Validation note for the MadAnalysis5 implementation of the monojet analysis of CMS (CMS-EXO-12-048)

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I. INTRODUCTION

In this note, we describe the validation of a reimplementation of the CMS-EXO-12-048 analysis [1] within the MadAnalysis5 (MA5) framework [2–4]. We have used the version 1.2 of MadAnalysis5 jointly with the standard Delphes3 program [5] that we have run from the MadAnalysis5 platform. The validation has been achieved on the basis of a single benchmark scenario that has been provided by CMS, 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 hadronization infrastructure of Pythia6 [7]. The necessary configuration files and UFO model [8] have been provided by CMS and can be found on the public analysis database webpage of Madanalysis,

http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase

together with the MA5tune detector card that we have used for the simulation of the detector. This card is the standard one provided with MA5.

The CMS monojet search relies on an integrated luminosity of 19.7 fb^{-1} of proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 8$ TeV. It focuses on a signal containing a very hard jet with a transverse momentum $p_T > 110$ GeV. A second jet is allowed, if its transverse momentum is larger than 30 GeV, its pseudorapidity satisfies $|\eta| < 4.5$ and if it is well separated from the first jet by 2.5 radians in azimuth. Events featuring more than two jets with a transverse momentum larger than 30 GeV and a pseudorapidity smaller than 4.5 in absolute value, isolated electrons or muons with a transverse momentum $p_T > 10$ GeV or hadronically decaying tau leptons with a transverse momentum $p_T > 20$ GeV and a pseudorapidity satisfying $|\eta| < 2.3$ are discarded. The analysis contains 7 inclusive signal regions in which the missing energy is required to be above specific thresholds of 250, 300, 350, 400, 450, 500 and 550 GeV respectively.

II. SIMULATION DETAILS

The CMS collaboration has kindly provided us information for one dark matter (DM) scenario inspired by Refs. [9–12]. Using the provided UFO model, we have made use of MadGraph5_aMC@NLO (version 1.5.13) to generate monojet signal events by typing in the MadGraph interpreter

```
generate     p p > chi chi~ j
add process  p p > chi chi~ j j
```

where chi represents a Dirac fermion identified with a dark matter candidate that will give rise to missing energy. The model under consideration includes two extra particles compared to the Standard Model, the dark matter candidate χ and an extra gauge boson Z'. We set their mass to 1 GeV and 40 TeV respectively, and the width of the Z' boson has been fixed to 10 GeV. In addition, the coupling strengths of all Z' interactions (both to quarks and to the dark matter candidate) have been set to 1. More precisely, we have modified the following entries of the block MASS of the param_card.dat,

```
1000022 1.00000000e+00   # DMMASS
101     4.00000000e+04   # ZpMASS
```

set the DECAY block related to the Z' as

```
DECAY        101    1.00000000E+01
```

and fixed the values of the entries of the block MGUSER to

```
1      1.00000000e+00   # gchi
2      1.00000000e+00   # gu
3      1.00000000e+00   # gd
4      1.00000000e+00   # gs
5      1.00000000e+00   # gc
```

	Selection step	CMS	$\epsilon_i^{\rm CMS} = (n_i/n_{i-1})^{\rm CMS}$	MA5	$\epsilon_i^{\rm MA5} = (n_i/n_{i-1})^{\rm MA5}$	$\delta_i^{\rm rel}$
0	Nominal	84653.7		84653.7		
1	One hard jet	50817.2	0.6	52008.60	0.614	2.3%
2	At most two jets	36061	0.7096	38306.70	0.736	3.72%
3	Requirements if two jets	31878.1	0.884	34364.93	0.897	1.47%
4	Muon veto	31878.1	1	34364.93	1	0
5	Electron veto	31865.1	1	34364.93	1	0
6	Tau veto	31695.1	0.995	34364.93	1	0.5%
	MET > 250 GeV	8687.22	0.274	7640.43	0.222	18.97%
	MET > 300 GeV	5400.51	0.621	4661.96	0.610	1.77%
	MET > 350 GeV	3394.09	0.628	2873.96	0.616	1.91%
	MET > 400 GeV	2224.15	0.6553	1851.60	0.644	1.72%
	MET > 450 GeV	1456.02	0.654	1195.02	0.645	1.37%
	MET > 500 GeV	989.806	0.679	804.25	0.673	0.883%
	MET > 550 GeV	671.442	0.678	511.18	0.635	6.34%

TABLE I: Comparison of results obtained with the MA5 reimplementation (MA5) and those provided by the CMS collaboration (CMS). The relative difference between the CMS and the MA5 results has been defined as $\delta_i^{\rm rel} = 1 - \epsilon_i^{\rm MA5}/\epsilon_i^{\rm CMS}$.

```
  6      1.00000000e+00   # gb
  7      1.00000000e+00   # gt
```

In this setup, all the interactions of the Z' have a vector structure, but the results are however not expected to depend on the exact form of the Z' interactions [1].

At the generator level, we have imposed all jets to have a transverse momentum larger than 20 GeV, the leading jet being further constrained to have a $p_T > 80$ GeV. We have moreover enforced the use of the leading order set of CTEQ6 parton densities [13] and set the `xqcut` merging paramater to 20 GeV. Those requirements have been implemented by modifying the following lines of the standard `run_card.dat` file,

```
 'cteq6l1' = pdlabel
 20        = ptj
 80        = ptj1min
 1         = ickkw
 20        = xqcut
```

From the hard scattering events generated as above, we have produced hadron-level events with the help of the `Pythia6` program as interfaced in `MadGraph5`. In the `pythia_card.dat`, we have set `QCUT = 30` for a proper setup of the merging procedure and in addition, we have used the Z_2^* tune that is known to yield a better agreement with early LHC data. Finally, we simulate the detector response with `Delphes`, using the `MA5tune` CMS detector card.

III. RESULTS

A. Cutflow

The selection strategy of the CMS monojet analysis consists of 6 preselection cuts followed by one region-dependent cut, when we ignore the first two requirements of the analysis, the `HLT Bit-1` and `NoiseClean` selections, that cannot be handled with `Delphes`. For the benchmark scenario under consideration, we compare the results that have been derived with our MA5 reimplementation to those provided by the CMS collaboration (see Table I). 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. The *relative difference* given in the table corresponds to the difference between the `MA5` and the CMS efficiencies, normalized to the CMS

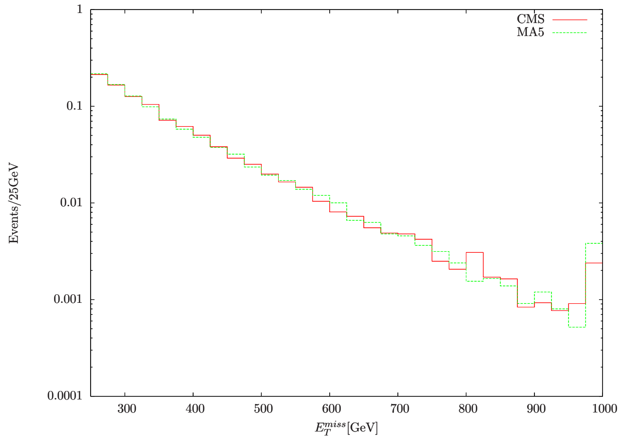

FIG. 1: Missing enegy spectra. Official results: solid lines, `MA5` results: dashed lines

result,

$$\delta_i^{\rm rel} = 1 - \frac{\epsilon_i^{\rm MA5}}{\epsilon_i^{\rm CMS}} \ .$$

We have found that all selection steps are properly described by the MA5 implementation, with the exception the missing energy cut MET $>$ 250 `GeV` for which some disagreement of about 20% has been observed. It is however known that low missing energy is difficult to simulate with a fast-simulation of the detector based on `Delphes`.

B. Histograms

We have also generated a figure depicting the missing transverse energy distribution obtained in the case of a benchmark scenario where the Z' mass has been set to 900 GeV. We jave then compared the results to the Figure 1 of the CMS publication [1]. In this figure, the last bin corresponds to the overflow bin and contains all events exhibiting $E_T^{miss} > 1000$ GeV. We have found a good agreement between `MA5` and the CMS results.

IV. CONCLUSION

We have validated our reimplementation of the CMS-EXO-12-048 monojet analysis by making use of `MadGraph` and `Pythia` to simulate DM events that can be compared to results provided by CMS. We have employed the standard `Delphes3` program for the modeling of the detector simulation, with the `MA5tune` CMS detector card shipped with `MadAnalysis5`. Our results agree very well with the CMS numbers, the dominant source of discrepancy being traced down to issues in correctly modeling the missing energy.

The validation of this analysis cannot be performed at a higher level due to the lack of information from CMS.

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