JOHANNES GUTENBERG
UNIVERSITÄT MAINZ

Prompt Photons at ATLAS

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(Universität Mainz)

Phenomenology Symposium 2012 – Pittsburgh

On Behalf of the ATLAS collaboration

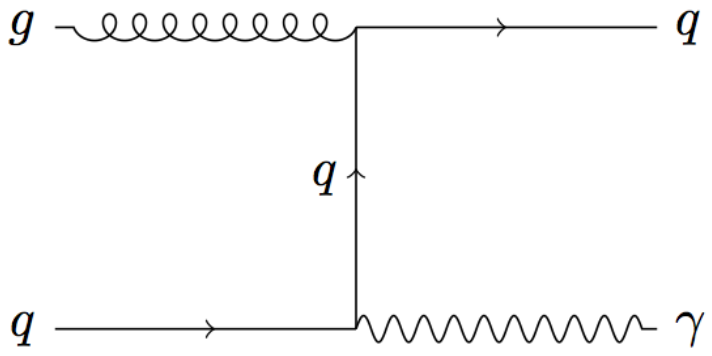
6 May 2012

Outline

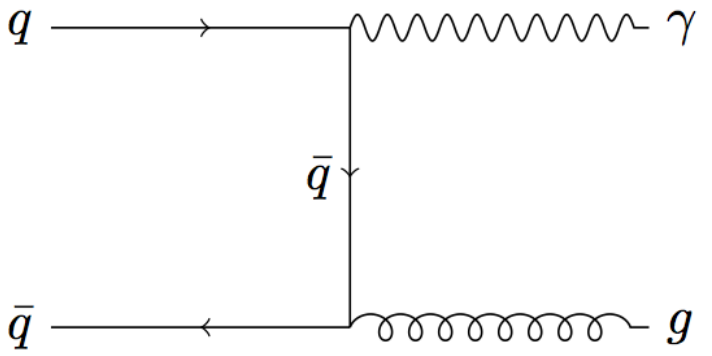
- Photons
  - A brief introduction from the Standard Model
- Photon ID in the ATLAS detector
- Cross section measurements
  - prompt photons
  - photon+jet
  - diphoton
- Summary and Conclusions
  - Standard Model and Beyond

Prompt Photons

- Direct photons
  - produced hard scatter
  - @LHC Compton dominate at Leading Order (LO)
- Diphoton production
- LO is not the whole story…
  - QED radiation off quarks: ISR, FSR
  - Fragmentation
    - +direct = prompt
- PHOX family and ResBos MC generation for Next-to-LO
  - parton level
  - to correct (PS Monte Carlo with hadronization and UE) or additional systematic



Compton Scattering



Annihilation

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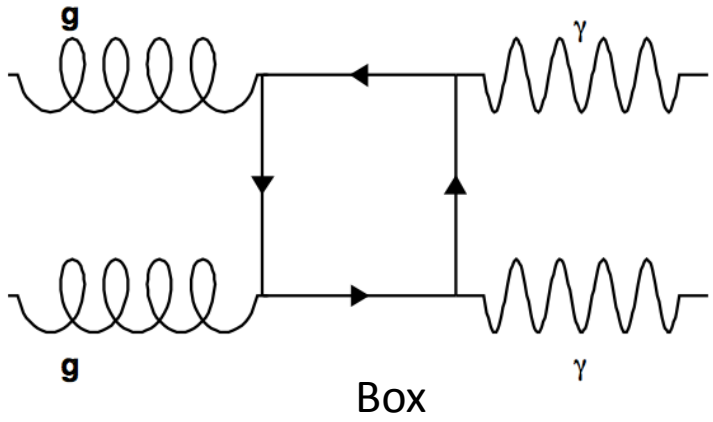
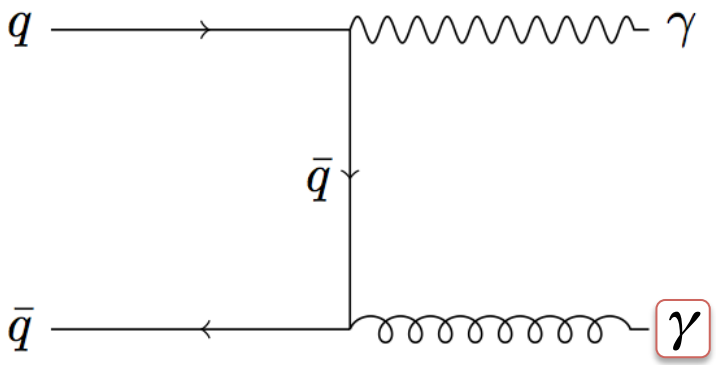


Box



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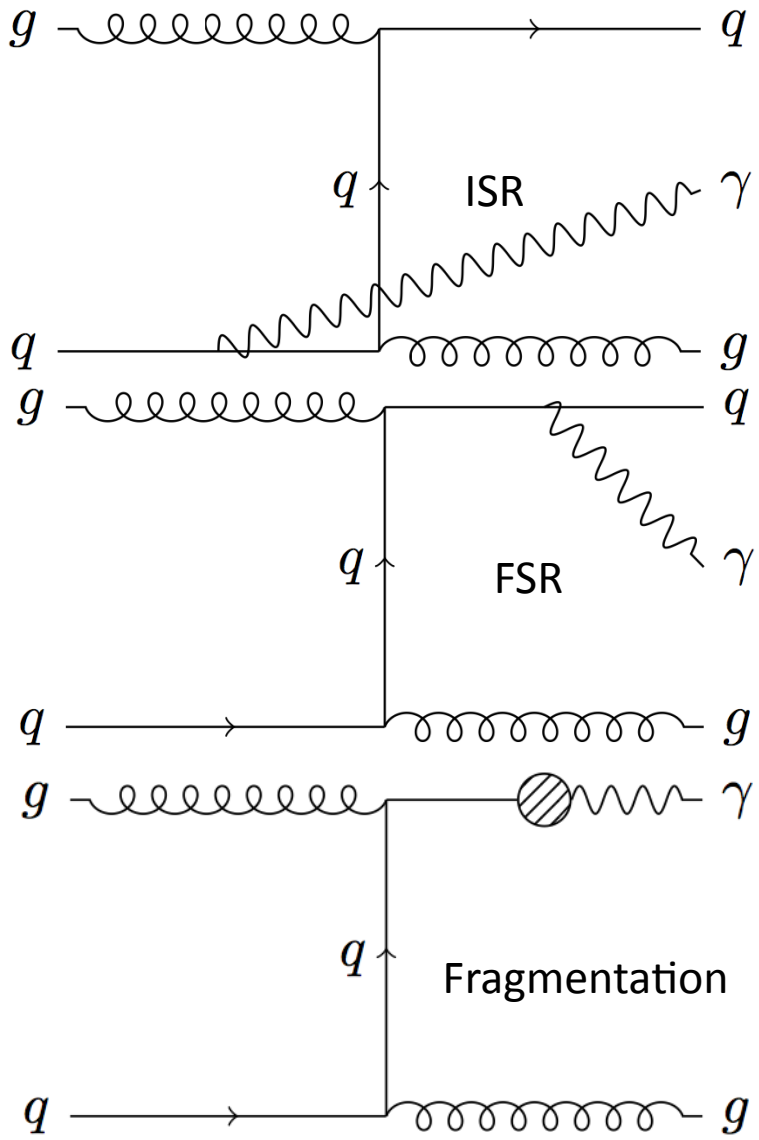

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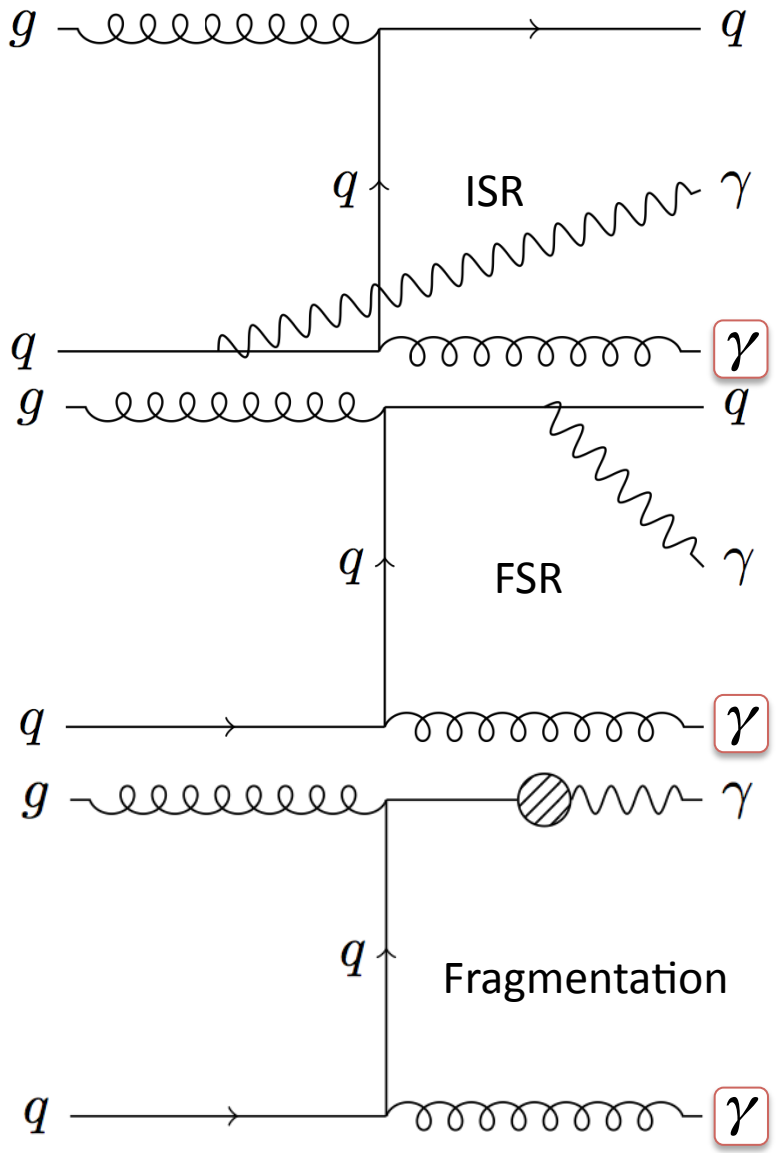


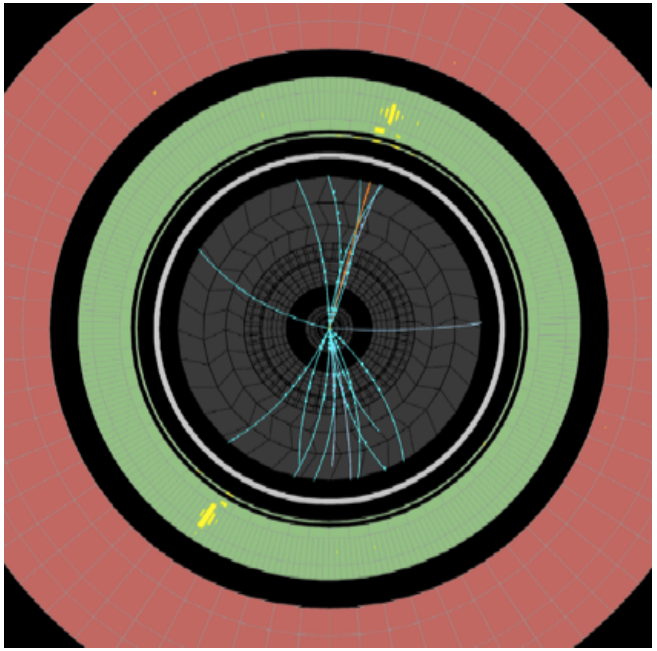
Photons can tell us

Standard Model

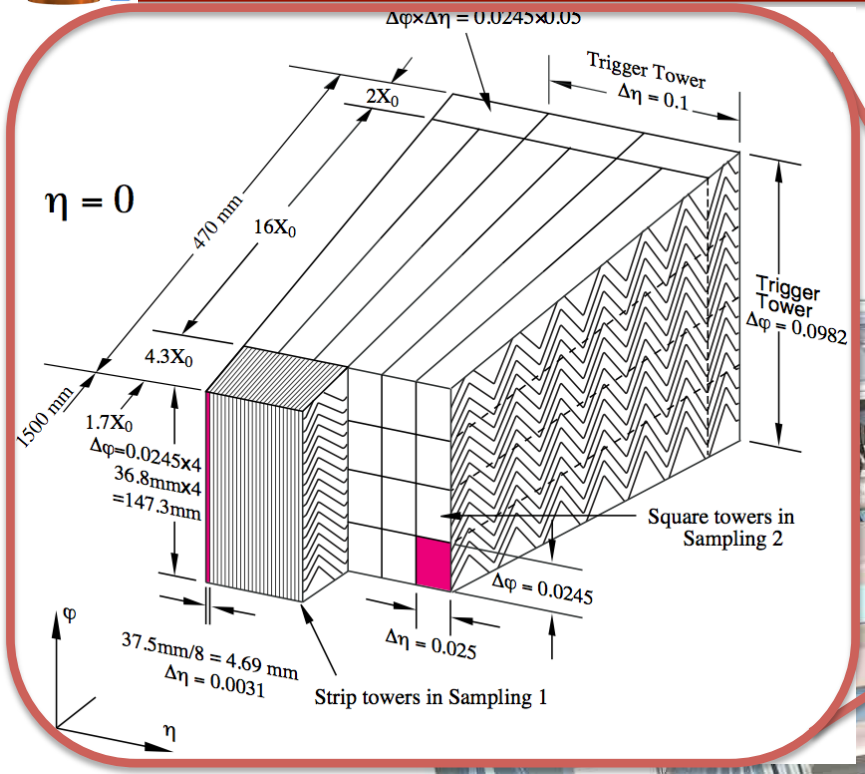
- Constrain Gluon PDF
  - sensitive to gluon content
  - high purity sample of quark jets
- Test pQCD
  - colorless probe of hard scattering
- Constrain photon fragmentation functions
- Calibrate jets

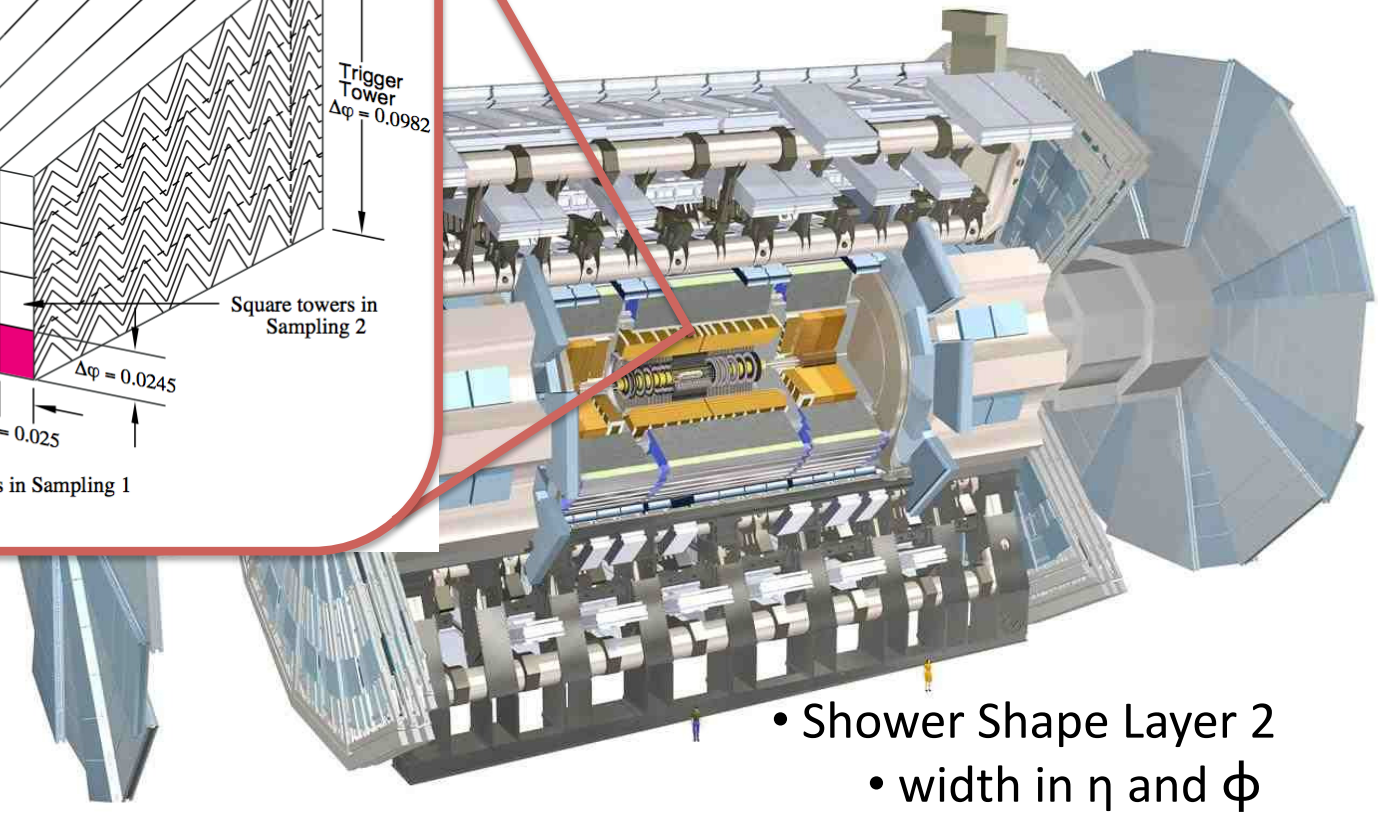
Beyond the Standard model

- Background to Higgs searches
- Background to SUSY/Exotics searches



Photons@ATLAS





- Particle requirements
  - Isolation

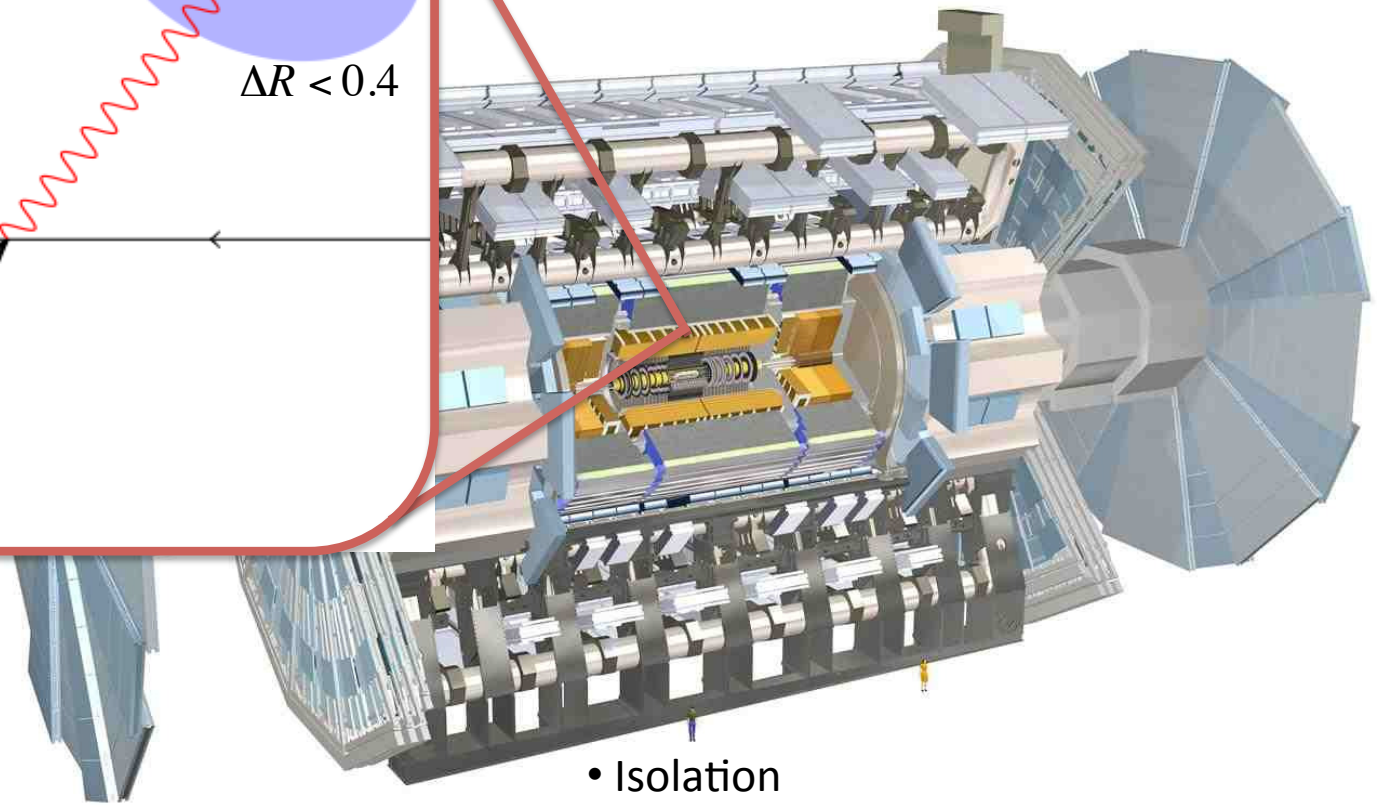
- Shower Shape Layer 2
  - width in η and ϕ
  - hadronic leakage
- Shower Shape Layer 1 (strips)
  - excellent η resolution (π^0)

Isolated Photons

prompt photons:
deposit
energy in
small radius

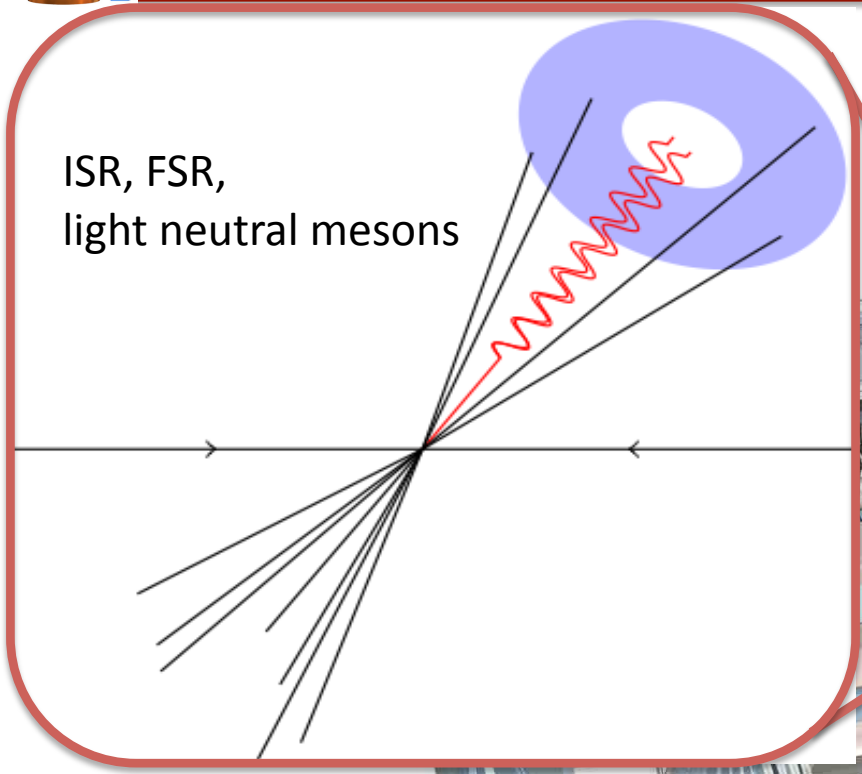
$\Delta R < 0.4$

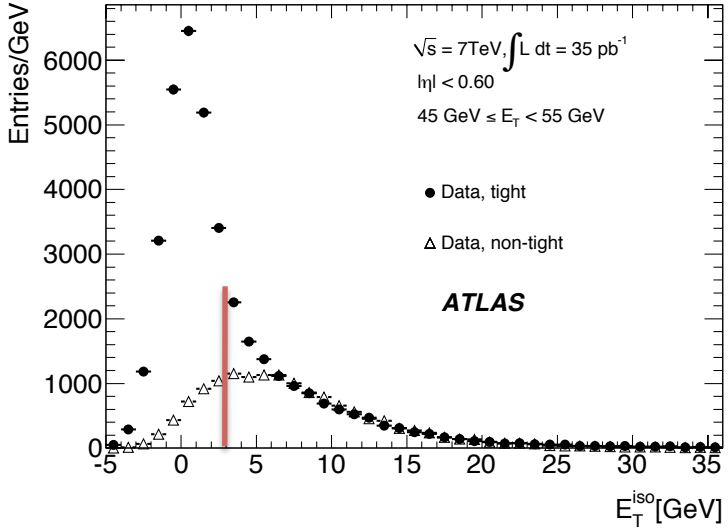
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

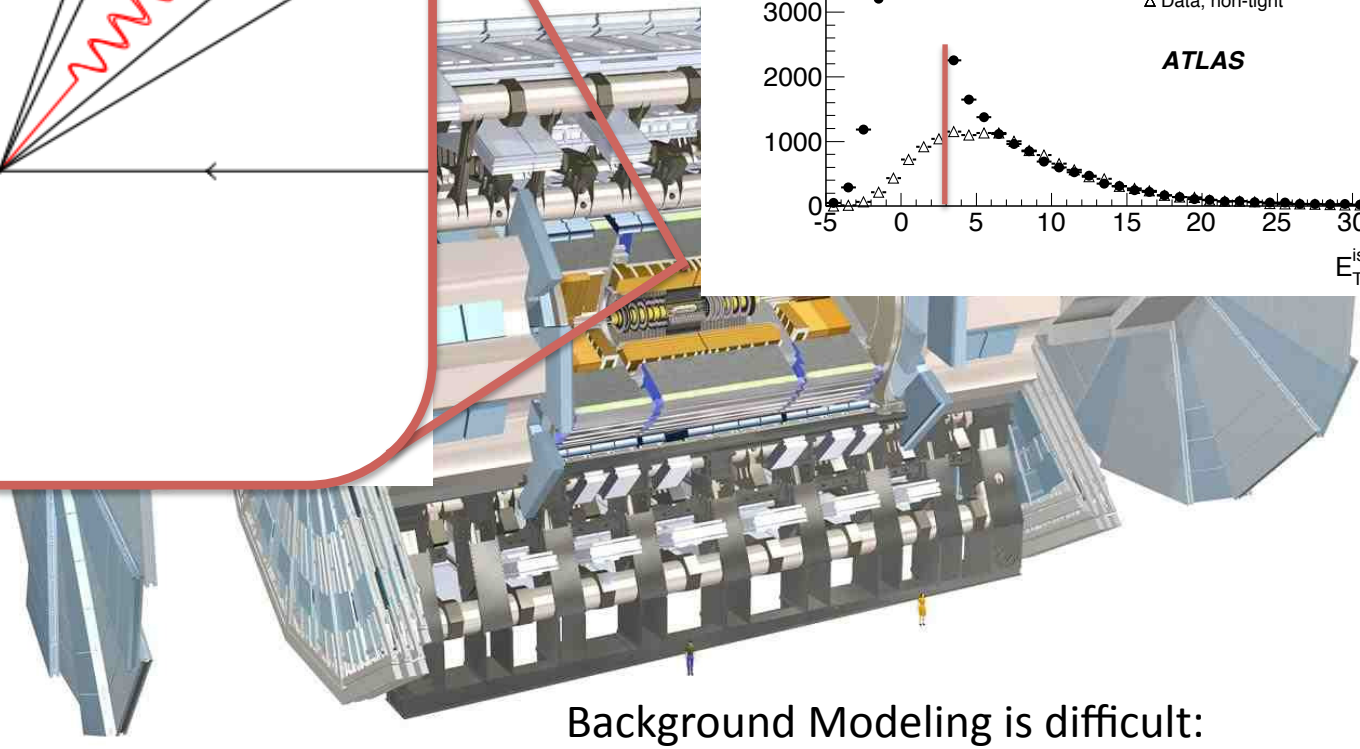


- Isolation
  - small amount of energy around core
  - out of core-leakage correction applied
  - pile-up contribution subtracted

Backgrounds to Photons





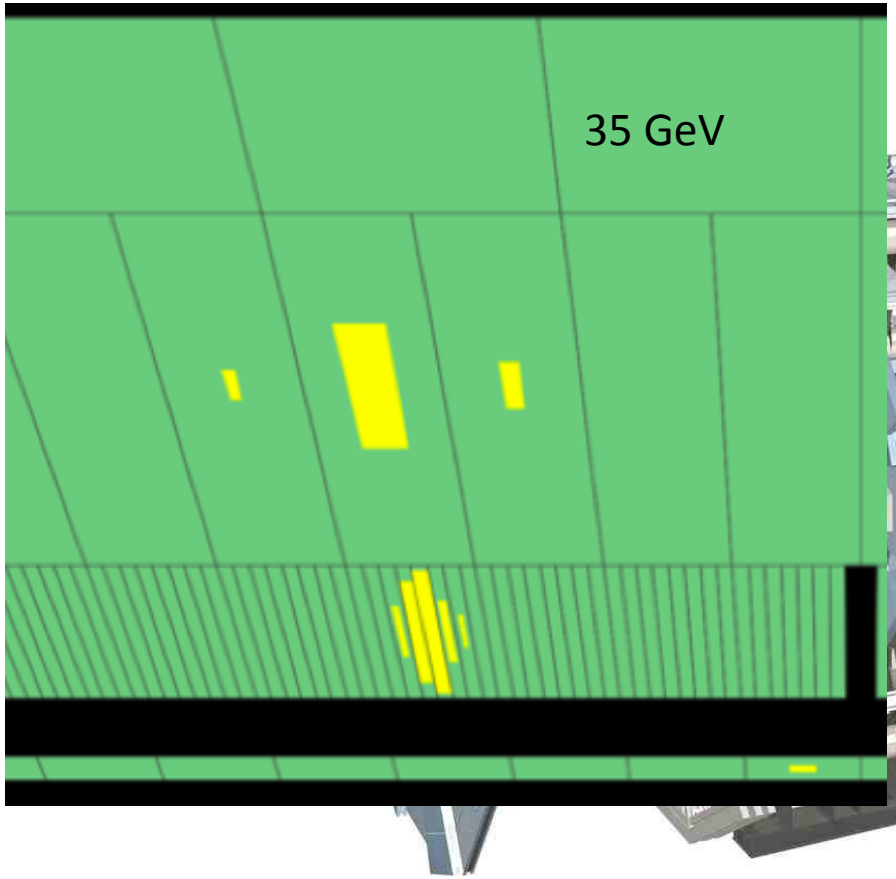


Background Modeling is difficult:

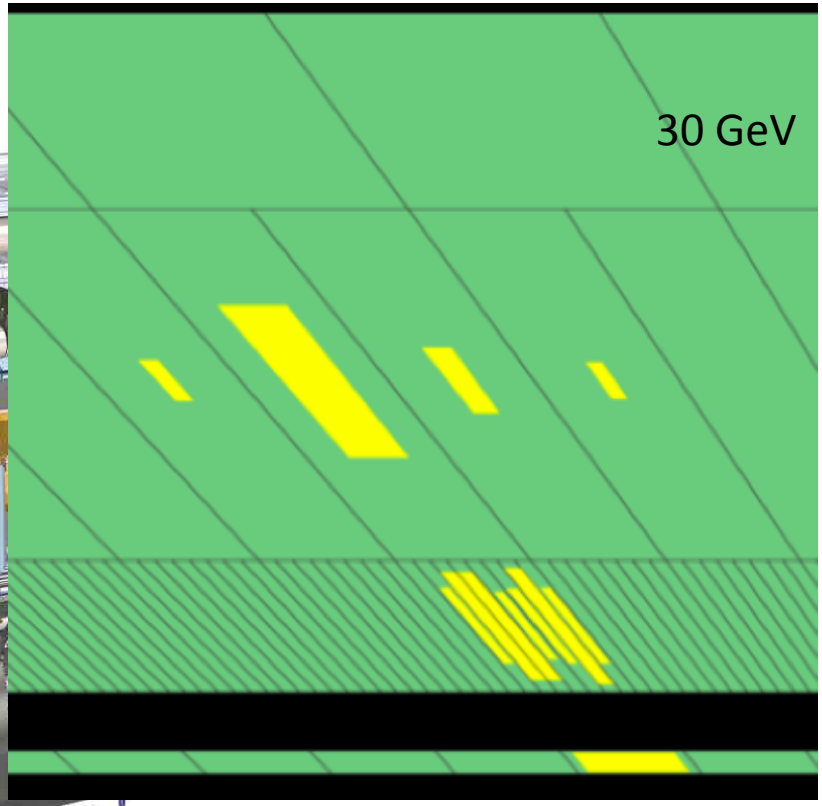
- Use data driven methods whenever possible
  - Reverse photon ID
  - Sideband method

Photons@ATLAS

Photon Candidate



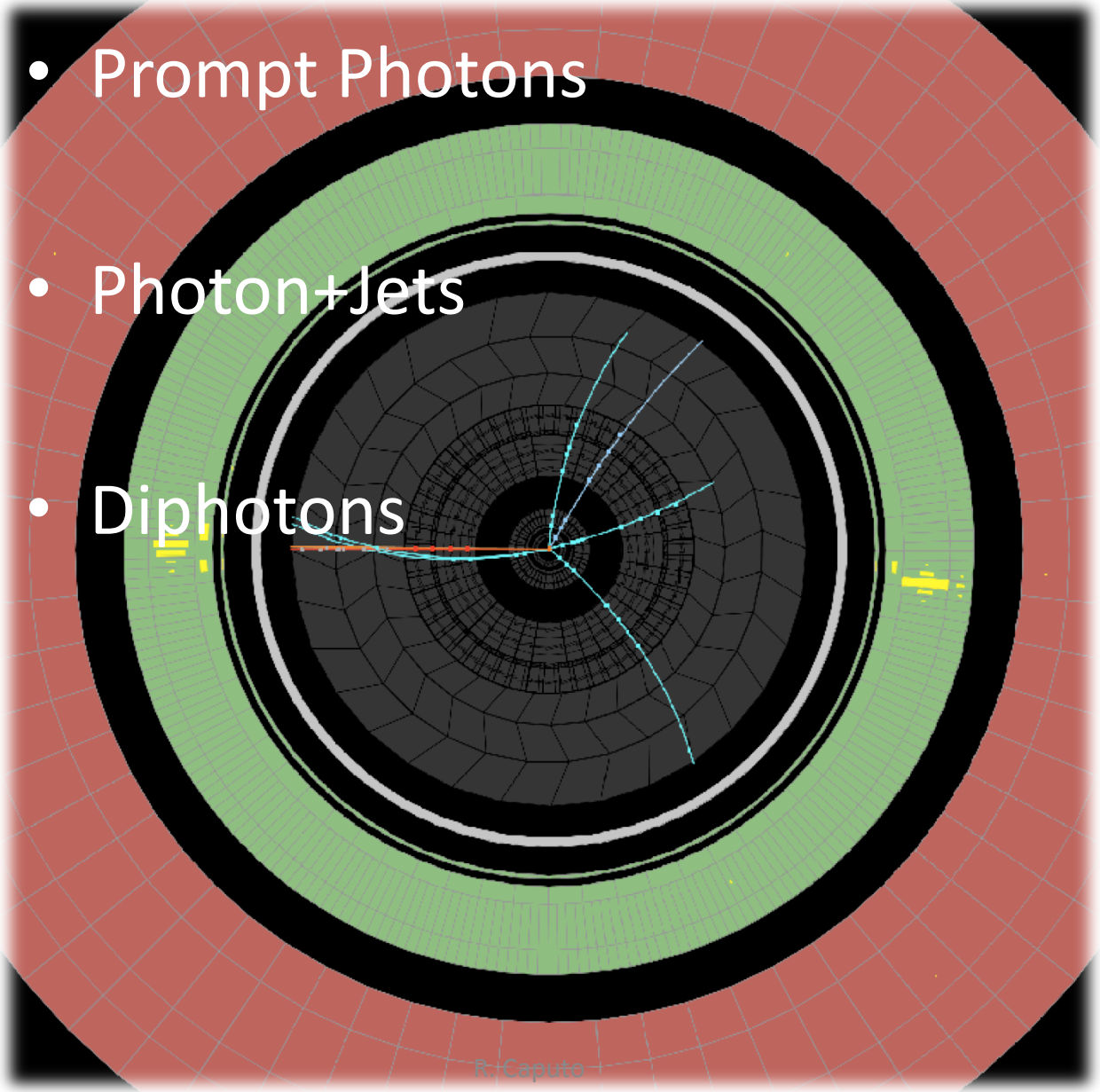
π^0 Candidate



- Hadronic background suppressed
  - shower shape variables, isolation
  - leakage variables

Photon Cross Sections

- Prompt Photons
- Photon+Jets
- Diphotons



Prompt Photons

Ingredients to measure the cross section:

$$\frac{d\sigma}{dE_T^\gamma} = \frac{N_{yield} U}{\left(\int L dt\right) \Delta E_T^\gamma \varepsilon_{trigger} \varepsilon_{reco} \varepsilon_{ID}}$$

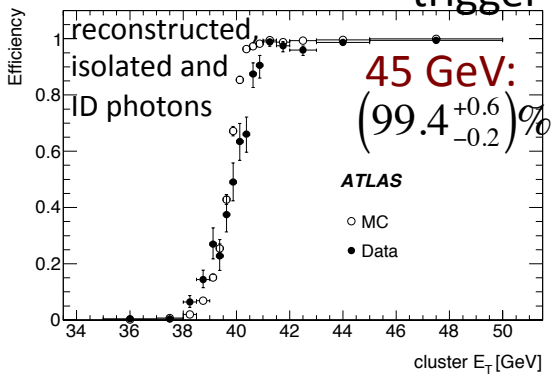
N_{yield}: events after background subtraction

U: Unfolding coefficients
- evaluated using Pythia
- bin-by-bin unfolding
- inversion + regularization
  Bayes or SVD
- ~1 (good resolution)

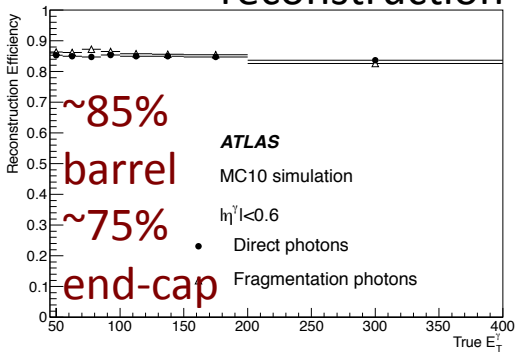
ΔE_T^γ : E_T bin size

ε: efficiencies

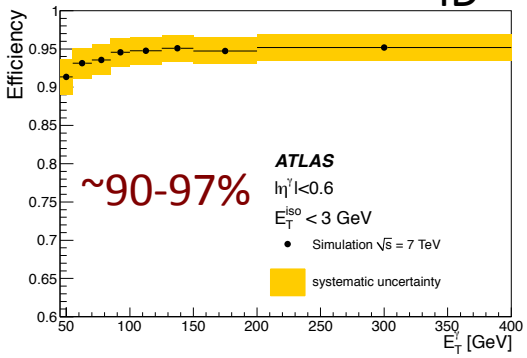
trigger



reconstruction



ID

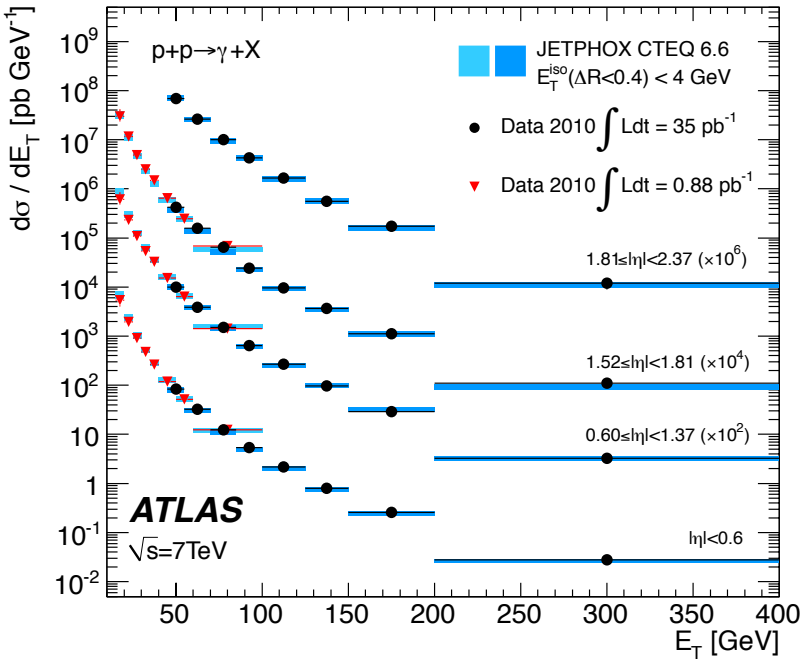


reconstructed & isolated photons

Phys.Lett. B706 (2011) 150-167

Prompt Photons

NLO pQCD calculations
JETPHOX using CTEQ 6.6 PDFs



$E_{T,\gamma} > 45$ GeV, $|\eta_\gamma|$ bins up to 2.37

- Theoretical predictions
  - Systematics from renormalization, factorization, fragmentation (~10%)
- Good in high E_T, fair in low E_T
  - NNLO corrections
- Results used to constrain PDFs by 20%
  - Nucl. Phys. B **3** 311-338 (2012)

Prompt Photons

NLO pQCD calculations

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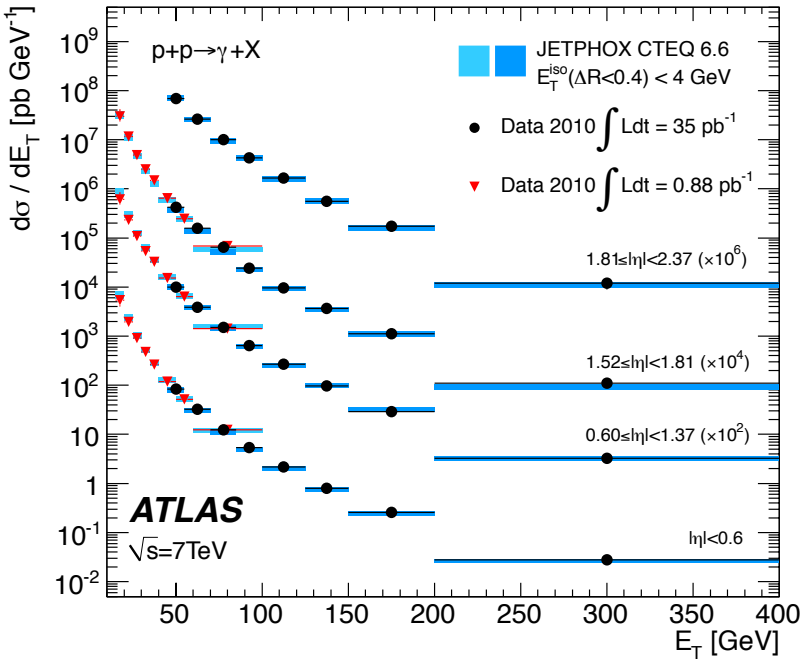
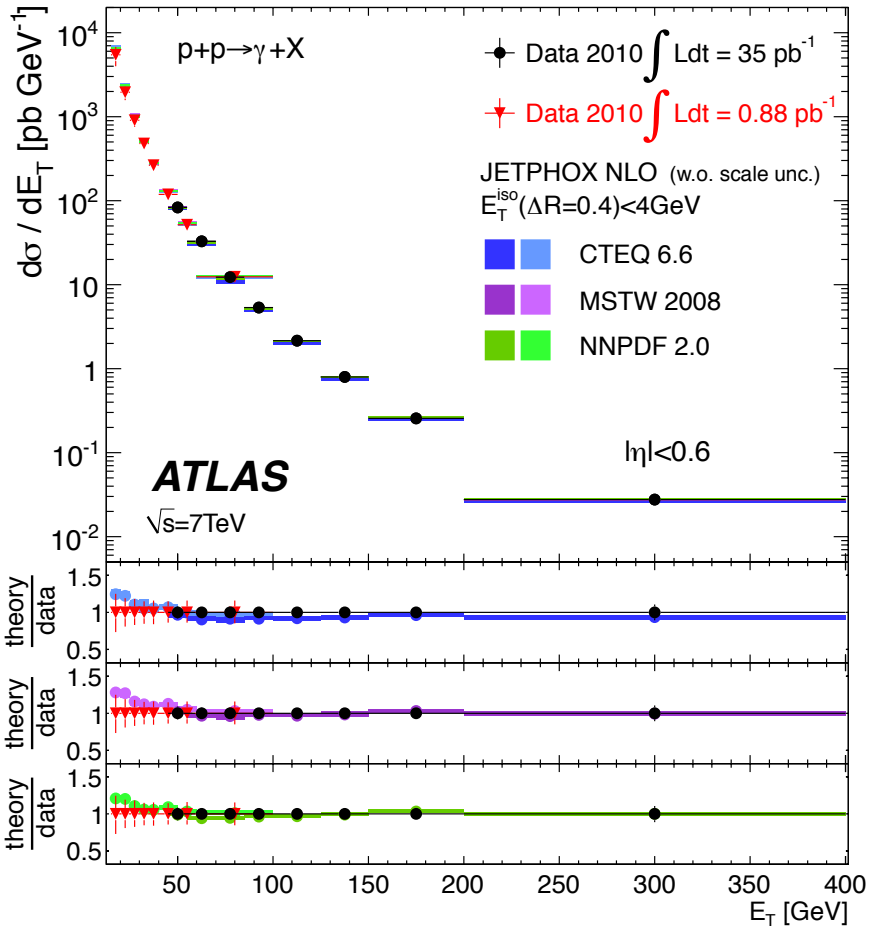


Comparing different PDF sets



Theoretical Predictions

Systematics -renormalization, factorization, fragmentation (~10%)

Results used to constrain PDFs by 20%

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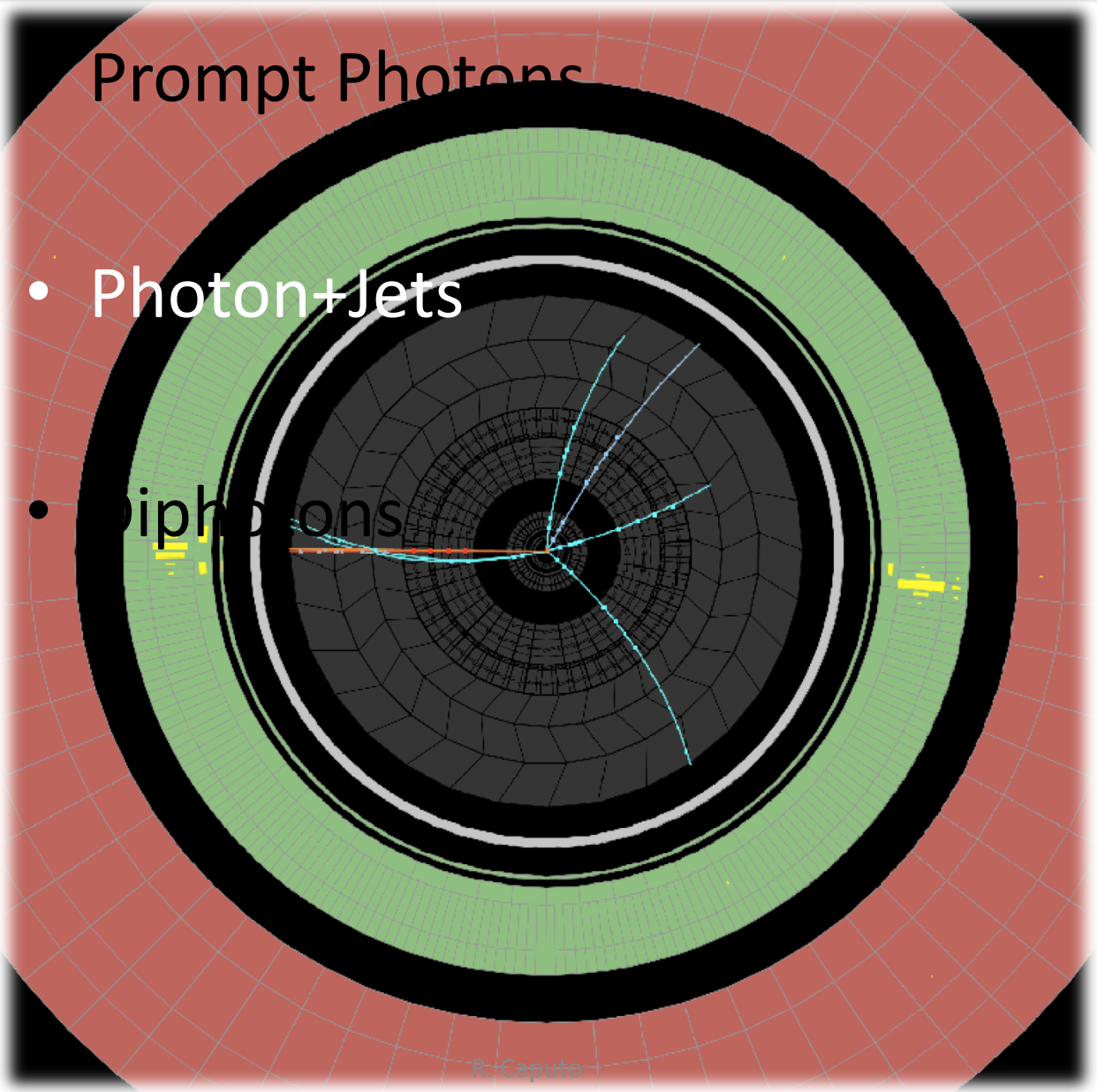
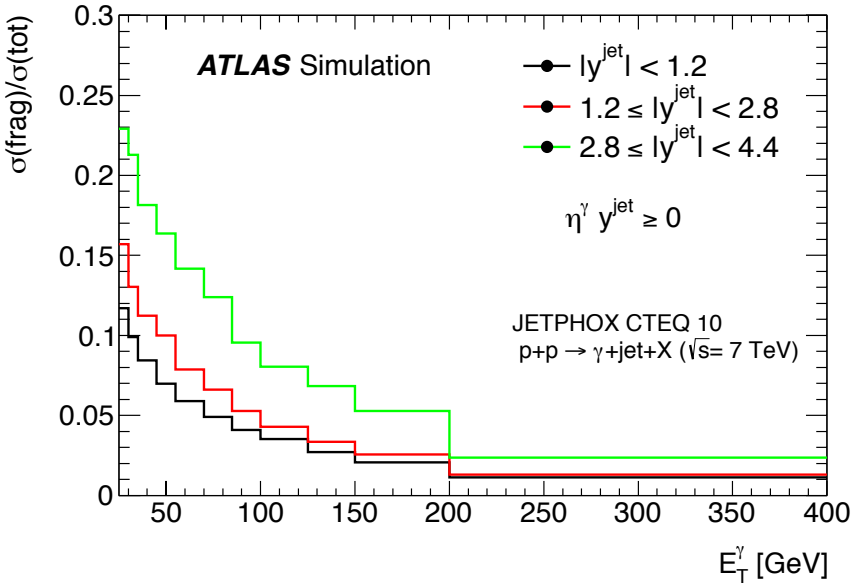
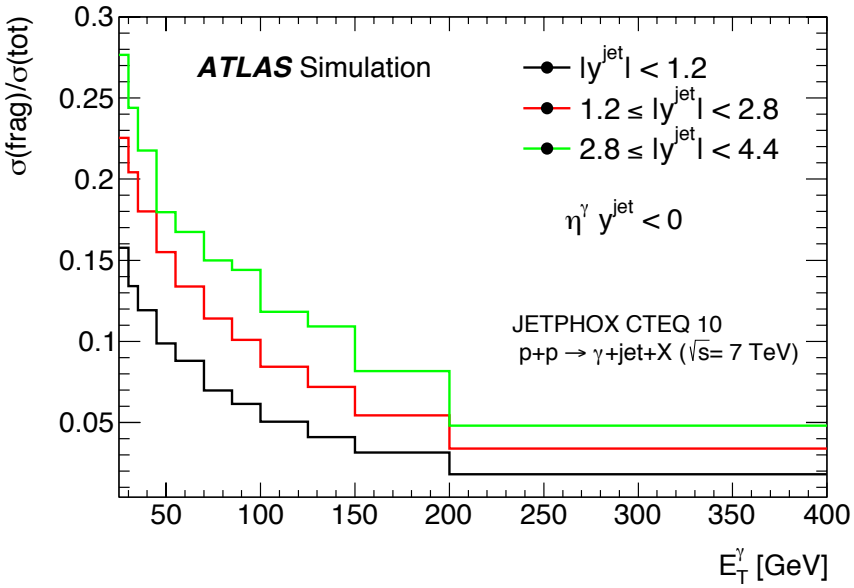
Photon Cross Sections



- Prompt Photons
- Photon+Jets
- Diphotons

Photon+jet



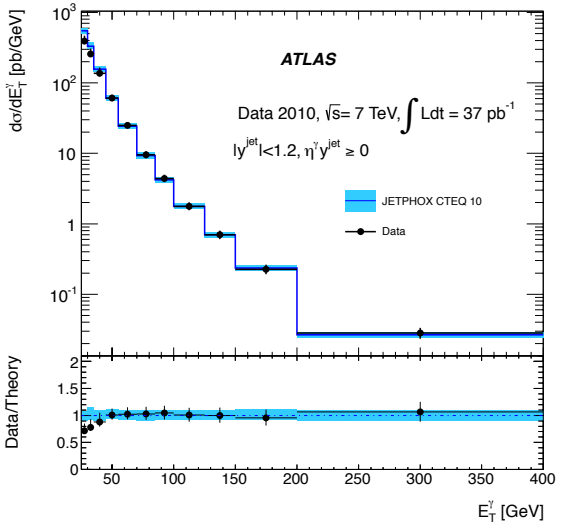


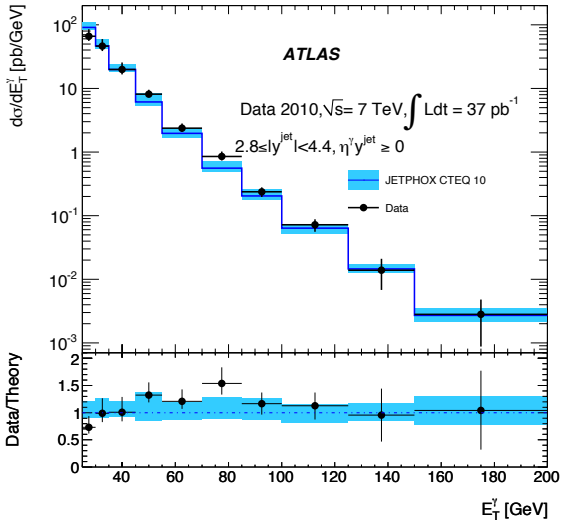
- Photons produced with jets
  - 3 jet rapidity regions as a function of E_t^{γ}
- Fiducial/reconstruction requirements
  - Jet Algorithm: anti-k_T, R=0.4
  - Jet: p_T>25 GeV, |y|>4.4
  - photon: E_T>25 GeV, |η|>1.37
  - separated by ΔR > 1.0
- Direction of photons/jets
  - $\eta^{\gamma}\, y^{jet} \ge$ or < 0
- Different composition of fragmentation component

Arxiv:1203.3161, Accepted PRD

Photon+jet

same sign





Theoretical Predictions:

Systematics from scale, PDF, Isolation, hadronization and underlying event correction.

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Photon+jet

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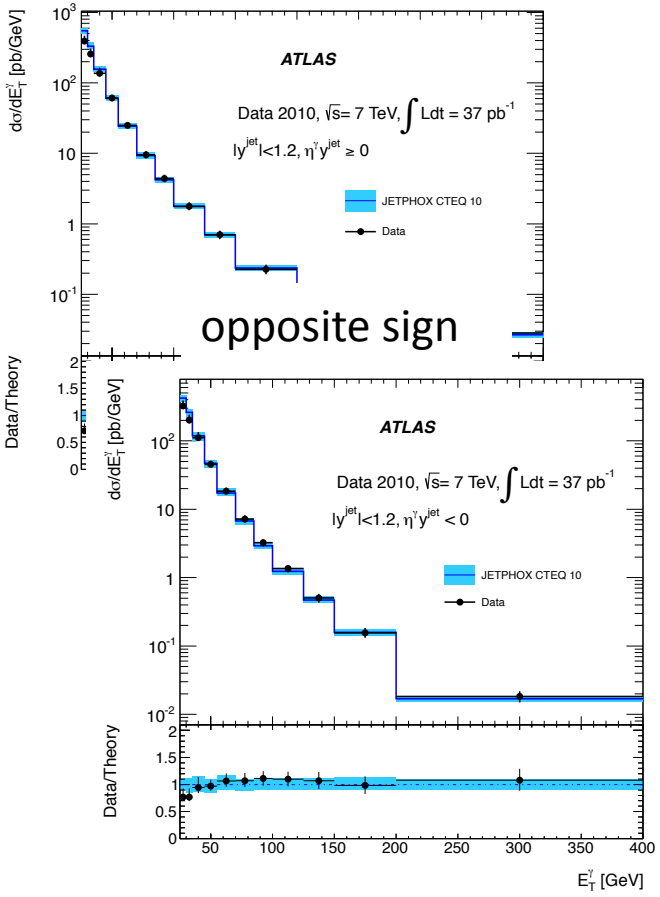
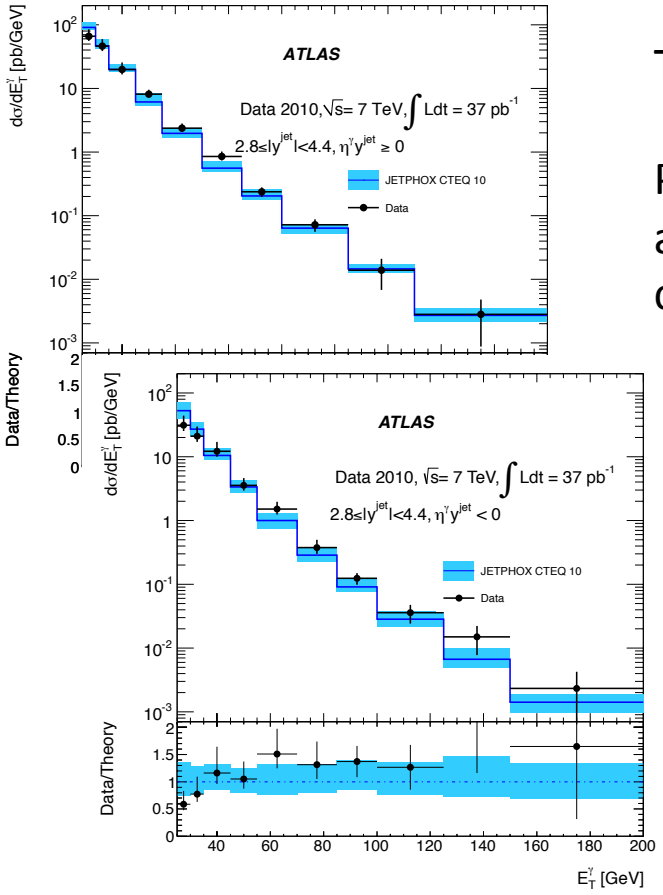


opposite sign



Theoretical Predictions:

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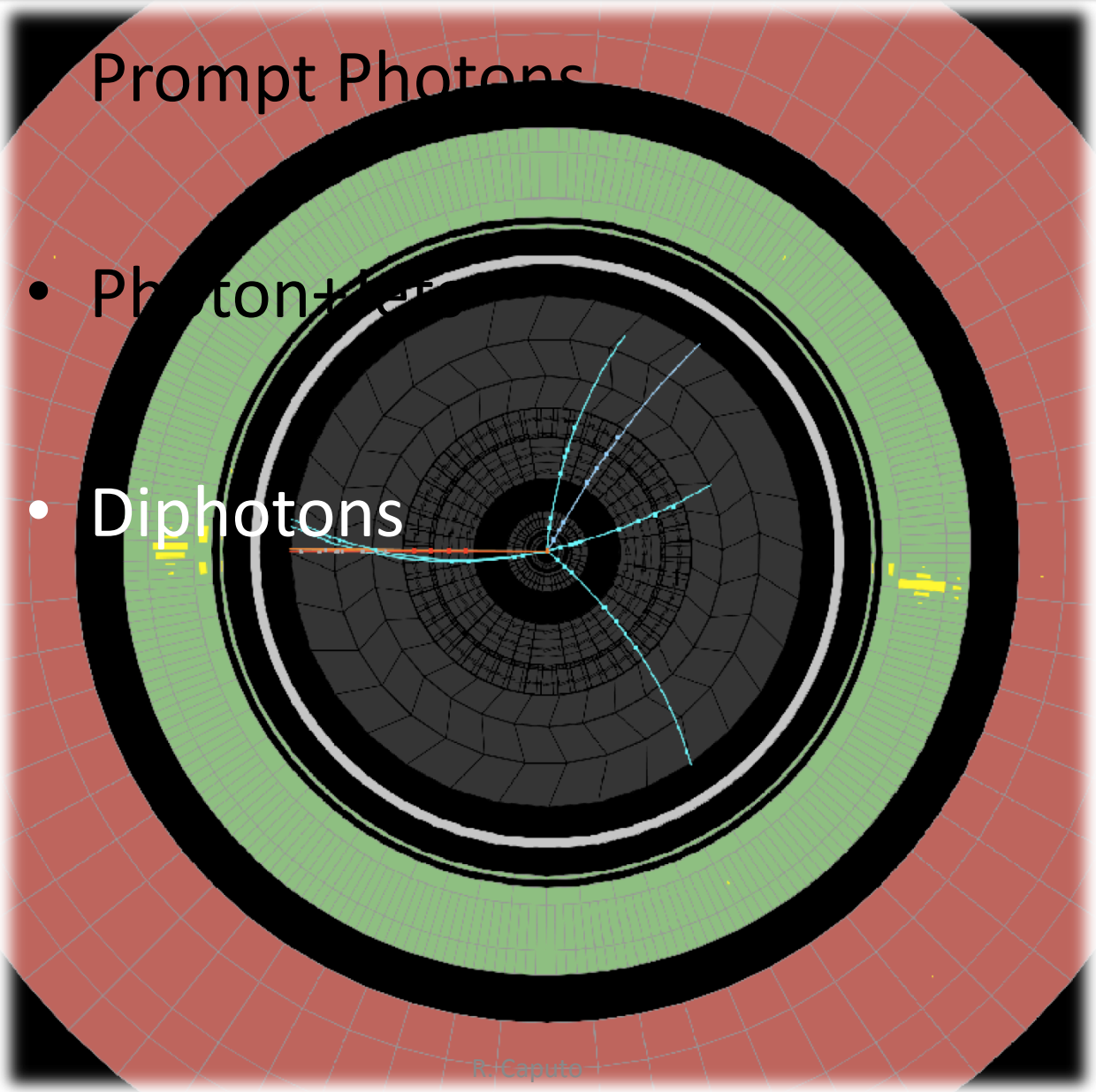
Fair agreement:

Data consistently lower than prediction in low E_t^{γ} region

- hint for need of NNLO (consistent with prompt photon results)

Arxiv:1203.3161, Accepted PRD

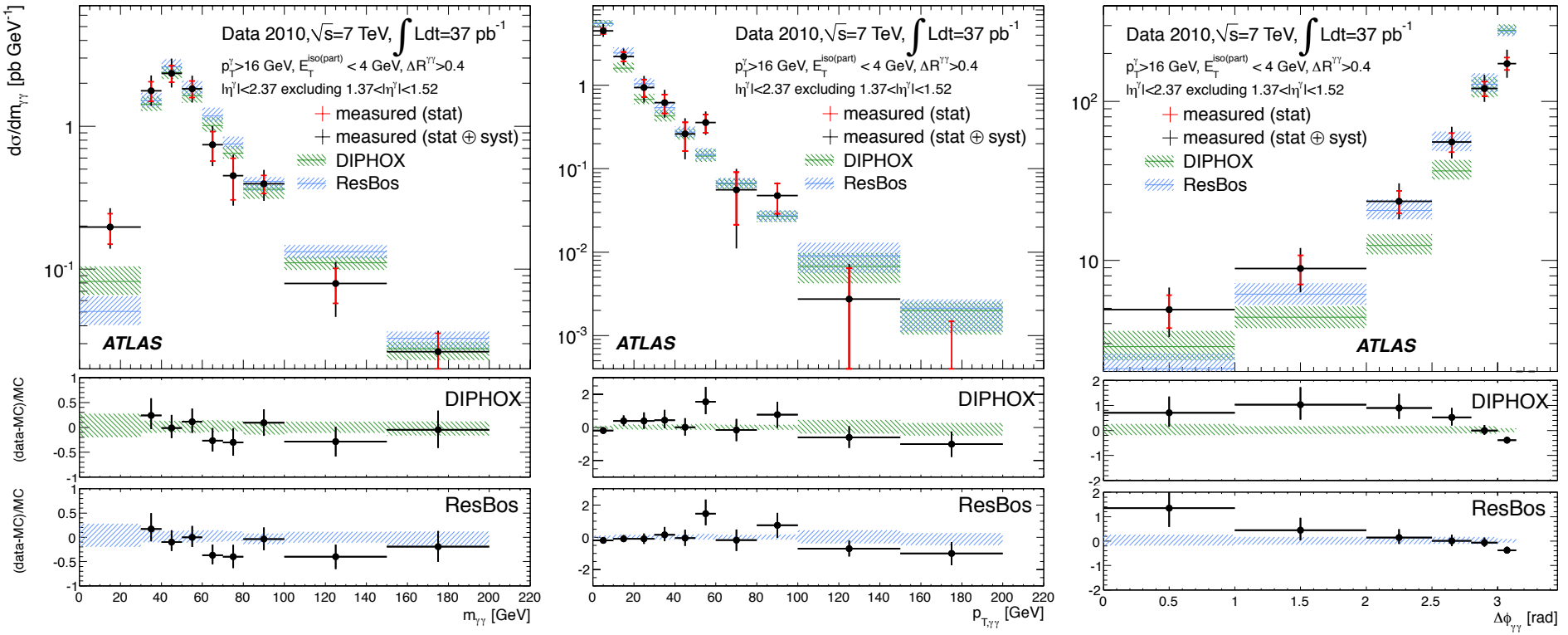
Photon Cross Sections



- Prompt Photons
- Photon+[illegible]
- Diphotons

Diphotons

$d\sigma/dm_{\gamma\gamma}$ $d\sigma/dp_{T,\gamma\gamma}$ $d\sigma/d\Delta\phi_{\gamma\gamma}$



Differential Cross section

$m_{\gamma\gamma}$, $p_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$

DIPHOX and ResBos provide NLO prediction

Theoretical Systematics

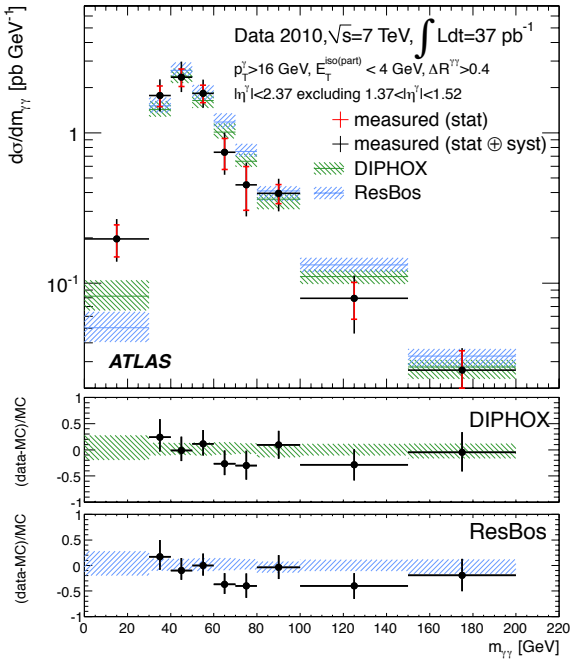
Isolation, PDF, and scales

$E_{T,\gamma} > 15$ GeV

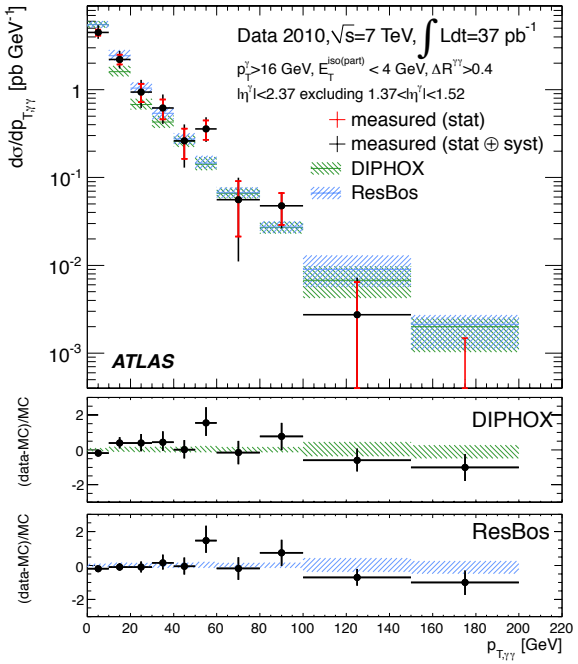
Phys.Rev. D85 (2012) 012003

Diphotons

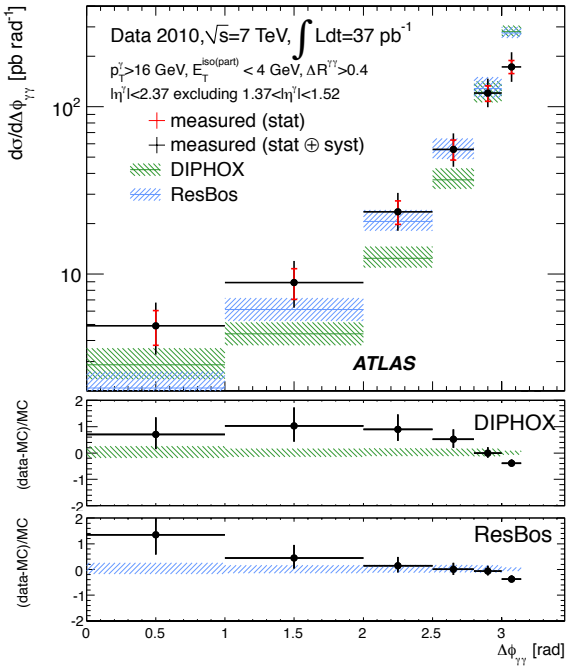
$d\sigma/dm_{\gamma\gamma}$



$d\sigma/dp_{T,\gamma\gamma}$



$d\sigma/d\Delta\phi_{\gamma\gamma}$



Generally good agreement:

Discrepancies in low $\Delta m_{\gamma\gamma}$ and $\Delta\phi_{\gamma\gamma}$

- same cause: fragmentation and 2→4 processes
- argument NNLO: 2gNNLO – box diagram (DeFlorian et. al)

Summary and Conclusions

Insight into QCD PDFs

- able to constrain PDFs with 2010 data
- analyzing ~5 fb^{-1} - results in progress
- more fragmentation, higher p_T, understand pileup

Backgrounds to new physics

- contributes to Higgs searches
- SUSY, model independent searches
- Also more exotic particles UED, graviton, resonance searches

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BACKUPS

The PHOX Family

- What it does
  - **NLO** FORTRAN codes allowing users to compute **single and double inclusive large p_T cross sections** for reactions involving **photons, hadrons and jets**.
  - DIPHOX, JETPHOX, EPHOX and TWINPHOX
  - MRST99, MRST01, CTEQ5 and CTEQ6 PDFs for the proton
  - photo-production programs also include the AFG and the new AFB04 PDFs for the photon.
  - option to link any parton distribution from the PDFLIB is also provided.
  - production of massive heavy quarks is not described by these codes in which a massless approximation is used
- Pros
  - flexible and allows the users to impose almost any experimental cuts, jet definitions, cross section definition via a histogram package
- Warnings
  - The production of massive heavy quarks is not described by these codes in which a massless approximation is used
  - Not full event generators:
  - **do not provide a full, exclusive portrait of events** which could for example be further processed through a detector simulation
  - **PHOX** codes are **not** designed to be interfaced with **parton showers** and **hadronisation models.**

See: http://lapth.in2p3.fr/PHOX_FAMILY/

Dominant Systematics

Theoretical

- Scale
  - renormalization, factorization, fragmentation
- PDF
  - from CTEQ 6.6 eigenvalues
- non-perturbative correction
  - maximum spread in Pythia (Perugia 2010) and Herwig (UE7000-2)
- Parton Isolation

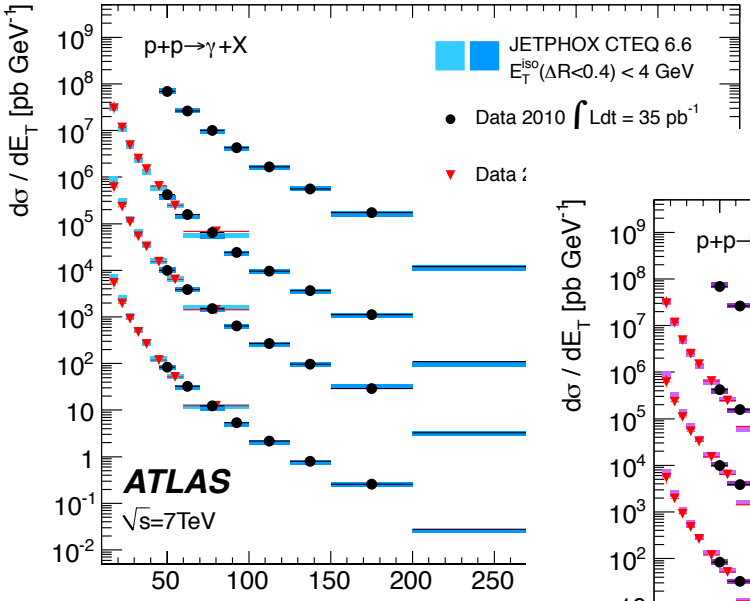
Experimental

- Electron energy scale
- Photon Purity
- Unfolding technique
  - compare methods
- Central jet
  - same/opposite sign

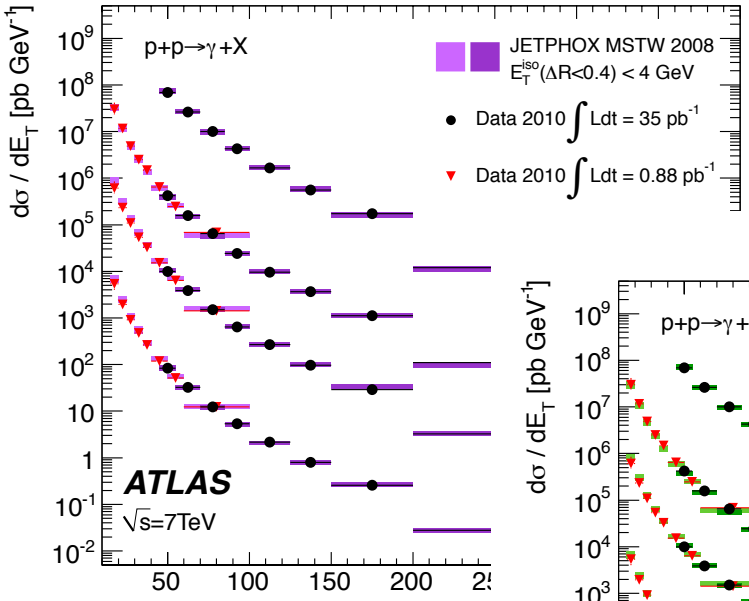
Prompt Photons

show CTEQ and then ratios for all three in 1 eta bin

$E_{T,\gamma} > 45$ GeV

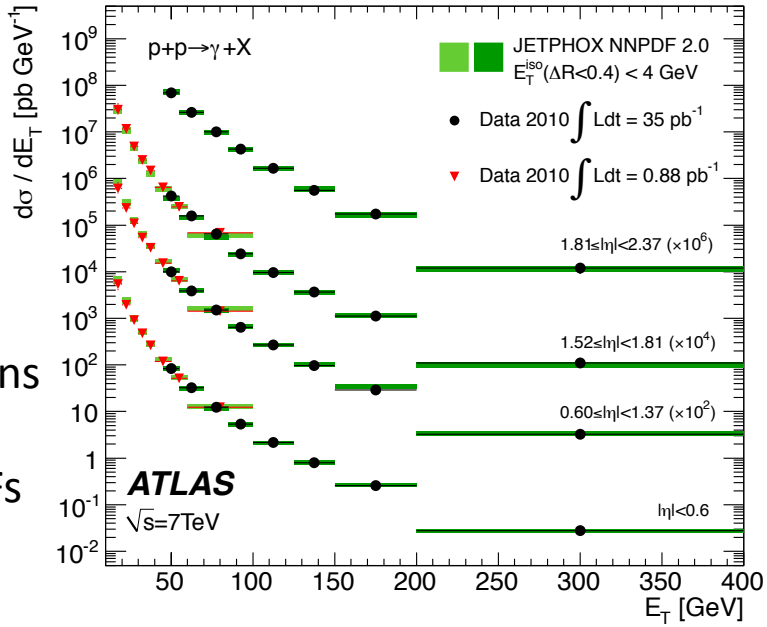


NLO pQCD calculations
JETPHOX using
CTEQ 6.6 PDFs



NLO pQCD calculations
JETPHOX using
MSTW 2008 PDFs

NLO pQCD calculations
JETPHOX using
NNPDF 2.0 PDFs



Results used in:

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

Comment on agreement…

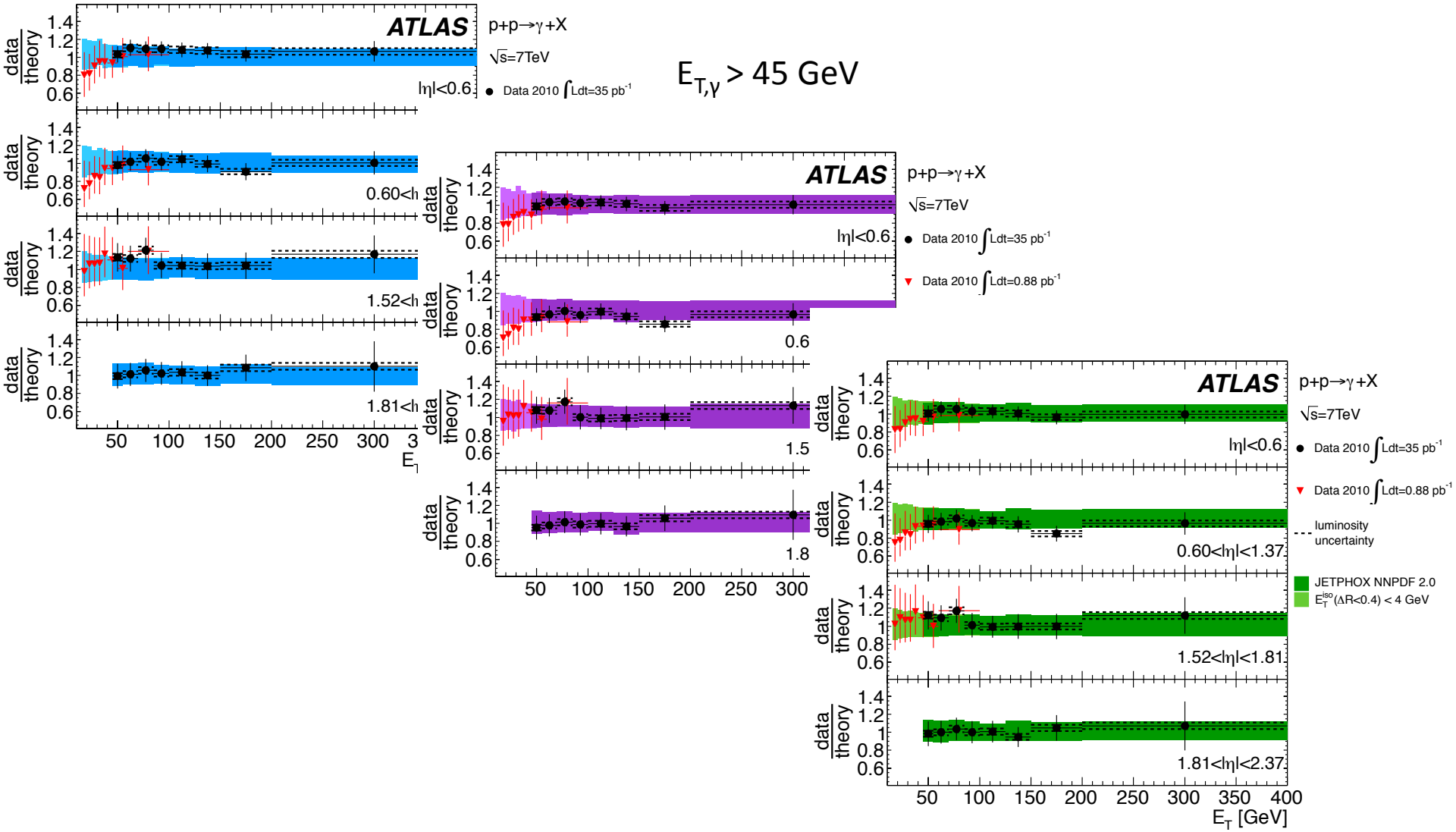
Dominant Systematics

Scale uncertainty ~10%

renormalization, factorization, fragmentation

Phys.Lett. B706 (2011) 150-167

Ratios to Theory

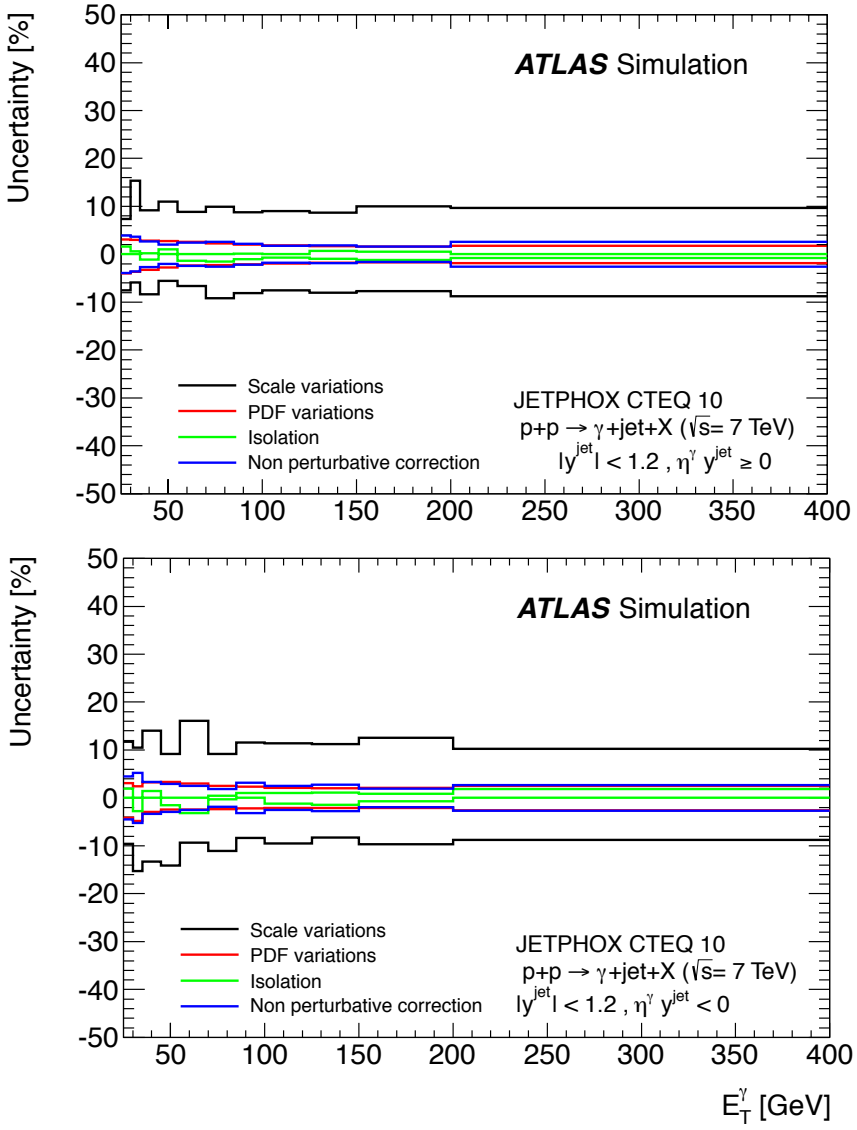


$E_{T,\gamma} > 45$ GeV

Phys.Lett. B706 (2011) 150-167

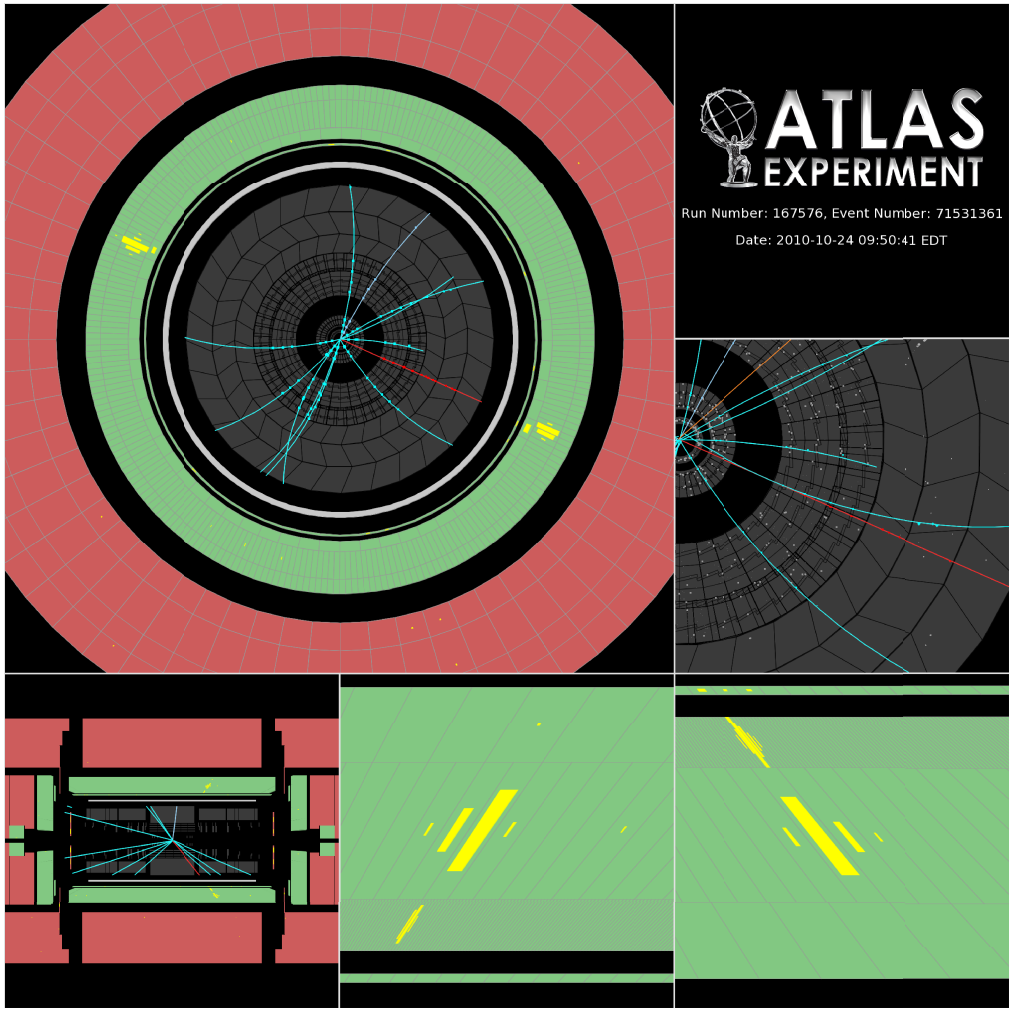
Photon+jet Systematics

- Central jet
  - same/opposite sign
- Dominant Systematics
  - Scale
    - renormalization, factorization, fragmentation
  - PDF
    - vary 68% CL
  - Isolation
    - 3/5 GeV
  - non-perturbative correction
    - maximum spread in Pythia (Perugia 2010) and Herwig (UE7000-2)



Diphotons

- Probe QCD
  - $\Delta\phi_{\gamma\gamma}$ sensitive to fragmentation model
  - soft gluon emission $\Delta\phi_{\gamma\gamma}\sim\pi$ and low $p_{T,\gamma\gamma}$
- Irreducible background Higgs and BSM
- Differential cross section
  - $m_{\gamma\gamma}$,$p_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$

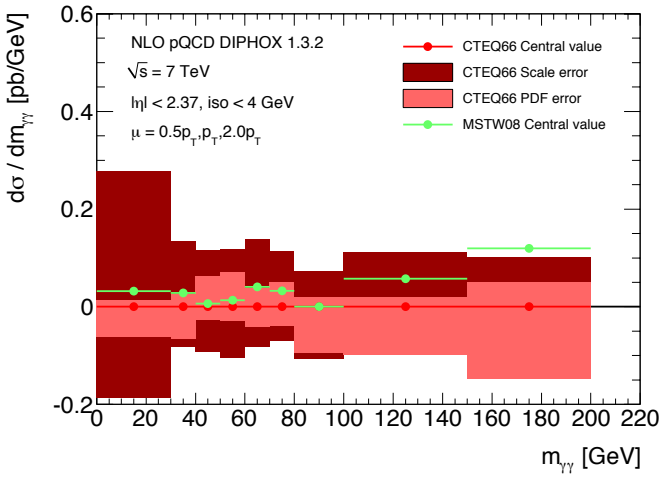


Phys.Rev. D85 (2012) 012003

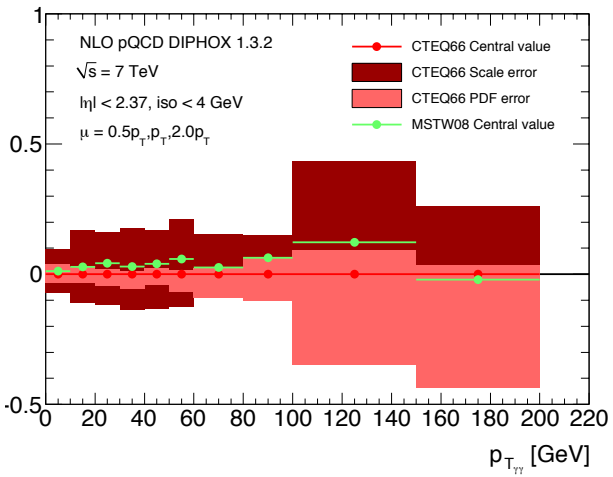
Diphoton Systematics

Labels wrong on y axis, no atlas label

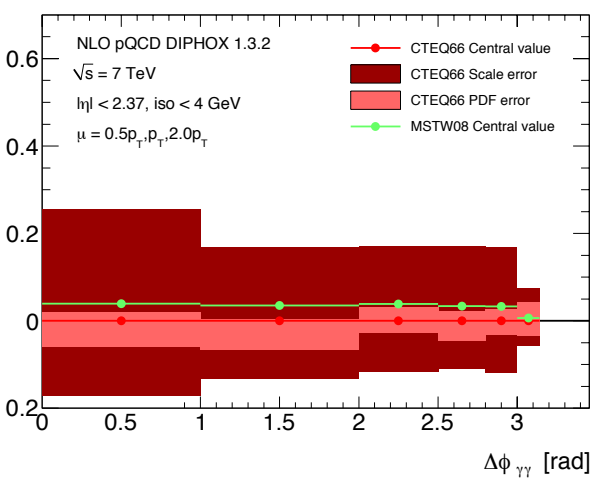
$d\sigma/dm_{\gamma\gamma}$



$d\sigma/dp_{T,\gamma\gamma}$



$d\sigma/d\Delta\phi_{\gamma\gamma}$



Dominant Systematics

- normalization, fragmentation and factorization scales
- eigenvalues of PDFs
- MSTW 2008 PDF (CTEQ6.6)