Recasting activities at LH2017

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Abstract

The scope of this report is to document the advancements obtained on the recasting activities and provide a first benchmark to compare different tools in reproducing ATLAS and CMS analysis results.

1. Introduction

Searches for new physics constitute a basic ingredient of the LHC physics program. Their large number and variety pose severe challenges to both the experimental and theory communities. In fact, hundreds of searches are performed by different collaborations, several final states are used, while new ideas to probe new models and non-trivial signatures and 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 task of visualizing, understanding, developing and interpreting analyses increasingly challenging.

One obvious way to cope with this complexity is to devise ways to enforce absolute clarity in the description of analyses. A discussion was started in the Les Houches PhysTeV workshop in 2011, and continued thereafter within a wider group of LHC physicists, in order to determine what information is crucial for describing an analysis. The outcome of this discussion was reported in the ”Recommendations for Presentation of LHC Results” [1–3], and has been embraced by many LHC physicists.

The current practice in our community is to write an analysis in non-public computer codes, which often rely on event objects specific to the experimental collaboration in question, and then make public a description of the analysis via journal publications or other documents.

These efforts, which merit our great appreciation, have significantly increased the scientific value of many important experimental results.

There is significant precedent for the effectiveness of such community standards. Several accords have been established to standardize the communication of physics modeling information, notably the Les Houches Event Accord (LHE) [4, 5] and the SUSY Les Houches Accord (SLHA) [6, 7]. These, respectively, standardize the description of hard-process particles in simulated collision events, and the details of all the parameters that define a new physics model point. Both accords are widely used in high-energy physics and have greatly helped to simplify and make more efficient the communication between physicists. In recent years, the need for a standardized format was also underscored, *i.e.* an “analysis description accord”, capable of describing the contents of an analysis in an unambiguous way, which can be fully exploited by the whole particle physics community. The accord must be capable of describing all object and event selections, as well as quantities such as efficiencies, analytic and algorithmic observables, and advanced multivariate selections. In the Les Houches PhysTeV workshop in 2015, a dedicated discussion has been initiated on how such an accord can be realized [3]. The important motivations and use-cases for a standard analysis description accord were envisaged as: analysis preservation, analysis design, analysis review and communication, interpretation studies and analysis reimplementation, as well as easier comparison of analyses. In addition, there are several desirable features which would further improve the utility of the accord, which, however, may be nontrivial to simultaneously fulfill. The features required for the success of such an accord would be divided into basic requirements (public availability, completeness, longevity, correctness and validatability) and desirable features (human readability and writeability, self-contained, language independence, framework independence, support for combination of analyses). Other proposals in this direction have been realized [8, 9].

Several discussions and progresses have been made, but the proposal is not yet final and has not been widely adopted yet.

The scope of this report is to document the advancements obtained on the recasting activities and provide a first benchmark to compare different tools in reproducing ATLAS and CMS analysis results provided through HEPDATA [10]. To test the reliability of this recasting approach, we realize feasibility studies of the implementation and portability of complicated multivariate techniques (boosted decision trees, neutral networks, *etc.*) into the recasting frameworks featuring different approaches like detector smearing (Delphes [11]) results and simple object smearing.

Further improvements in the presentation of the results and their recastability will include correlations among the signal systematics, as well as the possibility to provide unfolded distributions for key observables. Finally, in the future it might become possible to directly use particle-level measurements to constrain new models.

2. Benchmarking tools and comparison strategy

The idea behind the exercise described in this section is the implementation of LHC analyses of increasing complexity, both in the language-independent format (Analysis Description Format, LHADA Proposal) and frameworks like CheckMate [12, 13], MadAnalysis [14–16] and Rivet [17, 18], followed by a comparison of the results. We choose analyses of ATLAS and CMS which have a detailed cutflow and detector effects provided in some form. In the future it might be beneficial to use dedicated parsers to convert the analysis into different recasting codes. 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 [12, 13] 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

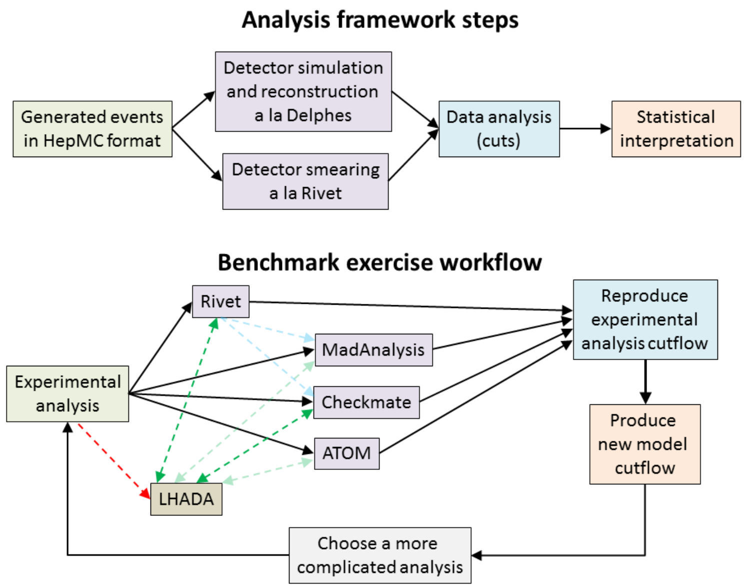

Fig. 1: Sketch of the recasting exercise workflow.

lepton reconstruction and flavour tagging. The soon-to-be published version 2.0 of the code adds the possibility of using Pythia 8 [19] 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 [14, 15] 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 [16] 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 [20], 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 [17, 18] (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

	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. [21]. Partly available Checkmate results for the total efficiencies are also indicated.

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.

2.14 Generic Analysis Description Proposal

A description of the Generic Analysis Description Proposal and its recent developments in contained in section **??** of the proceedings.

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. [21], 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 [22] with a radius parameter set to $R = 0.4$, with a transverse momentum larger than 20 GeV and a pseudorapidity $|\eta| < 2.8$. Events

	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.

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.

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. [23], 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 $1.37 < |\eta| < 2.37$ 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 [22] 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.

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 MadAnalysis 5 and Rivet. Whilst a fair agreement is obtained between two codes, differences of 5%-10% are observed for a cuople of cuts. This can be traced back to the missing energy modeling that is complicated to reproduce.

3.3 A CMS search for electroweakinos in multileptonic final states (13 TeV, 35.9 fb^{-1})

In the analysis of Ref. [24], the CMS collaboration investigates potential hints for electroweakinos, when the latter decays into leptons and missing energy carried away by neutralinos. The search analyzes 35.9 fb^{-1} of LHC proton-proton collisions at a center-of-mass energy of 13 TeV.

The CMS search preselects events featuring at least two isolated leptons (electrons or muons) with soft transverse-momentum rquirements or a single lepton with harder p_T requirements, which allows one to get sensitivity to topologies featuring hadronic taus. The analysis selection feature final states with eother two, three or four leptons and little hadronic activity.

The analysis is subdivided into numerous signals regions and a small number of aggregated signal re-

	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. [23].

gions.

A first class of signal regions requires a same-sign dilepton where each lepton have a transverse momentum larger than 25 GeV (20 GeV) for the leading electron (muon) and than 15 GeV (10 GeV) for the subleading electron (muon). The amount of missing energy is constrained to be larger than 60 GeV, and events compatible with a WZ event involving a looser lepton and an opposite-sign dilepton compatible with a Z-boson or a low-mass resonance are vetoed. Events are allowed to feature at most one jet with a transverse momentum larger than 40 GeV and a pseudorapidity $|\eta| < 2.4$, where jets are reconstructed by means of the anti-k_T algorithm [22] with a radius parameter set to $R = 0.4$. Additional selections on the missing energy, the transverse mass evaluated from the transverse momentum of each lepton and the missing momentum and the p_T of the dilepton system are imposed and allow for the definition of 30 independent signal regions.

Events featuring three or more leptons are required to contain more than 50 GeV of missing energy and at most two hadronic tau candidates. 123 signal regions are defined, depending on the number of leptons, their respective flavors, the their elcetric charge, amount of missing energy, the value of the m_{T2} variable [25] and the invariant mass of the possible lepton pairs.

The same observables are then used to define 8 aggregated signal regions.

The analysis has been implemented in MadAnalysis 5 but the lack of information from CMS renders its validation complicated.

3.4 A CMS search for top squarks in single leptonic events (13 TeV, 35.9 fb^{-1})

In the analysis of Ref. [26], the CMS collaboration studies potential hints for the production of a pair of top squarks that each decays into a top quark and missing energy carried away by a neutralino. This search focuses on top-antitop system further decaying semi-leptonically, the lepton being either a muon or an electron, and investigate 35.9 fb^{-1} of LHC proton-proton collisions at a center-of-mass of 13 TeV.

The analysis requires the presence of a single isolated lepton with a transverse momentum larger than 20 GeV and a pseudorapidity satisfying $|\eta| < 1.442$ and 2.4 for electrons and muons respectively. Jets are reconstructed by means of the anti-k_T algorithm [22] with a radius parameter set to $R = 0.4$, and only jets with a transverse momentum larger than 30 GeV and a pseudorapidity $|\eta| < 2.4$ are considered. The event selection asls for the presence of at least two jets, with at least one of the reconstructed jets is required to be b-tagged. Further requirements are then imposed on the transverse mass of the lepton-missing energy system and a veto is iplemented so that events featuring a second loosely isolated leptons are rejected. Finally, the missing energy is imposed to be well separated in azimuth from the two leading jets.

The analysis defines to categories of signal regions. The first of these categories characterize events relatively to the number of jets, the missing transverse energy, the invariant mass of the lepton-leading b-jet system and the topness variable [27]. The second class of signal regions are design to select featuring a hard initial-state radiation jet that boosted the supersymmetric system. The events are required to feature at least 5 jets, the leading jet being a light jet, and the lepton cannot have a transverse momentum greater than 150 GeV and be to far from the missing transverse momentum. The two leading jets are finally imposed to be quite separated from the missing momentum, and the events are categorized according to the amount of missing energy.

Implementations of this analysis in the recasting codes is on-going.

CONCLUSIONS

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