Search For W_R Using t/b Jets

LRSM / SNU group meeting

Chihwan.An.

2025.07.15

Motivation For t/b Channel

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A novel search strategy for right-handed charged gauge bosons at the Large Hadron Collider

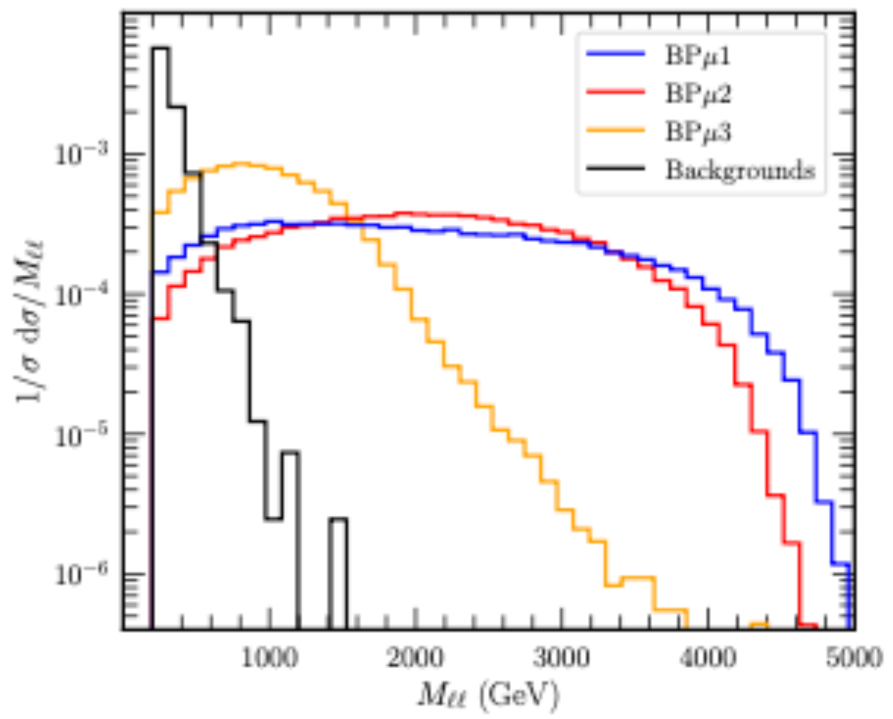
Mariana Frank[a], Benjamin Fuks[b], Adil Jueid[c], Stefano Moretti[d,e] and Özer Özdal[a,d]

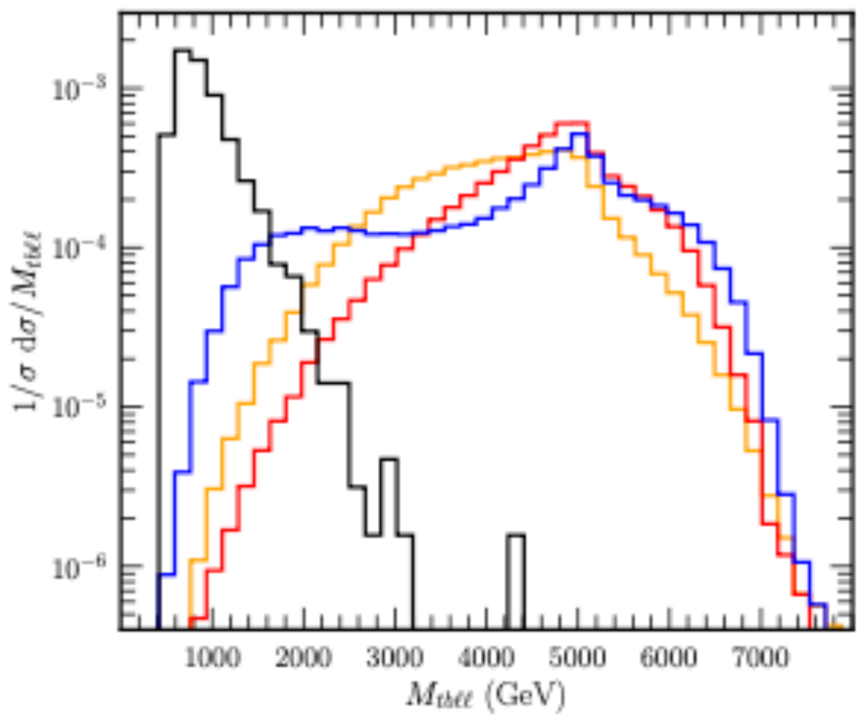
[a]Department of Physics, Concordia University, 7141 Sherbrooke St. West, Montreal, Quebec H4B 1R6, Canada
[b]Laboratoire de Physique Théorique et Hautes Énergies (LPTHE), UMR 7589, Sorbonne Université & CNRS, 4 place Jussieu, 75252 Paris Cedex 05, France
[c]Particle Theory and Cosmology Group, Center for Theoretical Physics of the Universe, Institute for Basic Science (IBS), Daejeon, 34126, Republic of Korea
[d]School of Physics & Astronomy, University of Southampton, Highfield, Southampton SO17 1BJ, UK
[e]Department of Physics & Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden

E-mail: mariana.frank@concordia.ca, fuks@lpthe.jussieu.fr, adiljueid@ibs.re.kr, s.moretti@soton.ac.uk; stefano.moretti@physics.uu.se, ozer.ozdal@soton.ac.uk

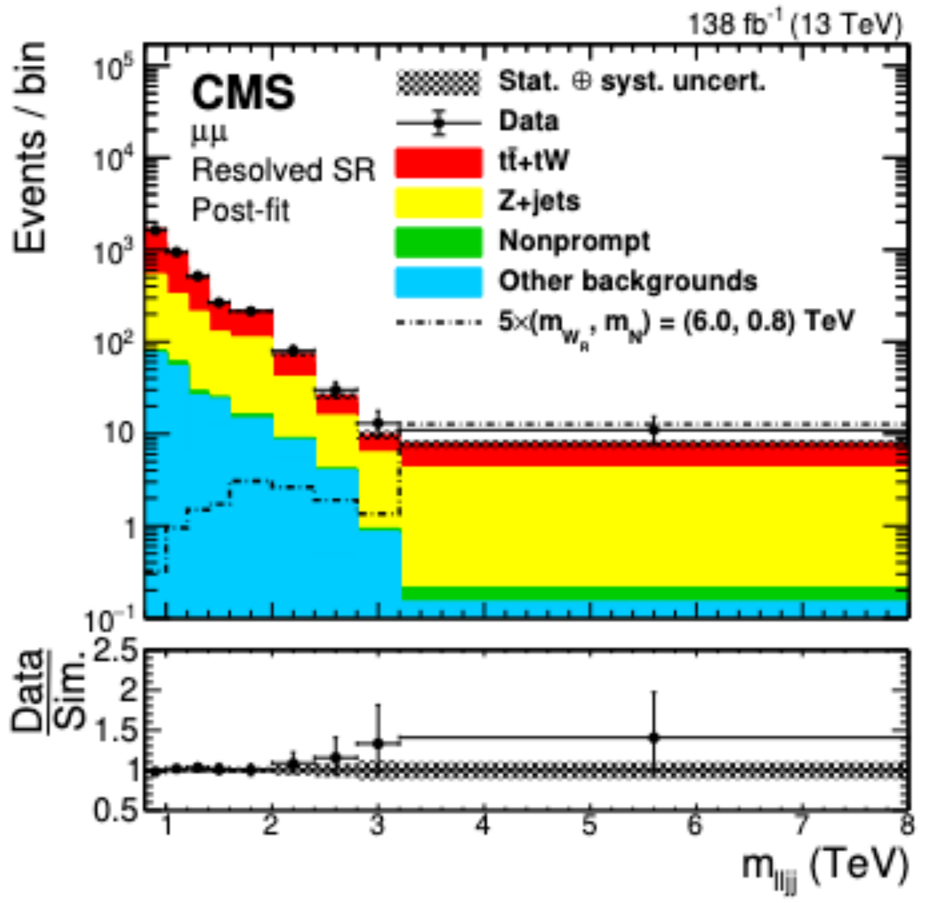
ABSTRACT: We explore the potential of the Large Hadron Collider (LHC) in detecting a signal originating from the production of a heavy $SU(2)_R$ charged gauge boson that then decays into a top-bottom quark pair via the mediation of a right-handed neutrino, $pp \to W_R \to N_R\ell \to (\ell' tb)\ell$. Such a channel, that we study in the context of the minimal Left-Right Symmetric Model, contrasts with conventional smoking-gun signatures targeted experimentally and phenomenologically in which only light quarks are involved. We propose a selection strategy aimed at extracting such a top-bottom signal and we estimate the resulting sensitivity of the LHC to the model. Our results demonstrate the potential impact of such a search and we therefore urge the experimental collaborations to carry out a similar analysis in the light of present and future data.

The aim of this study is to propose a *novel* search strategy for the production of an $SU(2)_R$ charged gauge boson W_R and a neutrino N_R at the LHC, relying on the $W_R \to N_R\ell \to tb\ell\ell$ decay chain with the W_R emerging from charged current Drell-Yan (DY) production. The top quark, being produced from a heavy neutrino decay, is highly boosted in most of the cases. Jet substructure methods and top taggers have therefore the potential to efficiently reduce the SM background, together with specific kinematics variables exploiting the richness of the final state. The use of this channel can thus be crucial not only for discovery purposes but also for diagnostics as a probe of the properties of the mLRSM as a whole.



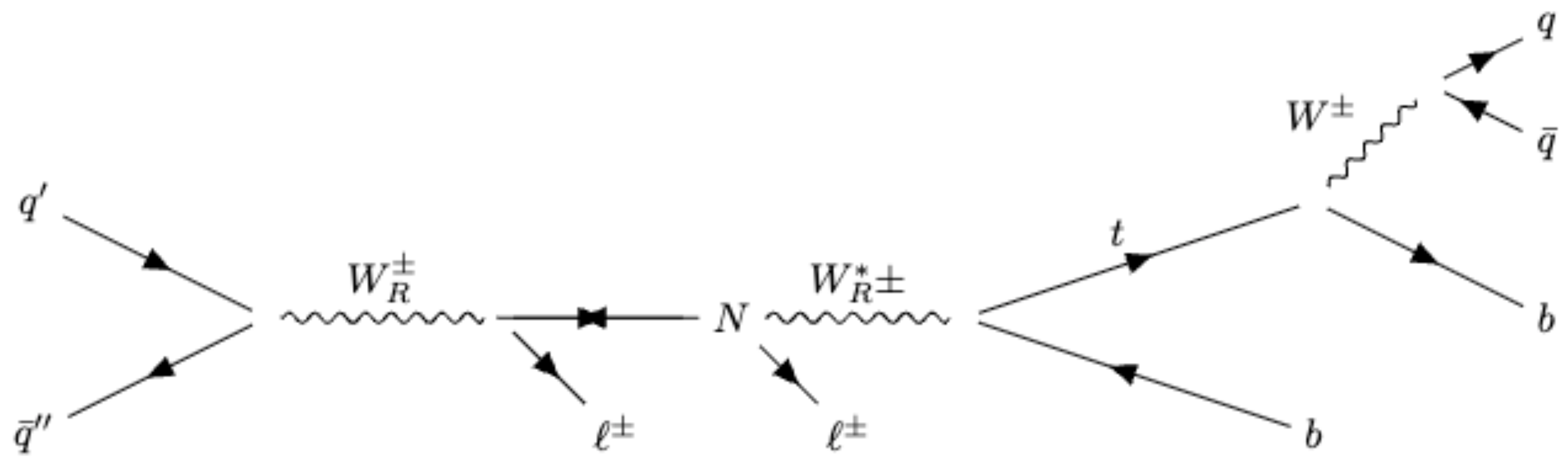


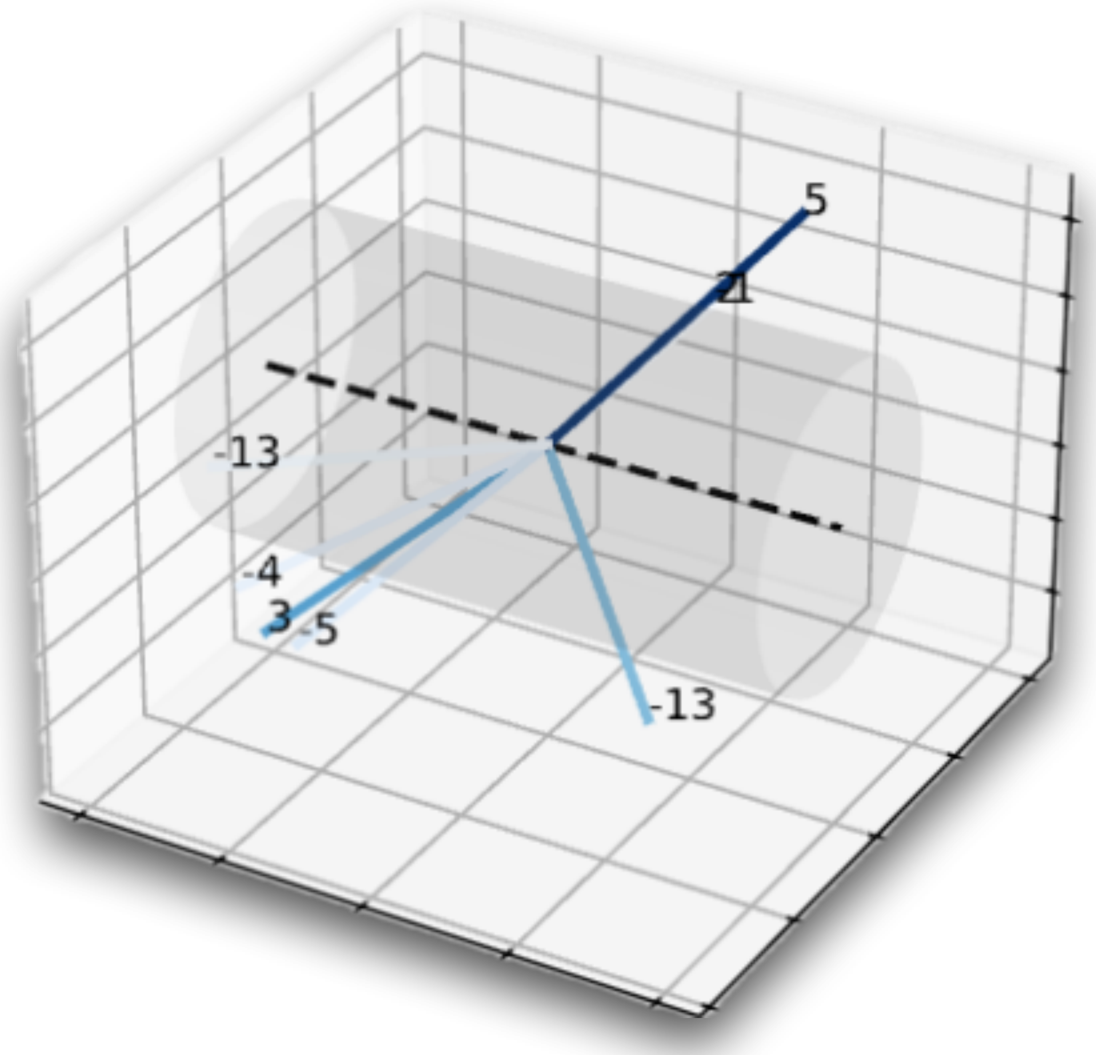
$BP\mu 1$: W_R 5100, N_R 1020
$BP\mu 2$: W_R 5100, N_R 2550
$BP\mu 3$: W_R 5100, N_R 4700



https://doi.org/10.1007/JHEP04(2022)047

Searching Mass Region

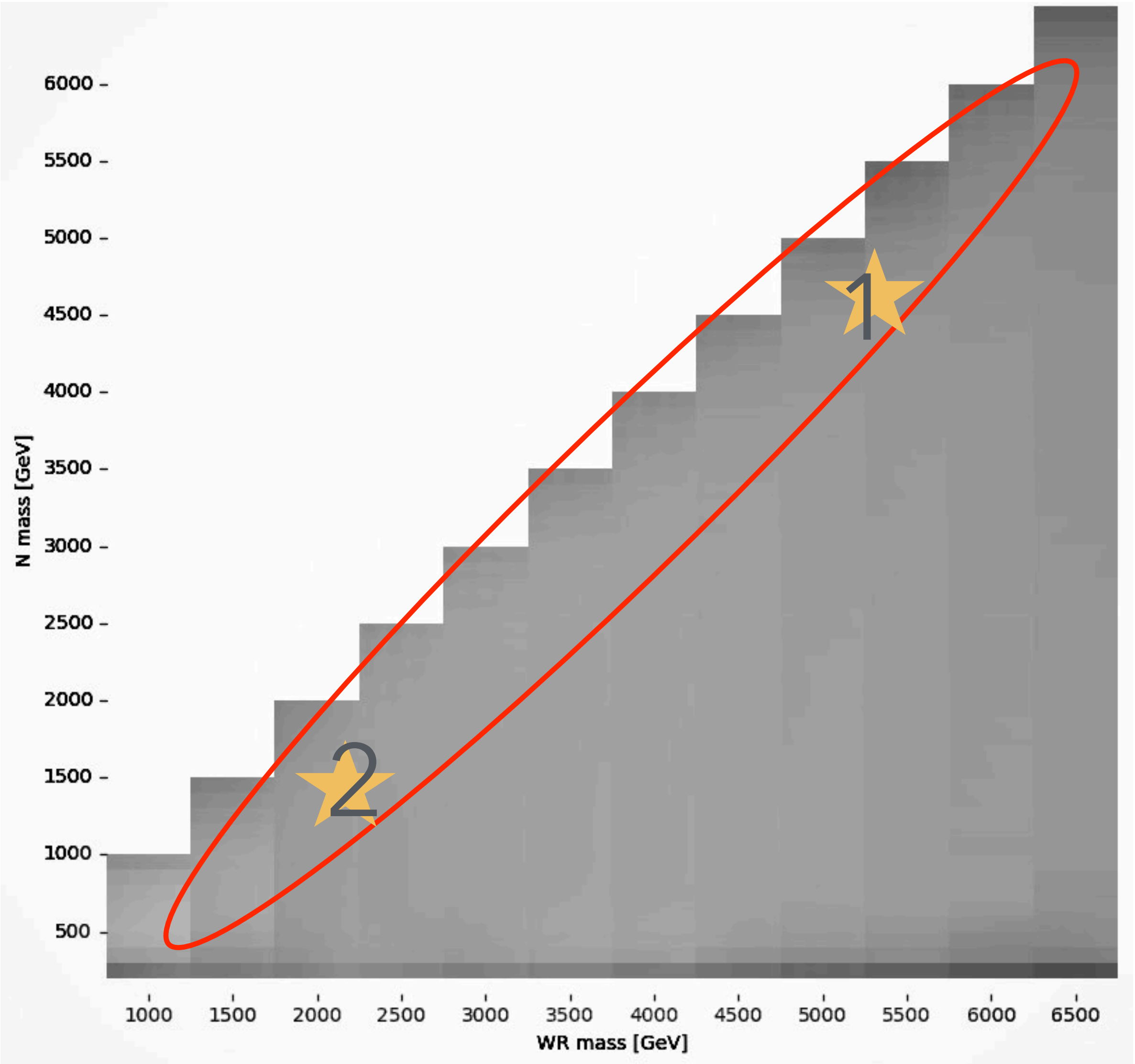


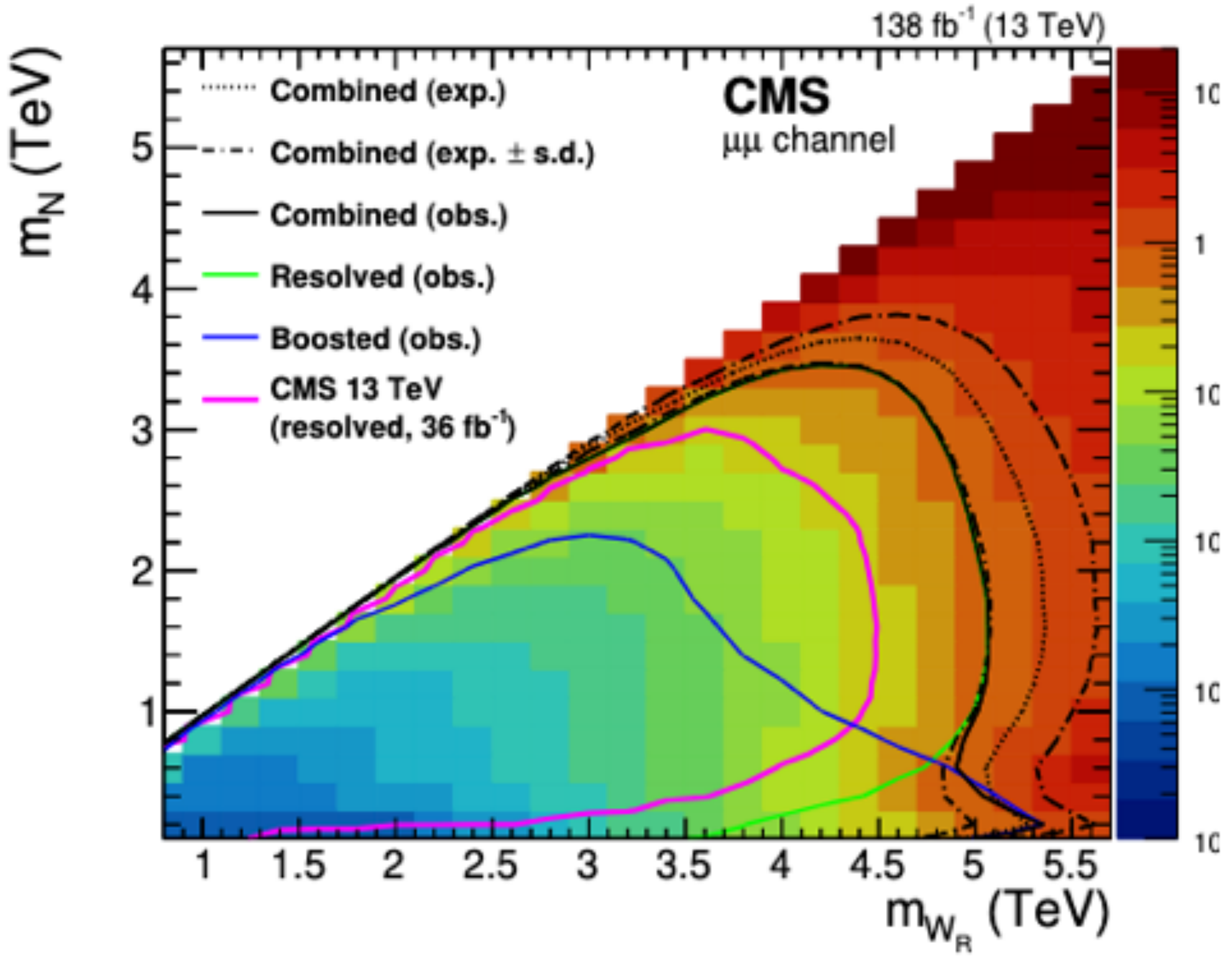


- Topology
  If N is small (boosted) , more than 5 substructure (top - 3 jets , b quark , leptons) mixed
  :resolved topology required

- Setting mass of W_R N similar -> makes N slow : W_R* , lepton separated
  -> makes W_R* slow : t jets & b jet separated (back to back)

Detailed Topology Of Main Target



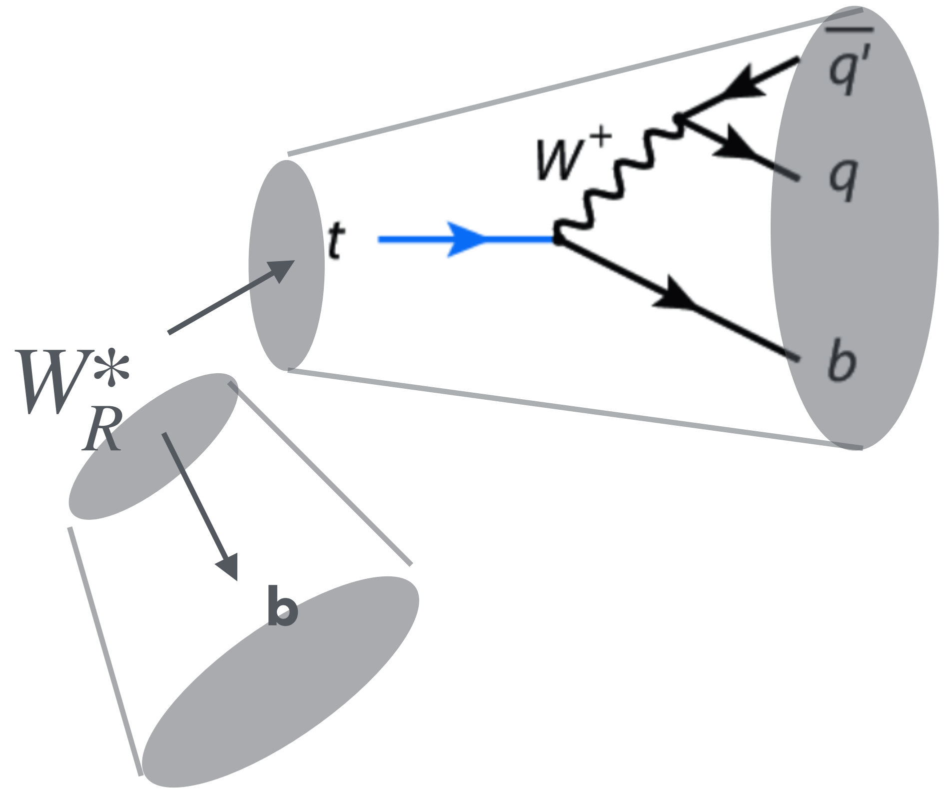


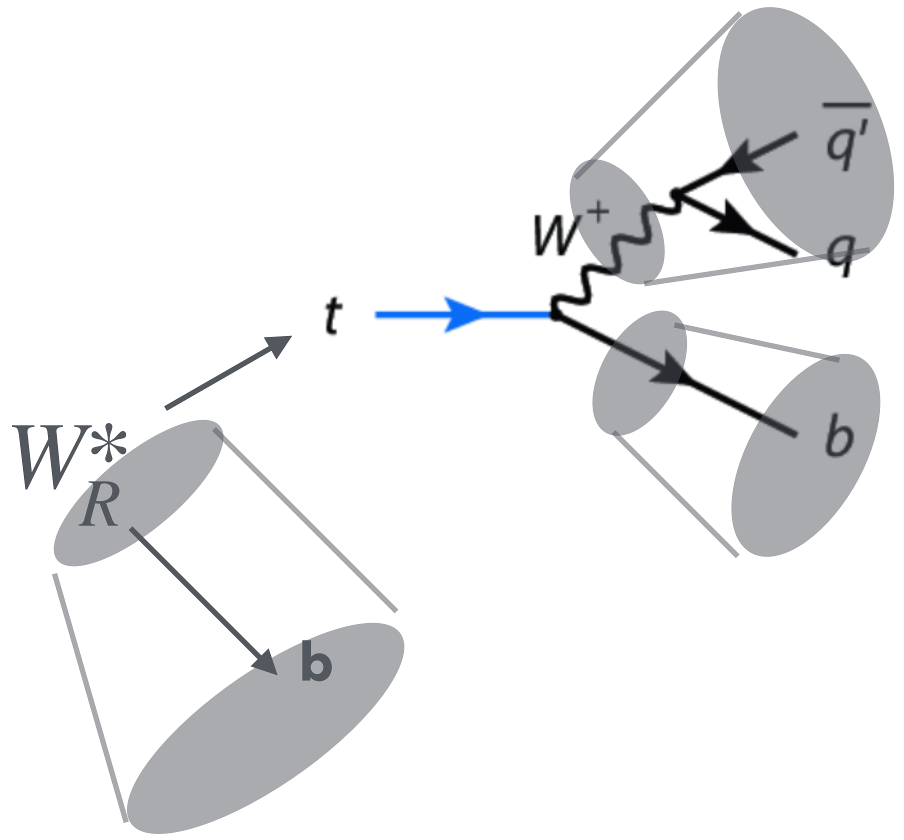
https://doi.org/10.1007/JHEP04(2022)047

Main target : W_R ~ N

1. High mass W_R
Jets are boosted which can be inside one jet

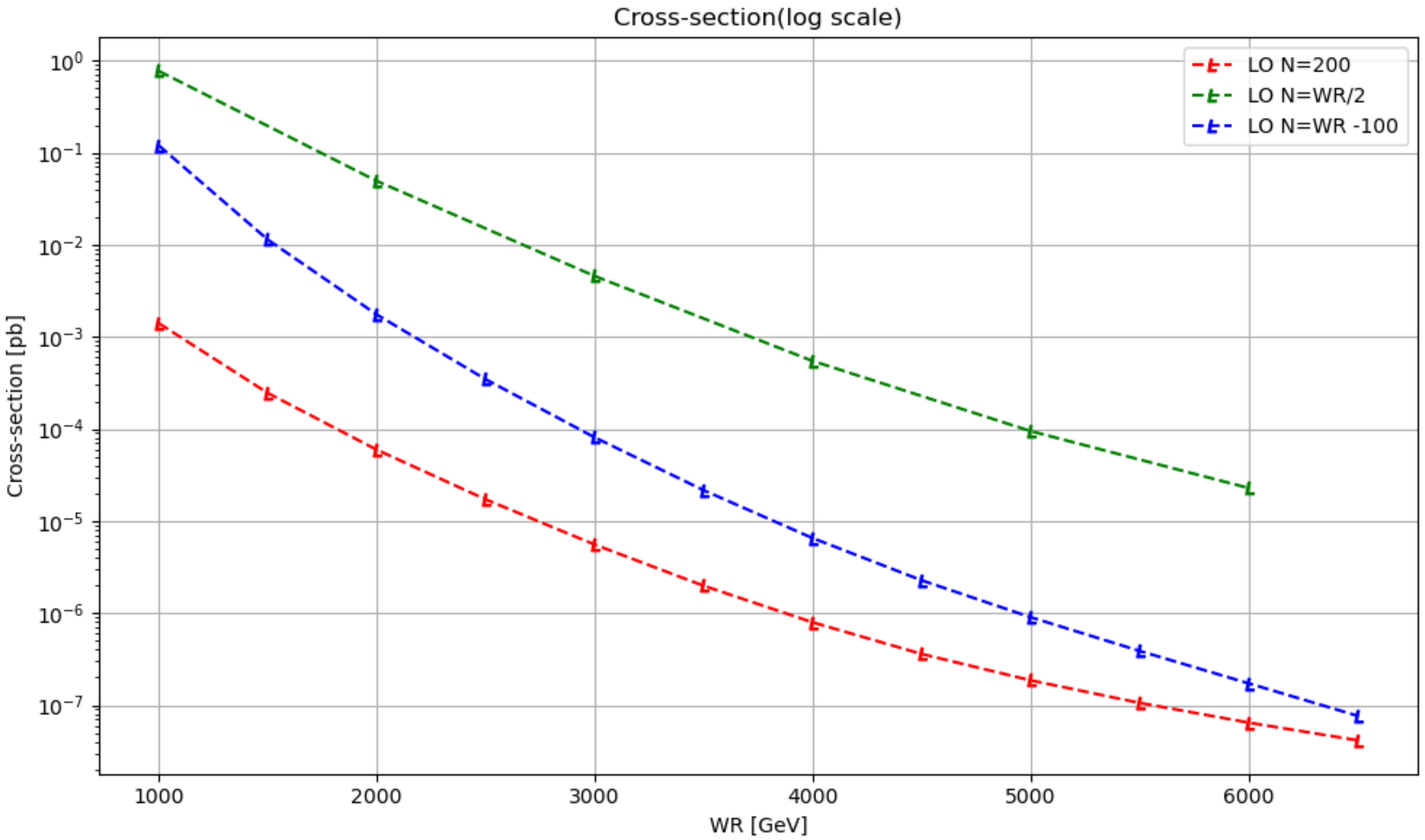
2. Low mass W_R
Jets are separated by two jets





Cross sections checking

Structure draft



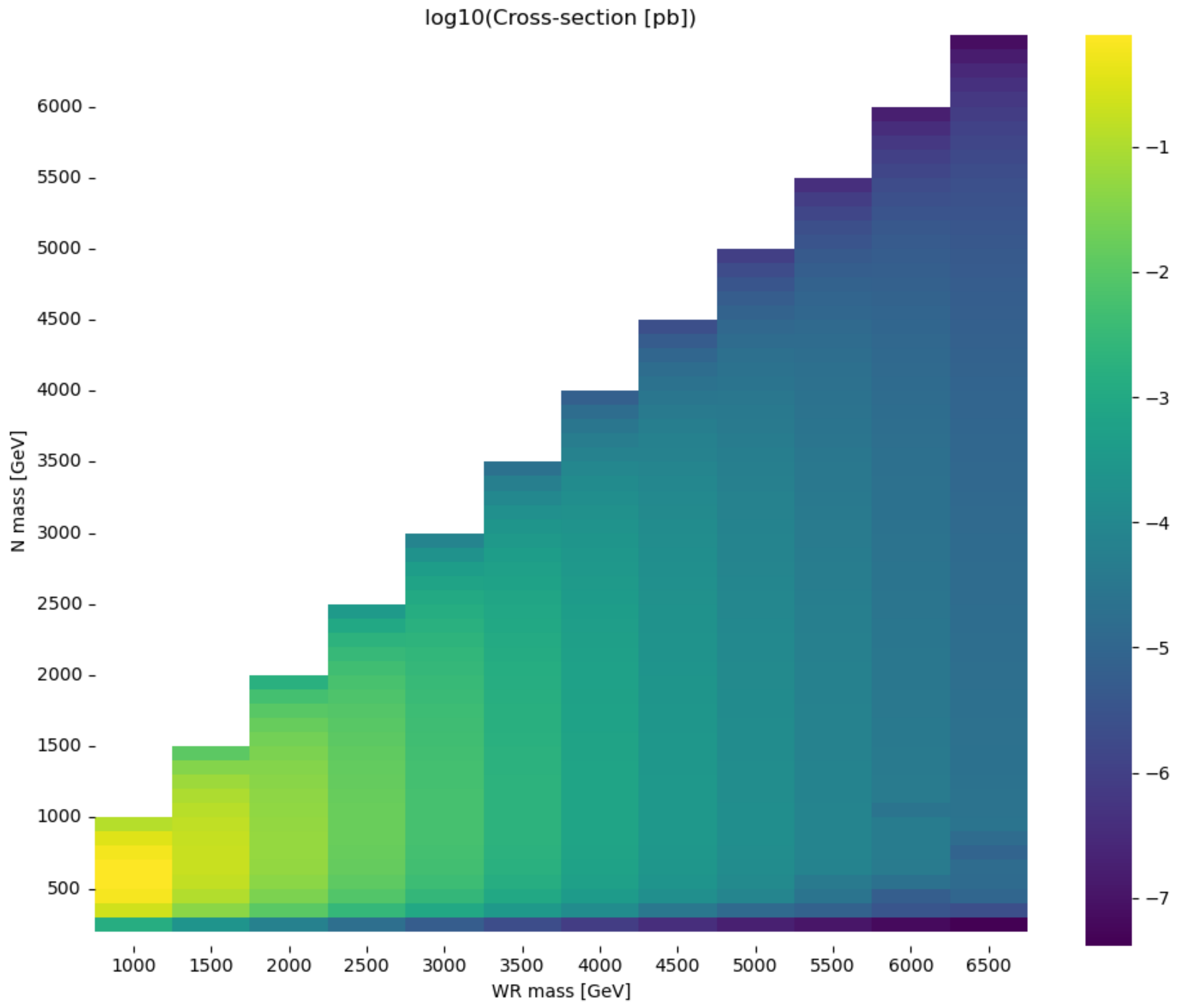
- Checked cross section with mad graph
  (v.2.9.18 20,000 run)

  - Due to phase space (top ~ 173GeV) cross section is constrained

  - N phase space makes N=WR/2 > N = WR-100

Cross Sections Checking

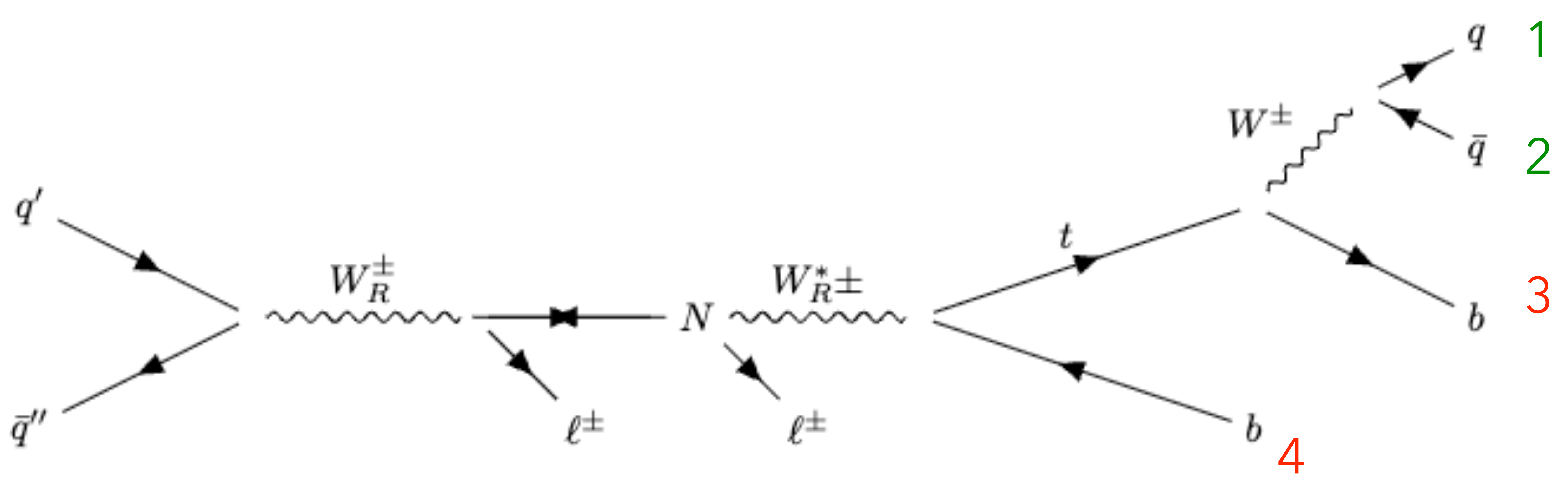
Full cross section

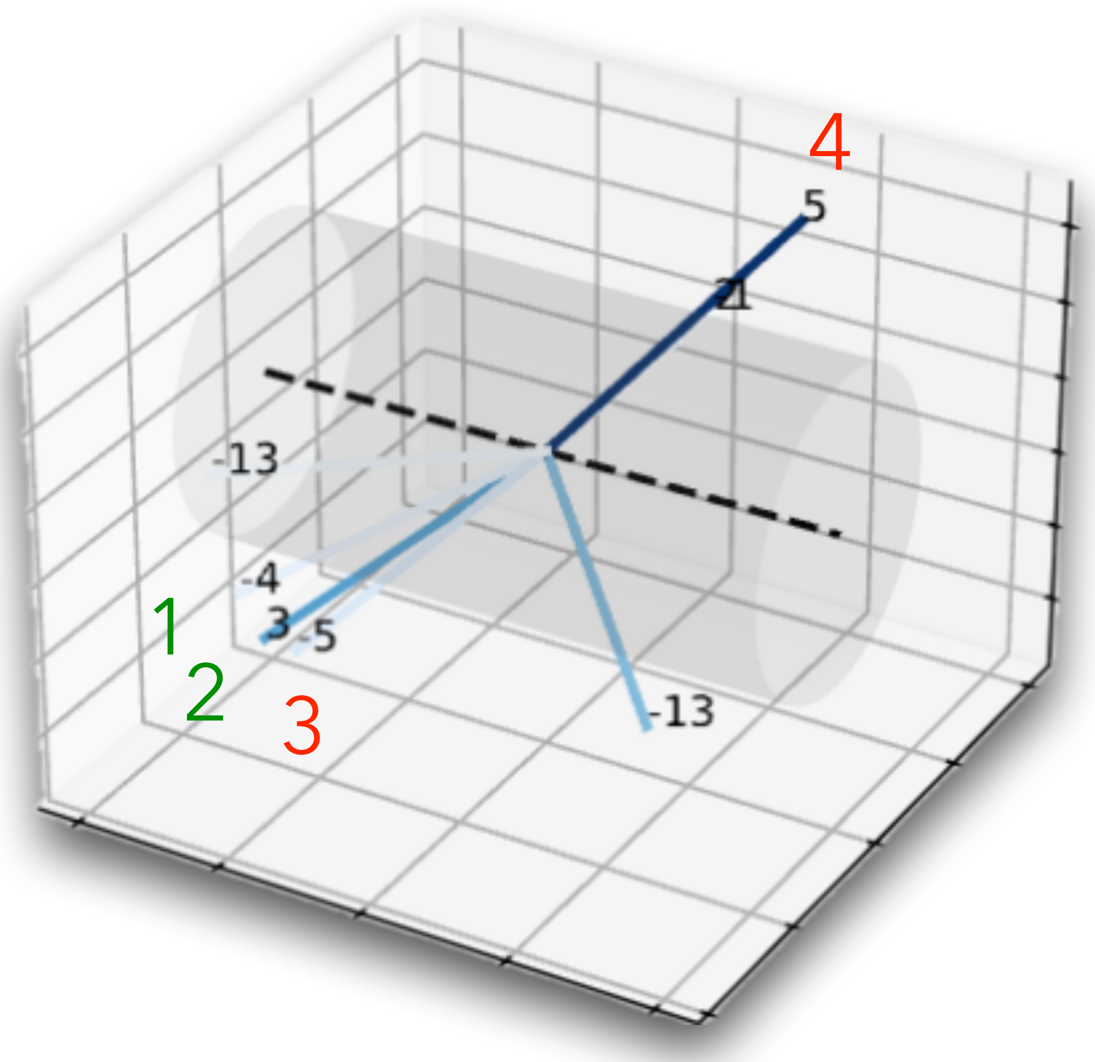


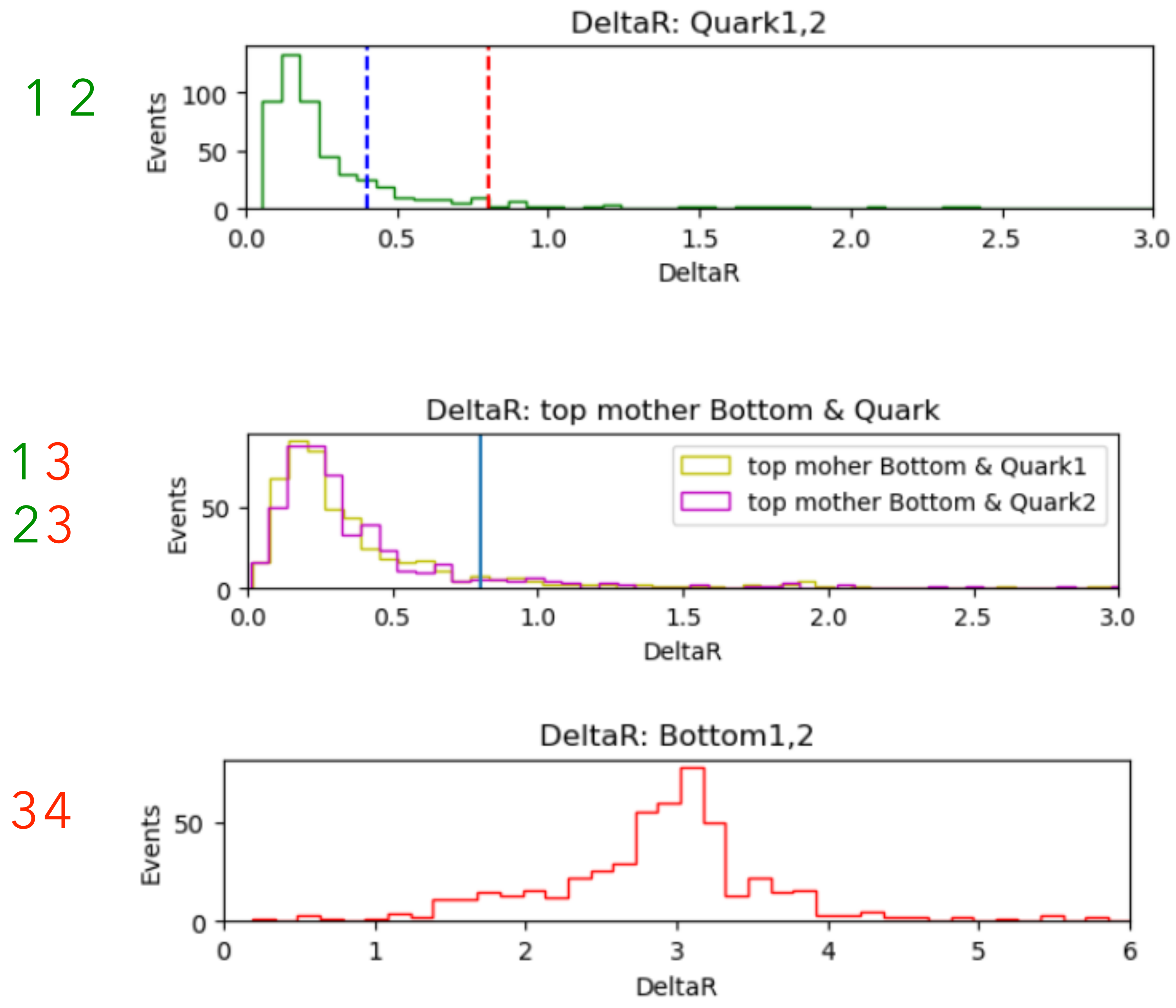
- W_R fixed & N increase
  Cross section increases -> decrease
  : top quark phase space constraint ->
  N phase space constraint -> ..

Topology check

Used LHE files to check each particles ΔR , p_t



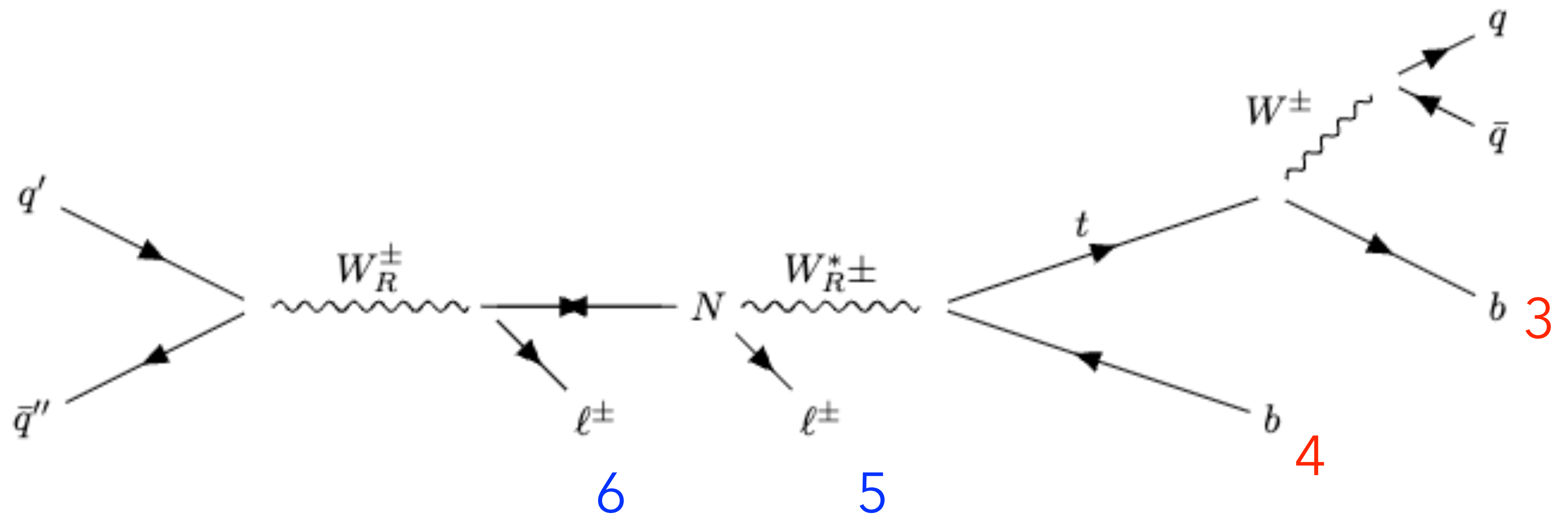


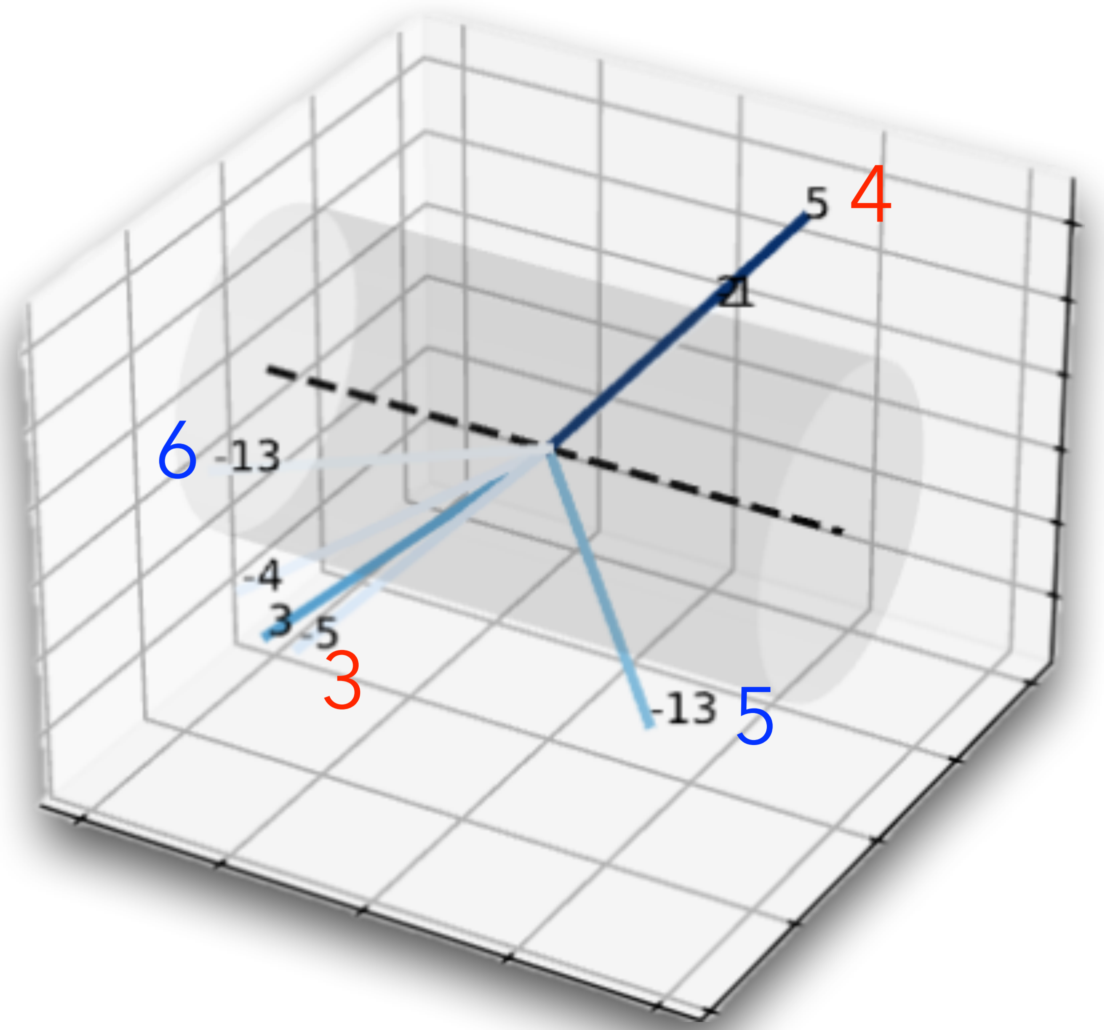


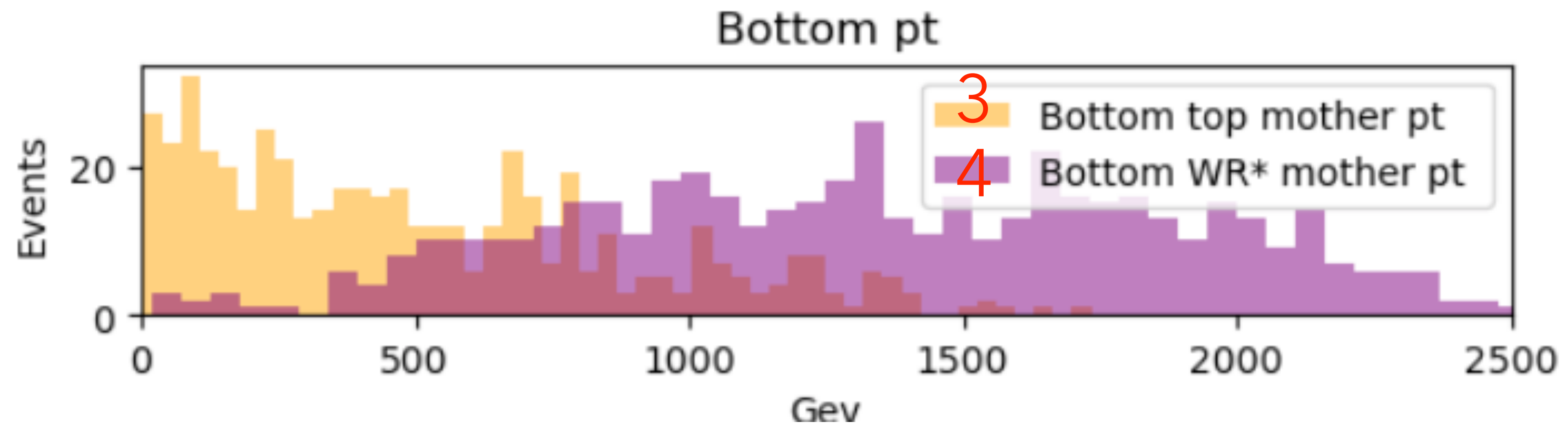
Mass for W_R 5000 , N4900

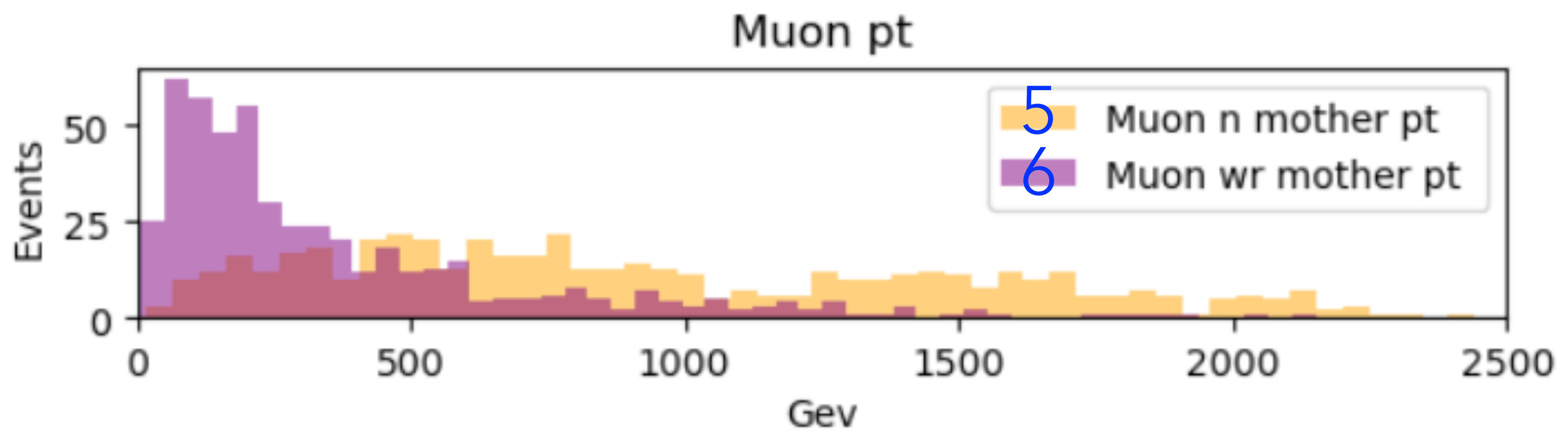
Topology check

Used LHE files to check each particles ΔR , p_t





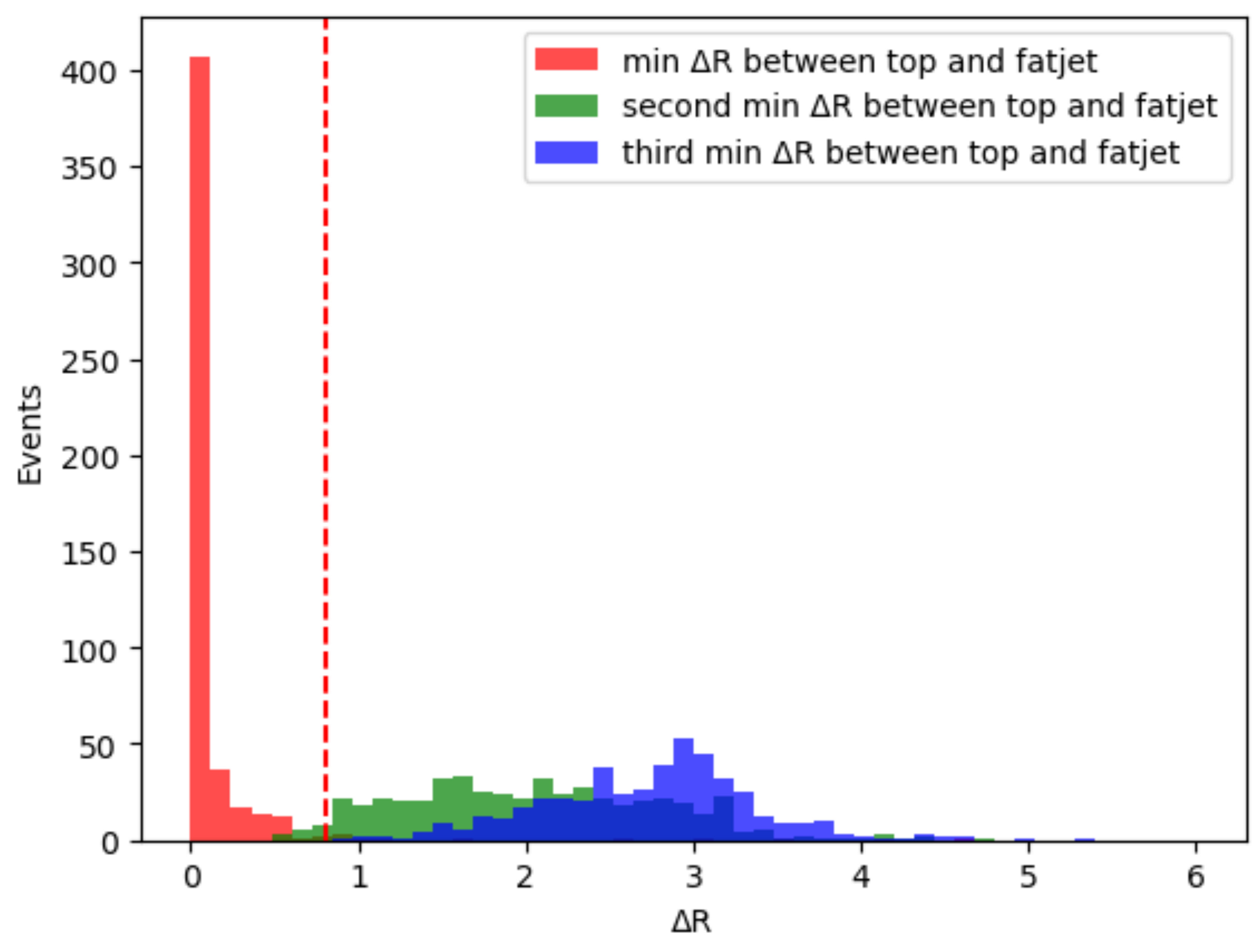


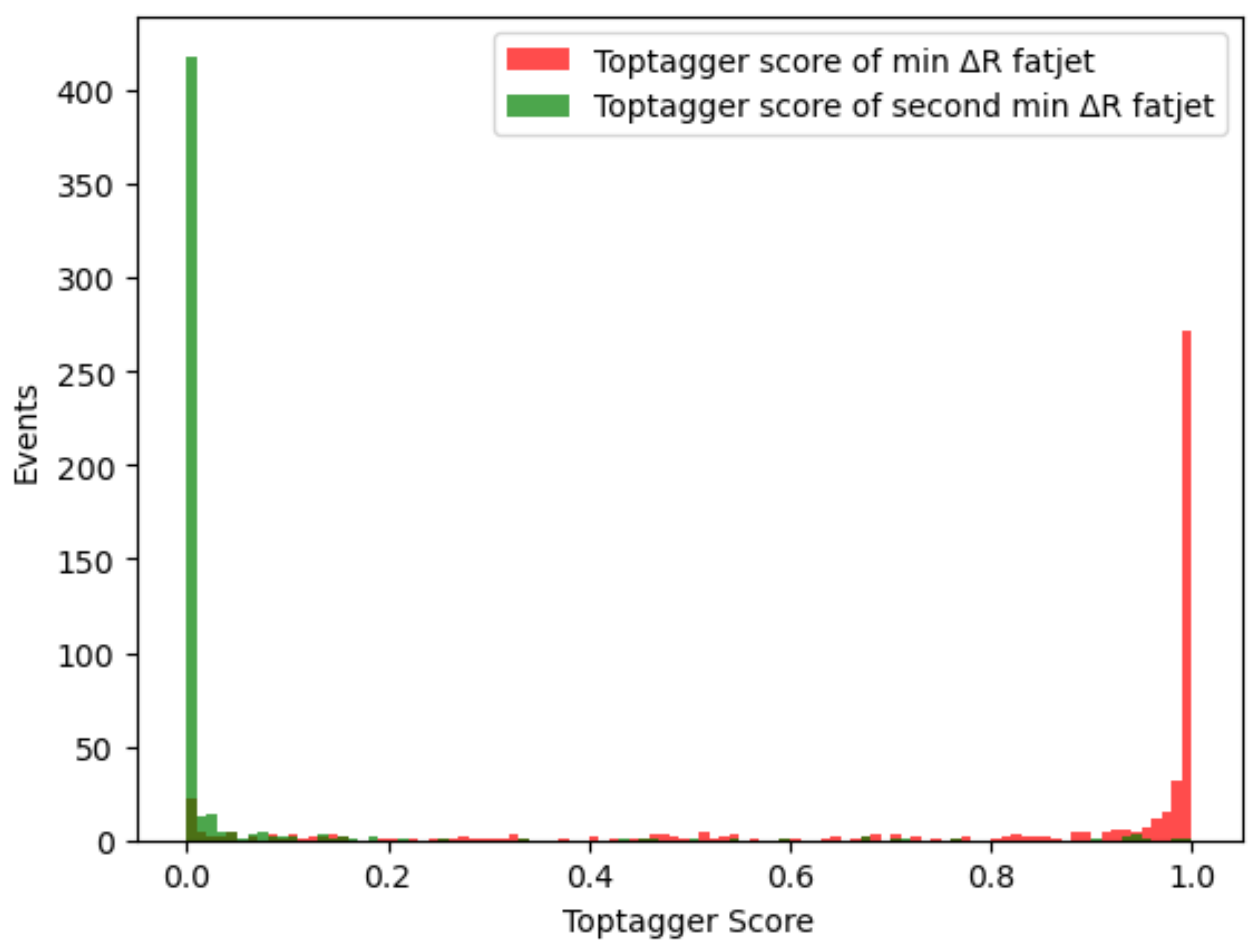


Mass for W_R 5000 , N4900

AK8 top jet check

Used top quark in genparticle to find closest Fatjet .





Most of Fatjet has $\Delta R < 0.8$ with top quark

Fatjet closest to top quark has ~ 1.0 top tagging score

FatJet_particleNetWithMass_TvsQCD

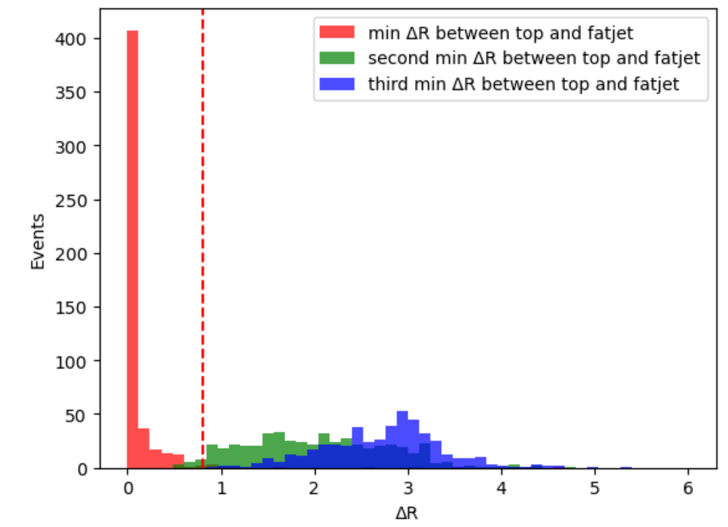
Mass for W_R 5000 , N4900

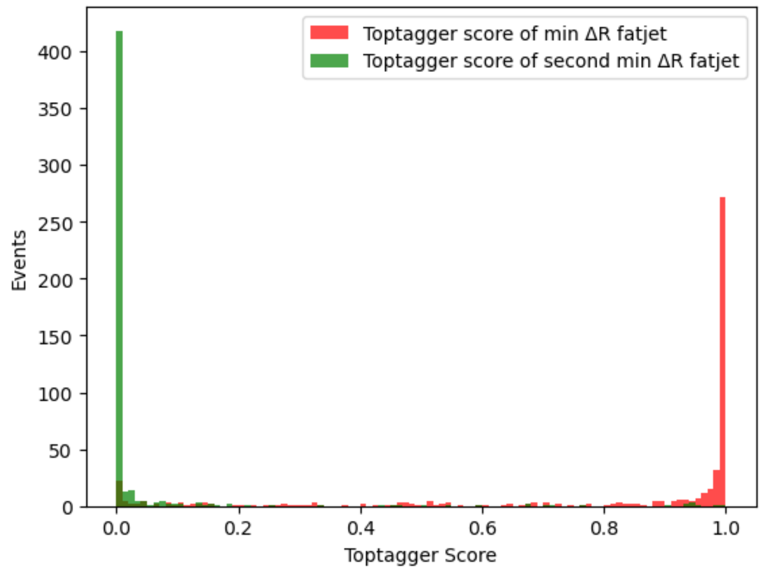
AK8 top jet check

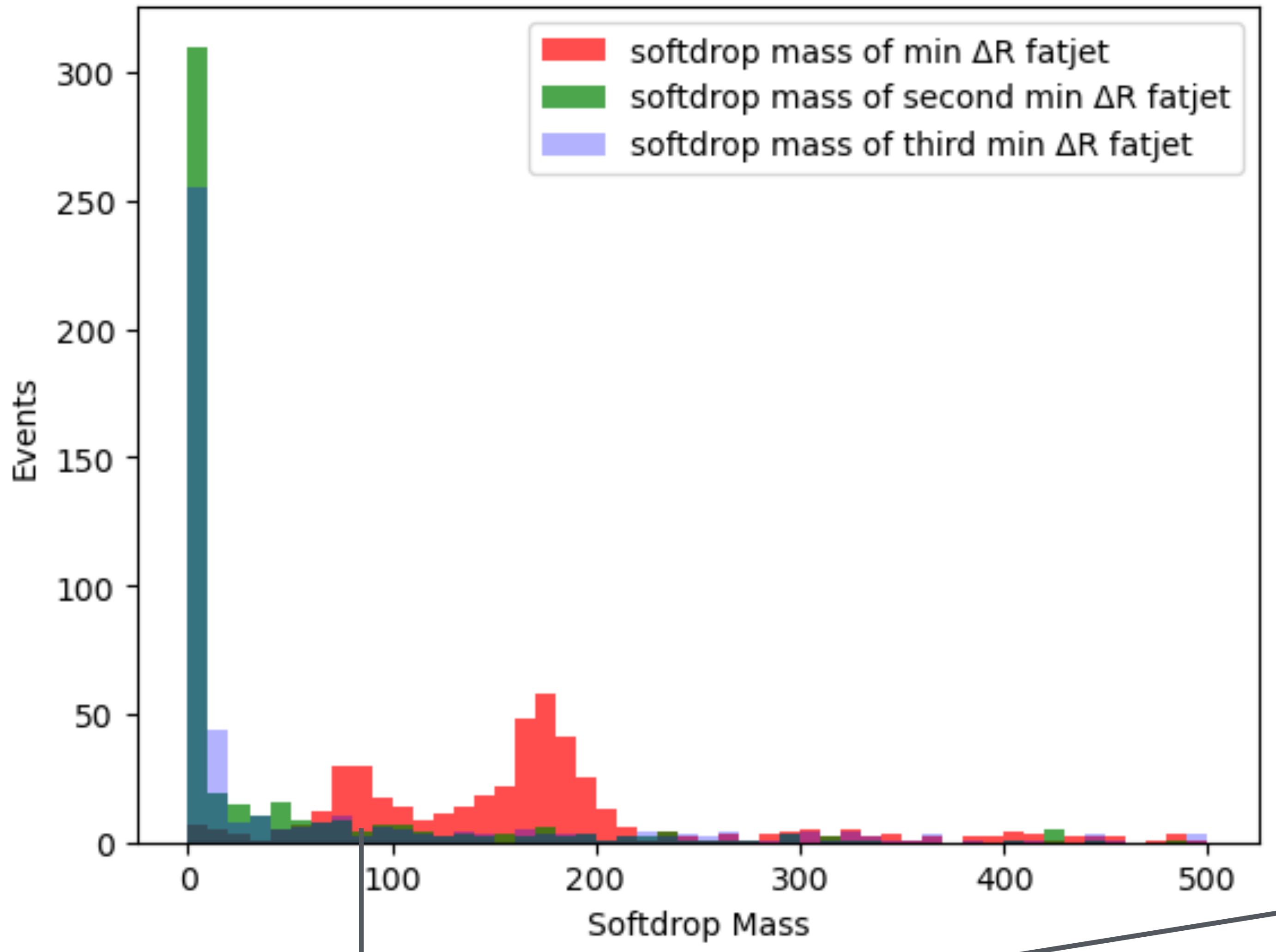
Checked softdropmass if its well matched,

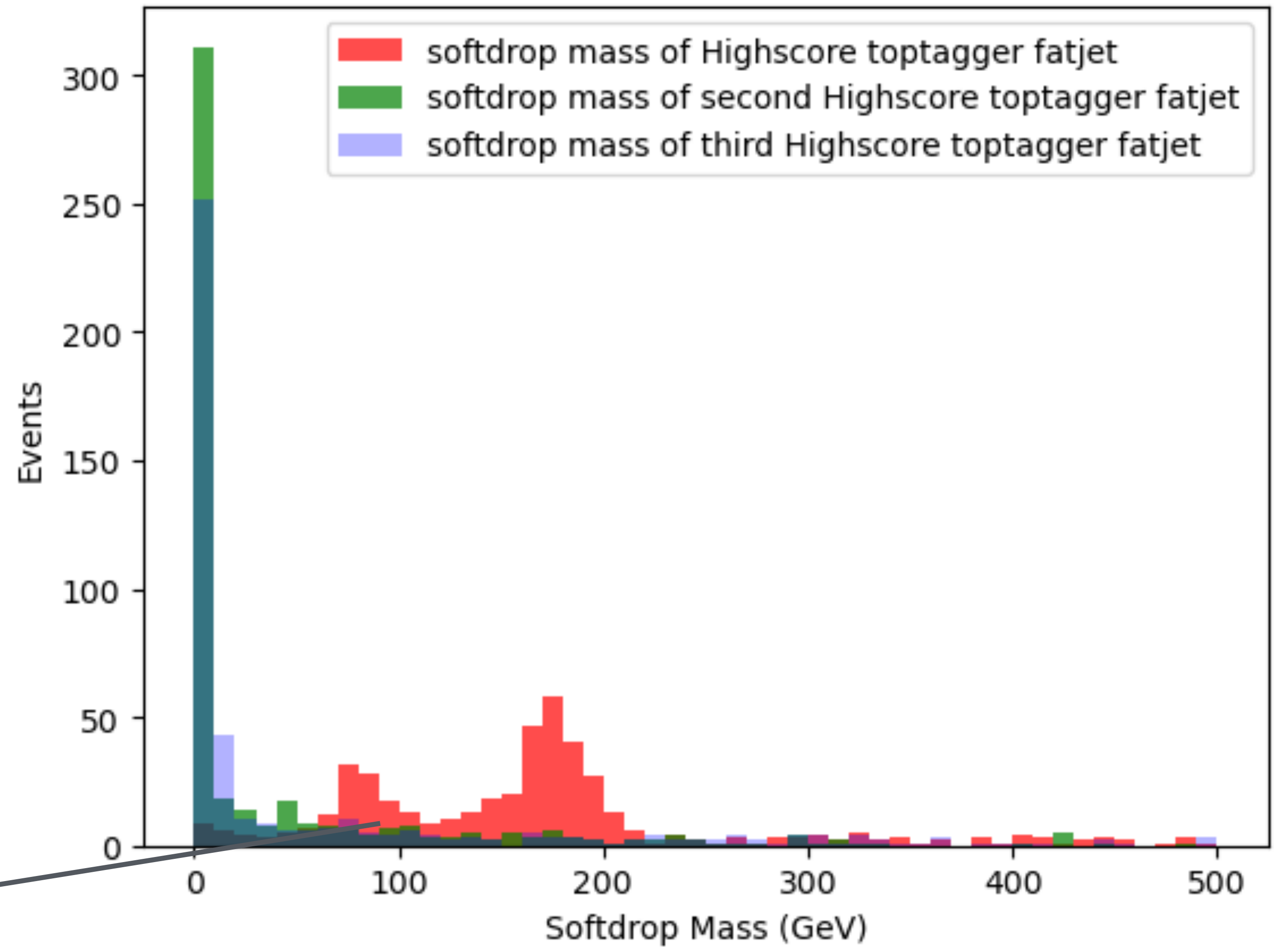
Fatjet closest from top quark

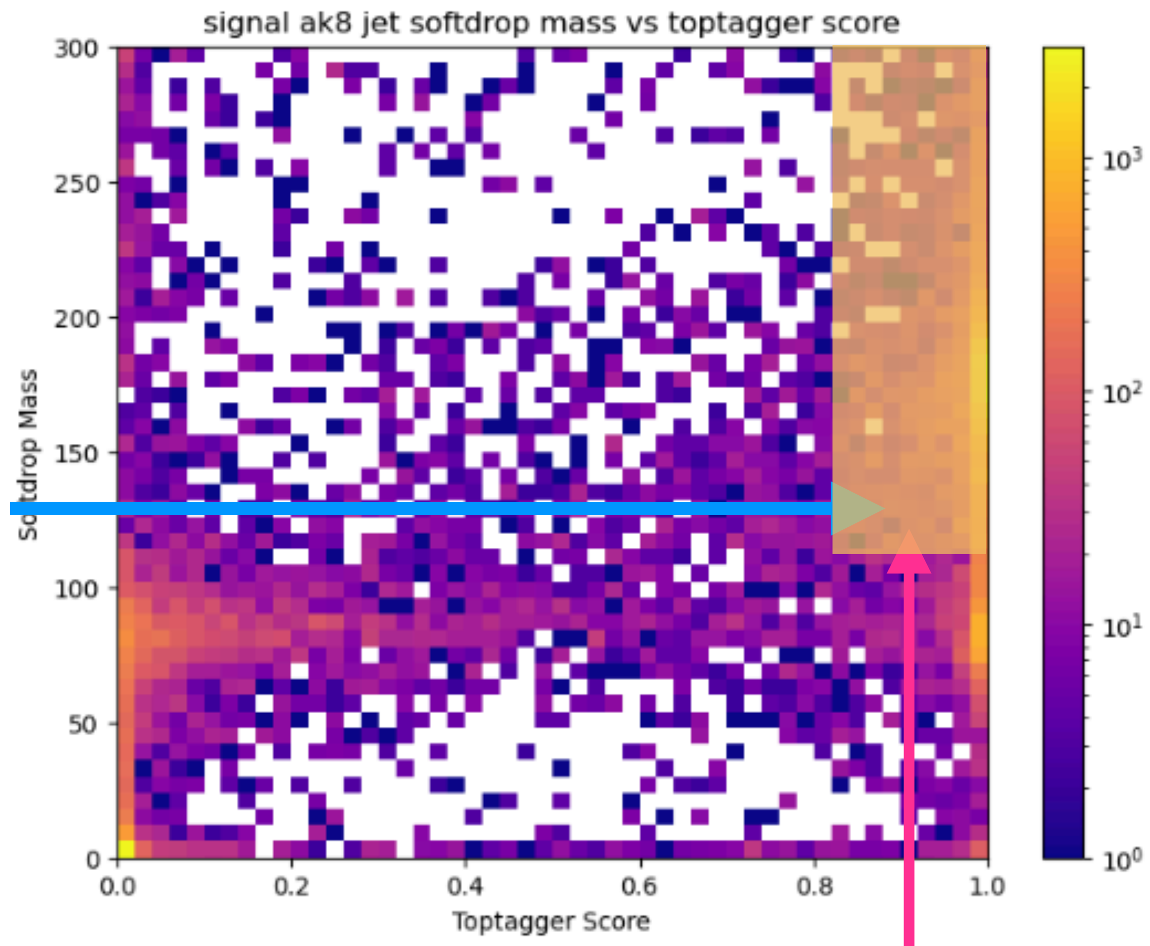
Fatjet highest top score











Tagger >0.9,
SDM >120
Eff ~ 60%

Due to quarks escaping from Jet (~ W mass)

-> Can find Top jet with top tagging score , SDM

Mass for W_R 5000 , $N4900$

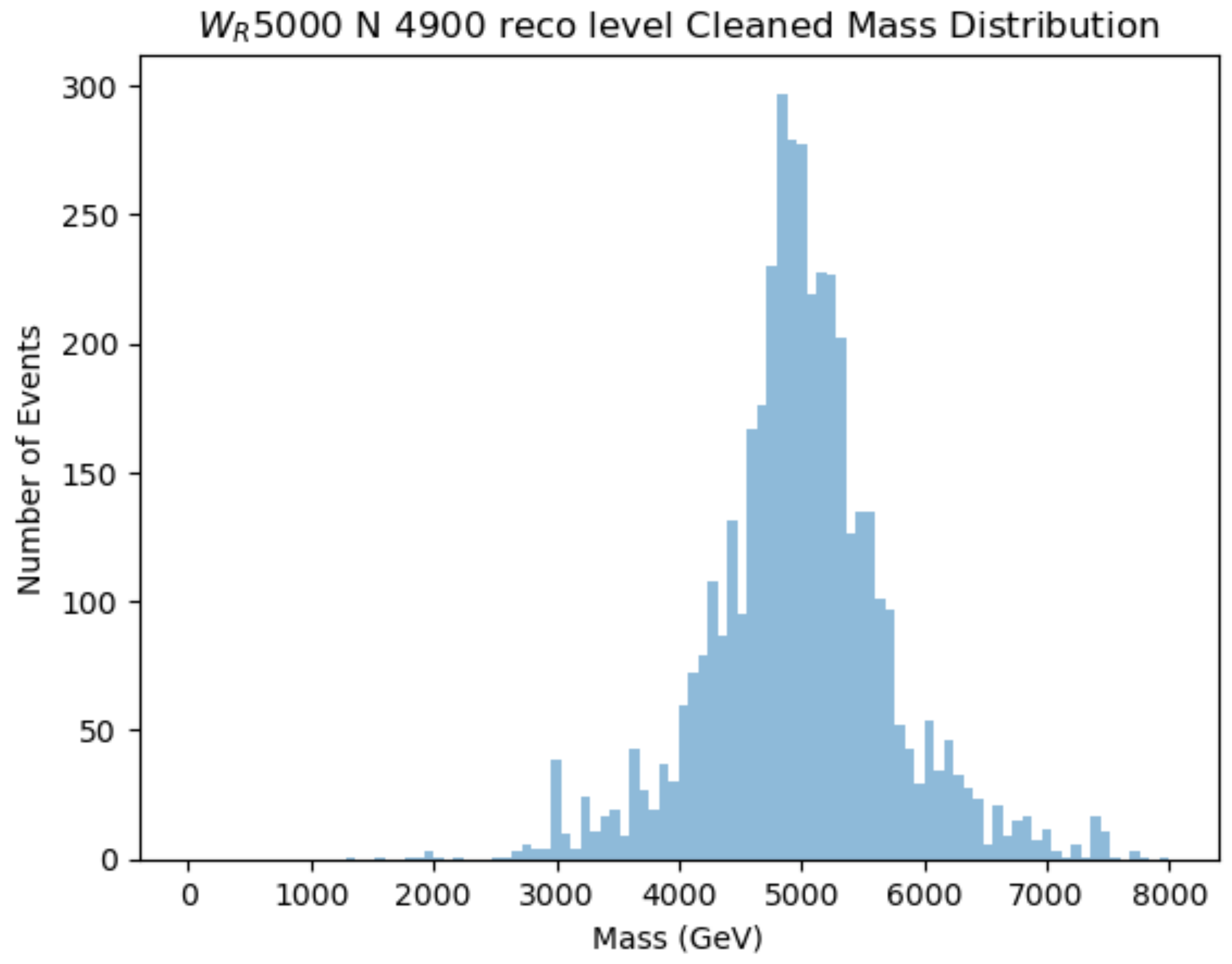
Cleaning Adjusting

Strategy 1 for cleaning

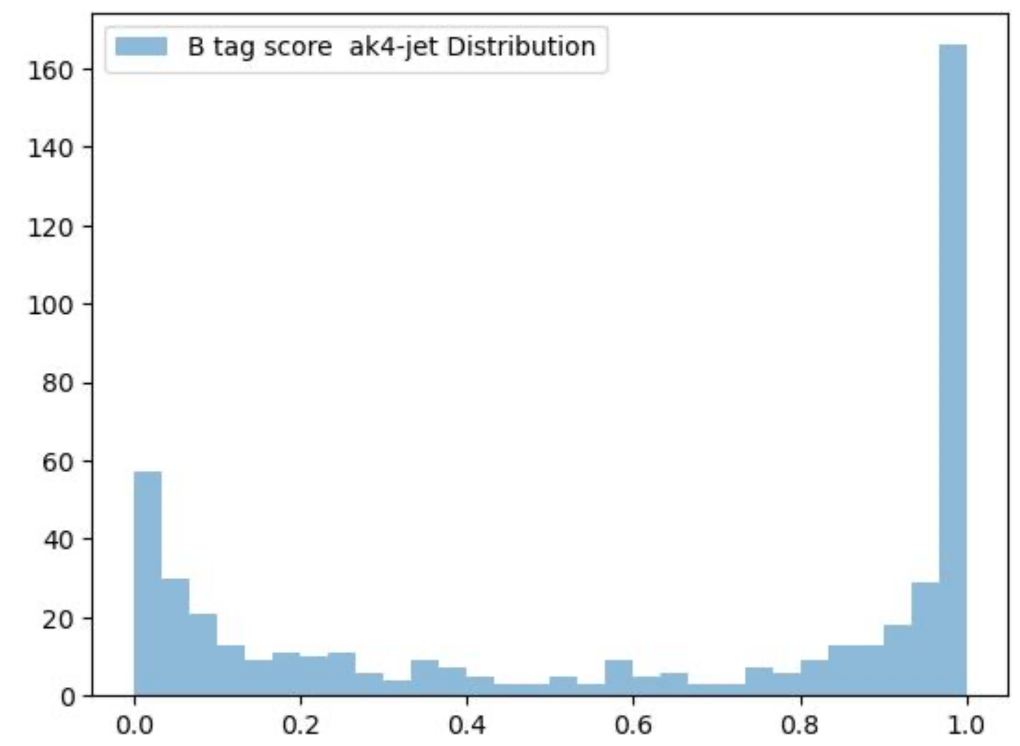
2 leading lepton : no cut
(no overlap with 2 leptons each)

AK8 with top tagged : top tagging score > 0.9
120 <soft drop mass < 250
[FatJet_particleNetWithMass_TvsQCD]
[FatJet_msoftdrop]
(no overlap with 2 leptons , AK8)

AK4 with leading p_t : b tagging score > 0.5
[Jet_btagDeepFlavB]
(no overlap with top tagged AK8 , AK4, 2 leptons)



* 40,000 events , 10.82% efficiency



Summary

- Not a super novel search , but it is very helpful to take a bird’s eye view

- Now checking signal efficiency
- Future plan

  Check Background samples , object ID , Triggers

Backups

$W_R \to tb$ channel searched

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

JHEP 12 (2023) 073
DOI: 10.1007/JHEP12(2023)073

CERN-EP-2023-149
15th January 2024

Search for vector-boson resonances decaying into a top quark and a bottom quark using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

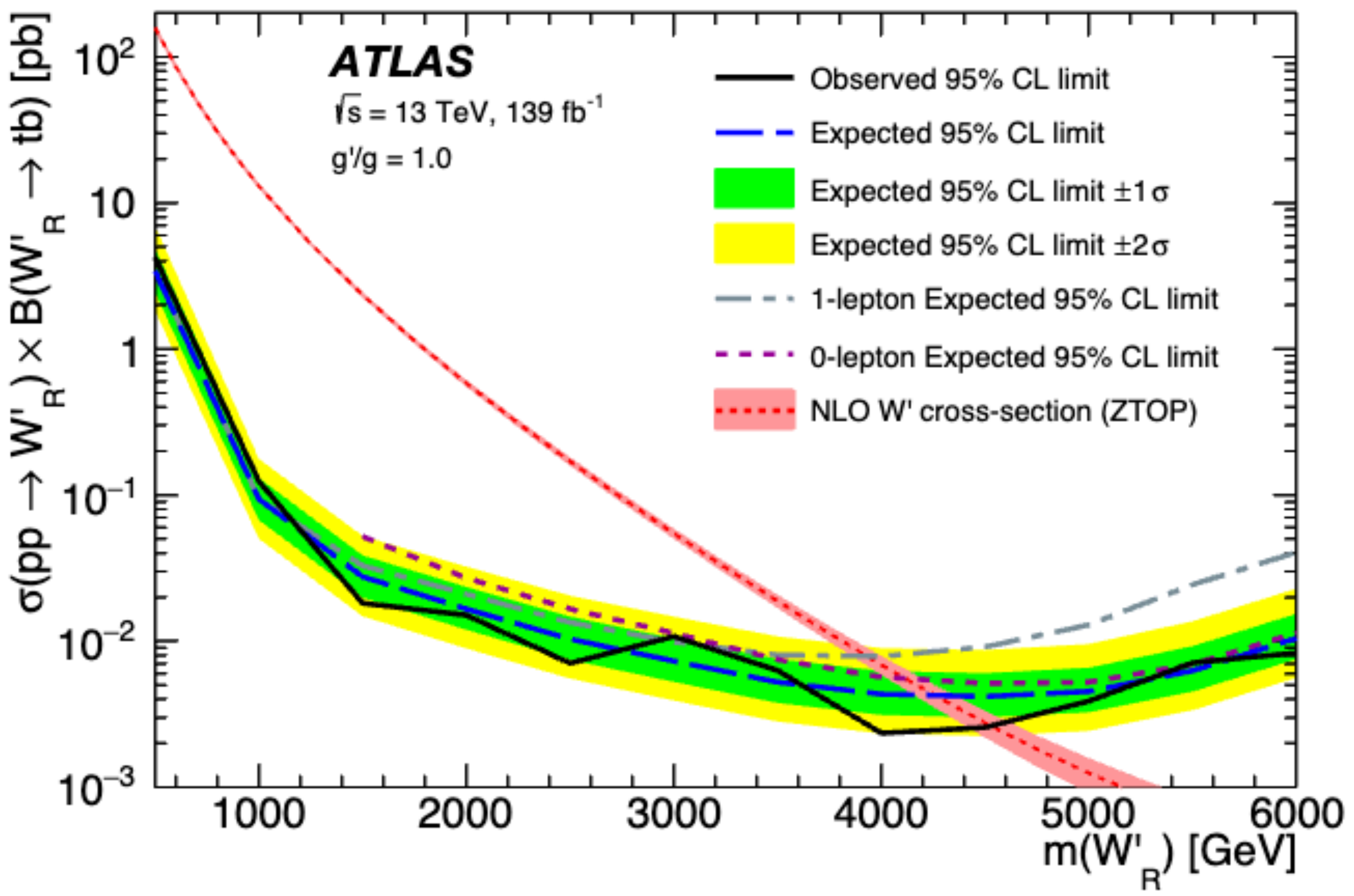
A search for a new massive charged gauge boson, W', is performed with the ATLAS detector at the LHC. The dataset used in this analysis was collected from proton–proton collisions at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV, and corresponds to an integrated luminosity of 139 fb^{-1}. The reconstructed tb invariant mass is used to search for a W' boson decaying into a top quark and a bottom quark. The result is interpreted in terms of a W' boson with purely right-handed or left-handed chirality in a mass range of 0.5–6 TeV. Different values for the coupling of the W' boson to the top and bottom quarks are considered, taking into account interference with single-top-quark production in the s-channel. No significant deviation from the background prediction is observed. The results are expressed as upper limits on the $W' \to tb$ production cross-section times branching ratio as a function of the W'-boson mass and in the plane of the coupling vs the W'-boson mass.

11 Conclusions

A search for $W' \to tb$ using 139 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collision data collected with the ATLAS detector at the LHC is presented. The search combines two channels, named according to the targeted decay of the top quark. The 0-lepton channel employs a DNN-based algorithm to identify large-radius jets originating from hadronically decaying top quarks. They are combined with small-radius jets selected with a b-tagging algorithm to reconstruct the W' boson. The dominant background from multi-jet production is estimated using a data-driven method. The 1-lepton channel selects events with one lepton (electron or muon), a certain amount of E_T^{miss}, and two or more jets. These objects are combined using top-quark and W-boson mass constraints to reconstruct the W' boson. The dominant backgrounds come from $t\bar{t}$ and W+jets production.

The observed distributions of the reconstructed W'-boson mass in various analysis regions are consistent with the background-only prediction, and exclusion limits at 95% CL are set on the production cross-section times branching ratio for $W' \to tb$. Several signal hypotheses are considered: W'-boson masses in the range 0.5–6 TeV, right-handed and left-handed couplings, and different coupling strengths relative to the coupling of the W boson to fermions in the SM. Effects of interference between the left-handed W' boson and the SM W boson are taken into account.

Right-handed W' bosons with masses below 4.6 TeV (4.2 TeV) are observed (expected) to be excluded for a coupling value of $g'/g = 1.0$. For the same coupling value, left-handed W' bosons with masses below 4.2 TeV (4.1 TeV) are observed (expected) to be excluded. The observed mass limits for right-handed W' bosons with $g'/g = 1.0$ are more than 1 TeV higher than in the previous 0-lepton-channel CMS search and the previous ATLAS combination of the two channels. The observed mass limits for left-handed W' bosons with the same coupling strength are approximately 0.8 TeV higher than in the previous 0-lepton-channel CMS search. The obtained limits are the most stringent to date.



EXO 20 -002 plots

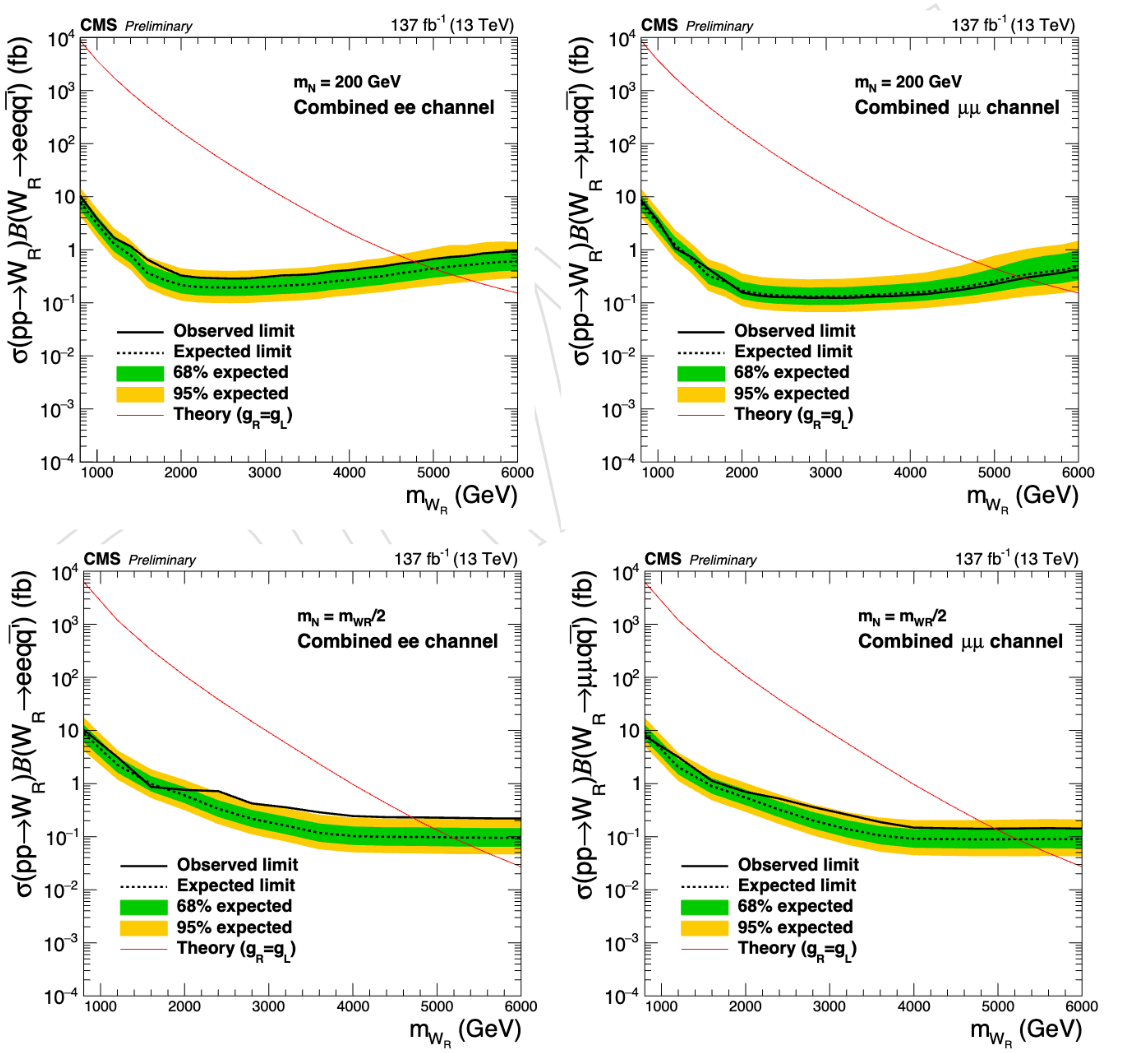
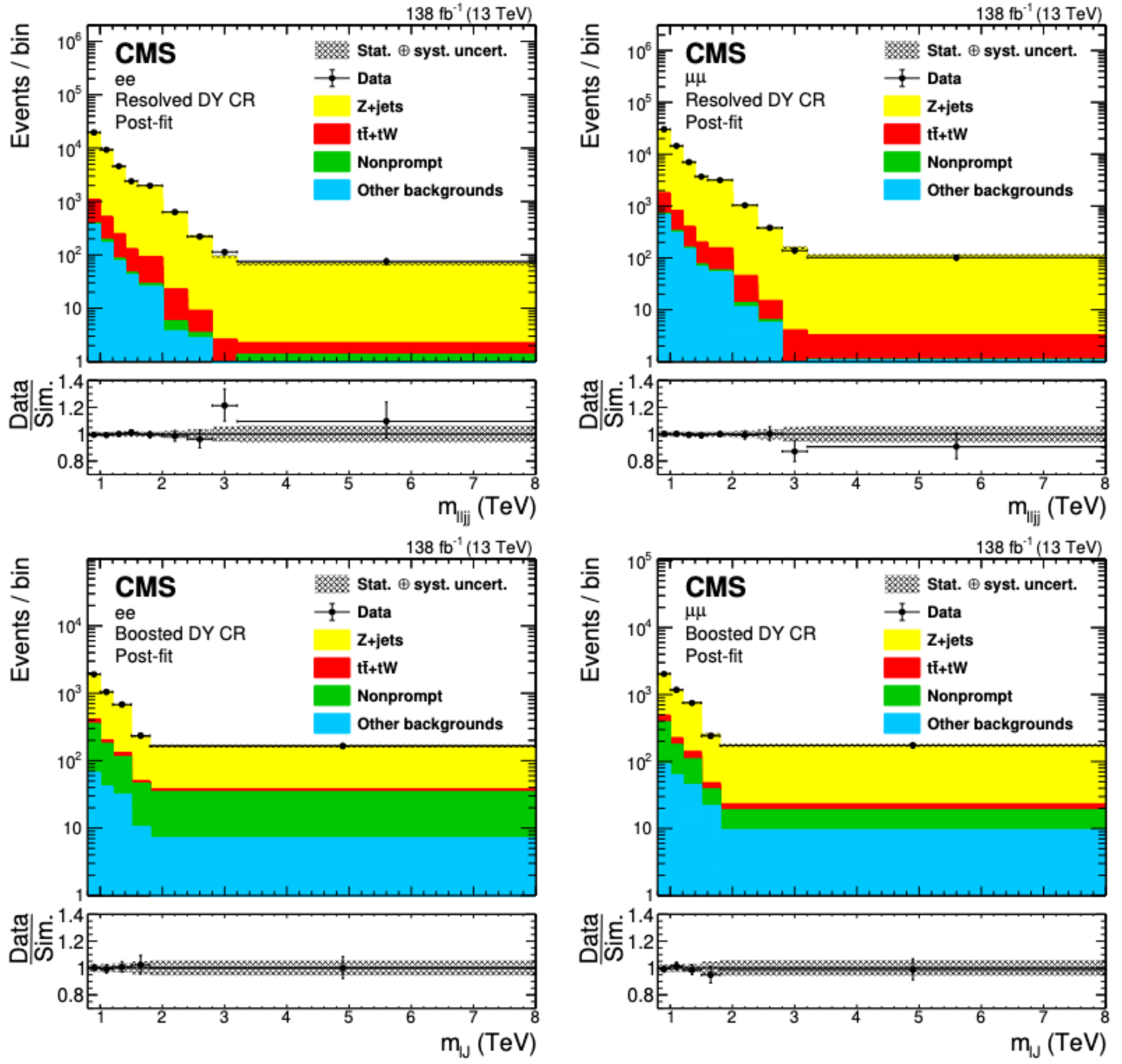
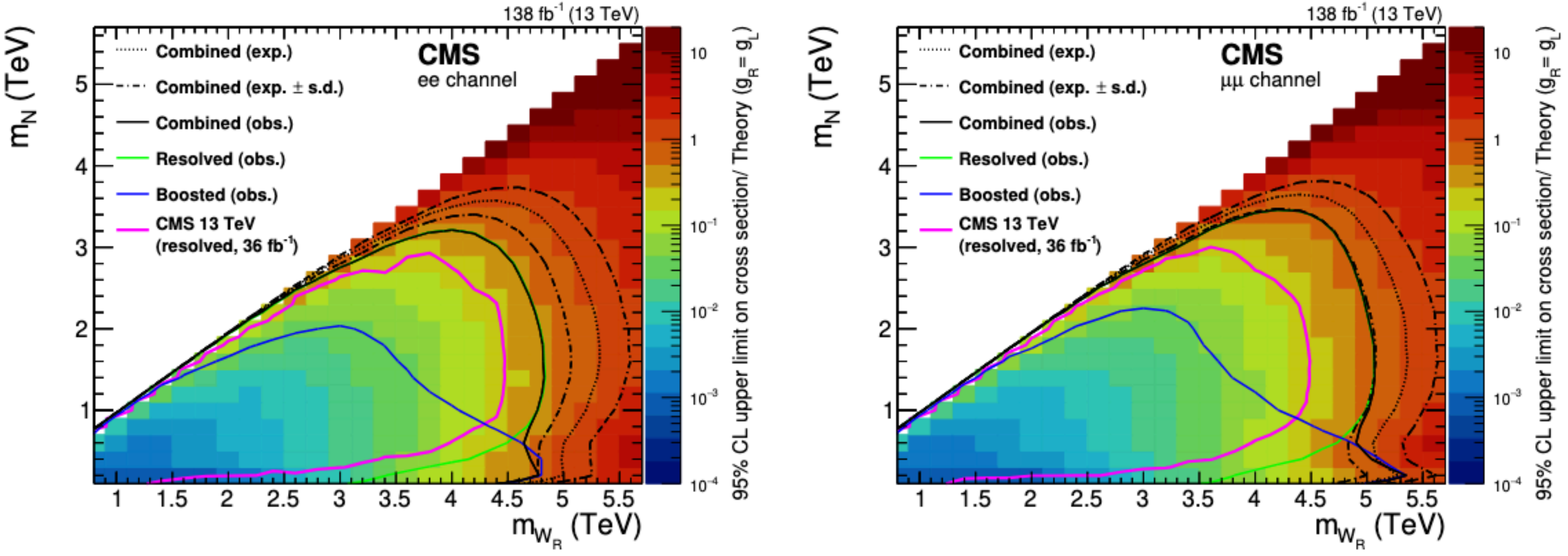


Figure 51: Upper limit on $\sigma(\mathrm{pp} \rightarrow \mathrm{W_R}) \times BR(\mathrm{W_R} \rightarrow \mathrm{ee}(\mu\mu)\mathrm{jj})$ cross section limit are shown on the left (right) for the entire Run2 dataset. The expected exclusions are shown.

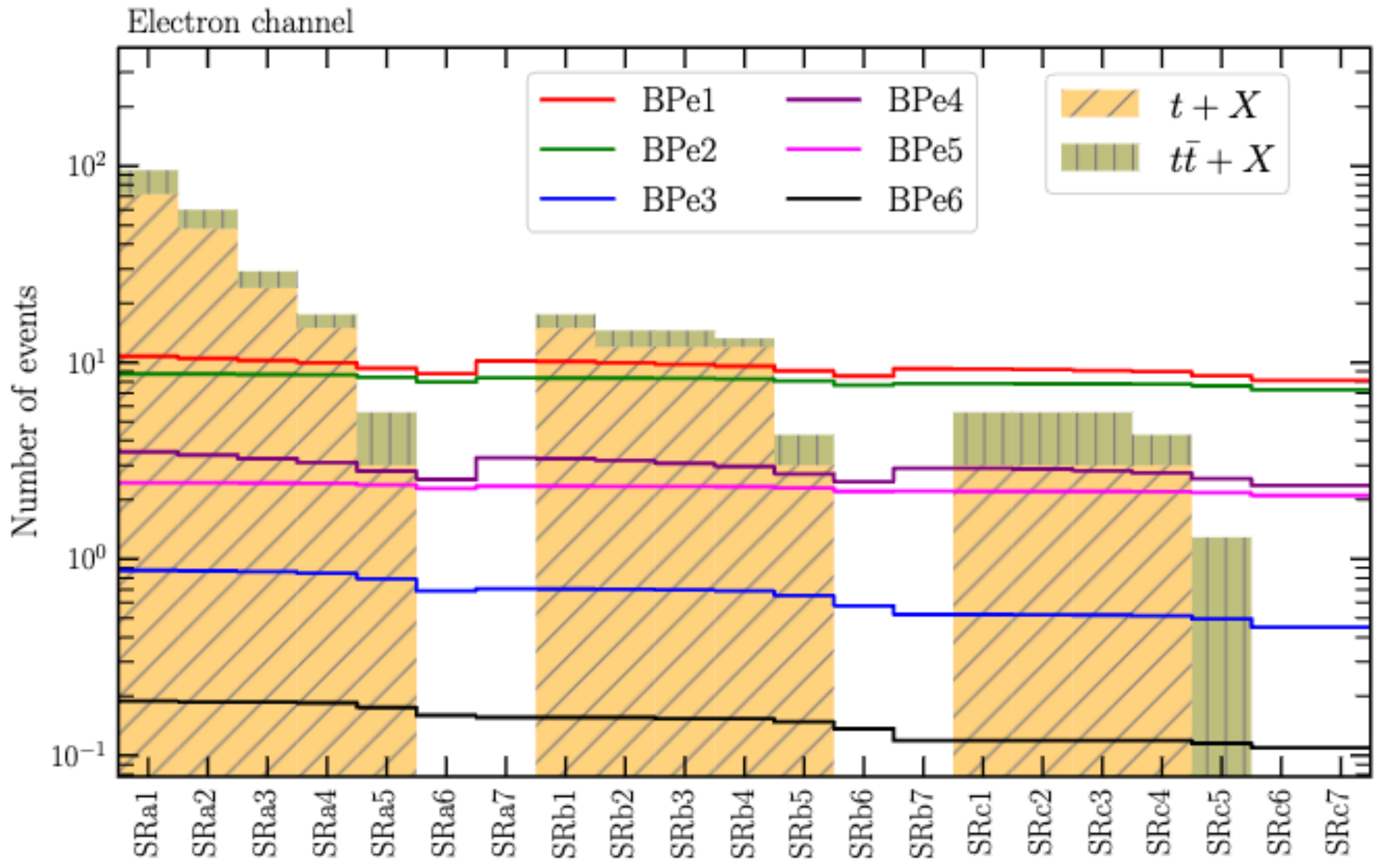


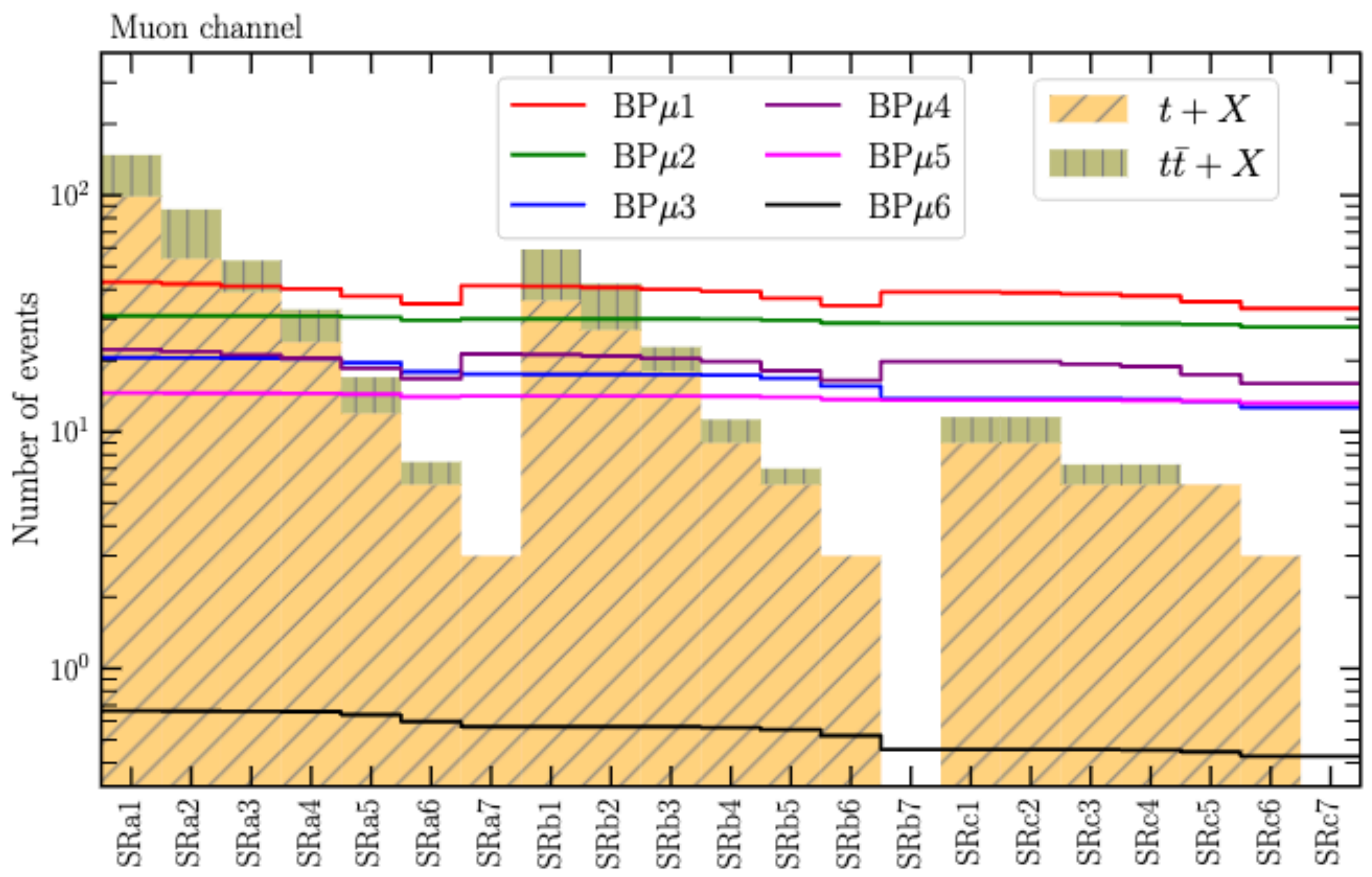
EXO 20 -002 plots



	Electron channel		Muon channel	
$]M_{\ell\ell jj}^{\min}, M_{\ell\ell jj}^{\max}]$	Data	Background	Data	Background
$]800, 1000]$ GeV	1106.0	1103.5 ± 26.607	1639.0	1670.7 ± 39.774
$]1000, 1200]$ GeV	646.0	631.51 ± 16.968	946.0	925.99 ± 23.917
$]1200, 1400]$ GeV	332.0	323.23 ± 10.736	518.0	500.33 ± 14.869
$]1400, 1600]$ GeV	170.0	169.69 ± 6.8418	268.0	263.88 ± 9.3498
$]1600, 2000]$ GeV	143.0	157.55 ± 9.505	216.0	215.18 ± 8.2146
$]2000, 2400]$ GeV	62.0	52.327 ± 3.9676	80.0	73.482 ± 4.4654
$]2400, 2800]$ GeV	25.0	19.567 ± 1.5493	30.0	25.943 ± 2.3125
$]2800, 3200]$ GeV	10.0	8.9907 ± 1.209	13.0	9.7557 ± 1.1603
$]3200, 8000]$ GeV	13.0	6.2463 ± 0.77892	11.0	7.8119 ± 0.84286

arXiv:2312.08521v2





BP	BPe1	BPe2	BPe3
M_{W_R} [GeV]	4800	4800	4800
M_{N_R} [GeV]	960	2400	4400
$\sigma(pp \to \ell\ell tb)_{\rm LO}$ [fb]	1.22×10^{-1}	7.77×10^{-2}	4.27×10^{-3}
$\sigma(pp \to \ell\ell tb)_{\rm NLO}$ [fb]	1.73×10^{-1}	1.13×10^{-1}	6.43×10^{-3}
Γ_{W_R} [GeV]	134	130	122
Γ_{N_R} [GeV]	2.47×10^{-5}	2.96×10^{-3}	1.21×10^{-1}

BP	BPe4	BPe5	BPe6
M_{W_R} [GeV]	5500	5500	5500
M_{N_R} [GeV]	1100	2750	5100
$\sigma(pp \to \ell\ell tb)_{\rm LO}$ [fb]	3.39×10^{-2}	1.73×10^{-2}	6.87×10^{-4}
$\sigma(pp \to \ell\ell tb)_{\rm NLO}$ [fb]	5.50×10^{-2}	3.13×10^{-2}	1.34×10^{-3}
Γ_{W_R} [GeV]	153	149	139
Γ_{N_R} [GeV]	2.88×10^{-5}	3.41×10^{-3}	1.52×10^{-1}

BP	BPμ1	BPμ2	BPμ3
M_{W_R} [GeV]	5100	5100	5100
M_{N_R} [GeV]	1020	2550	4700
$\sigma(pp \to \ell\ell tb)$ [fb]	6.99×10^{-2}	4.09×10^{-2}	1.54×10^{-3}
$\sigma(pp \to \ell\ell tb)_{\rm NLO}$ [fb]	1.04×10^{-1}	6.45×10^{-2}	3.25×10^{-3}
Γ_{W_R} [GeV]	142	138	129
Γ_{N_R} [GeV]	2.65×10^{-5}	3.15×10^{-3}	1.34×10^{-1}

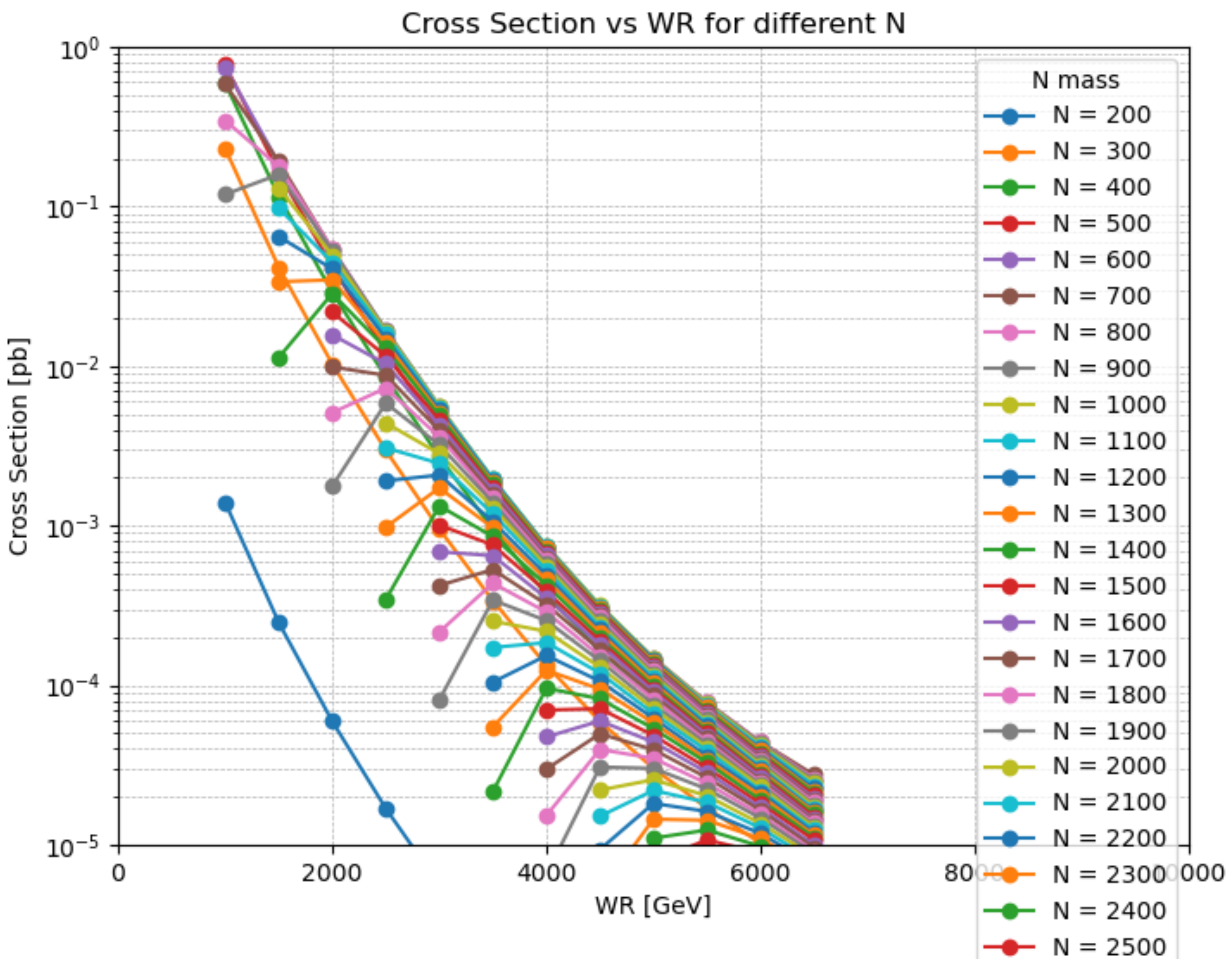
BP	BPμ4	BPμ5	BPμ6
M_{W_R} [GeV]	5500	5500	5500
M_{N_R} [GeV]	1100	2750	5100
$\sigma(pp \to \ell\ell tb)_{\rm LO}$ [fb]	3.39×10^{-2}	1.73×10^{-2}	6.87×10^{-4}
$\sigma(pp \to \ell\ell tb)_{\rm NLO}$ [fb]	5.50×10^{-2}	3.13×10^{-2}	1.34×10^{-3}
Γ_{W_R} [GeV]	153	149	139
Γ_{N_R} [GeV]	2.88×10^{-5}	3.41×10^{-3}	1.52×10^{-1}

$M_{\ell\ell tb}$ \ $M_{\ell\ell}$	$]400, \infty)$	$]600, \infty)$	$]800, \infty)$
$]1200, \infty)$	SRa1	SRb1	SRc1
$]1400, \infty)$	SRa2	SRb2	SRc2
$]1600, \infty)$	SRa3	SRb3	SRc3
$]1800, \infty)$	SRa4	SRb4	SRc4
$]2000, \infty)$	SRa5	SRb5	SRc5
$]2500, \infty)$	SRa6	SRb6	SRc6
$]3000, \infty)$	SRa7	SRb7	SRc7

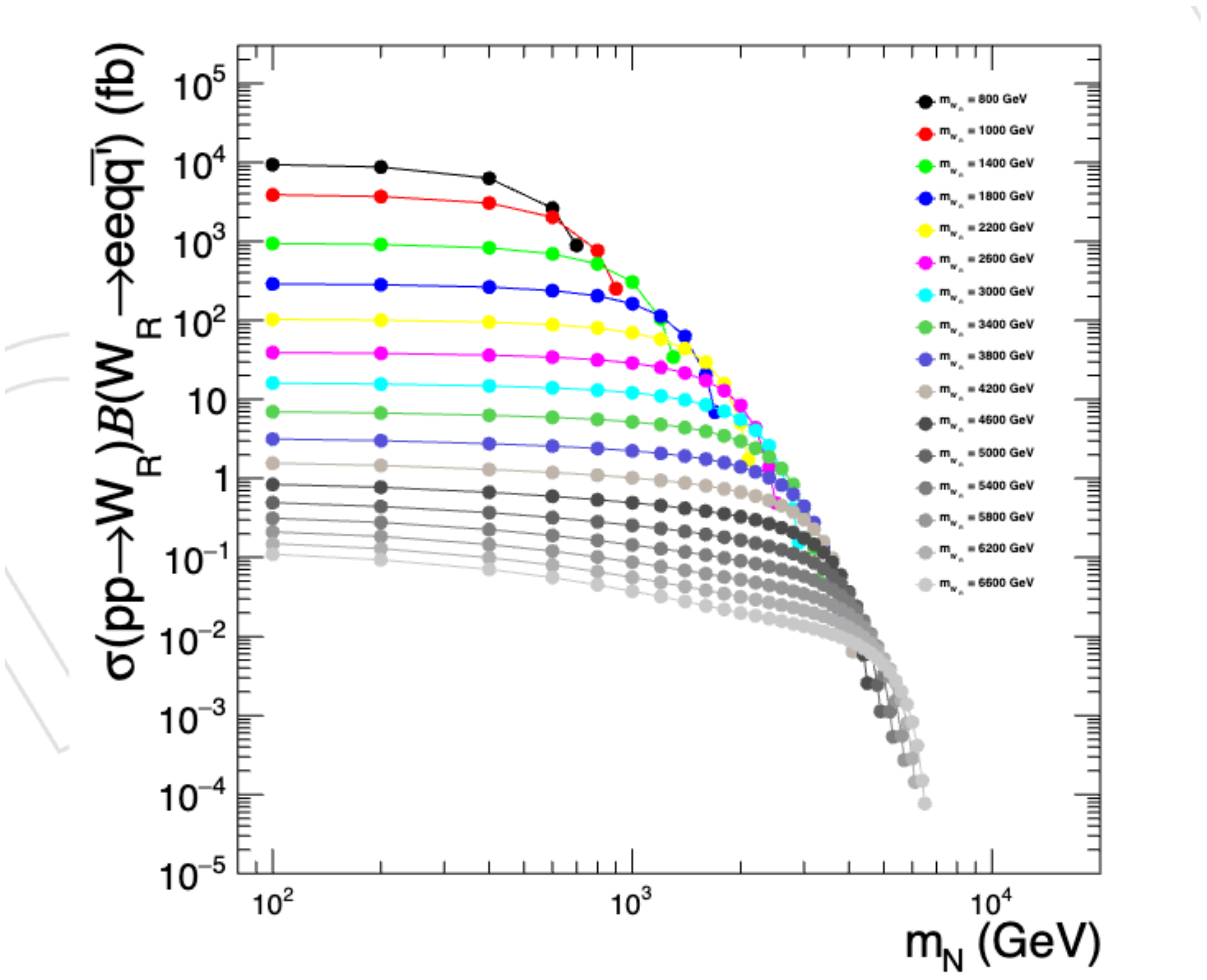
EXO 20 -002 data / bkg rates
(light quark channel)

T/b jet channel data / bkg rates (HL -LHC $3000 fb^{-1}$)

Cross sections for up to 10tev



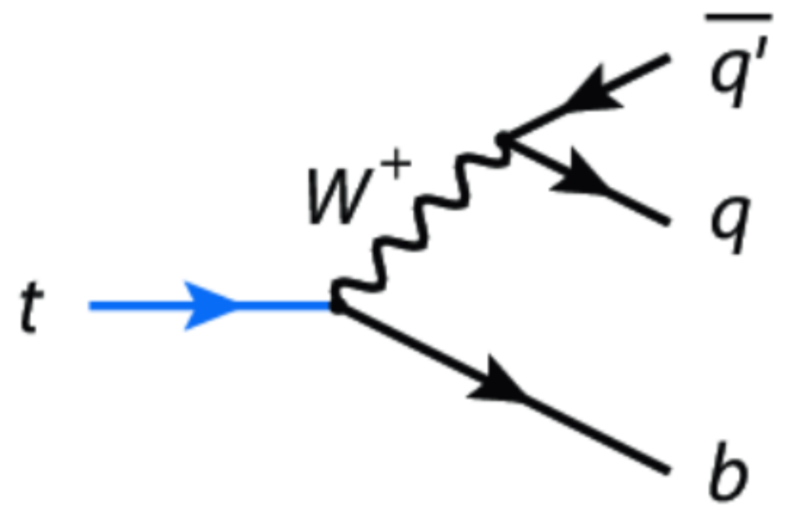
- Cross section up to 6.5 tev (t/b jet channel)



CMS AN-19-083

- Cross section up to 6.6 tev (light jet channel)

Right handed top?



How can right handed top can decay to SM W?

1. $t_R \rightarrow t_L$ 2. Just decays to right handed W

Due to lot of mass difference with t_R & W_R^* -> highly suppressed -> “will be almost decay to $t_L -> W_L$”

Checked with cross section in 2 Cases [LO]

```
import model EffLRSM_NLO
define p = g u c d s  u~ c~ d~ s~
define quark = u c d s u~ c~ d~ s~
define j = p
define ll = e+ e- mu+ mu-
define nn = n1 n2
define bot = b b~
define top = t t~
define wr = wr+ wr-
generate p p > nn ll,(nn > ll top bot,(top > quark quark bot))
```

```
import model EffLRSM_NLO
define p = g u c d s  u~ c~ d~ s~
define quark = u c d s u~ c~ d~ s~
define j = p
define ll = e+ e- mu+ mu-
define nn = n1 n2
define bot = b b~
define top = t t~
define wr = wr+ wr-
define w = w+ w-
generate p p > nn ll,(nn > ll top bot,(top > w bot ,(w > quark quark )))
```

On 2025-06-17 04:57, An Chihwan wrote:
> Dear Dr. Ruiz,
>
> I hope this message finds you well.
>
> My name is Chihwan An, and I am a first-year master’s student in
> the CMS group at Seoul National University. I was told by Sihyun Jeon
> who was in contact with you for other heavy neutrino publications that
> SNU group worked on during last few years to seek your insights on
> some questions I have. I am currently studying Left–Right Symmetric
> Models (LRSM), and have been making use of the LRSM UFO model that you
> and your collaborators developed . I encountered one questions during
> study and unfortunately those problems was not explained explicitly in
> following website and paper
> "https://feynrules.irmp.ucl.ac.be/wiki/EffLRSM [1]",
> "https://arxiv.org/abs/1610.08985 [2]".
>
> I am currently studying the process qq(pp) ->WR->N l ->WR* → t b,
> followed by the top quark decay t → W b, where the top quark is
> expected to be produced via a right-handed WR interaction. I would
> greatly appreciate your clarification on two points regarding the
> chirality and decay treatment of the top quark in the UFO
> implementation:
>
> Our question is the following : Will the current model file take into
> account the t_R -> W_R* b_R (which then W_R have to be offshell since
> our interest is when m_W_R >> m_t) and penalize t -> W_L b decay
> branching ratio? I understand that the mass suppression will be much
> larger for m_W_R but on the other hand, due to the preference of
> right-handedness of top (mixing to left hand top suppression (~mt/Et)
>), we weren't sure (a) if this is really ignorable and (b) if the
> model file accounts for these effect already.
>

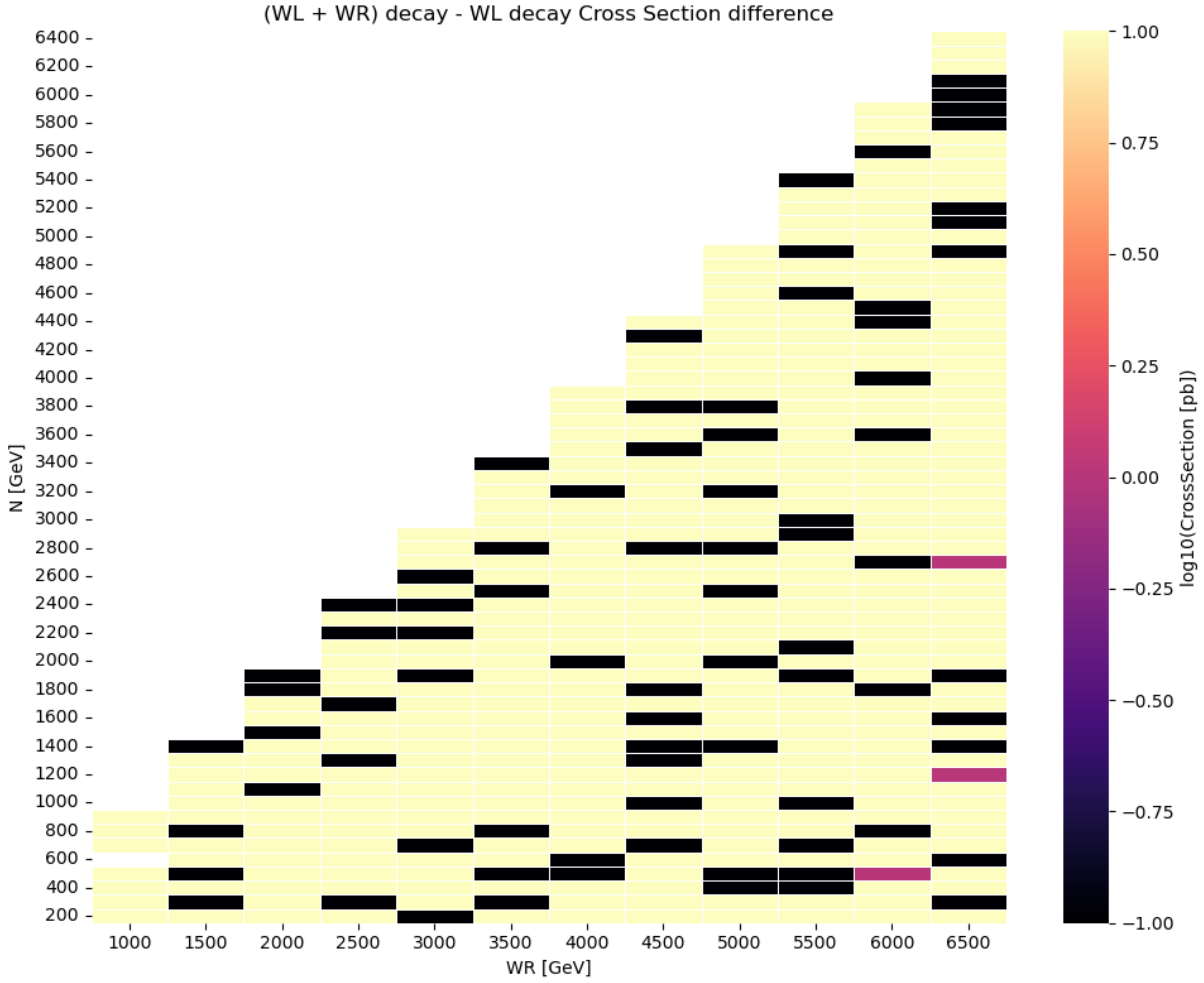
If MWR > mt, then the 2-body decay process t > WR b is *not* possible as
this kinematically forbidden.

If instead you simulate the full 3-body decay process t > b f f', where
f and f' are any SU(2)-pair of fermions (v/e, v/tau, Nk/mu, ud, etc),
then both WSM and WR will be included.

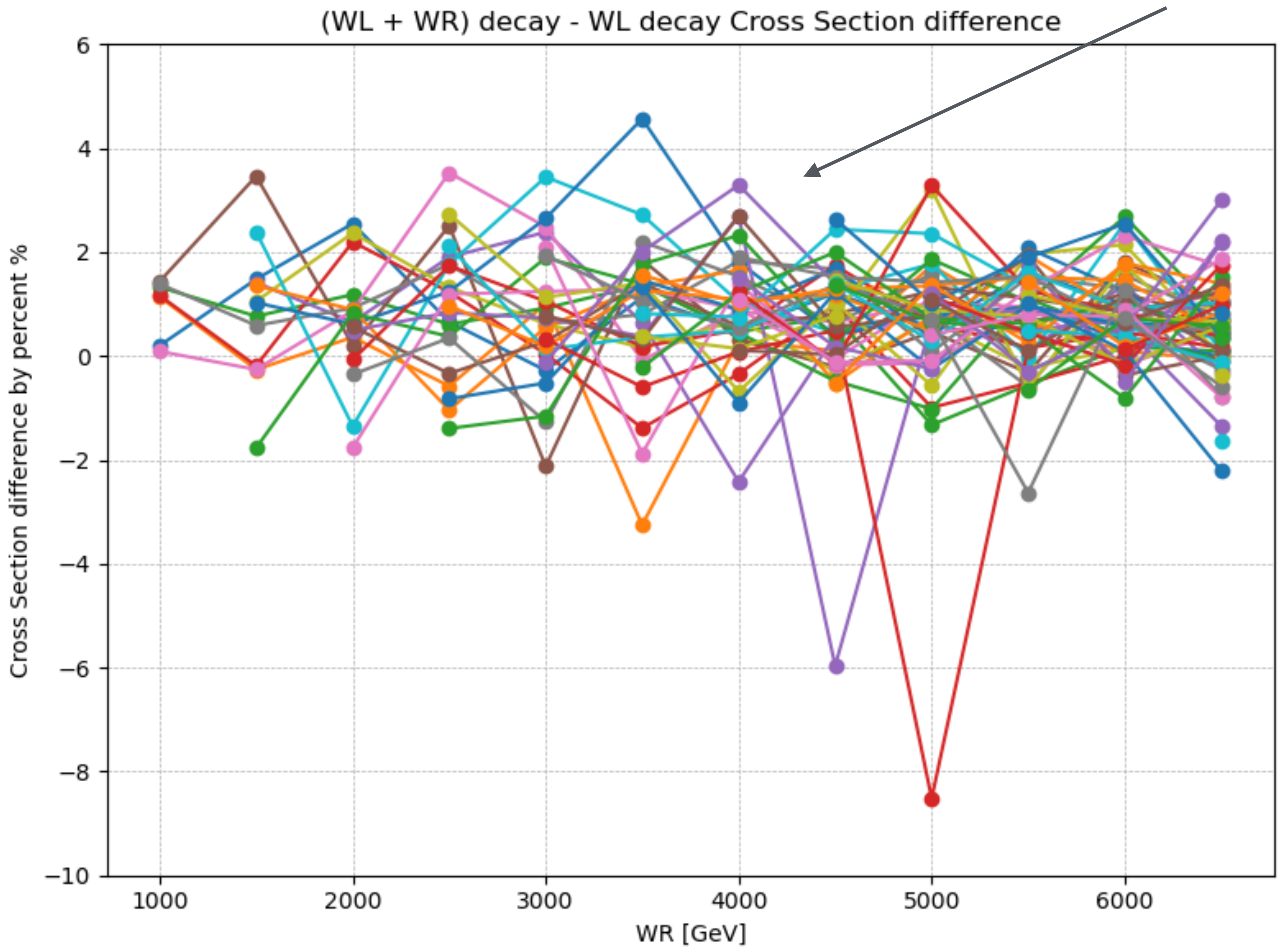
If you simulate, for example, the channel t > u d~ b, then you will have
two diagrams: one with t > W^(*)b and one with t > WR^* b

Full spin correlation and off-shell effects are taken into account. Just
be aware that the t > b f f' process will rely on the widths of WSM and
WR.

Right handed top?



Each colors stands for each N mass



Yellow region is when $W_L + W_R$ decay has more cross section

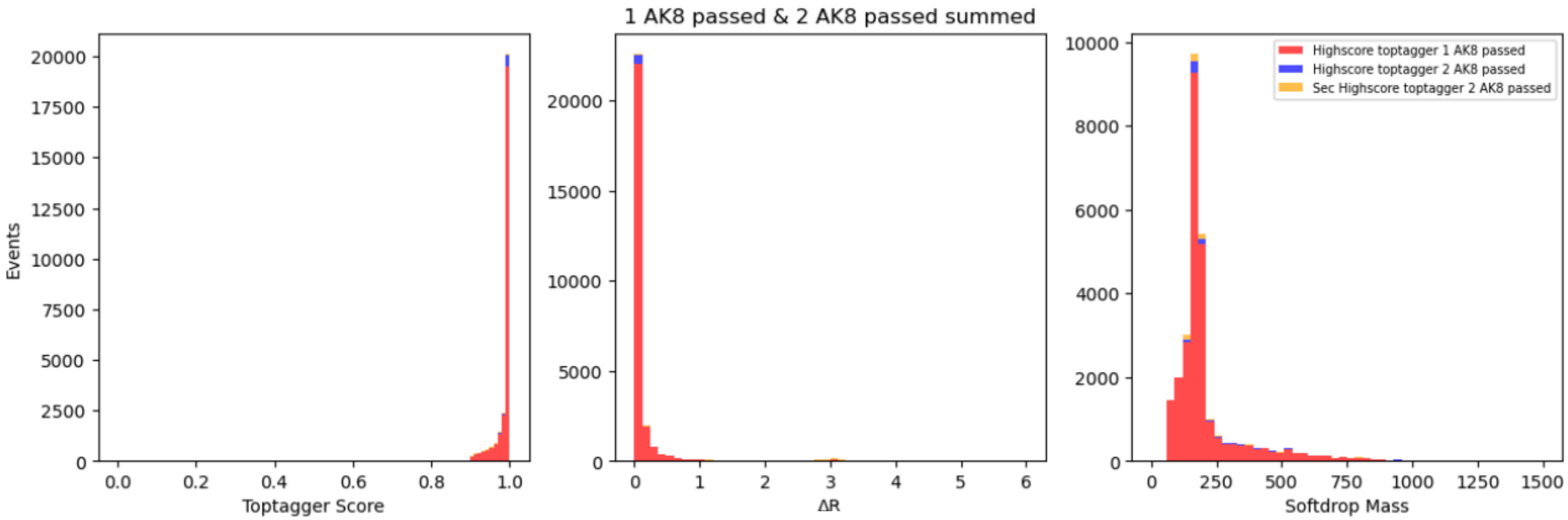
Black region is when W_L decay has more cross section

Average ~ 0.7% (which means W_R contributes cross-section about 0.7%)

-> It would not be a big problem to consider W_R topology..

AK8 top jet check

Adjusting Cut (top tagging score > 0.9 , SDM >120)
Is there could be fake top jets?



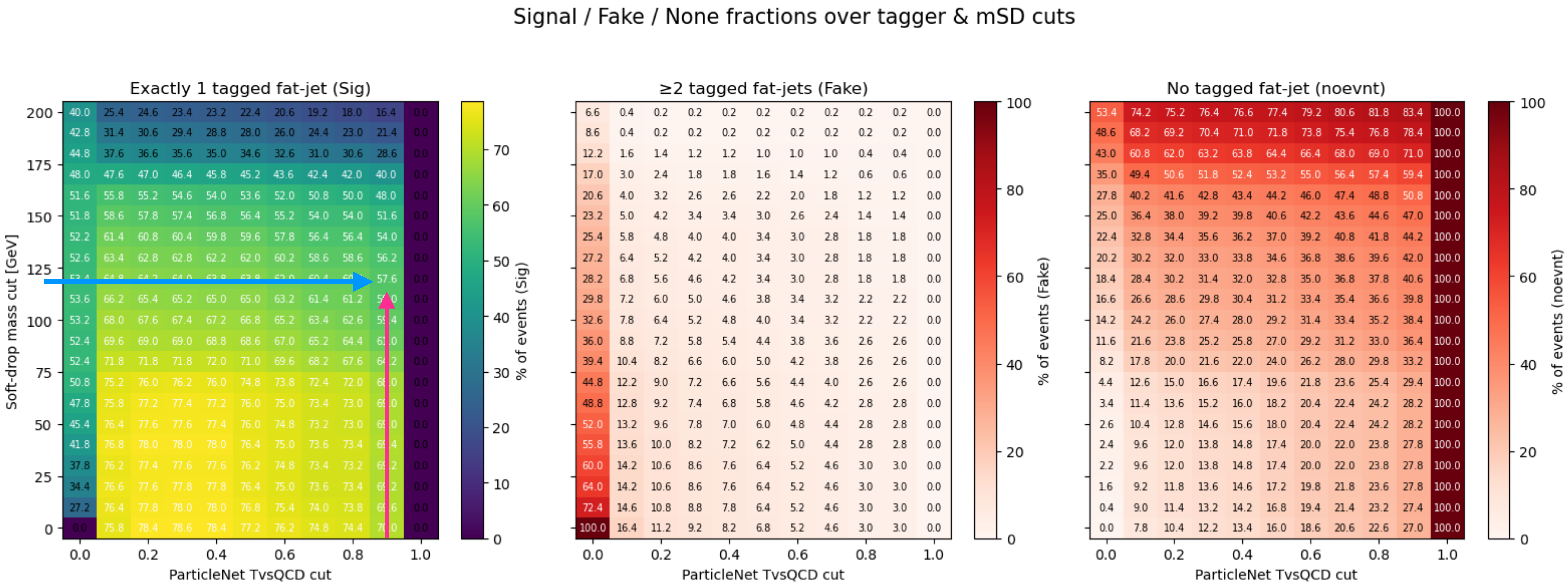
-> Max number of top jet was 2. (99% of event has 1 AK8 jet passed , 1% has 2 AK8 jet passed)
-> veto if there is 2 top jets.

Mass for W_R 5000 , N4900

AK8 top jet check

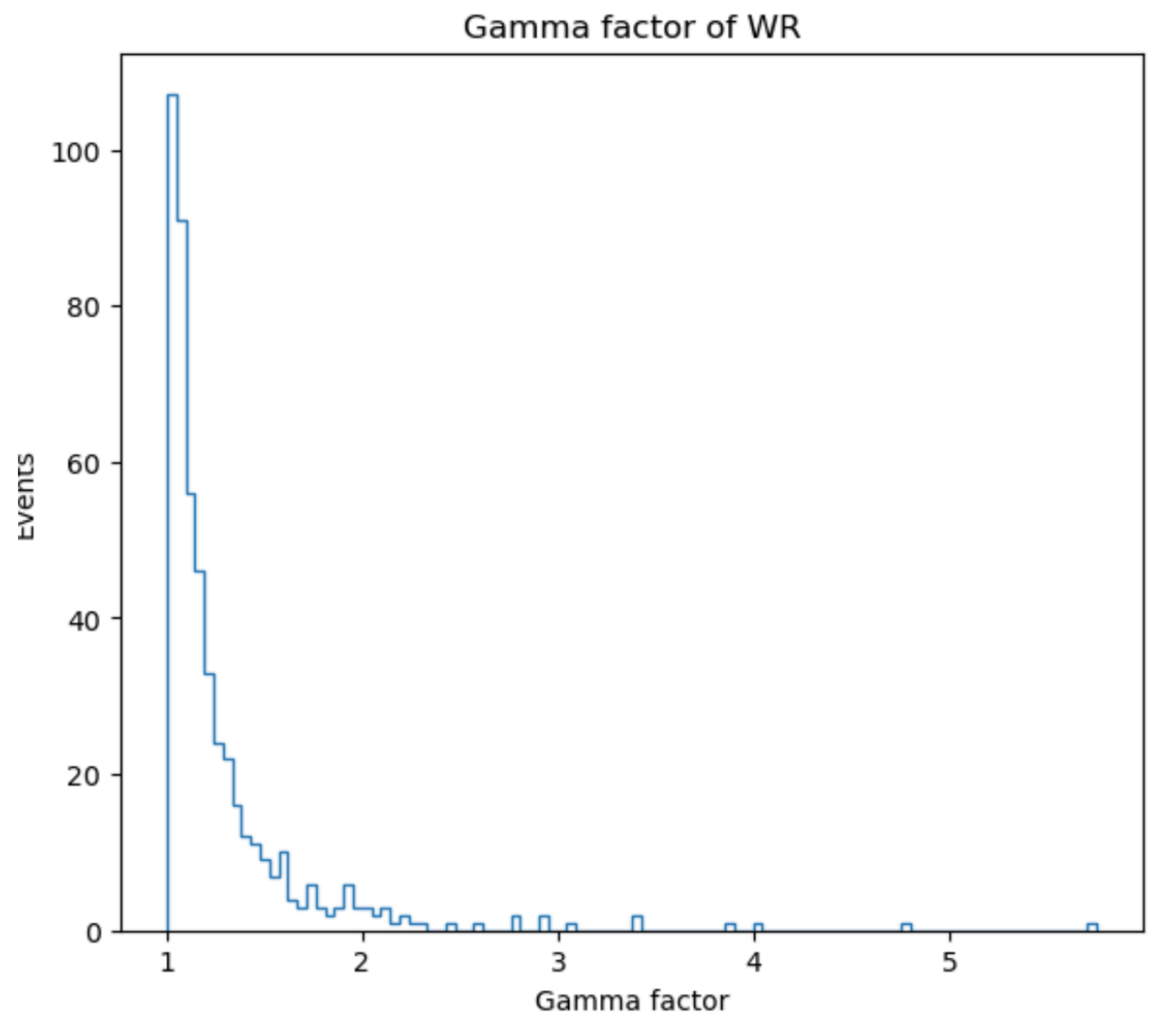
How much top jet we can use?

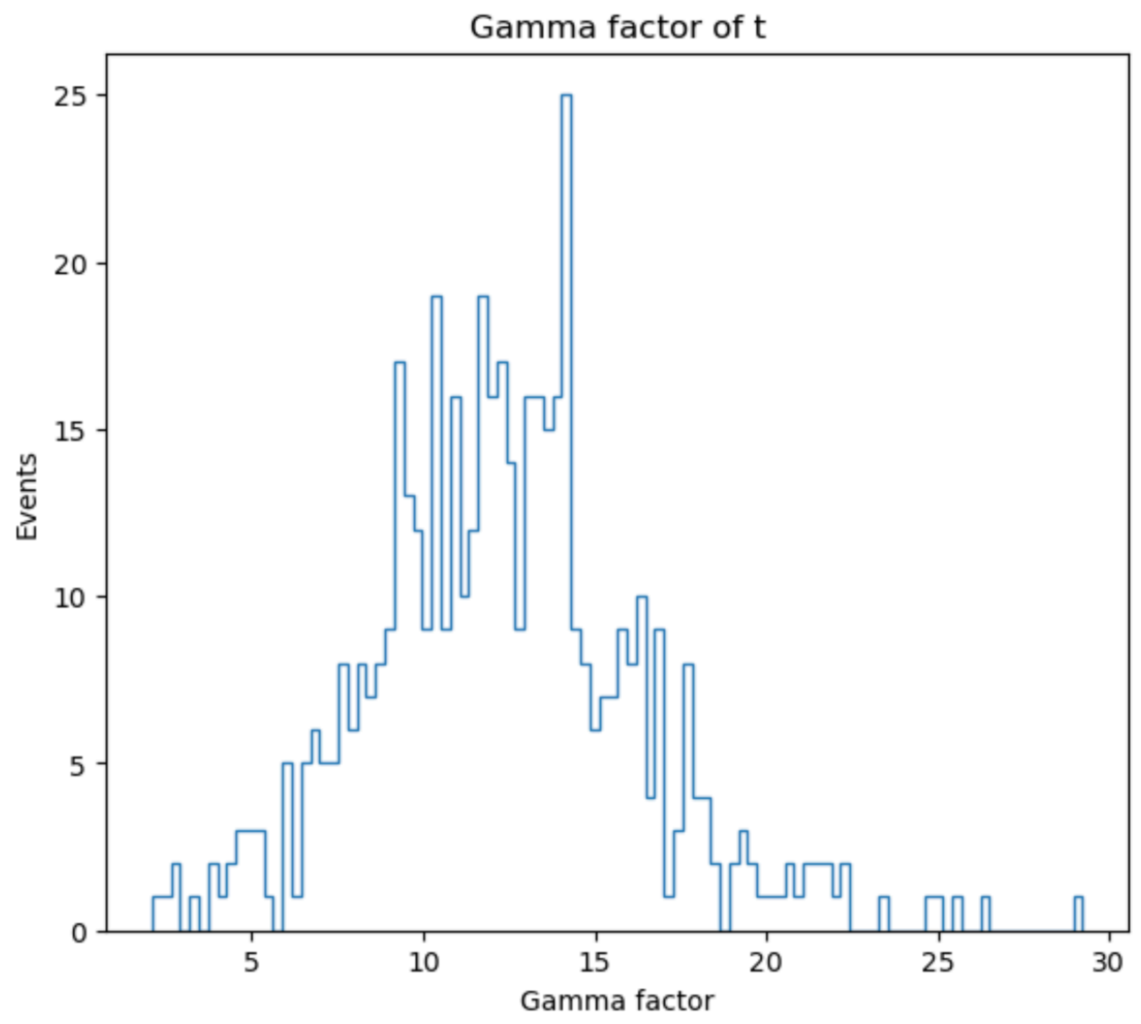
If I set top tagger cut > 0.9 , SDM > 120 ,



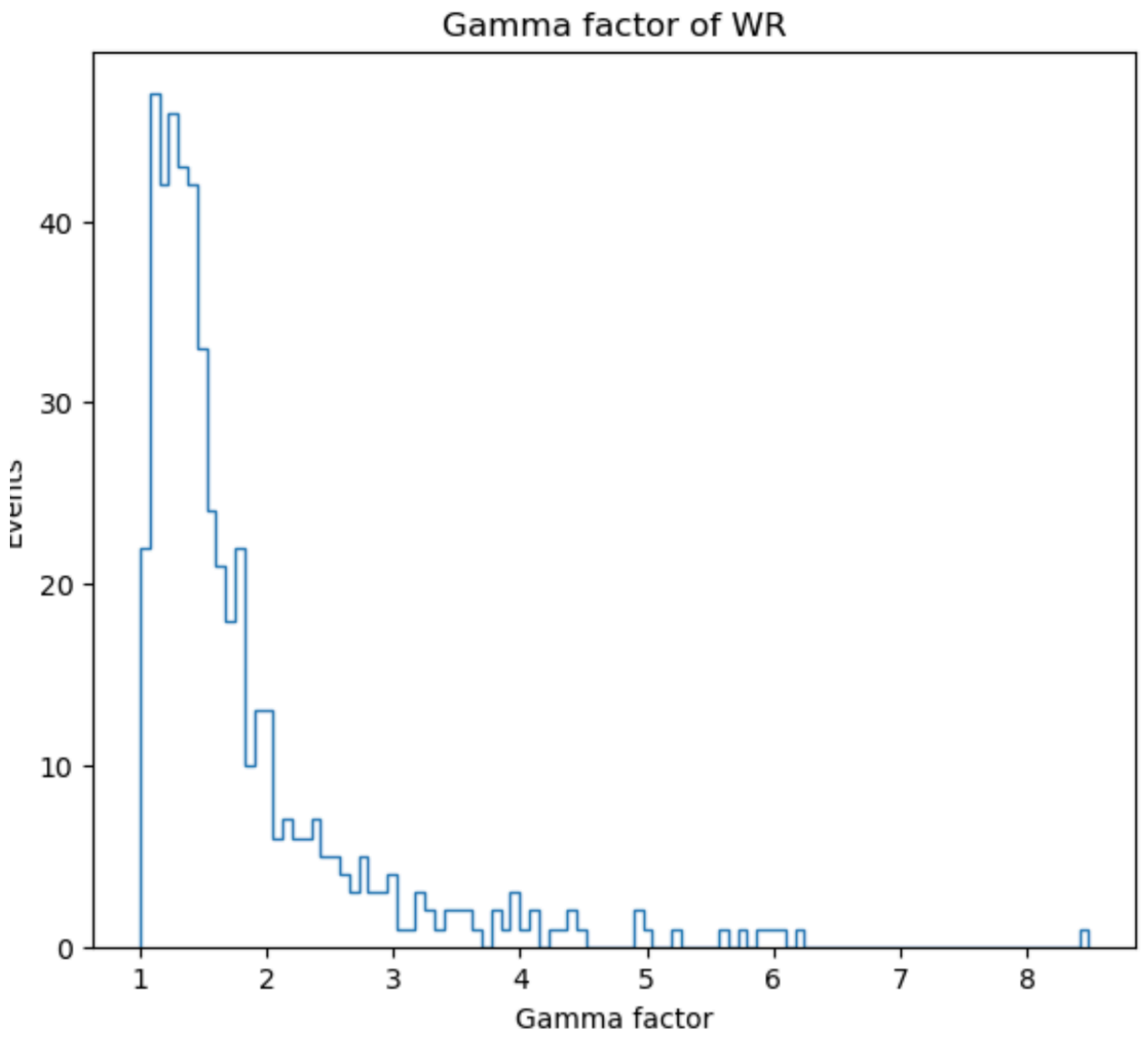
Mass for W_R 5000 , N4900

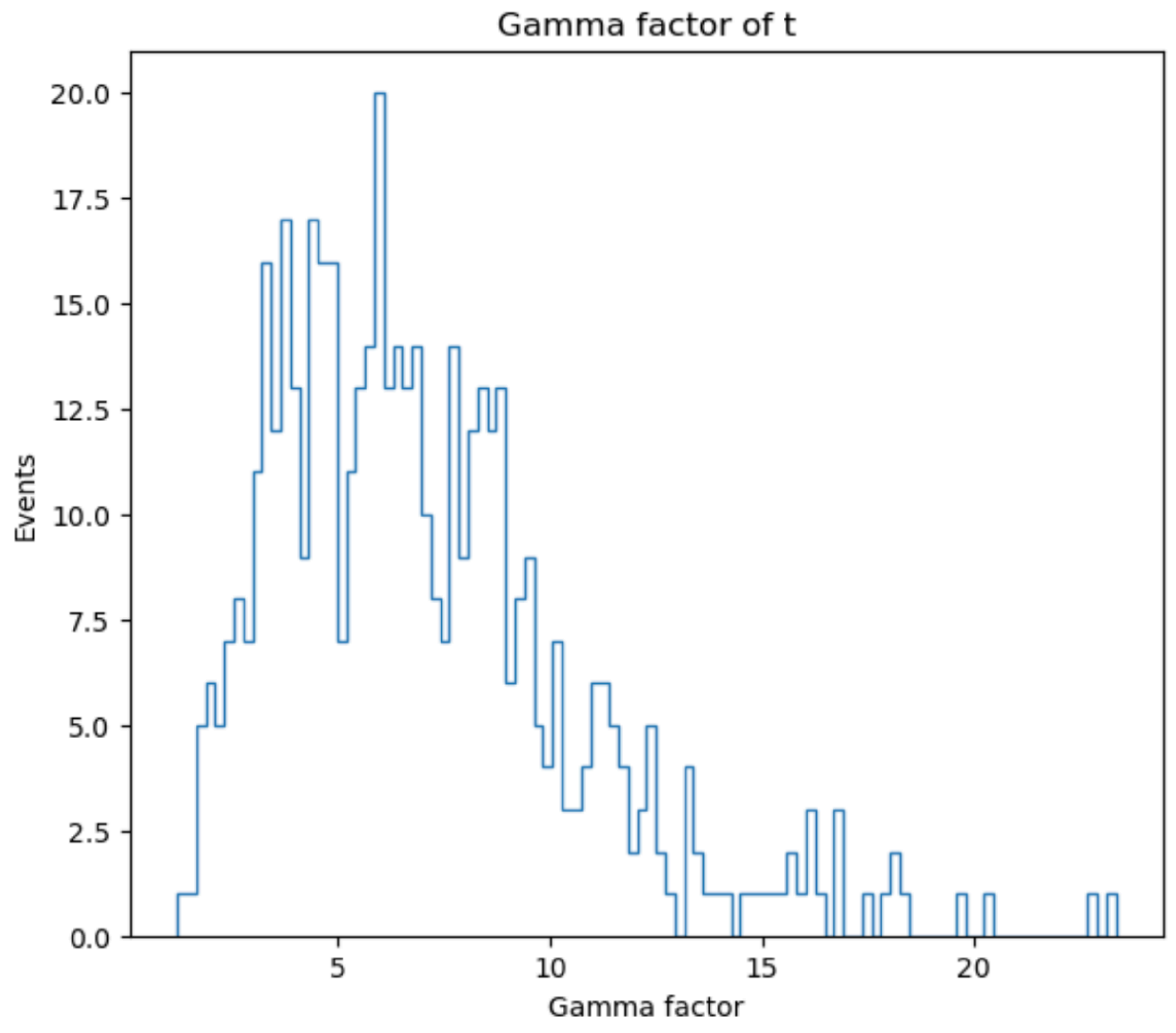
Boost factor for W_R, Top





W_R 5000 , N 4900

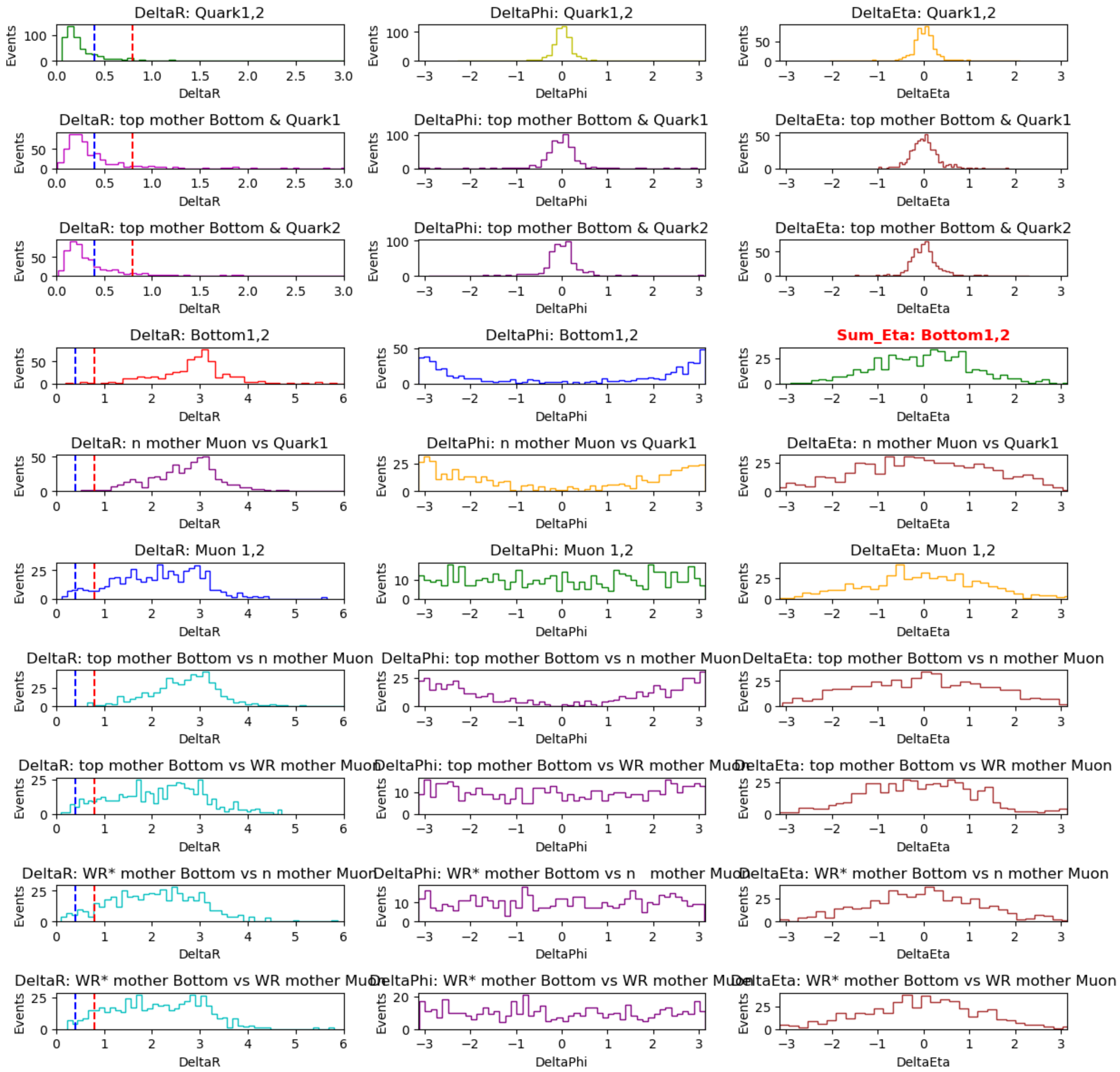




W_R 5000 , N 2500

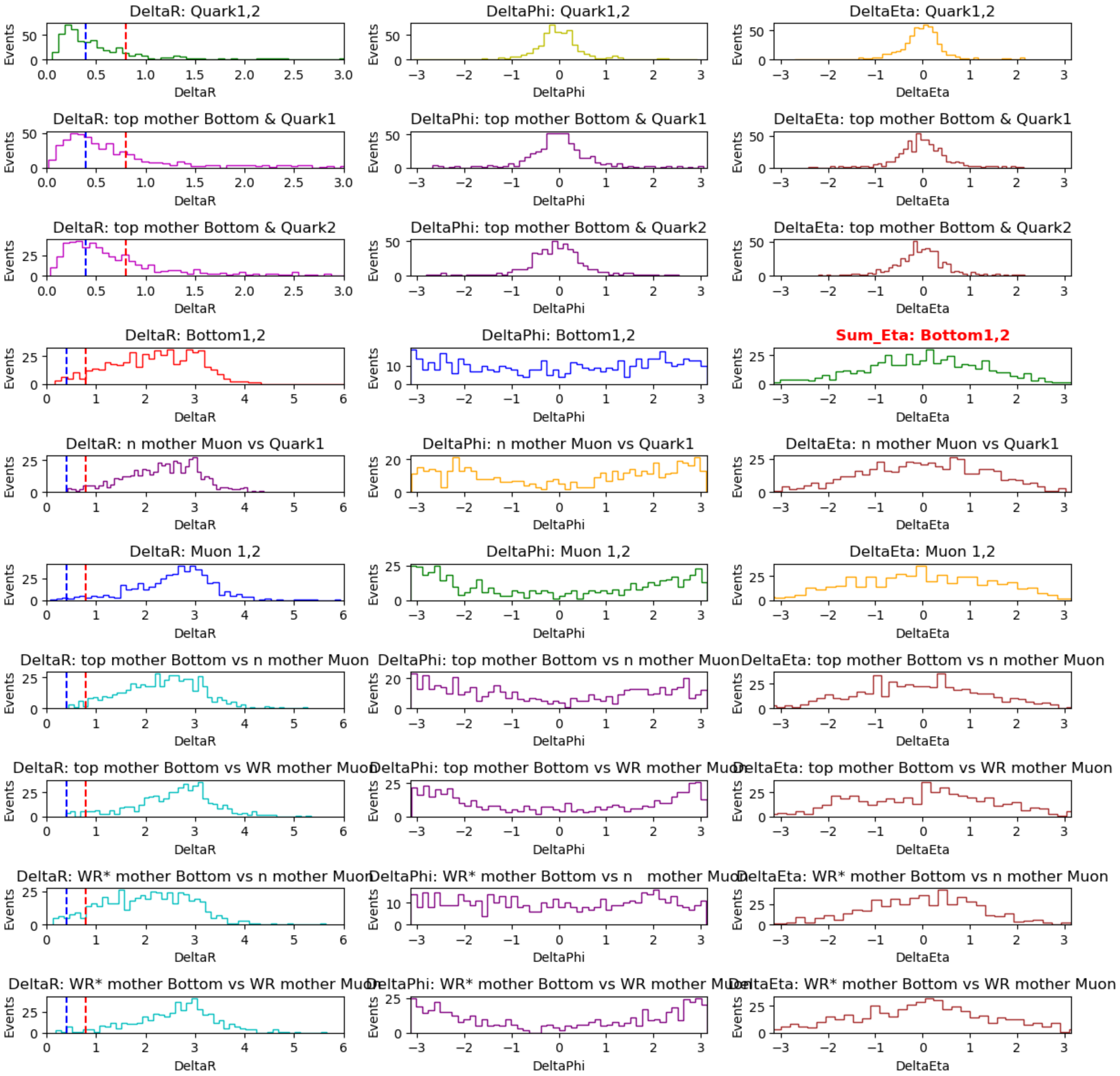
ΔR , $\Delta \eta$, $\Delta \phi$

For $W_R 5000$ $N4900$



ΔR , $\Delta\eta$, $\Delta\phi$

For $W_R5000\ N2500$



Number of reco muon

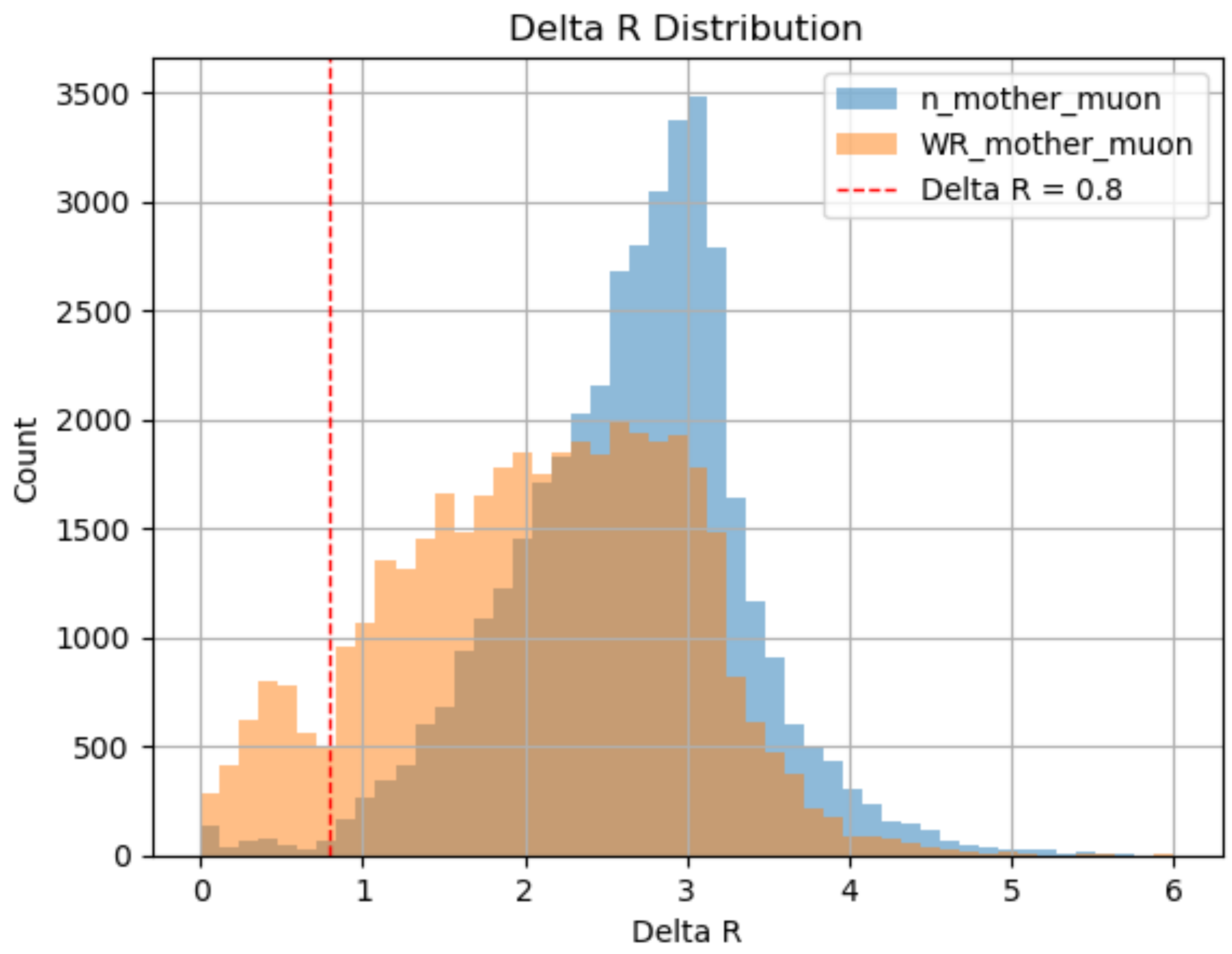
```
Event 0 has 5 muons with pt: [551, 103, 47.3, 28.5, 27.7]
Event 1 has 7 muons with pt: [567, 370, 334, 51.9, 28.2, 21.7, 12.4]
Event 2 has 3 muons with pt: [924, 67.1, 15.5]
Event 3 has 10 muons with pt: [1.99e+03, 279, 253, 226, 98, 89.9, 57.3, 22.9, 13.2, 3.7]
Event 4 has 5 muons with pt: [519, 397, 80.2, 79.9, 27]
Event 5 has 4 muons with pt: [724, 391, 29.2, 16.8]
Event 6 has 5 muons with pt: [1.51e+03, 906, 35.6, 27.4, 24.5]
Event 7 has 7 muons with pt: [452, 219, 64.1, 31, 29, 17.3, 16.2]
Event 8 has 4 muons with pt: [557, 147, 18.7, 15.3]
Event 9 has 4 muons with pt: [1.11e+03, 83.4, 47.5, 3.5]
Event 10 has 4 muons with pt: [969, 121, 7.78, 5.04]
Event 11 has 4 muons with pt: [1.06e+03, 121, 29.6, 26.1]
Event 12 has 5 muons with pt: [534, 423, 21.2, 20.8, 4.64]
Event 13 has 3 muons with pt: [834, 258, 7.33]
Event 14 has 5 muons with pt: [545, 423, 13.6, 9.88, 5.85]
Event 15 has 5 muons with pt: [1.88e+03, 995, 162, 92.6, 15.6]
Event 16 has 8 muons with pt: [244, 80.8, 68.4, 66.7, 45.7, 38.9, 19.2, 6.26]
Event 17 has 7 muons with pt: [552, 154, 116, 28.5, 27.2, 25.4, 21.6]
Event 18 has 2 muons with pt: [158, 123]
Event 19 has 3 muons with pt: [1.48e+03, 874, 230]
Event 20 has 10 muons with pt: [301, 282, 193, 99.2, 75.8, 48.4, 23.5, 22, 20.4, 15.9]
Event 21 has 2 muons with pt: [462, 192]
Event 22 has 2 muons with pt: [2.4e+03, 190]
Event 23 has 2 muons with pt: [89.8, 15.8]
Event 24 has 9 muons with pt: [805, 621, 63.1, 52.9, 51.5, 48.6, 29.9, 11.3, 10.4]
...
Event 497 has 3 muons with pt: [1.93e+03, 197, 5.15]
Event 498 has 2 muons with pt: [959, 176]
Event 499 has 5 muons with pt: [632, 308, 114, 23.7, 22.2]
5.647294589178356 averge muon number per event
```

W_R 5000 , N 4900

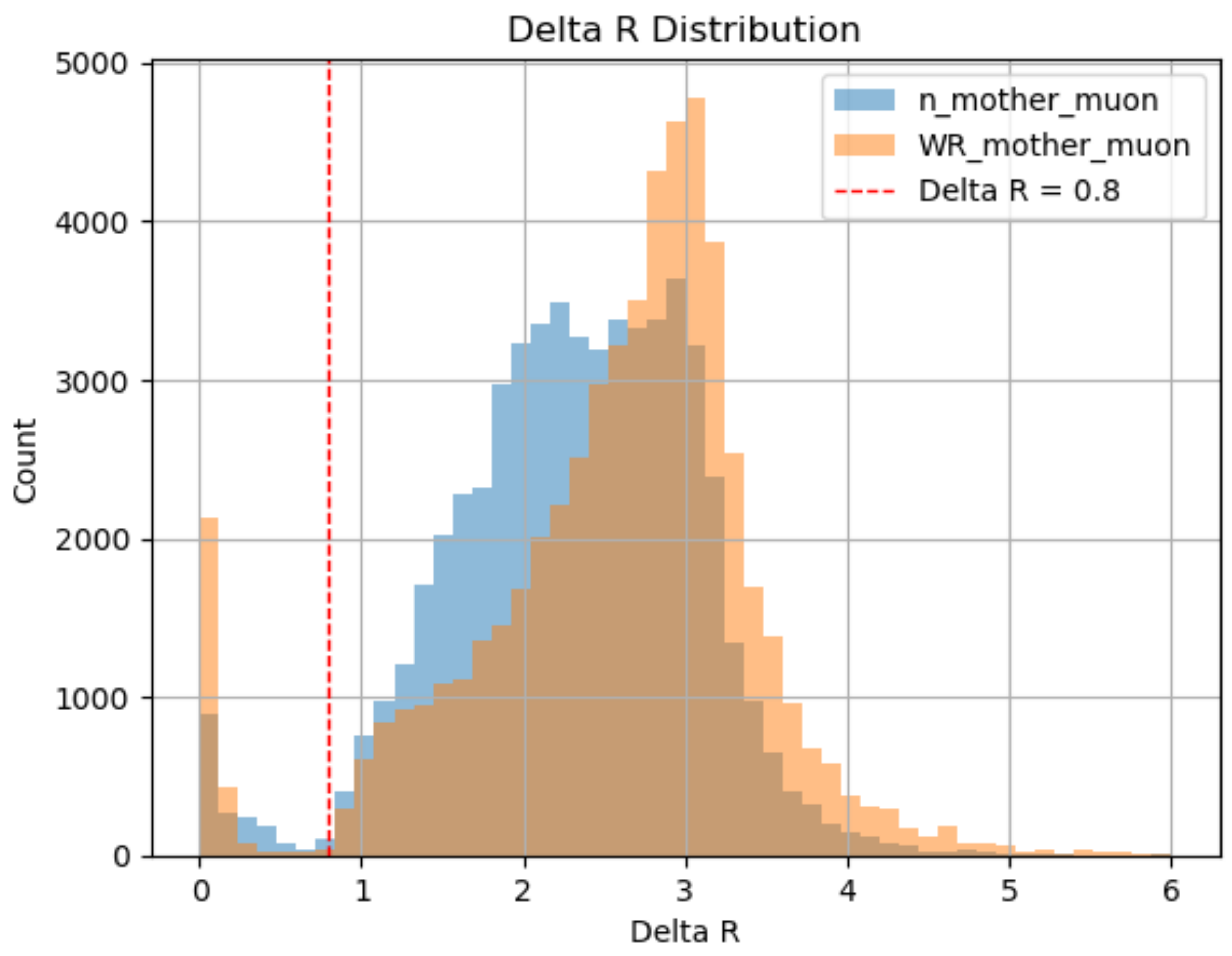
```
Event 0 has 2 muons with pt: [1.19e+03, 779]
Event 1 has 3 muons with pt: [745, 648, 4.5]
Event 2 has 7 muons with pt: [1.58e+03, 1.02e+03, 328, 120, 114, 40.9, 8.53]
Event 3 has 6 muons with pt: [1.67e+03, 673, 40.6, 36.9, 31.8, 25.1]
Event 4 has 6 muons with pt: [1.07e+03, 513, 26.3, 25, 18.5, 13.9]
Event 5 has 4 muons with pt: [1.15e+03, 865, 137, 64.5]
Event 6 has 2 muons with pt: [863, 628]
Event 7 has 3 muons with pt: [1.67e+03, 628, 4.7]
Event 8 has 4 muons with pt: [1.13e+03, 881, 5.45, 5.3]
Event 9 has 3 muons with pt: [1.36e+03, 255, 9.25]
Event 10 has 4 muons with pt: [1.93e+03, 747, 5.08, 3.96]
Event 11 has 4 muons with pt: [1.25e+03, 1.09e+03, 89.7, 44.1]
Event 12 has 7 muons with pt: [1.78e+03, 314, 89, 49.2, 46.6, 34.4, 23.8]
Event 13 has 5 muons with pt: [1.71e+03, 1.53e+03, 609, 41.1, 32.6]
Event 14 has 4 muons with pt: [1.9e+03, 427, 28.5, 10.2]
Event 15 has 2 muons with pt: [1.63e+03, 1.16e+03]
Event 16 has 3 muons with pt: [1.19e+03, 268, 4.62]
Event 17 has 3 muons with pt: [1.42e+04, 1.43e+03, 602]
Event 18 has 4 muons with pt: [1.69e+03, 1.39e+03, 10.7, 7.6]
Event 19 has 4 muons with pt: [1.4e+03, 243, 53.2, 6.67]
Event 20 has 3 muons with pt: [1.75e+03, 373, 21.8]
Event 21 has 4 muons with pt: [1.67e+03, 1.45e+03, 8.4, 4.85]
Event 22 has 2 muons with pt: [1.48e+03, 1.02e+03]
Event 23 has 3 muons with pt: [971, 650, 152]
Event 24 has 4 muons with pt: [1.15e+03, 476, 106, 69.1]
...
Event 497 has 4 muons with pt: [743, 666, 366, 3.27]
Event 498 has 7 muons with pt: [694, 243, 38.1, 27.2, 17.1, 13.8, 3.72]
Event 499 has 5 muons with pt: [1.04e+03, 944, 18.8, 15.8, 4.04]
4.040080160320641 averge muon number per event
```

W_R 5000 , N 2500

Number of muon inside top jets



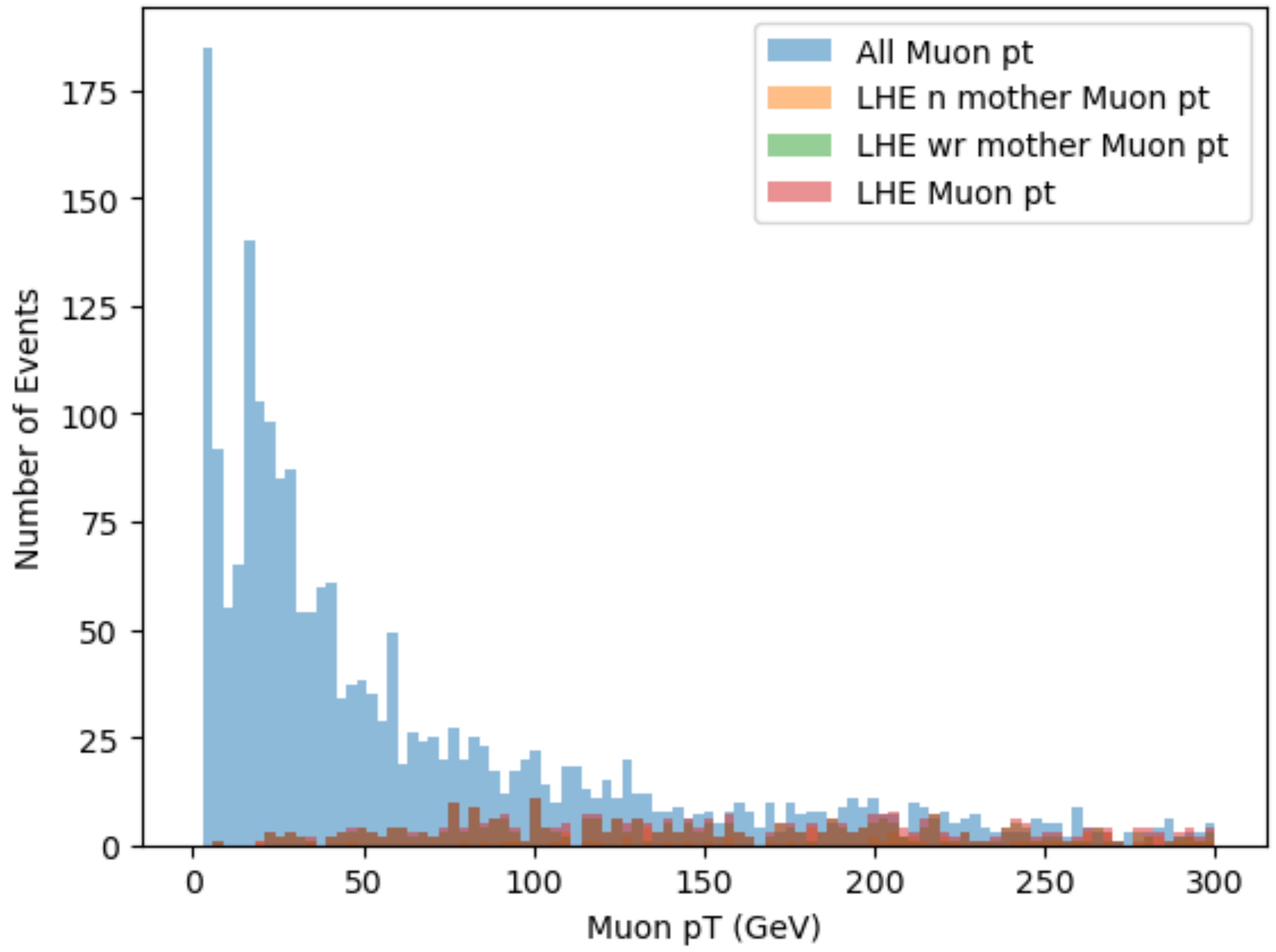
W_R 5000 , N 4900



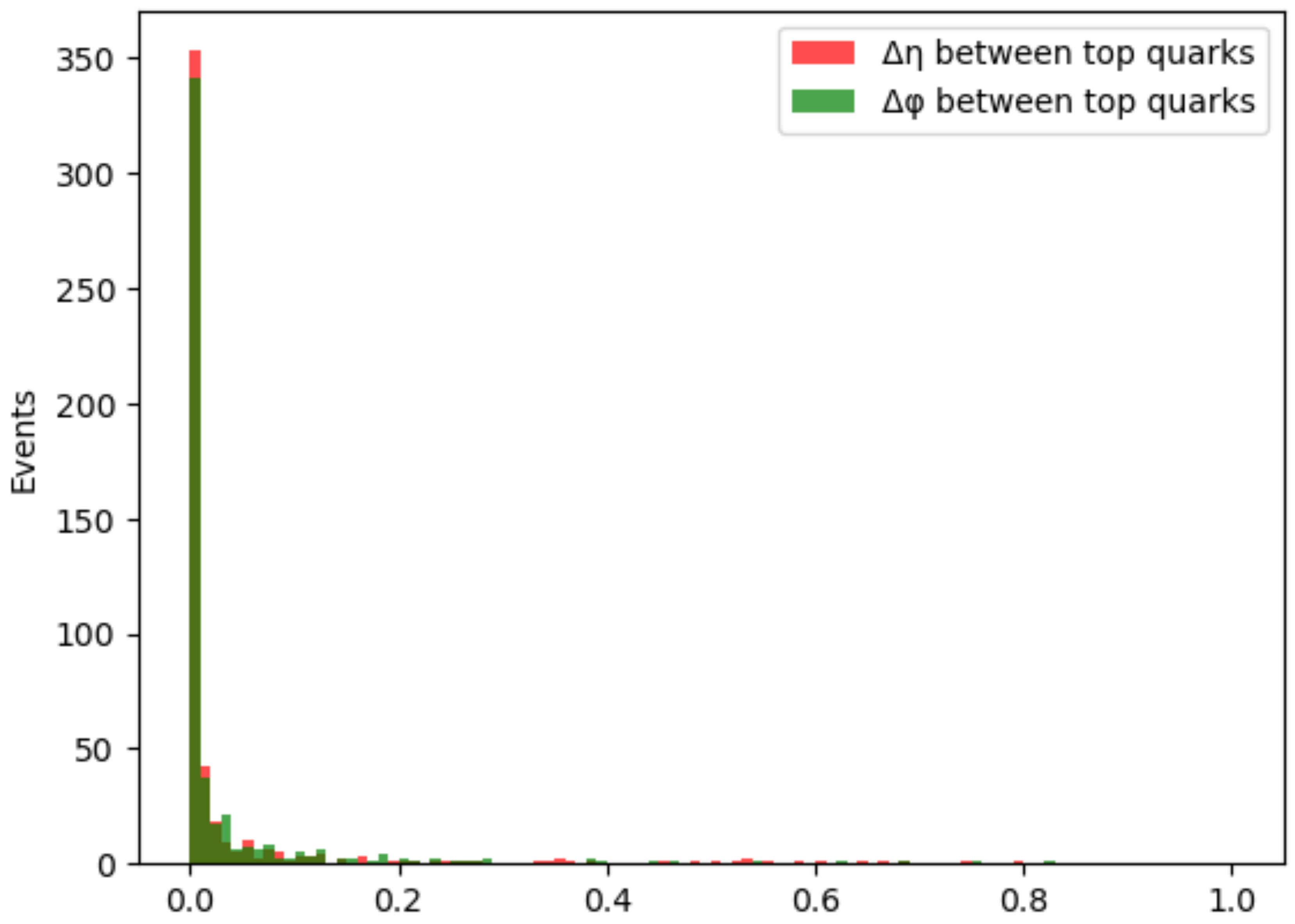
W_R 5000 , N 2500

Gets inside ~ 10%

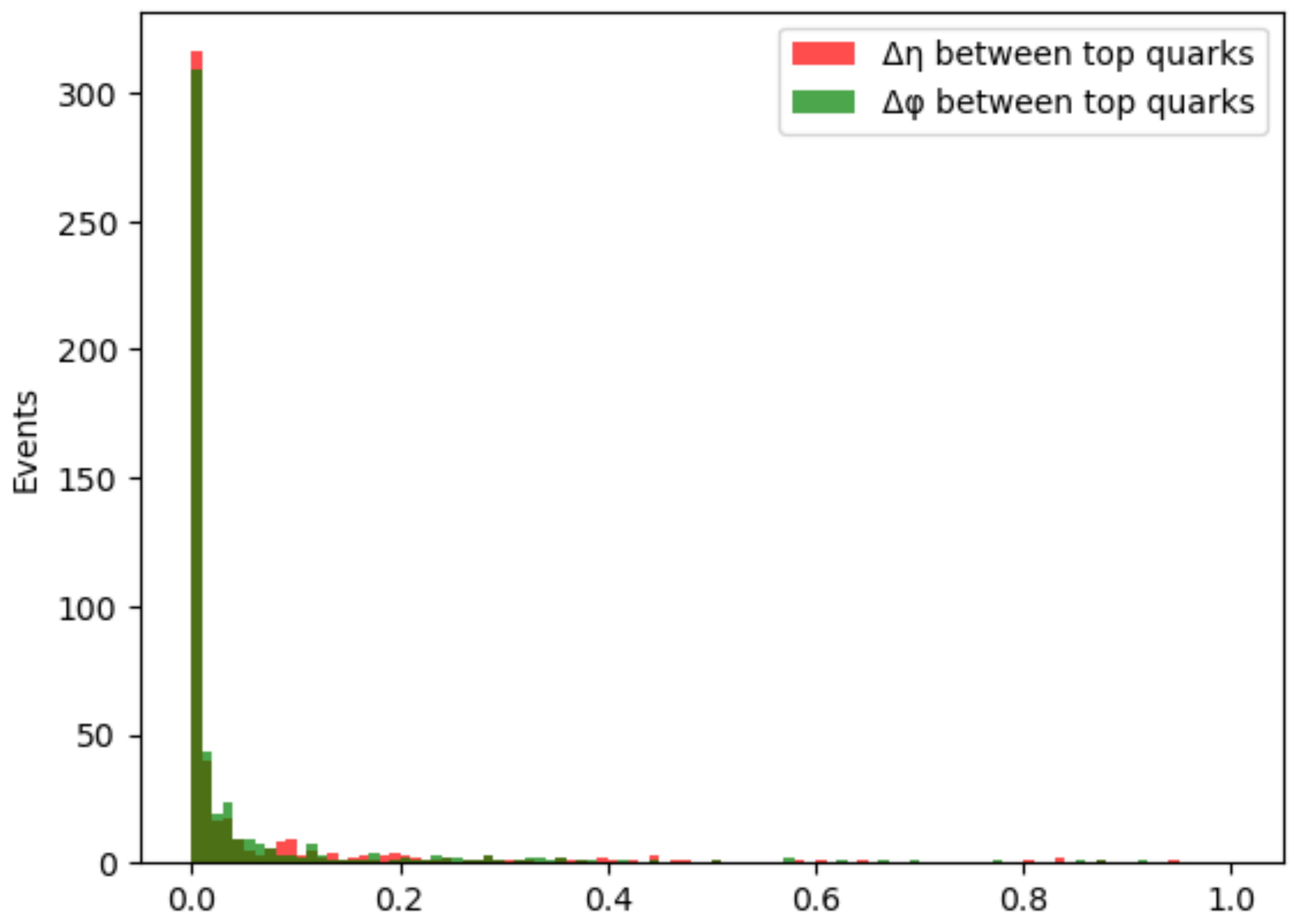
Muon p_t distribution with signal & bkg



Hard process & From Hard process top quark ΔR

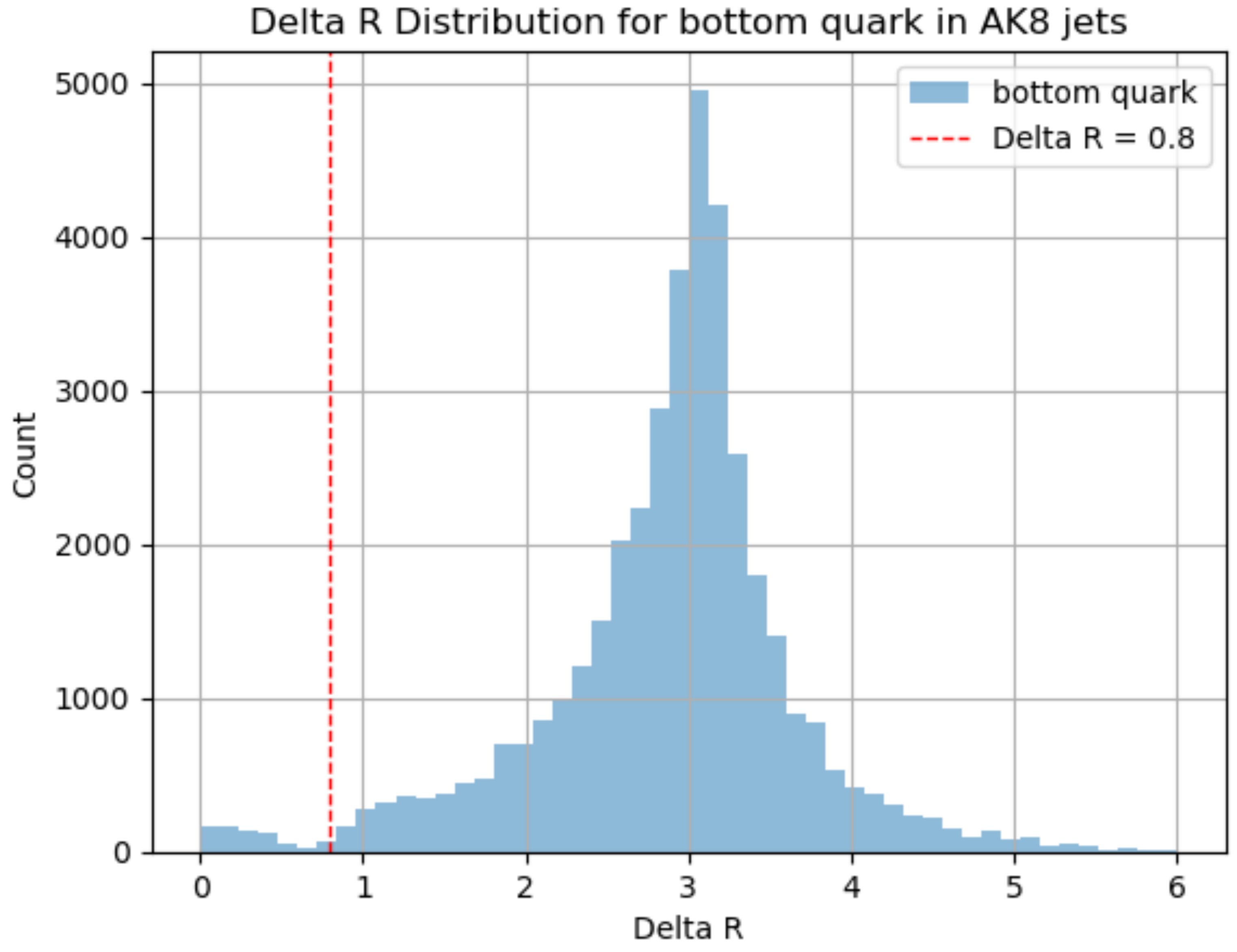


For W_R5000 $N2500$



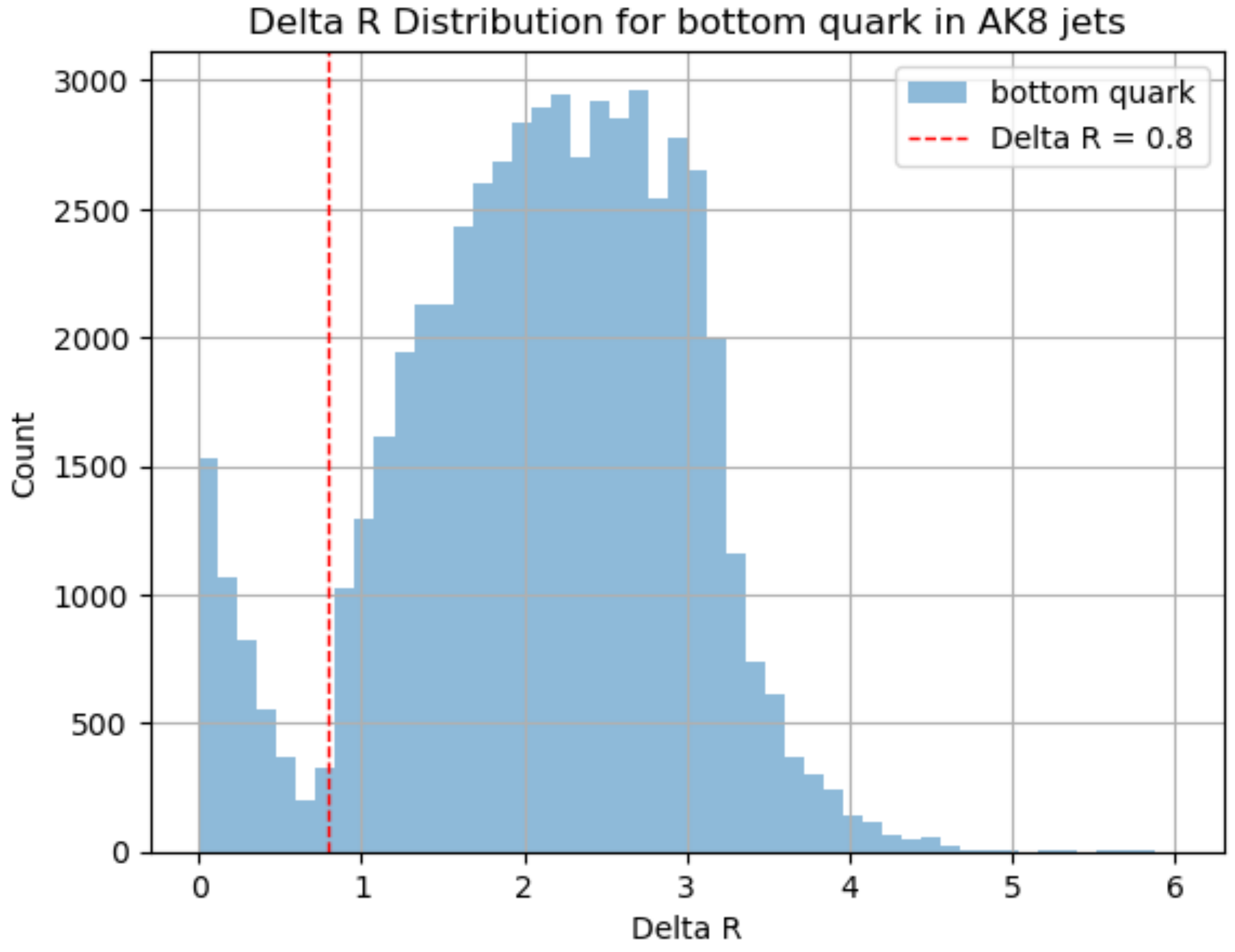
For W_R5000 $N4900$

B quark get outside top jet



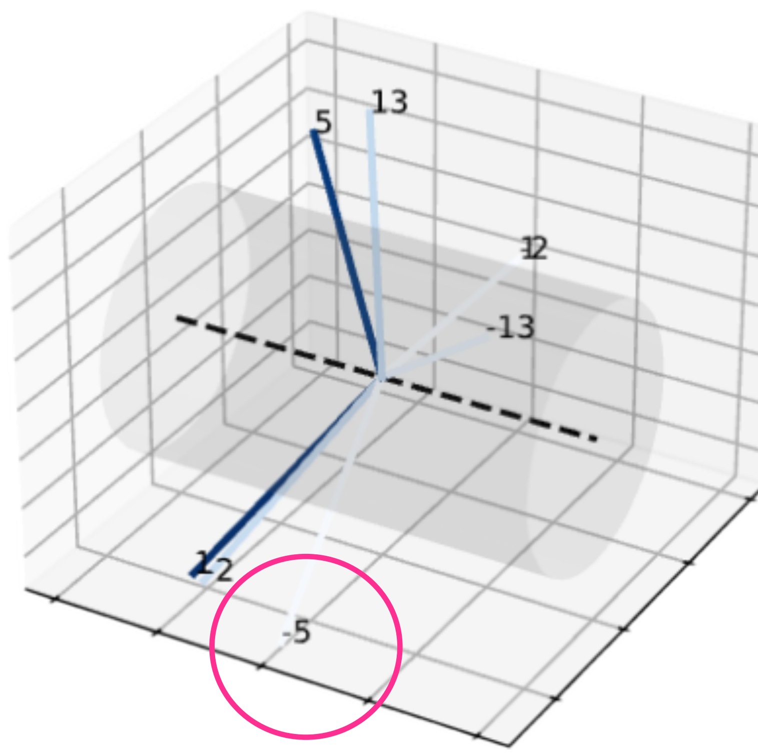
W_R 5000 N 4900

```
Number of WR* mother bottom quarks with Delta R < 0.8:  678
Number of t mother bottom quarks outside of AK8  3303
Total events processed:  39968
```

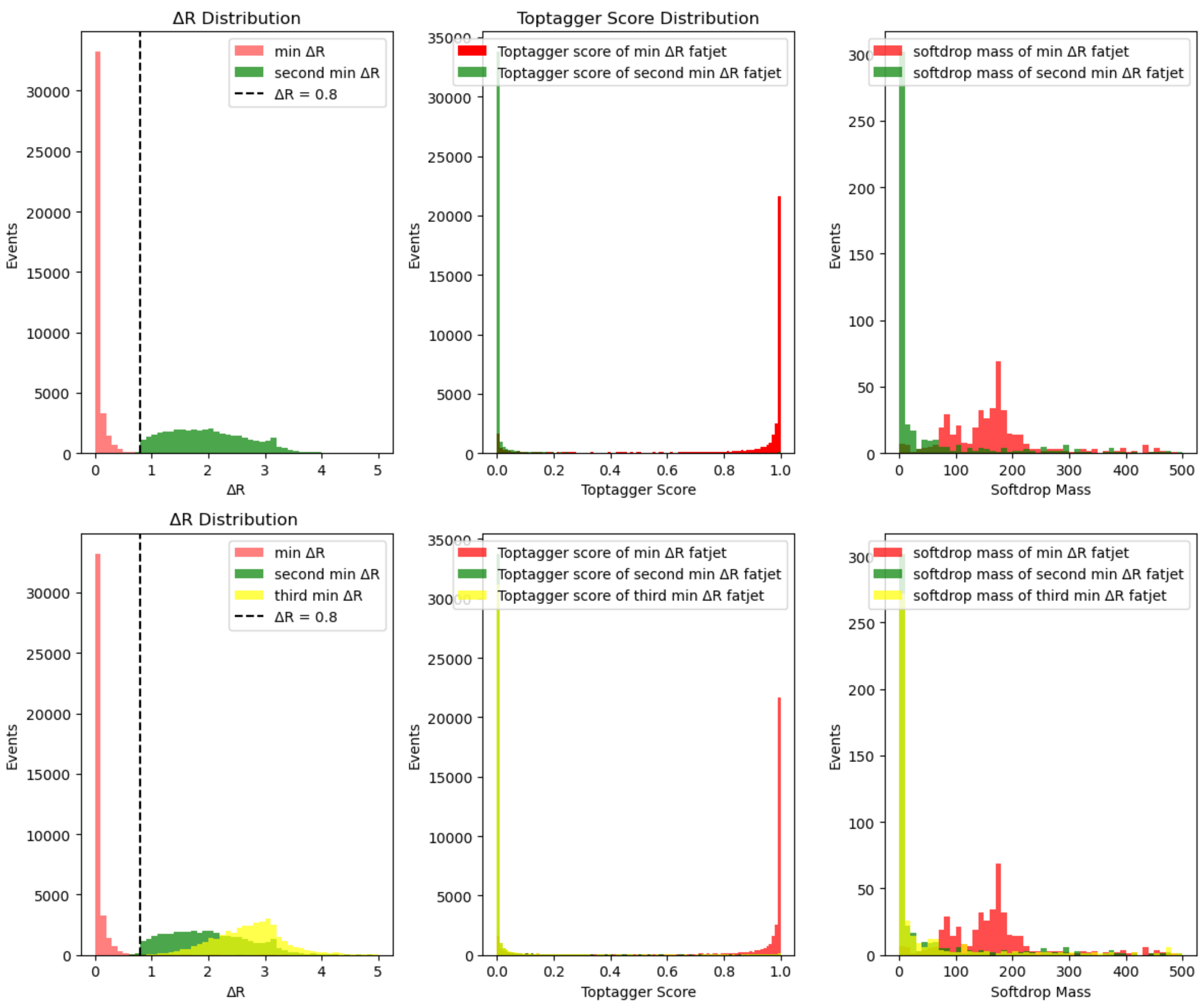


W_R 5000 N 2500

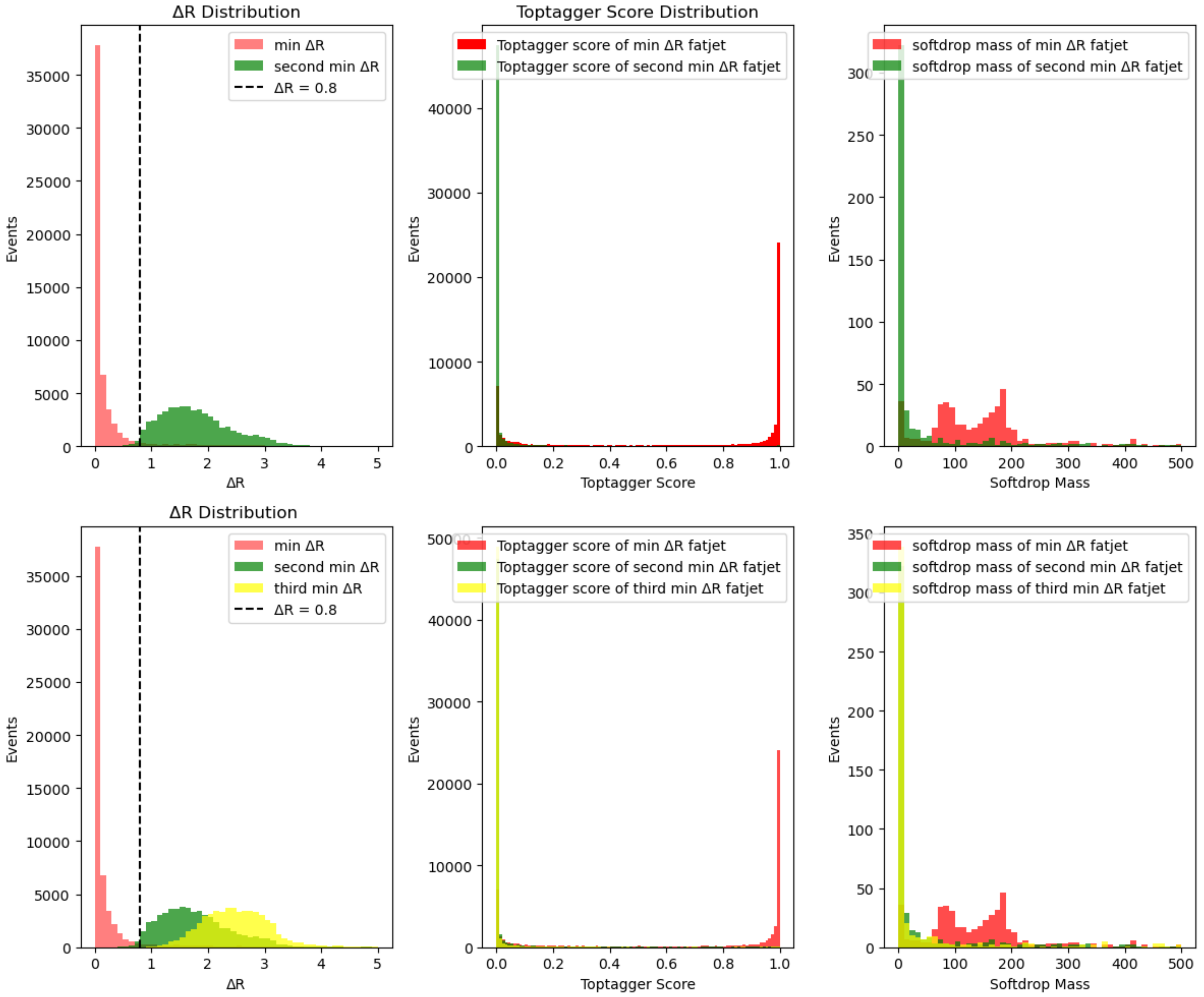
```
Number of WR* mother bottom quarks with Delta R < 0.8:  4710
Number of t mother bottom quarks outside of AK8  12591
Total events processed:  56759
```



Top tagger , ΔR , SDM with ΔR closest



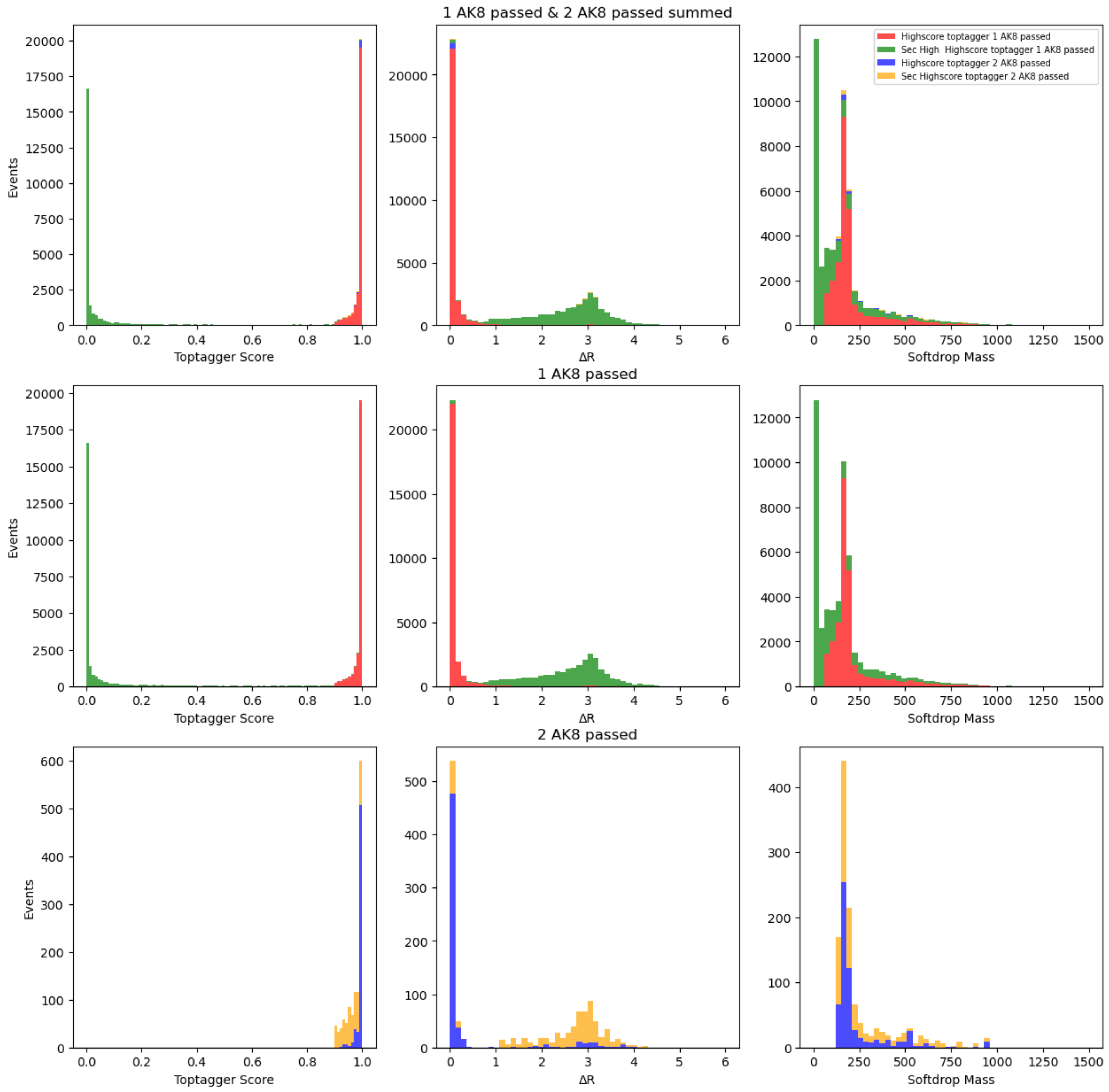
For $W_R 5000\ N4900$



For $W_R 5000\ N2500$

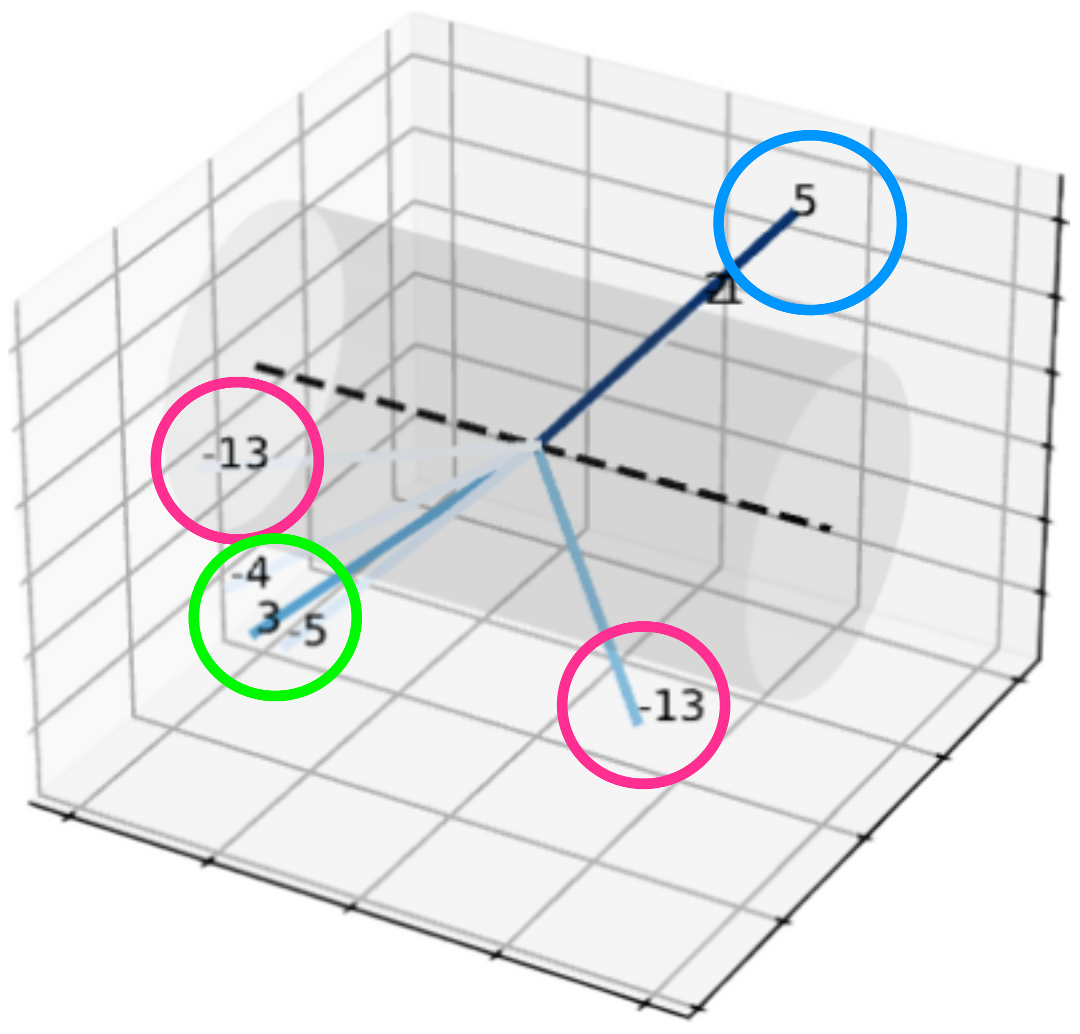
Case of 1 or 2 AK8 passed

For $W_R 5000\ N4900$

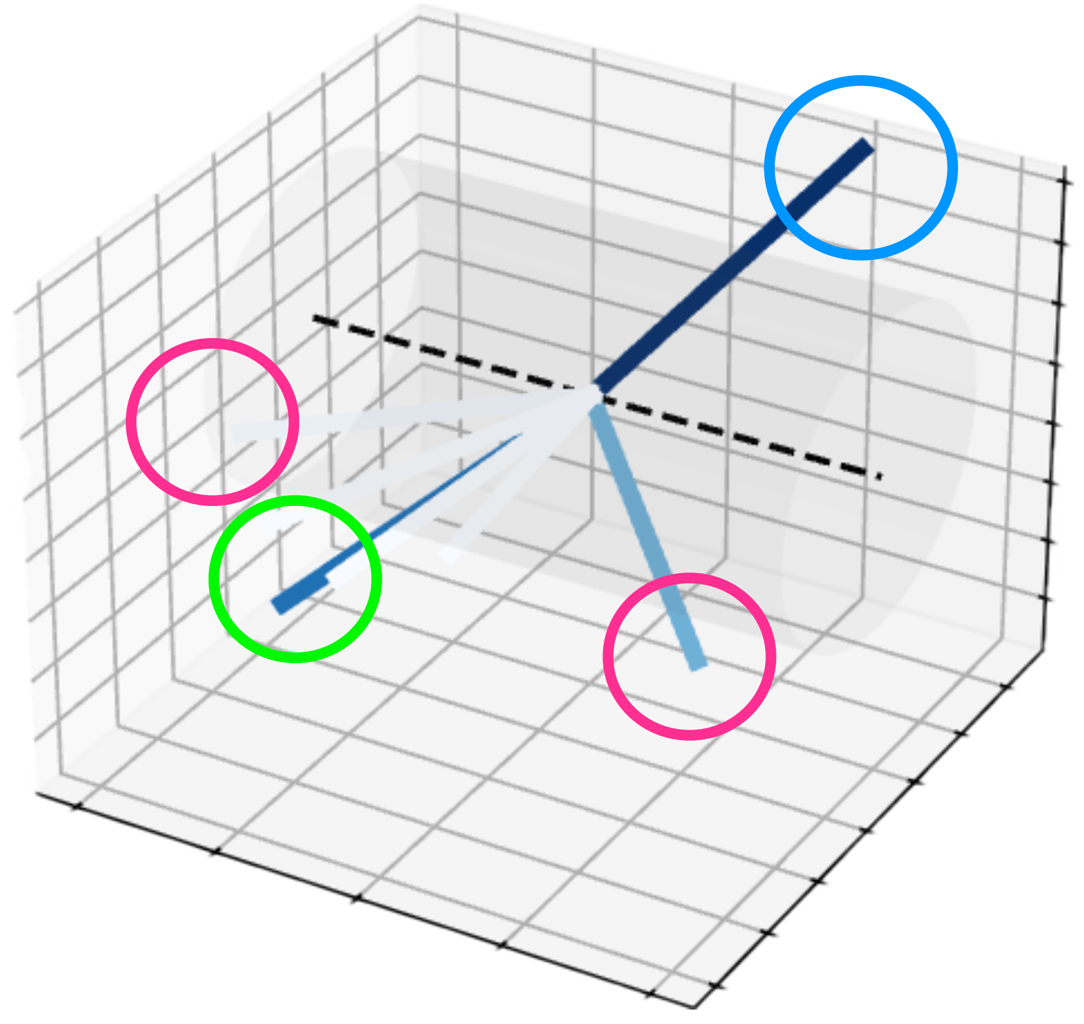


Cleaning Adjusting

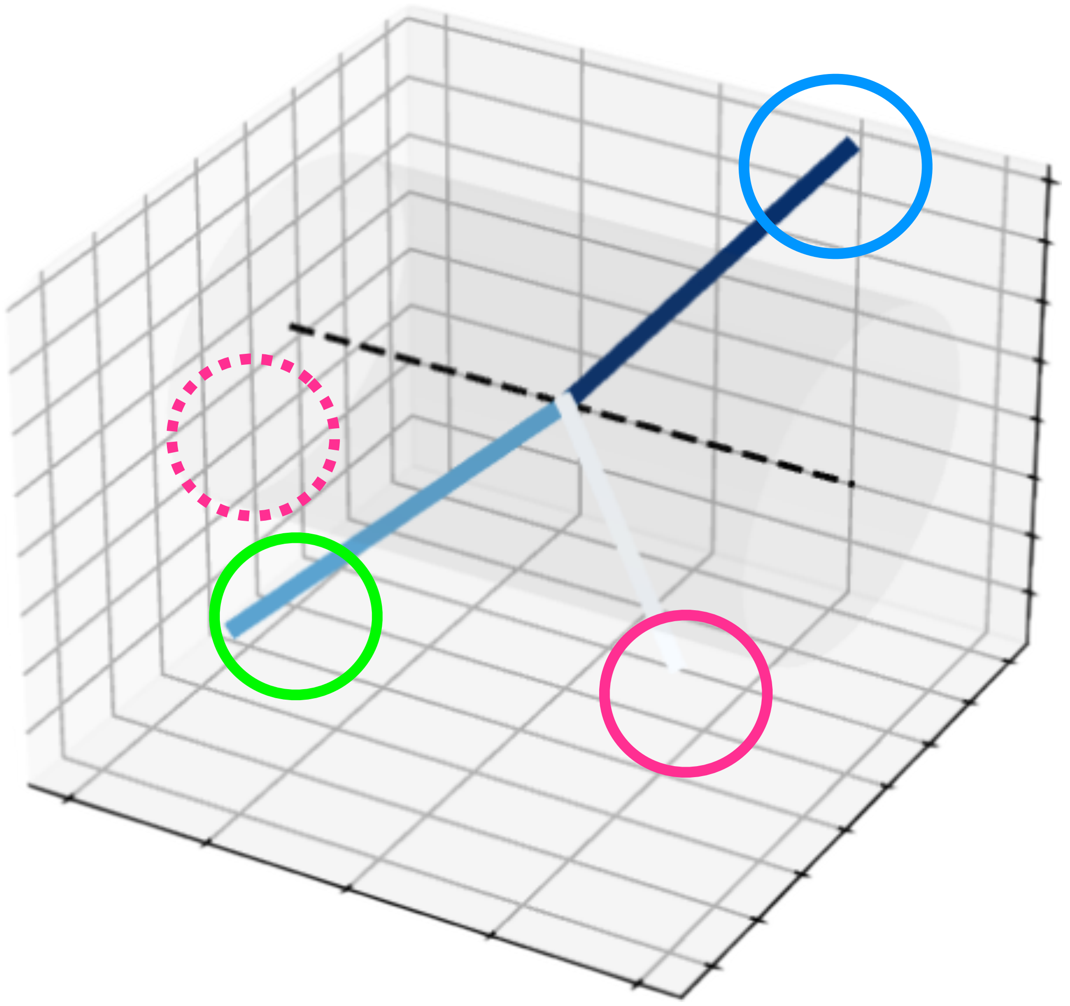
Strategy 1 for cleaning



LHE particle



AK4 jets

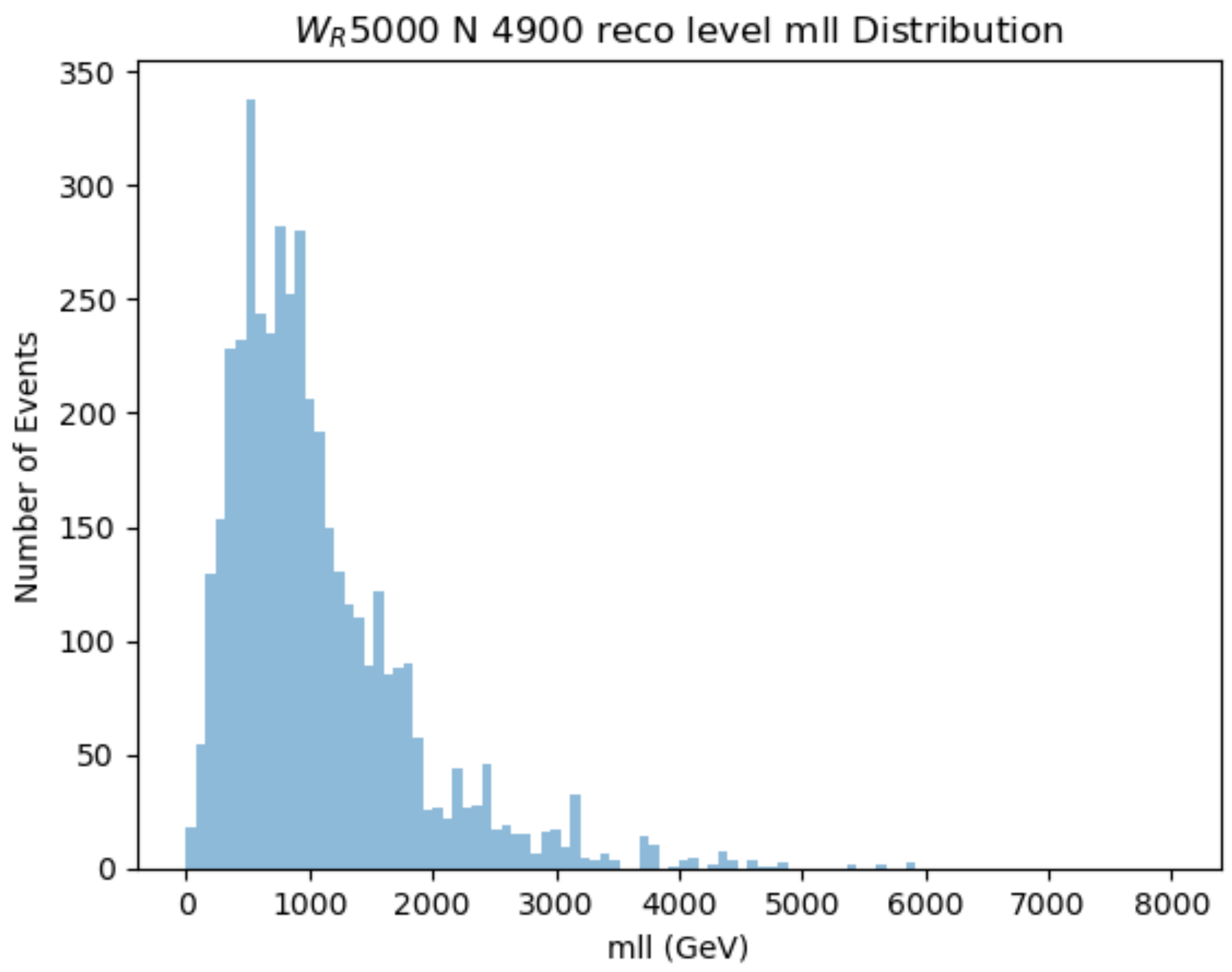


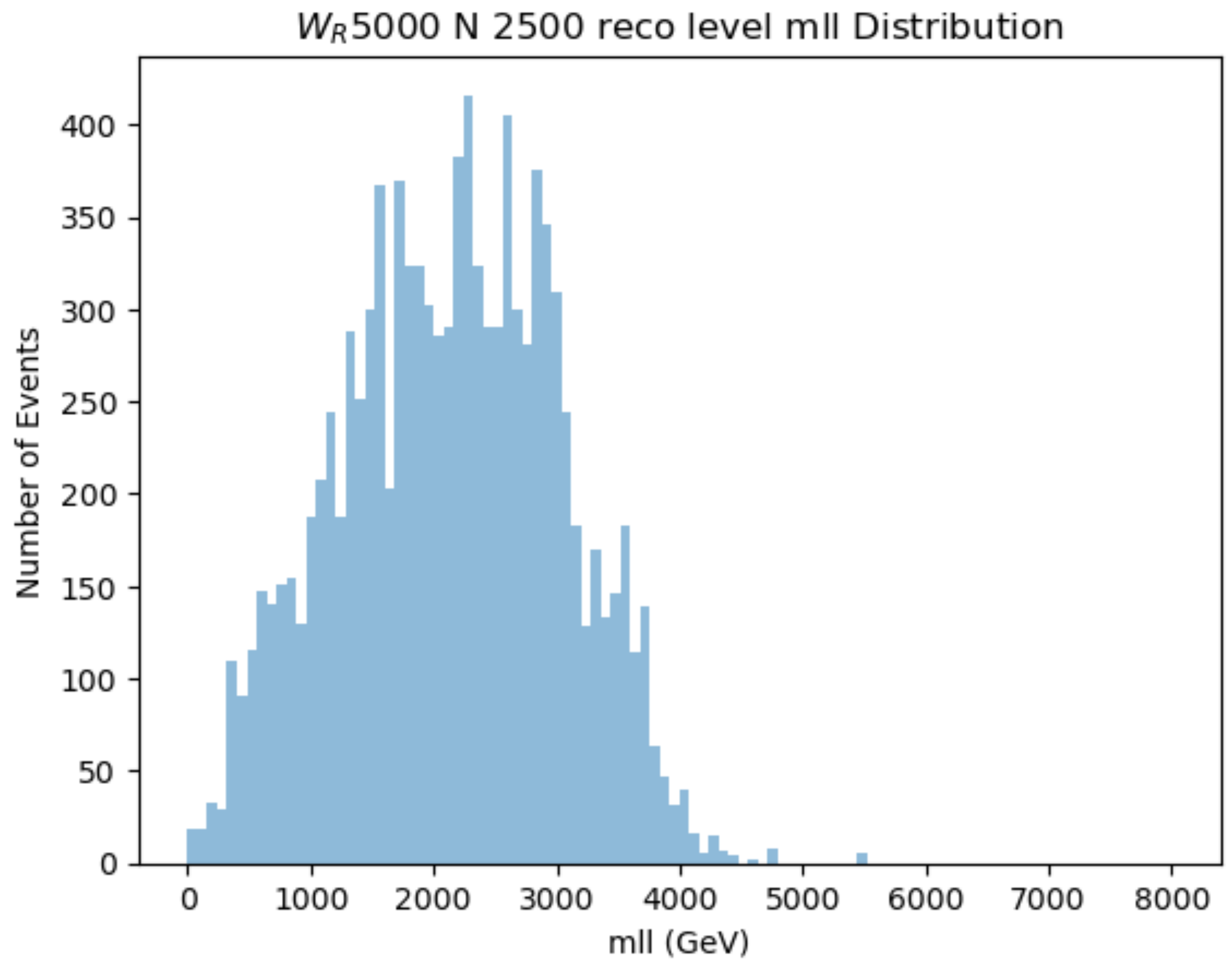
AK8 jets

1. 2 leading lepton
2. AK8 with top tagged
3. AK4 with leading p_t

M(ll) distribution

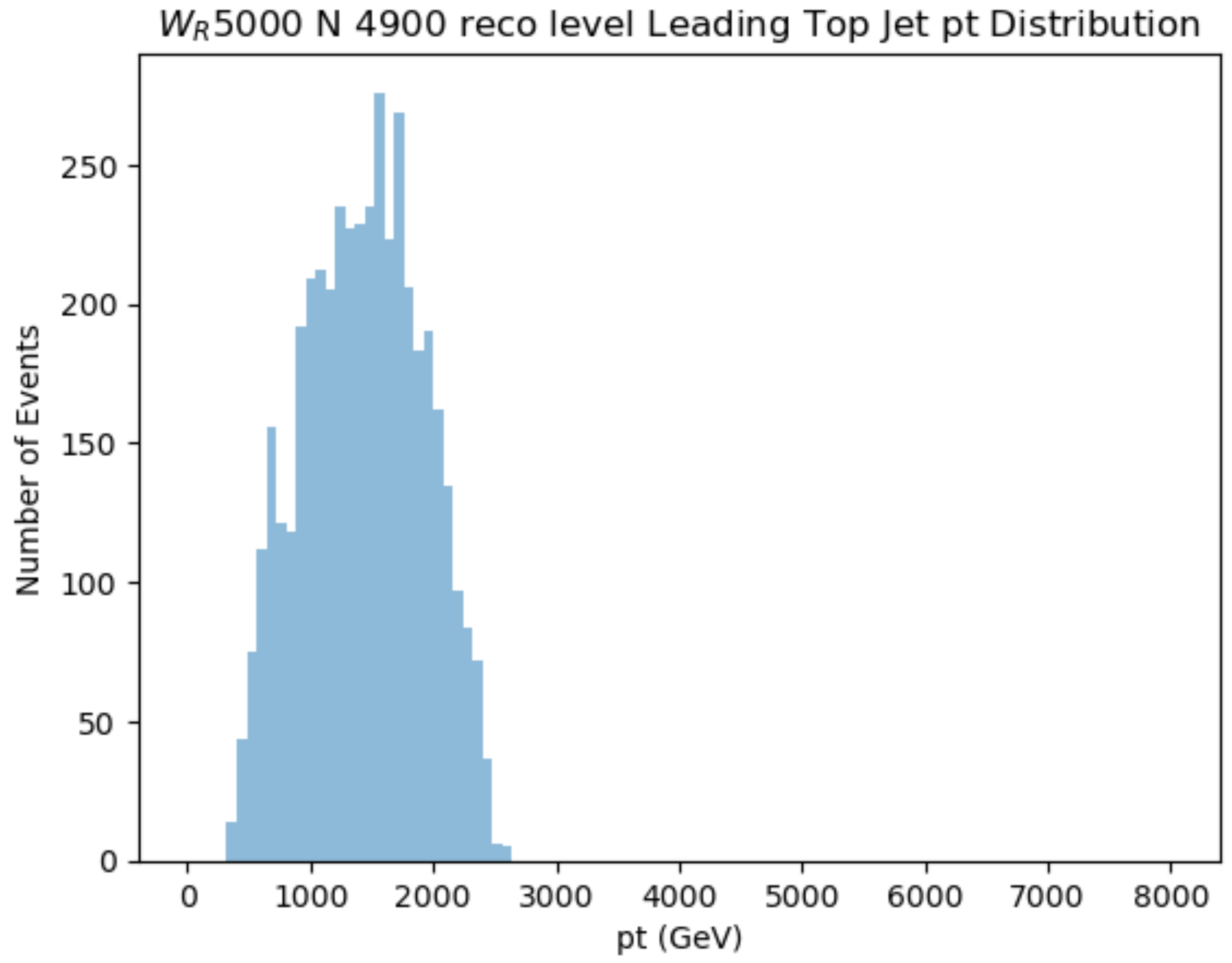
2 leptons & 1 AK8 & 1 AK4

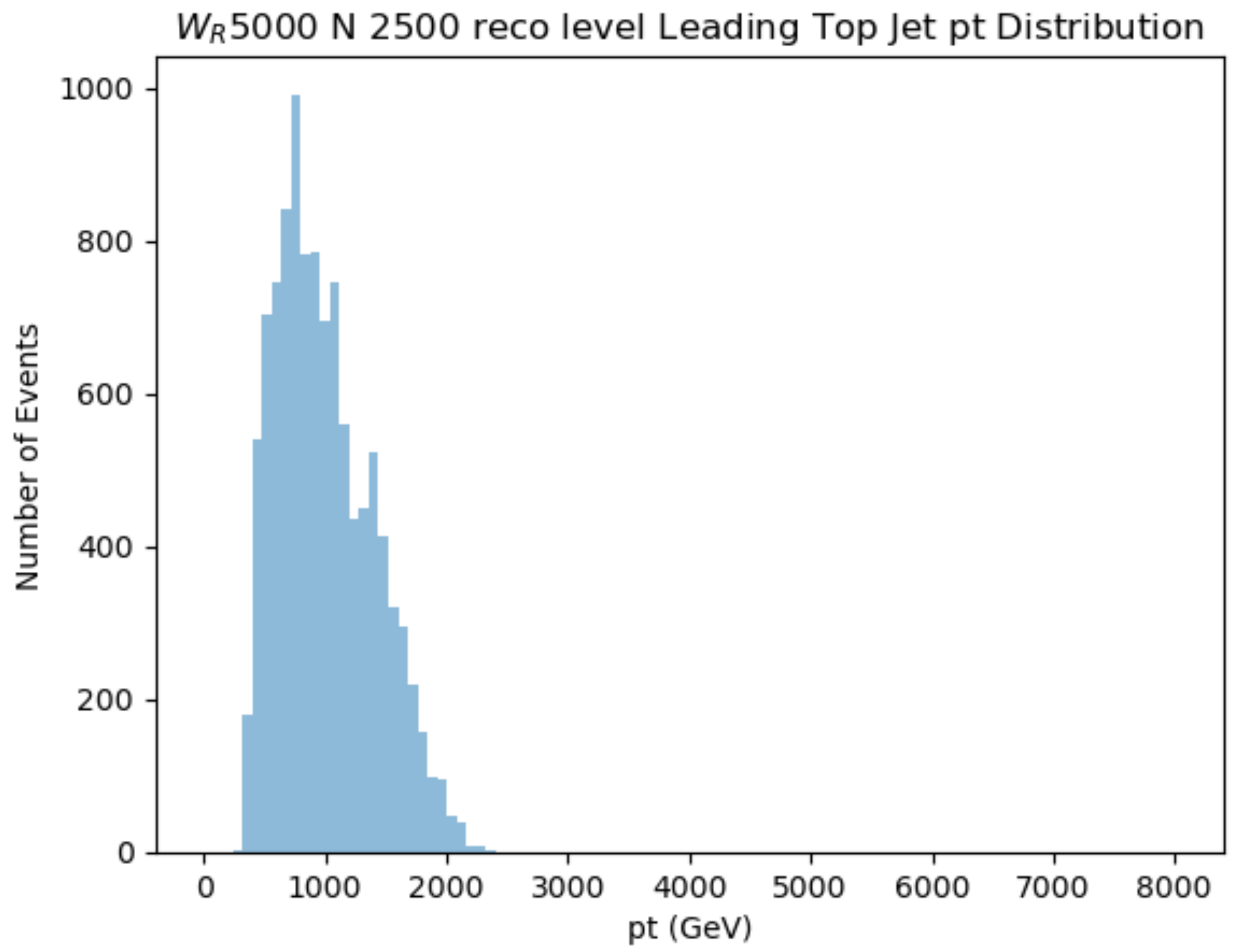


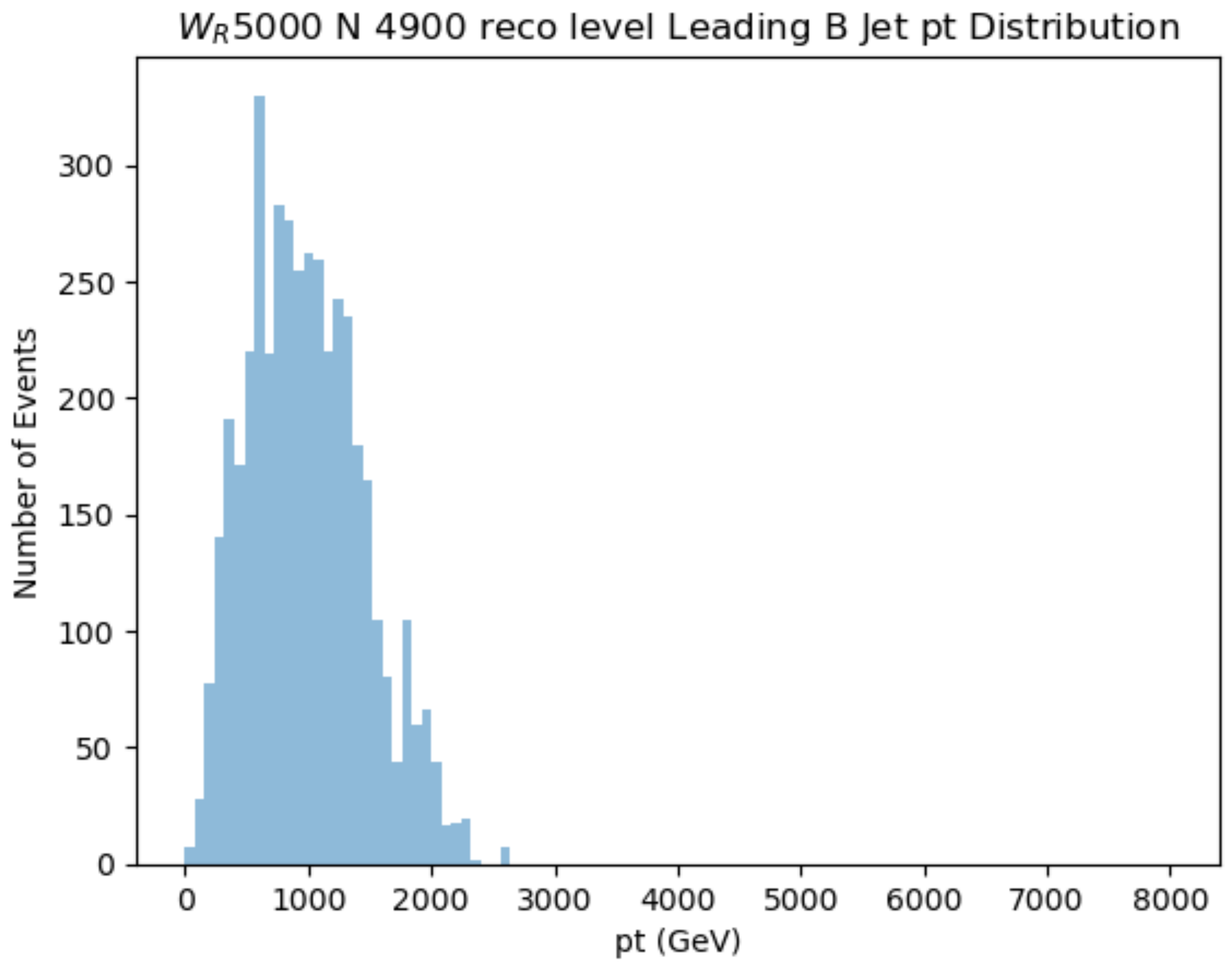


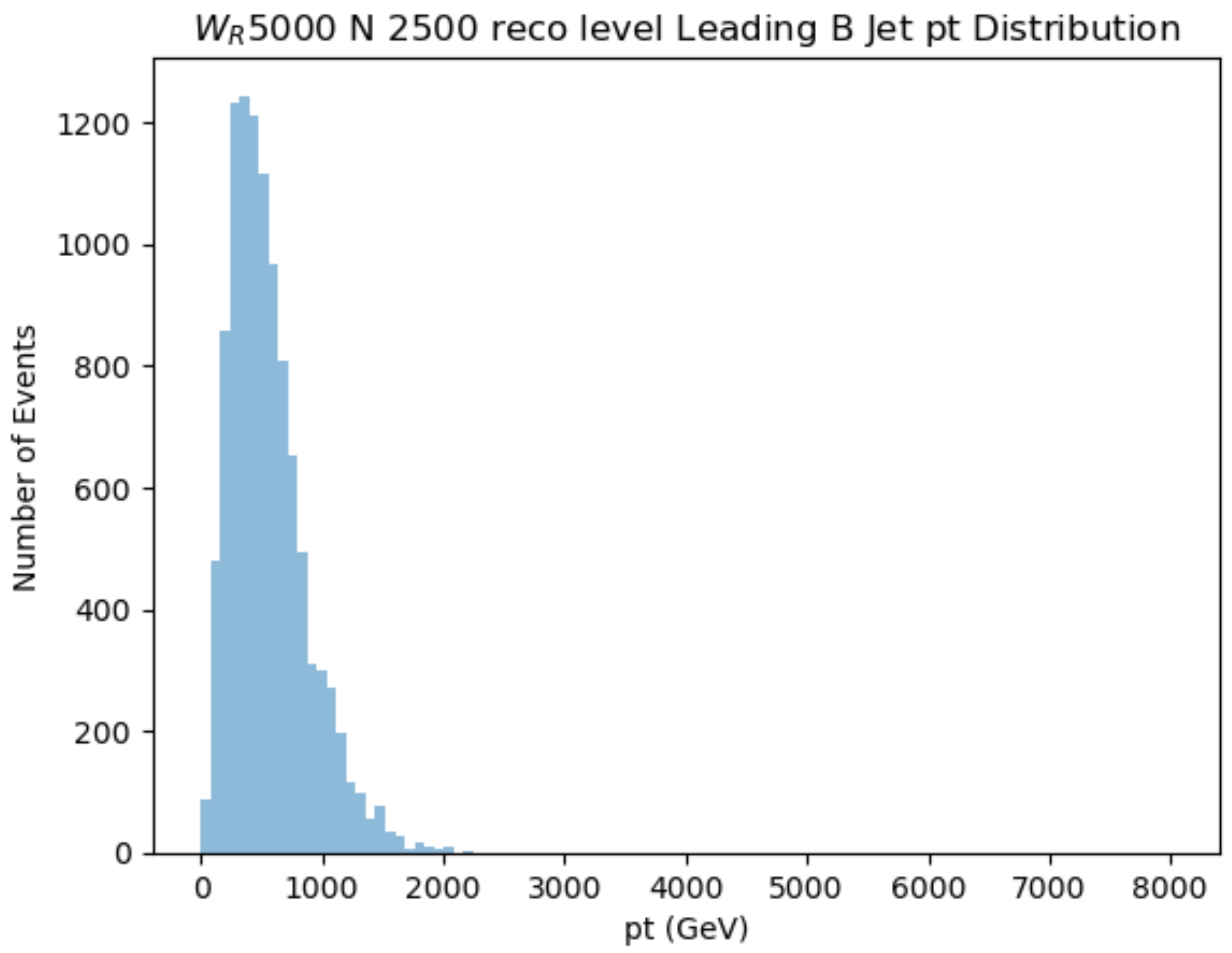
Jet p_t distribution

2 leptons & 1 AK8 & 1 AK4



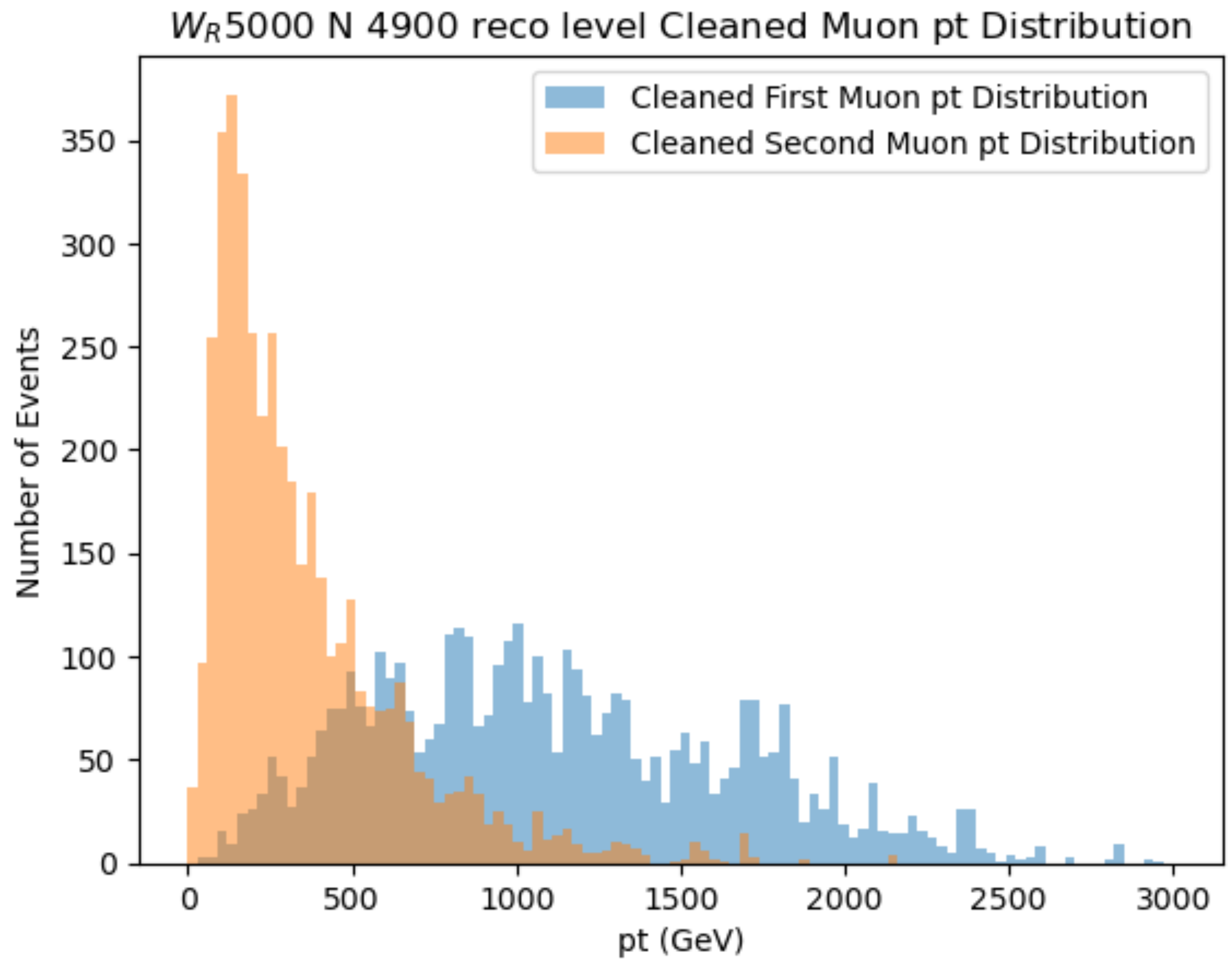


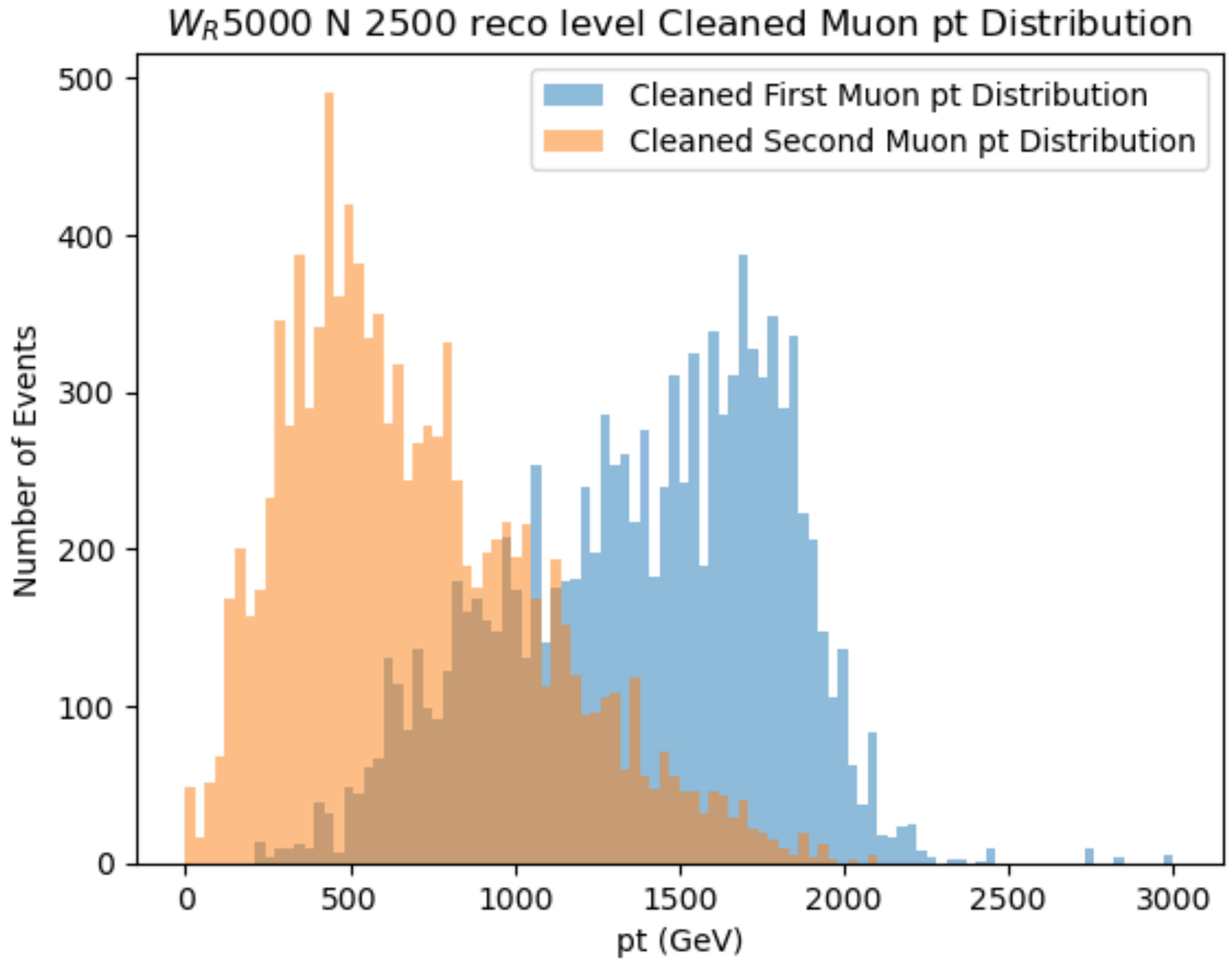




Muon p_t after cleaning

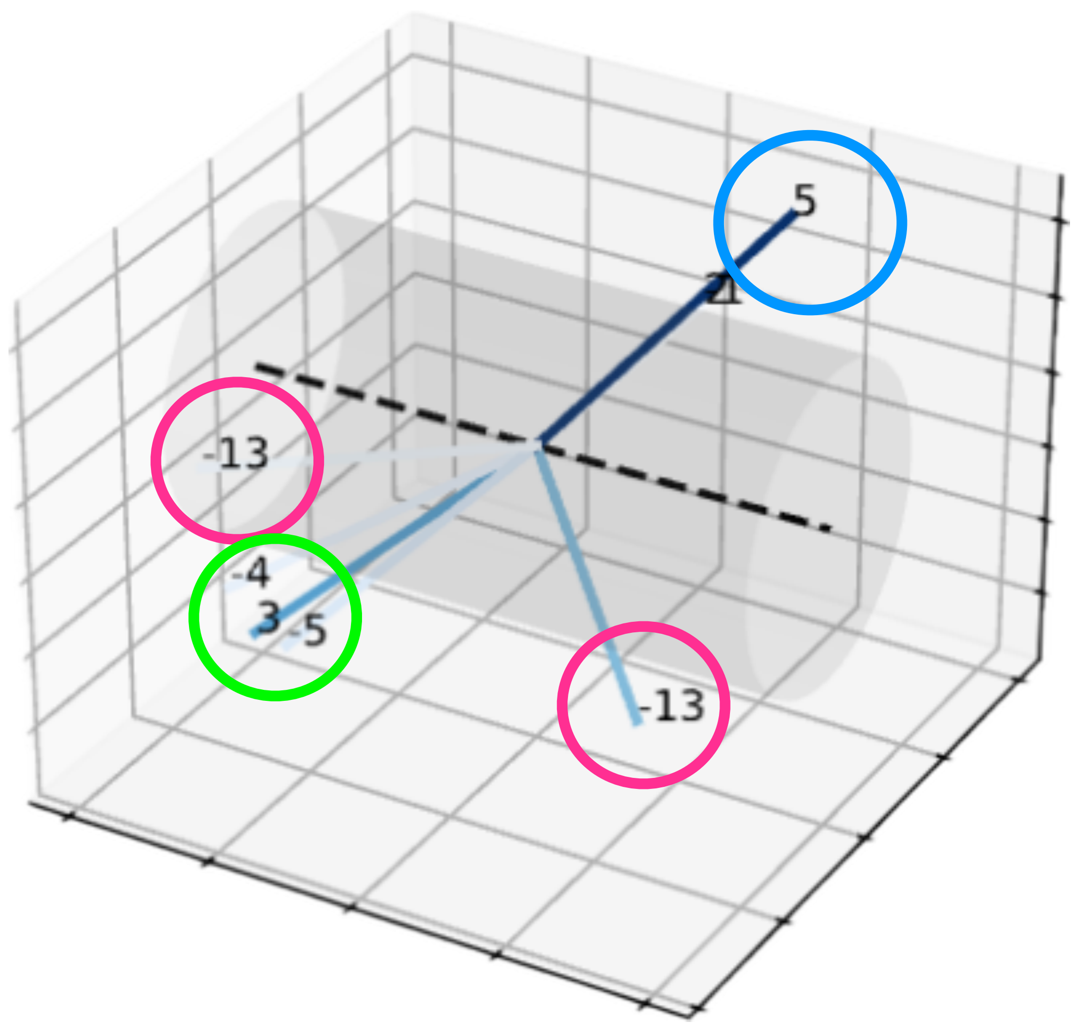
2 leptons & 1 AK8 & 1 AK4



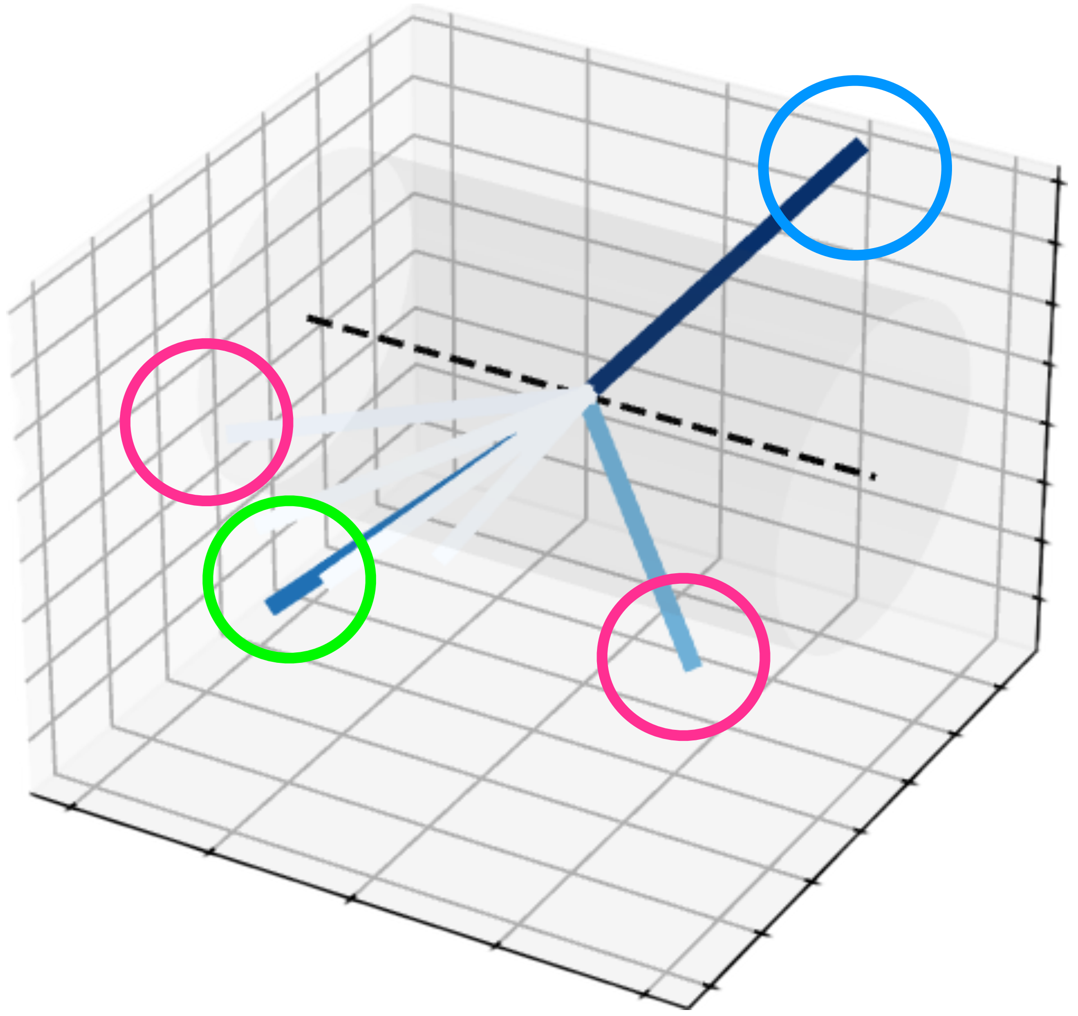


Cleaning Adjusting

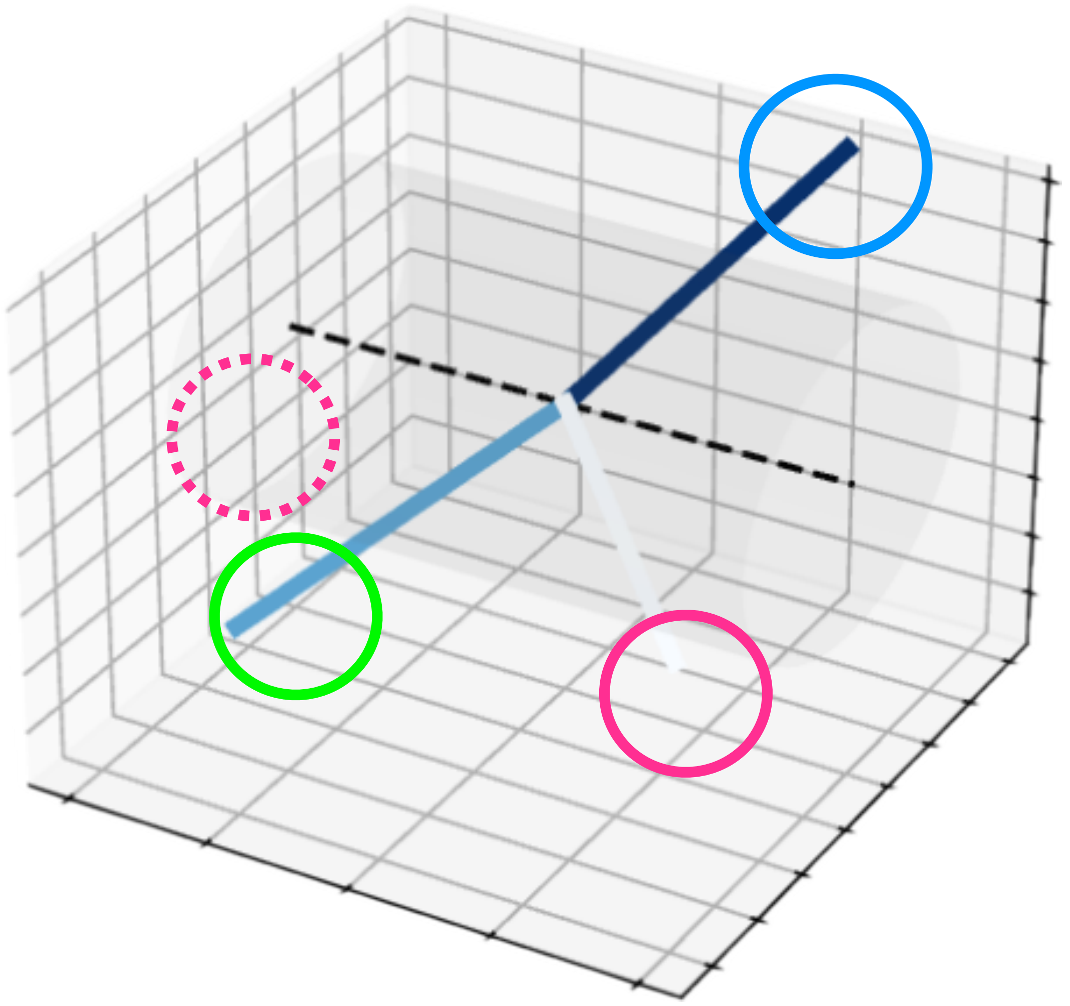
Strategy 2 for cleaning



LHE particle



AK4 jets



AK8 jets

1. 2 leading lepton
2. AK8 with top tagged
3. AK8 with leading p_t

Cleaning Adjusting

Strategy 2 for cleaning

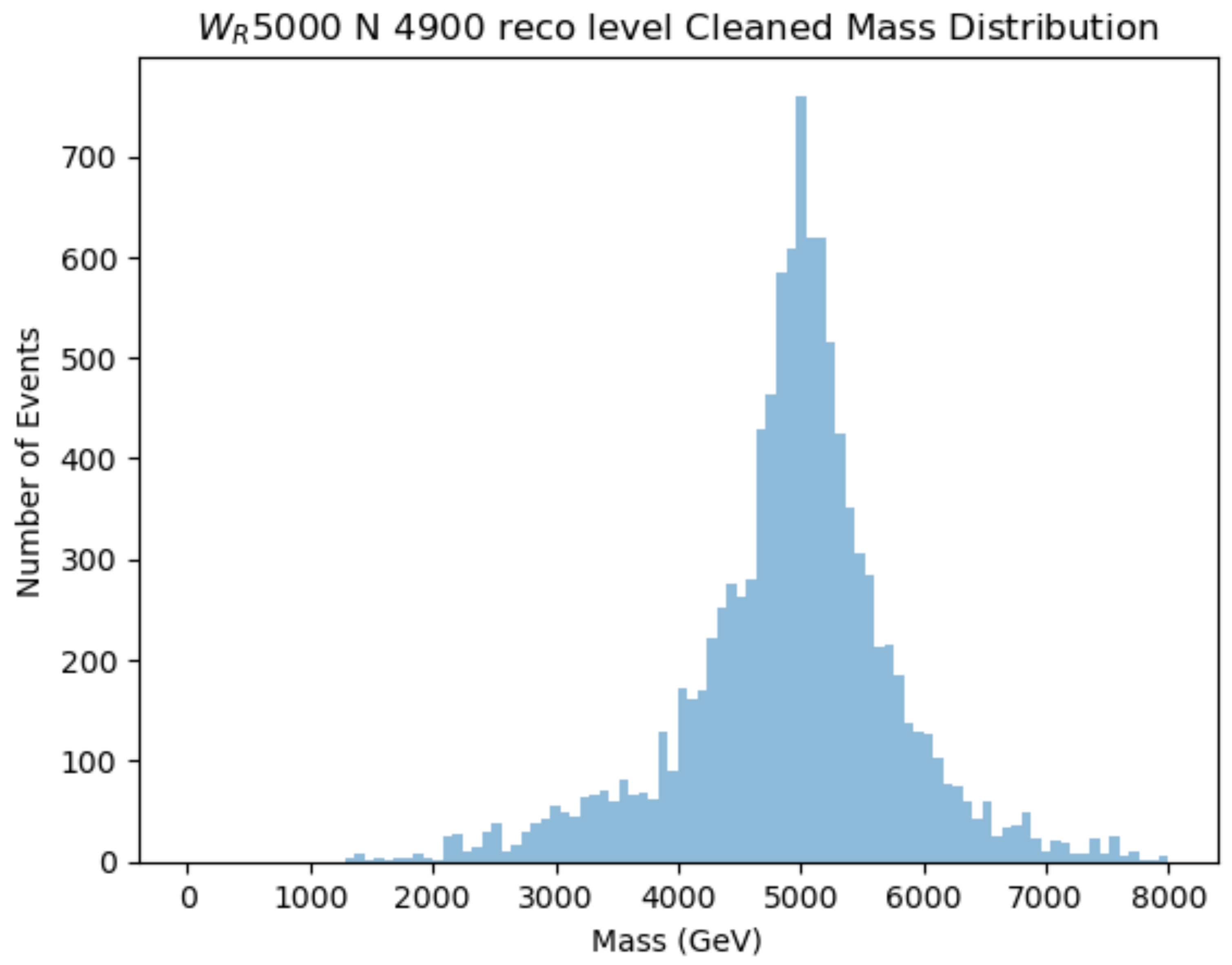
2 leading lepton : no cut
(no overlap with 2 leptons each)

↓

AK8 with top tagged : top tagging score > 0.9
120 <soft drop mass < 250
[FatJet_particleNetWithMass_TvsQCD]
[FatJet_msoftdrop]
(no overlap with 2 leptons , AK8)

↓

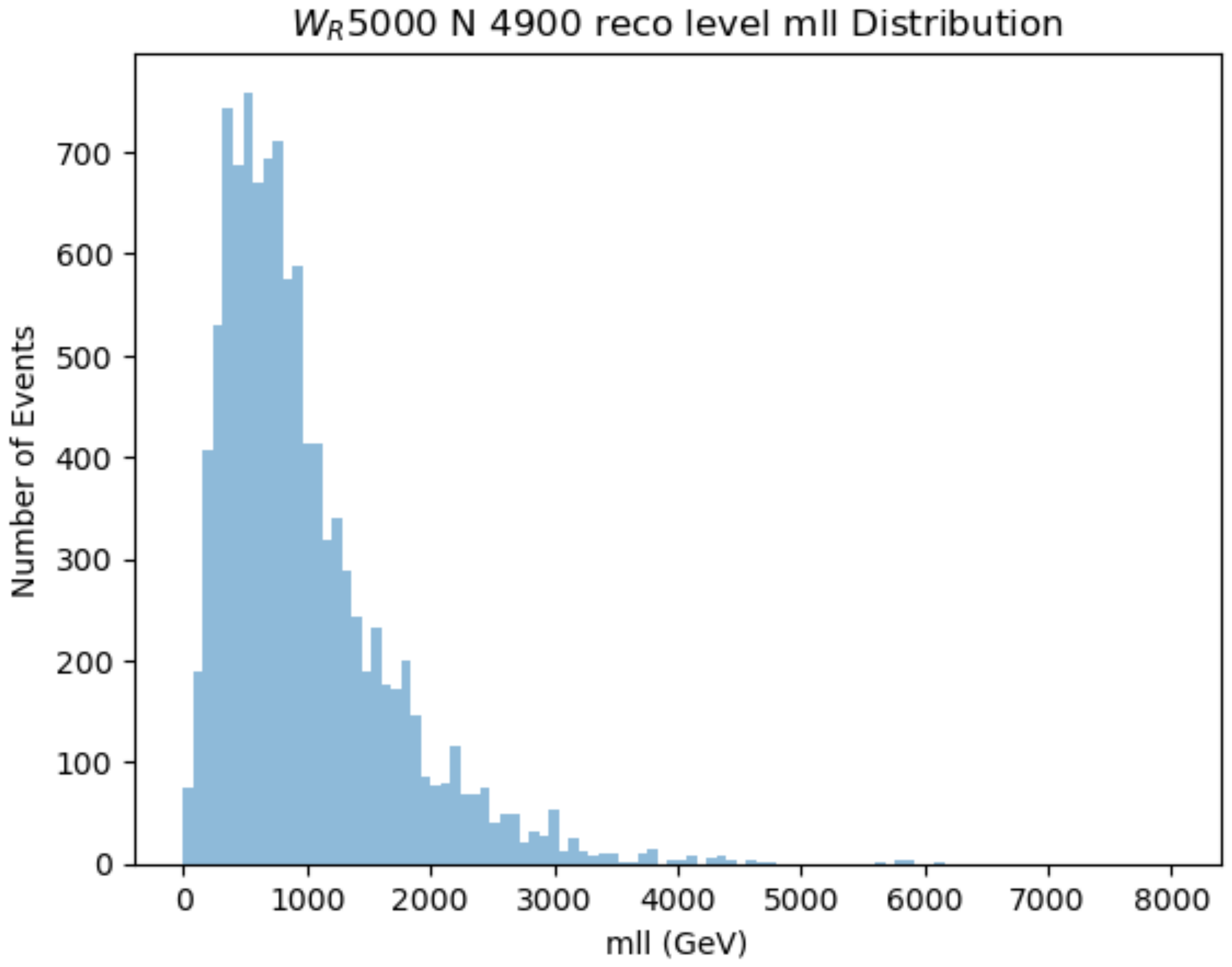
AK8 with leading p_t : top tagging score < 0.9
(no overlap with 2 leptons , top tagged AK8 , AK8)

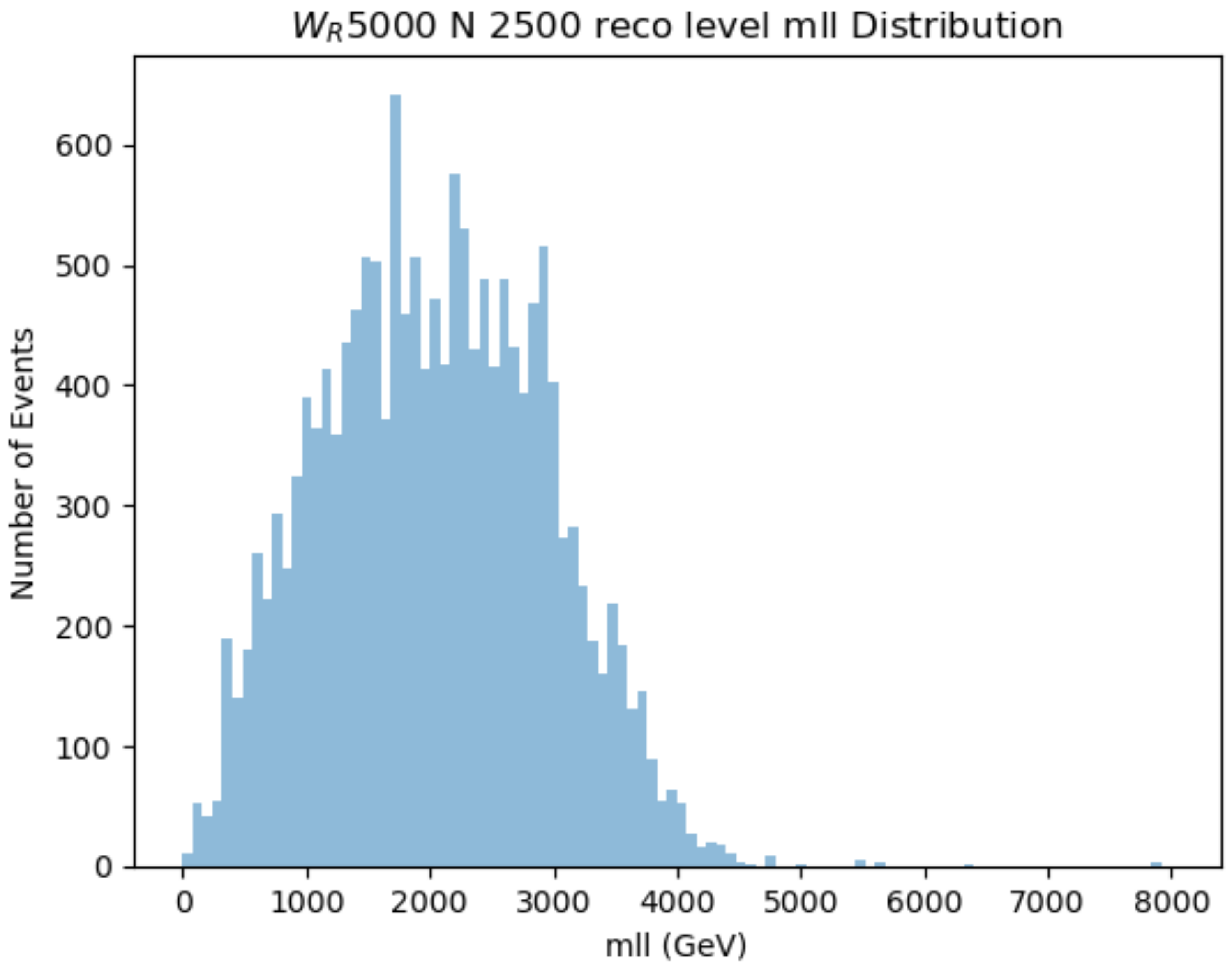


* 40,000 events , 26.9% efficiency

M(ll) distribution

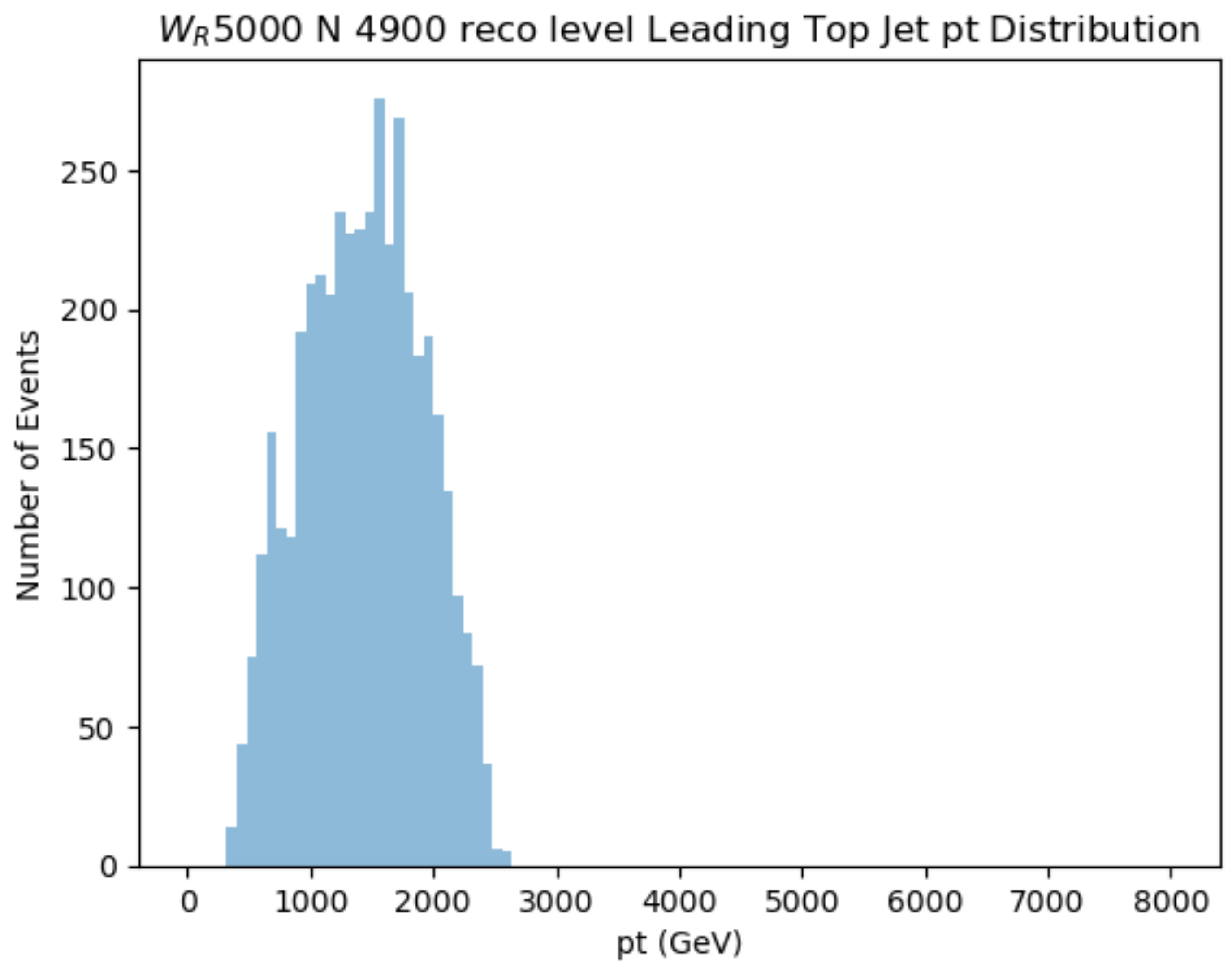
2 leptons & 2 AK8

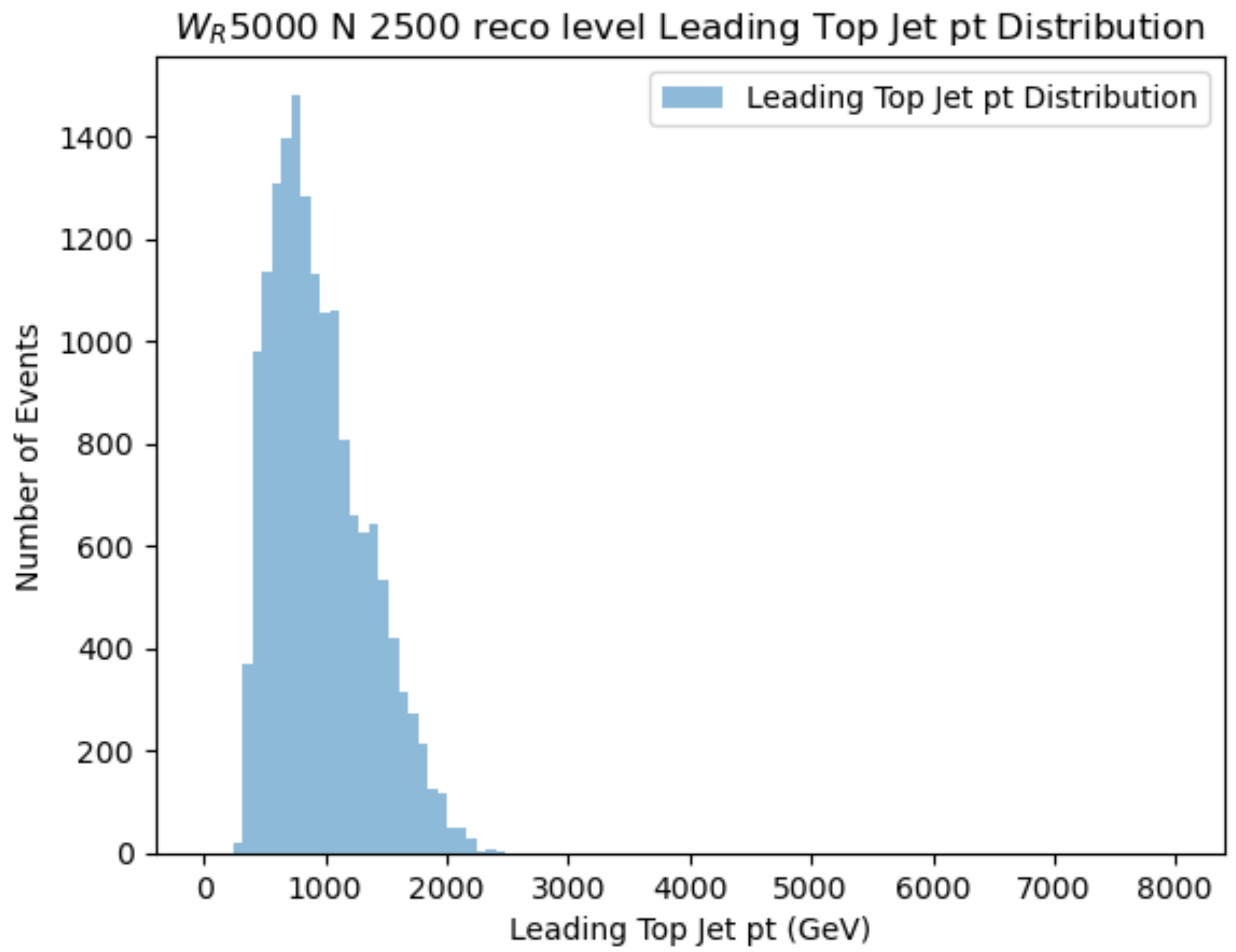


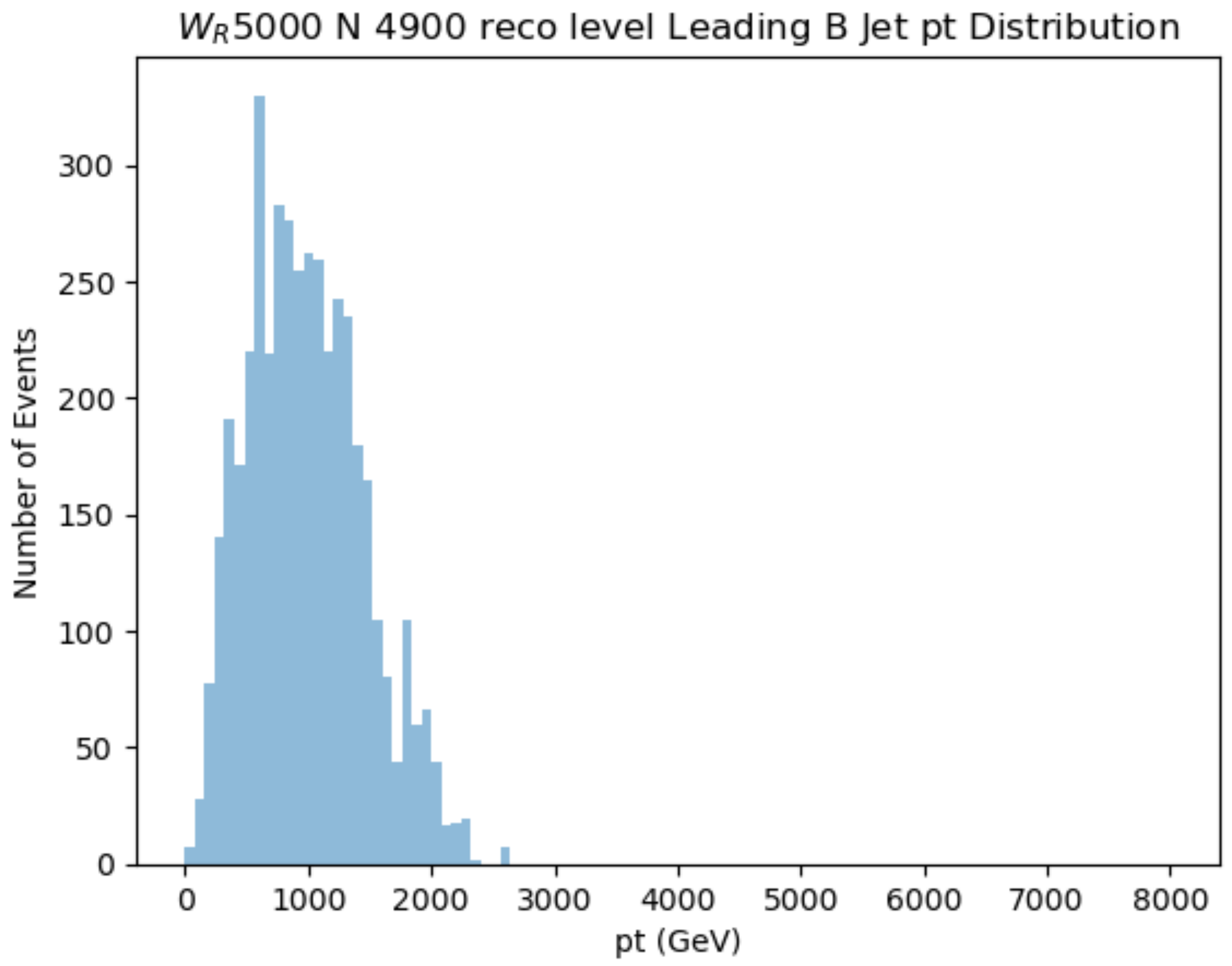


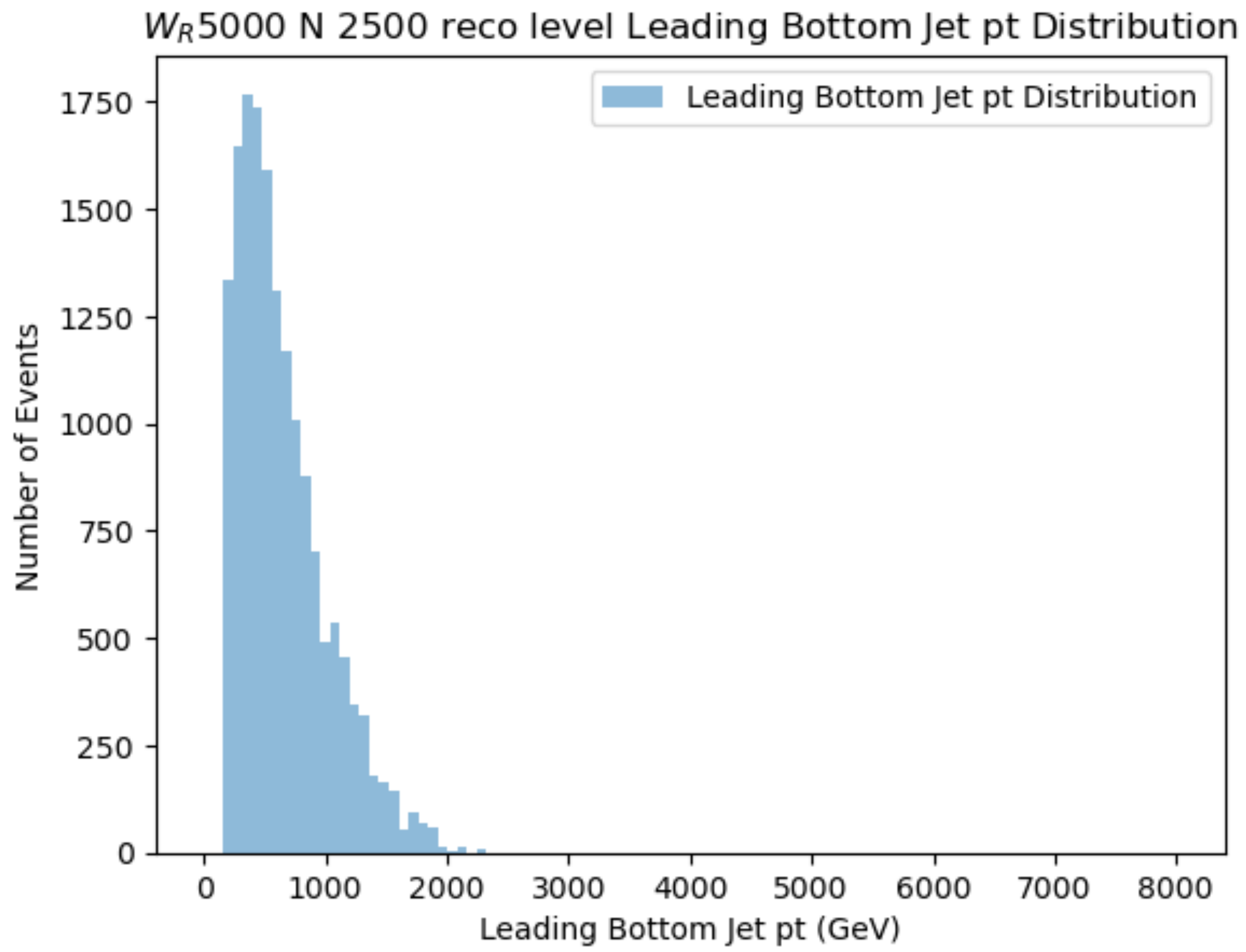
Jet p_t distribution

2 leptons & 2 AK8





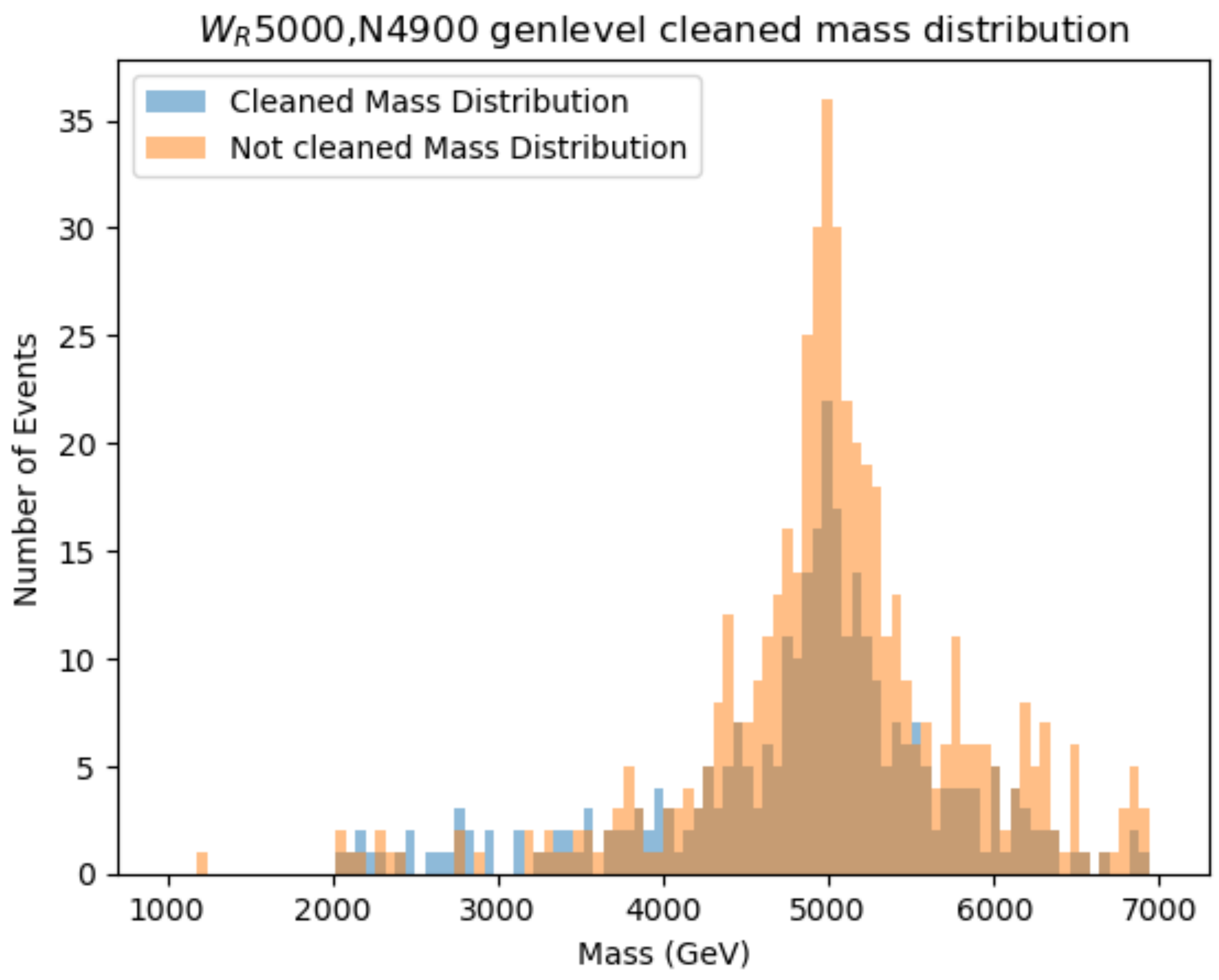




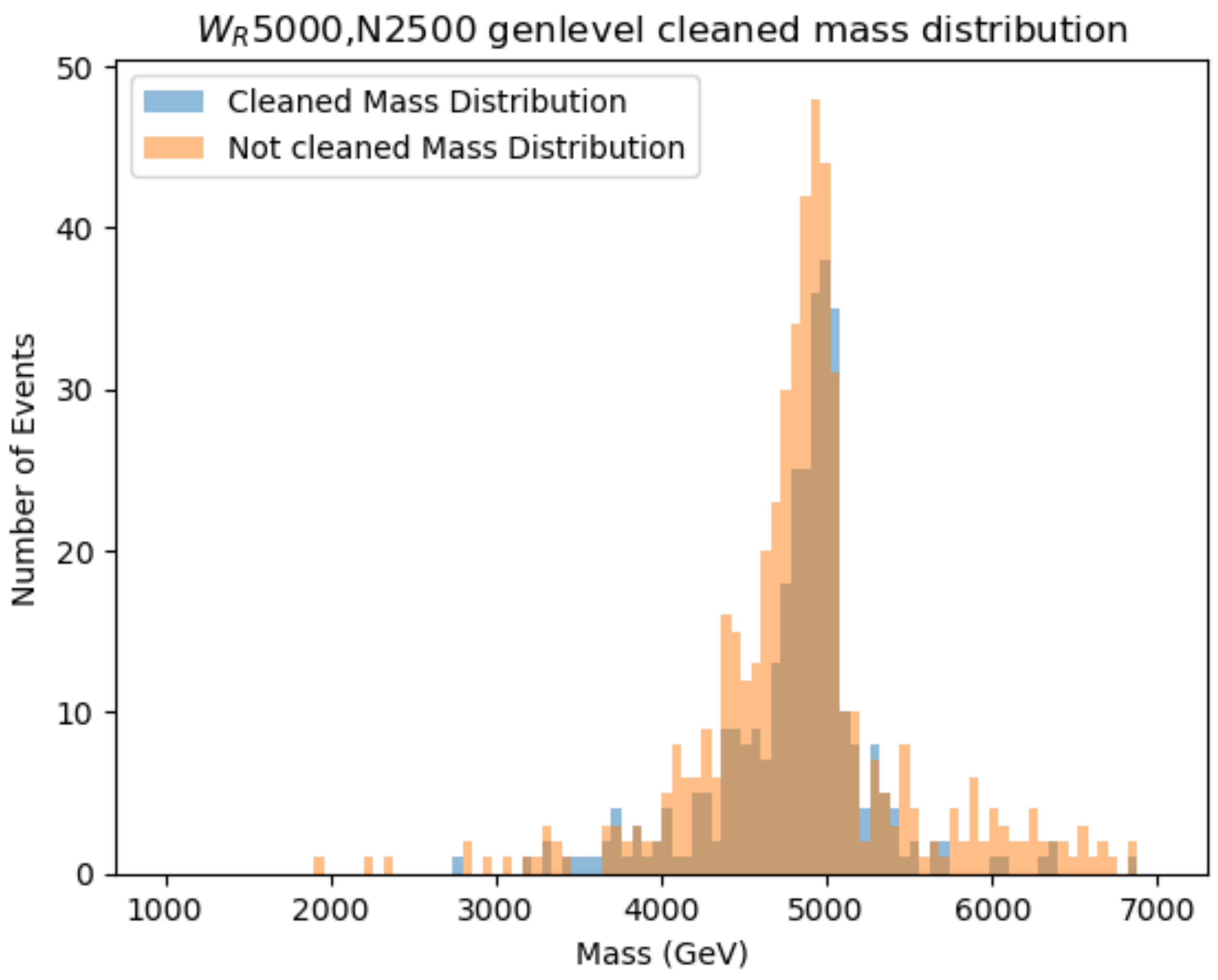
Same criteria selection in gen level

2 leptons , 2AK8

Not used top tagging , b tagging



83% efficiency



86% efficiency

Thanks!