Measurement of WW/WZ production in semileptonic decay channels and search for anomalous gauge couplings with the ATLAS detector at 8 TeV

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on behalf of the ATLAS Collaboration

ATLAS EXPERIMENT

CERN

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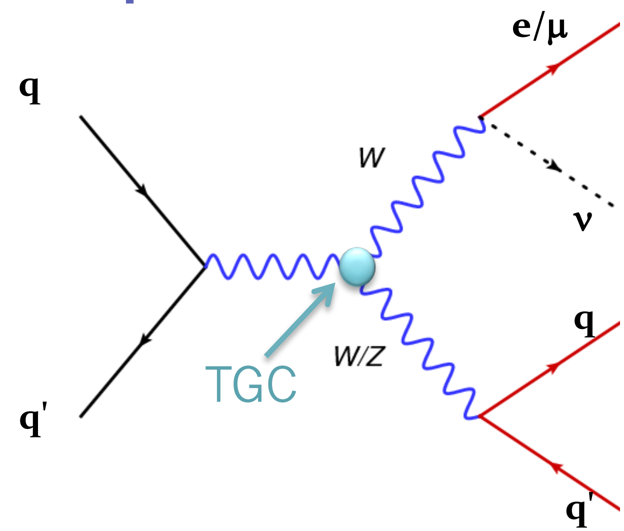
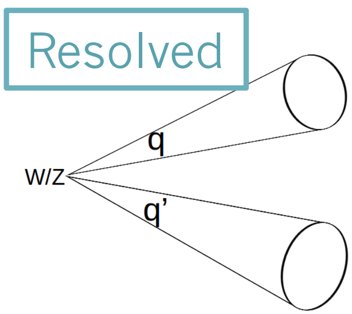
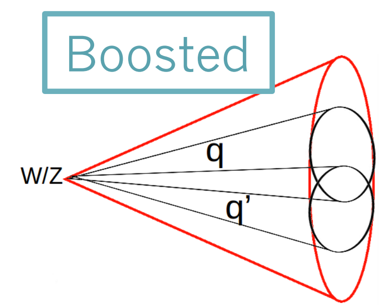
Semileptonic diboson production

- Aims of the analysis:
  - Diboson cross section measurement.
  - Constrain new physics through limits on anomalous Triple Gauge Couplings (aTGC)
- We use 20.2 fb^{-1} collision data at 8 TeV



- Two separate analysis channels for two hadronic W/Z topologies:
  - **Resolved topology**:
    - » Hadronic W/Z decay: two "standard" jets (W/Z → jj)
    - » Provides the largest significance in cross section measurement
  - **Boosted topology**:
    - » Hadronic W/Z decay: one single large-R jet (W/Z → J)
      - W/Z produced with a large Lorentz boost
    - » Provides best sensitivity to aTGC





Identifying WW/WZ→lν qq

1. Select leptonic W

Exactly one ELECTRON or MUON:

- with large p_T> 30 GeV
- in central η region
- isolated

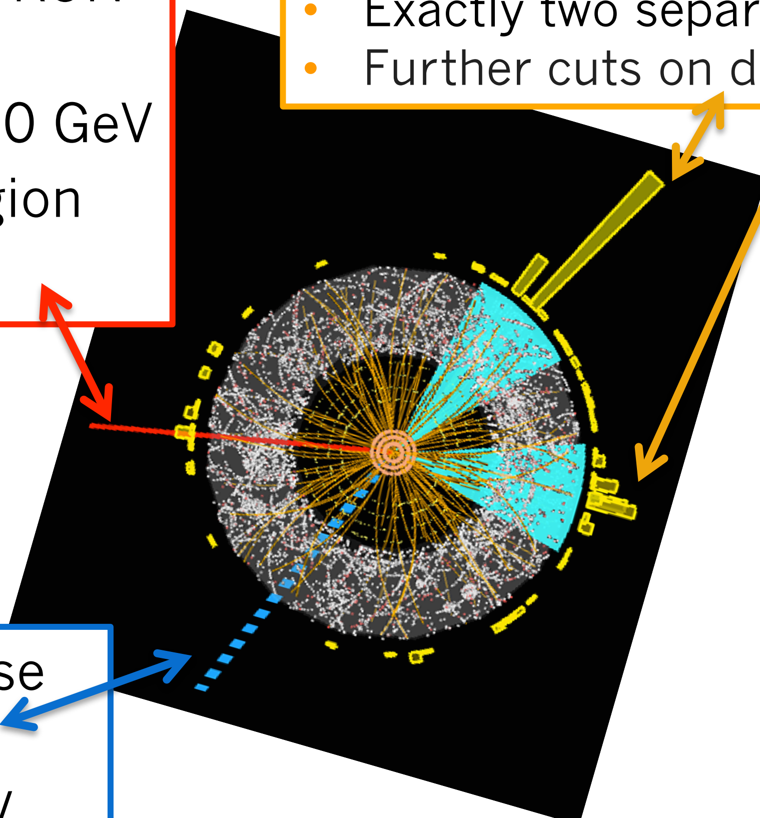
Missing transverse energy:

- E_T^{miss} > 40 GeV (resolved)

2. Select hadronic W/Z

Resolved channel: R=0.4 anti-K_t jets

- Exactly two separate jets of pt>25 GeV
- Further cuts on di-jet and lepton kinematics



Event display reference:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplaysFromHiggsSearches

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Exactly one ELECTRON or MUON:

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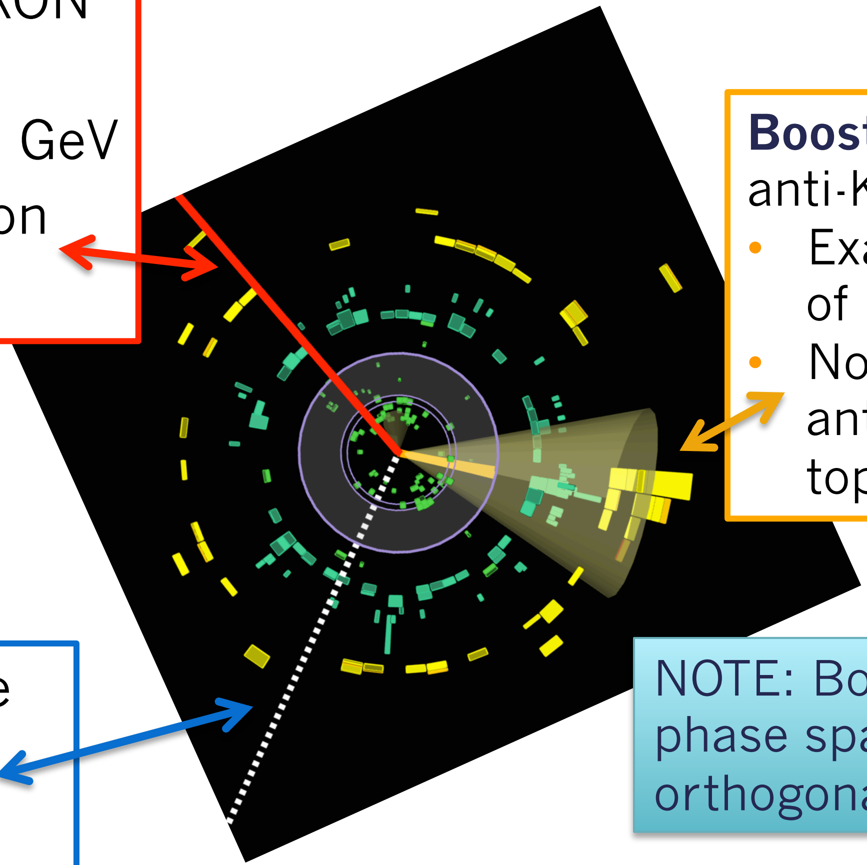
- isolated

2. Select hadronic W/Z

Boosted channel: R=1 anti-K_t jet (*large-R jet*)

- Exactly one large-R jet of high pt: pt>200 GeV
- No additional R=0.4 anti-K_t jets (to reduce top background)



Missing transverse energy:

- E_T^{miss} > 50 GeV (boosted)

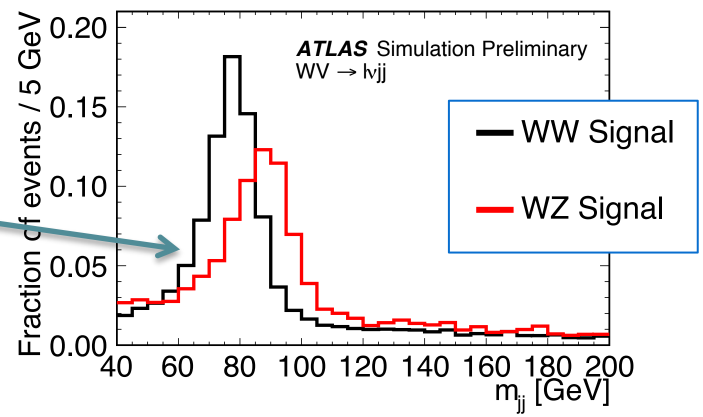
NOTE: Boosted and Resolved phase spaces are not orthogonal

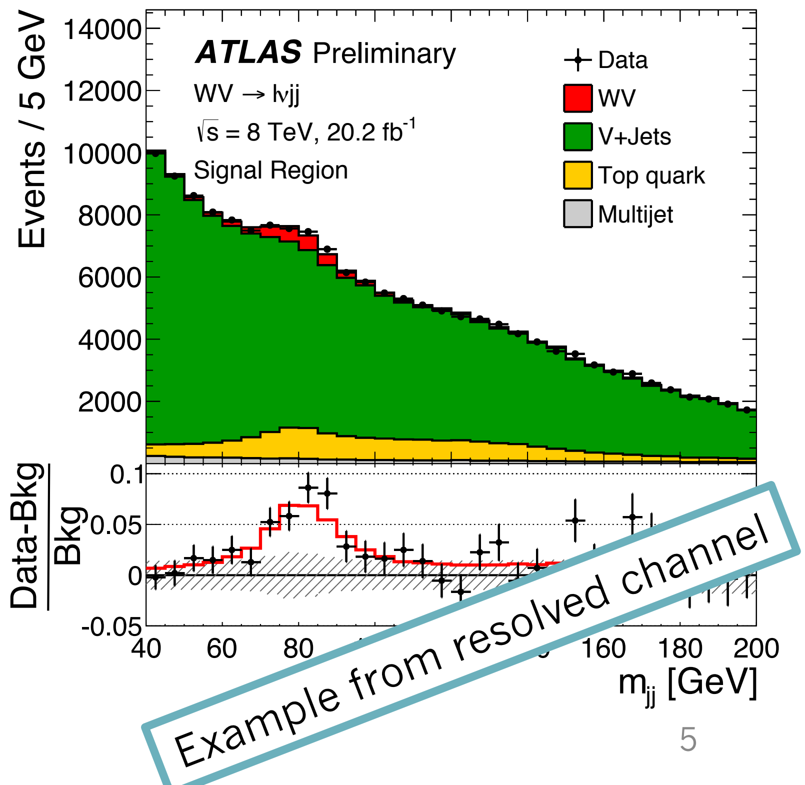
Event display reference:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Physics

Contributions to final state

MonteCarlo modelled

- Signal:
  - WW ~80%, WZ ~20%
  - Cannot separate the WW and WZ resonances
- W/Z + jets (V+jets)
  - Largest component
    - » ~84% of total selected events
- Top
  - top/anti-top and single top
  - contributes to the visible peak
- Minor backgrounds
  - QCD multijet:
    - » data-driven method based on modified event selection.
  - ZZ: ~ negligible
    - » only considered for resolved





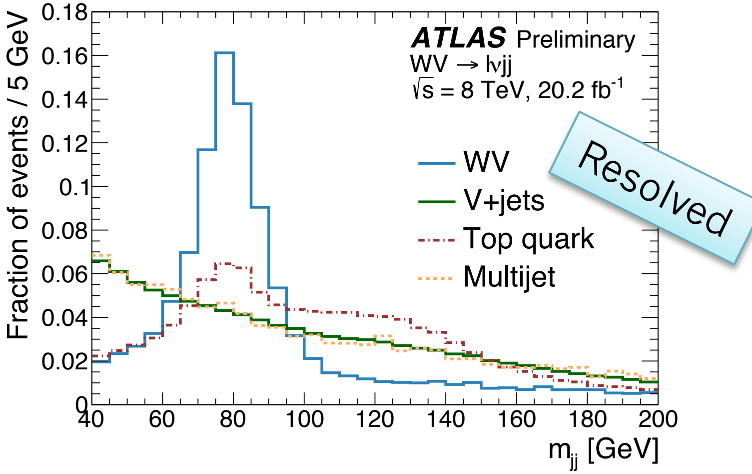
Cross section measurement

Cross section is measured in the ***fiducial phase space***.

- Kinematic acceptance of measurement.
- Defined from MonteCarlo particle-level objects.
  - » Nonzero boosted/resolved overlap

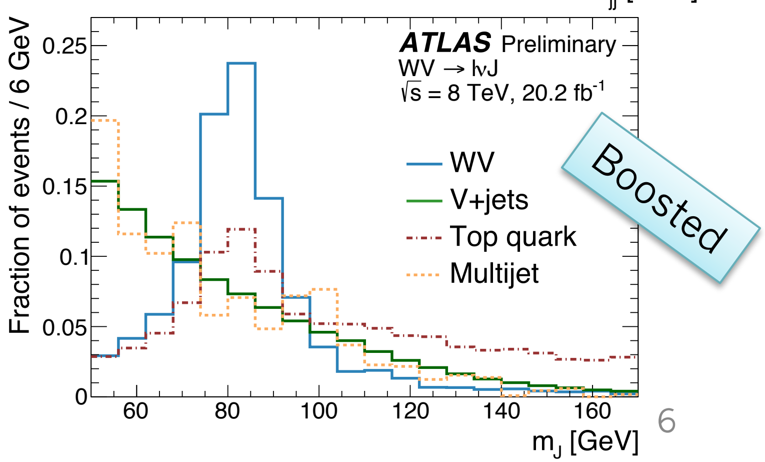
Cross section extraction

- From Binned Maximum Likelihood fit
  - Resolved: di-jet invariant mass m_{jj}
  - Boosted: large-R jet mass m_J



Largest systematics

- MonteCarlo modelling: generator comparison
  - » Resolved: Top, ~13%
  - » Boosted: W/Z+jets, ~60%



Cross section results

Resolved

Significance

Expected: 5.2 σ

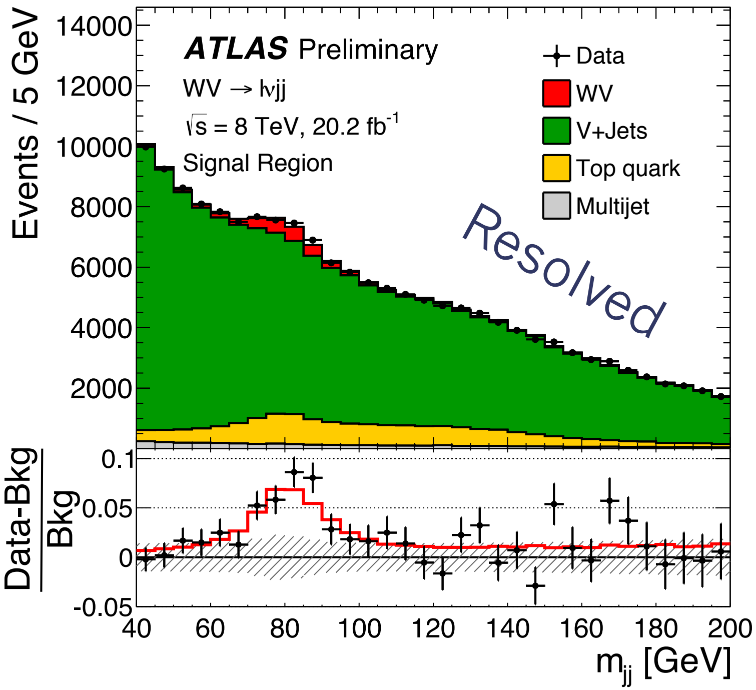
Observed: 4.5 σ

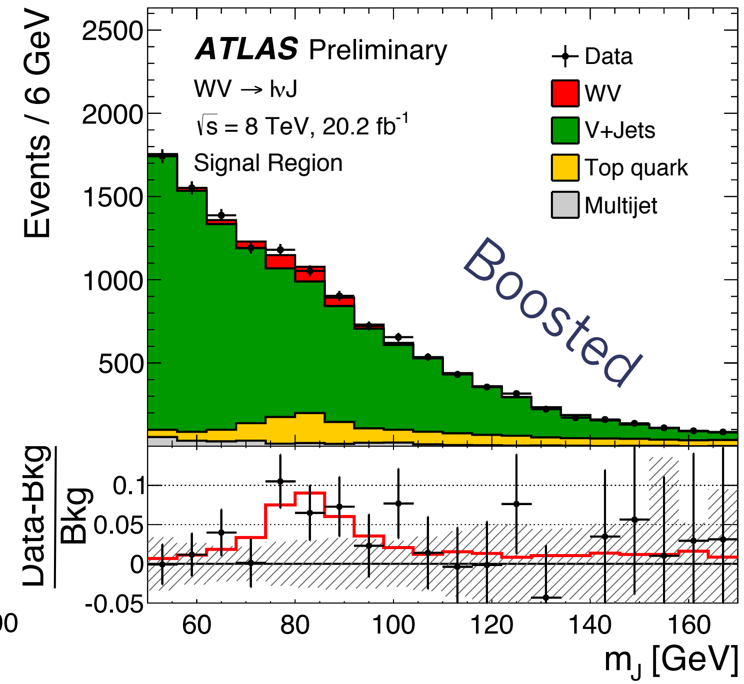
Boosted

Significance

Expected: 2.3 σ

Observed: 1.3 σ





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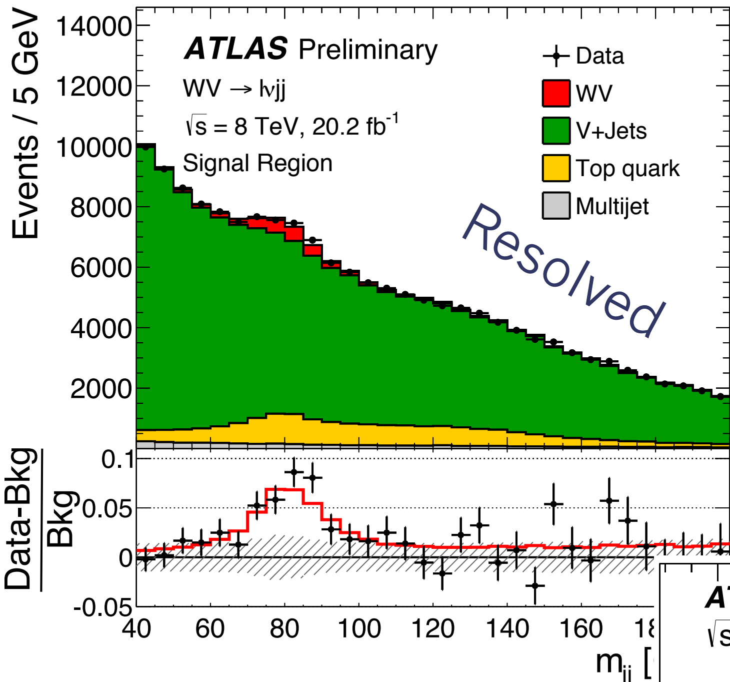
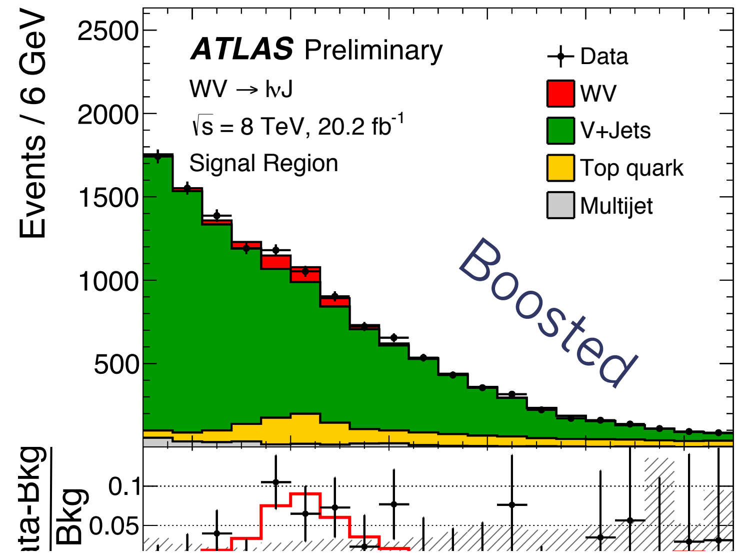




Resolved

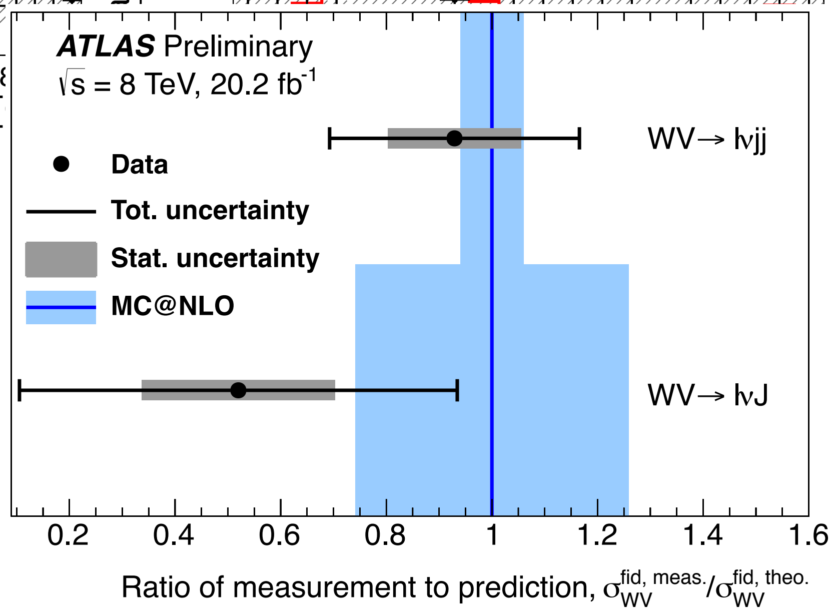
$$\sigma_{\text{fid}}(WV \to \ell\nu jj, \text{observed}) = 209 \pm 28(\text{stat}) \pm 45(\text{sys})\ \text{fb}$$

$$\sigma_{\text{fid}}(WV \to \ell\nu jj, \text{theory}) = 225 \pm 13\ \text{fb}$$

Boosted

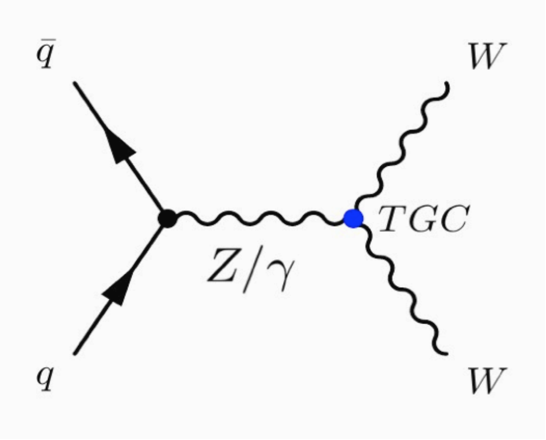
$$\sigma_{\text{fid}}(WV \to \ell\nu J, \text{observed}) = 30 \pm 11(\text{stat}) \pm 22(\text{sys})\ \text{fb}$$

$$\sigma_{\text{fid}}(WV \to \ell\nu J, \text{theory}) = 58 \pm 15\ \text{fb}$$



Search for anomalous Triple Gauge Couplings (aTGC)

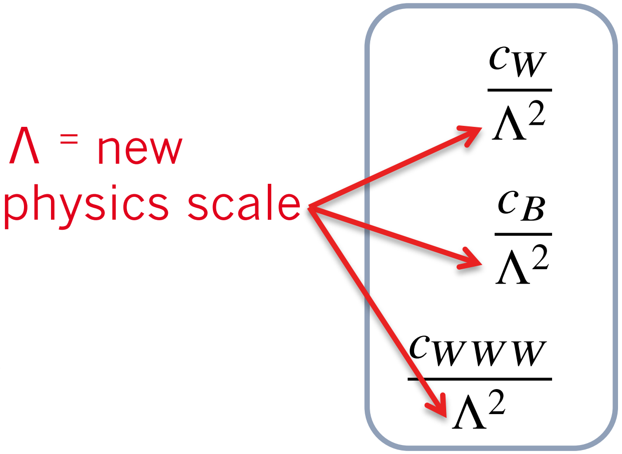
- Contribution from new physics: vector boson couplings may deviate from Standard Model.



- Model independent interpretations
  - Here results in Effective Field Theory framework
    - » Three free parameters

- aTGC tend to enhance the event rate at high p_T

- Strategy:
  - Cut on 65 GeV < m_{jj}/m_J < 95 GeV
  - Maximum Likelihood fit of $p_T(jj)$ or $p_T(J)$
    - » aTGC modelled with FullSim MonteCarlo
    - » Resolved only: m_{jj} sideband control region



Ref. in backup

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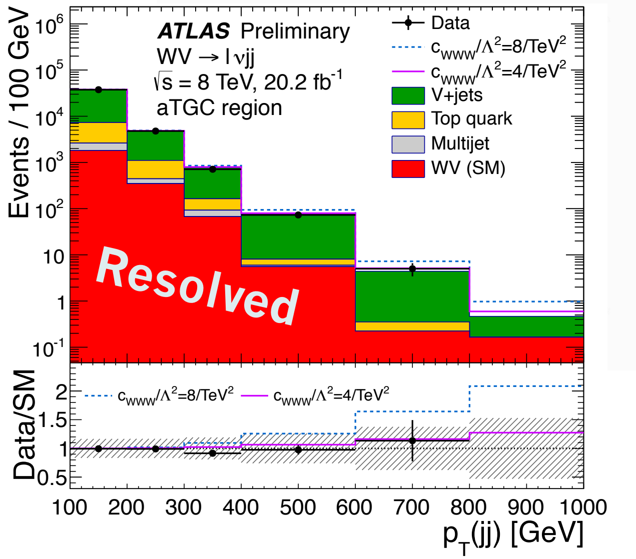
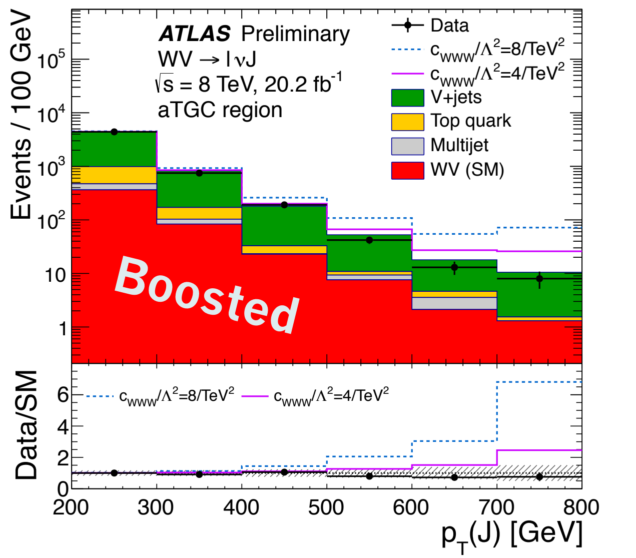
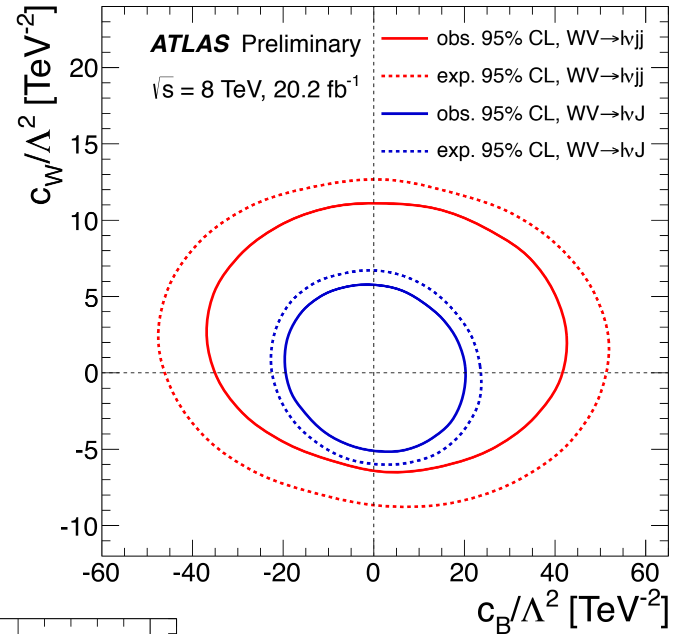
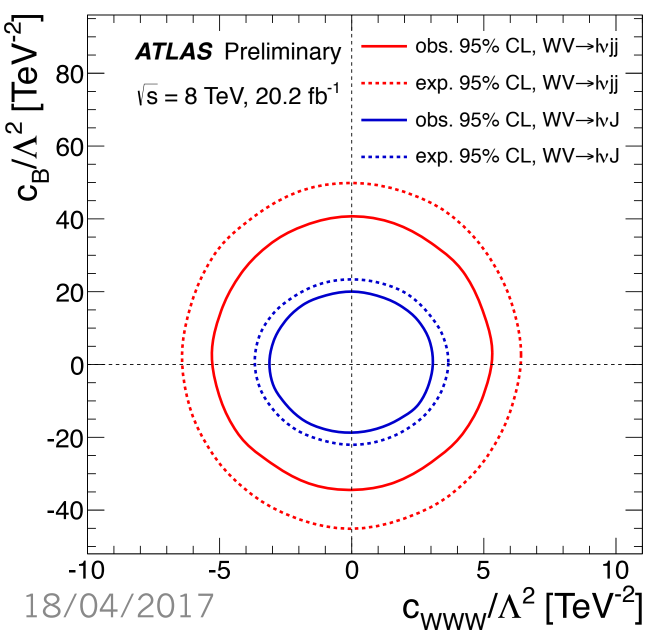


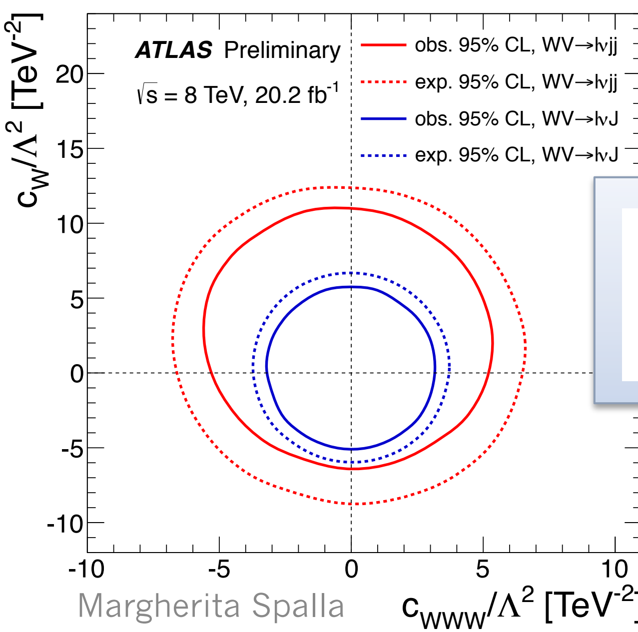


aTGC limits: 95% Confidence Interval

- Best sensitivity from boosted
- Boosted results similar to best previously published constraints
  - » leptonic WW and WZ at 8 TeV (ATLAS/CMS)
  - » CMS semileptonic WW/WZ at 8 TeV



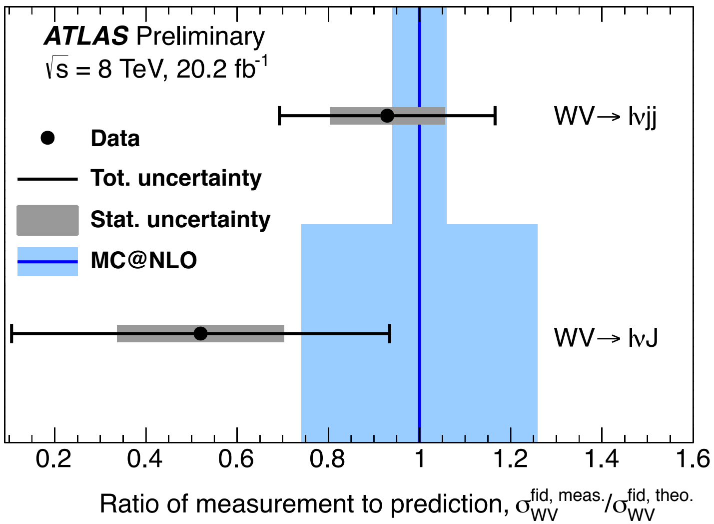




: boosted observed
: boosted expected
: resolved observed
: resolved expected

Summary

- Analysis exploits both resolved and boosted topologies
- 4.5 σ evidence of resolved WW/WZ
  - 1.3 σ in boosted channel
- Measured fiducial cross sections in agreement with SM (NLO)
- Constraint on aTGC
  - Boosted signature provides limits similar to current best published limits



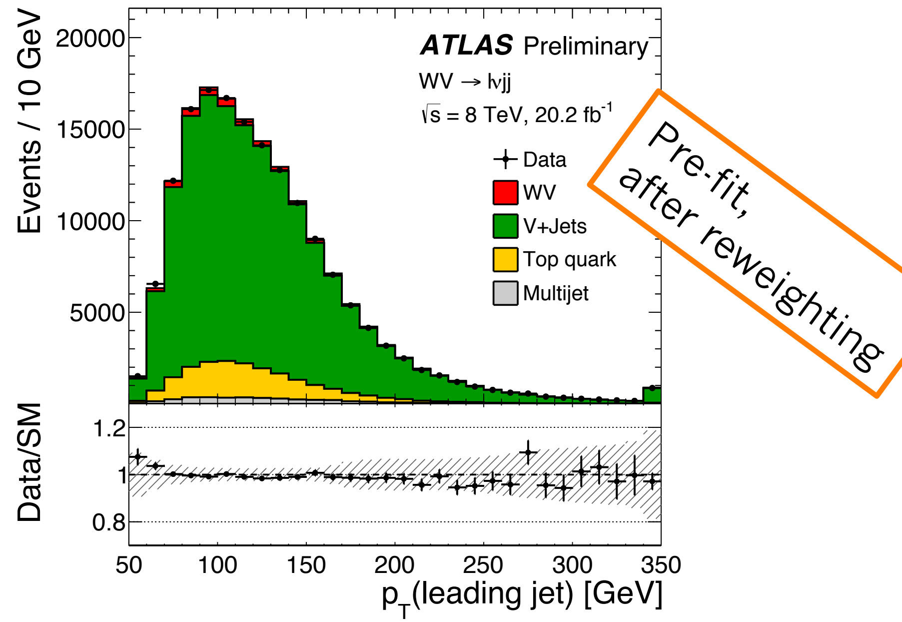
Ref. to shown plots: STDM-2015-23 (paper in preparation)
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2015-23/

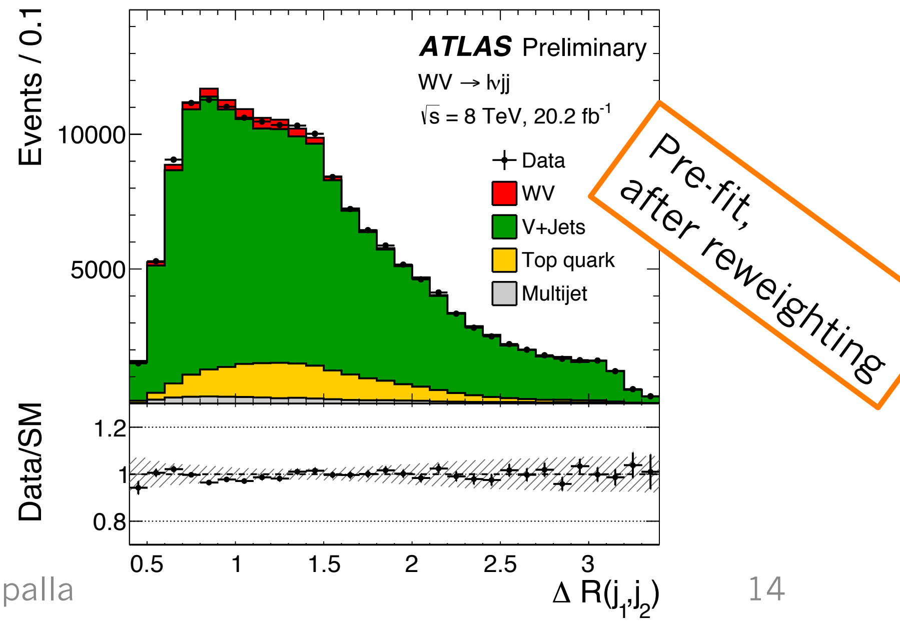
Backup

Data-driven corrections to MC: resolved channel

- Applied to W/Z+jets only
- Reweighting as a function of:
  - $\Delta\phi(jj)$
  - $p_T(j_1)$
- Order of 5-10%
- Derived in m_{jj} sideband control region:

$$m'_{jj} \notin [65, 95]\mathrm{GeV}$$





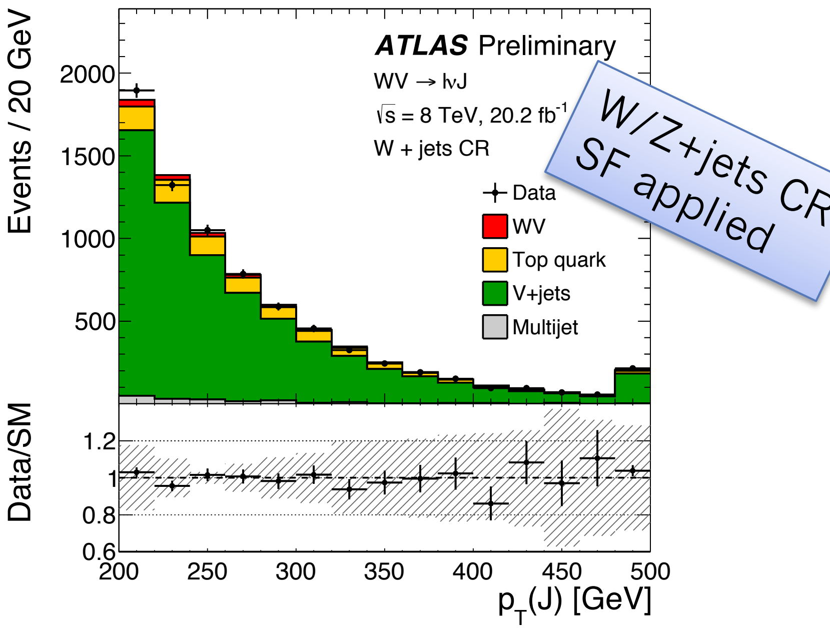
Data-driven corrections to MC: boosted channel

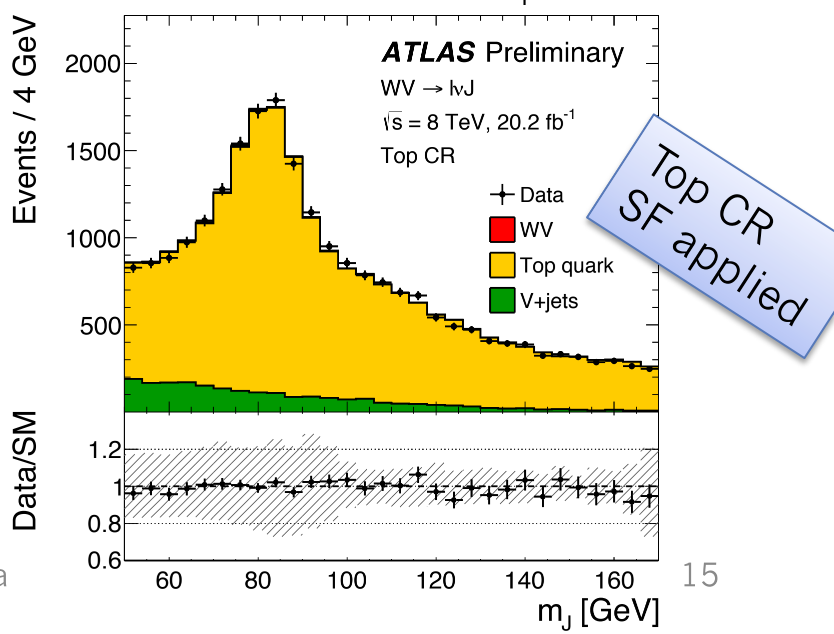
- Applied to top and W/Z+jets
- Constant Scale Factors (SF)
  - Top correction: order of 10%
  - W/Z+jets correction: order of 15%
  - each derived in specific control region

- W/Z + jets control region:
  - m_J sidebands.

$$m_J \notin [65, 95]\mathrm{GeV}$$

- Top control region:
  - at least one b-tagged small-R jet,
  - not overlapping with the large-R jet ($\Delta R(j,J)>1.$)





QCD multijet estimation

- Template shape estimated from QCD control region
  - » About 2.5% of total background

- Template normalization from E_T^{miss} fit
  - multijet E_T^{miss} template: from QCD control region
  - E_T^{miss} templates for other processes:
    - » WW/WZ, W/Z+jets, top
    - » from MC
    - » summed in a single template in the fit
  - Resulting normalization is scaled by efficiency of dropped cuts

<u>QCD control region</u>

- ➢ Electron channel: invert electron quality criteria and isolation
- ➢ Muon channel: invert muon impact parameter and isolation

E_T^{miss} FIT REGION	
Resolved	Boosted
All cuts but: E_T^{miss} $\Delta\eta(j,j)$ $\Delta\phi(E_T^{miss},j_1)$ (μ ch. only) m_T (μ ch. only)	All cuts but: E_T^{miss}

NOTE:
In boosted analysis, QCD multijet is negligible in muon channel

Cross section extraction

Number of signal events

- From Binned Maximum Likelihood fit
- Fit variable:
  - Resolved: di-jet invariant mass m_{jj}
  - Boosted: large-R jet mass m_J

$$\sigma_{\text{fid}} = \frac{N^{WV}}{\mathcal{L} \cdot D_{\text{fid}}}$$

- L: integrated luminosity
- D_{fid}: corrects for the difference between fiducial phase space and the actual selection on reconstructed objects.

$$D_{\text{fid}} \sim \frac{N^{WV}[\text{reco, selected}]}{N^{WV}[WV \to \ell\nu qq, \text{ inFiducial}]}$$

Systematic uncertainties

- Detector-related uncertainties
  - Larger component:
    - Resolved: small-R jet energy scale / resolution
    - Boosted: large-R jet energy <u>and mass</u> scale / resolution

- Modelling uncertainties
    - Generator comparison / theoretical uncertainties on process cross section
    - Data-driven SF where applicable
  - Larger contribution
    - Resolved: Top / signal modelling
    - Boosted Top / W/Z+jets modelling

aTGC parameters in Effective Field Theory

References

Phys. Rev. D **48** (1993) 2182
Annals Phys. **335** (2013) 21

- EFT assumed to be valid below an energy scale Λ
- Introduces three CP-conserving dimension-six operators
  - Their coupling constants are the aTGC parameters of interest

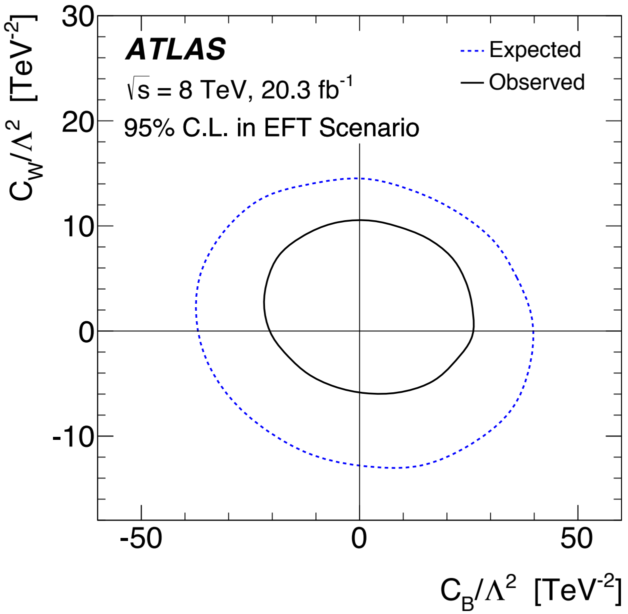
$$\begin{aligned} \mathcal{O}_W &= (D_\mu \Phi)^\dagger W^{\mu\nu} (D_\nu \Phi), \\ \mathcal{O}_B &= (D_\mu \Phi)^\dagger B^{\mu\nu} (D_\nu \Phi), \\ \mathcal{O}_{WWW} &= Tr[W_{\mu\nu} W^{\nu\rho} W^{\mu}_{\rho}]. \end{aligned} \quad \Longleftrightarrow \quad \frac{c_W}{\Lambda^2}, \quad \frac{c_B}{\Lambda^2}, \quad \frac{c_{WWW}}{\Lambda^2}$$

Λ = new physics scale

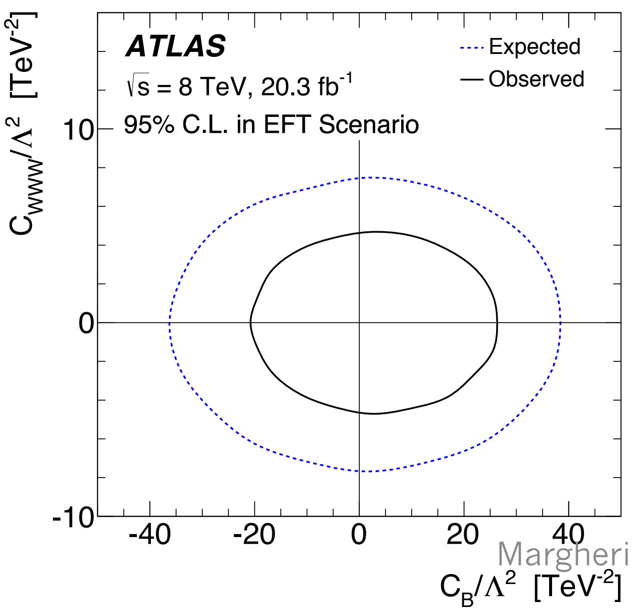
Φ = Higgs doublet
$B^{\mu\nu}$, $W^{\mu\nu}$ = combinations of derivatives of gauge-boson fields

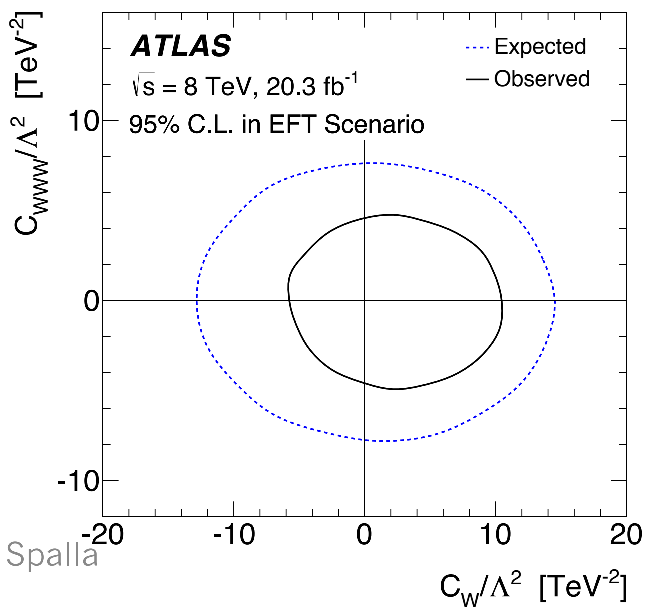
- Alternative description: effective Lagrangian, not discussed in this talk

aTGC results from ATLAS leptonic WW at 8 TeV



Ref: *JHEP 09 (2016) 029*





aTGC results from this analysis (for comparison)