VBS WH Analysis

Issues with the EWK W/Z samples

September 7th, 2022

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Overview

- New EWK samples add *a lot* of background
  - Entirely from EWK $W^{\pm}$ ($W \to \ell \nu$)
  - Not just VBS W/Z: also have diboson events
- **Goal:** check at the gen level how these EWK $W^{\pm}$ ($W \to \ell \nu$) samples are entering our analysis in the first place
  - Samples used listed in backup

Sample	σ [pb]
EWK W^{+}, $W \to \ell \nu$	39.33
EWK W^{+}, $W \to qq$	10.67
EWK W^{-}, $W \to \ell \nu$	32.26
EWK W^{-}, $W \to qq$	10.67
EWK Z, $Z \to \ell \ell$	6.22
EWK Z, $Z \to \nu \nu$	10.72
EWK Z, $Z \to qq$	10.67

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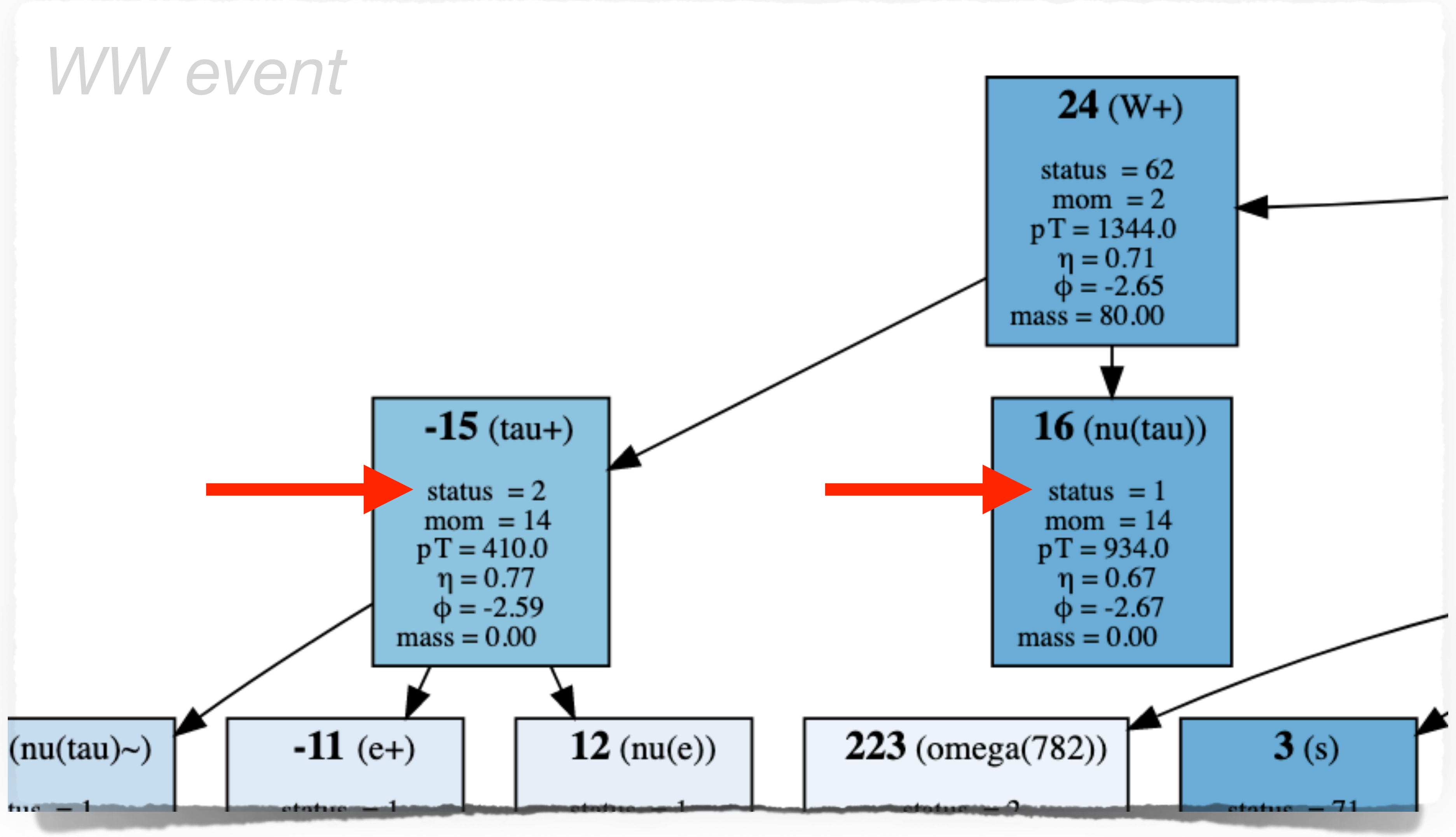
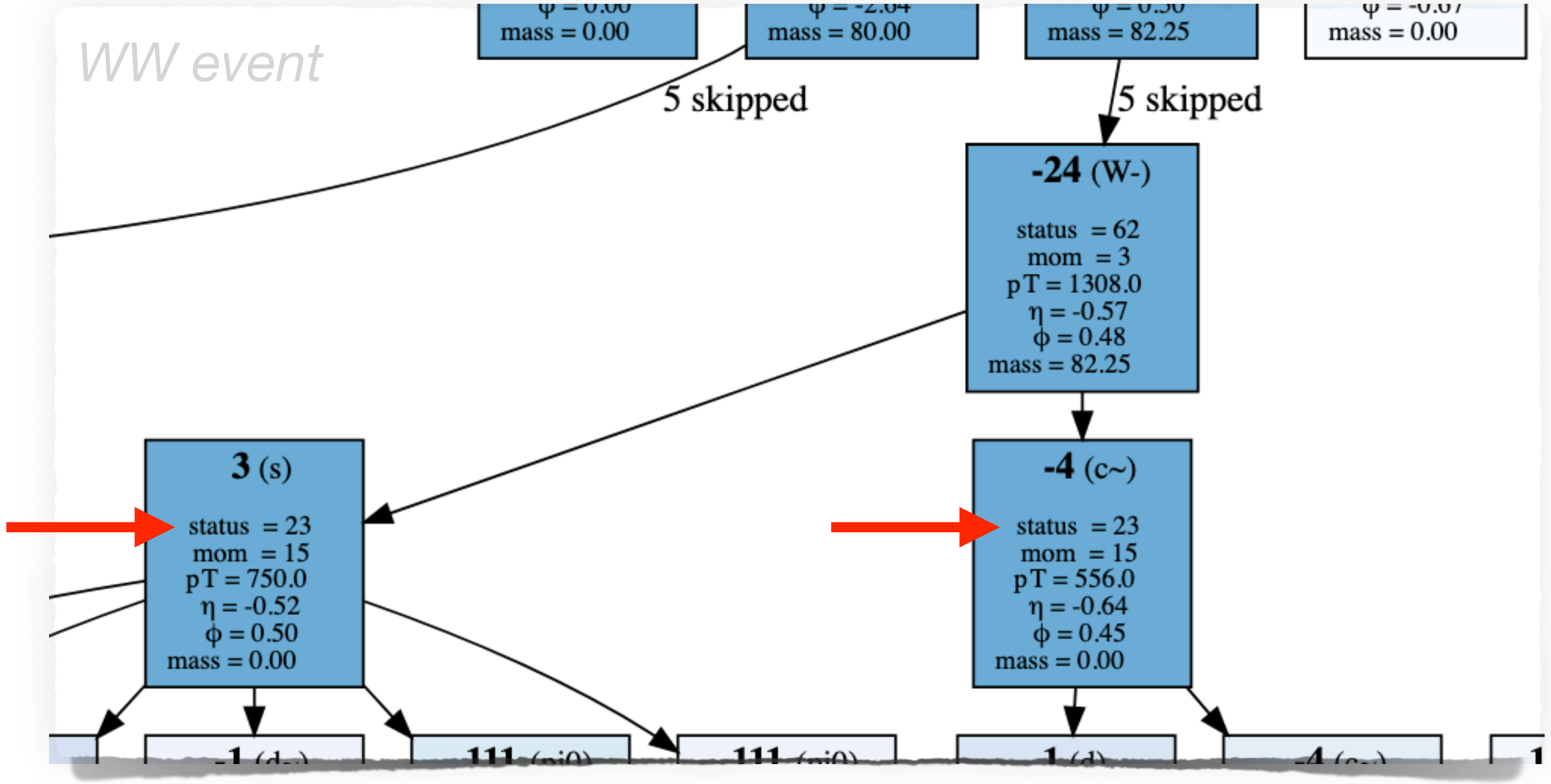
Strategy

- **Only consider** EWK WPlus/Minus WToLNu Samples
- Loop over "GenPart" record in NanoAOD
- For quarks:
  - Require status == 23
  - Mother == W boson ⇒ WW event
  - Mother idx == 0 or 1 ⇒ VBS event
- For leptons (e, μ, τ):
  - Require status ∈ {1, 2, 23}
  - Require mother == W boson





Strategy

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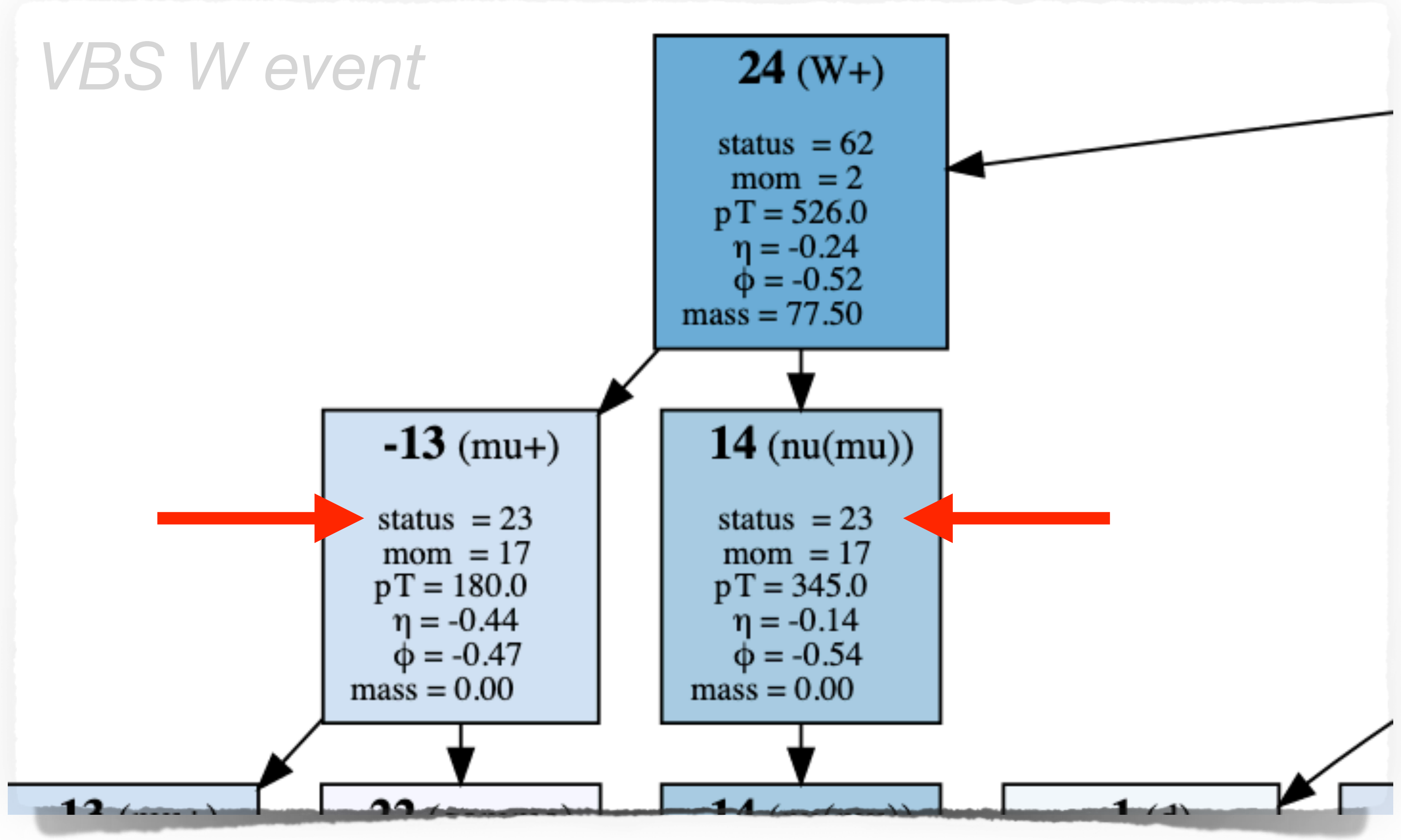
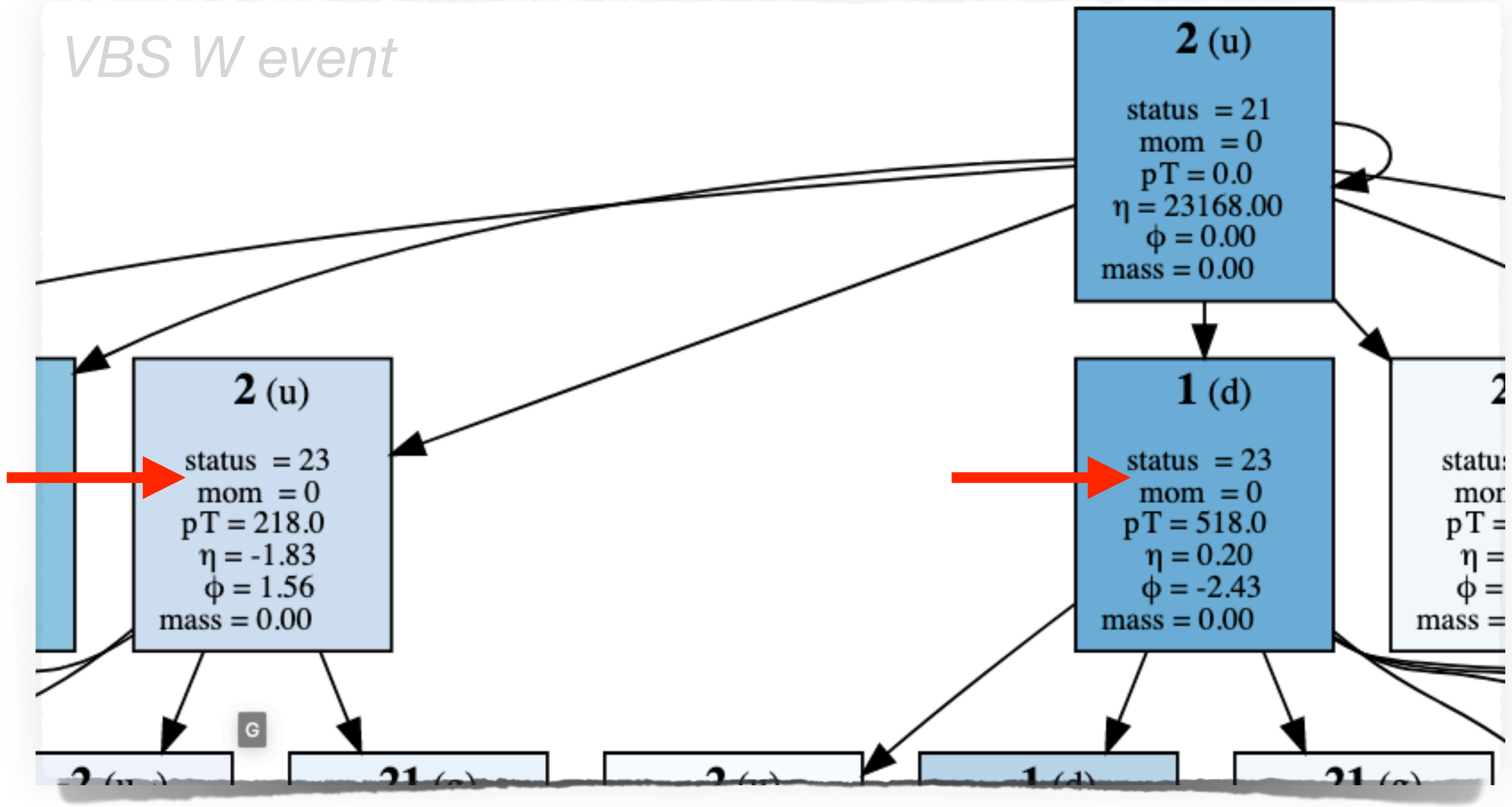




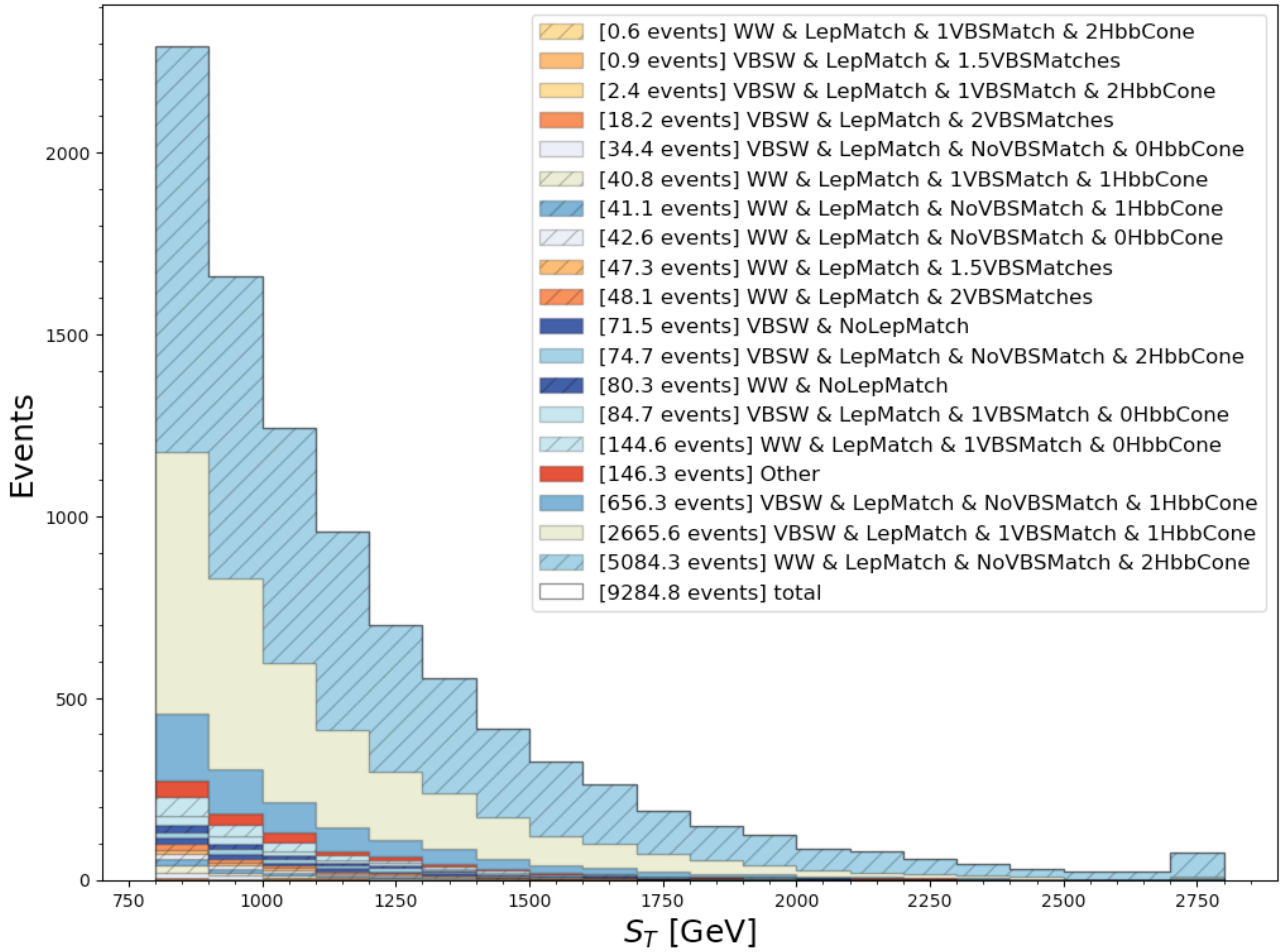
Strategy

- Try to match selected gen. quarks to reco jets:
  - VBS matching: $dR(q_{gen}, q_{reco}) < 0.4$
    - If the 2 gen. quarks match to ***unique*** VBS jets: 2 matches
    - If the 2 gen. quarks match to the ***same*** VBS jet: “1.5” matches
    - If only 1 gen. quark matches to ***one*** VBS jet: 1 match
    - ***Otherwise***: 0 matches
  - Hbb matching: $dR(q_{gen}, q_{reco}) < 0.8$
    - Count number of gen. quarks in Hbb fatjet cone
- Try to match gen. lepton to reco lepton: $dR(\ell_{gen}, \ell_{reco}) < 0.4$

EWK W Contribution Breakdown

Label	Yield
VBSW & NoLepMatch	71.5
WW & NoLepMatch	80.3
VBSW & LepMatch & NoVBSMatch & 0HbbCone	34.4
WW & LepMatch & NoVBSMatch & 0HbbCone	42.6
VBSW & LepMatch & NoVBSMatch & 1HbbCone	656.3
WW & LepMatch & NoVBSMatch & 1HbbCone	41.1
VBSW & LepMatch & NoVBSMatch & 2HbbCone	74.7
WW & LepMatch & NoVBSMatch & 2HbbCone	5084.3
VBSW & LepMatch & 1VBSMatch & 0HbbCone	84.7
WW & LepMatch & 1VBSMatch & 0HbbCone	144.6
VBSW & LepMatch & 1VBSMatch & 1HbbCone*	2665.6
WW & LepMatch & 1VBSMatch & 1HbbCone	40.8
VBSW & LepMatch & 1VBSMatch & 2HbbCone	2.4
WW & LepMatch & 1VBSMatch & 2HbbCone	0.6
VBSW & LepMatch & 1.5VBSMatches	0.9
WW & LepMatch & 1.5VBSMatches	47.3
VBSW & LepMatch & 2VBSMatches	18.2
WW & LepMatch & 2VBSMatches	48.1
Other	146.3
Total	9284.8

Object selection

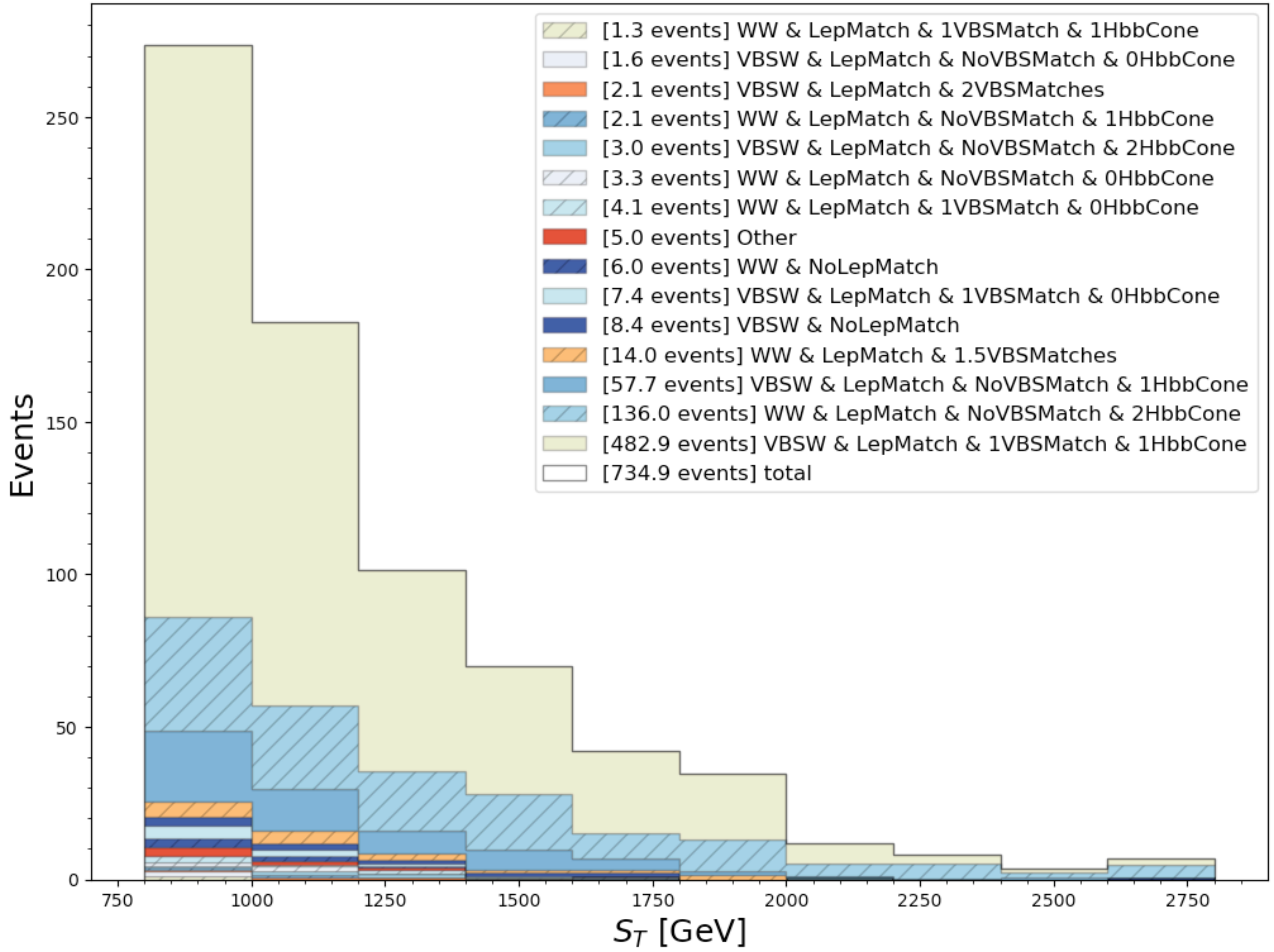


*At this point, there are *some* (43 raw events) occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

EWK W Contribution Breakdown

Label	Yield
VBSW & NoLepMatch	8.4
WW & NoLepMatch	6.0
VBSW & LepMatch & NoVBSMatch & 0HbbCone	1.6
WW & LepMatch & NoVBSMatch & 0HbbCone	3.3
VBSW & LepMatch & NoVBSMatch & 1HbbCone	57.7
WW & LepMatch & NoVBSMatch & 1HbbCone	2.1
VBSW & LepMatch & NoVBSMatch & 2HbbCone	3.0
WW & LepMatch & NoVBSMatch & 2HbbCone	136.0
VBSW & LepMatch & 1VBSMatch & 0HbbCone	7.4
WW & LepMatch & 1VBSMatch & 0HbbCone	4.1
VBSW & LepMatch & 1VBSMatch & 1HbbCone*	482.9
WW & LepMatch & 1VBSMatch & 1HbbCone	1.3
VBSW & LepMatch & 1VBSMatch & 2HbbCone	0.0
WW & LepMatch & 1VBSMatch & 2HbbCone	0.0
VBSW & LepMatch & 1.5VBSMatches	0.0
WW & LepMatch & 1.5VBSMatches	14.0
VBSW & LepMatch & 2VBSMatches	2.1
WW & LepMatch & 2VBSMatches	0.0
Other	5.0
Total	734.9

Object selection AND Preselection (no $\Delta\eta_{jj}$ cut)

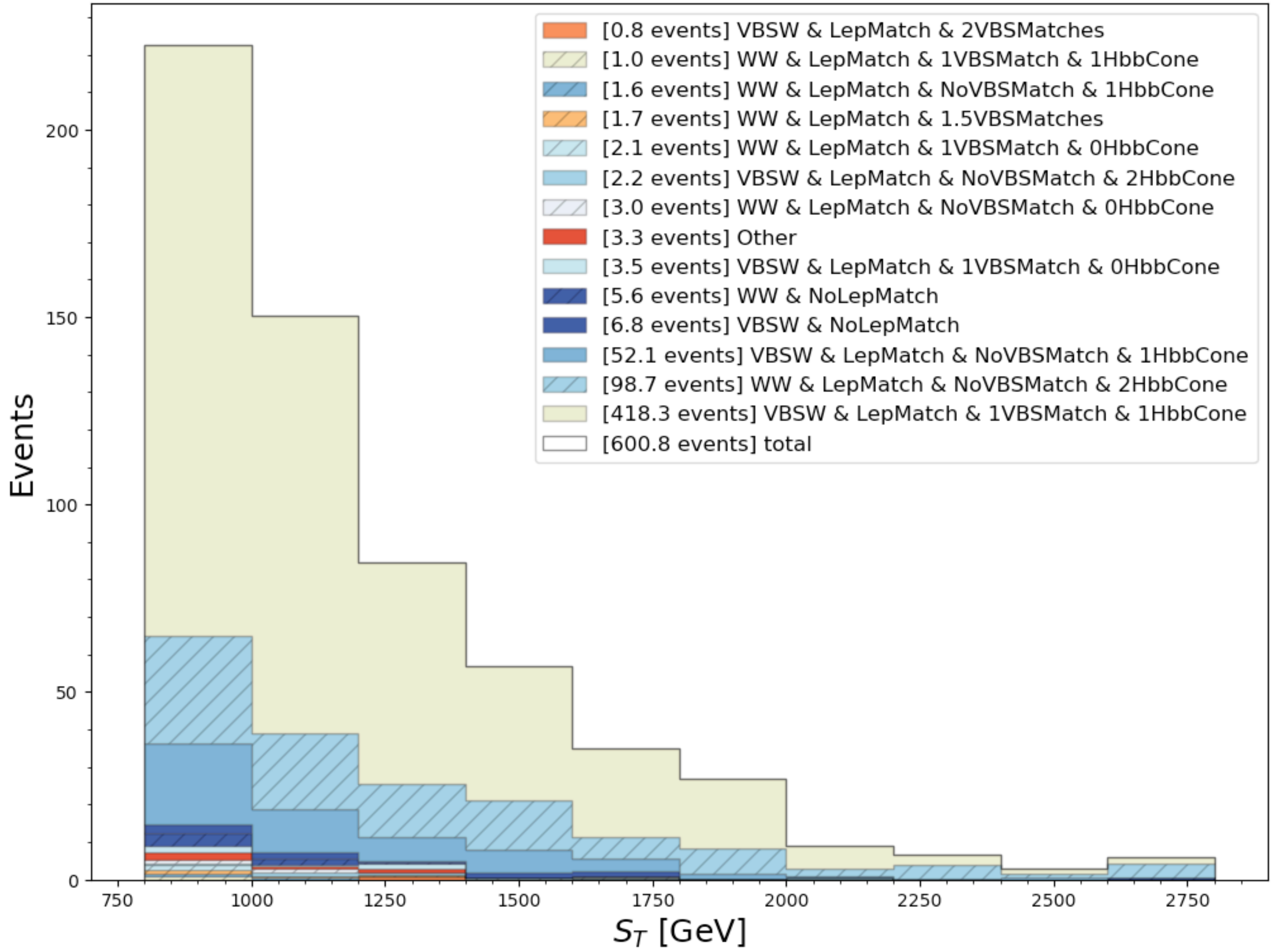


*At this point, there are *some* (6 raw events) occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

EWK W Contribution Breakdown

Label	Yield
VBSW & NoLepMatch	6.8
WW & NoLepMatch	5.6
VBSW & LepMatch & NoVBSMatch & 0HbbCone	0.0
WW & LepMatch & NoVBSMatch & 0HbbCone	3.0
VBSW & LepMatch & NoVBSMatch & 1HbbCone	52.1
WW & LepMatch & NoVBSMatch & 1HbbCone	1.6
VBSW & LepMatch & NoVBSMatch & 2HbbCone	2.2
WW & LepMatch & NoVBSMatch & 2HbbCone	98.7
VBSW & LepMatch & 1VBSMatch & 0HbbCone	3.5
WW & LepMatch & 1VBSMatch & 0HbbCone	2.1
VBSW & LepMatch & 1VBSMatch & 1HbbCone*	418.3
WW & LepMatch & 1VBSMatch & 1HbbCone	1.0
VBSW & LepMatch & 1VBSMatch & 2HbbCone	0.0
WW & LepMatch & 1VBSMatch & 2HbbCone	0.0
VBSW & LepMatch & 1.5VBSMatches	0.0
WW & LepMatch & 1.5VBSMatches	1.7
VBSW & LepMatch & 2VBSMatches	0.8
WW & LepMatch & 2VBSMatches	0.0
Other	3.3
Total	600.8

Object selection AND Preselection AND $|\Delta\eta_{jj}| > 4$

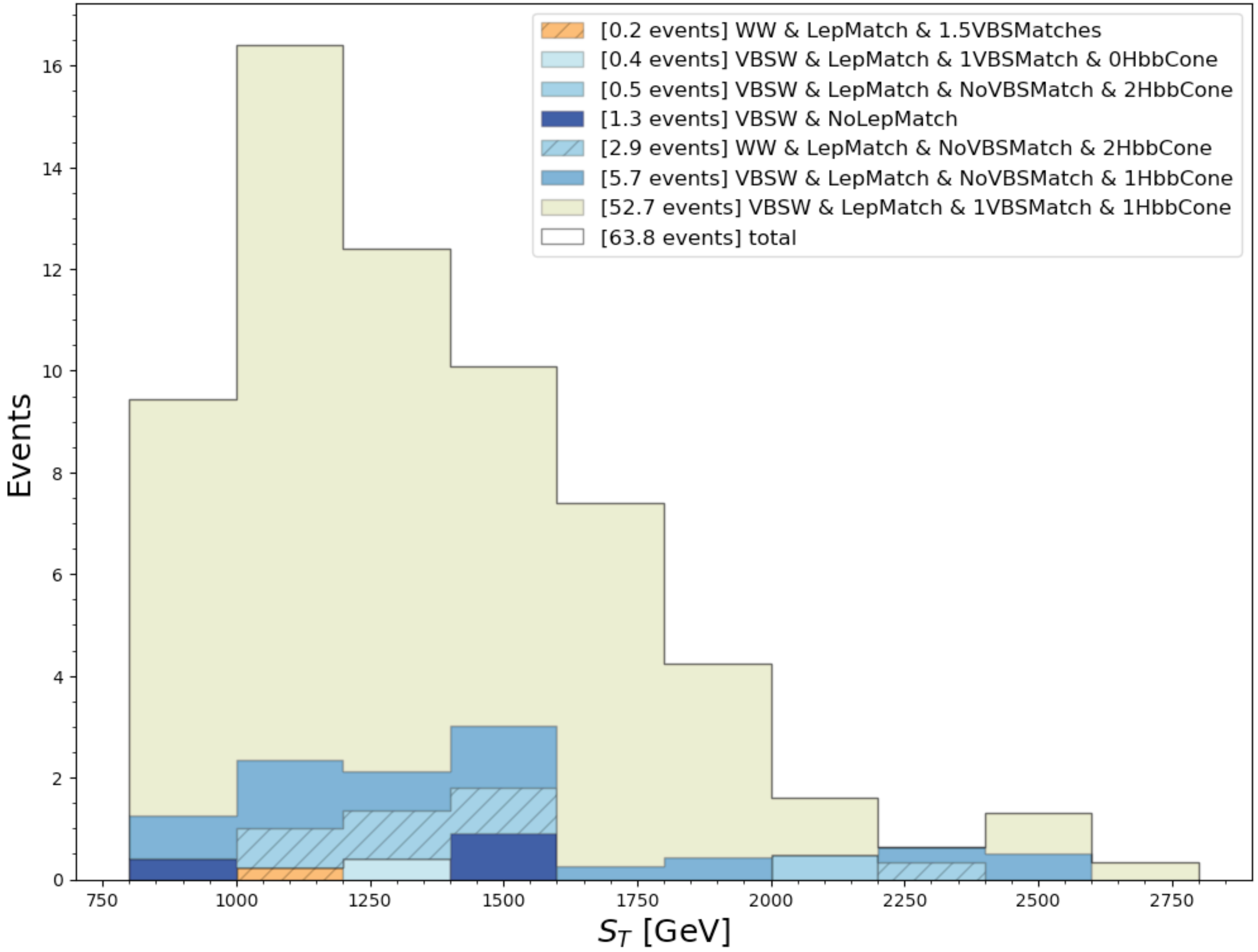


*At this point, there are *some* (1 raw event) occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

EWK W Contribution Breakdown

Label	Yield
VBSW & NoLepMatch	1.3
WW & NoLepMatch	0.0
VBSW & LepMatch & NoVBSMatch & 0HbbCone	0.0
WW & LepMatch & NoVBSMatch & 0HbbCone	0.0
VBSW & LepMatch & NoVBSMatch & 1HbbCone	5.7
WW & LepMatch & NoVBSMatch & 1HbbCone	0.0
VBSW & LepMatch & NoVBSMatch & 2HbbCone	0.5
WW & LepMatch & NoVBSMatch & 2HbbCone	2.9
VBSW & LepMatch & 1VBSMatch & 0HbbCone	0.4
WW & LepMatch & 1VBSMatch & 0HbbCone	0.0
VBSW & LepMatch & 1VBSMatch & 1HbbCone*	52.7
WW & LepMatch & 1VBSMatch & 1HbbCone	0.0
VBSW & LepMatch & 1VBSMatch & 2HbbCone	0.0
WW & LepMatch & 1VBSMatch & 2HbbCone	0.0
VBSW & LepMatch & 1.5VBSMatches	0.0
WW & LepMatch & 1.5VBSMatches	0.2
VBSW & LepMatch & 2VBSMatches	0.0
WW & LepMatch & 2VBSMatches	0.0
Other	0.0
Total	63.8

SR1 ABCD - Region A (in M_{SD} sideband)



*At this point, there are *zero* occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

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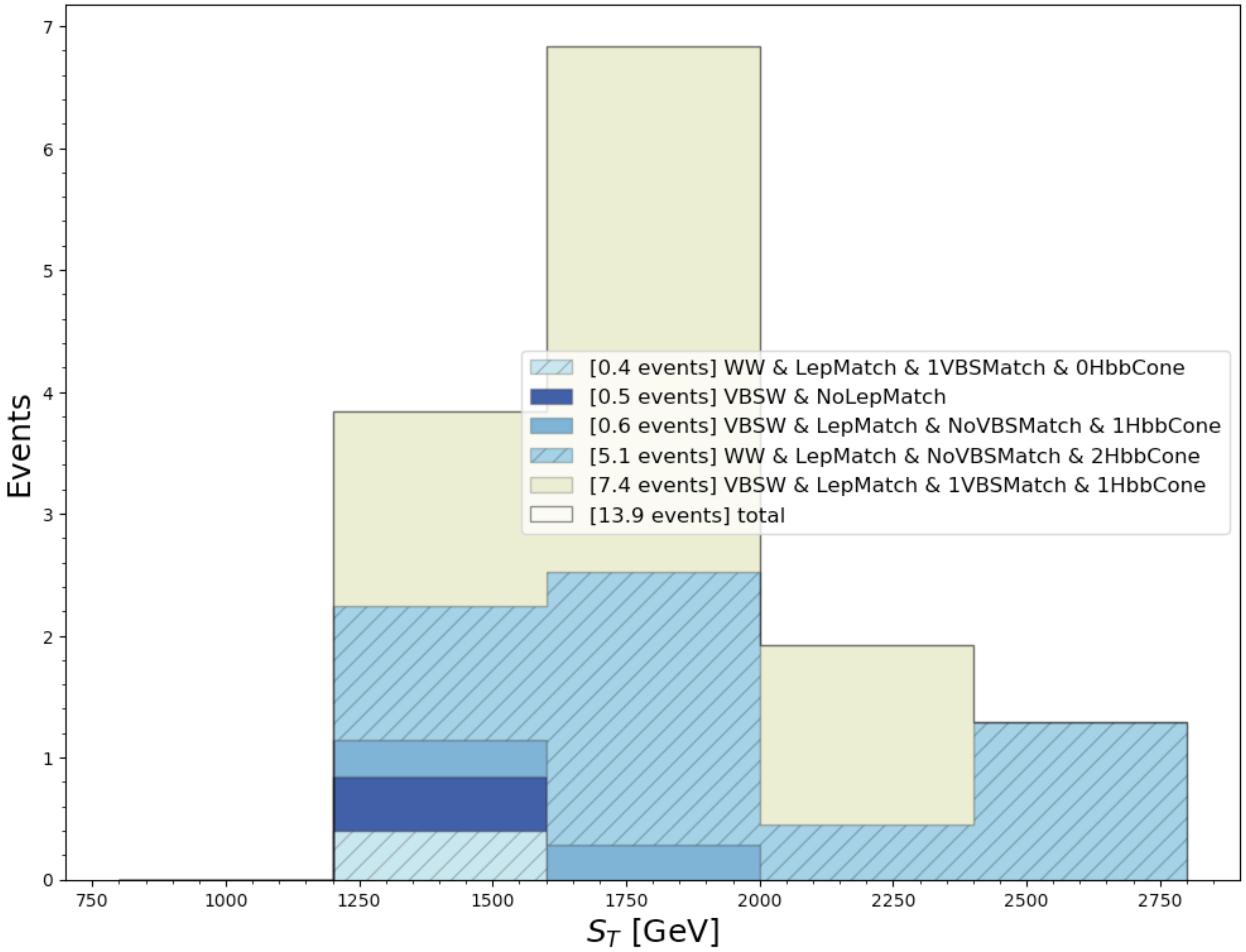
EWK W Contribution Breakdown

Label	Yield
VBSW & NoLepMatch	0.5
WW & NoLepMatch	0.0
VBSW & LepMatch & NoVBSMatch & 0HbbCone	0.0
WW & LepMatch & NoVBSMatch & 0HbbCone	0.0
VBSW & LepMatch & NoVBSMatch & 1HbbCone	0.6
WW & LepMatch & NoVBSMatch & 1HbbCone	0.0
VBSW & LepMatch & NoVBSMatch & 2HbbCone	0.0
WW & LepMatch & NoVBSMatch & 2HbbCone	5.1
VBSW & LepMatch & 1VBSMatch & 0HbbCone	0.0
WW & LepMatch & 1VBSMatch & 0HbbCone	0.4
VBSW & LepMatch & 1VBSMatch & 1HbbCone*	7.4
WW & LepMatch & 1VBSMatch & 1HbbCone	0.0
VBSW & LepMatch & 1VBSMatch & 2HbbCone	0.0
WW & LepMatch & 1VBSMatch & 2HbbCone	0.0
VBSW & LepMatch & 1.5VBSMatches	0.0
WW & LepMatch & 1.5VBSMatches	0.0
VBSW & LepMatch & 2VBSMatches	0.0
WW & LepMatch & 2VBSMatches	0.0
Other	0.0
Total	13.9

SR2



*At this point, there are *zero* occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

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Conclusions

- After some preselection (M_{jj} > 500 GeV, Xbb score > 0.3, b-jet veto), EWK W contribution mostly composed of VBS W events where
  - Prompt lepton is tagged
  - 1 VBS jet is tagged
  - 1 VBS jet is in the Hbb fatjet cone
- Around 35% of EWK W bkg in SR2 is from WW events where W→qq is within the Hbb fatjet cone

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Backup

*Professor
†Post-doc
‡Graduate Student
§Undergraduate Student

Who is involved?

- UC San Diego:
  A. Arora‡, P. Chang†, L. Giannini†, J. Guiang‡, F. Würthwein*, Y. Xiang‡, A. Yagil*

- U. Nebraska:
  F. Golf*

- Boston University:
  D. Spitzbart†, I. Suarez*

- UC Santa Barbara:
  C. Campagnari*

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University of Nebraska Lincoln

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BSM Signal Models

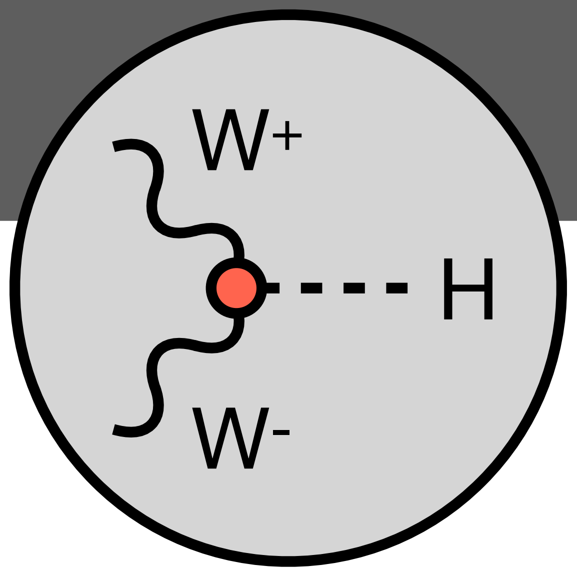
$\kappa_W = -1$

models/sm/couplings.py

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

models/sm/vertices.py

```
V_52 = Vertex(name = 'V_52',
              particles = [ P.W__minus__, P.W__plus__, P.H ],
              color = [ '1' ],
              lorentz = [ L.VVS1 ],
              couplings = {(0,0):C.GC_72})
```



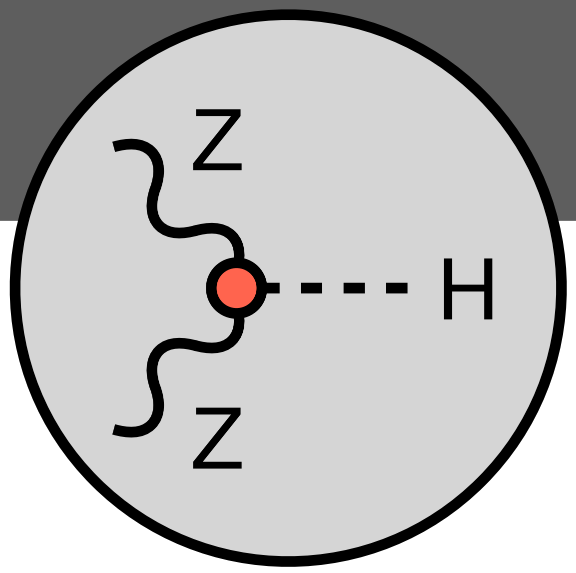
$\kappa_Z = -1$

models/sm/couplings.py

```
GC_81 = Coupling(name = 'GC_81',
                 value = 'ee**2*complex(0,1)*vev + …',
                 value = '-(ee**2*complex(0,1)*vev + … )',
                 order = {'QED':1})
```

models/sm/vertices.py

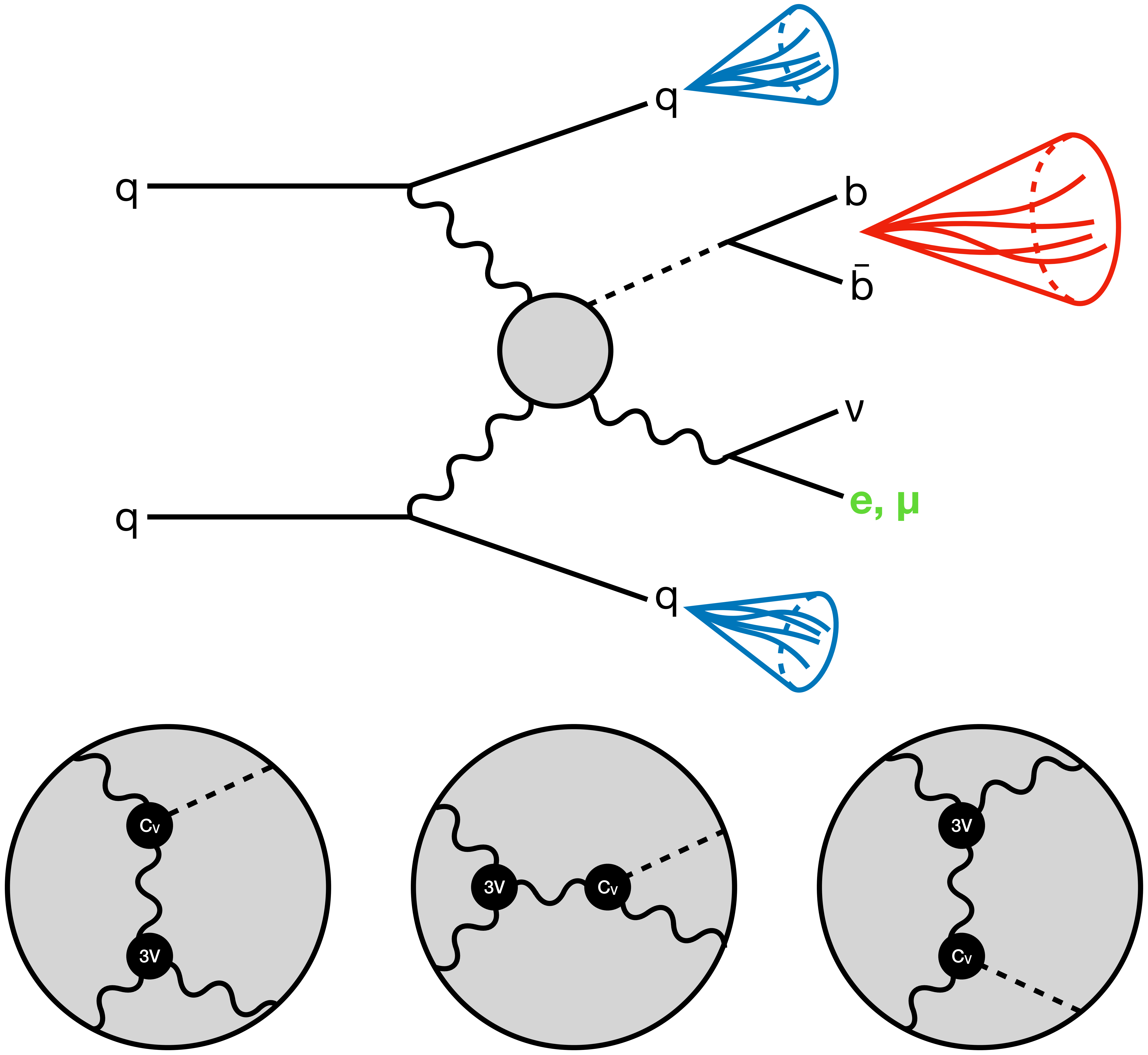
```
V_69 = Vertex(name = 'V_69',
              particles = [ P.Z, P.Z, P.H ],
              color = [ '1' ],
              lorentz = [ L.VVS1 ],
              couplings = {(0,0):C.GC_81})
```



Only changed one line in SM Madgraph model!

Target Final State

- Targeting **VBS** WH→$\ell\nu b\bar{b}$
- Sensitive to κ_V → $\lambda_{WZ} = \kappa_Z/\kappa_W$
  - Handle for ruling out λ_{WZ} = -1 (BSM)
- VBS WH BSM kinematics:
  - High-p_T H and W (high S_T)
  - VBS jets with large $\Delta\eta_{jj}$, M_{jj}



(a) (b) (c)

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EWK Samples Used

```
/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM

/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM

/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM

/EWKWPlus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM

/EWKWMinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL16NanoAODv9-106X_mcRun2_asymptotic_v17-v1/NANOAODSIM

/EWKWMinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL16NanoAODAPVv9-106X_mcRun2_asymptotic_preVFP_v11-v1/NANOAODSIM

/EWKWMinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL17NanoAODv9-106X_mc2017_realistic_v9-v2/NANOAODSIM

/EWKWMinus2Jets_WToLNu_M-50_TuneCP5_withDipoleRecoil_13TeV-madgraph-pythia8/
RunIISummer20UL18NanoAODv9-106X_upgrade2018_realistic_v16_L1v1-v2/NANOAODSIM
```

VBS WH Cross Sections

Model	σ [pb]
$\kappa_W = \kappa_Z = +1$ (SM)	0.075
$\kappa_W = -1$, $\kappa_Z = +1$	0.433
$\kappa_W = +1$, $\kappa_Z = -1$	0.433

×6

- Setting $\kappa_W = -1$ or $\kappa_Z = -1$ equivalently enhances cross section by a factor of 6
- These numbers are taken from MadGraph*: `generate p p > w h j j QCD=0`
  - Includes gen-level filters (e.g. jet $p_T > 10$ GeV)
  - Generated 10,000 events for each to obtain xsec value
- **Optimizing for $\kappa_W = -1$** (kinematics are equivalent to $\kappa_Z = -1$)
  - Generated 100k UL NanoAOD events for 2016 pre-VFP, 2016 post-VFP, 2017, and 2018

*More details in backup

Analysis Skim

Yields scaled to lumi×σ, rounded for readability

Cut	VH	VV/VVV/VBSWZ	W+Jets	SingleTop	TTbar+X	TTbar1L	TTbar2L	TotalBkg	Eff.*	VBSWH (λ_{WZ} = -1)	Eff.*
Skim	232	6.5K	122K	7.6K	1K	86K	10K	**233K**	—	**2K**	—

Object	Selection
Leptons (μ, e)	== 1 loose AND == 1 tight*
Fat Jets	≥ 1 w/ p_T > 250 GeV AND mass > 50 GeV AND M_{SD} > 40 GeV AND ΔR(fat jet, tight lepton) > 0.8
Jets	≥ 1 w/ p_T > 20 GeV AND ΔR(jet, any veto lepton) > 0.4
Other	S_T > 800 GeV

*Using the ttH lepton ID

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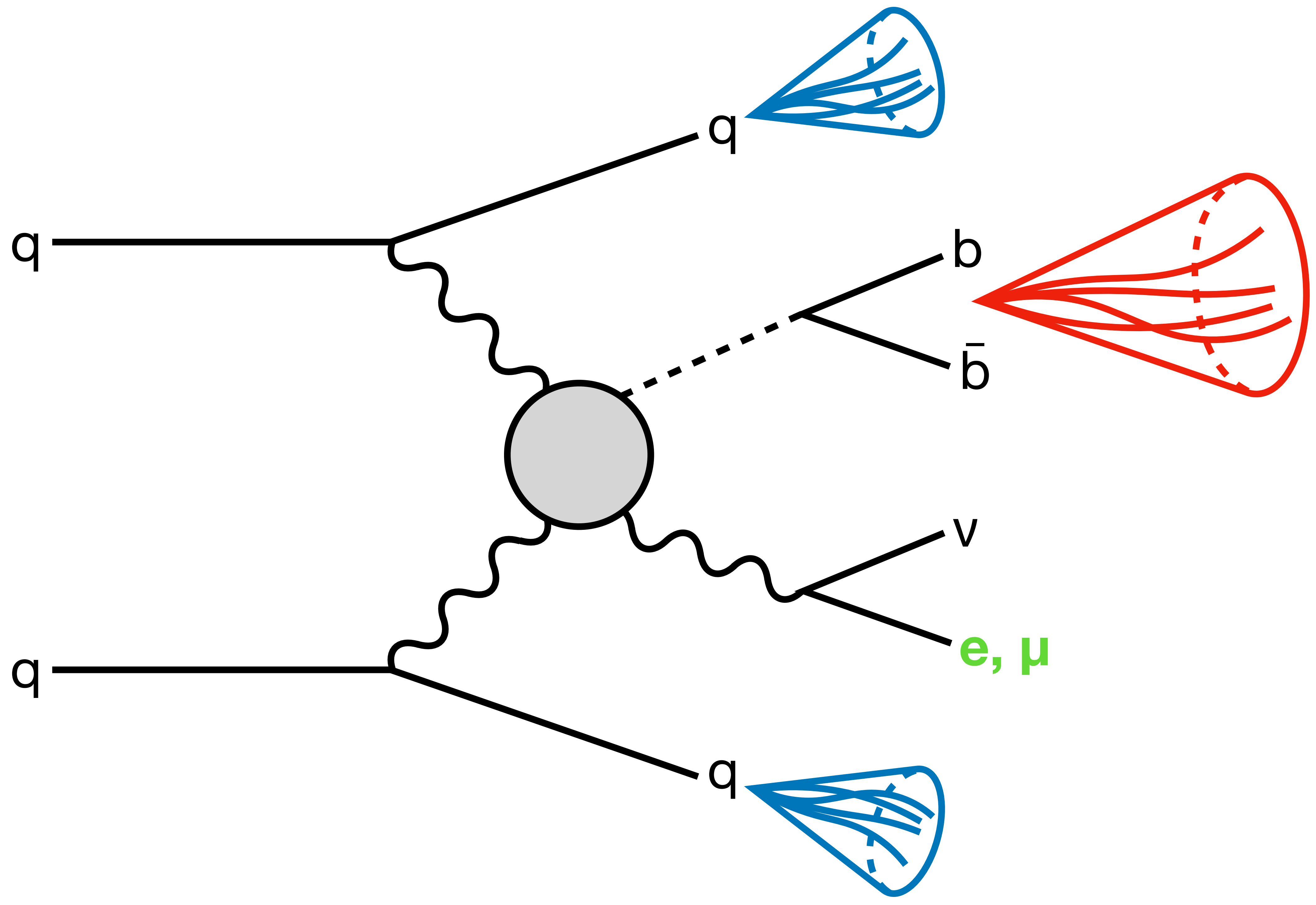
VBS WH Objects



Object	Selections
One **Lepton** (loose veto in postskim)	• Passes ttH tight ID • $p_T > 40$ GeV
One **Hbb** Ak8 Jet	• ΔR(Ak8 jet, any veto lep) > 0.8 • $p_T > 250$ GeV • mass > 50 GeV • M_{SD}* > 40 GeV • Has max(PNet Xbb vs. QCD score) • PNet Xbb vs. QCD score > 0.3

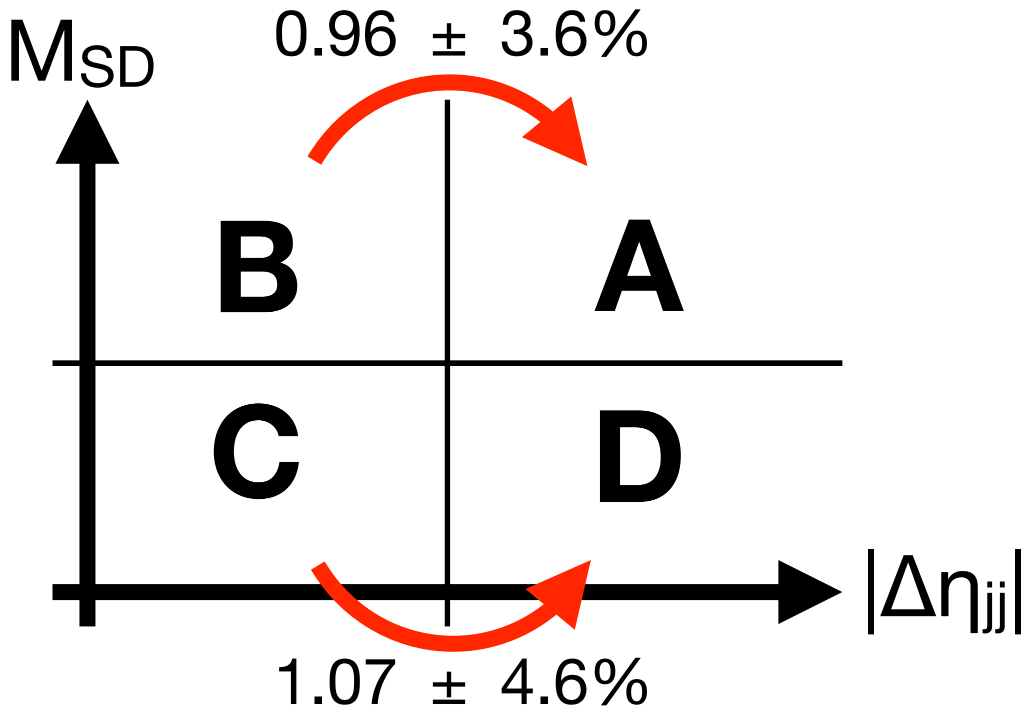
Two **VBS** Ak4 jets	• ΔR(Ak4 jet, any veto lep) > 0.4
	• ΔR(Ak4 jet, Hbb Ak8 jet) > 0.8
	• $p_T > 30$ GeV
	• Passes tight jet ID
	• For > 2 candidates**:
	  ◦ All in same η-hemisphere: leading/trailing (in P) jets
	  ◦ Else: leading (in P) jet from each η-hemisphere

*M_{SD} = soft drop mass
**Hereafter referred to as the "Max-E" selection

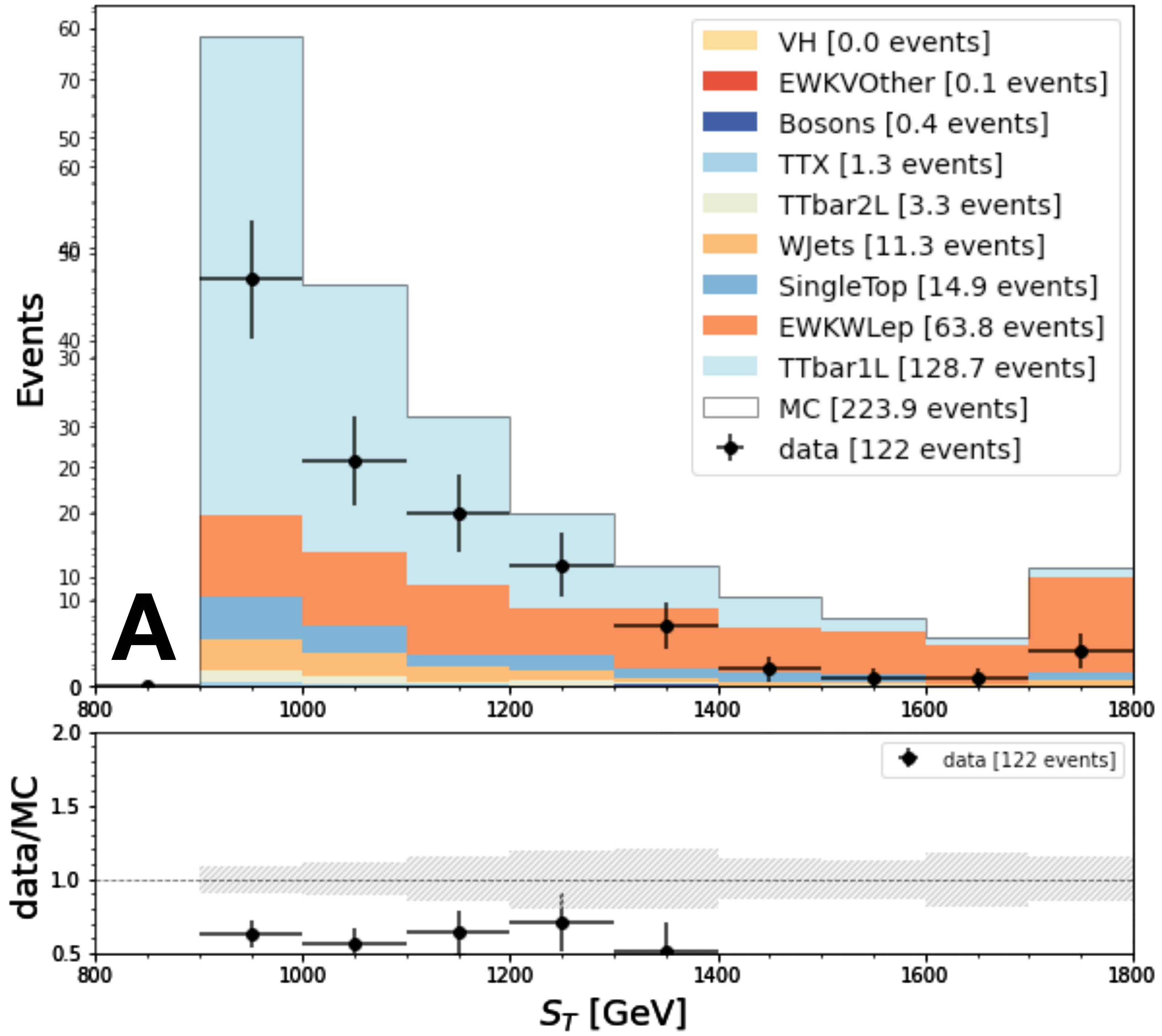
SR1 ABCD

Presel. (w/out $\Delta\eta_{jj}$ cut) AND M_{jj} > 600 GeV AND S_T > 900 GeV AND PNet Xbb > 0.9

Cut	Region	Bkg. (wgt)	Bkg. Err.*	Sig. (wgt)	Sig. Err.*	Data	Data Err.*
$\lvert\Delta\eta_{jj}\rvert$ > 4 AND M_{SD} ≥ 150 GeV	A	223.89	5.92	9.18	1.25	122	11.05
$\lvert\Delta\eta_{jj}\rvert$ ≤ 4 AND M_{SD} ≥ 150 GeV	B	232.05	5.59	1.00	0.45	179	13.38
$\lvert\Delta\eta_{jj}\rvert$ ≤ 4 AND M_{SD} < 150 GeV	C	174.37	4.85	14.07	1.55	142	11.92
$\lvert\Delta\eta_{jj}\rvert$ > 4 AND M_{SD} < 150 GeV (SR1)	D	186.76	6.90	371.20	8.16	—	—



- EWK W problematic here because it destroys data/MC agreement in Region A for SR1 ABCD
  - Preselection w/out $\Delta\eta_{jj}$ cut:
    M_{jj} > 500 GeV AND Hbb jet PNet Xbb score > 0.3 AND AK4 b-jet veto
  - Especially bad at high S_T
- ST = $p_T(\ell)$ + MET + p_T(Hbb jet)
  - Is there a specific culprit?



*err = $\sqrt{(\Sigma_i w_i^2)}$ for MC, $\sqrt{(\text{count})}$ for data

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