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Studying the Electroweak Sector with the ATLAS Detector

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Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

Overview

- Electroweak (EW) sector with ATLAS: some recent results
 - Electroweak production of (multiple) vector bosons
 Focus on massive vector bosons
 - Precision measurements from Z decay
 - W Mass measurement: separate talk by Fabrice Balli

Why Electroweak physics in ATLAS?

- Precision Electroweak (EW) measurements in *pp* collisions
 - relevant for Standard Model (SM) results

 \succ even when less precise than in e^+e^-

- sensitive to underlying QCD / PDF
- Direct test of SM through search for anomalous couplings
- Backgrounds for Higgs physics and beyond the SM searches

MULTI-BOSON PRODUCTION

- Diboson production
- 'Vector Boson Fusion' (VBF)
- 'Vector Boson Scattering' (VBS)
- Triboson production

and references therein.

29/05/18

Standard Model Production Cross Section Measurements Status: March 2018 L dt [fb⁻¹] pp ₿ ₋৹ Jets R=0.4 Dijets R=0.4 рт > 125 GeV 🛛 🗖 p_T > 25 GeV 🛛 🔥 γ 20.2 4.6 0.081 4.6 3.2 20.2 4.6 3.2 20.2 4.6 3.2 20.2 4.6 3.2 20.3 4.6 $p_{\rm T} > 100 \, {\rm GeV}$ °[□] w z ð tī å Ŏ. t_{t-chan} ww 20.3 4.6 20.2 4.9 3.2 20.3 2.0 3.2 20.3 4.6 Theory $E_{\rm T}^{\gamma}$ >40 (30) GeV E_{τ}^{γ} >25 (22) GeV γγ ō LHC pp $\sqrt{s} = 7 \text{ TeV}$ D Wt Data stat wz stat ⊕ syst 36.1 20.3 4.6 ΖZ LHC pp $\sqrt{s} = 8$ TeV t_{s-chan} W γ 20.3 Data stat 20.3 4.6 Zγ stat ⊕ syst wv LHC pp $\sqrt{s} = 13$ TeV tΖj Data tīW stat tīΖ stat ⊕ svst tīγ Wiiewk **ATLAS** Preliminary **Z**ji ewk Ζγγ Ŵγγ WŴγ Run 1,2 $\sqrt{s} = 7,8,13$ TeV γijέwκ J±₩±ijεwk Ref. Standard Model public results 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{2} 10⁵ 10^{11} 0.5 1.0 1.5 2.0 2.5 10^{1} 10^{3} 10^{6} 10^{4} https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults σ [pb] data/theory Margherita Spalla - CIPANP 2018

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- Diboson production
- 'Vector Boson Fusion' (VBF)
- **Vector Boson** Scattering' (VBS)

Triboson production

Ref. Standard Model public results and references therein. 29/05/18



Diboson production

- Well measured at 7/8 TeV:
 - WW, WZ, ZZ: leptonic and semi-leptonic decay channels
- First 13 TeV results: early WW and WZ
 - > 3.2 fb⁻¹ data

Standard Model public results

and references therein.

- differential ZZ ≥ 36.1 fb⁻¹ data
- Generally good agreement with SM prediction



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^{(ev}Latest diboson measurements

- $* W^+W^- \rightarrow \mu \nu_{\mu} e \nu_{e}$
 - About $1\sigma'$ deviation from SM at 8 TeV
 - 13 TeV data compared with more precise simulation.
 - $ZZ \rightarrow \ell^+ \ell^- \ell^+ \ell^-$ (+ any jets)
 - Differential cross section in 20 observables
 - Sensitivity to PDF and QCD
 - Towards measurement of ZZjj from EW VBS.
 - No significant discrepancy with SM emerges from 13 TeV results
 - Still room for modeling improvement



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VBF Zjj/Wjj

- A vector boson (W or Z) associated to forward-backward jets
- EW production interferring with larger QCD production
 - EW contribution larger at e.g.
 - low activity in central region
 > no color flow in EW
 - large jet-jet mass
- Tipical approach:
 - Fit simultaneously EW and QCD contribution
 - Control region used to rescale QCD W/Zjj to data
 - Effect of interference term treated as systematics
 - Found to be at percent level



EW contribution



QCD contribution



VBF Zjj/Wjj

- A vector boson (W or Z) associated to forward-backward jets
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VBF Zjj/Wjj: recent results

- Zjj: first measured at 8 TeV, repeated at 13 TeV (3.2 fb⁻¹)
- 7+8 TeV Wjj recently published. •
 - Include differential cross section in multiple fiducial regions
- Moving from first observations to kinematics measurement.



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Data $\sqrt{s} = 8 \text{ TeV}, 20.2 \text{ fb}^{-1}$

POWHEG+PYTHIA8 (QCD) SHERPA (QCD+EW)

POWHEG+PYTHIA8 (QCD+EW)=

Anomalous Gauge Couplings: the meaning Ζ

- Triple (Quartic) Gauge Coupling
- Particles beyond the Standard Model might contribute through loops.

> Anomalous Triple / Quartic Gauge Couplings (aTGC / aQGC)

- Would increase production rate at high energy.
- Parametrized with model independent method (e.g. Effective Field Theory)
- Limits on the parameters from fit to most sensitive variable
 - mass, leading object's p_{T} , etc.





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$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{i} \frac{c_i}{\Lambda^2} \mathcal{O}_i(\dim 6) + \sum_{i} \frac{d_i}{\Lambda^4} \mathcal{O}_i(\dim 8) + \dots$$
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$$aQGC$$
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aTGC

- Three bosons couplings: accessible by diboson and VBF analysis
- First 13 TeV results from $ZZ \rightarrow \ell^+ \ell^- \ell^+ \ell^-$ and $WZ \rightarrow \ell \nu \ell \ell$

	Septembe	per 2017 CMS				
		ATLAS	Channel	Limits	Ĺdt	vs.
_	2/		ZZ (41,212v)	[-1.5e-02, 1.5e-02]	4.6 fb ⁻¹	7 TeV
	f	' <u> </u>	ZZ (41.212v)	[-3.8e-03, 3.8e-03]	20.3 fb ⁻¹	8 TeV
* NESUILS	4		ZZ (4I)	[-1.8e-03, 1.8e-03]	36.1 fb ⁻¹	13 TeV
• • •			ZZ (4I)	[-5.0e-03, 5.0e-03]	19.6 fb ⁻¹	8 TeV
compatible		·	ZZ (2l2v)	[-3.6e-03, 3.2e-03]	24.7 fb ⁻¹	7,8 TeV
Companyle		· · · · · · · · · · · · · · · · · · ·	ZZ (41,212v)	[-3.0e-03, 2.6e-03]	24.7 fb ⁻¹	7,8 TeV
		· H	ZZ (4I)	[-1.2e-03, 1.3e-03]	35.9 fb ⁻¹	13 TeV
			ZZ (41,212v)	[-1.0e-02, 1.0e-02]	9.6 fb ⁻¹	7 TeV
	-7		ZZ (4I,2I2v)	[-1.3e-02, 1.3e-02]	4.6 fb ⁻¹	7 TeV
	t <u>∠</u>	⊢−−−−	ZZ (41,212v)	[-3.3e-03, 3.2e-03]	20.3 fb ⁻¹	8 TeV
	4		ZZ (4I)	[-1.5e-03, 1.5e-03]	36.1 fb ⁻¹	13 TeV
			ZZ (4I)	[-4.0e-03, 4.0e-03]	19.6 fb ⁻¹	8 TeV
		⊢−−−−	ZZ (2l2v)	[-2.7e-03, 3.2e-03]	24.7 fb ⁻¹	7,8 TeV
_		⊢−−−	ZZ (4I,2I2v)	[-2.1e-03, 2.6e-03]	24.7 fb ⁻¹	7,8 TeV
Bost procision		H	ZZ (4I)	[-1.2e-03, 1.0e-03]	35.9 fb ⁻¹	13 TeV
			ZZ (4I,2I2v)	[-8.7e-03, 9.1e-03]	9.6 fb ⁻¹	7 TeV
	εγ		ZZ (4I,2I2v)	[-1.6e-02, 1.5e-02]	4.6 fb ⁻¹	7 TeV
trom	T ₅		ZZ (4I,2I2v)	[-3.8e-03, 3.8e-03]	20.3 fb ⁻¹	8 TeV
			ZZ (4I)	[-1.8e-03, 1.8e-03]	36.1 fb ⁻¹	13 TeV
		⊢−−−−−	ZZ (4I)	[-5.0e-03, 5.0e-03]	19.6 fb ⁻¹	8 TeV
		⊢−−−− 4	ZZ(2l2v)	[-3.3e-03, 3.6e-03]	24.7 fb ⁻¹	7,8 TeV
		⊢−−− 4	ZZ(4I,2I2v)	[-2.6e-03, 2.7e-03]	24.7 fb ⁻¹	7,8 TeV
Г. – – – – – – – – – – – – – – – – – – –		H	ZZ (4I)	[-1.2e-03, 1.3e-03]	35.9 fb ⁻¹	13 TeV
raculta			ZZ (4I,2I2v)	[-1.1e-02, 1.1e-02]	9.6 fb ⁻¹	7 TeV
IESUILS	۶Z		ZZ (4I,2I2v)	[-1.3e-02, 1.3e-02]	4.6 fb ⁻¹	7 TeV
	1 ₅		ZZ (4I,2I2v)	[-3.3e-03, 3.3e-03]	20.3 fb ⁻¹	8 TeV
			ZZ (4I)	[-1.5e-03, 1.5e-03]	36.1 fb ⁻¹	13 TeV
			ZZ (4I)	[-4.0e-03, 4.0e-03]	19.6 fb ⁻¹	8 TeV
		►	ZZ (2l2v)	[-2.9e-03, 3.0e-03]	24.7 fb ⁻¹	7,8 TeV
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		· • •	ZZ (4I)	[-1.0e-03, 1.3e-03]	35.9 fb ⁻¹	13 TeV
	1		ZZ (41,212v)	[-9.1e-03, 8.9e-0β]	9.6 fb ⁻ '	7 TeV
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J^{s = 8} T^{eN} Processes involving four boson interaction: VBS W[±]W[±]jj



- Two leptons of same charge and two forward-backward jets
 - QCD and EW contribution
- Cross section measured
 - Both inclusive and EW
 - Large, statistically dominated uncertainty
- aQGC limits: improved precision





^{s = 8} ^{τeν} Processes involving four boson interaction: WWγ/WZγ

- WWγ → evµvγ : cross section^e measurement
 - Significance 1.4 σ
- - 2 to 5 time larger than SM cross section
- All channels combined for aQGC search
 - Results consistent with SM

wper	Observed	Expected	SM Prediction
limits	limit [fb]	limit [fb]	$\sigma_{ m theo}~[m fb]$
evjjy	10	16^{+6}_{-4}	2.4 ± 0.1
μνϳϳγ	8	10^{+4}_{-3}	2.2 ± 0.1
lvjjγ	6	$8.4^{+3.4}_{-2.4}$	2.3 ± 0.1

Eur. Phys. J. C 77, 646 (2017)

 $\sigma_{\rm fid}^{e\nu\mu\nu\gamma} = 1.5 \pm 0.9({\rm stat.}) \pm 0.5({\rm syst.}) \,{\rm fb}$ Theoretical prediction: $2.0 \pm 0.1 \,{\rm fb}$



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PRECISION MEASUREMENTS FROM Z DECAY

$\sqrt{5}^{=8} \tau e^{\sqrt{7}} \tau$ polarization from $Z \rightarrow \tau \tau$

- Measure parity violation in interaction producing τ
- First LHC measurement
 - Precisely measured at LEP
- Semileptonic channel.
 - One leptonic tau needed for triggering events
- Maximum likelyhood fit to variable sensitive to τ polarization

$$\Upsilon_{\text{theory}} = \frac{E_{\pi^{\pm}} - E_{\pi^{0}}}{E_{\pi^{\pm}} + E_{\pi^{0}}}.$$



τ polarization from $Z \rightarrow \tau \tau$

Observed:
$$P_{\tau} = -0.14 \pm 0.02 \text{ (stat)} \pm 0.04 \text{ (syst)}$$

SM: $P_{\tau} = -0.1517 \pm 0.0019$

- First LHC measurement
 - Precisely measured at LEP
- Semileptonic channel.
 - One leptonic tau needed for triggering events
- Maximum likelyhood fit to variable sensitive to τ polarization
- Still much less precise than LEP
 - Combination not done

arXiv:1709.03490



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JS = 8 TeV



Conclusions

- Electroweak studies in ATLAS go towards higher precision measurement and more rare processes.
- Can provide significant input to precision SM constraints.
 - And insight into non perturbative QCD.
- Direct test for deviation from SM (anomalous couplings) found no evidence of beyond the SM contribution.



EW and QCD contributions in VBF





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aTGC limits for WWZ vertex

From: $WZ \rightarrow \ell \nu \ell \ell$

Analysis paper: ATLAS-CONF-2016-043

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				1 C fb ⁻¹	7 ToV
$\Delta \kappa_{\pi}$		VVVV		4.6 ID	7 TeV
— 2			[-2.56-02, 2.06-02]	20.3 ID 10.4 fb ⁻¹	9 ToV
				19.4 ID	8 13 TeV
			[-1.3e-01, 2.4e-01]	33.0 ID	0,10100
r i i i i i i i i i i i i i i i i i i i			[-2.10-01, 2.30-01]	19.0 10	
				4.6 ID	7 TeV
		VV V	[4.0002, 3.0002]	5.0 fb	12 ToV
			[-4.00-02, 4.10-02]	2.3 10	0.20 ToV
-		LEP Comb.	[-7.40-02, 5.10-02]	0.7 ID	7.ToV
λ_{-}		~~~~	[-0.20-02, 5.90-02]	4.6 10	
12		~~~~		20.3 10	
		VV VV	[-4.66-02, 4.66-02]	4.9 ID	7 TeV
		VV VV \\\/Z	[-2.4002, 2.4002]	19.4 fb	
				4.6 10	8 13 ToV
		VVZ		33.0 ID	9. To 10 V
		VVZ	[-1.60-02, 1.60-02]	19.6 ID	
				4.6 fD	
			[-2.20-02, 2.20-02]	20.2 fb	o Tev
		VVV (IVJ)	[-1.30-02, 1.30-02]	20.2 fb	
		VV V		5.0 fb ⁻¹	
		VVV	[-1.1e-02, 1.1e-02]	19 10	
				2.3 fb	13 TeV
		VBF Z		35.9 10	13 Iev
		D0 Comb.	[-3.66-02, 4.46-02]	8.6 fb	1.96 TeV
7		LEP Comb.	[-5.96-02, 1.76-02]	0.7 tb 1	0.20 lev
Λq^2		VVVV	[-3.9e-02, 5.2e-02]	4.6 fb -	7 IeV
-9 ₁		VVVV	[-1.66-02, 2.76-02]	20.3 fb	8 TeV
		VVVV		4.9 fb	
		VVVV	[-4.70-02, 2.20-02]	19.4 fb	
		<u>vv</u> z	[150.02.200.02]	4 b tb	8 13 ToV
			[-1.80-02, 3.00-02]	33.6 ID	9 ToV
			[-1.00-02, 3.50-02]	19.6 ID	
				4.6 10	
			[-2.70-02, 4.50-02]	20.2 fb ⁻¹	o lev
		VVV (IV3)	[-2.10-02, 2.40-02]	20.2 10	o Tev
		VVV	[-0.70-03, 2.40-02]	19 10	8 Iev
				2.3 fb	13 TeV
				35.9 10	13 Iev
		LED Comb.	[-3.4 0 -02, 8.40-02]	8.6 fb '	1.96 IeV
		LEP Comp.	[-5.4e-02, 2.1e-02]	0.7 tb -	0.20 1eV
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		- 1	aTGC L	imits @9	5% C.L.

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Leptonic WZ at 13 TeV

ATLAS-CONF-2016-043



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