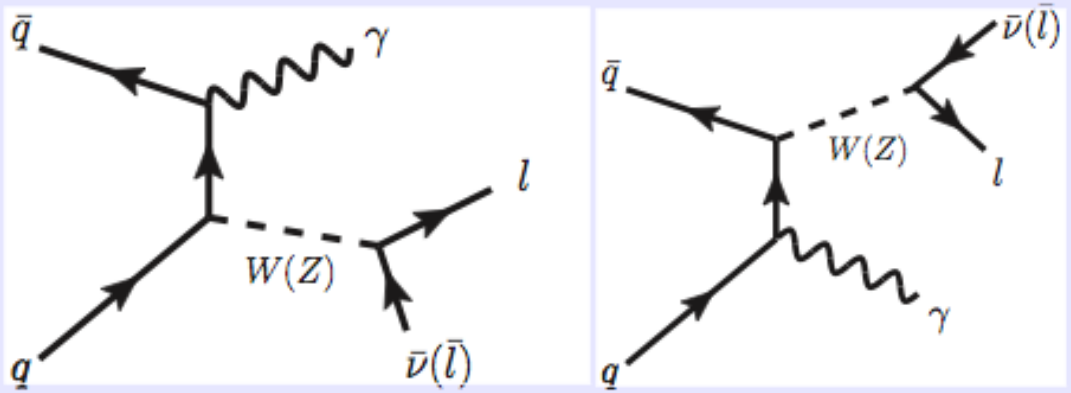
MEASUREMENT OF SM V+GAMMA BY ATLAS

Zhijun Liang
University of Oxford
For the ATLAS Collaboration

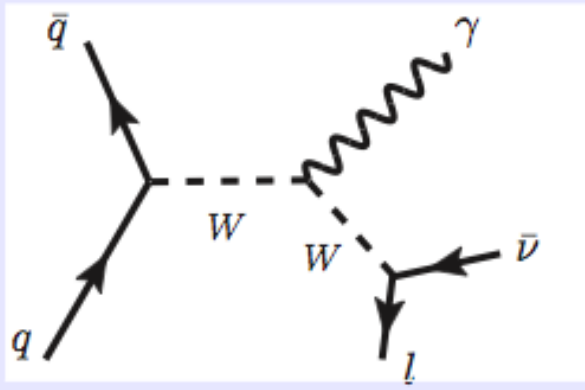
Introduction to Wγ/Zγ physics

- The Wγ and Zγ productions are direct test of the triple gauge boson (TGC) coupling of the Electroweak theory.
  - probing the WW γ TGC (s channel).
  - probing the existence of ZZγ and Zγγ TGC, which is forbidden at tree level in the Standard Model.
  - Highest cross sections among all diboson processes.

Initial State Radiation(ISR)



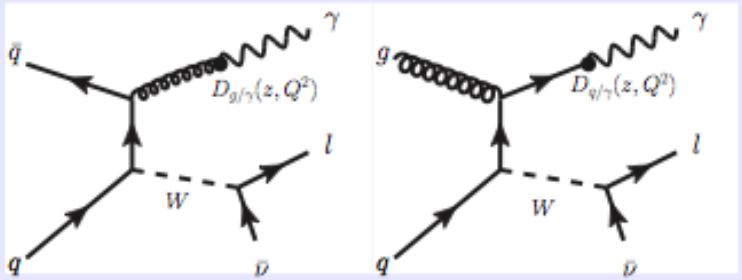
$WW\gamma$ TGC



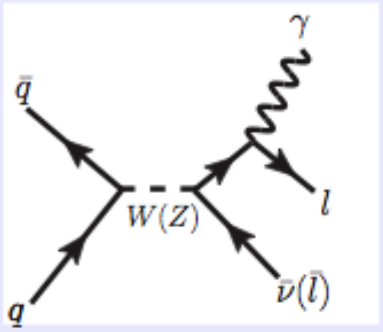
Introduction to Wγ/Zγ physics(2)

- Besides ISR and TGC diagram, other signal contributions include:
  - Final state photon radiation from W(Z) inclusive production.
  - Photons from fragmentation of jets produced in association with a W or a Z boson.
    - Isolated photons from fragmentation/FSR processes are also considered as signal.

Fragmentation Photon Production



FSR



Wγ/Zγ measurements by ATLAS

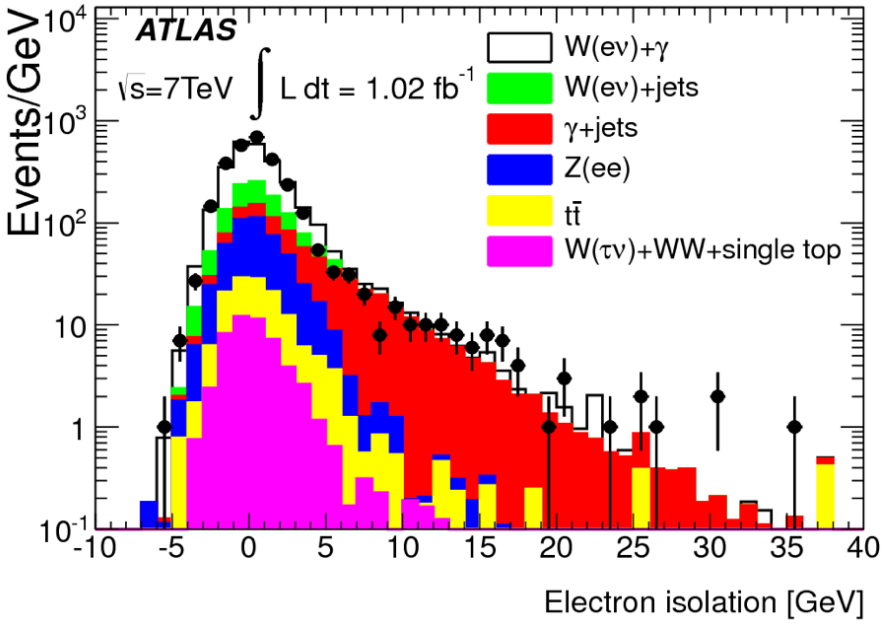
- 2010 , Wγ/Zγ cross section measurement
  - **35pb-1**
  - **JHEP 09 (2011) 072**
- 2011, Wγ/Zγ cross section measurement and Limits on the Anomalous Triple-Gauge-Boson Couplings
  - **1fb^{-1}**
  - **arXiv:1205.2531**
  - **Submitted to PLB**
-

Event selections

Wγ	Zγ
•Trigger : Single lepton trigger, 1.02 fb^{-1}	
• One good electron or muon p_T>25GeV • Missing E_T >25 GeV • Transverse mass M_T(lepton,ν)>40 GeV • Z veto for e channel: |M(e, γ)-M_Z|>10GeV	• Two opposite charged leptons p_T>25GeV • M(l^+,l^-)>40 GeV
Photon Selection Cuts	
• One good isolated photon • E_T>15 GeV, dR(e/μ,γ)>0.7, Isolation <6GeV	
Jet selection cuts (AntiKt4 jet)	
• p_T>30GeV, |η|<4.4 • dR(jet ,γ)>0.6, dR(jet ,leptons)>0.6	

Jet Background estimation

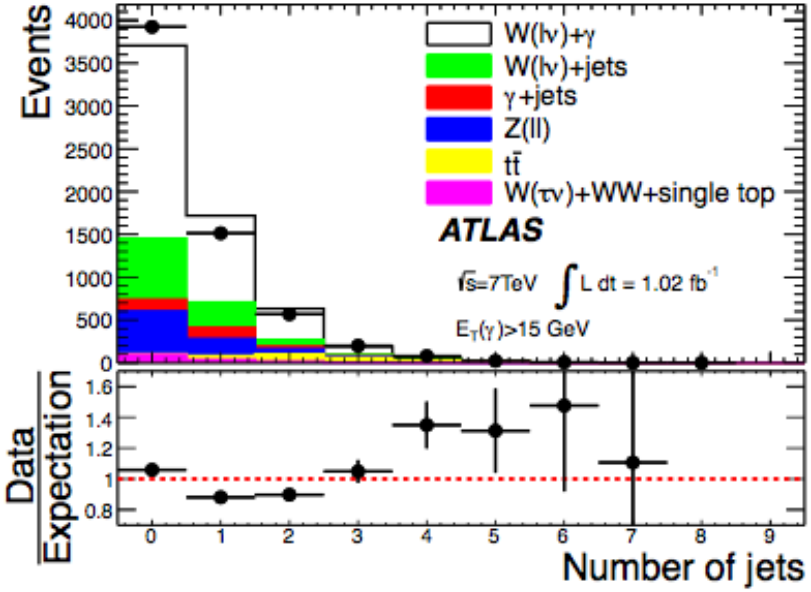
- V+jets and γ+jets backgrounds are estimated from data.
  - Use sideband method based on lepton/photon isolation distribution.



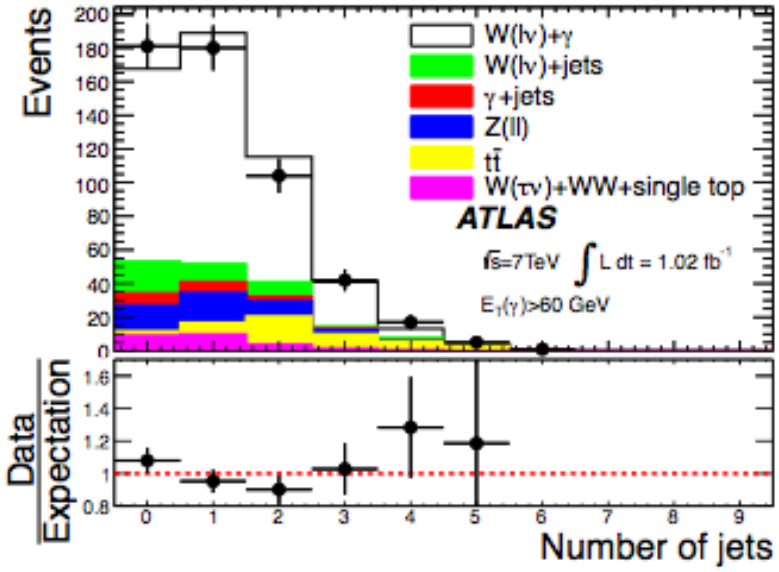
	$pp \to e\nu\gamma$	$pp \to \mu\nu\gamma$
Region	$E_{\mathrm{T}}^{\gamma} > 15$ GeV, $N_{\mathrm{jet}} \geq 0$	
$N_{W\gamma}^{\mathrm{obs}}$	2649	3621
W+jets	439 ± 108	685 ± 162
γ+jets	255 ± 58	67 ± 16
EW	405 ± 53	519 ± 67
$t\bar{t}$	85 ± 11	152 ± 20
$N_{W\gamma}^{\mathrm{sig}}$	1465 ± 139	2198 ± 183

Jet multiplicity in Vγ events

- Jet multiplicity in Wγ candidates increases significantly as photon p_T threshold increases.
- Significant contributions from Wγ+1jet and Wγ+2jets in high photon p_T region.
- MC full simulation can describe the jet multiplicity in data
  - Alpgen are used to generate Wγ+N partons (N=0,1,2,3,4,5)
  - with herwig for parton showering, use Geant4 for detector simulation



Wγ [$p_T(\gamma)$>15GeV]

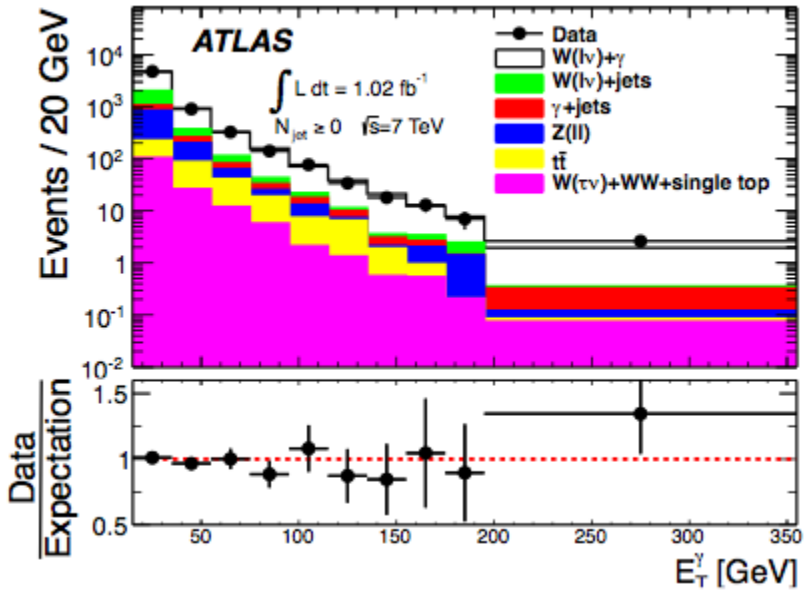


Wγ [$p_T(\gamma)$>60GeV]

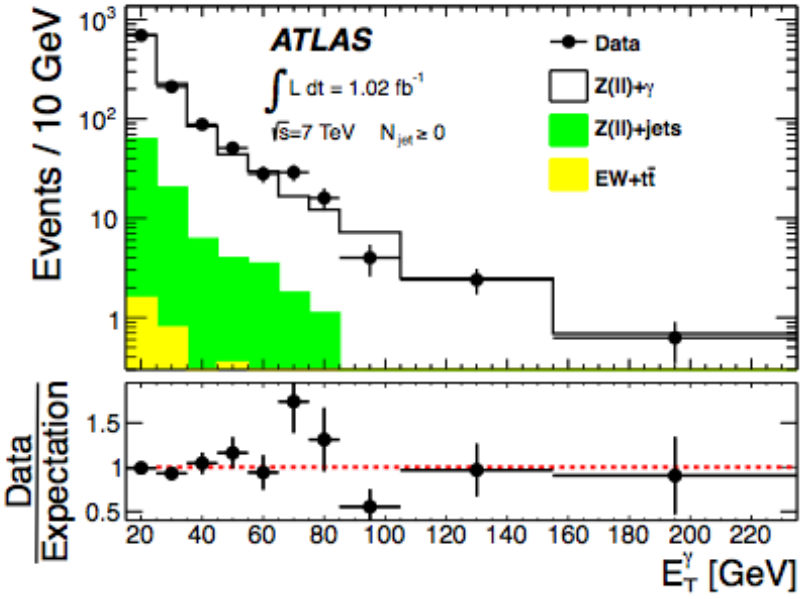
Photon p_T distribution in Vγ candidates

- MC full simulation can describe the Photon p_T distribution.
  - Sherpa Zγ+N partons (N=0,1,2,3) are used for Zγ full simulation.

Wγ



Wγ [Njet>=0]



Zγ [Njet>=0]

Fiducial region of Wγ/Zγ measurement

- Exclusive measurement
  - Fiducial region is defined with hard jet veto in particle levels
  - Apply hard jet veto in offline event selection cuts
- Inclusive measurement: without jet veto
- Three different photon pT threshold.

arXiv:1205.2531

Cuts	$pp \to l\nu\gamma$	$pp \to l^+l^-\gamma$
Lepton	$p_{\mathrm{T}}^{l} > 25$ GeV $p_{\mathrm{T}}^{\nu} > 25$ GeV $\lvert\eta_l\rvert < 2.47$	$p_{\mathrm{T}}^{l} > 25$ GeV $\lvert\eta_l\rvert < 2.47$
Boson		$m_{l^+l^-} > 40$ GeV
Photon	Low E_{T}^{γ}: $E_{\mathrm{T}}^{\gamma} > 15$ GeV Medium E_{T}^{γ}: $E_{\mathrm{T}}^{\gamma} > 60$ GeV High E_{T}^{γ}: $E_{\mathrm{T}}^{\gamma} > 100$ GeV $\lvert\eta^{\gamma}\rvert < 2.37$, $\Delta R(l,\gamma) > 0.7$ photon isolation fraction $\epsilon_h^p < 0.5$	
Jet	$E_{\mathrm{T}}^{\mathrm{jet}} > 30$ GeV, $\lvert\eta^{\mathrm{jet}}\rvert < 4.4$ $\Delta R(e/\mu/\gamma, \mathrm{jet}) > 0.6$ Inclusive : $N^{\mathrm{jet}} \geq 0$, Exclusive : $N^{\mathrm{jet}} = 0$	

Cross section measurement methods

Fiducial cross section

- Performed within phase space defined by kinematic cuts of event selection in analysis.
- $\sigma^{fid}_{W\gamma(Z\gamma)} = \frac{N^{sig}_{W\gamma(Z\gamma)}}{C_{W\gamma(Z\gamma)} \cdot L_{W\gamma(Z\gamma)}}$
  - $N^{sig}_{W\gamma(Z\gamma)}$ is the number of the extracted signal events
  - $C_{W\gamma(Z\gamma)}$ summarizes the reconstruction and identification efficiency for signal events

Total cross section

- Extrapolating from fiducial phase space to full W/Z decay space.
- $\sigma^{total}_{W\gamma(Z\gamma)} = \frac{\sigma^{fid}_{W\gamma(Z\gamma)}}{A_{W\gamma(Z\gamma)}}$
- $A_{W\gamma(Z\gamma)}$ is acceptance of total phase space respect to fiducial one.
- Use full simulation Monte Carlo to calculate the acceptance.

Main Systematics

- Main Systematics
  - Photon Identification efficiency:
    - 10% in low pT region, 4% in high pT region
  - Photon isolation efficiency : 3%
  - Jet energy scale uncertainty (for exclusive measurement): 5%

Vγ Cross section predictions

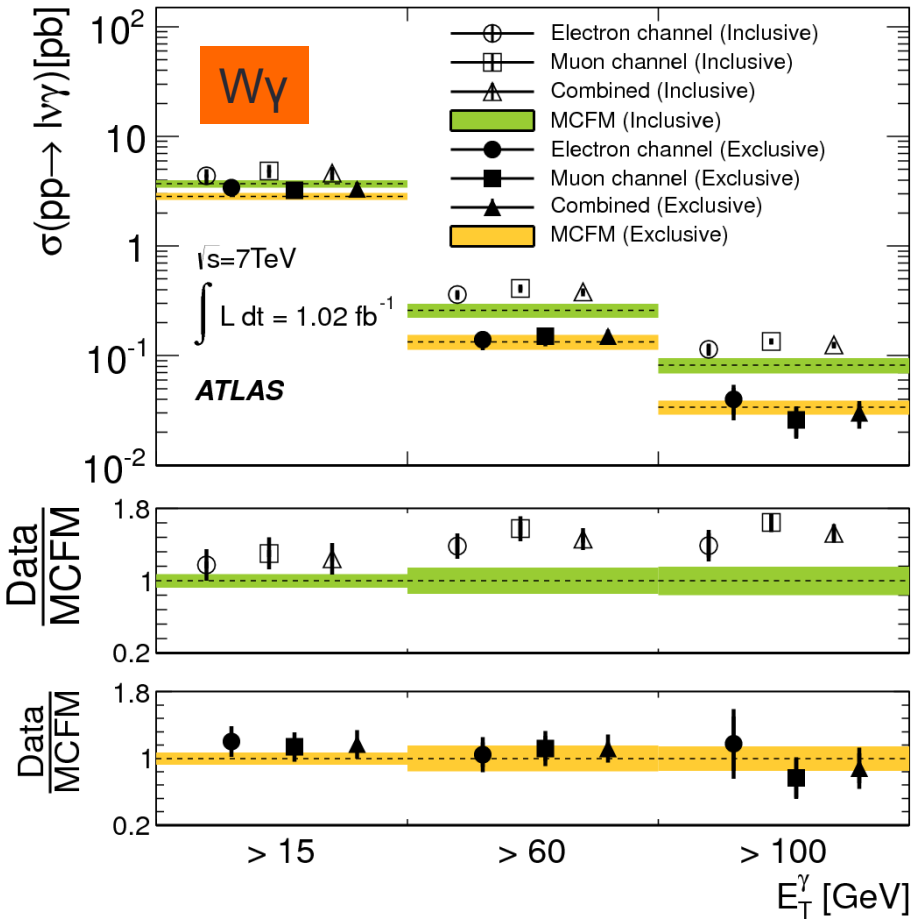
- Parton level NLO cross section predictions are from MCFM 6.1
- These predictions are corrected for photon isolation and jet definitions difference between parton and particle level:
  - Parton level isolation: (sum of partons energy around cone 0.4 of photons)/ (photon energy)
  - Particle level isolation: (sum of stable truth particles energy around cone 0.4 of photons)/ (photon energy)
  - Parton level jets defintion : hard partons above jet pT threshold
  - Particle level jets : AntiKt 4 truth jet built from stable truth particles above pT threshold
- Parton to particle level corrections factors are taken from Vγ full simulation samples (Alpgen for Wγ, Sherpa for Zγ).

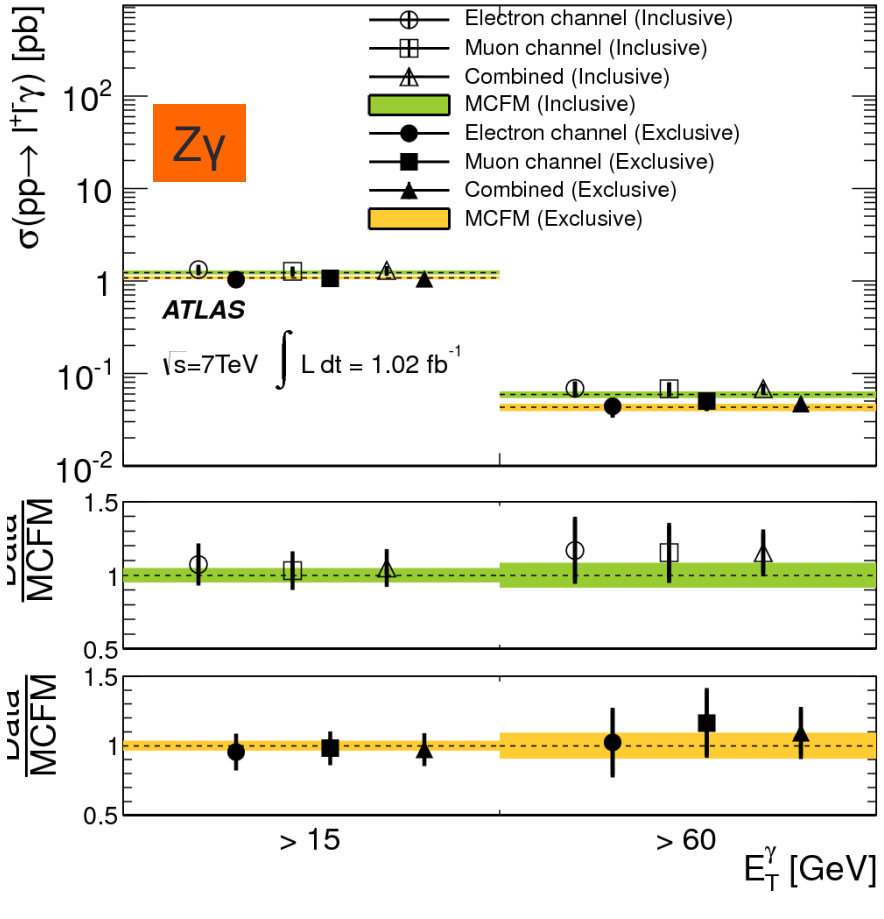
Channel	E_{T}^{γ} (GeV)	Cross section exclusive	Cross section inclusive
$pp \to l^{\pm}\nu\gamma$	> 15	2.84±0.20 pb (2.61±0.16 pb)	3.70±0.28 pb (3.58±0.26 pb)
$pp \to l^{\pm}\nu\gamma$	> 60	134±21 fb (118±16 fb)	260±38 fb (255±35 fb)
$pp \to l^{\pm}\nu\gamma$	> 100	34±5 fb (31± 4 fb)	82±13 fb (80±12 fb)
$pp \to l^{+}\, l^{-}\gamma$	> 15	1.08±0.04 pb (1.03 ± 0.04 pb)	1.23±0.06 pb (1.22±0.05 pb)
$pp \to l^{+}\, l^{-}\gamma$	> 60	43±4 fb (40±3 fb)	59±5 fb (58±5 fb)

Particle level prediction
(Parton level prediction)

Fiducial cross section measurement

- Inclusive phase space: MCFM based cross section predictions are 30%~40% lower than the measurement in high photon pT region in Wγ process.
- Exclusive phase space:
  - MCFM predictions agrees better with measurement after jet veto selections in Vγ processes.





Future plan

- Wγ
  - Missing ET cuts need to increase to 35GeV for rejecting Z background.
  - Z veto for e channel: $|M(e, \gamma)-M_Z|>15$ GeV
  - Lepton + photon trigger is used for 8TeV analysis
  - Plan to provide more measurement on event shape (unfolded spectrum)
    - Jet multiplicity
    - $|\eta_{lepton}-\eta_{\gamma}|$
- Zγ
  - Use di-leptons trigger in 8TeV analysis
  - Apply $\Delta R(l^+;l^-)>0.3$ in offline selection and fiducial volume
    - to avoid the acceptance lost due to highly boosted Z.
    - Lepton reconstruction efficiency goes down in low $\Delta R(l^+;l^-)$ region.

Wish list

- NNLO calculation for Vγ processes.
  - Especially for Wγ process.
- NLO calculation for Vγ+1jet / Vγ+2jet
- NLO generator of W+2photons and other triboson processes.
- NLO parton shower Monte Carlo for Vγ processes
  - Jet veto is needed for Vγ aTGC study.
  - Very important to have NLO predictions in particle level.
  - aMC@NLO is a good candidate.

Summary

- Inclusive and exclusive (with jet veto) fiducial measurement for Vγ processes have been performed based on 1fb^{-1} data collected by ATLAS.
- Observe significant contributions from events with high jet multiplicity in Wγ process.

- MCFM based NLO cross section predictions are 30~40% lower than the inclusive measurement for Wγ process.
  - MCFM predictions agrees better with exclusive measurement for Wγ process after jet veto selections are applied.
- Wish for higher order calculations (NNLO or beyond) for Vγ processes.