Measurement of Wγ/Zγ production at ATLAS and associated constraints on new physics

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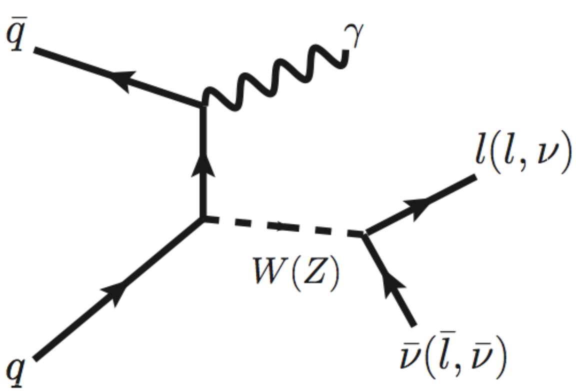
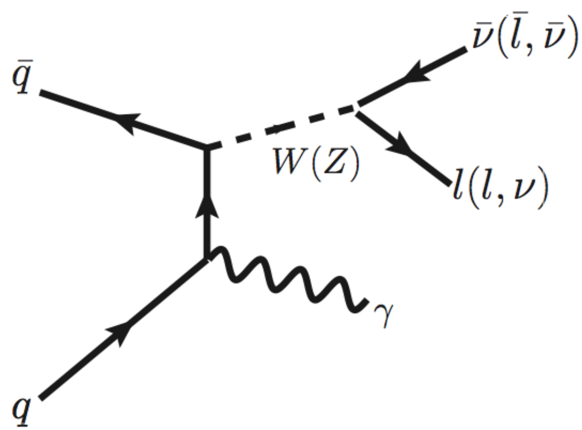
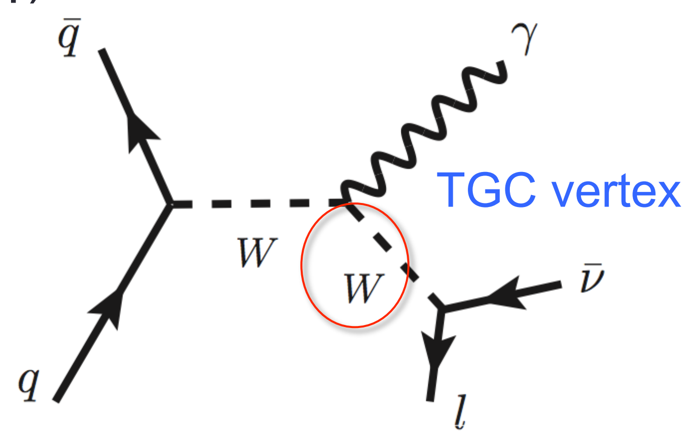
On behalf of the ATLAS Collaboration

Introduction

- Diboson production cross-section measurements
  - Test of SM electroweak theory and perturbative QCD at TeV scale
  - Irreducible SM background to Higgs (Zγ)
  - Sensitivity to new particles decaying to dibosons (Technicolor, Little Higgs, SUSY, etc...)
- Anomalous Triple Gauge Couplings (aTGC)
  - Vector boson self-couplings fundamental prediction of the Electroweak Sector of SM
  - aTGC modify total cross sections and kinematics
  - neutral TGC not allowed in the SM (ZZZ, ZZγ)

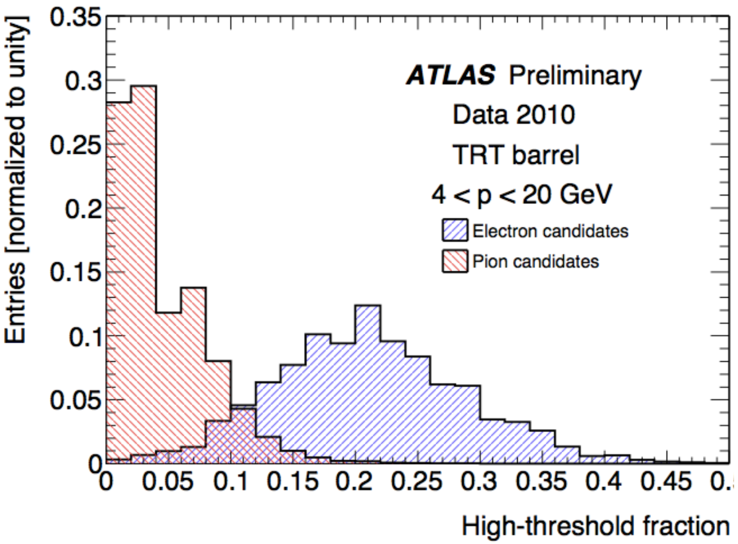


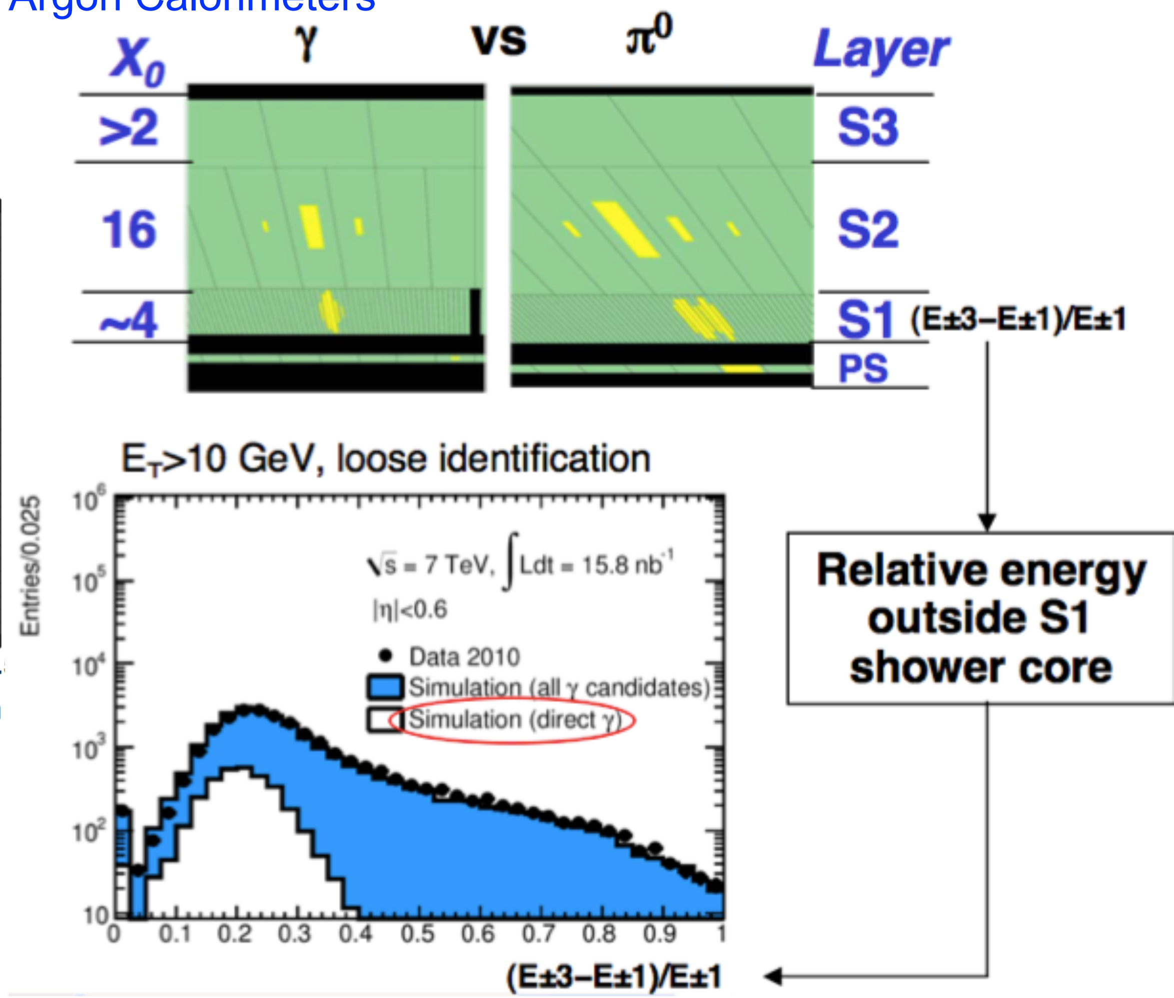




ATLAS electron and photon identification

- Photon identification
  - Use EM shower shape in Liquid Argon Calorimeters
- Electron identification
  - Use high threshold hits in Transition Radiation Tracker (TRT)
  - Use EM shower shape in Liquid Argon Calorimeters





Event selection

- Zγ ($l^+l^-γ$) Selection highlight
  - 2 high p_T leptons with pT>25GeV
  - $M(l^+,l^-)$>40 GeV
  - One isolated photon with E_T>15GeV
  - Major background
    - Z+jet : jet faking photon

- Wγ (lνγ) Selection highlight
  - One high pT lepton with p_T>25GeV
  - E_T^{miss}>35 GeV
  - One isolated photon with E_T>15GeV
  - Major background
    - W+jet : jet faking photon
    - γ+jet: jet faking lepton

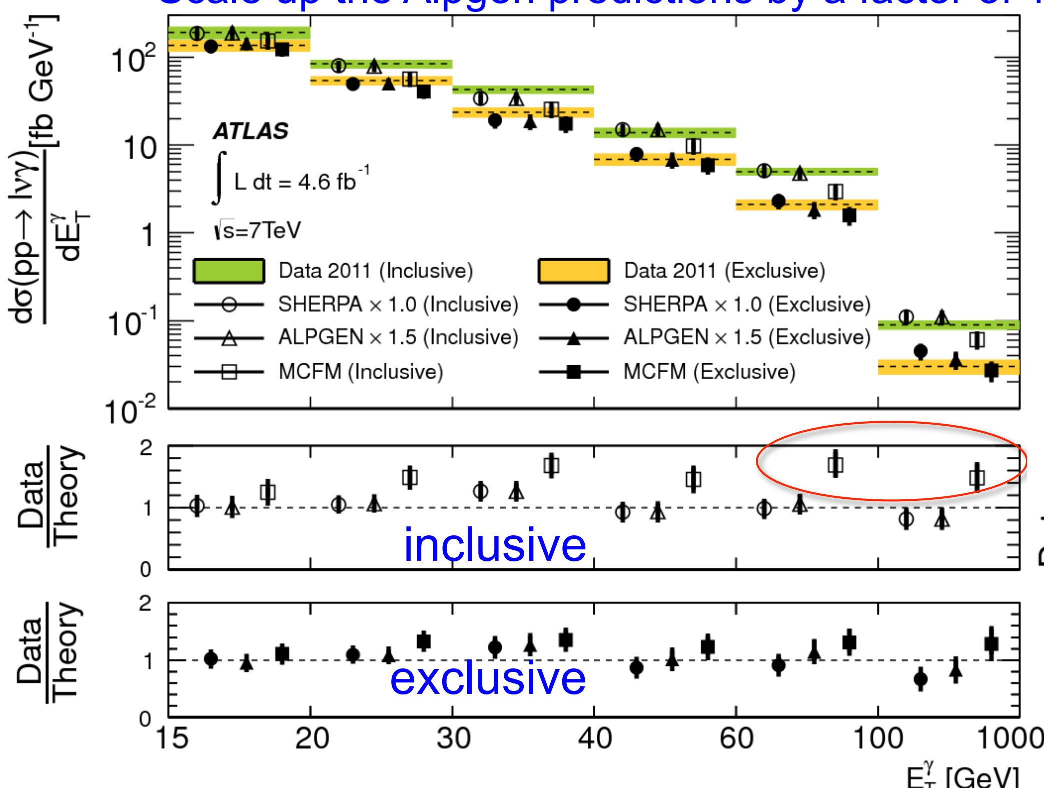
l=e,μ

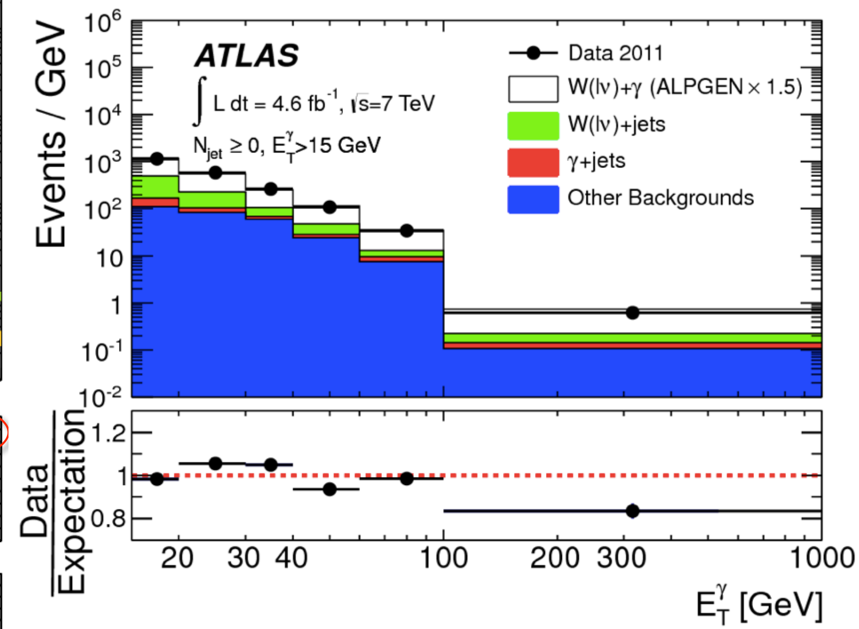
- Zγ (ννγ) Selection highlight
  - E_T^{miss}>90GeV
  - One isolated photon with E_T>100GeV
  - Veto event with good lepton
  - Major background
    - Z(νν)+jet : jet faking photon
    - W+jet : electron faking as photon
    - Wγ

Latest ATLAS Vγ publication:
4.6 fb^{-1}, 7 TeV
arXiv:**1302.1283**
Accepted by PRD

Wγ (lνγ): photon E_T spectrum

- Unfolded Photon E_T measurement compared to MCFM Wγ NLO predictions
  - Discrepancy in high E_T for inclusive measurement (without jet veto)
  - Agreement is improved for exclusive measurement (with jet veto)
- Data compared to Sherpa/Alpgen predictions (Wγ+ N partons LO predictions)
  - Very good agreement in event kinematics
    - Scale up the Alpgen predictions by a factor of 1.5 to match data.

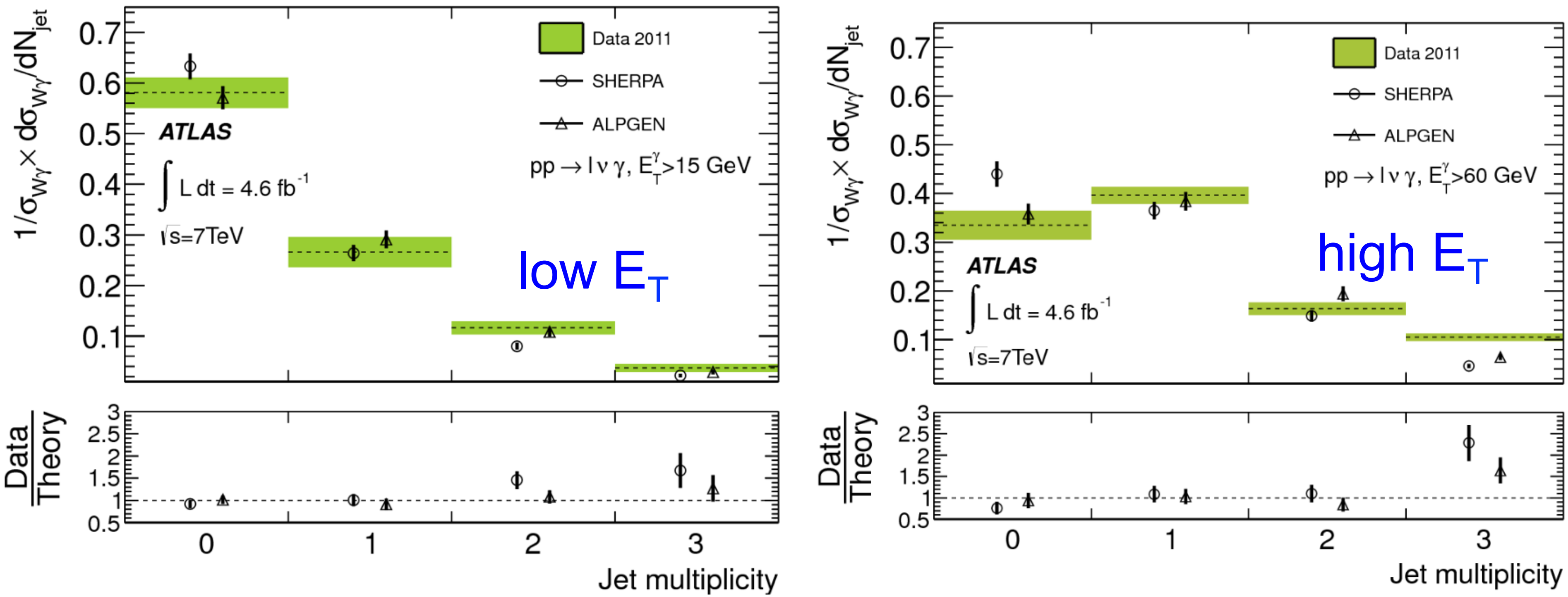




Sherpa :Matrix element calculation for Wγ+0/1/2/3 partons
Alpgen: Matrix element calculation for Wγ+0/1/2/3/4/5 partons

Wγ (lνγ): Jet multiplicity

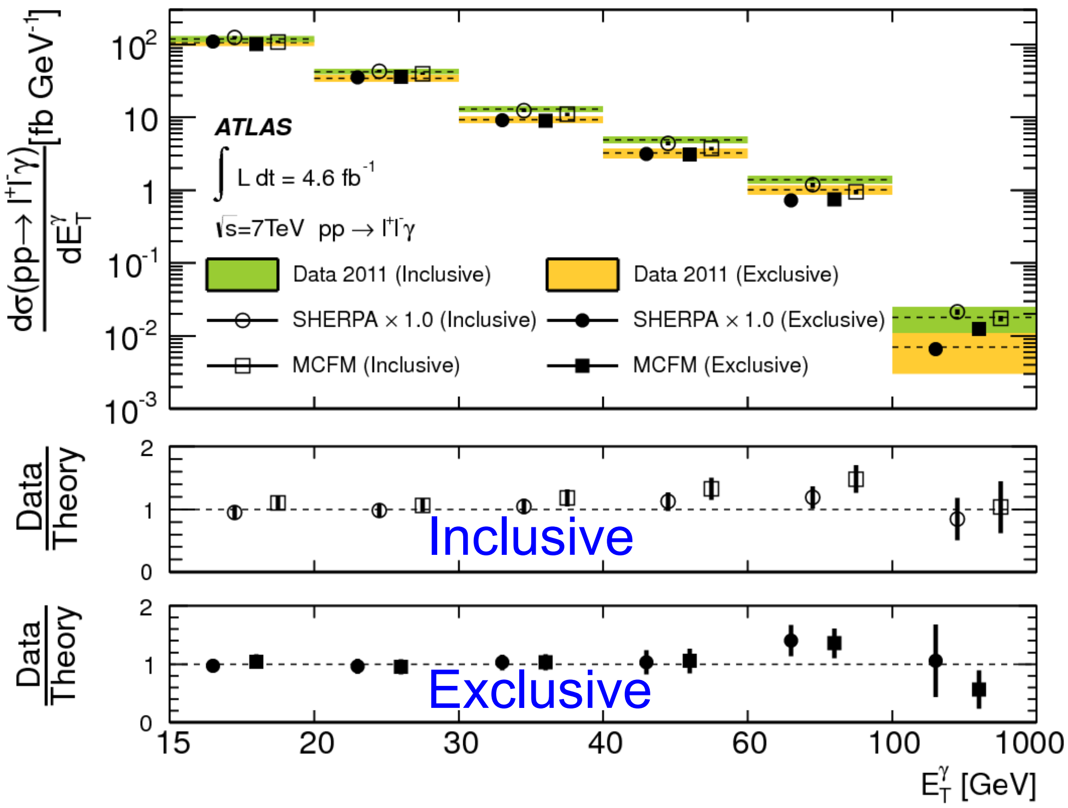
- Jet multiplicity depends strongly on photon E_T threshold.
  - Dominant contribution from 0jet bin in low E_T region
  - Dominant contribution from 1jet bin in high E_T region
  - Contributions from 2jet or 3jet bins are not negligible

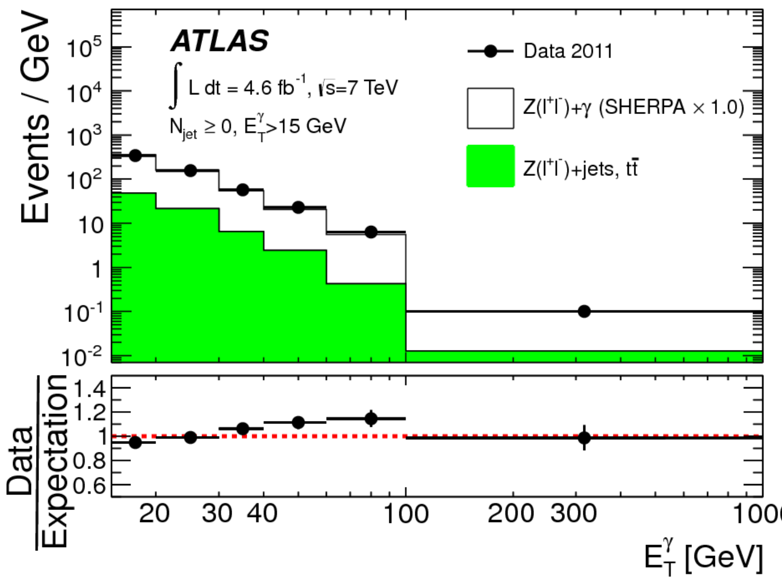


Sherpa :Matrix element calculation for Wγ+0/1/2/3 partons
Alpgen: Matrix element calculation for Wγ+0/1/2/3/4/5 partons

Zγ ($l^+l^-\gamma$): photon E_T spectrum

- First Zγ differential measurement:
  - Photon E_T , jet multiplicity and Zγ mass spectrum
- Photon E_T measurements
  - fair agreement with Sherpa and MCFM NLO predictions.





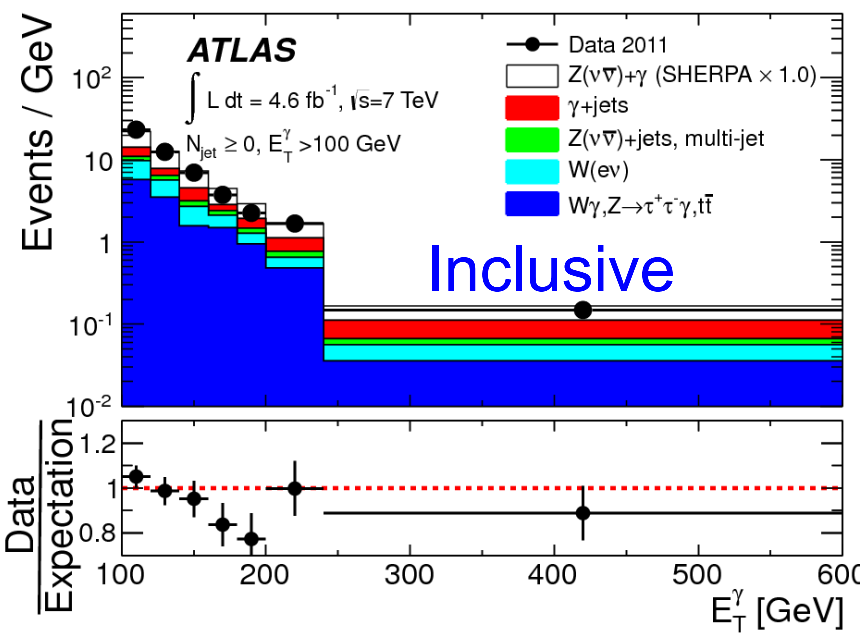
Inclusive

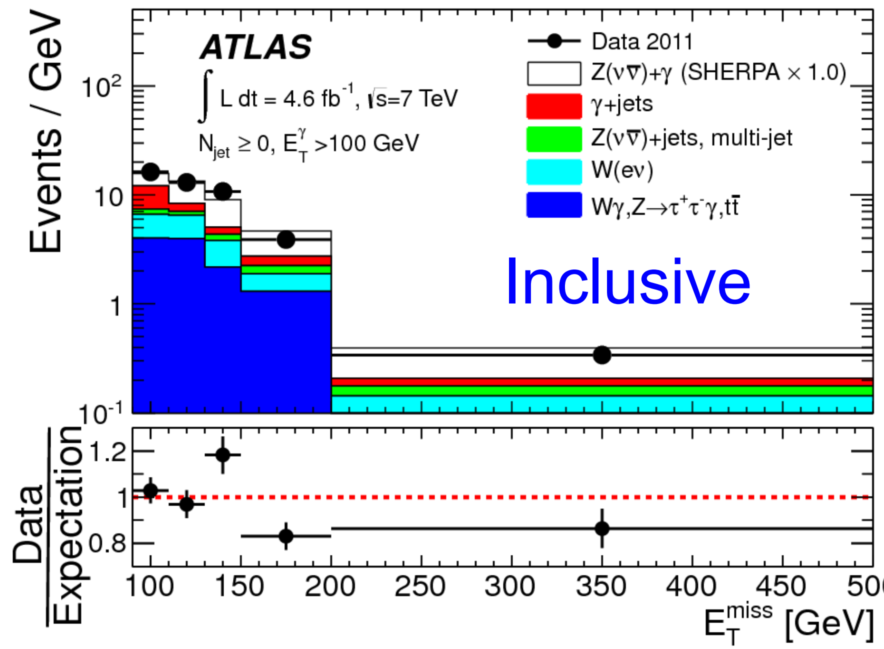
Zγ (ννγ)

- First measurement with neutrino decay channel (ννγ)
  - Very sensitive to Z-Z-γ and Z-γ-γ aTGC.

	$\nu\bar{\nu}\gamma$ $N_{\rm jet} \geq 0$
$N_{Z\gamma}^{\rm obs}$	1094
$W(e\nu)$	$171 \pm 2 \pm 17$
$Z(\nu\bar{\nu})$+jets, multi-jet	$70 \pm 13 \pm 14$
$W\gamma$	$238 \pm 12 \pm 37$
γ+jets	$168 \pm 20 \pm 42$
$Z(\tau^+\tau^-)\gamma$	$11.7 \pm 0.7 \pm 0.9$
$t\bar{t}$	$11 \pm 1.2 \pm 1.0$
$N_{Z\gamma}^{\rm sig}$	$420 \pm 42 \pm 60$

- Selection highlight
- ❑ E_T^{Miss}>90GeV
- ❑ One isolated photon with pT>100GeV
- ❑ Veto event with good lepton



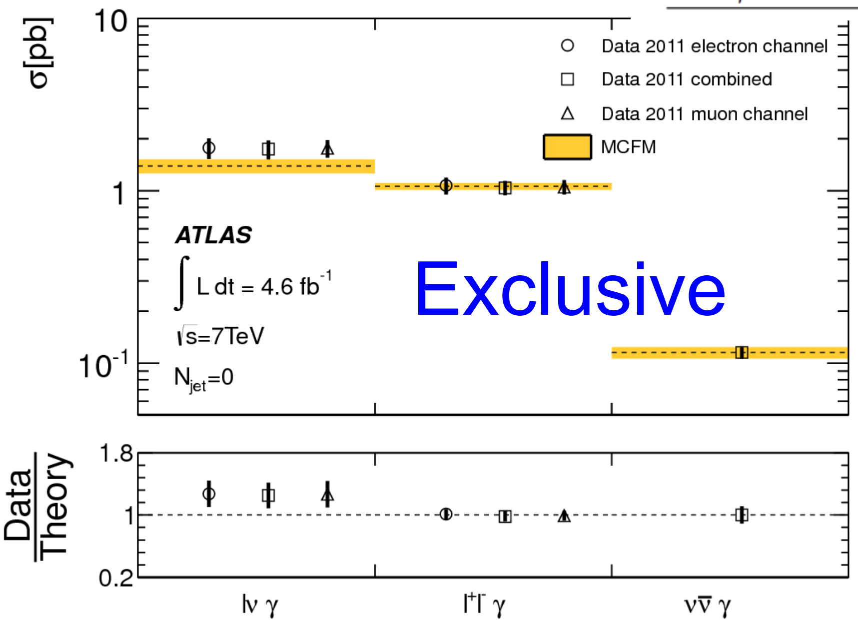


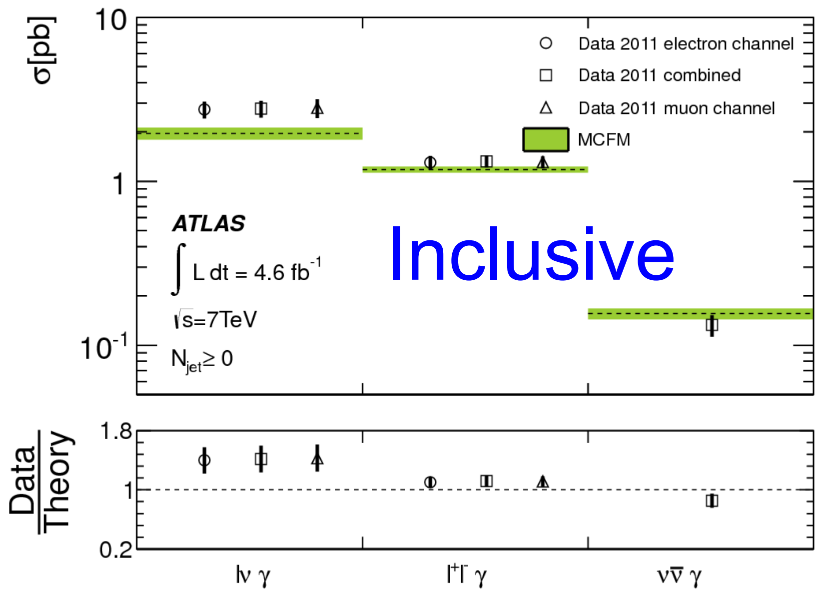
Integrated cross section measurement

- Measurement vs MCFM NLO predictions :
  - Inclusive Wγ measurement is about two sigma above predictions
  - Agreement is improved for exclusive Wγ measurement (with jet veto)

Fiducial cross section:

	$\sigma^{ext-fid}$[pb] Measurement	$\sigma^{ext-fid}$[pb] MCFM Prediction
	$N_{jet} \geq 0$	
$\ell\nu\gamma$	2.77 ± 0.03 (stat) ± 0.33 (syst) ± 0.14 (lumi)	1.96 ± 0.17
$\ell^+\ell^-\gamma$	1.31 ± 0.02 (stat) ± 0.11 (syst) ± 0.05 (lumi)	1.18 ± 0.05
$\nu\bar{\nu}\gamma$	0.133 ± 0.013 (stat) ± 0.020 (syst) ± 0.005 (lumi)	0.156 ± 0.012
	$N_{jet} = 0$	
$\ell\nu\gamma$	1.76 ± 0.03 (stat) ± 0.21 (syst) ± 0.08 (lumi)	1.39 ± 0.13
$\ell^+\ell^-\gamma$	1.05 ± 0.02 (stat) ± 0.10 (syst) ± 0.04 (lumi)	1.06 ± 0.05
$\nu\bar{\nu}\gamma$	0.116 ± 0.010 (stat) ± 0.013 (syst) ± 0.004 (lumi)	0.115 ± 0.009

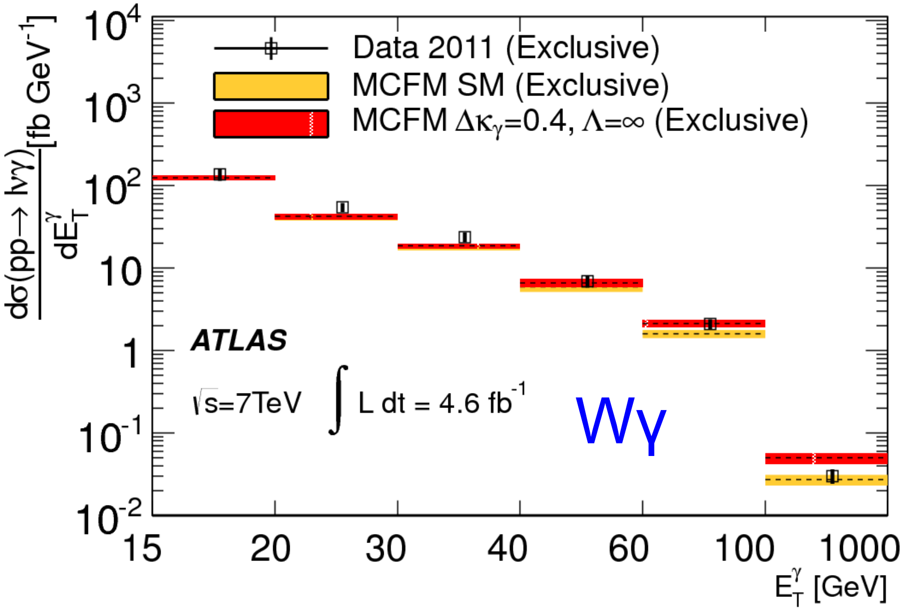


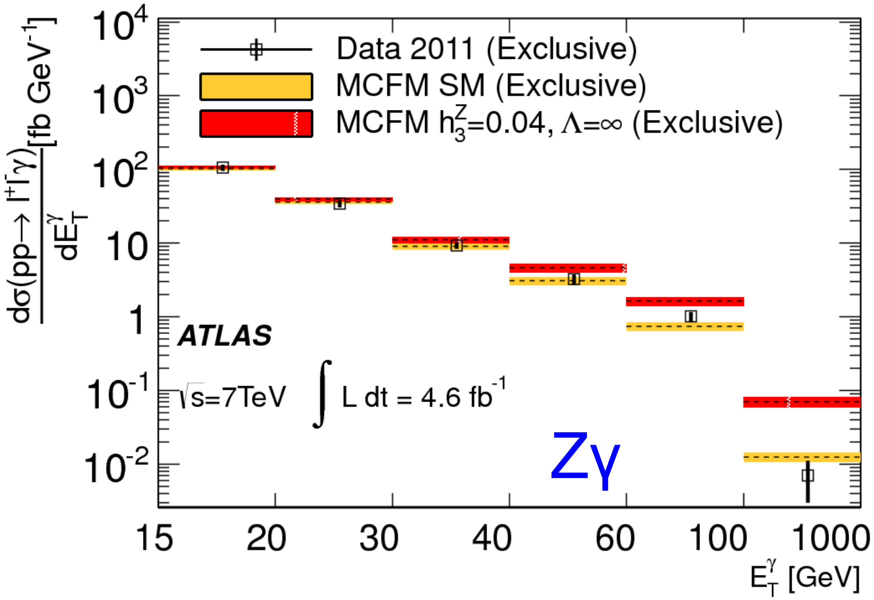


Triple Gauge Couplings

- The s-channel diagrams contain the triple gauge coupling vertex
  - New physics may modify these couplings.
- aTGCs modify the event kinematics
  - Effects of aTGCs increase with *s*ˆ

coupling	parameters	channel
$WW\gamma$	λ_γ, $\Delta\kappa_\gamma$	WW, Wγ
WWZ	λ_Z, $\Delta\kappa_Z$,Δg_1^Z	WW, WZ
$ZZ\gamma$	h_3^Z, h_4^Z	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma Z$	f_{40}^Z, f_{50}^Z	ZZ
ZZZ	f_{40}^γ, f_{50}^γ	ZZ

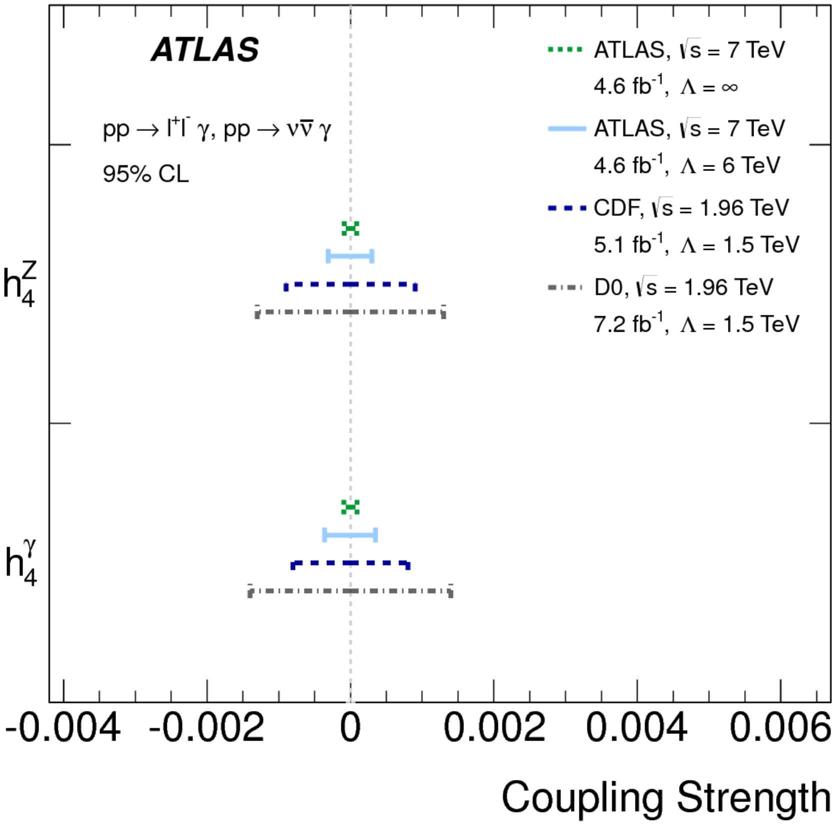




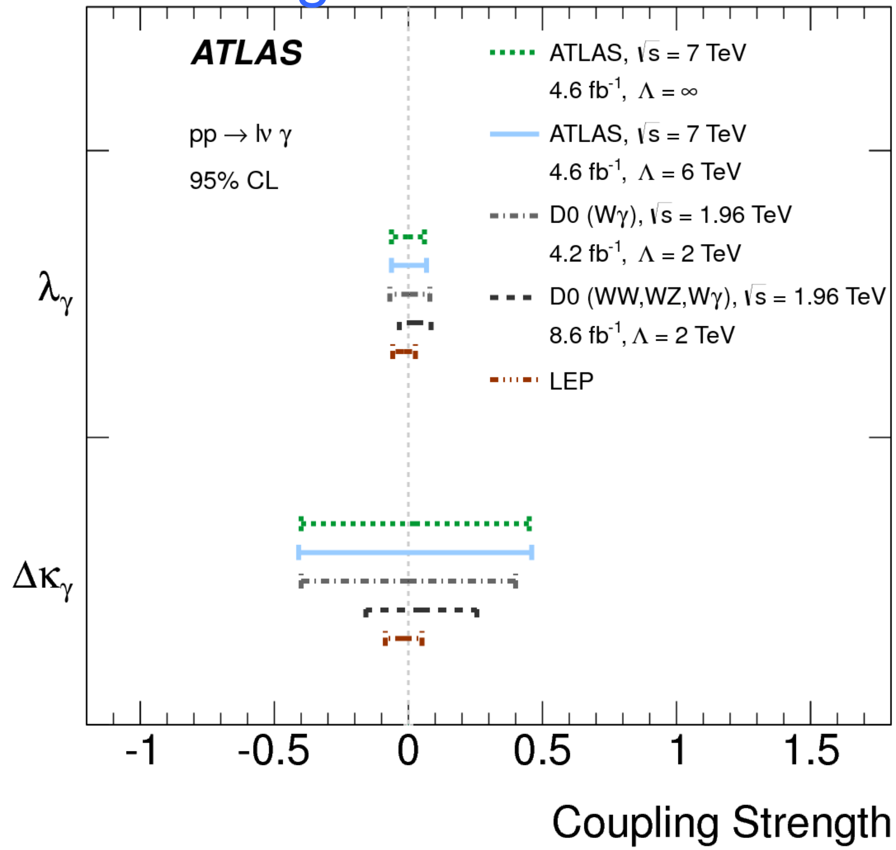
aTGC limits

- No sign of deviation from SM predictions
- aTGC limits is comparable or better than Tevatron results

neutral aTGCs

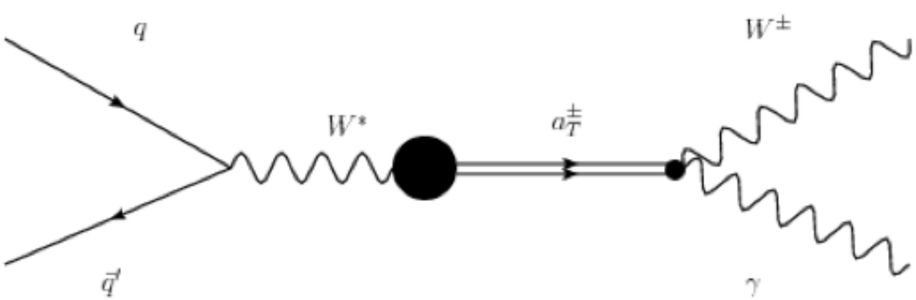


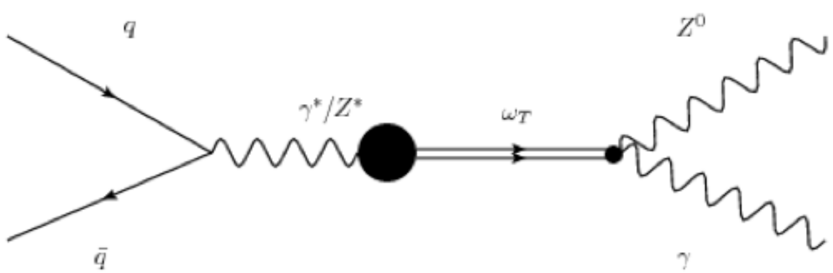
Charged aTGCs



Narrow resonance search

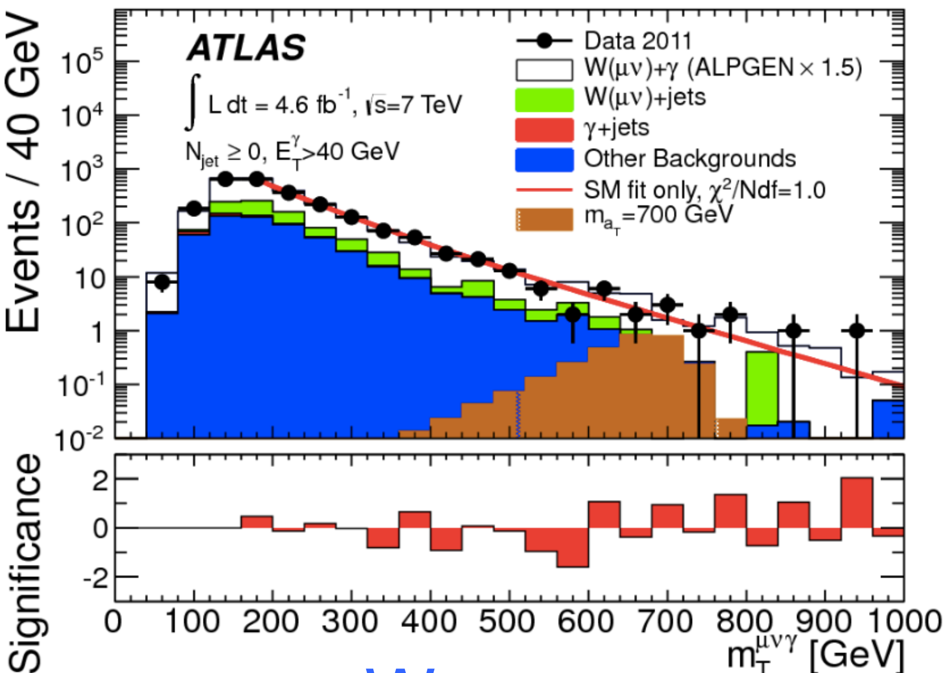
- First narrow resonance search using Wγ final state in all HEP experiments
  - No experimental limits from CMS/CDF/D0 in this final state.
  - Do the search as model independent as possible
  - Choose Low Scale Technicolor as benchmark model
- Low Scale Technicolor predicts narrow resonance decays into Vγ
  - $\omega_{T} \rightarrow Z\gamma$
  - $a_{T} \rightarrow W\gamma$



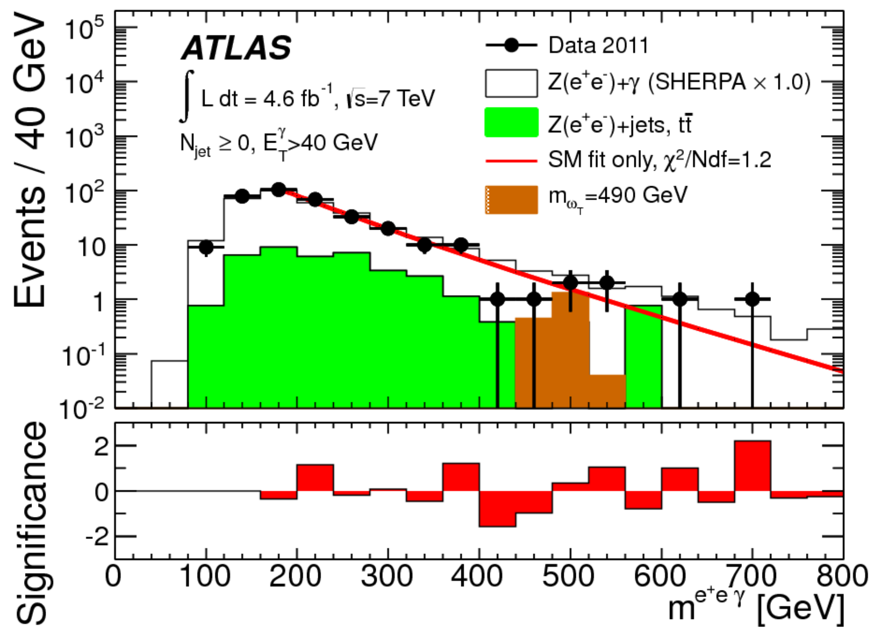


Narrow resonance search (2)

- First narrow resonance search using Wγ final state in all HEP experiments
- The most stringent limits in the Zγ final state.
  - Double-exponential function to model to the shape of Vγ mass
  - No deviation from SM predictions



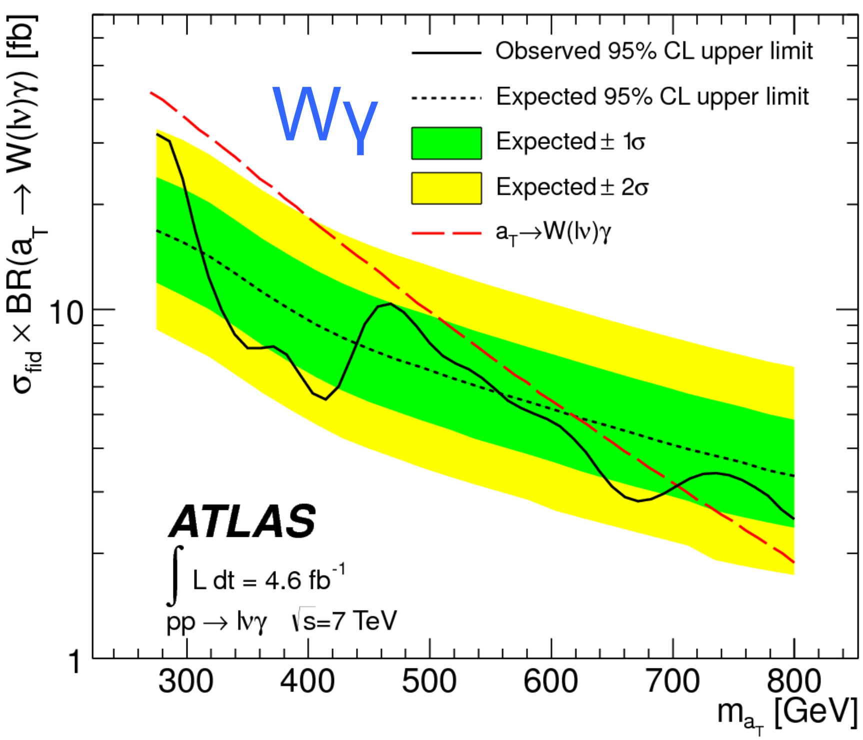
Wγ

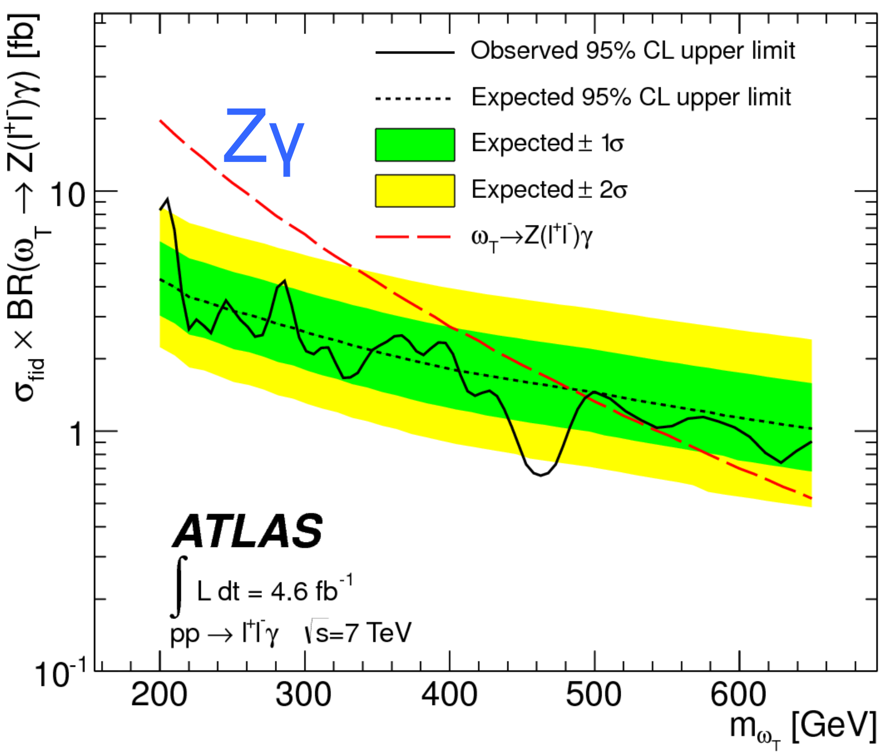


Zγ

Narrow resonance search (3)

- First narrow resonance search using Wγ final state in all HEP experiments
- The most stringent narrow resonance search in the Zγ final state.
  - Model independent limits on Vγ on "fiducial cross section * branching ratio"
  - Limit on LSTC model a_T->Wγ : excluded up to $M(a_T)$ = 703 GeV
  - Limit on LSTC model ω_T ->Zγ : excluded up to $M(\omega_T)$ = 494 GeV





Summary

- Integrated cross section
  - Good agreement with theory predictions in Zγ
  - Observe about two sigma excess in Wγ
    - Data/predictions agreement improve in exclusive measurement with jet veto
- Differential cross section
  - The shapes agree better with Alpgen/Sherpa predictions
  - Observe discrepancy with MCFM in high E_T^{γ} region of inclusive Wγ events
- Anomalous Triple Gauge Couplings
  - aTGC limits are comparable or better than Tevatron results
- Narrow resonance search
  - First narrow resonance search using Wγ final state in all HEP experiments
  - Most stringent narrow resonance search in Zγ

backup

Fiducial phase space

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	—
	$\lvert\eta_\ell\rvert < 2.47$	$\lvert\eta_\ell\rvert < 2.47$	—
	$N_\ell = 1$	$N_{\ell^+} = 1, N_{\ell^-} = 1$	$N_\ell = 0$
	$p_T^\nu > 35$ 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
	$\lvert\eta^\gamma\rvert < 2.37, \Delta R(\ell,\gamma) > 0.7$		
	$\epsilon_h^p < 0.5$		
Jet	$E_T^{\text{jet}} > 30$ GeV, $\lvert\eta^{\text{jet}}\rvert < 4.4$		
	$\Delta R(e/\mu/\gamma, \text{jet}) > 0.3$		
	Inclusive : $N_{\text{jet}} \geq 0$, Exclusive : $N_{\text{jet}} = 0$		

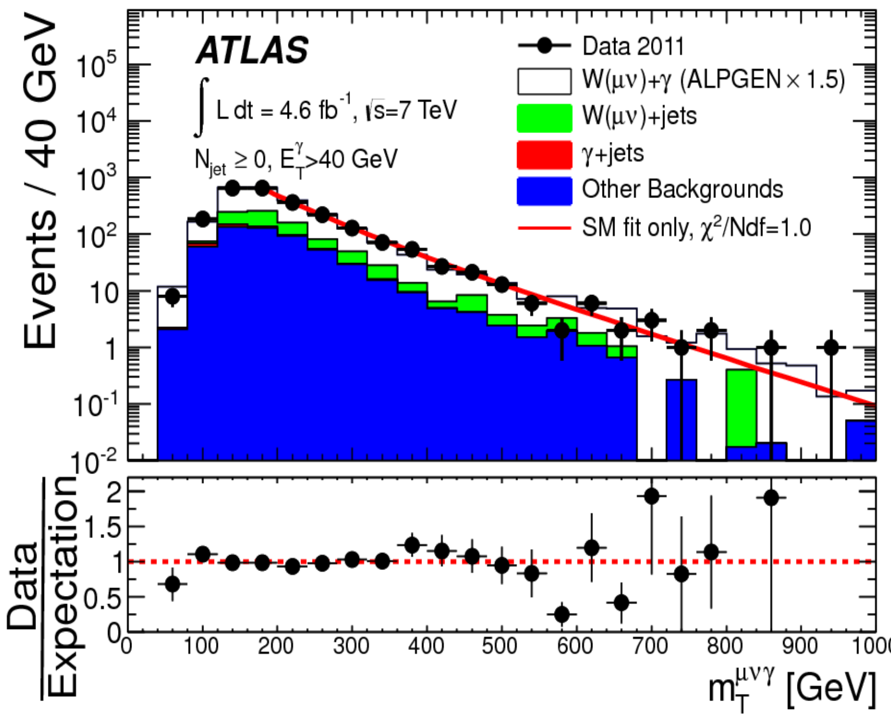
Systematic Uncertainties

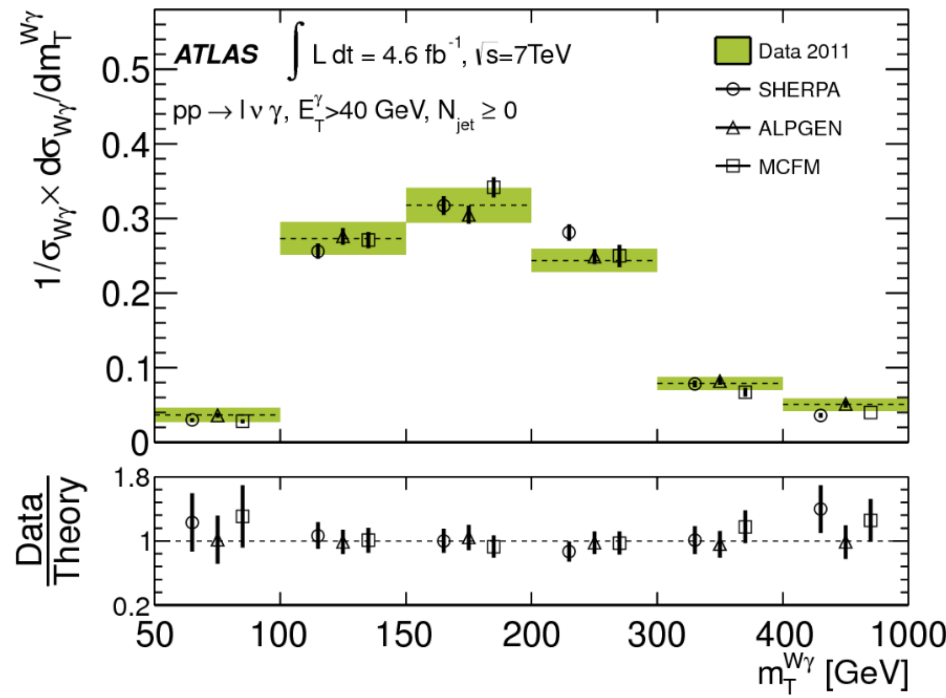
- Major experimental systematics
  - Photon Identification uncertainty : 5%
  - Photon isolation efficiency : 2~3%
  - EM scale and resolution: 2~3%
  - Jet energy scale (3% for exclusive measurement)

Wγ (lνγ): transverse mass

- Differential measurements on Wγ transverse mass
  - MCFM, Sherpa and Alpgen can describe the shape

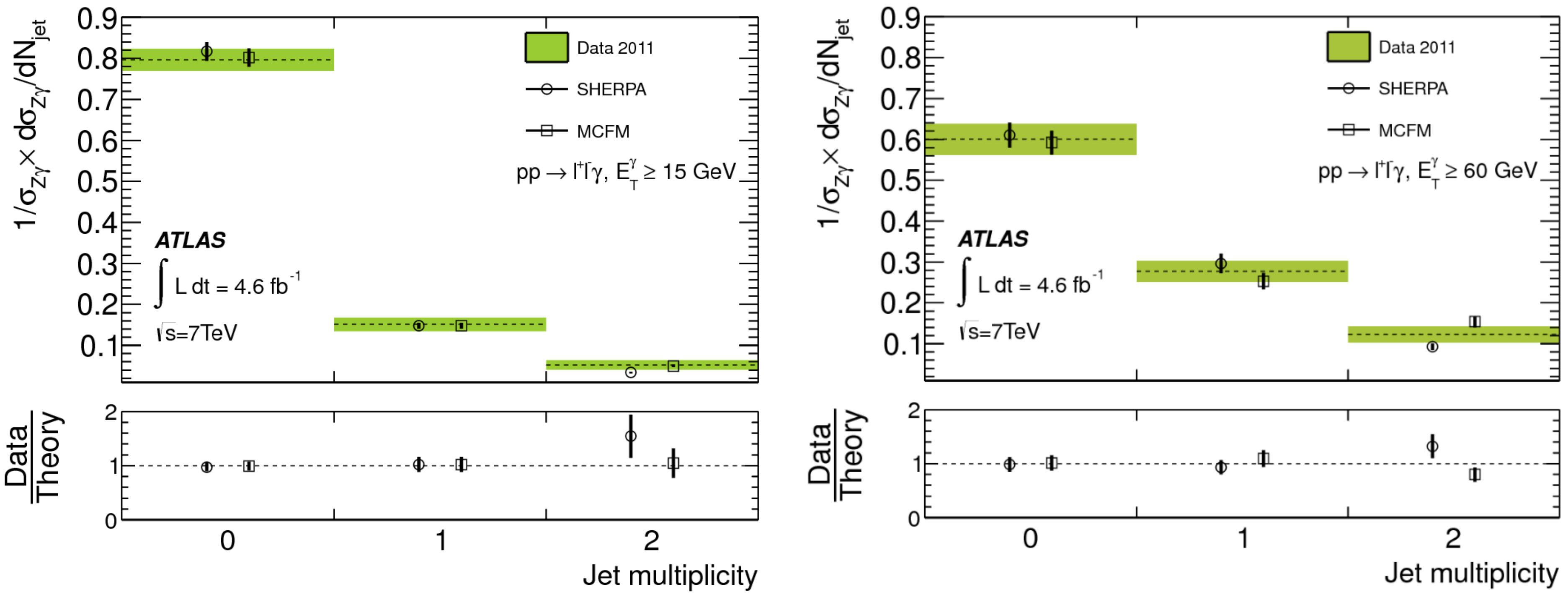
$$(m_{\mathrm{T}}^{W\gamma})^2 = \left(\sqrt{m_{\ell\gamma}^2 + |\vec{p}_{\mathrm{T}}(\gamma) + \vec{p}_{\mathrm{T}}(\ell)|^2} + E_{\mathrm{T}}^{\mathrm{miss}}\right)^2 - |\vec{p}_{\mathrm{T}}(\gamma) + \vec{p}_{\mathrm{T}}(\ell) + \vec{E}_{\mathrm{T}}^{\mathrm{miss}}|^2.$$





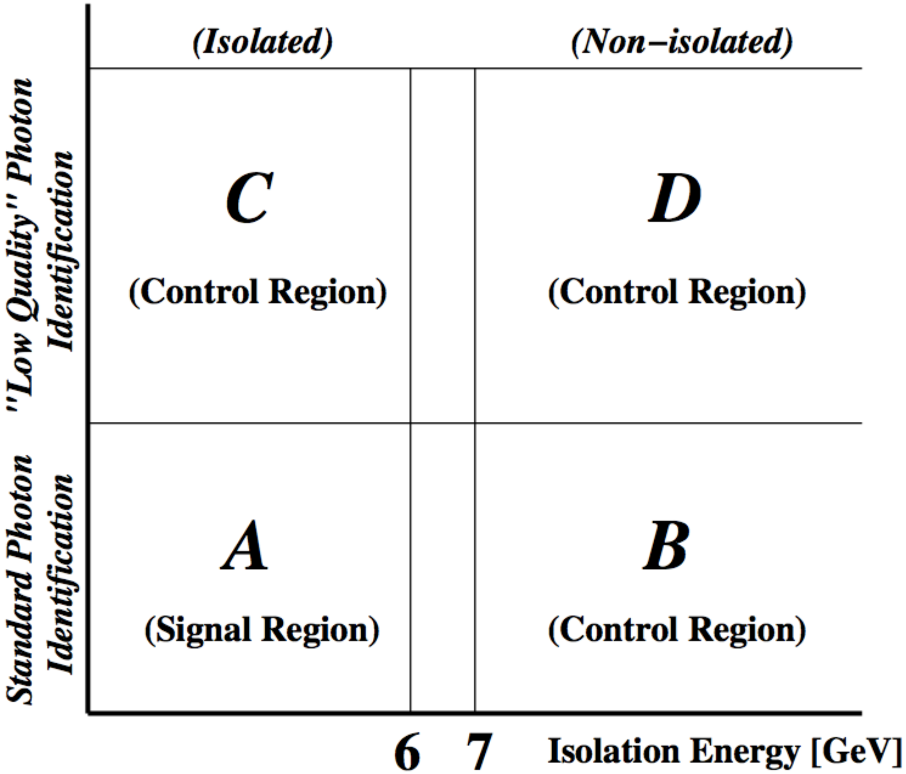
Zγ ($l^+l^-\gamma$): jet multiplicity

- Jet multiplicity depends strongly on photon pT threshold.
- Very different from jet multiplicity in Wγ.



Background

- Fake photons (or fake lepton) background estimated from isolation shape of signal candidates.
  - Background shapes are taken from background enriched region (C,D)
    - Fake photon enriched: select shower shape similar to $\pi^0 \to 2\gamma$
    - Fake electron enriched: select candidates without TRT high threshold hits
    - Fake muon enriched : candidates with large impact parameter (heavy flavor)



Wγ background

	$e\nu\gamma$	$\mu\nu\gamma$
	$N_{\text{jet}} \geq 0$	
$N^{\text{obs}}_{W\gamma}$	7399	10914
$W(\ell\nu)$+jets	$1240 \pm 160 \pm 210$	$2560 \pm 270 \pm 580$
$Z(\ell^+\ell^-) + X$	$678 \pm 18 \pm 86$	$779 \pm 19 \pm 93$
γ+jets	$625 \pm 80 \pm 86$	$184 \pm 9 \pm 15$
$t\bar{t}$	$320 \pm 8 \pm 28$	$653 \pm 11 \pm 57$
other background	$141 \pm 16 \pm 13$	$291 \pm 29 \pm 26$
$N^{\text{sig}}_{W\gamma}$	$4390 \pm 200 \pm 250$	$6440 \pm 300 \pm 590$