Measurements of the production of prompt photons, jets and vector bosons + jets in pp collisions with the ATLAS detector

XLVI International Symposium on Multiparticle Dynamics (ISMD2016)

Seogwipo KAL Hotel, Jeju Island, Korea

August 29th - September 2nd, 2016

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on behalf of the **ATLAS Collaboration**

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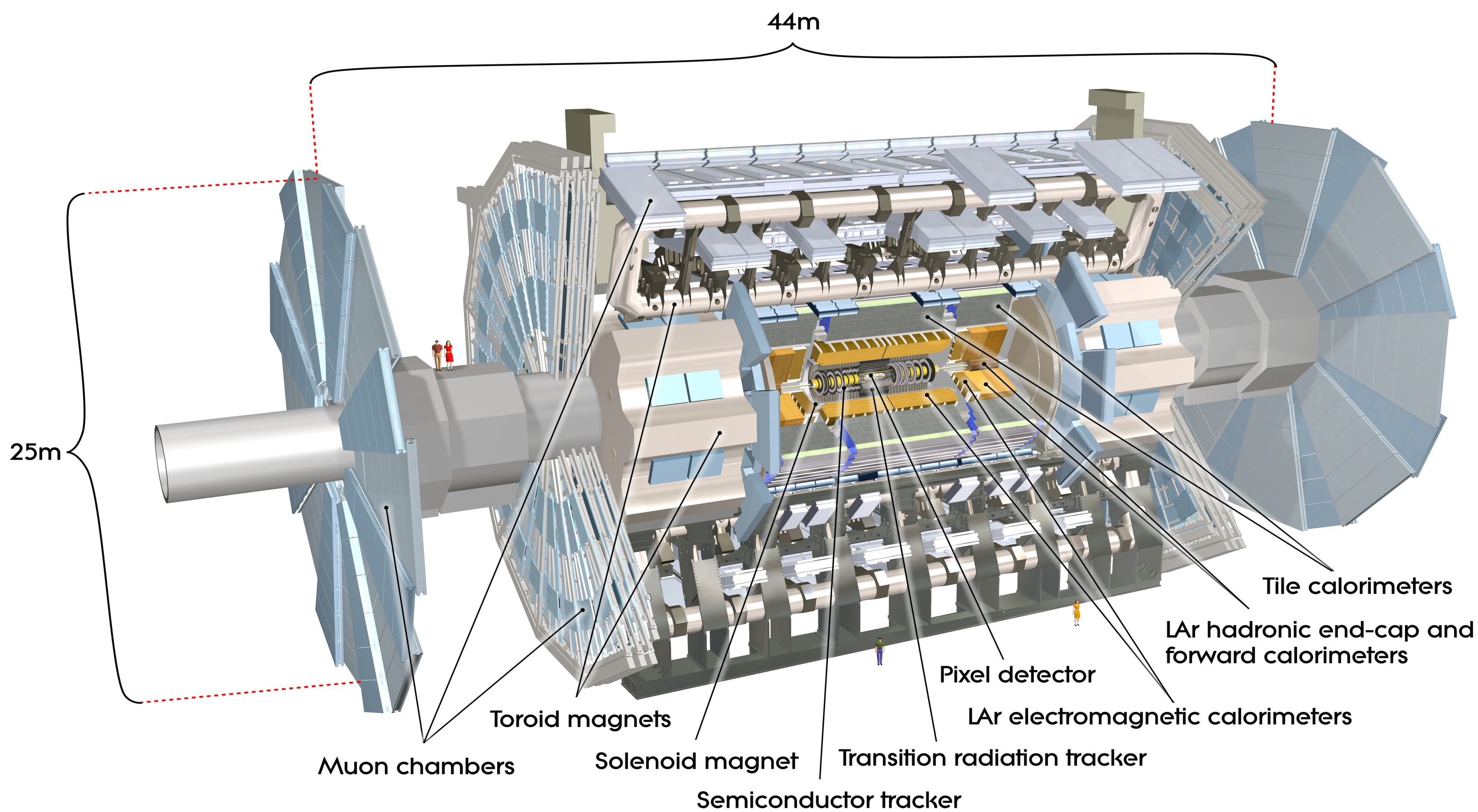
Outline

Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector	JHEP 06 (2016) 005	L = 20.2 fb^{-1}
Study of inclusive isolated-photon production in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	ATL-PHYS-PUB-2015-016	L = 6.4 pb^{-1}
Measurement of four-jet differential cross sections in $\sqrt{s}$ = 8 TeV pp collisions using the ATLAS detector	JHEP 12 (2015) 105	L = 20.3 fb^{-1}
☆ Measurement of inclusive-jet cross-sections in pp collisions at sqrt(s) =13 TeV centre-of-mass energy with the ATLAS detector	ATLAS-CONF-2016-092	L = 3.2 fb^{-1}
Measurement of W boson angular distributions in events with high transverse momentum jets with the ATLAS detector at $\sqrt{s}$ = 8 TeV	paper not yet submitted	L = 20.3 fb^{-1}
Measurements of the Production Cross Section of a Z boson in Association with Jets in pp collisions at $\sqrt{s}$ = 13TeV with the ATLAS Detector	ATLAS-CONF-2016-046	L = 3.16 fb^{-1}

☆ Brand new result!

ATLAS Detector



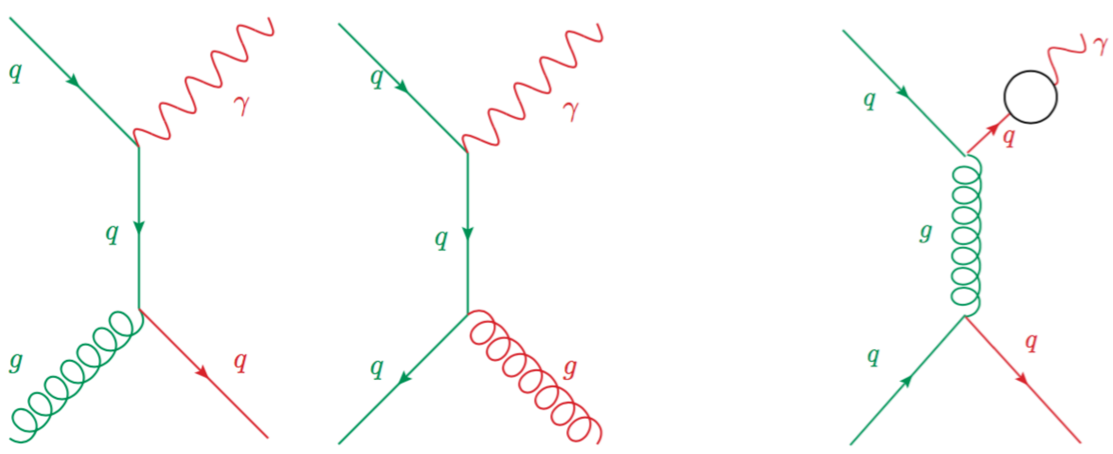
Inner Detector - Tracking in $|\eta| < 2.5$

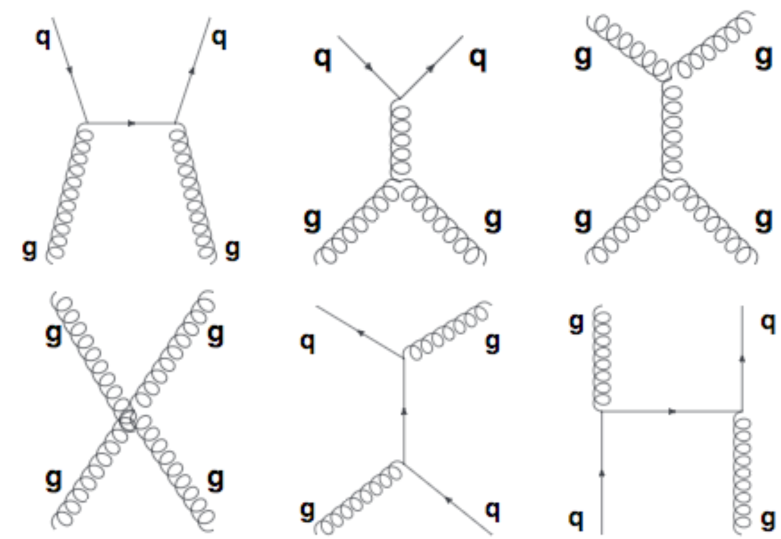
Calorimetry - $|\eta| < 4.9$

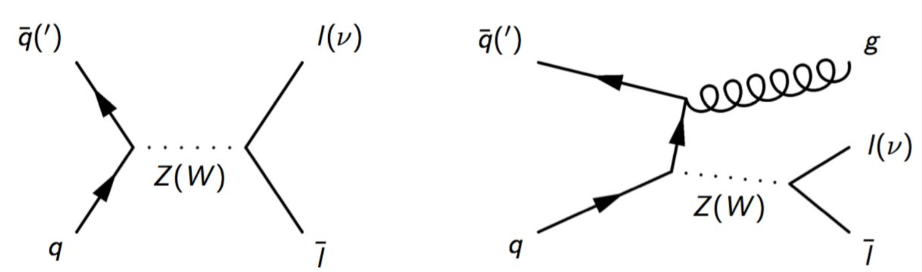
Muon Spectrometer - $|\eta| < 2.7$

Motivation

Prompt photons, jets and vector bosons + jets in pp collisions







- Their production provide a fertile testing ground of perturbative QCD;
- Experimental measurements can be used to extract information on the proton PDFs;
- They are essential in aiding analyses of processes for which they are important backgrounds (Higgs boson studies and search for new phenomena).

Particle Level and MC

LO ME + PS

ALPGEN v2.14 + PYTHIA v6.427 using CTEQ6L1

SHERPA v1.4.1, v.1.4.0 using CT10

PYTHIA v8.165 using CTEQ6L1

Madgraph5_aMC@NLO+Pythia 8 CKKWL (@13TeV results)

NLO ME + PS

Madgraph5_aMC@NLO with FxFx Merging (+2 jets) (@13TeV results)

SHERPA 2.X (NLO 0,1,2 jets + LO 3, 4 jets) (@13TeV results)

Fixed order NLO

BLACKHAT+ SHERPA

Fixed order NNLO

V + ≥ 1 jet N_{jetti} NNLO (@13TeV results, became available recently)

Higher orders

HEJ (W≥ 2 jets)

Isolated Prompt Photons

Differential cross sections from data and JetPhox

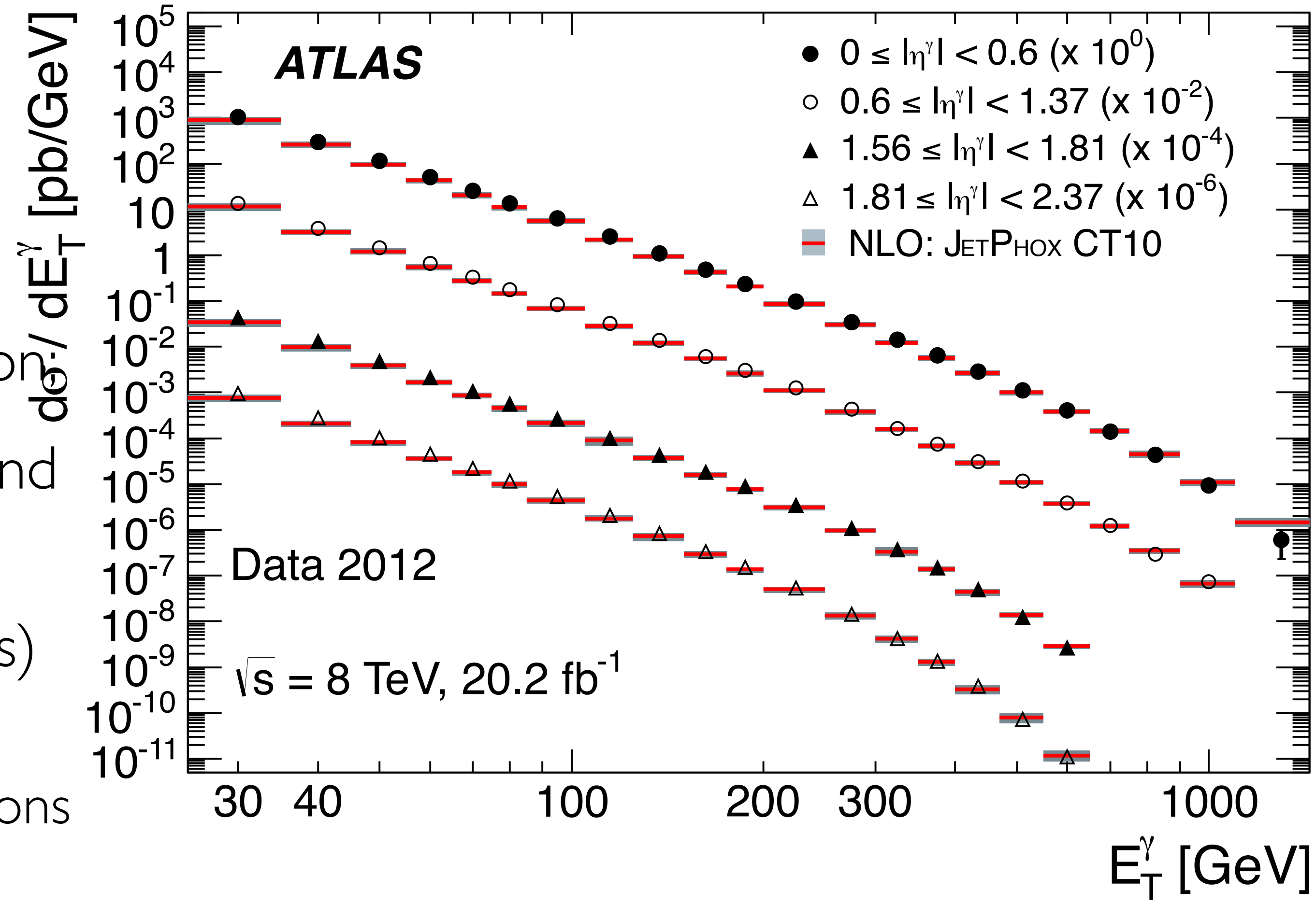
η range split into 4 bins

$d\sigma/dE_{\mathrm{T}}^{\gamma}$ for $25 < E_T^{\gamma} < 1500$ GeV

systematic uncertainties

- energy scale (~1%) dominates the high-E_T region
- uncertainty on the correlation in the background (±10%) dominates at low-E_T.

statistical uncertainty: 1-2 % (except high ET bins)



photon isolation (to avoid contribution of photons from neutral-hadron decays):

$E_{\mathrm{T}}^{\mathrm{iso}} \equiv \sum_i E_{\mathrm{T}}^i < E_{\mathrm{T}}^{\mathrm{max}}$ with the sum over the particles, except the photon, inside a cone

$$\Delta R = 4$$

centred on the photon in the η-Φ plane

$$E_{\mathrm{T}}^{\mathrm{iso}} < 4.8\ \mathrm{GeV} + 4.2 \times 10^{-3} \times \mathrm{E}_{\mathrm{T}}^{\gamma}$$

JetPhox describes shape of data well over 10 orders of magnitude in cross-section.

First measurement of photon production with E_T^{γ} **> 1 TeV.**

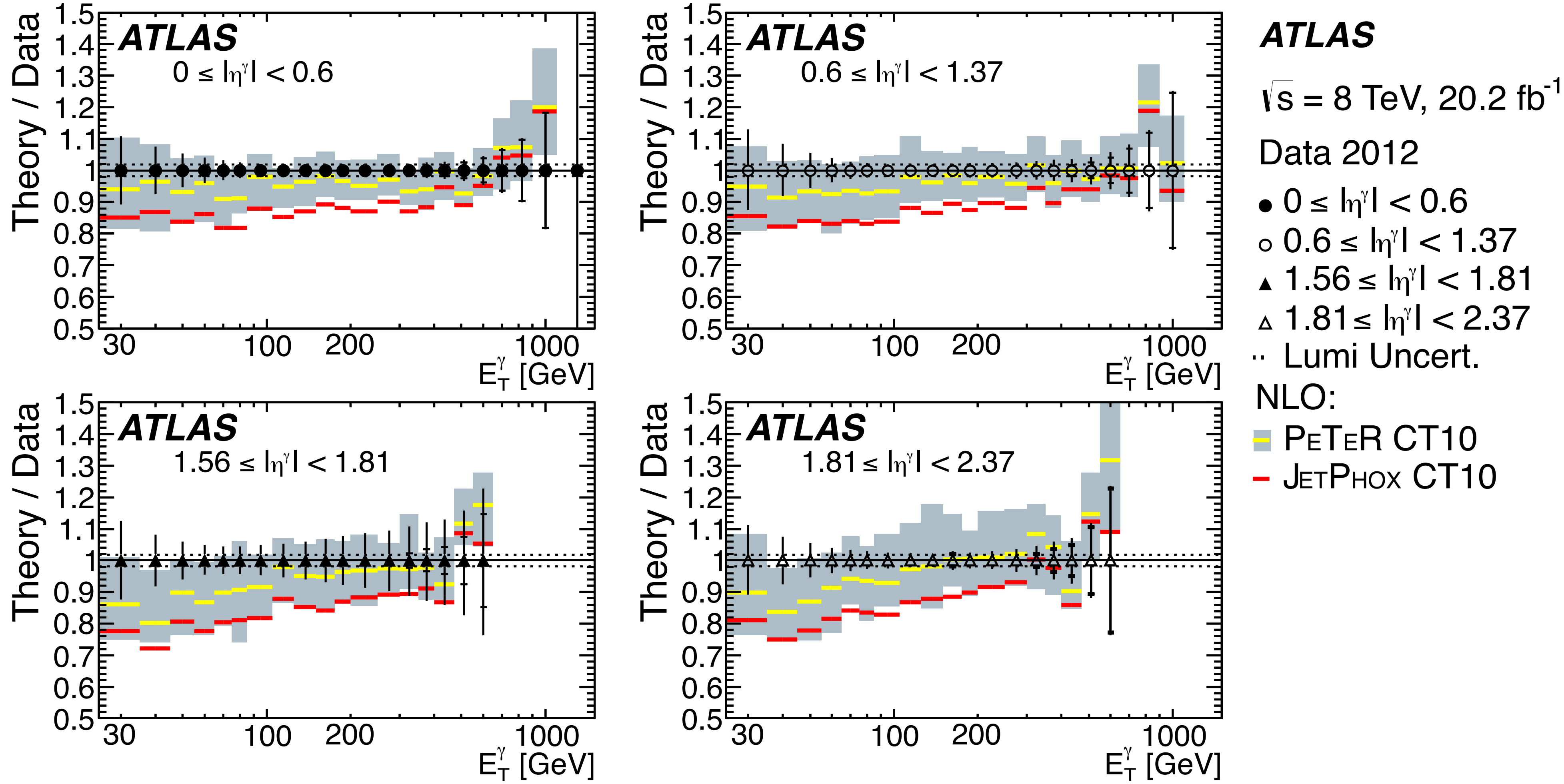
JHEP 06 (2016) 005

Ratio of JetPhox and PeTeR CT10 to 8 TeV data

JHEP 06 (2016) 005

η range split into 4 bins;

uncertainties:
statistical+systematic



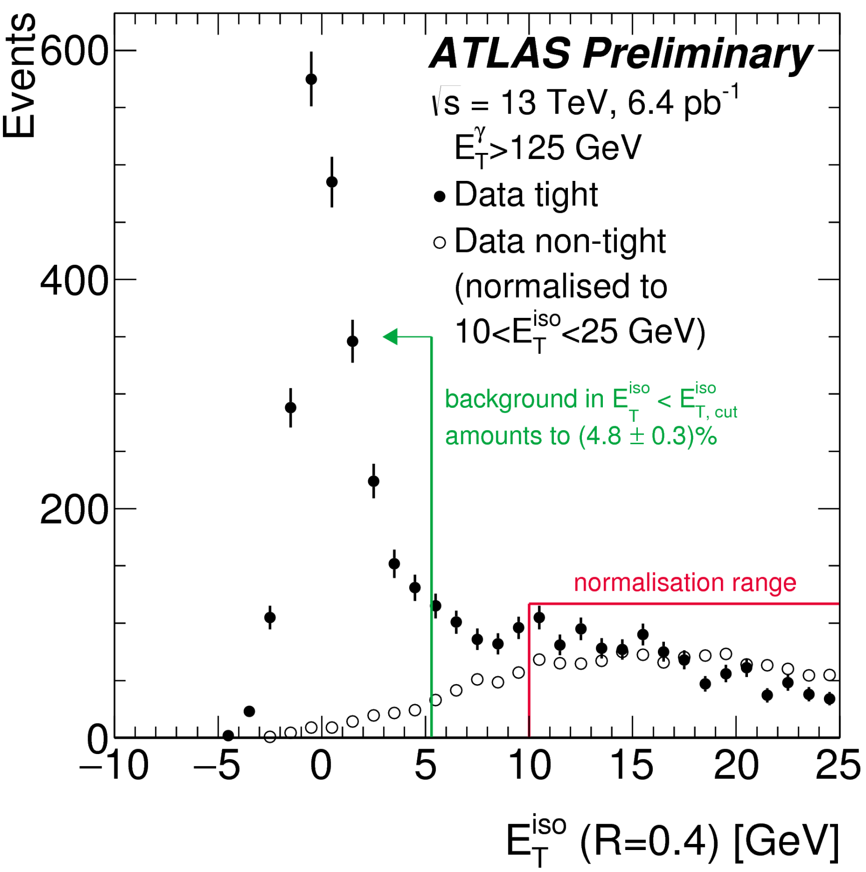
Comparison to improved NLO QCD calculations using **PeTeR:** resummation of QCD threshold logarithms at NNNLL and large electroweak Sudakov logarithms

- improved description of the data: **PeTeR vs JetPhox**;
- reduction of the theoretical uncertainty: ~ **20% smaller than** in NLO QCD (**JetPhox**).

Inclusive production of isolated photons at 13 TeV

ATL-PHYS-PUB-2015-016

background subtraction based on photon identification and E_T^{iso}



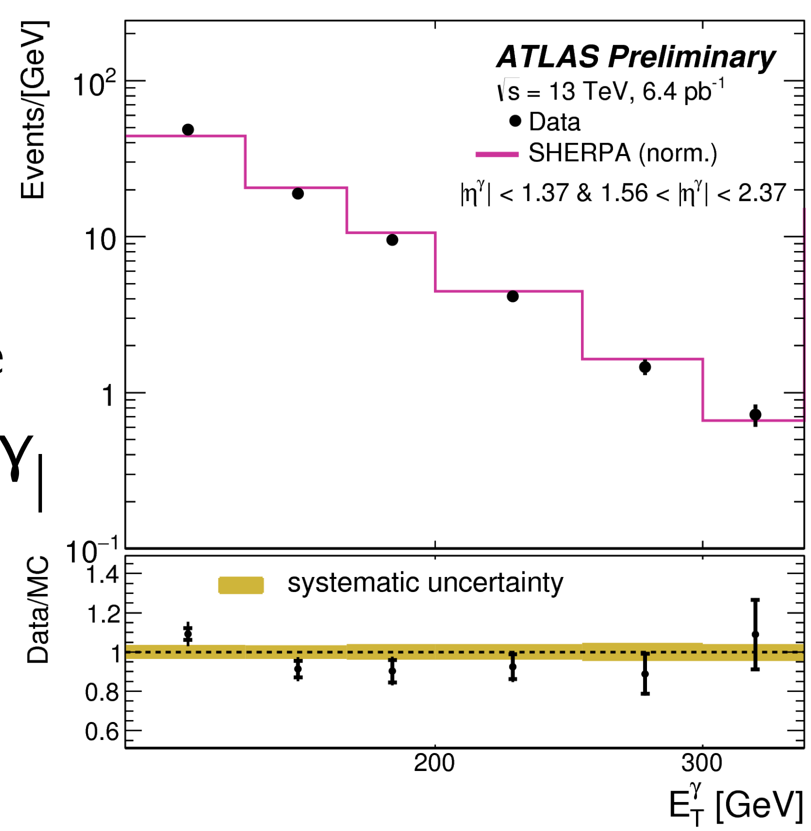
ranges: $125 < E_T^{\gamma} < 350$GeV , $|\eta^{\gamma}| < 2.37$

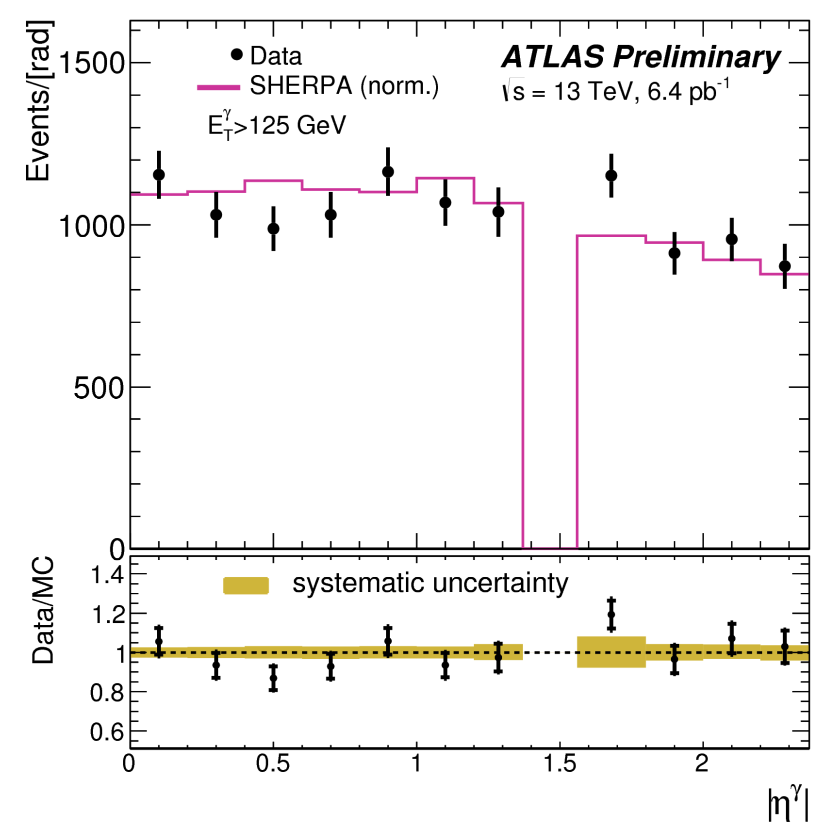
(except for $1.37 < |\eta^{\gamma}| < 1.56$)

systematic uncertainties

- photon energy scale (2-8 %);
- photon energy resolution (< 1%)
- photon identification efficiency (1 − 2%);
- modelling of E^{iso} in the MC (< 1%) ;
- trigger efficiency (2%).

Good description of the shape of the measured distributions in E_T^{γ} and $|\eta^{\gamma}|$ by the predictions of **Sherpa 2.1**





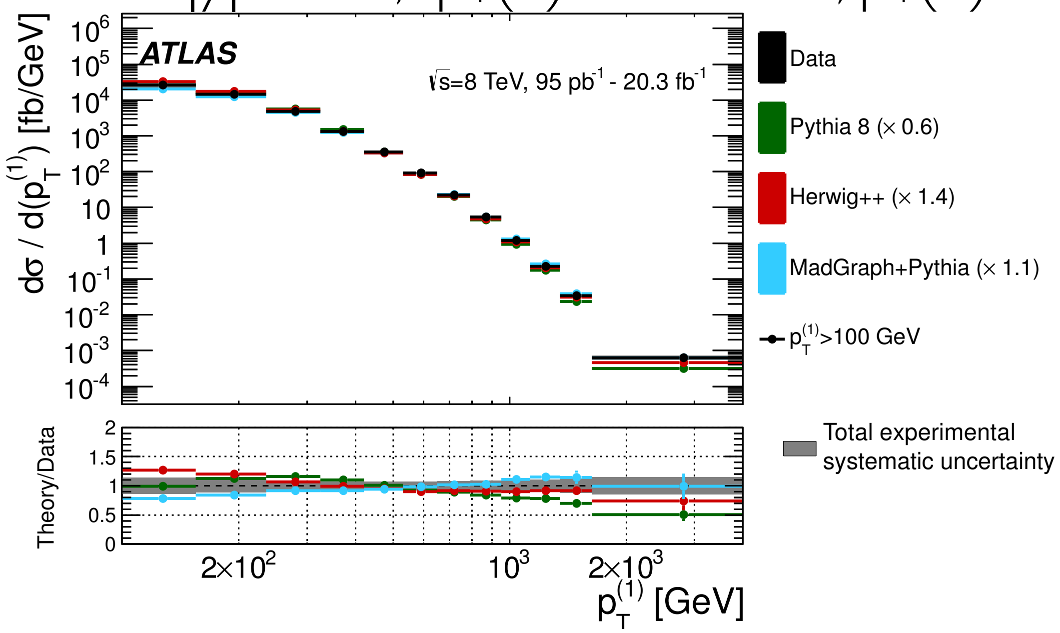
Jets

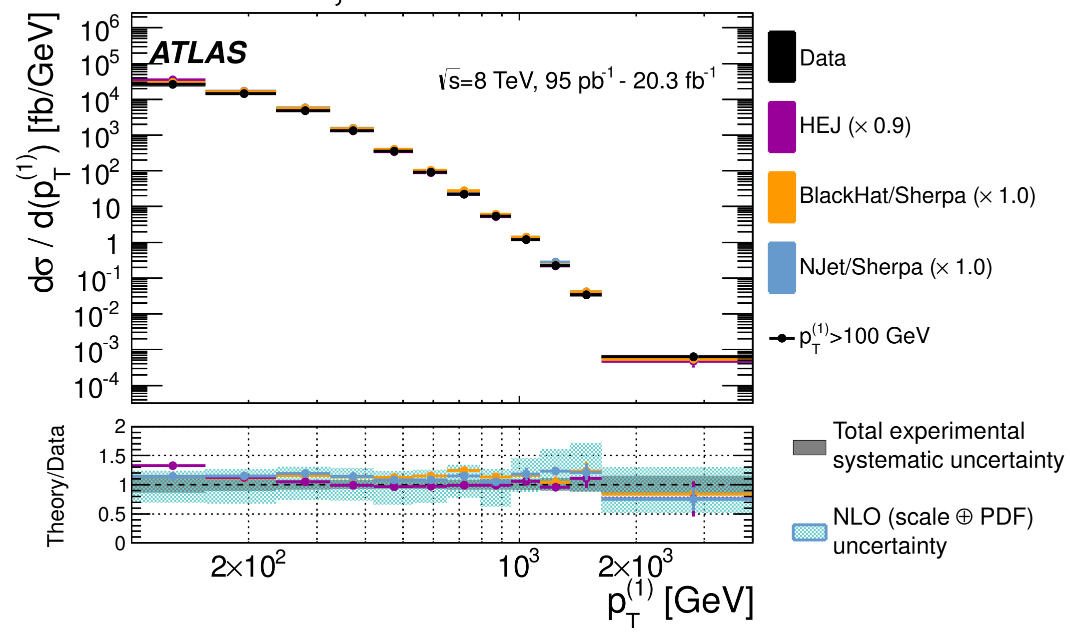
Four-jet production at 8 TeV

analysis cuts

$|y| < 2.8$, $p_T(4) > 64$ GeV, $p_T(1) > 100$ GeV, $\Delta R_{4j}^{min} > 0.65$ JHEP 12 (2015) 105

p_T

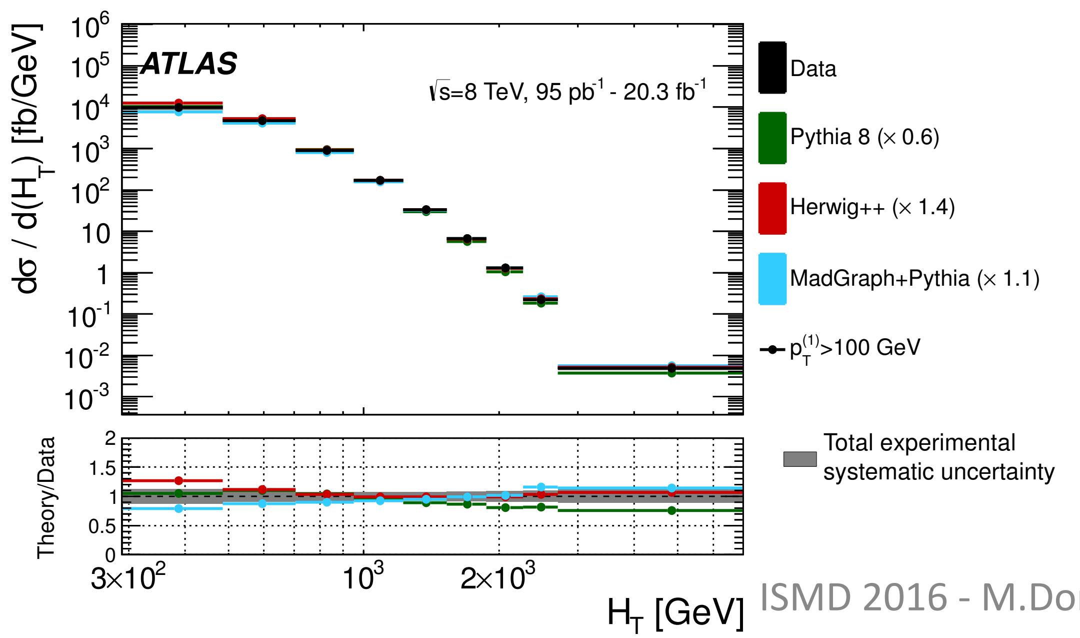


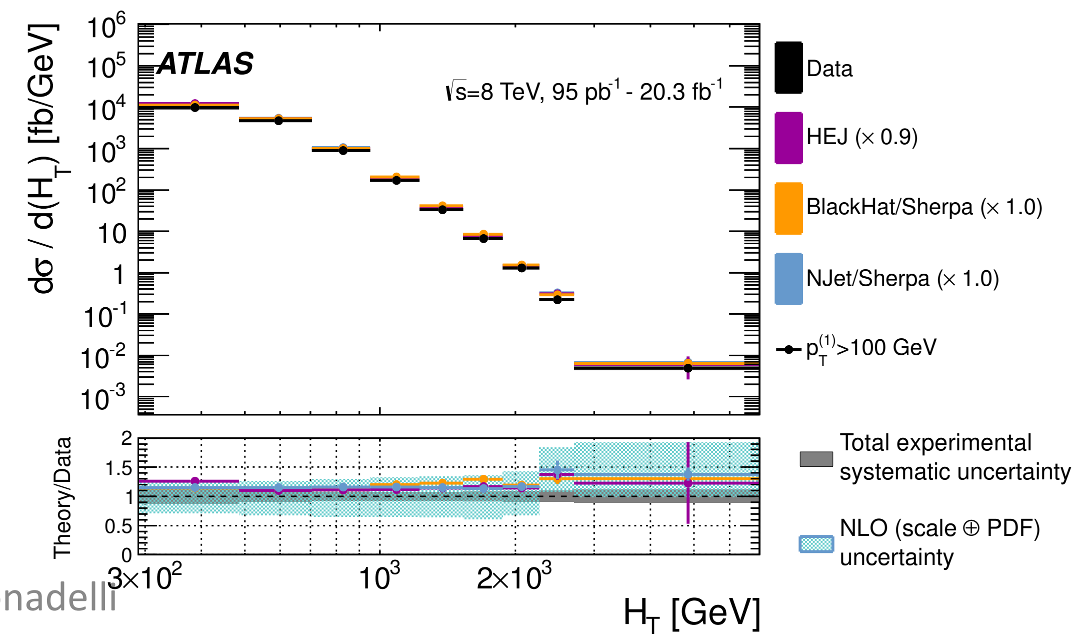


ratios of **Herwig++** and **HEJ** to data: flat above ~500 GeV and ~300 GeV

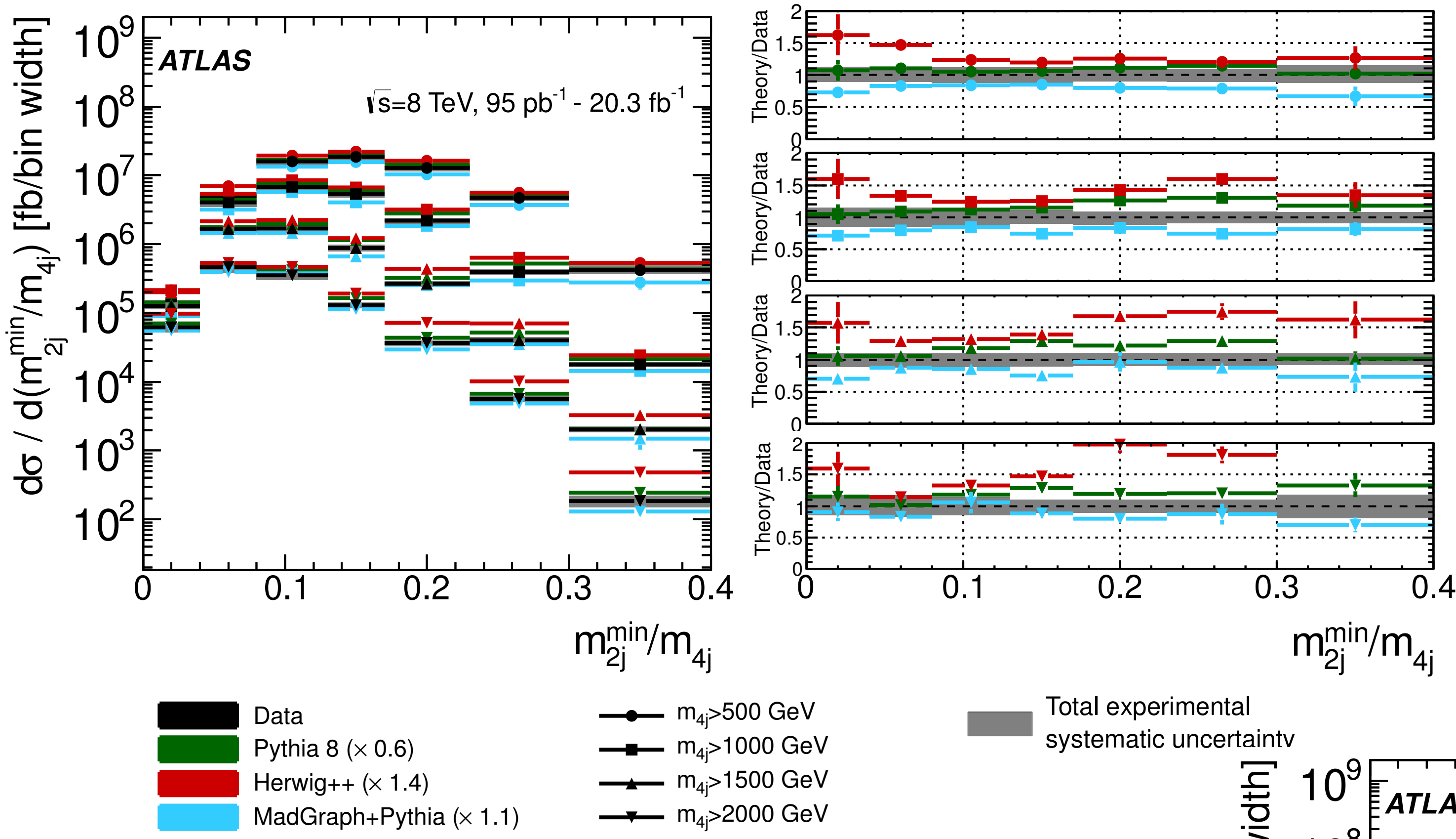
MadGraph+Pythia: within experimental uncertainties above ~300 GeV

H_T





Four-jet production at 8 TeV



well described by **Pythia**;

Herwig++ gets worse with increasing m4j, consistently overestimating the two ends of the m_{2j}^{min}/m_{4j} spectrum;

MadGraph+Pythia provides a very good description, with a flat ratio for all the m_{4j} cuts;

m_{2j}^{min}/m_{4j}

HEJ shows trends similar to those of Herwig++ at higher values of m4j.

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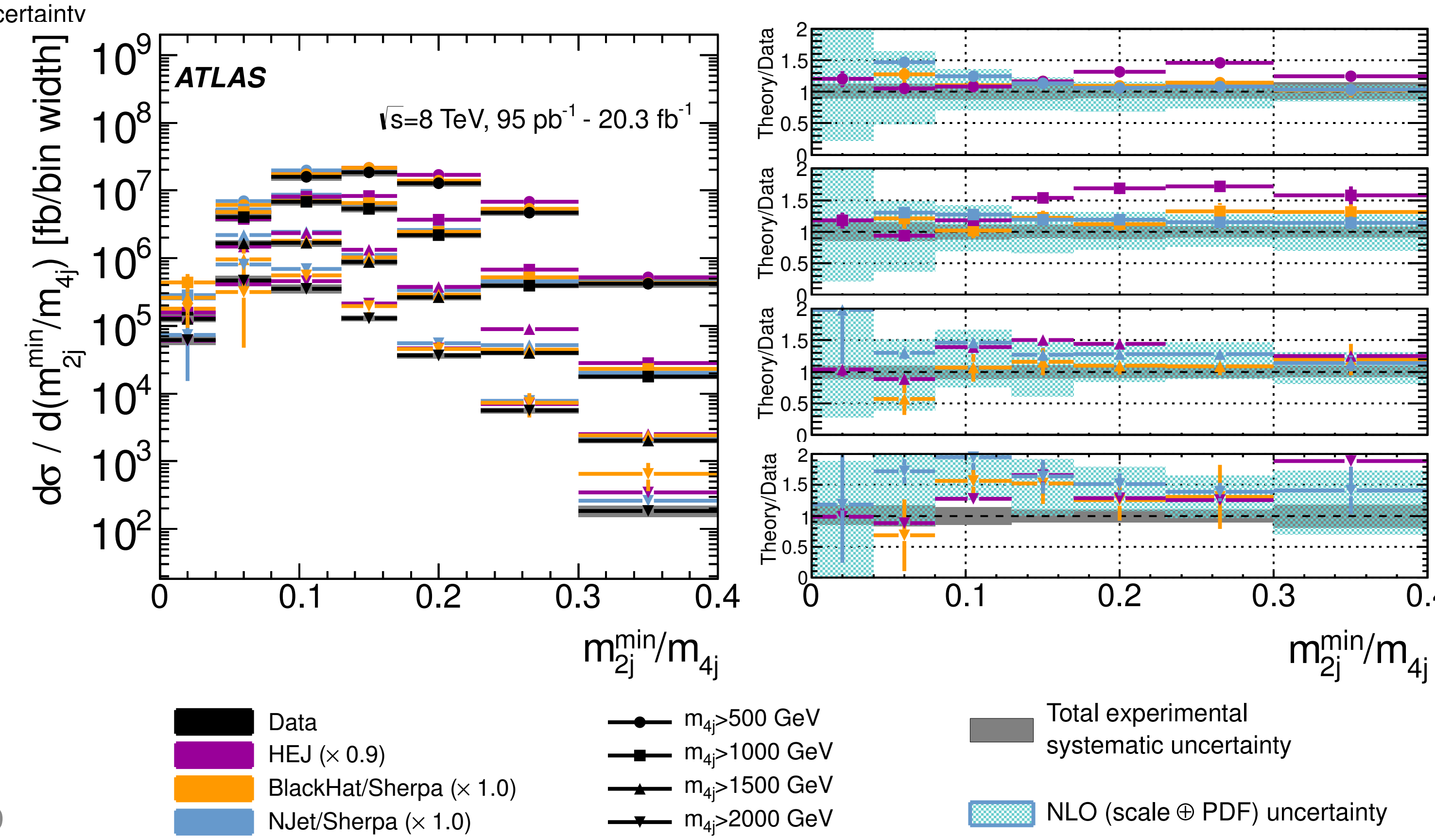
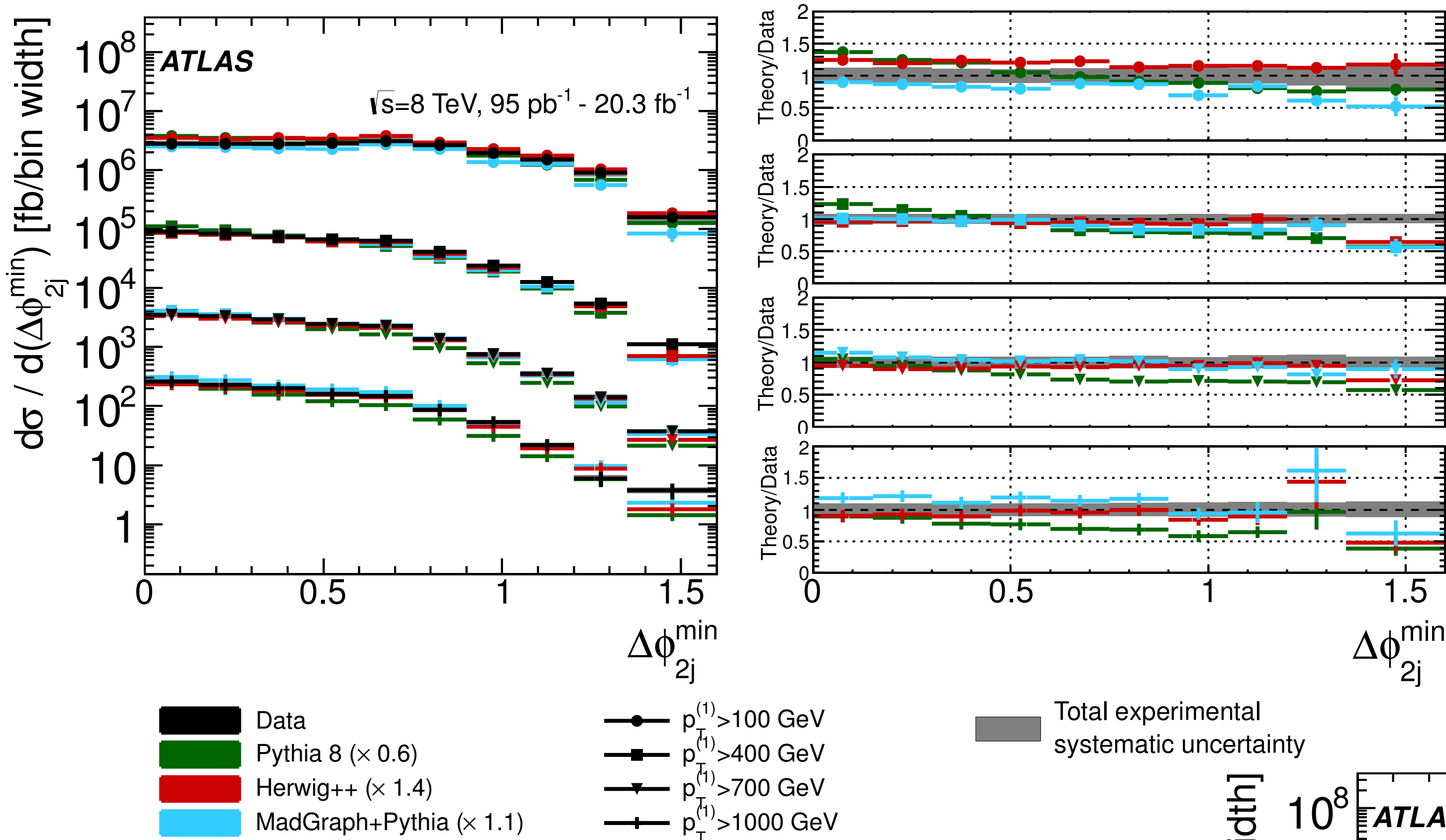


Four-jet production at 8 TeV



Pythia: small downwards slope with respect to data;

MadGraph+Pythia also shows a small slope;

Herwig++ provides very good description of the data.

$\Delta\phi_{2j}^{min}$

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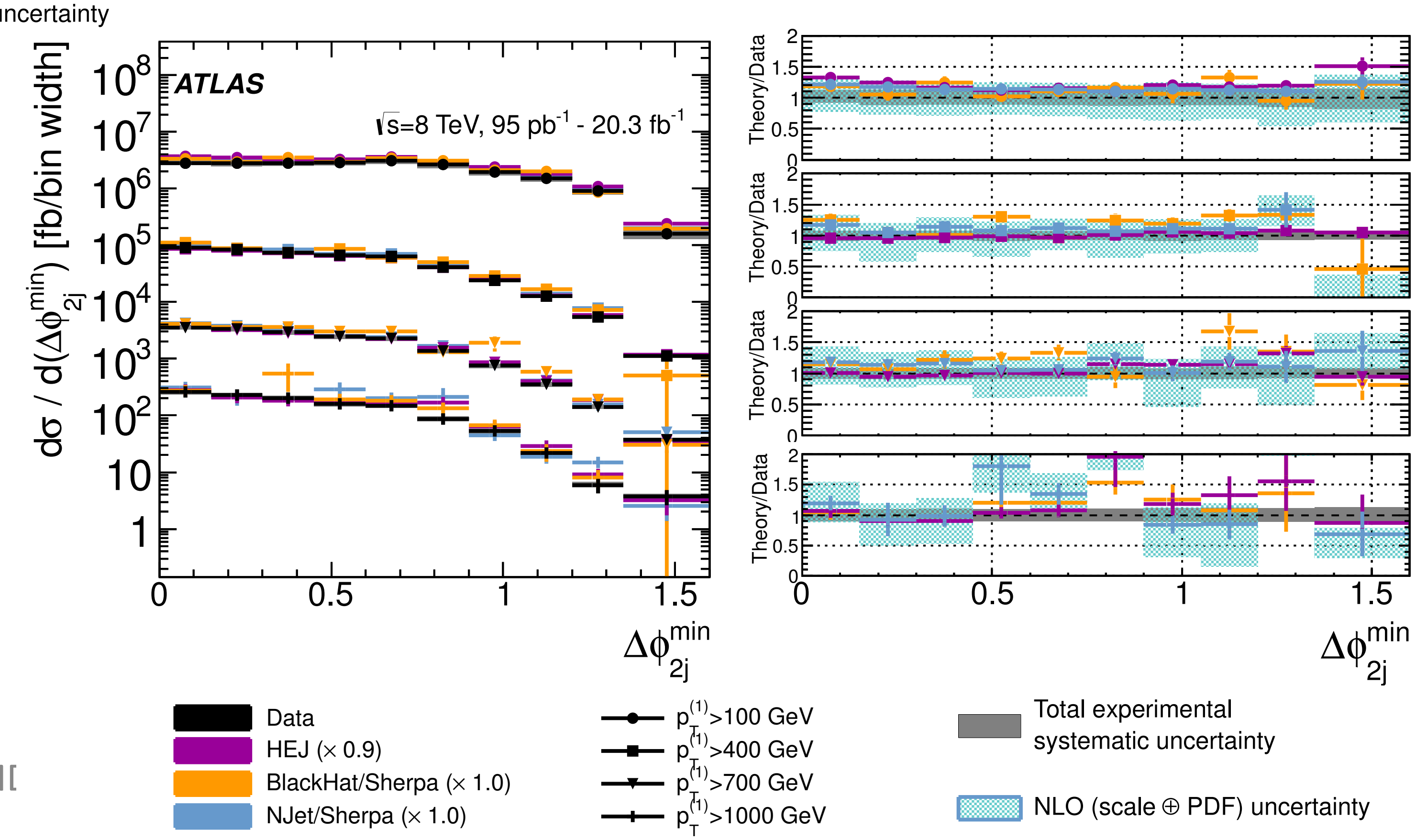
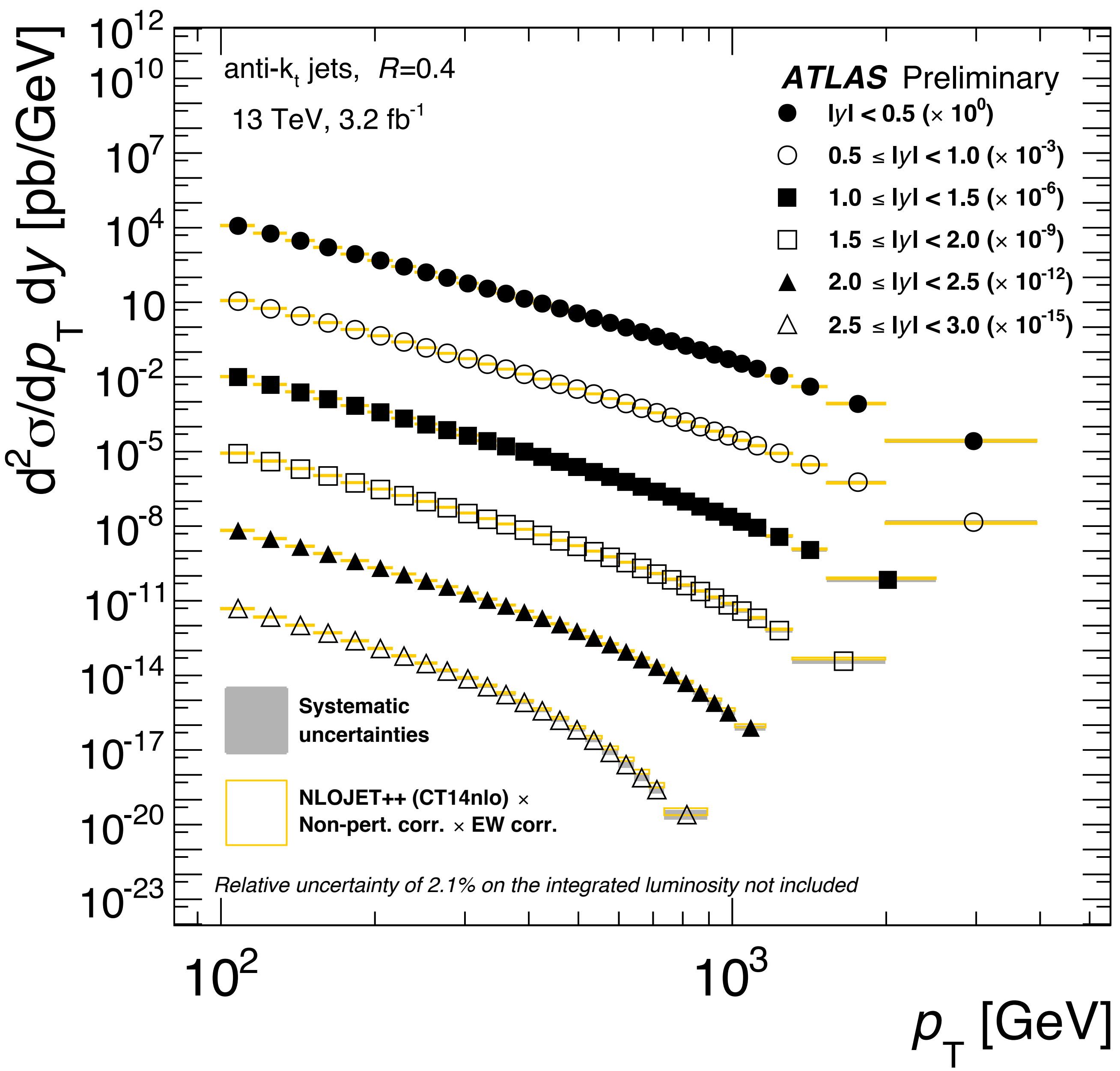


Unfolded inclusive jet cross-section at 13 TeV

ATLAS-CONF-2016-092

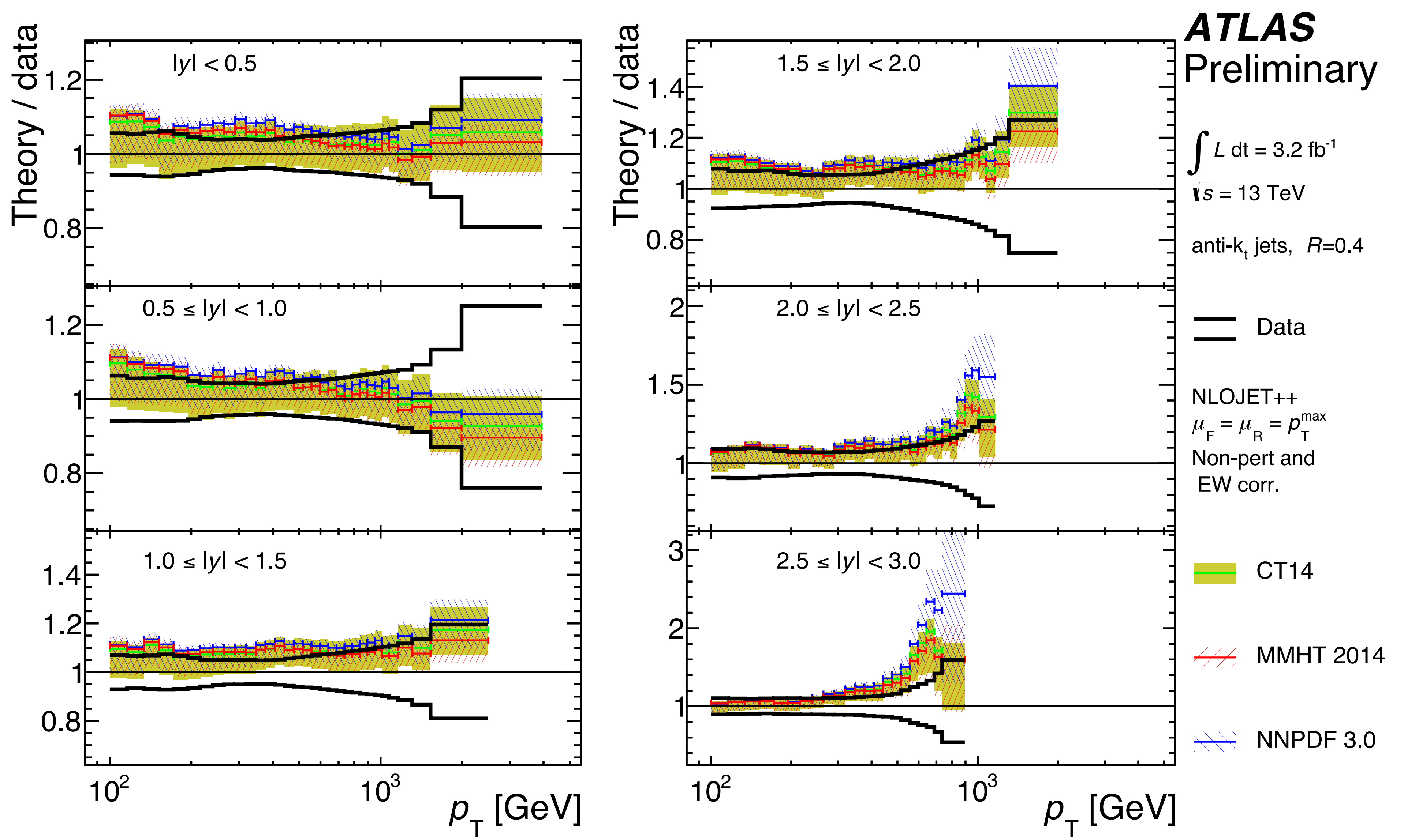
- six jet rapidity bins;
- **NLO pQCD** using **CT14** PDF set corrected for non perturbative and electroweak effects;
- extended range from 100 GeV to ~ 3.2 TeV!



Ratio NLO pQCD to unfolded inclusive jet cross-section

ATLAS-CONF-2016-092

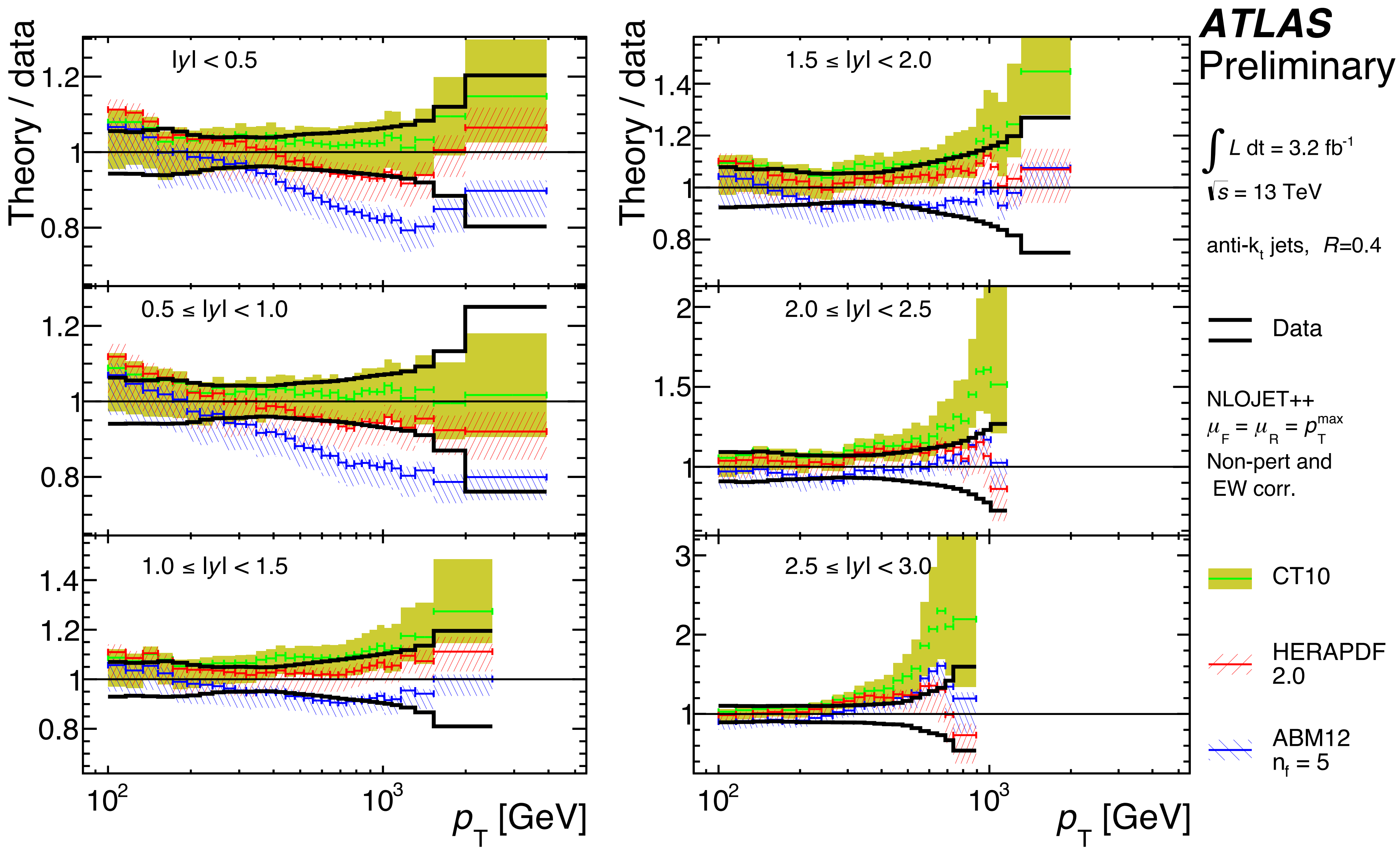
- six jet rapidity bins;
- **NLOJET++** with **CT14, MMHT 2014, NNPDF 3.0** set corrected with non-perturbative and electroweak corrections;
- no significant deviation is seen;
- **NNPDF 3.0** overestimates the cross-section for the last two |y| bins, however it's within uncertainties.



Ratio NLO pQCD to unfolded inclusive jet cross-section

ATLAS-CONF-2016-092

- six jet rapidity bins;
- **NLOJET++** with **CT10**, **HERAPDF 2.0**, **ABM12** with **n_f=15** corrected with non-perturbative and electroweak corrections;
- no significant deviation is seen;
- disagreement with **ABM12**, consistent with previous ATLAS 7 TeV measurement, observed for the first two |*y*| bins.



Vector Bosons + Jets

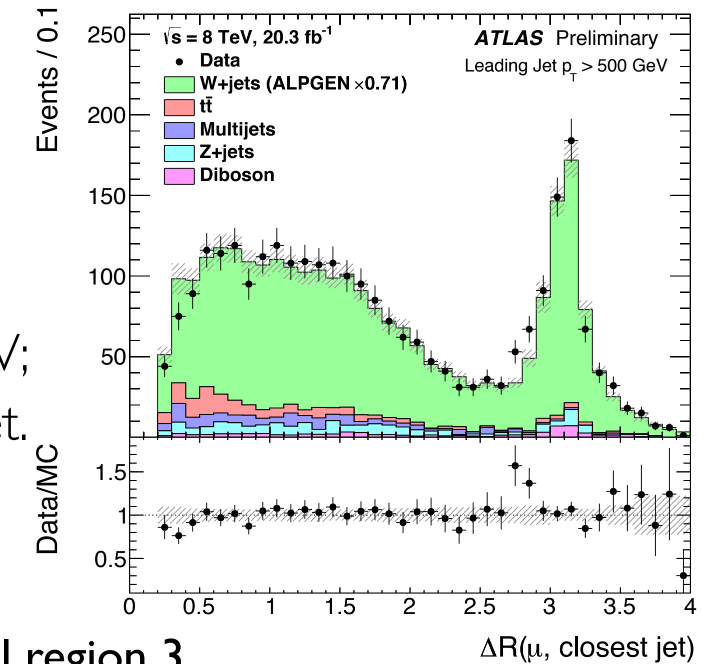
Collinear W production at 8 TeV

Analysis focus: contributions to W+jets processes from real W emission,
achieved by studying events where a muon is observed close to a high transverse momentum jet.

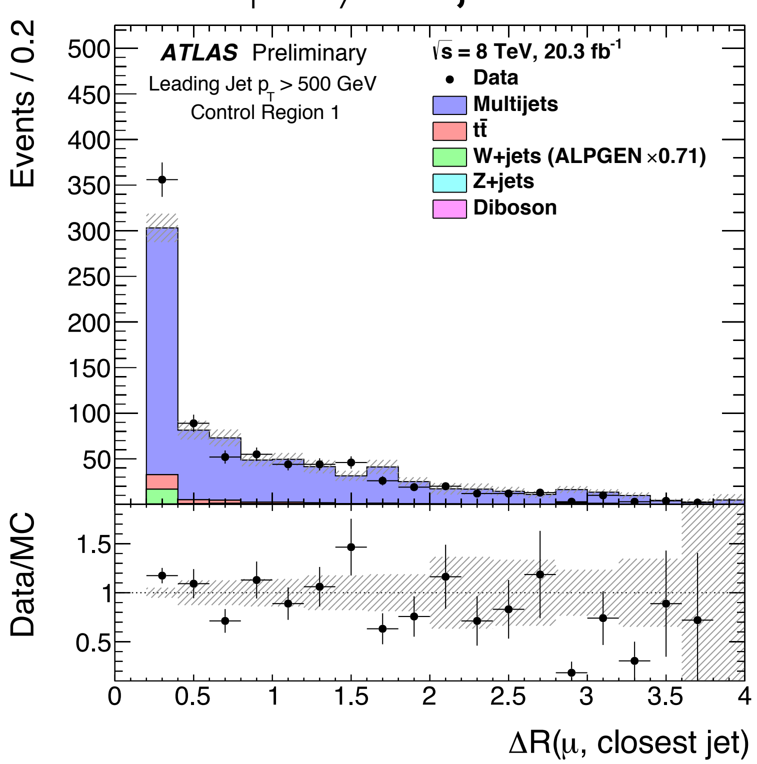
jets
- anti-k_t R = 0.4;
- $p_T^{\,jet} > 100$ GeV;
- $|\eta^{jet}| < 2.1$;

muons
- $p_T > 25$ GeV;
- $|\eta| < 2.4$.

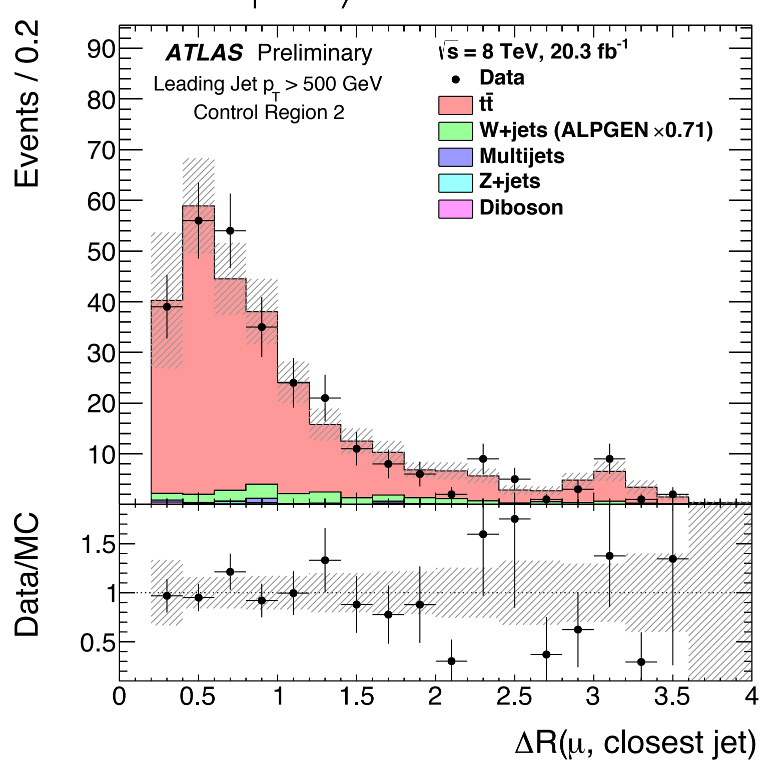
W + jets signal
- at least one jet with $p_T^{jet} > 500$ GeV;
- exactly one isolated muon;
- veto electrons;
- veto b-tagged jets;
- any additional jets with $p_T^{jet} > 100$ GeV;
- ΔR measured with respect to closest jet.



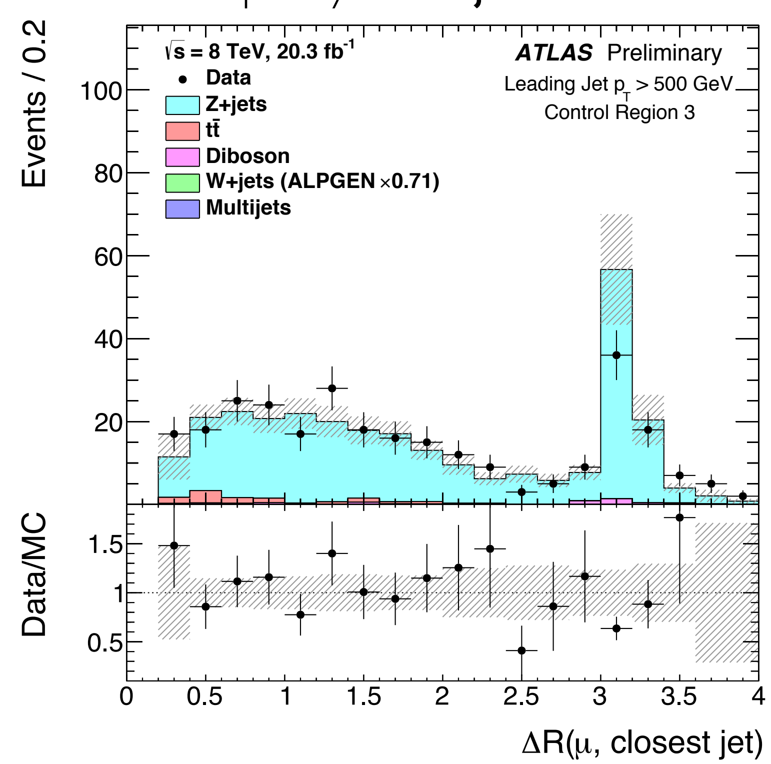
Control region 1
93% purity of **dijet** events



Control region 2
91% purity of **ttbar** events

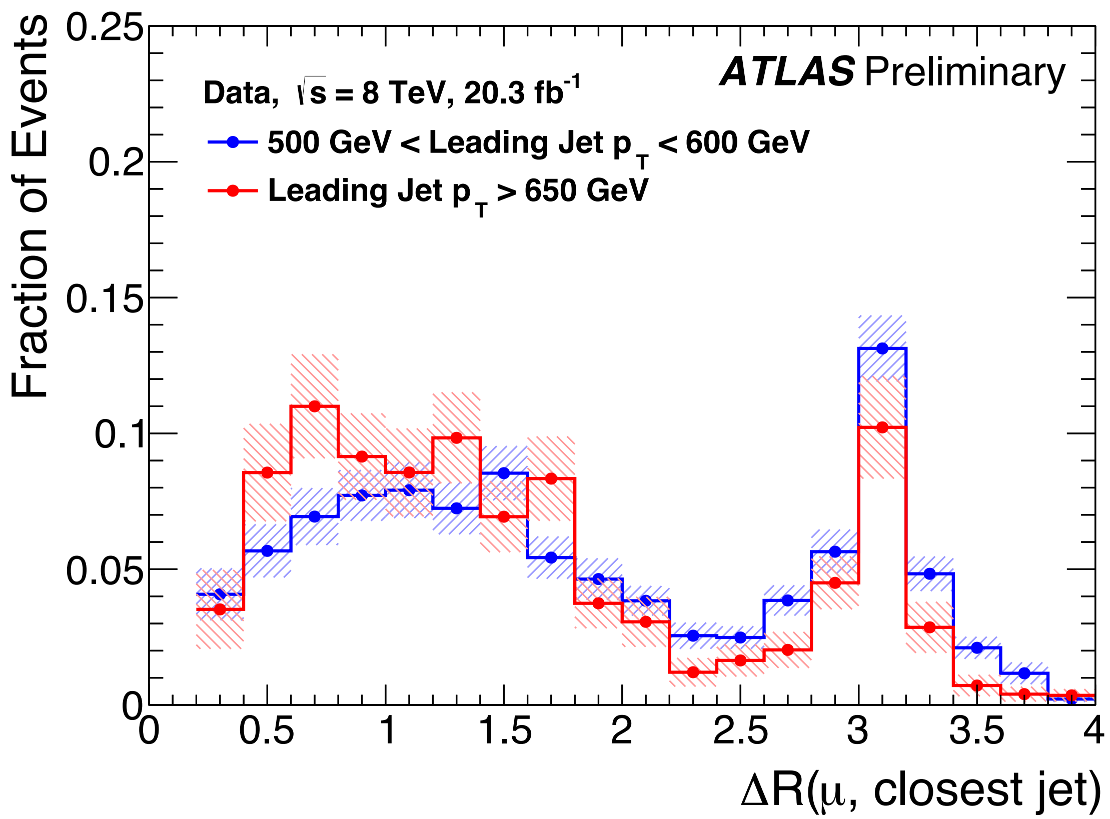


Control region 3
94% purity of **Z+jets** events

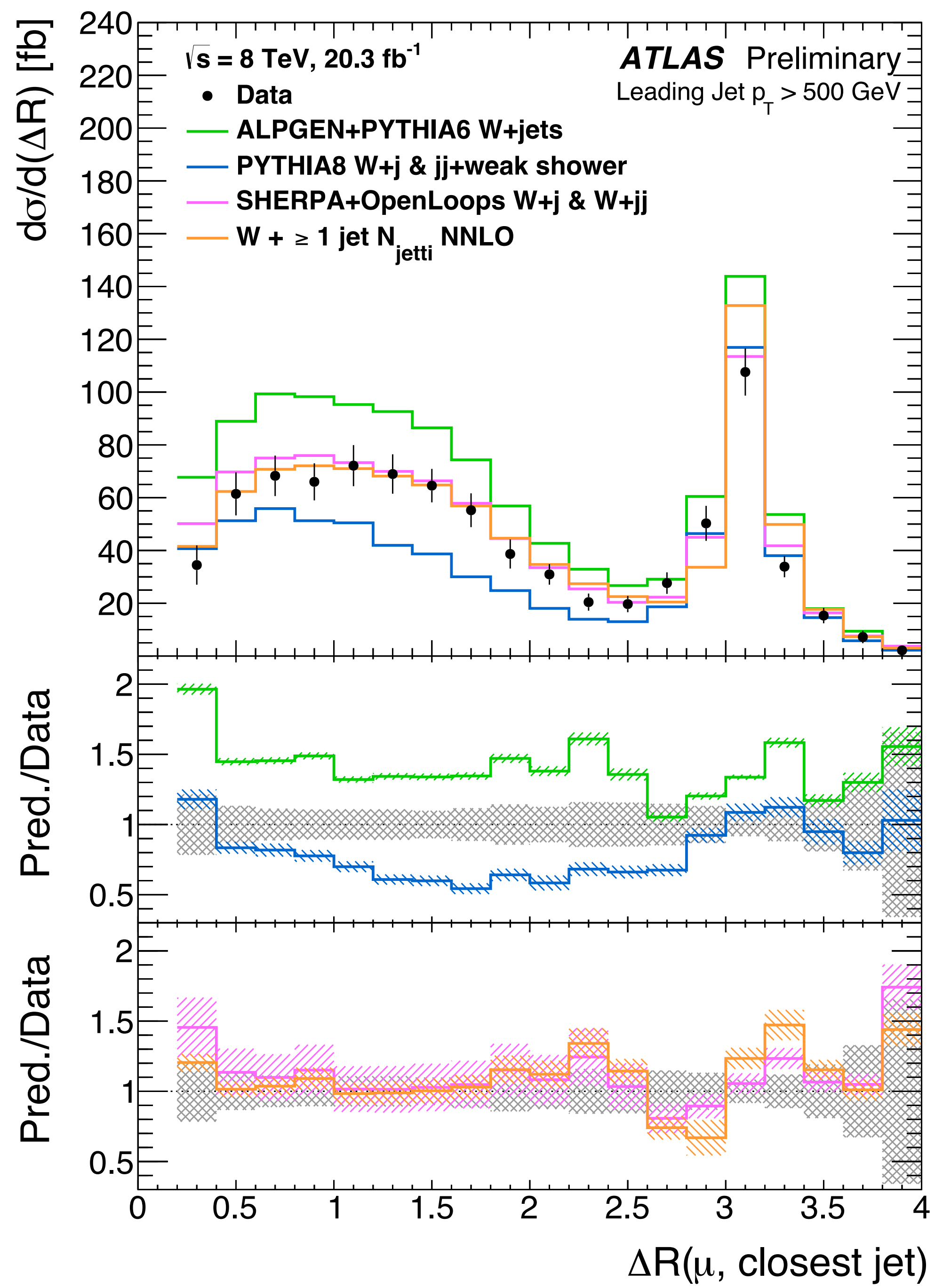


Collinear W production at 8 TeV

Differential cross-section of $W \rightarrow \mu\nu$ as a function of ΔR (μ, closest jet), obtained from the unfolded data of the signal region



SHERPA+OpenLoops (JHEP 04 (2016) 021) and $W + \geq 1$ jet N_{jetti} NNLO (Phys. Rev. Lett. 115 (2015) 062002, Phys. Lett. B760 (2016) 6–13) show much better agreement across the entire distribution, when compared to other calculations.



Z+jets at 13 TeV

ATLAS-CONF-2016-046

$Z^{\pm}$

$p_T^{l} > 25$ GeV

$|\eta_l| < 2.5$

two opposite-sign charged leptons

71 GeV < m_{ll} < 111 GeV

Jets

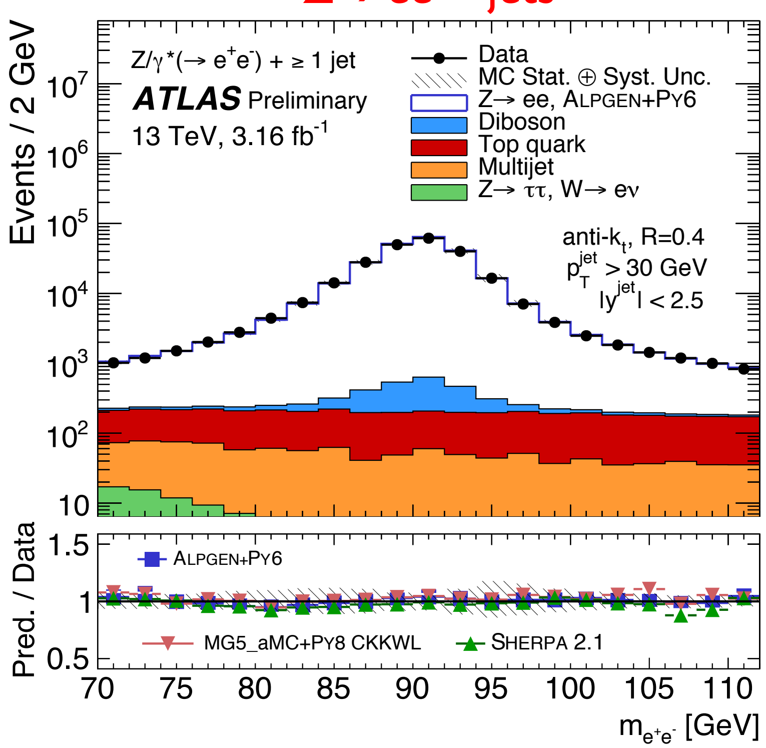
anti-k_t R = 0.4

$p_T^{jet} > 30$ GeV

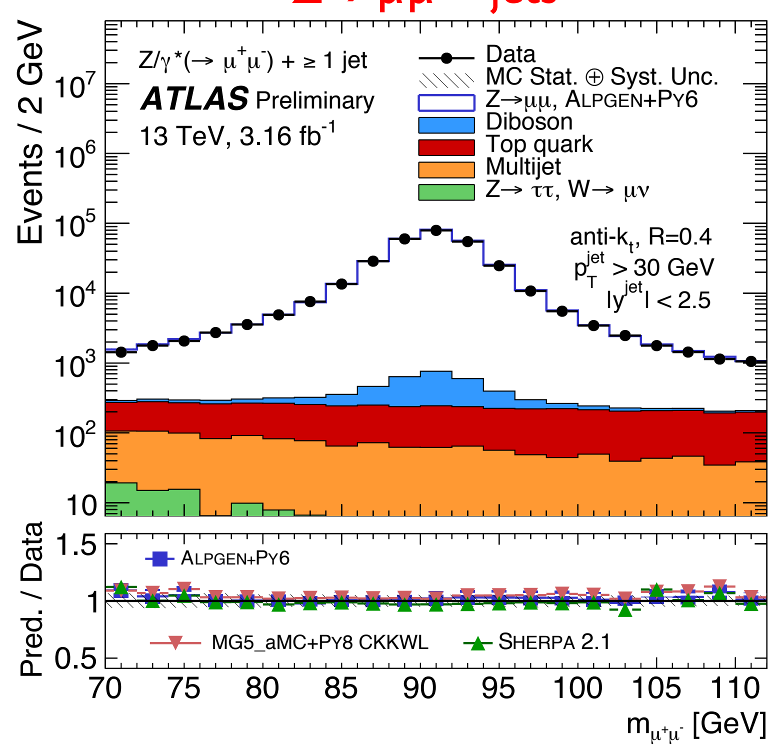
$|y^{jet}| < 2.5$,

$\Delta R(l, jet) > 0.4$

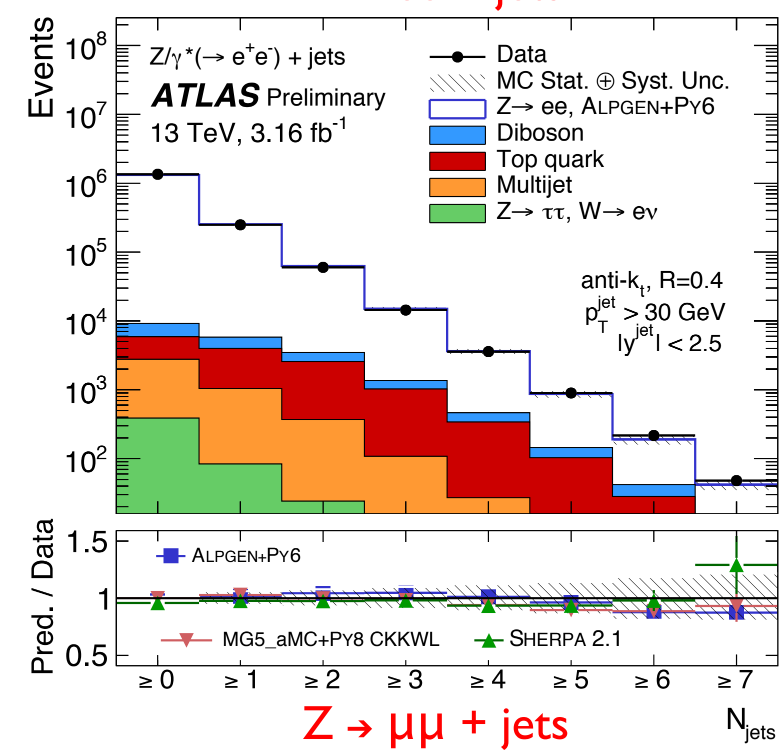
Z → ee + jets



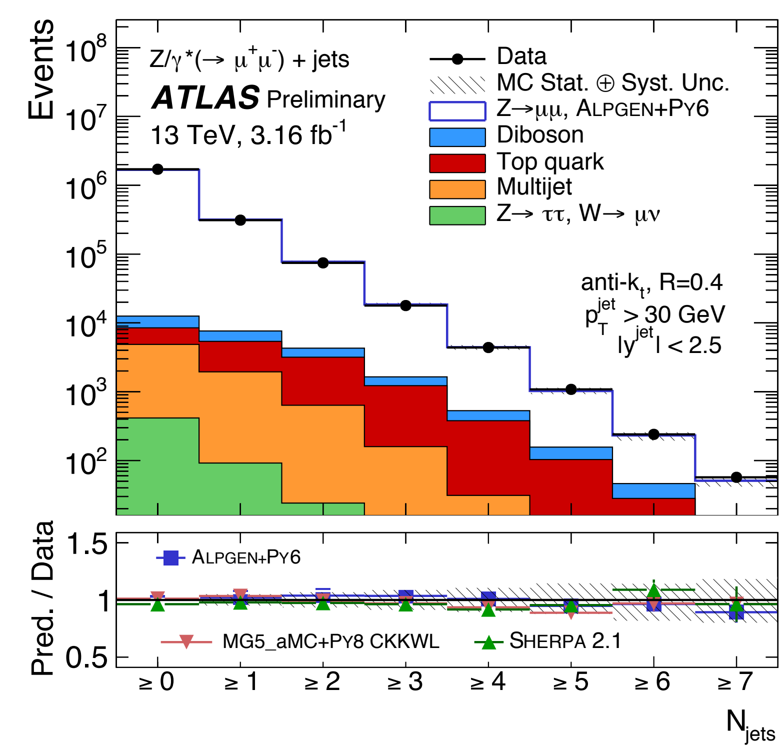
Z → μμ + jets



Z → ee + jets



Z → μμ + jets



Alpgen+Py6, **Sherpa 2.1** and **MG5_aMC+Py8 CKKWL** agree with data

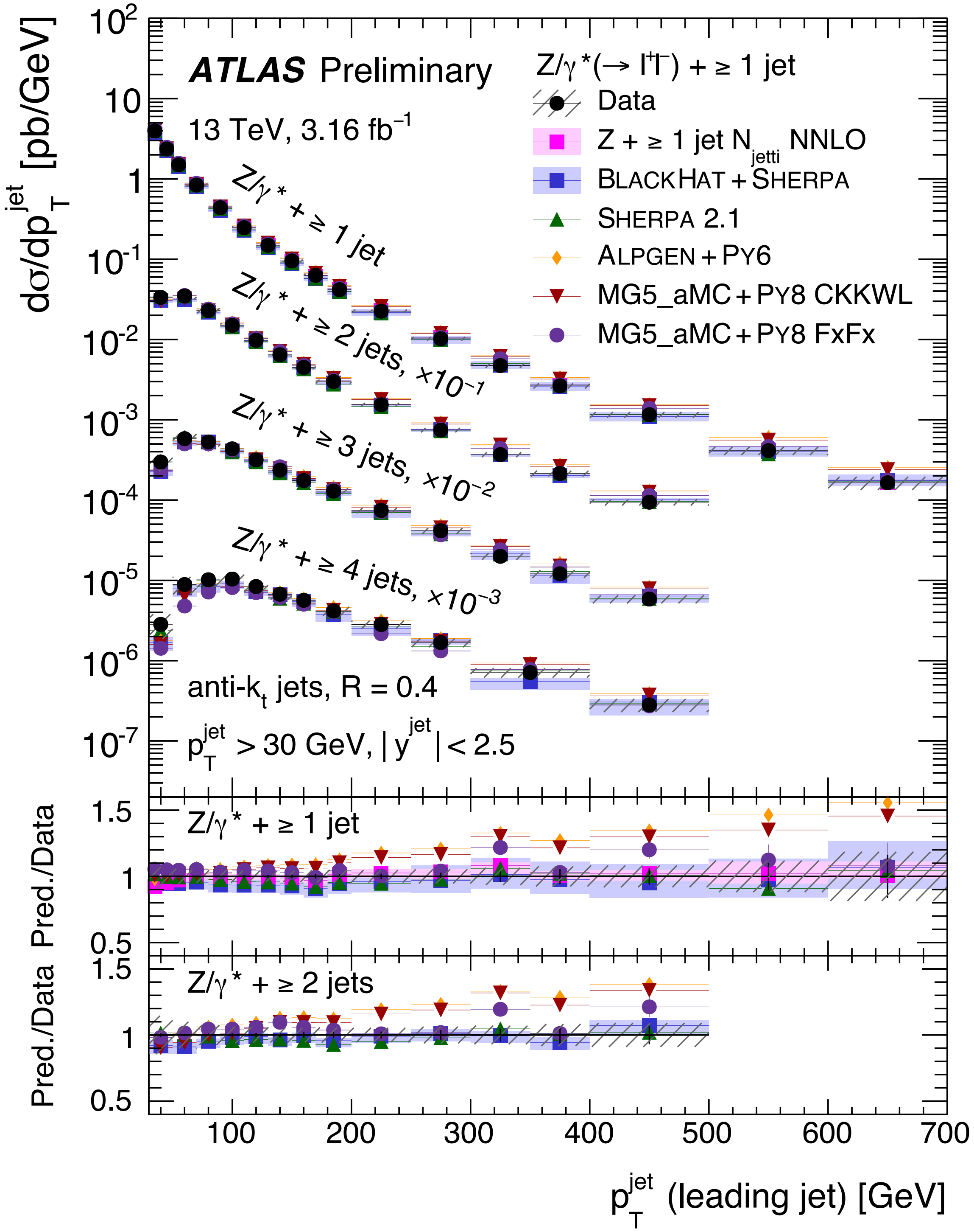
Z+jets at 13 TeV

ATLAS-CONF-2016-046

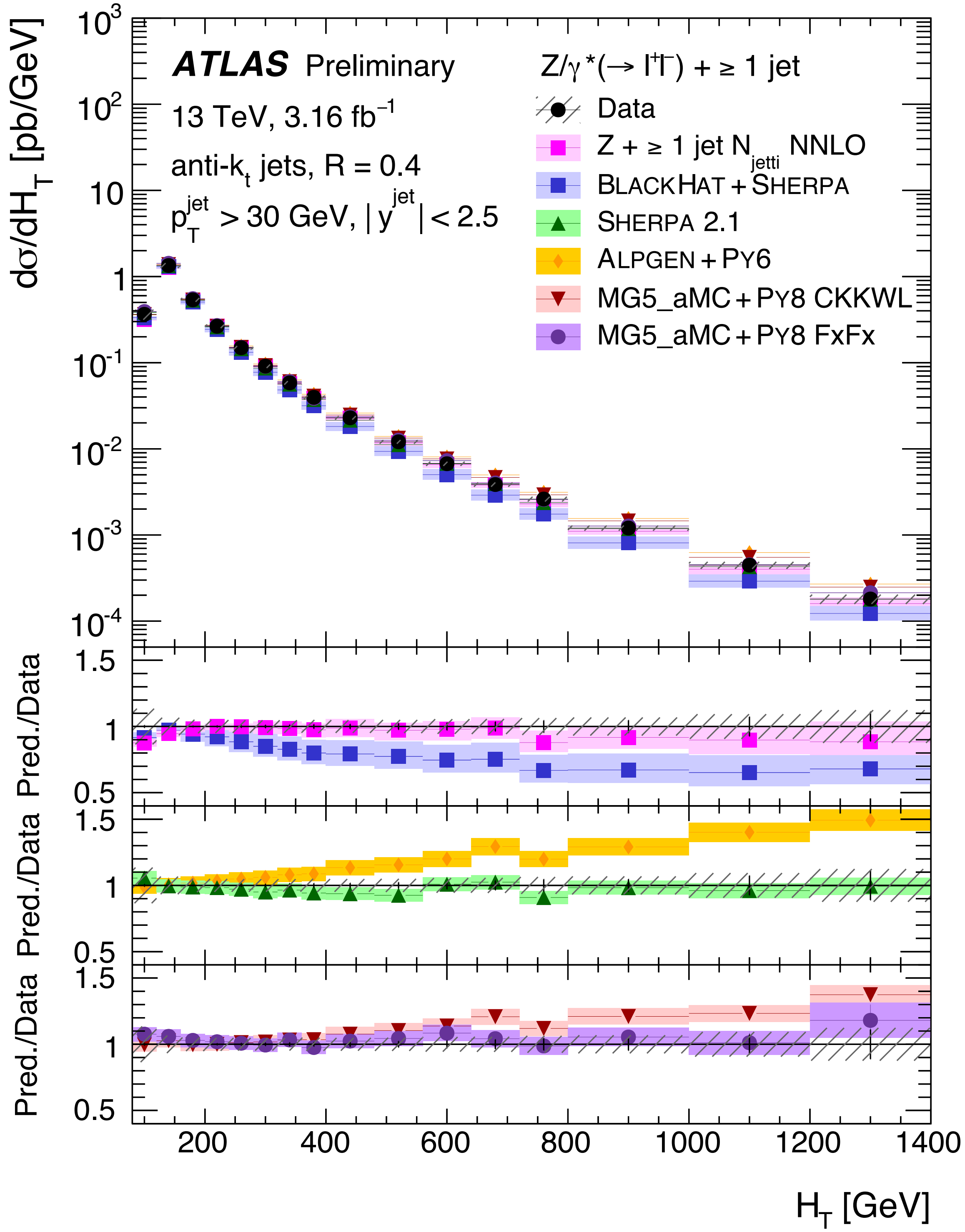
LO Alpgen+Py6 and **MG5_aMC+Py8 CKKWL** model in general a too-hard jet p_T spectrum and can be interpreted as an indication that the dynamic fragmentation and renormalisation scale used in the generation is not appropriate for the full jet p_T range;

NLO BlackHat+Sherpa, Sherpa 2.1, and **MG5_aMC +Py8 FxFx** are in agreement within the systematics uncertainties over the full range;

Njetti NNLO also models well the spectrum.



Z+jets at 13 TeV



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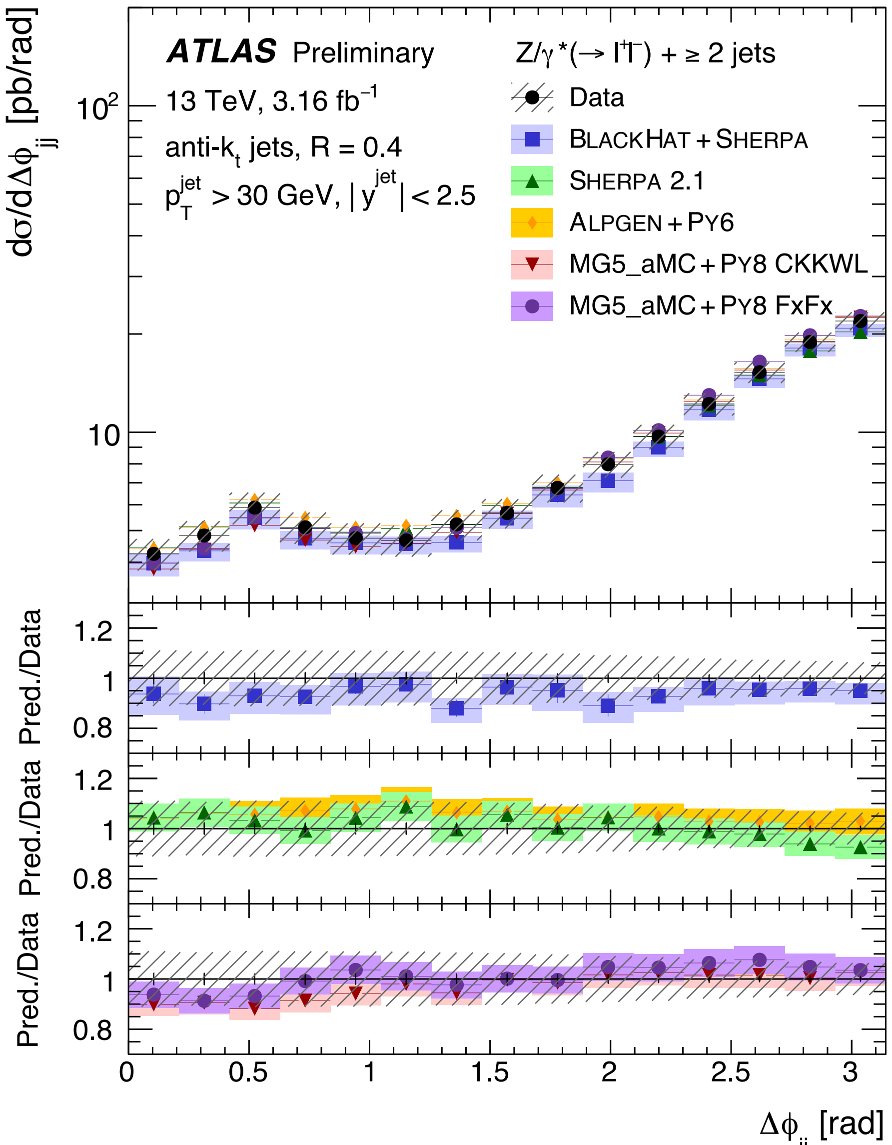
Sherpa 2.1 and **MG5_aMC+Py8 FxFx** describe well H_T;

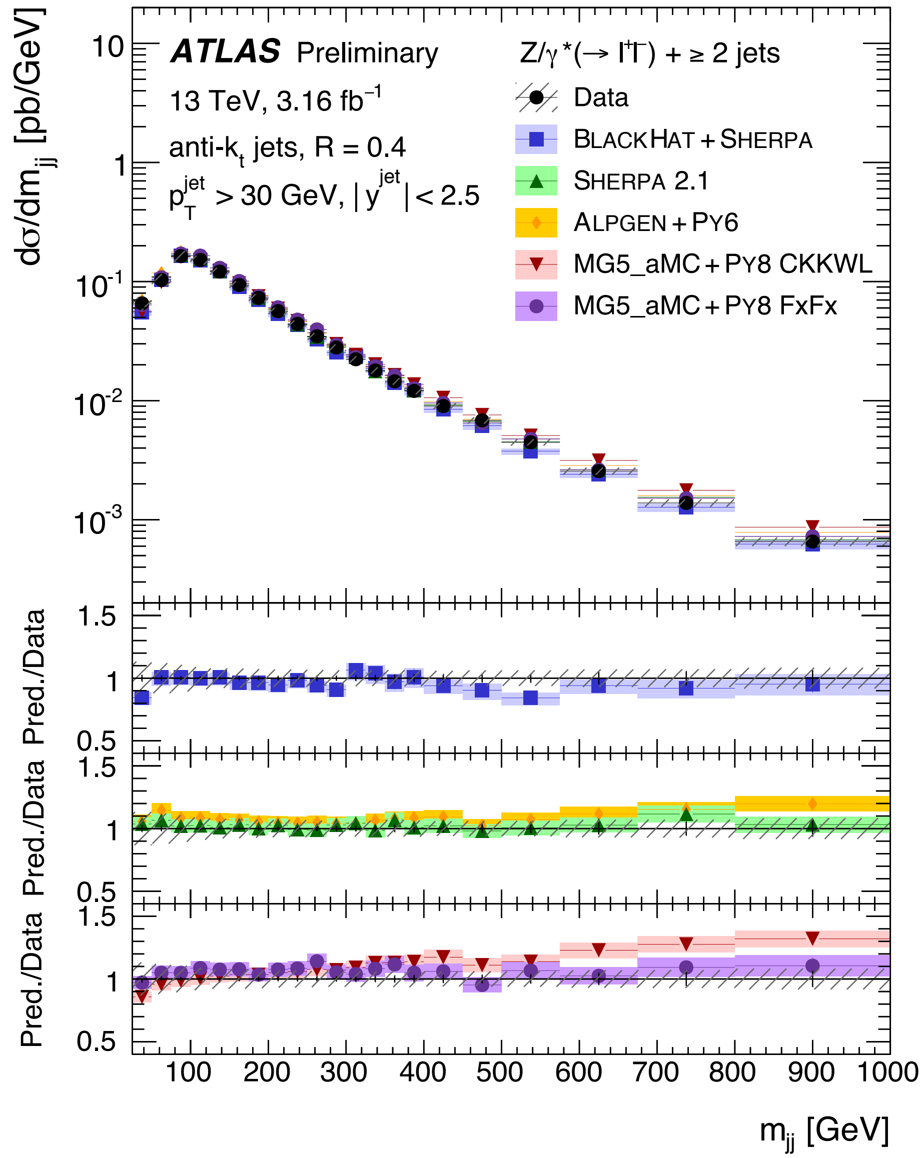
MG5_aMC+Py8 CKKWL and **Alpgen+Py6** over-estimate the contribution at large values of H_T;

BlackHat+Sherpa under-estimates the cross section for H_T > 300 GeV, as observed in similar measurements at lower centre-of-mass energies, due to the missing contributions from events with higher parton multiplicities;

agreement is recovered by adding higher orders in perturbative QCD, as demonstrated by the good description given by **N_{jetti} NNLO**.

Z+jets at 13 TeV





shape and drop of the dijet mass is modelled well by **BlackHat+Sherpa**, **Sherpa 2.1**, **Alpgen+Py6** and **MG5_aMC+Py8 FxFx**;

MG5_aMC+Py8 CKKWL shows a harder spectrum.

azimuthal angular difference

between the two leading jets for Z+ ≥ 2 jet

is well modelled by all predictions

ATLAS-CONF-2016-046

Summary

isolated prompt photons

- **@ 8TeV**: results shown for E_T^γ > 1 TeV, also revisiting lower-E_T data . NLO QCD (PeTeR) describes data well within uncertainties.
- **@ 13 TeV**: MC (SHERPA 2.1) of signal provides a good description of the shape of the measured kinematic distributions.

jets

- **four-jet @ 8TeV**: MadGraph+Pythia provides the best description of mass variables, whereas Herwig++ provides a very good description for the angular variables.
- **inclusive jets @ 13 TeV**: in general there is good agreement between data and theory, confirming the validity of perturbative QCD in the measured kinematic regions.

vector bosons + jets

- **collinear W @ 8 TeV:** brand new measurement has implications for Monte Carlo programs that incorporate real *W* boson emission, a process which is only just now being probed directly at the LHC.
- **Z+jets @ 13 TeV:** N_{jetti} NNLO modelling well $p_T^{(1)}$ and H_T.

Thank you!!!!

Additional slides

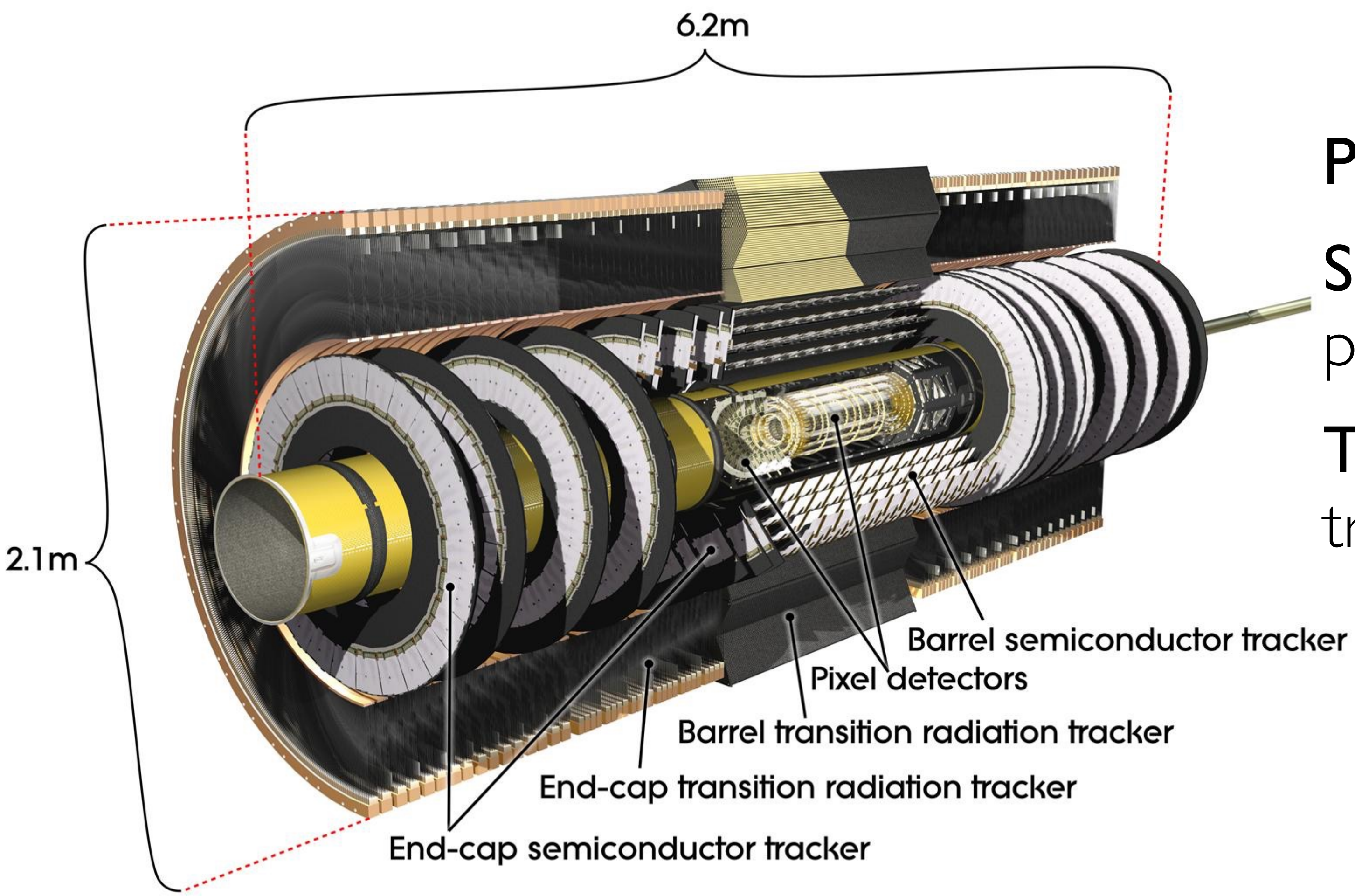
ATLAS Inner Detector and the photon reconstruction

Electron/photon discrimination

Based on track matching

Important for converted photon identification (~30% of all photons)

Based on vertex position



Pixel Tracker : 3 layers resolution 0.01 mm

Semi-Conducting Tracker: 4 layers (8 hits per track) resolution 0.017 mm

Transition Radiation Tracker: ~36 hits per track resolution 0.13 mm

ATLAS Electromagnetic Calorimeter and the photon reconstruction

Barrel |η| < 1.475
End-cap: 1.375 < |η| < 3.2

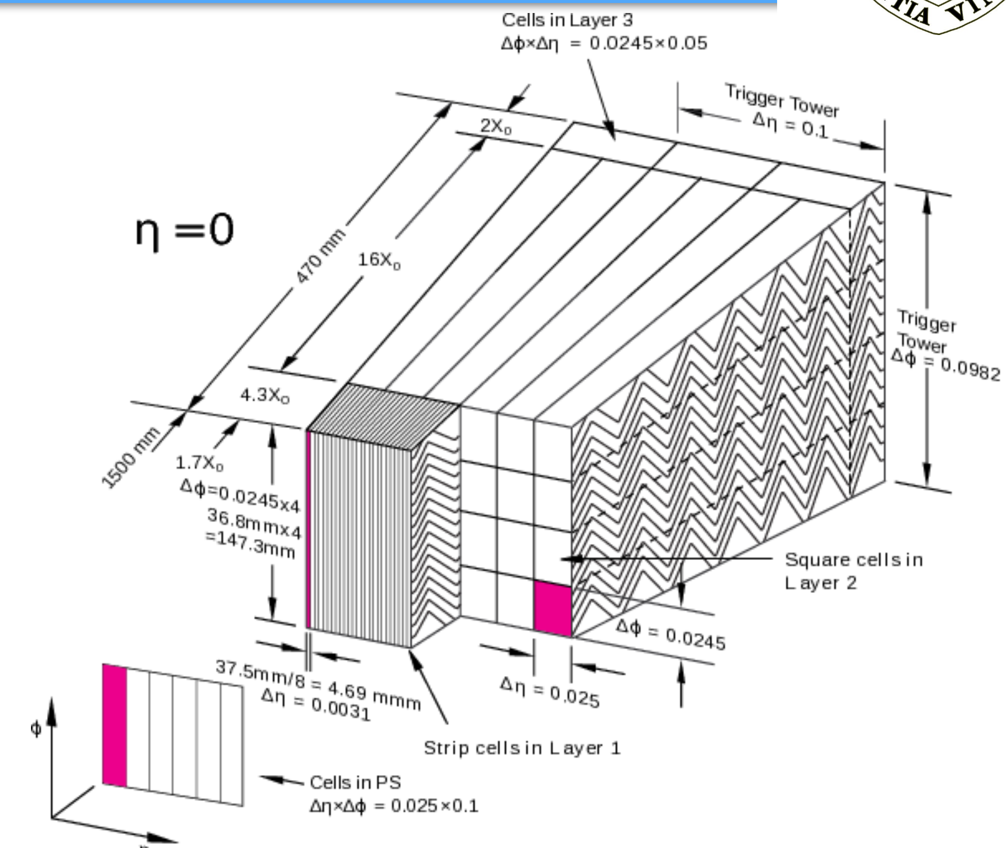
Depth segmentation allows measurement of photon direction

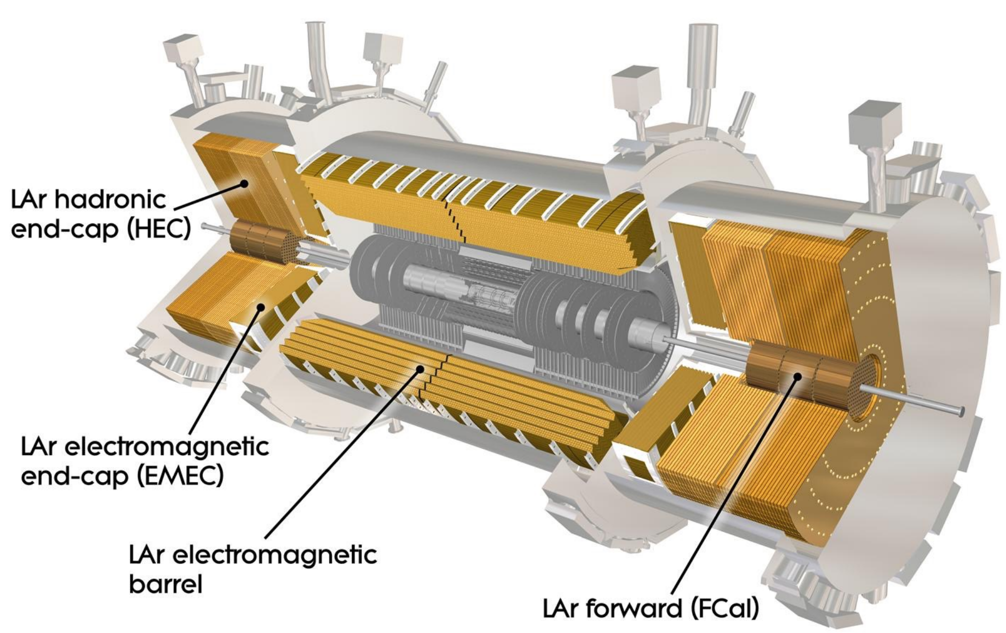
First layer: high granularity in η

Second layer: collects most of the energy, with granularity

$\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$

Third layer: used to correct for leakage





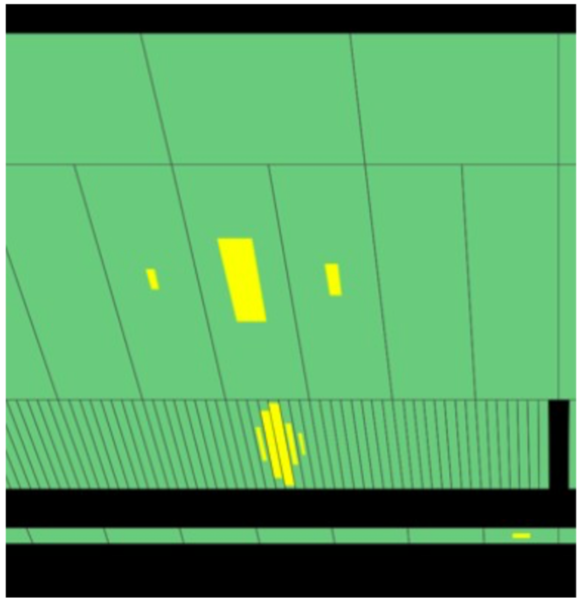
Cluster of EM cells without matching track:

→ "unconverted" photon candidate

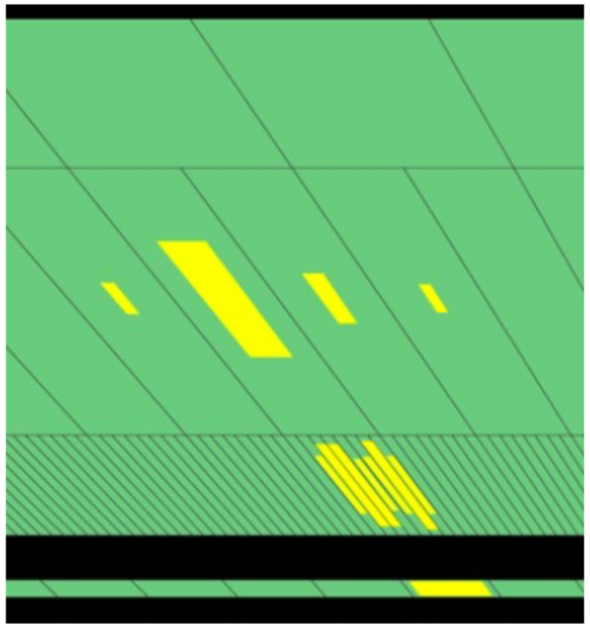
Cluster of EM cells matched to pairs of tracks (from reconstructed conversion vertices in the inner detector) or matched to a single track consistent with originating from a photon conversion

→ "converted" photon candidate

Photon reconstruction and identification



prompt photon candidate



π^0 candidate

Signal vs background discrimination: shape variables from the lateral and longitudinal energy profiles of the shower in the calorimeters; "loose" and "tight" identification criteria.

"Loose" identification criteria:

→ leakage: $R_{\rm had} = E_{\rm T}^{\rm had}/E_{\rm T}$ (1st layer hadronic calorimeter)

→ $R_\eta = E_{3\times7}^{\rm S_2}/E_{7\times7}^{\rm S_2}$ S_2 =second layer of EM calorimeter

→ RMS width of the shower in η direction in S2

"Tight" identification criteria:

→ the requirements applied in "Loose" are tightened

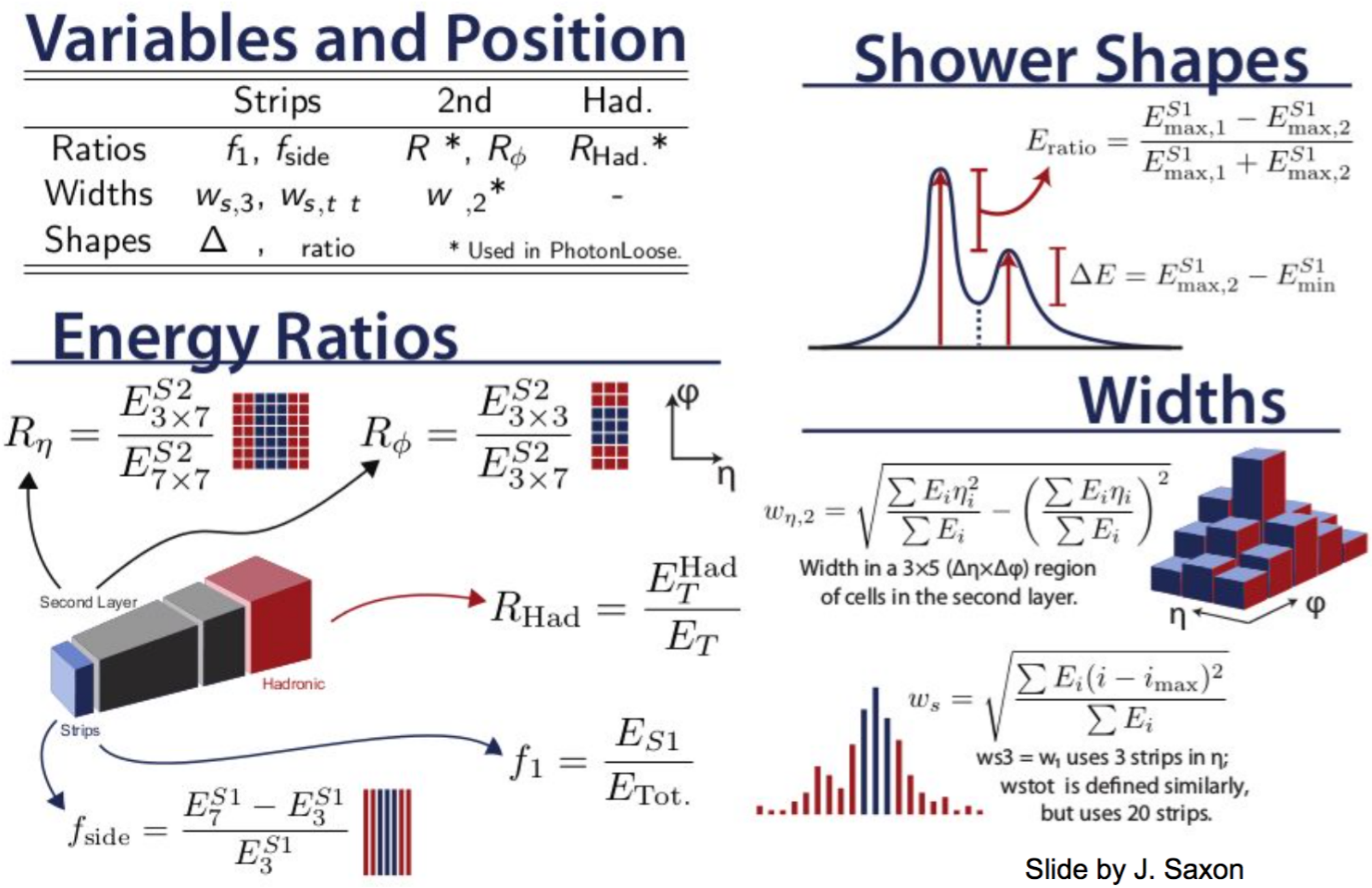
→ $R_\phi = E_{3\times3}^{\rm S_2}/E_{3\times7}^{\rm S_2}$

and shower shapes in the first layer (to discriminate single-photon showers from overlapping nearby showers, such as $\pi^0 \to \gamma\gamma$)

→ e.g. asymmetry between the 1st and 2nd maxima in the energy profile along η (S1)

Efficiency: 97 (85)% for loose (tight) photons with E_T^γ > 20 GeV

Photon identification variables



Photon isolation

E_T^{iso} computed using clusters of calorimeter cells (EM and HAD) in a cone R = 0.4, excluding the contribution from the photon

→ Subtraction of the leakage of the photon energy outside that region (few %)

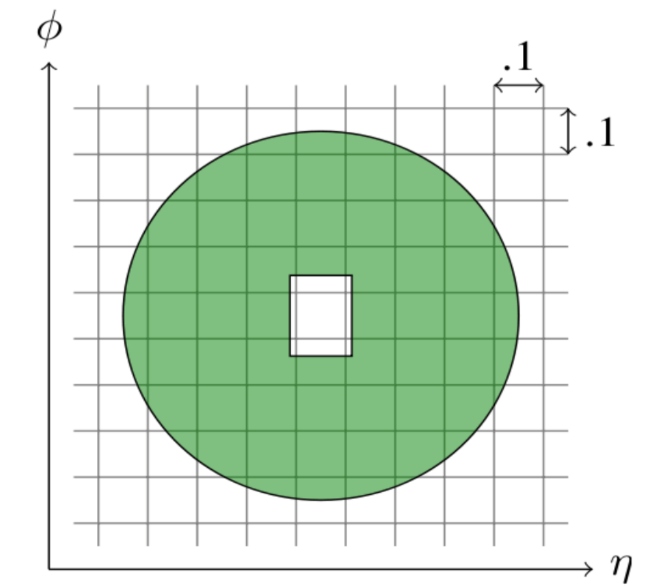
→ The underlying event and pileup contribute to E_T^{iso}:

→ subtracted on event-by-event basis using the jet-area method (JHEP 0804 (2008) 005)

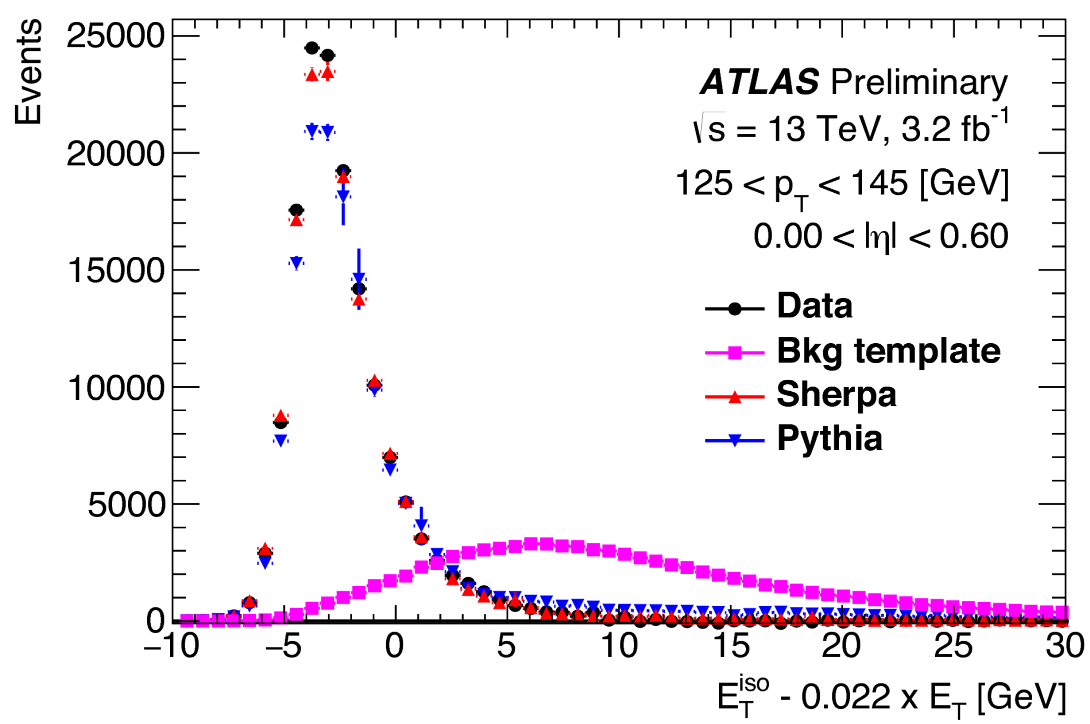
$(E_T^{iso})^{cor} < (E_T^{iso})^{cut}$

8TeV analysis cut: $4.8\ \mathrm{GeV} + 4.2\times10^{-3} \times E_T^{\gamma}$

→ After isolation requirement, residual background still expected



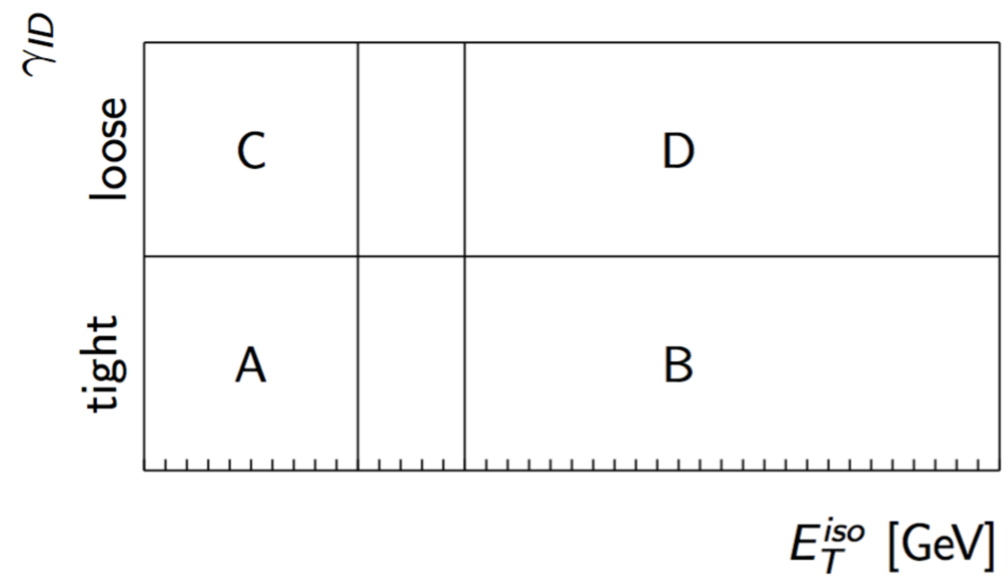
ATLAS-CONF-2016-018



Background subtraction

A data-driven method used to avoid relying on detailed simulations of the background processes:

photons separated into four regions (A-tight and isolated; B-tight and non-isolated, C-non-tight and isolated; D-non-tight and non-isolated) with two fractions in regions B,C,D (signal and background) and only signal in region A



$$N^{\mathrm{A,data}}_{\mathrm{signal}} = N^{\mathrm{A,data}} - R_{\mathrm{bkg}}\left((N^{\mathrm{B,data}} - f^{\mathrm{B,MC}} N^{\mathrm{A,data}}_{\mathrm{signal}}) \frac{(N^{\mathrm{C,data}} - f^{\mathrm{C,MC}} N^{\mathrm{A,data}}_{\mathrm{signal}})}{(N^{\mathrm{D,data}} - f^{\mathrm{D,MC}} N^{\mathrm{A,data}}_{\mathrm{signal}})}\right)$$

where: $f^{\mathrm{K,MC}} = N^{\mathrm{K,MC}}_{\mathrm{signal}} / N^{\mathrm{A,MC}}_{\mathrm{signal}}$ with K = B, C, D is the signal leakage fraction

$R_{\mathrm{bkg}} = N^{\mathrm{A,MC}}_{\mathrm{bkg}} N^{\mathrm{D,MC}}_{\mathrm{bkg}} / N^{\mathrm{B,MC}}_{\mathrm{bkg}} N^{\mathrm{C,MC}}_{\mathrm{bkg}}$ with the independence of the background variables

Purity: ≳ 90% for E_T > 40 GeV (ATLAS, PRD 83 (2011) 052005)

Inclusive production of isolated photons at 8 TeV

LO

- **Pythia 8.165** using **CTEQ6L1**
- **Sherpa 1.4.0** using **CT10**

JHEP 06 (2016) 005

NLO

- **JetPhox** using **CT10:**
  - parton-level generator for the prediction of processes with photons in the final state;
  - NLO accuracy for both direct and fragmentation photon processes.

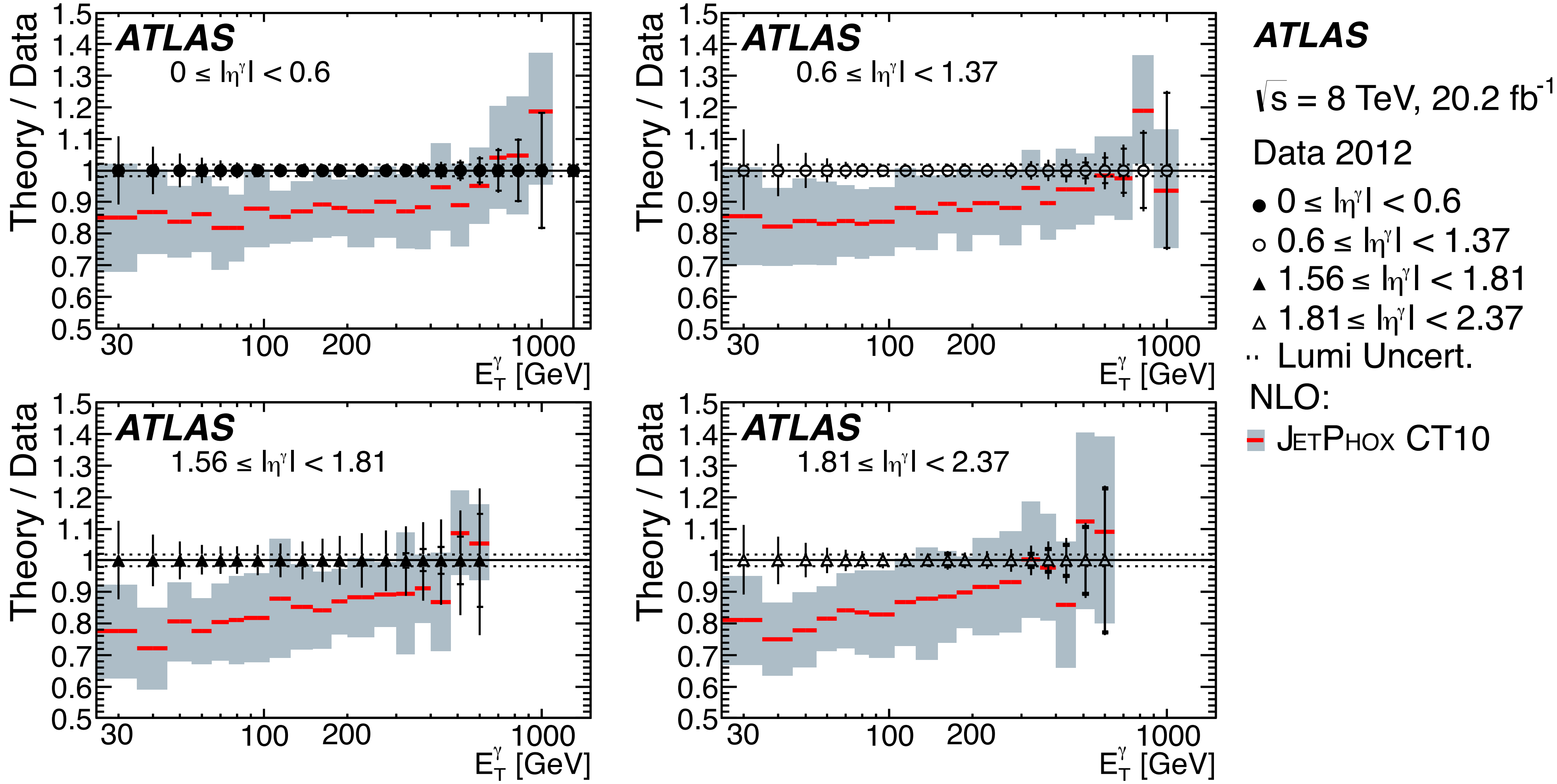
- **PeTer** using **CT10:**
  - parton-level generator including the resummation of QCD threshold logarithms at NNNLL

Ratio of JetPhox CT10 to 8 TeV data

JHEP 06 (2016) 005

η range split into 4 bins;

uncertainties:
statistical+systematic



Comparison to NLO QCD calculation using **JetPhox:**

- a similar trend is observed at low E_T^γ in all $|\eta^\gamma|$ regions, the NLO QCD predictions underestimate the data by ≈ 20%;
- the theoretical uncertainty (12-20%) prevents a more precise test of the SM predictions.

Four-jet production at 8 TeV

Definition of various kinematic variables

Name	Definition	Comment
$p_{\mathrm{T}}^{(i)}$	Transverse momentum of the ith jet	Sorted descending in p_{T}
H_{T}	$\sum_{i=1}^{4} p_{\mathrm{T}}^{(i)}$	Scalar sum of the p_{T} of the four jets
$m_{4\mathrm{j}}$	$\left(\left(\sum_{i=1}^{4} E_i\right)^2 - \left(\sum_{i=1}^{4} \mathbf{p}_i\right)^2\right)^{1/2}$	Invariant mass of the four jets
$m_{2\mathrm{j}}^{\min}/m_{4\mathrm{j}}$	$\min_{\substack{i,j\in[1,4] \\ i\neq j}} \left((E_i + E_j)^2 - (\mathbf{p}_i + \mathbf{p}_j)^2\right)^{1/2} \ / \ m_{4\mathrm{j}}$	Minimum invariant mass of two jets relative to invariant mass of four jets
$\Delta\phi_{2\mathrm{j}}^{\min}$	$\min_{i,j\in[1,4]\mathrm{1}\neq j} \left(\lvert\phi_i - \phi_j\rvert\right)$	Minimum azimuthal separation of two jets
$\Delta y_{2\mathrm{j}}^{\min}$	$\min_{i,j\in[1,4]\mathrm{1}\neq j} \left(\lvert y_i - y_j\rvert\right)$	Minimum rapidity separation of two jets
$\Delta\phi_{3\mathrm{j}}^{\min}$	$\min_{i,j,k\in[1,4]\mathrm{1}\neq j\neq k} \left(\lvert\phi_i - \phi_j\rvert + \lvert\phi_j - \phi_k\rvert\right)$	Minimum azimuthal separation between any three jets
$\Delta y_{3\mathrm{j}}^{\min}$	$\min_{i,j,k\in[1,4]\mathrm{1}\neq j\neq k} \left(\lvert y_i - y_j\rvert + \lvert y_j - y_k\rvert\right)$	Minimum rapidity separation between any three jets
$\Delta y_{2\mathrm{j}}^{\max}$	$\Delta y_{ij}^{\max} = \max_{i,j\in[1,4]} \left(\lvert y_i - y_j\rvert\right)$	Maximum rapidity difference between two jets
$\Sigma p_{\mathrm{T}}^{\mathrm{central}}$	$\lvert p_{\mathrm{T}}^{c}\rvert + \lvert p_{\mathrm{T}}^{d}\rvert$	If $\Delta y_{2\mathrm{j}}^{\max}$ is defined by jets a and b, this is the scalar sum of the p_{T} of the other two jets, c and d ('central' jets)

Four-jet production at 8 TeV

jets

- anti-k_t R = 0.4;

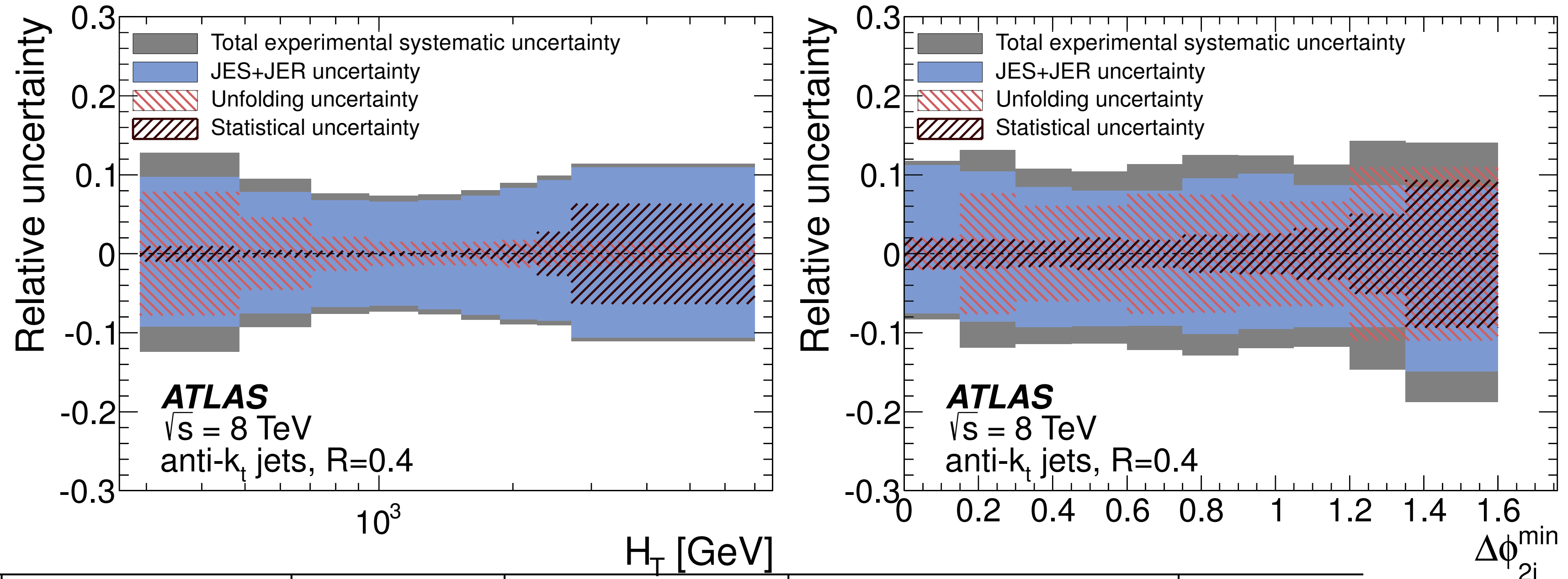
2012 Data: L = 20.3 fb^{-1}

inclusive analysis cuts:
$|y| < 2.8$, $p_T(4) > 64$ GeV, $p_T(1) > 100$ GeV, $\Delta R_{4j}^{min} > 0.65$

Uncertainties

- **unfolding** using **Bayesian Iterative** method as implemented in **RooUnfold** (arXiv:1105.1160)
- **JES** (4-15%);
- **JER** (1-10%);
- **jet angular resolution**: ≲ 2%
- **luminosity:** 2.8%

total systematic uncertainty



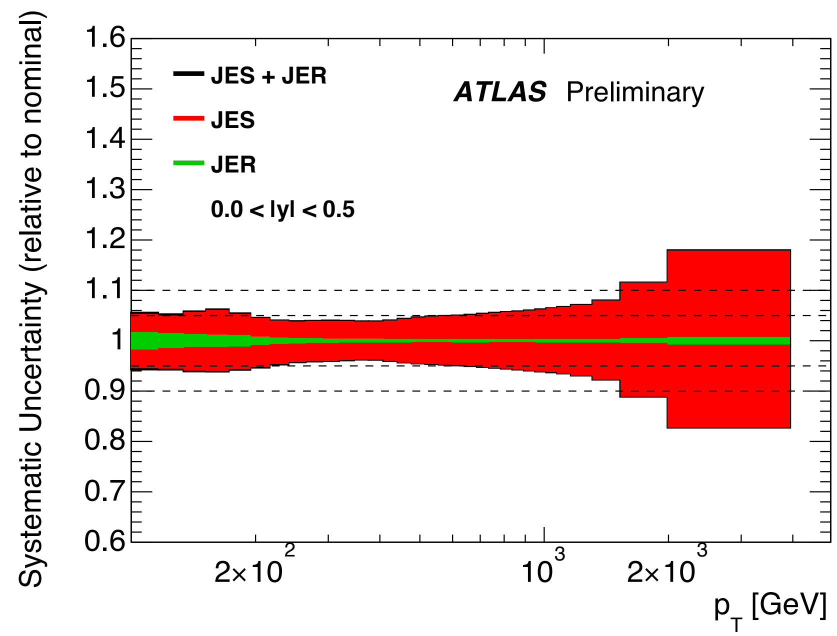
MC [JHEP 12 (2015) 105]

Name	Hard scattering	LO/NLO	PDF	PS/UE	Tune	Factor
Pythia 8	PYTHIA 8	LO (2 → 2)	CT10	PYTHIA 8	AU2-CT10	0.6
Herwig++	HERWIG++	LO (2 → 2)	CTEQ6L1	HERWIG++	UE-EE-3-CTEQ6L1	1.4
MadGraph+Pythia	MADGRAPH	LO (2 → 4)	CTEQ6L1	PYTHIA 6	AUET2B-CTEQ6L1	1.1
HEJ	HEJ	All †	CT10	—	—	0.9
BlackHat/Sherpa	BLACKHAT/SHERPA	NLO (2 → 4)	CT10	—	—	—
NJet/Sherpa	NJET/SHERPA	NLO (2 → 4)	CT10	—	—	—

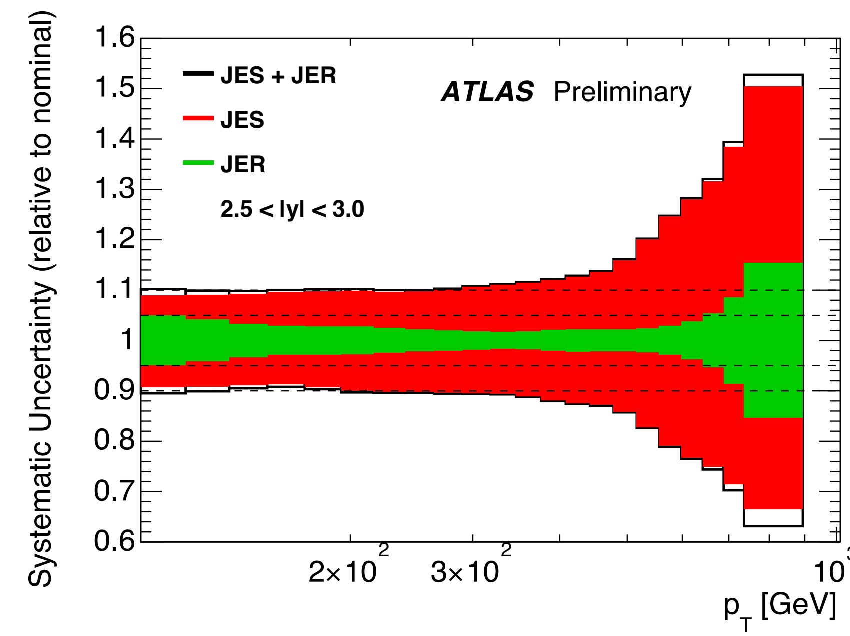
Inclusive jets at 13 TeV

ATLAS-CONF-2016-092

central



forward



Data (2015): L = 3.2 fb^{-1}

MC

LO

- **Pythia 8.186** using **A14** tune and **NNPDF2.3 LO** PDF set

Jet identification

- anti-k_t algorithm (R=0.4) inputs to the algorithm:

Cross-section

- using jets representing those clustered from stable particles with c**τ** > 10 mm
- muons, neutrinos from decaying hadrons included in the clustering
- $d^2\sigma/dp_{\mathrm{T}}dy$ for p_T^{jet} ≥ 100 GeV, |y| < 3 with six equidistant jet rapidity bins

luminosity: 2.1%

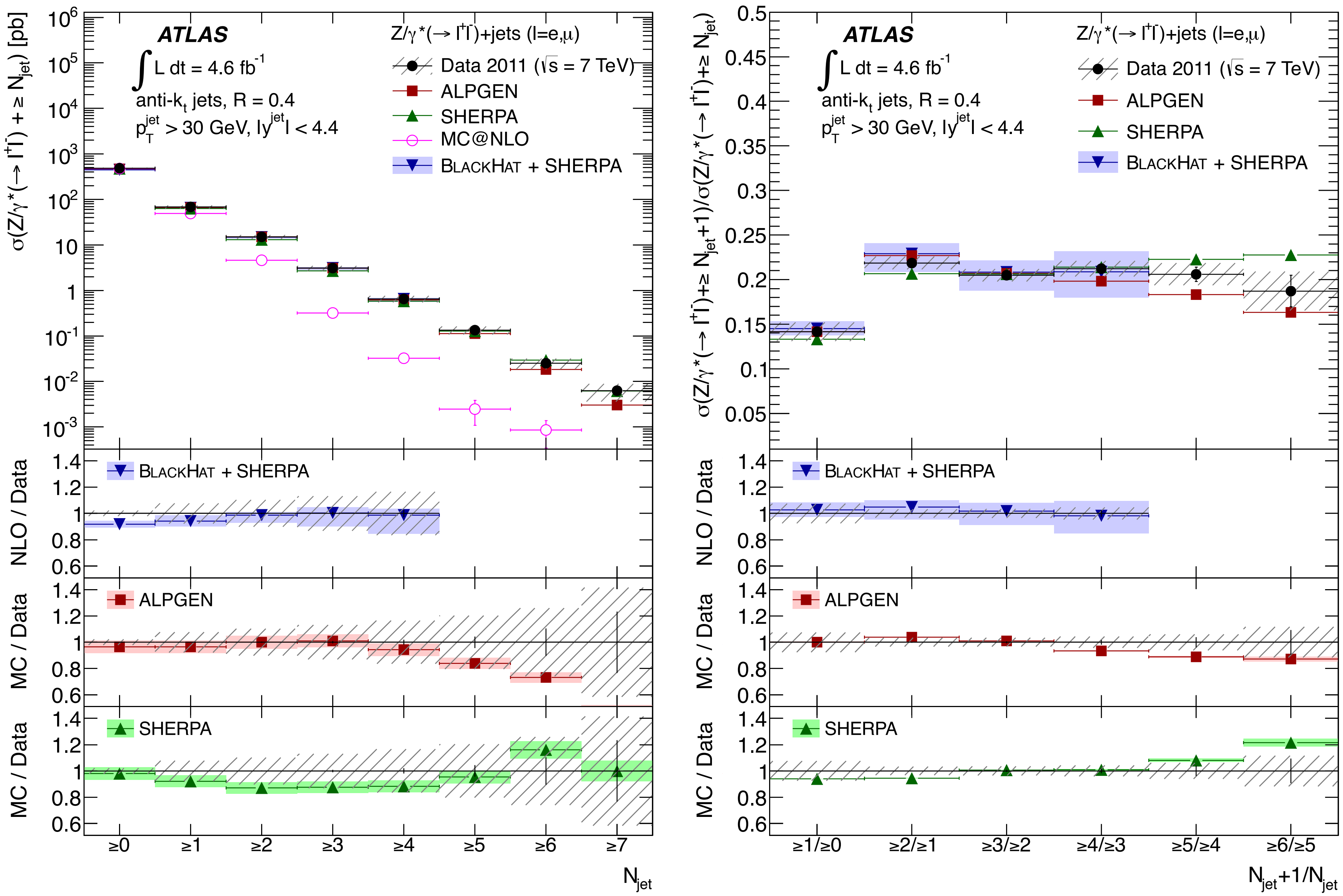
systematic uncertainties

- **JES, JER** and **unfolding** procedure (JHEP 1502 (2015) 153)

statistical uncertainties

- estimated using pseudo-experiments including effects from data and MC statistics

Z+jets at 7 TeV



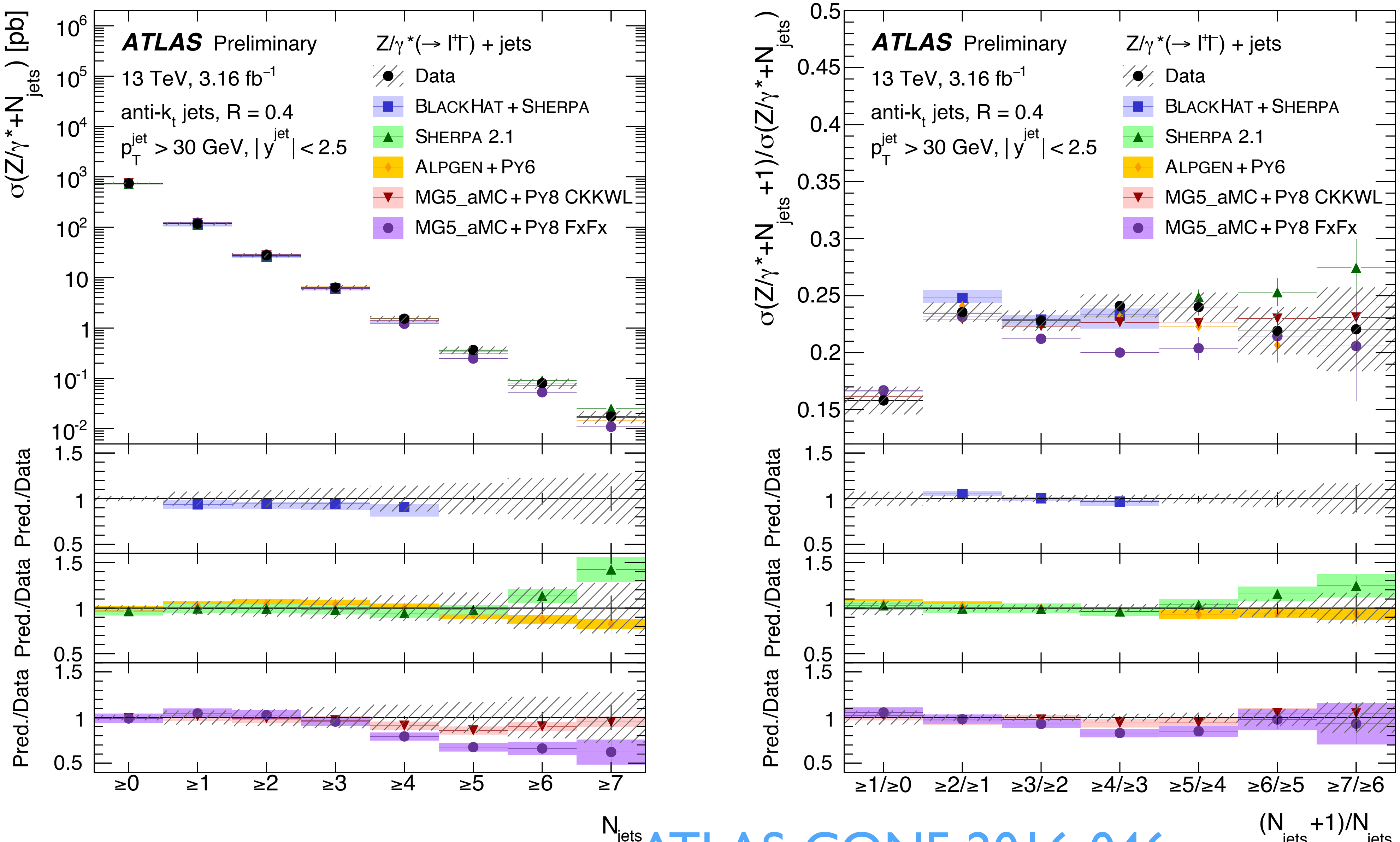
data consistent with:

→BLACKHAT+SHERPA
→ALPGEN
→SHERPA

MC@NLO underestimates observed rate leading to large offsets for higher multiplicities

$R_{\geq(n+1)/\geq n}$: ratio of cross sections for two successive multiplicities: more precise measurement of QCD process, due to cancellation of part of the systematic uncertainty

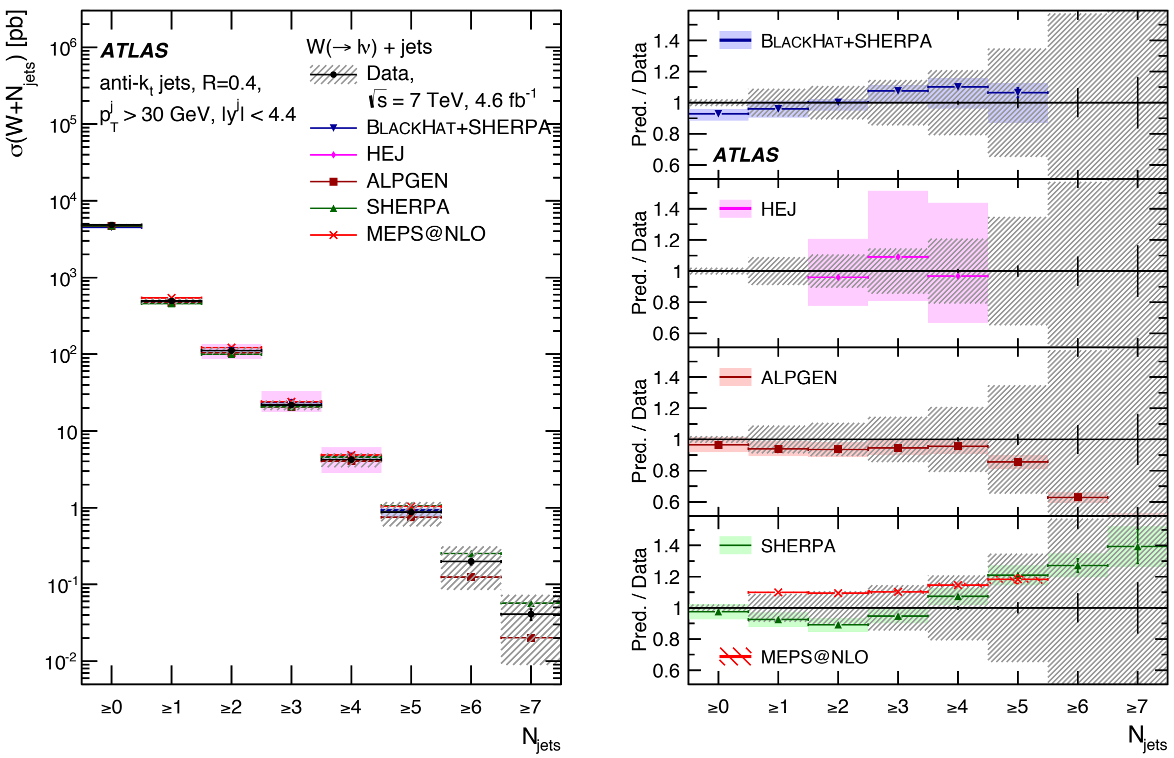
Z+jets at 13 TeV



[ATLAS-CONF-2016-046]

predictions show reasonable agreement with the observed cross sections and their ratios, **except for MG5_aMC+Py8 FxFx**, which is expected, since the samples only account for the production of up to two jets at NLO while subsequent jets are produced by the parton shower.

W+jets at 7 TeV



N$_{jets}$

good agreement with **BlackHat+SHERPA** up to 5 jets
ALPGEN and **SHERPA**: different trends for $N_{jets} > 4$, still in agreement with data within systematic uncertainties

H$_T$

ALPGEN and **SHERPA** tend to be higher than the data at HT > 600 GeV.

BlackHat+SHERPA lower than the data for Njets ≥ 1

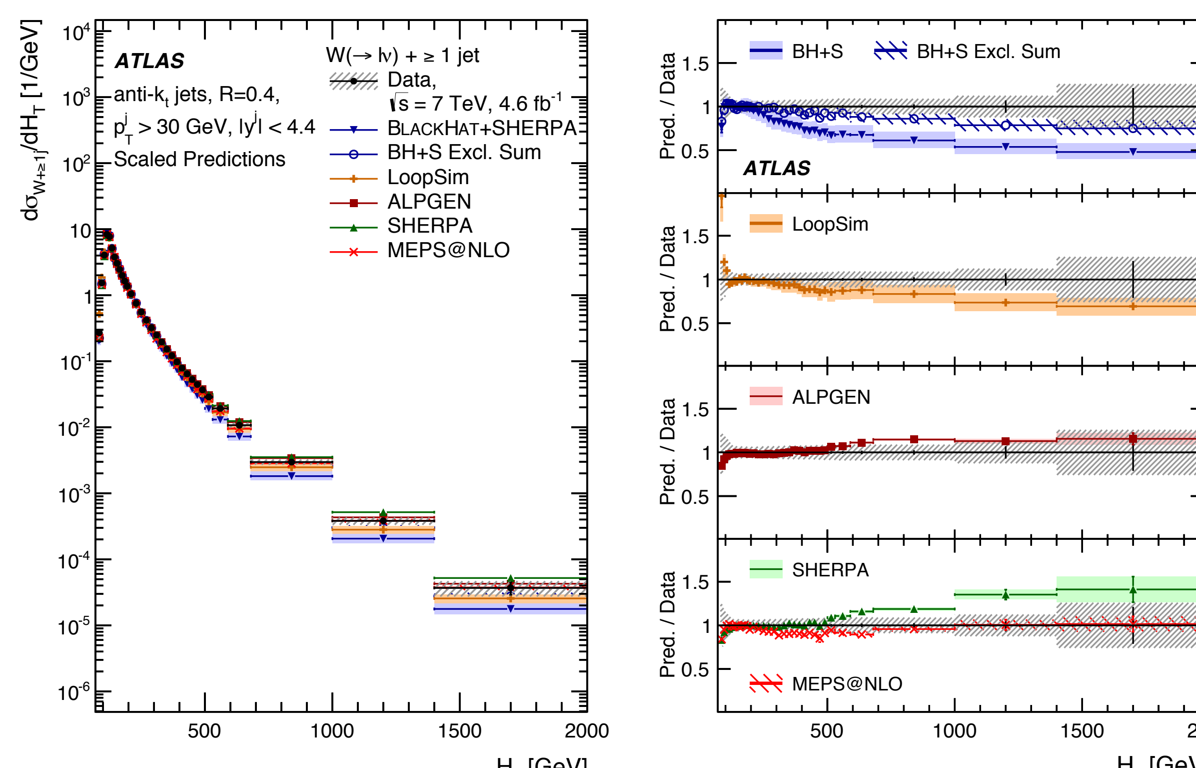
Data (2011): L = 4.6 fb^{-1}

W$^{\pm}$

Exactly one lepton required
$p_T^l > 25$ GeV
$p_T^{\nu} > 25$ GeV
$|\eta_l| < 2.4$ for e, (2.47 for **μ**)
$m_T > 40$ GeV

Jets

anti-k$_t$ R = 0.4
$p_T^{\,jet} > 30$ GeV
$|y^{jet}| < 4.4$,
$\Delta R(l, jet) > 0.5$



[Eur. Phys. J. C (2015) 75:82]

Ratio W+jets/Z+jets at 7 TeV

$W^{\pm}$

Exactly one lepton required

$p_T^l > 25$ GeV

$p_T^\nu > 25$ GeV

$|\eta_l| < 2.4$ for e, (2.47 for μ)

$m_T > 40$ GeV

$Z^{\pm}$

$p_T^l > 25$ GeV

$|\eta_l| < 2.4$ for e, (2.47 for μ)

two opposite-sign charged leptons

66 GeV $< m_{ll} <$ 116 GeV

$\Delta R(l, l) < 0.2$

Jets

anti-k_t R = 0.4

$p_T^{jet} > 30$ GeV

$|y^{jet}| < 4.4$,

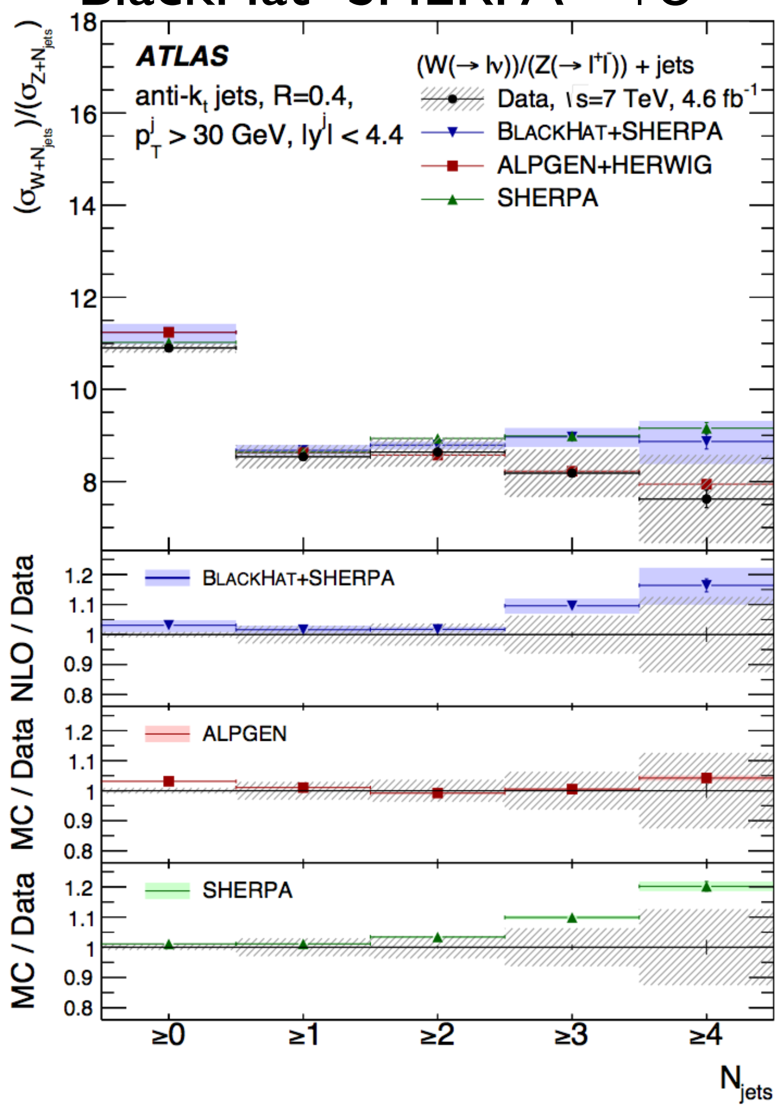
$\Delta R(l, jet) > 0.5$

[Eur. Phys. J. C (2014) 74: 3168]

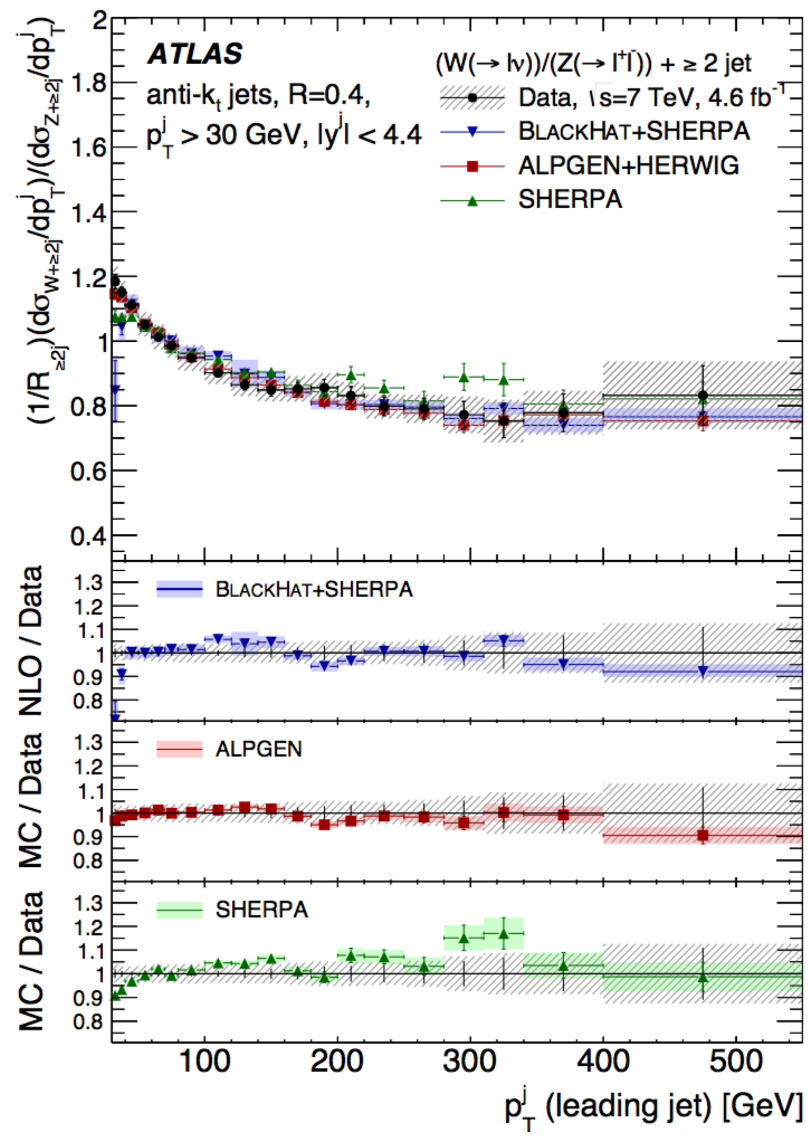
deviations at high jet multiplicities:

SHERPA is > 1.5σ

BlackHat+SHERPA ~1σ



p_T leading jet (≥ 2jets) well described, except at low p_T



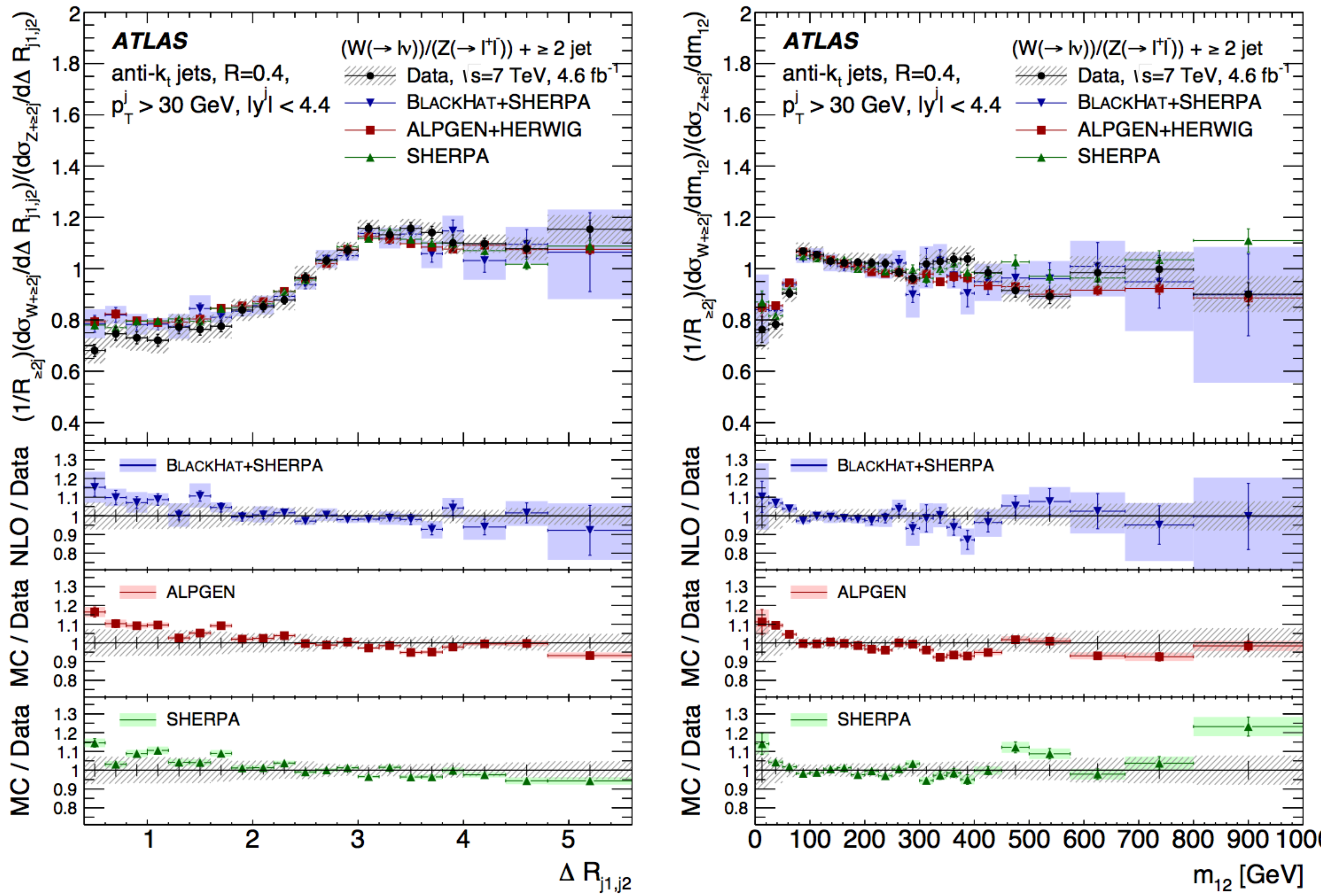
ttbar and multi jet backgrounds are data driven estimated, others are based on MC

Iterative Bayesian unfolding is used to compare data to theoretical predictions

Ratio W+jets/Z+jets at 7 TeV

At lowest $\Delta R_{j1,j2}$ and m_{12} values, predicted shapes differ from measured ones

Eur. Phys. J. C (2014) 74: 3168



Weak sensitivity to non-perturbative effects enhancing the difference in soft QCD radiation between W and Z events, but not cancelling completely in Rjets