Validation of the `MadAnalysis 5` implementation of CMS-EXO-16-052

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1 INTRODUCTION

This concerns the analysis CMS-EXO-16-052 with a signature of two leptons and missing transverse energy (MET)at a center of mass energy of 13 TeV and with an integrated luminosity of 35.9 fb[1]. A similar analysis was implemented for a smaller dataset, which can be found in inspire record 1618045.

2 Object definition

The following objects were defined:

- Electrons
  - pT > 20 GeV, —eta— < 2.4
  - Medium ID
  - PFiso04 < 0.077 (barrel electrons) or PFiso04 < 0.068) (endcap electrons)
- Muons
  - pT > 20 GeV, —eta— < 2.4
  - Tight ID (Loose ID for vetoing 3 leptons events)
  - PFiso04 < 0.15
  - To get isolation:

```
double Riso = PHYSICS->Isol->eflow->relIsolation(el,event.rec()
    ,0.4,0.,IsolationEFlow::ALL_COMPONENTS);
```

- Jets
  - pT > 20 GeV, —eta— < 5 (PFloose ID)
  - Identified leptons in deltaR < 0.4 disregarded
  - We categorize the selected events based on the number of selected jets with pT > 30 GeV for the corresponding requirements
- b-jets
  - pT > 20 GeV, —eta— < 2.4
  - CSVv2>0.8484 (medium)
- Taus
  - pT > 18 GeV, —eta— < 2.3
  - DecayModeFinding? ?
  - Loose isolation < 5 GeV

3 Event Selection

- Two same flavored lepton with opposite electric charge (that pass lepton selection?)
- el[0] pt > 25 and el[1] pt >20
- mu[0] pt > 20 and mu[1] pt > 20
- —dilep m - 91.1876(+- 0.0021)— < 15
- dilep pt > 60
- events having more than one jet with pT > 30 GeV - remove
- b-tagged jet Veto : at least one bjet pt > 20, —eta— < 2.4, CSVv2 < 0.8484 - remove
- if el[2 onwards] pt > 10 -remove
- if mu[2 onwards] pt > 5 -remove
- tau veto: loose id, tau pt > 18. (hadronically decaying tau leptons)

3.1 Optimization

For each possible set of selections the full analysis, including the estimation of backgrounds from control samples in data and the systematic uncertainties, is repeated. After optimization:

- MET > 100
- Delta phi (dilep.pt , ptmiss) > 2.6 rad
- —MET - dilep.pt— / dilep.pt < 0.4
- If event has one jet:
  - Delta phi (jet.pt , ptmiss) > 0.5
  - Delta R(ll) < 1.8

4 SIMULATION DETAILS

Leading order samples were produced. The models used were:

1. dark matter production in a simplified model with a spin-1 mediator A
2. dark matter production in a simplified model with a spin-0 mediator phi

The MC generator program used was `MAD-GRAPH5_aMC@NLO` 2.2.2; the shower program used was PYTHIA 8.205. The tune of Pythia used was CUETP8M1 and the coupling g(kai) is set to one. For 0.25 < g(q) < 1.0, the width ranges 1-5% of the mediator mass for g(q) = 0.25, 30-50% of the mediator mass for g(q) = 1.00

Events for ADD extra-dimension scenario were produced at LO with an EFT implementaion in PYTHIA 8. The masses used were M(D) = 1, 2 and 3 TeV, each with n = 2, 3, 4, 5, 6, 7 The events for the unparticle model were produced at LO, PYTHIA 8, tune CUETP8M1 assuming cutoff scale (U) =15TeV We took ZH and gluon-gluon fusion as WZ and ZZ processes.

To run MadGraph we used

```
import DMsimp_s_spin0
generate p p > xd xd~ z [QCD]
add process p p > xd xd~ z j [QCD]
output DM_spin0_noreallythistime
launch
```

We turned on madspin and the showering. Then we fixed:

```
madspin_card.dat -> set "z > l+ l-"
```

In the run card we set the number of events and changed shower to PYTHIA8, ickkw to 3 (FxFx? merging). In the shower card we set Qcut to 15 (50?) and njmax to 1 (since were generating 0 + 1 extra partons) In the parameter card we set the masses of Y0 (or Y1 for spin 1), the mediator, and Xd, the dark matter particle (the paper uses MY0=500, MXD=150GeV)

Reference plots cut-flows came from table 4 on the CMS results page.

Selections	MG5	Offical
cut1	0.9	0.9
cut2	0.9	0.9
cut3	0.9	0.9
cut4	0.9	0.9

Table 1: Cut flows, expressed in terms of efficiencies, for three signal samples in signal region SR2jl

5 RESULTS

5.1 Cut-flow

5.2 Various Samples

Theory σ is the cross-section output from MadGraph.

The efficiency is determined from the fraction of events reconstructed by Delphes and passing the analysis cuts into the signal region.

N_{exp} is the number of events resulting from the expected cross-section and efficiency for the CMS analysis using 34 fb^{-1}.

The exclusion limit is determined by taking the 95% C.L. upper limit based on the number of expected events and the results of CMS

6 CONCLUSION

Sample	σ Cross Section (pb)	Efficiency	$N_{Expected}$
./Samples/DMsimp_s_spin1-axial_0j.txt	0.021318904968	0.1272	97.3523531583
./Samples/DMsimp_s_spin1-axial_ee_0j.txt	0.010659482475	0.0978	37.4256561594
./Samples/DMsimp_s_spin1-axial_mm_0j.txt	0.010659482475	0.1481	56.6742298283
./Samples/DMsimp_s_spin1-vector_0j.txt	0.0393553945622	0.1227	173.357758169
./Samples/DMsimp_s_spin1-vector_0j_qcd.txt	0.06788	0.1251	304.8551892
./Samples/DMsimp_s_spin1-vector_1j.txt	0.0666819164253	0.0752	180.037839919
./Samples/DMsimp_s_spin1-vector_1j_qcd.txt	0.1251	0.1125	505.082719261
./Samples/DMsimp_s_spin1-vector_ee_0j.txt	0.0196775973111	0.1003	70.8545020699
./Samples/DMsimp_s_spin1-vector_mm_0j.txt	0.0196775973111	0.1572	111.050126873

Figure 1: Samples of spin-1 axial and vector DM models. 0j is for events generated without extra partons generated by MAdGraph, 1j for is for 1 extra parton generated by MadGraph, and QCD is including QCD NLO calculations in the MadGraph calcualtion. ee is for Z to electrons only, mm for muons, otherwise both the electron and muon channels are generated.

Sample	Cross Section (pb)	Eff.	Expected	Exclusion (sigma/sigma$_0$)
Run 30/10/2017				
./Samples/DMsimp_s_spin0P_0j_1000_1.txt	5.28328517293 (-06)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0P_0j_100_1.txt	5.29581021579 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0P_0j_10_1.txt	9.81497810099 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0P_0j_500_1.txt	2.10019490453 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0P_0j_50_1.txt	8.02167613779 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_1000_1.txt	6.46834888936 (-06)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_100_1.txt	9.65746285084 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_10_1.txt	0.00028727155715	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_500_1.txt	2.66324370678 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_50_1.txt	0.000177391817776	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0_default.txt	6.50211256127 (-06)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin1-axial_0j.txt	0.021318904968	0.1272	97.3523531583	0.864208980016
./Samples/DMsimp_s_spin1-axial_ee_0j.txt	0.010659482475	0.0978	37.4256561594	2.24554648455
./Samples/DMsimp_s_spin1-axial_mm_0j.txt	0.010659482475	0.1481	56.6742298283	1.48558733966
./Samples/DMsimp_s_spin1-vector_0j.txt	0.0393553945622	0.1227	173.357758169	0.484974465556
./Samples/DMsimp_s_spin1-vector_0j_10_1.txt	0.299915034487	0.0076	81.8288180094	1.02663162079
./Samples/DMsimp_s_spin1-vector_0j_50_1.txt	0.217641714014	0.0263	205.490777121	0.410468667038
./Samples/DMsimp_s_spin1-vector_0j_100_1.txt	0.168503454019	0.0490	296.414425965	0.283063751571
./Samples/DMsimp_s_spin1-vector_0j_500_1.txt	0.0419776079768	0.1291	194.553199914	0.430585232638
./Samples/DMsimp_s_spin1-vector_0j_1000_1.txt	0.0112635212815	0.1509	61.0179864735	1.37606381584
./Samples/DMsimp_s_spin1-vector_0j_qcd.txt	0.06788	0.1251	304.8551892	0.275613171719
./Samples/DMsimp_s_spin1-vector_1j.txt	0.0666819164253	0.0752	180.037839919	0.469328247868
./Samples/DMsimp_s_spin1-vector_1j_qcd.txt	0.1251	0.1125	505.082719261	0.166834705882
./Samples/DMsimp_s_spin1-vector_1j_qcd_Qcut10.txt	0.1251	-1.0000	-4491.09	ERR
./Samples/DMsimp_s_spin1-vector_1j_qcd_Qcut100.txt	0.1251	-1.0000	-4491.09	ERR
./Samples/DMsimp_s_spin1-vector_ee_0j.txt	0.0196775973111	0.1003	70.8545020699	1.1868190876
./Samples/DMsimp_s_spin1-vector_mm_0j.txt	0.0196775973111	0.1572	111.050126873	0.759155804105
Run 30/11/2017				
./Samples/DMsimp_s_spin0P_0j_1000_1.txt	5.28486997514 (-06)	0.0064	0.00121425172549	69140.5077591
./Samples/DMsimp_s_spin0P_0j_100_1.txt	5.29739882874 (-05)	0.0181	0.0344219678493	2447.54969572
./Samples/DMsimp_s_spin0P_0j_100_1_QCD.txt	0	-1.0000	-0.0	99999.9996275
./Samples/DMsimp_s_spin0P_0j_10_1.txt	9.8179223129 (-05)	0.0024	0.00845912186479	9942.6415468
./Samples/DMsimp_s_spin0P_0j_10_1_QCD.txt	0.0001969	-1.0000	-7.06871	ERR
./Samples/DMsimp_s_spin0P_0j_500_1.txt	2.10082494163 (-05)	0.0126	0.00950287154097	8841.97930621
./Samples/DMsimp_s_spin0P_0j_50_1.txt	8.0240824427 (-05)	0.0077	0.0221809710964	3788.30687204
./Samples/DMsimp_s_spin0P_0j_50_1_QCD.txt	0.0001702	-1.0000	-6.11018	ERR
./Samples/DMsimp_s_spin0S_0j_1000_1.txt	6.47028916275 (-06)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_100_1.txt	9.660359773 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_10_1.txt	0.0002873577256	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_500_1.txt	2.66404256188 (-05)	0.0000	0.0	99999.9996275
./Samples/DMsimp_s_spin0S_0j_50_1.txt	0.000177445033	0.0000	0.0	99999.9996275

Figure 2: As before, with 0P and 0S being for pseudo-scalar and scalar DM models respectively.