VBS experiments studies: SS WW, WZ, ZZ

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On behalf of ATLAS and CMS collaboration

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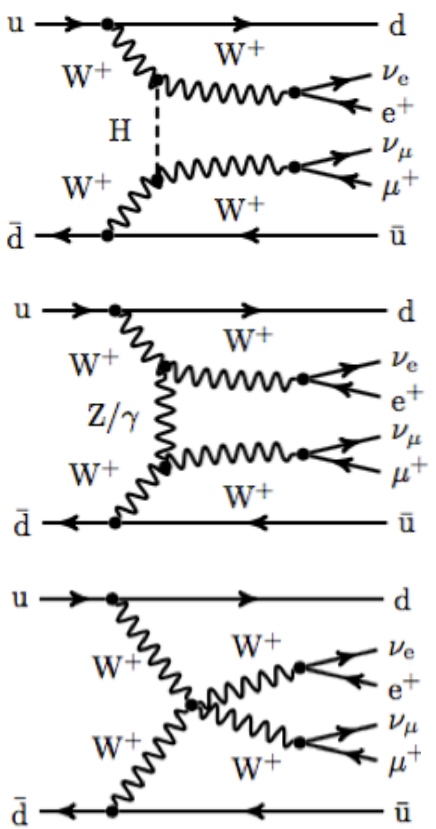
Vector boson scattering at HL-LHC

- Scattering of massive vector bosons provides a unique opportunity to study EWSB, as well as to probe BSM models
- In the SM the longitudinal scattering of massive vector bosons is unitarized by the interference with amplitudes involving the Higgs boson
- Any deviations from SM HV couplings or new physics would break this delicate cancellation: window for new physics
- VBS processes also probing the gauge sector with TGCs and QGCs

Example diagrams for $W^+W^+ \to W^+W^+$

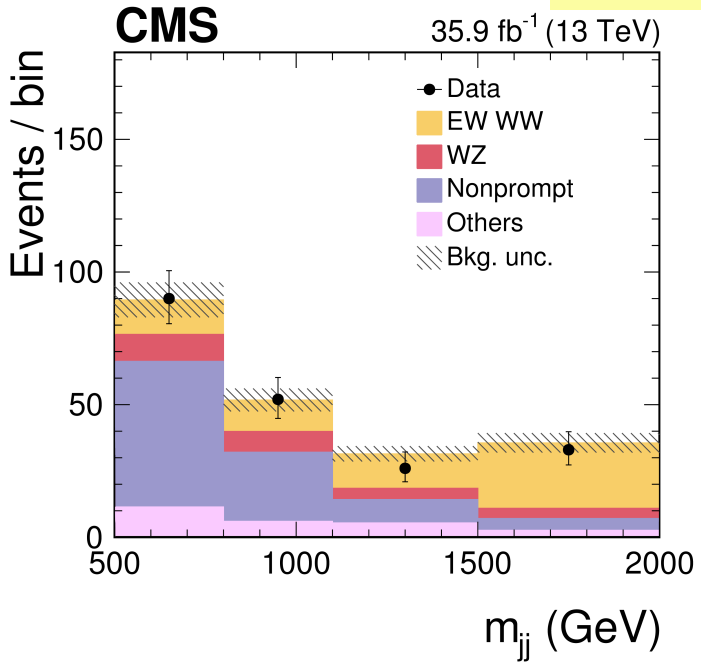


⇒ Massive Vector Boson scattering are rare processes, particularly well suited for HL-LHC

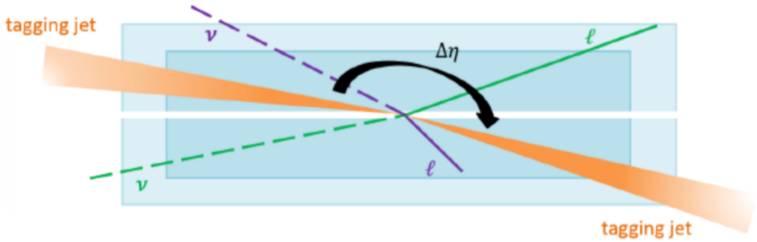
Vector boson scattering studies in Run II

- Most VBS final states already studied at run II, however with available statistics still low:
  - Only one observation of EWK signal
  - Not yet access to longitudinal scattering $V_L V_L \rightarrow V_L V_L$ (production is mainly transverse)
- Nevertheless run II studies pave the road toward $V_L V_L$ scattering measurement
  - VBS signal extraction
  - Polarization fraction extraction

PRL 120, 081801



VBS distinctive signature



- Two high energy (quark) jets in forward and backward directions: large m_{jj} and large $\Delta\eta_{jj}$
- Suppressed hadronic activity in the intermediate η region (rapidity gap)

$\Rightarrow$ $V_L V_L$ scattering will become accessible with HL-LHC luminosity

VBS leptonic final states

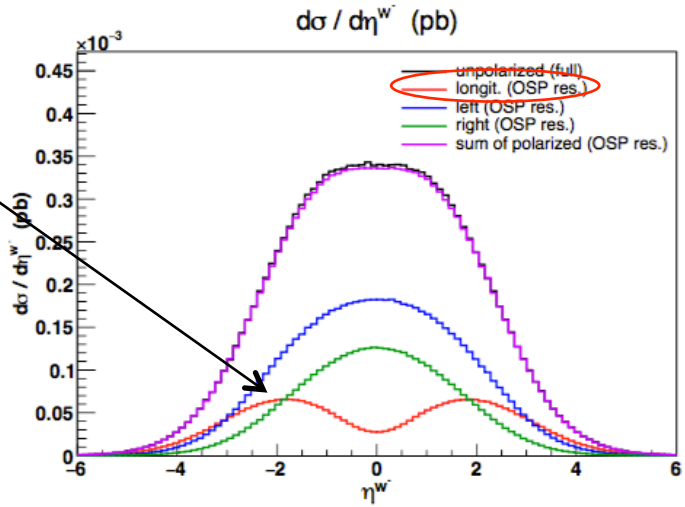
- SS WWjj→2l2njj : best S/B, limited capabilities for polarization measurement/extraction
- WZjj→3lnjj : good compromise for rate and S/B, polarization extraction using m_W constraint
- ZZjj→4ljj channel: fully reconstructible final state, precise access to scattering energy (m_{4l}) and bosons polarizations via lepton angular distributions, very low rate

=> All these final states are currently investigated for HL-LHC prospective

- Recently emphasized that the V_L are dominantly produced in the forward region
- Excellent case for the foreseen increased acceptance for leptons for the upgraded detectors

=> Large η coverage for leptons is important for V_L measurement

arXiv:1710.09339v1



VBS SS WW studies

- **Full sim** study in CMS
  - Similar to published 13 TeV analysis with upgraded detector configuration and 14 TeV
- Full set of MC backgrounds (mostly MadGraph5, ttbar and single t from Powheg)
  - Main backgrounds: ttbar, WZ, WWjj(QCD), but also ZZ, Vgamma, ttV,VVgamma and VVV (also QCD, Z+jets, ..)
- Signal extraction based on m_{jj} distribution
- Goal: significance vs luminosity, investigation of main experimental systematics with realistic simulation

- Extraction of $W_L W_L$ component
- MadGraph samples with polarization information for outgoing Ws
- Passed through **Delphes**
- Goal: discrimination between LL and LT+TT, significance for $W_L W_L$ vs luminosity

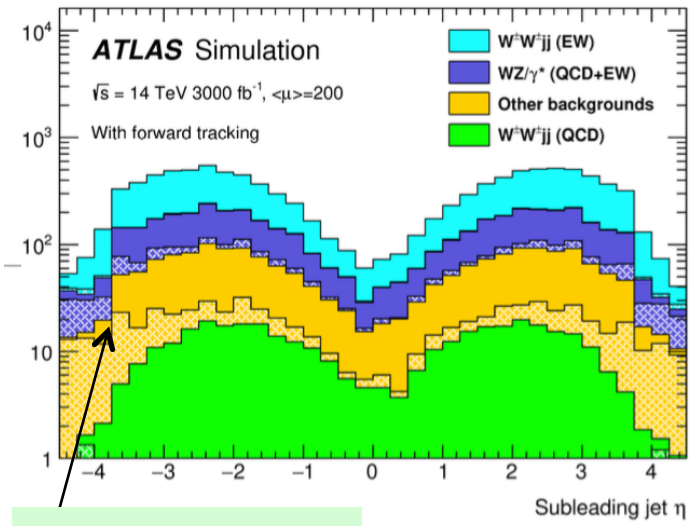
VBS SS WW studies

- **Smeared gen level** study in ATLAS
- Full set of backgrounds from MC (Madgraph, Powheg, Sherpa)
- Cut based signal extraction using m_{jj}
- Goal: optimization of cuts and selection, $W_L W_L$ significance

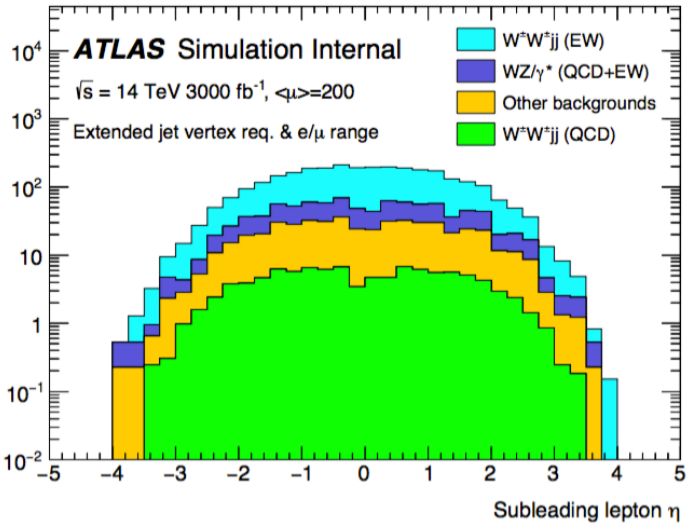
- Also foresee HE-LHC analysis:
- Plan is to use **Delphes**
- Goal: investigate potential of increased beam energy

VBS SS WW studies

- ATLAS investigated in details the gain from extended forward tracking ($|\eta|<4$) and forward muon tagger: extended lepton coverage, extended PU jet rejection



PU contribution



jet vertex requirement to reduce PU contamination / maintain low p_T threshold

ATL-PHYS-PUB-2017-023

η range extension gives additionnal signal but also better WZ rejection

	Signal variation	Background variation	Z_σ variation	$\frac{\Delta\mu}{\mu}$ variation
Extending jet vertex requirement range	+12%	+14%	-1.9%	+1.9%
Extending lepton range	+3.0%	-7.7%	+17%	-14%
Combination	+14%	+7.3%	+15%	-13%

VBS SS WW selections

CMS

- 2 SS leptons p_T>20 GeV, $|\eta|$<3
- 2 jets p_T>50 GeV, $|\eta|$<5
- 3rd lepton veto (p_T>10 GeV)
- m_{ll} Z veto (±15 GeV)
- MET>40 GeV
- b veto
- z_{lepton}<0.75
- m_{jj}>500 GeV
- $|\Delta\eta_{jj}|$>2.5

to reduce WZ

to reduce ttbar

to further enhance VBS signal

⇒ Similar selections overall

(*) rely on tracker extension, ECAL capability, and muon tagger

ATLAS

- 2 SS leptons p_T>25 GeV, $|\eta|$<4 (*)
- 2 jets p_T>30 GeV, $|\eta|$<4.5
- 3rd lepton veto (p_T>7(6) GeV)
- m_{ll} Z veto (±10 GeV)
- MET>40 GeV
- b veto
- centrality>0
- m_{jj}>500 GeV
- $|\Delta\eta_{jj}|$>2.4

VBS WZ studies

- **Smeared gen level** study in ATLAS
- MC backgrounds from Sherpa (signal, WZjj QCD, ZZ+jets), MadGraph + Pythia8 for other backgrounds (ttV, tZ)
- Prospective study based on established Run II analysis

- Ongoing activities and studies:
- Optimization on how low can be the jet p_T cut (from 30 GeV on)
- Cut based and multivariate analyses
- Methods to extract polarization fractions using Sherpa events

- Goal: precision on cross section and differential cross sections, precision on polarization fractions, sensitivity to aQGC
- Interest in studying prospects for HE-LHC

VBS WZ studies

- **Delphes** study in CMS
- Prospective study based on ongoing Run II analysis
- Backgrounds from tV, VV, VVV, reducible backgrounds (V+jets)
- Shape based signal extraction (m_{jj}, $|\Delta\eta_{jj}|$)
- Polarization information from MadGraph (as for WW and ZZ)

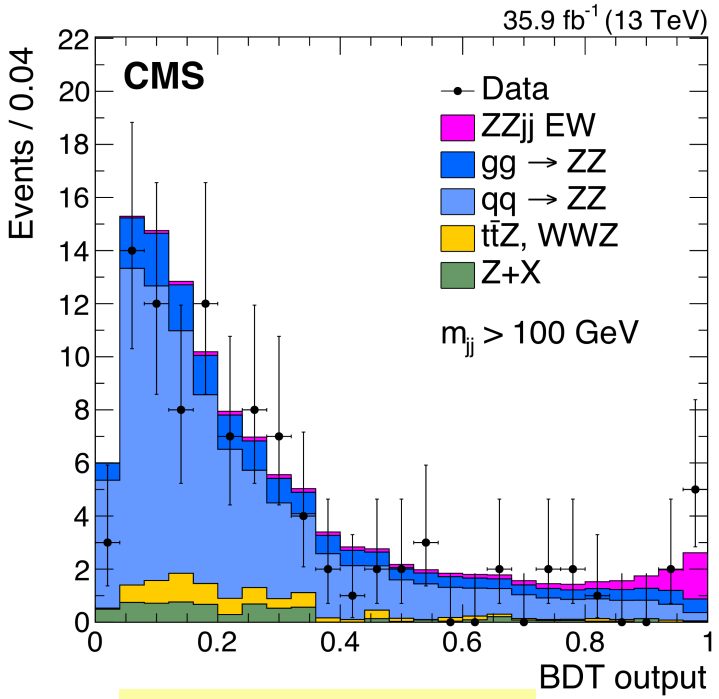
- Goal: sensitivity for VBS WZ vs luminosity, polarization, comparison between full sim and Delphes

VBS ZZ studies

- **Projection** studied in CMS, based on established run II analysis
- Signal extraction based on a BDT to discriminate ZZjj QCD induced contributions
- Extrapolation to 14 TeV and increased η coverage using **Delphes**
- Investigation of possibility to experimentally constrain main theory uncertainties

- Extraction of $Z_L Z_L$ component based on MadGraph samples with polarization information for outgoing Zs passed through **Delphes**

- Goal: significance vs luminosity, effect of main (theory) systematics, discrimination between LL and LT+TT, significance for LL vs luminosity



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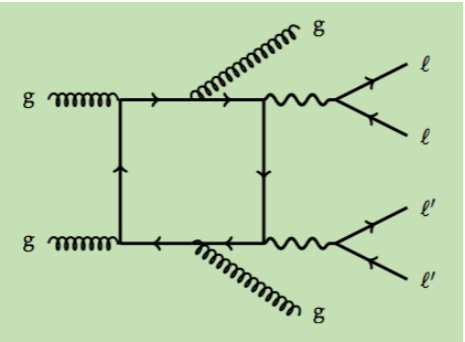
VBS ZZ ATLAS

- **Smeared gen level** study in ATLAS
- Based on 13 TeV MC samples (MadGraph + Pythia 8 for signal, Sherpa for QCD induced background, also alternative samples for EW and QCD)
- Extended lepton acceptance ($|\eta|<4$)
- Cut based signal extraction, potentially do MVA as well (studies already done within ongoing 13 teV analysis)
- Interest in differential distribution and longitudinal studies
- Goal: sensitivity vs luminosity for VBS signal, $Z_L Z_L$ significance

VBS ZZ studies

- Dominant systematics uncertainties from theory
- Dominant systematics from gg→ZZjj modeling (normalization and shape)
  - Challenging territory, gg→ZZ already part of NNLO contribution to pp→ZZ
  - Contributes very significantly: ~10% of inclusive yields but up to ~30% in most signal-like region
- Then comes PDF and QCD scales for VBS signal, QCD scales for qq→ZZjj

- Important to assess here what could be a reasonable projection for theory uncertainties at HL-LHC time, in particular for gg→ZZjj



Conclusion for VBS WW, WZ and ZZ

- Main interest is in the extraction of $V_L V_L$ scattering at 14 TeV
- Also studies on HE-LHC and aQGC limits at HL-LHC

- Good coverage of VBS VV fully leptonic final states from both experiments
- We will likely need to combine the different channels to get sensitivity to $V_L V_L$ in fully leptonic final states
- Various complementary tools used: gen level analysis with smeared momenta, Delphes, full simulation and extrapolation from Run II results

- Extended lepton acceptance with upgraded detectors is important (especially for WZ and ZZ)
- Input needed for projected theory systematics for VBS ZZ ($gg \rightarrow ZZjj$)

Backup