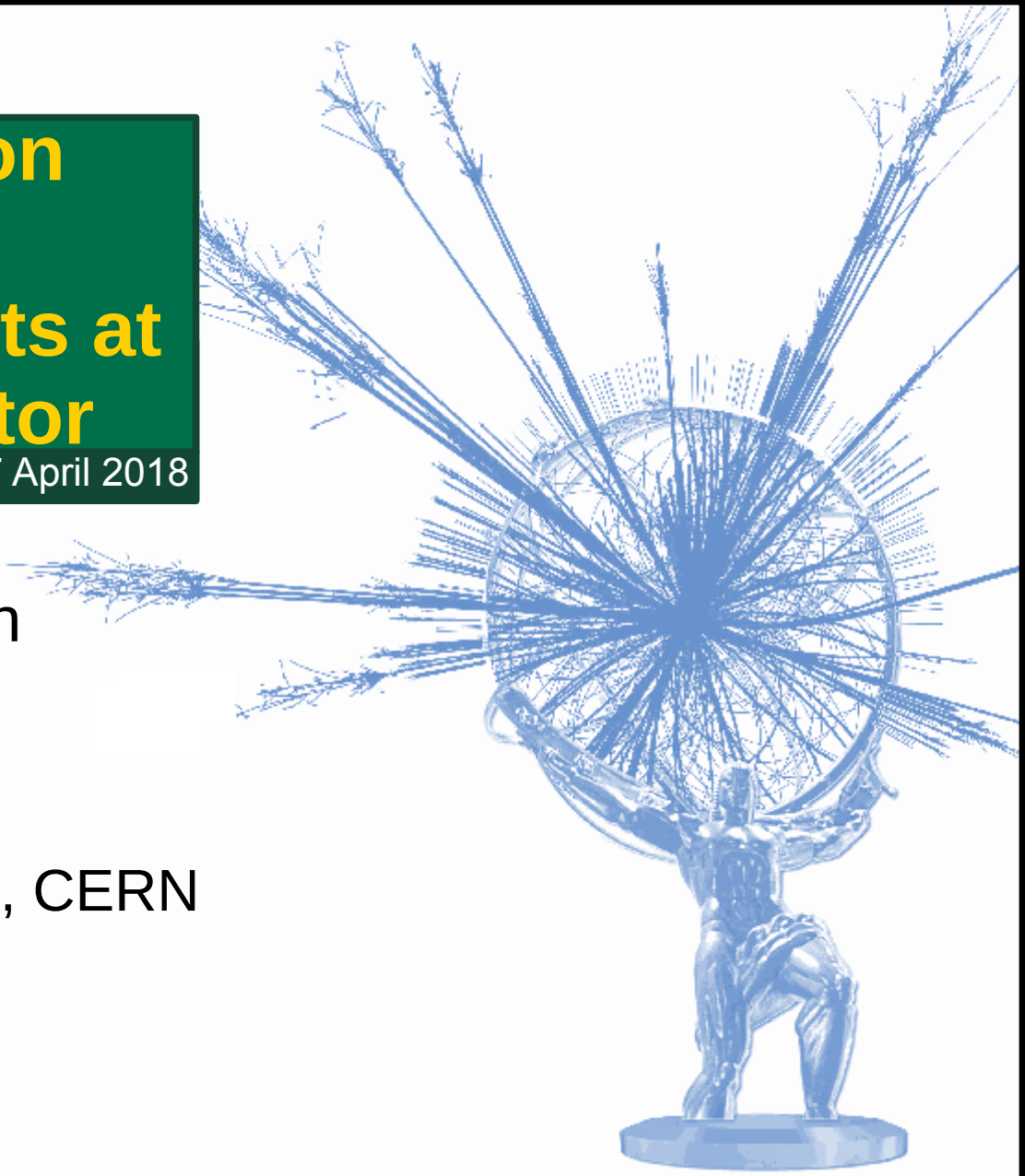
Studies of photon production in association with jets at the ATLAS detector

17 April 2018

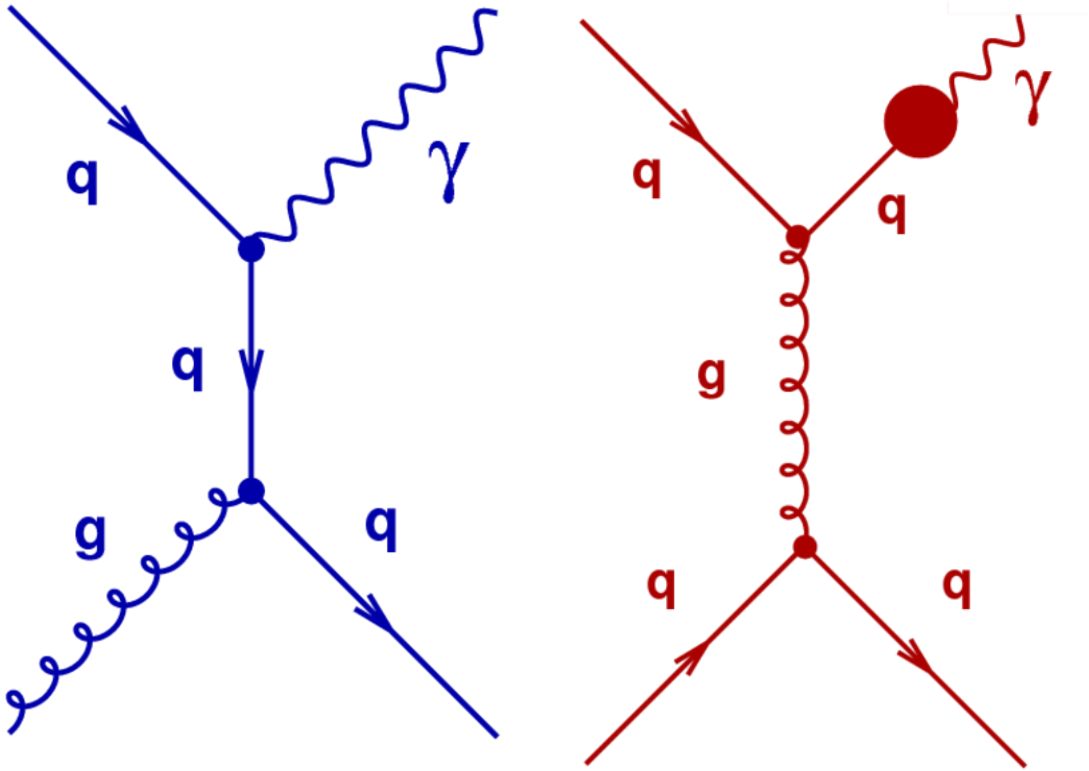


- DIS2018, Kobe, Japan

- Mark Stockton
  - University of Oregon, CERN

Introduction

- Bruno Lenzi already showed the latest ATLAS inclusive prompt-photon results
- A reminder that prompt photon production is made up of direct and fragmentation processes (only well defined at LO)



- These have different angular distributions ~$1/(1-|\cos(\theta^*)|)$ and ~$1/(1-|\cos(\theta^*)|)^2$ as depends on the spin of the exchanged particle

Introduction

- Previously at DIS the earlier ATLAS photon+jet measurements have been shown
  - Measurement of the production cross section of an isolated photon associated with jets in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector
    - Phys. Rev. D 85, 092014 (2012)
  - Dynamics of isolated-photon and jet production in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector
    - Nucl. Phys, B 875 (2013) 483-535
  - High-ET isolated-photon plus jets production in pp collisions at sqrt(s) = 8 TeV with the ATLAS detector
    - Nucl. Phys. B 918 (2017) 257
- **New and presented today**
  - Measurement of differential cross sections of isolated-photon plus heavy-flavour jet production in pp collisions at sqrt(s) = 8 TeV using the ATLAS detector
    - Phys. Lett. B 776 (2018) 295
  - Measurement of the cross section for isolated-photon plus jet production in pp collisions at sqrt(s) = 13 TeV using the ATLAS detector
    - Phys. Lett. B 780 (2018) 578

Data used

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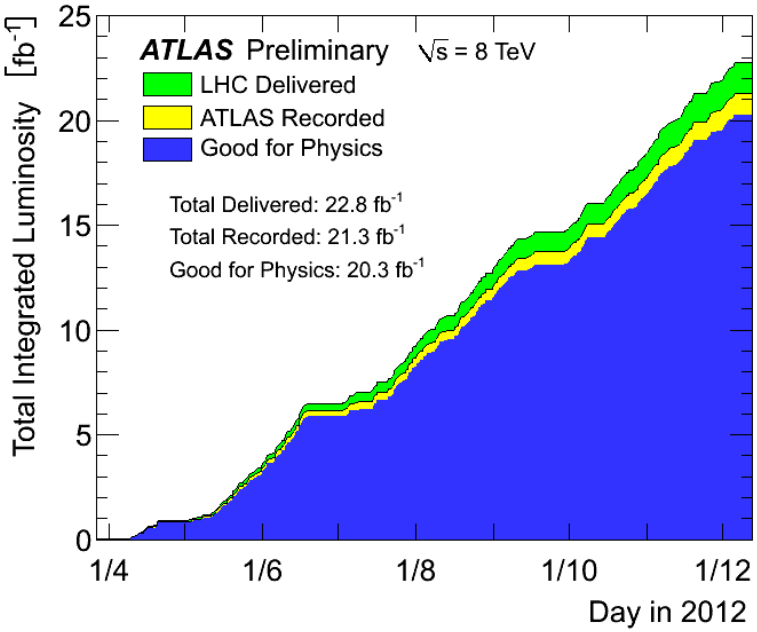

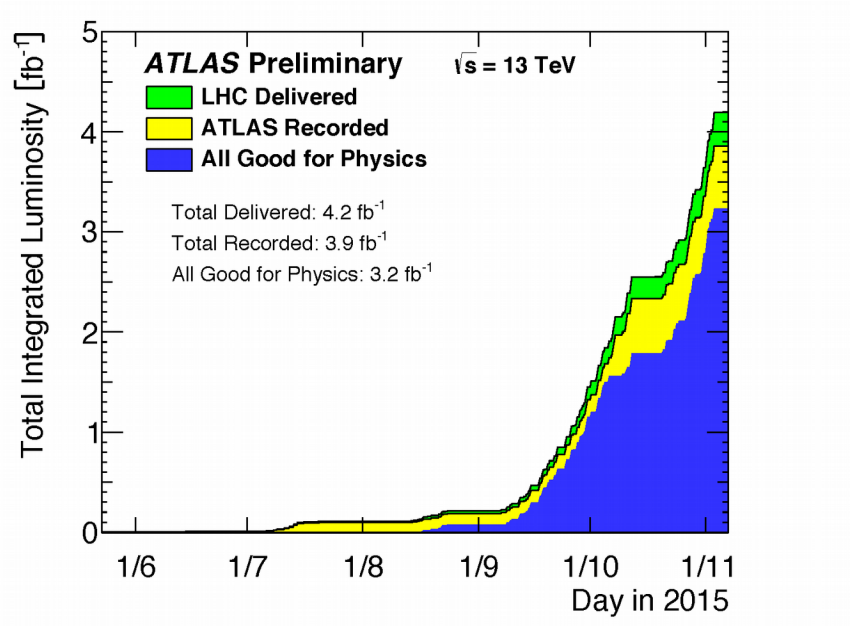

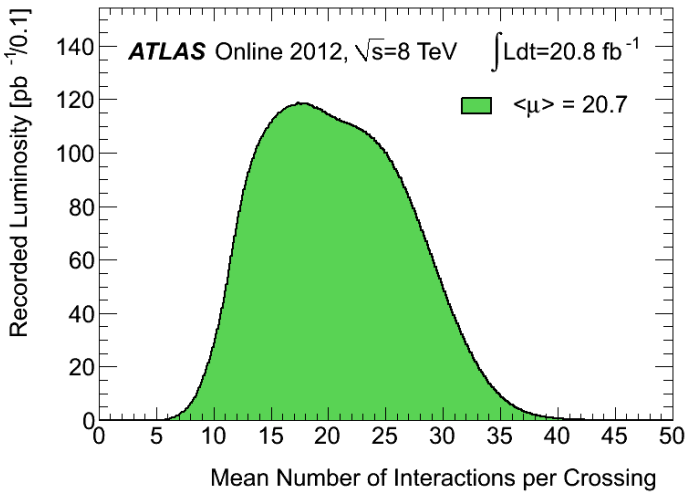

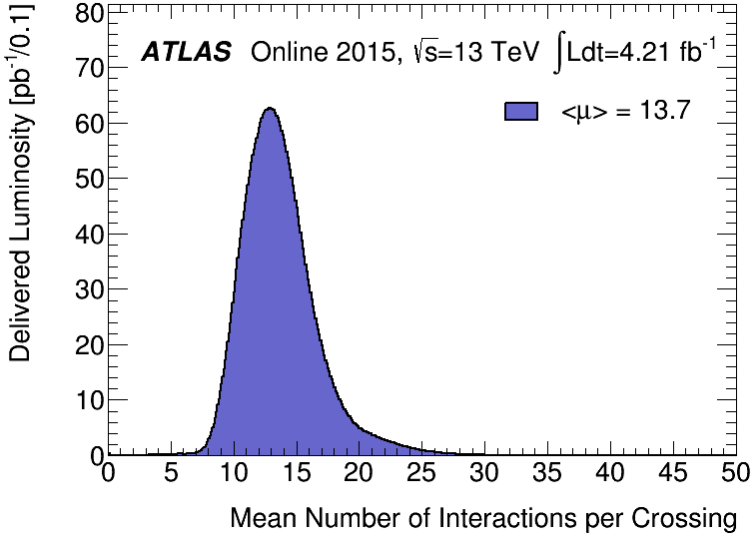

Photon selection

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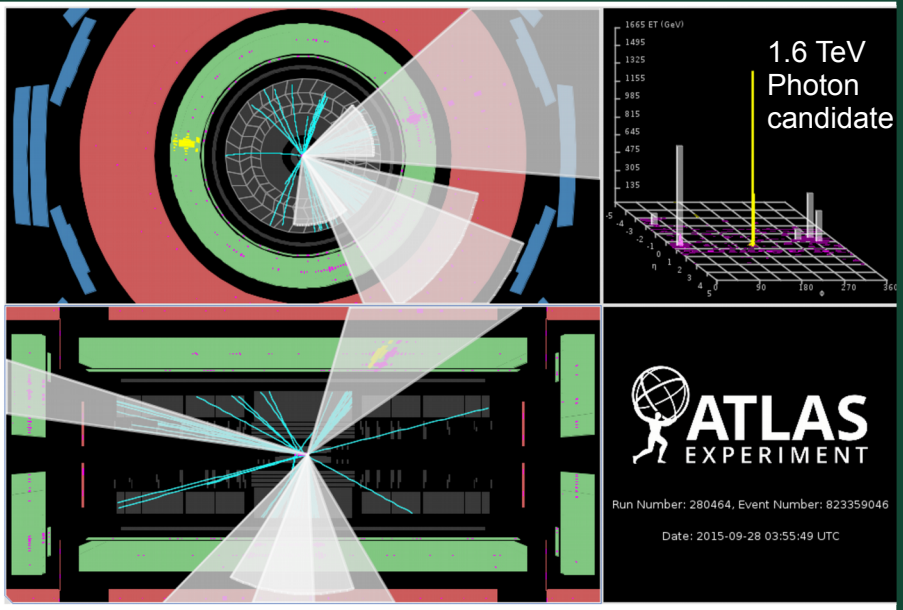
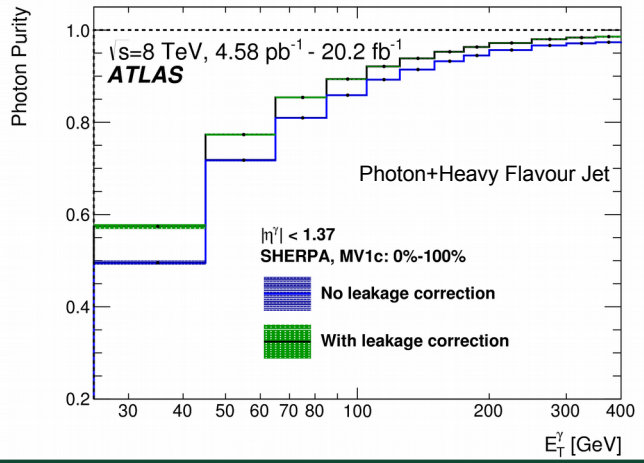
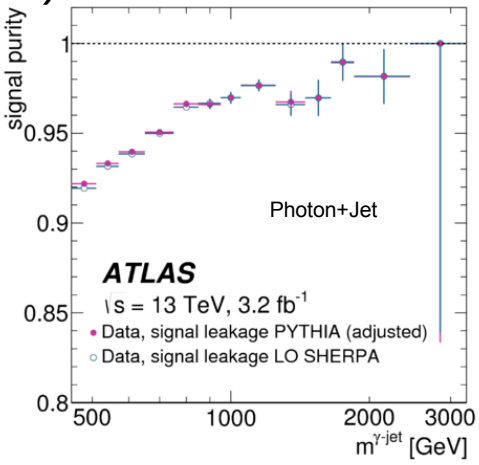
- Selected in barrel $|\eta^{\gamma}| < 1.37$ and end-cap $1.56 < |\eta^{\gamma}| < 2.37$



- Remove hadron and τ background
  - Photon Identification:
    - Lateral and longitudinal energy profiles of the shower
  - Calorimeter isolation:
    - $E_T^{iso} < 0.0042 \times E_T^{\gamma} + 4.8\,GeV$
    - Corrected for pileup using jet area method
  - Use 2D-sidebands for remaining background
    - $N_A^{sig} = N_A - N_B \times N_C / N_D$
    - Simulation used to include estimated signal contamination
- Small electron background removed using MC (checked in data)

N_C **Fail** Photon ID Isolated	N_D **Fail** Photon ID **Not** Isolated
N_A Pass Photon ID Isolated	N_B Pass Photon ID **Not** Isolated



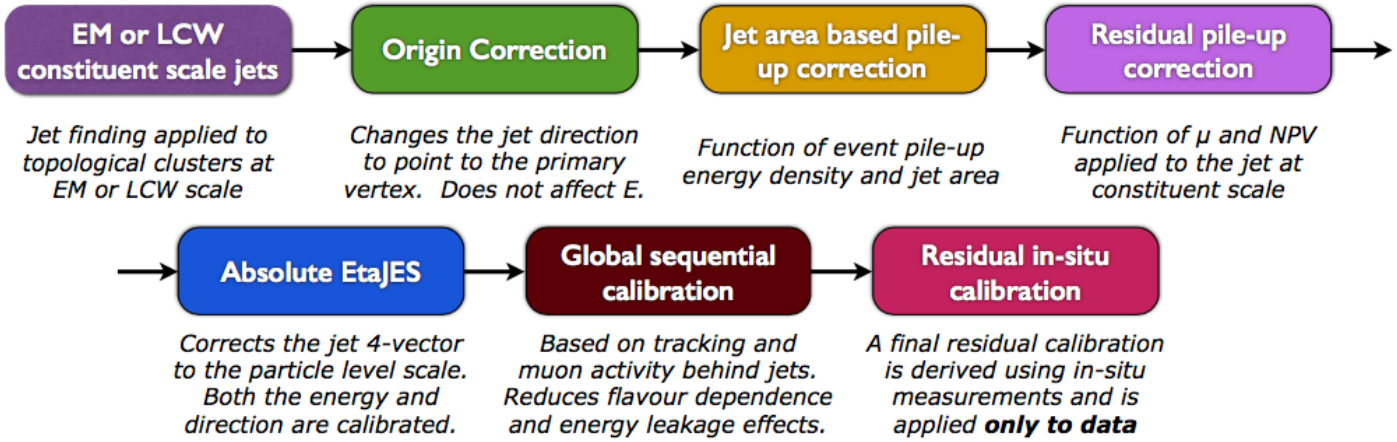


Photon+Jet

Phys. Lett. B 780 (2018) 578

Jet selection and cross section variables

- Use anti-k_t R = 0.4 jets
  - Based on topological clusters and then follow a multi-step calibration

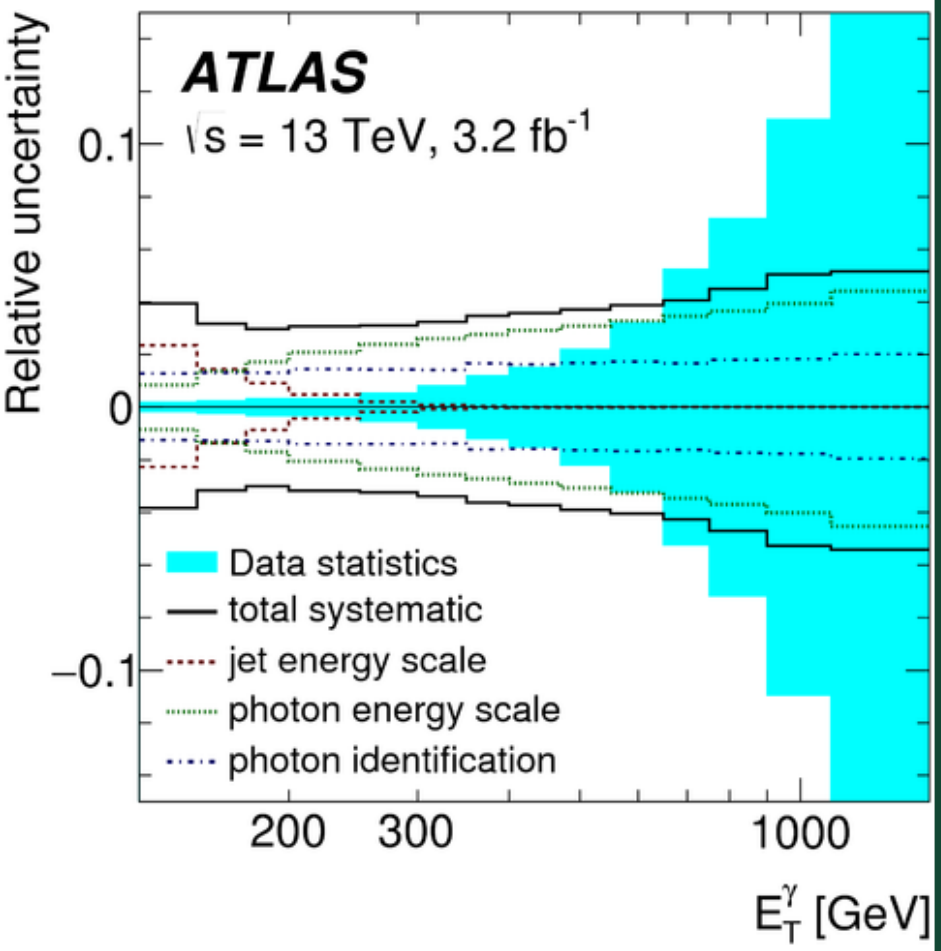


- Select Leading p_T^{jet} (>100 GeV)
  - $|y^{jet}| < 2.37$
  - $\Delta R > 0.8$
    - To separate photon isolation cone and the jet

- Use these selections for photons with $E_T > 125$ GeV to measure the cross sections:
  - E_T^{γ}, $p_T^{jet\text{-}lead}$, $\Delta\phi^{\gamma\text{-}jet}$
- Additional constraints for $m^{\gamma\text{-}jet}$ and $|\cos\theta^*|$ measurements:
  - $|\eta^{\gamma} + y^{jet\text{-}lead}| < 2.37$, $|\cos\theta^*| < 0.83$ and $m^{\gamma\text{-}jet} > 450$ GeV
  - To remove bias due to the selection requirements on the photon and jet

Systematics

- Jet energy scale
  - Individual sources of uncertainty are varied in MC simulations
  - Propagated through all steps of the analysis to keep correlations
- Photon energy scale
  - Mostly comes from the calibration studies made for 8 TeV data, with additions for the difference between 2012 and 2015 data.
  - Sources are applied as in case of jets
- Photon identification
  - Estimated from differences in shower shape variables in data/simulation
- Other smaller uncertainties:
  - Parton shower/hadronisation
  - Photon isolation modelling
  - Background control regions
  - Correlations in control regions
  - Pileup
  - Unfolding
  - Trigger and luminosity



Results

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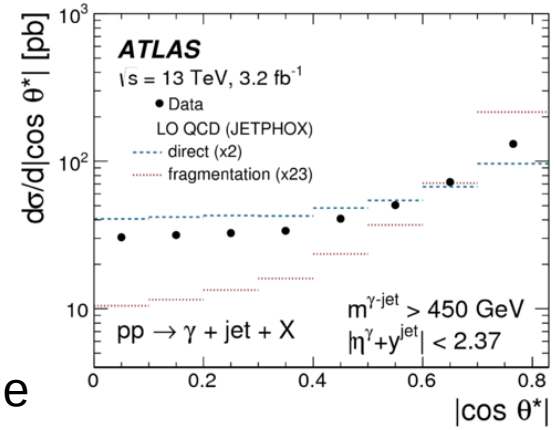
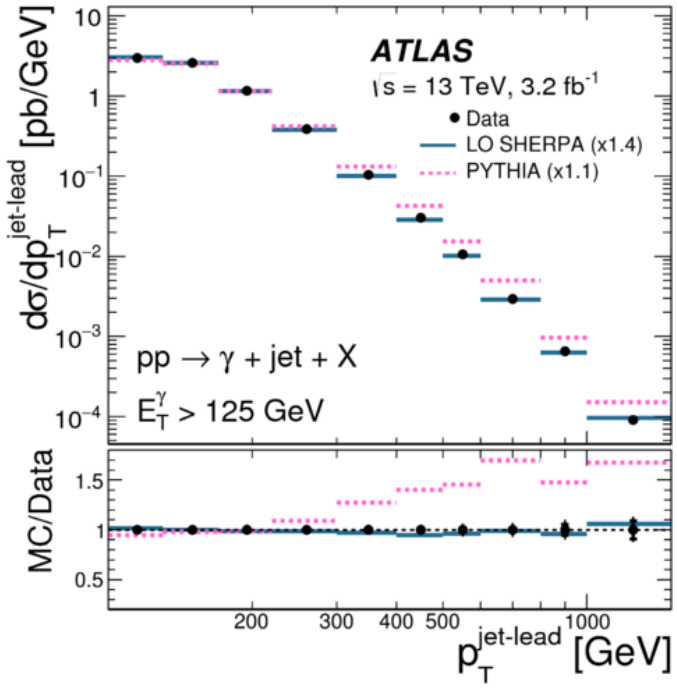
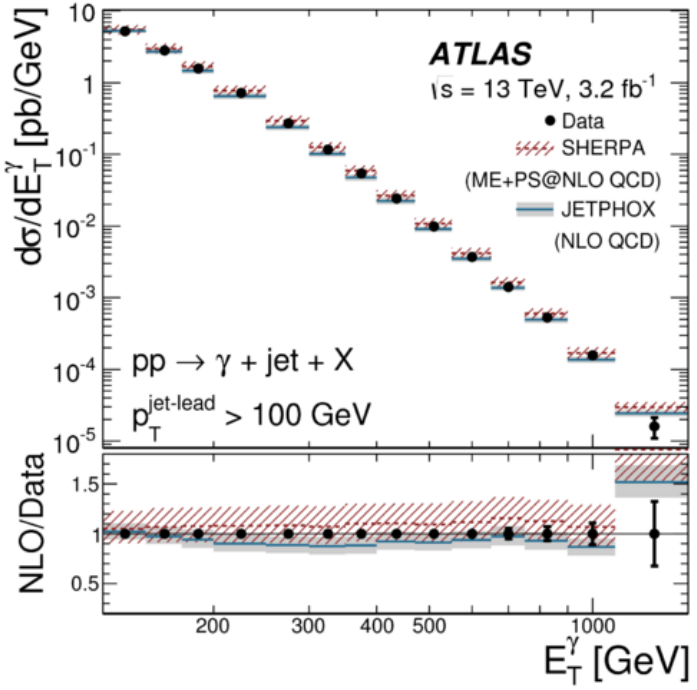
- Fiducial measured Cross Section: 300 $\pm$10 (exp.) $\pm$6 (lumi) pb
  - Consistent between experiment and NLO theory (both JetPhox and Sherpa)

- Differential results:
  - Data illustrates the contributions of the two process for production
  - At LO very good agreement in all variables for Sherpa and Pythia, except for Pythia in $p_T^{\text{jet-lead}}$
  - Good agreement with NLO over 6 orders of magnitude







Further results

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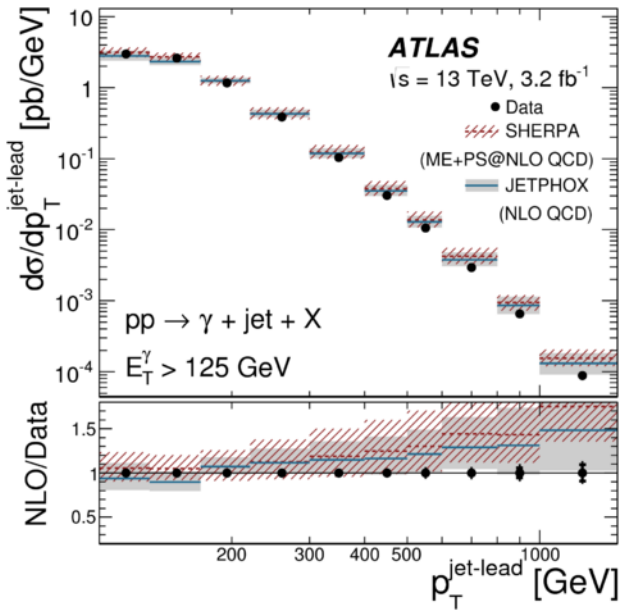
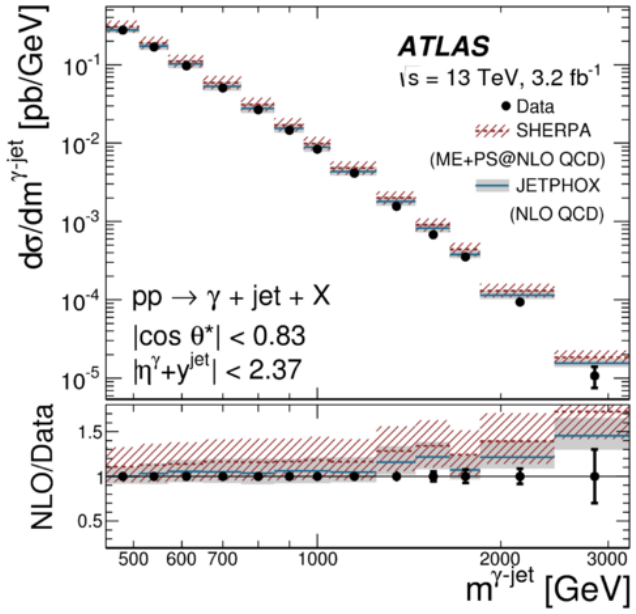
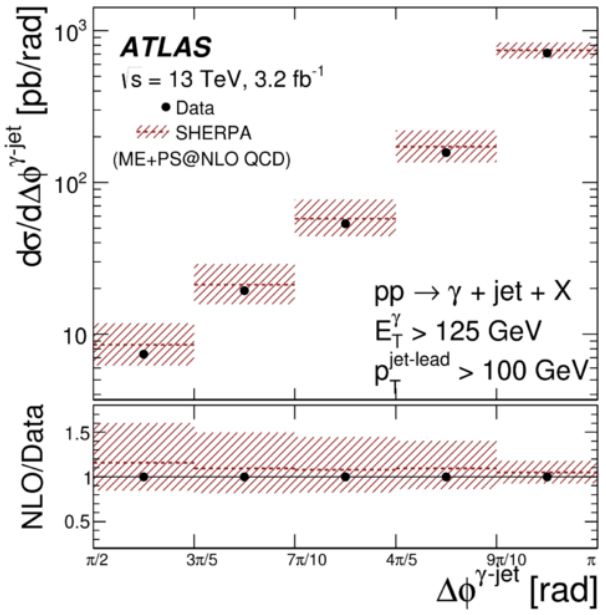
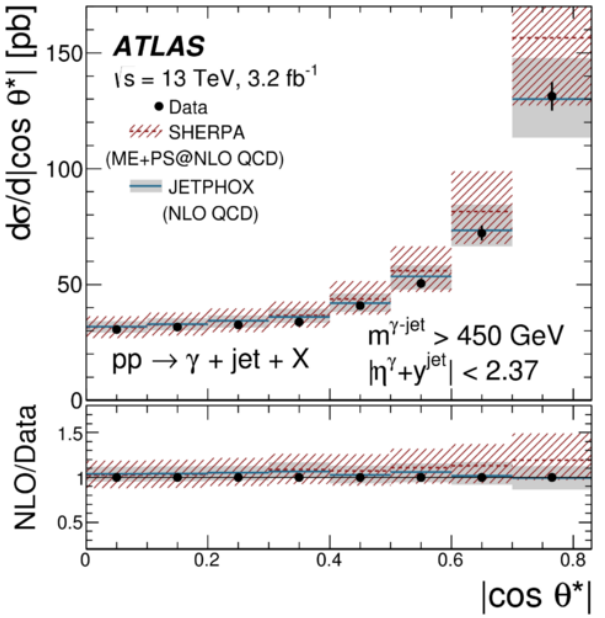




- Both predictions are within experimental uncertainties
- Sherpa includes $2 \rightarrow 4/5$ ME processes which allows it to reproduce data to $\pi/2$ in $\Delta\phi^{\gamma\text{-jet}}$
- JetPhox (Sherpa) shown with MMHT2014 (NNPDF3.0)
  - Results are not dependant on PDF as using alternative sets (incl. CT14) has differences of <5%
- Results show good agreement of pQCD in photon jet dynamics at 13 TeV





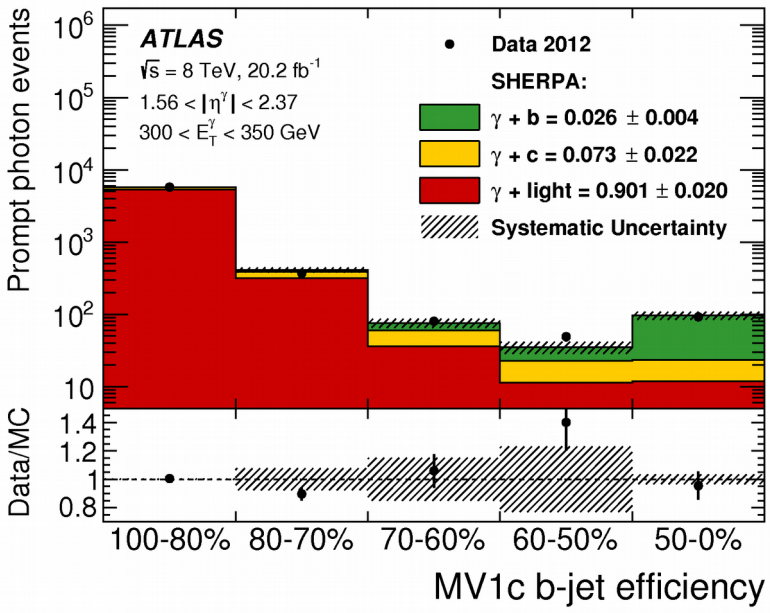
Photon+Heavy Flavour jet

Phys. Lett. B 776 (2018) 295

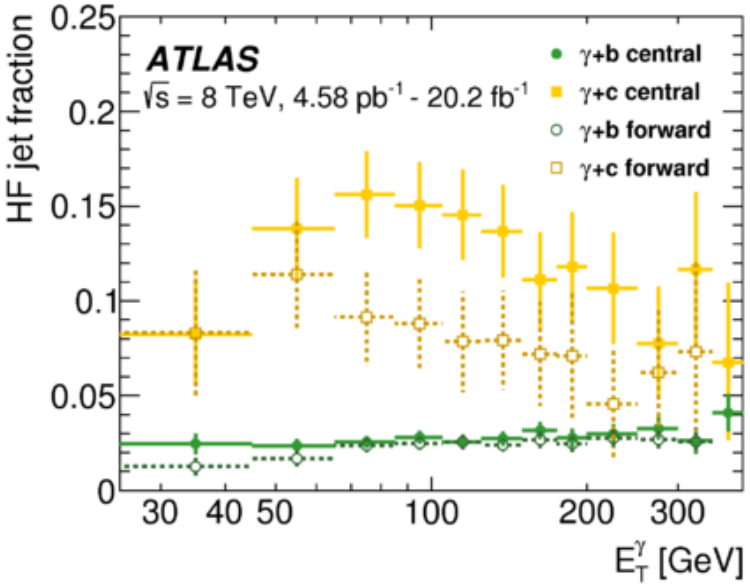
Event selection

- Very similar to Photon+Jet measurement, but probe lower energy:
  - Photon E_T requirement reduced to >25 GeV
    - Requires using prescaled triggers
  - Similarly jet p_T reduced to >20 GeV
    - Requires further suppression of pileup jets, using associated tracks for p_T^{jet}< 50 GeV

- Main difference is the addition of jet flavour – using MV1c (neural network) algorithm
  - Is trained to specifically identify b-jets with enhanced rejection of c-jets
  - Uses discriminants from three other algorithms based on different aspects of jet tracking information from secondary vertices
- Perform maximum likelihood template fit
  - Binned based on tagger working points

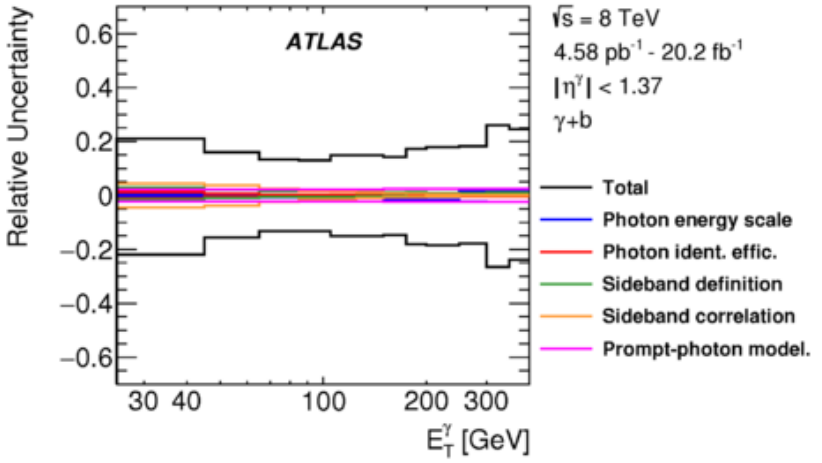


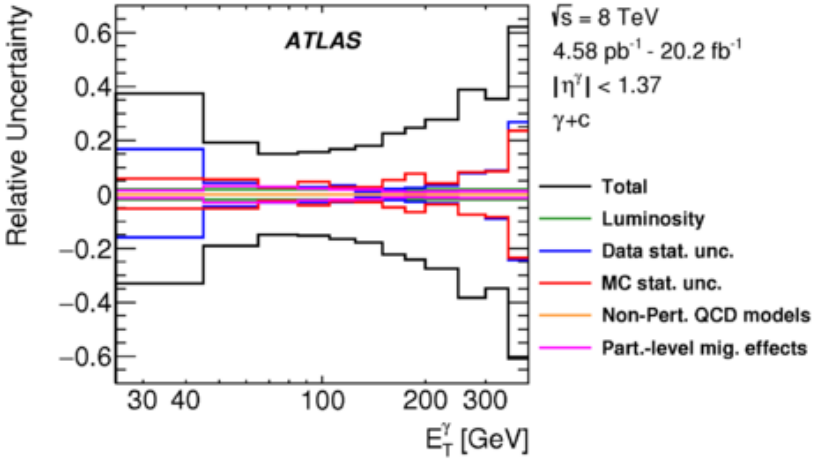
- Photon+b and photon+c contributions extracted simultaneously



Systematics

- Uncertainties are around 20% for most of the E_T range in the barrel region
- The uncertainties from the photon+jet measurement are measured here, but are not the dominant uncertainties
- The finite number of data statistics is one of dominant sources of uncertainty
- Larger uncertainties for photon+c as MV1c built to discriminate b-jets





Systematics

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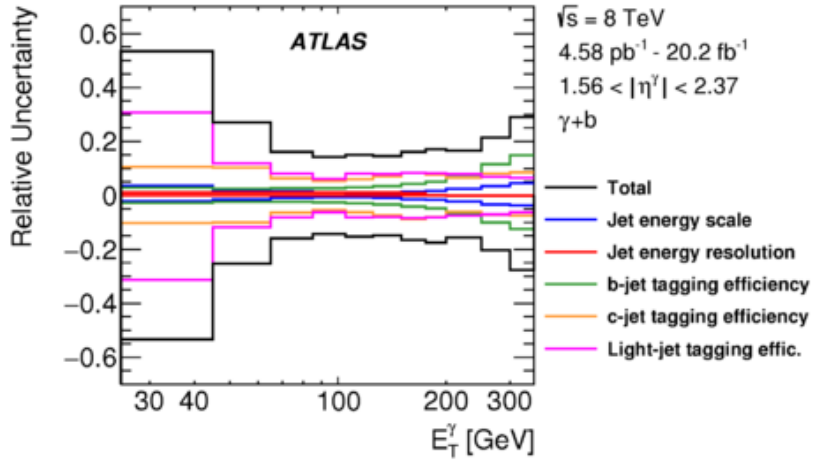
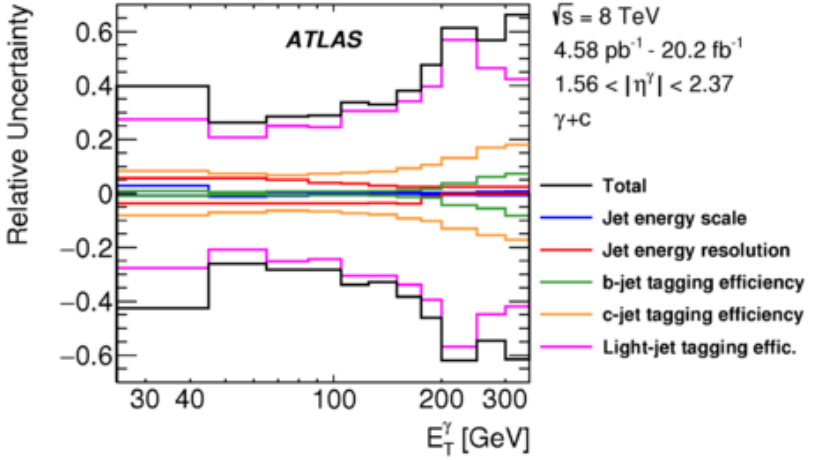
- The uncertainties from the photon+jet measurement are measured here, but are not the dominant uncertainties
- The finite number of data statistics is one of dominant sources of uncertainty
- Larger uncertainties for photon+c as MV1c built to discriminate b-jets
- In comparison the forward region has larger uncertainties due to larger statistical uncertainties and increased detector material
- The calibration of the tagger discriminant is the largest uncertainty
  - This calibration is performed using a fit of templates in tt events for b-jets and using reconstructed $D^{*\pm}$ mesons for c-jets

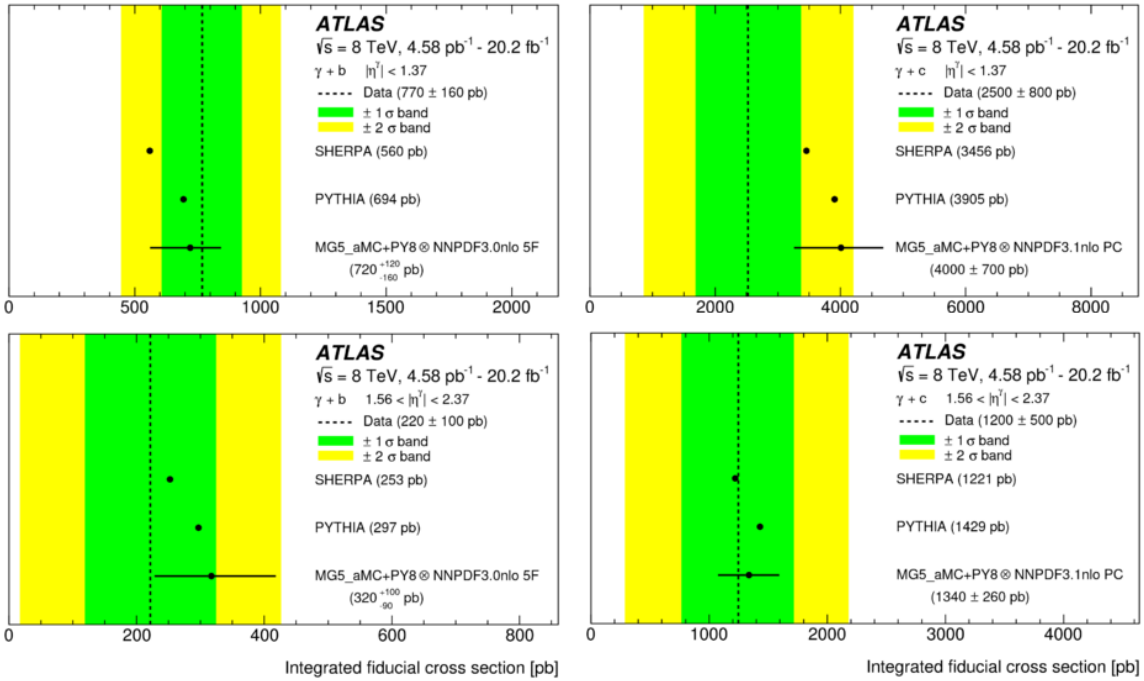




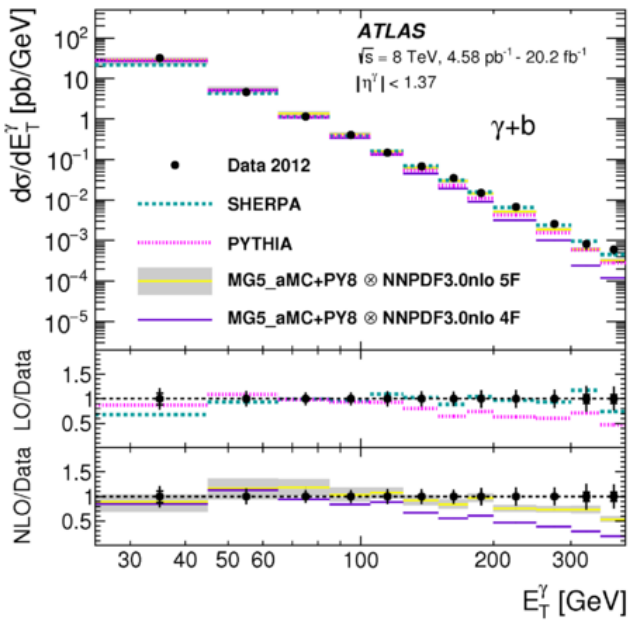
Theoretical predictions

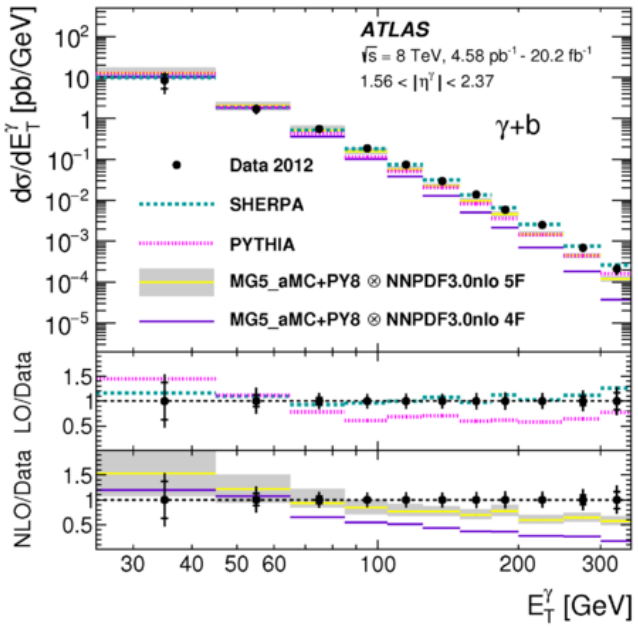
- MadGraph is interfaced with Pythia for its parton shower in NLO+PS mode
  - Also compare to LO predictions from Pythia and Sherpa
- Measurement tests the 4/5 flavour scheme
  - MadGraph also used in 4F scheme for photon+b
    - Treats b as massive in ME, so creates photon+bb events at parton level
- Measurement is sensitive to the intrinsic charm hypothesis
  - Include PDFs with this contribution
    - 0.6% (BHPS1), 2.1% (BHPS2), 0.26%(NNPDF FittedC)

- Fiducial cross sections show the overall good agreement of the calculations



Results

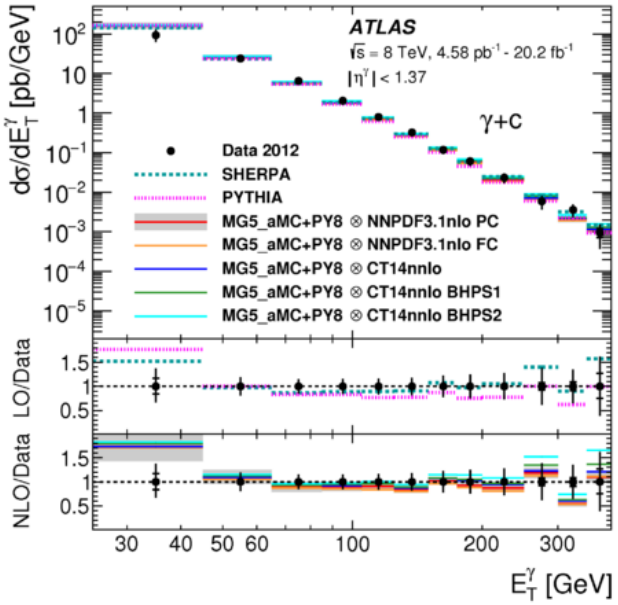


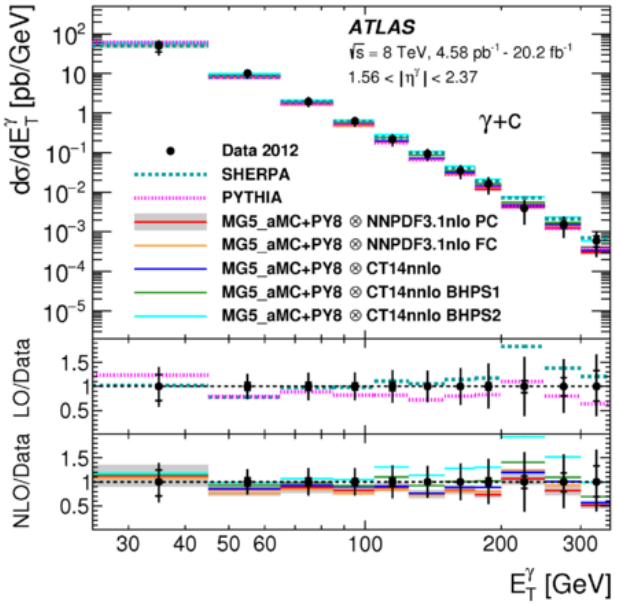


- Sherpa performs well in all measurements
- Above 150GeV in photon+b Pythia underestimates data
- Both NLO agree at low ET in photon+b, but 5F scheme performs better for $125<E_T<200$ GeV
  - At higher E_T gluon splitting is important → HO calc needed

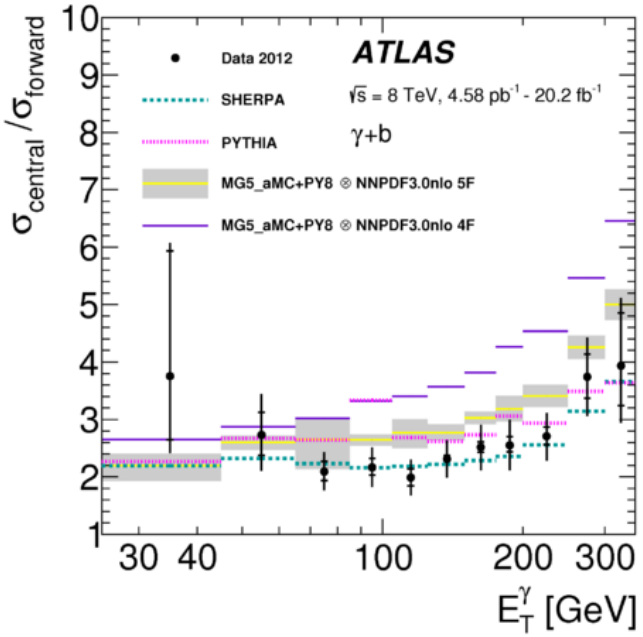
Good agreement seen in photon+c

- Gluon splitting less important at this E_T
- All IC predict higher forward cross section as expected
  - BHPS2 deviates the most

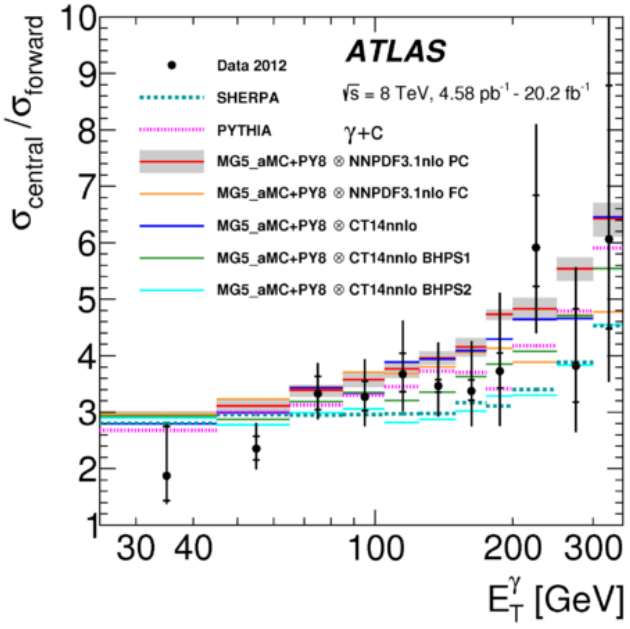




Results (ratios)



- Taking ratios between the barrel and end-cap shows even clearer the performance of Sherpa and the 5F scheme and the measurement accuracy (data statistics are main uncertainty)
- In photon+c the measurement accuracy matches the deviations between the theoretical predictions



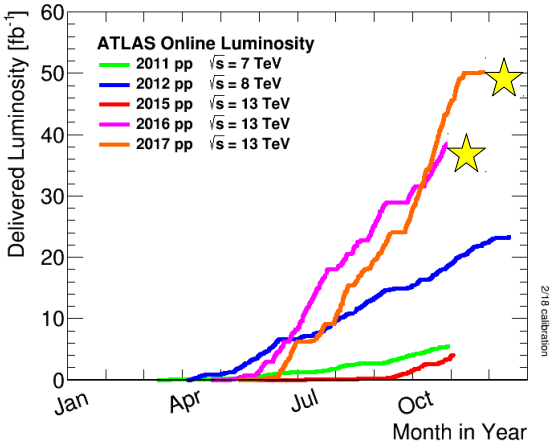
Summary

- Existing ATLAS Photon + jet measurements have been built upon

- Firstly by extending to 13 TeV
  - LO performs well in all measurements, apart from Pythia in p_T^{jet}
  - Measured cross sections are consistent with NLO pQCD predictions

- Secondly by performing first measurement of photon + Heavy Flavour at the LHC
  - For photon+b the best description is provided by Sherpa
    - The NLO underestimates the data, but the 5F scheme works better than 4F
  - The photon+c measurement has larger experimental uncertainties
    - All predictions are in agreement with data
    - PDFs with/without intrinsic charm give deviations similar to the measurement uncertainties

Looking forward to seeing these results performed with improved theory calculations and increased statistics



Backup

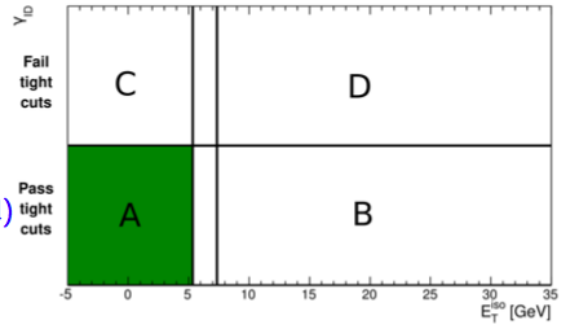
Expanded details

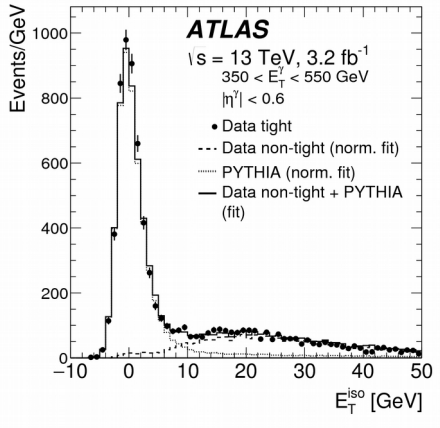
- Photon isolation distribution
- Full formula for background subtraction
  - Photon ID – tight is strictest level of photon selection

$$N_A^{sig} = N_A - R^{bg} \cdot (N_B - \epsilon_B N_A^{sig}) \cdot \frac{(N_C - \epsilon_C N_A^{sig})}{(N_D - \epsilon_D N_A^{sig})}$$

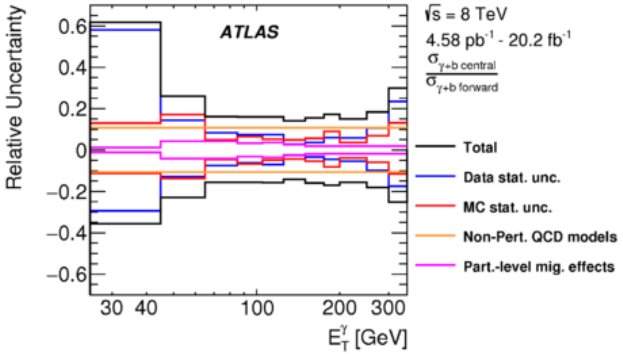
$$\epsilon_K = N_K^{sig} / N_A^{sig} \rightarrow \text{taken from signal MC}$$

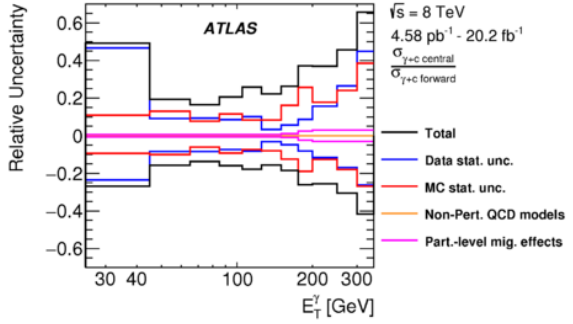
$$R^{bg} = \frac{N_A^{bg} \cdot N_D^{bg}}{N_B^{bg} \cdot N_C^{bg}} \rightarrow \text{set to 1 (Uncorrelated for background)}$$





- Photon+jet fiducial cross section comparison
  - Measured: 300 ±10 (exp.) ±6 (lumi) pb
  - JetPhox: 291 +25-21(scale) +2-3(PDF) +4-5(alpha s) +-6(non-pertub) pb
  - Sherpa: 319 +54-45(scale) +-3(PDF) +10-11(alpha s) pb
- Jet tagging algorithms used as input to MV1c:
  - IP3D – sensitive to the displacement of tracks associated to the jet from the primary vertex
  - SV1 – reconstructs secondary vertices
  - JetFitter – sensitive to secondary and tertiary vertices consistent with the b/c hadron decay chain
- Ratio of dominant systematics for photon+heavy flavour

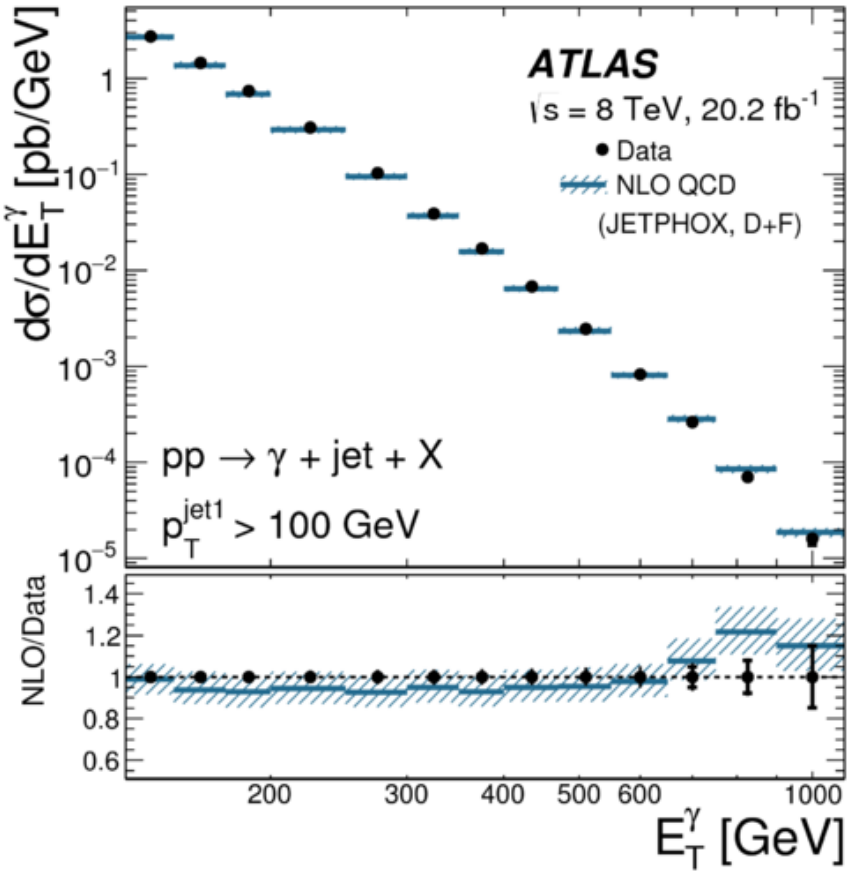


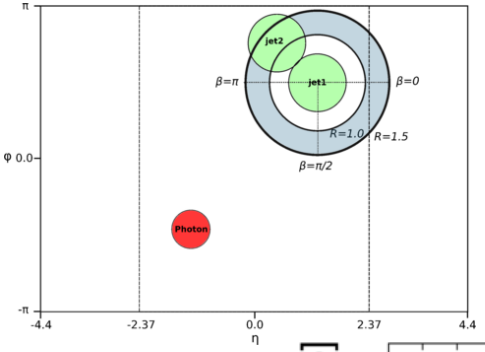


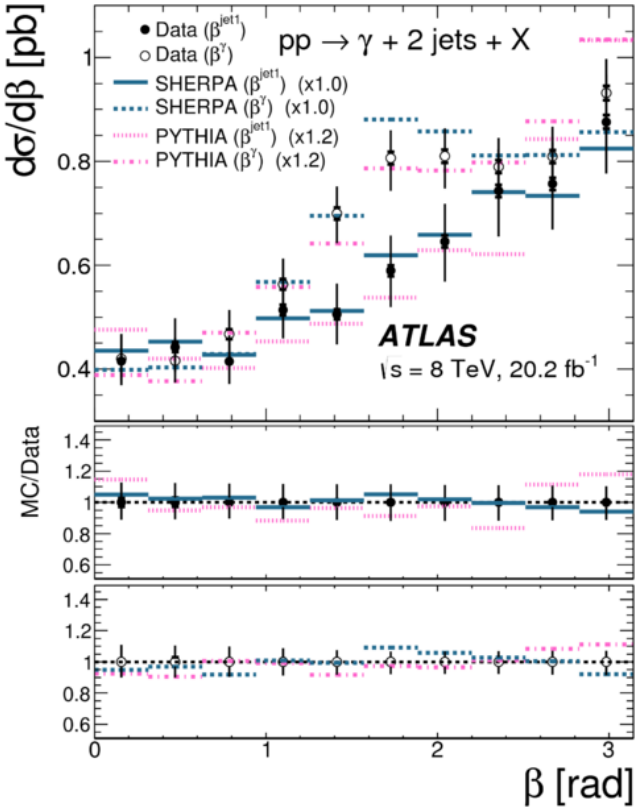
All info for presented results

- Measurement of differential cross sections of isolated-photon plus heavy-flavour jet production in pp collisions at s√=8 TeV using the ATLAS detector
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2017-02/
- Measurement of the cross section for isolated-photon plus jet production in pp collisions at sqrt(s) = 13 TeV using the ATLAS detector
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2017-01/
- Event display slide 5
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2016-08/
- Abstract
- The production of prompt photons in association with jets in proton–proton collisions provides a testing ground for perturbative QCD (pQCD) with a hard colourless probe less affected by hadronisation effects than jet production. The measurements of the angular correlations between the photon and the jets can be used to probe the dynamics of the hard-scattering process. We present here a cross-section measurement using final states with at least one, two or three hadronic jets in addition to an isolated photon, differential in a wide range of kinematic variables describing the photon+jet production dynamic. Colour-coherence effects were investigated in events with a photon accompanied by two jets. Moreover, we present the latest results on the measurement of isolated photons with jets at 13 TeV as well as on the production of photon-pairs in association with jets. We will also present for the first time measurements on the differential cross sections of isolated-photon plus heavy-flavour jet production at 8 TeV. The results are compared to recent theoretical predictions.
- Talk 15+5
- https://indico.cern.ch/event/656250/contributions/2872596/

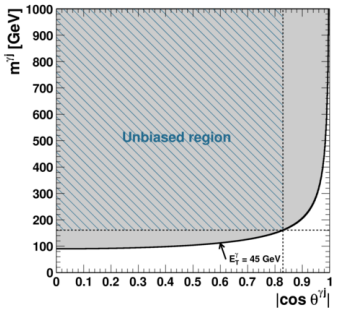
- Full information on result:
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2015-11/

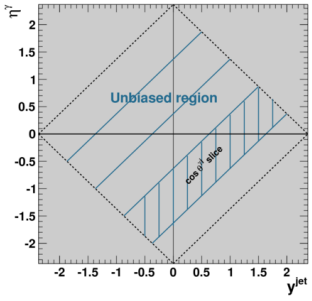


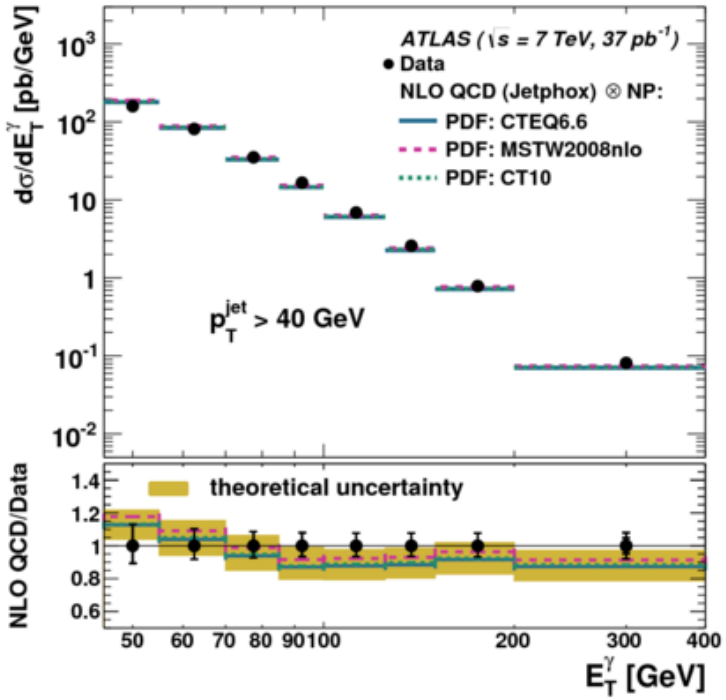


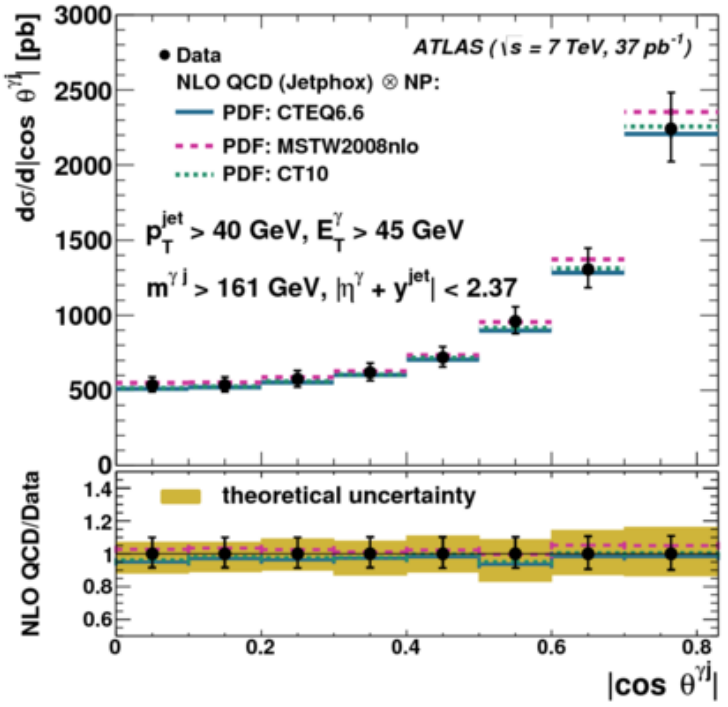


- Full information on result:
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2012-18/









- Full information on result:
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2011-28/