# QCD RESULTS IN ATLAS.

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on behalf of the ATLAS Collaboration

LHC Days 2018, Split, 17th–22nd September 2018

HELMHOLTZ | ASSOCIATION

ATLAS EXPERIMENT

DESY.

# Why make QCD measurements?

Measurements sensitive to QCD effects are precision tests of the SM

**Jet measurements**

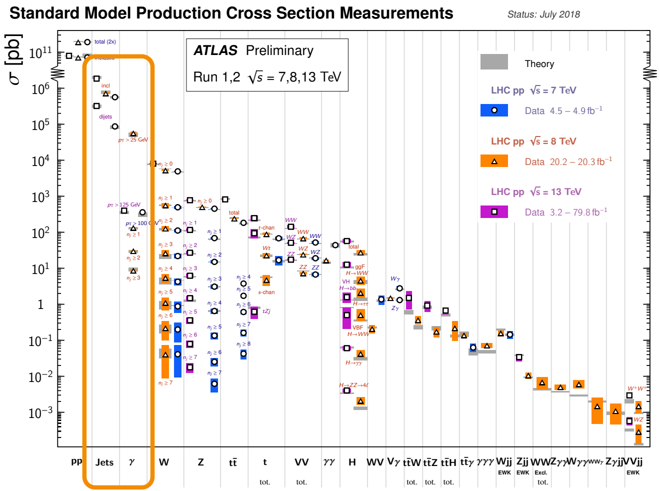
- Important components of PDF fits
- Determination of $\alpha_S$ from fits to kinematic distributions
- Powerful constraints on generic high-scale BSM searches

**Photon measurements**

- Colourless probe of hard partonic interactions
- Photon plus jet: direct probe of proton flavour content
- Rare multi-photon processes test higher-order QCD + EW

Test the validity of SM in challenging and previously unaccessible regions

# What has been measured by ATLAS?



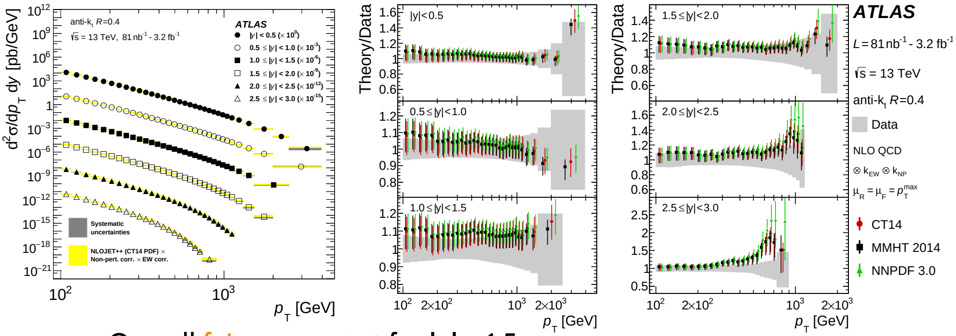

Full information on ATLAS public webpage

# Jet measurements

# Inclusive jet cross sections [13 TeV]

JHEP 05 (2018) 195
arXiv:1711.02692

- Double differential cross section as function of $p_T$ and $|y|$
- NLOJET++ prediction with non-perturbative and EW corrections




- Overall fair agreement for $|y| < 1.5$
- Significant data/theory tension when considering all bins
- Compatible with previous measurements at lower CoM energies

# Inclusive jet cross sections [13 TeV]

JHEP 05 (2018) 195
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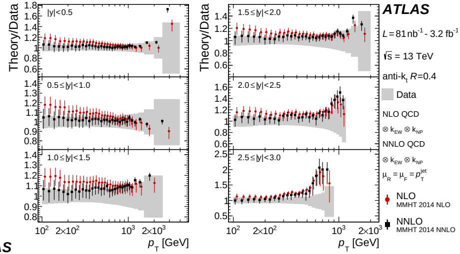
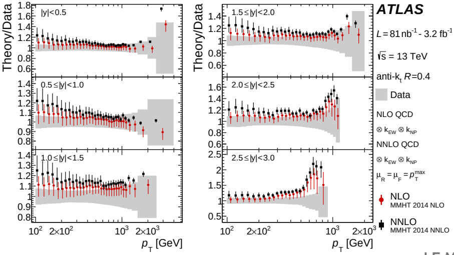
## NNLOJET predictions with $p_T^{jet}$ or $p_T^{max}$ as central scale




- Using $p_T^{jet}$ describes the data within uncertainties (except at highest |y|)
- NNLO performing better than NLO

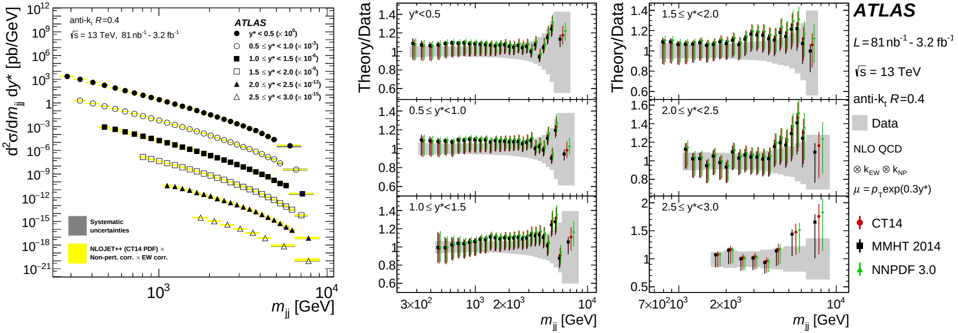



- $p_T^{max}$ overestimates data, particularly at low jet $p_T$
- NLO closer to data than NNLO!

# Dijet cross sections [13 TeV]

JHEP 05 (2018) 195
arXiv:1711.02692

- Cross section as function of $m_{jj}$ and $y^* = |y_1 - y_2|/2$
- NLOJET++ prediction with non-perturbative and EW corrections

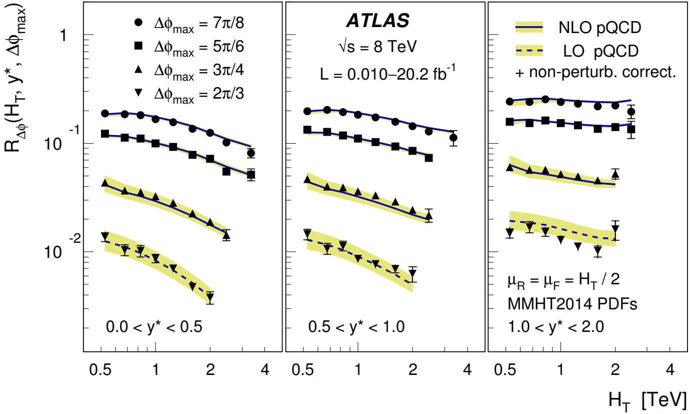



- Good agreement within experimental uncertainties across large mass range: 300 GeV < $m_{jj}$ < 9 TeV

# Dijet azimuthal decorrelations [8 TeV]

sub. PRD
arXiv:1805.04691

- Measure $R_{\Delta\phi}$: fraction of dijets with $\Delta\phi < \Delta\phi_{max}$
- Performed in y* bins for different $\Delta\phi_{max}$ choices

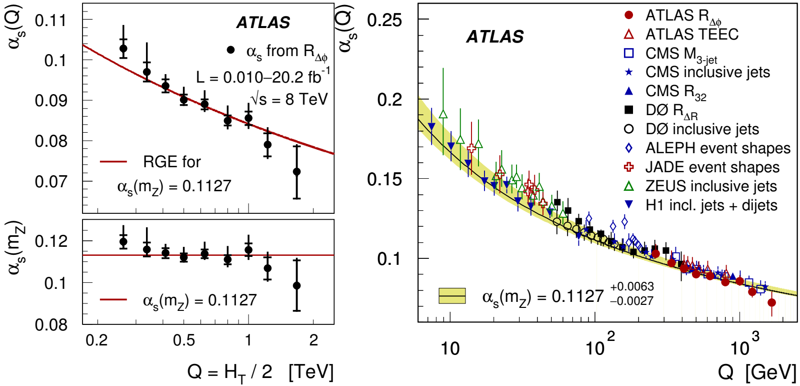



- NB. different $\Delta\phi_{max}$ values are not independent and hence only one is chosen in each bin when extracting $\alpha_S$

# Dijet azimuthal decorrelations [8 TeV]

sub. PRD
arXiv:1805.04691

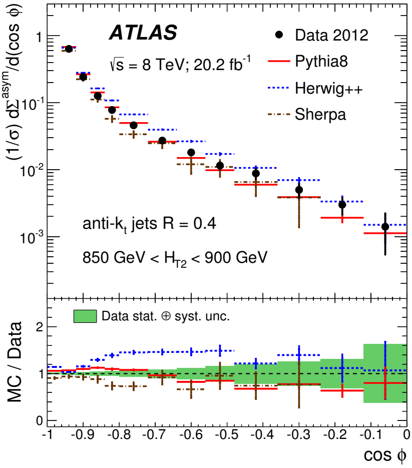
› $\chi^2$ fit of NLOJET++ predictions with varied $\alpha_S$ to data




| $\alpha_S(m_Z)$ | Total uncert. | Statistical | Experimental correlated | Non-perturb. corrections | MMHT2014 uncertainty | PDF set | $\mu_{R,F}$ variation |
|---|---|---|---|---|---|---|---|
| 0.1127 | $^{+6.3}_{-2.7}$ | $\pm 0.5$ | $^{+1.8}_{-1.7}$ | $^{+0.3}_{-0.1}$ | $^{+0.6}_{-0.6}$ | $^{+2.9}_{-0.0}$ | $^{+5.2}_{-1.9}$ |

# Transverse energy correlations [8 TeV]

EPJC 77 (2017) 872
arXiv:1707.02562




- Energy-weighted angular distribution of jet pairs

$$\frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi} \equiv \frac{1}{\sigma}\sum_{ij}\int \frac{d\sigma}{dx_{Ti}dx_{Tj}d\cos\phi}x_{Ti}x_{Tj}dx_{Ti}dx_{Tj}$$

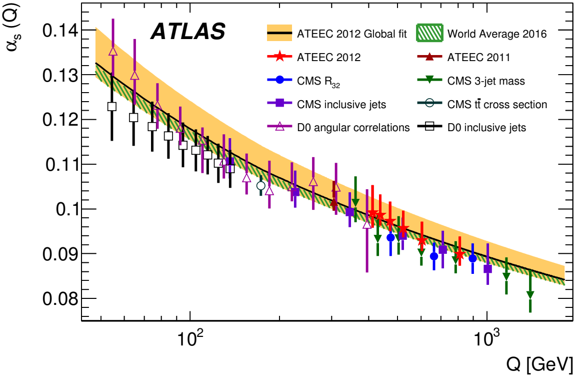
(where $x_{Ti} = E_{Ti}/\Sigma_k E_{Tk}$)

- Measured in bins of $H_{T2} = p_{T1} + p_{T2}$
- Unfolded results agree well with PYTHIA and SHERPA while disfavouring HERWIG++

# Transverse energy correlations [8 TeV]

EPJC 77 (2017) 872
arXiv:1707.02562

- Fit NLOJET++ predictions with varied $\alpha_S$ to data
- Extract $\alpha_S(M_Z)$ for each $H_{T2}$ bin
- Each value evolved to Q = $H_{T2}/2$ using two loop RGE



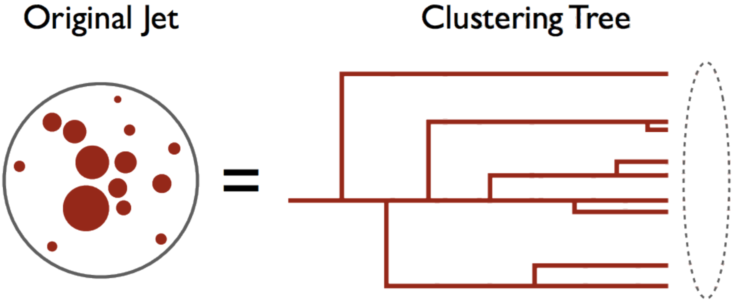

$$\alpha_s(m_Z) = 0.1162 \pm 0.0011\ (\text{exp.})\ ^{+0.0076}_{-0.0061}\ (\text{scale}) \pm 0.0018\ (\text{PDF}) \pm 0.0003\ (\text{NP})$$

# Soft-drop jet mass [13 TeV]

sub. PRL
arXiv:1711.08341

- First recluster anti-$k_t$ constituents with angular-ordered C-A:
  1. Undo the last clustering, labelling subjets $j_1$ and $j_2$
  2. If $\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} < z_c \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$ then remove lower $p_T$ subjet
  3. Iterate until the condition is satisfied

  $\rightarrow$ mass of remaining subjet is $m_{\text{soft-drop}}$



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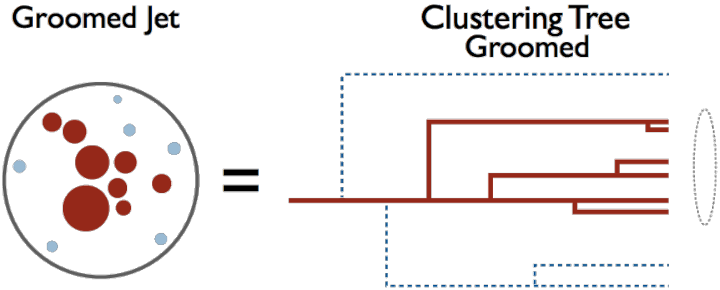
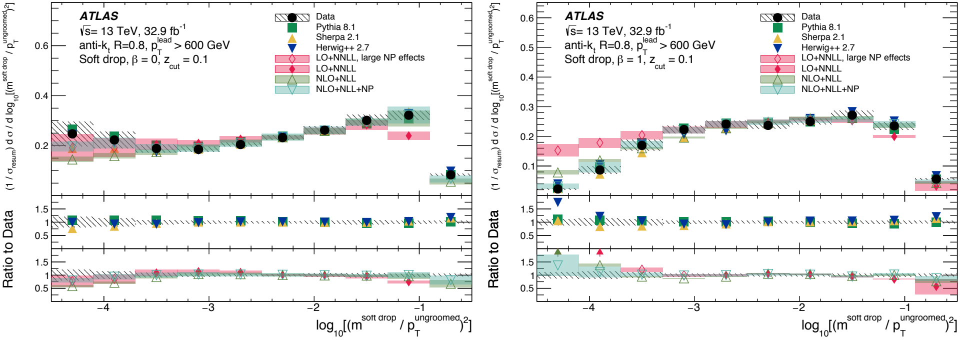


# Soft-drop jet mass [13 TeV]

sub. PRL
arXiv:1711.08341

› Cross section as function of $\log(\rho^2)$ where $\rho = m_{softdrop}/p_T^{original}$




$\beta$ = 0 $\qquad\qquad$ $\beta$ = 1

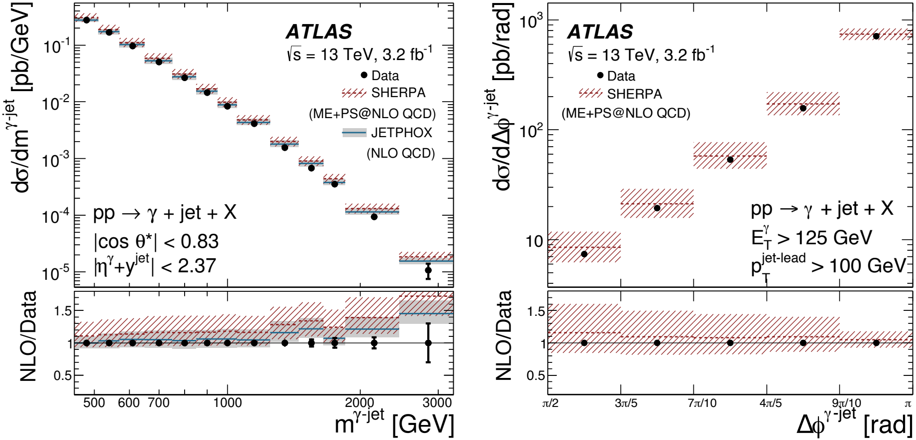
› High $\log(\rho^2)$: good agreement with perturbative calculations
› Significant non-perturbative effects → MC performs better

# Photon measurements

# Photon plus jet cross sections [13 TeV]

PLB 780 (2018) 578
arXiv:1801.00112

› Differential cross sections as functions of: $E_T^{\gamma}$, $p_T^{jet}$, $\Delta\phi^{\gamma-jet}$, $m^{\gamma-jet}$



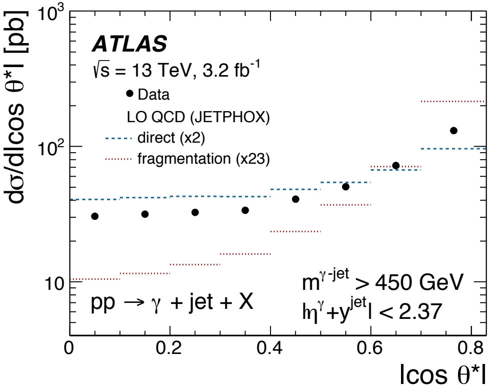

› JETPHOX and SHERPA NLO describe data within theory uncs.

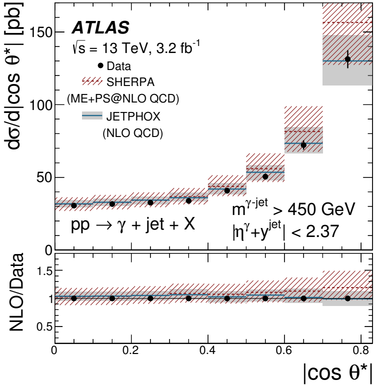
› Need $2 \rightarrow 4(5)$ processes for $\Delta\phi^{\gamma-jet}$ (not included in JETPHOX)

# Photon plus jet cross sections [13 TeV]

PLB 780 (2018) 578
arXiv:1801.00112

- Differential cross section as function of $\cos\theta^* = \tanh\left(\eta^\gamma - y^{jet}\right)$
- Direct production ($\gamma$ from ME) behaves as $(1 - |\cos\theta^*|)^{-1}$
- Fragmentation ($\gamma$ from high $p_T$ parton) behaves as $(1 - |\cos\theta^*|)^{-2}$



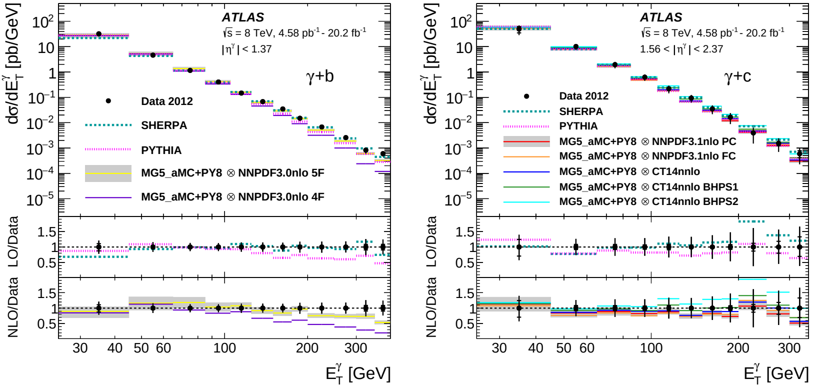




- Direct (quark-exchange) process dominant as predicted

# Photon plus heavy flavour jet[8 TeV]

PLB 776 (2018) 295
arXiv:1710.09560

- Sensitive to b/c-quark content → test 4FS vs. 5FS modelling
- For $\gamma$ + c: BHPS PDF sets with different intrinsic charm content

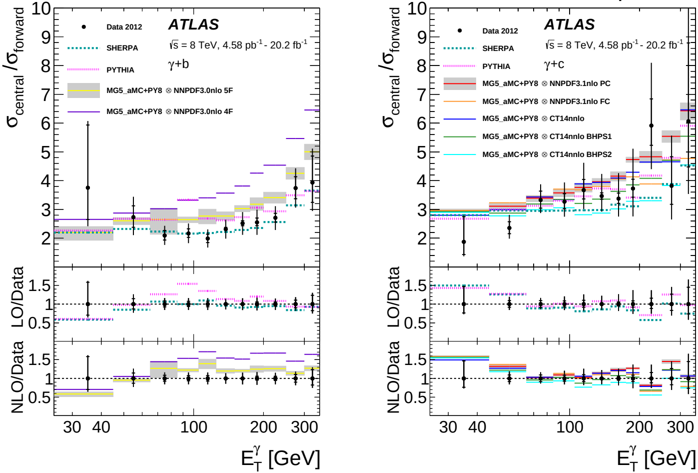



- LO SHERPA and PYTHIA (both 5FS) describe data well
- 5FS provides a better description for the data up to 200 GeV
- BHPS predictions higher in forward region than nominal PDFs

# Photon plus heavy flavour jet [8 TeV]

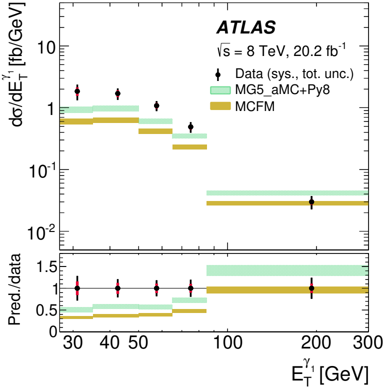
PLB 776 (2018) 295
arXiv:1710.09560

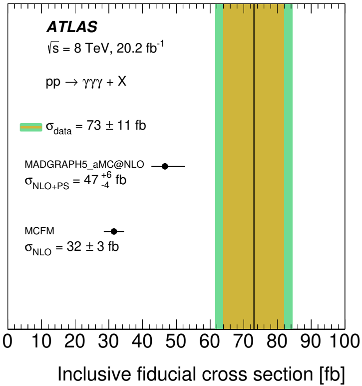
- Ratios of the central and forward cross sections vs. $E_T^{\gamma}$




- $\gamma$ + b: 4FS and 5FS predictions overestimate data at higher $E_T$
- Constraint of proton intrinsic charm needs better data precision

- Rare process ($\alpha_{EM}^3$ at LO) important bkg for BSM searches
- Study topology and kinematics of $\gamma$, $\gamma\gamma$ and $\gamma\gamma\gamma$ systems




- NLO predictions $\rightarrow$ poor description of data for low $E_T^\gamma$
- Parton shower improves the agreement with the data
- Improved modelling needed (eg. NNLO calculations for $\gamma\gamma\gamma$)

# Conclusions

# Conclusions

Perturbative QCD describes data within theoretical uncertainties

## Jets

- Inclusive jet and dijet measurements constraining PDFs
- First 13 TeV comparisons to NNLO
- Extracted $\alpha_S$ values in good agreement with PDG world average

## Photons

- First measurement of photon plus jet production at 13 TeV
- Photon probes of heavy flavour content in the proton
- Triphoton production: test of pQCD using rare SM process
  - higher order predictions needed to adequately describe the data