



SMU®



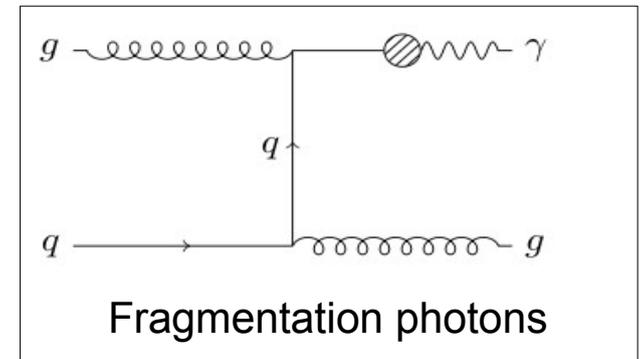
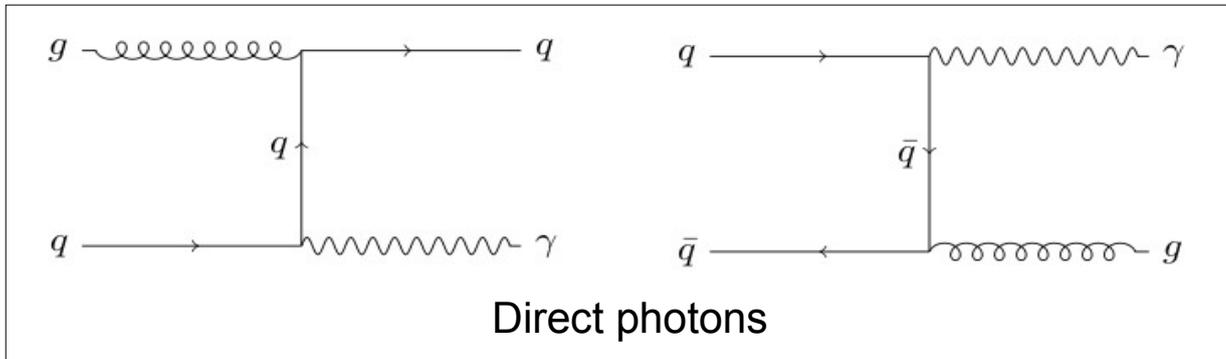
Direct photon measurements in ATLAS

Renat Ishmukhametov
(Southern Methodist University)

On behalf of the ATLAS collaboration

Deep Inelastic Scattering Workshop

- Prompt photons: those photons produced during hard QCD scattering
 - Produced at the beam interaction point
 - NOT those produced by decay of hadrons
 - More isolated than photons resulting from hadronic decays



- Prompt photon production cross-section is sensitive to gluon PDF
 - Dominant production process is Compton scattering
- Prompt photon pairs are also signatures of new physics
 - Standard Model Higgs boson search
 - Randall-Sundrum Graviton
 - Universal Extra Dimensions

ATLAS @ LHC

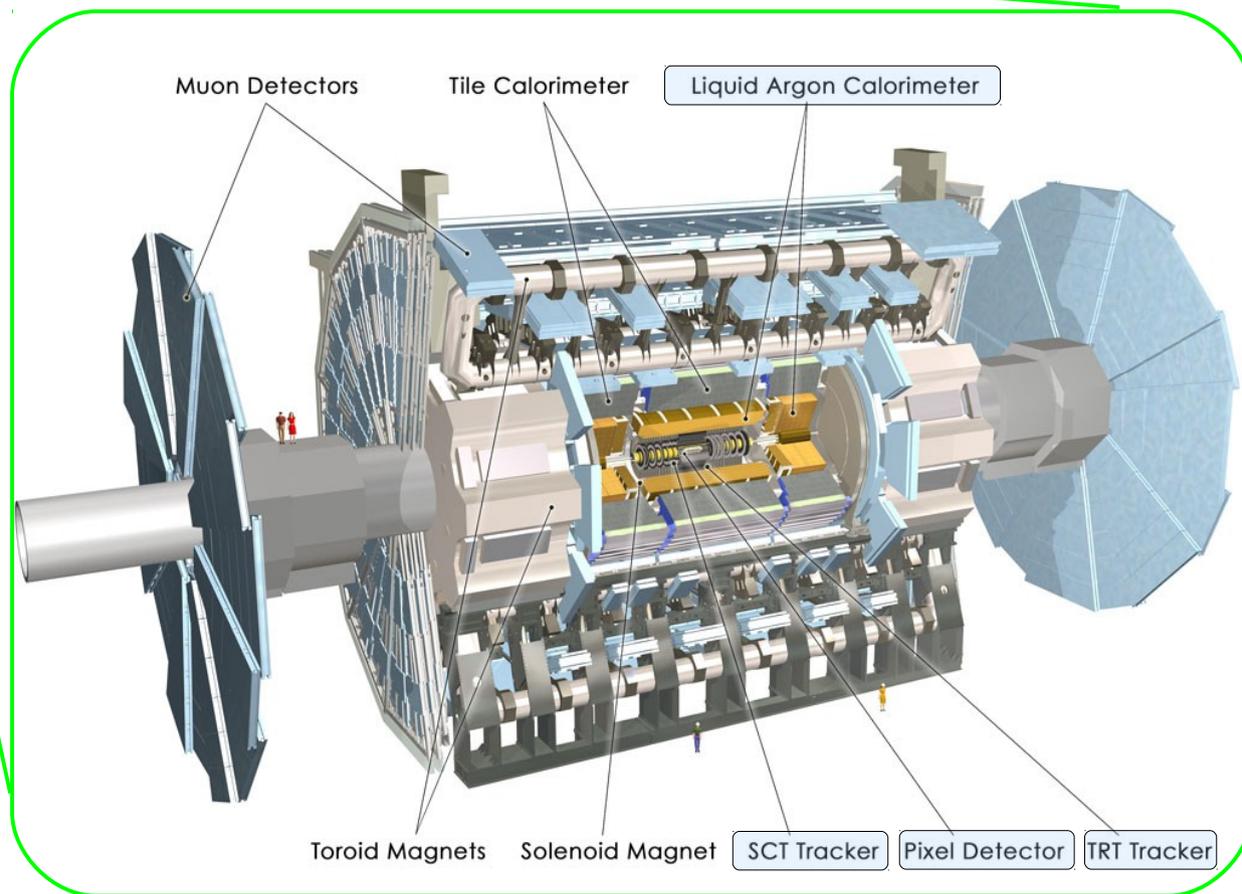


Collision Energy $\sqrt{s} = 7 \text{ TeV}$

2010 collected data $\sim 40 \text{ pb}^{-1}$

2011 collected data $\sim 26 \text{ pb}^{-1}$

Expected data by July 2011 $\sim 500 \text{ pb}^{-1}$

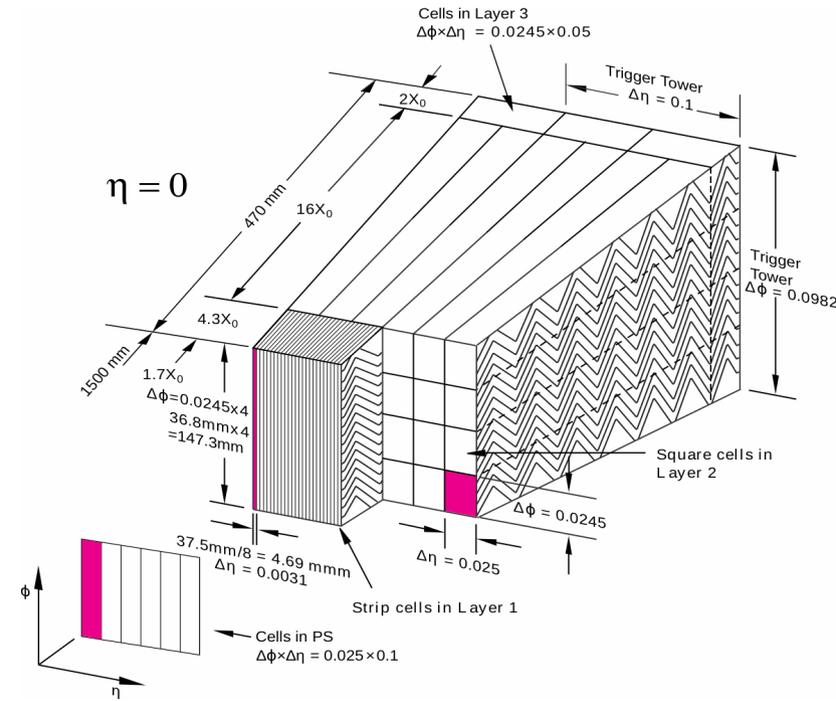
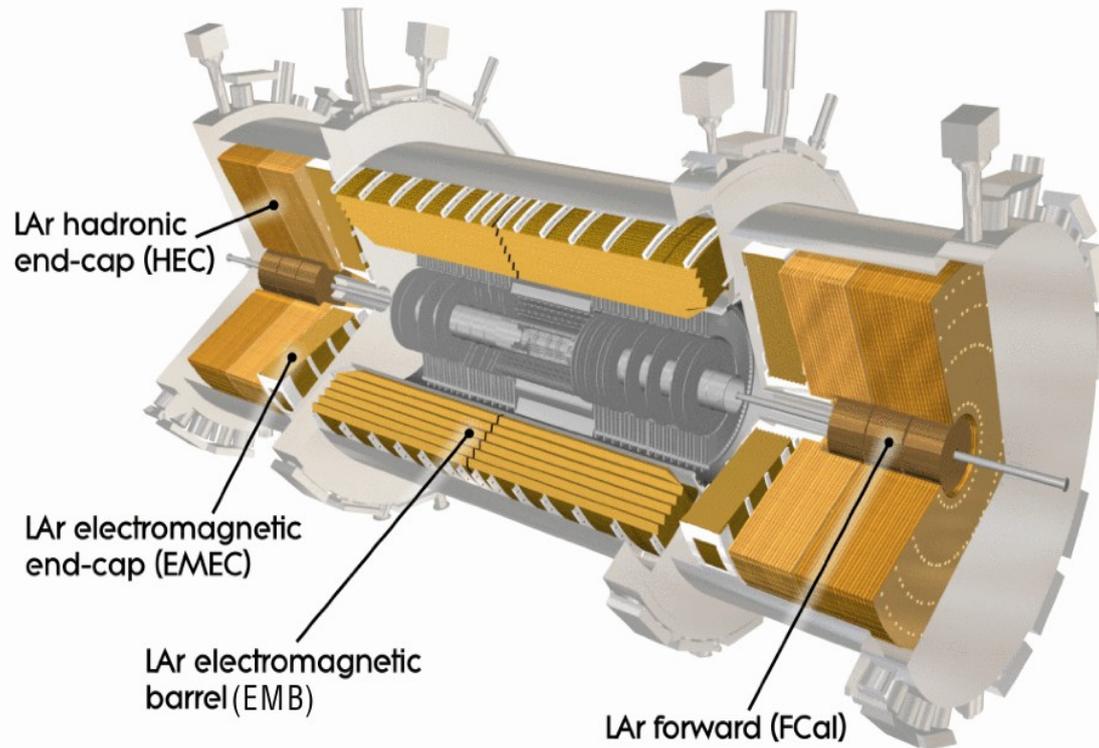


ATLAS electromagnetic calorimeter



Liquid Argon calorimeter
 Barrel $|\eta| < 1.475$
 Endcap $1.375 < |\eta| < 3.2$

Depth segmentation allows measurement of photon direction



Cells size in the core (second layer):
 $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$

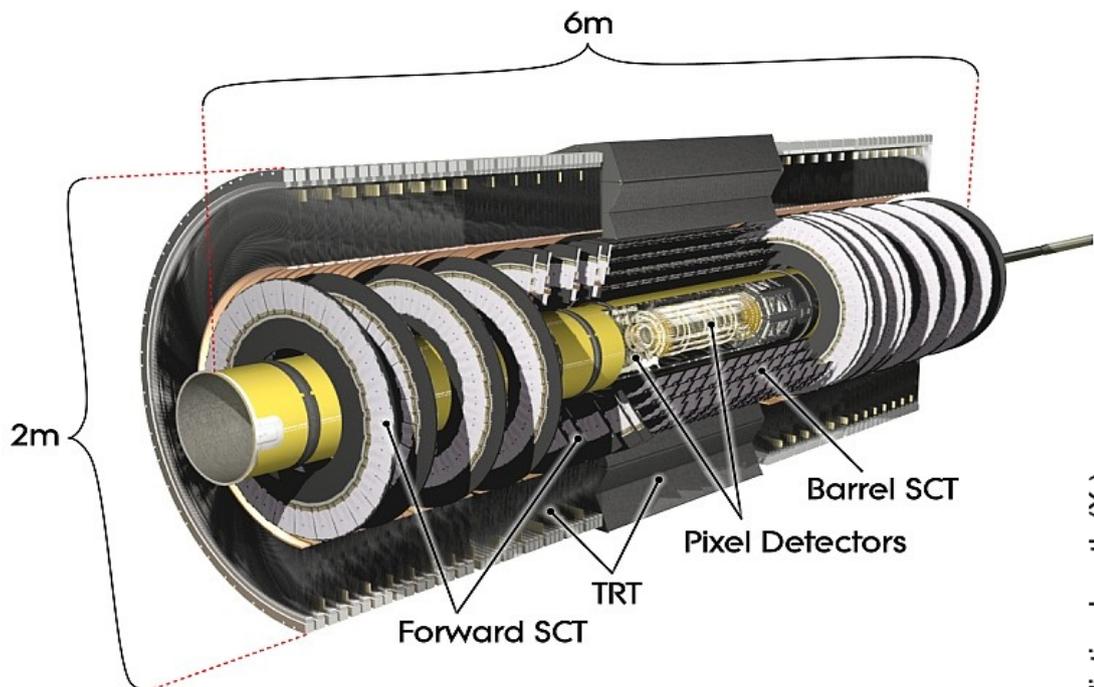
Energy resolution: $\frac{\sigma}{E} = \frac{10\%}{\sqrt{E}} \oplus 0.7\%$

Angular Resolution: $\frac{0.05\text{ rad}}{\sqrt{E}}$

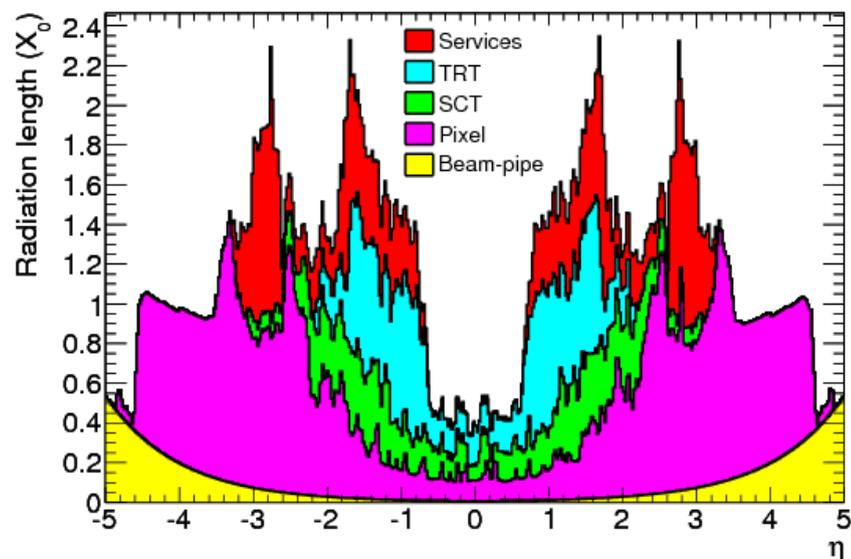
ATLAS Inner Detector



- Electron/photon discrimination
 - Based on track matching
- Important for converted photon identification (~30% of all photons)
 - Based on vertex position



Amount of material in the Inner Detector as a function of η



Pixel Tracker : 3 layers
resolution 0.01 mm

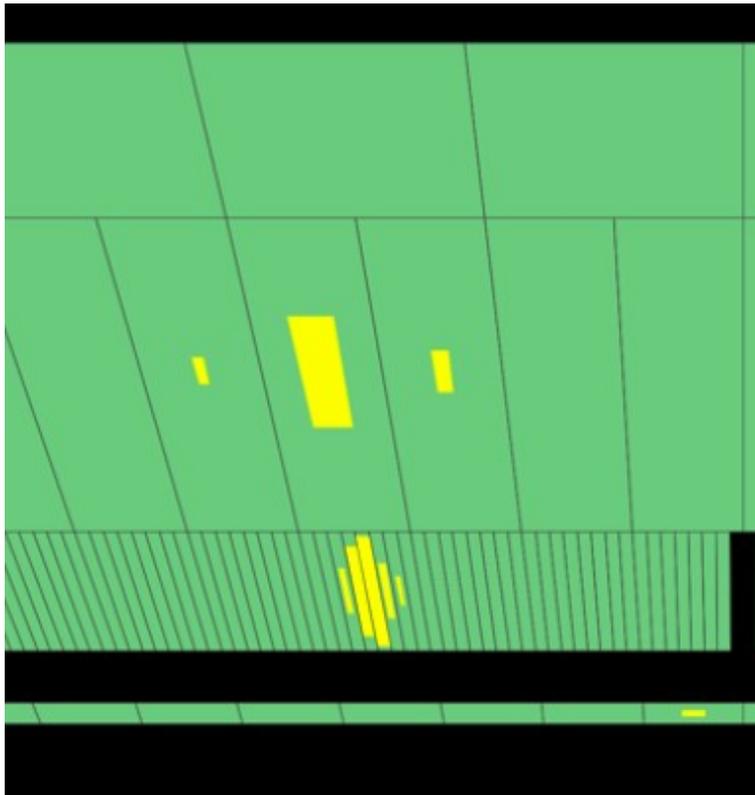
Semi-Conducting Tracker: 4 layers (8 hits per track)
resolution 0.017 mm

Transition Radiation Tracker: ~36 hits per track
resolution 0.13 mm

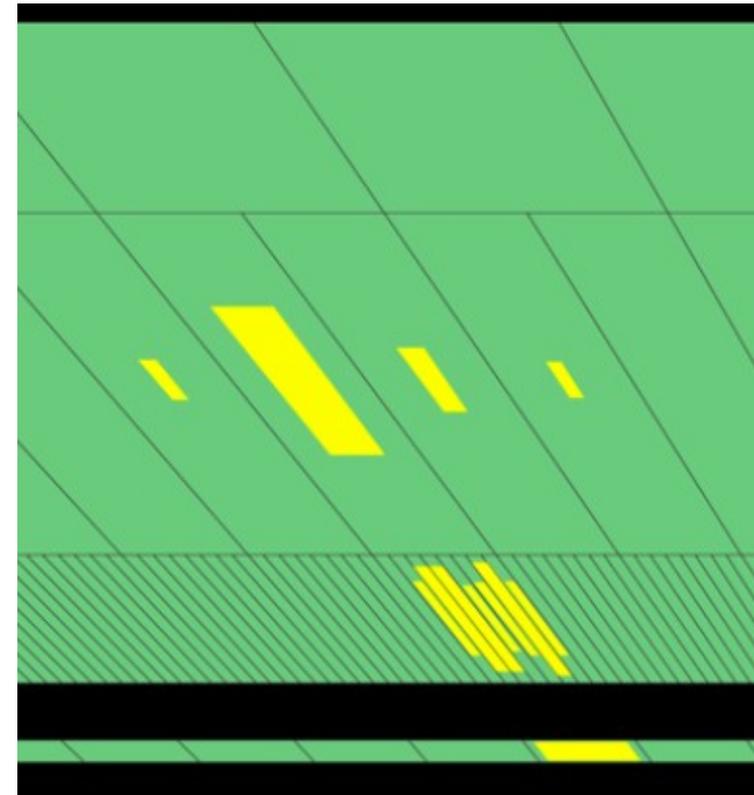
Photon Identification



- Hadronic background is suppressed using shower shape variables
 - **Converted and unconverted photons have the same selection criteria for “loose”**
 - Based on the hadronic leakage behind the EM calorimeter and lateral leakage and lateral width in the middle layer of EM calorimeter
 - **“Tight” photon selection criteria are based on information from highly segmented front layer**
 - Especially powerful to discriminate against π^0



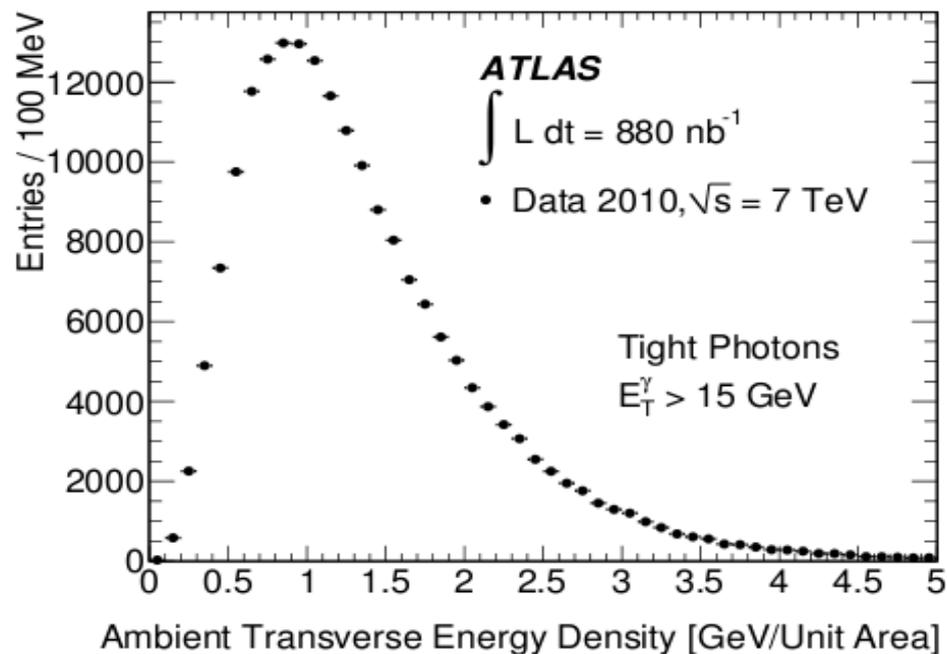
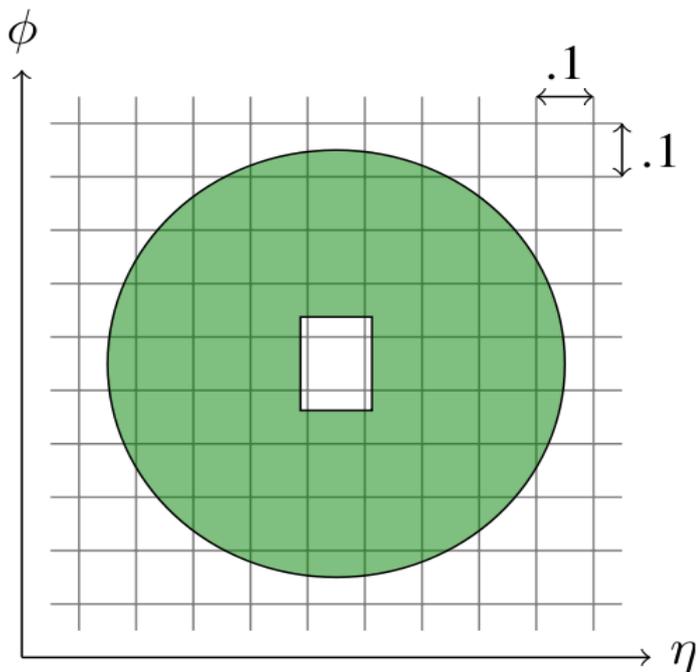
Prompt photon candidate



π^0 candidate

- Energy in the electromagnetic calorimeter in a cone of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$
- Correction for out of core leakage applied
- Underlying event energy correction (pile-up dependent)
 - Applied on event by event basis
 - With 1 primary vertex: 540 MeV / Unit Area

Cacciari *et al* - JHEP 04 (2010) 065



Direct Photon Cross-Section Components



- Two measurements of the direct photon cross-section have been released:

- Low E_T range with earlier data (0.88 pb^{-1})

Phys. Rev. D 83, 052005 (2011)

<http://arxiv.org/abs/1012.4389>

- $|\eta| < 1.37$ and $1.52 < |\eta| < 1.81$; $15 \text{ GeV} < E_T < 100 \text{ GeV}$

- Result on full 2010 dataset (35 pb^{-1})

ATLAS-CONF-2011-058

Focus of this talk

- $|\eta| < 1.37$ and $1.52 < |\eta| < 2.37$; $45 \text{ GeV} < E_T < 400 \text{ GeV}$

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

- N_{yield} is the number of photon events after background subtraction
- U is the inversed bin migration matrix of photon's E_T
 - Takes into account photon energy resolution
 - Based on MC study
- ε efficiencies corresponding to trigger, photon reconstruction and photon identification
- $\Delta E_T - E_T$ bin size

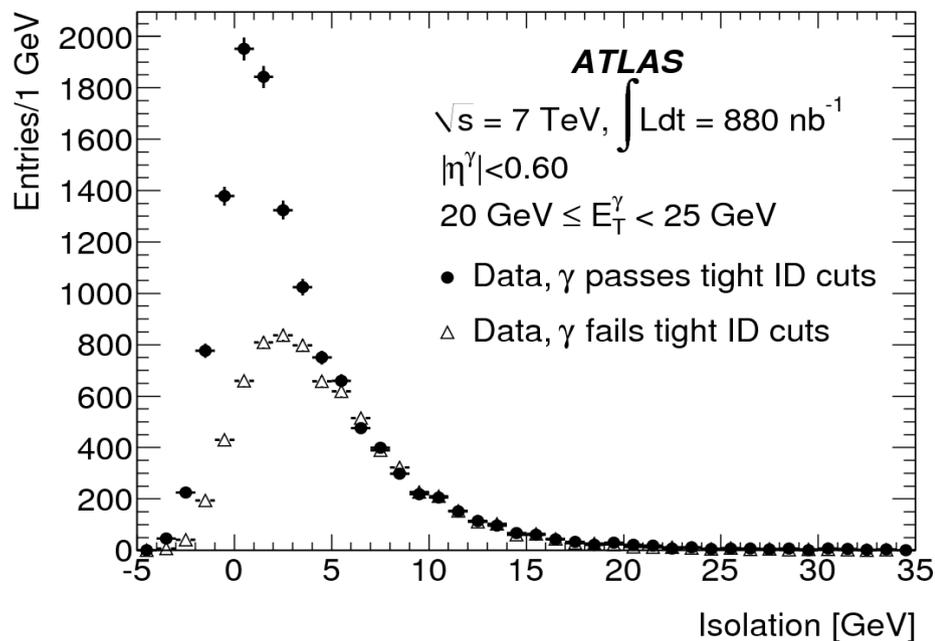
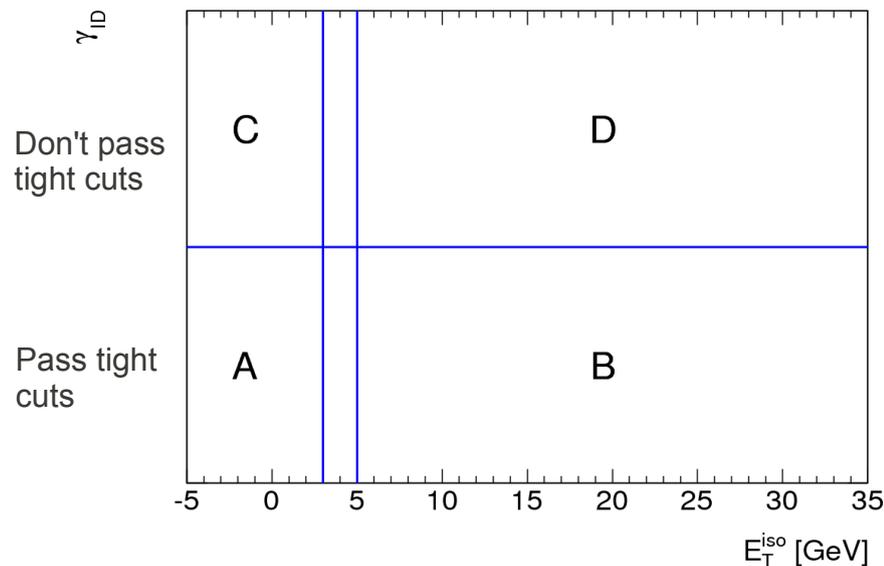
Background Subtraction



- Jet background is estimated with 2D sideband method
- Signal leakage to background regions is subtracted from the background numbers using MC results

$$N_A^{yield} = N_A - N_A^{bkg} = N_A - R^{bkg} \frac{(N_B^{obs} - N_B^{sig})(N_C^{obs} - N_C^{sig})}{N_D^{obs} - N_D^{sig}}$$

$$R^{bkg} = \frac{N_A^{bkg} N_D^{bkg}}{N_C^{bkg} N_B^{bkg}} \quad c_x = \frac{N_x^{sig}}{N_A^{sig}} \quad \text{from MC}$$



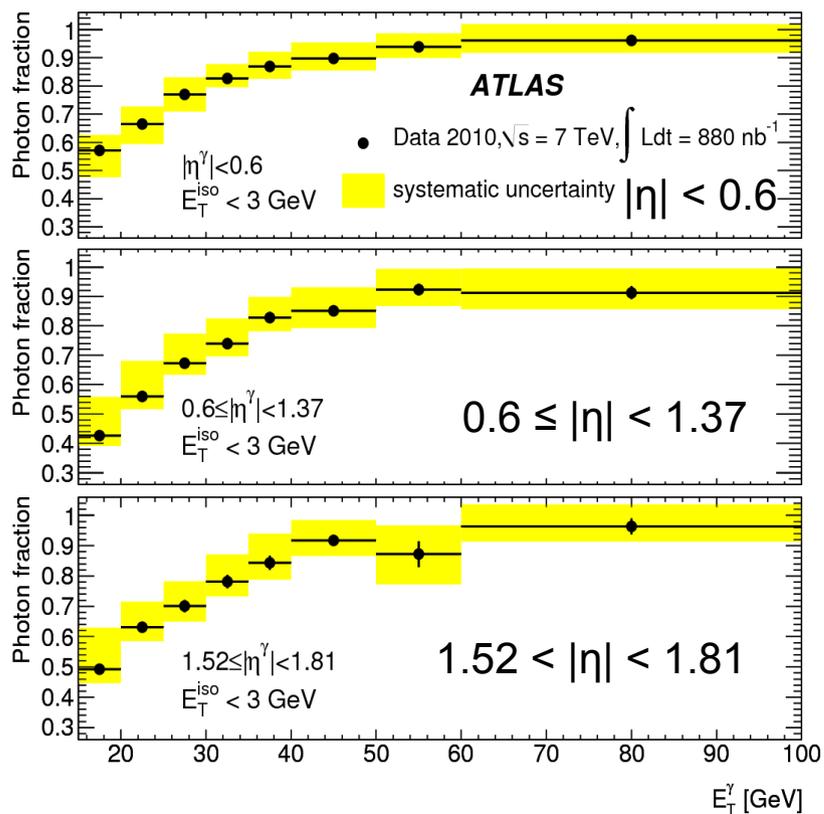
Correlation between isolation and reversed cuts for the background is small (leads to < 3.8% systematics)

Background from isolated **electrons** is estimated at **1.2%** in low η and **1.7%** at high η using electron-photon fake rate measured in data

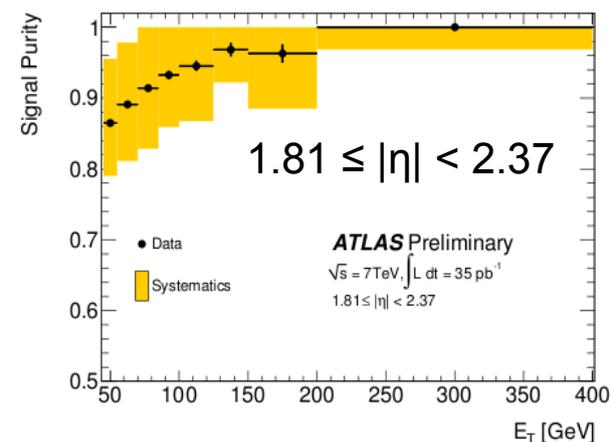
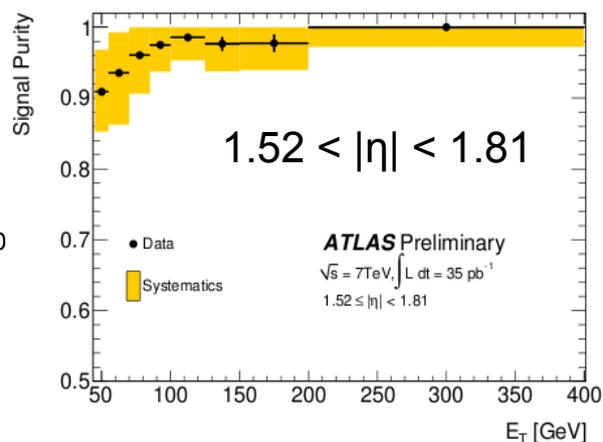
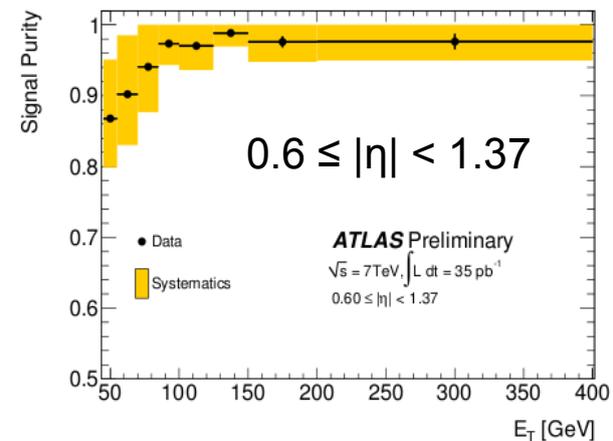
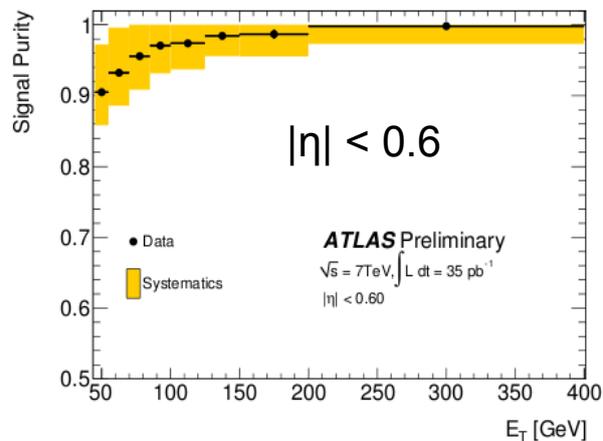
Photon Purity



880 nb⁻¹ data

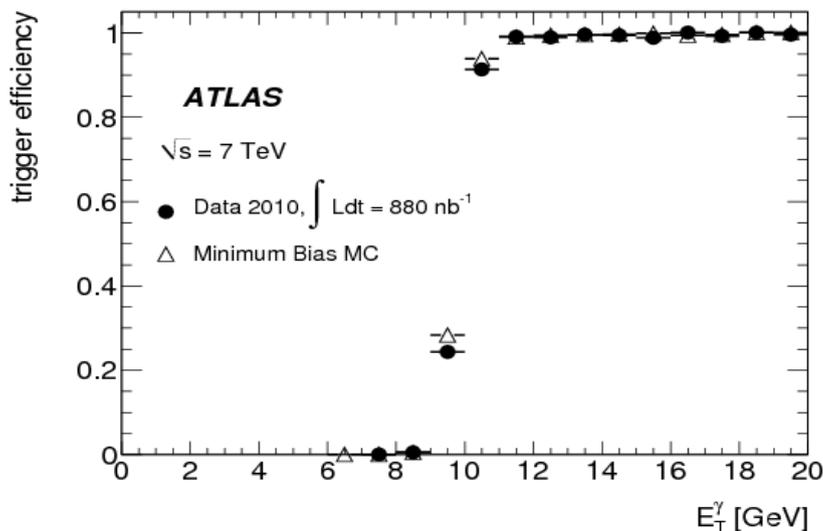


35 pb⁻¹ data

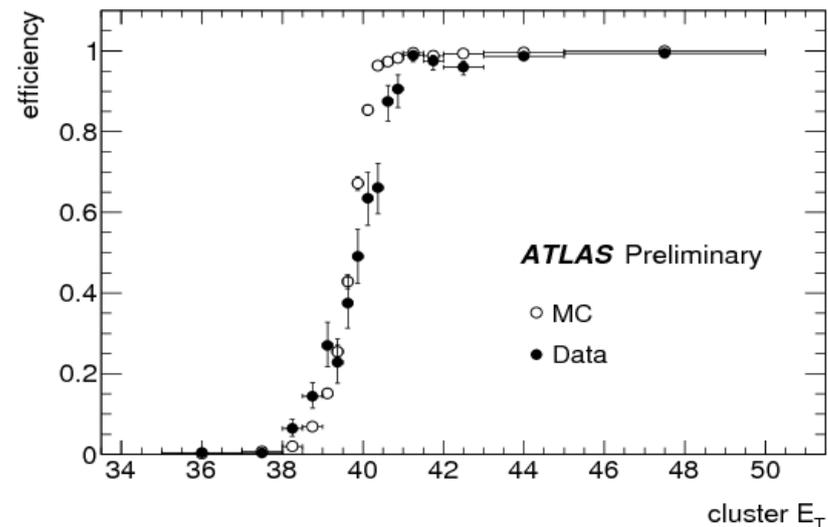


- Low purity at $E_T < 30 \text{ GeV}$
- High purity with $E_T > 100 \text{ GeV}$

Trigger and reconstruction Efficiencies



Trigger efficiency for 880 nb^{-1} analysis
 E_T threshold 10 GeV
 Efficiency with $E_T > 15 \text{ GeV}$ is 99.5%



Trigger efficiency for 45 pb^{-1} analysis
 E_T threshold 40 GeV
 Efficiency with $E_T > 45 \text{ GeV}$ is 99.4%

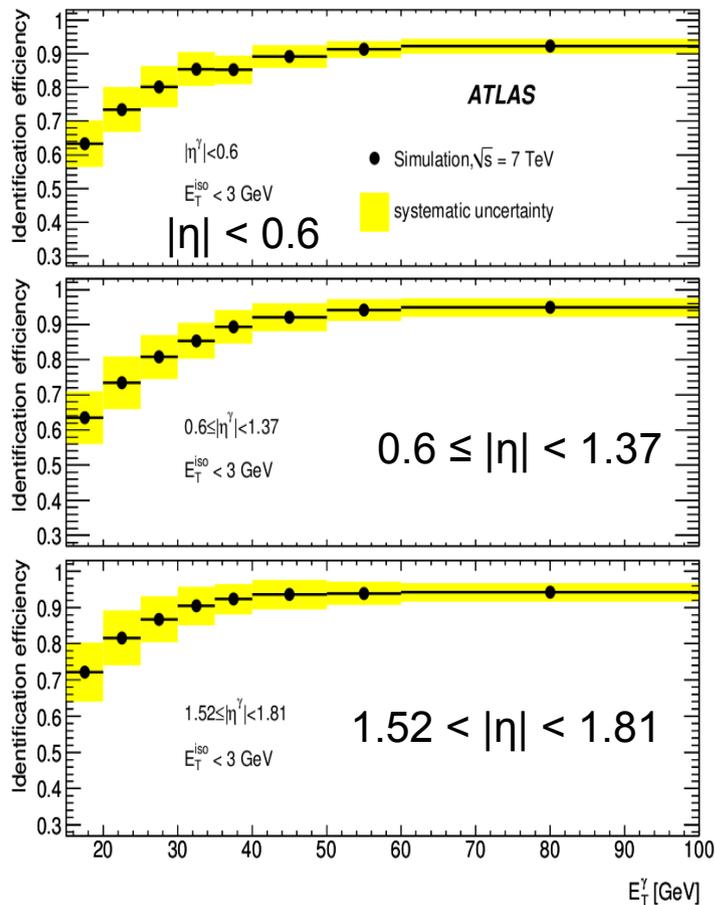
- ϵ_{reco} is taken from detector simulation $\epsilon_{\text{reco}} = N_{\text{reco}}(\text{isolated}) / N_{\text{produced}}^{\text{all prompt}}$ (true isolated)
- Sensitive to detector's disabled regions
 - Fixed during winter shutdown
- ϵ_{reco} is 80-85% in the Barrel, 70-78% in the Endcap

Photon Identification Efficiency

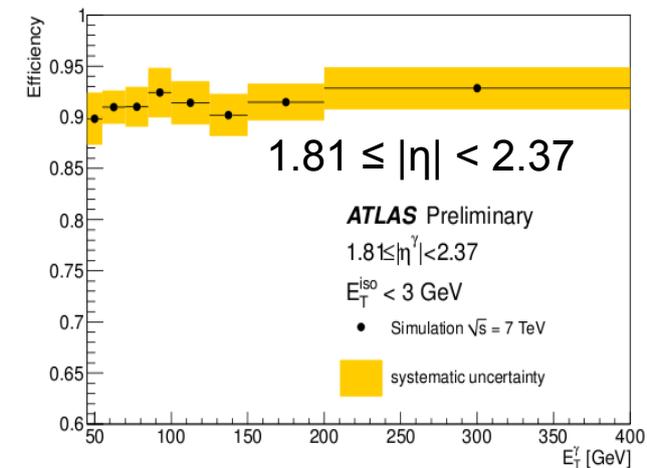
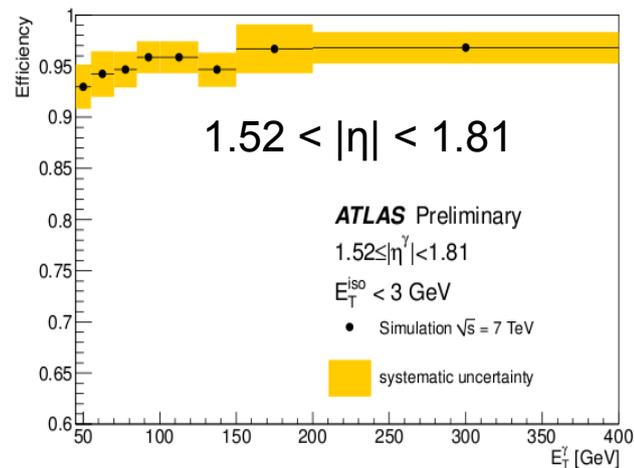
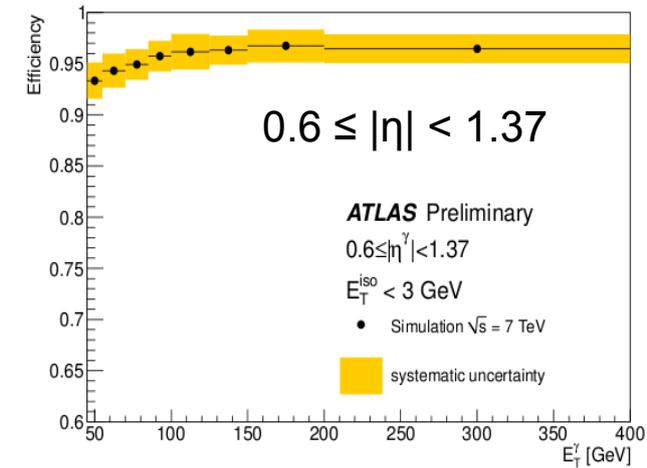
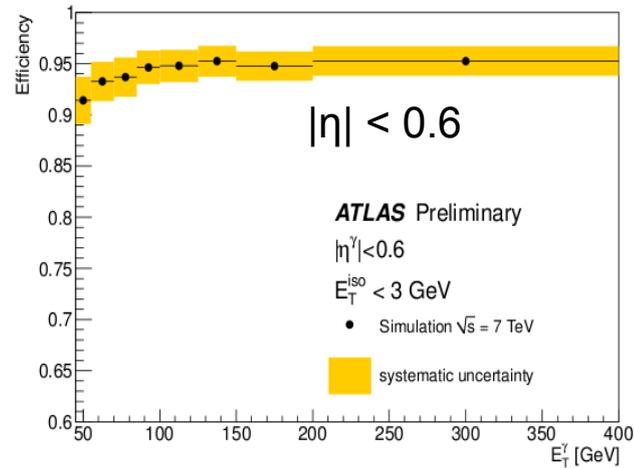


- Photon identification efficiency is estimated from MC using modified shower shape variables to match data
- Efficiencies and shower shapes are compared to electron's shower shapes from W decay

880 nb⁻¹ data



35 pb⁻¹ data

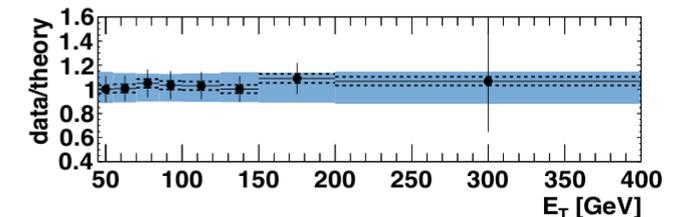
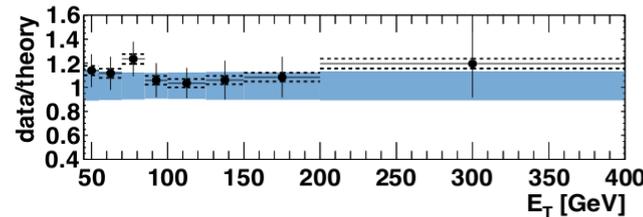
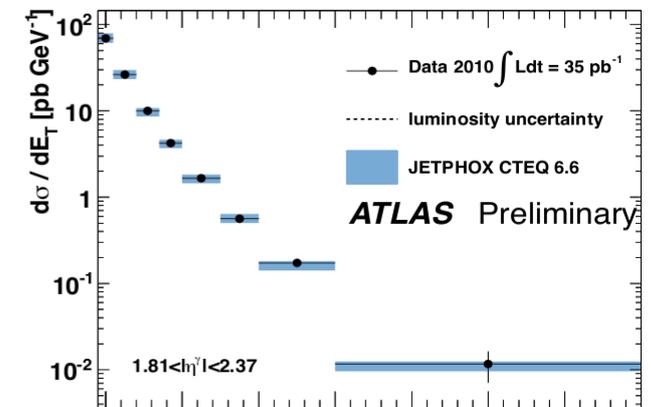
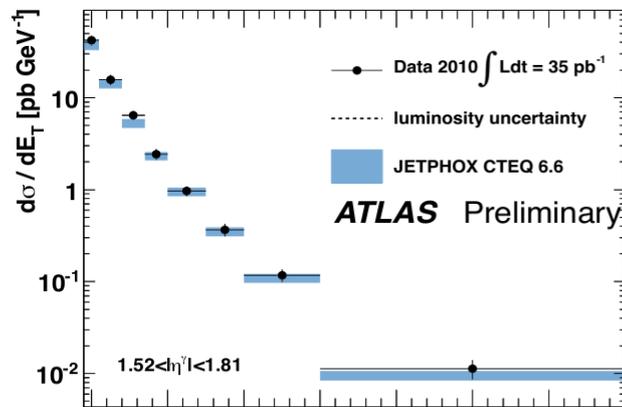
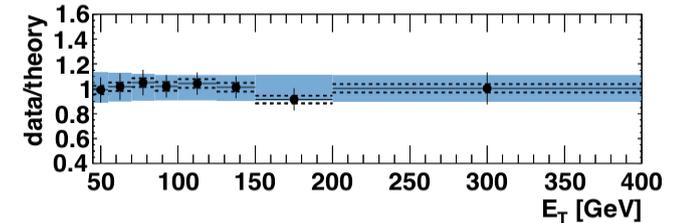
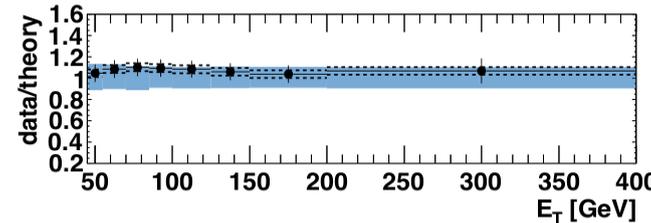
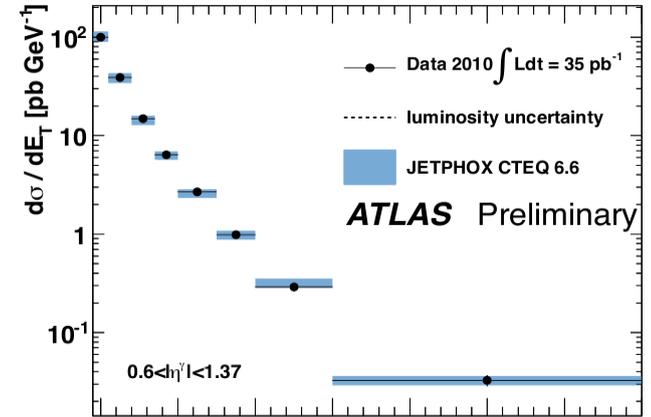
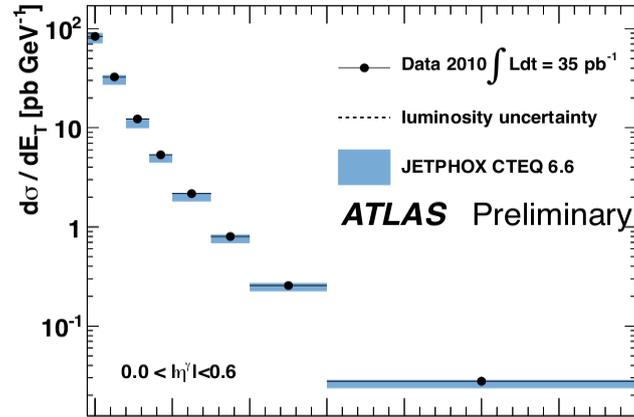


Cross-section results vs CTEQ6.6 prediction

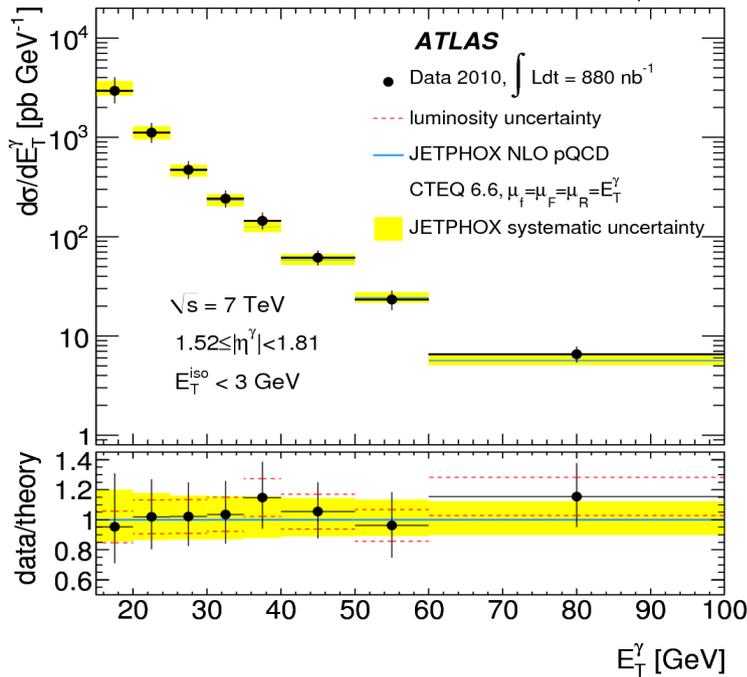
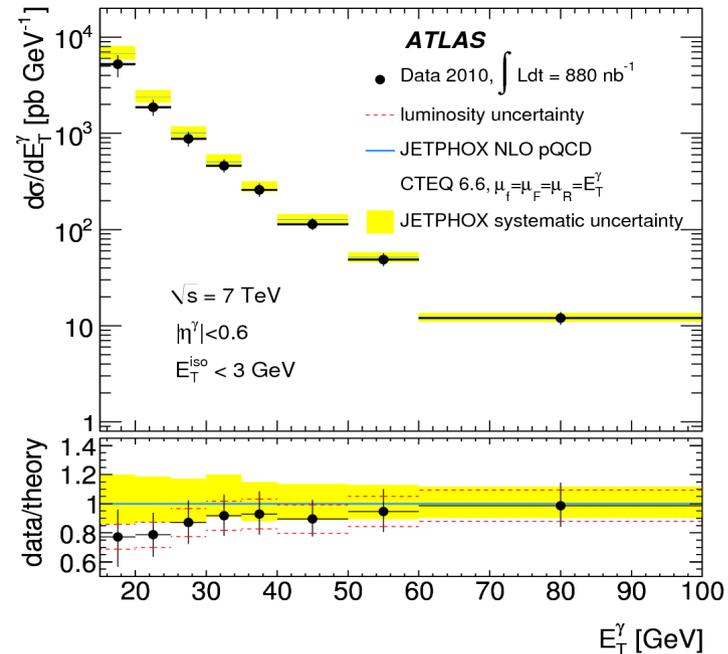
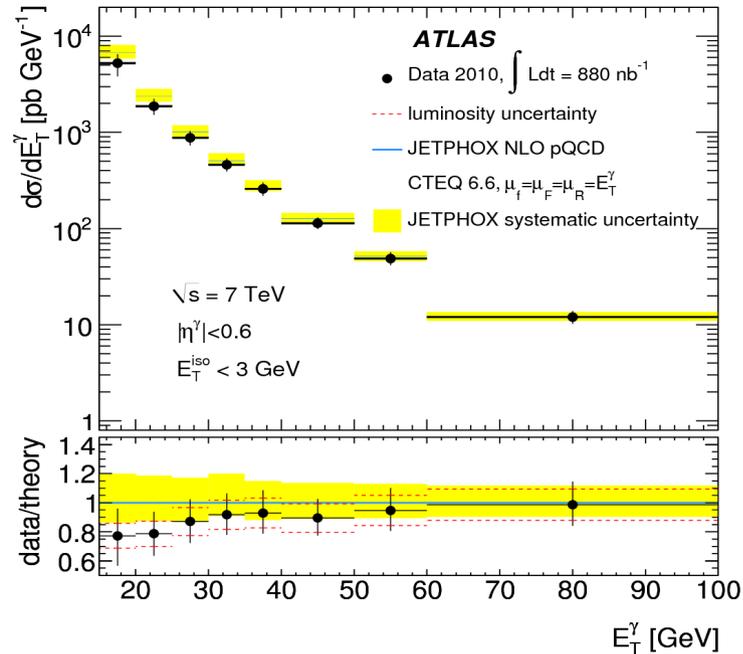


- Using JETPHOX
 - [hep-ph/0204023](#)
 - [Phys. Rev. D 73, 094007](#)

- Full 2010 dataset
- [ATLAS-CONF-2011-058](#)
- High E_T measurement
- PDFs from CTEQ6.6

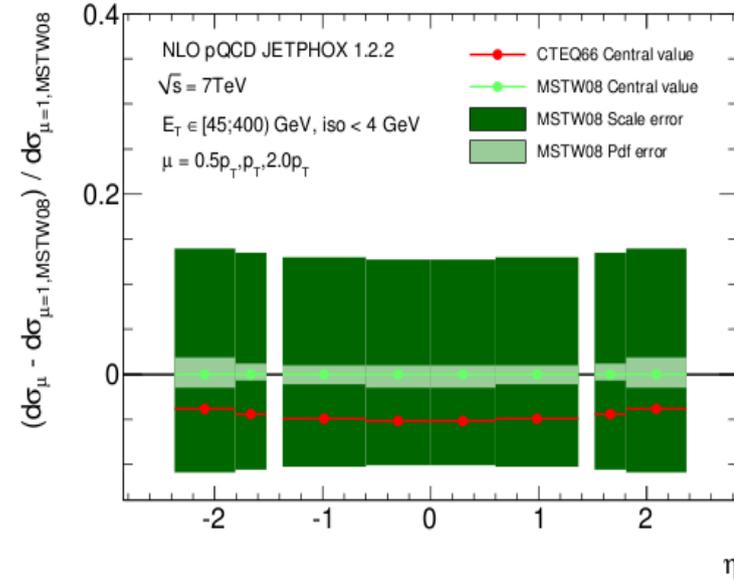
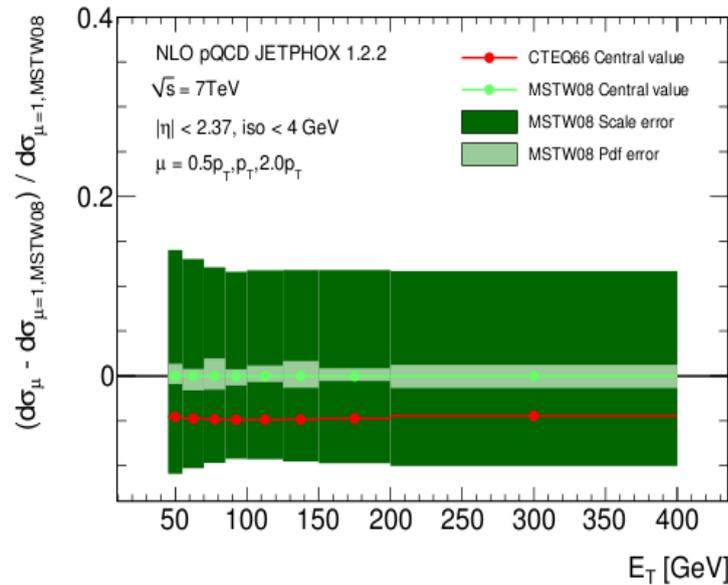
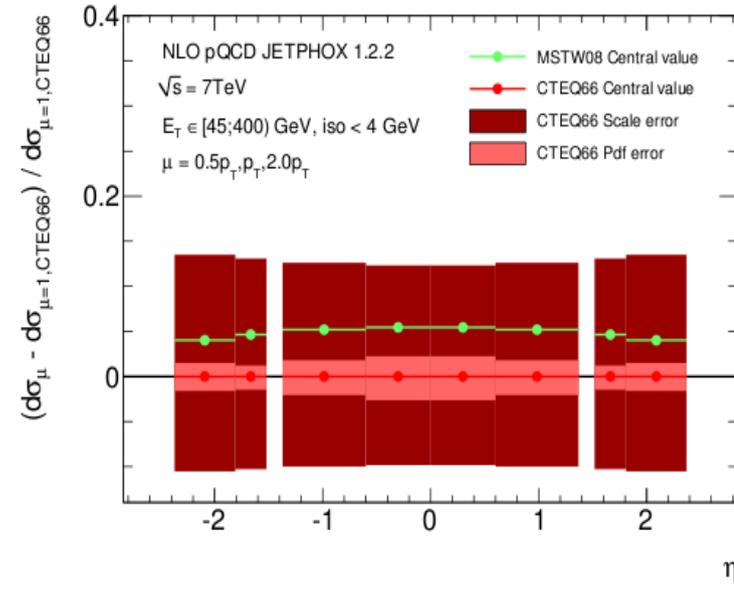
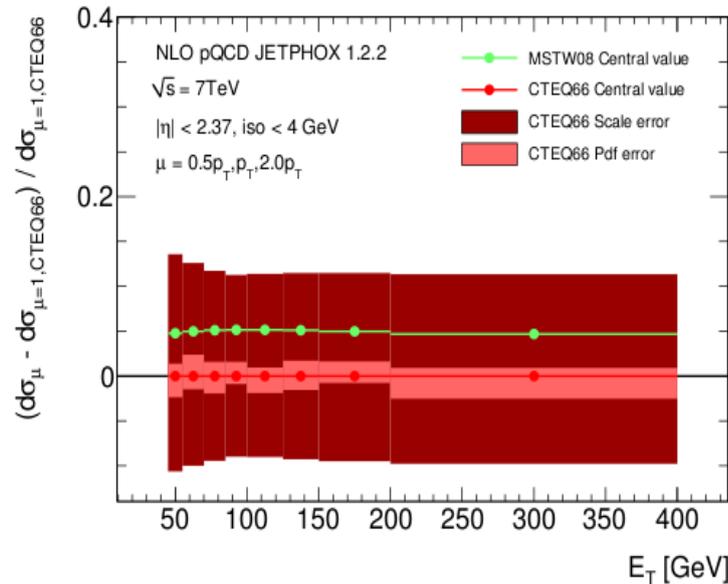


Cross-section results vs CTEQ6.6 prediction (2)



- 880 nb⁻¹ dataset
- Lower E_T measurement
- PDFs from CTEQ6.6
- Phys. Rev. D 83, 052005 (2011)

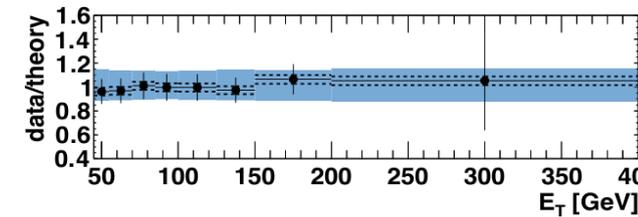
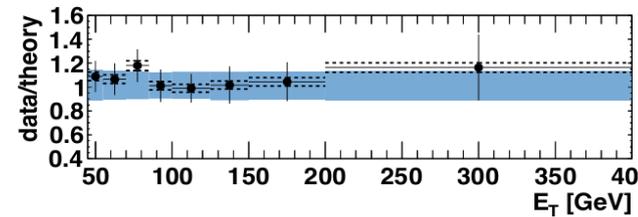
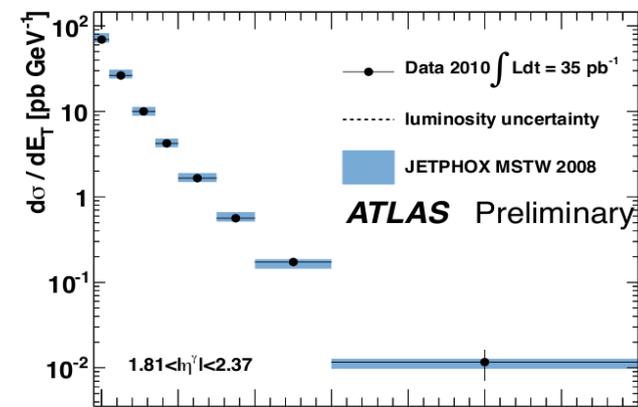
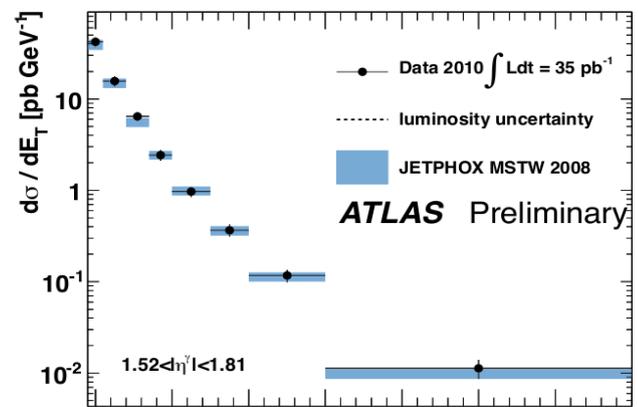
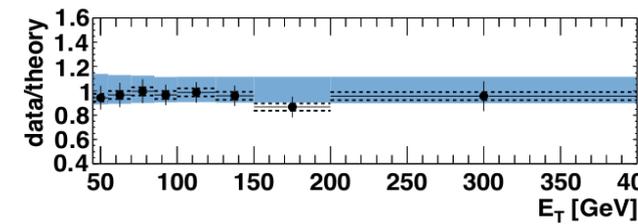
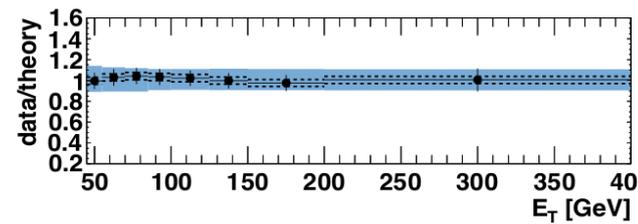
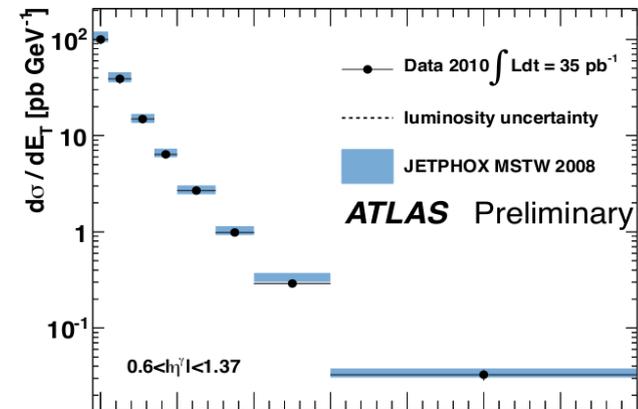
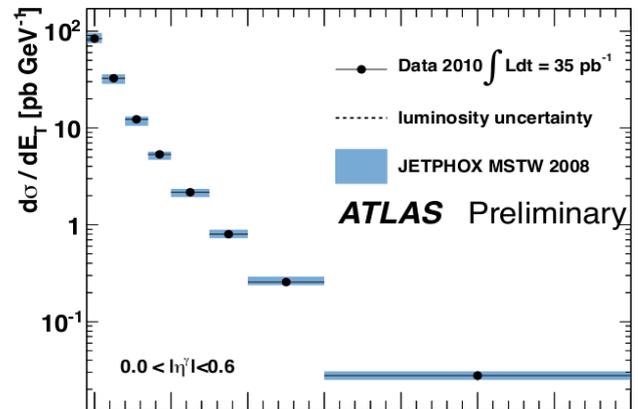
- Comparing theoretical cross-section prediction and uncertainty with CTEQ6.6 and MSTW08 PDF distributions
- Using JETPHOX with NLO calculation
- Renormalization, fragmentation, and factorization scales are chosen to be at photon's transverse energy
- Scale uncertainty estimated by independently varying the scales from 0.5 to 2.0 E_T



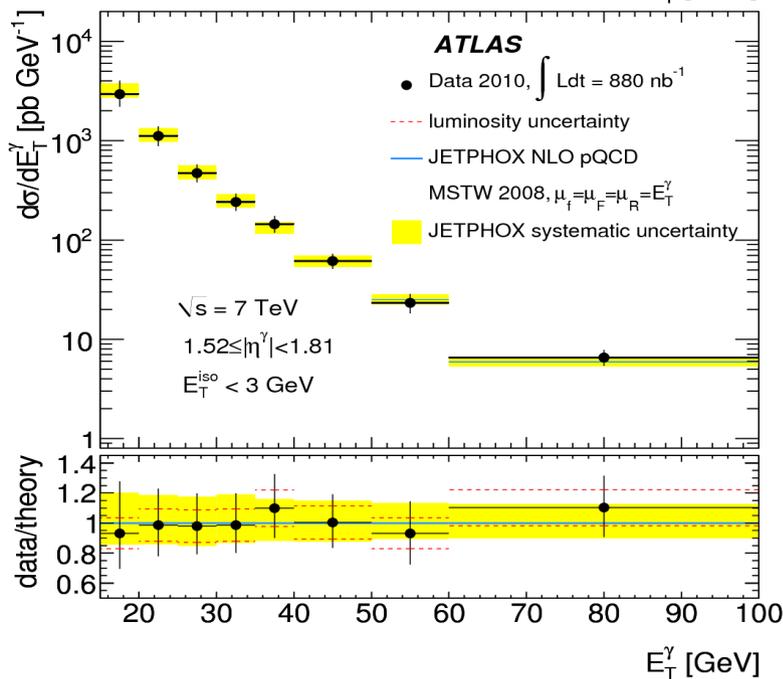
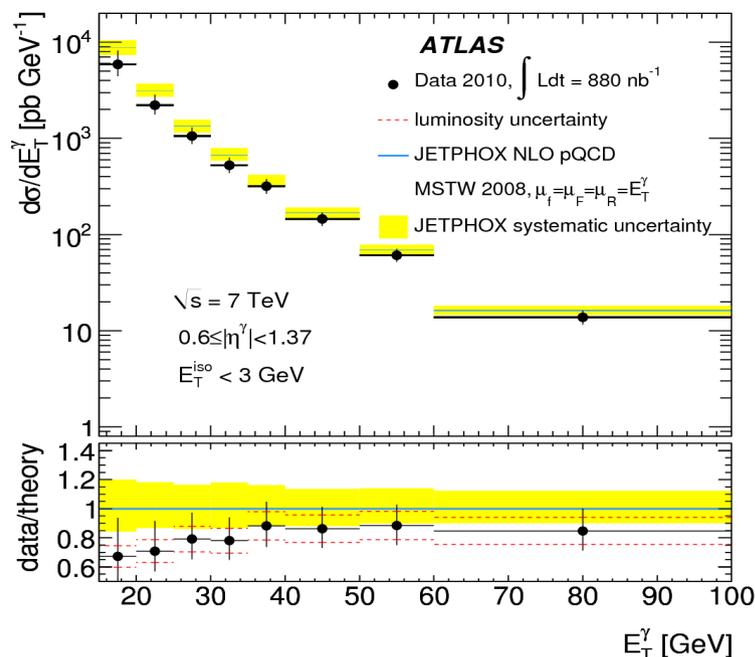
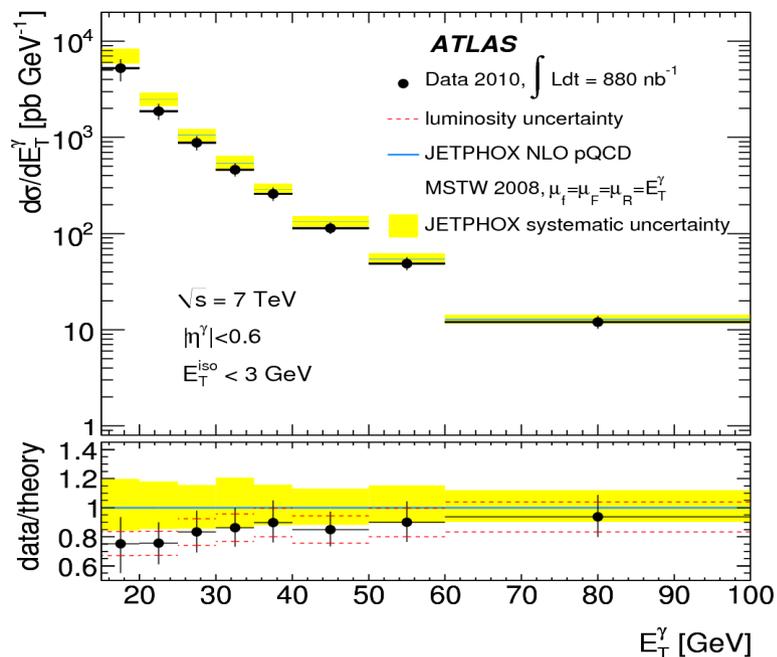
Cross-section results vs MSTW prediction



- Full 2010 dataset
- ATLAS-CONF-2011-058
- High E_T measurement
- PDFs from MSTW2008

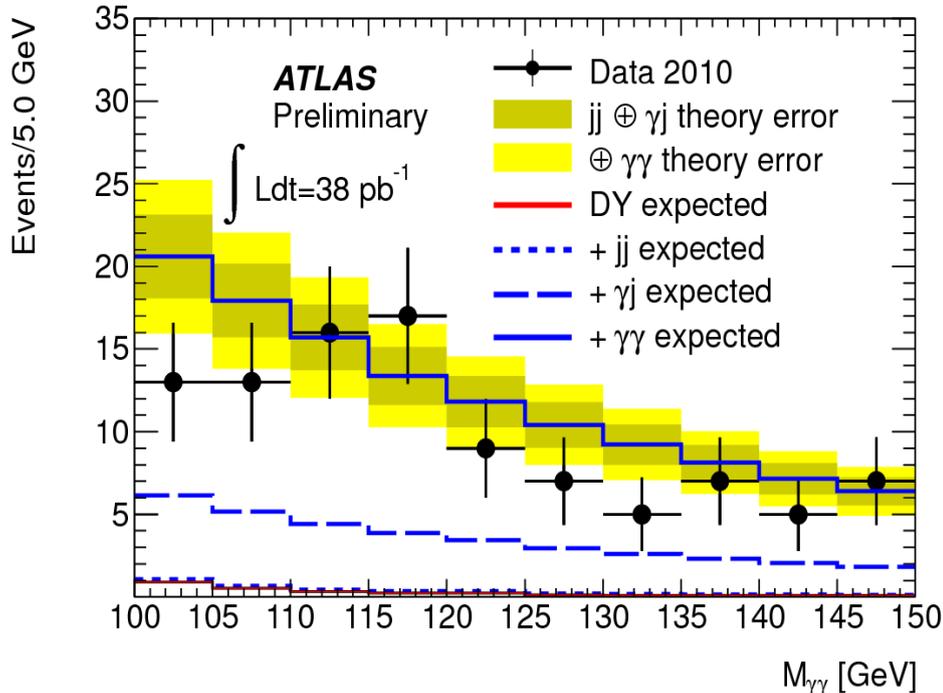


Cross-section results vs MSTW prediction (2)

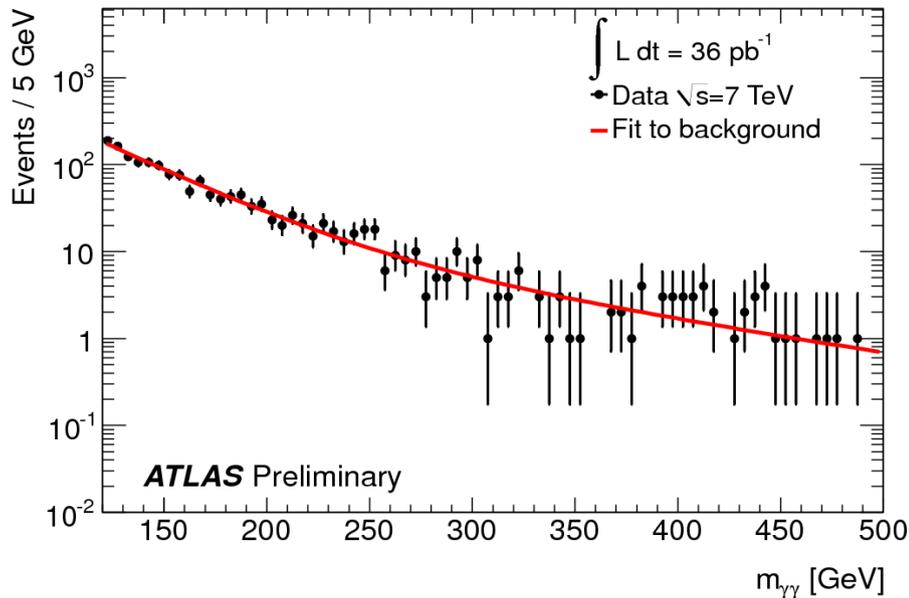


- 880 nb⁻¹ dataset
- Lower E_T measurement
- PDFs from MSTW2008
- Phys. Rev. D 83, 052005 (2011)

Diphoton mass spectrum



- Diphoton mass spectrum from **H**→**γγ** search **ATLAS-CONF-2011-025**
- **75 ± 13 out of 99** events are expected to be from direct diphoton events.
- 2D sidebands method applied for both selected photons.
- **Solid blue**: sum of all backgrounds predicted by theory, normalized to data luminosity
- **Brown and yellow bands**: the sum of uncertainties for the reducible and irreducible background.
- **Result**: Excluded Higgs signal with 7- 40 times SM Higgs Boson production cross-section



- Diphoton invariant mass spectrum from the **Randall-Sundrum Graviton** search **ATLAS-CONF-2011-044**
- Photons for this analysis pass “Loose” cuts
- No isolation required
- **Result**: RS Gravitons are excluded below 545 GeV (920 GeV) for the RS coupling constant 0.02 (0.1)



- High purity and efficiency of photon reconstruction at higher E_T
- Prompt photon cross-section is measured in 4 different η regions in a wide range of E_T , $15 \text{ GeV} < E_T < 400 \text{ GeV}$ ($0.004 < x < 0.114$)
- Agreement with theory at high E_T
- Low E_T spectrum requires more understanding
- Using prompt photons to search for new particles in diphoton spectrum sets a limit on SM Higgs cross-section and RS Graviton mass.
- We already have more than 50% of the amount of data we had last year; more results from analyses using prompt photons can be expected this summer!



Additional Information



- Photon reconstruction starts with a sliding window algorithm to find energy deposition in the calorimeter in the $\Delta\eta \times \Delta\phi = 0.075 \times 0.125$ size windows
- Checks if cluster corresponds to a photon candidate
 - If there is no track associated, reconstruct the candidate as an **unconverted photon**
 - If there is a track associated, the candidate is considered as an electron, but can be recovered:
 - If there is a conversion vertex found, the candidate is reconstructed as a **converted photon**
- Converted and unconverted photons have different cluster size, energy calibration and cuts for the discriminating variables



- Energy calibration includes correction for the energy loss in the upstream material and the leakage behind electromagnetic calorimeter
- Calibration is based on test beam studies
- The in-situ calibration with data is performed
 - Reduced uncertainty on the amount of upstream material
 - Calorimeter performance is improved using Z mass reconstruction with $Z \rightarrow ee$ events in data
 - Correction coefficients for energy rescale are extracted from this study

Cuts definitions



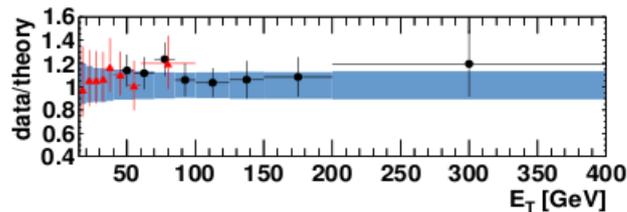
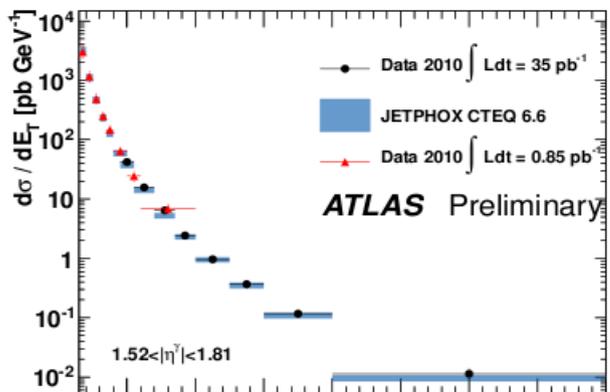
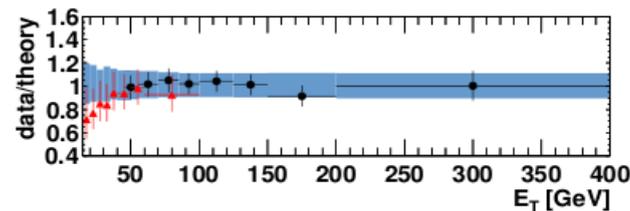
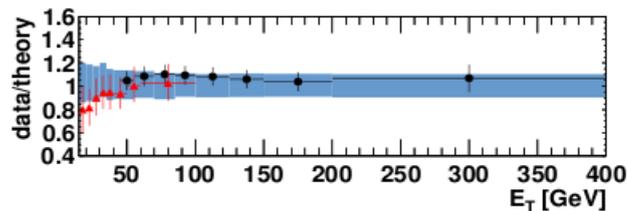
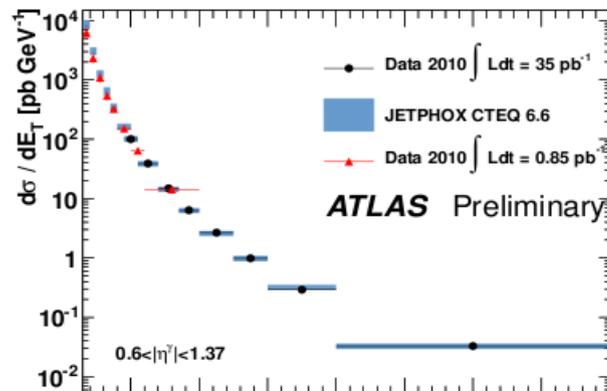
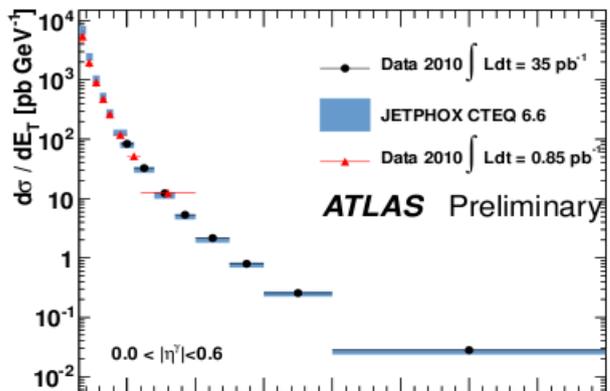
Category	Description	DV	Loose	Tight
Acceptance	$ \eta < 2.37, 1.37 < \eta < 1.52$ excluded	–		✓
Hadronic leakage	Ratio of E_T in the first sampling of the hadronic calorimeter to E_T of the EM cluster (used over the ranges $ \eta < 0.8$ and $ \eta > 1.37$)	R_{had_1}	✓	✓
	Ratio of E_T in all the hadronic calorimeter to E_T of the EM cluster (used over the range $0.8 < \eta < 1.37$)	R_{had}	✓	✓
EM Middle layer	Ratio between the sum $E_{3 \times 7}^{S2}$ of the energies of the cells contained in a 3×7 $\eta \times \phi$ rectangle (measured in cell units), and the sum $E_{7 \times 7}^{S2}$ of the cell energies in a 7×7 rectangle, both centered around the cluster seed	R_η	✓	✓
	Lateral width of the shower in the η direction	w_2	✓	✓
	Ratio between the sum $E_{3 \times 3}^{S2}$ of the energies of the cells contained in a 3×3 $\eta \times \phi$ rectangle (measured in cell units), and the sum $E_{3 \times 7}^{S2}$ of the cell energies in a 3×7 rectangle, both centered around the cluster seed	R_ϕ		✓
EM Strip layer	Lateral shower width for maximum strip and two neighbors	w_{s3}		✓
	Total lateral shower width	w_{stot}		✓
	Fraction of energy outside core of three central strips but within seven strips	F_{side}		✓
	Difference between the energy of the strip associated with the second maximum in the strip layer, and the energy reconstructed in the strip with the minimal value found between the first and second maxima	ΔE		✓
	Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies	E_{ratio}		✓

Summary of Systematic Effects

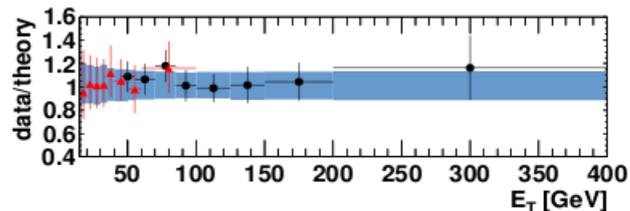
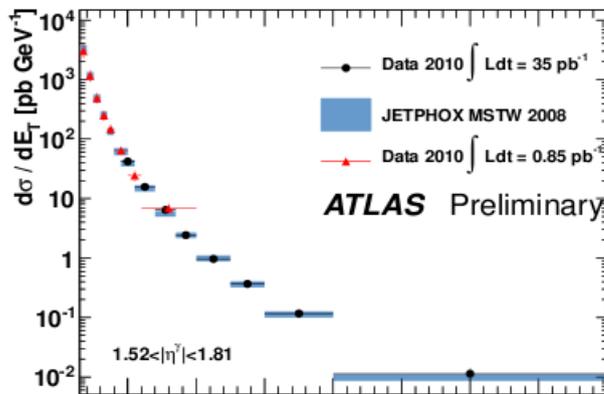
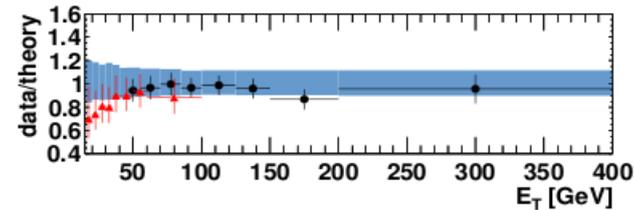
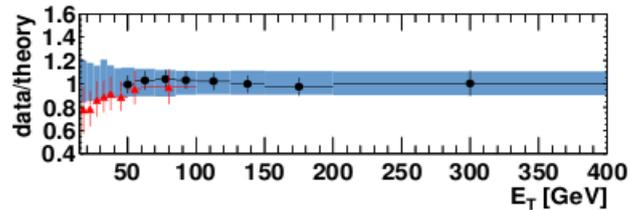
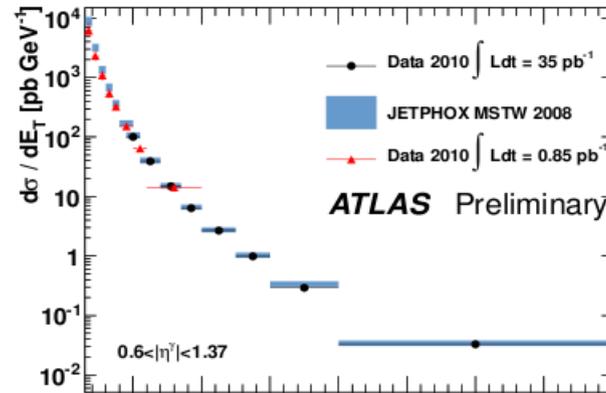
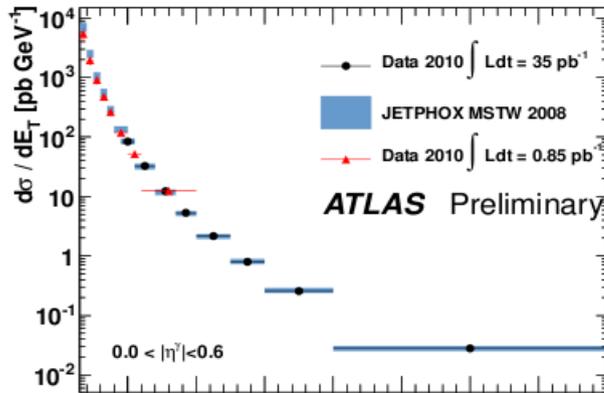


Systematic	Reco. Eff.	ID Eff.	Yield	Unfolding	Theory
Finite Statistics per bin				< 2%	
Generator	1%	< 1%	~ 1%	3%	
E_T Resolution				< 1%	
Photon ID			< 5%		
Photon Isolation			< 1%		
Signal Leakage			2% – 8%		
Background Correlations			< 4%		
Energy Scale			2% – 8%		
Material	1% – 4%	1% – 2%	< 1%		
Soft-jet Energy Density			3% – 7%		
Transverse Energy Leakage			1% – 4%		
Hard/Brem Composition	1%	< 1%	1% – 6%		
OTX	0.2%				
Photon Isolation Cut	3% – 4%				
Intrinsic Precision		1% – 3%			
Photon Sample Selection		0.5%			
Conv/Unconv. Photon Ratio		< 1%			
Scale uncertainty					10% – 20%
PDFs					2% – 5%
Parton level Isolation					< 2%

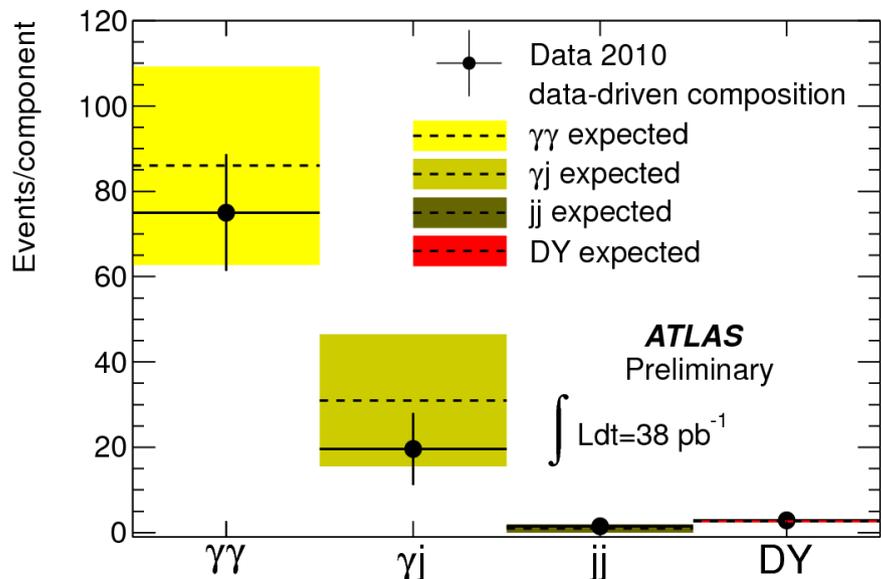
Cross-Section vs CTEQ6.6 combined



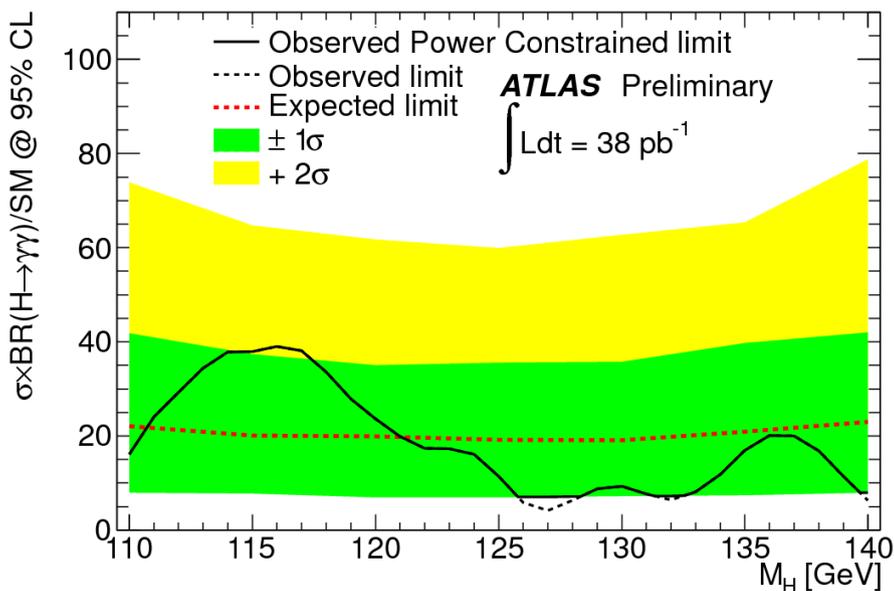
Cross-Section vs MSTW combined



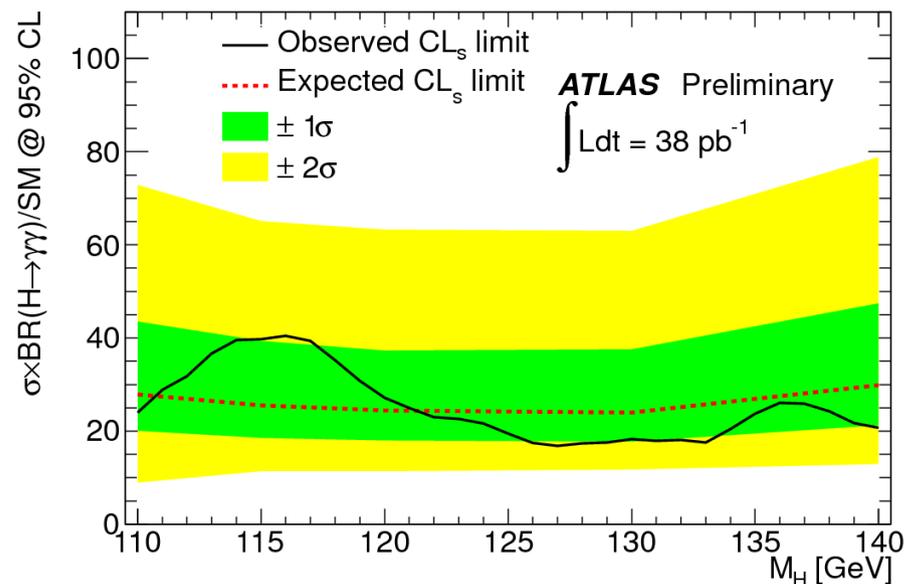
Higgs $\rightarrow \gamma\gamma$ exclusion limit



Background decomposition:
 Dashed lines – expected from MC
 Dots – output from 2 x 2D sideband on data

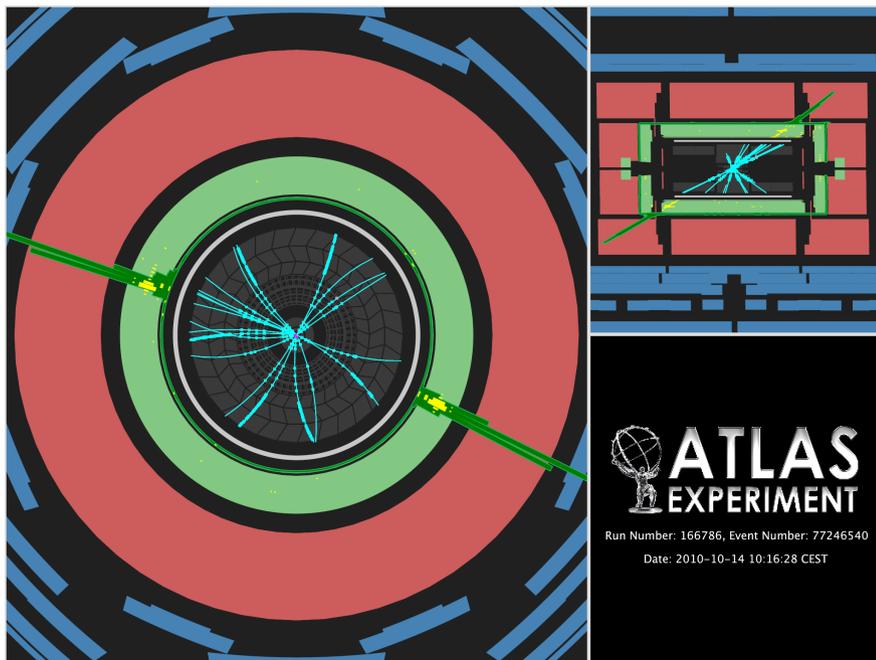
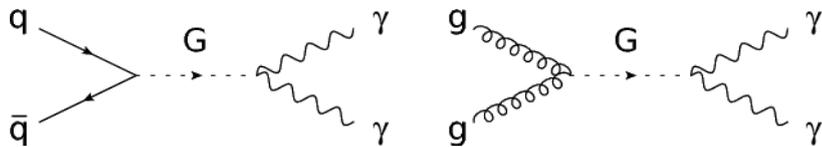


Power constrain limit

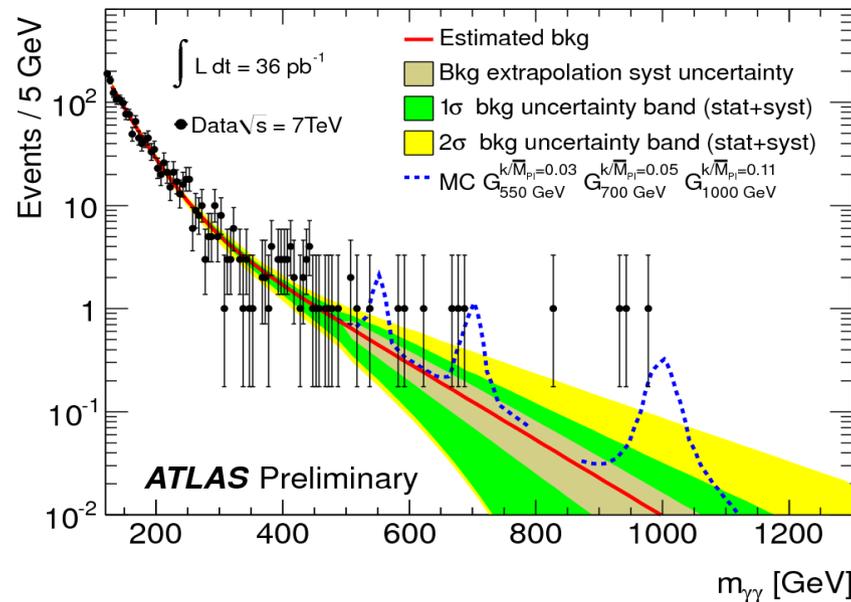


CLs limit

New Physics Searches: Graviton



- Event display of highest mass diphoton event observed with ATLAS with photons passing “tight” requirement
 $m_{\gamma\gamma} = 679 \text{ GeV}$



- Observed mass spectrum (points), expected background (red line) and signals of mass 550, 700 and 1000 GeV with couplings $k/M_{\text{Pl}} = 0.03, 0.05$ and 0.11 , respectively (blue dash)

