CMS Draft Analysis Note

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Search for Anomalous Higgs Boson Couplings in the Production of $W^{\pm}H$ via Vector Boson Scattering

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Abstract

This note describes the search for negative couplings between the Higgs boson with the W and Z bosons in the production of W[±]H via vector boson scattering. The target of the search is the rejection of the $\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z} = -1$ hypothesis, where κ_W and κ_Z are the coupling modifiers as defined in the κ -framework between the the Higgs boson and the W and Z bosons respectively. The search is performed in the one lepton, two b quark, and two jet final state using a cut-based approach. This work is based on a data sample of proton-proton collisions at $\sqrt{s} = 13$ TeV recorded by the CMS experiment during 2016, 2017, and 2018, corresponding to a total integrated luminosity of 138 fb⁻¹. The hypothesis of $\kappa_W = -1$, $\kappa_Z = +1$ is specifically excluded with a significance of 9.0 σ . Moreover, 625 such κ_W , κ_Z hypotheses are analyzed, and the $\lambda_{WZ} < 0$ scenario is excluded.

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Please also verify that the abstract does not use any user defined symbols

Changelog

2 Version 1

Incomplete first draft

4 Version 2

- Filled in missing sections
- Added abstract

7 Version 3

- Adressed internal comments and made changes to most sections
- First complete draft

10 Version 4

- 11 Section 1
- Changed sentence to make it more clear that this analysis targets the merged H \rightarrow $b\overline{b}$ final state

14 Section 4

- Added table with signal and background yields in the Preselection and signal region (Table 12)
- Added some missing MET filters
- Added a sentence to clarify that the Control Regions are only used to ensure that there is no significant mismodeling in the Monte Carlo and that they are not other-
- 20 wise used in the analysis

21 Appendix C

• Added another systematic to the background extrapolation for the diboson composition

24 Version 5

25 General

- Added changelog
- Removed SM VBS WH sample from set of backgrounds

28 Section 1

• Replaced duplicate diagram in Fig. 1 with a previously missing diagram

30 Section 2

- Added description of 2D κ_W , κ_Z scan signal samples
- Added plot of all $\kappa_{\rm W}$, $\kappa_{\rm Z}$ points scanned (Fig. 5)
- Added plot of all κ_W , κ_Z point cross sections (Fig. 6)
- Added validation plot of κ_W , κ_Z scan cross sections (Fig. 7)

35 Section 7

- Added description of 2D exclusion
- Added 2D exclusion result (Fig. 18)

38 Version 6

- 39 Section 2
- Added PYTHIA version and tune information
- Added description of MADGRAPH phase space cuts

42 Section 7

- Added table with estimated background yields for each year of UL NanoAOD (Table 17)
- 45 Version 7
- 46 General
- Every appendix is now referenced at least once in the text

48 Section 4

- Added some additional text to explain how the SR selections were chosen
- Changed caption for Table 12 for clarity

51 Section 5

• Added table with A, B, C, and D yields (Table 13)

53 Section 6, 7

- Decorrelated ParticleNet Xbb scale factors across years
- Added 1.27% uncertainty on the H \rightarrow bb BR
- Minor language fixes

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86 1 Introduction

The Higgs boson was the last missing particle to complete the standard model (SM). After its discovery [1, 2], the LHC experiments have measured many of its properties and have found no significant deviations from SM predictions [3, 4].

One commonly used framework used to quantify the deviations from the SM is the so-called *k*-framework [5], which introduces coupling modifiers for each fermion and boson coupling. If we consider in particular the gauge bosons (W⁺, W⁻, and Z) and their coupling modifiers (κ_W and κ_Z respectively), which are object of study of this note, we see that their magnitudes have been constrained to $|\kappa_W| = 1.02^{+0.11}_{-0.10}$ and $|\kappa_Z| = 1.04^{+0.07}_{-0.07}$ by the CMS Collaboration, showing precise agreement with the Standard Model [3]. However, there is no constraint on the sign of κ_W or κ_Z , nor the relative sign between them.

The relative sign between κ_W and κ_Z can be expressed as their ratio:

$$\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z} = \pm 1 \tag{1}$$

⁹⁷ These couplings have the same sign in the SM ($\lambda_{WZ} = 1$) in order to preserve the custodial ⁹⁸ symmetry. This property, however, has not yet been confirmed with experimental data, as ⁹⁹ the processes studied so far are quadratic in κ_W or κ_Z and therefore only sensitive to their ¹⁰⁰ magnitudes. A possible channel to directly probe the λ_{WZ} ratio at the LHC is the production ¹⁰¹ of VH via vector-boson scattering (VBS) [6]. Such a channel is sensitive to the relative sign of ¹⁰² κ_W and κ_Z since the since the cross section σ has an interference term that is linear in both κ_W ¹⁰³ and κ_Z :

$$\sigma \propto |\mathcal{M}|^2 = \kappa_W^2 |\mathcal{M}_W|^2 + \kappa_W \kappa_Z \mathcal{M}_{WZ}^2 + \kappa_Z^2 |\mathcal{M}_Z|^2$$
⁽²⁾

¹⁰⁴ Therefore, this channel provides the possibility to determine with certainty that λ_{WZ} is indeed ¹⁰⁵ positive, as the SM predicts.



Figure 1: Target Feynman diagrams of $pp \rightarrow W^{\pm}H + jj$ for this analysis.

A search for negative λ_{WZ} via the VBS production of VH with the CMS detector is documented in this note. In particular, we present a search for pp $\rightarrow W^{\pm}H + jj$ in the one lepton, two b quark (merged into a single, large-cone jet), and two jet final state (Fig. 1), where $\kappa_W = -1$. We do not consider ZH production here, since $Z \rightarrow \ell^+ \ell^-$ has a less favorable branching ratio and $Z \rightarrow q\bar{q}$ would require an entirely different analysis. We also do not explicitly perform a search for $\kappa_Z = -1$, however the cross-section and resultant kinematics are identical (Fig. 2).



Figure 2: The invariant mass of the $W^{\pm}H$ system (left) and S_T (right) are plotted using the pp $\rightarrow W^{\pm}H + jj$ Monte Carlo simulation. The data plotted is taken directly from MAD-GRAPH5_aMC@NLO.

The pp $\rightarrow W^{\pm}H + jj$ signal process for this analysis is accessible at the LHC because setting 112 $\kappa_{\rm W} = \pm 1$ and $\kappa_{\rm Z} = \pm 1$ catastrophically changes the interference between Feynman diagrams 113 that contribute to the final state of interest. This firstly results in a 6-fold increase in the overall 114 cross section versus the SM (Fig. 3). The cross section importantly changes most dramatically at 115 high values of the combined invariant mass of the scattering bosons–e.g. $M_{W^{\pm}Z}$ in the case of 116 VBS W[±]H. This can be seen explicitly for W⁺W⁻ \rightarrow ZH in Fig. 1 in the paper by D. Stolarski 117 and Y. Wu [6], or equivalently in Fig. 4a in this note, where the combined invariant mass of the 118 outgoing W and H is plotted using Monte Carlo simulation at the generator level. Importantly, 119 this implies that the decay products of W and H receive a significant boost, providing a power-120 ful discriminating feature in addition to the already distinct VBS signature of $pp \rightarrow W^{\pm}H + ij$. 121 See Section 4.3 for more details. 122

This note is structured as follows. The CMS proton-proton collision data and Monte Carlo 123 (MC) simulation samples used in this analysis are listed in Section 2. Section 3 details how, 124 using this data, leptons and jets are defined and more precisely selected for this analysis. The 125 definition of the kinematic "signal region" (SR) for this analysis is documented in Section 4, 126 and Section 5 illustrates how background contamination in this region is estimated. The sys-127 tematic uncertainties on the expected signal and background yields in the signal region are 128 cataloged in Section 6. Finally, Section 7 presents the yields in the signal region along with the 129 corresponding statistical interpretation, followed by a complete summary in Section 8. 130



Figure 3: The cross section is plotted as a function of enhancements to κ_W (keeping $\kappa_Z = +1$) on the left and to κ_Z (keeping $\kappa_W = +1$) on the right. The black points are taken from MAD-GRAPH5_aMC@NLO, and the blue curve is the best fit of a 2nd order polynomial to those points. The errors are also plotted, but are smaller than the width of the black points. Importantly, the cross section for $\kappa_W = -1$, $\kappa_Z = +1$ and $\kappa_W = +1$, $\kappa_Z = -1$ are exactly the same.



Figure 4: The invariant mass of the $W^{\pm}H$ system (left) and S_T (right) are plotted using the pp $\rightarrow W^{\pm}H + jj$ Monte Carlo simulation. The data plotted is taken directly from MAD-GRAPH5_aMC@NLO.

131 2 Samples

132 2.1 Collision data

This analysis uses an amount of CMS proton-proton collision data corresponding to an integrated luminosity of 138 fb⁻¹. In particular, the SingleMuon and SingleElectron datasets are analyzed using the NanoAOD data tier (version 9) under the "Ultra Legacy" (UL) reconstruction campaign. The "golden" JSON files used to certify the events used in this analysis are tabulated in Table 1, and the triggers used to filter this data are listed in Table 11.

Year	Golden JSON file
2016 (pre-VFP)	Cert_271036-284044_13TeV_Legacy2016_Collisions16_JSON.txt
2016 (post-VFP)	Cert_271036-284044_13TeV_Legacy2016_Collisions16_JSON.txt
2017	Cert_294927-306462_13TeV_UL2017_Collisions17_GoldenJSON.txt
2018	Cert_314472-325175_13TeV_Legacy2018_Collisions18_JSON.txt

Table 1: Golden JSON files used in to certify the proton-proton collision events used in this analysis.

138 2.2 Monte Carlo simulation

139 **2.2.1 Signal**

The MC simulation of pp $\rightarrow W^{\pm}H + ij$ was generated at leading order (LO) using the MAD-140 GRAPH5_aMC@NLO generator [7] using a modified version of the Standard Model MADGRAPH 141 model (see Appendix A), where $\kappa_W = -1$ and $\kappa_Z = +1$ in order to test $\lambda_{WZ} = -1$. Importantly, 142 the W and H bosons are decayed inclusively, and parton showers are handled by PYTHIA (ver-143 sion 8) with the CP5 tune[8]. Standard MADGRAPH phase space cuts are also applied, but two 144 cuts are specifically tightened for generating this signal process. In particular, the pseudorapid-145 ity of any jet is required to be less than 6.5 and the invariant mass of any two jets is required to 146 be larger than 100 GeV. Additional settings are taken from centrally generated CMS MC sam-147 ples at LO. The signal simulation was then processed through the same workflow as other UL 148 MC samples. This analysis has been specifically optimized for this point ($\kappa_W = -1, \kappa_Z = +1$). 149 An additional set of signal samples were generated using the reweighting feature of MAD-150 GRAPH5_aMC@NLO such that the values of κ_W and κ_Z could be varied in a two-dimensional 151 scan. Because the reweighting is done around a central point, two signal samples were gener-152 ated: one reweighted around $\kappa_W = -1$, $\kappa_Z = +1$ such that $\lambda_{WZ} \leq 0$ and another reweighted 153 around $\kappa_W = \kappa_Z = +1$ such that $\lambda_{WZ} > 0$. These samples are generated using the same ver-154 sion and settings of PYTHIA as the $\kappa_W = -1$, $\kappa_Z = +1$ sample. Moreover, the points scanned 155

are plotted in Fig. 5, and the reweighting has been validated against samples generated for

¹⁵⁷ individual κ_W , κ_Z points (Fig. 7).

158 2.2.2 Background

The MC simulation samples of background processes are listed in Tables 2, 3, 4, and 5 corresponding to the 2016 pre-VFP, 2016 post-VFP, 2017, and 2018 detector conditions respectively. The selected MC samples are intended to represent the major backgrounds for this analysis, and the completeness of this set is validated against data in sidebands of relevant phase space–see Section 4.5. All MC samples also use the NanoAOD data tier under the UL reconstruction campaign. Notably, the samples containing the production of a leptonically decaying W via vector



Figure 5: Scatter plot of the κ_W , κ_Z reweighting points that were scanned for this analysis, where the blue points were reweighted from $\kappa_W = -1$, $\kappa_Z = +1$ and the gold points were reweighted from $\kappa_W = \kappa_Z = +1$.

¹⁶⁵ boson scattering were erroneously produced and had to be corrected manually (Appendix D).

¹⁶⁶ However, these samples are a very small background for this analysis.



Figure 6: Two-dimensional histogram with bins centered at each κ_W , κ_Z point scanned for this analysis where the corresponding reweighted cross section is plotted on the *z*-axis.



Figure 7: The cross section is plotted as a function of enhancements to κ_W (keeping $\kappa_Z = +1$) on the left and to κ_Z (keeping $\kappa_W = +1$) on the right. The black points are obtained by reweighting the central κ_W , κ_Z point by the MADGRAPH5_AMC@NLO reweighting, and the blue curve is the best fit of a 2nd order polynomial to those points. Based on the best fit, it is clear that the cross sections are nearly identical to those obtained by generating separate signal samples at a fixed κ_W , κ_Z point (Fig. 3).

Process	Sample Name	σ [pb]			
SingleTop	/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia80	136.02			
0.01	/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia80	19,559			
	/ST tW antitop 5f inclusiveDecays TuneCP5 13TeV-powheg-pythia8 ⁰	19,559			
	/ST t-channel antitop 4f InclusiveDecays TuneCP5 13TeV-powheg-madspin-pythia8 ⁰	80.95			
TTbar1L	/TTToSemiLeptonic TuneCP5 13TeV-powheg-pythia8 ⁰	365.34			
TTbar2L	/TTTo2L2Nu TuneCP5 13TeV-powheg-pythia8 ⁰	88.29			
TTX	/TTToHadronic TuneCP5 13TeV-powbeg-pythia8 ⁰	377.96			
117	/TTWIetsToI Nu TuneCP5 13TeV-amcatnloEXEX-madspin-pythia8 ¹	0 2043			
	/TTZToLI NuNu M-10 TuneCP5 13TeV-amcatnlo-nythia80	0.2529			
	/ttHTobb M125 TuneCP5 13TeV-powbeg-pythia8 ¹	0.1279			
	/ttHToNonbb M125 TuneCP5 13TeV-powheg-pythia81				
	/TTWZ TuneCP5 13TeV-madgraph-pythia80				
	/TTWW TuneCP5 13TeV-madgraph-pythia8 ⁰	0.0115			
	/ Triver Interior of the Annual of Participation of the Annual State of the Annual Sta				
	/TTbb 4f TTToSemil entonic TuneCP5-Powhee Openloops-Pythia8	0.62			
WIote	/WigtsToLNu HT-70To100 TuneCP5 13ToWmadgraphMI M-pythia80	1310 78			
Wjets	/WJotsToLNu_HT-100To200 TuneCP5_13ToV_madgraphWLM-pythia8	1325.0			
	/WJotsToLNU_III-10010200_10neCI5_151eV-madgraphMLM.pythia8	248 5702			
	/WJotsToLNU_III-20010400_IURECI 5_151eV-madgraphMLM.pythia8	47 208275			
	/WJotsToLNU_III-40010000_IUNECI 5_151eV-InaugraphWLM.pythia8	11 258/87			
	/WJotsToLNU_III-00010000_IUNECI 5_151eV-InaugraphWLWI-pythiao	5 2086024			
	/WietsToLNu_HT 1000To2500 TuneCD5_15TeV-InaugraphWLM-pythia8	1 1 2 2 0 2 0 2 0 2 0 2 0 2 0 2 0 2 0 2			
	/WiletsToLNu_H1-1200102500_10neCP5_151ev-madgraphWLM-pythia8°	1.1880809			
Deceme	/ WjetsToLNU_FI-2500ToInf_TuneCP5_15TeV-madgraphiviLWi-pythia6*	0.024098031			
Dosons	/DYJetsToLL_W-10000_10neCP5_131eV-madgraphWLW-pythia8°	20657.0			
	/DYJETSTOLL_M-30_TUNECP3_13TeV-madgraphiviLivi-pythia8*	10.07			
	/EWKWpius2jels_w10QQ_upolekecolOn_luneCr5_151ev-maugraph-pythiao*	10.67			
	/EvvKvvminus2jets_vv ioQQ_aipoiekecoiiOn_luneCf5_131ev-madgraph-pythia8°				
	/EWK72lets ZToNuNu M-50 TuneCP5 with DinoleRecoil 13TeV-madgraph-pythia8 ¹				
	/EWKZ2Jets_ZIONuINU_M-50_TUNECP5_withDipolekecoll_131ev-madgraph-pythias*	10.72			
	/ Evy KZ2Jets Z 10QQ_alpolekecollOn_luneCP5_151eV-maagraph-pythia8°				
	/ vv vv 101L1Nu2Q_4f_1uneCP5_131e v-amcatnloFXFX-pythia8°				
	/ www.iozLzinu_iuneCr5_131ev-powneg-pythia8° /w/7T-11.1Nr-20.46 TenseCP5_12T-W ence to 1. EVEX worth is 90				
	/WZ101L1Nu2Q_4t_TuneCP5_T3TeV-amcatnloFXFX-pythia8 ^v				
	$/WZ101L3NU_4f_1uneCP5_131ev-amcatniofAFA-pytniaso$	3.054024			
	/WZ102Q2L_milmin4p0_luneCP5_131eV-amcatnioFXFX-pytnia8*	5.6			
	/WZ103LINU_IURECP5_131ev-amcatnloFXFX-pytnia8°	4.42965			
	/ZZT-01 0Nto Tome CD5 12T-M grande an unstation of XFX-pythia8*	3.28			
	/ZZT02L2Nu_luneCr5_131ev_powneg_pytnia8"	0.564			
	/INTATIAL AF True CDE 12TeV emocratele mythice?	0.2086			
	/ WWW W_4F_1UNECP5_131eV-amcatnio-pythia8-	0.2086			
	$/WZ_4F_1uneCP5_151ev-amcatnio-pythia8^{-2}$	0.1651			
	$\sqrt{WZZ_1}$ uneCP5_151eV-amcatnio-pytnia8 ⁻	0.05565			
	/ZZZ_IUNECTS_ISTEV-amcatnio-pytnias	0.01398			
	/ WWJJIOLINULINULEWK.noiop_iuneCP5_13iev-madgraph-pytnia8"	0.284			
	/WZJJ_EWK_Inclusiverolarization_iuneCr5_151ev_inaugraph-inauspin-pythiao	0.01701			
EWKWW are	/ ZZJJ 104L_1UIECI J_13 IEV-IIIdugraph-pythildo /EWKWDJug2loto WToL Nu M 50 TungCD5 with DingloDogoil 12ToV modernali wething0	20.22			
LVVKVVLep	/EWKWWinus/Jets WTol Nu M 50 TunoCP5 with Dipole Recoil 12ToV moderant with 200	37.33			
VL	/ Evy Kyvivinuszjeis_vvioLivu_ivi-50_runeeri 5_winiDipolekecoli_151ev-madgraph-pythla8°	2 207			
νп	/WminusH HTaR WTal Nu M 125 Tune (D5 12TaV nauthor nythin ⁰	2.207			
	/White HTOBE WTOLNULW-125_TUNCT 5_1516v-powneg-pythia0	0.04701230122			
	/ WPIUSHI HIODD W TOLINULWHIZD HUNCH DISTEV-powneg-pythiao	0.00407099411			
	/ggZH HToBB ZToLL M-125 TimeCP5 13TeV-nowhea-nythia80	0.02027400311			
1	/ Sectime of the sector of the	0.0021010/00/0			

⁰ /RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM
 ¹ /RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v2/NANOAODSIM
 ² /RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11_ext1-v1/NANOAODSIM

Table 2: Background MC samples used in this analysis, corresponding to 2016preVFP detector conditions (UL), with their respective cross sections in picobarns. The cross sections for the $H_{\rm T}$ -binned W+jets samples are scaled by a "stitching" factor such that the samples together fill a continuous $H_{\rm T}$ distribution.

Process	Cample Name	σ [ph]
Frocess	Sample Name	
SingleTop	/ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia80	80.95
	/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia80	136.02
	/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia81	19.559
	/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia81	19.559
TTbar1L	/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia80	365.34
TTbar2L	/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 ⁰	88.29
TTX	/TTToHadronic_TuneCP5_13TeV-powheg-pythia80	377.96
	/TTWJetsToLNu_TuneCP5_13TeV-amcatnloFXFX-madspin-pythia8 ⁰	0.2043
	/TTZToLLNuNu_M-10_TuneCP5_13TeV-amcatnlo-pythia80	0.2529
	/ttHTobb_M125_TuneCP5_13TeV-powheg-pythia81	0.1279
	/ttHToNonbb_M125_TuneCP5_13TeV-powheg-pythia81	0.215
	/TTWZ_TuneCP5_13TeV-madgraph-pythia80	0.003884
	/TTWW_TuneCP5_13TeV-madgraph-pythia8 ⁰	0.0115
	/TTbb_4f_TTTo2L2Nu_TuneCP5-Powheg-Openloops-Pythia80	0.04
	/TTbb_4f_TTToSemiLeptonic_TuneCP5-Powheg-Openloops-Pythia80	0.62
Wlets	/WIetsToLNu_HT-70To100_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰	1283.91
	/WIetsToLNu_HT-100To200_TuneCP5_13TeV-madgraphMLM-pvthia8 ⁰	1303.06
	/WletsToLNu HT-200To400 TuneCP5 13TeV-madgraphMLM-pythia8 ⁰	341.046
	/WletsToLNu HT-400To600 TuneCP5 13TeV-madgraphMLM-pythia8 ⁰	45.4362
	/WietsToLNu HT-600To800 TuneCP5 13TeV-madgraphMLM-pythia8 ⁰	11.0051
	/WIetsToI Nu HT-800To1200 TuneCP5 13TeV-madgraphMI M-pythia8 ⁰	4 94177
	/WlatsTol Nu HT-1200To2500 TuneCP5 13TeV-madgraphMI M-pythia8	1 15544
	/WlatsTol Nu HT-2500ToInf TuneCP5 13TeV-madgraphMI M-pythia8 ¹	0.0216234
Bosons	/DVIetsToLI_M_10to50_TuneCP5_13ToV_madgraphMLM_pythia0	20657.0
DOSOIIS	/DVIetsToLL_M-10000_1010CP5_13ToV_madgraphMLM_pythia8	6108.0
	/EWKWhlue2lots WToOO dinoloRecoilOn TunoCP5 13ToV moderant pythia8	10.67
	/EWKWpius2Jets_W10QQ_uipoleRecolOn_TuneCP5_13TeV=Maugraph=pythao	10.67
	/EWK721ate 7Tal L M 50 TuneCDE with Dinal Desail 12TaV medarante pythia	6.02
	/EWKZ2Jets_ZIOLL_W-50_TURECT5_withDipoleRecoil_15TeV-indugtaph-pythia6	0.22
	/EWKZ2Jets_ZIOWUWUW-30_TURECT 5_WIRDIPORCECOR_TSTEV-madgraph-pyrilao	10.72
	/ LIVERZZJEISZ IOQQ-UIPOIERECOIOILIUIECI 5-15 IEV-intaugiapii-pythiao	10.07 E1.6E
	/WWWTOTETNUZQ_4L_IURECT 5_15 Revalued number of the second	10 179
	/WWW02L2Nu_IURECF5_ISTEV-powneg-pythiao	12.176
	/WZ101LINu2Q_4I_1uneCr5_151eV-ancannorArA-pyunao*	49.997
	/WZ101L3Nu_4f_luneCP5_131ev-amcatnioFAFA-pytnia8*	3.054024 E.C
	$/WZ102Q2L_miimin4p0_1uneCP5_131eV-amcatnioFXFX-pytnia8^{-}$	5.6
	/WZ103LINU_IUNECP5_131eV-amcatnioFXFX-pytnia8°	4.42965
	$/2Z_102Q_2L_miimi4p_1ureCP_131ev-amcatniorXFX-pythias*$	3.28
	/ZZTOZLZINU_IUNECF5_I3TEV_powneg_pytnia8"	0.564
	/ZZ104L_W-ItoInf_IuneCF5_13TeV_powneg_pythia8~	1.256
	/ WWW VV_4F_1uneCP5_131eV-amcatnio-pytnia8-	0.2086
$\langle \rangle$	/WWZ_4F_IuneCP5_13TeV-amcatnio-pythia82	0.1651
	/ WZZ_luneCP5_131eV-amcatnlo-pythia8 ²	0.05565
	/ZZZ_luneCP5_131eV-amcatnlo-pythia8 ²	0.01398
	/WWJJIoLNuLNuLEWK_nolop_luneCP5_13leV-madgraph-pythia8°	0.284
	/WZJJ_EWK_InclusivePolarization_luneCP5_131eV_madgraph-madspin-pythia8°	0.01701
	$/ \Delta Z J J 104L_1 uneCP5_131eV-madgraph-pythia84$	0.00884
EWKWLep	/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia80	39.33
	/EWKWMinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia80	32.26
VH	/VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia81	2.207
	/WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia80	0.04901236122
	/WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰	0.08487599411
	/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia80	0.02627486511
	/ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰	0.002461395396

⁰ /RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM
 ¹ /RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v2/NANOAODSIM
 ² /RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17_ext1-v1/NANOAODSIM

Table 3: Background MC samples used in this analysis, corresponding to 2016postVFP detector conditions (UL), with their respective cross sections in picobarns. The cross sections for the H_{T} -binned W+jets samples are scaled by a "stitching" factor such that the samples together fill a continuous $H_{\rm T}$ distribution.

SingleTop /FIT-channel.op.#LinclusiveDecays.TuneCP5.13TeV-powheg-madspin-pythia8° 136.02 /FIT-channel.antitop.#LinclusiveDecays.TuneCP5.13TeV-powheg-madspin-pythia8° 80.95 /FIT-wh.mitop.SinclusiveDecays.TuneCP5.13TeV-powheg-pythia8' 19559 /FIT-W.mitop.SinclusiveDecays.TuneCP5.13TeV-powheg-pythia8' 19559 /ThatL /TTroBartine_timeCP5.13TeV-powheg-pythia8' 88.29 TTACL /TTroBartine_timeCP5.13TeV-ancathloPXP-madspin-pythia8' 88.29 TTX /TTroBartine_timeCP5.13TeV-ancathloPXP-madspin-pythia8' 0.2433 /TTZ/ELI.Nux.Nu-N10.TuneCP5.13TeV-ancathloPXP-madspin-pythia8' 0.2252 /HtfRoNonbM125.TuneCP5.13TeV-ancathlo-pythia8' 0.0215 /TTWW_TuneCP5.13TeV-andgraph-pythia8' 0.0215 /TTWW_TuneCP5.13TeV-andgraph-pythia8' 0.03844 /WestoI.Nu.HT-200100.TuneCP5.13TeV-madgraphMIM-pythia8' 139.76 /WestoI.Nu.HT-200100.TuneCP5.13TeV-madgraphMIM-pythia8' 134.24 /WestoI.Nu.HT-2001000.TuneCP5.13TeV-madgraphMIM-pythia8' 134.44 /WestoI.Nu.HT-2001000.TuneCP5.13TeV-madgraphMIM-pythia8' 134.84 /WestoI.Nu.HT-2001000.TuneCP5.13TeV-madgraphMIM-pythia8' 134.84 /WestoI.Nu.HT-20010200.TuneCP5.13TeV-madgraphMIM-pythia8' 134	Process	Sample Name	σ [pb]			
overlappendix Provides and spin spin spin spin spin spin spin spin	SingleTop	/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8 ⁰	136.02			
	0 1	/ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8 ⁰	80.95			
//ST.1W.antitop.5f.inclusiveDeays.TuneCP5.13TeV-poorheg-pythia8 ¹⁰ 19559 TTbarLL /TTT6stemiLeptonic.TuneCP5.13TeV-poorheg-pythia8 ¹⁰ 365.34 TTbarLL /TTT6alLNun.TuneCP5.13TeV-powheg-pythia8 ¹⁰ 377.96 TTX /TTT6alLNun.TuneCP5.13TeV-anotatio-pythia8 ¹⁰ 0.2043 /TTZ /TTT6alLNun.TuneCP5.13TeV-anotatio-pythia8 ¹⁰ 0.2259 /HTBob.M125.TuneCP5.13TeV-powheg-pythia8 ¹⁰ 0.2179 /HTBob.M125.TuneCP5.13TeV-powheg-pythia8 ¹⁰ 0.0135 /TTWZ.TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.0115 /TTWW.TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.0135 /TTbb.4.1TTD5emiLeptonic.TuneCP5.Fowheg-Openloops-Pythia8 ¹⁰ 0.04 /Ttbb.4.1TT0212Nu.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 139.76 /WjetsTol.Nu.HT-200T00.0.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 139.74 /WjetsTol.Nu.HT-200T0600.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 139.76 /WjetsTol.Nu.HT-200T0600.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 138.74 /WjetsTol.Nu.HT-200T0600.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 138.74 /WjetsTol.Nu.HT-200T0760.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 138.74 /WjetsTol.Nu.HT-200T0760.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 102.258083		/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia81	19,559			
TTbarll. /TTT6semil.eptonic.TumeCP5.13feV-powheg-pythia8 ¹⁰ 965.24 TTbarll. /TTT6dFadcronic.TumeCP5.13feV-powheg-pythia8 ¹⁰ 88.29 TTX /TTT6dFadcronic.TumeCP5.13feV-powheg-pythia8 ¹⁰ 377.96 /TTX1bit2L2Nu.TumeCP5.13feV-powheg-pythia8 ¹⁰ 0.2529 /tTT16bfadcronic.TumeCP5.13feV-powheg-pythia8 ¹⁰ 0.2529 /ttT16bb.M125.TumeCP5.13feV-powheg-pythia8 ¹⁰ 0.215 /TTWW.TumeCP5.13feV-powheg-pythia8 ¹⁰ 0.215 /TTWW.TumeCP5.13feV-powheg-pythia8 ¹⁰ 0.0115 /TTbb 4.1TT62cmICP5.13feV-powheg-Openloops-Pythia8 ¹⁰ 0.0115 /TTbb 4.1TF02cmICptonic.TumeCP5-Powheg-Openloops-Pythia8 ¹⁰ 0.62 /WjetsToLNu.HT-2007600.TumeCP5.13feV-madgraphMLM-pythia8 ¹⁰ 1.319.76 /WjetsToLNu.HT-2007600.TumeCP5.13feV-madgraphMLM-pythia8 ¹⁰ 1.319.76 /WjetsToLNu.HT-2007600.TumeCP5.13feV-madgraphMLM-pythia8 ¹⁰ 1.1485 /WjetsToLNu.HT-2007600.TumeCP5.13feV-madgraphMLM-pythia8 ¹⁰ 1.1485 /WjetsToLNu.HT-2007600.TumeCP5.13feV-madgraphMLM-pythia8 ¹⁰ 0.0258083 /WjetsToLNu.HT-2007600.TumeCP5.13feV-madgraphMLM-pythia8 ¹⁰ 0.0258083 /WjetsToLNu.HT-2007600.TumeCP5.13feV-madgraphMLM-pythia8 ¹⁰ 0.0258083 /WjetsT		/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 ¹	19.559			
TTbar2L /TTb012LNu_TuneCP5.13FeV-powheg.pythia8 ⁴ 88.29 TIX /TTI04fadronic.TuneCP5.13FeV-powheg.pythia8 ⁴ 377.96 TTX /TTWfef5IoLNu.TuneCP5.13FeV-amcathlo-pythia8 ⁶ 0.2529 /TTITALNUNU.M.10.TuneCP5.13FeV-amcathlo-pythia8 ⁶ 0.215 /TTWZ.TuneCP5.13FeV-powheg.pythia8 ¹ 0.115 /TTWZ.TuneCP5.13FeV-madgraph-pythia8 ⁶ 0.003884 /TTWV.TuneCP5.13FeV-madgraph-pythia8 ⁶ 0.003884 /TTWV.TuneCP5.13FeV-madgraph-pythia8 ⁶ 0.004 /TBb.44.TTToSemil.eptonic.TuneCP5-fowheg-Openloops-Pythia8 ⁶ 0.04 /TBb.44.TTToSemil.eptonic.TuneCP5.13FeV-madgraphMLM-pythia8 ⁶ 1319.76 /WjetsToLNu.HT-0070600.TuneCP5.13FeV-madgraphMLM-pythia8 ⁶ 1304.74 /WjetsToLNu.HT-0070600.TuneCP5.13FeV-madgraphMLM-pythia8 ⁶ 11.485 /WjetsToLNu.HT-20070500.TuneCP5.13FeV-madgraphMLM-pythia8 ⁶ 1.148 /WjetsToLLM.HT-20070500.TuneCP5.13FeV-madgraphMLM-pythia8 ⁶ 1.0258083 /D0.0258083 /D0.258083 1.1485 /WjetsToLLM.400.GonLmeCP5.13FeV-madgraphPythia8 ¹ 0.0258083 /D1/FeisToLLM.100.GonLmeCP5.13FeV-madgraph-pythia8 ¹ 1.067 /EWKZ/Jets.TLOLM.50.TuneCP5.13FeV-madgraph-pythia8 ⁹ 1.	TTbar1L	/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8 ⁰	365.34			
TTX /TTDeHadronic TuneCP5.13TeV-modesp.pythia8 ¹⁰ 377.96 /TTZToLLNuNu. TuneCP5.13TeV-amatathoPXPX-madspin-pythia8 ¹⁰ 0.2043 /TTZToLLNuNu. M-10. TuneCP5.13TeV-powheg-pythia8 ¹⁰ 0.1279 /HTHONONE M125. TuneCP5.13TeV-powheg-pythia8 ¹⁰ 0.215 /TTWW. TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.015 /TTWW. TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.0115 /TTWW. TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.0115 /TTb. 4f. TTTo2L2Nu. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 0.0115 /TTb. 4f. TTTO2COU. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 0.032 /WjetsToLNu. HT-2007000. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 1319.76 /WjetsToLNu. HT-2007000. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 1314.74 /WjetsToLNu. HT-2007000. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 11.485 /WjetsToLNu. HT-20070100. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 11.148 /WjetsToLNu. HT-20070100. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 11.183 /WjetsToLNu. HT-20070100. TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 0.0256903 /DYjetsToLLM-10105.01 TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 0.0256903 /DYjetsToLLM-10105.01 TuneCP5.13TeV-madgraphMIM-pythia8 ¹⁰ 0.02567.0 /DYjetsToLLM-1005.01	TTbar2L	/TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 ⁰	88.29			
/TTV/JetsToLNuECP5.13TeV-amactin/oFXP:madspin-pythia8 ⁰ 0.2043 /TTZToLLNuN.u.M-10.TumeCP5.13TeV-amactin/o-pythia8 ⁰ 0.2529 /tHTlobAnbb.M125.TumeCP5.13TeV-powheg-pythia8 ¹ 0.1279 /tHTlobAnbb.M125.TumeCP5.13TeV-powheg-pythia8 ¹ 0.215 /TTWZ_TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.00115 /TTWZ_TUNCCP5.13TeV-madgraph-pythia8 ¹⁰ 0.00115 /TTWb.4.fTTDS2LNU.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 0.62 WJets /WJetsToLNu.HT-20070.JuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 0.62 WJets /WJetsToLNu.HT-20070.JuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 0.62 //WJetsToLNu.HT-20070.JuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 1.34.74 //WJetsToLNu.HT-20070500.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 1.1485 //WJetsToLNu.HT-20070500.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 1.02528083 //WJetsToLLM-10050.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 0.0258083 //WJetsToLLM-40.0050.TuneCP5.13TeV-madgraphMLM-pythia8 ¹⁰ 0.0258083 //WJetsToLLM-50.TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.025 //WJetsToLM-50.TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.025 //WJetsToLM-50.TuneCP5.13TeV-madgraph-pythia8 ¹⁰ 0.067 //WKWTMUN2Q4LTUNECP5.13TeV-madgraph-	TTX	/TTToHadronic_TuneCP5_13TeV-powheg-pythia80	377.96			
/TTZ/DLLNuNu.M-10.TuneCP5.13TeV-anothe-pythia8 ⁰ 0.2529 /tHTobb.M125.TuneCP5.13TeV-powheg-pythia8 ¹ 0.217 /TTWW.TuneCP5.13TeV-powheg-pythia8 ¹ 0.215 /TTWW.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.003884 /TTWW.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.015 /TTW.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.04 /TTbb.4f.TTTbcSmil.eptonic.TuneCP5-Powheg-Openloops-Pythia8 ⁰ 0.04 /TDb.4f.TTTbcSmil.eptonic.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.62 Wjets (WjetsToLNu.HT-00100.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1319.76 /WjetsToLNu.HT-10010.00.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1314.74 /WjetsToLNu.HT-20070.00.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 /WjetsToLNu.HT-20070.500.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 /WjetsToLNu.HT-20070.500.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 10.67 /EWKWplus2lets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKWplus2lets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKWplus2lets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2lets.ZToLLM-50.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2lets.ZToQU.dipoleRecoilOn.TuneCP5.1		/TTWIetsToLNu_TuneCP5_13TeV-amcatnloFXFX-madspin-pythia8 ⁰	0.2043			
/ tHTlobb.M125.TuneCP5.13TeV-powheg-pythia8 ¹ 0.1279 //HTRNonbb.M125.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.215 //TTWJ.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.003884 //TTWJ.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.0115 //TTbb.4f.TTTol2L2N.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.04 //Ttbb.4f.TTTol2L2N.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.62 WJets //WjetsToLNu.HT-700To100.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1319.76 //WjetsToLNu.HT-100To200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1334.74 //WjetsToLNu.HT-00To800.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 46.5726 //WjetsToLNu.HT-00To800.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu.HT-200To200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 //WjetsToLNu.HT-200To200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 //WjetsToLL.M-50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 6198.0 //WjetsToLL.M-50.TuneCP5.3TeV-madgraphMLM-pythia8 ⁰ 6198.0 //WjetsToLL.M-50.TuneCP5.3TeV-madgraphPythia8 ⁰ 10.67 //EWKX2Jets.ZToNUN.M-50.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 //EWKX2Jets.ZToNUN.M-50.TuneCP5.3TeV-madgraph-pythia8 ⁰ 10.67 //EWKX2Jets.ZToNUN.M-50.TuneCP5.3TeV-madgr		/TTZToLUNuNu_M-10_TuneCP5_13TeV-amcatnlo-pythia8 ⁰	0.2529			
//HHTONombb M125 TuneCP5.13TeV-powheg-pythia8 ¹ 0.215 //TWZ.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.003884 //TWW.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.0115 /TTbb.4f.TTTo5cmiLeptonic.TuneCP5-Powheg-Openloops-Pythia8 ⁰ 0.04 //Tbb.4f.TTTo5cmiLeptonic.TuneCP5-Powheg-Openloops-Pythia8 ⁰ 0.62 WJets //WjetsToLNu.HT-20T0100.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1319.76 //WjetsToLNu.HT-200T0400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1314.74 //WjetsToLNu.HT-200T0400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu.HT-200T0400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu.HT-200T020.DuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu.HT-200T0400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.83 //WjetsToLNu.HT-200T0400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 10.67 //WjetsToLL.M-50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 10.67 //WKZ2Jets.ZToLNU.M-50.TuneCP5.vithDipoleRecoil.13TeV-madgraph-pythia8 ¹ 622 //WKWplus2Jets.WToQ.Q.dipoleRecoil.On.TuneCP5.13TeV-madgraph-pythia8 ¹ 622 //WKWplus2Jets.ZToNU.M.M-50.TuneCP5.vithDipoleRecoil.13TeV-madgraph-pythia8 ¹ 622 //WKZ2Jets.ZToLU.M-50.TuneCP5.vithDipoleRecoil.13TeV-madgraph-pythia8 ¹		/ttHTobb M125 TuneCP5_13TeV-powheg-pythia8 ¹	0.1279			
//TTWZ_TuneCP5_13TeV-madgraph-pythia8 ⁰ 0.003884 //TTWJ_TUWZ_TuneCP5_13TeV-madgraph-pythia8 ⁰ 0.0115 //TTbb.4f_TTT052LNL_InueCP5-Powheg-Openloops-Pythia8 ⁰ 0.62 Wjets //WjetsToLNu_HT7-00100_TuneCP5_13TeV-madgraphMLA-pythia8 ⁰ 1319.76 //WjetsToLNu_HT7-00100_TuneCP5_13TeV-madgraphMLA-pythia8 ⁰ 1334.74 //WjetsToLNu_HT-0010600_TuneCP5_13TeV-madgraphMLA-pythia8 ⁰ 330.435 //WjetsToLNu_HT-0010600_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu_HT-6001020_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 1.183 //WjetsToLNu_HT-200102_00_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 1.183 //WjetsToLNu_HT-200102_00_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 Bosons /D/JetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 0.067 //EWKWpius2Jets_VTiOQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia8 ⁰ 10.67 /EWKKZ2Jets_ZToLL_M-50_TuneCP5_withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 0.022 //EWKZ2Jets_ZToLU_M-50_TuneCP5_withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 10.67 //WWToLLNu2Q.4f_TuneCP5_13TeV-madgraph-pythia8 ⁰ 10.67 //EWKZ2Jets_ZToLU_M-50_TuneCP5_13TeV-madgraph-pythia8 ⁰ 10.67 //WWToLLNu2Q.4f_TuneCP5_13TeV-amcatnloFXK-pythia8 ⁰		/ttHToNonbb_M125_TuneCP5_13TeV-powheg-pvthia81				
/TTWW.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.0115 /TTbb.4f.TTToSemiLeptonic.TuneCP5-Powheg-Openloops-Pythia8 ⁰ 0.04 Wjets /WjetsToLNu.HT-70To100.TuneCP5-Powheg-Openloops-Pythia8 ⁰ 0.62 Wjets /WjetsToLNu.HT-20To200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1334.74 /WjetsToLNu.HT-20To200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1334.74 /WjetsToLNu.HT-20To800.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1334.74 /WjetsToLNu.HT-20To200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 /WjetsToLNu.HT-20To2500.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.183 /WjetsToLLM.HT-20To2500.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.0258083 /WjetsToLLM-10to50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.0258083 /WjetsToLLM-S0.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.067 /EWKWplus2lets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2lets.ZToLLM-S0.TuneCP5.31TeV-madgraphMLM-pythia8 ⁰ 10.67 /EWKZ2lets.ZToLLM-S0.TuneCP5.31TeV-madgraphPythia8 ⁰ 10.67 /EWKZ2lets.ZToLLM-S0.TuneCP5.31TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2lets.ZToLLM-S0.TuneCP5.31TeV-madgraphPythia8 ⁰ 10.67 /EWKZ2lets.ZToLLM-S0.TuneCP5.31TeV-madgraph-pythia8 ⁰ 10.67		/TTWZ_TuneCP5_13TeV-madgraph-pythia8 ⁰				
/TTbb.4f.TTTo2L2Nu.TuneCP3-Powheg-Openloops-Pythia8 ⁰ 0.04 /TTbb.4f.TTToSemiLeptonic.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.62 WJets /WjetsToLNu.HT7-TOIOI.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1319.76 /WjetsToLNu.HT7-20100.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1334.74 /WjetsToLNu.HT7-2000.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 350.435 /WjetsToLNu.HT-6007680.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 46.5726 /WjetsToLNu.HT-6007680.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 /WjetsToLNu.HT-200701200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.83 /WjetsToLNu.HT-25007161.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 Bosons /DYjetsToLL.M-10105.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0667.0 /EWKWplus2Jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZJets.ZToNUM.M-50.TuneCP5.31TeV-madgraph-pythia8 ⁰ 10.67 /WWTo1LNM2Q.4f.TuneCP5.13TeV-amcatholFXFX-pythia8 ⁰ 3.054024 /WZTo1LNM2Q.4f.TuneCP5.13TeV-amcatholFXFX-pythia8 ⁰ 3.28 <td></td> <td colspan="5">/TTWW TuneCP5 13TeV-madgraph-pythia8⁰</td>		/TTWW TuneCP5 13TeV-madgraph-pythia8 ⁰				
/TTbb 4f.TTT05emiLeptonic.TuneCP5-Bowheg-OpenLoops-Pythia8 ⁰ 0.62 WJets /WJetsToLNu_HT-70To100.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1319.76 /WJetsToLNu_HT-20070400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1334.74 /WJetsToLNu_HT-20070400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 350.435 /WJetsToLNu_HT-20070400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 46.5726 /WJetsToLNu_HT-800705200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 /WJetsToLNu_HT-200705200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 /Dosons /DYJetsToLL_M-100c500.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 /Bosons /DYJetsToLL_M-100c50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 /Dosons /DYJetsToLL_M-100c50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 10.67 /EWKWplus2Jets.WToQQ_dipoleRecoil0.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2Jets.ZToQU_IopleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2Jets.ZToQU_IopleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2Jets.ZToQU_IopleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2Jets.ZToQU_IopleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 6.24 /WWTo1L1Nu2Q.4f.TuneCP5.13TeV-macatInIoFXE-pythia8 ⁰ 10.67 </td <td></td> <td colspan="5">/TTbb 4f TTTo2L2Nu TuneCP5-Powheg-Openloops-Puthia80</td>		/TTbb 4f TTTo2L2Nu TuneCP5-Powheg-Openloops-Puthia80				
Wjets //WjetsToLNu.HT-707.0100.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1319.76 Wjets //WjetsToLNu.HT-1007.0200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1334.74 //WjetsToLNu.HT-2007.6400.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 350.435 //WjetsToLNu.HT-6007.6600.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 46.5726 //WjetsToLNu.HT-6007.6600.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu.HT-2007.0200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.133 //WjetsToLNu.HT-2007.0200.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.0258083 Bosons /DYjetsToLL.M-10to50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 10.0258083 Bosons /DYjetsToLL.M-10toC0_dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKWpius2jets.WToQQ_dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2jets.ZToLL.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2jets.ZToQQ_dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 //WTo1LNu2Q.4f.TuneCP5.13TeV-amcatnloFXF-pythia8 ⁰ 10.67 //WWTo2L2Nu.TuneCP5.13TeV-amcatnloFXF-pythia8 ⁰ 10.72 //WZTo1L1Nu2Q.4f.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 //WTTo1LNu2Q.4f.TuneCP5.13TeV-amcatnloFXF-pythia8 ⁰ 30.54024		/TTbb_4f_TTToSemiLeptonic_TuneCP5-Powheg-Openloops-Pythia80	0.62			
////interstock/interstore/inters	Wlets	/WJetsToLNu_HT-70To100_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰	1319.76			
//WjetsToLNu_HT-200To400_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 350.435 //WjetsToLNu_HT-400To600_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 46.5726 //WjetsToLNu_HT-600To800_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu_HT-600To2500_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu_HT-200To12500_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.183 //WjetsToLL_M-10to50_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 Bosons /DYjetsToLL_M-10to50_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 6198.0 //EWKWplus2jets_WToQQ_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKWplus2jets_ToTLL_M-50_TuneCP5_withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2jets_ZToLNU_M-50_TuneCP5_withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 10.67 /EWKZ2jets_TOQ_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8 ¹ 10.67 /WWToLLNu2Q_4T_TuneCP5.13TeV-ancatnloFXFx-pythia8 ⁰ 51.65 /WWTo2L2Nu_TuneCP5.13TeV-ancatnloFXFx-pythia8 ⁰ 51.65 /WZTo1L1Nu2Q_4T_TuneCP5.13TeV-ancatnloFXFx-pythia8 ⁰ 3.054024 /WZTo2QL_unllmin4p0_TuneCP5.13TeV-ancatnloFXFx-pythia8 ⁰ 3.054024 /WZTo2QL_unllmin4p0_TuneCP5.13TeV-ancatnloFXFx-pythia8 ⁰ 3.28 /ZZTo2QL_unllmin4p0_TuneCP5.13TeV-ancatnloFXFx-pyth	,	/WJetsToLNu_HT-100To200_TuneCP5_13TeV-madgraphMLM-pythia80	1334.74			
//WjetsToLNu_HT-400To600_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 46.5726 //WjetsToLNu_HT-600To800_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu_HT-200To2500_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu_HT-200To2500_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 //WjetsToLL_M-10to50_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 //WjetsToLL_M-10to50_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 //WjetsToLL_M-50_TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 10.67 //EWKWminus2jets.WToQQ_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 //EWKZ2jets_ZToLL_M-50_TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 6.22 //EWKZ2jets_ZToQL_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8 ¹ 10.67 //WWTo1L1Nu2Q_4f_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 10.67 //WWTo2L2Nu_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 12.178 //WZTo1L3Nu.4f_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 12.178 //WZTo1L3Nu.4f_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 3.054024 //WZTo1L3Nu.4f_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 3.28 //ZZTo2QL_mllmin4p0_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 3.28 //ZZTo3LNu_TuneCP5.13TeV-powheg.pythia8 ⁰ 0.564 //		/WJetsToLNu_HT-200To400_TuneCP5_13TeV-madgraphMLM-pythia80	350.435			
//WjetsToLNu_HT-600To800_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 11.1485 //WjetsToLNu_HT-800To8200_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 5.02246 //WjetsToLNu_HT-200To2500_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 1.183 //WjetsToLNu_HT-2500ToInf_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 Bosons /DYjetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 6198.0 //WjetsToLL_M-10tu50_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰ 6198.0 /EWKWplus2Jets_WToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2Jets_ZToLM-95_withDjoleRecoil_13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2Jets_ZToNuNu_M-50_TuneCP5_13TeV-madgraph-pythia8 ¹ 10.72 /EWKZ2Jets_ZToQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia8 ¹ 10.67 /WWTo1LNu2Q_4f_TuneCP5_13TeV-amcathloFXFX-pythia8 ⁰ 10.67 /WWTo1LNu2Q_4f_TuneCP5_13TeV-amcathloFXFX-pythia8 ⁰ 3.054024 /WZTo1LNu2Q_4f_TuneCP5_13TeV-amcathloFXFX-pythia8 ⁰ 3.054024 /WZTo2QL_mllmin4p0_TuneCP5_13TeV-amcathloFXFX-pythia8 ⁰ 3.28 /ZZTo2QL_mllmin4p0_TuneCP5_13TeV-amcathloFXFX-pythia8 ⁰ 3.28 /ZZTo2L2L.mlTuneCP5_13TeV-powheg_pythia8 ⁰ 0.2565 /ZZTo2L2L_mlTuneCP5_13TeV-powheg_pythia8 ⁰ 0.284 <td< td=""><td></td><td>/WJetsToLNu_HT-400To600_TuneCP5_13TeV-madgraphMLM-pythia80</td><td>46.5726</td></td<>		/WJetsToLNu_HT-400To600_TuneCP5_13TeV-madgraphMLM-pythia80	46.5726			
/WJetsToLNu_HT-800To1200 TuneCP5.13TeV-madgraphMLM-pythia8 ² 5.02246 /WJetsToLNu_HT-1200To12500.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.183 /WJetsToLNu_HT-2500ToInf_TuneCP5.13TeV-madgraphMLM-pythia8 ¹ 0.0258083 Bosons /DYJetsToLL_M-10to50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 20657.0 /DYJetsToLL_M-50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 6198.0 /EWKKPplus2lets.WToQQ_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2Jets_ZToLL_M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2Jets_ZToLL_M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2Jets_ZToQ_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8 ¹ 10.67 /WWTo1L1Nu2Q_4f_TuneCP5.13TeV-amcathloFXFx-pythia8 ⁰ 10.67 /WWTo1L3Nu_4f_TuneCP5.13TeV-amcathloFXFx-pythia8 ⁰ 10.67 /WZTo1L1Nu2Q_4f_TuneCP5.13TeV-amcathloFXFx-pythia8 ⁰ 5.6 /WZTo1L2Nu_TuneCP5.13TeV-amcathloFXFx-pythia8 ⁰ 3.054024 /WZTo2QL_mllmin4p0_TuneCP5.13TeV-amcathloFXFx-pythia8 ⁰ 3.28 /ZZTo2QL_mllmin4p0_TuneCP5.13TeV-amcathloFXFx-pythia8 ⁰ 3.28 /ZZTo2L2Nu_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 0.2564 /ZZTo2L2Nu_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 0.265 <tr< td=""><td></td><td>/WJetsToLNu_HT-600To800_TuneCP5_13TeV-madgraphMLM-pythia80</td><td>11.1485</td></tr<>		/WJetsToLNu_HT-600To800_TuneCP5_13TeV-madgraphMLM-pythia80	11.1485			
/WjetsToLNu.HT-1200To2500.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 1.183 /WjetsToLNu.HT-2500ToInf.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 0.0258083 Bosons /DYjetsToLL.M-10to50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 20657.0 /DYjetsToLL.M-50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 6198.0 /EWKWplus2jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKZ2jets.ZToLL.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2jets.ZToLL.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2jets.ZToQU.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 10.67 /WWTo1LINu2Q.4f.TuneCP5.13TeV-ancatnloFXFA-pythia8 ⁰ 51.65 /WWTo1LINu2Q.4f.TuneCP5.13TeV-ancatnloFXFA-pythia8 ⁰ 49.997 /WZTo1L1Nu2Q.4f.TuneCP5.13TeV-ancatnloFXFA-pythia8 ⁰ 3.054024 /WZTo2Q2L_mllmin4p0.TuneCP5.13TeV-ancatnloFXFA-pythia8 ⁰ 3.28 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-ancatnloFXFA-pythia8 ¹ 4.4965 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-ancatnloFXFA-pythia8 ⁰ 3.28 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-ancatnloFXFA-pythia8 ⁰ 0.264 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.264 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-ancatnloFXFA-pythia8 ⁰ 0.284		/WJetsToLNu_HT-800To1200_TuneCP5_13TeV-madgraphMLM-pythia82	5.02246			
/WJetsToLNu_HT-2500ToInf.TuneCP5.13TeV-madgraphMLM-pythia8 ¹ 0.0258083 Bosons /DYJetsToLL.M-10050.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 20657.0 /DYJetsToLL.M-10050.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 6198.0 /EWKWplus2Jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKWplus2Jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2Jets.ZToNuNu_M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 10.72 /EWKZ2Jets.ZToNuNu_M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 10.67 /WWTo1L1NuQ.4f.TuneCP5.13TeV-powheg-pythia8 ⁰ 10.67 /WWTo1L1NuQ.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 10.67 /WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 49.997 /WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 3.054024 /WZTo2L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia8 ¹ 4.42965 /ZZTo3LNu_TuneCP5.13TeV-amcatnloFXFX-pythia8 ¹ 4.42965 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 3.28 /ZZTo2L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 0.664 /ZZTo2L2Nu_TuneCP5.13TeV-amcatnlo-pythia8 ⁰ 0.01398 /WWZ.4F_TuneCP5.13TeV-amcatnlo-pythia8 ³ 0.000884 /WWZ.4F_TuneC		/WJetsToLNu_HT-1200To2500_TuneCP5_13TeV-madgraphMLM-pythia80	1.183			
Bosons /DYJets ToLL M-10to50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 20657.0 /DYJets ToLL M-50.TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 6198.0 /EWKWplus2Jets.WToQQ.dipoleRccoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67 /EWKWZJets.ZToLL.M-50.TuneCP5.withDipoleRccoil.13TeV-madgraph-pythia8 ¹ 6.22 /EWKZ2Jets.ZToQ.dipoleRccoilOn.TuneCP5.tmadgraph-pythia8 ¹ 6.22 /EWKZ2Jets.ZToQU.dipoleRccoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 10.67 /EWKZ2Jets.ZToQU.dipoleRccoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 10.67 /WWTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 10.67 /WWTo1L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 12.178 /WZTo1L3Nu.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 3.054024 /WZTo2Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ¹ 5.6 /WZTo2Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ¹ 4.42965 /ZZTo2Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ¹ 4.42965 /ZZTo2Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 0.564 /ZZTo2Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 0.1651 /WZZ-TuneCP5.13TeV-amcatnlo-pythia8 ³ 0.0398 /WZZTo1LNU.LWLEWK.noTop.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.01651		/WJetsToLNu_HT-2500ToInf_TuneCP5_13TeV-madgraphMLM-pythia81	0.0258083			
/ DYJets ToLL.M-50. TuneCP5.13TeV-madgraphMLM-pythia8 ⁰ 6198.0/ /EWKWplus2Jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67/ EWKWplus2Jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ⁰ 10.67/ EWKZ2Jets.ZToLL.M-50. TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8 ¹ 6.22/ EWKZ2Jets.ZToQU.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 10.72/ EWKZ2Jets.ZToQU.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8 ¹ 10.67/ WWToLL1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 51.65/ WWToLL1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 49.997/ WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 30.54024/ WZTo2QL.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 5.6/ WZTo2QL.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 3.28/ ZZTo2QL.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 3.28/ ZZTo2QL.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 3.564/ ZZTo2QL2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 0.564/ ZZTo2QL2Nu.TuneCP5.13TeV-powheg.pythia8 ⁰ 0.2565/ ZZTo4L.M-1toInf.TuneCP5.13TeV-powheg.pythia8 ⁰ 0.0565/ ZZTo4L.M-1toInf.TuneCP5.13TeV-amcatnloFXFX-pythia8 ⁰ 0.01651/ WZZ_TuneCP5.13TeV-amcatnlo-pythia8 ³ 0.01398/ WWJJFOLNuLNu_EWK_nOTOp.TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.284/ WZJJ_EWK_InclusivePolarization_TuneCP5.13TeV-madgraph-pythia8 ¹ 32.33/ ZZWJ_USE.WTOLNu_M-50.TuneCP5.uvithDipoleRecoil.13TeV-madgraph-pythia8 ¹ 32.33/ EWKWPIus2Jets.WTOLNu_M-50.TuneCP5.uvithDipoleRecoil.13TeV-madgraph-pythia8 ¹ 32.207/ WminusH_HT	Bosons	/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰	20657.0			
/EWKWplus2jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8010.67/EWKWminus2jets.WToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8010.67/EWKZ2jets.ZToLL.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia816.22/EWKZ2jets.ZToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8110.72/EWKZ2jets.ZToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8010.67/WWTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8051.65/WWTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8049.997/WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia803.054024/WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia803.054024/WZTo1L2Nu.4f.TuneCP5.13TeV-amcatnloFXFX-pythia803.054024/WZTo2QL_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia815.6/WZTo2QL_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia803.28/ZZTo2QL_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia800.564/ZZTo2QL_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia800.564/ZZTo2L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia800.05565/ZZTo2L2Nu.TuneCP5.13TeV-amcatnloPXFX-pythia800.05565/ZZZTo2L2Nu.TuneCP5.13TeV-amcatnlo-pythia830.01398/WWJJToLNuLNu_EWK_noTop.TuneCP5.13TeV-madgraph-pythia800.01398/WWJJToLNuLNu_EWK_noTop.TuneCP5.13TeV-madgraph-pythia800.010101/ZZJJTo4L_M-IncCP5.13TeV-amcatnlo-pythia830.2086EWKWLep/EWKWPUs2Jets.WToLNu_M-50.TuneCP5.13TeV-madgraph-pythia800.02086WWJJToLNuLNu_EWK_noTop.TuneCP5.13TeV-madgraph-pythia800.02086/WH//HToNonbb.M125.TuneCP5.13TeV-amcatnlo-pythia800.02086<		/DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8 ⁰	6198.0			
/EWKWminus2lets.WToQQ.dipoleRecoil.Dr.TuneCP5.13TeV-madgraph-pythia8110.67/EWKZ2lets.ZToLL.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia816.22/EWKZ2lets.ZToLQ.dipoleRecoil.Dr.TuneCP5.usithDipoleRecoil.13TeV-madgraph-pythia8110.72/EWKZ2lets.ZToQQ.dipoleRecoil.Dr.TuneCP5.13TeV-madgraph-pythia8010.67/WWT01L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8051.65/WWT02L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia8049.997/WZT01L3Nu.4f.TuneCP5.13TeV-amcatnloFXFX-pythia803.054024/WZT02Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia815.6/WZT03LNu.TuneCP5.13TeV-amcatnloFXFX-pythia814.42965/ZZTo2Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia814.42965/ZZT02L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia803.28/ZZT02L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia800.564/ZZT02L2Nu.TuneCP5.13TeV-powheg.pythia800.05565/WZZ.TuneCP5.13TeV-amcatnlo-pythia800.05565/ZZZT02L2Nu.TuneCP5.13TeV-amcatnloFXFX-pythia800.05565/ZZZT02L2Nu.TuneCP5.13TeV-amcatnlo-pythia830.005865/ZZZT02L2Nu.TuneCP5.13TeV-amcatnlo-pythia830.05565/ZZZ.TuneCP5.13TeV-amcatnlo-pythia830.005865/WZZ_TuneCP5.13TeV-amcatnlo-pythia830.00884/WWJJFOLNuLNu_EWK_noTop.TuneCP5.uithDipoleRecoil.13TeV-madgraph-pythia8132.26VH/VHToNonbb.M125.TuneCP5.13TeV-amcatnlo-pythia830.2086EWKWLep/EWKWMinus2lets.WToLNu_M-50.TuneCP5.13TeV-powheg-pythia800.0487599411/ZZJT04L_HToBB_WToLNu_M-50.TuneCP5.13TeV-powheg-pythia800.04867599411/ZZHHTOBB_WTOLNu_M-125.TuneCP5.13TeV-pow		/EWKWplus2Jets_WToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia80	10.67			
/EWKZ2Jets.ZToLL.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia816.22/EWKZ2Jets.ZToNuNu.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8110.72/EWKZ2Jets.ZToQQ.dipoleRecoilOn.TuneCP5.13TeV-madgraph-pythia8010.67/WWToLL1Nu2Q.4f.TuneCP5.13TeV-amcathloFXFX-pythia8051.65/WWToL2Nu.TuneCP5.13TeV-amcathloFXFX-pythia8049.997/WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcathloFXFX-pythia8030.54024/WZTo2QL.mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia8030.54024/WZTo2QL.mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia815.6/WZTo3LNu.TuneCP5.13TeV-amcathloFXFX-pythia815.6/WZTo3LNu.TuneCP5.13TeV-amcathloFXFX-pythia815.6/ZZTo2QL_mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia813.28/ZZTo1220L_mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia803.28/ZZTo2QL_mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia800.1651/WZZ.TuneCP5.13TeV-amcathlo-pythia800.1651/WZZ_TuneCP5.13TeV-amcathlo-pythia830.01398/WWJJToLNuLNU_EWK_noTop.TuneCP5.13TeV-madgraph-pythia800.01701/ZZJJTo4L_TuneCP5.13TeV-amcathlo-pythia830.00884/WZJJ_EWK_InclusivePolarization_TuneCP5.13TeV-madgraph-pythia800.01701/ZZJJTo4L_TuneCP5.13TeV-amcathlo-pythia830.2086EWKWLep/EWKWPUs2Jets.WToLNu_M-50.TuneCP5.13TeV-madgraph-madspin-pythia8132.26VH/VHToNonbb.M125.TuneCP5.13TeV-amcathloFXFX.madspin_pythia800.04901236122/WminusH_HToBB.WToLNu_M-125.TuneCP5.13TeV-powheg-pythia800.04901236122/WpiusH_HToBB.WToLNu_M-125.TuneCP5.13TeV-powheg-pythia800.04901236122/WinusH_HTo		/EWKWminus2Jets_WToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia80				
/EWKZ2Jets.ZToNuNu.M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8110.72/EWKZ2Jets.ZToQQ_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8010.67/WWT01L1Nu2Q_4f.TuneCP5.13TeV-owncatnloFXFX-pythia8051.65/WWT02L2Nu_TuneCP5.13TeV-powheg-pythia8112.178/WZT01L3Nu_4f.TuneCP5.13TeV-amcatnloFXFX-pythia8030.54024/WZT02Q2L_mllmin4p0_TuneCP5.13TeV-amcatnloFXFX-pythia815.6/WZT03LNu_TuneCP5.13TeV-amcatnloFXFX-pythia815.6/WZT02Q2L_mllmin4p0_TuneCP5.13TeV-amcatnloFXFX-pythia815.6/ZZT02Q2L_mllmin4p0_TuneCP5.13TeV-amcatnloFXFX-pythia814.42965/ZZT02Q2L_mllmin4p0_TuneCP5.13TeV-amcatnloFXFX-pythia803.28/ZZT02L2Nu_TuneCP5.13TeV-amcatnloFXFX-pythia800.564/ZZT02L2Nu_TuneCP5.13TeV-amcatnlo-pythia800.1651/WZZ_4F_TuneCP5.13TeV-amcatnlo-pythia800.1651/WZZ_4F_TuneCP5.13TeV-amcatnlo-pythia830.05565/ZZZ_TuneCP5.13TeV-amcatnlo-pythia830.01398/WWJJToLNuLNu_EWK_noTop_TuneCP5.13TeV-madgraph-pythia800.01701/ZZJJT04L_TuneCP5.13TeV-madgraph-pythia830.00884/WWW.4F_TuneCP5.13TeV-madgraph-pythia830.2086EWKWLep/EWKWPlus2Jets_WT0LNu_M-50_TuneCP5.uithDipoleRecoil.13TeV-madgraph-pythia813.226VH/VHT0NoNbb M125_TuneCP5.13TeV-amcatnloFXFX.madspin-pythia800.04901236122/WplusH_HT0BB_WT0LNu_M-125_TuneCP5.13TeV-powheg-pythia800.04901236122/WplusH_HT0BB_WT0LNu_M-125_TuneCP5.13TeV-powheg-pythia800.042674865111/ZZUT/ZUTT0N0Nbb_M125_TuneCP5.13TeV-powheg-pythia800.0224865111/ZUHT0N0Nbb_M125_TuneCP5.13TeV-powheg-pyt		/EWKZ2Jets_ZToLL_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia81				
/EWKZ2]ets_ZToQQ_dipoleRecoilOn_TuneCP5.13TeV-madgraph-pythia8010.67/WWT01L1Nu2Q_4f_TuneCP5.13TeV-amcathloFXFX-pythia8051.65/WWT02L2Nu_TuneCP5.13TeV-amcathloFXFX-pythia8012.178/WZT01L1Nu2Q_4f_TuneCP5.13TeV-amcathloFXFX-pythia8049.997/WZT01L3Nu_4f_TuneCP5.13TeV-amcathloFXFX-pythia803.054024/WZT02Q2L_mllmin4p0_TuneCP5.13TeV-amcathloFXFX-pythia815.6/WZT02Q2L_mllmin4p0_TuneCP5.13TeV-amcathloFXFX-pythia814.42965/ZZTo2Q2L_mllmin4p0_TuneCP5.13TeV-amcathloFXFX-pythia813.28/ZZTo2Q2L_mllmin4p0_TuneCP5.13TeV-powheg_pythia800.564/ZZTo2L2Nu_TuneCP5.13TeV-amcathloFXFX-pythia800.564/ZZTo2L2Nu_TuneCP5.13TeV-amcathlo-pythia800.1651/WZ_4F_TuneCP5.13TeV-amcathlo-pythia800.05565/ZZZ_To12L2Nu_LUNECP5.13TeV-amcathlo-pythia800.01538/WZ_2_TuneCP5.13TeV-amcathlo-pythia830.015365/ZZZ_TUNECP5.13TeV-amcathlo-pythia830.01398/WWJJToLNuLNu_EWK_noTop_TuneCP5.13TeV-madgraph-pythia800.01701/ZZJT04L_TuneCP5.13TeV-madgraph-pythia810.00884/WWZJJ_EWK_InclusivePolarization_TuneCP5.usthDipoleRecoil.13TeV-madgraph-pythia813.226VH/VHToNonbb_M125_TuneCP5.13TeV-amcathloFXFX_madspin_pythia800.04901236122/WhinusH_HT0BB_WToLNu_M-125_TuneCP5.13TeV-powheg-pythia800.04847599411/Z2L2.207/WminusH_HT0BB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.04267486511/ZZH/ZH_HT0BB_TTOLL_M-125_TuneCP5_13TeV-powheg-pythia800.02627486511/ZZH/ZH_HT0BB_TTOLL_M-125_TuneCP5_13TeV-powheg-pythia800.02627486511 <td></td> <td colspan="4">/EWKZ2Jets_ZToNuNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia81</td>		/EWKZ2Jets_ZToNuNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia81				
/WWTo1L1Nu2Q.4f.TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 51.65 /WWTo2L2Nu_TuneCP5.13TeV-powheg-pythia8 ¹ 12.178 /WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 49.997 /WZTo1L3Nu.4f.TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 3.054024 /WZTo2QL_mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia8 ¹ 5.6 /WZTo2QL_mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia8 ¹ 4.42965 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 3.28 /ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 0.564 /ZZTo2L2Nu_TuneCP5.13TeV-amcathloFXFX-pythia8 ⁰ 0.564 /ZZTo4L_M-1toInf_TuneCP5.13TeV-powheg_pythia8 ⁰ 0.1651 /WZZ_TuneCP5.13TeV-amcathlo-pythia8 ³ 0.01586 /WZZ_TuneCP5.13TeV-amcathlo-pythia8 ³ 0.01398 /WWJJToLNuLNu_EWK_noTop_TuneCP5.13TeV-madgraph-pythia8 ⁰ 0.284 /WWJJToLNuLNu_EWK_noTop.TuneCP5.13TeV-madgraph-madspin-pythia8 ⁰ 0.01701 /ZZJJTo4L_TuneCP5.13TeV-amcathlo-pythia8 ³ 0.2086 EWKWLep /EWKWPIus2Jets_WToLNu_M-50_TuneCP5.withDipoleRecoil_13TeV-madgraph-pythia8 ¹ 32.26 VH /VHToNonbb_M125_TuneCP5.13TeV-amcathloFXFX_madspin_pythia8 ¹ 2.207 /WminusH_HToBB_WToLNu_M-125_TuneCP5.13TeV-powheg-pythia8 ⁰ 0.04901236122 <t< td=""><td></td><td colspan="4">/EWKZ2Jets_ZToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia80</td></t<>		/EWKZ2Jets_ZToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia80				
/WWTo2L2Nu.TumeCP5.13TeV-powheg-pythia8112.178/WZTo1L1Nu2Q.4f.TumeCP5.13TeV-amcathloFXFX-pythia8049.997/WZTo1L3Nu.4f.TumeCP5.13TeV-amcathloFXFX-pythia803.054024/WZTo2Q2L.mllmin4p0.TumeCP5.13TeV-amcathloFXFX-pythia815.6/WZTo3LNu.TumeCP5.13TeV-amcathloFXFX-pythia815.6/WZTo2Q2L.mllmin4p0.TumeCP5.13TeV-amcathloFXFX-pythia813.28/ZZTo2Q2L.mllmin4p0.TumeCP5.13TeV-amcathloFXFX-pythia803.28/ZZTo2L2Nu.TumeCP5.13TeV-powheg.pythia800.564/ZZTo2L2Nu.TumeCP5.13TeV-powheg.pythia800.564/ZZTo4L_M-1toInf.TumeCP5.13TeV-powheg.pythia800.1651/WZ2.TumeCP5.13TeV-amcathlo-pythia800.05565/WZZ.TumeCP5.13TeV-amcathlo-pythia830.01398/WZJJ_EWK_InclusivePolarization_TumeCP5.13TeV-madgraph-pythia800.01701/ZZJJTo4L_TumeCP5.13TeV-amcathlo-pythia830.02086EWKWLep/EWKWPius2Jets.WToLNu_M-50.TumeCP5.withDipoleRecoil.13TeV-madgraph-pythia8139.33/EWKWLis2Jets.WToLNu_M-50.TumeCP5.13TeV-powheg-pythia800.04901236122/WH/VHToNonbb_M125.TumeCP5.13TeV-amcathloFXFX_madspin_pythia812.207/WminusH_HToBB_WToLNu_M-125.TumeCP5.13TeV-powheg-pythia800.04901236122/WplusH_HToBB_WToLNu_M-125.TumeCP5.13TeV-powheg-pythia800.042627486511/ZH_HToBB_ZToLL_M-125.TumeCP5.13TeV-powheg-pythia800.02627486511/ZH_HTOBB_ZToLL_M-125.TumeCP5.13TeV-powheg-pythia800.02461395396		/WWTo1L1Nu2Q_4f_TuneCP5_13TeV-amcatnloFXFX-pythia80				
/WZTo1L1Nu2Q.4f.TuneCP5.13TeV-amcatnloFXFX-pythia8049.997/WZTo1L3Nu.4f.TuneCP5.13TeV-amcatnloFXFX-pythia803.054024/WZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia815.6/WZTo3LNu.TuneCP5.13TeV-amcatnloFXFX-pythia814.42965/ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia803.28/ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia803.28/ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia800.564/ZZTo2Q2L_mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia800.564/ZZTo2L2Nu.TuneCP5.13TeV-amcatnlo-pythia800.1651/WZZ.TuneCP5.13TeV-amcatnlo-pythia830.005565/ZZZ.TuneCP5.13TeV-amcatnlo-pythia830.005565/ZZZ.TuneCP5.13TeV-amcatnlo-pythia830.01398/WZJJLEWK_InclusivePolarization_TuneCP5.13TeV-madgraph-pythia800.01701/ZZJJTo4L.TuneCP5.13TeV-amcatnlo-pythia830.2086EWKWLep/EWKWPlus2Jets_WToLNu_M-50.TuneCP5.withDipoleRecoil.13TeV-madgraph-pythia8132.26VH/VHToNonbb_M125.TuneCP5.13TeV-amcatnloFXFX_madspin_pythia800.04901236122/WminusH_HToBB_WToLNu_M-125_TuneCP5.13TeV-powheg-pythia800.04847599411/ZH_HTOBB_ZToLL_M-125_TuneCP5.13TeV-powheg-pythia800.02627486511/ZH_HTOBB_ZToLL_M-125_TuneCP5.13TeV-powheg-pythia800.02627486511/ZH_HTOBB_ZToLL_M-125_TuneCP5.13TeV-powheg-pythia800.02627486511		/WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia81				
/WZTo1L3Nu.4f.TuneCP5_13TeV-amcatnloFXFX-pythia8 ⁰ 3.054024/WZTo2Q2L_mllmin4p0.TuneCP5_13TeV-amcatnloFXFX-pythia8 ¹ 5.6/WZTo3LNu.TuneCP5_13TeV-amcatnloFXFX-pythia8 ¹ 4.42965/ZZTo2Q2L_mllmin4p0.TuneCP5_13TeV-amcatnloFXFX-pythia8 ⁰ 3.28/ZZTo2L2Nu.TuneCP5_13TeV-powheg_pythia8 ⁰ 0.564/ZZTo4L_M-1toInf_TuneCP5_13TeV-amcatnlo-pythia8 ⁰ 0.564/ZZTo4L_M-1toInf_TuneCP5_13TeV-amcatnlo-pythia8 ⁰ 0.1651/WZZ_TuneCP5_13TeV-amcatnlo-pythia8 ⁰ 0.05565/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8 ³ 0.005565/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8 ³ 0.01398/WWJJToLNuLNu_EWK_noTop_TuneCP5_13TeV-madgraph-pythia8 ⁰ 0.01701/ZZJJTo4L_TuneCP5_13TeV-amcatnlo-pythia8 ³ 0.00884/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8 ³ 0.00884/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia8 ³ 0.2086EWKWLep/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8 ¹ 39.33/EWKWInus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8 ¹ 32.26VH/VHToNonbb M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia8 ⁰ 0.04901236122/WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.048487599411/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.002627486511/ZgZH_HT0BB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.002627465511/ZgZH_HT0BB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.002627465511		/WZTo1L1Nu2Q_4f_TuneCP5_13TeV-amcatnloFXFX-pythia8 ⁰				
/WZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia815.6/WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia814.42965/ZZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia803.28/ZZTo2L2Nu_TuneCP5_13TeV_powheg_pythia800.564/ZZTo4L_M-ItoInf_TuneCP5_13TeV-powheg_pythia800.565/WZ_AF_TuneCP5_13TeV-amcatnlo-pythia800.1651/WZ_TuneCP5_13TeV-amcatnlo-pythia830.05565/ZZZ_TuneCP5_13TeV-amcatnlo-pythia830.01398/WZJJEWK_InclusivePolarization_TuneCP5_13TeV-madgraph-pythia800.01701/ZZJJTo4L_TuneCP5_13TeV-amcatnlo-pythia830.0284/WWW.4F_TuneCP5_13TeV-madgraph-pythia810.00884/WWW.4F_TuneCP5_13TeV-amcatnlo-pythia830.2086EWKWLep/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8132.26VH/VHTONonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia800.04901236122/WminusH_HTOBB_WTOLNu_M-125_TuneCP5_13TeV-powheg-pythia800.04847599411/ZEJ_H_HTOBB_ZTOLL_M-125_TuneCP5_13TeV-powheg-pythia800.02267486511/ZEH_HTOBB_ZTOLL_M-125_TuneCP5_13TeV-powheg-pythia800.02267486511		/WZTo1L3Nu_4f_TuneCP5_13TeV-amcatnloFXFX-pythia8 ⁰				
/WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia814.42965/ZZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia803.28/ZZTo2L2Nu_TuneCP5_13TeV_powheg_pythia800.564/ZZTo4L_M-1toInf_TuneCP5_13TeV-powheg_pythia801.256/WWZ.4F_TuneCP5_13TeV-amcatnlo-pythia800.1651/WZ2_TuneCP5_13TeV-amcatnlo-pythia830.05565/ZZZ_TuneCP5_13TeV-amcatnlo-pythia830.01398/WUJJToLNuLNu_EWK_noTop_TuneCP5_13TeV-madgraph-pythia800.01701/ZZJJTo4L_TuneCP5_13TeV-amcatnlo-pythia830.01701/ZZJJTo4L_TuneCP5_13TeV-amcatnlo-pythia830.0284/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia830.0286EWKWLep/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8139.33/EWKWLins2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8132.26VH/VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia800.04901236122/WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.049487599411/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.02461395396		/WZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia81	5.6			
/ZZTo2Q2L.mllmin4p0.TuneCP5.13TeV-amcatnloFXFX-pythia803.28/ZZTo2L2Nu.TuneCP5.13TeV-powheg_pythia800.564/ZZTo4L.M-1toInf_TuneCP5.13TeV-powheg_pythia801.256/WWZ_4F_TuneCP5.13TeV-amcatnlo-pythia800.1651/WZ_TuneCP5.13TeV-amcatnlo-pythia830.05565/ZZZ_TuneCP5.13TeV-amcatnlo-pythia830.05565/ZZZ_TuneCP5.13TeV-amcatnlo-pythia830.01398/WWJJToLNuLNu_EWK_noTop_TuneCP5.13TeV-madgraph-pythia800.01701/ZZJJTo4L_TuneCP5.13TeV-madgraph-pythia810.00884/WZJJ_EWK_InclusivePolarization_TuneCP5.13TeV_madgraph-madspin-pythia800.01701/ZZJJTo4L_TuneCP5.13TeV-madgraph-pythia810.2086EWKWLep/EWKWPLus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8139.33/EWKWLinus3Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8132.26VH/VHToNonbb_M125_TuneCP5_13TeV-powheg-pythia800.04901236122/WmiusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.0224865111/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.02248599411/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.02241895396		/WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia81	4.42965			
/ZZTo2L2Nu_TuneCP5_13TeV_powheg_pythia800.564/ZZTo4L_M-1toInf_TuneCP5_13TeV-powheg_pythia801.256/WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia800.1651/WZZ_TuneCP5_13TeV-amcatnlo-pythia830.05565/ZZZ_TuneCP5_13TeV-amcatnlo-pythia830.01398/WZJJ_EWK_InclusivePolarization_TuneCP5_13TeV-madgraph-pythia800.284/WZJJ_EWK_InclusivePolarization_TuneCP5_13TeV-madgraph-madspin-pythia800.01701/ZZJJTo4L_TuneCP5_13TeV-amcatnlo-pythia810.00884/WWW_4F_TuneCP5_13TeV-madgraph-pythia810.2086EWKWLep/EWKWPIus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8139.33/EWKWLis2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8132.26VH/VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia800.04901236122/WhinusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.048487599411/ZH_HToBB_ZTOLL_M-125_TuneCP5_13TeV-powheg-pythia800.02627486511/ZH_HToBB_ZTOLL_M-125_TuneCP5_13TeV-powheg-pythia800.002461395396		/ZZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia80	3.28			
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/WWZ.4F.TuneCP5.13TeV-amcatnlo-pythia8°0.1651/WZZ.TuneCP5.13TeV-amcatnlo-pythia8³0.05565/ZZZ_TuneCP5.13TeV-amcatnlo-pythia8³0.01398/WWJJToLNuLNu_EWK_noTop_TuneCP5_13TeV-madgraph-pythia8°0.284/WZJJ_EWK_InclusivePolarization_TuneCP5_13TeV-madgraph-pythia8°0.01701/ZZJJTo4L_TuneCP5_13TeV-madgraph-pythia8¹0.00884/WWW.4F_TuneCP5_13TeV-madgraph-pythia8¹0.2086EWKWLep/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8¹39.33/EWKWLis2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8¹32.26VH/VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia8¹2.207/WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8°0.04901236122/WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8°0.02627486511/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8°0.02627486511/ZH_HToBB_ZTOLL_M-125_TuneCP5_13TeV-powheg-pythia8°0.002461395396		/ZZTo4L_M-1toInf_TuneCP5_13TeV_powheg_pythia80	1.256			
/WZZ_luneCP5_131eV-amcatnlo-pythia830.05565/ZZZ_TuneCP5_13TeV-amcatnlo-pythia830.01398/WWJJToLNuLNu_EWK_noTop_TuneCP5_13TeV-madgraph-pythia800.284/WZJJ_EWK_InclusivePolarization_TuneCP5_13TeV_madgraph-madspin-pythia800.01701/ZZJJTo4L_TuneCP5_13TeV-madgraph-pythia810.00884/WWW_4F_TuneCP5_13TeV-madgraph-pythia830.2086EWKWLep/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8139.33/EWKWLinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8132.26VH/VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia812.207/WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.04847599411/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.02627486511/ZH_HToBB_ZTOLL_M-125_TuneCP5_13TeV-powheg-pythia800.002461395396		/WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia80	0.1651			
/ZZZ_1uneCP5_131eV-amcatnlo-pythia800.01398/WWJJToLNuLNu_EWK_noTop_TuneCP5_13TeV-madgraph-pythia800.284/WZJJ_EWK_InclusivePolarization_TuneCP5_13TeV_madgraph-pythia800.01701/ZZJJTo4L_TuneCP5_13TeV-madgraph-pythia810.00884/WWW_4F_TuneCP5_13TeV-madgraph-pythia830.2086EWKWLep/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8139.33/EWKWLinsLjets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8132.26VH/VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia812.207/WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.04901236122/WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.02627486511/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.002461395396		/WZZ_TuneCP5_13TeV-amcatnlo-pythia83	0.05565			
//WWJJ IoLNuLNu_EWK.noTop_TuneCP5_13TeV-madgraph-pythia8°0.284/WZJJ_EWK_InclusivePolarization_TuneCP5_13TeV_madgraph-madspin-pythia8°0.01701/ZZJJTo4L_TuneCP5_13TeV-madgraph-pythia810.00884/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia830.2086EWKWLep/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8139.33/EWKWLis2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8132.26VH/VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia812.207/WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.04901236122/WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.08487599411/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.002627486511/gzH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.002461395396		/ZZZ_luneCP5_131eV-amcatnlo-pythia8 ³	0.01398			
/WZJJ_EWK_InclusivePolarization_TuneCP5_131eV_madgraph-madspin-pythia8° 0.001701 /ZZJJTo4L_TuneCP5_13TeV-madgraph-pythia81 0.00884 /WWW_4F_TuneCP5_13TeV-amcatnlo-pythia83 0.2086 EWKWLep /EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia81 39.33 /EWKWLinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia81 32.26 VH /VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia81 2.207 /WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia80 0.04901236122 /WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia80 0.08487599411 /ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia80 0.02627486511 /ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia80 0.002461395396		/ W W JJ IOLINULINULEW K_no IOp_luneCr5_13 lev-madgraph-pythia8°	0.284			
VZ2J) 104L-1uneCP5.131eV-madgraph-pythia8 ³ 0.00084 /WWW.4F_TuneCP5.13TeV-amcatnlo-pythia8 ³ 0.2086 EWKWLep /EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8 ¹ 39.33 /EWKWLis2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8 ¹ 32.26 VH /VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia8 ¹ 2.207 /WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.04901236122 /WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.08487599411 /ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.02627486511 /gzH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.002461395396		/WZJJ_EWK_Inclusiverolarization_luneCr5_131ev_madgraph-madspin-pythia8°	0.01701			
WWW-4F-InfleCr95118ev-antatilito-pythia8 0.2086 EWKWLep /EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia81 39.33 /EWKWLinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia81 32.26 VH /VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia81 2.207 /WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia80 0.04901236122 /WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia80 0.08487599411 /ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia80 0.02627486511 /gzH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia80 0.002461395396		/ ZZJJ 104L_TUNECP5_13 Iev-madgraph-pythia8	0.00884			
EVENUE / EVENUE / EVENUE 39.55 /EWKW1 db2jets_W10L1v130_1uteCt 3_w11DipoteRecoil_131eV-inadgraph-pythia81 32.26 /EWKWMinus2jets_WToLNu_M-50_TuneCP5_withDipoteRecoil_13TeV-madgraph-pythia81 32.26 VH /VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia81 2.207 /WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia80 0.04901236122 /WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia80 0.08487599411 /ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia80 0.02627486511 /ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia80 0.002461395396	FWKWI	/ WWWW_HI_IUNECFOLISTEV-ANCAUNO-PYUNA6"	0.2000			
VH /VHToNonbb_M125_TuneCP5_13TeV-amcatnloFXFX_madspin_pythia8 ¹ 2.207 /WminusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.04901236122 /WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.08487599411 /ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.02627486511 /ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.002461395396	EVINIVLEP	/EVVKWYTUSZJES_VV10LINU_IVI-5U_1URECF5_WIThDipoleKecoil_131eV-madgraph-pythia81				
VII/ VII bit Volto 2.10125-10025-10025-10025-10025-10025-10025-10025-10025-10025-10025-10025-10	VH	/ EVVN VVIVIIIIUS2Jets_VV IOLINU_VI-50_IUNECT5_WIThDipoleKecoll_151eV-madgraph-pythia8'				
/Willings1211005.W1051Vu1W1251UneCP5_13TeV-powheg-pythia800.04901250122/WplusH_HToBB_WToLNu_M-125_TuneCP5_13TeV-powheg-pythia800.08487599411/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.02627486511/ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.002461395396	VII	/WminusH HTaRB WTaI Nu M.125 TuneCP5 13TaV-nowheg-pythis ⁰	0.04901236122			
/ZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.00407399411/ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia800.002627486511		/WnlusH HToBB WToLNu M-125 TuneCP5 13TeV-nowheg-nythia80	0.08487599411			
/ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰ 0.002/461395396		/ZH HToBB ZToLL M-125 TuneCP5 13TeV-powheg-pythia8 ⁰	0.02627486511			
		/ggZH_HToBB_ZToLL_M-125_TuneCP5_13TeV-powheg-pythia8 ⁰	0.002461395396			

⁰ /RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v1/NANOAODSIM

¹/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM

²/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v3/NANOAODSIM

³/RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9_ext1-v2/NANOAODSIM

Table 4: Background MC samples used in this analysis, corresponding to 2017 detector conditions (UL), with their respective cross sections in picobarns. The cross sections for the $H_{\rm T}$ -binned W+jets samples are scaled by a "stitching" factor such that the samples together fill a continuous $H_{\rm T}$ distribution.

Process	Sample Name	σ [pb]
SingleTop	/ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8 ⁰	19.559
0 1	/ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8 ²	136.02
	/ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia82	80.95
	/ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia80	19.559
TTbar1L	/TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8 ²	365.34
TTbar2L	/TTTo2L2Nu TuneCP5 13TeV-powheg-pythia8 ²	88.29
TTX	/TTToHadronic TuneCP5 13TeV-powheg-pythia8 ²	377 96
11/(/TTWIetsToI Nu TuneCP5 13TeV-amcatnloFXFX-madspin-pythia8 ²	0 2043
	/TTZToLLNuNu M-10 TuneCP5 13TeV-amcathlo-pythia8 ²	0.2529
	/ttHTobb M125 TuneCP5 13TeV-nowheg-nythia8 ⁰	0.1279
	/ttHToNonbh M125 TuneCP5 13TeV-nowbeg-nythia8 ⁰	0.215
	/TTWZ TuneCP5 13TeV-madgranh-nythia8 ²	0.003884
	/TTWW/TuneCP5_13TeV-madgraph-pythia8 ²	0.000004
	/TTbb 4f TTTo21 2Nu TuneCP5-Powheg-Openloops-Pythia8 ²	0.0115
	/TTbb 4f TTToSomil optonic TunoCP5 Powhag Openloops-Puthia8 ²	0.04
WIsta	/ MIdeta To Nu, HT 70To 100 Tune CD5 12To V moderanh MI M mythio ²	1221.16
wjets	/WiletsToLNu_HT 100To200 TuneCP5_13TeV-intaugraphiviLW-pythiao	1321.10
	/ WJets IoLNU_H1-10010200_1UneCP5_151eV-madgraphMLM-pythias ⁻	1555.7
	/ WJets IoLNu_H1-20010400_1uneCP5_131eV-madgraphMLM-pythia8-	351.689
	/ W Jets IoLNu_H I-40010600_1uneCP5_131eV-madgraphMLM-pythia8-	47.1663
	/WJetsIoLNu_HI-60010800_luneCP5_131eV-madgraphMLM-pythia8 ²	11.4196
	/WJetsToLNu_HT-800101200_TuneCP5_13TeV-madgraphMLM-pythia82	5.12389
	/WJetsToLNu_HT-1200To2500_TuneCP5_13TeV-madgraphMLM-pythia82	1.18295
	/WJetsToLNu_HT-2500ToInt_TuneCP5_13TeV-madgraphMLM-pythia80	0.0255202
Bosons	/WWW_4F_TuneCP5_13TeV-amcatnlo-pythia81	0.2086
	/DYJetsToLL_M-10to50_TuneCP5_13TeV-madgraphMLM-pythia82	20657.0
	/DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia82	6198.0
	/EWKWplus2Jets_WToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia82	10.67
	/EWKWminus2Jets_WToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia8 ²	10.67
	/EWKZ2Jets_ZToLL_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8 ⁰	6.22
	/EWKZ2Jets_ZToNuNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia80	10.72
	/EWKZ2Jets_ZToQQ_dipoleRecoilOn_TuneCP5_13TeV-madgraph-pythia8 ²	10.67
	/WWTo1L1Nu2Q_4f_TuneCP5_13TeV-amcatnloFXFX-pythia8 ²	51.65
	/WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8 ⁰	12.178
	/WZTo1L1Nu2Q_4f_TuneCP5_13TeV-amcatnloFXFX-pythia8 ²	49.997
	/WZTo1L3Nu_4f_TuneCP5_13TeV-amcatnloFXFX-pythia8 ²	3.054024
	/WZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia8 ²	5.6
	/WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia80	4.42965
	/ZZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia8 ²	3.28
	/ZZTo2L2Nu_TuneCP5_13TeV_powheg_pythia8 ²	0.564
	/ZZTo4L_M-1toInf_TuneCP5_13TeV_powheg_pythia82	1.256
	/WWZ_4F_TuneCP5_13TeV-amcatnlo-pythia8 ¹	0.1651
	/WZZ_TuneCP5_13TeV-amcatnlo-pythia81	0.05565
	/ZZZ_TuneCP5_13TeV-amcatnlo-pythia8 ¹	0.01398
	/WWIIToLNuLNu_EWK_noTop_TuneCP5_13TeV-madgraph-pythia8 ²	0.284
	/WZII EWK InclusivePolarization TuneCP5 13TeV madgraph-madspin-pythia8 ²	0.01701
	/ZZIITo4L_TuneCP5_13TeV-madgraph-pythia ⁸⁰	0.00884
EWKWLep	/EWKWPlus2lets/WToLNu/M-50/TuneCP5 withDipoleRecoil 13TeV-madgraph-pythia80	39.33
Zunniep	/EWKWMinus2lets WToL Nu M-50 TuneCP5 withDipoleRecoil 13TeV-madgraph-pythia8	32.26
VH	/VHToNonbh M125 TuneCP5 13TeV-amcatnloFXFX madenin nythia80	2 207
*11	/WminusH HToBB WToI Nu M-125 TuneCP5 13TeV-nowheg-nythia82	0.04901236122
	/WnlusH HToBB WToL Nu M-125 TuneCP5 12ToV nowhog pythia 9^2	0.08487500411
	/ TH HToBE 7ToL I M-125 Time (P5 13TaV-nowhog-pythias ²	0.00407077411
	/gg7H HToBB 7ToLL M-125 TuneCP5 13TeV-powheg-pythiao	0.02027400011
1	/ gg_11111000_1000_1000_101_120_1000C1 0_1010 v=p0w10g=py01000	0.002401070070

⁰ /RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM
 ¹ /RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1_ext1-v2/NANOAODSIM
 ² /RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v1/NANOAODSIM

Table 5: Background MC samples used in this analysis, corresponding to 2018 detector conditions (UL), with their respective cross sections in picobarns. The cross sections for the H_{T} binned W+jets samples are scaled by a "stitching" factor such that the samples together fill a continuous $H_{\rm T}$ distribution.

167 3 Objects

168 **3.1 Leptons**

The lepton identification criteria for this analysis are shared with a complimentary effort tar-169 geting the same final state, but with both jets from the Higgs boson resolved as AK4 jets-rather 170 than as a single AK8 "fat" jet. These criteria are primarily based on the central cut-based crite-171 ria developed by the E/Gamma and Muon Physics Object Groups (POGs), but some additional 172 selections are made as detailed in Tables 6 and 7 for electrons and muons respectively. Leptons 173 are furthermore considered as coming from the W boson in the pp $\rightarrow W^{\pm}H + jj$ final state if 174 they pass the Tight lepton ID and have $p_{\rm T}$ greater than 40 GeV. Finally, tau leptons are not 175 considered in this analysis for simplicity. 176

Electrons					
Observable	Condition	Veto	Tight		
p_T	_	> 10 GeV	> 35 GeV		
E/Gamma POG cut-based ID	_	Veto	Medium		
$ \eta $	_	_	< 2.5		
dz	$ \eta \ge 1.429$	- /	< 0.2		
dz	$ \eta < 1.429$		< 0.1		
dxy	$ \eta \ge 1.429$		< 0.1		
dxy	$ \eta < 1.429$	/-	< 0.05		

Table 6: Veto and tight selection criteria for identifying reconstructed electrons. An emdash (–) indicates selection criteria that are not applied.

Muons	Muons					
Observable	Veto	Tight				
p _T	> 10 GeV	> 26 GeV				
Muon POG cut-based ID	Tight	Tight				
Particle Flow relative isolation	0.4	0.15				
η	—	< 2.4				

Table 7: Veto and tight selection criteria for identifying reconstructed muons. An emdash (–) indicates selection criteria that are not applied.

177 3.2 Jets and missing $E_{\rm T}$

AK4 jets and AK8^w fat" jets reconstructed from Particle Flow (PF) candidates using anti- k_T 178 algorithm with a cone of $\Delta R < 0.4$ and $\Delta R < 0.8$ respectively are considered in this analysis. 179 In particular, a single AK8 fat jet is selected as the H \rightarrow bb candidate, since the Higgs boson is 180 expected to be significantly boosted when $\lambda_{WZ} = -1$, and two AK4 jets are selected as the VBS 181 quark candidates. The jet energy corrections (JECs) applied to AK4 and AK8 jets as well as the 182 prescriptions used for AK4 jet energy resolution smearing-such that the resolution in MC better 183 matches what is measured in data-are tabulated in Table 8. Importantly, jets that overlap with 184 any lepton passing the Veto lepton ID are not considered. This overlap is computed for AK4 jets 185 in the NanoAOD processing, where two objects are considered as overlapping if they share a 186 packed PF candidate. For AK8 jets, a lepton is considered to be overlapping if $\Delta R(\ell, \text{jet}) < 0.8$. 187 The type-1 PF-MET is used in the analysis, and jet energy corrections (JECs) are propagated 188 to $E_{\rm T}^{\rm miss}$. Next, those AK4 and AK8 jets that remain are further processed using the selections 189 detailed below. 190

Year	JEC era	JER era	
2016 (pro VED)	Summer19UL16APV_V7_MC	Summer20111 164 PV IRV3 MC	
2010 (pic VII)	Summer19UL16APV_RunBCDEF_V7_DATA	Summerzoo Erorar v jakvo jake	
2016 (post-VFP)	Summer19UL16_V7_MC	Summar20111 16 IBV2 MC	
	Summer19UL16_RunBCDEFGH_Combined_V7_DATA	Summer200L10_JKVS_WC	
2017	Summer19UL17_V5_MC	Summer 101 II 17 IBV2 MC	
2017	Summer19UL17_Run[BCDEF]_V5_DATA	Summer190L17_JKV2_WC	
2018	Summer19UL18_V5_MC	Summor 101 II 18 IPV2 MC	
	Summer19UL18_Run[ABCD]_V5_DATA	Juniner 190 L 10 JKV 2 LVIC	

Table 8: Jet energy corrections (JECs) and applied to AK4 and AK8 jets for data and MC are sorted by "era," corresponding to a year of NanoAOD UL processing. The equivalent era for jet energy resolution corrections are also tabulated. Brackets indicate that there are separate eras for each character in the brackets.

191 3.2.1 AK8 jets

¹⁹² AK8 fat jets used in this analysis must firstly have $p_T > 300 \text{ GeV}$ and be within the tracker ¹⁹³ acceptance ($|\eta| < 2.5$). In addition, they must have M > 50 GeV and $M_{\text{SD}} > 40 \text{ GeV}$, where M

is the invariant mass of the fat jet and $M_{\rm SD}$ is the soft drop mass corrected with PUPPI.

195 3.2.2 AK8 jet originating from b quarks

Since the only AK8 fat jet of interest to this analysis originates from $H \rightarrow b\overline{b}$, just one AK8 candidate is ultimately selected. A graph neural network (GNN) referred to as "ParticleNet" [9] is used to tag fat jets as having come from a b quark jet and anti-b quark jet merged into a single fat jet. Specifically, ParticleNet yields an "Xbb" discriminant for each fat jet, and the fat jet with the highest Xbb score is selected as the $H \rightarrow b\overline{b}$ candidate. In NanoAOD, this discriminant is stored as follows:

FatJet_particleNetMD_Xbb FatJet_particleNetMD_Xbb + FatJet_particleNetMD_QCD (3)

196 3.2.3 AK4 jets

First, only only jets with $p_{\rm T} > 20$ GeV are considered. Then, any jet that overlaps with the H \rightarrow bb AK8 fat jet candidate are ignored, where an AK4 and AK8 jet are considered to be overlapping if ΔR (jet, fat jet) < 0.8. The remaining jets are further cleaned using the Tight Lep-Veto PF jet ID detailed in Tables 9 and 10 following the JetMET (JME) POG recommendation.

202 3.2.4 AK4 jets originating from VBS quarks

The event must have at least two AK4 jets that pass the aforementioned selections and also have $p_T > 30 \text{ GeV}$ and $|\Delta \eta_{jj}| < 4.7$ to be considered in this analysis. If there are exactly two such jets, they are taken as the VBS quark candidates. However, if there are more than two, then the following prescription is followed. First, the jets are split by whether they are located in the positive or negative η hemisphere, then sorted by the magnitude of the three-momenta. If all of the jets are in one η hemisphere, then the leading and trailing jets in that hemisphere are taken as the VBS candidates. Otherwise, the leading jet from each η hemisphere is selected.

210 3.2.5 AK4 jets originating from b quarks

The signal process for this analysis has no b quarks resolved as AK4 jets in the final state, except in the subleading case where one of the VBS quarks is a b quark, as the $H \rightarrow b\overline{b}$ candidate is

3.2 Jets and missing $E_{\rm T}$

2016APV/2016 UL (106X) AK4 Jets						
Variable	$ \eta \le 2.4$	$2.4 < \eta \le 2.7$	$2.7 < \eta \le 3.0$	$ 3.0 < \eta \le 5.0$		
Neutral Hadron Fraction	< 0.90	< 0.90	< 0.90	> 0.2		
Neutral EM Fraction	< 0.90	< 0.99	> 0 and < 0.99	< 0.9		
Number of Constituents	> 1	-	-	-		
Muon Fraction	$< 0.80^{+}$	_	_	_		
Charged Hadron Fraction	> 0	_	_	_		
Charged Multiplicity	> 0	_	_	_		
Charged EM Fraction	$< 0.80^{+}$	_	_	_		
Number of Neutral Particles	_	_	> 1	> 10		

⁺ For analyses that veto jets based on lepton overlap, referred to as "LepVeto" by the JetMET POG.

Table 9: Tight JetMET POG PF jet ID criteria for AK4 jets in 2016 post-VFP and pre-VFP NanoAOD UL samples. An emdash (–) indicates that no selection is applied.

2017/2018 UL (106X) AK4 Jets						
Variable	$ \eta \le 2.6$	$2.6 < \eta \le 2.7$	$2.7 < \eta \le 3.0$	$ 3.0 < \eta \le 5.0$		
Neutral Hadron Fraction	< 0.90	< 0.90	- /	> 0.2		
Neutral EM Fraction	< 0.90	< 0.99	> 0.01 and < 0.99	< 0.9		
Number of Constituents	> 1	-	-	-		
Muon Fraction	$< 0.80^{+}$	$< 0.80^{+}$		-		
Charged Hadron Fraction	> 0	- /	- \	-		
Charged Multiplicity	> 0	> 0 <	< - ·	<u> </u>		
Charged EM Fraction	$< 0.80^{+}$	< 0.80 ⁺		<u> </u>		
Number of Neutral Particles	_	-	>1	> 10		

⁺ For analyses that veto jets based on lepton overlap, referred to as "LepVeto" by the JetMET POG.

Table 10: Tight JetMET POG PF jet ID criteria for AK4 jets in 2017 and 2018 NanoAOD UL samples. An emdash (–) indicates that no selection is applied.

expected to be resolved as an AK8 fat jet. However, the main backgrounds for this analysis do

have at least one b quark in the final state. Thus, any event with a "b-tagged" jet can be vetoed.

²¹⁵ In particular, a deep neural network referred to as "DeepJet" is used to tag jets as having come

from a b quark, using the Medium working point. Only jets within the tracker acceptance $(|\eta| < 2.4)$ are considered for this tagging.

218 4 Selections





219 4.1 Triggers and data quality cuts

To start, the single lepton High Level Triggers (HLTs) tabulated in Table 11 are applied. Notably, 220 since there is ultimately a selection of $p_T > 40$ GeV applied to the leptons in the event, this 221 analysis should sit on the plateau of the trigger efficiency curve. For collision data, events 222 from the SingleMuon dataset are required to pass the single muon triggers, while events from 223 the SingleElectron dataset and required to pass the single electron triggers and fail the single 224 muon triggers. Since the trigger information is available in MC as well as data, the simulated 225 events are required to pass the same triggers as the actual collision data. In particular, the single 226 electron and single muon triggers are both applied, and the event is rejected only if both sets 227 of triggers fail. A centrally derived scale factor is applied in MC such that the efficiency of the 228 triggers in MC matches that measured in data. Finally, the following event filters recommended 229 by the JME are applied in data in order to remove detector noise and unphysical events [10]: 230

- Flag_goodVertices
- Flag_HBHENoiseFilter
- Flag_HBHENoiseIsoFilter
- Flag_EcalDeadCellTriggerPrimitiveFilter
- Flag_BadPFMuonFilter
- Flag_BadPFMuonDzFilter
- Flag_hfNoisyHitsFilter
- Flag_eeBadScFilter
- Flag_ecalBadCalibFilter (2016 only)
- Flag_globalSuperTightHalo2016Filter

The last filter is applied to specifically remove beam-halo events. These filters are also applied
to MC events, but have no effect.

243 4.2 Preselection

In addition to the triggers and JME-recommended event filters, a set of basic selections referred to as the "Preselection" are applied. These cuts are common to the signal regions and control regions defined later in this text. That is, the Preselection is applied to all events used in this analysis. In general, it selects events with one lepton, two AK4 jets, and one AK8 jet passing

Year	Single lepton HLT path
	HLT_IsoMu24
2016	HLT_IsoTkMu24
	HLT_Ele27_WPTight_Gsf
2017	HLT_IsoMu27
2017	HLT_Ele32_WPTight_Gsf_L1DoubleEG
2010	HLT_IsoMu24
2010	HLT_Ele32_WPTight_Gsf

Table 11: Triggers used to filter events for this analysis.

the object selections defined in the previous section. It also applies more stringent selections on
each object in order to narrow in on a signal-like phase space.

First, a loose selection is made on the combined VBS jet invariant mass: $M_{ii} > 500$ GeV. Next,

the ParticleNet Xbb score of the H $\rightarrow b\overline{b}$ fat jet candidate is required to be greater than 0.3.

²⁵² The event is also required to have no AK4 jets passing the Medium DeepJet working point, as

²⁵³ mentioned in Section 3.2.5. The event must furthermore have one and only one lepton with

 $p_{\rm T} > 40 \,\text{GeV}$ that passes the Tight lepton ID. If there are any additional leptons that pass the

Veto lepton ID, the event is vetoed-these leptons are not required pass the $p_{\rm T}$ threshold. Finally,

the event must have $S_{\rm T} > 800 \,{\rm GeV}$ (where $S_{\rm T}$ is defined in Eq. 5).

257 4.3 Signal signature

258 4.3.1 VBS signature

The VBS signature of pp \rightarrow W[±]H + jj provides a distinct kinematic signature, namely two nearly back-to-back jets–i.e. a large absolute difference in pseudorapidity $|\Delta \eta_{jj}|$ –with a large combined invariant mass M_{jj} . In particular, the background processes fall off exponentially in M_{jj} whereas the signal process is more flatly distributed. Combined with the fact that the signal has a distinctly larger average value of $|\Delta \eta_{jj}|$ than background, these VBS characteristics form a strong handle for distinguishing signal from background. These variables are plotted after reconstruction, and after applying the Preselection, in Fig. 9.

266 4.3.2 W^{\pm}H signature

Because they are a proxy for the hard scattering energy of the event, the following variables provide access to the enhancement of M_{WH} from $\lambda_{WZ} = -1$:

$$L_{\rm T} = p_{\rm T}(\ell) + E_{\rm T}^{\rm miss} \tag{4}$$

$$S_{\rm T} = L_{\rm T} + p_{\rm T}({\rm H} \to {\rm b}\overline{{\rm b}} {\rm fat \, jet})$$
 (5)

where L_T is the scalar sum of "leptonic" transverse energy, and S_T is the scalar sum of the 269 transverse energy of the $W^{\pm}H$ decay products. As mentioned in Section 1, the cross section for 270 signal events with large M_{WH} is significantly increased when $\lambda_{WZ} = -1$, which is seen in the 271 distribution of $L_{\rm T}$ and $S_{\rm T}$. In particular, the background falls off exponentially in these vari-272 ables, whereas there are a significant number of signal events in the high $L_{\rm T}$ and $S_{\rm T}$ tails. These 273 variables are plotted after reconstruction in Fig. 10, where it is clear that they provide powerful 274 signal-versus-background discrimination, even after already applying the Preselection detailed 275 in Section 4.2 below. 276



Figure 9: The VBS jet combined invariant mass (left) and absolute difference in pseudorapidity (right) are plotted after applying the Preselection.



Figure 10: The variables $L_{\rm T}$ (left) and $S_{\rm T}$ (right) are plotted after applying the Preselection.

In addition, the softdrop mass of the $H \rightarrow b\overline{b}$ candidate fat jet shows a distinct peak around the Higgs mass and is highly concentrated in the high ParticleNet Xbb score (Fig. 11).

279 4.4 Signal region

The signal region for this analysis is defined on top of the Preselection with similar, but tighter selections. First, the $S_{\rm T}$ threshold is increased to $S_{\rm T} > 900$ GeV. Then, the selections on the VBS jet variables are tightened to $M_{\rm jj} > 600$ GeV and $|\Delta \eta_{\rm jj}| > 4$. Finally, the selections on the H \rightarrow bb fat jet candidate are made much more strict, where the ParticleNet Xbb score is required to be greater than 0.9 and $M_{\rm SD}$ is required to be less than 150 GeV.

The background in this region is estimated using a data-driven technique, as described in Section 5. Moreover, the selections described above were specifically designed such that this could



Figure 11: The H \rightarrow bb fat jet candidate soft drop mass (left) and ParticleNet Xbb score (right) are plotted after applying the Preselection.

287 b	e done at all.	Looser cuts are	preferred in	particular, as i	it was found	that the	"arms" o	f the
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background extrapolation become correlated in a more restricted phase space. Therefore, the

289 signal region selections are not optimized for maximal purity, though such a region can be

²⁹⁰ formed (see Appendix E).

The Monte Carlo yields of both signal and background after applying the Preselection and signal region selections are each tabulated in Table 12.

Cut	VH	EWK W	Bosons	W+jets	Single top	$t\bar{t} + X$	$t\bar{t} + 1\ell$	$t\overline{t}+2\ell$
Preselection	5.37	71.20	367.67	1014.45	319.55	44.45	2734.64	349.92
SR	0.85	2.96	5.98	21.21	13.05	0.95	49.90	21.43
Cut Total I Preselection 4907 SR 116.				bkg. VB 7.25 33	S W [±] H (λ _{WZ} 656.39 397.44	z = -1)	-	

Table 12: The the background yields separated by sample (top) as well as the total background and signal yields (bottom) are tabulated after applying the Preselection followed by the signal region (SR) selections. All yields are taken from Monte Carlo and weighted by cross section to the total integrated luminosity of Run 2 (138 fb^{-1}).

293 4.5 Control regions

²⁹⁴ Two regions orthogonal to the signal region are defined as "control" regions. Both are signal ²⁹⁵ depleted, so data and Monte Carlo can be compared in order to test the validity of the simu-²⁹⁶ lation in otherwise relevant phase space. In particular, these regions are used only to ensure ²⁹⁷ that there is no significant mismodeling or missing background Monte Carlo. The first is a ²⁹⁸ control region in $\Delta \eta_{ij}$ that consists of the Preselection and $|\Delta \eta_{ij}| \leq 3$. The second is a control ²⁹⁹ region in $M_{\rm SD}$ that consists of the Preselection, $|\Delta \eta_{ij}| > 3$, and $M_{\rm SD} \geq 150$ GeV. See Fig. 8 for a ³⁰⁰ pictorial representation of these regions. In Figures 12 and 13, it can be seen that there is satisfactory agreement in both regions between data and MC for variables relevant to this analysis.
 Additional control region plots can be found in Appendix B.1.



Figure 12: The VBS jet combined invariant mass (left) and absolute difference in pseudorapidity (right) are plotted in the M_{SD} control region.



Figure 13: The H \rightarrow bb fat jet candidate soft drop mass (left) and ParticleNet Xbb score (right) are plotted in the $\Delta \eta_{ij}$ control region.

5 Background estimation

The background in the signal region is estimated using the "ABCD" method, where regions A, B, C, and D are illustrated in Fig. 14. First, let the background yield in regions A, B, C, and D in Monte Carlo be defined as A_{MC} , B_{MC} , C_{MC} , and D_{MC} . Likewise, let the the same yields in data be defined as A_{data} , B_{data} , C_{data} , and D_{data} . Under these definitions, the estimated background yield in Region D, which will be referred to as D_{data}^{pred} , can be computed with data as follows:

$$D_{data}^{pred} = C_{data} \times \frac{A_{data}}{B_{data}} \tag{6}$$

where the same can be done in MC, yielding D_{MC}^{pred} . First, it can be seen in Fig. 15 that data and MC agree reasonably well in regions A, B, and C which have already been unblinded since they have nearly zero contribution from signal by design. More plots comparing data and MC can be found in Appendix B.2. In addition, it has been verified that the "transfer factor" that scales the actual yield in Region C to the estimated yield in region D is consistent within statistical uncertainty across data and MC:

$$\frac{A_{MC}}{B_{MC}} = 0.71 \pm 3.1\% \qquad \frac{A_{data}}{B_{data}} = 0.71 \pm 11.0\%$$

The closure of the ABCD method described here is tested by comparing D_{MC}^{pred} to D_{MC} . This checks how closely the estimation in Monte Carlo predicts the actual yield in Monte Carlo.

$$D_{MC}^{pred} = C_{MC} \times \frac{A_{MC}}{B_{MC}} = 129.4 \qquad D_{MC} = 116$$

It is clear that the ABCD method for this analysis systematically over-predicts the background yield in Region D. The difference between the predicted and actual yield in MC is therefore taken as a systematic on this method. An additional 6.0% systematic is added to account for uncertainty in the W+jets background composition (see Appendix C). Thus, the systematic and statistical uncertainties ϵ_{syst} and ϵ_{stat} are

$$\epsilon_{syst} = \left| 1 - \frac{D_{MC}^{pred}}{D_{MC}} \right| \oplus 6.0\% \approx 12.7\%$$

$$\epsilon_{stat} = \frac{\sqrt{A_{data}}}{A_{data}} \oplus \frac{\sqrt{B_{data}}}{B_{data}} \oplus \frac{\sqrt{C_{data}}}{C_{data}} \approx 13.4\%$$

and the final estimated background yield in the signal region is therefore given by

$$D_{data}^{pred} = 120 \pm 16.1 \pm 15.3$$

Finally, the yields in Regions A, B, C, and D are tabulated in Table 13, where it can be seen that there is negligable signal pollution in Regions A, B, and C. In particular, while there are some signal events in Regions A and C, they are much smaller than the signal yield in Region D, the signal region.



Figure 14: The ABCD configuration for estimation of background in the signal region is shown graphically (a) and as a flowchart (b). The set of selections applied to all regions is referred to as the "SR-like" region in (b).

Region	Total bkg. (MC)	Total sig.	Total data
A	172.8 ± 3.2	12.2 ± 1.5	142 ± 11.9
В	241.7 ± 5.8	0.9 ± 0.4	201 ± 14.2
С	181.0 ± 4.4	16.7 ± 1.8	170 ± 13.0
D	116.3 ± 3.8	397.4 ± 8.7	-

Table 13: The signal and background MC yields are tabulated in Regions A, B, C, and D alongside the data yields in Regions A, B, and C.



Figure 15: The softdrop mass of the H $\rightarrow b\overline{b}$ fat jet candidate is plotted in Regions A and D (left), which share the selection $|\Delta \eta_{jj}| > 0.4$, and Regions B and C (right), which share the selection $|\Delta \eta_{jj}| \leq 0.4$, showing closure of the ABCD method.

308 6 Systematic uncertainties

The systematics on the background yield in the signal region are already derived in Section 5. Since the estimation strategy is data-driven, the systematics on the Monte Carlo, which are more numerous, only need to be evaluated for the signal yield. Most sources of systematic uncertainty are derived by varying the renormalization and factorization scales (μ_R and μ_F), PDF, and various experimental corrections by one standard deviation and taking the maximal difference in yield as the error. In particular, the corrections and their uncertainties are typically derived centrally in order to augment the efficiency of a specific selection in MC to match that measured in data. In general, these corrections are applied as an event weight ω , such that the weighted contribution W of each raw Monte Carlo event is given by the product of the event weights for that same event. The yield in a given signal region *y* containing *N* raw Monte Carlo events is therefore given by

$$y = \sum_{i=1}^{N} W_i \tag{7}$$

Then, the yield y_{var} is computed after applying a systematic variation (up or down) of each source of systematic uncertainty independently:

$$y_{var} = \sum_{i=1}^{N} W_i \times \frac{\omega_{var}}{\omega}$$
(8)

Finally, the maximum of the percent differences δ_{up} or δ_{down} are taken as the systematic uncertainty for that source, where

$$\delta_{var} = \left| 1 - \frac{y_{var}}{y} \right| \tag{9}$$

Although most of the systematic uncertainties in this analysis are centrally computed, and thus their values in Table 14 are derived as shown above, not all of them are. Those systematics that are privately computed or are otherwise derived following a different prescription from that described already are discussed in more detail below.

6.1 PDF systematic uncertainty

The signal Monte Carlo simulation was generated using a Hessian Parton Distribution Function (PDF). After generation, 100 eigenvectors of a covariance matrix are stored as event weights ω_i^{PDF} , where i = 1, 2, ..., 100 [11]. These variations are derived such that the systematic uncertainty is derived as follows. First, in a signal region with N events, the ratio R_i of the sum of the *i*th PDF variation and the sum of the MADGRAPH generator weights ω_i^{gen} is computed:

$$R_i = \frac{\sum_{j=1}^N \omega_{i,j}^{PDF}}{\sum_{j=1}^N \omega_j^{gen}}$$
(10)

Next, the yield y_i^{var} for the *i*th PDF variation is given by

$$y_i^{var} = \sum_{j=1}^N W_j \times \frac{\omega_i^{PDF}}{R_i}$$
(11)

This decouples the systematic on the PDF from the systematic on the cross section, which would otherwise be double counted. Finally, the systematic uncertainty on the PDF is given by

$$\delta_{PDF} = \left[\sum_{i=1}^{100} \left|1 - \frac{y_i^{var}}{y}\right|^2\right]^{\frac{1}{2}}$$
(12)

Туре	Systematic	Value
Paalvaraund	ABCD syst. unc.	12.7%
Dackground	Data stat. unc.	13.4%
	PDF variations	2.2%
	μ_F scale	17.7%
	Parton shower ISR weights	0.2%
	Parton shower FSR weights	1.5%
	Pileup reweighting	0.1%
	Pileup jet ID	1.0%
	L1 pre-fire corrections	1.0%
Signal	HLT scale factors	0.8%
	Simulation stat. unc.	2.2%
	Lepton scale factors	0.03% - 1.6%
	ParticleNet Xbb scale factors	1.0% - 1.9%
	DeepJet b-tagging scale factors	0.3%
	MET unc.	0.3%
	Jet energy scale	6.4%
	Jet energy resolution	0.6%
	Luminosity	1.6%
	$H \rightarrow b\overline{b} BR$	1.27%

Table 14: The size of the systematic uncertainties on the signal and estimated background yield in the signal region are tabulated. The systematics tabulated here represent the full set of nuisance parameters used in the fitting procedure that produced the final result.

6.2 ParticleNet Xbb scale factor uncertainty

Corrections for the ParticleNet Xbb discriminator distribution shape are computed for signal 315 using a central tool originally developed for the $H \rightarrow c\bar{c}$ analysis [12, 13]. This tool utilizes a 316 Boosted Decision Tree (BDT), referred to as "sfBDT," that isolates the phase space populated 317 by H \rightarrow bb jets in signal, then selects g \rightarrow bb jets in that phase space from Monte Carlo 318 simulation of QCD multijet events. The sfBDT is therefore trained to select suitable $g \rightarrow bb$ 319 jets to serve as proxies for the H \rightarrow bb jets in signal, in particular by vetoing jets with a high 320 gluon contamination rate. Moreover, the sfBDT receives as input the variables involving the 321 basic kinematics of the subjets and secondary vertices associated with the jet. Thus trained, the 322 sfBDT can also be used to select the same kind of proxy jets from data. 323

The signal-like jets selected by the sfBDT can then be used to measure the efficiency of the ParticleNet Xbb discriminant in QCD Monte Carlo and data. A "pass" and "fail" region is defined by jets passing or failing the ParticleNet Xbb tagging threshold–corresponding to the requirement of Xbb > 0.9 in the signal region for this analysis. In each region, a fit of the mass of the secondary vertex with the maximum impact parameter d_{xy} significance is performed in order to distinguish the contribution of b-type (g \rightarrow bb), c-type, and light-type jets. Three scale factors, one for each type of jet, are allowed to float in this fit, where each scale factor is defined as follows:

$$SF_i = \frac{\epsilon_{\text{data},i}}{\epsilon_{\text{MC},i}} \tag{13}$$

where *i* stands for the jet category and ϵ is the efficiency of the ParticleNet tagger. This measurement is done in bins of $p_{\rm T}$ for a more robust correction, and it is repeated for each year of

326 UL NanoAOD individually. The post-fit distributions of the secondary vertex mass variable



for 2018 are shown in Fig. 16. Additional plots can be found in Appendix B.3

Figure 16: The post-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} \text{ sig max}}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2018 in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.

³²⁸ The scale factors are finally collected (Table 15) and applied to signal as an event weight to cor-

rect the efficiency of ParticleNet in Monte Carlo to match that in data, and the systematic un-

³³⁰ certainty is computed using the upwards and downwards 1σ fluctuations of the event weights.

Voar	$p_{\rm T}$ range in GeV:					
Ital	[250, 500)	[500, 700)	[700 , ∞)			
2018	$0.990\substack{+0.027\\-0.031}$	$1.040\substack{+0.038\\-0.034}$	$1.069\substack{+0.056\\-0.038}$			
2017	$1.020\substack{+0.027\\-0.025}$	$1.049\substack{+0.041\\-0.031}$	$1.030\substack{+0.041\\-0.030}$			
2016 (post-VFP)	$1.028\substack{+0.046\\-0.047}$	$1.090\substack{+0.104\\-0.098}$	$1.045\substack{+0.102\\-0.087}$			
2016 (pre-VFP)	$1.038\substack{+0.116\\-0.115}$	$1.084\substack{+0.137\\-0.132}$	$1.027\substack{+0.145 \\ -0.142}$			

Table 15: Summary of the ParticleNet Xbb-tagging scale factors for the Xbb > 0.9 working point.

331 7 Results

The background yield in the signal region estimated from data and the signal yield predicted by Monte Carlo simulation are tabulated in Table 16. Using these yields, and the systematics tabulated in Table 14, we perform a maximum-likelihood fit using the Combine statistical tool maintained by the Higgs Physics Analysis Group (PAG). The tool is, in particular, run with the following parameters:

```
combine -M MultiDimFit -d vbswh.root -m 125 -t -1 \
337
        --expectSignal=0 \
338
        --setParameters r_VBSWH_mKW=0 \
339
        --setParameterRanges r_VBSWH_mKW=0.0,2.0 \
340
        --saveNLL \
341
        --algo grid \
342
        --points 101 \setminus
343
        --rMin 0 ∖
344
        --rMax 5 \setminus
345
        --alignEdges 1
346
```

where vbswh.root is the datacard (Fig. 19) translated into a Combine workspace ROOT file. The fit is performed using an "observed" yield that is artificially set to be equal to the predicted background yield. Under this background-only hypothesis, we expect to exclude $\kappa_{\rm W} = -1, \kappa_{\rm Z} = +1$ at 9.0 σ (Fig. 17).

A two-dimensional exclusion is also performed, where each κ_W , κ_Z point is processed by Combine using same the parameters as the single-point result above, such that each point is treated as a distinct signal model. The exclusions for a signal strength of 1 are thus derived and plotted on the z-axis of a two-dimensional (κ_W , κ_Z) histogram, which is then interpolated such that smooth exclusion contours can be obtained (Fig. 18). Additional details can be found in Appendix F.

 Туре	Yield	E	stat.	±	syst.
Signal	397	\pm	8.7	\pm	77.9
Background	120	\pm	16.1	\pm	15.3

Table 16: The background yield estimated from data and signal yield predicted by Monte Carlo simulation in the signal region are tabulated with their associated statistical and systematic uncertainties. The systematic uncertainty for signal quoted here is the sum of all of the independent systematics (percent errors) listed in Table 14 in quadrature multiplied by the total yield.

Туре	Yield	\pm	stat.	\pm	syst.
Bkg. 2016 (pre-VFP)	16	±	6.6	±	7.5
Bkg. 2016 (post-VFP)	6	\pm	2.4	\pm	1.4
Bkg. 2017	36	\pm	8.5	\pm	2.3
Bkg. 2018	69	\pm	13.9	±	5.6

Table 17: The background yield for each year of UL NanoAOD estimated from data in the signal region is tabulated with its associated statistical and systematic uncertainties. The sum of the background yields tabulated here does not match the total yield in Table 16, because they are each individually estimated using only data from each data taking period.



Figure 17: The maximum-likelihood fit for the background-only hypothesis, where the observed yield is artifically set to be equal to the predicted background yield, is plotted for the signal region. This shows a strong exclusion of r = 1 with a significance of 9.0 σ .



Figure 18: The interpolated exclusion of κ_W , κ_Z values with $\sigma = 1, 2, 5$ boundaries plotted as white contours. In addition, the current best limits ($|\kappa_W| = 1.02 \pm 0.08$, $|\kappa_Z| = 1.04 \pm 0.07$) are plotted as capped error bars. As was done for the single-point exclusion, the plot is made for the background-only hypothesis, where the observed yield is artificially set to be equal to the predicted background yield. Together with the exclusion contours, this plot clearly shows $\lambda_{WZ} < 0$ is excluded.

imax 1 number of chan jmax 1 number of back kmax 24 number of num	nnels kground isance	ls parameters	
bin observation		bin1 120	
bin process process rate		bin1 VBSWH_mkW 0 397.44	binl TotalBkg 1 120.10
<pre>abcd_syst abcd_stat pdf_vars muF_scale isr_weights fsr_weights pu_rwgt puid_sf L1_prefire hlt_sfs</pre>	lnN lnN lnN lnN lnN lnN lnN lnN lnN lnN	- 1.0215 1.1771 1.0019 1.0153 1.0012 1.0100 1.0097 1.0079 1.0210	1.1270 1.1340 - - - - - - - - - - - - -
<pre>mc_stat lep_id elec_reco muon_iso xbb_sfs_2016preVFP xbb_sfs_2016postVFP xbb_sfs_2017 xbb_sfs_2018 btag_sfs met_unc</pre>	INN INN INN INN INN INN INN INN	1.0218 1.0156 1.0031 1.0003 1.0177 1.0102 1.0104 1.0185 1.0030 1.0029	
jes jer lumi hbb_br	lnN lnN lnN lnN	1.0642 1.0059 1.0160 1.0127	- - -

Figure 19: Combine datacard used to produce the final result under the null hypothesis, where the observed count is artificially set to be equal to the predicted background yield.

357 8 Summary

An analysis has been performed as described in this note, searching for anomalous values of the Higgs boson couplings to W and Z bosons in the production of $W^{\pm}H$ via vector boson scat-

- the Higgs boson couplings to W and Z bosons in the production of W⁺H via vector boson scattering. The work is based on a data sample of proton-proton collisions at $\sqrt{s} = 13$ TeV recorded
- ³⁶¹ by the CMS experiment during 2016, 2017, and 2018, corresponding to a total integrated lumi-
- nosity of 138 fb^{-1} . In particular, the search was done in the one lepton, two b quark, two jet
- final state where we ultimately exclude $\kappa_W = -1$ at 9.0 σ . A two-dimensional exclusion is also
- presented, showing a wide exclusion of opposite-sign κ_W , κ_Z values. This, in conjunction with
- previous work, provides strong evidence that $\lambda_{WZ} \neq -1$.

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34

A Signal MADGRAPH model

⁴⁰³ The MADGRAPH model representing $pp \rightarrow W^{\pm}H + jj$ was created by making the following ⁴⁰⁴ modification to the Standard Model:

```
405 GC_72 = Coupling(name = 'GC_72',
406 value = '-((ee**2*complex(0,1)*vev)/(2.*sw**2))',
407 order = {'QED':1})
```

where GC_72 represents κ_W . In particular, a minus sign was placed in front of the value of the value key word argument. This sets the value of κ_W to be the opposite of κ_Z , thus enforcing $\lambda_{WZ} = -1$. A MC sample using this model was generated as follows:

```
411 import model sm_mkw

412

413 define w = w+ w-

414

415 generate p p > w h j j QCD=0
```

416 where the model sm_mkw has the aforementioned modification applied. Finally, PYTHIA was

used to handle parton showers with the same settings used to generated other CMS MC sam-ples at LO.

419 **B** Additional plots

420 B.1 Control regions



Figure 20: $S_{\rm T}$ is plotted in the $M_{\rm SD}$ (left) and $\Delta \eta_{\rm ji}$ (right) control regions.



Figure 21: The VBS jet combined invariant mass (left) and absolute difference in pseudorapidity (right) are plotted in the $\Delta \eta_{ii}$ control region.

36



Figure 22: The H \rightarrow bb fat jet candidate soft drop mass (left) and ParticleNet Xbb score (right) are plotted in the M_{SD} control region.

421 B.2 Background estimation



Figure 23: The variable S_T is plotted in regions A (left), B (center), and C (right) in both data and Monte Carlo, showing fair agreement in each region. The signal contamination is negligible in the total yield, but concentrated at high S_T , where there is little background. As such, the high S_T tail in Regions A and C are blinded. The same tail in Region B has little signal, so it has been unblinded.



Figure 24: The VBS jet combined invariant mass is plotted in Regions A (left), B (center), and C (right) in both data and Monte Carlo, showing fair agreement in each region.



Figure 25: The VBS jet absolute difference in pseudorapidity is plotted in Regions A (left), B (center), and C (right) in both data and Monte Carlo, showing fair agreement in each region.



Figure 26: The number of AK8 fat jets passing the selections detailed in Section 3.2.1 is plotted in Regions A (left), B (center), and C (right) in both data and Monte Carlo, showing fair agreement in each region.



422 B.3 ParticleNet Xbb scale factor uncertainty

Figure 27: The pre-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} \text{ sig max}}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2018 in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.



Figure 28: The pre-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} \text{ sig max}}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2017 in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.



Figure 29: The post-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} sig max}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2017 in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.



Figure 30: The pre-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} \text{ sig max}}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2016 (post-VFP) in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.



Figure 31: The post-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} \text{ sig max}}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2016 (post-VFP) in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.



Figure 32: The pre-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} \text{ sig max}}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2016 (pre-VFP) in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.



Figure 33: The post-fit distribution of the natural logarithm of the secondary vertex mass $m_{SV_1,d_{xy} \text{ sig max}}$ is plotted in the "pass" (top) and "fail" (bottom) region for 2016 (pre-VFP) in the [250, 500) GeV (left), [500, 700) GeV (center), and [700, ∞) GeV (right) p_T bins. The subscript "SV₁, d_{xy} sig max" stands for the secondary vertex with the maximum impact parameter d_{xy} significance, and the natural logarithm is taken to account for the variable's long tail due to limited resolution.

423 C ABCD subleading background composition uncertainty



Figure 34: The VBS jet absolute difference in pseudorapidity is plotted in Regions A and B (left) versus Regions C and D (right) in Monte Carlo. It is clear that the subdominant W+Jets background is distributed in $\Delta \eta_{jj}$ in a significantly different way from the dominant TTbar backgrounds, which are consistent with each other.

Based on Fig. 34, it is clear that the W+Jets background is distributed in $\Delta \eta_{jj}$ in a significantly different way from the dominant TTbar backgrounds. To account for this, the W+Jets background yield is first varied up and down by a factor of 2 in Regions A and B, which in turn affects the expected value of the transfer factor used to perform the estimation of the background yield in the signal region:

$$\frac{A_{MC}}{B_{MC}} = 0.71 \pm 3.1\% \qquad \frac{A_{MC}^{up}}{B_{MC}^{up}} = 0.68 \pm 2.9\% \qquad \frac{A_{MC}^{down}}{B_{MC}^{down}} = 0.74 \pm 3.2\%$$

⁴²⁴ The maximal the percent difference between the up and down variations versus the nominal

transfer factor in Monte Carlo is taken as a systematic uncertainty, amounting to about 5.4%.

Upon close inspection of the plots in Appendix 5, it is clear that the Bosons background (mostly diboson processes) is also distributed differently between the regions. As such, it is appropriate to derive a systematic uncertainty on the Bosons background composition as was done for W+jets above:

$$\frac{A_{MC}}{B_{MC}} = 0.71 \pm 3.1\% \qquad \frac{A_{MC}^{up}}{B_{MC}^{up}} = 0.7 \pm 4.5\% \qquad \frac{A_{MC}^{down}}{B_{MC}^{down}} = 0.72 \pm 2.6\%$$

Again, the maximal the percent difference between the up and down variations versus the

nominal transfer factor in Monte Carlo is taken as a systematic uncertainty, amounting to about
 2.6%.

D Erroneous EWK samples

While constructing this analysis, it became clear that an abnormally large yield of EWKWLep 430 samples survived past the Preselection. In particular, introducing those samples ruined the oth-431 erwise satisfactory closure of the ABCD background estimation method-compare Figures 15 432 and 35. After applying only the Preselection and $|\Delta \eta_{ij}| > 3$, which contains the relevant EWK-433 WLep events, it is clear that the EWKWLep samples are abnormal. First, the vast majority of 434 EWKWLep events in this region had one or both incoming b quarks (Fig. 36a). Moreover, most 435 EWKWLep events that are VBS W events at the generator level in this region have just one 436 outgoing quark matched to a VBS quark, where the other outgoing quark is matched to the 437 $H \rightarrow bb$ fat jet candidate and that outgoing quark is predominantly a b quark. Therefore, it 438 became apparent that the kinematics of these b initiated VBS events were somehow simulated 439 incorrectly. 440



Figure 35: The softdrop mass of the $H \rightarrow b\bar{b}$ fat jet candidate is plotted in Regions A and D (left), which share the selection $|\Delta \eta_{jj}| > 0.4$, and Regions B and C (right), which share the selection $|\Delta \eta_{jj}| \leq 0.4$, showing poor closure of the ABCD method when compared to Fig. 15. An erroneously large yield of the EWK W leptonic sample is evident in Regions A and D in particular.

It was finally determined that there was an issue at the MADGRAPH level. In the process card, the following line was originally used to generate the EWKWLep samples:

443 pp > l vl j j / t t~ h QCD = 0

where the '/' excludes diagrams containing t, \bar{t} , and H diagrams from generation, and ignores any interference from them. However, the process should have instead been generated using

```
446 pp > l vl j j $ t t^{\sim} h QCD = 0
```

where the '\$' excludes diagrams containing t, \bar{t} , and H diagrams from generation, but includes any interference from them. That is, the interference from diagrams containing t and \bar{t} is significant. This can be seen in Fig. 37a, where it is clear that the $p_{\rm T}$ of outgoing b quarks is significantly boosted when using the incorrect MADGRAPH generation line. Put simply, the



Figure 36: The incoming quark flavors (left) and event type (right) are plotted for only the EWKWLep samples after applying the Preselection and $|\Delta \eta_{jj}| > 3$. The event types are as follows. First, an event is classified as being a VBS W or WW event, as the EWKWLep samples contain both. Next, the generator-level lepton is matched using $\Delta R(\ell_{gen}, \ell_{reco}) < 0.4$ to the reconstructed lepton, and the event is classified as having or not having a matched lepton. Then, the generator-level quarks are matched to the reconstructed VBS quarks using $\Delta R(q_{gen}, q_{reco}) < 0.4$, and the event is classified according to the number of matches. Finally, the number of generator-level quarks in the H \rightarrow bb fat jet $\Delta R < 0.8$ cone are counted, and the event is classified accordingly.

EWKWLep samples are BSM samples where the top quark does not exist, so they inhabit a 451 familiarly boosted phase space. As a temporary fix, a scale factor was derived by taking the 452 ratio of the histograms of the outgoing b quark $p_{\rm T}$ for the correctly (numerator) and incorrectly 453 (denominator) generated samples. This scale factor, binned in $p_{\rm T}$ of the outgoing b quark, is 454 sufficient to completely remove the issue. In addition, the EWKWLep samples have no restric-455 tion on the minimum dijet mass, so diboson events are also included in the sample. Since this 456 analysis uses a dedicated diboson sample already, these events are removed in order to avoid 457 double counting. At the time of writing, the EWKWLep samples have been decommissioned 458 and are being centrally generated with the correct MADGRAPH line. 459



Figure 37: The $p_{\rm T}$ of outgoing b quarks are plotted for the correctly versus incorrectly generated samples. The plots are the same, except the left plot is binned evenly while the right plot is binned such that ratio of correctly to incorrectly generated samples can be taken as a scale factor.

460 E High-purity signal region

A high-purity signal region can be constructed by tightening the $S_{\rm T}$ cut in the signal region 461 used in this analysis to $S_T > 1500$ GeV. Doing an ABCD background estimation as was done 462 in Section 5 is not possible, however, since Regions A and C are too signal polluted to be un-463 blinded. Instead, Region B can be used to validate data-MC agreement, and the extrapolation 464 factor that scales the actual yield in Region C to the estimated yield in Region D can be taken 465 from MC, provided data and MC agree reasonably well in Region B-this is indeed the case. 466 Then, the signal yield would again be taken from Monte Carlo. A table of systematics can then 467 be produced as was done in Section 6. 468

Туре	Systematic	Value
Background	Estimation syst. unc.	35.7%
Dackground	Data stat. unc.	13.4%
	PDF variations	2.2%
	μ_F scale	21.1%
	Parton shower ISR weights	0.3%
	Parton shower FSR weights	0.8%
	Pileup reweighting	0.5%
	Pileup jet ID	1.0%
	L1 pre-fire corrections	1.0%
Signal	HLT scale factors	0.8%
	Simulation stat. unc.	4.2%
	Lepton scale factors	0.03% - 1.5%
	ParticleNet Xbb scale factors	1.2% - 2.4%
	DeepJet b-tagging scale factors	0.3%
	MET unc.	0.2%
	Jet energy scale	8.0%
	Jet energy resolution	0.5%
	Luminosity	1.6%
	$H \rightarrow b\overline{b} BR$	1.27%

Table 18: The size of the systematic uncertainties on the signal and estimated background yield in the high-purity signal region are tabulated. The systematics tabulated here represent the full set of nuisance parameters that could be used in a fitting procedure.

From just MC, it is clear that this region is very pure in signal, with 111 signal events expected versus 6 predicted background events. Such a region was devised in case the signal region used in the analysis was at all ambiguous, and it could be worth exploring in its own right.

⁴⁷¹ used in the analysis was at all ambiguous, and it could be worth exploring in its own right. ⁴⁷² It was not considered for the final result of this analysis since it is not orthogonal to the main

signal region, and the main signal region is anyway sufficient to exclude $\lambda_{WZ} = -1$.

Туре	Yield	\pm	stat.	\pm	syst.
Signal	106	\pm	4.5	\pm	25.0
Background	5	\pm	0.7	\pm	1.9

Table 19: The background yield estimated from data and signal yield predicted by Monte Carlo simulation in the high-purity signal region are tabulated with their associated statistical and systematic uncertainties.

474 F Two-dimensional exclusion

A two-dimensional exclusion (i.e. an exclusion of λ_{WZ} values) is obtained by repeating the pro-475 cess used to obtain a single-point exclusion of $\kappa_W = -1$, $\kappa_Z = +1$ for each κ_W , κ_Z reweighting 476 generated for this analysis. This effectively treats each point as a separate signal model. The ex-477 clusion of a signal strength of 1 for each point is then plotted on the z-axis of a two-dimensional 478 (κ_W, κ_Z) histogram (Fig. 38). However, Combine did not scan enough signal strength values 479 for a small number of points, so the exclusion was instead inferred by fitting the tail of the log-480 likelihood plot (Fig. 39, 40). In order to obtain the final result, the two-dimensional histogram 481 of actual and inferred exclusions is interpolated such that a smooth exclusion contour can be 482 drawn. Moreover, certain reweightings failed to correctly modify the signal acceptance, lead-483 ing to discontinuities in the otherwise smoothly-varying histogram of r = 1 exclusions. These 484 discontinuities, however, do not affect any of the exclusion contours and are anyway smoothed 485 out by the interpolation. 486



Figure 38: A two-dimensional histogram is plotted where the z-axis corresponds to the exclusion $\sigma = \sqrt{-2\Delta \log L}$ of a signal strength of 1 computed by Combine. The bins are centered on the κ_W , κ_Z plots scanned for this analysis.



Figure 39: The single-point exclusion of $\kappa_W = -1$, $\kappa_Z = +1$ is plotted on the left as an example of an exclusion that can be taken directly from Combine. The exclusion of $\kappa_W = 1.1$, $\kappa_Z = -2.0$ is plotted on the right as an example of where the r = 1 exclusion must be inferred from the exclusions computed by Combine.



Figure 40: A two-dimensional histogram is plotted where the z-axis corresponds to the exclusion $\sigma = \sqrt{-2\Delta \log L}$ of a signal strength of 1 computed by Combine. The bins are centered on the κ_W , κ_Z plots scanned for this analysis. Red stars are plotted for κ_W , κ_Z points where the exclusion was inferred from the exclusions computed by Combine, while black x's are plotted for κ_W , κ_Z points are taken directly from Combine.