VBS VVH All-Hadronic Adding more backgrounds February 15th, 2023

P. Chang, L. Giannini, J. Guiang, Y. Xiang, E. Zenhom









Cut-based

	QCD	tī+jets	tī+1ℓ	tŦW	tīH	Single top	Bosons	TotalBkg	Eff.*	VBSVVH (C _{2V} = 2)	Eff.
Skim	136,950K	748K	85K	2.6K	1.3K	53K	1,512K	139,353K		175	
HLTs and MET filters	88,614K	574K	70K	2.2K	1.1K	41K	1,119K	90,423K	65%	168	96%
≥ 3 fat jets	686K	16K	2.2K	161	72	1.3K	20K	725K	1%	35	21%
Object selection	290K	10K	1.4K	92	49	739	8.1K	310K	43%	20	58%
M _{jj} > 500 GeV	87K	3.1K	443	24	14	263	2.3K	93K	30%	18	88%
Δη _{jj} > 3	81K	2.9K	413	22	13	246	2.1K	87K	94%	18	1009
H→bb̄ fat jet PNet Xbb > 0.9	4K	947	161	7	6	79	173	5.3K	6%	12	65%
V→qq fat jets PNet XVqq > 0.9	21	17	3	1	0	5	3	51	1%	4	39%
S _T > 1300 GeV	10	11	2	1	0	4	2	30	60%	4	95%
H→bb̄ fat jet PNet mass < 150	3	6	1	0	0	3	2	14	48%	4	98%
V→qq fat jets PNet mass < 120	0	2	0	0	0	1	1	4	30%	4	89%

• Not optimized



Yields scaled to lumi $\times \sigma$, rounded for readability





BDT: No ParticleNet features

	QCD	tī+jets	tī+1l	tŦW	tīH	Single top	Bosons	TotalBkg	Eff.*	VBSVVH (C $_{2V}$ = 2)	Eff.
Object selection	290K	10K	1.4K	92	49	739	8.1K	310K		20	
BDT Preselection	622	134	23	3	1	49	77	910	0%	9	43%

- First apply BDT preselection:
 - S_T > 1300 GeV AND H→bb̄ fat jet PNet Xbb > 0.5 AND V→qq fat jets PNet XVqq > 0.5 AND M_{SD}(H→bb̄ fat jet) < 150 GeV AND M_{SD}(V→qq fat jet) < 120 GeV
- Train BDT using XGBoost with the input features listed on the right
 - 40/60 test/train split
 - Hyperparameters listed in backup



Yields scaled to lumi $\times \sigma$, rounded for readability

Object	Features
H→bb̄ fat jet	 ParticleNet Xbb score p⊤ ParticleNet mass
V→qq fat jets	 ParticleNet XVqq score pT ParticleNet mass
Other	 MET N_{jets} (AK4)

i.e. BDT tightens S_T cut and mass windows







BDT: No ParticleNet features

- Performs worse than BDT trained with ParticleNet scores as input features (backup)
- Of course, still have three handles to optimize along with BDT cut:
 - H→bb PNet Xbb score
 - Leading (Id) V→qq PNet XVqq score
 - Trailing (tr) V→qq PNet XVqq score



Solastian	Signal (C ₂)	v = 2)	Total Backgro	ound
Selection	wgt.	raw	wgt.	ra
$M_{jj} > 500$ and $ \Delta \eta_{jj} > 3$	8.81	16190	285.52	270
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.80	5.89	10577	7.38	22
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.85	5.17	9252	5.30	15
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.86	4.06	7250	2.52	77
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.87	3.77	6695	1.87	66
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.88	3.44	6078	1.69	5
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.89	3.02	5313	1.29	37
$M_{jj} > 500$ and $ \Delta\eta_{jj} > 3$ and BDT > 0.90	2.61	4580	0.98	2







BDT: No ParticleNet features

	QCD	tī+jets	tī+1ℓ	tŦW	tīH	Single top	Bosons	TotalBkg	Eff.*	VBSVVH (C $_{2V}$ = 2)	Eff.
BDT Preselection	622	134	23	3	1	49	77	910		10	
$M_{jj} > 600 \text{ and } \Delta \eta_{jj} > 4$	145	26	5	0	0	13	17	208	23%	8	88%
BDT > 0.8 and $H \rightarrow b\bar{b}$ PNet Xbb > 0.9 and Id $V \rightarrow qq$ PNet XVqq > 0.6 and tr $V \rightarrow qq$ PNet XVqq > 0.7	0.00	0.21	0.09	-0.07	0.01	0.25	0.17	0.65	0%	4.49	53%
Raw yield:	0	3	2	18	11	2	32	68		8098	

- SR obtained from brute-force scan over cuts on BDT and ParticleNet scores
 - Used S/\sqrt{B} as figure of merit
- Selected SR above from top 15 with non-negative bkg and signal ≈ 4.5
 - Rounded cuts to nearest 0.X



Yields scaled to lumi $\times \sigma$, rounded for readability

	selection	sig	bkg	1
3910	bdt > 0.79 and hbbfatjet_score > 0.9 and ld_vq	4.526214	0.704336	5.393
3899	bdt > 0.79 and hbbfatjet_score > 0.9 and ld_vq	4.593207	0.739712	5.340
3580	bdt > 0.79 and hbbfatjet_score > 0.78 and ld_v	4.540158	0.748414	5.248
3878	bdt > 0.79 and hbbfatjet_score > 0.9 and ld_vq	4.573396	0.846456	4.970
3877	bdt > 0.79 and hbbfatjet_score > 0.9 and ld_vq	4.689965	0.890959	4.968
3338	bdt > 0.79 and hbbfatjet_score > 0.7 and ld_vq	4.624939	0.877442	4.937
5109	bdt > 0.8099999999999999 and hbbfatjet_score >	4.543640	0.847193	4.936
5208	bdt > 0.8099999999999999 and hbbfatjet_score >	4.517215	0.838593	4.932
3889	bdt > 0.79 and hbbfatjet_score > 0.9 and ld_vq	4.533466	0.846230	4.928
3888	bdt > 0.79 and hbbfatjet_score > 0.9 and ld_vq	4.647162	0.890733	4.923
3690	bdt > 0.79 and hbbfatjet_score > 0.8200000000	4.587557	0.869126	4.920
3789	bdt > 0.79 and hbbfatjet_score > 0.86 and ld_v	4.650946	0.899611	4.903
3459	bdt > 0.79 and hbbfatjet_score > 0.74 and ld_v	4.578963	0.875124	4.894
4306	bdt > 0.8099999999999999 and hbbfatjet_score >	4.548790	0.867414	4.884
3778	bdt > 0.79 and hbbfatjet_score > 0.86 and ld_v	4.721453	0.934987	4.882



- 2844
- 080
- 771
- 587
- 955
- 2817
- 427
- '384
- 8677
- 917
- 3075
- 535

- %

Summary

- Now have a more complete list of background MC
- A less-performant BDT can be trained without ParticleNet scores as input features
- Overall performance can be mostly rescued by manual cuts on ParticleNet scores
- Obtained preliminary SR with 4.5 signal vs 0.6 bkg.
- Next steps:
 - Start looking at control regions for QCD validation, check for missing bkgs, bkg estimation strategy, etc.





Backup





All-Hadronic VBS VVH

- Targeting the following final states:
 - WWH → qq qq qq bb
 - $ZZH \rightarrow qq qq qq b\bar{b}$
 - WZH → qq qq qq bb
- Sensitive to C_{2V} , C_3 , and C_V in principle
- BSM signature:
 - W/Z/H jets with large p⊤
 - VBS jets with large $\Delta \eta_{jj}$, M_{jj}





All-Hadronic VBS VVH

- One interesting N_{jets} vs. N_{fatjets} channel:
 - 3 AK8 fat jets, ≥ 2 AK4 jets (right)
 - 2 AK8 fat jets, \geq 4 AK4 jets
 - 2 AK8 fat jets, 3 AK4 jets
- Practically zero signal with N_{fatjets} > 3 (backup)
- From previous studies, N_{fatjets} == 1 channel not worthwhile pursuing right now







Analysis Skim

Cut	QCD	TTbarJets	TotalBkg	Eff.*	VBSVVH ($C_{2V} = 2$)	Eff.
Skim	136,95	0K 748K	137,698K		175	
	Object	Select	ion			
	Leptons (µ, e)	== 0 ve	eto*			
	Fat Jets	≥ 2 w/ p _T > AND η AND mass > AND M _{SD} > AND fat jet	300 GeV < 2.5 > 50 GeV 40 GeV t ID > 0			
	Jets	≥ 2 w/ p⊤ > AND passes f AND ΔR(jet, fa	20 GeV tight jet ID at jet) > 0.8			
	Other	≥ 1 pair of AK4 jets AND Δη	w/ M _{jj} > 500 C _{jj} > 3	GeV		
	L	*Using the ttH leptor	ו ID			

				110		
QCD		TTbarJets	TotalBkg	Eff.*	VBSVVH (C $_{2V}$ = 2)	Eff.
136,950)K	748K	137,698K		175	
Object		Selecti	on			
Leptons (µ, e)		== 0 ve	eto*			
Fat Jets		\geq 2 w/ p _T > 3 AND $ \eta <$ AND mass > AND M _{SD} > AND fat jet	300 GeV < 2.5 50 GeV 40 GeV ID > 0			
Jets		≥ 2 w/ p⊤ > AND passes t AND ∆R(jet, fa	20 GeV ight jet ID t jet) > 0.8			
Other	≥ 1 pa	ir of AK4 jets v AND Δη _j	v/ M _{jj} > 500 G j > 3	ieV		
	*Usina	the ttH lepton	ID			

Yields scaled to lumi $\times \sigma$, rounded for readability









*ParticleNet XWqq = mass-decorrelated, W-to-qq-like tagger **Used in Yanxi's analysis, but can easily be changed to sync with Yifan

Object	Selections
AK8 jets (same as skim)	• $p_T > 300 \text{ GeV}$ • Fat jet ID > 0 • $ \eta < 2.5$ • Mass > 50 GeV • M _{SD} > 40 GeV
H→bb̄ fat jet	 Has max(ParticleNet Xbb)
V→qq fat jets	 Leading in ParticleNet XVqq
AK4 jets (same as skim)	 p_T > 20 GeV Passes tight jet ID ΔR(AK4, AK8) > 0.8
VBS (AK4) jets	 p_T > 30 GeV For > 2 candidates**: Take pair with maximum Δ

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Nfatjets

- Plotting sum of all VBS VVH signals here
- Selections applied: skim, HLT triggers, • gen-level H, W, Z decay hadronically
- Practically 0 events with more than three fatjets













ParticleNet Taggers



Mass-correlated taggers more sharply peaked, but MD taggers may be sufficient





MET

0 250 500 750 1000 1250 1500

ld_vqqfatjet_msoftdrop









*From: <u>https://xgboost.readthedocs.io/en/stable/parameter.html</u>







= Background

Parameter	Value	Description*
objective	binary:logistic	Learning objective; 'binary:logistic specifies logistic regression for binary classification, output probability
eta	0.1	Step size shrinkage (alias: learning_rate)
<pre>max_depth</pre>	3	Max. depth of tree: larger = more complex = more prone to overfitti
verbosity	1	0 (silent), 1 (warning), 2 (info), 3 (debug)
nthread	8	Number of parallel threads
eval_metric	auc	Evaluation metrics for validation data. 'auc' = Area Under the Curv
subsample	0.6	Subsample ratio of the training instances
alpha	8.0	L1 regularization term on weights Larger = more conservative
gamma	2.0	Min. loss rediction to make leaf (alias: min_split_loss)
lambda	1.0	L2 regularization term on weights Larger = more conservative
<pre>min_child_weight</pre>	1.0	Minimum sum of instance weight (hessian) needed in a child
colsample_bytree	1.0	The subsample ratio of columns when constructing each tree
<pre>scale_pos_weight</pre>	92.6	Control the balance of positive an negative weights, useful for unbalanced classes







BDT: Using ParticleNet features

- Using ParticleNet discriminators as input features here only to see how much we lose in the current BDT
- Not much different!



Selection	Signal (C ₂	v = 2)	Total Background			
Selection	wgt.	raw	wgt.	ra		
$M_{jj} > 500$ and $ \Delta \eta_{jj} > 3$	8.81	16190	285.52	27		
$M_{jj} > 500$ and $ \Delta\eta_{jj} > 3$ and BDT > 0.80	6.95	12774	3.97	30		
$M_{jj} > 500$ and $ \Delta\eta_{jj} > 3$ and BDT > 0.85	6.43	11799	2.29	21		
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.86	5.62	10311	1.13	12		
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.87	5.38	9847	0.80	10		
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.88	5.11	9328	0.67	8		
M_{jj} > 500 and $ \Delta \eta_{jj} $ > 3 and BDT > 0.89	4.80	8744	0.66	6		
$M_{jj} > 500$ and $ \Delta\eta_{jj} > 3$ and BDT > 0.90	4.38	7986	0.51	4		







H_T-binned QCD Samples

- Ignoring the $H_T \in [50, 100)$ GeV sample due to low stats and irrelevant anyway
- Cross sections taken from AN-21-045
 - Measurement of the Higgs boson production via Vector Boson Fusion process with subsequent decay of the Higgs boson into a pair of bottom quarks



Table 3: List of simulated samples along with the rates used in this analysis, where [*] denotes the ultra legacy production campaign of the simulated samples, for 2016-APV, 2016-NonAPV and 2018.

Process	Sample	$\sigma \times BR$
$\text{VBFH} \rightarrow b\bar{b}$	- VBFHToBB_M-125_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	2.233
	VBFHToBB_M-125_dipoleRecoilOn_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	
	/VBFHToBB_M-125_TuneCH3_13TeV-powheg-herwig/[*]/MINIAODSIM	
ggH→bb	/GluGluHToBB_M-125_TuneCP5_13TeV-amcatnloFXFX-pythia8/[*]/MINIAODSIM	28.293
	/GluGluHToBB_M-125_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	
QCD multijet	QCD_HT100to200_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	2784988
in H_T bins	QCD_HT200to300_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	1716992
	QCD_HT300to500_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	351302
	QCD_HT500to700_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	31630
	QCD_HT700to1000_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	6802
	QCD_HT1000to1500_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	1206
	QCD_HT1500to2000_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	98.71
	QCD_HT2000toInf_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	20.2
$t\bar{t} + X$	TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	88.29
	TTToHadronic_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	377.96
	TTToSemiLeptonic_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	365.34
single top	ST_tW_antitop_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	34.91
	ST_tW_top_5f_inclusiveDecays_TuneCP5_13TeV-powheg-pythia8/[*]/MINIAODSIM	34.40
	ST_t-channel_antitop_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/[*]/MINIAODSIM	115.30
	ST_t-channel_top_4f_InclusiveDecays_TuneCP5_13TeV-powheg-madspin-pythia8/[*]/MINIAODSIM	69.09
QCD Z + jets	ZJetsToQQ_HT-200to400_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	973.70
	ZJetsToQQ_HT-400to600_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	110.78
	ZJetsToQQ_HT-600to800_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	25.34
	ZJetsToQQ_HT-800toInf_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	19.00
EWK Z + jets	EWKZ2Jets_ZToQQ_TuneCP5_13TeV-madgraph-pythia8/[*]/MINIAODSIM	9.92
QCD W + jets	WJetsToQQ_HT-200to400_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	2549.00
	WJetsToQ0_HT-400to600_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	276.50
	WJetsToQQ_HT-600to800_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	59.25
	WJetsToQQ_HT-800toInf_TuneCP5_13TeV-madgraphMLM-pythia8/[*]/MINIAODSIM	28.75







VBSVVH All-Hadronic Cutflow

	QCD		TTHad		TT1L		ттw		ттн		SingleTop		Bosons		TotalBkg		VBSVVH	
cut	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt
Bookkeeping	23348898	136950279.23	11563843	747778.20	1952781	85454.40	291342	2575.19	1457254	1341.29	801492	53422.41	18001906	1511762.55	57417516	139352613.28	323711	175.10
SaveSystWeights	23348898	136950279.23	11563843	747778.20	1952781	85454.40	291342	2575.19	1457254	1341.29	801492	53422.41	18001906	1511762.55	57417516	139352613.28	323711	175.10
PassesEventFilters	23228634	136757063.13	11539080	746223.20	1946259	85173.90	290178	2567.40	1452921	1337.48	799328	53267.65	17946508	1507856.05	57202908	139153488.81	320310	173.29
PassesTriggers	19971141	88614027.81	8948283	574450.50	1610549	70170.19	261105	2236.61	1270751	1142.25	620348	41242.43	15012150	1119345.31	47694327	90422615.10	314509	168.28
SelectLeptons	19971141	88614027.81	8948283	574450.50	1610549	70170.19	261105	2236.61	1270751	1142.25	620348	41242.43	15012150	1119345.31	47694327	90422615.10	314509	168.28
NoLeptons	19971141	88614027.81	8948283	574450.50	1610549	70170.19	261105	2236.61	1270751	1142.25	620348	41242.43	15012150	1119345.31	47694327	90422615.10	314509	168.28
SelectFatJets	19971141	88614027.81	8948283	574450.50	1610549	70170.19	261105	2236.61	1270751	1142.25	620348	41242.43	15012150	1119345.31	47694327	90422615.10	314509	168.28
Geq3FatJets	718294	685582.18	235834	15550.80	49625	2210.40	26622	161.33	78364	72.16	14486	1303.98	319735	19841.44	1442960	724722.28	64241	34.92
AllMerged_SelectVVHFatJets	718294	685582.18	235834	15550.80	49625	2210.40	26622	161.33	78364	72.16	14486	1303.98	319735	19841.44	1442960	724722.28	64241	34.92
AllMerged_SelectJets	718294	685582.18	235834	15550.80	49625	2210.40	26622	161.33	78364	72.16	14486	1303.98	319735	19841.44	1442960	724722.28	64241	34.92
AllMerged_SelectVBSJets	354860	289619.58	157671	10370.18	32308	1433.83	17994	92.02	52245	49.44	8539	738.60	132246	8061.11	755863	310364.76	37317	20.27
AllMerged_SaveVariables	354860	289619.58	157671	10370.18	32308	1433.83	17994	92.02	52245	49.44	8539	738.60	132246	8061.11	755863	310364.76	37317	20.27
AllMerged_MjjGt500	116156	86612.96	47891	3104.37	10145	442.64	4324	23.66	15218	14.27	3126	262.57	37628	2301.81	234488	92762.29	32917	17.86
AllMerged_detajjGt3	103727	81288.26	44880	2907.33	9469	412.90	4072	21.87	14339	13.42	2927	245.85	34479	2111.98	213893	87001.61	32788	17.80
AllMerged_XbbGt0p9	5229	3974.41	14644	947.29	3694	160.88	1447	6.60	7854	6.09	884	79.33	4205	173.23	37957	5347.83	21783	11.53
AllMerged_XVqqGt0p9	23	20.97	268	17.25	65	2.95	213	0.97	611	0.39	39	5.25	212	2.73	1431	50.50	8570	4.49
AllMerged_STGt1300	18	9.86	172	11.01	42	1.94	144	0.80	411	0.25	30	4.08	155	2.21	972	30.14	8108	4.25
AllMerged_HbbMSDLt150	9	2.68	88	5.51	29	1.34	86	0.44	317	0.18	18	2.68	139	1.63	686	14.46	7963	4.18
AllMerged_VqqMSDLt120	1	0.20	29	1.84	8	0.38	36	0.07	50	0.03	6	0.90	95	0.85	225	4.28	6929	3.72

	QCD		TTHad		TT1L		TTW		ттн		SingleTop		Bosons		TotalBkg		VBSVVH	
cut	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	wgt	raw	W
bdt_presel	925	622.25	2033	134.14	520	22.82	987	3.01	1263	1.08	388	49.15	3375	77.21	9491	909.65	17849	9.
M_jj_gt_600_and_abs(deta_jj)_gt_4	210	145.43	402	26.10	113	4.96	156	0.43	246	0.20	107	13.32	651	17.18	1885	207.63	15602	8.
SR	0	0.00	3	0.21	2	0.09	18	-0.07	11	0.01	2	0.25	32	0.17	68	0.65	8098	4.

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75.10 3.29 8.28 8.28 8.28 8.28 1.92 4.92 1.92).27).27 7.86 7.80 1.53 .49 .25 .18 .72



VBSVVH All-Hadronic Triggers

Year	HLT paths
2016	HLT_PFHT800 HLT_PFHT900 HLT_AK8PFHT650_TrimR0p1PT0p03Mass50 HLT_AK8PFHT700_TrimR0p1PT0p03Mass50 HLT_AK8PFJet450 HLT_AK8PFJet360_TrimMass30 HLT_AK8DiPFJet280_200_TrimMass30 HLT_AK8DiPFJet280_200_TrimMass30_BTagCSV_p20
2017	HLT_PFHT1050 HLT_AK8PFHT800_TrimMass50 HLT_PFJet320 HLT_PFJet500 HLT_AK8PFJet320 HLT_AK8PFJet500 HLT_AK8PFJet400_TrimMass30 HLT_AK8PFJet420_TrimMass30
2018	HLT_PFHT1050 HLT_AK8PFHT800_TrimMass50 HLT_PFJet500 HLT_AK8PFJet500 HLT_AK8PFJet400_TrimMass30 HLT_AK8PFJet420_TrimMass30

