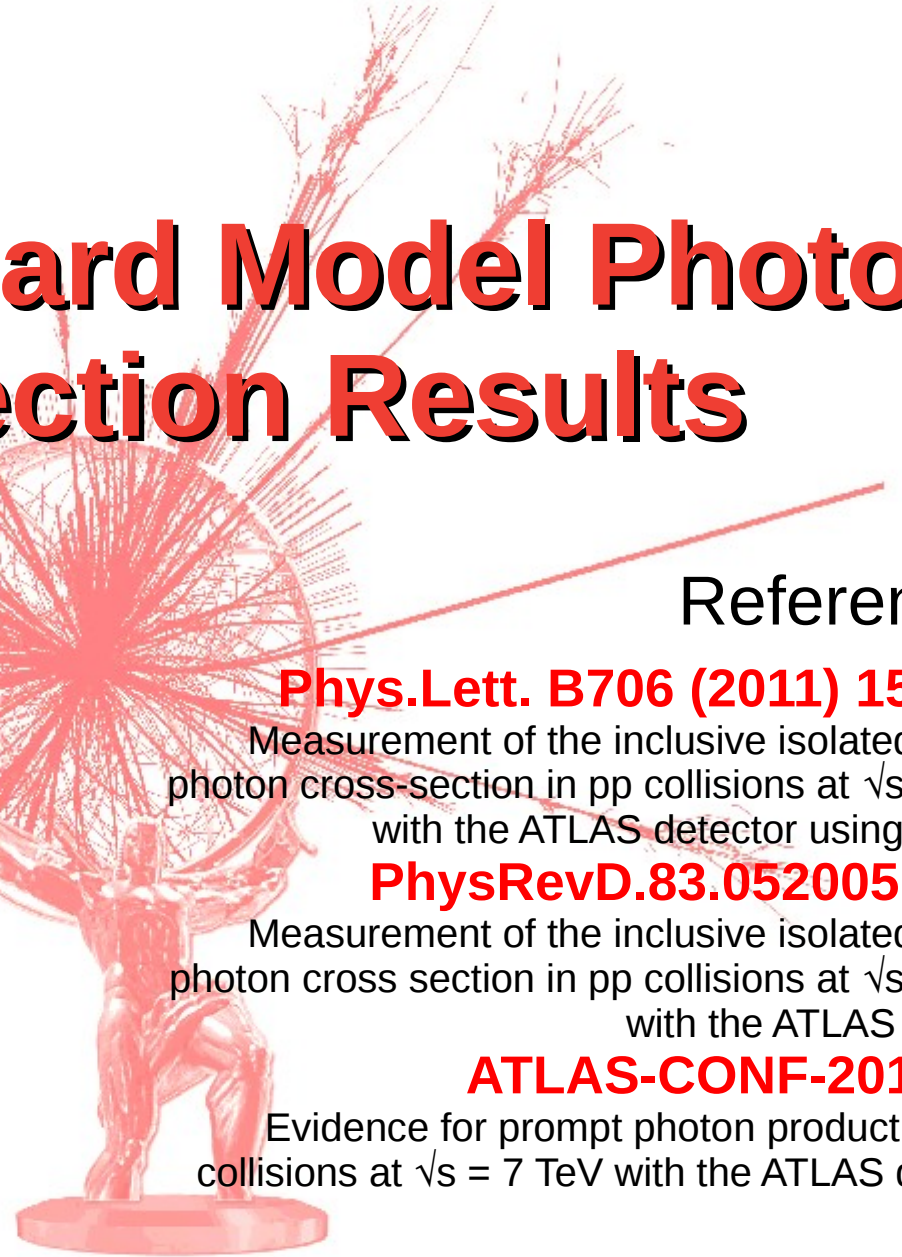
ATLAS Standard Model Photon Cross Section Results



Outline:

- Motivation
- ATLAS detector
- Efficiencies
- Purity
- NLO theory
- Inclusive Cross-section

References:

Phys.Lett. B706 (2011) 150-167
Measurement of the inclusive isolated prompt photon cross-section in pp collisions at √s = 7 TeV with the ATLAS detector using 35 pb-1

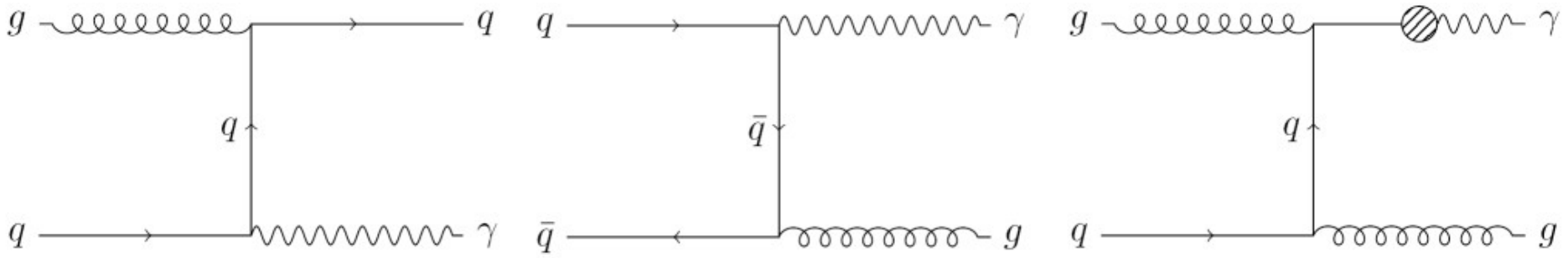
PhysRevD.83.052005(2011)
Measurement of the inclusive isolated prompt photon cross section in pp collisions at √s = 7 TeV with the ATLAS detector

ATLAS-CONF-2010-077
Evidence for prompt photon production in pp collisions at √s = 7 TeV with the ATLAS detector

Motivation

- Prompt photon production is a useful test of perturbative QCD
- Gaining a deeper understanding of this process is essential for searches for new physics
- Differential cross-section measurements of photon production can be used to constrain parton density functions
- Processes:

  Compton scattering, annihilation and fragmentation



Measurement details

- Two inclusive prompt photon measurements carried out with 2010 7TeV pp collision data

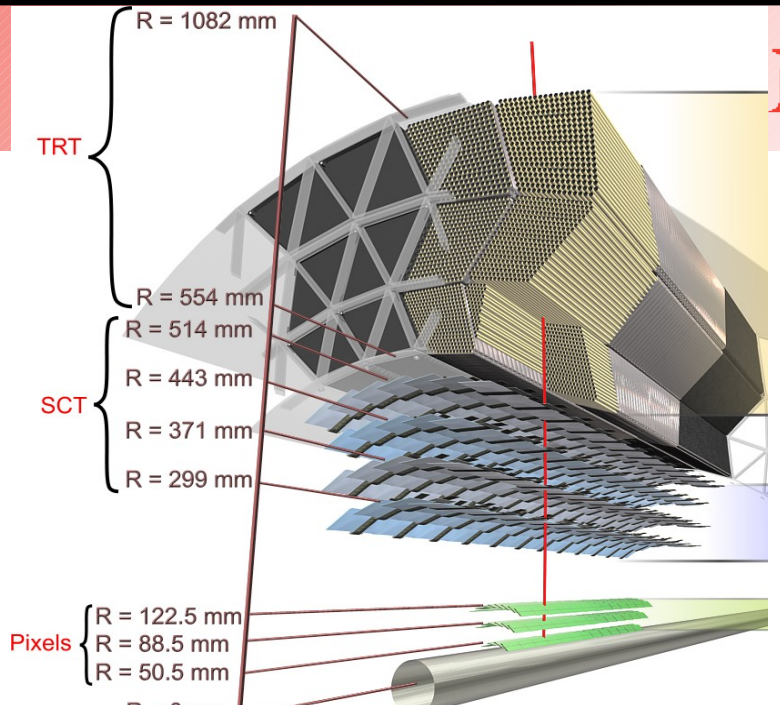
Data	$880nb^{-1}$	$35pb^{-1}$
E_T	15-100 GeV	45-400 GeV
$\|\eta\|$	$\|\eta\|<0.6$ $0.6<\|\eta\|<1.37$ $1.52<\|\eta\|<1.81$	$\|\eta\|<0.6$ $0.6<\|\eta\|<1.37$ $1.52<\|\eta\|<1.81$ $1.81<\|\eta\|<2.37$

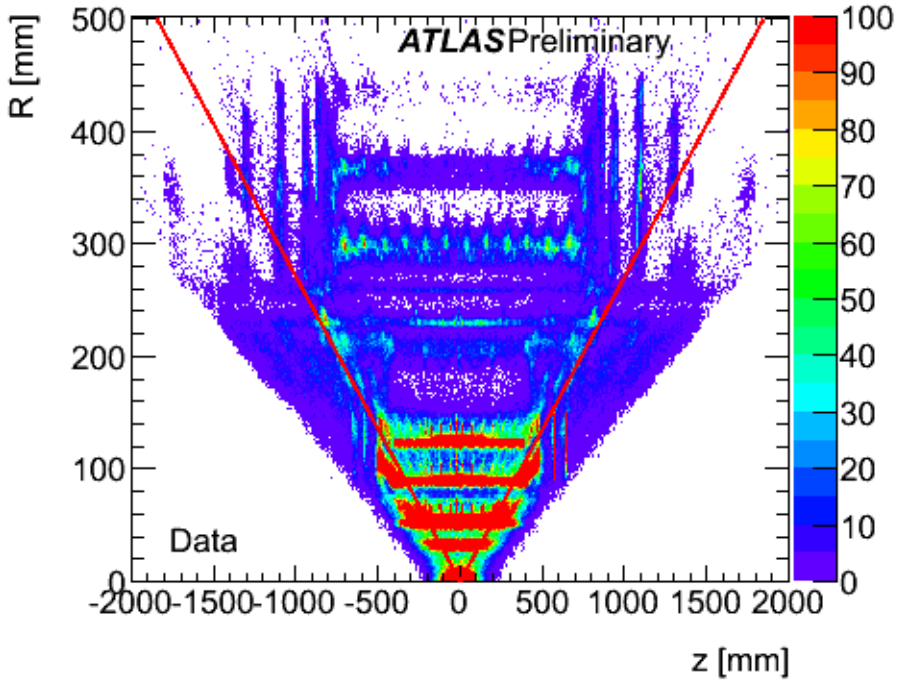
- Also apply isolation in a cone of $\Delta R=(\Delta\eta^2+\Delta\phi^2)=0.4$
  - 4GeV at parton/particle level and 3GeV at experimental
  - Reduces the main QCD backgrounds along with the fragmentation contribution
    - ~30% of total σ at 15GeV

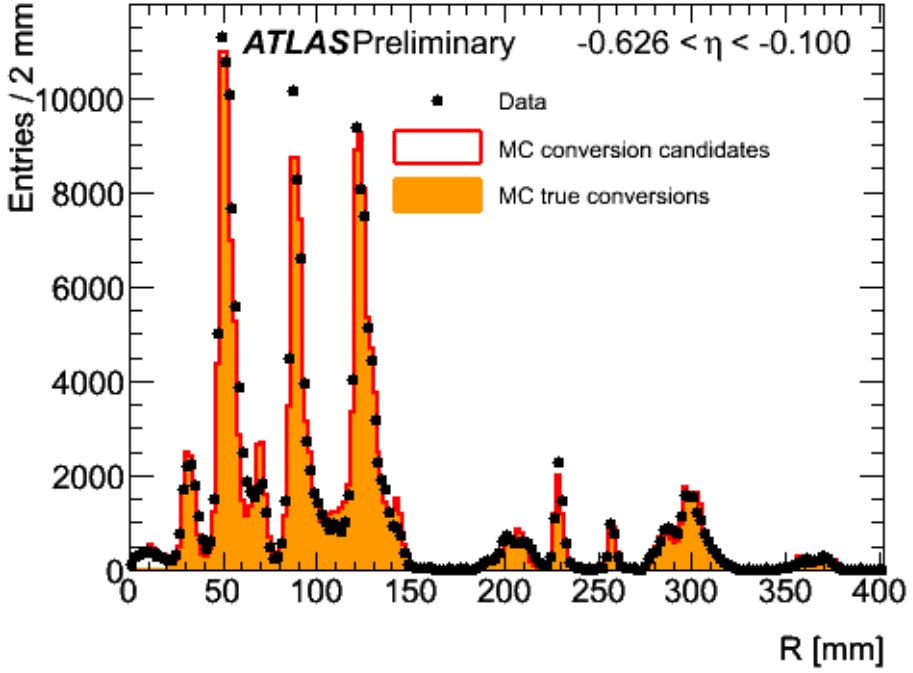
Conversions

McGill

- The Inner detector consists of pixel, semi-conductor and transition radiation trackers
- Leads to photon conversions
- Dedicated algorithms reconstruct these vertices
- Useful to map out the detector material



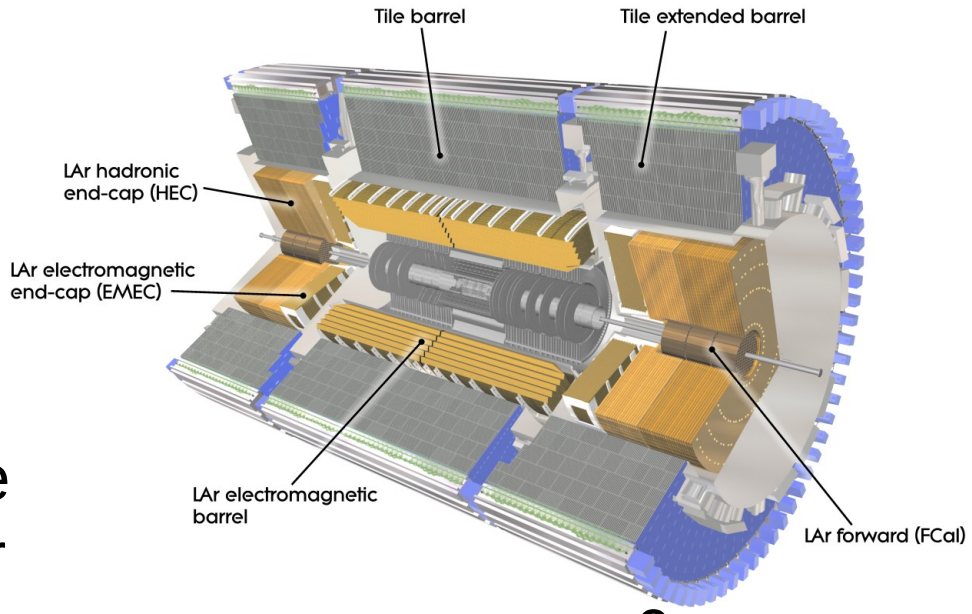


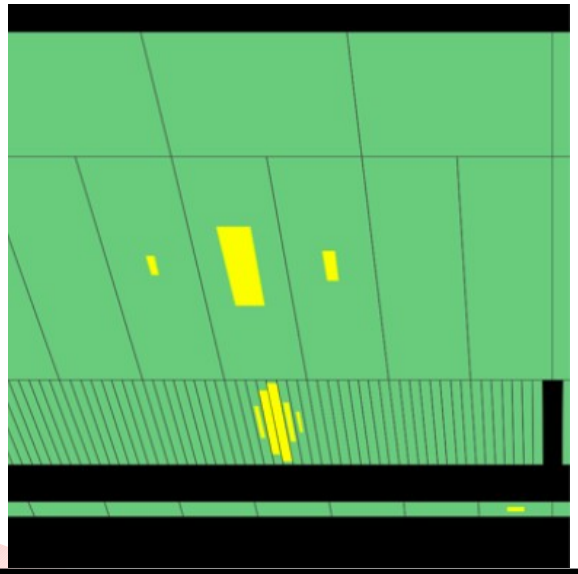


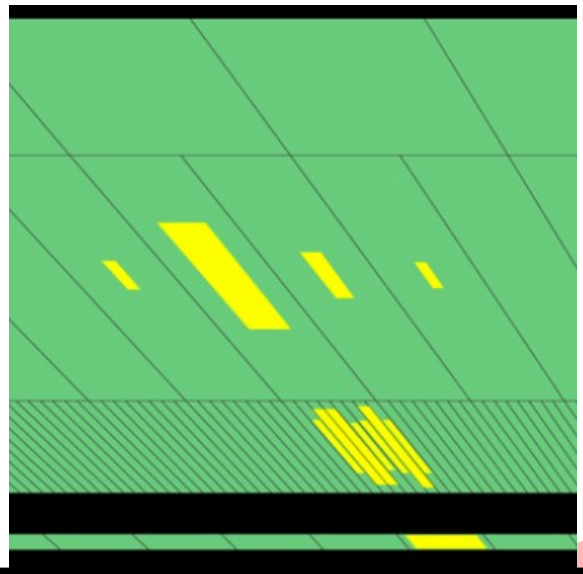
ATLAS Calorimeters

McGill

- The Calorimeters are split into electromagnetic and hadronic parts (in 2011: 99.9% and 98.8% operational respectively)
- For photon measurements the fine segmentation of the electromagnetic calorimeter allows discrimination between photons (left) and π^0s (right)

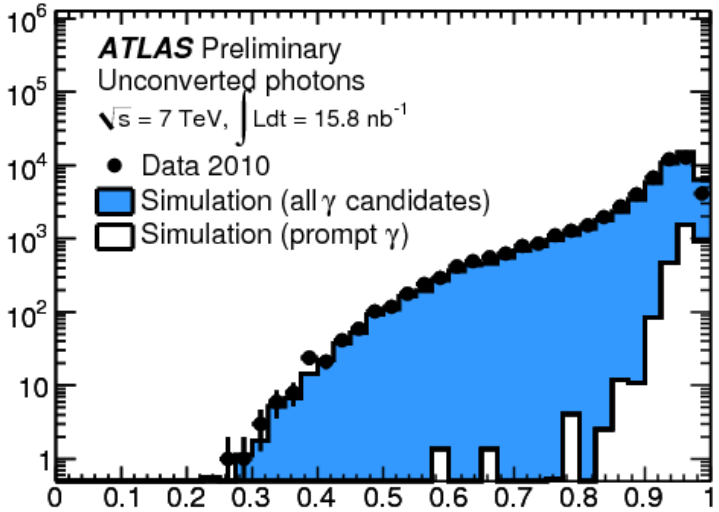






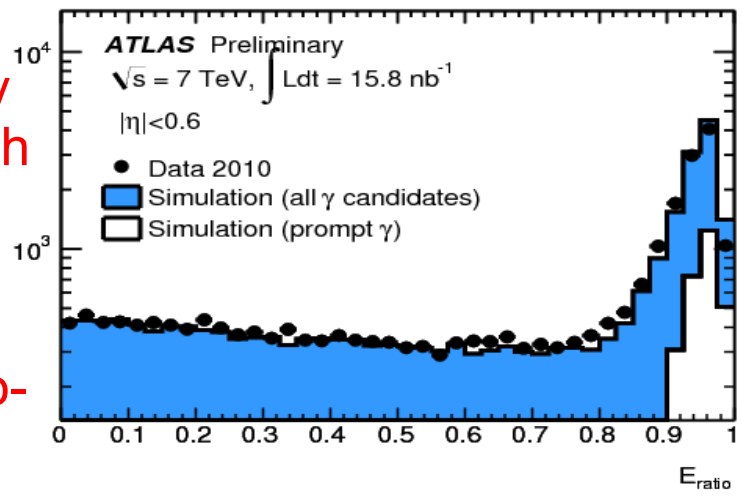
Photon selection

- Calorimeter clusters are selected by running a sliding window algorithm in 5x5 cells
  - Cluster sizes: unconverted photons (3x5), converted photons (3x7) and electrons (3x7, identified by associated track)
  - Cluster energy is calibrated offline
- Apply tight photon ID selection, uses shower profiles in the 1st and 2nd layers to separate photons from π^0s



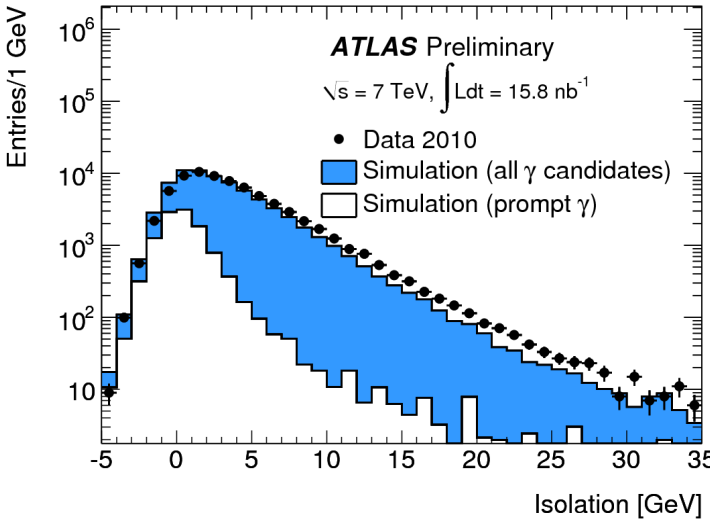
Left:
2nd layer energy distribution, width in η

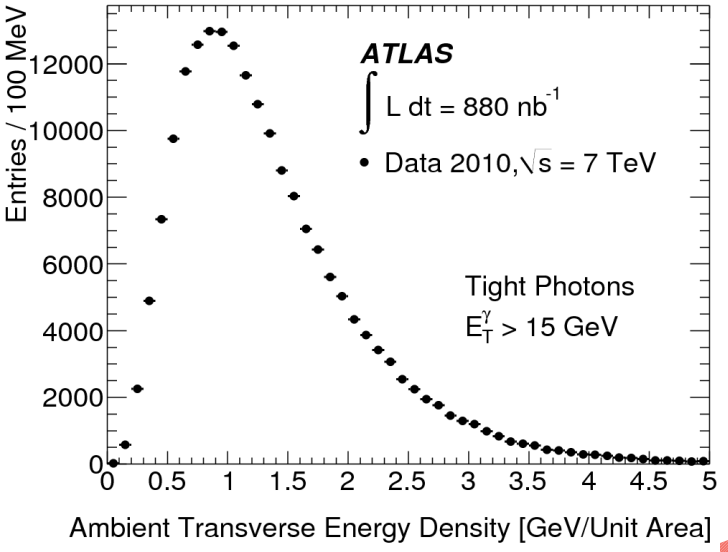
Right:
1st layer peak–to-trough ratio



Photon Isolation

- 3GeV isolation cut on the sum of cells outside the central core within $\Delta R=0.4$
- Subtract out of core leakage
- Correct for non-perturbative effects (pileup and underlying event)
  - Use a technique of calculating the event ambient energy from low p_T jet areas [1]
  - For events with 1 primary vertex: Pythia 440MeV, Herwig 550MeV and Data 540MeV
  - Scales linearly with # primary vertices





[1] M. Cacciari, G. P. Salam, and S. Sapeta, On the characterisation of the underlying event, JHEP 04 (2010) 065, arXiv:0912.4926

Cross-section

- The elements used to calculate the cross-section are:

$$\frac{d\sigma}{dE_T} = \frac{N.Purity.Unfolding}{(\int L dt).\Delta E_T.\varepsilon_{trigger}.\varepsilon_{reco}.\varepsilon_{ID}}$$

- Trigger Efficiency:
  - 99.5% (for 10GeV) and 99.4% (for 40GeV) (±0.5%)
- Reco Efficiency: (from MC)
  - MC photons have particle isolation of 4GeV
  - ~80-85% $|\eta|<1.37$ and ~70% $1.52|\eta|<2.37$
  - Significant part of inefficiency (dead readout) recovered during 2010 winter shutdown
  - Errors in measurement from:
    - Extra material (1-2%)
    - Generator, fragmentation fraction (<2%)
    - Exeprimental isolation efficiency (3-4%)

Cross-section (2)

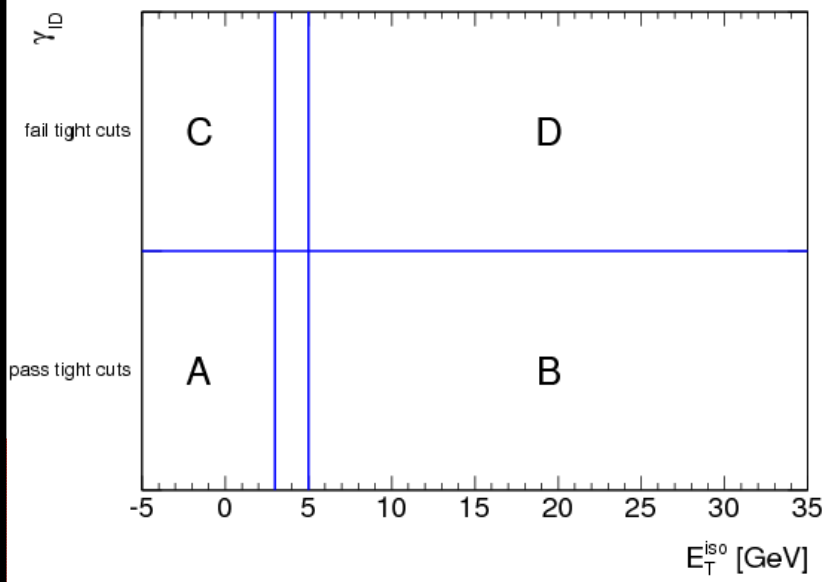
- The elements used to calculate the cross-section are:

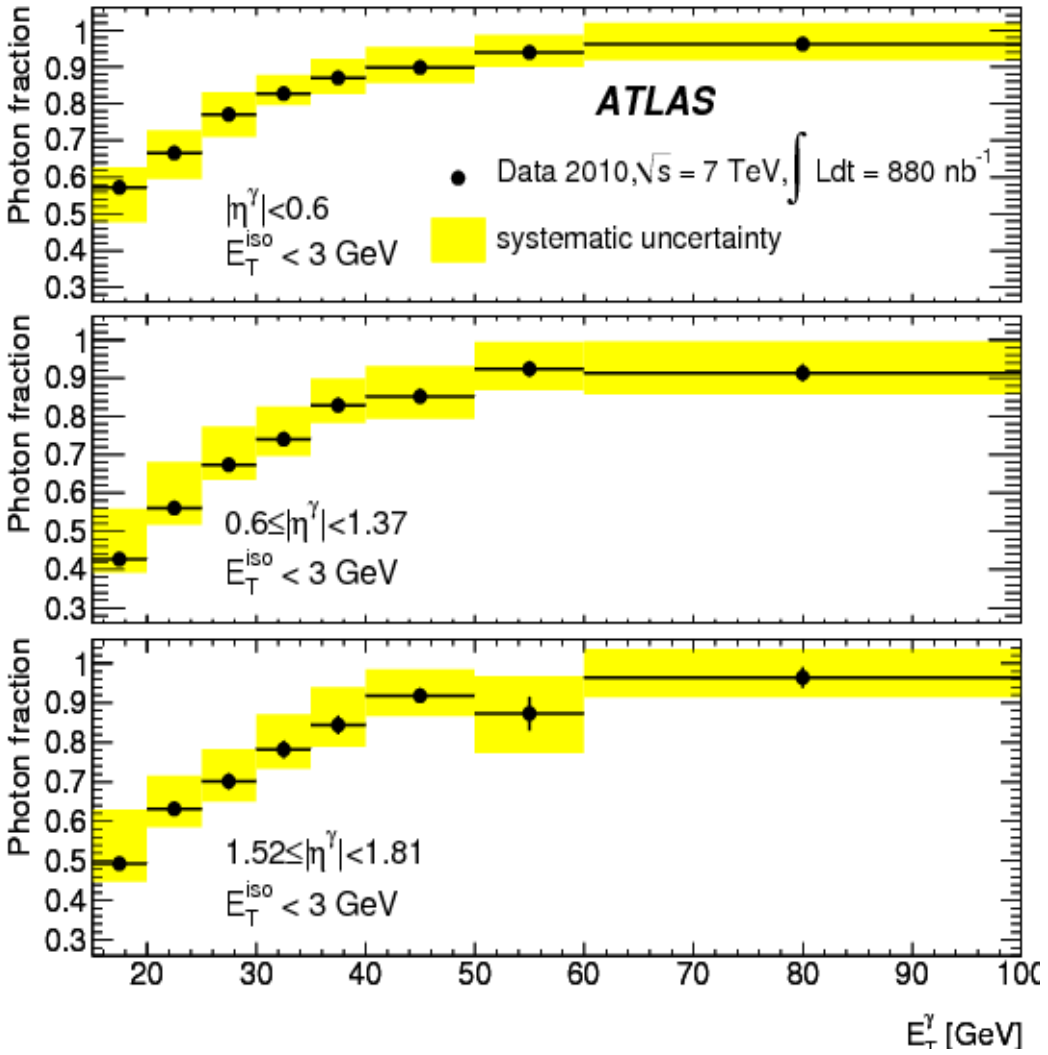
$$\frac{d\sigma}{dE_T} = \frac{N.Purity.Unfolding}{(\int L dt).\Delta E_T.\varepsilon_{trigger}.\varepsilon_{reco}.\varepsilon_{ID}}$$

- ID Efficiency:
  - ~60% at 15GeV rising to 90-95% above 45GeV
  - Shift shower-shapes in MC to match data
  - Separate out converted photons ~30% of the candidates
  - Verified from data with $W \rightarrow e\nu$
  - Factors contributing to the uncertainty:
    - Method, selection (~5-2%)
    - Extra material (~6-1%)
    - Pileup, generator (~2-3%)
    - Conversion fraction (~2-1%)
- Unfolding coefficients: (from MC)
  - Takes into account the photon energy resolution
  - EM energy scale: Test-beams (3%) and Z-ee peak (1.5%)
  - Translates into 5-10% on σ

Purity from data

- Use isolation profile
- Reverse some ID cuts (not correlated to iso)
- $N_A^{sig}=N_A-N_B(N_C/N_D)$
- MC used to correct for signal leakage into B/C/D
- Main Uncertainties:
  - MC inputs (<10%)
  - Background control regions (<6%)





- See backup for the full formula and higher p_T results

Theoretical prediction

- Use JetPhox, a standalone NLO photon + X MC
- Calculates σ for all the inclusive processes (direct+fragmentation)
  - No underlying event/pileup
  - Isolation is calculated at the parton level

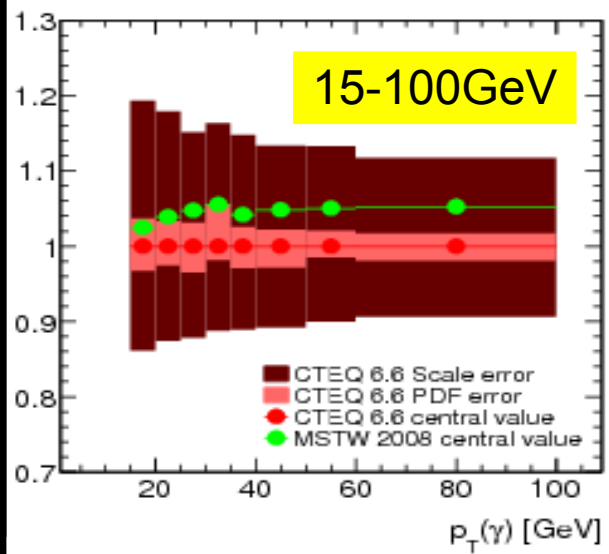
- Isolation cut set to 4GeV in $\Delta R=0.4$
  - Matches the 4GeV particle and 3GeV experimental cuts
  - ~2% error from varying between 2 and 6 GeV

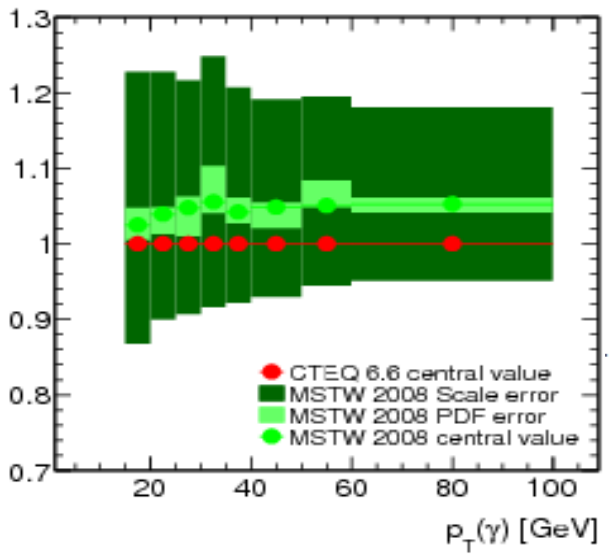
- Use scale setting $\mu_R=\mu_F=\mu_f=E_T^{\gamma}$
  - Largest source of uncertainty (20% reducing to 10%) from varying between $0.5E_T^{\gamma}$ and $2.0E_T^{\gamma}$

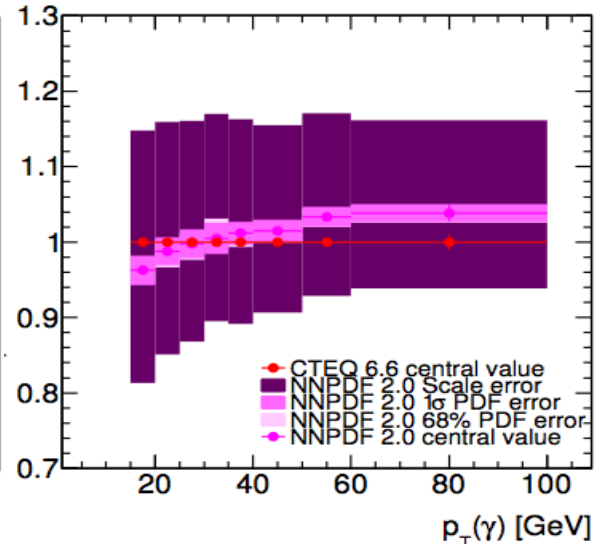
- Central value calculated for CTEQ6.6 PDF
  - ~4% PDF error is calculated by using the eigenvectors
    - Also compare to MSTW2008 and NNPDF2.0

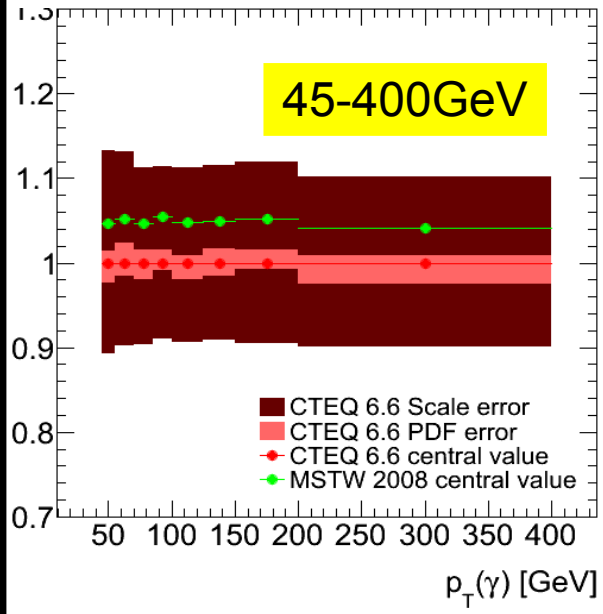
Theoretical prediction(2)

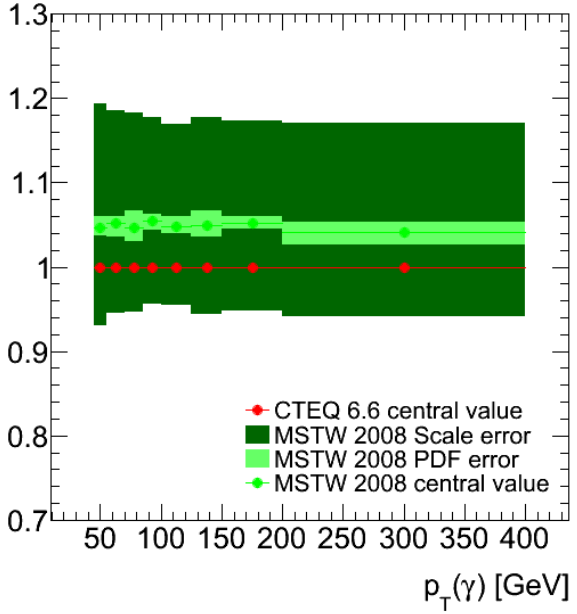
McGill

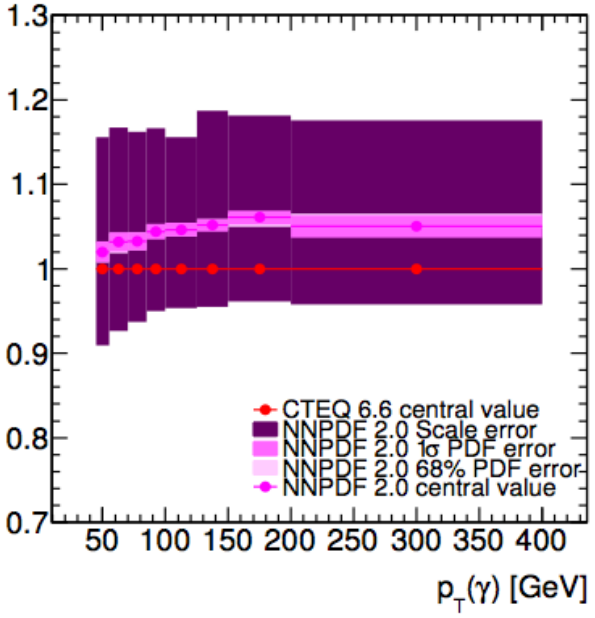






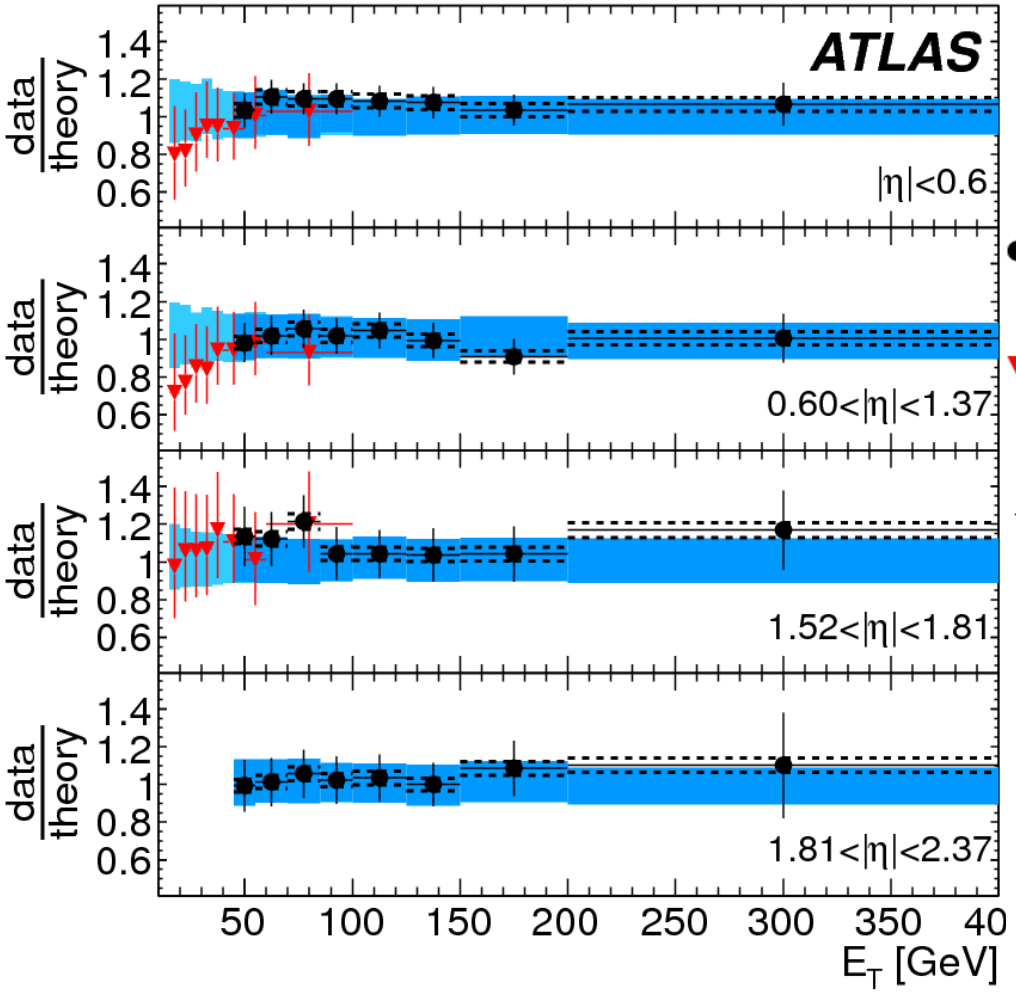






CTEQ MSTW NNPDF

Results wrt CTEQ PDF



p+p→γ+X

√s=7TeV

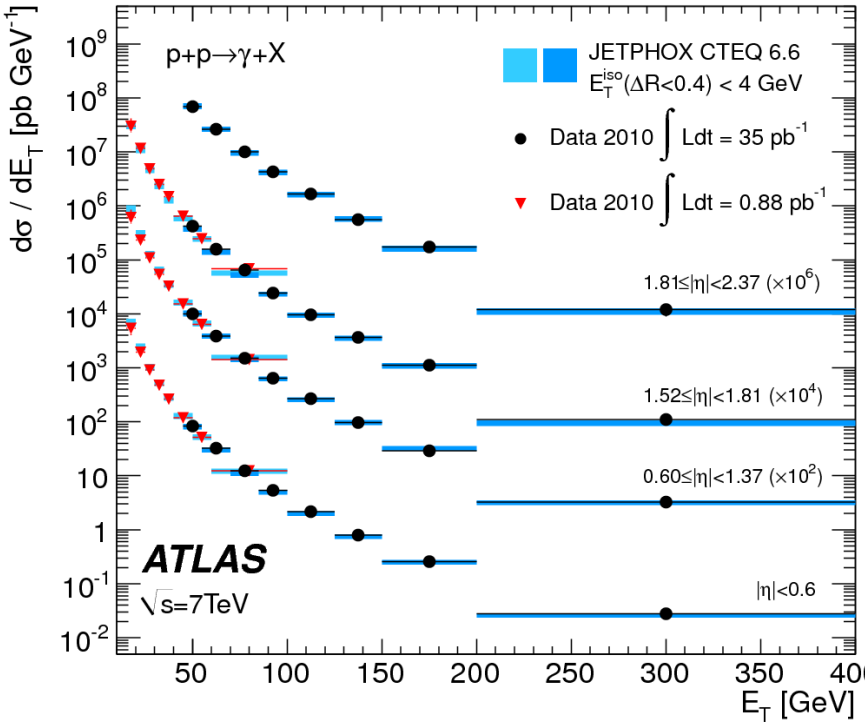
luminosity uncertainty

Data 2010 ∫ Ldt=35 pb^{-1}

Data 2010 ∫ Ldt=0.88 pb^{-1}

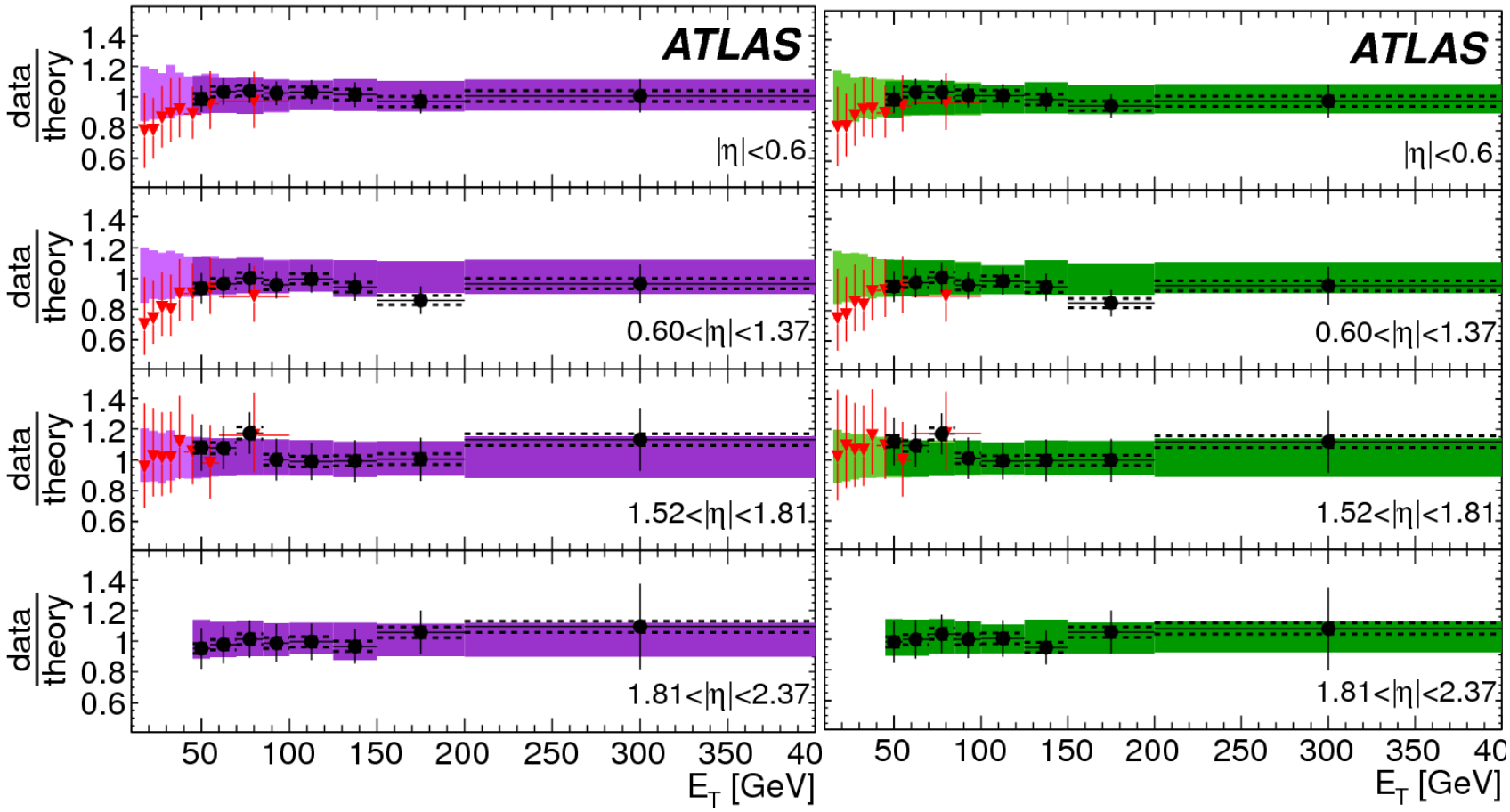
JETPHOX CTEQ 6.6

E_T^{iso}(ΔR<0.4) < 4 GeV



Results wrt other PDFs

McGill

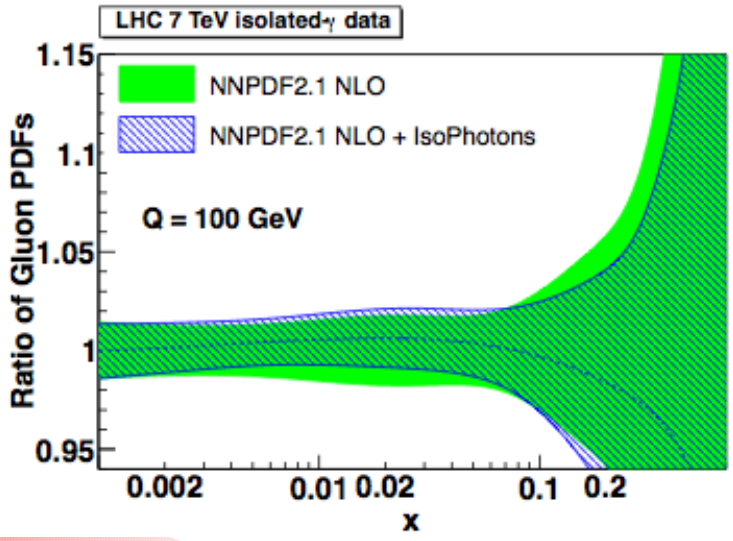


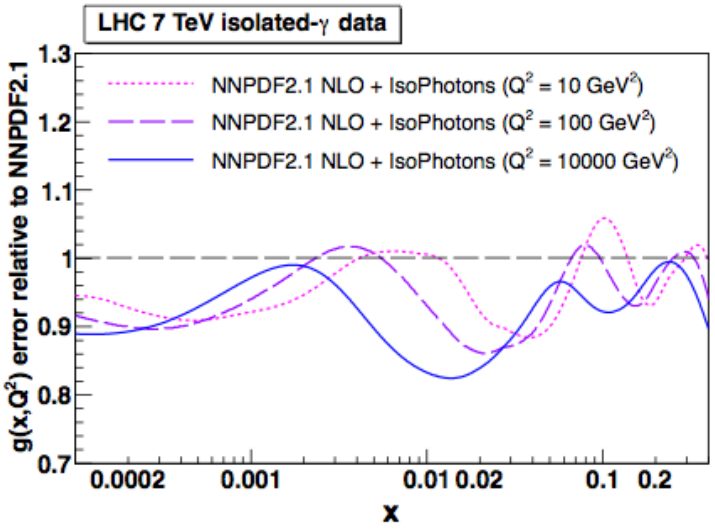
Impact on PDFs

- The last PDF to include photon data was MRST99
  - Mainly due to discrepancies at the Tevatron

- Improvements in understanding photon NLO calculations and by requiring isolated photons we now see agreement (within errors) between NLO and experimental data.

- Our ATLAS (along with CMS and more) results have now been used to see the impact on the gluon PDF (using the NNPDF method)
  - David d'Enterria and Juan Rojo: arXiv:1202.1762v1



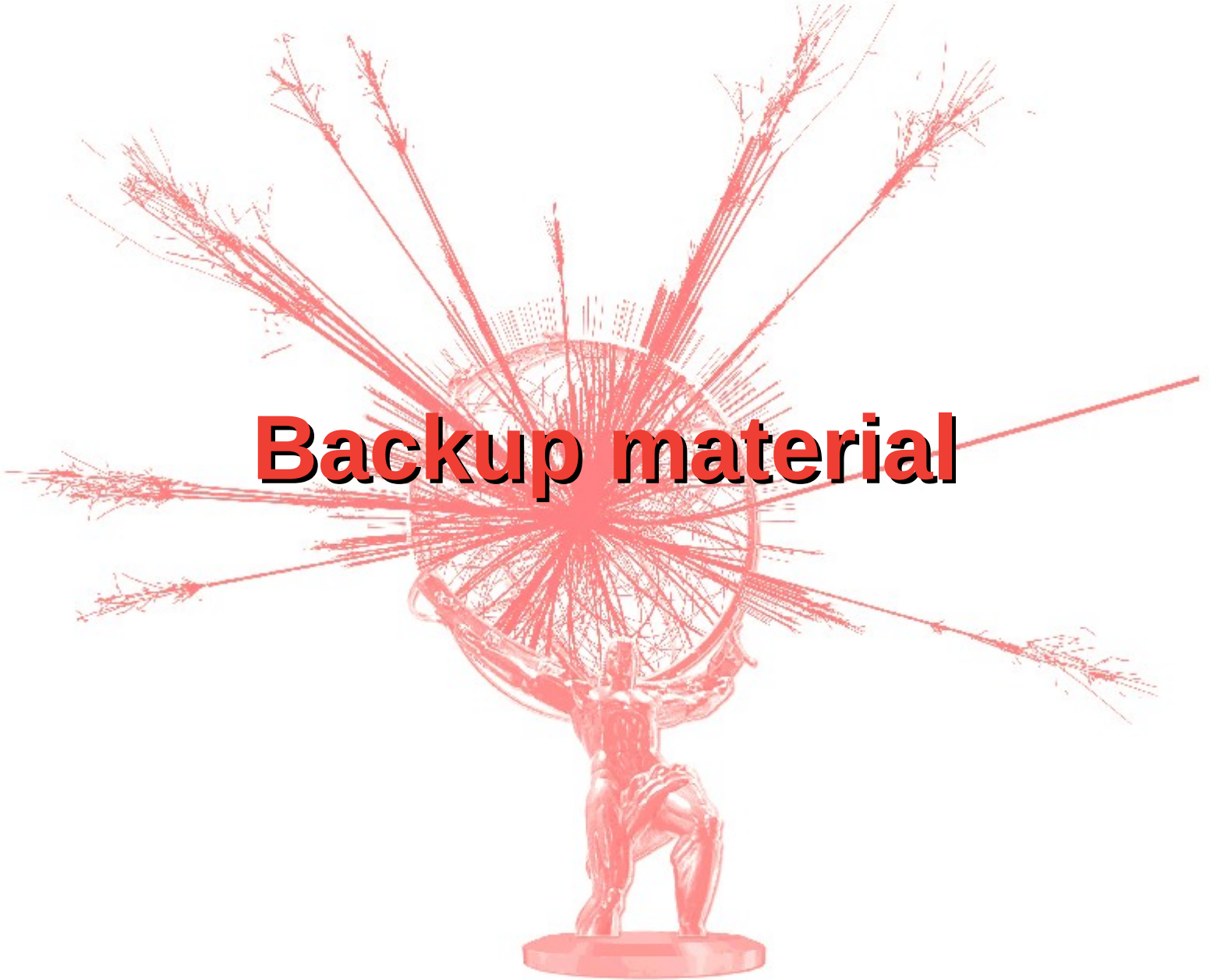


Conclusion

- Inclusive cross-section now reaches E_T^{γ}=400GeV using the full photon η acceptance
  - Very good agreement at high E_T^{γ}
- Observe a lower cross-section than NLO for E_t^{γ}<35GeV
- Result may be used to reduce gluon PDF error by ~10%

Future

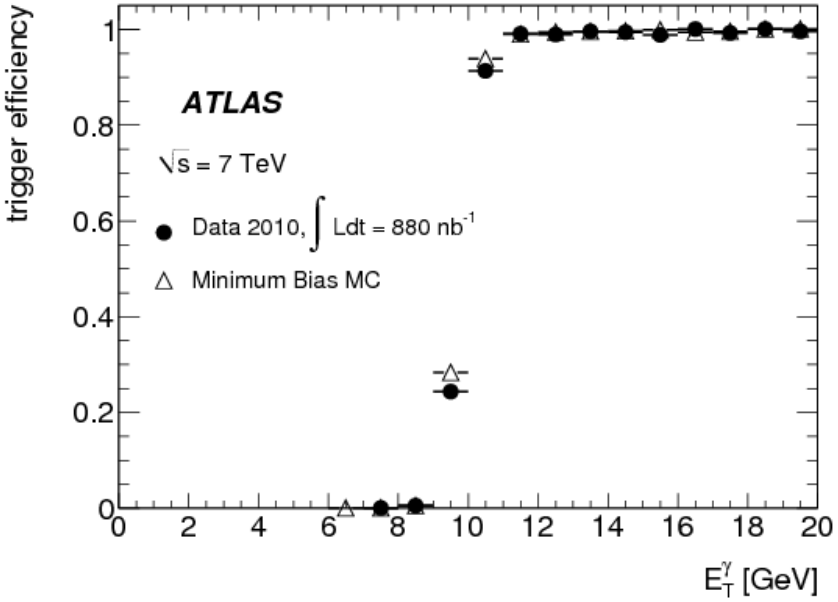
- Analysis will continue to be updated to reach higher E_T^{γ} and also to compare to different theory predictions
  - Alread analysing the 5fb^{-1} of data from 2011
- Other photon QCD measurements:
  - Di-photon Phys.Rev. D85 (2012) 012003
  - Photon+Jet (in preparation)

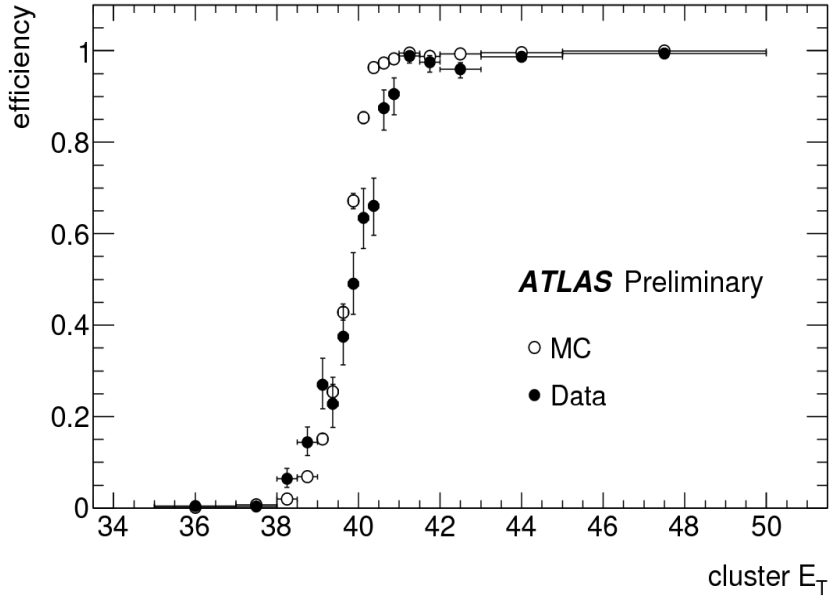


Backup material

Efficiencies

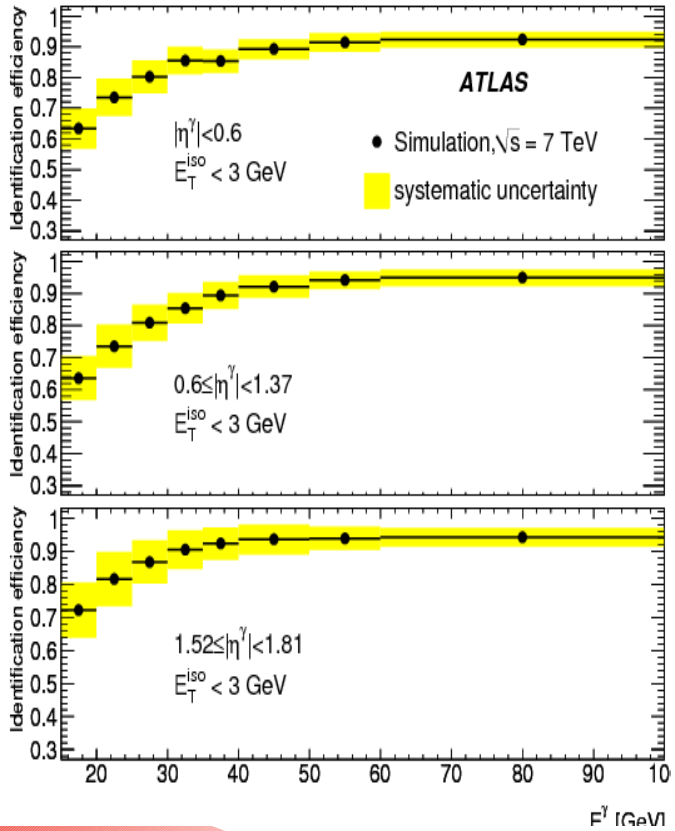
- Trigger: 99.5% (for 10GeV) and 99.4% (for 40GeV)

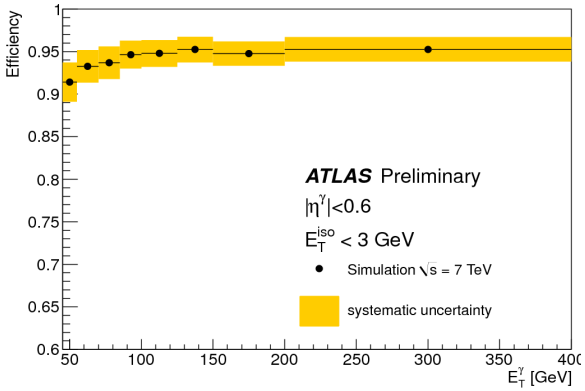


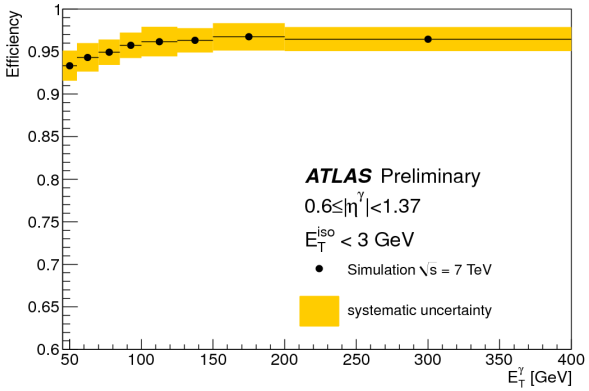


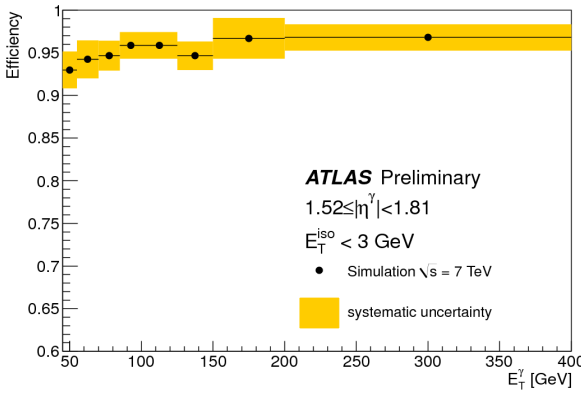
Efficiencies

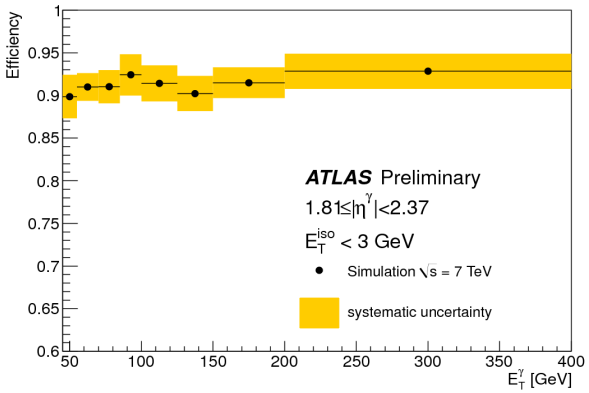
- Offline ID:





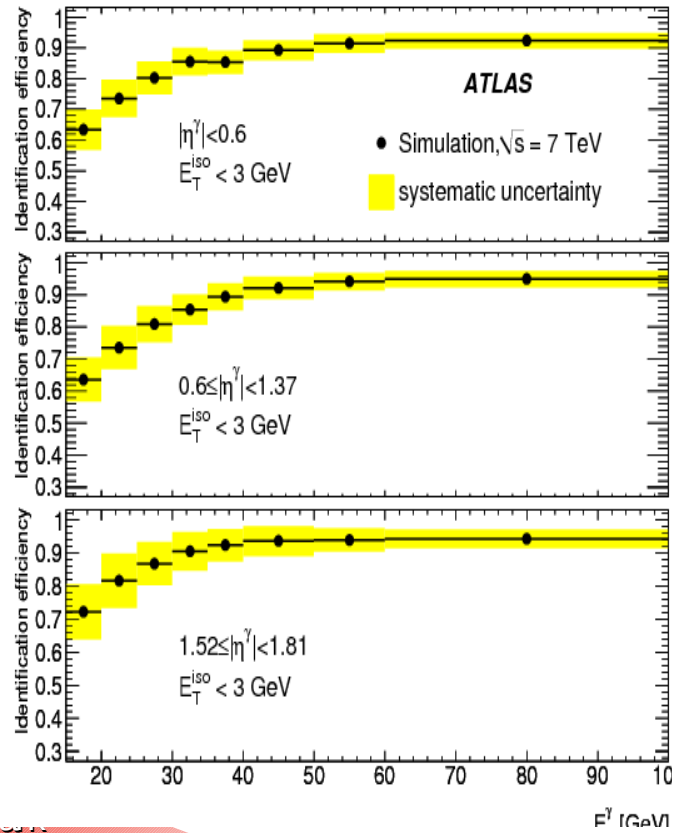


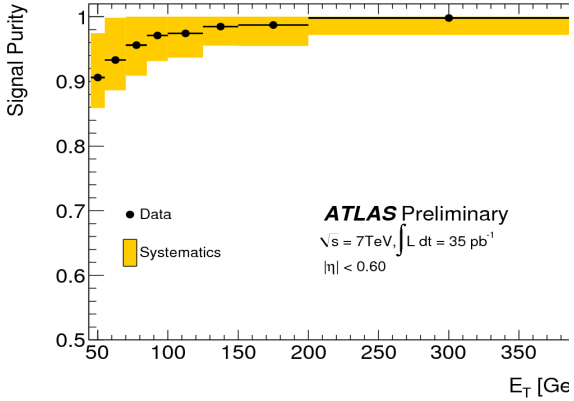


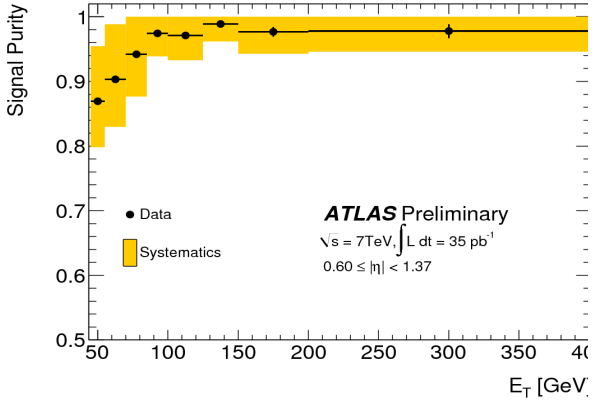


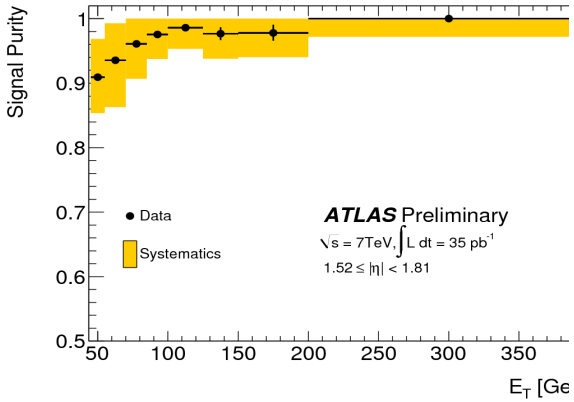
Purity

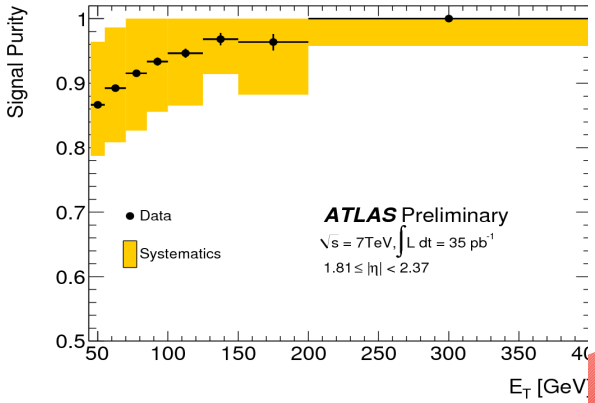
- $N_A^{sig} = N_A - [\ N_A^{bkg} N_D^{bkg} / N_C^{bkg} N_B^{bkg}\ ]\ [\ (N_B^{obs} - N_B^{sig})(N_C^{obs} - N_C^{sig}) / (N_D^{obs} - N_D^{sig})]$
- Results cross-checked with isolation template fit (signal electrons from W/Z in data and bkg photons failing tight ID)
- Isolated electron contamination estimated from data and MC control samples





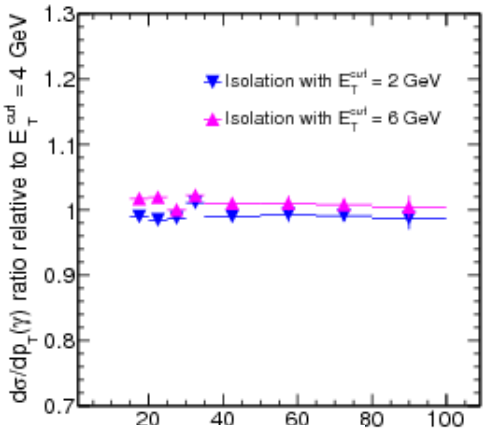




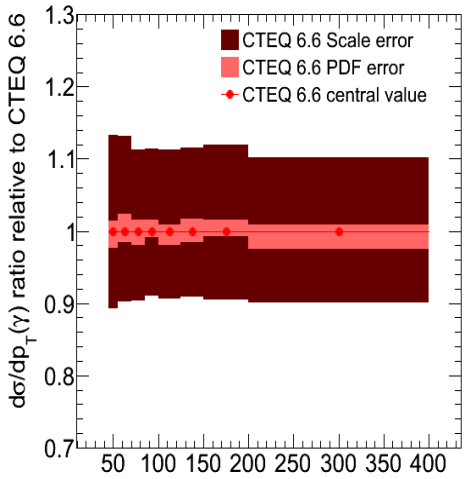


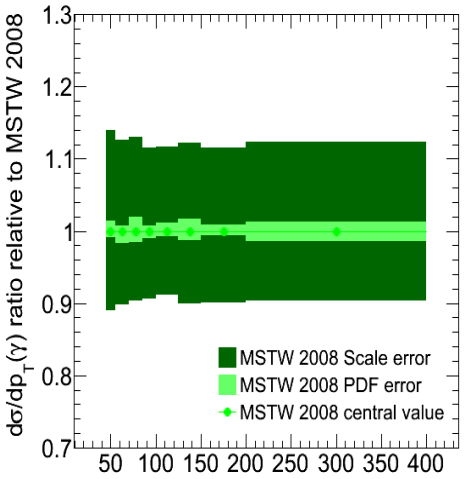
Theoretical prediction

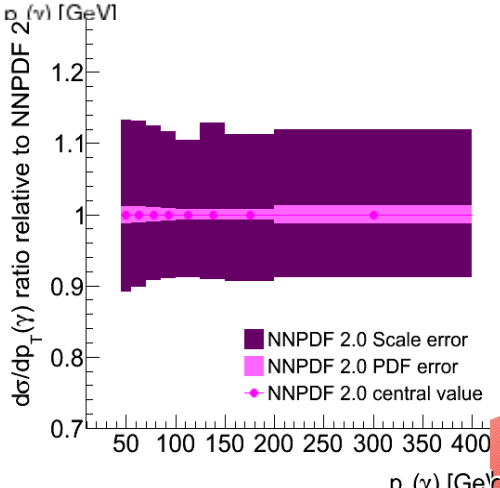
- PDF error:
  - $\sigma^{up}=\sqrt{(\sum_i[\max(evec_i^{up}-central, evec_i^{down}-central, 0)^2])}$
  - $\sigma^{down}=\sqrt{(\sum_i[\max(central-evec_i^{up}, central-evec_i^{down}, 0)^2])}$
- NNPDF ($N_{rep}=100$ = # replicas used)
  - $\sigma^2 = \frac{1}{N_{rep}-1}\sum_i[X_i-\langle X\rangle]^2$
- Isolation error ---------->



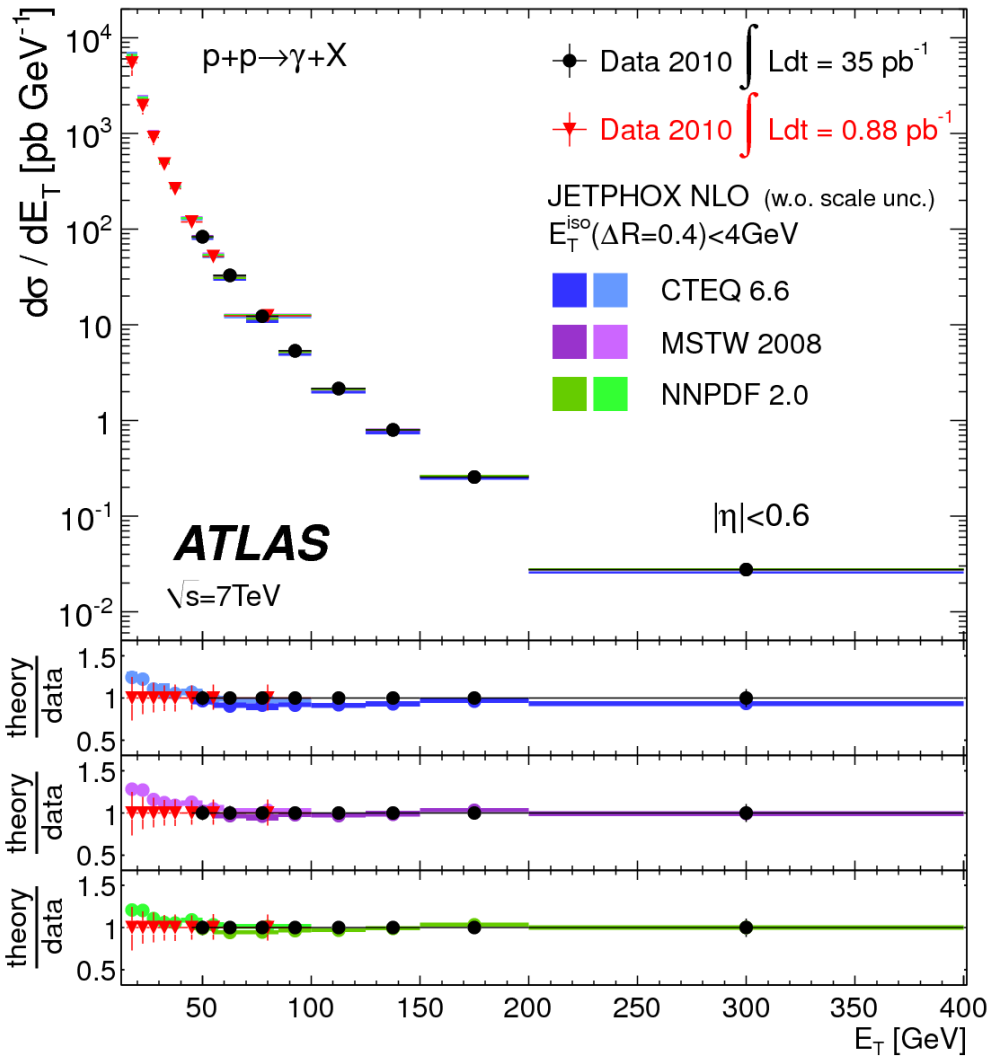
- Relative error:

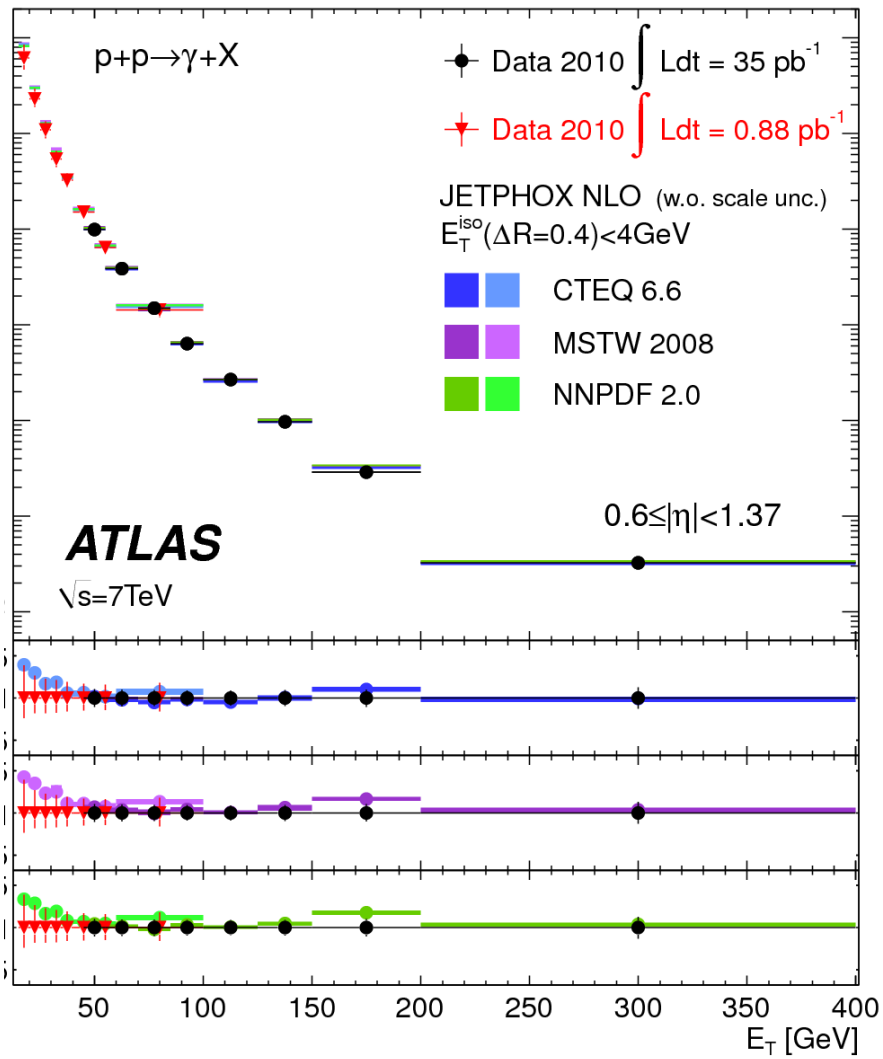






Results with many PDFs





Results with many PDFs