ATLAS measurements of photons, jets and subjets

Stephen Gibson
CERN

on behalf of the ATLAS Collaboration

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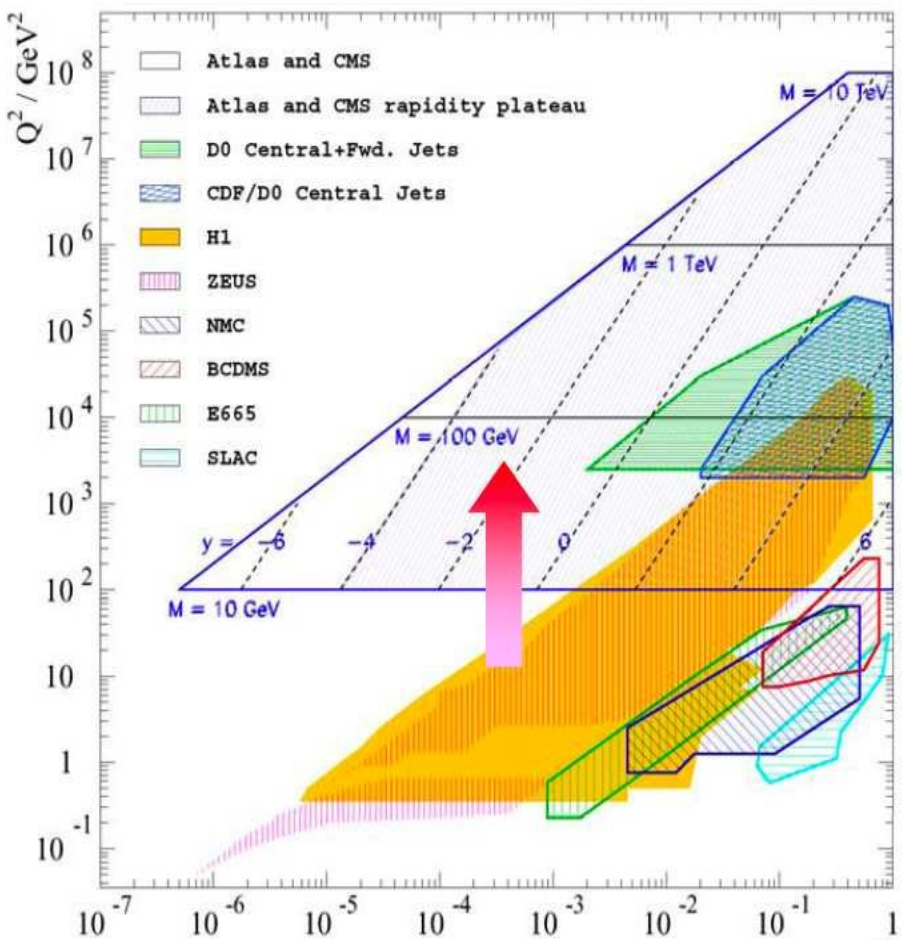
Outline

- Motivation:
  - Hard processes and precision tests of QCD
- Photons
  - Reconstruction and isolation
  - Prompt photons, diphotons and photon + jets.
- Jets
  - Clustering, cleaning and energy calibration
  - Inclusive and dijet cross sections
- Subjets
  - Jet mass and substructure
  - Tagging heavy boosted topologies
- Conclusion

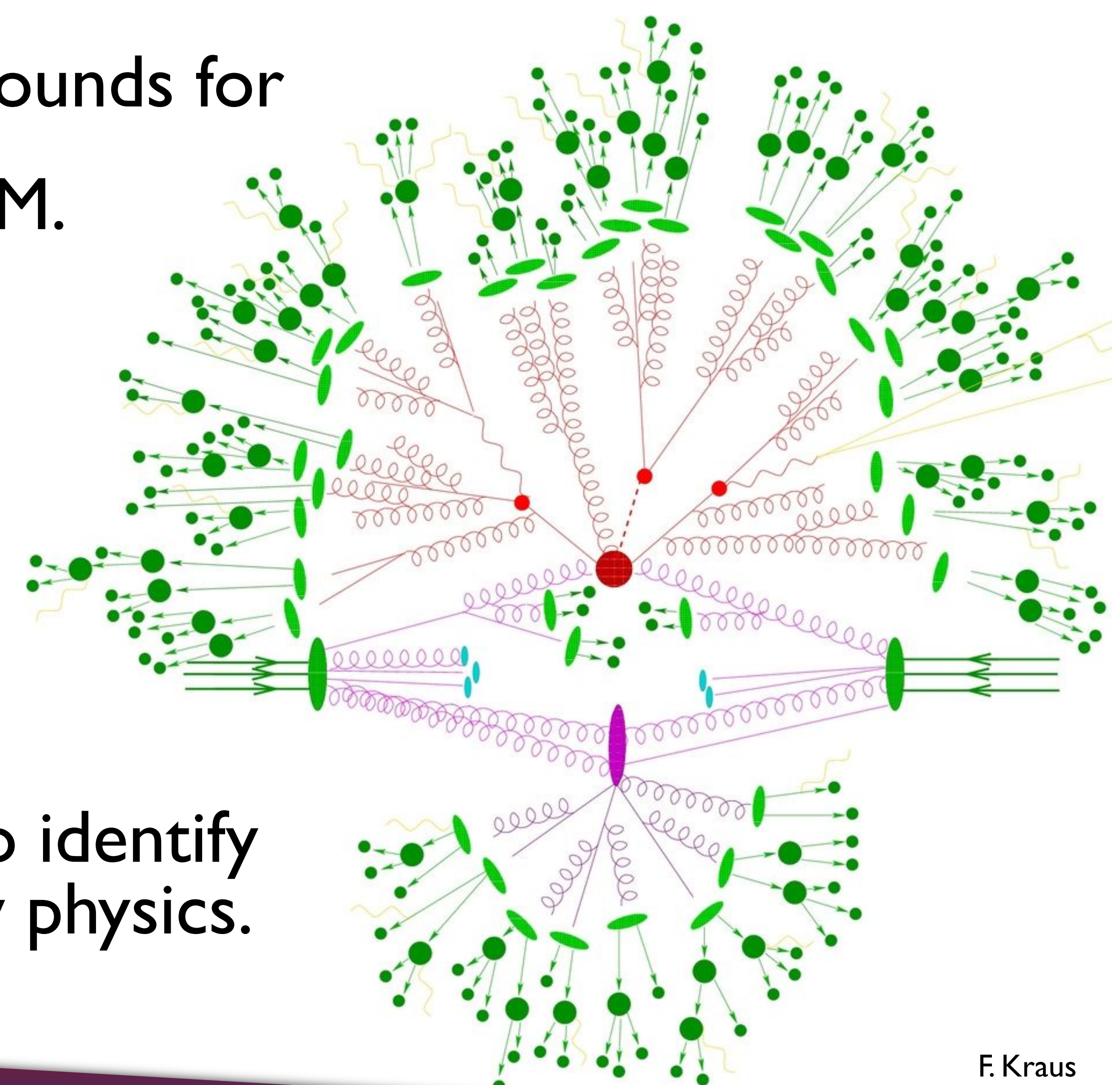
Motivation

- Why measure prompt photons and jets at the LHC?



arXiv:0811.1544v1

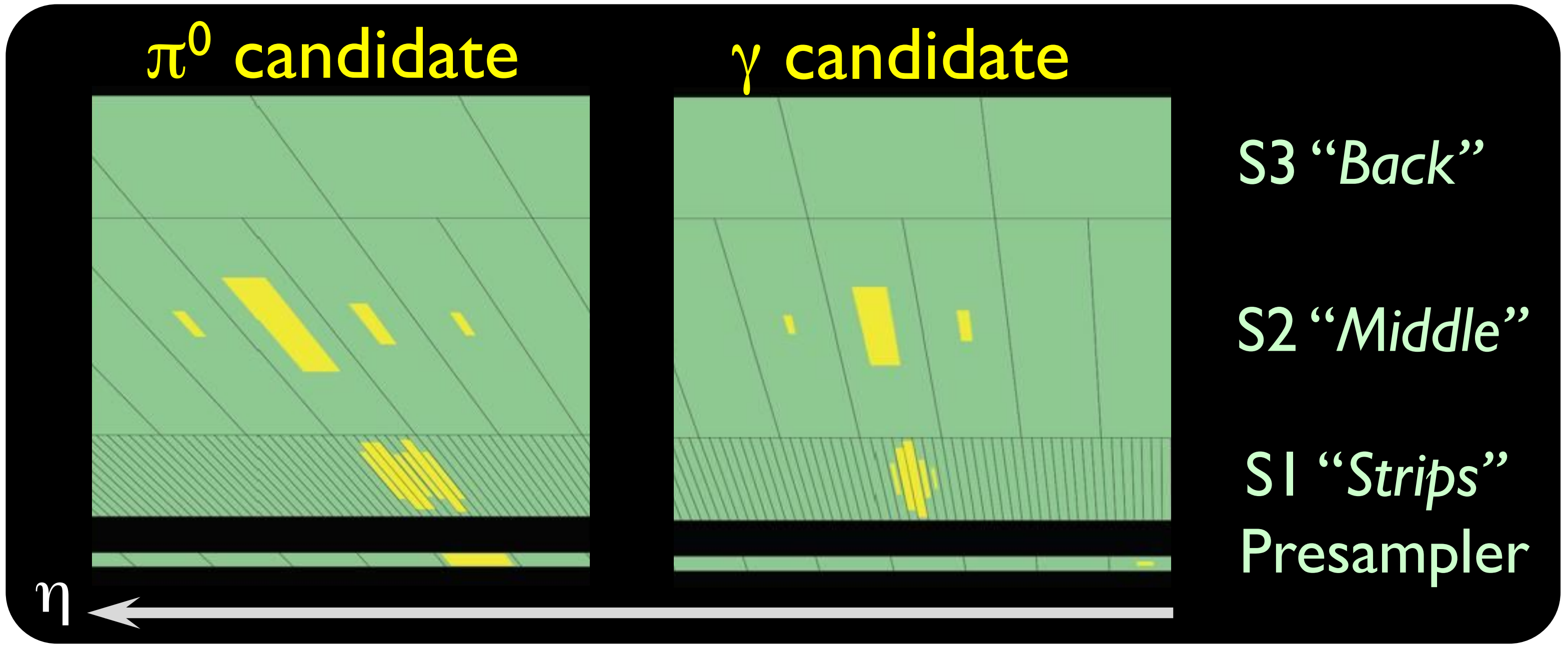
- Precision tests of perturbative QCD in a new kinematic regime.
- Help constrain the parton densities in the proton (PDFs).
- Photon + jet is particularly sensitive to gluon content and photon fragmentation function.
- Important backgrounds for Higgs (γγ) and BSM.
- γ/jet calibration.

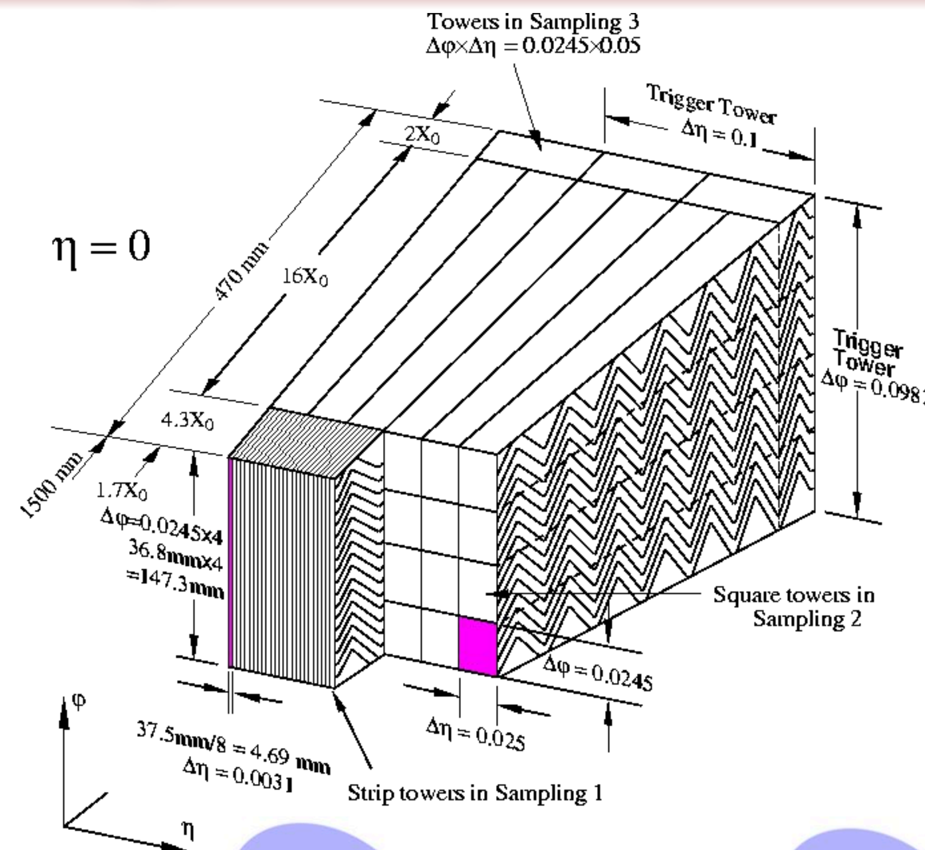


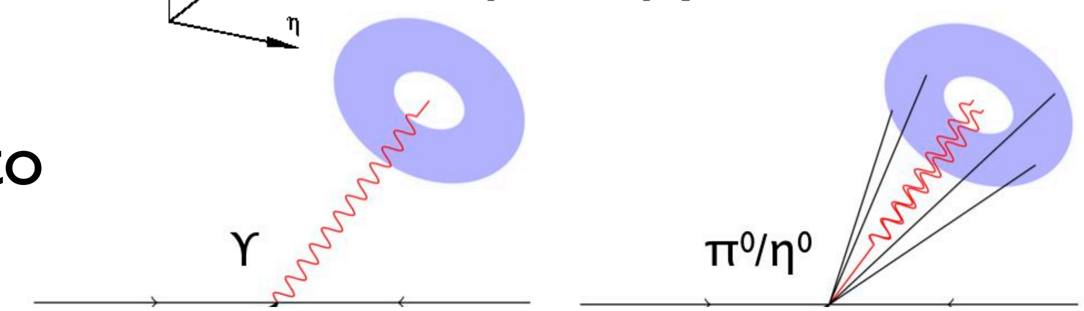
F. Kraus

- Why measure subjets?
  - Jet shape is sensitive to non-perturbative fragmentation and underlying event.
  - Jet substructure provides an extra handle to identify boosted heavy particles in searches for new physics.

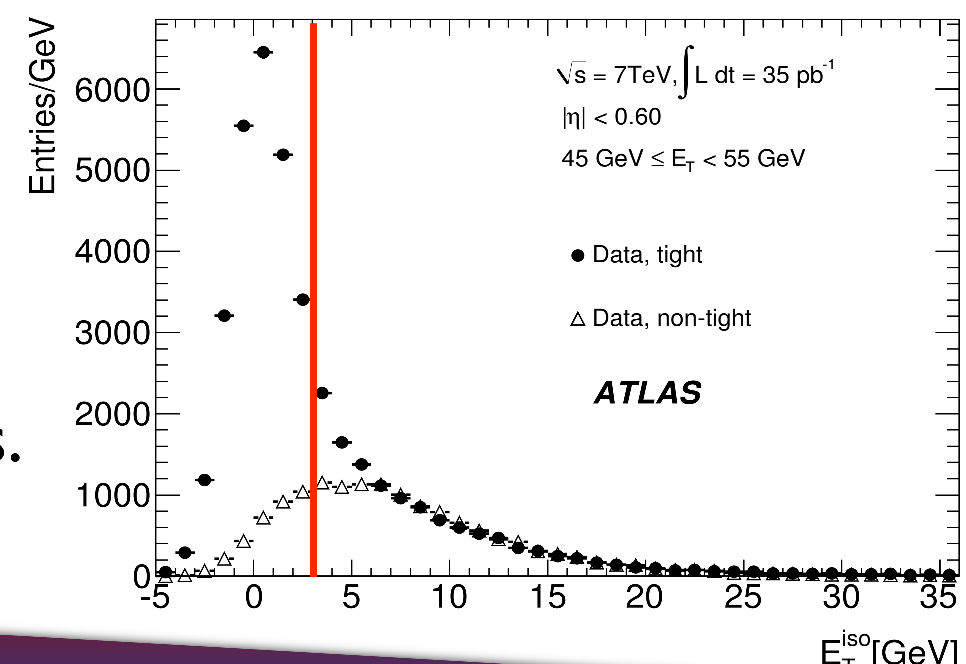
Identifying isolated photons







- Reconstruct photon clusters using finely segmented liquid argon-lead sampling calorimeter
  - Lateral and longitudinal shower shapes used to suppress hadronic background.
  - 9 discriminating variables with different cuts for converted (e^+e^-) and unconverted photons.
- Isolation requirement, E_T^{ISO}< 3GeV
  - Select prompt photons which deposit energy in small radius; unlike ISR, FSR, light neutral mesons.



Prompt photons

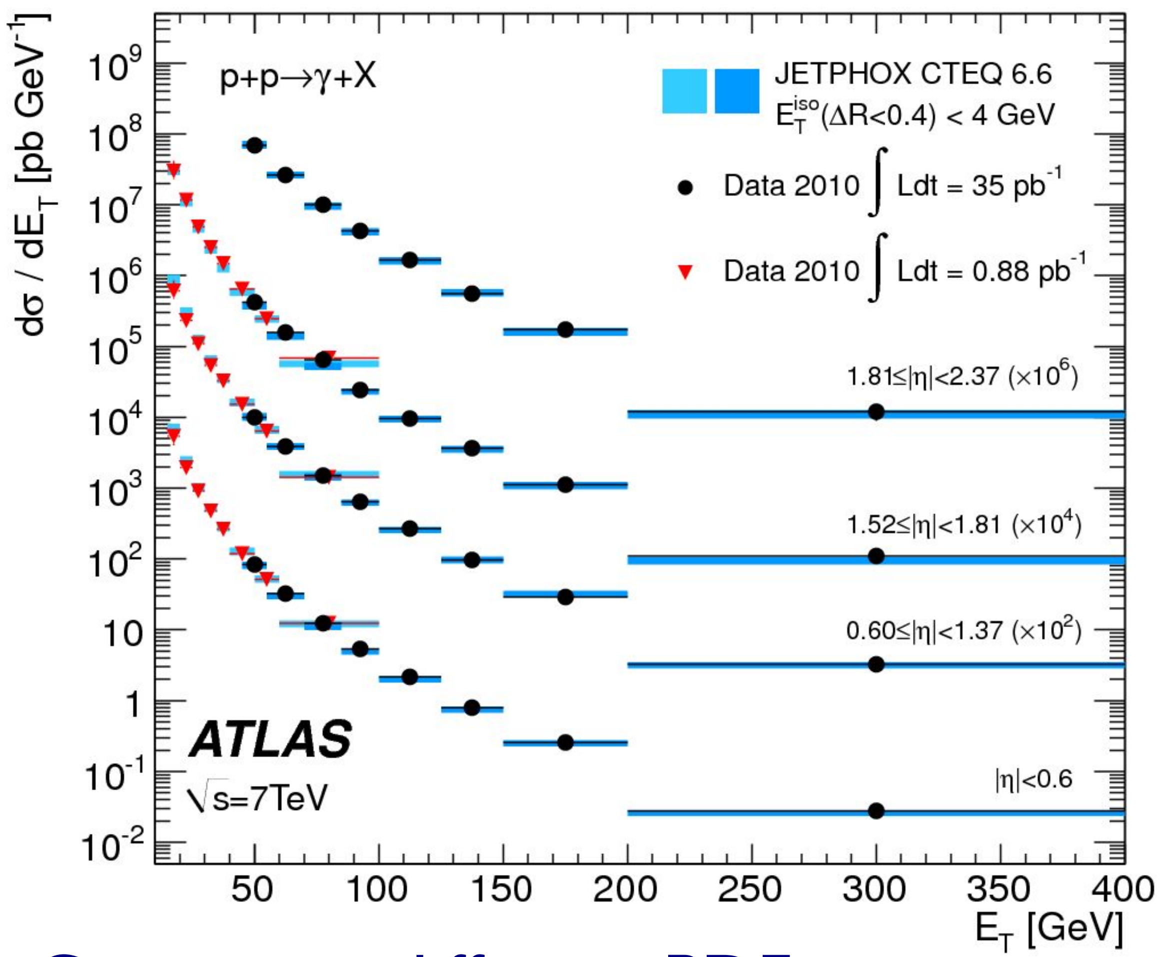
- Two papers, using 0.88 pb^{-1} and 35 pb^{-1}, focus on different photon E_T regions: [15-100] and [45 – 400] GeV. Measurements consistent in overlap bins.

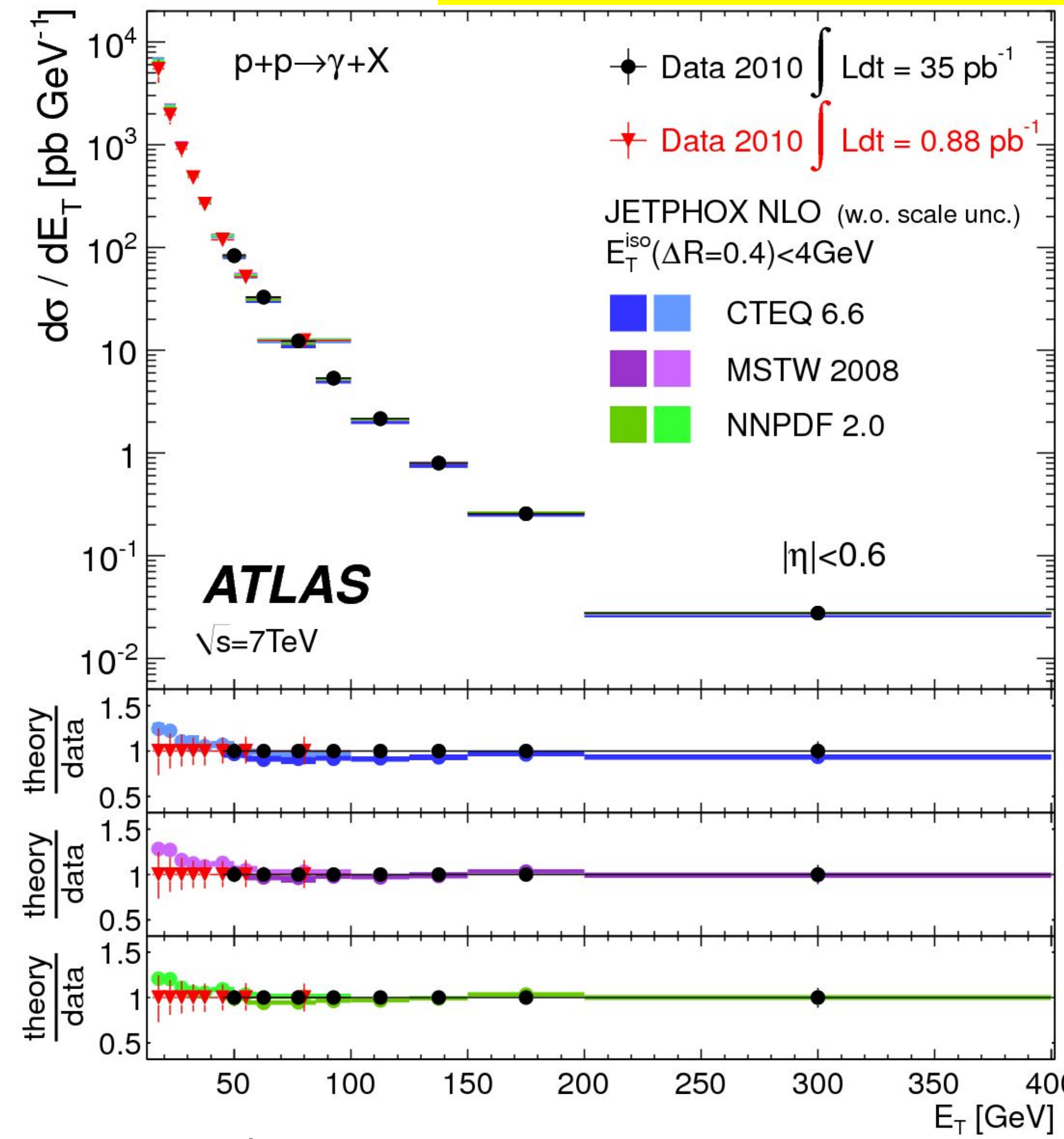
Phys.Rev.D 83, 052005 (2011)

Phys.Lett.B706 150 (2011)

ATL-PHYS-PUB-2011-013

- NLO pQCD, JETPHOX using CTEQ 6.6 PDFs



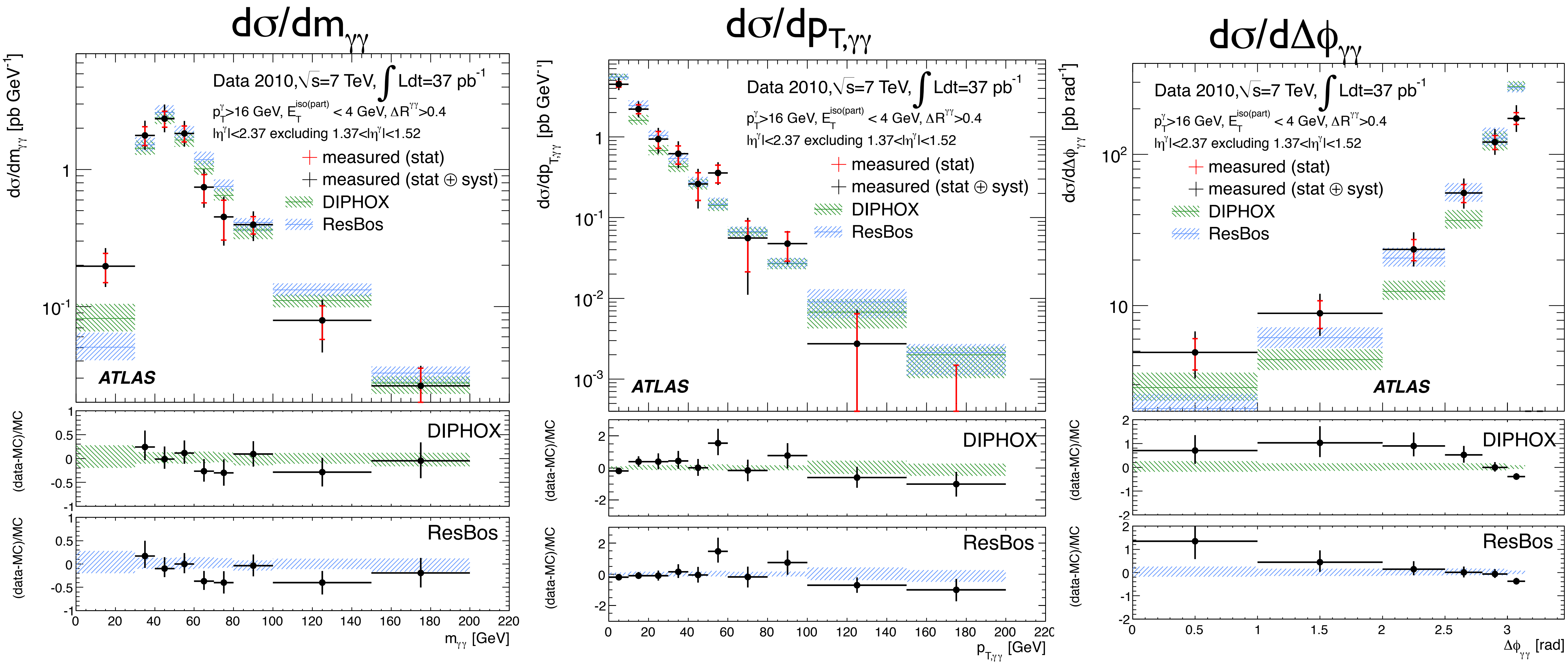


- Comparing different PDF sets:
  - Disagreement below 25 GeV for central photons, |η|<1.7, good agreement above.
  - Results helped to constrain the gluon PDF and reduce uncertainty by up to 20%:

Nucl. Phys. B 3 311-338 (2012)

Diphotons

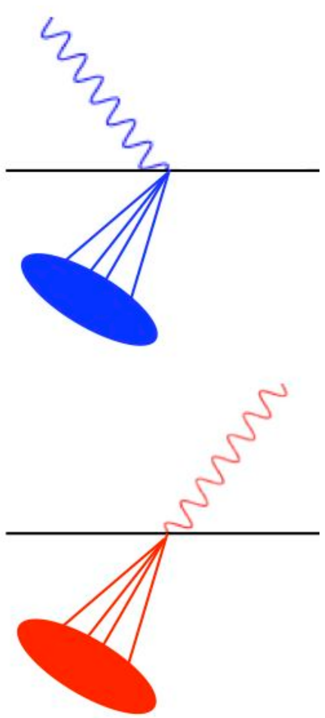
- Diphoton differential cross-sections, with 37 pb^{-1}: Phys.Rev. D85, 012003 (2012)



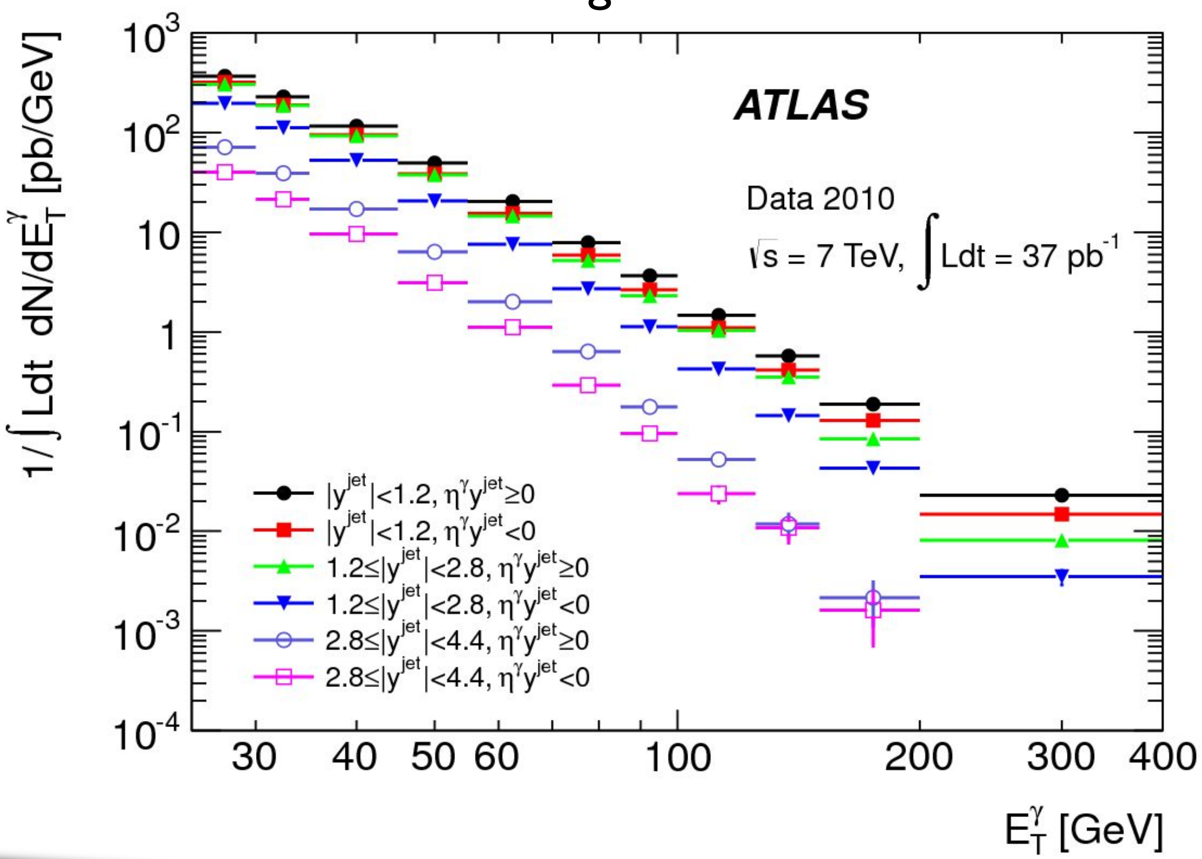
- Generally good agreement; discrepancy with NLO at low $\Delta\phi$ (low $m_{\gamma\gamma}$) and $\Delta\phi \sim \pi$
  - Measurements comparable with those from CMS and Tevatron.
  - Recent $\gamma\gamma$NNLO calculations improve the agreement. arXiv:1110.2375v1 [hep-ex]

Isolated photon with jets

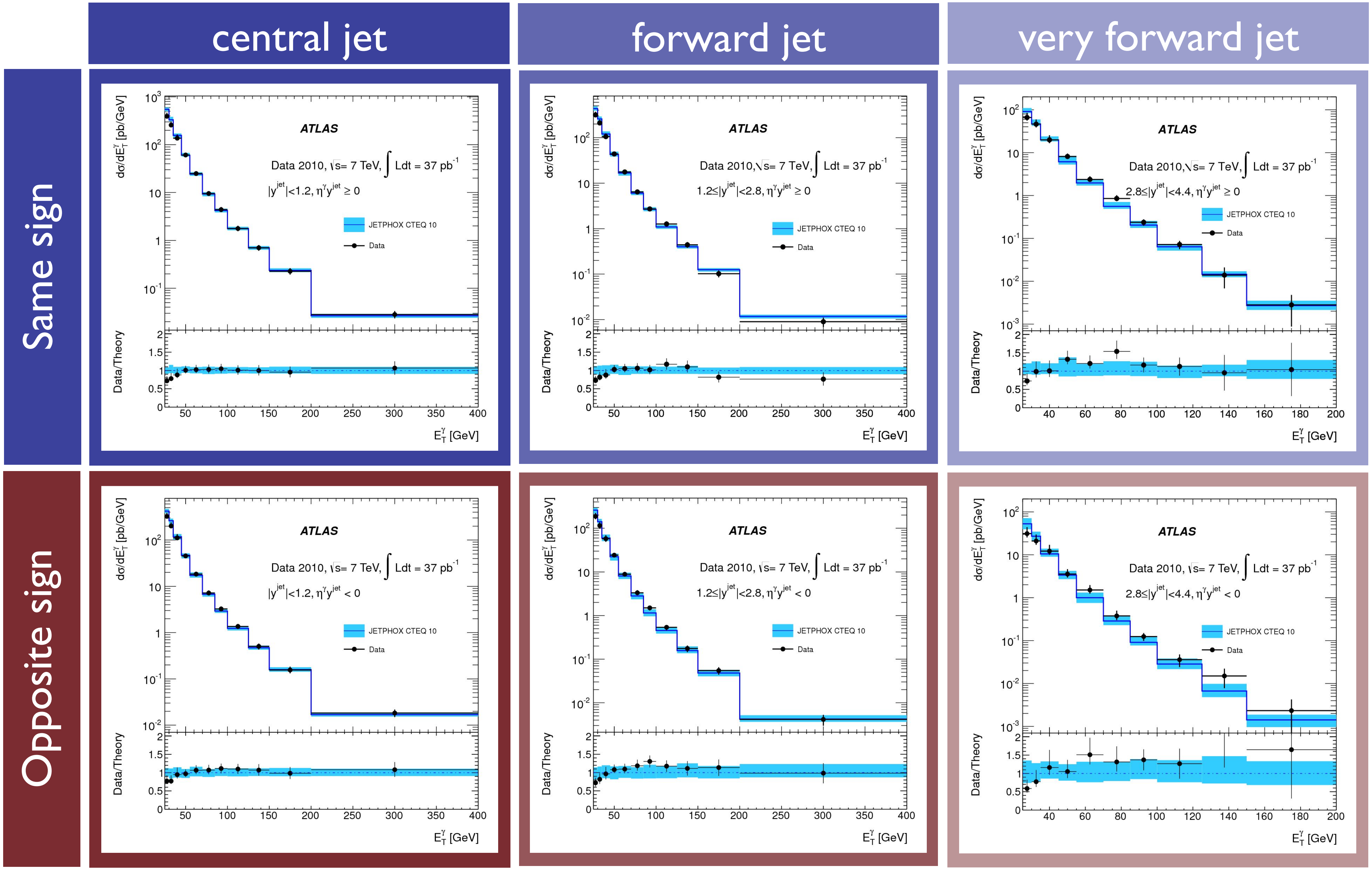
- New analysis with 37 pb^{-1} recently published (23 May): Phys.Rev. D85, 092014 (2012)
  - Prompt photon with jet provides test of large hard-scattering scales (Q^2) over a wide range of parton momentum fractions (x).
  - $X \geq 0.001$ and $625\ GeV^2 < Q^2 < 1.6\times10^5\ GeV^2$ extends to kinematic regions previously unexplored with this final state.
- Calculate cross-section separately in 6 angular configurations of jet and photon rapidity, to access regions of differing fragmentation contributions and parton momentum fractions.
  - Jet rapidity:
    - Central: $|\eta| < 1.2$
    - Forward: $1.2 \leq |\eta| < 2.8$
    - Very forward: $|\eta| \geq 2.8$
  - Photon and jet rapidity:
    - Same sign: $\eta_\gamma * y_j \geq 0$
    - Opposite sign: $\eta_\gamma * y_j < 0$.



Transverse energy of photon candidates, before background subtraction.



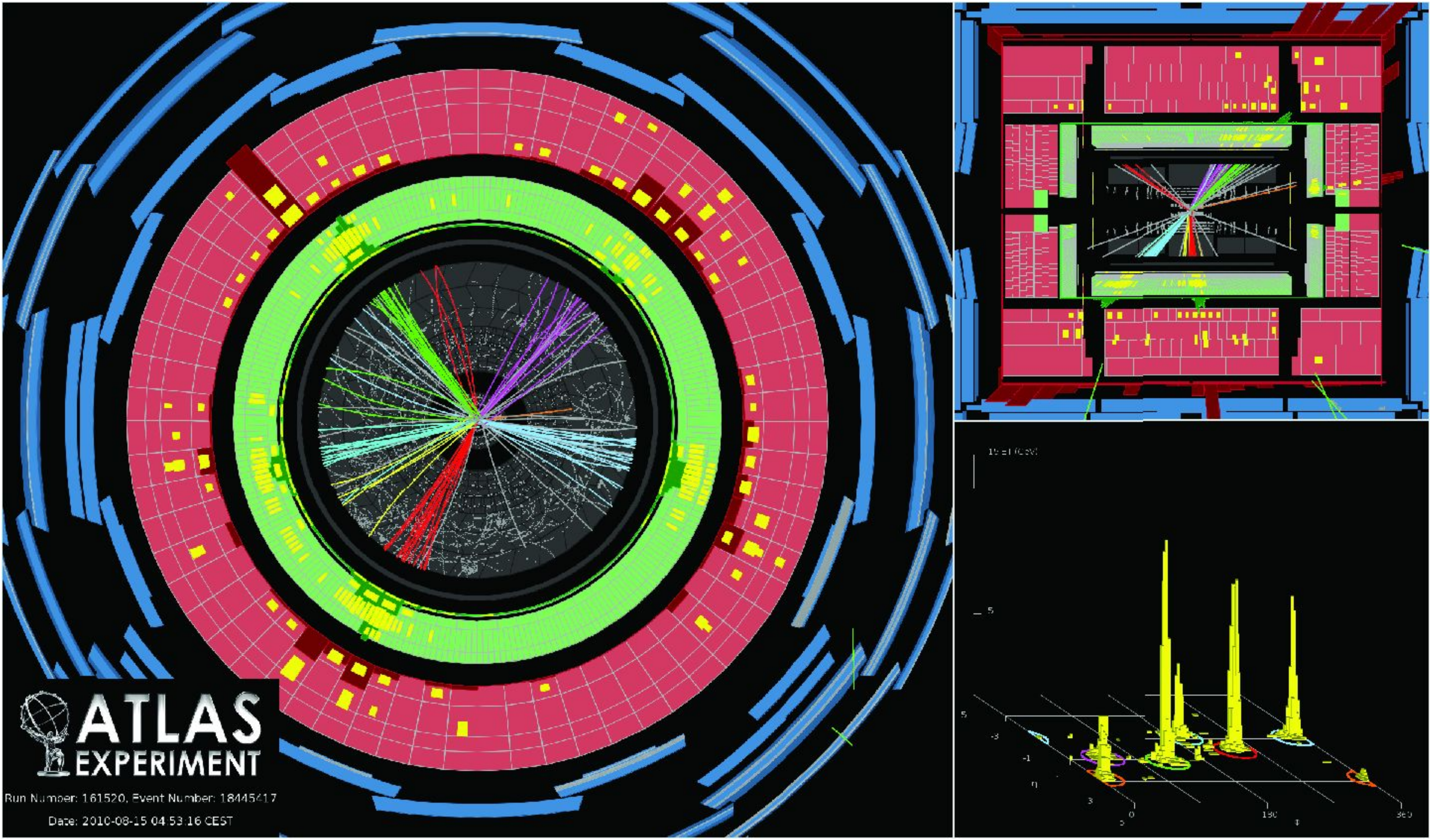
Photon + jet cross section



At low E_T^{γ} < 45 GeV, NLO pQCD over-estimates measurement, as observed for prompt photon.

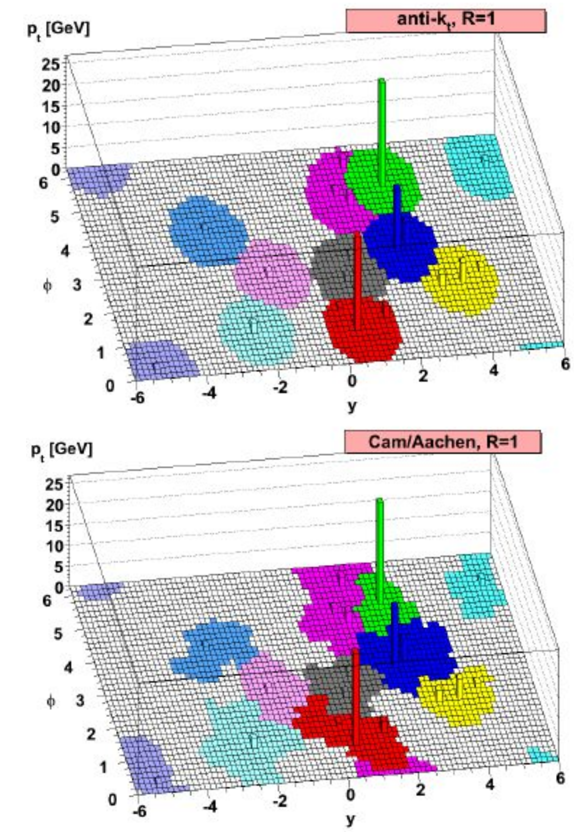
Phys.Rev. D85, 092014 (2012)

Jets in ATLAS

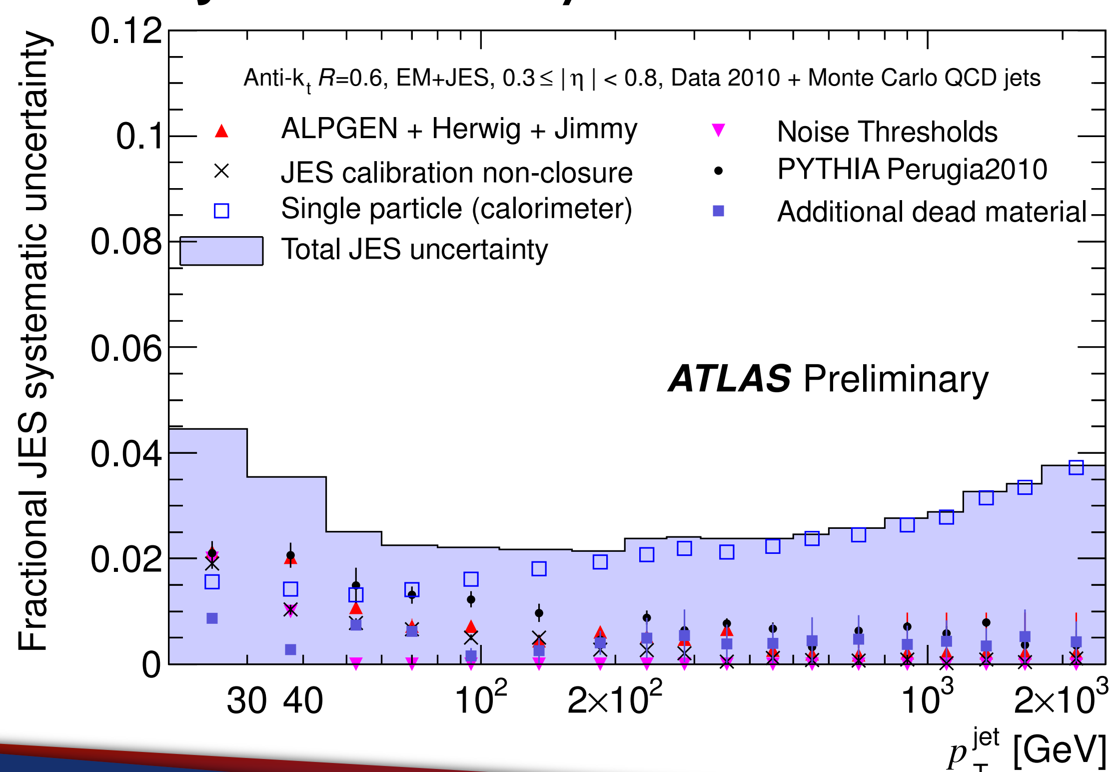


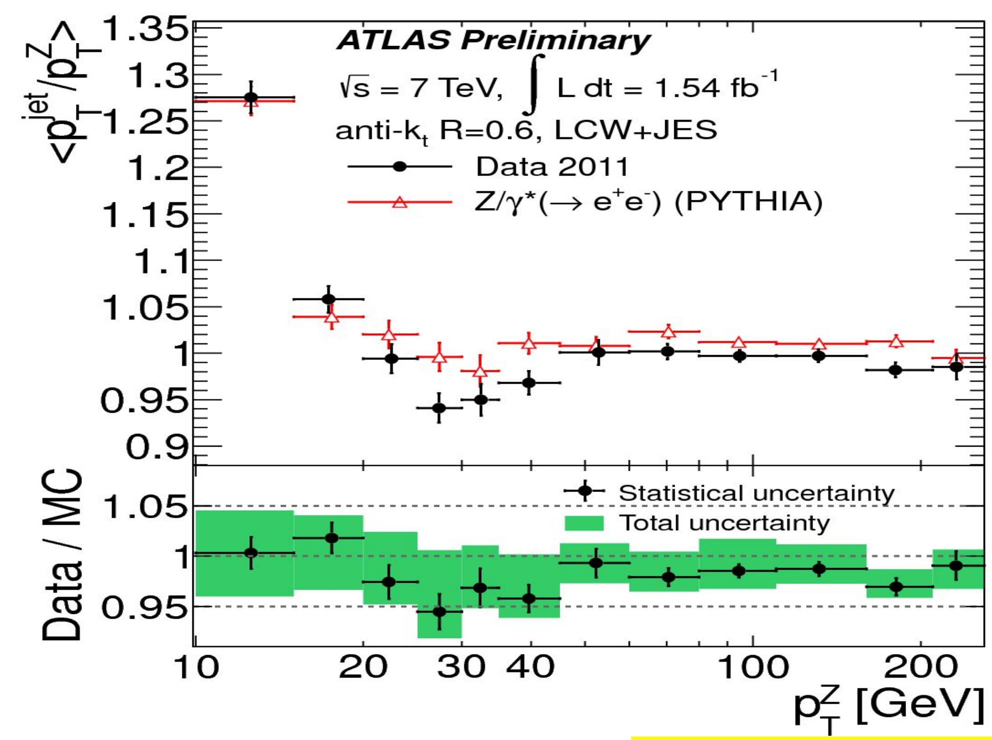
Jet reconstruction and calibration

- Jets are reconstructed as 4-vector summations of noise-suppressed 3D clusters, grouped by a clustering algorithm:
  - ***Anti-k$_T$***, hardest constituent first; circular jet resilient to soft radiation. [standard in ATLAS, typically, R=0.4 or R=0.6]
  - ***Cambridge-Aachen***, closest constituents first. [used in jet substructure and boosted object studies, R=1.2]
- Jet calibration restores the jet energy scale (JES)
  - Correct for non-compensating calorimeters, dead material, out-of-cone effects, pile-up.
  - <5% JES uncertainty, validated *in situ* with Z+jet p_T balance:



Cacciari, Salam, Soyez
JHEP 0804:063,2008

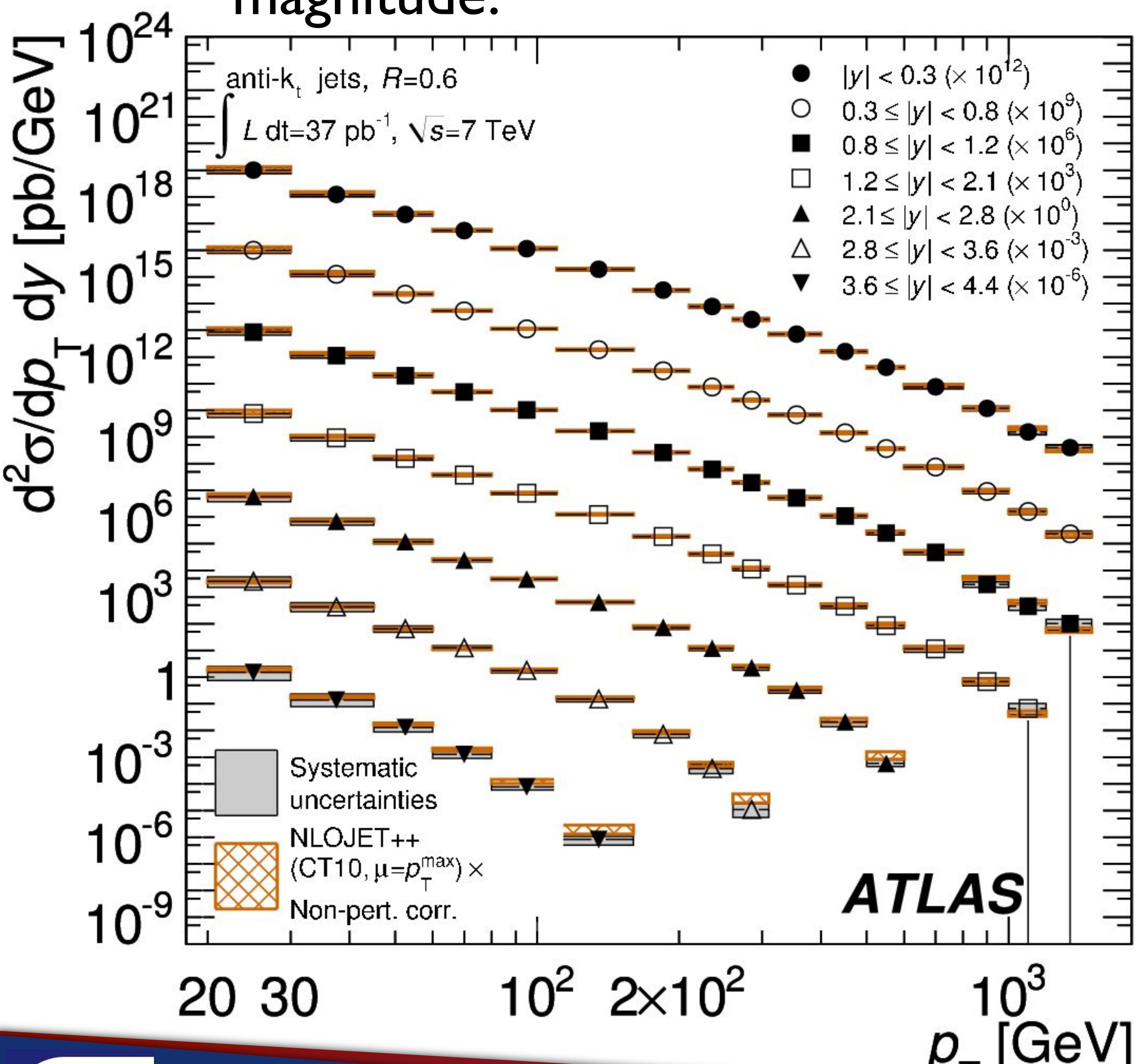


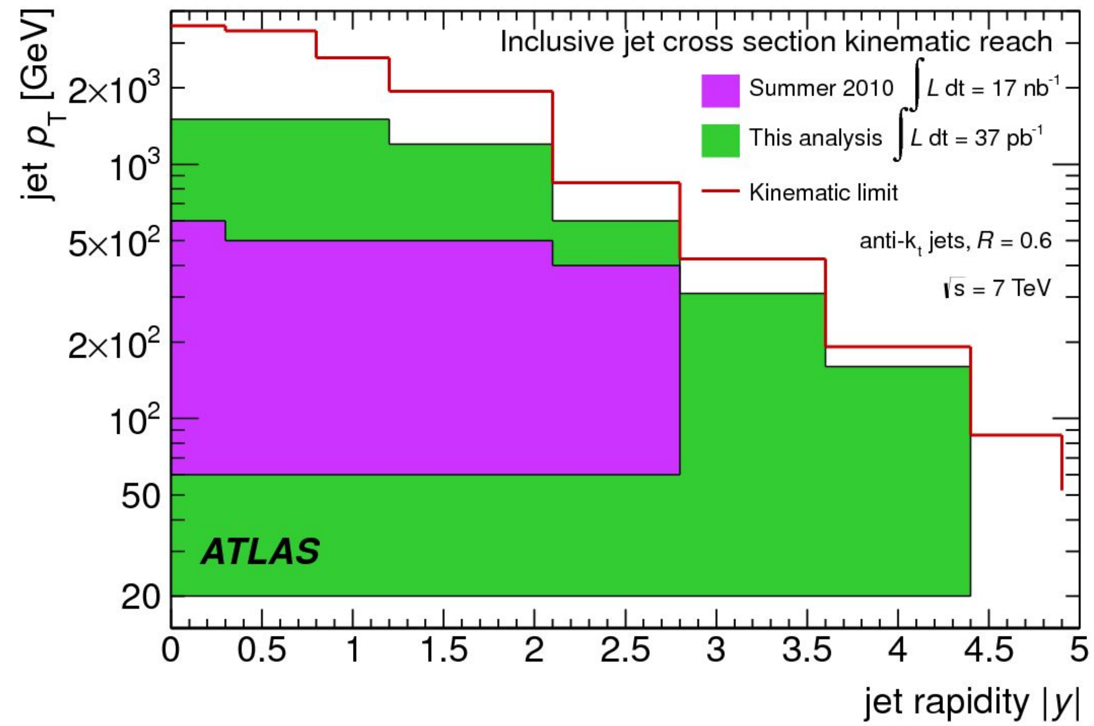


ATLAS-CONF-2011-032
ATLAS-CONF-2011-159

Inclusive jet and dijets, 37 pb^{-1}

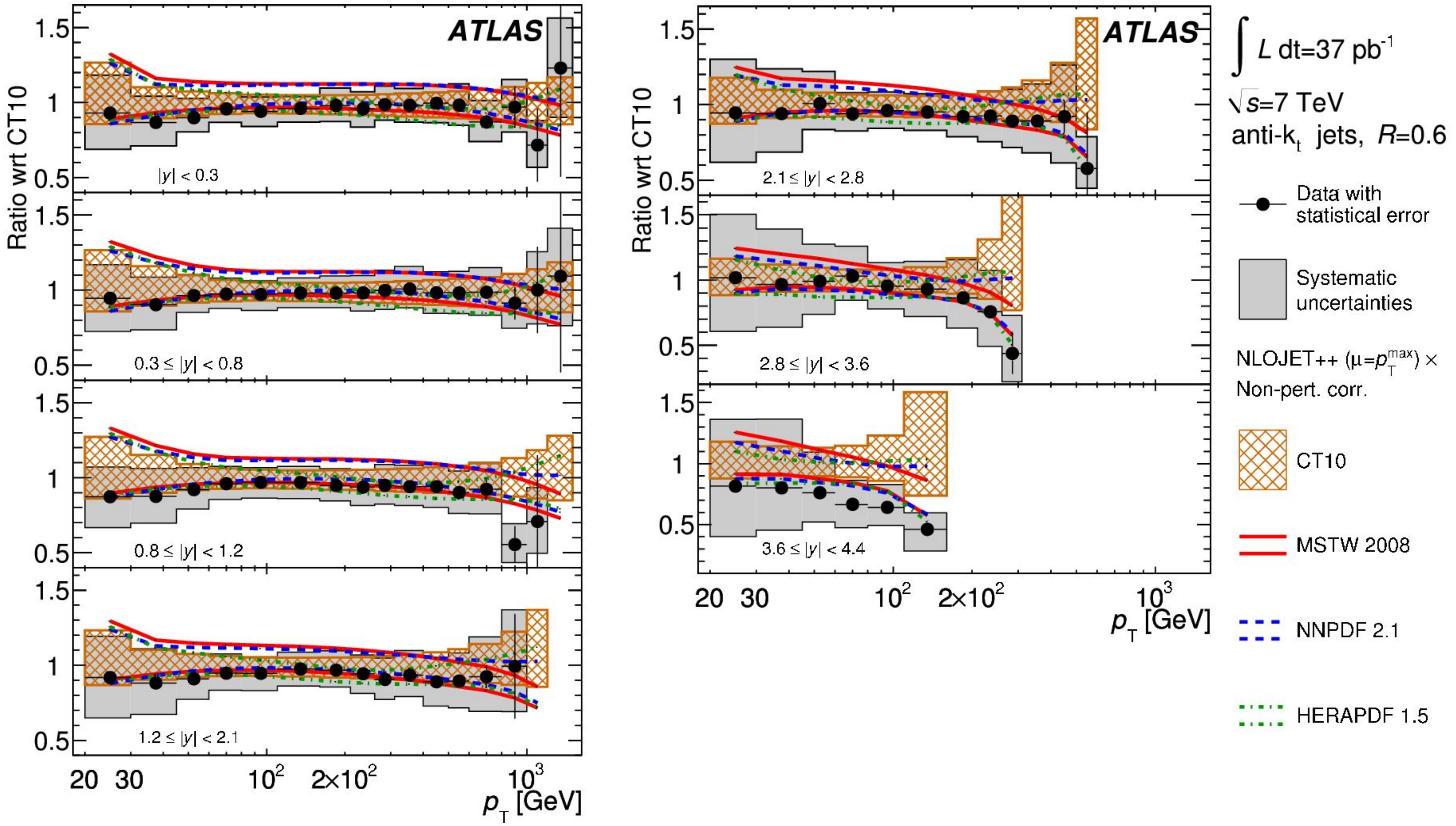
- Measure inclusive jet cross section for jet rapidity, |y|< 4.4 and 20 <pT<1500 GeV.
  - Data agrees well with NLO pQCD prediction over many orders of magnitude.





- Final 2010 paper extends kinematic reach of first publication (EPJC 71.1512): arXiv:1112.6297
  - 17 nb^{-1} → 37 pb^{-1}
  - Max jet p_T: 600 GeV → 1.5TeV
  - Low pT: 60 GeV → 20 GeV
  - Max dijet mass, m_{12}: 1.8 → 4.8 TeV
  - Forward rapidity: |y| < 2.8 → 4.4

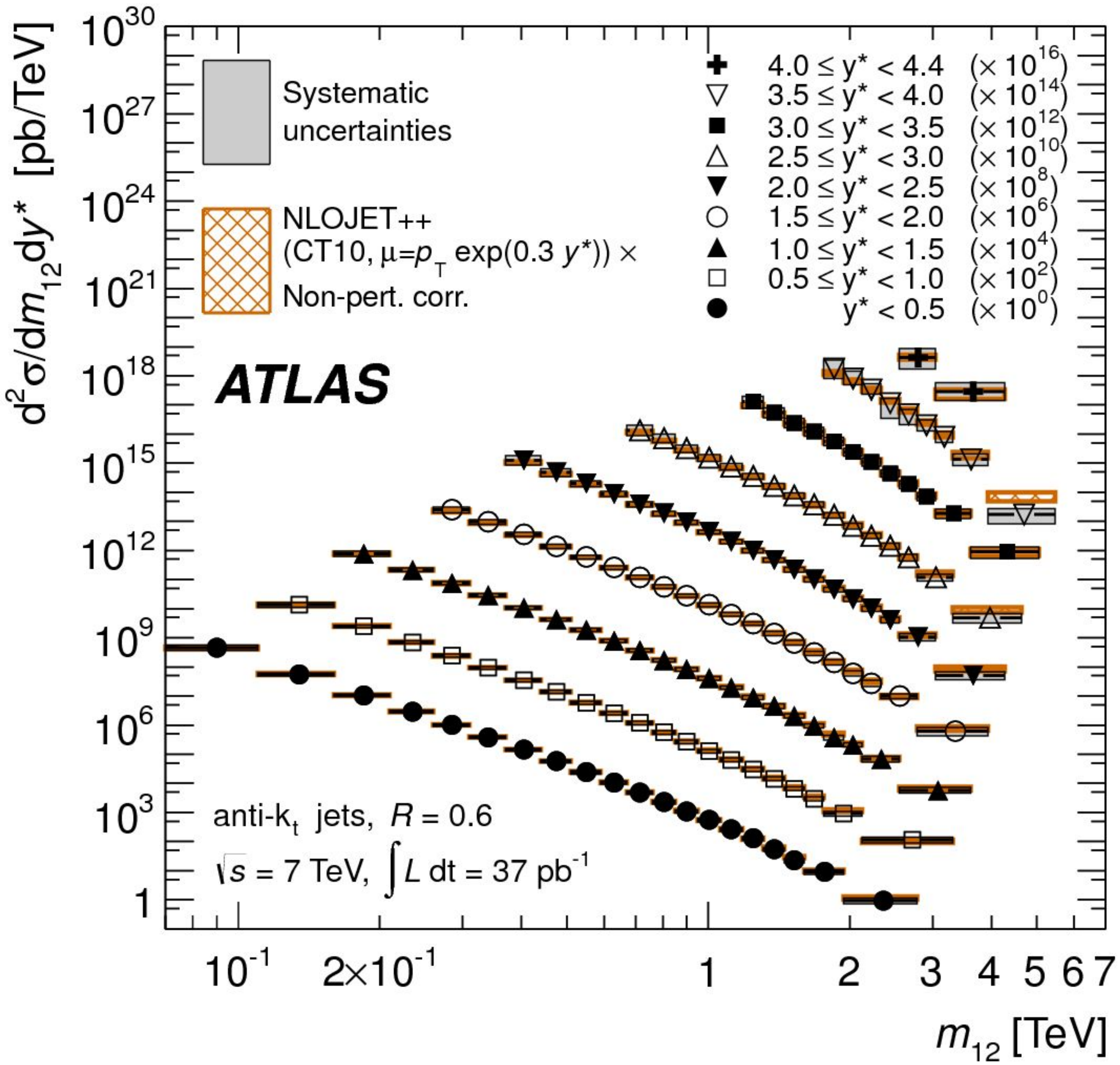
Inclusive jets $37 pb^{-1}$

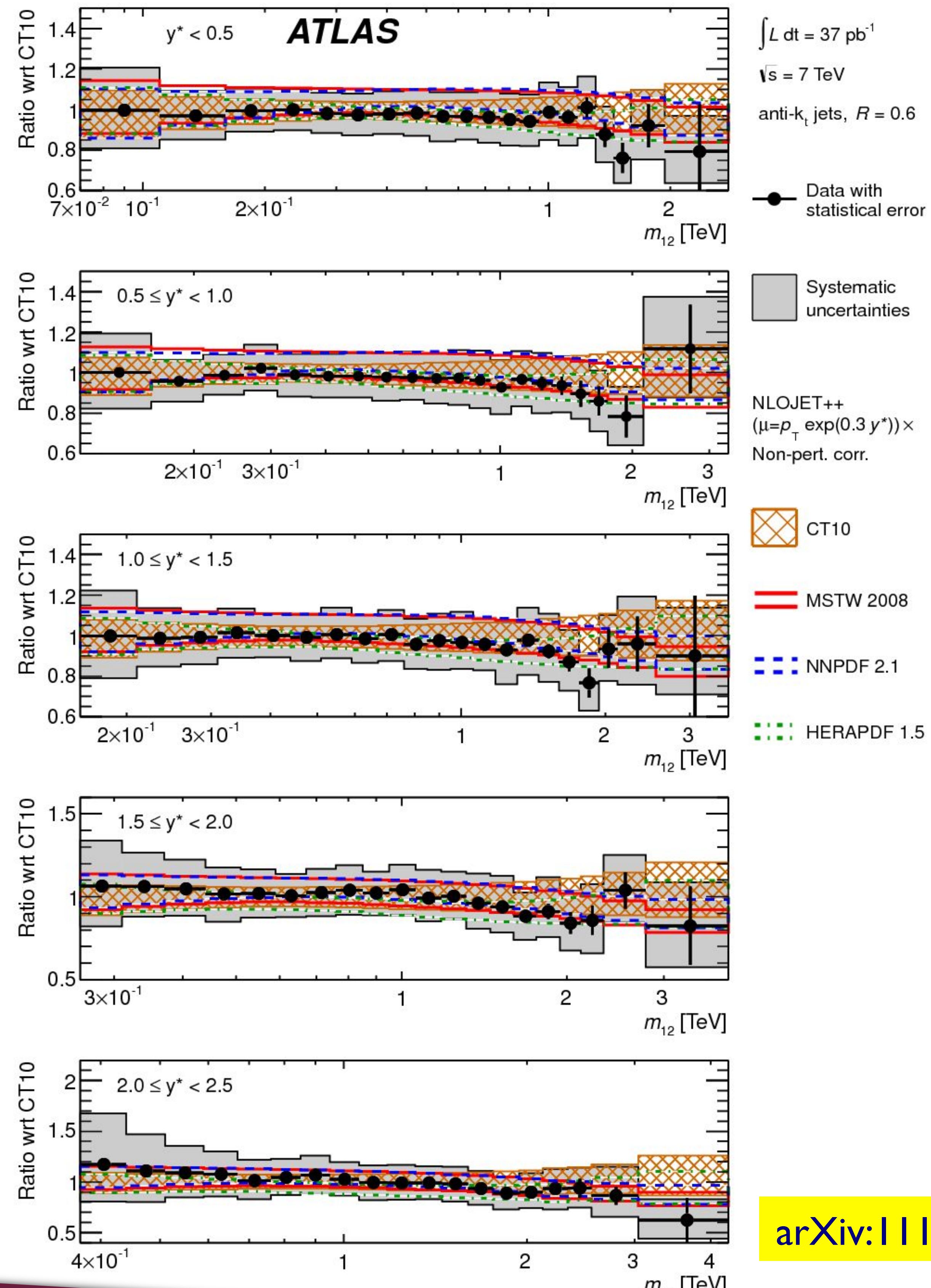


- Comparison with NLO pQCD (including non-pQCD corrections)
  - Measured cross-section in agreement with NLO pQCD predictions
  - Data at edge of phase space promises to further constrain gluon PDFs (in p_T limited region, where no new physics is expected).

Dijet cross-sections 37 pb^{-1}

- Dijet double differential cross section, in bins of half the rapidity separation between leading jets: $y^* = |y_1 - y_2| / 2 < 4.4$. Anti-$k_T$, R=0.6



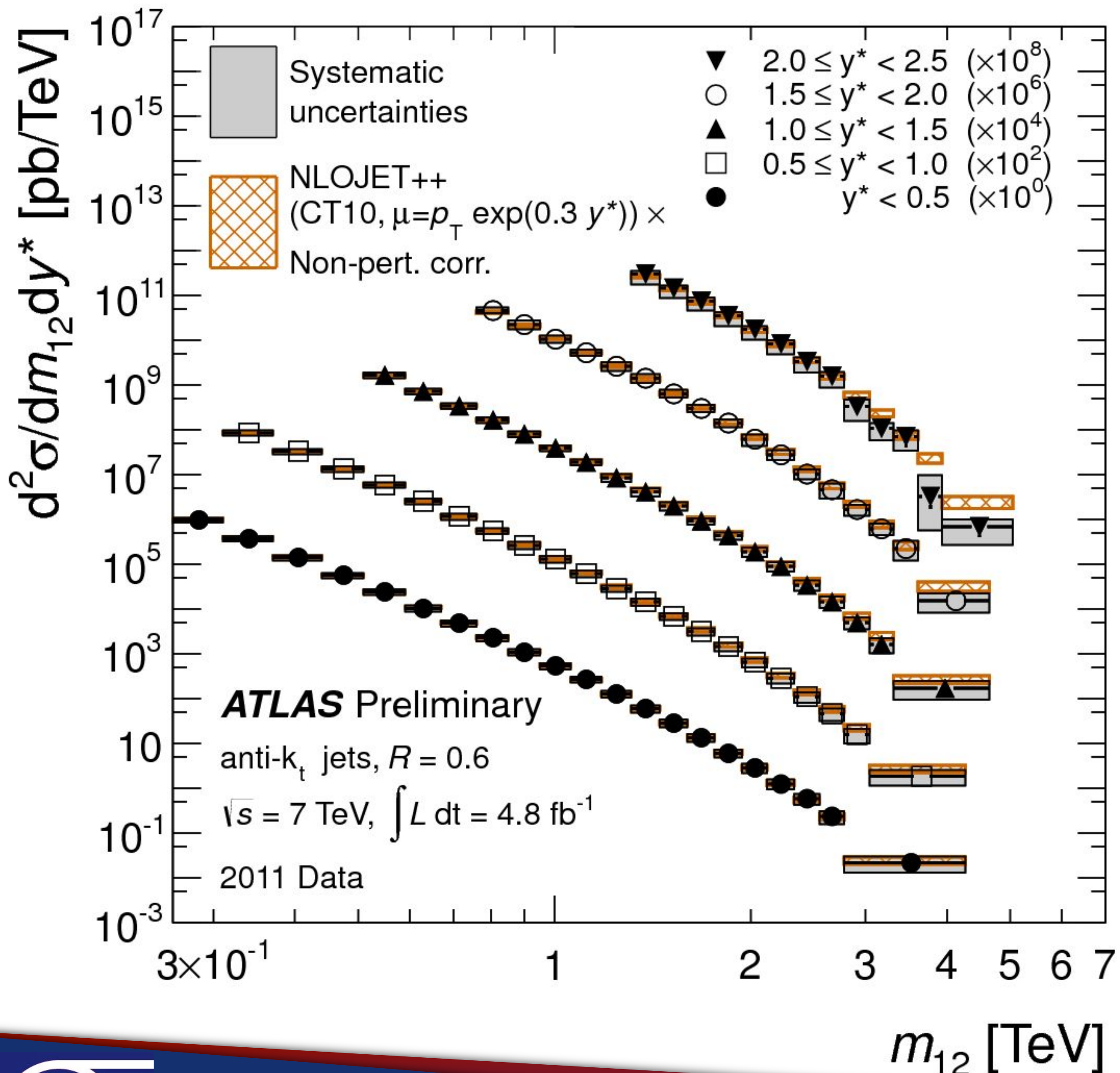


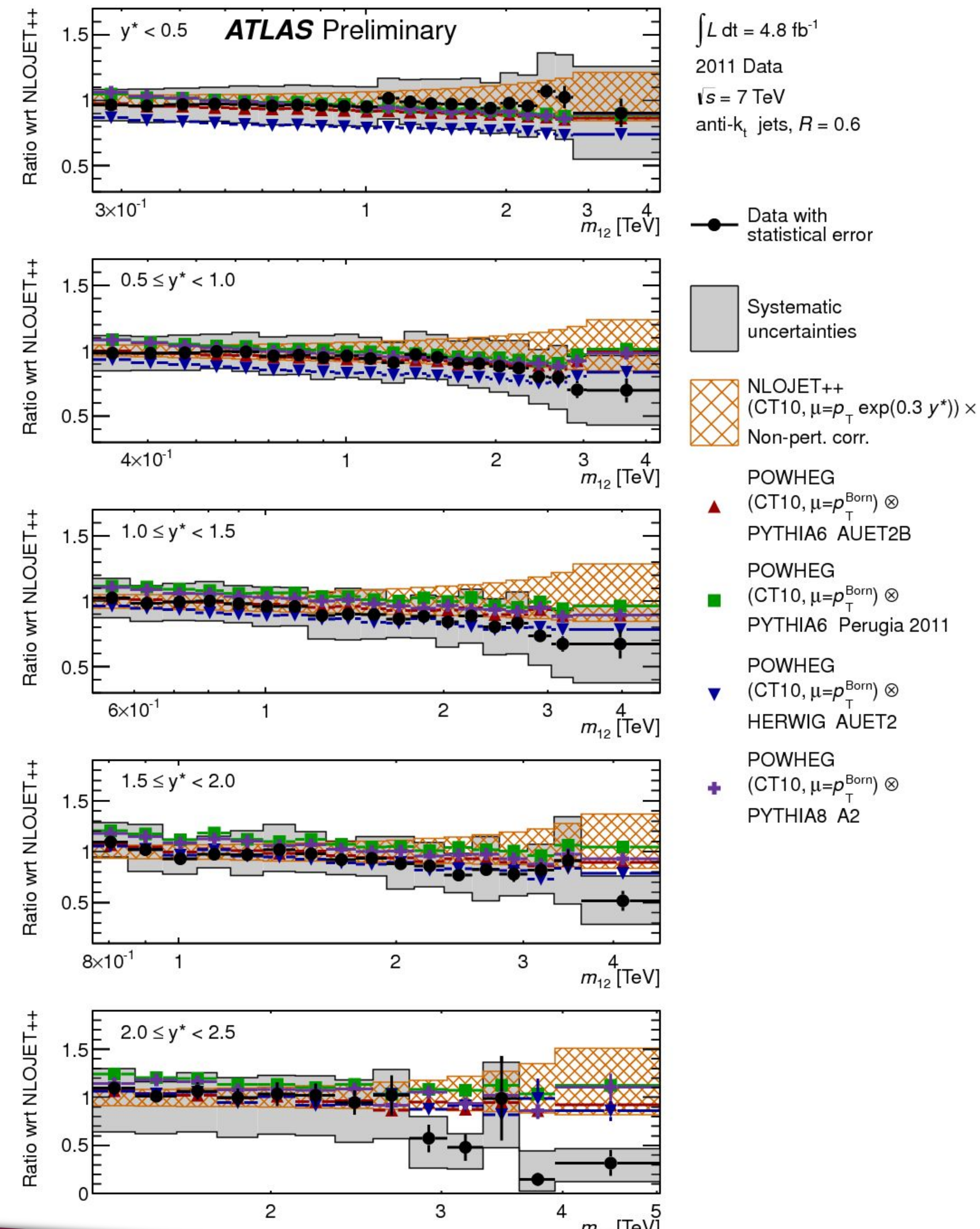
arXiv:1112.6297

High mass dijets 4.8 fb^{-1}

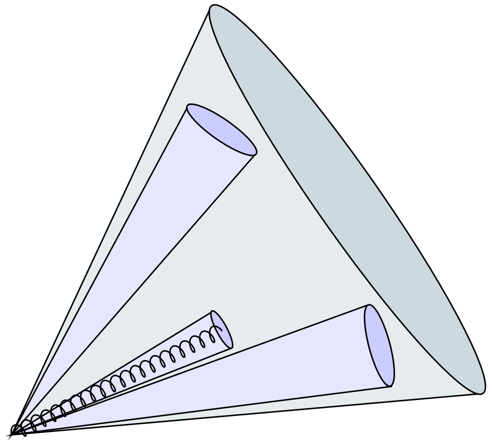
ATLAS-CONF-2012-021

- Dijet mass: 260 GeV < m_{12} < 4.6 TeV, y^* < 2.5
- Negative trend in data emerging at large y^* and m_{12} (up to 40%).
  - POWHEG showered with Pythia 6 describes the data better than NLOJET++

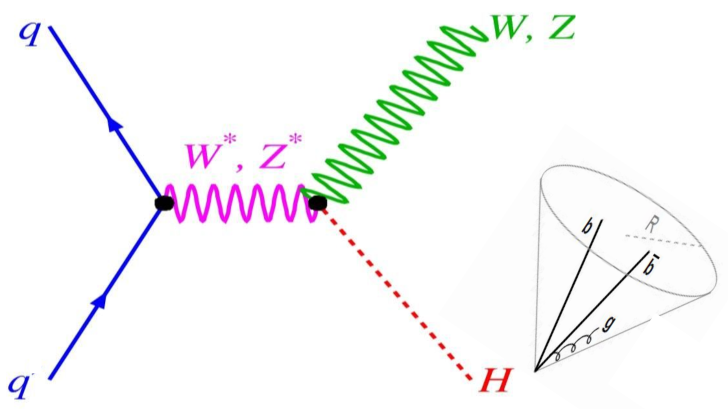




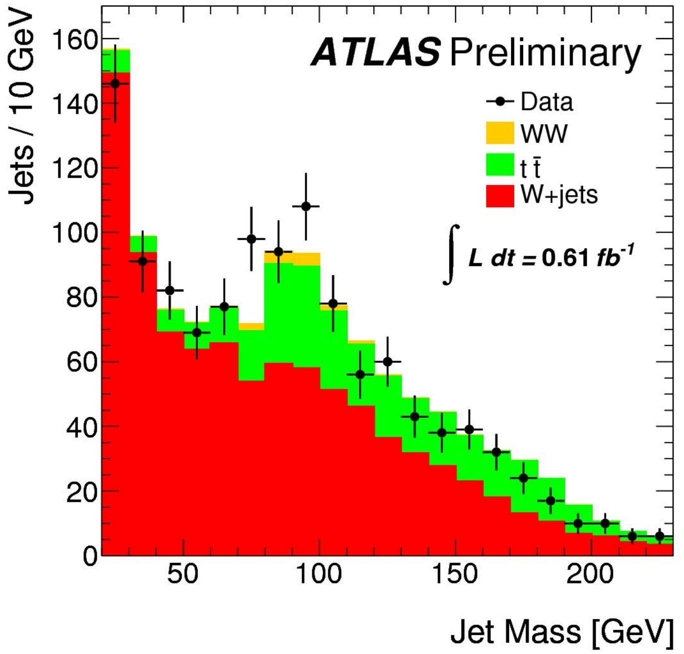
Jet mass and substructure



- Jets are composite objects:
  - Jets formed from two- and three- body decays have different internal structure to quark / gluon initiated jets.
  - Boosted objects can be identified by jet substructure and suppress background QCD.
  - Studies of jet substructure motivated by boosted H(bb):
  - Also a test of non-perturbative effects like fragmentation and hadronisation.



- Several ATLAS publications to date:
  - Jet shapes: Phys. Rev. D83 (2011) 052003
  - Jet fragmentation: Eur. Phys. J. C 71 (2011) 1795
  - Jet mass and substructure variables: JHEP 05 (2012) 128
  - Jets properties for boosted objects: ATLAS-CONF-2012-044

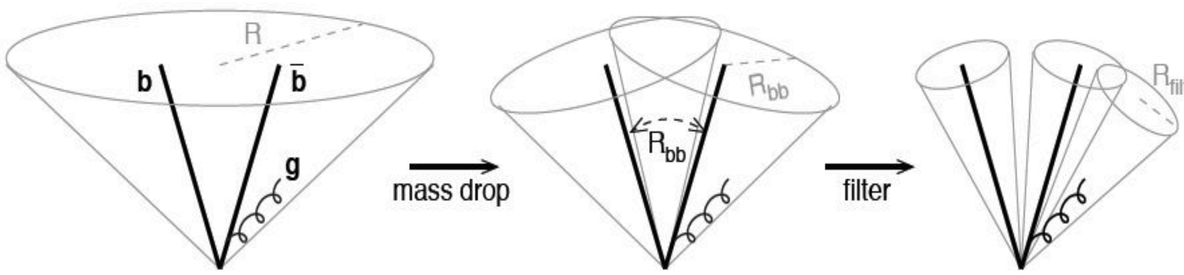


ATLAS-CONF-2011-103

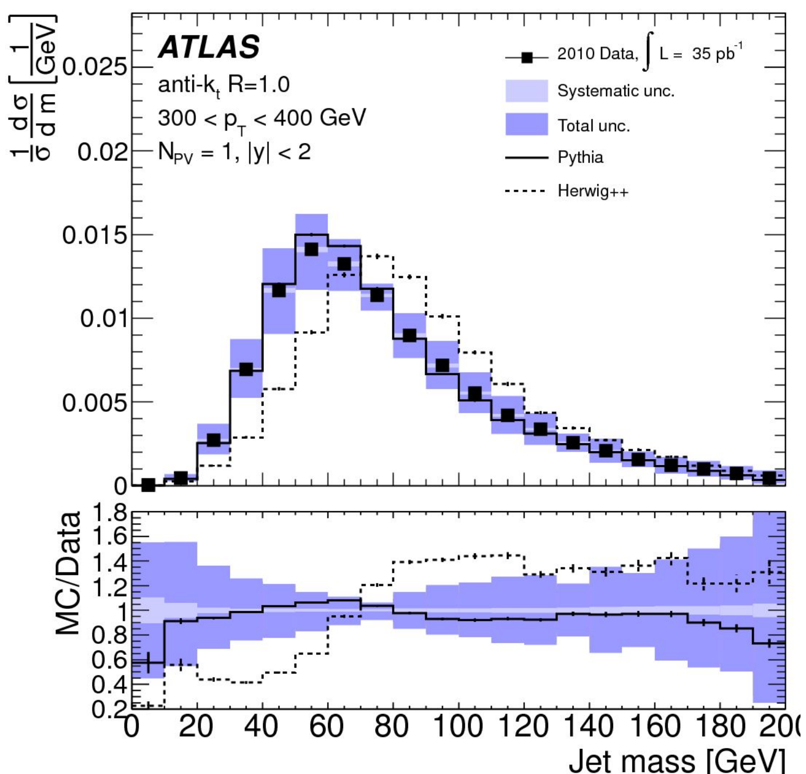
Jet mass and substructure

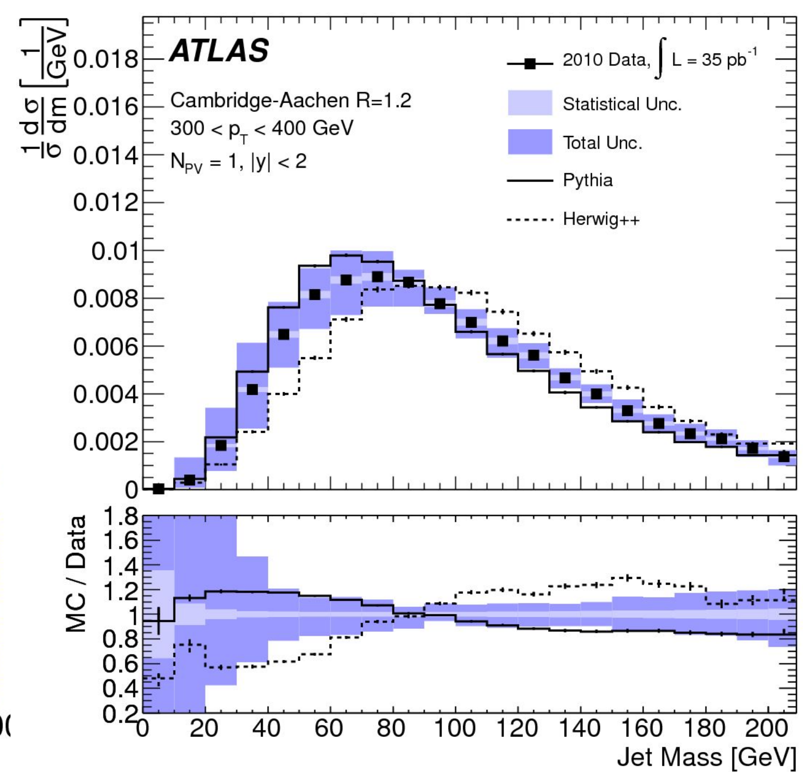
JHEP 05 (2012) 128

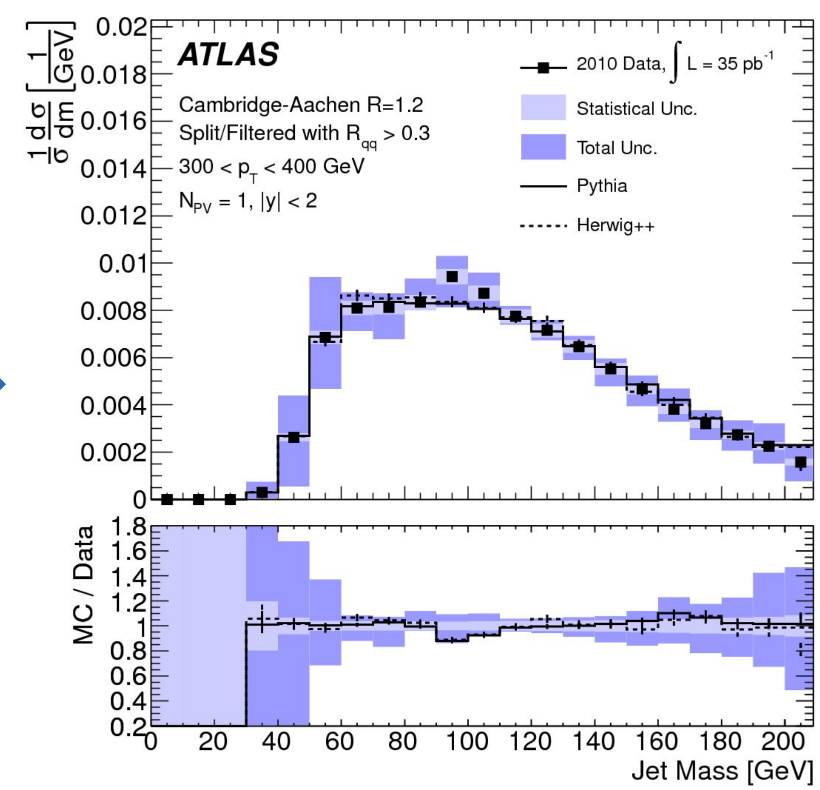
- Measure mass of jets, clustered by anti-kT R=1.0 and Cambridge-Aachen R=1.2.
  - Jet p_T 200 - 600 GeV, $|y|<2$
- NLO predictions generally agree with overall shape:
  - Pythia tends to be too soft.
  - Herwig++ tends to be too hard.
- Applying splitting and filtering improves the agreement.



PRL 100, 242001 (2008)







Properties of boosted jets

- Variables designed for new physics searches are generally well modelled by Pythia, while Herwig++ 2.4.2 predicts a more isotropic energy flow.

ATLAS-CONF-2012-044

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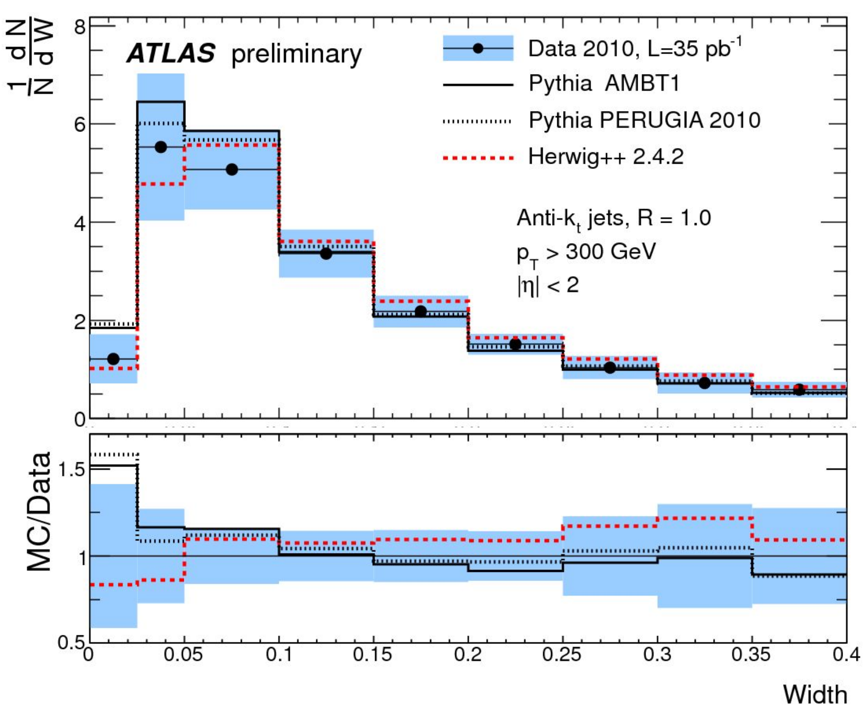
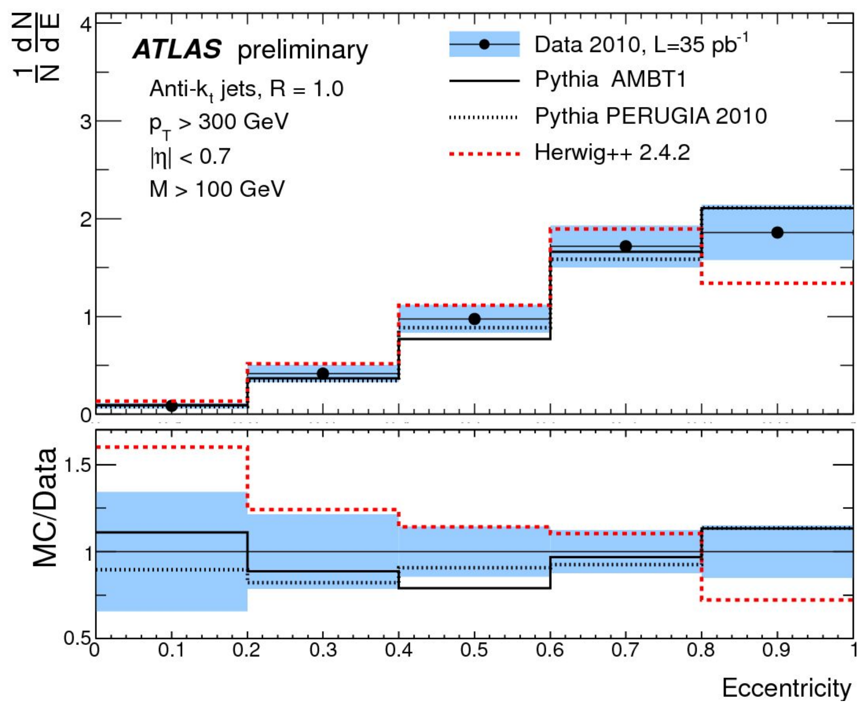
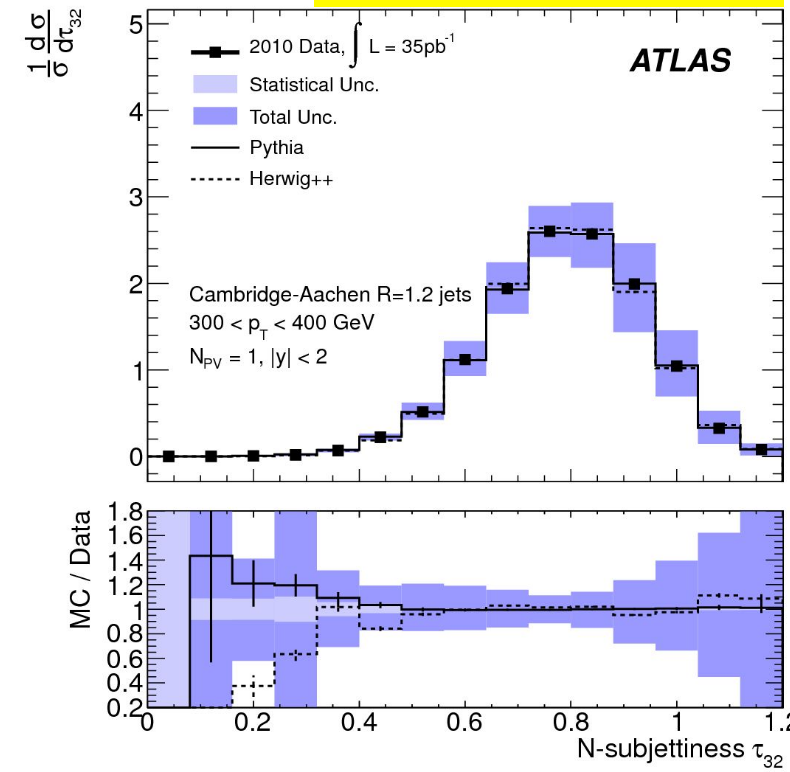
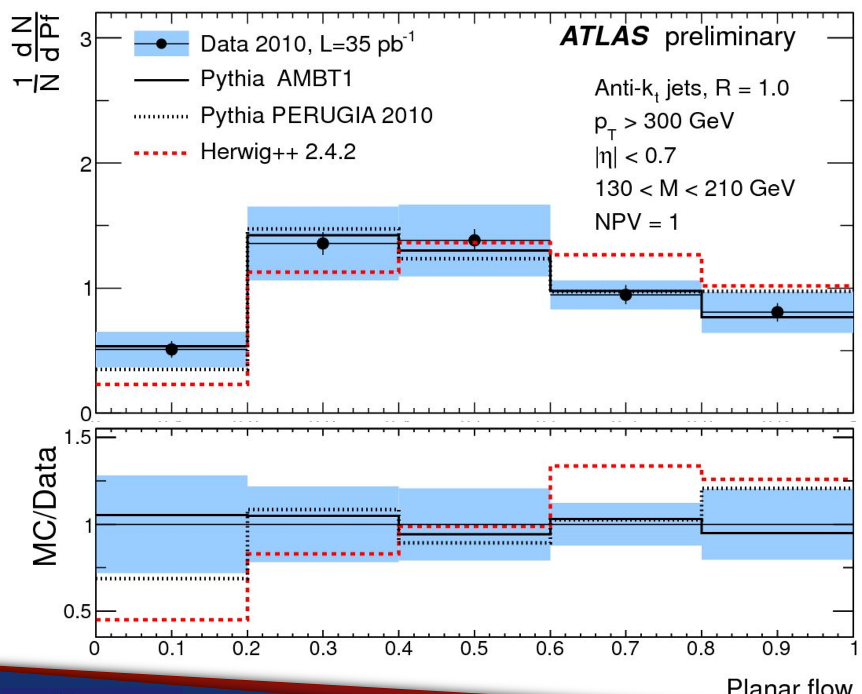
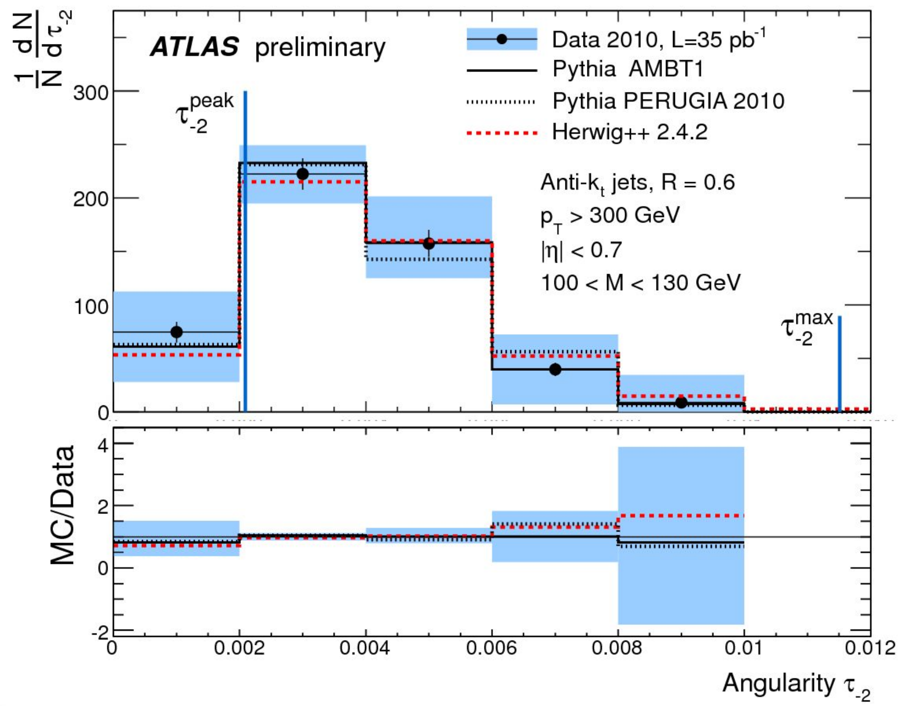
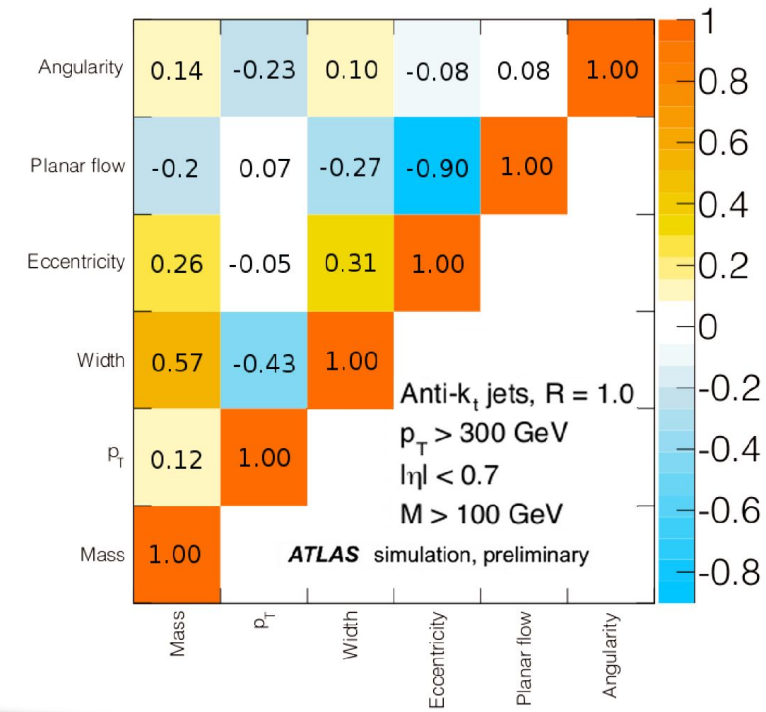












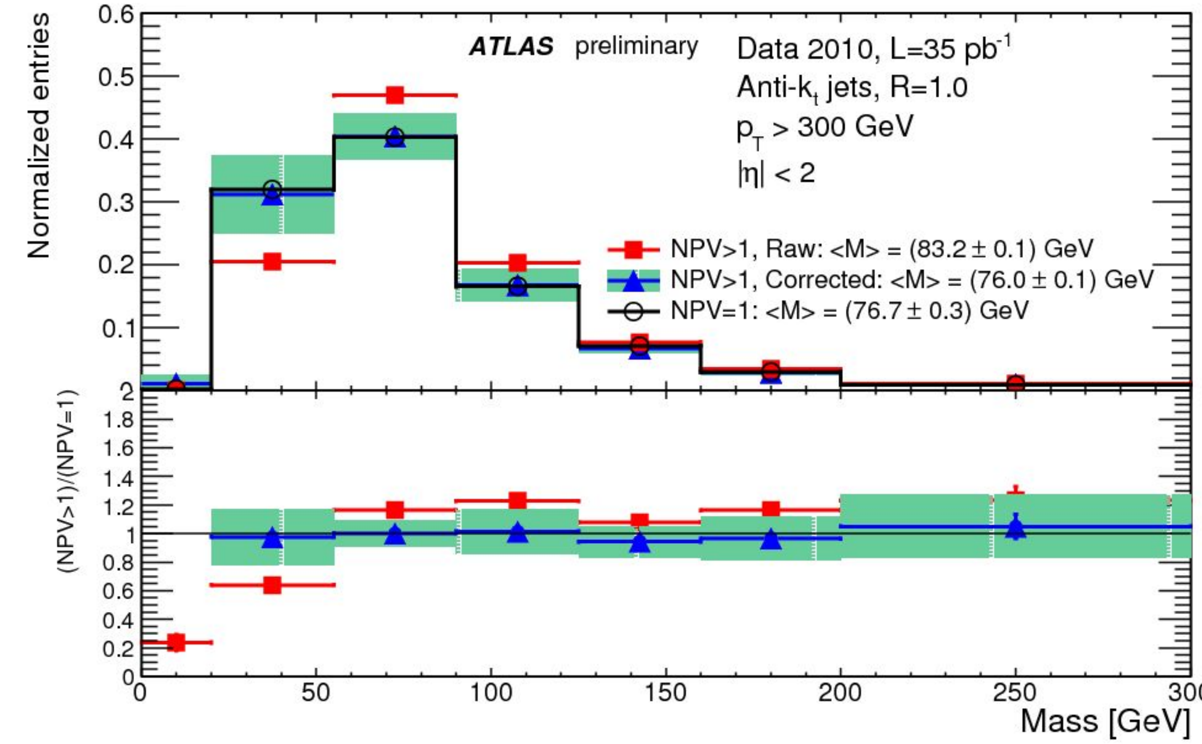
Pile-up corretions

- Correct overlap from multiple proton-proton interactions:
  - Data-driven *complementary cone* method applied to individual variables.

    Phys. Rev. D 84, 114025 (2011)
  - *Splitting and filtering* largely eliminates dependence of jet mass on pile-up.

    PRL 100, 242001 (2008)

ATLAS-CONF-2012-044



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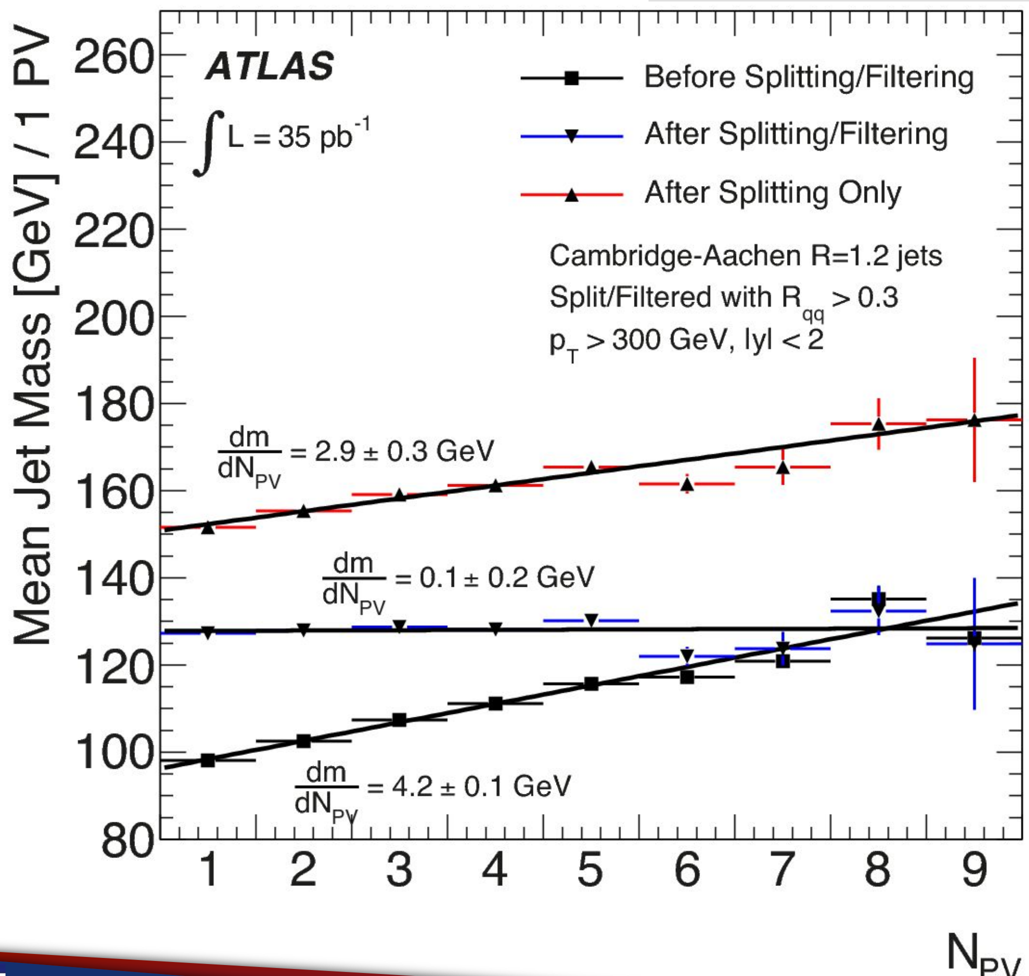

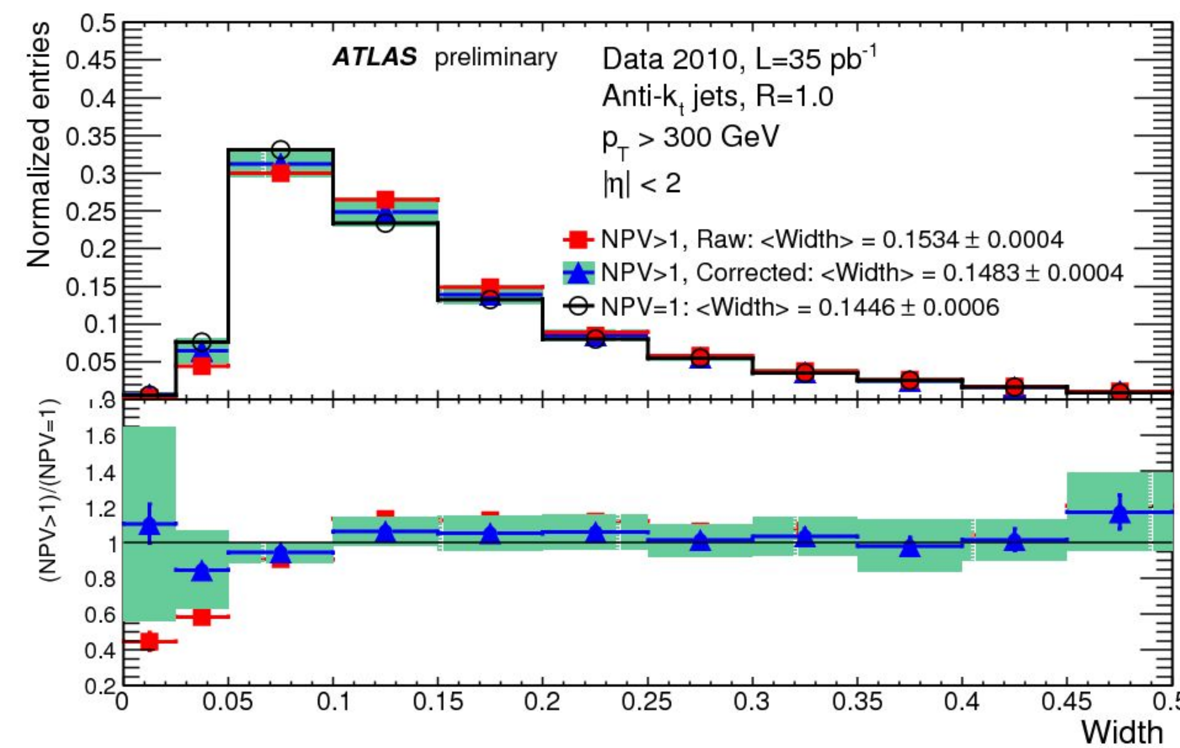

Summary and outlook

- Comprehensive measurements of photons, jets and subjets provide precision tests of perturbative QCD in a new kinematic regime.
- Photon and diphoton cross-sections highlight regions where modelling can be improved, e.g. low $E_T^{\gamma} < 45$ GeV region.
  - Inputs helped to constrain gluon PDFs and reduce uncertainty by up to 20%.
  - Diphoton: $\gamma\gamma$NNLO needed for best agreement.
- Extended range of inclusive and dijet cross-sections measurements with 2010 and 2011 data:
  - Good agreement with NLO pQCD over many orders of magnitude.
  - Parton shower tunes constrained for high mass dijets.
- Many jet substructure observables have been measured in 2010 data:
  - Great progress in understanding jet substructure techniques.
  - Useful for identifying boosted hadronic topologies in searches for new physics in 2011 and 2012 data.

Back up

Further studies

- Jets with flavour:
  - Measurements of $D^{*+/-}$ meson production in jets: Phys. Rev. D85 (2012) 052005
    - ➢ see poster by Andrea Ferretto Parodi: *"Measuring the b-jet tagging efficiency on c-jets containing D* mesons with ATLAS data"*
  - b-jet inclusive and dijet cross-sections: Eur.Phys.J.C 71 (2011) 1846
    - ➢ see Peter Krieger's talk: *"Inclusive jet and multijet physics"*