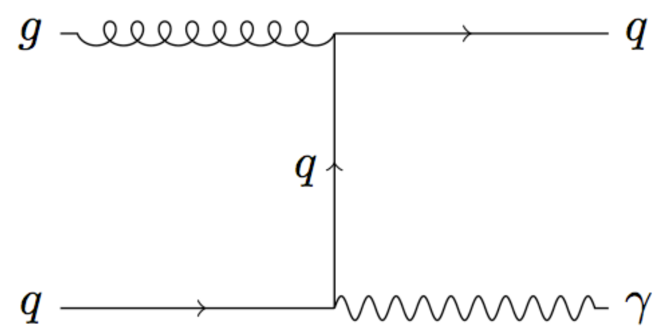
Direct photon and jet properties

Darko Mekterović
National Central University Taiwan
On behalf of ATLAS and CMS

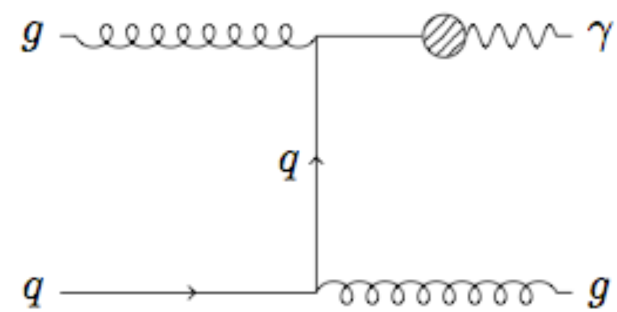
Direct photons – definitions

- **Direct (prompt)** photons are created before hadronization. They come from hard sub-process (for example qg Compton scattering) or fragmentation of partons. They do **not** include photons from neutral meson decays.
- **Isolated**: transverse energy of all particles within a cone around the photon direction less than a given threshold.

Compton scattering



Fragmentation



Motivation

- Test perturbative QCD over a wide and previously inaccessible kinematic range
- Possibility to constrain non-perturbative part of calculation (for example fragmentation model)
- Possibility to constrain gluon PDF
- Can be used for detector performance studies
- (Irreducible) background for measurements with photons in final states
  - $H \rightarrow \gamma\gamma$
  - Gravitons, excited fermions, some SUSY searches etc.

Overview of published results

Inclusive isolated prompt photon cross section

Experiment	Reference	Lum. (pb^-1)	E_T^γ (GeV)	$\lvert\eta^\gamma\rvert$
CMS	Phys. Rev. Lett 106 (2011) 082001	2.9	21 - 300	< 1.45
ATLAS	Phys. Rev. D 83 (2011) 052005	0.88	15 - 100	< 1.81
ATLAS	Phys.Lett.B 706 (2011) 150-167	35	45 - 400	< 2.37
CMS	Phys. Rev. D 84 (2011) 052011	36	25 - 400	< 2.5

Isolated diphoton cross section

Experiment	Reference	Lum. (pb^-1)	$m_{\gamma\gamma}$ (GeV)
ATLAS	Phys.Rev.D 85 (2012) 012003	37	0 - 200
CMS	JHEP 01 (2012) 133	36	0 - 300

New: Cross section of an isolated photon associated with jet

Experiment	Reference	Lum. (pb^-1)	E_T^γ (GeV)	p_T^{jet} (GeV)	$\lvert y^{jet}\rvert$
ATLAS	Phys. Rev. D85 (2012) 092014	37	25 - 400	> 20	< 4.4

Cross section measurement

$$\frac{d\sigma}{d\Omega} = \frac{U \cdot p \cdot N}{L \cdot \varepsilon \cdot \Delta\Omega}$$

- N – number of events that satisfy all photon selection requirements. It contains non-negligible amount of background.
- p – fraction of true (signal) photons
- L – total integrated luminosity
- ε – total detection efficiency
- U – unfolding correction
- $\Delta\Omega$ – phase space size

Electromagnetic calorimeter

ATLAS

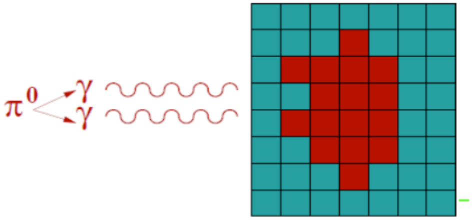
- three longitudinal readouts (3-5, 17,4-15 X_0)
- $\Delta\eta x \Delta\phi$= 0.003-0.006x0.098, 0.025x0.0245, 0.05x0.0245
- tracker: 0.5-2.5 X_0, B=2.0 T
- 1.6-2.5% energy resolution at 50 GeV

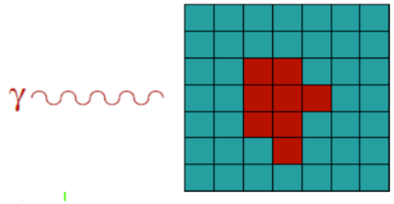
CMS

- ~25 X_0, $\Delta\eta x \Delta\phi$=0.0174x0.0174
- tracker: 0.5-2 X_0, B=3.8 T
- < 1% energy resolution for unconverted barrel photons above 20 GeV

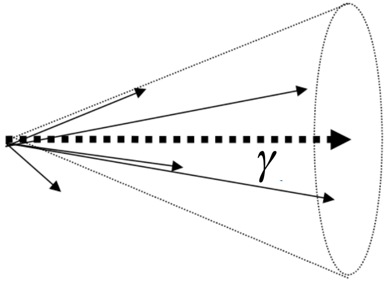
Photon selection

- Trigger selects clusters of energy deposits above a given threshold in electromagnetic calorimeter
- Selections applied to reduce background:
  - Leakage variables: true photons should deposit only small fraction of energy outside ECAL
  - Shower shape variables: electromagnetic shower profiles are different for one photon and a pair $\pi^0 \rightarrow \gamma\gamma$





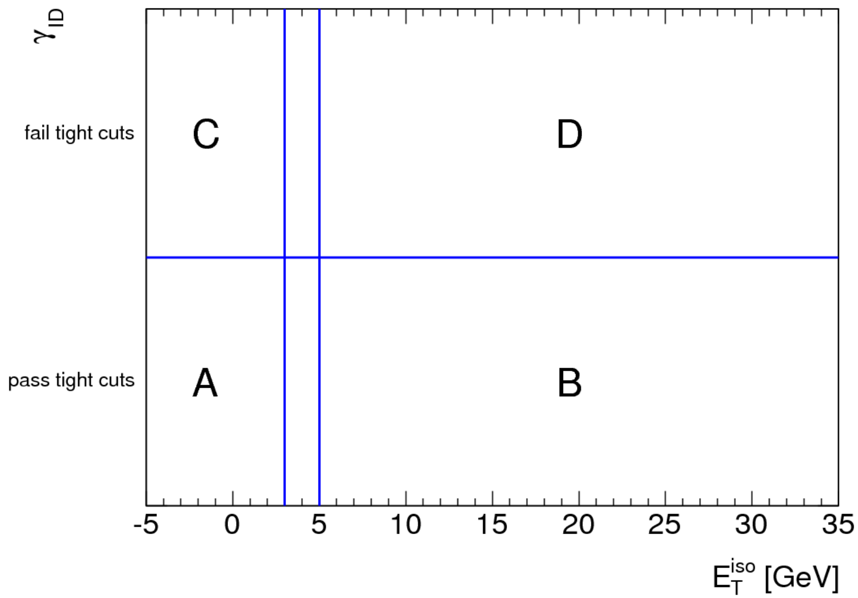
  - Isolation variables: total transverse energy or momentum in a given cone around the photon direction (excluding photon energy)



Fraction of signal photons

ATLAS

- Two-dimensional-sideband

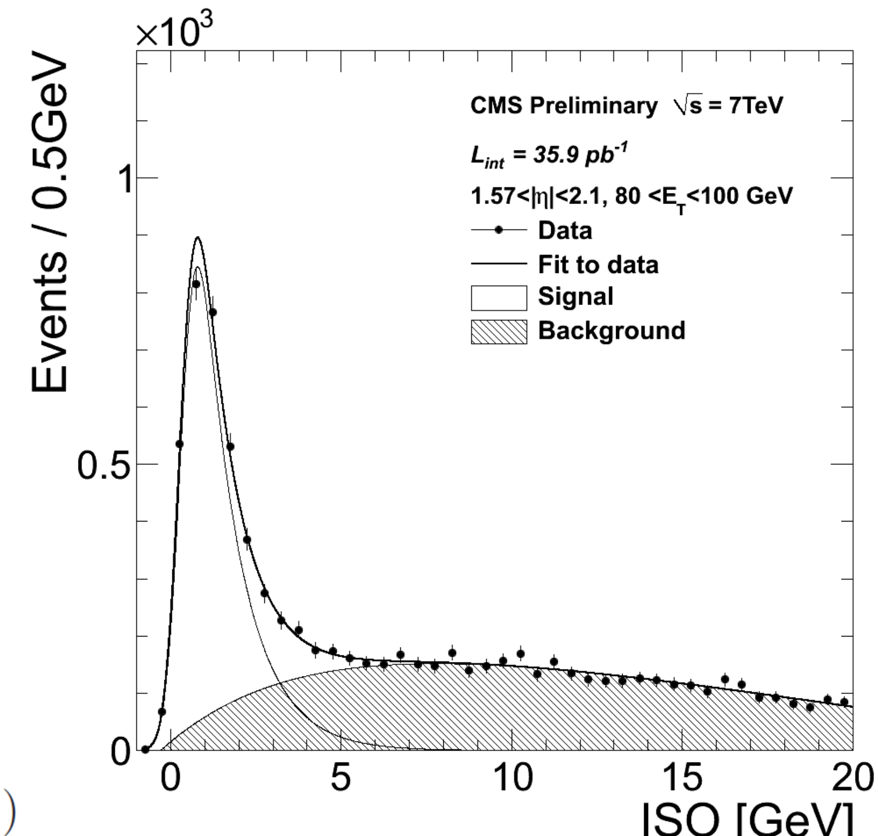


$$N_A^{\text{sig}} = N_A - N_B \frac{N_C}{N_D}$$

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

CMS

- Template fit

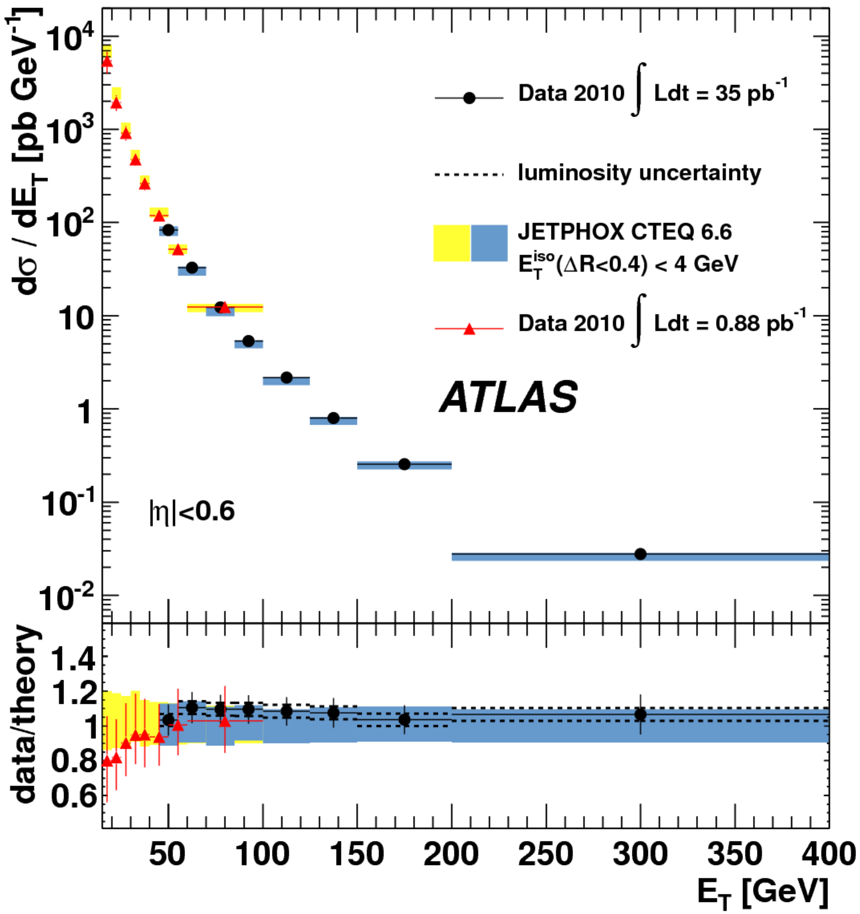


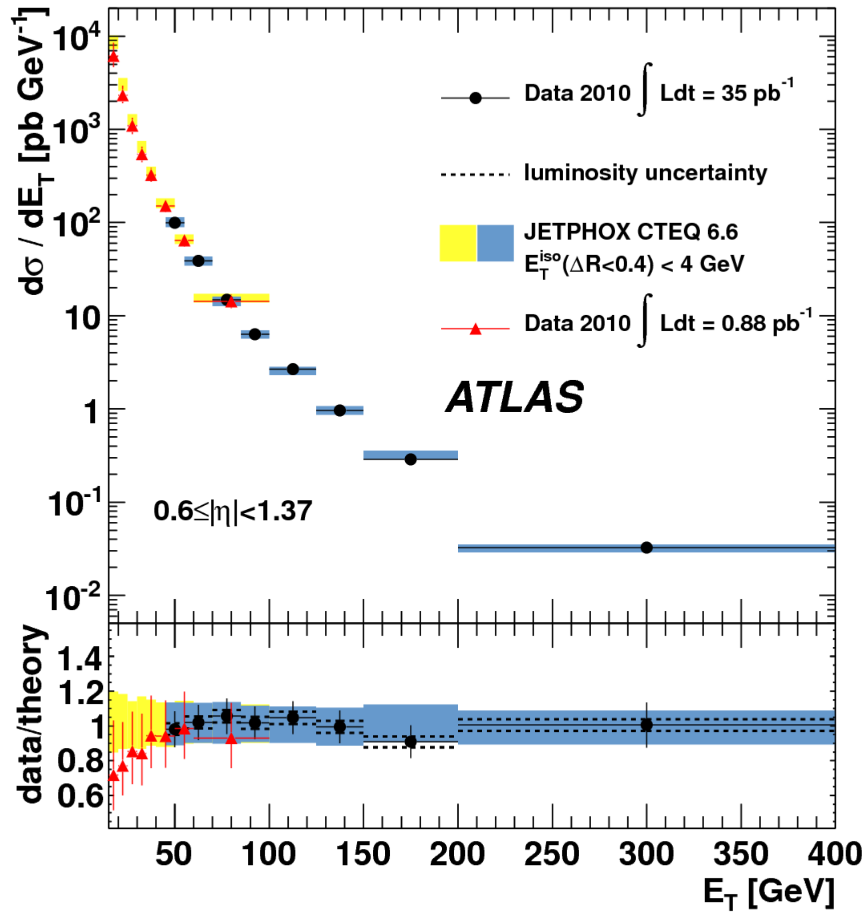
Efficiency and unfolding correction

$$N_i^{meas} = \sum_j c^{ij} N_j^{true}$$

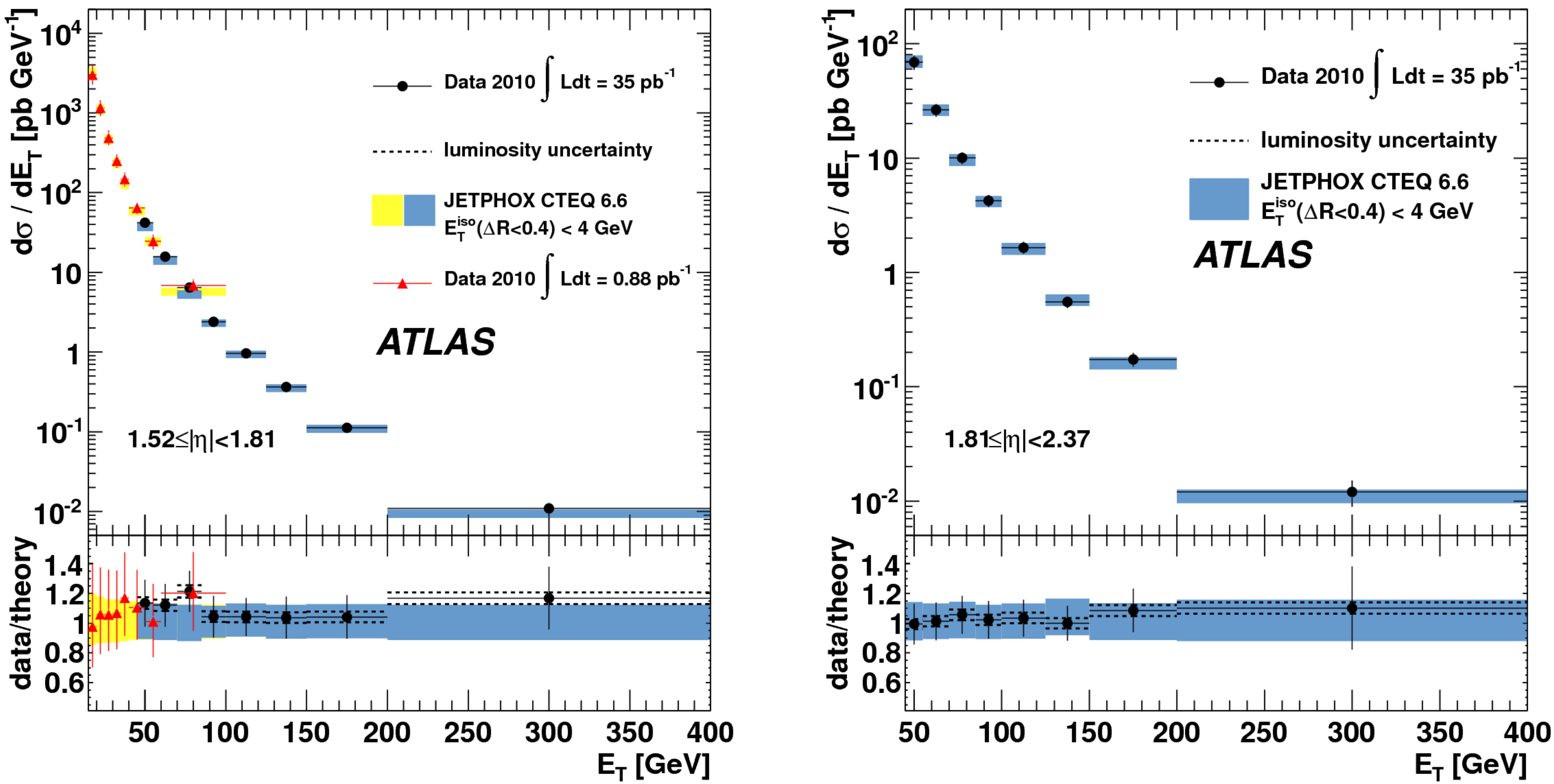
- Trigger efficiency measured in data and in plateau region is very close to 100%.
- Unfolding (off-diagonal elements) is calculated with Monte Carlo. Small effect due to a good energy resolution and calibration.
- Various photon selection efficiencies measured or estimated in a data-driven way ($Z \to e^+e^-$ control sample, *random cone*, etc.)

ATLAS inclusive photon cross section (1)

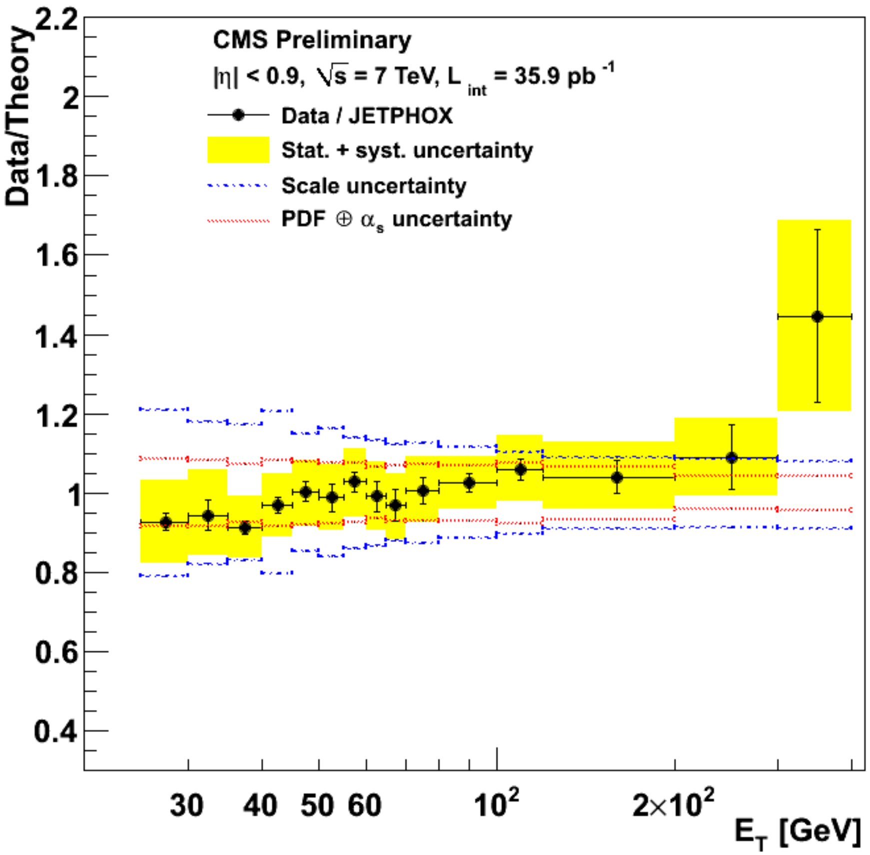


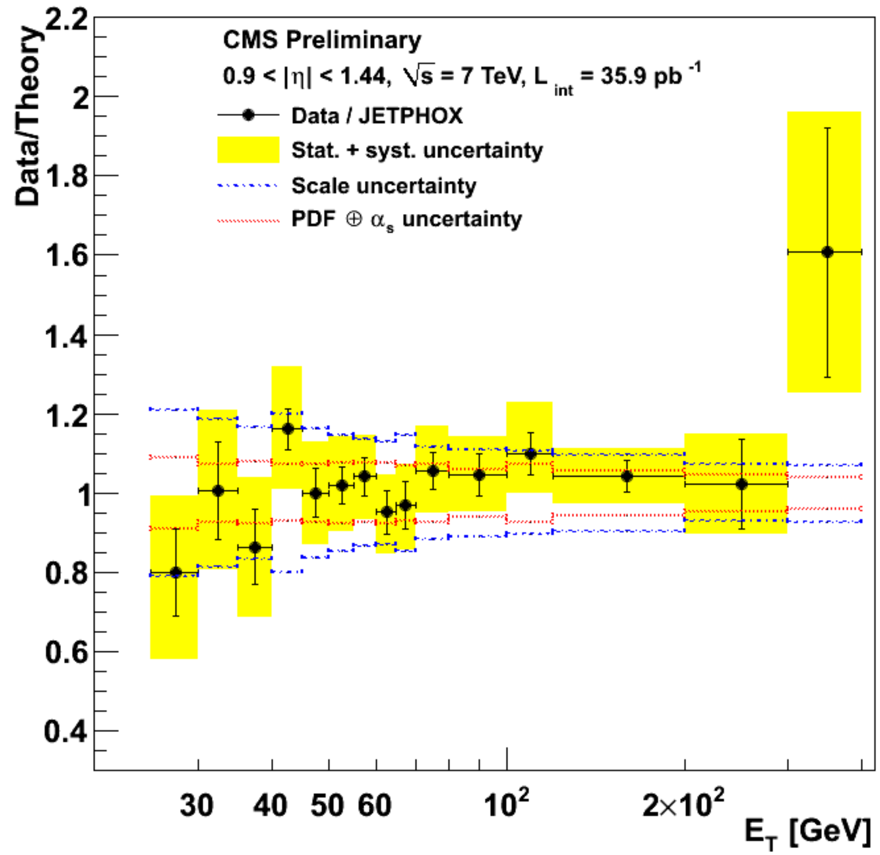


ATLAS inclusive photon cross section (2)

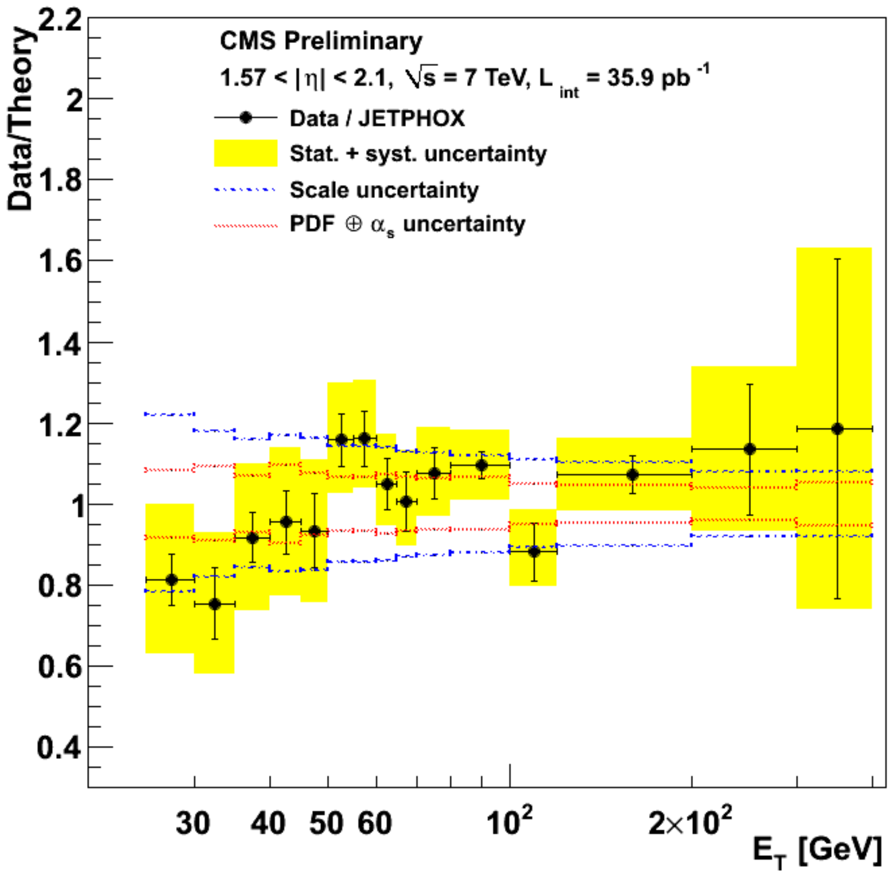


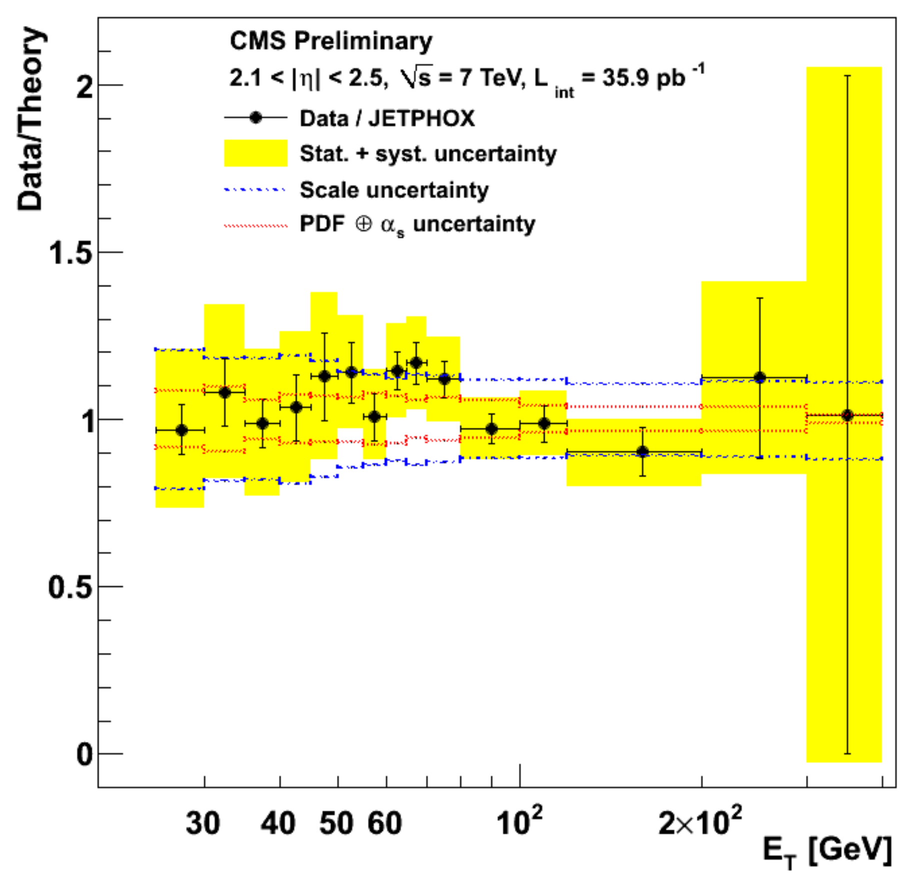
CMS inclusive photon cross section-data/theory ratio (1)





CMS inclusive photon cross section-data/ theory ratio (2)



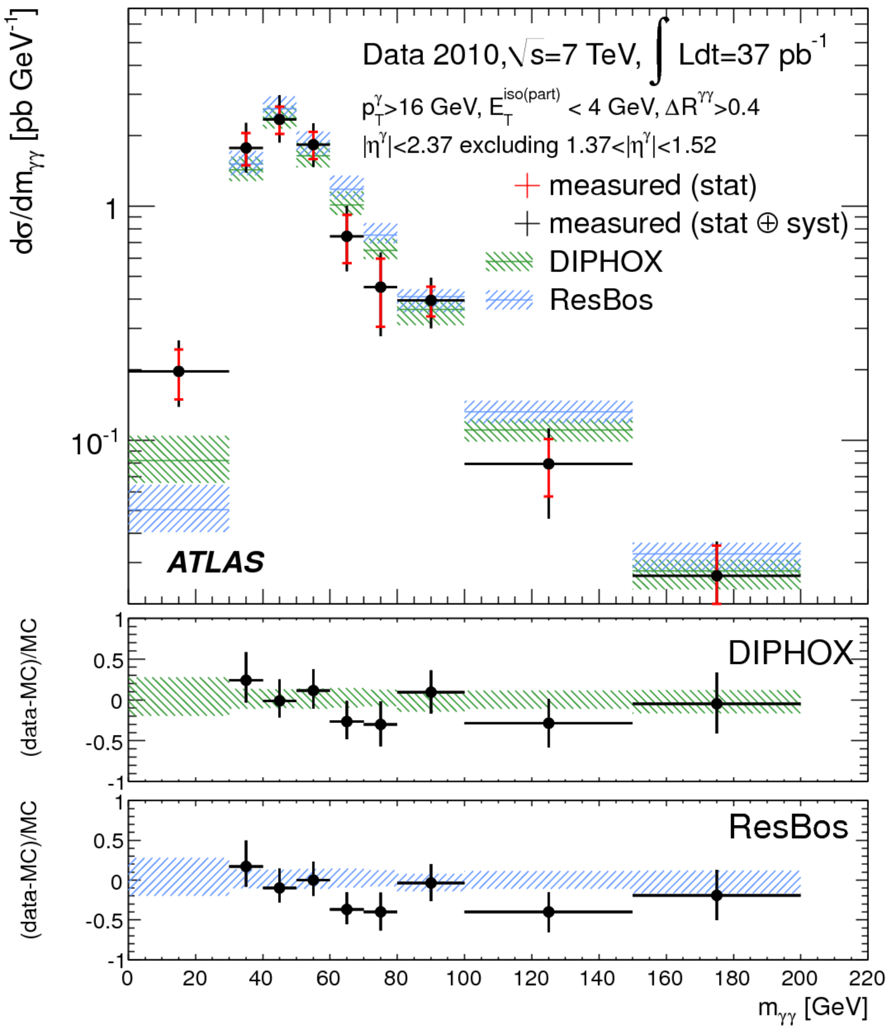


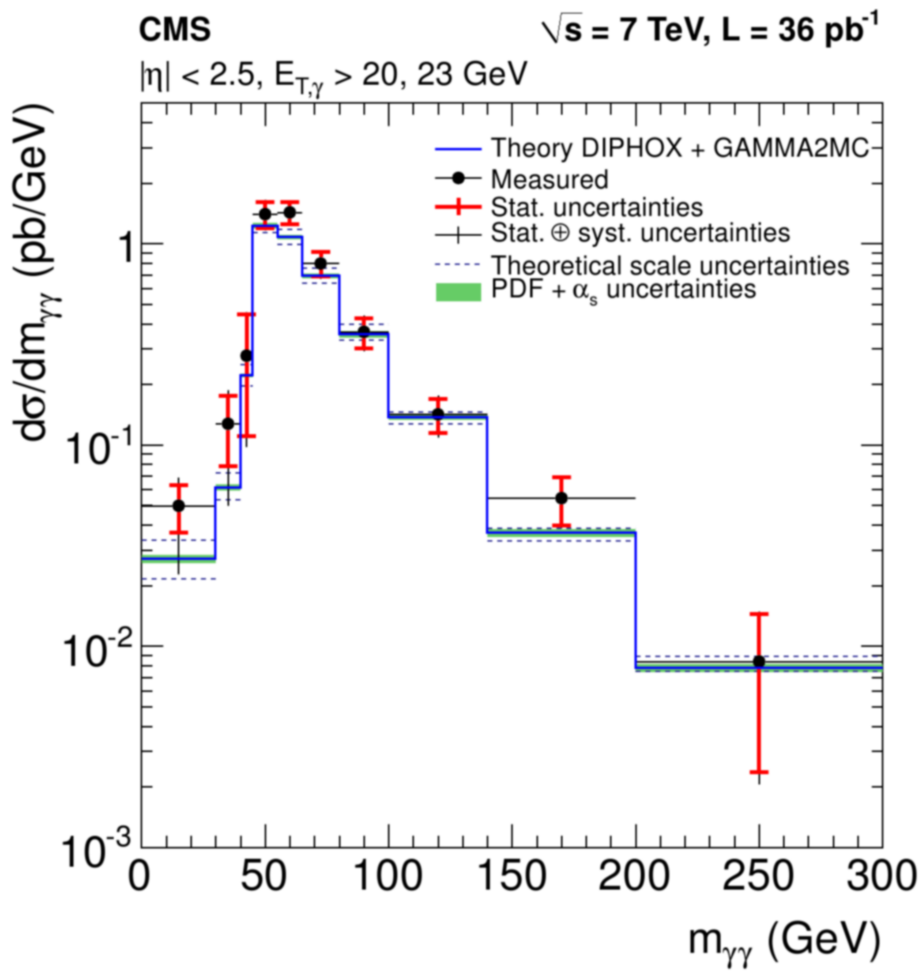
Diphoton

- Production
  - quark-antiquark annihilation
  - Gluon-gluon interaction mediated by quark box diagram

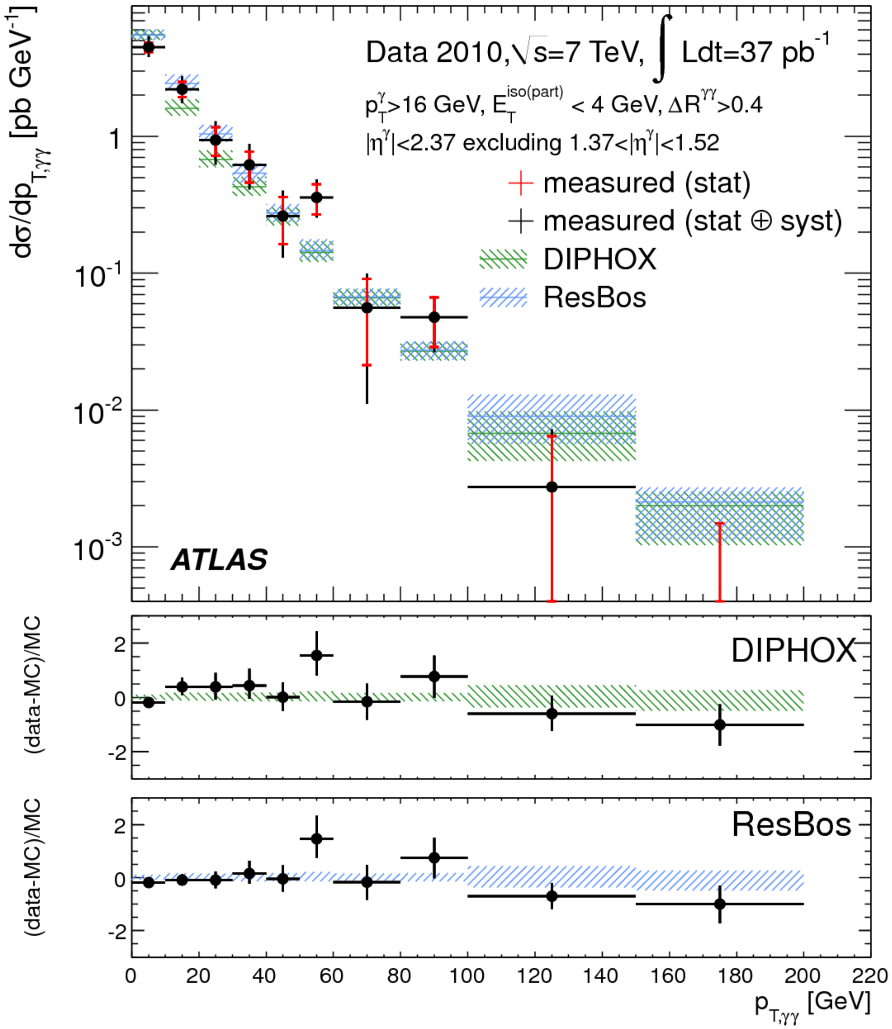
- Variables
  - Photon-pair invariant mass $m_{\gamma\gamma}$
  - Azimuthal separation of photons $\Delta\varphi_{\gamma\gamma}$
  - Photon pair transverse momentum $p_{T,\gamma\gamma}$
  - $|\cos\theta^*| = |\tanh \frac{y_{\gamma 1} - y_{\gamma 2}}{2}|$ (only CMS)

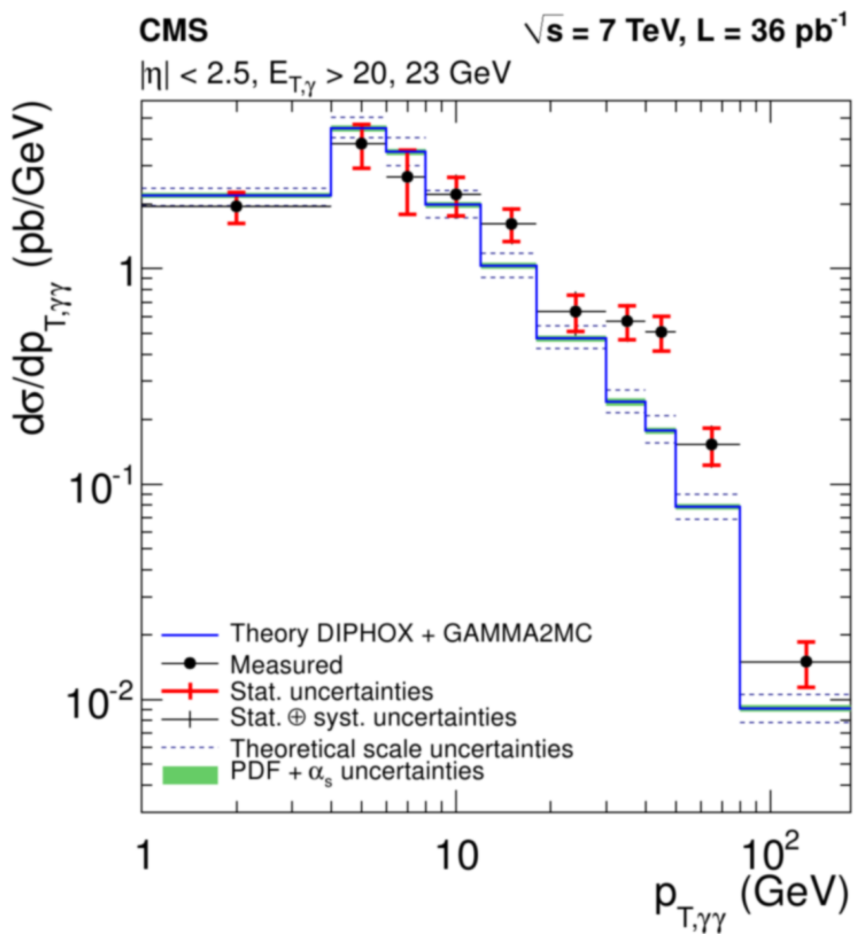
ATLAS and CMS diphoton cross section in $m_{\gamma\gamma}$



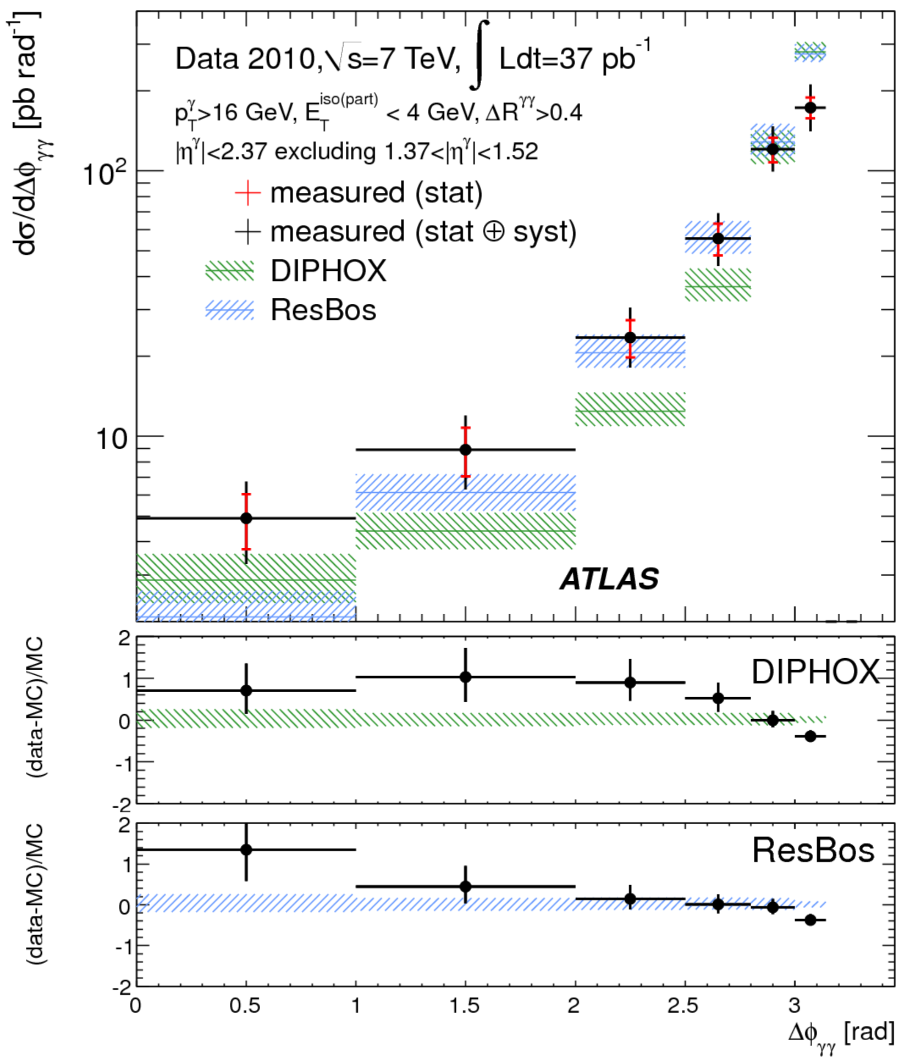


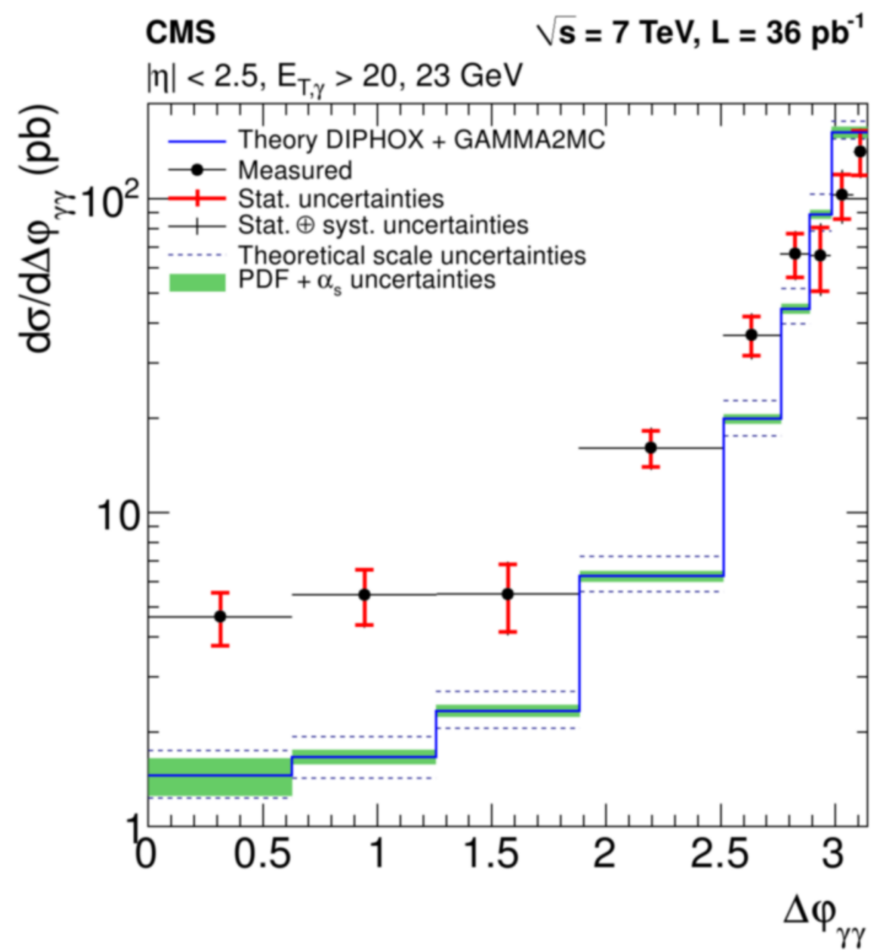
ATLAS and CMS diphoton cross section in $p_{T,\gamma\gamma}$





ATLAS and CMS diphoton cross section in $\Delta\varphi_{\gamma\gamma}$

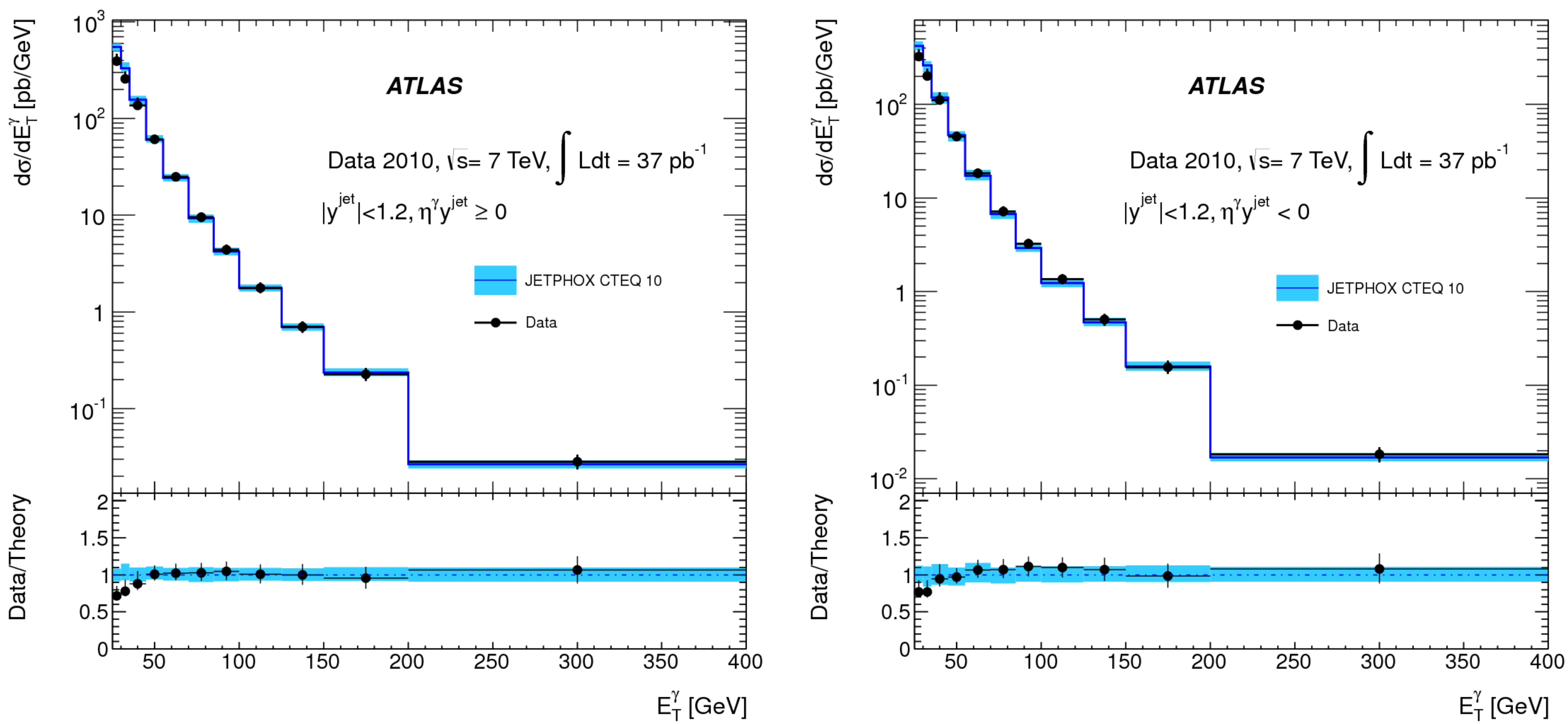




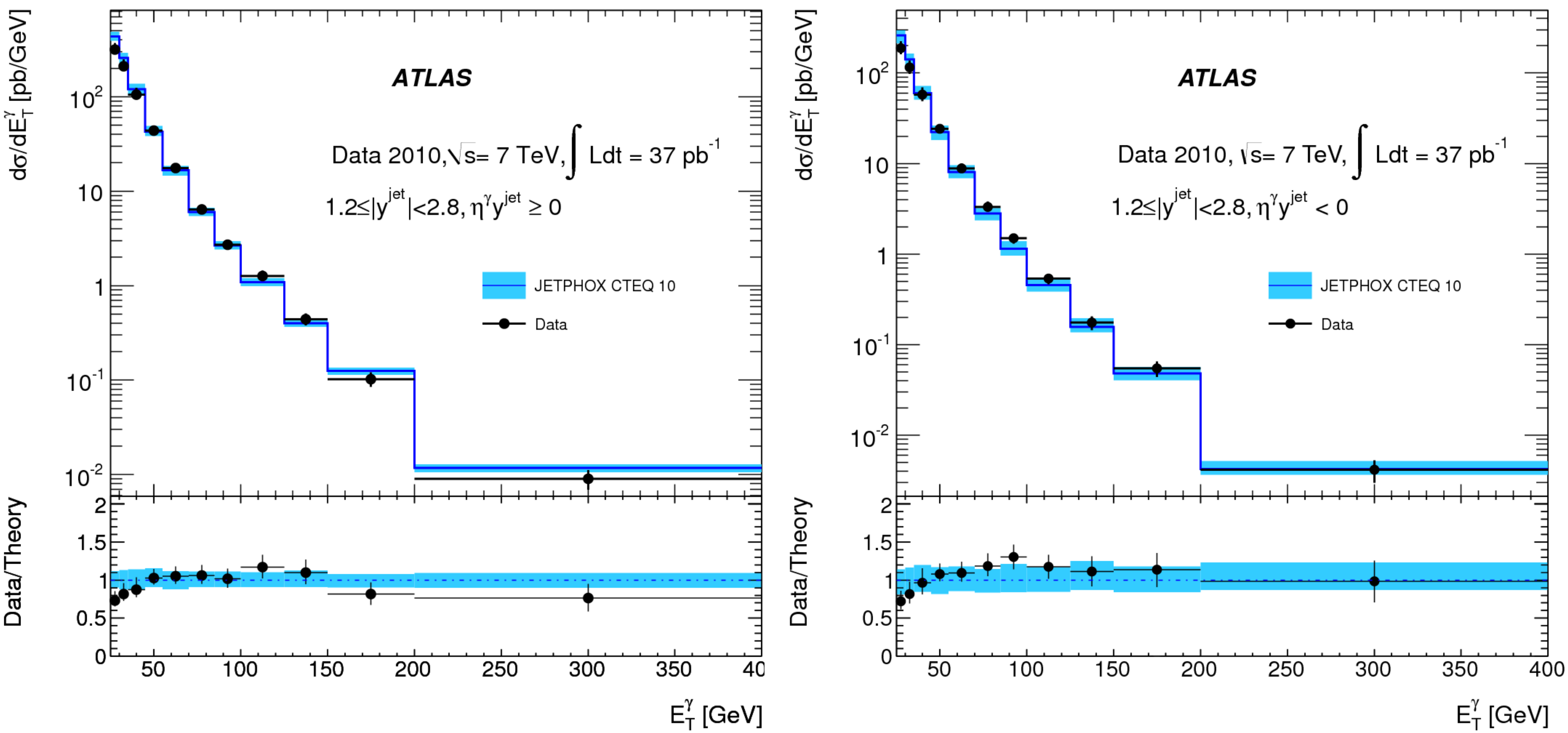
Photon + jet

- Cross sections calculated for three jet rapidity intervals and two photon-jet configurations:
  - $\eta^{\gamma} y^{jet} \geq 0$ and $\eta^{\gamma} y^{jet} < 0$
- Jet selection
  - Leading jet with $p_T^{jet} > 20 GeV$ and $| y^{jet} | < 4.4$
  - Built from calorimeter with anti-kt algorithm and R=0.4
  - Recalibrated to account for instrumental effects and pile up
  - Separated from photon: $\Delta R > 1.0$

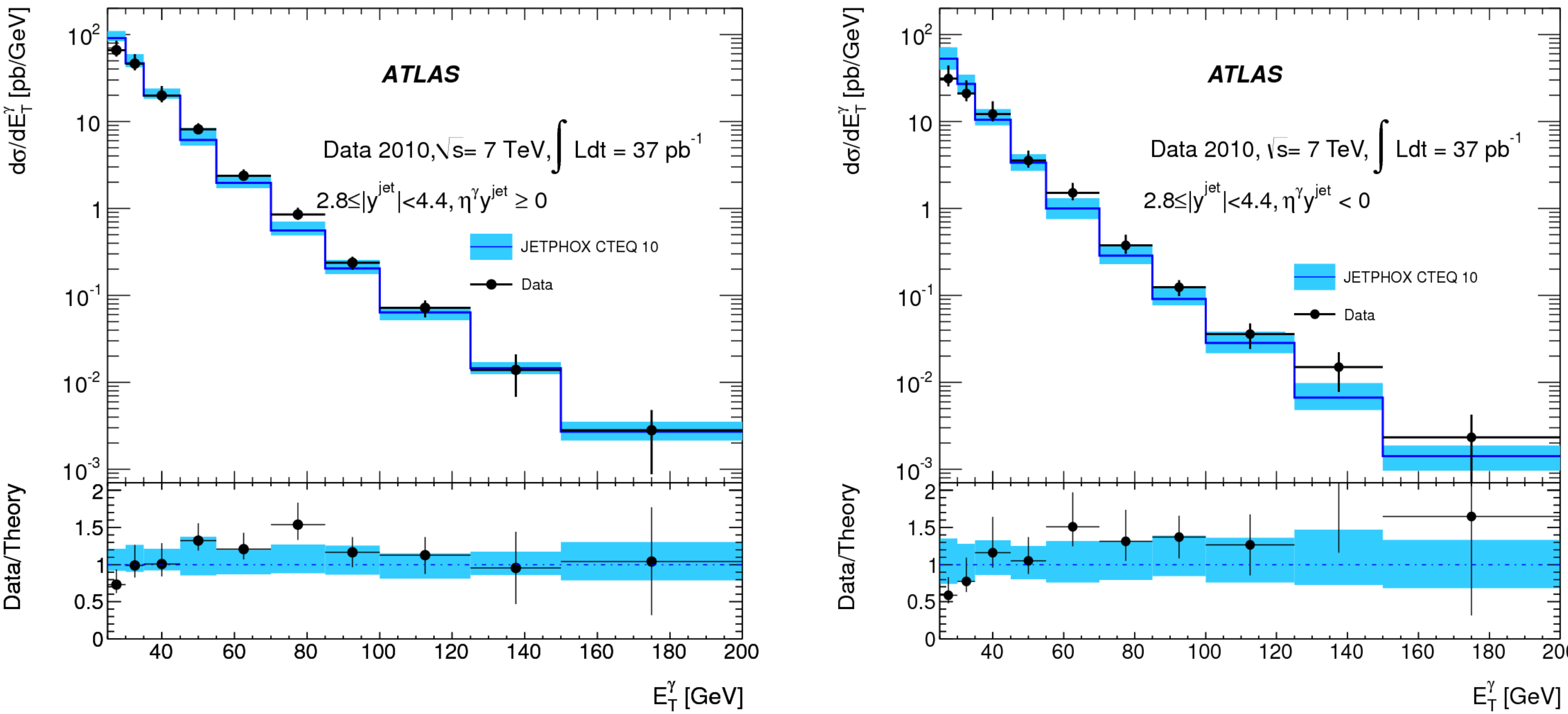
ATLAS photon+jet cross section for central jet rapidity interval



ATLAS photon+jet cross section for forward jet rapidity interval



ATLAS photon+jet cross section for very forward jet rapidity interval



Summary on direct photon measurements (1)

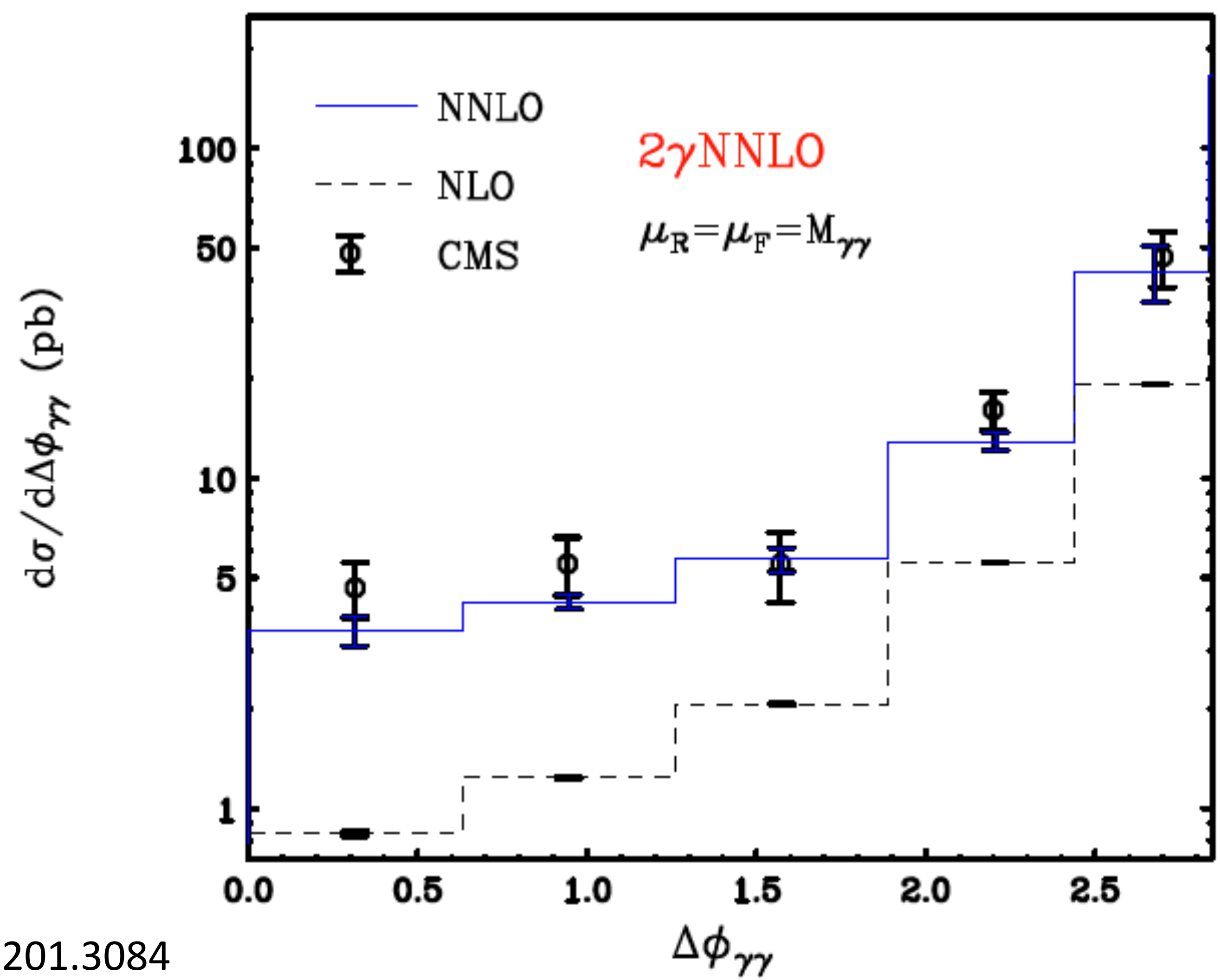
- Published results include cross section measurements with 2010 data set for **inclusive isolated photon** (ATLAS+CMS), **isolated diphoton** (ATLAS+CMS) and **isolated photon associated with jet** (ATLAS)
- In most cases the uncertainty of measurement is dominated by systematic uncertainty. Main contribution is usually related to the estimates of background coming from neutral hadron decays.

Summary on direct photon measurements (2)

- Results are compared to QCD NLO theory
- While there are some kinematic regions that exhibit tension between measurement and theory, overall the agreement is good
  - Low E_T^{γ} in inclusive photon and photon plus jet
  - $\Delta\varphi_{\gamma\gamma}$ in diphoton significant underprediction for low values corresponds to collinear regime where no LO terms contribute. Preliminary NNLO calculation (arXiv: 1110.2375) is in good agreement with CMS data (arXiv: 1201.3084)

Backup slides

NNLO predictions (arXiv:1110.2375)



arXiv:1201.3084