ATLAS VBF W and VBF Theory Uncertainties

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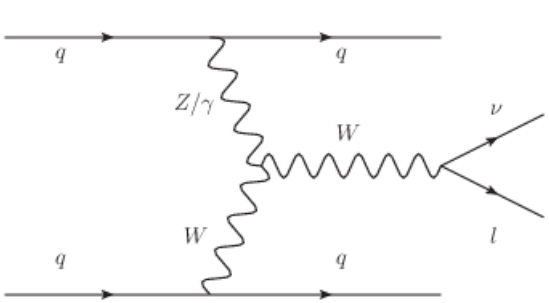
Introduction

- Currently no public VBF W results
- Will present ATLAS VBF W analysis work in progress
  - Selection Overview
  - Interference
  - Modeling
  - Signal Extraction

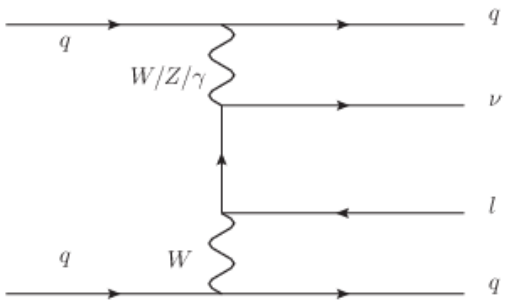
- Theoretical uncertainties on all analyses
- Using control regions to limit errors

Experimental Signature

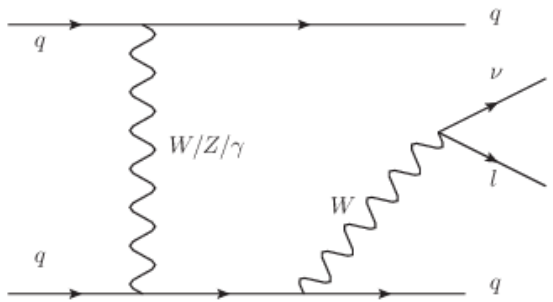
- VBF diagram not physical in isolation
- Large (negative) interference with other pure EWK V + 2 Jets diagrams (excluding dibosons)
- Possible issues with QCD interference discussed later



VBF



Non-resonant



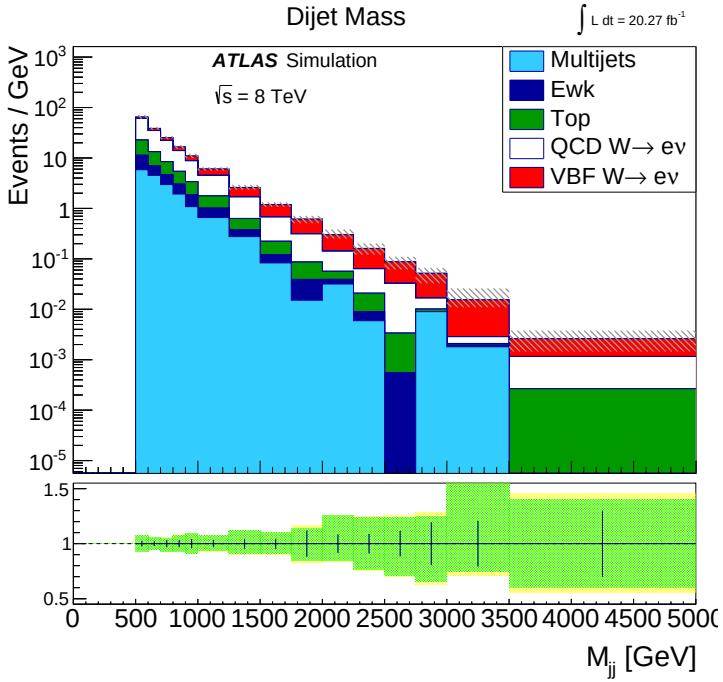
Bremsstrahlung

- Experimental signature:
  - Well reconstructed boson
  - 2 high p_T jets with large dijet mass
  - Minimal hadronic activity - ISR/FSR only
  - Boson produced at centre of tagged jet rapidity gap

ATLAS Analysis Overview

- Signal sample: SHERPA EWK W+Jets (excludes dibosons)
- QCD W+Jets background sample: SHERPA or Alpgen

- Siganl Phase-Space:
  - Jet 1 $p_T > 80$ GeV
  - Jet 2 $p_T > 60$ GeV
  - W $M_T > 40$ GeV
  - $M_{jj} > 500$ GeV
  - Jet 3 Centrality > 0.4
  - Lepton Centrality < 0.3

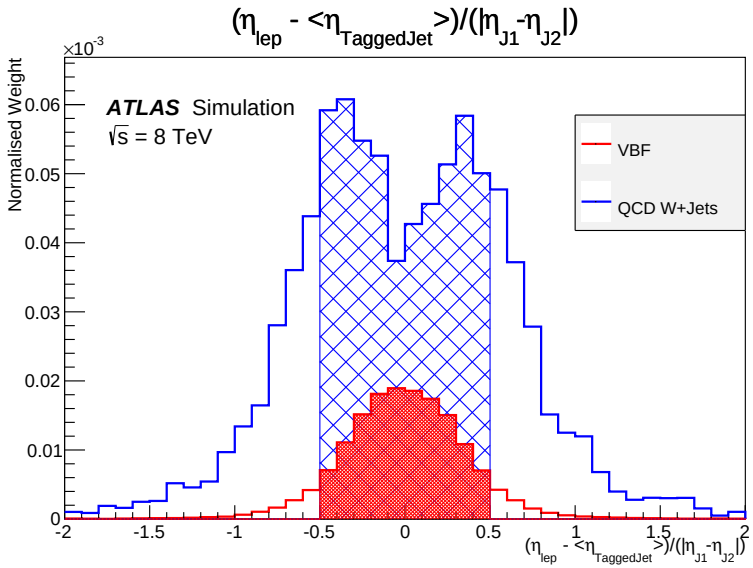


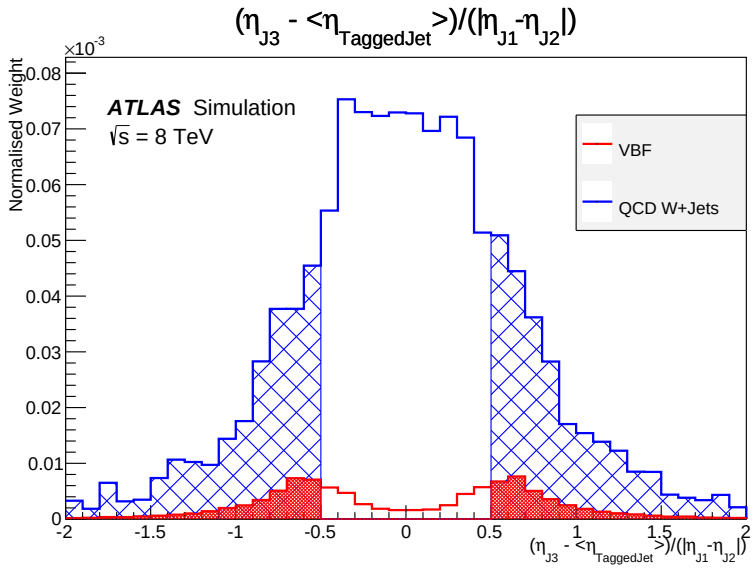
- Plot shows electron channel M_{jj} after signal phase-space cuts
- Signal extraction method is fit in M_{jj} distribution

Centrality Variables

- Cutflow uses continuous variables rather than more conventional outside-lepton and central-jet vetoes
- Quantify how central the lepton (jet) is in the tagged jet gap
- Akin to Zeppenfeld variable but normalised to rapidity gap
- Allows physical meaning from value, > 0.5 is outside jet gap
- Shaded areas show remaining events from simple vetoes

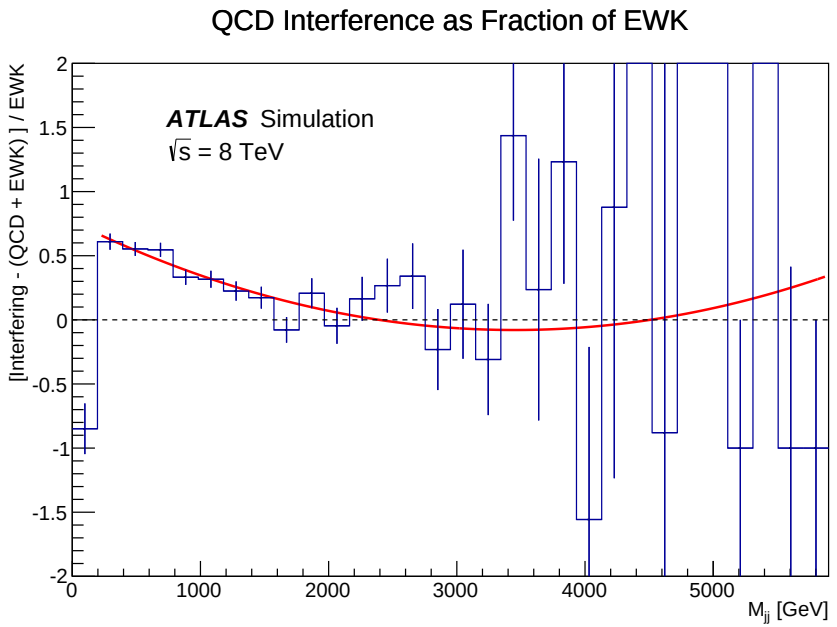
$$\frac{\eta_X - \frac{\eta_{Jet1}+\eta_{Jet2}}{2}}{\eta_{Jet1} - \eta_{Jet2}} \quad (1)$$





QCD - EWK Interference

- Interference between QCD and EWK W+Jets has been studied
- ATLAS VBF Z assigned conservative 6% uncertainty assuming maximal impact on the analysis
- High stats SHERPA generator level samples created for QCD-only, EWK-only and interfering
- Difference between addition of (QCD-only + EWK-only) and interfering shows interference
- Taken as error in M_{jj} fits by reweighting the QCD W+Jets up to (interfering - EWK-only)



Signal Extraction

- General method the same as for ATLAS VBF Z - using anti-CJV control region
- Cross check with simpler, signal region only, M_{jj} fits
- Simultaneous fits in electron and muon channel
- 2 component fit- signal and W+Jets allowed to float, other backgrounds constant
- Dominant errors are jet energy scale for signal and renormalisation scale for QCD W+Jets
- Uncertainty evaluated by change in scale factor on pseudo-data fit using:
  - Make pseudo-data from nominal templates Gaussian fluctuated by each systematic's 1σ band
  - Fit with nominal templates for expected precision
  - Repeat 4×10^7 times and fit without signal for expected significance

Control Region - Contraint on Background shape

- SHERPA used for QCD W+Jets but over-predicts data at high M_{jj}
- Anti-CJV control region used to derive 1st order QCD reweighting function (2nd order in VBF Z)
- Will also do full chain with Alpgen and POWHEG for cross-check
- Appears to be same mis-modeling as observed in ATLAS VBF Z (shown on right)
- VBF W plots on next slide

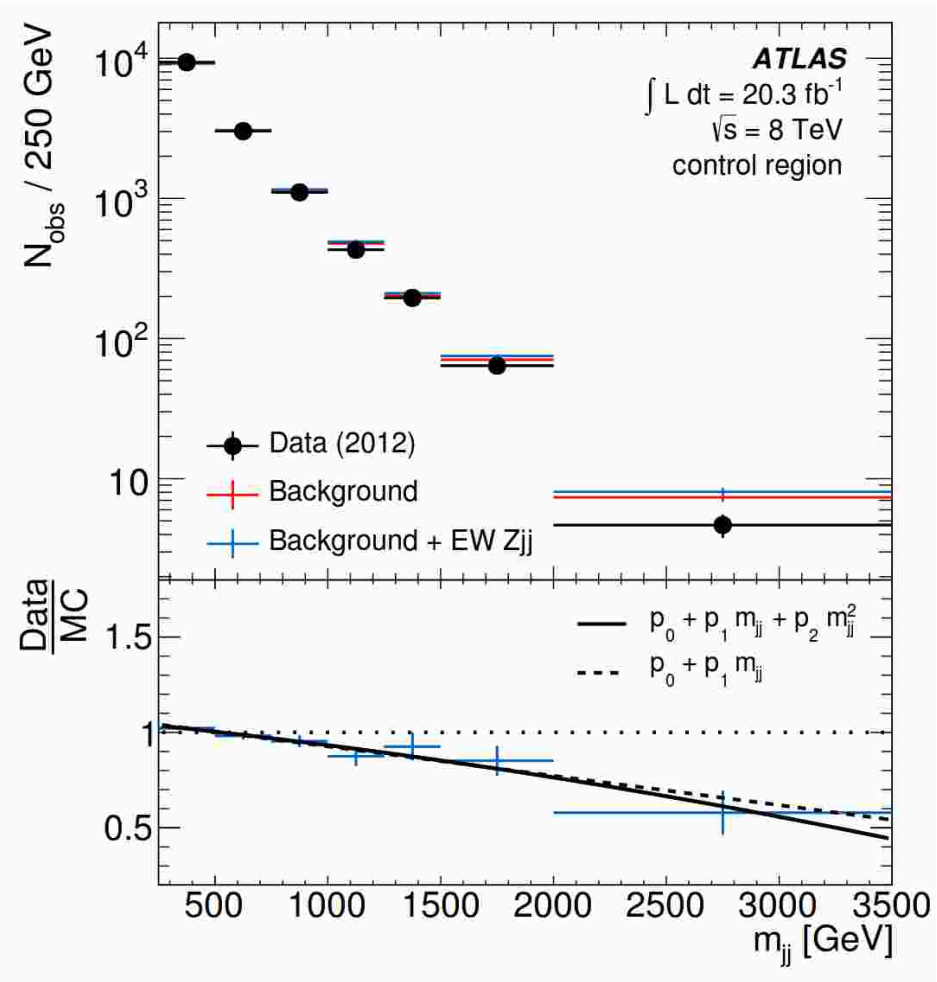
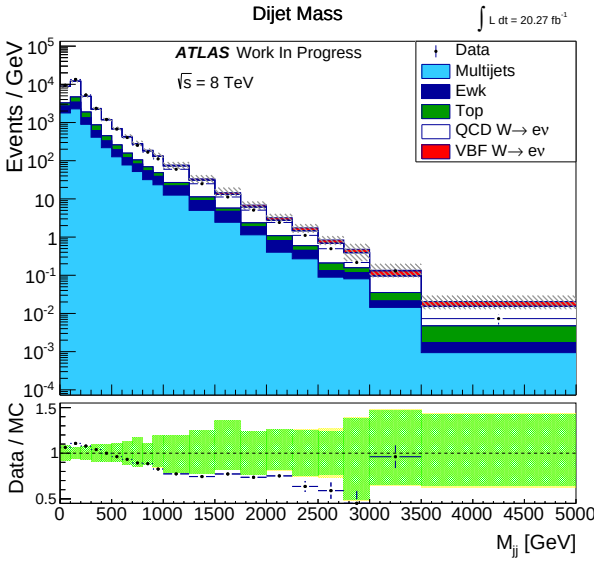


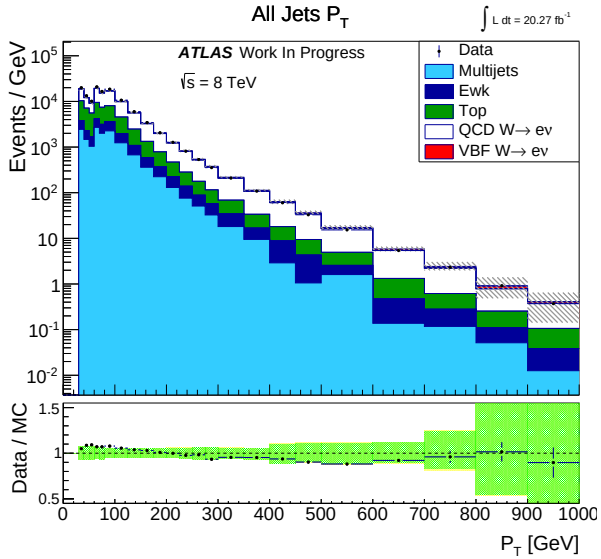
Figure: VBF Z Control Region reweighting - [1]

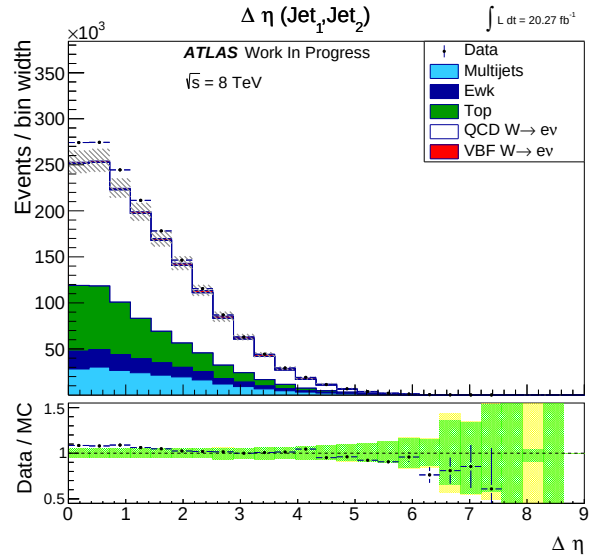
Control Region reweighting effects

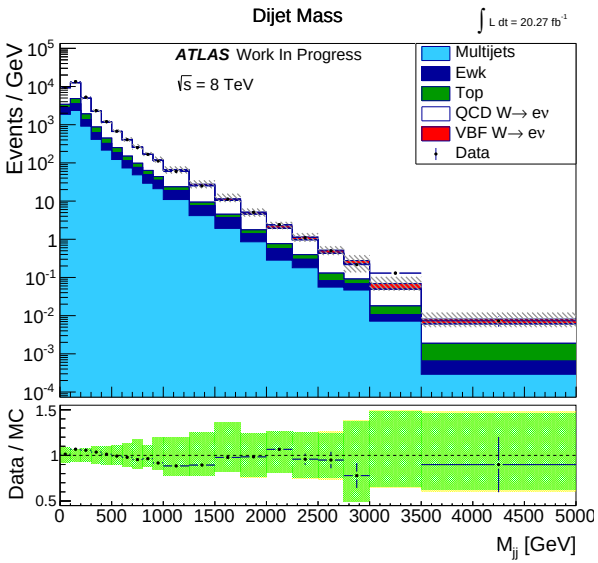
Top row- before reweighting

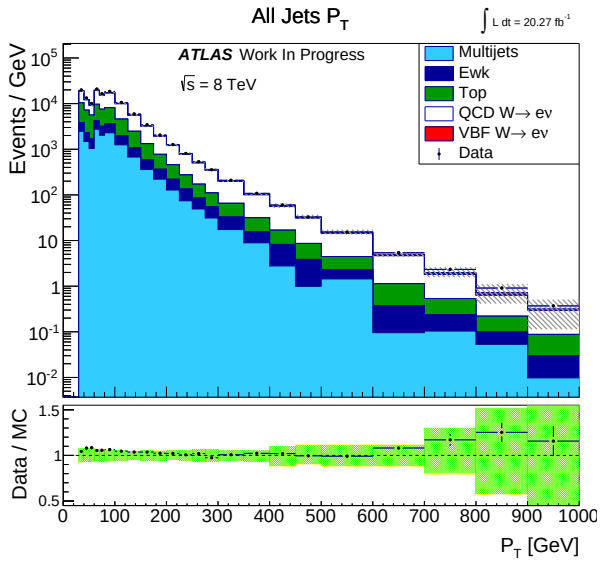
Bottom row - After

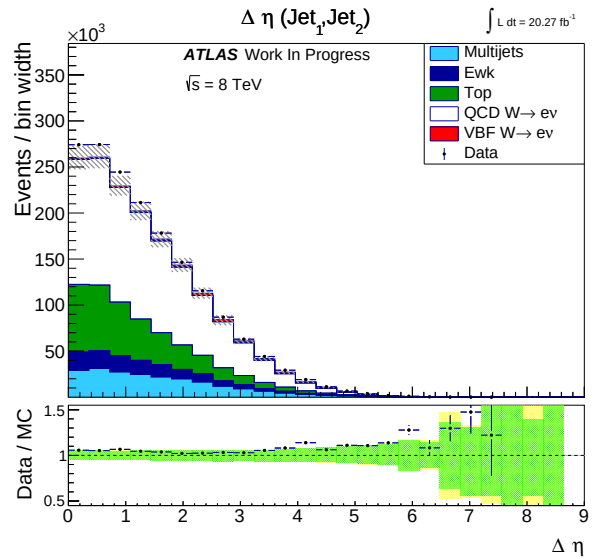






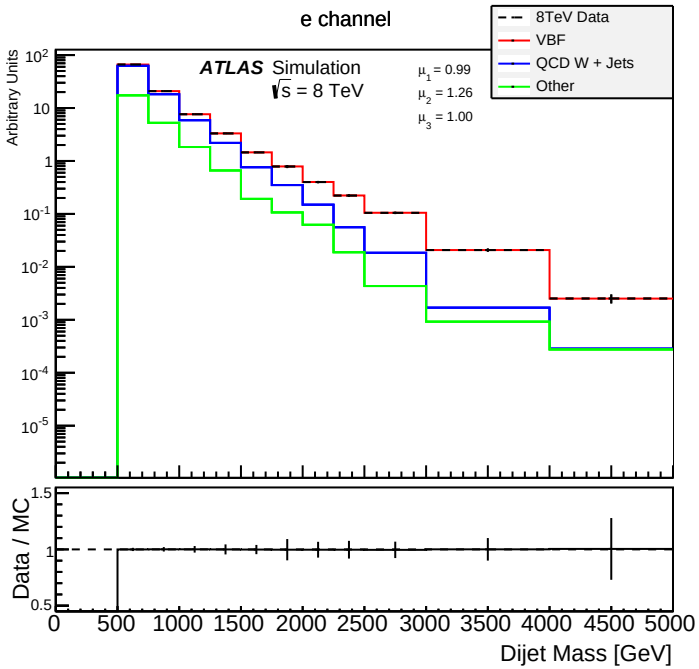


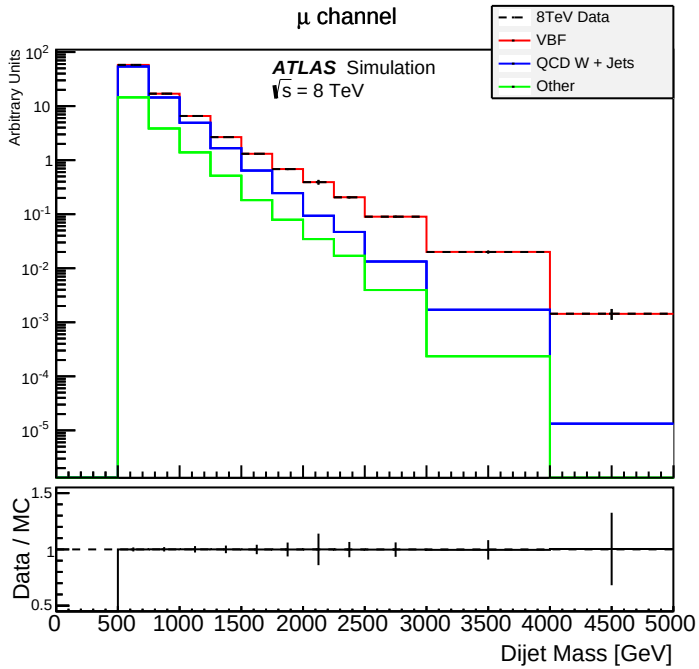




Theory Errors - ATLAS - W

- NLO theory varied generator level samples made with POWHEG for signal and QCD W+Jets
- Signal phase-space ratio of theory variation over nominal fitted with 2nd order fit
- Nominal sample reweighted using function and fit performed of nominal templates to reweighted
- Plots show fit for W+Jets μ_R down fluctuation - 26% normalisation change





CJV Uncertainty

- To quantify CJV (/centrality) uncertainty - Stewart-Tackmann approach is used
- Calculate the scale errors for no CJV and anti-CJV case and combine
- Overestimate of errors but safe approach

$$\sigma_{CJV} = \sigma_{\geq 2Jets} - \sigma_{!CJV} \tag{2}$$

- The corresponding, uncorrelated uncertainties are then:

$$\Delta\sigma_{CJV} = \sqrt{\Delta\sigma^2_{\geq 2Jets} + \Delta\sigma^2_{!CJV}} \tag{3}$$

- Scale errors on the expected fiducial cross-section are $313.82 \pm 0.52(\text{stat.}) \pm 6.71(\text{scale})$ fb.

ATLAS Z - Theory Systematics

- Generator level samples used for μ_R, μ_F, MPI, shower and CKKW for both VBF and QCD Z+Jets
- Signal:
  - Theory variation is Gaussian fluctuated (search phase-space)
  - Nominal reweighted to variation
  - Fit repeated and N_{EWK} extracted in 1000 such pseudoexperiments
  - Resulting distribution of N_{EWK} fitted with Gaussian and difference between mean and nominal N_{EWK} taken as uncertainty
- QCD Z+Jets:
  - Variation in search and control regions fluctuated by Gaussians
  - Ratios taken to nominal in both regions
  - Double ratio of search to control found
  - Z+Jets reweighted to double ratio and fit performed, ΔN_{EWK} noted

Source	ΔN_{EWK} (signal)	ΔN_{EWK} (background)
factorization scale	±8.9 %	±2.7 %
renormalization scale	±1.7 %	±6.4 %
CKKW scale	±7.1 %	±2.9 %
Parton shower	±0.4 %	±4.3 %
MPI	±1.7 %	±7.5 %
envelope	±8.9 %	±7.5 %

Figure: Table from [1]

PDF Errors - ATLAS VBF Z

- Nominal PDF for signal and background is CT10
- ATLAS recommendations followed to investigate variations over 3 PDFs
- Considered:
  - CT10 and eigenvector / α_S variations at 68%
  - MSTW2008nlo and eigenvectors
  - NNPDF 2.3 and 100 variations
- Where the eigenvectors are combined with the Hessian prescription
- Signal reweighted to PDF variation, background reweighted to double ratio from search to control ratios as above
- CT10 taken as central value, envelope as error

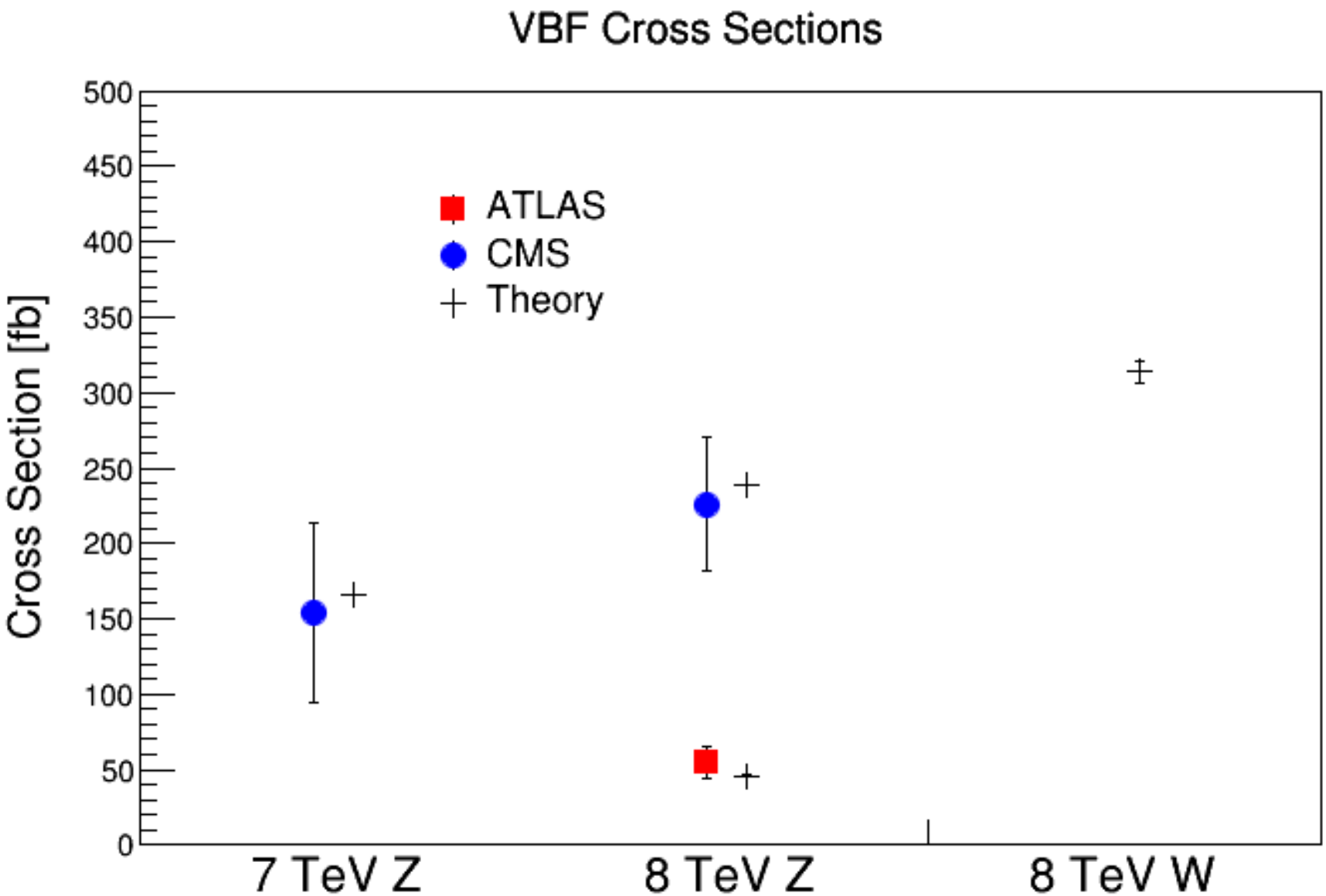
PDF	N_{EWK}
CT10	1657^{+25}_{-31}
NNPDF 2.3	1616 ± 25
MSTW 2008nlo	1651 ± 13
Envelope	1657^{+25}_{-65}

- Total PDF error: +1.5%, -3.9%

CMS Z Theory Errors

- CMS Z analysis fits to BDT and consider the following errors from theory sources
- On VBF Signal:
  - PDF errors - CTEQ6L1 and associated eigenvectors at 90% CL and added in quadrature
  - Renom. and Fact. scales
    - LO $\pm 4\%$ normalisation changes, NLO $= \pm 0.5\%$
    - Reweight kinematics using dilepton p_T on event-by-event basis
  - PDF and QCD scale errors on diboson and top background processes - allowed to float about these in fits
- QCD Z+Jets errors reduced by using data-driven template of γjj selection
- Normalisation allowed to float with nuisance parameter
- Shape allowed to change by statistics of data-driven technique and contamination by EWK γjj

Cross-section summary



Conclusions

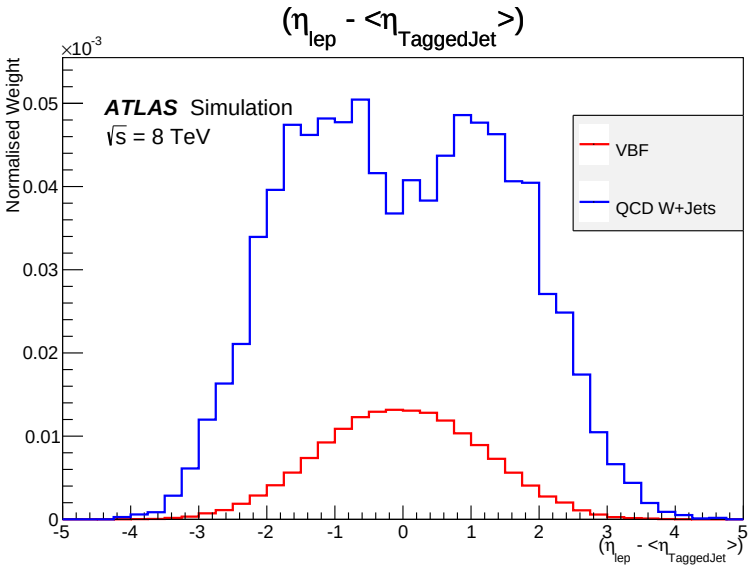
- Continuous centrality variables may offer increased purity
- Signal Extraction through M_{jj} fits for ATLAS, MVAs for CMS
- Theory errors evaulated with generator level samples
- Effect significantly reduced by using control region to constrain MC templates
- PDF errors evaluated by recalculating event weight and using above control-region procedure

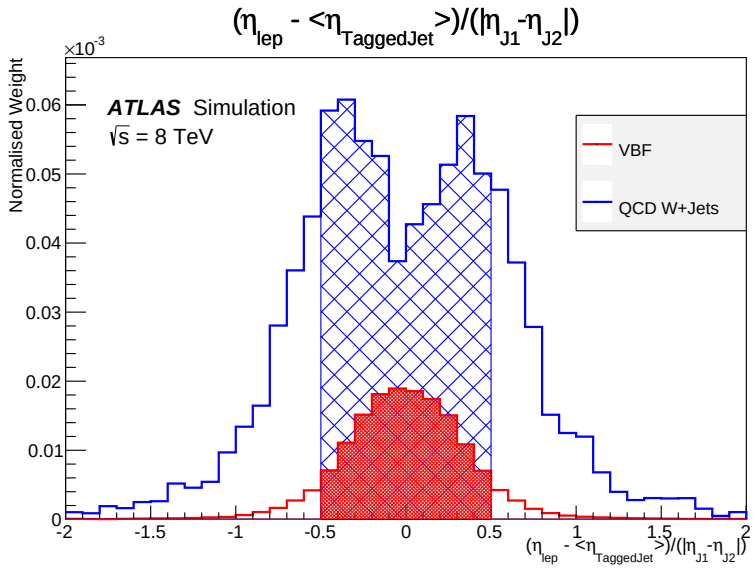
Backup

Centralities comparison

Left: no gap size normalisation

Right: With normalisation





References

ATLAS Collaboration

Measurement of the electroweak production of dijets in association with a Z-boson and distributions sensitive to vector boson fusion in proton-proton collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector

10.1007/JHEP04(2014)031, Link

CMS Collaboration

Measurement of the hadronic activity in events with a Z and two jets and extraction of the cross section for the electroweak production of a Z with two jets in pp collisions at $\sqrt{s} = 7$ TeV

10.1007/JHEP10(2013)062, Link

CMS Collaboration

Measurement of pure electroweak production of a Z boson in association with two forward/backward jets in proton-proton collisions at $\sqrt{s} = 8$ TeV

CMS-PAS-FSQ-12-035 (2013), Link