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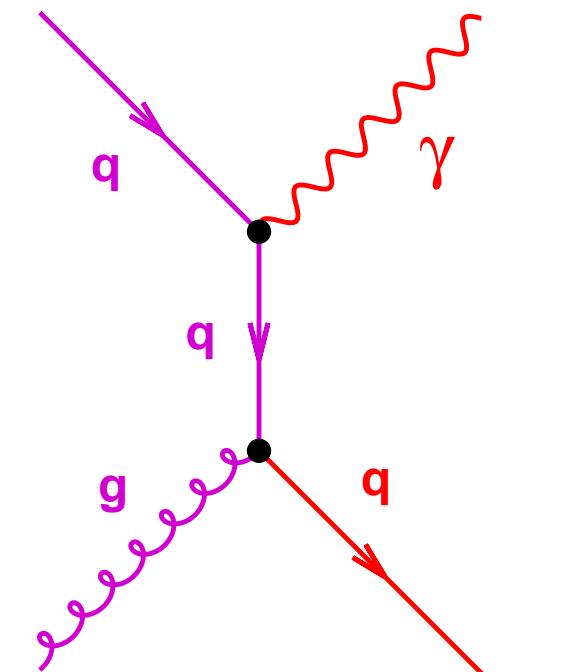
# Inclusive-photon production and its dependence on photon isolation in $pp$ collisions at $\sqrt{s} = 13$ TeV using $139\text{ fb}^{-1}$ of ATLAS data

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## Physics with photons at LHC

- Measurements of the production of high  $p_T$  prompt photons (in association with jets) in hadron colliders provide
  - tests of pQCD predictions
    - ★ the photon comes directly from the hard interaction (no hadronisation)
      - cleaner reaction than jet production
    - ★ probe of the underlying production mechanism
  - experimental information on the proton PDFs
    - ★ dominant production mechanism:  $qg \rightarrow q\gamma$
    - ★ constraints on the proton PDFs, especially the gluon PDF at high  $x$
  - input to understand the background to Higgs production and BSM searches in photon decaying channels
    - ★ validation of Monte Carlo models



direct photon (plus jet(s))

## Physics with photons at LHC

- Other sources of photons:

- hadron decays (eg,  $\pi^0 \rightarrow \gamma\gamma$ )

- photons are produced copiously inside jets

- ⇒ isolating photons largely removes this background

- photon bremsstrahlung off quarks →

- ⇒ fragmentation photon process: signal

- Thus, to study prompt photons in hadron colliders, it is essential to require the photon to be isolated

- This is achieved by requiring

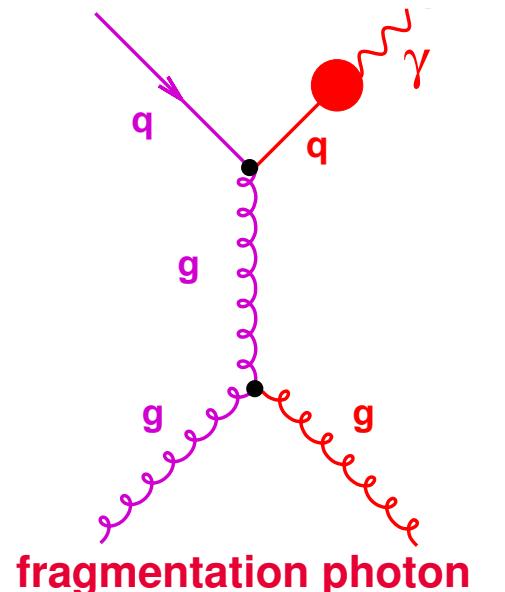
- ★ cone isolation:  $E_T^{\text{iso}} \equiv \sum_i E_T^i < E_T^{\max}$ , with the sum over the particles (except the photon) inside a cone of radius  $R$  centered on the photon in the  $\eta - \phi$  plane

- used in experiment to suppress the contribution of photons inside jets

- ★ Frixione isolation:  $E_T^{\max}(\tau) = \epsilon E_T^\gamma ((1 - \cos \tau) / (1 - \cos \mathcal{R}))^n$  for all  $\tau < \mathcal{R}$ , where  $\mathcal{R}$  is the maximal cone size and  $\epsilon$  is a constant

- ★ hybrid (Frixione+cone) isolation

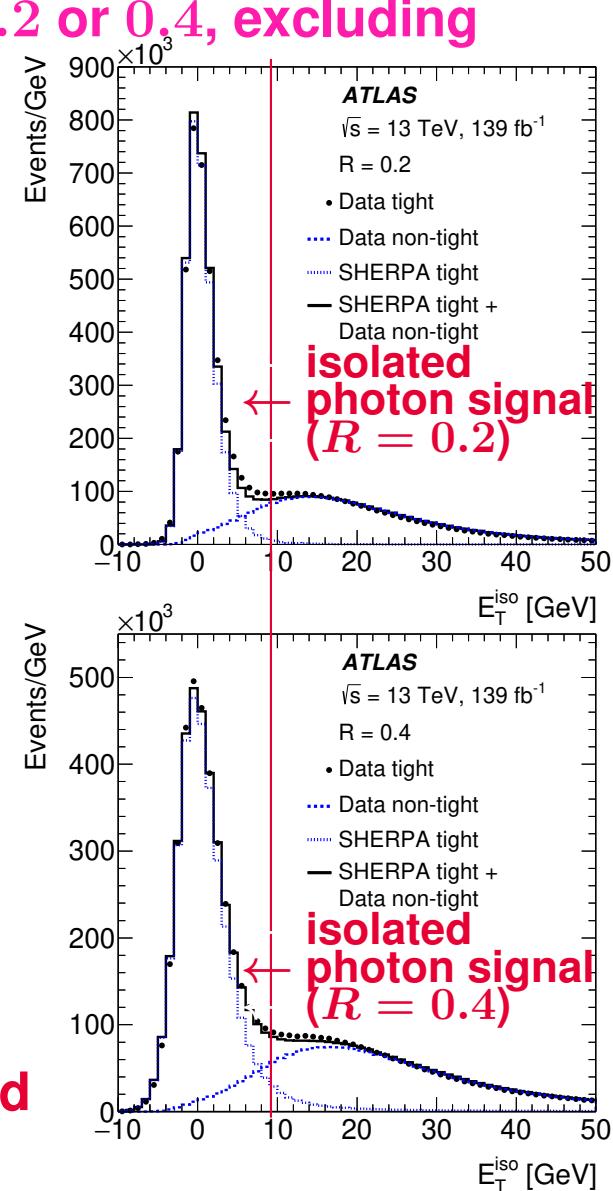
- Frixione or hybrid isolation can be used in theory to avoid divergencies in the matrix elements when the photon is collinear with a parton



## Photon isolation in ATLAS

- $E_T^{\text{iso}}$  is computed by using all particles in a cone of  $R=0.2$  or  $0.4$ , excluding the contribution from the photon
- The leakage of the photon energy is subtracted (few %)
- The underlying event and pileup contribute to  $E_T^{\text{iso}}$   
→ event-by-event correction computed using the jet-area method (M Cacciari et al, JHEP 0804 (2008) 005)
- After these corrections, the  $E_T^{\text{iso}}$  distribution is centered at zero
- A photon candidate is considered isolated if  

$$E_T^{\text{iso}}(R) < 4.2 \cdot 10^{-3} \cdot E_T^\gamma + 4.8 \text{ GeV}$$
- Clear signal of photon production observed
- Residual background removed using a data-driven method



ATLAS Collab, arXiv:2302.0051

## Fixed-order QCD calculations

### JETPHOX (fixed order)

- Full fixed-order NLO pQCD calculations for direct and fragmentation processes
- **Scales:**  $\mu_R = \mu_F = \mu_f = E_T^\gamma / 2$  ( $E_T^\gamma$ )
- **Fragmentation functions:** BFG II
- **PDFs:** MMHT2014, CT18, NNPDF3.1, and HERAPDF2.0 at NLO; ATLASpdf21 at NNLO
- **Isolation:** fixed cone at parton level
- **Non-perturbative corrections:** estimated using PYTHIA samples. Consistent with unity within  $\pm 1\%$  (no correction applied)

### SHERPA NLO (multi-leg merged)

- Parton-level calculations for  $\gamma + 1, 2 (3, 4)$  jets at NLO (LO) supplemented with PS
- Only direct contribution (Frixione's isolation at ME level)
- **Scales:** dynamic scale setting ( $E_T^\gamma$ )
- **PDFs:** NNPDF3.0 NNLO
- **Fragmentation into hadrons and UE simulated as for SHERPA LO**
- **Isolation:** fixed cone at particle level

### NNLOJET (fixed order)

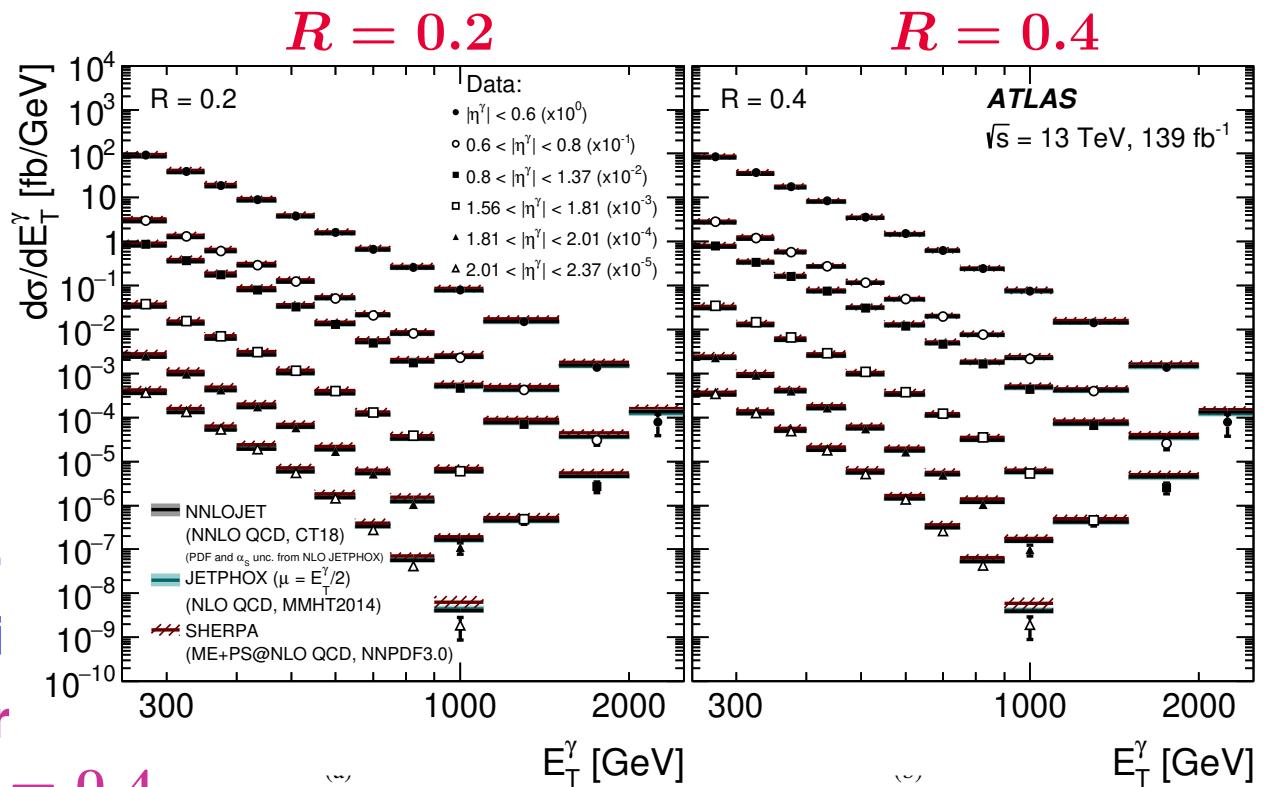
- Full fixed-order NNLO pQCD calculations for direct and fragmentation processes
- **Scales:**  $\mu_R = \mu_F = E_T^\gamma$   
 $\mu_f = \sqrt{E_T^\gamma \cdot E_T^{\max}} \cdot R$
- **Fragmentation functions:** BFG II
- **PDFs:** CT18 NNLO
- **Isolation:** fixed cone at parton level
- **Non-perturbative corrections:** same estimation as for JETPHOX

## Inclusive isolated photons: testing pQCD

$pp \rightarrow \gamma + X$ : inclusive isolated-photon cross sections

$\mathcal{L} = 139 \text{ fb}^{-1}$

- $E_T^\gamma > 250 \text{ GeV}$  and  $|\eta^\gamma| < 2.37$  (excluding  $1.37 < |\eta^\gamma| < 1.56$ )
- $d\sigma/dE_T^\gamma$  decreases by six orders of magnitude in the measured range
- Values of  $E_T^\gamma$  up to 2.5 TeV are measured
- Shape of  $d\sigma/dE_T^\gamma$  similar for different  $\eta^\gamma$  regions and radii
- Normalisation of  $d\sigma/dE_T^\gamma$  for  $R = 0.2$  is higher than for  $R = 0.4$

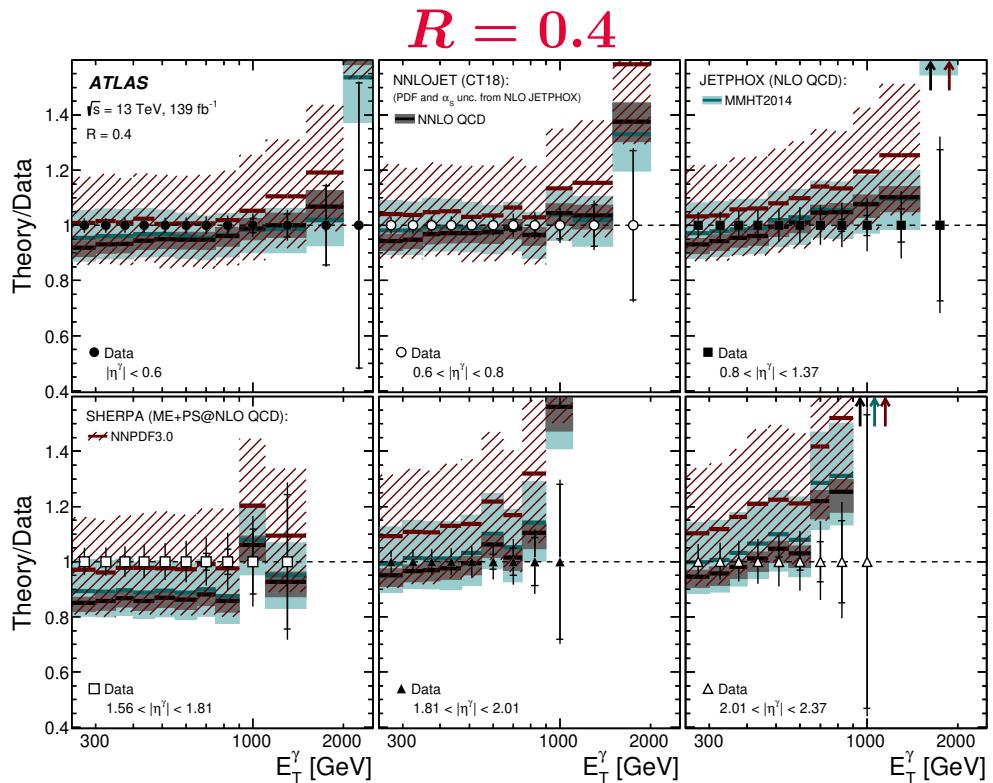
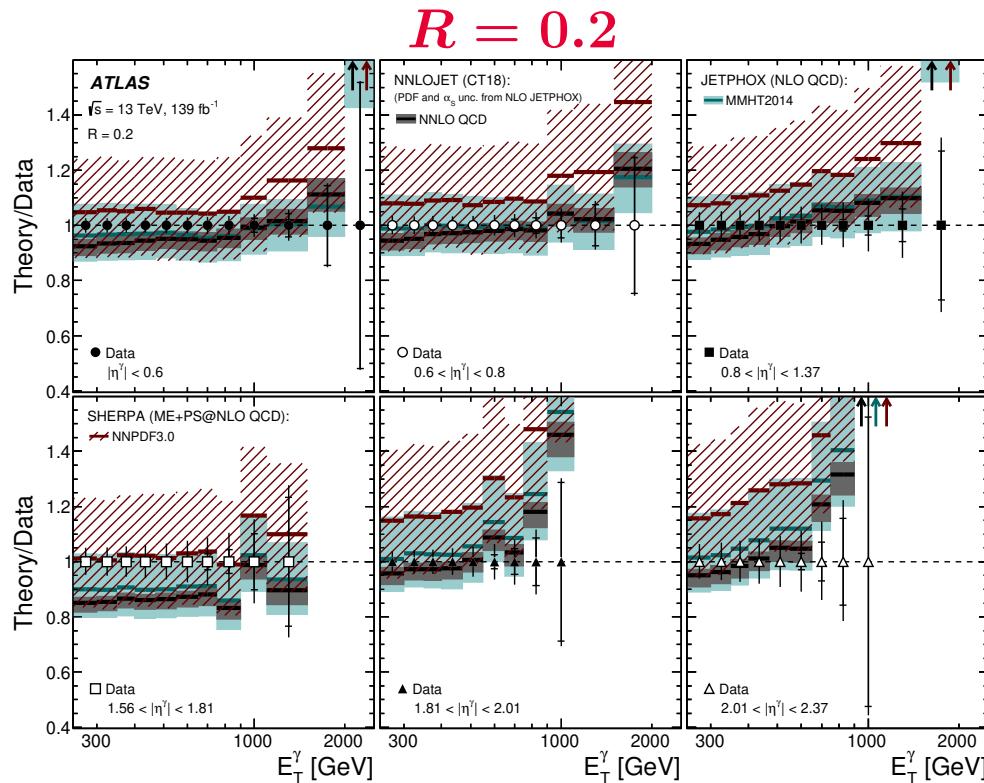


- Comparison with pQCD predictions:  
→ NLO and NNLO predictions generally describe the data within the uncertainties

# Inclusive isolated photons: testing pQCD

$pp \rightarrow \gamma + X$ : inclusive isolated-photon cross sections

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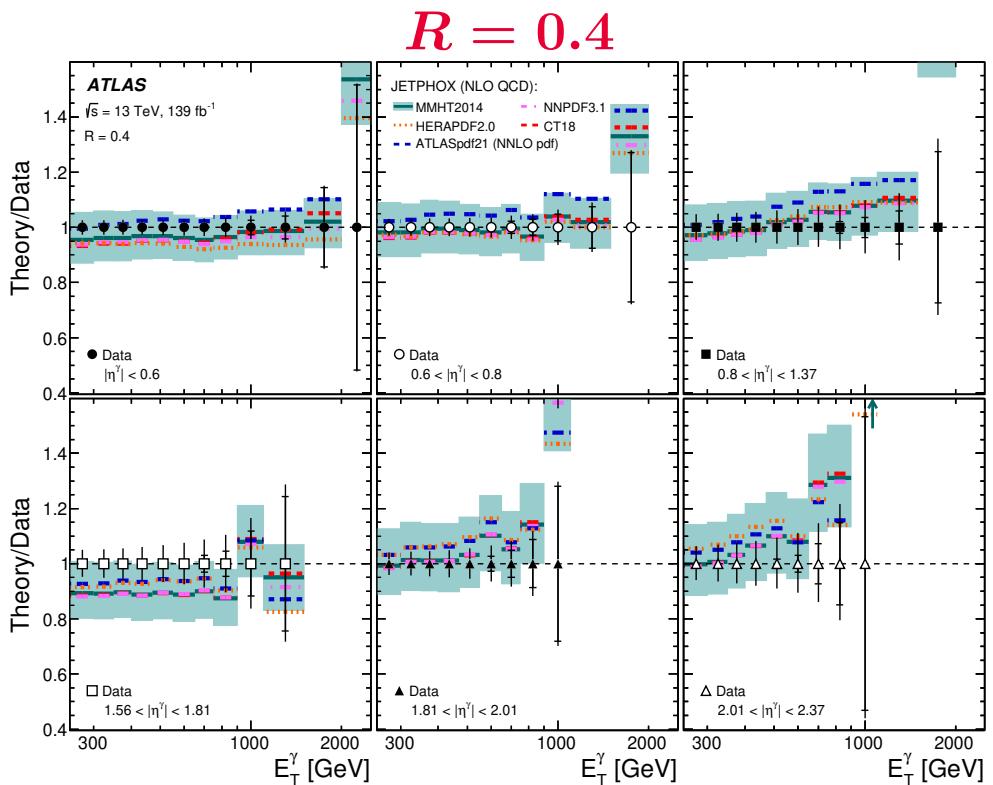
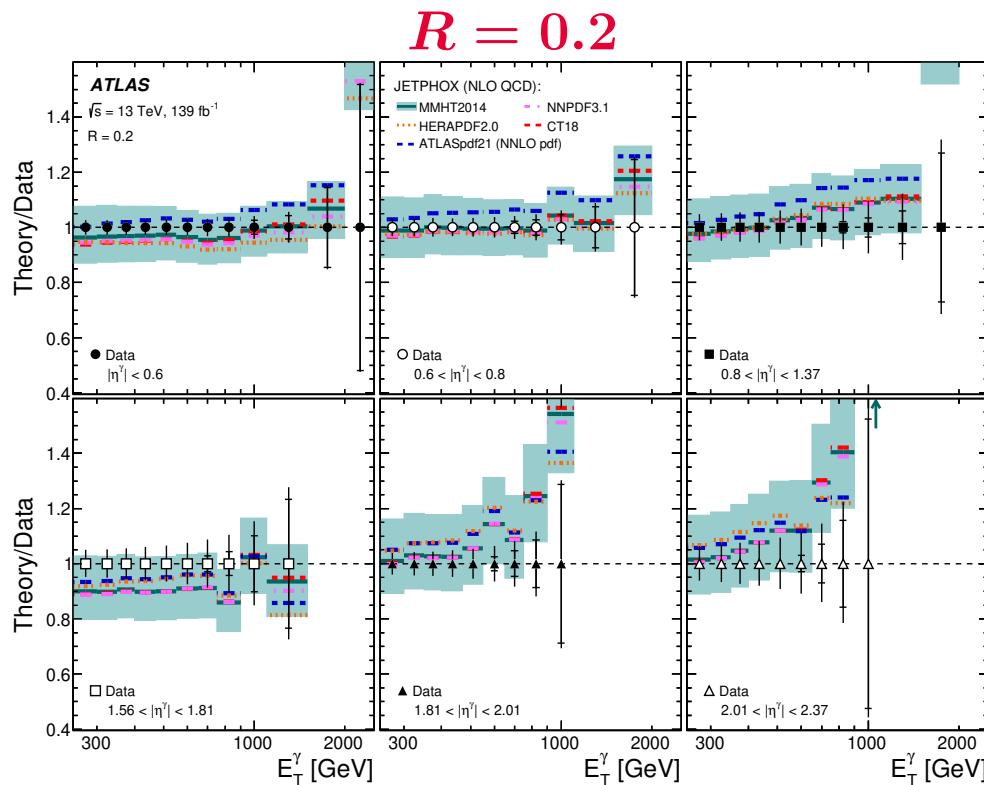


- Comparison with pQCD predictions:  
→ NLO and NNLO predictions generally describe the data within the uncertainties

## Inclusive isolated photons: sensitivity to PDFs

$pp \rightarrow \gamma + X$ : inclusive isolated-photon cross sections

$\mathcal{L} = 139 \text{ fb}^{-1}$



- Comparison with pQCD predictions based on different PDFs show differences  
→ The measurements have the potential to further constrain the PDFs

ATLAS Collab, arXiv:2302.0051

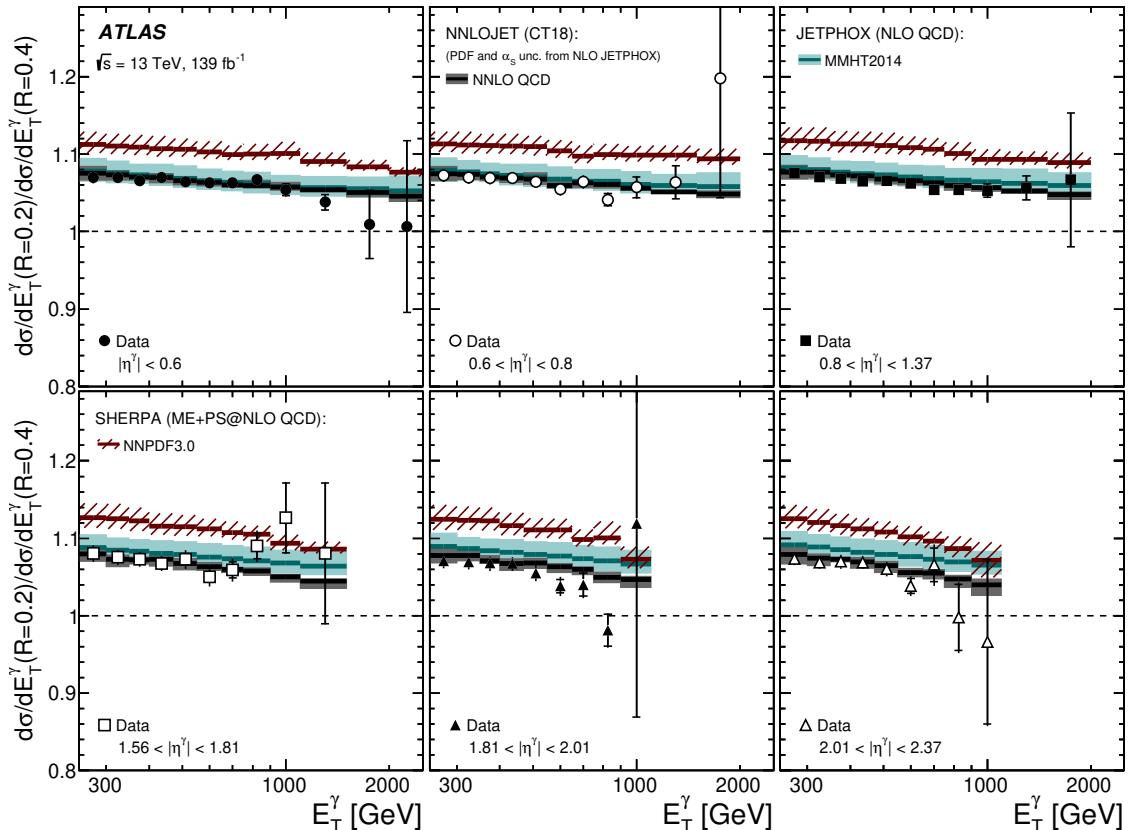
## Ratios of differential cross sections: tests of pQCD

$pp \rightarrow \gamma + X$ : inclusive isolated-photon cross sections

$\mathcal{L} = 139 \text{ fb}^{-1}$

- Dependence on  $R$  studied by measuring the ratios of the differential cross sections for  $R=0.2$  and  $R=0.4$  as functions of  $E_T^\gamma$  in different regions of  $\eta^\gamma$

- These measurements provide a very stringent test of pQCD with reduced experimental and theoretical uncertainties (both  $\approx 1\%$ !)



⇒ Validation of the underlying pQCD theoretical description up to  $\mathcal{O}(\alpha_s^2)$

ATLAS Collab, arXiv:2302.0051

## Conclusions

- Measurements of cross sections for inclusive isolated-photon production in  $pp$  collisions at  $\sqrt{s} = 13$  TeV using  $139 \text{ fb}^{-1}$  of ATLAS data were presented
- Differential cross sections measured as functions of  $E_T^\gamma$  in six different regions of  $\eta^\gamma$  for isolated photons with  $E_T^\gamma > 250 \text{ GeV}$  and  $|\eta^\gamma| < 2.37$  and for two isolation cone radii → ratios of differential cross sections
  - test of pQCD predictions in a wide range of  $E_T^\gamma$
  - more detailed experimental information for PDF fits is provided
- NLO pQCD predictions from SHERPA and JETPHOX using several PDFs give an adequate description of measured  $d\sigma/dE_T^\gamma$  within uncertainties
  - dependence on  $R$  well described by the JETPHOX predictions, whereas SHERPA overestimates the data
- NNLO pQCD predictions give a good description of the data within the uncertainties, except for  $1.56 < |\eta^\gamma| < 1.81$ 
  - ⇒ comparison of the ratios between data and NNLO predictions validates the underlying pQCD theoretical description up to  $\mathcal{O}(\alpha_s^2)$

# **Back-up slides**

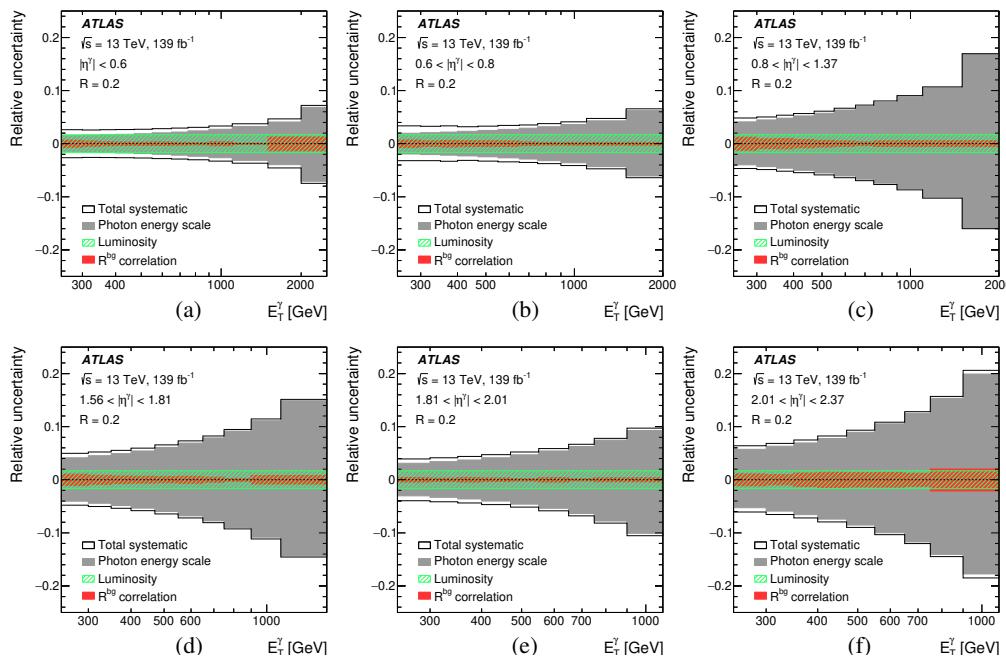
# Systematic uncertainties

$pp \rightarrow \gamma + X$ : inclusive isolated-photon cross sections

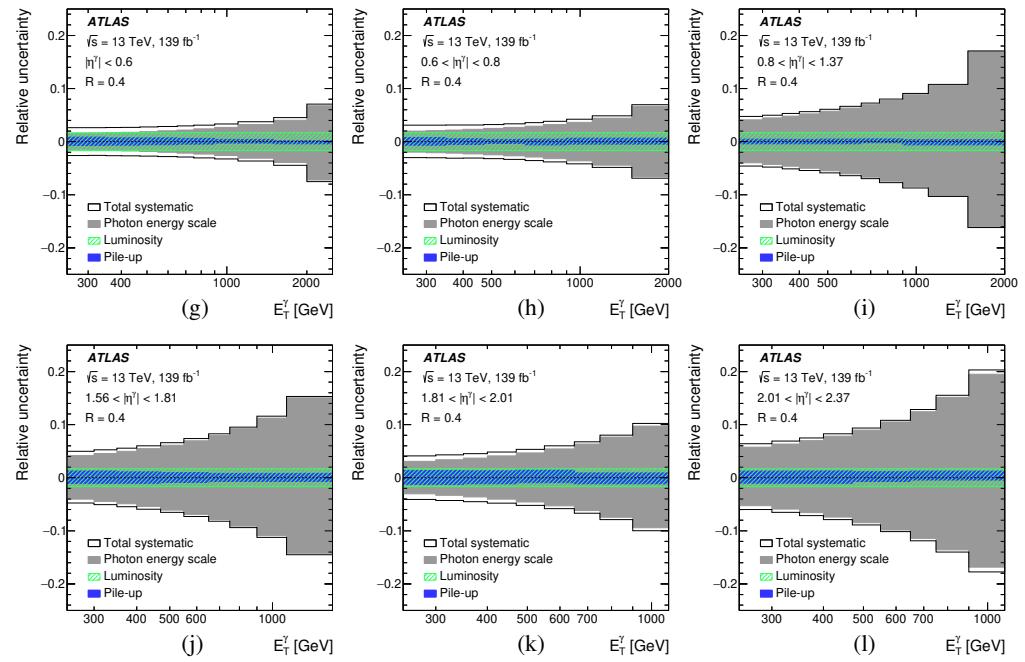
$\mathcal{L} = 139 \text{ fb}^{-1}$

- Systematic uncertainties in differential cross sections:

$$R = 0.2$$



$$R = 0.4$$



# Systematic uncertainties

$pp \rightarrow \gamma + X$ : inclusive isolated-photon cross sections

$\mathcal{L} = 139 \text{ fb}^{-1}$

- Systematic uncertainties in ratio of differential cross sections:

