Measurement of Wγ and Zγ Production at ATLAS

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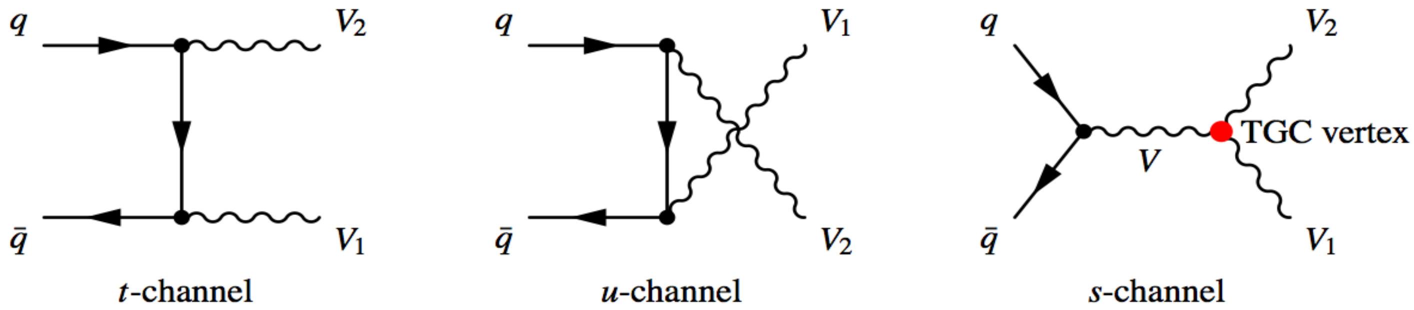
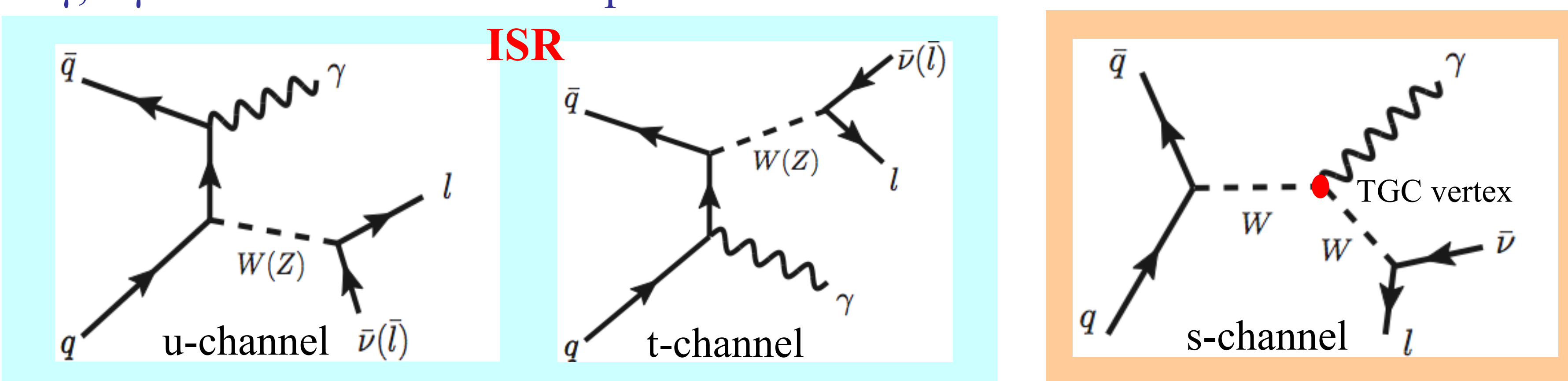
On behalf of the ATLAS Collaboration

Introduction

- At LHC di-bosons can be produced through :



- Wγ, Zγ are two such di-bosons produced :



- Measurement of Wγ and Zγ production provides a direct test of the Triple Gauge Boson Coupling (TGC) of the Electroweak theory
  - Measure the WWγ vertex in the s-channel
  - Probing the existence of the ZZγ and Zγγ TGC (forbidden in SM at the tree level)

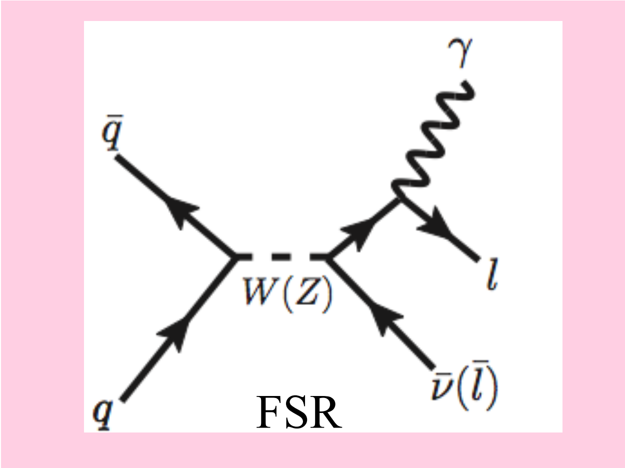
Definition of Signal

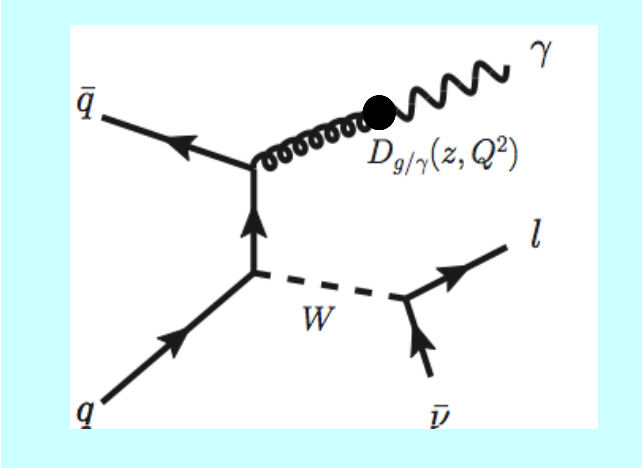
- Measurement of Wγ, Zγ in the final state :
  - Wγ : $l\,\nu\,\gamma + X$
  - Zγ : $l^+ l^- \gamma + X$

  l : e , μ

  γ : is isolated

- Final state can include contributions from :
  - Final State Radiation (FSR) γ from inclusive W(Z) production
  - γ from fragmentation in jets produced in association with W or Z boson



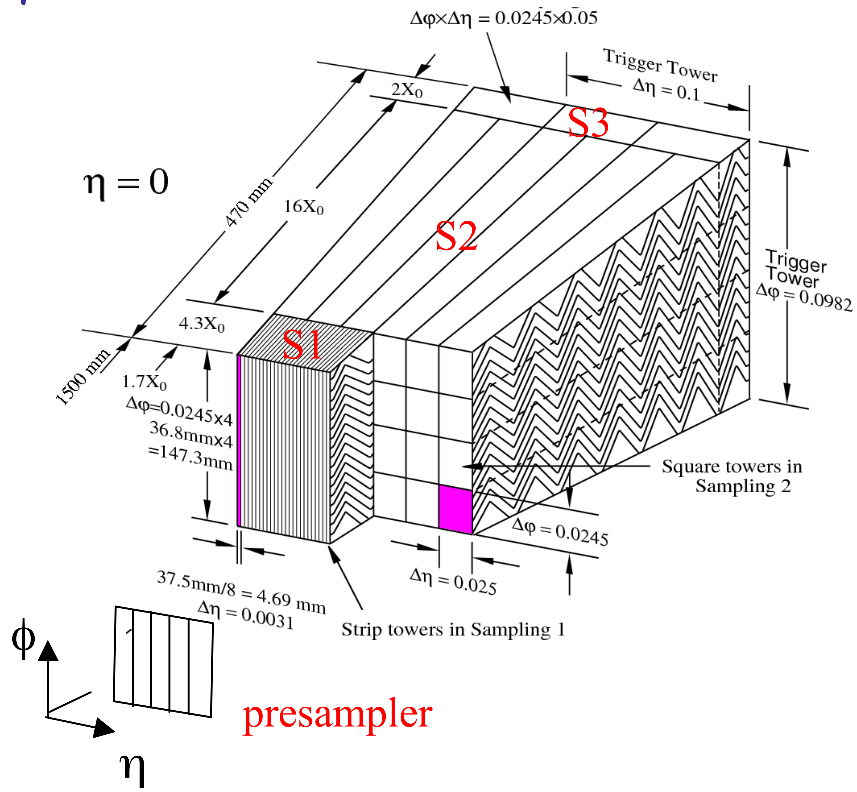


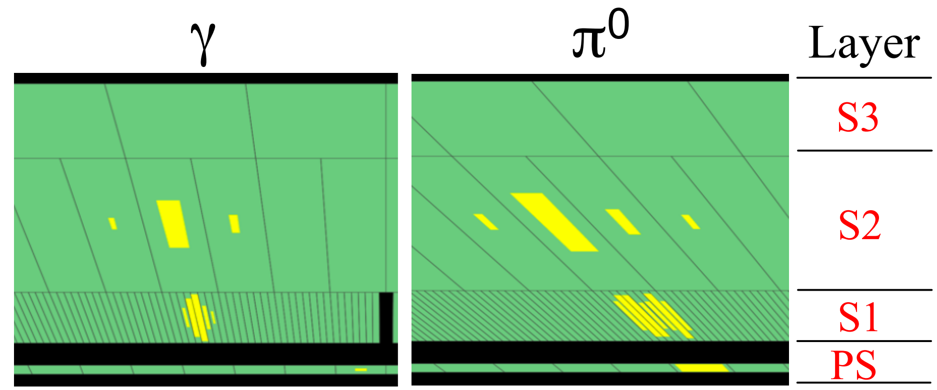
γ from fragmentation

- Phase space of production measurement :
  - $E_T^\gamma > 15$ GeV
  - $M(l^+l^-) > 40$ GeV (for Zγ)
  - $dR(l, \gamma) > 0.7$ (to reduce FSR contribution)
  - particle level isolation : $\sum_{\Delta R < 0.4} E_T^{had} < 0.5 \times E_T^\gamma$

Photon Identification

- γ identified in ATLAS LAr calorimeter

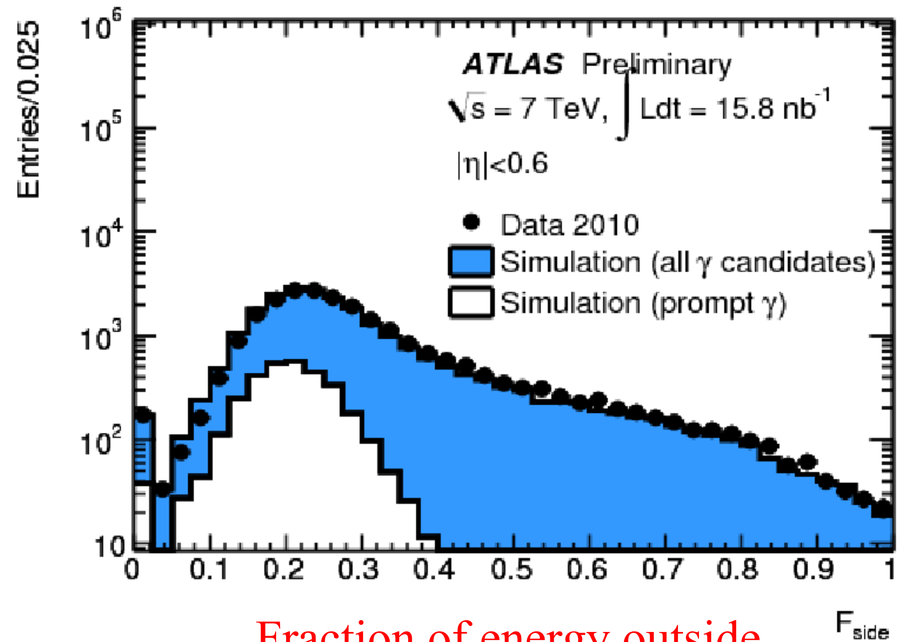




Fine granularity in S1 for γ/π^0 separation

γ Reconstruction :

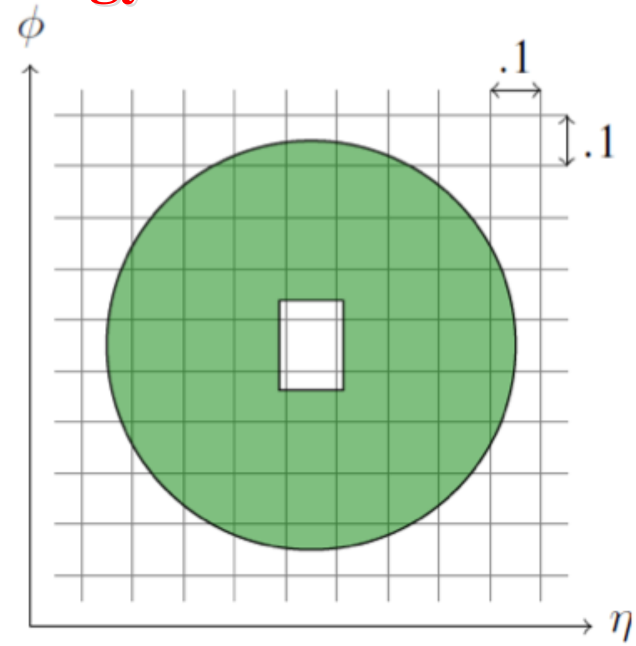
- Narrow energy cluster, allow no/small energy leakage into hadronic calorimeter
- Cut on shower shape variables to discriminate γ from jets and π^0, η

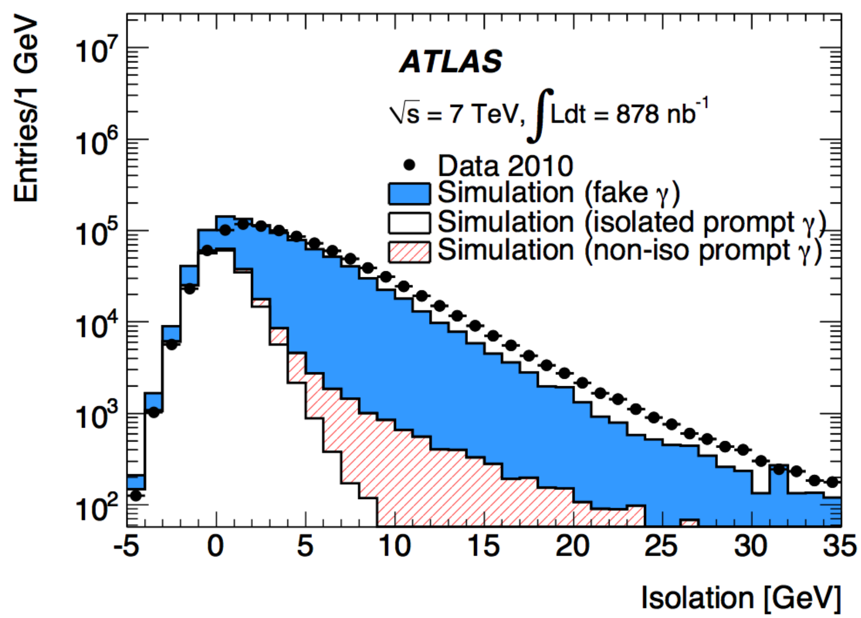


Fraction of energy outside shower core in layer S1

Photon Isolation Energy

- Isolation energy is another important quantity to discriminate γ from jet
- Isolation : sum of transverse energy in ΔR=0.4 cone around γ
- Exclude energy from central core
- Correct for:
  - Leakage from photon energy into isolation cone
  - Energy deposition from pile-up and underlying event by using "jet-area/median" method (Cacciari, Salam and Sapeta, JHEP 04 (2010) 065) to measure the ambient energy density
- Photon isolation energy different between direct photon and photon from fragmentation
- Isolation not well modeled by simulation





Event Selection

•Measurements performed on data set collected in 2010 ($L \sim 35\ pb^{-1}$) (arXiv:1106.1592)

Wγ	Zγ
• One lepton, $p_T(e,\mu)>20$ GeV • $\lvert\eta_e\rvert<2.47$, $\lvert\eta_\mu\rvert<2.4$ • $E_T^{miss}>25$ GeV • $M_T(l,\nu)>40$ GeV	• 2 opposite charged leptons (e^+e^-, $\mu^+\mu^-$) • $p_T(e,\mu)>20$ GeV • $\lvert\eta_e\rvert<2.47$, $\lvert\eta_\mu\rvert<2.4$ • $M(l^+l^-)>40$ GeV
Photon Selection	
• 1 photon, $E_T^\gamma>15$ GeV • $\lvert\eta_\gamma\rvert<2.37$ • $dR(e/\mu,\gamma)>0.7$ • Isolation : $E_T^{iso} < 5$ GeV	

Identification Efficiency:

- e : ~73% (tight), ~90% (medium)
- μ : ~88%
- γ : ~70%

Number of Selected Candidate Events

	e	μ
Wγ	95	97
Zγ	25	23

Background Estimation

- Main sources of background:

Wγ :
- W+jets *
- W→τν
- *Z→ll*
- ttbar
- negligible contribution from QCD multi-jet, WW, single-top

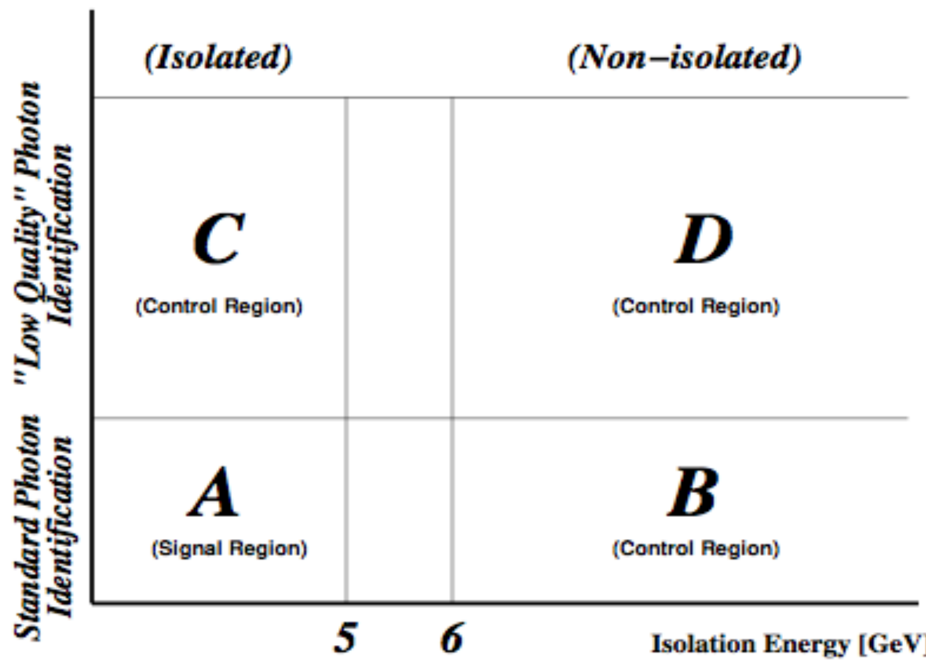
Zγ :
- Z+jets *
- Z→ττ
- ttbar

*: most dominate source jet fakes as photon.

- For Wγ, estimate W+jets background from data control regions
- Assume photon identification (ID) cuts not strongly correlated to photon isolation for W+jets

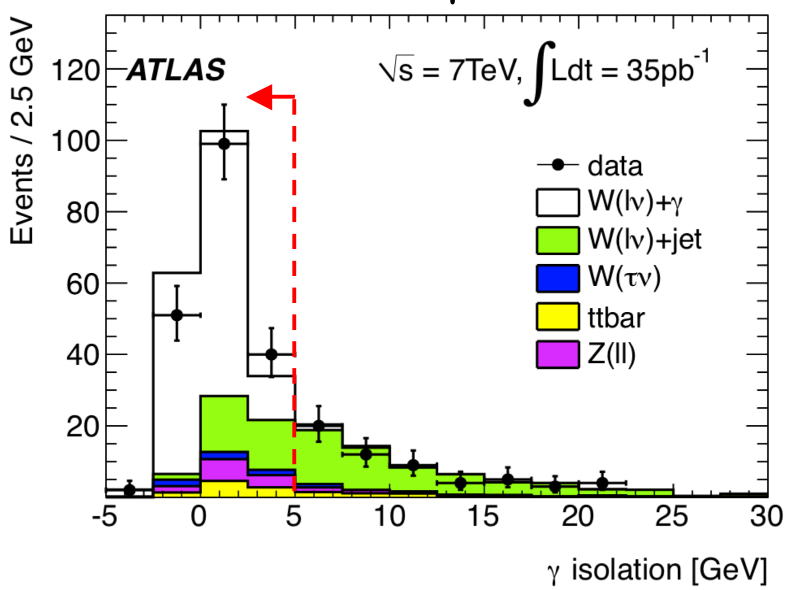
$$N_A^{W+jets} = N_B \cdot \frac{N_C}{N_D}$$

(Contributions from non-W+jets backgrounds and signal leakage in control regions B,C and D are removed)

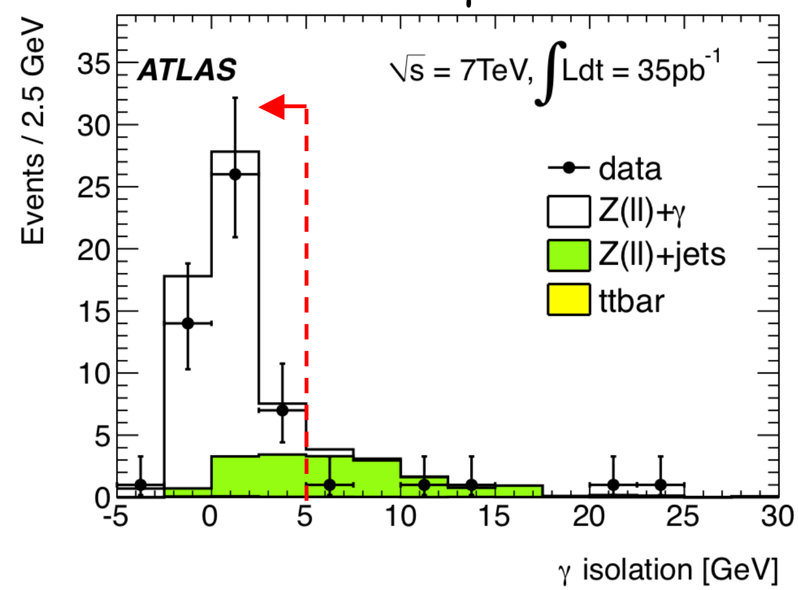


Background Estimation

Wγ



Zγ



- W+jets background (green) isolation shape is taken from data's "low-quality" ID control region
- Since low statistics in Zγ events, estimate Z+jets background based on simulation (assign large systematic uncertainty)

Signal Yield

Process	Observed events	EW+$t\bar{t}$ background	W+jets background	Extracted signal
$N_{obs}(W\gamma \to e^{\pm}\nu\gamma)$	95	$10.3 \pm 0.9 \pm 0.7$	$16.9 \pm 5.3 \pm 7.3$	$67.8 \pm 9.2 \pm 7.3$
$N_{obs}(W\gamma \to \mu^{\pm}\nu\gamma)$	97	$11.9 \pm 0.8 \pm 0.8$	$16.9 \pm 5.3 \pm 7.4$	$68.2 \pm 9.3 \pm 7.4$
Process	Observed events	EW+$t\bar{t}$ background		Extracted signal
$N_{obs}(Z\gamma \to e^{+}e^{-}\gamma)$	25	3.7 ± 3.7		$21.3 \pm 5.8 \pm 3.7$
$N_{obs}(Z\gamma \to \mu^{+}\mu^{-}\gamma)$	23	3.3 ± 3.3		$19.7 \pm 4.8 \pm 3.3$

Systematic Uncertainties on Extracted Signal:

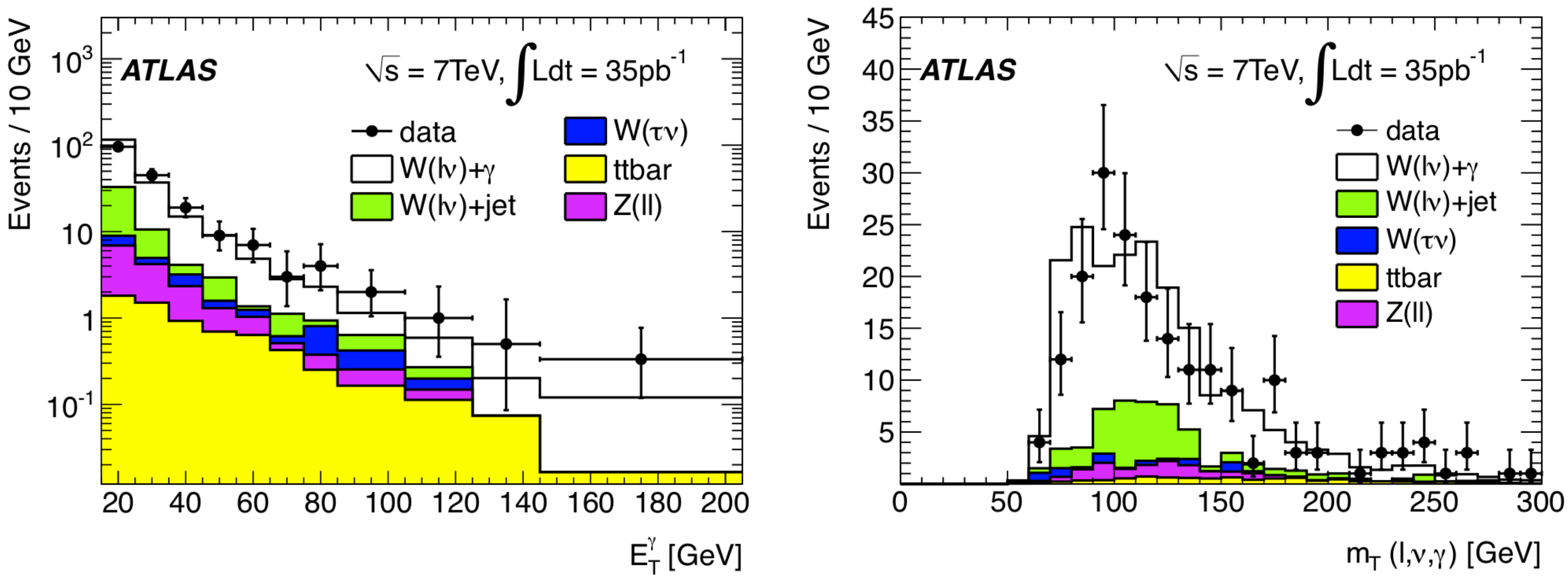
•Stability of control regions using shower shape : ~9%

•Stability of control regions using isolation : ~4%

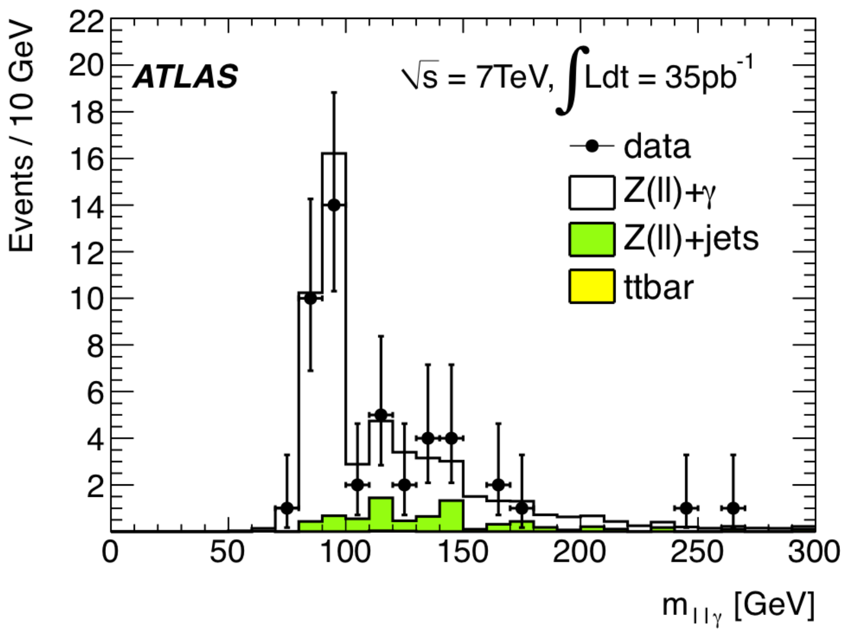
•Modeling of signal leakage : ~3%

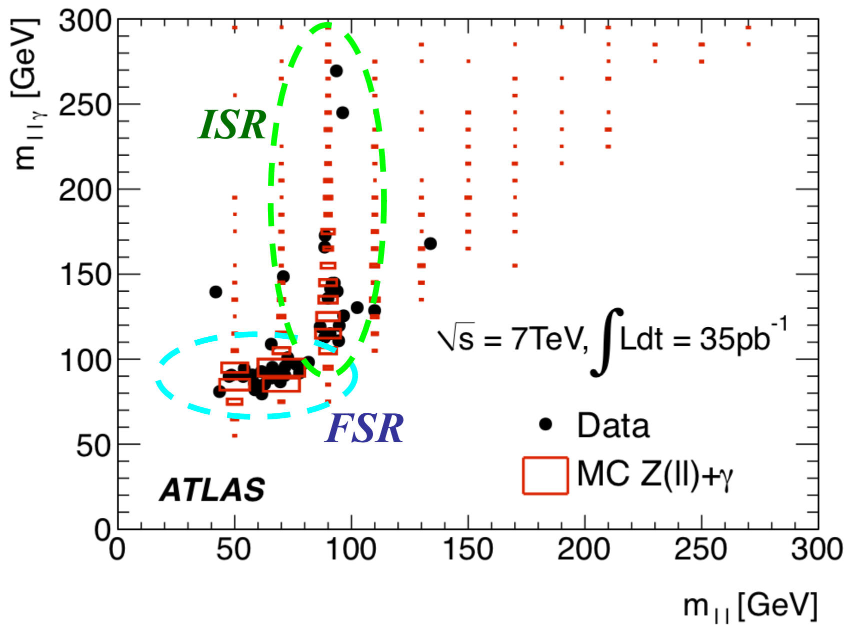
•Background correlation in control regions : ~3%

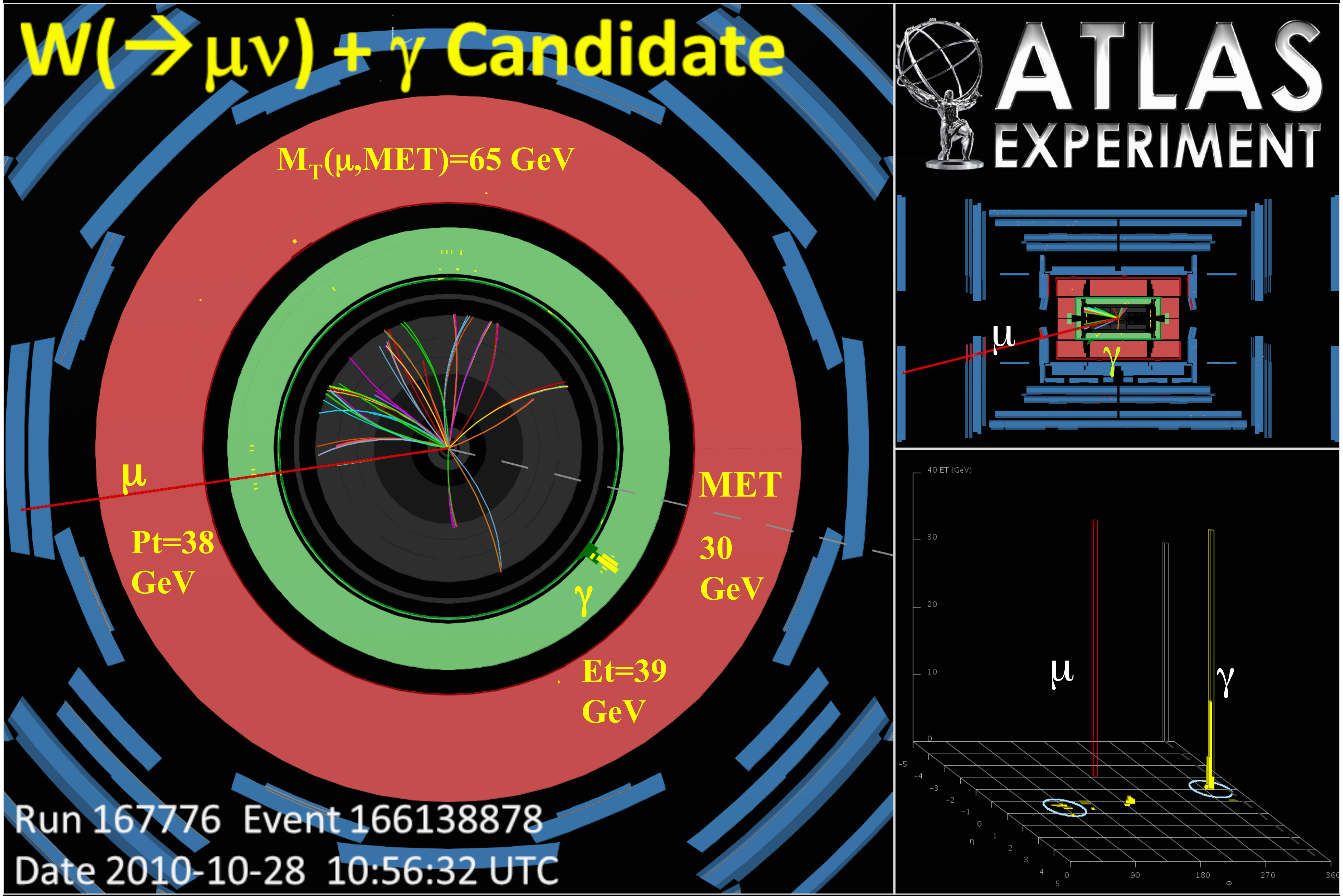
Kinematic Distributions of Selected Events (Wγ)



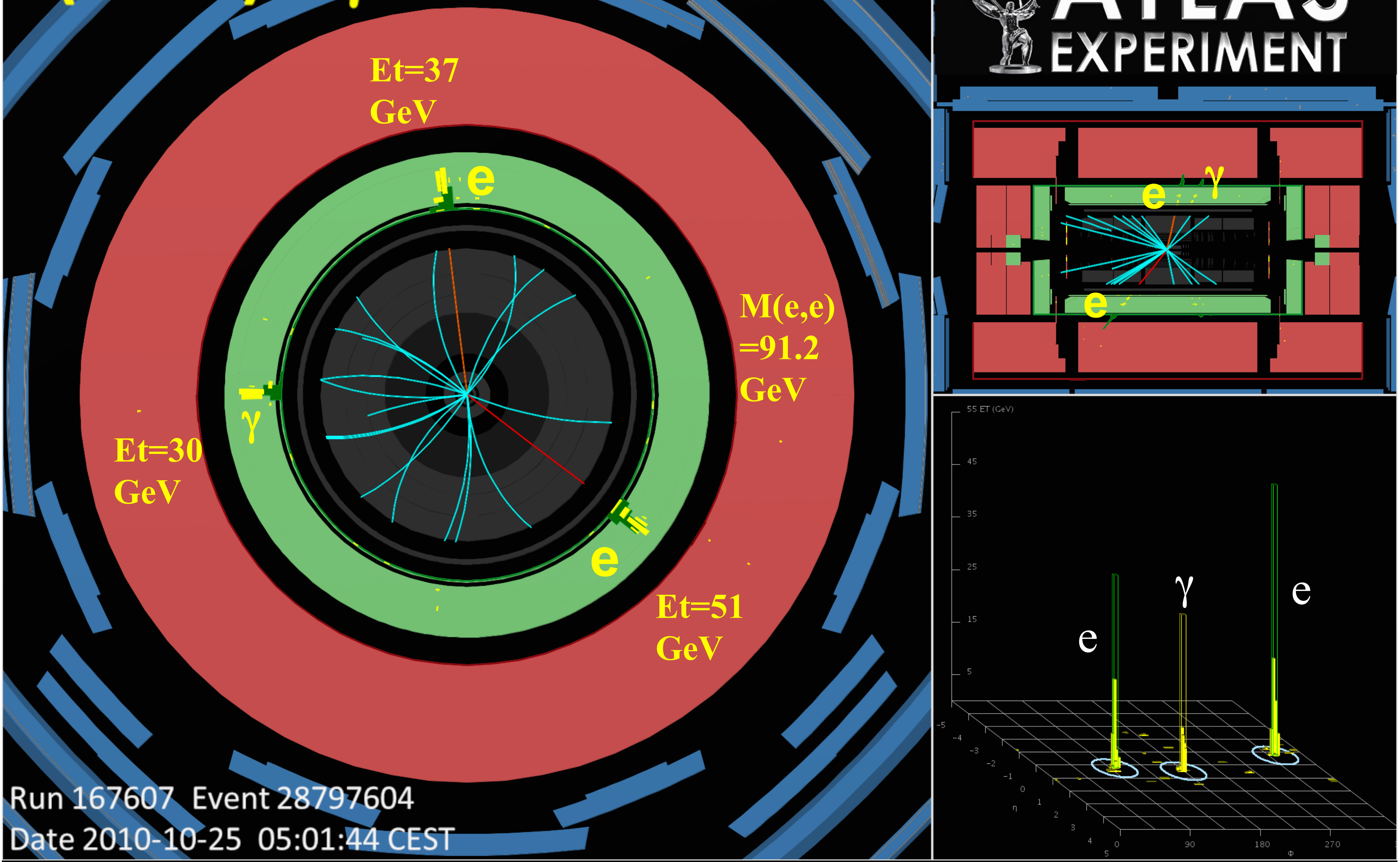
Kinematic Distributions of Selected Events (Zγ)






W(→μν) + γ Candidate
ATLAS
EXPERIMENT
M_T(μ,MET)=65 GeV
μ
Pt=38
GeV
MET
30
GeV
γ
Et=39
GeV
Run 167776 Event 166138878
Date 2010-10-28 10:56:32 UTC
μ
γ
40 ET (GeV)
μ
γ

Z(→ee) + γ Candidate



Cross Section Measurements

Fiducial Cross Section:

- Performed in the phase space defined by kinematic cuts in event selection

$$\sigma^{fid}_{W\gamma(Z\gamma)} = \frac{N^{Sig}_{W\gamma(Z\gamma)}}{C_{W\gamma(Z\gamma)} \cdot L_{W\gamma(Z\gamma)}}$$

$N^{Sig}_{W\gamma(Z\gamma)}$: Number of measured signal events

$C_{W\gamma(Z\gamma)}$: Reconstruction and identification efficiency

Production Cross Section:

- Extrapolate the measurement in fiducial phase space to full decay phase space of W and Z boson

$$\sigma^{prod}_{W\gamma(Z\gamma)} = \frac{\sigma^{fig}_{W\gamma(Z\gamma)}}{A_{W\gamma(Z\gamma)}}$$

$A_{W\gamma(Z\gamma)}$: Acceptance of fiducial phase space with respect to total production phase space

- Use full simulation to calculate acceptance $A_{W\gamma(Z\gamma)}$

Uncertainties

- Total uncertainties : ~12% (13%) for muon (electron) channel
- Dominant Uncertainties :
  - Photon reconstruction/ID efficiency : ~10% (uncertainty in upstream material and contribution from fragmentation photon)
  - Electron reconstruction/ID : ~4.5%
  - Electromagnetic energy scale and resolution : ~3 - 4.5%
  - Others (trigger, muon ID, photon isolation…) : ~1 - 2%

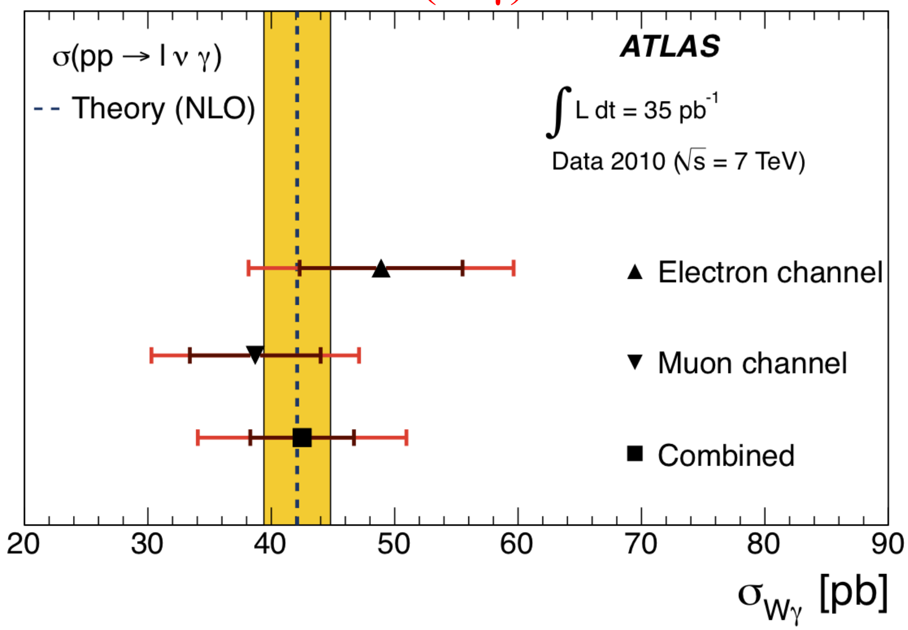
Cross Section

		Experimental measurement	SM prediction	
		σ^{fid}[pb]	σ^{fid}[pb]	
Wγ	$pp \to e^{\pm}\nu\gamma$	$5.4 \pm 0.7 \pm 0.9 \pm 0.2$	4.7 ± 0.3	Fiducial cross section
	$pp \to \mu^{\pm}\nu\gamma$	$4.4 \pm 0.6 \pm 0.7 \pm 0.2$	4.9 ± 0.3	
Zγ	$pp \to e^{+}e^{-}\gamma$	$2.2 \pm 0.6 \pm 0.5 \pm 0.1$	1.7 ± 0.1	
	$pp \to \mu^{+}\mu^{-}\gamma$	$1.4 \pm 0.3 \pm 0.3 \pm 0.1$	1.7 ± 0.1	
		σ[pb]	σ[pb]	
Wγ	$pp \to e^{\pm}\nu\gamma$	$48.9 \pm 6.6 \pm 8.3 \pm 1.7$	42.1 ± 2.7	Production cross section
	$pp \to \mu^{\pm}\nu\gamma$	$38.7 \pm 5.3 \pm 6.4 \pm 1.3$	42.1 ± 2.7	
	$pp \to l^{\pm}\nu\gamma$	$42.5 \pm 4.2 \pm 7.2 \pm 1.4$	42.1 ± 2.7	
Zγ	$pp \to e^{+}e^{-}\gamma$	$9.0 \pm 2.5 \pm 2.1 \pm 0.3$	6.9 ± 0.5	
	$pp \to \mu^{+}\mu^{-}\gamma$	$5.6 \pm 1.4 \pm 1.2 \pm 0.2$	6.9 ± 0.5	
	$pp \to l^{+}l^{-}\gamma$	$6.4 \pm 1.2 \pm 1.6 \pm 0.2$	6.9 ± 0.5	

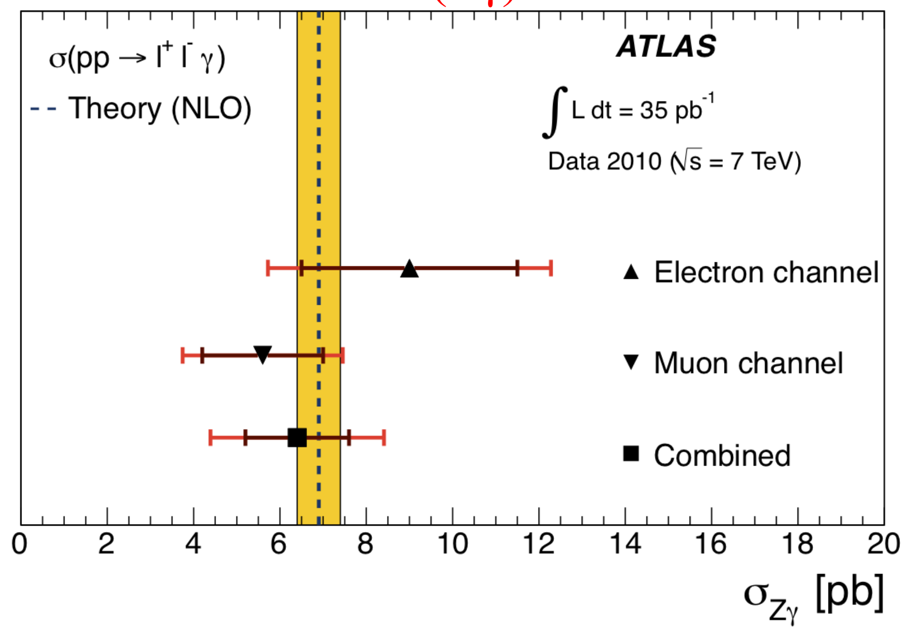
(stat) (syst) (lumi)

Production Cross Section

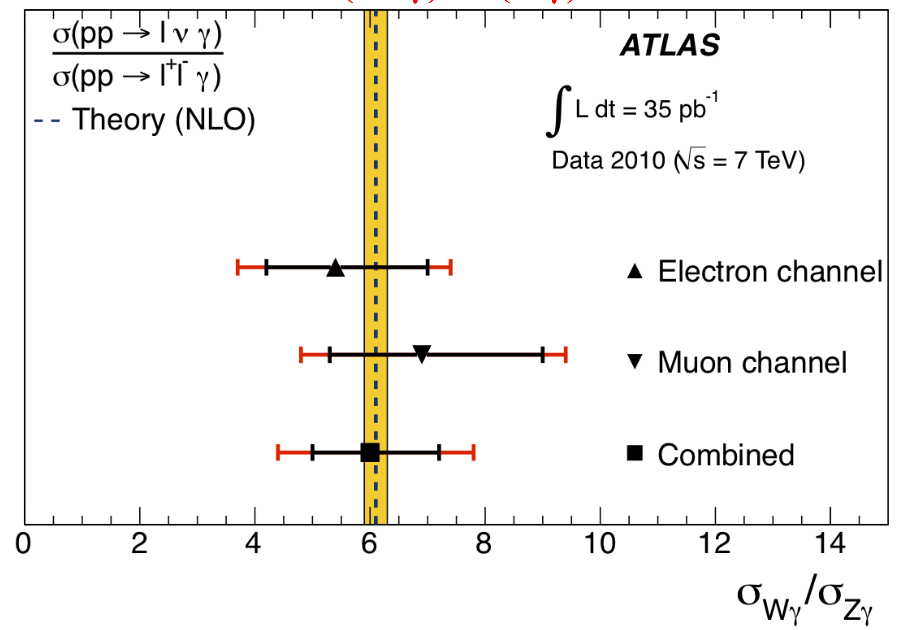
$\sigma(W\gamma)$



$\sigma(Z\gamma)$



$\sigma(W\gamma)/\sigma(Z\gamma)$



- All measurements are consistent within their uncertainties with the SM expectation

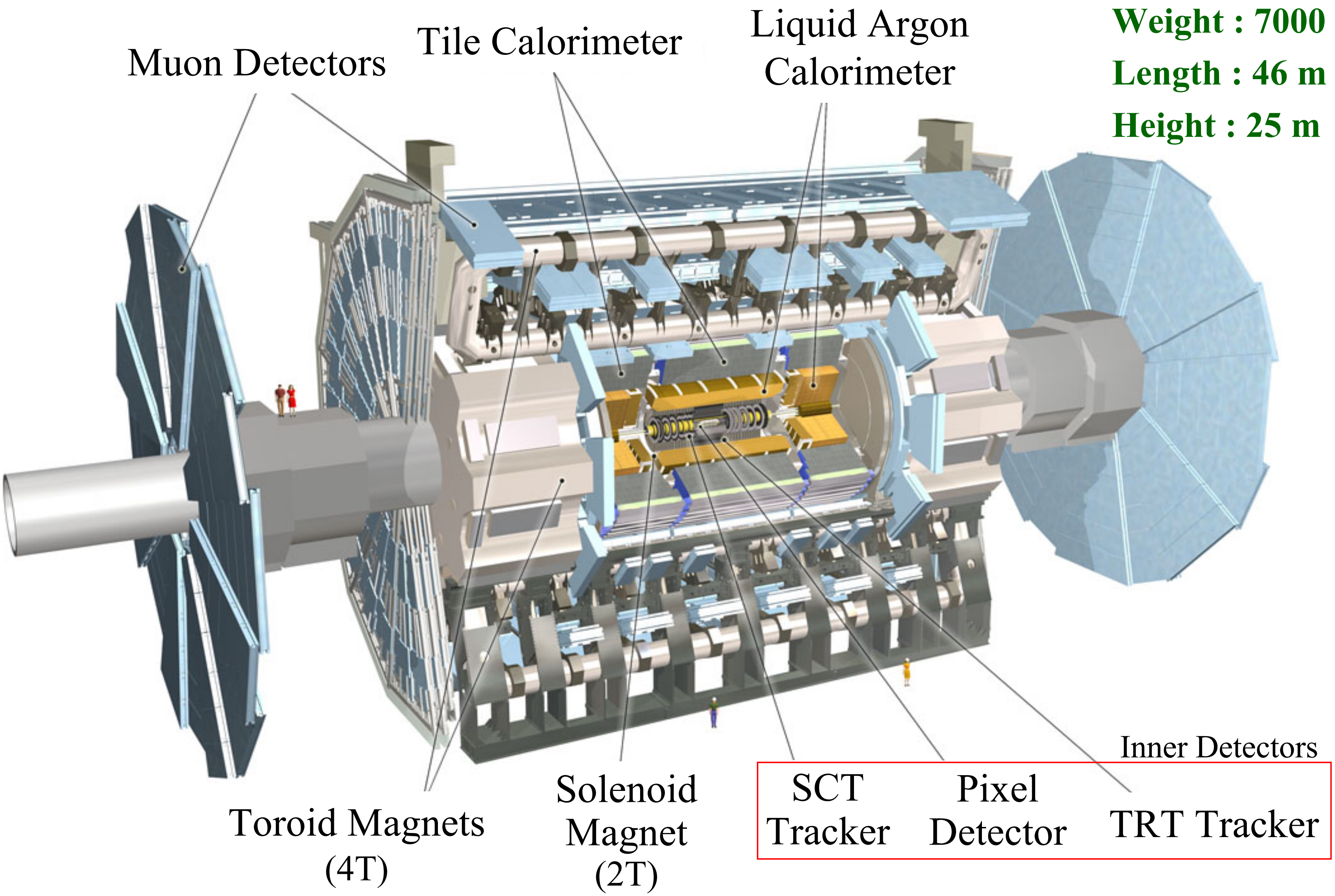
Summary

- Have performed the first measurement of $W\gamma$, $Z\gamma$ production at $\sqrt{s}=7$ TeV with the ATLAS detector, using data sample of 35 pb^{-1} (arXiv:1106.1592, submitted to JHEP)
- Experimental measurements are consistent with Standard Model expectation within their uncertainties
- Dominant uncertainty is due to photon identification efficiency
- Expect to improve the precision of measurement with larger data sample available this year
- Extend analysis to search for new physics and to measure the anomalous TGC limits.

BACK UP

ATLAS Experiment

Weight : 7000 ton
Length : 46 m
Height : 25 m



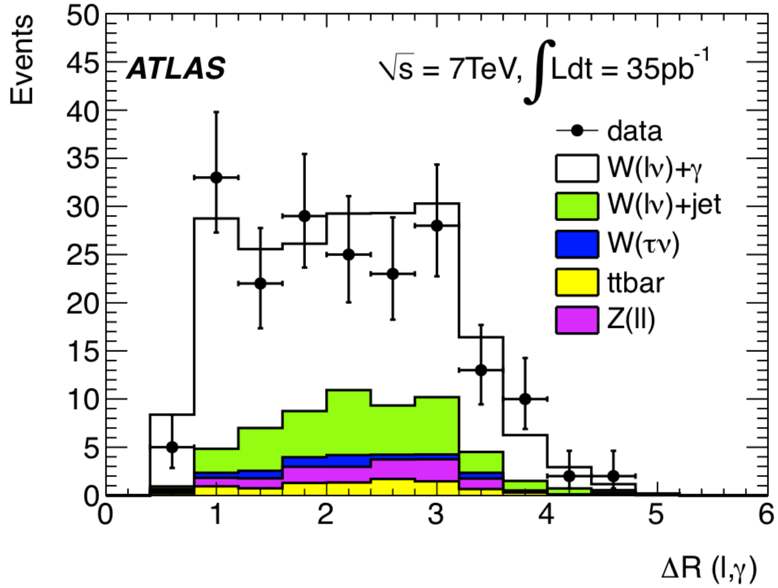
Cross Section

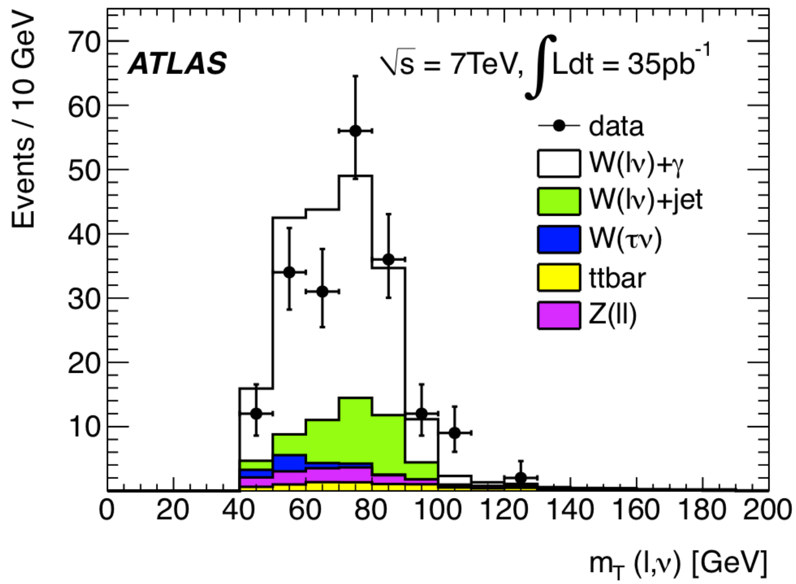
		Experimental measurement	SM prediction	
		σ^{fid}[pb]	σ^{fid}[pb]	
Wγ	$pp \to e^{\pm}\nu\gamma$	$5.4 \pm 0.7 \pm 0.9 \pm 0.2$	4.7 ± 0.3	Fiducial cross section
Wγ	$pp \to \mu^{\pm}\nu\gamma$	$4.4 \pm 0.6 \pm 0.7 \pm 0.2$	4.9 ± 0.3	Fiducial cross section
Zγ	$pp \to e^{+}e^{-}\gamma$	$2.2 \pm 0.6 \pm 0.5 \pm 0.1$	1.7 ± 0.1	Fiducial cross section
Zγ	$pp \to \mu^{+}\mu^{-}\gamma$	$1.4 \pm 0.3 \pm 0.3 \pm 0.1$	1.7 ± 0.1	Fiducial cross section
		σ[pb]	σ[pb]	
Wγ	$pp \to e^{\pm}\nu\gamma$	$48.9 \pm 6.6 \pm 8.3 \pm 1.7$	42.1 ± 2.7	Production cross section
Wγ	$pp \to \mu^{\pm}\nu\gamma$	$38.7 \pm 5.3 \pm 6.4 \pm 1.3$	42.1 ± 2.7	Production cross section
Wγ	$pp \to l^{\pm}\nu\gamma$	$42.5 \pm 4.2 \pm 7.2 \pm 1.4$	42.1 ± 2.7	Production cross section
Zγ	$pp \to e^{+}e^{-}\gamma$	$9.0 \pm 2.5 \pm 2.1 \pm 0.3$	6.9 ± 0.5	Production cross section
Zγ	$pp \to \mu^{+}\mu^{-}\gamma$	$5.6 \pm 1.4 \pm 1.2 \pm 0.2$	6.9 ± 0.5	Production cross section
Zγ	$pp \to l^{+}l^{-}\gamma$	$6.4 \pm 1.2 \pm 1.6 \pm 0.2$	6.9 ± 0.5	Production cross section

$\sigma(W\gamma)/\sigma(Z\gamma)$

Cross section ratio	Experimental measurement	SM prediction	
Fiducial phase space			
$\sigma^{\text{fid}}_{pp\to e^{\pm}\nu\gamma}/\sigma^{\text{fid}}_{pp\to e^{+}e^{-}\gamma}$	$2.5^{+0.8}_{-0.6} \pm 0.5$	2.8 ± 0.3	Fiducial cross section ratio
$\sigma^{\text{fid}}_{pp\to \mu^{\pm}\nu\gamma}/\sigma^{\text{fid}}_{pp\to \mu^{+}\mu^{-}\gamma}$	$3.1^{+1.1}_{-0.8} \pm 0.6$	2.9 ± 0.3	Fiducial cross section ratio
Phase space for production cross section			
$\sigma_{pp\to e^{\pm}\nu\gamma}/\sigma_{pp\to e^{+}e^{-}\gamma}$	$5.4^{+1.8}_{-1.3} \pm 1.2$	6.1 ± 0.2	Production cross section ratio
$\sigma_{pp\to \mu^{\pm}\nu\gamma}/\sigma_{pp\to \mu^{+}\mu^{-}\gamma}$	$6.9^{+2.3}_{-1.7} \pm 1.4$	6.1 ± 0.2	Production cross section ratio
$\sigma_{pp\to l^{\pm}\nu\gamma}/\sigma_{pp\to l^{+}l^{-}\gamma}$	$6.0^{+1.3}_{-1.0} \pm 1.3$	6.1 ± 0.2	Production cross section ratio

Kinematic Distributions of Selected Events (Wγ)





Uncertainties

Electron Channel

Parameter	$\frac{\delta C_{W\gamma}}{C_{W\gamma}}$	$\frac{\delta C_{Z\gamma}}{C_{Z\gamma}}$
Channel	$e^{\pm}\nu\gamma$	$e^{+}e^{-}\gamma$
Trigger efficiency	1%	0.02%
Electron efficiency	4.5%	4.5%
Photon efficiency	10.1%	10.1%
EM scale and resolution	3%	4.5%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution	2%	-
Inoperative readout modeling	1.4%	2.1%
Photon simulation modeling	0.3%	0.3%
Photon isolation efficiency	3.3%	3.3%
Total uncertainty	12.1%	12.5%

Muon Channel

Parameter	$\frac{\delta C_{W\gamma}}{C_{W\gamma}}$	$\frac{\delta C_{Z\gamma}}{C_{Z\gamma}}$
Channel	$\mu^{\pm}\nu\gamma$	$\mu^{+}\mu^{-}\gamma$
Trigger efficiency	0.6%	0.2%
Muon efficiency	0.5%	1%
Muon isolation efficiency	1%	2%
Momentum scale and resolution	0.3%	0.5%
Photon efficiency	10.1%	10.1%
EM scale and resolution	4%	3%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution	2%	-
Inoperative readout modeling	0.7%	0.7%
Photon simulation modeling	0.3%	0.3%
Photon isolation efficiency	3.3%	3.3%
Total uncertainty	11.6%	11.2%

Dominant Uncertainties :

- Photon reconstruction/ID efficiency : ~10% (uncertainty in upstream material and contribution from fragmentation photon)
- Electron reconstruction/ID : ~4.5%
- Electromagnetic energy scale and resolution : ~3 - 4.5%

Table for Cross Section Calculation

	Central value	Statistical uncertainty	Systematic uncertainty	Luminosity uncertainty
	$pp \to e^{\pm}\nu\gamma$			
$N_{W\gamma}^{sig}$	67.8	9.2	7.3	-
$L_{W\gamma}[\text{pb}^{-1}]$	35.1	-	-	1.2
$C_{W\gamma}$	0.359	0.010	0.043	-
$A_{W\gamma}$	0.110	0.001	0.005	-
	$pp \to e^{+}e^{-}\gamma$			
$N_{Z\gamma}^{sig}$	21.3	5.8	3.7	-
$L_{Z\gamma}[\text{pb}^{-1}]$	35.1	-	-	1.2
$C_{Z\gamma}$	0.280	0.010	0.035	-
$A_{Z\gamma}$	0.240	0.002	0.016	-
	$pp \to \mu^{\pm}\nu\gamma$			
$N_{W\gamma}^{sig}$	68.2	9.3	7.4	-
$L_{W\gamma}[\text{pb}^{-1}]$	33.9	-	-	1.2
$C_{W\gamma}$	0.455	0.010	0.053	-
$A_{W\gamma}$	0.114	0.001	0.005	-
	$pp \to \mu^{+}\mu^{-}\gamma$			
$N_{Z\gamma}^{sig}$	19.7	4.8	3.3	-
$L_{Z\gamma}[\text{pb}^{-1}]$	33.9	-	-	1.2
$C_{Z\gamma}$	0.429	0.010	0.048	-
$A_{Z\gamma}$	0.242	0.002	0.016	-

Table 6. Summary of input quantities for the calculation of the $W\gamma$ and $Z\gamma$ fiducial and production cross sections. For each channel, the observed numbers of signal events after background subtraction, the correction factors $C_{W\gamma(Z\gamma)}$, the acceptance factors $A_{W\gamma(Z\gamma)}$ (see Section 8.2), and the integrated luminosities are given, with their statistical, systematic, and luminosity uncertainties. For $C_{W\gamma(Z\gamma)}$ and $A_{W\gamma(Z\gamma)}$, the statistical uncertainty reflects the limited statistic of the signal MC samples.