Validation note for the MadAnalysis5 implementation of the multijet analysis of ATLAS (arXiv: 1605.03814)

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I. INTRODUCTION

In this note we describe the validation of the implementation in MadAnalysis5 (MA5) framework [1–3] of the ATLAS's multijet+MET analysis presented in [4]. We have used the version MA5 1.5.5 jointly with the standard Delphes3 program [5] that we have run from the MA5 platform. The validation has been achieved on the basis of three benchmarks that have been provided ATLAS, for which we have generated hard scattering events with the MadGraph5_aMC@NLO program [6]. We have then matched those events with the parton showering and hadronisation infrastructure of Pythia 8 [7, 8]. The necessary configuration files and UFO model [9] have been provided by ATLAS and can be found on the public analysis database webpage of Madanalysis,
`http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase`
together with the detector card that we have used for the simulation of the detector. This card is the standard one provided with MA5.

The ATLAS multijet search relies on an integrated luminosity of 3.2 fb^{-1} of proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 13$ TeV. The analysis contains 7 inclusive signal regions (SRs) covering jet multiplicities from two to six, with jets having $p_T > 50$ GeV and the missing energy of the event required to be larger than 200 GeV. Events are further discarded if a baseline electron or muon with $p_T > 10$ GeV remains. Some of the SRs require the same jet multiplicity, but are distinguished by increasing background rejection through cuts in variables like: p_T of the leading jets, $\Delta\phi$ between jets and missing energy, and the effective mass variable m_{eff}, among others (see details below).

II. SIMULATION DETAILS

The analysis interpretation used for the present validation is the MSSM scenario, whose UFO model is included by default in MadGraph5_aMC@NLO (version 1.5.13). We have considered the three benchmarks utilised by the collaboration, which are defined by:

- Benchmark#1: gluino pair production, with $m_{\text{gluino}} = 1600$ GeV and $m_N = 0$ GeV
- Benchmark#2: gluino pair production, with $m_{\text{gluino}} = 1100$ GeV and $m_N = 700$ GeV
- Benchmark#3: squark pair production, with $m_{\text{squark}} = 1000$ GeV and $m_N = 400$ GeV ,

where m_{gluino}, m_{squark} and m_N are the gluino, squark and neutralino dark matter masses, respectively. The rest of the SUSY particle spectrum is decoupled from this set. We have generated the multijet signal events by typing in the MadGraph interpreter:

```
generate p p > go go $ susysq susysq~ @1
add process p p > go go j $ susysq susysq~ @2
add process p p > go go j j $ susysq susysq~ @3
```

for benchmarks #1 and #2 (gluino pair production), and

```
generate p p > susysq susysq~ $ go @1
add process p p > susysq susysq~ j $ go @2
add process p p > susysq susysq~ j j $ go @3
```

for benchmark #3 (squark pair production). Here `go` represents the gluinos and `susysq` the squarks, each of them producing a decay chain which give rise to dark matter in the form of missing energy.

At the generator level, we have imposed all jets to have a transverse momentum larger than 20 GeV. We have moreover enforced the use of the leading order set of NNPDF23 [10–13] parton densities. The merging is performed in Pythia 8 following the CKKW-L [14, 15] procedure. Those requirements have been implemented by modifying the following lines of the standard run_card.dat file:

Selections	benchmark # 1		benchmark # 2		benchmark # 3	
	MA5	Official	MA5	Official	MA5	Official
Preselection, $E_T^{\rm miss} > 200$ GeV, $p_T(\text{jet}_1) > 200$ GeV	0.92	0.90	0.63	0.58	0.86	0.85
Jet multiplicity	1.00	1.00	1.00	1.00	0.98	0.99
$\min\Delta\phi(E_T^{\rm miss}, \text{jet})$ cut	0.61	0.61	0.71	0.71	0.79	0.79
$p_T(\text{jet}_2)$ cut	0.99	0.99	0.49	0.52	0.76	0.75
$E_T^{\rm miss}/\sqrt{H_T}$ cut	0.53	0.54	0.35	0.34	0.64	0.64
$m_{\rm eff}(\text{incl.})$ cut	1.00	1.00	0.76	0.74	0.93	0.91

TABLE I: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region `Seraglio`.

Selections	benchmark # 1		benchmark # 2		benchmark # 3	
	MA5	Official	MA5	Official	MA5	Official
Preselection, $E_T^{\rm miss} > 200$ GeV, $p_T(\text{jet}_1) > 300$ GeV	0.91	0.90	0.37	0.35	0.79	0.77
Jet multiplicity	1.00	1.00	1.00	1.00	0.98	0.99
$\min\Delta\phi(E_T^{\rm miss}, \text{jet})$ cut	0.80	0.80	0.83	0.83	0.90	0.89
$p_T(\text{jet}_2)$ cut	1.00	1.00	1.00	1.00	1.00	1.00
$E_T^{\rm miss}/\sqrt{H_T}$ cut	0.48	0.48	0.40	0.40	0.65	0.66
$m_{\rm eff}(\text{incl.})$ cut	0.99	0.99	0.28	0.28	0.52	0.47

TABLE II: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region `Masaryk`

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```
'nn23lo1' = pdlabel
20        = ptj
0         = ickkw
362.5     = ktdurham
0.4       = dparameter
```

where in a later stage the `ktdurham` and `dparameter` are read by `Pythia 8` as described in
`http://home.thep.lu.se/Pythia/pythia82html/MatchingAndMerging.html`
which also produced the hadron-level events. The pythia code on top of which we have worked is the `main89.cc` example, as shown in the pythia cards using for merging and hadronisation, as can be found on
`http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase`
Finally, we simulate the detector response with `Delphes3`, using the `MA5` ATLAS detector card.

III. RESULTS

A. Cut-flow

The selection strategy of the ATLAS multijet analysis consists of two preselection cuts, one on the p_T of the hardest jet, and the second one on the missing energy, $E_T^{\rm miss}$. Also, a lepton veto is required for all the events. We have ignored the 'LooseBad' and 'TightBad' criteria used in the original analysis, since they are said to affect less than 1% of the events used in the search. For each cut, we have calculated the related efficiency defined as

$$\epsilon_i = \frac{n_i}{n_{i-1}} ,$$

where n_i and n_{i-1} mean the event number after and before the considered cut, respectively. We have found that all selection steps are properly described by the MA5 implementation, showing an agreement greater than 80% for all the cuts and signal regions. Tables I-VII show the cut-flows of the seven signal regions, comparing the 'official' (ATLAS) result with the MA5 result, for the three benchmarks defined above.

Selections	benchmark # 1		benchmark # 2		benchmark # 3	
	MA5	Official	MA5	Official	MA5	Official
Preselection, $E_T^{\text{miss}} > 200$ GeV, $p_T(\text{jet}_1) > 200$ GeV	0.92	0.90	0.63	0.58	0.86	0.85
Jet multiplicity	1.00	1.00	1.00	1.00	0.98	0.99
$\min\Delta\phi(E_T^{\text{miss}}, \text{jet})$ cut	0.61	0.61	0.71	0.71	0.79	0.79
$p_T(\text{jet}_2)$ cut	0.99	0.99	0.49	0.52	0.76	0.75
$E_T^{\text{miss}}/\sqrt{H_T}$ cut	0.31	0.31	0.11	0.11	0.39	0.40
$m_{\text{eff}}(\text{incl.})$ cut	0.96	0.96	0.21	0.20	0.21	0.19

TABLE III: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region `Strict`.

Selections	benchmark # 1		benchmark # 2		benchmark # 3	
	MA5	Official	MA5	Official	MA5	Official
Preselection, $E_T^{\text{miss}} > 200$ GeV, $p_T(\text{jet}_1) > 200$ GeV	0.92	0.90	0.63	0.58	0.86	0.85
Jet multiplicity	0.95	0.95	0.76	0.79	0.36	0.35
$\min\Delta\phi(E_T^{\text{miss}}, \text{jet})$ cut	0.69	0.70	0.78	0.78	0.82	0.81
$p_T(\text{jet}_2)$ cut	1.00	1.00	0.98	0.98	0.99	0.98
$p_T(\text{jet}_4)$ cut	0.88	0.88	0.44	0.43	0.37	0.36
Aplanarity cut	0.68	0.68	0.67	0.68	0.60	0.57
$E_T^{\text{miss}}/m_{\text{eff}}(\text{Nj})$ cut	0.71	0.71	0.95	0.93	0.86	0.89
$m_{\text{eff}}(\text{incl.})$ cut	0.85	0.85	0.04	0.04	0.25	0.23

TABLE IV: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region `SR4jt`.

Selections	benchmark # 1		benchmark # 2		benchmark # 3	
	MA5	Official	MA5	Official	MA5	Official
Preselection, $E_T^{\text{miss}} > 200$ GeV, $p_T(\text{jet}_1) > 200$ GeV	0.92	0.90	0.63	0.58	0.86	0.85
Jet multiplicity	0.73	0.71	0.44	0.46	0.14	0.13
$\min\Delta\phi(E_T^{\text{miss}}, \text{jet})$ cut	0.67	0.68	0.75	0.75	0.77	0.78
$p_T(\text{jet}_2)$ cut	1.00	1.00	0.99	0.99	0.99	0.99
$p_T(\text{jet}_4)$ cut	0.93	0.92	0.58	0.57	0.56	0.55
Aplanarity cut	0.71	0.71	0.71	0.71	0.65	0.62
$E_T^{\text{miss}}/m_{\text{eff}}(\text{Nj})$ cut	0.48	0.49	0.65	0.65	0.69	0.73
$m_{\text{eff}}(\text{incl.})$ cut	0.99	0.99	0.30	0.30	0.75	0.76

TABLE V: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region `SR5j`.

Selections	benchmark # 1		benchmark # 2		benchmark # 3	
	MA5	Official	MA5	Official	MA5	Official
Preselection, $E_T^{\text{miss}} > 200$ GeV, $p_T(\text{jet}_1) > 200$ GeV	0.92	0.90	0.63	0.58	0.86	0.85
Jet multiplicity	0.45	0.41	0.19	0.20	0.04	0.04
$\min\Delta\phi(E_T^{\text{miss}}, \text{jet})$ cut	0.65	0.64	0.71	0.71	0.73	0.75
$p_T(\text{jet}_2)$ cut	1.00	1.00	0.99	0.99	1.00	1.00
$p_T(\text{jet}_4)$ cut	0.96	0.95	0.71	0.70	0.71	0.71
Aplanarity cut	0.76	0.75	0.75	0.73	0.69	0.69
$E_T^{\text{miss}}/m_{\text{eff}}(\text{Nj})$ cut	0.42	0.45	0.57	0.54	0.71	0.68
$m_{\text{eff}}(\text{incl.})$ cut	1.00	0.99	0.41	0.42	0.85	0.82

TABLE VI: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region `SR6jm`.

Selections	benchmark # 1		benchmark # 2		benchmark # 3	
	MA5	Official	MA5	Official	MA5	Official
Preselection, $E_T^{\rm miss} > 200$ GeV, $p_T(\rm jet_1) > 200$ GeV	0.92	0.90	0.63	0.58	0.86	0.85
Jet multiplicity	0.45	0.41	0.19	0.20	0.04	0.04
min$\Delta\phi(E_T^{\rm miss}, \rm jet)$ cut	0.65	0.64	0.71	0.71	0.73	0.75
$p_T(\rm jet_2)$ cut	1.00	1.00	0.99	0.99	1.00	1.00
$p_T(\rm jet_4)$ cut	0.96	0.95	0.71	0.70	0.71	0.71
Aplanarity cut	0.76	0.75	0.75	0.73	0.69	0.69
$E_T^{\rm miss}/m_{\rm eff}(\rm Nj)$ cut	0.61	0.63	0.82	0.81	0.85	0.80
$m_{\rm eff}(\rm incl.)$ cut	0.95	0.93	0.12	0.13	0.55	0.46

TABLE VII: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region `SR6jt`.

IV. CONCLUSION

We have validated our reimplementation of the ATLAS multijet analysis presented in [4] by making use of `MadGraph` and `Pythia 8` to simulate the events that can be compared to results provided by ATLAS. We have employed the standard `Delphes3` program for the modeling of the detector simulation, with the ATLAS detector card shipped with `MadAnalysis5`. Our results agree between 84%-100% with the ATLAS numbers, with the majority of the efficiencies having an agreement greater than 90%.

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