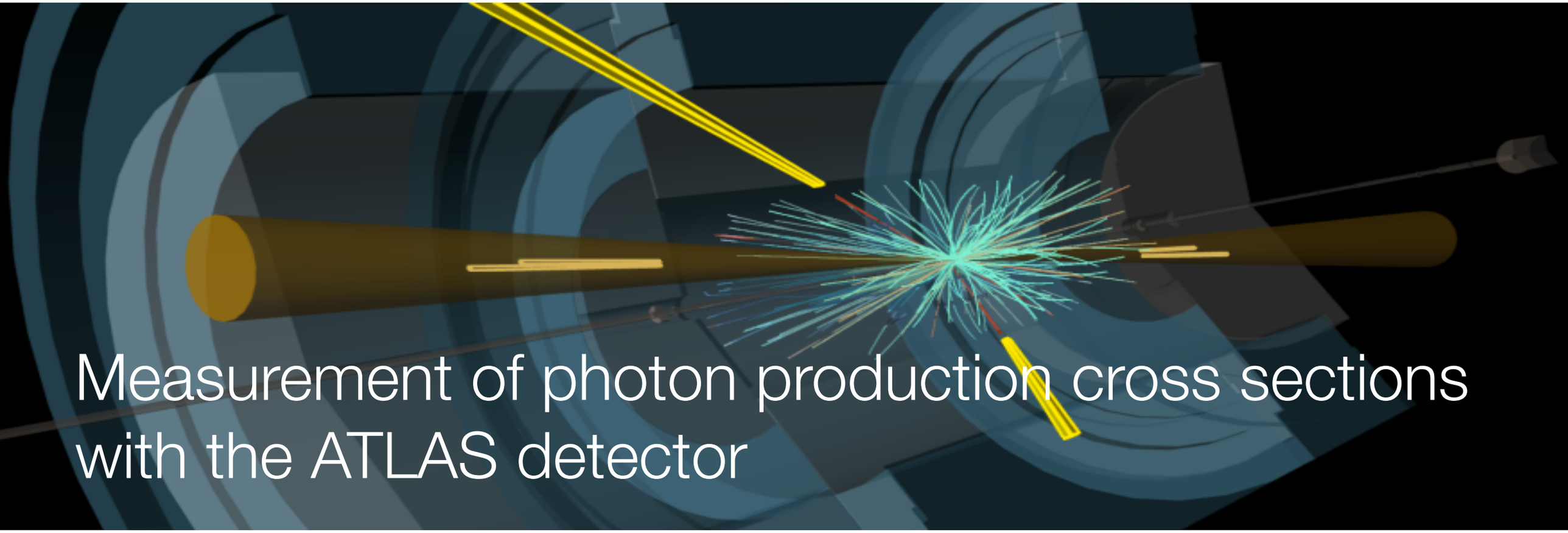


Measurement of photon production cross sections with the ATLAS detector

Bruno Lenzi
on behalf of the ATLAS collaboration

DIS 2018 - Kobe, Japan

17/04/2018

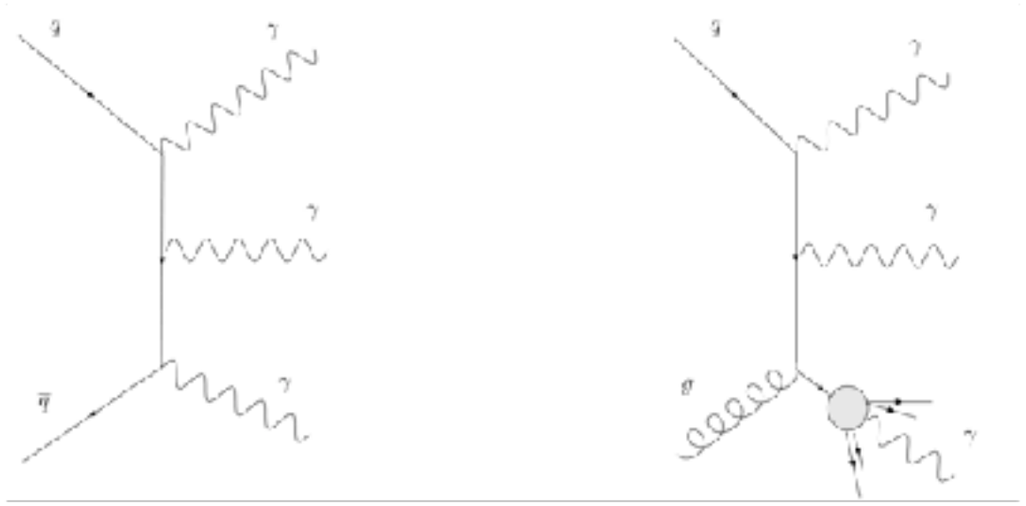
Introduction to photon measurements

- Photons are colourless probes, well suited to test QCD at hadron collisions
  - Clean signature
  - Test resummation, pQCD and EW corrections, gluon PDF, …
  - Fixed-order calculations available up to NNLO for γ+X and γγ

See also talk by Mark Stockton on γ+jets

- Background to Higgs boson studies and searches for new phenomena
  - New resonances (scalar, graviton, Z'), SUSY, …
- Measurements of isolated γ (13 TeV, 3.2 fb^{-1}), γγ and γγγ (8 TeV, 20 fb^{-1})

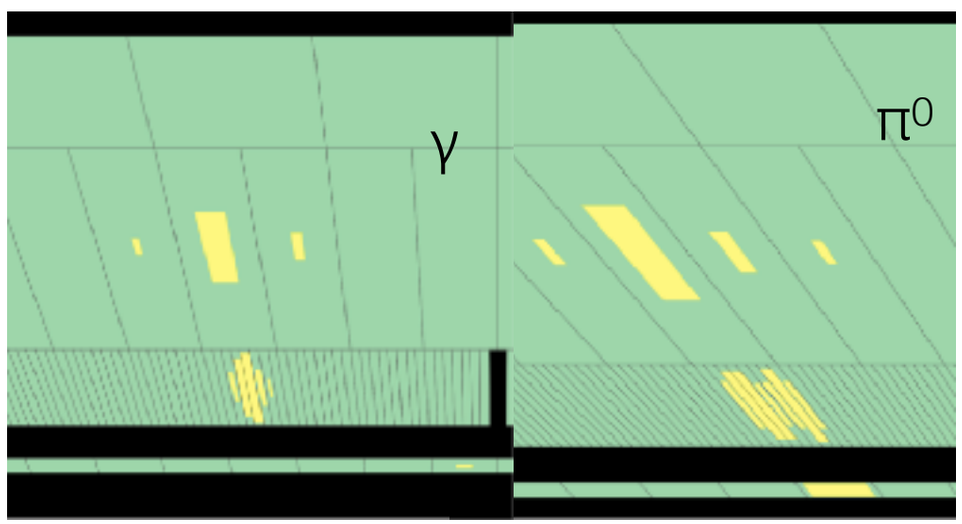
Direct



Fragmentation
(reduced by isolation cuts)

Measurement strategy

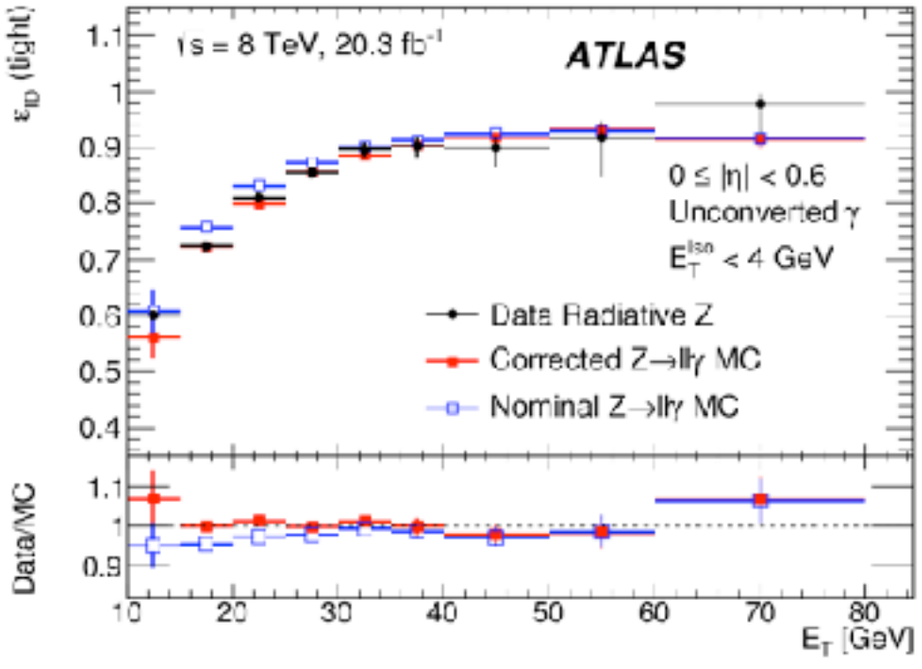
- Main background from jets (with e.g. π^0) rejected by ID cuts and isolation
  - Finely segmented EM calorimeter ($|\eta| < 2.37$, excluding $1.37 < |\eta| < 1.56$)
  - Isolation corrected by photon, UE and pileup contributions
  - Data-driven background subtraction using ID and isolation (also e → γ, usually small)



- Correction for detector effects, unfolding to particle-level (bin-by-bin)

$$\frac{\mathrm{d}\sigma}{\mathrm{d}A}(i) = \frac{N^{\mathrm{sig}}(i)C(i)}{\Delta A(i)\,\mathcal{L}}$$

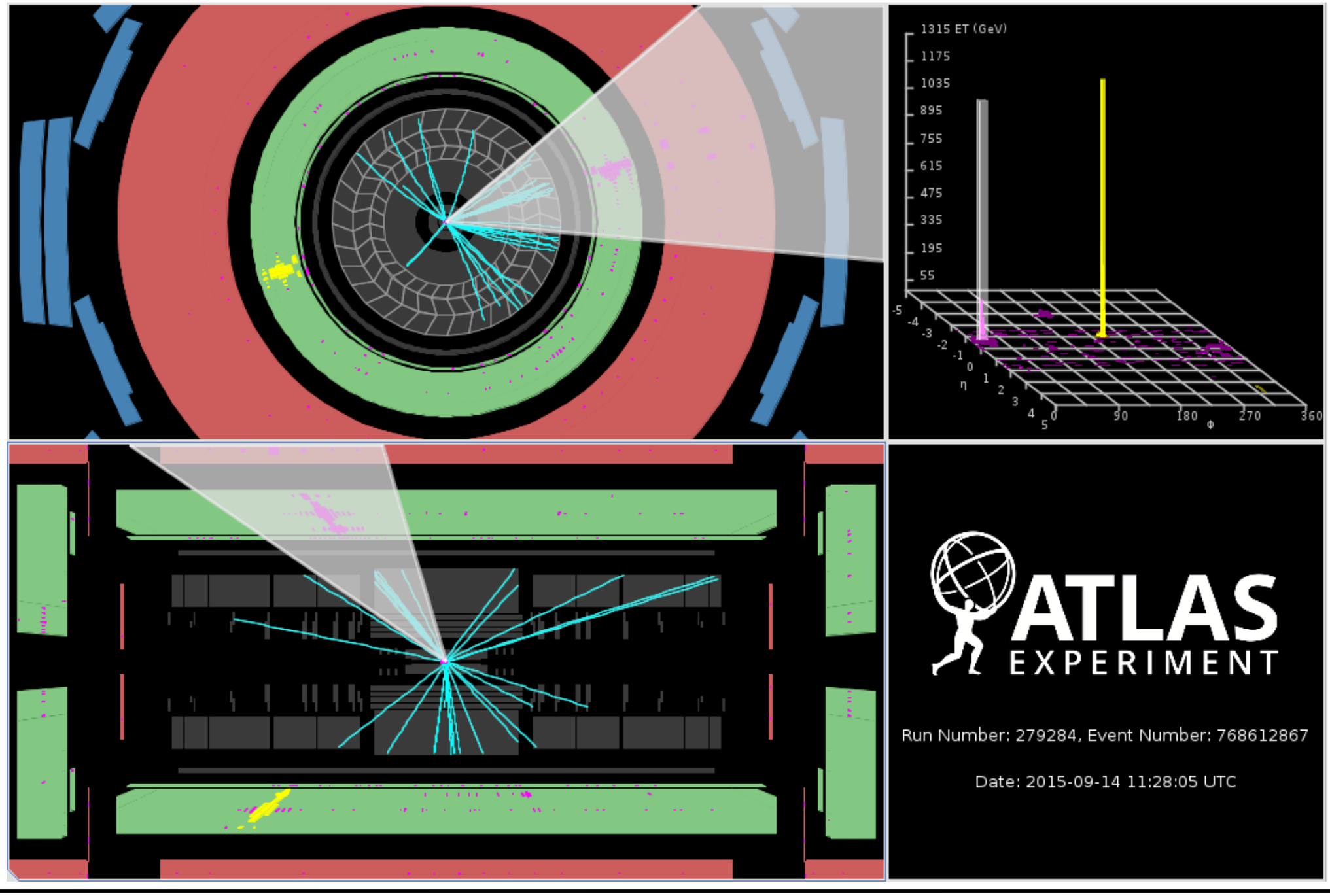
- Systematic uncertainties dominant in most of the phase-space
  - Efficiencies measured in data. e.g. photon ID



Inclusive isolated photons at 13 TeV

Phys. Lett. B 770 (2017) 473

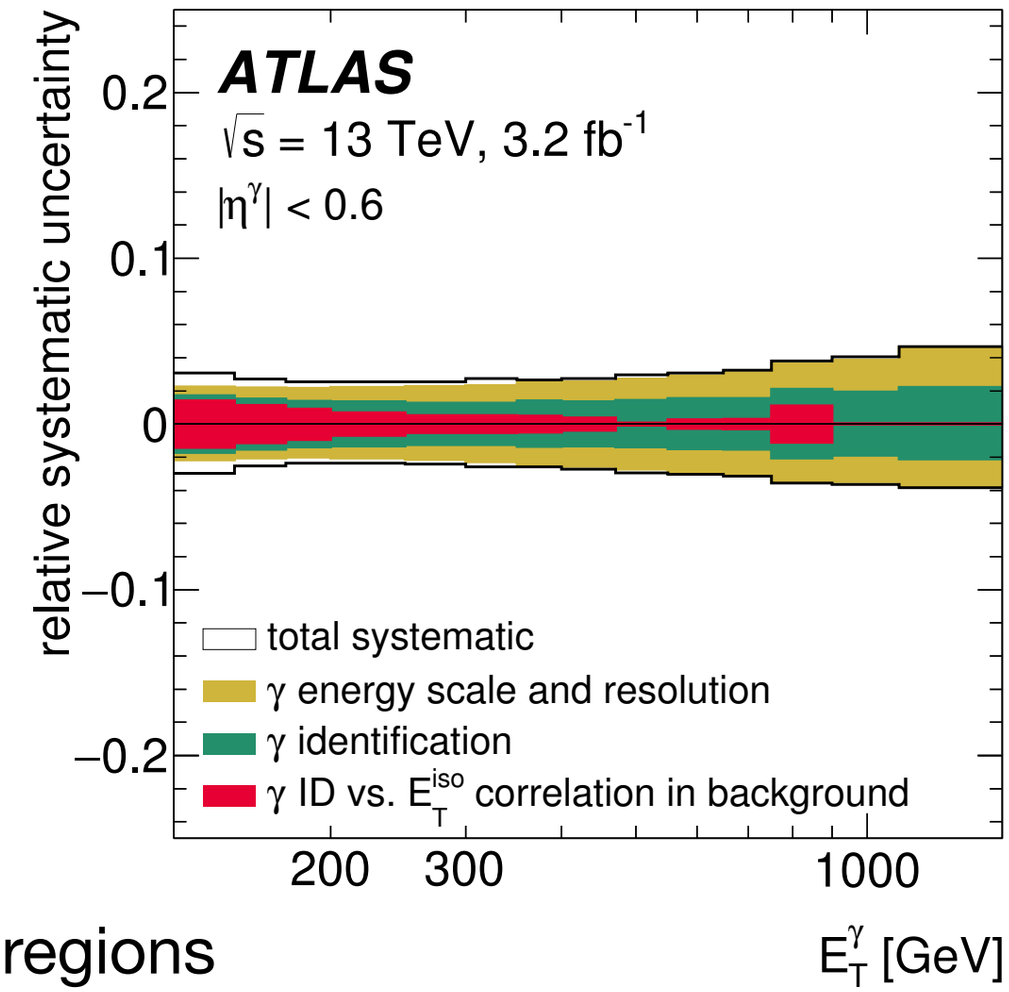
Candidate with E_T = 1.3 TeV



Inclusive isolated photons at 13 TeV

Phys. Lett. B 770 (2017) 473

- 2015 dataset: 3.2 fb^{-1} at 13 TeV
- Selection (also at particle level):
  - E_T > 125 GeV (trigger)
  - Isolation: E_T^{iso} < 4.8 GeV + 4.2e-3 * E_T
- Jet background subtracted with 2D sidebands methods (ID, iso)
  - Other sources (e.g. e → γ) negligible
- Inclusive cross-section and $d\sigma/dE_T$ in 4 η regions
- Syst uncertainties dominant for E_T < 600 GeV
  - Energy scale and resolution: 2-5%, larger for 1.56 < |η| < 1.81
  - Photon ID and background subtraction typically 1-2%



Inclusive isolated photons at 13 TeV

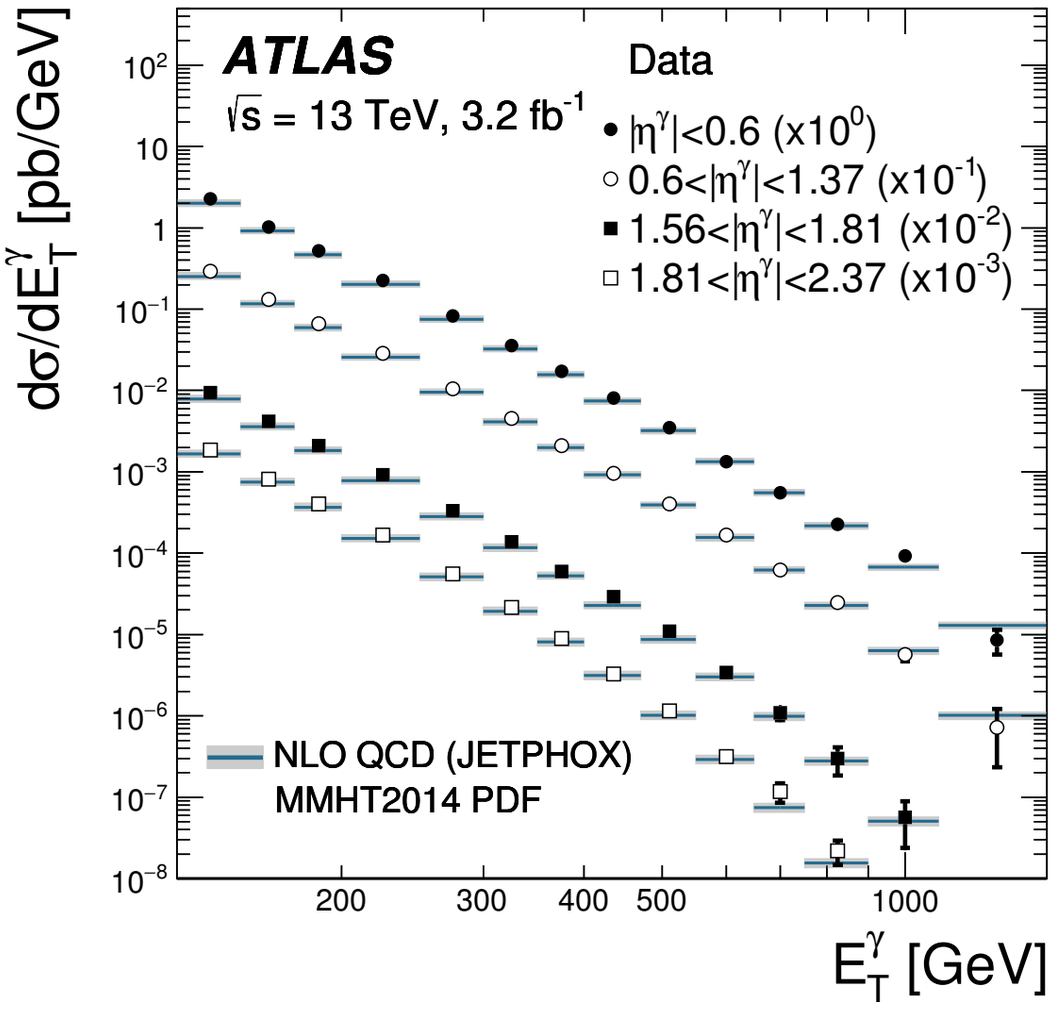
Phys. Lett. B 770 (2017) 473

- Comparison with NLO JETPHOX and MC generators (Pythia, Sherpa)

$$\sigma_{\text{meas}} = 399 \pm 13\ (\text{exp.}) \pm 8\ (\text{lumi.})\ \text{pb}$$

$$\sigma_{\text{NLO}} = 352^{+36}_{-29}\ (\text{scale}) \pm 3\ (\text{PDF}) \pm 6\ (\alpha_s) \pm 4\ (\text{non-perturb.})\ \text{pb}$$

- $d\sigma/dE_T$ over 5 orders of magnitude
- Shape well described by MC, except for $E_T > 500$ GeV in the regions $|\eta| < 1.37$
- Adequate description by NLO calculation
  - Differences up to 10-15%, covered by theoretical uncertainties (scale)
  - Calls for higher order calculation!



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Phys. Lett. B 770 (2017) 473

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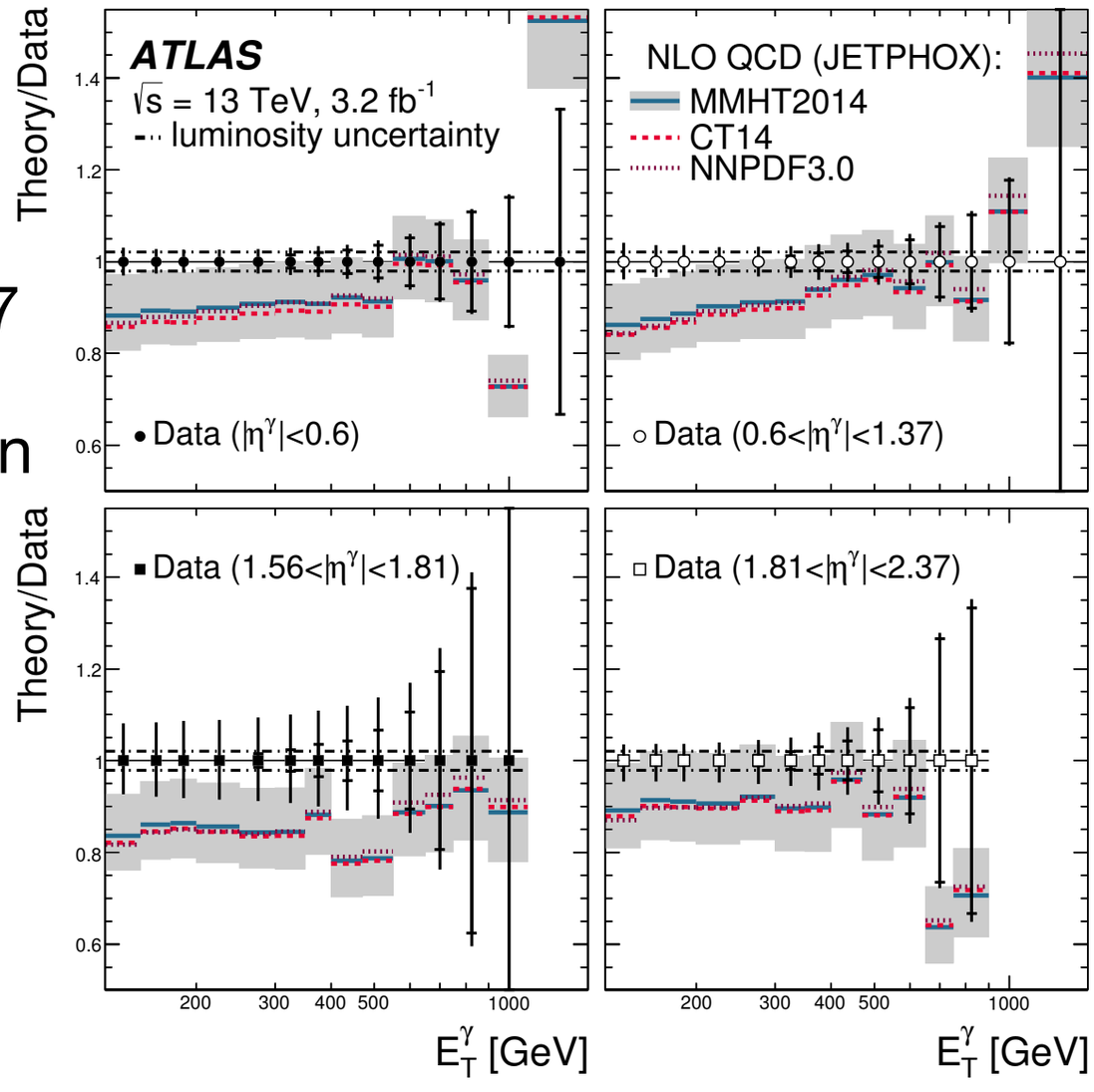
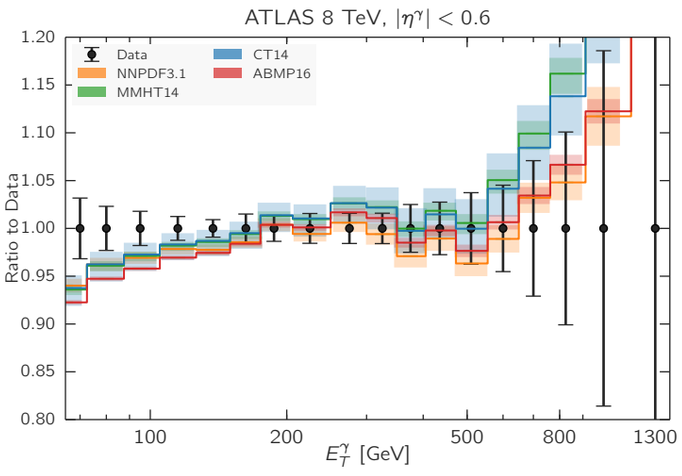
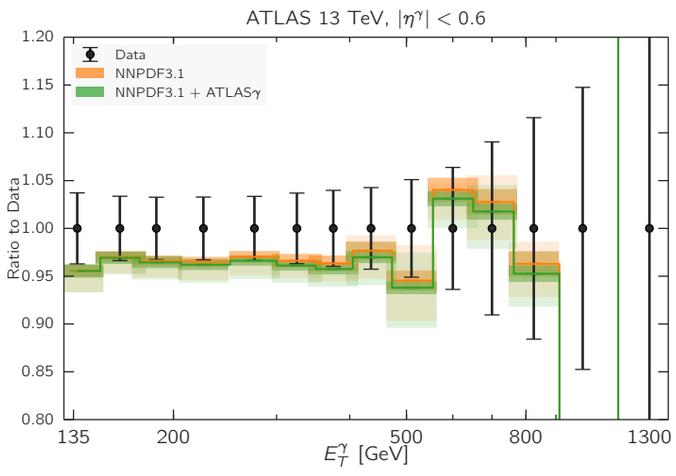
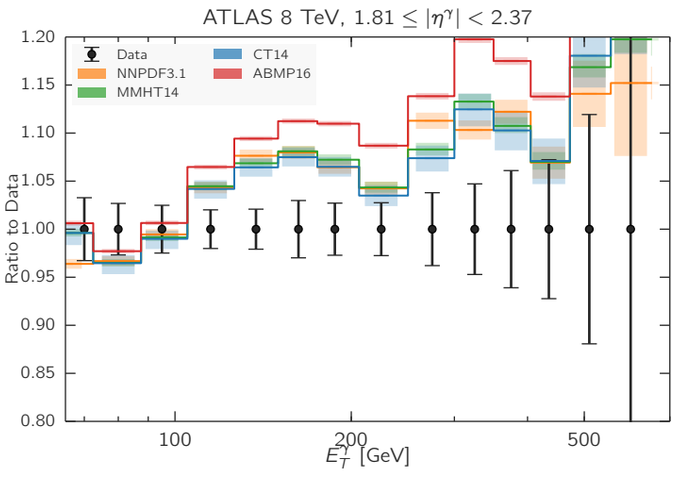


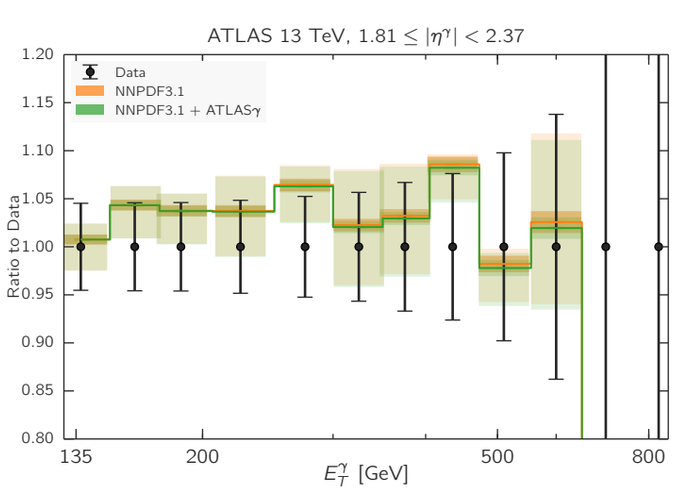
Comparison with NNLO calculations of pp → γ + X

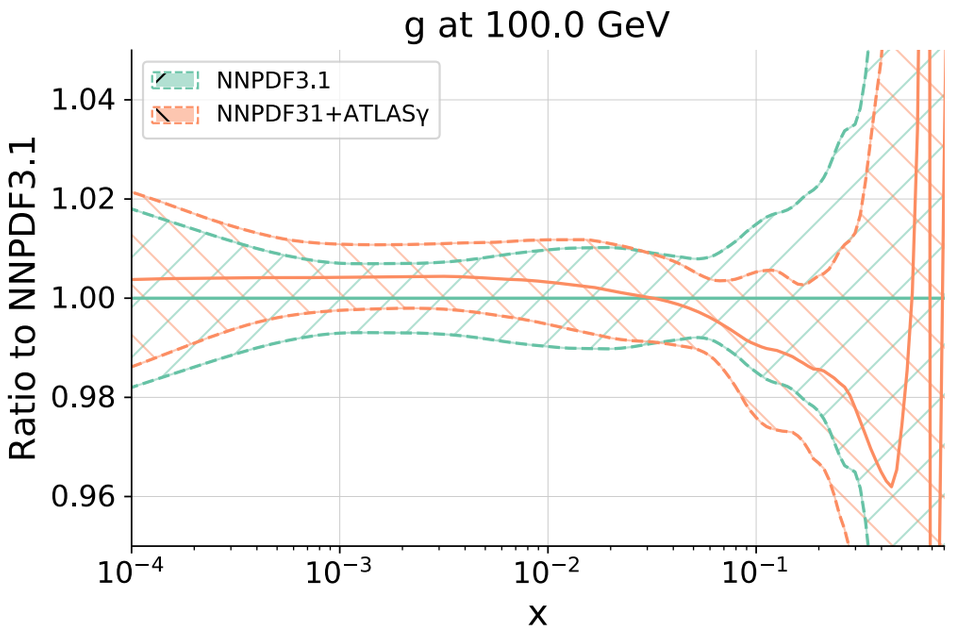
- NNLO calculation: Campbell et al, PRL 118, 222001 (2017), 1802.03021
  - Scale uncertainties halved
  - Overall good agreement. Small discrepancies in the forward bin for 8 TeV, cancel out when taking the ratio to 13 TeV data











Potential to include measurements in PDF fits

Photon pair production at 8 TeV

Phys. Rev. D 95 (2017) 112005

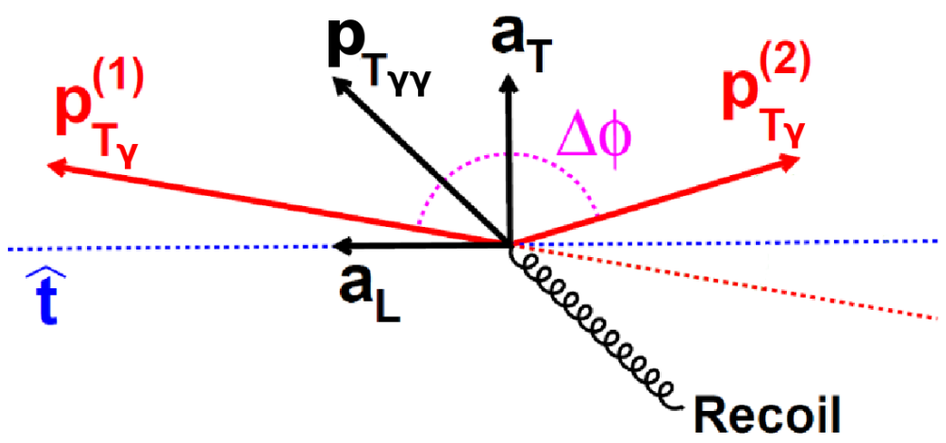
- Integrated cross-section and differential as a function of 6 variables:

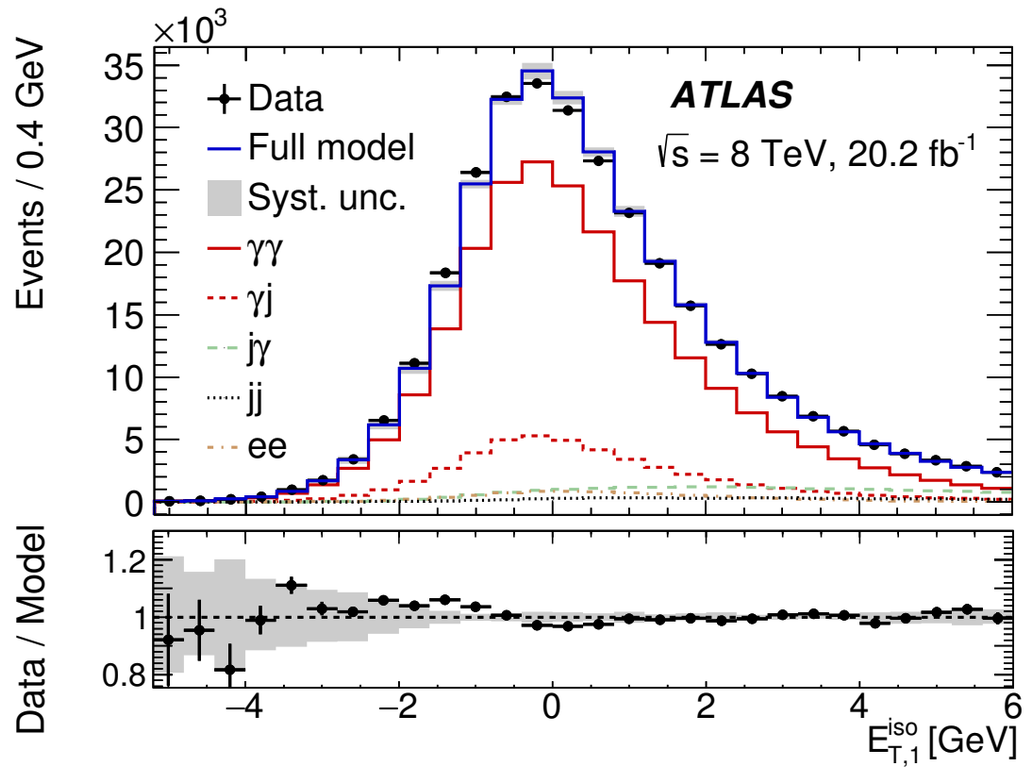
$$m_{\gamma\gamma},\ p_{\mathrm{T},\gamma\gamma},\ \Delta\phi_{\gamma\gamma},\ |\cos\theta^*_\eta|,\ a_{\mathrm{T}}, \phi^*_\eta$$

- Larger dataset (20 fb^{-1}), reduced uncertainties and new variables w.r.t. to previous result at 7 TeV (better sensitivity to soft-gluon emission)

- E_T > 40 GeV, 30 GeV; ΔR > 0.4; $E_T^{part,iso}$ < 11 GeV

- Jet and electron backgrounds from template fit to calo isolation





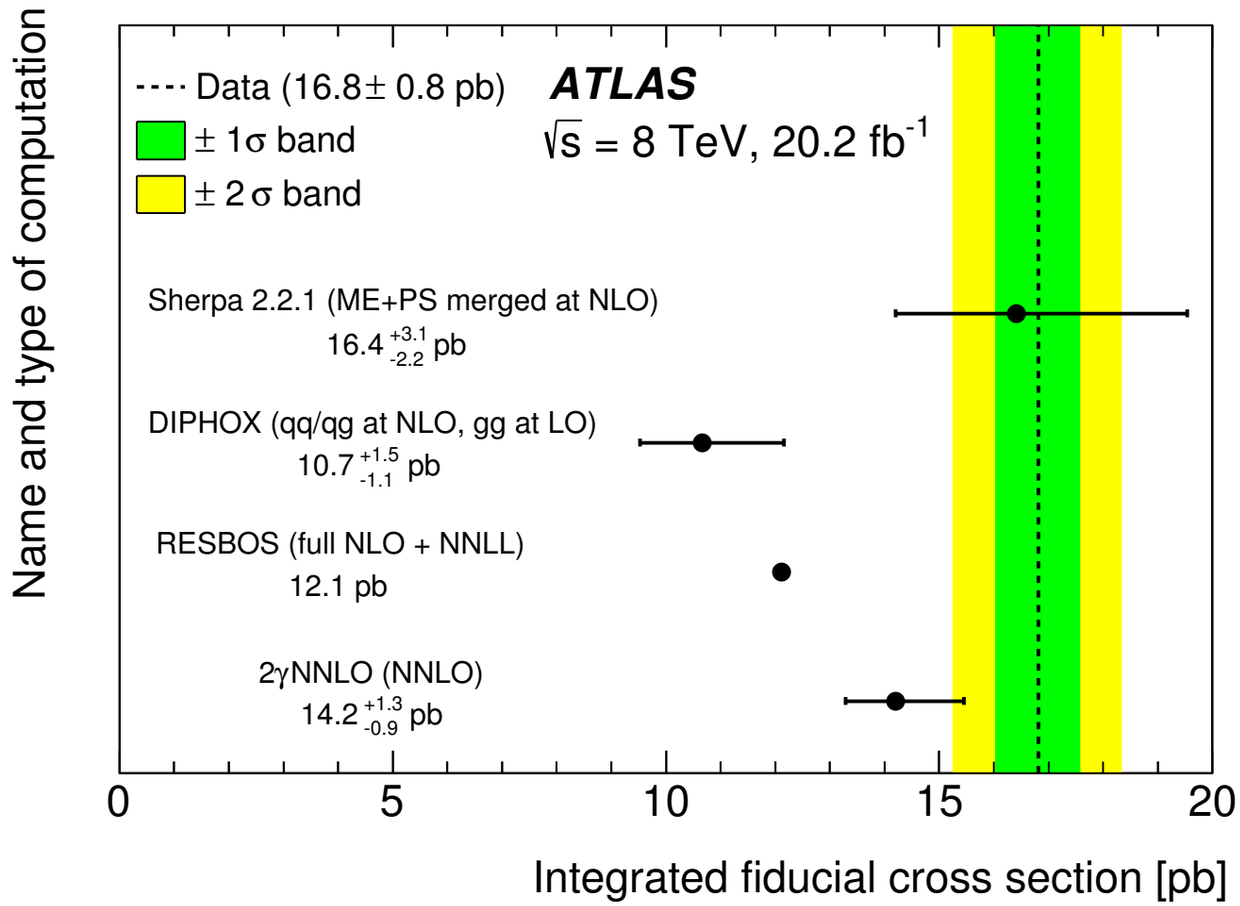
Photon pair production at 8 TeV

Phys. Rev. D 95 (2017) 112005

- Syst. uncertainties dominated by photon ID (2.5%), isolation modelling (2%) and efficiency (1.5%), background control region def. ($^{+1.5\%}_{-1.7\%}$)

$$\sigma_{\text{tot}}^{\text{fid.}} = 16.8 \pm 0.1\ (\text{stat}) \pm 0.7\ (\text{syst}) \pm 0.3\ (\text{lumi})\ \text{pb}$$

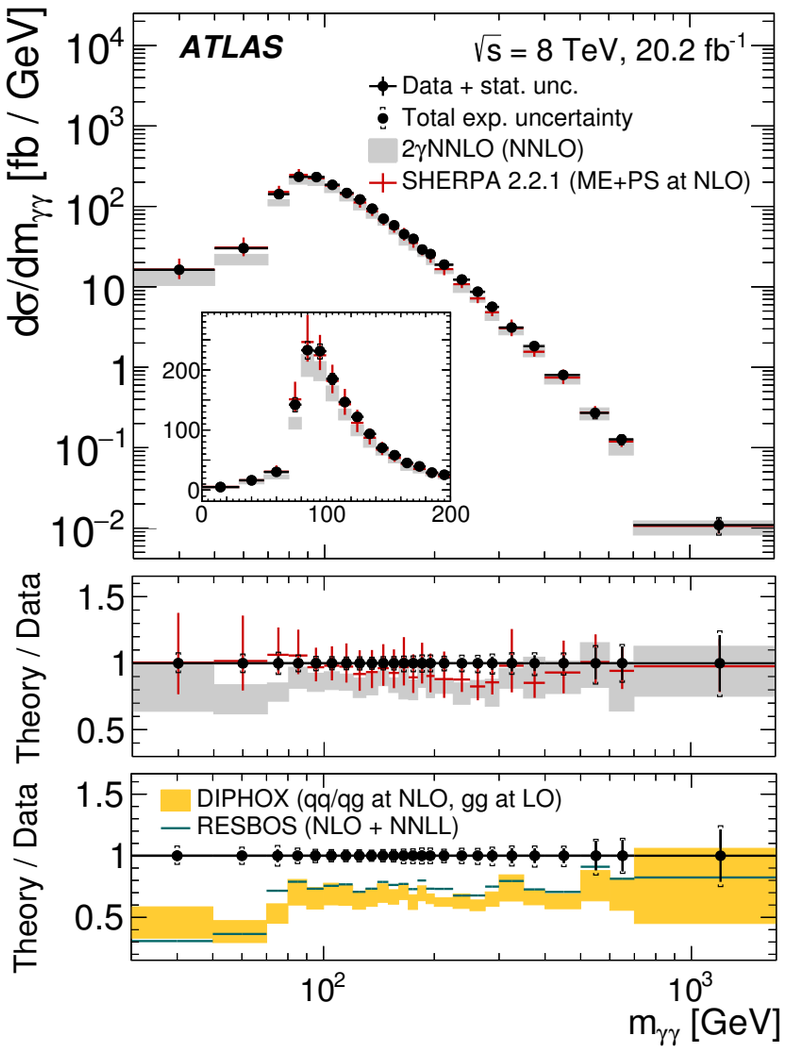
- Compared to calculations up to NNLO or NLO + PS / gluon-resummation:

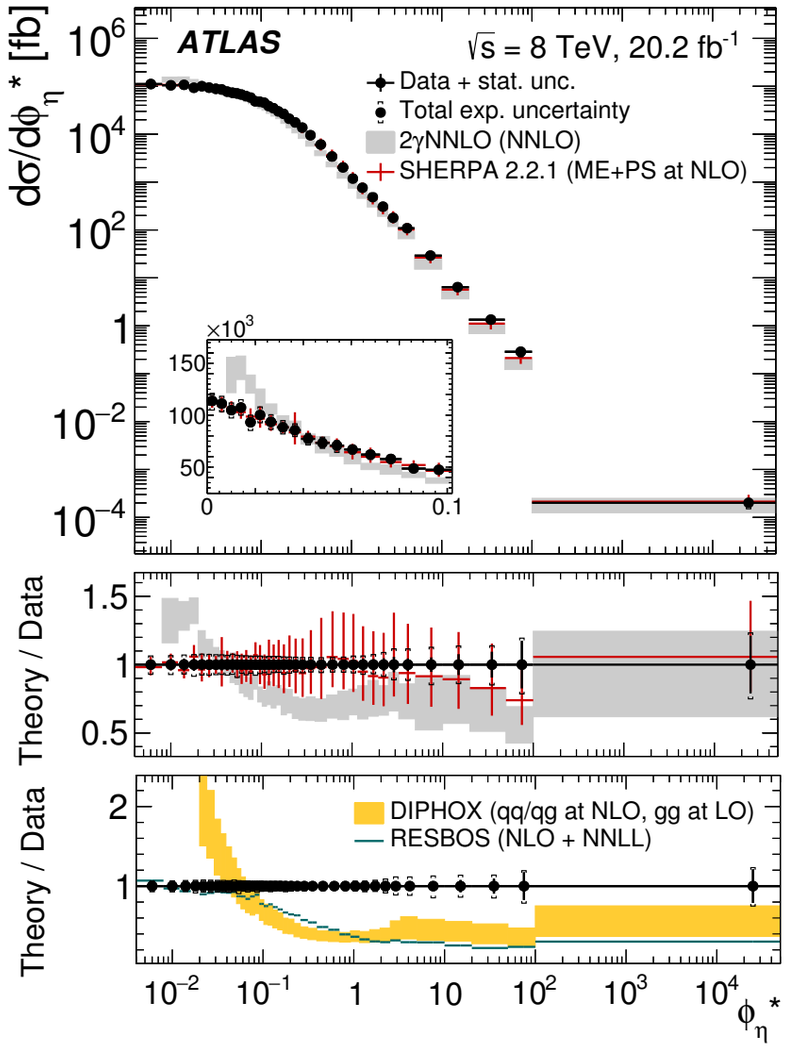


Photon pair production at 8 TeV

Phys. Rev. D 95 (2017) 112005

- Uncertainties typically < 5% per bin, up to 25% in few bins with low stats
- Sherpa 2.2.1 with ME+PS at NLO describes the data well
- Impact of IR emissions (a_T and ϕ^*) well reproduced by gluon resummation

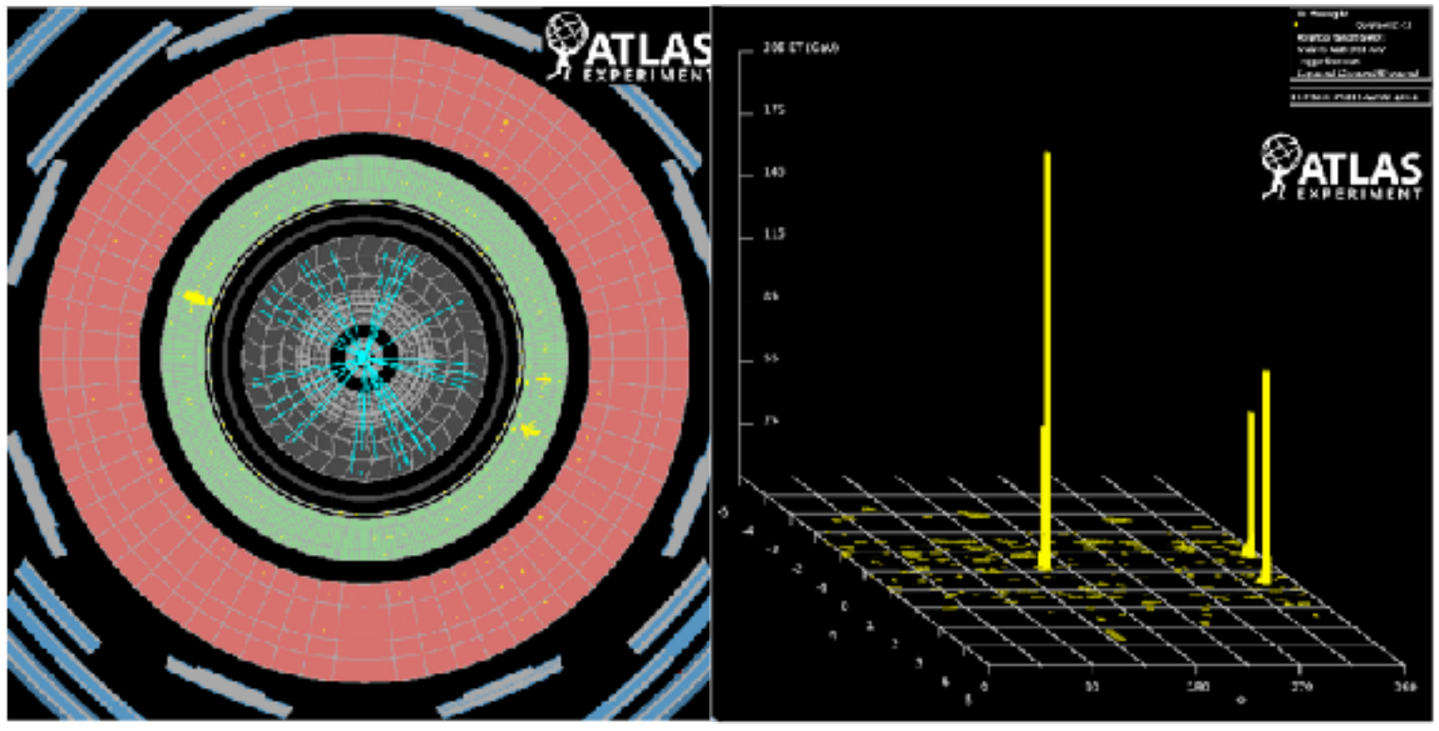


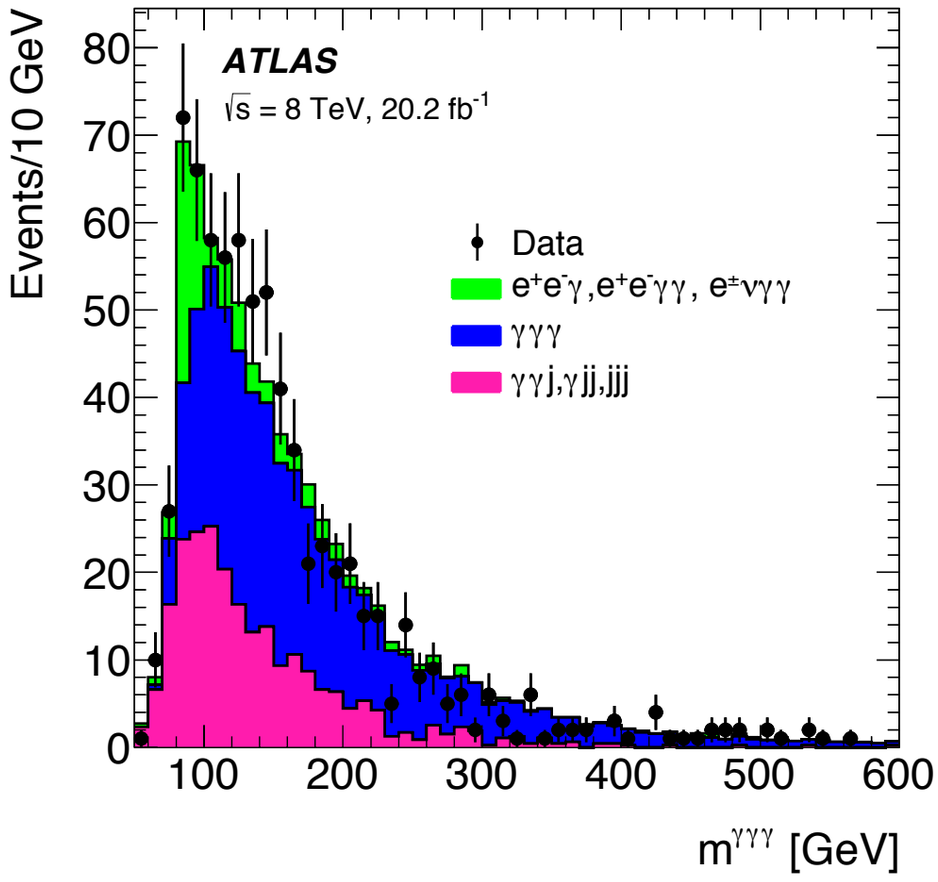


Production of three photons at 8 TeV

arXiv:1712.07291

- Integrated cross-section and differential as a function of $E_{T1,2,3}$, $\Delta\phi_{\gamma\gamma}$ and $\Delta\eta_{\gamma\gamma}$, $m_{\gamma\gamma}$ and $m_{3\gamma}$
- $E_T > 27, 25, 15$ GeV; $m_{3\gamma} > 50$ GeV; $\Delta R > 0.45$; $E_T^{iso,part} > 10$ GeV
- Jet background subtracted by 2D sideband method (ID and iso); $e \rightarrow \gamma$ from MC, checked with data around m_Z

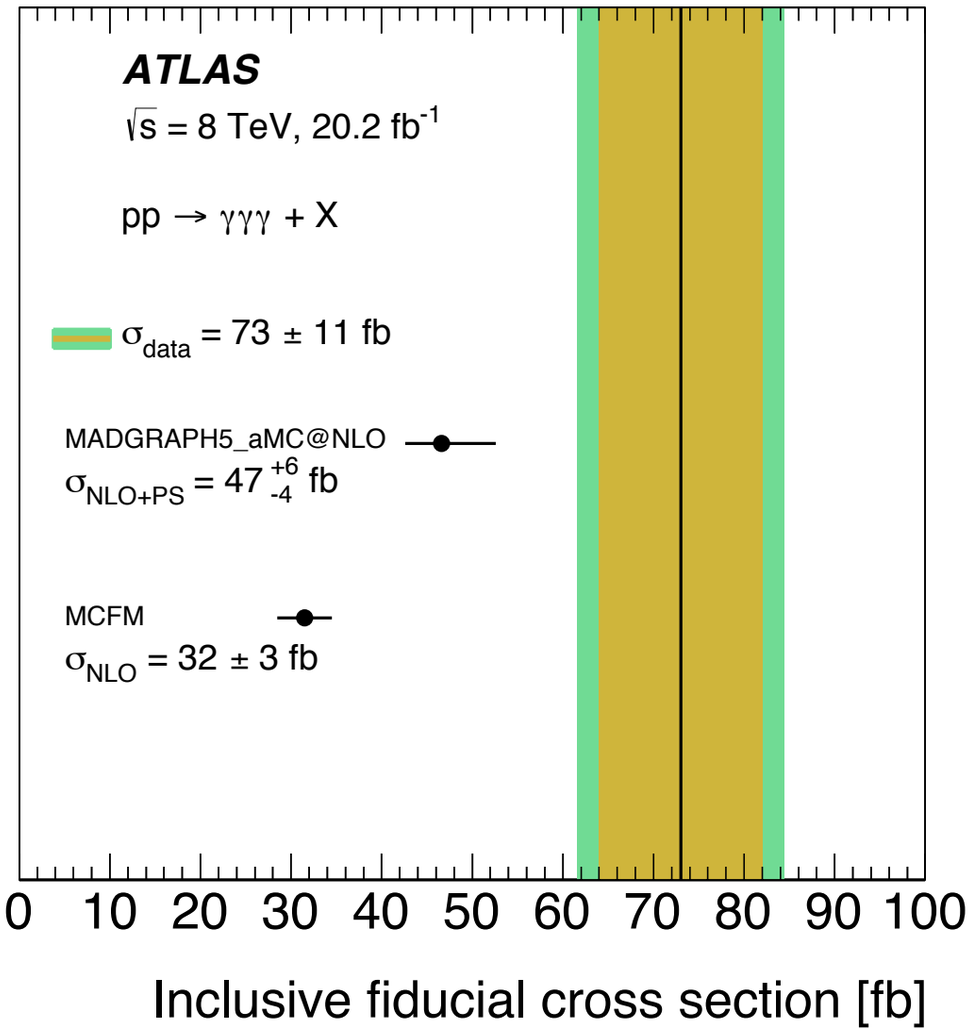




Production of three photons at 8 TeV

arXiv:1712.07291

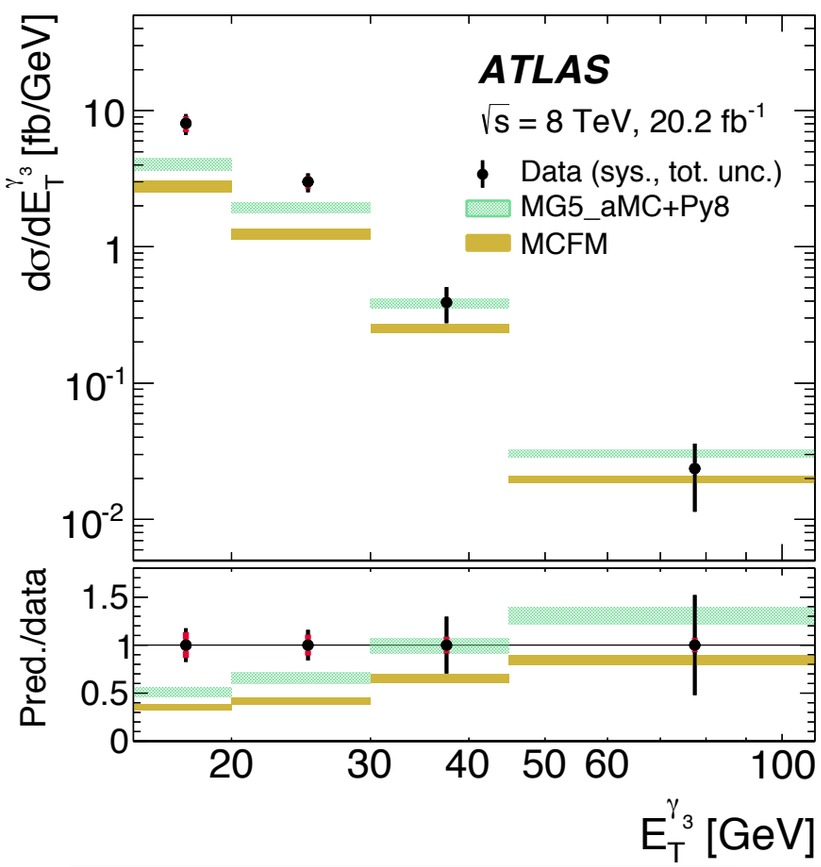
- Stat uncertainty: ~9%. Syst: ~13%
  - ID eff. (7.9%)
  - Correlation between ID and iso (7.7%)
  - Iso modelling (5.8%)
- Compared to NLO (MCFM with BFG II frag.) and NLO+PS (MG5_aMC@NLO+Pythia)
  - Scale uncertainty: 10-12%
  - Underestimate the data by ~ factor 2
- Would benefit from NNLO

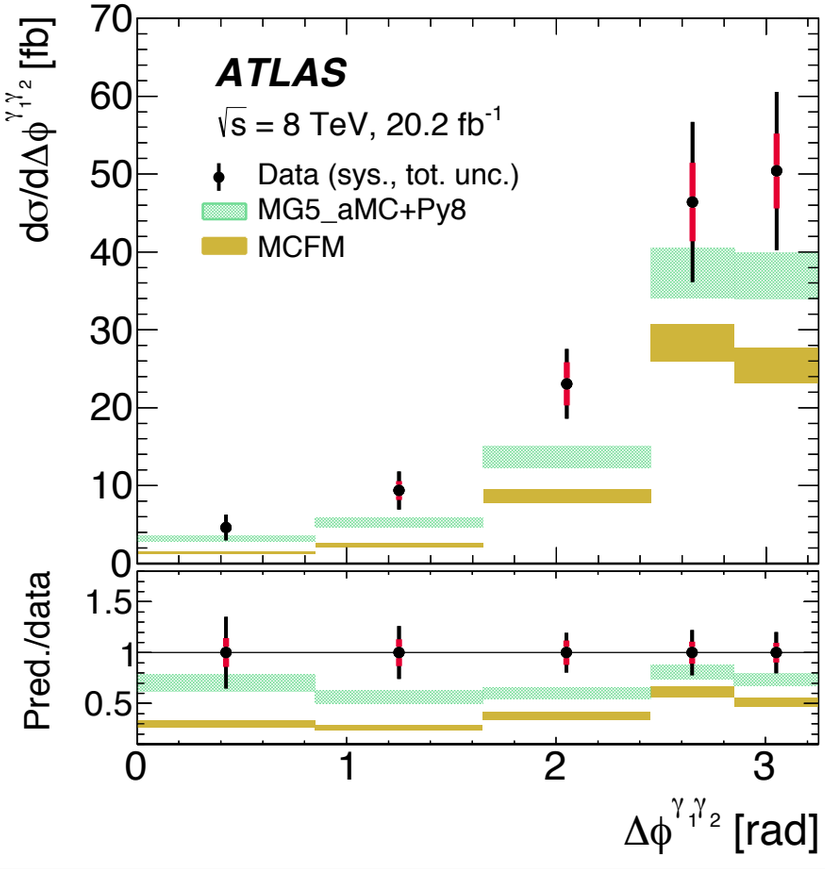


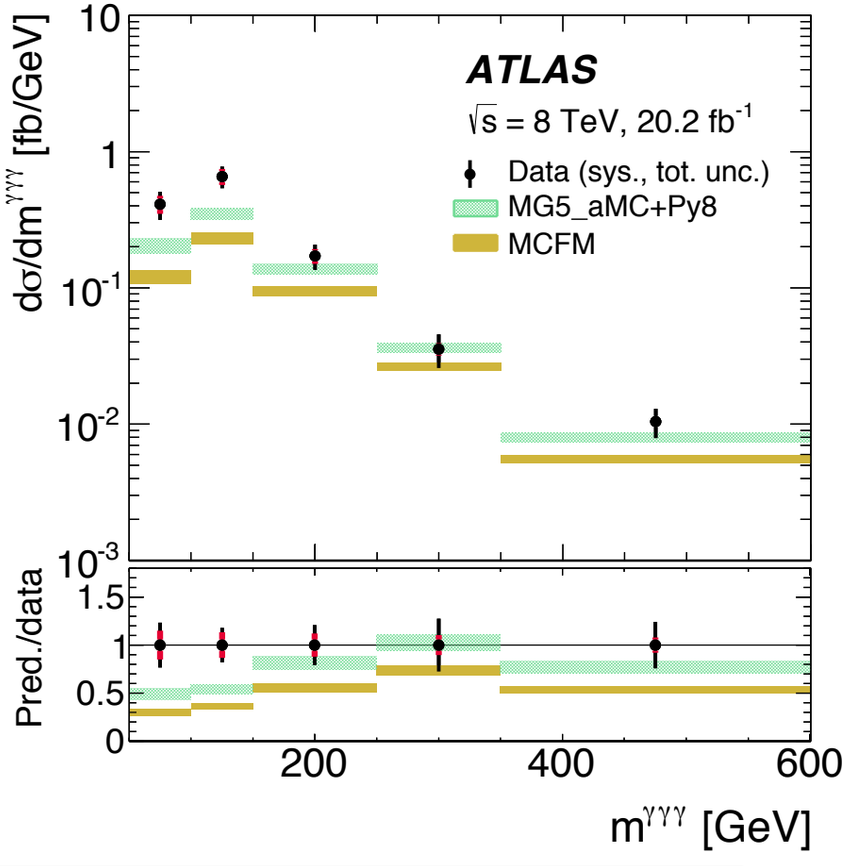
Production of three photons at 8 TeV

arXiv:1712.07291

- Differential cross-section as a function of $E_{T1,2,3}$, $\Delta\phi_{\gamma\gamma}$ and $\Delta\eta_{\gamma\gamma}$, $m_{\gamma\gamma}$ and $m_{3\gamma}$
  - Stat 20-50% in some bins. Dominates for $E_{T1,2} > 50$ GeV or $E_{T3} > 30$ GeV
  - Syst: 15-10%
- Significant discrepancies between data and theory at low E_T and low inv. masses. Adequate description of $\Delta\eta_{\gamma\gamma}$, less so of $\Delta\phi_{\gamma\gamma}$

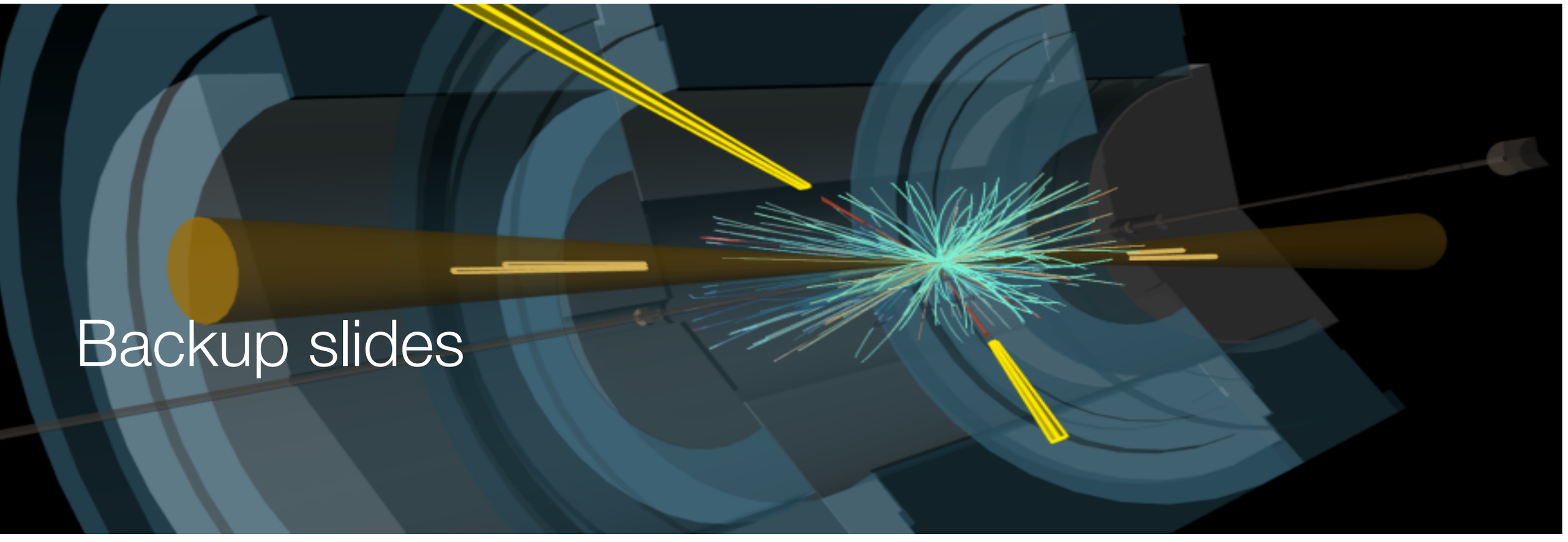






Summary

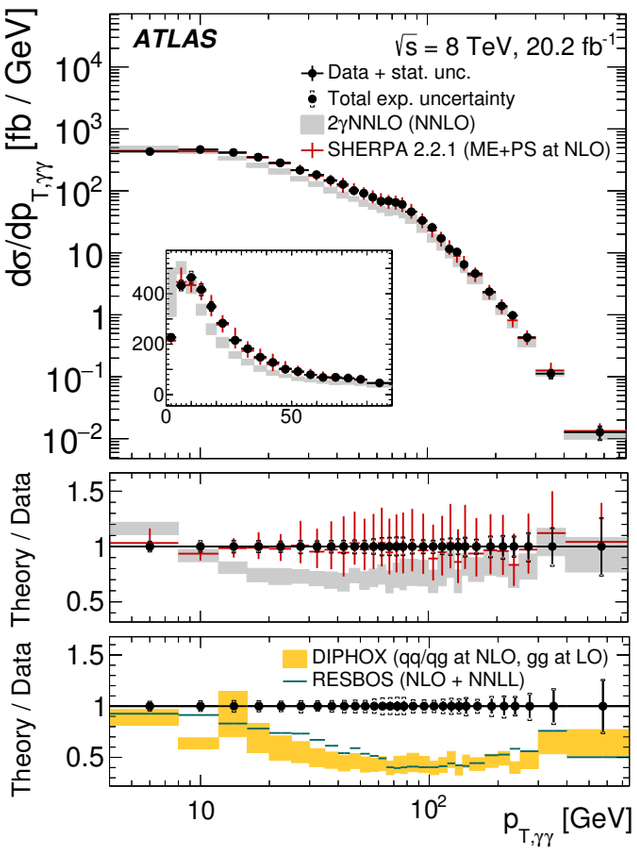
- Measurements of cross-sections of pp → up to 3 photons
  - Reach ~1 TeV in E_T and $m_{\gamma\gamma}$
  - Differential measurements of several variables
  - Precision of few % in many cases, similar or better than theory errors
- Comparisons with calculations up to NNLO or NLO+PS
  - Some discrepancies but overall agreement with data ok (less so for 3γ)
- Looking forward to improved calculations and updated measurements

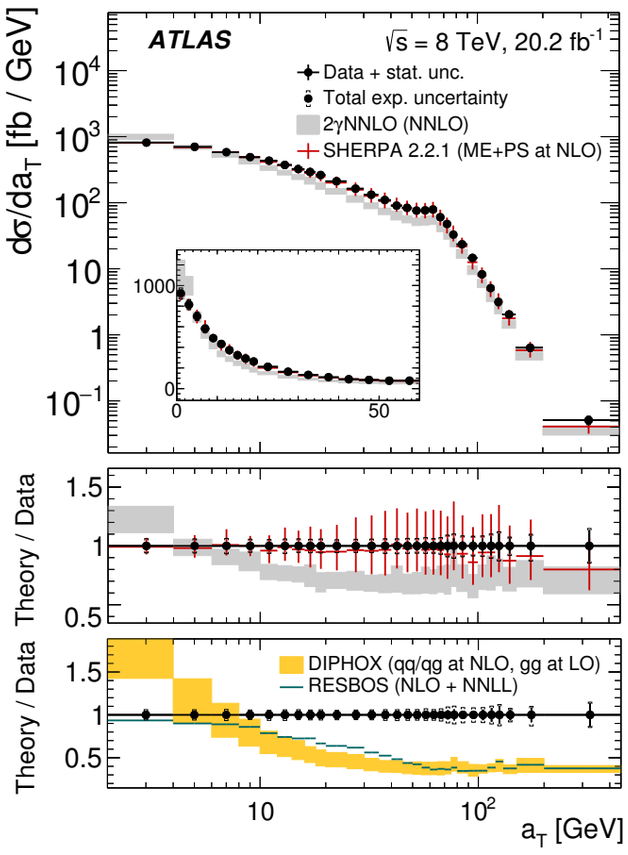


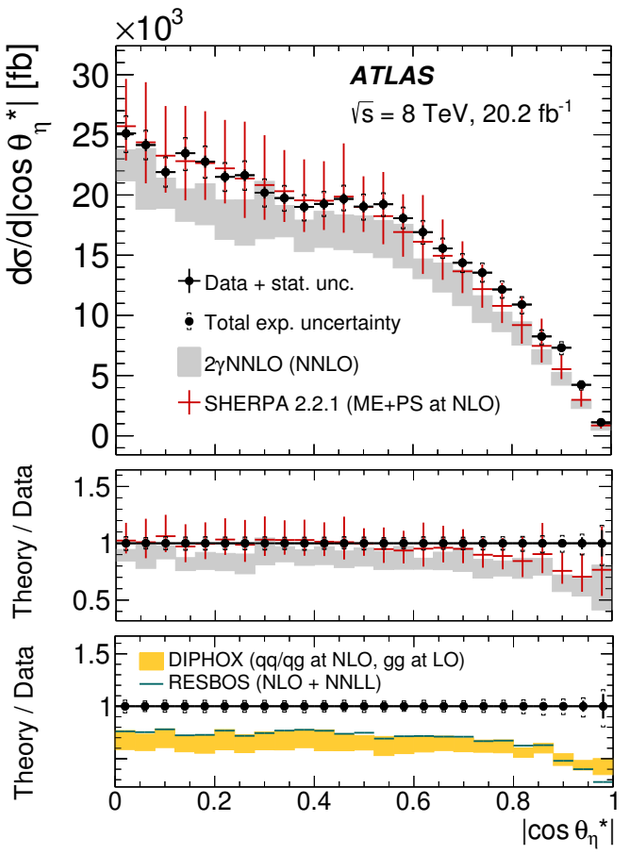
Backup slides

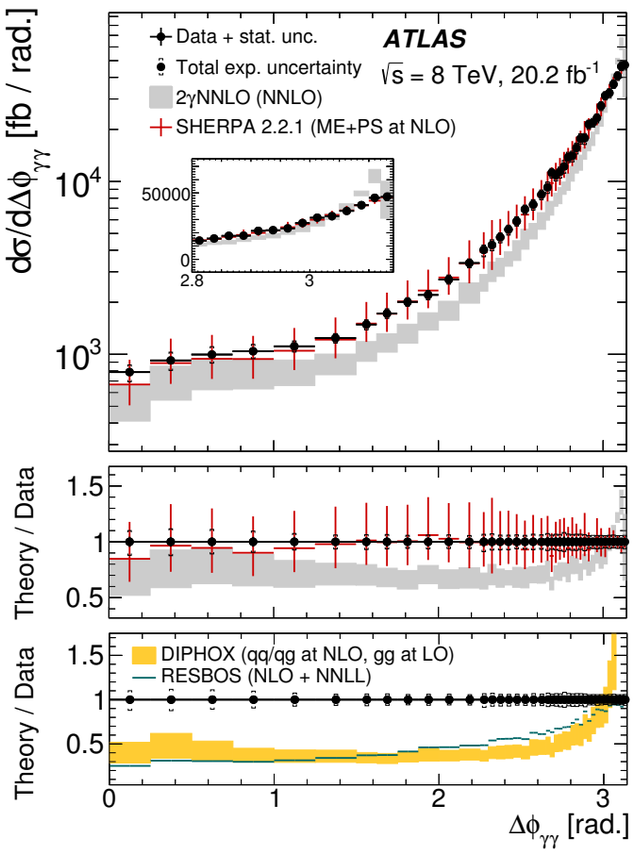
Photon pair production at 8 TeV

Phys. Rev. D 95 (2017) 112005









Three photon production at 8 TeV

arXiv:1712.07291