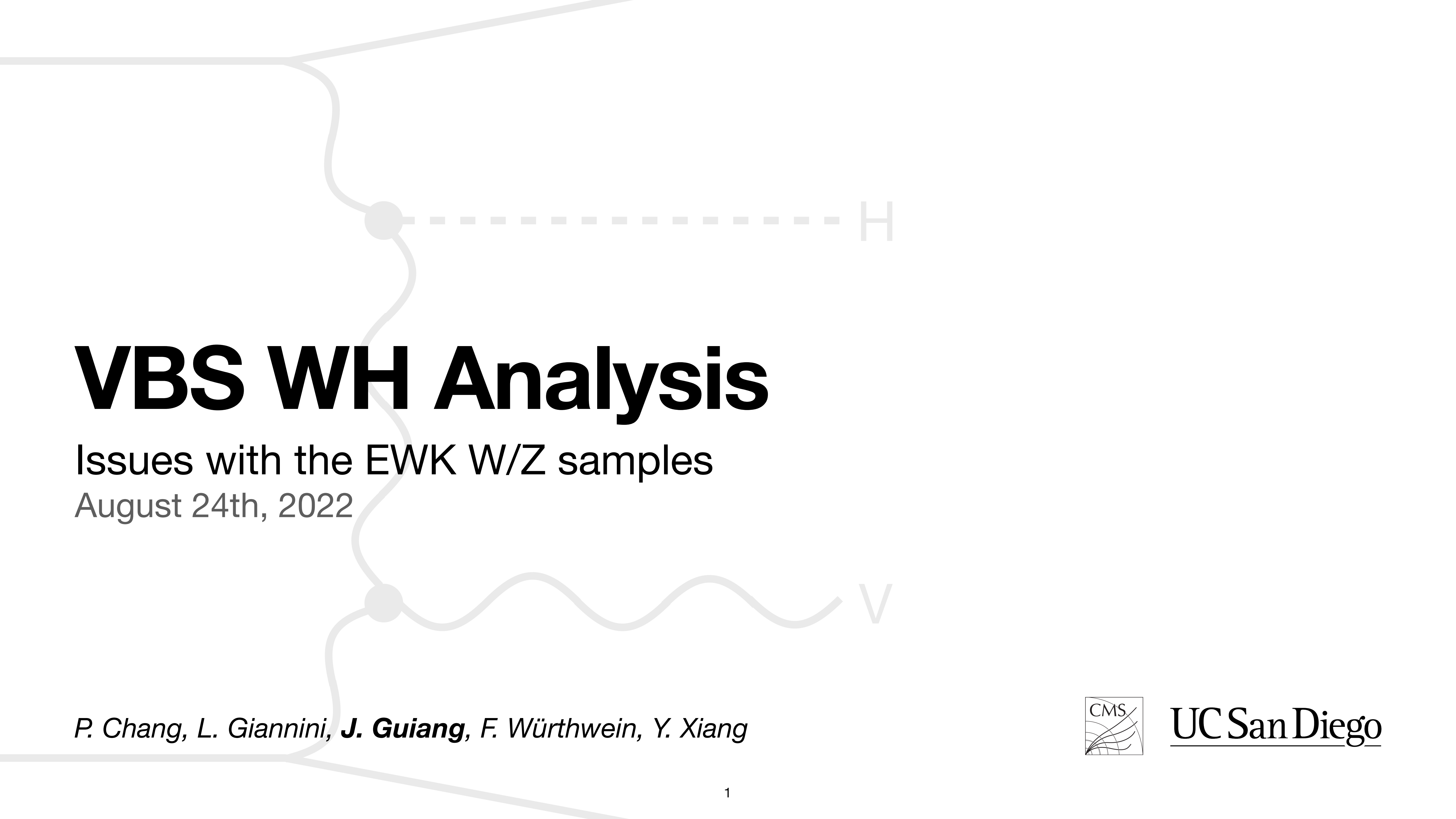


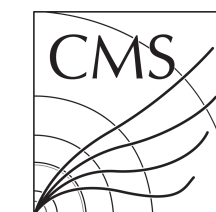


VBS WH Analysis

Issues with the EWK W/Z samples

August 24th, 2022

*P. Chang, L. Giannini, **J. Guiang**, F. Würthwein, Y. Xiang*



UC San Diego

Overview

- New EWK samples add *a lot* of background
 - Entirely from EWK $W^\pm$ ($W \rightarrow \ell \nu$)
 - Not just VBS W/Z: also have diboson events
- **Goal:** compare diboson contribution from EWK samples to dedicated diboson samples
 - For simplicity, compare only EWK W vs. WW sample
 - If good match: EWK samples may be correct
 - If bad match: EWK samples may be wrong

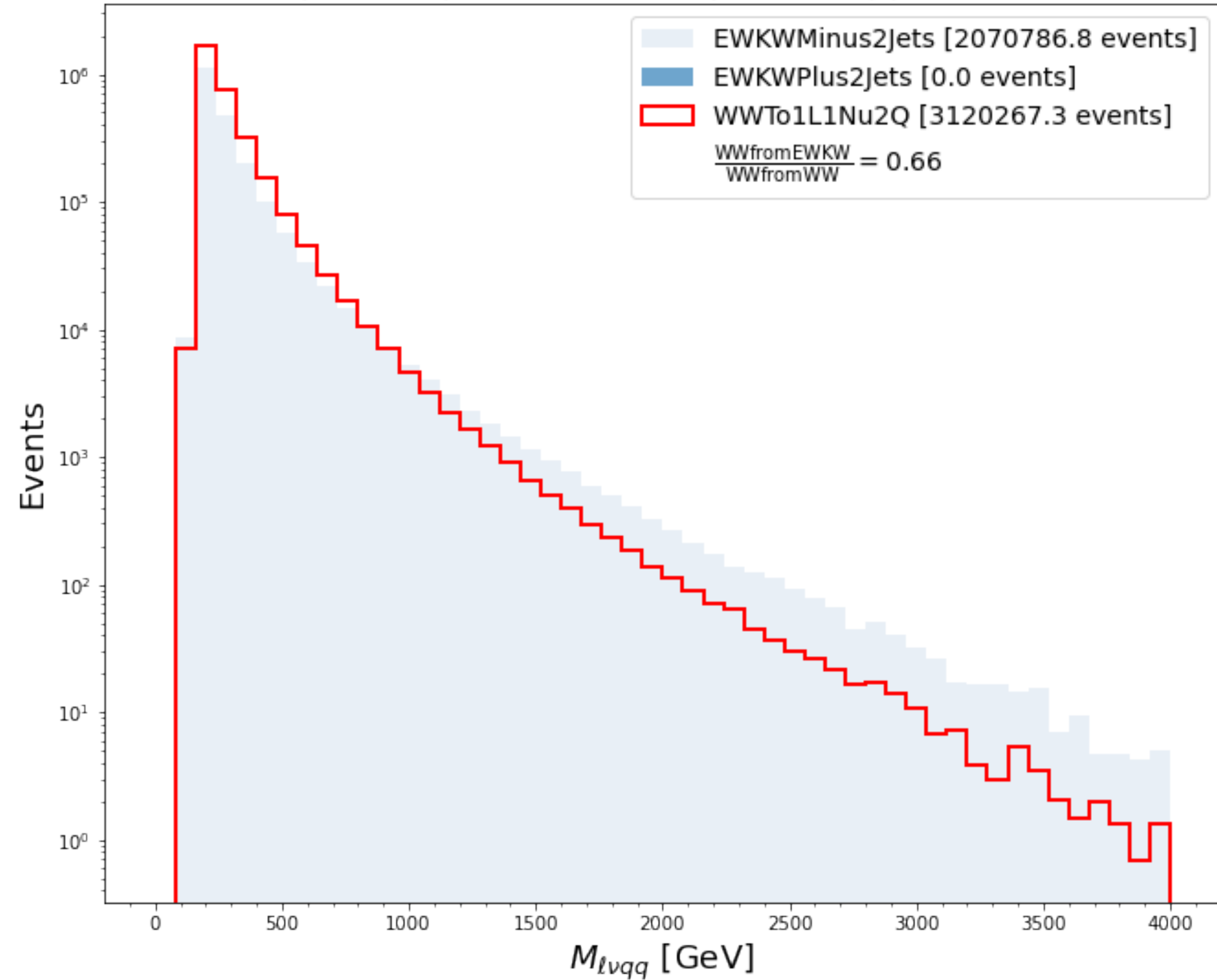
Sample	σ [pb]
EWK W^+ , $W \rightarrow \ell \nu$	39.33
EWK W^+ , $W \rightarrow qq$	10.67
EWK W^- , $W \rightarrow \ell \nu$	32.26
EWK W^- , $W \rightarrow qq$	10.67
EWK Z, $Z \rightarrow \ell \ell$	6.22
EWK Z, $Z \rightarrow \nu \nu$	10.72
EWK Z, $Z \rightarrow qq$	10.67



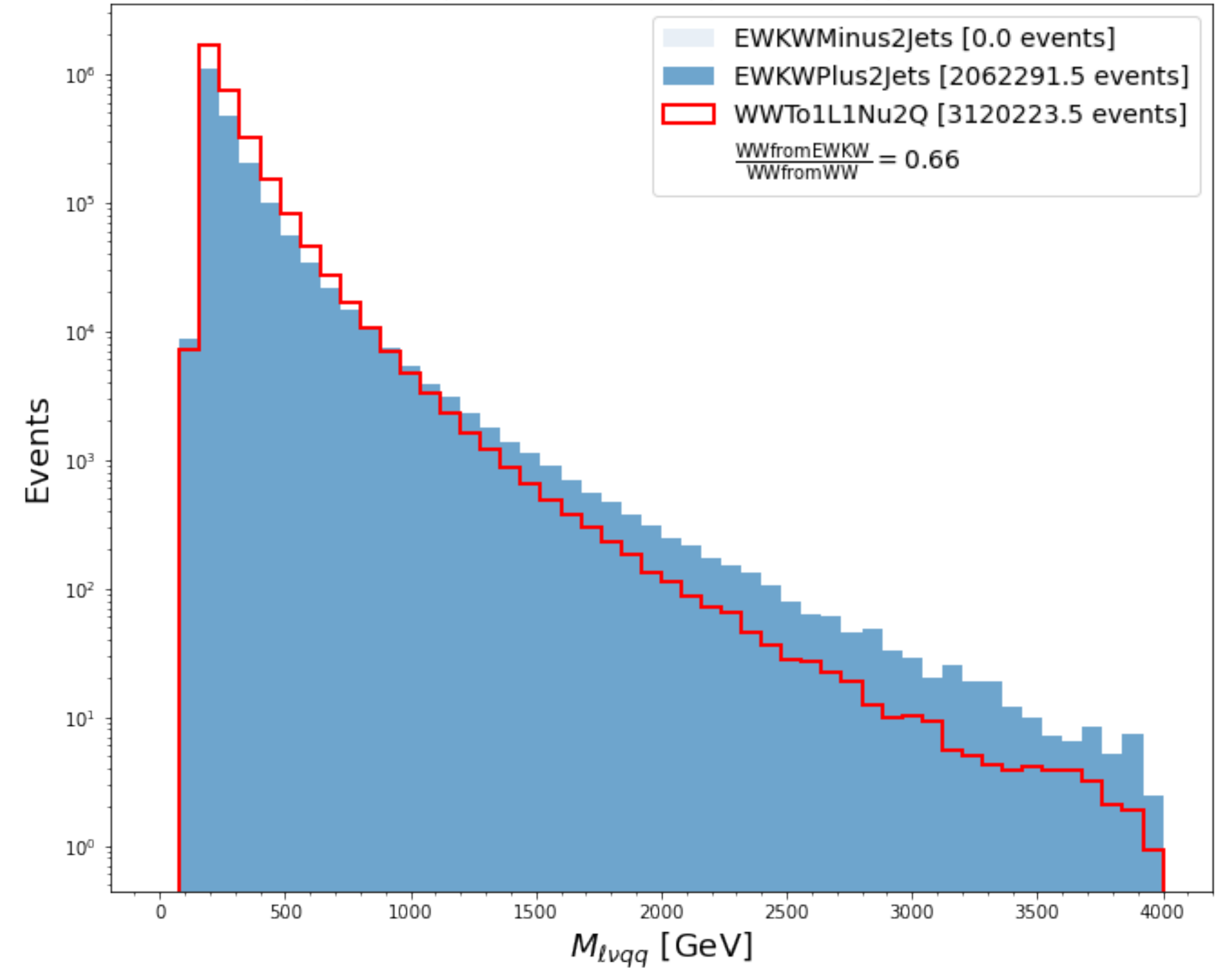
Comparing Diboson Contributions

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

SeparateWpWmFromWmWp ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



SeparateWpWmFromWmWp ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)

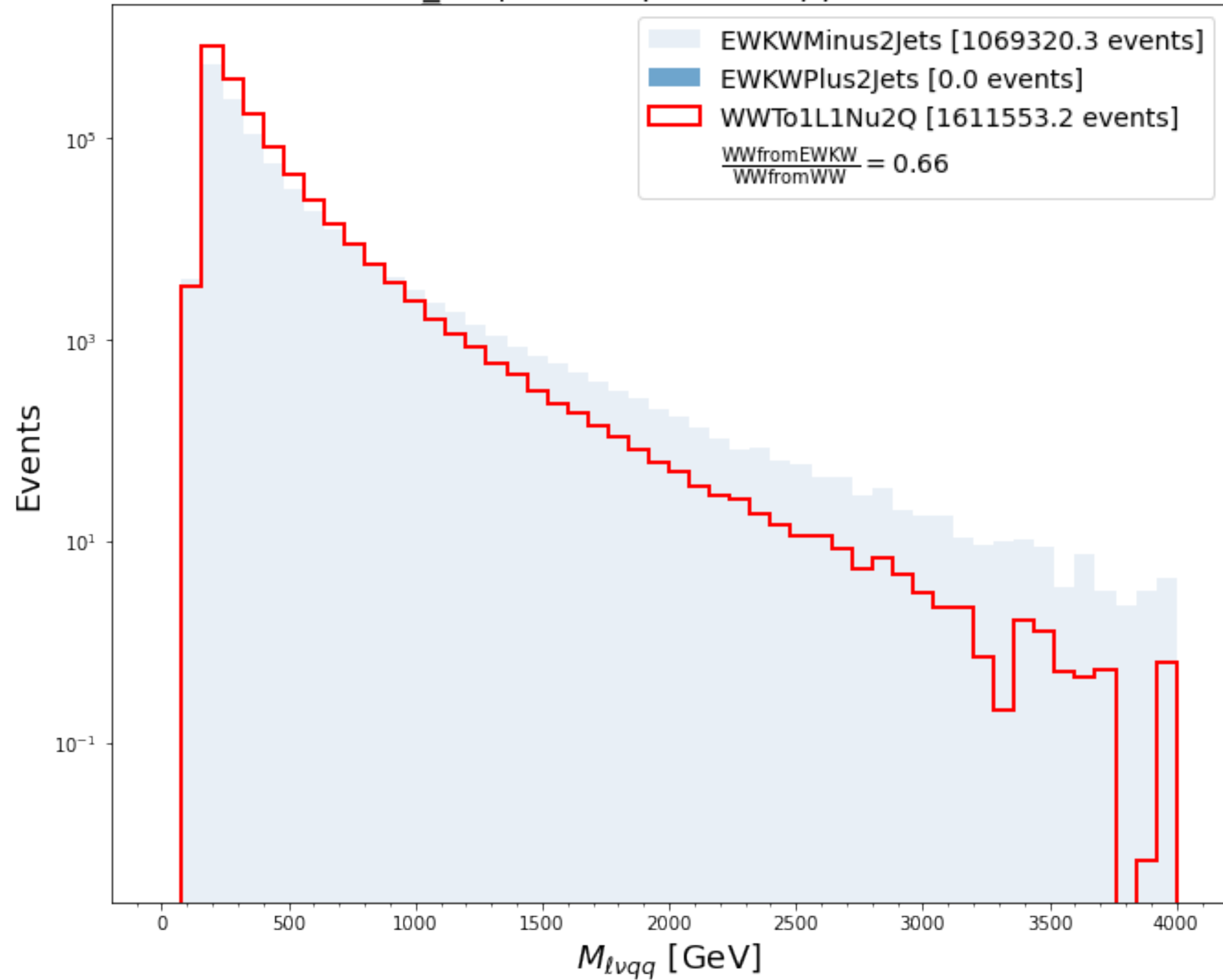




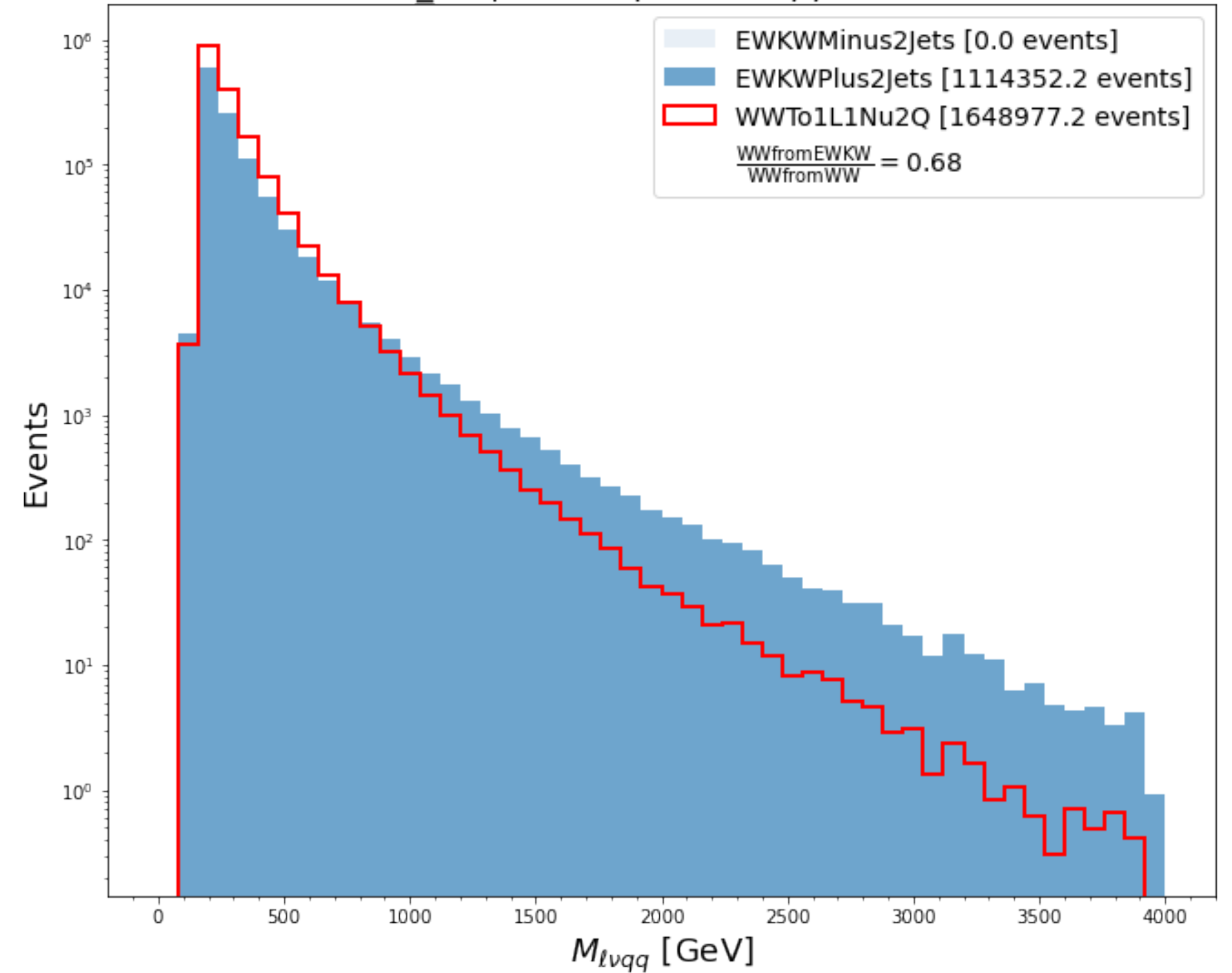
Comparing Diboson Contributions

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

SKIM_Geq1VetoLep ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



SKIM_Geq1VetoLep ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)

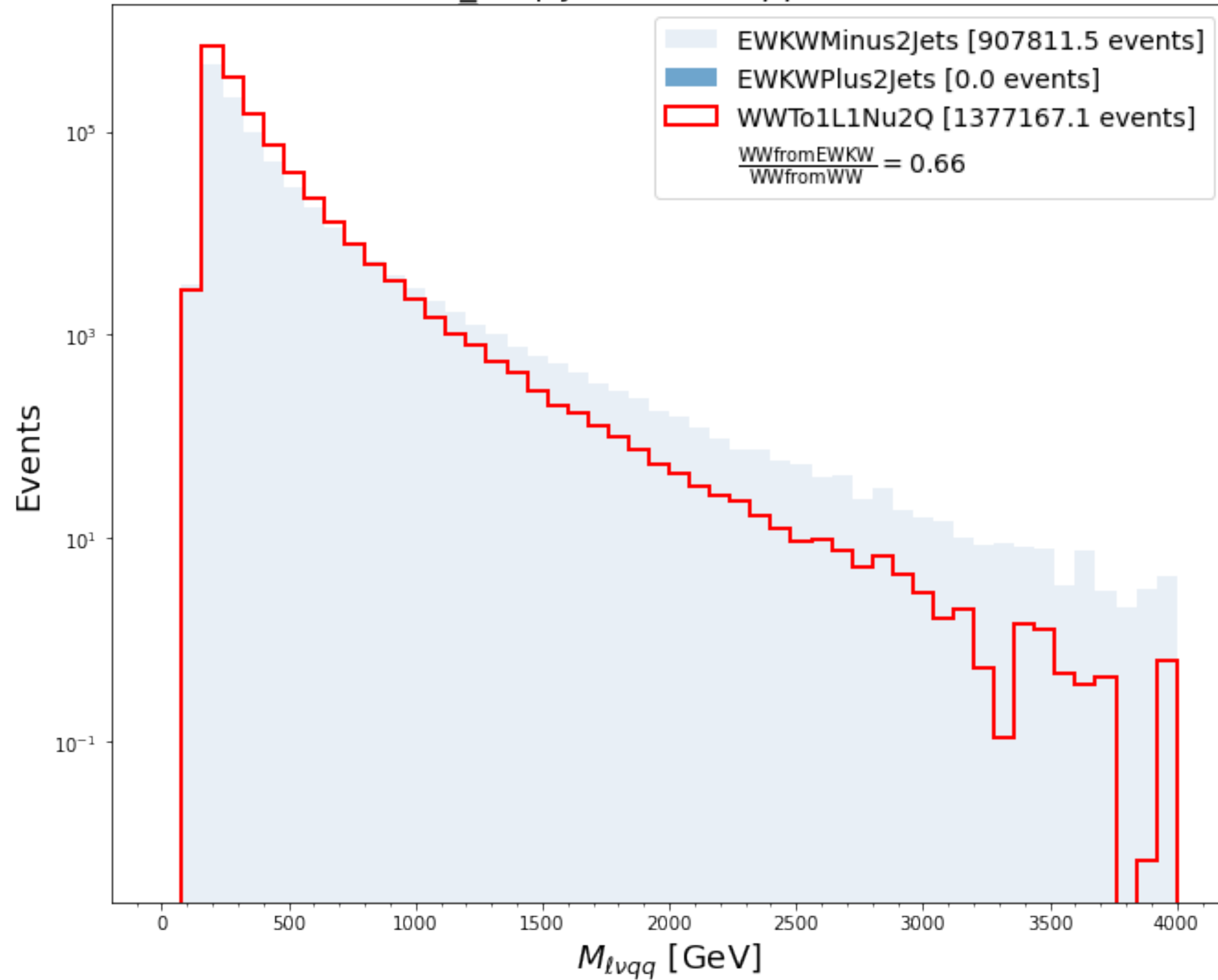




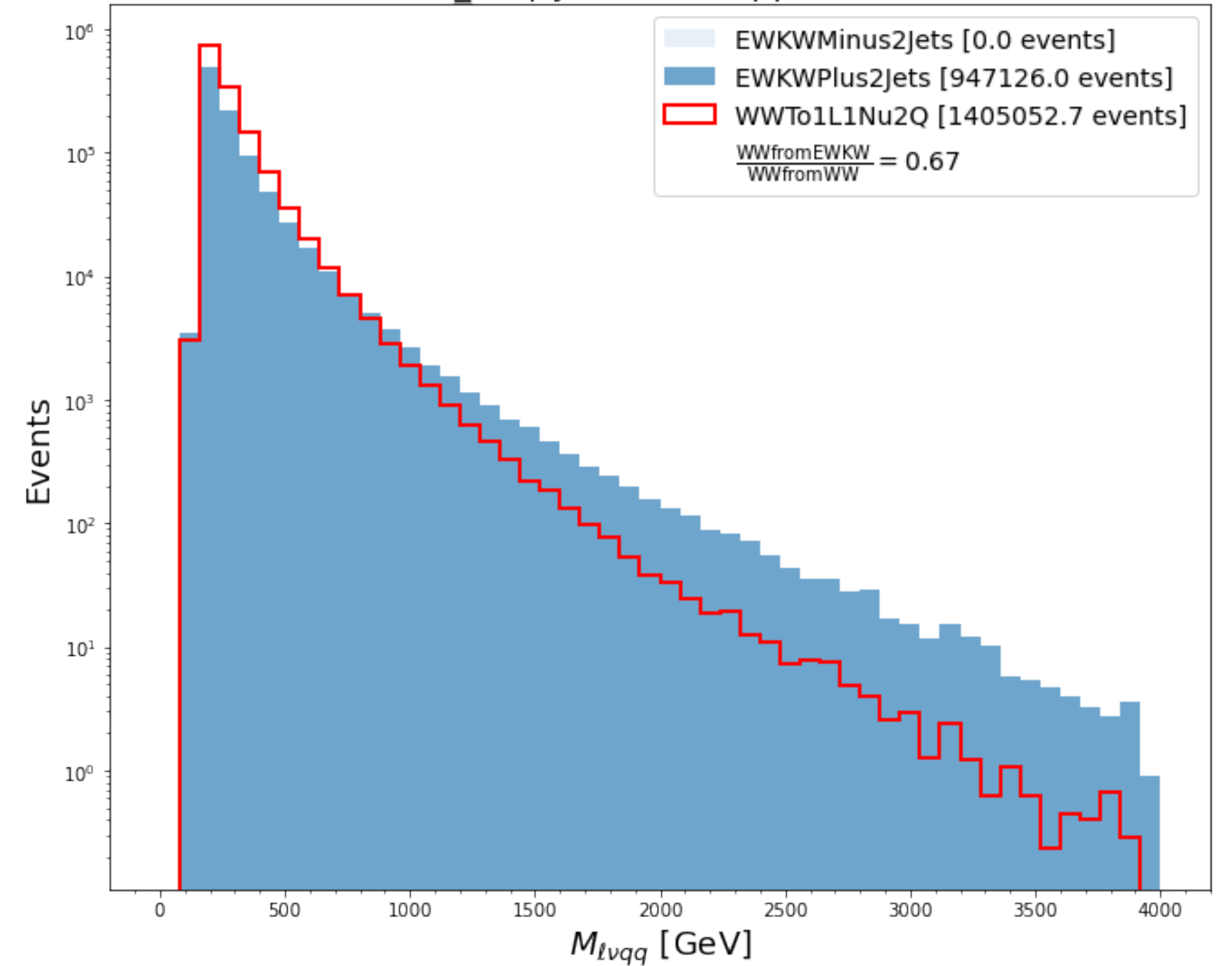
Comparing Diboson Contributions

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

SKIM_Geq2Jets ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



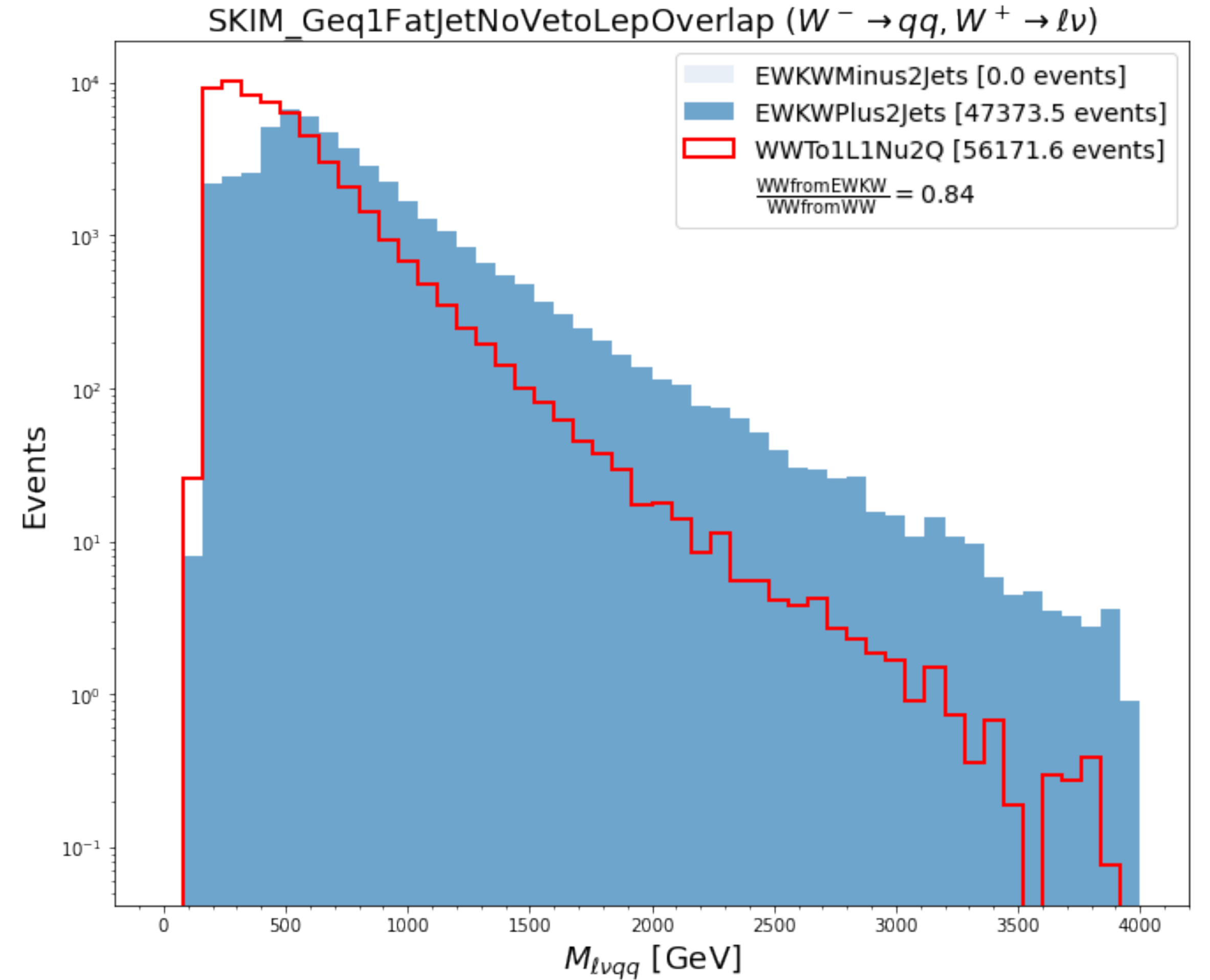
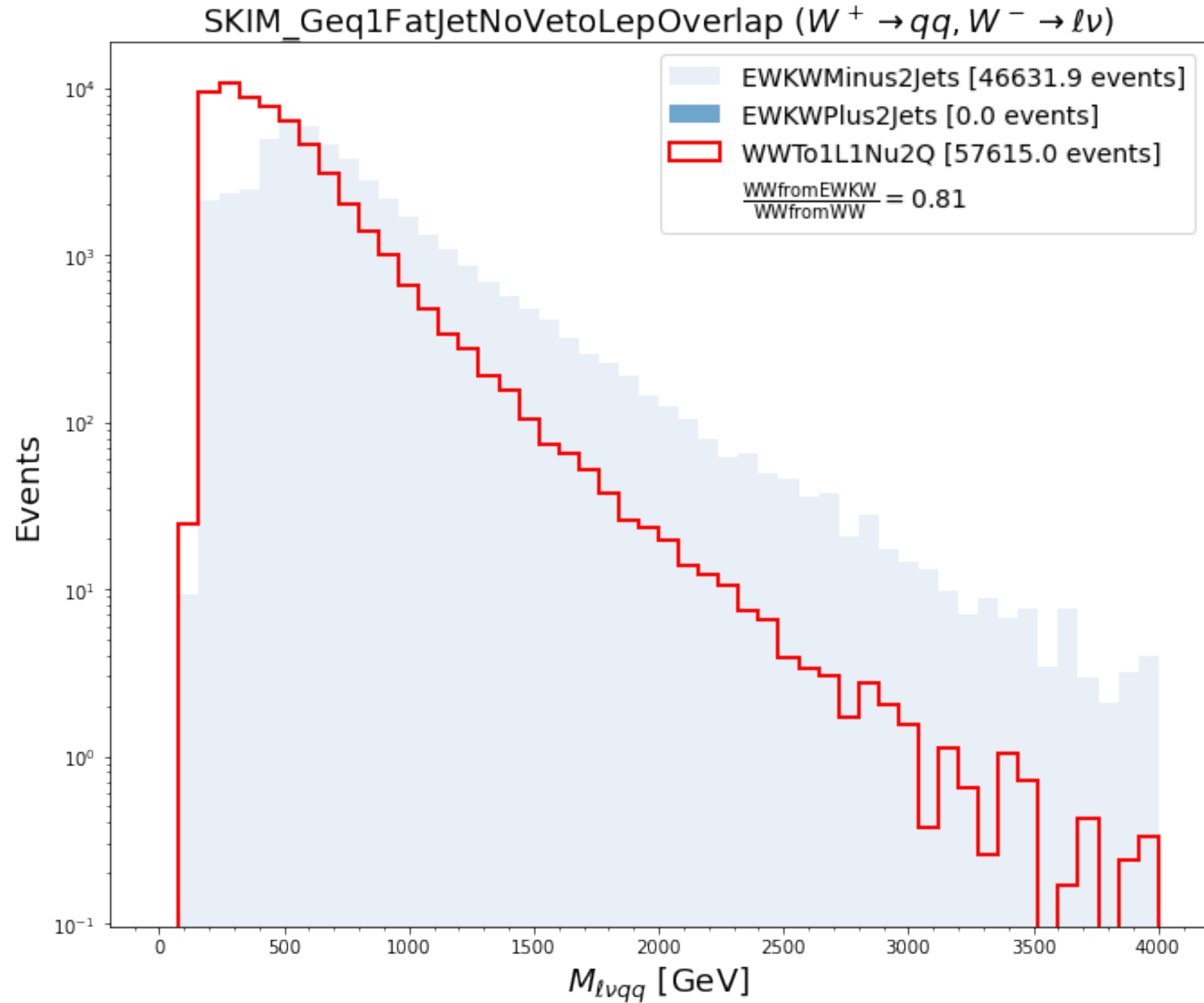
SKIM_Geq2Jets ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)





Comparing Diboson Contributions

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



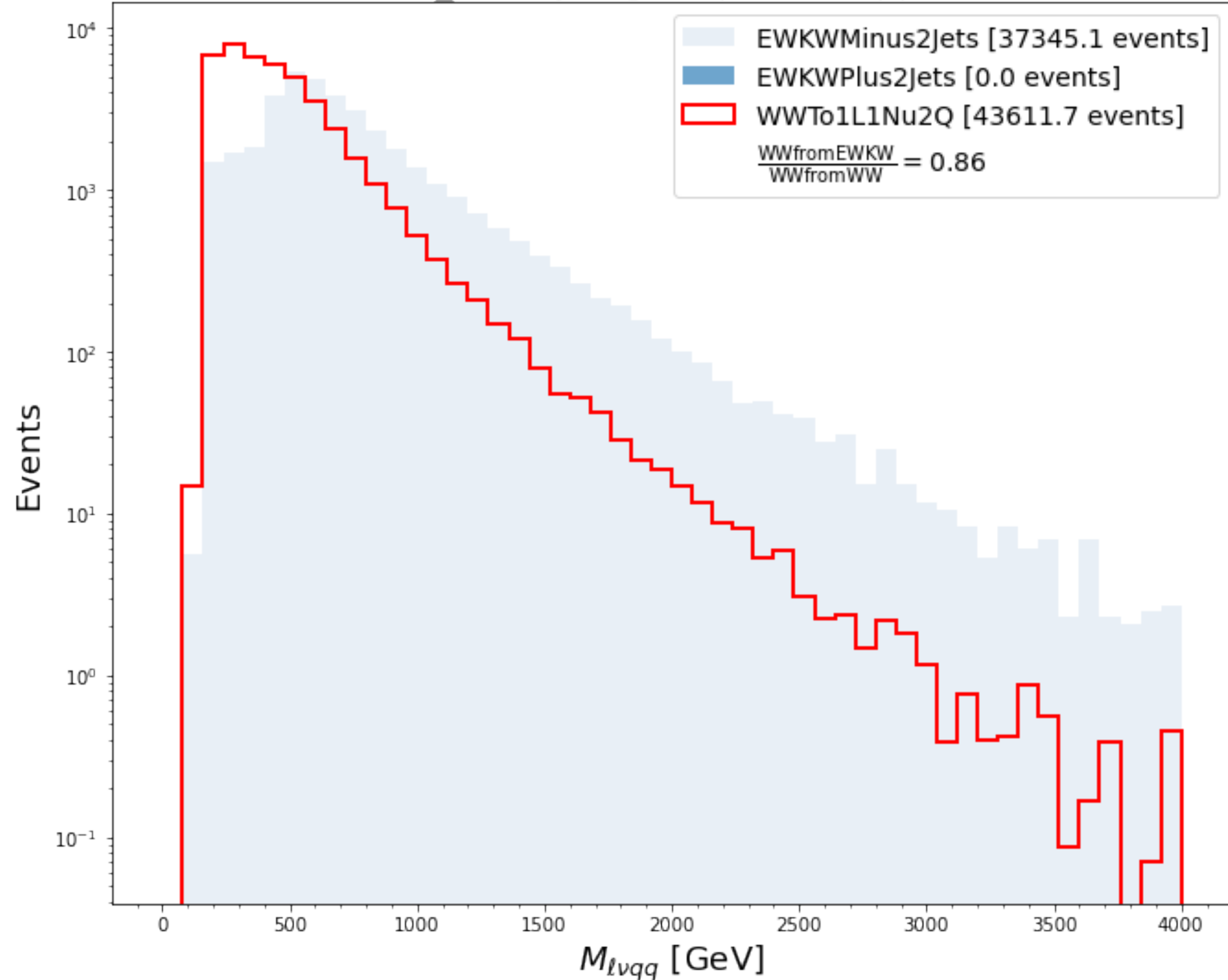
Weird feature at 700 GeV develops after fatjet selection



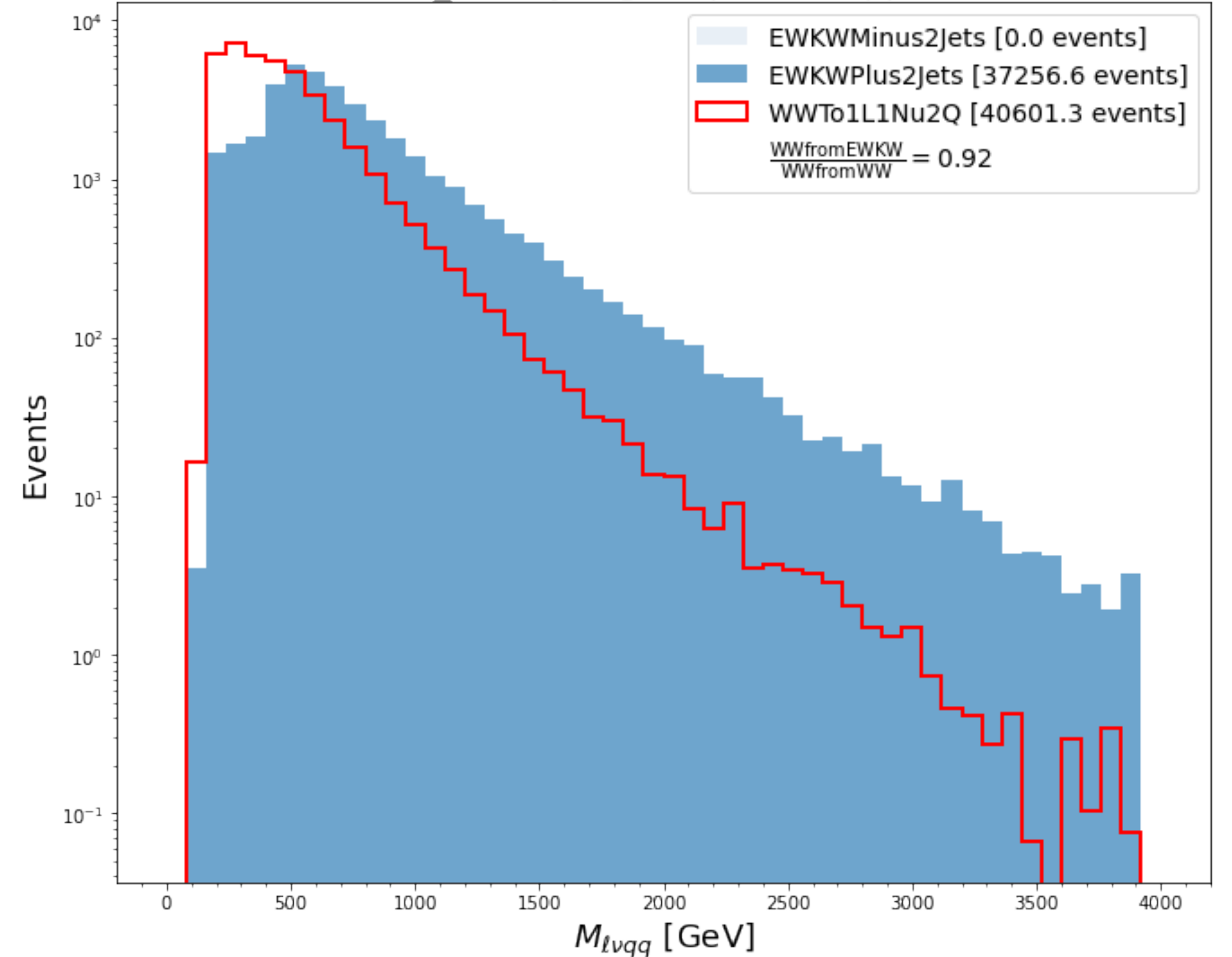
Comparing Diboson Contributions

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

POSTSKIM_Exactly1TightLep ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



POSTSKIM_Exactly1TightLep ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)

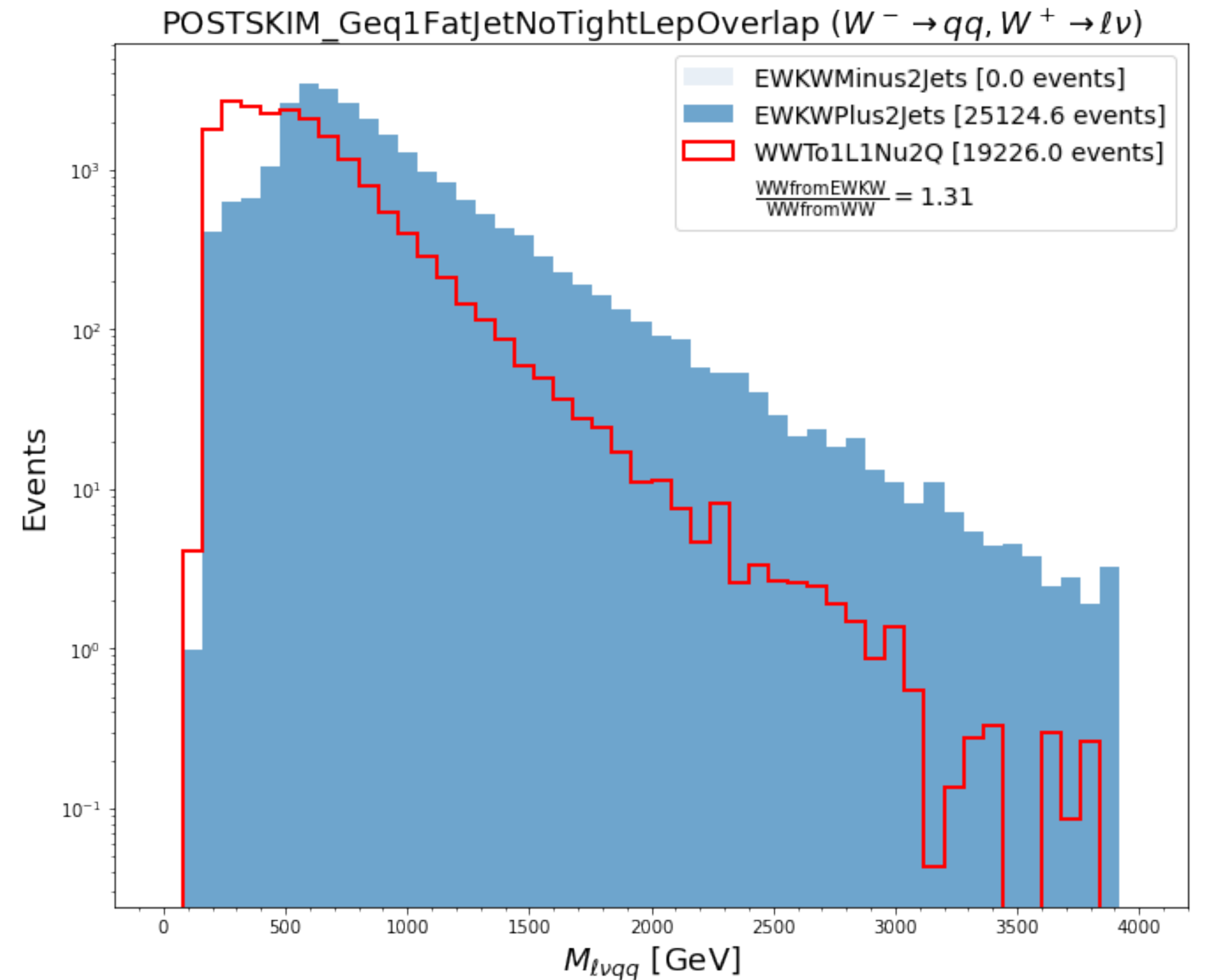
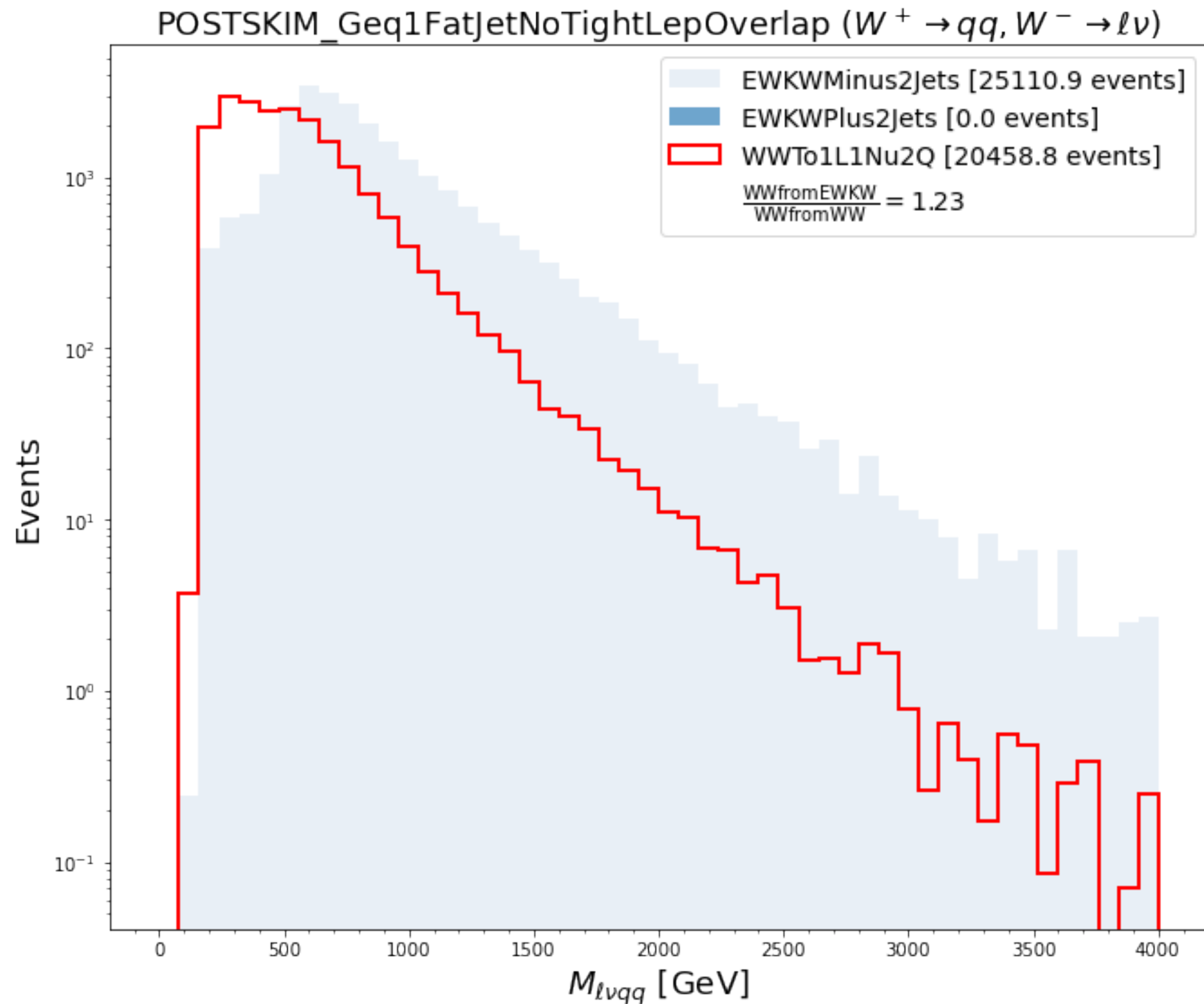


Weird feature at 700 GeV develops after fatjet selection



Comparing Diboson Contributions

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



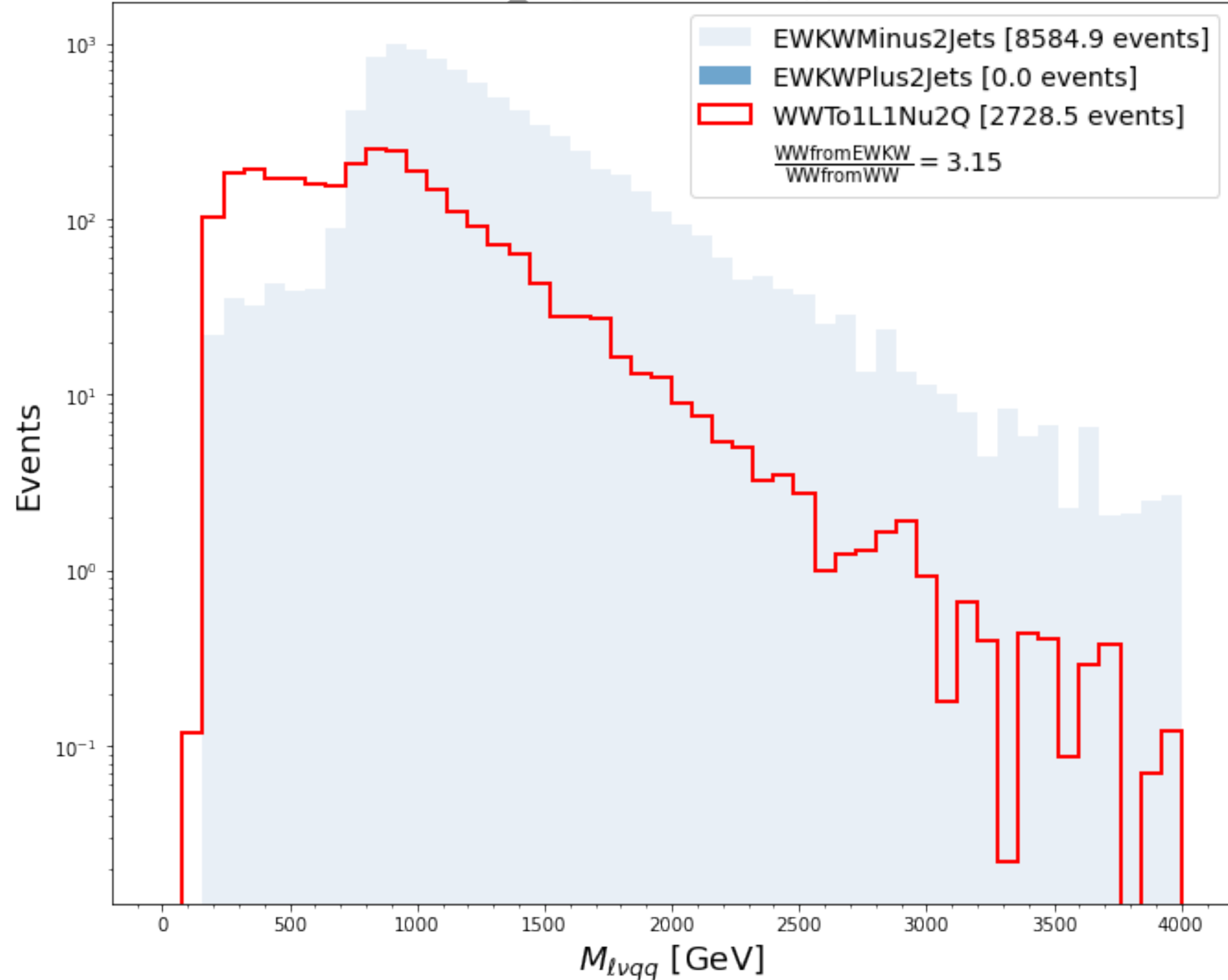
Weird feature at 700 GeV develops after fatjet selection



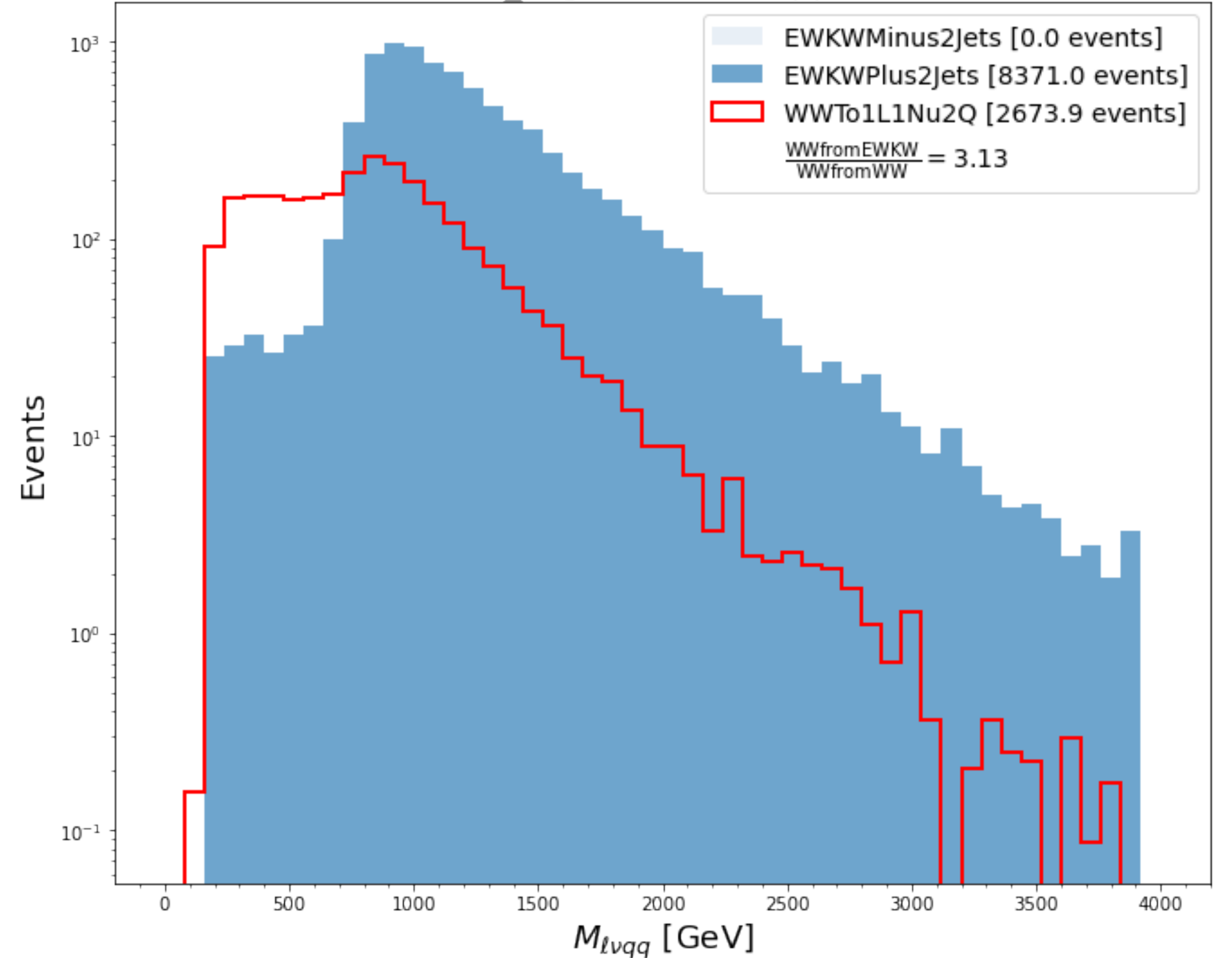
Comparing Diboson Contributions

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

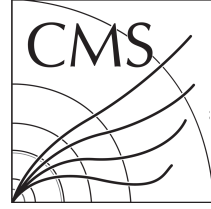
POSTSKIM_STgt800 ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



POSTSKIM_STgt800 ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)

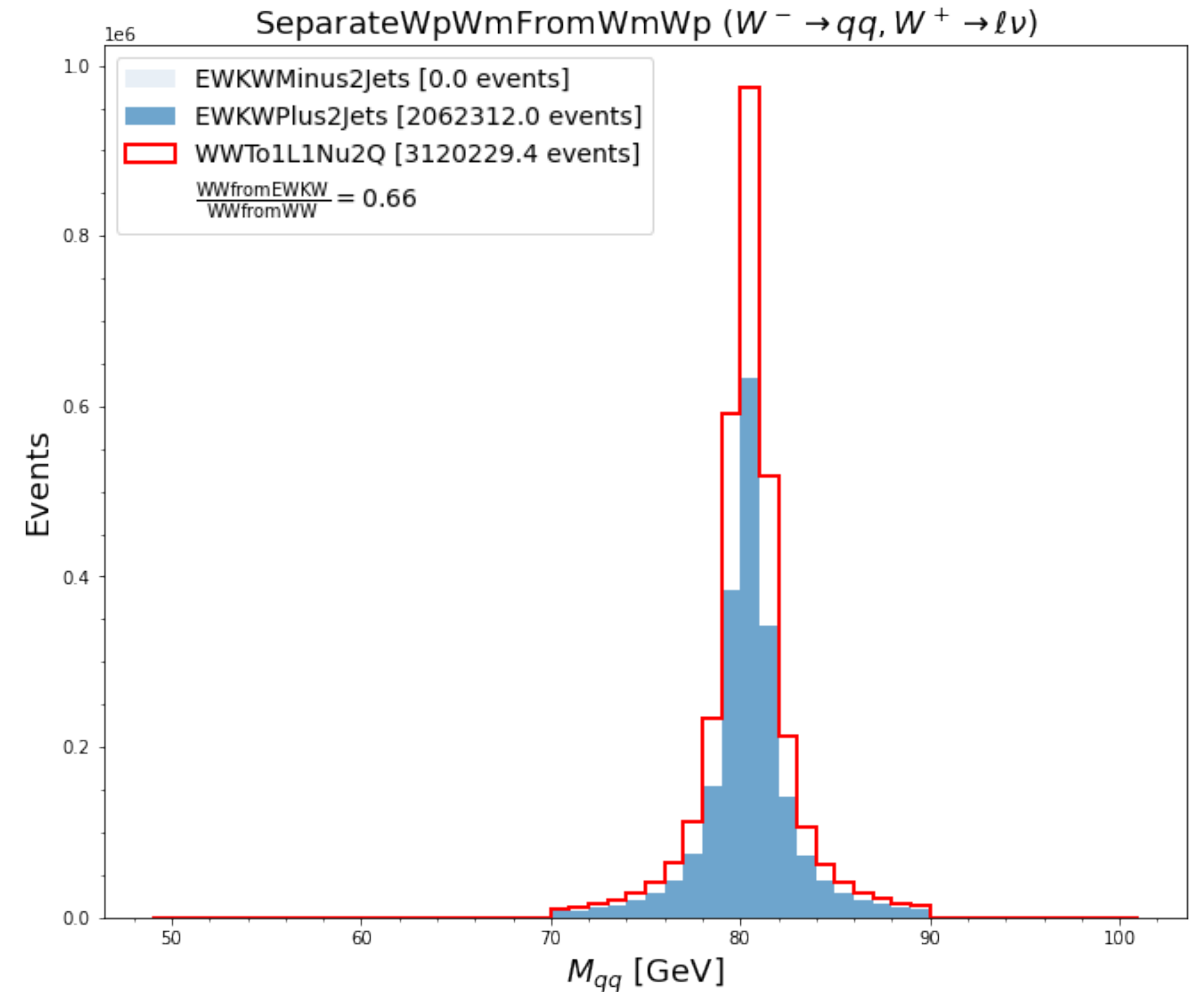
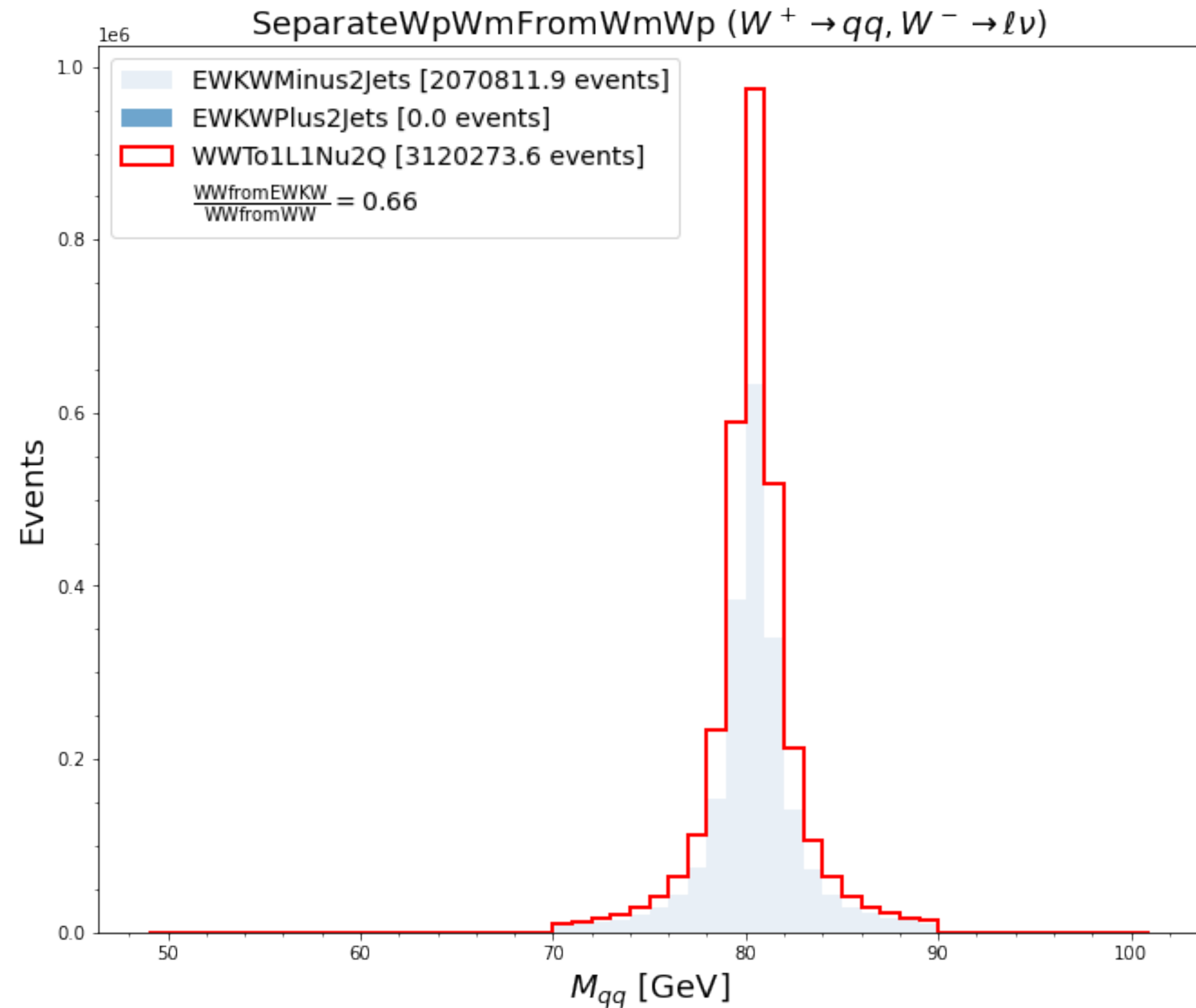


Weird feature at 700 GeV worsens after S_T selection



Comparing Diboson Contributions

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

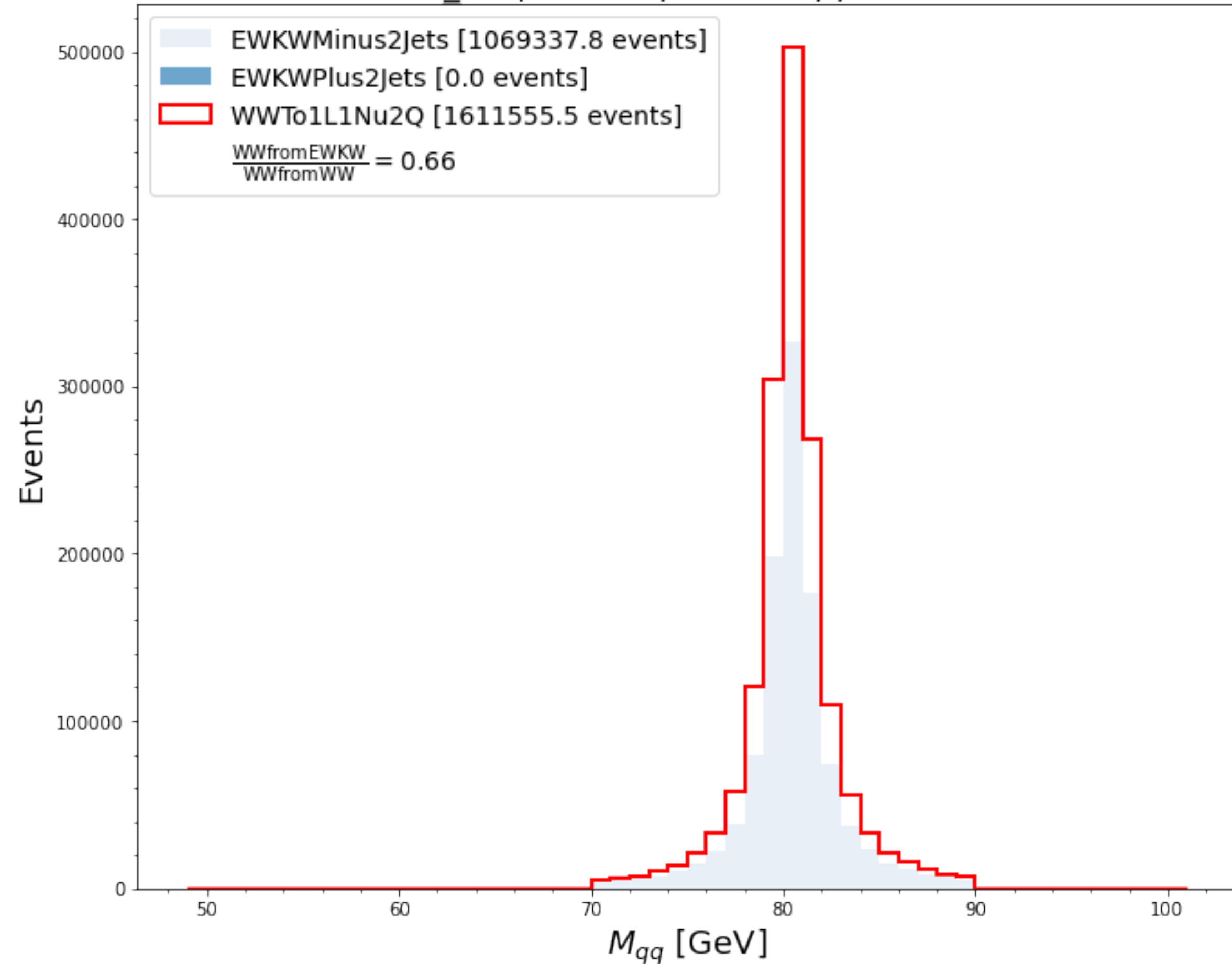




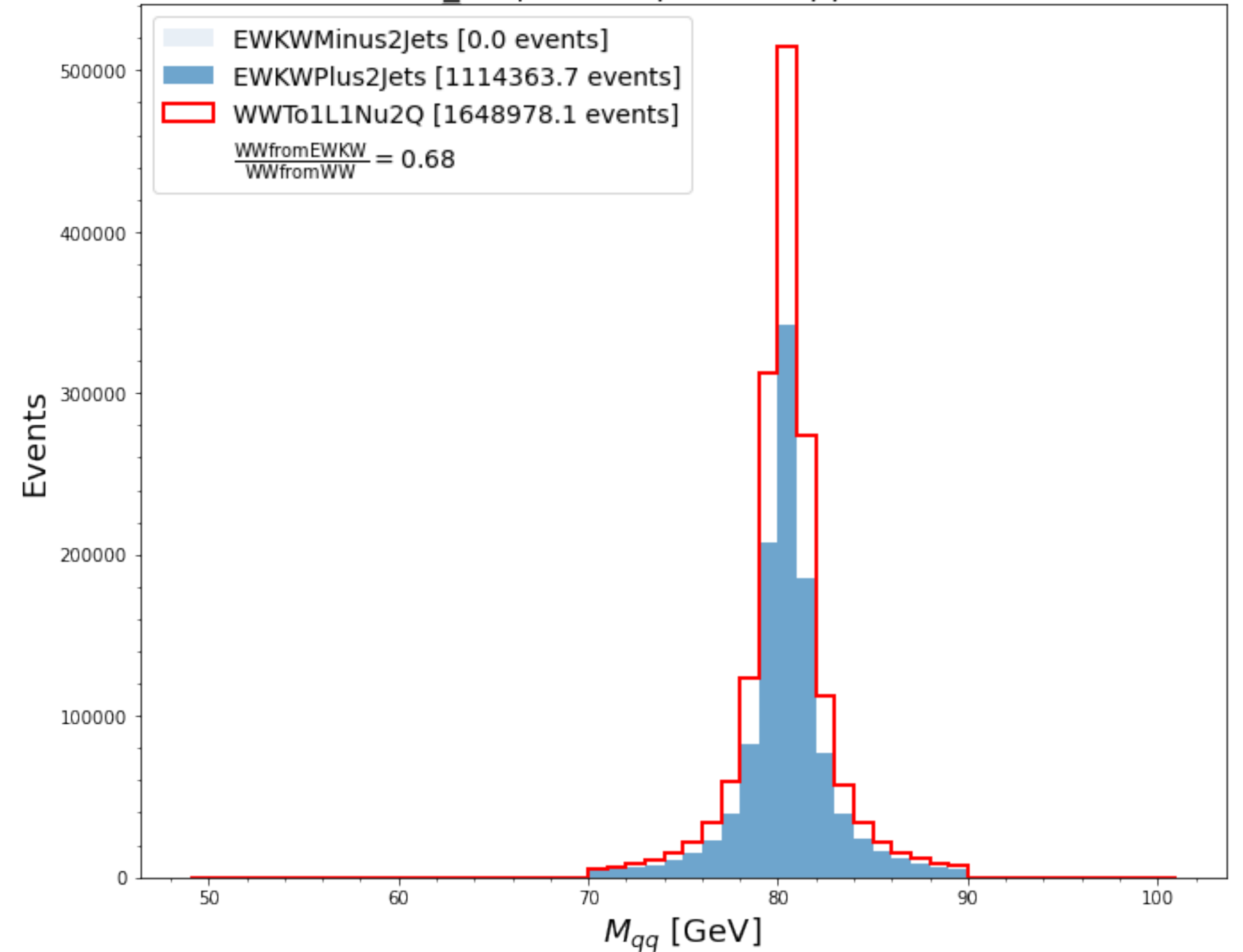
Comparing Diboson Contributions

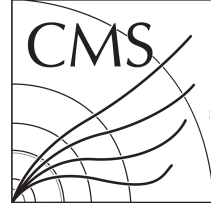
Overall Selection: $M_{\ell\nu} \in [70, 90)$ GeV AND $M_{qq} \in [70, 90)$ GeV AND $|\text{charge}_{qq}| == 1$

SKIM_Geq1VetoLep ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



SKIM_Geq1VetoLep ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)

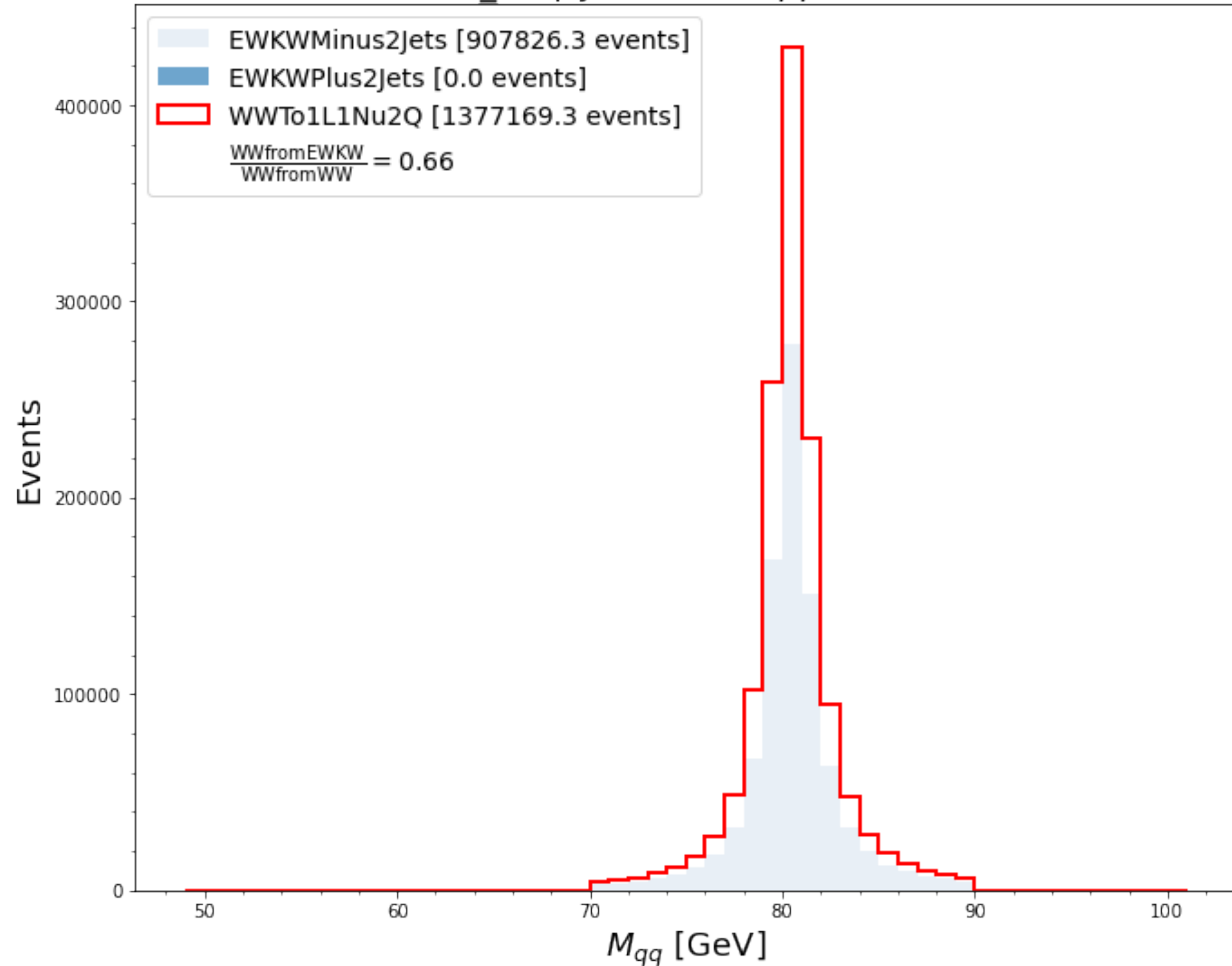




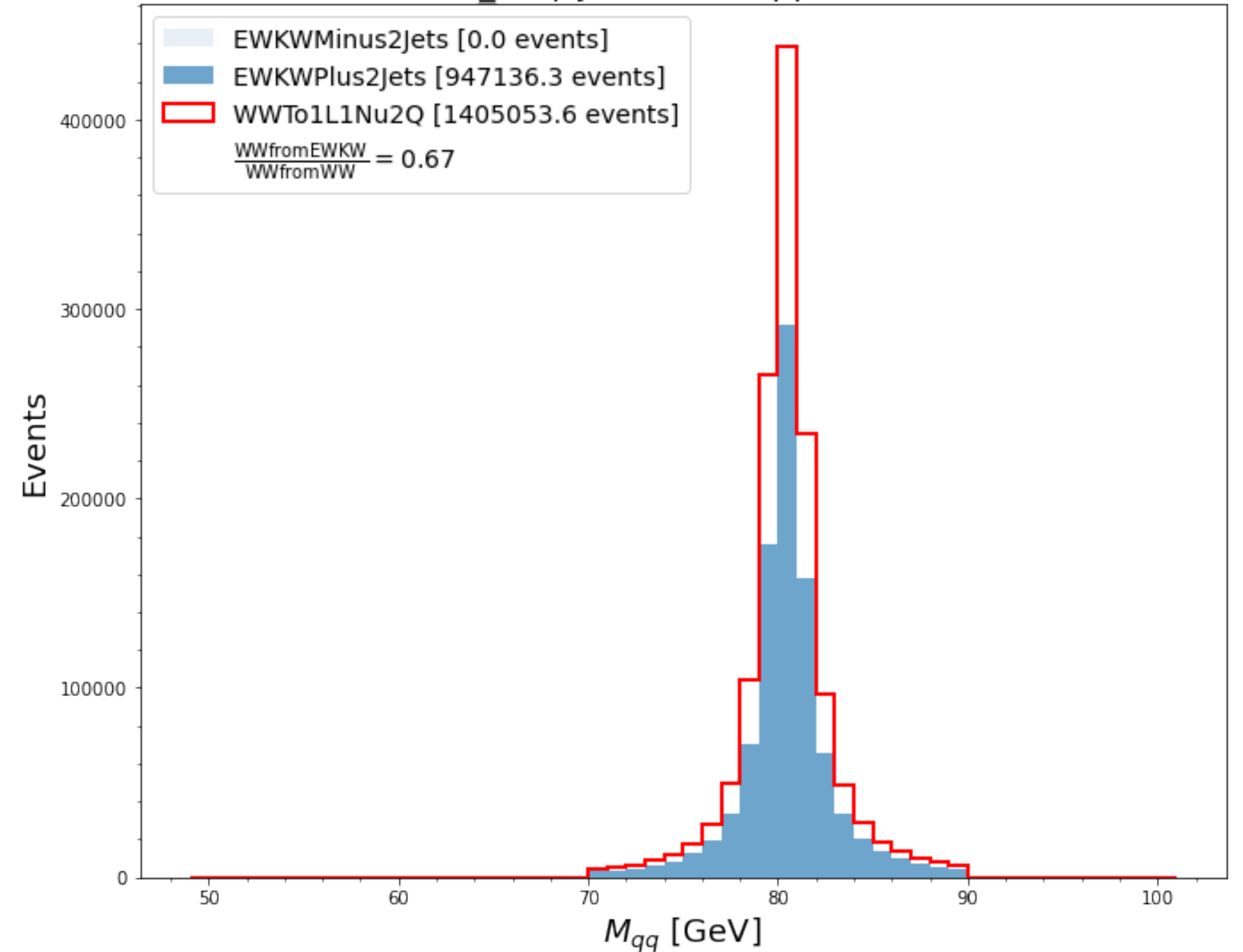
Comparing Diboson Contributions

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

SKIM_Geq2Jets ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



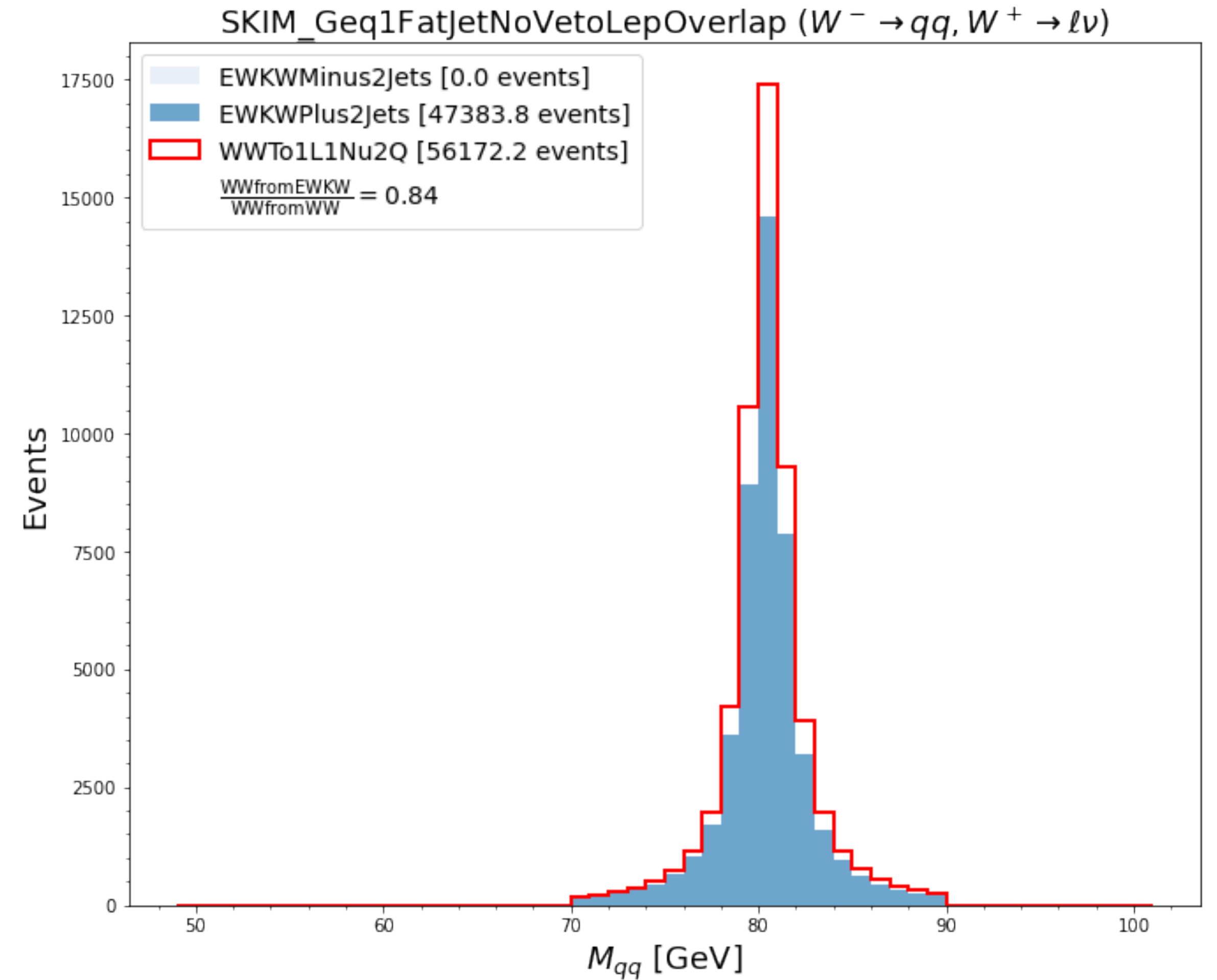
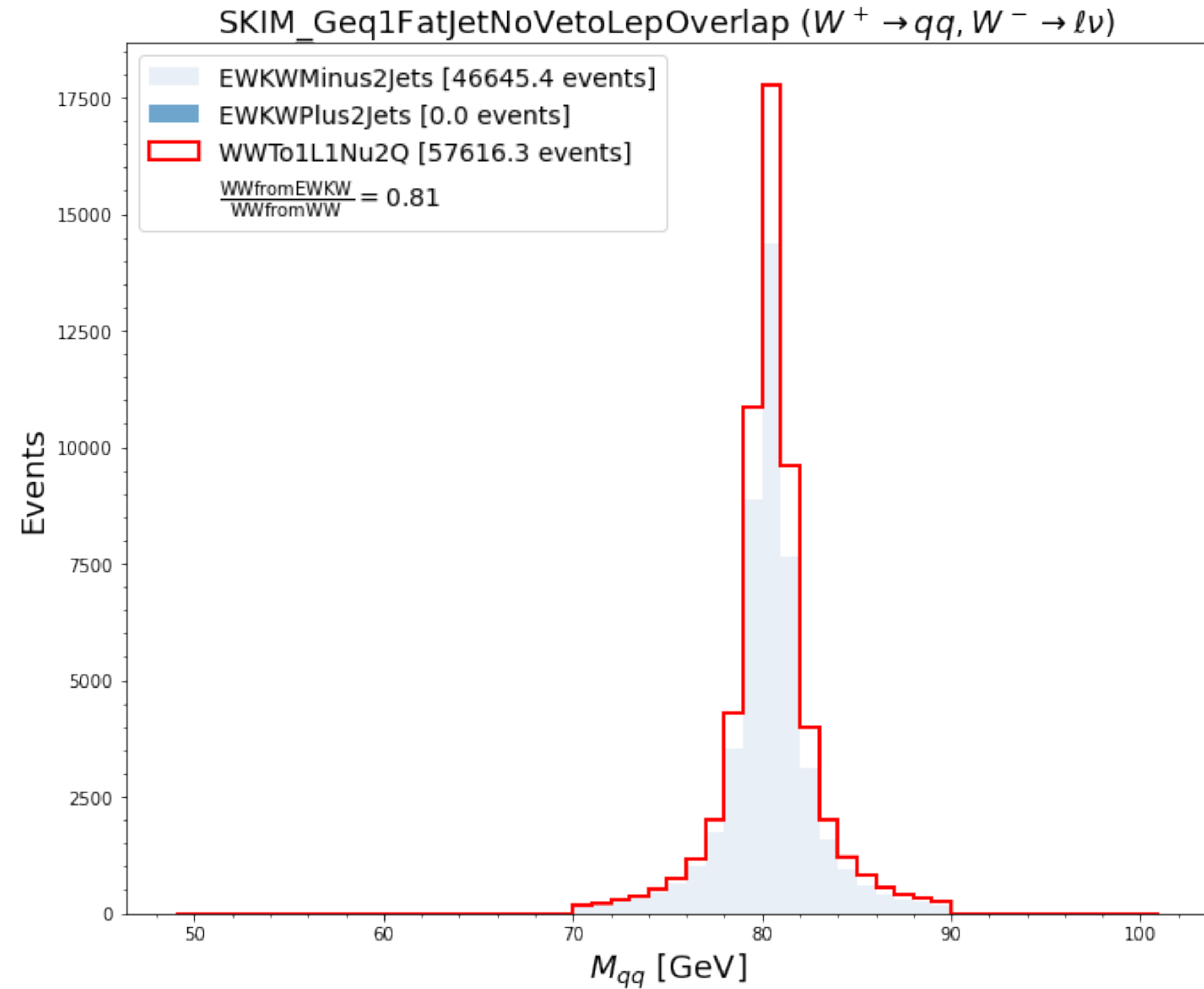
SKIM_Geq2Jets ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)

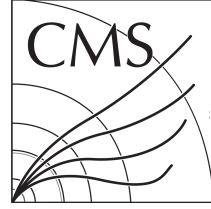




Comparing Diboson Contributions

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

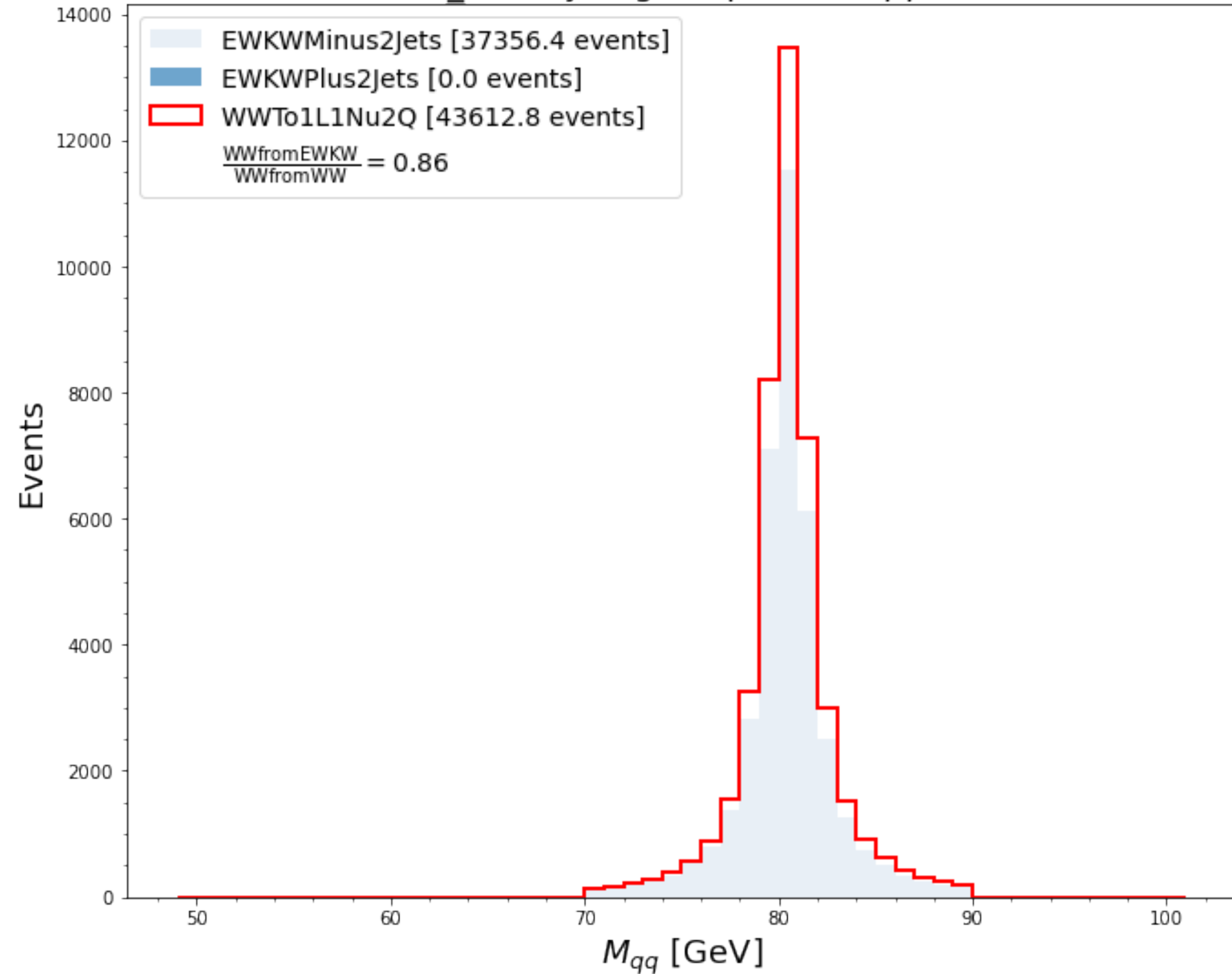




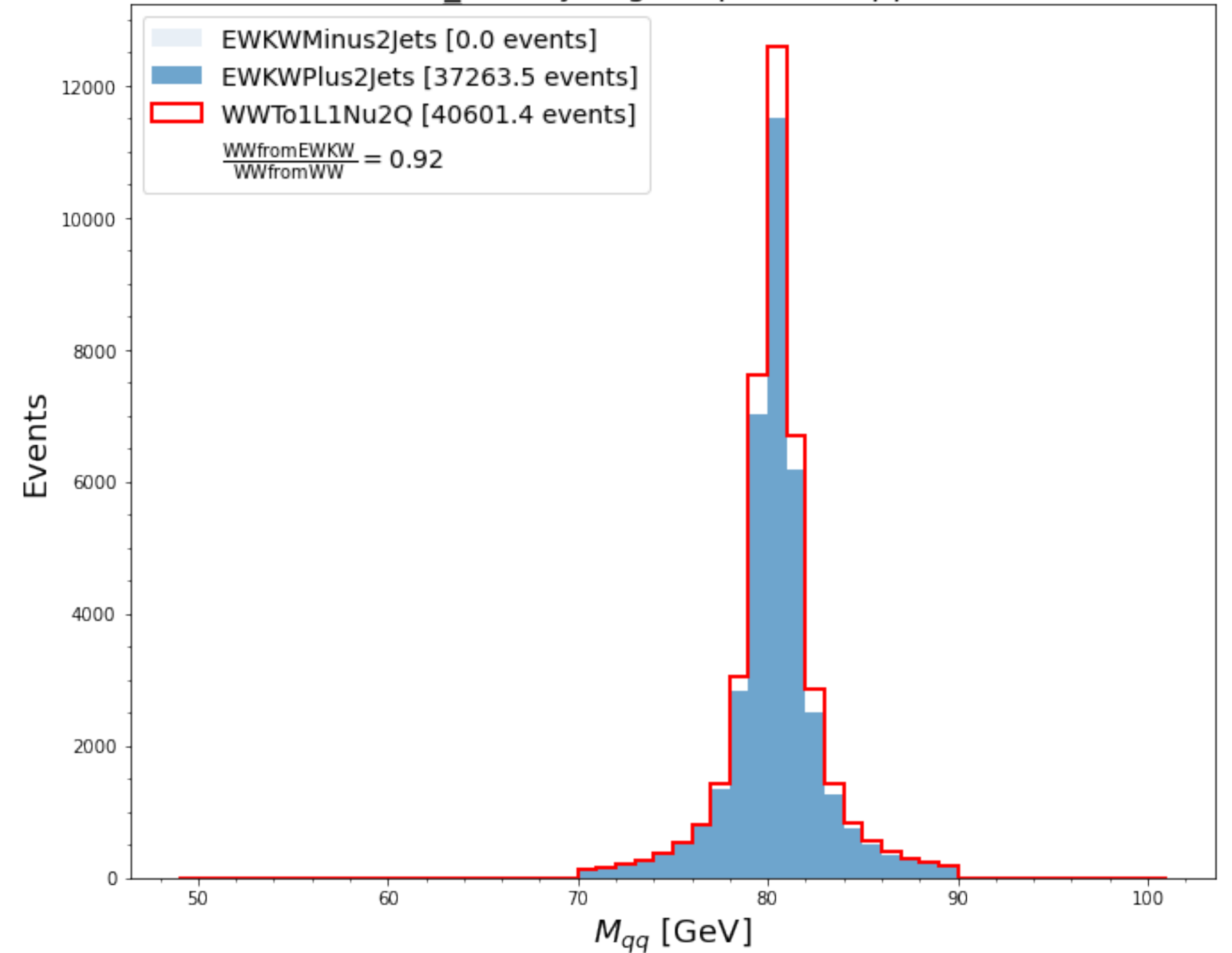
Comparing Diboson Contributions

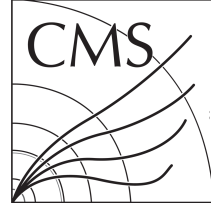
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POSTSKIM_Exactly1TightLep ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



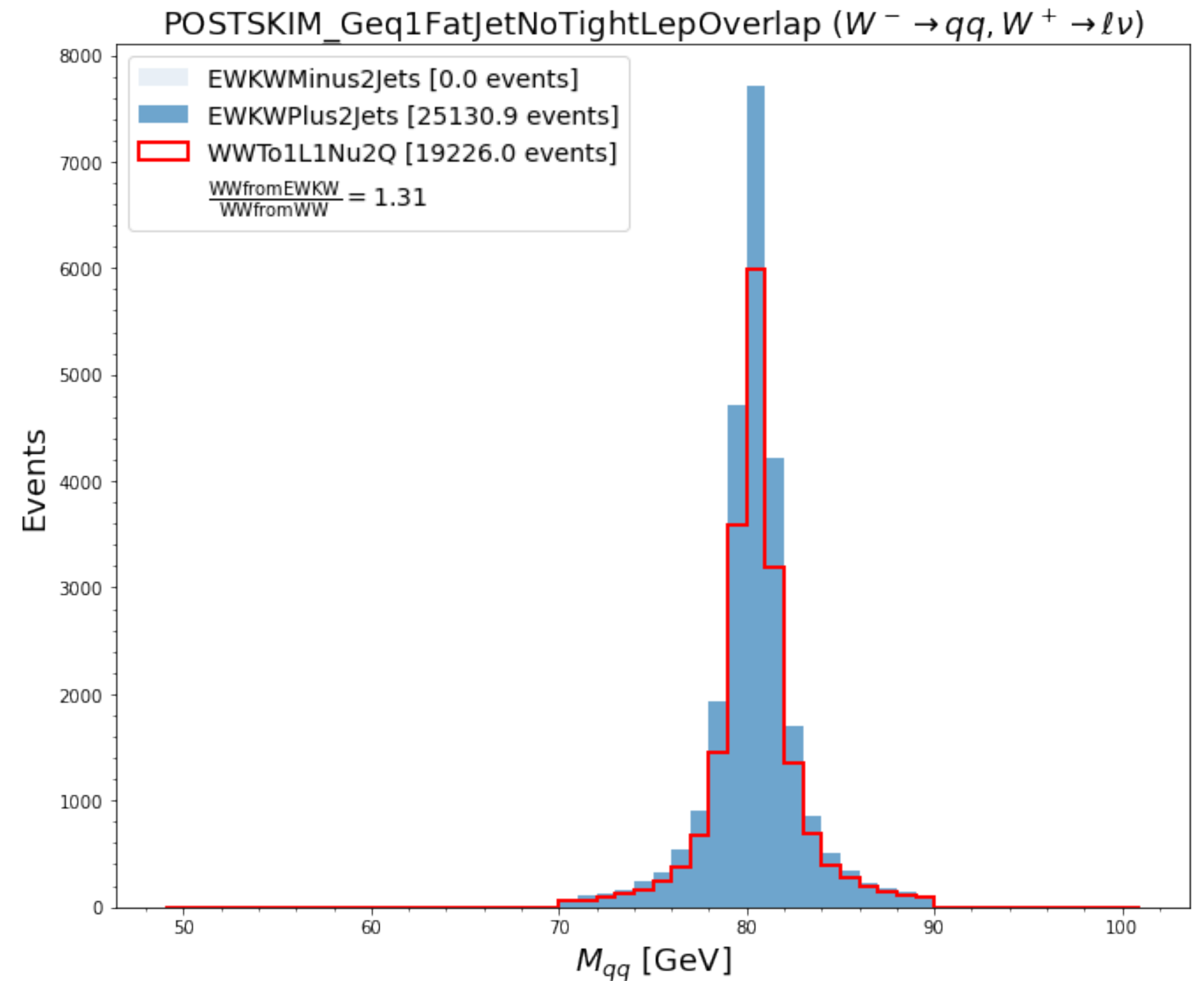
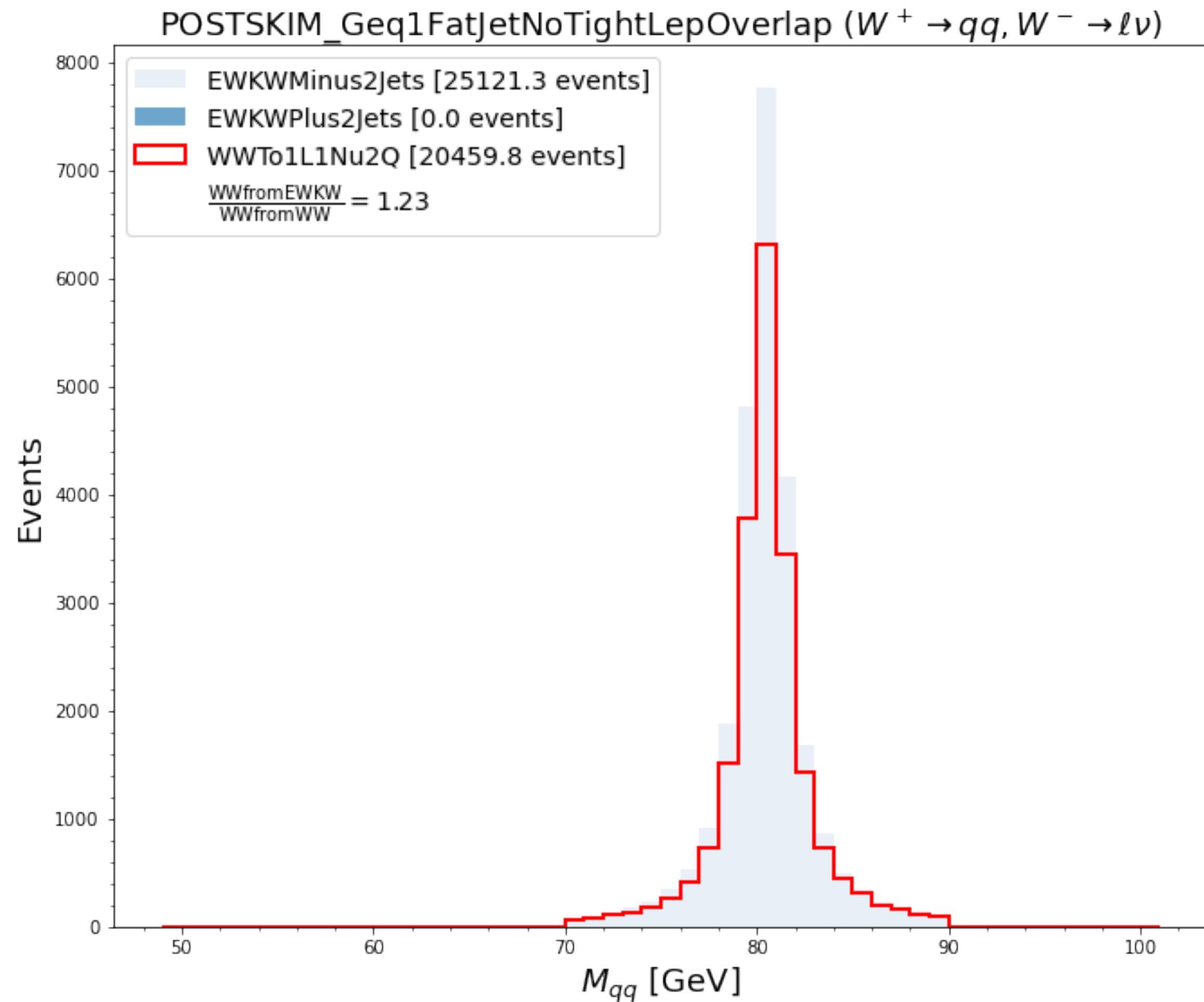
POSTSKIM_Exactly1TightLep ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)





Comparing Diboson Contributions

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

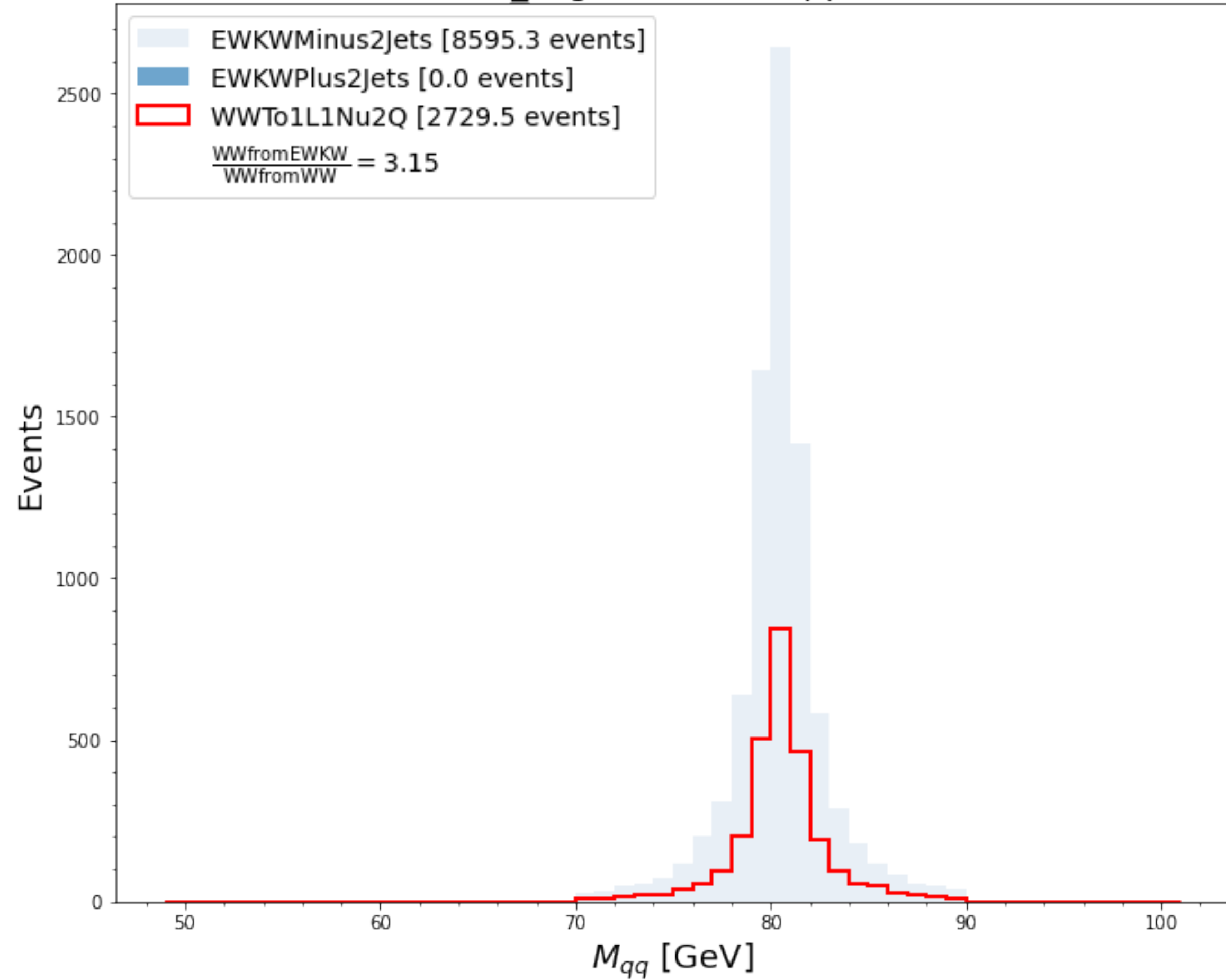




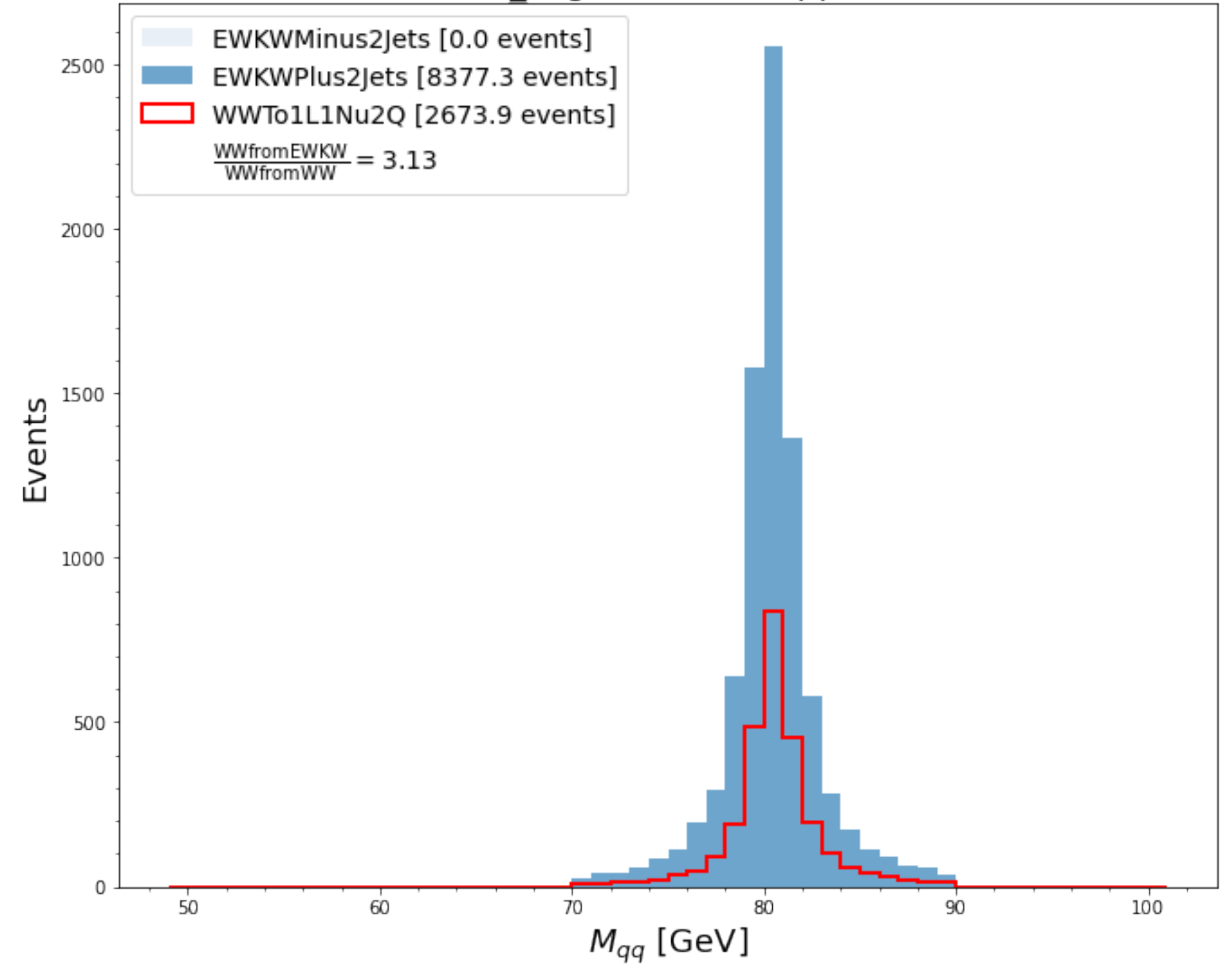
Comparing Diboson Contributions

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

POSTSKIM_STgt800 ($W^+ \rightarrow qq, W^- \rightarrow \ell\nu$)



POSTSKIM_STgt800 ($W^- \rightarrow qq, W^+ \rightarrow \ell\nu$)



Conclusions

- Weird feature at $M_{\ell\nu qq} \approx 700$ GeV in EWK W sample is develops after fatjet selection

Backup

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*

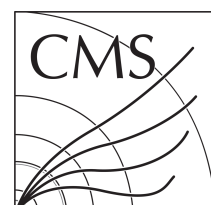
UC San Diego

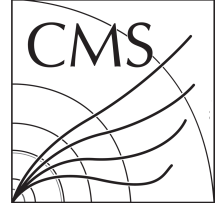
UNIVERSITY OF
Nebraska
Lincoln



UC SANTA BARBARA

UC San Diego





BSM Signal Models

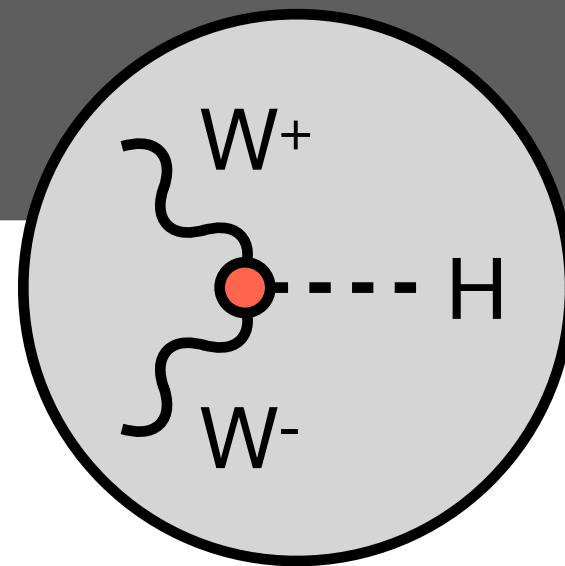
$$K_W = -1$$

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})
```



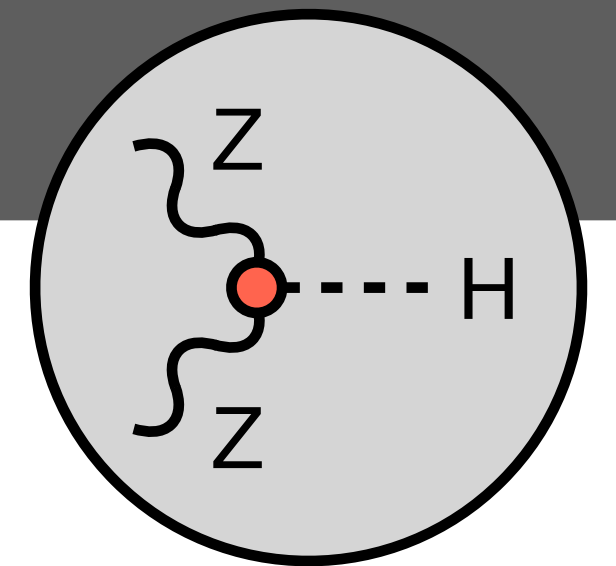
$$K_Z = -1$$

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

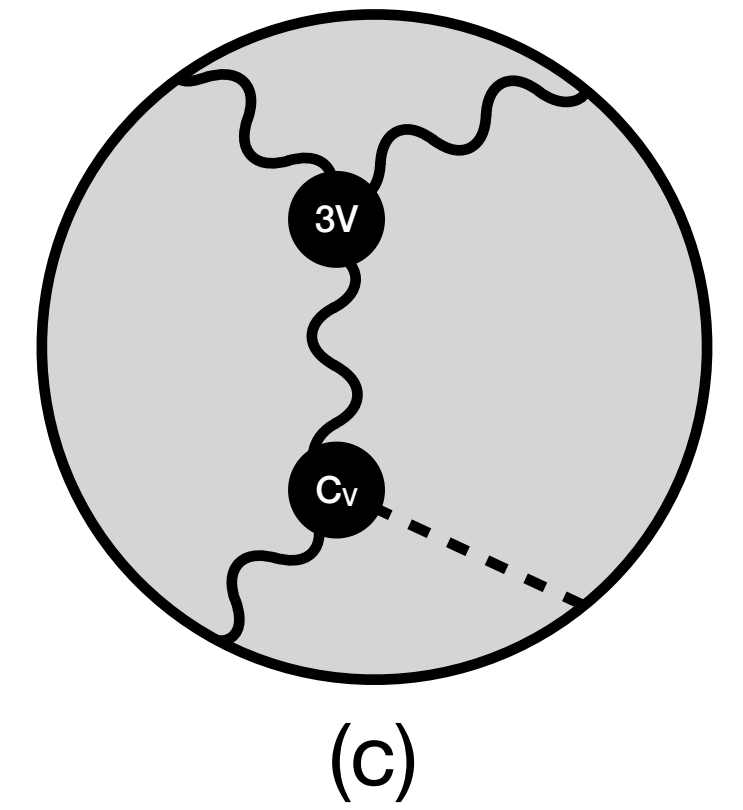
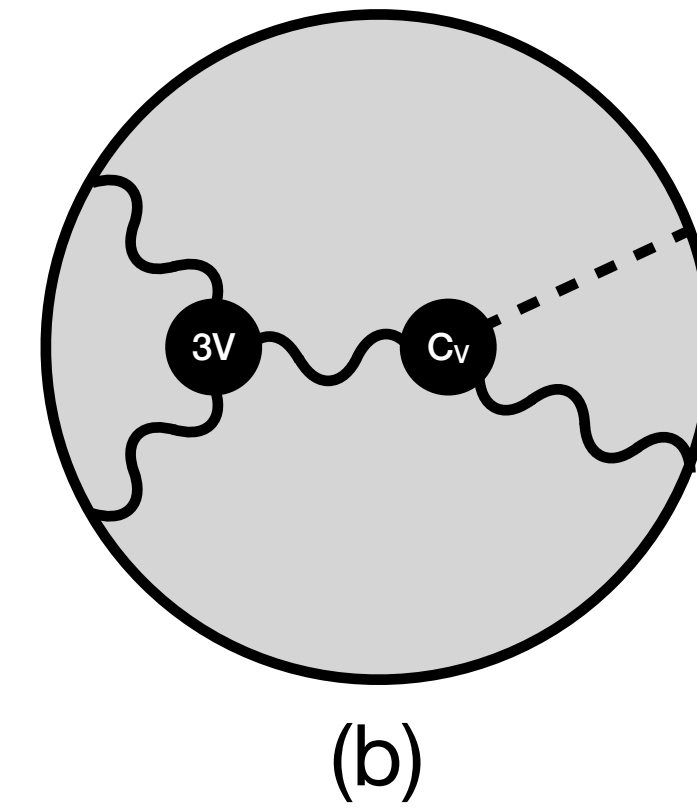
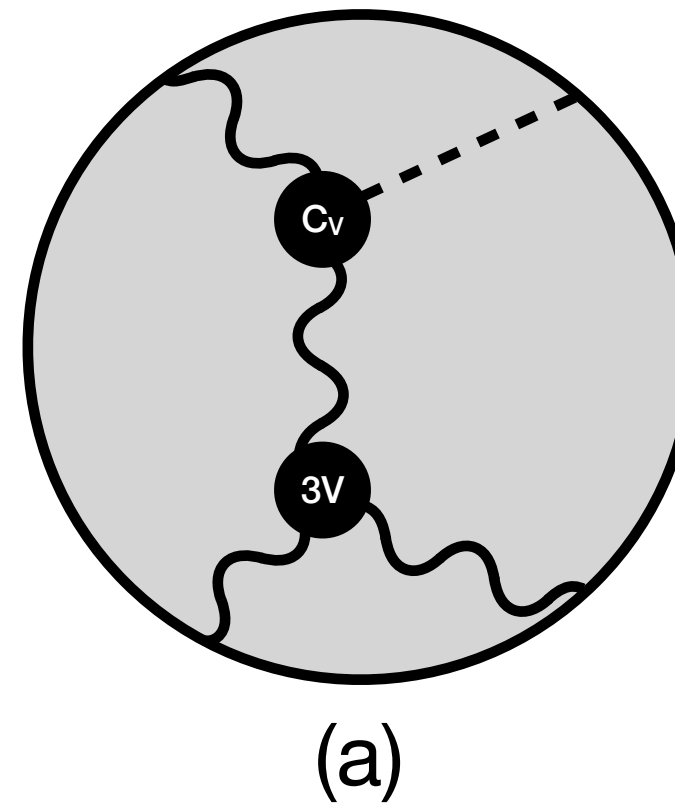
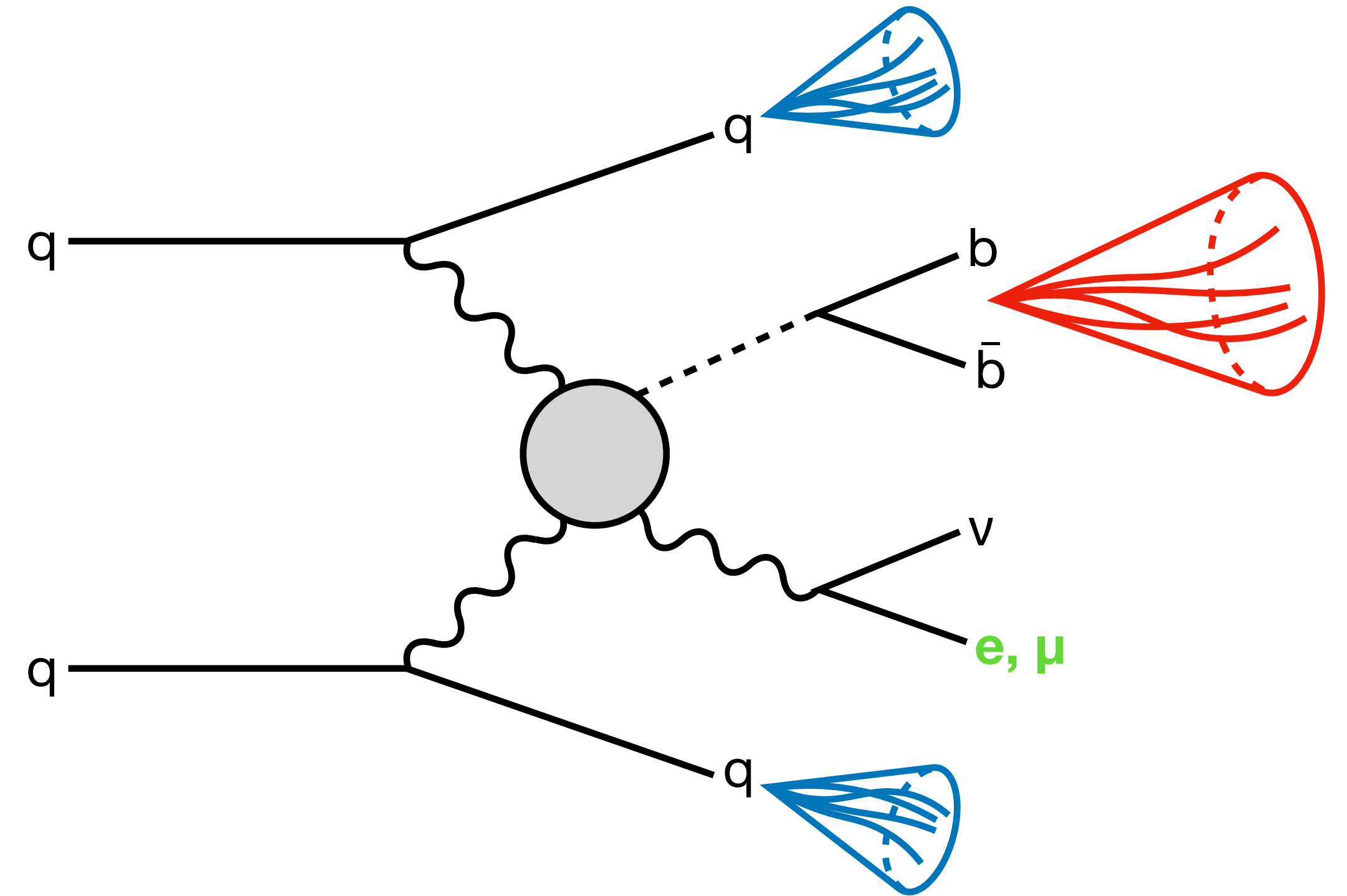
```
V_69 = Vertex(name = 'V_69',  
              particles = [ P.Z, P.Z, P.H ],  
              color = [ '1' ],  
              lorentz = [ L.VVS1 ],  
              couplings = {(0,0):C.GC_81})
```



Only changed one line in SM Madgraph model!

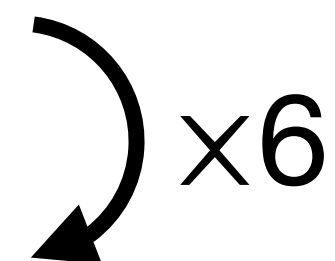
Target Final State

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



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



- 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



Analysis Skim

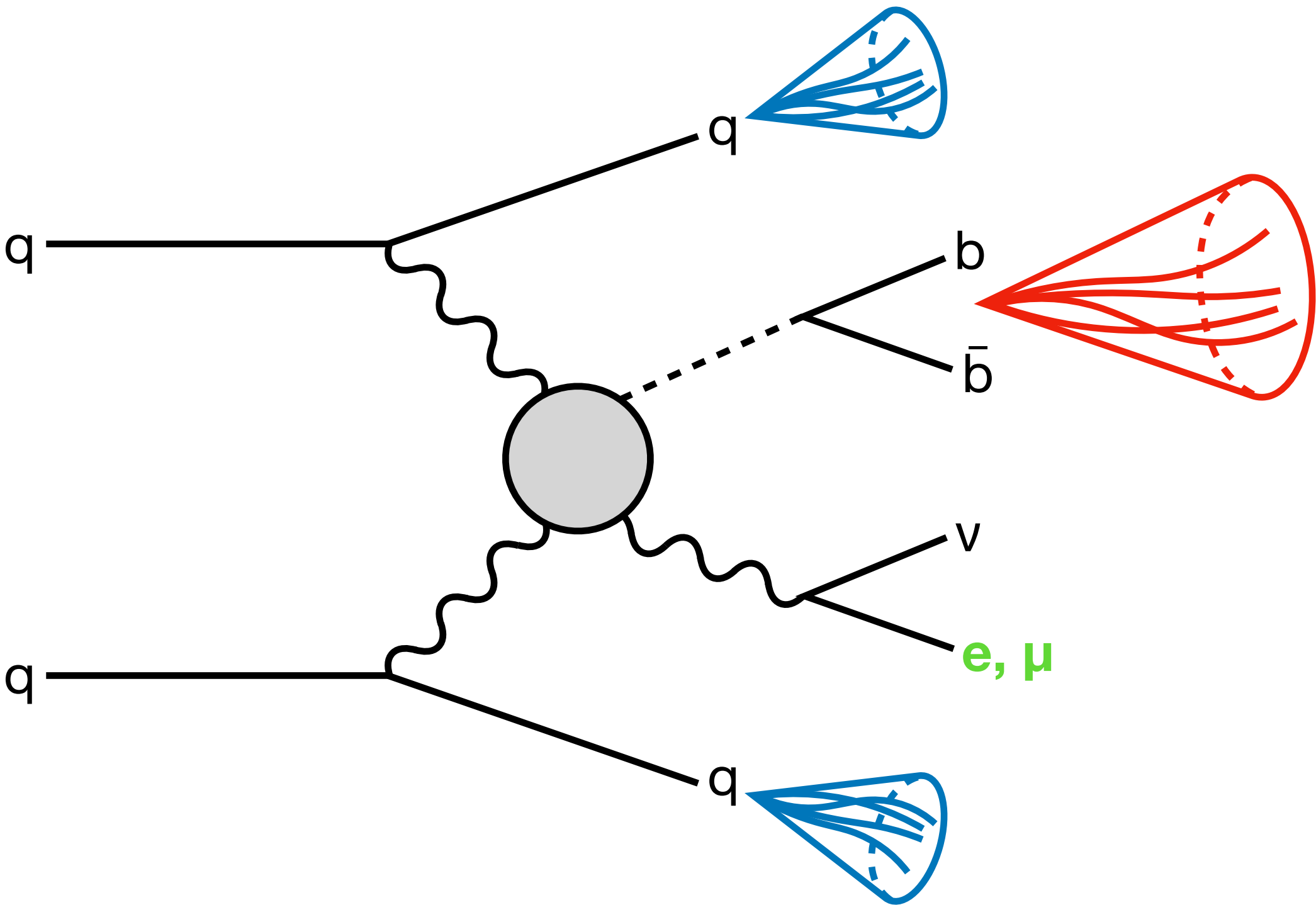
Yields scaled to $\text{lumi} \times \sigma$, rounded for readability

Cut	VH	VV/VV/VBSWZ	W+Jets	SingleTop	TTbar+X	TTbar1L	TTbar2L	TotalBkg	Eff.*	VBSWH ($\lambda_{WZ} = -1$)	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 $\Delta R(\text{fat jet, tight lepton}) > 0.8$
Jets	≥ 1 w/ $p_T > 20$ GeV AND $\Delta R(\text{jet, any veto lepton}) > 0.4$
Other	$S_T > 800$ GeV

*Using the ttH lepton ID

VBS WH Objects

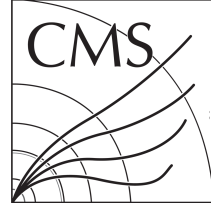


Object	Selections
One Lepton (loose veto in postskim)	• Passes ttH tight ID • $p_T > 40$ GeV
One Hbb Ak8 Jet	• $\Delta R(\text{Ak8 jet, any veto lep}) > 0.8$ • $p_T > 250$ GeV • $\text{mass} > 50$ GeV • $M_{SD}^* > 40$ GeV • Has max(PNet Xbb vs. QCD score) • PNet Xbb vs. QCD score > 0.3
Two VBS Ak4 jets	• $\Delta R(\text{Ak4 jet, any veto lep}) > 0.4$ • $\Delta R(\text{Ak4 jet, Hbb Ak8 jet}) > 0.8$ • $p_T > 30$ 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

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:
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- 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



Comparing Diboson Contributions

Proc Card	Notes
<pre>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</pre>	• Used to generate EWKWPlus...WToLNu samples • From here • LO sample • Both W's can be off-shell • 5-flavor scheme
<pre>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</pre>	• Used to generate WWTo1L1Nu2Q samples • From here • NLO sample • One W can be off-shell, the other must be on-shell • 4-flavor scheme



Comparing Diboson Contributions

EWKWPlus Run Card (from here)	WWTo1L1Nu2Q Run Card (from here)
<pre># 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</pre>	<pre># 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</pre>

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

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- 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

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- 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 $M_{\ell\nu} \in [70, 90) \text{ GeV}$
 6. Require $M_{qq} \in [70, 90) \text{ GeV}$
 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