Electroweak measurements with the ATLAS detector

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Outline

Standard Model (SM) electroweak measurements aim to:

- validate SM in new energy scale
- improve accuracy of known SM parameters
- estimate new physics contributions

This talk is devoted to Run 1, 8 TeV studies:

- SM production cross section measurements
- WW production
- Inclusive 4l production
- Vector boson fusion Z
- Vector boson scattering WW
- Wyy production

WW production

ATLAS-CONF-2014-033

- Important test of the non-Abelian structure of SM
- Cross section measurements are sensitive to anomalous triple gauge couplings (aTGC)
- Non-resonant WW production is an irreducible background process to Higgs boson studies
- Signature
 - two isolated leptons
 - high missing energy (MET)
- Dominant backgrounds

Channel	$e^\pm \mu^\mp$	$e^+ e^-$	$\mu^+ \mu^-$
Observed Events	5067	594	975
Total expected events	$4376 \pm 26 \pm 280$	$536 \pm 10 \pm 42$	$873 \pm 12 \pm 63$
MC WW signal	$3224 \pm 10 \pm 248$	$346 \pm 3 \pm 32$	$610 \pm 5 \pm 56$
Top(data-driven)	$609 \pm 18 \pm 52$	$92 \pm 7 \pm 8$	$127 \pm 9 \pm 11$
W+jets(data-driven)	$220 \pm 15 \pm 112$	$14 \pm 5 \pm 9$	$3 \pm 5 \pm 6$
Z+jets (data-driven)	$166 \pm 3 \pm 26$	$55 \pm 1 \pm 23$	$96 \pm 2 \pm 27$
Other dibosons (MC)	$157 \pm 4 \pm 31$	$30 \pm 2 \pm 5$	$39 \pm 1 \pm 5$
Total background	$1152 \pm 24 \pm 130$	$190 \pm 9 \pm 26$	$264 \pm 11 \pm 30$

WW results

- The individual channels are compatible within their uncertainties.
- The measured combined cross section differs from the partial NNLO SM prediction computed using CT10 PDF by $+2.1\sigma$ using the standard PDF and scale uncertainties.

Meanwhile

- Compatible with full NNLO prediction at about 1σ
- New result from CMS (arXiv:1507.03268) Measured total σ agree well with NNLO prediction.

Fiducial cross sections:

$$\sigma_{e\mu}^{\text{fid}} = 377.8^{+6.9}_{-6.8} \text{ (stat)} \quad +^{25.1}_{-22.2} \text{ (syst)} \quad +^{11.4}_{-10.7} \text{ (lumi)} \text{ fb}$$

Compatible with approximate NNLO+NNLL calculation

$$357.9 \pm 14.4 \text{ fb}$$

arXiv:1410.4745

4l inclusive

ATLAS-CONF-2015-031

Goal

- To test the validity of the Standard Model through the interplay of QCD and Electroweak effects for different 4l production mechanisms.

4l production at the LHC

- $q\bar{q}$ -originated 4l production
- 4l from Higgs boson decays
- Non-resonant $ZZ \rightarrow 4l$ production via ggF, VBF and VBS processes

4l inclusive

Event yield

Selection (leptonic channel is clean)

- Two pairs of same-flavor isolated opposite-charge leptons
- Mass window: $80 < m_{4l} < 1000$
- The overall background estimation uncertainty is 12% (the impact on the measured cross sections is $< 1\%$).

Channel	N^{Data}	$N^{Total}_{expected}$	N^{signal}_{non-gg}	N^{signal}_{gg}	N_{τ}^{MC}	N_{bkg}
$4e$	85	80 ± 4	68.4 ± 3.4	6.24 ± 0.31	1.28 ± 0.06	3.6 ± 0.5
4μ	156	150.2 ± 2.9	128.2 ± 2.5	11.00 ± 0.21	2.18 ± 0.09	9.0 ± 1.5
$2e2\mu$	235	205 ± 5	172 ± 5	16.0 ± 0.4	3.08 ± 0.13	13.6 ± 2.1
Total	476	435 ± 9	369 ± 9	33.3 ± 0.8	6.54 ± 0.14	26.2 ± 3.6

- Generally good agreement
- Small excess over the best available theory predictions (could be explained by statistical fluctuations)

4l inclusive

	Cross Section in the extended phase space [fb]			SM Prediction [fb]
σ_{4e}^{ext}	$17.8^{+2.1}_{-2.0}$ (stat.)	$^{+1.5}_{-1.1}$ (syst.)	$^{+0.5}_{-0.5}$ (lumi.)	16.4 ± 1.4
$\sigma_{4\mu}^{ext}$	$17.3^{+1.5}_{-1.4}$ (stat.)	$^{+0.9}_{-0.7}$ (syst.)	$^{+0.5}_{-0.5}$ (lumi.)	16.4 ± 1.4
Combined $\sigma_{4e+4\mu}^{ext}$	$35.0^{+2.4}_{-2.3}$ (stat.)	$^{+1.9}_{-1.5}$ (syst.)	$^{+1.1}_{-1.0}$ (lumi.)	32.9 ± 1.9
$\sigma_{2e2\mu}^{ext}$	$37.7^{+2.7}_{-2.6}$ (stat.)	$^{+2.5}_{-2.0}$ (syst.)	$^{+1.1}_{-1.1}$ (lumi.)	32.1 ± 2.0
Combined $\sigma_{4\ell}^{ext}$	73^{+4}_{-4} (stat.)	$^{+4}_{-4}$ (syst.)	$^{+2}_{-2}$ (lumi.)	65 ± 4

Data / Theory

- We interpret discrepancies between signal strength and current LO prediction as missing higher order correction to $gg \rightarrow 4l$:
 $\mu_{gg} = 2.4 \pm 1.0(\text{stat.}) \pm 0.5(\text{syst.}) \pm 0.8(\text{theory})$
- Inclusive gg component is extracted from data in $m(4l) > 180 \text{ GeV}$ region

Vector boson fusion Z

arXiv:1401.7610
JHEP04(2014)031

- Zjj production is dominated by the strong channel.
- VBF process is component of EWK Zjj production which needs to be correctly evaluated before aTGC (WWZ) measurements

Signature EWK process

- harder mjj and rapidity gap DeltaYjj distributions
- better balance pT of the system Zjj than strong production

Generator mismodelling at high mjj

Selection

- opposite-sign same-flavor lepton pair within $81 \text{ GeV} < m_Z < 101 \text{ GeV}$
- ≥ 2 high pT jets search region: $m_{jj} > 250 \text{ GeV}$ and central jet veto

Vector boson fusion Z

Results

- background-only hypothesis rejected with significance **above 5σ**
- good agreement with Powheg prediction

Fiducial cross section:

$$\sigma_{EWK}(\text{measured}) = 54.7 \pm 11.5 \text{ fb}$$

$$\sigma_{SM}(\text{Powheg}) = 46.1 \pm 1.0 \text{ fb}$$

aTGC	$\Lambda = 6 \text{ TeV (obs)}$	$\Lambda = 6 \text{ TeV (exp)}$	$\Lambda = \infty \text{ (obs)}$	$\Lambda = \infty \text{ (exp)}$
$\Delta g_{1,Z}$	$[-0.65, 0.33]$	$[-0.58, 0.27]$	$[-0.50, 0.26]$	$[-0.45, 0.22]$
λ_Z	$[-0.22, 0.19]$	$[-0.19, 0.16]$	$[-0.15, 0.13]$	$[-0.14, 0.11]$

➤ aTGC

- different from WZ (space-like vs timelike propag.)
- search region + cut on $m_{jj} > 1 \text{ TeV}$
- Modified by a dipole form factor, depending on unitarization scale Λ

Vector boson scattering WW

Motivation

- VBS WW production is observed for the first time and is sensitive to the mechanism of electroweak symmetry breaking as well as beyond the standard model physics

Results

- 34 candidates in VBS region (combined results)
- Measured cross-sections in agreement with theory prediction

arXiv:1405.6241

Phys. Rev. Lett. 113, 141803 (2014)

- VBS region is used to set first anomalous quartic gauge coupling (aQGC) limits on parameters: α_4 , α_5

W $\gamma\gamma$ production

arXiv:1503.03243
Phys. Rev. Lett. 115,
031802 (2015)

First measurement of triboson process in ATLAS!

➤ Selection

- Two isolated photons
- W decayed into leptons
(isolated lepton + missing energy)

➤ The largest Backgrounds

- Jets faking photons and leptons
- Data-driven techniques were used.

➤ Results

Above 3σ significance for SM
W $\gamma\gamma$ process for combined results.

W $\gamma\gamma$ production

➤ Cross sections

- Higher by 1.9σ than SM NLO prediction in inclusive case
- Better agreement in exclusive case

	σ^{fid} [fb]	σ^{MCFM} [fb]
Inclusive ($N_{\text{jet}} \geq 0$)		
$\mu\nu\gamma\gamma$	$7.1^{+1.3}_{-1.2} \text{ (stat.)} \pm 1.5 \text{ (syst.)} \pm 0.2 \text{ (lumi.)}$	2.90 ± 0.16
$e\nu\gamma\gamma$	$4.3^{+1.8}_{-1.6} \text{ (stat.)} \pm 1.9 \text{ (syst.)} \pm 0.2 \text{ (lumi.)}$	
$\ell\nu\gamma\gamma$	$6.1^{+1.1}_{-1.0} \text{ (stat.)} \pm 1.2 \text{ (syst.)} \pm 0.2 \text{ (lumi.)}$	
Exclusive ($N_{\text{jet}} = 0$)		
$\mu\nu\gamma\gamma$	$3.5 \pm 0.9 \text{ (stat.)}^{+1.1}_{-1.0} \text{ (syst.)} \pm 0.1 \text{ (lumi.)}$	1.88 ± 0.20
$e\nu\gamma\gamma$	$1.9^{+1.4}_{-1.1} \text{ (stat.)} \pm 1.1 \text{ (syst.)} \pm 0.1 \text{ (lumi.)}$	
$\ell\nu\gamma\gamma$	$2.9^{+0.8}_{-0.7} \text{ (stat.)} \pm 1.0 \text{ (syst.)} \pm 0.1 \text{ (lumi.)}$	

➤ Anomalous quartic couplings limits are set for exclusive case

- $M_{\gamma\gamma} > 300$ GeV
- Limits better or similar to LEP and D0

$$\begin{aligned}
 a_C^W/\Lambda^2 &= -2m_W^2(g^{-2}+g'^{-2})g'^2f_{M3}/\Lambda^4 \\
 a_0^W/\Lambda^2 &= 2m_W^2(g^{-2}+g'^{-2})g'^2f_{M2}/\Lambda^4, \\
 f_{T0}^E/\Lambda^4 &= g^4f_{T0}/\Lambda^4
 \end{aligned}$$

BONUS: Run 2 measurements

ATL-PHYS-PUB-2015-021

Reasonable agreement with MC

$W \rightarrow \mu \nu$:
 Pt > 25 GeV,
 E_{miss} > 20 GeV,
 MT > 50 GeV
 $\eta < 2.4$

$Z \rightarrow \mu \mu$:
 Pt > 25 GeV,
 66 < M(II) < 116 GeV
 $\eta < 2.4$

Display of a Z(ee)Z(μμ) candidate event from proton-proton collisions recorded by ATLAS, with LHC beams at a collision energy of 13 TeV.

Summary

The measurements presented in this talk provide important tests of electroweak sector in the Standard model (SM) and probes of new physics:

- Measurements of **WW production**
- **4l production** and strength of the **gluon-gluon fusion component**
- Electroweak production of Zjj , sensitive to **vector boson fusion** and limits on aTGCs
- First evidence of **vector boson scattering** and limits on aQGCs
- First measurement of triboson (**W $\gamma\gamma$**) **production** in ATLAS and limits on aQGCs

ATLAS public results are available here:

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults>

More electroweak results with 8 TeV will come soon!

The end.
Thank you!

Back up slides

exclusive di-lepton

arXiv:1506.07098

- The cross-section of the $pp(\gamma\gamma) \rightarrow l+l-X$ process has been predicted to increase with energy and constitutes a non-negligible background to Drell–Yan reactions.
- Can be calculated in the framework of quantum electrodynamics (QED)
- Preselection
 - exactly 2 back-to-back leptons
 - Z region removed
 - binned maximum-likelihood fit to the measured dilepton acoplanarity distribution
- Exclusive selection
 - 3 mm dilepton-vertex longitudinal isolation
 - p_T of the dilepton system < 1.5 GeV

Agreement with similar CMS measurement 20% below the nominal EPA prediction, and consistent with the suppression expected due to proton absorption contributions.

The weak mixing angle

- Angle by which EWSB rotates the pure gauge fields into physical fields of Z and photon.
- Template fit used to extract the most probable mixing angle w.r.t. measured forward-backward asymmetry of electron and muon pair-production in Z decays

$$A_{FB} = \frac{N_{\cos \theta_{CS}^* \geq 0} - N_{\cos \theta_{CS}^* < 0}}{N_{\cos \theta_{CS}^* \geq 0} + N_{\cos \theta_{CS}^* < 0}}$$

- **ATLAS measurement:**

$$\sin^2 \theta_{\text{eff}}^{\text{lept}} = 0.2308 \pm 0.0005 (\text{stat}) \pm 0.0006 (\text{syst}) \pm 0.0009 (\text{PDF})$$

- **World average (PDG 2014):**

$$\sin^2 \theta_{\text{eff}} = 0.23155 \pm 0.00005$$