Wγ and Zγ Production and Searches for Anomalous Triple Gauge Couplings at the LHC

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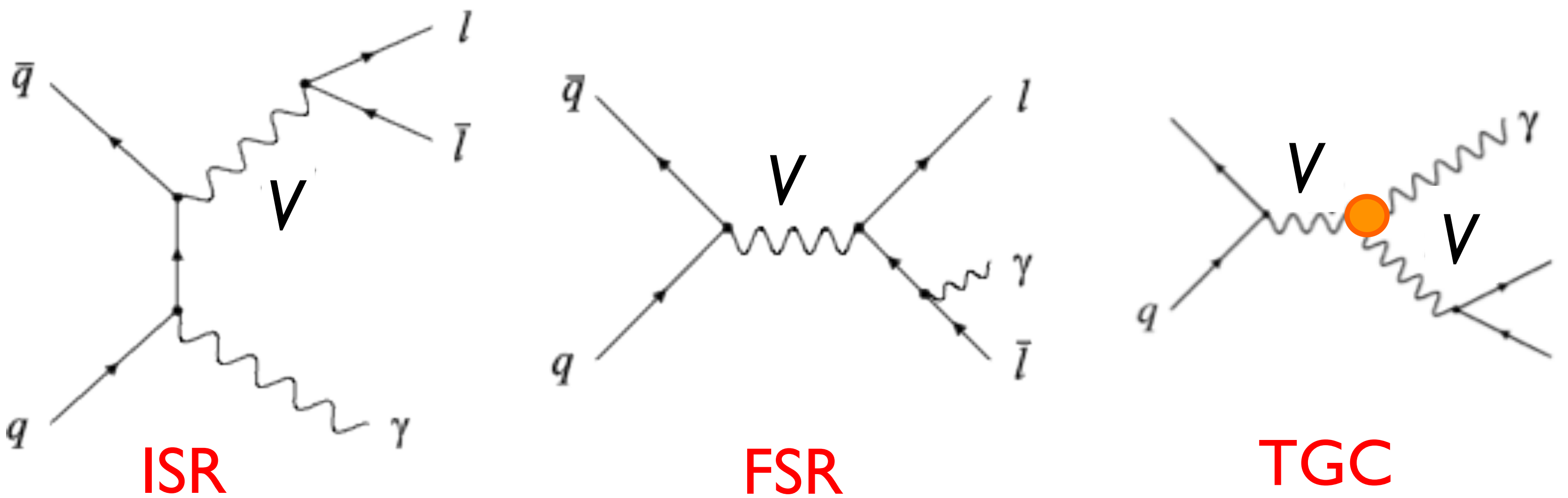
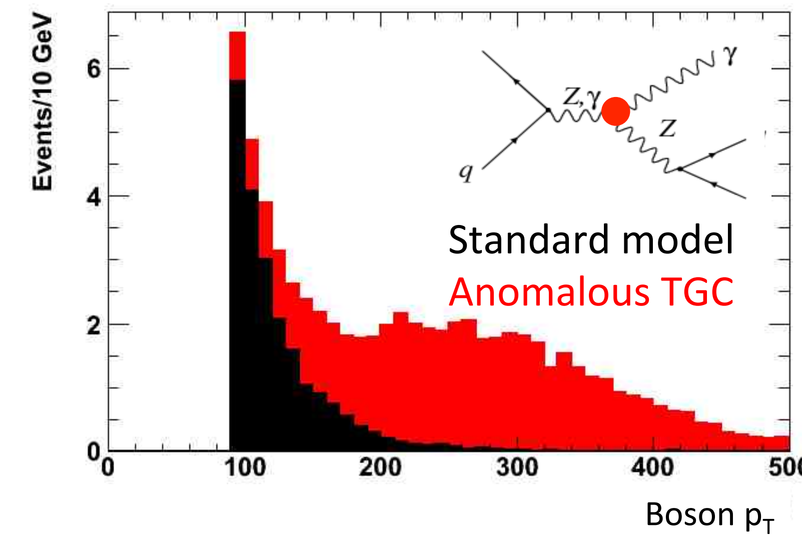
on behalf of the ATLAS and CMS collaborations

LHC Electroweak Working Group

Introduction

- Wγ and Zγ production supply a high statistics probe of associated and trilinear diboson production

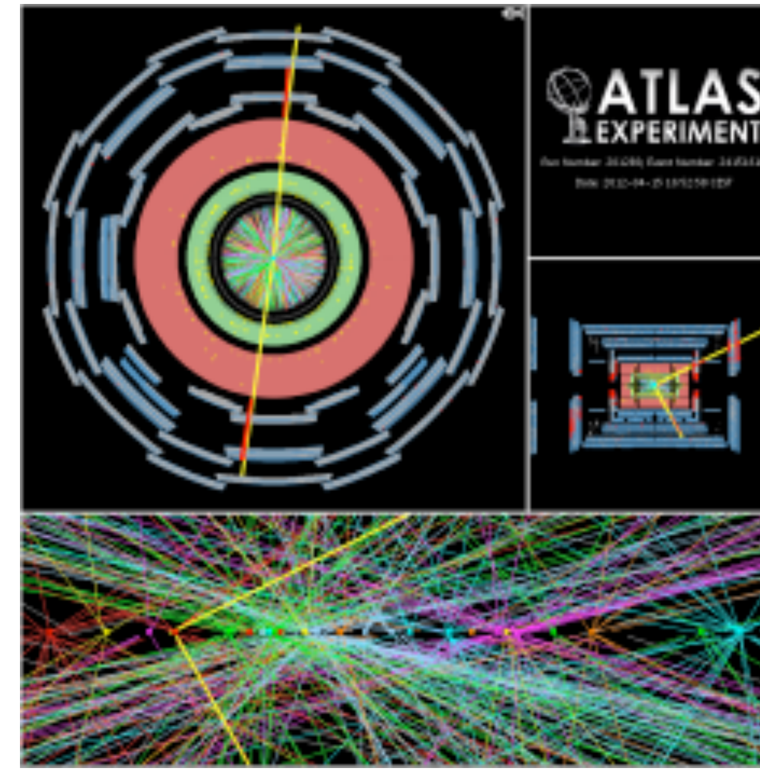




  - The values of triple gauge couplings (TGCs) are precisely predicted by SM $SU(2)_L x U(1)_Y$ symmetry
  - Use this to search for new physics in dibosons
    - General search for tree-level and loop effects of new physics
    - Many models predict excesses of dibosons: Technicolor, SUSY, Dark Matter, Extra Dimensions...
- Recent ATLAS and CMS results: arXiv:1302.1283, SMP-12-020, EWK-11-009
  - Cross sections and TGC limits using the lνγ, llγ, and ννγ final states at 7 TeV

Lepton Identification

- μ: Extrapolate muon system tracks to charged tracks in inner tracker
  - ATLAS: $|\eta| < 2.4$ and $p_T > 25$ GeV
  - CMS: $|\eta| < 2.1(2.4)$ and $p_T > 35(20)$ GeV for W(Z)
  - Resolution for muons below 200 GeV in p_T dominated by tracking resolution
    - 1-2%, depending on η, for both ATLAS and CMS



- e: Form electrons from ECAL clusters associated to tracks
  - ATLAS: $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$, $p_T > 25$ GeV
  - CMS: $|\eta| < 1.44$ or $1.57 < |\eta| < 2.5$, $p_T > 35(20)$ GeV for W(Z)
    - p_T resolution is typically 1-2% in barrel regions
- Standard selection criteria:
  - Isolation in $\Delta R < 0.3$ (0.4) for ATLAS (CMS); correction for pileup (PU)
  - Quality of track match, impact parameter, shower shape (electrons)

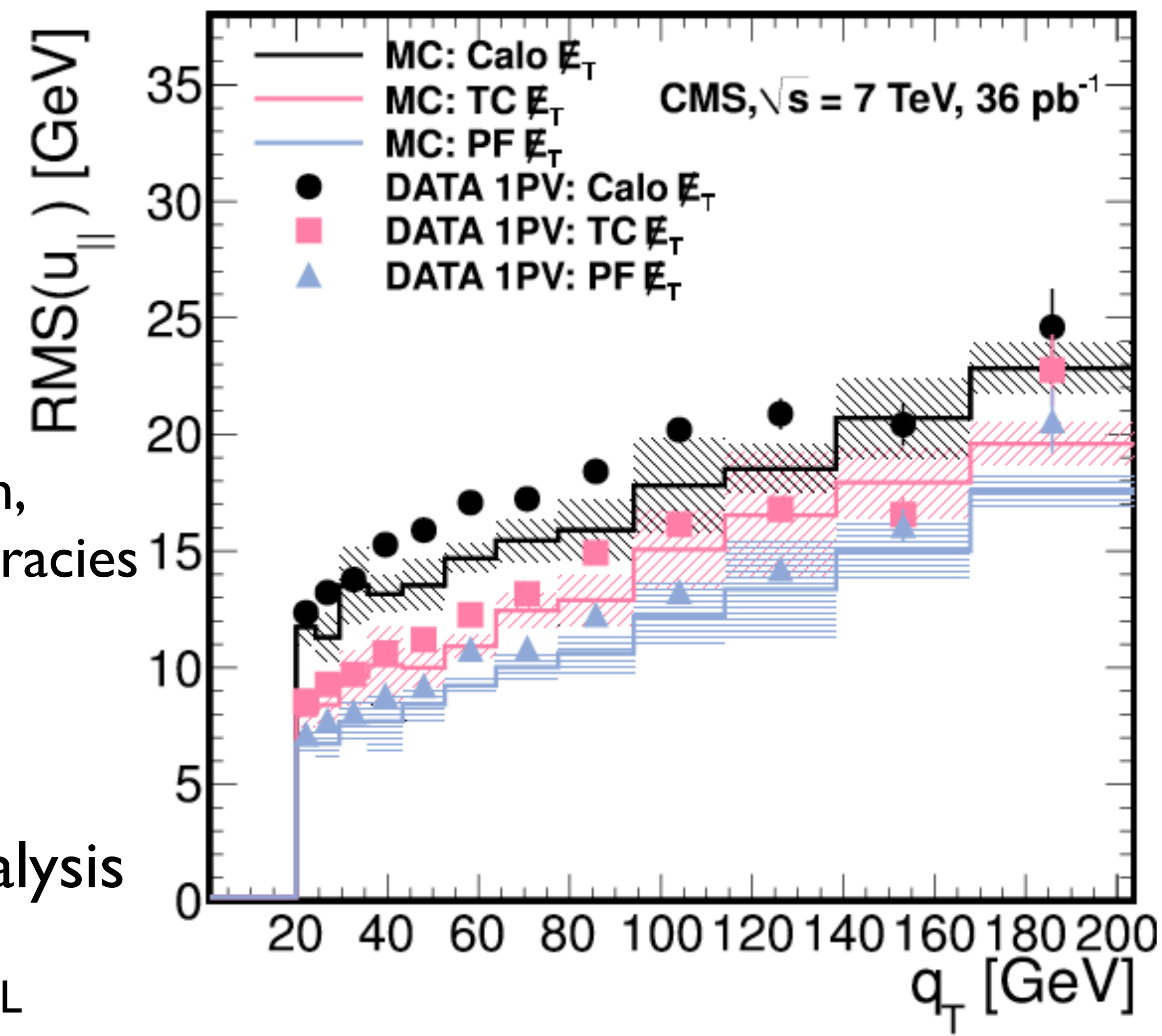
Missing Transverse Energy

ATLAS:

- Use vector sum of calorimeter cluster within $|\eta| < 4.9$ and reconstructed muon momenta
  - Clusters are corrected based on association to reconstructed objects (jets, taus, electrons, photons)
- MET > 40 GeV is required for lνγ analysis

CMS:

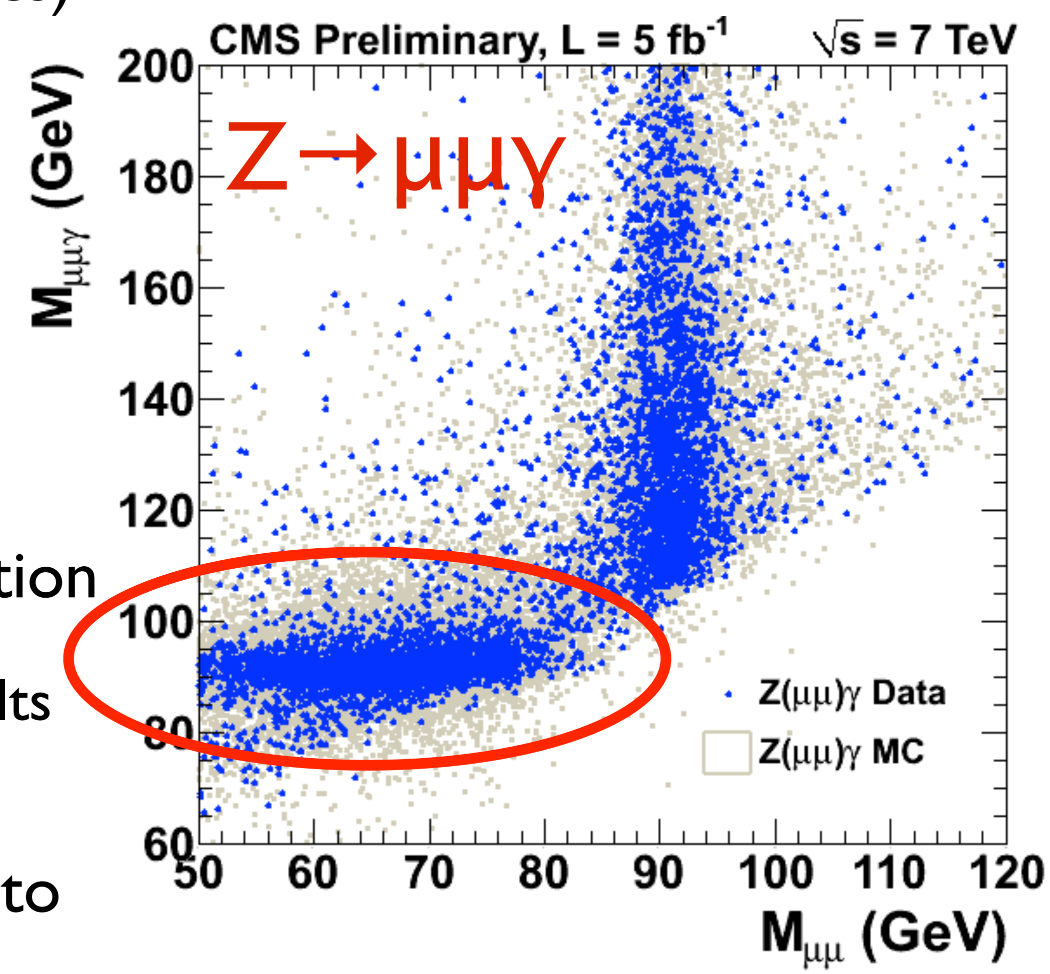
- Use 'Global Event Description' (Particle Flow)
  - Create exclusive lists of electron, muon, photons, hadrons, resolving any degeneracies
  - Resolution improved 2x over calorimeter only MET
- M_T(lepton,MET) > 70 GeV for lνγ analysis



Photon Identification

- Cluster of energy in ECAL, not consistent with prompt electron
  - lνγ and llγ: pT > 15 GeV, ΔR(γ,l) > 0.7
  - ννγ: pT > 100 GeV (ATLAS), pT > 145 GeV (CMS)
  - Selection criteria: isolation, shower shape, suppression of non-prompt backgrounds (beam-halo and cosmics)

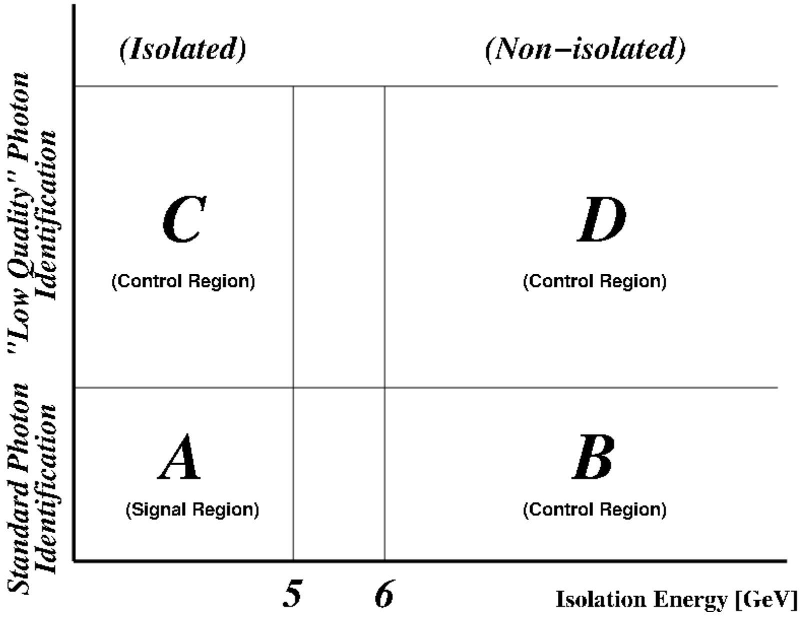
- Precise knowledge of photon energy scale is important for cross section measurement (steeply-falling pT spectra)
  - CMS: uses Z→μμγ to derive data-based estimate of photon energy scale and resolution
    - Exploiting the kinematics of μμγ system results in ~99% pure sample of genuine photons
  - Calibrate photon p_T response with respect to muon and track system

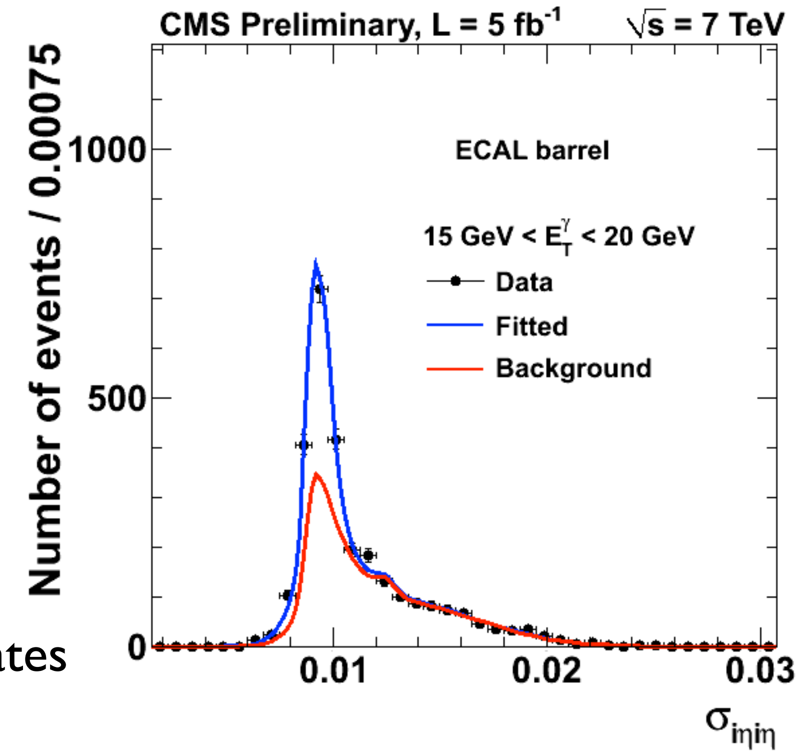


jet→γ Fake Rate Estimation

- W/Z + jets where a jet results in a reconstructed and identified photon are the primary background in both ATLAS and CMS analyses

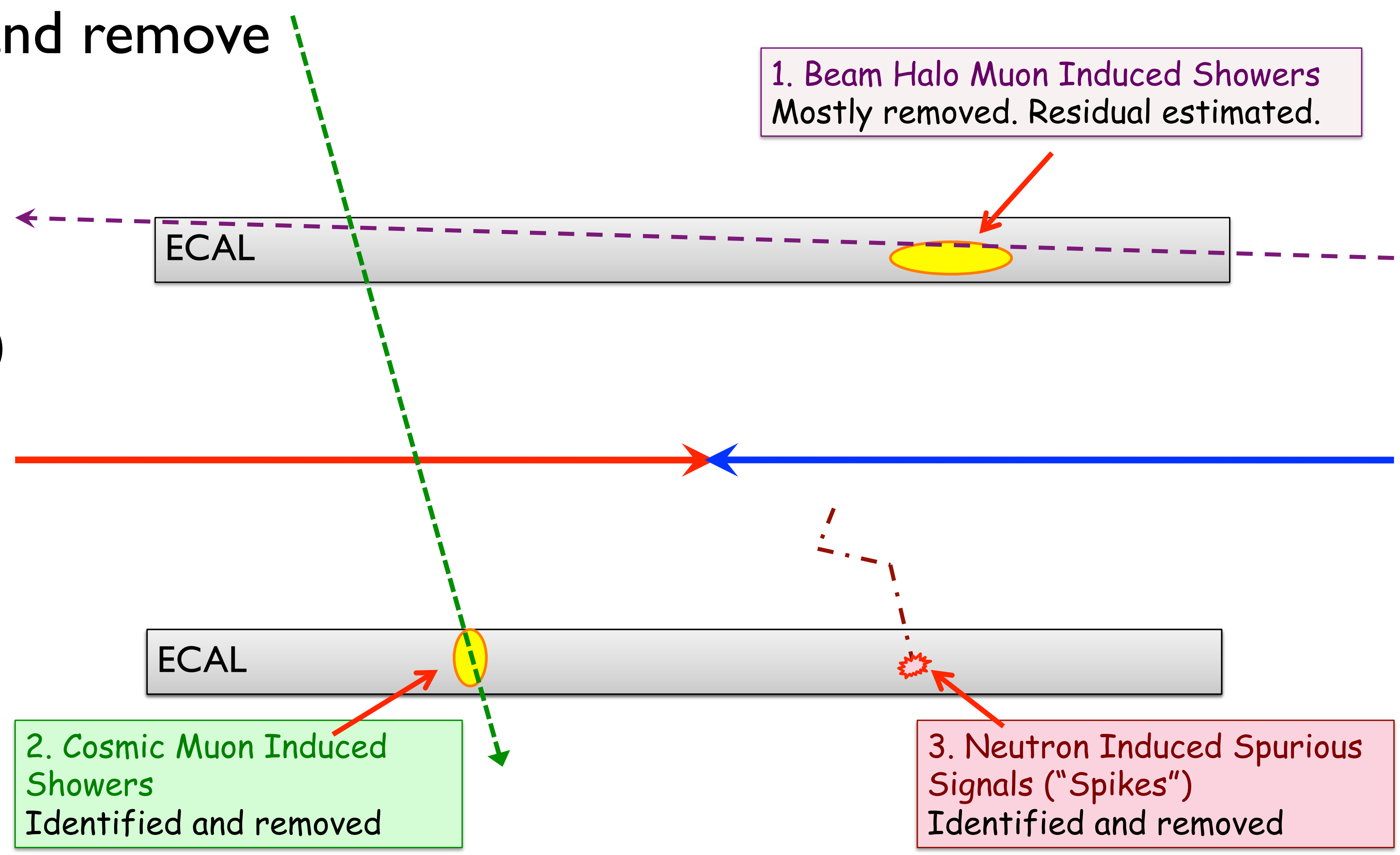
- Rates of this occurring are not well predicted in MC and data-based estimates must be used
  - ATLAS: infer background from three control regions using ID and isolation
  - CMS: employs two methods
    - Use η-width of the photon candidate estimated in data and confirmed with simulation to extract background
    - Use 2D template fitting method (η-width and isolation)
      - ➡ Estimation of systematics due to difference between quark and gluon misidentification rates





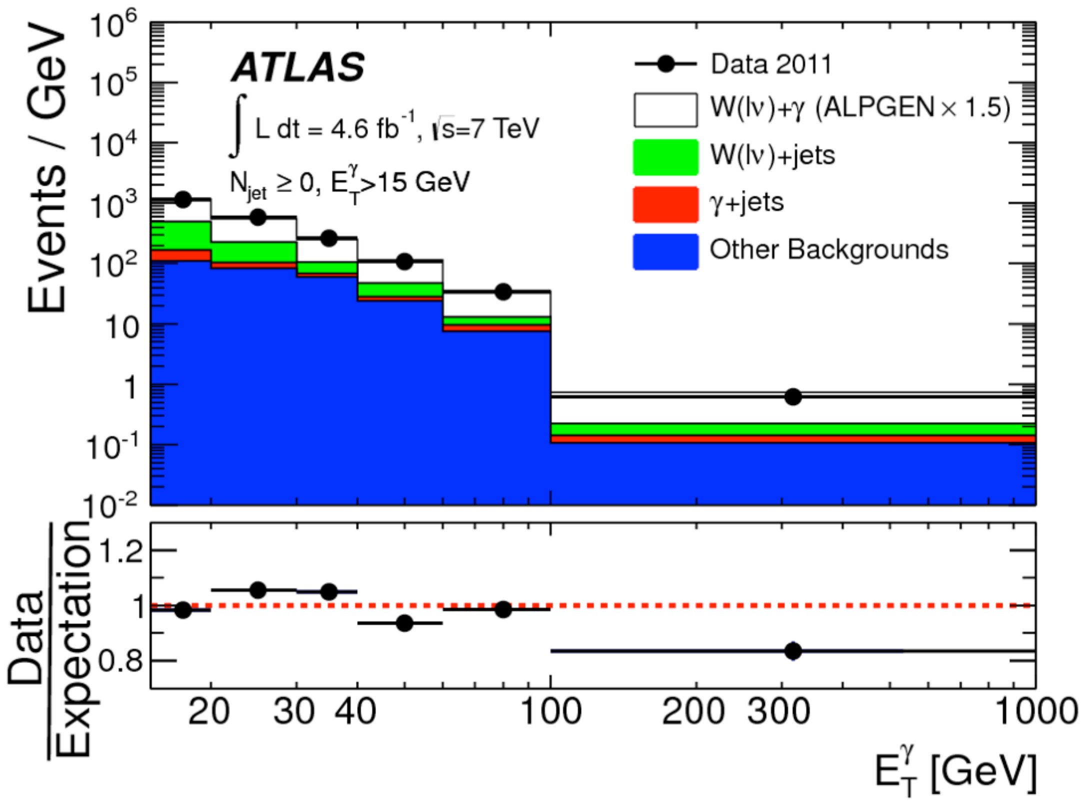
Additional Background Estimates

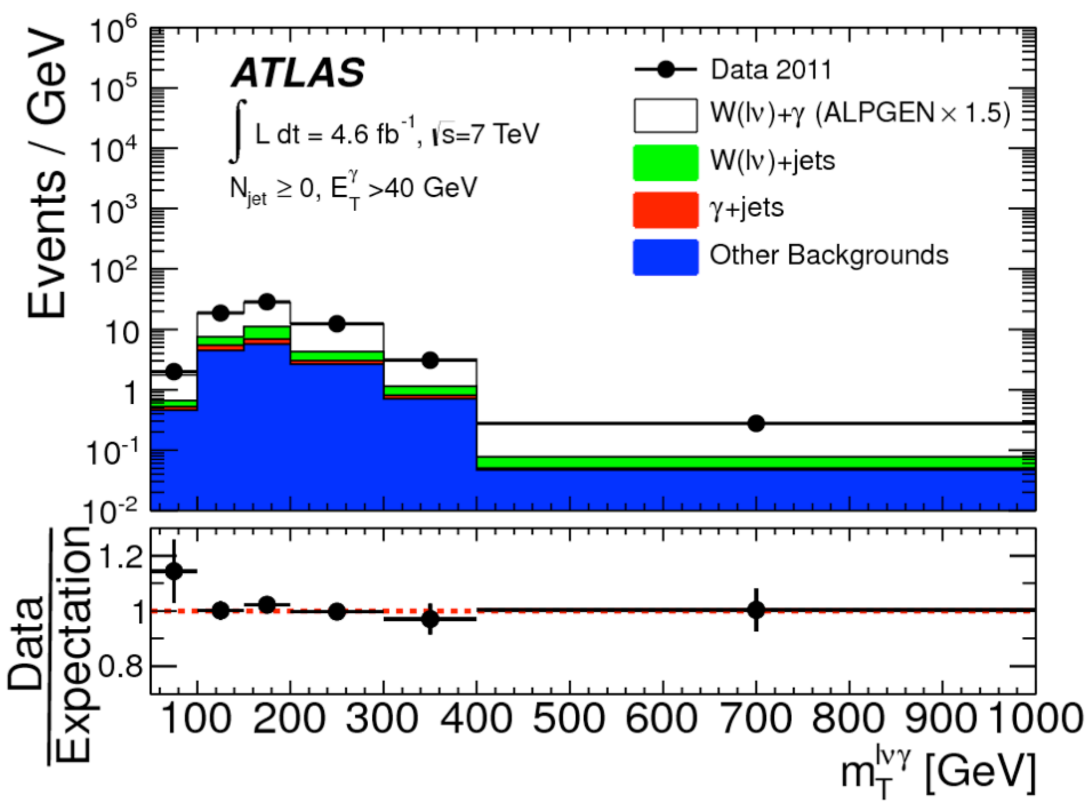
- e→γ misidentification (Wγ)
  - Measured in data using Z→ee process
- Non-prompt sources (beam-halo, cosmics, noise) are estimated from shower shape + muon information (Zγ→ννγ)
  - ATLAS: found to be negligible
  - CMS: use data to identify and remove
- γ+jets (Wγ)
  - ATLAS: use 2D sideband method (isolation vs. MET)
  - CMS: use simulation
- Other sources (All)
  - Top pairs, single top, diboson, are small and estimated from simulation



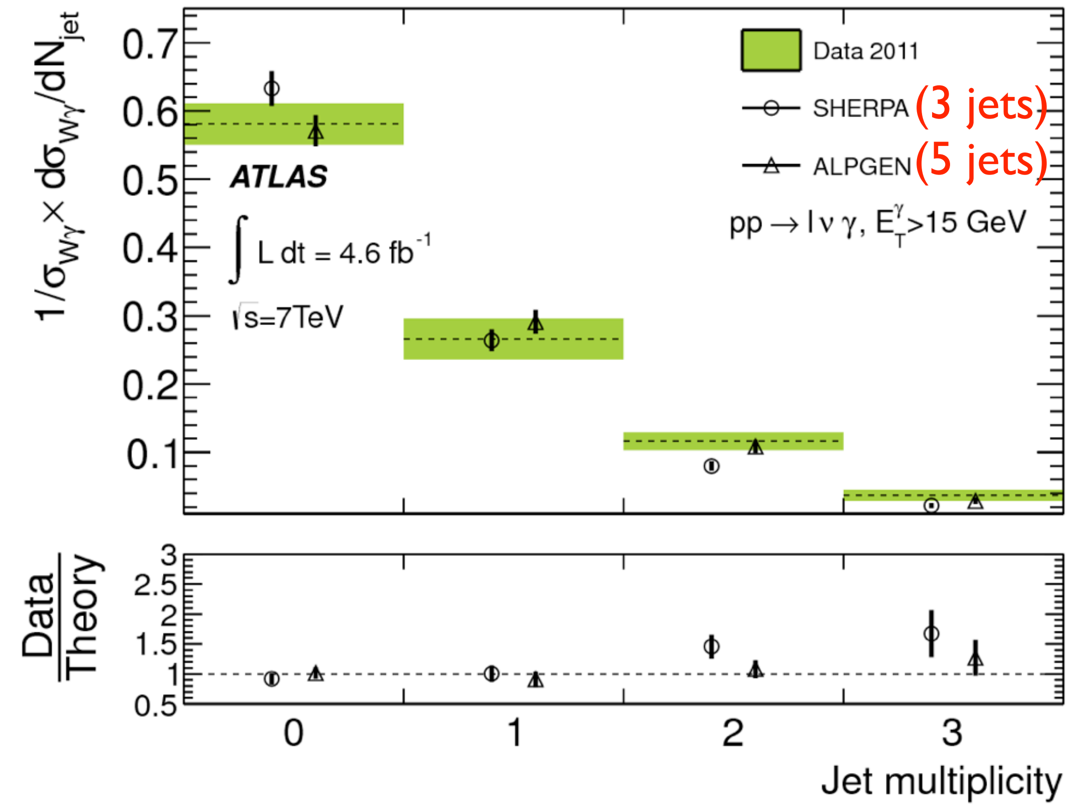
ATLAS Wγ Results

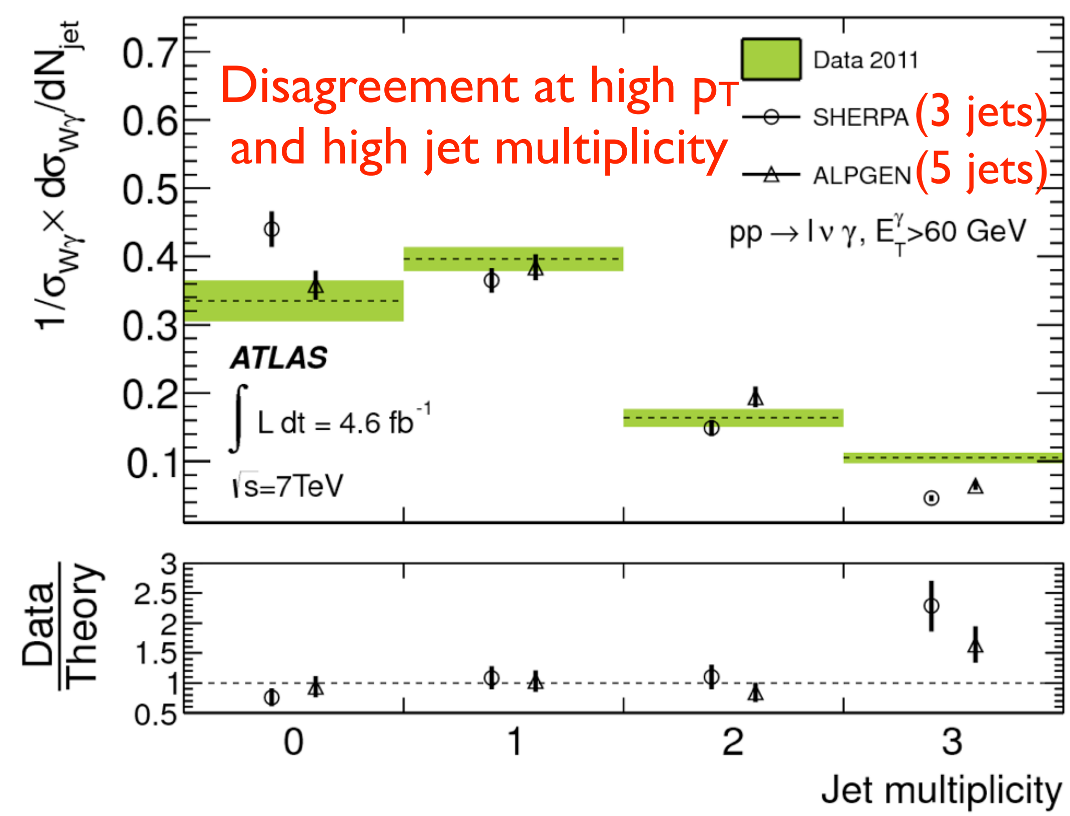
Inclusive



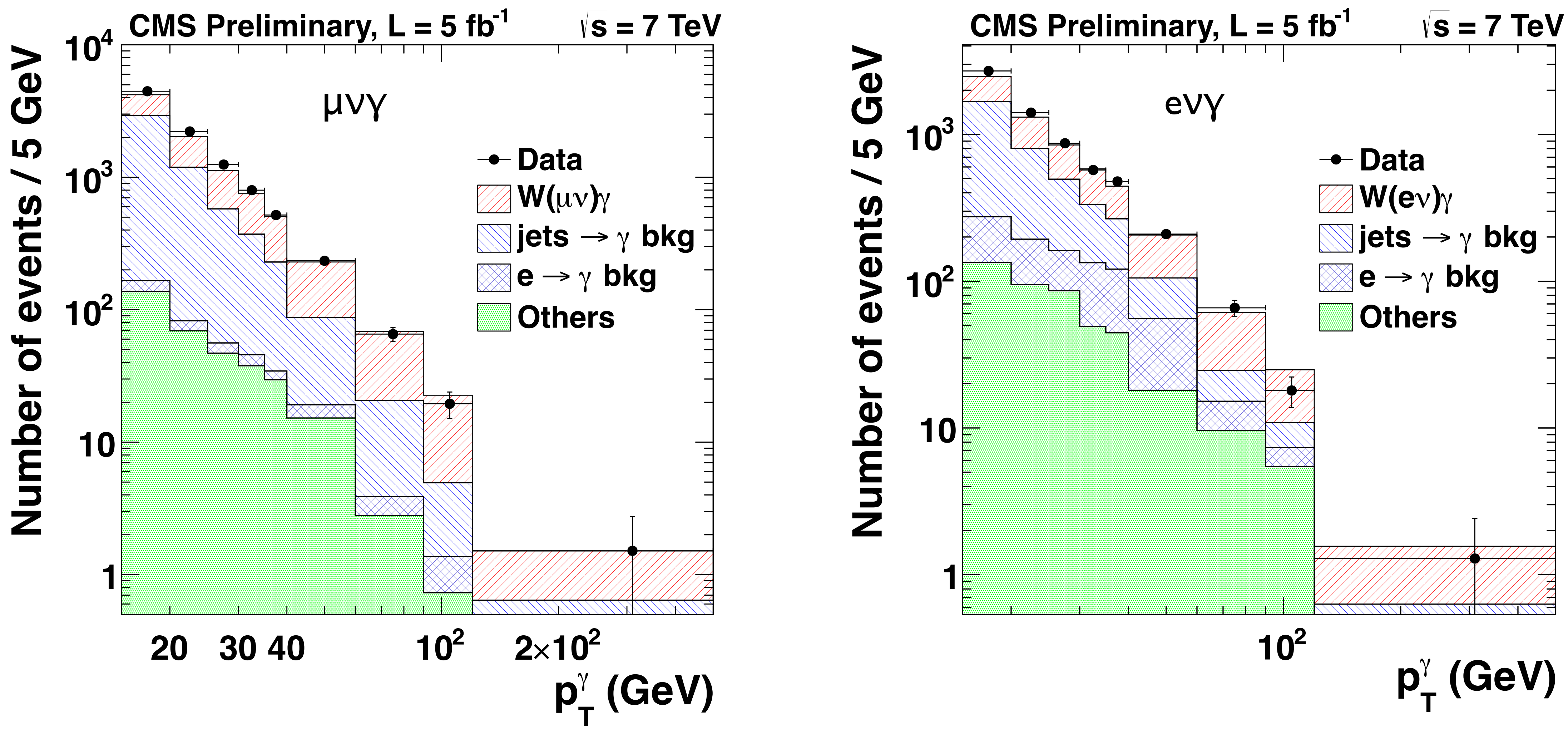


Exclusive



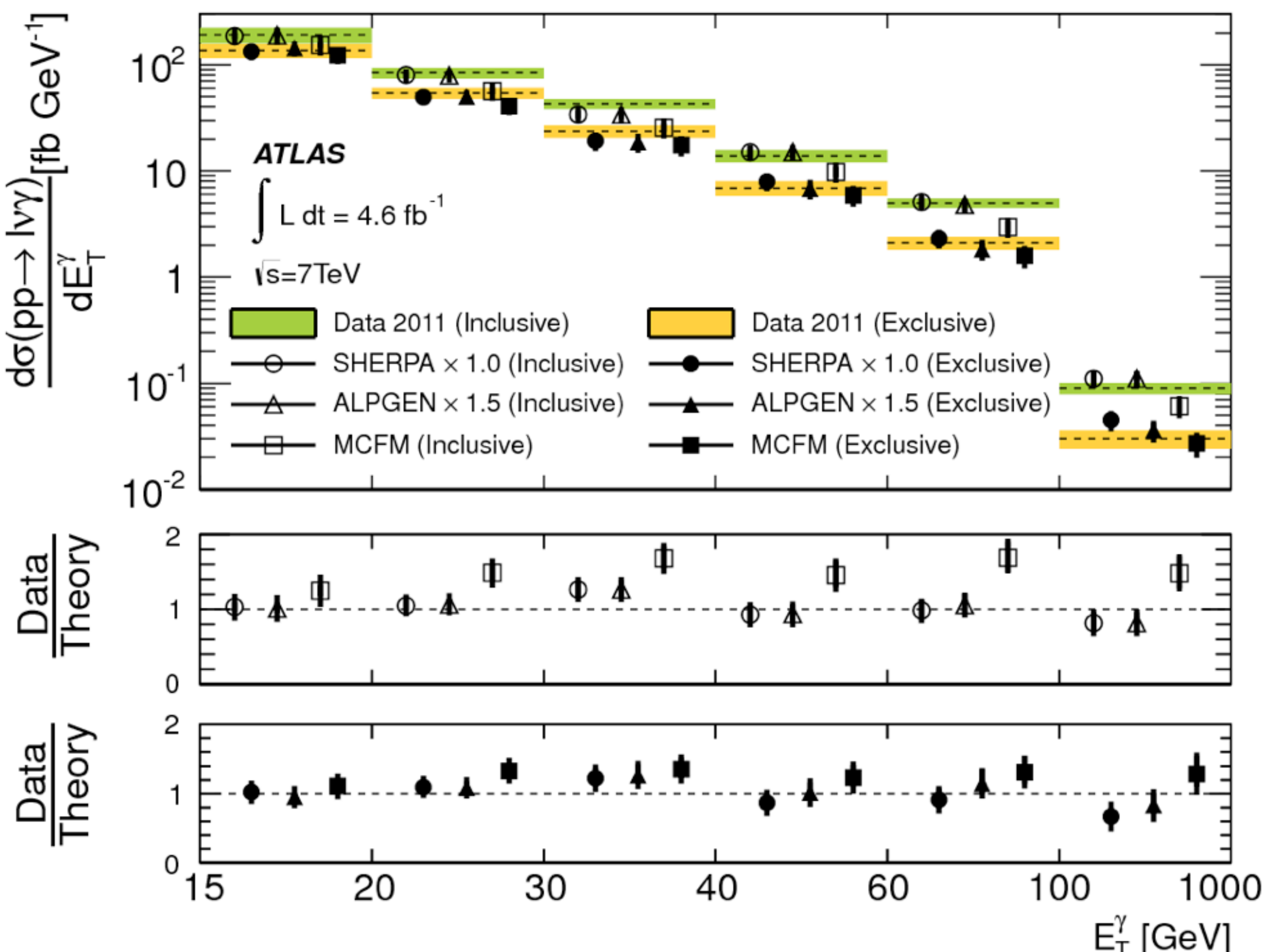


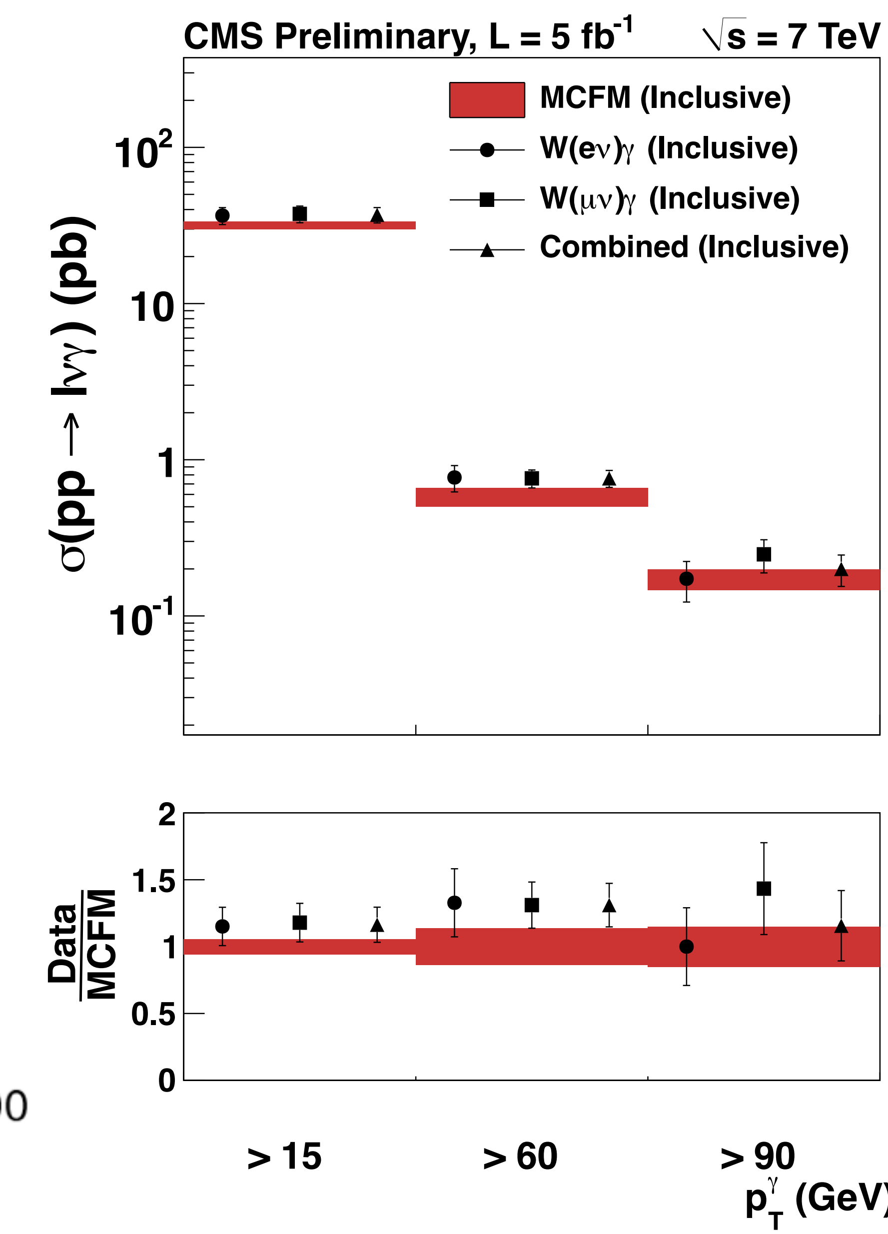
CMS Wγ Results



- Inclusive measurement only
  - MadGraph v5 inclusively matched with up to two jets is used for signal scaled to NLO prediction from MCFM

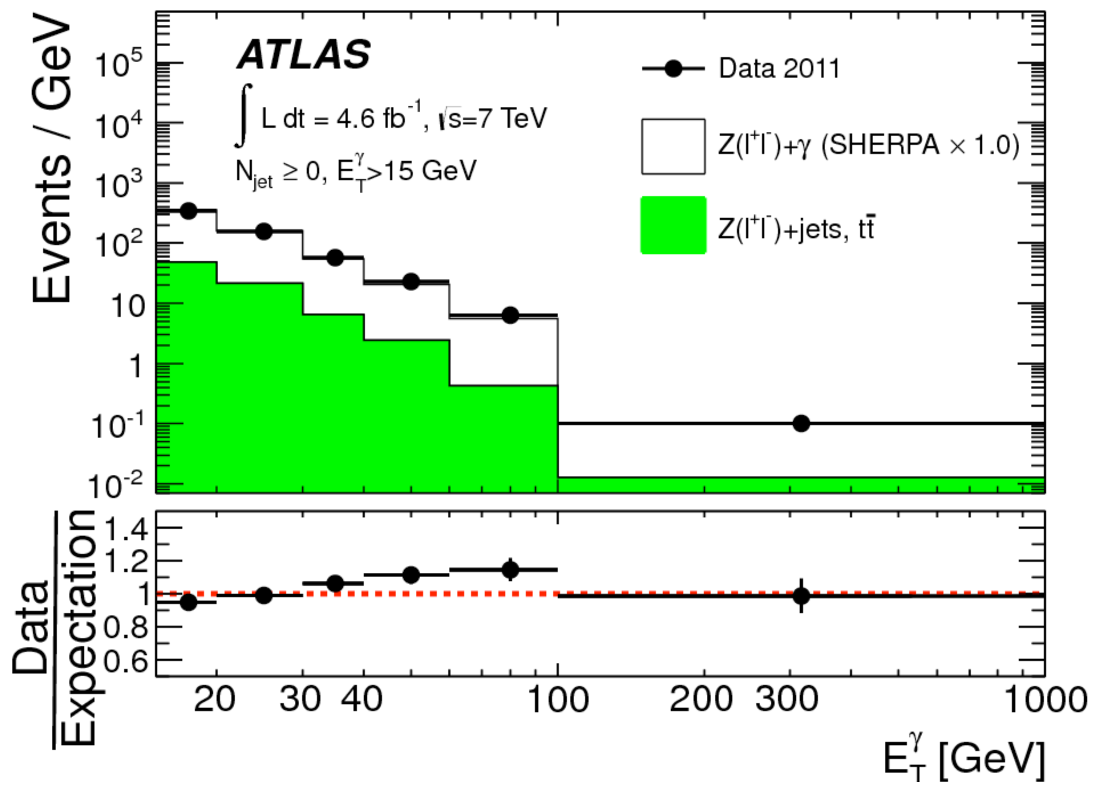
Wγ Results Summary

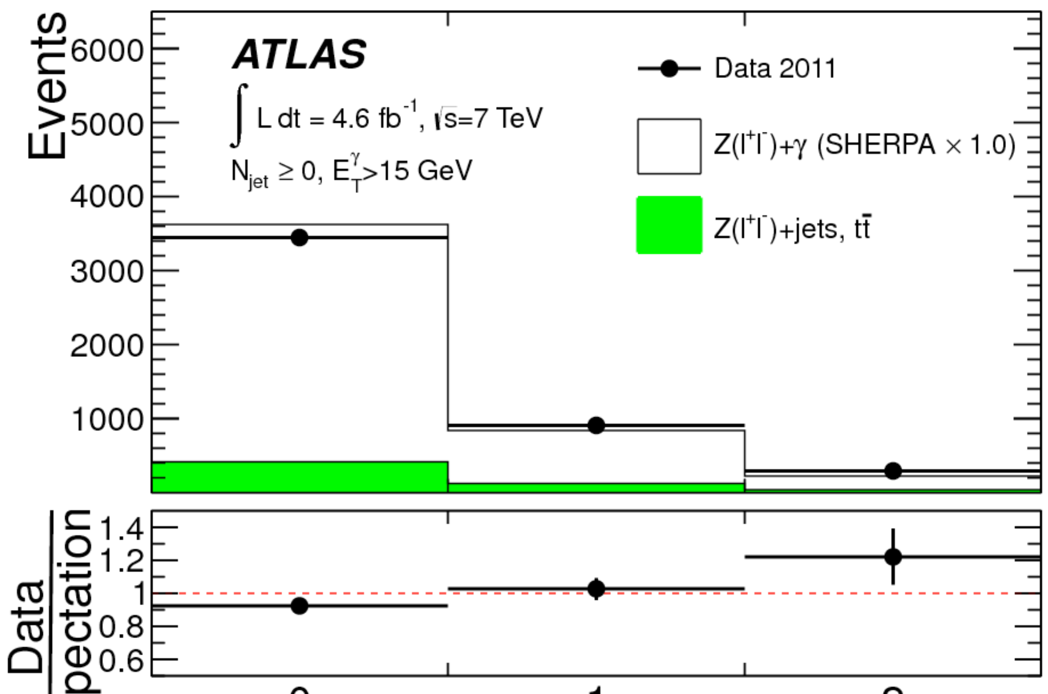




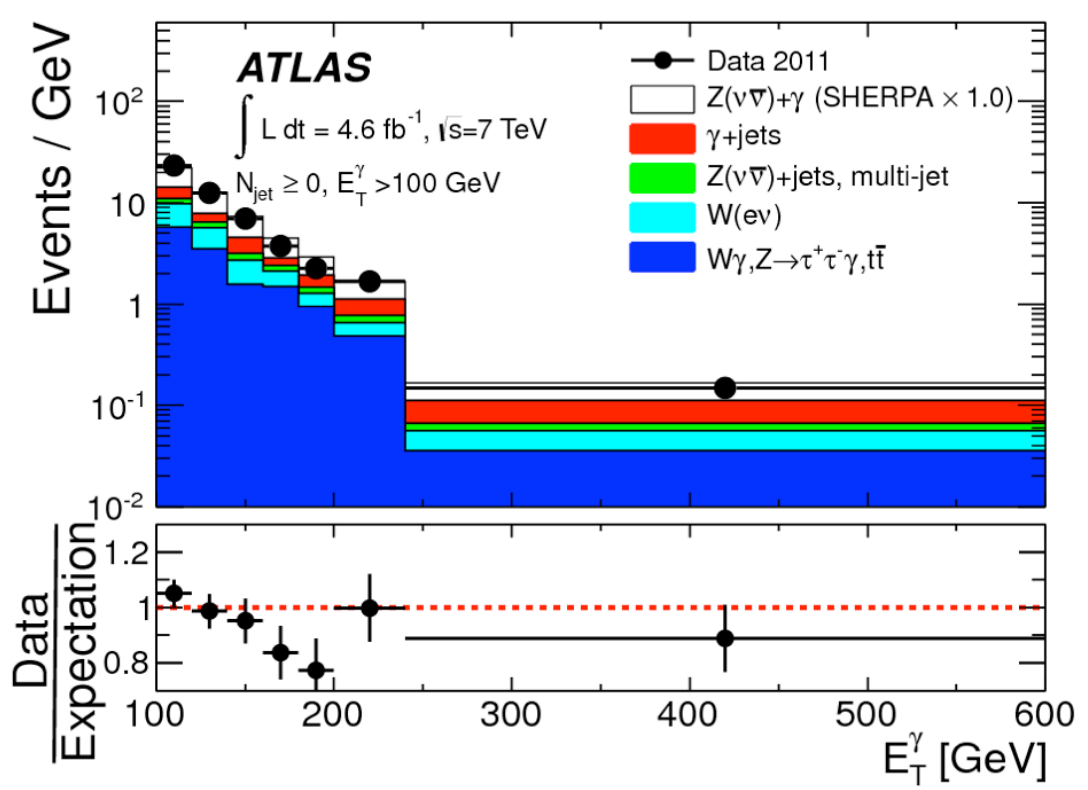
- Slight excess compared to MCFM seen by ATLAS
  - Increases with photon p_T and jet multiplicity
  - ATLAS results are given in the fiducial volume
- CMS finds a less pronounced excess
  - Errors are larger at lower p_T due to correlation of MET and fake-photon shower shape

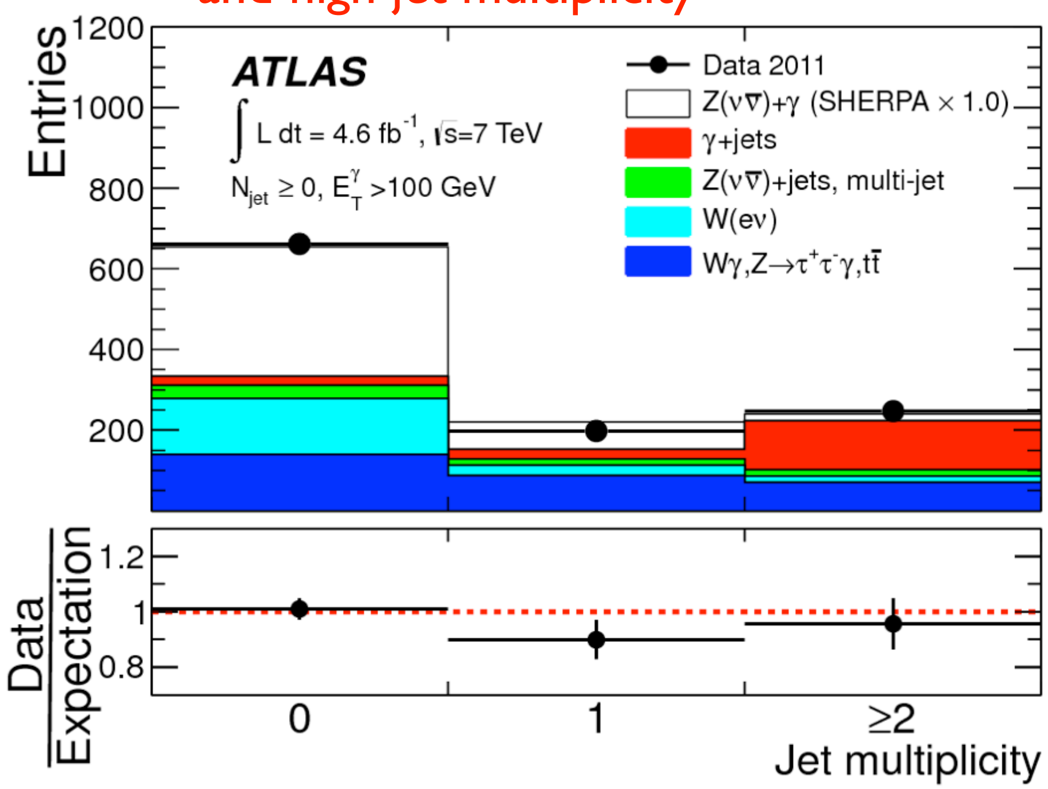
ATLAS Zγ Results





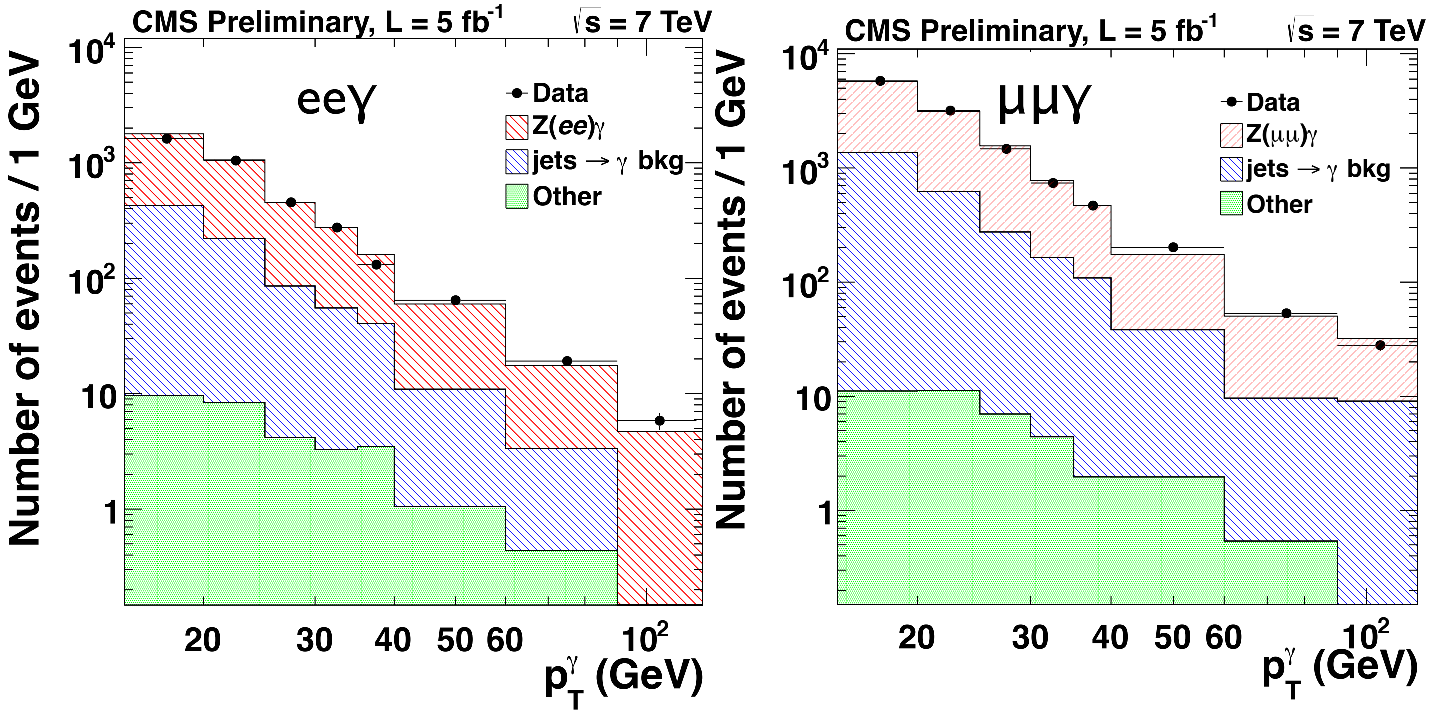
Less disagreement at high p_T and high jet multiplicity

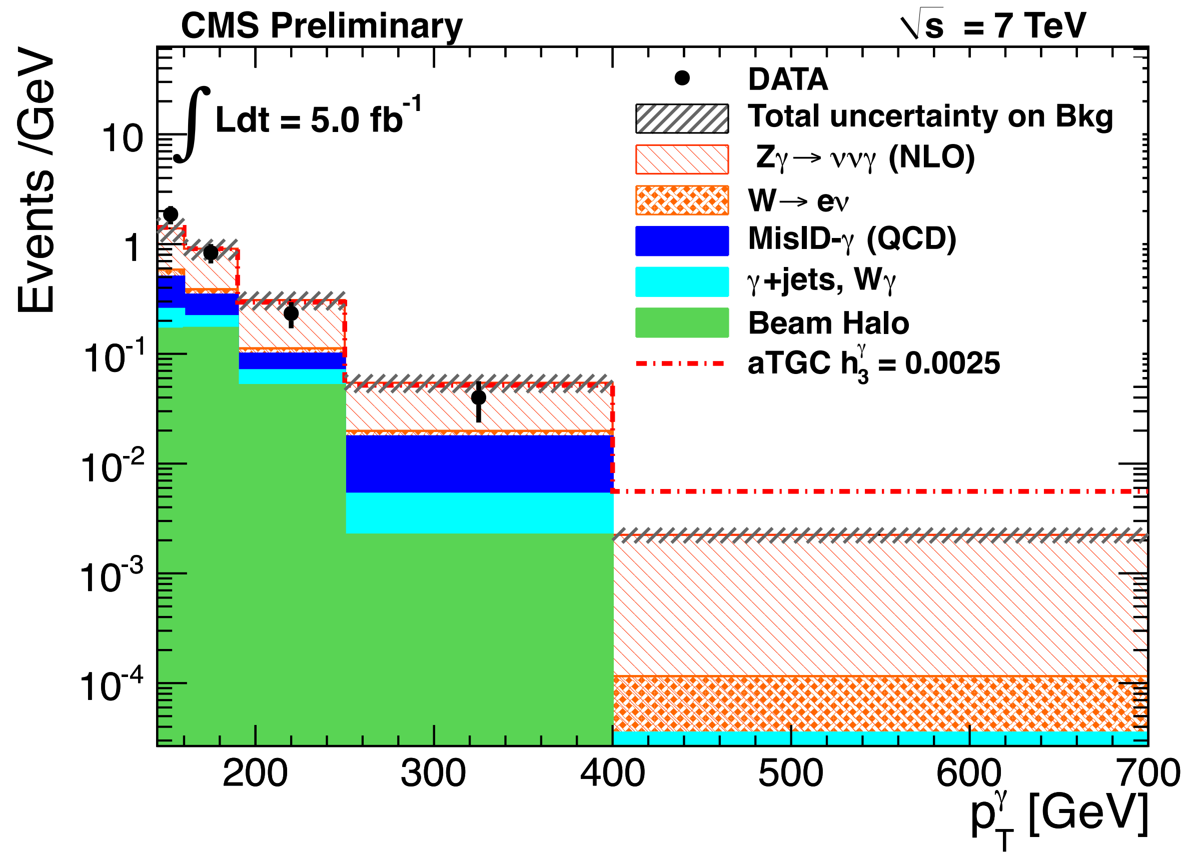




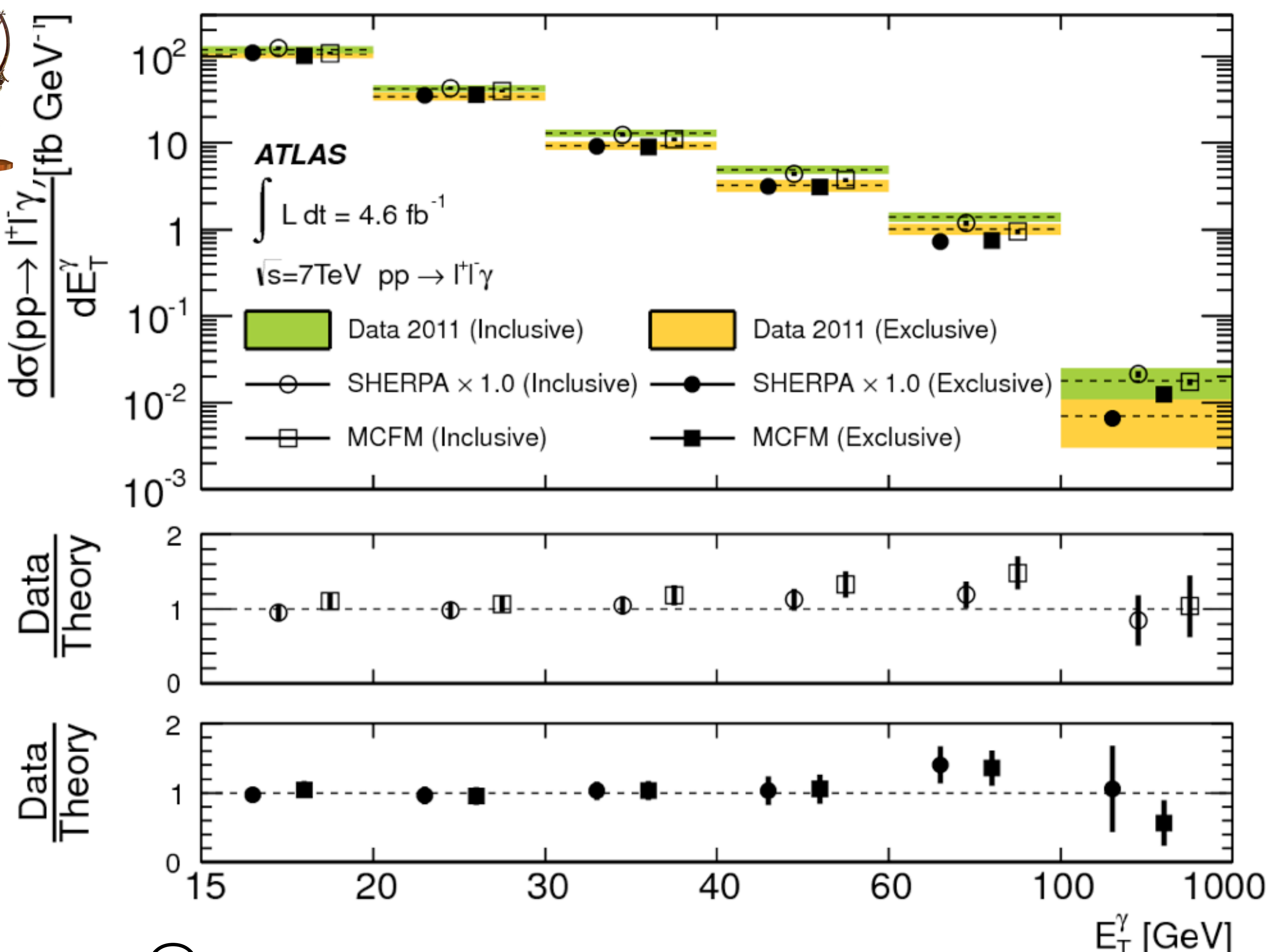
CMS Zγ Results

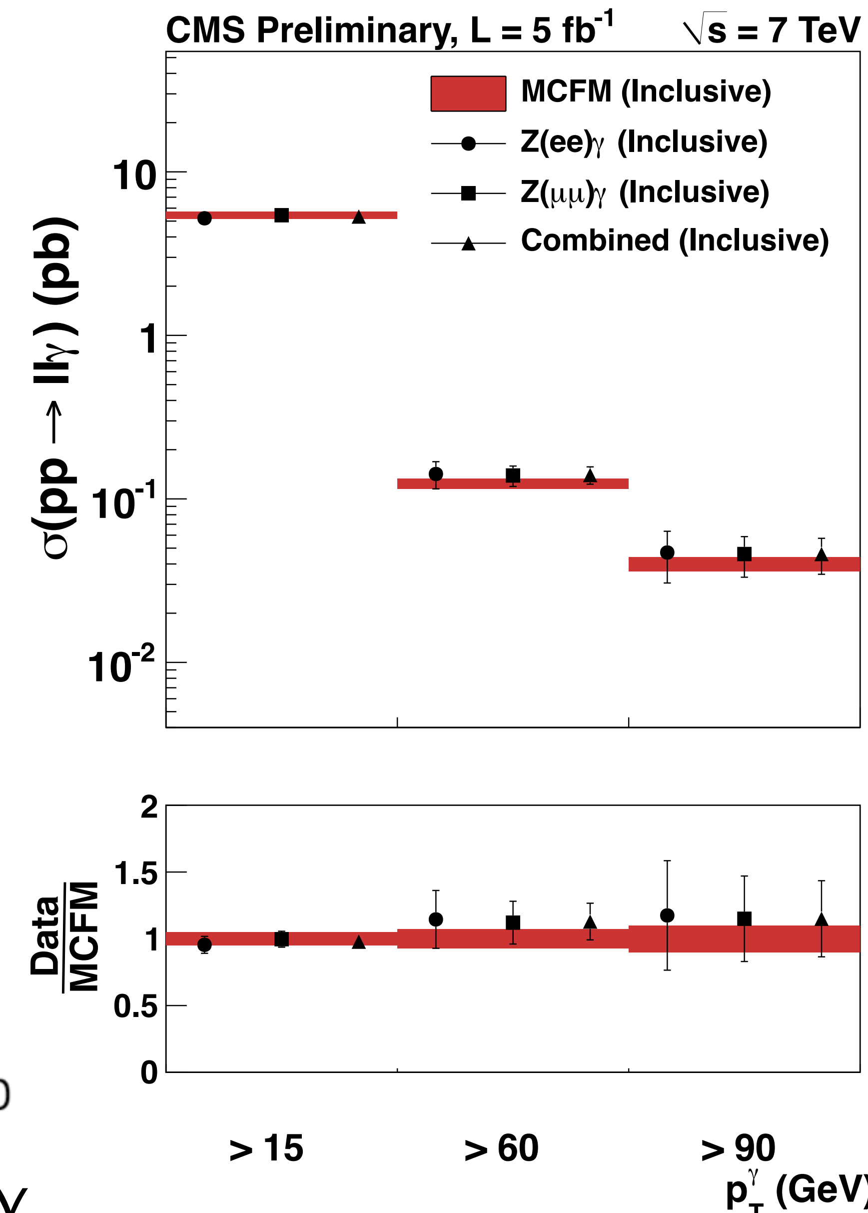
- Again CMS only has inclusive analysis
  - However, there is no observed jet multiplicity dependence by ATLAS





Zγ Results Summary





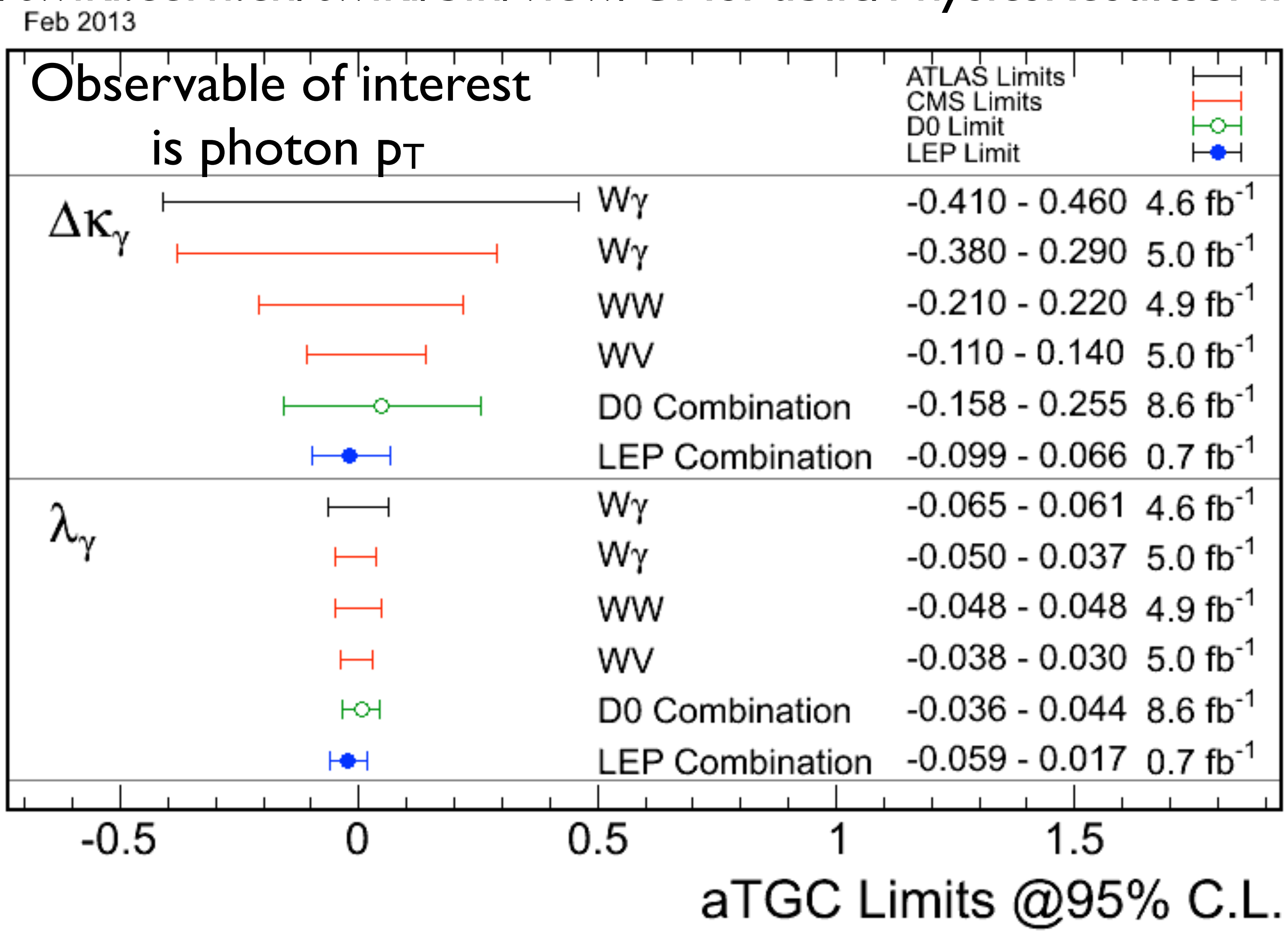
- Data to NLO simulation agreement better in Zγ
  - Higher p_T bins are statistically limited
  - Possibly similar trends to Wγ seen in inclusive analysis
  - CMS uses MadGraph (+up to 2 jets) acceptance extrapolation
  - ATLAS results are given in the fiducial volume

Limits on ATGCs Using Wγ

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC

Scales as $s^{1/2}$

Scales as s



- CMS and ATLAS Wγ limits roughly equivalent
  - CMS last p_T bin is 120 GeV, inclusive
  - ATLAS last p_T bin is 100 GeV, exclusive
- LEP combination exploits angular correlations

Limits on ATGCs Using Zγ

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC

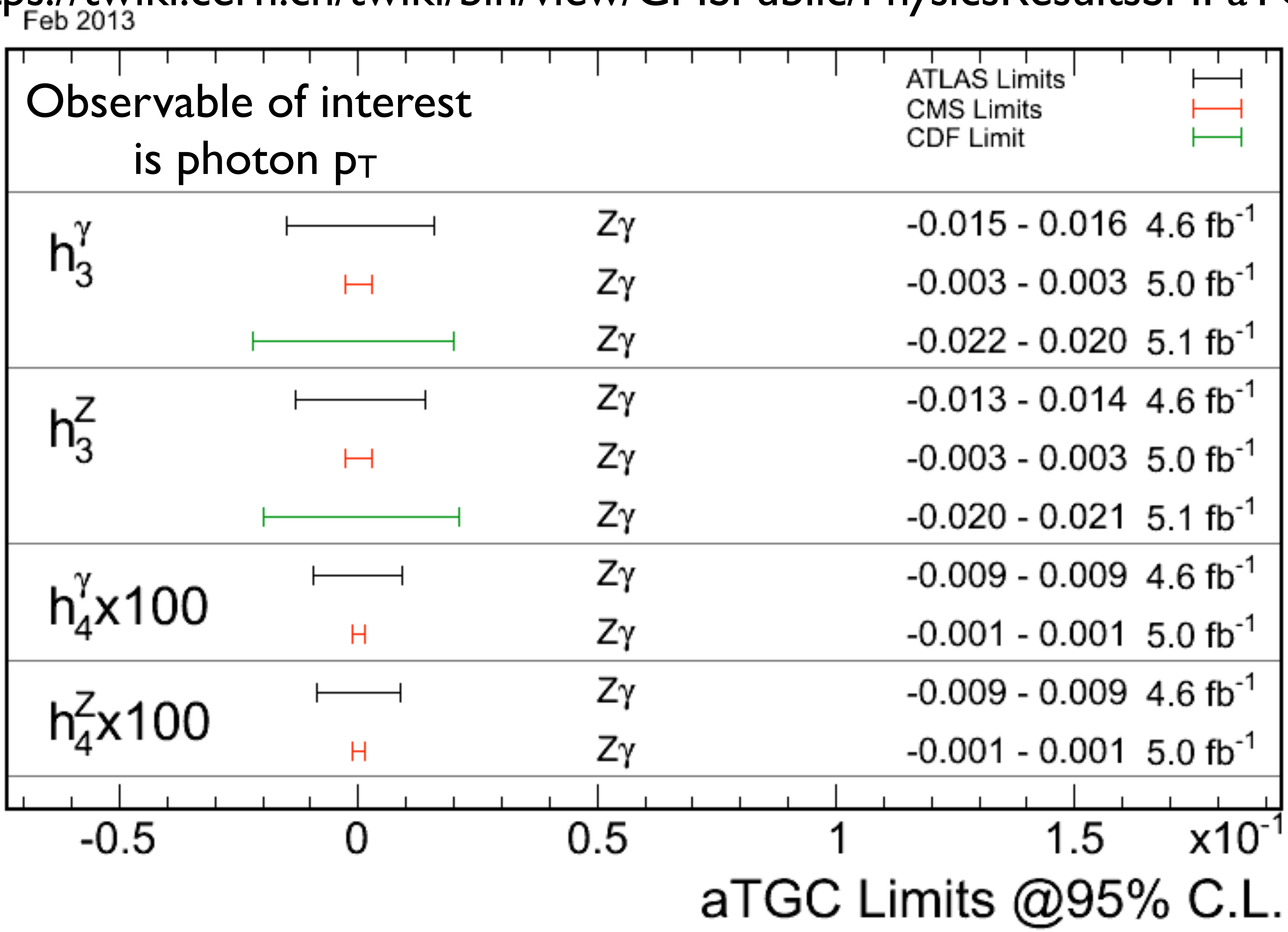
CDF limit uses form factor with Λ=1.5 TeV

Scales as s

Scales as s

Scales as s*p_T

Scales as s*p_T



- CMS Limits are tighter due to 400 GeV p_T threshold of last bin in the ννγ channel which drives the limit
  - Along with previous bins, heavily constrains shape and normalization.
- Cut for ATLAS analysis in ννγ and llγ final states is 100 GeV

Summary

- Both ATLAS and CMS have Wγ and Zγ results using the full 7 TeV dataset
- Wγ event sample is well populated, allowing for study of differential distributions
  - ATLAS studied jet multiplicity and p_T dependence of cross section
    - Excess over MCFM prediction at high p_T and multiplicity
    - ALPGEN(+5 jets) prediction matches data well in this region
  - CMS studied p_T dependence, observed similar behavior
- Zγ also in the regime of high statistics
  - ATLAS inclusive analysis shows similar trend to Wγ
    - Exclusive analysis removes MCFM disagreement in both cases
  - CMS analysis shows less disagreement with MCFM
- ATGC results from both experiments are similar where the p_T cuts used are similar
  - ATLAS sets ATGC limits using exclusive analysis
  - CMS limits more stringent in some cases due to exploitation of higher p_T bins

Backup

Cross Section Measurements

ATLAS

Cuts	$pp \to \ell\nu\gamma$	$pp \to \ell^+\ell^-\gamma$	$pp \to \nu\bar{\nu}\gamma$
Lepton	$p_T^\ell > 25$ GeV	$p_T^\ell > 25$ GeV	—
	$\|\eta_\ell\| < 2.47$	$\|\eta_\ell\| < 2.47$	—
	$N_\ell = 1$	$N_{\ell^+} = 1, N_{\ell^-} = 1$	$N_\ell = 0$
	$p_T^\nu > 35$ GeV	—	—
Boson	—	$m_{\ell^+\ell^-} > 40$ GeV	$p_T^{\nu\bar{\nu}} > 90$ GeV
Photon	$E_T^\gamma > 15$ GeV	$E_T^\gamma > 15$ GeV	$E_T^\gamma > 100$ GeV
	$\|\eta^\gamma\| < 2.37, \Delta R(\ell,\gamma) > 0.7$		
	$\epsilon_h^p < 0.5$		
Jet	$E_T^{\rm jet} > 30$ GeV, $\|\eta^{\rm jet}\| < 4.4$		
	$\Delta R(e/\mu/\gamma, {\rm jet}) > 0.3$		
	Inclusive : $N_{\rm jet} \geq 0$, Exclusive : $N_{\rm jet} = 0$		

When defining the fiducial acceptance ATLAS uses dressed leptons

		MCFM
$\ell\nu\gamma$	2.77 ± 0.03 (stat) ± 0.33 (syst) ± 0.14 (lumi) pb	1.96 ± 0.17 pb
$\ell^+\ell^-\gamma$	1.31 ± 0.02 (stat) ± 0.11 (syst) ± 0.05 (lumi) pb	1.18 ± 0.05 pb
$\nu\bar{\nu}\gamma$	0.133 ± 0.013 (stat) ± 0.020 (syst) ± 0.005 (lumi) pb	0.156 ± 0.012 pb

CMS

Cuts	$pp \to \ell\nu\gamma$	$pp \to \ell^+\ell^-\gamma$	$pp \to \nu\bar{\nu}\gamma$
hline Boson	—	$m_{\ell^+\ell^-} > 50$ GeV	$p_T^{\nu\bar{\nu}} > 130$ GeV
Photon	$E_T^\gamma > 15$ GeV	$E_T^\gamma > 15$ GeV	$E_T^\gamma > 145$ GeV, $\|\eta\| < 1.4$
	$\Delta R(\ell,\gamma) > 0.7$		
	$\epsilon_h^\gamma < 0.5$		

CMS extrapolates the acceptance to the full lepton phase space using shower MG5 + up to 2 jet events

		MCFM
$\ell\nu\gamma$	37.0 ± 0.8 (stat) ± 4.0 (syst) ± 0.8 (lumi) pb	31.8 ± 1.8 pb
$\ell^+\ell^-\gamma$	5.33 ± 0.08 (stat) ± 0.25 (syst) ± 0.12 (lumi) pb	5.45 ± 0.27 pb
$\nu\bar{\nu}\gamma$	0.021 ± 0.004 (stat) ± 0.004 (syst) ± 0.001 (lumi) pb	0.022 ± 0.001 pb

Further ATLAS Wγ Results