VBS/VBF Measurements (without photons) at ATLAS

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On behalf of the ATLAS collaboration

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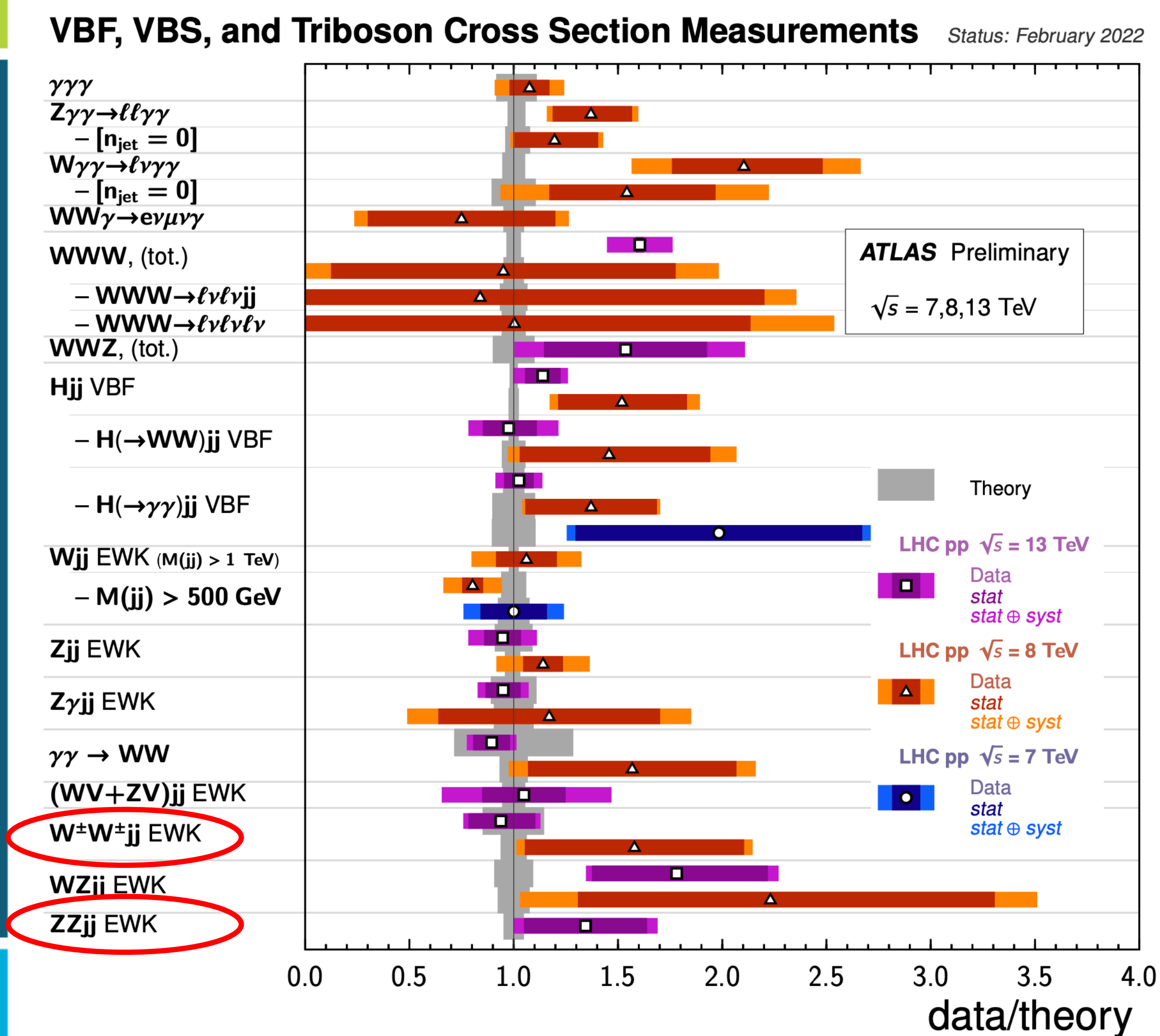
Overview of Run2 SM Measurements in ATLAS

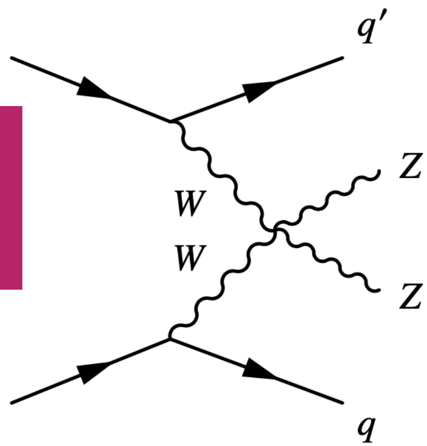


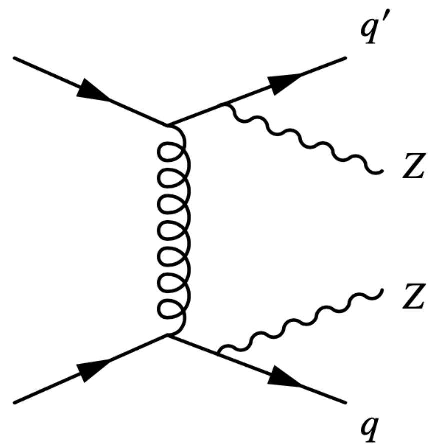
- Wealth of VBS/VBF measurements with Run2 data
- This talk focuses on the VBS/VBF ZZjj and $W^{\pm}W^{\pm}jj$ measurements using full Run2 data
  - Observed previously by ATLAS at 5.7σ (link) and 6.5σ (link) respectively
  - Will now present new results;
    - **ZZjj**: differential cross sections and EFT interpretation
    - $\boldsymbol{W^{\pm}W^{\pm}jj}$: Fiducial+differential cross sections, EFT interpretation and doubly charged Higgs searches
- Both processes are important probes for Vector Boson Scattering (VBS)

$ZZjj$: Introduction

- Interesting VBS process sensitive to a diverse range of physics Beyond the Standard Model

Electroweak production sensitive to WWZ and $WWZZ$ weak boson self-interactions





Strong production sensitive to the accuracy of perturbative QCD calculations

- Only show differential cross section measurements as a function of observables sensitive to VBS
- Differential cross-sections as a function of observables sensitive to the polarization of the Z boson as well as QCD-sensitive observables are also measured (back-up)

$ZZjj$: Event selection

- Two pairs of same-flavor opposite-charge leptons with $m_{ll} > 5$ GeV and $\Delta R(l,l) > 0.05$
- Large lepton quadruplet invariant mass ($m_{4l} > 130$ GeV)
- Two forward jets with high transverse momentum ($p_T > 30\ [40]$ GeV), large dijet invariant mass ($m_{jj} > 300$ GeV and large separation in rapidity ($|\Delta y_{jj} > 2|$)

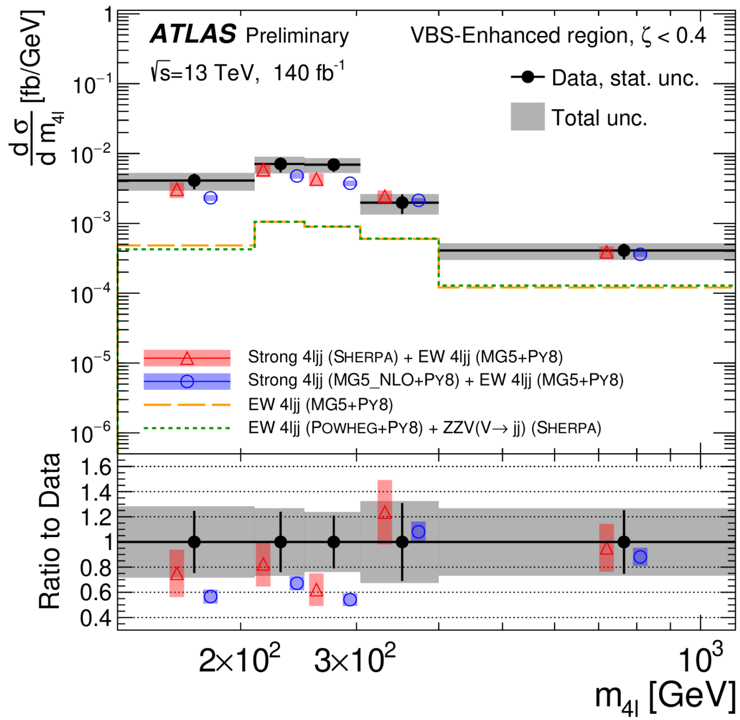
- Events are further categorized into two SRs;
  - A VBS-enhanced SR ($\zeta < 0.4$)
  - A VBS-suppressed SR ($\zeta > 0.4$)

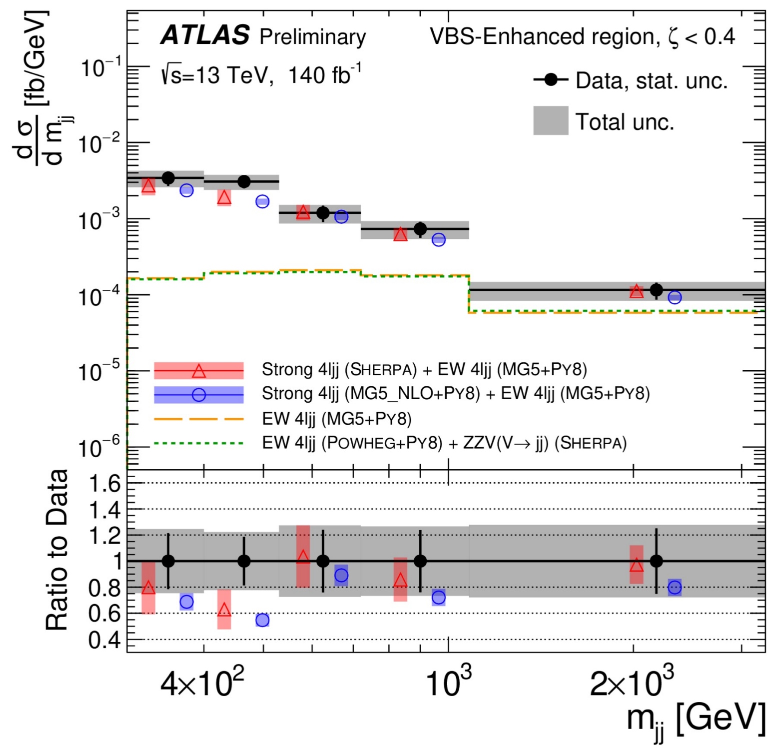
$$\zeta = \frac{(y_{4l} - 0.5(y_{j_1} + y_{j_2}))}{\Delta y_{jj}}$$

- ❖ Signal constitutes both the EW and strong $ZZjj$ processes, hence measurements are inclusive
- ❖ **Signal samples**
- Nominal Strong $ZZjj$: SHERPA
- Alternative Strong $ZZjj$: MG5_NLO+PY8
- Nominal EW $ZZjj$: MG5+PY8
- Alternative EW $ZZjj$: POWHEG+PY8

$ZZjj$: Differential cross section measurement

- Particle-level measurements were carried out in the VBS-enhanced and VBS-suppressed fiducial regions
- Correction to particle level was performed using an iterative Bayesian unfolding method





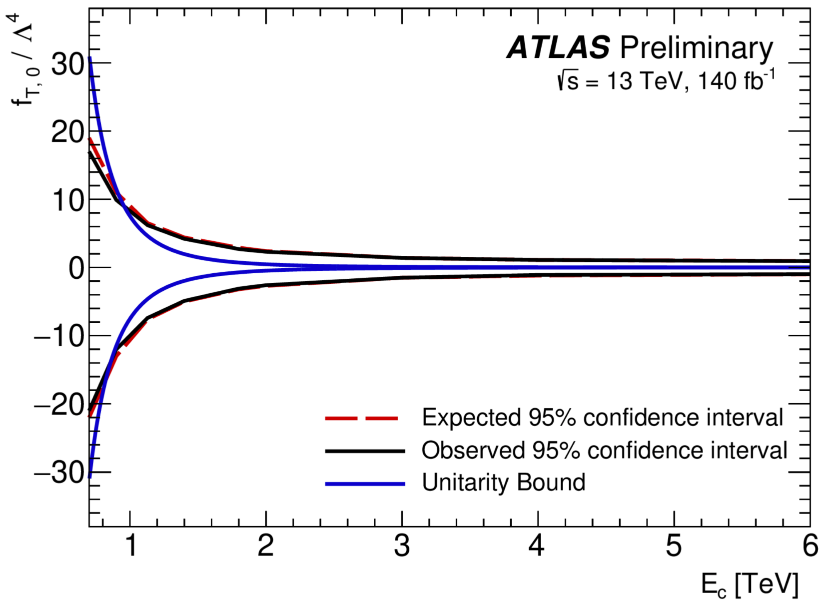
- Good agreement between data and Sherpa prediction (for strong $ZZjj$ signal)
- MG5_NLO+PY8 prediction underestimates the data. More prominently seen at low m_{4l} and low m_{jj}
- Powheg+PY8 EW $ZZjj$ prediction agrees well with the MG+PY8 prediction
- Choice of the EW $ZZjj$ model has very little impact on the inclusive $ZZjj$ production

$ZZjj$: EFT interpretation Results

- Differential cross-sections as a function of m_{4l} and m_{jj} were used to set limits on anomalous Quartic Gauge Couplings (aQGCs) using dimension 8 (and 6) Effective Field Theory (EFT) operators

Wilson coefficient	$\|\mathcal{M}_{d8}\|^2$ Included	95% confidence interval [TeV^{-4}] Expected	Observed
$f_{T,0}/\Lambda^4$	yes	[-0.98,0.93]	[-1.0,0.97]
	no	[-23, 17]	[-19, 19]
$f_{T,1}/\Lambda^4$	yes	[-1.2, 1.2]	[-1.3, 1.3]
	no	[-160, 120]	[-140, 140]
$f_{T,2}/\Lambda^4$	yes	[-2.5, 2.4]	[-2.6, 2.5]
	no	[-74, 56]	[-63, 62]
$f_{T,5}/\Lambda^4$	yes	[-2.5, 2.4]	[-2.6, 2.5]
	no	[-79, 60]	[-68, 67]
$f_{T,6}/\Lambda^4$	yes	[-3.9, 3.9]	[-4.1, 4.1]
	no	[-64, 48]	[-55, 54]
$f_{T,7}/\Lambda^4$	yes	[-8.5, 8.1]	[-8.8, 8.4]
	no	[-260, 200]	[-220, 220]
$f_{T,8}/\Lambda^4$	yes	[-2.1, 2.1]	[-2.2, 2.2]
	no	[-4.6, 3.1]$\times 10^4$	[-3.9, 3.8]$\times 10^4$
$f_{T,9}/\Lambda^4$	yes	[-4.5, 4.5]	[-4.7, 4.7]
	no	[-7.5, 5.5]$\times 10^4$	[-6.4, 6.3]$\times 10^4$

- Constraints were also placed on each Wilson coefficient after restricting the interference and pure D8 contributions to have $m_{4l} < E_c$



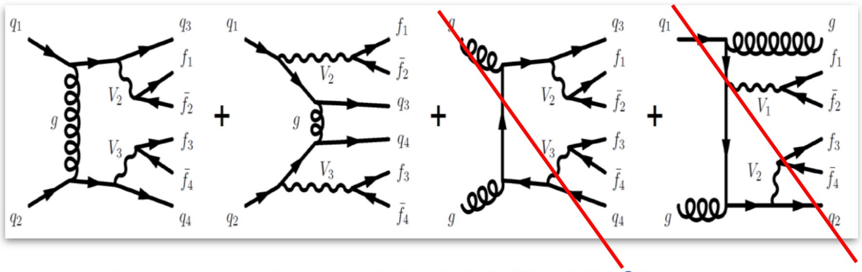
➢ Wilson coefficients are consistent with zero when the pure D8 contribution is included

See back-up for results related to D6 Wilson coefficients

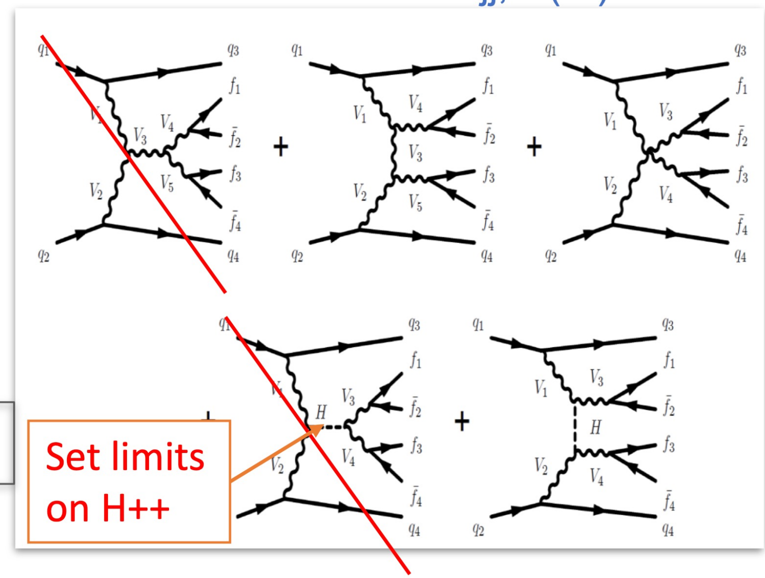
$W^{\pm}W^{\pm}jj$: Introduction

- This process has the largest ElectroWeak (EW) to QCD ratio, hence the QCD-induced background is suppressed.
  - ➢ Gluons in the initial state are not allowed

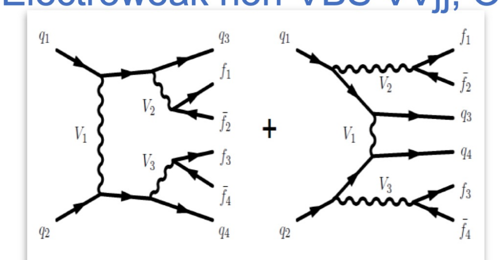
Strong VVjj, $O(\alpha^4\alpha_s^2)$



Electroweak VBS VVjj, $O(\alpha^6)$



Electroweak non-VBS VVjj, $O(\alpha^6)$

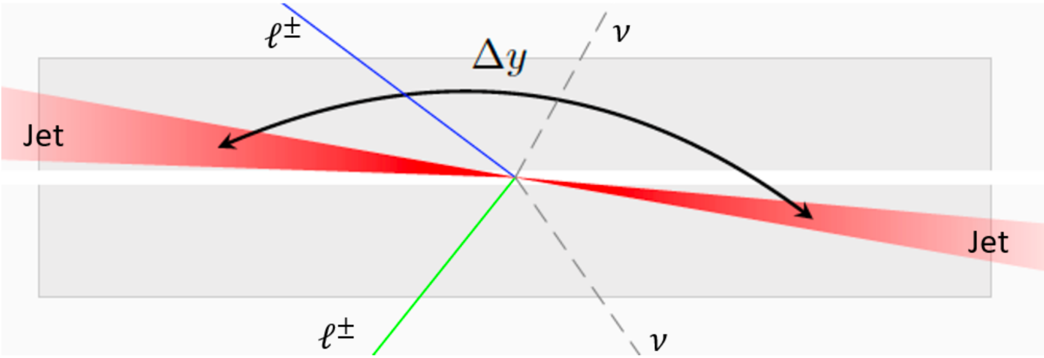


Not in SM $W^{\pm}W^{\pm}$

- EW VBS and EW non-VBS diagrams can not be separated in a gauge invariant way
  - ➢ EW measurement includes both
- Total (inclusive) measurement includes EW + QCD + EW/QCD interference

$W^{\pm}W^{\pm}jj$: Event selection

- Two isolated same-sign leptons with high transverse momentum ($p_T > 27$ GeV)
- Large missing transverse energy ($E_{T,miss} > 30$ GeV)
- Two forward jets with high transverse momentum ($p_T > 65$ [30] GeV), large dijet invariant mass ($m_{jj} > 500$ GeV) and large separation in rapidity ($|\Delta y_{jj} > 2|$)

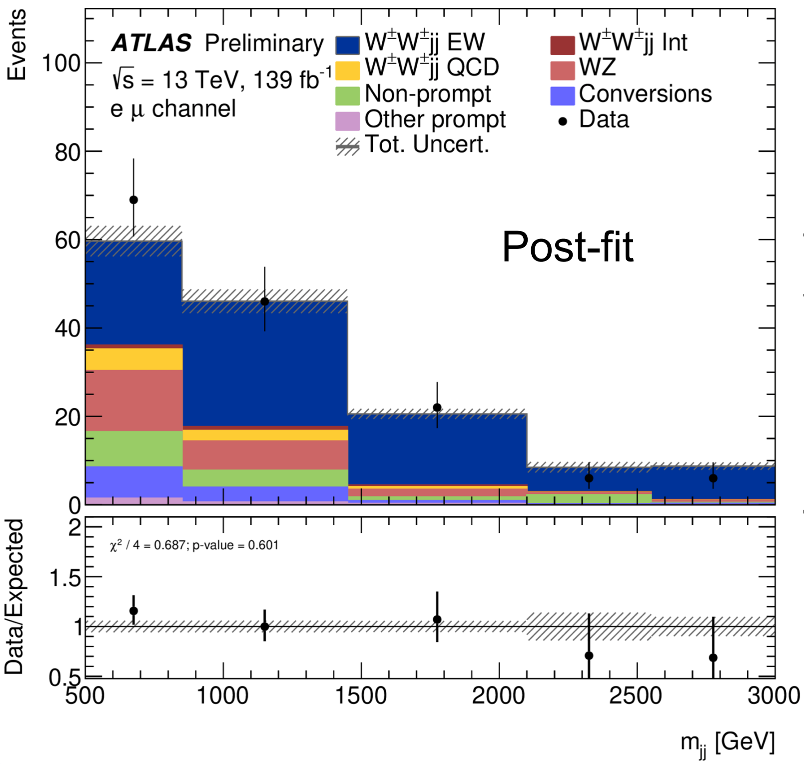


❖ **Signal samples**

- Nominal $W^{\pm}W^{\pm}jj$ EW, QCD, interference: MG+H7
- Alternative $W^{\pm}W^{\pm}jj$ EW, QCD, interference: MG+PY8

$W^{\pm}W^{\pm}jj$: Fiducial cross section measurement

- The fiducial phase space is defined at particle level (see back-up for fiducial region definition)
- Separate maximum likelihood fits in m_{jj} are performed for EW and total cross section measurements
- SR is split in four regions depending on lepton flavor



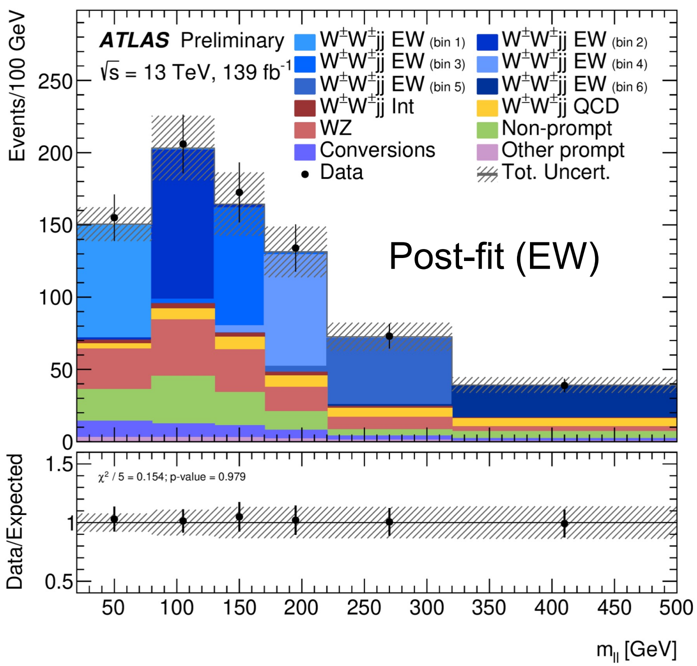
- Good agreement between data and MC
- Good EW signal purity

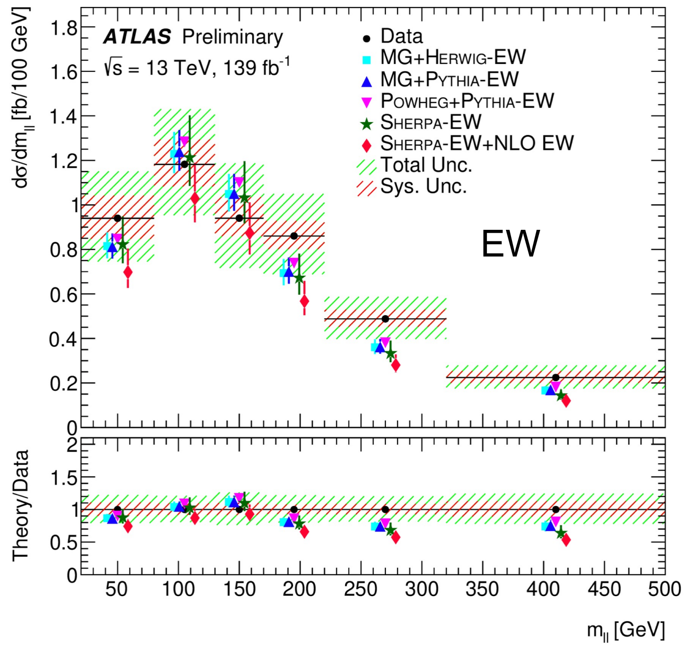
Description	$\sigma_{\text{fid}}^{\text{EW}}$, fb	$\sigma_{\text{fid}}^{\text{EW+Int+QCD}}$, fb
Measured cross section	2.88 ± 0.22 (stat.) ± 0.19 (syst.)	3.35 ± 0.22 (stat.) ± 0.20 (syst.)
MG_AMC@NLO+HERWIG	2.53 ± 0.04 (PDF) $\pm^{0.22}_{0.19}$ (scale)	2.93 ± 0.05 (PDF) $\pm^{0.34}_{0.27}$ (scale)
MG_AMC@NLO+PYTHIA	2.55 ± 0.04 (PDF) $\pm^{0.22}_{0.19}$ (scale)	2.94 ± 0.05 (PDF) $\pm^{0.33}_{0.27}$ (scale)
SHERPA	2.44 ± 0.03 (PDF) $\pm^{0.40}_{0.27}$ (scale)	2.80 ± 0.03 (PDF) $\pm^{0.53}_{0.36}$ (scale)
POWHEG BOX +PYTHIA	2.67	–

- Slightly higher cross section is observed compared to MC prediction

$W^{\pm}W^{\pm}jj$: Differential cross section measurement

- Measured in the same fiducial phase space mentioned previously (no split in lepton flavor)
- Likelihood-based unfolding (2-D fit) for correction to particle level





- Five observables measured
- χ^2 and p-values quantify data/MC compatibility

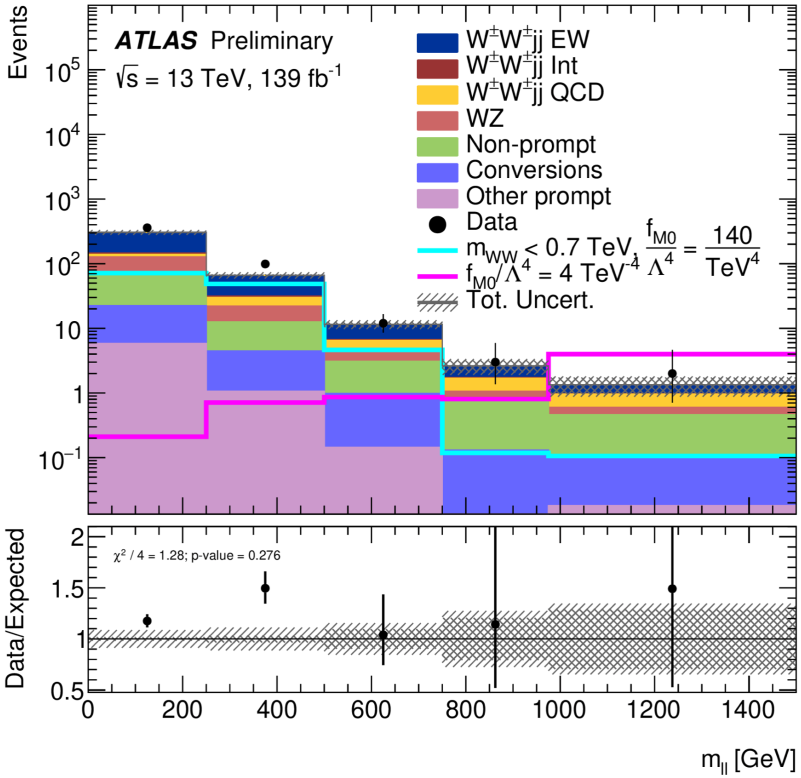
Variable	EW $W^{\pm}W^{\pm}jj$ χ^2/N_{dof}	EW $W^{\pm}W^{\pm}jj$ p-value	Inclusive $W^{\pm}W^{\pm}jj$ χ^2/N_{dof}	Inclusive $W^{\pm}W^{\pm}jj$ p-value
$m_{\ell\ell}$	4.4/6	0.623	7.0/6	0.322
m_{T}	12.9/6	0.045	15.9/6	0.014
m_{jj}	7.2/6	0.300	7.8/6	0.250
$N_{\text{gap jets}}$	2.3/2	0.316	2.3/2	0.316
ξ_{j3}	4.3/5	0.511	5.2/5	0.396

➢ Prediction generally underestimates data but good agreement within uncertainties

➢ p-values range between 0.3 and 0.62 indicating reasonable agreement. p-value for m_T is 0.045

$W^{\pm}W^{\pm}jj$: EFT interpretation

- m_{ll} distribution with optimized binning is used to set limits on aQGCs using dimension-8 operators
- Table (right below) shows two sets of 95% CL limits: unclipped and clipped EFT limits at the unitarity bound
- See back-up for clipping scan plots per operator

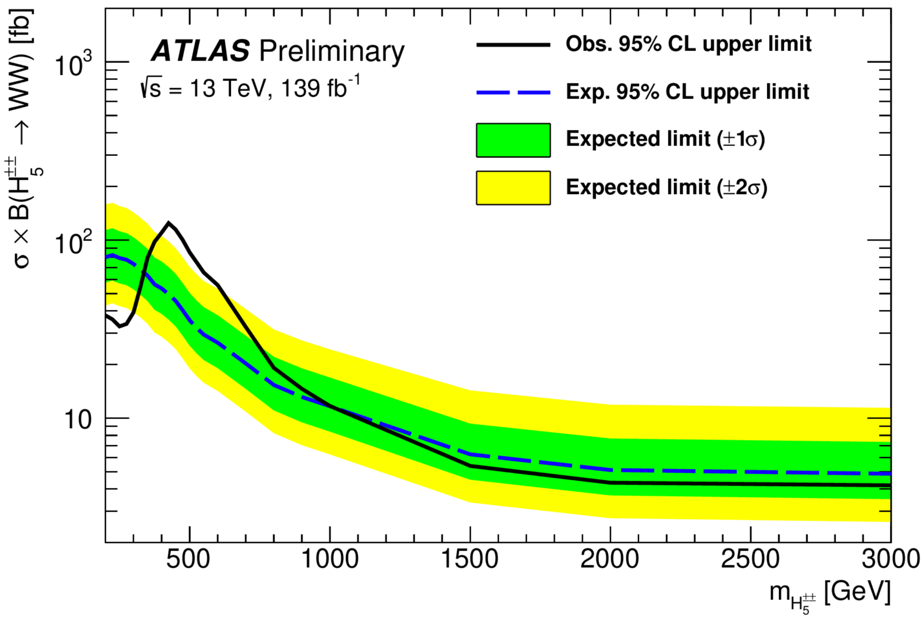


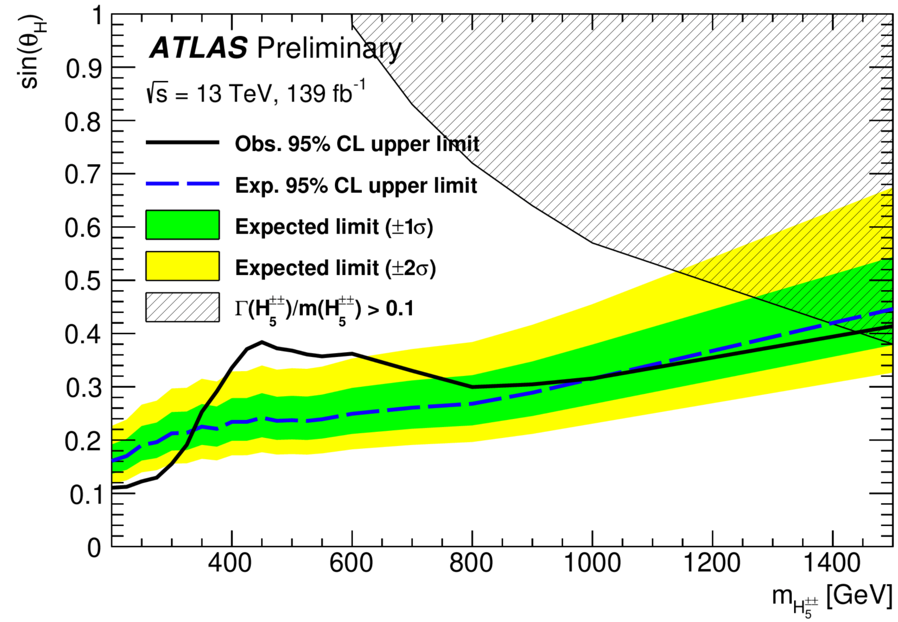
Coefficient	Type	No unitarisation cut-off [TeV^{-4}]	Lower and upper limit at the respective unitarity bound [TeV^{-4}]
f_{M0}/Λ^4	exp.	[-3.9, 3.8]	-64 at 0.9 TeV, 40 at 1.0 TeV
	obs.	[-4.1, 4.1]	-140 at 0.7 TeV, 117 at 0.8 TeV
f_{M1}/Λ^4	exp.	[-6.3, 6.6]	-25.5 at 1.6 TeV, 31 at 1.5 TeV
	obs.	[-6.8, 7.0]	-45 at 1.4 TeV, 54 at 1.3 TeV
f_{M7}/Λ^4	exp.	[-9.3, 8.8]	-33 at 1.8 TeV, 29.1 at 1.8 TeV
	obs.	[-9.8, 9.5]	-39 at 1.7 TeV, 42 at 1.7 TeV
f_{S02}/Λ^4	exp.	[-5.5, 5.7]	-94 at 0.8 TeV, 122 at 0.7 TeV
	obs.	[-5.9, 5.9]	–
f_{S1}/Λ^4	exp.	[-22.0, 22.5]	–
	obs.	[-23.5, 23.6]	–
f_{T0}/Λ^4	exp.	[-0.34, 0.34]	-3.2 at 1.2 TeV, 4.9 at 1.1 TeV
	obs.	[-0.36, 0.36]	-7.4 at 1.0 TeV, 12.4 at 0.9 TeV
f_{T1}/Λ^4	exp.	[-0.158, 0.174]	-0.32 at 2.6 TeV, 0.44 at 2.4 TeV
	obs.	[-0.174, 0.186]	-0.38 at 2.5 TeV, 0.49 at 2.4 TeV
f_{T2}/Λ^4	exp.	[-0.56, 0.70]	-2.60 at 1.7 TeV, 10.3 at 1.2 TeV
	obs.	[-0.63, 0.74]	–

➢ Constraints are generally consistent with zero

$W^{\pm}W^{\pm}jj$: $H^{\pm\pm}$ Searches

- Model independent upper limits at 95% CL on $\sigma_{VBF}\times\mathcal{B}(H_5^{\pm\pm} \rightarrow W^{\pm}\,W^{\pm})$ are extracted
- Results are also interpreted to search for a doubly charged Higgs boson produced in VBF processes within the Georgi-Machacek model using $m_{H_5^{\pm\pm}}$ and $\sin\theta_H$ as model parameters
- Limit setting: maximum likelihood fit to the distribution for transverse mass (m_T) of the dilepton and $E_{T,miss}$ system





- Largest excess seen at $m_{H_5^{\pm\pm}}$ = 450 GeV
- Local significance: 3.2σ, global significance: 2.5σ
- $\sin\theta_H$ > 0.11-0.41 for $200 < m_{H_5^{\pm\pm}} < 1500$ are excluded

Summary

- Measurements of VBS/VBF $ZZjj$ and $W^{\pm}W^{\pm}jj$ processes using the full Run2 dataset have been presented
- $ZZjj$ differential cross-section measurements as a function of observables sensitive to VBS are reported
  - Data is found to be in good agreement with prediction and the measurement is used to search for anomalous weak boson couplings using dimension 8 EFT operators (coefficients are consistent with zero)
- EW and inclusive $W^{\pm}W^{\pm}jj$ fiducial cross sections are measured and found to be consistent with prediction
- $W^{\pm}W^{\pm}jj$ differential cross sections are also measured as a function of five observables sensitive to VBS
  - The m_{ll} distribution is used to search for anomalous couplings using dimension 8 EFT operators and constraints are competitive with those previously published by CMS
- Model independent upper limits at 95% CL on $\sigma_{VBF}\times\mathcal{B}(H_5^{\pm\pm}\rightarrow W^{\pm}W^{\pm})$ are extracted for $m_{H_5^{\pm\pm}}$ between 200 GeV and 3 TeV and a GM model is used to exclude $sin\,\theta_H$ > 0.11-0.41 for $200 < m_{H_5^{\pm\pm}} < 1500$ at 95% CL
  - A local excess of events at 450 GeV is noted with a global significance of 2.5σ

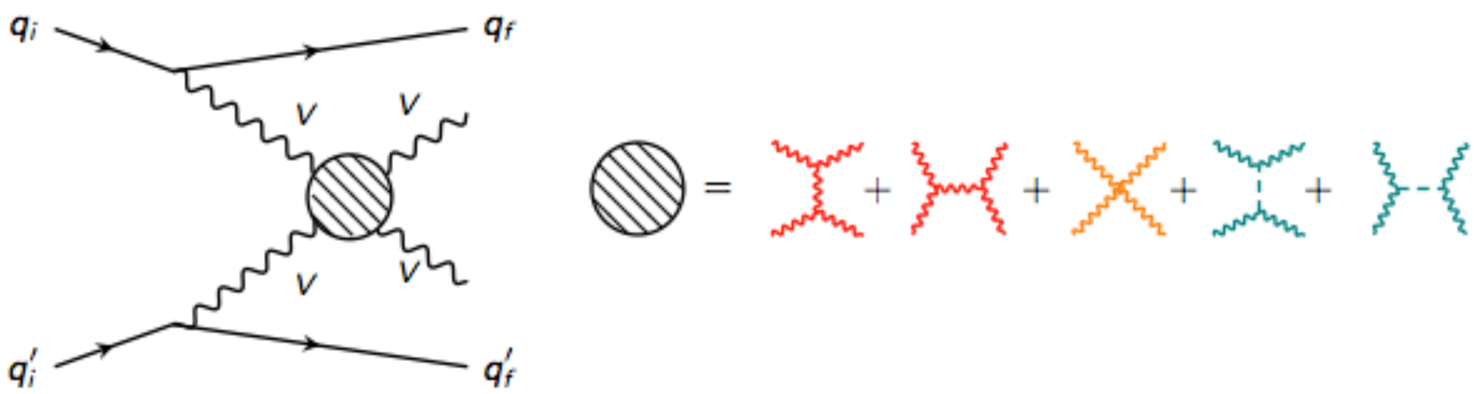
link to ZZjj results

Link to $W^{\pm}W^{\pm}jj$ results

Back-up

Vector boson scattering

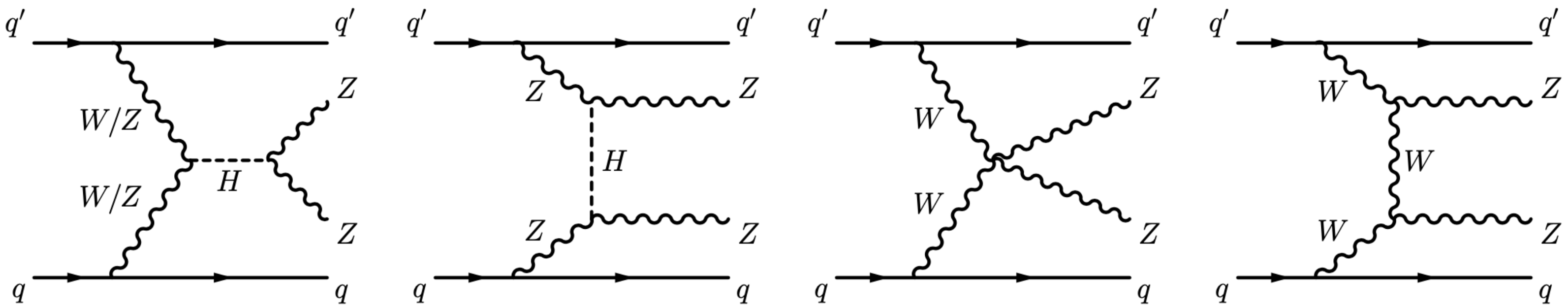
- Both the ZZjj and $W^{\pm}W^{\pm}$jj processes are important probes for Vector Boson Scattering (VBS)



- VBS allows us to test Standard Model (SM) predictions to **triple** and **quartic** gauge couplings
- VBS requires the presence of the SM Higgs boson for unitarity preservation at high energies
  - In the absence of **Higgs** diagrams, amplitudes of longitudinally polarized vector bosons increase as a function of energy at high $\sqrt{s}$.
  - Cancellation of divergences by Higgs diagrams can be altered by new physics effects

Measurements of differential cross-sections for the inclusive and electroweak production of ZZ in association with two jets

ZZjj EWK production



$ZZjj$: Signal and background estimation

❖ Prompt background

- Processes with 4 prompt leptons
- Main sources: $t\bar{t}Z, WWZ, WZZ$
- Estimated from Monte Carlo (MC) simulation

❖ Non-prompt background

- Processes with one or more non-prompt leptons (leptons from jets)
- Main sources: $t\bar{t}$ (b-hadrons from top/antitop decays non-prompt leptons), $WZjj$ (non-prompt lepton from additional jet)
- Estimated using a data-driven method (fake-factor method)

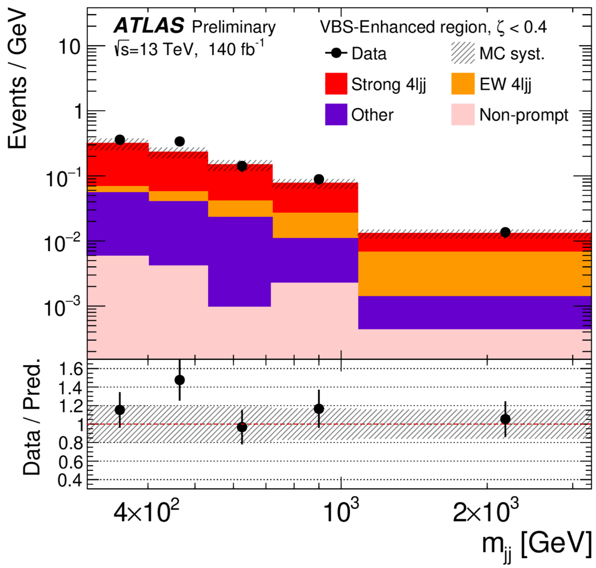
❖ Signal samples

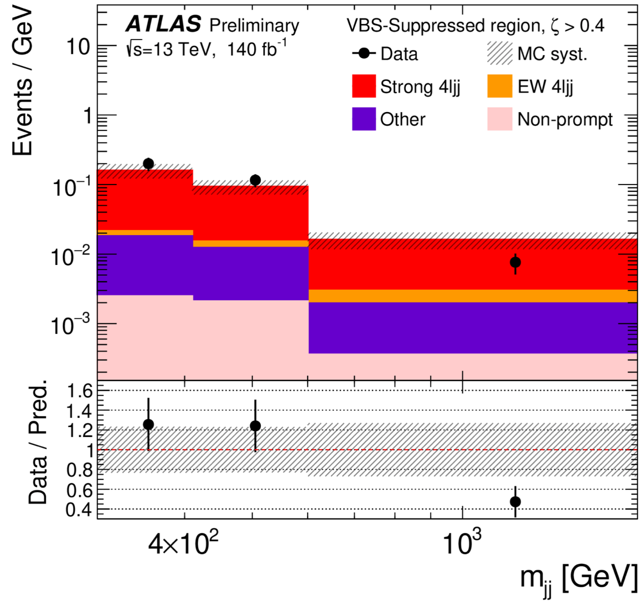
- Nominal Strong $ZZjj$: SHERPA
- Alternative Strong $ZZjj$: MG5_NLO+PY8
- Nominal EW $ZZjj$: MG5+PY8
- Alternative EW $ZZjj$: POWHEG+PY8

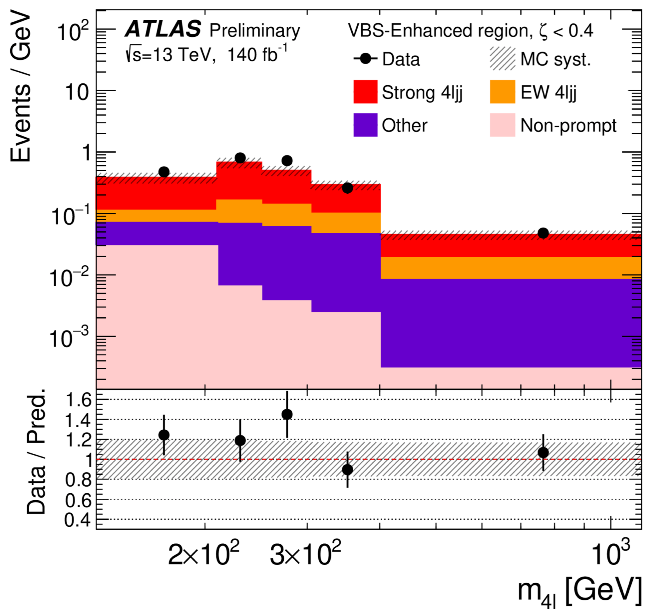
ZZjj systematics

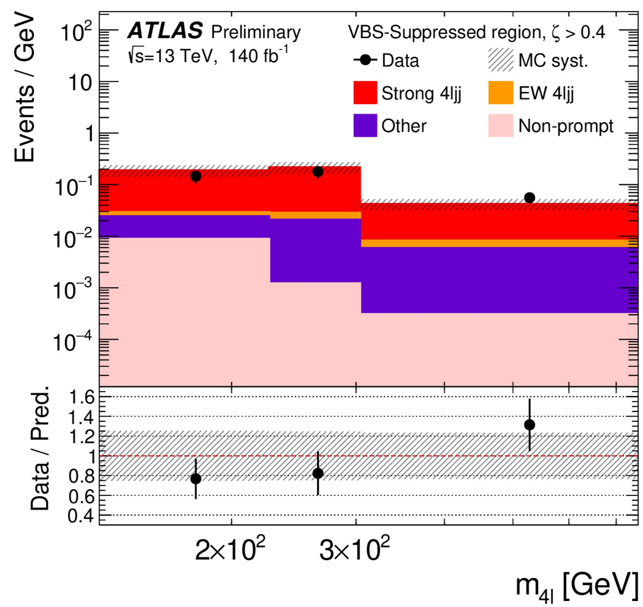
Source	Uncertainty (%)
Luminosity	0.8 – 1.3
Leptons	0.8 – 1.6
Jets	2.7 – 18
Pile-up	0.0 – 2.5
Backgrounds	0.9 – 9.0
Theory modelling	0.6 – 8.8
Unfolding method	0.9 – 12
Total systematic	5 – 22

ZZjj event yields



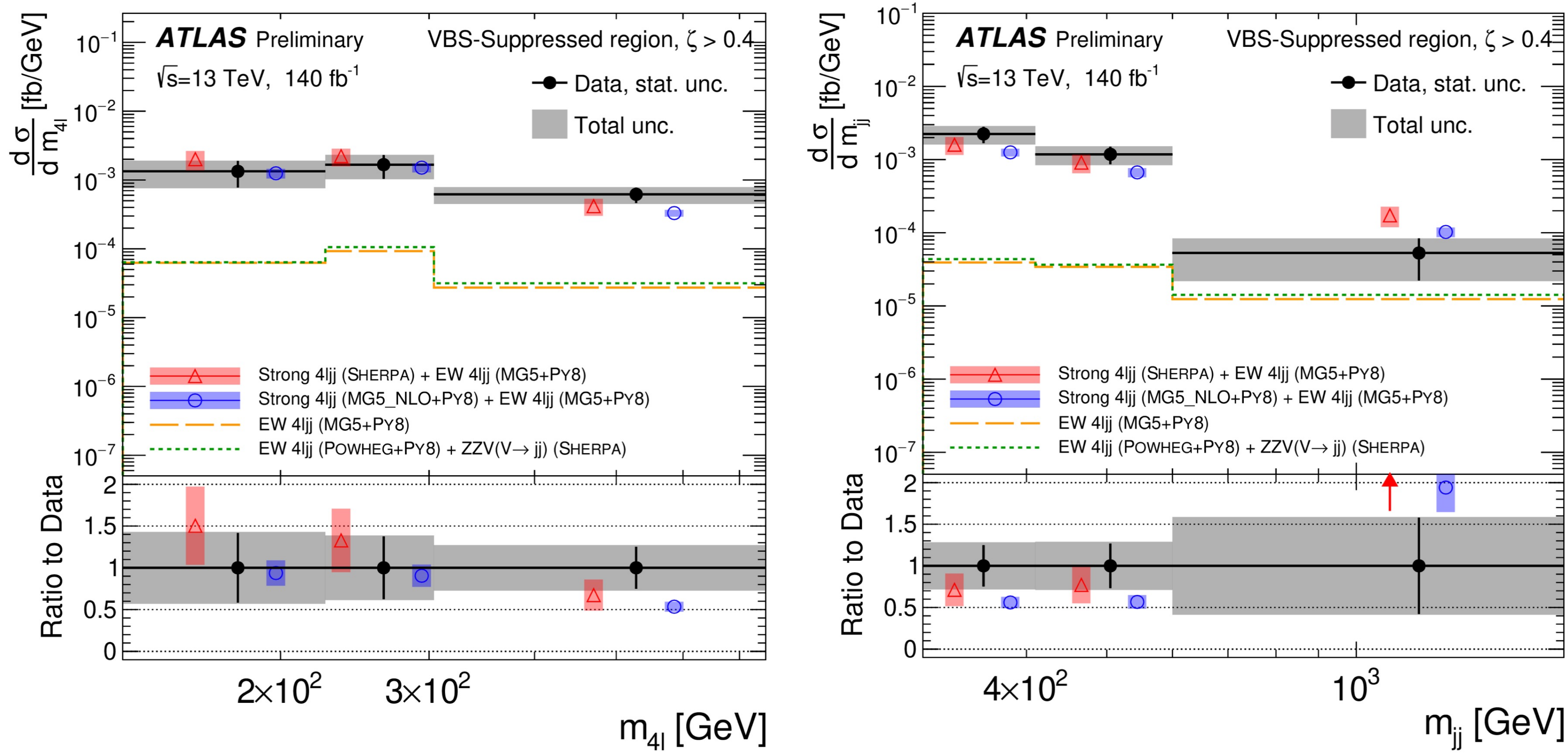




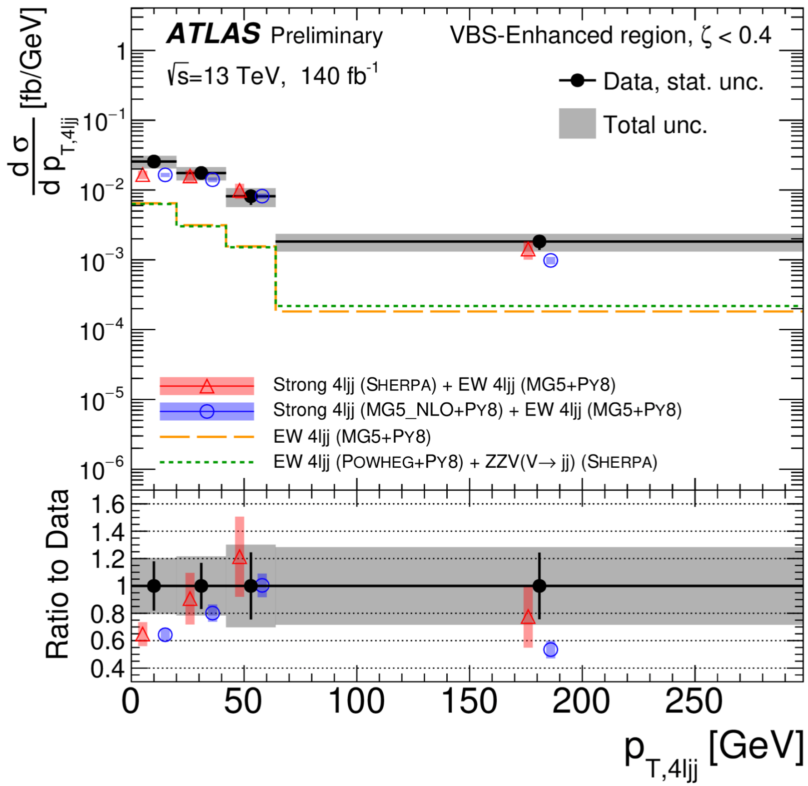


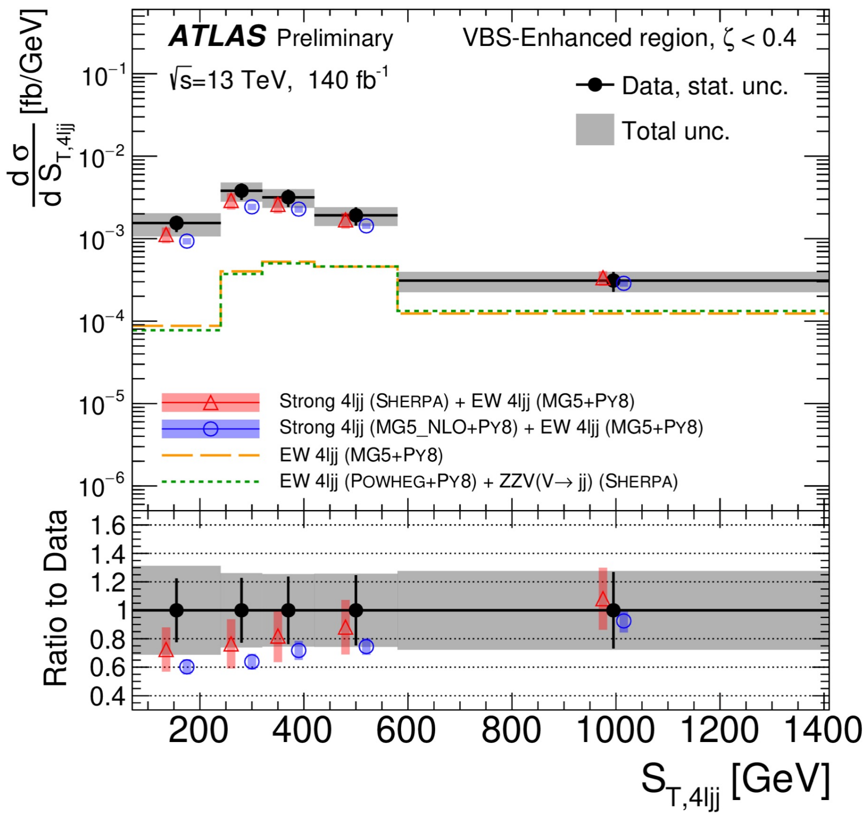
- VBS-enhanced (left)
- VBS-suppressed (right)

ZZjj differential cross-sections in VBS-suppressed SR



ZZjj results: QCD-sensitive observables

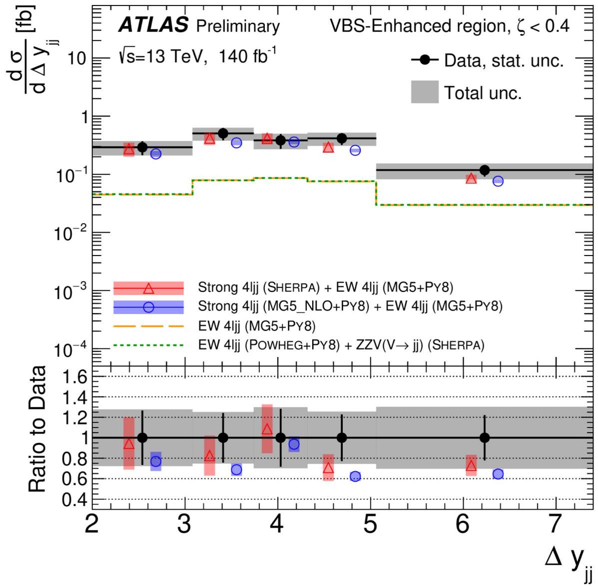


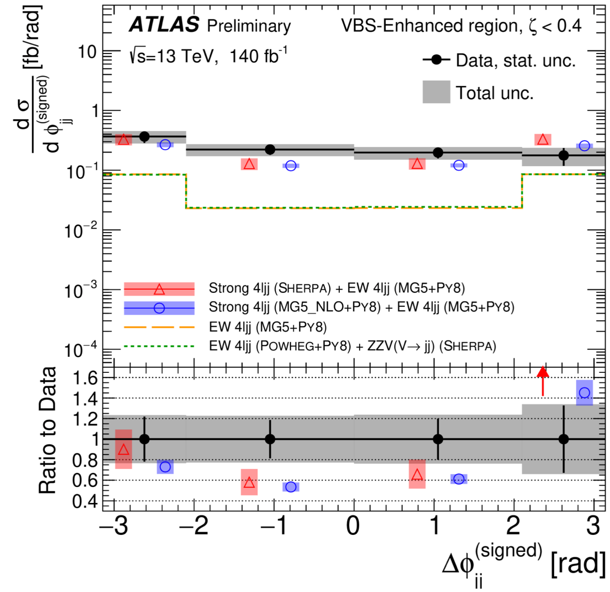


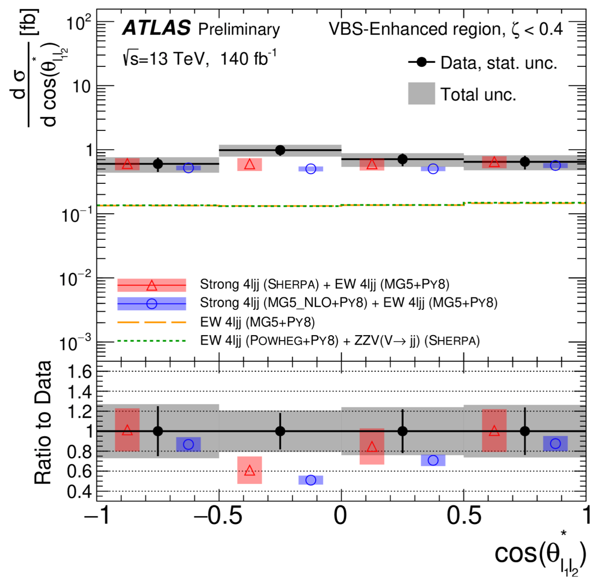
PT4ljj: transverse momentum of the 4l*j j* system

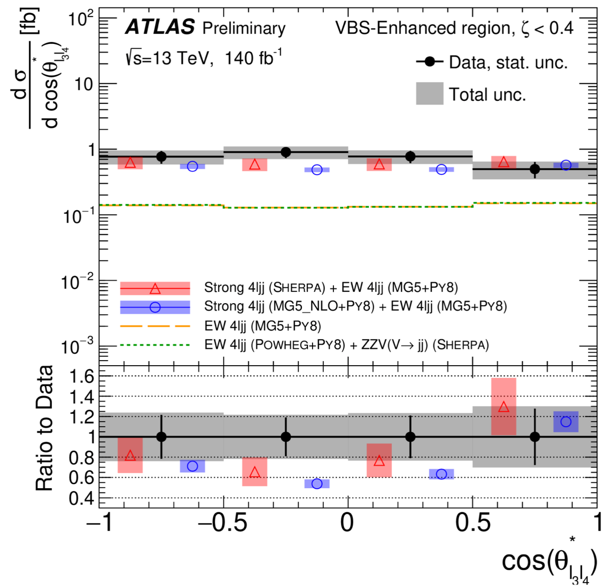
ST4ljj: scalar sum of transverse momentum of the four leptons and the two jets

ZZjj results: Observables sensitive to Z polarization









$ZZjj$: EFT interpretation method

- Differential cross-sections as a function of m_{4l} and m_{jj} were used to set limits on anomalous quartic gauge couplings using dimension 8 (and 6) Effective Field Theory (EFT) operators

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{f_{\mathrm{T},i}}{\Lambda^4} \mathcal{O}_{\mathrm{T},i}$$

Wilson coefficients specify the strength of anomalous couplings

- For each operator, the EFT prediction is given by the sum of the interference, pure D8, nominal EW $ZZjj$, and the nominal strong $ZZjj$ predictions (Interference and pure D8 EW $ZZjj$ samples are generated using Madgraph)
- A profile likelihood test was then used to set confidence level limits per Wilson coefficient
- Constraints were also placed on each Wilson coefficient after restricting the interference and pure D8 contributions to have $m_{4l} < E_c$, where E_c is a cut-off that prevents unitarity violation at large energy scales

ZZjj results: D6 Wilson coefficients

Wilson coefficient	$\lvert\mathcal{M}_{\mathrm{d6}}\rvert^2$ Included	95% confidence interval [TeV^{-2}] Expected	Observed
c_W/Λ^2	yes	[-1.3, 1.3]	[-1.2, 1.2]
	no	[-32, 32]	[-37, 28]
$c_{\widetilde{W}}/\Lambda^2$	yes	[-1.3, 1.3]	[-1.2, 1.2]
	no	[-17, 17]*	[0, 30]*
c_{HWB}/Λ^2	yes	[-16, 7]	[-16, 6]
	no	[-12, 12]	[-15, 10]
$c_{H\widetilde{W}B}/\Lambda^2$	yes	[-1.3, 1.3]	[-1.2, 1.2]
	no	[-67, 67]*	[-25, 130]*
c_{HB}/Λ^2	yes	[-13, 13]	[-12, 12]
	no	[-38, 38]	[-38, 38]
$c_{H\widetilde{B}}/\Lambda^2$	yes	[-13, 13]	[-12, 12]
	no	[-420, 420]*	[-200, 790]*

Measurement and interpretation of same-sign W boson pair production in association with two jets

Same-sign WW object and event selection

Signal electrons:
- LHTight
- Gradient isolation
- ECIDS (charge ID selector)
- p_T > 27 GeV
- $|\eta_e|<2.47$ excluding $1.37 < |\eta_e|<1.52$

Jets:
- AntiKt4EMPFlowJets
- p_T > 25 GeV
- $|\eta_j|<4.5$
- JVT

Signal muons:
- Medium ID
- FixedCutPflowTight isolation
- p_T > 27 GeV
- $|\eta_\mu|<2.5$

b-jets (for b-veto):
- AntiKt4EMPFlowJets
- p_T > 20 GeV
- $|\eta_j|<2.5$
- DL1r @ 85% efficiency WP

Analysis objects are after passing overlap removal (OR)

Event selection:
- Two same-sign signal leptons; 3rd lepton veto
- m_{ll} >= 20 GeV
- $|m_{ee} – m_Z|$> 15 GeV, $|\eta_e|<1.37$ in the ee channel
- $E_{T,miss}$ > 30 GeV
- $p_{T,jet,1(2)}$ > 65 (35) GeV
- m_{jj} > 500 GeV
- $|\Delta y_{jj}|$ > 2

3rd lepton veto:

Reject event if there is a 3rd lepton surviving the OR, with:
- $p_{T,e}$ > 4.5 GeV
- $p_{T,\mu}$ > 3 GeV

or if there is a lepton not surviving the OR and is forming a dilepton with one of the signal leptons, with
- $|m_{ll} – m_Z|$< 15 GeV

Same-sign WW samples

Process, short description	ME Generator + parton shower	Order	Tune	PDF set in ME
EW, Int, QCD $W^\pm W^\pm jj$, nominal signal	MadGraph5_aMC@NLO2.6.7 + Herwig7.2	LO	default	NNPDF3.0nlo
EW, Int, QCD $W^\pm W^\pm jj$, alternative shower	MadGraph5_aMC@NLO2.6.7 + Pythia8.244	LO	A14	NNPDF3.0nlo
EW $W^\pm W^\pm jj$, NLO QCD approx.	Sherpa2.2.11	+0,1j@LO	Sherpa	NNPDF3.0nnlo
EW $W^\pm W^\pm jj$, NLO QCD approx.	Powheg Boxv2 + Pythia8.230	NLO (VBS approx.)	AZNLO	NNPDF3.0nlo
QCD $W^\pm W^\pm jj$, NLO QCD approx.	Sherpa2.2.2	+0,1j@LO	Sherpa	NNPDF3.0nnlo
VV (leptonic)	Sherpa2.2.2	+0,1j@NLO; +2,3j@LO	Sherpa	NNPDF3.0nnlo
VVV	Sherpa2.2.1 (leptonic) & Sherpa2.2.2 (one $V \to jj$)	+0,1j@LO	Sherpa	NNPDF3.0nnlo
W/Z + jets	MadGraph5_aMC@NLO2.3.2.p1 + Pythia8.210	+0,1,2,3,4j@LO	A14	NNPDF3.0nlo
$t\bar{t}$ Single t (s- and Wt-channel)	Powheg Boxv2 + Pythia8	NLO	A14	NNPDF3.0nlo
Single t (t-channel)	Powheg Boxv2 + Pythia8	NLO	A14	NNPDF3.0nlo4f
$t\bar{t}V$	MadGraph5_aMC@NLO2.3.3.p0 + Pythia8.210	NLO	A14	NNPDF3.0nlo
$V\gamma$	Sherpa2.2.11	MEPS@NLO	A14	NNPDF3.0nnlo

$W^{\pm}W^{\pm}jj$: Signal and Background estimation

❖ WZ EW and WZ QCD background

- WZ QCD is the most dominant background
- WZ final states are modelled using Monte-Carlo (MC) simulations and are dominated by WZ QCD
- The normalization of the WZ QCD process is estimated from data in a dedicated WZ control region

❖ Charge flip and γ conversions background

- Main sources: $W^{\pm}W^{\mp}$ and $V\gamma$ processes
- This is the third-largest background source
- Charge flip is estimated using a data-driven method
- $V\gamma$ processes are estimated from MC simulation

❖ Non-prompt background

- Main sources: Semi-leptonic $t\bar{t}$, W+jets processes
- This is the second-largest
- Estimated using a data-driven method

❖ Other prompt background

- Main sources: ZZ and VVV processes
- Smallest background contribution
- Estimated from simulation

❖ Signal samples

- Nominal $W^{\pm}W^{\pm}jj$ EW, QCD, interference: MG+H7
- Alternative $W^{\pm}W^{\pm}jj$ EW, QCD, interference: MG+PY8

Same-sign yields and systematics

Source	Impact [%]
Experimental	
Electron calibration	0.4
Muon calibration	0.5
Jet energy scale and resolution	1.8
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution	0.2
b-tagging inefficiency	0.7
Background, misid. leptons	3.1
Background, charge misrec.	0.8
Pileup modelling	0.2
Modelling	
EW $W^{\pm}W^{\pm}jj$, shower, scale, PDF & α_s	0.8
EW $W^{\pm}W^{\pm}jj$, QCD corrections	3.5
EW $W^{\pm}W^{\pm}jj$, EW corrections	0.8
Int $W^{\pm}W^{\pm}jj$, shower, scale, PDF & α_s	0.1
QCD $W^{\pm}W^{\pm}jj$, shower, scale, PDF & α_s	2.3
QCD $W^{\pm}W^{\pm}jj$, QCD corrections	0.9
Background, WZ scale, PDF & α_s	0.2
Background, WZ reweighting	1.7
Background, other	1.0
Model statistical	1.8
Experimental and modelling	6.7
Luminosity	1.9
Data statistical	7.4
Total	10.0

Process	Pre-fit yield	Post-fit yield
$W^{\pm}W^{\pm}jj$ EW	235 ± 27	278 ± 30
$W^{\pm}W^{\pm}jj$ QCD	24 ± 6	27 ± 7
$W^{\pm}W^{\pm}jj$ Int	7.6 ± 0.6	8.1 ± 0.7
$W^{\pm}Zjj$	98 ± 11	71 ± 8
Non-prompt	56 ± 11	55 ± 11
$V\gamma$	11 ± 4	13 ± 5
Charge mis-ID	10.1 ± 3.4	11.0 ± 3.5
Other prompt	7.1 ± 2.4	6.7 ± 1.9
Total Expected	448 ± 34	470 ± 40
Data	475	

Same-sign fiducial region definition

- Two same-sign leptons (e or μ), dressed
- e or μ from tau lepton decays are excluded
- $p_{T,lep1,2} > 27$ GeV, $|\eta_{lep1,2}|<2.5$
- $m_{ll} >= 20$ GeV
- $|m_{ee} - m_{Z}| > 15$ GeV
- $E_{T,miss} > 30$ GeV
- Two jets from AntiKt4TruthJets
- Overlap removal between electrons and jets
- $p_{T,jet,1(2)} > 65$ (35) GeV, $|\eta_{j}| < 4.5$
- $m_{jj} > 500$ GeV
- $|\Delta y_{jj}| > 2$

Same-sign EFT limits