Recent ("Hot Topic") Electroweak Measurements with the ATLAS detector

Vasiliki Kouskoura (BNL)

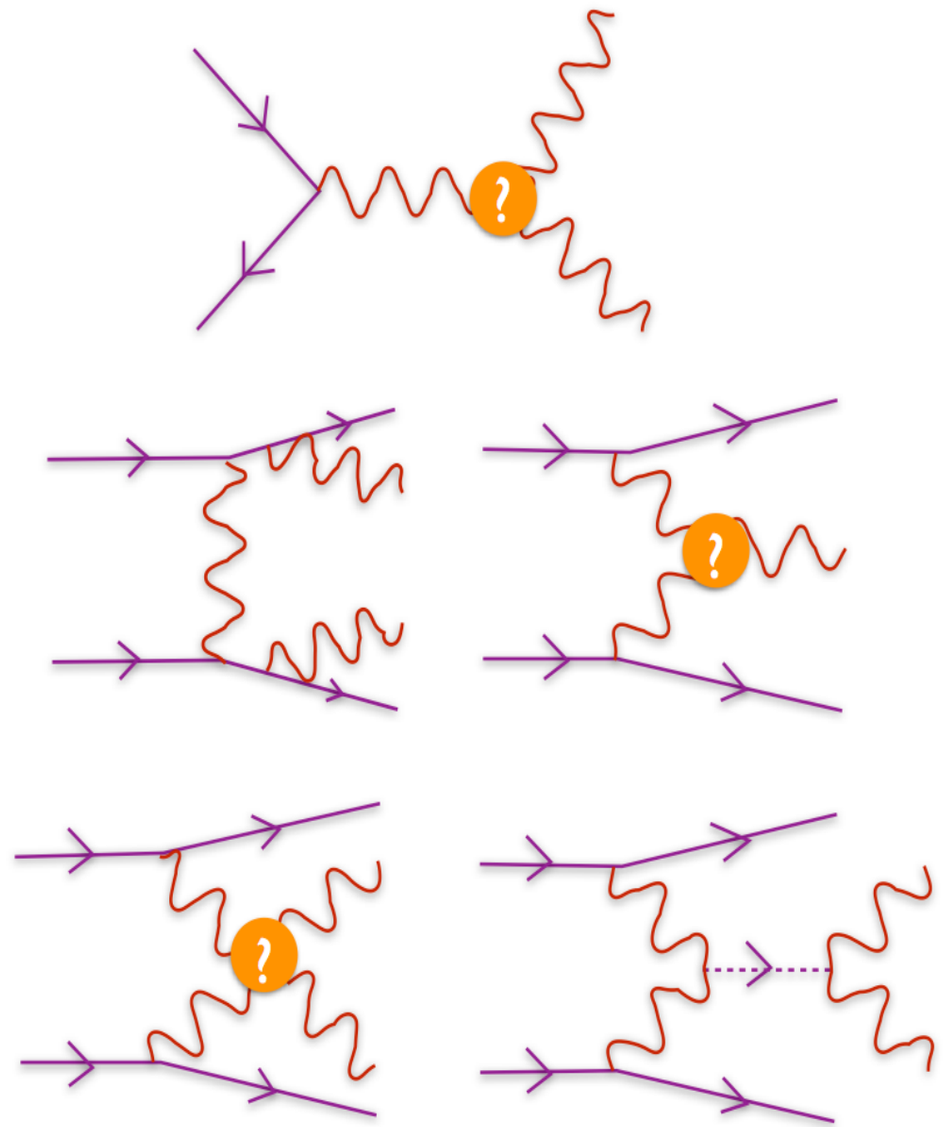
on behalf of the ATLAS Collaboration

SM@LHC, Florence, Italy *(21-25 April 2015)*

Physics motivation

- Di-boson and Tri-boson processes
  - important tests of the Electroweak (EW) Sector of the Standard Model (SM) at high energy regimes
  - sensitivity to new heavy particles

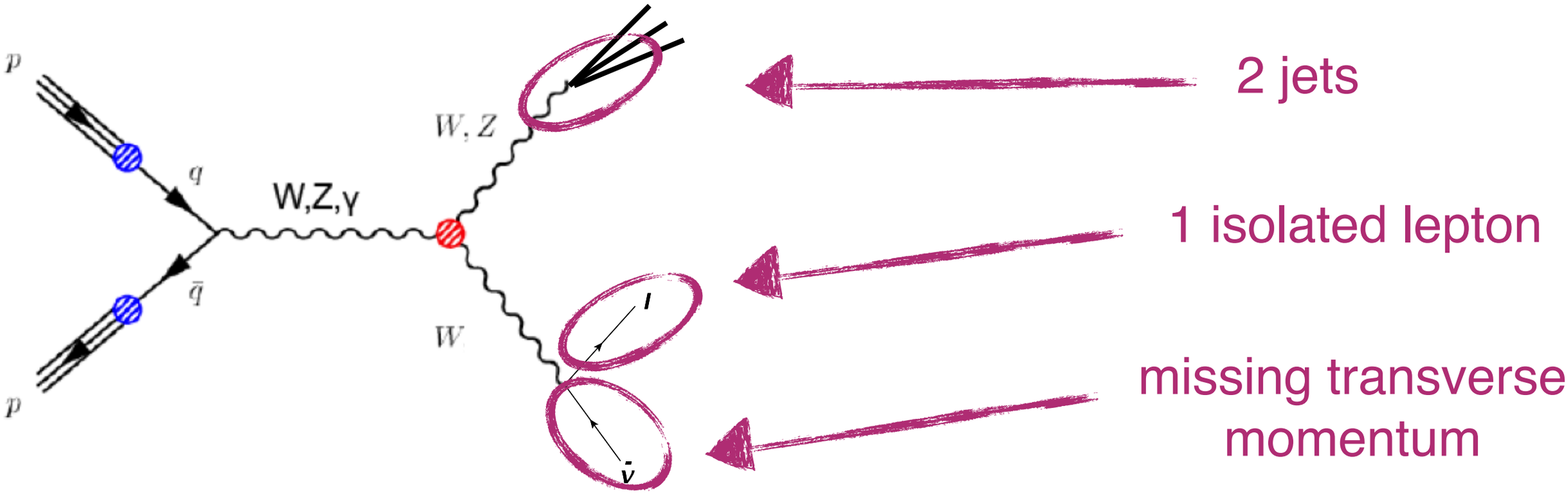
- Anomalous Triple/Quartic Gauge Couplings (aTGC/aQGC)
  - self-couplings fundamental predictions of the SM
  - probe for new physics through deviations from predictions



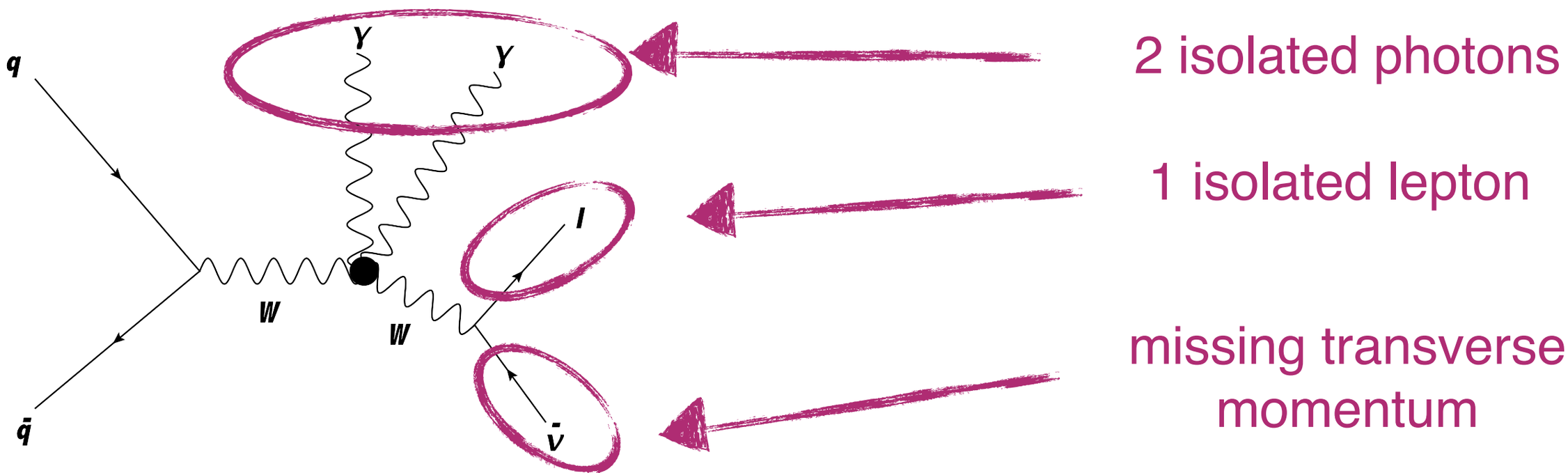
Interesting measurements with ATLAS

- Semi-leptonic WW and WZ combined cross section at 7TeV

branching ratio advantage important for aTGC study



- First evidence of Wγγ production in pp collisions at 8TeV



WW+WZ @ 7TeV

JHEP01(2015)049

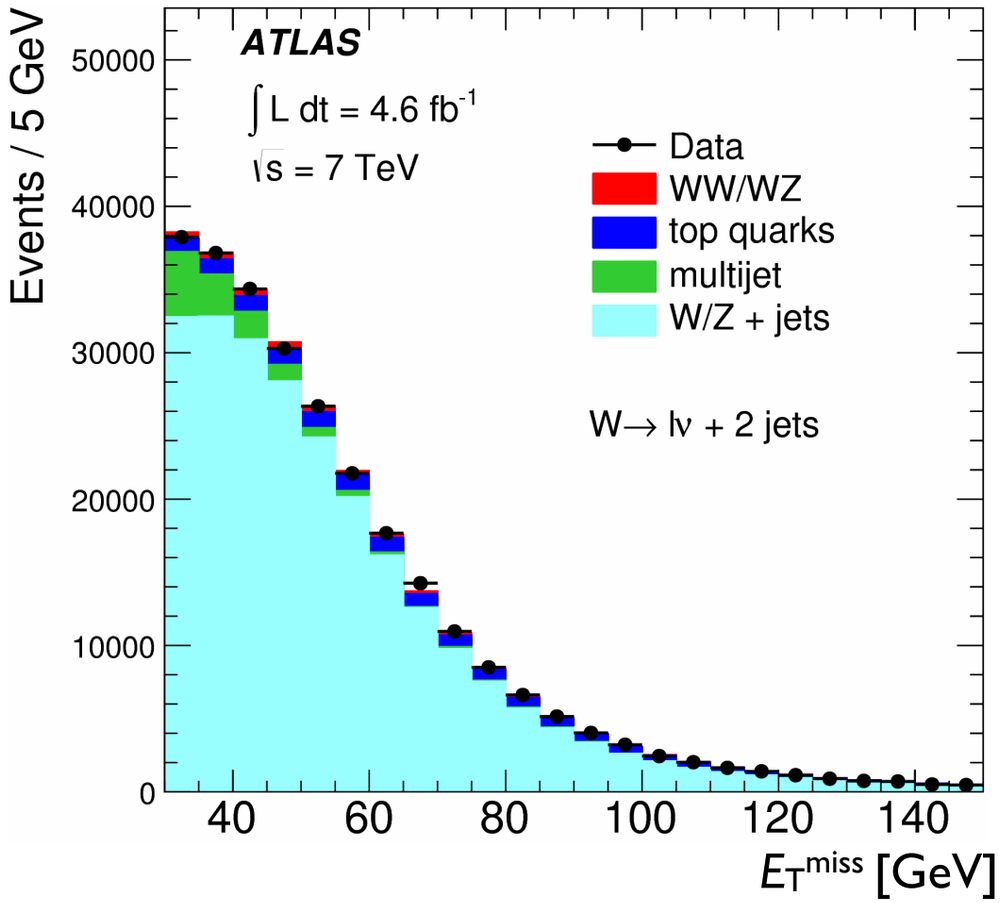
Analysis Selection & Background

Selection highlights

- single lepton triggers
- isolated high-p_T lepton, E_T^{miss} and two jets
- p_T (e,μ ,jets) > 25 GeV
- E_T^{miss} > 30 GeV
- $m_T(W)$ > 40 GeV

} *to suppress multijet bkg*

- $\Delta\phi(E_T^{miss}, j)$ > 0.8
- $\Delta\eta(j_1,j_2)$ < 1.5 *to increase signal-to-bkg ratio*
- 25 GeV < m_{jj} < 250 GeV



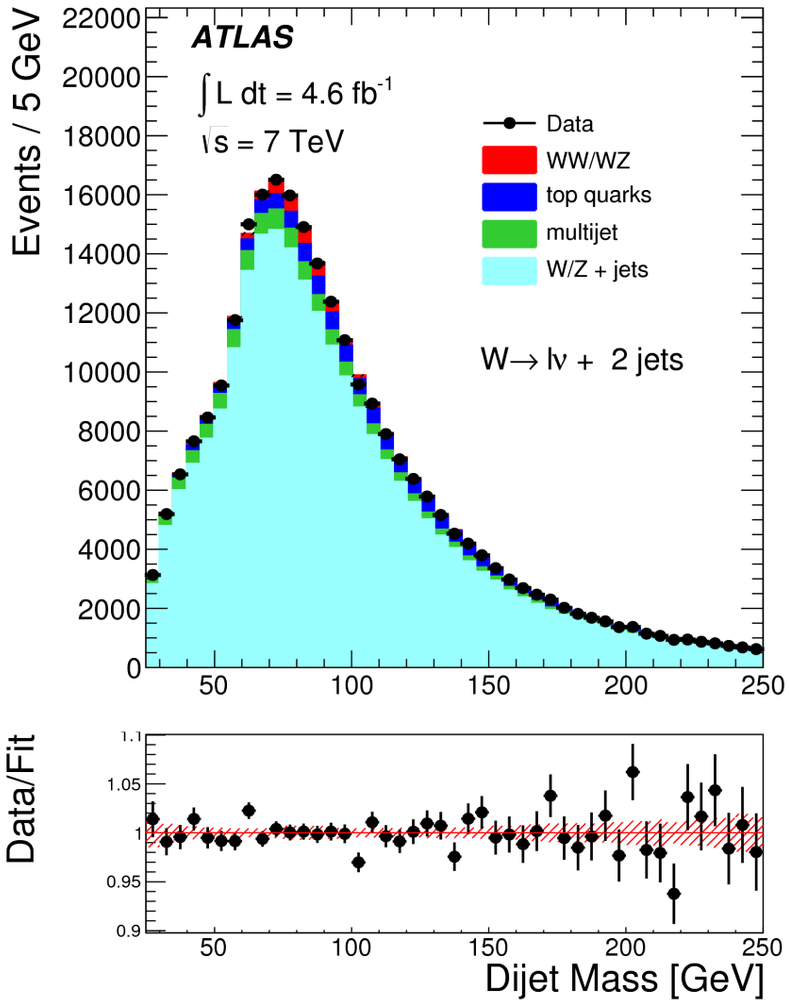
Background composition

- W/Z+jets (89%), multijet (~5%) - data driven
- top (~4%) - MC estimate

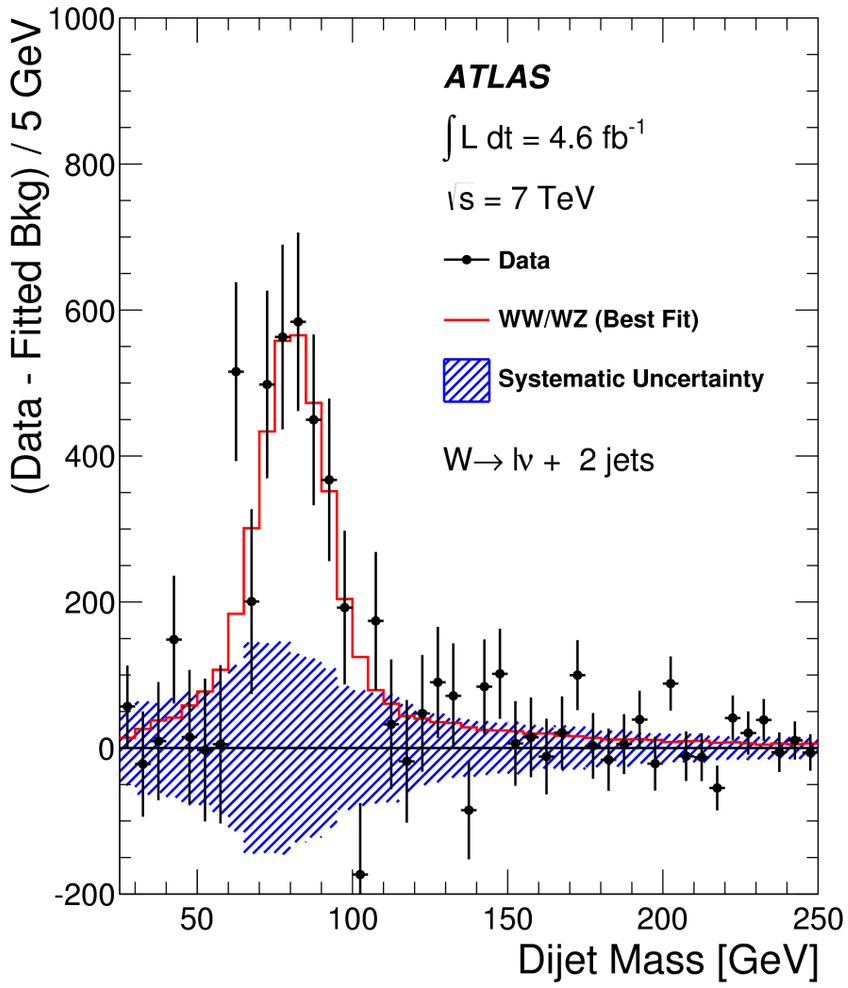
	Electron channel	Muon channel
Total Background	~126000	~132500
Data	127650	134846

Cross section measurement

- fiducial cross section measurement and extrapolation to the total phase space
  - simultaneous maximum likelihood fit to m_{jj}



dijet invariant mass after the likelihood fit



background-subtracted data

dominant systematics on the measured cross section

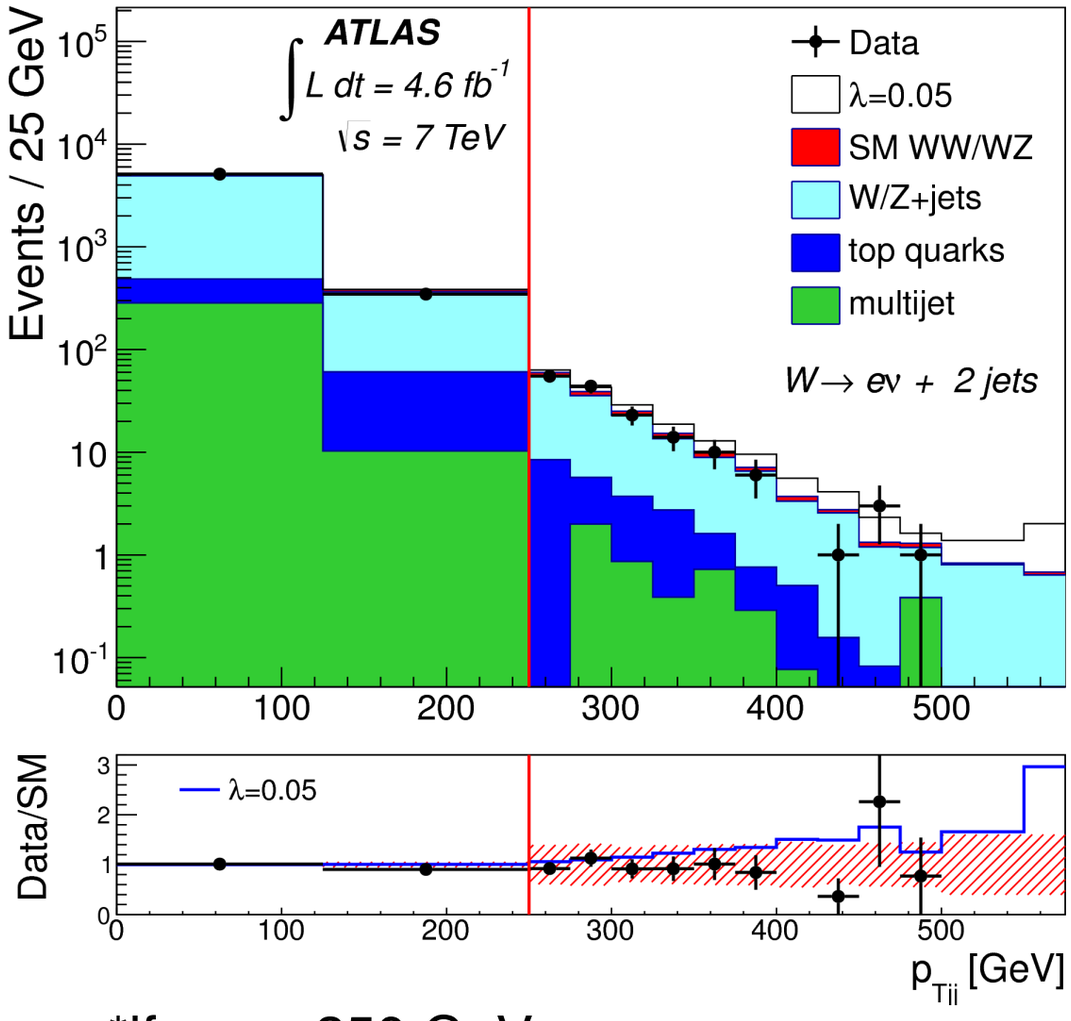
- W/Z+jets rate (17%)
- Jet energy resolution (11%)
- Jet energy scale (9%)

	Measurement [pb]	Theory (MC@NLO) [pb]
σ^{tot}	68±7(stat)±19(syst)	61.1±2.2

signal significance 3.4σ

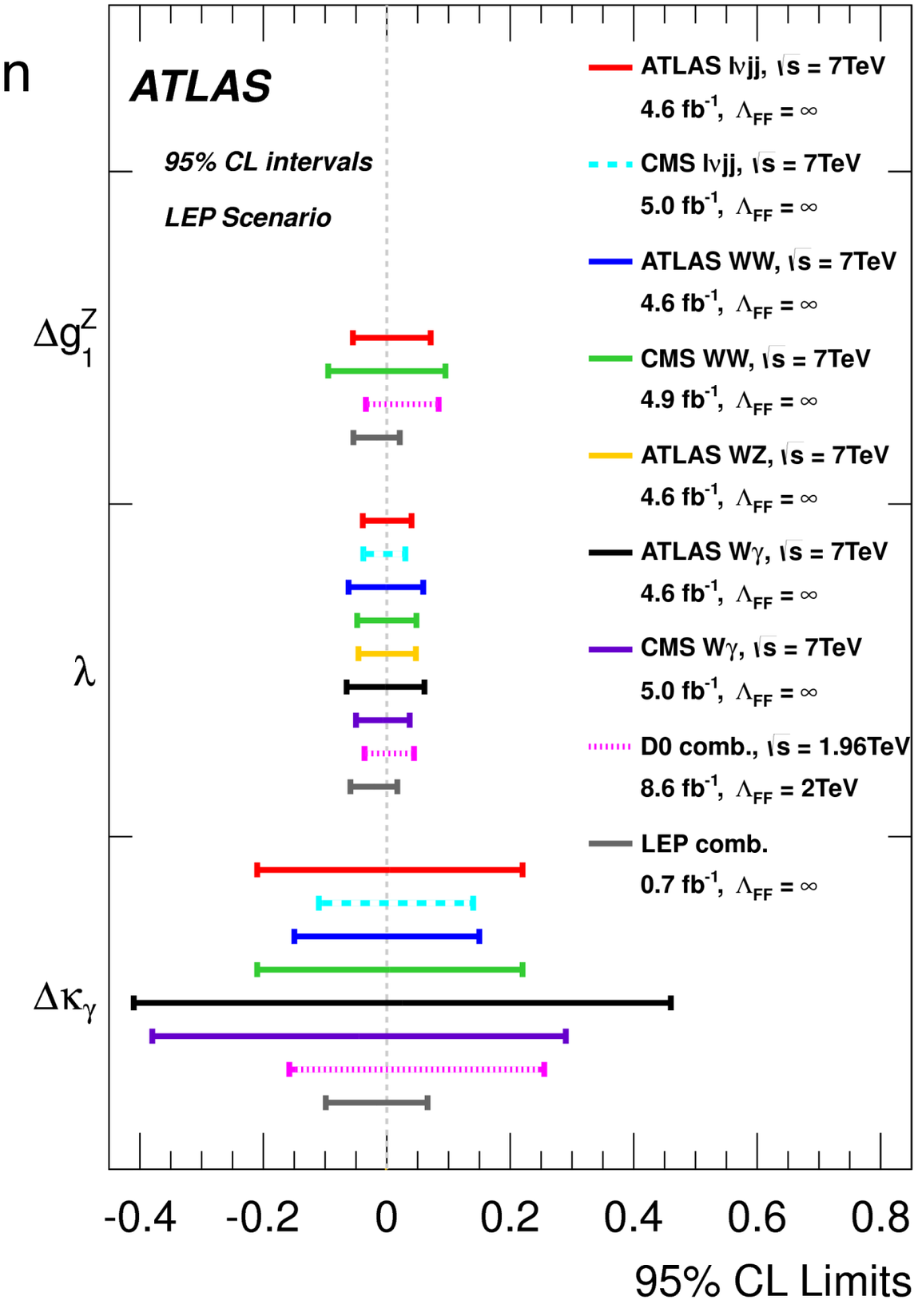
Limits on aTGC

- binned maximum likelihood fit of a chosen observable $p_{T\ell\ell}$ $(V \to \ell\ell)$
  - 75 GeV < m_{jj} < 95 GeV



*if $p_{T\ell\ell} < 250$ GeV

$\Delta R(j_1, j_2) > 0.7$



Wγγ @ 8TeV

arXiv: 1503.03243

Analysis Selection

Selection highlights

Two different phase spaces

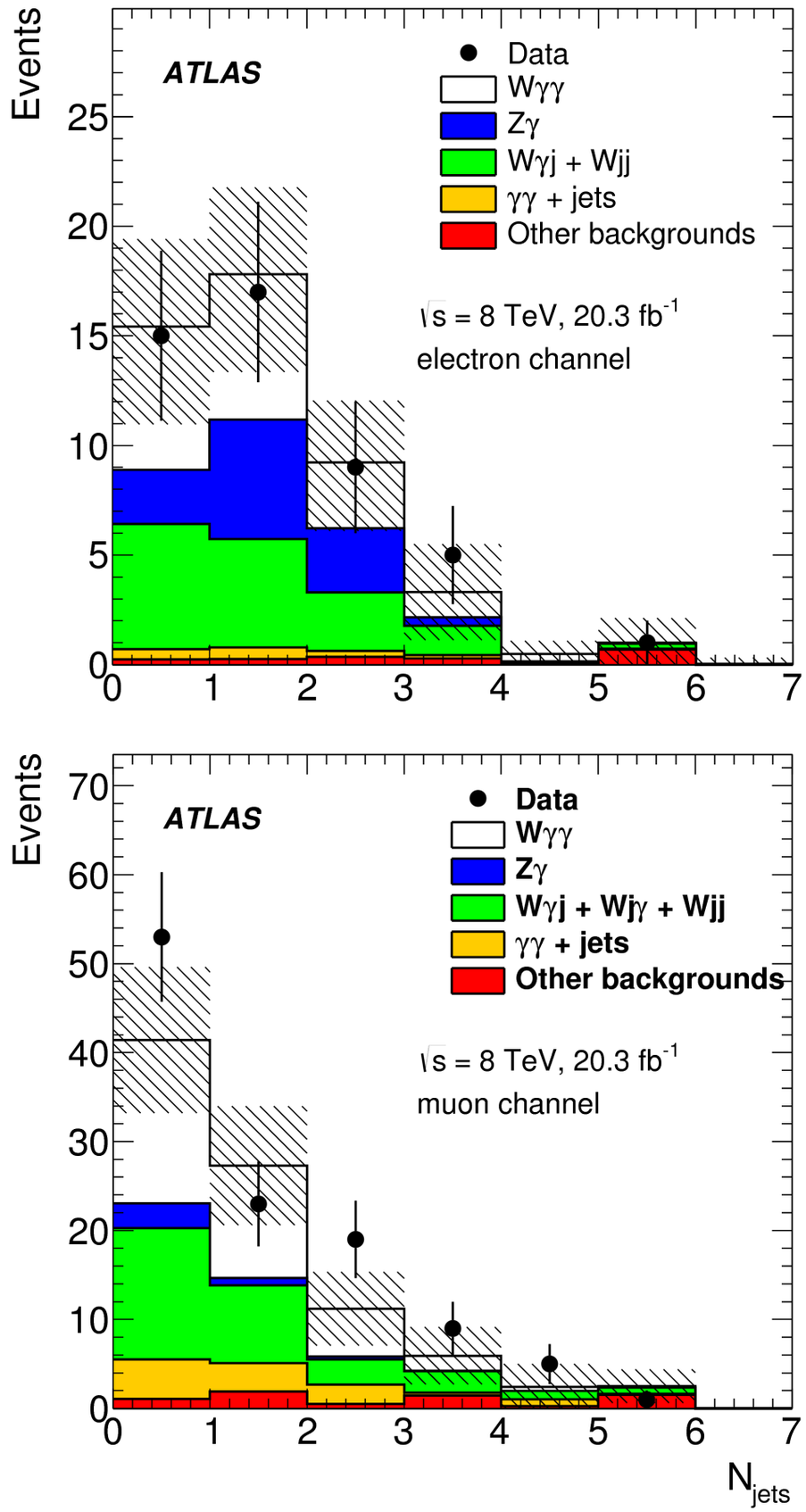
Inclusive

no restriction on the Wγγ recoil system

- muon and electromagnetic triggers
- $p_T(e,\mu,\gamma) > 20$ GeV
- $m_T(W) > 40$ GeV
- $\Delta\eta(\ell,\gamma) > 0.7$ *to suppress FSR contribution*
- additional requirements in the eγγ system to suppress Zγ background

Exclusive

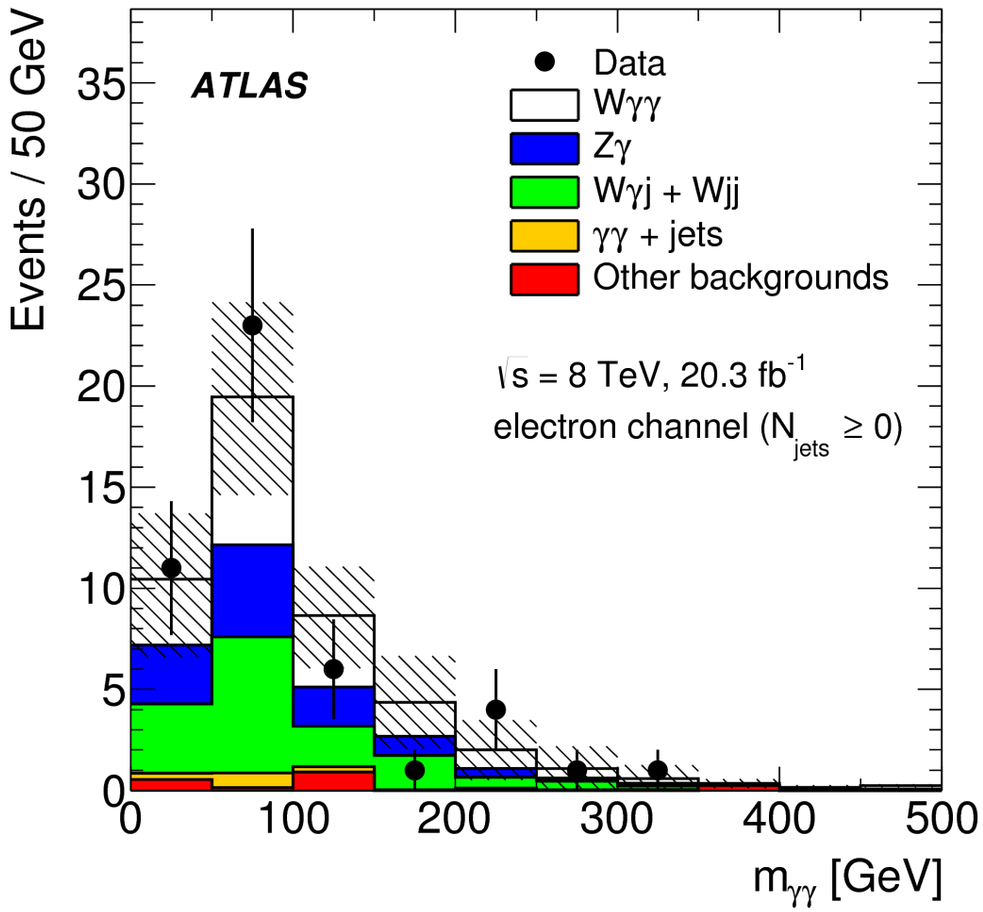
veto on events with jets pT > 30 GeV and |η| < 4.4

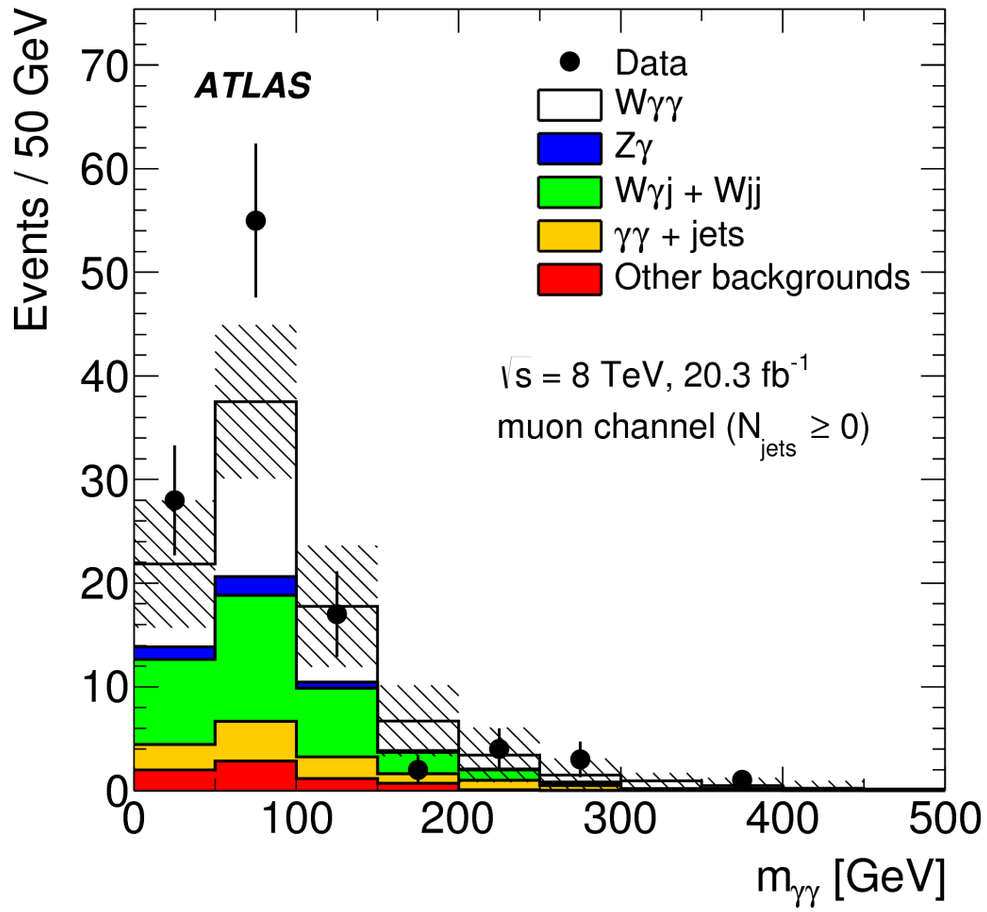


Background composition

- jets identified as photons (Wγ+jets, W+2jets) or leptons (γγ+jets)
- Zγγ, ttbar+γγ, diboson and W(τν)γγ, Zγ

	Inclusive		Exclusive	
	Electron channel	Muon channel	Electron channel	Muon channel
Wγj + Wjj	$15.3 \pm 4.8_{(stat)} \pm 5.3_{(syst)}$	$30.5 \pm 7.7_{(stat)} \pm 6.8_{(syst)}$	$5.8 \pm 2.1_{(stat)} \pm 2.0_{(syst)}$	$14.4 \pm 4.9_{(stat)} \pm 4.9_{(syst)}$
γγ+jets	$1.5 \pm 0.6_{(stat)} \pm 1.0_{(syst)}$	$11.0 \pm 4.0_{(stat)} \pm 4.9_{(syst)}$	$0.2 \pm 0.2_{(stat)} \pm 0.2_{(syst)}$	$6.1 \pm 3.5_{(stat)} \pm 3.1_{(syst)}$
Total Background	$30.2 \pm 5.0_{(stat)} \pm 5.4_{(syst)}$	$52.1 \pm 8.9_{(stat)} \pm 8.4_{(syst)}$	$8.7 \pm 2.2_{(stat)} \pm 2.0_{(syst)}$	$24.4 \pm 6.0_{(stat)} \pm 5.8_{(syst)}$
Data	47	110	15	53





Cross section measurement

- ***Evidence for the Wγγ process is reported for the first time!***
- Inclusive and exclusive cross section measurement
- Inclusive case: ***measured cross section higher by 1.9σ from the MCFM prediction***
- Better agreement for the exclusive case

signal significance for the inclusive production: 3σ

	σ^{fid}[fb]	σ^{MCFM}[fb]
μνγγ	$7.1^{+1.3}_{-1.2(stat)} \pm 1.5_{(syst)} \pm 0.2_{(lumi)}$	Inclusive
eνγγ	$4.3^{+1.8}_{-1.6(stat)}{}^{+1.9}_{-1.8(syst)} \pm 0.2_{(lumi)}$	2.90 ± 0.16
ℓνγγ	$6.1^{+1.1}_{-1.0(stat)} \pm 1.2_{(syst)} \pm 0.2_{(lumi)}$	
μνγγ	$3.5 \pm 0.9_{(stat)}{}^{+1.1}_{-1.0(syst)} \pm 0.1_{(lumi)}$	Exclusive
eνγγ	$1.9^{+1.4}_{-1.1(stat)}{}^{+1.1}_{-1.2(syst)} \pm 0.1_{(lumi)}$	1.88 ± 0.20
ℓνγγ	$2.9^{+0.8}_{-0.7(stat)}{}^{+1.0}_{-0.9(syst)} \pm 0.1_{(lumi)}$	

- ***dominant systematics*** on the measured cross section
  - ☑ 14% (incl.) and 23% (excl.) data-driven background estimate
  - ☑ 5% (incl.) and 7% (excl.) jet energy scale
  - ☑ 3% luminosity

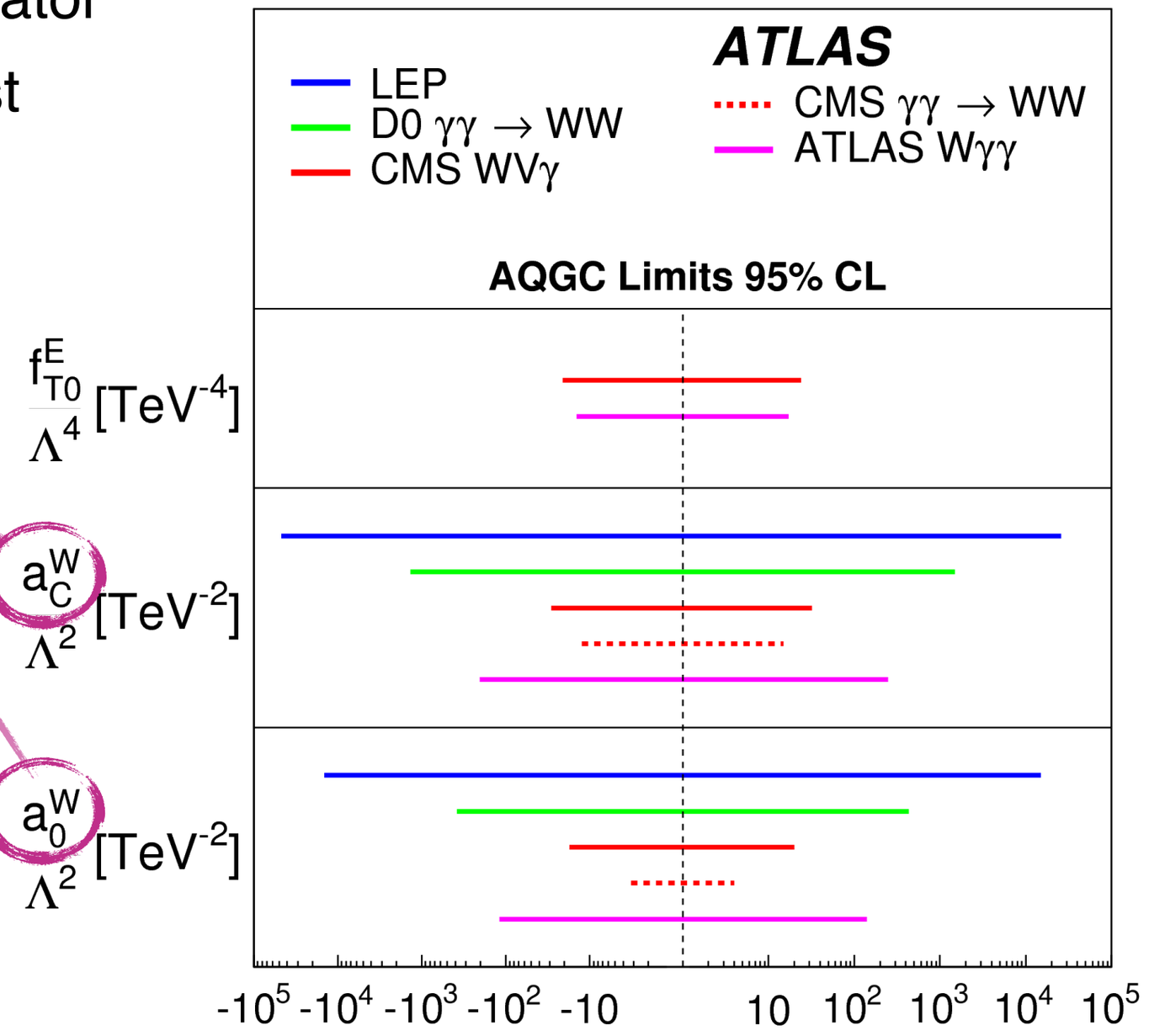
- Similar to the Wγ production cross section measurement
  - ☑ ***disagreement with the SM prediction in the inclusive case***

  Phys. Rev. D 87, 112003 (2013)
- New NNLO QCD corrections have sizable effect; provide better agreement with the measurement
  - Corrections for Wγ: ~ 19% - 26% ***arXiv: 1504.01330v1 [hep-ph]***

Limits on aQGC

- optimal phase space to study the aQGC parameters
  - ***exclusive*** selection with $m_{\gamma\gamma} > 300$ GeV
  - larger sensitivity to the T0 operator
  - frequentist profile likelihood test

parametrized f_{M2} & f_{M3} to match conventions at LEP and CMS



Limits assuming Form Factor to preserve unitarity at high energy scales

		Observed [TeV^{-4}]	Expected [TeV^{-4}]
$n = 0$	f_{T0}/Λ^4	$[-0.9, 0.9] \times 10^2$	$[-1.2, 1.2] \times 10^2$
	f_{M2}/Λ^4	$[-0.8, 0.8] \times 10^4$	$[-1.1, 1.1] \times 10^4$
	f_{M3}/Λ^4	$[-1.5, 1.4] \times 10^4$	$[-1.9, 1.8] \times 10^4$
$n = 1$	f_{T0}/Λ^4	$[-7.6, 7.3] \times 10^2$	$[-9.6, 9.5] \times 10^2$
	f_{M2}/Λ^4	$[-4.4, 4.6] \times 10^4$	$[-5.7, 5.9] \times 10^4$
	f_{M3}/Λ^4	$[-8.9, 8.0] \times 10^4$	$[-11.0, 10.0] \times 10^4$
$n = 2$	f_{T0}/Λ^4	$[-2.7, 2.6] \times 10^3$	$[-3.5, 3.4] \times 10^3$
	f_{M2}/Λ^4	$[-1.3, 1.3] \times 10^5$	$[-1.6, 1.7] \times 10^5$
	f_{M3}/Λ^4	$[-2.9, 2.5] \times 10^5$	$[-3.7, 3.3] \times 10^5$

No Form Factor

Conclusions

- Very good understanding of the physics processes with high precisions (NLO QCD) and
- Excellent performance of the ATLAS detector
  - Cross section measurement of semi-leptonic WV decays and limits on triple gauge couplings
  - First evidence of Wγγ production and limits on quartic gauge couplings
- Looking forward for new exciting measurements at Run II!

back up

Details for WW and WZ measurement

- **signal** samples
  - ***di-boson***:MC@NLO (v4.07) + HERWIG (parton shower and hadronisation) + JIMMY (underlying event)
  - ***on-shell gauge bosons***: MC@NLO+HERWIG → zero width for the W/Z and loss of the spin-correlation info for the decay products
  - CT10 PDF set, normalized to NLO cross sections
  - central values with factorization and renormalisation scales: $\sqrt{(m_W^2 + p_{\mathrm{T},W}^2 + m_V^2 + p_{\mathrm{T},V}^2)/2}$
  - gg →WW, H→WW, γγ→WW not included
  - if included, it would increase the total predicted WV cross section by about 2-4% (gg) and 5% (H) but after the event selection only by about 2%
  - NNLO QCD corrections for WW would increase the WV cross section by about 4%

  - *HERWIG: v6.520, JIMMY: v4.31, PYTHIA: v6.425*

Details for WW and WZ measurement

- **background** samples
  - ***W/Z+jets***: ALPGEN (v2.13) CTEQ6L1 + HERWIG + JIMMY scaled to NNLO times BR for a single lepton species $\sigma(W \to \ell\nu)$ and $\sigma(Z \to \ell\ell)$ for $m_{\ell\ell} > 40$ GeV
  - ***ttbar***:MC@NLO (v4.01) CT10 + HERWIG + JIMMY, NLO QCD including resummation of NNLL soft gluon terms with TOP++2.0
  - ***single-top from Wt and s-channel processes***: MC@NLO (v4.01) CT10 + HERWIG + JIMMY
  - ***single-top t-channel process***: ACERMC (v3.8) + PYTHIA MRST LO**
  - ***ZZ***: HERWIG MRST LO** normalised to NLO ($m_{\ell\ell} > 60$ GeV)
  - ***Wγ***: MADGRAPH v4 + PYTHIA (>0.5% so neglected)

Details for WW and WZ measurement

- **Fiducial volume definition**
  - identical for muons and electrons
  - 1 W decaying leptonically
  - 1 W or Z decaying hadronically
  - W→τν decays are not included in the definition of the fiducial volume
- **W decaying leptonically**
  - electron or muon with pT > 25 GeV
  - |η| < 2.47
  - lepton pT is obtained by summing together the lepton transverse momentum and the transverse momenta of all photons within a cone of ΔR=0.1 of the selected lepton
  - mT(W) > 40 GeV
  - E_T^{miss}: transverse momentum of the neutrino
  - E_T^{miss} > 30 GeV and $|\Delta\phi(E_T^{miss}, j_1)| > 0.8$

Details for WW and WZ measurement

- **Fiducial volume definition**
  - **W or Z decaying hadronically**
    - 2 particle-level jets separated by $\Delta R > 0.5$ from the selected leptons
    - particle-level jets reconstructed from particles with a mean decay length $c\tau > 10$mm using the anti-k_t algorithm with $R = 0.4$
    - decay products from leptonically decaying W/Z bosons are excluded from particle-level jets
    - 2 selected jets: $|\eta| < 2.0$, $pT > 25$GeV with at least one of them with $pT > 30$ GeV
    - events with more than 2 particle-level jets with $pT > 25$ GeV and $|\eta| < 2.8$ are rejected
    - 2 selected jets: $|\Delta\eta(j_1,j_2)| < 1.5$, $25 < m_{jj} < 250$ GeV and $\Delta R(j_1,j_2) > 0.7$ (ΔR cut only if $pT_{jj} < 250$ GeV)

Details for Wγγ measurement

- **signal** and **background** samples (all with CT10)
  - SHERPA (v1.4.1) with up to three partons in the final state
  - Zγ, Zγγ, WZ and W(τν)γγ: SHERPA
  - ttbar, single-top, WW: MC@NLO (v4.02) + HERWIG (v6.520) + JIMMY (v.4.30)
  - ZZ: POWHEG + PYTHIA (v8.163)
- **Fiducial volume definition**

Definition of the fiducial region
$p_{\mathrm{T}}^{\ell} > 20$ GeV, $p_{\mathrm{T}}^{\nu} > 25$ GeV, $\lvert\eta_{\ell}\rvert < 2.5$
$m_{\mathrm{T}} > 40$ GeV
$E_{\mathrm{T}}^{\gamma} > 20$ GeV, $\lvert\eta^{\gamma}\rvert < 2.37$, iso. fraction $\epsilon_{\mathrm{h}}^{\mathrm{p}} < 0.5$
$\Delta R(\ell,\gamma) > 0.7$, $\Delta R(\gamma,\gamma) > 0.4$, $\Delta R(\ell/\gamma,\mathrm{jet}) > 0.3$
Exclusive: no anti-k_t jets with $p_{\mathrm{T}}^{\mathrm{jet}} > 30$ GeV, $\lvert\eta^{\mathrm{jet}}\rvert < 4.4$

ε_h^p: fractional energy carried by the closest particle-level jet in a cone of ΔR = 0.4 around each photon direction

background composition - details

	Electron channel	Muon channel	Electron channel	Muon channel
	$N_{\text{jet}} \geq 0$		$N_{\text{jet}} = 0$	
$W\gamma$j + Wjj	$15.3 \pm 4.8(\text{stat.}) \pm 5.3(\text{syst.})$	$30.5 \pm 7.7(\text{stat.}) \pm 6.8(\text{syst.})$	$5.8 \pm 2.1(\text{stat.}) \pm 2.0(\text{syst.})$	$14.4 \pm 4.9(\text{stat.}) \pm 4.9(\text{syst.})$
$\gamma\gamma$ + jets	$1.5 \pm 0.6(\text{stat.}) \pm 1.0(\text{syst.})$	$11.0 \pm 4.0(\text{stat.}) \pm 4.9(\text{syst.})$	$0.2 \pm 0.2(\text{stat.}) \pm 0.2(\text{syst.})$	$6.1 \pm 3.5(\text{stat.}) \pm 3.1(\text{syst.})$
$Z\gamma$	$11.2 \pm 1.1(\text{stat.})$	$3.9 \pm 0.2(\text{stat.})$	$2.4 \pm 0.5(\text{stat.})$	$2.8 \pm 0.2(\text{stat.})$
Other backgrounds	$2.2 \pm 0.6(\text{stat.})$	$6.7 \pm 2.0(\text{stat.})$	$0.3 \pm 0.1(\text{stat.})$	$1.1 \pm 0.3(\text{stat.})$
Total background	$30.2 \pm 5.0(\text{stat.}) \pm 5.4(\text{syst.})$	$52.1 \pm 8.9(\text{stat.}) \pm 8.4(\text{syst.})$	$8.7 \pm 2.2(\text{stat.}) \pm 2.0(\text{syst.})$	$24.4 \pm 6.0(\text{stat.}) \pm 5.8(\text{syst.})$
Data	47	110	15	53

- Wγj+Wjj: 2D template fit to the isolation energy distributions of the leading and sub-leading photons
- γγ+jets: two-dimensional sideband method using the lepton isolation and the E_T^{miss} variables