Electron charge identification and study of the electroweak $W^{\pm}W^{\pm}jj$ production with the ATLAS detector at 13 TeV

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Overview

Vector boson scattering

- The role in the EWK simmetry breaking investigation
- Features

The WW channel

Background composition

Electron charge mis-identification: efficiencies measurement

Analysis overview

Electron charge mis-identification: background in the $W^{\pm}W^{\pm}jj$ analysis

Summary

Why keeping working after the Higgs boson discovery?

- Is this the only Higgs boson in Nature?
- Is it doing the Higgs boson's job?

Different paths to follow to answer (one or more of) these questions

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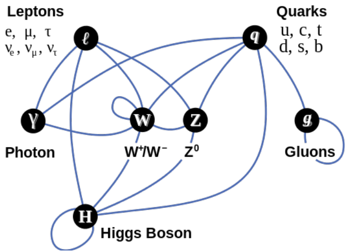
Many tools for the higgs investigation

- Measuring with higher precision its properties and couplings
- Investigating the high mass region
- **Measuring the electroweak (EWK) vector boson interactions**

The Standard Model (SM) lagrangian predicts *triple* (TGC) and *quartic* (QGC) gauge bosons vertices

$$\mathcal{L}_{gauge} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W^{a}_{\mu\nu}W_{a}^{\mu\nu}$$
$$= \mathcal{L}_{GC} + \mathcal{L}_{TGC} + \mathcal{L}_{QGC}$$



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Ultimately: aiming to study quartic couplings

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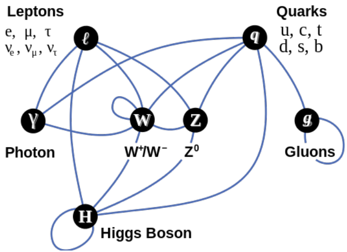

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Vector boson scattering

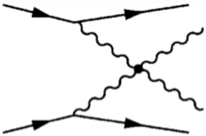
The role of Vector Bosons Scattering

- CERN Large Hadron Collider is providing promising statistics to access these processes
- quartic couplings can be accessed in **V**ector **B**oson **S**cattering signatures

At hadron colliders VBS can be idealized as $VVjj$

at leading order (LO):

- two vector bosons (i.e. their respective decay products)
- two outgoing jets



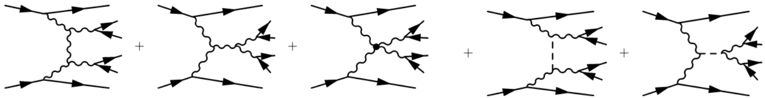
BUT

VBS diagrams are not separately gauge invariant and must be studied in conjunction with additional Feynman diagrams leading to the same $VVjj$ final state.

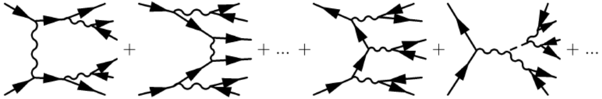
VVjj final state diagrams

Theoretically there are **two classes** of physical processes.

- **Electroweak production**: Only Weak interaction
  - $O(\alpha_{EWK}^6)$
  - VBS signal in it



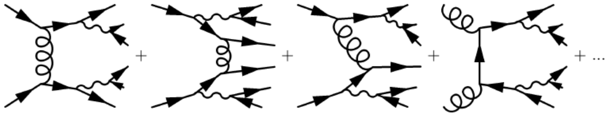
  - It contains also:
    purely EWK process which give the same final state
    processes with 3 decaying vector boson (only 1 decaying hadronically)



VVjj final state diagrams

Theoretically there are **two classes** of physical processes.

- **Electroweak production**: Only Weak interaction
- **Strong production**: Both strong and EWK interaction
  - $O(\alpha_{EWK}^4 \alpha_S^2)$



The WW channel

Without a light SM Higgs boson the VBS amplitude of longitudinally polarized W bosons increases with $\sqrt{s}$ and **violates unitarity** at energies around 1 TeV.

$\downarrow$

The SM Higgs boson should avoid this problem

WW scattering is a key process to probe EWKSB

We can establish if the Higgs boson can preserve unitarity of the VBS at all energies

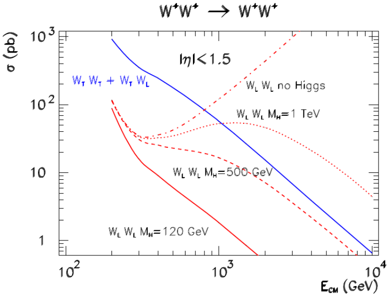
- Test of the Higgs boson nature
  - The discovered Higgs boson contribute fully to the EWKSB

    $\downarrow$

    WW interaction remain weak at high energies
- Model independent research of alternative theory
  - The discovered Higgs boson is partially responsible for the EWKSB

    $\downarrow$

    WW interaction get strong at high energy



arXiv:1412.8367

Choosing the right process: $W^\pm W^\pm jj$ channel

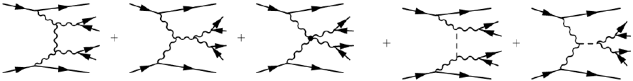
final state	sensitive to $VV \to$	σ^{EWK} [fb] 8 TeV	13 TeV	σ^{QCD} [fb] 8 TeV	13 TeV
$\ell^+\ell^-\ell'^+\ell'^-jj$	ZZ	0.027	0.098	0.024	0.100
$\ell^+\ell^-\ell'^\pm\nu'jj$	$W^\pm Z$	0.571	2.34	1.12	4.38
$\ell^+\ell'^-\nu\nu'jj$	W^+W^-, ZZ	3.64	12.3	5.51	21.8
$\ell^\pm\ell'^\pm\nu\nu'jj$	$W^\pm W^\pm$	1.13	3.97	0.110	0.346
$\ell^\pm\nu\nu'\nu'jj$	$W^\pm Z$	1.81	7.64	3.78	15.5
$\nu\nu\nu'\nu'jj$	ZZ	0.484	1.68	0.294	1.38

C. Gumpert, PhD Thesis, CERN-THESIS-2014-290

$W^\pm W^\pm jj$ production:

- lower background from QCD production: $\sigma_{EWK}/\sigma_{QCD} \simeq 11$ ($\sigma_{EWK}/\sigma_{QCD} \simeq 0.6$ for opposite sign)

The same-charge selection restricts the number of diagrams involved



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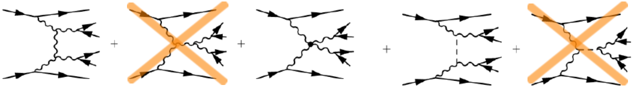

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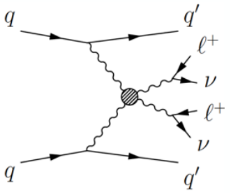
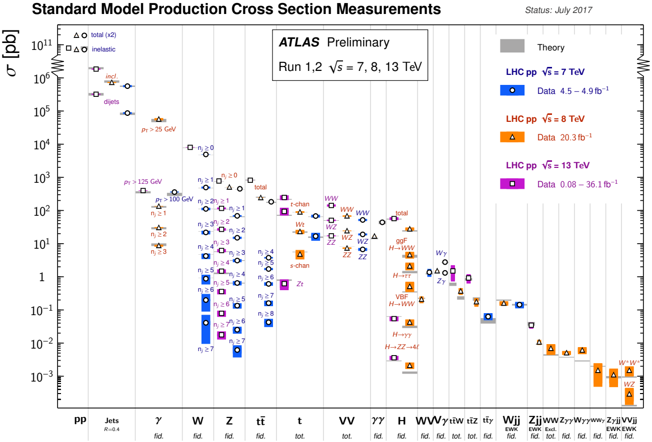


SM processes can mimic the signature $\ell\ell' + E_T^{miss}$+2 jets

Type	Sources	Reduction
1 SC leptons	WZ+jets ZZ+jets $t\bar{t}V$	veto on third lepton
2 OC charge mis-ID	$t\bar{t} \to \ell\nu\ell\nu b\bar{b}$ $W^{\pm}W^{\mp}$ + jets Z/γ^*+jets$\to \ell^{\pm}\ell^{\mp}$+jets	b-jet veto +SC req. large E_T^{miss}+m_Z peak excl.
3 Jets, γ mis-reco	W+jets $t\bar{t} \to \ell\nu jjb\bar{b}$ single top $W\gamma$+jets	b-jet veto+E_T^{miss} tight isolation+veto on third lepton

It's important to keep in mind that the other SM processes have much larger cross section compared to our signal!



The challenges

Many challenges enter this analysis:

- very low cross-section compared to other SM processes
- many SM backgrounds can be reduced with dedicated cuts, but still some of them need to be estimated
- big impact of background from non-prompt leptons (*fakes*)
- big impact of background from charge mis-reconstruction

$\downarrow$

always better to estimate these backgrounds with **data-driven** methods (*"Data model data better than Monte Carlo"*)

In the following focus on **charge mis-identification** background

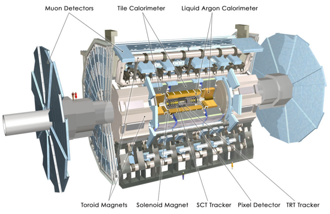
In order to estimate the charge mis-ID background it's important to precisely know the probability of an electron to have its charge wrongly reconstructed:

- measurement of electron charge mis-identification efficiencies
- data-driven estimation of background from charge mis-identification

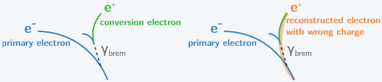
Electron charge mis-identification: efficiencies measurement

The source of charge mis-ID

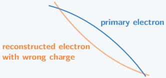
Charge (mis-)reconstruction



- Conversion of bremsstrahlung photon



- Wrong track reconstruction



- very rare effects
- very hard to properly model in detector simulation
- the effect have to be measured on **data**

In ATLAS objects measurements are performed inside *Combined Performance* groups. This one in particular has been carried out in the *Electron-photon* CP group

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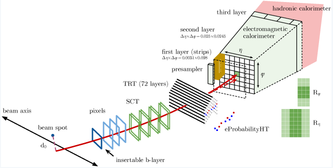

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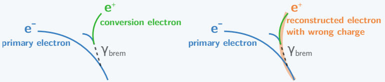

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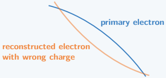

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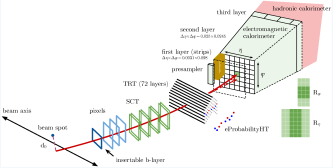

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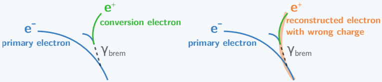

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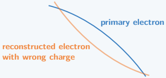

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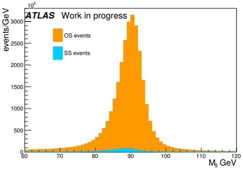
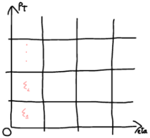
Measuring the efficiencies



- Double differential measurement in 4×6 bins in $p_T \times |\eta|$
- measured in $Z \rightarrow e^+e^-$ events



- ϵ_i probability electron charge mis-reconstructed in bin i. Assume ϵ_i independent

$$N_{sc}^{exp} = np = n\left[(1-\epsilon_i)\,\epsilon_j + (1-\epsilon_j)\,\epsilon_i\right]$$

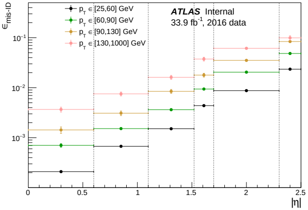
Building likelihood function:

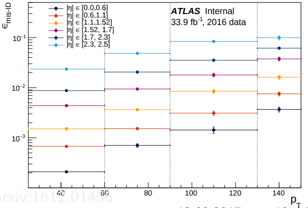
- binomial counting: probability of nsc SC events: $\binom{n}{nsc} p^{nsc}(1-p)^{n-nsc}$
- approximated Poisson distribution

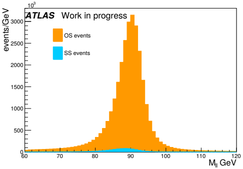
$$P\left(nsc|\epsilon_i,\epsilon_j\right) = \frac{(N_{sc}^{exp})^{nsc} e^{-N_{sc}^{exp}}}{nsc!} \equiv L(\epsilon_i,\epsilon_j)$$

- $L = \prod_{i,j} L(\epsilon_i,\epsilon_j)$

Efficiencies obtained by minimizing $-ln(L)$







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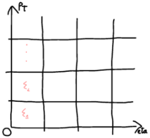

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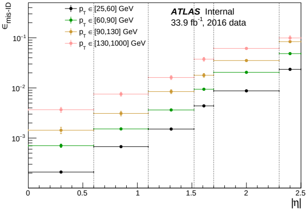
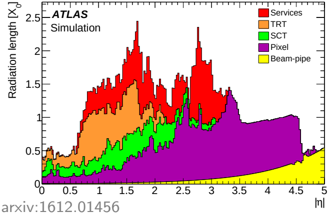
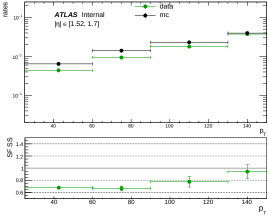
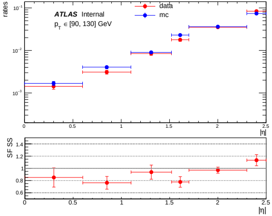




arxiv:1612.01456

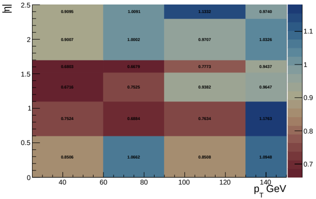
Scale factors

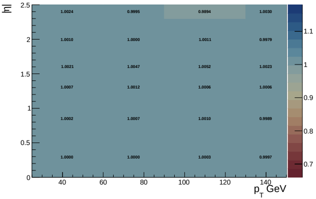




- efficiencies highly dependent on process and kinematic selection
- scale factors are produce where these effects cancel
- they can also be used to study the effeiciencies of other processes
- scale factors are derived for right charge and wrong charge electrons to correct MC

$$SF_{wrong} = \frac{\epsilon_{data}}{\epsilon_{MC}} \qquad SF_{right} = \frac{1 - \epsilon_{data}}{1 - \epsilon_{MC}}$$

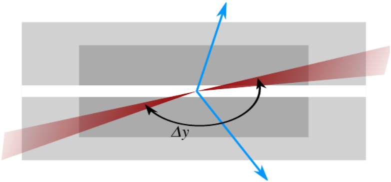


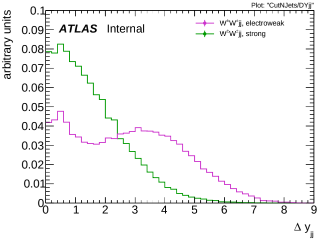


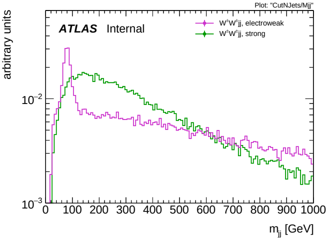
- corrections for wrong charge electrons up to ∼30%
- corrections for right charge electrons never bigger than 0.5%

Analysis overview

Prelude: $W^{\pm}W^{\pm}jj$ analysis topology







- 2 high-p_T jets in the forward regions (2 jets with highest p_T)
- No color exchange in the hard scattering process $\rightarrow$ rapidity gap in the central part of the detector
- large m_{jj} and m_{WWjj}

Two analysis regions could be defined, using the EWK specific topologies as discriminant cuts:

- **Inclusive region: signal = EWK+QCD**
- **VBS region: signal = EWK** $\rightarrow$ additional cut on $|\Delta y_{jj}| > 2.4$

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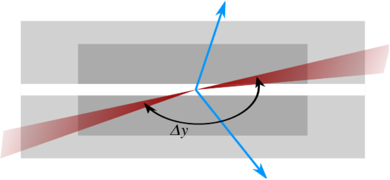

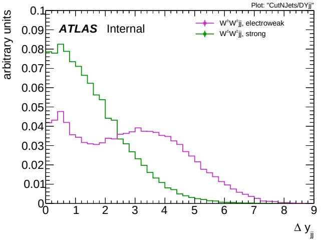

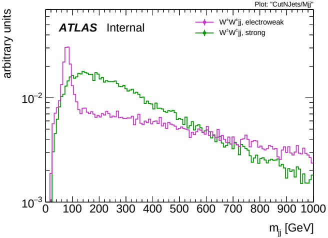

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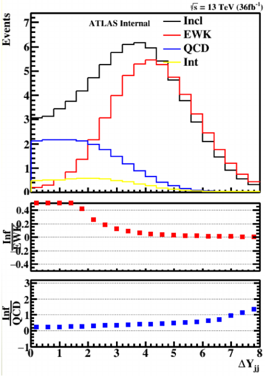
Studies of EWK-QCD separation and interference

Interference between $\mathcal{O}\left(\alpha_{QCD}^4\right)$ strong and $\mathcal{O}\left(\alpha_{EWK}^6\right)$ electroweak $W^\pm W^\pm jj$ production to be studied:

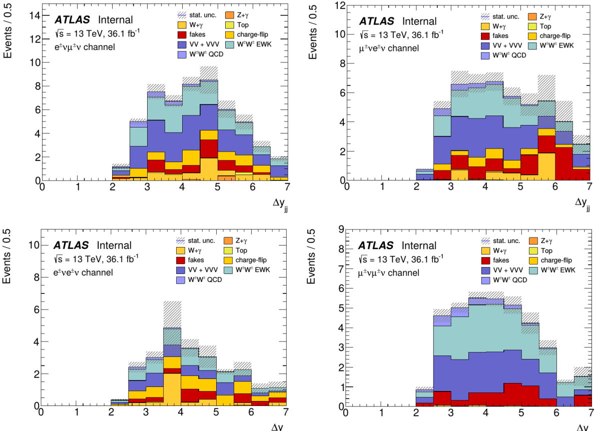
$$\left|\mathcal{M}_{SM}^{WWjj}\right|^2 = \left|\mathcal{M}_{QCD}^{WWjj} + \mathcal{M}_{EWK}^{WWjj}\right|^2 = \left|\mathcal{M}_{QCD}^{WWjj}\right|^2 + \left|\mathcal{M}_{EWK}^{WWjj}\right|^2 + \left|\mathcal{M}_{INT}^{WWjj}\right|^2$$



- interference varies from few percent to few ten-percent
- negative in some regions
- will be included as systematic uncertainty on the EWK signal

Contributions at final selection

- analysis performed in four channels: $e\mu$, μe, $\mu\mu$ and ee
- different background composition between channels
- main backgrounds: WZ, fakes and charge mis-ID (not $\mu\mu$ channel)



As anticipated the main challenges in this analysis are related to the fake background and the charge mis-identification one

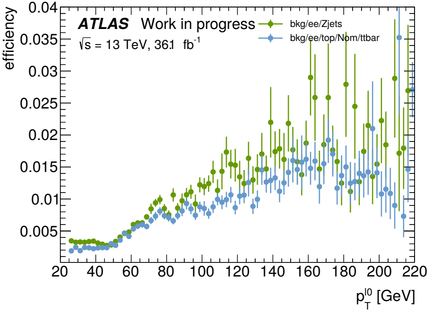
Electron charge mis-identification: background in the $W^{\pm}W^{\pm}jj$ analysis

Charge mis-ID background

The technique

- charge mis-ID background estimated from data
- same-charge events are estimated from opposite-charge events
- opposite charge data are scaled with

$$w = \frac{\epsilon_1 + \epsilon_2 - 2\epsilon_1\epsilon_2}{1 - (\epsilon_1 + \epsilon_2 - 2\epsilon_1\epsilon_2)}$$



- $\epsilon_{1,2}$: charge mis-ID rates for $e_{1,2}$
- rates appear to be process dependent

The data-driven estimate

The final aim

We want a data-driven estimation of the charge mis-identification background remaining in the SR

opposite-charge data

$$\text{weight} = \frac{\epsilon_1(1-\epsilon_2)+\epsilon_2(1-\epsilon_1)}{(1-\epsilon_1)(1-\epsilon_2)+\epsilon_1\epsilon_2}$$

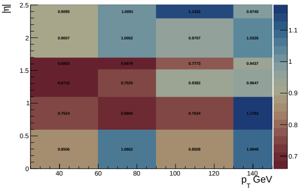
same-charge estimation

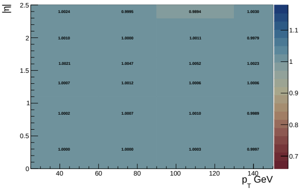
where

$\epsilon_{1,2}$: charge misID rates. $\mathcal{P}$ for $\ell_{1,2}$ charge to be mis-identified

$\rightarrow$ rates from data are needed to build the weights

From SF to rates

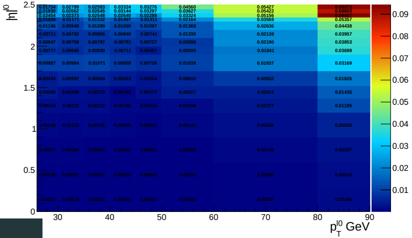




↓

- apply the SF to MC so that it matches the probability of mis-identification of data
- get rates from MC using the truth information

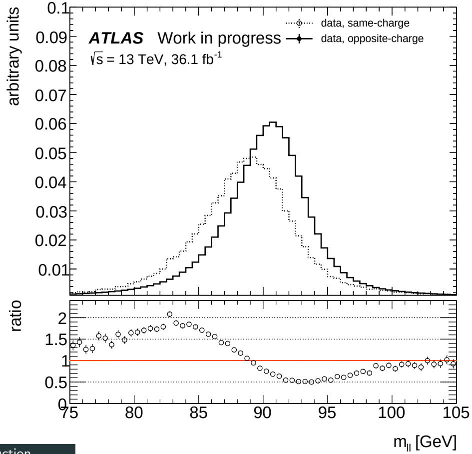
$$\epsilon = \frac{\text{wrong charge ele}}{\text{all ele}}$$



Energy corrections needed

Up to this point of the workflow a simple *scaling* is applied to OC data:

- the integral is modified
- the distribution of charge flip estimation is identical to OC data one
- SC events have lower energy wrt OC one, because of the energy leakage due to Bremsstrahlung emission



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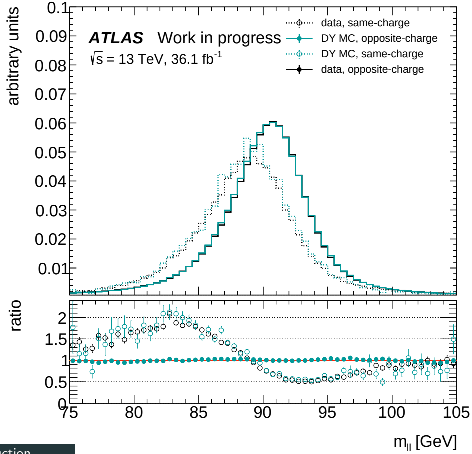

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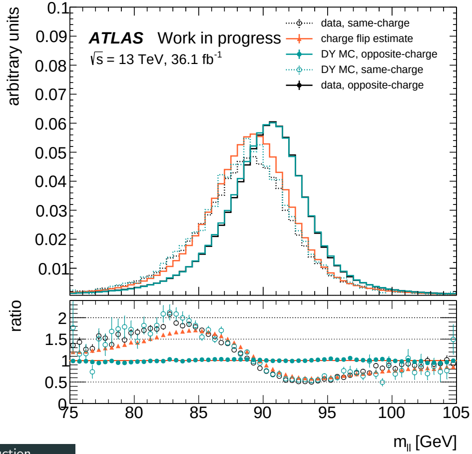


The scaling and the smearing

The four-momentum of OC data used for the estimation is modified

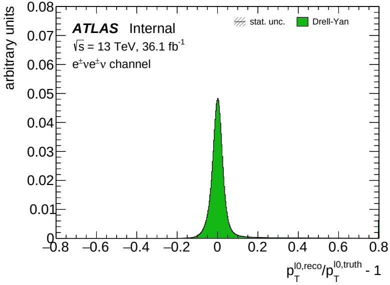
- p_T is shifted towards smaller values
- p_T is smeared to match the worse resolution

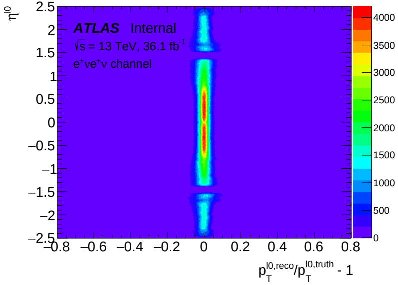
$$p_T^{corrected} = p_T^{scaled} + dE$$

The scaling is based on the energy response

$$response = \frac{p_T^{reco}}{p_T^{truth}} - 1$$

which is different for **correctly** reconstructed and **wrongly** reconstructed electrons





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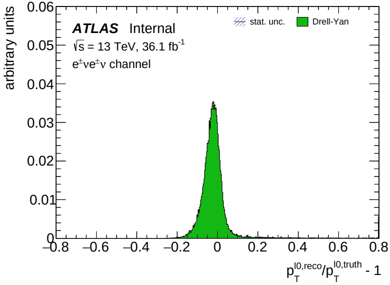
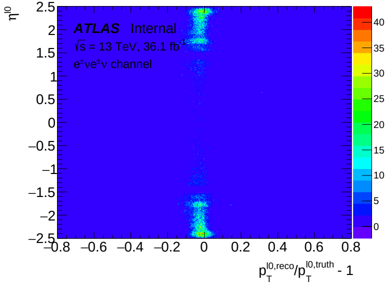
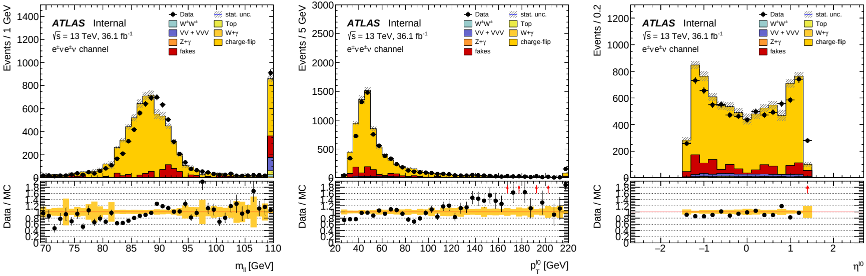




The estimation in the *ee* channel



- the *ee* channel is dominated by charge mis-ID background
- the estimation seems to match quite nicely with data
- studies and optimizations ongoing

Summary

Summary

Two main working areas have been shown...

→ electron charge mis-ID SF measurement

- performed within the ATLAS e/γ combined performance group
- official recommendations provided to physics analyses inside the collaboration
- the work will be documented in the e/γ paper

→ estimation of the charge mis-ID background in the $W^{\pm}W^{\pm}jj$ analysis

- process of estrapolation of the rates for the analysis has been shown
- the impact of this background is huge in the SR, much work needed to get a precise estimation
- the technique for this has been studied and implemented inside the analysis framework
- further corrections have been performed

WW scattering is a key process for SM and EWSB mechanism

- same charge final state is a clean signature of electroweak production
- on the other side the low cross-section and the large background from charge mis-identification make the $W^{\pm}W^{\pm}jj$ analysis a difficult path

Very challenging time yet to come to put Standard Model to stringent test

Thank you!

Backup

Phase space for fiducial cross sections (slide 8)

- Sherpa
- defined at parton level
- $p_T^{lep} \geq 25$ GeV
- $|\eta^{lep}| \leq 2.5$
- $\Delta R^{lep} \geq 0.3$
- minimum $m_{\ell\ell}$ of all charged lepton pair combinations $\geq$ 20 GeV
- at least 2 jets $p_T^{jet} \geq$30 GeV
- $|\eta^{jet}| \leq 4.5$
- $\Delta R^{lep,jet} \geq 0.3$
- $m_{jj} \geq 500$ GeV
- $|\Delta\eta| \geq 2.4$

ATLAS Run 1 results in the $W^{\pm}W^{\pm}jj$ channel

First evidence for $W^{\pm}W^{\pm}jj$ production and EWK-only $W^{\pm}W^{\pm}jj$ production @ 8 TeV

PRL 113, 141803 (2014) PHYSICAL REVIEW LETTERS week ending 3 OCTOBER 2014

Evidence for Electroweak Production of $W^{\pm}W^{\pm}jj$ in pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector

G. Aad *et al.*[*]
(ATLAS Collaboration)
(Received 23 May 2014; published 3 October 2014)

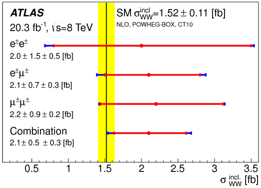
This Letter presents the first study of $W^{\pm}W^{\pm}jj$, same-electric-charge diboson production in association with two jets, using 20.3 fb^{-1} of proton-proton collision data at $\sqrt{s} = 8$ TeV recorded by the ATLAS detector at the Large Hadron Collider. Events with two reconstructed same-charge leptons ($e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$,

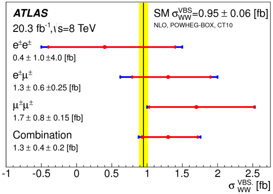
$\sigma^{fid}_{incl} = 2.1 \pm 0.5$ (stat) ± 0.3 (syst) fb

- Significance: 4.5σ
- $\sigma_{exp} = 1.52 \pm 0.11$ fb

$\sigma^{fid}_{VBS} = 1.3 \pm 0.4$ (stat) ± 0.2 (syst) fb

- Significance: 3.6σ
- $\sigma_{exp} = 0.95 \pm 0.06$ fb



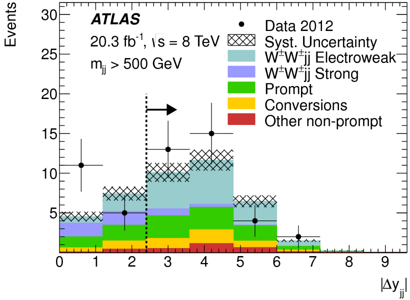


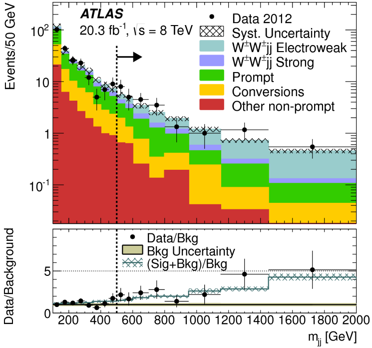
Goal for Run 2

Measurement of the EWK production cross section → 5σ observation reachable within LHC operation plans

Yields Run 1 analysis

	Inclusive region			VBS region		
	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$
$W^\pm W^\pm jj$ QCD	0.89 $\pm$ 0.15	2.5 $\pm$ 0.4	1.42 $\pm$ 0.23	0.25 $\pm$ 0.06	0.71 $\pm$ 0.14	0.38 $\pm$ 0.08
$W^\pm W^\pm jj$ EWK	3.07 $\pm$ 0.30	9.0 $\pm$ 0.8	4.9 $\pm$ 0.5	2.55 $\pm$ 0.25	7.3 $\pm$ 0.6	4.0 $\pm$ 0.4
Total background	6.8 $\pm$1.2	10.3 $\pm$ 2.0	3.0 $\pm$ 0.6	5.0 $\pm$ 0.9	8.3 $\pm$ 1.6	2.6 $\pm$ 0.5
Total predicted	10.7 $\pm$ 1.4	21.7 $\pm$ 2.6	9.3 $\pm$ 1.0	7.6 $\pm$ 1.0	15.6 $\pm$ 2.0	6.6 $\pm$ 0.8
Data	12	26	12	6	18	10





50 signal candidates with 20 background expectation for ISR
34 signal candidates with 16 background expectation for VBS

Fiducial regions Run 1 analysis

Two fiducial regions are defined to follow the selections applied in the analysis

- **Inclusive region:**
  - 2 same sign leptons with
    - $p_T > 25$ GeV
    - $|\eta| < 2.5$
    - $m_{\ell\ell} > 20$ GeV
    - $\Delta R_{\ell\ell} = \sqrt{(\Delta\Phi)^2 + (\Delta\eta)^2} > 0.3$
  - At least 2 anti-k_t jets with
    - R = 0.4
    - $p_T > 30$ GeV
    - $|\eta| < 4.5$
    - $\Delta R_{\ell j} > 0.3$
    - m_{jj} (highest p_T jets) > 500 GeV
  - $E_T^{miss} > 40$ GeV
- **VBS region**: cuts above + rapidity cut
  $|\Delta y_{jj}| > 2.4$

Run 1 event selection

Events selection used for the analysis:

- event cleaning
- exactly two selected leptons with $m_{\ell\ell} > 20$ GeV
- veto events with additional veto leptons
- $q_{\ell_1} \times q_{\ell_2} > 0$
- $p_T > 25$ GeV
- $|m_{\ell\ell} - m_Z| > 10$ GeV in the ee channel
- $E_T^{miss} \geq 40$ GeV
- at least two jets with $p_T > 30$ GeV and $|\eta| < 4.5$
- b-jet veto
- $m_{jj} > 500$ GeV
- $|\Delta y_{jj}| > 2.4$ - VBS analysis region

Cross section changes from 8 TeV to 13 TeV

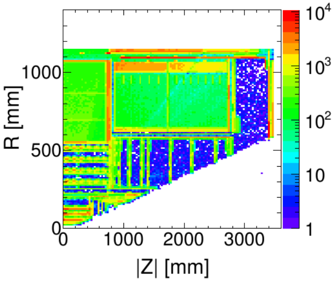
Signal samples generated with Sherpa 2.1.1, LO up to 3 additional partons:

	QCD			EWK		
	8 TeV	13 TeV	13 TeV/8 TeV	8 TeV	13 TeV	13 TeV/8 TeV
σ_{prod} [fb]	10.1	25.9	2.6	16.4	43.0	2.6

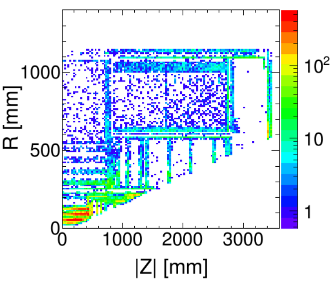
- Rate of wrongly reconstructed charge strongly depends on material distribution:

Z and R for the first detector interaction using Z MC truth:
wrong sign interact primarily with beam pipe and pixel

Right reconstructed sign



Wrong reconstructed sign



Current selection

- $p_T^{\ell 1,\ell 2}$ >27 GeV $\rightarrow$ under optimization studies
- $m_{\ell\ell} > 20$ GeV $\rightarrow$ under optimization studies
- $q_{\ell_1} \times q_{\ell_2} > 0$
- 3^{rd} lepton veto
- $p_T^j > 30$ GeV $\rightarrow$ under optimization studies
- $|\eta|^j < 4.5$
- $E_T^{miss} \geq 30$ GeV
- $m_{jj} > 500$ GeV $\rightarrow$ under optimization studies
- $|\Delta y_{jj}| > 2.4$ $\rightarrow$ under optimization studies

Energy correction derivation

- *response* is derived

$$response = \frac{p_T^{reco}}{p_T^{truth}} - 1$$

for right charge and wrong charge electrons, differentially in η

- defining α as

$$\alpha = \frac{1 + response^{right}}{1 + response^{wrong}}$$

- p_T is corrected as:

$$p_T^{scaled} = \frac{p_T^{old}}{\alpha}$$

- smearing is based on dE, random number in Gauss distribution:

$$dE = \mathrm{Gauss}\left(0\,,\mathrm{sqrt}\left(\frac{err_{wrong}^2}{(1 + response^{wrong})^2} - \frac{err_{right}^2}{(1 + response^{right})^2}\right)\right) p_T^{scaled}$$

Acceptances and efficiencies for $W^{\pm}W^{\pm}jj$

- Calculated on `Sherpa 2.2.1`
- $\sigma^{tot}_{EWK} = 37.4$fb and $\sigma^{tot}_{QCD} = 23.5$fb
- acceptance on fiducial selection is a few percent
  $\rightarrow \sigma^{fid}_{EWK} = 1.97$fb and $\sigma^{tot}_{QCD} = 0.30$fb

ssWW EW:

	$\sum w_{i,fid}$	N_{fid}	A	rel. stat. uncertainty [%]	$\sum w_{i,signal}$	N_{signal}	C	rel. stat. uncertainty [%]	A x C	rel. stat. uncertainty [%]
ee	6513.4	6468	0.0132	1.24	1937.7	2180	0.2975	1.91	0.0039	2.28
em	12967.7	12946	0.0263	0.87	6868.7	7638	0.5297	0.83	0.014	1.20
mm	6506.5	6487	0.0132	1.24	4545.4	5061	0.6986	0.82	0.0092	1.48
nn	6551.3	6525	0.0133	1.23	3586	3979	0.5474	1.13	0.0073	1.67
pp	19436.2	19376	0.0395	0.71	9765.9	10900	0.5025	0.71	0.0198	1.01
combined	25987.5	25901	0.0528	0.61	13351.8	14879	0.5138	0.60	0.0271	0.86

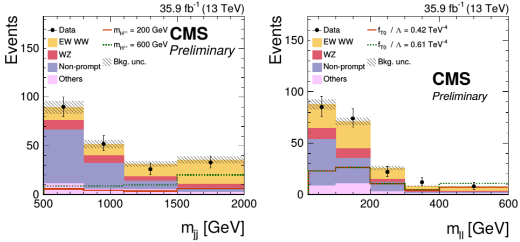
ssWW QCD:

	$\sum w_{i,fid}$	N_{fid}	A	rel. stat. uncertainty [%]	$\sum w_{i,signal}$	N_{signal}	C	rel. stat. uncertainty [%]	A x C	rel. stat. uncertainty [%]
ee	1516.1	1511	0.0031	2.57	246.2	290	0.1624	5.84	0.0005	6.38
em	3162.2	3144	0.0064	1.77	1169	1286	0.3697	2.33	0.0024	2.92
mm	1513.9	1510	0.0031	2.57	1051.8	1173	0.6947	1.71	0.0021	3.08
nn	1591.7	1591	0.0032	2.51	726.5	818	0.4565	2.74	0.0015	3.71
pp	4600.6	4574	0.0093	1.47	1740.4	1931	0.3783	1.9	0.0035	2.4
combined	6192.3	6165	0.0126	1.26	2466.9	2749	0.3984	1.57	0.0050	2.01

CMS analysis - Selection and yields

	$\mu^+\mu^+$	e^+e^+	$e^+\mu^+$	$\mu^-\mu^-$	e^-e^-	$e^-\mu^-$	Total
Data	40	14	63	26	10	48	201
Signal+Total bkg.	44.1 ± 3.4	19.0 ± 1.9	67.6 ± 3.8	23.9 ± 2.8	11.8 ± 1.8	38.9 ± 3.3	204.8 ± 7.2
Signal	18.3 ± 0.4	6.2 ± 0.2	24.7 ± 0.4	6.5 ± 0.2	2.5 ± 0.1	8.7 ± 0.2	66.9 ± 0.7
Total bkg.	25.7 ± 3.4	12.8 ± 1.9	42.9 ± 3.8	17.4 ± 2.8	9.4 ± 1.8	30.2 ± 3.3	137.9 ± 7.1
Non-prompt	18.4 ± 3.3	5.6 ± 1.7	24.9 ± 3.6	14.2 ± 2.8	5.0 ± 1.6	19.9 ± 3.2	87.9 ± 6.9
WZ	4.4 ± 0.2	3.0 ± 0.2	8.5 ± 0.3	2.2 ± 0.1	1.9 ± 0.2	5.2 ± 0.3	25.1 ± 0.6
QCD WW	1.3 ± 0.1	0.6 ± 0.1	1.7 ± 0.1	0.4 ± 0.1	0.2 ± 0.1	0.6 ± 0.1	4.8 ± 0.2
Wγ	0.2 ± 0.2	1.4 ± 0.5	3.6 ± 0.9	-	0.8 ± 0.4	2.3 ± 0.7	8.3 ± 1.3
Triboson	1.2 ± 0.3	0.8 ± 0.2	2.2 ± 0.4	0.5 ± 0.2	0.3 ± 0.1	0.9 ± 0.3	5.8 ± 0.7
Wrong sign	-	1.5 ± 0.6	1.4 ± 0.4	-	1.1 ± 0.5	1.2 ± 0.4	5.2 ± 1.0

	ATLAS	CMS
dataset	2015+2016	2016
$\mathcal{L}dx$	36.1 fb^{-1}	35.9 fb^{-1}
p_T^ℓ	26 GeV	25/20 GeV
$\lvert\eta\rvert$	2.5	2.4/2.5
p_T^j/E_T^j	25/30 GeV	30 GeV
$m_{\ell\ell}$	20 GeV	20 GeV
E_T^{miss}	30 GeV	40 GeV
Z-veto (ee)	15 GeV	15 GeV
m_{jj}	500 GeV	500 GeV
$\Delta y_{jj}/\Delta\eta_{jj}$	2.4	2.5
max(z_ℓ^*)	-	0.75
veto 3ℓ	$<$ 10 GeV	$<$10 GeV
veto τ_{had}	-	$>$18 GeV
veto b-jet	✓	✓



With respect to ATLAS analysis:

- less WZ background
- higher non-prompt

Zeppenfeld variable $z^* = \dfrac{\left|\eta_\ell - \left(\eta_{j1} | \eta_{j2}\right)/2\right|}{\left|\Delta\eta_{jj}\right|}$

CMS analysis - Some details

General information

- charge flip rate: 0.01% in the barrel, 0.3% in the endcap (ATLAS: 0.07% barrel, 3.5% endcap)
- charge flip contribution estimated from MC with data scale factors
- fake-factor method yields 30% uncertainty
- third lepton CR (with Z mass window) yields 20%-40% uncertainty
- significance extracted from 2-dim fit in $m_{\ell\ell}$ and m_{jj}

Signal:

- purely EWK6, contributions from EWK4 are subtracted
- theoretical uncertainties 12% (α_s), 5% (PDF) and 4.5% (EWK6-EWK4 interference)
- LO cross-section from Madgraph (also signal sample): $\sigma_{\mathrm{fid}}^{\mathrm{theo}} = 4.25 \pm 0.21$ fb^{-1}

Cross section result:

$$\sigma_{fid}(W^{\pm}W^{\pm}jj) = 3.83 \pm 0.66(\mathrm{stat.}) \pm 0.35(\mathrm{syst.})\,\mathrm{fb}$$

CMS analysis - BSM interpretation

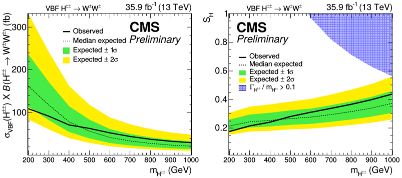
Anomalous Quartic Couplings

	Observed limits (TeV $^{-4}$)	Expected limits (TeV $^{-4}$)	Run-I limits (TeV $^{-4}$)
f_{S0}/Λ	[-7.7, 7.7]	[-7.0, 7.2]	[-38 , 40] [11]
f_{S1}/Λ	[-21.6,21.8]	[-19.9,20.2]	[-118 , 120] [11]
f_{M0}/Λ	[-6.0, 5.9]	[-5.6, 5.5]	[-4.6 , 4.6] [29]
f_{M1}/Λ	[-8.7 ,9.1]	[-7.9, 8.5]	[-17 , 17] [29]
f_{M6}/Λ	[-11.9,11.8]	[-11.1,11.0]	[-65 , 63] [11]
f_{M7}/Λ	[-13.3,12.9]	[-12.4,11.8]	[-70 , 66] [11]
f_{T0}/Λ	[-0.62,0.65]	[-0.58,0.61]	[-3.8 , 3.4] [30]
f_{T1}/Λ	[-0.28,0.31]	[-0.26,0.29]	[-1.9 , 2.2] [11]
f_{T2}/Λ	[-0.89,1.02]	[-0.80,0.95]	[-5.2 , 6.4] [11]

- EFT lagrangian of nine C- and P-conserving dim-8 operators modifying quartic couplings

Doubly charged Higgs boson

- Doubly charged Higgs bosons predicted by models with Higgs triplet field
- couplings depend on $m(H^{\pm})$ and $\sin^2\theta_H$
- Georgi-Machacek model of Higgs triplet considered
- limits presented for $\sigma_{VBF}(H^{\pm\pm}) \times B(H^{\pm\pm} \to W^{\pm}W^{\pm})$ and $s_H \equiv \sin\theta_H$



Scale factor systematics

Four sources:

- $m_{\ell\ell}$ variation (nominal: 15GeV)
- trigger matchig requirement on sub-leading candidate
- background subtraction on/off
- truth matching comparison

These are combined and propagated in the derivation of the data-driven background
$\rightarrow$ variation up/down (7-15%)
$\rightarrow$ energy correction on/off (2-7%)