Validation of the MadAnalysis5 implementation of the ATLAS 2-6 jet analysis arXiv:1405.7875

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This ATLAS analysis [1] searches for new physics in the 0 lepton + multi-jets (2-6 jets) + missing energy (E_T^{miss}) final state. The dataset corresponds to 20.3 fb^{-1} of integrated luminosity at $\sqrt{\mathrm{s}} = 8$ TeV. In the context of supersymmetry, the analysis targets gluino pair production ($\tilde{\mathrm{g}}\tilde{\mathrm{g}}$), squark pair production ($\tilde{\mathrm{q}}\tilde{\mathrm{q}}$), and squark gluino production($\tilde{\mathrm{q}}\tilde{\mathrm{g}}$). For each of the production modes the following cases are investigated;

- Gluino pair production :
  1. Direct: $\tilde{\mathrm{g}} \to \mathrm{q}\bar{\mathrm{q}}\tilde{\chi}_1^0$.
  2. One step: $\tilde{\mathrm{g}} \to \mathrm{q}\mathrm{q}'\tilde{\chi}_1^{\pm}$ followed by $\tilde{\chi}_1^{\pm} \to \mathrm{W}\tilde{\chi}_1^0$
- Squark pair production :
  1. Direct : $\tilde{\mathrm{q}} \to \mathrm{q}\tilde{\chi}_1^0$.
  2. One step : $\tilde{\mathrm{q}} \to \mathrm{q}'\tilde{\chi}_1^{\pm}$ followed by $\tilde{\chi}_1^{\pm} \to \mathrm{W}\tilde{\chi}_1^0$
- Squark gluino production :
  1. Direct : $\tilde{\mathrm{g}} \to \mathrm{q}\bar{\mathrm{q}}\tilde{\chi}_1^0$, $\tilde{\mathrm{q}} \to \mathrm{q}\chi_1^0$.

For all of the above cases, all branching ratios are assumed to be 100 % and the rest of the spectrum is decoupled from this set.

The analysis has 15 signal regions in jet bins of 2-6 jets, with loose (l), medium (m) and tight (t) criteria. The SLHA files for the benchmark points are provided in [3] by the collaboration. The masses of the relevant particles corresponding to the benchmark points used to validate each of these signal regions are documented in Table 1.

The specific criteria for each signal region and the cuts employed for each of these signal regions are documented below. The cutflows for 13 signal regions are provided by the ATLAS collaboration in [2] Out of these 13 signal regions, our validation and recast code does not include the 2jW and the 3jW signal regions, which target at reconstructing the W bosons from chargino decays.

We use Madgraph5 (v-5.0.07) to generate signal events correspoding to each of these benchmark points. 100,000 events were generated for all the bennchmark points. All the processes at the production level were generated up to one additional parton at the matrix element level in Madgraph. The LHE files obtained were passed to PYTHIA6 (6.4.24) for showering and hadronization. A merging scale of 0.25 times the mass of the outgoing particles was applied, as is recommended by the ATLAS collaboration in [1]. The STDHEP file generated was passed on to delphesMA5 tune for detector simulation.

Jets were reconstructed with an anti-$\mathrm{k_T}$ algorithm with a jet radius of 0.4 and a transverse momentum threshold (p_T^j) of 20 GeV within $|\eta_j| < 2.8$. Leptons (electrons and muons) were selected with $p_T^l \geq 10\ GeV$, and $|\eta_l| \leq 2.5$. The isolation criteria for leptons as noted in the ATLAS paper [1] were implemented. Finally, leptons are vetoed with the above criteria. The cross sections for all the processes were obtained from [4].

The following basic cuts are applied, depending on the jet bin.

- $E_T^{miss} > 160\ GeV,\ p_T^{j1} > 130\ GeV,\ p_T^{j2} > 60\ GeV$ (Applied to all signal regions).
- $p_T^{j3,j4,j5,j6} > 60$ GeV (applied to all signal regions from the 3,4,5 and 6 jet bins respectively).
- $\Delta\phi^{j_{i\leq 3},E_T^{miss}} > 0.4$ (applied to all signal regions) .
- $\Delta\phi^{j_{i>3},\mathrm{E_T^{miss}}} > 0.2$, (applied to all signal regions from 4-6 jets respectively).

Additionally, signal regions specific cuts $E_T^{miss}/\sqrt{H_T}$, $E_T^{miss}/M_{eff}(N_J)$ and M_{eff}(incl) are applied. In the above cuts H_T is defined as the scalar sum of the transverse momenta of all jets greater than 40 GeV. While applying the cut $E_T^{miss}/M_{eff}(N_j)$, $M_{eff}(N_j)$ is defined as the sum of E_T^{miss} and the scalar sum of the transverse momenta of all jets upto N_j (with $p_T^J > \ 40\ GeV$), the number of jets specific to the signal region. However while applying the $M_{eff}(incl)$ cut, $M_{eff}(incl)$ is defined as the sum of transverse momenta of all jets in the event sample.

The signal region specific cuts are tabulated in Table 2. Hence a total of 10 cutflows were validated and are documented in Tables 3 –5 below.

From Tables 3-5, we can conclude that the agreement between MA5 results and official results is decent. In Table 3 (2 jet and 3 jet bins) we note that the numbers after the final cut agree to within 10 % of the official numbers (For the 3j bin, it is about 5 %). The agreement in individual cuts in this Table are also within 15 %. In Table 4 (for the 4 jet bin), the largest discrepancy in the final numbers occur for the 4jl- signal region, about 12 %. The other bins are agree within 10 %. The same can be concluded for Table 5, for the 5 and 6 jet bins.

References

[1] G. Aad *et al.* [ATLAS Collaboration], JHEP **1409** (2014) 176 [arXiv:1405.7875 [hep-ex]].

decay to LSP	2jm ($\tilde{q}\tilde{q}$)	2jt ($\tilde{q}\tilde{q}$)	3j ($\tilde{g}\tilde{q}$)	4jl- ($\tilde{q}\tilde{q}$)	4jl ($\tilde{g}\tilde{g}$)	4jt ($\tilde{g}\tilde{g}$)	5j1 ($\tilde{q}\tilde{q}$)	5j2 ($\tilde{g}\tilde{g}$)	6jl ($\tilde{q}\tilde{q}$)	6jt ($\tilde{g}\tilde{g}$)
	direct	direct	direct	direct	direct	direct	one step	direct	one step	one step
$m_{\tilde{q}/\tilde{g}}$	475	1000	1612	400	800	1425	665	1087	465	1265
$m_{\tilde{\chi}_1^{\pm}}$	–	–	–	–	–	–	465		385	945
$m_{\tilde{\chi}_1^0}$	425	100	337	250	650	75	265	562	305	625

Table 1: The benchmark scenarios used for the valiaion of the 10 signal regions. For the direct squark pair or gluino pair production, the rest of the spectrum is decoupled. For squark-gluino production, the gluino and squark masses are assumed to be degenerate. All masses are in GeV. The SLHA files were obtained from `http://hepdata.cedar.ac.uk/view/ins1298722`.

	2jm	2jt	3j	4jl-	4jl	4jt	5j1,5j2	6jl	6jt
$E_T^{miss}/\sqrt{H_T}$	15	15	–	10	10	–	–	–	–
$E_T^{miss}/M_{eff}(N_j)$	–	–	0.3	–	–	0.25	0.2	0.2	0.25
$M_{eff}(incl)$	1200	1600	2200	700	1000	2200	1200	900	1500

Table 2: The signal region specific cuts. All energy units are in GeV.

	2jm ($\tilde{q}\tilde{q}$)		2jt($\tilde{q}\tilde{q}$)		3j($\tilde{g}\tilde{q}$)	
cut	ATLAS	MA 5	ATLAS	MA 5	ATLAS	MA 5
$E_T^{miss} > 160$, $p_T^{j1,j2} > 130{,}60$	1781.2	1656.1	61.6	62.1	18.6	18.8
$+\ p_T^{j3} > 60$	–	–	–	–	14.8	15.1
$+\ \Delta\phi(j_i, E_T^{miss}) > 0.4$	1462.7	1295.9	55.7	56.9	12.9	13.3
$+\ E_T^{miss}/\sqrt{H_T}$	566.1	449.1	38.5	40.1	–	–
$+\ E_T^{miss}/M_{eff}(N_j)$	–	–	–	–	9.6	10.1
$+\ M_{eff}(incl)$	102.4	122.2	21.7	23.8	5.9	6.2

Table 3: Cutflows for signal regions 2jm,2jt and 3j, compared to the official ATLAS results documented in [1]. All energy units are in GeV.

	4jl-($\tilde{q}\tilde{q}$)		4jl($\tilde{g}\tilde{g}$)		4jt($\tilde{g}\tilde{g}$)	
cut	ATLAS	MA 5	ATLAS	MA 5	ATLAS	MA 5
$E_T^{miss} > 160$, $p_T^{j1,j2} > 130{,}60$	16135.8	15097	634.6	679.0	13.2	12.7
+ $p_T^{j3,j4} > 60$	2331	2112	211.4	185.7	12.0	12.0
+ $\Delta\phi(j_{i\leq 3}, E_T^{miss}) > 0.4$ $\Delta\phi(j4, E_T^{miss}) > 0.2$	1813.7	1723.0	154.6	144.9	8.4	8.9
+ $E_T^{miss}/\sqrt{H_T}$	1009	943	98.7	84.4	–	–
+ $E_T^{miss}/M_{eff}(N_j)$	–	–	–	–	4.8	5.5
+ $\mathrm{M_{eff}}$(incl)	884	843	39.5	41.5	2.5	2.9

Table 4: Cutflows for signal regions 4jl-,4jl and 4jt, compared to the official ATLAS results documented in [1].

	5j1($\tilde{q}\tilde{q}$)		5j2($\tilde{g}\tilde{g}$)		6jl($\tilde{g}\tilde{g}$)		6jt($\tilde{g}\tilde{g}$)	
cut	ATLAS	MA 5	ATLAS	MA 5	ATLAS	MA 5	ATLAS	MA 5
$E_T^{miss} > 160$, $p_T^{j1,j2} > 130{,}60$	317.3	262.2	190.4	190.4	451.3	913.6	27.9	28.8
+ $p_T^{j_i} > 60$	141.8	138.1	60.7	60.7	43.5	29	13.9	12.1
+ $\Delta\phi(j_{i\leq 3}, E_T^{miss}) > 0.4$ $\Delta\phi(j_i > 3, E_T^{miss}) > 0.2$	103.9	107.1	44.5	45.8	23.7	19.0	9.5	9.0
+ $E_T^{miss}/\sqrt{H_T}$	–	–	–	–	–	–	–	–
+ $E_T^{miss}/M_{eff}(N_j)$	85.6	91.9	38	39.2	20	17.4	5.7	5.7
+ $M_{eff}(incl)$	20.5	24.2	23.8	27.5	20	15.4	2.2	2.8

Table 5: Cutflows for signal regions 5j1,5j2, 6jl and 6jt compared to the official ATLAS results documented in [1].

[2] https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2013-02/.

[3] http://hepdata.cedar.ac.uk/view/ins1298722

[4] https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections#SUSY_Cross_Sections_us