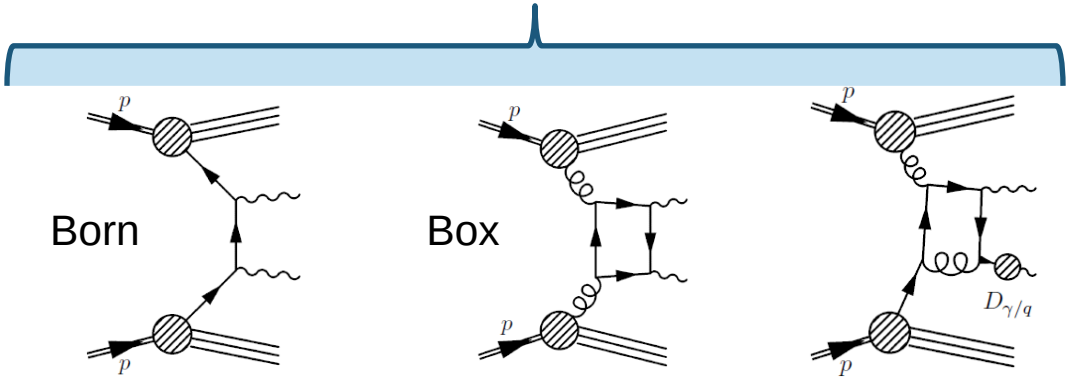
Photon production at the LHC

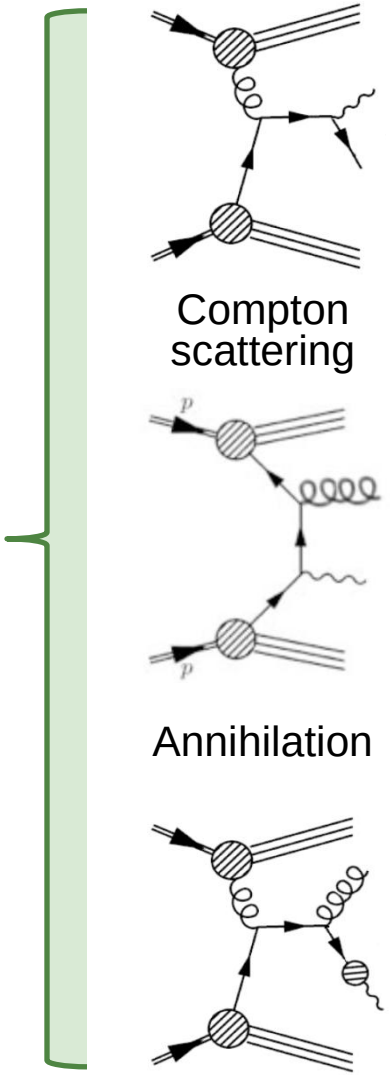
Remi Lafaye

On behalf of the ATLAS and CMS collaborations

Photon production at LHC

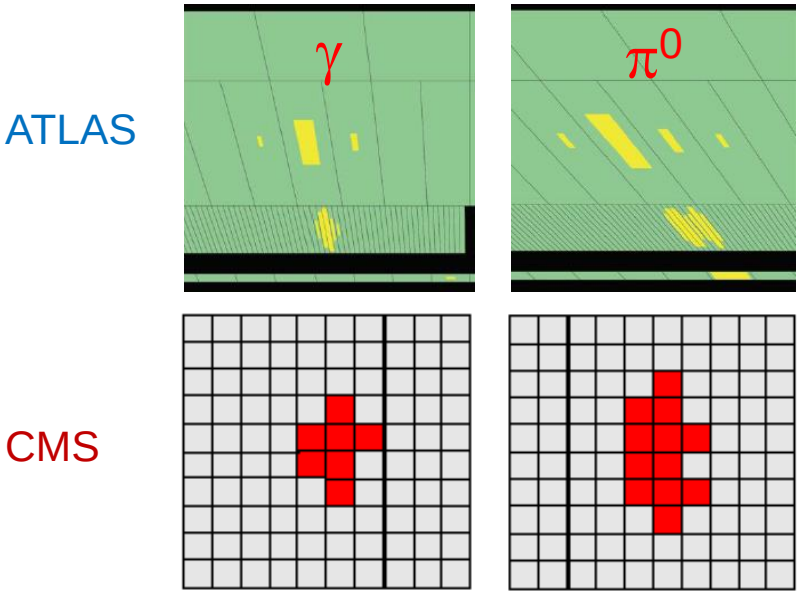
- Goals
  - Test of perturbative QCD predictions
  - Probe gluon content of the proton (direct photon produced mainly from qg)
  - Understand photon background for Higgs to 2γ and New Physics searches
- Prompt photons & Photon-jet
  - **pQCD** and **PDF** tests
  - Photon-jet: +information on the fragmentation component
- Di-photons
  - Test of collinear and k_T **factorization** approaches and **soft gluon** logarithmic resummation techniques
  - Understanding of the **fragmentation** component

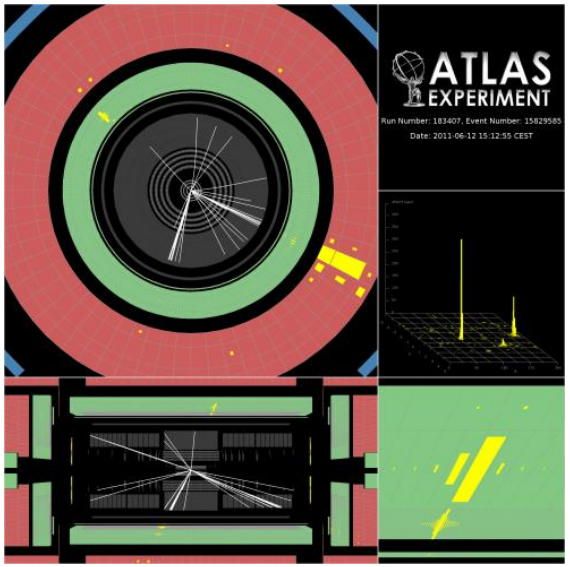




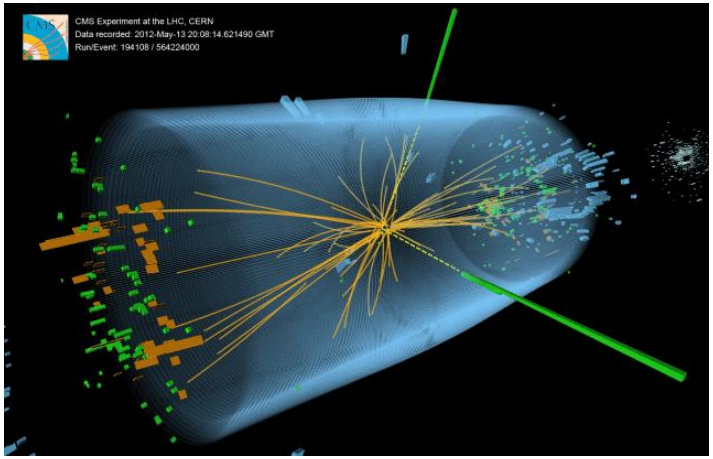
Reconstruction & identification

- Photon reconstruction:
  - From EM calorimeter cells
  - Not matched to tracks (unconverted)
  - 2 & 1 track matching for converted γ
- Photon identification:
  - Main background from jets with π^0 & η
  - CMS: topological fit of the cluster shape
  - ATLAS: shower shape variables in first layer (high η granularity)





960 GeV photon in ATLAS @ 7TeV

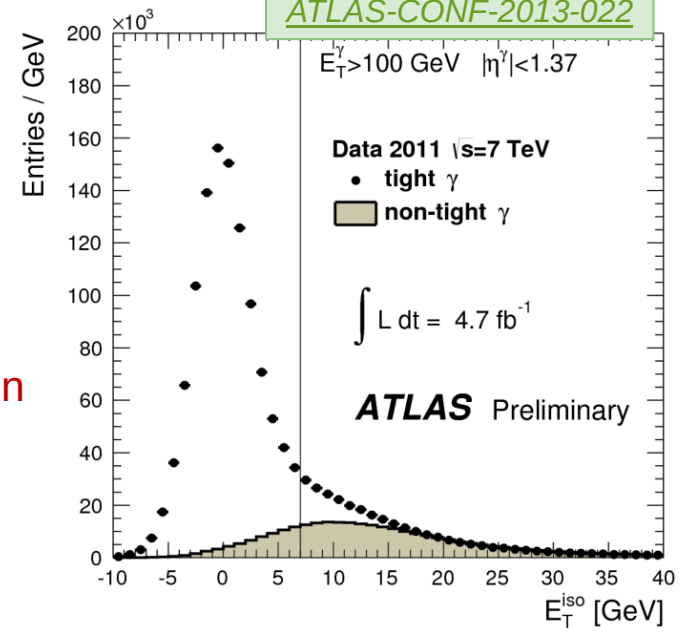


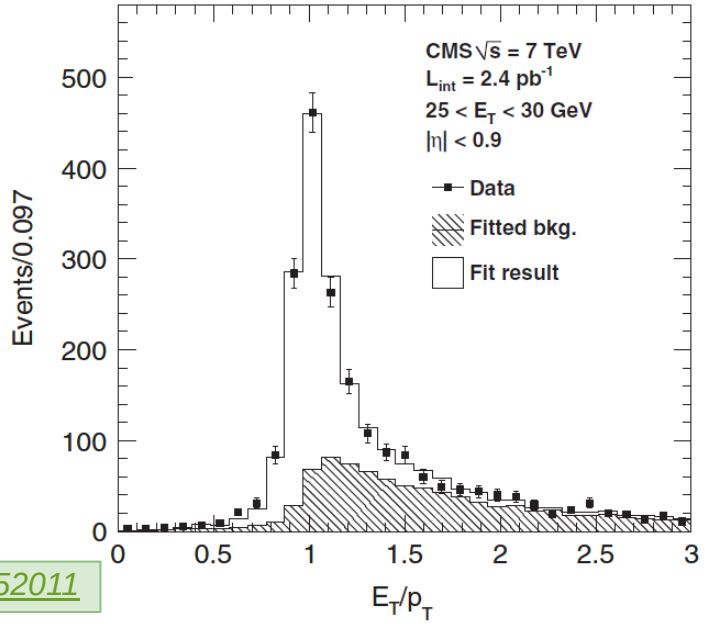
Higgs to $\gamma\gamma$ candidate in CMS

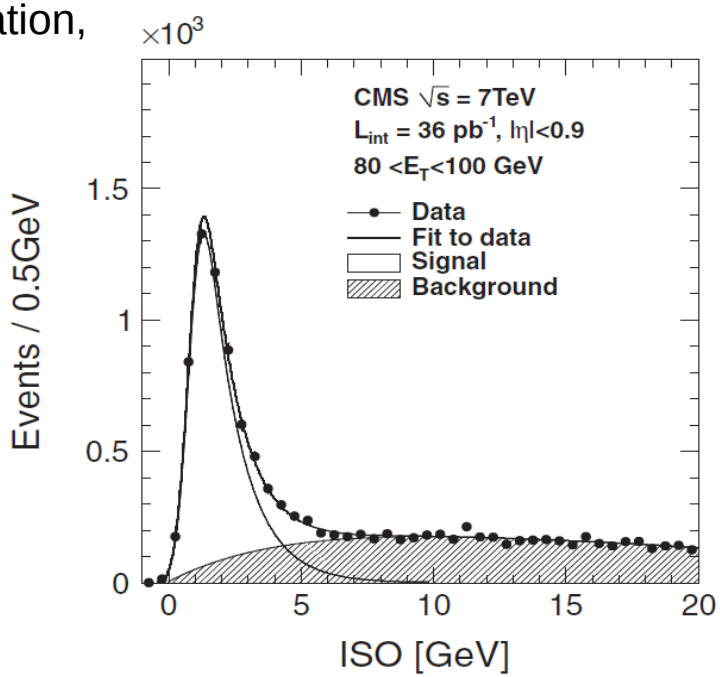
Prompt photons - Signal extraction

- QCD jet production is orders of magnitudes above the signal: Jet rejection uses shower shape and isolation ($\Delta R<0.4$) criteria
- Signal extraction largely data-driven:
  - CMS: E_T/p_T for photon conversions (@low E_T) + isolation
  - ATLAS: 2D sideband (isolation + identification)
  - Signal pdf taken from MC, corrected using electron samples
  - Background pdf from data (with reverse identification, or isolation)

ATLAS-CONF-2013-022

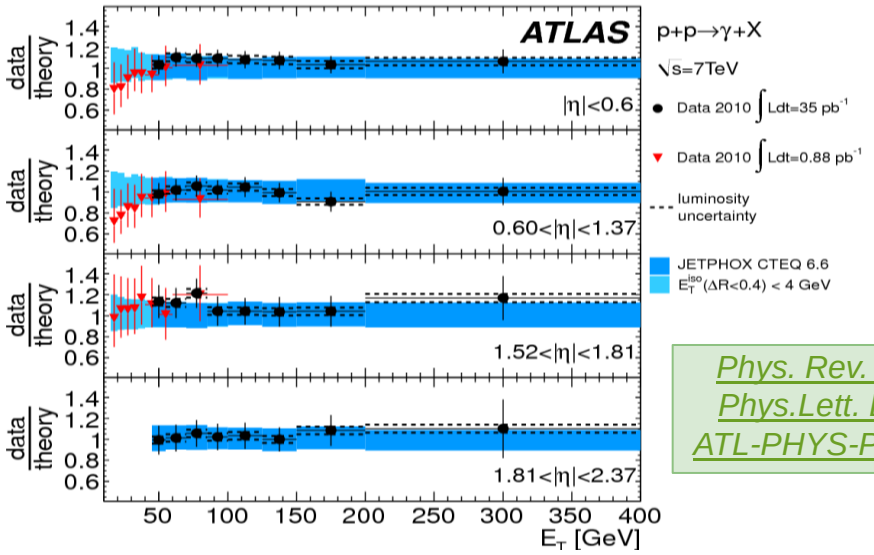




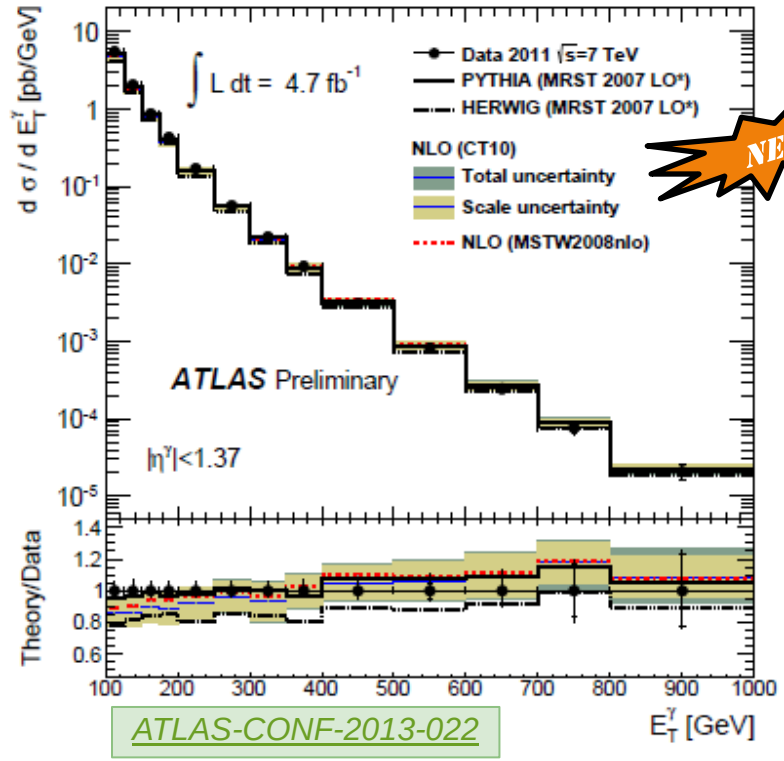


Phys. Rev. D 84 (2011) 052011

Prompt photons - Cross section vs E_T



Phys. Rev. D 83 (2011)
Phys.Lett. B706 (2011)
ATL-PHYS-PUB-2011-013



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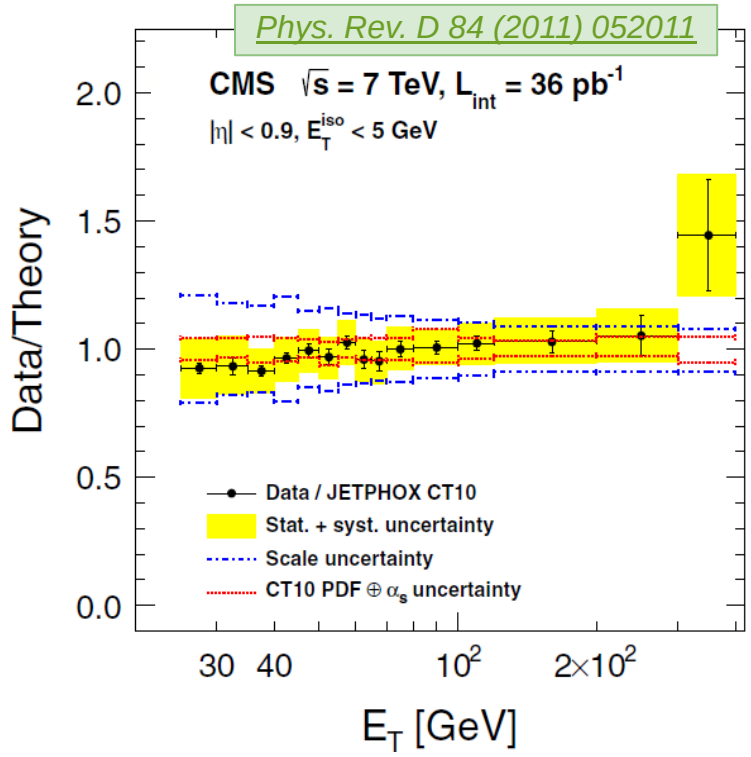
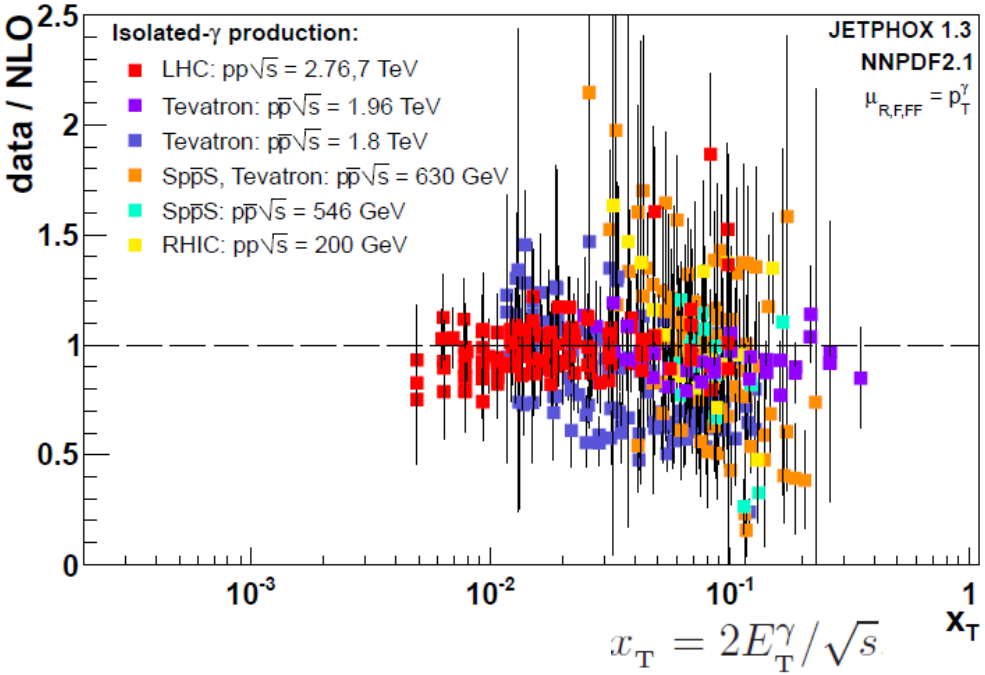
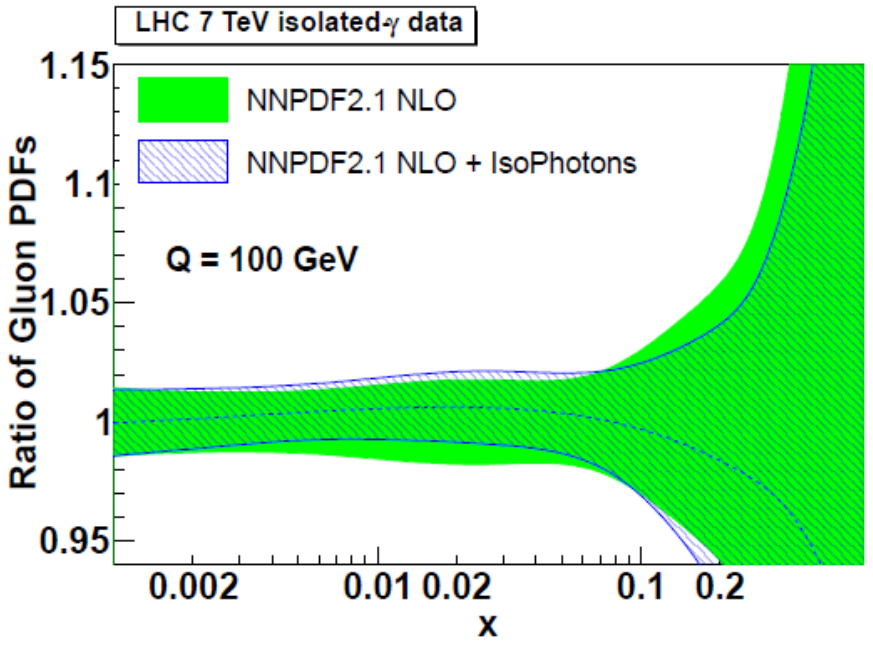


- Highest disagreement at low E_T
- Above 100 GeV: data systematically higher
- Slope at very high E_T maybe because of missing fragmentation component?
- Large PDF (gluon) uncertainties at E_T>700 GeV
- PYTHIA in good agreement with data
- HERWIG systematically lower but within errors

Prompt photons – Constraining PDFs

- Adding LHC 2010 measurements together with RHIC, Sp$\bar{p}$S, Tevatron
- Constraints on quark PDF are negligible
- LHC data lead to up to 20% gluon PDF uncertainty reduction





D. d'Enterria, J. Rojo
Nucl.Phys. B860 (2012) 311-338

- Note: leads to >20% PDF uncertainty reduction for σ(gg→H)

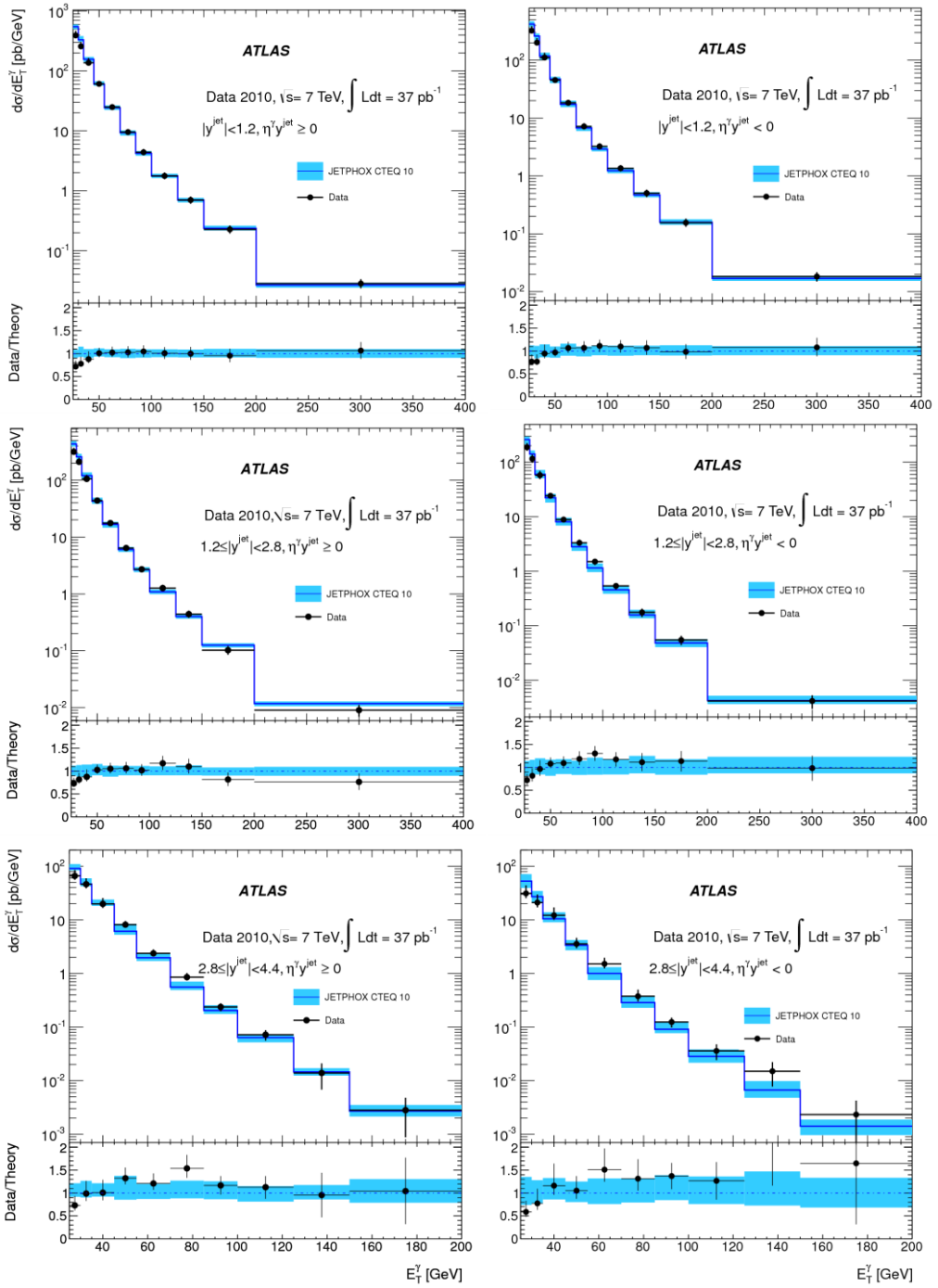
Process / Cross section	$gg \to H(120)$
NNPDF2.1	11640 ± 181 fb
NNPDF2.1 + LHC IsoPhotons	11701 ± 140 fb

Photon-jet

ATLAS:

Compared to JETPHOX predictions

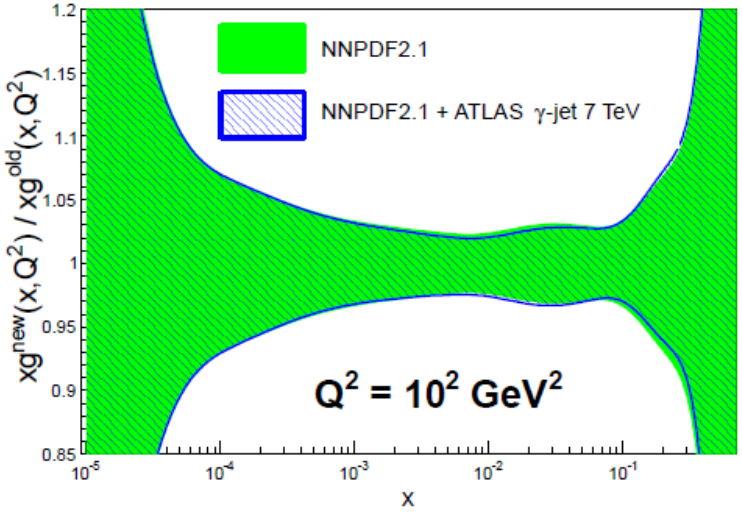
- E_T^{γ}>25 GeV, p_T^{jet}>20 GeV
- Two regions with different fragmentation contributions: Same and opposite eta signs
- 3 regions in y^{jet}: different x values
- 3 different PDF tested (CTEQ10, MSTW2008 & NNPDF2.1)
- JETPHOX overestimates the data at low E_T (same as for prompt γ)
- Worse agreement for the most forward rapidities

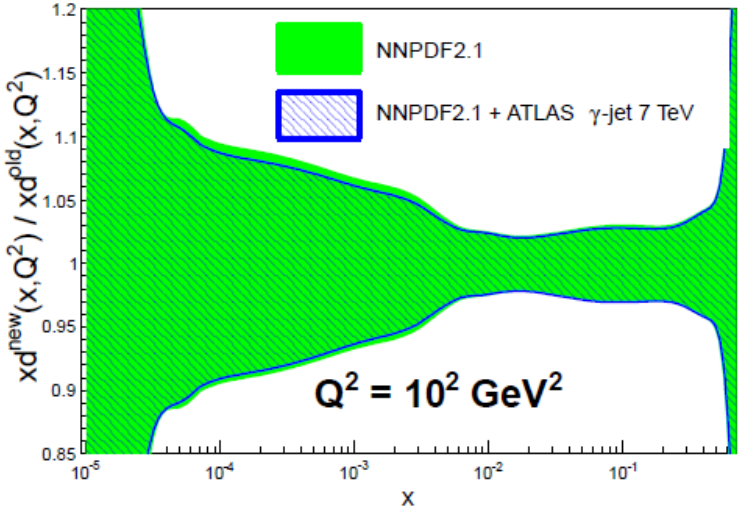


Phys. Rev. D 85, 092014 (2012)

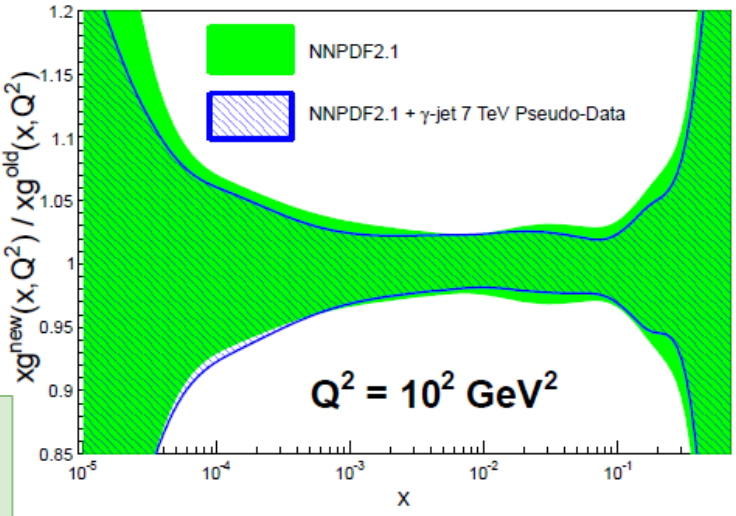
Photon-jet – Constraining PDFs

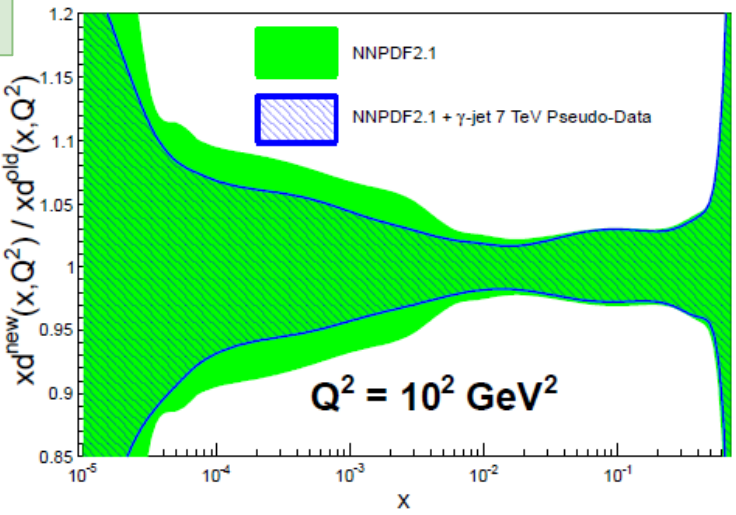
- Current LHC data gives little constraint on gluon and light quarks PDF
- ~5% PDF uncertainty reduction





Carminati, Costa, d'Enterria, Koletsou, Marchiori, Rojo, Stockton, Tartarelli (2012)
arXiv:1212.5511 [hep-ph]

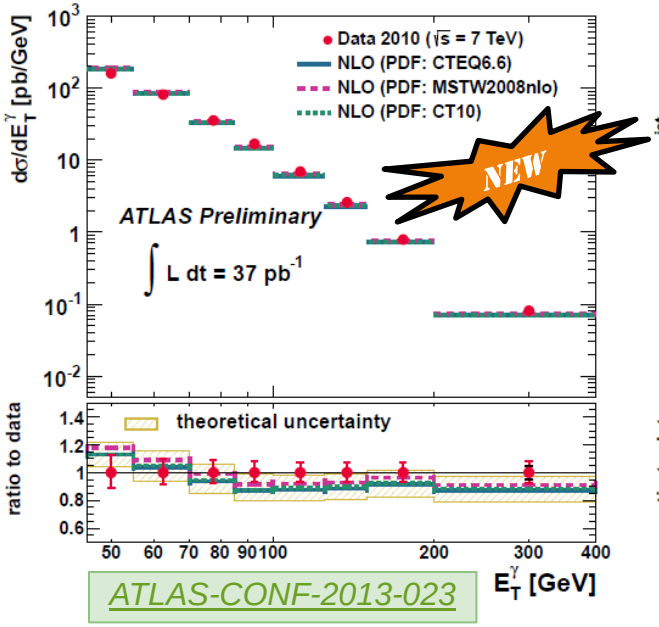




- Pseudo DATA with factor 2 to 3 lower uncertainties is promising
- Could be up to 40% reduction in some regions (gluon + quarks @ low x)

Photon-jet dynamics with 37 pb^{-1}

ATLAS



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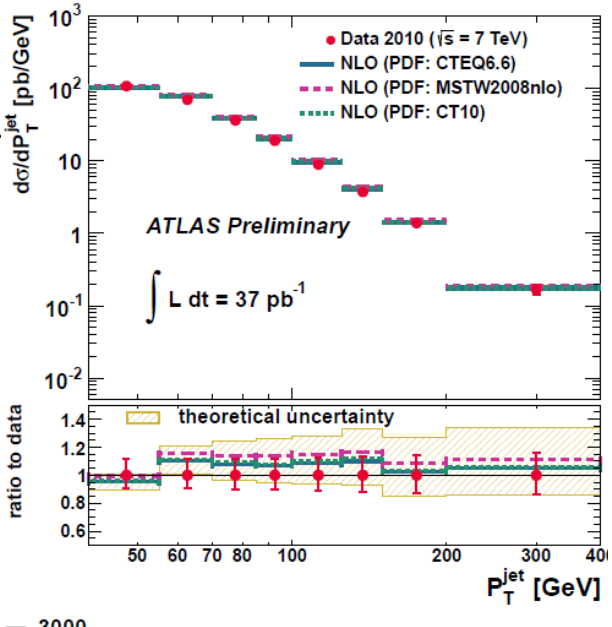
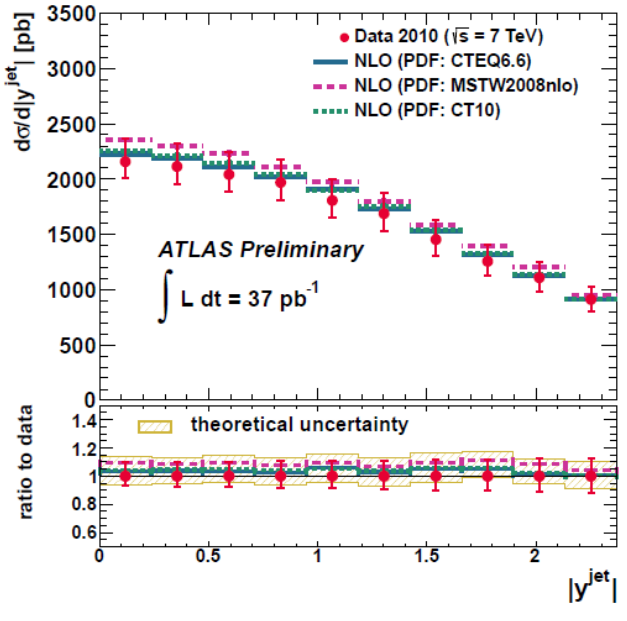
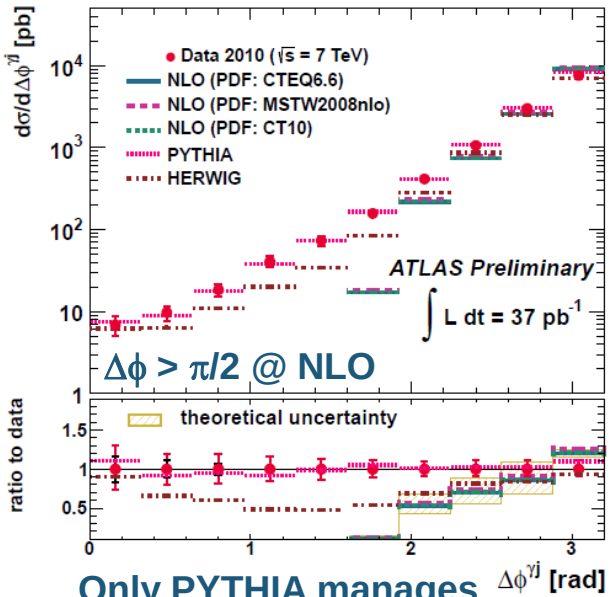
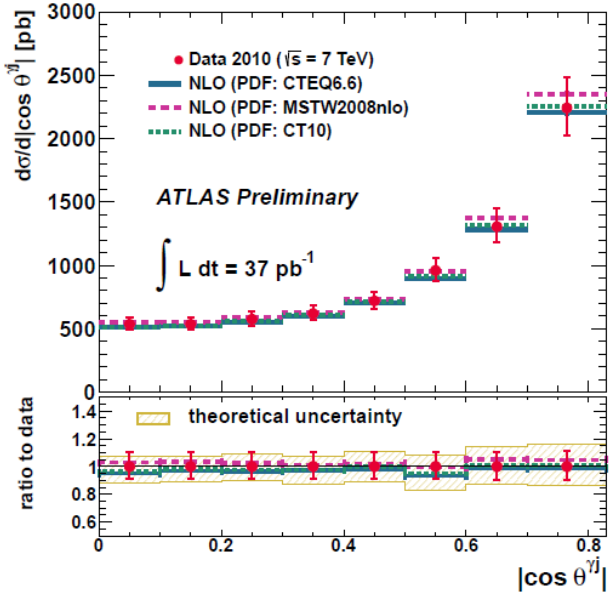






Only PYTHIA manages to reproduce Δφ



cosθ: Sensitive to the spin of the exchanged particle in the t-channel

Possibility to tune the direct photon and fragmentation relative contributions

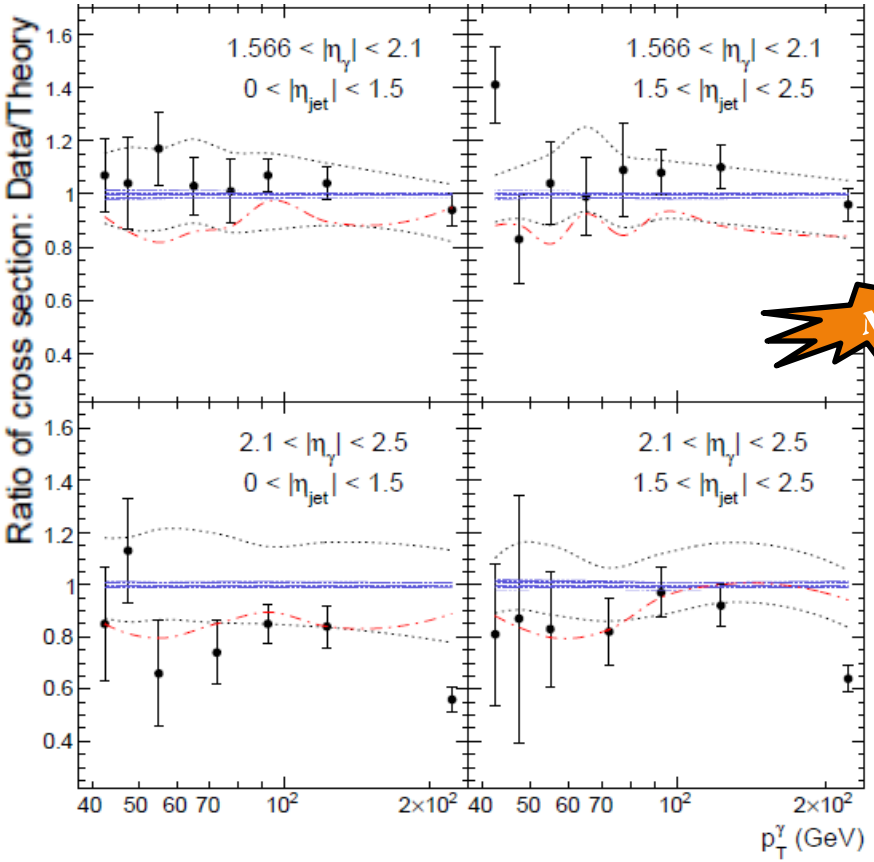
Photon-jet 2.14 fb^{-1}

CMS-PAS-QCD-11-005

CMS:

Compared to JETPHOX and SHERPA predictions

- JETPHOX in good agreement
- SHERPA underestimates the data



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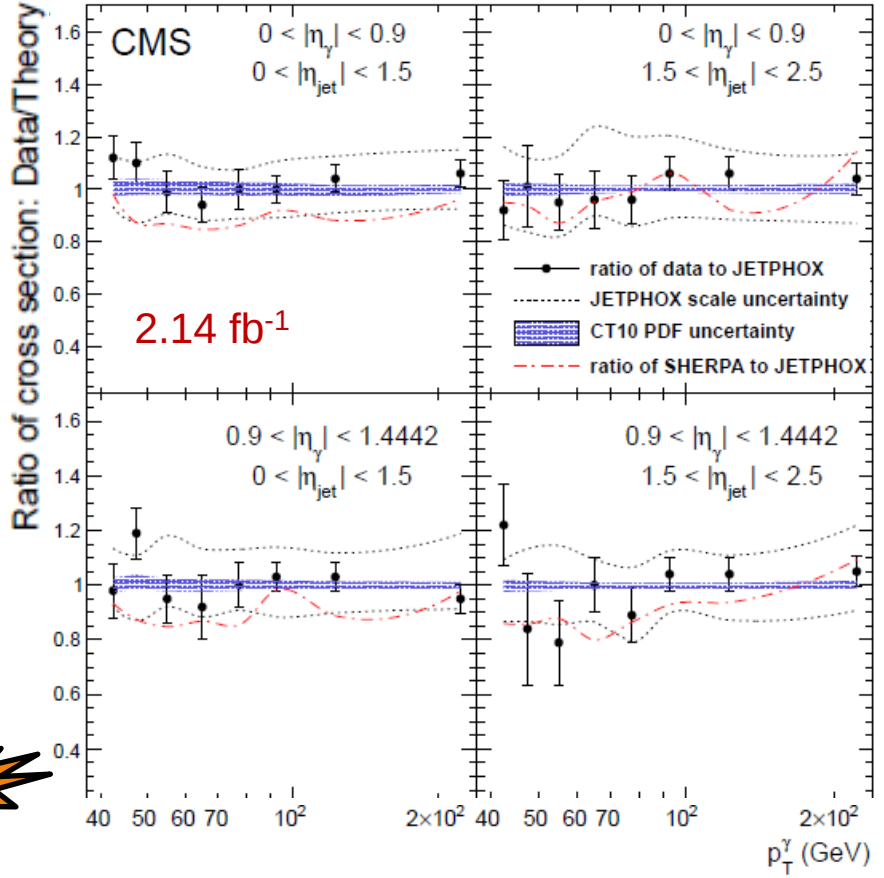


- E_T^{γ}>40 GeV, p_T^{jet}>30 GeV
- 4 regions in η^{γ}
- 2 regions in η^{jet}
- PDF used: CTEQ6 (SHERPA) and CT10 (JETPHOX)

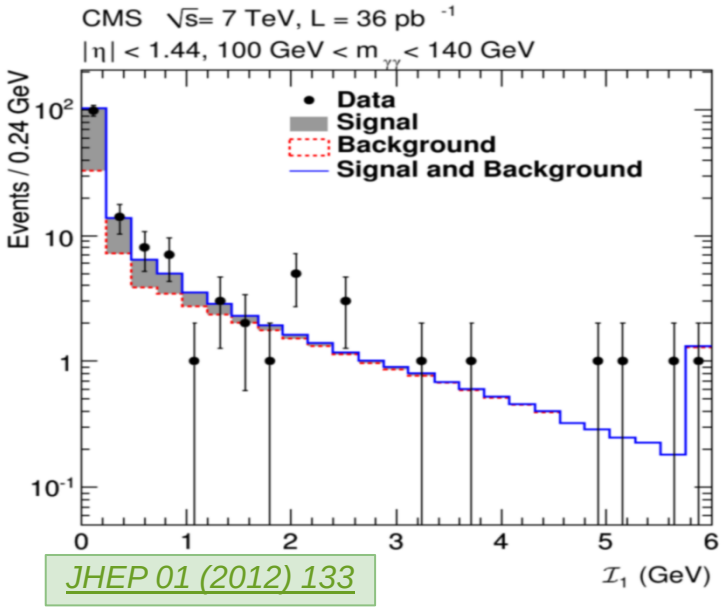
Di-photons - Signal extraction

CMS: 2D Template fit

- Two isolated photons E_T>23, 20 GeV
- separated by ΔR > 0.45
- di-photon trigger efficiency >99.9%

ATLAS: Two methods to subtract the jet background (jet-jet and γ-jet events)

- 2D Template Fit with leakage correction
- 2x2D Sideband, extended with jj isolation correlation
- Two isolated photons E_T>25, 22 GeV
- separated by ΔR > 0.4
- di-photon trigger efficiency ~98%



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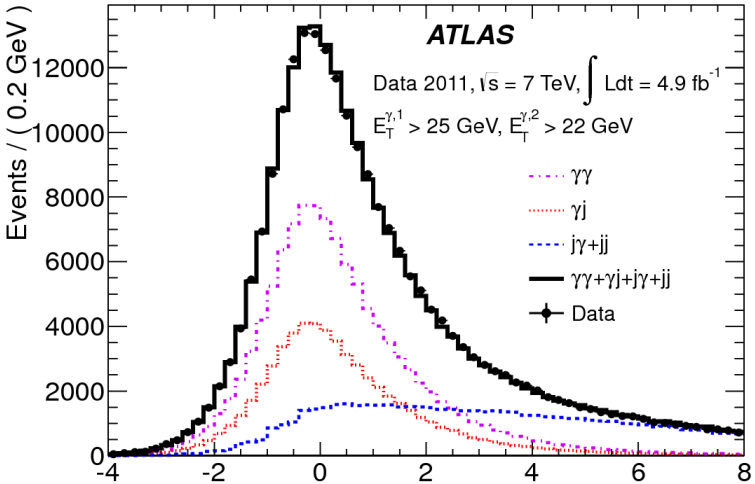

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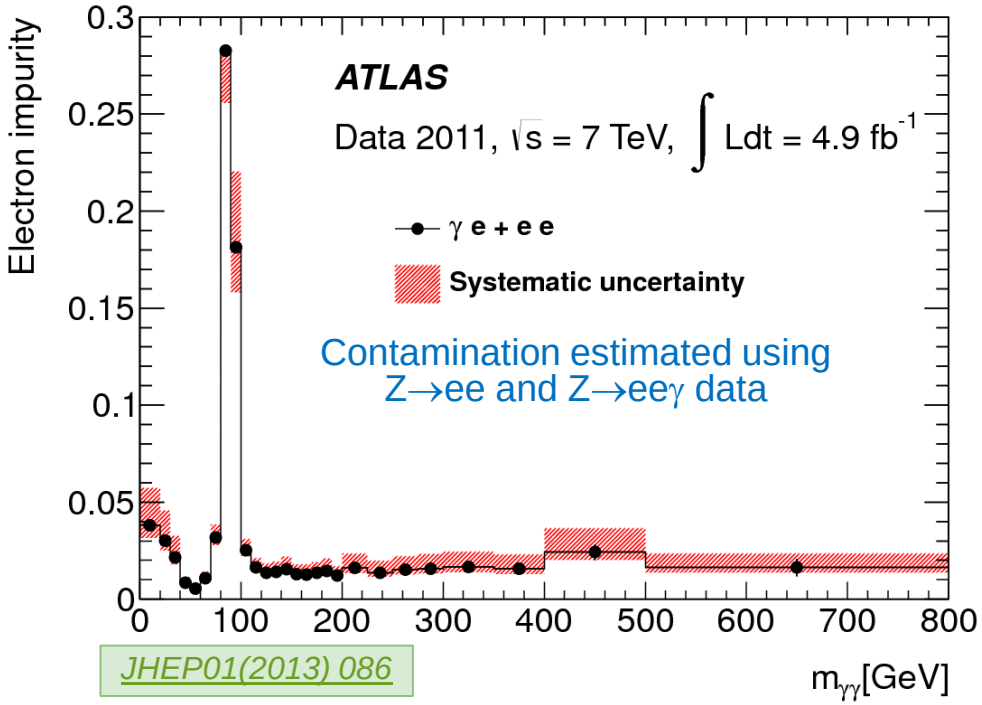
Di-photons – Drell-Yan subtraction

- Second background for di-photon events is Drell-Yan
- Electron background subtraction
  - Impurity is measured bin by bin
  - And then subtracted from the differential yields



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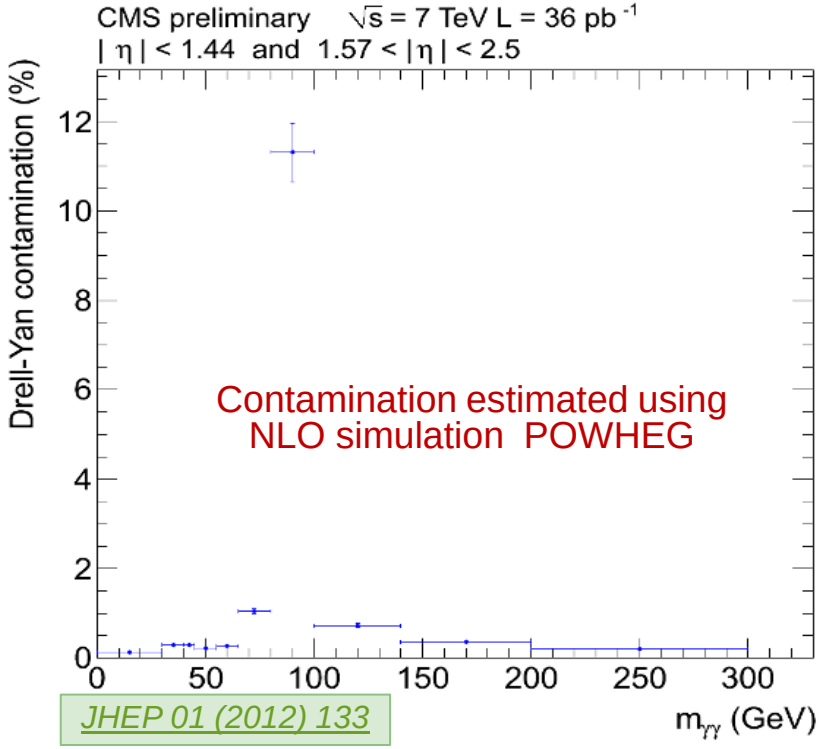

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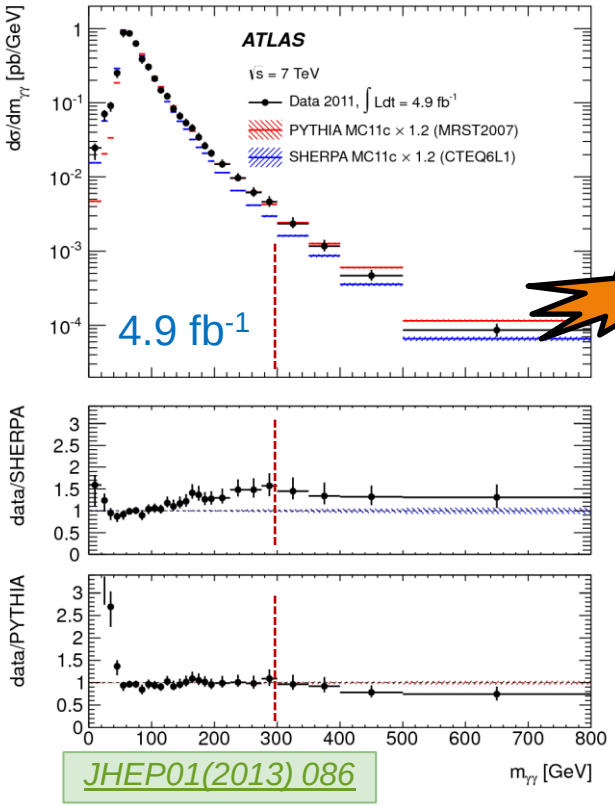
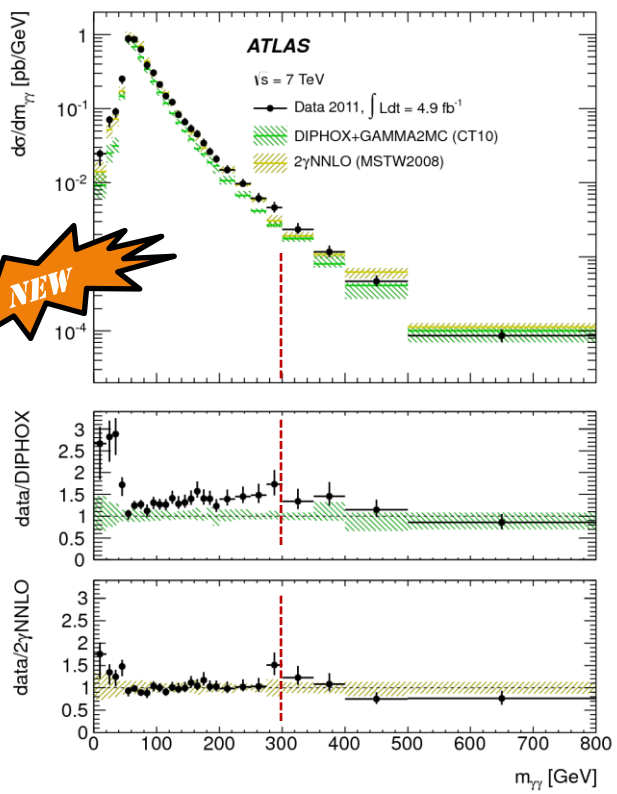
Di-photons - Cross section vs $m_{\gamma\gamma}$

Total cross section in acceptance with current ATLAS selection: $\sigma=44.0^{+3.2}_{-4.2}$ pb

DIPHOX+GAMMA2MC:39^{+7}_{-6} pb, 2γNNLO: 44^{+6}_{-5} pb

SHERPA & PYTHIA: 36 pb, rescaled by factor 1.2





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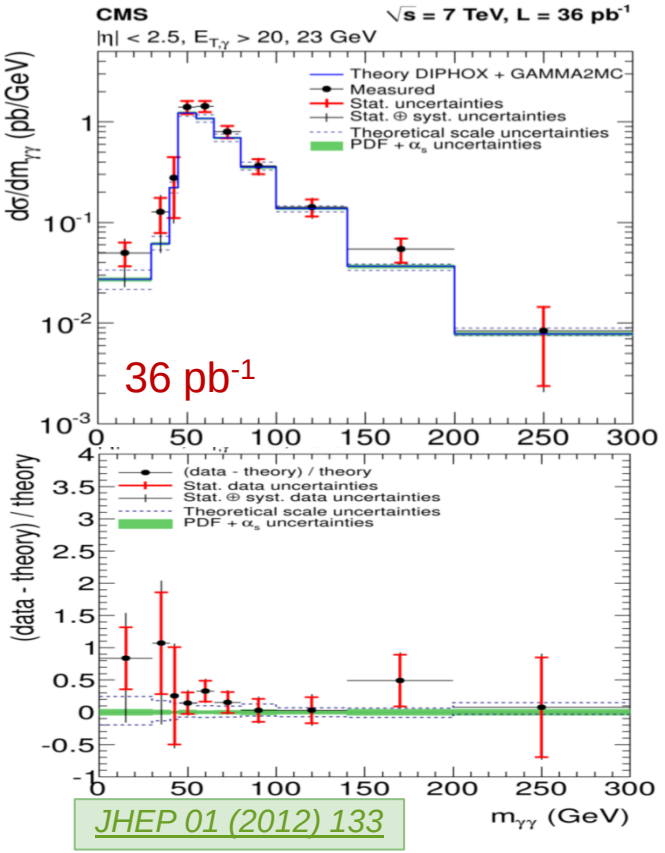

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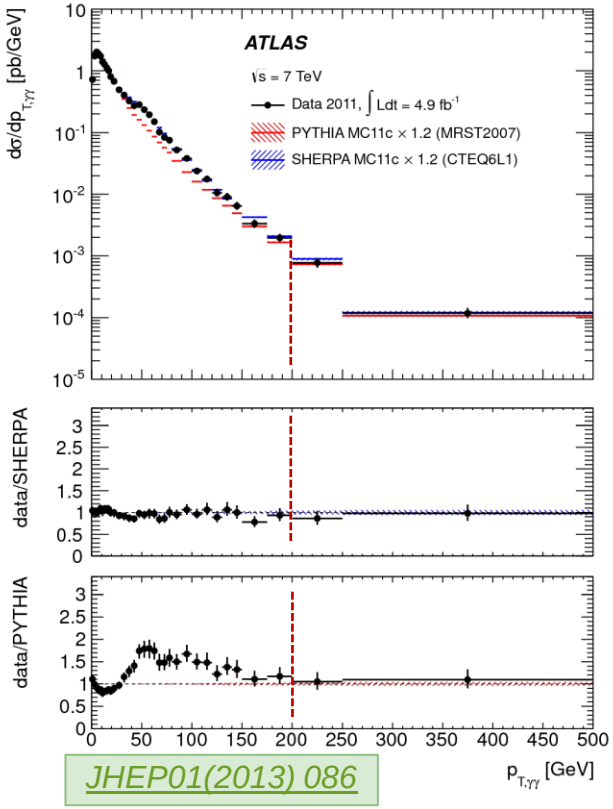
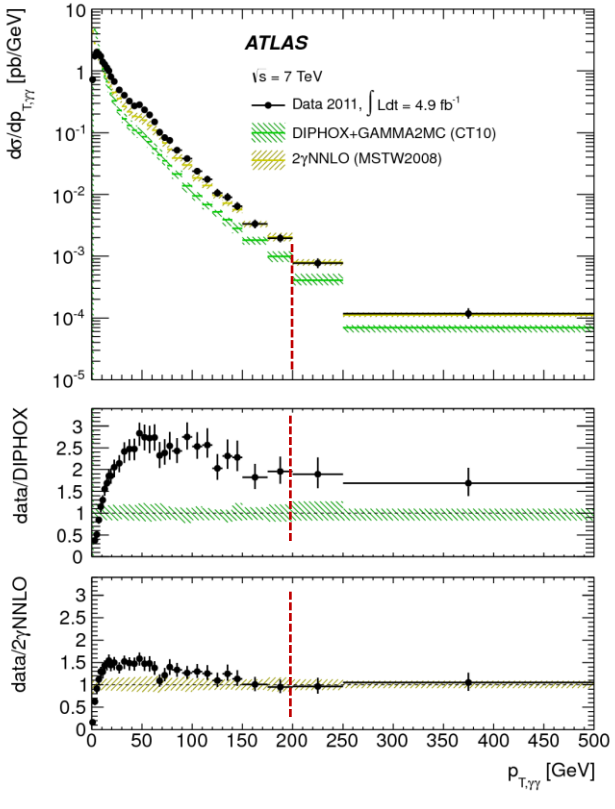
Th. uncertainties: dominated by scale error and then PDFs

Large fragmentation contribution at low mass:

- SHERPA better than PYTHIA because it includes the real part of NLO γ emission
- At intermediate and high masses SHERPA performance is worse than PYTHIA's
- 2γNNLO better overall than DIPHOX because of NNLO γ emission
- 2γNNLO prediction is very close to data over the whole $m_{\gamma\gamma}$ range

Di-photons - Cross section vs $p^T_{\gamma\gamma}$





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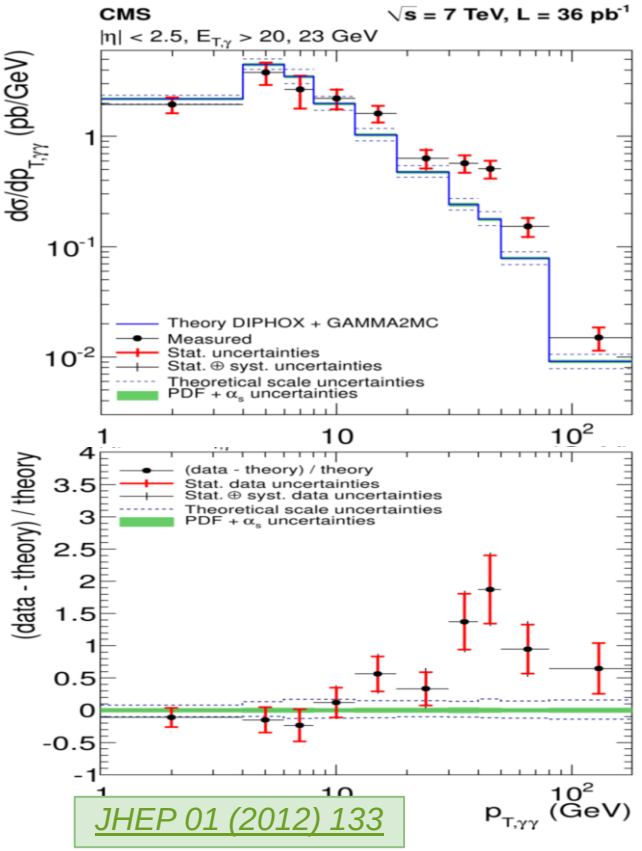

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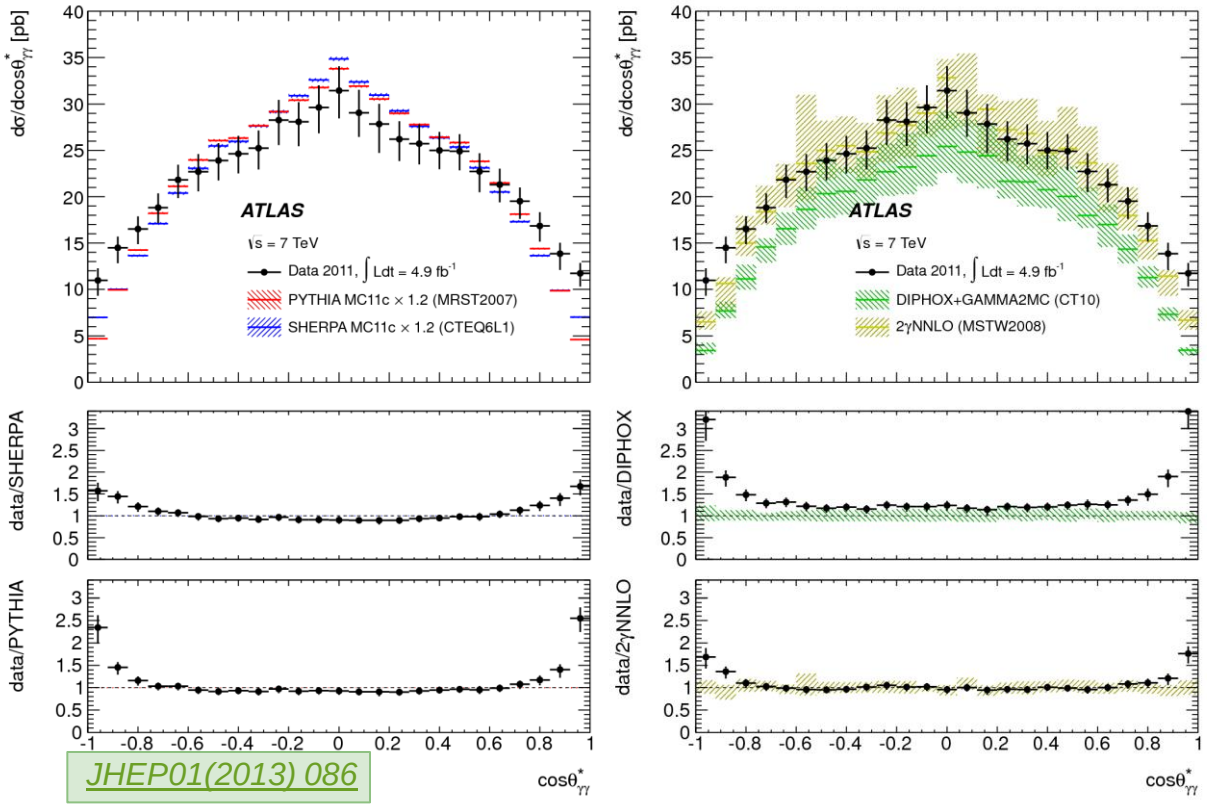
$p_{T\gamma\gamma}$ ~0 sensitive to initial state soft gluon radiation

⇒ as expected, cross section is over estimated by DIPHOX and 2γNNLO

Guillet shoulder clearly visible, except for PYTHIA (fragmentation suppressed by isolation requirements)

SHERPA is in very good agreement with data, as well as 2γNNLO except @ low p_T

Di-photons - Cross section vs $\cos\theta^*_{\gamma\gamma}$



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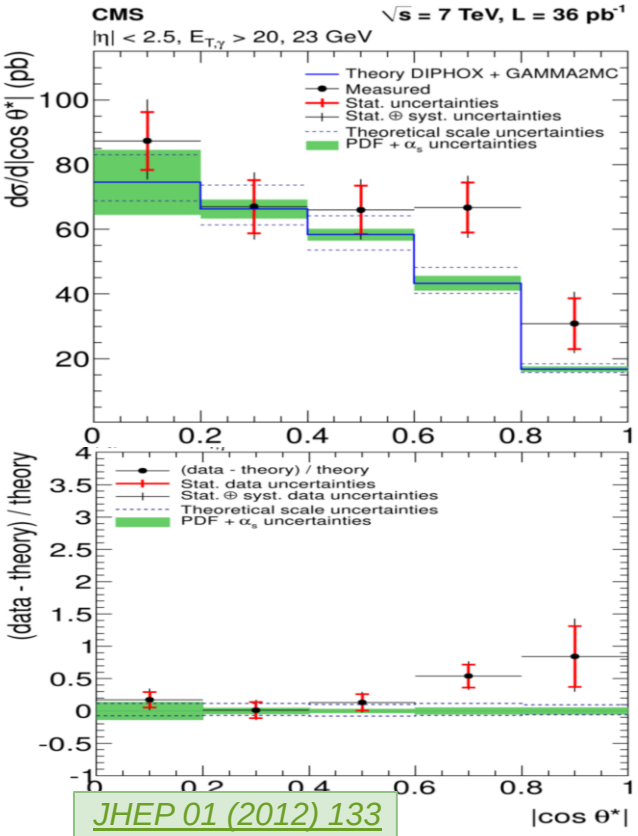

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$\cos\theta^* = 2\, p_{T\gamma 1}\, p_{T\gamma 2} \sinh(\eta_{\gamma 1}-\eta_{\gamma 2})/(m_{\gamma\gamma}\, m_{T\gamma\gamma})$
[Collins-Soper]

$$|\cos\theta^*| = |\tanh\frac{\Delta y_{\gamma\gamma}}{2}|$$

Large $\cos\theta^*_{\gamma\gamma}$ generally badly reproduced (fragmentation enhanced region)

Otherwise very good agreement

Photon production at the LHC - Conclusion

- Measured photon differential cross sections are in good agreement with Monte-Carlo generators and fixed order calculations.

  With highest disagreement at low p_T
- Constraints on gluon PDF from LHC photon data are promising (up to 20% uncertainty reduction on gluon PDF from prompt photons)
- Potential for gluon and light quark PDF reduced uncertainties using latest photon-jet measurements
- Lots of new results in 2013:
  - Measurement of the di-photon cross-section with ATLAS 4.9 fb^{-1} @ 7 TeV, 2011 dataset, published January 2013, *JHEP01(2013) 086*
  - Measurement of the triple differential photon-jet cross-section with CMS 2.14 fb^{-1} @ 7 TeV 2011 dataset, *CMS-PAS-QCD-11-005*
  - Measurement of photon-jet dynamics (37 pb^{-1}) with ATLAS, *ATLAS-CONF-2013-023*
  - Prompt photon cross section (4.7 fb^{-1}) with ATLAS, *ATLAS-CONF-2013-022*
  - *…*

THANK YOU!