Jet measurements at ATLAS and CMS

Giannis Flouris
Vrije Universiteit Brussel
On behalf of the CMS and ATLAS collaborations

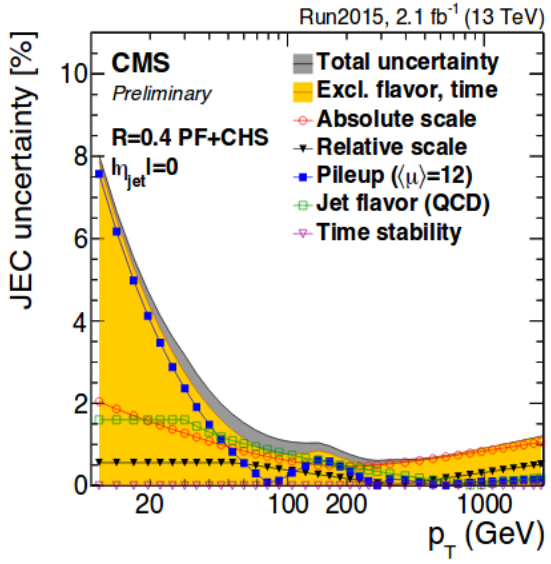
SM@LHC 2017
Amsterdam, Netherlands
2-5 May 2017

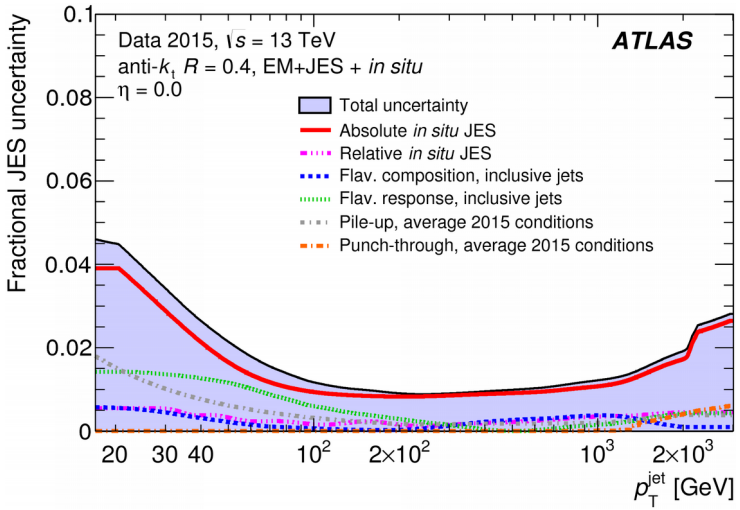
Introduction

- Jets are signatures of quarks and gluons in the detectors.
  - SM measurements.
  - Important background for many new physics models.
- The understanding of jets and QCD is a key component to extend our understanding of the SM and for searches beyond the SM.
- This presentation will cover:
  - Charged particles multiplicity.
  - Cross section measurements.
  - Strong coupling measurements.
  - PDF constrains.
- Both ATLAS and CMS recorded high quality data.
- Theoretical calculations and tools:
  - NLO calculations.
  - EWK corrections.
  - NLO generators matched to PS.
  - Various MC generators.

Jet Reconstruction

- ATLAS+CMS use the anti-kt algorithm for jet clustering.
- The input is different.
  - ATLAS: topological calorimeter-cell clusters.
  - CMS: Particle flow objects. All sub-detectors are exploited to reconstruct the particles.
- Pile-up corrections are applied in jets.
  - CMS also uses the charged hadron subtraction (CHS) algorithm.
- Both collaborations delivered jet energy corrections with equally small uncertainties.
  - Less than 2% in the region p_T > 100 GeV.

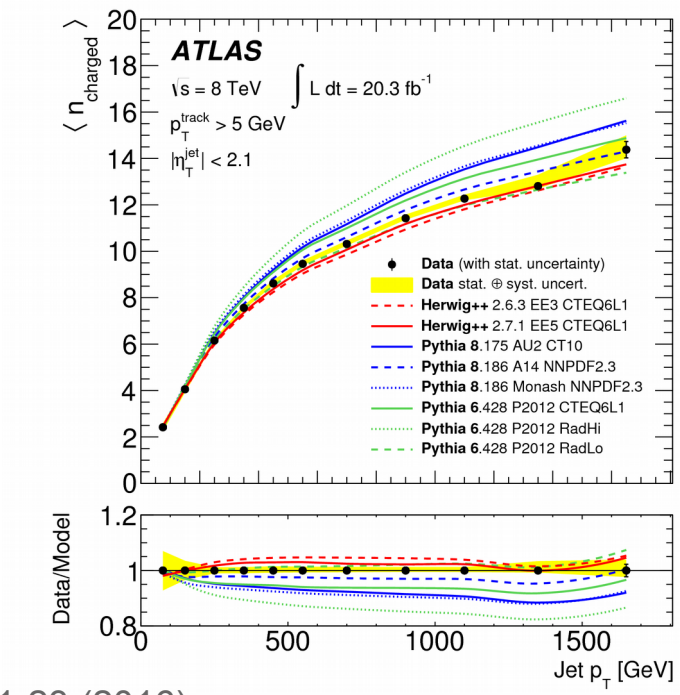


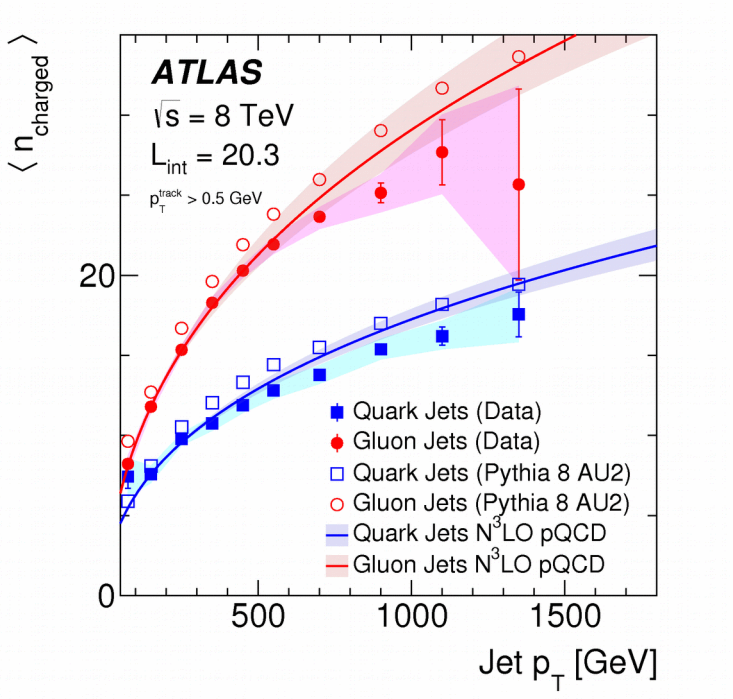


CMS-DP-2016-020
arXiv:1703.09665

Charged particle multiplicity

- Average number of charged particles inside a jet vs $p_{T.}$
- Tracks with p_T > 0.5 GeV (2.0 and 5.0 GeV are also reported in the paper).
- Comparisons with various MC generators and tunes.
- Comparisons with quark/gluon initiated jets.
- The understanding of jet properties is very important to improve the simulation models and to develop better quark/gluon discriminators.

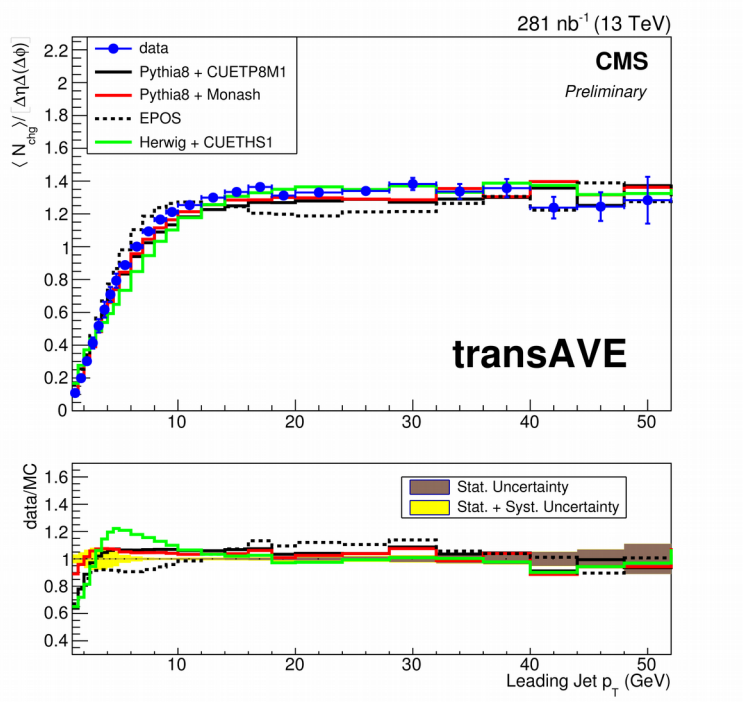


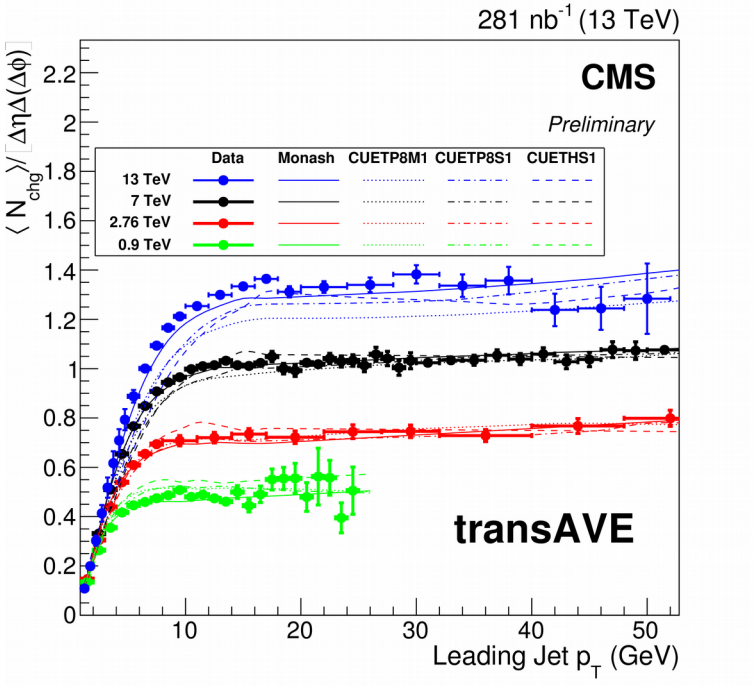


Eur. Phys. J. C76(6), 1-23 (2016)

Underlying Event Measurements

- Average number of charged particles in the transverse region divided by its area in η-φ space.
- The transverse regions are defined by the leading jet and they are sensitive to UE activity.
- Also the average sum of p_T in the region divided by its area in η-φ, space is reported in the analysis.
- Tracks with $p_T > 0.5$ GeV.
- Comparisons with various MC generators(left) and tunes/energies(right).

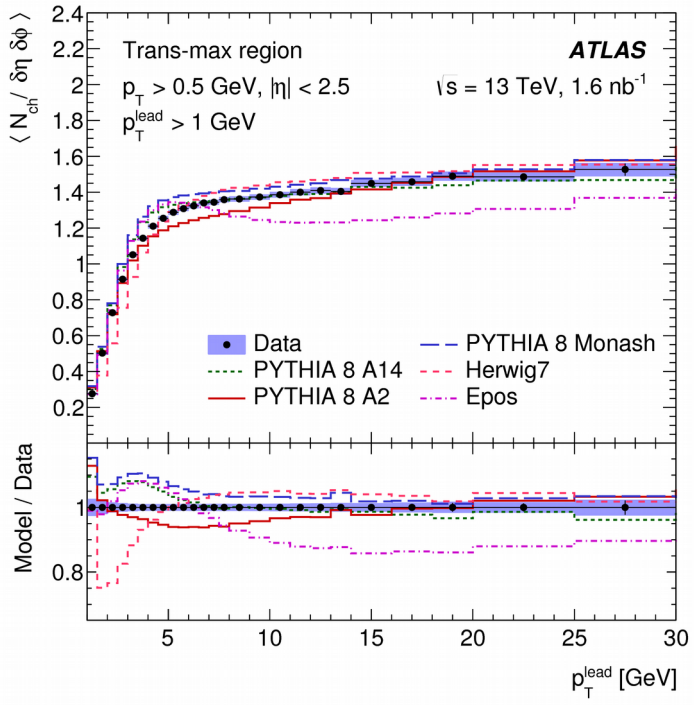


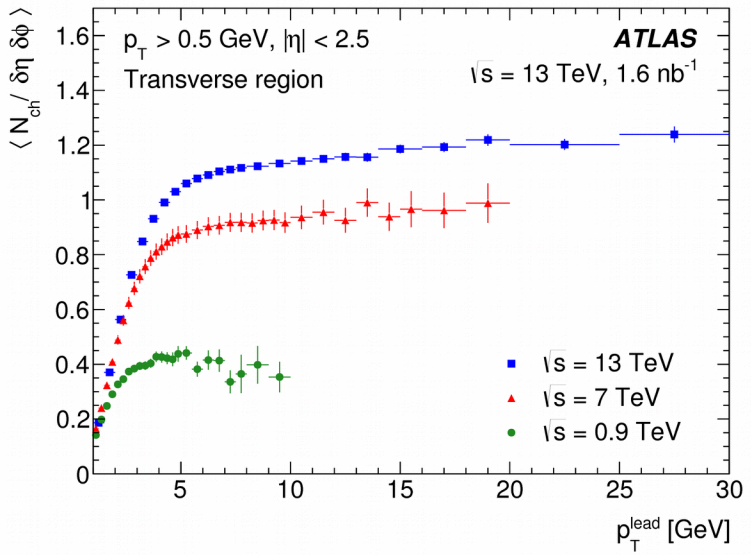


CMS-PAS-FSQ-15-007

Underlying Event Measurements

- Average number of charged particles in the transverse region divided by its area in η-φ space.
- Several observables presented in the same analysis vs $p_T/N_{ch}/\Delta\varphi$.
- Comparisons with various MC generators(left) and tunes/energies(right).
- Systematic mis-modeling. Consistent with CMS results.



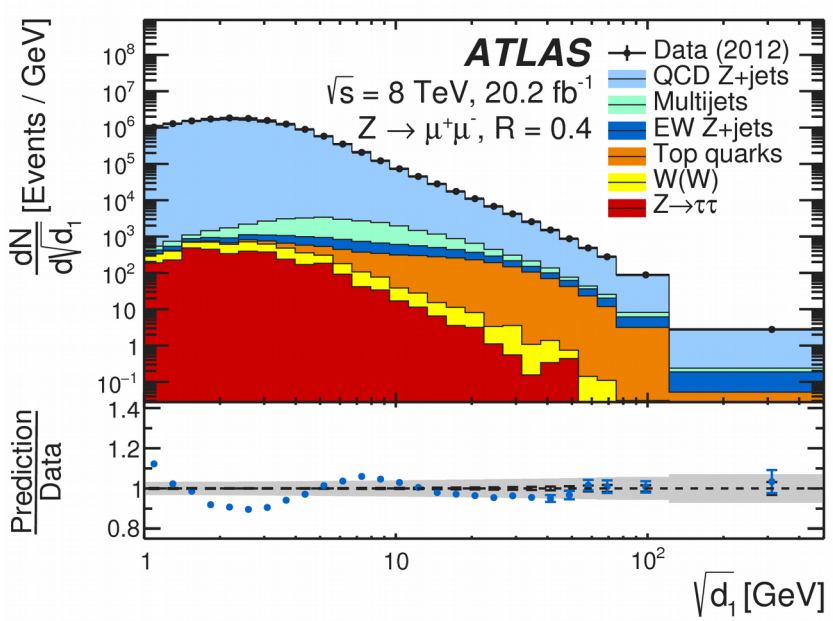


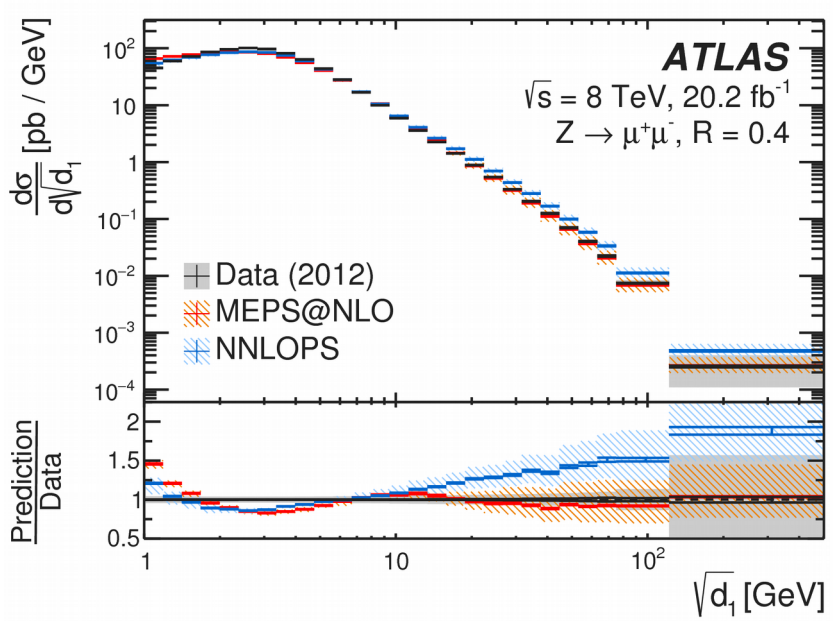
JHEP03(2017)157

k_t splitting scales in Z→ll events 8TeV

- Measurement of the splitting scales occurring in the k_t jet-clustering algorithm.
- Charged only particle-tracks distributions (reduced systematics) and charged+neutral.
- Measured independently Z→ee, Z→μμ and jet-radius R=0.4 and R=1.0.
- Left: Detector level splitting scale distributions.
- Right: Charged-only unfolded differential cross section.
- Deviations in both perturbative and non-perturbative region.

$$d_{ij} = min(p_{T,i}^2, p_{T,j}^2) \times \frac{\Delta R_{ij}^2}{R^2}$$
$$d_{ib} = p_{T,i}^2$$
$$d_k = \min_{i,j}(d_{ij}, d_{ib}) \quad k = 0..7$$

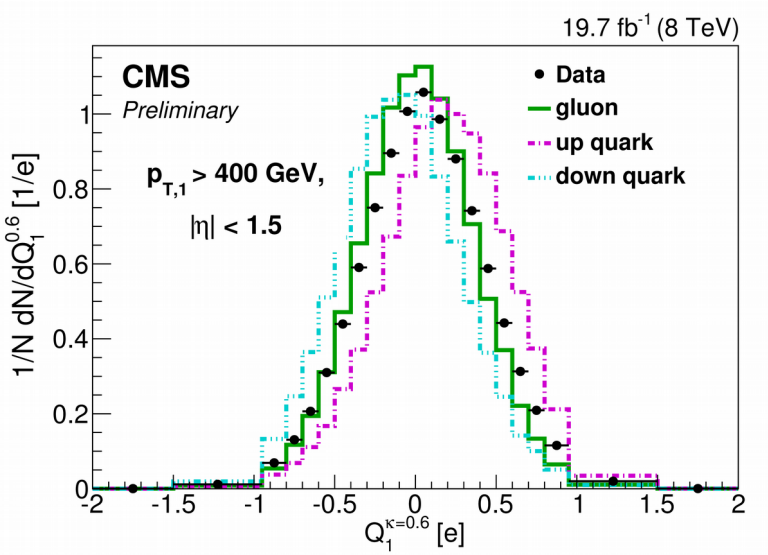


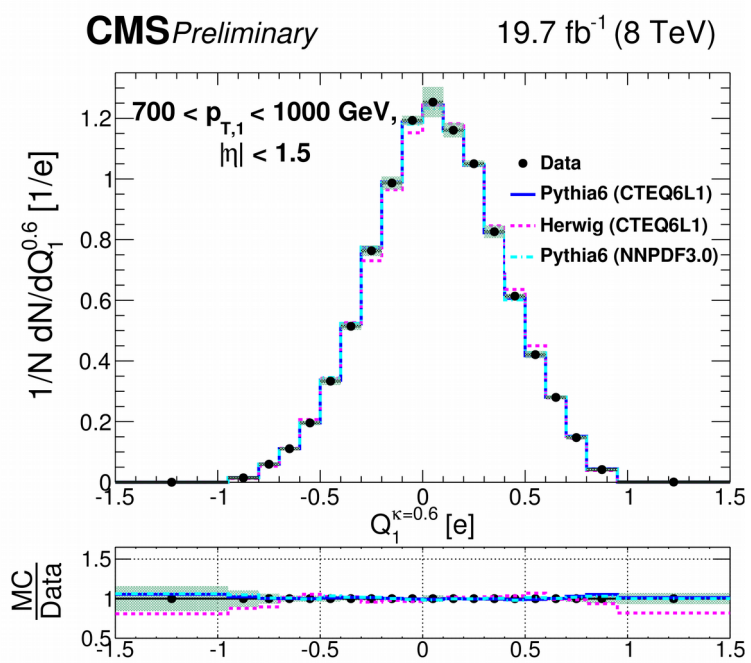


arXiv:1704.01530

Measurement of jet charge observables in dijet events at 8 TeV

- Measurement of charge observables using various definitions.
- Presented jet charge: $Q^{\kappa}=\frac{1}{(p_T)^{\kappa}}\sum_i Q_i (p_T^i)^{\kappa}$
- Estimator of the parton's charge that initiated the jet.
- Comparison of measured charge with LO MC generators.
- Right: unfolded spectrum for one p_T bin.
- Left: detector level distribution. Mean values of g/u/d peak in 0/+/- as expected.

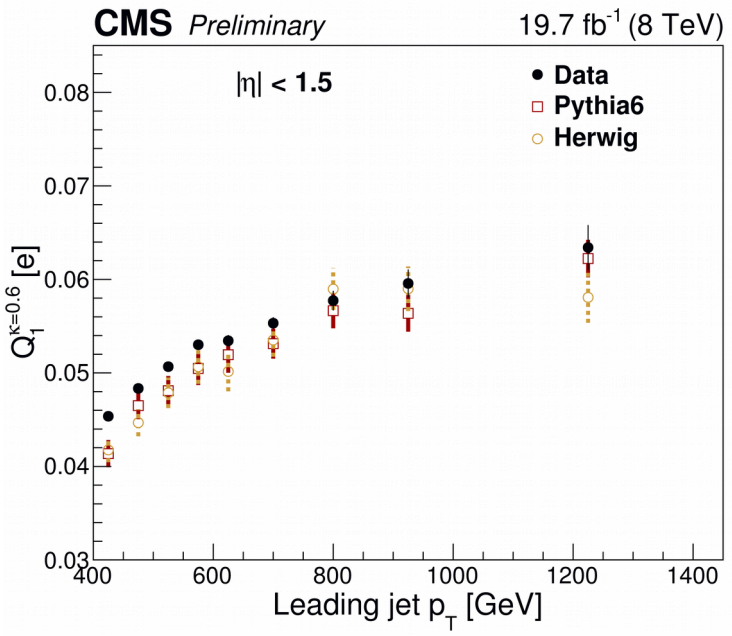


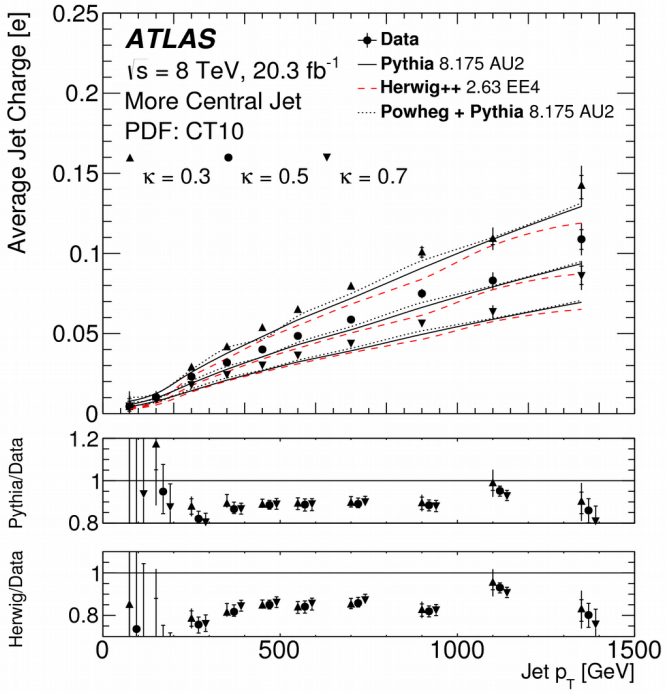


CMS-PAS-SMP-15-003

Measurement of jet charge observables in dijet events at 8 TeV

- Measurement of charge observables using various definitions.
- Both collaborations performed a similar measurement.
- Jet charge as a function of the leading jet p_T
  - Left: CMS, κ=0.6
  - Right: ATLAS, κ=0.3, 0.5, 0.7.
- ATLAS measures separately more central/forwards jet.

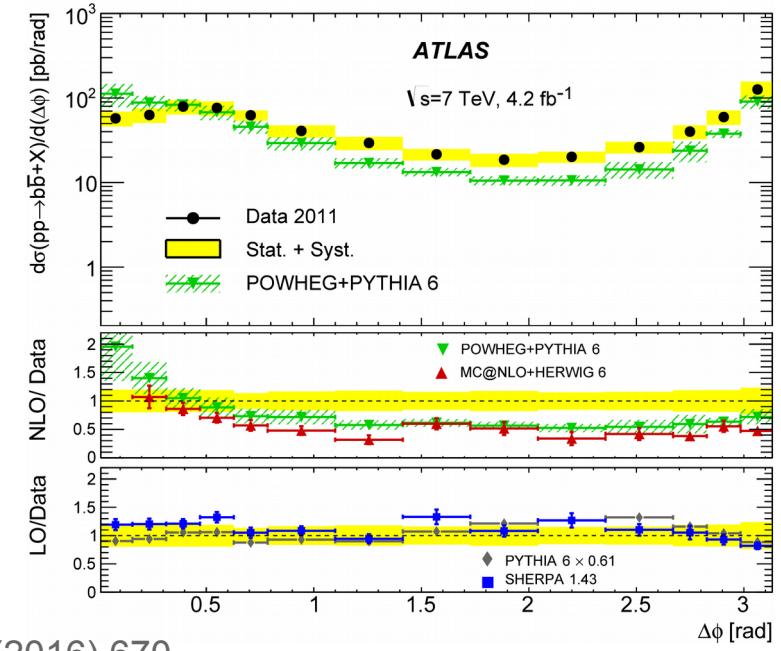


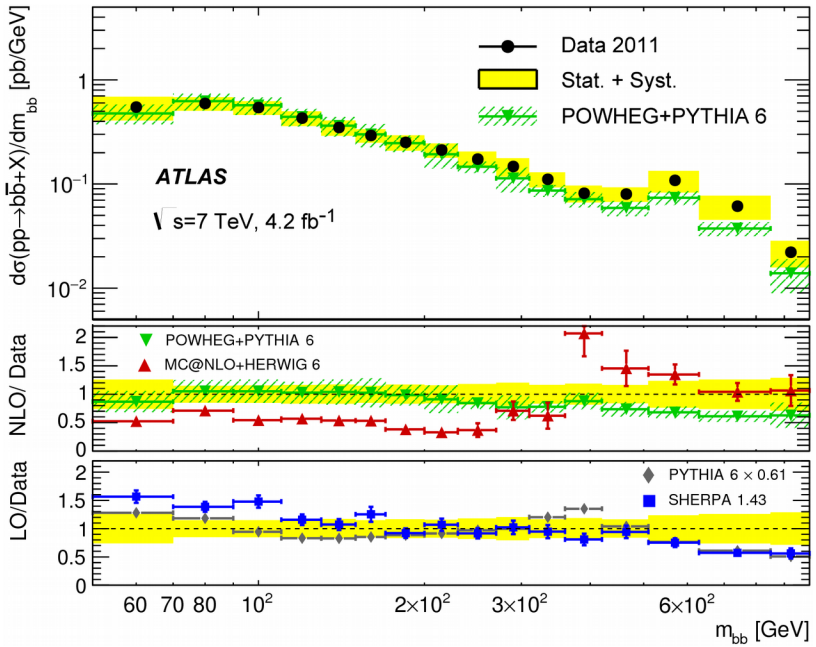


CMS-PAS-SMP-15-003
Phys. Rev. D 93, 052003 (2016)

Measurement of the bb~ dijet cross section at 7 TeV

- Measurement of the bb(bar) dijet cross section at 7 TeV.
- Dijet system: p_T>20 GeV, |η|<2.5, ΔR=0.4.
- Several variables presented in the paper: m_{bb}(right), $p_{T,bb}$, Δφ (left), ΔR, y_B, y^*.
- Comparisons with LO and NLO generators. POWHEG gives the best agreement for most of the variables.



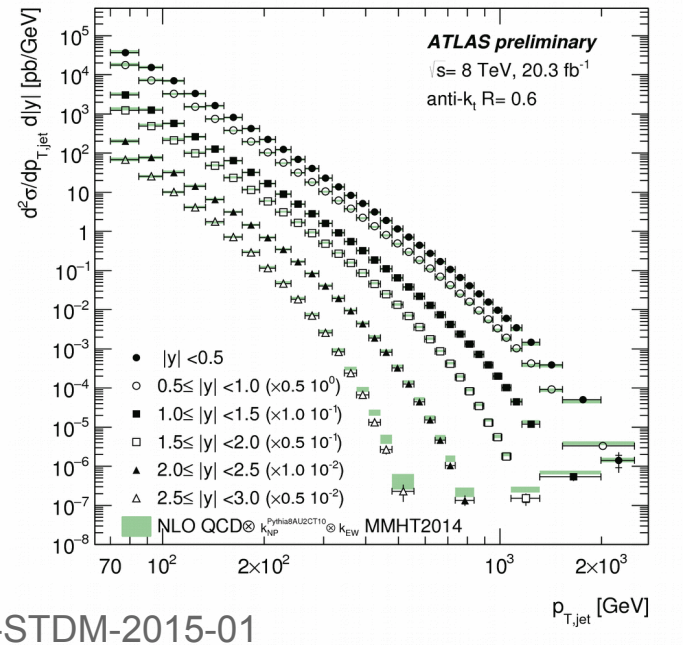


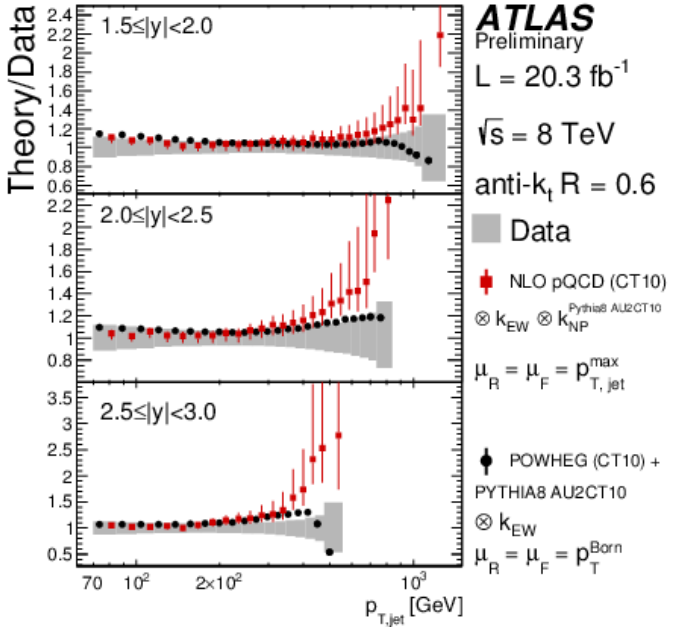
Eur. Phys. J. C 76 (2016) 670

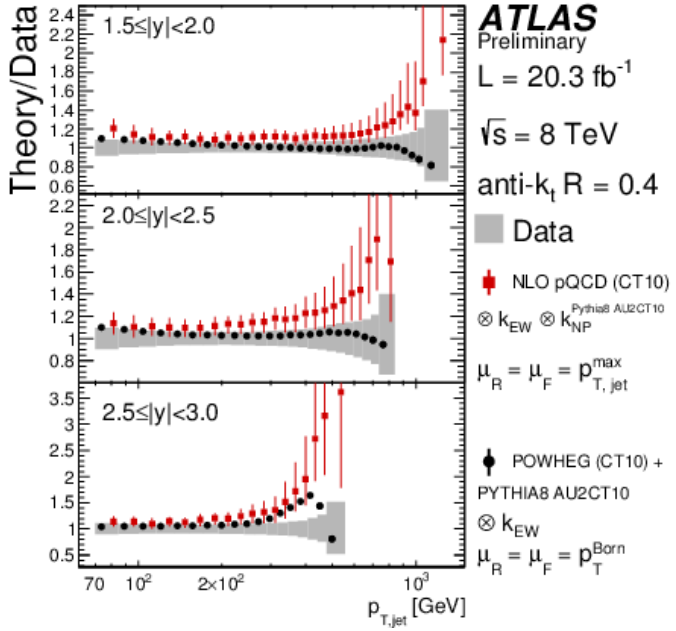
Inclusive jet differential cross sections 8TeV

- Measurement of inclusive jet cross section in six rapidity regions.
- 70 GeV < p_T < 2.5 TeV, six rapidity bins |y|<3.0.
- pQCD calculations (NLOJet++), corrected for NP and EWK effects.
- Measured jets in the region 70 GeV – 2.5 TeV and |y|<3.0.
- PS importance is observed by comparing different cone sizes of anti-k_T algo.
- Overall good agreement.

8 TeV
20.3 fb^{-1}
Anti-k_t R=0.4
Anti-k_t R=0.6





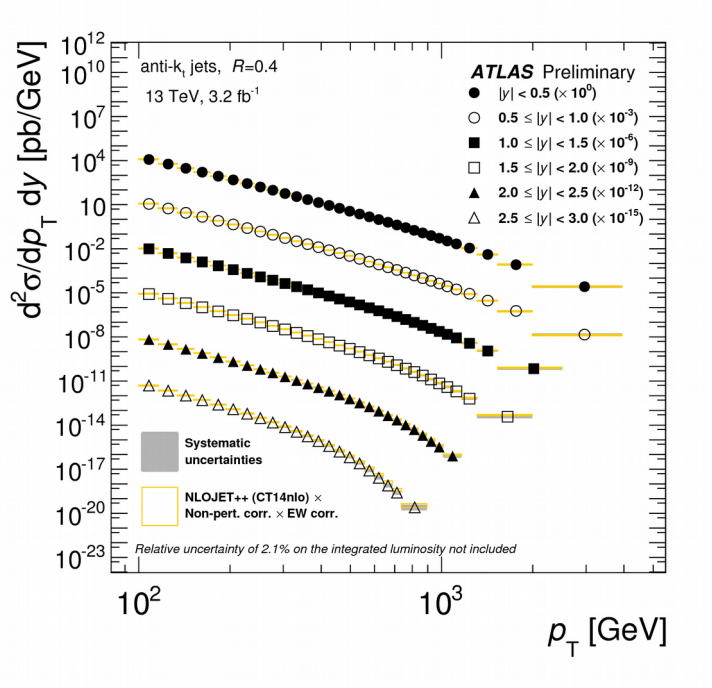


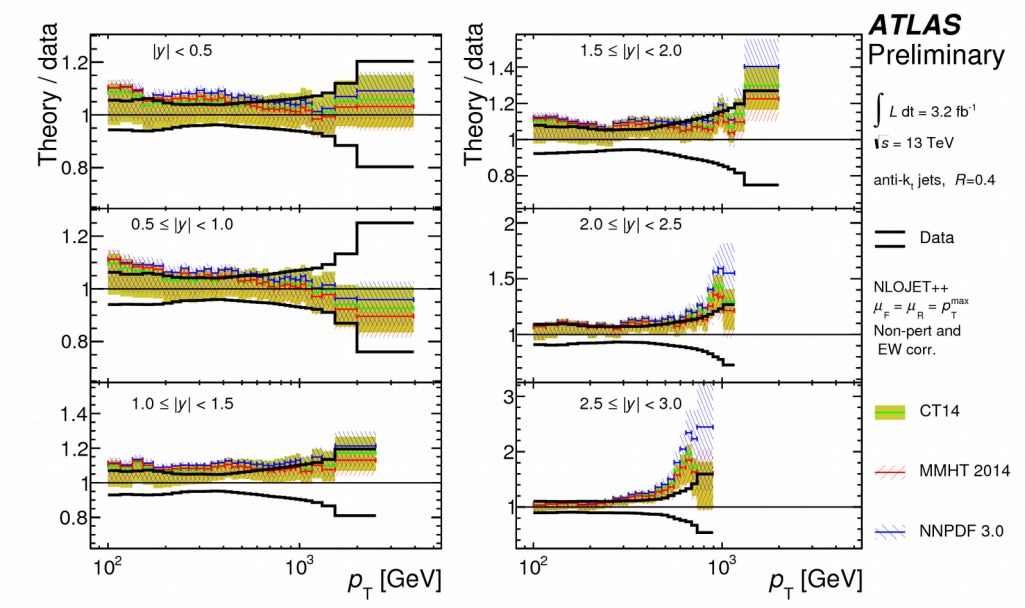
ATLAS-STDM-2015-01

Inclusive jet differential cross sections 13TeV

- Measurement of inclusive jet cross section in six rapidity regions.
- Comparisons with NLOJet++ using CT14, MMHT, NNPDF3.0.
- Corrected for NP and EWK effects.
- Measured jets in the region 100 GeV – 3.2 TeV and |y|<3.0.
- Good overall agreement with predictions.

13 TeV
3.2 fb^{-1}
Anti-k_t R=0.4



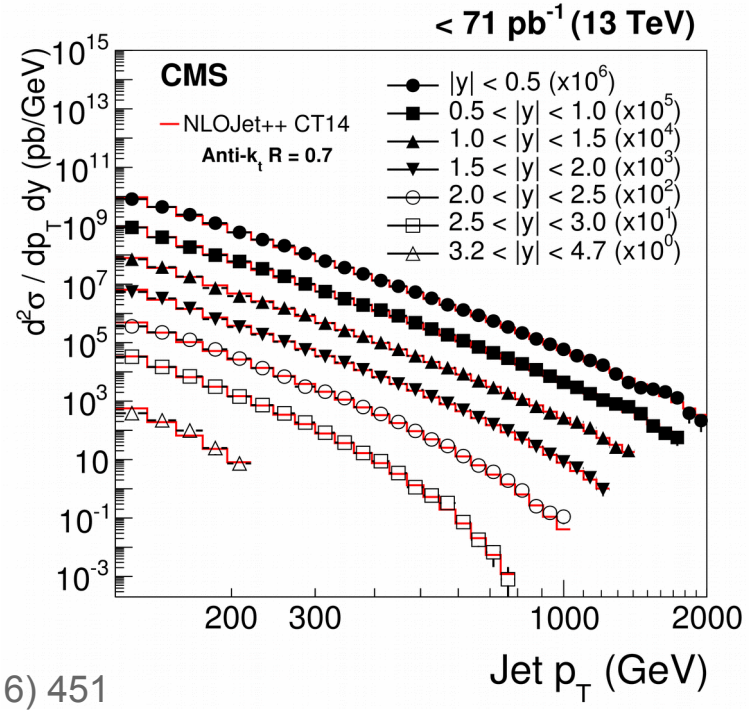


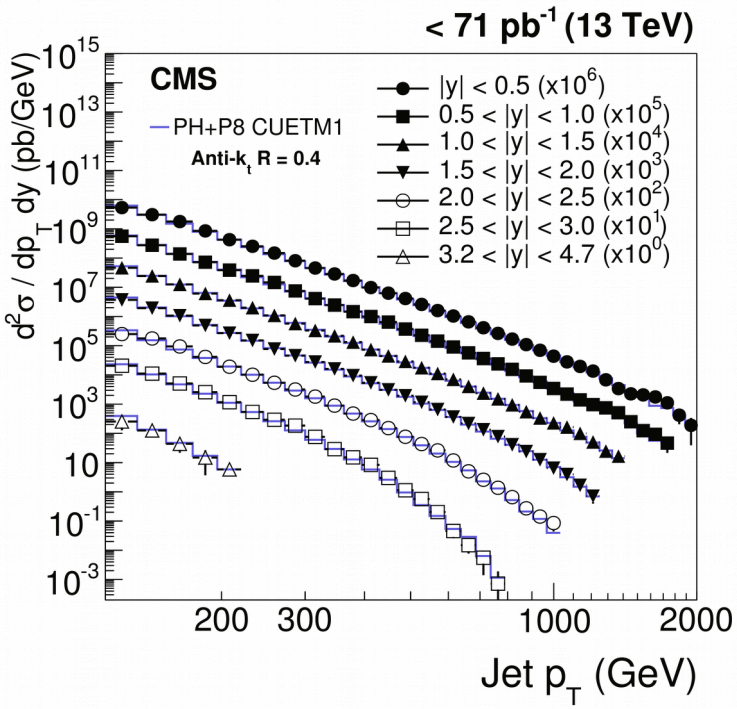
ATLAS-CONF-2016-092

Inclusive jet differential cross sections 13TeV

- Measurement of inclusive jet cross section in seven rapidity regions.
- Comparisons with NLOJet++ and POWHEG+Pythia8. Corrected for NP and EWK effects.
- Two measurements using anti-k_t R=0.4 and R=0.7.
- Measured jets in the region up to 2 TeV and |y|<4.7.
- POWHEG+Pythia8 gives a good agreement in both values of R (0.4 and 0.7).

13 TeV
71 pb^{-1}
Anti-k_t R=0.4
Anti-k_t R=0.7

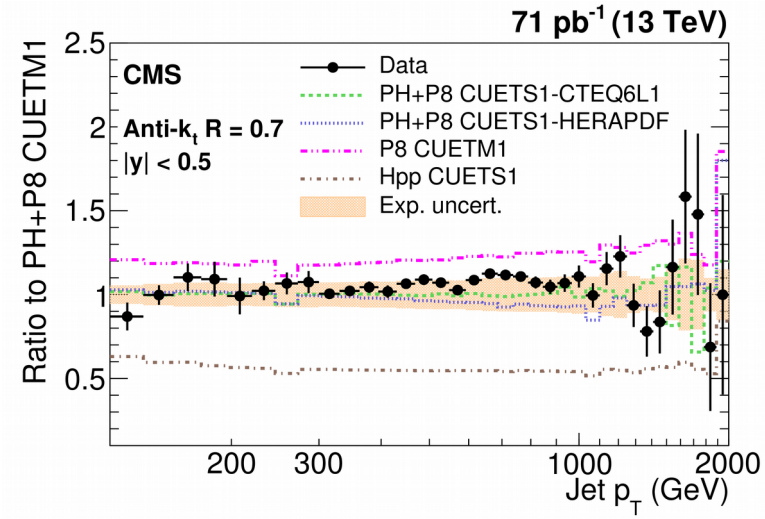


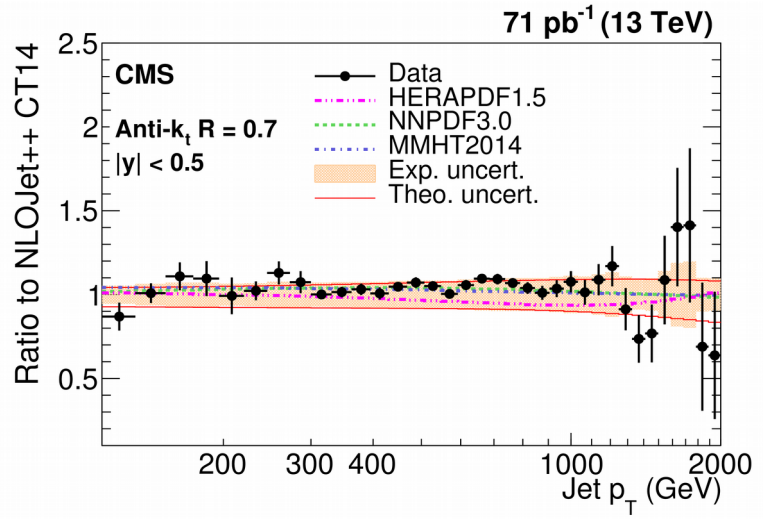


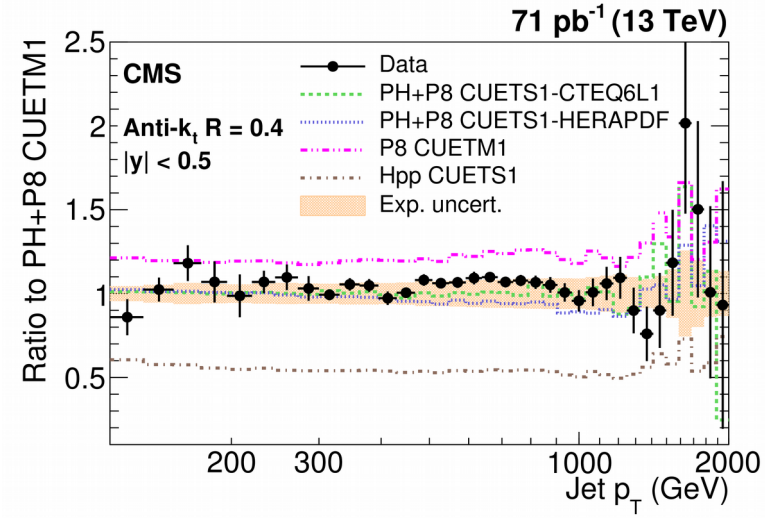
Eur. Phys. J. C 76 (2016) 451

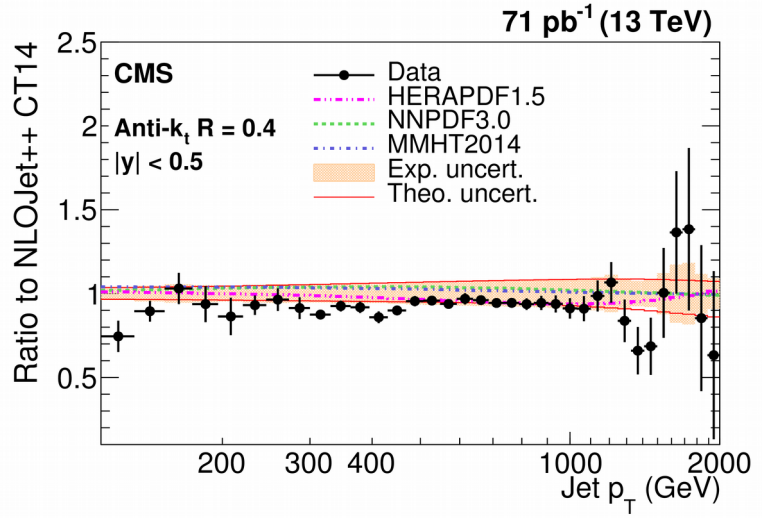
Inclusive jet differential cross sections 13TeV

- Left: MC with PS. Right: fixed order QCD.
- Top: Anti-kt R=0.7. Bottom: Anti-kt R=0.4.
- Both POWHEG+Pythia8 and NLOJet++ describe very well the data when the jet are clustered using Anti-kt R=0.7.
- POWHEG+Pythia8 describes better the data with Anti-kt R=0.4 since it simulates parton showers.





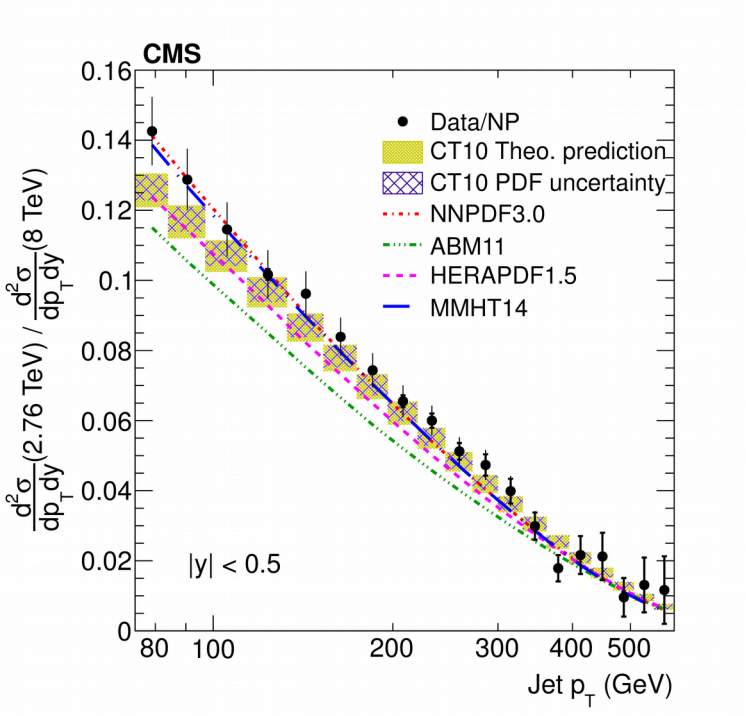


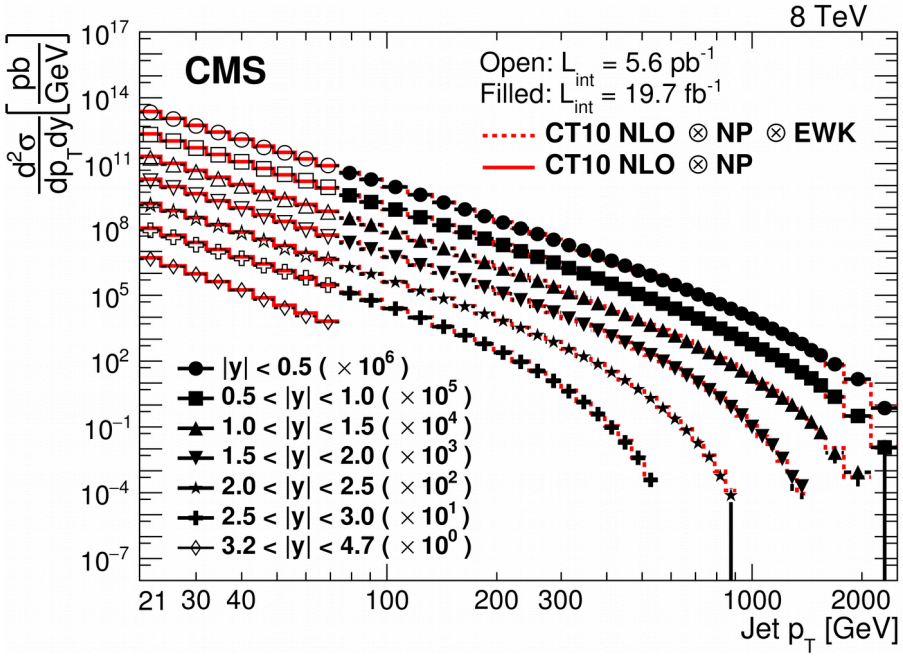


Eur. Phys. J. C 76 (2016) 451

Measurement and QCD analysis of double-differential inclusive jet cross sections

- Measurement of double differential cross section on p_T and y as a function of p_T.
- Comparison with theoretical calculations using CT10NLO.
- Theoretical calculations corrected for non perturbative (NP) and electroweak (EWK) effects.
- Measured jets in the region up to p_T~2.5 TeV and |y|<4.7.
- Ratios between different energies.





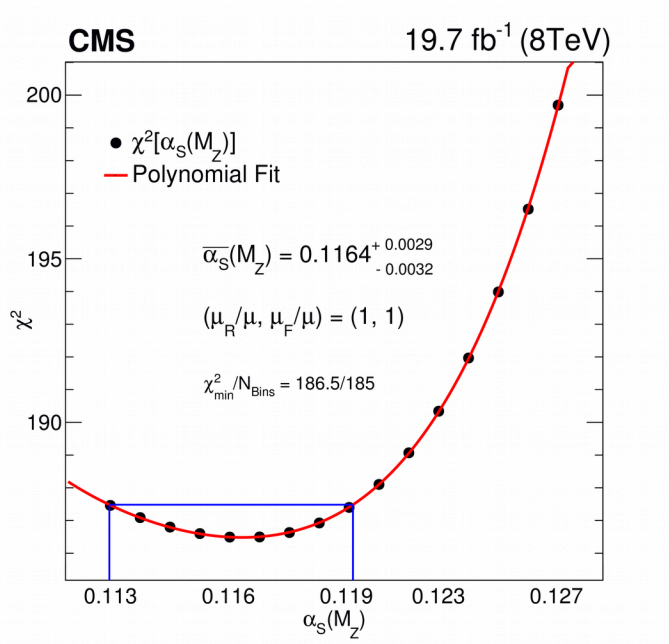
JHEP 03 (2017) 156

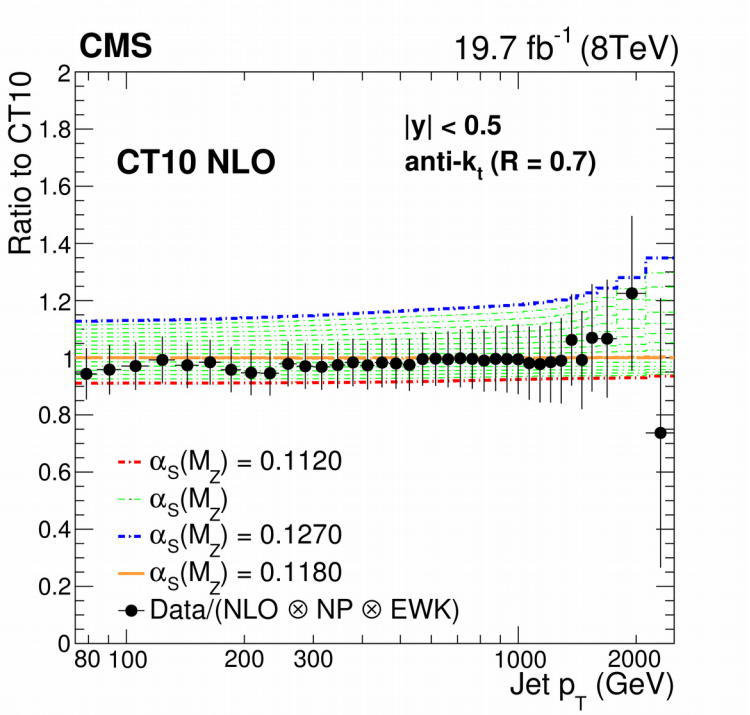
Measurement and QCD analysis of double-differential inclusive jet cross sections

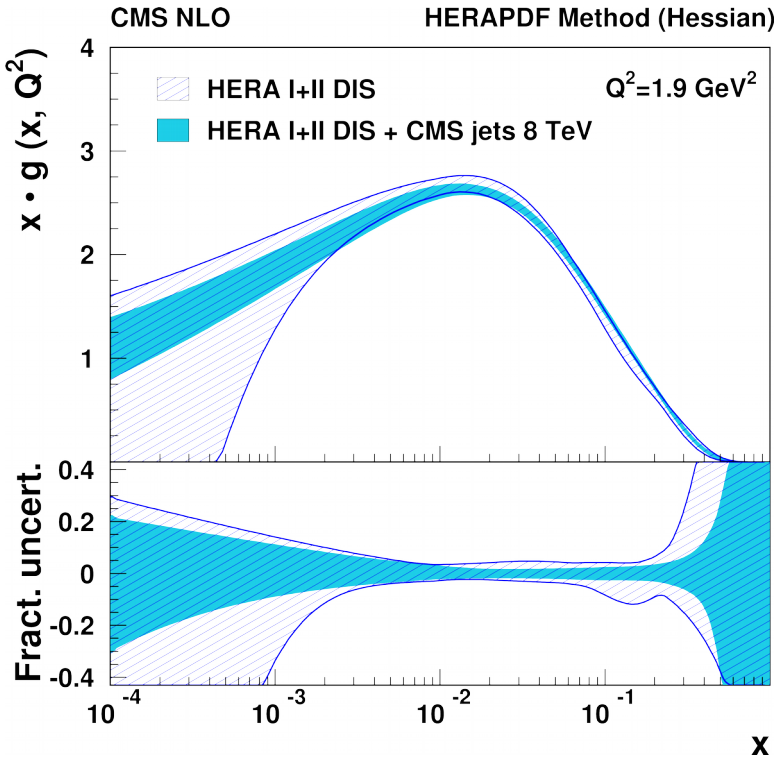
- Measurement of double differential cross section on p_T and y as a function of p_T.
- Strong coupling measurement:

$$\alpha_s = 0.1164^{+0.0014}_{-0.0015}(\exp)^{+0.0025}_{-0.0029}(PDF)\pm 0.0001(NP)^{+0.0053}_{-0.0028}(scale)$$

- PDF constraints using HERAFitter



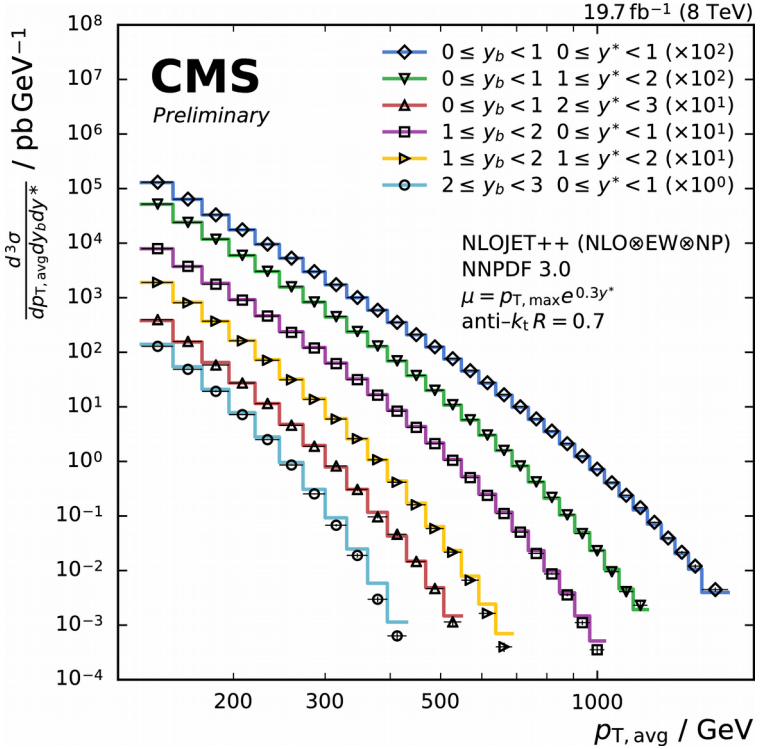


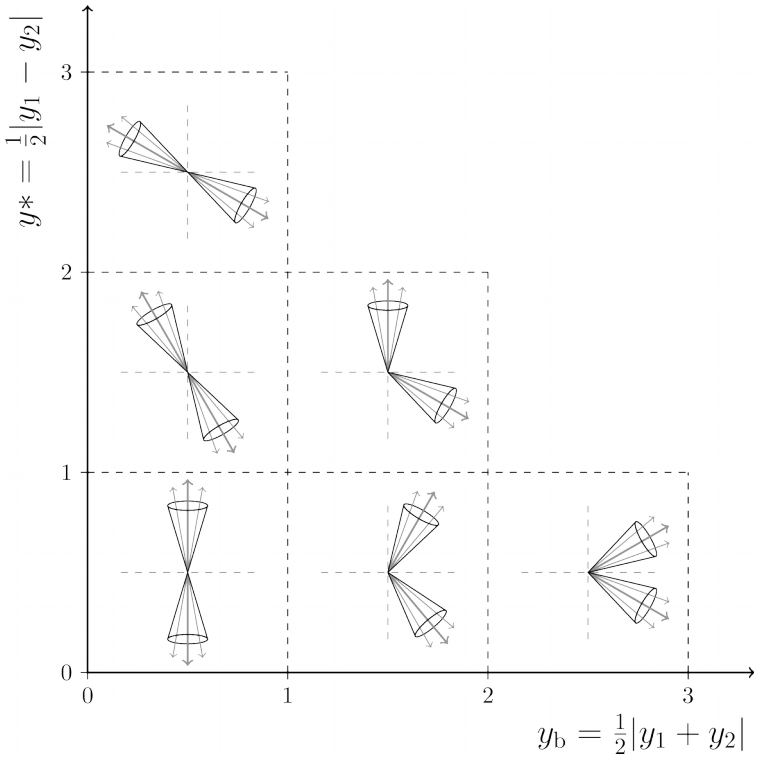


JHEP 03 (2017) 156

Triple-Differential Dijet Cross Sections at 8 TeV and Constraints on PDFs

- Measurement of triple differential dijet cross sections at 8 TeV.
- Triple differential on $p_{T,}$ $y^* = 0.5|y_1-y_2|$ and $y_b=0.5|y_1-y_2|$ as a function of the average p_T of the two leading jets.
- Measured in six bins of y_b and y^*.
- NP and EWK corrections applied.



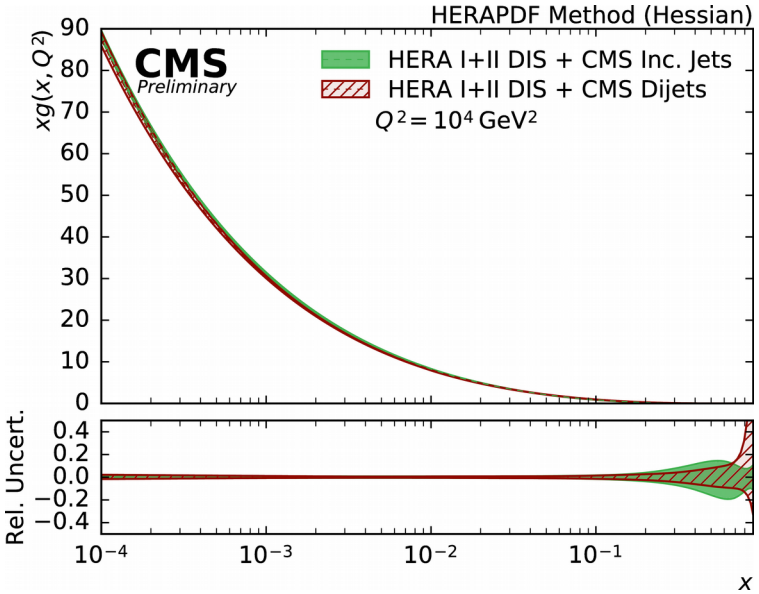


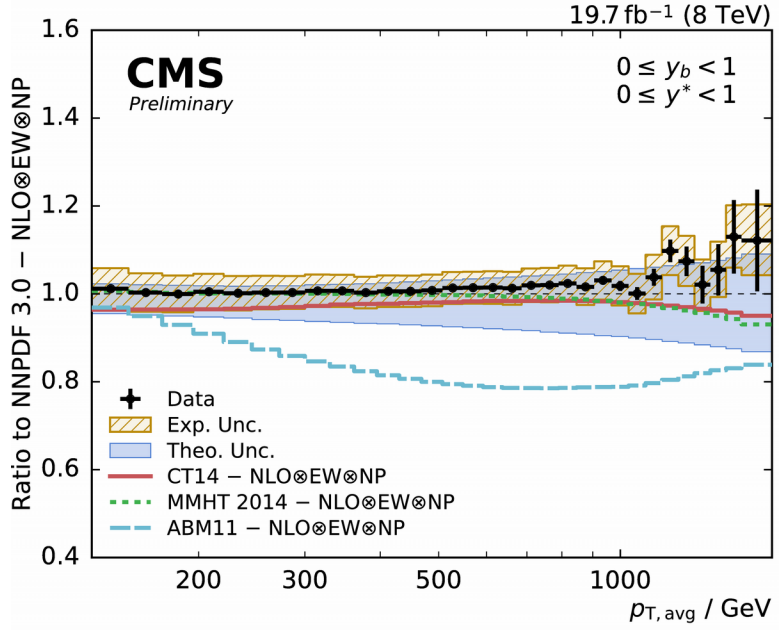
CMS-PAS-SMP-16-011

Triple-Differential Dijet Cross Sections at 8 TeV and Constraints on PDFs

- Measurement of triple differential dijet cross sections.
- Right: comparisons with NLO calculations using various PDF sets.
- Left: Gluon PDF using xFitter (HERAFitter).
- PDF fitting repeated with strong coupling treated a free parameter.

$$\alpha_s = 0.1199 \pm 0.0015(\exp) \pm 0.0002(mod)^{+0.0002}_{-0.0004}(par)^{+0.0031}_{-0.0019}(scale)$$

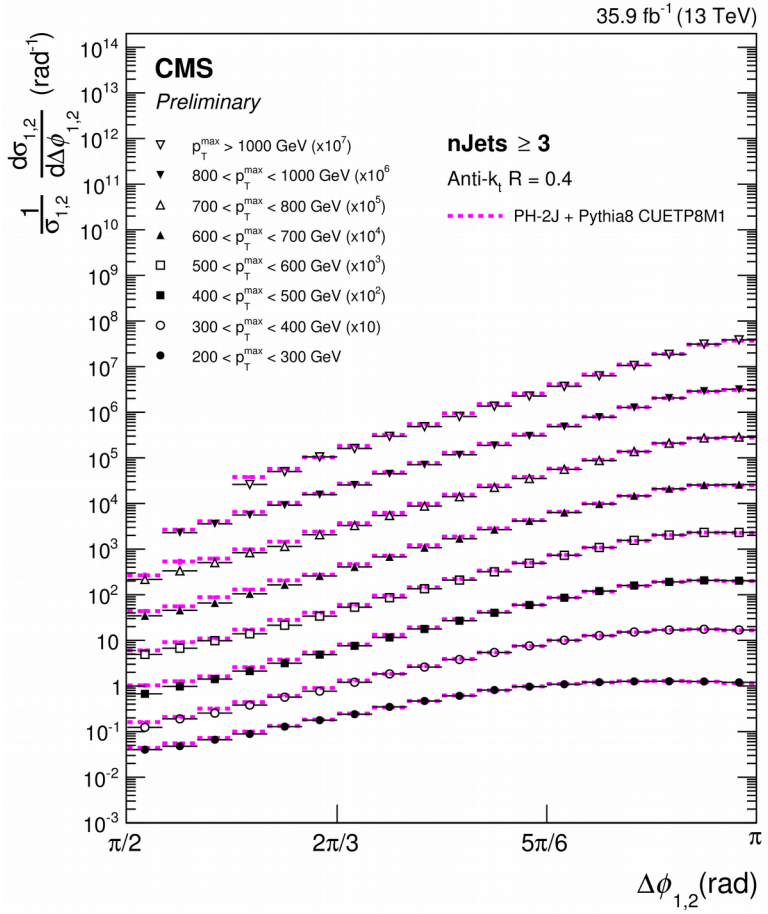


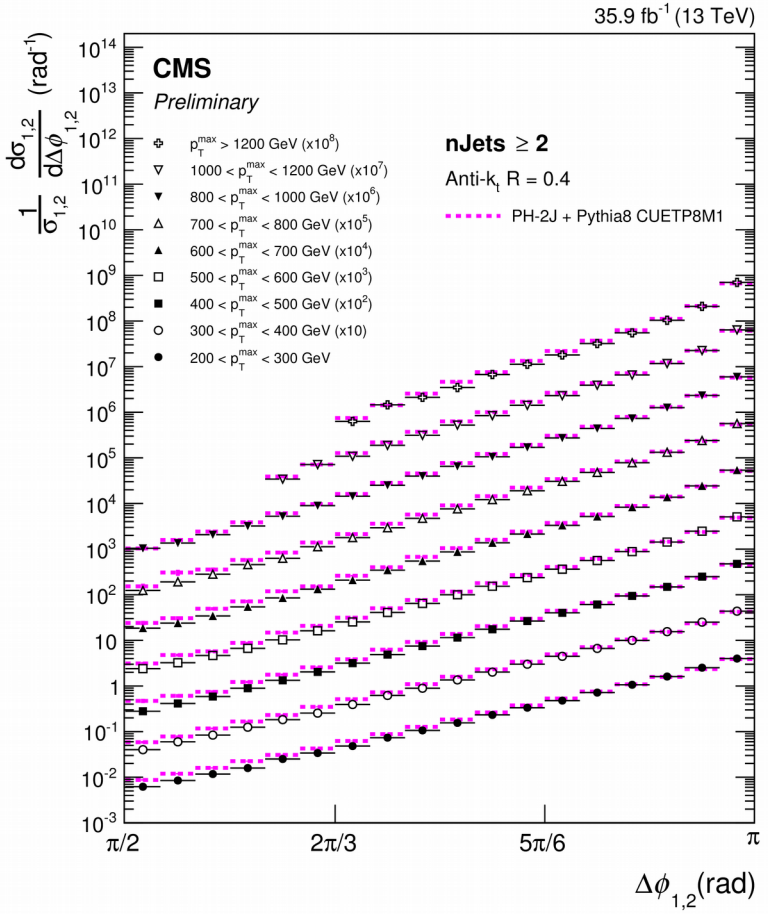


CMS-PAS-SMP-16-011

Measurements of inclusive 2-jet, 3-jet and 4-jet azimuthal correlations

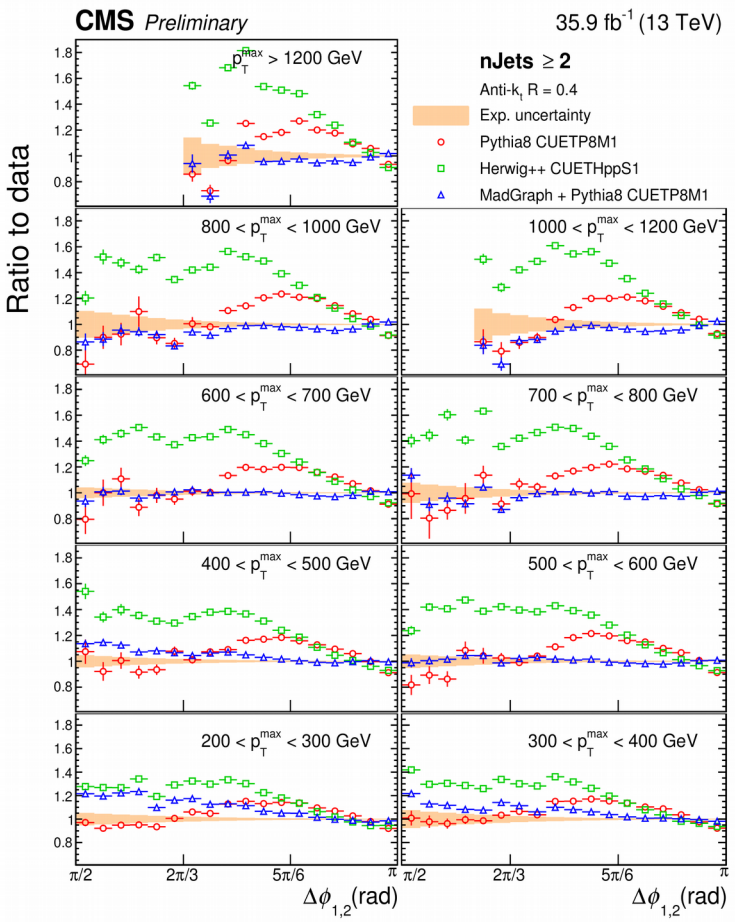
- Measurements of the correlation of azimuthal angles between the two leading jets.
- Inclusive 2-(right plot), 3-(left plot), 4-jet topologies.
- Measured in bins of p_T^{max}.
- Compared to POWHEG + Pythia8.

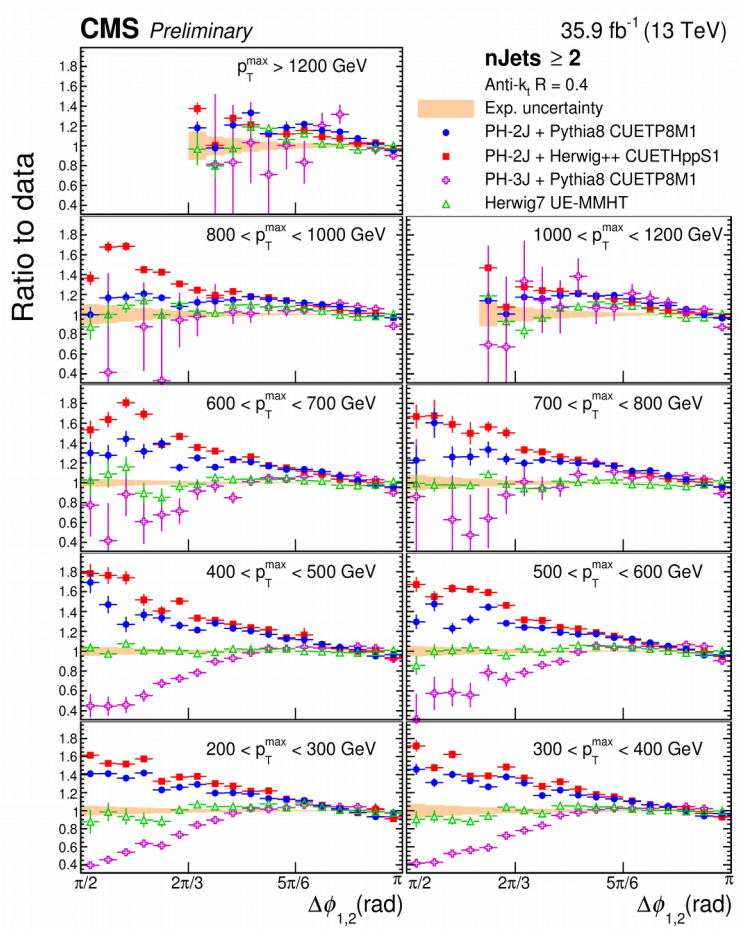




Measurements of inclusive 2-jet, 3-jet and 4-jet azimuthal correlations

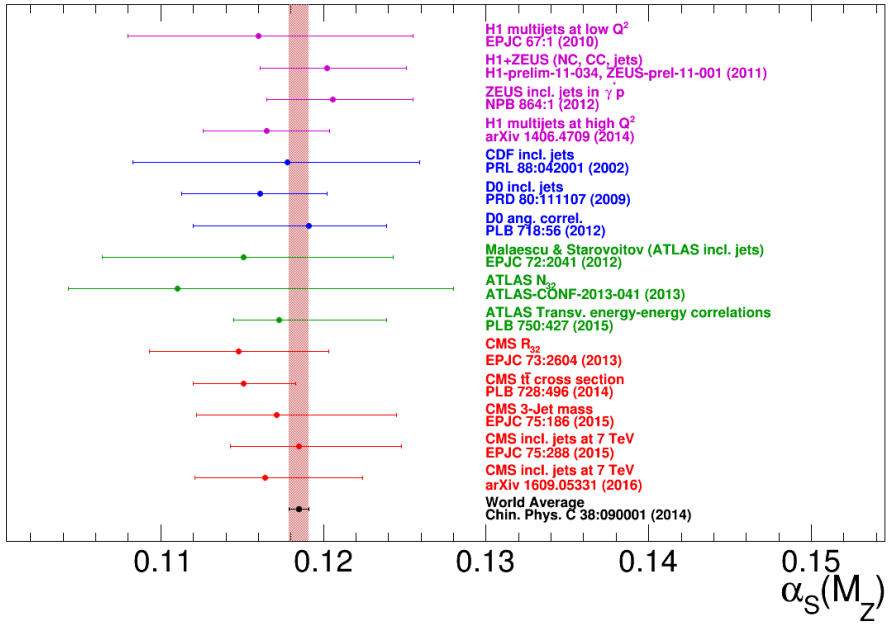
- Measurements of the correlation of azimuthal angles between the two leading jets.
- Inclusive 2-(right/left plot), 3-, 4-jet topologies.
- Measured in bins of p_T^{max}.
- Compared to POWHEG + Pythia8, Herwig, Madgraph + Pythia8.
- Probes multijet events by measuring the azimuthal separation of the two leading jets.
- Comparisons with 2→2, multileg generators, and different PS models.





Summary

- Excellent job by both experiments in data taking and by LHC in data delivering.
- Both ATLAS and CMS published several SM measurements.
- The results are publicly available in HepData for further interpretation.
- Measurements of cross sections and the strong coupling indicate that QCD is valid in the new phase space.
- Even bigger datasets are coming.
  - More SM measurements to come.
  - Possibility to perform for more complex measurements.

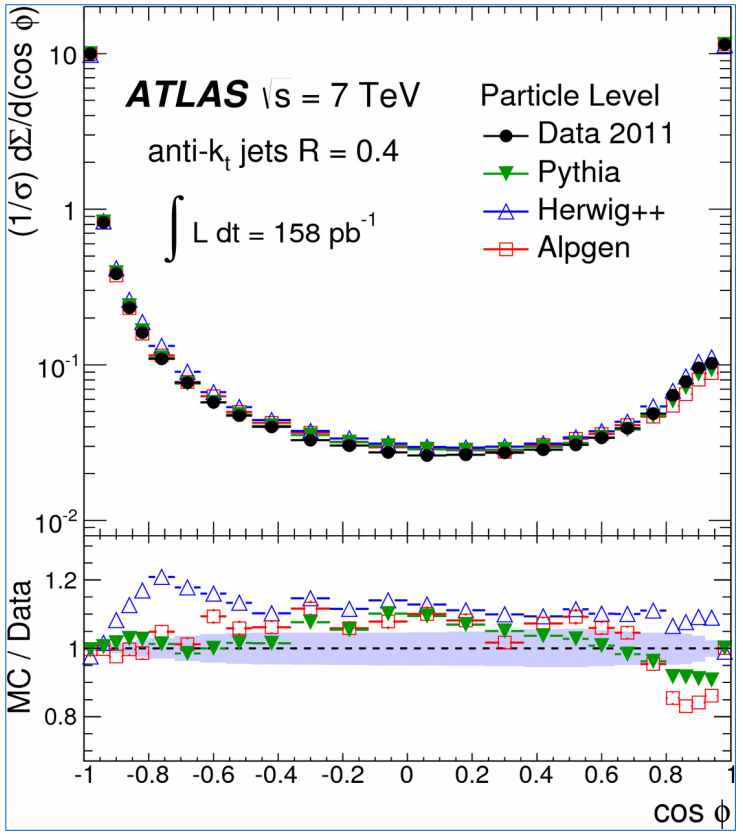


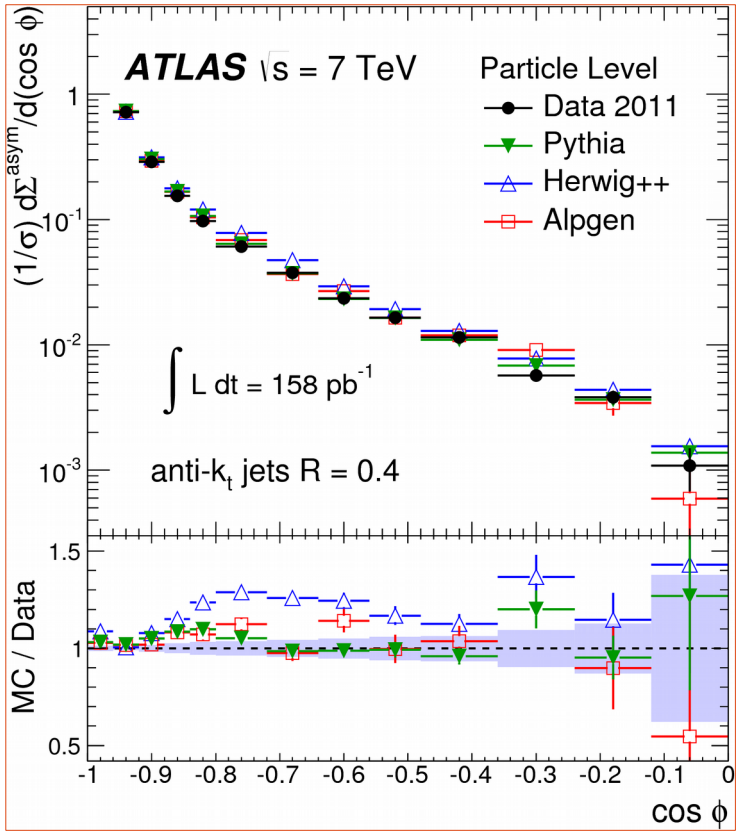
- For published and preliminary results:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults
  - http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/index.html
  - http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SMP/index.html

SPARE SLIDES

Measurement of transverse energy–energy correlations and determination of the strong coupling

- Transverse energy-energy correlation(TEEC)[left] and its asymmetry(AEEC)[right].
- p_T>50GeV, |η|<2.5, anti k_t - R=0.4
- Comparisons with various MC generators.
- Unfolded distributions fitted to NLO calculations.
- NLO calculations using NLOJet++, $\mu_{r,f}=<p_{T1,2}>$





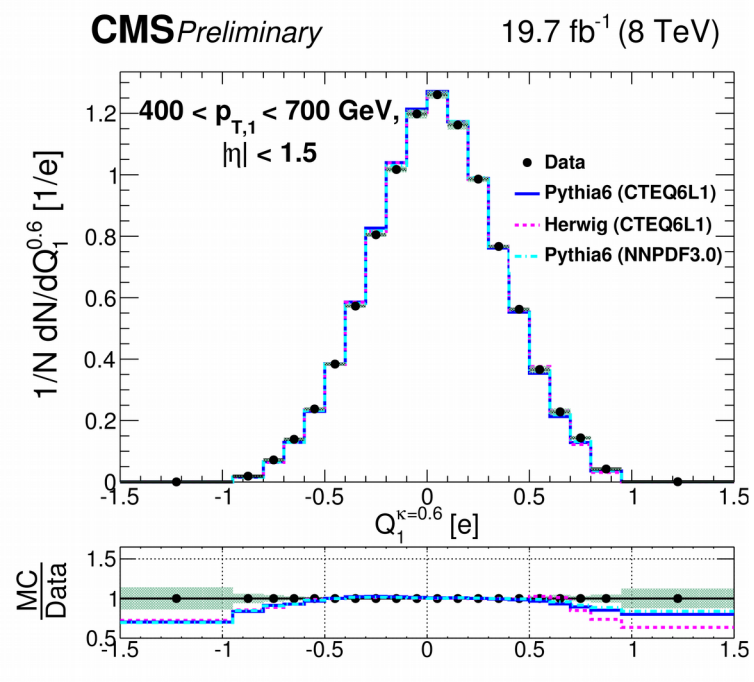
- Results using CT10:

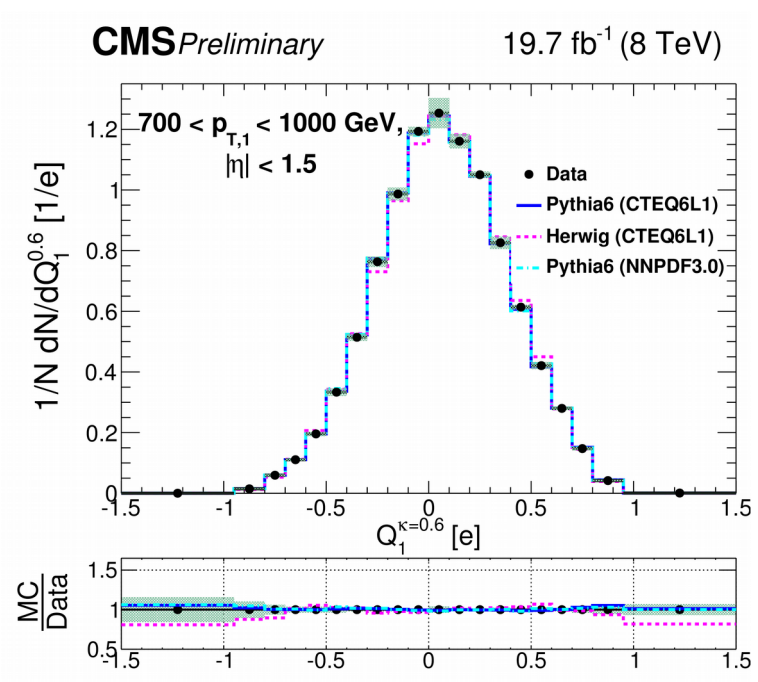
$$\alpha_s = 0.1173 \pm 0.0010\,(\exp) \pm 0.0017\,(PDF) \pm 0.0002\,(NP)^{+0.0063}_{-0.0020}\,(scale)$$

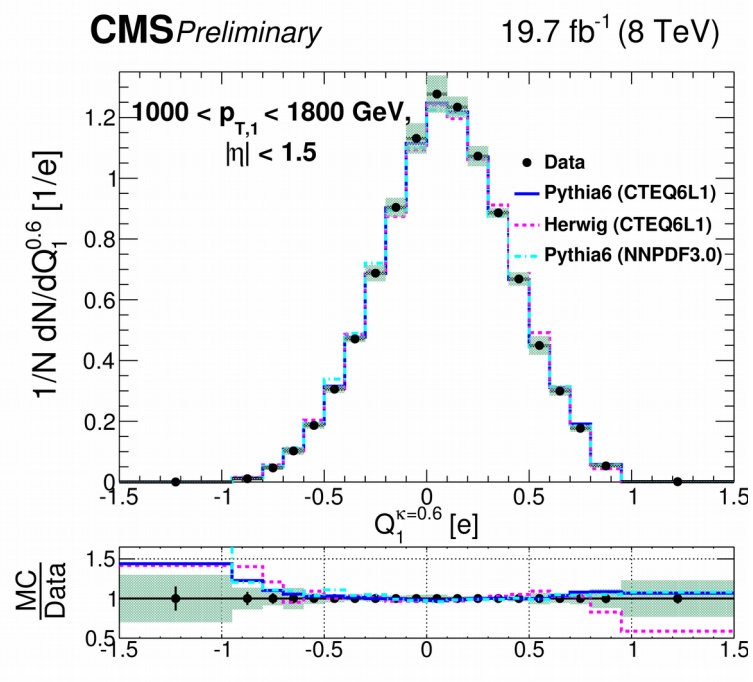
$$\alpha_s = 0.1195 \pm 0.0018\,(\exp) \pm 0.0016\,(PDF)^{+0.0060}_{-0.0015}\,(scale)$$

Physics Letters B 750 (2015) 427-447

Measurement of jet charge observables in dijet events at 8 TeV

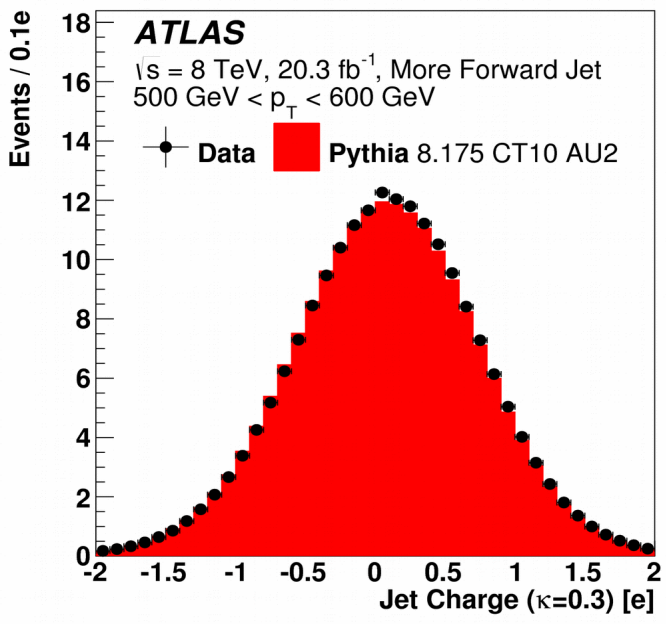


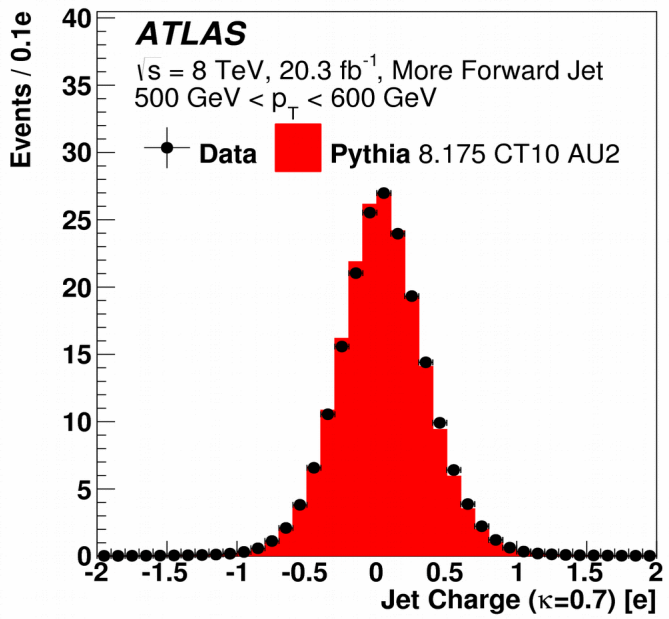


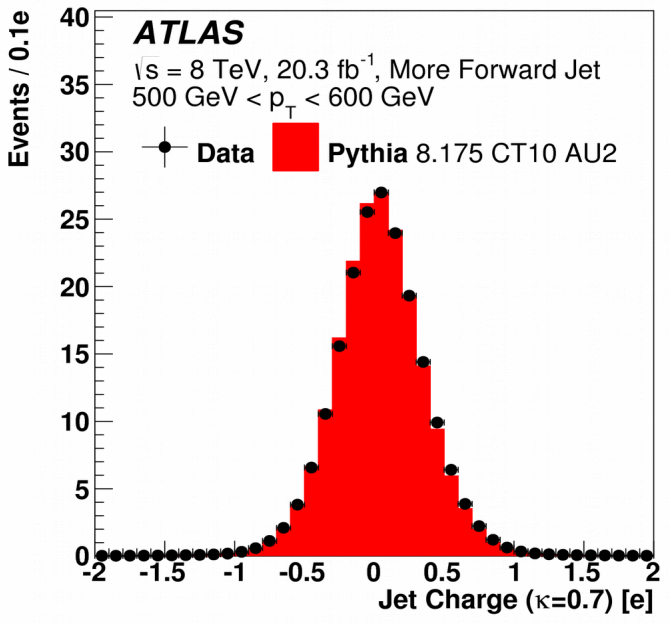


CMS-PAS-SMP-15-003

Measurement of jet charge observables in dijet events at 8 TeV



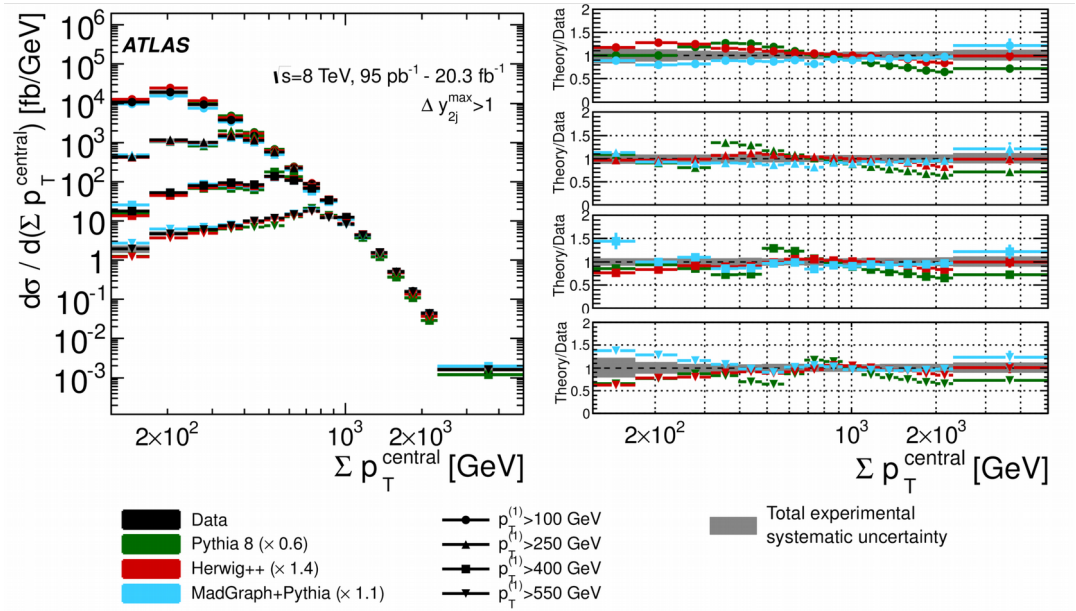


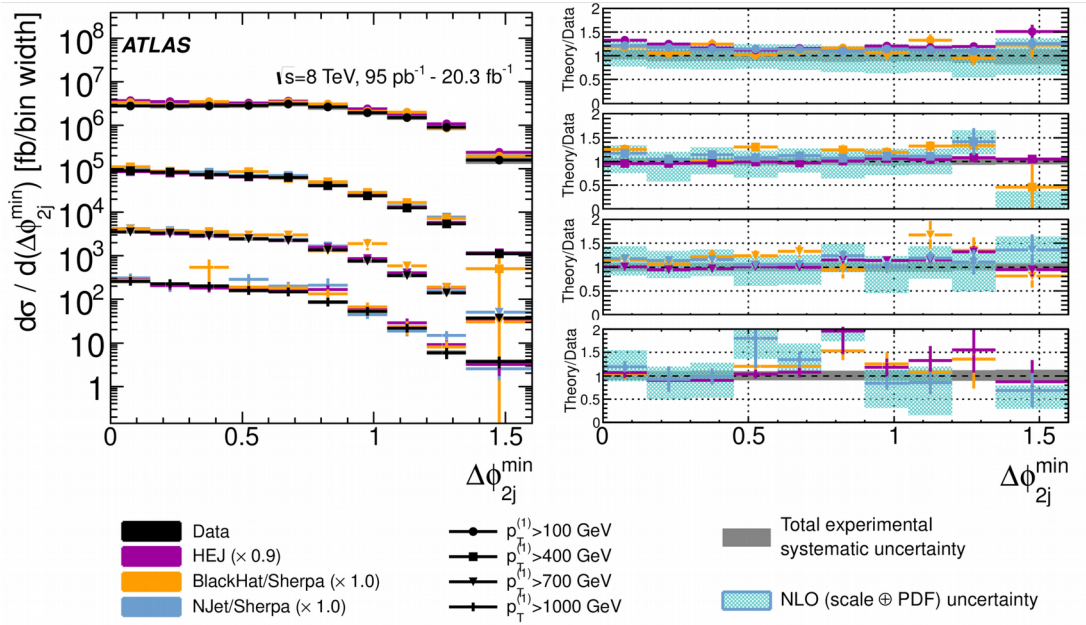


CMS-PAS-SMP-15-003
Phys. Rev. D 93, 052003 (2016)

Measurement of four-jet differential cross sections in 8 TeV

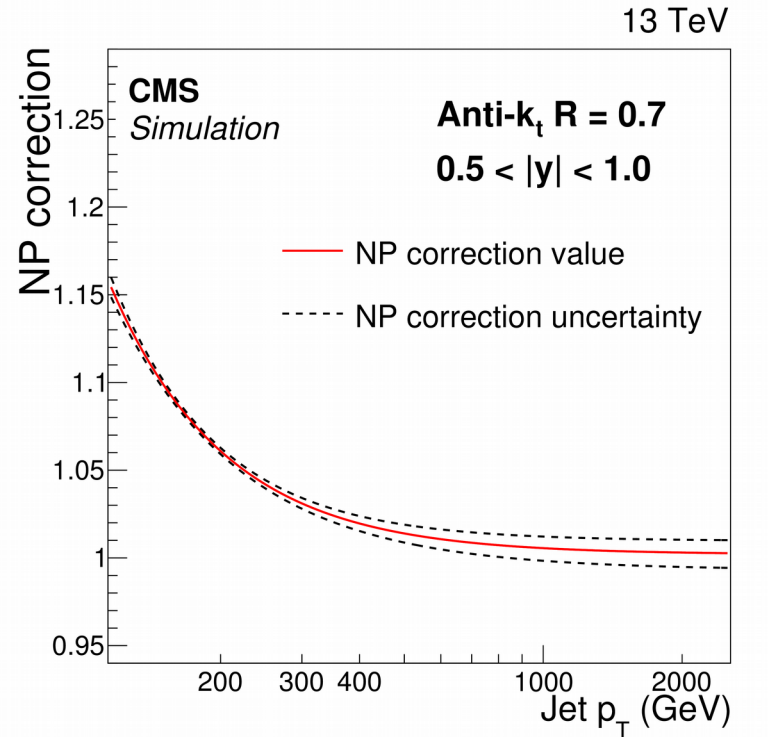
- Differential cross sections for the production of at least four jets.
- p_T>64 GeV, |y|<2.8, ΔR_{4j}^{min}>0.65, anti k_t – R=0.4.
- **Ten** kinematic variables presented in the paper.
- Comparisons with LO and NLO generators.
- Scale factors applied to LO generators: 0.6-1.4.
- BlackHat/SHERPA and Njet/SHERPA give the best description.

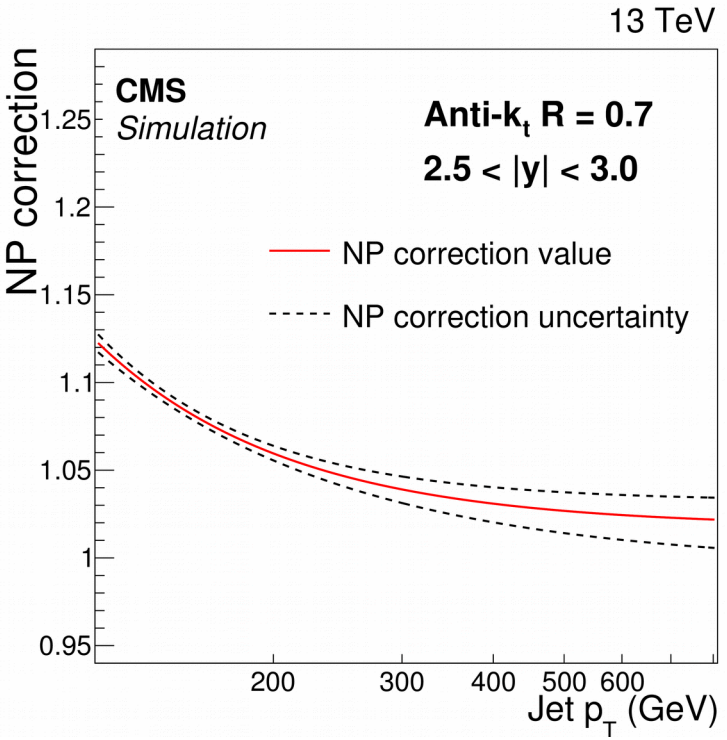


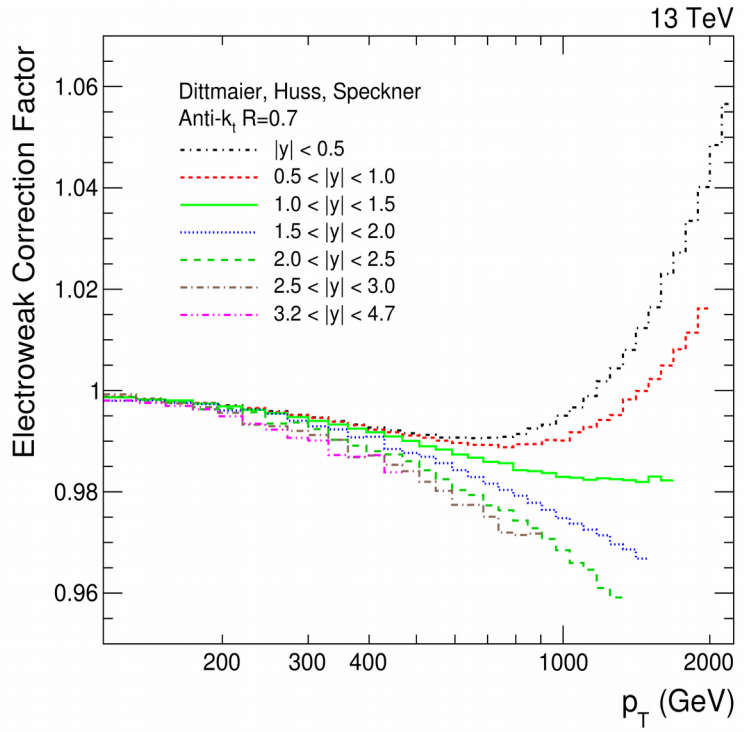


JHEP 12 (2015) 105

Inclusive jet differential cross sections 13TeV

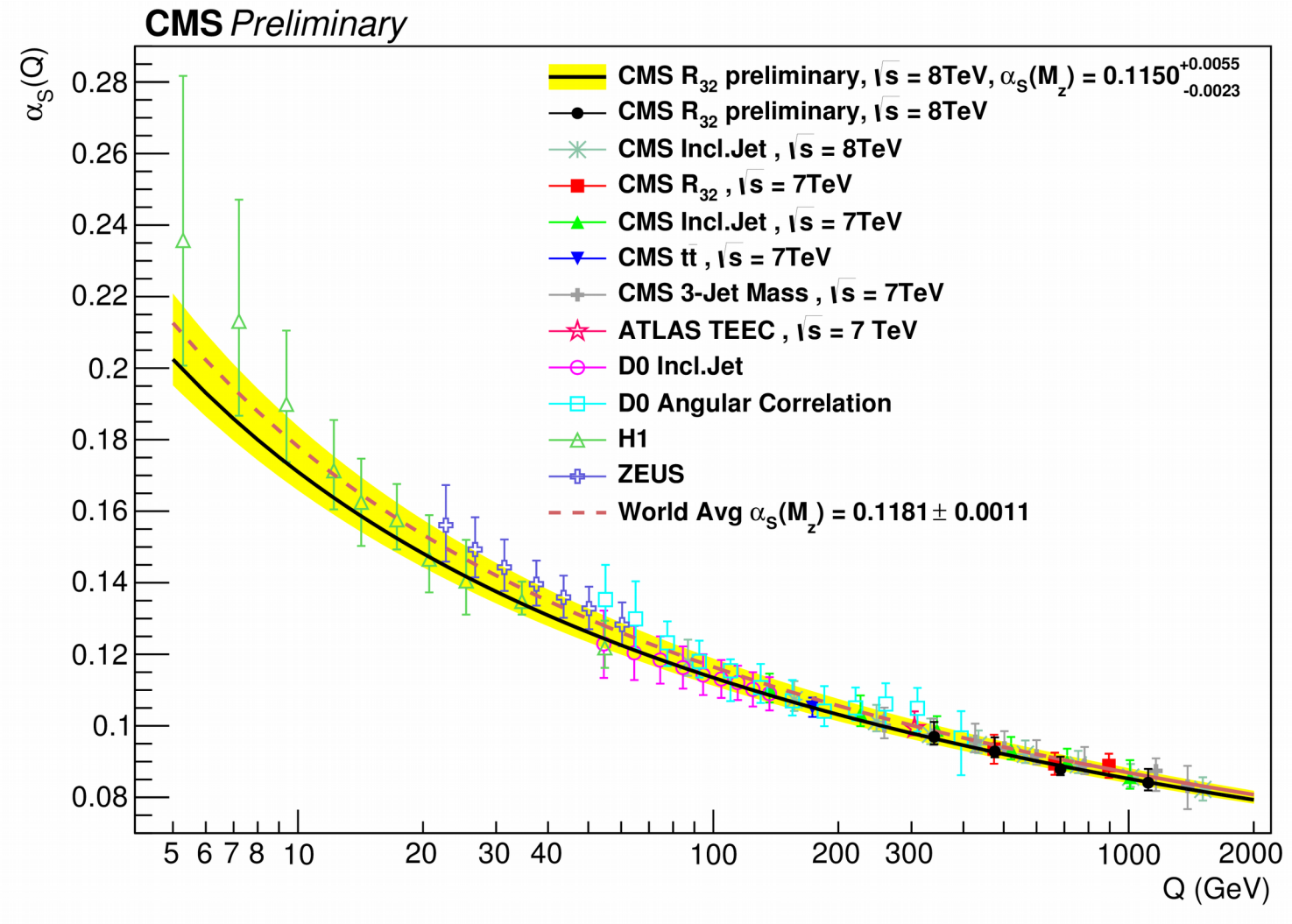






Eur. Phys. J. C 76 (2016) 451

Measurement and QCD analysis of double-differential inclusive jet cross sections



JHEP 03 (2017) 156