University of California
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Search for new physics using the $\mathbf{M_{T2}}$ variable in all-hadronic final states produced in 13 TeV proton-proton collisions at the CMS detector

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in
Physics

by

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Curriculum Vitæ

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Education

2020	Ph.D. in Physics (Expected), University of California, Santa Barbara.
2018	M.A. in Physics, University of California, Santa Barbara.
2015	B.Sc. in Physics and Mathematics, Purdue University, West Lafayette, IN.

Publications

- CMS Collaboration, "Search for new physics with the M_{T2} variable in hadronic final states, with or without disappearing tracks, in proton-proton collisions at $\sqrt{s} =$ 13 TeV." [**CMS-PAS-SUS-19-005**] *(In progress)*.
- CMS Collaboration, "Constraints on models of scalar and vector leptoquarks decaying to a quark and a neutrino at $\sqrt{s} = 13$ TeV." *Phys. Rev.* **D98** (2018), no. 3, 032005, [arXiv:1805.10228].
- CMS Collaboration, "Search for new phenomena with the M_{T2} variable in the all-hadronic final state produced in proton-proton collisions at $\sqrt{s} = 13$ TeV." *Eur. Phys J.* **C77** (2017), no. 10, 710, [arXiv:1705.04650].
- A. Ball et al. "A Letter of Intent to Install a milli-charged Particle Detector at LHC P5". [arXiv:1607.04669].

Abstract

Search for new physics using the M_{T2} variable in all-hadronic final states produced in 13 TeV proton-proton collisions at the CMS detector

by

Bennett J. Marsh

Two related searches for Standard Model and beyond the Standard Model physics with a final state containing a pair of same-charged leptons and jets are performed using a sample of $\sqrt{s} = 13$ TeV data corresponding to an integrated luminosity of 137 fb^{-1}, collected by the CMS detector between 2016 and 2018. The first inclusive search observes no excess above the Standard Model and thus places constraints on R-parity violating and R-parity conserving supersymmetric models with pair production of gluinos and squarks. Gluino masses are excluded up to 2.1 TeV, while top and bottom squarks are excluded up to 0.9 TeV. The second search measures the cross-section of the production of four top quarks within the Standard Model using both cut-based and multivariate approaches. The observed (expected) significance of the multivariate approach is 2.6 (2.7) standard deviations, with a measured cross-section of $12.6^{+5.8}_{-5.2}$ fb, consistent with the Standard Model prediction of $12.0^{+2.2}_{-2.5}$ fb. These results are translated into constraints on the Yukawa coupling of the top quark, as well as constraints on heavy scalar or pseudoscalar production in a type II 2HDM scenario.

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Table A.1: Predictions and observations for the 12 search regions with $N_j = 1$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$N_j = 1$						
N_j, N_b	p_T^{jet1} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
1j, 0b	250-350	$70700 \pm 400 \pm 4100$	$167000 \pm 1000 \pm 11000$	$530 \pm 20 \pm 160$	$\mathbf{238000} \pm 1000 \pm 14000$	**251941**
	350-450	$13440 \pm 130 \pm 790$	$40100 \pm 500 \pm 3100$	$55 \pm 5 \pm 16$	$\mathbf{53600} \pm 500 \pm 3700$	**54870**
	450-575	$3050 \pm 50 \pm 180$	$10850^{+230}_{-220} \pm 690$	$5.6 \pm 1.1 \pm 1.6$	$\mathbf{13910} \pm 230 \pm 840$	**14473**
	575-700	$603^{+20}_{-19} \pm 38$	$2590^{+110}_{-100} \pm 160$	$0.38 \pm 0.06 \pm 0.11$	$\mathbf{3200} \pm 110 \pm 190$	**3432**
	700-1000	$220 \pm 13 \pm 16$	$1076^{+70}_{-66} \pm 66$	$0.12 \pm 0.03 \pm 0.03$	$\mathbf{1295}^{+71}_{-67} \pm 79$	**1304**
	1000-1200	$11.7^{+4.1}_{-3.2} \pm 0.9$	$86^{+23}_{-19} \pm 6$	< 0.01	$\mathbf{98}^{+24}_{-19} \pm 7$	**98**
	≥ 1200	$2.8^{+2.7}_{-1.5} \pm 0.6$	$23^{+12}_{-8} \pm 2$	< 0.01	$\mathbf{26}^{+13}_{-9} \pm 2$	**30**
1j, $\geq$ 1b	250-350	$4210 \pm 110 \pm 260$	$9030 \pm 230 \pm 630$	$58 \pm 10 \pm 17$	$\mathbf{13310}^{+260}_{-250} \pm 820$	**13549**
	350-450	$878 \pm 38 \pm 56$	$2180^{+110}_{-100} \pm 170$	$4.6 \pm 0.4 \pm 1.3$	$\mathbf{3060} \pm 110 \pm 220$	**3078**
	450-575	$211^{+16}_{-15} \pm 13$	$651^{+57}_{-53} \pm 44$	$0.63 \pm 0.18 \pm 0.18$	$\mathbf{863}^{+59}_{-55} \pm 53$	**810**
	575-700	$40.3^{+6.0}_{-5.5} \pm 2.5$	$164^{+30}_{-26} \pm 11$	$0.04 \pm 0.02 \pm 0.02$	$\mathbf{205}^{+31}_{-26} \pm 13$	**184**
	≥ 700	$19.2^{+5.7}_{-4.6} \pm 1.3$	$74^{+21}_{-16} \pm 7$	< 0.01	$\mathbf{94}^{+21}_{-17} \pm 7$	**83**

Table A.2: Predictions and observations for the 30 search regions with $250 \leq H_T < 450$ GeV. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$250 \leq H_T < 450$ GeV						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
2-3j, 0b	200-300	$73700 \pm 500 \pm 5000$	$156000 \pm 1000 \pm 12000$	$580 \pm 20 \pm 140$	$\mathbf{231000} \pm 1000 \pm 16000$	**240867**
	300-400	$12030 \pm 200 \pm 820$	$31300 \pm 200 \pm 2500$	$50 \pm 5 \pm 10$	$\mathbf{43400} \pm 300 \pm 3200$	**44074**
	≥ 400	$417^{+51}_{-47} \pm 28$	$1450 \pm 10 \pm 140$	$0.44 \pm 0.09 \pm 0.09$	$\mathbf{1870} \pm 50 \pm 160$	**2022**
2-3j, 1b	200-300	$12450 \pm 170 \pm 820$	$18700 \pm 300 \pm 1500$	$90 \pm 8 \pm 21$	$\mathbf{31300} \pm 300 \pm 2200$	**32120**
	300-400	$2380 \pm 80 \pm 160$	$3750 \pm 60 \pm 310$	$6.9 \pm 1.0 \pm 1.5$	$\mathbf{6130} \pm 100 \pm 430$	**6258**
	≥ 400	$97 \pm 8 \pm 39$	$174 \pm 3 \pm 17$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{271}^{+9}_{-8} \pm 45$	**275**
2-3j, 2b	200-300	$2240 \pm 70 \pm 150$	$2340^{+110}_{-100} \pm 200$	$9.7 \pm 1.1 \pm 2.3$	$\mathbf{4600}^{+130}_{-120} \pm 320$	**4709**
	300-400	$398^{+34}_{-32} \pm 27$	$469^{+21}_{-20} \pm 39$	$0.68 \pm 0.17 \pm 0.15$	$\mathbf{868}^{+40}_{-38} \pm 61$	**984**
	≥ 400	$13.3 \pm 2.3 \pm 5.4$	$21.7^{+1.0}_{-0.9} \pm 2.2$	< 0.01	$\mathbf{35.0} \pm 2.5 \pm 6.0$	**30**
2-6j, $\geq$ 3b	200-300	$507^{+32}_{-31} \pm 38$	$179^{+35}_{-30} \pm 27$	$1.77 \pm 0.46 \pm 0.46$	$\mathbf{688}^{+47}_{-43} \pm 54$	**699**
	300-400	$69 \pm 6 \pm 15$	$40.0^{+7.8}_{-6.6} \pm 6.0$	$0.16 \pm 0.12 \pm 0.04$	$\mathbf{109}^{+10}_{-9} \pm 16$	**102**
	≥ 400	$1.50 \pm 0.80 \pm 0.61$	$1.43^{+0.28}_{-0.24} \pm 0.25$	< 0.01	$\mathbf{2.92}^{+0.85}_{-0.83} \pm 0.67$	**0**
4-6j, 0b	200-300	$12500 \pm 180 \pm 800$	$21600 \pm 300 \pm 1800$	$250 \pm 17 \pm 58$	$\mathbf{34400} \pm 400 \pm 2400$	**35187**
	300-400	$2070 \pm 80 \pm 130$	$4660 \pm 70 \pm 410$	$18.2 \pm 3.6 \pm 3.8$	$\mathbf{6750} \pm 110 \pm 510$	**6725**
	≥ 400	$42 \pm 5 \pm 17$	$155 \pm 2 \pm 64$	$0.06 \pm 0.03 \pm 0.01$	$\mathbf{197} \pm 5 \pm 67$	**170**
4-6j, 1b	200-300	$5750 \pm 100 \pm 380$	$4300 \pm 150 \pm 360$	$61 \pm 7 \pm 15$	$\mathbf{10120} \pm 180 \pm 680$	**10564**
	300-400	$784^{+43}_{-42} \pm 52$	$928^{+32}_{-31} \pm 84$	$2.07 \pm 0.29 \pm 0.45$	$\mathbf{1710} \pm 50 \pm 120$	**1769**
	≥ 400	$14.0 \pm 2.5 \pm 5.7$	$31 \pm 1 \pm 13$	$0.04 \pm 0.02 \pm 0.01$	$\mathbf{45} \pm 3 \pm 14$	**40**
4-6j, 2b	200-300	$2550^{+70}_{-60} \pm 170$	$921^{+68}_{-63} \pm 87$	$10.0 \pm 1.5 \pm 2.2$	$\mathbf{3480} \pm 90 \pm 230$	**3621**
	300-400	$220^{+23}_{-21} \pm 15$	$198^{+15}_{-14} \pm 20$	$0.47 \pm 0.15 \pm 0.11$	$\mathbf{419}^{+27}_{-25} \pm 31$	**496**
	≥ 400	$3.2 \pm 0.8 \pm 1.3$	$6.6 \pm 0.5 \pm 2.7$	< 0.01	$\mathbf{9.8} \pm 0.9 \pm 3.1$	**14**
$\geq$ 7j, 0b	200-300	$55^{+15}_{-13} \pm 4$	$61^{+23}_{-17} \pm 26$	$2.64 \pm 0.39 \pm 0.57$	$\mathbf{119}^{+28}_{-22} \pm 27$	**108**
	300-500	$3.8^{+2.1}_{-2.0} \pm 0.8$	$8.1^{+3.1}_{-2.3} \pm 4.3$	$0.08 \pm 0.04 \pm 0.02$	$\mathbf{12.0}^{+3.7}_{-3.1} \pm 4.4$	**30**
	≥ 500	$0.0^{+3.2}_{-0.0} \pm 0.0$	$0.0^{+1.2}_{-0.0} \pm 0.0$	< 0.01	$\mathbf{0.0}^{+3.4}_{-0.0} \pm 0.0$	**0**
$\geq$ 7j, 1b	200-300	$48.0^{+9.1}_{-8.2} \pm 3.5$	$19^{+19}_{-11} \pm 10$	$0.33 \pm 0.14 \pm 0.09$	$\mathbf{68}^{+21}_{-13} \pm 11$	**95**
	≥ 300	$3.0 \pm 1.4 \pm 1.2$	$2.5^{+2.4}_{-1.3} \pm 1.7$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{5.6}^{+2.8}_{-1.9} \pm 2.1$	**12**
$\geq$ 7j, 2b	200-300	$41.3^{+7.7}_{-7.0} \pm 3.1$	$6.0^{+5.8}_{-3.2} \pm 3.7$	$0.29 \pm 0.14 \pm 0.06$	$\mathbf{47.6}^{+9.7}_{-7.7} \pm 5.0$	**30**
	≥ 300	$2.15^{+0.78}_{-0.76} \pm 0.87$	$0.74^{+0.72}_{-0.40} \pm 0.57$	< 0.01	$\mathbf{2.9}^{+1.1}_{-0.9} \pm 1.1$	**1**
$\geq$ 7j, $\geq$ 3b	200-300	$7.3^{+1.7}_{-1.5} \pm 0.9$	$1.0^{+1.0}_{-0.6} \pm 1.1$	$0.04 \pm 0.04 \pm 0.01$	$\mathbf{8.4}^{+1.9}_{-1.6} \pm 1.5$	**17**
	≥ 300	$0.47 \pm 0.35 \pm 0.20$	$0.12^{+0.11}_{-0.06} \pm 0.14$	< 0.01	$\mathbf{0.59}^{+0.37}_{-0.35} \pm 0.24$	**0**

Table A.3: Predictions and observations for the 28 search regions with $450 \leq H_T < 575$ GeV, $N_j < 7$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$450 \leq H_T < 575$ GeV, $N_j < 7$						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
2-3j, 0b	200-300	$8860 \pm 110 \pm 640$	$20100 \pm 200 \pm 1300$	$69 \pm 13 \pm 16$	$\mathbf{29100} \pm 300 \pm 1900$	**28956**
	300-400	$4230 \pm 80 \pm 300$	$11770 \pm 140 \pm 790$	$10.6 \pm 0.8 \pm 2.4$	$\mathbf{16000} \pm 200 \pm 1000$	**15876**
	400-500	$1510 \pm 60 \pm 110$	$5020 \pm 60 \pm 360$	$2.86 \pm 0.62 \pm 0.60$	$\mathbf{6540} \pm 80 \pm 440$	**6527**
	≥ 500	$121^{+24}_{-21} \pm 9$	$580 \pm 7 \pm 63$	$0.07 \pm 0.03 \pm 0.02$	$\mathbf{701}^{+25}_{-22} \pm 68$	**740**
2-3j, 1b	200-300	$1326 \pm 43 \pm 88$	$2500 \pm 80 \pm 170$	$17.0 \pm 8.4 \pm 3.8$	$\mathbf{3840}^{+100}_{-90} \pm 240$	**3859**
	300-400	$737 \pm 35 \pm 49$	$1464^{+49}_{-48} \pm 99$	$1.62 \pm 0.20 \pm 0.43$	$\mathbf{2200} \pm 60 \pm 140$	**2065**
	400-500	$259^{+25}_{-23} \pm 19$	$626^{+21}_{-20} \pm 45$	$0.49 \pm 0.10 \pm 0.12$	$\mathbf{885}^{+32}_{-31} \pm 58$	**907**
	≥ 500	$19.1^{+2.8}_{-2.7} \pm 7.8$	$72.4 \pm 2.4 \pm 7.9$	$0.04 \pm 0.02 \pm 0.02$	$\mathbf{92} \pm 4 \pm 11$	**79**
2-3j, 2b	200-300	$201 \pm 15 \pm 13$	$322^{+31}_{-28} \pm 25$	$1.34 \pm 0.62 \pm 0.47$	$\mathbf{524}^{+35}_{-32} \pm 35$	**463**
	300-400	$83.8^{+9.6}_{-9.1} \pm 9.1$	$188^{+18}_{-17} \pm 15$	$0.26 \pm 0.07 \pm 0.07$	$\mathbf{272}^{+21}_{-19} \pm 20$	**304**
	400-500	$31.8^{+4.1}_{-4.0} \pm 6.7$	$80.4^{+7.7}_{-7.1} \pm 6.6$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{112}^{+9}_{-8} \pm 10$	**120**
	≥ 500	$2.16^{+0.67}_{-0.66} \pm 0.88$	$9.3^{+0.9}_{-0.8} \pm 1.1$	< 0.01	$\mathbf{11.4} \pm 1.1 \pm 1.4$	**15**
2-6j, ≥ 3b	200-300	$232^{+17}_{-16} \pm 15$	$57^{+17}_{-13} \pm 7$	$2.20 \pm 0.70 \pm 0.80$	$\mathbf{291}^{+24}_{-21} \pm 19$	**297**
	300-400	$81^{+12}_{-11} \pm 6$	$33.6^{+9.9}_{-7.8} \pm 4.3$	$0.26 \pm 0.08 \pm 0.08$	$\mathbf{115}^{+16}_{-14} \pm 8$	**76**
	400-500	$10.7^{+2.1}_{-2.0} \pm 2.3$	$11.4^{+3.4}_{-2.7} \pm 1.5$	< 0.01	$\mathbf{22.1}^{+4.0}_{-3.4} \pm 2.8$	**24**
	≥ 500	$1.08 \pm 0.58 \pm 0.44$	$1.03^{+0.30}_{-0.24} \pm 0.17$	< 0.01	$\mathbf{2.11}^{+0.65}_{-0.62} \pm 0.48$	**0**
4-6j, 0b	200-300	$5660 \pm 90 \pm 370$	$8560 \pm 170 \pm 600$	$143 \pm 7 \pm 35$	$\mathbf{14360} \pm 190 \pm 890$	**15047**
	300-400	$2250 \pm 60 \pm 150$	$4790^{+100}_{-90} \pm 350$	$24.3 \pm 2.6 \pm 6.2$	$\mathbf{7060} \pm 110 \pm 460$	**6939**
	400-500	$428^{+32}_{-30} \pm 28$	$1220 \pm 20 \pm 110$	$1.42 \pm 0.21 \pm 0.52$	$\mathbf{1650} \pm 40 \pm 130$	**1817**
	≥ 500	$14.8 \pm 2.2 \pm 6.0$	$86 \pm 2 \pm 35$	$0.04 \pm 0.02 \pm 0.01$	$\mathbf{101} \pm 3 \pm 36$	**104**
4-6j, 1b	200-300	$2810 \pm 60 \pm 190$	$1880 \pm 80 \pm 130$	$63 \pm 15 \pm 19$	$\mathbf{4750} \pm 100 \pm 300$	**4736**
	300-400	$937 \pm 36 \pm 63$	$1054^{+45}_{-43} \pm 78$	$5.4 \pm 0.4 \pm 1.4$	$\mathbf{2000} \pm 60 \pm 130$	**2039**
	400-500	$138^{+17}_{-16} \pm 10$	$269 \pm 11 \pm 25$	$0.36 \pm 0.10 \pm 0.10$	$\mathbf{407}^{+20}_{-19} \pm 31$	**403**
	≥ 500	$7.5 \pm 2.2 \pm 3.0$	$19.1 \pm 0.8 \pm 7.9$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{26.5} \pm 2.3 \pm 8.5$	**27**
4-6j, 2b	200-300	$1343^{+38}_{-37} \pm 89$	$414^{+39}_{-35} \pm 33$	$11.5 \pm 1.0 \pm 3.3$	$\mathbf{1770} \pm 50 \pm 110$	**1767**
	300-400	$418^{+24}_{-23} \pm 29$	$232^{+22}_{-20} \pm 19$	$1.35 \pm 0.35 \pm 0.39$	$\mathbf{651}^{+32}_{-31} \pm 43$	**636**
	400-500	$45.6^{+3.9}_{-3.8} \pm 9.6$	$59.1^{+5.5}_{-5.1} \pm 5.9$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{105}^{+7}_{-6} \pm 12$	**120**
	≥ 500	$1.59 \pm 0.89 \pm 0.65$	$4.2 \pm 0.4 \pm 1.7$	< 0.01	$\mathbf{5.8} \pm 1.0 \pm 1.9$	**7**

Table A.4: Predictions and observations for the 12 search regions with $450 \leq H_T < 575$ GeV, $N_j \geq 7$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$450 \leq H_T < 575$ GeV, $N_j \geq 7$						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
$\geq$ 7j, 0b	200-300	$149^{+17}_{-16} \pm 13$	$169^{+31}_{-27} \pm 34$	$11.5 \pm 0.8 \pm 3.0$	$\mathbf{329}^{+36}_{-31} \pm 38$	**354**
	300-400	$38.9^{+5.8}_{-5.6} \pm 8.2$	$64^{+12}_{-10} \pm 17$	$1.24 \pm 0.42 \pm 0.32$	$\mathbf{104}^{+13}_{-12} \pm 20$	**110**
	≥ 400	$1.28 \pm 0.82 \pm 0.52$	$8.8^{+1.6}_{-1.4} \pm 3.8$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{10.1}^{+1.8}_{-1.6} \pm 3.8$	**10**
$\geq$ 7j, 1b	200-300	$191^{+13}_{-12} \pm 15$	$67^{+19}_{-15} \pm 15$	$4.4 \pm 0.5 \pm 1.2$	$\mathbf{262}^{+23}_{-19} \pm 23$	**268**
	300-400	$37.8^{+3.4}_{-3.3} \pm 8.0$	$25.3^{+7.2}_{-5.7} \pm 7.3$	$0.30 \pm 0.07 \pm 0.08$	$\mathbf{63}^{+8}_{-7} \pm 11$	**65**
	≥ 400	$2.31 \pm 0.69 \pm 0.94$	$3.5^{+1.0}_{-0.8} \pm 1.5$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{5.8}^{+1.2}_{-1.0} \pm 1.8$	**3**
$\geq$ 7j, 2b	200-300	$173^{+12}_{-11} \pm 13$	$19.9^{+5.7}_{-4.5} \pm 5.2$	$1.24 \pm 0.18 \pm 0.33$	$\mathbf{194}^{+13}_{-12} \pm 15$	**197**
	300-400	$26.8 \pm 2.6 \pm 5.7$	$7.6^{+2.2}_{-1.7} \pm 2.4$	$0.09 \pm 0.04 \pm 0.03$	$\mathbf{34.6}^{+3.4}_{-3.1} \pm 6.3$	**44**
	≥ 400	$1.40 \pm 0.44 \pm 0.57$	$1.02^{+0.29}_{-0.23} \pm 0.46$	< 0.01	$\mathbf{2.42}^{+0.53}_{-0.49} \pm 0.73$	**3**
$\geq$ 7j, $\geq$ 3b	200-300	$55.4^{+4.8}_{-4.7} \pm 7.3$	$2.3^{+0.7}_{-0.5} \pm 1.1$	$0.15 \pm 0.06 \pm 0.06$	$\mathbf{57.8}^{+4.8}_{-4.7} \pm 7.4$	**37**
	300-400	$6.4 \pm 1.2 \pm 1.5$	$0.86^{+0.25}_{-0.20} \pm 0.46$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{7.3} \pm 1.2 \pm 1.6$	**9**
	≥ 400	$0.06 \pm 0.01 \pm 0.03$	$0.12 \pm 0.03 \pm 0.06$	< 0.01	$\mathbf{0.18}^{+0.04}_{-0.03} \pm 0.07$	**0**

Table A.5: Predictions and observations for the 20 search regions with $575 \leq H_T < 1200$ GeV, $N_j < 7$, $N_b = 0$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$575 \leq H_T < 1200$ GeV, $N_j < 7$, $N_b = 0$						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
2-3j, 0b	200-300	$5270 \pm 60 \pm 370$	$11550 \pm 160 \pm 790$	$93 \pm 20 \pm 30$	$\mathbf{16900} \pm 200 \pm 1100$	**17256**
	300-400	$2560 \pm 50 \pm 180$	$7770^{+110}_{-100} \pm 540$	$11.9 \pm 1.3 \pm 4.4$	$\mathbf{10340}^{+120}_{-110} \pm 680$	**10145**
	400-500	$1101^{+32}_{-31} \pm 77$	$3900 \pm 50 \pm 280$	$1.33 \pm 0.24 \pm 0.41$	$\mathbf{5000} \pm 60 \pm 340$	**5021**
	500-600	$502^{+24}_{-23} \pm 35$	$2250 \pm 30 \pm 170$	$0.37 \pm 0.07 \pm 0.12$	$\mathbf{2760} \pm 40 \pm 200$	**2706**
	600-700	$180^{+16}_{-15} \pm 13$	$746 \pm 10 \pm 73$	$0.09 \pm 0.03 \pm 0.03$	$\mathbf{926}^{+19}_{-18} \pm 80$	**1066**
	700-800	$52.1^{+7.3}_{-6.5} \pm 5.5$	$256 \pm 3 \pm 36$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{308}^{+8}_{-7} \pm 38$	**347**
	800-900	$17.7^{+2.6}_{-2.3} \pm 2.2$	$107 \pm 1 \pm 20$	< 0.01	$\mathbf{125} \pm 3 \pm 21$	**111**
	900-1000	$6.0 \pm 0.9 \pm 1.3$	$39.4 \pm 0.5 \pm 8.5$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{45.4}^{+1.1}_{-1.0} \pm 8.7$	**39**
	1000-1100	$3.3^{+1.1}_{-1.0} \pm 1.0$	$13.3 \pm 0.2 \pm 3.9$	< 0.01	$\mathbf{16.6} \pm 1.1 \pm 4.1$	**11**
	≥ 1100	$0.31^{+0.09}_{-0.08} \pm 0.12$	$2.5 \pm 0.0 \pm 1.1$	< 0.01	$\mathbf{2.8} \pm 0.1 \pm 1.1$	**2**
4-6j, 0b	200-300	$6280 \pm 70 \pm 420$	$9470 \pm 160 \pm 650$	$360 \pm 20 \pm 110$	$\mathbf{16100} \pm 180 \pm 1000$	**16292**
	300-400	$2700 \pm 50 \pm 180$	$5410 \pm 90 \pm 380$	$53 \pm 1 \pm 17$	$\mathbf{8160} \pm 100 \pm 520$	**8330**
	400-500	$927^{+28}_{-27} \pm 62$	$2420 \pm 40 \pm 180$	$7.7 \pm 0.4 \pm 2.4$	$\mathbf{3350} \pm 50 \pm 230$	**3576**
	500-600	$324^{+17}_{-16} \pm 22$	$1171^{+20}_{-19} \pm 100$	$1.46 \pm 0.12 \pm 0.46$	$\mathbf{1500} \pm 30 \pm 110$	**1516**
	600-700	$95.4^{+9.4}_{-8.7} \pm 6.4$	$413 \pm 7 \pm 47$	$0.33 \pm 0.06 \pm 0.10$	$\mathbf{509}^{+12}_{-11} \pm 50$	**543**
	700-800	$35.6^{+5.0}_{-4.5} \pm 3.6$	$171 \pm 3 \pm 27$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{206}^{+6}_{-5} \pm 27$	**178**
	800-900	$13.4^{+2.0}_{-1.8} \pm 1.6$	$64 \pm 1 \pm 11$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{77} \pm 2 \pm 11$	**62**
	900-1000	$4.39^{+0.78}_{-0.73} \pm 0.93$	$23.6 \pm 0.4 \pm 5.3$	< 0.01	$\mathbf{28.0}^{+0.9}_{-0.8} \pm 5.4$	**20**
	1000-1100	$0.64 \pm 0.16 \pm 0.20$	$6.3 \pm 0.1 \pm 2.0$	< 0.01	$\mathbf{6.9} \pm 0.2 \pm 2.0$	**3**
	≥ 1100	$0.78 \pm 0.58 \pm 0.32$	$0.89^{+0.02}_{-0.01} \pm 0.40$	< 0.01	$\mathbf{1.68} \pm 0.58 \pm 0.52$	**1**

Table A.6: Predictions and observations for the 27 search regions with $575 \leq H_T < 1200$ GeV, $N_j < 7$, $N_b \geq 1$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$575 \leq H_T < 1200$ GeV, $N_j < 7$, $N_b \geq 1$							
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
2-3j, 1b	200-300	$826^{+27}_{-26} \pm 54$	$1480^{+60}_{-50} \pm 100$	$38 \pm 15 \pm 12$	$\mathbf{2340} \pm 60 \pm 140$	**2499**
	300-400	$426^{+21}_{-20} \pm 28$	$994^{+38}_{-37} \pm 69$	$2.33 \pm 0.26 \pm 0.84$	$\mathbf{1422}^{+43}_{-42} \pm 90$	**1366**
	400-600	$282^{+18}_{-17} \pm 20$	$788^{+30}_{-29} \pm 55$	$0.27 \pm 0.06 \pm 0.10$	$\mathbf{1071}^{+35}_{-34} \pm 69$	**1057**
	600-800	$43.5^{+3.2}_{-3.1} \pm 6.5$	$129 \pm 5 \pm 12$	< 0.01	$\mathbf{172} \pm 6 \pm 15$	**225**
	800-1000	$4.6 \pm 0.7 \pm 1.3$	$18.8 \pm 0.7 \pm 3.3$	< 0.01	$\mathbf{23.4} \pm 1.0 \pm 3.6$	**22**
	≥ 1000	$0.34 \pm 0.08 \pm 0.14$	$2.05 \pm 0.08 \pm 0.90$	< 0.01	$\mathbf{2.38} \pm 0.11 \pm 0.91$	**1**
2-3j, 2b	200-300	$105.1^{+9.2}_{-8.7} \pm 7.6$	$181^{+20}_{-18} \pm 15$	$3.8 \pm 0.5 \pm 1.3$	$\mathbf{290}^{+22}_{-20} \pm 20$	**316**
	300-400	$55.0^{+6.7}_{-6.3} \pm 7.5$	$122^{+14}_{-12} \pm 10$	$0.27 \pm 0.06 \pm 0.10$	$\mathbf{177}^{+15}_{-14} \pm 14$	**159**
	400-600	$36.5^{+4.6}_{-4.3} \pm 5.5$	$97^{+11}_{-10} \pm 8$	$0.08 \pm 0.03 \pm 0.03$	$\mathbf{133}^{+12}_{-11} \pm 11$	**107**
	600-800	$4.7 \pm 0.8 \pm 1.3$	$15.8^{+1.8}_{-1.6} \pm 1.6$	< 0.01	$\mathbf{20.6}^{+1.9}_{-1.8} \pm 2.2$	**21**
	≥ 800	$0.59 \pm 0.19 \pm 0.24$	$2.56^{+0.29}_{-0.26} \pm 0.45$	< 0.01	$\mathbf{3.14}^{+0.35}_{-0.32} \pm 0.52$	**1**
4-6j, 1b	200-300	$2900 \pm 50 \pm 200$	$2220^{+80}_{-70} \pm 150$	$154 \pm 16 \pm 50$	$\mathbf{5270} \pm 90 \pm 330$	**5335**
	300-400	$1066 \pm 29 \pm 74$	$1267^{+44}_{-42} \pm 89$	$19.2 \pm 0.9 \pm 6.2$	$\mathbf{2350} \pm 50 \pm 150$	**2547**
	400-600	$504^{+22}_{-21} \pm 35$	$840^{+29}_{-28} \pm 61$	$2.98 \pm 0.21 \pm 0.93$	$\mathbf{1347}^{+36}_{-35} \pm 88$	**1284**
	600-800	$35.3^{+5.9}_{-5.2} \pm 2.6$	$138 \pm 5 \pm 14$	$0.09 \pm 0.03 \pm 0.03$	$\mathbf{174}^{+8}_{-7} \pm 16$	**151**
	800-1000	$3.89^{+0.83}_{-0.77} \pm 0.82$	$19.3^{+0.7}_{-0.6} \pm 4.3$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{23.2}^{+1.1}_{-1.0} \pm 4.5$	**18**
	≥ 1000	$0.18 \pm 0.07 \pm 0.07$	$1.57 \pm 0.05 \pm 0.65$	< 0.01	$\mathbf{1.75} \pm 0.09 \pm 0.65$	**1**
4-6j, 2b	200-300	$1500 \pm 30 \pm 100$	$473^{+36}_{-33} \pm 36$	$42 \pm 2 \pm 13$	$\mathbf{2020} \pm 50 \pm 130$	**1968**
	300-400	$508 \pm 20 \pm 35$	$270^{+20}_{-19} \pm 21$	$4.9 \pm 0.3 \pm 1.6$	$\mathbf{783}^{+29}_{-28} \pm 50$	**788**
	400-600	$167 \pm 12 \pm 12$	$179^{+14}_{-13} \pm 14$	$0.57 \pm 0.08 \pm 0.18$	$\mathbf{346}^{+18}_{-17} \pm 23$	**354**
	600-800	$11.9^{+1.3}_{-1.2} \pm 2.5$	$29.5^{+2.2}_{-2.1} \pm 3.5$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{41.4}^{+2.6}_{-2.4} \pm 4.6$	**37**
	≥ 800	$0.91 \pm 0.23 \pm 0.37$	$4.4 \pm 0.3 \pm 1.8$	< 0.01	$\mathbf{5.4} \pm 0.4 \pm 1.9$	**7**
2-6j, ≥ 3b	200-300	$299^{+17}_{-16} \pm 22$	$73^{+15}_{-13} \pm 10$	$6.2 \pm 0.4 \pm 2.1$	$\mathbf{379}^{+22}_{-21} \pm 28$	**345**
	300-400	$100 \pm 10 \pm 7$	$43.5^{+8.8}_{-7.4} \pm 6.2$	$0.68 \pm 0.09 \pm 0.24$	$\mathbf{144}^{+14}_{-12} \pm 11$	**132**
	400-600	$32.5^{+6.3}_{-5.6} \pm 2.5$	$31.2^{+6.3}_{-5.3} \pm 4.4$	$0.08 \pm 0.03 \pm 0.03$	$\mathbf{63.8}^{+8.9}_{-7.7} \pm 5.8$	**48**
	600-800	$3.16^{+0.95}_{-0.90} \pm 0.68$	$5.4^{+1.1}_{-0.9} \pm 0.8$	< 0.01	$\mathbf{8.6}^{+1.4}_{-1.3} \pm 1.1$	**4**
	≥ 800	$0.10 \pm 0.03 \pm 0.04$	$0.71^{+0.14}_{-0.12} \pm 0.15$	< 0.01	$\mathbf{0.81}^{+0.15}_{-0.12} \pm 0.16$	**0**

Table A.7: Predictions and observations for the 34 search regions with $575 \leq H_T < 1200$ GeV, $N_j \geq 7$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$575 \leq H_T < 1200$ GeV, $N_j \geq 7$						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
7-9j, 0b	200-300	$589^{+27}_{-26} \pm 39$	$573^{+47}_{-43} \pm 64$	$90 \pm 10 \pm 28$	$\mathbf{1252}^{+55}_{-52} \pm 93$	**1340**
	300-400	$265^{+19}_{-18} \pm 18$	$279^{+23}_{-21} \pm 42$	$14.9 \pm 0.5 \pm 4.7$	$\mathbf{559}^{+29}_{-28} \pm 51$	**581**
	400-600	$92^{+10}_{-9} \pm 6$	$159^{+13}_{-12} \pm 28$	$2.72 \pm 0.18 \pm 0.85$	$\mathbf{253}^{+16}_{-15} \pm 30$	**243**
	600-800	$8.6 \pm 1.2 \pm 1.8$	$22.8^{+1.9}_{-1.7} \pm 6.4$	$0.10 \pm 0.03 \pm 0.03$	$\mathbf{31.6}^{+2.2}_{-2.1} \pm 6.8$	**32**
	≥ 800	$0.51 \pm 0.16 \pm 0.21$	$3.0 \pm 0.2 \pm 1.3$	< 0.01	$\mathbf{3.5} \pm 0.3 \pm 1.3$	**2**
7-9j, 1b	200-300	$733 \pm 21 \pm 52$	$278^{+28}_{-25} \pm 33$	$48 \pm 3 \pm 16$	$\mathbf{1059}^{+35}_{-33} \pm 73$	**1052**
	300-400	$252^{+13}_{-12} \pm 18$	$135^{+14}_{-12} \pm 21$	$7.7 \pm 0.4 \pm 2.5$	$\mathbf{395}^{+19}_{-17} \pm 32$	**387**
	400-600	$71.3^{+6.9}_{-6.5} \pm 5.2$	$77^{+8}_{-7} \pm 14$	$1.36 \pm 0.13 \pm 0.45$	$\mathbf{150} \pm 10 \pm 16$	**131**
	600-800	$4.26^{+0.73}_{-0.71} \pm 0.90$	$11.0^{+1.1}_{-1.0} \pm 3.1$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{15.3}^{+1.3}_{-1.2} \pm 3.3$	**20**
	≥ 800	$0.11 \pm 0.04 \pm 0.05$	$1.48^{+0.15}_{-0.13} \pm 0.63$	< 0.01	$\mathbf{1.60}^{+0.15}_{-0.14} \pm 0.63$	**1**
7-9j, 2b	200-300	$675 \pm 20 \pm 51$	$82^{+8}_{-7} \pm 10$	$20.9 \pm 3.0 \pm 6.7$	$\mathbf{777}^{+22}_{-21} \pm 56$	**750**
	300-400	$211 \pm 11 \pm 16$	$39.8^{+4.0}_{-3.6} \pm 6.4$	$2.42 \pm 0.19 \pm 0.79$	$\mathbf{253}^{+12}_{-11} \pm 19$	**259**
	400-600	$55.4^{+5.5}_{-5.2} \pm 4.2$	$22.7^{+2.3}_{-2.1} \pm 4.2$	$0.50 \pm 0.07 \pm 0.16$	$\mathbf{78.6}^{+5.9}_{-5.6} \pm 6.6$	**72**
	600-800	$3.00^{+0.63}_{-0.62} \pm 0.64$	$3.25^{+0.32}_{-0.30} \pm 0.93$	$0.01 \pm 0.01 \pm 0.01$	$\mathbf{6.3} \pm 0.7 \pm 1.2$	**7**
	≥ 800	$0.27 \pm 0.20 \pm 0.11$	$0.44 \pm 0.04 \pm 0.19$	< 0.01	$\mathbf{0.71} \pm 0.20 \pm 0.22$	**1**
7-9j, 3b	200-300	$185 \pm 8 \pm 18$	$11.3^{+1.1}_{-1.0} \pm 1.9$	$3.6 \pm 0.2 \pm 1.2$	$\mathbf{200} \pm 8 \pm 18$	**184**
	300-400	$52.0 \pm 3.8 \pm 5.0$	$5.5 \pm 0.5 \pm 1.2$	$0.72 \pm 0.12 \pm 0.26$	$\mathbf{58.3}^{+3.9}_{-3.8} \pm 5.3$	**59**
	400-600	$13.6 \pm 1.8 \pm 1.3$	$3.13^{+0.31}_{-0.29} \pm 0.82$	$0.05 \pm 0.02 \pm 0.02$	$\mathbf{16.8} \pm 1.8 \pm 1.6$	**14**
	≥ 600	$0.49 \pm 0.21 \pm 0.20$	$0.51 \pm 0.05 \pm 0.21$	< 0.01	$\mathbf{1.00} \pm 0.21 \pm 0.29$	**2**
7-9j, ≥ 4b	200-300	$38.8 \pm 3.1 \pm 7.4$	$2.01^{+0.20}_{-0.18} \pm 0.71$	$0.55 \pm 0.08 \pm 0.19$	$\mathbf{41.3}^{+3.2}_{-3.1} \pm 7.4$	**38**
	300-400	$14.5^{+2.0}_{-1.9} \pm 2.8$	$0.98^{+0.10}_{-0.09} \pm 0.43$	$0.06 \pm 0.02 \pm 0.02$	$\mathbf{15.6}^{+2.0}_{-1.9} \pm 2.8$	**16**
	≥ 400	$3.75^{+0.98}_{-0.97} \pm 0.70$	$0.65 \pm 0.06 \pm 0.35$	< 0.01	$\mathbf{4.40}^{+0.98}_{-0.97} \pm 0.79$	**3**
≥ 10j, 0b	200-300	$11.5 \pm 1.6 \pm 1.0$	$4.4^{+0.4}_{-0.3} \pm 2.3$	$3.1 \pm 0.8 \pm 1.1$	$\mathbf{19.0} \pm 1.8 \pm 2.8$	**27**
	300-500	$5.6 \pm 1.0 \pm 0.5$	$3.0 \pm 0.2 \pm 1.7$	$0.55 \pm 0.08 \pm 0.20$	$\mathbf{9.1} \pm 1.0 \pm 1.8$	**4**
	≥ 500	$0.30 \pm 0.11 \pm 0.12$	$0.44^{+0.04}_{-0.03} \pm 0.24$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{0.76} \pm 0.11 \pm 0.27$	**3**
≥ 10j, 1b	200-300	$21.0 \pm 1.8 \pm 1.6$	$3.5 \pm 0.3 \pm 1.9$	$1.92 \pm 0.18 \pm 0.72$	$\mathbf{26.4} \pm 1.8 \pm 2.7$	**32**
	300-500	$7.7 \pm 1.0 \pm 0.6$	$2.4 \pm 0.2 \pm 1.4$	$0.45 \pm 0.07 \pm 0.17$	$\mathbf{10.5} \pm 1.1 \pm 1.6$	**15**
	≥ 500	$0.83^{+0.42}_{-0.41} \pm 0.07$	$0.36^{+0.04}_{-0.03} \pm 0.20$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{1.20}^{+0.42}_{-0.41} \pm 0.22$	**0**
≥ 10j, 2b	200-300	$21.8 \pm 1.8 \pm 1.6$	$1.05 \pm 0.10 \pm 0.66$	$0.64 \pm 0.08 \pm 0.24$	$\mathbf{23.5} \pm 1.8 \pm 1.8$	**26**
	300-500	$8.8 \pm 1.2 \pm 0.6$	$0.69^{+0.07}_{-0.06} \pm 0.45$	$0.16 \pm 0.04 \pm 0.06$	$\mathbf{9.6}^{+1.3}_{-1.2} \pm 0.8$	**9**
	≥ 500	$0.22 \pm 0.13 \pm 0.02$	$0.10 \pm 0.01 \pm 0.06$	< 0.01	$\mathbf{0.32} \pm 0.13 \pm 0.07$	**0**
≥ 10j, 3b	200-300	$9.9 \pm 1.3 \pm 1.2$	$0.25 \pm 0.02 \pm 0.20$	$0.29 \pm 0.05 \pm 0.12$	$\mathbf{10.4} \pm 1.3 \pm 1.2$	**14**
	≥ 300	$1.59 \pm 0.50 \pm 0.18$	$0.19 \pm 0.02 \pm 0.16$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{1.80} \pm 0.50 \pm 0.25$	**2**
≥ 10j, ≥ 4b	≥ 200	$3.9 \pm 1.2 \pm 0.8$	$0.00^{+0.17}_{-0.00} \pm 0.00$	$0.05 \pm 0.02 \pm 0.02$	$\mathbf{4.0} \pm 1.2 \pm 0.8$	**6**

Table A.8: Predictions and observations for the 12 search regions with $1200 \leq H_\mathrm{T} < 1500$ GeV, $N_\mathrm{j} < 7$, $N_\mathrm{b} = 0$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$1200 \leq H_\mathrm{T} < 1500$ GeV, $N_\mathrm{j} < 7$, $N_\mathrm{b} = 0$						
N_j, N_b	M_T2 [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
2-3j, 0b	200-400	$315 \pm 15 \pm 21$	$656^{+51}_{-47} \pm 73$	$39 \pm 16 \pm 12$	$\mathbf{1009}^{+55}_{-52} \pm 85$	**1128**
	400-600	$43.0^{+5.2}_{-4.7} \pm 4.9$	$185^{+14}_{-13} \pm 30$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{228}^{+15}_{-14} \pm 31$	**207**
	600-800	$14.1^{+2.1}_{-2.0} \pm 1.7$	$64 \pm 5 \pm 17$	< 0.01	$\mathbf{78} \pm 5 \pm 17$	**83**
	800-1000	$6.4^{+1.1}_{-1.0} \pm 1.3$	$32.5^{+2.5}_{-2.3} \pm 7.6$	< 0.01	$\mathbf{38.9}^{+2.7}_{-2.5} \pm 7.8$	**36**
	1000-1200	$3.23^{+0.61}_{-0.59} \pm 0.99$	$17.5 \pm 1.3 \pm 5.2$	< 0.01	$\mathbf{20.7}^{+1.5}_{-1.4} \pm 5.3$	**19**
	≥ 1200	$0.87^{+0.14}_{-0.13} \pm 0.35$	$6.0^{+0.5}_{-0.4} \pm 2.6$	< 0.01	$\mathbf{6.9} \pm 0.5 \pm 2.6$	**4**
4-6j, 0b	200-400	$606^{+21}_{-20} \pm 41$	$909^{+63}_{-59} \pm 90$	$208 \pm 12 \pm 64$	$\mathbf{1720}^{+70}_{-60} \pm 130$	**1768**
	400-600	$84.3^{+7.4}_{-6.9} \pm 5.8$	$234^{+16}_{-15} \pm 34$	$0.88 \pm 0.09 \pm 0.27$	$\mathbf{319}^{+18}_{-17} \pm 36$	**301**
	600-800	$21.1^{+3.2}_{-2.9} \pm 2.3$	$75 \pm 5 \pm 17$	$0.06 \pm 0.02 \pm 0.02$	$\mathbf{96} \pm 6 \pm 17$	**99**
	800-1000	$7.6^{+1.2}_{-1.1} \pm 1.1$	$35.2^{+2.4}_{-2.3} \pm 8.0$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{42.7}^{+2.7}_{-2.5} \pm 8.2$	**41**
	1000-1200	$2.23^{+0.36}_{-0.33} \pm 0.61$	$14.1^{+1.0}_{-0.9} \pm 4.2$	< 0.01	$\mathbf{16.3} \pm 1.0 \pm 4.2$	**15**
	≥ 1200	$0.47^{+0.10}_{-0.09} \pm 0.19$	$3.0 \pm 0.2 \pm 1.3$	< 0.01	$\mathbf{3.5} \pm 0.2 \pm 1.3$	**5**

Table A.9: Predictions and observations for the 25 search regions with $1200 \leq H_T < 1500$ GeV, $N_j < 7$, $N_b \geq 1$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$1200 \leq H_T < 1500$ GeV, $N_j < 7$, $N_b \geq 1$						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
2-3j, 1b	200-400	$61.5^{+7.2}_{-6.5} \pm 4.2$	$78^{+19}_{-16} \pm 10$	$9.7 \pm 0.7 \pm 3.0$	$\mathbf{149}^{+21}_{-17} \pm 12$	**157**
	400-600	$10.1 \pm 1.4 \pm 1.0$	$21.9^{+5.4}_{-4.4} \pm 3.8$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{32.0}^{+5.6}_{-4.6} \pm 4.1$	**27**
	600-800	$2.36^{+0.36}_{-0.35} \pm 0.41$	$7.5^{+1.9}_{-1.5} \pm 2.0$	< 0.01	$\mathbf{9.8}^{+1.9}_{-1.6} \pm 2.1$	**9**
	800-1000	$0.78^{+0.16}_{-0.15} \pm 0.19$	$3.84^{+0.95}_{-0.78} \pm 0.93$	< 0.01	$\mathbf{4.62}^{+0.97}_{-0.79} \pm 0.96$	**6**
	1000-1200	$0.43 \pm 0.08 \pm 0.14$	$2.13^{+0.53}_{-0.43} \pm 0.64$	< 0.01	$\mathbf{2.56}^{+0.54}_{-0.44} \pm 0.66$	**2**
	≥ 1200	$0.14^{+0.05}_{-0.04} \pm 0.06$	$0.71^{+0.18}_{-0.14} \pm 0.31$	< 0.01	$\mathbf{0.86}^{+0.18}_{-0.15} \pm 0.31$	**0**
2-3j, 2b	200-400	$4.8^{+2.0}_{-1.6} \pm 0.3$	$11^{+11}_{-6} \pm 2$	$1.38 \pm 0.13 \pm 0.43$	$\mathbf{18}^{+11}_{-6} \pm 2$	**18**
	400-600	$0.61^{+0.30}_{-0.25} \pm 0.07$	$3.2^{+3.1}_{-1.7} \pm 0.7$	< 0.01	$\mathbf{3.8}^{+3.1}_{-1.8} \pm 0.7$	**5**
	600-800	$0.21^{+0.11}_{-0.09} \pm 0.04$	$1.1^{+1.1}_{-0.6} \pm 0.4$	< 0.01	$\mathbf{1.3}^{+1.1}_{-0.6} \pm 0.4$	**2**
	800-1000	$0.07^{+0.04}_{-0.03} \pm 0.02$	$0.56^{+0.55}_{-0.31} \pm 0.18$	< 0.01	$\mathbf{0.63}^{+0.55}_{-0.31} \pm 0.18$	**1**
	≥ 1000	$0.03 \pm 0.02 \pm 0.01$	$0.42^{+0.41}_{-0.23} \pm 0.18$	< 0.01	$\mathbf{0.46}^{+0.41}_{-0.23} \pm 0.18$	**1**
2-6j, ≥ 3b	200-400	$22.6^{+4.7}_{-4.2} \pm 1.8$	$0.0^{+6.6}_{-0.0} \pm 0.0$	$4.4 \pm 0.2 \pm 1.5$	$\mathbf{27.0}^{+8.1}_{-4.2} \pm 2.4$	**25**
	400-600	$1.58^{+0.51}_{-0.48} \pm 0.34$	$0.0^{+1.6}_{-0.0} \pm 0.0$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{1.6}^{+1.7}_{-0.5} \pm 0.3$	**3**
	≥ 600	$0.47^{+0.27}_{-0.26} \pm 0.19$	$0.00^{+0.94}_{-0.00} \pm 0.00$	< 0.01	$\mathbf{0.47}^{+0.98}_{-0.26} \pm 0.19$	**4**
4-6j, 1b	200-400	$278^{+15}_{-14} \pm 20$	$254^{+33}_{-30} \pm 28$	$97 \pm 2 \pm 30$	$\mathbf{629}^{+36}_{-33} \pm 50$	**579**
	400-600	$30.3^{+4.0}_{-3.7} \pm 2.7$	$65^{+9}_{-8} \pm 10$	$0.33 \pm 0.06 \pm 0.10$	$\mathbf{96}^{+9}_{-8} \pm 11$	**79**
	600-800	$8.2^{+1.4}_{-1.3} \pm 1.0$	$21.0^{+2.8}_{-2.5} \pm 4.8$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{29.2}^{+3.1}_{-2.8} \pm 5.0$	**16**
	800-1000	$2.36^{+0.56}_{-0.54} \pm 0.50$	$9.8^{+1.3}_{-1.1} \pm 2.3$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{12.2}^{+1.4}_{-1.3} \pm 2.4$	**9**
	1000-1200	$1.00 \pm 0.24 \pm 0.31$	$4.0 \pm 0.5 \pm 1.2$	< 0.01	$\mathbf{5.0}^{+0.6}_{-0.5} \pm 1.2$	**6**
	≥ 1200	$0.07 \pm 0.02 \pm 0.03$	$0.86^{+0.11}_{-0.10} \pm 0.37$	< 0.01	$\mathbf{0.92}^{+0.11}_{-0.10} \pm 0.37$	**1**
4-6j, 2b	200-400	$120.4^{+9.1}_{-8.7} \pm 9.8$	$45^{+18}_{-13} \pm 5$	$26.0 \pm 0.6 \pm 8.1$	$\mathbf{191}^{+20}_{-16} \pm 15$	**194**
	400-600	$11.9 \pm 1.4 \pm 1.5$	$11.5^{+4.6}_{-3.4} \pm 1.8$	$0.11 \pm 0.03 \pm 0.04$	$\mathbf{23.4}^{+4.8}_{-3.7} \pm 2.6$	**27**
	600-800	$3.49 \pm 0.83 \pm 0.75$	$3.7^{+1.5}_{-1.1} \pm 1.0$	< 0.01	$\mathbf{7.2}^{+1.7}_{-1.4} \pm 1.3$	**7**
	800-1000	$0.66 \pm 0.16 \pm 0.20$	$1.73^{+0.69}_{-0.51} \pm 0.48$	< 0.01	$\mathbf{2.38}^{+0.71}_{-0.54} \pm 0.53$	**3**
	≥ 1000	$0.15 \pm 0.04 \pm 0.06$	$0.84^{+0.34}_{-0.25} \pm 0.36$	< 0.01	$\mathbf{1.00}^{+0.34}_{-0.25} \pm 0.36$	**0**

Table A.10: Predictions and observations for the 31 search regions with $1200 \leq H_{\mathrm{T}} < 1500$ GeV, $N_{\mathrm{j}} \geq 7$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$1200 \leq H_{\mathrm{T}} < 1500$ GeV, $N_{\mathrm{j}} \geq 7$						
N_{j}, N_{b}	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
7-9j, 0b	200-400	$120.4^{+9.8}_{-9.2} \pm 9.0$	$108^{+26}_{-21} \pm 21$	$91 \pm 3 \pm 29$	$\mathbf{319}^{+28}_{-24} \pm 38$	**379**
	400-600	$16.5^{+1.9}_{-1.8} \pm 2.0$	$25.8^{+6.3}_{-5.1} \pm 5.7$	$0.80 \pm 0.09 \pm 0.25$	$\mathbf{43.1}^{+6.5}_{-5.4} \pm 6.3$	**45**
	600-800	$2.94 \pm 0.42 \pm 0.63$	$8.6^{+2.1}_{-1.7} \pm 2.1$	$0.06 \pm 0.02 \pm 0.02$	$\mathbf{11.6}^{+2.1}_{-1.8} \pm 2.2$	**17**
	800-1000	$0.77^{+0.14}_{-0.13} \pm 0.24$	$2.90^{+0.70}_{-0.58} \pm 1.00$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{3.7}^{+0.7}_{-0.6} \pm 1.0$	**3**
	≥ 1000	$0.11 \pm 0.03 \pm 0.05$	$1.09^{+0.26}_{-0.22} \pm 0.50$	< 0.01	$\mathbf{1.21}^{+0.27}_{-0.22} \pm 0.50$	**0**
7-9j, 1b	200-400	$133.8^{+8.0}_{-7.7} \pm 9.8$	$36^{+13}_{-10} \pm 8$	$58 \pm 2 \pm 18$	$\mathbf{228}^{+15}_{-13} \pm 23$	**247**
	400-600	$16.6^{+2.9}_{-2.7} \pm 1.3$	$8.7^{+3.2}_{-2.4} \pm 2.1$	$0.46 \pm 0.07 \pm 0.14$	$\mathbf{25.8}^{+4.3}_{-3.6} \pm 2.7$	**23**
	600-800	$1.83^{+0.43}_{-0.41} \pm 0.28$	$2.9^{+1.1}_{-0.8} \pm 0.8$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{4.8}^{+1.1}_{-0.9} \pm 0.8$	**7**
	800-1000	$0.65^{+0.24}_{-0.23} \pm 0.18$	$0.95^{+0.34}_{-0.26} \pm 0.34$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{1.62}^{+0.42}_{-0.35} \pm 0.39$	**2**
	≥ 1000	$0.22 \pm 0.19 \pm 0.09$	$0.36^{+0.13}_{-0.10} \pm 0.17$	< 0.01	$\mathbf{0.58}^{+0.23}_{-0.21} \pm 0.19$	**0**
7-9j, 2b	200-400	$124.0^{+7.6}_{-7.4} \pm 9.1$	$9.9^{+3.6}_{-2.7} \pm 2.5$	$21.4 \pm 0.5 \pm 6.9$	$\mathbf{155} \pm 8 \pm 12$	**162**
	400-600	$15.0^{+2.8}_{-2.6} \pm 1.3$	$2.41^{+0.87}_{-0.66} \pm 0.67$	$0.12 \pm 0.03 \pm 0.04$	$\mathbf{17.5}^{+3.0}_{-2.7} \pm 1.5$	**18**
	600-800	$2.47^{+0.78}_{-0.76} \pm 0.53$	$0.81^{+0.29}_{-0.22} \pm 0.26$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{3.29}^{+0.83}_{-0.79} \pm 0.60$	**1**
	≥ 800	$0.24 \pm 0.11 \pm 0.10$	$0.36^{+0.13}_{-0.10} \pm 0.16$	< 0.01	$\mathbf{0.60}^{+0.17}_{-0.15} \pm 0.19$	**1**
7-9j, 3b	200-400	$30.0 \pm 2.6 \pm 3.2$	$1.89^{+0.68}_{-0.52} \pm 0.64$	$5.0 \pm 0.3 \pm 1.8$	$\mathbf{36.9}^{+2.7}_{-2.6} \pm 3.8$	**46**
	400-600	$4.1^{+1.1}_{-1.0} \pm 0.6$	$0.45^{+0.16}_{-0.12} \pm 0.18$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{4.6}^{+1.1}_{-1.0} \pm 0.6$	**2**
	≥ 600	$0.92^{+0.50}_{-0.49} \pm 0.38$	$0.23^{+0.08}_{-0.06} \pm 0.11$	< 0.01	$\mathbf{1.15} \pm 0.50 \pm 0.40$	**1**
7-9j, ≥ 4b	200-400	$9.1 \pm 1.6 \pm 1.8$	$0.26^{+0.10}_{-0.07} \pm 0.23$	$0.88 \pm 0.10 \pm 0.32$	$\mathbf{10.3} \pm 1.6 \pm 1.9$	**9**
	≥ 400	$0.44^{+0.24}_{-0.23} \pm 0.08$	$0.10^{+0.04}_{-0.03} \pm 0.09$	< 0.01	$\mathbf{0.53} \pm 0.24 \pm 0.12$	**0**
≥ 10j, 0b	200-400	$7.7^{+1.2}_{-1.1} \pm 0.8$	$2.7^{+0.6}_{-0.5} \pm 2.8$	$8.3 \pm 0.9 \pm 3.0$	$\mathbf{18.7}^{+1.6}_{-1.5} \pm 4.1$	**17**
	400-600	$1.00 \pm 0.32 \pm 0.22$	$0.56^{+0.13}_{-0.11} \pm 0.62$	$0.11 \pm 0.03 \pm 0.04$	$\mathbf{1.66}^{+0.35}_{-0.34} \pm 0.66$	**1**
	≥ 600	$0.10^{+0.35}_{-0.04} \pm 0.04$	$0.14^{+0.08}_{-0.03} \pm 0.14$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{0.24}^{+0.36}_{-0.05} \pm 0.15$	**0**
≥ 10j, 1b	200-400	$15.2 \pm 1.8 \pm 1.4$	$1.1^{+0.4}_{-0.3} \pm 1.2$	$5.3 \pm 0.2 \pm 1.9$	$\mathbf{21.6}^{+1.9}_{-1.8} \pm 2.7$	**22**
	400-600	$1.27^{+0.38}_{-0.36} \pm 0.11$	$0.22^{+0.08}_{-0.06} \pm 0.26$	$0.05 \pm 0.02 \pm 0.02$	$\mathbf{1.55}^{+0.39}_{-0.37} \pm 0.29$	**6**
	≥ 600	$0.03 \pm 0.02 \pm 0.01$	$0.05^{+0.10}_{-0.01} \pm 0.05$	< 0.01	$\mathbf{0.07}^{+0.11}_{-0.02} \pm 0.05$	**0**
≥ 10j, 2b	200-400	$16.9 \pm 1.8 \pm 1.5$	$0.44^{+0.16}_{-0.12} \pm 0.50$	$2.7 \pm 0.2 \pm 1.0$	$\mathbf{20.1} \pm 1.8 \pm 1.9$	**16**
	400-600	$2.62^{+0.71}_{-0.68} \pm 0.30$	$0.09 \pm 0.03 \pm 0.11$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{2.73}^{+0.71}_{-0.68} \pm 0.32$	**2**
	≥ 600	$0.23 \pm 0.15 \pm 0.10$	$0.02^{+0.08}_{-0.01} \pm 0.02$	< 0.01	$\mathbf{0.25}^{+0.17}_{-0.15} \pm 0.10$	**0**
≥ 10j, 3b	200-400	$5.58^{+0.86}_{-0.85} \pm 0.61$	$0.12^{+0.11}_{-0.03} \pm 0.16$	$1.04 \pm 0.10 \pm 0.42$	$\mathbf{6.74}^{+0.87}_{-0.86} \pm 0.76$	**6**
	≥ 400	$0.51 \pm 0.22 \pm 0.06$	$0.03^{+0.11}_{-0.01} \pm 0.04$	< 0.01	$\mathbf{0.54}^{+0.25}_{-0.22} \pm 0.08$	**0**
≥ 10j, ≥ 4b	≥ 200	$2.59 \pm 0.82 \pm 0.62$	$0.10^{+0.13}_{-0.03} \pm 0.13$	$0.31 \pm 0.06 \pm 0.13$	$\mathbf{3.00}^{+0.83}_{-0.82} \pm 0.65$	**7**

Table A.11: Predictions and observations for the 30 search regions with $H_T \geq 1500$ GeV, $N_j < 7$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$H_T \geq 1500$ GeV, $N_j < 7$						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
2-3j, 0b	400-600	$27.2^{+4.4}_{-3.9} \pm 2.5$	$150^{+14}_{-13} \pm 19$	$0.16 \pm 0.04 \pm 0.05$	$\mathbf{177}^{+15}_{-13} \pm 20$	**125**
	600-800	$7.8^{+1.4}_{-1.2} \pm 0.8$	$38.7^{+3.6}_{-3.3} \pm 8.4$	< 0.01	$\mathbf{46.5}^{+3.9}_{-3.6} \pm 8.6$	**37**
	800-1000	$2.29^{+0.39}_{-0.34} \pm 0.35$	$17.2^{+1.6}_{-1.5} \pm 3.4$	< 0.01	$\mathbf{19.5}^{+1.7}_{-1.5} \pm 3.4$	**19**
	1000-1200	$1.20^{+0.21}_{-0.19} \pm 0.26$	$9.0 \pm 0.8 \pm 1.8$	< 0.01	$\mathbf{10.2}^{+0.9}_{-0.8} \pm 1.9$	**14**
	1200-1400	$0.80^{+0.16}_{-0.14} \pm 0.22$	$4.9^{+0.5}_{-0.4} \pm 1.3$	< 0.01	$\mathbf{5.7}^{+0.5}_{-0.4} \pm 1.4$	**4**
	1400-1800	$0.43^{+0.09}_{-0.08} \pm 0.15$	$2.80^{+0.26}_{-0.24} \pm 0.98$	< 0.01	$\mathbf{3.23}^{+0.28}_{-0.26} \pm 0.99$	**3**
	≥ 1800	$0.05 \pm 0.02 \pm 0.02$	$0.41^{+0.04}_{-0.03} \pm 0.19$	< 0.01	$\mathbf{0.46} \pm 0.04 \pm 0.19$	**0**
2-3j, 1b	400-600	$5.2^{+1.1}_{-1.0} \pm 0.6$	$13.4^{+4.9}_{-3.7} \pm 1.9$	$0.09 \pm 0.03 \pm 0.03$	$\mathbf{18.7}^{+5.0}_{-3.8} \pm 2.1$	**23**
	600-800	$1.52^{+0.43}_{-0.41} \pm 0.27$	$3.5^{+1.3}_{-1.0} \pm 1.0$	< 0.01	$\mathbf{5.0}^{+1.3}_{-1.0} \pm 1.0$	**3**
	800-1000	$0.38 \pm 0.09 \pm 0.10$	$1.53^{+0.55}_{-0.42} \pm 0.35$	< 0.01	$\mathbf{1.90}^{+0.56}_{-0.43} \pm 0.37$	**3**
	1000-1200	$0.10 \pm 0.03 \pm 0.03$	$0.81^{+0.29}_{-0.22} \pm 0.24$	< 0.01	$\mathbf{0.91}^{+0.29}_{-0.22} \pm 0.24$	**4**
	≥ 1200	$0.19 \pm 0.06 \pm 0.08$	$0.73^{+0.26}_{-0.20} \pm 0.31$	< 0.01	$\mathbf{0.92}^{+0.27}_{-0.21} \pm 0.32$	**0**
2-3j, 2b	≥ 400	$0.63^{+0.49}_{-0.36} \pm 0.26$	$0.0^{+3.0}_{-0.0} \pm 0.0$	< 0.01	$\mathbf{0.6}^{+3.0}_{-0.4} \pm 0.3$	**2**
2-6j, ≥ 3b	400-600	$1.72^{+0.73}_{-0.68} \pm 0.42$	$1.1^{+2.4}_{-0.9} \pm 0.3$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{2.8}^{+2.5}_{-1.1} \pm 0.6$	**1**
	≥ 600	$0.37^{+0.19}_{-0.18} \pm 0.16$	$0.5^{+1.2}_{-0.4} \pm 0.2$	< 0.01	$\mathbf{0.9}^{+1.2}_{-0.5} \pm 0.2$	**0**
4-6j, 0b	400-600	$46.4^{+5.6}_{-5.1} \pm 3.6$	$176^{+15}_{-14} \pm 23$	$1.62 \pm 0.13 \pm 0.46$	$\mathbf{224}^{+16}_{-15} \pm 24$	**207**
	600-800	$10.6^{+2.3}_{-1.9} \pm 1.2$	$45.5^{+4.0}_{-3.7} \pm 9.9$	$0.07 \pm 0.03 \pm 0.02$	$\mathbf{56}^{+5}_{-4} \pm 10$	**62**
	800-1000	$4.5^{+1.1}_{-1.0} \pm 0.5$	$20.3^{+1.8}_{-1.6} \pm 3.9$	< 0.01	$\mathbf{24.8}^{+2.1}_{-1.9} \pm 4.1$	**31**
	1000-1200	$1.35^{+0.30}_{-0.26} \pm 0.24$	$10.6 \pm 0.9 \pm 2.1$	< 0.01	$\mathbf{11.9}^{+1.0}_{-0.9} \pm 2.2$	**12**
	1200-1400	$0.89^{+0.27}_{-0.25} \pm 0.23$	$5.7 \pm 0.5 \pm 1.5$	< 0.01	$\mathbf{6.6}^{+0.6}_{-0.5} \pm 1.6$	**9**
	1400-1600	$0.20 \pm 0.05 \pm 0.07$	$2.64^{+0.23}_{-0.21} \pm 0.92$	< 0.01	$\mathbf{2.84}^{+0.24}_{-0.22} \pm 0.92$	**3**
	≥ 1600	$0.09 \pm 0.03 \pm 0.04$	$1.18 \pm 0.10 \pm 0.51$	< 0.01	$\mathbf{1.27}^{+0.11}_{-0.10} \pm 0.51$	**2**
4-6j, 1b	400-600	$21.0^{+3.7}_{-3.3} \pm 2.0$	$32.6^{+7.0}_{-5.8} \pm 5.5$	$0.81 \pm 0.09 \pm 0.23$	$\mathbf{54.5}^{+7.9}_{-6.7} \pm 6.3$	**72**
	600-800	$4.79^{+0.91}_{-0.83} \pm 0.62$	$8.4^{+1.8}_{-1.5} \pm 2.3$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{13.2}^{+2.0}_{-1.7} \pm 2.5$	**20**
	800-1000	$1.27^{+0.26}_{-0.24} \pm 0.27$	$3.71^{+0.79}_{-0.66} \pm 0.92$	$0.03 \pm 0.02 \pm 0.01$	$\mathbf{5.01}^{+0.84}_{-0.71} \pm 0.97$	**8**
	1000-1400	$0.89^{+0.21}_{-0.20} \pm 0.28$	$3.00^{+0.64}_{-0.54} \pm 0.93$	< 0.01	$\mathbf{3.89}^{+0.68}_{-0.57} \pm 0.98$	**6**
	≥ 1400	$0.40^{+0.34}_{-0.33} \pm 0.16$	$0.72^{+0.15}_{-0.13} \pm 0.31$	< 0.01	$\mathbf{1.12}^{+0.37}_{-0.36} \pm 0.36$	**3**
4-6j, 2b	400-600	$7.2^{+1.2}_{-1.1} \pm 1.1$	$4.3^{+2.9}_{-1.9} \pm 1.4$	$0.17 \pm 0.04 \pm 0.05$	$\mathbf{11.7}^{+3.2}_{-2.2} \pm 1.9$	**11**
	600-800	$1.66^{+0.41}_{-0.40} \pm 0.46$	$1.12^{+0.76}_{-0.48} \pm 0.55$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{2.79}^{+0.86}_{-0.63} \pm 0.73$	**3**
	≥ 800	$0.32 \pm 0.13 \pm 0.13$	$0.99^{+0.67}_{-0.43} \pm 0.52$	< 0.01	$\mathbf{1.31}^{+0.68}_{-0.45} \pm 0.54$	**4**

Table A.12: Predictions and observations for the 21 search regions with $H_T \geq 1500$ GeV, $N_j \geq 7$. For each of the background predictions, the first uncertainty listed is statistical (from the limited size of data control samples and Monte Carlo samples), and the second is systematic.

$H_T \geq 1500$ GeV, $N_j \geq 7$						
N_j, N_b	M_{T2} [GeV]	Lost lepton	$Z \to \nu\bar{\nu}$	Multijet	Total background	Data
7-9j, 0b	400-600	$14.3^{+1.8}_{-1.7} \pm 1.7$	$32.3^{+7.5}_{-6.2} \pm 4.3$	$1.50 \pm 0.13 \pm 0.44$	$\mathbf{48.1}^{+7.7}_{-6.4} \pm 5.0$	**36**
	600-800	$3.77^{+0.56}_{-0.55} \pm 0.69$	$8.3^{+1.9}_{-1.6} \pm 2.2$	$0.18 \pm 0.04 \pm 0.05$	$\mathbf{12.3}^{+2.0}_{-1.7} \pm 2.3$	**9**
	800-1000	$1.16^{+0.18}_{-0.17} \pm 0.30$	$3.70^{+0.86}_{-0.71} \pm 0.83$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{4.86}^{+0.88}_{-0.73} \pm 0.90$	**6**
	1000-1400	$0.58 \pm 0.11 \pm 0.19$	$2.96^{+0.69}_{-0.57} \pm 0.86$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{3.55}^{+0.69}_{-0.58} \pm 0.89$	**4**
	≥ 1400	$0.05 \pm 0.01 \pm 0.02$	$0.71^{+0.17}_{-0.14} \pm 0.30$	< 0.01	$\mathbf{0.76}^{+0.17}_{-0.14} \pm 0.30$	**2**
7-9j, 1b	400-600	$12.8^{+2.5}_{-2.3} \pm 1.6$	$9.2^{+4.2}_{-3.0} \pm 1.4$	$0.82 \pm 0.09 \pm 0.24$	$\mathbf{22.9}^{+4.9}_{-3.8} \pm 2.3$	**25**
	600-800	$3.49^{+0.94}_{-0.89} \pm 0.76$	$2.4^{+1.1}_{-0.8} \pm 1.0$	$0.06 \pm 0.02 \pm 0.02$	$\mathbf{5.9}^{+1.4}_{-1.2} \pm 1.2$	**7**
	≥ 800	$1.09^{+0.34}_{-0.32} \pm 0.45$	$2.10^{+0.96}_{-0.69} \pm 0.93$	< 0.01	$\mathbf{3.2}^{+1.0}_{-0.8} \pm 1.0$	**2**
7-9j, 2b	400-600	$8.1^{+1.8}_{-1.6} \pm 1.0$	$2.4^{+1.1}_{-0.8} \pm 0.4$	$0.35 \pm 0.06 \pm 0.10$	$\mathbf{10.9}^{+2.1}_{-1.8} \pm 1.2$	**10**
	600-800	$1.78^{+0.54}_{-0.52} \pm 0.40$	$0.62^{+0.28}_{-0.20} \pm 0.25$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{2.41}^{+0.61}_{-0.56} \pm 0.49$	**5**
	≥ 800	$0.40^{+0.19}_{-0.18} \pm 0.17$	$0.55^{+0.25}_{-0.18} \pm 0.25$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{0.96}^{+0.31}_{-0.26} \pm 0.30$	**0**
7-9j, 3b	400-800	$2.40^{+0.74}_{-0.72} \pm 0.29$	$0.32^{+0.15}_{-0.10} \pm 0.12$	$0.10 \pm 0.03 \pm 0.03$	$\mathbf{2.82}^{+0.76}_{-0.72} \pm 0.32$	**2**
	≥ 800	$0.16 \pm 0.09 \pm 0.07$	$0.08^{+0.04}_{-0.03} \pm 0.04$	< 0.01	$\mathbf{0.24} \pm 0.09 \pm 0.08$	**0**
7-9j, ≥ 4b	≥ 400	$0.52^{+0.23}_{-0.22} \pm 0.08$	$0.07^{+0.03}_{-0.02} \pm 0.06$	$0.02 \pm 0.01 \pm 0.01$	$\mathbf{0.61}^{+0.23}_{-0.22} \pm 0.10$	**1**
≥ 10j, 0b	400-800	$1.41 \pm 0.38 \pm 0.33$	$1.52^{+0.35}_{-0.29} \pm 0.34$	$0.23 \pm 0.05 \pm 0.08$	$\mathbf{3.17}^{+0.52}_{-0.48} \pm 0.49$	**11**
	≥ 800	$0.05 \pm 0.02 \pm 0.02$	$0.37^{+0.09}_{-0.07} \pm 0.17$	$0.01 \pm 0.01 \pm 0.00$	$\mathbf{0.43}^{+0.09}_{-0.08} \pm 0.17$	**0**
≥ 10j, 1b	400-800	$2.16^{+0.71}_{-0.69} \pm 0.25$	$0.56^{+0.25}_{-0.18} \pm 0.16$	$0.14 \pm 0.04 \pm 0.05$	$\mathbf{2.85}^{+0.76}_{-0.71} \pm 0.31$	**3**
	≥ 800	$0.55 \pm 0.30 \pm 0.22$	$0.13^{+0.06}_{-0.04} \pm 0.07$	< 0.01	$\mathbf{0.68}^{+0.31}_{-0.30} \pm 0.23$	**0**
≥ 10j, 2b	≥ 400	$1.98^{+0.69}_{-0.67} \pm 0.24$	$0.30^{+0.14}_{-0.10} \pm 0.12$	$0.05 \pm 0.02 \pm 0.02$	$\mathbf{2.33}^{+0.70}_{-0.68} \pm 0.28$	**0**
≥ 10j, 3b	≥ 400	$0.77 \pm 0.35 \pm 0.09$	$0.00^{+0.45}_{-0.00} \pm 0.00$	$0.05 \pm 0.03 \pm 0.02$	$\mathbf{0.82}^{+0.57}_{-0.35} \pm 0.09$	**1**
≥ 10j, ≥ 4b	≥ 400	$0.09 \pm 0.05 \pm 0.01$	$0.00^{+0.45}_{-0.00} \pm 0.00$	< 0.01	$\mathbf{0.09}^{+0.45}_{-0.05} \pm 0.01$	**0**

Appendix B

Bonus: A Search for Milli-Charged Particles at the LHC

B.1 Overview of the Milliqan experiment

B.2 Bench tests for PMT calibration

B.3 Generation of signal Monte Carlo

Bibliography

[1] CMS Collaboration, "Search for new phenomena with the M_{T2} variable in the all-hadronic final state produced in proton-proton collisions at $\sqrt{s} = 13$ TeV." *Eur. Phys. J.* **C77** (2017), no. 10, 710, [arXiv:1705.04650].

[2] CMS Collaboration, "Search for new physics with the M_{T2} variable in all-jets final states produced in pp collisions at $\sqrt{s} = 13$ TeV." *J. High Energy. Phys.* (2016), no. 6, [arXiv:1603.04053].