中国科学技术大学

University of Science & Technology of China (USTC)

W/Z+γ Measurement @ ATLAS

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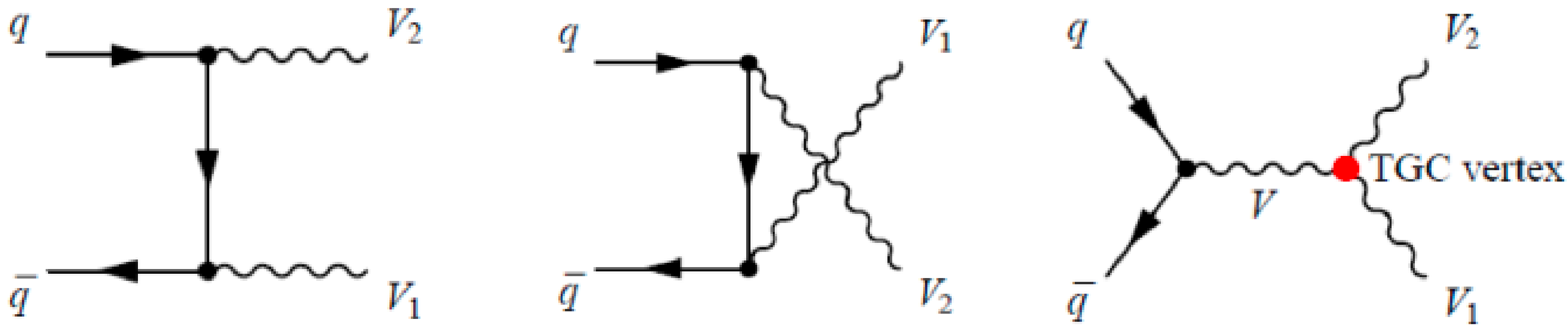
University of Science & Technology of China (USTC)

On behalf of ATLAS Collaboration

ICHEP2012

Melbourne, Australia

Physics Motivations



- Di-Boson production cross-sections are sensitive to the coupling of the triple gauge-boson vertices (TGCs)
  - Provide direct test of SM predictions
  - WWγ and WWZ vertices are predicted and have been measured
  - ZZγ, ZγZ, Zγγ and ZZZ vertices are forbidden
- The presence of new physics could:
  - Give anomalous Triple Gauge Couplings (aTGC)
  - Modify cross-sections and/or kinematic distributions
- Backgrounds to the searches of Higgs and new physics

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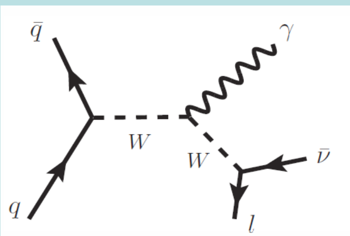
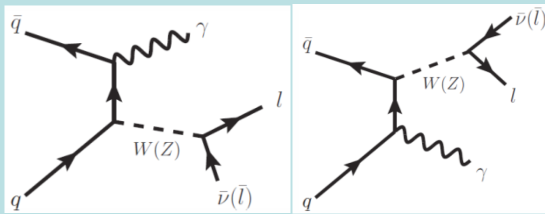
Motivation of Wγ, Zγ

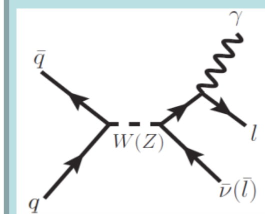
➢ **W($l\nu$)/Z(ll)+γ production measurement:**



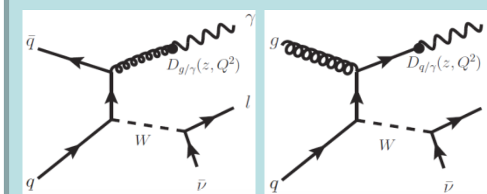
s-channel TGC



ISR: t/u-channel



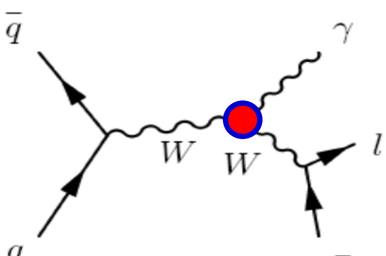
FSR



gluon/quark fragmentation

➢ **Searching anomalous triple gauge couplings (aTGC):**

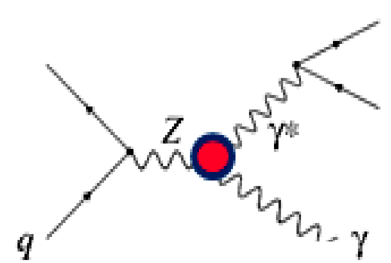
- **W magnetic dipole and electric quadrupole moment**



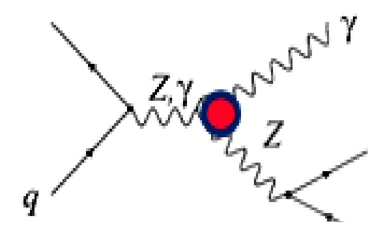
$$\begin{cases} \mu_W = \dfrac{e}{2M_W}(2+\Delta\kappa_\gamma+\lambda_\gamma) \\ Q_W = -\dfrac{e}{M_W^2}(1+\Delta\kappa_\gamma-\lambda_\gamma) \end{cases}$$

WWγ aTGC: $\Delta\kappa_\gamma$, λ_γ

- ***ZZγ/Zγγ*** **prohibited by SM**



Zγγ aTGC: $h^\gamma_{3/4}$



ZZγ aTGC: $h^Z_{3/4}$

- **Prior-LHC results**
  + D0, 4.2fb^{-1} Wγ, PRL107(2011)241803
  + CDF, 5fb^{-1} Zγ, PRL107(2011)051802
  + D0, 6.2fb^{-1} Zγ, PRD85(2012)052001

Background

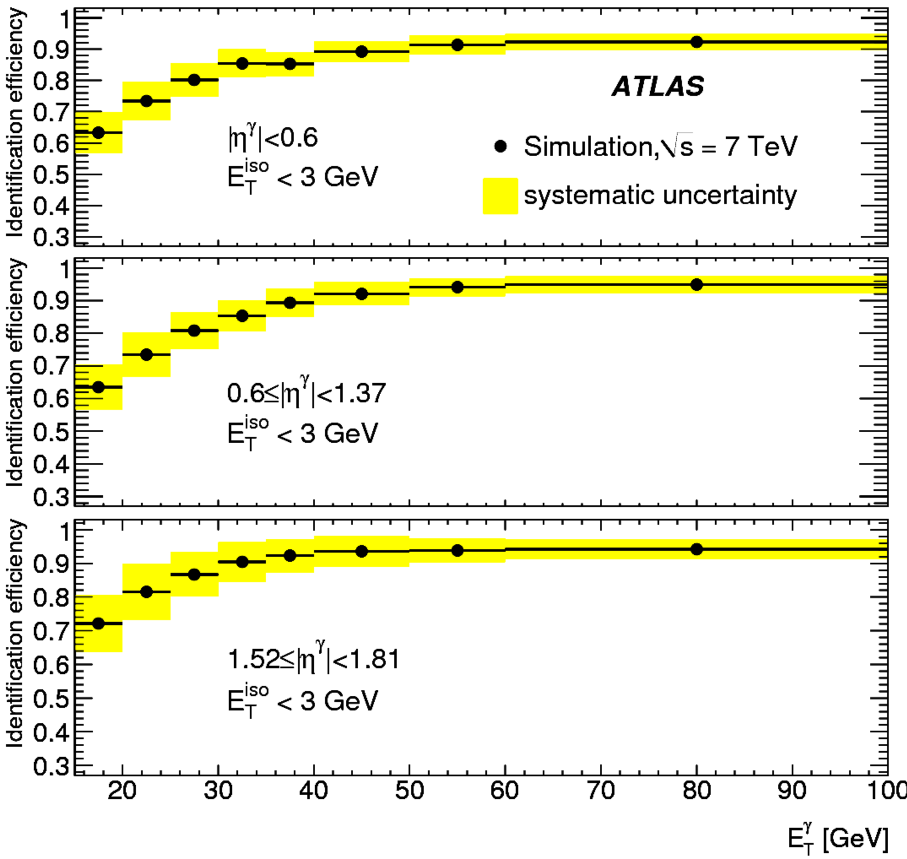
- Z/W+jets: photon from the jet (mainly $\pi0 \rightarrow \gamma\gamma$)
  → data driven method
- Diboson backgrounds: ZZ, WW, WZ → MC
- Top background → MC
- γ+jets: fake lepton from jet and mis-measured ETmiss (Wγ analysis only) → data driven method

Event Selection

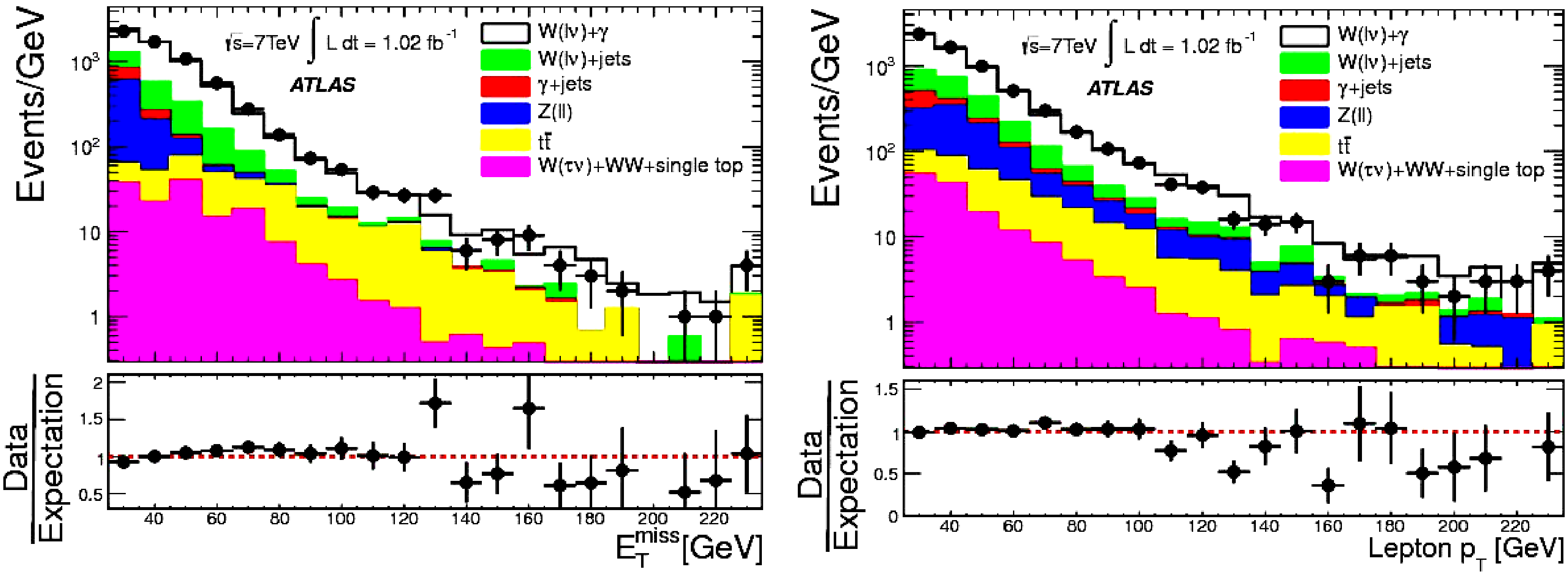
- ✓ *ATLAS 35pb^{-1} result as* **JHEP 1109,072**
- ✓ *ATLAS 1.02fb^{-1} result as* **arXiv:1205.2531**

➢ **ATLAS 7TeV 1fb^{-1} (35pb^{-1}) data:**

- **Lepton :**
  - + e/μ p_T>25GeV, detector fiducial |η| coverage; isolated in calorimeter;
  - + Tight electron identification
- **W/Z events** : MET>25GeV, MT($l\nu$)>40GeV; M(ll)>40GeV
- **Photon :**
  - + p_T>15GeV,
  - + | η |< 1.37 or 1.52 <| η |< 2.37
  - + Isolated in calorimeter
  - + Tight photon identification
  - + FSR suppression dR(l,γ)>0.7
  - + Simulation corrected to *Z→llγ data*
- **Jet** : p_T>30GeV, |η|<4.4, dR(j,γ/*lepton*)>0.6
  → Inclusive (>=0jet) vs.
  Exclusive (==0jet)



W($l\nu$)+γ control plot

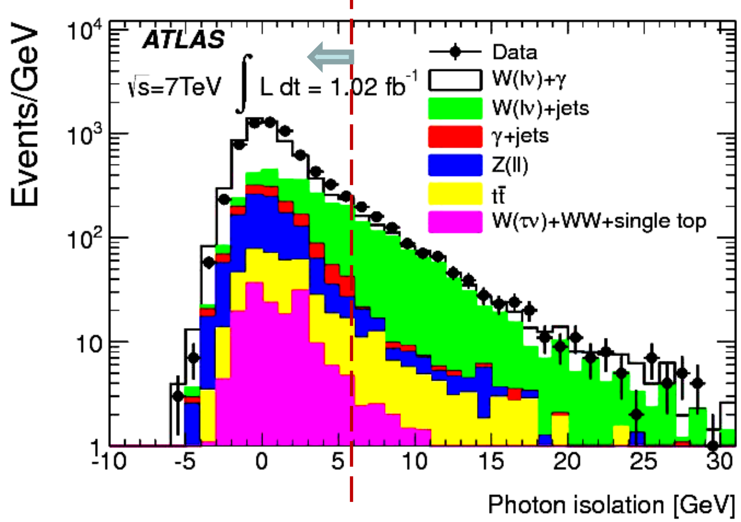


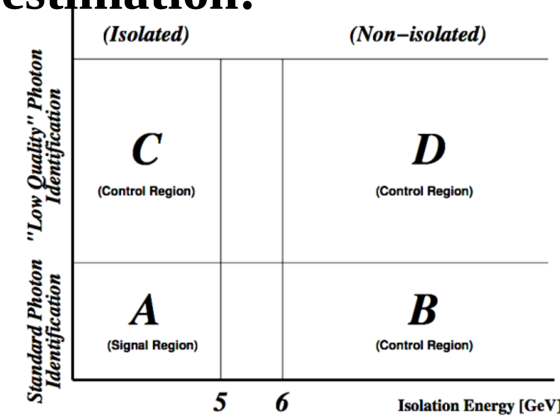
- **Electroweak background derived from simulation**
- **Dominant background, *W+jet* has to be estimated from data**

W/Z+jet background

- **Data driven: 2D sideband *jet*→ "γ" background estimation:**

  - **Photon Identification: based on calorimeter shower-shape**
  - **Photon Isolation:** $$IsoE_T^{30} = \left[\sum_{dR<0.3} E_T^i\right] - E_T^\gamma$$





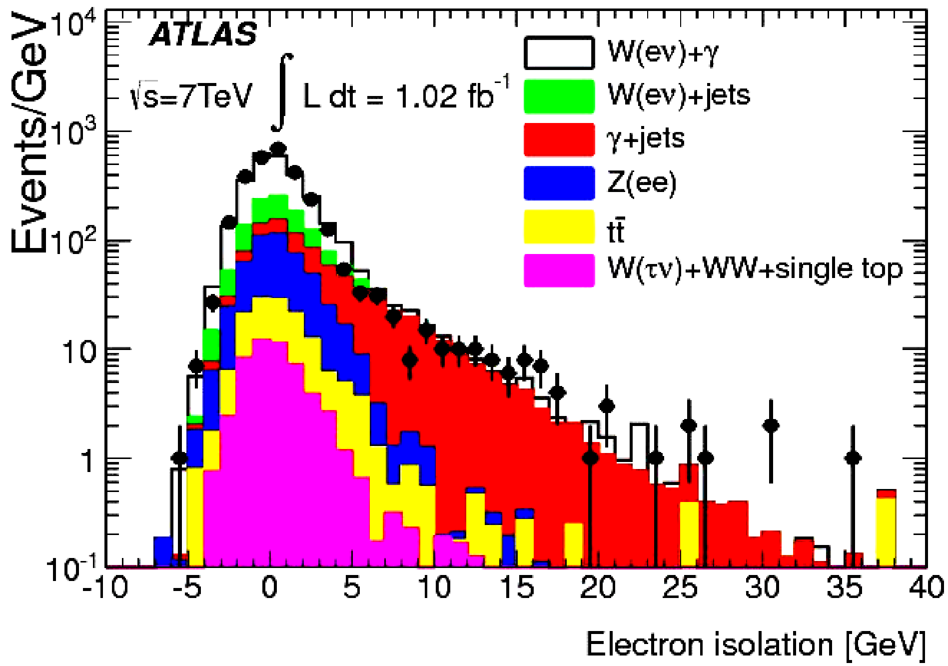
$$N_A = N_A^{W\gamma} + N_A^{Wjet}$$

$$N_{B/C/D} = N_{B/C/D}^{Wjet}$$

$$N_A^{Wjet} = N_B^{Wjet} \cdot \frac{N_C^{Wjet}}{N_D^{Wjet}}$$

Jet+γ background in *Wγ*

- **Date-driven *jet*→ "*e*/*μ*" estimation:**
  1) **jet+γ : real γ; non-isolated letpon from heavy b/c decay;**
  2) **Control region : MET<20GeV to extract faked "*e*/*μ*" isolation shape**

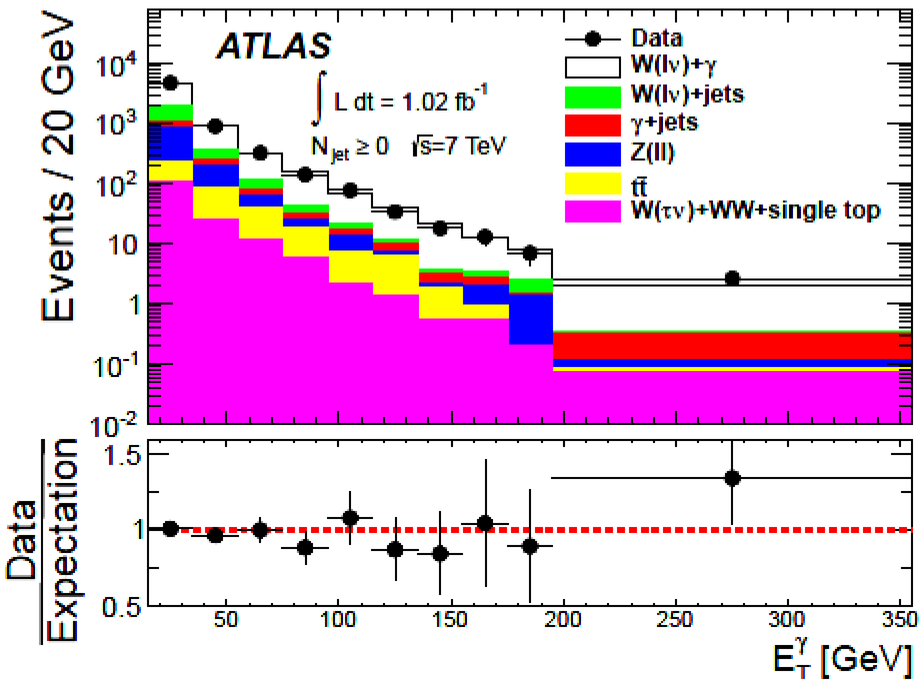


W(eν)γ :MET vs. isolation 2-d sideband

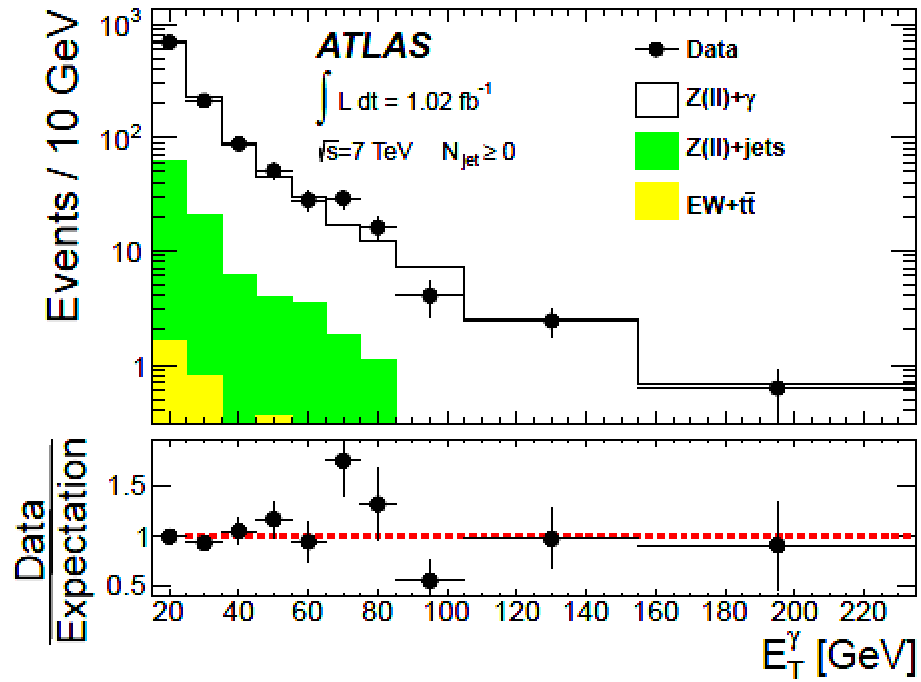
Signal event yield

- **Photon E_T spectrum:**

$W(l\nu)\gamma$ inclusive



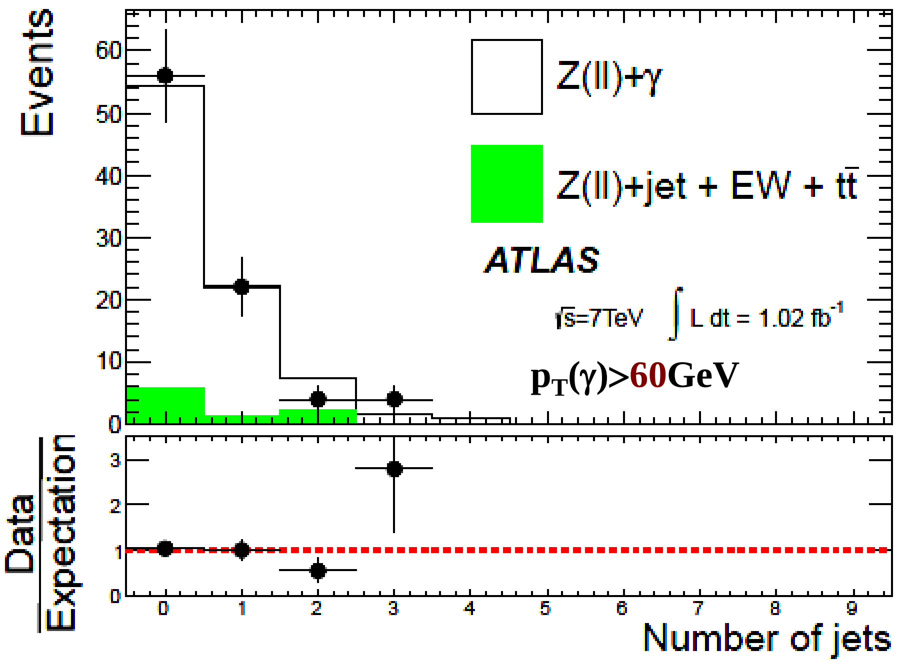
$Z(ll)\gamma$ inclusive



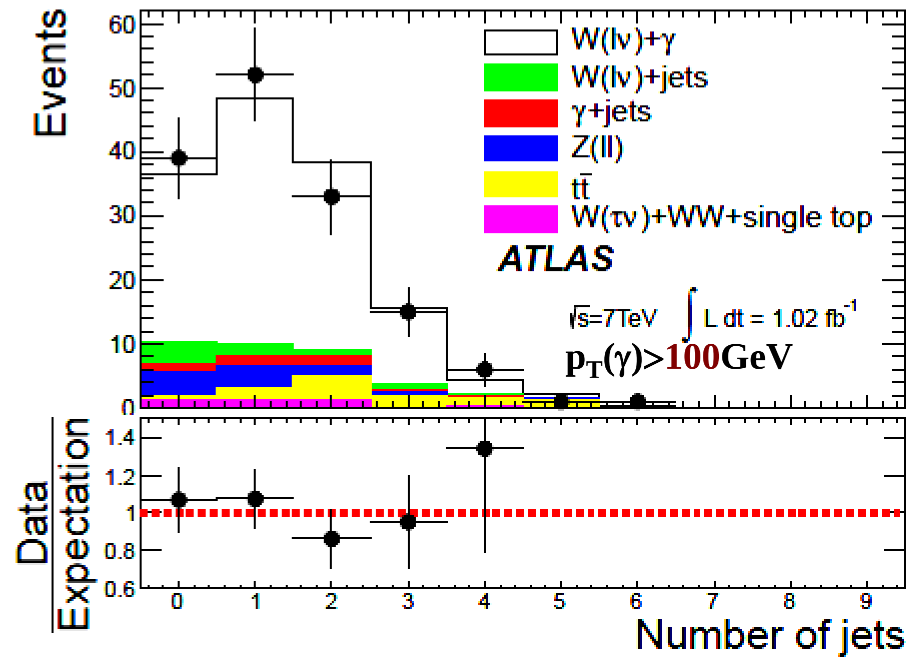
* Signal distribution normalized to the number of extracted data

- **Number of jet distribution:**

$Z(ll)\gamma$: $p_T(\gamma)$>60GeV



$W(l\nu)\gamma$: $p_T(\gamma)$>100GeV



Inclusive (>=0jet) vs. Exclusive (==0jet)

Cross section measurement

$$\sigma^{\mathrm{ext-fid}}_{pp\to l\nu\gamma(l^+l^-\gamma)} = \frac{N^{\mathrm{sig}}_{W\gamma(Z\gamma)}}{A_{W\gamma(Z\gamma)} \cdot C_{W\gamma(Z\gamma)} \cdot L}$$

- $C_{W\gamma}$ ($C_{Z\gamma}$): Correction factor→reconstruction efficiency with fiducial selection requirements (trigger, rec. PID, event selection)
- $A_{W\gamma}$ ($A_{Z\gamma}$): acceptances with geometrical and kinematic constraints of fiducial cross section at particle level
- L: Integrated luminosity: **1.024fb^{-1}± 3.8%**
- **Unfold detection efficiency:**

- Systematic δ_C~ 10 %, dominated by photon identification & jet energy scale
- Correction factor $C_{W\gamma(Z\gamma)}$ ~ 40 - 60%

$$\sigma^{fid}_{pp\to l\nu\gamma(ll\gamma)} = \frac{N^{sig}_{W\gamma(Z\gamma)}}{C_{W\gamma(Z\gamma)} \cdot L_{W\gamma(Z\gamma)}}$$

$$\sigma^{ext\,fid}_{pp\to l\nu\gamma(ll\gamma)} = \frac{\sigma^{fid}_{pp\to l\nu\gamma(ll\gamma)}}{A_{W\gamma(Z\gamma)}}$$

- **Unfold for detector acceptance :**

  - $$A_{W(Z)\gamma} = \frac{N_{fiducial}}{N_{extented\_fidual}}$$

    Estimated from **Alpgen/Sherpa**

+ **Extend detector fiducial to a uniform lepton |η| coverage**

+ **Theoretical uncertainty on acceptance**

$\delta_{Theo.} \sim$ **1-3%**

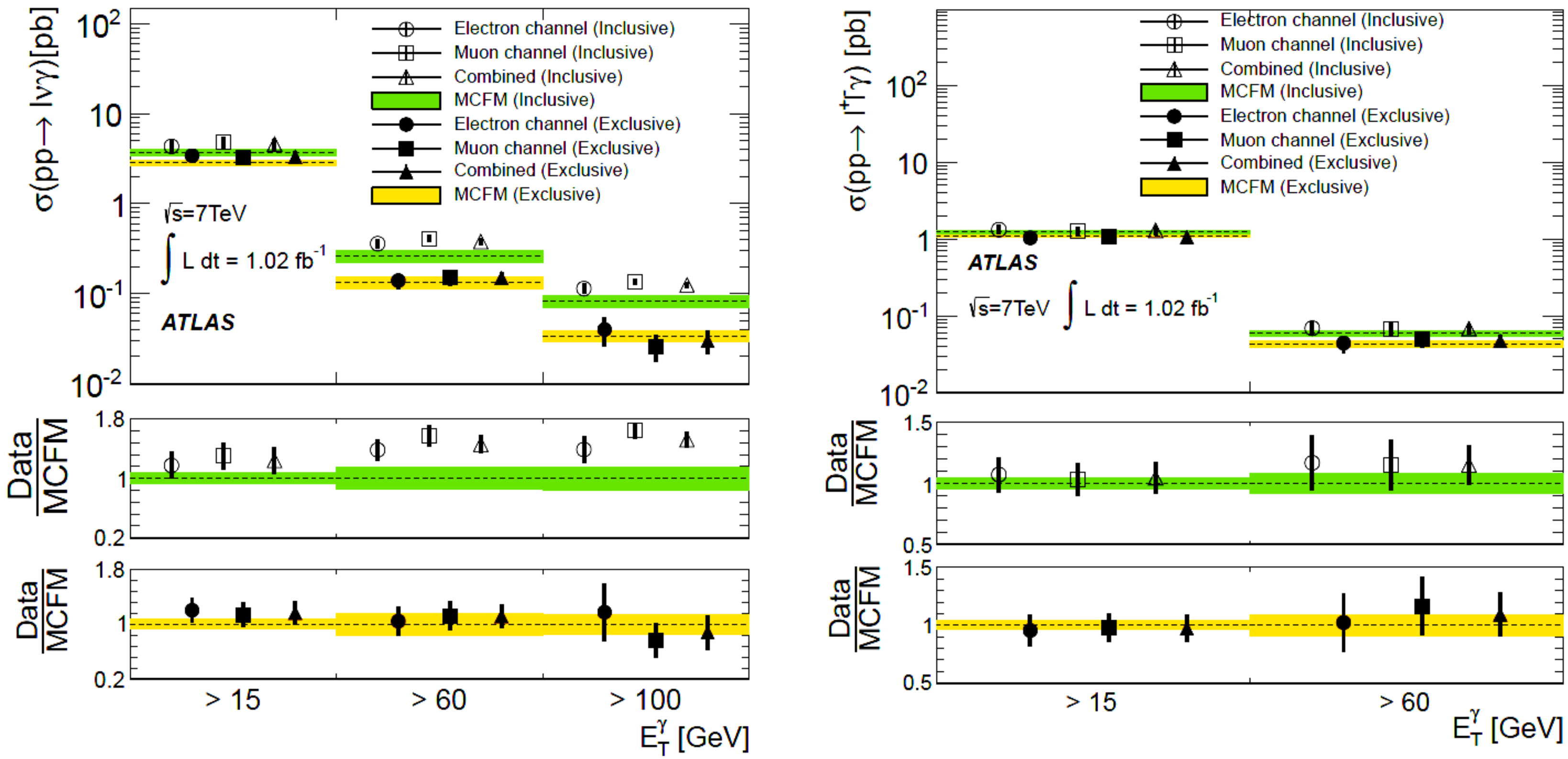
- **Compare to SM prediction:**

  - $$\sigma^{ext\,fid}_{pp\to l\nu\gamma(ll\gamma)} = \frac{\sigma^{fid}_{pp\to l\nu\gamma(ll\gamma)}}{A_{W\gamma(Z\gamma)}}$$

    Compared against **MCFM** (ISR + FSR + QCD NLO)

Differential cross sections

1) **Photon p_T>15,60,100GeV**; 2) **Inclusive** (≥0jet) vs. **Exclusive** (=0jet)



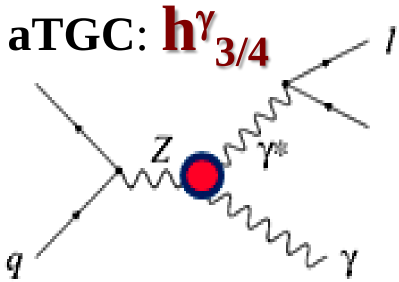
- **The Exclusive measurements are consistent with MCFM predictions (SM NLO)**
- **The Wγ Inclusive are higher than MCFM, especially in high $p_T(\gamma)$ region**
  → high order effects (NNLO and beyond)

Anomalous couplings

+ **aTGC $h^V_{3/4}$: *ZVγ* electric dipole / magnetic quadrupole transition moment**

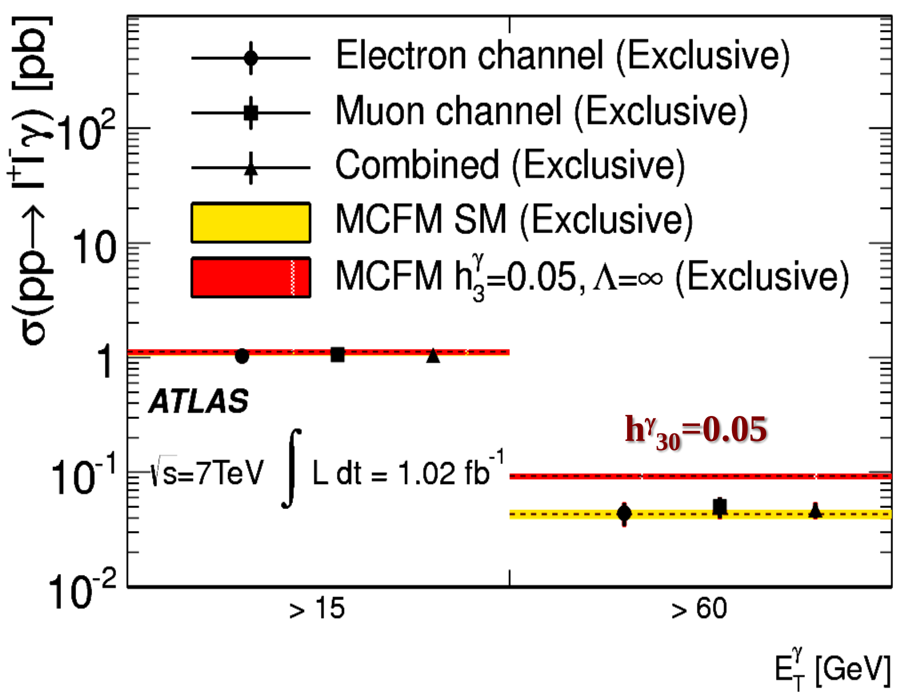
+ **non-zero aTGC will result in increasing of W/Z+γ cross section, especially in high photon p_T region**

Zγγ aTGC: $h^\gamma_{3/4}$



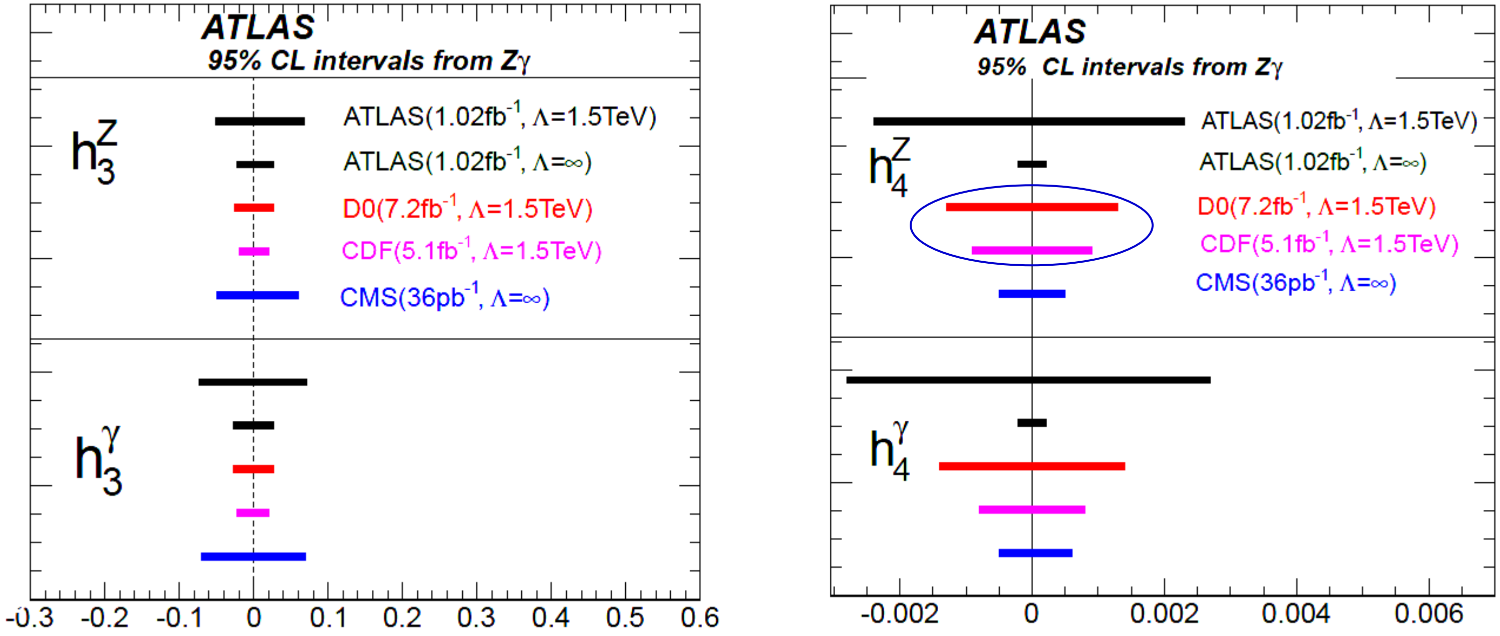
ZZγ aTGC: $h^Z_{3/4}$

$$h_i^V = \frac{h_{i0}^V}{(1+\hat{s}/\Lambda^2)^n}$$



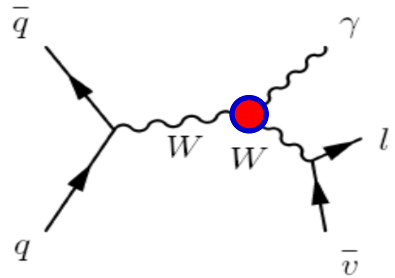
➢ Extract *ZVγ* aTGC:

+ Exclusive $E_T(\gamma)>60GeV$ measurement $\sigma_{Z\gamma}^{obs}$ against aTGC hypotheses $\sigma_{Z\gamma}^{aTGC}$



+ Bayesian probability with nuisance parameters to set limits

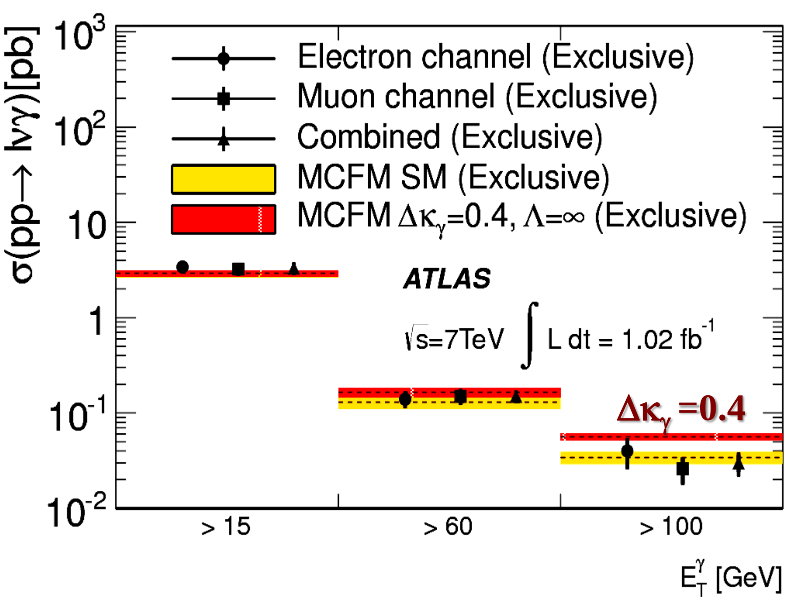
- **Extract *WWγ* aTGC:**

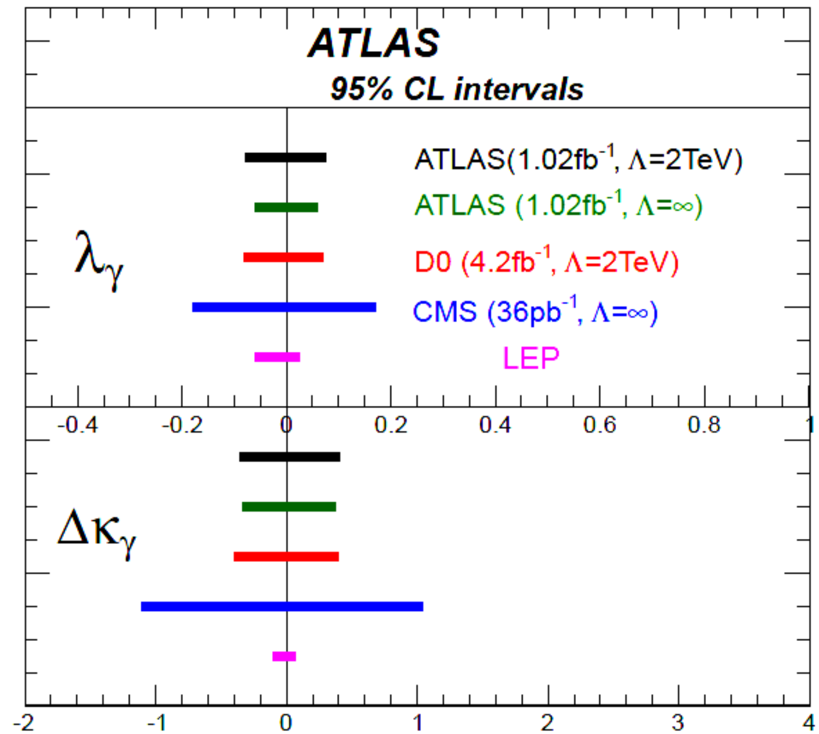


WWγ aTGC: $\Delta\kappa_\gamma$, λ_γ

Exclusive *$E_T(\gamma)$>100GeV* measurement $\sigma^{obs}_{W\gamma}$

against aTGC $\sigma^{aTGC}_{W\gamma}$ hypotheses





Summary

- **The differential cross section *W(lν)γ/Z(ll)γ* measured @ 1fb^{-1} 7TeV ATLAS:**
  - **Exclusive (=0jet) measurement is consistent with SM NLO**
  - **High order effect (NNLO and beyond) is observed in Wγ inclusive (≥0jet) data, especially in high photon $p_T(\gamma)$>60GeV region**
- **Limits on anomalous TGC couplings derived from high photon pT spectrum**
  - **WWγ aTGC results better than the existing Tevatron limits**

Table 52: The list of systematics uncertainties used in aTGC limits setting in $Z\gamma$ analysis. The uncertainties due to QCD scale dependence is mentioned in Section 7.3.3. The addtional systematics due to the potential loss in low $dR(l^+, l^-)$ has been discussed in Section 7.3.2.

systematics	fractional uncertainty(e channel)	fractional uncertainty(μ channel)
Trigger efficiency	0.02%	1.0%
electron reco efficiency	1.0%	
electron ID efficiency	2.2%	
electron iso efficiency	1.0%	
muon ID efficiency		1.4%
Momentum scale and resolution		0.3%
photon ID efficiency	4.3%	4.3%
photon isolation efficiency	2.0%	2.0%
EM scale and resolution	2.2%	1.5%
Jet scale	4.5%	3.8%
Jet resolution	1.0%	1.0%
luminosity	3.7%	3.7%
background	81.0%	76.0 %
$A_{W\gamma} * C_{W\gamma}$ within aTGC sample	15.0%	15.0%
uncertainty for $h_{30}^{\gamma/Z}$ due to accptance loss in $dR(l^+, l^-) < 0.3$ phase space	16.0%	16.0%
uncertainty for $h_{40}^{\gamma/Z}$ due to accptance loss in $dR(l^+, l^-) < 0.3$ phase space	40.0%	40.0%
theoretical		
QCD scale dependence in aTGC grid for $h_{40}^{\gamma/Z}$	8.0%	8.0%
QCD scale dependence in aTGC grid for $h_{30}^{\gamma/Z}$	4.0%	4.0%
PDF	3.4%	3.4%

Table 56: The systematics used in $W\gamma$ aTGC limits setting. The uncertainties due to QCD scale dependence is mentioned in Section 8.3.

systematics	fractional uncertainty(e channel)	fractional uncertainty(μ channel)
Trigger efficiency	0.5%	1.0%
electron reco efficiency	0.7%	
electron ID efficiency	1.5%	
electron iso efficiency	1.0%	
muon ID efficiency		0.7%
Momentum scale and resolution		1.0%
photon ID efficiency	4.3%	4.3%
photon isolation efficiency	2.5%	2.5%
EM scale and resolution	2.5%	1.5%
Jet scale	4.8%	6.8%
Jet resolution	1.0%	1.0%
luminosity	3.7%	3.7%
background	45.0%	17.0 %
MET scale/resolution uncertainty	3.2%	3.0%
$A_{W\gamma} * C_{W\gamma}$ within aTGC sample	11.0%	11.0%
theoretical		
QCD scale dependence in aTGC grid for λ	6.0%	6.0%
QCD scale dependence in aTGC grid for $\Delta\kappa$	4.0%	4.0%
PDF	4.6%	4.6%

Signal event yield

- $W(l\nu)\gamma$:

	$pp \to e\nu\gamma$	$pp \to \mu\nu\gamma$	$pp \to e\nu\gamma$	$pp \to \mu\nu\gamma$
Region	$E_T^\gamma > 15$ GeV $N_{jet} \geq 0$		$E_T^\gamma > 15$ GeV $N_{jet} = 0$	
$N_{W\gamma}^{obs}$	2649	3621	1666	2238
W+jets	439 ± 108	685 ± 162	242 ± 68	473 ± 128
γ+jets	255 ± 58	67 ± 16	119 ± 34	28.9 ± 7.4
EW	405 ± 53	519 ± 67	229 ± 30	366 ± 48
$t\bar{t}$	85 ± 11	152 ± 20	1.6 ± 0.4	8.1 ± 1.3
$N_{W\gamma}^{sig}$	1465 ± 139	2198 ± 183	1074 ± 91	1362 ± 145

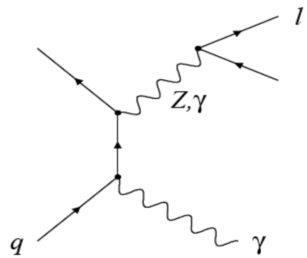
- Dominate background as **W+jet**("**γ**"), **γ+jet** ("**e**"), **Z(*ll*)**

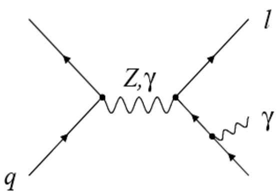
- $Z(ll)\gamma$:

	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$
Region	$E_T^\gamma > 15$ GeV $N_{jet} \geq 0$		$E_T^\gamma > 15$ GeV $N_{jet} = 0$	
$N_{Z\gamma}^{obs}$	514	634	376	495
$N_{Z\gamma}^{BG}$	43.7 ± 16.5	56.8 ± 16.2	29.3 ± 11.0	39.3 ± 15.8
$N_{Z\gamma}^{sig}$	471 ± 28	578 ± 29	347 ± 22	456 ± 27

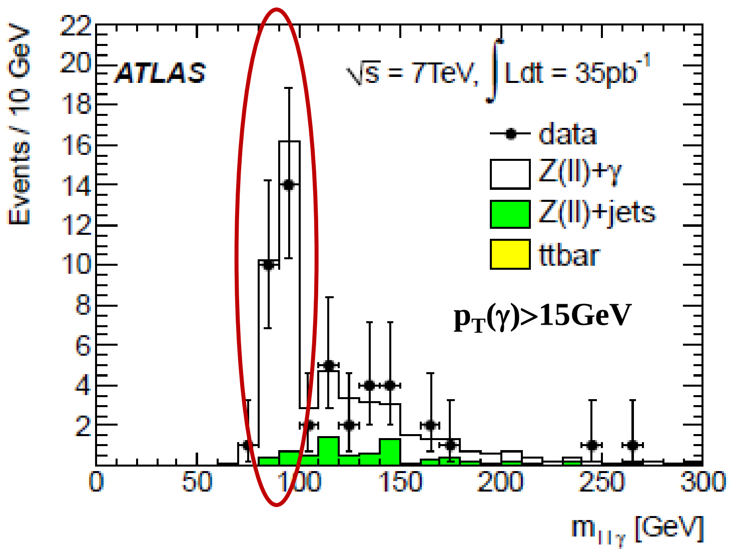
- Dominate background as **Z+jet**

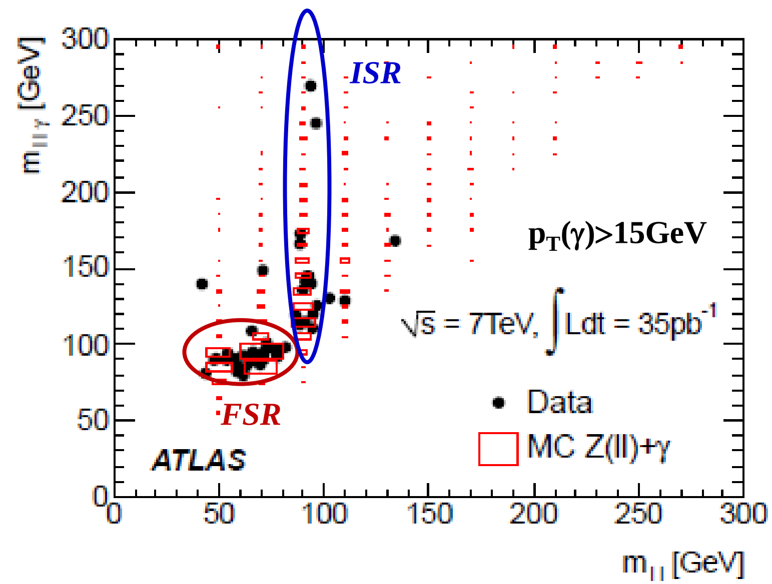
- **ISR/FSR vs. $p_T(\gamma)$ cut:**





ISR: $M(ll\gamma) > M_Z$ **FSR: $M(ll\gamma) \leq M_Z$**





High photon p_T cut to suppress FSR as

$Z\gamma$: $p_T(\gamma)>15$, 60GeV; $W\gamma$: $p_T(\gamma)>15$, 60, 100GeV