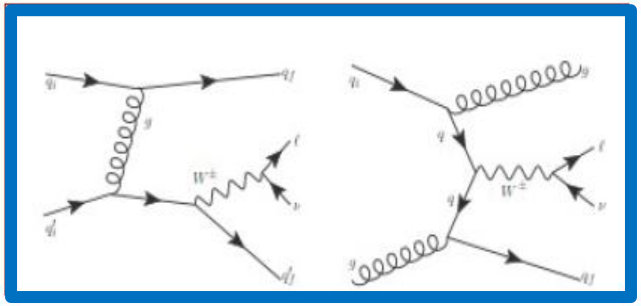
W + >= 1 j



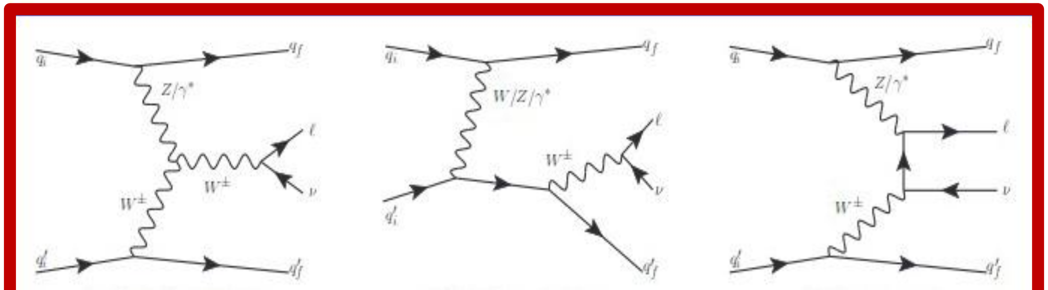
Exploring phase-space

- **Now focus more on regions interesting/accesible in Run II**
  - **V-jet collinear: regions where pQCD could not work and mimic boosted signatures sensitive to New Physics**
  - **Enhanced EW-production: important to understand Higgs and BSM backgrounds.**

QCD production



EW production



(a) Vector boson fusion (b) W bremsstrahlung (c) Non-resonant

- **EW production is roughly 10 times smaller than QCD production.**
- **To enhance EW component to 15-40%: large Δy_{jj}, m_{jj}, p_T^{jet}; lepton(s) in the central region or p_T balance; low n_{jets} in the gap region between leading jets.**

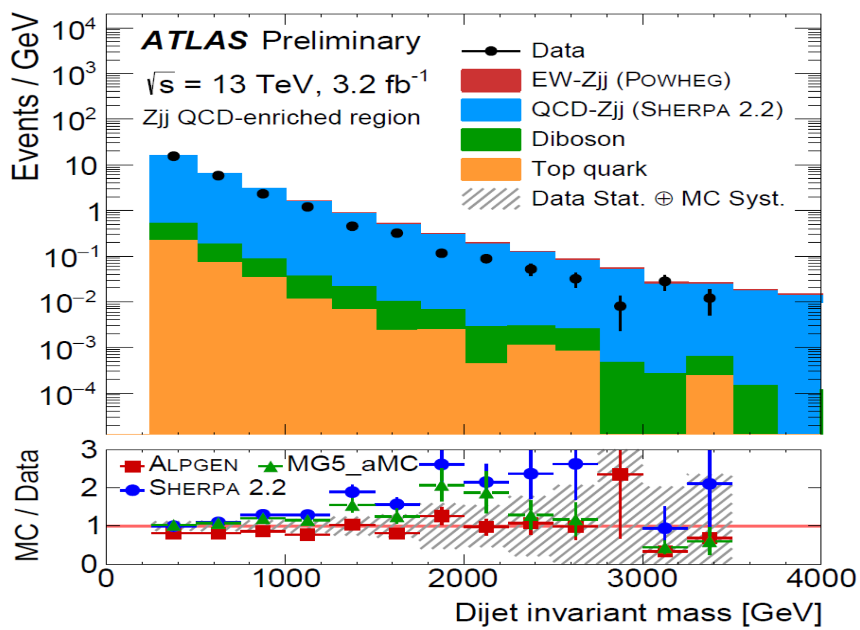
NEW ATLAS: QCD + EW Z+jets @ 13 TeV (3.2 fb^{-1})

CERN-EP-2017-115

Analysis performed in EW-enriched and QCD-enriched regions. Fits to templates in the EW-enriched region to measure fiducial cross-section.

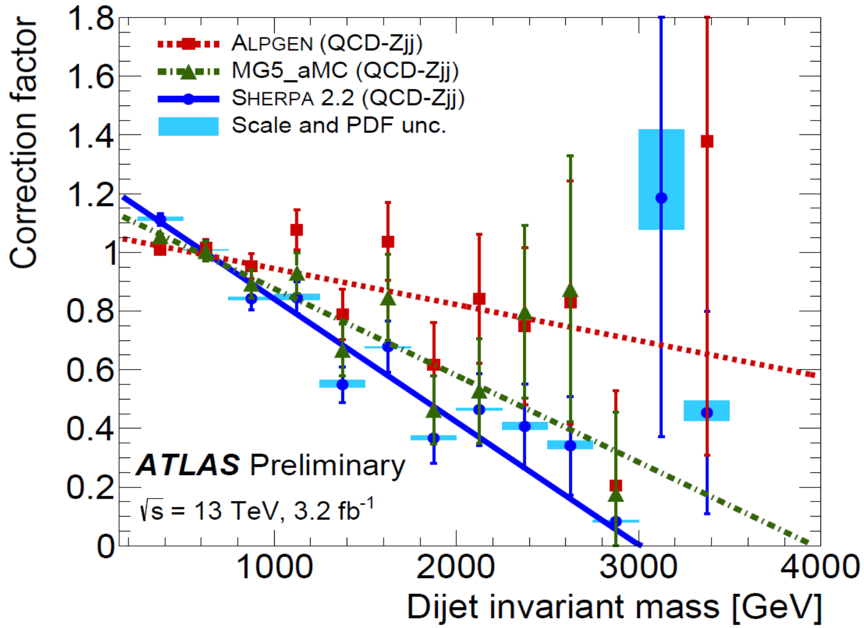
QCD Zjj simulated with Alpgen 2, Sherpa 2.2 and MG5_aMC, EW Zjj with Powheg;

Zjj QCD-enriched region



Zjj QCD largely mismodelled by Sherpa 2.2 and MG5_aMC at high m_{jj} in QCD enriched region;

Data-derived correction factors



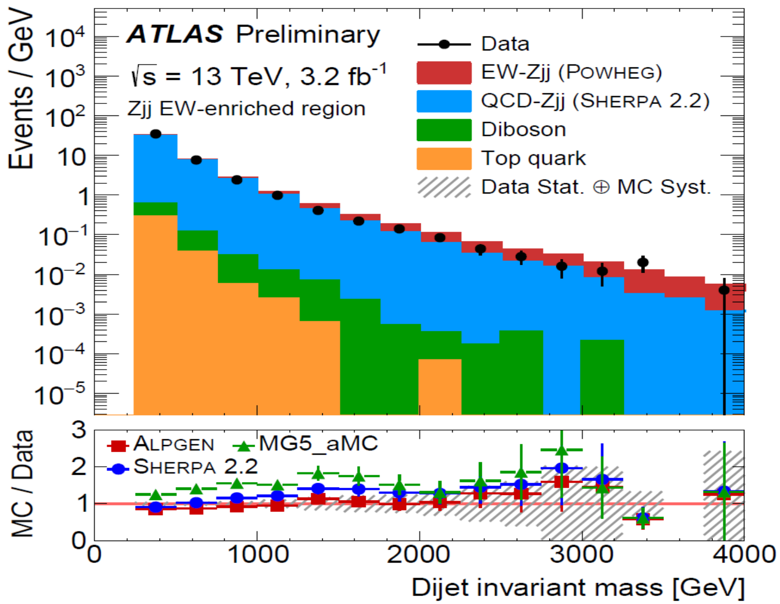
Data-driven correction factors to QCD Zjj templates before fitting QCD+EW Zjj in EW-enrichted region.

ATLAS: QCD + EW Z+jets @ 13 TeV (3.2 fb^{-1})

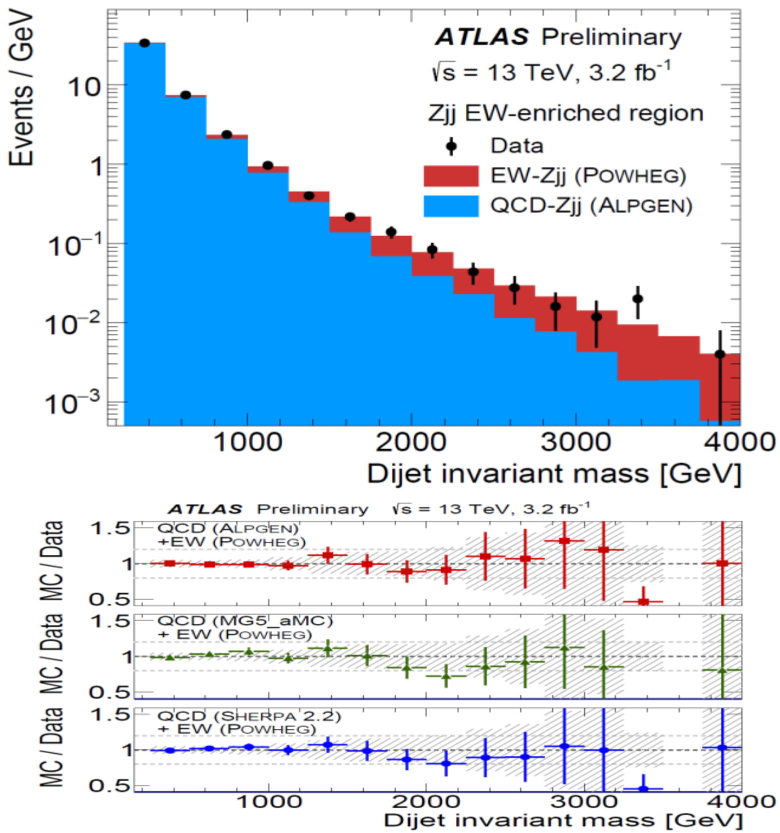
CERN-EP-2017-115

Analysis performed in EW-enriched and QCD-enriched regions. Fits to templates in the EW-enriched region to measure fiducial cross-section.

Zjj EW-enriched region (before corrections)



Post-fit Zjj EW-enriched region (after corrections and bgd subract.)

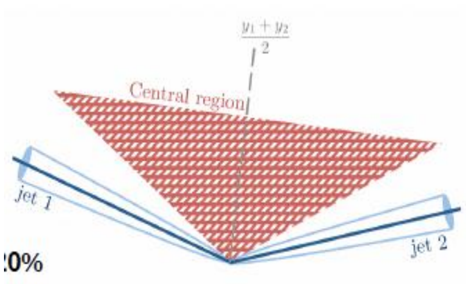


Inclusive Zjj cross-sections measured in six different fiducial regions with varying EW Zjj fractions.

ATLAS: QCD + EW W+jets @7, 8 TeV

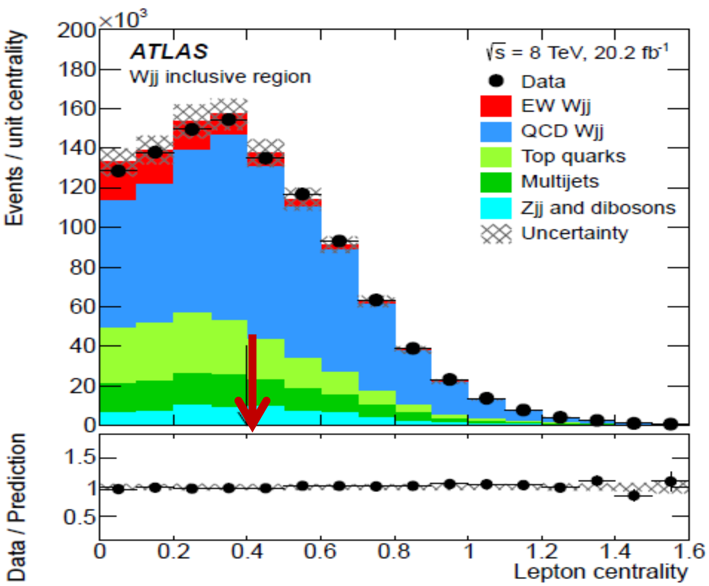
Eur. Phys. J. C77 (2017) 474

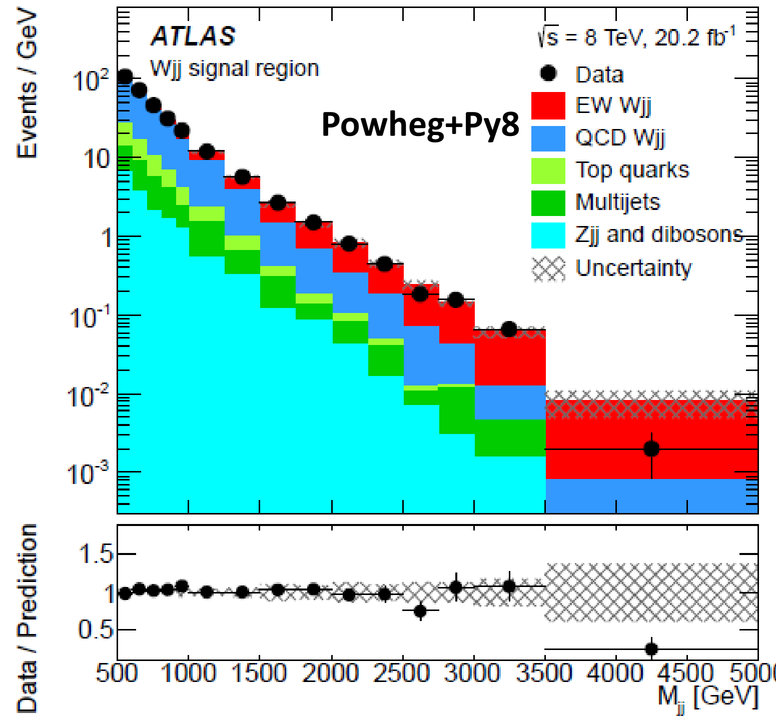
EW signal region defined by centrality vs tagging jets



$$C_{\ell\,(j)} \equiv \left| \frac{y_{\ell\,(j)} - \frac{y_1+y_2}{2}}{y_1 - y_2} \right| < 0.4$$

Signal region:
$N_{lep}=1$, $N_{jet}=0$
Enhanced EW Wjj
to 15-20%



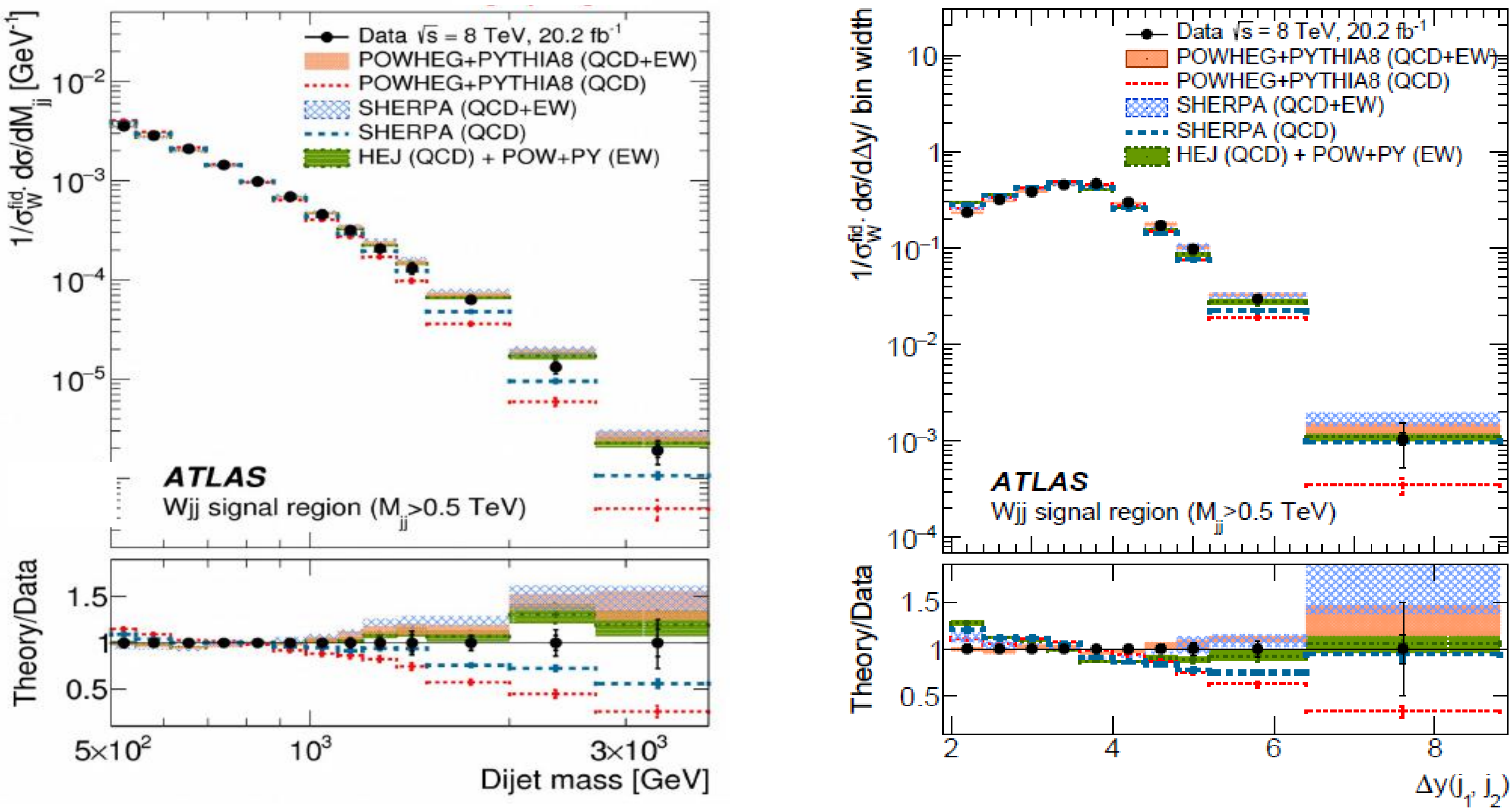


Cross-section measured with simultaneous fit of μ_{QCD} and μ_{EW} in the signal region.
Measured also normalised differential cross-sections.

ATLAS: QCD + EW W+jets @8TeV

Particle-level data-theory comparison

EPJ C77 (2017) 474

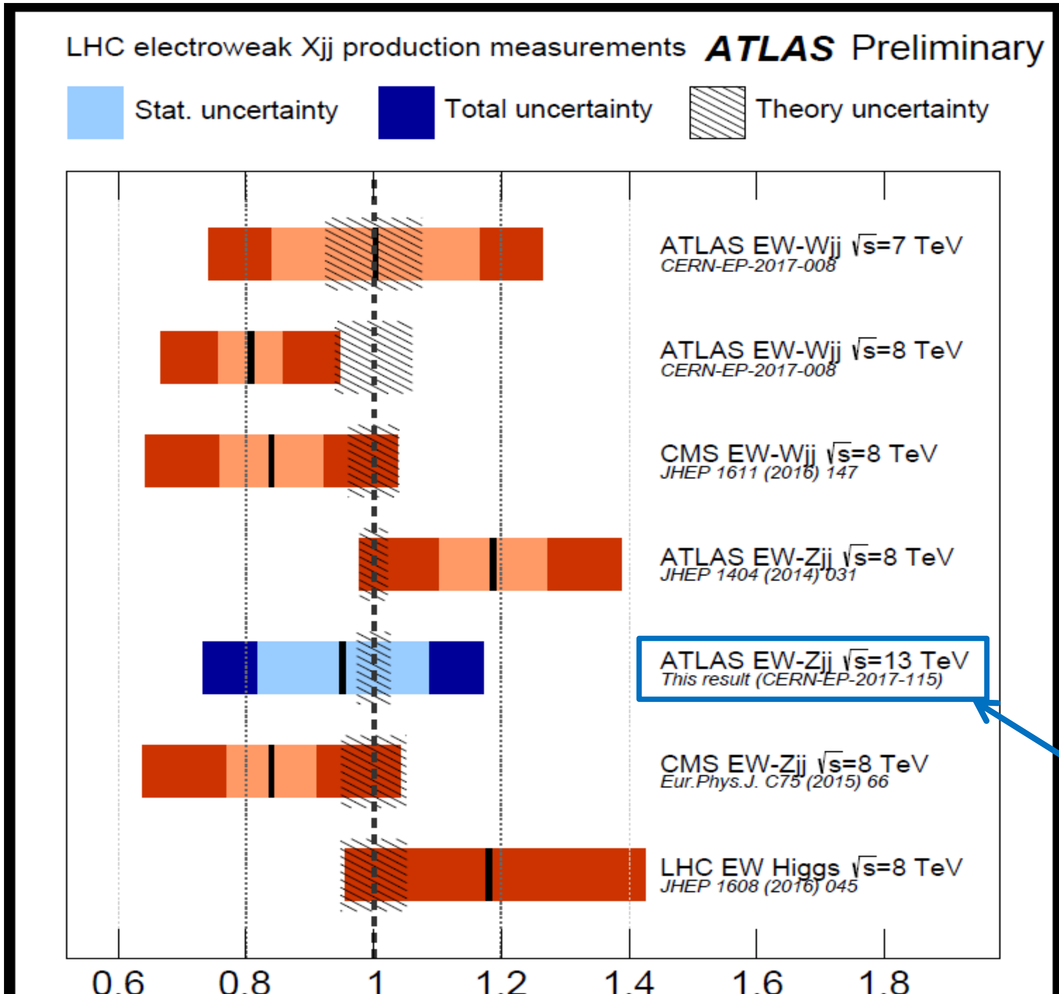


LO ME Sherpa 1.4 and **NLO Powheg+Pythia** give satisfactory description when both EW and QCD processes included.

Very good agreement for HEJ (NNLO QCD)+ Powheg (EW) description.

LHC: EW V+2j @ 7, 8, 13 TeV

Fiducial cross-section measurements



CERN-EP-2017-115

Not included (on the left plot)

EW Z+jj @ 13 TeV (35.9 fb^{-1})

$$\sigma(\mathrm{EW}\ \ell\ell jj) = 552 \pm 19\,(\mathrm{stat}) \pm 55\,(\mathrm{syst})\,\mathrm{fb} = 552 \pm 58\,(\mathrm{total})\,\mathrm{fb},$$

$$\text{SM prediction } \sigma_{\mathrm{LO}}(\mathrm{EW}\ \ell\ell jj) = 543 \pm 24\,\mathrm{fb}$$

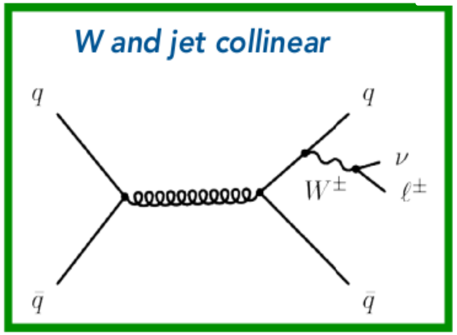
Mesurement agrees with predictions within uncert. (10% exp; 5% theory)

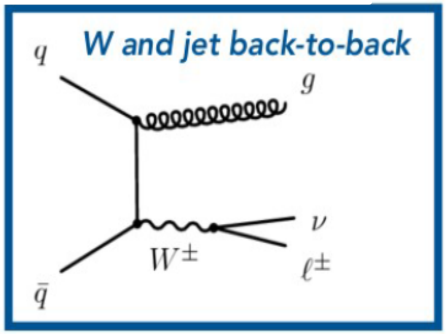
CMS-PAS-SMP-16-018

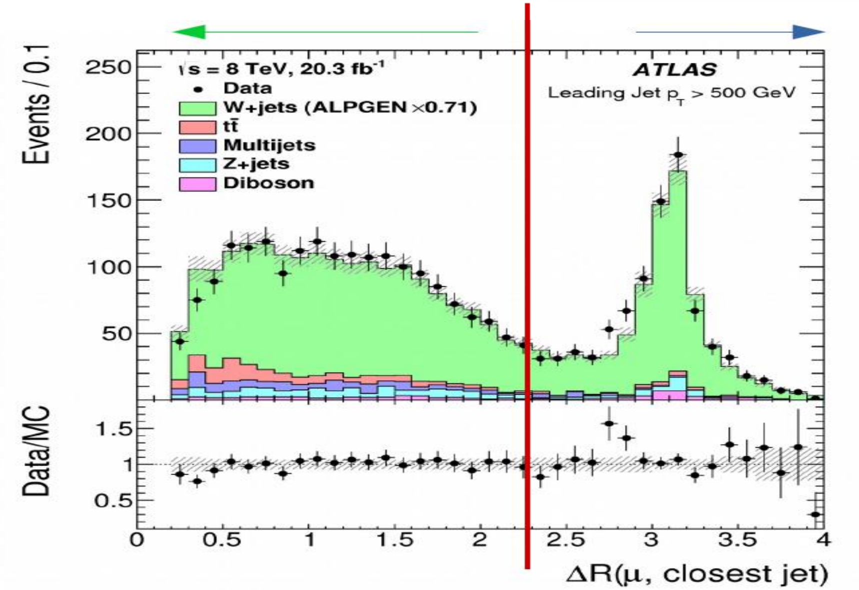
@13 TeV (3.2 fb^{-1})
(~25% exp; ~3% theory)

ATLAS, CMS: Collinear W+jets

- Analysis done in W->$\mu\nu$ channel
- Key observable: ΔR(μ, closest > 100 GeV jet): lepton and initial W direction highly correlated
- Requiring p_T^{jet} > 500 GeV enriches collinear production
- Two inclusive regions:
  - 0.4< ΔR <2.4
  - ΔR > 2.4
- Normalisation corrections for multi-jet, ttbar, Z+jet control regions





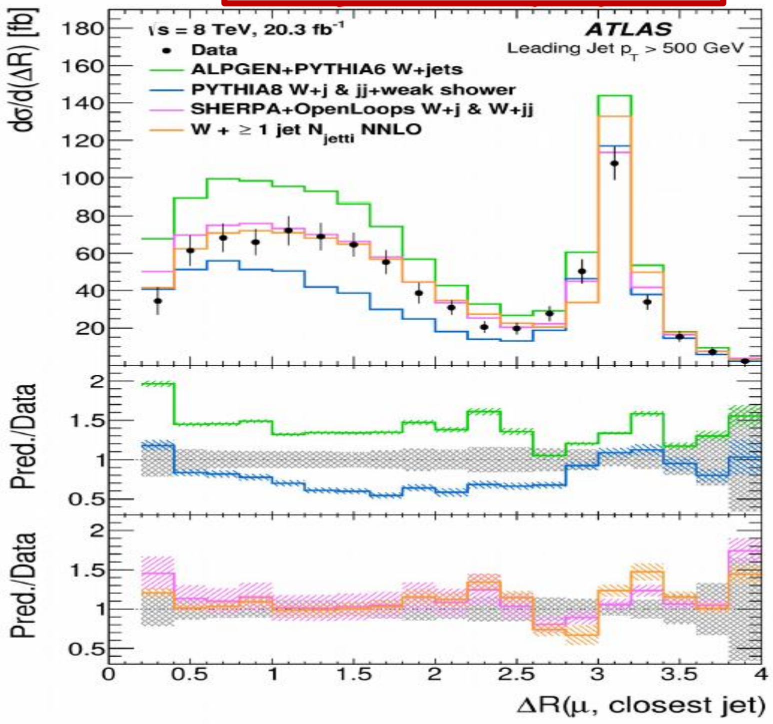


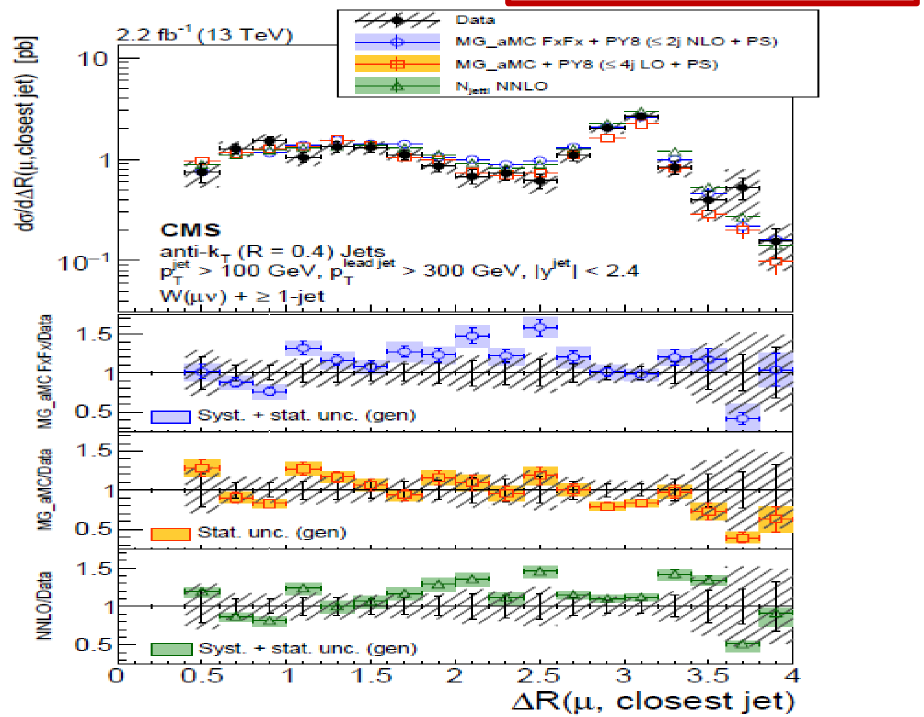
Phys. Lett. B 765 (2017) 132

ATLAS, CMS: collinear W+jets

Phys. Lett. B 765 (2017) 132

arXiv:1707.05979





NLO QCD+EW Sherpa and Njetti NNLO agree with data within uncertainties

LO Alpgen describes shape well but overestimates total cross-section

Pythia8 well describes back-to-back region while underestimates data at low ΔR („weak shower”)

Lower p_T^{jet} threshold, p_T^{jet} > 300 GeV

Two versions of MG_aMC compared:

MG_aMC FxFx+Py8 (<=2j) NLO+PS

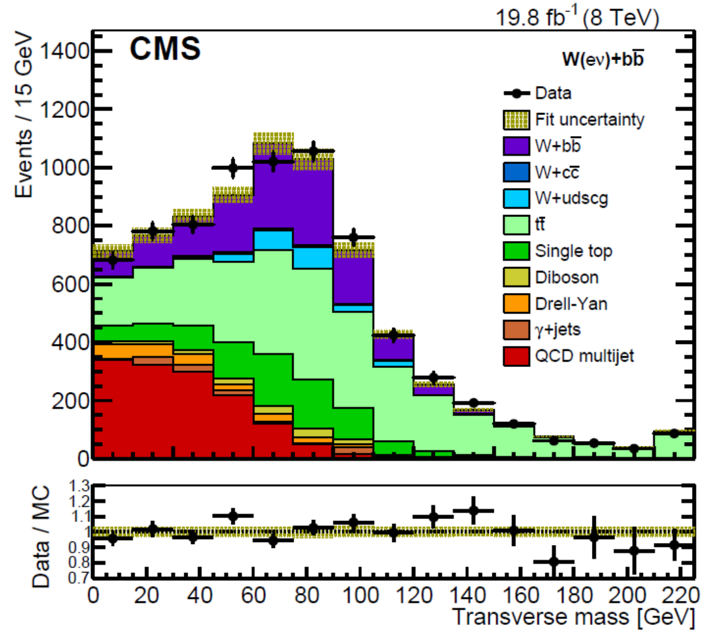
MG_aMC +Py8 (<=4j) LO+PS

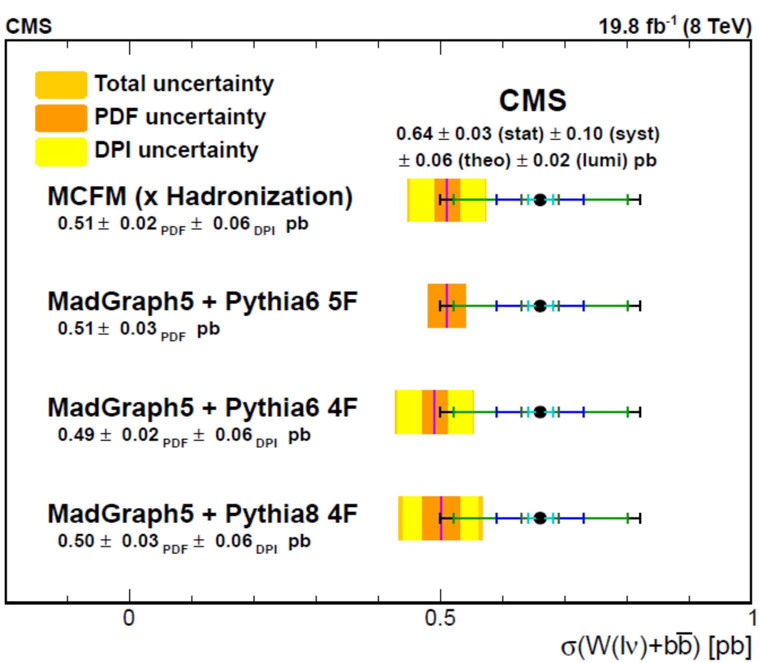
The Njetti NNLO describes ΔR(μ,jets) best.

CMS: W + 2b production @ 8 TeV

EPJC 77 (2017) 92

- Test of pQCD, **the need for 4 or 5 flavour scheme** (major background to V+Higgs measurements)
- Fiducial region: $p_T^l > 30$ GeV, $|\eta^l| < 2.1$, two b-jets $p_T^j > 25$ GeV, $|\eta^j| < 2.4$, veto 3-rd jet
- B-tagging $\varepsilon_b = 40\%$, $R_j = 10^3$, $R_c = 10^2$
- Difficult: relative high bgd contamination



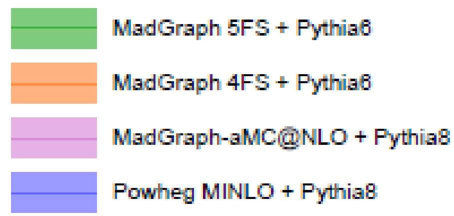


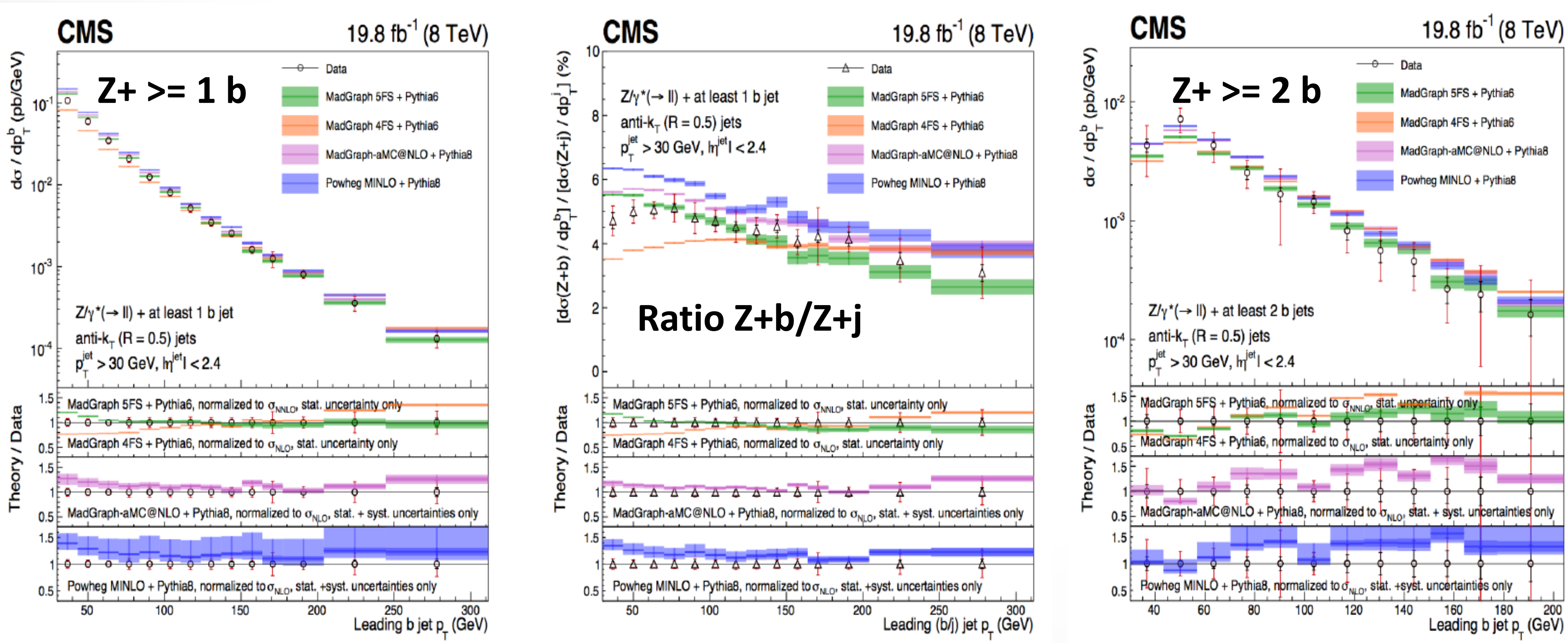
- Signal extracted using a **binned fit to m_T distribution**, bgd controlled using fit in control regions (3-steps fit procedure)
- Different theoretical predictions resonably consistent
- Show good agreement with the data measurement

CMS: Z+b (b) production @ 8 TeV

arXiv: 1611.06507

- **Measured Z+b(b) differential in several observables; also measured differential Z+b/Z+j; unfolded to particle level**
  - Z(>= 1b) low p_T region not well described
  - Z(bb) generally agree with predictions
  - Ratio Z+b/Z+j discrepant at low p_T





V+jets from leptons „perspective”

- **The DY cross-section can be reorganised by factorising the dynamics of the boson production and the kinematic of the boson decay:**

lepton 4-vector

Z-boson rest frame

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

Breit-Wigner

NNLO pQCD

ME, PS, Resum.

EW couplings

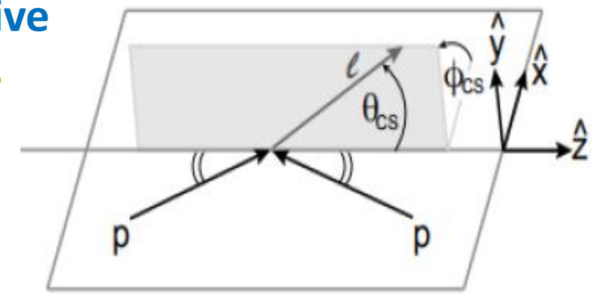
- **This factorisation allows building a composite model and use the most appropriate or accurate model for each term. Note that first three components are calculated in the laboratory frame, the last one in the Z-boson rest frame**
- **Allows to use ancillary DY measurements for validation, and when possible, to fit a free parameter of the model and access the uncertainties**

A_i's measurement @ 8 TeV

$$\frac{d\sigma}{dp_T^Z\, dy^Z\, dm^Z\, d\cos\theta\, d\phi} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dp_T^Z\, dy^Z\, dm^Z}$$
$$\Big\{(1+\cos^2\theta) + \frac{1}{2}\boxed{A_0}(1-3\cos^2\theta) + \boxed{A_1}\sin 2\theta\,\cos\phi$$
$$+\frac{1}{2}\boxed{A_2}\sin^2\theta\,\cos 2\phi + \boxed{A_3}\sin\theta\,\cos\phi + \boxed{A_4}\cos\theta$$
$$+A_5\,\sin^2\theta\,\sin 2\phi + A_6\,\sin 2\theta\,\sin\phi + A_7\,\sin\theta\,\sin\phi\Big\}$$

pQCD sensitive

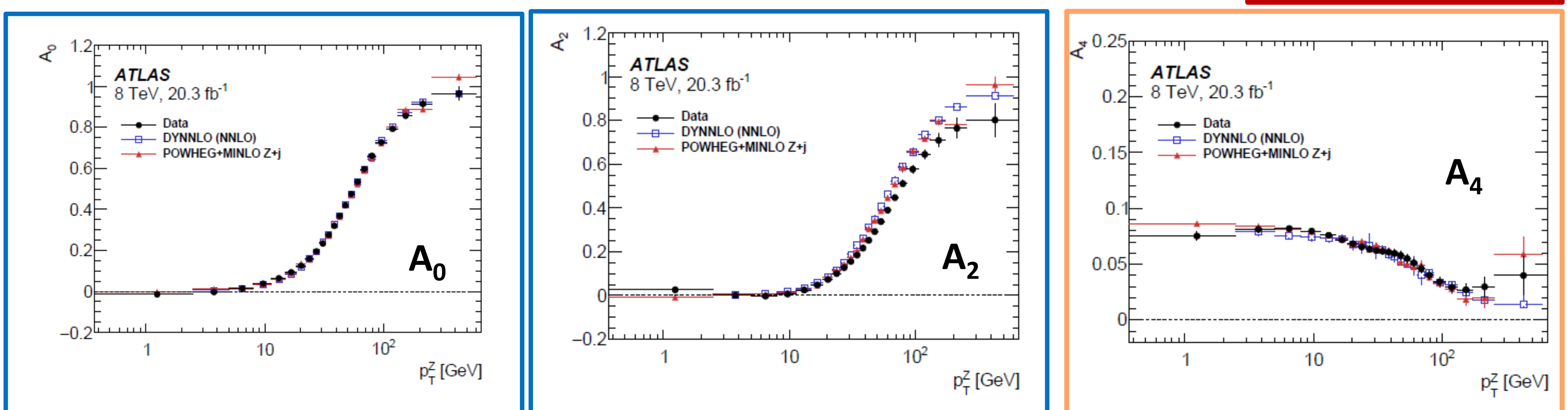
EW sensitive



ATLAS (JHEP 08 (2016) 159) : Measured A_0-A_7, in three Y^Z bins and integrated-Y^Z.
Used MC build templates representing polynomials, propagated to fiducial region (detector level) . Simultaneus fit of all A_i's in 23 pT bins.

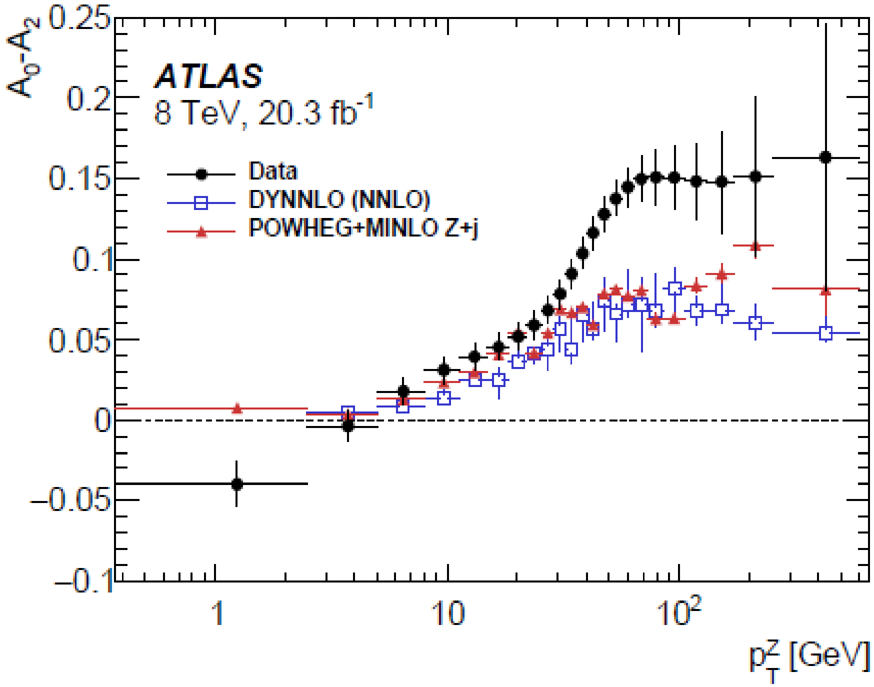
CMS (Phys. Lett. B750 (2015) 154) : Measured A_0-A_4, in two Y^Z bins. Different technique for building templates and bigger exp.uncertainties.

JHEP 08 (2016) 159



ATLAS: A_i's measurement @ 8 TeV

JHEP 08 (2016) 159



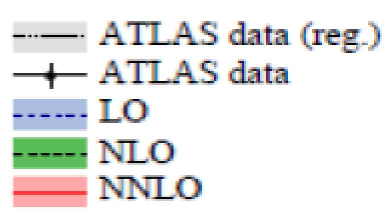
- **Lam-Tung relation A_0-A_2=0 broken as expected beyond V+J LO.**
- **BUT almost factor 2 larger A_0-A_2 in data than predicted by pQCD calculations or MC's**

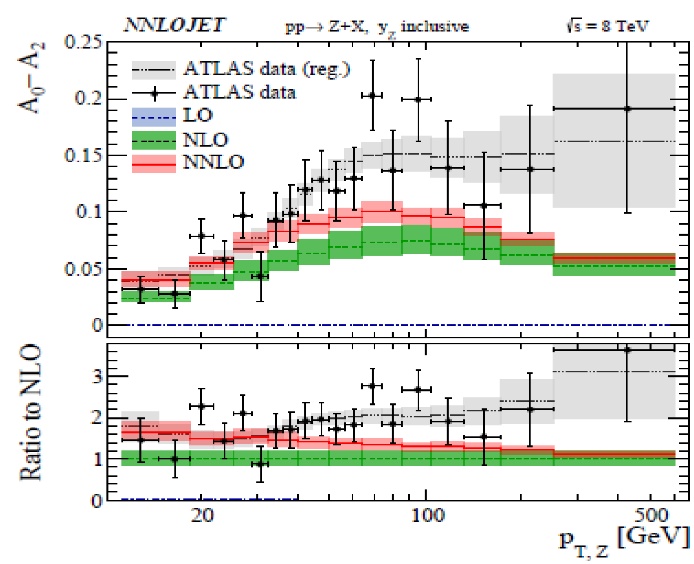
arXiv:1708.0008

Recently published NNLO Z+j predictions

(R. Gaudi et al., arXiv:1708.0008)

- improve Data/MC comparison
- do not fully explain measured A_0-A_2 at high p_T





ATLAS: A_i's measurement @ 8 TeV

JHEP 08 (2016) 159

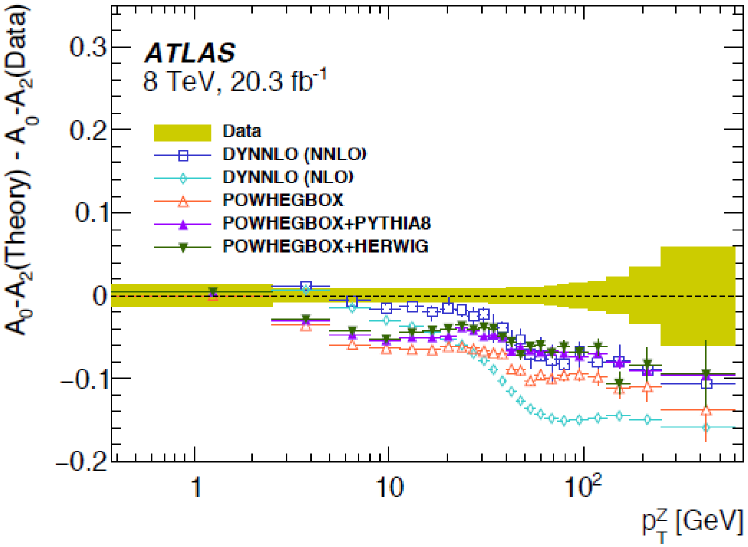
- **Significant differences between simulations! (shown only stat errors predictions)**
- **Neither generator describes A_0-A_2**
  - **Best: Sherpa 2.1**

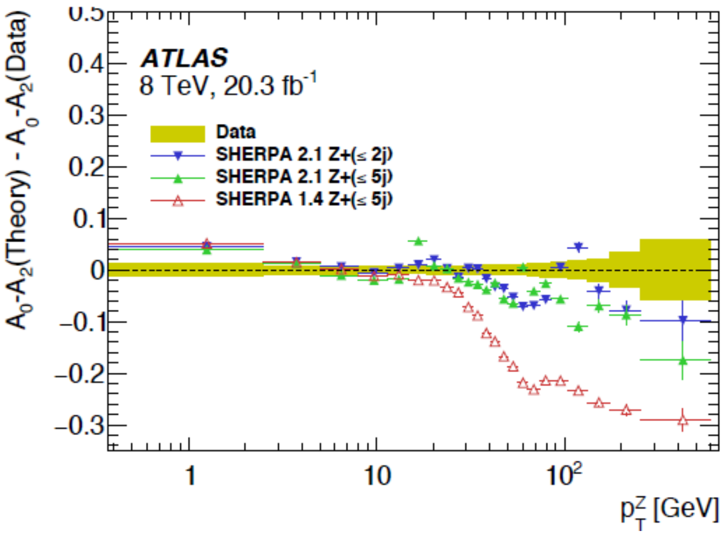
Orthonormal polynomials used to Parametrize angula distribution:

$$\langle P(\cos\theta,\phi)\rangle = \frac{\int P(\cos\theta,\phi)\,d\sigma(\cos\theta,\phi)\,d\cos\theta\,d\phi}{\int d\sigma(\cos\theta,\phi)\,d\cos\theta\,d\phi}$$

$$<\frac{1}{2}(1-3\cos^2\theta)> = \frac{3}{20}(\boxed{A_0}-\frac{2}{3})$$

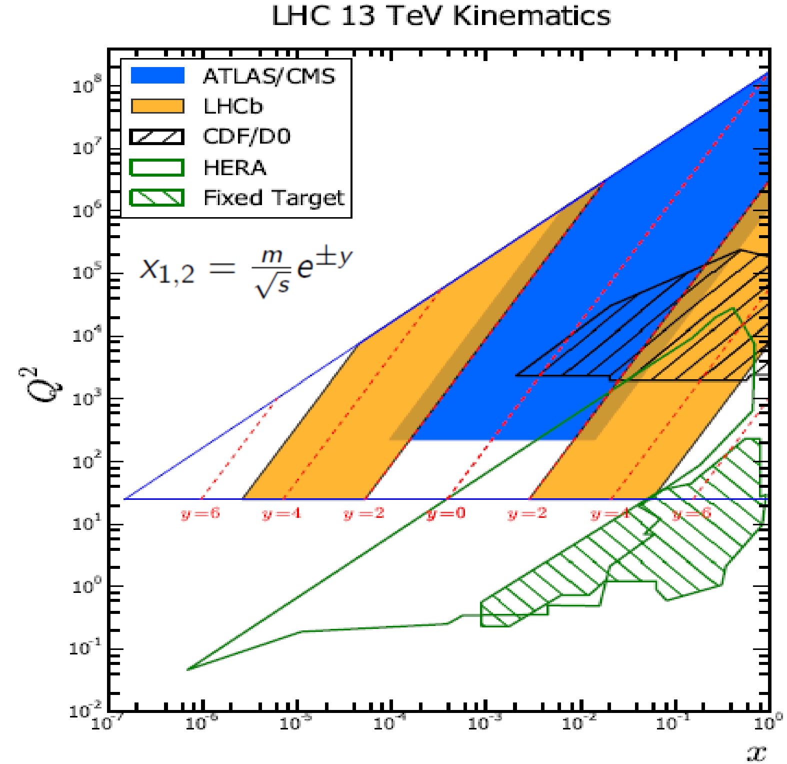
$$<\sin^2\theta\ \cos 2\phi> = \frac{1}{10}\boxed{A_2}$$



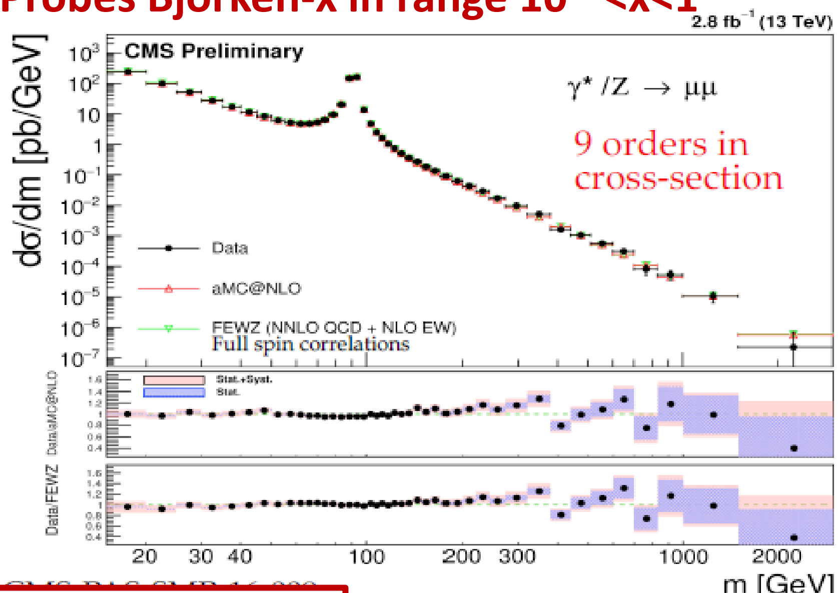


Drell-Yan production and PDFs

- **Large number of measurements with increasing precisions and different $\sqrt{s}$**
  - **Total and differential cross-sections in boson (lepton) kinematics (y, p_T, ϕ^*, …)**
  - **A_{FB}, charge A_l**
  - **Cross-section ratios(W^+/W^-, W/Z, Z/tt)**
- **ATLAS/CMS and LHCb complementary**
- **Low & high Bjorken-x accessed by off-shell data**



Probes Bjorken-x in range $10^{-4} < x < 1$



CMS-PAS-SMP-16-009

- **Large statistics, clean signature, excellent detector calibration -> typical experimental systematics ~1%**
- **Luminosity systematics (2-3%) and also other contributions cancel in ratios.**

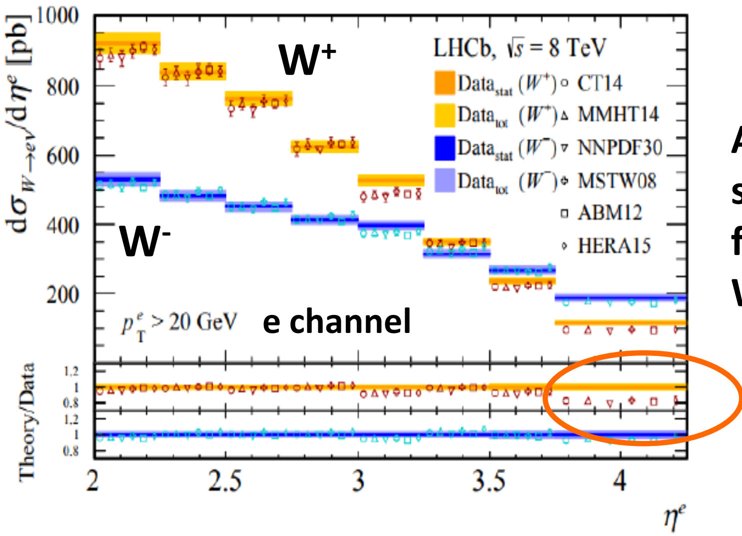
LHCb: W, Z in the forward region @ 7, 8 TeV

JHEP 10 (2016) 030

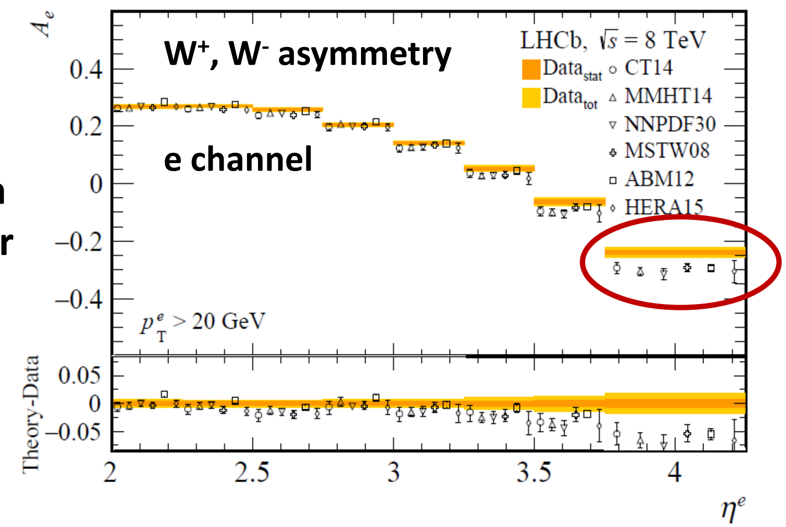
$p_T^l > 20$ GeV, $2.0 < \eta^l < 4.5$

$$A_\ell = \frac{d\sigma_{W+}/d|\eta_\ell| - d\sigma_{W-}/d|\eta_\ell|}{d\sigma_{W+}/d|\eta_\ell| + d\sigma_{W-}/d|\eta_\ell|}$$

@ 8 TeV

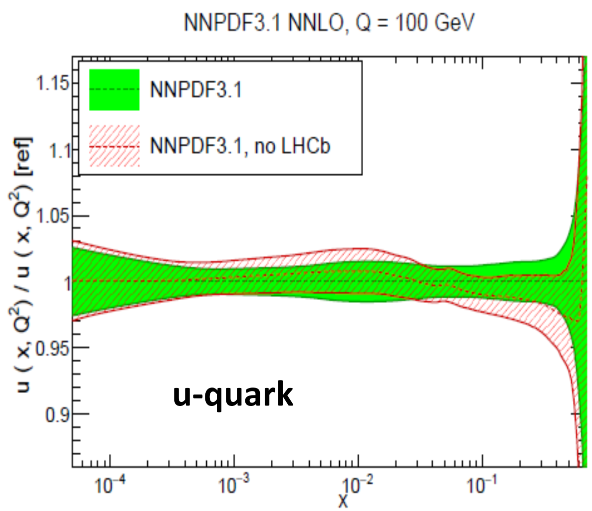


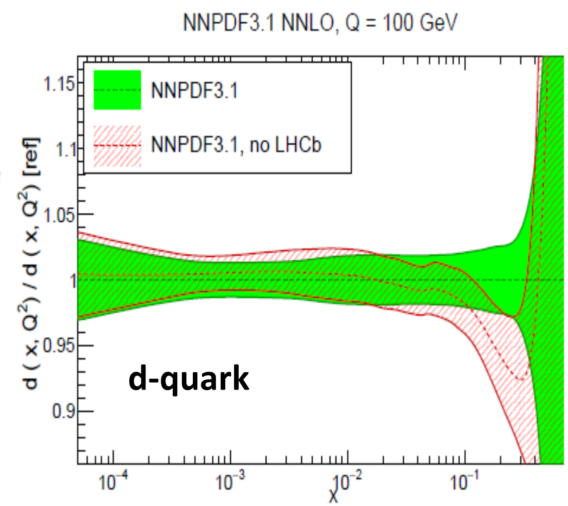
At far forward η^e significant deviation from predictions for W^+ data



LHCb data signif. constraint u/d PDF's at x > 0.1

J. Rojo, arXiv:1705.04468





LHCb data W,Z included:

JHEP 08 (2015) 039 @ 7 TeV

JHEP 01 (2016) 155 @ 8 TeV

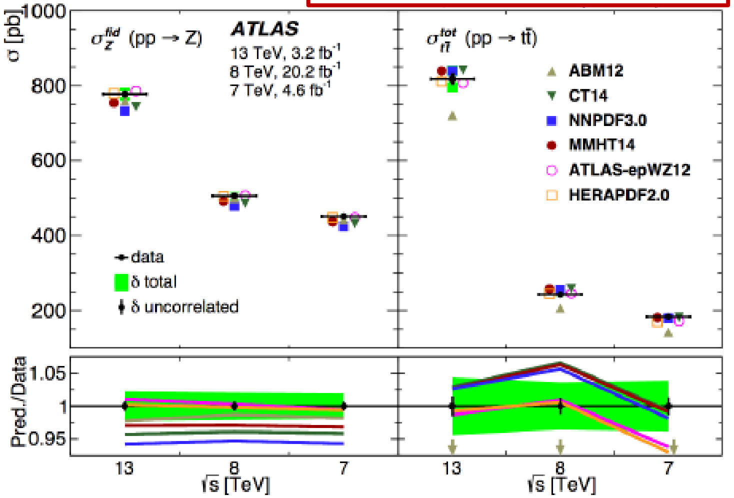
ATLAS: tt/Z cross-section ratio @ 7, 8, 13 TeV

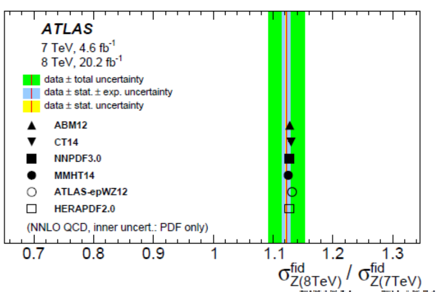
JHEP 02 (2017) 117

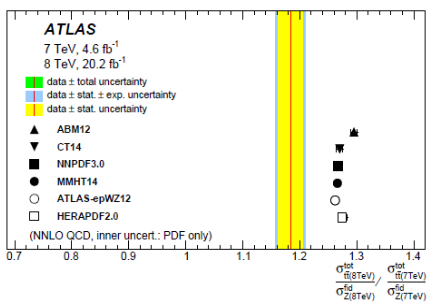
- **Luminosity uncertainty cancels out**
- **High precison (stat, syst, beam, lumi):**

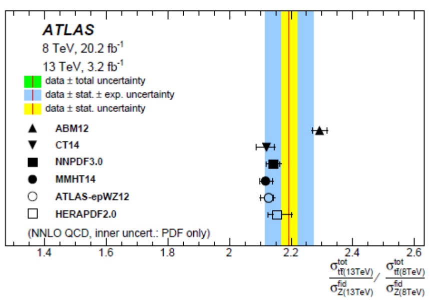
$$\sigma_Z^{fid}(13\text{ TeV}) = 777 \pm 1 \pm 3 \pm 5 \pm 16$$
$$\sigma_{tt}^{tot}(13\text{ TeV}) = 818 \pm 8 \pm 27 \pm 12 \pm 19$$

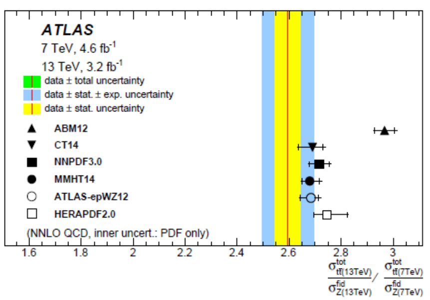
- **Challenging to take correlations precisely into account.**
- **In double ratio most uncertaintities cancel out.**

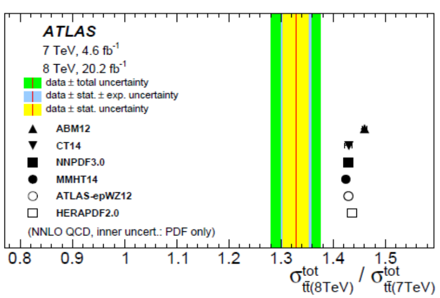






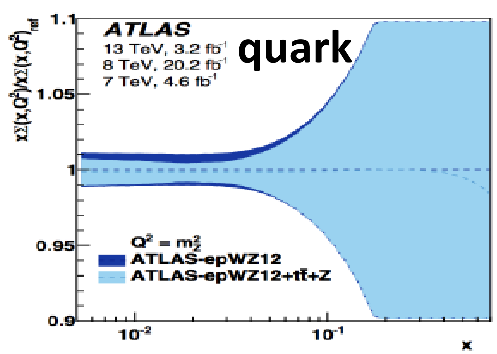


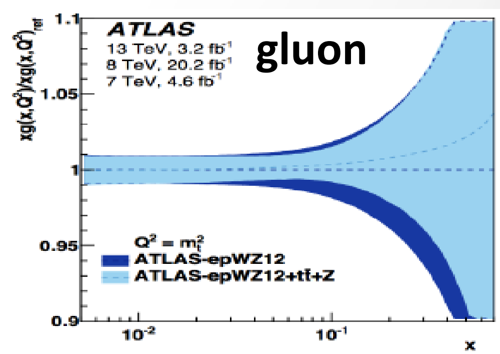




Effect on PDF

σ(tt) ratios of X TeV / 7 TeV are lower than predicted





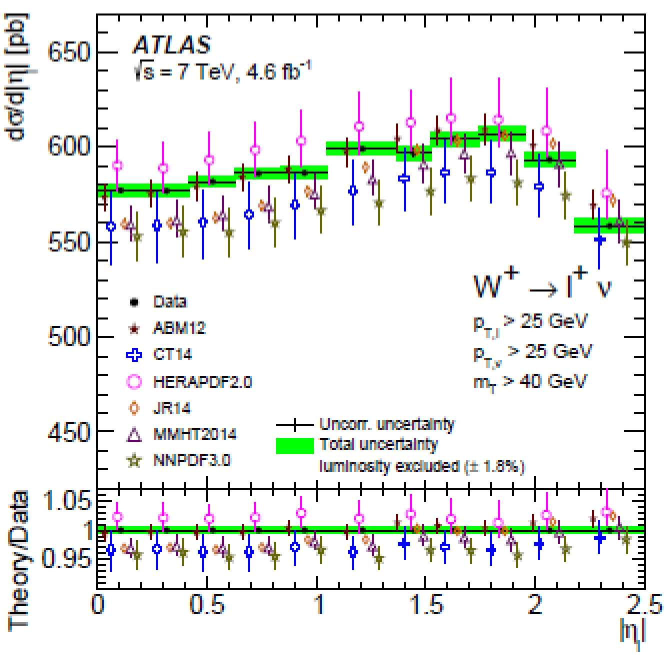
ATLAS: W/Z differential @ 7 TeV

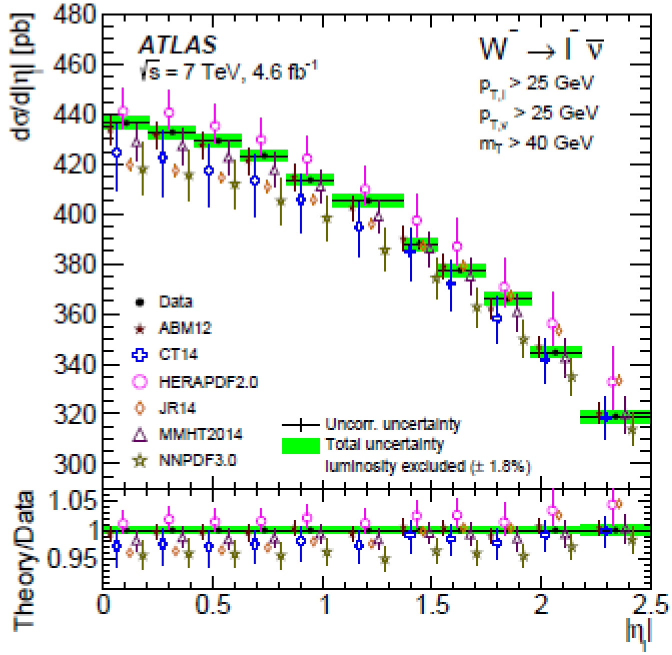
EPJC 77 (2017) 367

Significant sensitivity to inital state also from the differential lepton $|\eta^l|$. Uncertainty on measured shape is of 0.1-0.2%.

Large strange-quark component in W production which is theoretically not well constrained.

All predictions but HERAPDF2.0 lower than measurements and all with large PDF uncertainties. Discrepancy in shape.





Data: unfolded to particle-level (dressed leptons)

TH predictions:
(NNLO QCD + NLO EW)
DYNNLO 1.5
FEWZ 3.1.b2
MCSANC

ATLAS: W/Z differential @ 7, 8 TeV

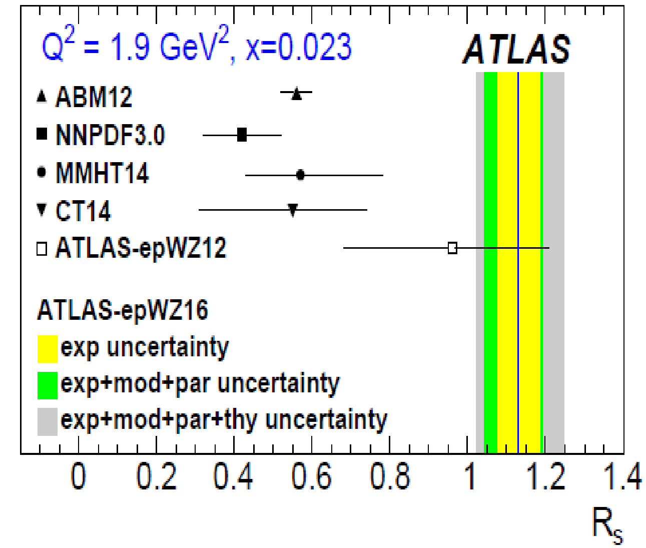
New PDF set **ATLAS-epWZ16** is derived using QCD fit xFitter platform in conjuction with HERA data;

Confirmed unsuppressed strange fraction at x = 0.023, in **contradictions** to most contemporary PDF sets that predict strange fraction around 0.5.

However, there is a large parametrisation uncertainty in $R_s(x)$ away from x=0.023 where data is less constraining.

EPJC 77 (2017) 367

@7 TeV



NEW

Cross-section measurements: **1D** in m_{ll}, **2D** in (m_{ll}, y_{ll}) and **3D** in (m_{ll}, y_{ll}, $\cos\theta_{CS}$). Range: m_{ll} = 40-200 GeV.

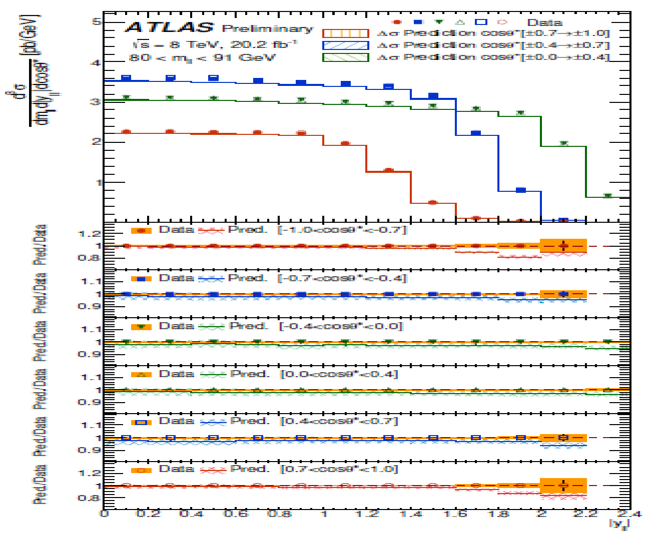
The data accuracy better than 0.5% in the Z-peak region and $|y_{ll}|<1.4$;

Overall **good agreement** between data and Powheg-based predictions. Combination of ele/mu channels yields **χ^2/NDF=489.4/451**

Also measured A_{FB} in y_{ll} bins

Unfolded measurement sensitive to PDFs and $\sin^2\theta_W$

@8 TeV



Conclusions

- **LHC experiments published during last year a vast set of interesting measurements on EW gauge boson and jet production with Run 1 and Run 2 data.**
- **Significant progress on the theoretical predictions from Run 1 to Run 2 paradigm.**
  - **QCD NLO became a „standard"; QCD NNLO is becoming necessary for high statistics processes.**
  - **NNLO calculations only exist with full final-state kinematics as tools for a handful of processes and are generally very slow**
- **For several measurements experimental < theoretical uncertainties. The reliable estimate of theoretical uncertainties become more and more a „burning" avenue.**
- **Wealth of LHC data makes it now really interesting to adapt PDF fits to precision of measurements (PS, EW corr, etc.). It makes it also interesting to limit them to high-Q^2 processes which often provide much more advanced treatment of uncertainties.**

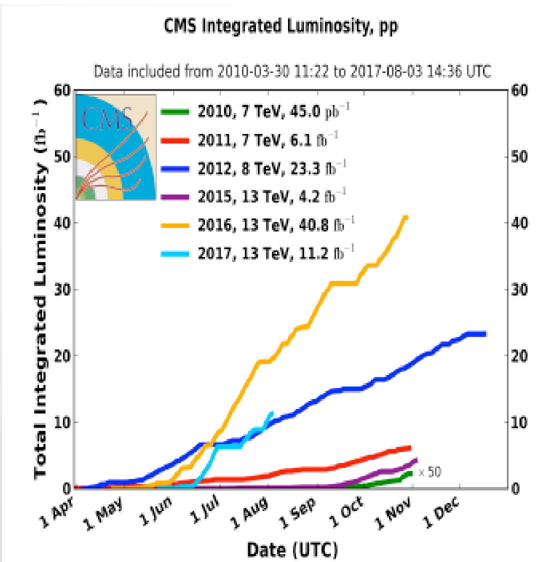
Backup slides

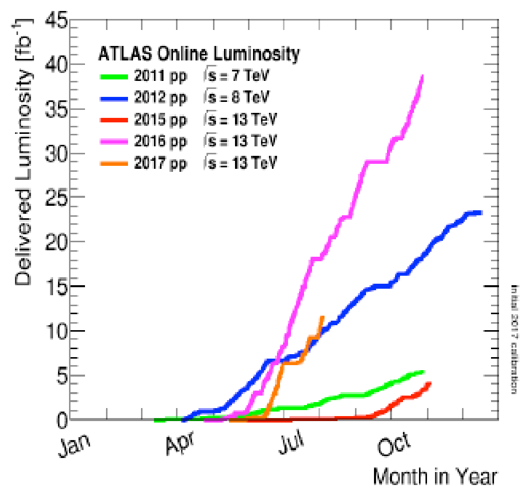
Public results from LHC

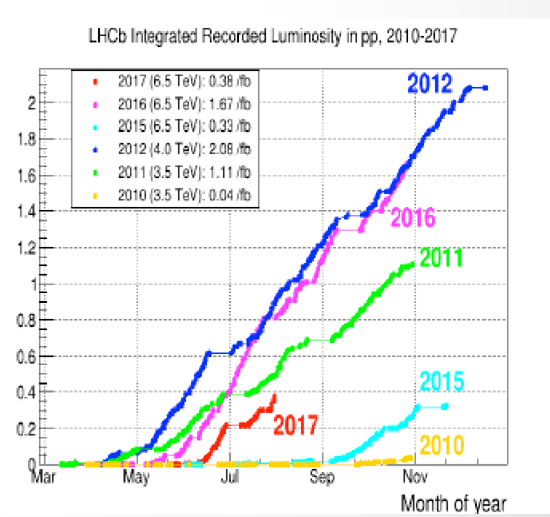
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

http://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/Summary_QEE.html



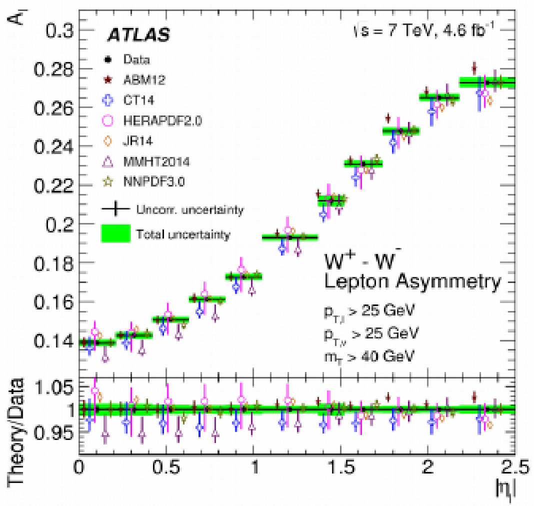


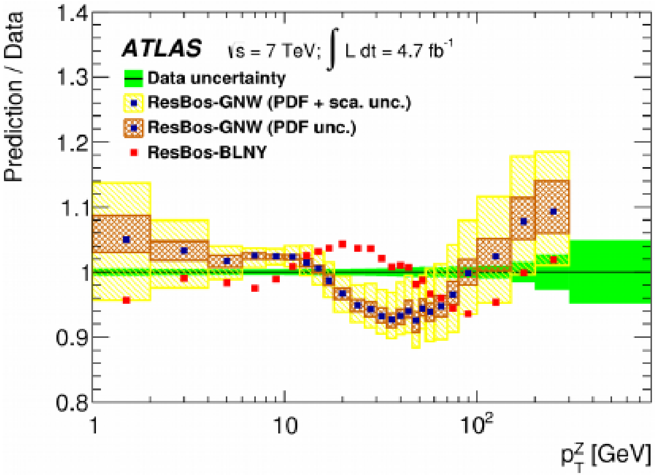


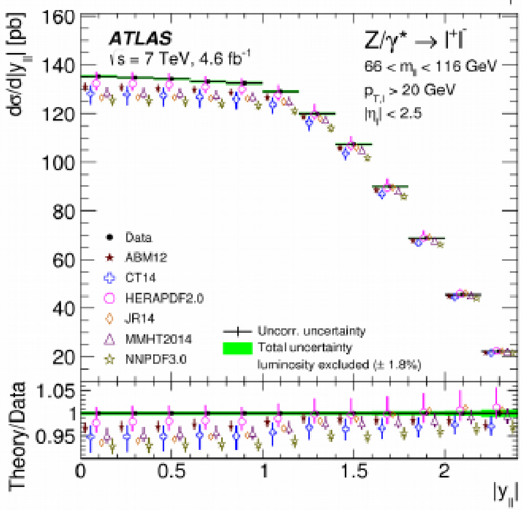
LHCb: luminosity-leveled

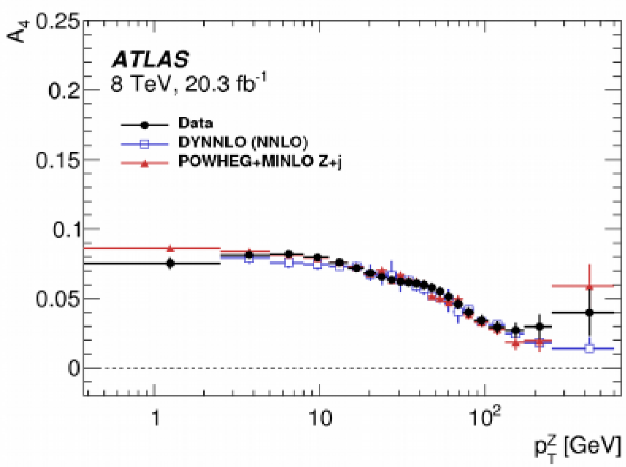
Physics modelling: DY ancillary measurements

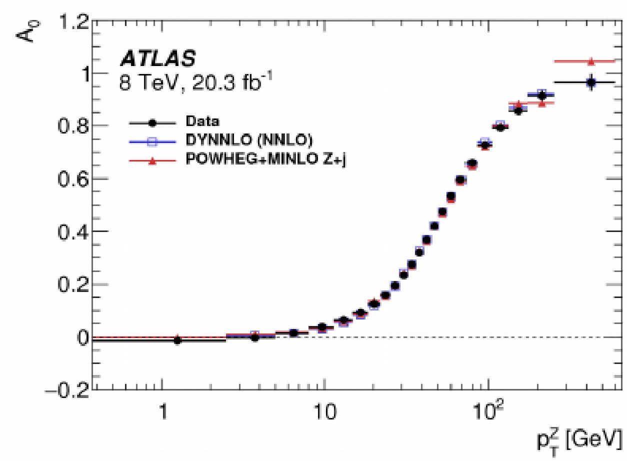
$$\frac{d\sigma}{dp_1\,dp_2} = \left[\frac{d\sigma(m)}{dm}\right]\left[\frac{d\sigma(y)}{dy}\right]\left[\frac{d\sigma(p_T, y)}{dp_T\,dy}\left(\frac{d\sigma(y)}{dy}\right)^{-1}\right]\left[(1+\cos^2\theta) + \sum_{i=0}^{7} A_i(p_T, y)P_i(\cos\theta, \phi)\right]$$







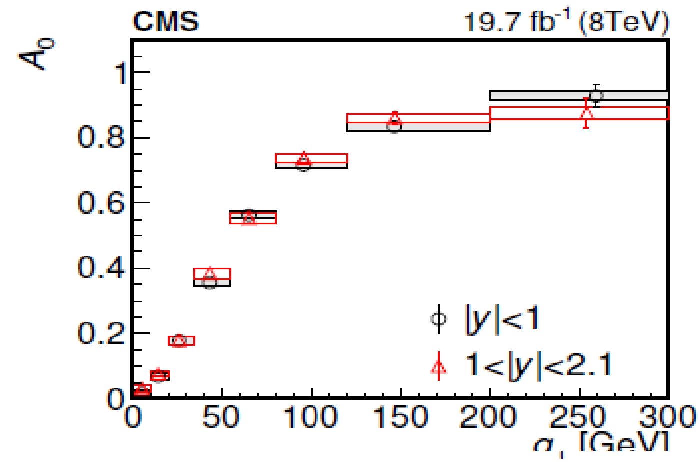


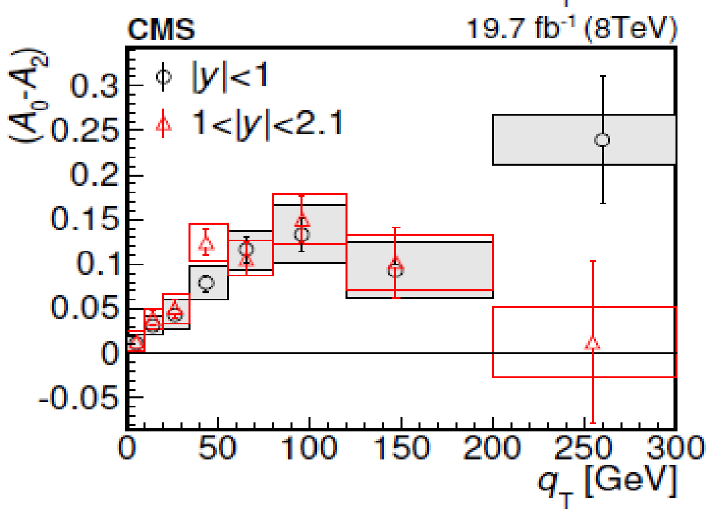


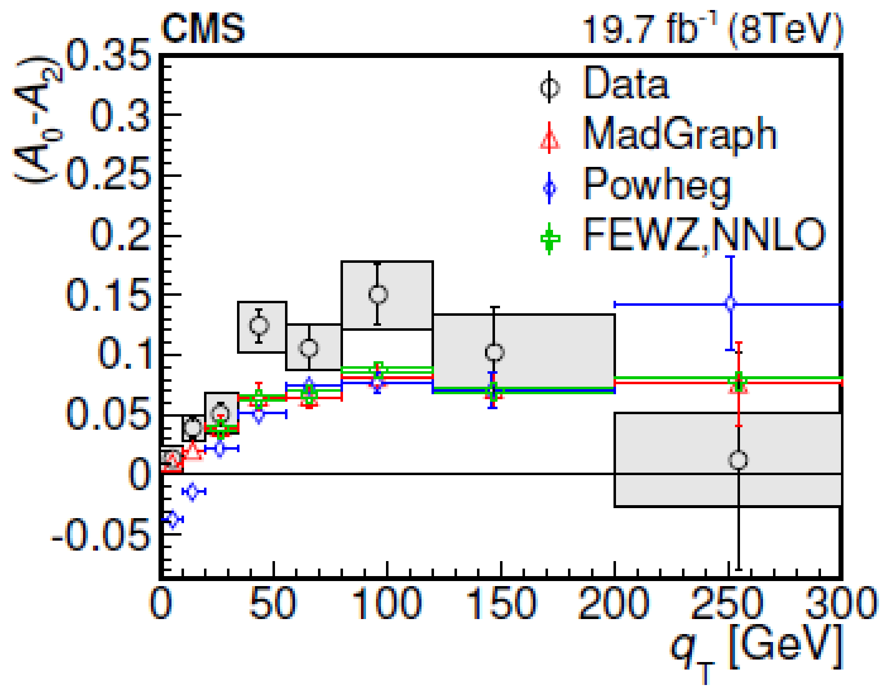
CMS: A_i's measurement @ 8 TeV

Phys. Lett. B750 (2015) 154

- **Measured $A_{0\text{-}4}$, in 2 rapidity bins.**







Lam-Tung relation broken as expected.
not conclusive if reproduced by MC's

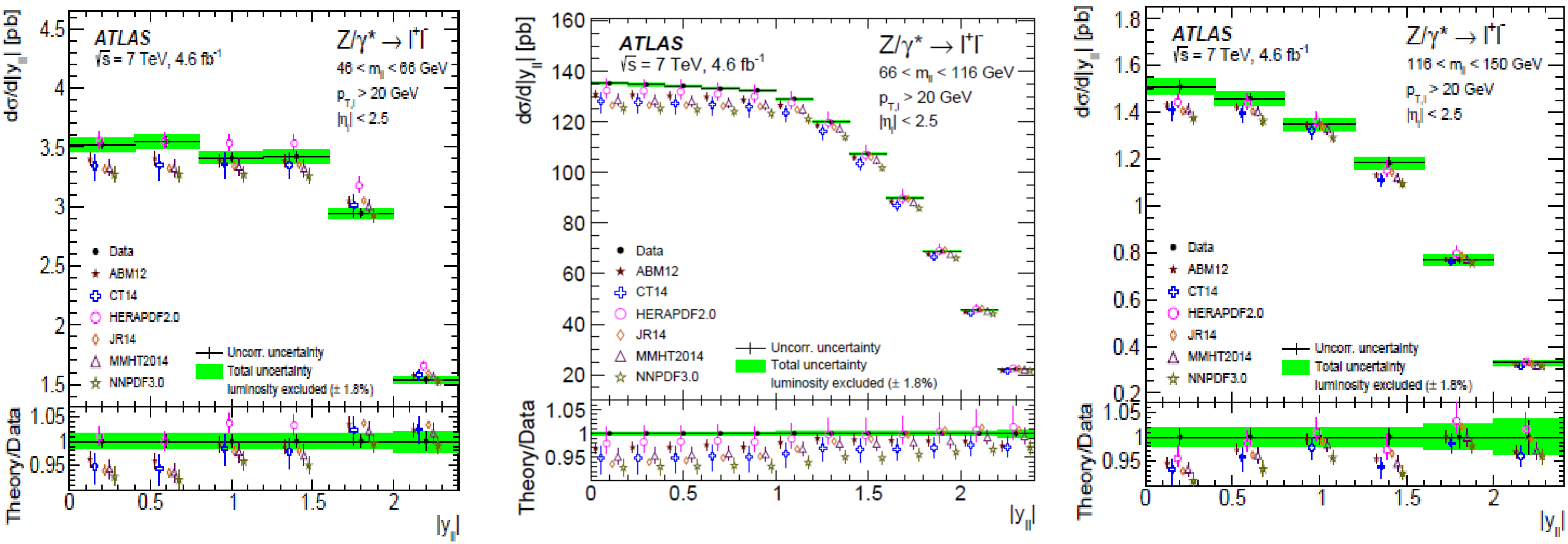
ATLAS: W/Z differential @ 7 TeV

EPJC 77 (2017) 367

Complementary measurement performed with Z-bosons across rapidity and mass. Sub-percent precision of measurement around Z-peak.

Forward electrons (not shown) also used to extend rapidity acceptance to $|Y^{ll}| < 3.6$, though with lower sensitivity compared to central region.

m_{ll} = 46-66 GeV **m_{ll} = 66-116 GeV** **m_{ll} = 116-150 GeV**

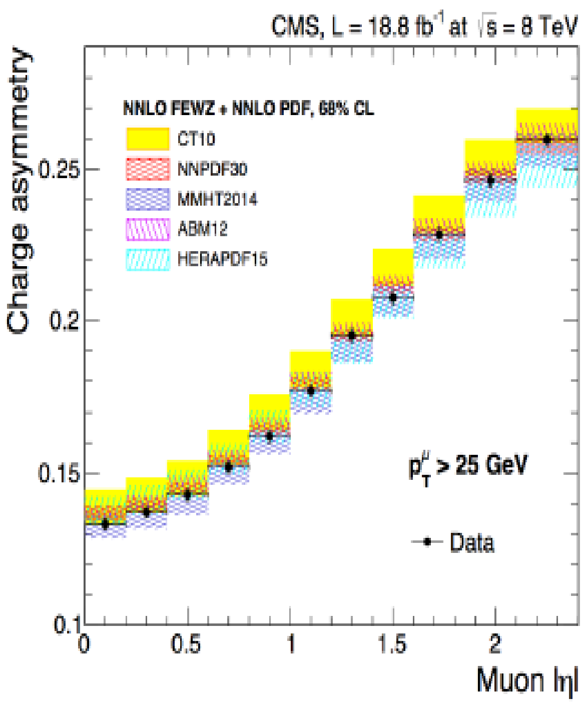


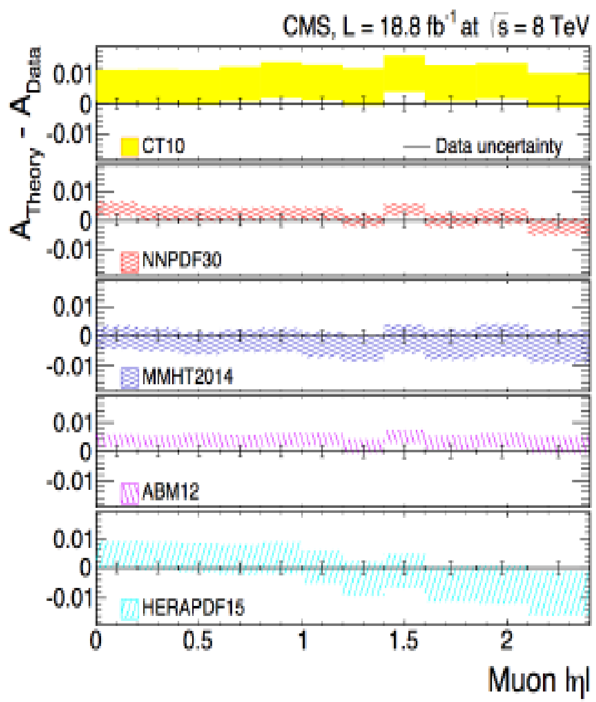
CMS: W charge asymmetry at 8 TeV

EPJC 76 (2016) 469

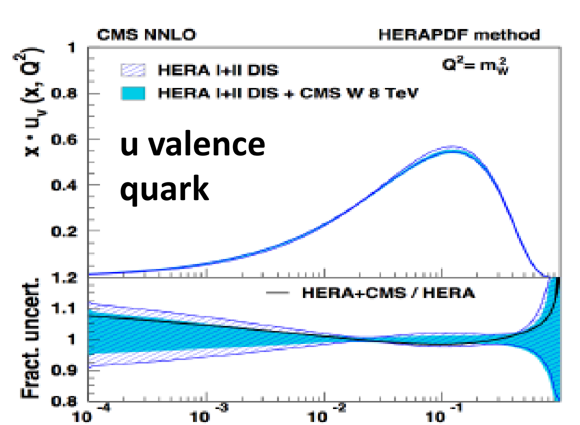
- **Main production mechanisms for W's:**
  $u\bar{d} \to W^{+} \quad d\bar{u} \to W^{-}$
- **Charge asymmetry PDF sensitive, constraints u(x)/d(x) ratio**

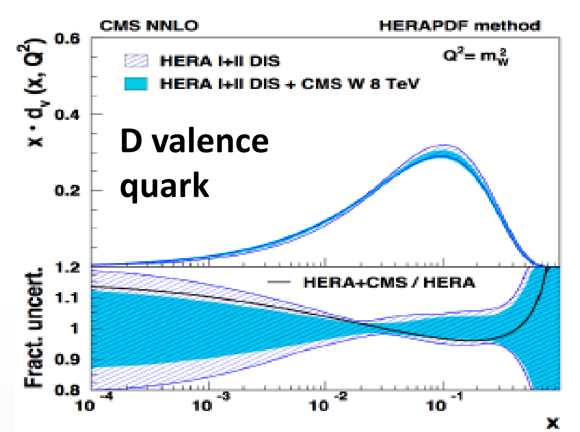
$$\mathcal{A}(\eta) = \frac{\sigma_\eta^{+} - \sigma_\eta^{-}}{\sigma_\eta^{+} + \sigma_\eta^{-}} \quad \text{with } \sigma_\eta^{\pm} = \frac{d\sigma}{d\eta}(pp \to W^{\pm} + X \to \mu^{\pm}\nu + X)$$





Effect of CMS data on PDF's



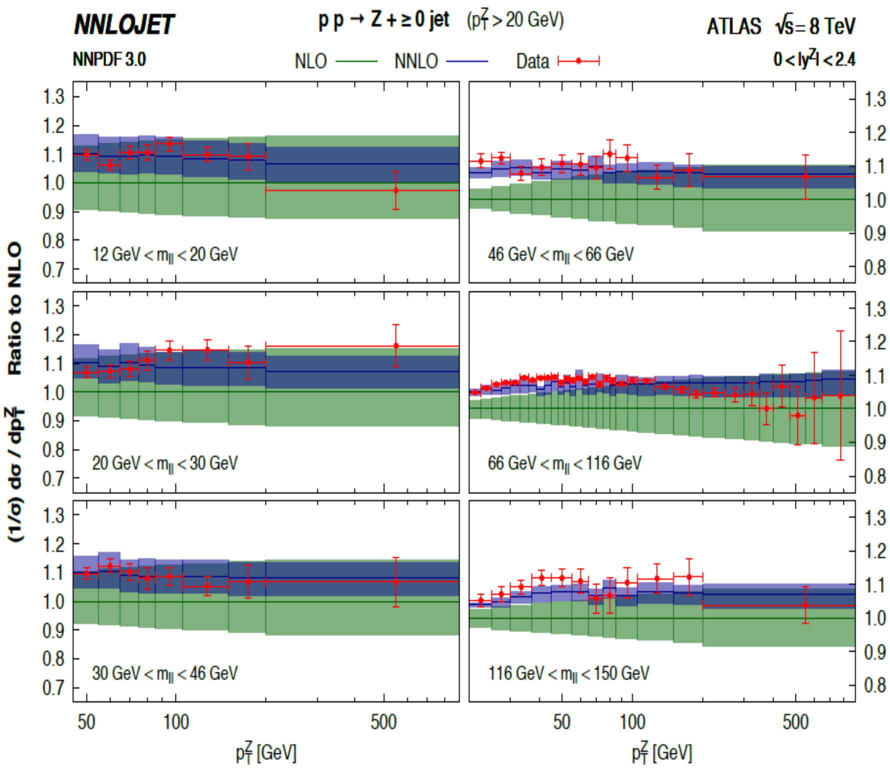


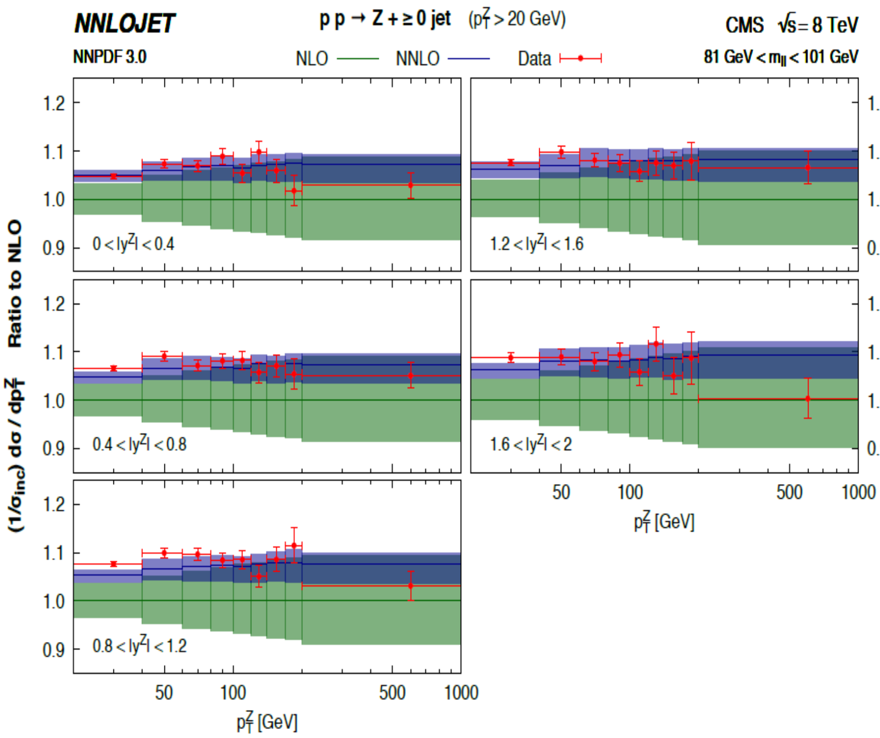
Significant improvement in valence-quark accuracy for $10^{-3} < x < 10^{-1}$

Theory - data: NNLO Z+jets

A. Gehrmann-De Ridder et al.
arXiv: 1607.01749

Inclusion of NNLO QCD results in a substantial improvement in the agreement between theory and data to the normalised distributions.





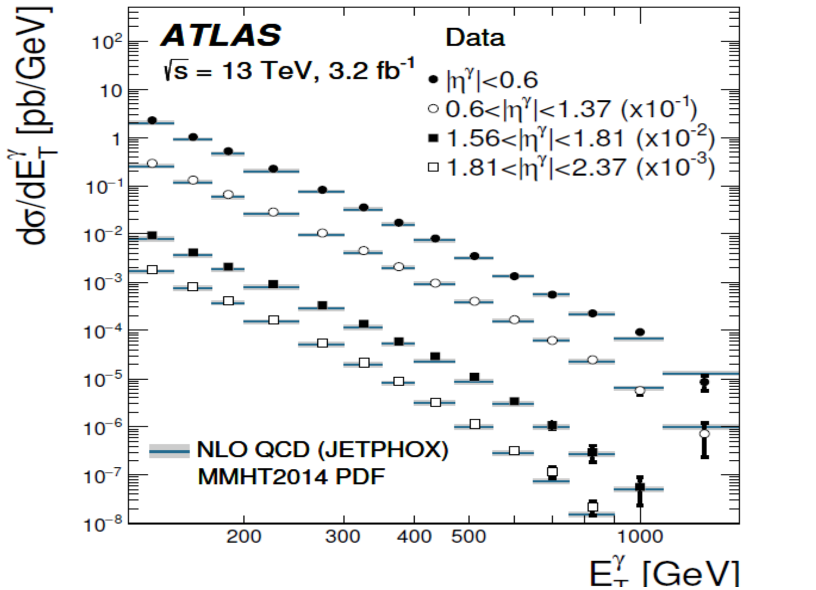
ATLAS data: EPJC 76 (2016) 1

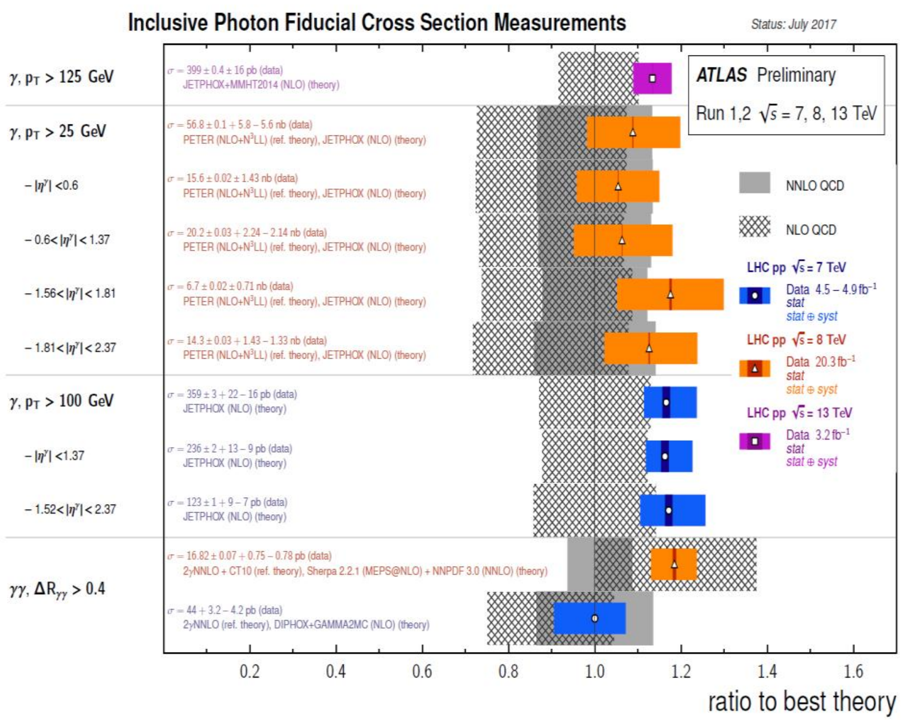
CMS data: Phys. Lett. B 749 (2015) 187

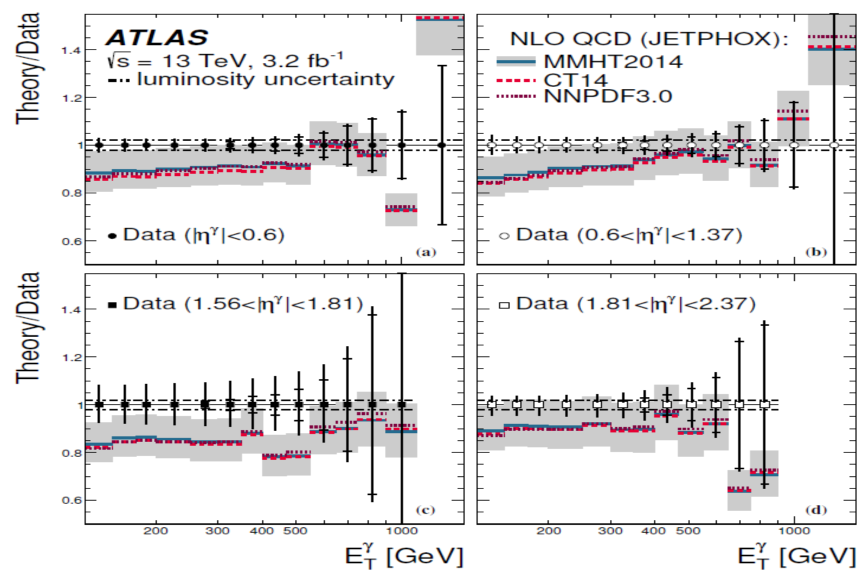
ATLAS: inclusive photon @ 13 TeV (3.2 fb^{-1})

PLB 70 (2017) 473

- **Tests pQCD with hard colorless probes**
- **Sensitive to gluon PDF at LO**
- **JETPHOX (NLO) provide reasonable description but need for QCD NNLO. Pythia8 or Sherpa 2.1 give good description of the shape except $E_T > 500$ GeV and $|\eta| < 1.37$**
- **Experimental < theoretical uncertainty!**







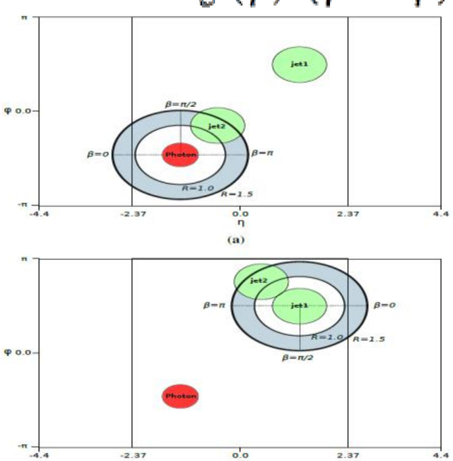
ATLAS: photon+ 1 jet @ 13 TeV (3.2 fb^{-1})

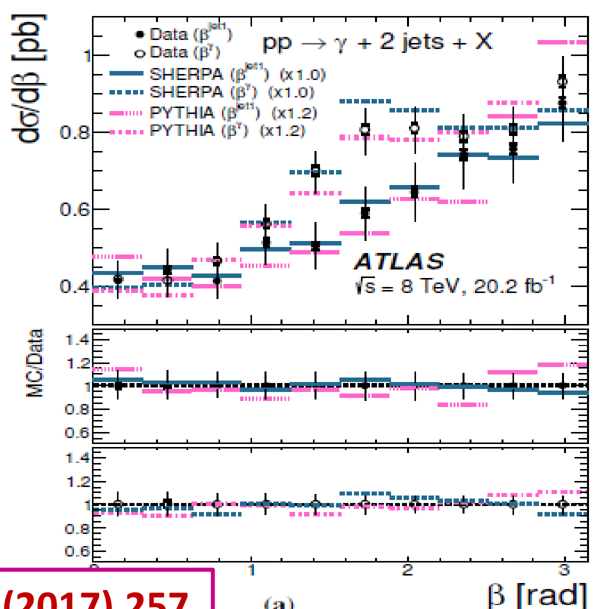
NEW

ATLAS-CONF-2017-059

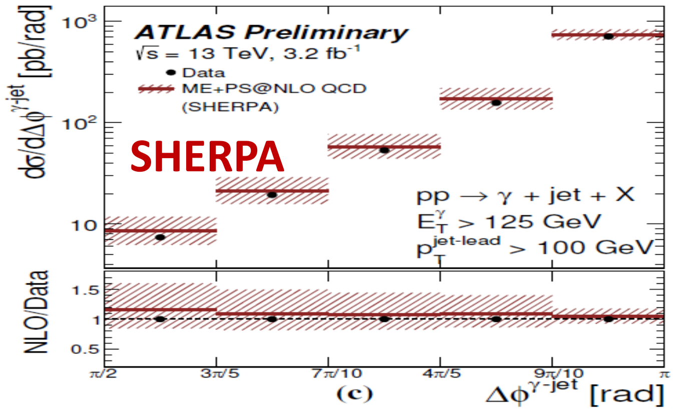
- **JETPHOX (NLO)** cannot describe $\Delta\phi(\gamma,\text{jet})$ due to limitations in the number of final state partons
- **SHERPA ME 2->4/5@NLO** agrees well with the data. Jet p_T better described by SHERPA@LO than @NLO
- **Experimental < theory** uncertainties
- **@8 TeV** observed different QCD radiation pattern around leading jet and photon

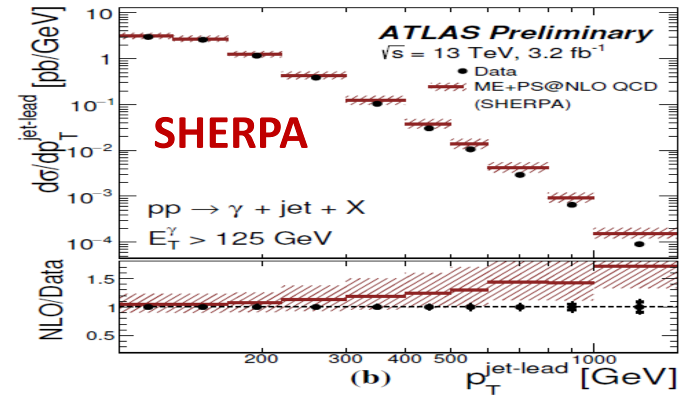
$$\beta^{\gamma} = \tan^{-1}\frac{|\phi^{\text{jet2}} - \phi^{\gamma}|}{\text{sign}(\eta^{\gamma})\cdot(\eta^{\text{jet2}} - \eta^{\gamma})}$$

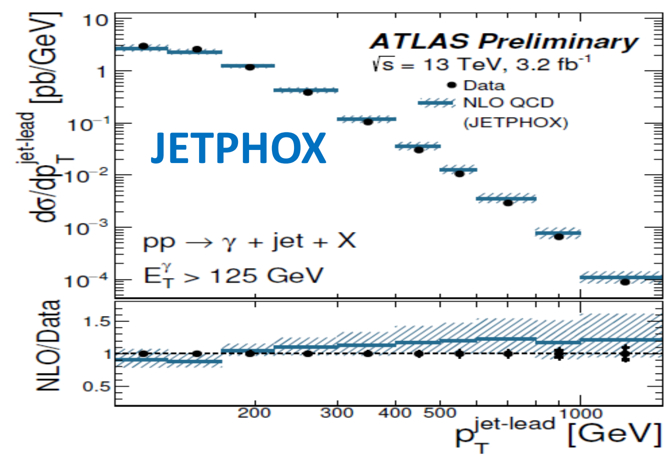




NPB 918 (2017) 257







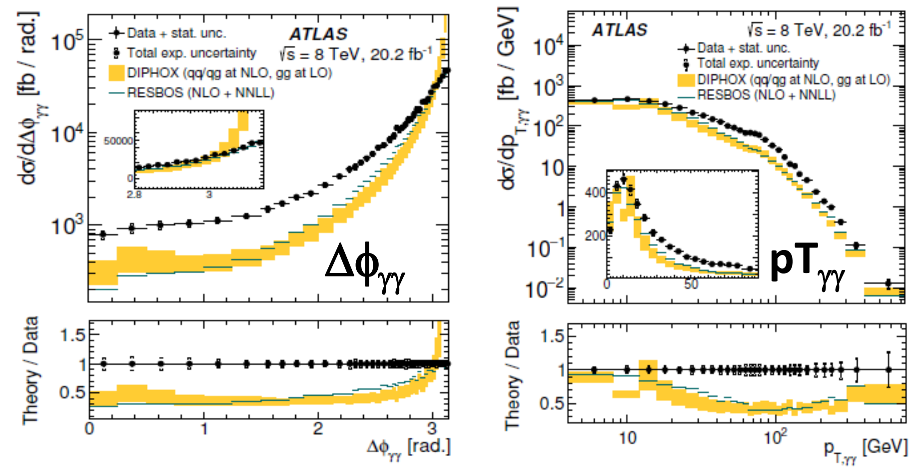
ATLAS: diphoton cross-section @ 8 TeV

PRD 95 (2017) 112005

- **Sensitive to α_s corrections, QCD infrared emission**
- **SHERPA provides the best description for shape and normalisation.**
- **Fixed order calculations lower than data, improvement with NNLO**

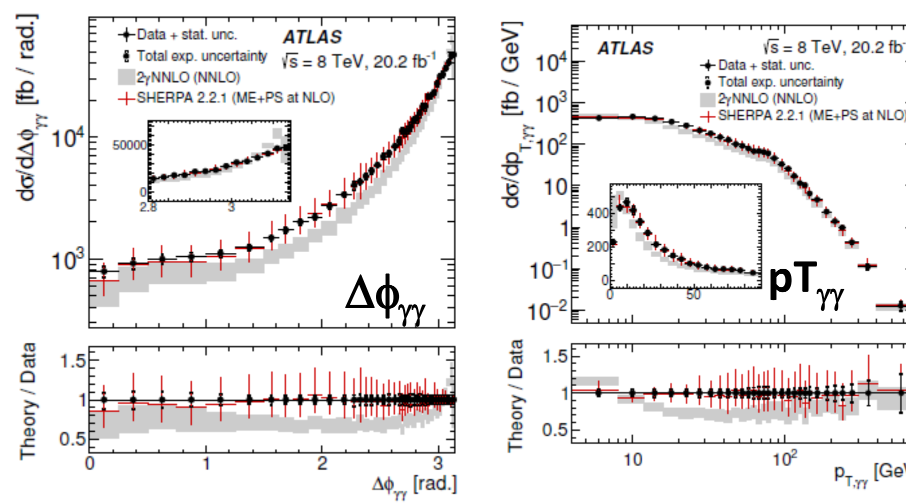
DIPHOX (NLO)

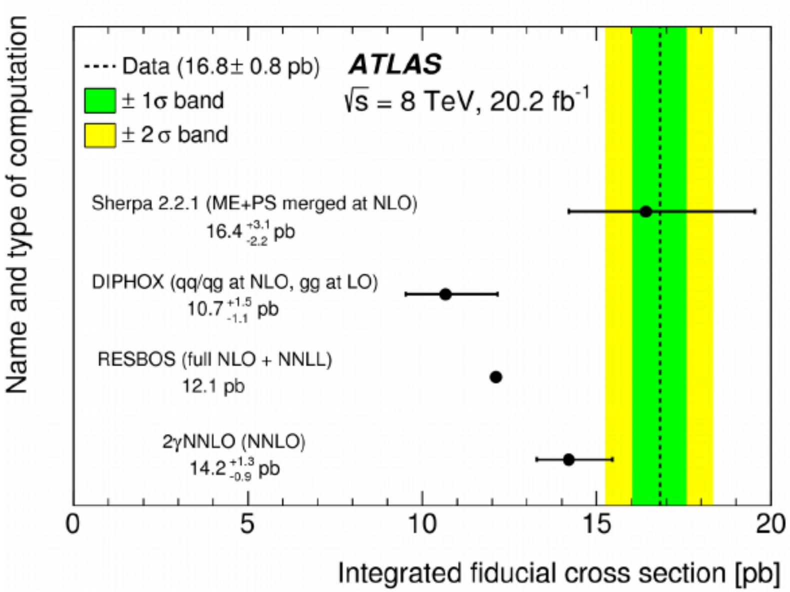
ResBos (NLO+NLL)



2γNLLO (NNLO)

SHERPA (γγ+0,1@NLO, γγ+2,3 @LO)

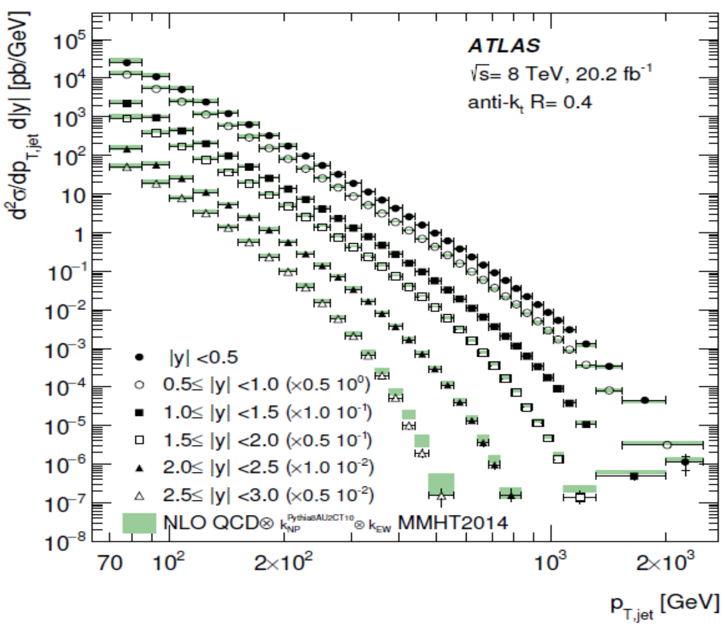




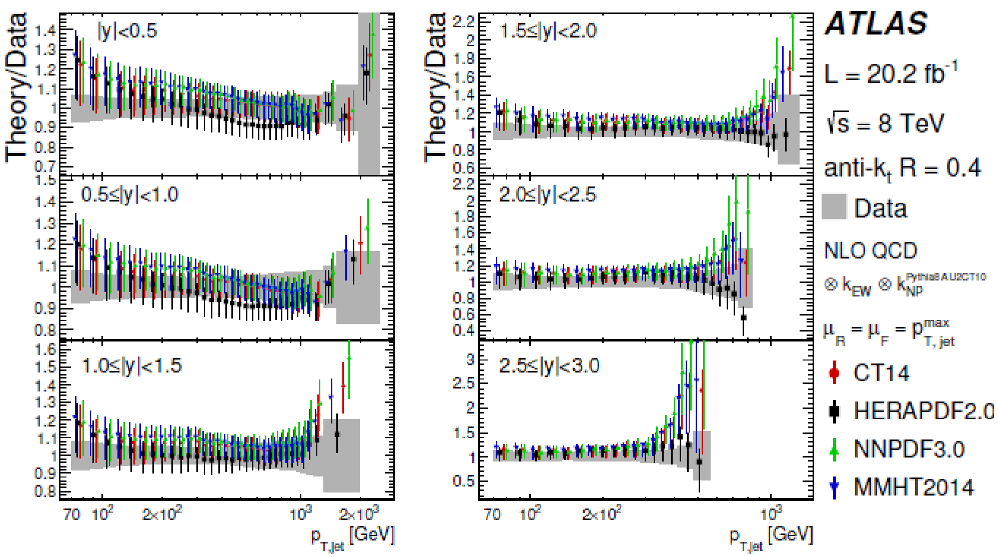
ATLAS: jets @ 8 TeV

arXiv:1706.03192

- Data covers more than **12 orders** of magnitude in cross-section
- **Doubly-differential inclusive jet cross-section**. Dominant syst. from jet energy scale, significant reduction vs previous measurement.
- Predictions from fixed order **NLO QCD (Powheg)**, corrected for nonpert. + EW effects. **Exp. < theory** uncertainty, power to constrain PDFs.
- Reasonably agreement in individual p_T, y bins, but tension when fitting all bins (p-values << 10^{-3})



$\mu_R=\mu_F=\max(p_T^{jet})$



Better agreement with $\mu_R=\mu_F=p_T^{jet}$

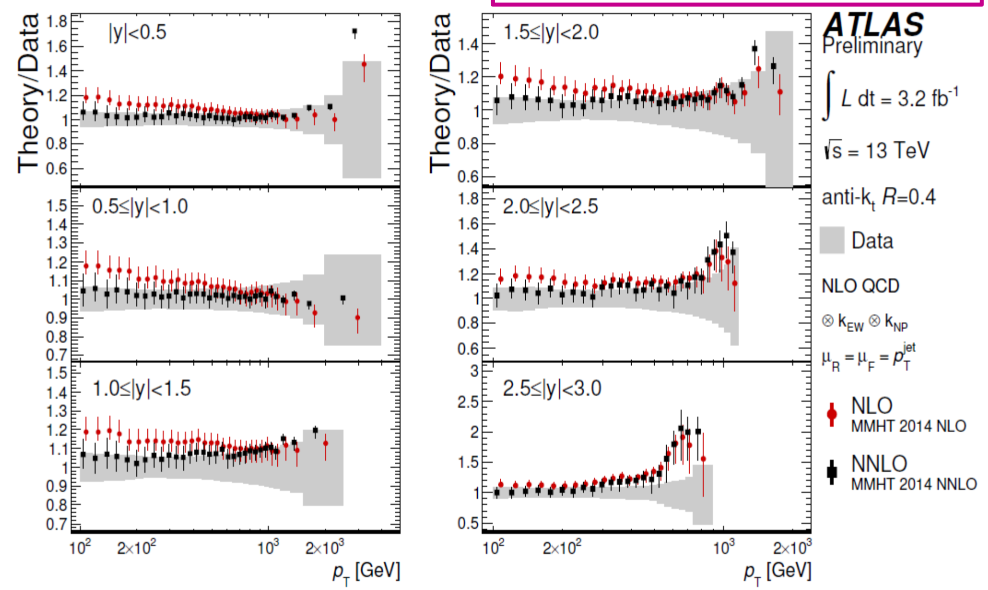
ATLAS: jets @ 13 TeV (3.2 fb^{-1})

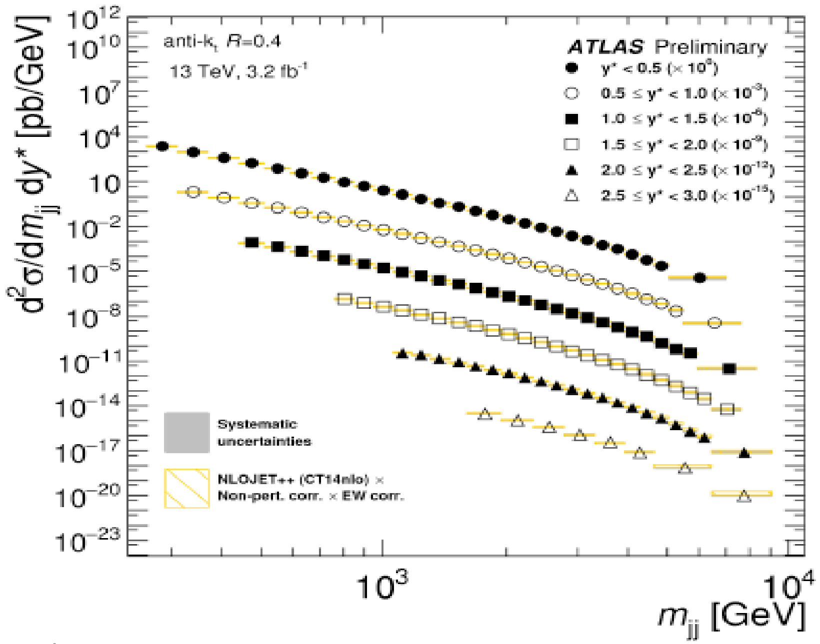
ATLAS-CONF-2017-048

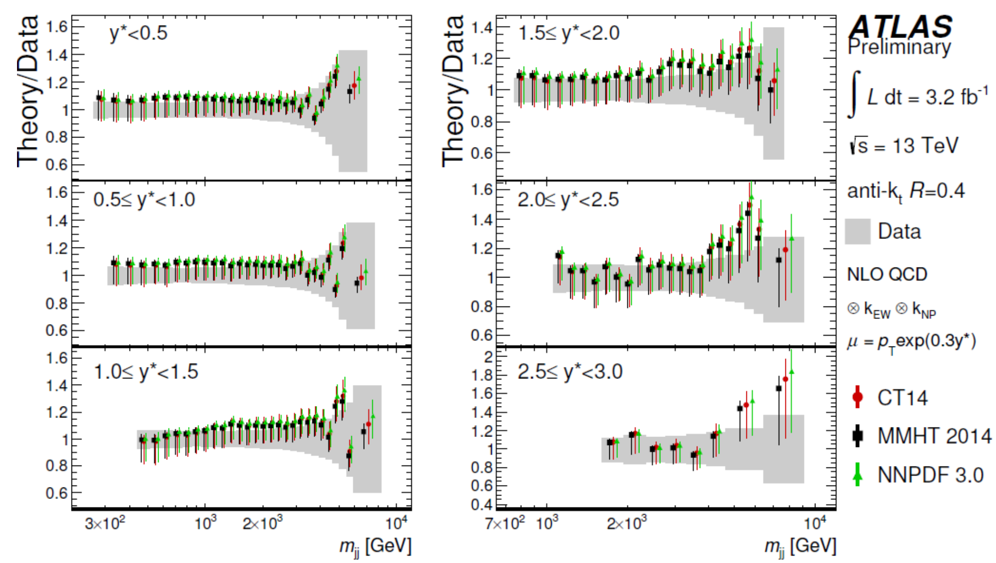
Doubly-differential measurements inclusive jet in p_T^{jet}, y^{jet} and dijet in m_{jj}, Δy^{jj}

NLOJet++ and **NNLOJet** used **(first time)**. **NNLO predictions** generally better but still rather sensitive to central scale choice

Overall **fair agreement with NLO pQCD** in individual y^{jet}, p_T^{jet} bins, strong tension in inclusive jet xsection measurement when considering all points (p_T^{jet}, y^{jet}) .





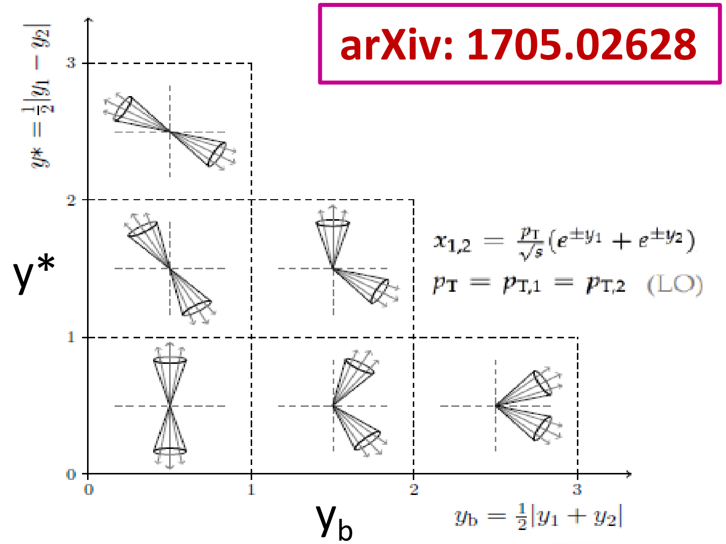


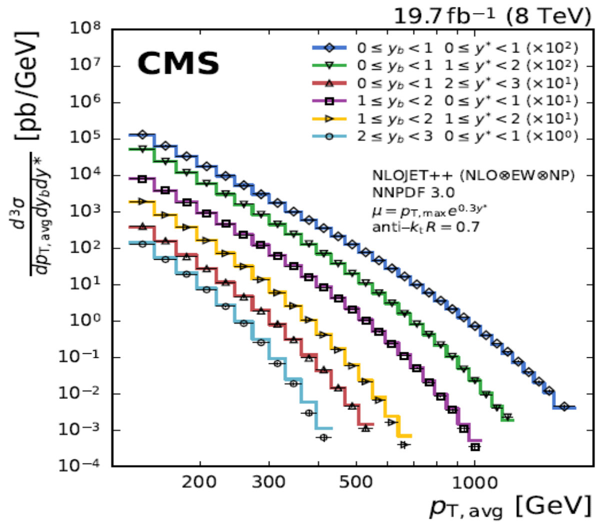
CMS: jets @ 8 TeV (19.7 fb^{-1})

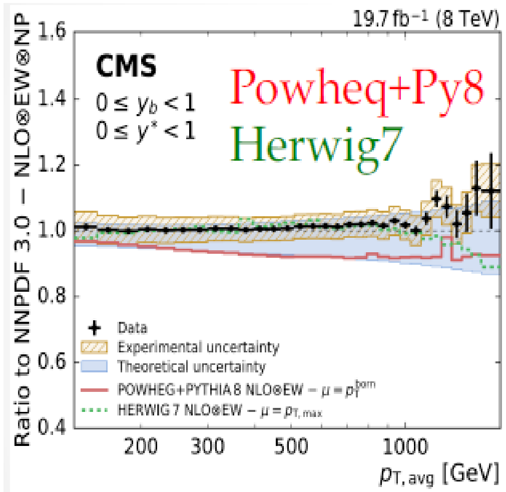
arXiv: 1705.02628

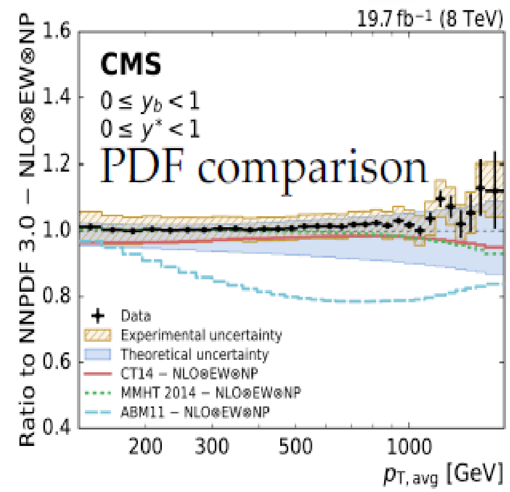
Tripple-differential dijet cross-section

- At high y_b and large p_T (less known x region) differences observed
- Both Powheg+Py8 (CT10) and Herwig7 (MMHT 2014) show differences
  - Central region better described by Herwig7, boosted by Powheg+Py8







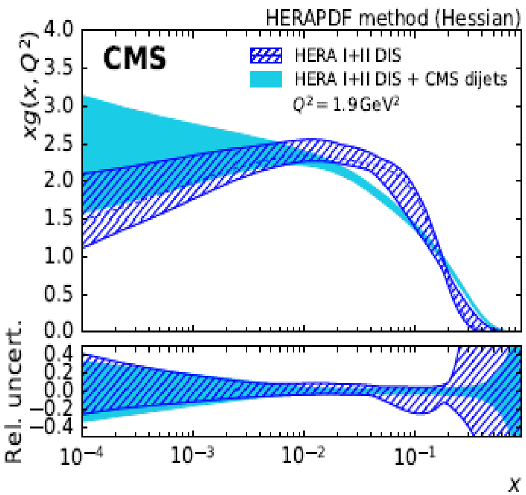


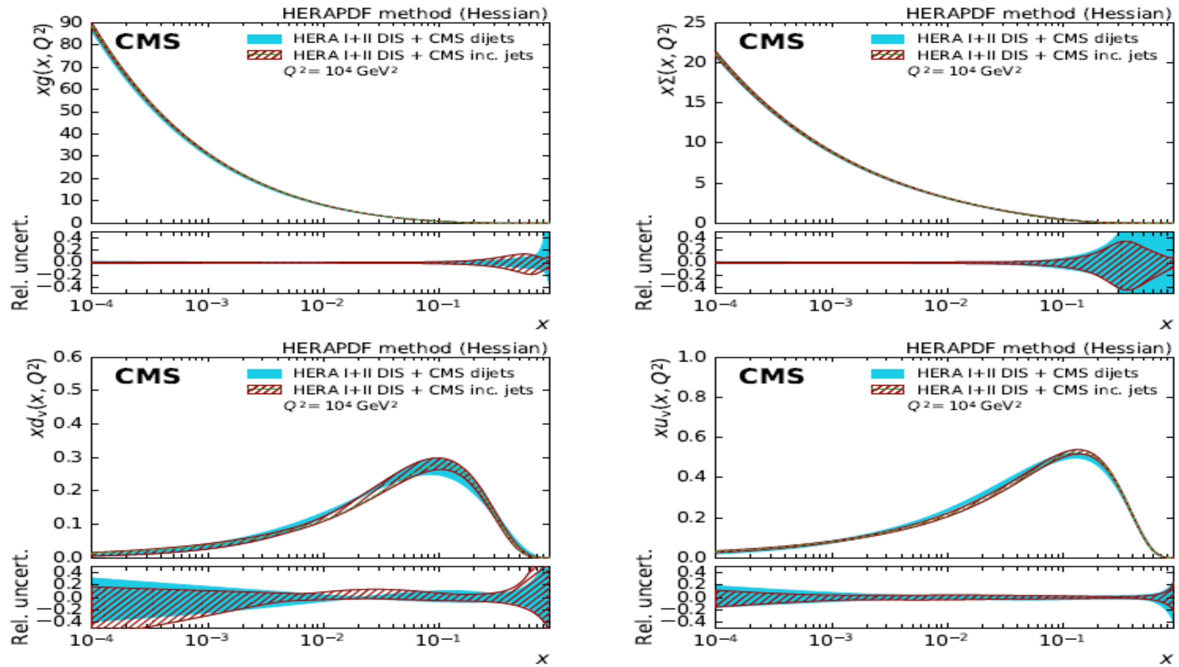
Dijet mass distribution (CMS-PAS-SMP-16-010) : sensitive to PS modeling, important for„boosted" searches.

CMS: jets and PDFs @8TeV

arXiv: 1705.02628

- Gluon-quark production dominates jet production for almost the full kinematic range except at high p_T where quark-quark takes over.
  - Inclusive jets analysis published in JHEP 03 (2017) 156





If α_s left free in the fit

$$\alpha_S(MZ) = 0.1199 \pm 0.0015(\mathrm{exp})^{+0.0002}_{-0.0002}(\mathrm{mod})^{+0.0002}_{-0.0004}(\mathrm{par})$$ dijet

$$\alpha_S(M_Z) = 0.1185^{+0.0019}_{-0.0021}(\mathrm{exp})^{+0.0002}_{-0.0015}(\mathrm{model})^{+0.0000}_{-0.0004}(\mathrm{param})^{+0.0022}_{-0.0018}(\mathrm{scale})$$ inclus. jet

Compatible with world average α_s=0.1181±0.0011