Comparison of ATLAS and CMS VBS Monte Carlo simulation

(studies performed within the LHC EWK physics working group)

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LHC EWK Multiboson Discussion

[1]**CMS Collaboration** [2]**ATLAS Collaboration**

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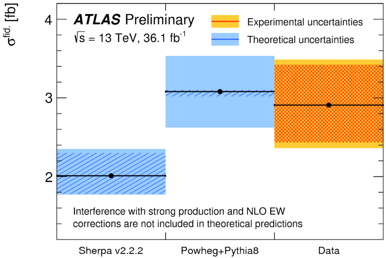
Overview

- VBS processes: interesting probes to study EWSB & BSM scenarios
- Multiboson & VBS processes entering the precision era

- VBS signal strength extracted using fits → based on SM MC predictions
- Potentially large differences depending on used MC configurations (shower, color-flow, tuning, etc.)
- Different interference/NLO EW correction treatments

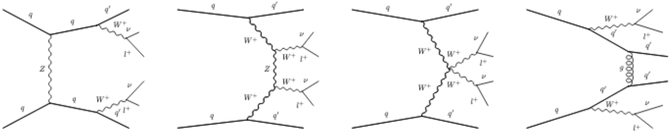


How different are ATLAS & CMS??

- Common phase space cuts required to start with
- Step 1: Compare MC predictions → easier with "dressed leptons" → RIVET-based

VBS with same-sign WW (ssWW) final state (*briefly*)

- ssWW produced in association with two jets via the EW interaction
- Tagged jets with a large rapidity separation and a large dijet mass
- Same-sign lepton events → reduces contribution from strong production of WW → clean experimental signature
- Largest background contribution from nonprompt lepton productions
- An excess of events with respect to SM expectation could signal the presence of anomalous quartic gauge couplings



Observation by both ATLAS & CMS based on 13 TeV data

- ATLAS: observed (expected) signal significance of 6.9 (4.6) s.d.
- CMS: observed (expected) signal significance 5.5 (5.7) s.d.

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Abstract

This is a collection of comparison plots, giving an overview over the different samples and settings employed at the ATLAS and CMS experiments to model VBS processes. This document contains a set of plots showing preliminary results of the comparison.

What's in the NOTE??

Introduction

This is a collection of plots comparing nominal and alternative MC samples of same-sign WW VBS (ssWW) production by the ATLAS and CMS experiments, observed at $\sqrt{s} = 13$ TeV by both the ATLAS [1] and the CMS Collaborations [2]. The comparisons are made employing the nominal as well as alternative samples used in these measurements as well as samples produced for further studies (by the VBScan COST Action [3] and the ATLAS Collaboration [4]). A common phase space region is chosen targeting the $W^{\pm}W^{\pm}$ events, where one W boson decays to an electron and the other to a muon. The most-sensitive distributions to the ssWW are scattering compared between the different MC samples, which include: inclusive and exclusive jet multiplicities, the invariant mass of the tagging jets, m_{jj}, the difference in jet pseudorapidity of the two tagging jets, $\Delta\eta_{jj}$, p_T of a possible third jet its centrality ($z(j3)$) in the event. Also reported are the measured fiducial cross-sections for different MC samples in the common phase space region.

$$z_{j3} = \frac{|\eta_{j3} - \frac{\eta_{j1}+\eta_{j2}}{2}|}{|\eta_{j1} - \eta_{j2}|}$$

Event selection criteria for the fiducial region

Kinematic event selection (Table 1) relies on the selection of $W^{\pm}W^{\pm}jj$ events, where one W boson decays to an electron and the other to a muon. It is based on the Rivet routine developed for Ref. [1][1]

Selection requirement	Selection value
dressed leptons with dressing cone of $\Delta R = 0.1$ and minimum p_{T}^{ℓ}	> 20 GeV
η^{ℓ}	$\lvert\eta^{\ell}\rvert \leq 2.5$
Charge of leading electron and muon	$c^{e} \times c^{\mu} > 0$
minimum ΔR between any of the leptons	$\Delta R \geq 0.3$
Jets, anti-k_t with $R = 0.4$, excluding leptons and neutrinos	$p_{\mathrm{T}} > 30$ GeV, $\lvert\eta\rvert < 4.5$
Minimum jet distance to lepton, otherwise jet is removed	$\Delta R \geq 0.3$
Minimum number of jets with above criteria	2
distance in pseudo-rapidity of the jets	$\Delta\eta_{jj} \geq 2.5$
$p_{\mathrm{T}}^{\mathrm{miss}}$	> 40 GeV
Signal region: invariant mass of jet system	$m_{jj} \geq 500$ GeV
Control region: invariant mass of jet system	200GeV $< m_{jj} < 500$ GeV

Table 1: Summary of selection criteria for the ssWW fiducial region phase space.

[1] Available online: https://vbscan.fisica.unimib.it/MCcomparison/VBScomparison-data

List of MC samples

Nominal samples from the resp. publications: SHERPA (ATLAS) & MG5_AMC@NLO +PYTHIA8 (CMS) samples, whilst POWHEG+PYTHIA8 (ATLAS) & POWHEG+PYTHIA8 (CMS) were used as alternative samples for systematic studies. This study compares these samples except for the POWHEG+PYTHIA8 (CMS) one as well as alternative ATLAS samples from Ref. [4], MG5_AMC@NLO +PYTHIA8-DIPOLE-RECOIL (ATLAS) & POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS)[1], & the POWHEG+PYTHIA8 (VBScan) sample from [3].

Sample name	Generator	μ-scale	Shower	Tune	PDF	further settings
			ATLAS			
Sherpa (ATLAS)	SHERPA V2.2.2	dynamic scale, m_{WW}	internal	internal	NNPDF3.0-NNLO	multileg-LO, exactly six EW vertices with one additional parton at LO accuracy in QCD
PW+Py8 (ATLAS)	POWHEG V2, VBS approx.	fixed scale, m_W	PYTHIA 8.212	AZNLO	NNPDF3.0-NLO	NLO
PW+Py8 dipole-recoil (ATLAS)	POWHEG V2	fixed scale, m_W	PYTHIA 8.235	AZNLO	NNPDF3.0-NLO	Dipole Recoil [5]
MG5+Py8 dipole-recoil (ATLAS)	MG5_AMCNLO v2.6.2	dynamic scale, $\sqrt{pT^{\text{jet1}}pT^{\text{jet1}}}$	PYTHIA 8.235	A14	NNPDF3.0-NLO	LO, Dipole Recoil [5]
			CMS			
MG5+Py8 (CMS)	MG5_AMCNLO v2.3.3	dynamic scale, using a 2→2 topology from the clustered external state	PYTHIA 8.212	CUETP8M1 [6]	NNPDF3.0-LO	LO, exactly six EW vertices
			generic samples (VBScan)			
PW+Py8 (VBScan)	POWHEG V2	dynamic scale, $\sqrt{pT^{\text{jet1}}pT^{\text{jet2}}}$	PYTHIA 8.230	Monash	NNPDF3.0-NLO	NLO

Table 2: Summary of the samples that are compared in this note

[1] This sample uses the new dipole-recoil scheme [5] which reduces radiation in the central rapidity region.

Fiducial cross-sections

ATLAS		
Sample name	Fiducial cross-section [fb] $W^+W^+ \to e^+\mu^+\nu_e\nu_\mu$	Fiducial cross-section [fb] $W^\pm W^\pm \to e^\pm\mu^\pm\nu_e\nu_\mu$
Sherpa (ATLAS)	0.968 ± 0.005	1.136 ± 0.005
PW+Py8 (ATLAS)	1.320 ± 0.009	1.768 ± 0.009
PW+Py8 dipole-recoil (ATLAS)	1.322 ± 0.009	1.769 ± 0.009
MG5+Py8 dipole-recoil (ATLAS)	1.313 ± 0.028	1.734 ± 0.028
CMS		
MG5+Py8 (CMS)	1.281 ± 0.018	1.707 ± 0.021
generic samples (VBScan)		
PW+Py8 (VBScan)	1.364 ± 0.0004	n/a

Table 2: Fiducial cross-sections for different samples. Since the VBScan studies were only conducted on W^+W^+ samples, fiducial cross-sections are also given for the W^+W^+ case. The given uncertainties are statistical only.

In general, the fiducial cross-sections agree reasonably well. SHERPA (ATLAS) has a 30% lower cross-section than the other ATLAS samples due to a known issue. SHERPA VBS samples suffer from a non-optimal setting of the color flow setup for the parton shower on top of VBS-like scattering processes, leading to an excess of central emissions from the parton shower. The same-sign SHERPA sample includes one additional jet in the matrix element, thus correcting for the shape effects of this shower mismodelling, but leading to significantly reduced predicted cross-sections due to the large suppression from spuriously large Sudakov factors [7]. The MG5_AMC@NLO +PYTHIA8 (CMS) sample has a lower cross-sections than the other samples.

Comparisons of Powheg samples-I

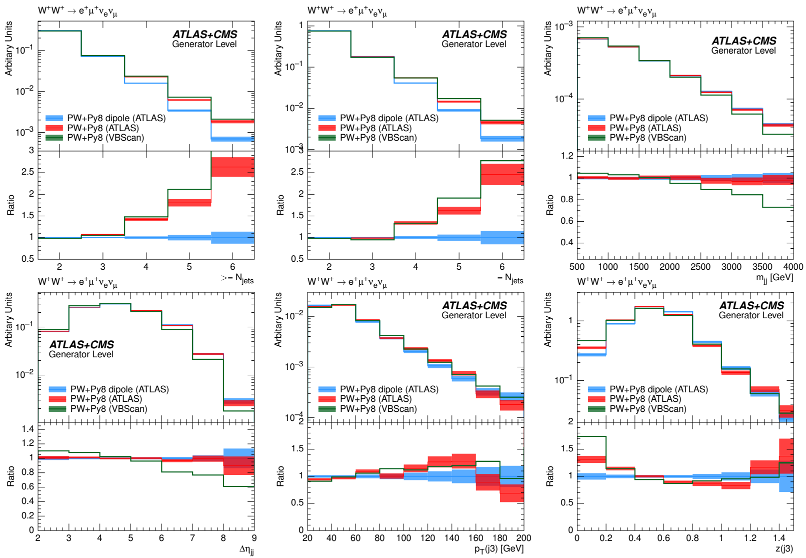

Fig. 1: Comparison of the inclusive and exclusive jet multiplicities, $\Delta\eta_{jj}$ and m_{jj} and p_T as well as the centrality of the third jet are compared for the available Powheg samples. All uncertainty bands are statistical only. The samples have been normalised to unity.

Comparisons of Powheg samples-II

Fig. 1 compares the normalised differential distributions for $W^+W^+ \to e^+\mu^+\nu_e\nu_\mu$ production as predicted by the various Powheg samples. As reference sample, the POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS) sample with the new dipole-recoil scheme is used. As expected, the POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS) sample with the new dipole-recoil scheme has a significantly smaller jet multiplicity compared to the other sam-ples. Its m_{jj} and $\Delta\eta_{jj}$ distribution however agree very well with the nominal POWHEG+PYTHIA8 (ATLAS) sample, whilst the POWHEG+PYTHIA8 (VBScan) has a much softer mjj spectrum and more central tagging jets (smaller $\Delta\eta_{jj}$). The third jet has a much smaller centrality for the POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS) sample with the new dipole-recoil scheme, which again is expected.

Comparisons of nominal and alternative samples-I

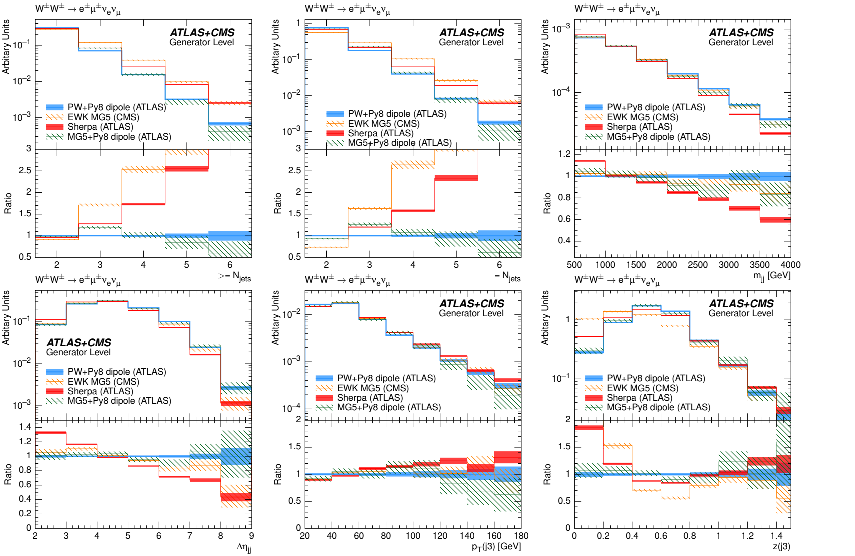

Fig. 2: Comparison of the inclusive and exclusive jet multiplicities, $\Delta\eta_{jj}$ and m_{jj} and p_T as well as the centrality of the third jet are compared for the nominal and alternative samples. All uncertainty bands are statistical only. The samples have been normalised to unity.

Comparisons of nominal and alternative samples-II

Fig. 2 compares differential distributions for the nominal and alternative samples used by the ATLAS and CMS analyses for WW ee production. As reference sample, the POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS) sample is used. Again it predicts a much lower inclusive and exclusive jet multiplicity compared to the other samples with the exception of the MG5_AMC@NLO +PYTHIA8-DIPOLE-RECOIL (ATLAS), that also uses the dipole-recoil scheme. m_{jj} distribution is the softest for the SHERPA (ATLAS) sample and falls off much quicker than the others, whilst the other samples are more similar. Only the MG5_AMC@NLO +PYTHIA8 (CMS) sample tends to exhibt a slight smaller rapidity gap compared to the dipole samples. The third jet is also much more central for SHERPA (ATLAS) and the MG5_AMC@NLO +PYTHIA8 (CMS) sample and has a harder p_T spectrum.

Comparisons of QCD background samples

QCD control region with $200 < m_{jj} \leq 500$ GeV

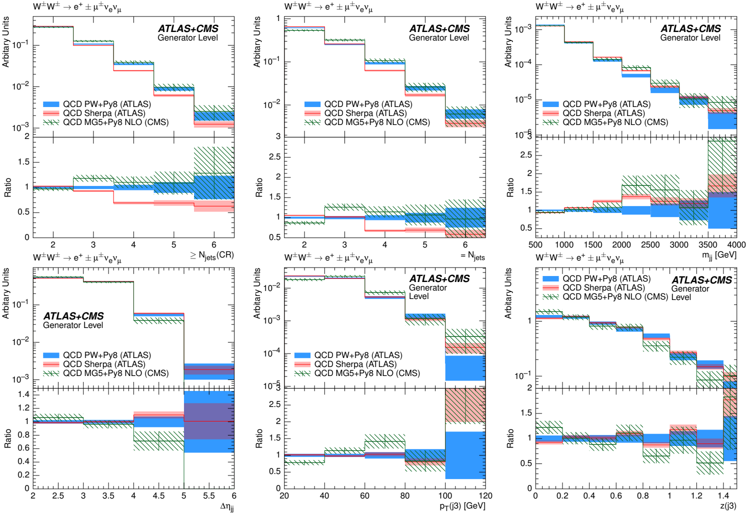

Fig. 3: Comparison of the inclusive and exclusive jet multiplicities, $\Delta\eta_{jj}$ and m_{jj} and p_T as well as the centrality of the third jet are compared for the QCD samples in the low-m_{jj} control region. (Note, that $m_{jj} < 500$ GeV cut is not applied for the m_{jj} distribution). All uncertainty bands are statistical only. The samples have been normalised to unity.

Summary & Review Status

Conclusions

Distributions from MC samples for same-sign WW production used in the respective measurements by the ATLAS and CMS Collaborations and in further studies have been compared.

Review Status

- Analysis note already approved by ATLAS
- From the CMS side, analysis note already reviewed by CMS GENERATOR GROUP experts. Pre-approval today in the SMP-VV meeting
- Next step would need to get the note approved in one of the CMS WEEKLY GENERAL MEETINGS which would need a set of slides with exact information from the NOTE and a twiki with the same details

References

[1] ATLAS Collaboration, “Observation of electroweak production of a same-sign W boson pair in association with two jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector,” 2019.

[2] CMS Collaboration, “Observation of electroweak production of same-sign W boson pairs in the two jet and two same-sign lepton final state in proton-proton collisions at $\sqrt{s} = 13$ TeV,” Phys. Rev. Lett., vol. 120, no. 8, p. 081801, 2018.

[3] A. Ballestrero et al., “Precise predictions for same-sign W-boson scattering at the LHC,” Eur. Phys. J., vol. C78, no. 8, p. 671, 2018.

[4] “Modelling of the vector boson scattering process $pp \rightarrow W^{\pm}W^{\pm}jj$ in Monte Carlo generators in ATLAS,” Tech. Rep. ATL-PHYS-PUB-2019-004, CERN, Geneva, Jan 2019.

[5] B. Cabouat and T. Sjöstrand, “Some Dipole Shower Studies,” Eur. Phys. J., vol. C78, no. 3, p. 226, 2018.

[6] CMS Collaboration, “Event generator tunes obtained from underlying event and multiparton scattering measurements,” Eur. Phys. J. C, vol. 76, p. 155, 2016.

[7] Hoche, “Status of sherpa event generator.” Multi-Boson Interactions Workshop at the University of Michigan, August 2018.