Validation of the MadAnalysis 5 implementation of CMS-SUS-13-012

Samuel Bein (Florida State U.), Dipan Sengupta (LPSC Grenoble)
emails: samuel.bein@gmail.com, dipan@lpsc.in2p3.fr

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1 T1qqqq simplified model

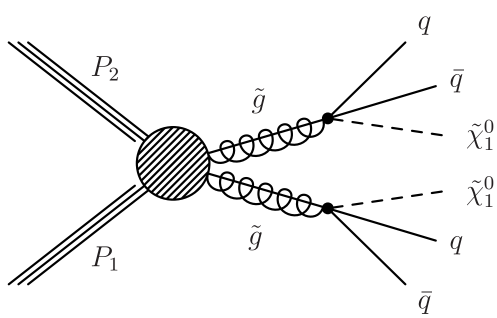

Figure 1: Diagram of the dominant SUSY production mechanism for the T1qqqq working point.

Cut Name	Official Count (Eff)	MA5 Count (Eff)
MET Cleaning	190.6 (xxx)	190.6 (xxx)
No Lepton	190.3 (99%)	190.6 (100%)
NJets>2	188.1 (98%)	188.49 (98%)
H_T>500	187.6 (99%)	188.07 (99%)
$\not{H}_T$>200	158.7 (84%)	159.72 (84%)
Min $\Delta(\phi)$	130.8 (82%)	131.11 (82%)

Table 1: The cut flow for the baseline selection in CMS SUS-13-012 for the T1qqqq working point $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1100, 125)$ GeV. The second column is the official account as reported by https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS13012/T1qqqq.pdf, and our own results are given in column 3. The official counts are normalized to luminosity $\mathcal{L} = 19.5$/fb and cross section $\sigma = 10.17$ pb, and our counts are normalized to match the official count after the first cut, MET Cleaning.

Signal Region Name	Official	MA5
NJets3-5, H_T500-800, $\not{H}_T$200-300	1.4	1.21
NJets3-5, H_T500-800, $\not{H}_T$300-450	2.4	2.08
NJets3-5, H_T500-800, $\not{H}_T$450-600	1.7	1.36
NJets3-5, H_T500-800, $\not{H}_T$>600	0.6	0.60
NJets3-5, H_T800-1000, $\not{H}_T$200-300	2.1	1.81
NJets3-5, H_T800-1000, $\not{H}_T$300-450	2.9	3.75
NJets3-5, H_T800-1000, $\not{H}_T$450-600	4.2	3.74
NJets3-5, H_T800-1000, $\not{H}_T$>600	4.1	4.04
NJets3-5, H_T1000-1250, $\not{H}_T$200-300	4.2	3.70
NJets3-5, H_T1000-1250, $\not{H}_T$300-450	8.1	6.93
NJets3-5, H_T1000-1250, $\not{H}_T$450-600	7.6	7.18
NJets3-5, H_T1000-1250, $\not{H}_T$>600	10.6	10.63
NJets3-5, H_T1250-1500, $\not{H}_T$200-300	3.9	3.64
NJets3-5, H_T1250-1500, $\not{H}_T$300-450	7.3	6.74
NJets3-5, H_T1250-1500, $\not{H}_T$>450	15.6	16.52
NJets3-5, H_T>1500, $\not{H}_T$200-300	4.5	4.41
NJets3-5, H_T>1500, $\not{H}_T$>300	17.9	18.80
NJets6-7, H_T500-800, $\not{H}_T$200-300	0.1	0.08
NJets6-7, H_T500-800, $\not{H}_T$300-450	0.1	0.05
NJets6-7, H_T500-800, $\not{H}_T$>450	0.1	0.04
NJets6-7, H_T800-1000, $\not{H}_T$200-300	0.3	0.24
NJets6-7, H_T800-1000, $\not{H}_T$300-450	0.6	0.51
NJets6-7, H_T800-1000, $\not{H}_T$>450	0.8	0.71
NJets6-7, H_T1000-1250, $\not{H}_T$200-300	0.9	0.91
NJets6-7, H_T1000-1250, $\not{H}_T$300-450	1.8	1.74
NJets6-7, H_T1000-1250, $\not{H}_T$>450	2.8	2.94
NJets6-7, H_T1250-1500, $\not{H}_T$200-300	1.2	1.16
NJets6-7, H_T1250-1500, $\not{H}_T$300-450	2.4	2.46
NJets6-7, H_T1250-1500, $\not{H}_T$>450	4.1	5.16
NJets6-7, H_T>1500, $\not{H}_T$200-300	2.3	2.56
NJets6-7, H_T>1500, $\not{H}_T$>300	9.8	11.50
NJets>7, H_T500-800, $\not{H}_T$>200	0.0	0.0
NJets>7, H_T800-1000, $\not{H}_T$>200	0.0	0.01
NJets>7, H_T1000-1250, $\not{H}_T$>200	0.2	0.28
NJets>7, H_T1250-1500, $\not{H}_T$>200	0.5	0.75
NJets>7, H_T>1500, $\not{H}_T$>200	2.2	2.69

Table 2: The signal region (SR) counts in CMS SUS-13-012 for the T1qqqq scenario after all selection has been applied. Column 2 is the official account obtained through generous correspondence with Christian Sanders, and our own results displayed in column 3. These counts were determined by applying the SR selection to the end of the cut flow featured in table 1.

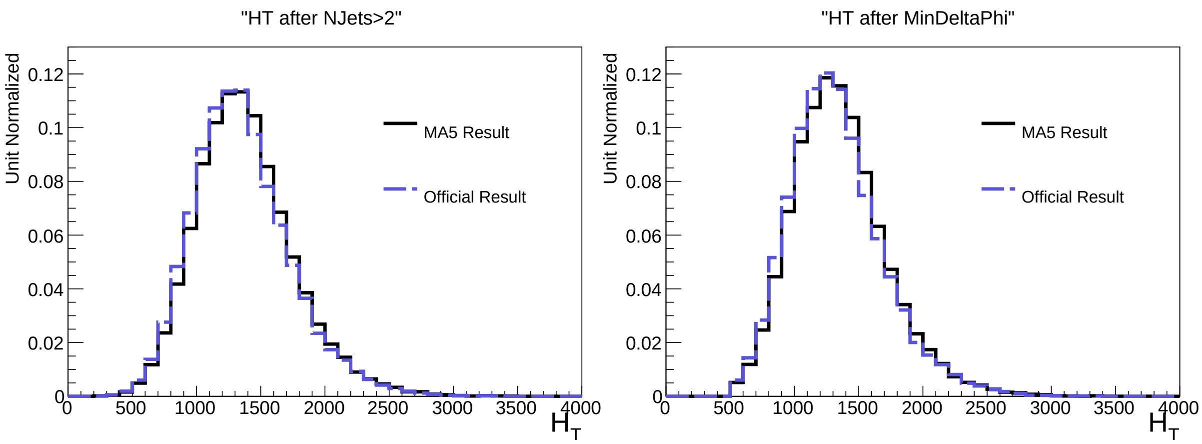

Figure 2: Comparison of the distributions of H_T between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T1qqqq working point.

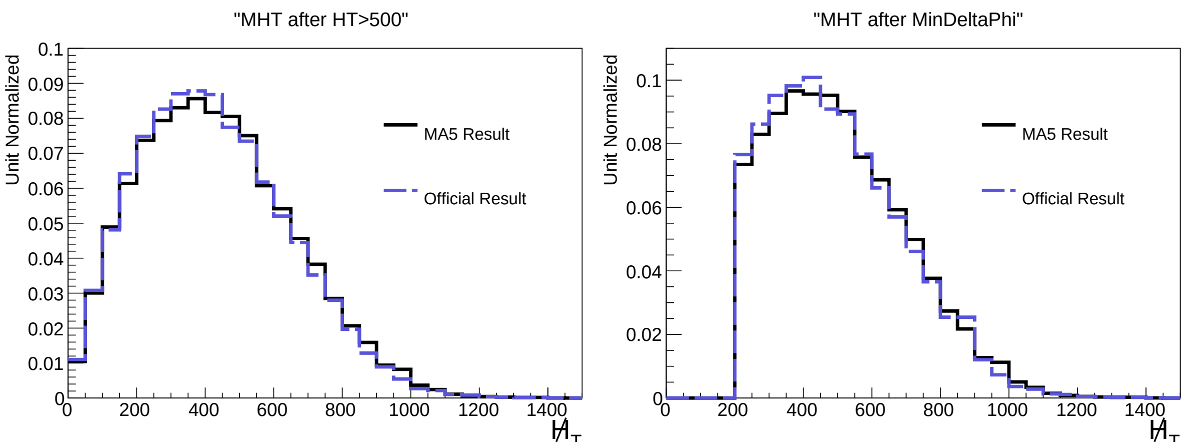

Figure 3: Comparison of the distributions of $\not{H}_T$ between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T1qqqq working point.

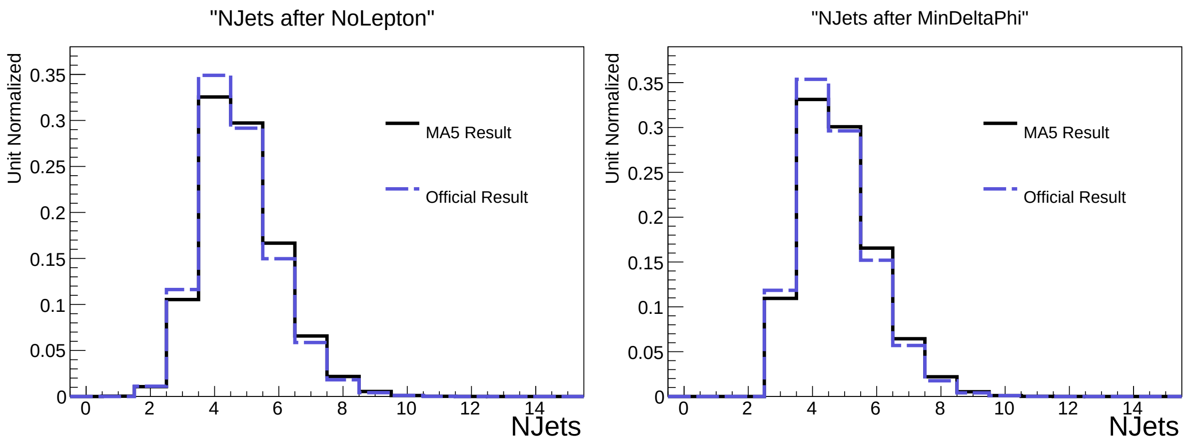

Figure 4: Comparison of the distributions of NJets between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T1qqqq working point.

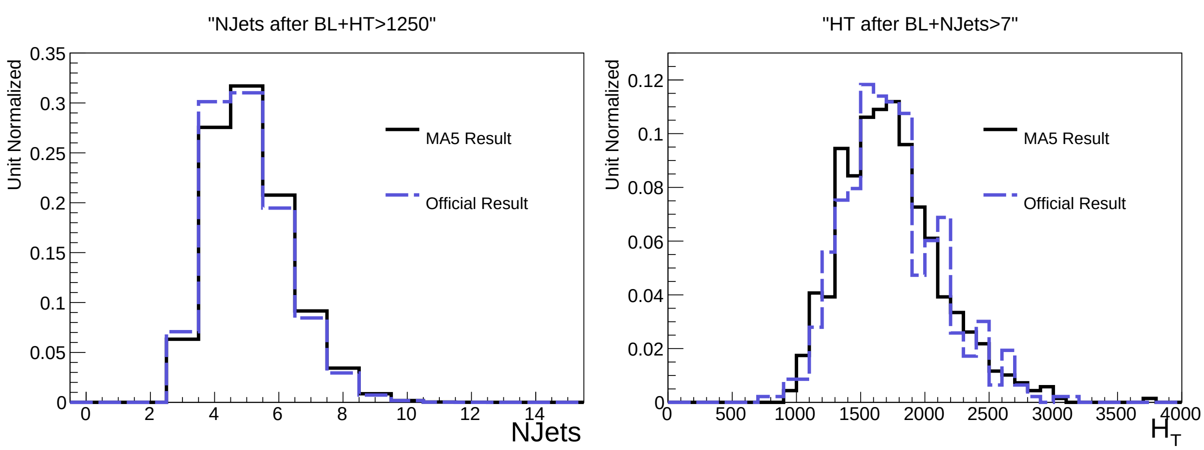

Figure 5: Additional checks: comparison between ours and the official distributions of NJets after BL+H_T>1250 cuts (left), and H_T after BL+NJets>7 cuts (right), for the T1qqqq working point.

2 T1tttt simplified model

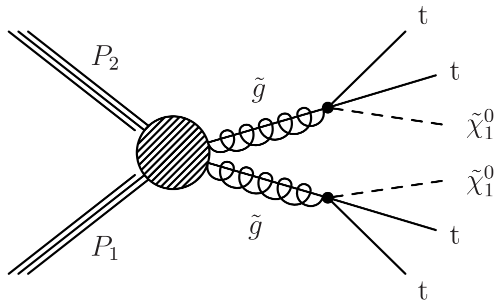

Figure 6: Diagram of the dominant SUSY production mechanism for the T1tttt working point.

Cut Name	Official Count (Eff)	MA5 Count (Eff)
MET Cleaning	190.5 (xxx)	190.5 (xxx)
No Lepton	95.9 (50%)	101.04 (53%)
NJets>2	95.8 (99%)	100.87 (99%)
H_T>500	95.1 (99%)	100.01 (99%)
$\not{H}_T$>200	75.4 (79%)	81.23 (81%)
Min $\Delta(\phi)$	62.3 (82%)	66.92 (82%)

Table 3: The cut flow for the baseline selection in CMS SUS-13-012 for the T1tttt working point $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1100, 125)$ GeV. The second column is the official account as reported by https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS13012/T1tttt.pdf, and our own results are given in column 3. The official counts are normalized to luminosity $\mathcal{L} = 19.5$/fb and cross section $\sigma = 10.17$ pb, and our counts are normalized to match the official count after the first cut, MET Cleaning.

Signal Region Name	Official	MA5
NJets3-5, H_T500-800, $\not{H}_T$200-300	0.8	0.85
NJets3-5, H_T500-800, $\not{H}_T$300-450	1.4	1.22
NJets3-5, H_T500-800, $\not{H}_T$450-600	0.8	0.85
NJets3-5, H_T500-800, $\not{H}_T$>600	0.2	0.31
NJets3-5, H_T800-1000, $\not{H}_T$200-300	0.5	0.45
NJets3-5, H_T800-1000, $\not{H}_T$300-450	0.7	1.00
NJets3-5, H_T800-1000, $\not{H}_T$450-600	1.0	1.03
NJets3-5, H_T800-1000, $\not{H}_T$>600	0.8	0.79
NJets3-5, H_T1000-1250, $\not{H}_T$200-300	0.5	0.53
NJets3-5, H_T1000-1250, $\not{H}_T$300-450	1.0	0.83
NJets3-5, H_T1000-1250, $\not{H}_T$450-600	0.8	0.87
NJets3-5, H_T1000-1250, $\not{H}_T$>600	0.9	1.01
NJets3-5, H_T1250-1500, $\not{H}_T$200-300	0.4	0.40
NJets3-5, H_T1250-1500, $\not{H}_T$300-450	0.5	0.58
NJets3-5, H_T1250-1500, $\not{H}_T$>450	0.8	0.81
NJets3-5, H_T>1500, $\not{H}_T$200-300	0.3	0.34
NJets3-5, H_T>1500, $\not{H}_T$>300	0.9	1.01
NJets6-7, H_T500-800, $\not{H}_T$200-300	0.9	0.81
NJets6-7, H_T500-800, $\not{H}_T$300-450	1.2	0.85
NJets6-7, H_T500-800, $\not{H}_T$>450	0.6	0.44
NJets6-7, H_T800-1000, $\not{H}_T$200-300	1.5	1.16
NJets6-7, H_T800-1000, $\not{H}_T$300-450	2.5	2.35
NJets6-7, H_T800-1000, $\not{H}_T$>450	2.5	2.59
NJets6-7, H_T1000-1250, $\not{H}_T$200-300	1.8	1.71
NJets6-7, H_T1000-1250, $\not{H}_T$300-450	3.4	3.37
NJets6-7, H_T1000-1250, $\not{H}_T$>450	4.5	5.21
NJets6-7, H_T1250-1500, $\not{H}_T$200-300	1.4	1.46
NJets6-7, H_T1250-1500, $\not{H}_T$300-450	2.2	2.43
NJets6-7, H_T1250-1500, $\not{H}_T$>450	2.8	3.34
NJets6-7, H_T>1500, $\not{H}_T$200-300	1.1	1.16
NJets6-7, H_T>1500, $\not{H}_T$>300	3.4	3.99
NJets>7, H_T500-800, $\not{H}_T$>200	0.2	0.15
NJets>7, H_T800-1000, $\not{H}_T$>200	1.9	1.69
NJets>7, H_T1000-1250, $\not{H}_T$>200	5.7	6.37
NJets>7, H_T1250-1500, $\not{H}_T$>200	5.9	7.28
NJets>7, H_T>1500, $\not{H}_T$>200	6.0	7.53

Table 4: The signal region (SR) counts in CMS SUS-13-012 for the T1tttt scenario after all selection has been applied. Column 2 is the official account obtained through generous correspondence with Christian Sanders, and our own results displayed in column 3. These counts were determined by applying the SR selection to the end of the cut flow featured in table 3.

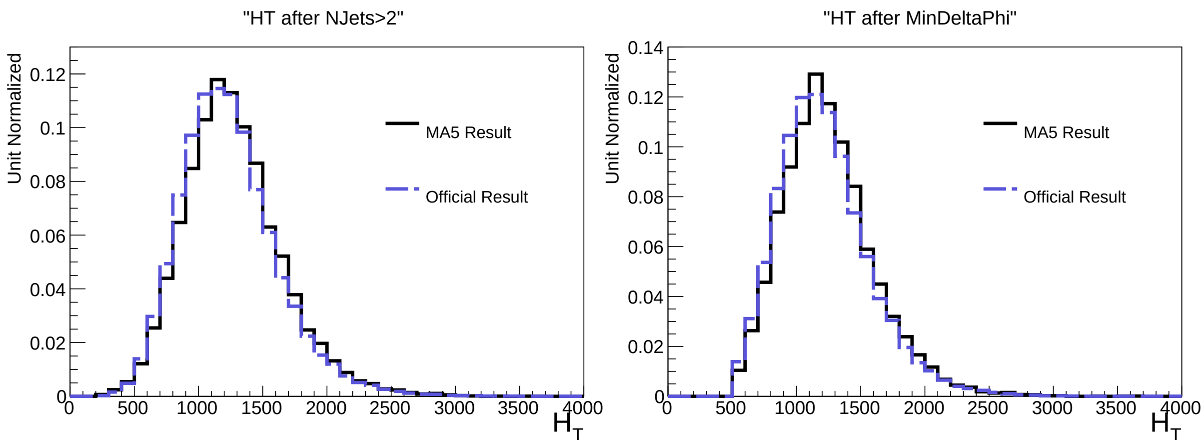

Figure 7: Comparison of the distributions of H_T between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T1tttt working point.

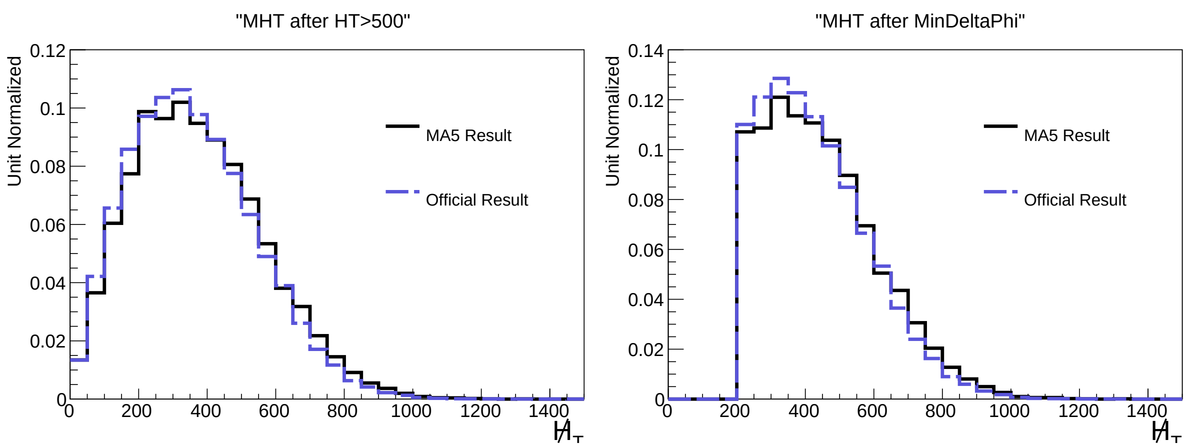

Figure 8: Comparison of the distributions of $\not{H}_T$ between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T1tttt working point.

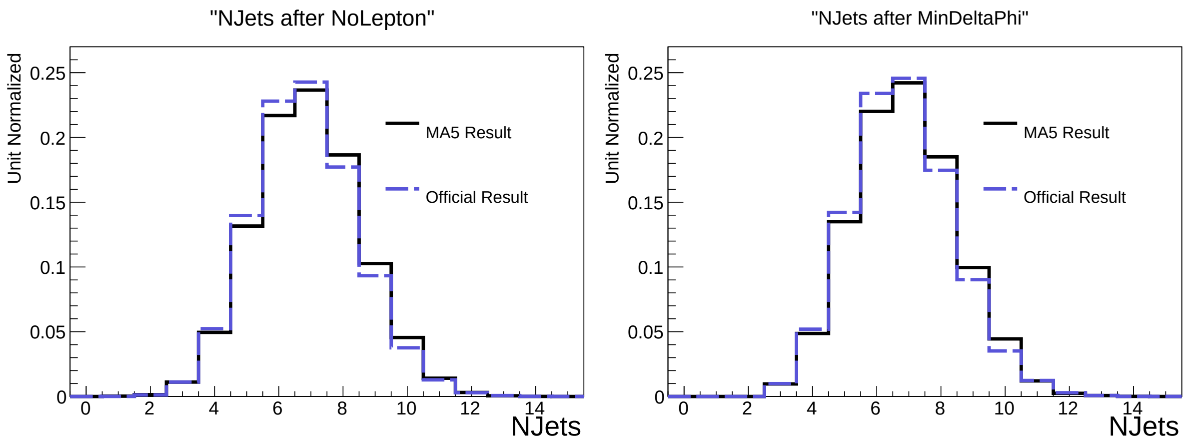

Figure 9: Comparison of the distributions of NJets between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T1tttt working point.

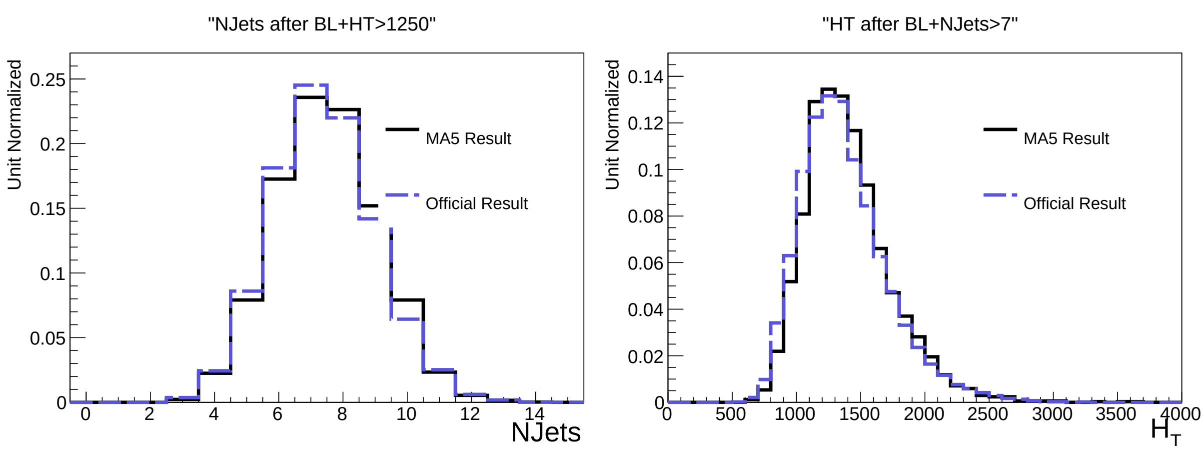

Figure 10: Additional checks: comparison between ours and the official distributions of NJets after BL+H_T>1250 cuts (left), and H_T after BL+NJets>7 cuts (right), for the T1tttt working point.

3 T5VV simplified model

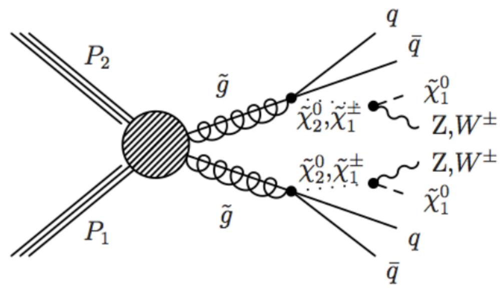

Figure 11: Diagram of the dominant SUSY production mechanism for the T5VV working point.

Cut Name	Official Count (Eff)	MA5 Count (Eff)
MET Cleaning	189.9 (xxx)	189.9 (xxx)
No Lepton	136.2 (71%)	142.07 (74%)
NJets>2	135.9 (99%)	141.69 (99%)
H_T>500	135.5 (99%)	141.26 (99%)
$\not{H}_T$>200	108.8 (80%)	115.23 (81%)
Min $\Delta(\phi)$	89.6 (82%)	95.22 (82%)

Table 5: The cut flow for the baseline selection in CMS SUS-13-012 for the T5VV working point $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1100, 125)$ GeV. The second column is the official account as reported by https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS13012/T5VV.pdf, and our own results are given in column 3. The official counts are normalized to luminosity $\mathcal{L} = 19.5$/fb and cross section $\sigma = 10.17$ pb, and our counts are normalized to match the official count after the first cut, MET Cleaning.

Signal Region Name	Official	MA5
NJets3-5, H_T500-800, $\not{H}_T$200-300	1.0	1.18
NJets3-5, H_T500-800, $\not{H}_T$300-450	1.8	1.77
NJets3-5, H_T500-800, $\not{H}_T$450-600	1.1	1.09
NJets3-5, H_T500-800, $\not{H}_T$>600	0.3	0.31
NJets3-5, H_T800-1000, $\not{H}_T$200-300	1.5	1.08
NJets3-5, H_T800-1000, $\not{H}_T$300-450	1.7	2.40
NJets3-5, H_T800-1000, $\not{H}_T$450-600	2.1	2.12
NJets3-5, H_T800-1000, $\not{H}_T$>600	1.2	1.43
NJets3-5, H_T1000-1250, $\not{H}_T$200-300	1.9	1.84
NJets3-5, H_T1000-1250, $\not{H}_T$300-450	3.1	3.23
NJets3-5, H_T1000-1250, $\not{H}_T$450-600	2.8	2.66
NJets3-5, H_T1000-1250, $\not{H}_T$>600	2.1	2.41
NJets3-5, H_T1250-1500, $\not{H}_T$200-300	1.3	1.35
NJets3-5, H_T1250-1500, $\not{H}_T$300-450	2.3	2.03
NJets3-5, H_T1250-1500, $\not{H}_T$>450	3.2	3.67
NJets3-5, H_T>1500, $\not{H}_T$200-300	1.1	1.06
NJets3-5, H_T>1500, $\not{H}_T$>300	3.7	3.77
NJets6-7, H_T500-800, $\not{H}_T$200-300	0.4	0.29
NJets6-7, H_T500-800, $\not{H}_T$300-450	0.4	0.32
NJets6-7, H_T500-800, $\not{H}_T$>450	0.2	0.15
NJets6-7, H_T800-1000, $\not{H}_T$200-300	1.2	1.06
NJets6-7, H_T800-1000, $\not{H}_T$300-450	1.9	1.73
NJets6-7, H_T800-1000, $\not{H}_T$>450	1.7	1.65
NJets6-7, H_T1000-1250, $\not{H}_T$200-300	3.1	2.66
NJets6-7, H_T1000-1250, $\not{H}_T$300-450	4.6	4.72
NJets6-7, H_T1000-1250, $\not{H}_T$>450	5.9	5.77
NJets6-7, H_T1250-1500, $\not{H}_T$200-300	2.7	2.89
NJets6-7, H_T1250-1500, $\not{H}_T$300-450	4.4	4.72
NJets6-7, H_T1250-1500, $\not{H}_T$>450	5.8	6.57
NJets6-7, H_T>1500, $\not{H}_T$200-300	2.7	3.01
NJets6-7, H_T>1500, $\not{H}_T$>300	9.2	10.94
NJets>7, H_T500-800, $\not{H}_T$>200	0.0	0.01
NJets>7, H_T800-1000, $\not{H}_T$>200	0.4	0.33
NJets>7, H_T1000-1250, $\not{H}_T$>200	2.3	2.50
NJets>7, H_T1250-1500, $\not{H}_T$>200	3.8	4.48
NJets>7, H_T>1500, $\not{H}_T$>200	6.0	7.84

Table 6: The signal region (SR) counts in CMS SUS-13-012 for the T5VV scenario after all selection has been applied. Column 2 is the official account obtained through generous correspondence with Christian Sanders, and our own results displayed in column 3. These counts were determined by applying the SR selection to the end of the cut flow featured in table 5.

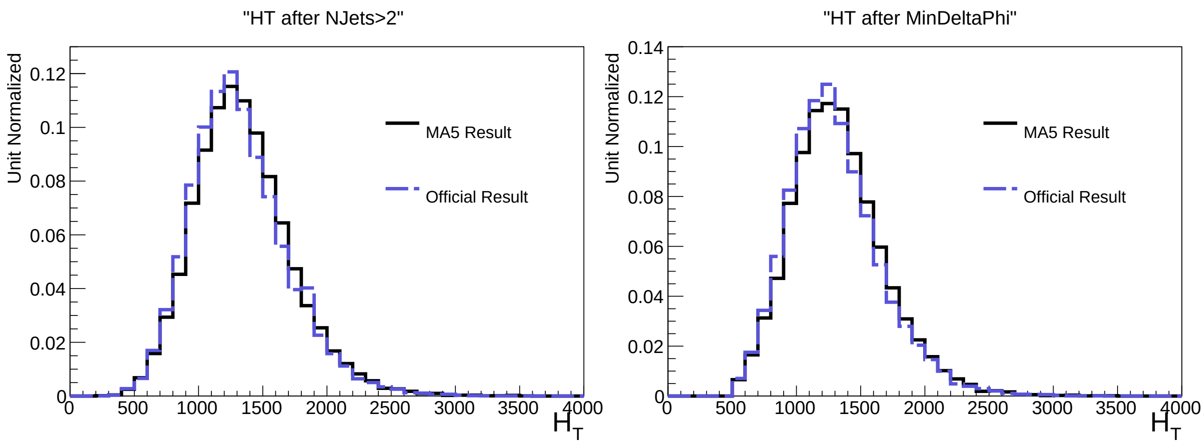

Figure 12: Comparison of the distributions of H_T between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T5VV working point.

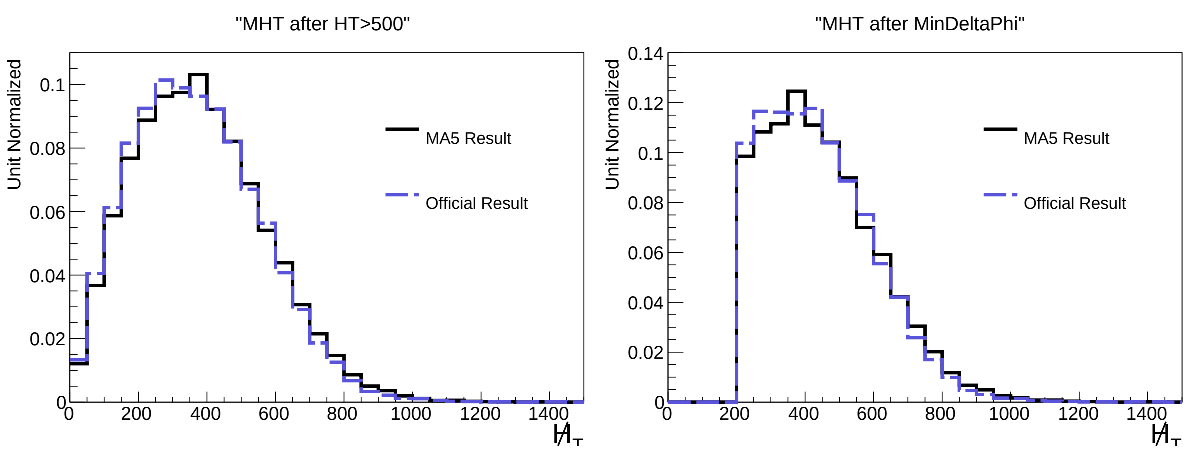

Figure 13: Comparison of the distributions of $\not{H}_T$ between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T5VV working point.

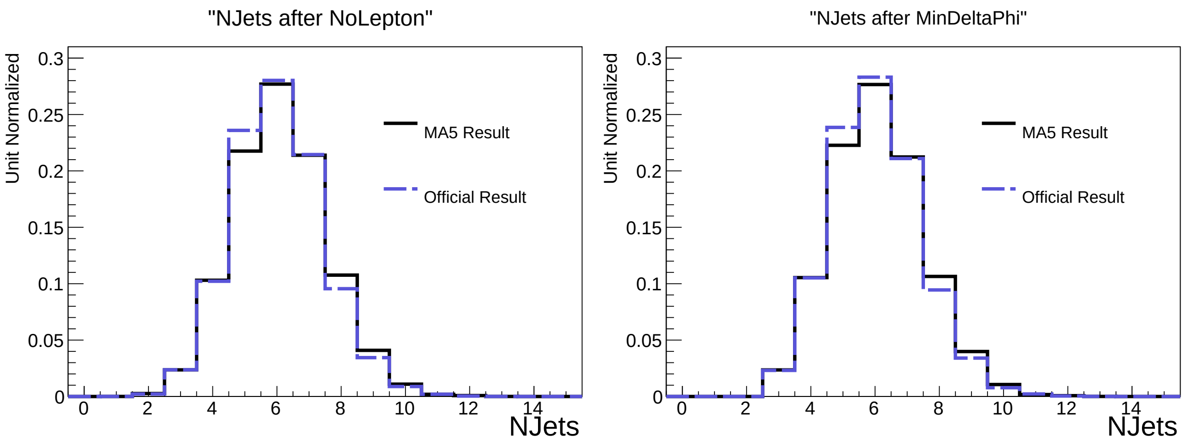

Figure 14: Comparison of the distributions of NJets between the official and our own samples after the “n-1” cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T5VV working point.

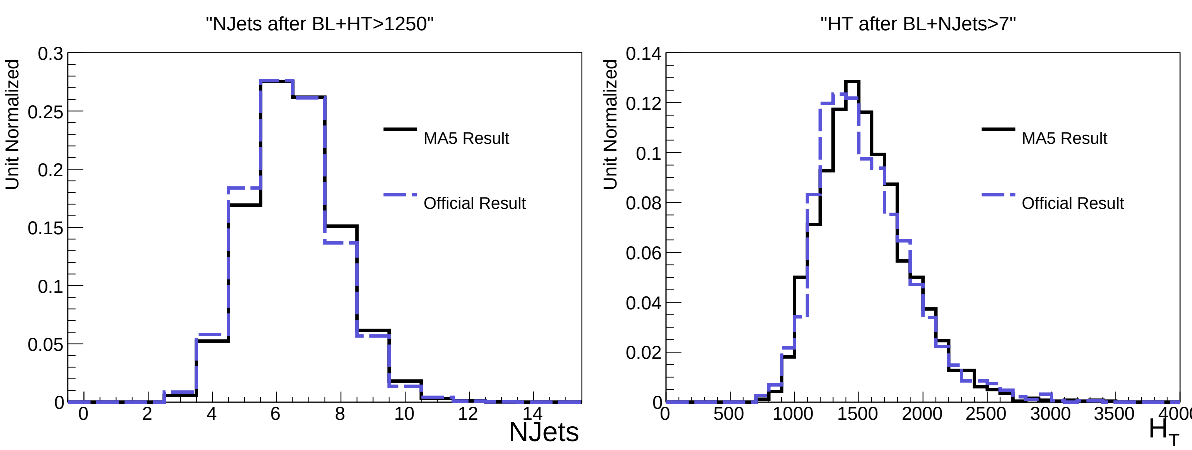

Figure 15: Additional checks: comparison between ours and the official distributions of NJets after BL+H_T>1250 cuts (left), and H_T after BL+NJets>7 cuts (right), for the T5VV working point.

4 T2qq simplified model

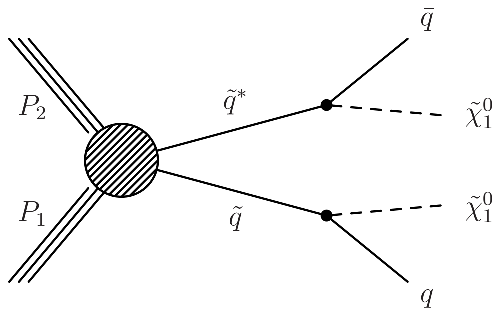

Figure 16: Diagram of the dominant SUSY production mechanism for the T2qq working point.

Cut Name	Official Count (Eff)	MA5 Count (Eff)
MET Cleaning	1215.2 (xxx)	1215.2 (xxx)
No Lepton	1212.8 (99%)	1215.2 (100%)
NJets>2	675.9 (55%)	691.54 (56%)
H_T>500	619.5 (91%)	638.41 (92%)
$\not{H}_T$>200	524.0 (84%)	539.59 (84%)
Min $\Delta(\phi)$	460.7 (87%)	476.12 (88%)

Table 7: The cut flow for the baseline selection in CMS SUS-13-012 for the T2qq working point $(m_{\tilde{q}}, m_{\tilde{\chi}_1^0}) = (700, 100)$ GeV. The second column is the official account as reported by https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS13012/T2qq.pdf, and our own results are given in column 3. The official counts are normalized to luminosity $\mathcal{L} = 19.5$/fb and cross section $\sigma = 63.4$ pb, and our counts are normalized to match the official count after the first cut, MET Cleaning.

Signal Region Name	Official	MA5
NJets3-5, H_T500-800, $\not{H}_T$200-300	35.3	35.10
NJets3-5, H_T500-800, $\not{H}_T$300-450	70.4	73.44
NJets3-5, H_T500-800, $\not{H}_T$450-600	71.5	73.82
NJets3-5, H_T500-800, $\not{H}_T$>600	23.6	28.78
NJets3-5, H_T800-1000, $\not{H}_T$200-300	18.1	17.20
NJets3-5, H_T800-1000, $\not{H}_T$300-450	21.9	32.19
NJets3-5, H_T800-1000, $\not{H}_T$450-600	38.1	38.14
NJets3-5, H_T800-1000, $\not{H}_T$>600	35.2	36.74
NJets3-5, H_T1000-1250, $\not{H}_T$200-300	10.9	12.15
NJets3-5, H_T1000-1250, $\not{H}_T$300-450	21.7	20.31
NJets3-5, H_T1000-1250, $\not{H}_T$450-600	20.7	21.54
NJets3-5, H_T1000-1250, $\not{H}_T$>600	21.8	23.59
NJets3-5, H_T1250-1500, $\not{H}_T$200-300	4.3	5.53
NJets3-5, H_T1250-1500, $\not{H}_T$300-450	8.1	7.85
NJets3-5, H_T1250-1500, $\not{H}_T$>450	16.1	16.86
NJets3-5, H_T>1500, $\not{H}_T$200-300	3.7	3.68
NJets3-5, H_T>1500, $\not{H}_T$>300	13.	13.45
NJets6-7, H_T500-800, $\not{H}_T$200-300	0.8	0.40
NJets6-7, H_T500-800, $\not{H}_T$300-450	1.0	0.44
NJets6-7, H_T500-800, $\not{H}_T$>450	0.4	0.44
NJets6-7, H_T800-1000, $\not{H}_T$200-300	0.5	0.58
NJets6-7, H_T800-1000, $\not{H}_T$300-450	1.1	1.26
NJets6-7, H_T800-1000, $\not{H}_T$>450	1.5	1.63
NJets6-7, H_T1000-1250, $\not{H}_T$200-300	1.0	0.61
NJets6-7, H_T1000-1250, $\not{H}_T$300-450	1.2	1.33
NJets6-7, H_T1000-1250, $\not{H}_T$>450	2.5	3.24
NJets6-7, H_T1250-1500, $\not{H}_T$200-300	0.6	0.61
NJets6-7, H_T1250-1500, $\not{H}_T$300-450	1.2	0.61
NJets6-7, H_T1250-1500, $\not{H}_T$>450	1.4	1.84
NJets6-7, H_T>1500, $\not{H}_T$200-300	0.6	0.30
NJets6-7, H_T>1500, $\not{H}_T$>300	2.3	1.80
NJets>7, H_T500-800, $\not{H}_T$>200	0.0	0.0
NJets>7, H_T800-1000, $\not{H}_T$>200	0.0	0.0
NJets>7, H_T1000-1250, $\not{H}_T$>200	0.2	0.27
NJets>7, H_T1250-1500, $\not{H}_T$>200	0.3	0.10
NJets>7, H_T>1500, $\not{H}_T$>200	0.3	0.13

Table 8: The signal region (SR) counts in CMS SUS-13-012 for the T2qq scenario after all selection has been applied. Column 2 is the official account obtained through generous correspondence with Christian Sanders, and our own results displayed in column 3. These counts were determined by applying the SR selection to the end of the cut flow featured in table 7.

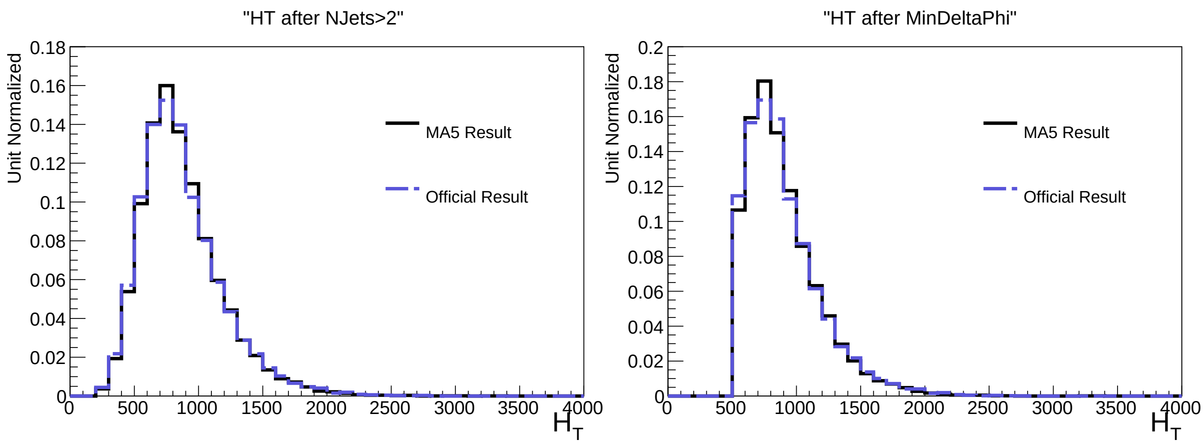

Figure 17: Comparison of the distributions of H_T between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T2qq working point.

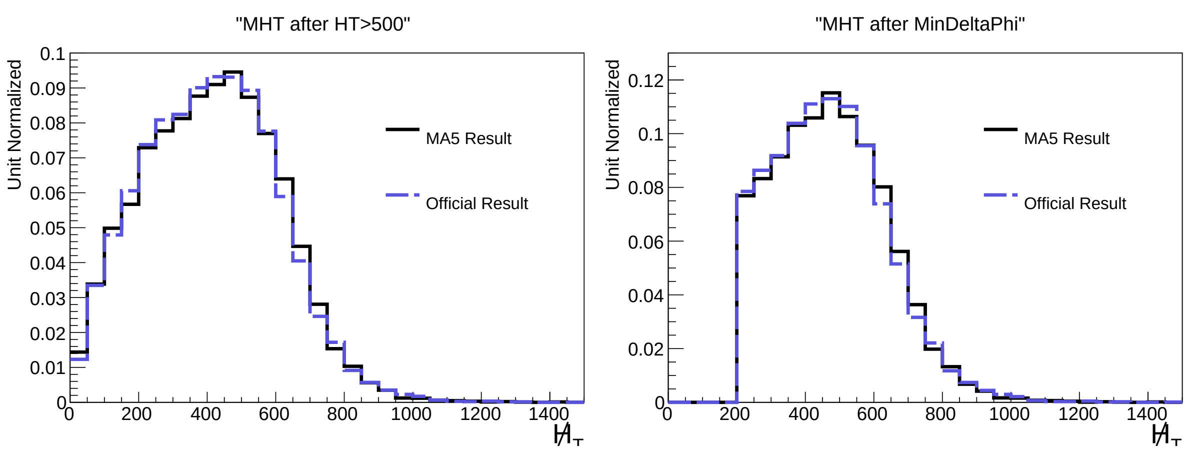

Figure 18: Comparison of the distributions of $\not{H}_T$ between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T2qq working point.

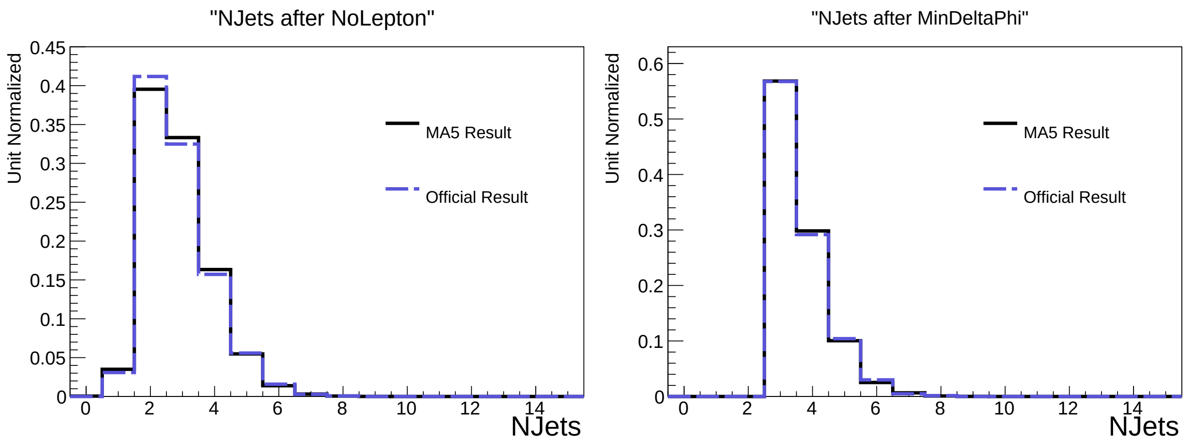

Figure 19: Comparison of the distributions of NJets between the official and our own samples after the "n-1" cut, Min $\Delta(\phi)$ (left), and after all baseline cuts (right), for the T2qq working point.

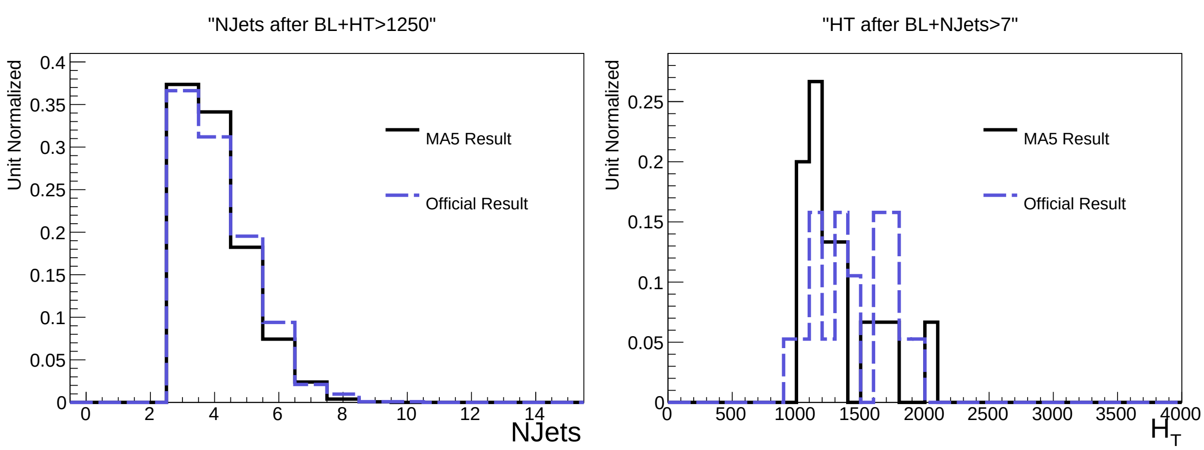

Figure 20: Additional checks: comparison between ours and the official distributions of NJets after BL+H_T>1250 cuts (left), and H_T after BL+NJets>7 cuts (right), for the T2qq working point.

5 Exclusion Limits

It is also instructive to reproduce the 95% CL exclusion lines in the ($m_{\tilde{g}}$, $m_{\tilde{\chi}_1^0}$) and ($m_{\tilde{q}}$, $m_{\tilde{\chi}_1^0}$) mass planes. Figure 21 shows the limit curves (in red) obtained with our MadAnalysis 5 implementation and using the `exclusion_CLs.py` code described in arXiv:1407.3278 superimposed on the official CMS exclusion with its $\pm 1\sigma$ theoretical uncertainty (solid and dashed black lines). For the T1qqqq ($\tilde{g} \to q\bar{q}\chi_1^0$) and T5VV ($\tilde{g} \to q\bar{q}V\chi_1^0$) simplified models, the limits are reproduced very well. Also for T1tttt ($\tilde{g} \to t\bar{t}\chi_1^0$) the agreement is reasonably fine. For T2qq ($\tilde{q} \to q\chi_1^0$), however, we encounter a rather erratic behavior for LSP masses above about 200–250 GeV.

It should be noted that our limit setting procedure differs from that used by CMS, and so should be considered a rough estimate. Our procedure is as follows. For any given point on the mass plane, the production cross section is taken from the LHC SUSY cross sections twiki and the signal acceptance is computed with our MadAnalysis 5 recast code for the analysis. Then, the most sensitive signal region (SR), out of the 36 total SRs, is determined based on the number of expected signal and background counts. Finally, the CLs exclusion value is determined from the expected signal, expected background, expected uncertainty on the background, and observed counts in the most sensitive SR.

The primary difference between our method and that used by CMS is that we consider only the most sensitive SR in the exclusion calculation, whereas CMS uses all signal regions simultaneously and considers correlations in the uncertainty between signal regions. This difference introduces a certain volatility in our exclusion limits, which can however be mitigated by demanding that jumps in exclsusion between two neighbouring points close in mass be not too large. As can be seen in Fig.!21, we obtain excellent results for the T1qqqq and T5VV scenarios; the exclusion curve for T1tttt shows more fluctuations but none the less matches the official result reasonably well. The only problematic case is the T2qq topology with LSP masses above 200–250 GeV: here our procedure clearly does not well reproduce the official limit curve. To improve the situation, we would need the statistical model from CMS for combining the 36 SRs. Unfortunately, this is currently not available.

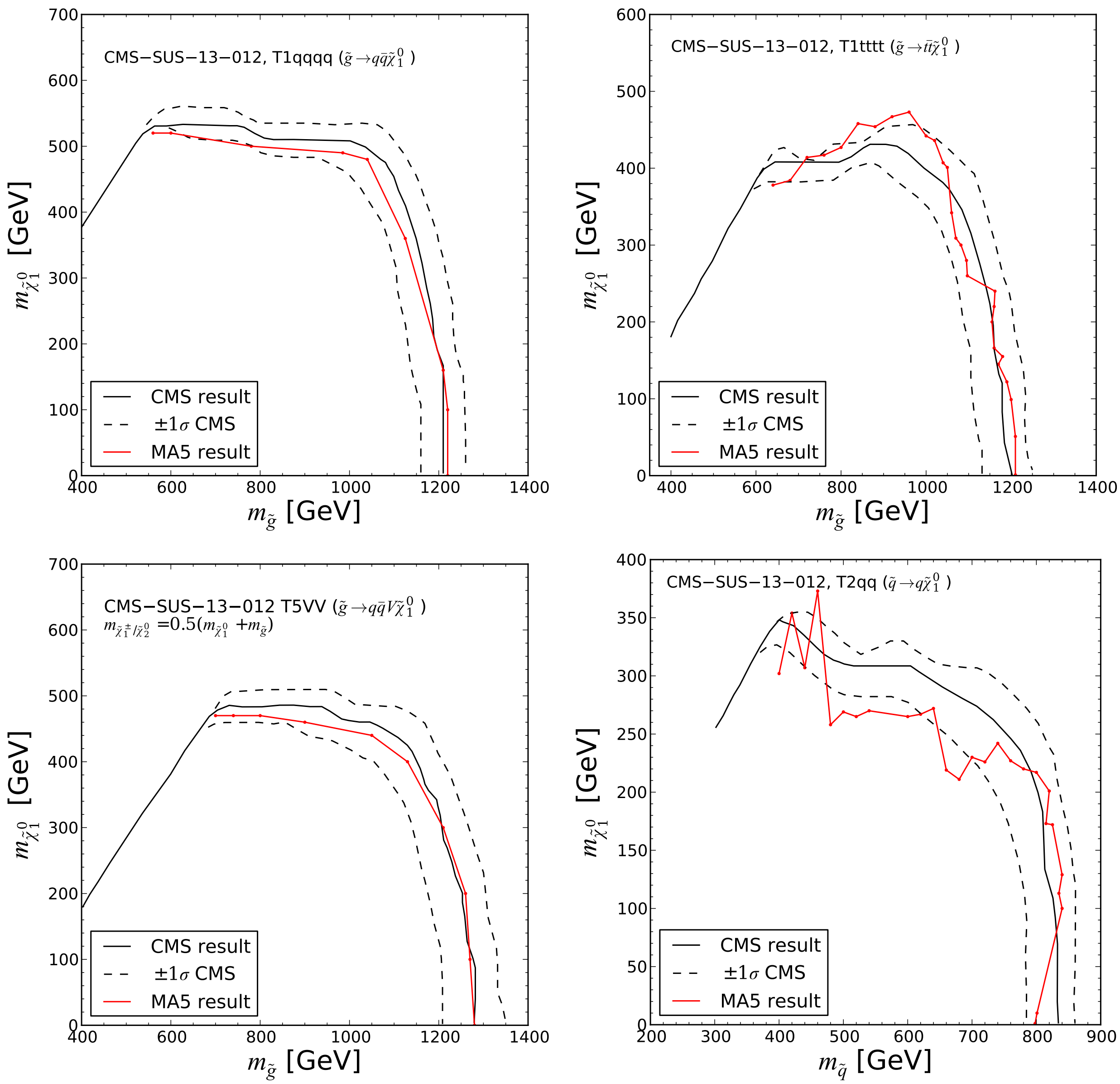

Figure 21: The 95% CL exclusion limits (in red) reproduced with our MadAnalysis 5 implementation compared to the official limits (in black) from CMS-SUS-13-012. Top left: T1qqqq, top right: T1tttt, bottom left: T5VV, bottom right: T2qq simplified models.