Measurements of production cross sections of polarized same-sign W boson pairs in association with two jets in proton-proton collisions at 13 TeV

https://arxiv.org/abs/2208.02686

Topics in Particle Physics

Johan Wulff

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TÉCNICO LISBOA

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

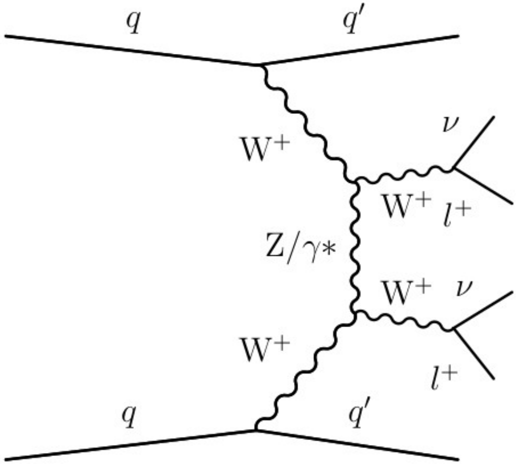
Fundação para a Ciência e a Tecnologia

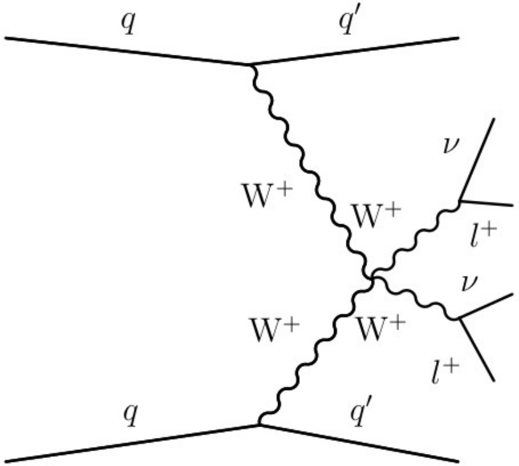
Physics Case – VBS at LHC

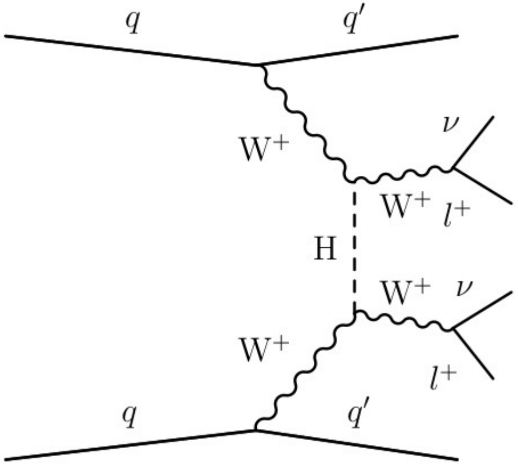
- The measurement of a Higgs boson with a mass of 125GeV provides an explanation for W & Z masses → via the Brout-Englert-Higgs mechanism
- However, further Higgs bosons could be present
- BSM scenarios considering the existance of additional Higgs bosons (or other resonances) predict modifications of the VBS cross-section w.r.t. the SM prediction

Physics Case – VBS at LHC

- VBS is one of the few processes that allow us to access a quartic gauge coupling!







Signatures @ LHC

- VBS interactions are characterized by the presence of 2 gauge bosons in assoc. with 2 forward jets
- The two jets can be identified by a large rapidity separation
- These classes of processes proceed via the EW interaction at tree level $O(\alpha^4)$

Event Selection

- Events are reconstructed with ParticleFlow
- Jets reconstructed using the anti-k_T algorithm (dist. 0.4)
  - Calibrated seperately in simulation and data
- Electrons and muons are reconstructed by associationg a track with a cluster of energy either in the ECAL or muon system

Event Selection

- SR requirements: same sign leptons
- Remove Candidates with 15GeV around the Z mass
- Require pt_{miss} of >30GeV to account for the neutrinos

Variable	Requirement
Leptons	Exactly 2 same-sign leptons, $p_T > 25/20$ GeV
p_T^j	>50 GeV
$\lvert m_{\ell\ell} - m_Z \rvert$	>15 GeV (ee)
$m_{\ell\ell}$	>20 GeV
p_T^{miss}	>30 GeV
b quark veto	Required
$Max(z_\ell^*)$	<0.75
m_{jj}	>500 GeV
$\lvert \Delta\eta_{jj} \rvert$	>2.5

Extracting polarization information

- In the $W^{+-}W^{+-}$ channel, the W bosons can be longitudinally or transversely polarized
  - Leading to different kinematic distributions of l, j and pt_{miss}
  - W_L bosons tend to be radiated at a smaller angle with respect to the incoming quark direction, resulting in a smaller pT compared to W_T pT.
  - In addition, there are differences in the behavior of the scattering amplitudes as a function of the W^{+-} W^{+-} center-of-mass energy and the scattering angle
- 2 BDTs are trained to separate between the different processes (W_LW_L, W_XW_T and W_LW_X , W_TW_T)

Background Estimation

- Background processes are final states from tt, tW, W^+W^- and DY where one lepton has been identified to carry the wrong charge
- MisID Rate assumed to be 0.01% in the barrel and 0.3% in the endcap region
- Most nonprompt lepton backgrounds (from heavy quarks, hadrons misidentified as leptons) are suppressed by the iD and isolation requirements
- Four Background CR’s (enriched in WZ, nonprompt lepton, tZq and ZZ) are used to estimate the normalization of the main background processes from data
- All other background processes are estimated from simulation

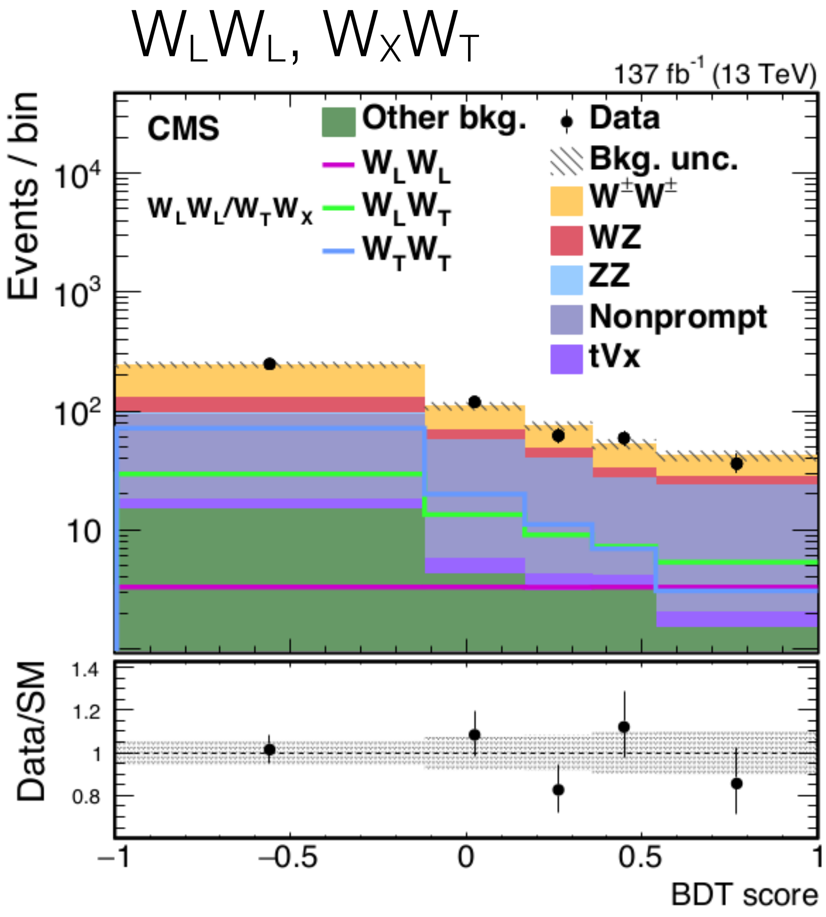
Systematic Uncertainties

Source of uncertainty	$W^{\pm}_{L}W^{\pm}_{L}$ (%)	$W^{\pm}_{X}W^{\pm}_{T}$ (%)	$W^{\pm}_{L}W^{\pm}_{X}$ (%)	$W^{\pm}_{T}W^{\pm}_{T}$ (%)
Integrated luminosity	3.2	1.8	1.9	1.8
Lepton measurement	3.6	1.9	2.5	1.8
Jet energy scale and resolution	11	2.9	2.5	1.1
Pileup	0.9	0.1	1.0	0.3
b tagging	1.1	1.2	1.4	1.1
Nonprompt lepton rate	17	2.7	9.3	1.6
Trigger	1.9	1.1	1.6	0.9
Limited sample size	38	3.9	14	5.7
Theory	6.8	2.3	4.0	2.3
Total systematic uncertainty	44	6.6	18	7.0
Statistical uncertainty	123	15	42	22
Total uncertainty	130	16	46	23

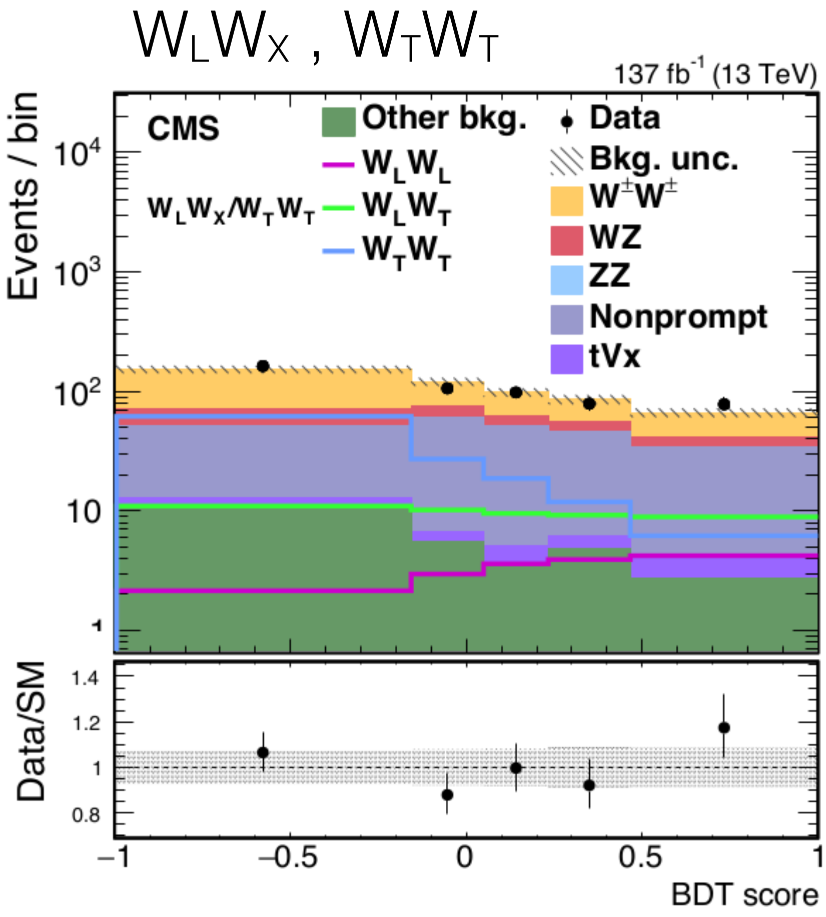
Results

- To distinguish Signal from background, before extracting the polarizations, another BDT is trained
- Simultaneously fit the SR and all CR (nonprompt, WZ, tZq, ZZ)
  - Normalizations of ZZ, tZq, EW WZ, and QCD WZ are included
  - Sys. unc. treated as nuisance parameters with shape & normalisation varying within their uncertainties within the fit
  - Norm. uncertainties are treated as log-normal nuisance parameters
  - Normalisation of tZq, ZZ, and WZ backgrounds

Results



W_LW_L, W_XW_T
137 fb-1 (13 TeV)
CMS
W_LW_L/W_TW_X
Other bkg.
W_LW_L
W_LW_T
W_TW_T
Data
Bkg. unc.
$W^{\pm}W^{\pm}$
WZ
ZZ
Nonprompt
tVx
Events / bin
Data/SM
BDT score



W_LW_X , W_TW_T
137 fb-1 (13 TeV)
CMS
W_LW_X/W_TW_T
Other bkg.
W_LW_L
W_LW_T
W_TW_T
Data
Bkg. unc.
$W^{\pm}W^{\pm}$
WZ
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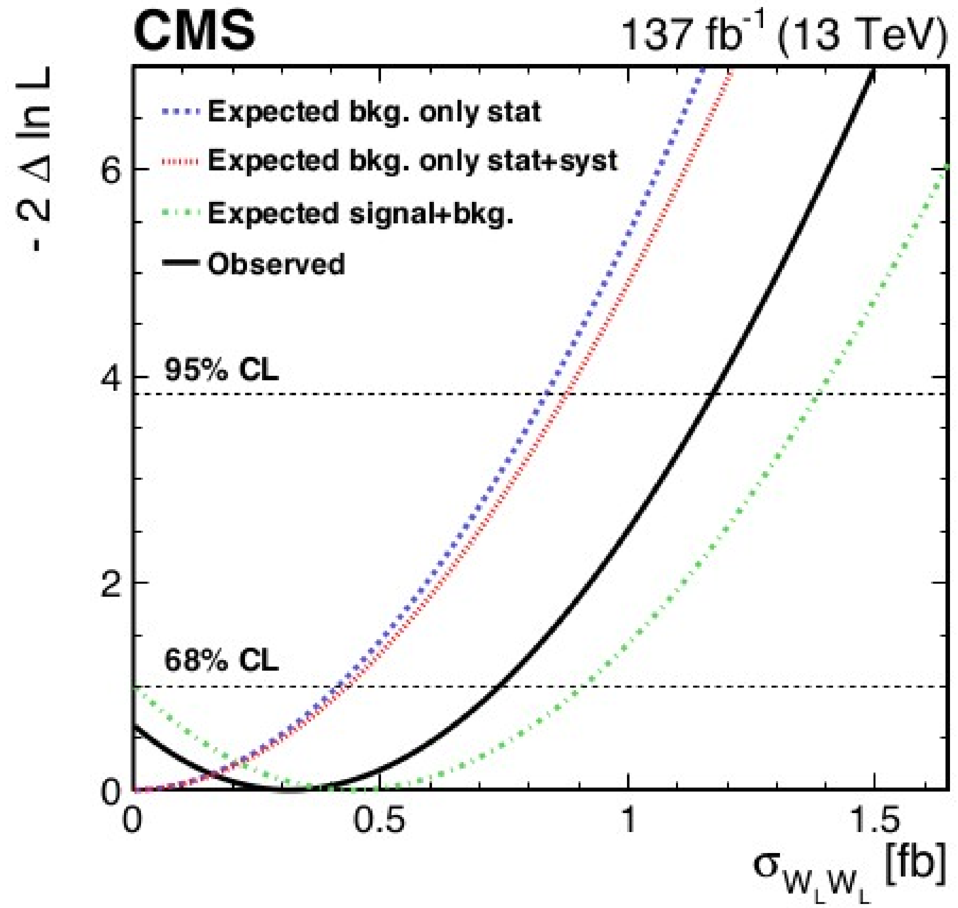
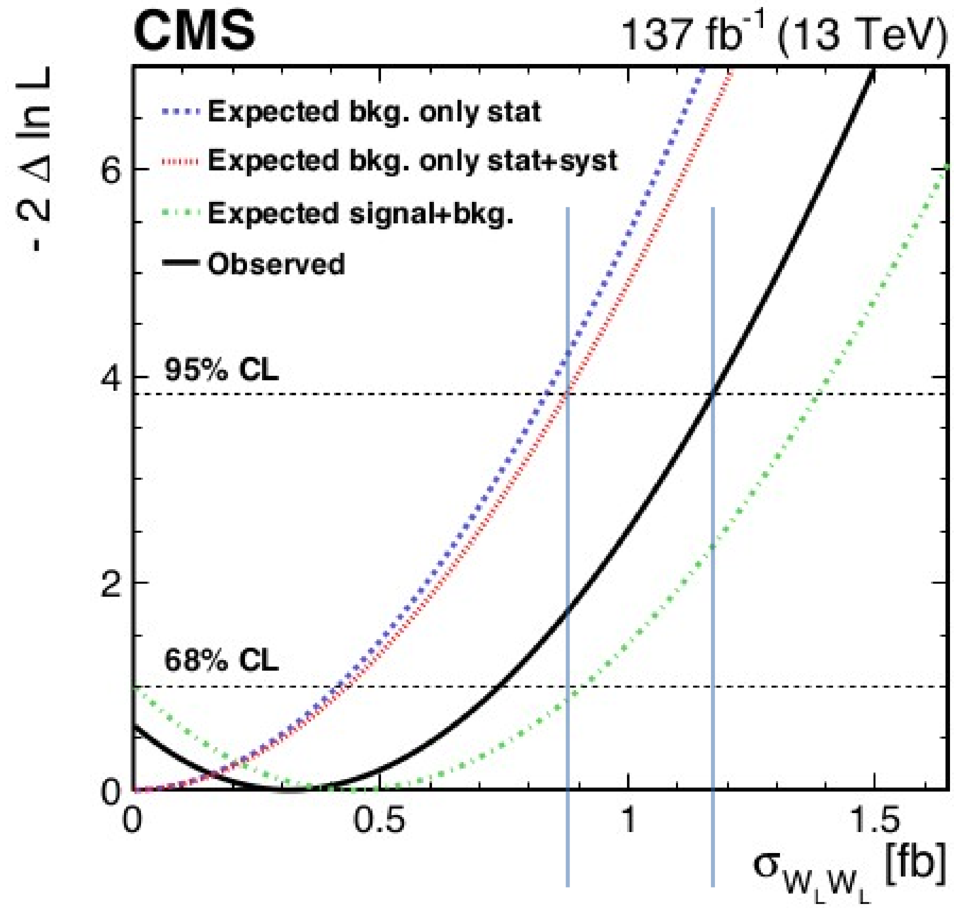
Results



Observed (expected) 95% CL upper limit on the production cross section for longitudinally polarized same sign WW boson pairs of:

1.17 (0.88) fb

Results



Observed (expected) 95% CL upper limit on the production cross section for longitudinally polarized same sign WW boson pairs of:

1.17 (0.88) fb

Thank you for your Attention!

Inclusive BDT Inputs

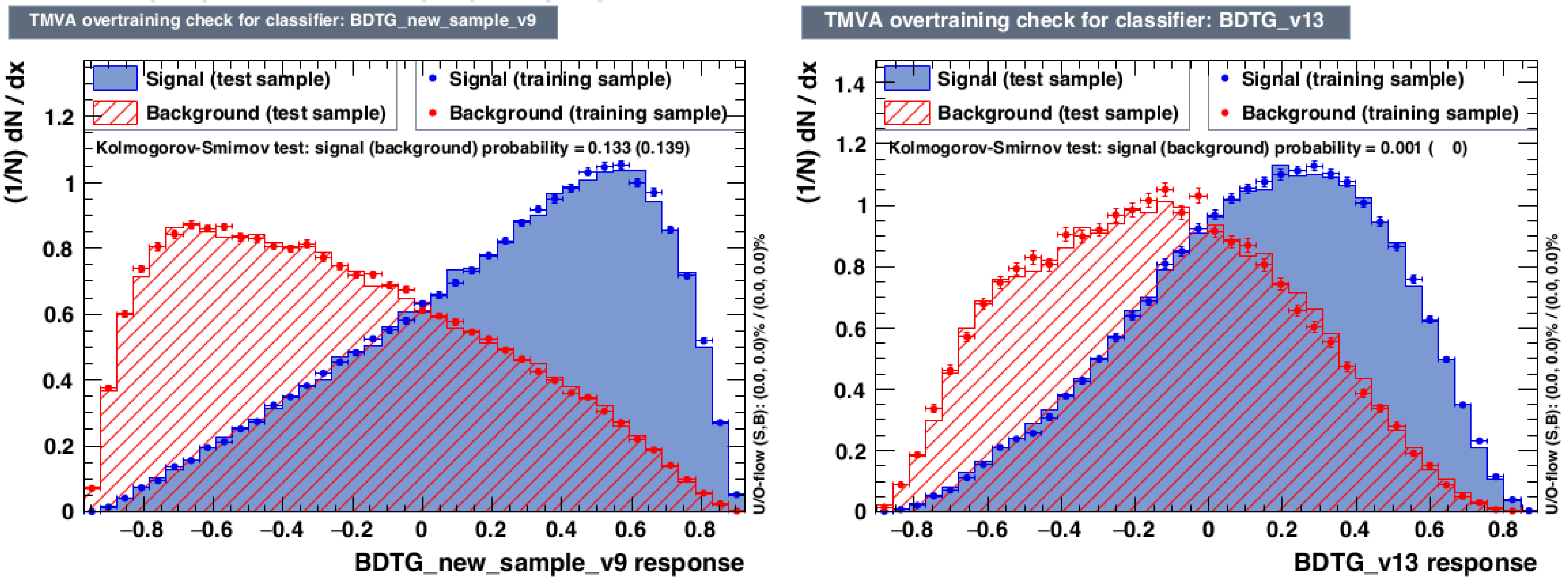
Variables	Definitions
m_{jj}	Dijet mass
$\lvert\Delta\eta_{\mathrm{jj}}\rvert$	Difference in pseudorapidity between the leading and subleading jets
$\Delta\phi_{\mathrm{jj}}$	Difference in azimuth angles between the leading and subleading jets
$p_{\mathrm{T}}^{\mathrm{j1}}$	p_{T} of the leading jet
$p_{\mathrm{T}}^{\mathrm{j2}}$	p_{T} of the subleading jet
$p_{\mathrm{T}}^{\ell_1}$	Leading lepton p_{T}
$p_{\mathrm{T}}^{\ell\ell}$	Dilepton p_{T}
$z^*_{\ell_1}$	Zeppenfeld variable of the leading lepton
$z^*_{\ell_2}$	Zeppenfeld variable of the subleading lepton
$p_{\mathrm{T}}^{\mathrm{miss}}$	Missing transverse momentum

Signal BDT Inputs

Variables	Definitions
$\Delta\phi_{jj}$	Difference in azimuthal angle between the leading and subleading jets
p_T^{j1}	p_T of the leading jet
p_T^{j2}	p_T of the subleading jet
$p_T^{\ell_1}$	Leading lepton p_T
$p_T^{\ell_2}$	Subleading lepton p_T
$\Delta\phi_{\ell\ell}$	Difference in azimuthal angle between the two leptons
$m_{\ell\ell}$	Dilepton mass
$p_T^{\ell\ell}$	Dilepton p_T
m_T^{WW}	Transverse WW diboson mass
$z^*_{\ell_1}$	Zeppenfeld variable of the leading lepton
$z^*_{\ell_2}$	Zeppenfeld variable of the subleading lepton
$\Delta R_{j1,\ell\ell}$	ΔR between the leading jet and the dilepton system
$\Delta R_{j2,\ell\ell}$	ΔR between the subleading jet and the dilepton system
$(p_T^{\ell_1} p_T^{\ell_2})/(p_T^{j1} p_T^{j2})$	Ratio of p_T products between leptons and jets
p_T^{miss}	Missing transverse momentum

$$z_l = \frac{|\eta_l - \langle \eta_{jj} \rangle|}{\Delta\eta_{jj}}$$

Signal BDT Outputs



Region Definitions

Variable	WW	WZ
Leptons	2 leptons, $p_T > 25/20$ GeV	3 leptons, $p_T > 25/10/20$ GeV
p_T^j	> 50 GeV	> 50 GeV
$\|m_{\ell\ell} - m_Z\|$	> 15 GeV (ee)	< 15 GeV
$m_{\ell\ell}$	> 20 GeV	-
$m_{\ell\ell\ell}$	-	> 100 GeV
p_T^{miss}	> 30 GeV	> 30 GeV
Anti b-tagging	Applied	Applied
τ veto	Applied	Applied
$max(z_l^*)$	< 0.75	< 1.0
m_{jj}	> 500 GeV	> 500 GeV
$\|\Delta\eta_{jj}\|$	> 2.5	> 2.5

Region Definitions

Variable	Nonprompt	WZb	ZZ
Leptons	2 leptons, $p_T > 25/20$ GeV	3 leptons, $p_T > 25/10/20$ GeV	4 leptons, $p_T > 25/20/10/10$ GeV
p_T^j	> 50 GeV	> 50 GeV	> 50 GeV
$\lvert m_{\ell\ell} - m_Z \rvert$	> 15 GeV (ee)	< 15 GeV	< 15 GeV (both pairs)
$m_{\ell\ell}$	> 20 GeV	-	-
$m_{\ell\ell\ell}$	-	> 100 GeV	-
p_T^{miss}	> 30 GeV	> 30 GeV	-
Anti b-tagging	Inverted	Inverted	-
τ veto	Applied	Applied	-
$max(z_l^*)$	< 0.75	< 1.0	< 0.75
m_{jj}	> 500 GeV	> 500 GeV	> 500 GeV
$\lvert \Delta\eta_{jj} \rvert$	> 2.5	> 2.5	> 2.5

Final Binnings

The chosen binning on each region is the following:

- WW SR: two-dimensional $\mathrm{BDT}^{WW} - \mathrm{BDT}^{\text{non-VBS}}$ distributions with 5 bins in BDT^{WW} and 5 bins in $\mathrm{BDT}^{\text{non-VBS}}$;
- nonprompt CR: 4 bins in m_{jj} ([500, 800, 1200, 1800, ∞] GeV);
- WZ CR: 4 bins in m_{jj} ([500, 800, 1200, 1800, ∞] GeV);
- ZZ CR: 4 bins in m_{jj} ([500, 800, 1200, 1800, ∞] GeV);
- WZb CR: 4 bins in m_{jj} ([500, 800, 1200, 1800, ∞] GeV).