ATLAS/CMS perspectives for HL/HE-LHC

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CERN Yellow Report & European Strategy

- **HL/HE LHC Physics workshop** initiated by CERN to provide information on the **physics potential of HL/HE LHC for the European Strategy** by 2019
- Coordination: Michelangelo Mangano and Gavin Salam (TH), Andrea Dainese (ALICE), Aleandro Nisati (ATLAS), Andreas Meyer (CMS), Mika Vesterinen (LHCb)
- Several working groups defined, involving experiments/theory:
  - **WG 1: Standard Model**
  - **WG 2: Higgs**
  - **WG 3: Beyond the Standard Model**
  - **WG 4: Flavour**
  - **WG 5: QCD matter at high density**
- Meetings: Quick-off in Oct. 2017, mid-term in June 2018, final jamboree beg. March (CERN)
- More information at https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop

CERN Yellow Report publication status

- Two summaries produced and submitted to the European Strategy Group by Dec. 2018:
  - **The physics potential of HL-LHC**
  - **The physics potential of HE-LHC**
- Full reports available in CDS and being submitted to arXiv (vol.1)
  - **Standard Model physics at the HL-LHC and HE-LHC** (WG1 report), CERN-LPCC-2018-03
  - Higgs physics at the HL-LHC and HE-LHC (WG2 report), CERN-LPCC-2018-04
  - Beyond the Standard Model physics at the HL-LHC and HE-LHC (WG3 report), CERN-LPCC-2018-05
  - Flavour physics at the HL-LHC and HE-LHC (WG4 report), CERN-LPCC-2018-06
  - Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams (WG5 report), CERN-LPCC-2018-07
- **Full collection of notes** by ATLAS and CMS also in CDS and being published in arXiv (vol.2)

CERN Yellow Report VBS analyses

- **ATLAS**
  - https://cds.cern.ch/record/2652447 (ATL-PHYS-PUB-2018-052, ssWW)
  - https://cds.cern.ch/record/2645271 (ATL-PHYS-PUB-2018-023, WZ)
  - https://cds.cern.ch/record/2647219 (ATL-PHYS-PUB-2018-029, ZZ)
  - https://cds.cern.ch/record/2645269 (ATL-PHYS-PUB-2018-022, WV semileptonic)

- **CMS**
  - https://cds.cern.ch/record/2646870 (CMS-PAS-FTR-18-005, ssWW)
  - https://cds.cern.ch/record/2650774 (CMS-PAS-FTR-18-038, WZ)
  - https://cds.cern.ch/record/2650915 (CMS-PAS-FTR-18-014, ZZ)

Prospectives analyses

- Either based on fast simulations or projections from run 2 analyses
- Delphes for CMS and home-made for ATLAS
- Parameterized efficiencies and fake rates from full sim and/or data
- ssWW CMS based on full simulation (Delphes for LL part)

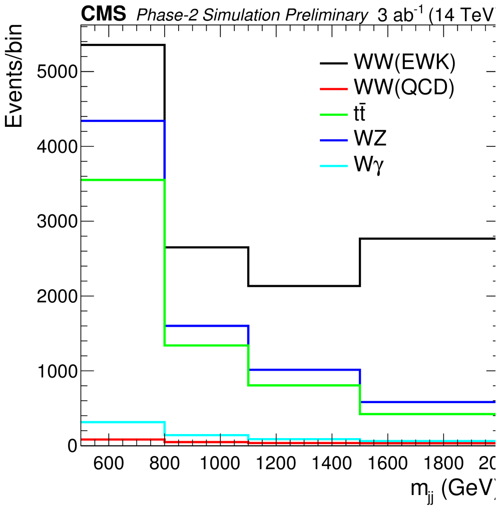
- Machine parameters:
  - **HL-LHC:** $\sqrt{s} = 14$ TeV; $L = 3\ ab^{-1}$, 200 PU ($6\ ab^{-1}$ for ATLAS+CMS)
  - **HE-LHC:** $\sqrt{s} = 27$ TeV; $L = 15\ ab^{-1}$; 800 PU

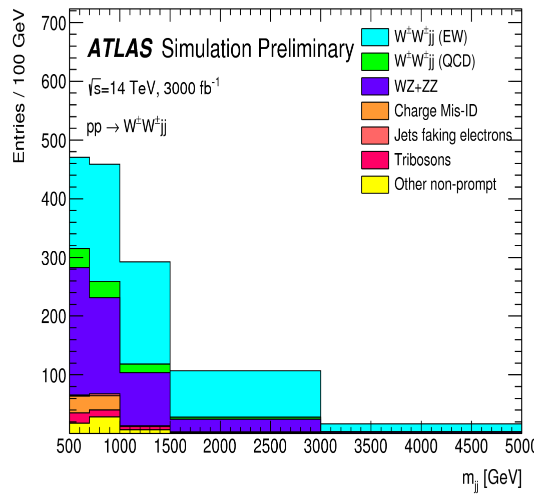
- Personal notes:
- At >15 years from HL-LHC final samples everything here is to be taken with care
- We know that in general we do better than projections. e.g. for Higgs 5σ was reached way before initial projections

SS WW

- ❑ Signal (VBS and non-VBS EW) and QCD backgd from NLO MadGraph
- ❑ Polarisation information using DECAY from v1.5.14
- ❑ Main backgrounds: top (ttbar, single top), diboson (Wγ, WW and WZ) and tri-boson (WWγ, WZγ, WWW, WWZ, WZZ and ZZZ) from NLO Madgraph or POWHEG
- ❑ Full simulation (CMS) or parameterized detector response (ATLAS)

- ❑ Exactly 2 isolated SS leptons
- ❑ >= 2 jets well separated in η
- ❑ Moderate E_T^{miss}
- ❑ m_{ll} to reduce low mass DY (q-misID)
- ❑ Z veto in ee channel (q-misID)
- ❑ Additional lepton veto (WZ)
- ❑ VBS jet topology

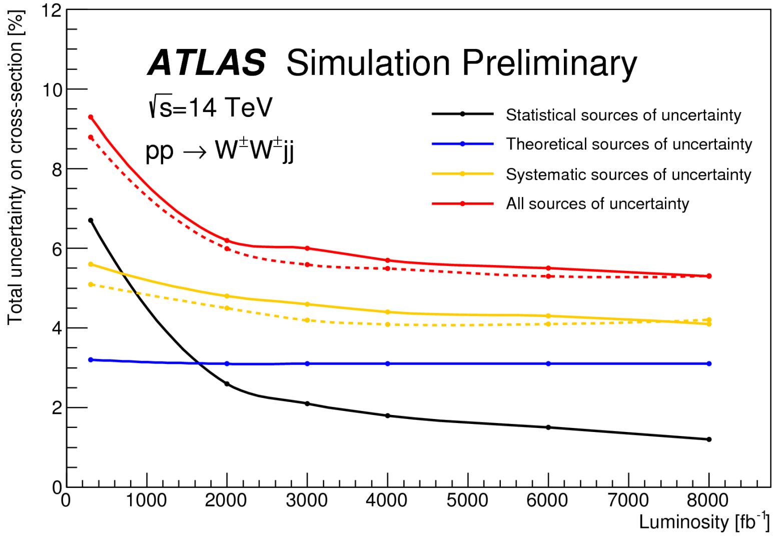


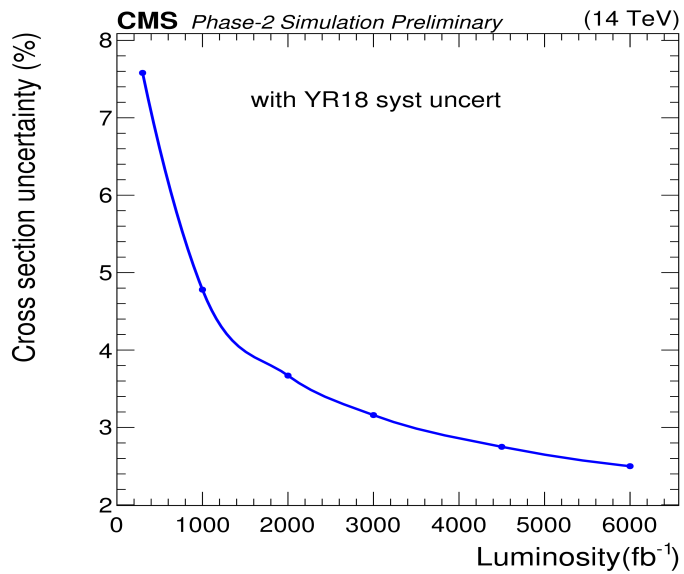


Event selection maximizes signal acceptance (CMS) or minimize fake background (ATLAS)

SS WW uncertainties & cross section

- ❑ Uncertainty in the cross section measurement from binned likelihood fit of m_{jj}
- ❑ CMS: 4.5% total uncertainty @ 3/ab, 3.2% (stat +syst. exp.), 3% theory, 1% lumi
- ❑ ATLAS: experimental syst. from 13 TeV analysis unchanged, uncertainty in backgd rates halved; also uses an 'optimistic' scenario for which uncertainties in non-data driven background are aggressively reduced



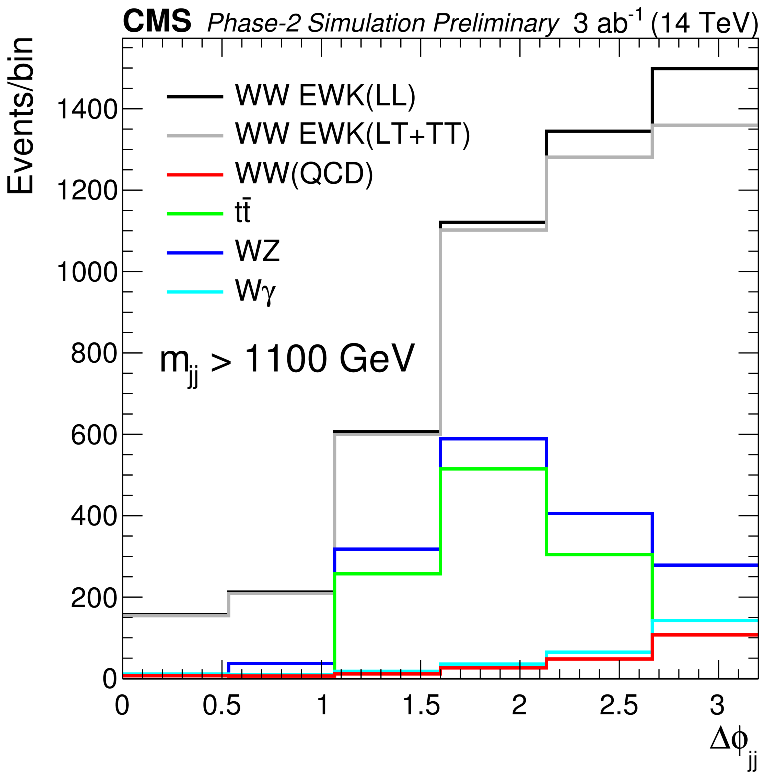


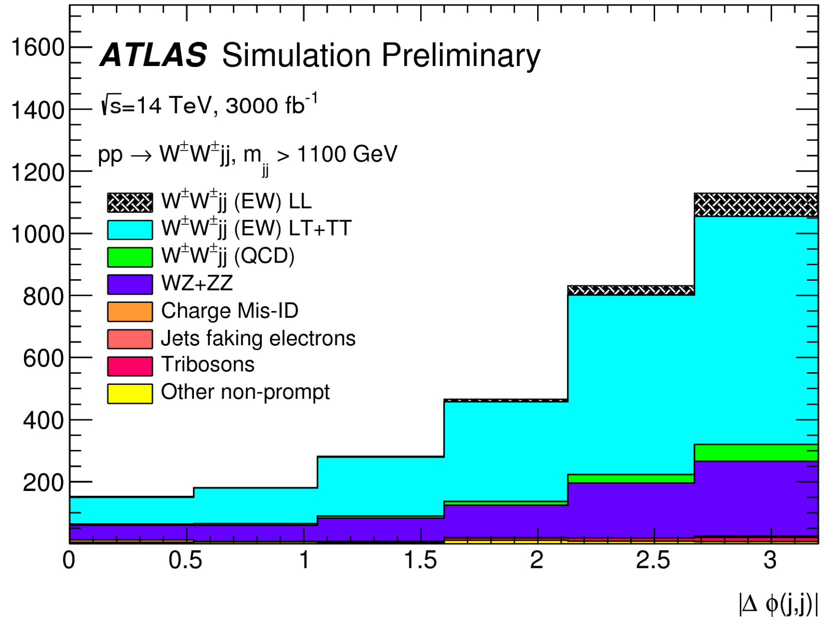
Measurement dominated by systematics (exp. + theory), more conservative in ATLAS

CMS finds a factor 2 decrease with the more stat. (although none of the syst. uncertainties has a statistical origin)

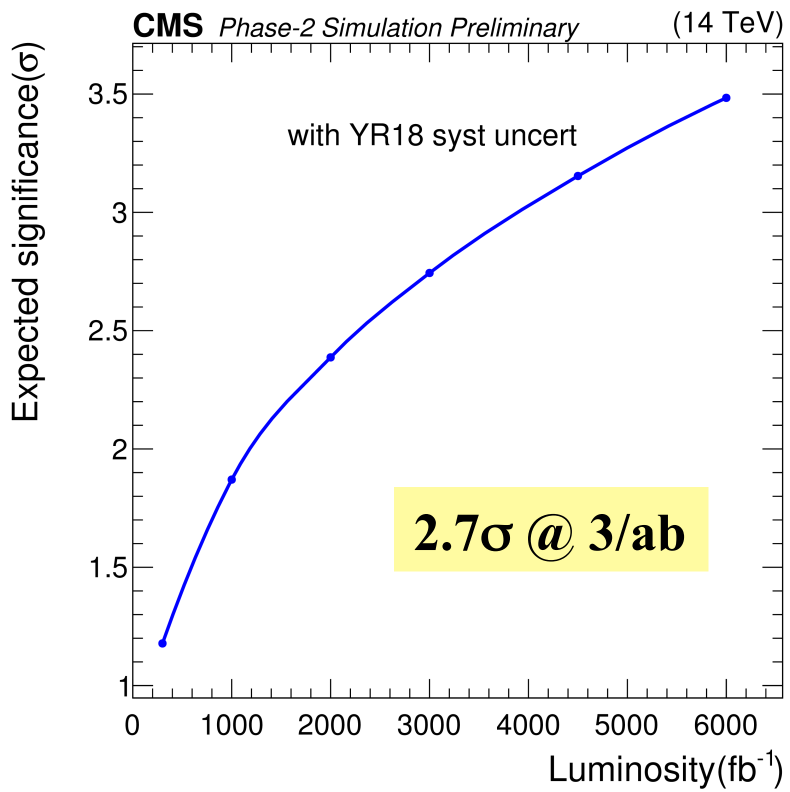
SS $W_L W_L$

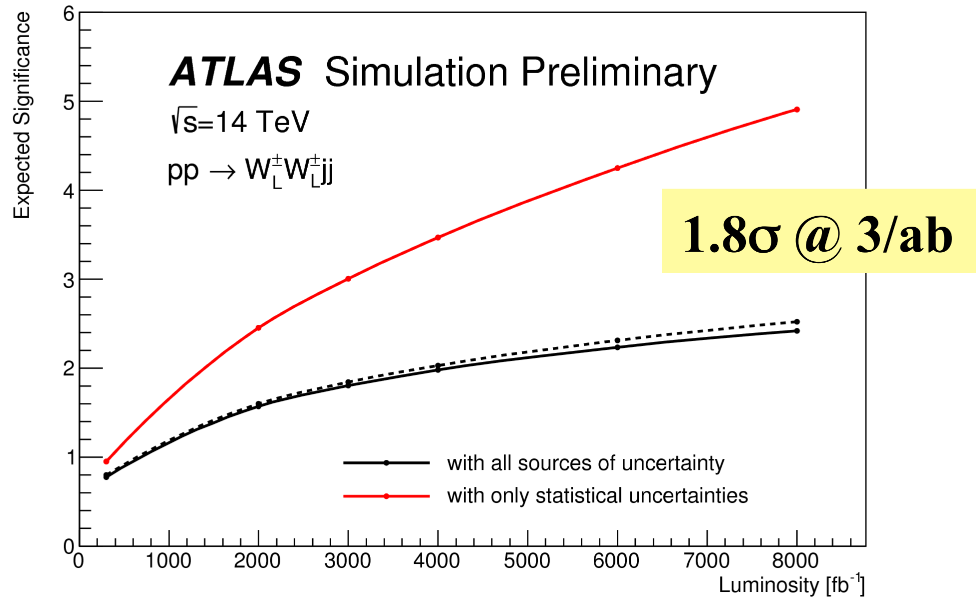
- $\Delta\phi_{jj}$ used to separate LL from LT+TT
- Simultaneous fit of 2D ($\Delta\phi_{jj}$,mjj) distribution
- Low mass region allows to constrain tt/fake background





SS $W_L W_L$





Reducing the signal yield in CMS analysis most sensitive bin to that of ATLAS would reduce sensitivity from 2.7 -> 1.8σ => difference mostly driven by signal event acceptance

WZ fully leptonic

- Results based on fast simulation (ATLAS) and projection based on 13 TeV analysis (CMS)
- Delphes to correct for energy, acceptance and PU effects, as well for LL sensitivity

- Signal from LO Sherpa (v2.2.2) for ATLAS, scaling from MadGraph for CMS
- Main backgds from WZ-QCD, diboson (ZZ, Zgamma), triboson and tV+ttV
- Non-prompt/fake backgrd

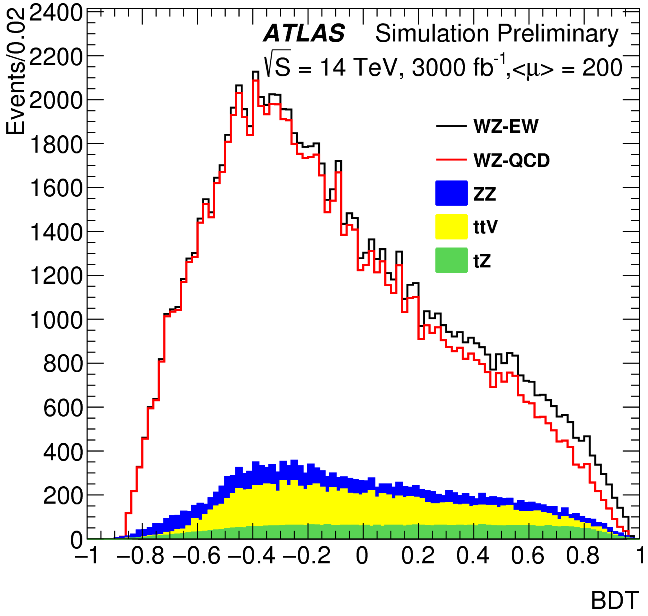
Variables	ATLAS	CMS	
$p_T(\ell)$ [GeV]	> 15	> 15	
$p_T(\ell_{lead})$	> 25	–	
$p_T(\ell_{Z,1})$, $p_T(\ell_{Z,2})$ [GeV]		$> 25, > 15$	
$p_T(\ell_W)$ [GeV]	> 20	> 20	
$\|\eta(\mu)\|$	< 4.0	< 2.8	
$\|\eta(e)\|$	< 4.0	< 3.0	
$\|m_Z - m_Z^{PDG}\|$ [GeV]	< 10	< 15	ttW, WWW
$m_{3\ell}$ [GeV]	–	> 100	
$m_{\ell\ell}$ [GeV]	–	> 4	
E_T^{miss} [GeV]	–	> 30	
M_T^W [GeV]	> 30	–	
n_j	≥ 2	≥ 2	
$\|\eta(j)\|$	< 3.8	< 4.7	
p_T^{jet} [GeV]	> 30	> 50	
$\Delta R(j,\ell)$	–	> 0.4	
$p_T(b)$ [GeV]	–	> 30	
n_{b-jet}	–	$= 0$	ttV, tV
m_{jj}	> 500 *	> 500	
$\Delta\eta_{jj}$	Opp. hemis.	> 2.5	VBS
$\|\eta_{3\ell} - \frac{1}{2}(\eta_{j_1} + \eta_{j_2})\|$	–	< 2.5	

* or BDT

Jet acceptance in ATLAS reduced to tracker acceptance

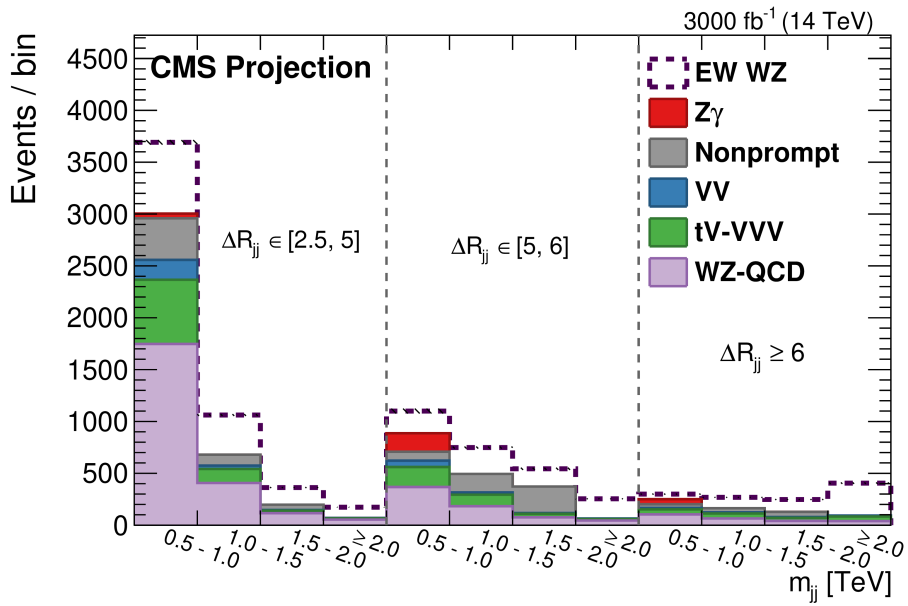
WZ fully leptonic

- ❑ Major backgd from QCD induced WZjj production



- ❑ ATLAS: BDT based on 25 variables
- ❑ 9 best ranked: m_{jj}, $p_T(j_2)$, m_{Tjj}, Sum $p_T(l)$/ $E(j_1)+E(j_2)$, $p_T(j_1)$, centrality, Sum $p_T(l)$/Sum E(l) / Sum $p_T(j)$ / Sum E(j), max m_{jj} with extra jet, angular separation in space between the two jets

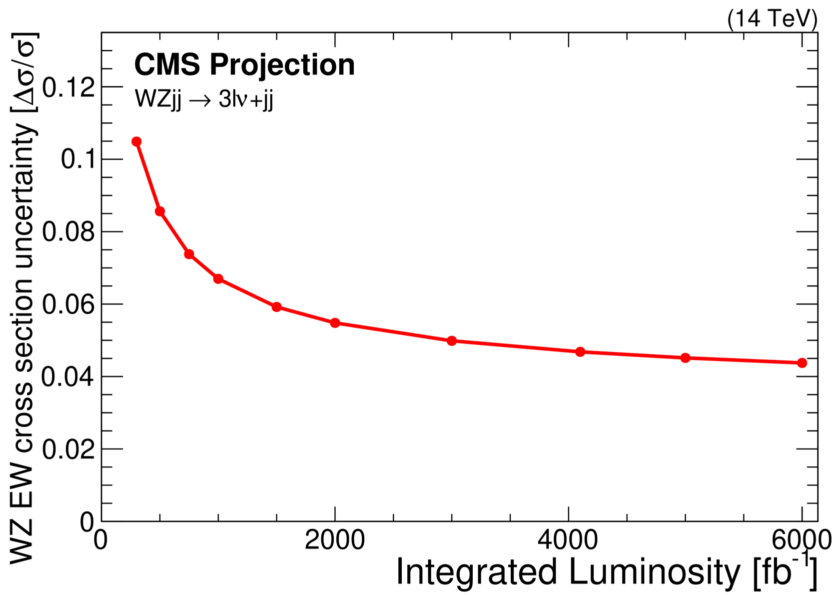
- ❑ CMS: 2D distribution m_{jj} vs angular separation between the 2 jets

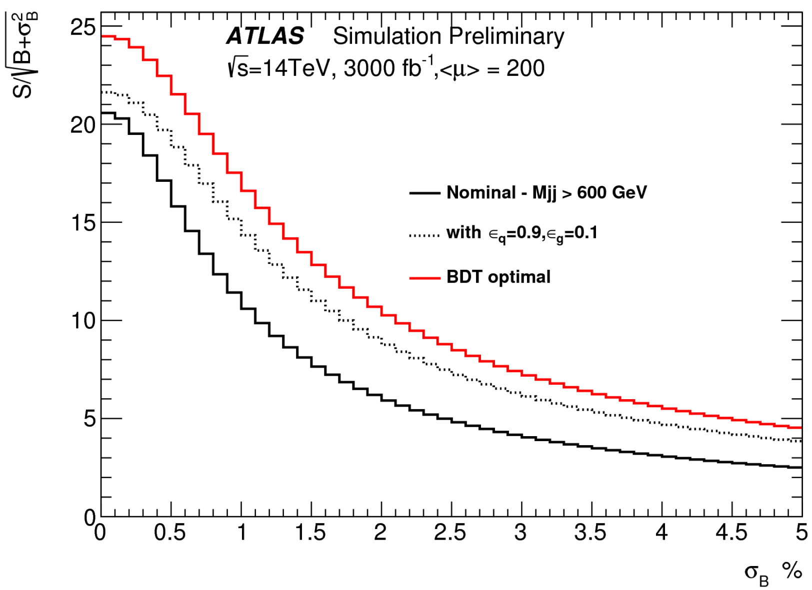


In both cases follows what was done in 13 TeV run 2 analyses

WZ sensitivity

- Results for VBS WZ on cross section precision and significance as function of the background uncertainty for different scenarios



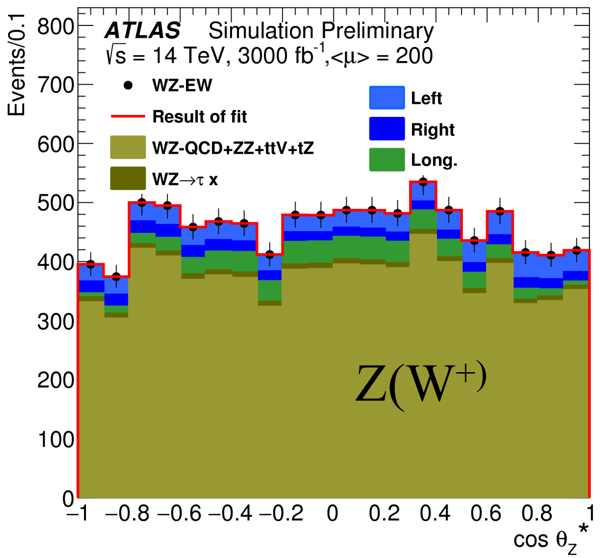


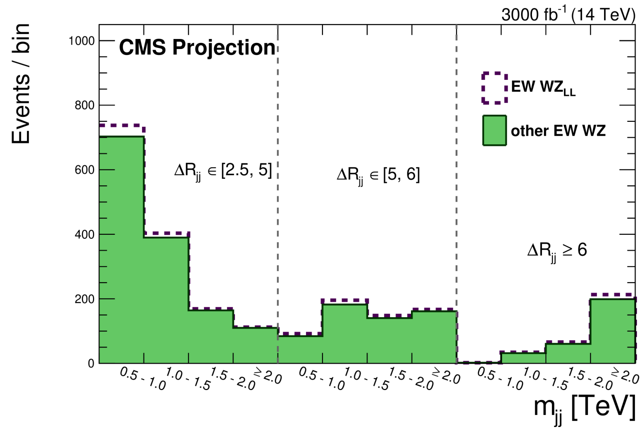
Dominant uncertainties are from QCD scales (theory), JES and JER (exp.)

Most uncertainties expected to decrease to o(%) at HL-LHC

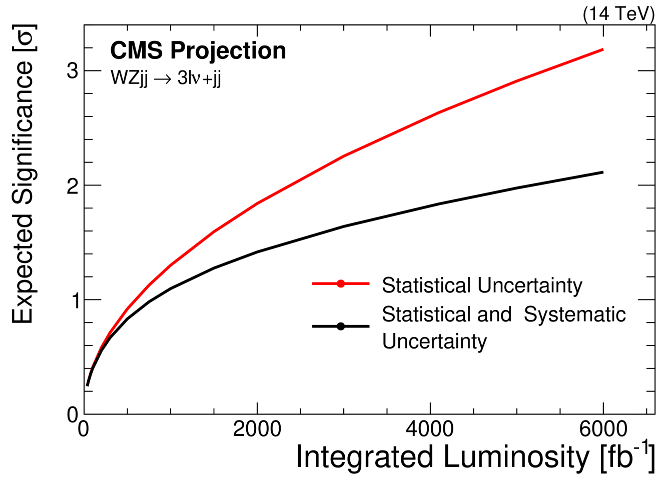
Polarized WZ fully leptonic

- Different approaches used: sensitivity for f0 in individual Z or W bosons based on cosθ* (ATLAS) or LL signal extraction from 2D (m_{jj}, ΔR_{jj}) (CMS)





Significance for LL:
1.6σ @ 3/ab



1.5-2.5σ for Z(W+) and **0.7-1.5σ** for Z(W-) (with σ_B=2.5%, depending on the selection, best result obtained with BDT)

No yet results for doubly polarized WZ
But clearly MVA method will improve

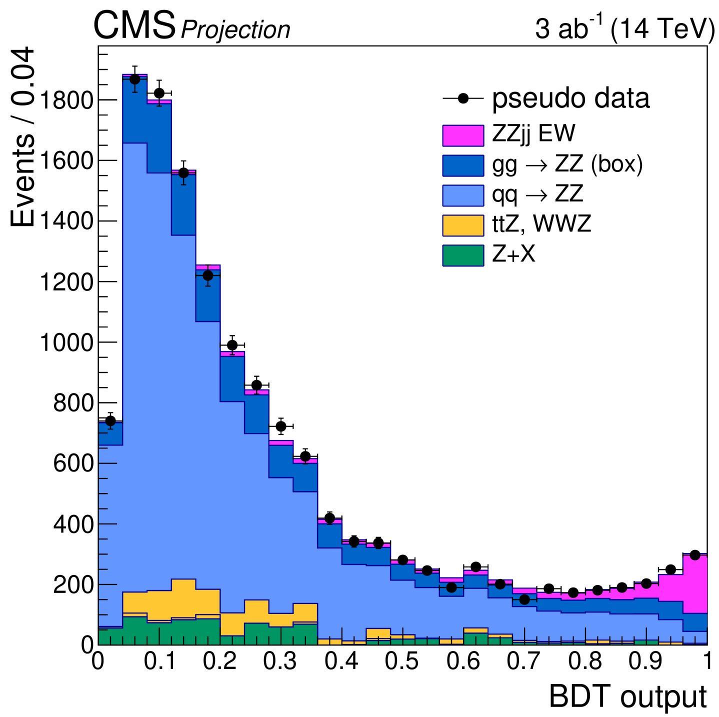
ZZ fully leptonic

- Fast simulation + efficiency parameterization (ATLAS), projection from 2016 result CMS + Delphes for LL (CMS)
- Background dominated by QCD-ZZjj simulated by SHERPA (v2.2.2) in ATLAS and NLO MadGraph in CMS
- Effect of extended lepton acceptance investigated

	ATLAS	CMS
lepton η	$\|\eta\| < 4.0$	$\|\eta\| < 3.0(2.8)$ ($\|\eta\| < 4.0(2.8)$, extended option)
lepton p_T	$p_T > 20, 20, 10, 7$ GeV	$p_T > 20, 12(10), 10, 7(5)$ GeV
N leptons	exactly 4	≥ 4
Z mass	$60 < m_{ll} < 120$ GeV	$60 < m_{ll} < 120$ GeV
Z_1 definition	m_{ll} closest to PDG [408] value	p_T-leading Z
jet η	$\|\eta\| < 4.5$	$\|\eta\| < 4.7$
jet p_T	$p_T > 30(70)$ GeV for $\|\eta\| < 3.8(> 3.8)$	$p_T > 30$ GeV
N jets	≥ 2, with $\eta^{j_1} \times \eta^{j_2} < 0$	≥ 2
VBS cuts	$m_{jj} > 600$ GeV and $\|\Delta\eta_{jj}\| > 2$	$m_{jj} > 100$ GeV, signal extraction from BDT

ZZ fully leptonic

- Low statistics, don't want to throw away events => multivariate classifier (BDT) used in CMS
- $p_{Tj1,2}$>30 GeV, p_T(lepton)>7(5) GeV, |η(lepton)| <2.5(2.4), m_{jj}>100 GeV
- Input variables: m_{jj}, $\Delta\eta_{jj}$, z_1^*, z_2^*, p_T balance, dijet p_T balance, m_{4l} (no 3rd jet veto)
- BDT optimized, performance checked against Matrix Element Approach
- Signal extracted from template fit of the BDT distributions to the data
- Background validated in QCD enriched CR (m_{jj}<400 GeV or $|\Delta\eta_{jj}|$<2.4)



Scaled from 2016 analysis, taking into account acceptance and energy increase

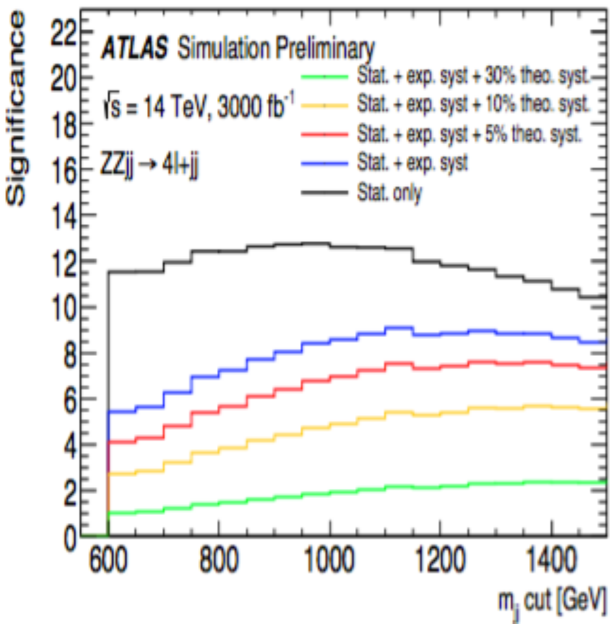
VBS ZZ results

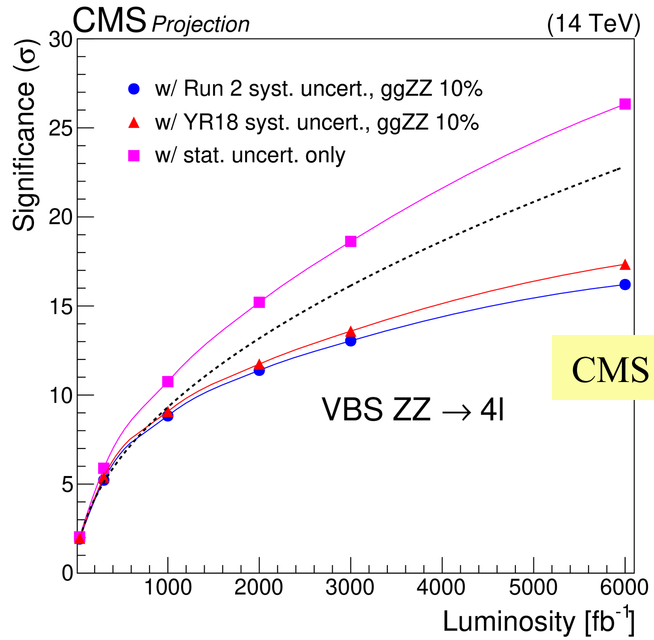
ATLAS

Selection	$N_{EW-ZZjj}$	$N_{QCD-ZZjj}$	$N_{EW-ZZjj} / \sqrt{N_{QCD-ZZjj}}$
Baseline	432 ± 21	1402 ± 37	11.5 ± 0.6
Leptons with $\lvert\eta\rvert < 2.7$	373 ± 19	1058 ± 33	11.5 ± 0.6
PU jet suppression only in $\lvert\eta\rvert < 2.4$	536 ± 23	15470 ± 124	4.3 ± 0.2

Large impact of the extended PU rejection

Small impact from extended lepton acceptance (inclusive on polarisation)





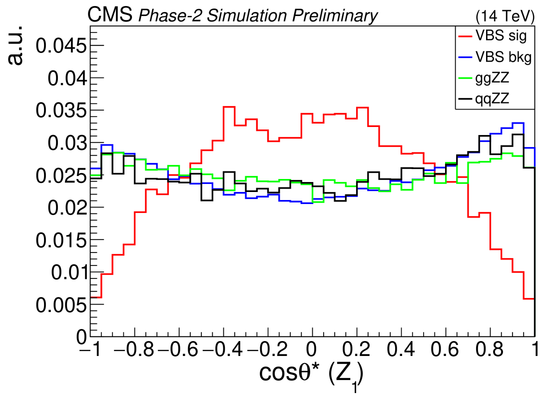
CMS

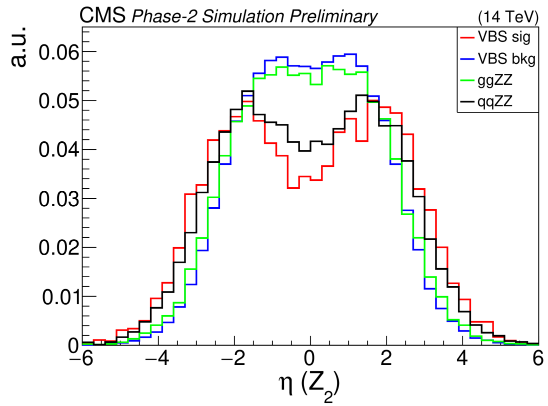
Large effect of systematic uncertainties, dominant uncertainties are from theory and JES

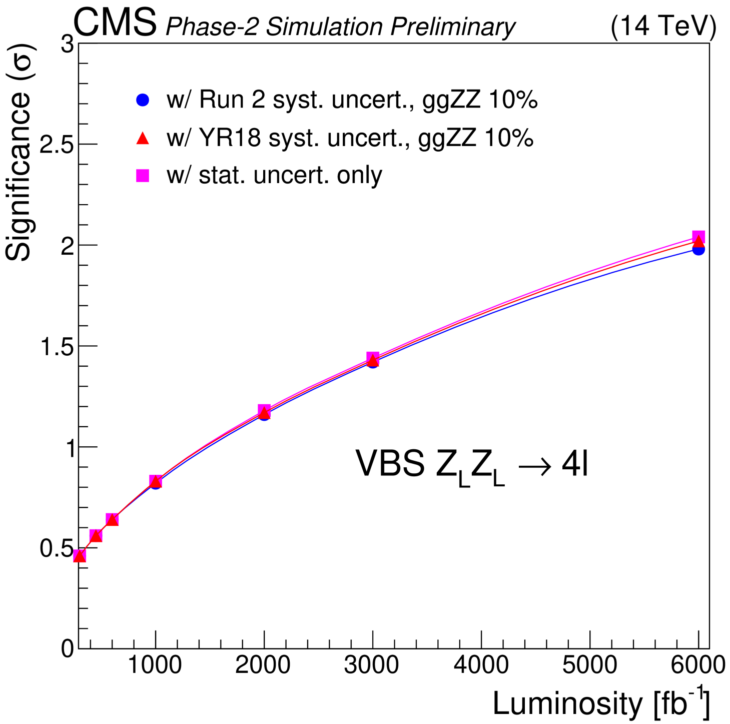
Clear benefit of BDT approach in very low signal analyses

Polarized VBS ZZ

- LL fraction extracted from an extended BDT
- VBS observables used in 2016 analysis for VBS against QCD + cosθ*, p_T and η of both Z







η coverage	significance	VBS $Z_L Z_L$ fraction uncertainty (%)
$\|\eta\| < 2.5(2.4)$	1.22σ	88
$\|\eta\| < 3.0(2.8)$	1.38σ	78
$\|\eta\| < 4.0(2.8)$	1.43σ	75

Expected sensitivity: ~1.4σ @ 3000/fb

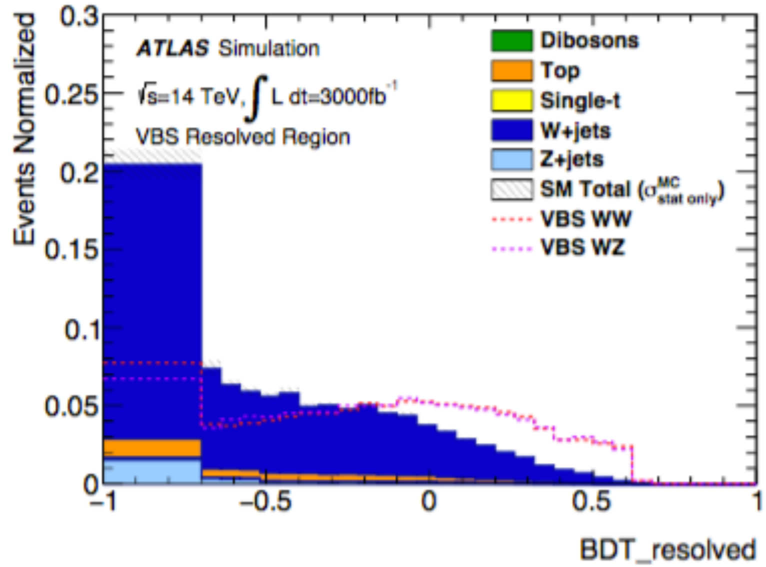
~4% increase in sensitivity from extended e^- acceptance for $Z_L Z_L$

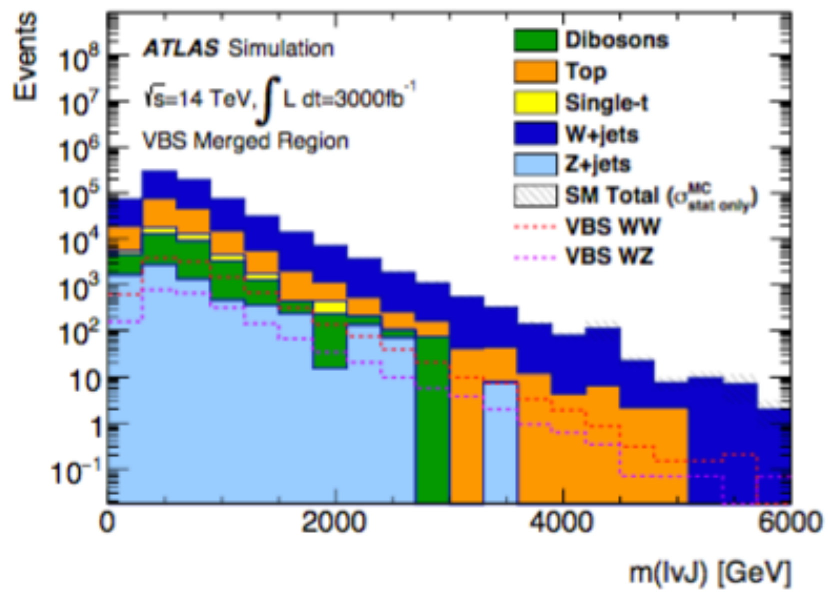
VBS VW semileptonic

- lvqq final state, analysis includes boosted/merged jet topology
- Signal modelled with NLO MadGraph
- Main backgrounds: W+jets, top quark production, non resonant diboson production (ZZ, WZ and WW)

- Exactly 1 lepton p_T>27 GeV |η|<2.5 (2.47 for e^-)
- 1 reconstructed hadronic W/Z: Small-R jets p_T>20 GeV, |η|<2.5 or large-R jet p_T>200 GeV, |η|<2 and |m(J)-m(W/Z)|<50 GeV, boson tagger efficiency and smearing
- E_T^{miss}>60 GeV (multijets), $p_L(\nu)$ from W mass
- VBS: >=2 non b-tagged jets with m_{jj}>400 GeV and BDT based on m(lvJ), lepton η, second tag jet p_T and boson centrality

Increase of lepton acceptance not considered



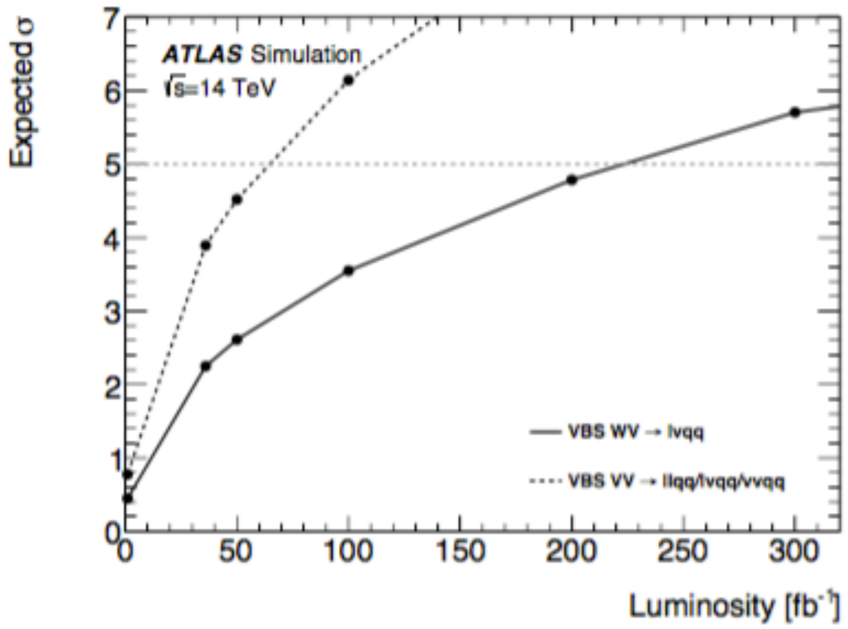


VBS VW semileptonic

- ❑ Signal extracted from simultaneous fit of the BDT distributions in the signal and W+jets and tt CR

Merged jet W/Z tagger efficiency assumed similar or better than current performance

- ❑ Experimental systematics dominated by JER in the resolved/merged jet(s) and mass resolution in the merged case
  - ❑ Taken from run 2 and reduced by 50%
- ❑ Normalization and shape uncertainties considered for backgrounds, dominated by diboson normalization , W+jet and ttbar modelling
- ❑ Also reduced by a factor 2 wrt run 2, apart from W +jets that is reduced by a factor 10



5.7σ significance for VBS @ 300/fb (comparable with 225-280/fb for ZZ→4l depending on syst. uncert.)

If CR are not used to constrain systematics expected significance is 3.6σ

HE-LHC

- Only few analyses for now, machine assumptions: 27 TeV, 15/fb, 800 PU
- Very preliminary studies (yield increase, PU mitigation)

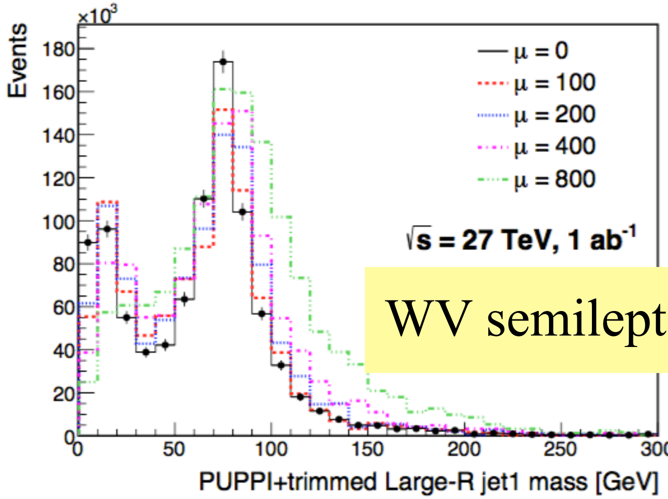
	EW ZZ	QCD qqZZ	QCD ggZZ
$\sigma_{14\,\text{TeV}} / \sigma_{13\,\text{TeV}}$	1.15	1.17	1.13
$\sigma_{27\,\text{TeV}} / \sigma_{14\,\text{TeV}}$	3.25	3.41	3.57

ZZ→4l

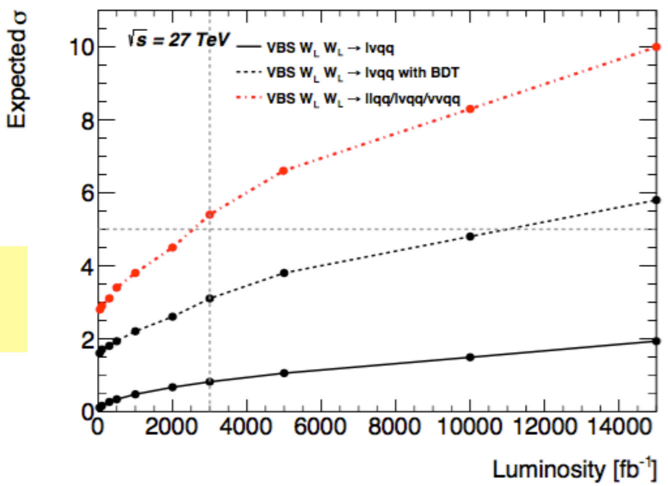
Major impact of yield increase for VBS ZZ

5σ reachable for $Z_L Z_L$

	significance		VBS $Z_L Z_L$ fraction uncertainty (%)	
	w/ syst. uncert.	w/o syst. uncert.	w/ syst. uncert.	w/o syst. uncert.)
HL-LHC	1.4σ	1.4σ	75%	75%
HE-LHC	5.2σ	5.7σ	20%	19%



WV semileptonic



5σ could be reached with 3/ab in semileptonic with llqq/lνqq/ννqq

Conclusions

- SS WW, WZ and ZZ investigated in fully leptonic final states, also semi-leptonic
- Variety of methods used (fast sim/projection of existing results/full sim), also various level of sophistication for the analyses
- Interesting studies on PU mitigation, acceptance effects

- SS WW is expected to be the most sensitive channel for the LL measurement, however no single channel reaches 5σ alone at HL-LHC
- WZ and ZZ results largely dominated by QCD induced background uncertainties, mostly from theory; it remains to be seen how much these can be reduced or eventualy constrained from data (CR and/or ratio to measurements from other channels)
- 5σ could be reached by semi-leptonic VW and fully leptonic ZZ at HE-LHC thanks to increase in energy and lumi

Backup

CMS SS WW backgrounds

Process	Sample name	Nevents	σ (pb)
WW EWK	WWJJ_SS_WToLNu_EWK_TuneCUETP8M1_14TeV-madgraph-pythia8	1.416e+05	0.03252
WW QCD	WWJJTo2L2NuJJ_SS_14TeV-madgraphMLM-pythia8	5.897e+04	0.03093
single Top	ST_tW_DR_14TeV_top_incl-powheg-pythia8	3.279e+05	45.06
single anti-top	ST_tW_DR_14TeV_antitop_incl-powheg-pythia8	3.095e+05	45.06
$t\bar{t}$ (upto 2 jets)	TTTo2L2Nu_TuneCUETP8M1_14TeV-powheg-pythia8	2.264e+06	90.46
$t\bar{t}W$	TTWJetsToLNu_TuneCUETP8M1_14TeV-amcatnloFXFX-madspin-pythia8	2.801e+05	0.2253
$t\bar{t}Z$	TTZJetsToLNu_TuneCUETP8M1_14TeV-amcatnloFXFX-madspin-pythia8	5.455e+05	0.7152
QCD jets	QCD_Flat_Pt-15to7000_TuneCUETP8M1_14TeV_pythia8	7.141e+05	2.2e+09
W + 0jet	WToLNu_0J_14TeV-madgraphMLM-pythia8	3.08e+05	38210
W + 1jet	WToLNu_1J_14TeV-madgraphMLM-pythia8	1.866e+05	10330
W + 2jets	WToLNu_2J_14TeV-madgraphMLM-pythia8	5.312e+05	3314
DY +0jet	DYToLL-M-50_0J_14TeV-madgraphMLM-pythia8	1.676e+06	3668
DY + 1jet	DYToLL-M-50_1J_14TeV-madgraphMLM-pythia8	9.119e+05	1094
DY + 2jets	DYToLL-M-50_2J_14TeV-madgraphMLM-pythia8	8.783e+05	369.7
DY + 3jets	DYToLL-M-50_3J_14TeV-madgraphMLM-pythia8	1.406e+05	190.2
$W\gamma$	WGToLNuG_PtG-40_TuneCUETP8M1_14TeV-madgraphMLM-pythia8	1.058e+05	18.79
WZ + 0jet	WZTo3LNu_0Jets_14TeV-madgraphMLM-pythia8	4.212e+05	3.111
WZ + 1jet	WZTo3LNu_1Jets_14TeV-madgraphMLM-pythia8	2.073e+05	9.5e-01
WZ + 2jets	WZTo3LNu_2Jets_14TeV-madgraphMLM-pythia8	1.212e+05	2.7e-01
W(JJ)Z(LL) + 2jets	WZJJTo2L2QJJ_MLL-4_EWK_14TeV-madgraph-pythia8	1.523e+05	5.3e-02
ZZ (2Q2L)	ZZTo2Q2L_14TeV_powheg_pythia8	1.871e+05	2.214
ZZ (4L)	ZZTo4L_14TeV_powheg_pythia8	4.946e+05	1.357
WWW to 4F	WWW_4F_TuneCUETP8M1_14TeV-amcatnlo-pythia8	1.64e+05	0.2362
WWZ	WWZ_TuneCUETP8M1_14TeV-amcatnlo-pythia8	1.348e+05	0.1889
WZZ	WZZ_TuneCUETP8M1_14TeV-amcatnlo-pythia8	2e+05	0.06376
ZZZ	ZZZ_TuneCUETP8M1_14TeV-amcatnlo-pythia8	4.582e+04	0.0158
$WW\gamma$	WWG_TuneCUETP8M1_14TeV-amcatnlo-pythia8	1.658e+04	0.04611
$WZ\gamma$	WZG_TuneCUETP8M1_14TeV-amcatnlo-pythia8	3.072e+04	0.2382

Jet pT>50 reduces W+jet background by 1/3 after jet veto, asking 2 SS leptons kills it completely

SS WW selections

Selection requirement	ATLAS Selection	CMS Selection
Signal lepton p_T	$p_T > 28(25)$ GeV	$p_T > 20$ GeV
Signal lepton η	$\lvert\eta\rvert \leq 4.0$	$\lvert\eta\rvert \leq 3.0$
Tag jet p_T	$p_T > 90(45)$ GeV	$p_T > 50$ GeV
Tag jet η	$\lvert\eta\rvert \leq 4.5$	$\lvert\eta\rvert \leq 4.7$
Dilepton mass	$m_{\ell\ell} > 28$ GeV	$m_{\ell\ell} > 20$ GeV
Z_{ee} veto	$\lvert m_{ee} - m_Z\rvert > 10$ GeV	$\lvert m_{ee} - m_Z\rvert > 15$ GeV
E_T^{miss}	$E_T^{miss} > 40$ GeV	$E_T^{miss} > 40$ GeV
Number of b-tagged jets	0	0
Jet selection	Anti-k_T [364] jets with $\Delta R_{\ell,j} > 0.3$	Anti-k_T PUPPI [365] jets with $\Delta R_{\ell,j} > 0.4$
Preselected lepton veto	$p_T > 7(6)$ GeV	$p_T > 10$ GeV
Dijet rapidity separation	$\Delta\eta_{j,j} > 2.5$	$\Delta\eta_{j,j} > 2.5$
Dijet mass	$m_{jj} > 520$ GeV	$m_{jj} > 500$ GeV
Lepton centrality	$\zeta > -0.5$	$Z_{MAX} < 0.75$

CMS SS WW systematics

Source of uncertainty	Input	300 fb^{-1} (1 year)	3000 fb^{-1} (10 years)
Statistical uncertainty		5.7%	1.8%
Trigger efficiency (electron)	1.0%	0.5%	0.2%
Trigger efficiency (muon)	1.0%	1.1%	0.6%
Electron id + iso. efficiency	1.0%	0.6%	0.3%
Muon id + iso. efficiency	0.5%	0.9%	0.6%
Jet energy scale	0.5–3.7%	1.0%	0.4%
b tag (stat. component)	1.0%	0.2%	0.3%
b tag misidentification	1–2%	1.4%	1.2%
Misidentified lepton from $t\bar{t}$	5–20%	3.5%	1.0%
Misidentified lepton from $W\gamma$	20%	0.3%	0.1%
Stat. accuracy of $W\gamma$ sample	30%	0.4%	0.1%
Total (stat + experimental syst)		7.6%	3.2%
Luminosity	1.0%	1.0%	1.0%
Theoretical/QCD scale	3.0%	3.0%	3.0%
Total (stat + syst + lumi + theory)		8.2%	4.5%

ATLAS SS WW systematics

Source	Uncertainty (%)	
	Baseline	Optimistic
$W^{\pm}W^{\pm}jj$ (EW)	3	
Luminosity	1	
Trigger efficiency	0.5	
Lepton reconstruction and identification	1.8	
Jets	2.3	
Flavour tagging	1.8	
Jets faking electrons	20	
Charge mis-ID	25	
$W^{\pm}W^{\pm}jj$ (QCD)	20	5
Top	15	10
Diboson	10	5
Triboson	15	10

ATLAS VW semi-leptonic

Selection	Resonance Resolved	Resonance Merged
$W \to \ell\nu$	1 isolated “tight" lepton 0 additional “loose" leptons	
	$E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV $p_{\mathrm{T}}(\ell\nu) > 75$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV $p_{\mathrm{T}}(\ell\nu) > 200$ GeV
	$E_{\mathrm{T}}^{\mathrm{miss}}/p_{\mathrm{T}}(e\nu) > 0.2$	
$V \to jj$	2 small-R jets $min\lvert m(jj) - m(W/Z)\rvert$ $p_{\mathrm{T}}(j_1) > 60$ GeV, $p_{\mathrm{T}}(j_2) > 40$ GeV $66 < m(jj) < 94$ GeV or $82 < m(jj) < 106$ GeV	large-R jet highest p_T $p_{\mathrm{T}}(J) > 200$ GeV, $\lvert\eta(J)\rvert < 2$ $\lvert m(J) - m(W/Z)\rvert < 50$ GeV Scale by W/Z-tagger efficiency
Tagged jets (VBF Category)	Non-b-tagged $\eta(j_1^{\mathrm{tag}}) \cdot \eta(j_2^{\mathrm{tag}}) < 0$, highest $m(jj)$ $p_{\mathrm{T}}(j_{1,2}^{\mathrm{tag}}) > 30$ GeV, $m(jj) > 770$ GeV, $\Delta\eta(j,j) > 4.7$	
Topology	$p_{\mathrm{T}}(\ell\nu)/m(\ell\nu jj) > 0.35$ (0.3 for VBF) $p_{\mathrm{T}}(jj)/m(\ell\nu jj) > 0.35$ (0.3 for VBF) $\Delta\phi(j,\ell) > 1$, $\Delta\phi(j, E_{\mathrm{T}}^{\mathrm{miss}}) > 1$ $\Delta\phi(j,j) < 1$, $\Delta\phi(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 1$	$p_{\mathrm{T}}(\ell\nu)/m(\ell\nu J) > 0.4$ (0.3 for VBF) $p_{\mathrm{T}}(J)/m(\ell\nu J) > 0.4$ (0.3 for VBF)
b-veto	No b-tagged jets in the event beside 1 (2) from $W(Z) \to jj$	

CERN Yellow report conclusions

- Extract from the HL-LHC summary:
  - « In particular, the extraction of individual polarization contributions to same-sign $W W$ scattering will yield **a > 3 s.d. evidence for $W_L W_L$ production, combining ATLAS and CMS results.** "
- Extract from the HE-LHC summary:
  - "Preliminary studies show that, thanks to pile-up mitigation techniques that retain Run-2 performance of hadronically decaying W/Z-boson tagging, the precision on the VBS cross section measurement in the semileptonic WV + jj → lν + jjjj channel can be reduced from 6.5 % (HL-LHC) to about 2 % at HE-LHC. From this measurement and from the measurement of the EW production of a Z boson pair, the purely longitudinal final state of the **WW and ZZ scattering processes can be extracted with a significance of 5σ or more.** "