

EFT re-interpretation of $WZjj$ Vector Boson Scattering production

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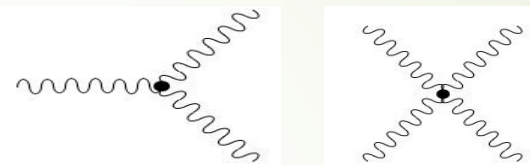


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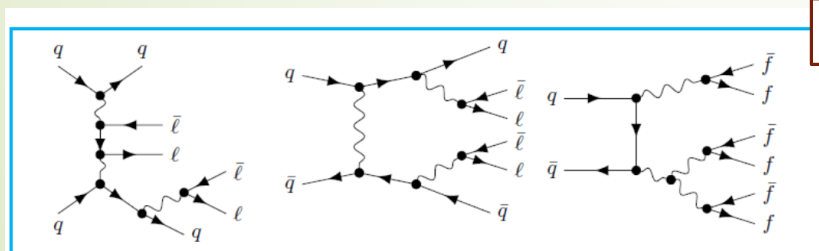
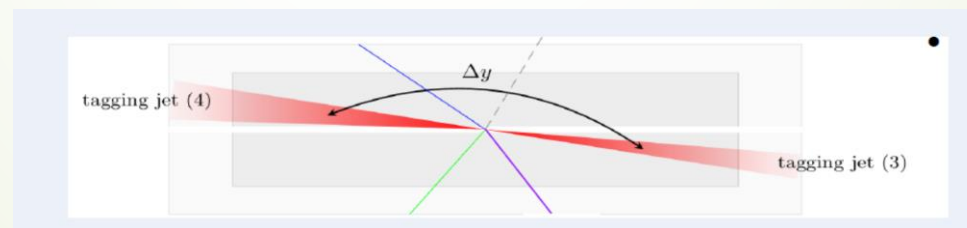
Vector Boson Scattering (VBS)

Vector Boson Scattering(VBS)

- Standard Model predicts self-interactions between the electroweak gauge bosons
- These self-couplings can involve either three or four gauge bosons at a single vertex, known as triple and quartic gauge couplings, respectively.

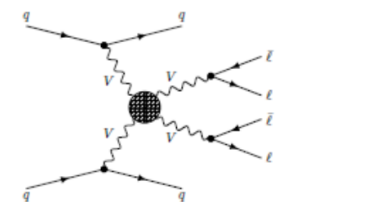


- EWK WZjj production (signal)
 - Fully leptonic final state which contains three leptons and two jets
 - Characteristic kinematic signature with the products of two bosons produced centrally and two forward jets with large spatial separation in rapidity and a high invariant mass
 - Challenging separation between the signal and the backgrounds



EWK WZjj productions

VBS



Study of
electroweak
symmetry
breaking through
the vector boson
self-couplings

Vector Boson Scattering(VBS) (2)

Backgrounds:

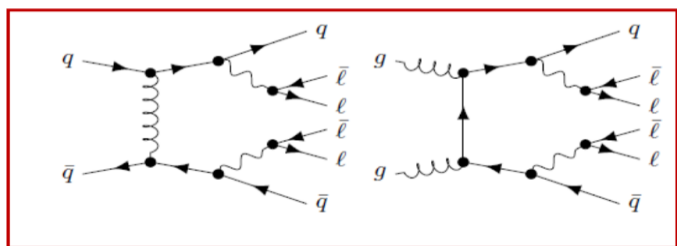
➤ Reducible background: $Z + jets$, $Z\gamma$, $t\bar{t}$ and Wt →

- At least one "fake" lepton
- Matrix method technique

➤ Irreducible background: $WZjj - QCD$, $t\bar{t}V$, tZ , VVV , $ZZjj - QCD$ and $ZZjj - EWK$ →

- At least three prompt leptons in the final state
- Simultaneous fit in dedicated CRs

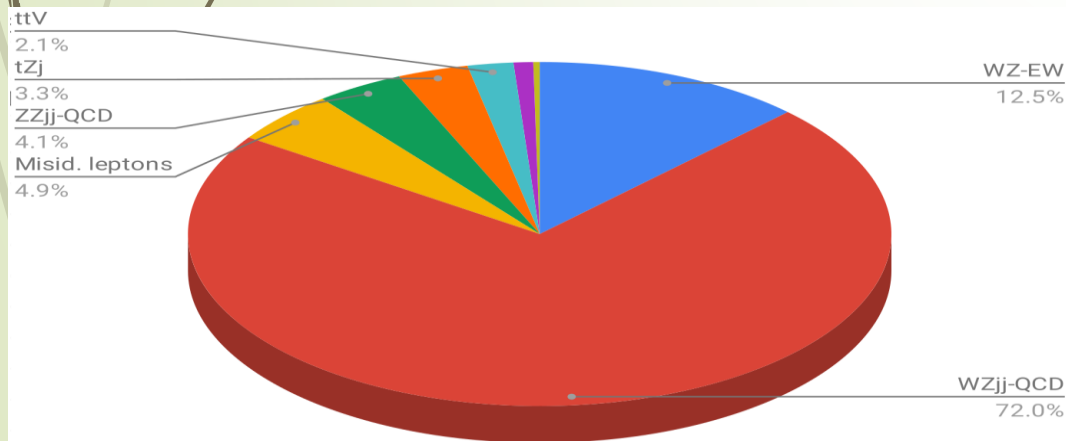
QCD VVjj



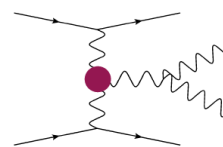
Main background

Fit in SR

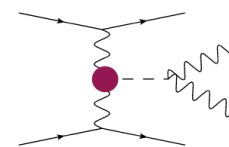
- Presence of gluons
- Low rapidity separation and low invariant mass of the two jets system



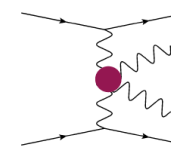
WZjj probes:



TGC



Higgs couplings



QGC

Explore the existence of New Physics through deviations from SM

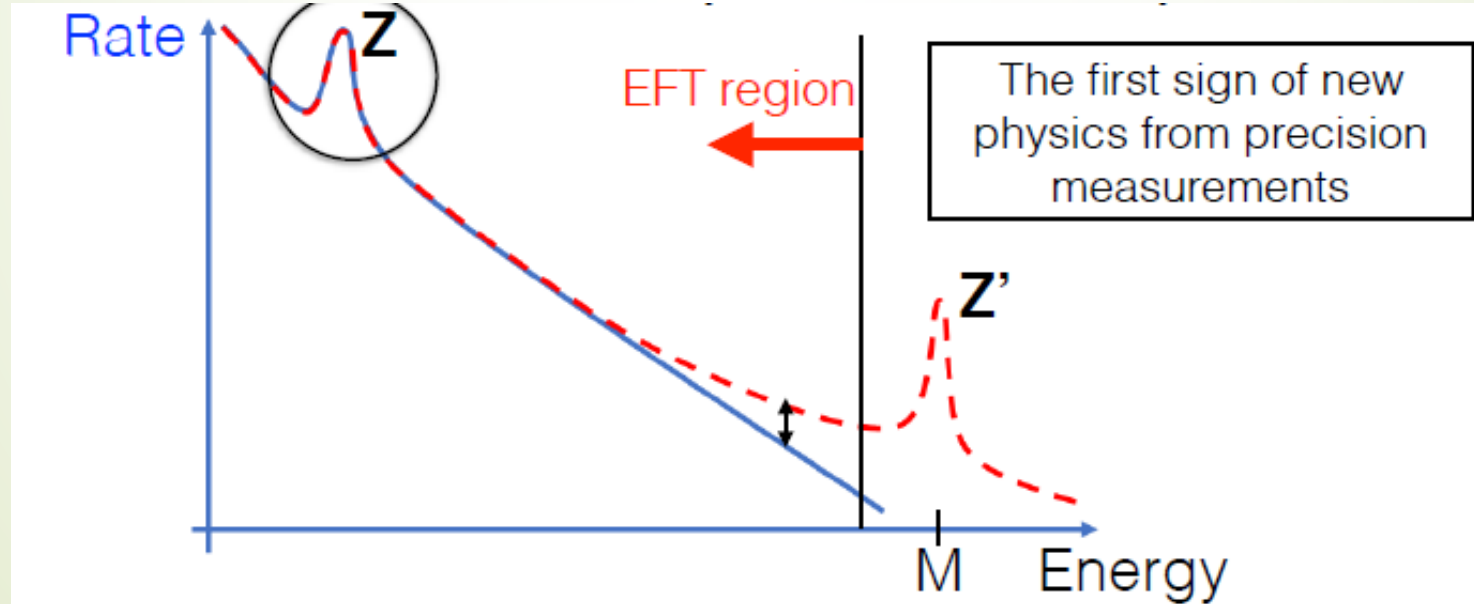


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Effective Field Theory

Effective Field Theory (1)

- There are two methods to look for physics beyond the Standard Model (BSM).
 - Look for new particles (model-dependent)
 - Look for new interactions of SM particles (model-independent)
- We use the second method and we try to notice deviations in the tails of the distributions of some kinematical variables.



Effective Field Theory (2)

- The Effective Field Theory (EFT) is the natural way to expand the SM such that the gauge symmetries are respected
- The EFT provides a way to search for effects of BSM
- Construction of an EFT Lagrangian:
 - SM: general theory of quark and lepton fields and their interactions with vector boson and the Higgs fields
 - Extend the theory: Add operators of higher dimension
- The EFT Lagrangian can be expressed as:

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda_i^2} O_i^{(6)} + \sum_i \frac{c_i^{(8)}}{\Lambda_i^4} O_i^{(8)} + \dots$$

Where: Λ is the scale of new physics

$O_i^{(6)}$, $O_i^{(8)}$ are the Lorentz and gauge invariant dimension-6 and dimension-8 operators

$c_i^{(6)}$, $c_i^{(8)}$ are the dimensionless Wilson coefficients of the dimension-6 and 8 effective operators

- Λ can be assumed as common to all the coefficients, the Wilson coefficients can be written as:

$$f_i^{(6)} = \frac{c_i^{(6)}}{\Lambda^2}, f_i^{(8)} = \frac{c_i^{(8)}}{\Lambda^4}, \dots$$

Energy scale of the
interaction must be
 $E < \Lambda$

Effective Field Theory (3)

- We use the dimension-8 operators because they are dominant in anomalous QGC

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{L}_{S,0}, \mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O	O
$\mathcal{L}_{M,0}, \mathcal{L}_{M,1}, \mathcal{L}_{M,6}, \mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O	O
$\mathcal{L}_{M,2}, \mathcal{L}_{M,3}, \mathcal{L}_{M,4}, \mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O	O
$\mathcal{L}_{T,0}, \mathcal{L}_{T,1}, \mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}, \mathcal{L}_{T,6}, \mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,9}, \mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X	X

They are divided into three categories: Longitudinal (L_S), transverse (L_T) and mixed (L_M)

- In order to avoid the production of large amounts of Monte Carlo samples, we will profit from the decomposition method

$$\begin{aligned}
 & |\mathcal{A}_{\text{SM}} + \sum_i c_i \mathcal{A}_i|^2 \\
 &= |\mathcal{A}_{\text{SM}}|^2 + \sum_i c_i 2\text{Re}(\mathcal{A}_{\text{SM}}^* \mathcal{A}_i) + \sum_i c_i^2 |\mathcal{A}_i|^2 + \sum_{ij, i \neq j} c_i c_j 2\text{Re}(\mathcal{A}_i^* \mathcal{A}_j)
 \end{aligned}$$

Interference term
between SM-EFT
(Linear term)

Pure EFT
contribution
(Quadratic term)

Interference
term between
EFT operators
(Cross term)

SM term

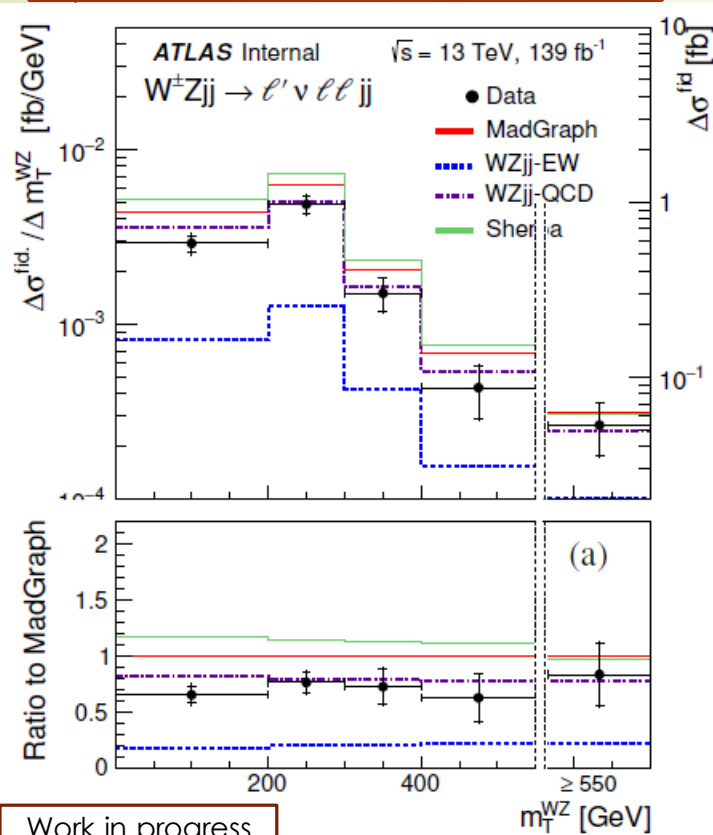
Strategy and results for the extraction of truth level limits

Procedure for the extraction of truth level limits

- For the unfolded $WZjj$ measurements the Fiducial $WZjj$ -EW phase space is used and a [Rivet routine](#) was created
- The asymptotic approximation is used in order to extract the truth level limits
- Limits are extracted using seven different kinematical variables trying one kinematical variable at a time in order to define the most sensitive to dimension-8 operators
- The binning used for each kinematical variable is the one used in the respective differential distribution which is guided by the minimum required statistics for each bin
- Extraction of expected 95% CL lower and upper limits on the aQGC for two different cases:
 - 1) using one aQGC operator at a time setting all the other anomalous couplings to the SM value and
 - 2) using simultaneously two aQGC operators of the same family and setting all the other anomalous couplings to SM value
- Both experimental and theory uncertainties that affect the $WZjj$ SM and EFT processes are taken into account
- The [EFTFun tool](#) implemented based on the decomposition property of the EFT samples, is used for the extraction of the limits

Results for truth level limits (1)

Input measurements:
unfolded distributions



Expected lower
and upper 95% CL
limits on the Wilson
coefficients

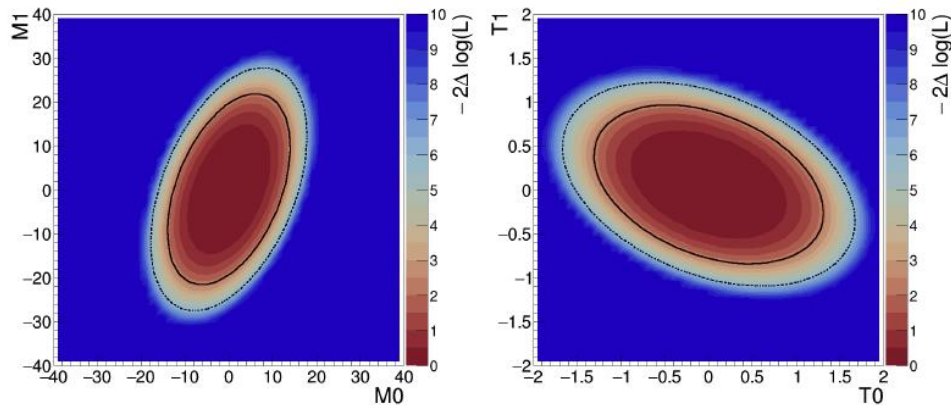
Variable	Expected (TeV^{-4})
f_{S02}/Λ^4	M_T^{WZ} [-27.4, 28.0] $\sum P_T^{Lep}$ [-32.5, 32.9] $\Delta\phi_{WZ}$ [-48.8, 49.8] m_{jj} [-46.4, 47.5] $\Delta\phi_{jj}$ [-66.8, 67.2] Δy_{jj} [-50.5, 51.7] N_{jets} [-60.6, 62.1]
f_{S1}/Λ^4	M_T^{WZ} [-78.8, 79.4] $\sum P_T^{Lep}$ [-93.8, 94.1] $\Delta\phi_{WZ}$ [-140.2, 141.4] m_{jj} [-130.7, 132.6] $\Delta\phi_{jj}$ [-187.8, 186.8] Δy_{jj} [-143.5, 146.0] N_{jets} [-171.2, 174.6]

The transverse mass of
the diboson system
 M_T^{WZ} gives the best
expected limits for all
the operators

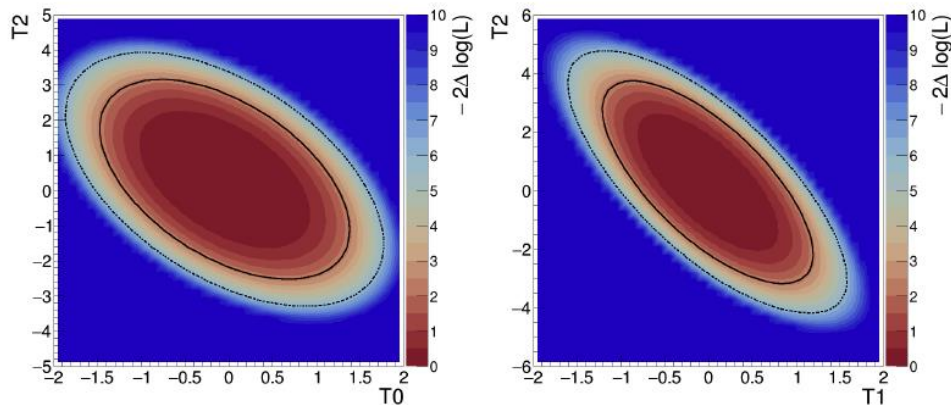
Variable	Expected (TeV^{-4})	Variable	Expected (TeV^{-4})
f_{T0}/Λ^4	M_T^{WZ} [-1.36, 1.42] $\sum P_T^{Lep}$ [-1.55, 1.59] $\Delta\phi_{WZ}$ [-2.84, 2.96] m_{jj} [-2.99, 3.07] $\Delta\phi_{jj}$ [-3.37, 3.42] Δy_{jj} [-3.94, 3.99] N_{jets} [-3.75, 3.84]	<i>Work in progress</i>	f_{M0}/Λ^4 M_T^{WZ} [-14.4, 14.3] $\sum P_T^{Lep}$ [-16.4, 16.3] $\Delta\phi_{WZ}$ [-29.0, 28.6] m_{jj} [-29.4, 28.3] $\Delta\phi_{jj}$ [-34.4, 34.4] Δy_{jj} [-34.8, 33.8] N_{jets} [-36.4, 35.4]
f_{T1}/Λ^4	M_T^{WZ} [-0.90, 1.03] $\sum P_T^{Lep}$ [-1.04, 1.15] $\Delta\phi_{WZ}$ [-1.80, 1.96] m_{jj} [-2.09, 2.27] $\Delta\phi_{jj}$ [-2.39, 2.51] Δy_{jj} [-2.74, 2.89] N_{jets} [-2.56, 2.73]		f_{M1}/Λ^4 M_T^{WZ} [-22.1, 22.4] $\sum P_T^{Lep}$ [-25.5, 25.8] $\Delta\phi_{WZ}$ [-43.4, 44.0] m_{jj} [-44.3, 45.4] $\Delta\phi_{jj}$ [-54.1, 54.7] Δy_{jj} [-51.9, 53.1] N_{jets} [-55.1, 56.4]
f_{T2}/Λ^4	M_T^{WZ} [-2.52, 3.06] $\sum P_T^{Lep}$ [-2.96, 3.41] $\Delta\phi_{WZ}$ [-5.20, 5.90] m_{jj} [-5.91, 6.63] $\Delta\phi_{jj}$ [-6.81, 7.33] Δy_{jj} [-7.83, 8.43] N_{jets} [-7.28, 8.04]		f_{M7}/Λ^4 M_T^{WZ} [-27.7, 27.7] $\sum P_T^{Lep}$ [-31.7, 31.7] $\Delta\phi_{WZ}$ [-56.6, 56.6] m_{jj} [-58.3, 58.3] $\Delta\phi_{jj}$ [-63.7, 63.7] Δy_{jj} [-75.4, 75.4] N_{jets} [-72.6, 72.6]

Results for truth level limits (4)

- Limits on aQGC Wilson coefficients are also derived fitting two parameters simultaneously
- The M_T^{WZ} gives the best expected limits



Work in progress



Variable	Expected (TeV^{-4})	Work in progress	Variable	Expected (TeV^{-4})
$f_{M0}/\Lambda^4, f_{M1}/\Lambda^4$	M_T^{WZ} [-17.9, 17.9], [-27.5, 27.9]		$f_{T0}/\Lambda^4, f_{T1}/\Lambda^4$	M_T^{WZ} [-1.67, 1.67], [-1.10, 1.23]
	$\sum P_T^{Lep}$ [-20.5, 20.5], [-32.2, 32.6]			$\sum P_T^{Lep}$ [-1.89, 1.87], [-1.26, 1.37]
	$\Delta\phi_{WZ}$ [-35.1, 34.9], [-52.9, 53.3]			$\Delta\phi_{WZ}$ [-3.50, 3.53], [-2.20, 2.35]
	m_{jj} [-32.7, 31.7], [-49.5, 50.7]			m_{jj} [-3.60, 3.60], [-2.50, 2.68]
	$\Delta\phi_{jj}$ [-43.2, 43.5], [-69.3, 70.5]			$\Delta\phi_{jj}$ [-4.02, 4.02], [-2.84, 2.97]
	Δy_{jj} [-42.1, 41.1], [-63.2, 64.1]			Δy_{jj} [-4.72, 4.70], [-3.27, 3.42]
	N_{jets} [-45.7, 44.5], [-68.7, 69.6]			N_{jets} [-4.53, 4.54], [-3.07, 3.25]

Variable	Expected (TeV^{-4})	Variable	Expected (TeV^{-4})
$f_{T0}/\Lambda^4, f_{T2}/\Lambda^4$	M_T^{WZ} [-1.87, 1.77], [-3.30, 3.93]	$f_{T1}/\Lambda^4, f_{T2}/\Lambda^4$	M_T^{WZ} [-1.61, 1.58], [-4.19, 4.78]
	$\sum P_T^{Lep}$ [-2.10, 2.00], [-3.88, 4.43]		$\sum P_T^{Lep}$ [-1.73, 1.72], [-4.75, 5.23]
	$\Delta\phi_{WZ}$ [-3.76, 3.68], [-6.71, 7.49]		$\Delta\phi_{WZ}$ [-3.01, 2.98], [-8.48, 9.55]
	m_{jj} [-4.06, 3.92], [-7.80, 8.67]		m_{jj} [-3.38, 3.38], [-9.36, 10.08]
	$\Delta\phi_{jj}$ [-4.47, 4.36], [-8.89, 9.53]		$\Delta\phi_{jj}$ [-3.79, 3.77], [-10.59, 11.37]
	Δy_{jj} [-5.26, 5.12], [-10.24, 11.16]		Δy_{jj} [-4.37, 4.37], [-13.35, 14.68]
	N_{jets} [-4.99, 4.86], [-9.49, 10.41]		N_{jets} [-4.12, 4.11], [-11.92, 13.33]

Strategy and results for the extraction of reconstructed level limits

Procedure for the extraction of reconstructed level limits

- For the reconstructed measurements the phase space of the $WZjj$ VBS signal region is used
- Optimization of the binning of the kinematical variables
- The asymptotic approximation is used in order to extract the truth limits
- To maximally profit from the sensitive kinematical variables two variables relatively uncorrelated are selected. This template is created by binning two kinematical variables simultaneously.
- Also a comparison between the limits derived using the two-variable fit template and the limits derived using only one kinematical variable is done
- The limits are extracted using one operator at a time
- The experimental and theory uncertainties that affect the $WZjj$ process are taken into account
- The tool used for the extraction of the limits is the [EFTFun tool](#)

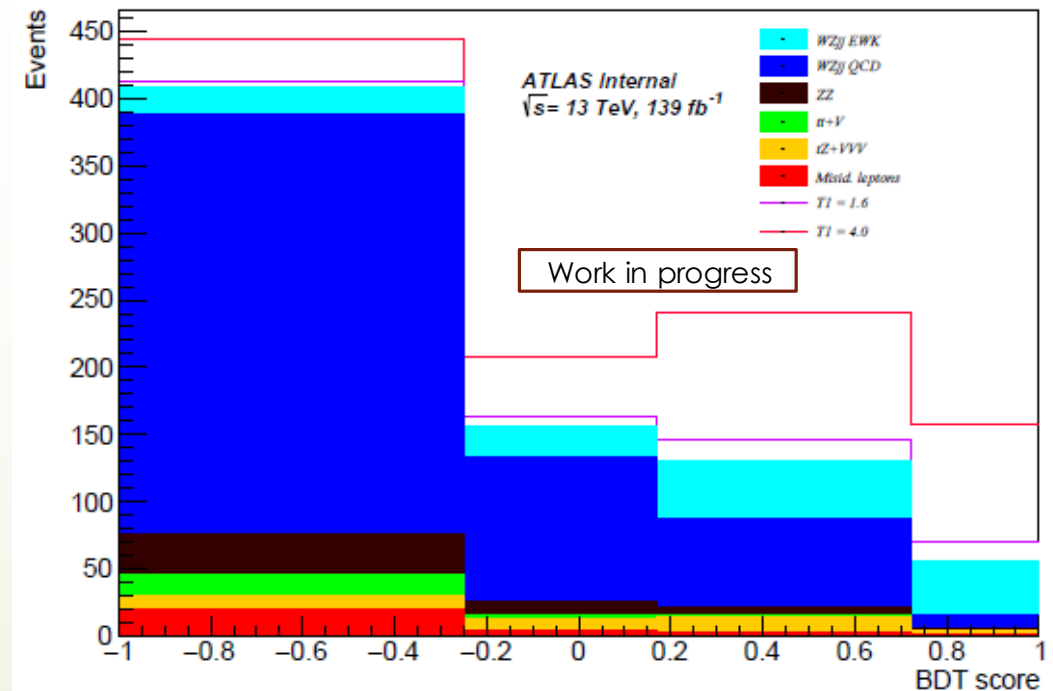
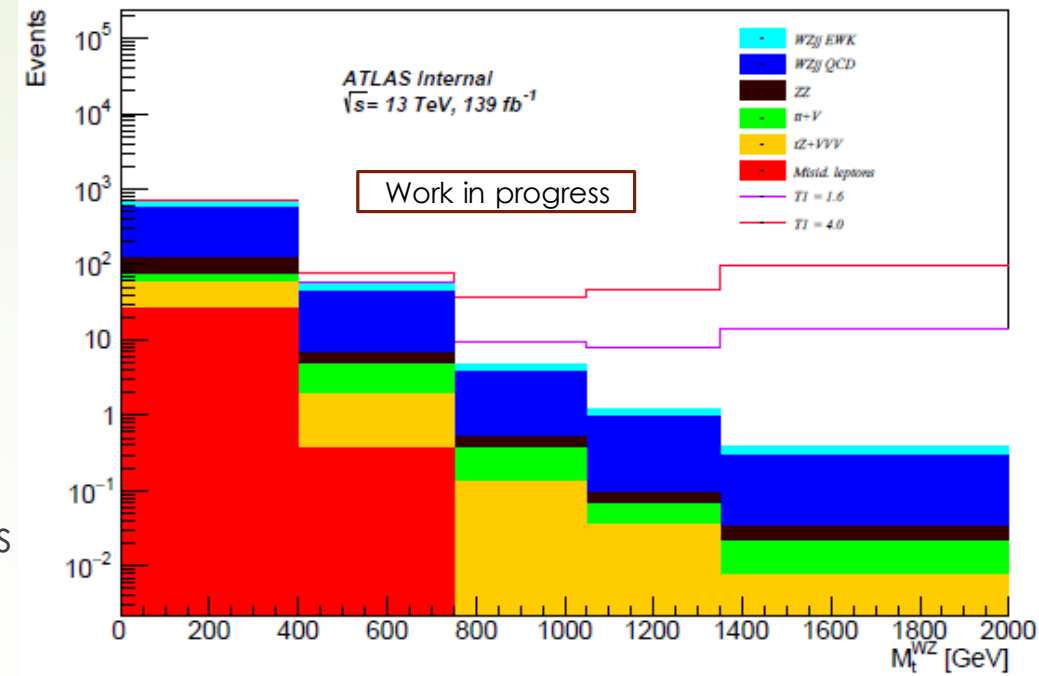
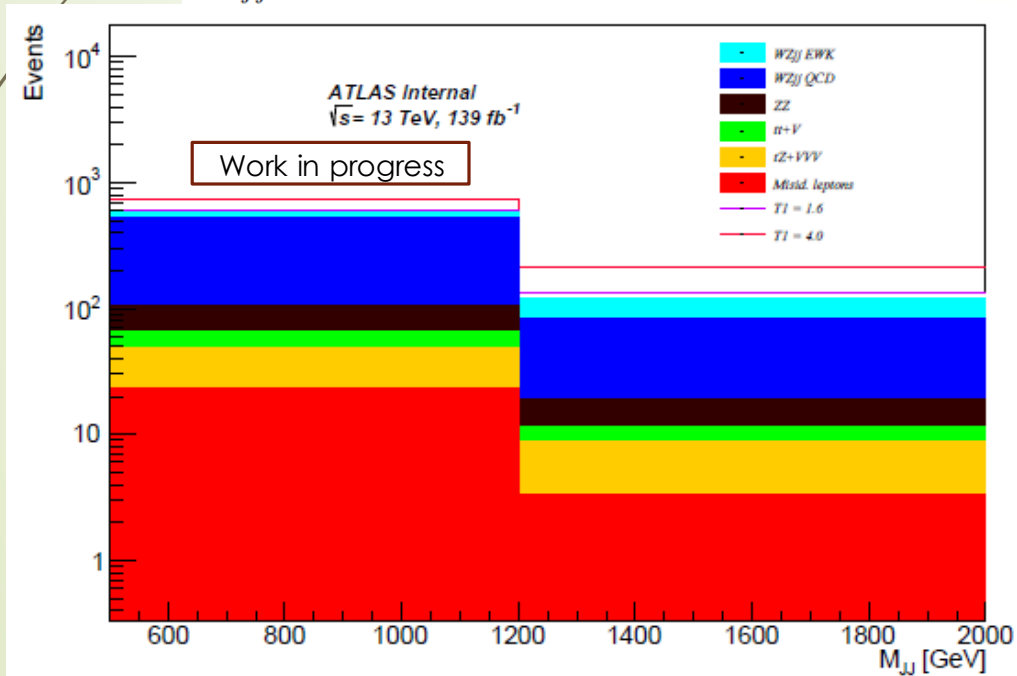
Binning Optimization

- After performing a binning optimization, the results for the optimized binnings are:

$$\begin{aligned} M_T^{WZ} \text{ (GeV)} & [0, 450, 700, 1050, 1550, \infty] \\ M_{jj} \text{ (GeV)} & [500, 1050, \infty] \\ \text{BDT Score} & [-1.0, -0.25, 0.17, 0.72, 1.0] \end{aligned}$$

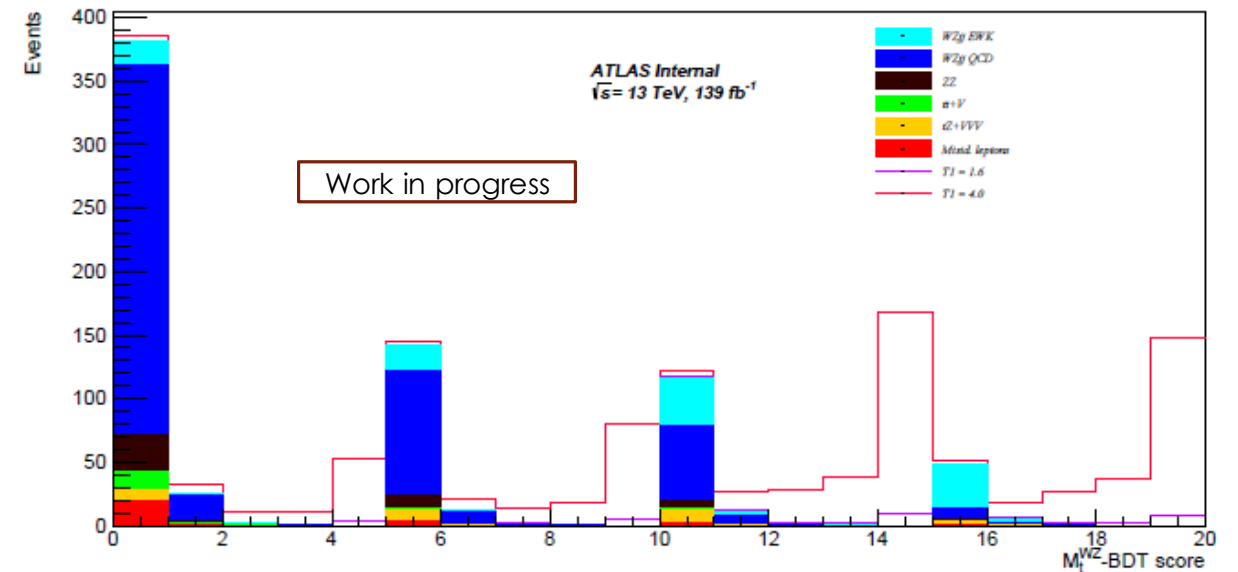
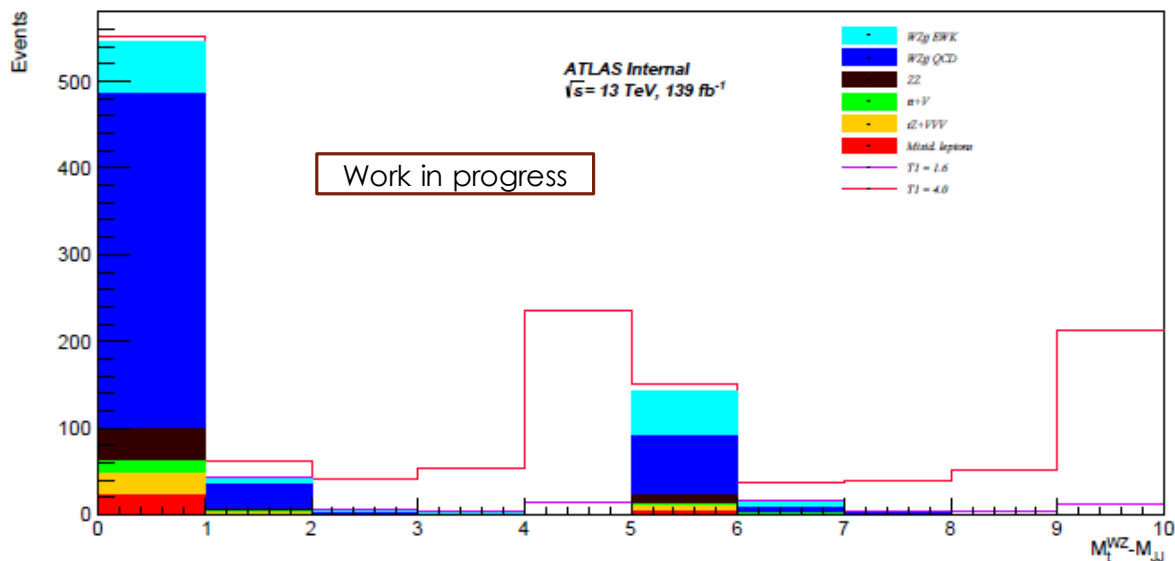
- For the M_T^{WZ} and the M_{jj} the **CMS** binning will be used for comparison reasons, as the differences in the 95 % CL limits when using either the optimized binning or this binning are negligible.

$$\begin{aligned} M_T^{WZ} \text{ (GeV)} & [0, 400, 750, 1050, 1350, \infty] \\ M_{jj} \text{ (GeV)} & [500, 1200, \infty] \end{aligned}$$



Results for reconstructed level limits (1)

- Extraction of the limits using
 - one dimensional distribution (M_T^{WZ}) in the fit
 - two-dimensional distributions (M_T^{WZ} - M_{jj} and M_T^{WZ} - BDT score) in the fit
 - Create two-dimensional templates by binning two kinematic variables simultaneously
 - Create one dimension by 'unrolling' the bin contents



Results for reconstructed level limits (2)

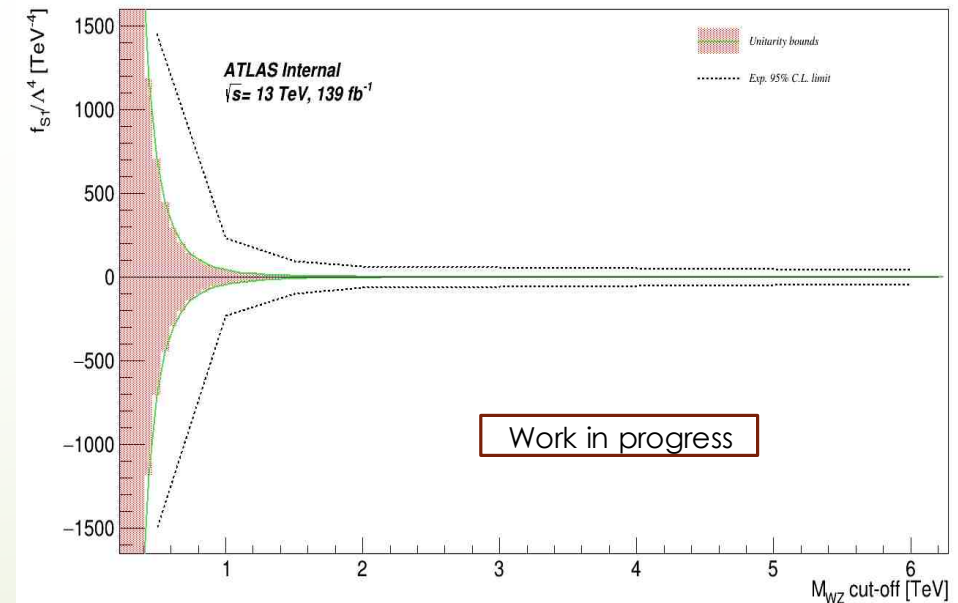
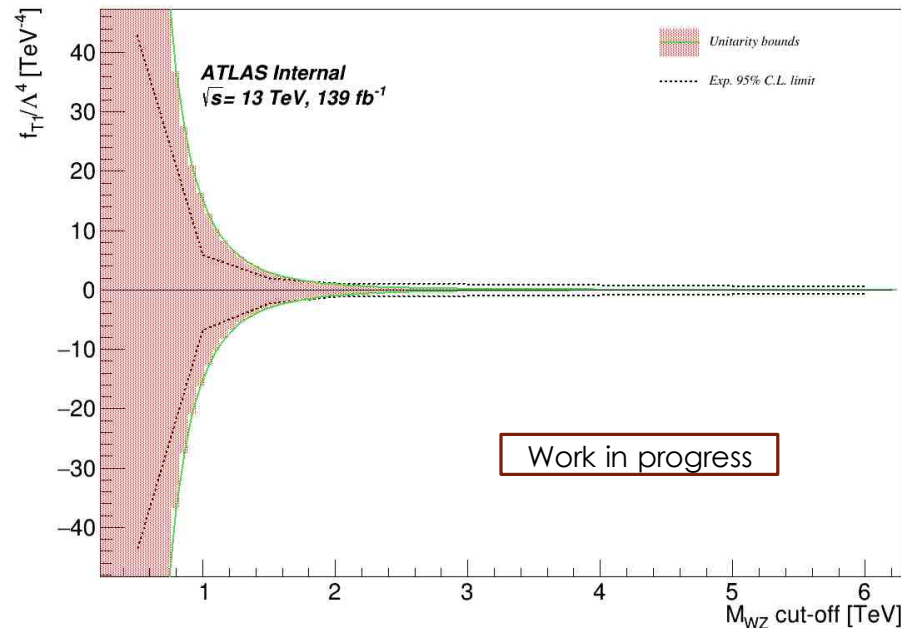
Expected lower and upper 95% CL limits on the Wilson coefficients

	Variable	Expected (TeV^{-4})
f_{S02}/Λ^4	M_T^{WZ}	[-16.09, 16.08]
	$M_T^{WZ} vs M_{jj}$	[-15.17, 15.19]
	$M_T^{WZ} vs BDT score$	[-14.22, 14.25]
f_{S1}/Λ^4	M_T^{WZ}	[-49.09, 48.87]
	$M_T^{WZ} vs M_{jj}$	[-46.13, 45.84]
	$M_T^{WZ} vs BDT score$	[-42.81, 42.41]
f_{T0}/Λ^4	M_T^{WZ}	[-0.83, 0.83]
	$M_T^{WZ} vs M_{jj}$	[-0.82, 0.83]
	$M_T^{WZ} vs BDT score$	[-0.81, 0.81]
f_{T1}/Λ^4	M_T^{WZ}	[-0.54, 0.51]
	$M_T^{WZ} vs M_{jj}$	[-0.53, 0.51]
	$M_T^{WZ} vs BDT score$	[-0.53, 0.50]
f_{T2}/Λ^4	M_T^{WZ}	[-1.62, 1.50]
	$M_T^{WZ} vs M_{jj}$	[-1.60, 1.49]
	$M_T^{WZ} vs BDT score$	[-1.59, 1.46]
f_{M0}/Λ^4	M_T^{WZ}	[-8.90, 8.85]
	$M_T^{WZ} vs M_{jj}$	[-8.74, 8.65]
	$M_T^{WZ} vs BDT score$	[-8.31, 8.26]
f_{M1}/Λ^4	M_T^{WZ}	[-13.16, 13.03]
	$M_T^{WZ} vs M_{jj}$	[-12.91, 12.76]
	$M_T^{WZ} vs BDT score$	[-12.34, 12.23]
f_{M7}/Λ^4	M_T^{WZ}	[-15.39, 15.39]
	$M_T^{WZ} vs M_{jj}$	[-15.17, 15.17]
	$M_T^{WZ} vs BDT score$	[-14.63, 14.63]

The two dimensional template of the M_T^{WZ} with the BDT score gives the best expected limits

Results for reconstructed level limits (5)

- EFT is not a complete model
 - the presence of non-zero aQGCs will violate tree-level unitarity at sufficiently high energy
- More physical limits can be obtained using the clipping method by:
 - cutting the EFT integration at the unitarity limit and
 - keeping the SM predictions at invariant mass of parton level WZ, even above the unitarity limit



Discussion

Discussion (1)

- Comparison between truth and reconstructed level expected 95% CL lower and upper limits on the aQGC Wilson coefficients of the corresponding dimension-8 operators
 - Kinematical variable: M_T^{WZ}
 - Binning: the one used for the extraction of the truth level limits

	Expected Truth (TeV^{-4})	Expected Reco (TeV^{-4})
f_{S1}/Λ^4	[-79, 79]	[-66, 66]
f_{S02}/Λ^4	[-27, 28]	[-22, 22]
f_{T0}/Λ^4	[-1.36, 1.42]	[-1.27, 1.24]
f_{T1}/Λ^4	[-0.90, 1.03]	[-0.87, 0.82]
f_{T2}/Λ^4	[-2.52, 3.06]	[-2.59, 2.35]
f_{M0}/Λ^4	[-14.4, 14.3]	[-12.6, 12.4]
f_{M1}/Λ^4	[-22.1, 22.4]	[-19.1, 19.1]
f_{M7}/Λ^4	[-27.7, 27.7]	[-22.4, 22.4]

The reconstructed level limits are better than the truth level limits

Discussion (2)

- Comparison of the reconstructed level expected 95% CL lower and upper limits of this study with the [CMS experiment](#)
 - Kinematical variable: two dimensional template of M_T^{WZ} - M_{jj}
 - Binning: the one used for the extraction of the reconstructed level limits

	ATLAS Expected (TeV ⁻⁴)	CMS Expected (TeV ⁻⁴)
f_{T0}/Λ^4	[-0.82,0.83]	[-0.82,0.85]
f_{T1}/Λ^4	[-0.53,0.51]	[-0.49,0.55]
f_{T2}/Λ^4	[-1.6,1.5]	[-1.4,1.7]
f_{M0}/Λ^4	[-8.7,8.7]	[-7.6,7.6]
f_{M1}/Λ^4	[-13,13]	[-11,11]
f_{M7}/Λ^4	[-15,15]	[-14,14]
f_{S1}/Λ^4	[-43,42]	[-38,39]

Work in progress

A direct comparison of the two results cannot be made as the CMS experiment is using an older version of the Eboli-Garcia model.

Conclusion and next steps

Conclusion

Conclusions

Truth level

- Results on single operator 95% C.L. expected limits for some dimension-8 operators for the WZjj VBS fully leptonic channel were presented corresponding to full Run2 luminosity (139 fb^{-1})
- Results on 95% C.L. expected limits using two operators simultaneously for some dimension-8 operators for the WZjj VBS fully leptonic channel were presented corresponding to full Run2 luminosity (139 fb^{-1})
 - Limits are extracted using seven different kinematical variables assuming one kinematical variable at a time in order to obtain which is the most sensitive to dimension-8 operators
 - The transverse mass of the diboson system M_T^{WZ} gives the best expected limits for all the operators

Reconstructed level

- Binning optimization
- Results on single operator 95% C.L. expected limits for some dimension-8 operators for the WZjj VBS fully leptonic channel were presented corresponding to full Run2 luminosity (139 fb^{-1})
 - Extraction of the limits using
 - one dimensional distribution (M_T^{WZ}) in the fit
 - two-dimensional distributions (M_T^{WZ} - M_{jj} and M_T^{WZ} - BDT score) in the fit
 - The two dimensional template of the M_T^{WZ} with the BDT score gives the best expected limits
 - clipping method
- Comparison of expected truth and reconstructed level limits
- Comparison of expected reconstructed level limits between ATLAS and CMS experiments

Next steps

- Next steps:
 - All issues of the analysis have been addressed and unblinding will start very soon.
 - Extraction of observed limits from differential and reconstructed distributions
 - All these results will be published soon
 - Extracted limits will be available for combination with other analyses
- Run3 WZ VBS analysis
 - We are planning to perform a complete study of both dim-6 and dim-8 operators for the WZjj VBS channel using the new [SmeftFR v3](#)



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Backup

Phase space definition for the cross section measurements

Variable	Fiducial $WZjj$ -EW	
Lepton $ \eta $	< 2.5	Concerning the three leptons
p_T of ℓ_Z , p_T of ℓ_W [GeV]	$> 15, > 20$	
m_Z range [GeV]	$ m_Z - m_Z^{\text{PDG}} < 10$	
m_T^W [GeV]	> 30	
$\Delta R(\ell_Z^-, \ell_Z^+), \Delta R(\ell_Z, \ell_W)$	$> 0.2, > 0.3$	
p_T two leading jets [GeV]	> 40	Concerning the two jets
$ \eta_j $ two leading jets	< 4.5	
Jet multiplicity	≥ 2	
$\eta_{j1} \cdot \eta_{j1}$	< 0	
m_{jj} [GeV]	> 500	
$\Delta R(j, \ell)$	> 0.3	
$N_{b\text{-quark}}$	$= 0$	

Electroweak $WZjj$ cross section prediction by MadGraph+Pythia8:
(our signal MC sample)

$$\sigma_{WZjj\text{-EW}}^{\text{MadGraph+Pythia8}} = 0.370 \pm 0.001 \text{ (stat.)}^{+0.006}_{-0.006} \text{ (PDF)}^{+0.030}_{-0.026} \text{ (scale) fb}$$

WZ Event selection

Object selection

Muon object selection				Electron object selection			
Selection	Baseline selection	Z selection	W selection	Selection	Baseline selection	Z selection	W selection
$p_T > 5 \text{ GeV}$	✓	✓	✓	$p_T > 5 \text{ GeV}$	✓	✓	✓
$ \eta < 2.7$	✓	✓	✓	Electron object quality	✓	✓	✓
Loose quality	✓	✓	✓	$ \eta^{\text{cluster}} < 2.47, \eta < 2.5$	✓	✓	✓
$ d_0^{\text{BL}}/\sigma(d_0^{\text{BL}}) < 3$ (for $ \eta < 2.5$ only)	✓	✓	✓	LooseLH+BLayer identification	✓	✓	✓
$ \Delta z_0^{\text{BL}} \sin \theta < 0.5 \text{ mm}$ (for $ \eta < 2.5$ only)	✓	✓	✓	$ d_0^{\text{BL}}/\sigma(d_0^{\text{BL}}) < 5$	✓	✓	✓
PflowLoose_FixedRad isolation	✓	✓	✓	$ \Delta z_0^{\text{BL}} \sin \theta < 0.5 \text{ mm}$	✓	✓	✓
μ -jet Overlap Removal		✓	✓	FCLoose isolation	✓	✓	✓
$p_T > 15 \text{ GeV}$		✓	✓	e -to- μ and e -to- e overlap removal	✓	✓	✓
$ \eta < 2.5$		✓	✓	e -to-jets overlap removal		✓	✓
Medium quality		✓	✓	$p_T > 15 \text{ GeV}$		✓	✓
$p_T > 20 \text{ GeV}$			✓	Exclude $1.37 < \eta^{\text{cluster}} < 1.52$		✓	✓
Tight quality			✓	MediumLH identification		✓	✓
PflowTight_FixedRad isolation			✓	FCHighPtCaloOnly isolation		✓	✓
				$p_T > 20 \text{ GeV}$			✓
				TightLH identification			✓
				FCTight isolation			✓

Baseline event selection:

Inclusive event selection	
ZZ veto	Less than 4 baseline leptons
N leptons	Exactly three leptons passing the Z lepton selection
Leading lepton p_T	$p_T^{\text{lead}} > 25 \text{ GeV}$ (in 2015) or $p_T^{\text{lead}} > 27 \text{ GeV}$ (in 2016)
Z leptons	Two same flavor oppositely charged leptons passing Z lepton selection
Mass window	$ M_{\ell\ell} - M_Z < 10 \text{ GeV}$
W lepton	W lepton passes W selection
W transverse mass	$m_T^W > 30 \text{ GeV}$

Global WZjj strategy

Define the SR and the three background CR:

Jet multiplicity	≥ 2
p_T of two tagging jets	$> 40 \text{ GeV}$
$ \eta $ of two tagging jets	< 4.5
η of two tagging jets	opposite sign
m_{jj}	$> 150 \text{ GeV}$

QCD-CR

Not used in the cross section measurement
No impact on any result other than the expected sensitivity

b-CR ($\#V$ and $\#Z$)

$$N_{b\text{-jet}} > 0$$

QCD-CR (WZjj-QCD)

$$m_{JJ} < 500 \text{ GeV}$$
$$N_{b\text{-jet}} = 0$$

SR (WZjj-EW)

$$m_{JJ} > 500 \text{ GeV}$$
$$N_{b\text{-jet}} = 0$$

Signal region: where the measurement is done

+ **one ZZ CR defined by inverting the 4th lepton veto**

$$\begin{aligned}\sigma_{WZjj-EW}^{\text{fid.}} &= 0.57^{+0.14}_{-0.13} \text{ (stat.) } ^{+0.05}_{-0.04} \text{ (exp. syst.) } ^{+0.05}_{-0.04} \text{ (mod. syst.) } ^{+0.01}_{-0.01} \text{ (lumi.) fb} \\ &= 0.57^{+0.16}_{-0.14} \text{ fb.}\end{aligned}$$

$$\sigma_{WZjj-EW}^{\text{fid., Sherpa}} = 0.321 \pm 0.002 \text{ (stat.) } \pm 0.005 \text{ (PDF)}^{+0.027}_{-0.023} \text{ (scale) fb,}$$

$$\begin{aligned}\sigma_{W^\pm Zjj}^{\text{fid.}} &= 1.68 \pm 0.16 \text{ (stat.) } \pm 0.12 \text{ (exp. syst.) } \pm 0.13 \text{ (mod. syst.) } \pm 0.044 \text{ (lumi.) fb,} \\ &= 1.68 \pm 0.25 \text{ fb,}\end{aligned}$$

$$\sigma_{W^\pm Zjj}^{\text{fid., Sherpa}} = 2.15 \pm 0.01 \text{ (stat.) } \pm 0.05 \text{ (PDF)}^{+0.65}_{-0.44} \text{ (scale) fb.}$$