

*All hadronic final  
states VVH events  
study — — different  
 $C_{2v}$  points*

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## *Selections on Skimming*



- *0 lepton*
- *At least one fatjet*
- *If the event has 1 or 2 fatjets, at least one  $UB\bar{F}$  method pair should pass the requirement( $mass > 500 GeV$ ,  $|\Delta\eta| > 3.0$ )*
- *If the event has  $\geq 3$  fatjets, at least have one more jet*



# Cut flow for signal( $C_{2V}=3$ )



cross section( $\text{fb}^{-1}$ )		SS WWH(5.19)	OS WWH(8.23)	WZH(5.37)	ZZH(4.24)
Total number of events after skim		254.291	365.81	288.356	271.433
Select Hbb at Gen level(only for signal)		161.220	231.07	182.931	172.859
Trigger		138.066	186.63	151.407	141.265
3+ fatjets	3+ fatjets	28.542	33.440	28.978	21.534
	2 + jets	23.822	28.207	22.666	17.828
	VBF cut 2	21.110	24.442	19.912	15.617
2 fatjets	2 fatjets	68.488	94.020	72.424	66.805
	4+ jets	38.945	53.073	39.738	33.875
	VBF cut 2	38.278	51.967	38.966	33.178
	3 jets	21.871	29.579	21.944	20.013
	VBF cut 2	21.297	28.888	21.441	19.488



# Cut flow for QCD bkg



cross section(fb <sup>-1</sup> )		HT 300-500	HT 500-700	HT 700-1000	HT 1000-1500
Total number of events after skim		47355570	2.0177333e+08	1.0993690e+08	26015168.
Trigger		44476.775	689928.69	24283753.	23596149.
3+ fatjets	3+ fatjets	717.367(1 event)	4474.574	202937.66	715935.05
	2 + jets	0	2617.204	116692.73	460335.68
	VBF cut 2	0	590.982	24347.511	100421.44
2 fatjets	2 fatjets	5021.571	58253.891	2236894.0	3392842.5
	4+ jets	4304.204(6 events)	23048.279	850731.72	1641452.5
	VBF cut 2	4304.204	21866.316	769960.95	1447474.9
	3 jets	717.367(1 event)	19502.390	745166.21	1037650.2
	VBF cut 2	717.367	18320.427	701211.89	960392.60



# Cut flow for QCD bkg

cross section( $\text{fb}^{-1}$ )		HT 1500-2000	HT 2000-Inf
Total number of events after skim		2666280.9	551198.67
Trigger		2666041.0	551198.67
3+ fatjets	3+ fatjets	214966.56	70337.745
	2 + jets	148967.36	49771.261
	VBF cut 2	35509.342	11918.907
2 fatjets	2 fatjets	534045.95	123978.50
	4+ jets	285481.86	67762.551
	VBF cut 2	248910.98	58741.123
	3 jets	152875.74	35131.745
	VBF cut 2	140263.79	31844.944

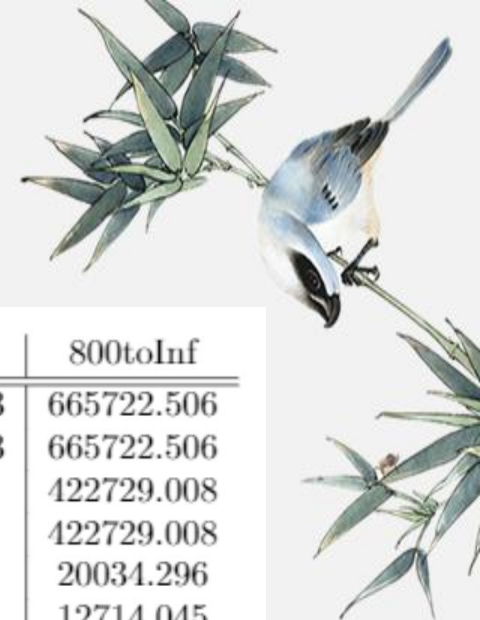
# Cut flow for TTbar bkg



cross section( $\text{fb}^{-1}$ )		TT to Semi-leptonic	TT to hadronic
Total number of events after skim		245958	1008181
Trigger		59922.600	245109.88
3+ fatjets	3+ fatjets	4218.119	30456.374
	2 + jets	3355.430	24661.906
	VBF cut 2	797.65605	5572.0422
2 fatjets	2 fatjets	13714.685	87674.264
	4+ jets	9268.740	61482.557
	VBF cut 2	8195.384	54430.385
	3 jets	3035.4567	18029.594
	VBF cut 2	2850.3149	17037.113



# Cut flow for WJets and ZJets bkg



Cut	200to400	400to600	600to800	800toInf
Total (weighted to 137fb-1)	13481.58	507752.594	775235.853	665722.506
Selected Hbb at Gen level	13481.58	507752.594	775235.853	665722.506
Trigger	266.243	901.957	18234.723	422729.008
0 lepton	266.243	901.957	18234.723	422729.008
3+ fatjets	0.0	4.081	316.202	20034.296
2+ jets	0.0	4.081	202.847	12714.045
VBF cut2	0.0	0.0	46.535	2603.98

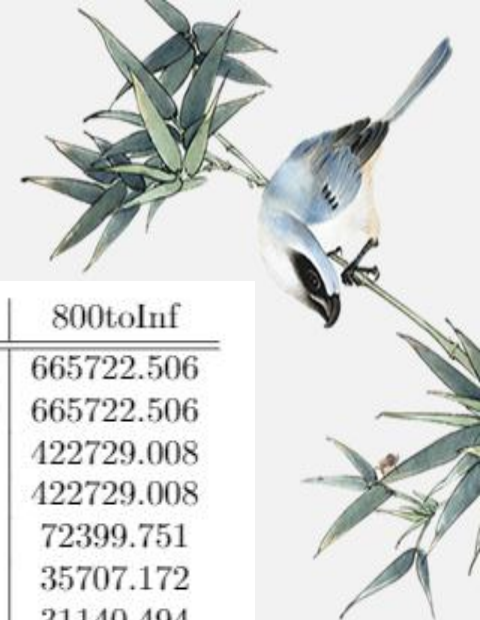
Table 1: WJetsToQQ\_HT

Cut	200to400	400to600	600to800	800toInf
Total (weighted to 137fb-1)	2.481	131314.156	284471.279	300505.839
Selected Hbb at Gen level	2.481	131314.156	284471.279	300505.839
Trigger	0.125	133.533	3492.092	169455.169
0 lepton	0.125	133.533	3492.092	169455.169
3+ fatjets	0.0	0.0	36.159	9399.727
2+ jets	0.0	0.0	21.117	5882.279
VBF cut2	0.0	0.0	2.603	1152.434

Table 2: ZJetsToQQ\_HT



# Cut flow for WJets and ZJets bkg



Cut	200to400	400to600	600to800	800toInf
Total (weighted to 137fb-1)	13481.58	507752.594	775235.853	665722.506
Selected Hbb at Gen level	13481.58	507752.594	775235.853	665722.506
Trigger	266.243	901.957	18234.723	422729.008
0 lepton	266.243	901.957	18234.723	422729.008
2+ fatjets	72.612	155.088	2336.316	72399.751
4+ jets	24.204	77.544	1098.952	35707.172
VBF cut2	24.204	61.219	979.63	31140.494

Table 3: WJetsToQQ\_HT

Cut	200to400	400to600	600to800	800toInf
Total (weighted to 137fb-1)	2.481	131314.156	284471.279	300505.839
Selected Hbb at Gen level	2.481	131314.156	284471.279	300505.839
Trigger	0.125	133.533	3492.092	169455.169
0 lepton	0.125	133.533	3492.092	169455.169
2+ fatjets	0.01	21.32	301.711	30910.125
4+ jets	0.01 3	14.588	131.908	15574.899
VBF cut2	0.01	12.343	116.287	13587.165

Table 4: ZJetsToQQ\_HT





# Cut flow for WJets and ZJets bkg



Cut	200to400	400to600	600to800	800toInf
Total (weighted to 137fb-1)	13481.58	507752.594	775235.853	665722.506
Selected Hbb at Gen level	13481.58	507752.594	775235.853	665722.506
Trigger	266.243	901.957	18234.723	422729.008
0 lepton	266.243	901.957	18234.723	422729.008
2+ fatjets	72.612	155.088	2336.316	72399.751
3+ jets	48.408	40.813	708.77	21898.133
VBF cut2	48.408	36.731	674.167	20135.475

Table 5: WJetsToQQ\_HT

Cut	200to400	400to600	600to800	800toInf
Total (weighted to 137fb-1)	2.481	131314.156	284471.279	300505.839
Selected Hbb at Gen level	2.481	131314.156	284471.279	300505.839
Trigger	0.125	133.533	3492.092	169455.169
0 lepton	0.125	133.533	3492.092	169455.169
2+ fatjets	0.01	21.32	301.711	30910.125
3+ jets	0.0	3.366	96.617	9334.478
VBF cut2	0.0	3.366	92.567	8596.14

Table 6: ZJetsToQQ\_HT





*Back up*



# Lepton Selection

- **Lepton loose Id selection (from ttH study)**

## Electron

loose Id electrons:

- Electron  $P_T > 7\text{GeV}$
- $|\eta_{\text{Electron}} + \text{Electron\_deltaEtaSC}| < 2.5$
- $|\text{Electron } d_{xy}| < 0.05$
- $|\text{Electron } d_z| < 0.1$
- $|\text{Electron sip3d}| < 8$
- $\text{Electron\_miniPFRelIso\_all} < 0.4$
- $\text{Electron\_miniPFRelIso\_all} \leq 1$
- $\text{Electron\_mvaFall17V2noIso\_WPL} = \text{true}$

## Muon

loose Id muons:

- Muon  $P_T > 5\text{GeV}$
- $|\eta_{\text{Muon}}| < 2.4$
- $|\text{Muon } d_{xy}| < 0.05$
- $|\text{Muon } d_z| < 0.1$
- $|\text{Muon sip3d}| < 8$
- $\text{Muon\_miniPFRelIso\_all} < 0.4$
- $\text{Muon\_looseId} = \text{true}$

- **We require the number of leptons passing these selections should be 0**

# Jet/Fatjet Selection

- **Fatjet selection**

- Fatjet  $P_T > 250\text{GeV}$
- Fatjet\_jetId  $> 0$
- $|\eta_{fatjet}| < 2.5$
- Fatjet\_msoftdrop  $> 40\text{GeV}$

- **Jet selection**

- Jet  $P_T > 25\text{GeV}$
- $|\eta_{jet}| < 4.7$
- $\Delta R(fatjet, jet) > 0.8$

# VBF Jet Selection methods



- **Method 1: max  $M_{jj}$** 
  - pick jet pairs with the largest  $M_{jj}$ , and their  $M_{jj} > 500\text{GeV}$
- **Method2: max  $\Delta\eta_{jj}$** 
  - pick jet pairs with the largest  $\Delta\eta_{jj}$
- **Method3: double side max energy**
  - pick jet1 with maximum energy
  - among the jets which have different  $\eta$  sign as jet1, pick max energy jet2
  - if there's no jets have different  $\eta$  sign with jet1, pick jet2 with the max  $\Delta\eta$  with jet 1

require  $M_{jj} > 500\text{GeV}$ ,  $\Delta\eta_{jj} > 3$

# Trigger reference

- Search for a massive scalar resonance decaying to a light scalar and a Higgs boson in the four b quark final state with boosted topology (Draft:11/29/2021)
- Using a logic “OR” for all these triggers

Hadronic	$\mathcal{L}_{eff}(\text{fb}^{-1})$	Semileptonic	$\mathcal{L}_{eff}(\text{fb}^{-1})$
2016			
PFHT800	27.71	IsoMu24	36.47
PFHT900	36.47	IsoTkMu24	36.47
PFHT650_WideJetMJJ900DEtaJJlp5	36.47	HLT_Ele27_WPTight_Gsf	36.47
AK8PFHT650_TrimR0p1PT0p03Mass50	20.20	HLT_Photon175	36.47
AK8PFHT700_TrimR0p1PT0p03Mass50	36.47		
AK8PFJet450	33.64		
AK8PFJet360_TrimMass30	36.47		
AK8DiPFJet280_200_TrimMass30	36.47		
AK8DiPFJet280_200_TrimMass30_BTagCSV_p20	36.47		
2017			
PFHT1050	41.54	IsoMu27	41.54
AK8PFHT800_TrimMass50	36.75	HLT_Ele35_WPTight_Gsf	41.54
PFJet320	41.54	HLT_Photon200	41.54
PFJet500	41.54		
AK8PFJet320	41.54		
AK8PFJet500	41.54		
AK8PFJet400_TrimMass30	36.75		
AK8PFJet420_TrimMass30	36.75		
2018			
PFHT1050	59.96	IsoMu24	59.96
AK8PFHT800_TrimMass50	59.96	HLT_Ele32_WPTight_Gsf	59.96
PFJet500	59.96	HLT_Photon200	59.96
AK8PFJet500	59.96		
AK8PFJet400_TrimMass30	59.96		
AK8PFJet420_TrimMass30	59.96		

# Cut flow for VVH( $C_{2V}=3$ ) before skim

cross section( $\text{fb}^{-1}$ )		SS WWH(5.19)	OS WWH(8.23)	WZH(5.37)	ZZH(4.24)
Total number of events weighted to $137 \text{ fb}^{-1}$		711.030	1127.51	735.690	580.880
Select Hbb at Gen level		409.180	648.176	422.728	334.450
Trigger		270.548	367.713	260.587	213.702
0 lepton		162.330	222.376	182.866	173.672
3+ fatjets	3+ fatjets	29.097	34.066	27.492	21.987
	2 + jets	23.822	28.207	22.666	17.863
		VBF cut 1	21.224	24.596	20.010
		VBF cut 2	21.110	24.442	19.912
		VBF cut 3	21.213	24.582	19.989
	1 jet	1 jet	4.720	5.235	4.315
	0 jet	0 jet	0.554	0.624	0.415
2 fatjets	2 fatjets	81.745	113.447	88.275	82.352
	4+ jets	41.123	56.766	42.495	36.058
		VBF cut 1	38.438	52.257	39.171
		VBF cut 2	38.287	51.985	38.970
		VBF cut 3	38.147	52.020	38.935
	3 jets	3 jets	25.584	34.967	25.955
		VBF cut 1	21.524	29.201	21.615
		VBF cut 2	21.301	28.896	21.446
		VBF cut 3	21.247	28.890	21.376

# Cut flow for VVH( $C_{2V}=3$ ) before skim

cross section( $\text{fb}^{-1}$ )		SS WWH(5.19)	OS WWH(8.23)	WZH(5.37)	ZZH(4.24)
2 fatjets	2 fatjets	81.745	113.447	88.275	82.352
	2 jets	12.278	17.846	15.612	17.389
	VBF cut 1	7.683	11.379	10.760	12.929
	VBF cut 2	7.671	11.366	10.745	12.920
	VBF cut 3	7.671	11.370	10.745	12.920
	<2 jets	2.760	3.869	4.213	5.229
1 fatjets	1 fatjets	5.473	66.163	58.910	60.805
	6+ jets	15.606	23.452	17.537	14.892
	VBF cut 1	14.265	21.333	15.946	13.539
	VBF cut 2	14.670	21.808	16.342	13.892
	VBF cut 3	14.148	21.180	15.772	13.404
	5 jets	13.363	19.496	15.097	13.674
	VBF cut 1	11.695	16.932	13.220	12.142
	VBF cut 2	12.179	17.605	13.681	12.409
	VBF cut 3	11.618	16.749	13.132	12.000
	4 jets	10.871	15.388	14.525	15.563
	VBF cut 1	8.780	12.301	12.059	13.384
	VBF cut 2	9.238	12.935	12.520	13.596
	VBF cut 3	8.741	12.258	12.045	13.295



# Cut flow for VVH( $C_{2v}=3$ ) before skim



cross section( $\text{fb}^{-1}$ )		SS WWH(5.19)	OS WWH(8.23)	WZH(5.37)	ZZH(4.24)
1 fatjets	1 fatjets	45.473	66.163	58.910	60.805
	3 jets	4.548	6.409	8.572	10.740
	VBF cut 1	3.103	4.351	6.480	8.324
	VBF cut 2	3.347	4.572	6.590	8.304
	VBF cut 3	3.094	4.326	6.394	8.202
	2 jets	0.983	1.287	2.753	4.823
	VBF cut 1	0.460	0.578	1.499	3.191
	VBF cut 2	0.458	0.573	1.499	3.185
	VBF cut 3	0.458	0.573	1.498	3.186
	<2 jets	0.102	0.130	0.425	1.113
none of the above		6.014	8.701	8.189	8.529

*\*none of the above means no fatjet, and after trigger, these events are greatly cut out*

