High-E_{T} isolated-photon plus jets production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

Héctor de la Torre Pérez
On behalf of the ATLAS Collaboration

Michigan State University

April 4, 2017

ATLAS

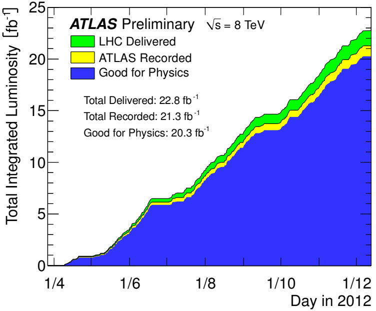
DIS 17

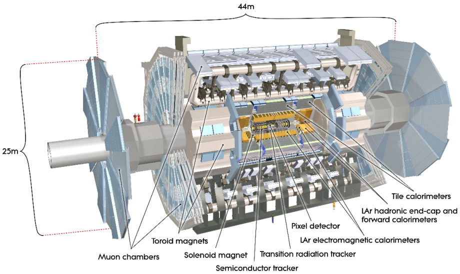
MICHIGAN STATE UNIVERSITY

ATLAS, LHC and Outline

Outline of the talk

- Photon reconstruction in ATLAS
- Jet reconstruction in ATLAS
- High-E_T isolated-photon plus jets production
  - Motivation
  - Analysis strategy
  - Results





2012 dataset

$\sqrt{s} = 8$ **TeV**

20.2 fb^{-1}

Isolated prompt photons in ATLAS.

Prompt photon production in pp collisions

- From the hard parton scattering (**Direct**).
- From parton fragmentation (**Fragmentation**).

Main source of background

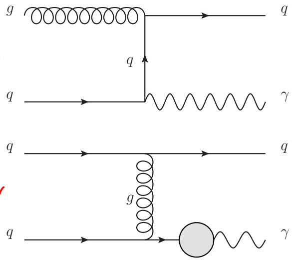
- From hadron and tau decays **(Background)**

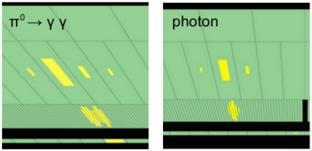
Reconstruction seeded by fixed-size clusters in the em calorimeter.

- Calibrated to account for upstream energy loss, lateral leakage and longitudinal leakage

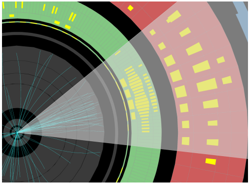
Two main ways to differentiate prompt photons from background

- Prompt photons are expected to be more isolated than background:
  - $E_{\mathrm{T}}^{\mathrm{iso}} \equiv \sum_i E_{\mathrm{T}}^{i} < E_{\mathrm{T}}^{\mathrm{max}}$ in a cone of $\Delta R = 0.4$ around the photon
  - Calculated using calorimeter topo-clusters
  - In analysis: $E_{\mathrm{T}}^{\mathrm{max}} = 4.2 \cdot 10^{-3} \times E_{\mathrm{T}}^{\gamma} + 4.8$ GeV
- Photon identification: Lateral and longitudinal energy profiles of the shower.





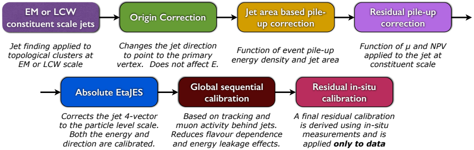
Jets in ATLAS



This analysis uses calorimeter jets

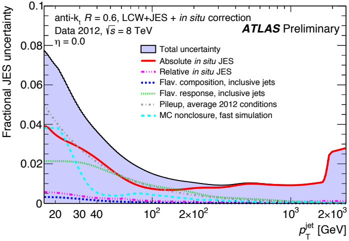
- Input are 3-D topological clusters of calorimeter cells (topo-clusters)
- Anti-k_T algorithm with R=0.6

Jet Calibration is a multi-step process



Jet energy scale is the dominant uncertainty in analysis involving jets

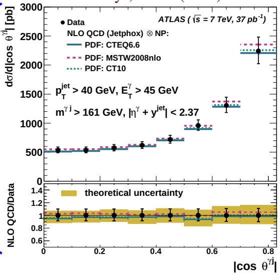
ATLAS-CONF-2015-037



High-E_T isolated-photon plus jets production

Measurement of photon + one, photon + two and photon + three jets cross sections as functions of 15 variables

Nucl. Phys, B 875 (2013) 483-535



Study of photon + jets production provides:

- Tests of pQCD: Dynamics, kinematics and scale evolution of photon+multijet production
- Characterisation of an important background to many searches involving photons
- Can be used as inputs for PDF fits

Built on top of previous studies at $\sqrt{s} = 7$ TeV

- Increased kinematic range in photon+one jet studies
- Studies of photon+two jets and photon+three jets

Results are compared with NLO predictions and leading logarithm parton shower Monte Carlo models

- NLO: JETPHOX for photon + one jet production and BLACKHAT for photon + two and photon + three jets production. Both use CT10 PDF set
- MC models: PYTHIA contains 2→2 processes, SHERPA contains 2→2, 2→3, 2→4 and 2→5 processes.

Event selection

Different cross sections measured in different selections

Common selection

- Single photon trigger with a E_T threshold of 120 GeV
- At least one isolated photon, $E_\mathrm{T}^{\gamma} > 130$ GeV, $|\eta^{\gamma}| < 2.37$
  - **Leading photon kept for analysis**
- At least one jet (anti-k_T, R=0.6) with $P_T{}^{\mathrm{jet}} > 50$ GeV, $|y^{\mathrm{jet}}| < 4.4$.

Photon+one jet selection: $p_\mathrm{T}^{\mathrm{jet1}} > 100$ GeV

- Kinematics: E_T^{γ}, $p_\mathrm{T}^{\mathrm{jet1}}$,
- Dynamics: $m^{\gamma-jet1}$
- Scale evolution and spin of exchanged particle: $\cos\theta^* \equiv \tanh(\Delta y^{\gamma j}/2)$

Photon+two jet selection: $p_\mathrm{T}^{\mathrm{jet1}} > 100$ GeV, $p_\mathrm{T}^{\mathrm{jet2}} > 65$ GeV

- Kinematics: E_T^{γ}, $p_\mathrm{T}^{\mathrm{jet2}}$
- Dynamics: $\Delta\phi$ between objects

Photon+three jet selection: $p_\mathrm{T}^{\mathrm{jet1}} > 100$ GeV, $p_\mathrm{T}^{\mathrm{jet2}} > 65$ GeV, $p_\mathrm{T}^{\mathrm{jet3}} > 50$ GeV

- Kinematics: E_T^{γ}, $p_\mathrm{T}^{\mathrm{jet3}}$,
- Dynamics: $\Delta\phi$ between objects

Jet production around the leading jet and photon

Variables sensitive to pattern of parton radiation around the photon and leading jet

$$\beta^{x} = \tan^{-1}\left(|\Delta\phi^{x-\mathrm{jet2}}|, H^{x}\right) \text{ with } H^{x} = \mathrm{sign}(\eta^{x}) \cdot (\eta^{\mathrm{jet2}} - \eta^{x})$$

Direction in the $\eta - \phi$ plane of the sub-leading jet in a ring around another object

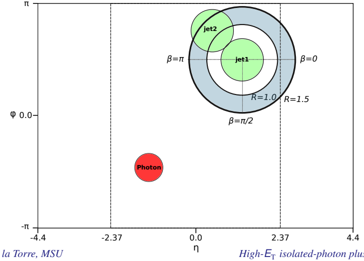
$\beta = 0$ **always points to the closest beam**

Two orthogonal samples: Modified photon+two jet selection

At least two jets: $p_{\mathrm{T}}^{\mathrm{jet1}} > 130$ GeV, $p_{\mathrm{T}}^{\mathrm{jet2}} > 50$ GeV
Additional cuts: $|\eta^{\mathrm{jet1}}| < 2.37$ and $\Delta R_{\gamma-\mathrm{jet1}} > 3.0$

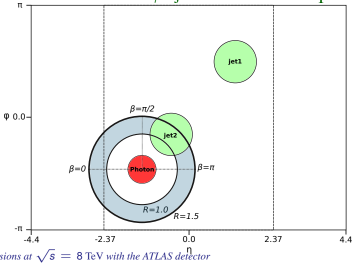
β^{jet1}

Measure if $1 < \Delta R_{\mathrm{jet1-jet2}} < 1.5$



β^{γ}

Measure if $1 < \Delta R_{\gamma-\mathrm{jet2}} < 1.5$ and $E_{\mathrm{T}}^{\gamma} > p_{\mathrm{T}}^{\mathrm{jet2}}$



Background subtraction and cross section measurement

Residual background still expected even after identification and isolation criteria

Data driven "2D-sideband" method used to subtract background

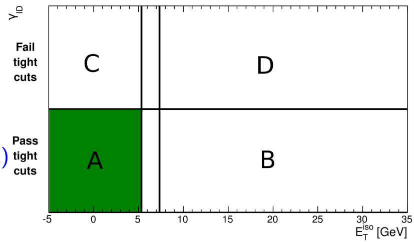
Plane defined by tight identification criteria and E_T^{iso}

Tight and non-tight are different tiers of photon identification efficiency

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

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

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



Cross sections measured using the bin-by-bin method

$$\frac{d\sigma}{dA}(i) = \frac{N_A^{\text{sig}}(i)\, C^{\text{MC}}(i)}{\mathcal{L}\, \Delta A(i)} \quad \text{with} \quad C^{\text{MC}}(i) = \frac{N_{\text{part}}^{\text{MC}}(i)}{N_{\text{reco}}^{\text{MC}}(i)}$$

Non perturbative corrections to NLO predictions

- Measurements → jets of hadrons with UE
- NLO → jets of partons without UE
- NLO corrected to hadron level using MC models

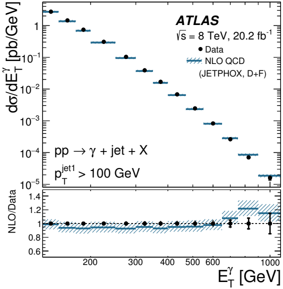
Nucl. Phys. B 918 (2017) 257

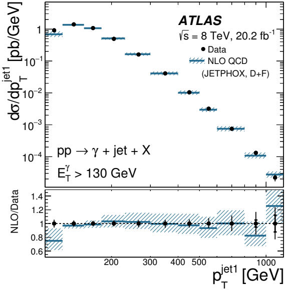
Photon+one jet results (Comparison with NLO)

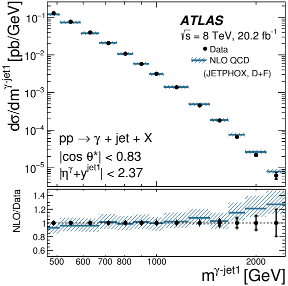
E_T^{γ}, P_T^{jet1}, $m^{\gamma-jet1}$ and $\cos\theta^* \equiv \tanh(\Delta y^{\gamma j}/2)$

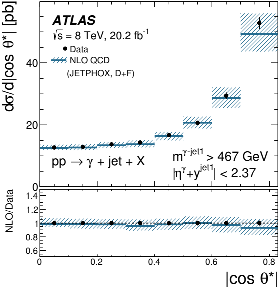
Additional cuts for $m^{\gamma-jet1}$ and $\cos\theta^*$

Increased range with respect to previous measurements









Good description of data by NLO QCD calculations obtained with JETPHOX

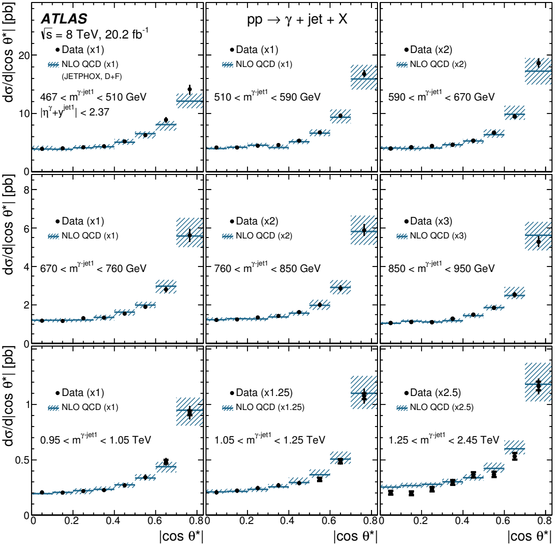
Nucl. Phys. B 918 (2017) 257

Photon+one jet results ($d\sigma/d|\cos\theta^*|$ evolution, NLO)

$d\sigma/d|\cos\theta^*|$ in regions of $m^{\gamma-jet1}$

Normalised to improve visibility

NLO QCD calculations by JETPHOX describe well the evolution with the scale

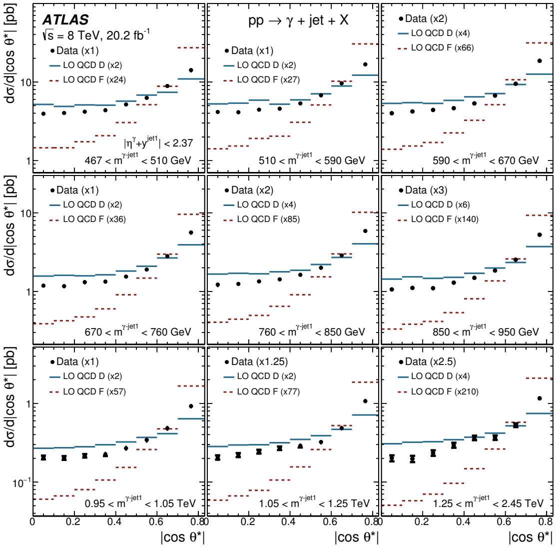


Photon+one jet results ($d\sigma/d|\cos\theta^*|$ evolution, LO)

Comparison with LO JETPHOX, direct (D) and fragmentation (F) contributions shown separately

Different behavior due to the spin of the exchanged particle

Shape closer to the direct contribution, consistent with quark exchange in the t-channel

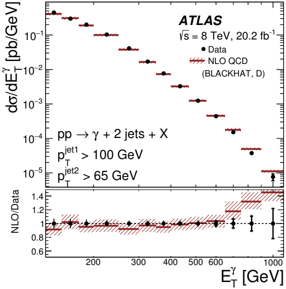


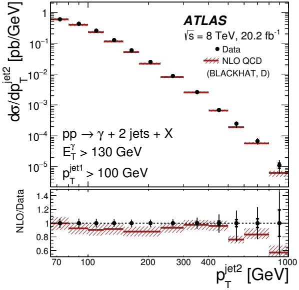
Nucl. Phys. B 918 (2017) 257

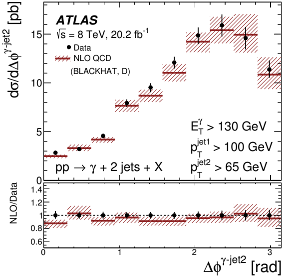
Photon+two jets results (Comparison with NLO)

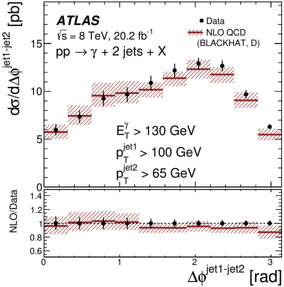
E_T^{γ}, P_T^{jet2}, $\Delta\phi^{\gamma-\text{jet2}}$ and $\Delta\phi^{\text{jet1}-\text{jet2}}$

First ATLAS measurement of photon+two jet dynamics







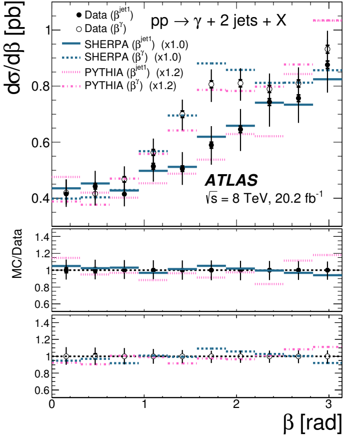


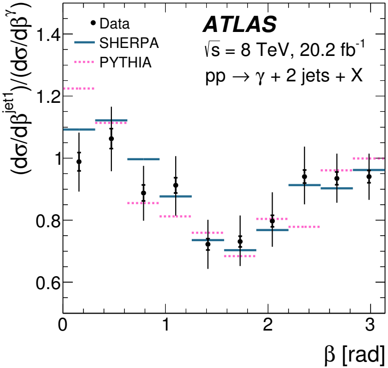
Good description of data by NLO QCD calculations obtained with BLACKHAT up to $E_T^{\gamma} \approx 750$ GeV

Nucl. Phys. B 918 (2017) 257

Jet production around the leading jet and photon

Direction in the $\eta - \phi$ plane of the sub-leading jet in a ring around another object





Different shape, Ratio enhanced at $\beta = 0$ and π rad, in the directions towards the beams

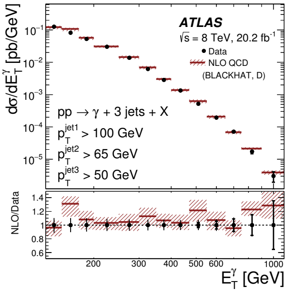
Patterns of QCD radiation around the photon and jet1 are observed to be different

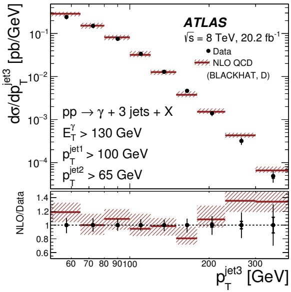
Photon+three jets results (Comparison with NLO)

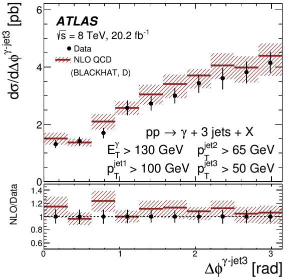
E_T^{γ}, P_T^{jet3}, $\Delta\phi^{\gamma-jet3}$, $\Delta\phi^{jet1-jet3}$ and $\Delta\phi^{jet2-jet3}$

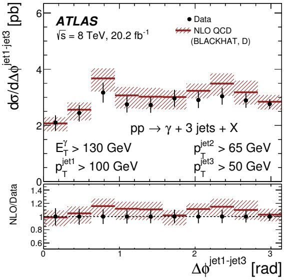
First ATLAS measurement of photon+three jets dynamics

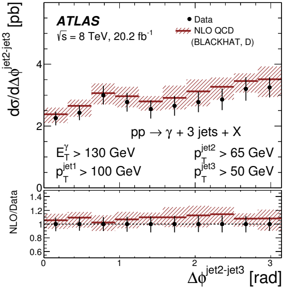
BLACKHAT photon + three jets calculation tend to overestimate the data











Summary

Measurement of photon + one, photon + two and photon + three jets cross sections as functions of 15 variables

- Observables related to the kinematics, dynamics, scale evolution and spin of the exchanged particle
- Patterns of QCD radiation around the photon and leading jet are observed to be different
- Results are compared with NLO QCD calculations:
  - JETPHOX provides a good description of photon + one jet production
  - BLACKHAT provides a good description of photon + two jet production
  - BLACKHAT provides an adequate description of photon + three jet production but tends to overestimate the data

BACKUP

- Results are also compared with leading-logarithm parton-shower MC models;
  - PYTHIA provides better description of the measured shape for E_T^γ
  - SHERPA provides better description of the measured shape for variables involving jets

All these studies provide stringent tests of pQCD and scrutinise the description of the dynamics of isolated-photon plus jets production in pp collisions up to $\mathcal{O}(\alpha_{em}\alpha_s^4)$

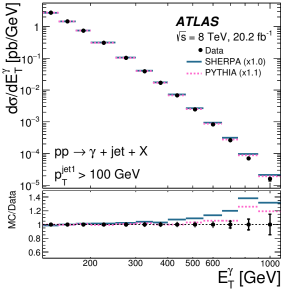
Backup

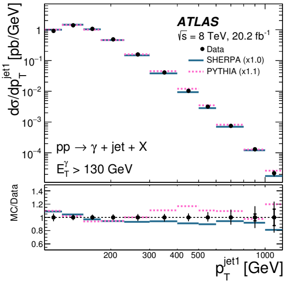
Nucl. Phys. B 918 (2017) 257

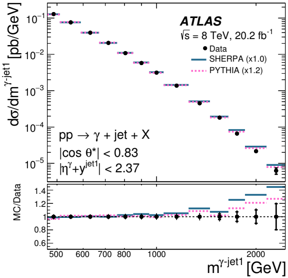
Photon+one jet results (Comparison with MC)

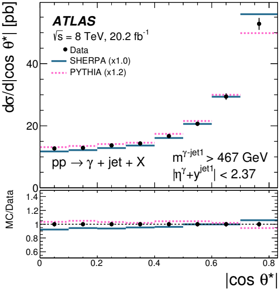
E_T^{γ}, P_T^{jet1}, $m^{\gamma-jet1}$ and $|\cos\theta^*|$

Increased range with respect to previous measurements









Both leading-logarithm PS MC, SHERPA and PYTHIA give an adequate description of the shape of the data, except at high E_T^{γ} and high $m^{\gamma-jet1}$

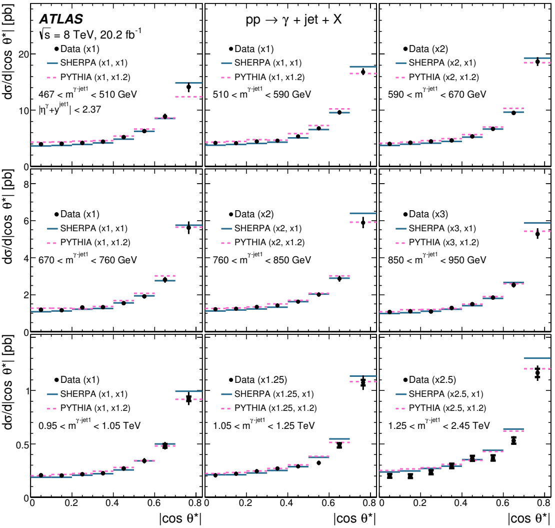
Nucl. Phys. B 918 (2017) 257

Photon+one jet results ($d\sigma/d|\cos\theta^*|$ evolution, MC)

$d\sigma/d|\cos\theta^*|$ in regions of $m^{\gamma-jet1}$

Normalised to improve visibility

Both SHERPA and PYTHIA describe well the evolution with the scale

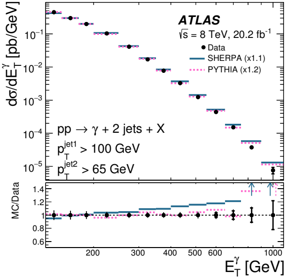


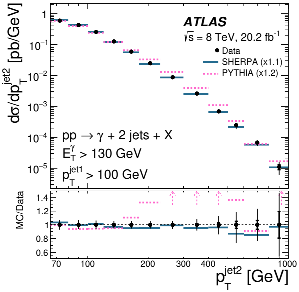
Nucl. Phys. B 918 (2017) 257

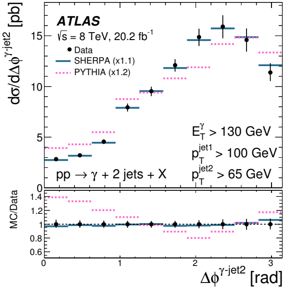
Photon+two jets results (Comparison with MC)

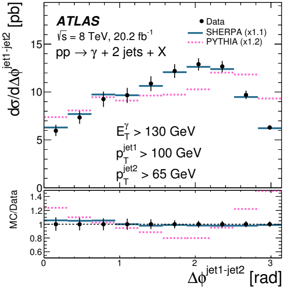
E_T^γ, P_T^{jet2}, $\Delta\phi^{\gamma-\text{jet2}}$ and $\Delta\phi^{\text{jet1}-\text{jet2}}$

First ATLAS measurement of photon+two jet dynamics







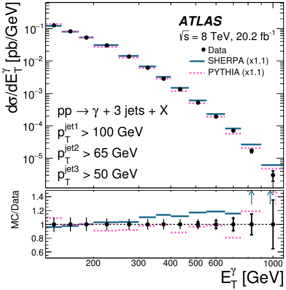


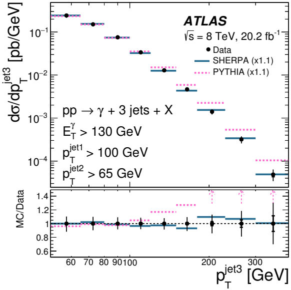
PYTHIA provides a better description of the shape of $d\sigma/dE_T^\gamma$ while SHERPA provides better description of the shape of observables involving jets

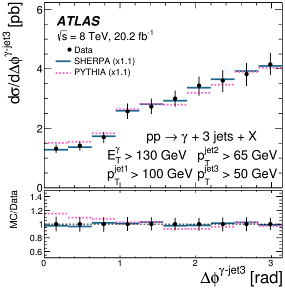
Nucl. Phys. B 918 (2017) 257

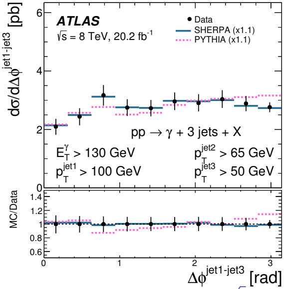
Photon+three jets results (Comparison with MC)

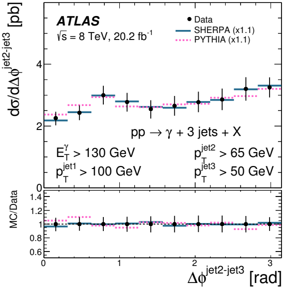
Shape of $d\sigma/dE_T^\gamma$ described better by PYTHIA, shape of $d\sigma/dP_T^{\text{jet3}}$ described better by SHERPA, shape of $\Delta\phi$ observables described well by both







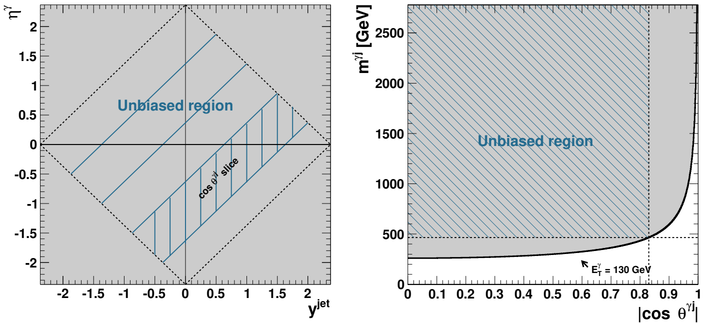




Nucl. Phys, B 875 (2013) 483-535

Unbiased region to measure $d\sigma/dm^{\gamma-jet1}$ and $d\sigma/d|\cos\theta^*|$

$|\eta^\gamma + y^{jet}| < 2.37$, $|\cos\theta^*| < 0.83$ and $m^{\gamma-jet1} > 467$ GeV



- First two requirements avoid bias induced by cuts in η^γ and y^{jet}
  - Slices of $\cos\theta^*$ have the same length along $\eta^\gamma + y^{jet}$ axis
- Third requirement avoids bias due to $E_T^\gamma > 130$ GeV