

WG3 Summary

Philip Sommer, University of Sheffield
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Mandate

WG3: experimental measurements	
Main aim	Foster the optimal deployment of VBS studies in the hadron collider experiments data analyses.
Tasks & Deliverables	<ul style="list-style-type: none">● Promote the development of VBS-specific target-oriented reconstruction algorithms, pile-up-resilient, adapted to high-multiplicity environments● Foster the deployment of the data analyses in the experiments● Perform a joint interpretation of the public results in light of the Action knowledge
Milestones	<ul style="list-style-type: none">● First tests of dedicated reconstruction algorithms at the end of the year 1● First coherent data analyses deployment, following the recommendations of WG1 and WG2, within year 2
	<ul style="list-style-type: none">● Updating of the analyses with new data throughout the Action. Final results interpretation in year 4





Particle reconstruction

Strong focus on jet reconstruction:

- Flavour tagging, quark/gluon discrimination
- Pileup mitigation
- Substructure techniques

WG3 at Split Meeting

Talks by experts in all
early in-person meetings

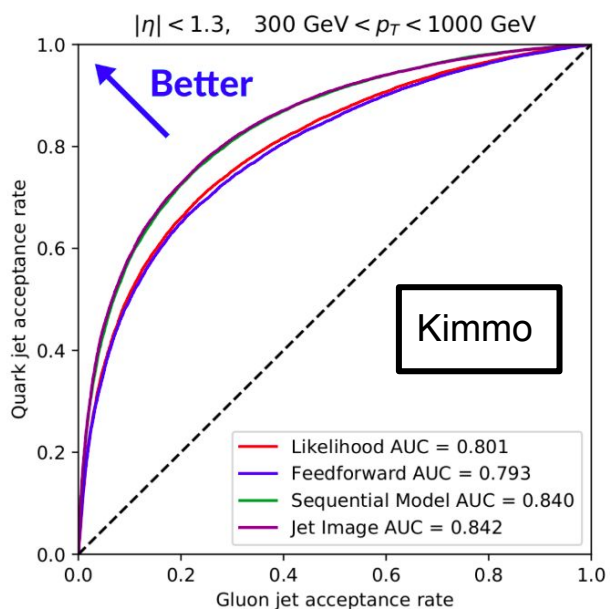
WG3 introduction	<i>Lucrezia Stella Bruni et al.</i>	
<i>Split, Croatia</i>		16:30 - 16:40
Boosted jets tagging techniques in ATLAS	<i>Christoph Falk Anders</i>	
<i>Split, Croatia</i>		16:40 - 17:05
Boosted jets tagging techniques in CMS	<i>Andreas Hinzmann</i>	
<i>Split, Croatia</i>		17:05 - 17:30
Quark/gluon discrimination techniques in ATLAS	<i>Johannes Balz</i>	
<i>Split, Croatia</i>		17:30 - 17:55
Quark/gluon discrimination and systematic uncertainties	<i>Philippe Gras</i>	
<i>Split, Croatia</i>		17:55 - 18:20

Particle reconstruction

- Review of existing reco algorithms
- Training on theoretical aspects of quark fragmentation to a jet
- Tutorials on machine learning techniques
- Understanding of limitations of existing reco algorithms, that were accounted for in analyses






See e.g. our workshop on “New techniques in particle reconstruction for VBS” in Krakow:

<https://indico.cern.ch/event/751034/>



Data analysis in experiments

When VBSCan started, none of the VBS processes had been experimentally confirmed!

	ATLAS	CMS
same-sign WWjj	6.5 σ 	>>5 σ
WZjj	5.3 σ 	6.8 σ 
ZZjj	5.5 σ	4.0 σ 
Wyjj	---	5.3 σ
Zyjj	9.7 σ 	9.4 σ

Today, all relevant diagrams are observed (W^+W^- and semi-leptonic VV are still missing, but are not fundamentally different)

ATLAS+CMS Comparisons

- Forum for detailed comparison of corresponding ATLAS and CMS analyses, with talks by the relevant experts from each experiment
- Discussing all aspects
 - Selection
 - Bkg estimates
 - Systematics
 - MC predictions

⇒ Last few editions were held together with the LHC EW multiboson group

Main sources of systematic uncertainty

Iro

ATLAS WWjj analysis

Source	Impact [%]
Experimental	
Electron energy scale and resolution, and efficiency	0.6
Muon momentum scale and resolution, and efficiency	1.3
Jet energy and E_T^{miss} scale and resolution	3.2
b -tagging inefficiency	2.1
Pileup modeling	1.6
Background, statistical	3.2
Background, misid. leptons	3.3
Background, charge misrec.	0.3
Background, other	1.8
Theory modeling	
$W^\pm W^\pm jj$ electroweak-strong interference	1.0
$W^\pm W^\pm jj$ electroweak, EW corrections	1.4
$W^\pm W^\pm jj$ electroweak, shower, scale, PDF & α_s	2.8
$W^\pm W^\pm jj$ strong	2.9
WZ	3.3
Luminosity	2.4

Main unc:

- jet and E_T^{miss} reconstruction and calibration
- Contamination from WZ events
- Fake background

CMS: 7% on the yields

CMS: 30% on the yields

CMS: 20–40%, on the yields (statistically dominated)

QCD scale: 10-15% for signal

PDF uncertainties: 1-2%

scale and PDF considered shape (and normalization) uncertainties

CMS: similar effect

Parton shower uncertainty:

- $W^\pm W^\pm$ EW and QCD: internal shower variations in Sherpa (larger effect than Sherpa vs Powheg+Pythia)
- WZ: Powheg-Box v2 generator at NLO, interfaced either to Pythia 8.210 or Herwig++ 2.7.1

Additional shape uncertainty for:

- NLO EW correction (provided in m_{jj} bins)
- QCD-EW interference (computed using MadGraph, as in WZjj analysis)

ATLAS+CMS Comparisons

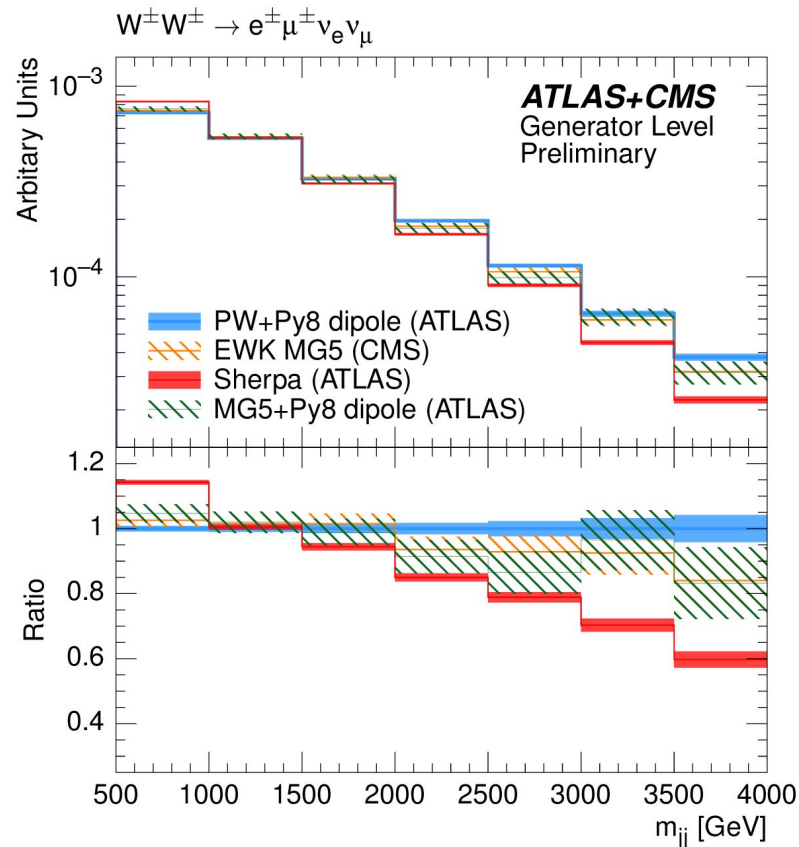
Comparisons of our theory modelling:

LHCEWMB Note:

[ATL-PHYS-PUB-2020-026](#)

⇒ Will be incorporated in a future Yellow report

The analyses in the experiments have greatly benefited from the personal relations formed in VBSCan, between ATLAS+CMS colleagues, and between experimentalists and theorists!



Combination Efforts

Early on we had plans for a combined ATLAS+CMS EFT interpretation

- Definition of information/material to be published by experiments
- However, resistance to share internal information on experiment's side

Several meetings discussing tools, available data, ...

see e.g.

<https://indico.cern.ch/event/787344/>

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

The ATLAS collaboration
 Aadoud, Morad , Aad, Gerbers , Abbott, Brad , Abdinov, Orin , Ableson, Dipette , Abolins, Dickinson-Sokolov , Abolins, Steve, Haller , Akeroyd, Osamu , Abrahm, Nicola , Abramowicz, Halina

Phys.Rev.Lett. 123 (2019) 101801, 2019.
<https://doi.org/10.1126/hepdata.34643>

Journal | INSPIRE | BibCross

Abstract (data abstract)
 CMS-LHC: Observation and fiducial cross-section measurement of electroweak production of a same-sign W boson pair in association with two jets using 36.1 fb⁻¹ of data recorded at a center-of-mass energy of $\sqrt{s} = 13$ TeV by the ATLAS detector at the Large Hadron Collider. Events containing two same-sign leptons, electron or muon, and at least two jets with a large invariant mass and rapidity difference, are selected.

Table 2
 Data from Figure 2, page 7
 The m_{jj} distribution for events meeting all selection criteria for the signal region. Signal and individual background distributions are shown...

Table 3
 Data from Figure 3, page 8
 The m_{jj} distribution for events meeting all selection criteria for the signal region is presented after the fit. The fit...

Table 4
 Data from Table 2, page 9
 Impact of different components of systematic uncertainty on the measured fiducial cross section, without taking into account correlations. The impact...

Table 5
 Data from Table 2 of the auxiliary material
 Efficiency correction factor C_{EW} , defined as the ratio of

Table 2
 Data from Figure 2, page 7

cmenergies
 1300

phrases
 Photon-Photon Scattering, W pair Production, Vector Boson Scattering, VBS

reactions
 PP → H+H- JET, JET, PP → W+ W- JET, JET

Dijet invariant mass, m_{jj} [GeV]	Data	Other prompt	WZ	e/γ conversions	Non-prompt	W^+W^+jj strong	W^+W^+jj electroweak
500-700	39 39.27 stat. syst.	1.13 0.8 stat. syst.	12.0 10.8 stat. syst.	5.9 5.8 stat. syst.	6.4 6.4 stat. syst.	2.6 2.6 stat. syst.	10.2 10.2 stat. syst.
700-1000	20 20.4 stat. syst.	0.64 0.64 stat. syst.	6.4 6.4 stat. syst.	3.2 3.2 stat. syst.	5.7 5.8 stat. syst.	2.1 2.1 stat. syst.	13.9 13.9 stat. syst.
1000-1500	28 28.12 stat. syst.	0.42 0.42 stat. syst.	6.0 6.0 stat. syst.	3.1 3.1 stat. syst.	1.9 1.9 stat. syst.	1.5 1.5 stat. syst.	16.9 16.9 stat. syst.

Visualize
 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000
 Dijet invariant mass in 10 GeV

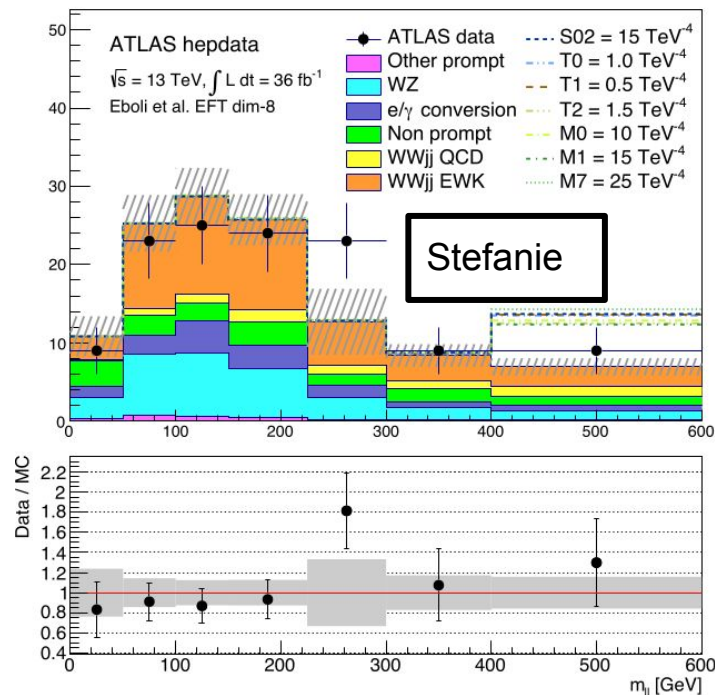
ATLAS Combination

- The reinterpretation of ATLAS VBS same-sign WW and WZ data is still ongoing
- Results anticipated in autumn this year

⇒ However, again this needed to be done as “ATLAS Collaboration” while work was largely carried out with support of VBSCan

EFT model

and unitarisation techniques have very well been aligned between experiments!



Conclusions

- Progress in understanding the limitations of jet-reconstruction techniques in VBS signatures, with promising developments ahead (e.g. phase-II upgrades)
- Strong involvement of the VBSCan community in the experimental confirmation and the measurement of all VBS channels in ATLAS and CMS
- Public material available for reinterpretation (e.g. in a combination); the interpretation within experiments largely aligned