中国科学技术大学

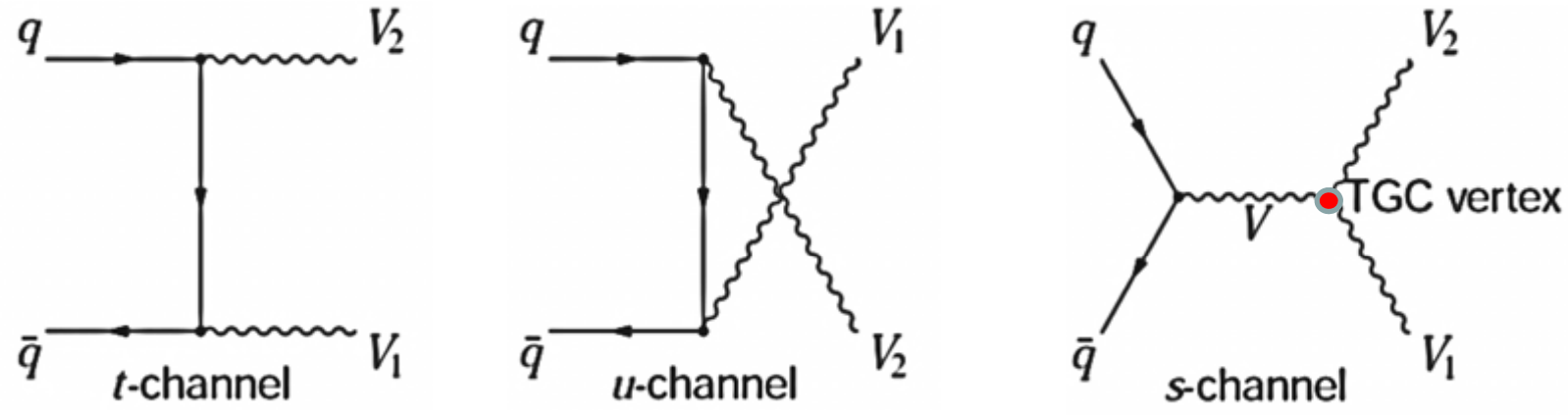
University of Science & Technology of China (USTC)

Di-boson production @ ATLAS

HAN, Liang

Modern Physics Department, USTC

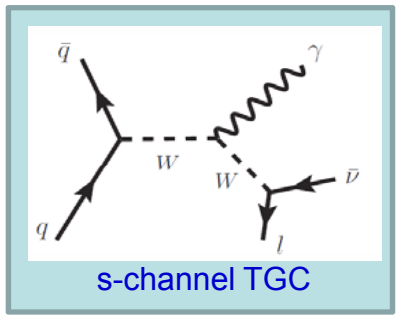
7th China TeV Workshop
Tsinghua University

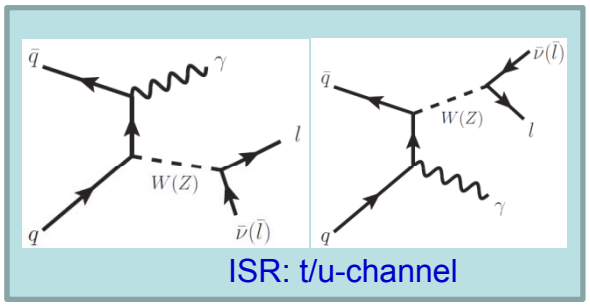


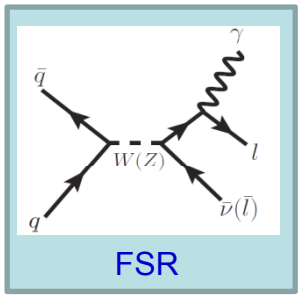
- Precise test of non-Abelian $SU(2)_L \times U(1)_Y$
  -- *higher energy* compared to Tevatron, new couplings of charged currents $W\gamma$/WZ vs. LEP
- Topology : ≥2 isolated high pT(>15 GeV) lepton(l=e,μ)/γ, MET(>20 GeV) for W
- Background to hunting Higgs, top and SUSY
- Probe ***TGC*** (trilinear gauge couplings)
  -- sensitive to "*low*" energy remnants of new physics @ high scale

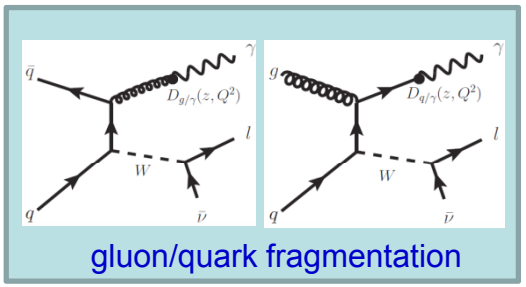
Measurements of W(lν)γ, Z(ll)γ

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

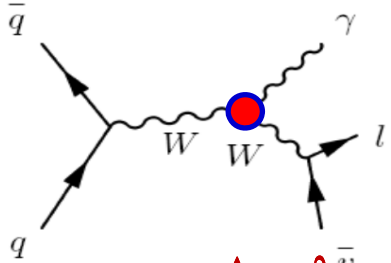








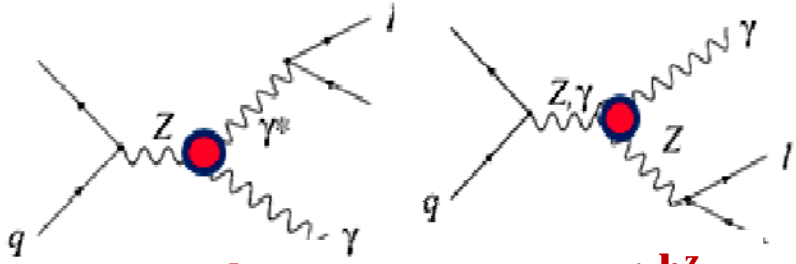
- **Searching anomalous triple gauge couplings (aTGC):**
  - **W magnetic dipole and electric quadrupole moment**



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

WWγ aTGC: $\Delta\kappa_\gamma$, λ_γ

  - **$ZZ\gamma/Z\gamma\gamma$ 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**

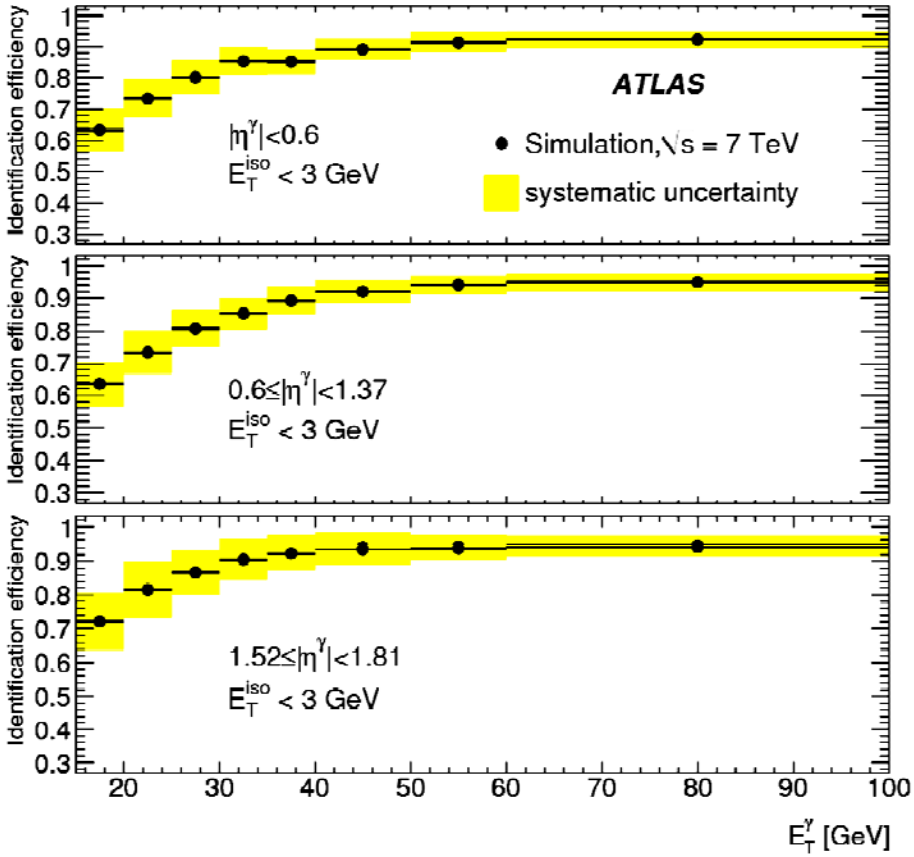
Event Selection

✓ *ATLAS 35pb^{-1} result as* **JHEP 1109,072**

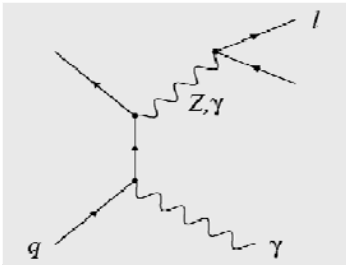
✓ *ATLAS 1.02fb^{-1} result as* **arXiv:1205.2531**

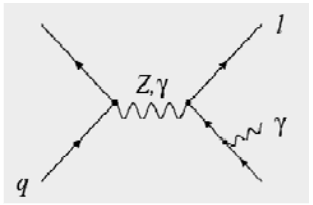
➢ **ATLAS 7TeV 1fb^{-1} (35pb^{-1}) data:**

- **Lepton :**
  - + e/μ p_T>25GeV, detector fiducial |η| coverage; isolated in calorimeter;
  - + Tight electron identification
- **W/Z events** : MET>25GeV, MT(*lν*)>40GeV; M(*ll*)>40GeV
- **Photon :**
  - + p_T>15GeV, in fiducial |η|
  - + 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)

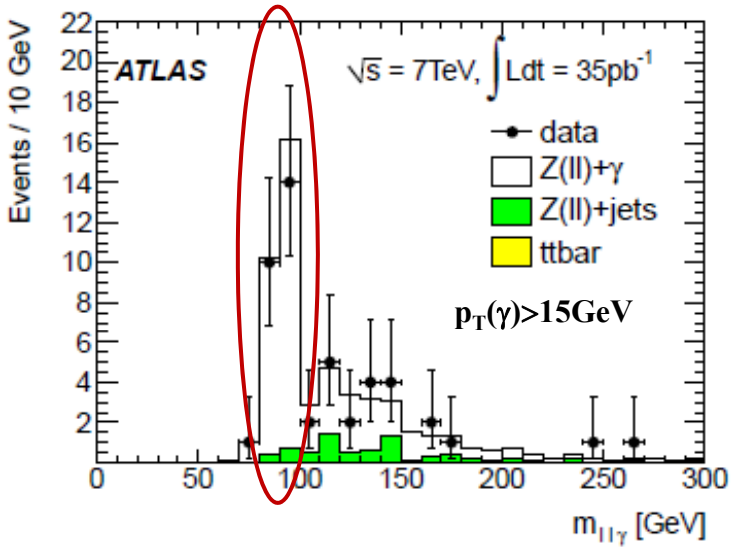


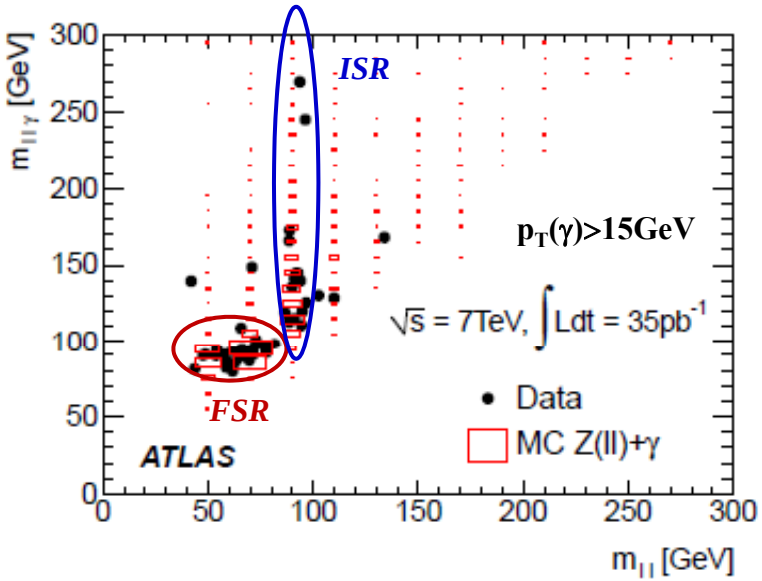
➢ **ISR/FSR vs. $p_T(\gamma)$ cut:**





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

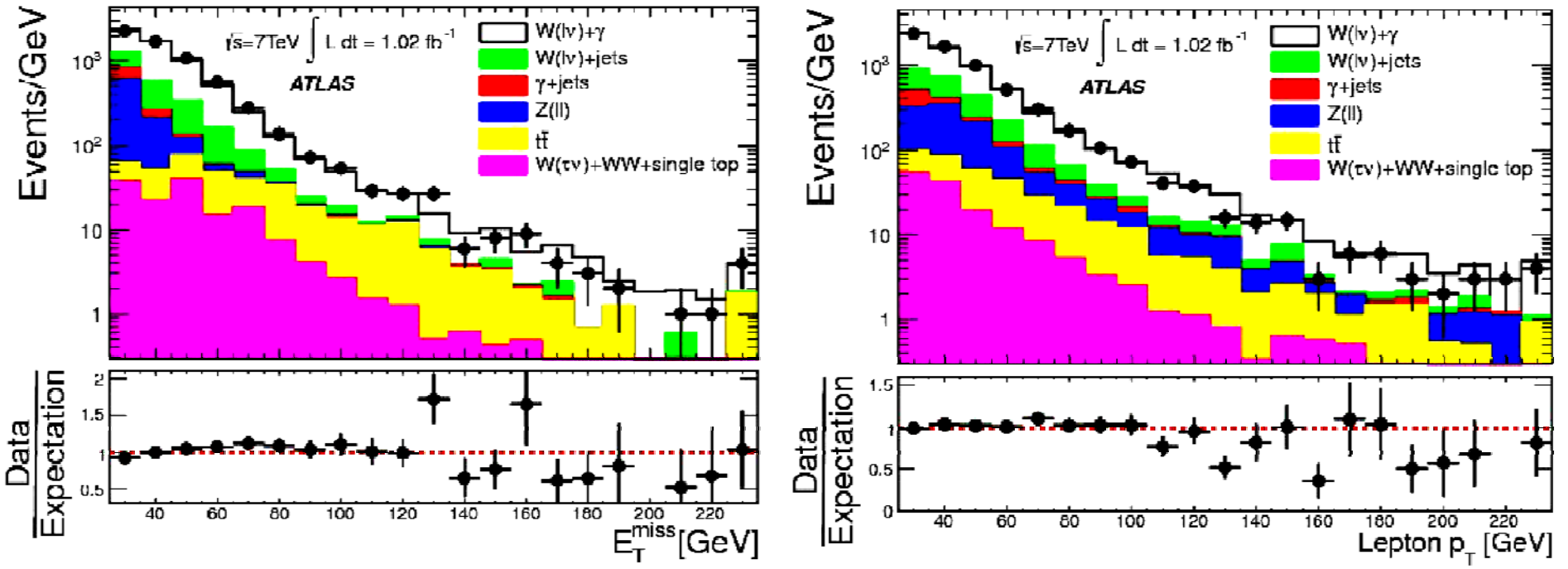




High photon p_T cut to suppress FSR as

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

W($l\nu$)+γ control plot

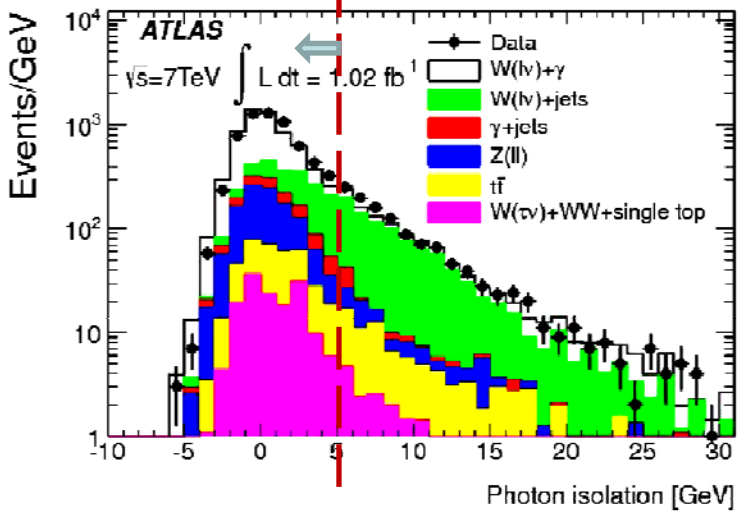


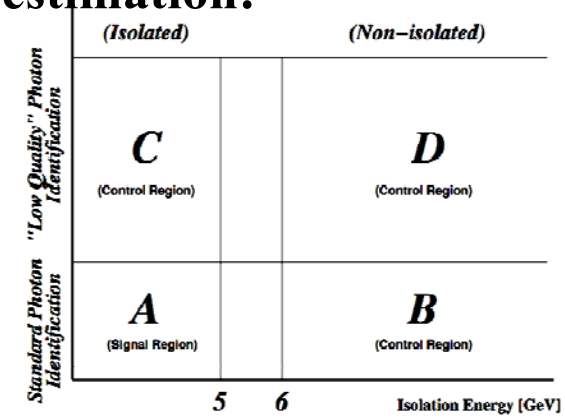
- **Electroweak background** derived from simulation
- Dominant background, ***W+jet*** has to be estimated from data

W/Z+jet background

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

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





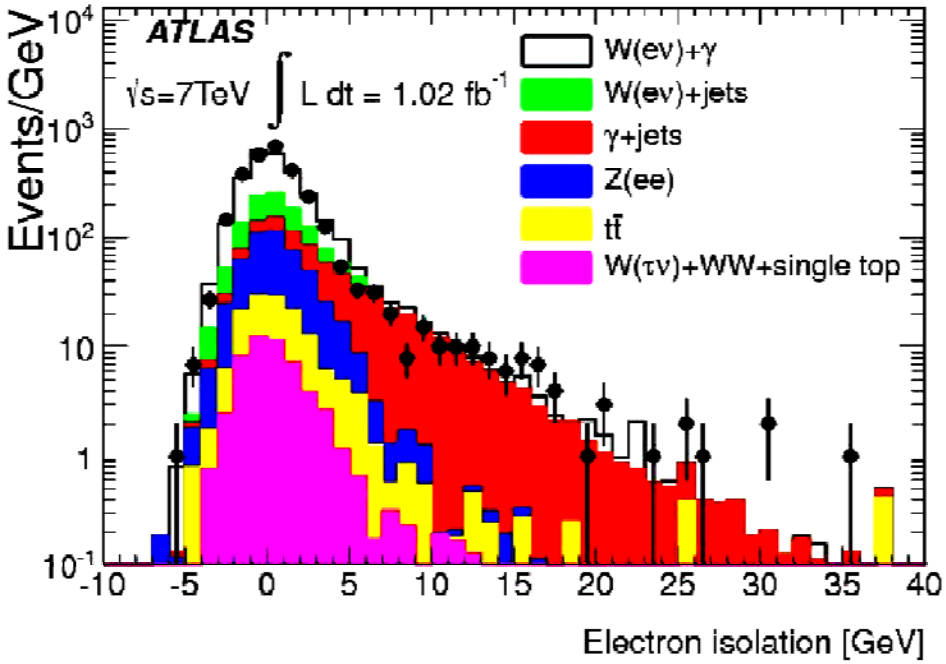
$$N_A = N_A^{W\gamma} + N_A^{Wjet}$$

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

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

Jet+γ background in $W\gamma$

- **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**

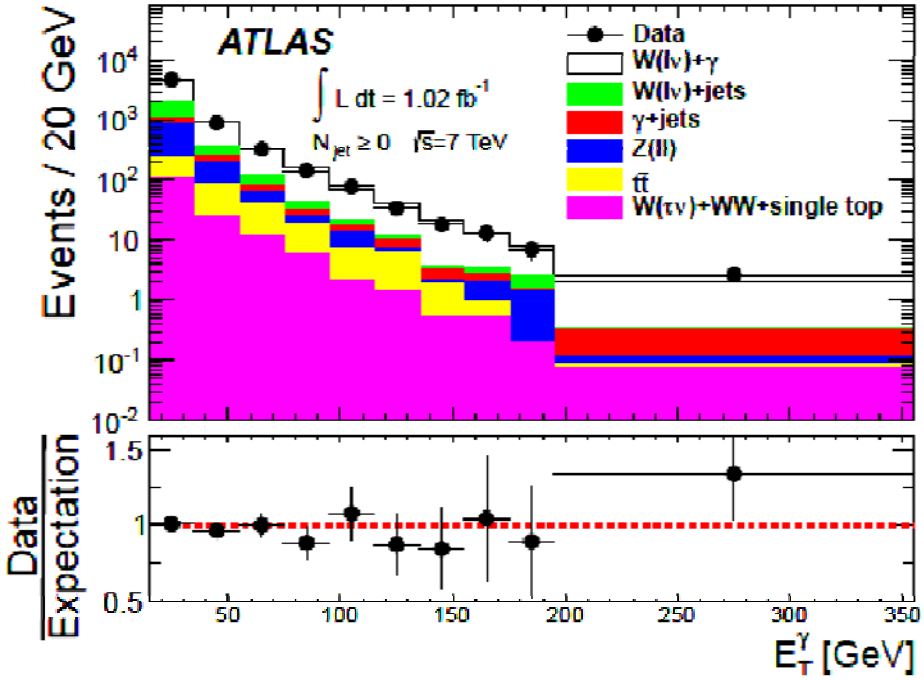


W(eν)γ :MET vs. isolation 2-d sideband

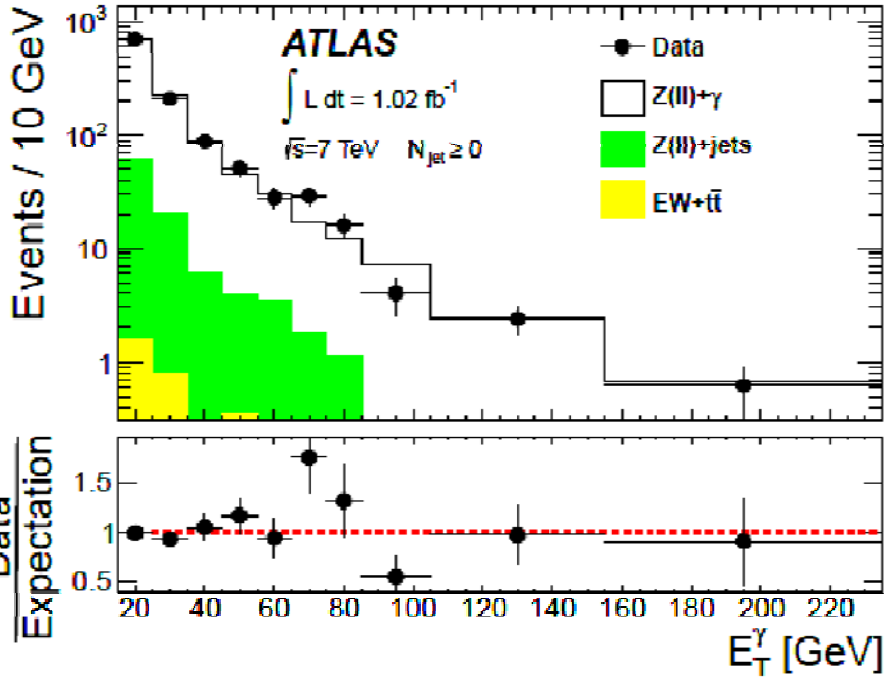
Signal event yield

➢ **Photon E_T spectrum:**

$W(l\nu)\gamma$ inclusive



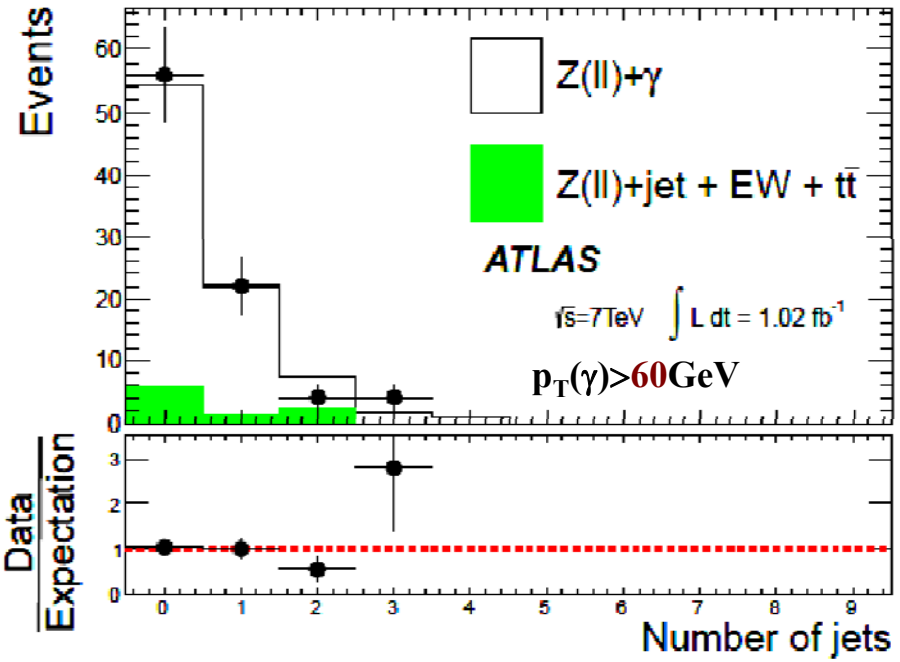
$Z(ll)\gamma$ inclusive



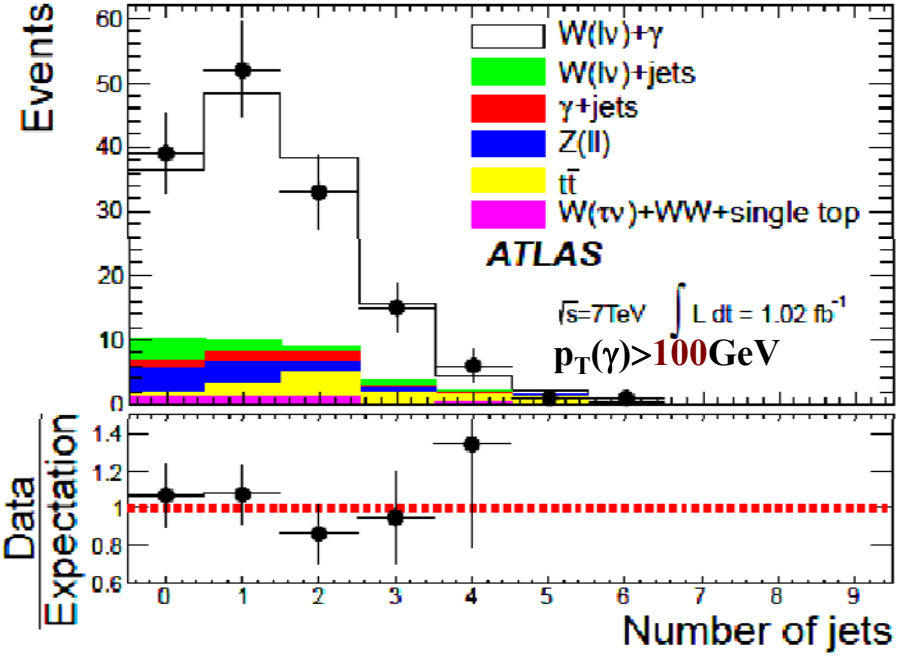
* Signal distribution normalized to the number of extracted data

➢ **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%**

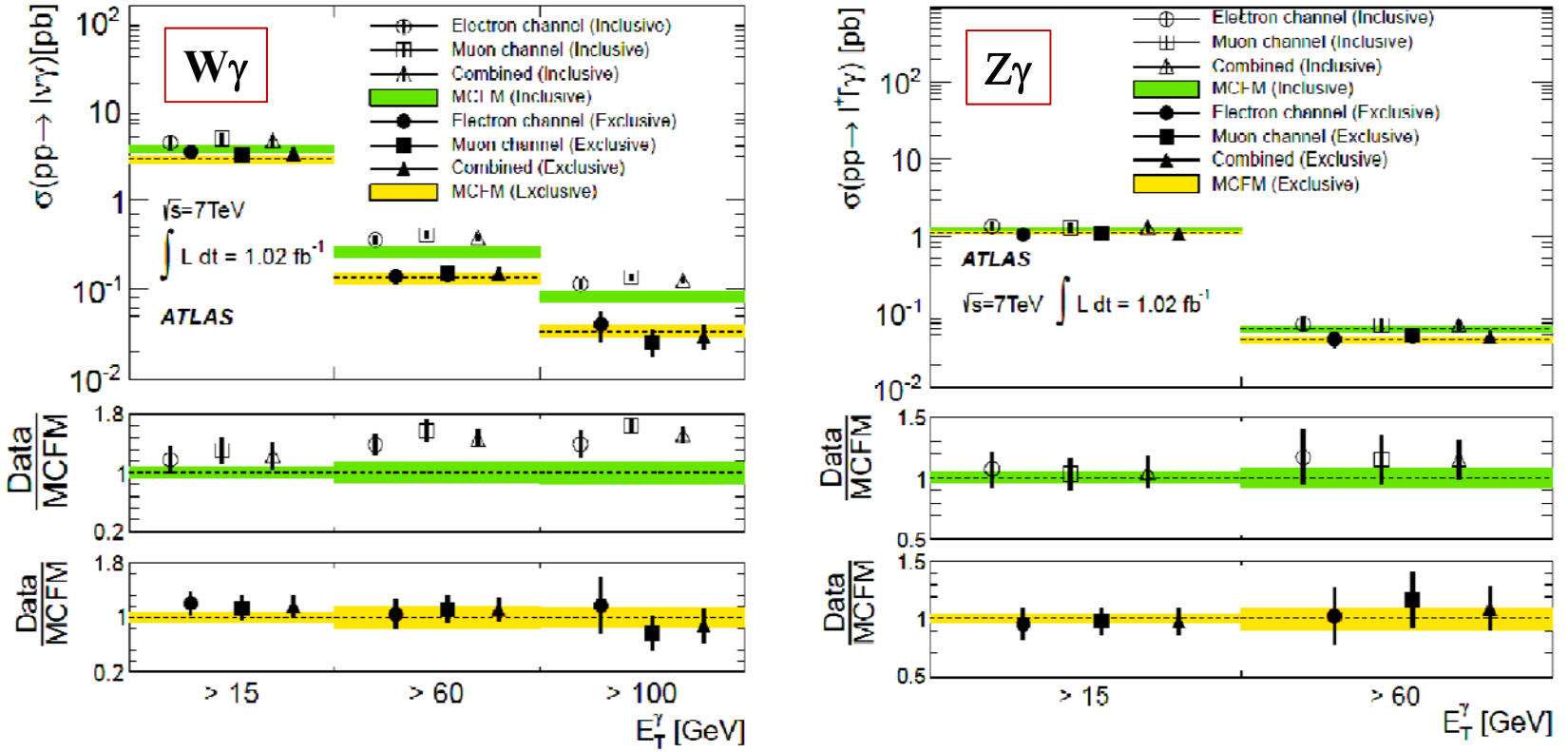
- **Compare to SM prediction:**
  - $\sigma^{ext\,fid}_{pp\to l\nu\gamma(ll\gamma)} = \frac{\sigma^{fid}_{pp\to l\nu\gamma(ll\gamma)}}{A_{W\gamma(Z\gamma)}}$

    Compared against

    MCFM (ISR + FSR + QCD NLO)

Differential cross sections

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



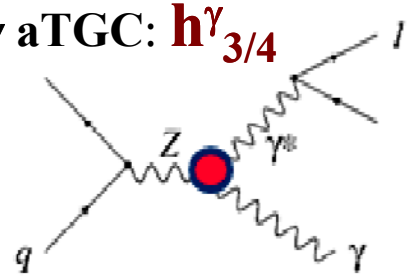
- The Exclusive measurements are consistent with MCFM predictions (SM NLO)
- The Wγ Inclusive are higher than MCFM, especially in high $p_T(\gamma)$ region
  → high order effects (NNLO and beyond)

Anomalous couplings

+ aTGC $h^V_{3/4}$: $ZV\gamma$ electric dipole / magnetic quadrupole transition moment

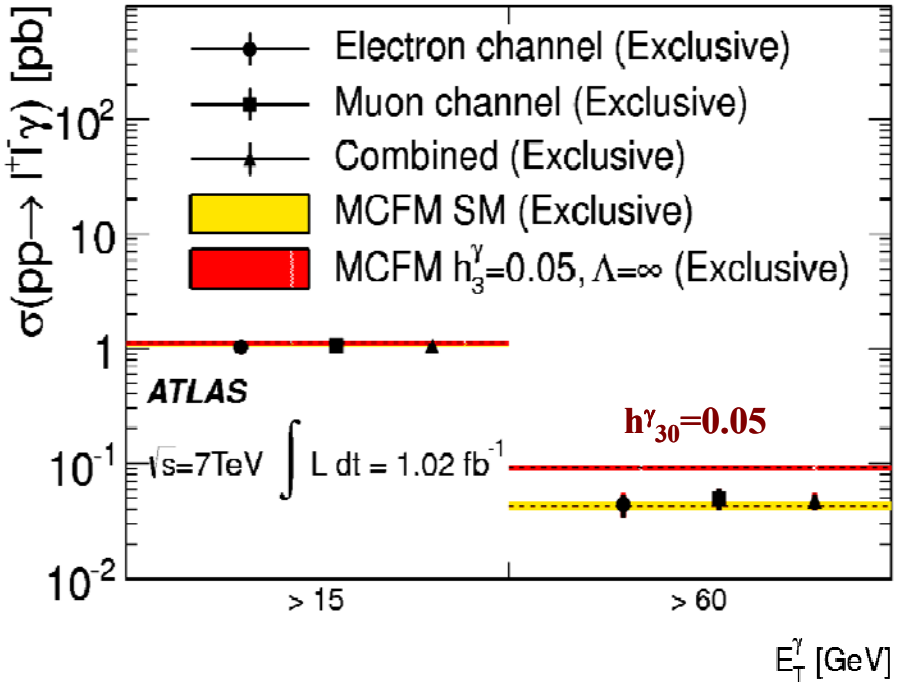
+ non-zero aTGC will result in increasing of W/Z+γ cross section, especially in high photon p_T region

Zγγ aTGC: $h^\gamma_{3/4}$



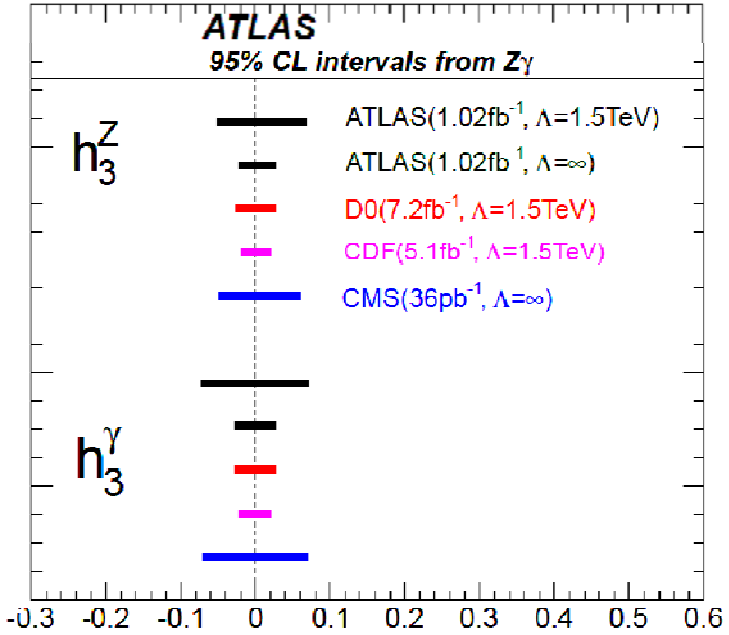
ZZγ aTGC: $h^z_{3/4}$

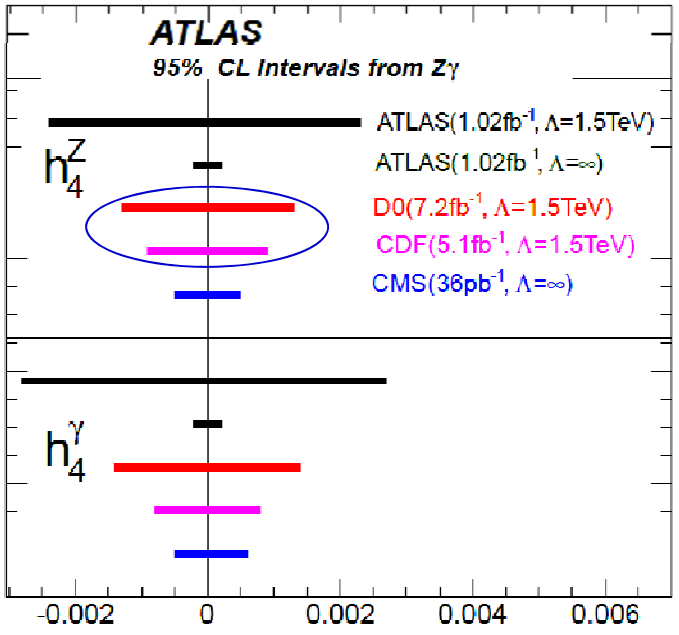
$$h_i^V = \frac{h_{i0}^V}{(1+\hat{s}/\Lambda^2)^n}$$



➢ Extract $ZV\gamma$ aTGC:

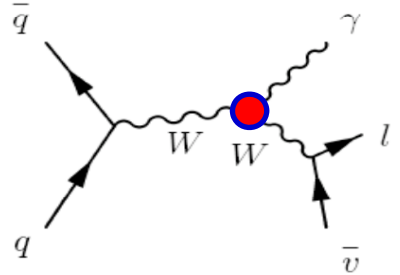
+ Exclusive $E_T(\gamma)>60GeV$ measurement $\sigma_{Z\gamma}^{obs}$ against aTGC hypotheses $\sigma_{Z\gamma}^{aTGC}$





+ Bayesian probability with nuisance parameters to set limits

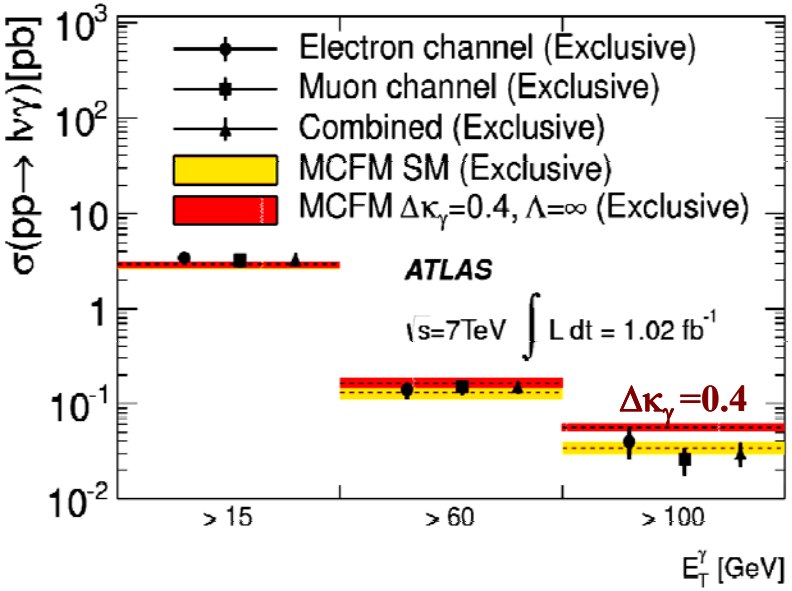
➢ Extract $WW\gamma$ aTGC:

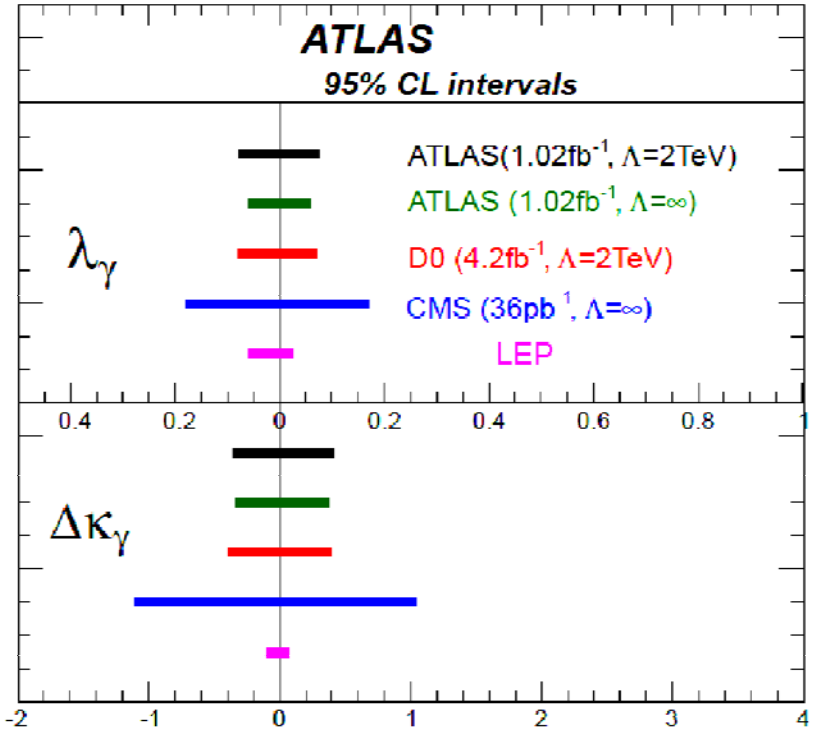


WWγ aTGC: $\Delta\kappa_\gamma$, λ_γ

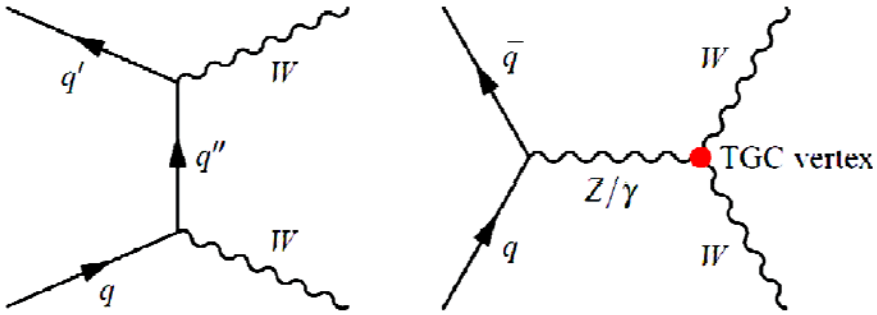
Exclusive $E_T(\gamma)$>100GeV measurement $\sigma^{obs}_{W\gamma}$

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



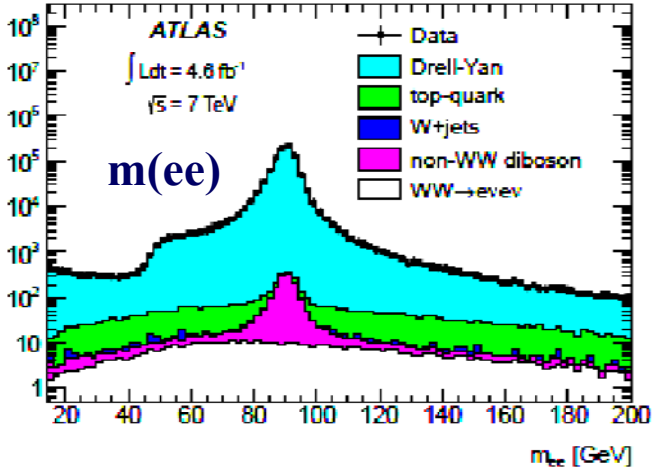


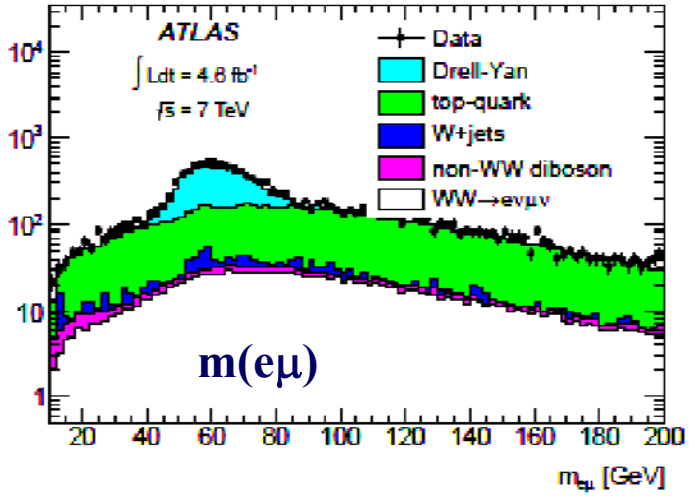
Measurements of WW



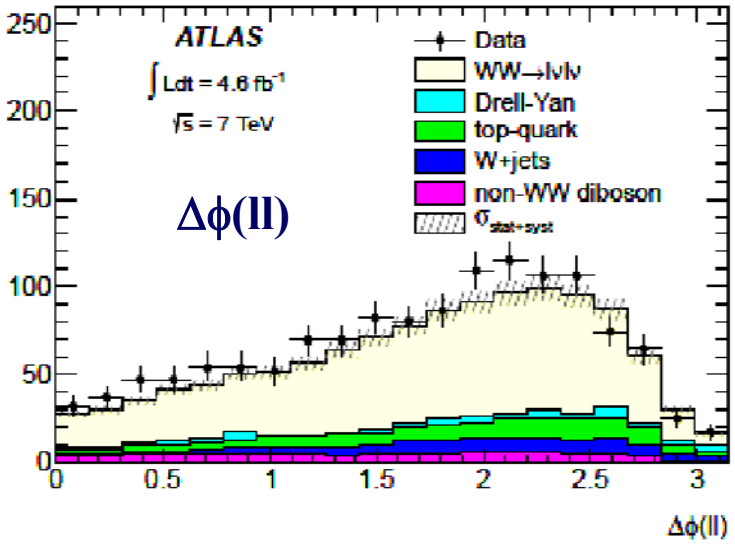
- **Strategy**: lepton decay channel ***(l=e,μ)***
  - High pT and opposite charged
    ll'+MET
  - Veto on jets and mZ-window in ee/μμ

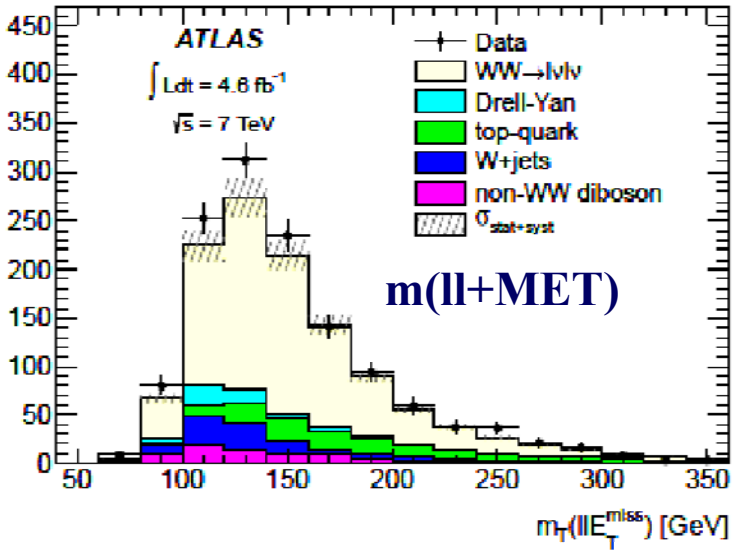
- **Background:** SM **EW** estimated by MC, **W+j** and **top** decay derived from data





➢ Distributions :





➢ Cross-section:

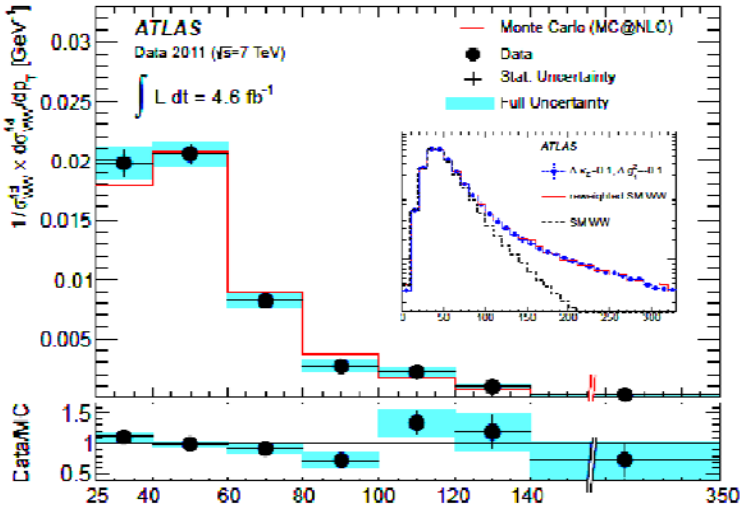
$\sigma(pp \rightarrow W^+W^-@7TeV, 4.6fb^{-1}) = 51.9 \pm 2.0(stat) \pm 3.9(syst) \pm 2.0(lum)$ **pb**

• SM NLO $44.7^{+2.1}_{-1.9}$ pb

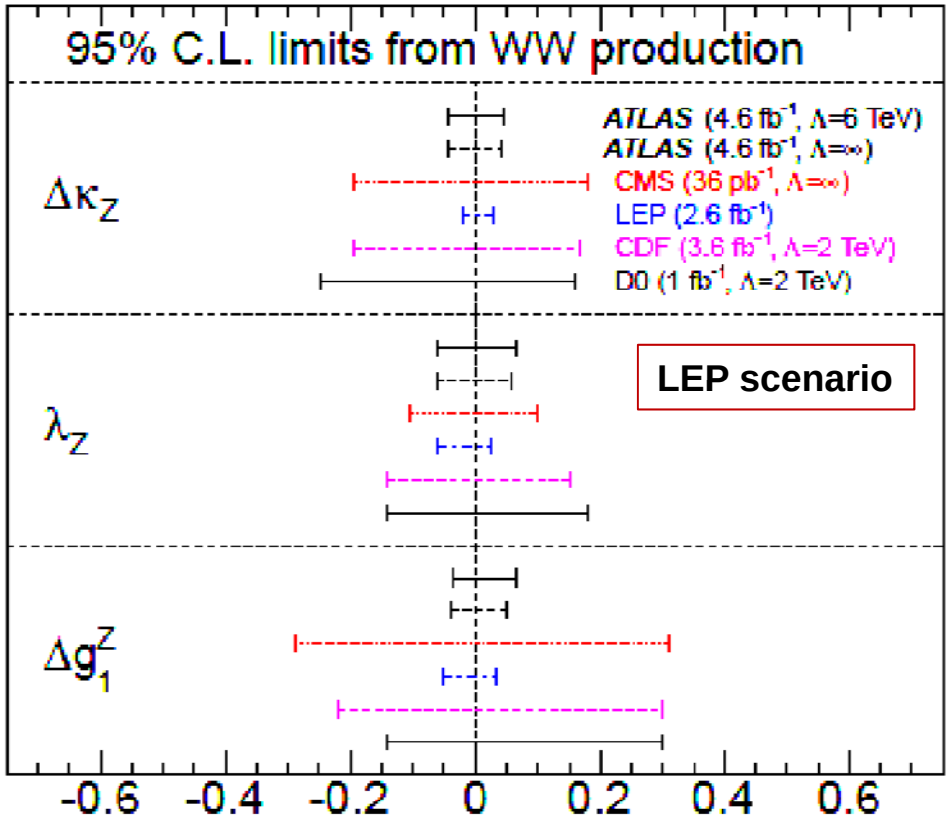
• Systematic dominated by jet algorithm

➢ **Extract *WWV* (*V=Z,γ*) aTGC:**

$$L/g_{WWV} = ig_1^V(W_{\mu\nu}^* W^\mu W^\nu - W_{\mu\nu} W^{*\mu} V^\nu) + i\kappa^V W_\mu^* W_\nu V^{\mu\nu} + \frac{\lambda^V}{M_W^2} W_{\rho\mu}^* W_\nu^\mu V^{\nu\rho}$$

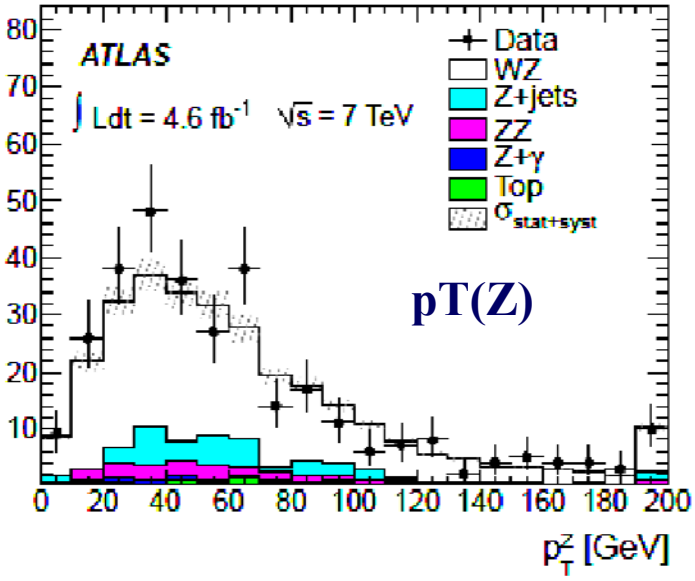


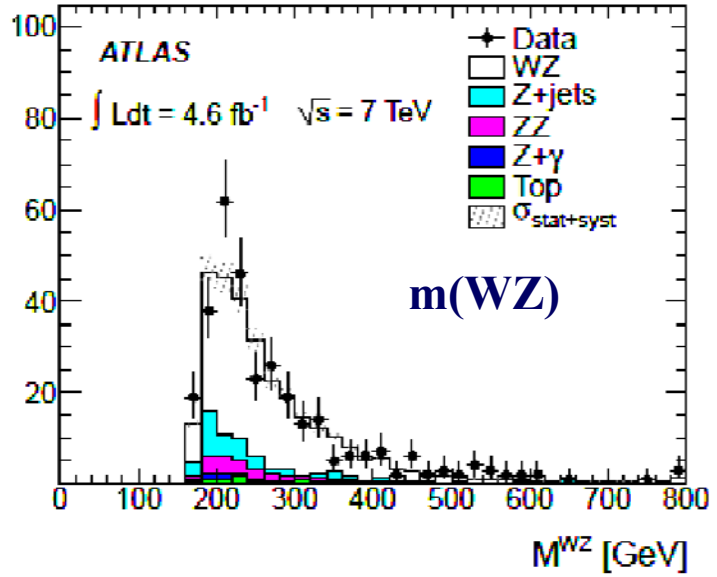
Leading lepton pT



Measurements of WZ

- **Search channel : $WZ \rightarrow l\nu + ll$**
  - -- eee, eeμ, eμμ and μμμ combined, Br~1.5%
  - -- high pT isolated lepton + MET + o.s. di-lepton of invariant mass around Z



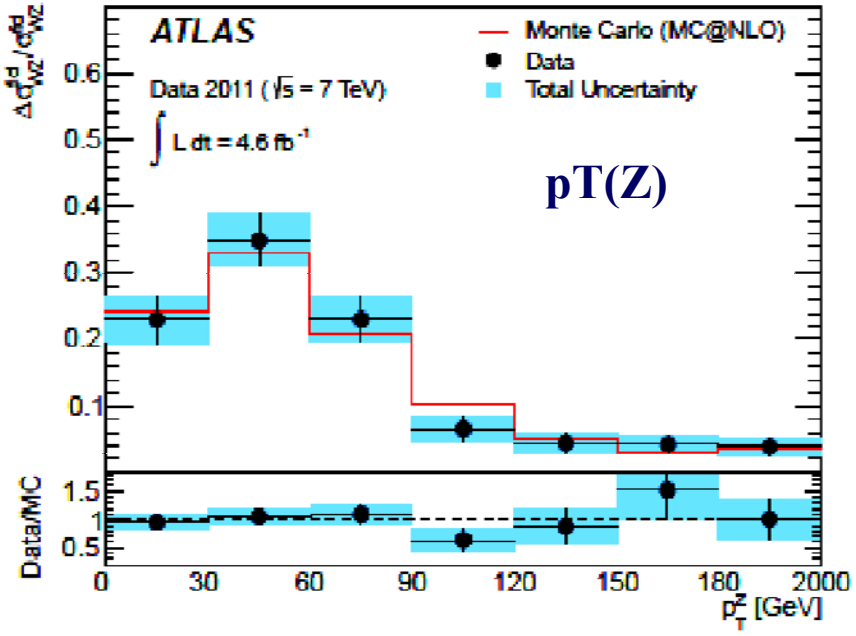


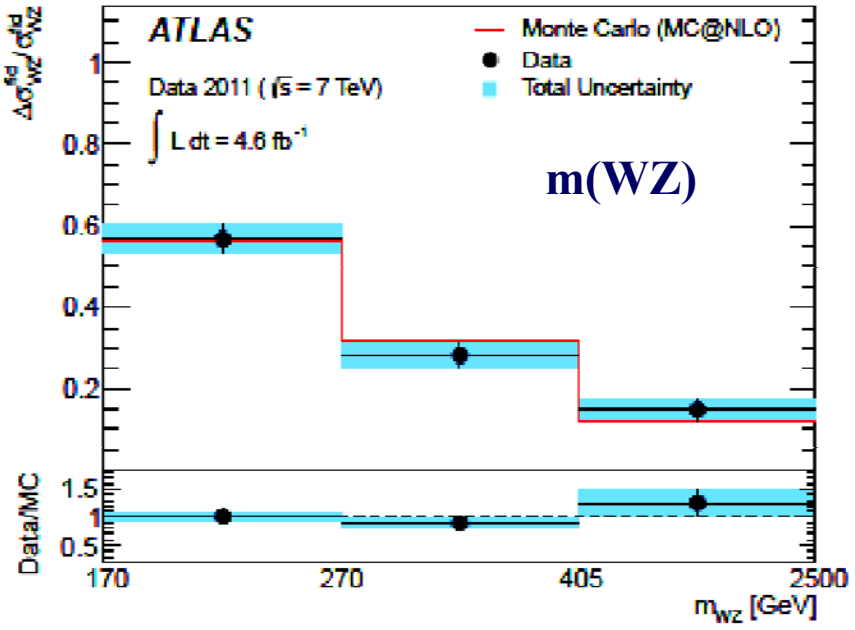
- **Background:** EW **ZZ** estimated by MC, **Z+j** and **top** decay derived from data

- **Cross-section:**

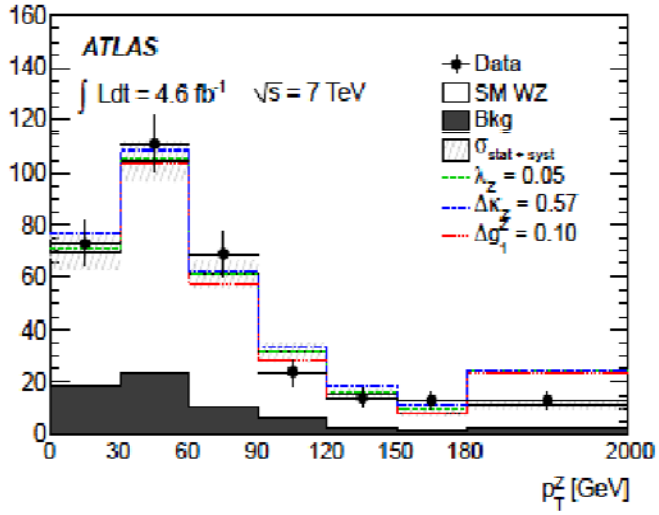
$$\sigma(\mathbf{pp\rightarrow WZ@7TeV},\ \mathbf{4.6fb^{-1}}) = 19.0^{+1.4}_{-1.3}(\text{stat.}) \pm 0.9(\text{syst.}) \pm 0.4(\text{lumi.})\ pb$$

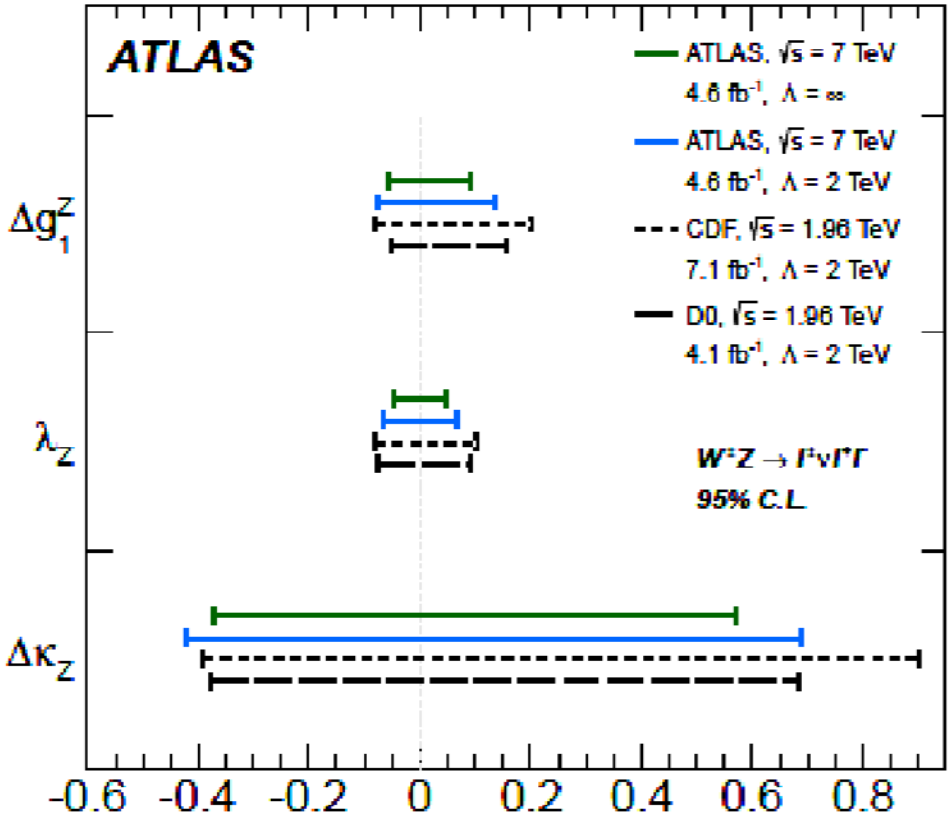
- SM NLO $17.6^{+1.1}_{-1.0}$ pb





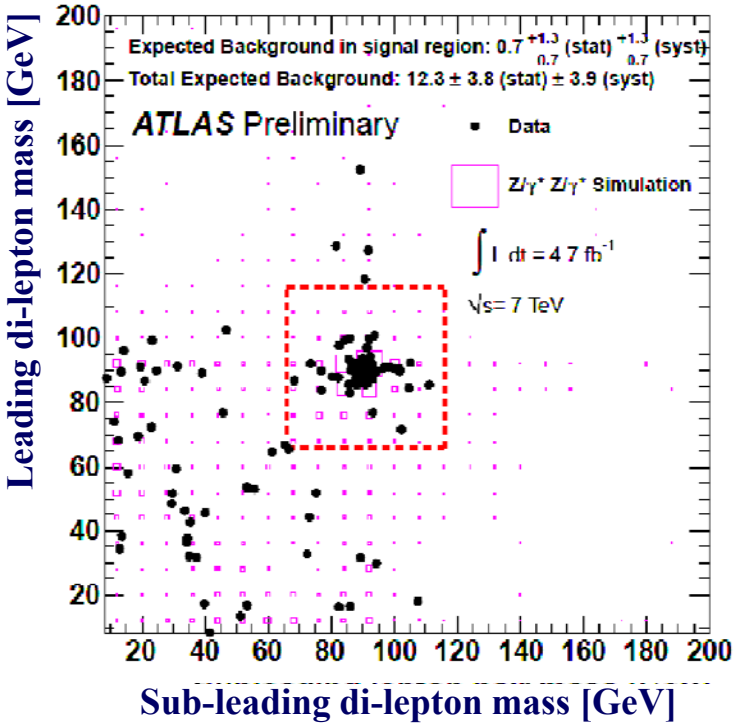
- **Extract *WWZ* aTGC:**

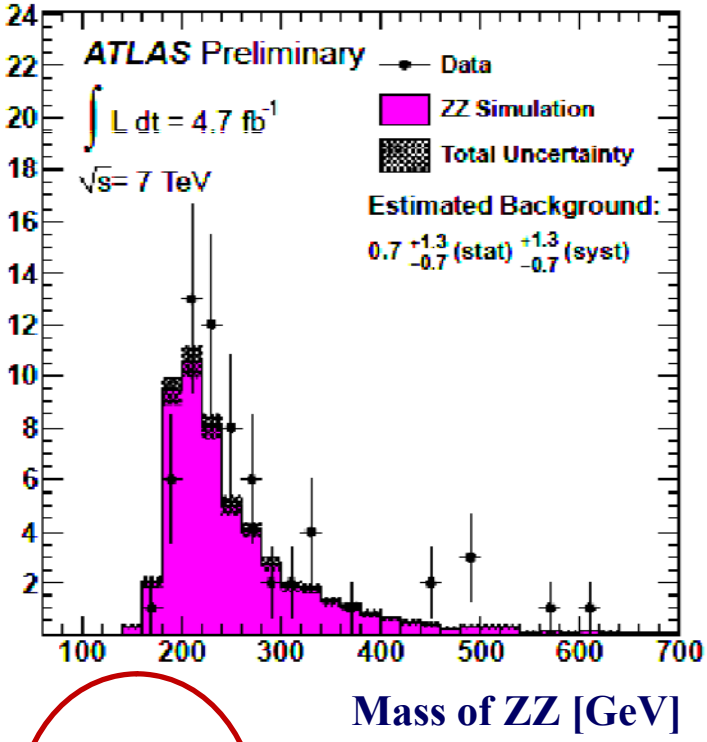




Measurements of ZZ (l)

- Search channel : $ZZ \rightarrow 4l$, two pairs of di-lepton of invariant mass around Z

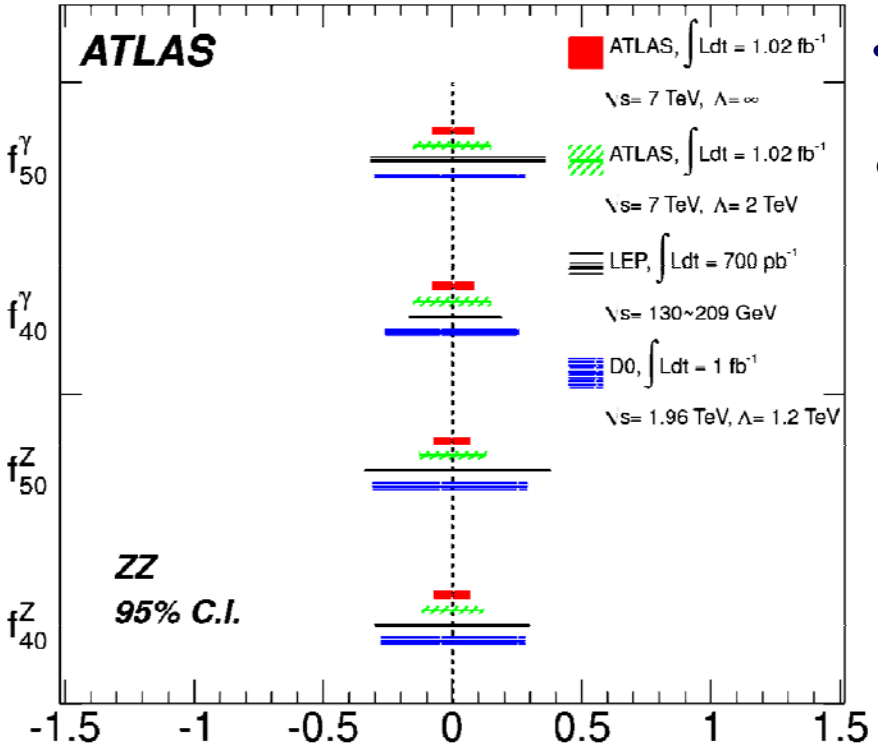




$$\sigma(pp \rightarrow ZZ@7TeV,\ 4.7fb^{-1}) = 7.2^{+1.1}_{-0.9}(\text{stat.}) \pm ^{+0.4}_{-0.3}(\text{syst.}) \pm 0.3(\text{lumi.})\ pb$$

- SM NLO $6.5^{+0.3}_{-0.2}\ pb$

➢ **Extract *ZZV* (*V*=*Z*,*γ*) aTGC:** $L = -\frac{e}{M_Z^2}[f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) + f_5^V(\partial^\sigma V_{\sigma\mu})\tilde{Z}^{\mu\beta}Z_\beta]$



• **Using the total number of observed events only**

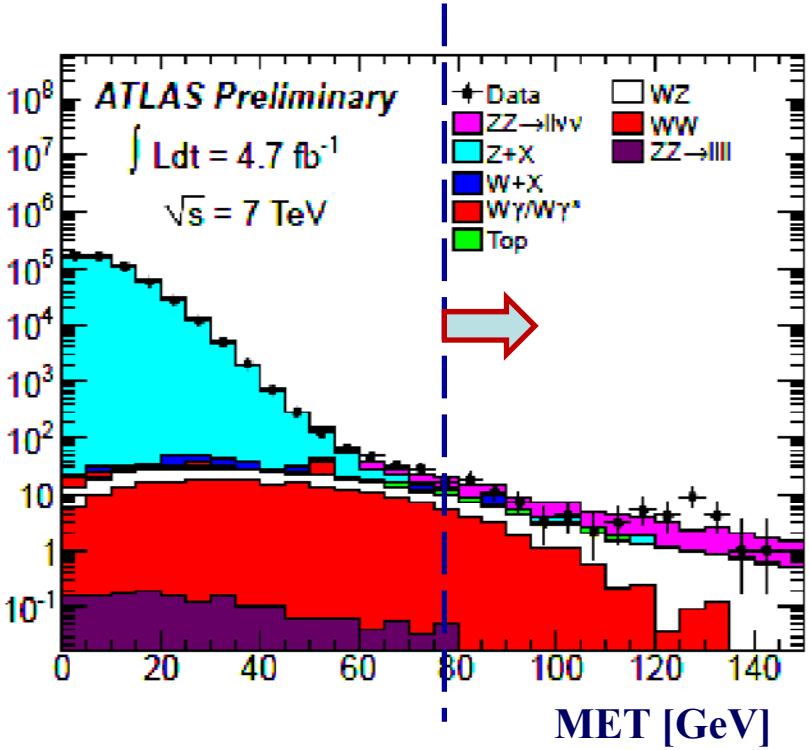
σ(**pp→ZZ@7TeV**, **1fb^{-1}**) =

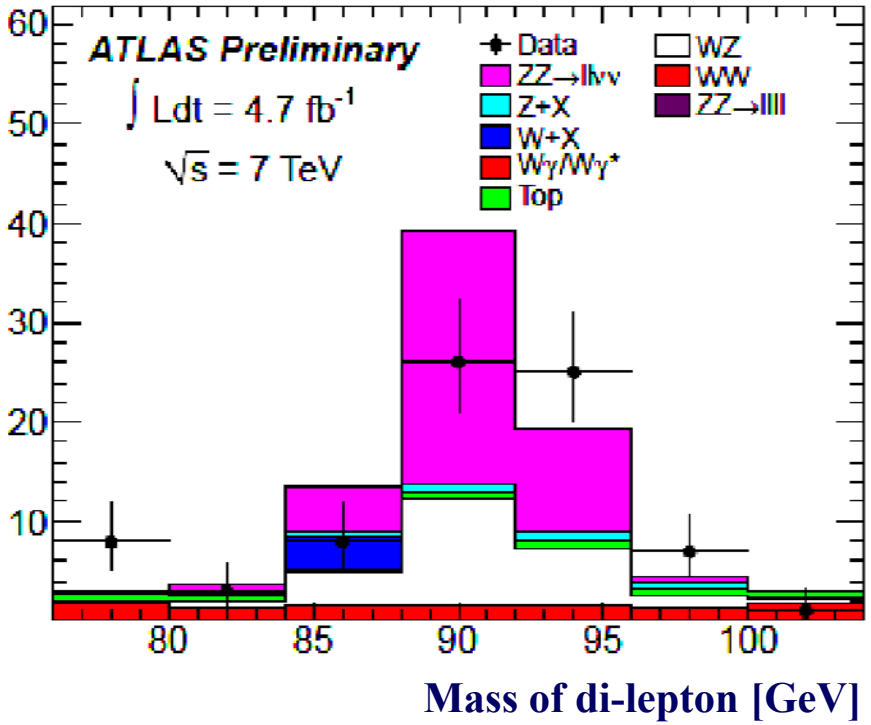
$$8.5^{+2.7}_{-2.3}(\text{stat.})\pm^{+0.4}_{-0.3}(\text{syst.})\pm 0.3(\text{lumi.})\ pb$$

• SM NLO $6.5^{+0.3}_{-0.2}$ *pb*

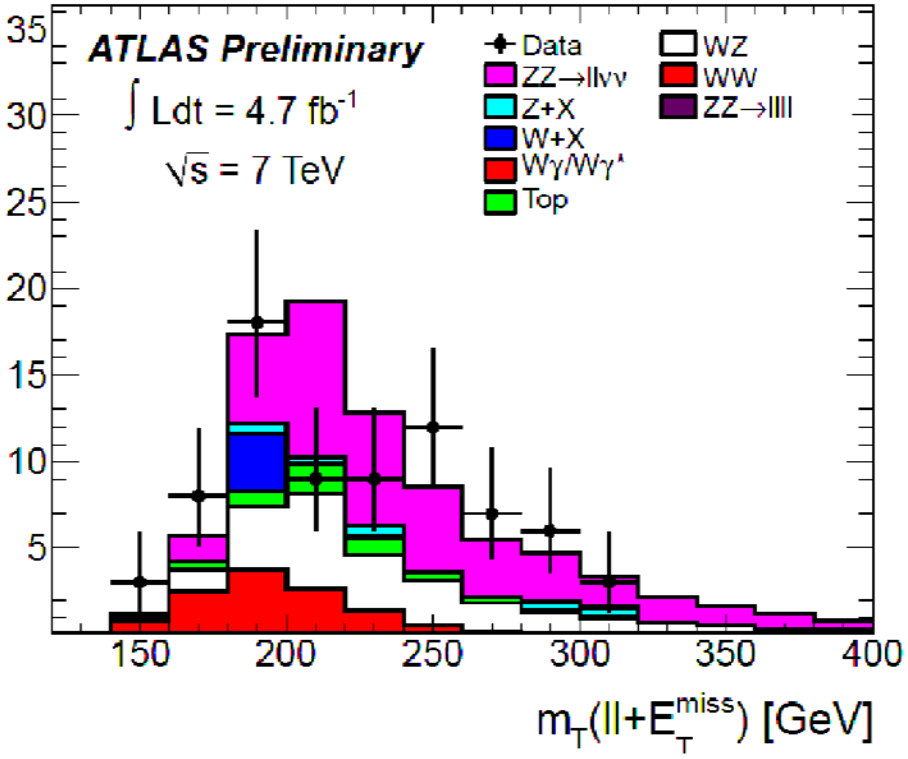
Measurements of ZZ (ll)

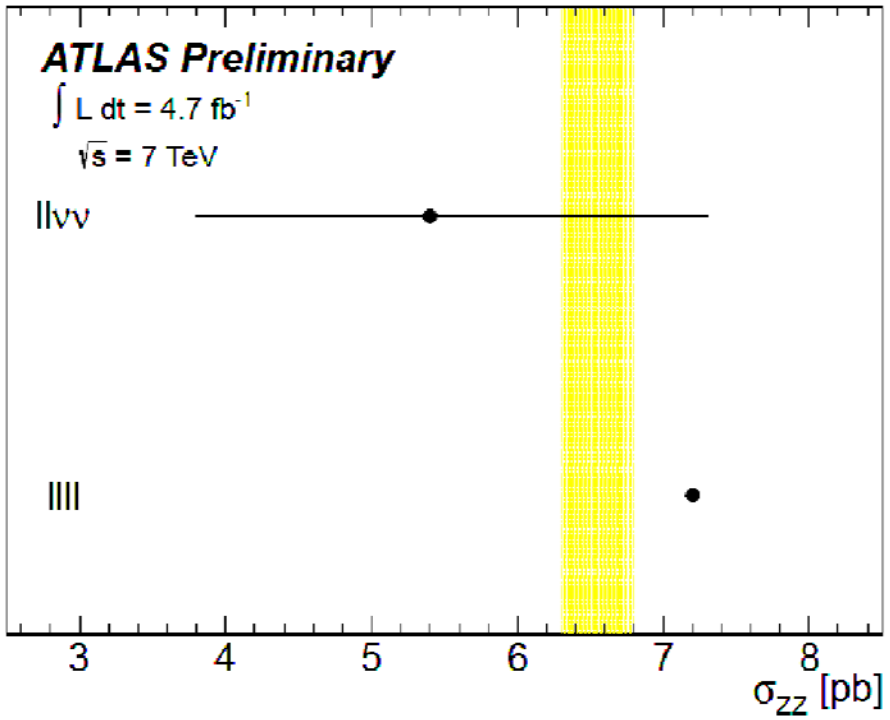
- Search channel : $ZZ \rightarrow 2l + 2\nu$, di-lepton around Z and significant MET





* Jet veto as Njets=0





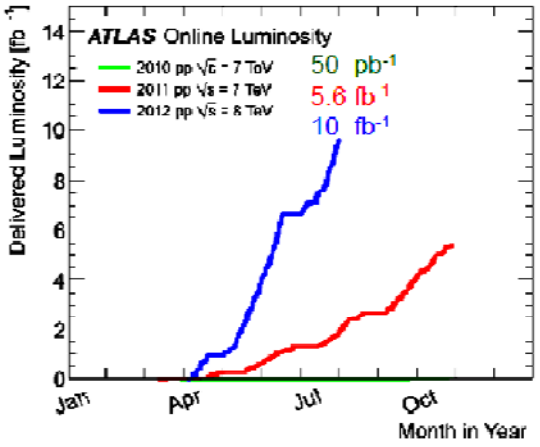
$$\sigma(\mathbf{pp\rightarrow ZZ@7TeV},\ \mathbf{4.7fb^{-1}}) = 5.4^{+1.3}_{-1.2}(\text{stat.})\pm^{+1.4}_{-1.0}(\text{syst.})\pm 0.2(\text{lumi.})\ pb$$

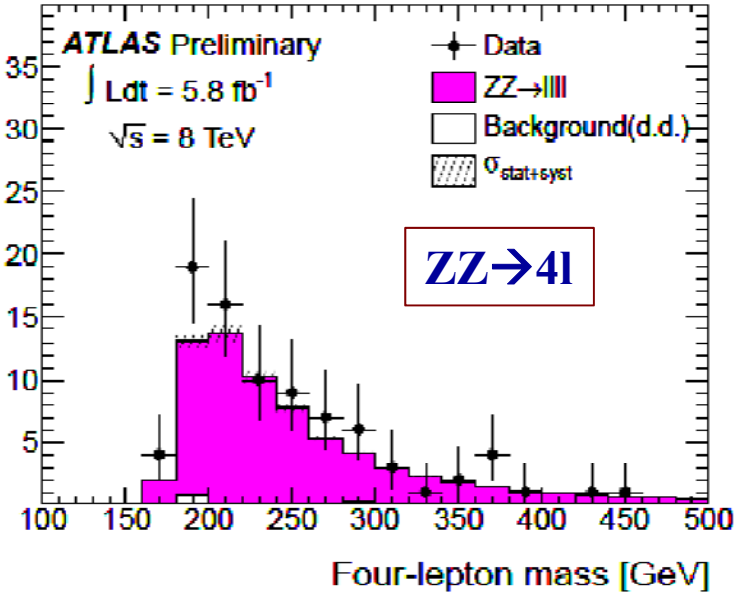
Summary

- The 7TeV p-p collision di-boson measurements at ATLAS:
  - $W(l\nu)\gamma/Z(ll)\gamma$ @ 1.0fb^{-1}
  - $W(l\nu)W(l\nu)$ @ 4.6fb^{-1}
  - $W(l\nu)Z(ll)$ @ 4.6fb^{-1}
  - $Z(ll)Z(ll)$ @ 4.7fb^{-1}
  - $Z(ll)Z(\nu\nu)$ @ 4.7fb^{-1}

- No apparent deviation observed, **stringent limits on aTGC comparable to LEP/Tevatron**

- The 8TeV di-boson data analysis on-going:





Summary

- The 7TeV p-p collision di-boson measurements at ATLAS:
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  - $Z(ll)Z(\nu\nu)$ @ 4.7fb^{-1}

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- The 8TeV di-boson data analysis on-going: