Validation note for the MadAnalysis 5 implementation of the dark matter plus top quark pairs analysis of CMS (CMS-B2G-14-004)

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1. INTRODUCTION

In this note, we detail the implementation, within the MadAnalysis 5 framework [1–3], of the CMS dark matter B2G-14-004 analysis [4] that probes final states comprised of a top-antitop system produced in association with a pair of invisible dark matter particles. Our reimplementation has been validated within the version 1.3 of MadAnalysis 5, and the simulation of the detector response has been performed with the standard Delphes 3 package [5] that we have run from the MadAnalysis 5 platform. To this aim, we have designed a dedicated detector card in which jets are reconstructed on the basis of the anti-k_T algorithm [6] with a radius parameter set to 0.5, as implemented in FastJet [7].

The validation of our reimplementation is based on material provided by CMS. A UFO model [8] has been shared so that we have been allowed to generate specific dark matter signals for which CMS has released public cutflow charts and differential distributions. Using Madgraph5_aMC@NLO [9] (with the leading order set of CTEQ6 parton densities [10]) and Pythia 6 [11] (with the Z_2^* tune [12] for the description of the underlying events) for the simulation of the hard scattering process and of the parton showering and hadronization, respectively, we have generated signal events that have been analyzed with MadAnalysis 5. A comparison with the official CMS numbers allowed us to assess the validity of our recasting code. Our simulation procedure moreover includes the generation of matrix elements containing up to two extra jets that we have merged according to the MLM prescription [13, 14], the merging scale being set to 40 GeV.

All Pythia 6, Delphes 3 and Madgraph5_aMC@NLO configuration cards can be downloaded from the public analysis database webpage of MadAnalysis 5,

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

2. ANALYSIS AND VALIDATION DESCRIPTION

In order to validate our reimplementation of the CMS-B2G-14-004 search in MadAnalysis 5, we focus on a new physics model that features the production of a pair of dark matter particle X of mass $m_X = 1$ GeV in association with a top-antitop pair via a four-fermion interaction. The CMS event selection strategy requires a large amount of missing transverse energy, a single isolated lepton and multiple jets, and uses 19.7 fb^{-1} of proton-proton collision data recorded at a center-of-mass energy of $\sqrt{s} = 8$ TeV.

The CMS-B2G-14-004 analysis relies on single electron and muon triggers, with lower p_T thresholds of 27 GeV and 24 GeV respectively, and the reconstructed electron (muon) candidate is imposed to be isolated in such a way that the sum of the transverse momenta of all objects lying in a cone of radius $R = 0.3$ centered on the lepton has to be smaller than 10% (12%) of the lepton p_T. Event preselection finally requires that the lepton p_T is larger than 30 GeV and pseudorapidity $|\eta|$ is smaller than 2.5 (2.1 for muons). It additionally demands the presence of at least three jets of $p_T > 30$ GeV and $|\eta| < 2.4$ with one of them being b-tagged, as well as missing energy $\not{E}_T > 160$ GeV. The signal region is defined by selecting events with a large amount of missing transverse energy $\not{E}_T > 320$ for which the transverse mass M_T that is constructed from the lepton and the missing energy is larger than 160 GeV. Moreover, the missing transverse momentum and the two leading jets are asked to be well separated in azimuth, $\Delta\Phi\left(j_{1,2}, \not{E}_T\right) > 1.2$, and the M_{T2}^W variable [15] is enforced to be greater than 200 GeV.

In Table I, we confront the cutflow chart that has been obtained with MadAnalysis 5 to the official results of CMS for the benchmark scenario under consideration. For each cut, we have calculated the related efficiency defined as

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

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

	Selection step	CMS	$\epsilon_i^{\rm CMS}$	MA5	$\epsilon_i^{\rm MA5}$	$\delta_i^{\rm rel}$
0	Nominal	224510		224510		
1	Preselection			15468.5	0.069	
2	$\not{E}_T > 320$ GeV	4220.8		4579.8	0.296	
3	$M_T > 160$ GeV	3390.1	0.803	3648.2	0.797	0.75%
4	$\Delta\Phi(j_{1,2}, \not{E}_T) > 1.2$	2963.5	0.874	3124.3	0.856	2.06%
5	$M_{T2}^W > 200$ GeV	2267.6	0.765	2403	0.769	-0.52%

TABLE I: Comparison of results obtained with our MadAnalysis 5 reimplementation (MA5) and those provided by the CMS collaboration (CMS). The efficiencies are defined in Eq. (1) and the relative difference between the CMS and the MadAnalysis 5 results $\delta_i^{\rm rel}$ in Eq. (2).

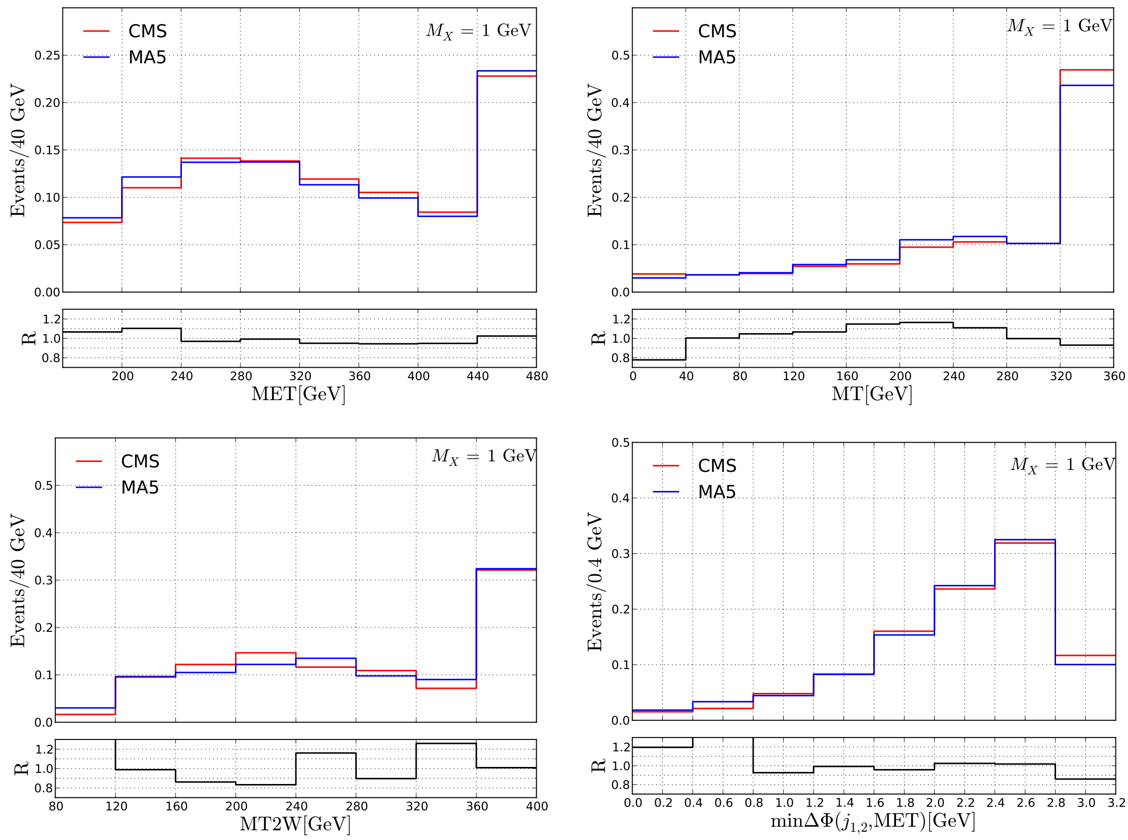

FIG. 1: Missig transverse energy, M_T, M_{T2}^W and $\Delta\Phi\left(j_{1,2}, \not{E}_T\right)$ spectrum as obtained with MadAnalysis 5 (blue) once all selection steps but the one related to the represented variable are applied, compard to the CMS official results (red).

result,

$$\delta_i^{\rm rel} = 1 - \frac{\epsilon_i^{\rm MA5}}{\epsilon_i^{\rm CMS}} \ . \tag{2}$$

At each step of the validation, an agreement at the percent level has been found. Moreover, we compare several (normalized) differential distributions as calculated with MadAnalysis 5 when all selection steps but the one related to the represented kinematic variable are included with the public CMS results on Figure 1. A very good agreement can again be observed.

3. CONCLUSION

We have validated our reimplementation of the CMS-B2G-14-004 analysis dedicated to the probe of dark matter production in association with a pair of top quarks. To this aim, we have used MADGRAPH5_aMC@NLO and PYTHIA 6 to simulate new physics events that can be compared to results provided by CMS. We have employed the standard DELPHES 3 program for the modeling of the detector simulation, with a specific tune of the CMS detector card. Our results agree very well with the CMS numbers, both at the level of cutflow charts and differential distributions.

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[1] E. Conte, B. Fuks, and G. Serret, Comput. Phys. Commun. **184**, 222 (2013), 1206.1599.
[2] E. Conte, B. Dumont, B. Fuks, and C. Wymant, Eur. Phys. J. **C74**, 3103 (2014), 1405.3982.
[3] B. Dumont, B. Fuks, S. Kraml, S. Bein, G. Chalons, E. Conte, S. Kulkarni, D. Sengupta, and C. Wymant, Eur. Phys. J. **C75**, 56 (2015), 1407.3278.
[4] V. Khachatryan et al. (CMS), JHEP **06**, 121 (2015), 1504.03198.
[5] J. de Favereau, C. Delaere, P. Demin, A. Giammanco, V. Lemaître, A. Mertens, and M. Selvaggi (DELPHES 3), JHEP **02**, 057 (2014), 1307.6346.
[6] M. Cacciari, G. P. Salam, and G. Soyez, JHEP **0804**, 063 (2008), 0802.1189.
[7] M. Cacciari, G. P. Salam, and G. Soyez, Eur. Phys. J. **C72**, 1896 (2012), 1111.6097.
[8] C. Degrande, C. Duhr, B. Fuks, D. Grellscheid, O. Mattelaer, and T. Reiter, Comput. Phys. Commun. **183**, 1201 (2012), 1108.2040.
[9] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, JHEP **07**, 079 (2014), 1405.0301.
[10] J. Pumplin, D. R. Stump, J. Huston, H. L. Lai, P. M. Nadolsky, and W. K. Tung, JHEP **07**, 012 (2002), hep-ph/0201195.
[11] T. Sjostrand, S. Mrenna, and P. Z. Skands, JHEP **05**, 026 (2006), hep-ph/0603175.
[12] R. Field, Acta Phys. Polon. **B42**, 2631 (2011), 1110.5530.
[13] M. L. Mangano, M. Moretti, F. Piccinini, and M. Treccani, JHEP **01**, 013 (2007), hep-ph/0611129.
[14] J. Alwall, S. de Visscher, and F. Maltoni, JHEP **02**, 017 (2009), 0810.5350.
[15] Y. Bai, H.-C. Cheng, J. Gallicchio, and J. Gu, JHEP **07**, 110 (2012), 1203.4813.