Recasting activities at LH2017

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Abstract

We discuss a first benchmark comparison assessing the performance of different public recasting tools in reproducing ATLAS and CMS analysis results.

1. Introduction

Searches for new physics constitute a primary objective of the LHC physics program. Their large number and variety pose severe challenges to both the experimental and theory communities. In fact, a plethora of searches in different final states are performed by different physics groups in ATLAS and CMS, while new ideas to probe new models and non-trivial signatures and to improve the sensitivity of existing searches constantly emerge. The ultimate goal of this effort is to discover new physics if such exists within the reach of the LHC, and to test the widest possible range of hypothetical new physics models.

A typical analysis defines quantities to classify events as signal or background. They include properties of analysis objects such as jets, electrons, muons, or global event variables such as object multiplicities, transverse momenta or transverse masses. An analysis can be very complex and feature many intricate definitions of object and event variables, some of which cannot be expressed in closed algebraic form and must be defined algorithmically. This complexity renders the tasks of visualizing, understanding, developing and interpreting analyses increasingly challenging.

In the paper publications describing the analyses and their results, the experimental collaborations provide interpretations of the results in terms of one or more theoretical scenarios the analysis has been designed for. Often this is done in the context of so-called simplified models, which consider just a subset of physics states and production/decay modes out of a full theory. There are, however, a multitude of theories beyond the Standard Model and they come in ever increasing variants. To fully assess the implications of the LHC searches for new physics requires the interpretation of the experimental results in the context of all these models. This is a very active field with close theory-experiment interaction, see e.g. [1], and with several public tools being developed for the (re)interpretation of the experimental results.[1] In particular, CheckMate [5,6], MadAnalysis [7–9] and Rivet [10,11] aim at reproducing experimental analyses in Monte Carlo simulation, including an approximate emulation of detector effects, as new physics searches, which have given only null results so far, are typically not unfolded. The scope of this contribution is to provide a first benchmark to compare different public tools in reproducing ATLAS and CMS analysis results.[2]

2. Benchmarking tools and comparison strategy

The idea behind the exercise described in this section is the implementation of LHC analyses of increasing complexity, in different frameworks followed by a comparison of the results. The exercise is

[1]This includes also dedicated efforts at Les Houches to provide "Recommendations for Presentation of LHC Results" [2–4].

[2]It is highly appreciated that many of these results are provided numerically through HEPDATA [12] or on the collaboration twiki pages.

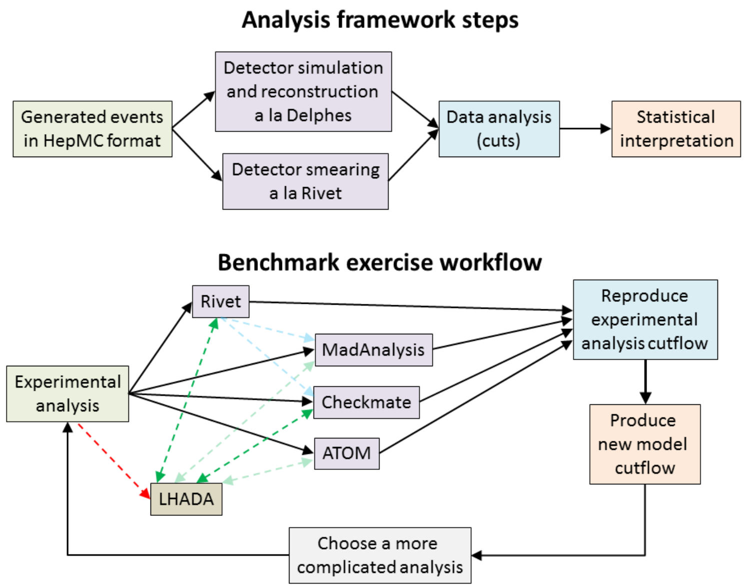

Fig. 1: Sketch of the recasting exercise workflow.

performed with three frameworks, CheckMate [5, 6], MadAnalysis [7–9] and Rivet [10, 11], followed by a comparison of the results. We choose two analyses for which a detailed cutflow and detector effects were available. In the future it might be beneficial to use dedicated parsers to convert the analysis described in a common format (denoted LHADA in Fig. 1) into different recasting codes using for instance the technique described in Contribution **??**. Once the analysis are available in the needed format, we attempt to reproduce the new physics interpretations presented in the original experimental research papers, validating in this way our reimplementations. A further step consists in the recasting of the analyses within different new physics contexts and compare the results among the different frameworks. A sketch of the recasting exercise workflow is presented in Fig. 1.

Aside the current scope of the exercise, it is interesting to check how the performance of the Delphes simulation behave across different phase spaces, since they are generally referred to as analysis-spedfic.

2.1 Analysis frameworks and tools

In this section we describe the analysis frameworks and tools used for the comparison and benchmarking

2.11 CheckMate

CheckMATE [5, 6] takes simulated event files in .hep or .hepmc for any model as input and simply returns if the underlying model is 'excluded' or 'allowed' after performing a detector simulation and testing various implemented analyses. The embedded AnalysisManager allows for the embedding of additional current and prospective future LHC results from ATLAS and CMS which have not yet been implemented. Detector effects are modeled by Delphes with a tune containing efficiency functions for lepton reconstruction and flavour tagging. The soon-to-be published version 2.0 of the code adds the possibility of using Pythia 8 [13] to generate supersymmetric events on-the-fly or to shower provided Les Houches event files for any model. Currently, the collaboration is working on an extension to enable the on-the-fly simulation of events for any model.

2.12 MadAnalysis

MadAnalysis 5 [7,8] is a generic user-friendly framework for phenomenological investigations at particle colliders, *i.e.* to perform physics analyses of Monte Carlo event files. While prospective analyses of hard scattering events, parton showered events, hadronized events or reconstructed events can be designed easily thanks to its Python-based meta-language, MadAnalysis also allows for the recasting of LHC analyses on new physics signals provided under the form of .hep and .hepmc event files. The output here consists in the confidence level at which the model signals are excluded. Its Public Analysis Database [9] comprises a growing collection of LHC analyses which have been implemented in the MadAnalysis 5 framework for the purpose of recasting. Delphes is used for the detector simulation. For each implemented analysis, a detailed validation note is provided and the public analysis database follows an open-source policy. Only contributed codes provided with a detailed validation note are published, and they are moreover citable via Inspire. The framework being integrated within MadGraph5_aMC@NLO [14], it provides a full recast chain linking a model and its associated signatures to limit setting.

2.13 Rivet

Originally developed as a toolkit for the validation of Monte Carlo event generators, Rivet [10, 11] (Robust Independent Validation of Experiment and Theory) has become a standard for documenting (unfolded) Standard Model (SM) measurements. The top and Higgs physics working groups of all LHC experiments are increasingly providing Rivet routines for their analyses. Rivet analyses are written in a user-friendly subset of C++11, and are picked up at runtime as 'plugin libraries'; they can be executed on an event stream either through a Python script interface, or by direct code interfacing to a C++ API. The original SM-focused requirement of unfolded observables made Rivet inappropriate for beyond the Standard Model (BSM) searches (other than those using just jets and missing energy) until the addition of detector-smearing/efficiency machinery in Rivet 2.5.0. This detector machinery provides equivalent efficiency effects to a Delphes-type simulation, and imitates the less important kinematic smearing of physics objects to within a few percent. A novel feature is that the Rivet detector implementation allows for using different jet algorithms, lepton and b-tagging operating points, full-detailed object isolation algorithms, and resolutions/efficiencies specific to each analysis procedure and event selection. This hence allows for a more accurate detector modelling and more robust analysis preservation than 'global' detector simulations in addressing some experiment requests for 'official fast-sim' tools. The aim is to encourage Rivet code provision directly from BSM data analysers, as is already the case for SM results: additional tools to assist BSM analysis implementation are being added on request.

3. Analyses benchmarking, comparisons and results

3.1 An ATLAS search for supersymmetry in a final state with jets and missing energy (13 TeV, 3.2 fb^{-1})

In the analysis of Ref. [15], the ATLAS collaboration targets the production of the strongly-interacting superpartners of the Standard Model QCD partons, followed by their decay into jets and missing energy carried by neutralinos. 3.2 fb^{-1} of proton-proton LHC collisions at a center-of-mass energy of 13 TeV are analyzed.

The analysis focuses on jets reconstructed by means of the anti-k_T algorithm [16] with a radius parameter set to $R = 0.4$, with a transverse momentum larger than 20 GeV and a pseudorapidity $|\eta| < 2.8$. Events featuring loosely reconstructed electrons and muons are vetoed. Event preselection requires a significant amount of missing energy, $\not\!\!E_T > 200$ GeV and the transverse-momentum of the leading jet is imposed to be larger than 200 GeV and 300 GeV if two or more than two jets are reconstructed, respectively.

The analysis is then divided into seven signal regions focusing on different jet multiplicities (from 2 to 6) with different transverse-momentum thresholds. The missing transverse momentum is then enforced to be well separated from the leading reconstructed jets, and its significance is constrained for events featuring only two jets. For cases where at least four jets are reconstructed, additional selections on the aplanarity variable and the effective mass, *i.e* the scalar sum of the transverse momenta of the reconstructed and the missing transverse energy.

Implementations of this analysis are available in Checkmate, MadAnalysis 5 (recast code [17]) and Rivet (ATLAS_2016_I1458270 [18]).

We generated signal events for a gluino pair production in the simplified model considered in Ref [15] with a direct decay of the gluino into SM particles and the lighest supersymmetric particle (LSP). The gluino mass is set to 1.6 TeV mass and the LSP is assumed to be massless. The pseudo-data samples have been generated by using MadGraph5_aMC@NLO [14] and Pythia8 [19].

The comparison of predictions for the cutflows as obtained with MadAnalysis 5 and Rivet are reported in Table 1 and Table 2 for all seven signal regions. The tables include the total number of events surviving each selection, the associated cut efficiency and the total efficiency evaluated with respect to the initial number of events. Partially available Checkmate results are also indicated for what concern the total efficiencies and for a few signal regions. An excellent agreement between the three codes has been obtained.

3.2 An ATLAS search for dark matter in the monophoton final state (13 TeV, 36.1 fb^{-1})

In the analysis of Ref. [20], the ATLAS collaboration has searched for dark matter when it is produced in association with a very energetic photon. The search results have been reinterpreted in dark matter simplified scenarios in which a pair of dark matter particles is produced in association with a photon arising from initial state radiation. 36.1 fb^{-1} of proton-proton LHC collisions at a center-of-mass energy have been analyzed.

The analysis requires the presence of at least one tightly-isolated photon with a transverse energy $E_T >$ 150 GeV and with a pseudorapidity satisfying $|\eta| < 2.37$, the pseudorapidity region $1.37 < |\eta| < 2.37$

	Rivet			**MadAnalysis 5**			**CheckMATE**
Description	#evt	tot.eff	rel.eff	#evt	tot.eff	rel.eff	tot.eff
2jl cut-flow	31250	1	-	31250	1	-	
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	
Njet	28592	0.91	1	28625	0.92	1	
Dphi_min(j,MET)	17297	0.55	0.6	17301	0.55	0.6	
pT2	17067	0.55	0.99	17042	0.55	0.99	
MET/sqrtHT	8900	0.28	0.52	8898	0.28	0.52	
m_eff(incl)	8896	0.28	1	8897	0.28	1	
2jm cut-flow	31250	1	-	32150	1	-	1
Pre-sel+MET+pT1	28472	0.91	0.91	28478	0.91	0.91	0.91
Njet	28472	0.91	1	28477	0.91	1	0.91
Dphi_min(j,MET)	22950	0.73	0.81	22889	0.73	0.8	0.73
pT2	22950	0.73	1	22889	0.73	1	0.73
MET/sqrtHT	10730	0.34	0.47	10710	0.34	0.47	0.33
m_eff(incl)	10630	0.34	0.99	10609	0.34	0.99	0.32
2jt cut-flow	31250	1	-	31250	1	-	
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	
Njet	28592	0.91	1	28625	0.92	1	
Dphi_min(j,MET)	17297	0.55	0.6	17301	0.55	0.6	
pT2	17067	0.55	0.99	17042	0.55	0.99	
MET/sqrtHT	5083	0.16	0.3	5098	0.16	0.3	
Pass m_eff(incl)	4861	0.16	0.96	4889	0.16	0.96	

Table 1: Number of events surviving each selection, total and relative selection efficiencies as obtained with Rivet and MadAnalysis 5 for the dijet signal regions of the multijet+missing energy ATLAS analysis of Ref. [15]. Partly available Checkmate results for the total efficiencies are also indicated.

	Rivet			MadAnalysis 5			CheckMATE
Description	#evt	tot.eff	rel.eff	#evt	tot.eff	rel.eff	tot.eff
4jt cut-flow	31250	1	-	31250	1	-	1
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	0.91
Njet	27322	0.87	0.96	27128	0.87	0.95	0.87
Dphi_min(j,MET)	18929	0.61	0.69	18829	0.6	0.69	0.6
pT2	18715	0.6	0.99	18825	0.6	1	–
pT4	16610	0.53	0.89	16430	0.53	0.87	0.52
Aplanarity	11849	0.38	0.71	11395	0.36	0.69	0.36
MET/m_eff(Nj)	8334	0.27	0.7	7971	0.26	0.7	0.25
m_eff(incl)	7201	0.23	0.86	6972	0.22	0.87	0.21
5j cut-flow	31250	1	-	31250	1	-	1
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	0.91
Njet	21234	0.68	0.74	21185	0.68	0.74	0.68
Dphi_min(j,MET)	14294	0.46	0.67	14292	0.46	0.67	0.45
pT2	14146	0.45	0.99	14289	0.46	1	–
pT4	13229	0.42	0.94	13228	0.42	0.93	0.42
Aplanarity	9836	0.31	0.74	9576	0.31	0.72	0.3
MET/m_eff(Nj)	4643	0.15	0.47	4506	0.14	0.47	0.13
m_eff(incl)	4620	0.15	1	4476	0.14	0.99	0.13
6jm cut-flow	31250	1	-	31250	1	-	1
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	0.91
Njet	13235	0.42	0.46	13236	0.42	0.46	0.41
Dphi_min(j,MET)	8520	0.27	0.64	8553	0.27	0.65	0.26
pT2	8436	0.27	0.99	8551	0.27	1	–
pT4	8135	0.26	0.96	8217	0.26	0.96	0.25
Aplanarity	6365	0.2	0.78	6307	0.2	0.77	0.19
MET/m_eff(Nj)	2675	0.09	0.42	2665	0.09	0.42	0.08
m_eff(incl)	2670	0.09	1	2656	0.08	1	0.08
6jt cut-flow	31250	1	-	31250	1	-	
Pre-sel+MET+pT1	28592	0.91	0.91	28626	0.92	0.92	
Njet	13235	0.42	0.46	13236	0.42	0.46	
Dphi_min(j,MET)	8520	0.27	0.64	8553	0.27	0.65	
pT2	8436	0.27	0.99	8551	0.27	1	
pT4	8135	0.26	0.96	8217	0.26	0.96	
Aplanarity	6365	0.2	0.78	6307	0.2	0.77	
MET/m_eff(Nj)	3900	0.12	0.61	3839	0.12	0.61	
m_eff(incl)	3715	0.12	0.95	3672	0.12	0.96	

Table 2: Same as in Table 1 but for the signal regions targeting final states containing four, five and six jets.

	Rivet			MadAnalysis 5		
Description	#evt	tot.eff	rel.eff	#evt	tot.eff	rel.eff
Initial	1198	1	-	1198	1	-
ETmiss $>$ 150 GeV	798.3	0.67	0.67	736	0.61	0.61
Photon w/ ET $>$ 150 GeV	703.5	0.59	0.88	700	0.58	0.95
Pass Tight photon	598.1	0.50	0.85	658	0.55	0.94
Pass Isolated photon	598.1	0.50	1.00	620	0.52	0.94
Pass $\delta\phi$(gamma,MET) $>$ 0.4	597.5	0.50	1.00	596	0.50	0.96
Pass MET/sqrt(SET) $>$ 8.5	538.2	0.45	0.90	-	-	
Pass Jet veto	476.8	0.40	0.89	461	0.38	0.77
Pass Lepton veto	475.5	0.40	1.00	460	0.38	1.00

Table 3: Number of events surviving each selection, total and relative selection efficiencies as obtained with Rivet and MadAnalysis 5 for the SRI1 signal region of the monophoton ATLAS analysis of Ref. [20].

being excluded. Events featuring loose eletrons and muons and more than one jets with a transverse momentum larger than 30 GeV and a pseudorapidity $|\eta| < 4.5$ are vetoed. As in the previous analysis, jets are reconstructed by means of the anti-k_T algorithm [16] and a radius parameter set to $R = 0.4$. In addition, event selection requires a missing transverse energy significance larger than 8.5 GeV$^{1/2}$, and the missing transverse momentum has top be well separated from the photon and the jet (for events featuring one reconstructed jet).

Five signal regions are defined according to different requirements on the amount of missing transverse energy, namely three inclusive regions and two non-overlapping exclusive regions.

We generated events using the simplified model of dark matter (DM) production involving an axial-vector operator, Dirac DM and couplings $\mathrm{g_q} = 0.25$ and $\mathrm{g}_\chi = 1$ with $\mathrm{m}_\chi = 10\,\mathrm{GeV}$ and $\mathrm{m_{med}} = 800\,\mathrm{GeV}$ described in Ref. [20].

In Table 3, we compare the total number of events surviving each selection, the associated cut efficiency and the total efficiency evaluated with respect to the initial number of events as obtained with MadAnalysis5 (recast code [21]) and Rivet . Whilst a fair agreement is obtained between two codes, differences of 5%–10% are observed for a few cuts. This can be traced back to the missing energy modelling that is complicated to reproduce. The final acceptances of about 40% (Rivet) and 38% (MadAnalysis) are however in good agreement.

CONCLUSIONS

We presented a first benchmark comparison of the performance of different recasting tools which reproduce LHC analyses in Monte Carlo simulation. For the two cases treated here, good agreement is found between the different frameworks and detector simulation techniques. The comparison is ongoing with several more analyses which are currently being validated. It will also be interesting to compare performances for different signal scenarios, to assess the reliability of the recasting methods in, e.g. extreme regions of phase space and/or for very different signal hypotheses the the one the analyses have been designed for.

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