VBS WH Analysis

Issues with the EWK W/Z samples

September 21st, 2022

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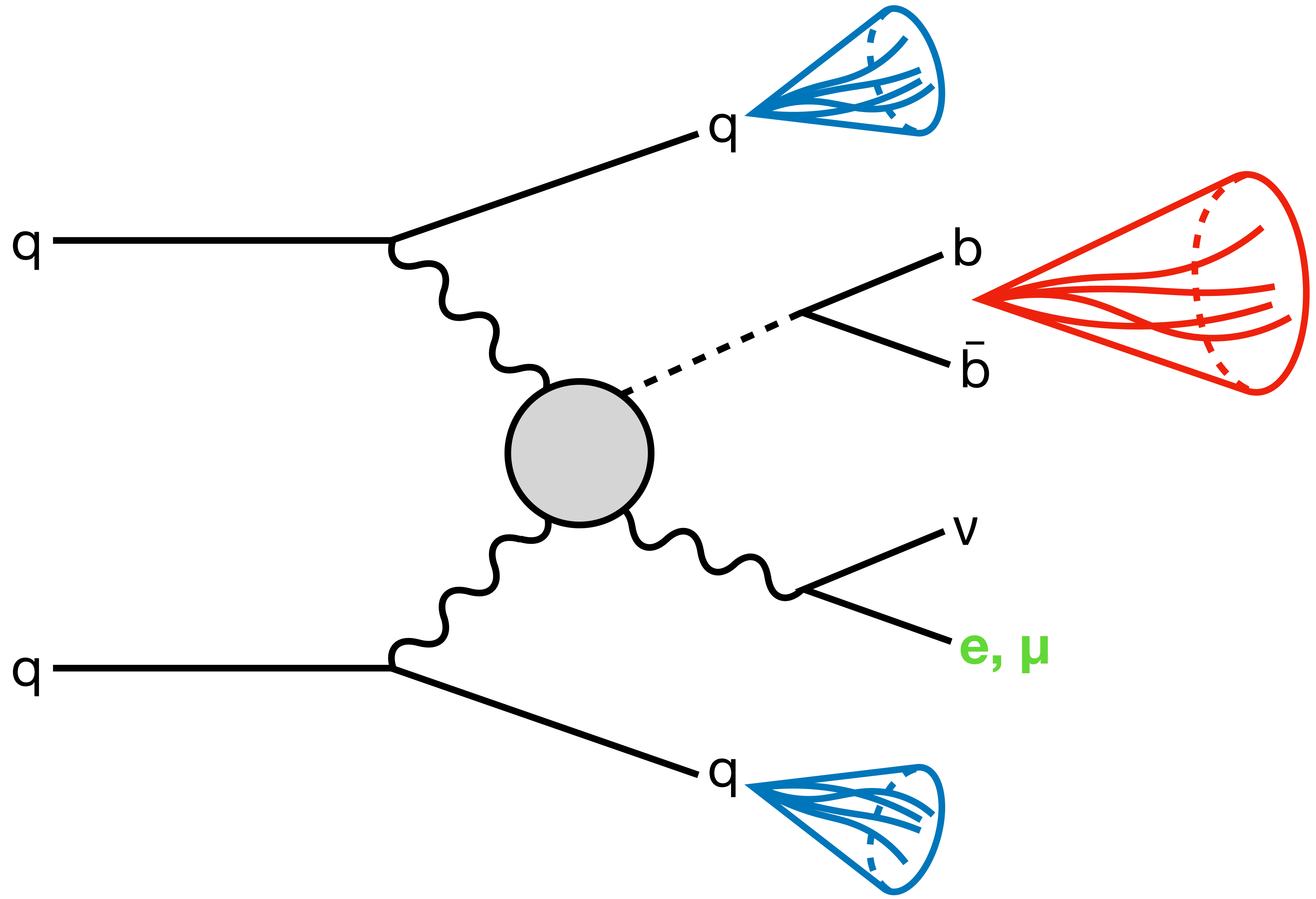
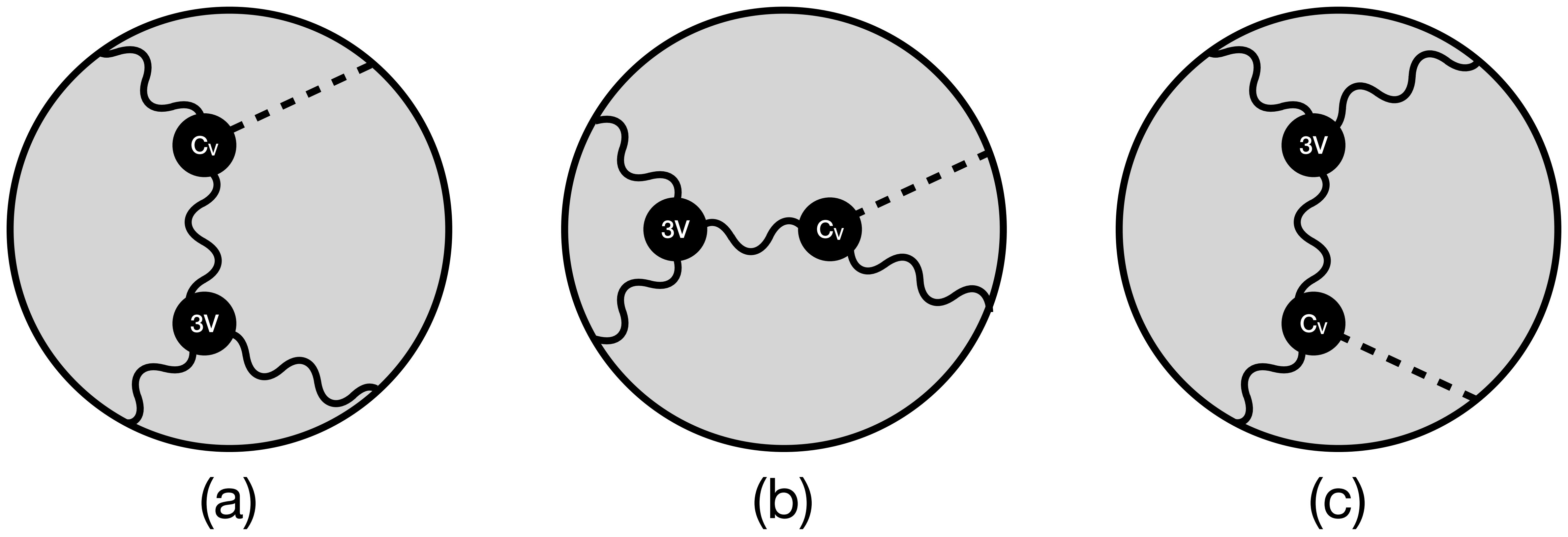
Target Final State

- 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}





Analysis Skim

Yields scaled to lumi×σ, rounded for readability

Cut	VH	VV/VVV/VBSVV	W+Jets	SingleTop	TTbar+X	TTbar1L	TTbar2L	TotalBkg	Eff.*	VBSWH (λ_{WZ} = -1)	Eff.*
Skim	263	27K	136K	8.4K	1.1K	96K	11K	279K	—	2.2K	—

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	≥ 2 w/ p_T > 20 GeV AND ΔR(jet, tight lepton) > 0.4
Other	S_T** > 800 GeV

*Using the ttH lepton ID
**ST = $p_T(\ell)$ + MET + p_T(Hbb jet)

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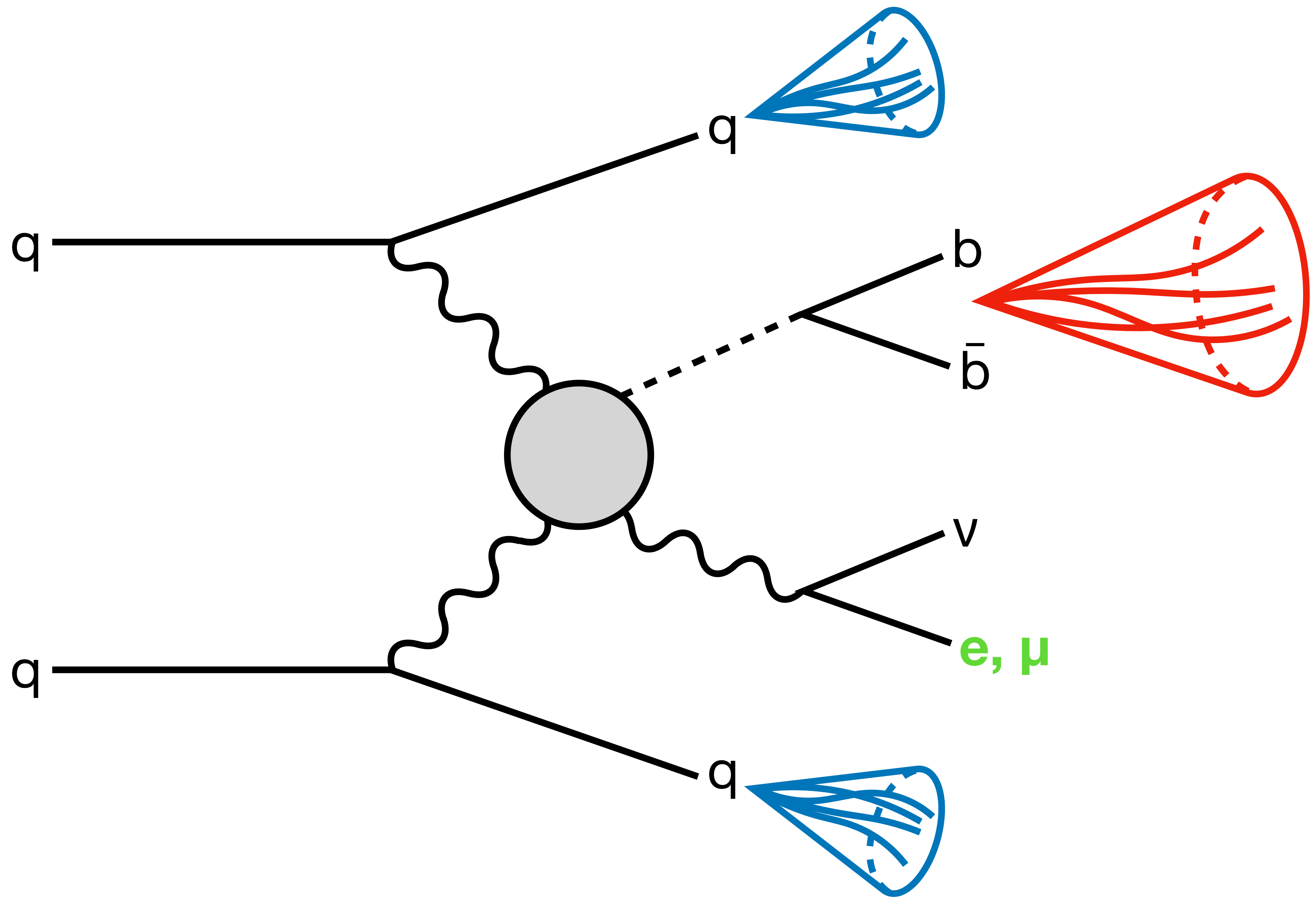
VBS WH Objects



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 • $\|\eta\|$ < 2.5 • 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

Signal Regions

Yields scaled to lumi×σ, rounded for readability

	Cut	VH	VV/VVV/VBSVV	W+Jets	SingleTop	TTbar+X	TTbar1L	TTbar2L	TotalBkg	Eff.*	VBSWH (λ_{WZ} = -1)	Eff.*
	Skim	263	27K	136K	8.4K	1.1K	96K	11K	279K	—	2.2K	—
	Object Selection	53	11K	51K	4.6K	663	53K	6K	126K	55%	1.2K	45%
	Preselection	3	208	517	204	20	1.8K	112	2.8K	98%	622	48%
SR1	**M_{jj} > 600 GeV AND $\lvert\Delta\eta_{jj}\rvert$ > 4**	1	93	253	127	11	1K	60	1.6K	44%	586	6%
SR1	**S_T > 900 GeV**	1	62	155	82	6	535	29	872	44%	477	19%
SR1	**PNet Xbb vs. QCD > 0.9 AND M_{SD} < 150**	1	6	20	13	1	47	10	**97**	89%	**370**	22%
SR2	**S_T > 1500 GeV**	0	1	1	0	0	1	0	**4**	96%	**103**	72%

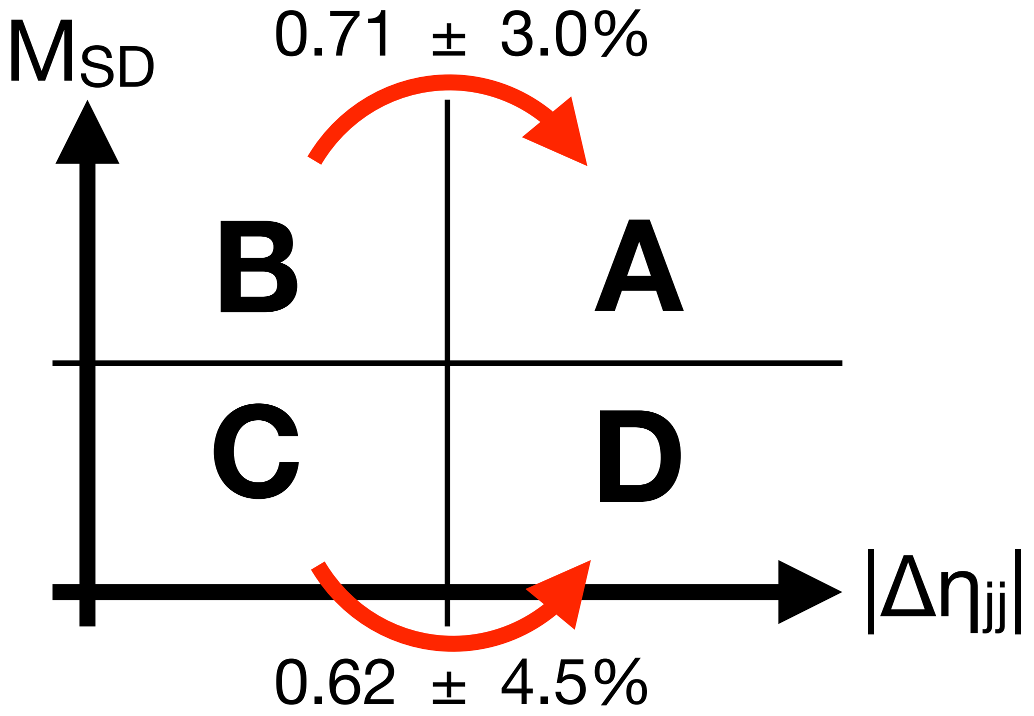
- **Signal Region 1 (SR1): 370 signal vs. 97 background**
  - Can exclude λ_{WZ} = -1
  - Background can be estimated via ABCD
- **Signal Region 2 (SR2): 103 signal vs. 4 background**
  - High purity via tighter kinematics; worth exploring in its own right
  - Most valuable if data in SR1 is not consistent with either λ_{WZ} = -1 or λ_{WZ} = +1 hypotheses

*eff = 1 - after/before

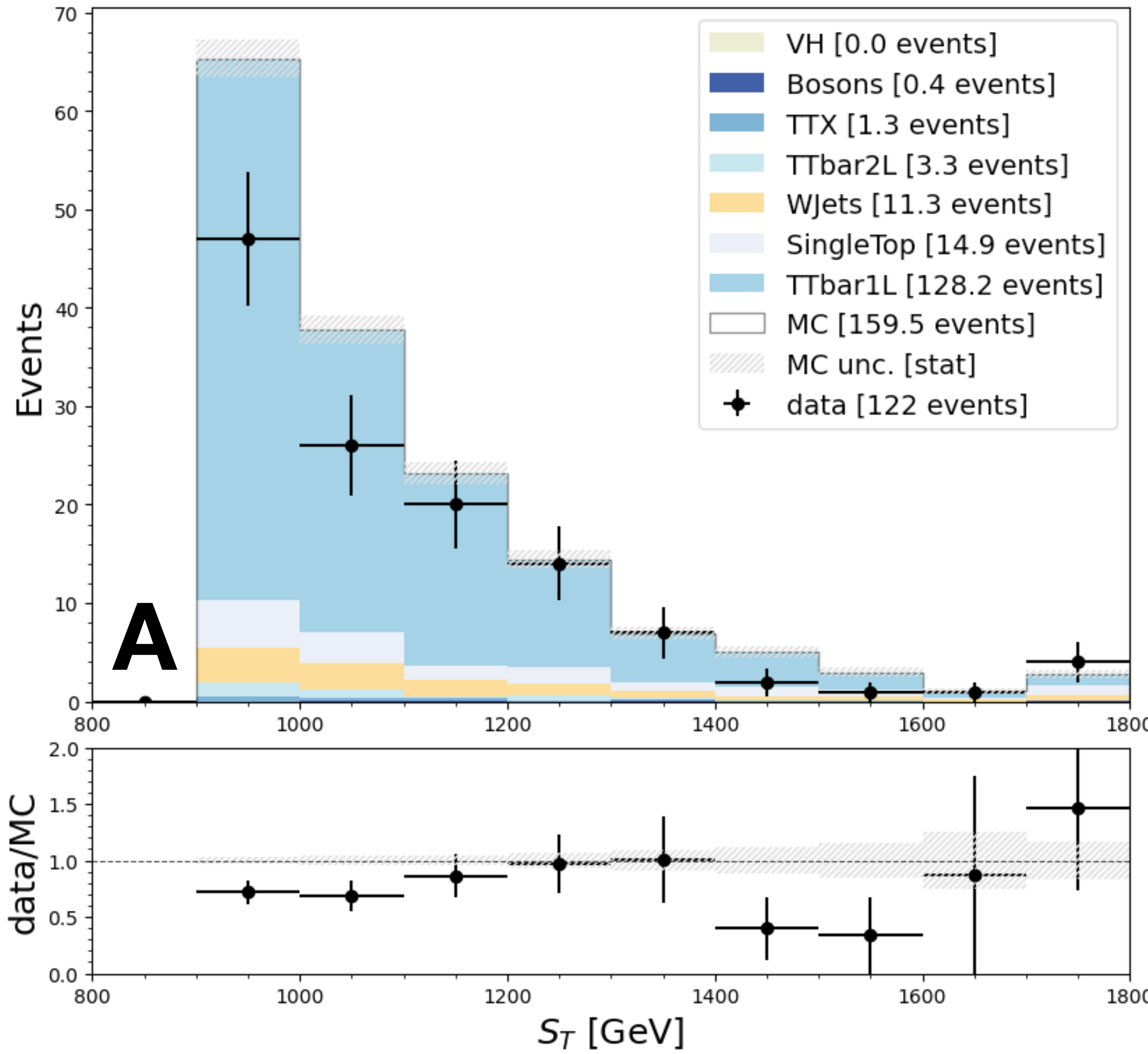
SR1 ABCD: Before EWK

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 $M_{SD} \geq 150$ GeV	A	159.46	3.01	9.18	1.25	122	11.05
$\lvert\Delta\eta_{jj}\rvert \leq 4$ AND $M_{SD} \geq 150$ GeV	B	224.25	5.36	1.00	0.45	179	13.38
$\lvert\Delta\eta_{jj}\rvert \leq 4$ AND $M_{SD} < 150$ GeV	C	157.34	4.16	14.00	1.55	142	11.92
$\lvert\Delta\eta_{jj}\rvert > 4$ AND $M_{SD} < 150$ GeV (SR1)	D	96.96	3.48	370.22	8.16	—	—



- Showed this ABCD extrapolation at the Hbb subgroup meeting
  - Preselection w/out $\Delta\eta_{jj}$ cut:
    M_{jj} > 500 GeV AND Hbb jet PNet Xbb score > 0.3
    AND AK4 b-jet veto
- Was asked to add EWK W/Z samples



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

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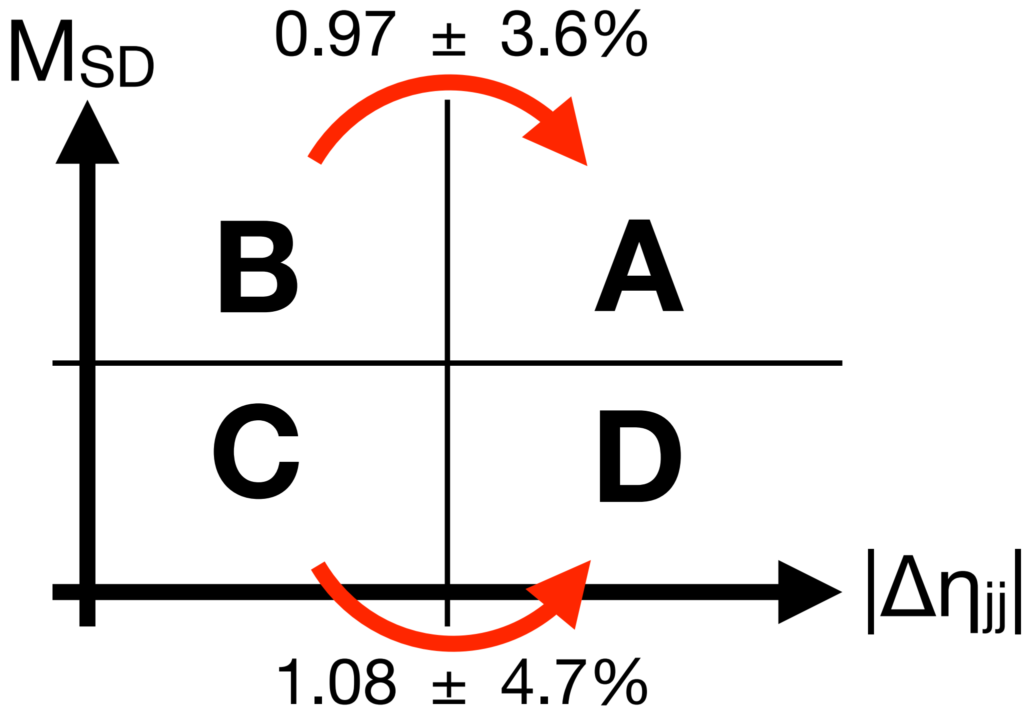
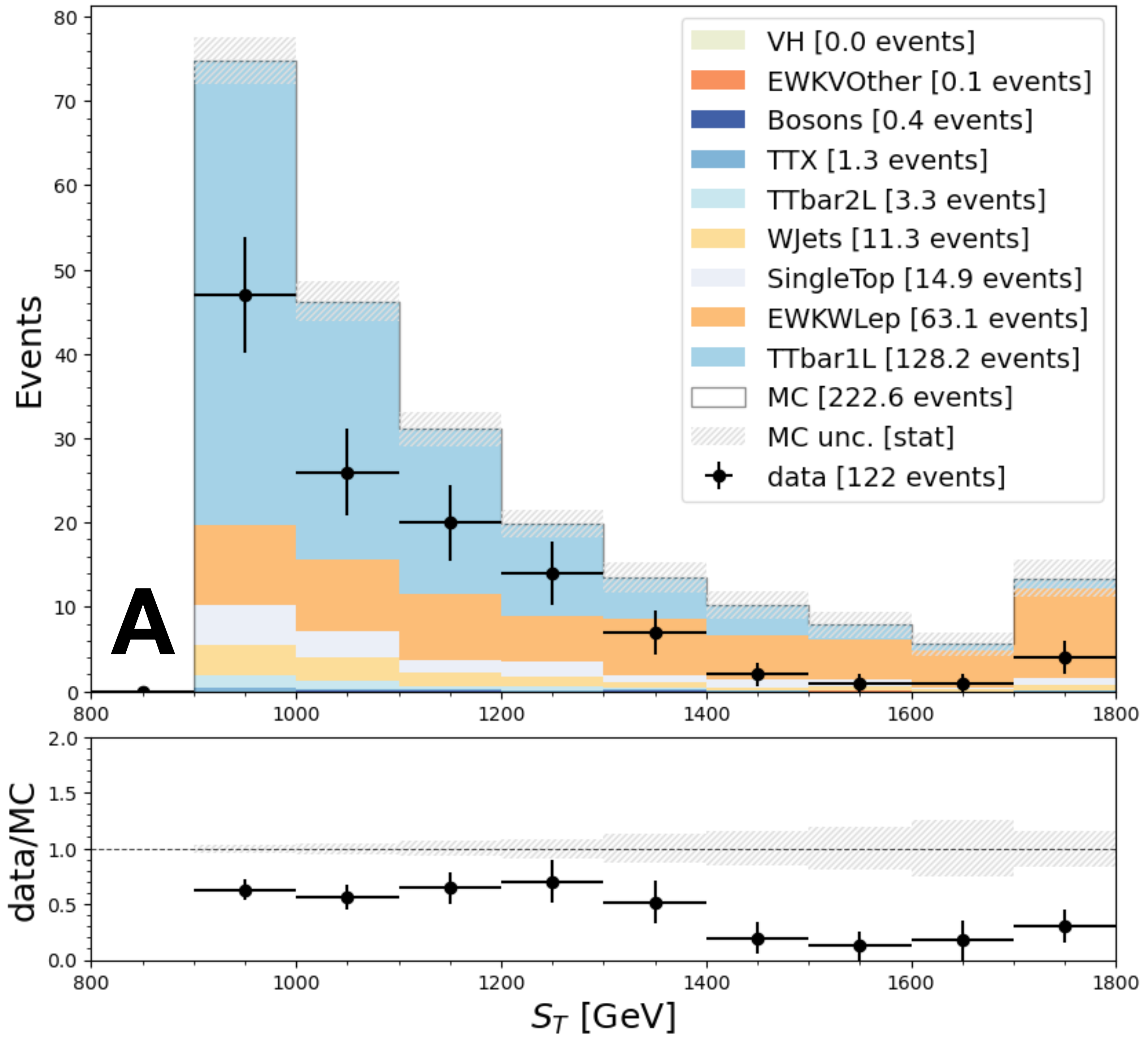
SR1 ABCD: After EWK

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	222.65	5.89	9.18	1.25	122	11.05
$\lvert\Delta\eta_{jj}\rvert$ ≤ 4 AND M_{SD} ≥ 150 GeV	B	230.24	5.58	1.00	0.45	179	13.38
$\lvert\Delta\eta_{jj}\rvert$ ≤ 4 AND M_{SD} < 150 GeV	C	171.95	4.84	14.00	1.55	142	11.92
$\lvert\Delta\eta_{jj}\rvert$ > 4 AND M_{SD} < 150 GeV (SR1)	D	185.91	6.90	370.22	8.16	—	—



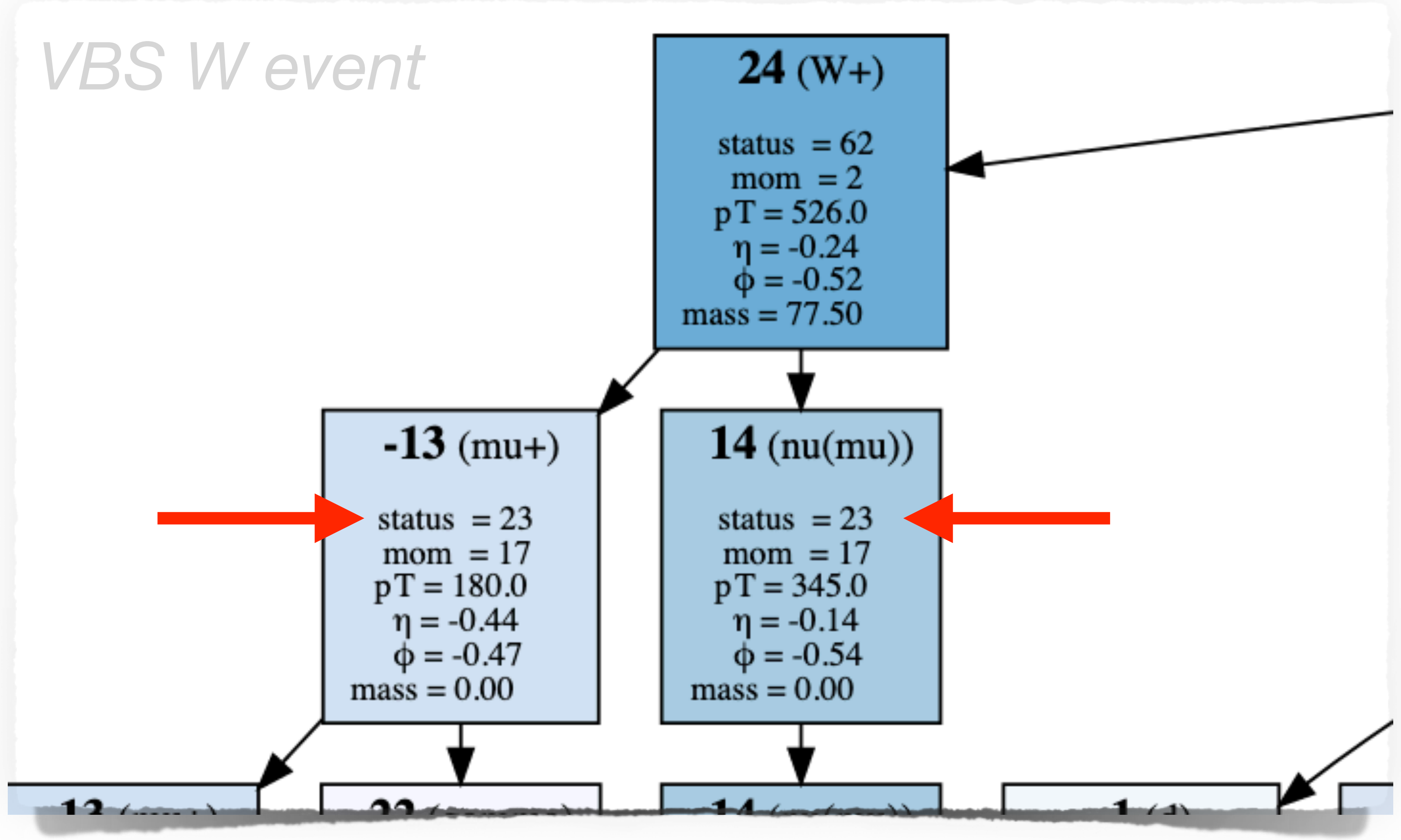
- EWK W ($W \to \ell\nu$) problematic here because it destroys data/MC agreement in Region A for SR1 ABCD
  - Preselection w/out $\Delta\eta_{jj}$ cut: M_{jj} > 500 GeV AND Hbb jet PNet Xbb score > 0.3 AND AK4 b-jet veto
  - Especially bad at high $S_T = p_T(\ell) + \text{MET} + p_T(\text{Hbb jet})$
- How do they enter this analysis in the first place?
  - Focus only on relevant samples

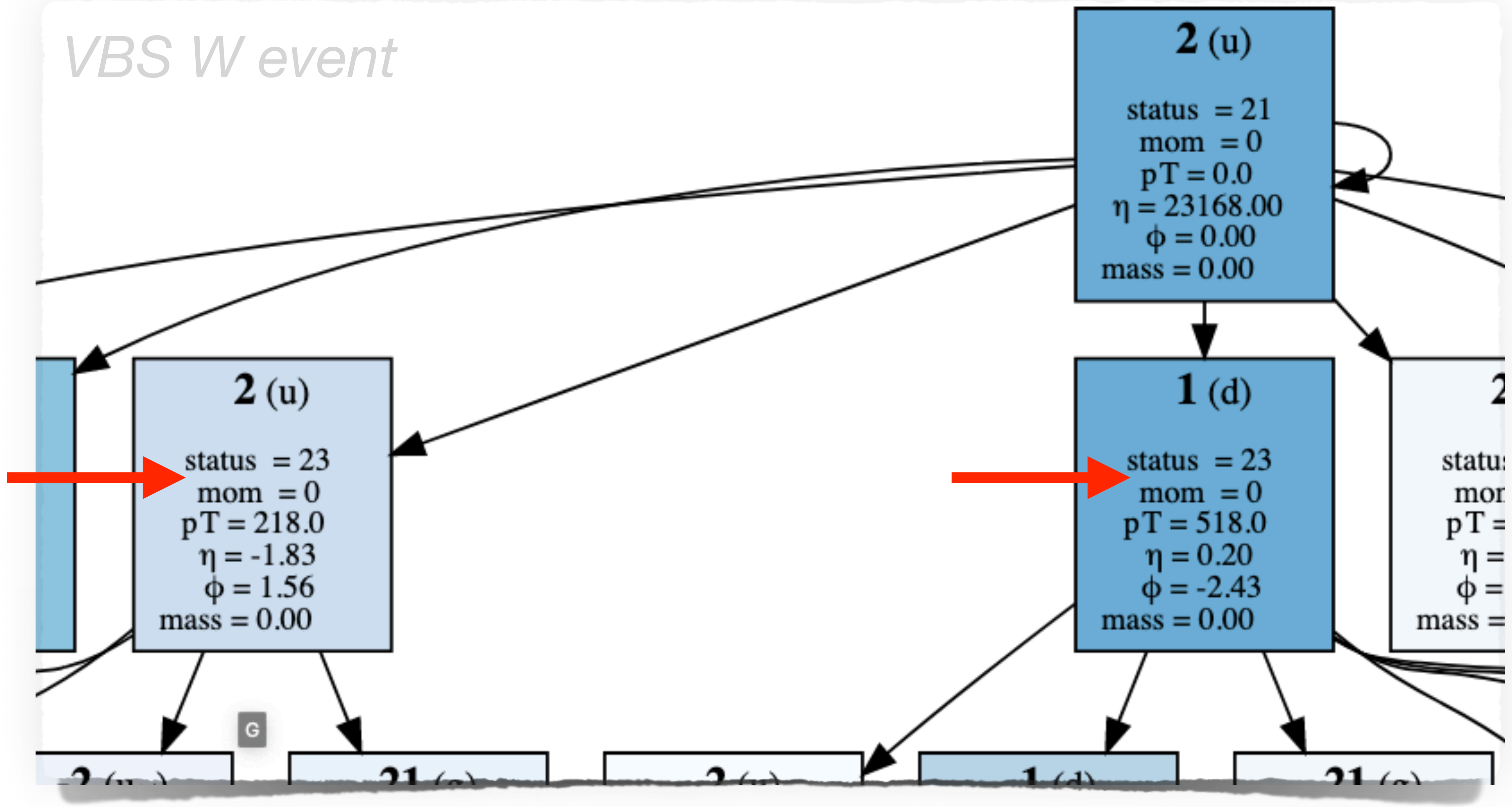


*err = $\sqrt{(\Sigma_i w_i^2)}$ for MC, $\sqrt{(\text{count})}$ for data

Gen-level Study

- **Only consider** EWK WPlus/Minus WToLNu samples
- For quarks:
  - Require status == 23
  - Mother == W boson ⇒ **WW event***
  - Mother idx == 0 ⇒ **VBS event**
- For leptons (e, μ, τ):
  - Require status ∈ {1, 2, 23}
  - Require mother == W boson





*EWK W samples also contain WW/WZ events; see backup

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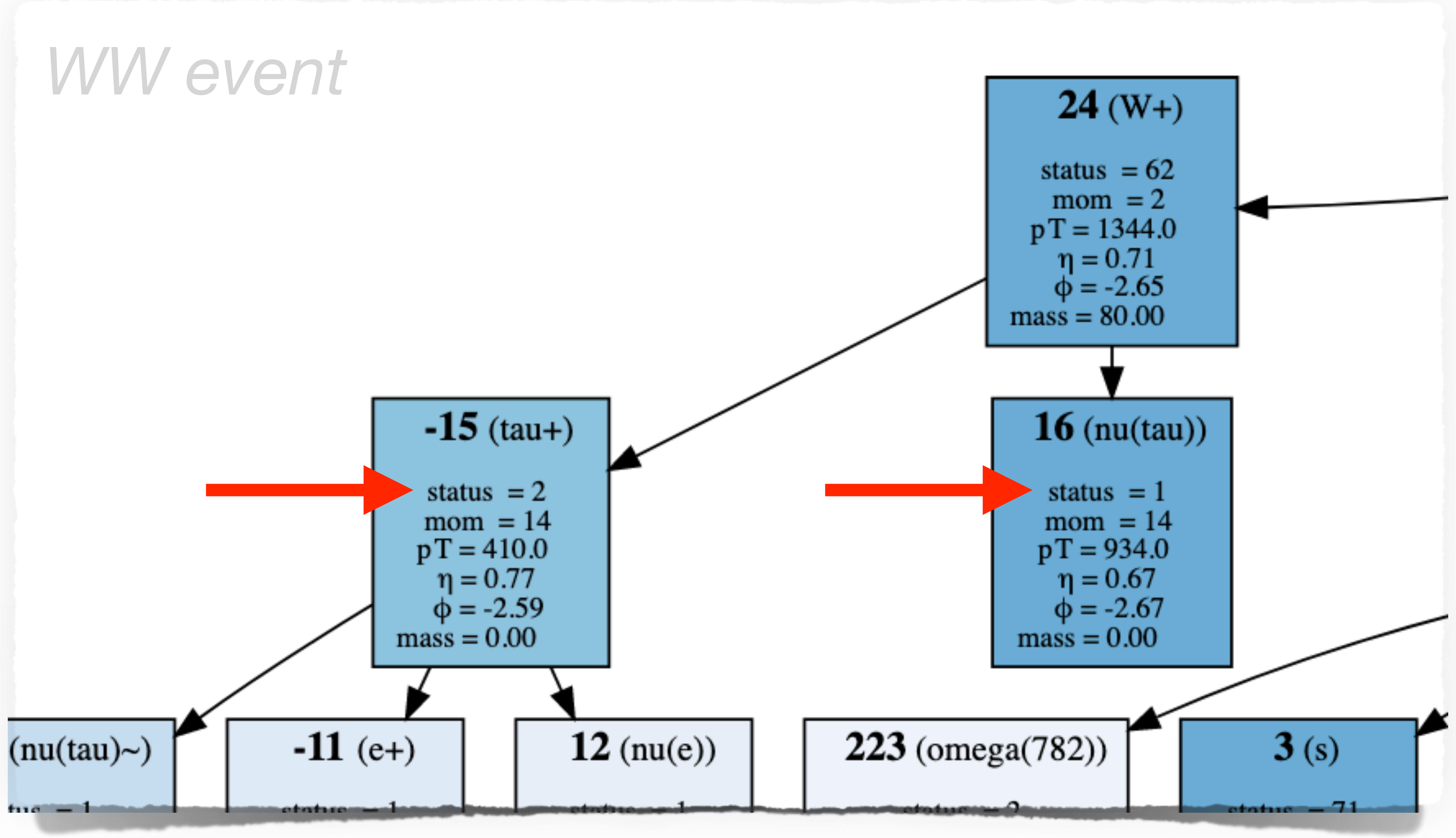
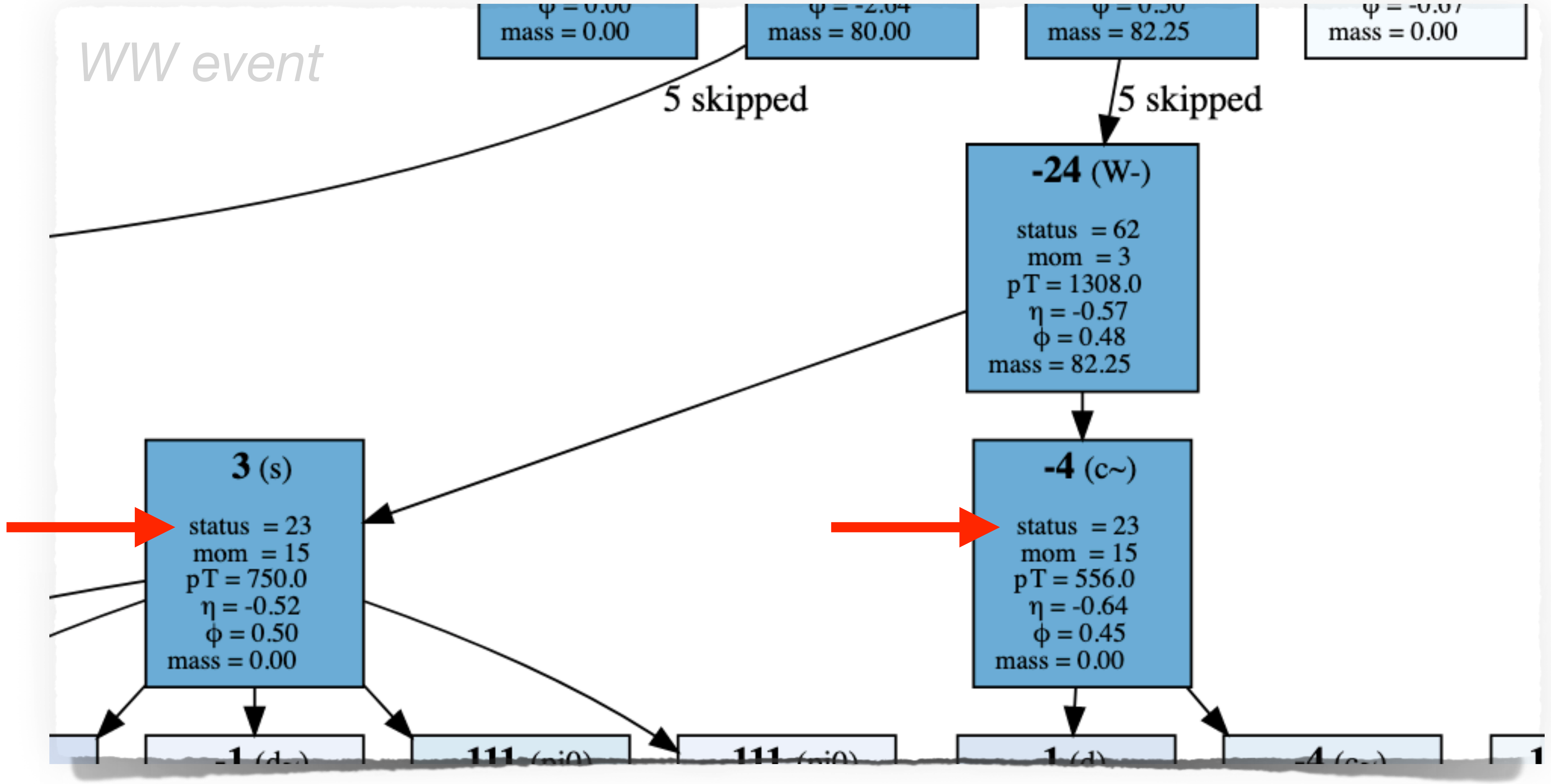
Gen-level Study

- **Only consider** EWK WPlus/Minus WToLNu samples
- For quarks:
  - Require status == 23
  - Mother == W boson ⇒ **WW event***
  - Mother idx == 0 ⇒ **VBS event**
- For leptons (e, μ, τ):
  - Require status ∈ {1, 2, 23}
  - Require mother == W boson





*EWK W samples also contain WW/WZ events; see backup

Gen-level Study

- Try to match selected gen. quarks to reco jets:
  - VBS matching: $dR(q_{gen}, q_{reco}) < 0.4$
    - If the 2 gen. quarks ∊ ***unique*** VBS jets: 2 matches
    - If the 2 gen. quarks ∊ ***same*** VBS jet: "1.5" matches
    - If only 1 gen. quark ∊ ***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: $dR(\ell_{gen}, \ell_{reco}) < 0.4$

Label
VBSW & NoLepMatch
WW & NoLepMatch
VBSW & LepMatch & NoVBSMatch & 0HbbCone
WW & LepMatch & NoVBSMatch & 0HbbCone
VBSW & LepMatch & NoVBSMatch & 1HbbCone
WW & LepMatch & NoVBSMatch & 1HbbCone
VBSW & LepMatch & NoVBSMatch & 2HbbCone
WW & LepMatch & NoVBSMatch & 2HbbCone
VBSW & LepMatch & 1VBSMatch & 0HbbCone
WW & LepMatch & 1VBSMatch & 0HbbCone
VBSW & LepMatch & 1VBSMatch & 1HbbCone
WW & LepMatch & 1VBSMatch & 1HbbCone
VBSW & LepMatch & 1VBSMatch & 2HbbCone
WW & LepMatch & 1VBSMatch & 2HbbCone
VBSW & LepMatch & 1.5VBSMatches
WW & LepMatch & 1.5VBSMatches
VBSW & LepMatch & 2VBSMatches
WW & LepMatch & 2VBSMatches
Other

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Gen-level Study

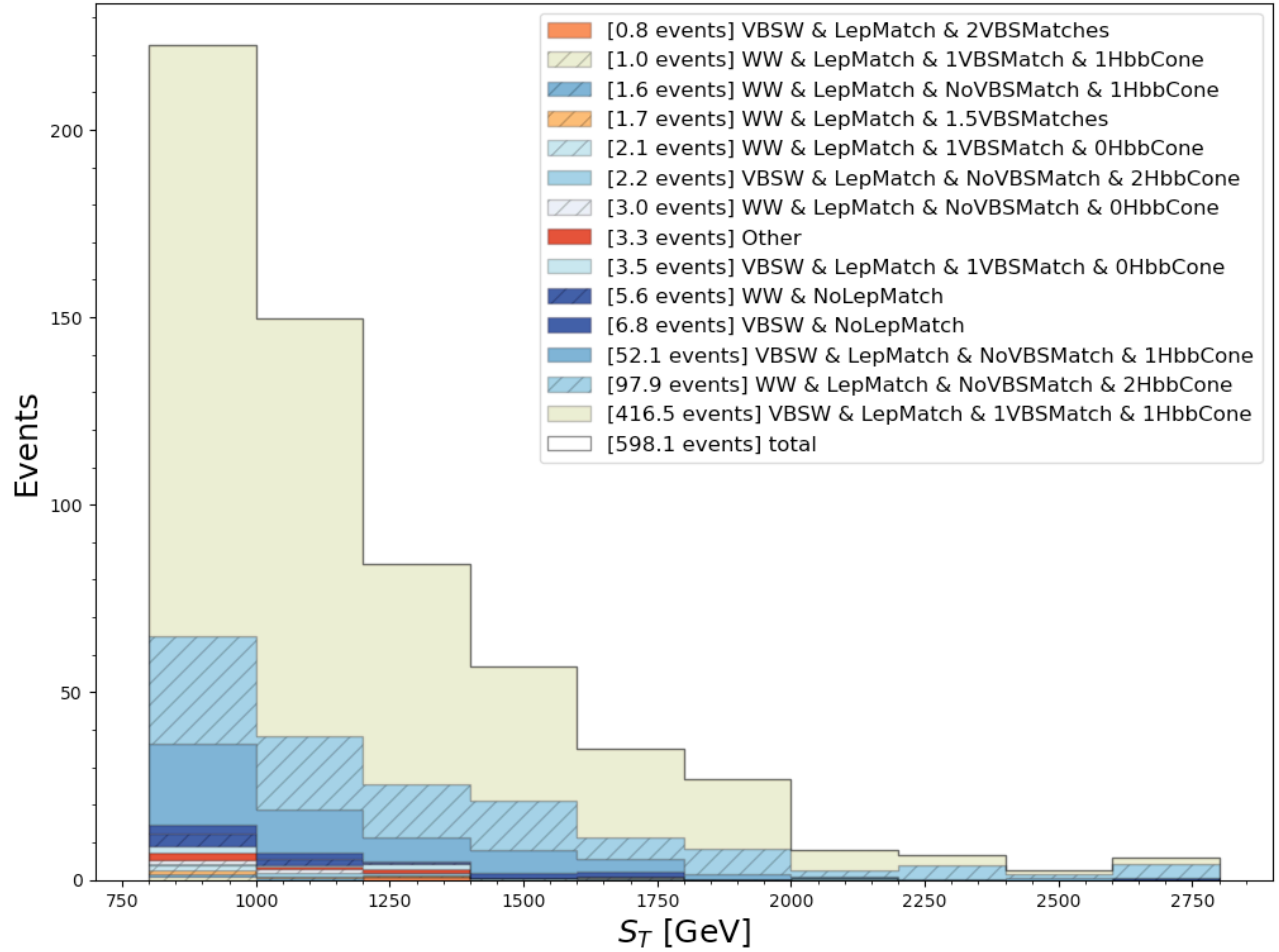
- Try to match selected gen. quarks to reco jets:
  - VBS matching: $dR(q_{gen}, q_{reco}) < 0.4$
    - If the 2 gen. quarks ∈ ***unique*** VBS jets: 2 matches
    - If the 2 gen. quarks ∈ ***same*** VBS jet: “1.5” matches
    - If only 1 gen. quark ∈ ***one*** VBS jet: 1 match
    - ***Otherwise***: 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: $dR(\ell_{gen}, \ell_{reco}) < 0.4$

Label
VBSW & NoLepMatch
WW & NoLepMatch
VBSW & LepMatch & NoVBSMatch & 0HbbCone
WW & LepMatch & NoVBSMatch & 0HbbCone
VBSW & LepMatch & NoVBSMatch & 1HbbCone
WW & LepMatch & NoVBSMatch & 1HbbCone
VBSW & LepMatch & NoVBSMatch & 2HbbCone
WW & LepMatch & NoVBSMatch & 2HbbCone
VBSW & LepMatch & 1VBSMatch & 0HbbCone
WW & LepMatch & 1VBSMatch & 0HbbCone
VBSW & LepMatch & 1VBSMatch & 1HbbCone
WW & LepMatch & 1VBSMatch & 1HbbCone
VBSW & LepMatch & 1VBSMatch & 2HbbCone
WW & LepMatch & 1VBSMatch & 2HbbCone
VBSW & LepMatch & 1.5VBSMatches
WW & LepMatch & 1.5VBSMatches
VBSW & LepMatch & 2VBSMatches
WW & LepMatch & 2VBSMatches
Other

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	97.9
VBSW & LepMatch & 1VBSMatch & 0HbbCone	3.5
WW & LepMatch & 1VBSMatch & 0HbbCone	2.1
VBSW & LepMatch & 1VBSMatch & 1HbbCone	416.5
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	598.1

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

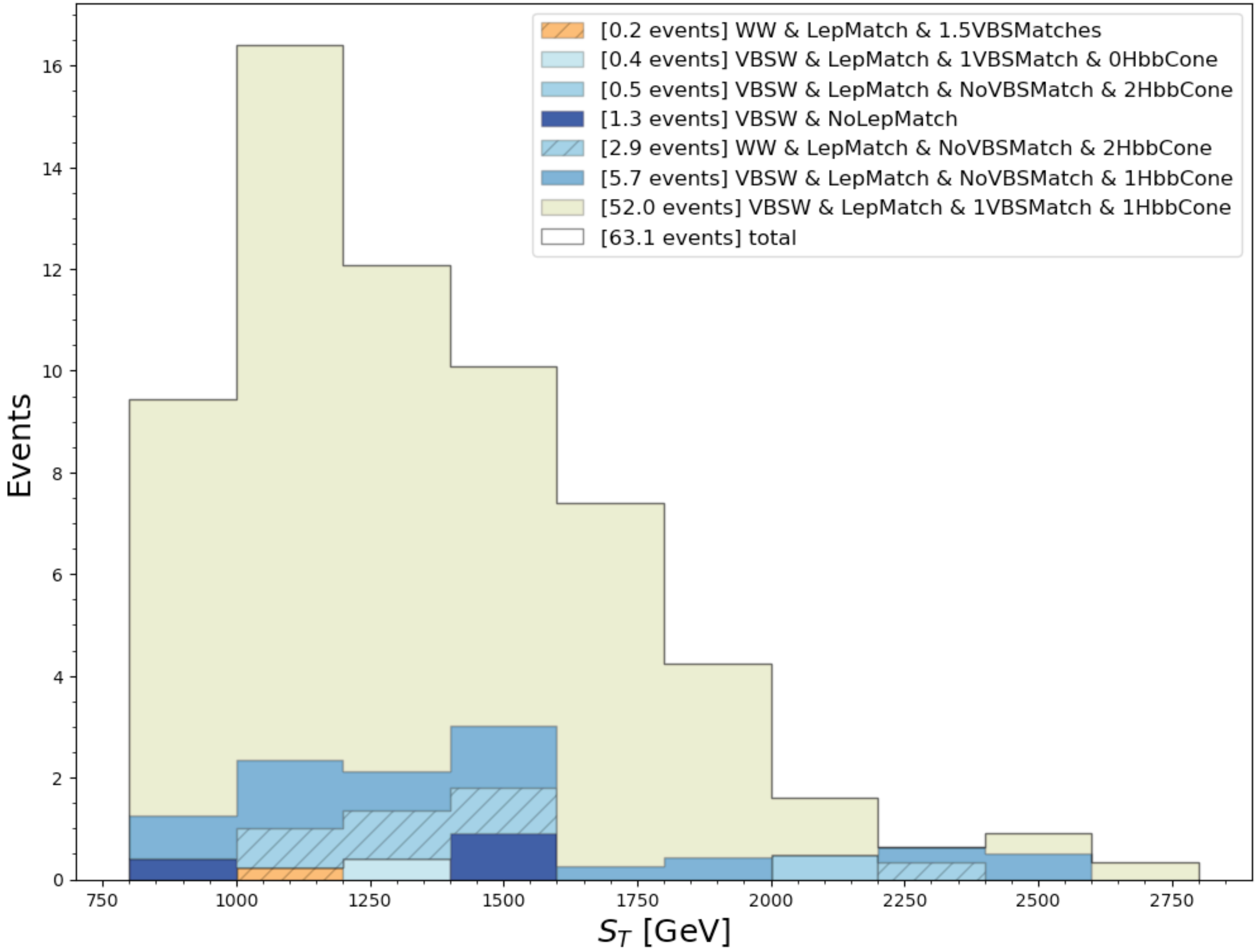


*At this point, there are *some* (1 raw event) occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

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	52.0
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	63.1

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

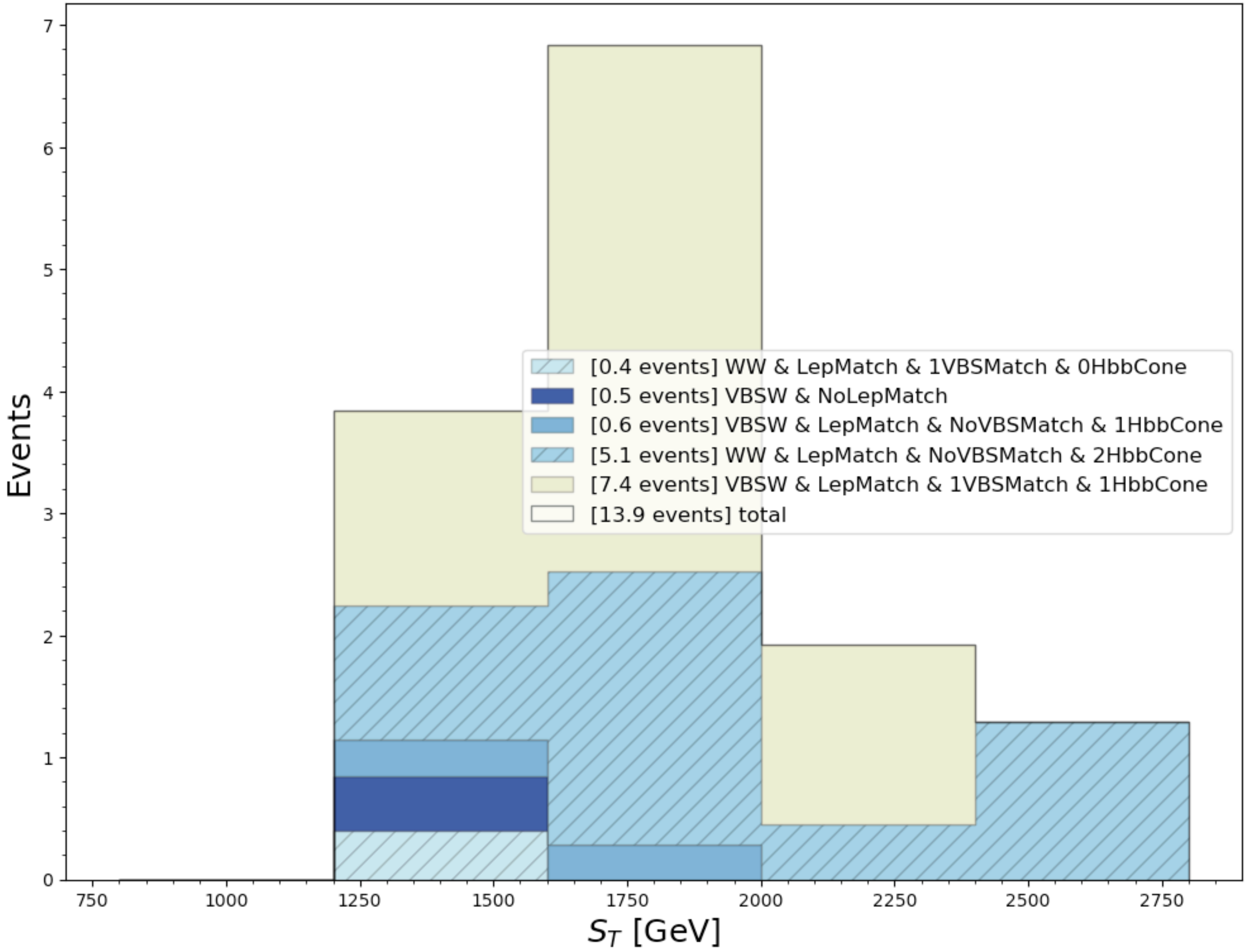


*At this point, there are *zero* occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

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

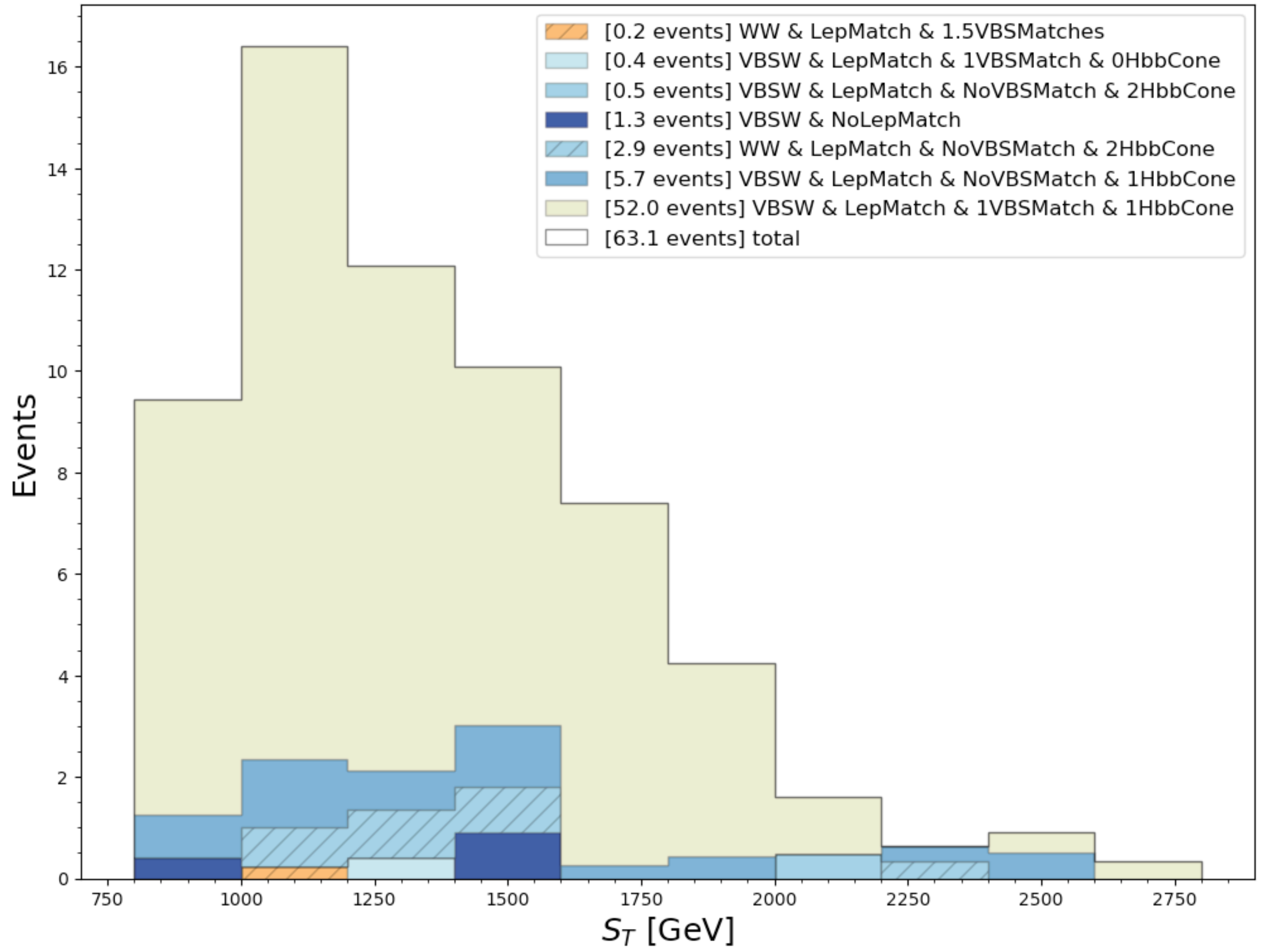
SR2



*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

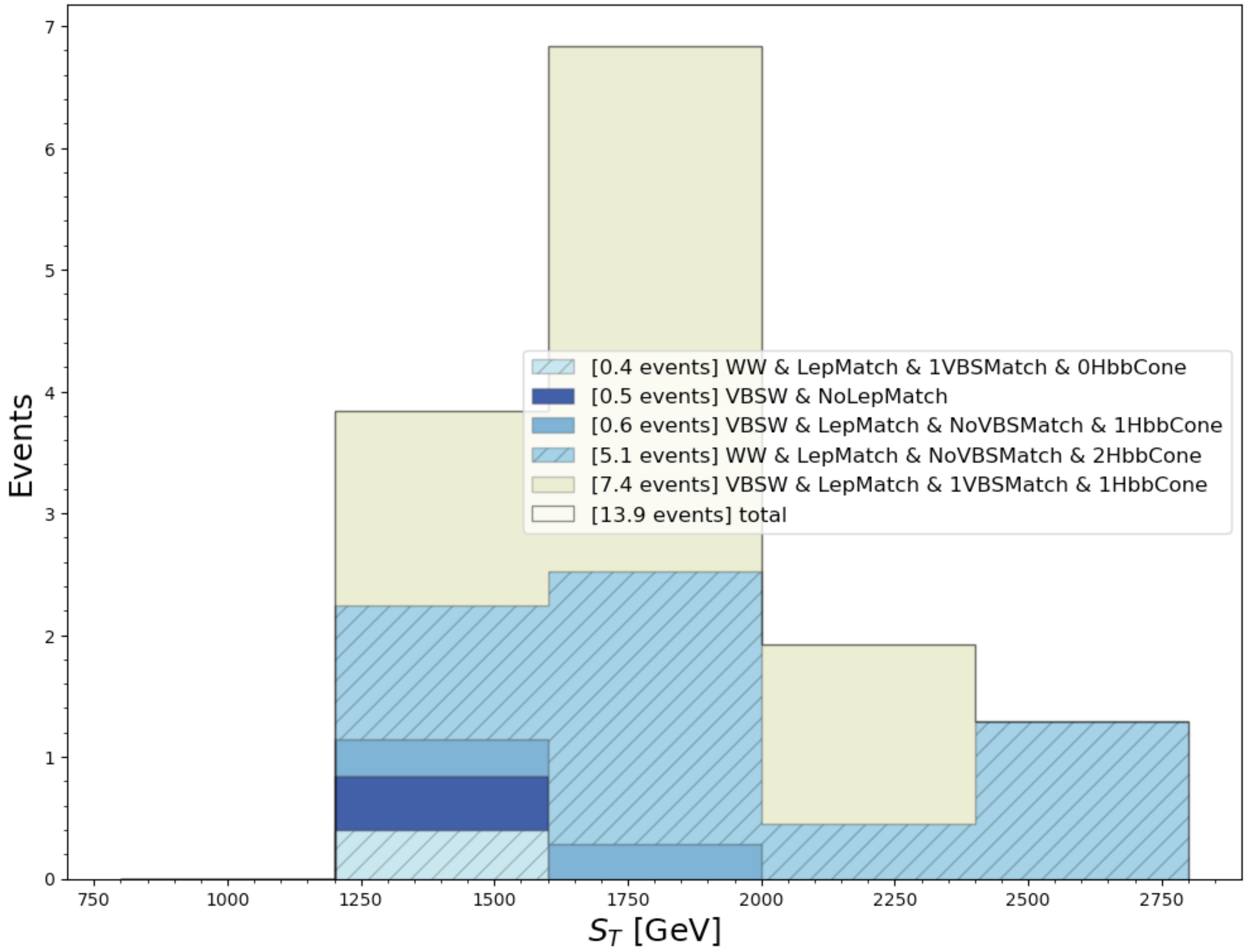
EWK W Contribution Breakdown

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



98% of events have at least one incoming parton == b quark

SR2



96% of events have at least one incoming parton == b quark

EWK Generation Details

Proc Card	Notes

`import model sm-ckm_no_b_mass`
 	
`define l+ = e+ mu+ ta+`
`define vl = ve vm vt`
 	
`generate p p > l+ vl j j / t t~ h QCD=0`
 	
`output` **`ewkwplvjj_5f_LO`** `-nojpeg`
	• Used to generate EWKWPlus…WToLNu samples
	    • From here
	• **LO** sample
	• Both W's are decayed by MadGraph
	• **5-flavor scheme**

- Indeed, EWK W samples generated using 5-flavor scheme
- Next question: when do the events with incoming b quarks become dominant?

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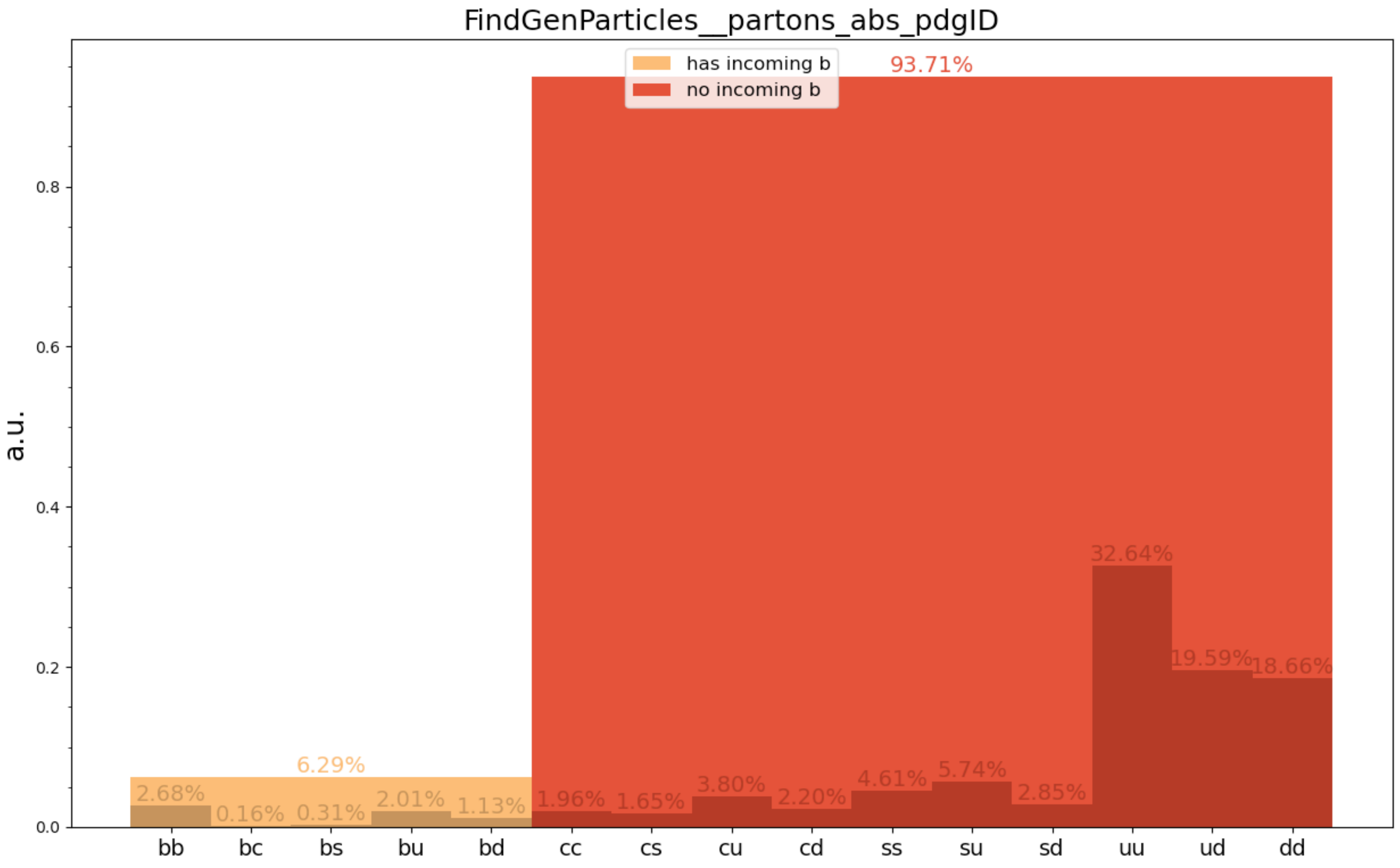
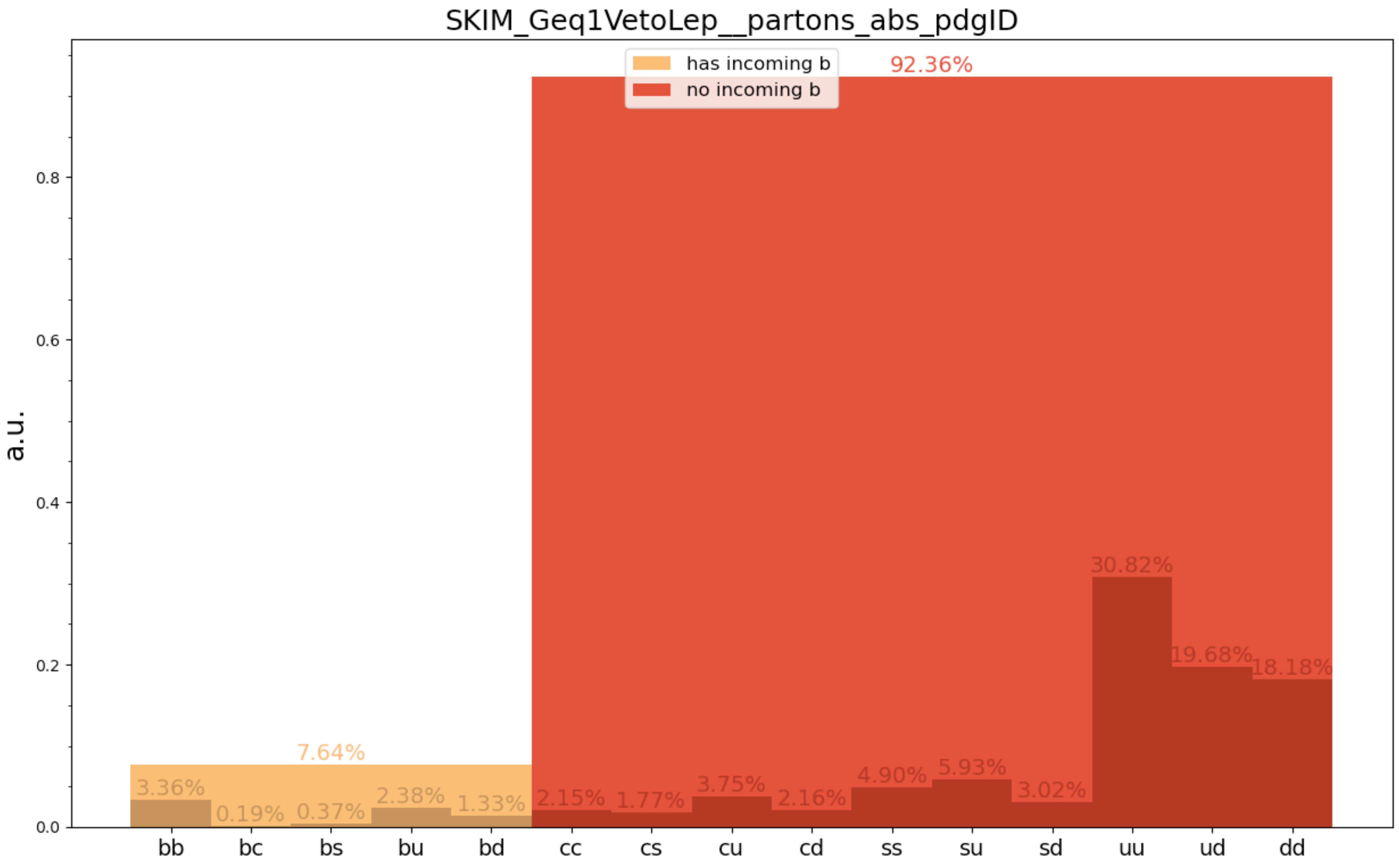
EWK W Contribution Breakdown

No selections applied



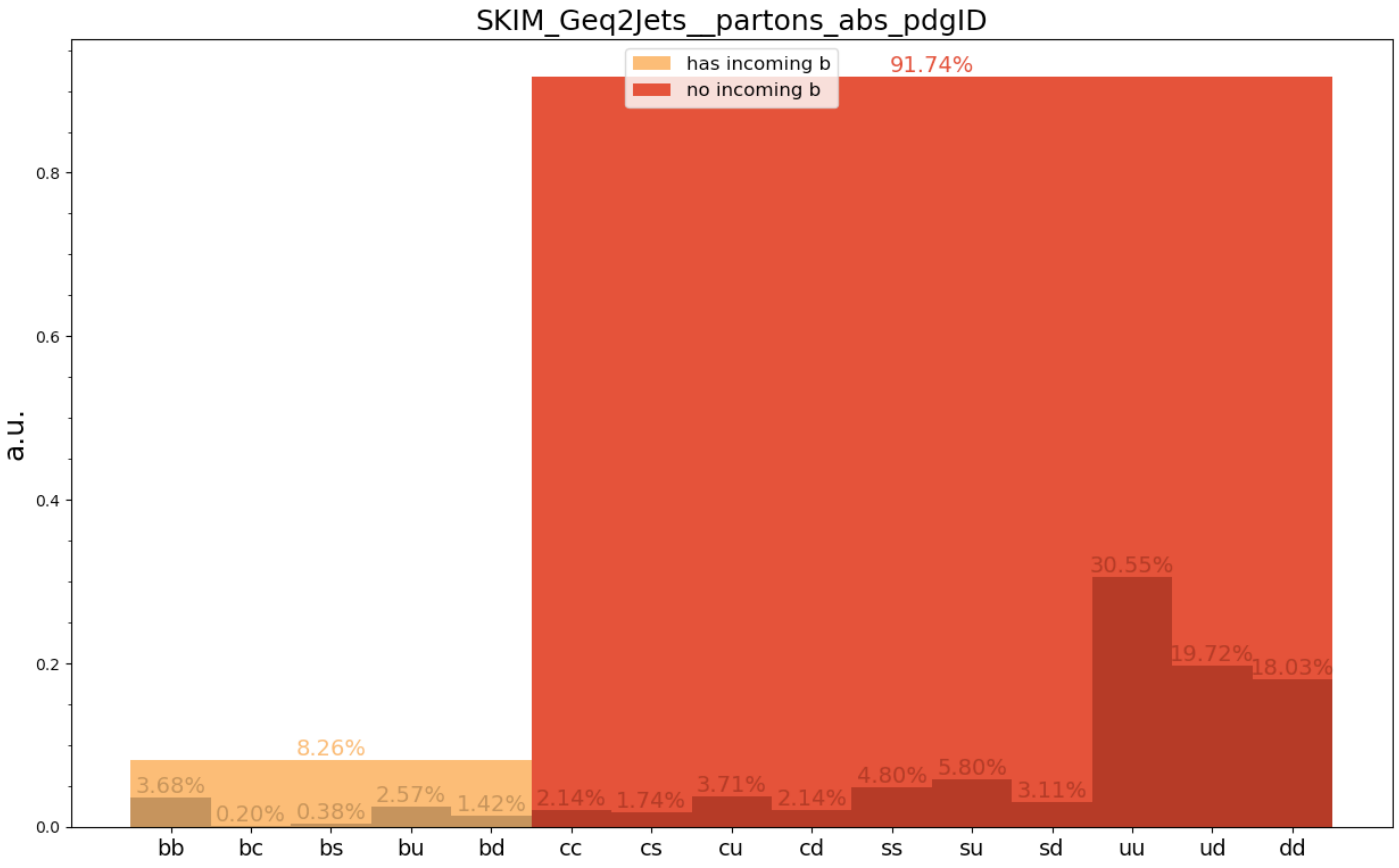
EWK W Contribution Breakdown

≥ 1 lepton passing ttH “veto” ID



EWK W Contribution Breakdown

≥ 2 AK4 jets with p_T > 20 GeV AND dR(jet, any veto lep) > 0.4



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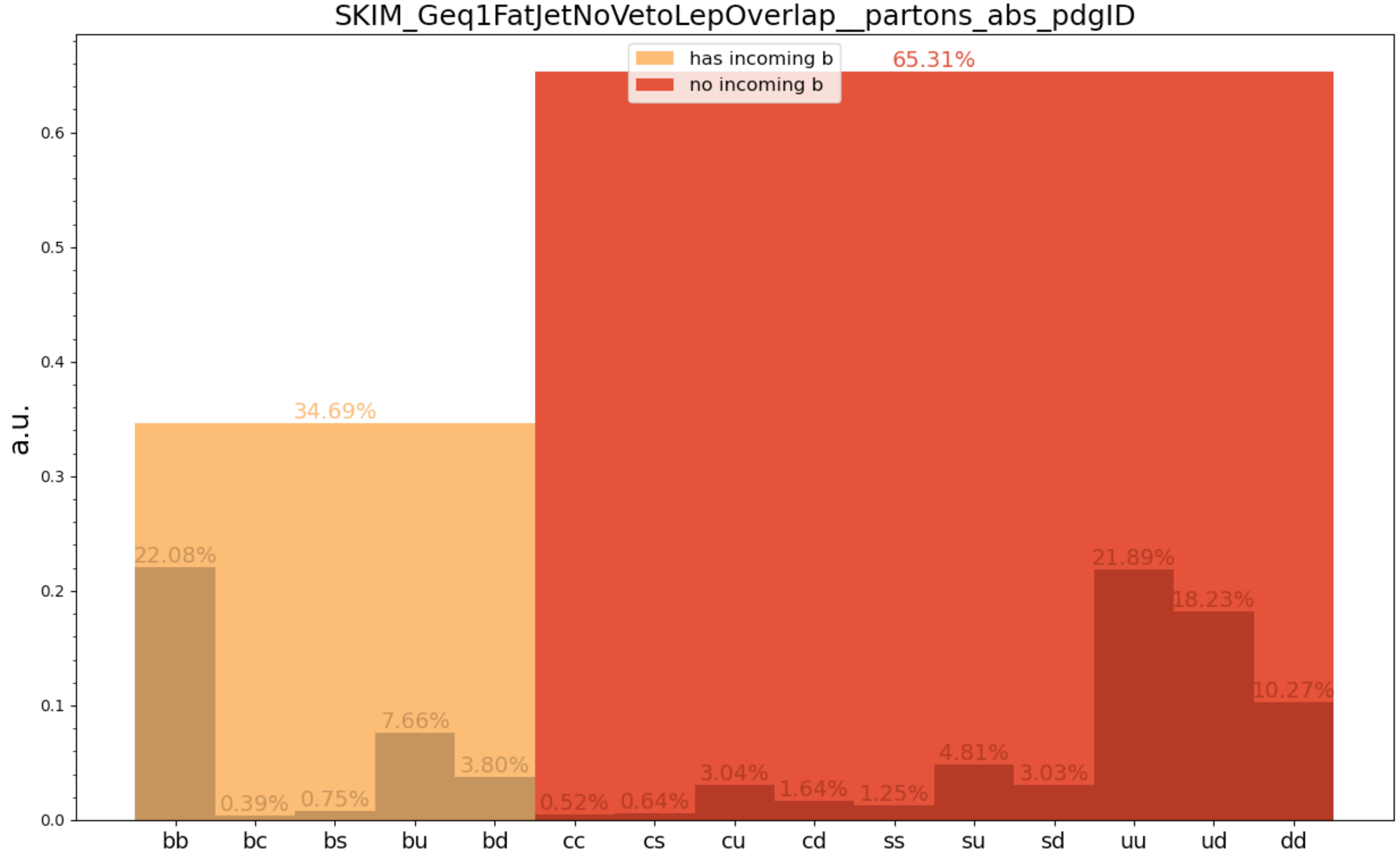
EWK W Contribution Breakdown

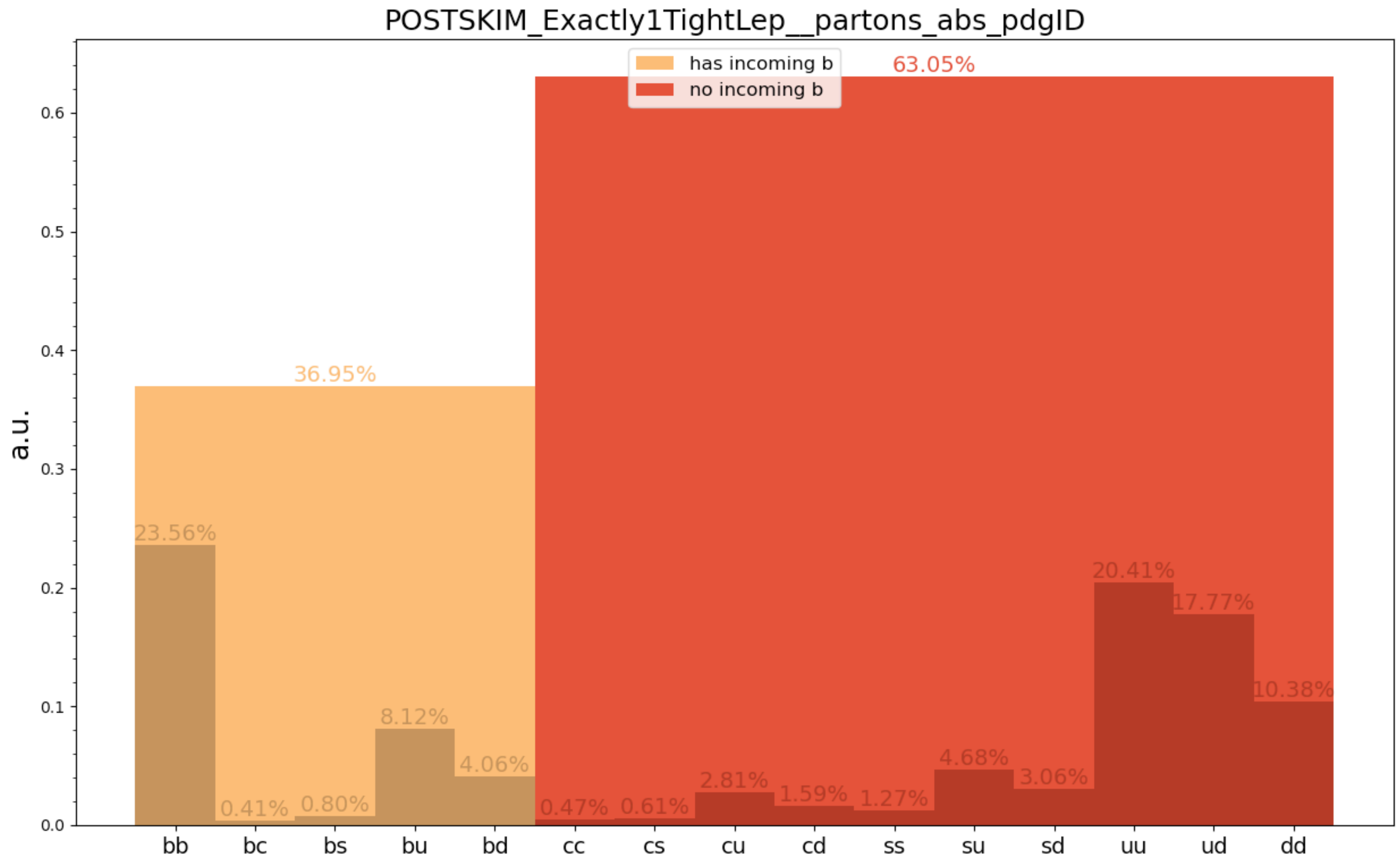
≥ 1 AK8 jets with p_T > 200 GeV AND mass > 10 GeV AND M_{SD} > 10 GeV AND dR(jet, any veto lep) > 0.8



Proportion of events with at least one incoming b quark has increased by x4

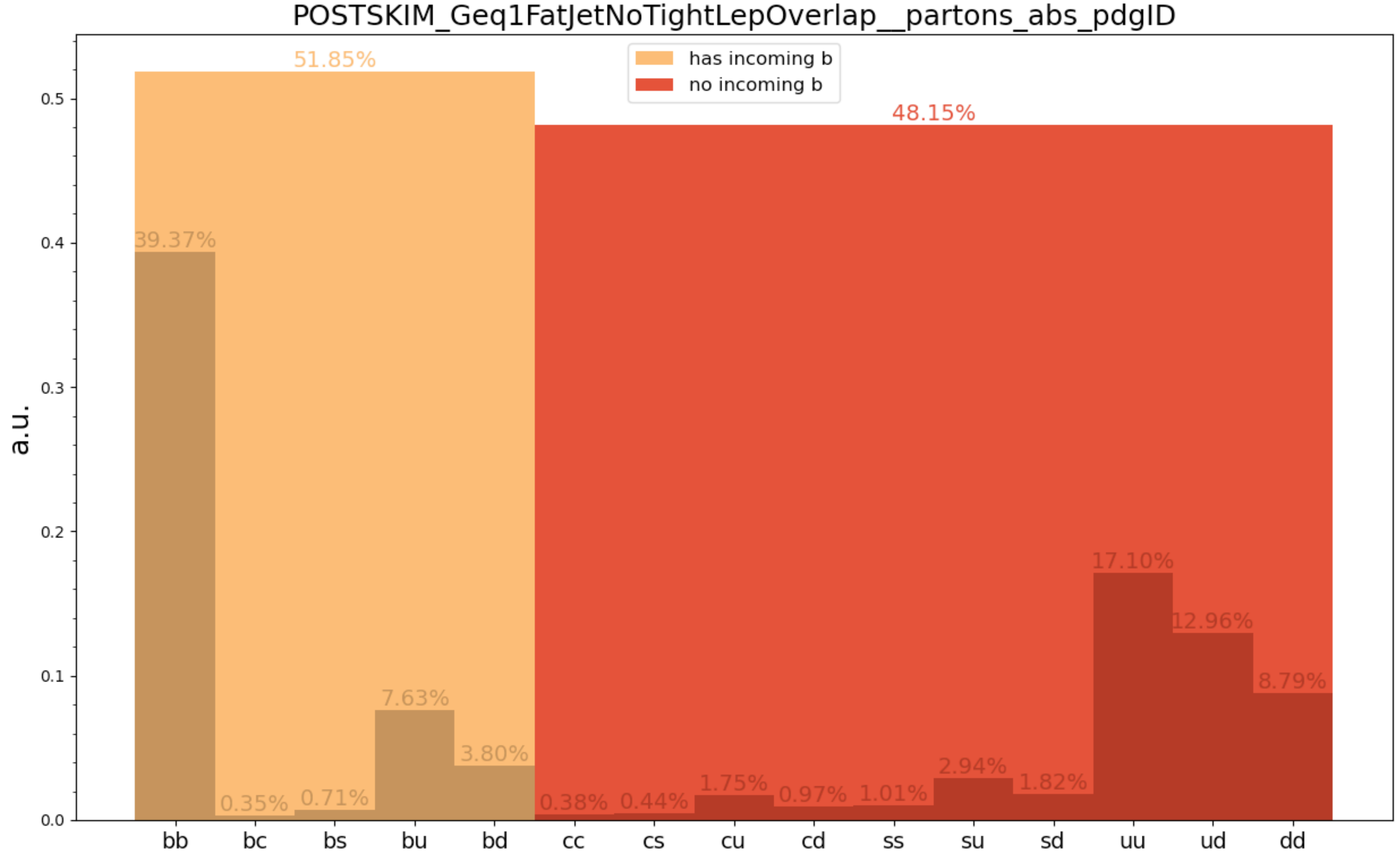
EWK W Contribution Breakdown

== 1 lepton passing ttH tight ID AND == 1 lepton passing ttH loose ID



EWK W Contribution Breakdown

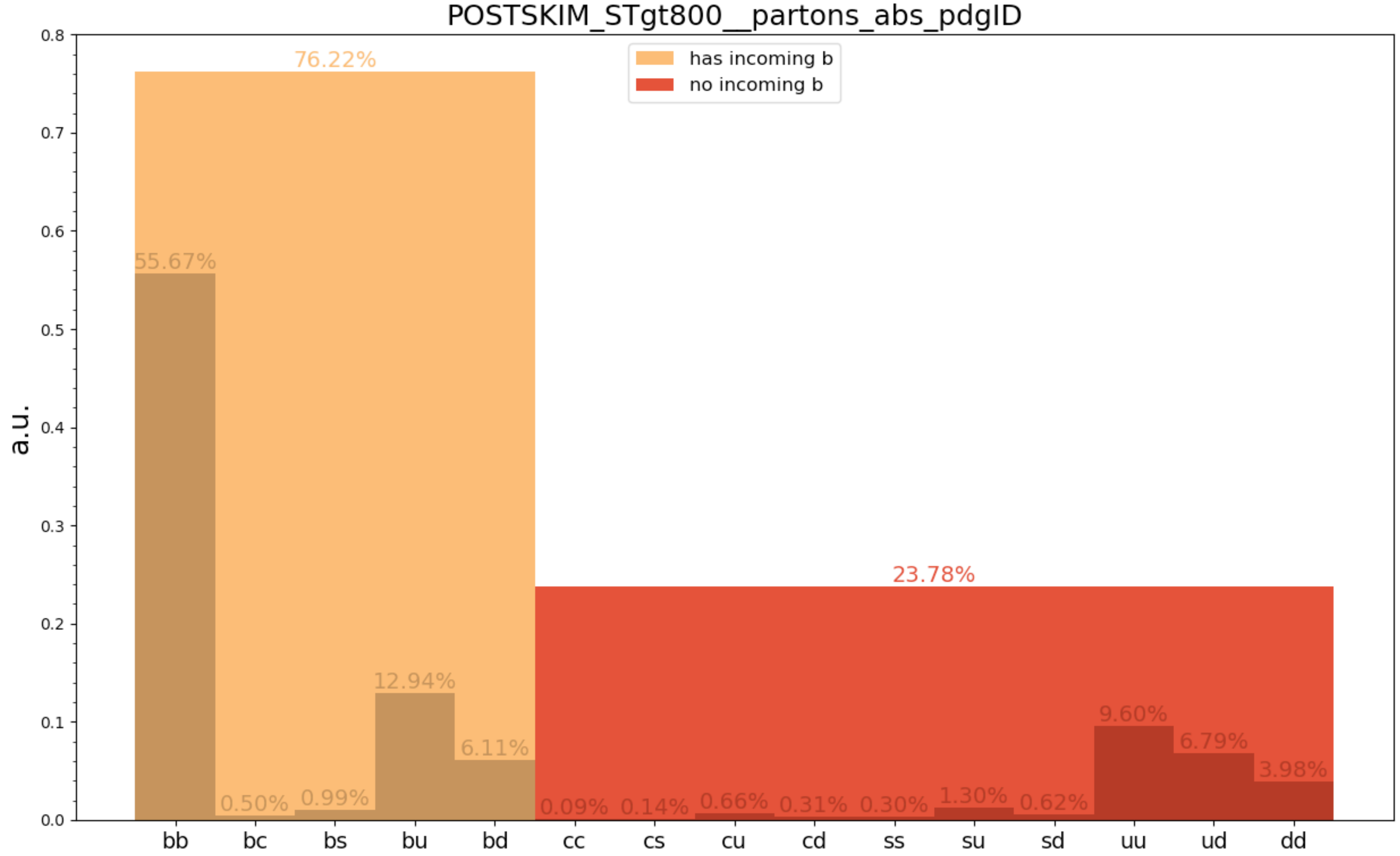
≥ 1 AK8 jets with p_T > 250 GeV AND mass > 50 GeV AND M_{SD} > 40 GeV AND dR(jet, tight lep) > 0.8



Proportion of events with at least one incoming b quark has increased by x1.5

EWK W Contribution Breakdown

S_T > 800 GeV where $S_T = p_T(\ell)$ + MET + p_T(AK8 jet w/ highest Xbb score)



Proportion of events with at least one incoming b quark has again increased by x1.5

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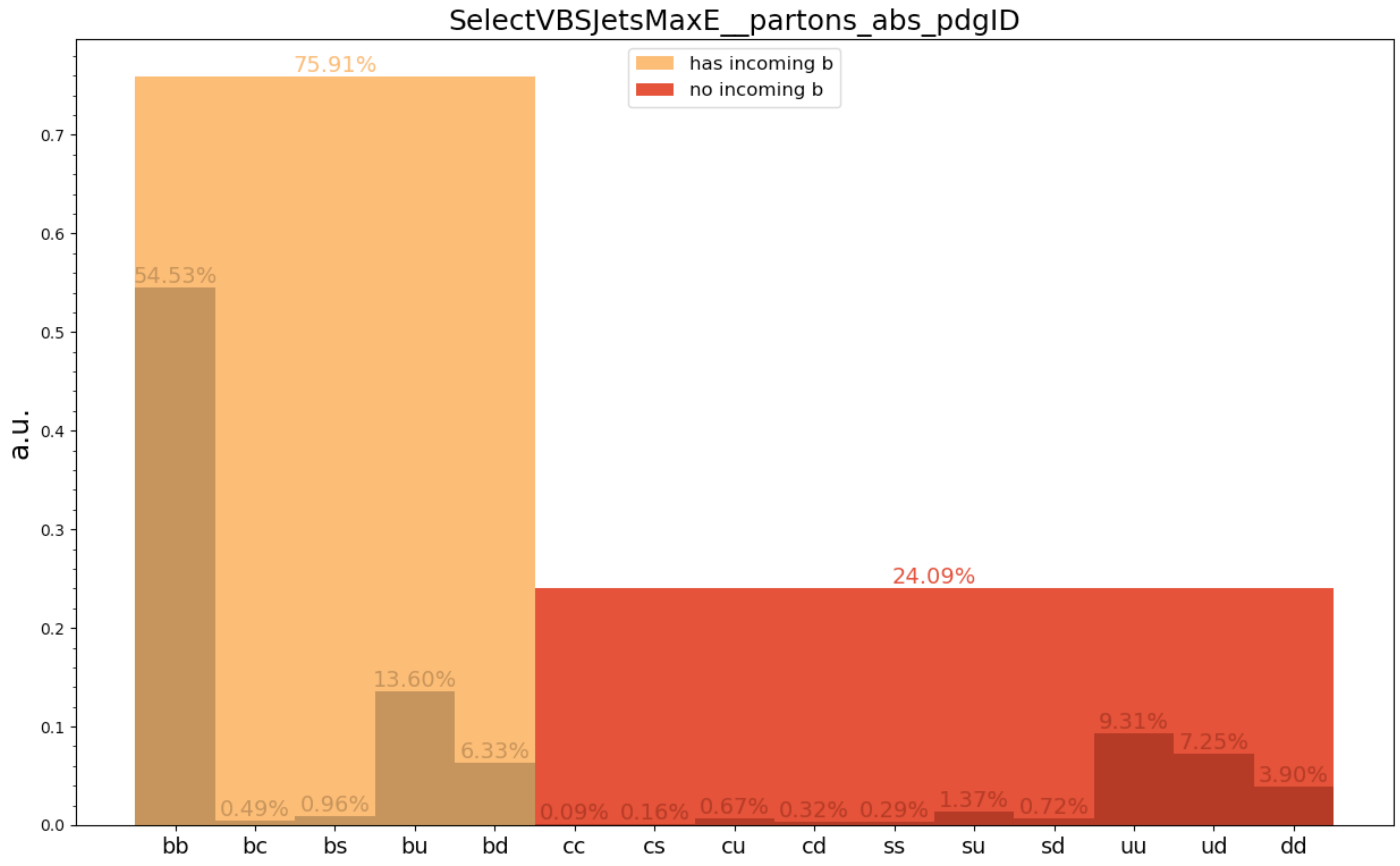
EWK W Contribution Breakdown

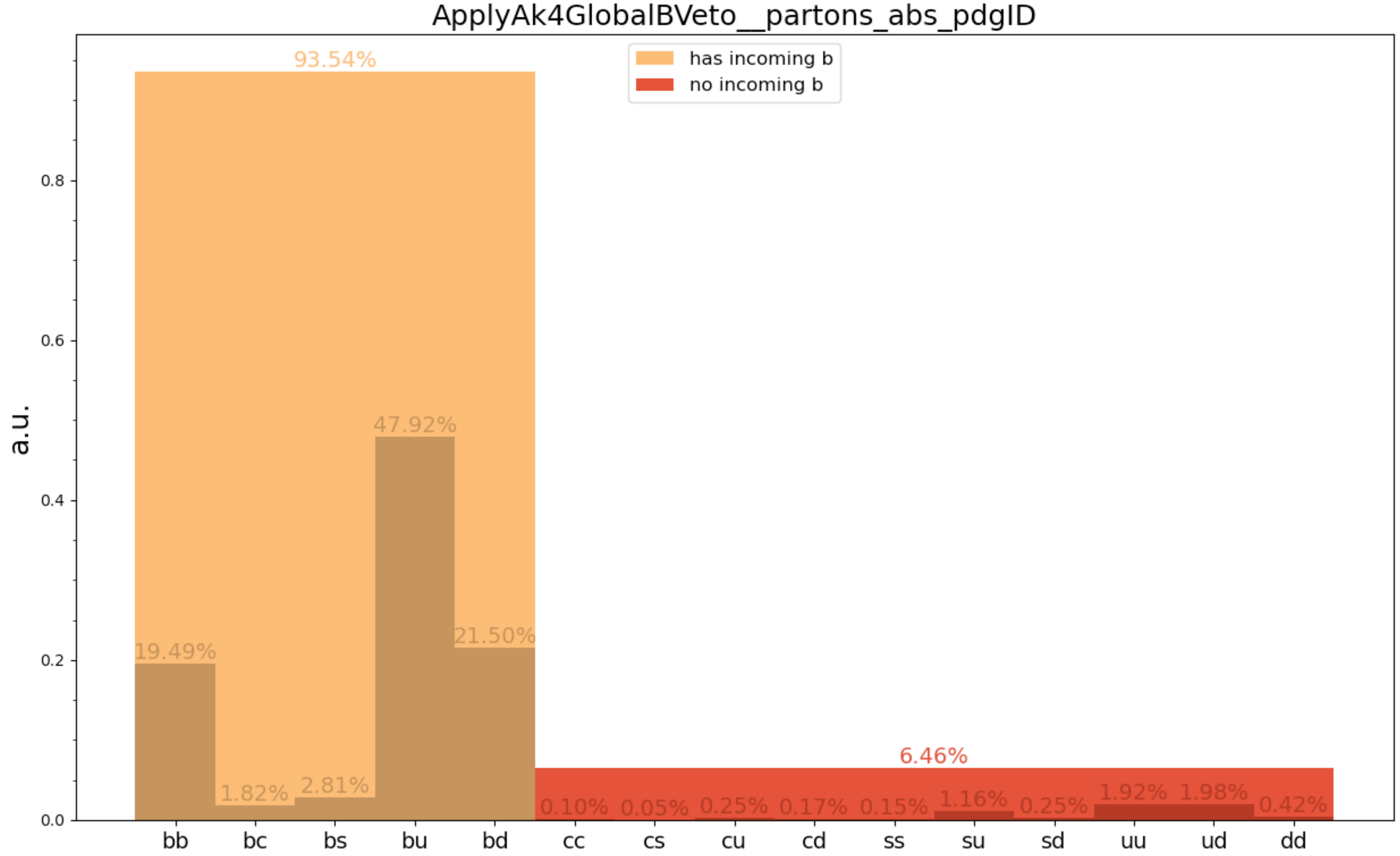
Object selection



EWK W Contribution Breakdown

M_{jj} > 500 GeV AND $|\Delta\eta_{jj}|$ > 3 AND Hbb jet Xbb score > 0.3 AND == 0 jets passing medium DeepJet b-tag

(Preselection)

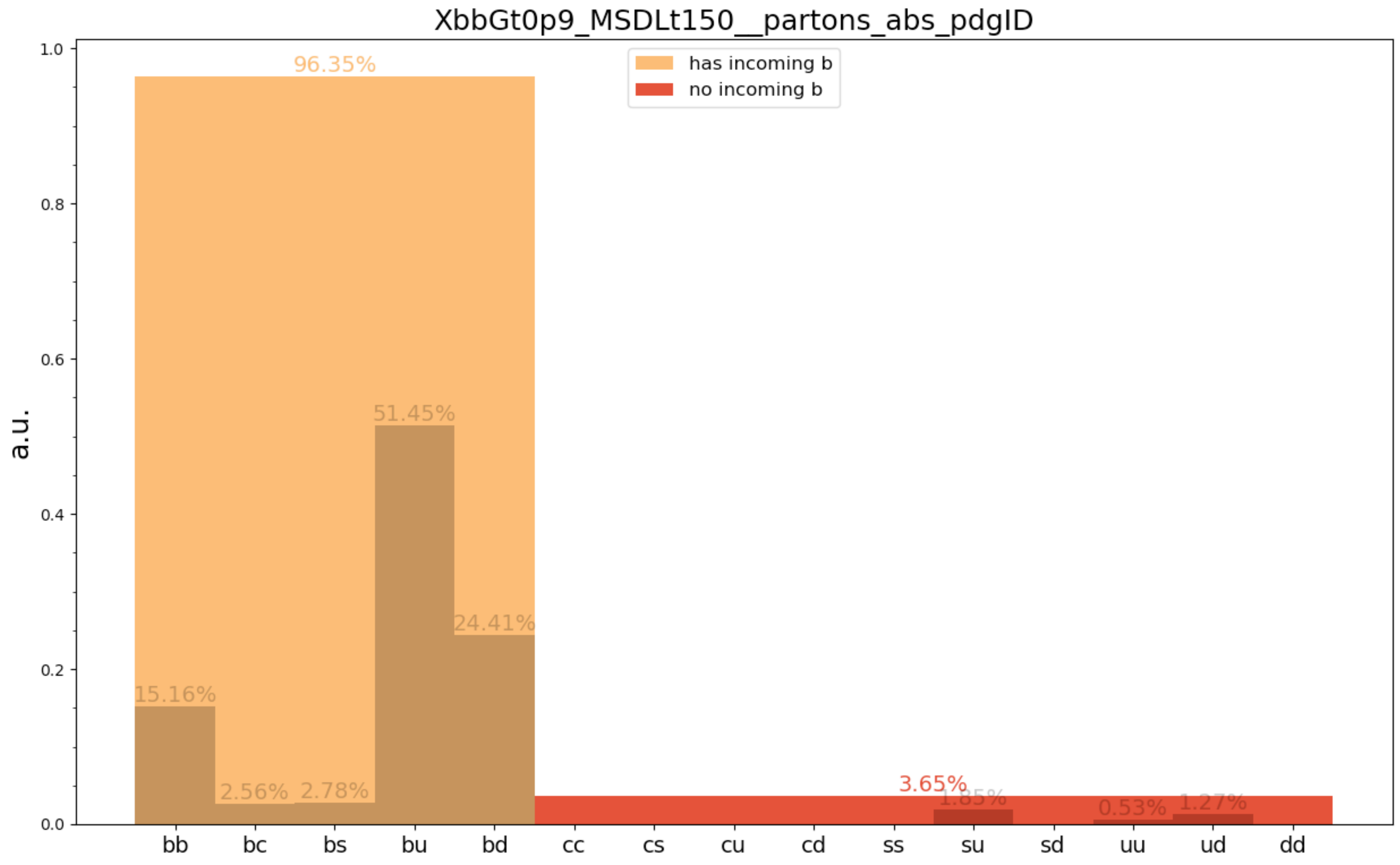


Proportion of events with at least one incoming b quark has again increased (now by x1.2)

EWK W Contribution Breakdown

M_{jj} > 600 GeV AND $|\Delta\eta_{jj}|$ > 4 AND S_T > 900 GeV AND Hbb jet Xbb score > 0.9 AND M_{SD} < 150 GeV

(SR1)

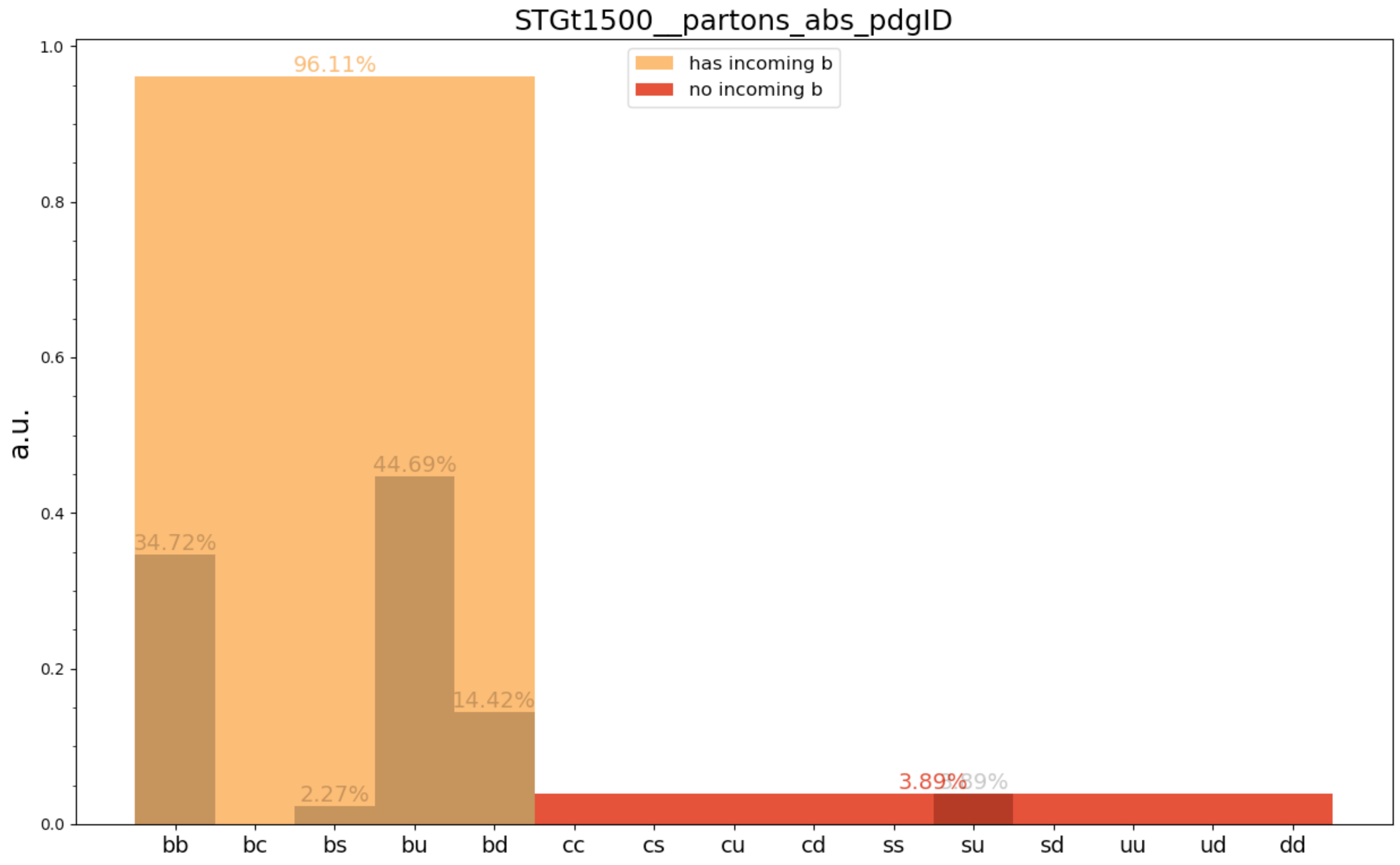


Almost all events have at least one incoming b quark

EWK W Contribution Breakdown

$S_T > 1500$ GeV

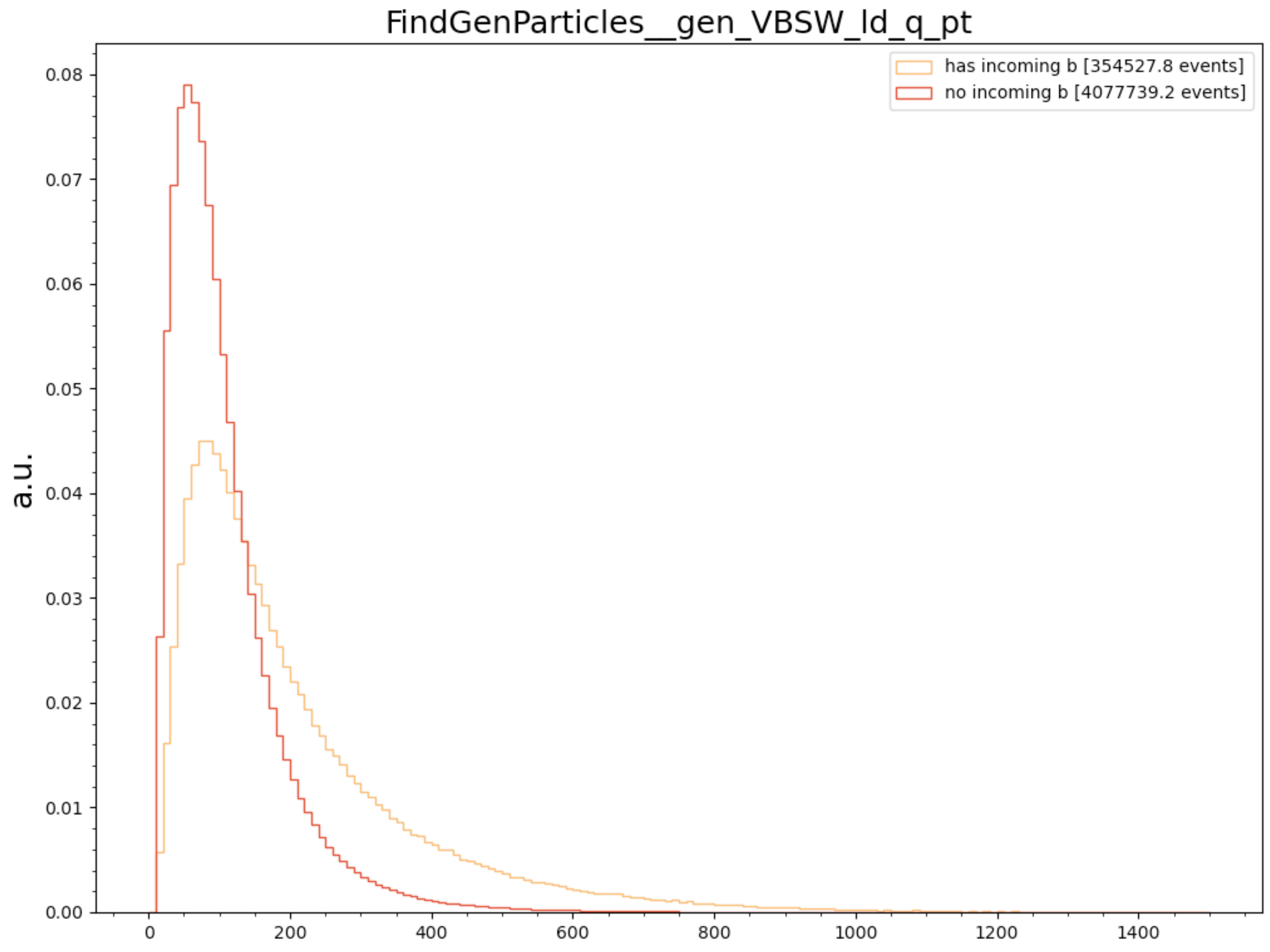
(SR2)

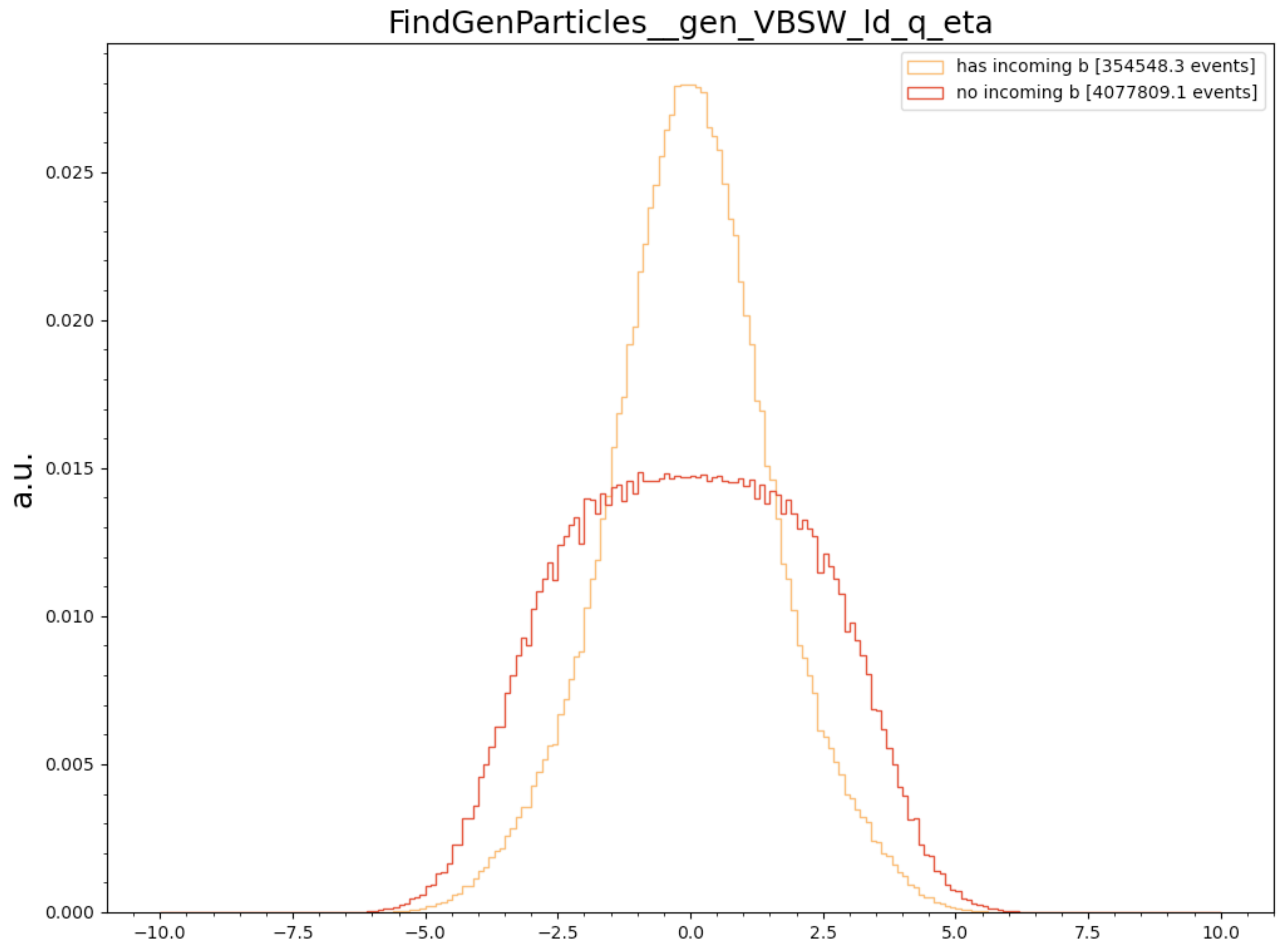


Almost all events have at least one incoming b quark

EWK W Contribution Breakdown

No selections applied





Leading VBS quark from events with incoming b quark has higher p_T and more central η

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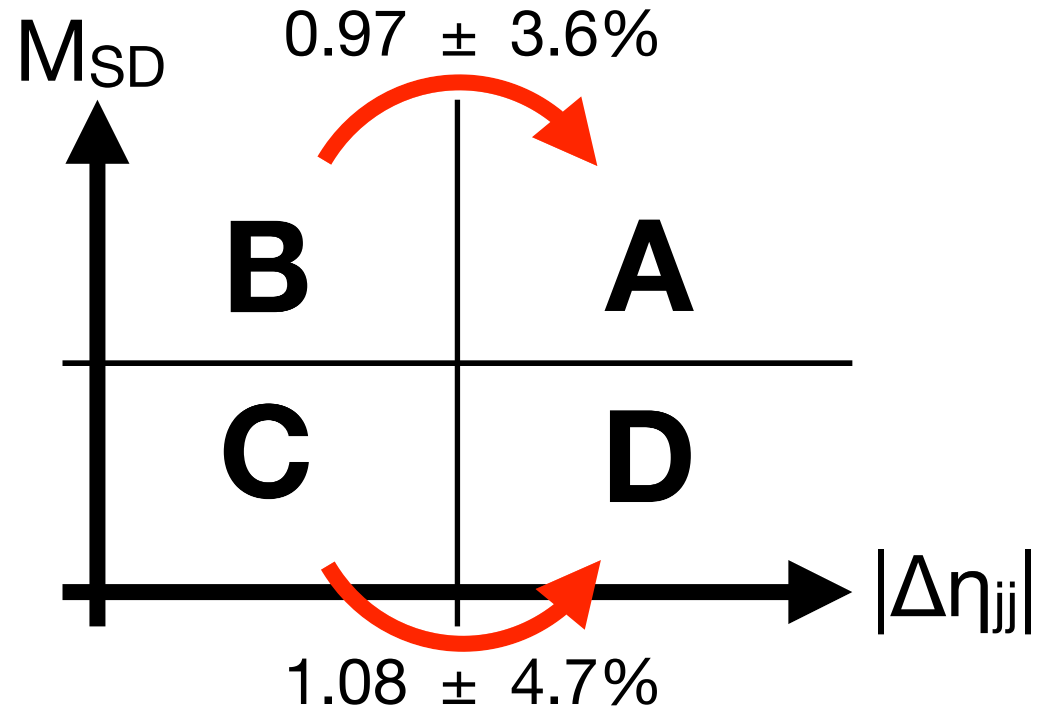
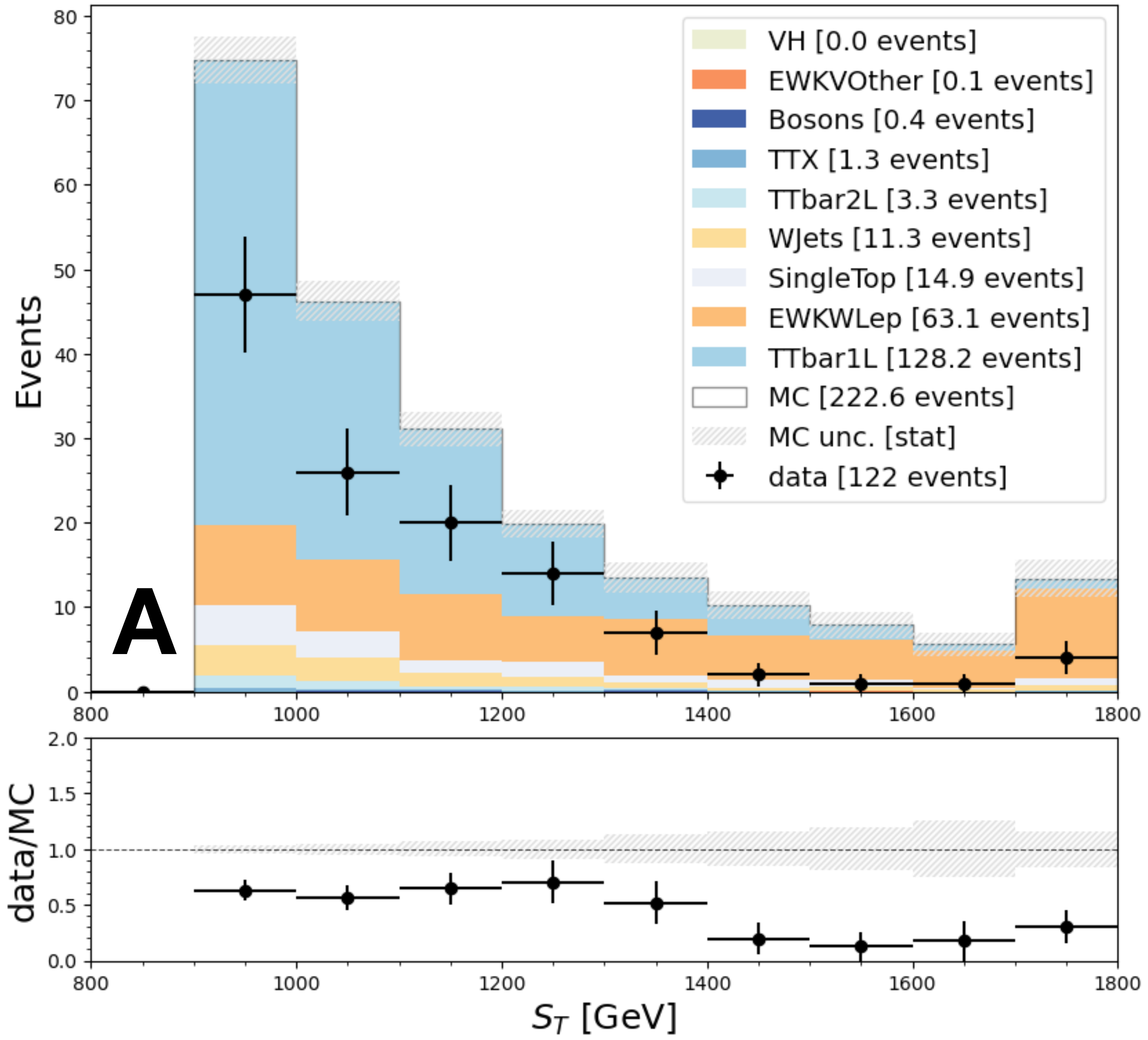
SR1 ABCD: After EWK

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.*
$\|\Delta\eta_{jj}\| > 4$ AND $M_{SD} \geq 150$ GeV	A	222.65	5.89	9.18	1.25	122	11.05
$\|\Delta\eta_{jj}\| \leq 4$ AND $M_{SD} \geq 150$ GeV	B	230.24	5.58	1.00	0.45	179	13.38
$\|\Delta\eta_{jj}\| \leq 4$ AND $M_{SD} < 150$ GeV	C	171.95	4.84	14.00	1.55	142	11.92
$\|\Delta\eta_{jj}\| > 4$ AND $M_{SD} < 150$ GeV (SR1)	D	185.91	6.90	370.22	8.16	–	–



- If we remove events with incoming b quarks, what happens?
- Recall: EWK W ($W \to \ell\nu$) 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
  - Now understand that almost ~all of these events come from incoming b quarks



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

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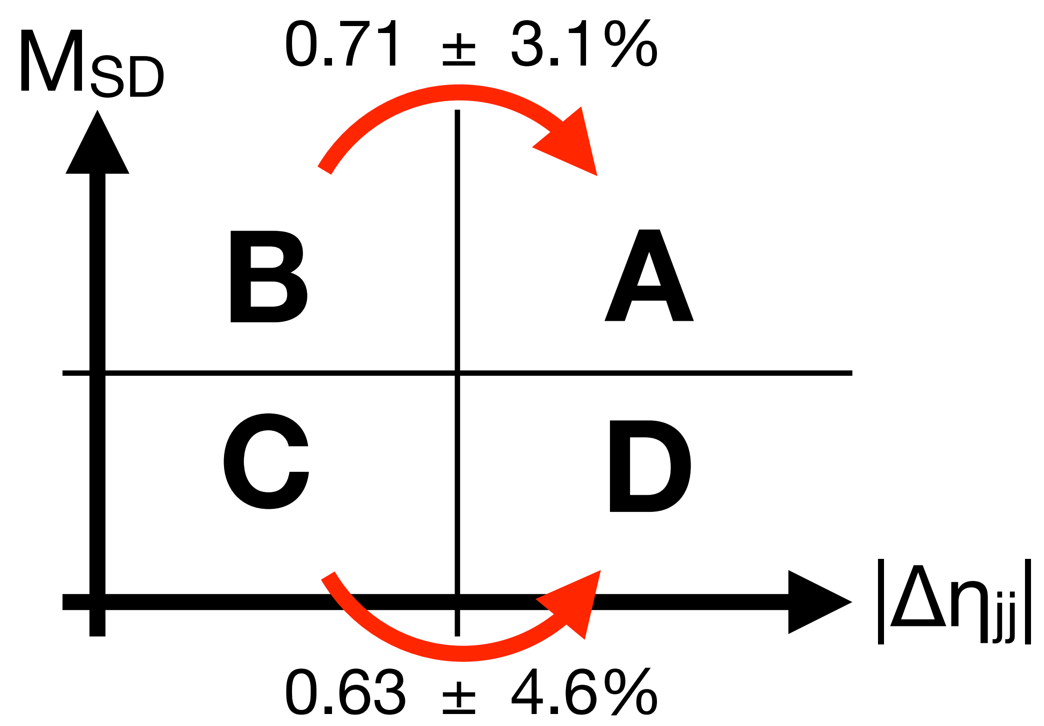
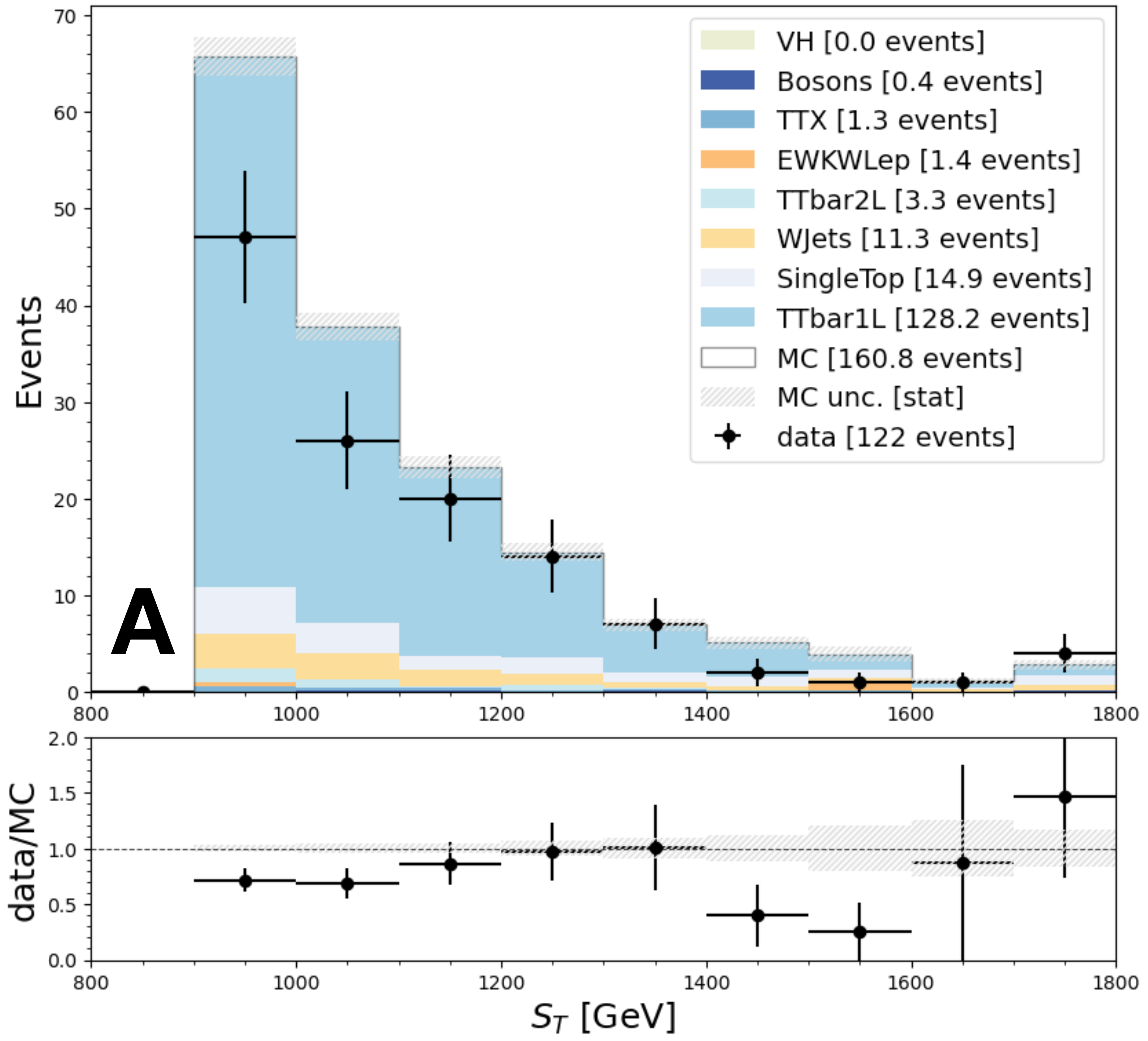
SR1 ABCD: EWK Fix

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.*
$\|\Delta\eta_{jj}\| > 4$ AND $M_{SD} \geq 150$ GeV	A	160.83	3.11	9.18	1.25	122	11.05
$\|\Delta\eta_{jj}\| \leq 4$ AND $M_{SD} \geq 150$ GeV	B	225.18	5.40	1.00	0.45	179	13.38
$\|\Delta\eta_{jj}\| \leq 4$ AND $M_{SD} < 150$ GeV	C	160.85	4.33	14.00	1.55	142	11.92
$\|\Delta\eta_{jj}\| > 4$ AND $M_{SD} < 150$ GeV (SR1)	D	100.61	3.71	370.22	8.16	–	–



- If we remove EWK W events with incoming b quarks, what happens?
  - `abs(LHEPart_pdgId[0]) != 5 && abs(LHEPart_pdgId[1]) != 5`
- Data/MC agreement is rescued
- Yields make more sense



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

Conclusions

- Adding EWK W samples results in disagreement in our CRs
- All of the events in this region and others come from events where at least one incoming quark is a b quark
    - EWK W samples are generated using 5-flavor scheme
- Given the problematic physics comes specifically from the 5f events, removing them resolves the original issue

Backup

Who is involved?

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

- U. Florida:
  P. Chang*

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

- UC Santa Barbara:
  C. Campagnari*

UC San Diego

UF UNIVERSITY of FLORIDA

BOSTON UNIVERSITY

UC SANTA BARBARA

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

BSM Signal Models

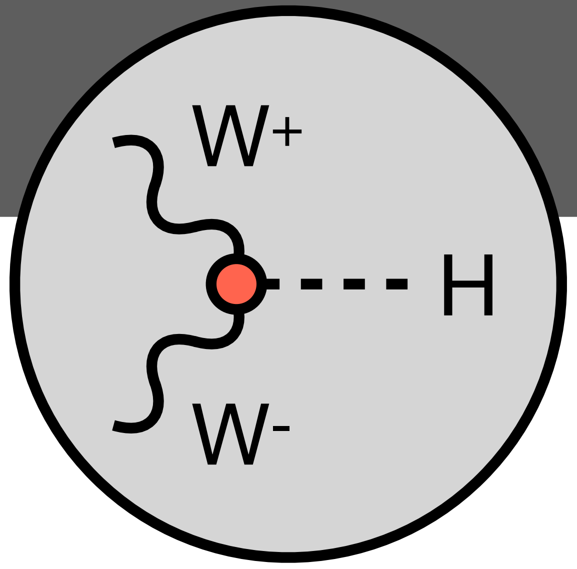
$\kappa_W = -1$

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})
```



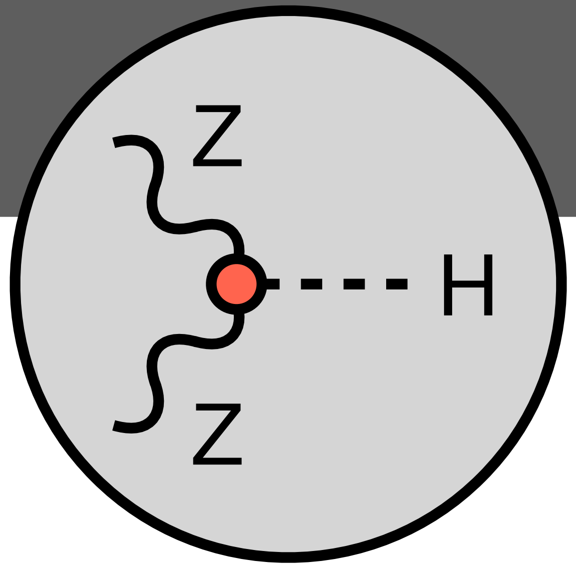
$\kappa_Z = -1$

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!

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

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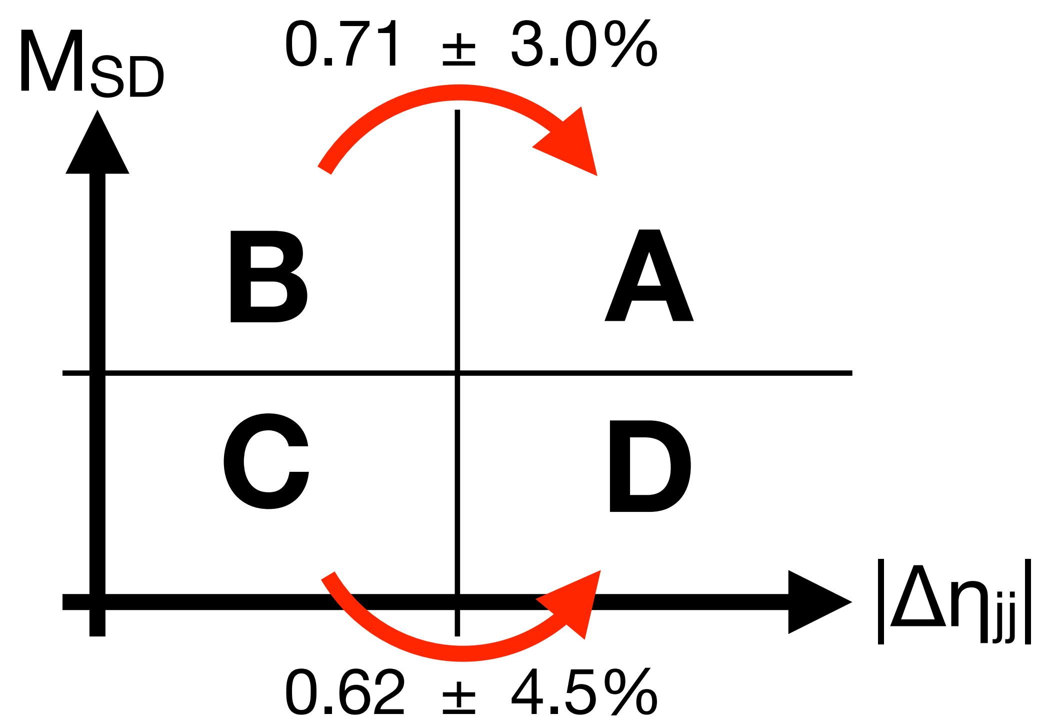
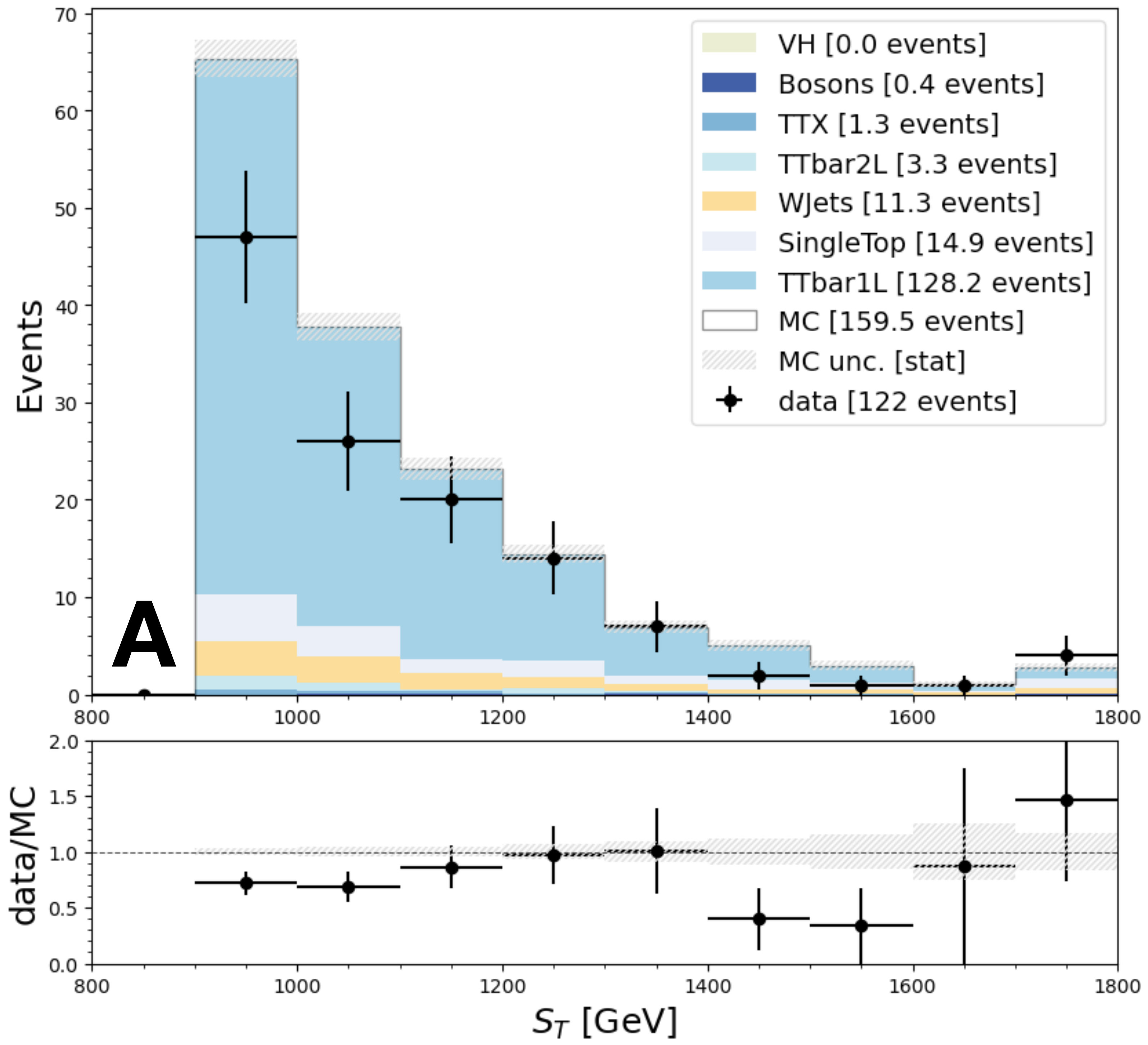
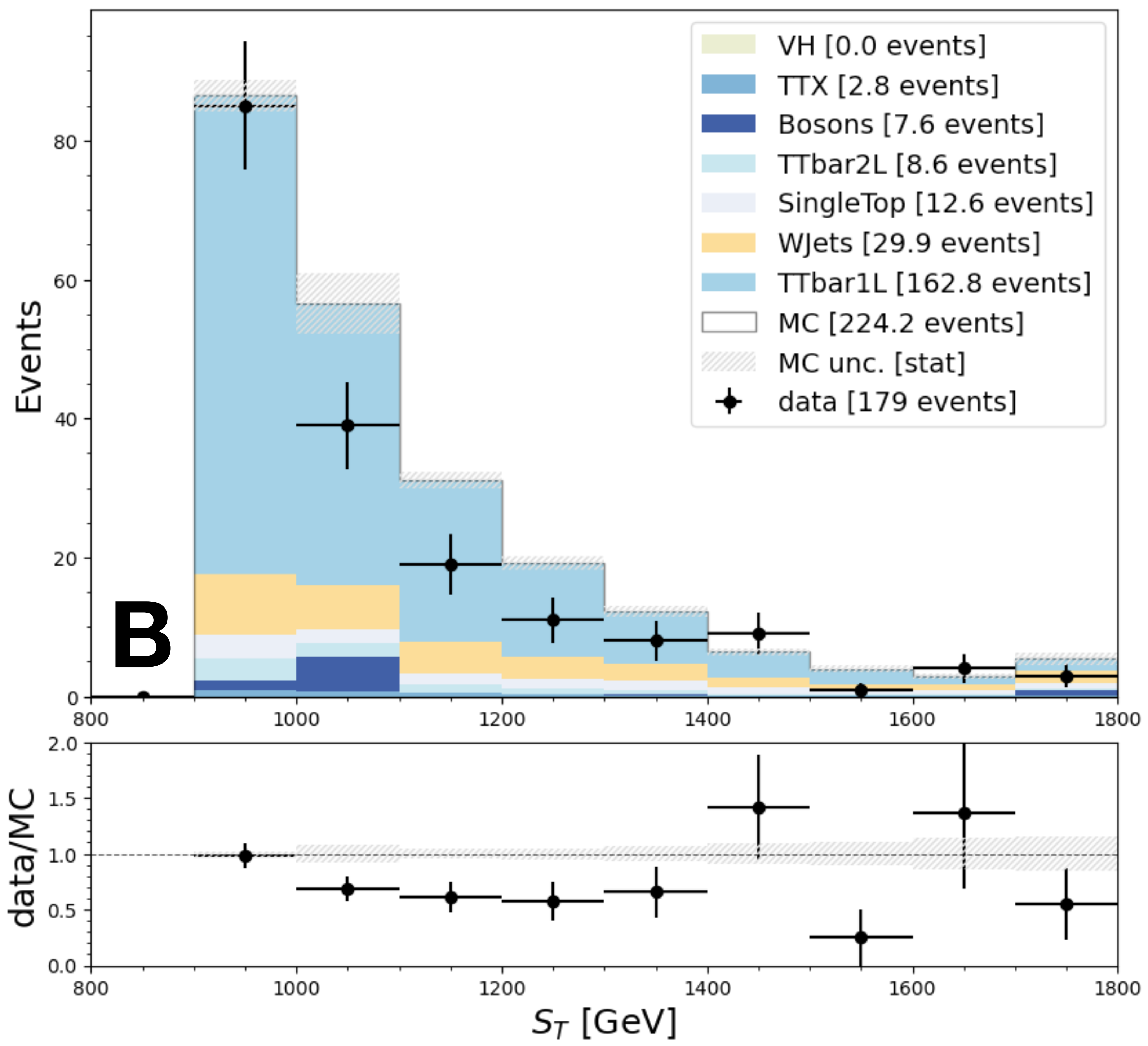
SR1 ABCD: Before EWK

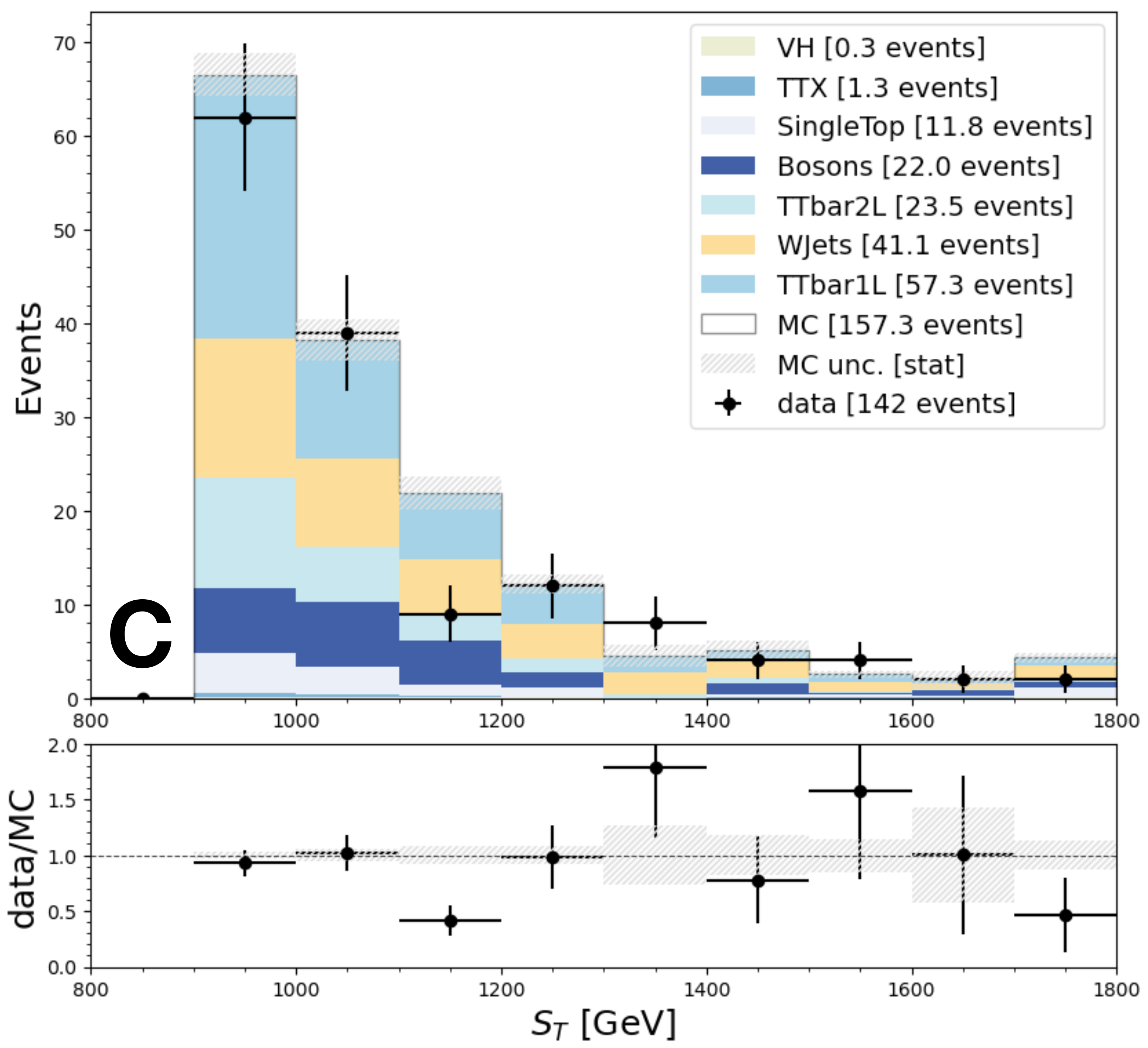
Presel. (w/out $\Delta\eta_{jj}$ cut) AND M_{jj} > 600 GeV AND S_T > 900 GeV AND PNet Xbb > 0.9

Cut	Region	Bkg. (wgt)	Bkg. Err.*	Sig. (wgt)	Sig. Err.*	Data	Data Err.*
$\lvert\Delta\eta_{jj}\rvert > 4$ AND $M_{SD} \geq 150$ GeV	A	159.46	3.01	9.18	1.25	122	11.05
$\lvert\Delta\eta_{jj}\rvert \leq 4$ AND $M_{SD} \geq 150$ GeV	B	224.25	5.36	1.00	0.45	179	13.38
$\lvert\Delta\eta_{jj}\rvert \leq 4$ AND $M_{SD} < 150$ GeV	C	157.34	4.16	14.00	1.55	142	11.92
$\lvert\Delta\eta_{jj}\rvert > 4$ AND $M_{SD} < 150$ GeV (SR1)	D	96.96	3.48	370.22	8.16	—	—







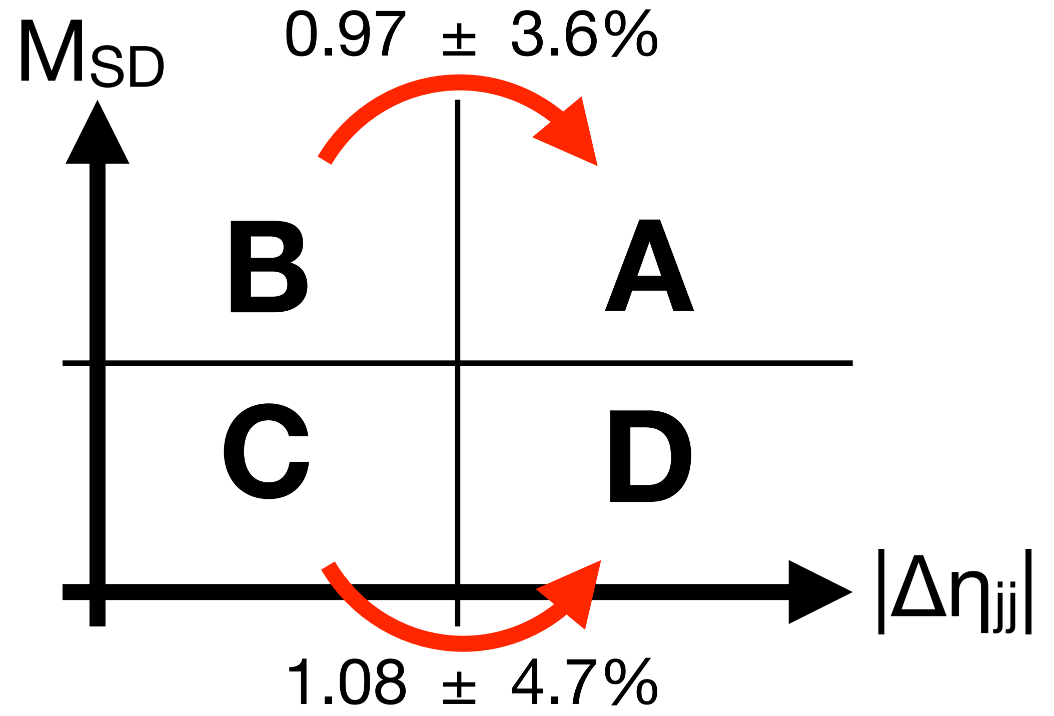


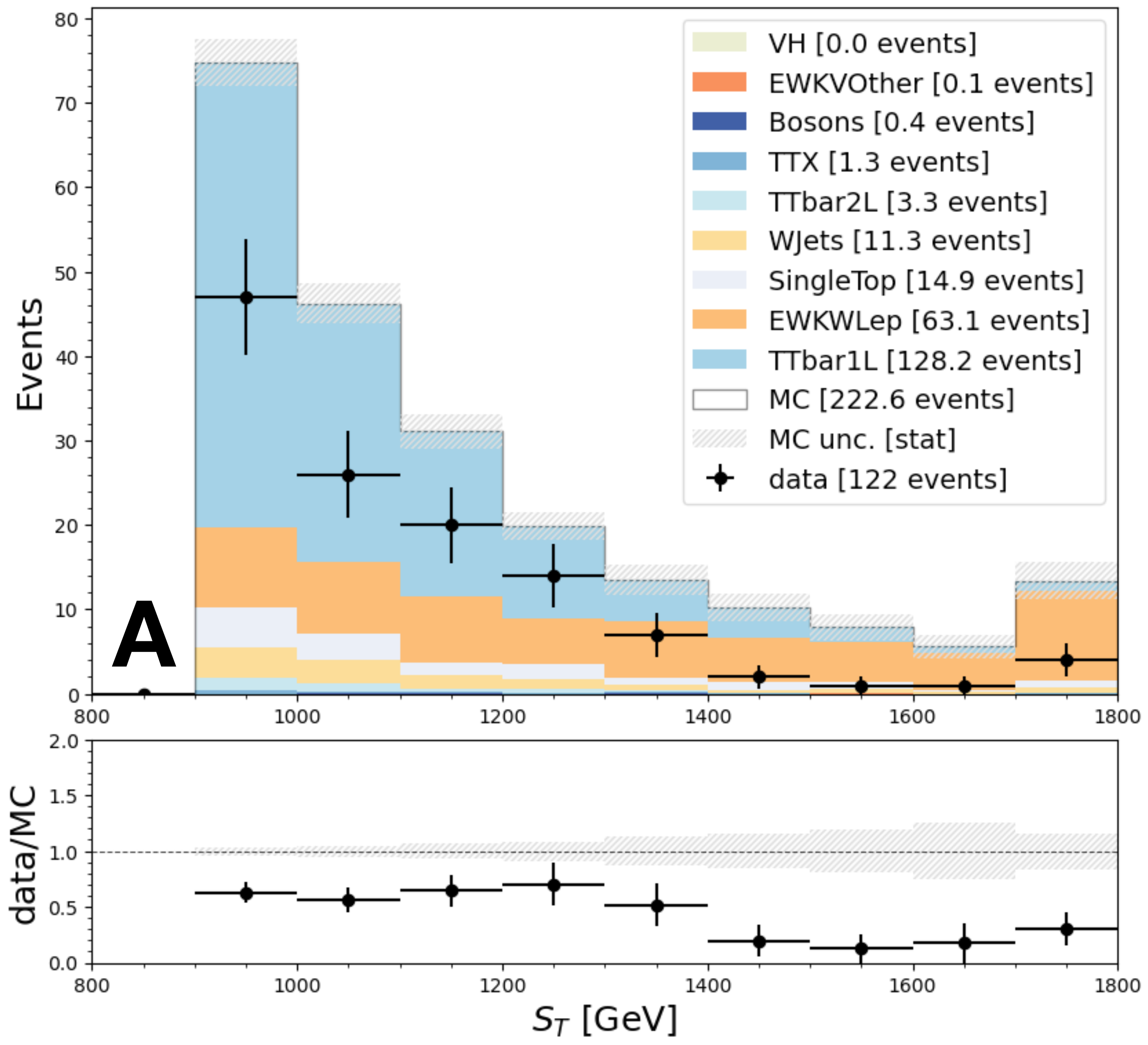
*err = $\sqrt{(\Sigma_i w_i^2)}$ for MC, $\sqrt{(\text{count})}$ for data

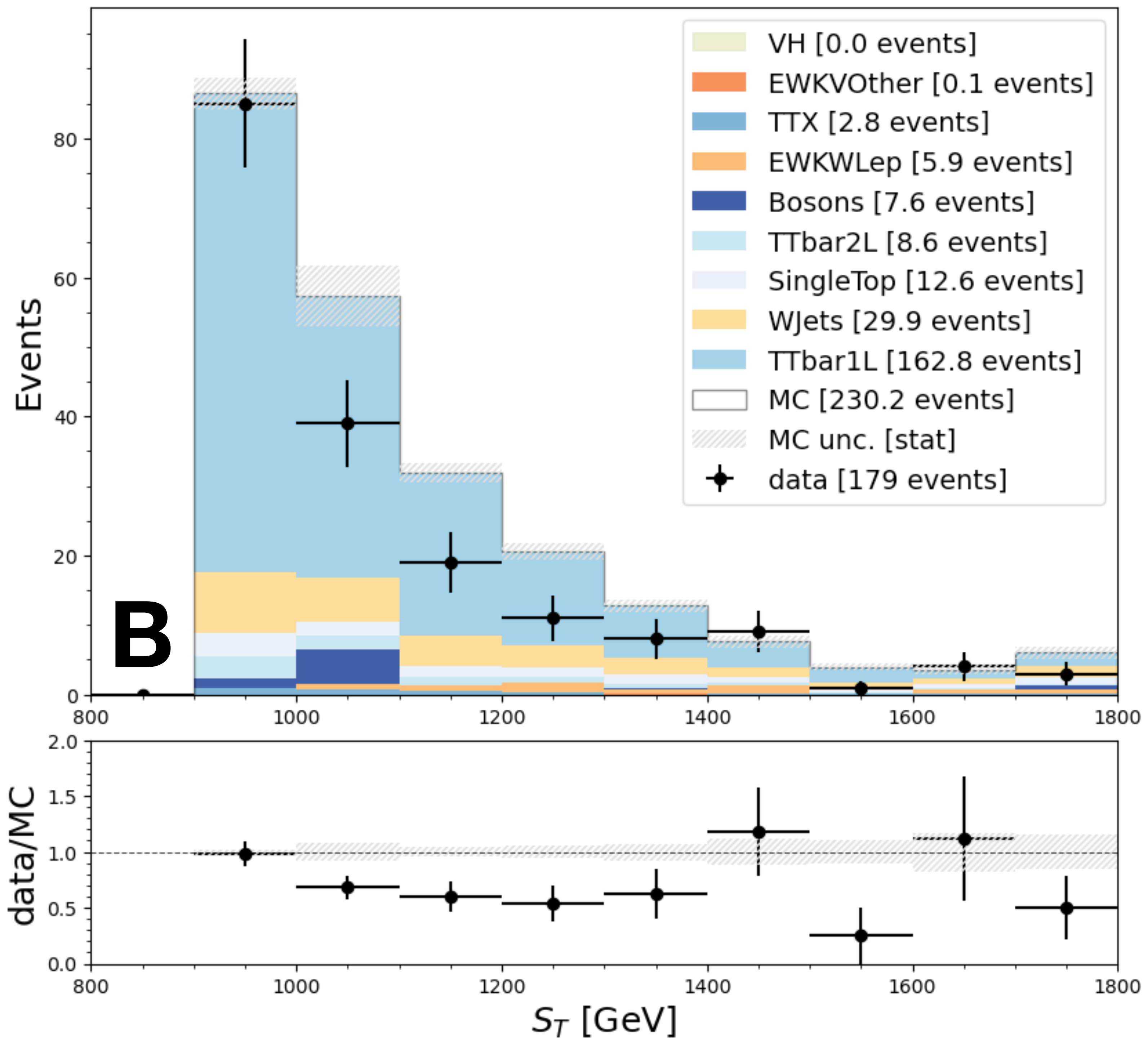
SR1 ABCD: After EWK

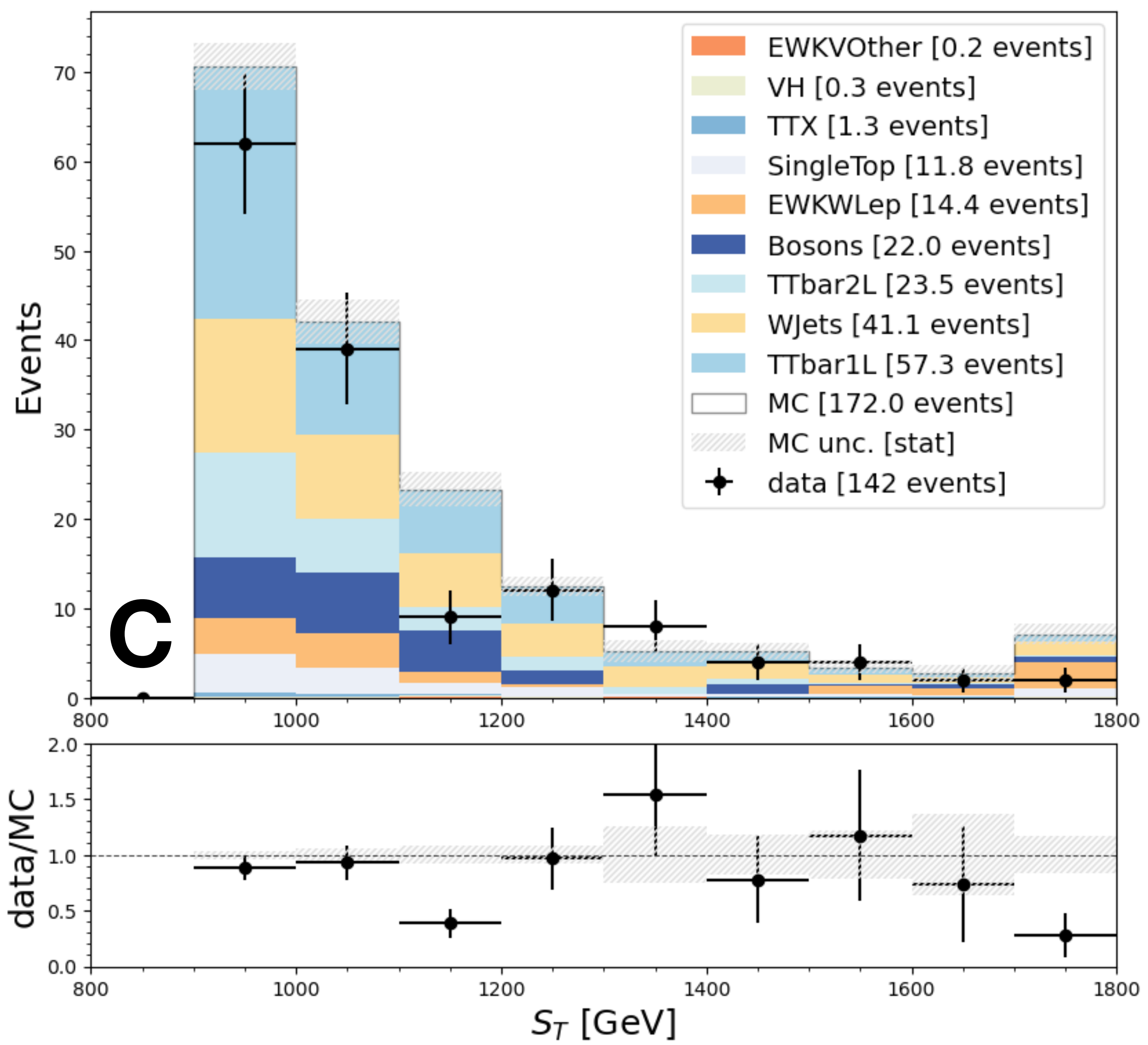
Presel. (w/out $\Delta\eta_{jj}$ cut) AND M_{jj} > 600 GeV AND S_T > 900 GeV AND PNet Xbb > 0.9

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	222.65	5.89	9.18	1.25	122	11.05
$\lvert\Delta\eta_{jj}\rvert$ ≤ 4 AND M_{SD} ≥ 150 GeV	B	230.24	5.58	1.00	0.45	179	13.38
$\lvert\Delta\eta_{jj}\rvert$ ≤ 4 AND M_{SD} < 150 GeV	C	171.95	4.84	14.00	1.55	142	11.92
$\lvert\Delta\eta_{jj}\rvert$ > 4 AND M_{SD} < 150 GeV (SR1)	D	185.91	6.90	370.22	8.16	–	–









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

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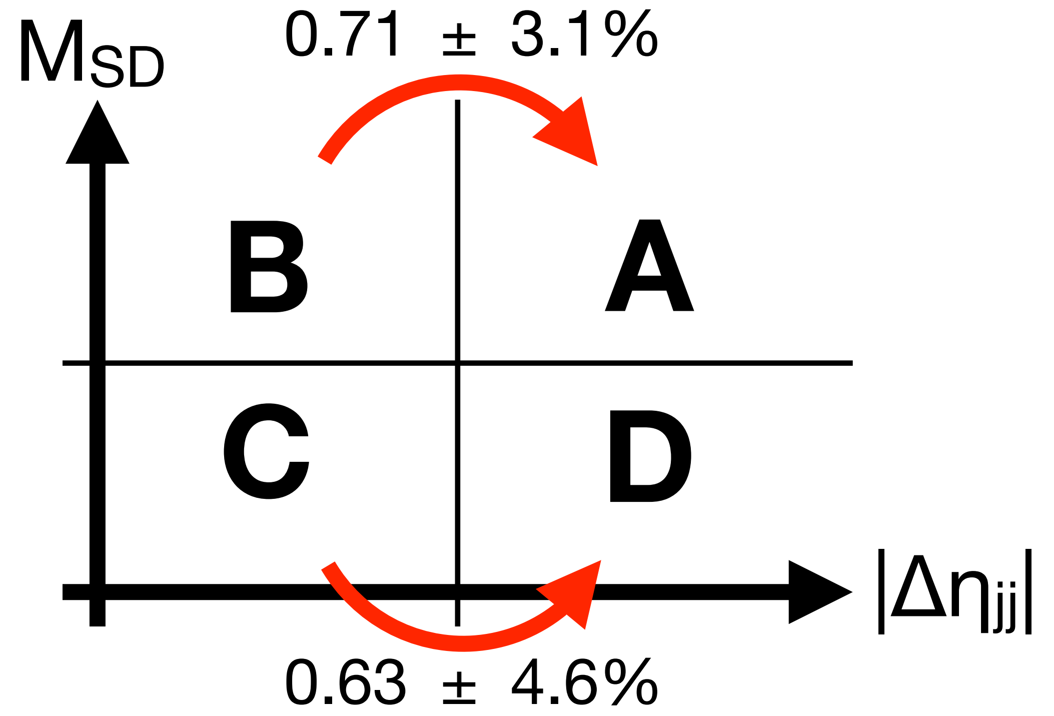
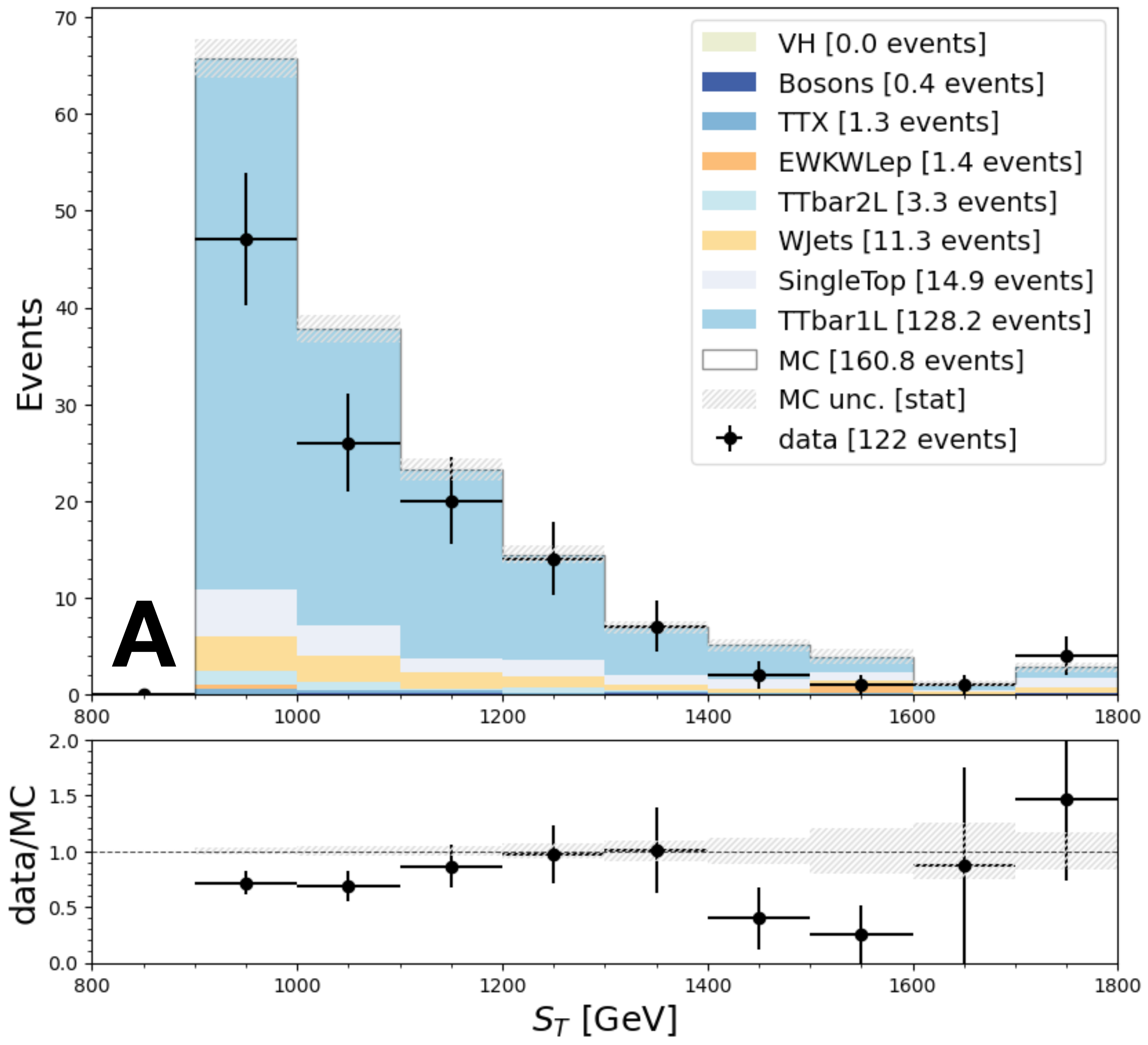
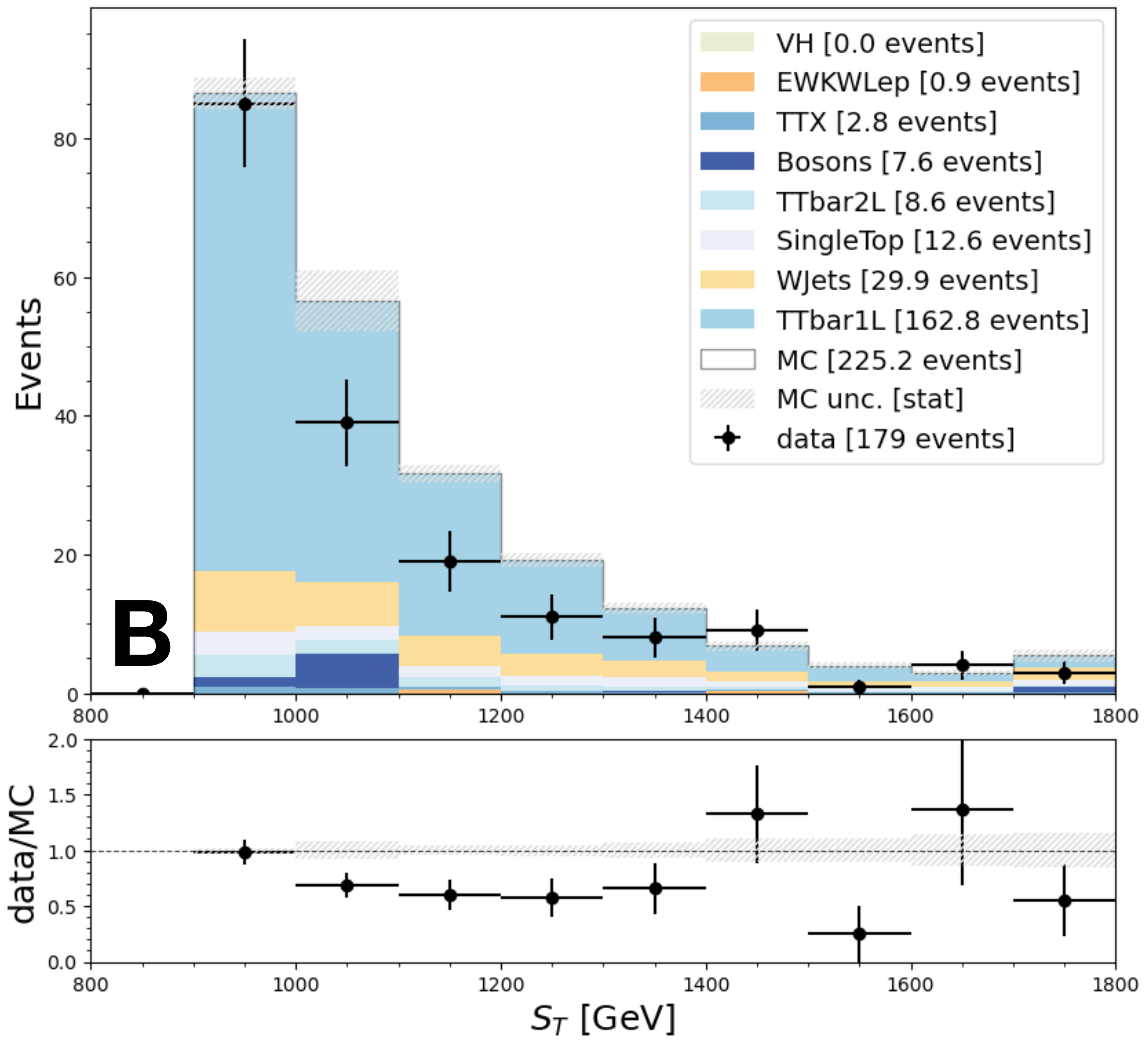
SR1 ABCD: EWK Fix

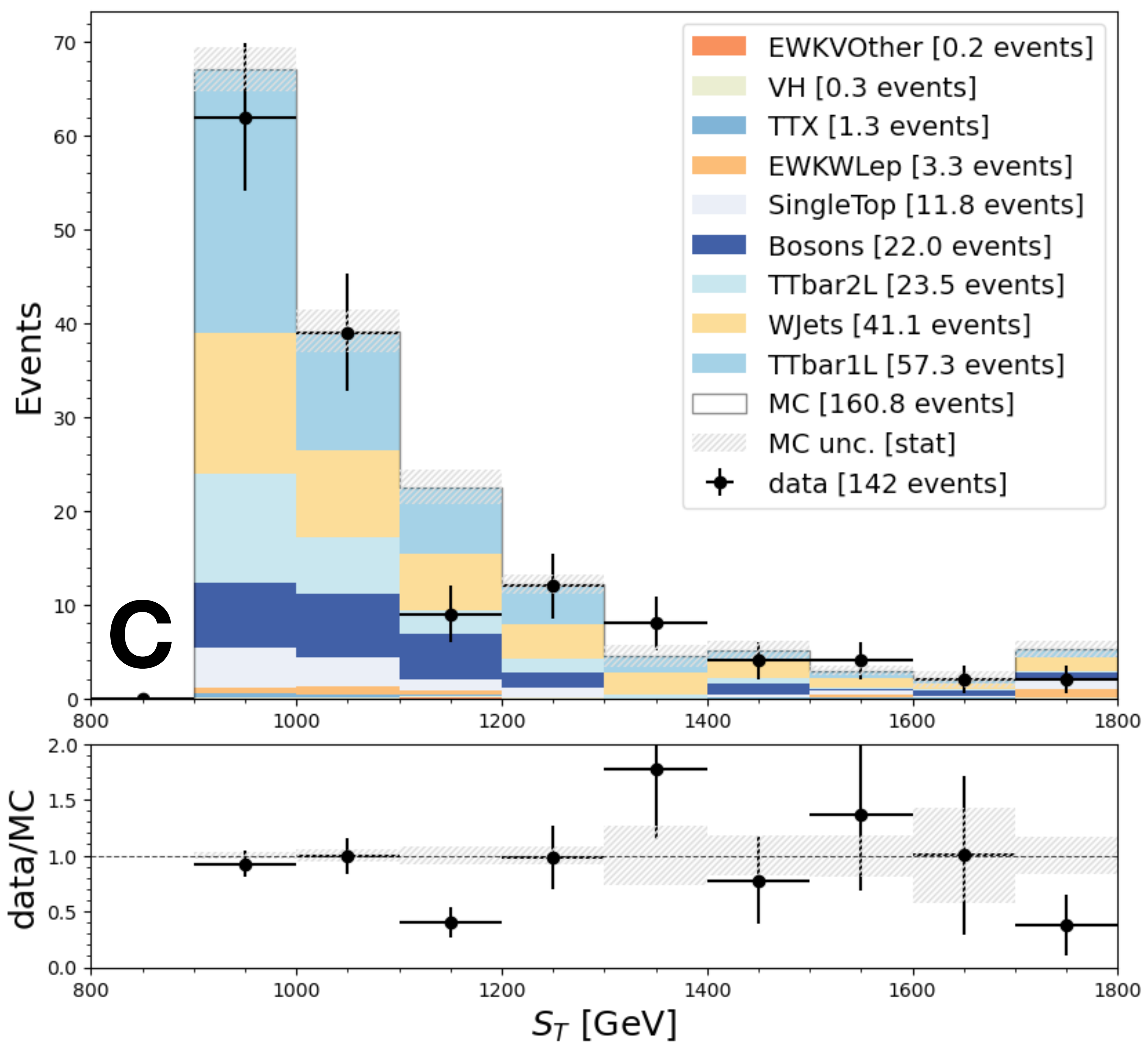
Presel. (w/out $\Delta\eta_{jj}$ cut) AND M_{jj} > 600 GeV AND S_T > 900 GeV AND PNet Xbb > 0.9

Cut	Region	Bkg. (wgt)	Bkg. Err.*	Sig. (wgt)	Sig. Err.*	Data	Data Err.*
$\|\Delta\eta_{jj}\|$ > 4 AND M_{SD} ≥ 150 GeV	A	160.83	3.11	9.18	1.25	122	11.05
$\|\Delta\eta_{jj}\|$ ≤ 4 AND M_{SD} ≥ 150 GeV	B	225.18	5.40	1.00	0.45	179	13.38
$\|\Delta\eta_{jj}\|$ ≤ 4 AND M_{SD} < 150 GeV	C	160.85	4.33	14.00	1.55	142	11.92
$\|\Delta\eta_{jj}\|$ > 4 AND M_{SD} < 150 GeV (SR1)	D	100.61	3.71	370.22	8.16	–	–









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

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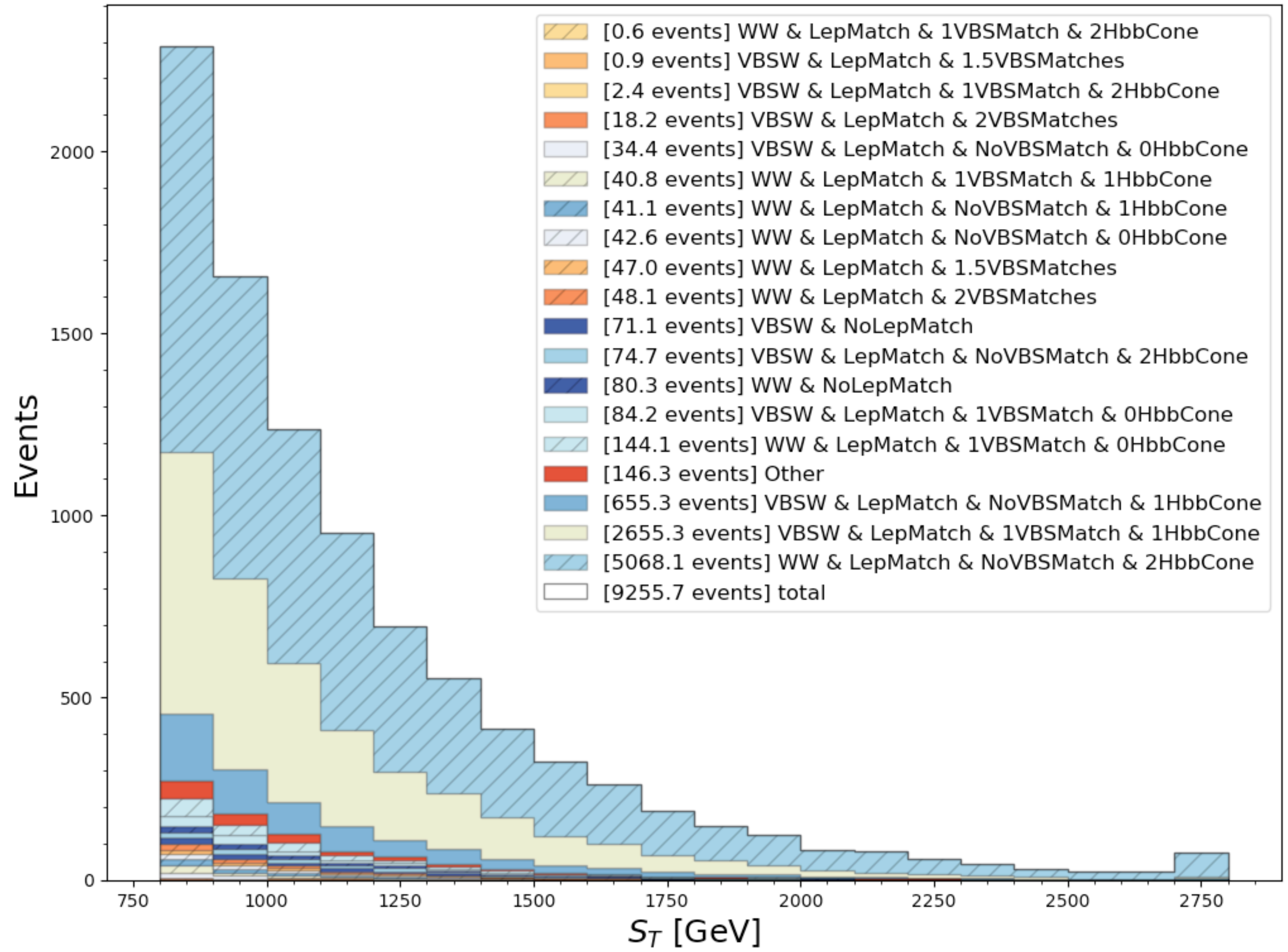
EWK W Contribution Breakdown

Label	Yield
VBSW & NoLepMatch	71.1
WW & NoLepMatch	80.3
VBSW & LepMatch & NoVBSMatch & 0HbbCone	34.4
WW & LepMatch & NoVBSMatch & 0HbbCone	42.6
VBSW & LepMatch & NoVBSMatch & 1HbbCone	655.3
WW & LepMatch & NoVBSMatch & 1HbbCone	41.1
VBSW & LepMatch & NoVBSMatch & 2HbbCone	74.7
WW & LepMatch & NoVBSMatch & 2HbbCone	5068.1
VBSW & LepMatch & 1VBSMatch & 0HbbCone	84.2
WW & LepMatch & 1VBSMatch & 0HbbCone	144.1
VBSW & LepMatch & 1VBSMatch & 1HbbCone	2655.3
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	47.0
VBSW & LepMatch & 2VBSMatches	18.2
WW & LepMatch & 2VBSMatches	48.1
Other	146.3
Total	9255.7

Object selection

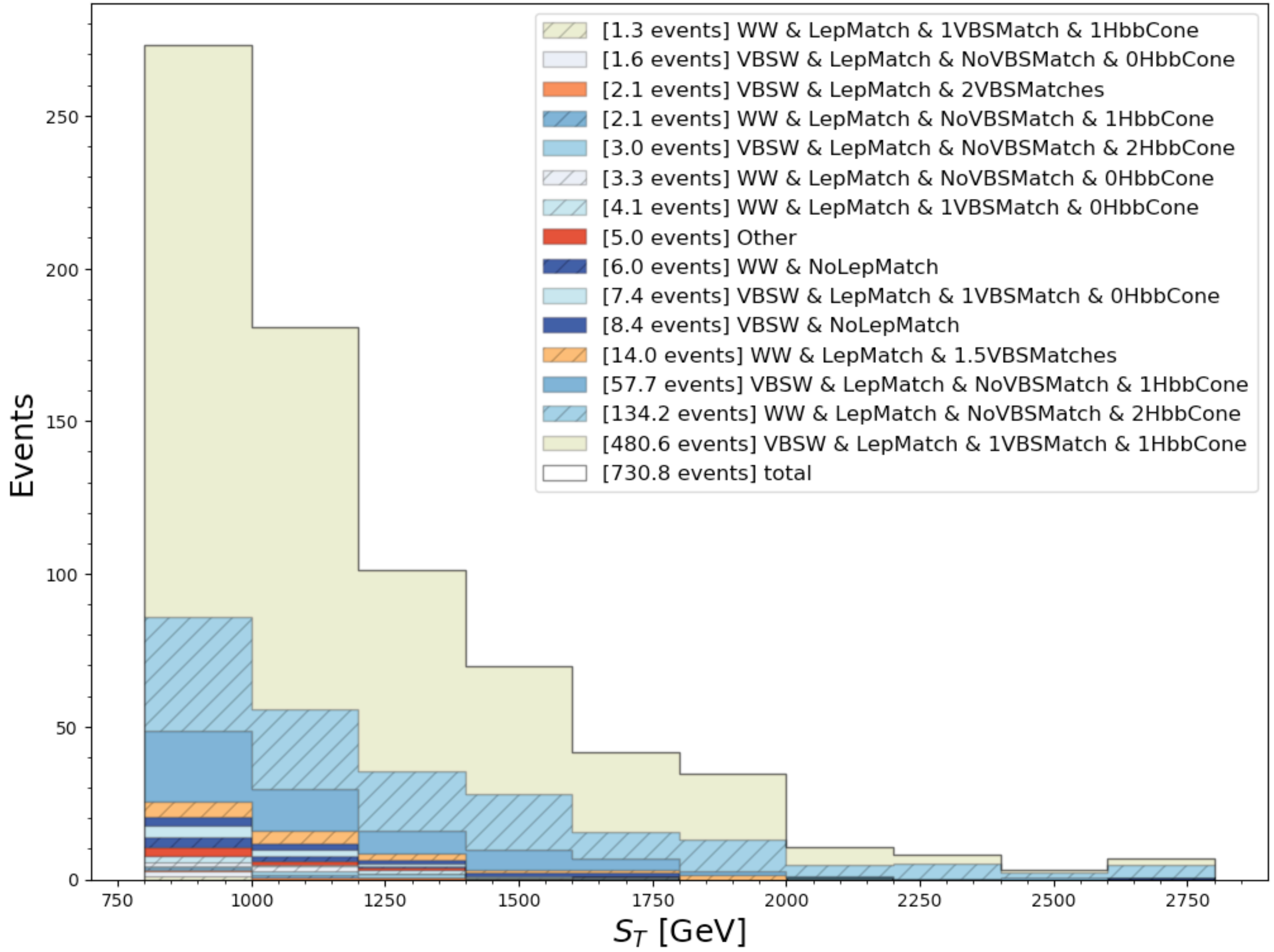


*At this point, there are *some* (43 raw events) occasions where 1 gen. quark matched to both a VBS jet and landed within the Hbb cone; due to dR < 0.8 reco overlap removal

EWK W Contribution Breakdown

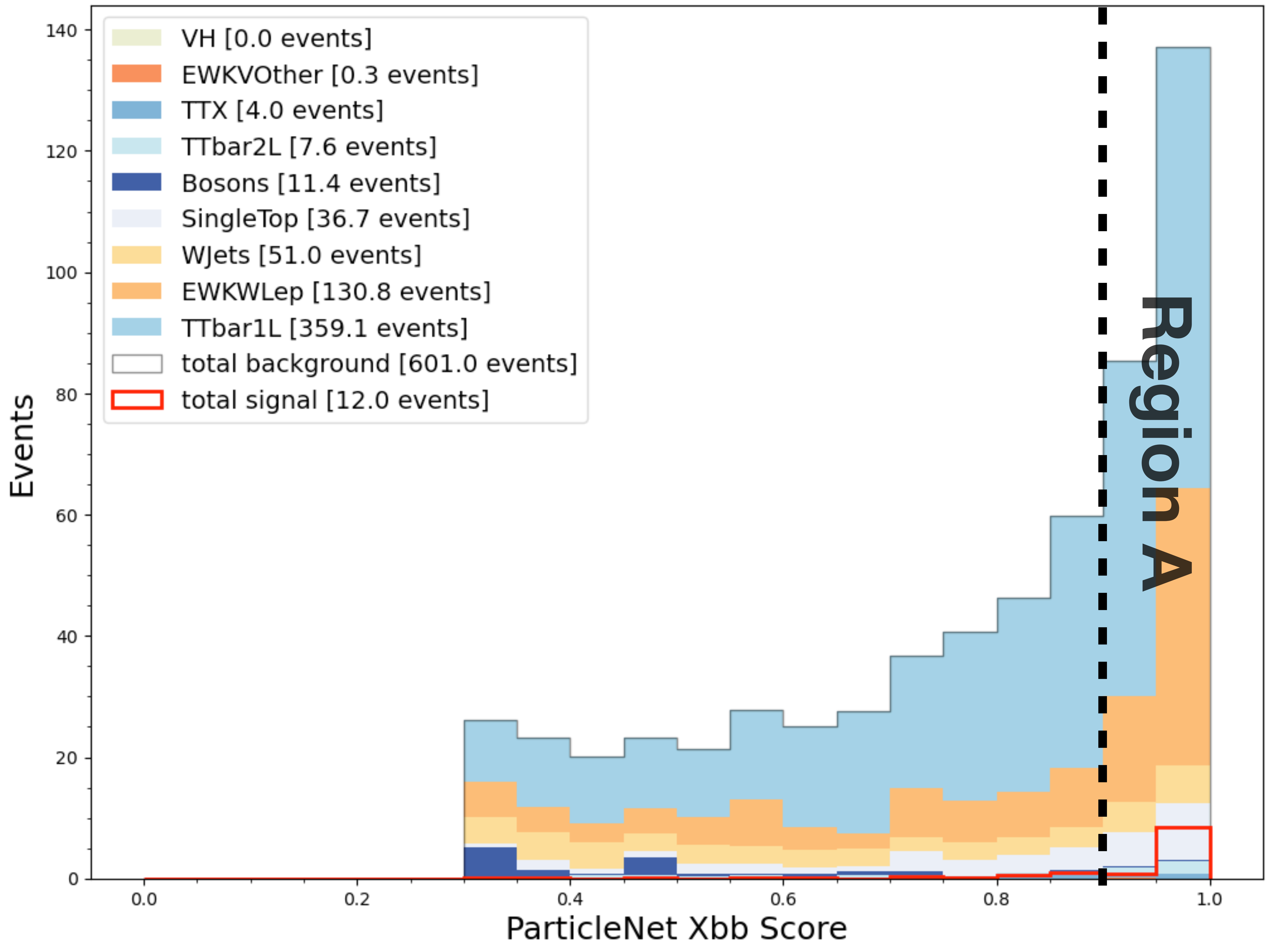
Label	Yield
VBSW & NoLepMatch	8.4
WW & NoLepMatch	6.0
VBSW & LepMatch & NoVBSMatch & 0HbbCone	1.6
WW & LepMatch & NoVBSMatch & 0HbbCone	3.3
VBSW & LepMatch & NoVBSMatch & 1HbbCone	57.7
WW & LepMatch & NoVBSMatch & 1HbbCone	2.1
VBSW & LepMatch & NoVBSMatch & 2HbbCone	3.0
WW & LepMatch & NoVBSMatch & 2HbbCone	134.2
VBSW & LepMatch & 1VBSMatch & 0HbbCone	7.4
WW & LepMatch & 1VBSMatch & 0HbbCone	4.1
VBSW & LepMatch & 1VBSMatch & 1HbbCone	480.6
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	730.8

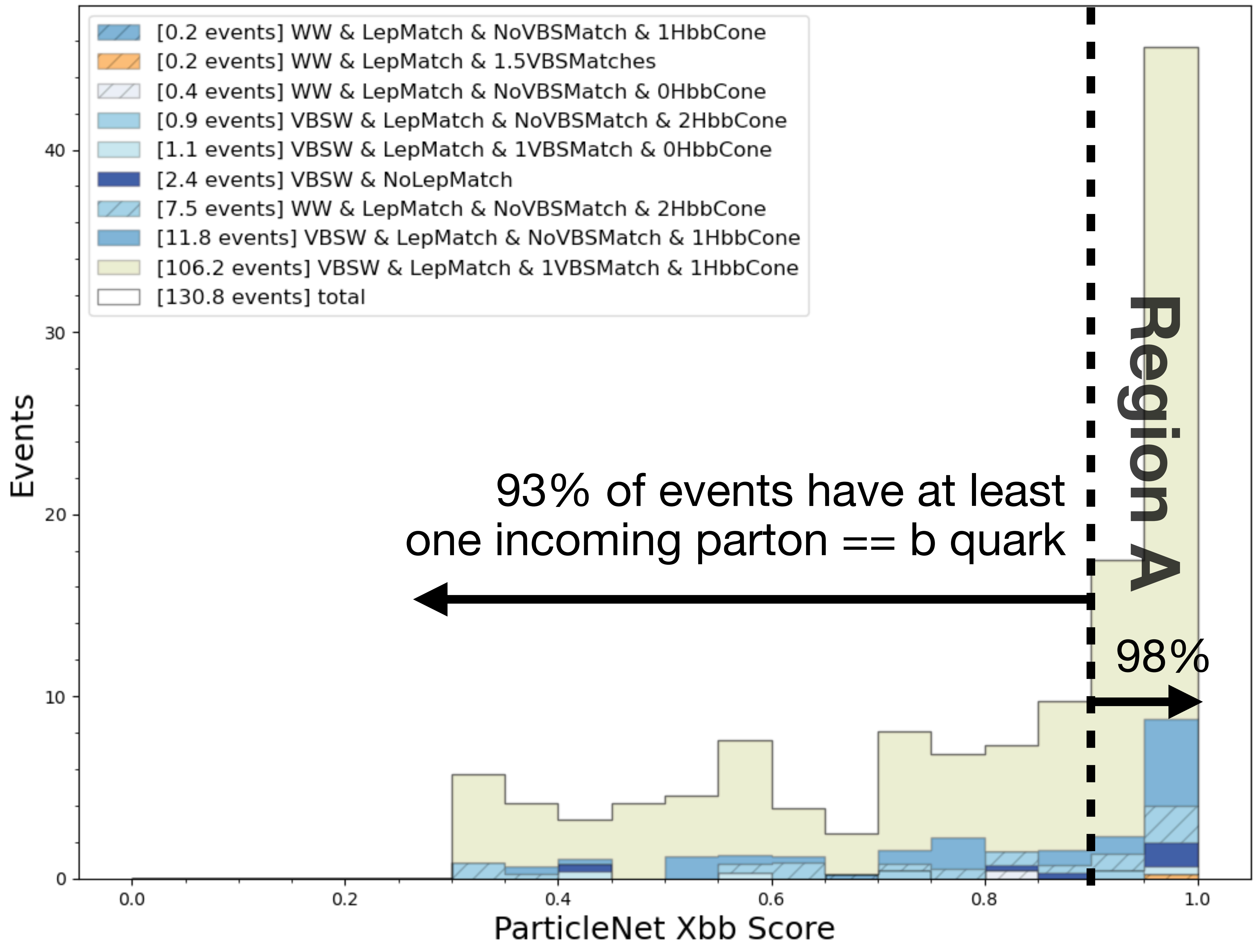
Object selection AND Preselection (no $\Delta\eta_{jj}$ cut)



*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





Checking the Production Steps

- wmLHEGEN: https://cms-pdmv.cern.ch/mcm/public/restapi/requests/get_setup/HIG-RunIISummer20UL18wmLHEGEN-00832
- SIM: https://cms-pdmv.cern.ch/mcm/public/restapi/requests/get_setup/HIG-RunIISummer20UL18SIM-00481
- DIGIPREMIX: https://cms-pdmv.cern.ch/mcm/public/restapi/requests/get_setup/HIG-RunIISummer20UL18DIGIPremix-00481
- HLT: https://cms-pdmv.cern.ch/mcm/public/restapi/requests/get_setup/HIG-RunIISummer20UL18HLT-00481
- RECO: https://cms-pdmv.cern.ch/mcm/public/restapi/requests/get_setup/HIG-RunIISummer20UL18RECO-00481
- MiniAOD (v2): https://cms-pdmv.cern.ch/mcm/public/restapi/requests/get_setup/HIG-RunIISummer20UL18MiniAODv2-00571
- NanoAOD (v9): https://cms-pdmv.cern.ch/mcm/public/restapi/requests/get_setup/HIG-RunIISummer20UL18NanoAODv9-00525

EWKW (W→ℓν) 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
```

Comparing Diboson Contributions

Proc Card	Notes

`import model sm-ckm_no_b_mass`
 	
`define l+ = e+ mu+ ta+`
`define vl = ve vm vt`
 	
`generate p p > l+ vl j j / t t~ h QCD=0`
 	
`output` **`ewkwplvjj_5f_LO`** `-nojpeg`
	• Used to generate EWKWPlus…WToLNu samples
	    • From here
	• **LO** sample
	• Both W's decayed by MadGraph
	• 5-flavor scheme

`import model loop_sm`
 	
`define ell+ = e+ mu+ ta+`
`define ell- = e- mu- ta-`
 	
`generate p p > ell+ vl` **`w-`** `$$ t t~ H [QCD] @0`
`add process p p > ell+ vl` **`w-`** `j $$ t t~ H [QCD] @1`
`add process p p > ell- vl~` **`w+`** `$$ t t~ H [QCD] @2`
`add process p p > ell- vl~` **`w+`** `j $$ t t~ H [QCD] @3`
 	
`output` **`WWTo1L1Nu2Q01j_4f_NLO_FXFX`** `-nojpeg`
	• Used to generate WWTo1L1Nu2Q samples
	    • From here
	• **NLO** sample
	• One W decayed by MadGraph, the **other** decayed by Pythia
	• 4-flavor scheme

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Comparing Diboson Contributions

EWKWPlus Run Card (from here)	**WWTo1L1Nu2Q Run Card** (from here)

`# Matching - Warning! ickkw > 1 is still beta`
`0 = ickkw ! 0 no matching, 1 MLM, 2 CKKW matching`
 	
`# Minimum and maximum pt's`
`10 = ptj ! minimum pt for the jets`
`10 = pta ! minimum pt for the photons`
 	
`# Maximum and minimum absolute rapidity`
`6.5 = etaj ! max rap for the jets`
`2.5 = etaa ! max rap for the photons`
 	
`# Minimum and maximum DeltaR distance`
`0.1 = draj ! min distance between gamma and jet`
`0.1 = dral ! min distance between gamma and lepton`
 	
`# Minimum and maximum invariant mass for pairs`
`10 = mmjj ! min invariant mass of a jet pair`
 	
`# Minimum and maximum invariant mass for all letpons`
`50 = mmnl ! min invariant mass for all letpons (l+- and vl)`
 	
`# Photon-isolation cuts, according to hep-ph/9801442`
`# When ptgmin=0, all the other parameters are ignored`
`0 = ptgmin ! Min photon transverse momentum`
 	
`# maximal pdg code for quark to be considered as a light jet`
`5 = maxjetflavor ! Maximum jet pdg code`
 	
`# Store info for systematics studies`
`T = use_syst ! Enable systematics studies`
	`# Merging - WARNING! Applies merging only at the hard-event level.`
	`3 = ickkw ! 0 no merging, 3 FxFx merging`
	
	`# Cuts on the jets`
	`1 = jetalgo     ! FastJet jet algorithm (1=kT, 0=C/A, -1=anti-kT)`
	`1.0 = jetradius ! The radius parameter for the jet algorithm`
	`15 = ptj        ! Min jet transverse momentum`
	
	`# Photon-isolation cuts, according to hep-ph/9801442`
	`# When ptgmin=0, all the other parameters are ignored`
	`20 = ptgmin    ! Min photon transverse momentum`
	`0.4 = R0gamma  ! Radius of isolation code`
	`1.0 = xn       ! n parameter of eq.(3.4) in hep-ph/9801442`
	`1.0 = epsgamma ! epsilon_gamma parameter of eq.(3.4) in hep-ph/9801442`
	`.true. = isoEM ! isolate photons from EM energy (photons and leptons)`
	
	`# Maximal PDG code for quark to be considered a jet when applying cuts`
	`4 = maxjetflavor`

All cuts that MadGraph ignores have been excluded here
unless one run card explicitly excludes something the other does not

Comparing Diboson Contributions

- NanoAOD stores LHE-level particles (right)
  - For both:
    - 0, 1 = incoming partons
    - 2, 3 = outgoing ℓ, ν from W
  - For EWK W samples (LO), 6 particles:
    - 4, 5 = outgoing q, q from VBS or extra W/Z
  - For WW samples (NLO), ≥ 6 particles:
    - 4, 5 = outgoing q, q from W
    - 6, … = extra q's or q's from NLO

Index	Particle	Status
0	q	Incoming
1	q	Incoming
2	ℓ	Outgoing
3	ν	Outgoing
4	q	Outgoing
5	q	Outgoing
6	q/g	Outgoing
…	q/g	Outgoing

LHE particle record

Comparing Diboson Contributions

- Strategy:
  1. Select ℓ, ν (index 2, 3)
  2. Store $M_{\ell\nu}$, charge_{ℓ}
  3. Select q, q (index 4, 5)
  4. Store M_{qq}, charge_{q}
  5. Require $M_{\ell\nu} \in [70, 90)$ GeV
  6. Require $M_{qq} \in [70, 90)$ GeV
  7. Require $|\text{charge}_{qq}| == 1$
  8. Separate into $W^{-}W^{+}$, $W^{+}W^{-}$ and compare

Selects WW events

Index	Particle	Status
0	q	Incoming
1	q	Incoming
2	ℓ	Outgoing
3	ν	Outgoing
4	q	Outgoing
5	q	Outgoing
6	q/g	Outgoing
…	q/g	Outgoing

LHE particle record

CMS

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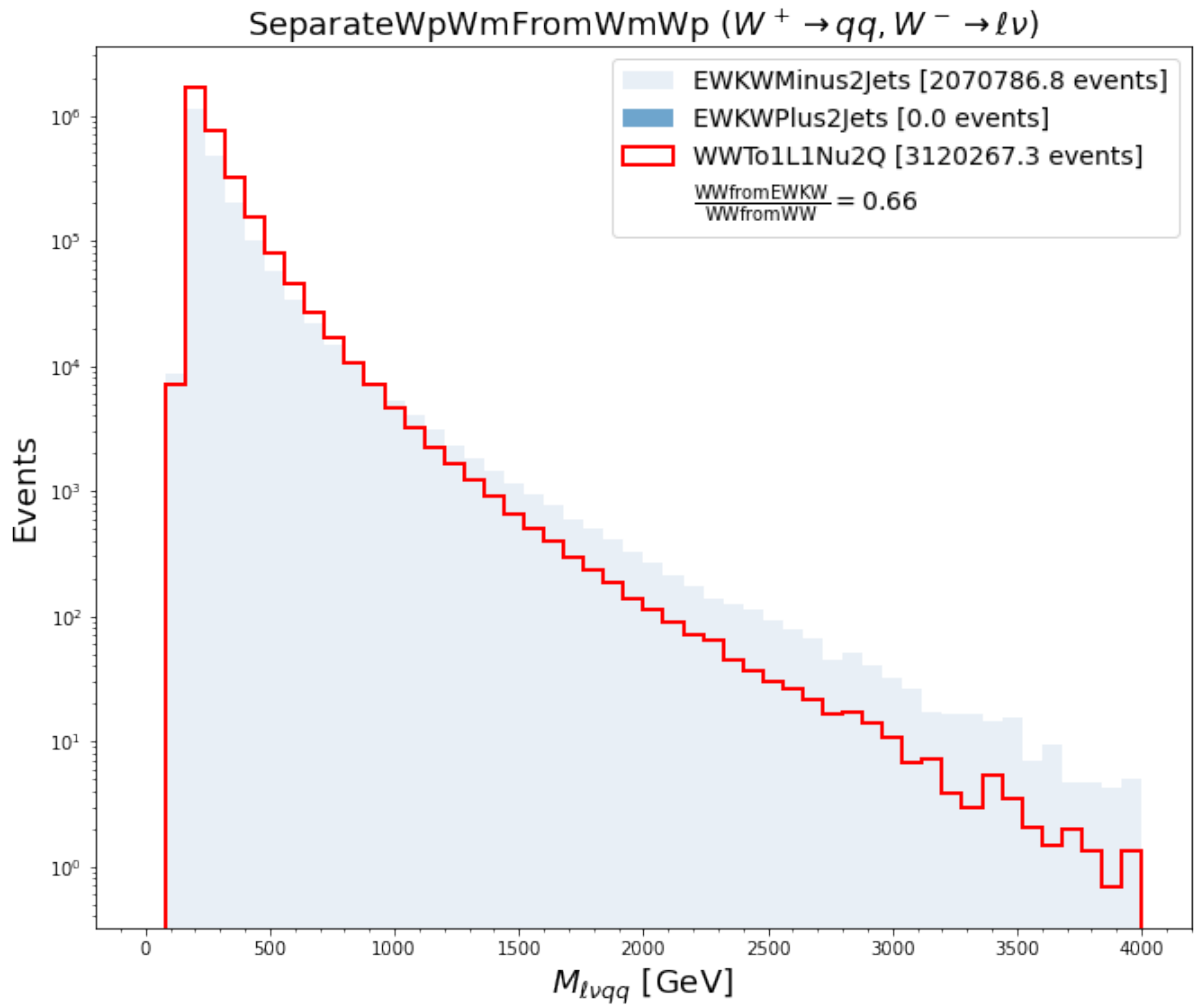
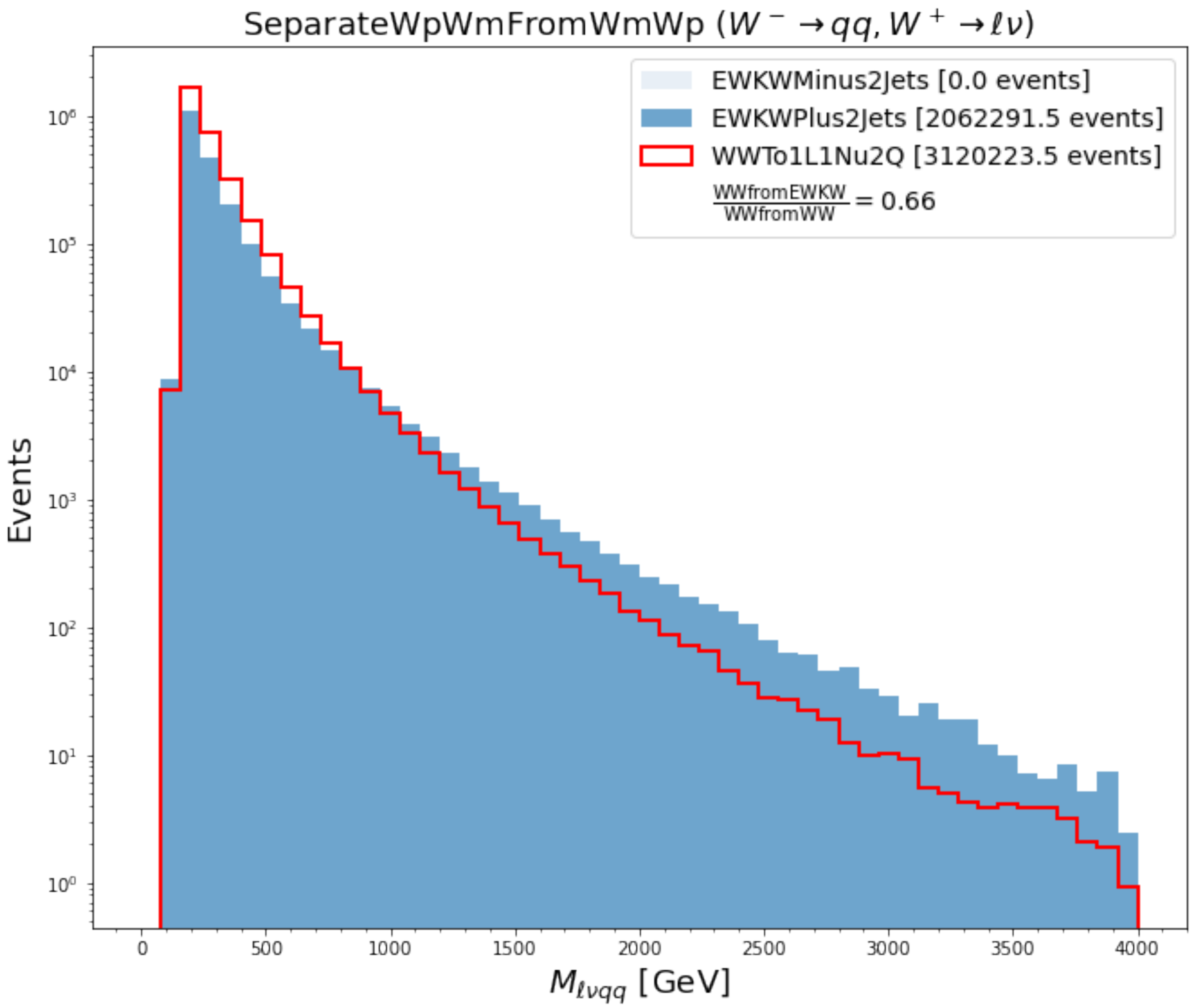
Comparing Diboson Contributions

Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|charge_{qq}| == 1$





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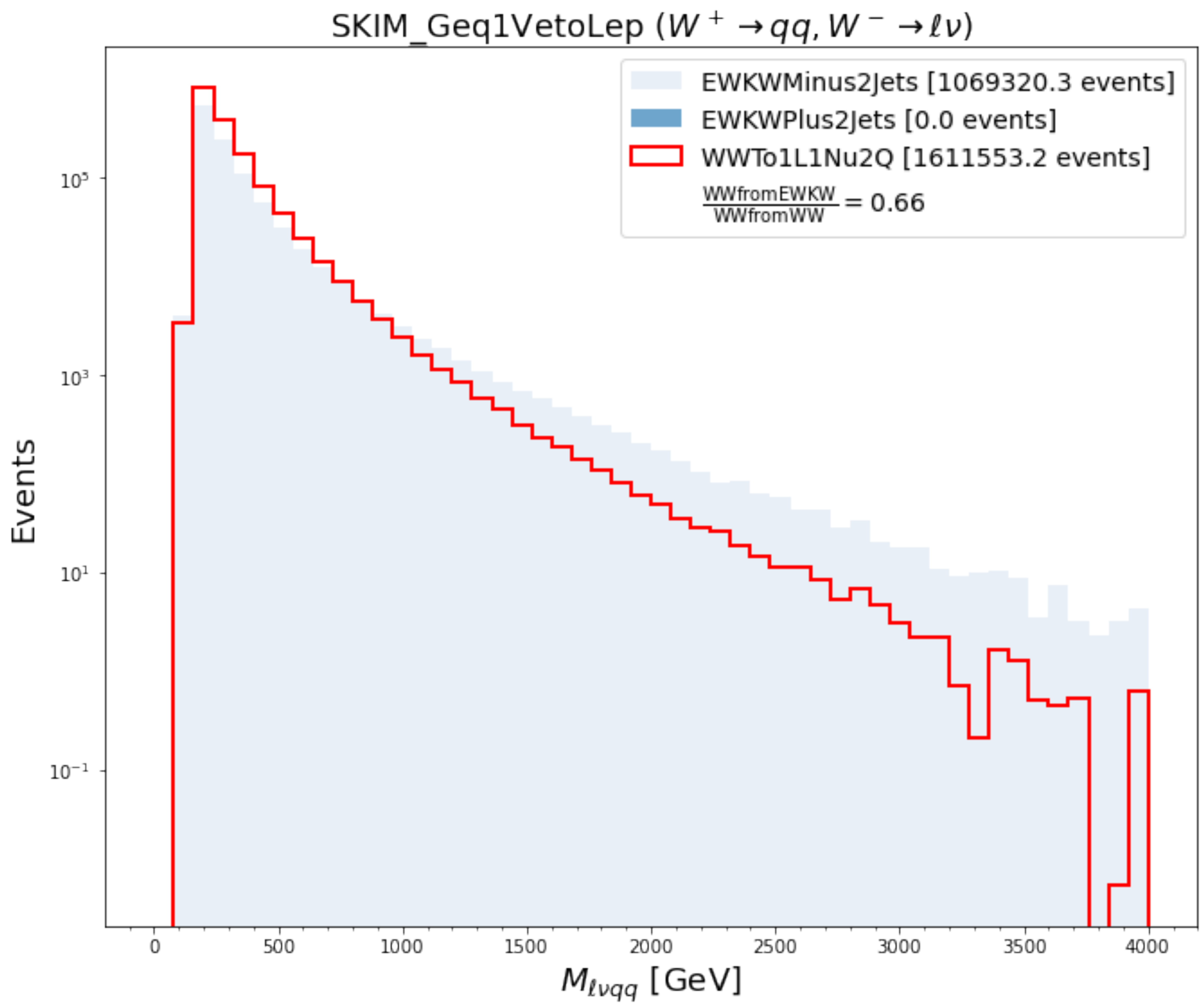
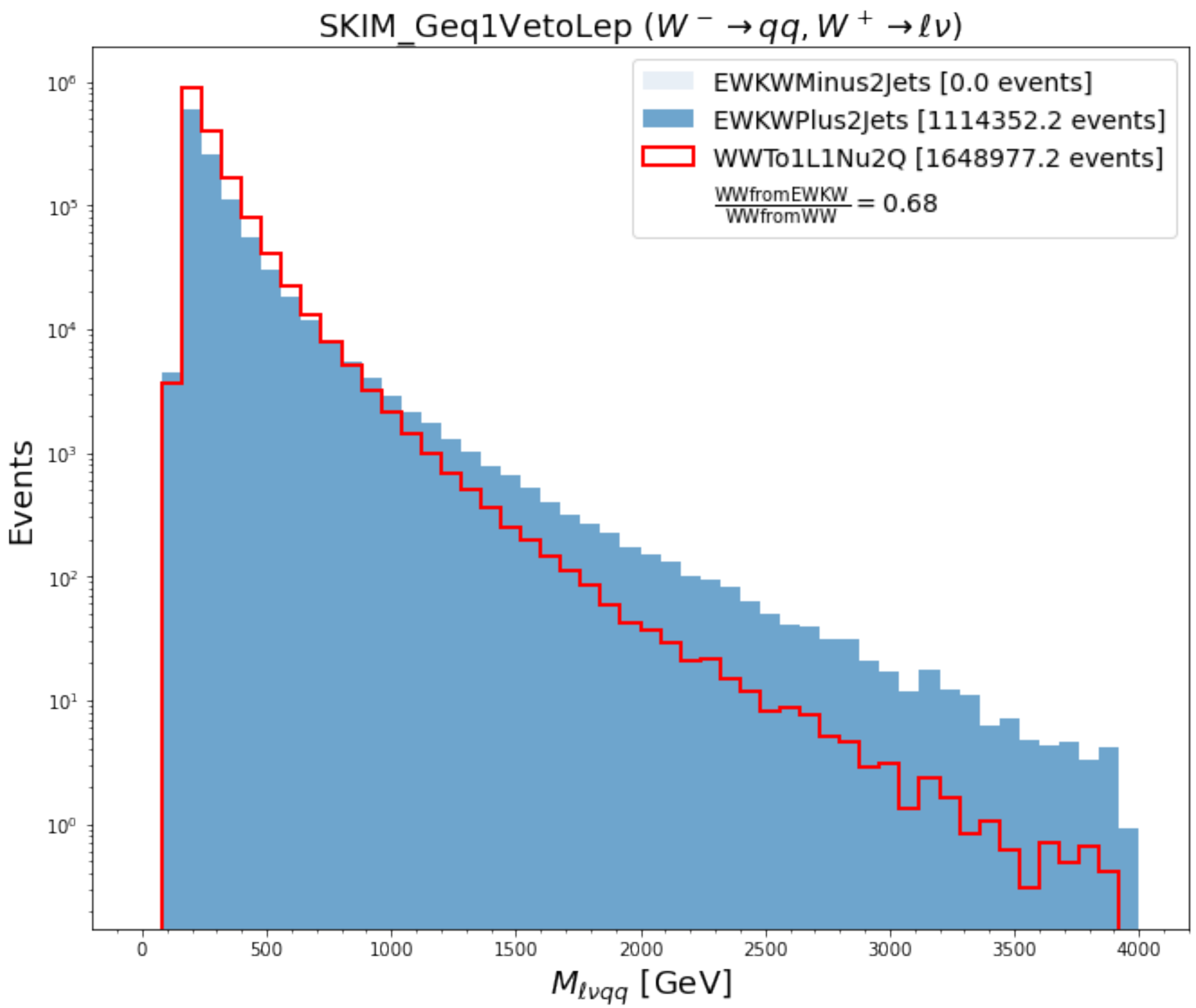
Comparing Diboson Contributions

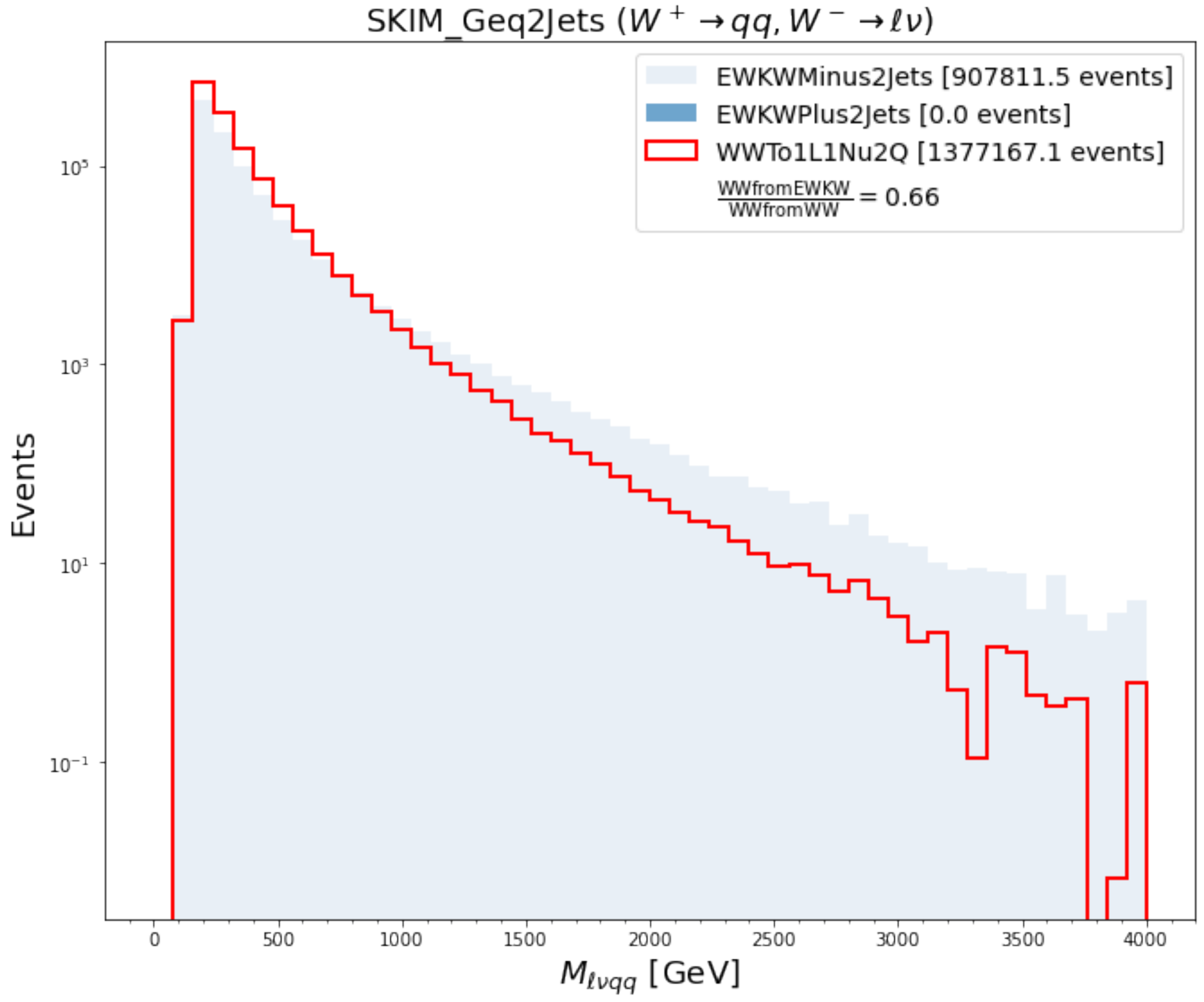
Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|charge_{qq}| == 1$

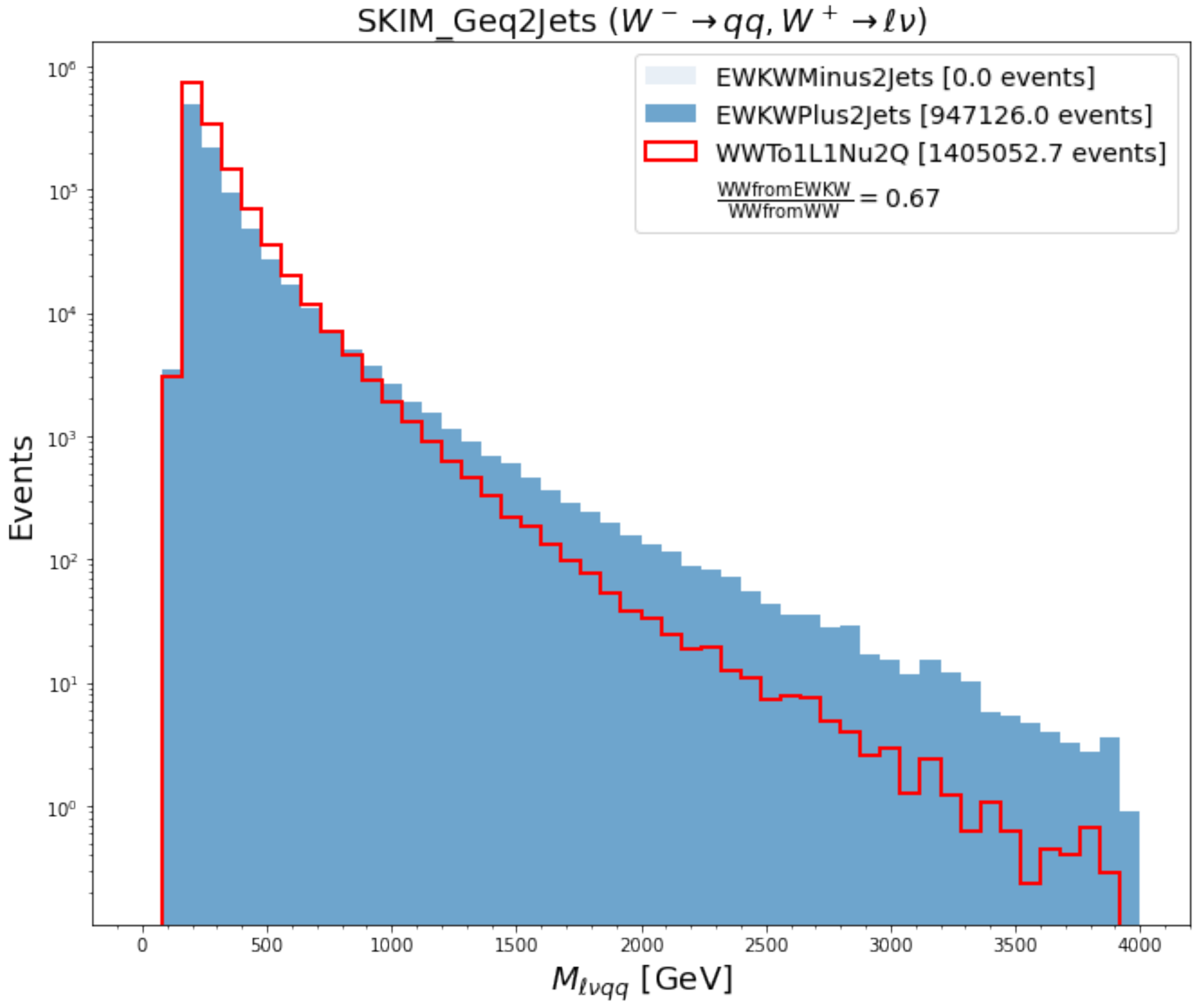




Comparing Diboson Contributions

Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|charge_{qq}| == 1$





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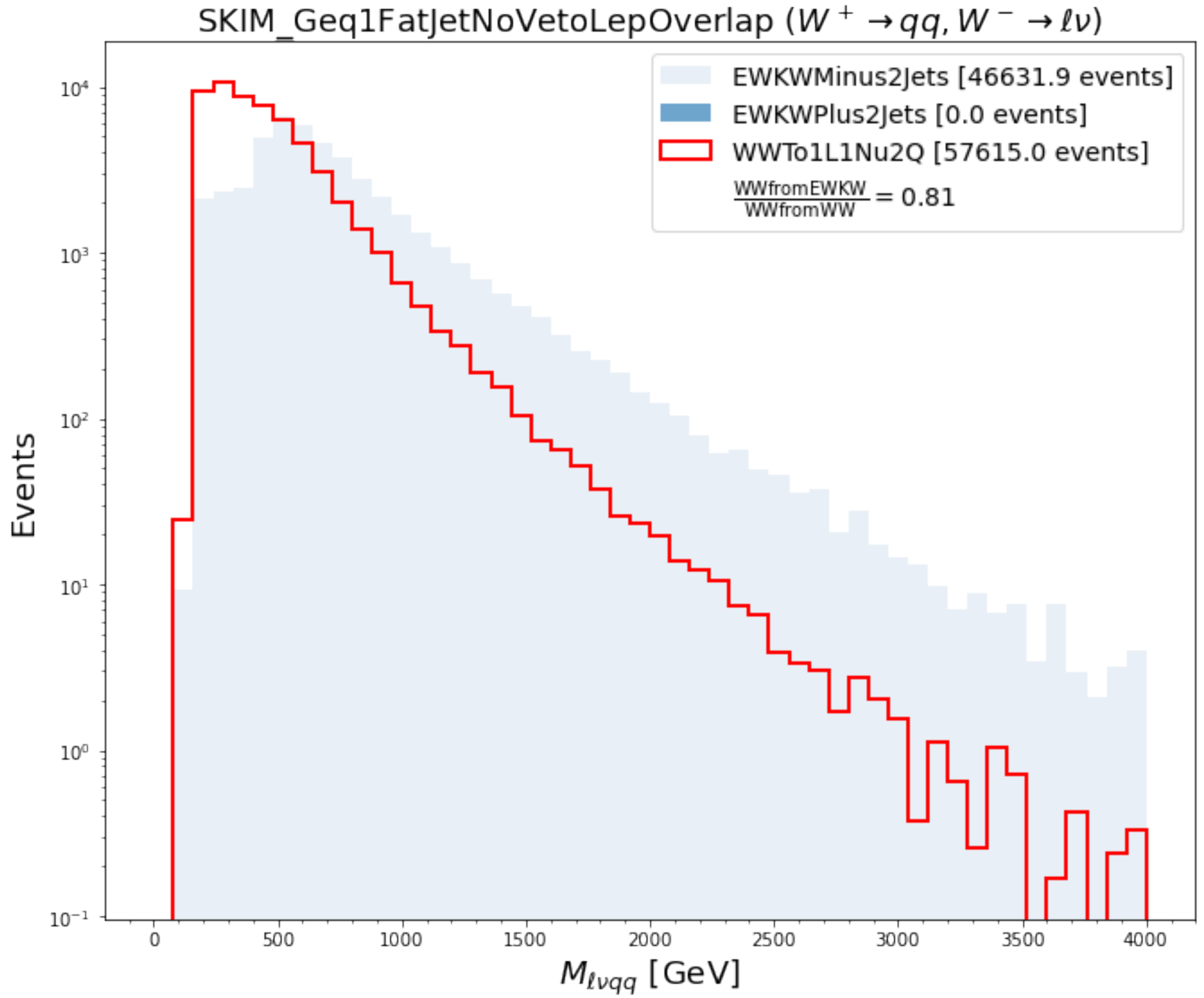
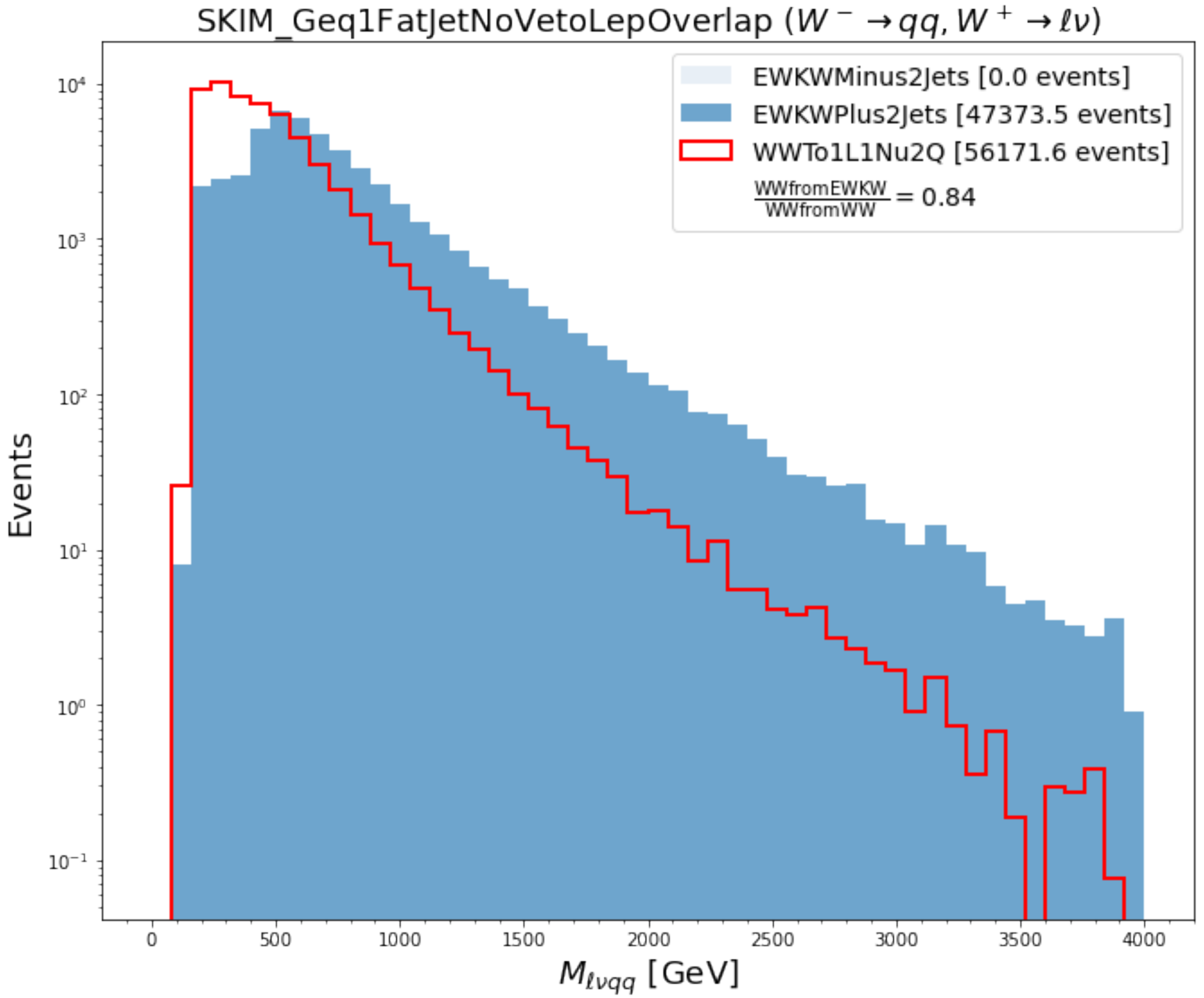
Comparing Diboson Contributions

Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|charge_{qq}| == 1$

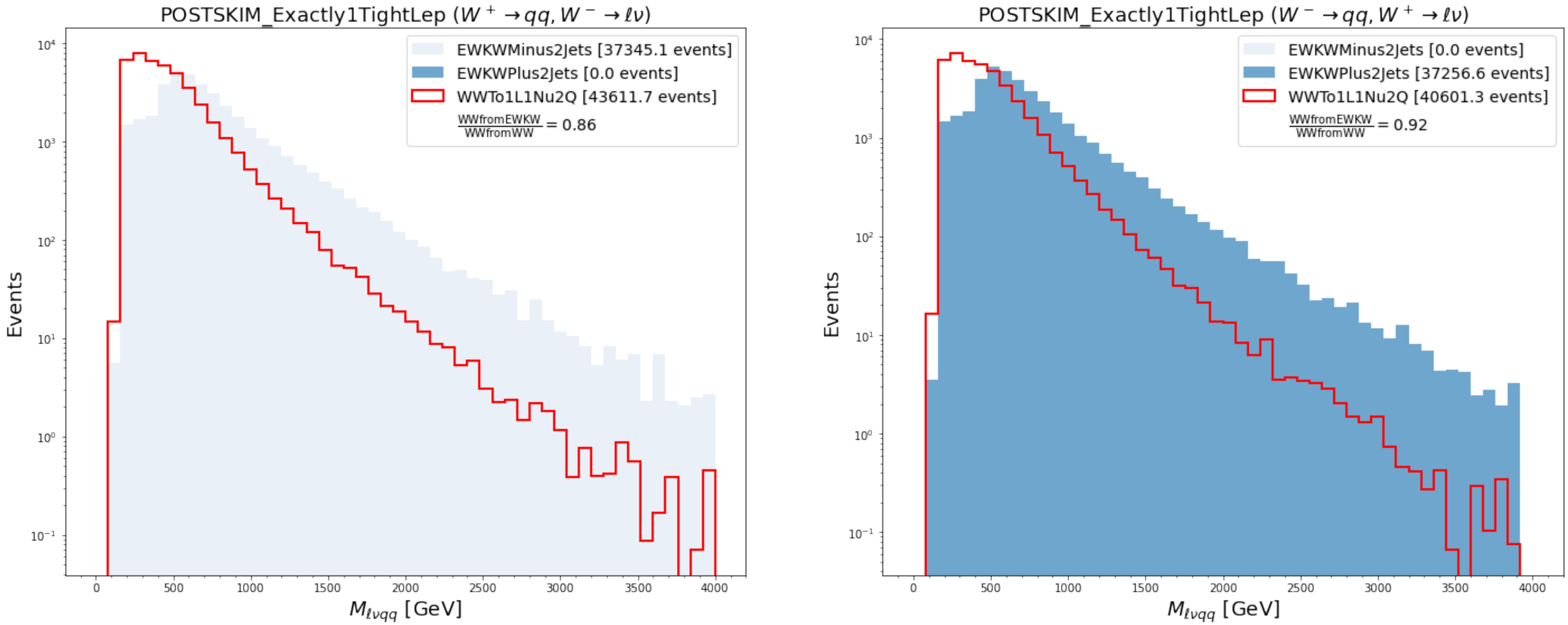




Cutoff starts to develop after fatjet selection

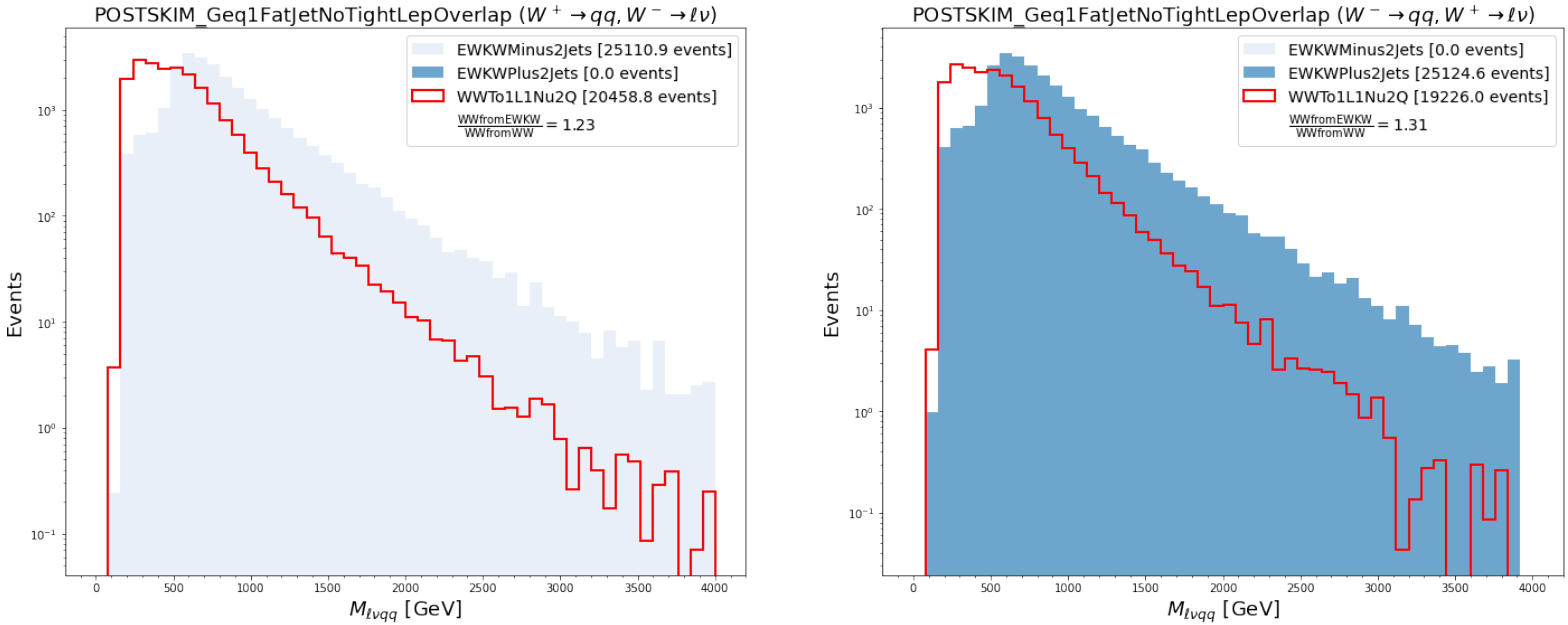
Comparing Diboson Contributions

Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|charge_{qq}|$ == 1



Comparing Diboson Contributions

Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|charge_{qq}| == 1$



Cutoff gets worse after stricter fatjet selection

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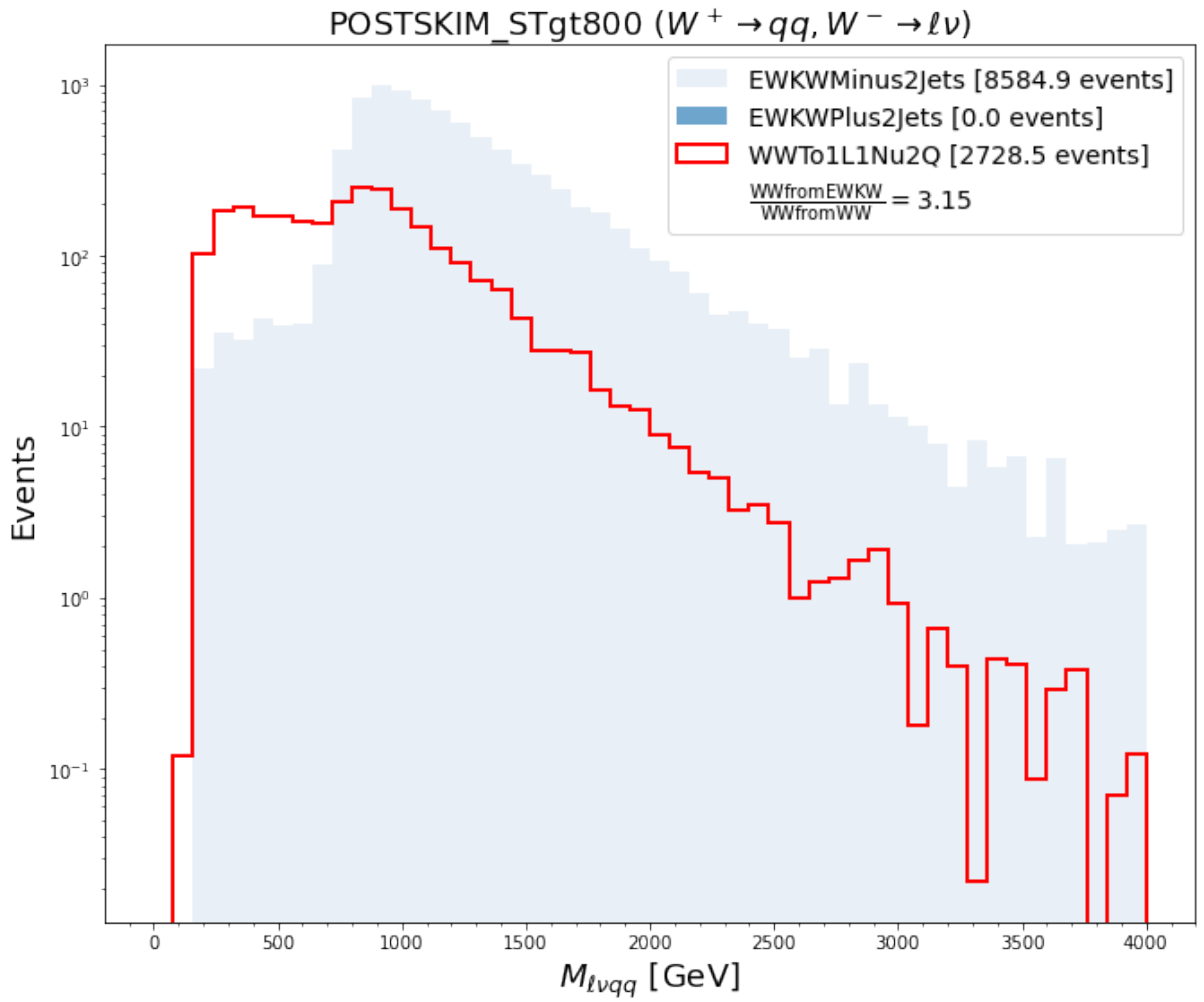
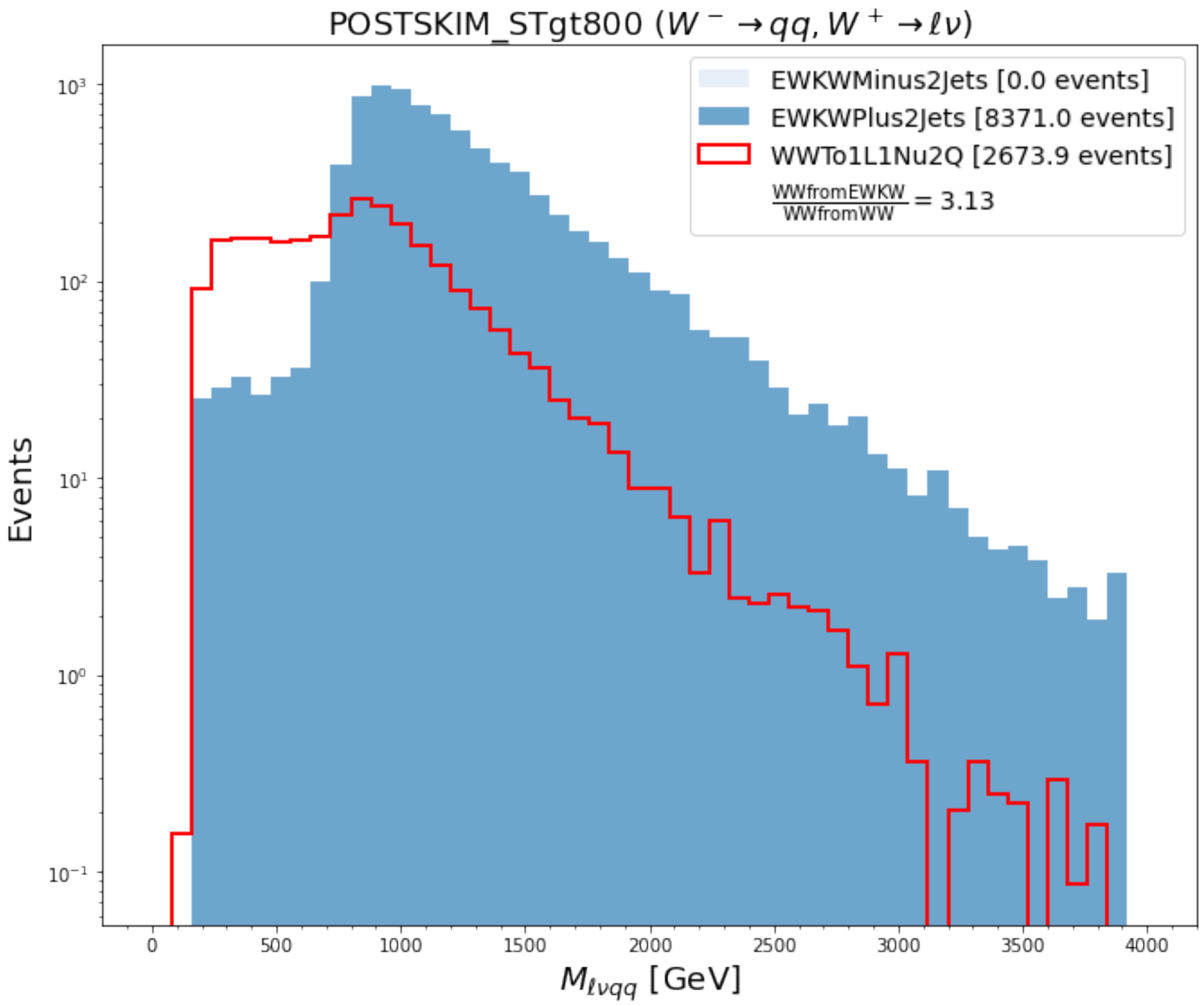
Comparing Diboson Contributions

Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|charge_{qq}| == 1$

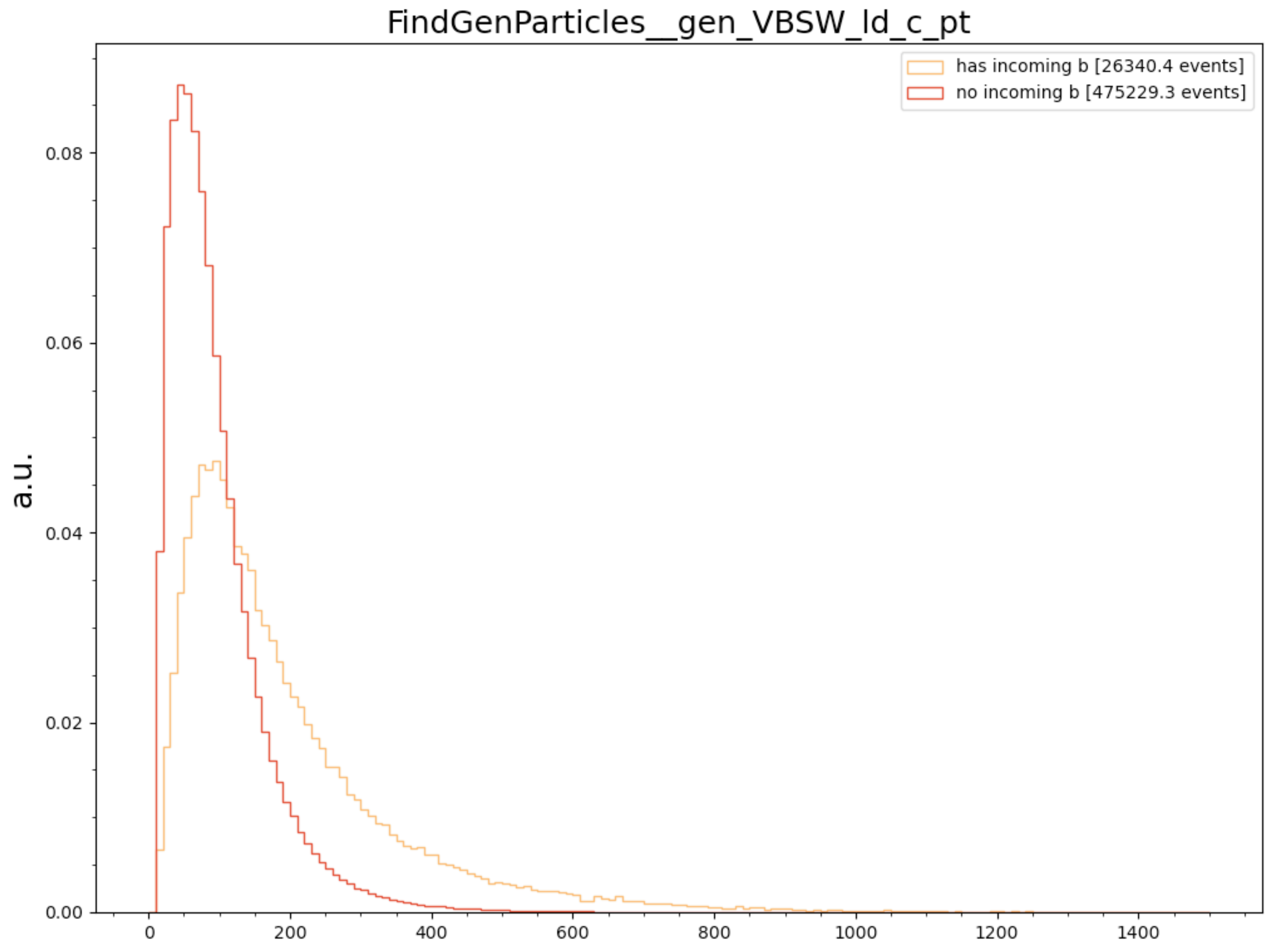


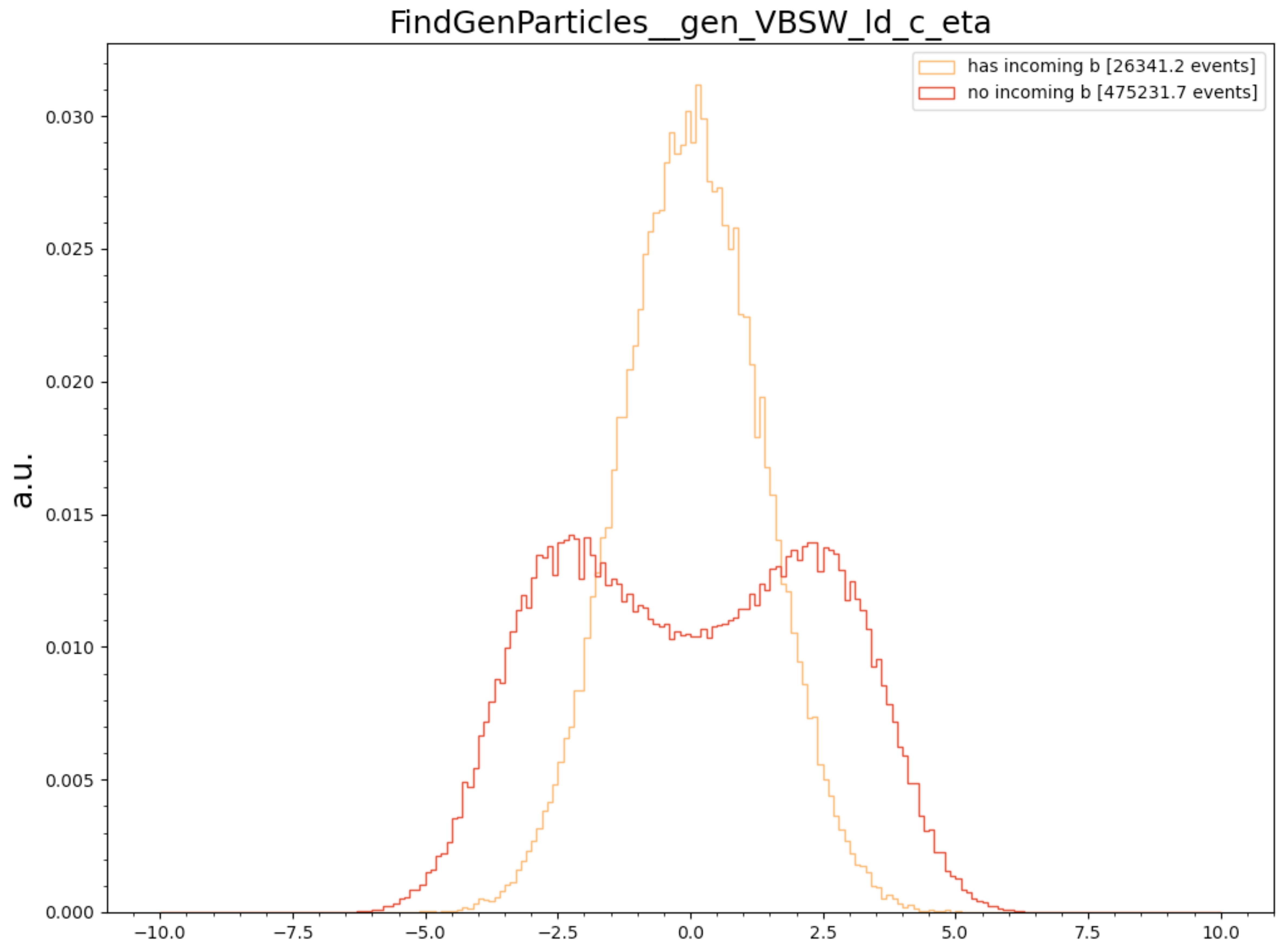


Cutoff at 700 GeV established after S_T selection

EWK W Contribution Breakdown

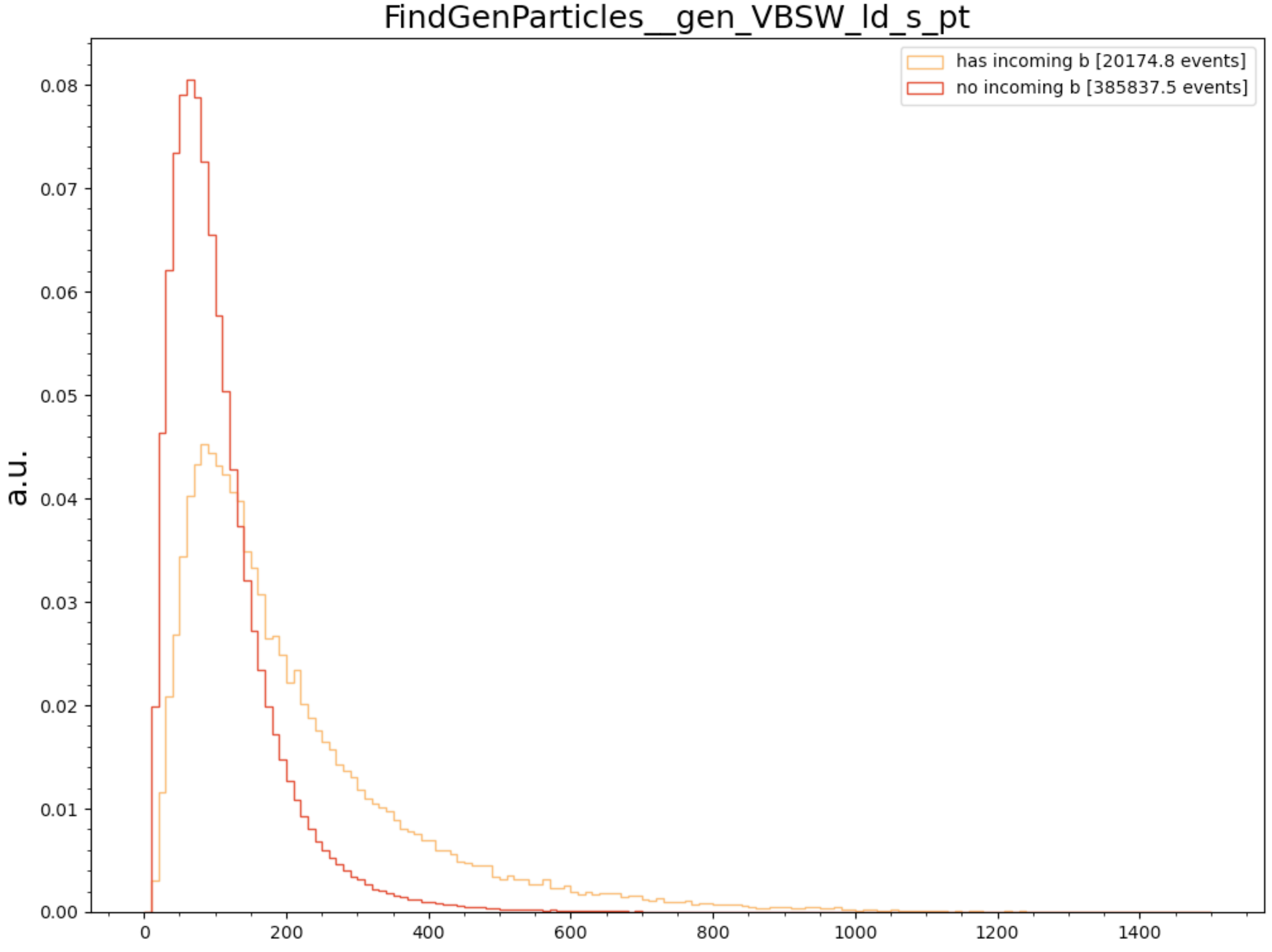
No selections applied

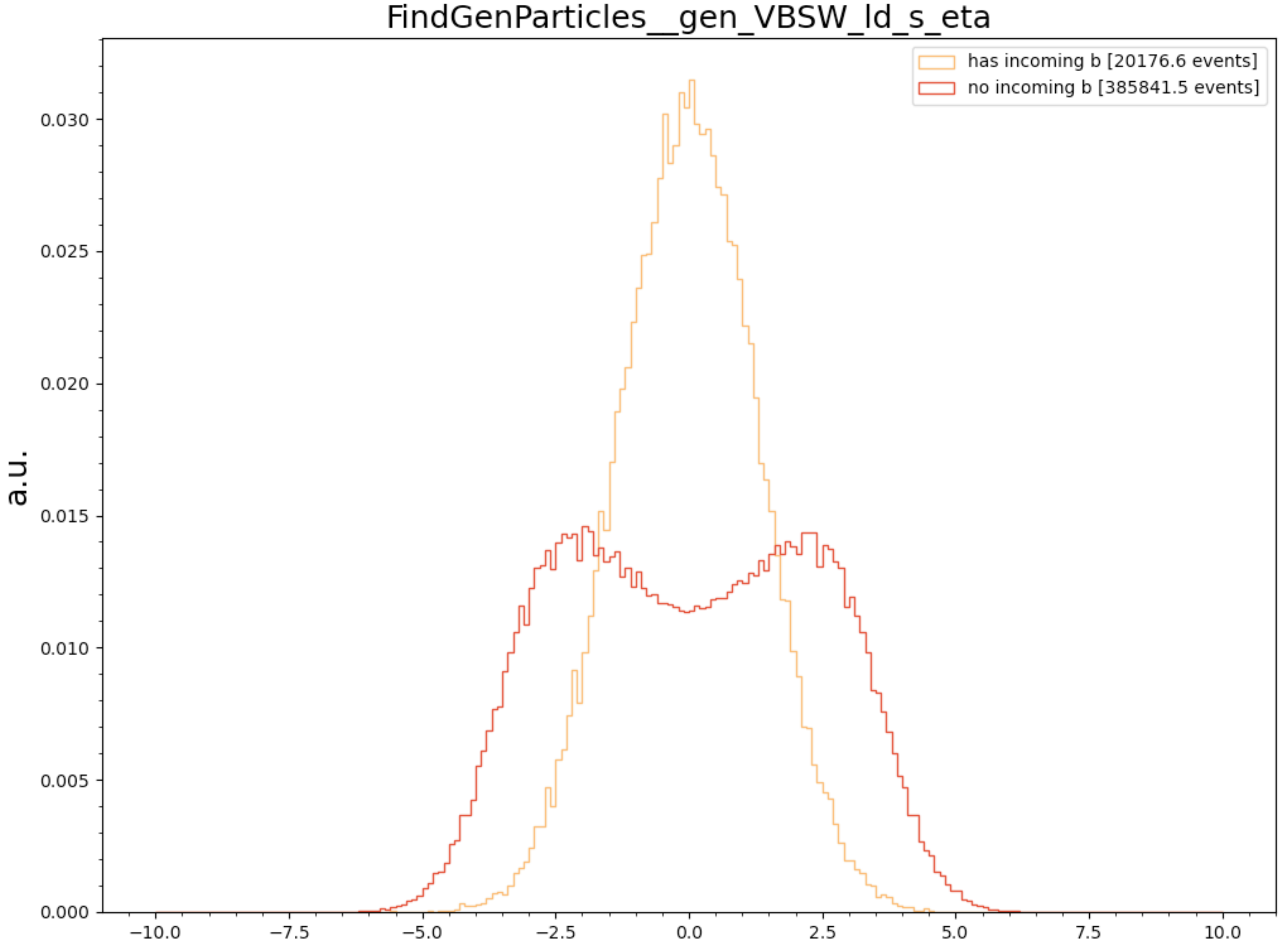




EWK W Contribution Breakdown

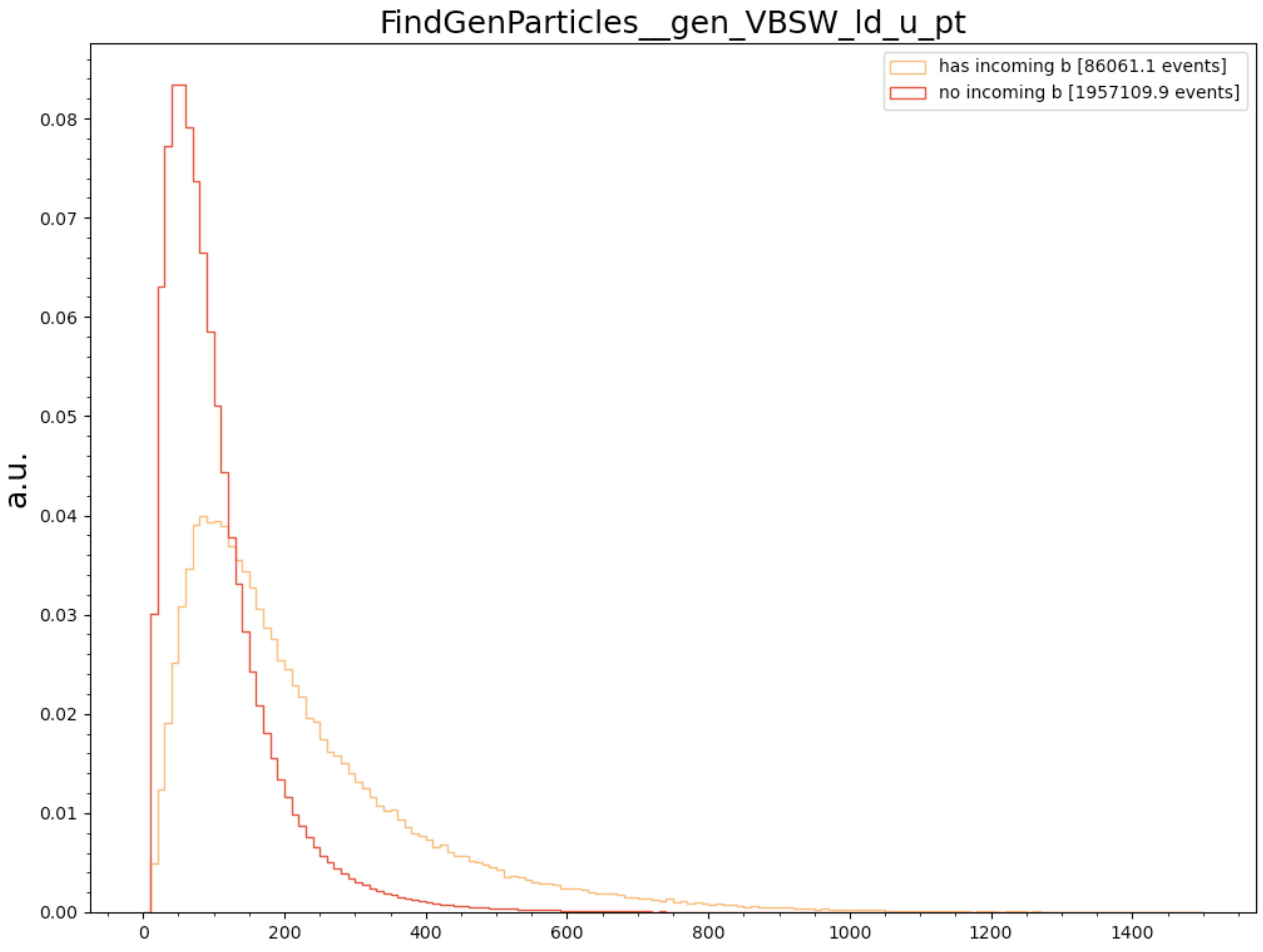
No selections applied

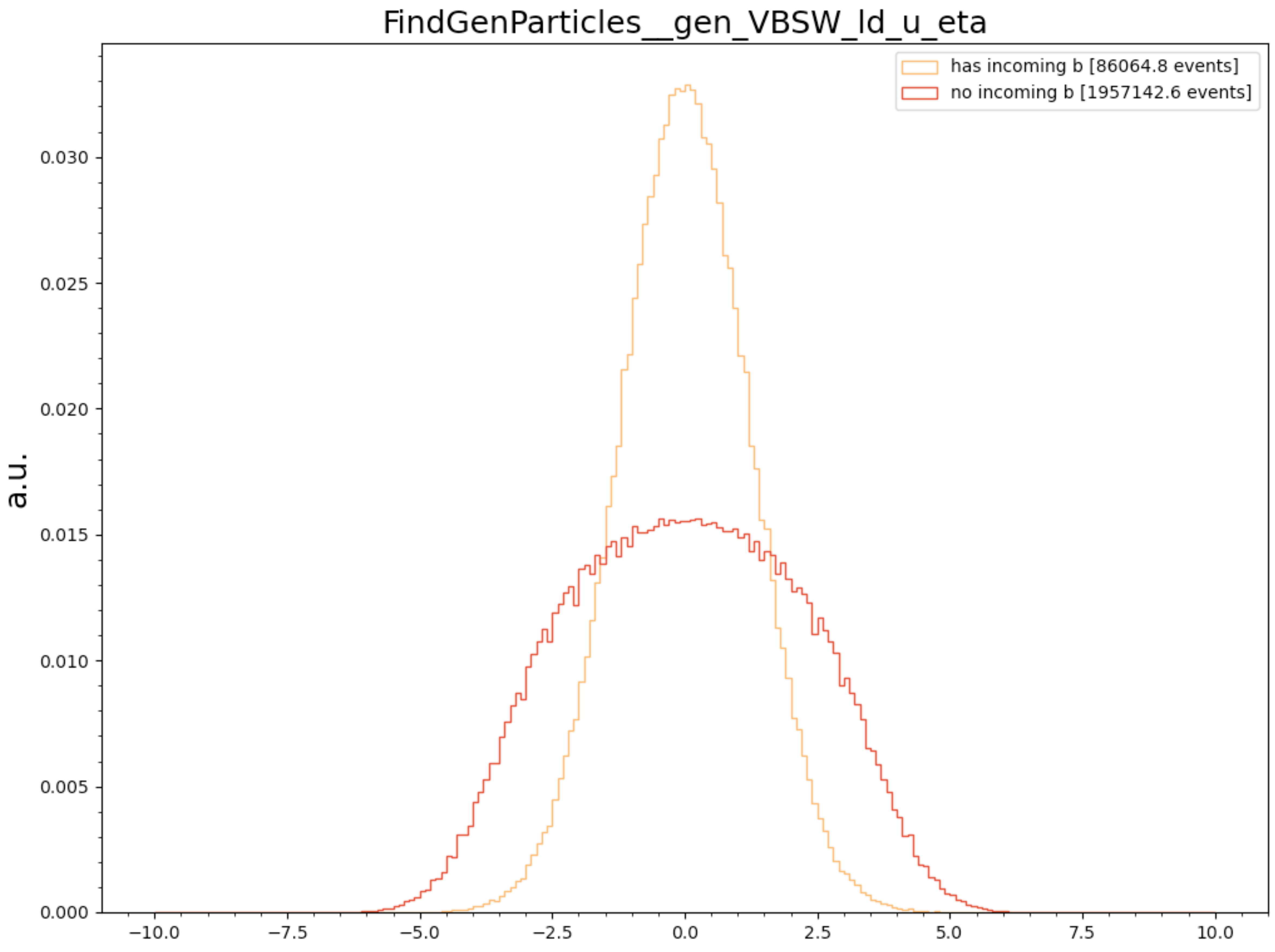




EWK W Contribution Breakdown

No selections applied





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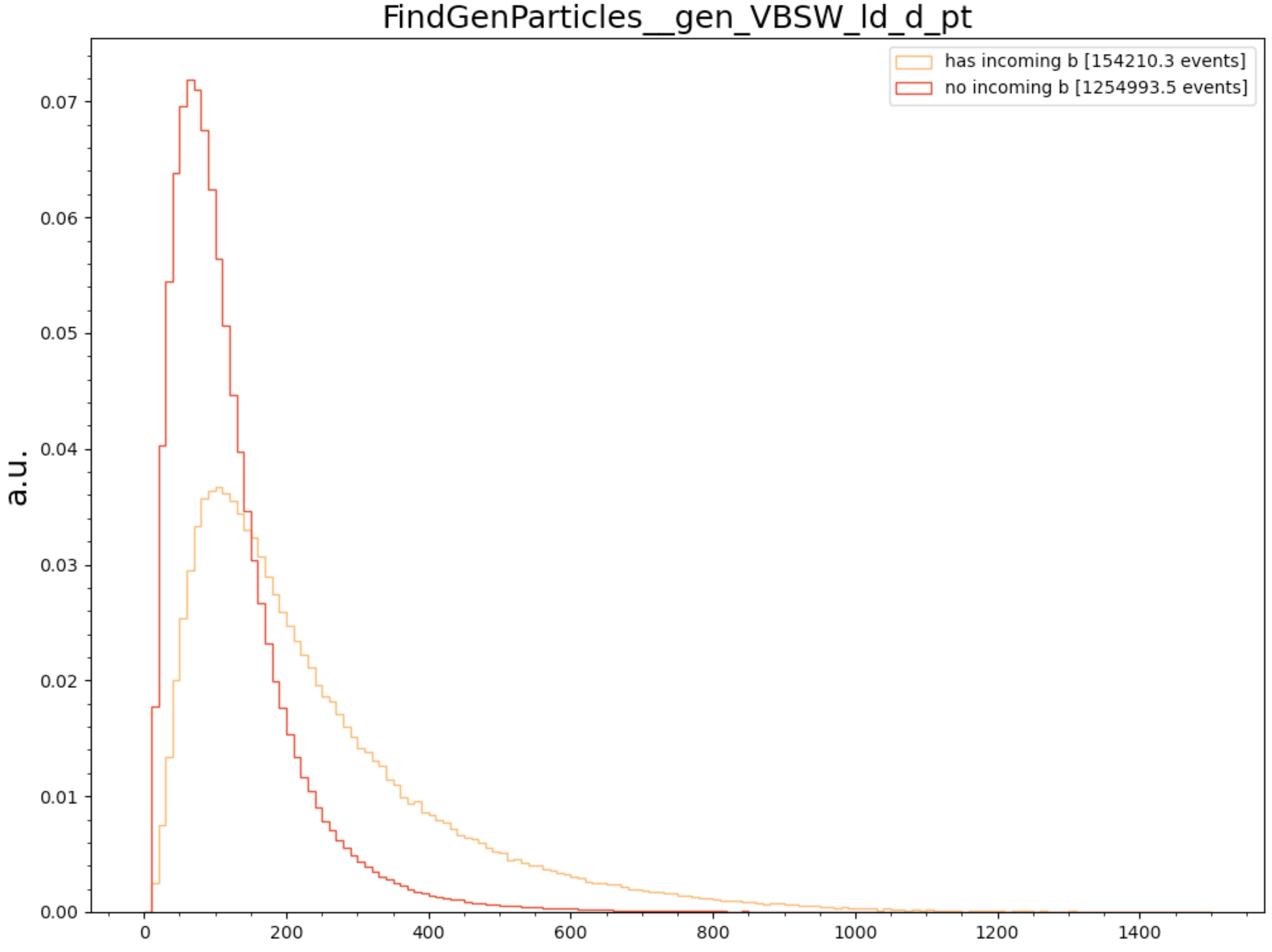
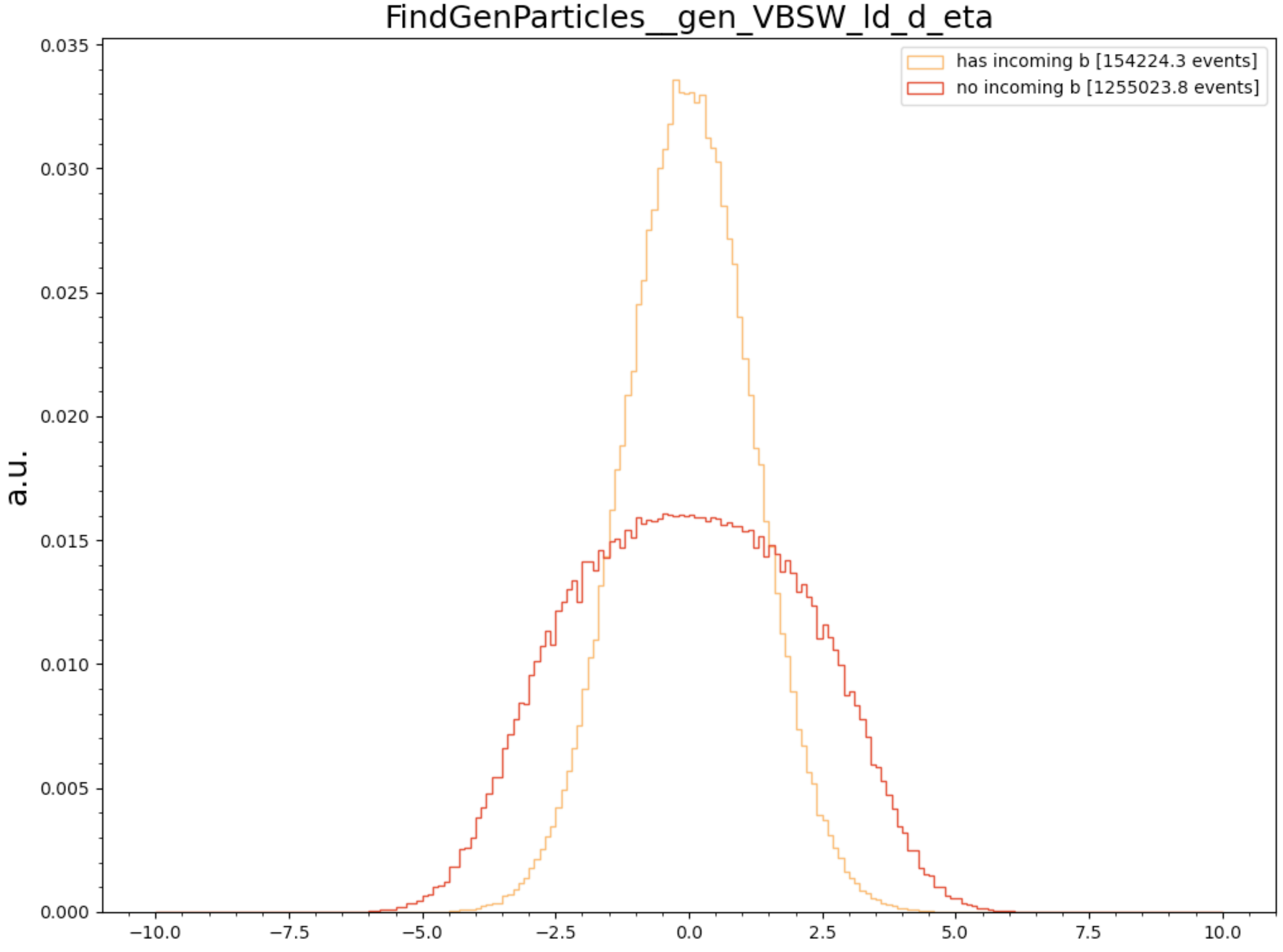
EWK W Contribution Breakdown

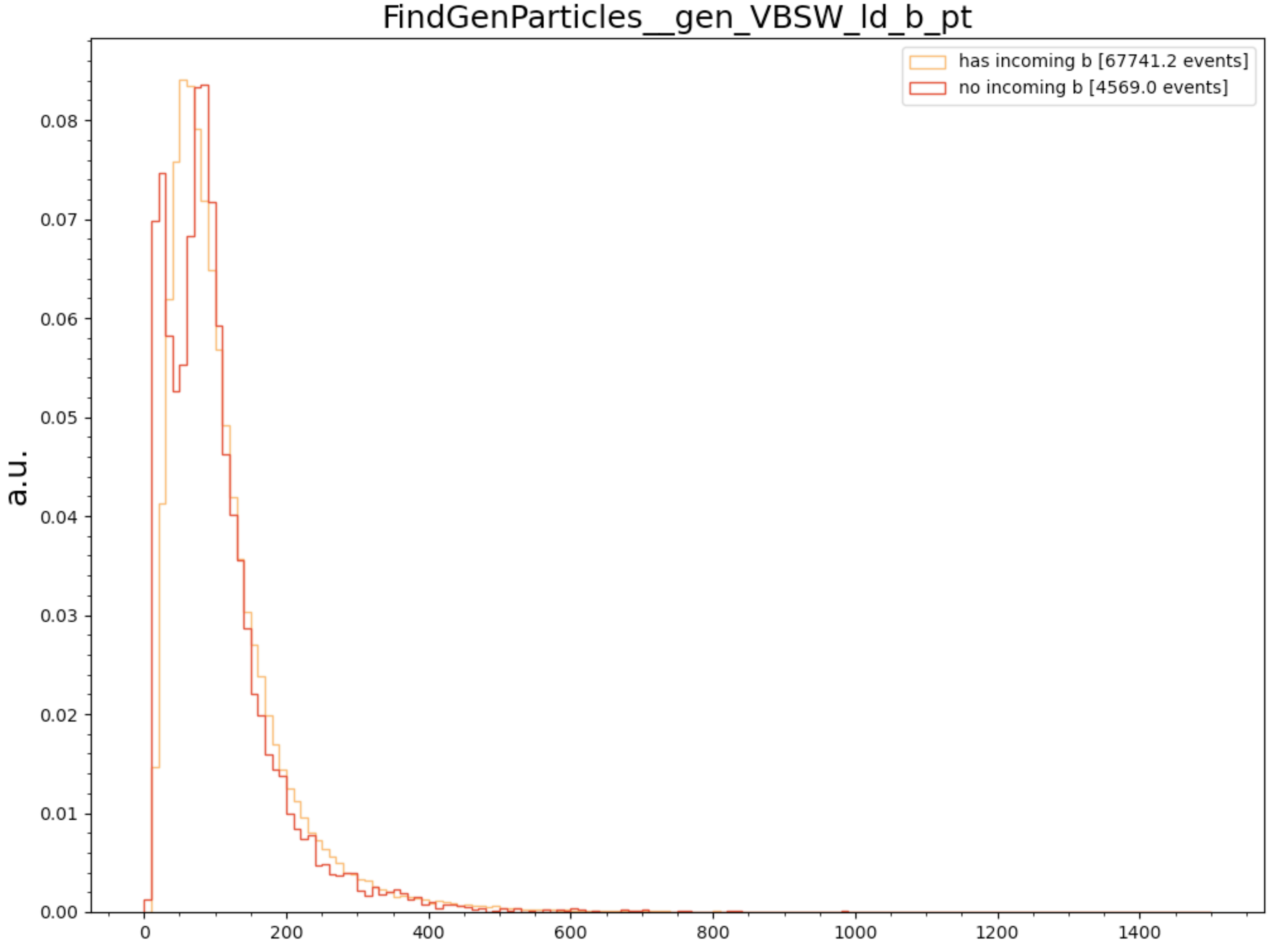
No selections applied

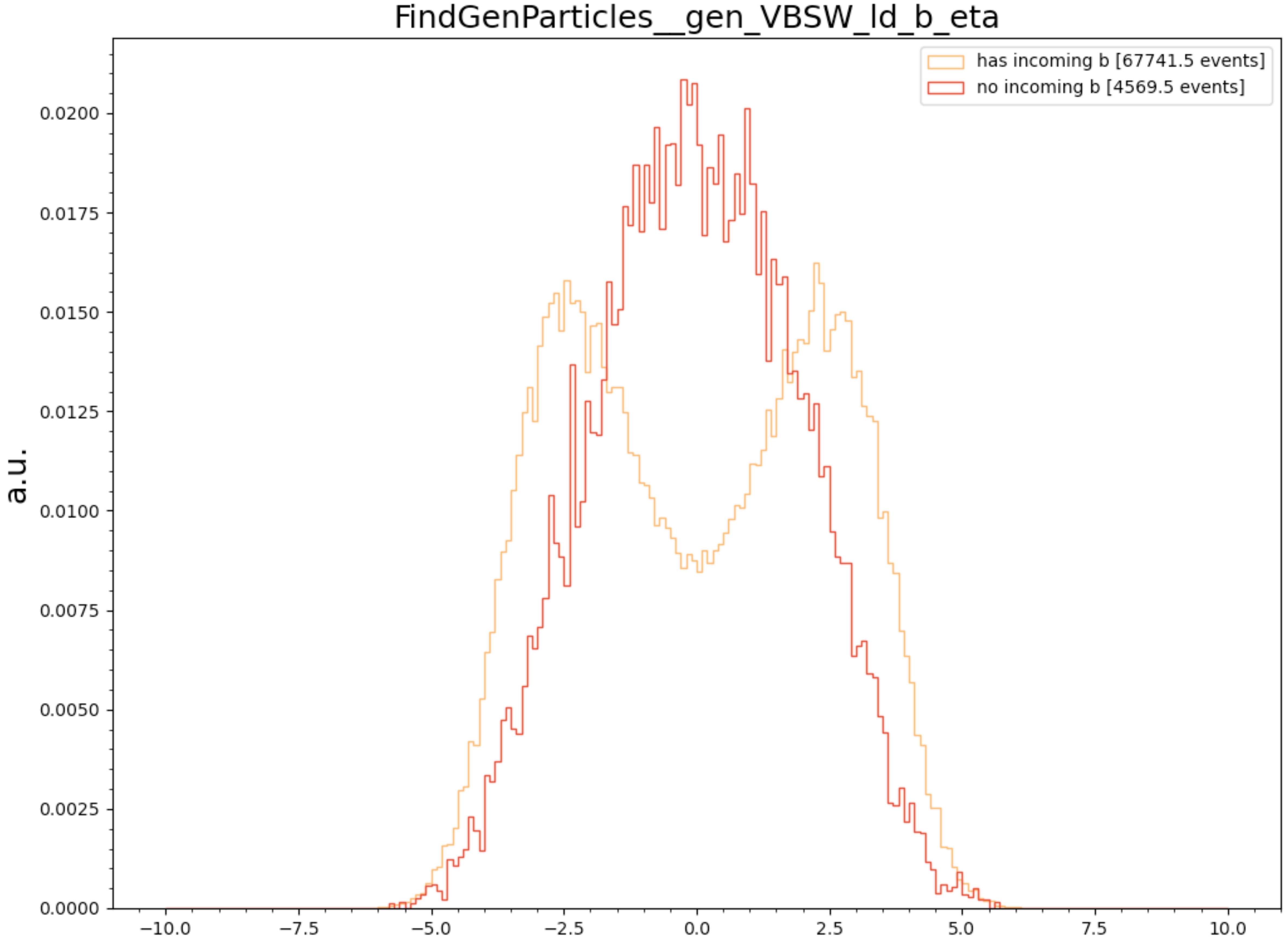




EWK W Contribution Breakdown

No selections applied





5f Outgoing Quark Kinematics

Kinematics of outgoing LHE quarks in privately generated 5f VBS W sample

(M_{jj} > 150 GeV)