Photon production (direct photon and di-photon) at ATLAS and CMS

Ted Kolberg (UMD) for ATLAS and CMS collaborations

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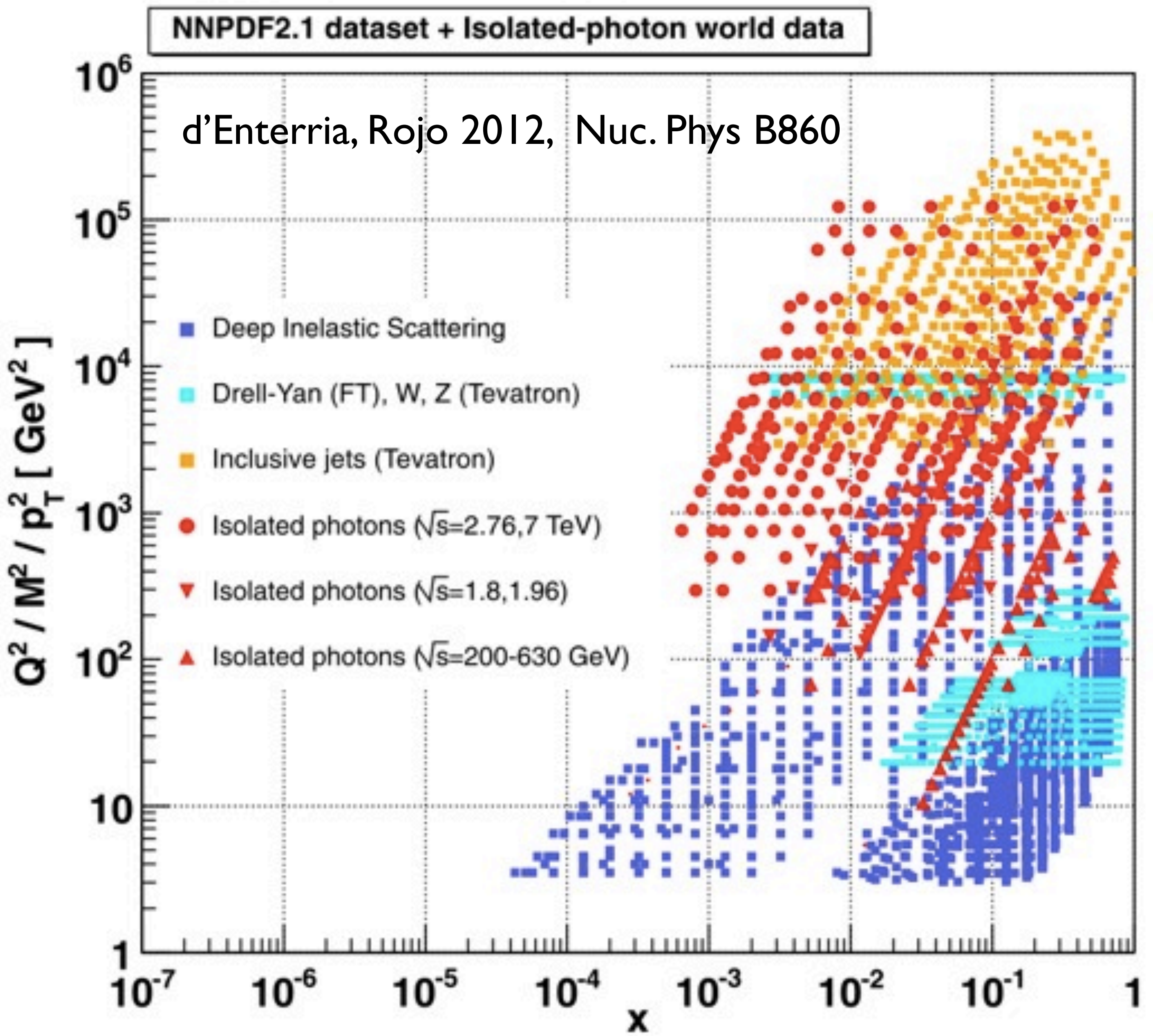
UNIVERSITY OF MARYLAND

Overview

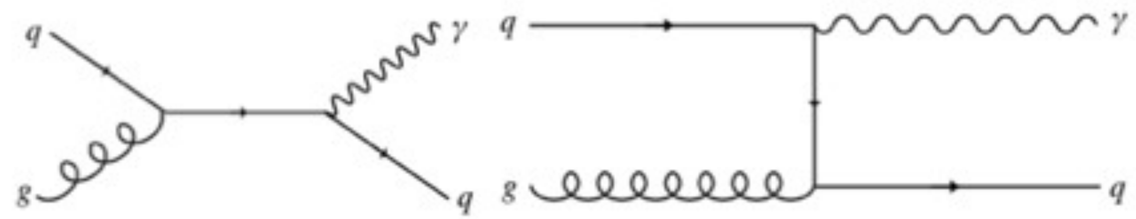
- Why direct (di)photons?
- What are the experimental challenges?
- Photon identification techniques used in the analyses.
- Single and diphoton differential cross section measurements, and comparison of LHC measurements with theoretical predictions.
- Conclusion and outlook.

Why (di)photons?

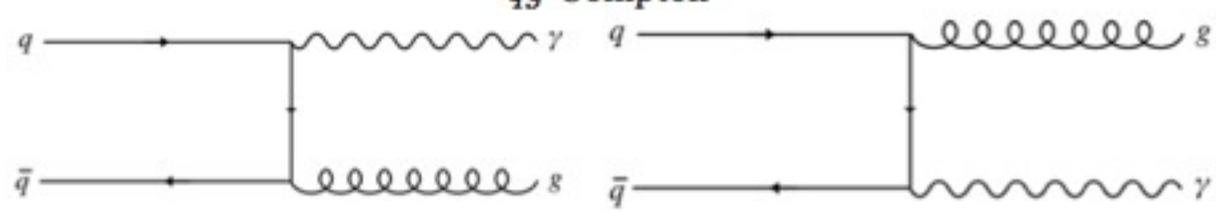
- LHC E_{CM} and CMS/ATLAS detectors allow us to probe new regimes of E_T/x/rapidity when compared with previous generation of experiments. Single photon x/Q_T reach for LHC on right.
- Higgs decay to two photons is a hot topic: direct measurements of photon and diphoton processes can reduce uncertainties on the rate of reducible (photon +jet) and irreducible (QCD diphoton) background processes. In addition
- Study of QCD photon processes at the LHC provides a large cross-section standard candle for understanding photon isolation and identification in the challenging LHC environment, with applications for studying BSM signatures which contain photons in the final state.
- Photon cross section measurements are a classic probe of the structure of the proton, photon+X is especially sensitive to the gluon PDFs. At LHC, "Compton" process dominates over annihilation and fragmentation diagrams (next slide). Photon measurements can reduce gluon PDF uncertainties for gluon fusion *H* production significantly.



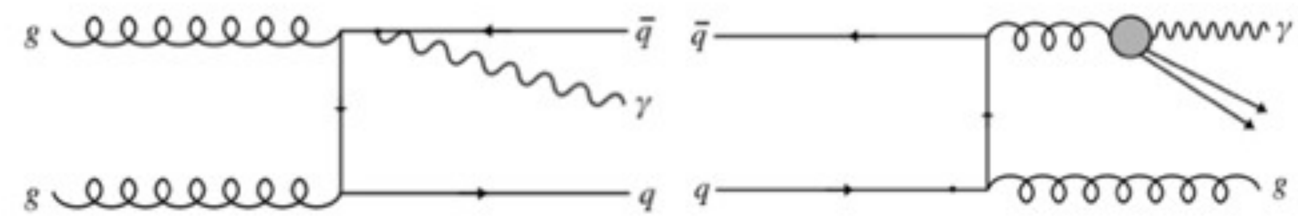
Single photon diagrams



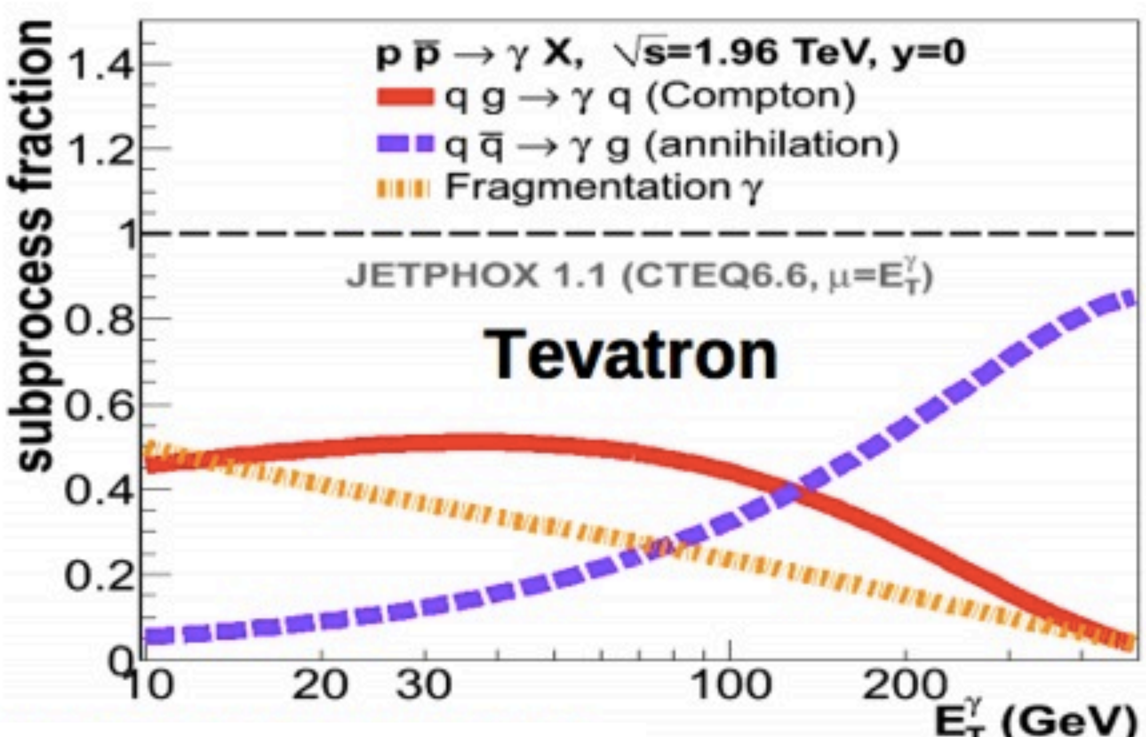
qg Compton

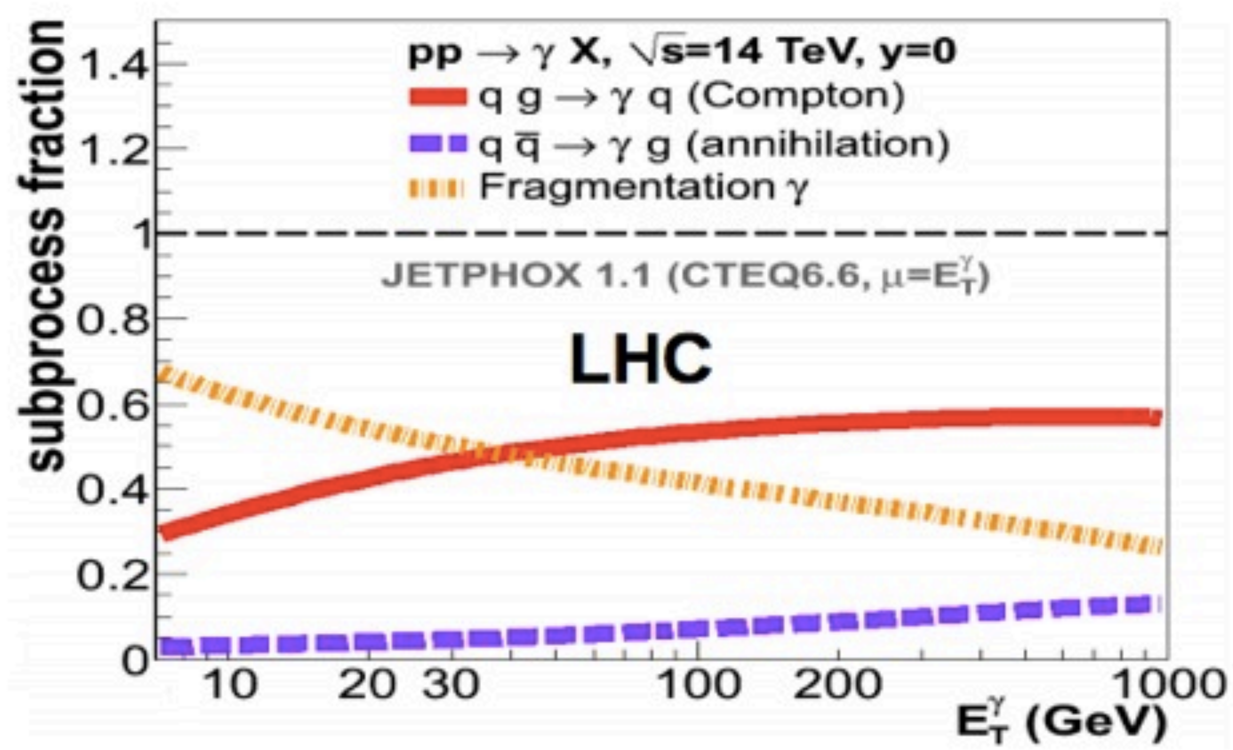


$q\bar{q}$ annihilation



fragmentation

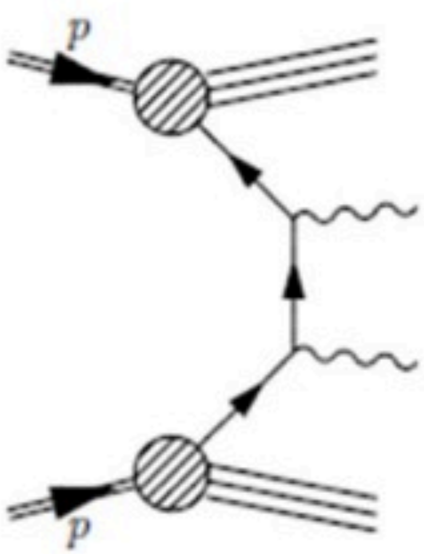




R. Ichou & D. d'Enterria, PRD 82 2010 014015

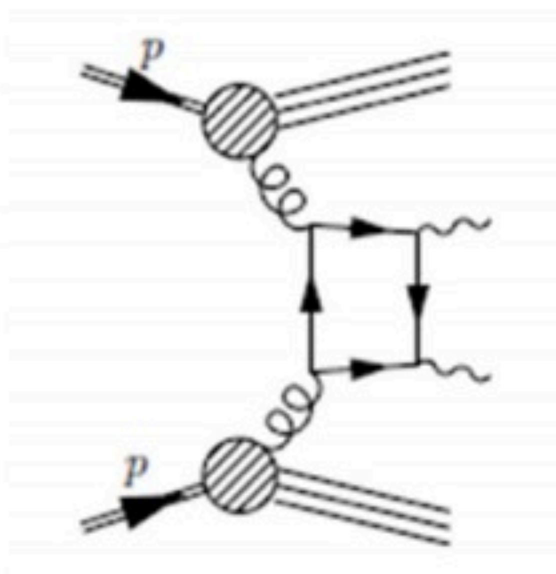
Diphoton diagrams

Direct Born



26 pb @ NLO

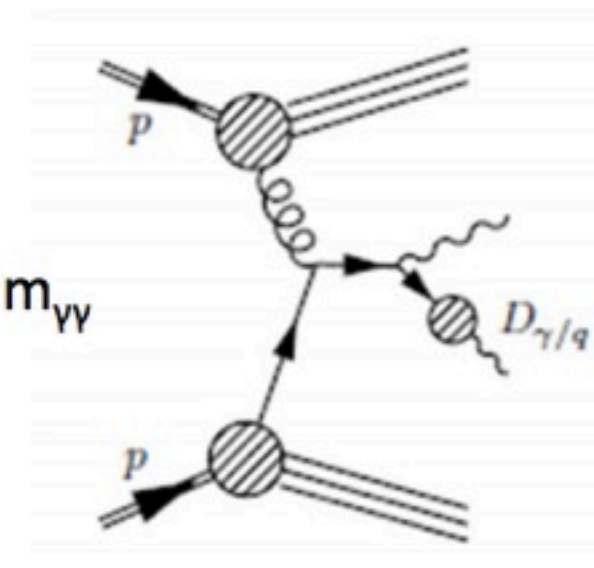
Direct Box



15 pb @ NLO

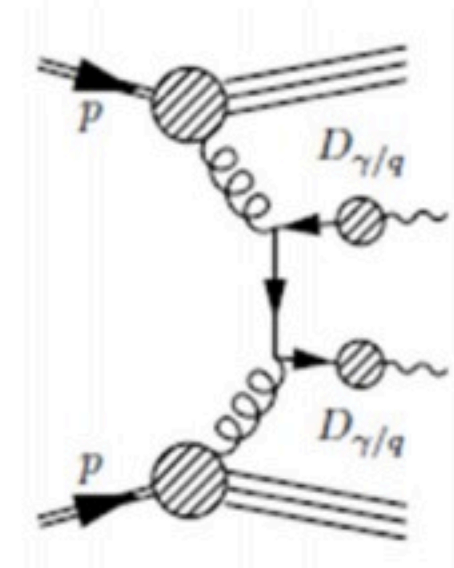
One Fragmentation

$\mu_{frag} = m_{\gamma\gamma}$



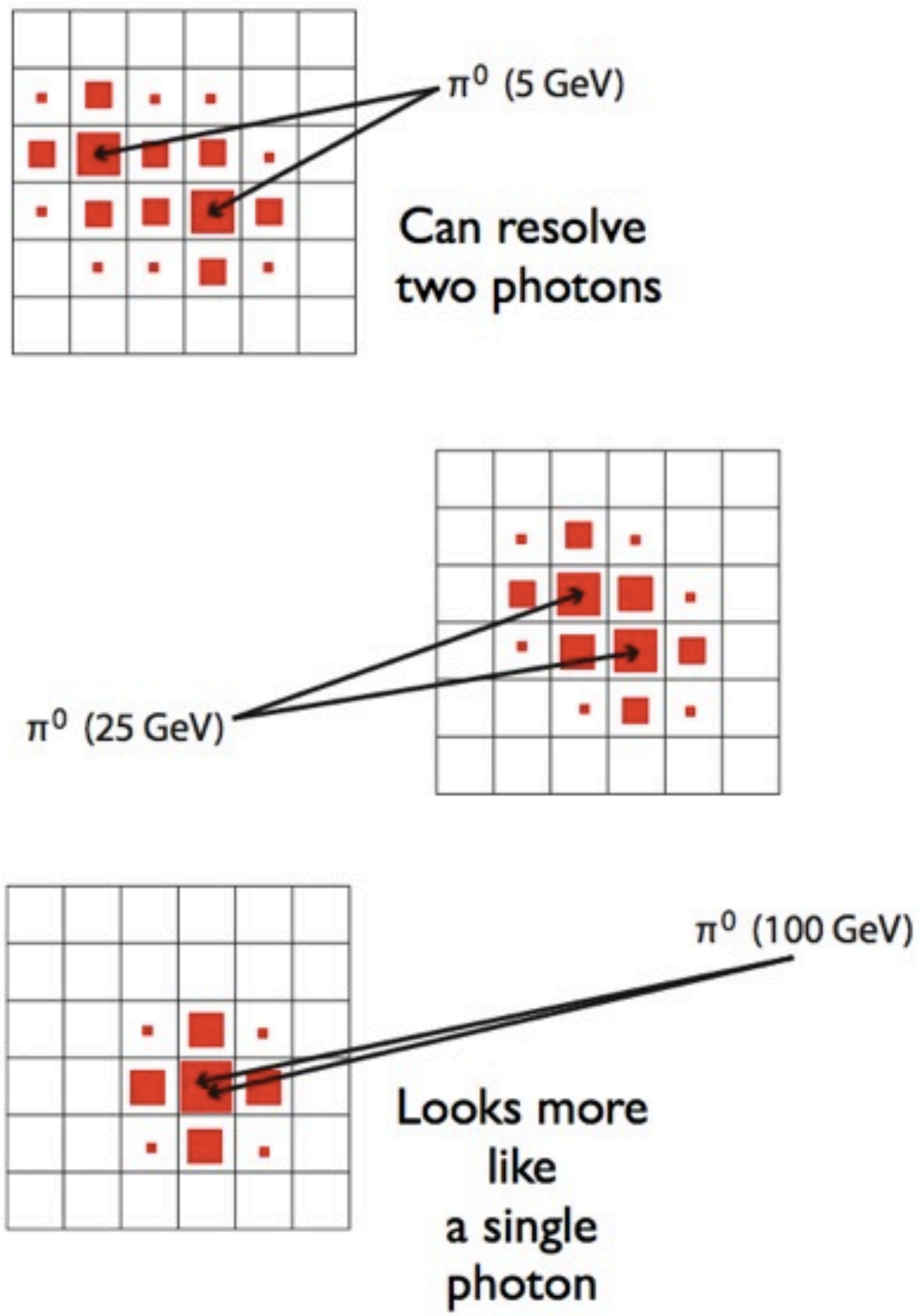
10 pb @ NLO

Two Fragmention



0.5 pb @ NLO

Identifying photons

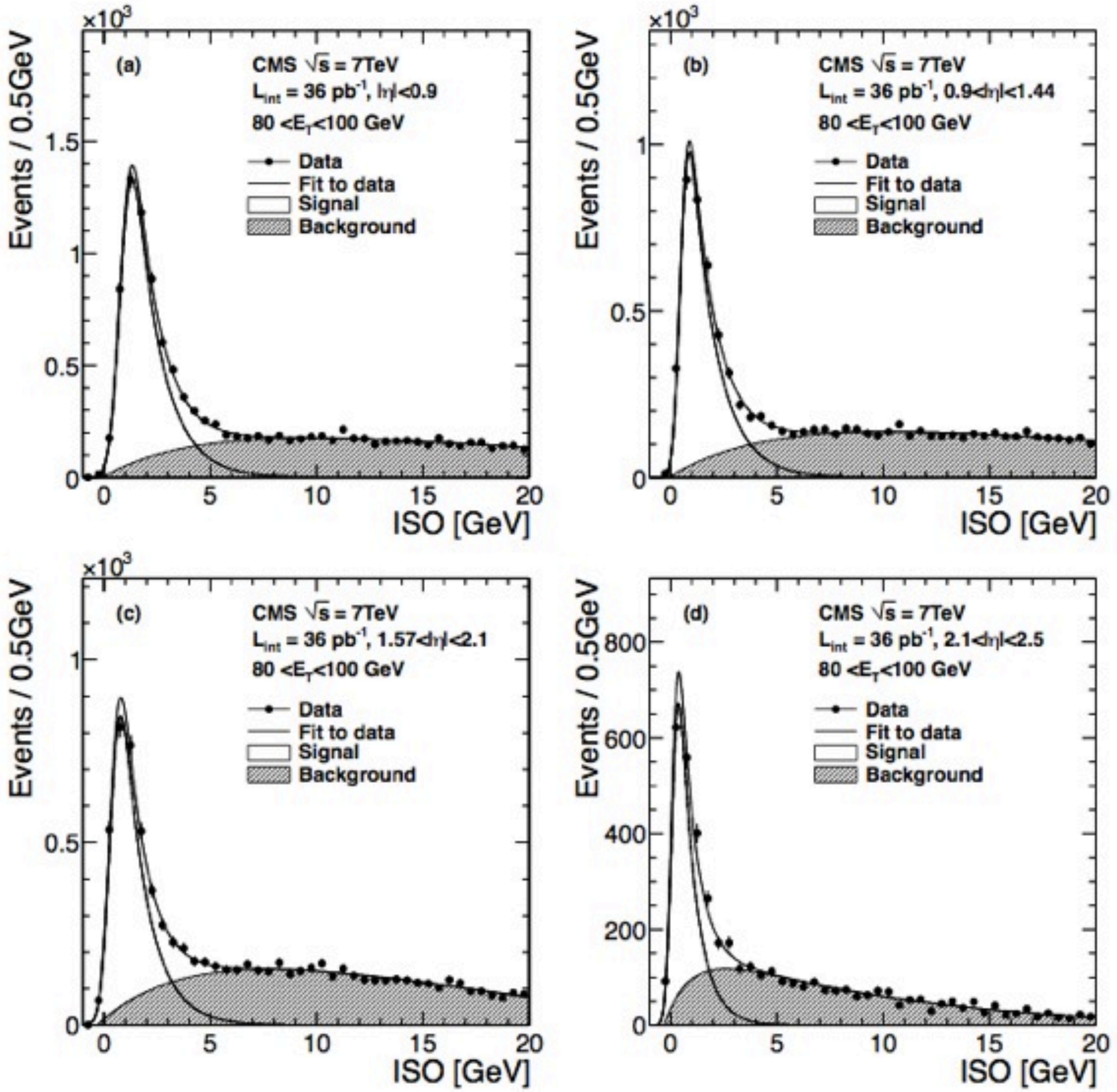


Primary challenge in these measurements is separating the real photon signal from the dominant background, jets with a high EM fraction faking photons.

- Jets typically have higher isolation sums than true photons.
- Shape of the photon candidate in EM calorimeter is broader for jets than for photons.
- Photon conversions can be exploited for photon ID.

In addition, where possible, find techniques to extract distributions for the above variables from data in order to reduce the dependence of these measurements on fine details of the event generator and detector simulation.

Identifying the photon signal (1)



CMS photon+X PRD 84, 052011

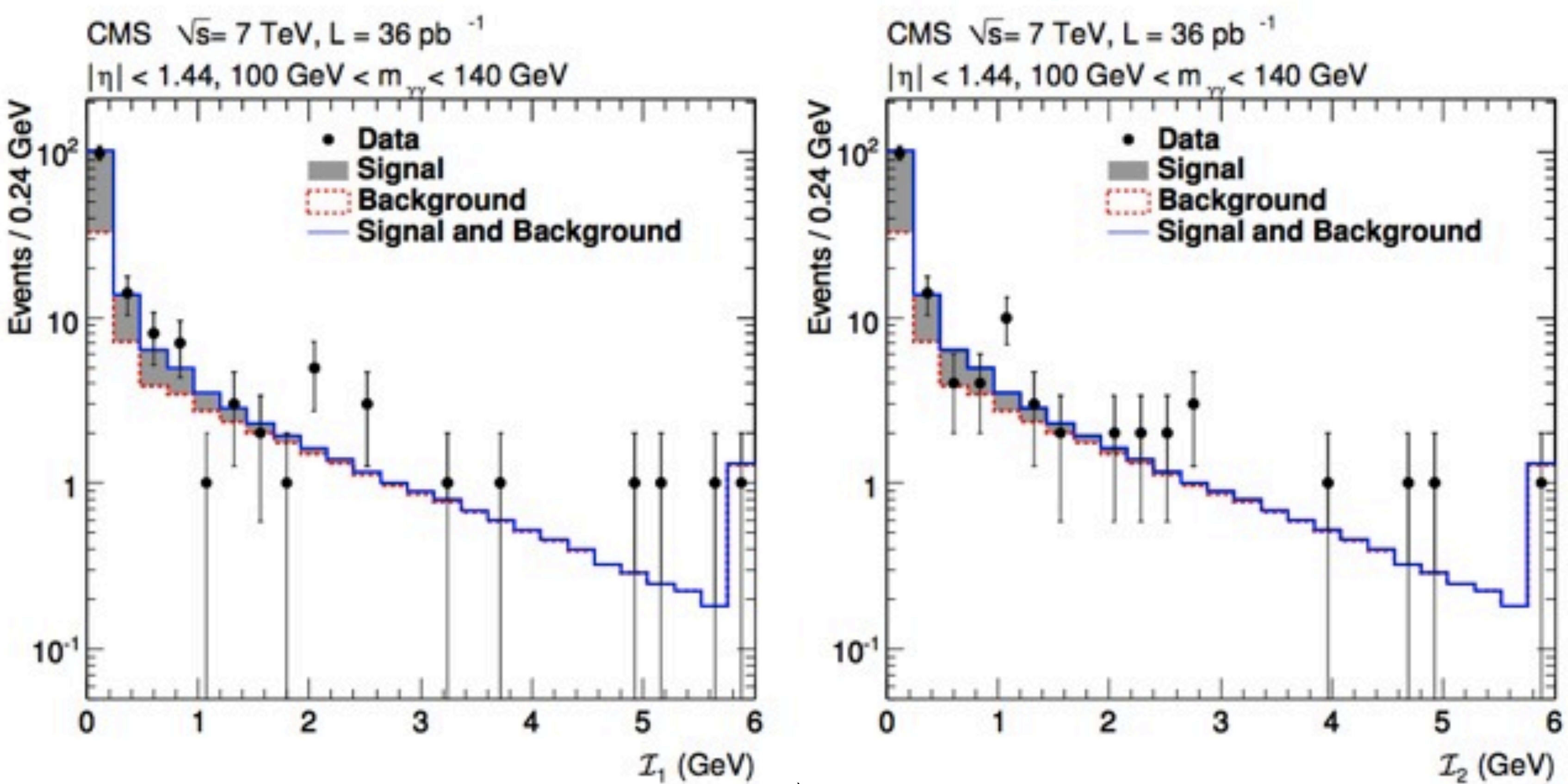
Jets typically have higher isolation sums than true photons.

- Isolation distributions can be used to fit the contribution from isolated photons after selecting on the shower shape of the candidate.
- Photon isolation distribution can be checked against electrons from Z decay.
- Background shape can be extracted from data by looking at a background-dominated sideband of the shower shape.

ECAL+HCAL+trk

Identifying the photon signal (2)

CMS diphotons JHEP 01 2012 133



ECAL iso

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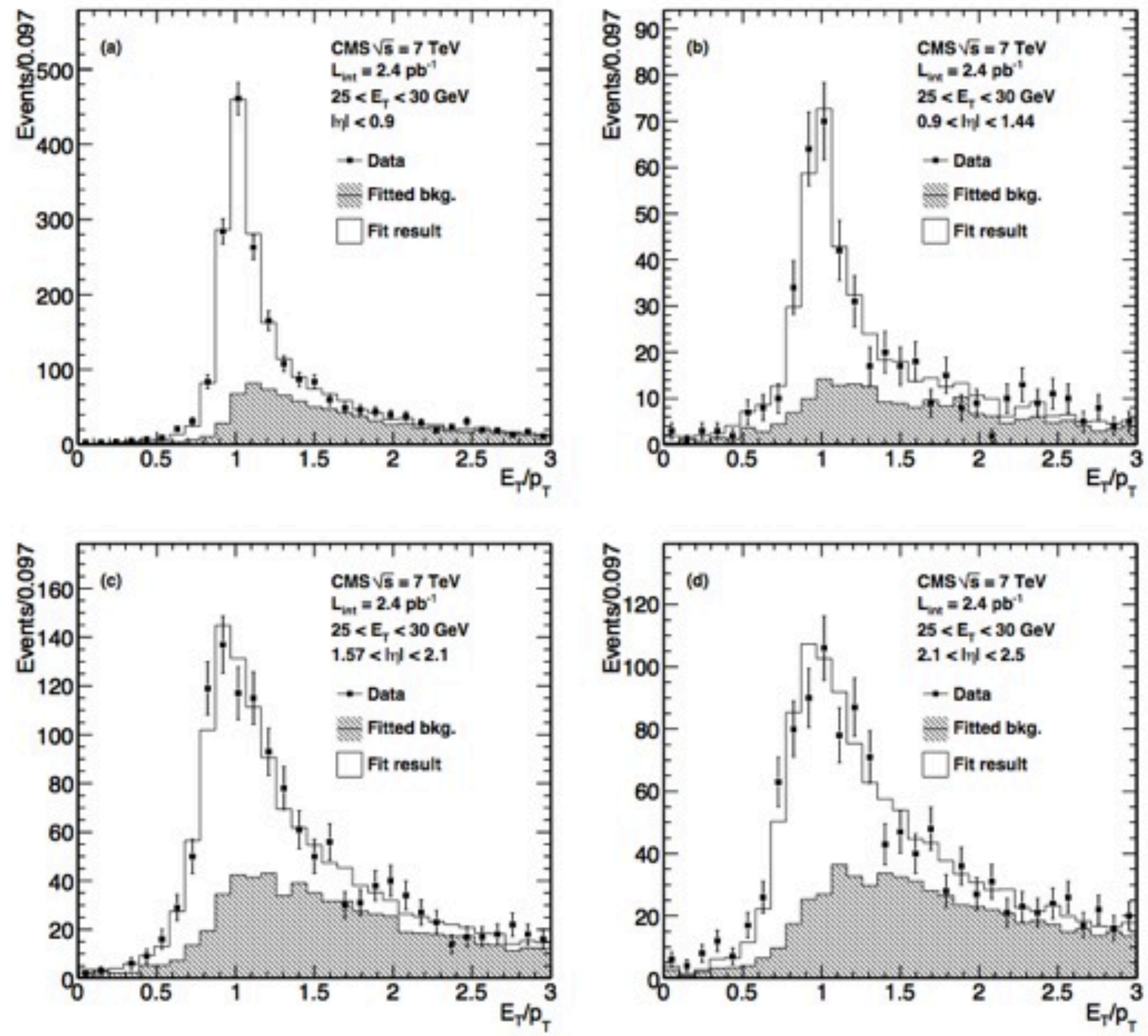
- Photon isolation distribution can be checked against electrons from Z decay.
- Background shape can be extracted from data by looking at a background-dominated sideband of the shower shape.
- DY contribution can be estimated from simulation and cross-checked with measurements of the DY differential XS.

Identifying the photon signal (3)

Matching of conversion track p_T with photon candidate E_T can provide additional handle to discriminate photon signal from jet background.

- Allows us to select on both the isolation energy and the cluster shape–do not need a sideband in either to perform the background subtraction.
- Signal templates come from MC, background templates from data sidebands.



CMS photon+X PRD 84, 052011

Identifying the photon signal (4)

ATLAS photon+X PLB 706 2011 150

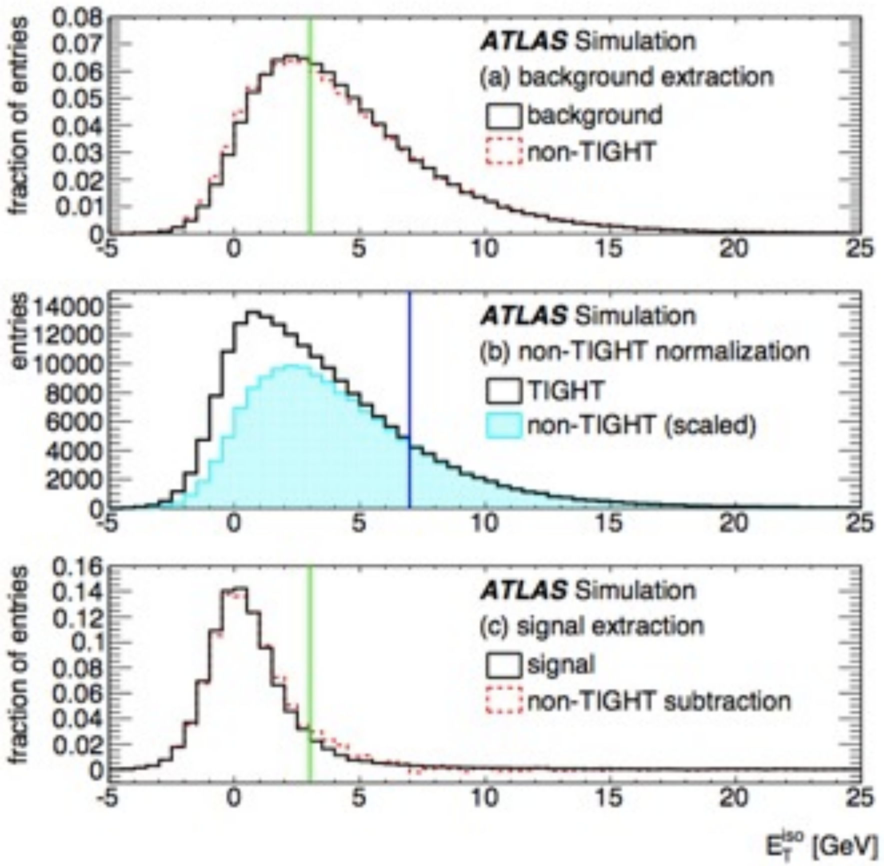
ATLAS uses a 2D background subtraction technique (ABCD) using both photon ID selection (shape in calorimeter) and isolation selection.

	iso	non-iso
non-ID	C	D
ID	A	B

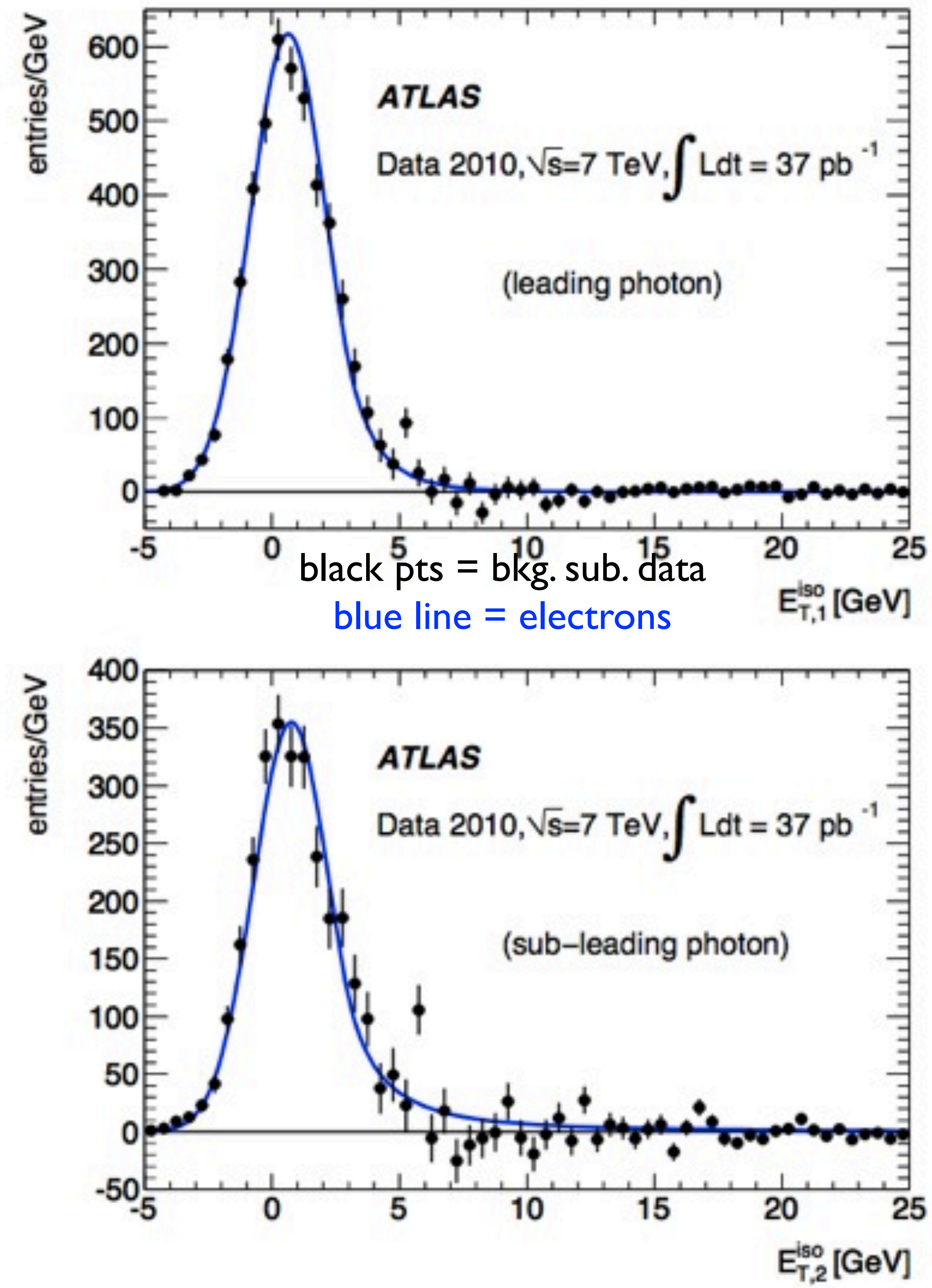
$$N_A^{\text{sig}} = N_A - (N_B - c_B N_A^{\text{sig}}) \frac{(N_C - c_C N_A^{\text{sig}})}{(N_D - c_D N_A^{\text{sig}})}$$

where c_Ks are signal leakage fractions from A to K (from MC)

Identifying the photon signal (5)

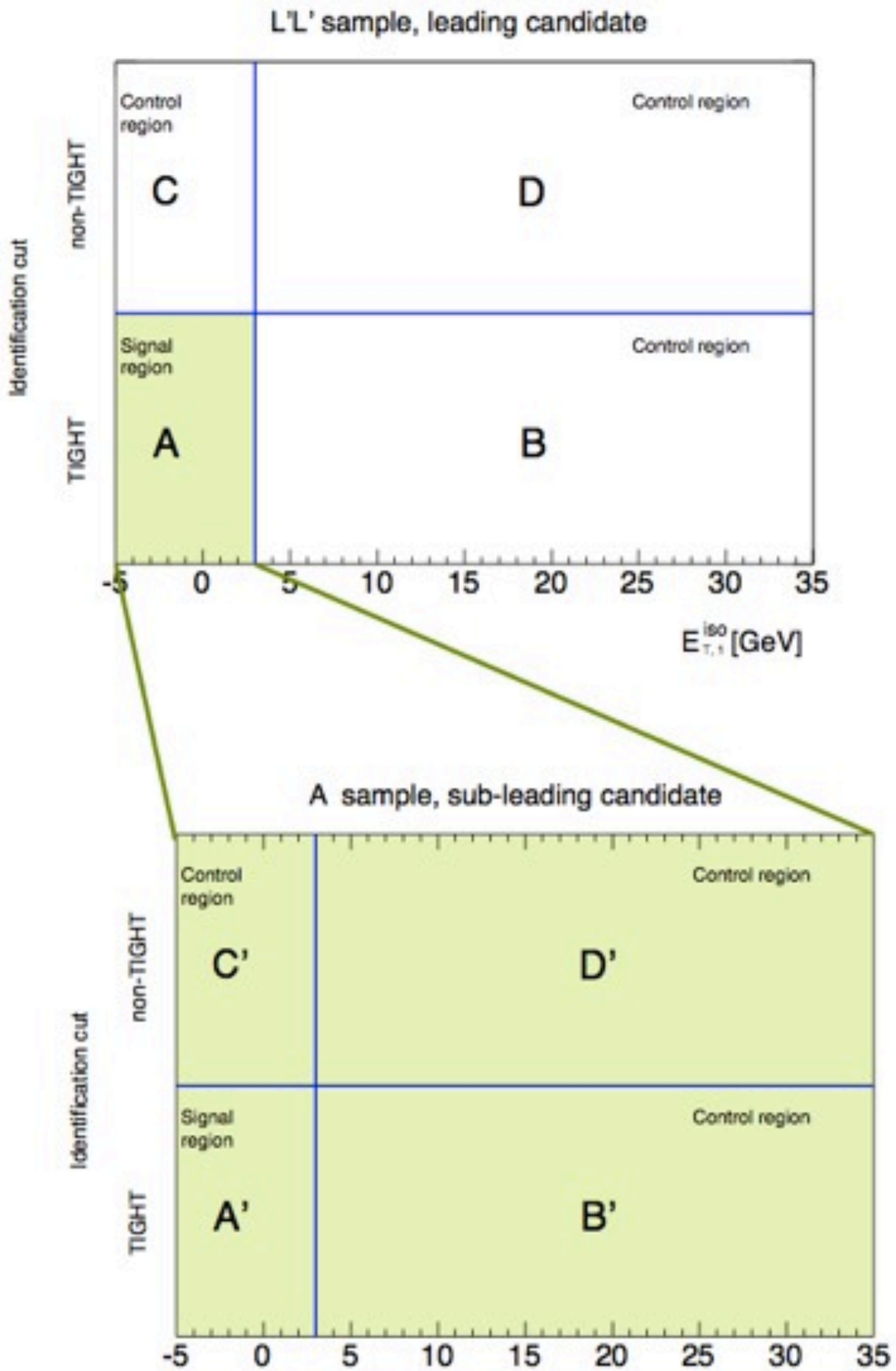


ATLAS diphotons PRD 85 2012 012003



The difference in isolation distribution for the ID vs. non-ID samples can also be used to determine a signal shape.

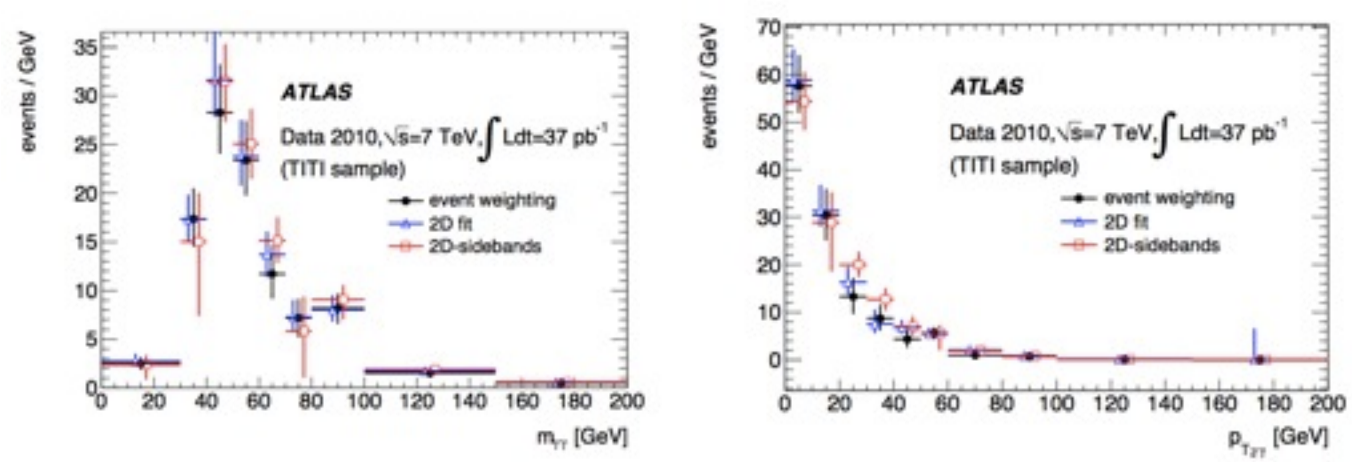
Extracting diphoton yields



ATLAS diphotons PRD 85 2012 012003

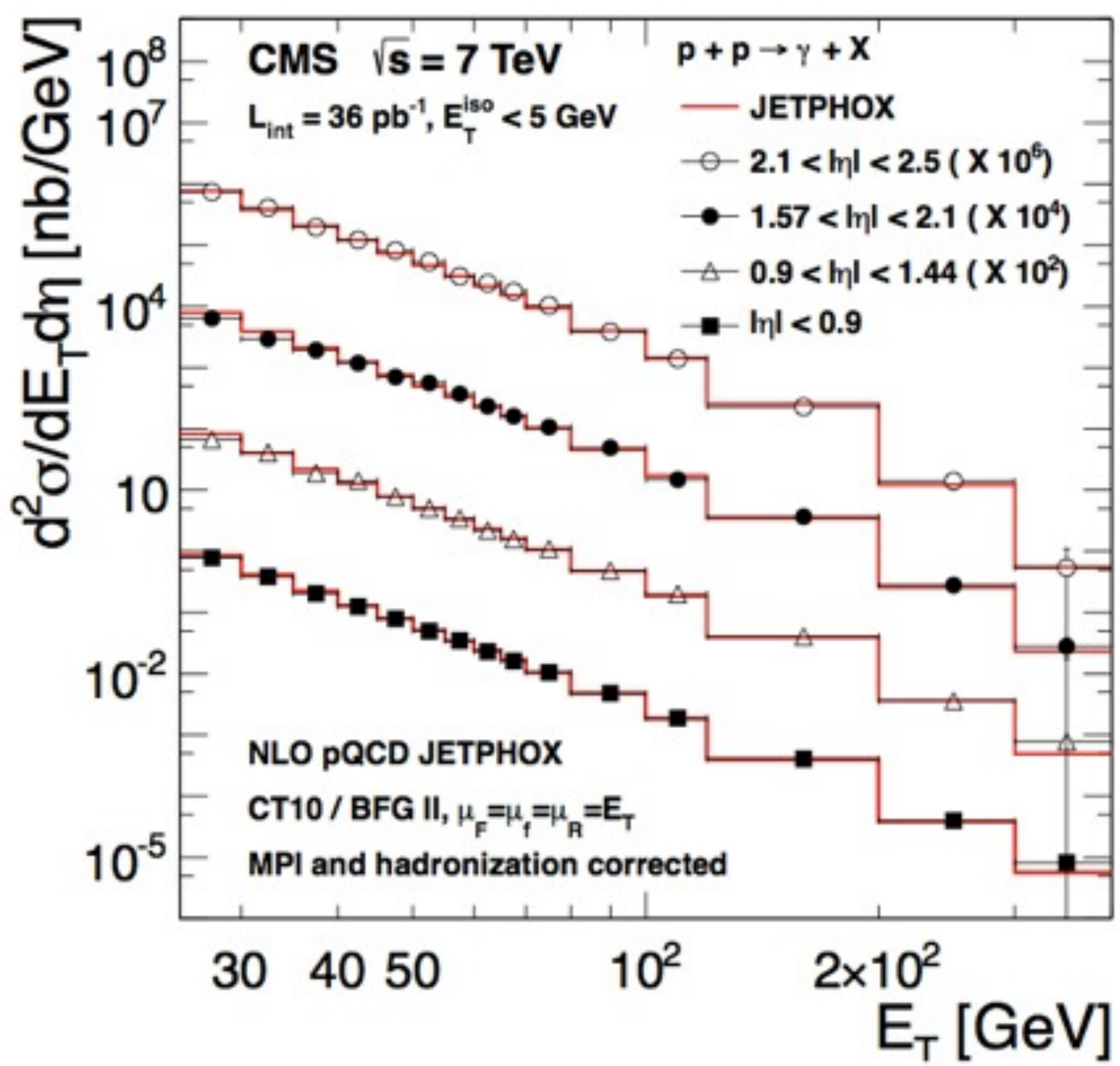
In the diphoton measurements, determining the number of signal events requires us to consider both photon candidates.

- CMS: 2D ML fit over the isolation distributions for each photon candidate passing the ID requirement.
- ATLAS: three techniques are used.
  - Event weighting: for each event where both candidates pass the ID requirement, each candidate is classified by whether they pass the isolation requirement, resulting in PP, PF, FP, and FF categories. Each type is then weighted by its probability to be a diphoton event. Used in final reported XS.
  - 2D fit: 2D ML fit over the isolation distributions for each photon candidate passing the ID requirement.
  - 2D sideband: use double sideband or "double ABCD" (left).

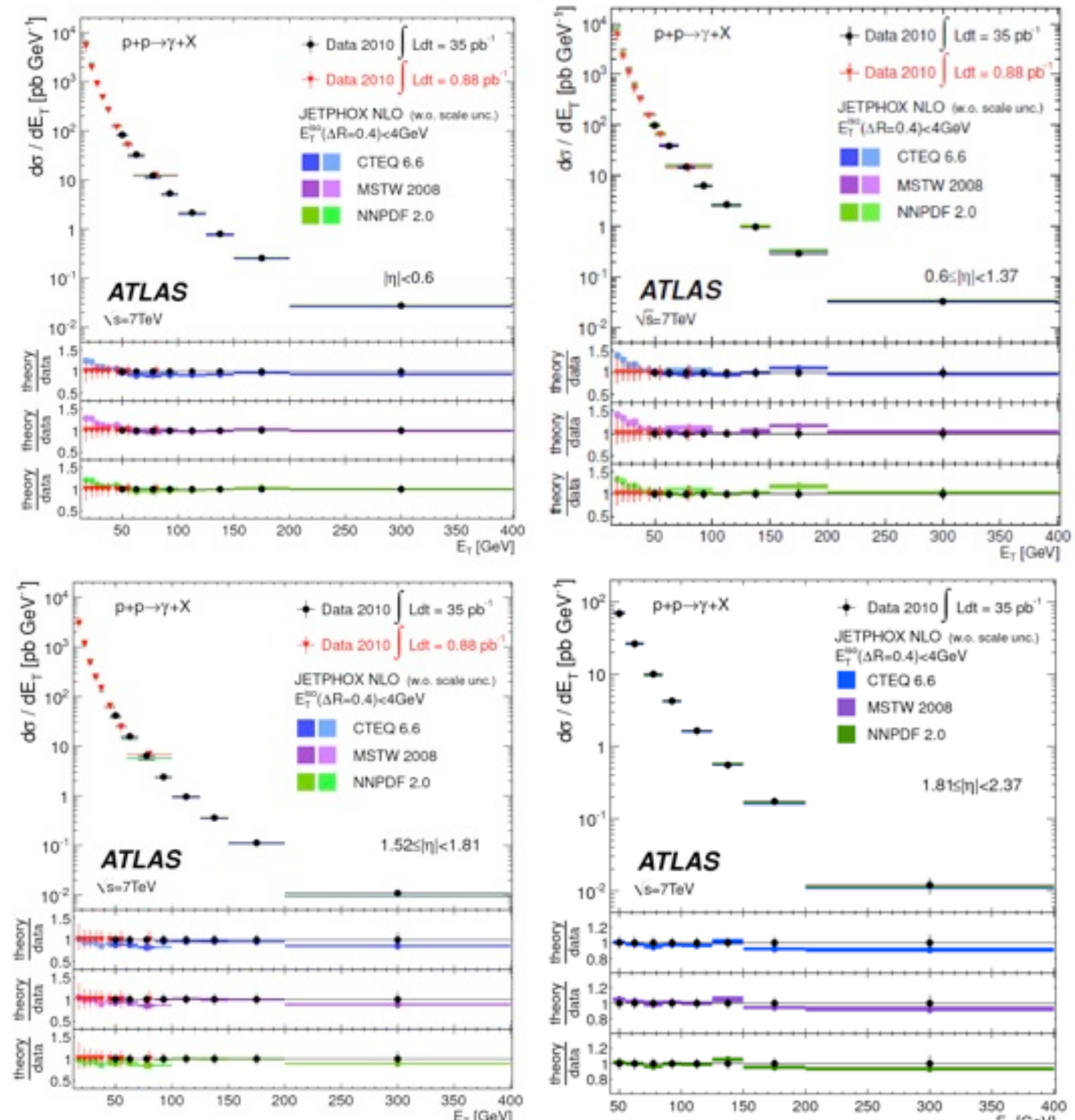


Results: inclusive photon XS

CMS photon+X PRD 84, 052011



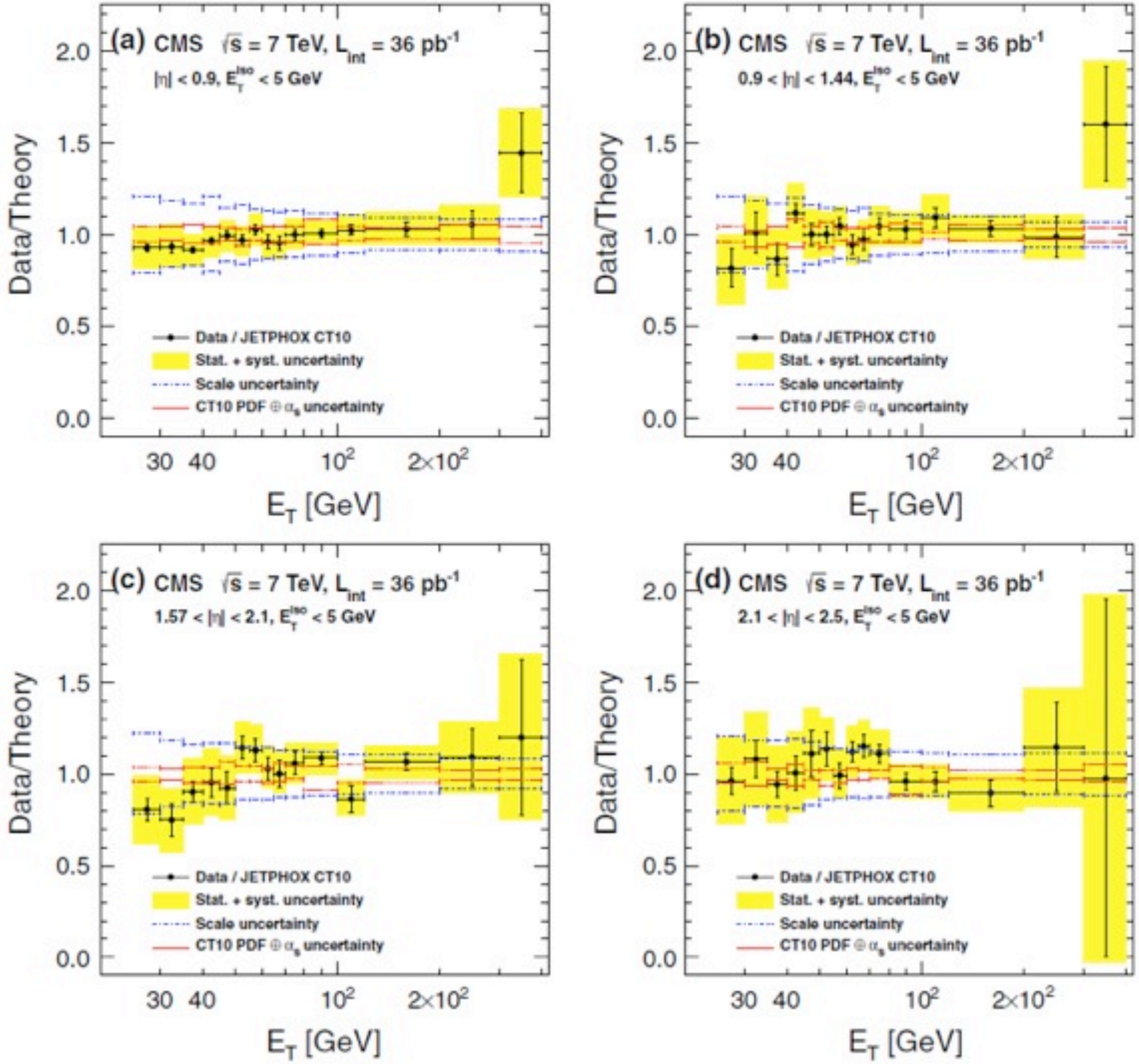
Good agreement with pQCD over a wide range of ET and rapidity



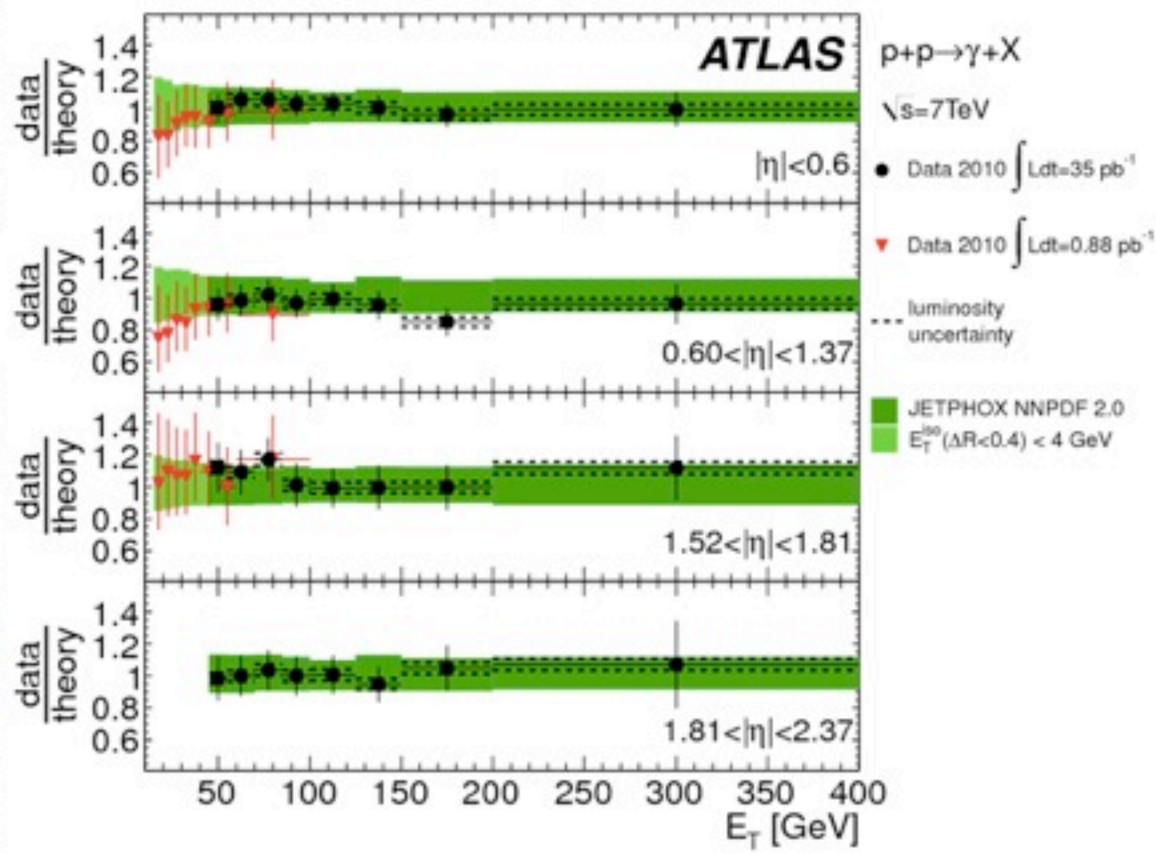
ATLAS photon+X PLB 706 2011 150

Photon+X ratio to theory

CMS photon+X PRD 84, 052011

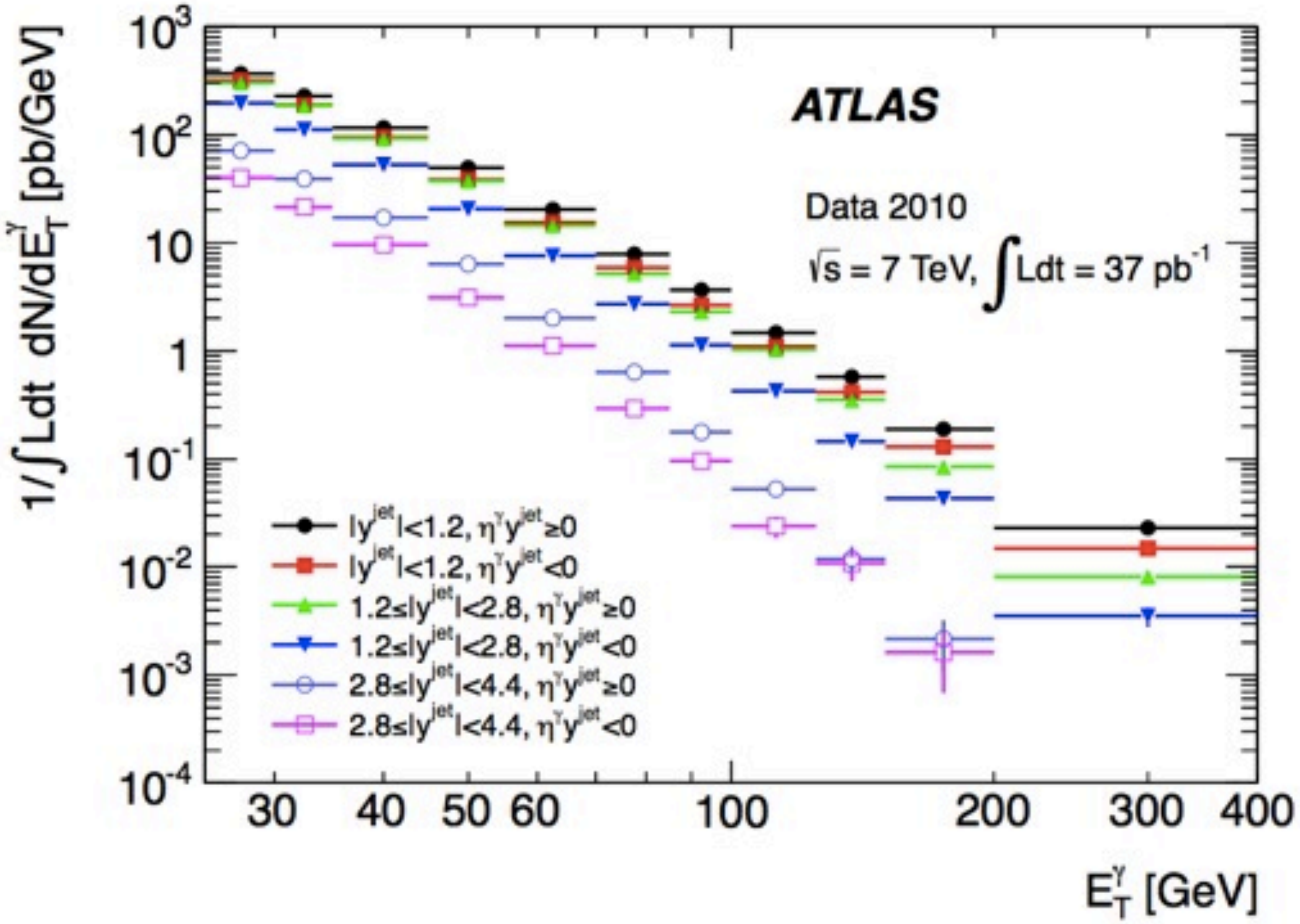


Good agreement with pQCD over a wide range of ET and rapidity

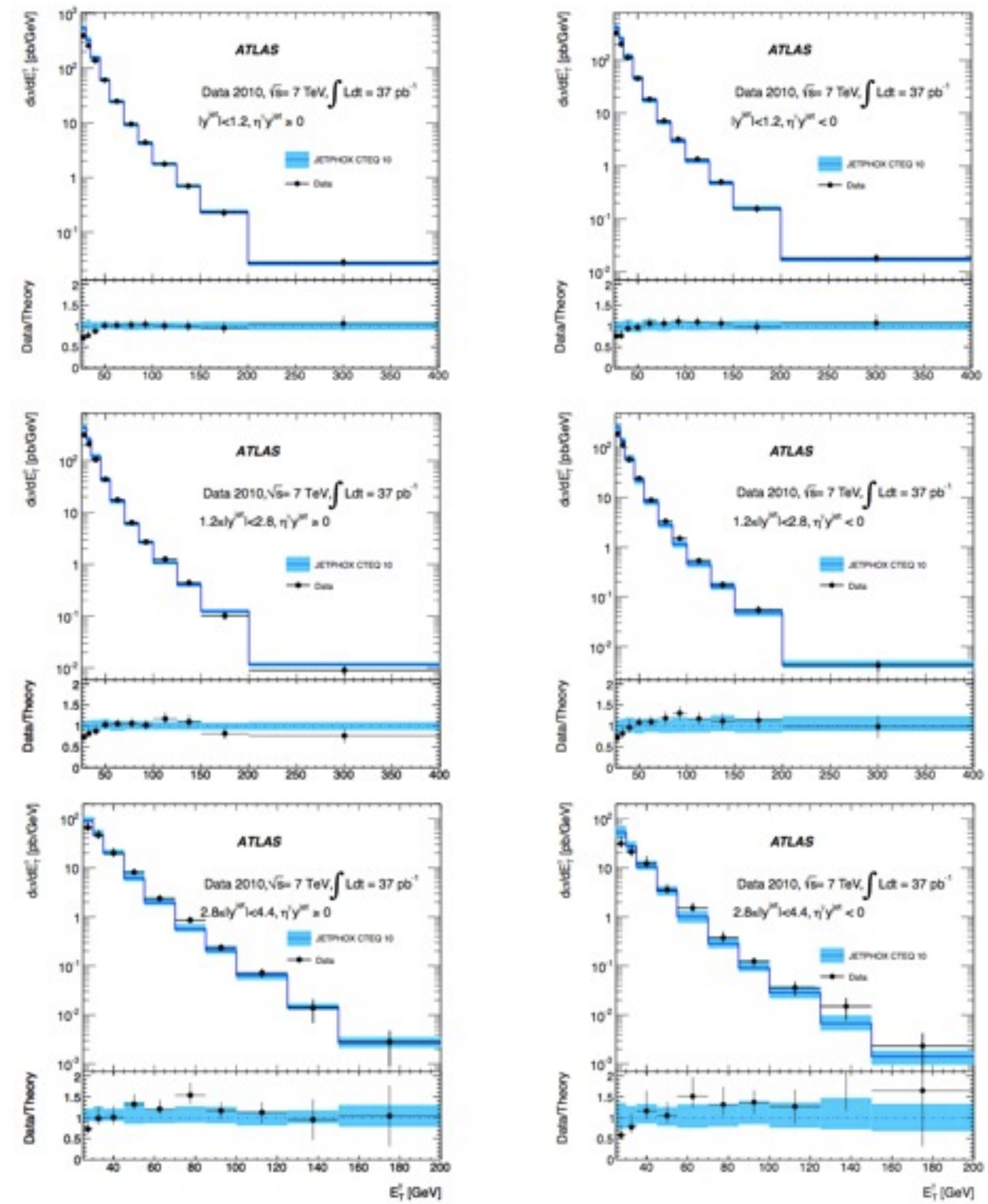


ATLAS photon+X PLB 706 2011 150

ATLAS photon+jet



ATLAS photon+jet, PRD 85 2012 092014



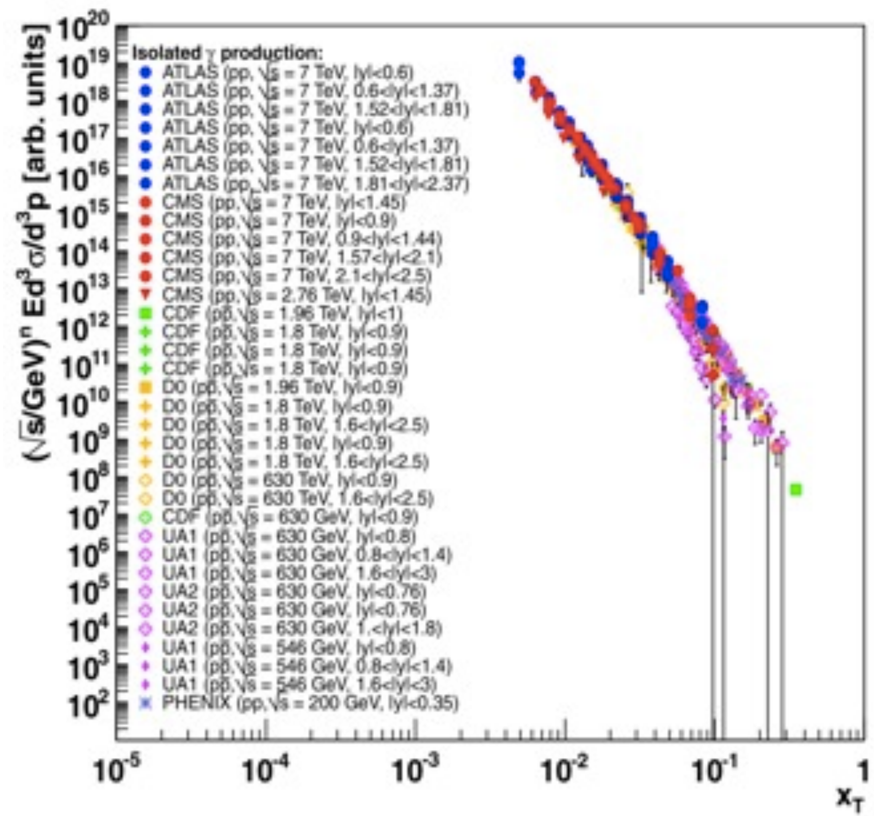
Good agreement with pQCD over a wide range of ET and rapidity

Single photons for PDFs?

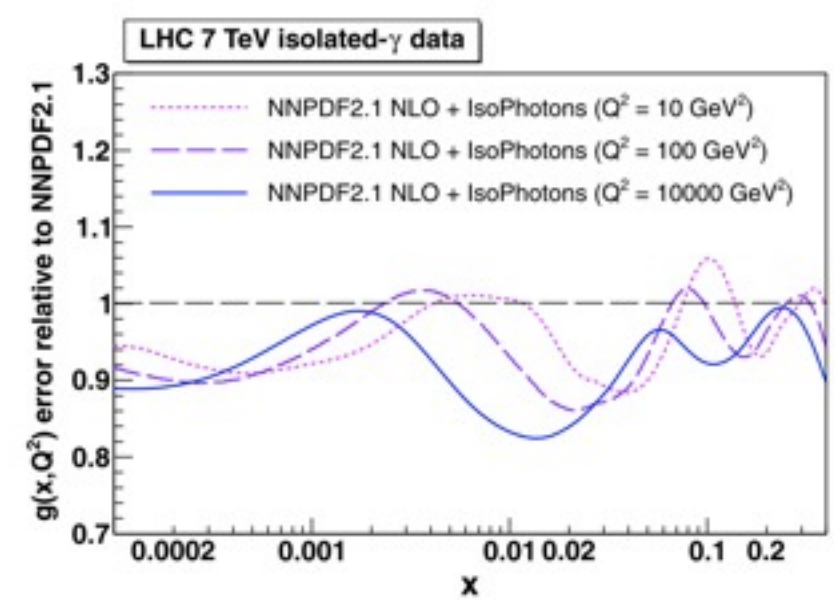
Three decades of single photon data from hadron colliders at left. Impressive consistency over a wide range of x_T.

- These data are not used in PDF fits due to some outliers from fixed-target experiments. But nuclear target or other effects may be responsible.
- d'Enterria & Rojo illustrate reduction in the PDF uncertainty for gluon fusion of more than 20% by including LHC isolated photon measurements:

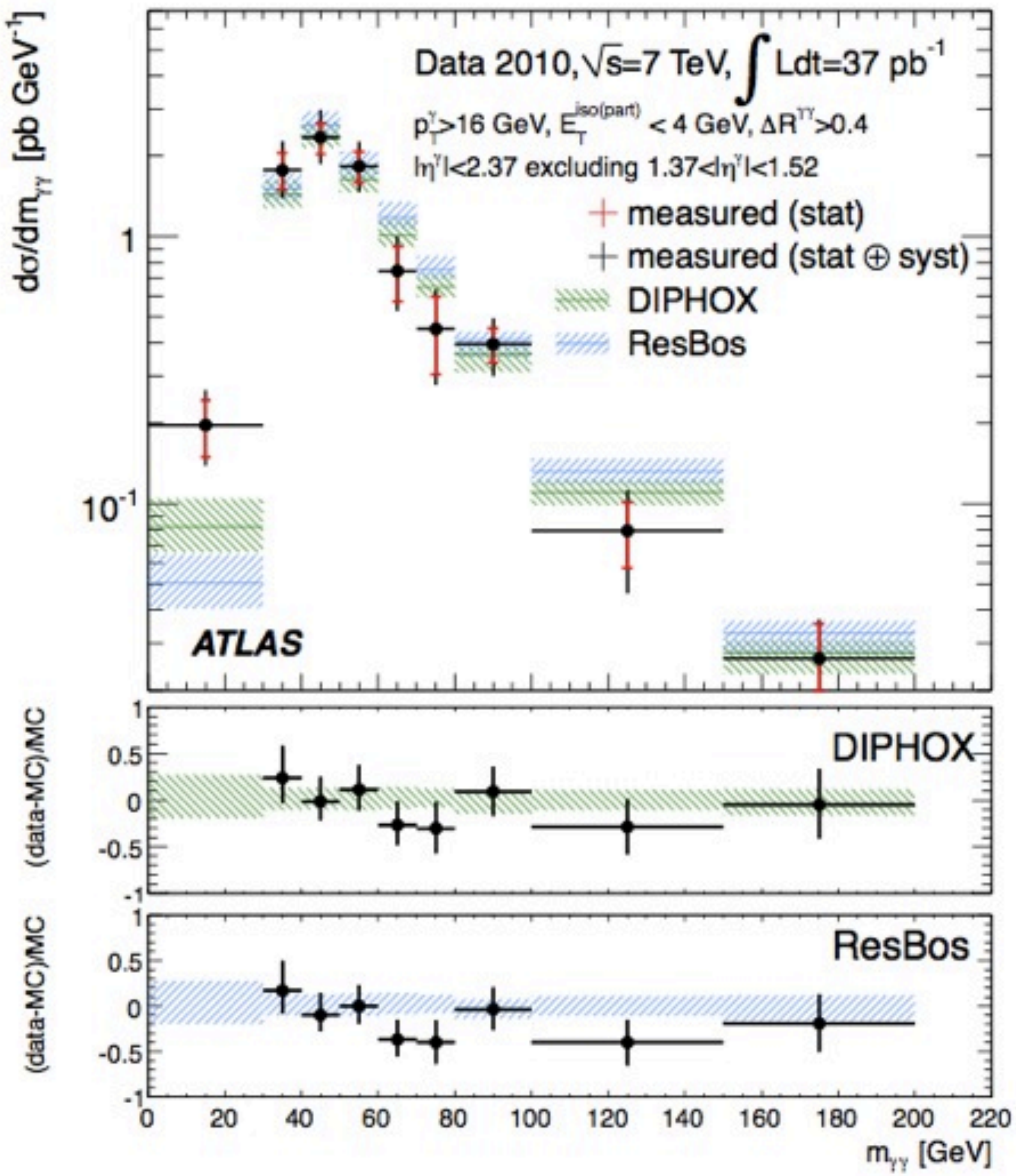
Process/cross section	$gg \to H(120)$
NNPDF2.1	11640 ± 181 fb
NNPDF2.1 + LHC IsoPhotons	11701 ± 140 fb



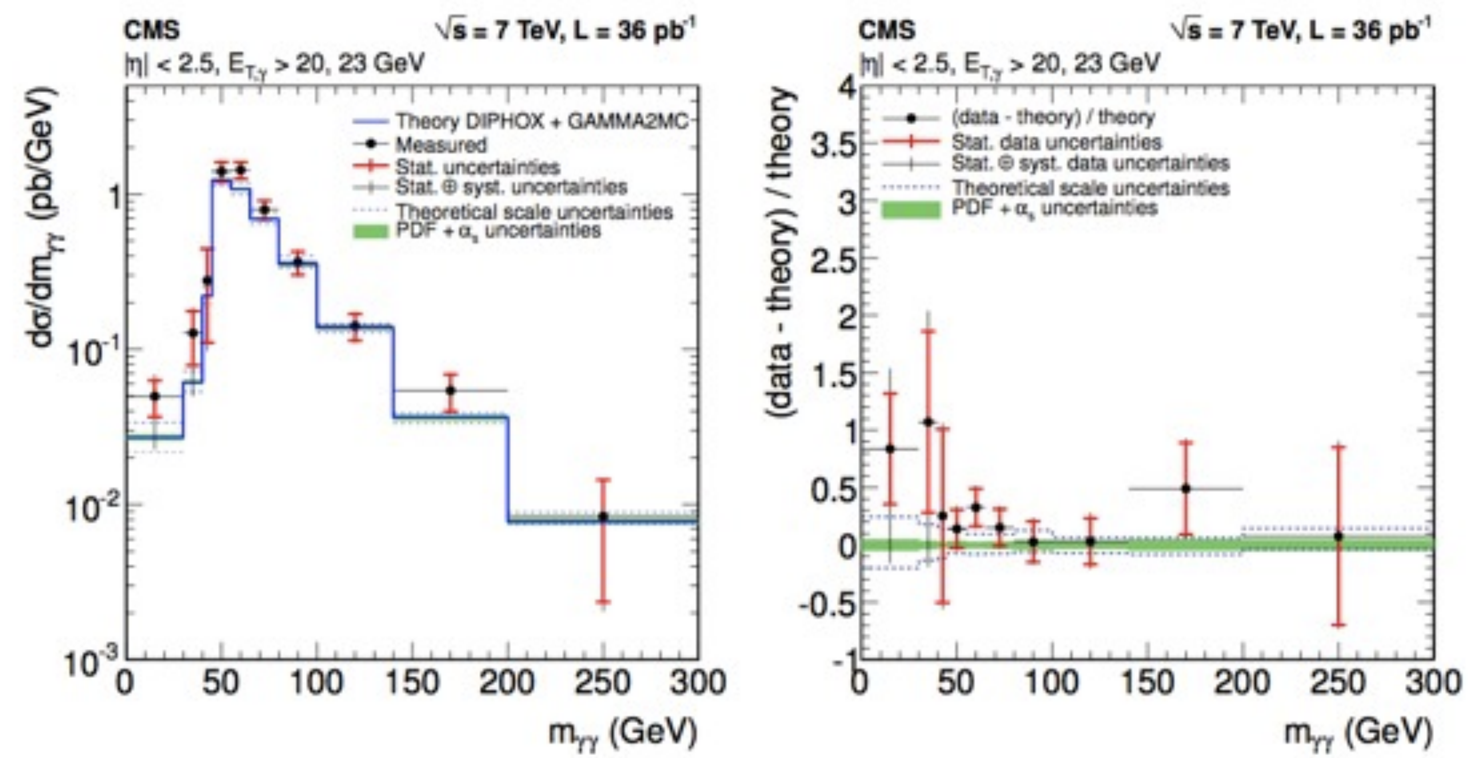
d'Enterria, Rojo 2012, Nuc. Phys B860



Diphotons: invariant mass



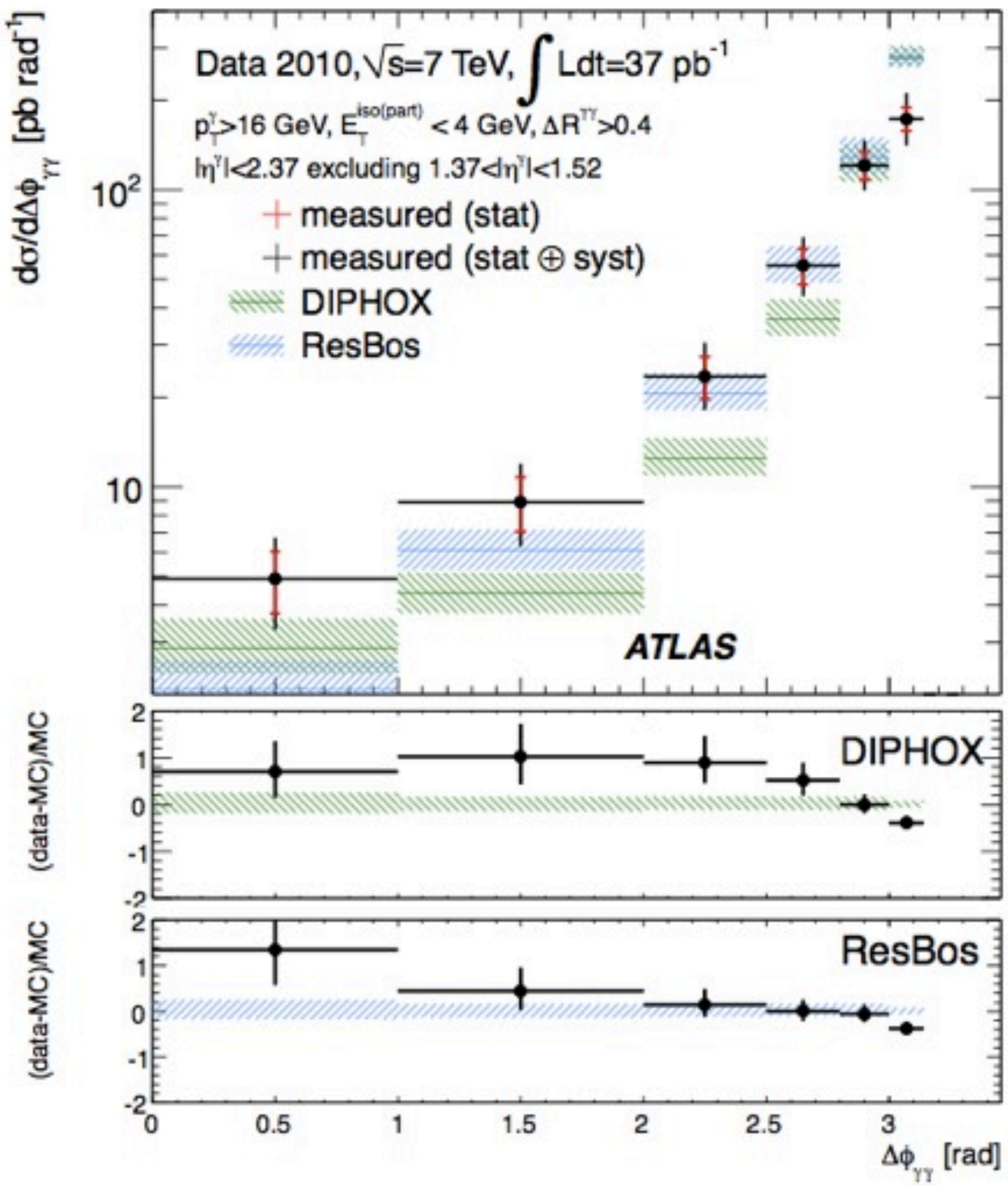
ATLAS diphotons PRD 85 2012 012003



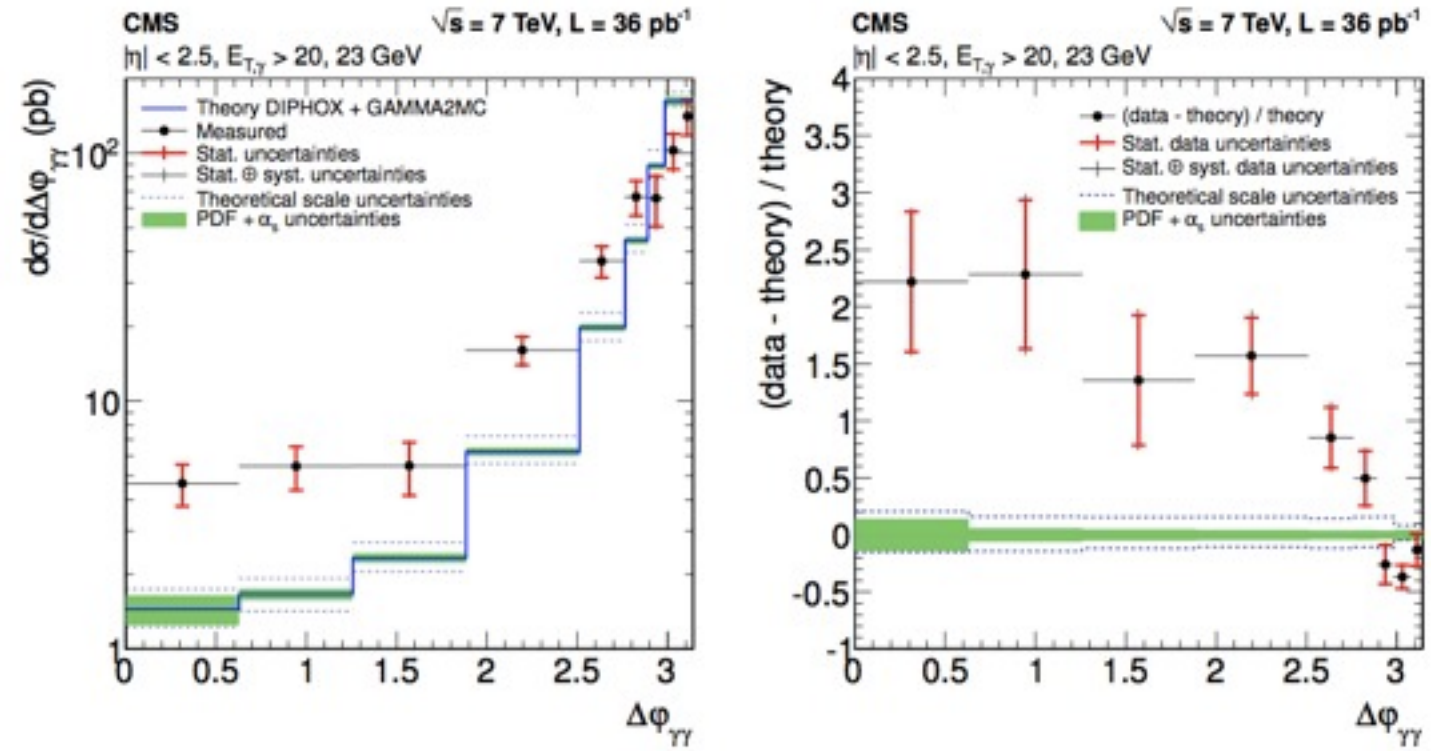
CMS diphotons JHEP 01 2012 133

Theory underpredicts low M region where higher order terms become important (near collinear).

Diphotons: angular separation



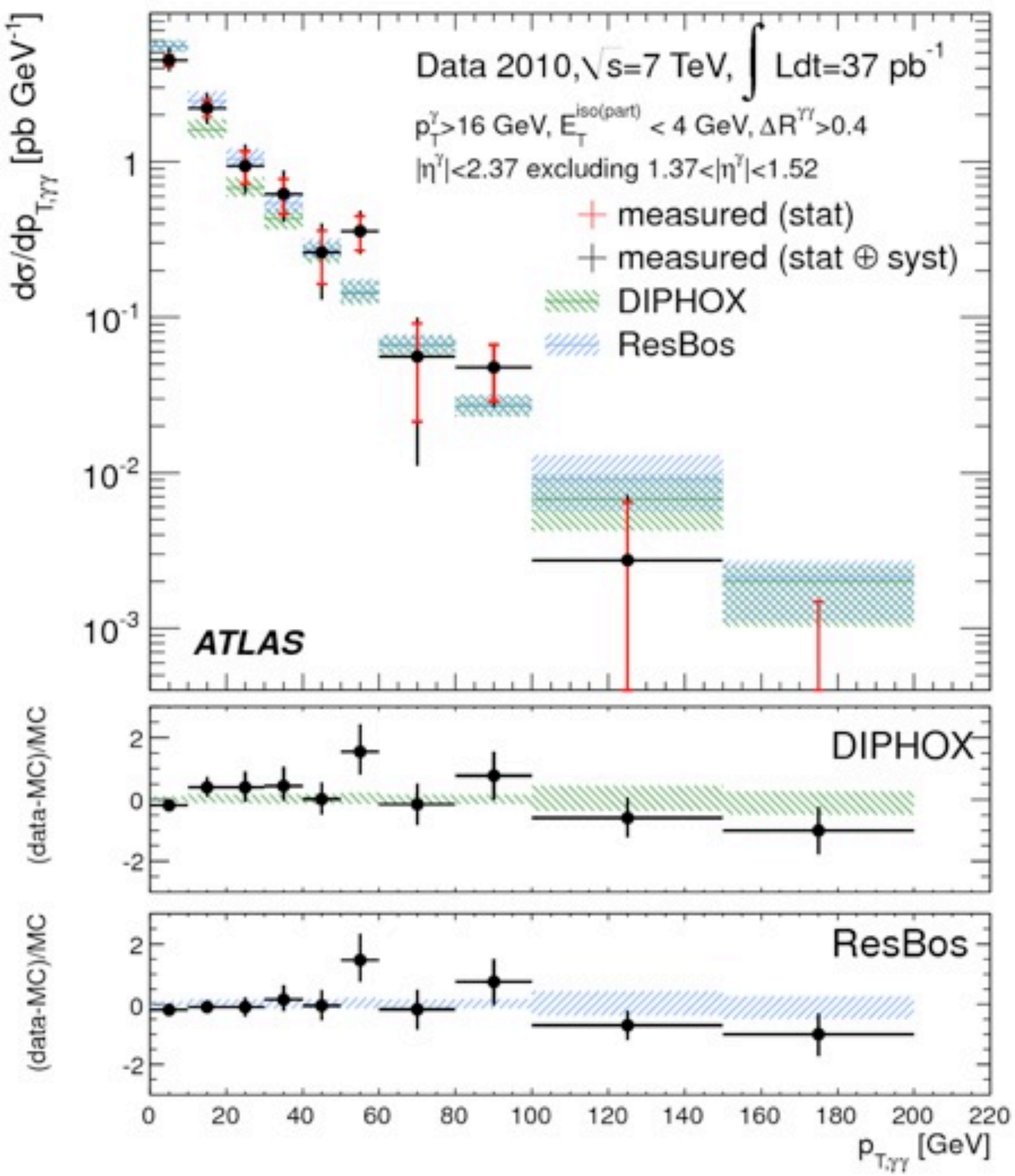
ATLAS diphotons PRD 85 2012 012003



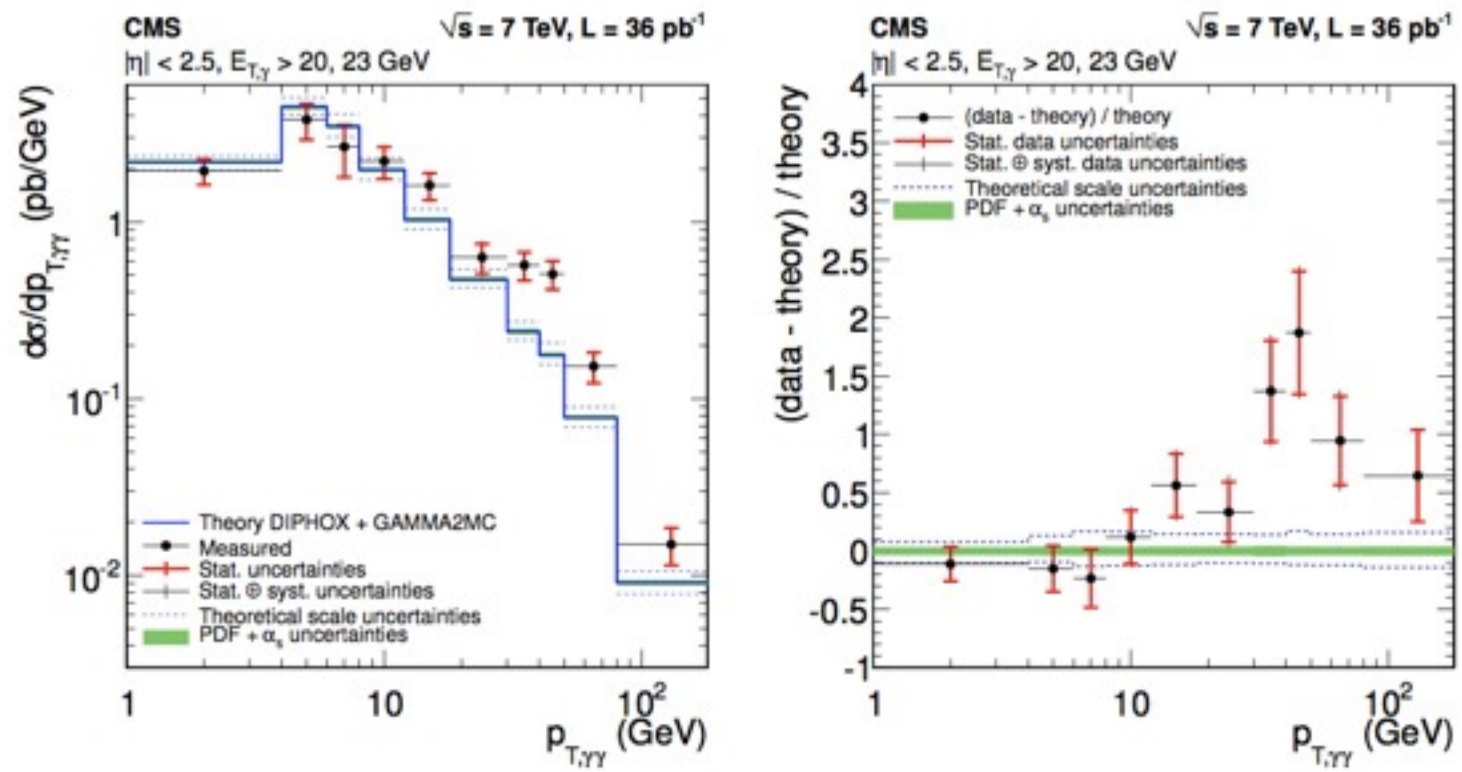
CMS diphotons JHEP 01 2012 133

Theory underpredicts low angle region where higher order terms become important.

Diphotons: p_T



ATLAS diphotons PRD 85 2012 012003



CMS diphotons JHEP 01 2012 133

"Shoulder" region with theory underprediction is due to interaction of photon pT thresholds with small angle configurations.

Conclusions and outlook.

- Single photon measurements at CMS and ATLAS show impressive agreement with pQCD over a wide range of momenta and rapidities. Could be used to further constrain gluon PDFs.
- Diphoton measurements show necessity to include higher-order effects to complete the picture.
- Large 7 TeV dataset would allow extension to higher photon momentum, and 8 TeV measurements need to be done...
- ...pileup and trigger thresholds make these measurements increasingly challenging as LHC performance improves.