ATLAS measurements of Vector Boson Scattering

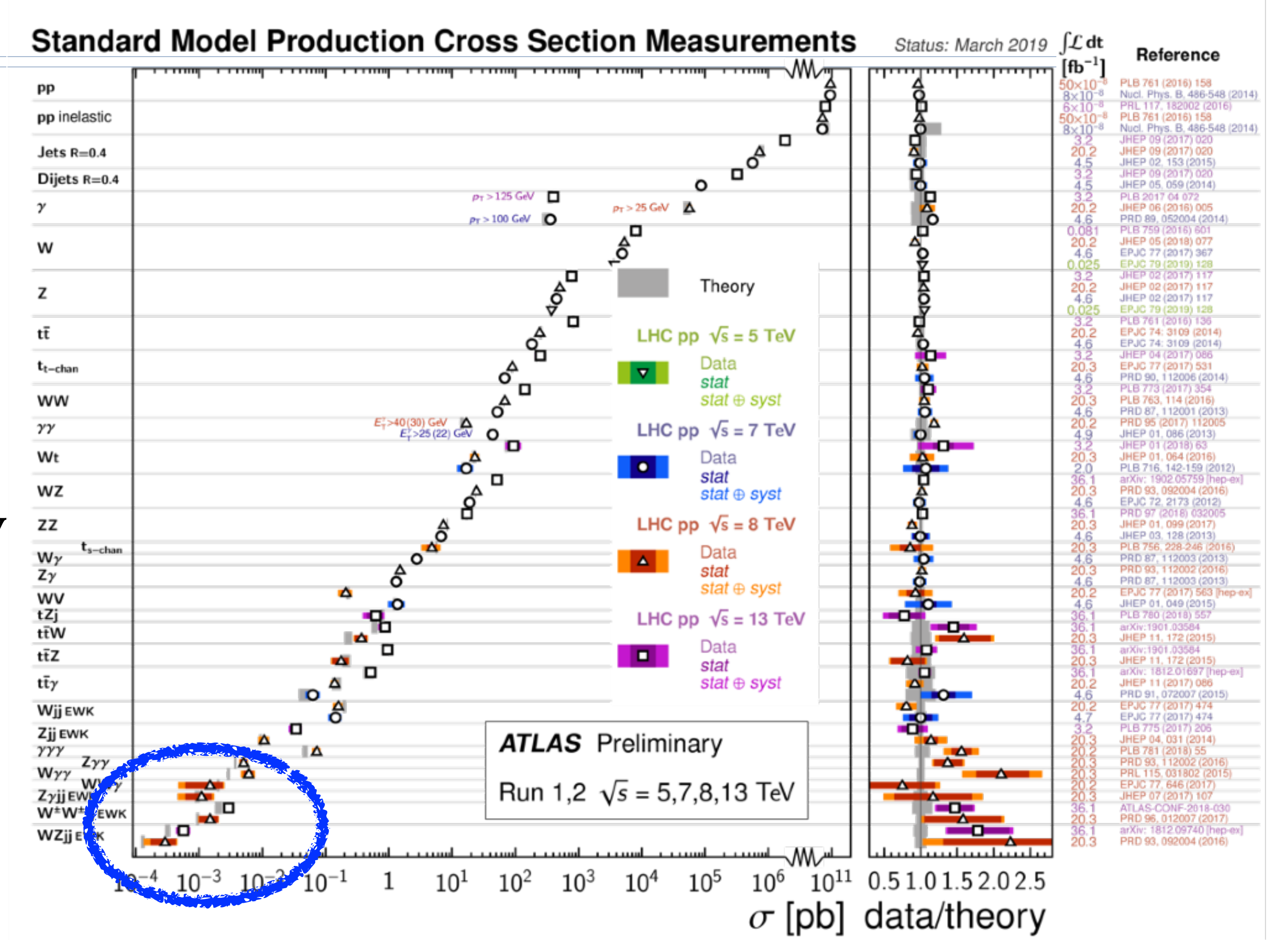
Narei Lorenzo Martinez (LAPP-Annecy, France),

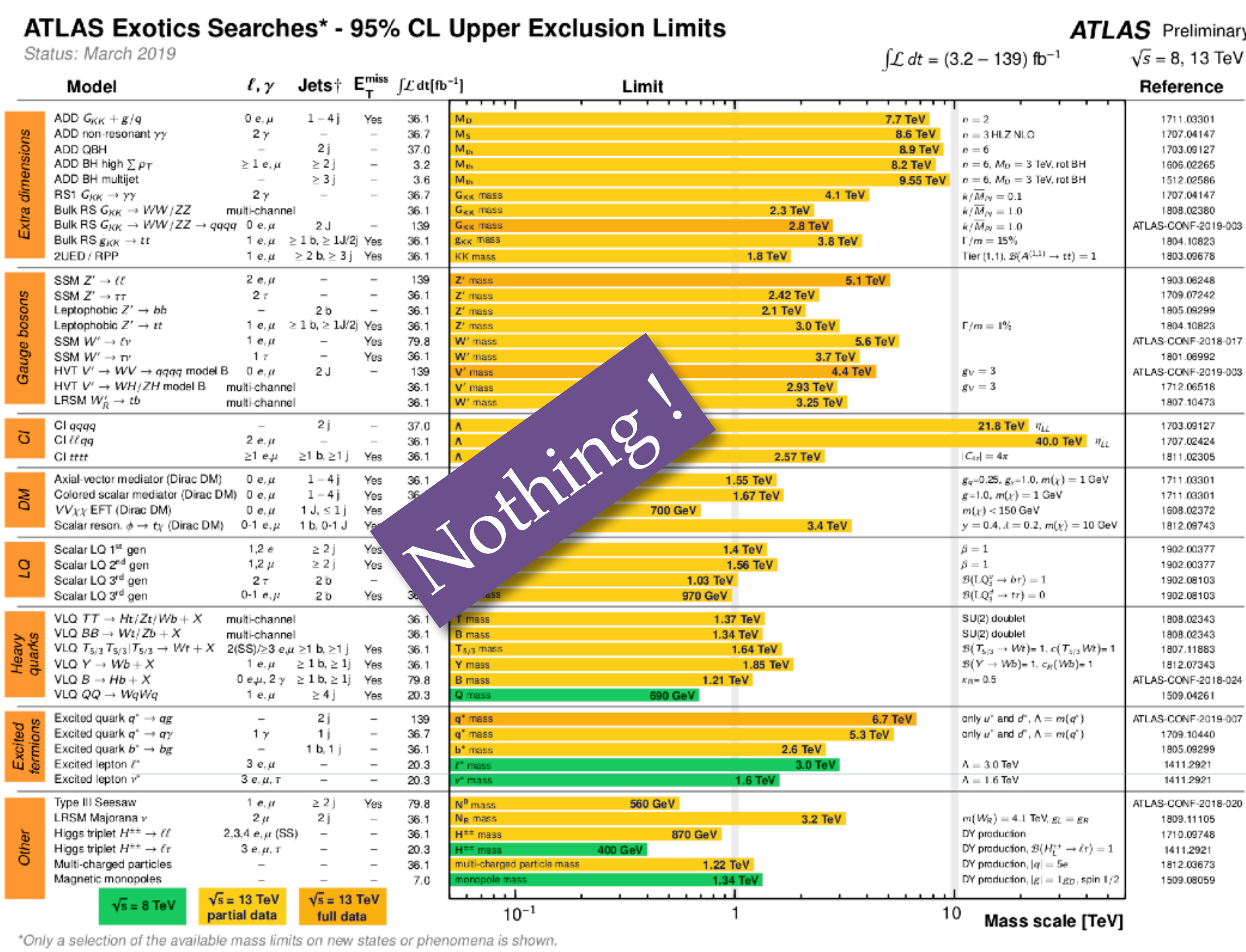
on behalf of the ATLAS collaboration

June 4th, 2019 - Rencontre de Blois 2019

Introduction

- Vector boson scattering (VBS) processes have the smallest cross-section that can be measured currently
- Important test of electroweak (EW) sector and EW Symmetry Breaking (unitarisation by Higgs boson)

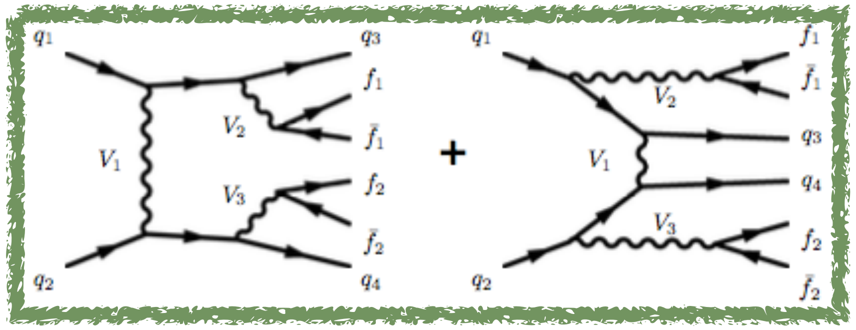




- After Higgs discovery 7 years ago, no deviation found in its properties !
- No sign of new physics with direct searches @LHC
- **VBS tool for indirect search for new physics**

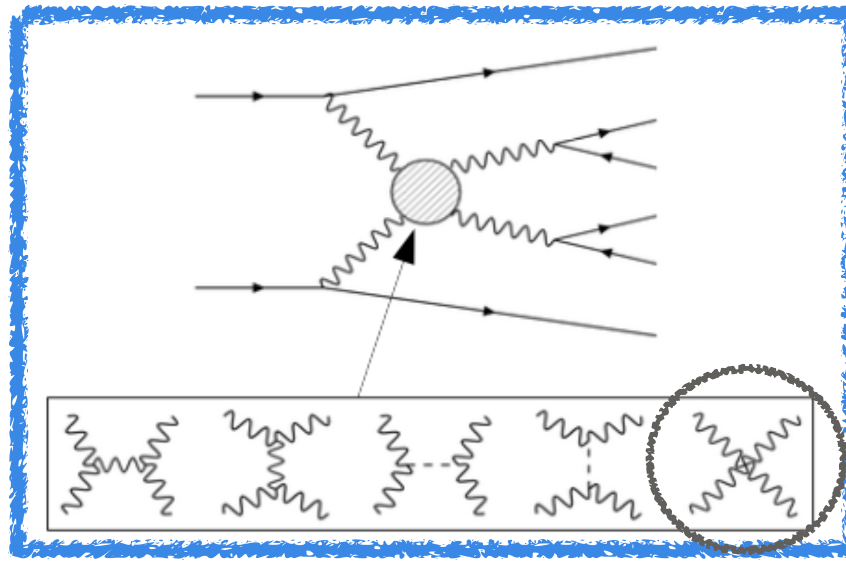
Phenomenology of VBS

- **Cannot access pure VBS and pure quartic couplings (no independently gauge invariant):**



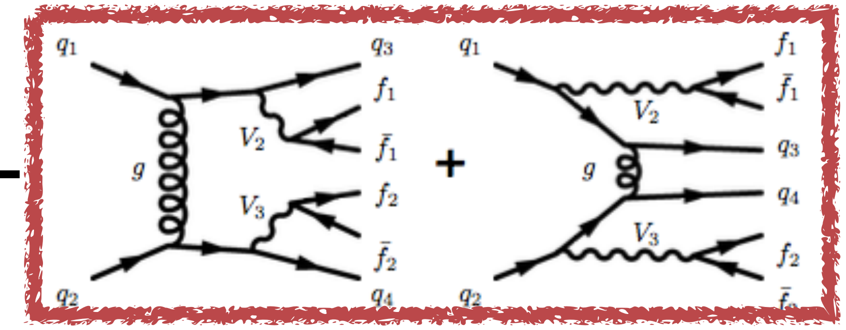
EW non-VBS (including tribosons)

+



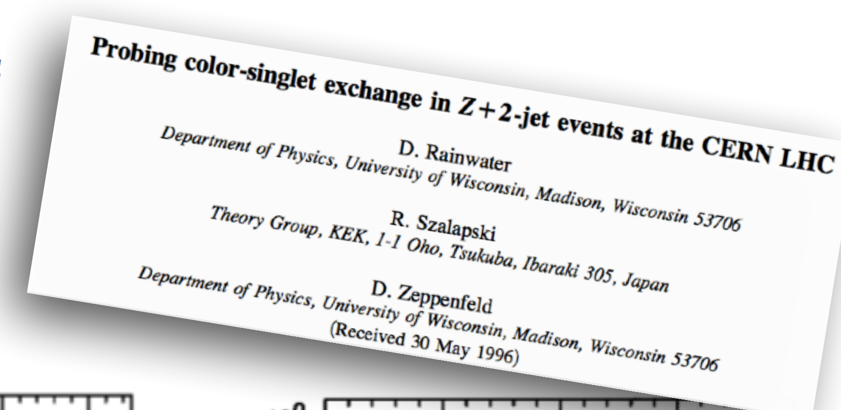
VBS with triple and quartic couplings

+



QCD-induced dibosons final state

- **Typical final states topology**
  1. Two hadronic jets at large angles, high energy
  2. Hadronic activity suppressed between the two jets
  3. Two bosons produced ~back-to-back

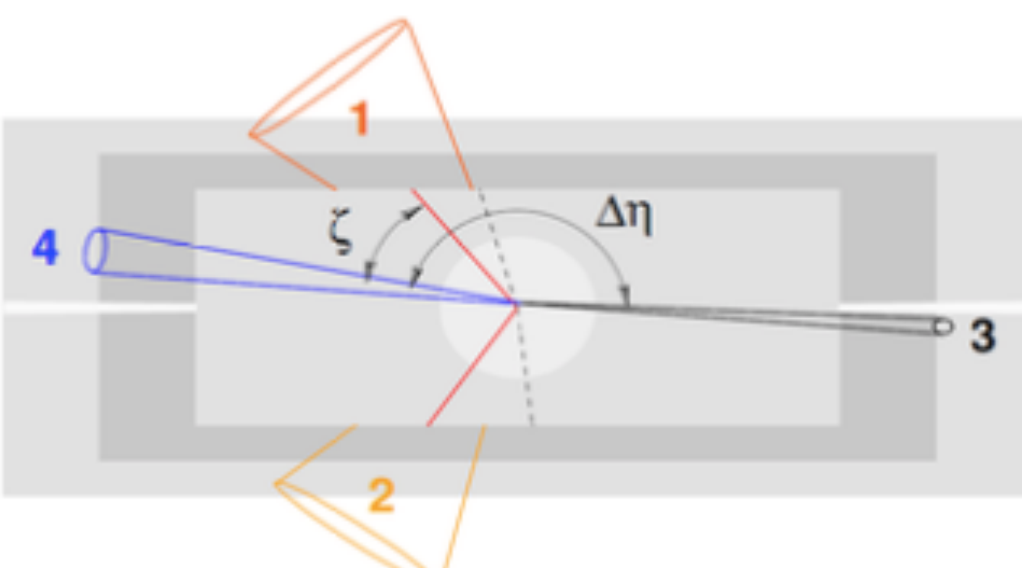

Probing color-singlet exchange in $Z+2$-jet events at the CERN LHC

D. Rainwater
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706

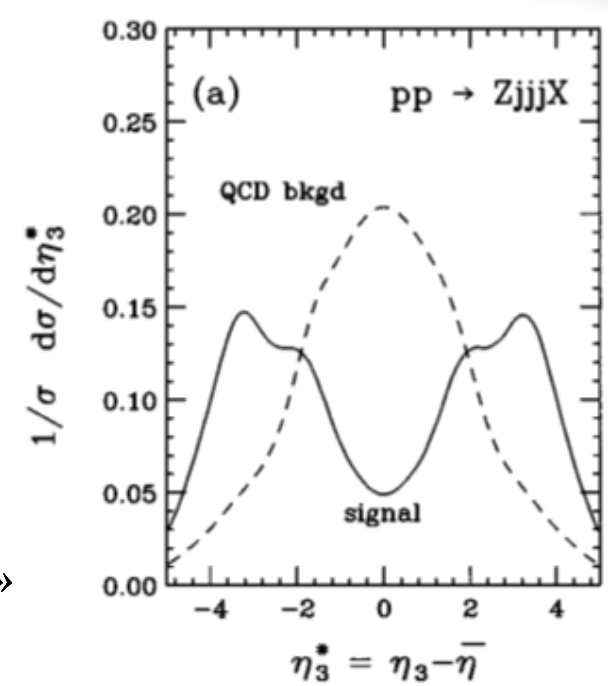
R. Szalapski
Theory Group, KEK, 1-1 Oho, Tsukuba, Ibaraki 305, Japan

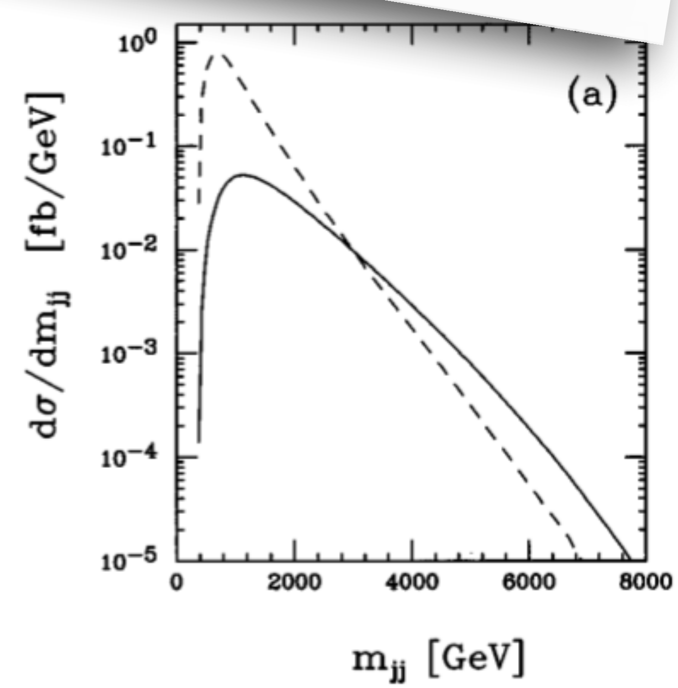
D. Zeppenfeld
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706

(Received 30 May 1996)



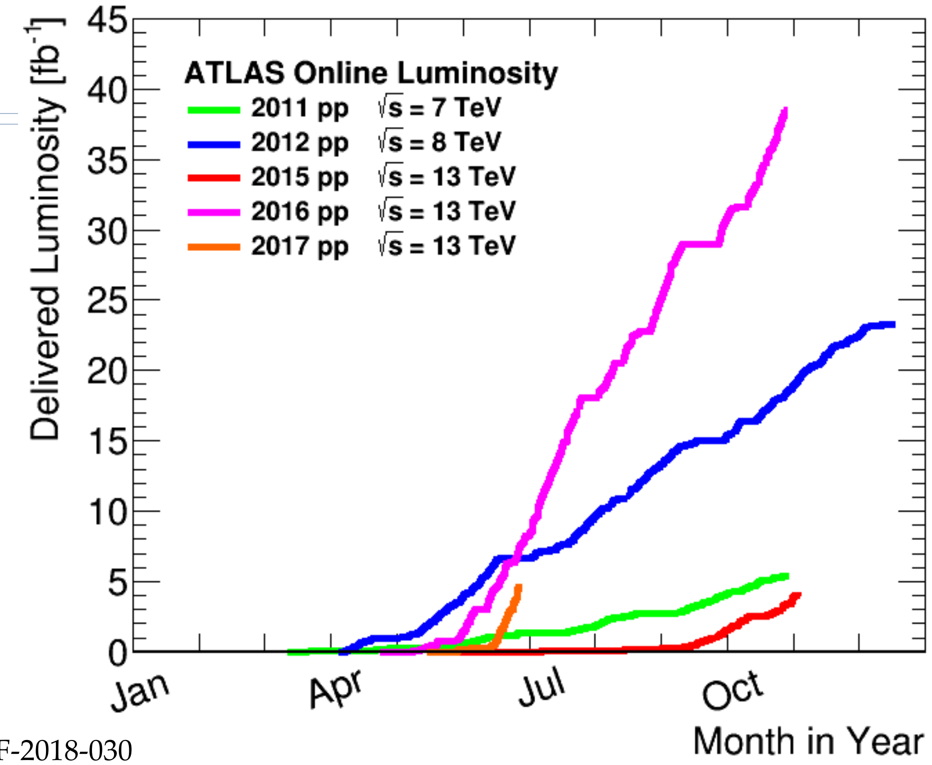
Zeppenfeld variable « centrality »





ATLAS VBS studies

- **Datasets**
  - ATLAS: 8 TeV (20.3 fb^{-1}) and 13 TeV (2015+2016, 36.1 fb^{-1})
- **Significance for all channels studied: observed (expected)**



	8 TeV	13 TeV
$W^\pm W^\pm$	3.6 (2.3) σ Phys. Rev. D 96 (2017) 012007	6.9 (4.6) σ — ATLAS-CONF-2018-030
$W^\pm Z$	<2 σ Phys. Rev. D 93 (2016) 092004	5.3 (3.2) σ — Phys. Lett. B 793 (2019) 469
Zγ	2.0 (1.8) σ JHEP07(2017)107	-
WV semi-lept.	aQGCs limits Phys. Rev. D 95 (2017) 032001	-
VV semi-lept	-	2.7 (2.5) σ — arxiv :905.07714

Only 13 TeV results reported in this talk.

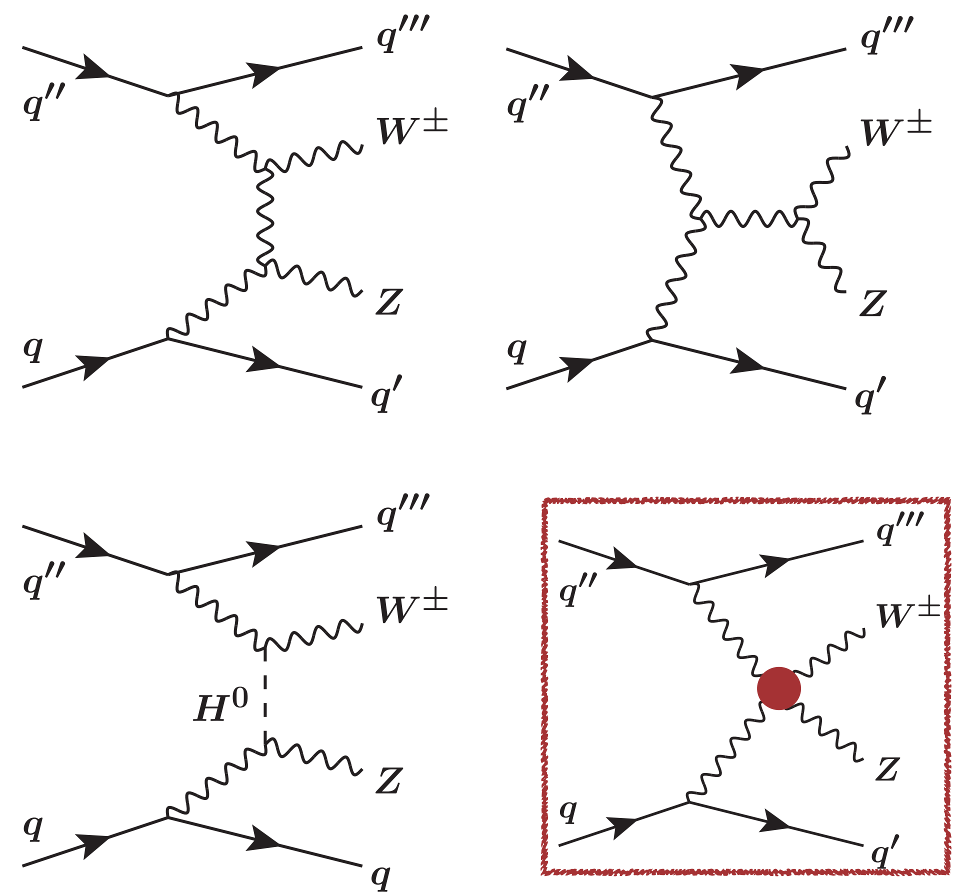
- Semi-leptonic channels less sensitive to EW cross-section but very powerful for QGC constraints (high-energy range accessed)
- Channels studied @ ATLAS allow to probe all types of quartic couplings (EFT operators)

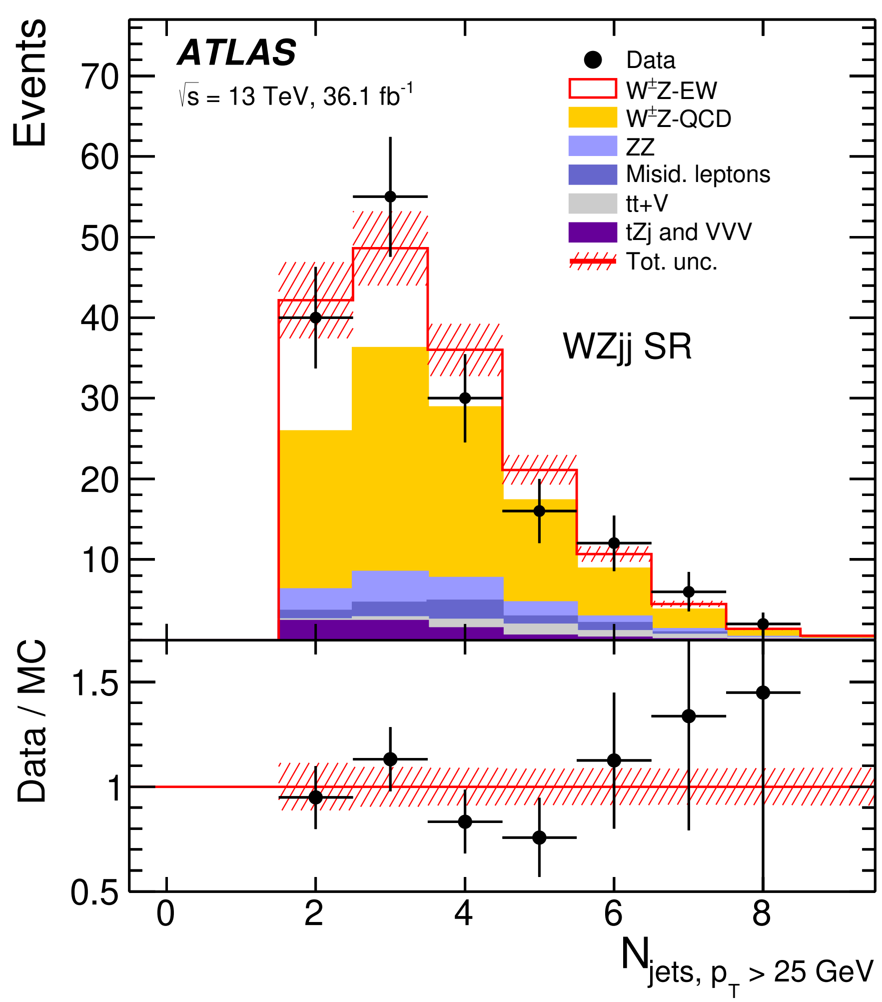
VVjj final state	ZZ	Zγ γγ	W^+W^- WZ	$W^\pm W^\pm$	Wγ
$f_{S,0}$, $f_{S,1}$	✔		✔	✔	
$f_{M,0}$, $f_{M,1}$, $f_{M,6}$, $f_{M,7}$	✔	✔	✔	✔	✔
$f_{M,2}$, $f_{M,3}$, $f_{M,4}$, $f_{M,5}$	✔	✔	✔		✔
$f_{T,0}$, $f_{T,1}$, $f_{T,2}$	✔	✔	✔	✔	✔
$f_{T,5}$, $f_{T,6}$, $f_{T,7}$	✔	✔	✔		✔
$f_{T,8}$, $f_{T,9}$	✔	✔			

Phys. Lett. B 793 (2019) 469

Observation of EW WZ(lllν) + 2 j

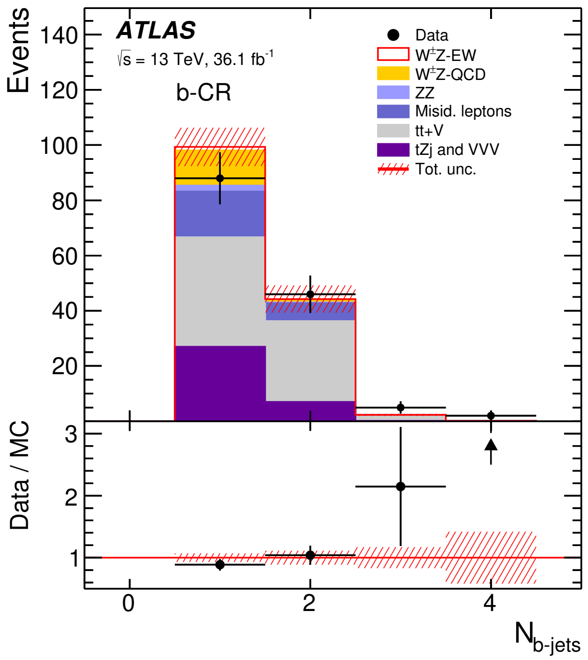
- **Selection:**
  - **3 leptons (e/μ) with p_T > 15 GeV and |η| < 2.5**
    - at least one with 25(27) p_T threshold in 2015(2016) data
  - **Z selection**: $|M_{ll} - M_Z^{PDG}| < 10$ GeV
  - **W selection**: p_T > 20GeV + tighter quality cuts, $m_T(W)$>30 GeV
  - **Jets:** 2 jets with p_T>40 GeV, |η| <4.5, η of opposite sign, m_{jj}>150 GeV





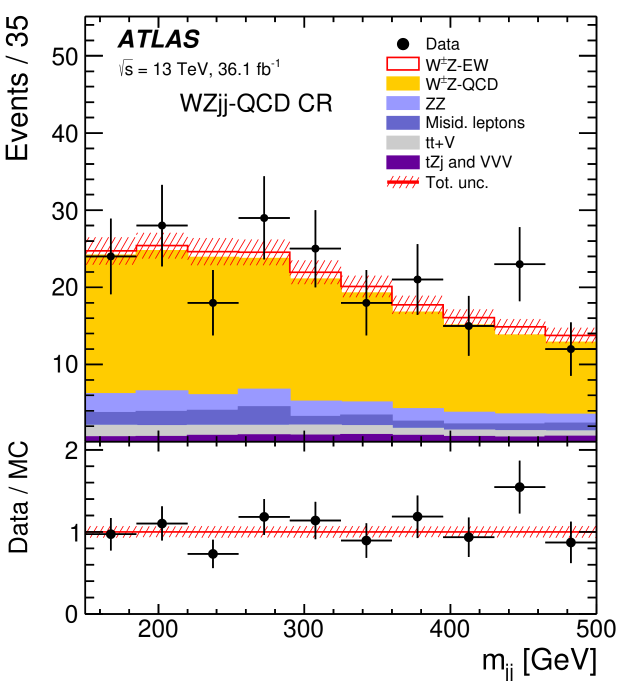
- **Signal and backgrounds:**
  - **EW WZjj** (Sherpa 2.2.2)
  - **QCD WZjj**: **main background**, MC (Sherpa 222) normalised in CR
  - **Misidentified leptons (Z+jets, Zγ, (tt)‾, Wt,WW)**: data-driven
  - ZZ QCD+EW: MC (Sherpa 222), normalised in CR
  - ttV: MC (MadGraph5), normalised in CR
  - **tZ, VVV**: MC (MadGraph5, Sherpa 2.1)

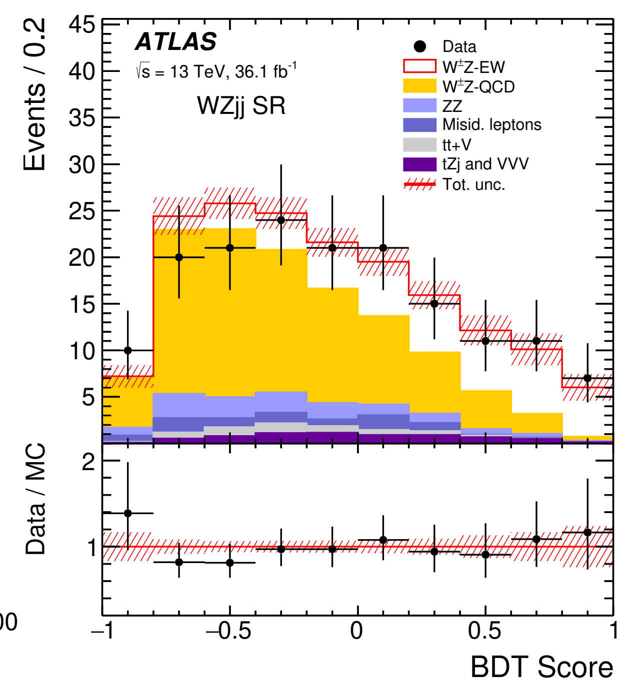
Analysis strategy

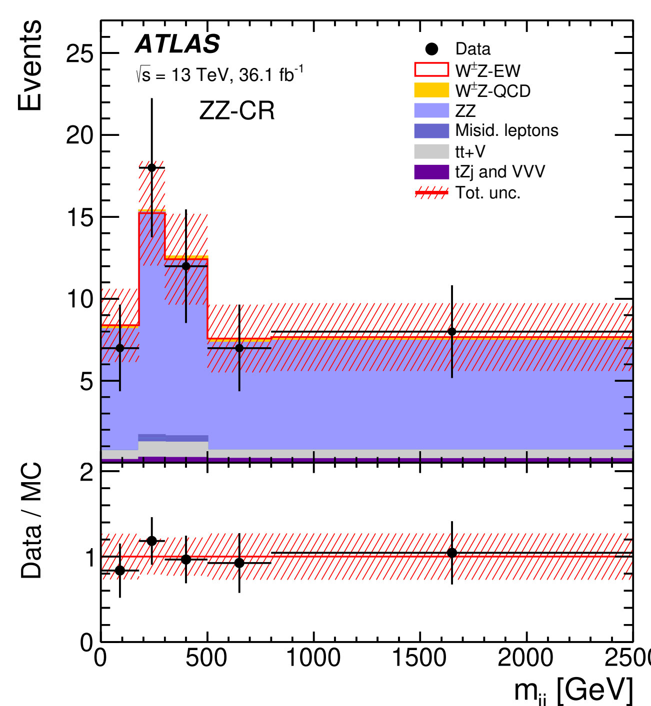


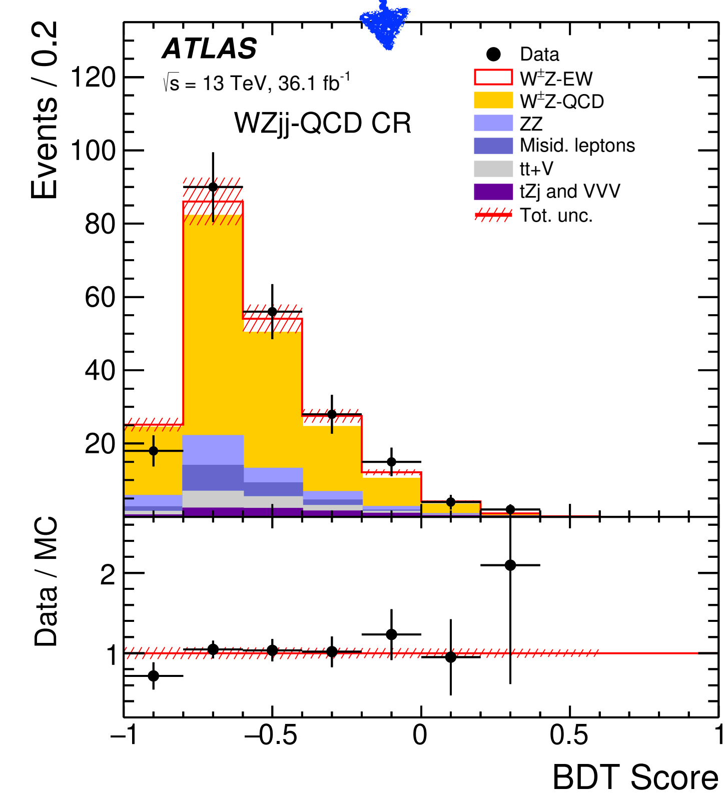
b-control region:
N_{bjet}>0
To normalise ttbarV

- **3 orthogonal regions + 1 ZZ CR**
- **BDT discriminant used in signal region to extract XS (15 variables)**
  - Description of BDT score controlled in QCD-CR
- **Combined fit on the SR + 3CRs** to extract simultaneously the background and signal normalisations









QCD control region:
m_{jj}<500 GeV, N_{bjet}=0

Search region:
m_{jj}>500 GeV, N_{bjet}=0
For cross section measurement WZjj EW

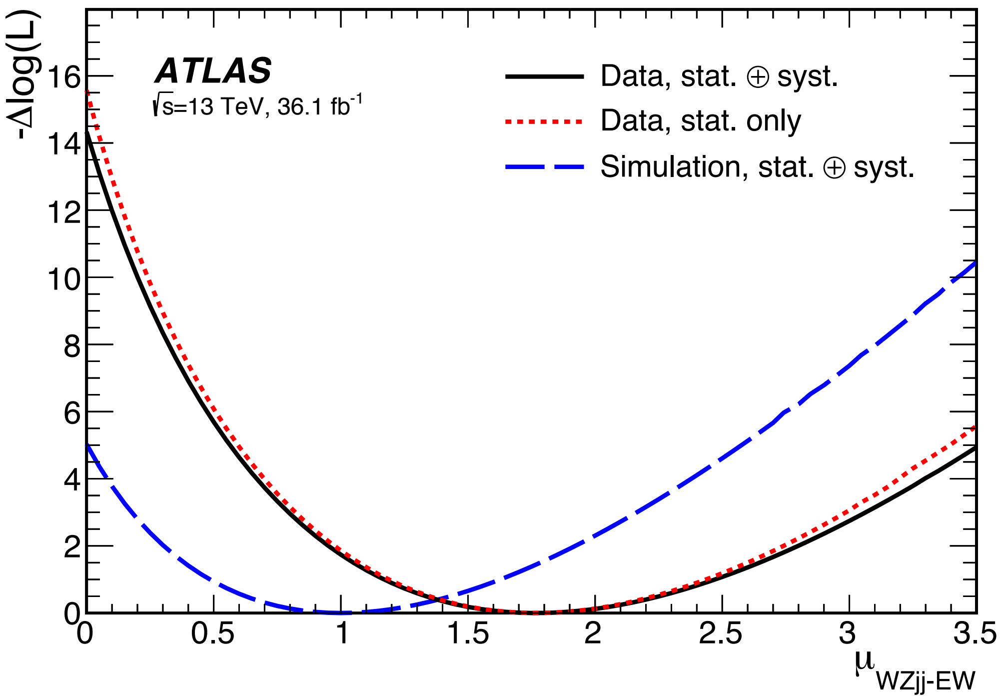
ZZ-CR
4 loose leptons
(reverting ZZ veto)

Post-fit distribution

EWjj cross-section results

- **Result on mu:**

$$\mu_{WZjj-\mathrm{EW}} = 1.77\ ^{+0.44}_{-0.40}\,(\mathrm{stat.})\ ^{+0.15}_{-0.12}\,(\mathrm{exp.\ syst.})\ ^{+0.15}_{-0.12}\,(\mathrm{mod.\ syst.})\ ^{+0.04}_{-0.02}\,(\mathrm{lumi.}) = 1.77\ ^{+0.49}_{-0.43}$$



5.3σ observed
(3.2σ expected)

Main systematics from:
jet (6.6%),
QCD theory modelling (5.2%)
EW theory modelling (4.8%),

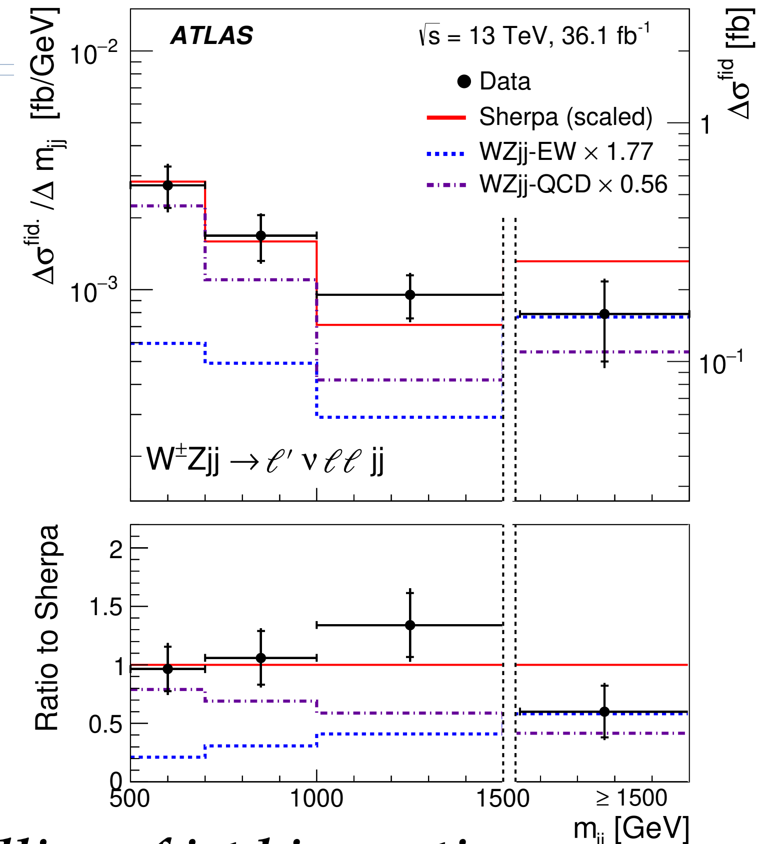
Process	Fitted normalisation
$WZjj$-QCD	0.56 ± 0.16
$t\bar{t}+V$	1.07 ± 0.23
ZZ-QCD	1.34 ± 0.24

- **Observed WZjj-EW cross-section and comparison with SM LO prediction from Sherpa and MadGraph**

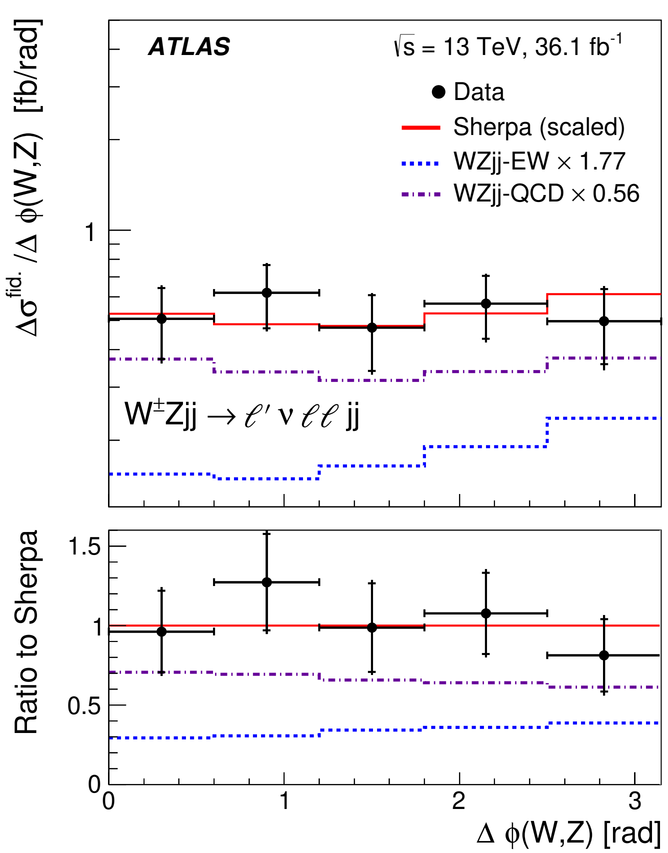
	Cross section in fb
$\sigma^{fid}_{WZjj-EW}$	$0.57\ ^{+0.14}_{-0.13}$ (stat) $^{+0.05}_{-0.04}$ (exp.syst.) $^{+0.05}_{-0.04}$ (mod.syst.) $^{+0.01}_{-0.01}$ (lumi)
$\sigma^{fid,Sherpa}_{WZjj-EW}$	0.321 ± 0.002 (stat) ± 0.005 (PDF) $^{+0.027}_{-0.023}$ (scale)
$\sigma^{fid,MadGraph}_{WZjj-EW}$	0.366 ± 0.004 (stat)

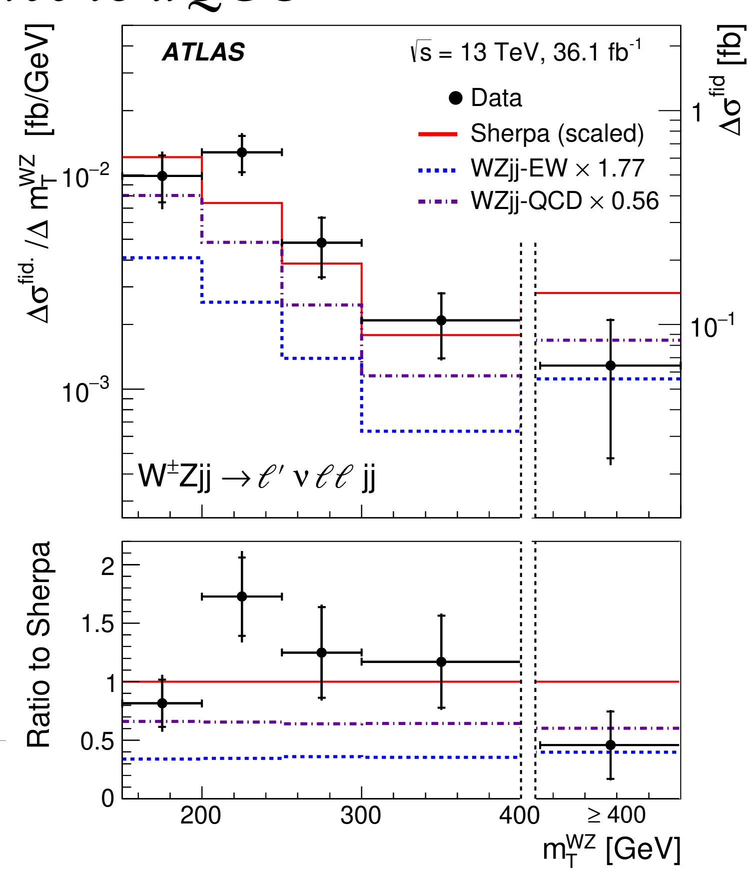
Differential cross-sections

- **Differential cross section computed in the SR (dominated by QCD)**
  - iterative Bayesian unfolding method
  - Sherpa QCD and EW prediction normalised by their corresponding μ
- **Two categories of variables:**
  - **Sensible to aQGCs**: $m_T(WZ)$, $\sum p_T^l$, $\Delta\phi(W,Z)$
  - **Constraining jets kinematic in MC :** N_{jets}, m_{jj}, $\Delta\phi(j_1,j_2)$, $\Delta y(j_1,j_2)$, N_{jets}^{gap} (p_T>25 GeV)

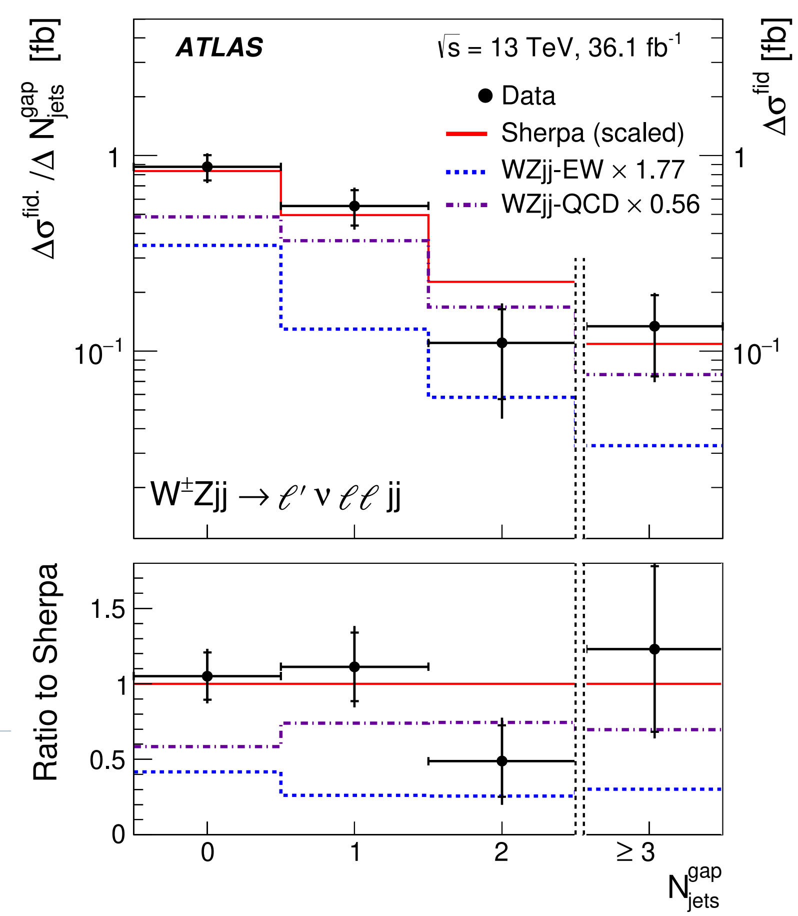


Variables sensitive to aQGC



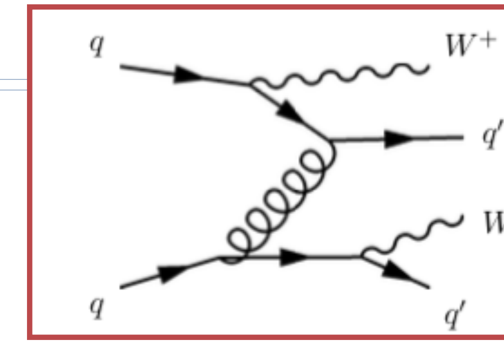


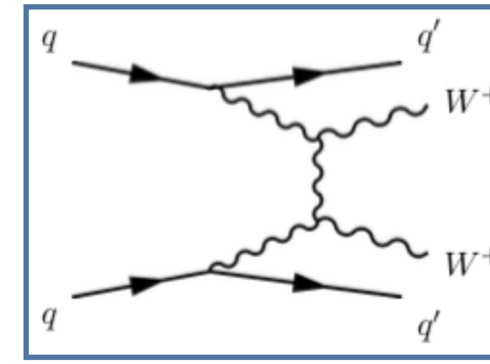
MC modelling of jet kinematics

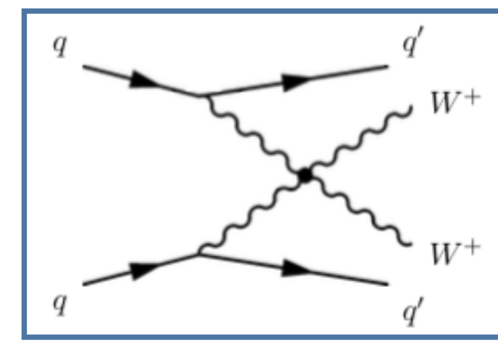


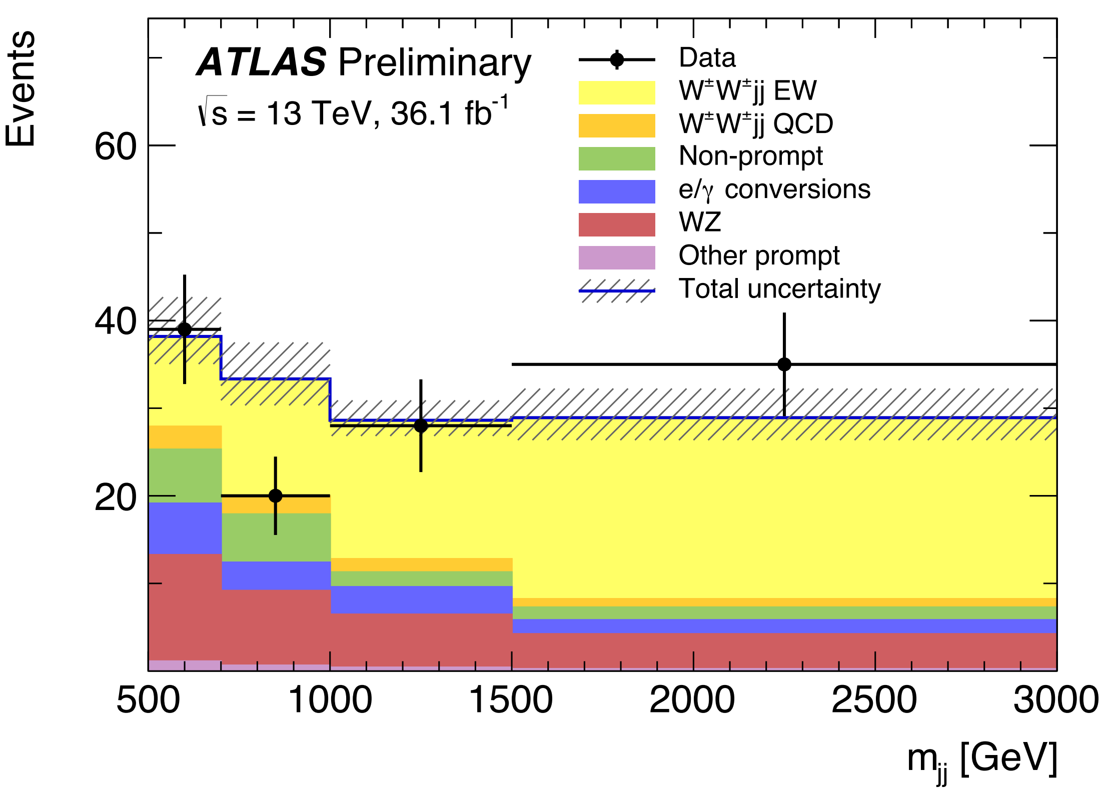
Observation of EW W±W±jj

- **Strong production** doest not dominate the **EW** one + same sign leptons in final state reducing other backgrounds —> **golden channel**
- **Selection:**
  - **2 leptons with pT>27 GeV**, E_T^{miss}> 30 GeV, m_{ll}> 40 GeV
    - Events with |m_{ee}-91.2|<15 GeV removed for |η|<1.37 (reduce electron charge misID)
  - **Jets** with p_T >65, 35 GeV , m_{jj}> 200 GeV, |ΔY|>2
    - Events with >=1 b-tagged jet rejected (reduce ttbar background)
  - **Signal region:** m_{jj}> 500 GeV (4 bins)
    - Region 200<m_{jj}<500 GeV used as CR (1 bin)







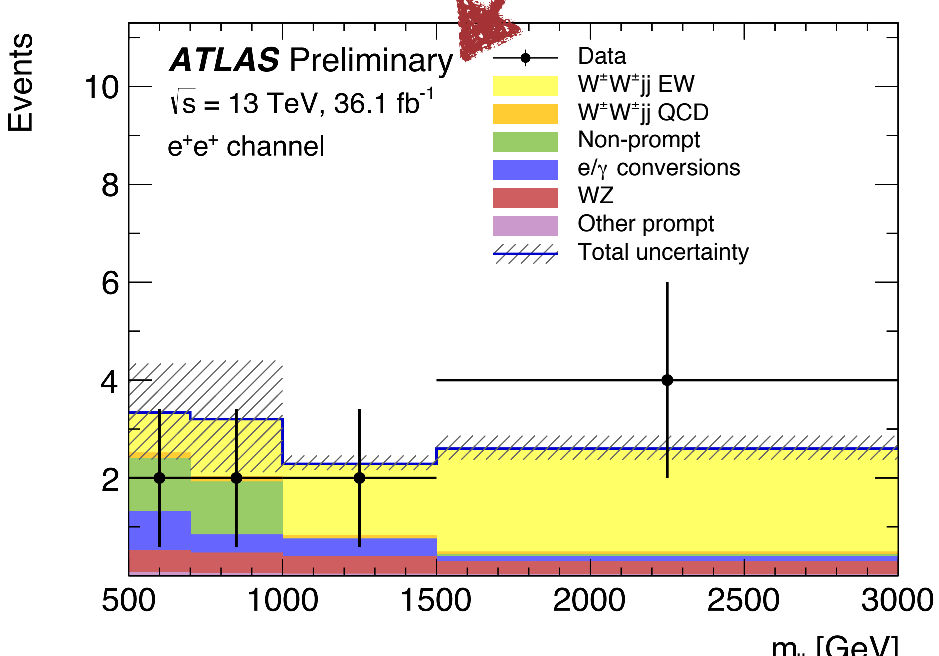


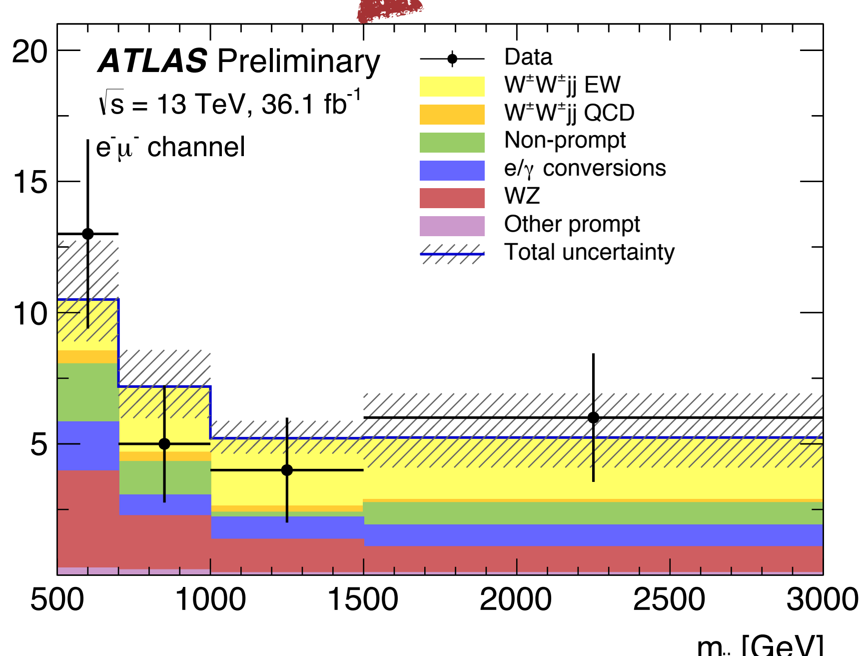
- **Backgrounds:**
  - **WWjj QCD** : MC (Sherpa 222)
  - **Non-prompt** (ttbar, W+jets): data-driven
  - **e/γ conversion** :
    - Charge misID: data-driven estimate
    - Wγ, Zγ: MC (Sherpa 2.1), pre-normalised in CR
  - **WZ:** MC (Sherpa 222), normalised from CR
  - **Other prompt**: MC (Sherpa 222 for VVV and ZZ, MadGraph5 for ttV)

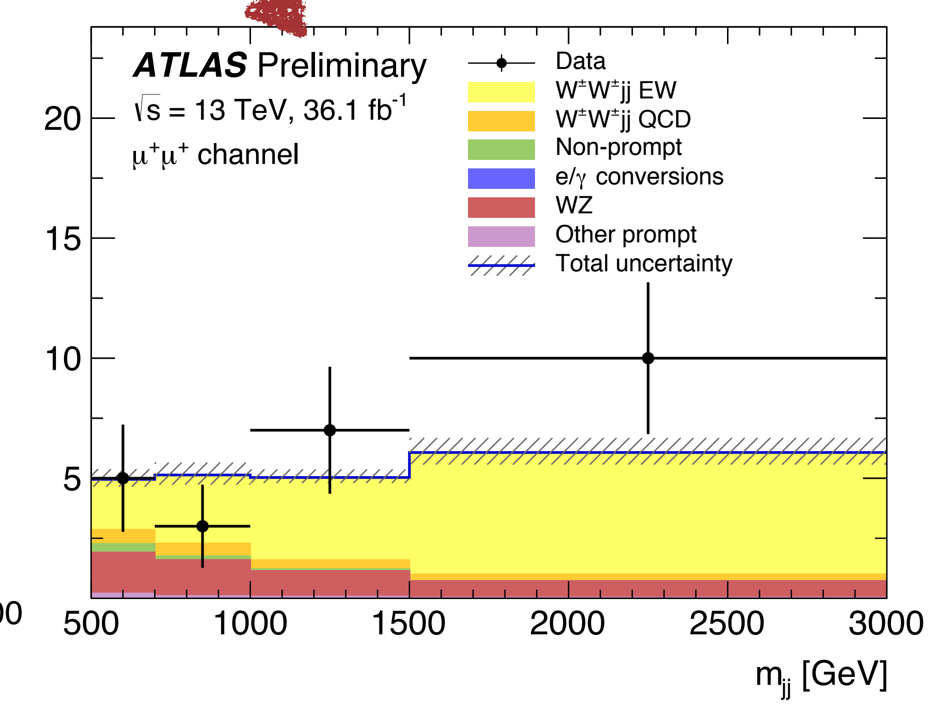
Event yield in channels

- **Events categorised in 6 channels (lepton flavour and charge)**
- **30 bins combined in likelihood fit to extract EW ssWW cross-section** (5 bins of m_{jj} x 6 channels)
  - + WZ control region (1 bin) with 1 WZ free norm. parameter

	e^+e^+	e^-e^-	$e^+\mu^+$	$e^-\mu^-$	$\mu^+\mu^+$	$\mu^-\mu^-$	combined
WZ	1.7 ± 0.6	1.2 ± 0.4	13 ± 4	8.1 ± 2.5	5.0 ± 1.6	3.3 ± 1.1	32 ± 9
Non-prompt	4.1 ± 2.4	2.3 ± 1.8	9 ± 6	6 ± 4	0.57 ± 0.16	0.67 ± 0.26	23 ± 12
e/γ conversions	1.74 ± 0.31	1.8 ± 0.4	6.1 ± 2.4	3.7 ± 1.0	-	-	13.4 ± 3.5
Other prompt	0.17 ± 0.06	0.14 ± 0.05	0.90 ± 0.24	0.60 ± 0.25	0.36 ± 0.12	0.19 ± 0.07	2.4 ± 0.5
$W^\pm W^\pm$jj strong	0.38 ± 0.13	0.16 ± 0.06	3.0 ± 1.0	1.2 ± 0.4	1.8 ± 0.6	0.76 ± 0.26	7.3 ± 2.5
Expected background	8.1 ± 2.4	5.6 ± 1.9	32 ± 7	20 ± 5	7.7 ± 1.7	4.9 ± 1.1	78 ± 15
$W^\pm W^\pm$jj electroweak	3.80 ± 0.30	1.49 ± 0.13	16.5 ± 1.2	6.5 ± 0.5	9.1 ± 0.7	3.50 ± 0.29	40.9 ± 2.9
Data	10	4	44	28	25	11	122

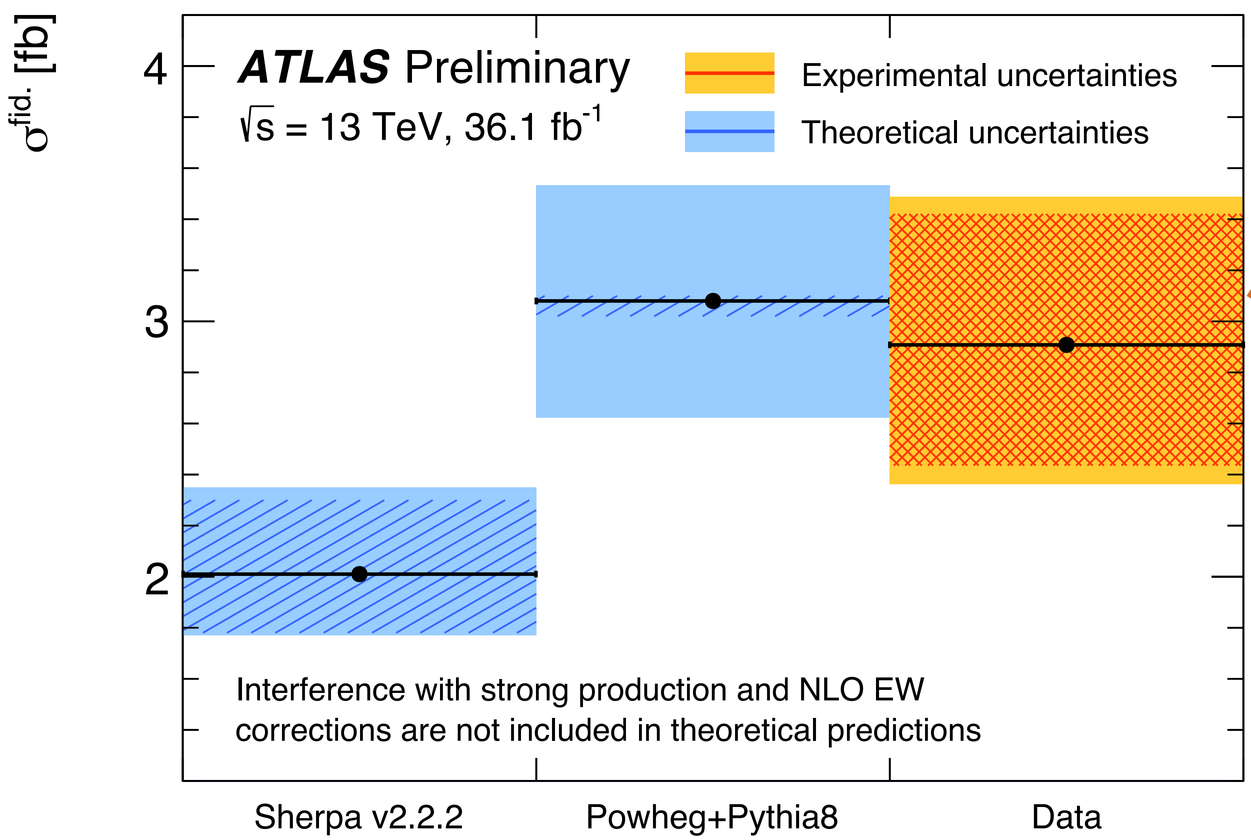






Results

$$\mu_{EW} = 1.45^{+0.25}_{-0.24}(\text{stat})^{+0.13}_{-0.14}(\text{sys})$$



6.9σ observed
(4.6σ expected)

WZ norm. parameter: 0.88

- **Dominant systematic uncertainties:**
  - **Backgrounds:**
    - Non-prompt lepton: 50% μμ, 40-90% ee, eμ
    - Electron charge misID: 10-20%
    - Theoretical modelling for ZZ, Vγ, triboson, ttV = 20-30%
  - **Object syst:**
    - JES (2% for signal and 10% for WZ)

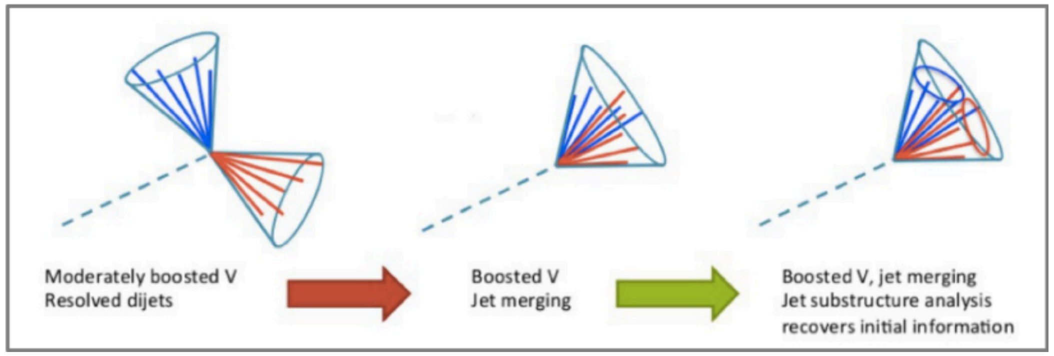
	Cross section in fb
σ^{fid}_{WWjj}	$2.91^{+0.51}_{-0.47}$ (stat) $\pm$ 0.27 (syst) fb
$\sigma^{fid,Sherpa}_{WWjj}$	$2.01^{+0.33}_{-0.23}$ (stat+syst) fb
$\sigma^{fid,Powheg}_{WWjj}$	$3.08^{+0.45}_{-0.46}$ (stat+syst) fb

Note: Complete NLO (QCD+EW) corrections to ssWWjj EW calculated (arXiv:1708.00268)
σ^{NLO}= 1.69 fb
-> decrease of 16% compared to Sherpa 222

VV (WW, ZZ, WZ) semileptonic

Submitted to PRD
arXiv:1905.07714

- 3 channels : ZV->ννqq (0-lept), WV->lνqq (1-lept), ZV ->llqq (2 lept)
- 2 techniques for V->qq:
  - **resolved**: identify 2 small-radius jets (j)
  - **merged**: jet substructure large radius jet (J).



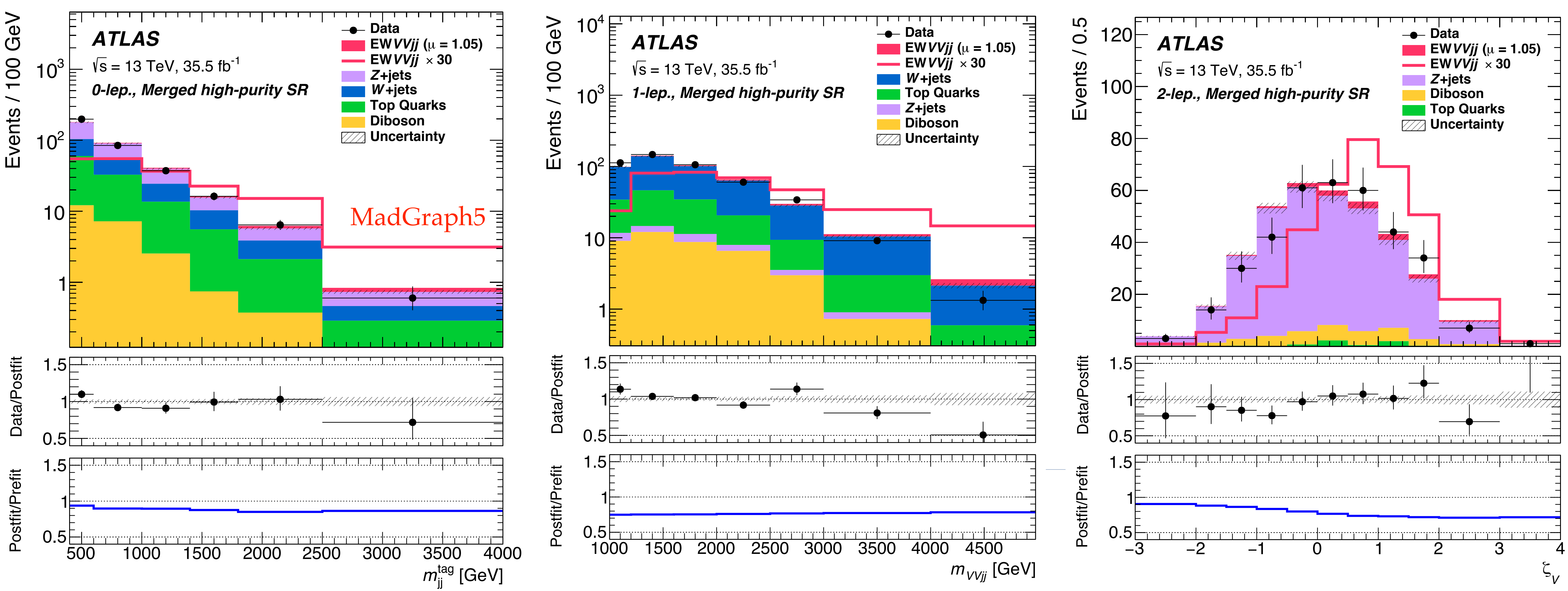
- **Channel interesting because strong production is small for all channels.**
- **Selection**: Vlept+Vhad+ 2 tagging jets (small-R)

Selection	0-lepton	1-lepton	2-lepton
Leptons	0 'loose' leptons with $p_T > 7$ GeV	1 'tight' lepton with $p_T > 27$ GeV 0 'loose' leptons with $p_T > 7$ GeV	2 'loose' leptons with $p_T > 20$ GeV ≥ 1 lepton with $p_T > 28$ GeV
E_T^{miss}	> 200 GeV	> 80 GeV	–
$m_{\ell\ell}$	–	–	$83 < m_{ee} < 99$ GeV $-0.0117 \times p_T^{\mu\mu} + 85.63 < m_{\mu\mu} < 0.0185 \times p_T^{\mu\mu} + 94$ GeV
Small-R jets	$p_T > 20$ GeV if $\|\eta\| < 2.5$, and $p_T > 30$ GeV if $2.5 < \|\eta\| < 4.5$		
Large-R jets	$p_T > 200$ GeV, $\|\eta\| < 2$		
$V_{had} \to J$ $V_{had} \to jj$	V boson tagging, $\min(\|m_J - m_W\|, \|m_J - m_Z\|)$ $64 < m_{jj} < 106$ GeV, jj pair with $\min(\|m_{jj} - m_W\|, \|m_{jj} - m_Z\|)$, leading jet with $p_T > 40$ GeV		
Tagging-jets	$j \notin V_{had}$, not b-tagged, $\Delta R(J, j) > 1.4$ $\eta_{tag,j_1} \cdot \eta_{tag,j_2} < 0$, $m_{jj}^{tag} > 400$ GeV, $p_T > 30$ GeV		
Num. of b-jets	–	0	–

+ p_T^{miss} selection and angular selection (0-lepton) to suppress Multijet background

Main Backgrounds, control regions

- Shape of kinematic variables taken from MC in almost all cases
- **0-lepton category:**
  - all backgrounds important -> **VjjCR** from mass window of Vhad
- **1-lepton category:**
  - **W+jet** (Sherpa 2.1)-> **WCR** by reverting invariant mass requirement of Vhad
  - **ttbar** (PowhegBox v2)-> **TopCR** by reverting b-jet requirement
- **2-lepton category:**
  - **Z+jet** dominant (Sherpa 2.2.1)-> **ZCR** by reversing m_J or m_{jj} requirement

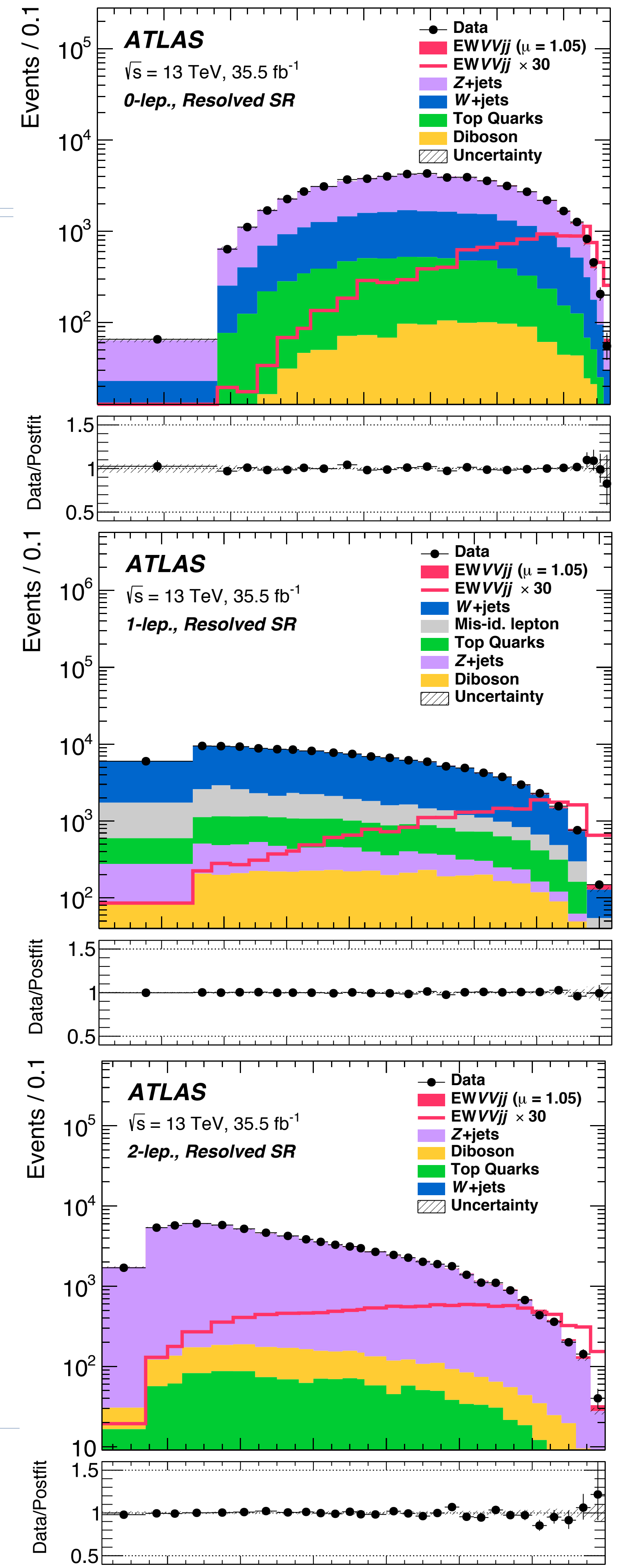


Analysis strategy

BDT distribution in the 3 channels Resolved jets

- **21 regions fitted simultaneously**
  - **9 signal region**: 0,1,2 lept x (resolved, low purity merged, high purity merged)
    - high purity (HP): pass 50% boson tagger working point (WP)
    - low purity (LP): pass 80% boson tagger WP requirement but fail 50%
  - **12 control regions**: ZCR, WCR, TopCR, VjjCR for the 3 lepton channels
- **Distribution used in the global likelihood:**
  - BDT in signal regions
  - m_{jj} or unique bin histograms for CRs
- **BDT trained in each channel and region separately**
- **Main systematics:**

Category	Systematic	Size
Jets	small-R jet pT	6-2% (low-high pT)
	small-R jet resolution	10-20% (low-high pT)
	large-R jet pT	2-5% (low-high pT)
	large-R jet resolution	20-15% (low-high pT)
Backgrounds norm	VVjj QCD	30%
	single-top	20%
	Z+jets	22(42)% in merged (resolved)
	W+jets	8(14)% in merged (resolved)
EW VVjj modelling	PDF, PS, QCD scale	3-5%, 1-5%, 1-3%
	Interference shape and norm	5-10%
Discriminant modelling		5-30%

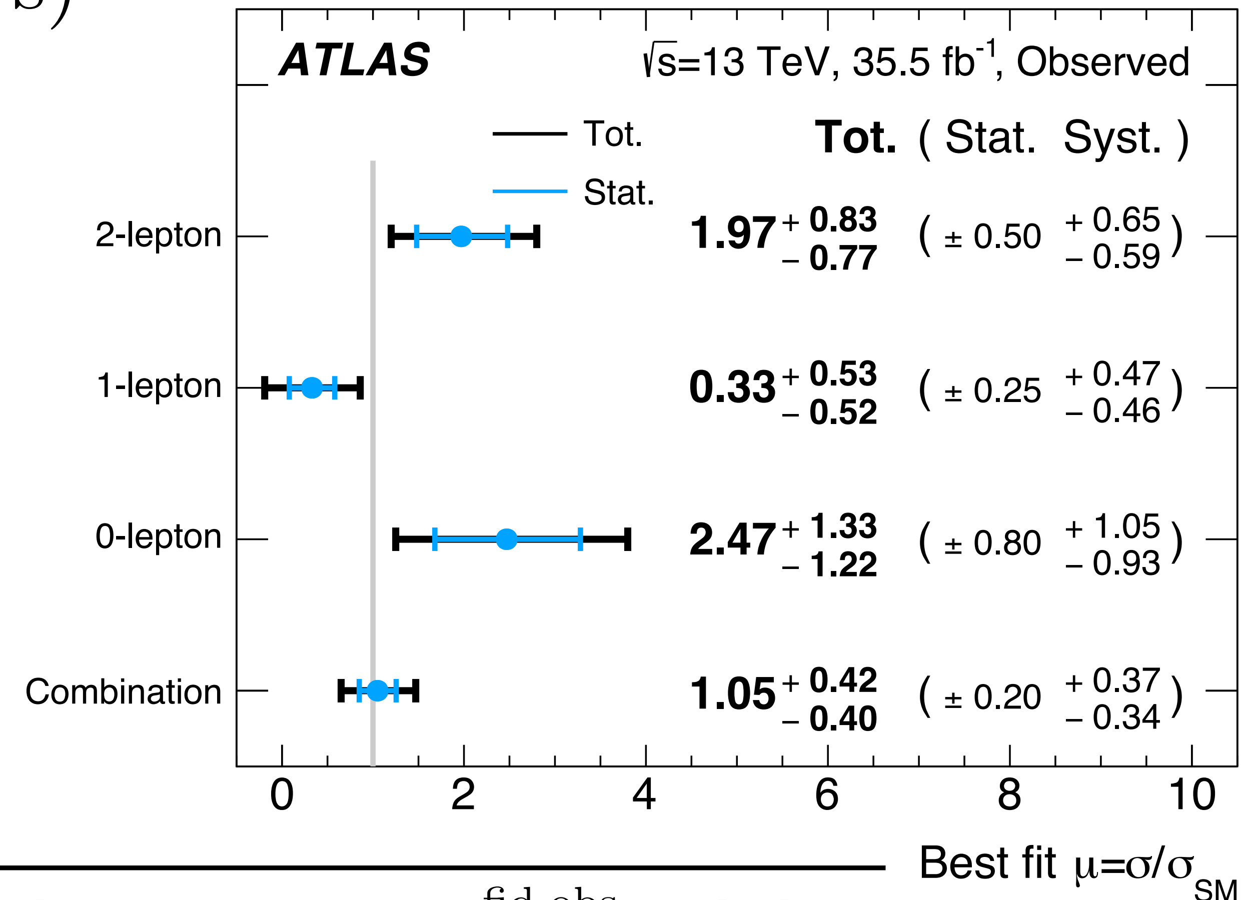


Results

$$\mu_{EW} = 1.05 \pm 0.20(\text{stat})^{+0.37}_{-0.34}(\text{sys})$$

2.7σ observed
(2.5σ expected)

Good compatibility between different channels (prob. that there are compatible = 36%)



- Cross section prediction from MadGraph5_aMC@NLO 2.4.3 at LO

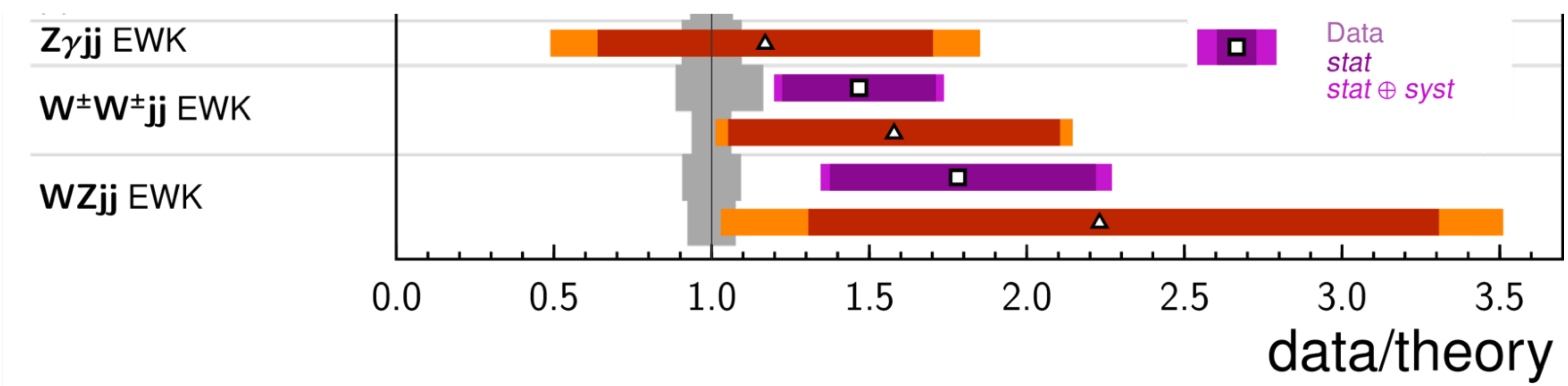
- Cross-section measurements:

Fiducial phase space	Predicted $\sigma^{\text{fid,SM}}_{\text{EW}\,VVjj}$ [fb]	Measured $\sigma^{\text{fid,obs}}_{\text{EW}\,VVjj}$ [fb]
Merged	11.4 ± 0.7 (theo.)	12.7 ± 3.8 (stat.) $^{+4.8}_{-4.2}$ (syst.)
Resolved	31.6 ± 1.8 (theo.)	26.5 ± 8.2 (stat.) $^{+17.4}_{-17.1}$ (syst.)
Inclusive	43.0 ± 2.4 (theo.)	45.1 ± 8.6 (stat.) $^{+15.9}_{-14.6}$ (syst.)

Conclusions

- **VBS processes = last corner of Standard Model to be explored**
  - Cross-section ~1-10fb, measurements dominated by stat. error (except for VV semilept, huge systematic uncertainties)
- **Dominant uncertainties generally from theory modelling** -> needs for more precise predictions
- **Differential cross-section in EW VV enriched region provided for the first time**
- **Start including EW NLO corrections** -> tends to reduce predicted cross-section

Data/Theory cross-section ratio of selected VV EW processes
(8 TeV and 13 TeV)



Excess in all channels (w/o NLO EW corrections)
Analysis of full Run2 data will bring a lot of new interesting results !

Back-up

Systematic uncertainties

- **Object-related systematics mostly coming from jet reconstruction and calibration**
- **Conservative normalisation uncertainties applied on non-dominant background**
  - 40% for reducible (misid. leptons) background
  - 20% for VVV
  - 15% for tZj
- **Theory uncertainties:**
  - **QCD scale:** vary renormalisation and factorization scale by 0.5 and 2
    - 20% to 30% effect in QCD, 5% for EW
  - **PDF and α_s:** standard PDF4LHC description:
    - Small effect (1-2%)
  - **Signal modelling (including parton shower)**
    - shape difference on the BDT templates between Sherpa and MadGraph
      - Up to 14% effect
  - **Modelling uncertainty for QCD**
    - shape difference on the BDT templates between Sherpa and MadGraph
      - 5-20% effect

Post-fit uncertainties on the cross-section

Source	Uncertainty [%]
$WZjj$–EW theory modelling	4.8
$WZjj$–QCD theory modelling	5.2
$WZjj$–EW and $WZjj$–QCD interference	1.9
Jets	6.6
Pile-up	2.2
Electrons	1.4
Muons	0.4
b-tagging	0.1
MC statistics	1.9
Misid. lepton background	0.9
Other backgrounds	0.8
Luminosity	2.1
Total Systematics	10.7

- **Treatment of the interference**
  - **Interference impact included as shape uncertainty on signal**
  - Estimated at LO w/ MadGraph5_aMC@NLO 2.2
  - **Size of interference: +10% of EW WZjj**
    - **10-5% uncertainty (low-high BDT values)**

Multivariate analysis

Full set of variables

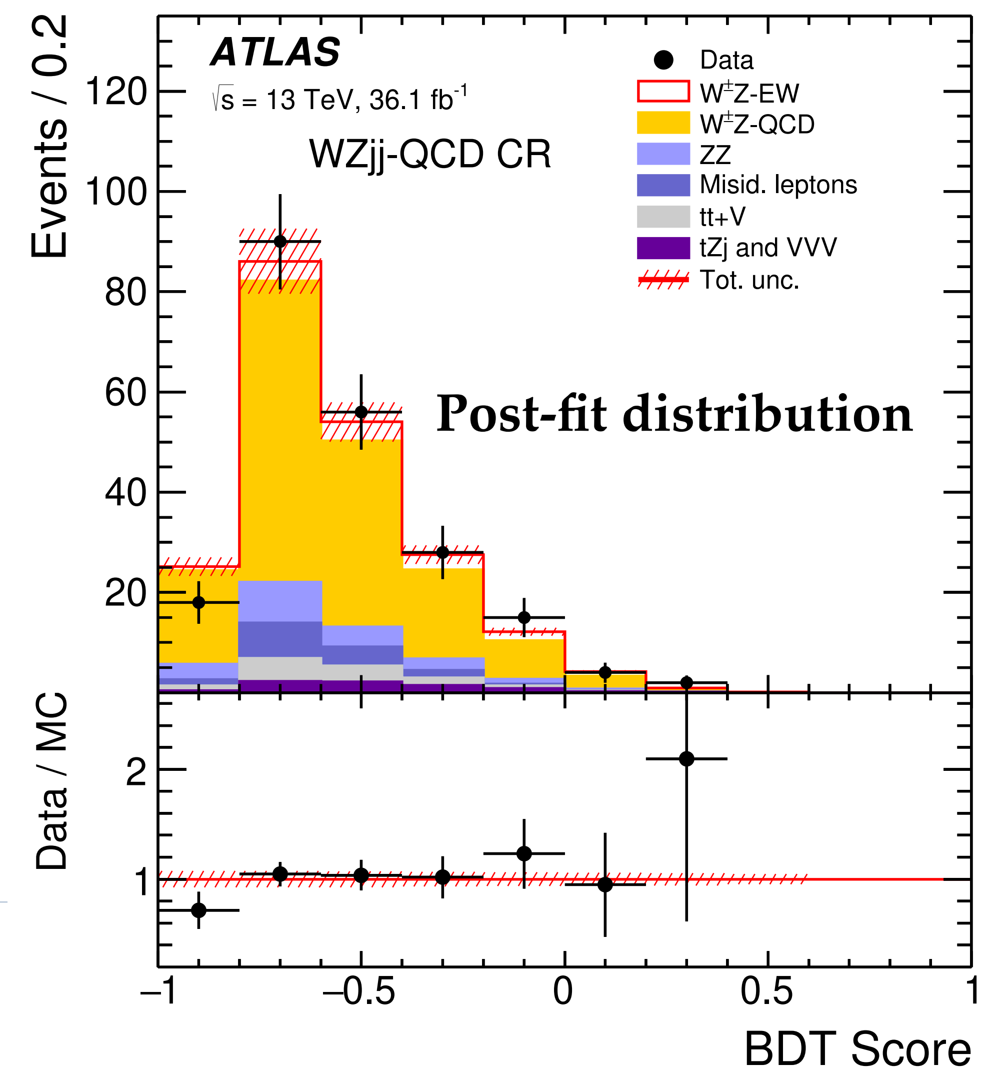
$\Delta y(\ell_W, Z)$	m_{jj}	η_W
ζ	$\Delta R(j1, Z)$	p_T^{j2}
$R_{p_T^{hard}}$	$\Delta\eta(j1, j2)$	p_T^{j1}
N_{jets}	p_T^W	m_T^{WZ}
$\Delta\phi(j1, j2)$	η_{j1}	p_T^Z

- **BDT discriminant used in signal region to extract XS**
- **BDT build from 15 discriminative variables**
  - Order of importance:
    1. $|y_Z - y_{\ell,W}|$
    2. ζ_{lep}
    3. $R_{p_T{}^{har}}$
    4. the multiplicity of jets with $p_T > 25$ GeV
    5. $\Delta\phi_{jj}$

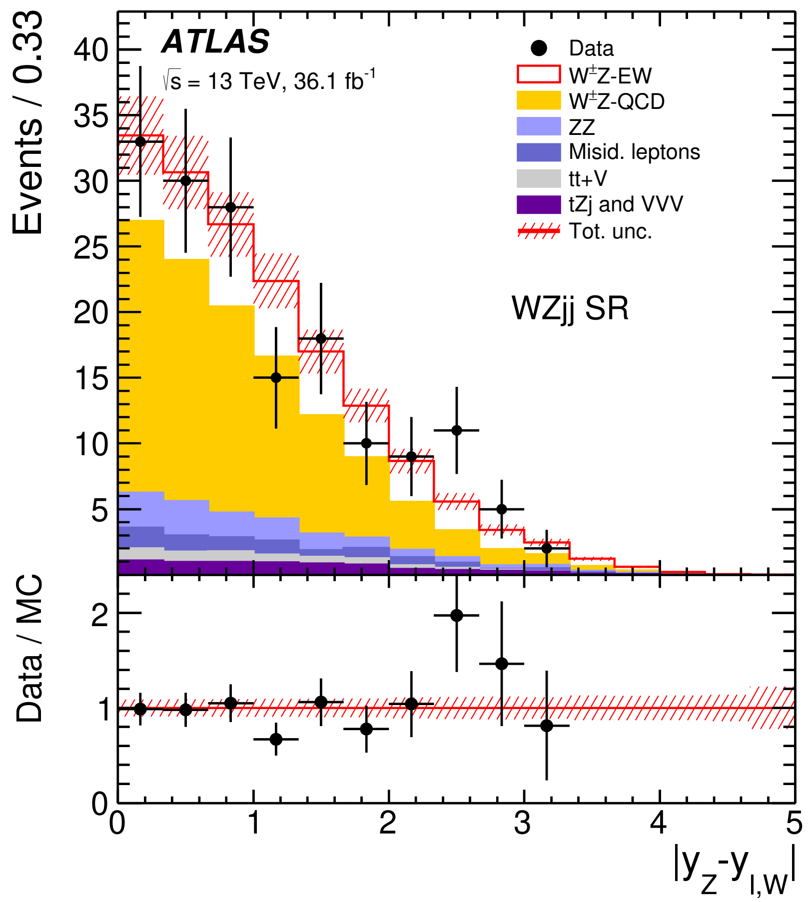
$$\zeta = min(\Delta\eta_-, \Delta\eta_+)$$
$$\Delta\eta_- = min(\eta_l^W, \eta_{l1}^Z, \eta_{l2}^Z) - min(\eta_{j1}, \eta_{j2})$$
$$\Delta\eta_+ = max(\eta_{j1}, \eta_{j2}) - max(\eta_l^W, \eta_{l1}^Z, \eta_{l2}^Z)$$

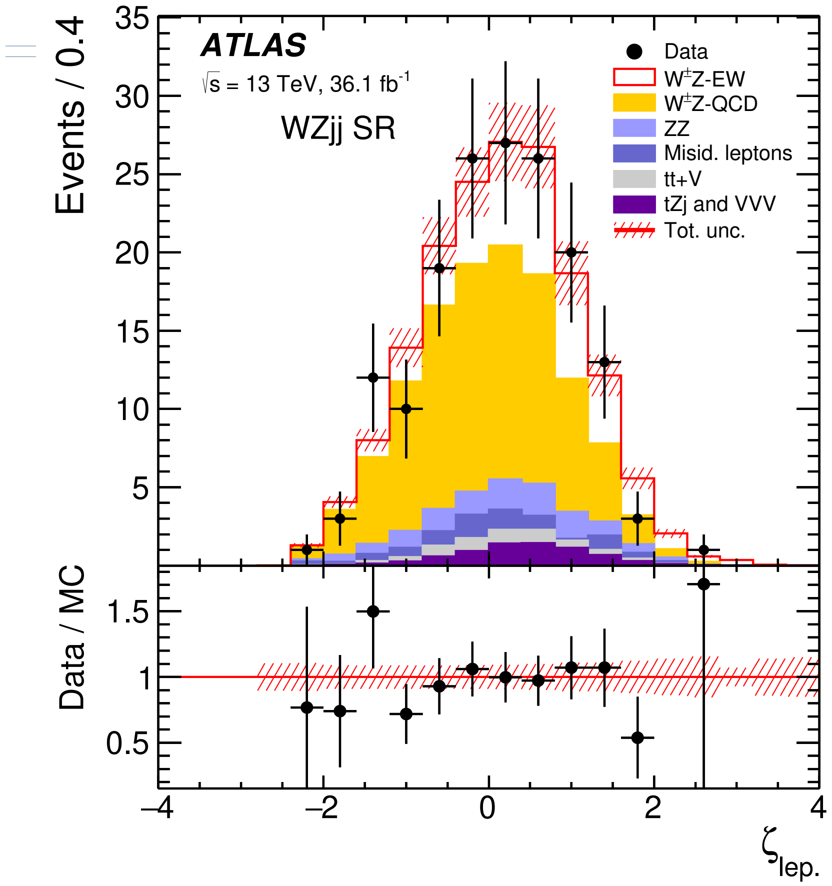
$$R_{p_T}^{hard} = \frac{\left(\sum_{l,j} p\right)_T}{\sum_{l,j} p_T}$$

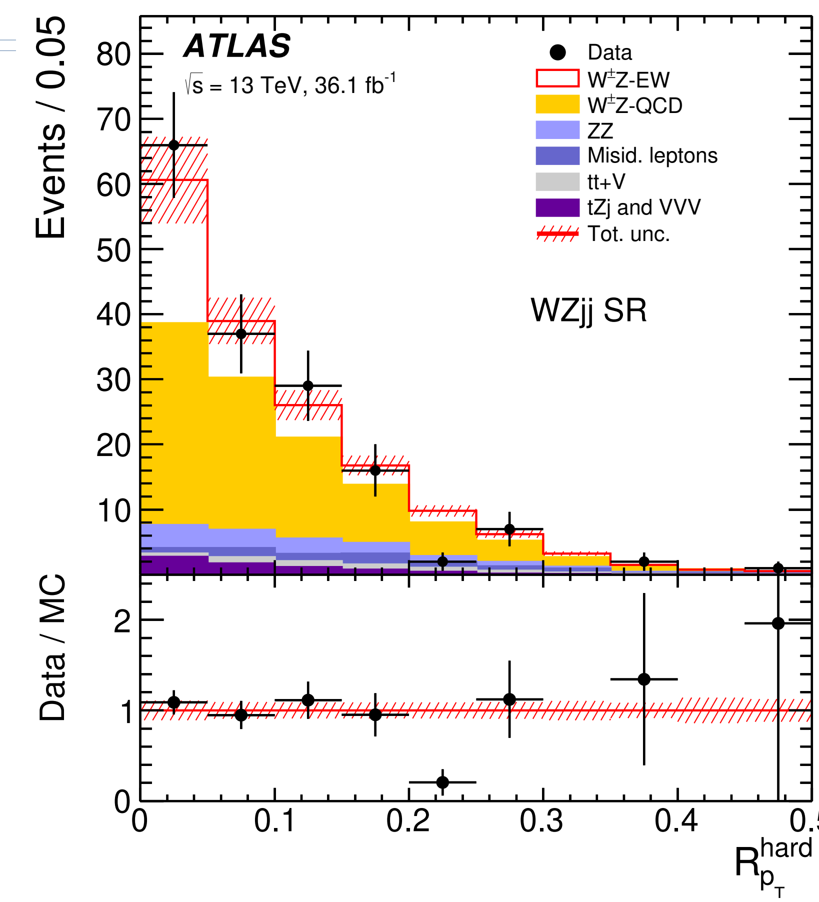
- **Trained on simulation events,** to separate WZjj-EW from backgrounds
- **Description of BDT score distribution for background and of all BDT input variables controlled in QCD-CR**
  - **good agreement observed with data.**

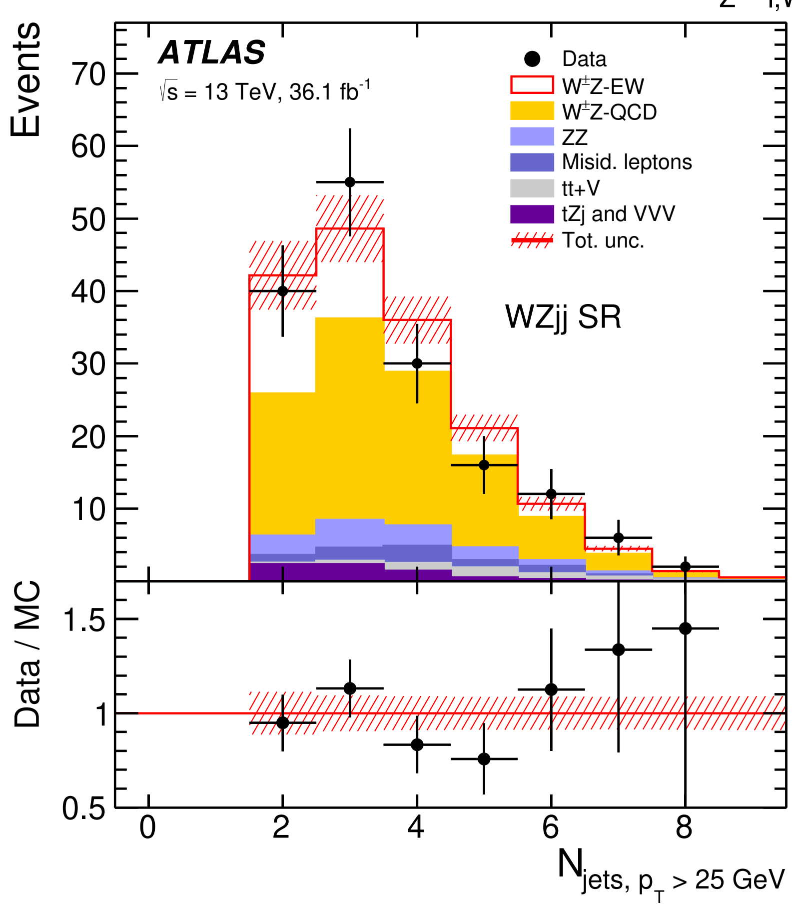


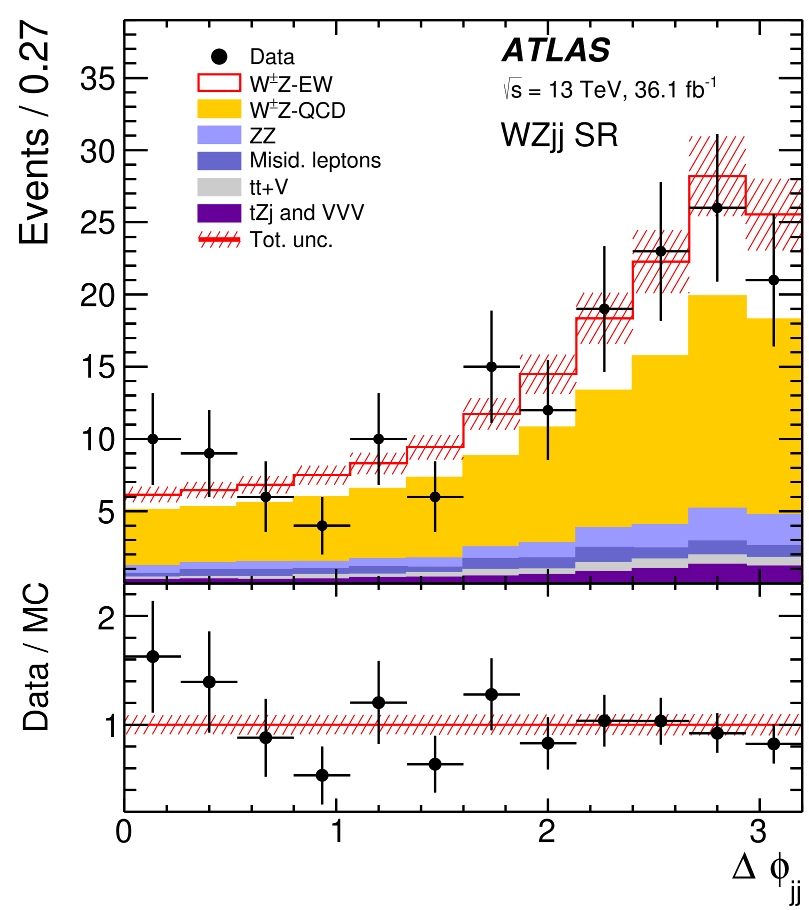
Multivariate analysis







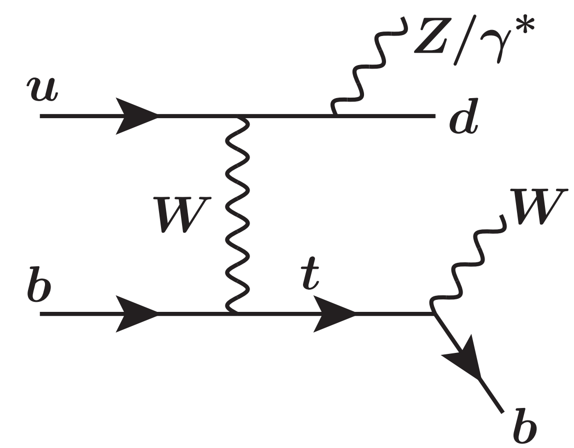




Modelling of 5 most important variables in BDT checked in SR and QCD-CR.
Post-fit distributions in SR

EW WZjj Cross-section extraction

- **Fiducial phase-space:**
  - Leptons (Z): p_T>15 GeV, |η|<2.5, |mll-mPDG|<10 GeV, ΔR(l1(Z), l2(Z))>0.2
  - Lepton(W): p_T>20 GeV, , |η|<2.5, m_T(W)>30 GeV
  - ΔR(l(W), l(Z))>0.3
  - >=2 jets anti-kt with p_T>40 GeV, |η|<4.5
  - ΔR(j,l)>0.3
  - $\eta_{j1} x \eta_{j2}$<0
  - m_{jj}>500 GeV
  - **no b-quark in initial state for signal (remove tZj)**

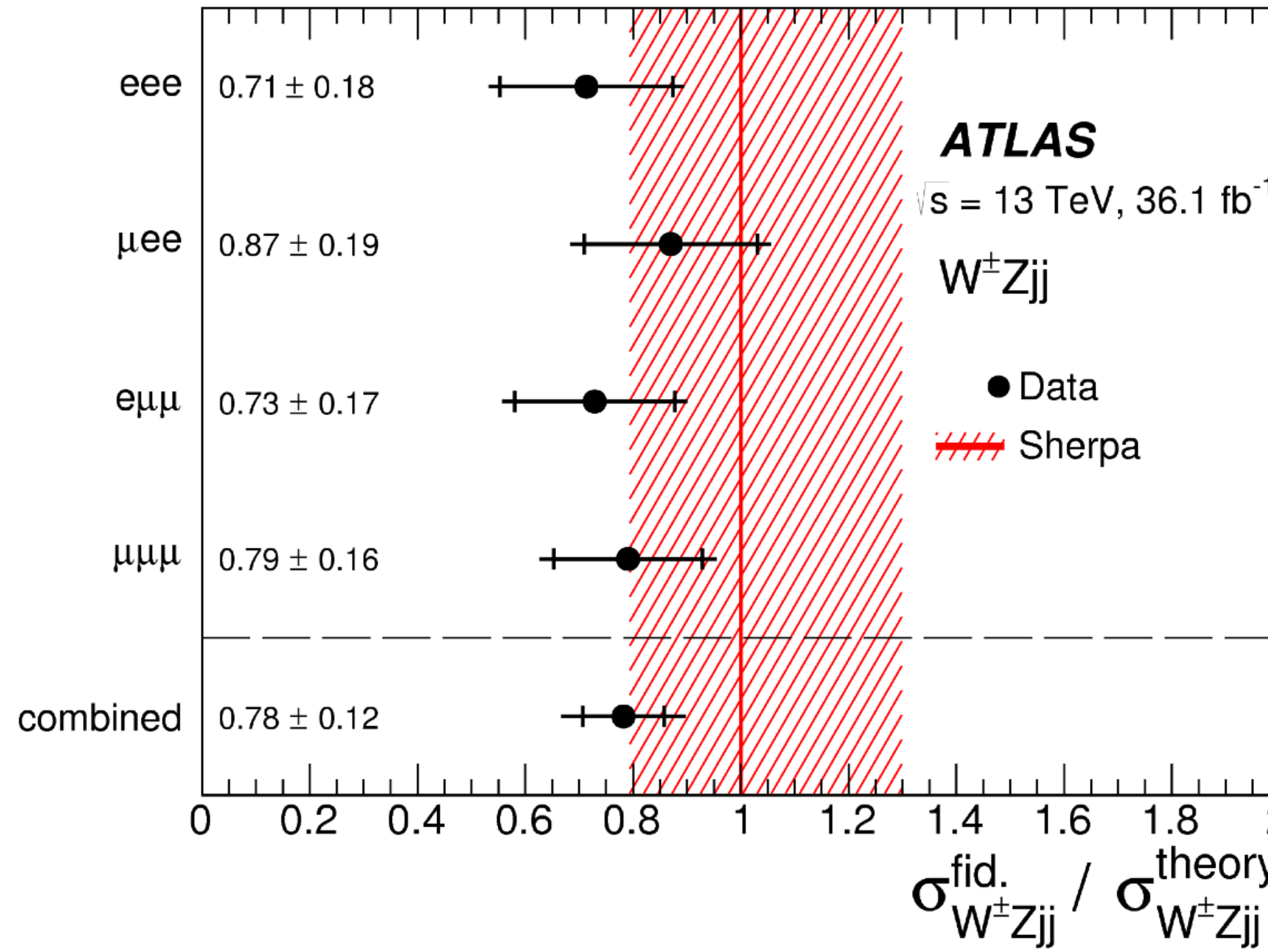


- **Observed WZjj-EW cross-section and comparison with SM LO prediction** from Sherpa and MadGraph (no interference, no EW correction)

	Cross section in fb
$\sigma^{fid}_{WZjj-EW}$	$0.57\ ^{+0.14}_{-0.13}$ (stat) $^{+0.05}_{-0.04}$ (exp.syst.) $^{+0.05}_{-0.04}$ (mod.syst.) $^{+0.01}_{-0.01}$ (lumi)
$\sigma^{fid,Sherpa}_{WZjj-EW}$	0.321 ± 0.002 (stat) ± 0.005 (PDF) $^{+0.027}_{-0.023}$ (scale)
$\sigma^{fid,MadGraph}_{WZjj-EW}$	0.366 ± 0.004 (stat)

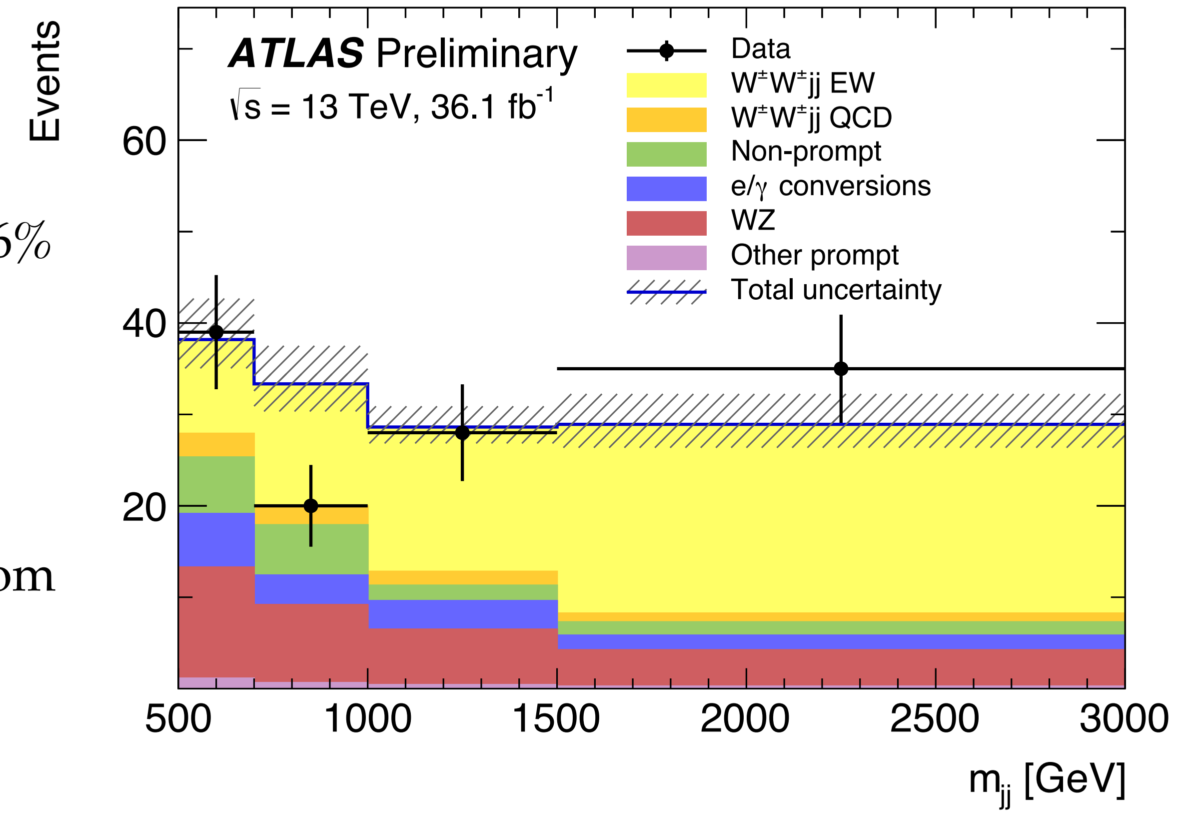
Inclusive WZjj cross section

- **Integrated WZjj cross section in same fiducial phase space**
  - obtained from number of observed events in SR
  - Using C-factor = 0.52 for WZjj
- **Good compatibility between different channels**

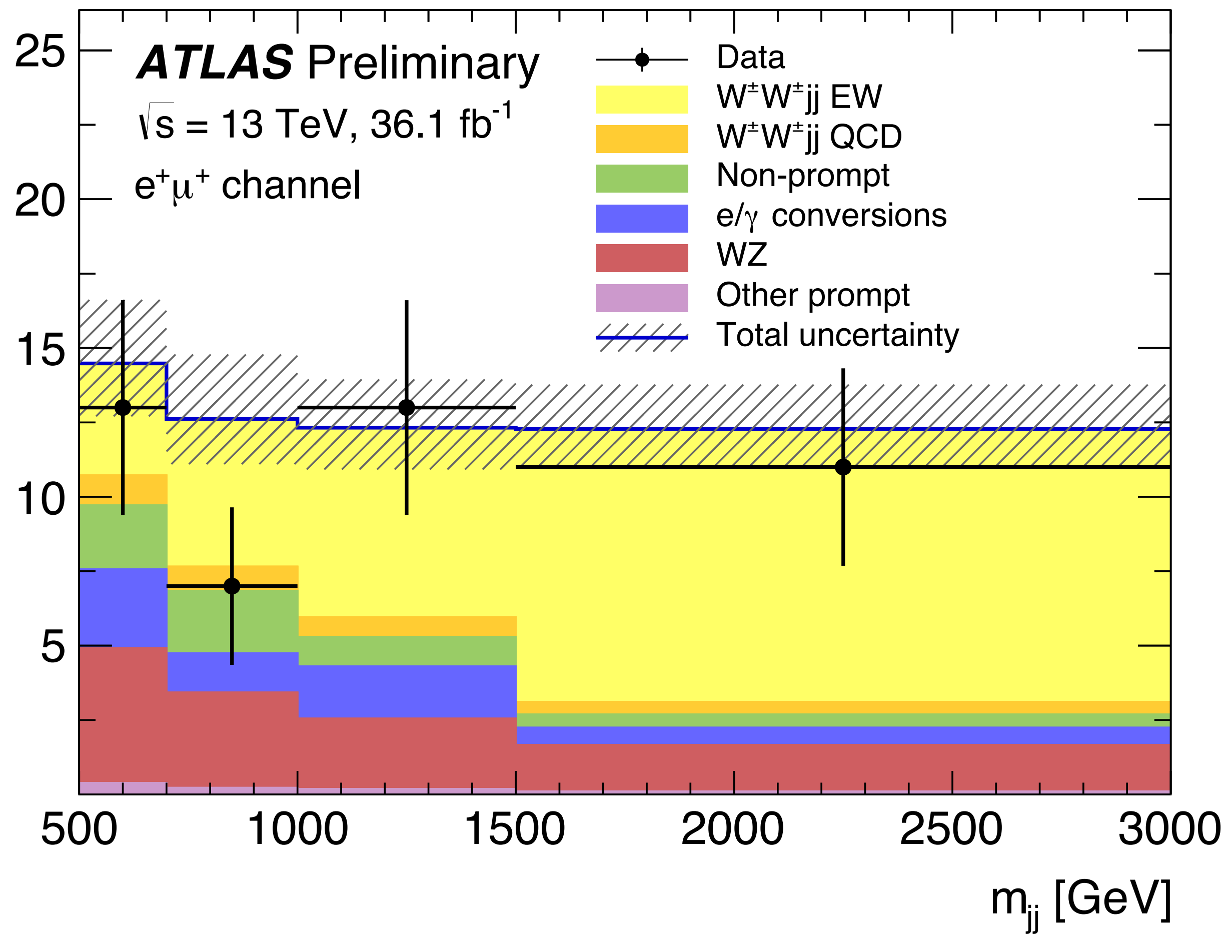


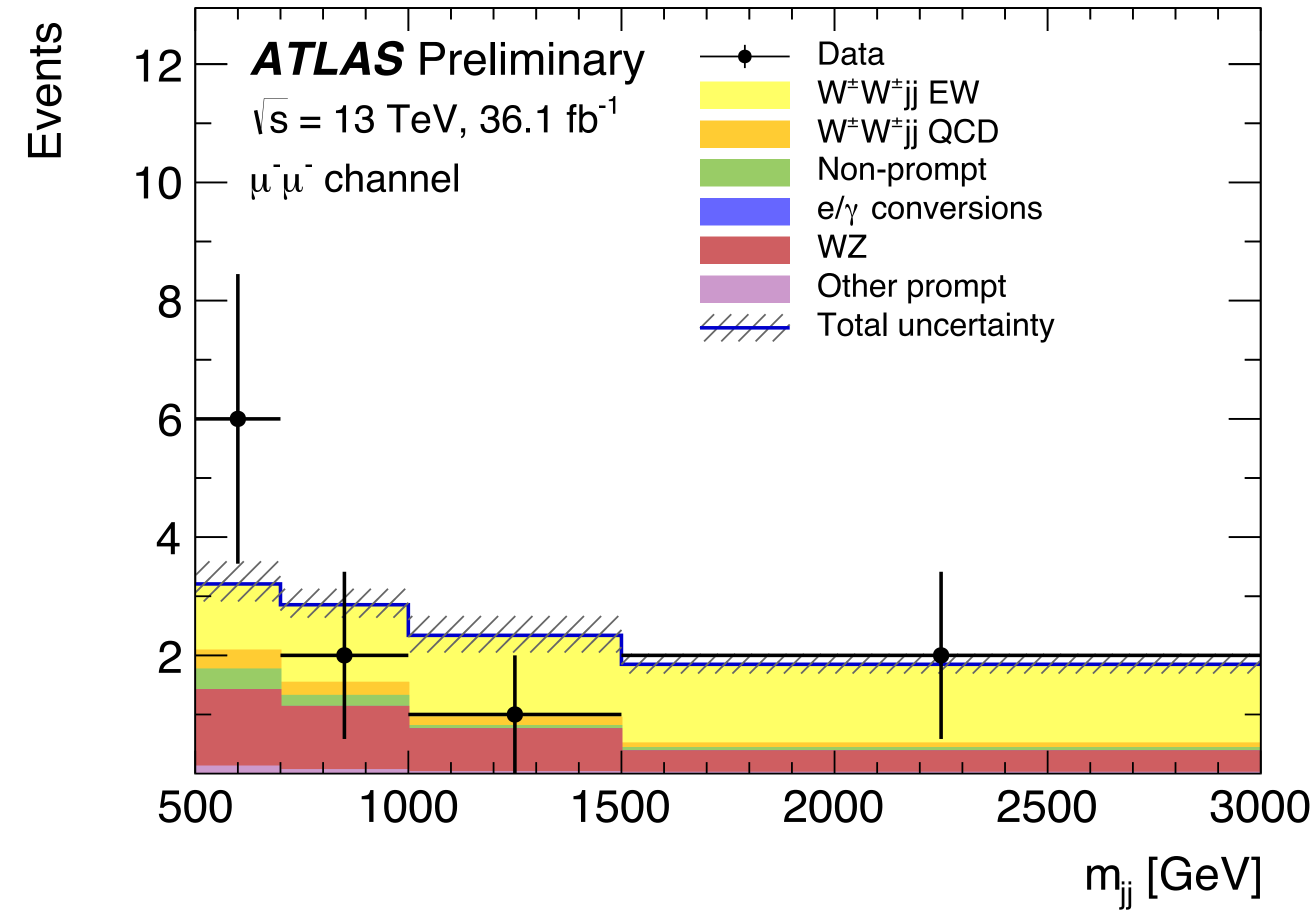
	Cross section in fb
σ_{WZjj}^{fid}	1.68 ± 0.16 (stat) ± 0.12 (exp.syst.) ± 0.13 (mod.syst.) ± 0.044 (lumi)
$\sigma_{WZjj}^{fid,Sherpa}$	2.15 ± 0.01 (stat) ± 0.05 (PDF) $^{+0.65}_{-0.44}$ (scale)

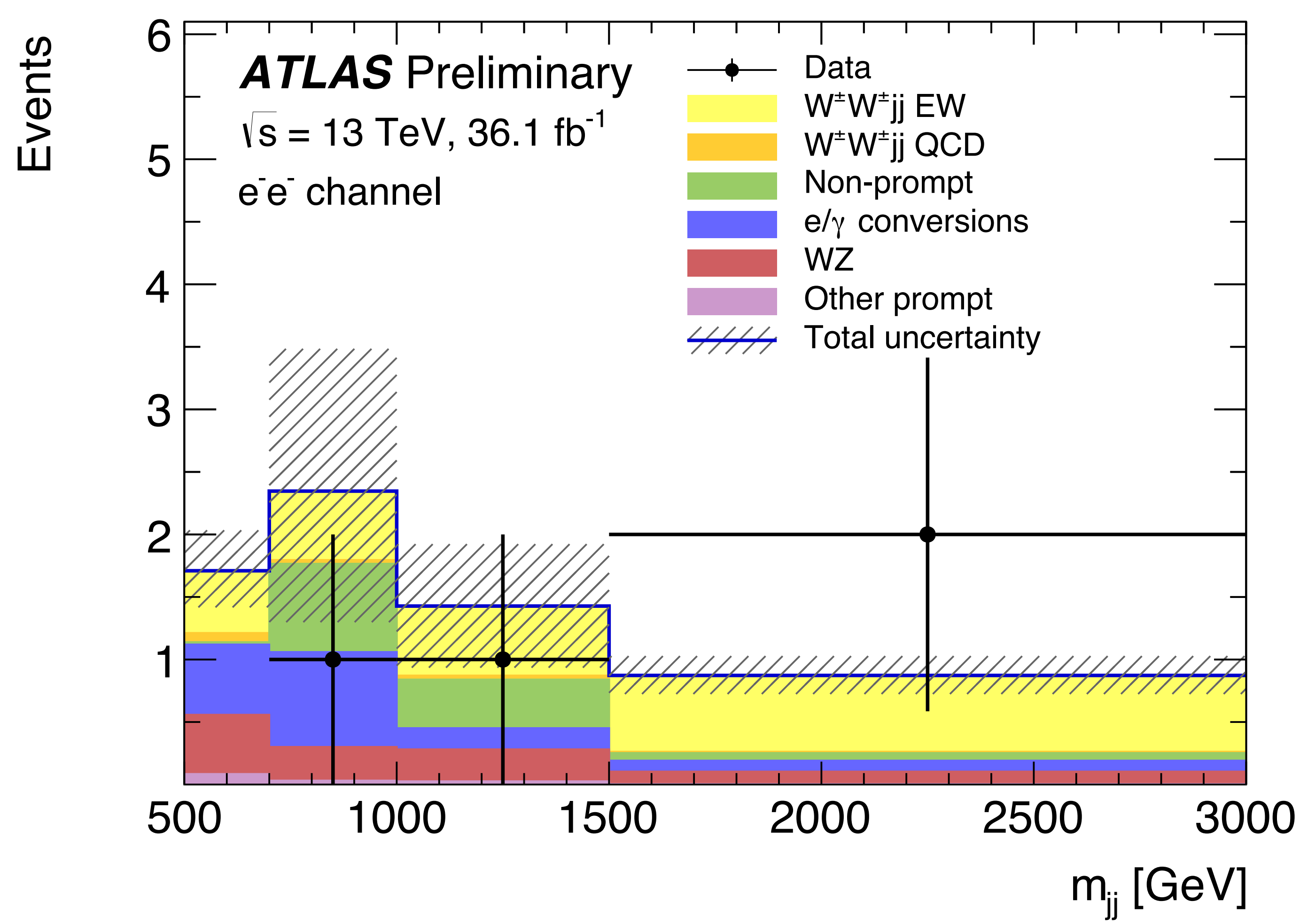
Backgrounds



- **WWjj QCD** : MC (Sherpa 222)
  - Interference EW/QCD computed with MadGraph -> +6%
- **Non-prompt**: ttbar, W+jets
  - Data-driven estimated using scale factors in region 1 lepton+1bjet
  - Validated in regions enriched in non-prompt leptons from ttbar (2 ss leptons + 1 b-jet +>=2jets) and W+jet (2ss leptons +0 b-jet and <= 2 jets)
- **e/γ conversion** : charge misreconstruction (only for ee events) + νγ
  - Charge misreco:
    - Probability measured in MC Zee, 0.1% (central) -> few % (eta>2)
    - Data-driven estimate, method validated in region |mllSS-91.2|<15 GeV
  - Wγ from MC (Sherpa 2.1) but normalised in control region : =2OS signal muons + 1 signal electron + Etmiss<30 GeV, trilepton mass close to mZ mass
- **WZ:** from MC (Sherpa 222) but normalised from control region:
  - =3 leptons, 2 passing signal lepton selection
- **Other prompt**: from MC
  - VVV, ZZ: Sherpa 222
  - ttV: MadGraph5_aMC@NLO


ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
e+μ+ channel
Data
W±W±jj EW
W±W±jj QCD
Non-prompt
e/γ conversions
WZ
Other prompt
Total uncertainty
m_jj [GeV]


Events
ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
μ-μ- channel
Data
W±W±jj EW
W±W±jj QCD
Non-prompt
e/γ conversions
WZ
Other prompt
Total uncertainty
m_jj [GeV]


Events
ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
e-e- channel
Data
W±W±jj EW
W±W±jj QCD
Non-prompt
e/γ conversions
WZ
Other prompt
Total uncertainty
m_jj [GeV]

MVA analysis

BDT distribution in the 3 channels Resolved jets

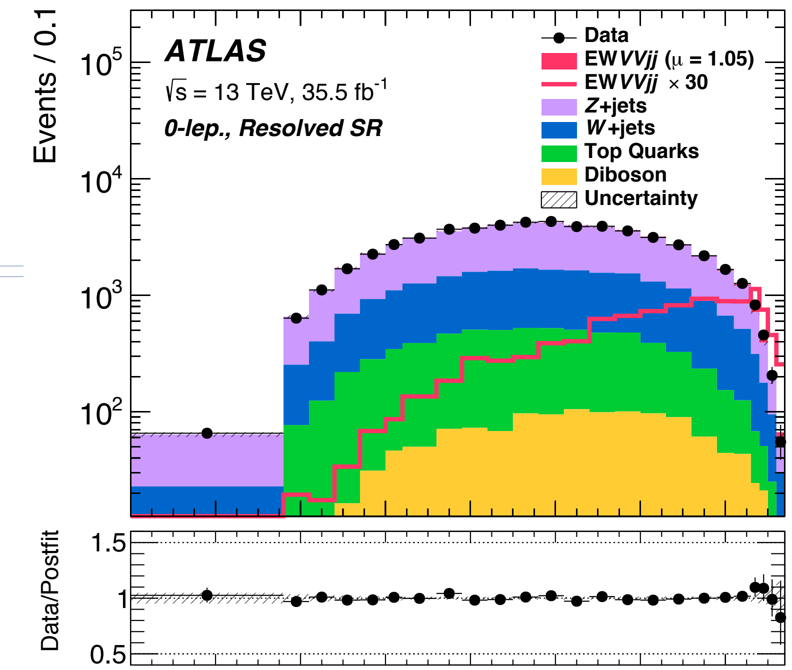
- BDT trained in each channel and region separately
  - LP and HP merged due to low stat
- Variables used in the BDT:

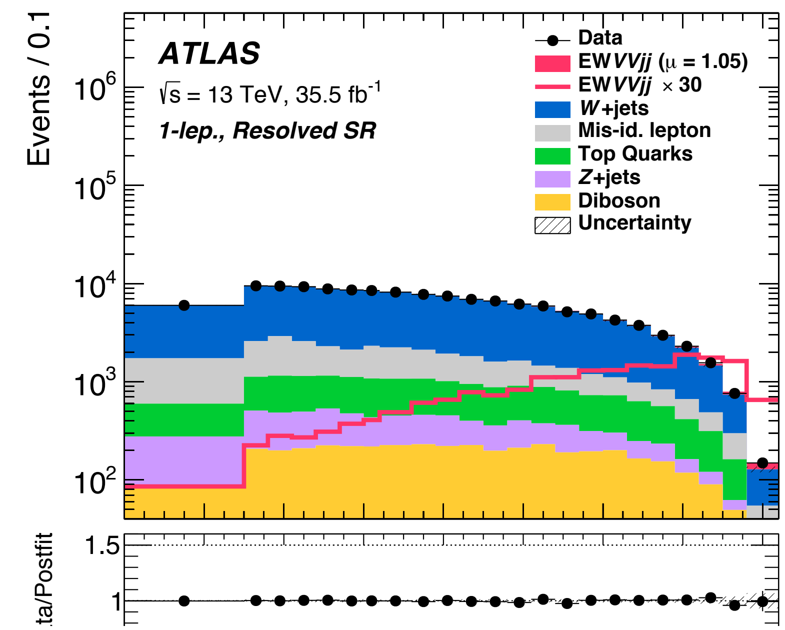
Resolved analysis

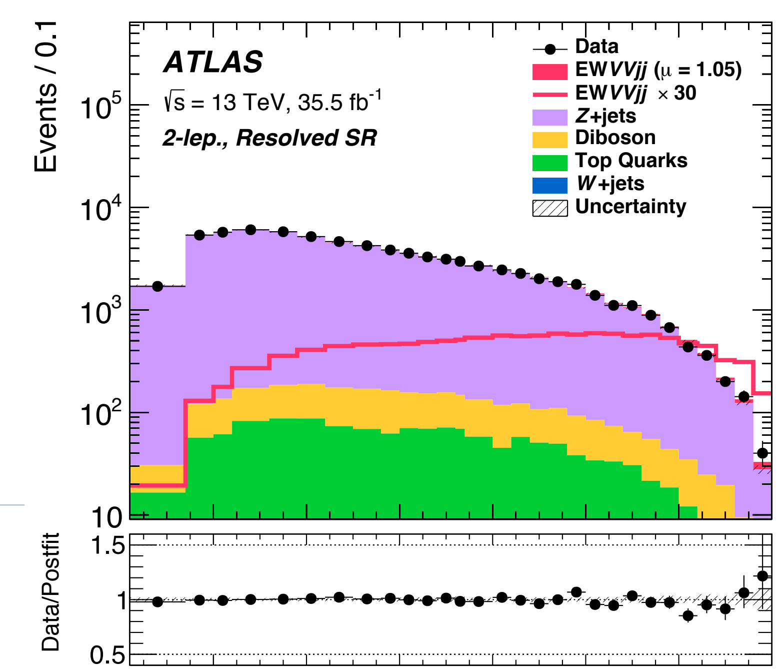
Variable	0-lepton	1-lepton	2-lepton
m_{jj}^{tag}	✓	–	✓
$\Delta\eta_{jj}^{\text{tag}}$	–	–	✓
$p_{\text{T}}^{\text{tag},j_1}$	✓	✓	–
$p_{\text{T}}^{\text{tag},j_2}$	✓	✓	✓
$\Delta\eta_{jj}$	✓	✓	✓
$p_{\text{T}}^{j_1}$	✓	–	–
$p_{\text{T}}^{j_2}$	✓	✓	✓
w^{j_1}	✓	✓	✓
w^{j_2}	✓	✓	✓
$n_{\text{tracks}}^{j_1}$	–	✓	✓
$n_{\text{tracks}}^{j_2}$	–	✓	✓
w^{tag,j_1}	✓	✓	✓
w^{tag,j_2}	✓	✓	✓
$n_{\text{tracks}}^{\text{tag},j_1}$	–	✓	✓
$n_{\text{tracks}}^{\text{tag},j_2}$	–	✓	✓
$n_{j,\text{track}}$	✓	–	✓
$n_{j,\text{extr}}$	✓	–	–
$E_{\text{T}}^{\text{miss}}$	✓	–	–
η_ℓ	–	✓	–
$\Delta R(\ell,\nu)$	–	✓	–
ζ_V	–	✓	✓
m_{VV}	–	–	✓
m_{VVjj}	–	✓	–

Variable	0-lepton	1-lepton	2-lepton
m_{jj}^{tag}	✓	–	✓
$\Delta\eta_{jj}^{\text{tag}}$	–	–	✓
$p_{\text{T}}^{\text{tag},j_2}$	✓	✓	✓
m_J	✓	–	–
$D_2^{(\beta=1)}$	✓	–	✓
$E_{\text{T}}^{\text{miss}}$	✓	–	–
$\Delta\phi(\vec{E}_{\text{T}}^{\text{miss}}, J)$	✓	–	–
η_ℓ	–	✓	–
$n_{j,\text{track}}$	✓	–	–
ζ_V	–	✓	✓
m_{VV}	–	–	✓
p_{T}^{VV}	–	–	✓
m_{VVjj}	–	✓	–
p_{T}^{VVjj}	–	–	✓
w^{tag,j_1}	✓	–	–
w^{tag,j_2}	✓	–	–

Merged analysis







Fiducial phase space		Predicted $\sigma^{\text{fid,SM}}_{\text{EW}\,VVjj}$ [fb]	Measured $\sigma^{\text{fid,obs}}_{\text{EW}\,VVjj}$ [fb]
Merged	0-lepton	$4.1 \pm 0.3\,(\text{theo.})$	$10.1 \pm 3.3\,(\text{stat.})\,^{+4.2}_{-3.8}\,(\text{syst.})$
	1-lepton	$6.1 \pm 0.5\,(\text{theo.})$	$2.0 \pm 1.5\,(\text{stat.})\,^{+2.9}_{-2.8}\,(\text{syst.})$
	2-lepton	$1.2 \pm 0.1\,(\text{theo.})$	$2.4 \pm 0.6\,(\text{stat.})\,^{+0.8}_{-0.7}\,(\text{syst.})$
Resolved	0-lepton	$9.2 \pm 0.6\,(\text{theo.})$	$22.8 \pm 7.4\,(\text{stat.})\,^{+9.4}_{-8.5}\,(\text{syst.})$
	1-lepton	$16.4 \pm 1.0\,(\text{theo.})$	$5.5 \pm 4.1\,(\text{stat.})\,^{+7.7}_{-7.5}\,(\text{syst.})$
	2-lepton	$6.0 \pm 0.4\,(\text{theo.})$	$11.8 \pm 3.0\,(\text{stat.})\,^{+3.8}_{-3.5}\,(\text{syst.})$
Inclusive	0-lepton	$13.3 \pm 0.8\,(\text{theo.})$	$32.9 \pm 10.7\,(\text{stat.})\,^{+13.5}_{-12.3}\,(\text{syst.})$
	1-lepton	$22.5 \pm 1.5\,(\text{theo.})$	$7.5 \pm 5.6\,(\text{stat.})\,^{+10.5}_{-10.2}\,(\text{syst.})$
	2-lepton	$7.2 \pm 0.4\,(\text{theo.})$	$14.2 \pm 3.6\,(\text{stat.})\,^{+4.6}_{-4.2}\,(\text{syst.})$