Measurement of photon production at ATLAS

Josu Cantero (Oklahoma State University)

On behalf of the ATLAS collaboration

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Outline

Physics with Photons

- Inclusive photon 13 TeV/8 TeV ratio

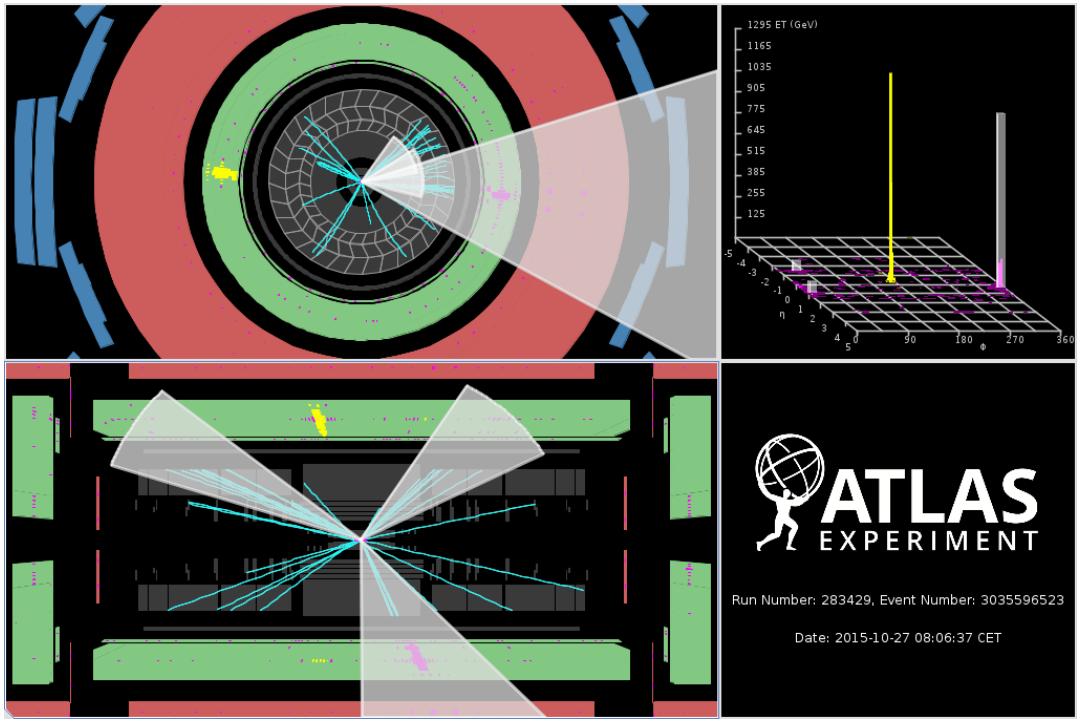
  JHEP 04 (2019) 093

- γ + jet at 13 TeV

  Phys. Lett. B 780 (2018) 578

- Inclusive photon at 13 TeV

  STDM-2017-29



→ γ + jet at 13 TeV: E_T^{γ}, p_T^{jet}, $|\cos\theta^*|$, $m^{\gamma j}$ and $\Delta\phi^{\gamma j}$.

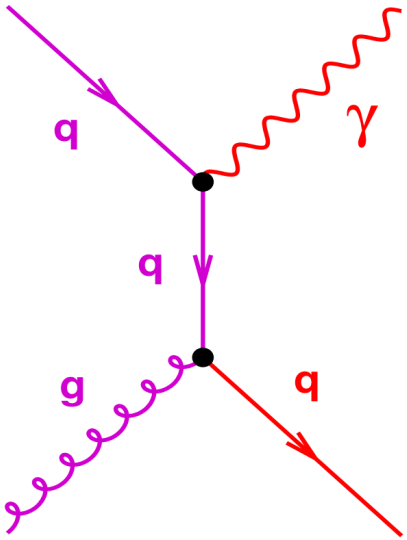
→ Inclusive γ 13 TeV/8 TeV ratio: E_T^{γ} ratio in different η^{γ} regions: $|\eta| \in$ [0,0.6], [0.6,1.37], [1.56,1.81], [1.81,2.37].

→ Inclusive γ at 13 TeV: E_T^{γ} in different η^{γ} regions: $|\eta| \in$ [0,0.6], [0.6,1.37], [1.56,1.81], [1.81,2.37].

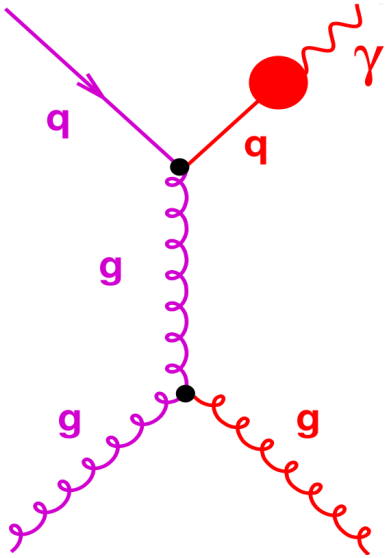
Prompt photon production at LHC

→ Prompt photons: photons not coming from hadron decays

Direct



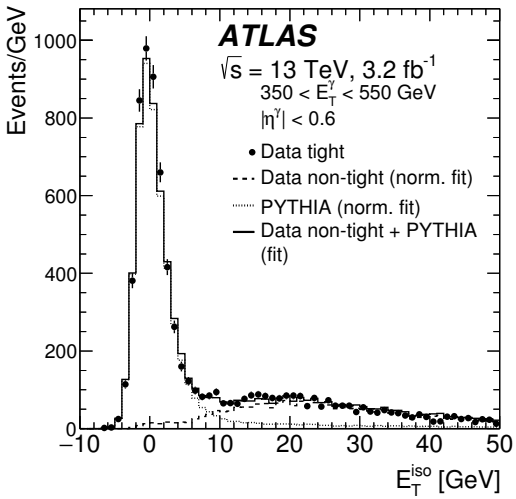
Fragmentation



- Test of pQCD with a hard colorless probe.
  - → Sensitive to gluon PDF at LO through Compton scattering.
- Background of BSM searches and SM measurements (H→ $\gamma\gamma$):
  - → BSM: Monophoton/jet, extra dimensions, $q*$, exotic neutral particles, spin-2 gravitons ...
- Possibilities of studies of inclusive photon or in association with jets.
  - → Study of the dynamics of the hard process.
  - → Improving MC modelling.
  - → PDF fits in certain regions of (x, Q^2) plane.

Jet background subtraction

- Main background in inclusive photon and photon + jets measurements.
  - → Contribution strongly depends on the E_T^γ range.



→ Clear signal observed after applying photon identification (γ_{ID}) and isolation requirements.

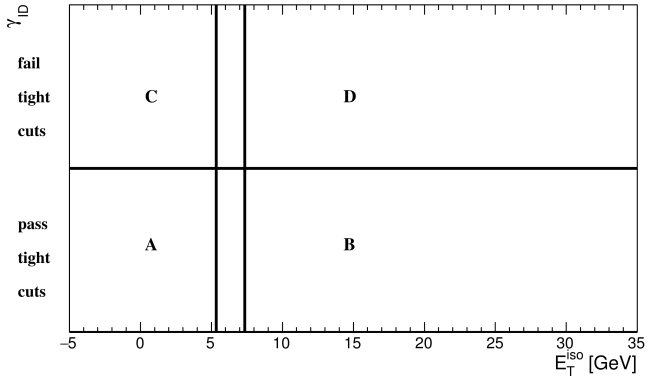
→ Residual background remains due to jet mis-identified as photons.

→ Good description of the photon isolation distribution.

→ SR: $E_T^{iso} < 4.8$ GeV $+ 4.2{\cdot}10^{-3}{\cdot}\ E_T^\gamma$ (high efficiency in the whole E_T^γ range) and tight γ_{ID}.

- Data-driven background subtraction:
  - → 2D-sideband method in γ_{ID} vs E_T^{iso} plane.
  - → The leading loose γ_{ID} photon is classified into one of the four regions in the plane.

$$\frac{N_A^{bg}}{N_B^{bg}} = R^{bg}\frac{N_C^{bg}}{N_D^{bg}}$$



→ Accounting for signal leakage factors (from MC*) ϵ_i → $N_i^{bg} = N_i^D - \epsilon_i{\cdot}\ N_A^S$ → second order equation for N_A^S (two solutions $N_A^S > 0$ and $N_A^S < 0$)→ $P_A^S \gtrsim 92\%$ for $E_T^\gamma > 125$ GeV.

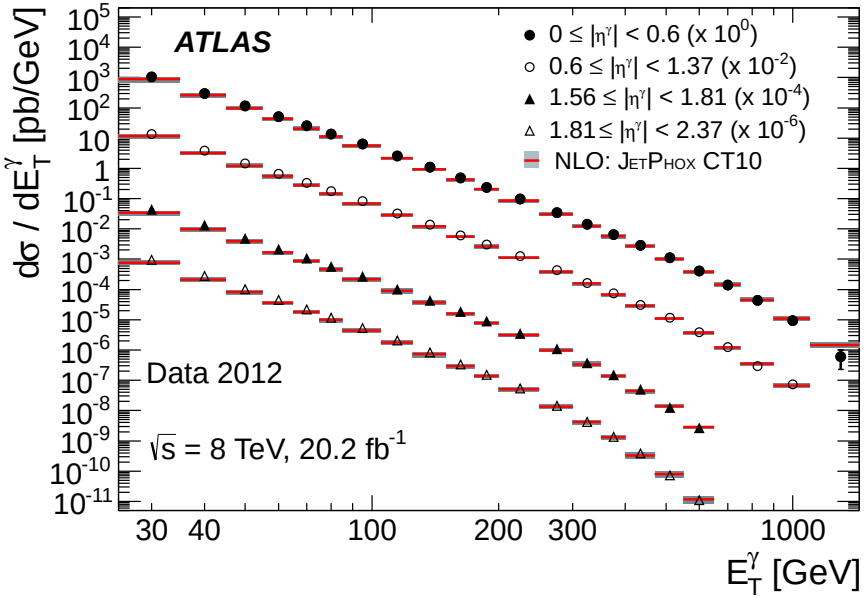
→ *LO Sherpa (multi-leg 2→5 ME, QCD PS) and Pythia (2→2 ME, QCD+QED PS)

Inclusive cross-section ratios between $\sqrt{s}$= 13 and 8 TeV

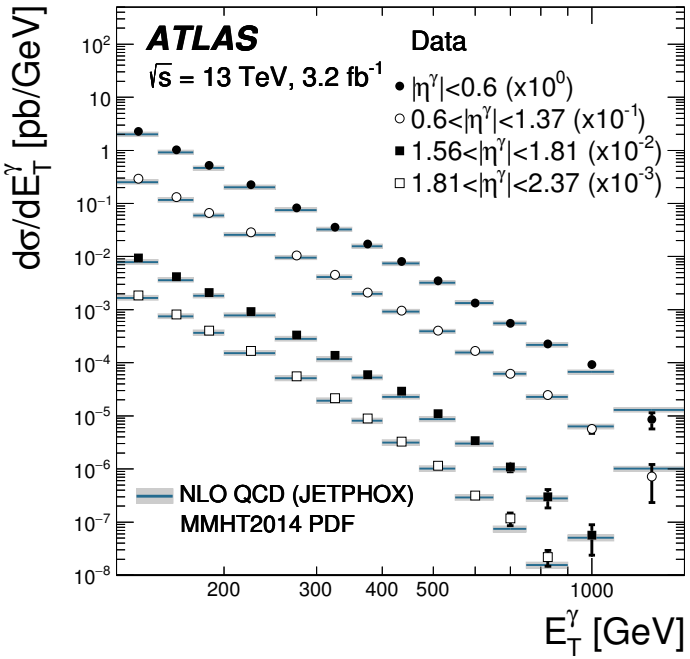
→ Ratio of the mesured differential cross sections as a function of E_T^γ at $\sqrt{s} = 13$ and 8 TeV.

→ Phase space region: $E_T^\gamma > 125$ GeV, $|\eta^\gamma| < 2.37 \notin 1.37 < |\eta^\gamma| < 1.56$, $E_T^{iso} < 4.8$ GeV + $4.2{\cdot}10^{-3}{\cdot}\ E_T^\gamma$ in $\Delta R = 0.4$.

JHEP 06 (2016) 005



Phys. Lett. B 770 (2017) 473



→ Comparisons to NLO QCD limited by the size of the theoretical uncertainties (typically larger than the experimental uncertainties).

→ More stringent test of theory through cross-section ratios at different $\sqrt{s}$.

- Test the evolution as function of $\sqrt{s}$

→ Detailed study of the correlation of the uncertainties.

Inclusive cross-section ratios between $\sqrt{s}$= 13 and 8 TeV

→ Full correlation of uncertainties used when justified.

- Mainly in the estimation of the photon energy scale (extra uncertaintes at 13 TeV for changes in configuration of the ATLAS detector).
- Other uncertainties taken conservatively as uncorrelated: changes in running conditions, optimization of the photon identification or differences in the estimation of the systematic uncertainties.

→ Luminosity uncertainty (2.8%, uncorrelated between $\sqrt{s}$) plays an important role.

- Reduce the uncertainty by performing measurement of double ratios

$$D_{13/8}^{\gamma/Z} = \frac{R_{13/8}^{\gamma}(\mathrm{E_T^{\gamma}})}{\sigma_Z^{\mathrm{fid}}(13\ \mathrm{TeV})/\sigma_Z^{\mathrm{fid}}(8\ \mathrm{TeV})}$$

$\sigma_Z^{\mathrm{fid}}(13\ \mathrm{TeV})/\sigma_Z^{\mathrm{fid}}(8\ \mathrm{TeV}) = 1.537 \pm 0.001\ (\mathrm{stat}) \pm 0.010\ (\mathrm{syst}) \pm 0.044\ (\mathrm{lumi})$

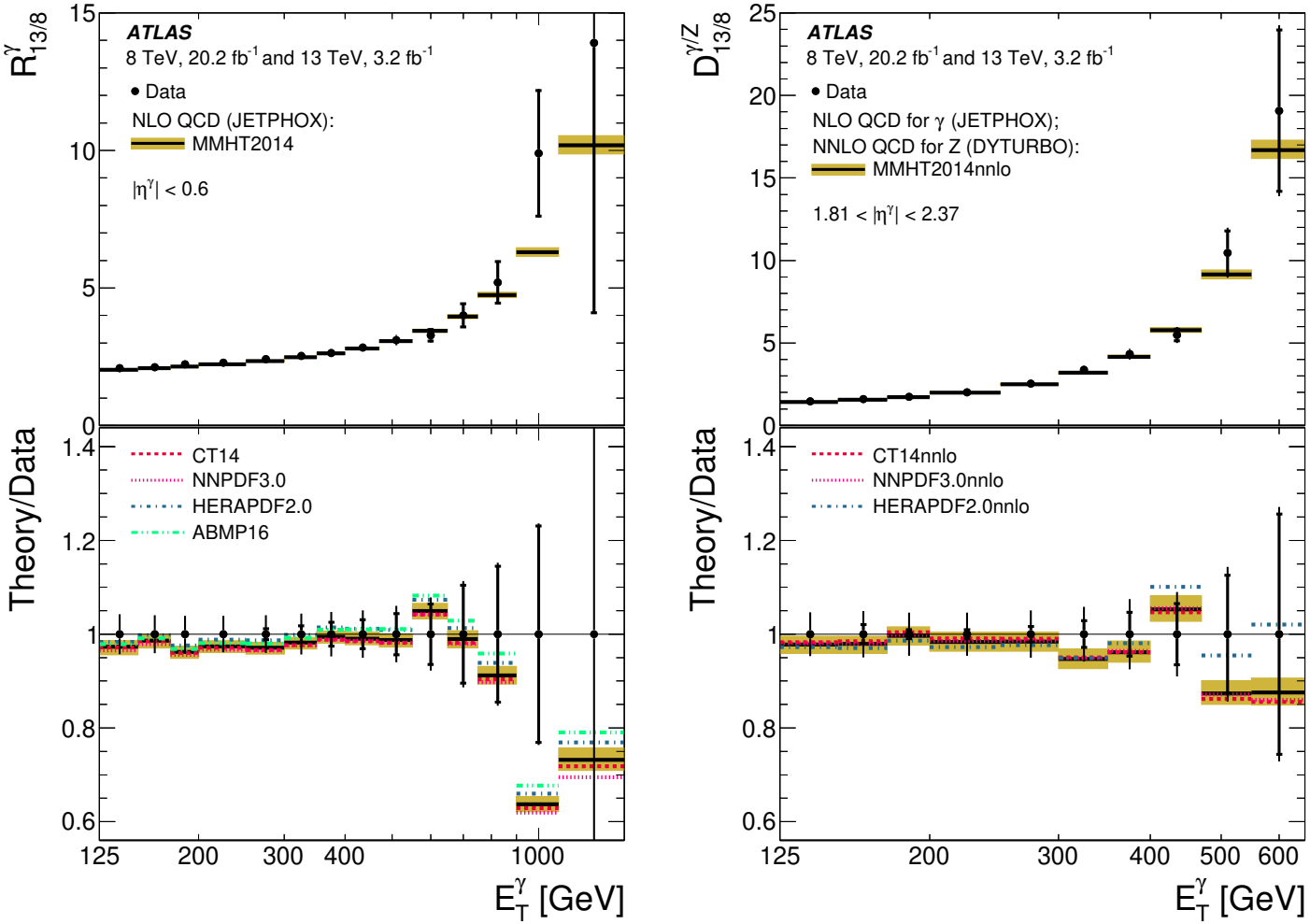
(measured by ATLAS in JHEP 02 (2017) 117)

→ Systematic uncertainty of 0.7% dominated by lepton efficiency. Predictions computed with Dyturbo at NNLO QCD ($\Delta_{\mathrm{th}} \sim O(1\%)$) → uncorrelated with respect to $R_{13/8}^{\gamma}(\mathrm{E_T^{\gamma}})$ theoretical uncertainties.

- Theoretical predictions for $R_{13/8}^{\gamma}(\mathrm{E_T^{\gamma}})$ at NLO QCD obtained using JETPHOX
  - → Uncertainties due to scale variations, PDF, α_S,beam energy and non-perturbative corrections are considered as correlated between both $\sqrt{s}$ → large reduction of the theoretical uncertainties compared to the individual inclusive photon measurements.

Inclusive cross-section ratios between $\sqrt{s}$= 13 and 8 TeV

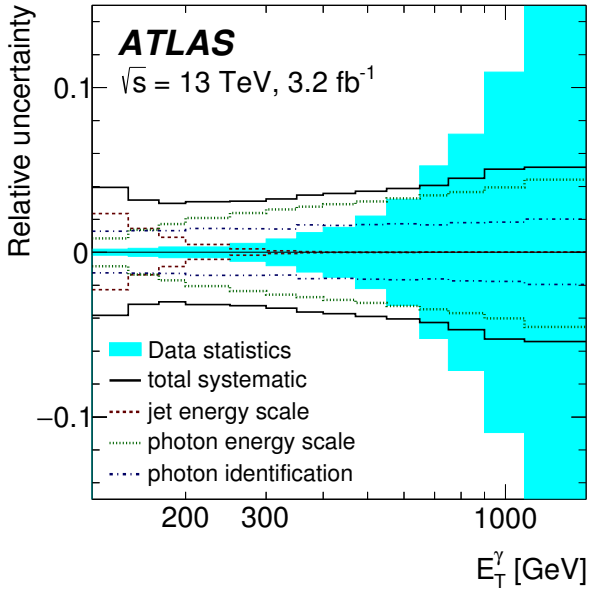
- Measured $R^{\gamma}_{13/8}(\mathrm{E}^{\gamma}_{\mathrm{T}})$ compared to NLO QCD calculations.

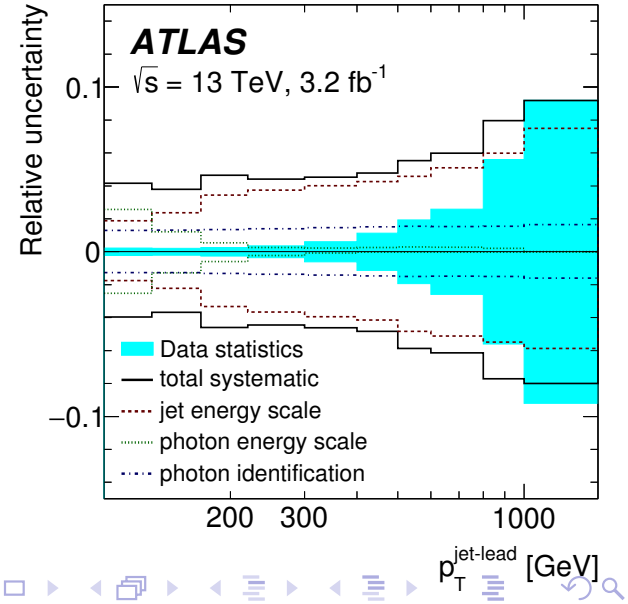


- NLO predictions agree with the measured $R^{\gamma}_{13/8}(\mathrm{E}^{\gamma}_{\mathrm{T}})$ within the reduced theoretical uncertainties (2-4%).

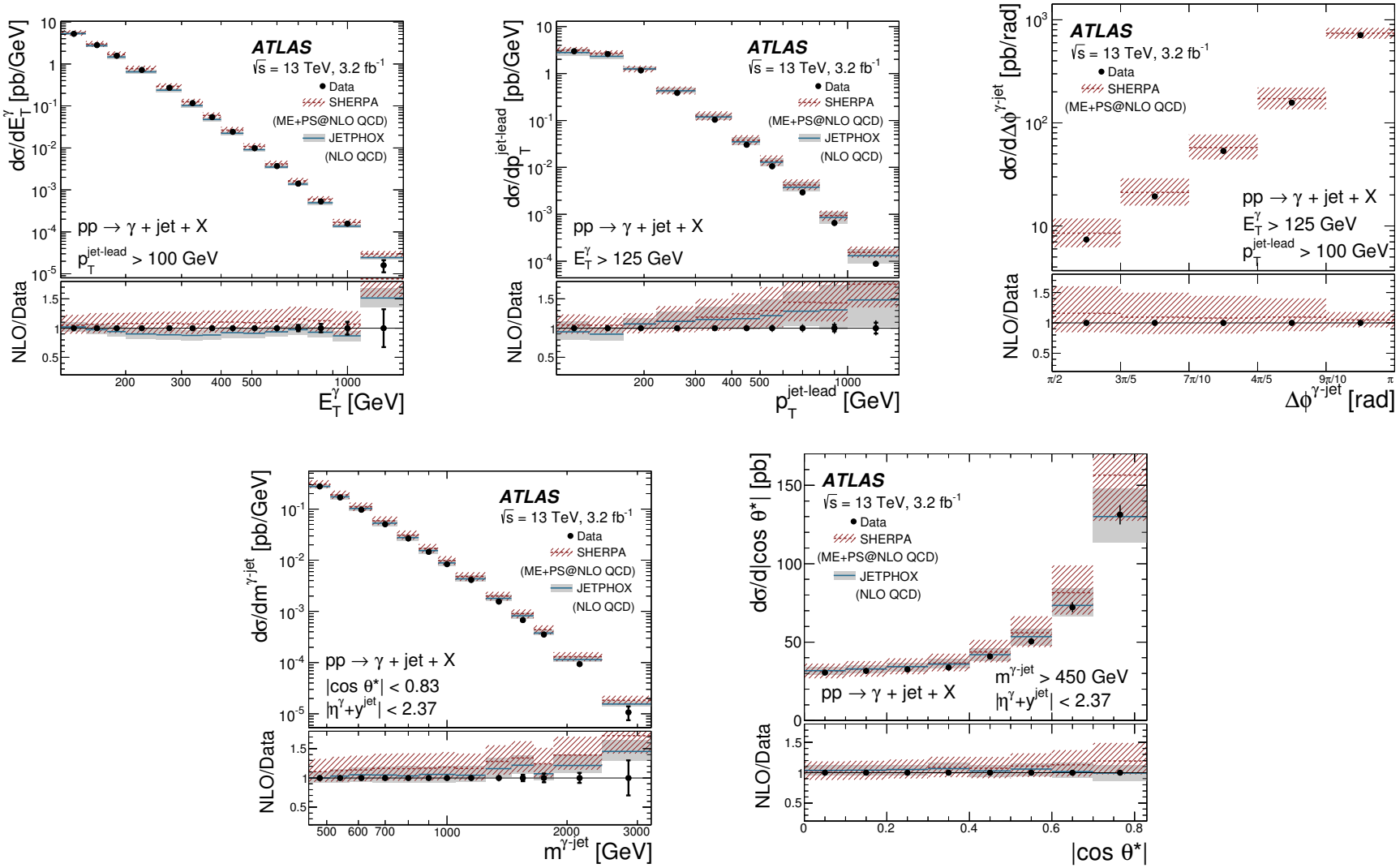
Photon plus jet production at $\sqrt{s} = 13$ TeV

- → Measurement of the γ + jet differential cross sections as functions of E_T^γ, p_T^{jet}, $\Delta\phi^{\gamma-j}$, $m^{\gamma-j}$ and $|\cos\theta^*|$ with $\mathcal{L} = 3.2$ fb^{-1}.
- → Phase space region: $E_T^\gamma > 125$ GeV, $|\eta^\gamma| < 2.37 \notin 1.37 < |\eta^\gamma| < 1.56$, $E_T^{iso} < 10$ GeV $+ 4.2{\cdot}10^{-3}{\cdot}\ E_T^\gamma$ in $\Delta R = 0.4$; $\Delta R^{\gamma-j} > 0.8$, $p_T^{jet} > 100$ GeV and $|y^{jet}| < 2.37$.
  - → Unbiased selection for $m^{\gamma-j}$ and $|\cos\theta^*|$: $|\eta^\gamma| + |y^{jet}| < 2.37$, $m^{\gamma-j} > 450$ GeV.
- → Total systematic uncertainty (4-5%) dominated by jet energy scale, photon energy scale and γ-ID.
- → Statistical uncertainty dominates in the tail of the measurements as functions of E_T^γ, p_T^{jet} and $m^{\gamma-j}$.
- → Measurements comparared to:
  - LO SHERPA (multi-leg 2→5 ME, QCD PS)
  - PYTHIA (2→2 ME, QCD+QED PS)
  - NLO SHERPA (merged 1,2 jets at NLO + 3,4 LO ME, QCD PS)
  - NLO pQCD JETPHOX → corrected to include hadronisation + UE effects





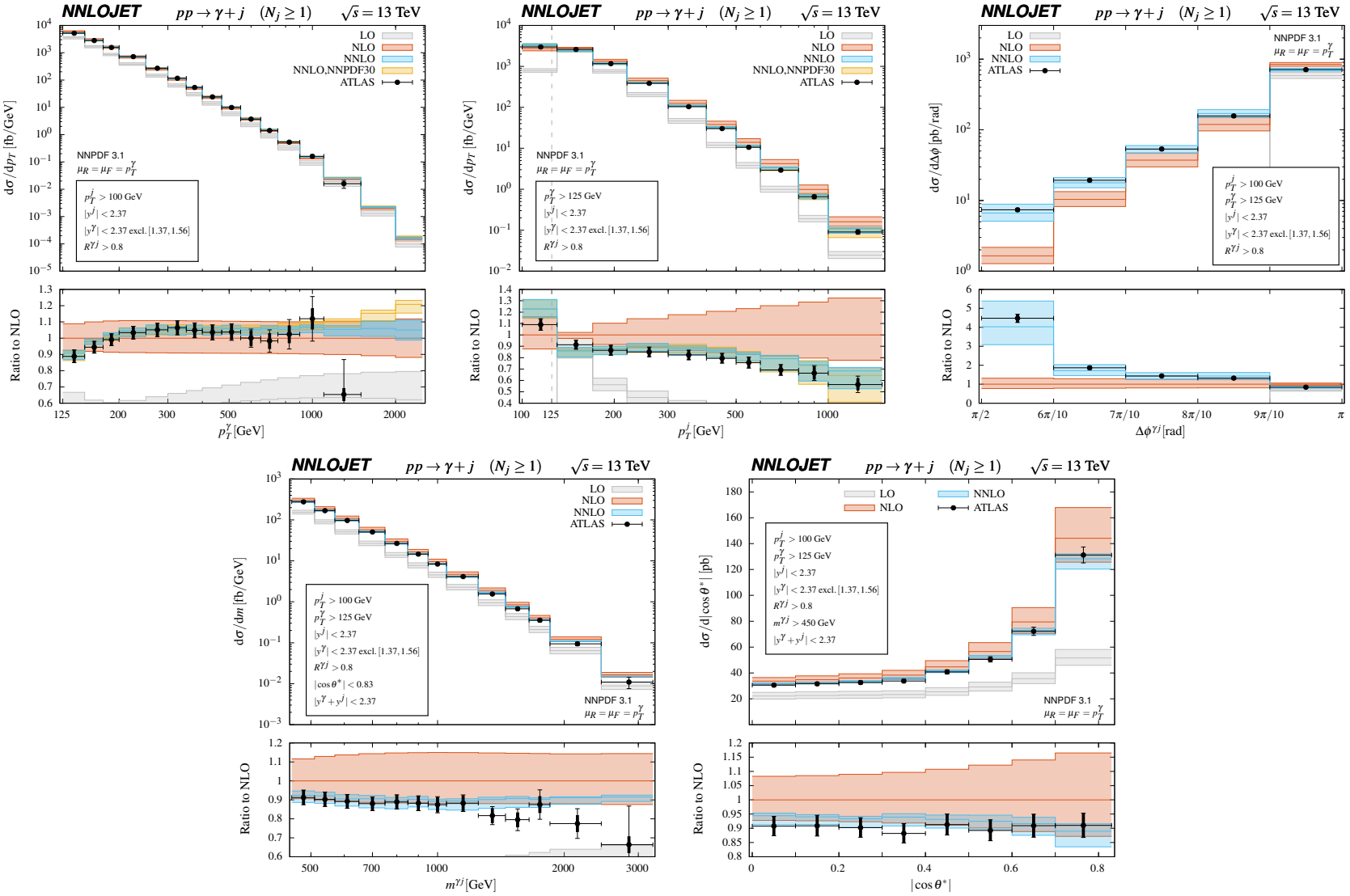
Photon plus jet production at $\sqrt{s} = 13$ TeV



→ Good description of the measurements by the NLO pQCD calculations within theoretical uncertainties (O(10-20%)).

→ The pQCD calculations tend to overestimate the measurements at high values of p_T^{jet}

Photon plus jet production at $\sqrt{s} = 13$ TeV

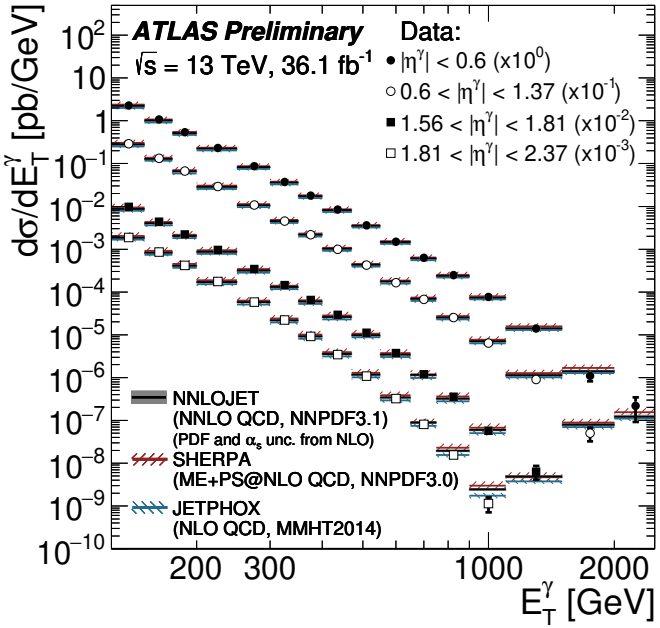


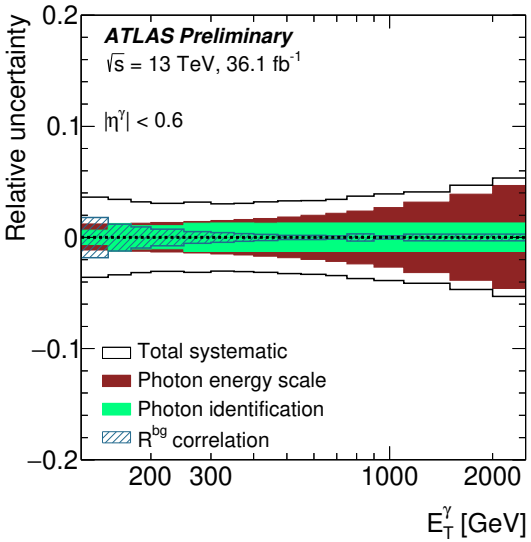
→ Recently NNLO pQCD calculations were published arXiv:1904.01044 (X. Chen, T. Gehrmann, N. Glover, M. Hoefer, A. Huss) and compared to γ + jet ATLAS measurements.

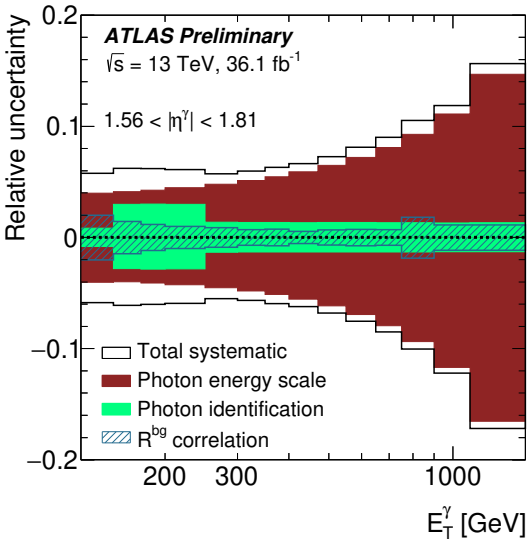
→ Excelent agreement between the NNLO pQCD calculations and the measurements.

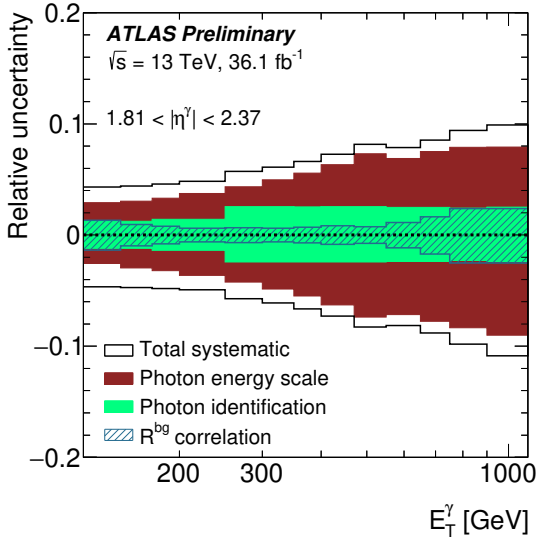
Inclusive photon production at $\sqrt{s} = 13$ TeV

- → Measurement of inclusive photon production in different pseudorapidity regions with $\mathcal{L} = 36.1$ fb^{-1}
- → Phase space region: $E_T^\gamma > 125$ GeV, $|\eta^\gamma| < 2.37 \notin 1.37 < |\eta^\gamma| < 1.56$, $E_T^{iso} < 4.8$ GeV $+ 4.2{\cdot}10^{-3}{\cdot}\ E_T^\gamma$ in $\Delta R = 0.4$.
- → The E_T^γ range extended to 2.5 TeV.
- → The statistical uncertainty dominates from $E_T^\gamma > 1$-1.5 TeV.
- → Total systematic uncertainty of 4-6% (5-16%) in $|\eta^\gamma| < 0.6$ ($1.56 < |\eta^\gamma| < 1.81$) dominated by photon energy scale (especially at high E_T^γ) and γ-ID.









Inclusive photon production at $\sqrt{s} = 13$ TeV

- → Inclusive photon production with $\mathcal{L} = 36.1$ fb^{-1}
- → Phase-space region: $E_T^\gamma > 125$ GeV, $|\eta^\gamma| < 2.37 \notin 1.37 < |\eta^\gamma| < 1.56$, $E_T^{iso} < 4.8$ GeV $+ 4.2{\cdot}10^{-3}{\cdot}\ E_T^\gamma$ in $\Delta R = 0.4$.
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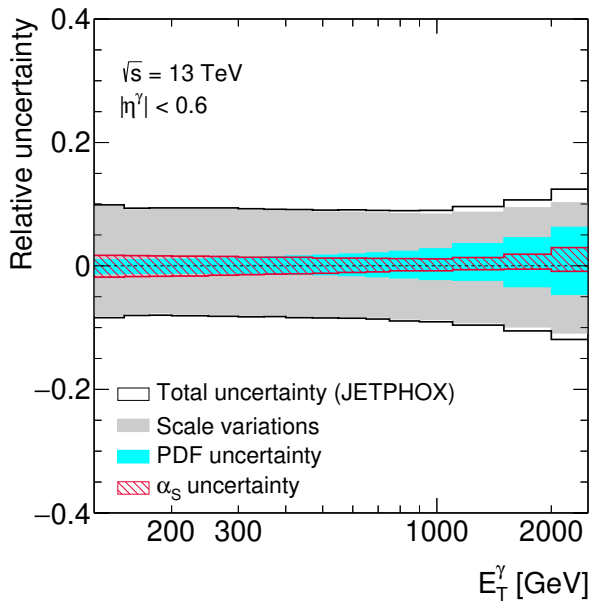
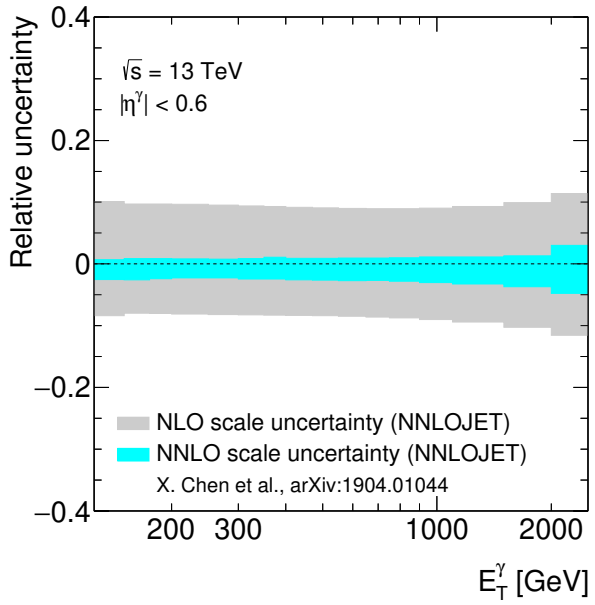
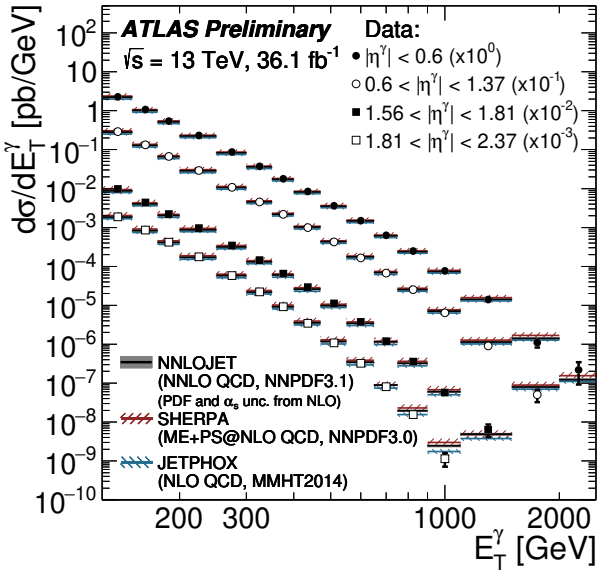
- → Measurements comparared to:
  - NLO SHERPA (merged 1,2 jets at NLO + 3,4 LO ME, QCD PS): only direct contribution due to hybrid-cone isolation approach, dynamical scale setting ($\Delta_{th} \sim O(20\%)$).
  - NLO pQCD JETPHOX : had. + UE effects added, direct and fragmentation (BFG set II for FFs) contributions due to fixed-cone isolation approach, $\Delta_{th} \sim O(10\%)$.
  - NNLO pQCD NNLOJET : had. + UE effects added, only direct contribution due to hybrid-cone isolation approach, $\mu_R = \mu_F = E_T^\gamma$, $\Delta_{th} \sim O(2-4\%)$.

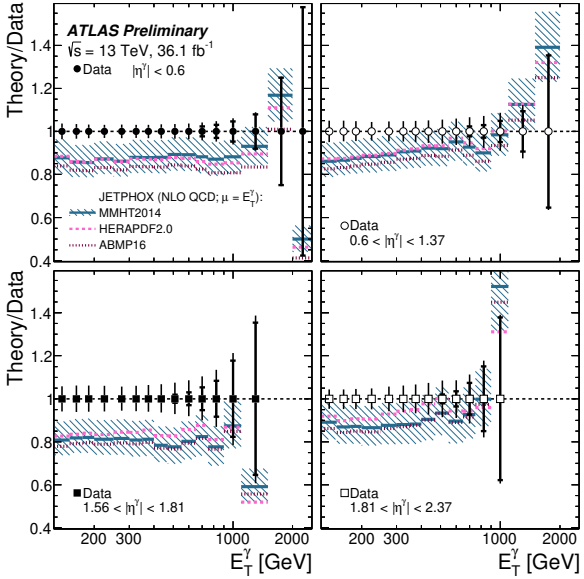


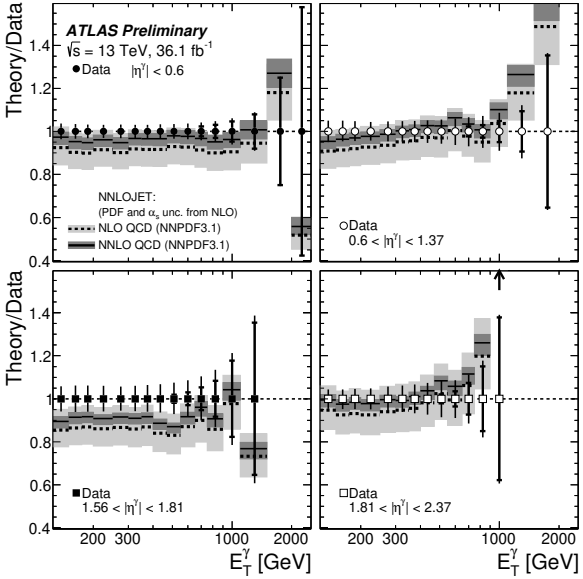


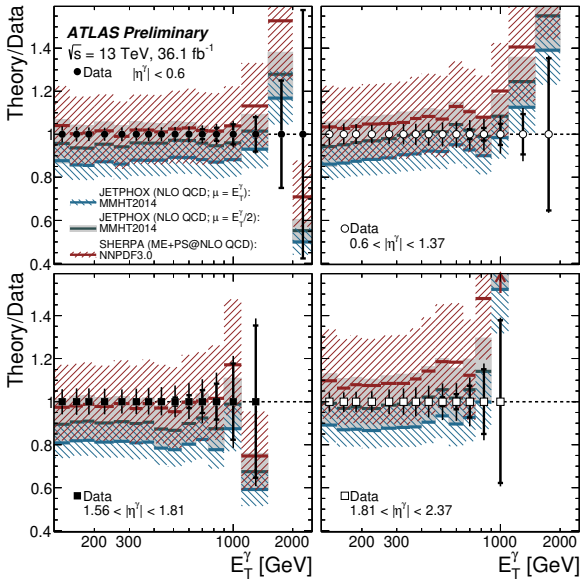
Inclusive photon production at $\sqrt{s} = 13$ TeV

- → The theoretical predidictions of JETPHOX and SHERPA NLO provide an adequate description of the measurements within the experimental and theoretical uncertainties.
- → The NNLO pQCD calculations give an excellent description of the measurements with much reduced theoretical uncertainties
- → Stringent test of the theory for isolated-photon production at $O(\alpha_{\mathrm{EM}}\alpha_{\mathrm{S}}^3)$ for E_{T}^{γ} from 125 GeV up to beyond 1 TeV
- → Potencial to further constraint the proton PDFs within the global NNLO QCD fit.









Summary and conclusions

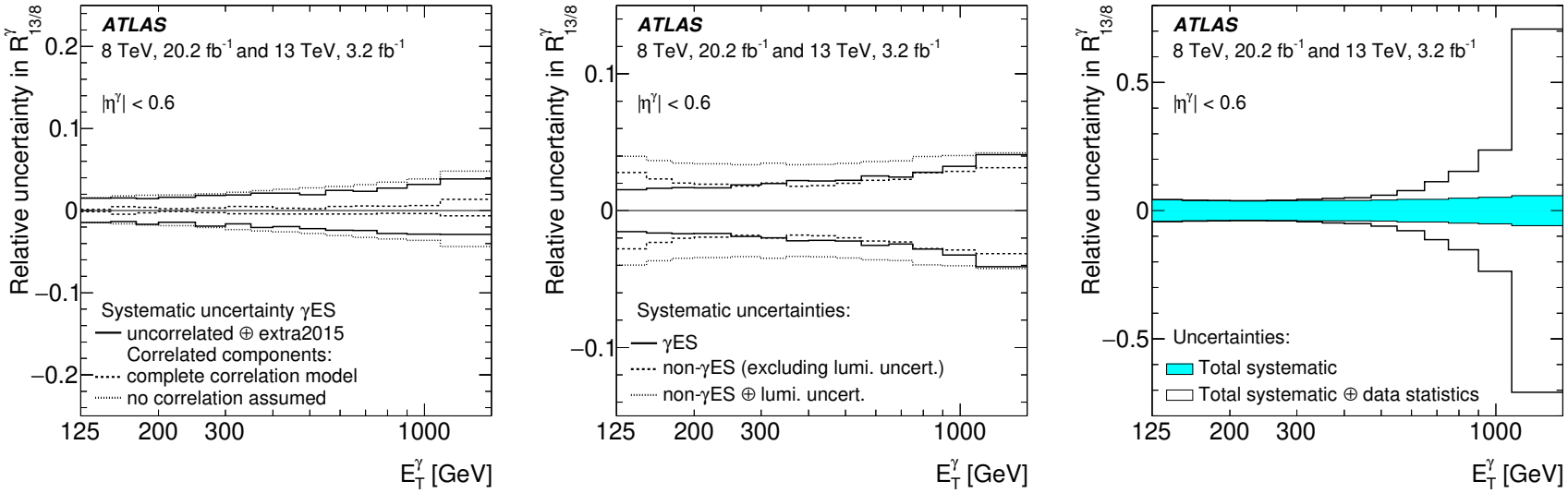
- Stringent test of the SM predictions by measuring ratio of inclusive-photon cross sections at 13 and 8 TeV.
  - → Cancelation of correlated uncertainties (especially γES) allows to have uncertainties below 5% for most of the phase-space;
  - → theoretical uncertainties coming from terms beyond NLO highly reduced;
  - → the level of agreement between NLO pQCD predictions based on different PDFs and data validates the description of the evolution of isolated-photon production from $\sqrt{s}$ = 8 to 13 TeV;
- Excellent description of the photon plus jet production by the NNLO pQCD calculations.
- The measurement of inclusive photon production at $\sqrt{s} = 13$ TeV with $\mathcal{L} = 36.1$ fb^{-1} was presented.
  - → The range $125 < \mathrm{E}_{\mathrm{T}}^{\gamma} < 2500$ GeV is covered.
  - → Measurements compared to NNLO pQCD calculations which give an excellent description of the data with reduced theoretical uncertainties
  - → The measurements have the potencial to constrain further the PDFs within a global NNLO QCD fit.

BACK UP

Inclusive cross-section ratios between $\sqrt{s}$= 13 and 8 TeV

→ Full correlation of uncertainties used when justified.

- Mainly in the estimation of the photon energy scale (extra uncertaintes at 13 TeV for changes in configuratio of the ATLAS detector). item[-] Other uncertainties taken conservatively as uncorrelated: changes in running conditions, optimization of the photon idenification or differences in the estimation of the systematic uncertainties.



→ Luminosity uncertainty (2.8%, uncorrelated between $\sqrt{s}$) plays an important role.

- Reduce the uncertainty by performing measurement of double ratios

$$D^{\gamma/Z}_{13/8} = \frac{R^{\gamma}_{13/8}(\mathrm{E}^{\gamma}_{\mathrm{T}})}{\sigma^{\mathrm{fid}}_{Z}(13\ \mathrm{TeV})/\sigma^{\mathrm{fid}}_{Z}(8\ \mathrm{TeV})}$$

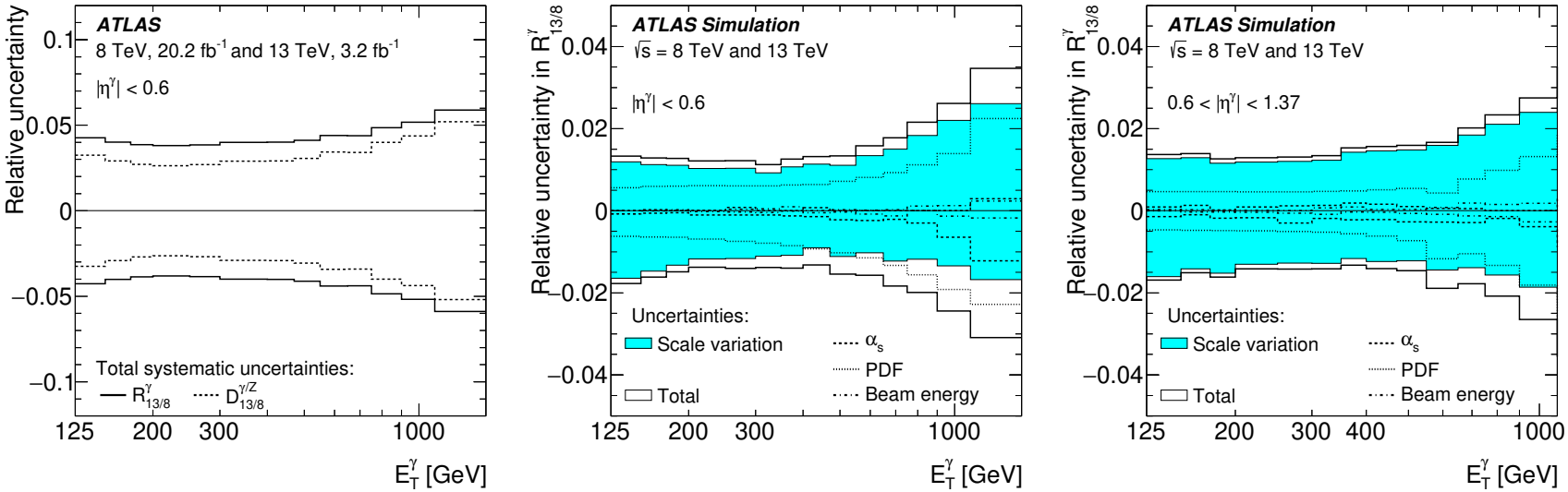
→ $\sigma^{\mathrm{fid}}_{Z}(13\ \mathrm{TeV})/\sigma^{\mathrm{fid}}_{Z}(8\ \mathrm{TeV})$ measured by ATLAS in JHEP 02 (2017) 117

Inclusive cross-section ratios between $\sqrt{s}$= 13 and 8 TeV

$\sigma_Z^{\rm fid}(13\ {\rm TeV})/\sigma_Z^{\rm fid}(8\ {\rm TeV})$ = 1.537 ± 0.001 (stat) ± 0.010 (syst) ± 0.044 (lumi)

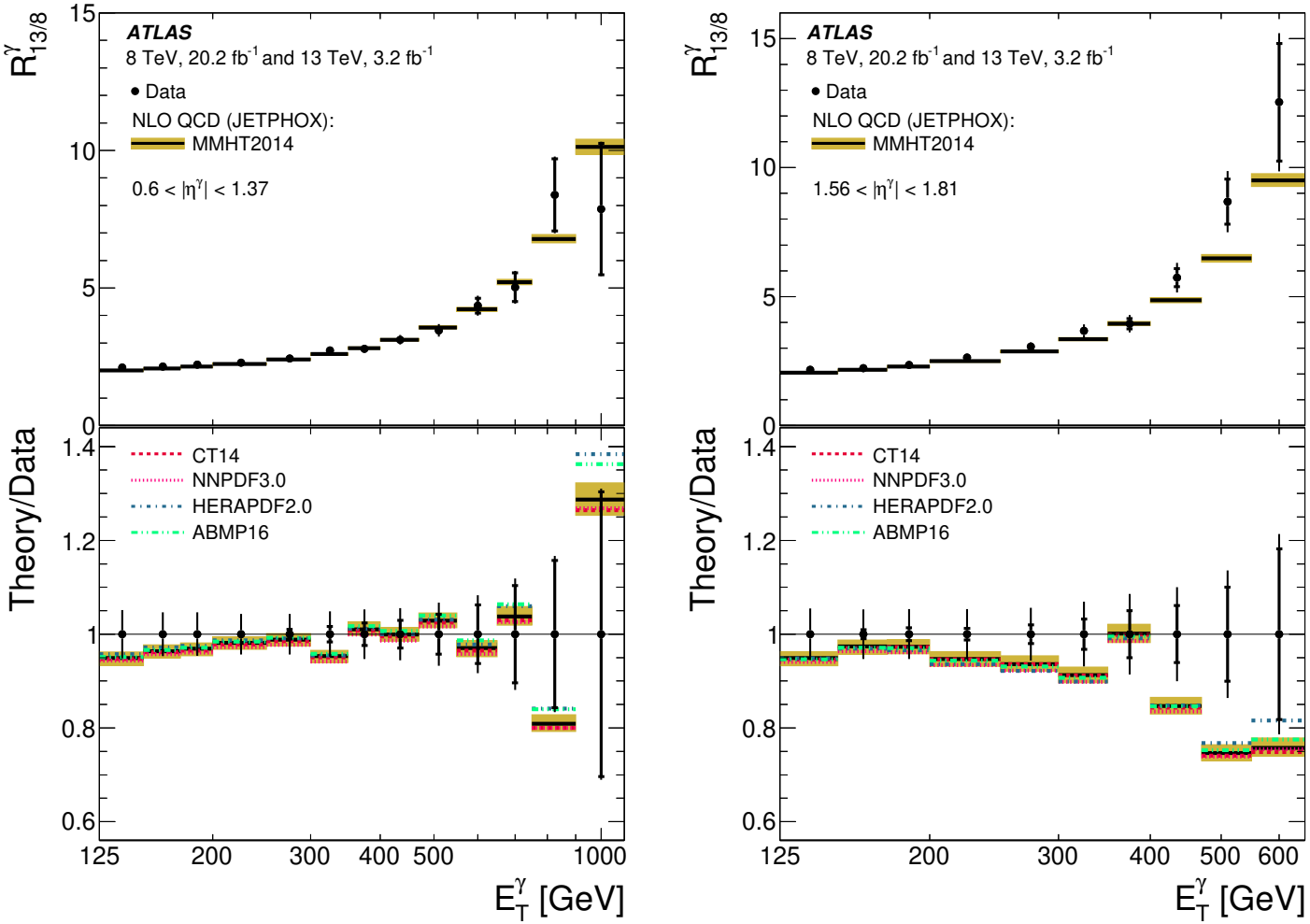
→ Systematic uncertainty of 0.7% dominated by lepton efficiency; three times smaller than systematic uncertainties in $R^{\gamma}_{13/8}$. Small correlations between electron and photon energy scale can be safely neglected. Predictions computed with Dyturbo at NNLO QCD ($\Delta_{\rm th}$ ~ $O(1\%)$) → uncorrelated with respect to $R^{\gamma}_{13/8}(\mathrm{E}^{\gamma}_{\mathrm{T}})$ theoretical uncertainties.

- Theoretical predictions for $R^{\gamma}_{13/8}(\mathrm{E}^{\gamma}_{\mathrm{T}})$ at NLO QCD obtained using JETPHOX
  - → All relevant scales set to $\mathrm{E}^{\gamma}_{\mathrm{T}}$, 5FS; BFG II quark/gluon-to-photon fragmentation functions and several PDFs investigated.
  - → Uncertainties due to scale variations, PDF, α_S,beam energy and non-perturbative corrections are considered as correlated between both $\sqrt{s}$ → large reduction of the theoretical uncertainties compared to the individual inclusive photon measurements.



Inclusive cross-section ratios between $\sqrt{s}$= 13 and 8 TeV

- Measured $R^{\gamma}_{13/8}(\mathrm{E}^{\gamma}_{\mathrm{T}})$ compared to NLO QCD calculations.



- NLO predictions agree with the measured $R^{\gamma}_{13/8}(\mathrm{E}^{\gamma}_{\mathrm{T}})$ within the reduced theoretical uncertainties (2-4%).

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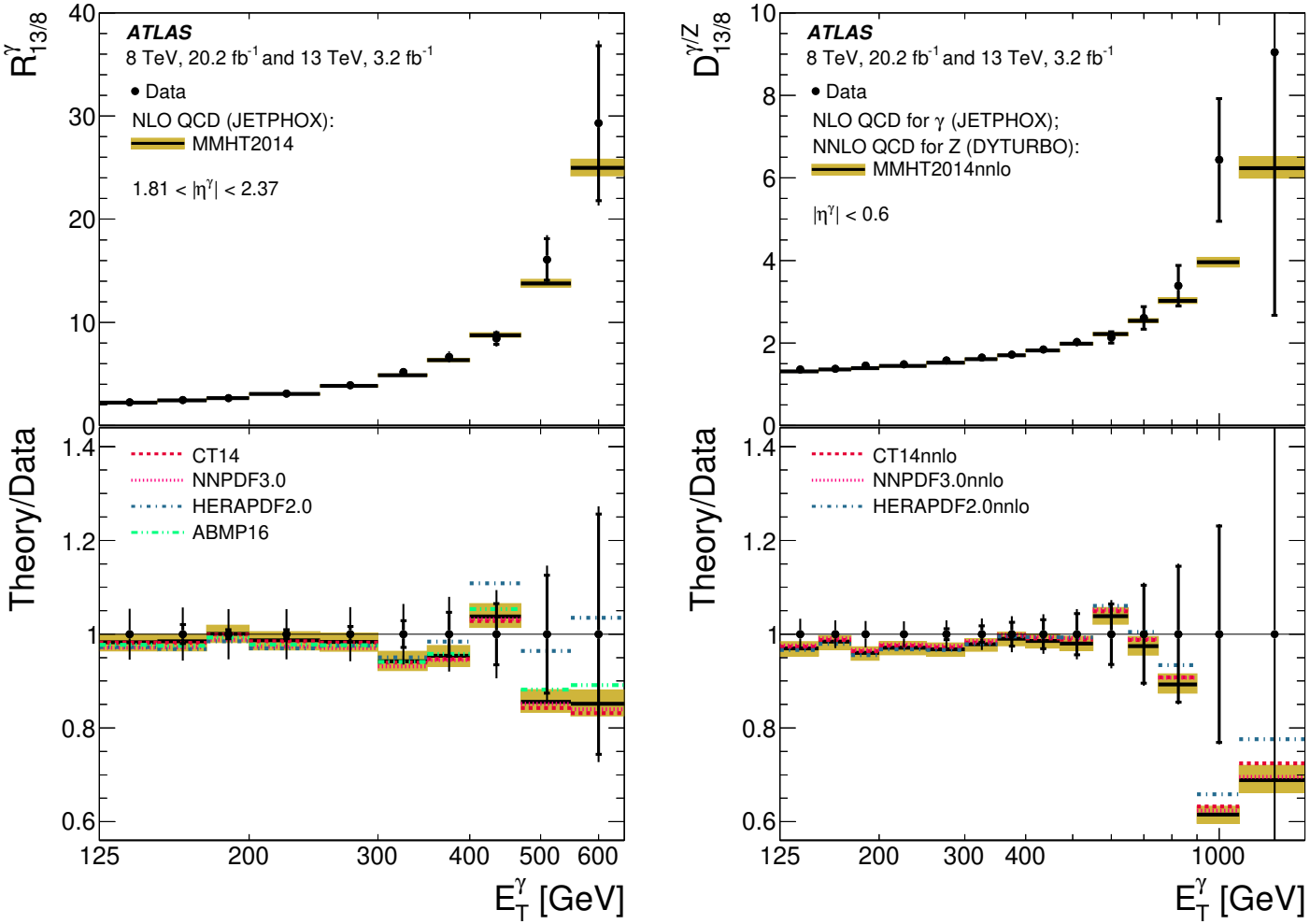

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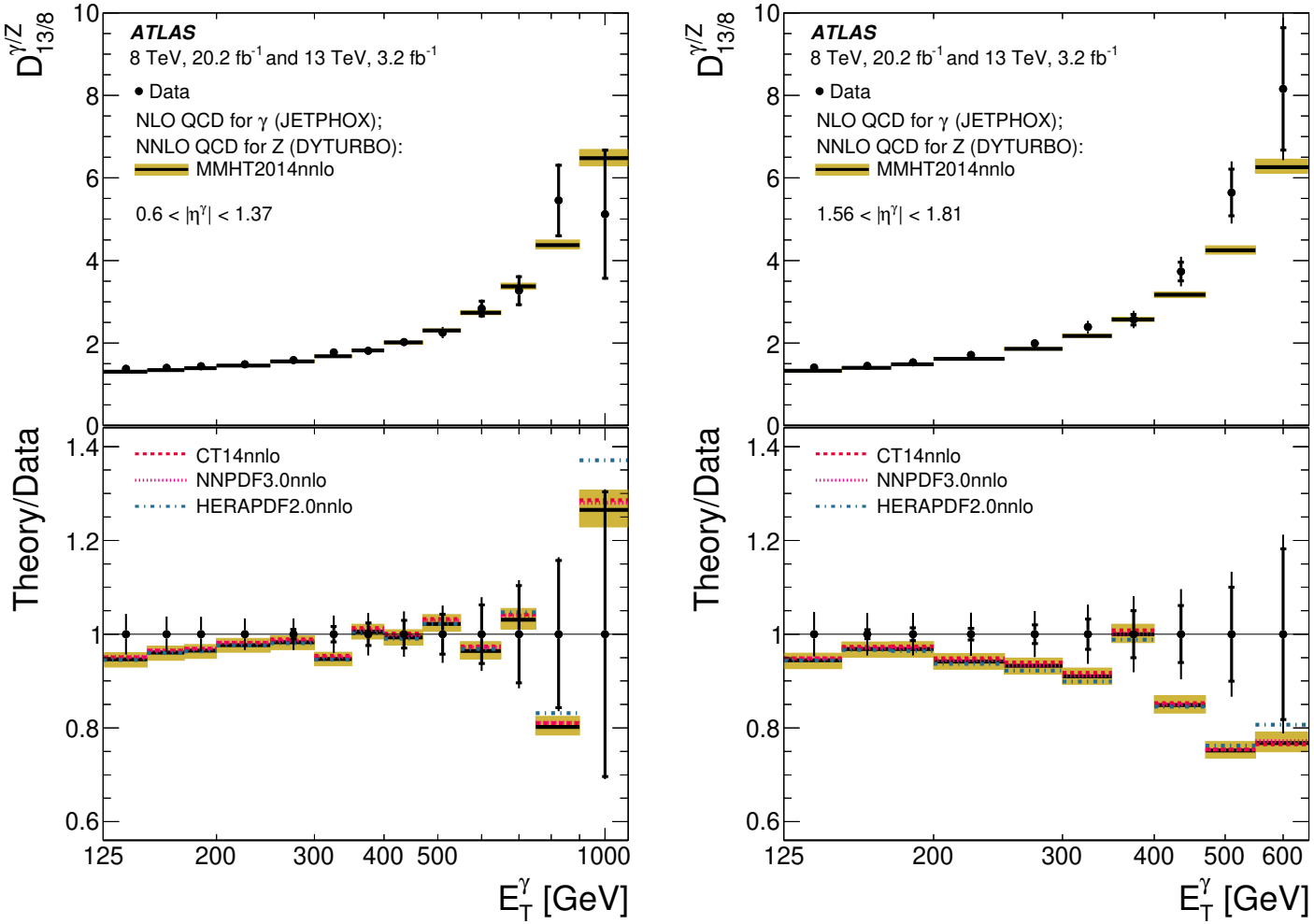

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