Validation of the MadAnalysis 5 implementation of CMS-EXO-16-012

Jiwon Park, Seohyun Ahn (Hanyang Unibversity)
Wenxing Zhang (ITP of Chinese Academy of Science)
email: jiwon.park@cern.ch

November 4, 2017

1 Setup

In this document, the MadAnalysis 5 implementation of search for associated production of dark matter with a Higgs boson decaying to $b\bar{b}$ or $\gamma\gamma$ at $\sqrt{s} = 13$ TeV (2.3 fb^{-1}), (see also arXiv:1703.05236) is validated.

For this purpose, model UFO, MG5 cards, and a pythia8 card for Monte Carlo production were provided by CMS to generate events with MadGraph MG5_aMC, showered with Pythia 8

This paper is written in the context of Z'-two-Higgs-doublet model, where a high-mass resonance Z' decays into a pseudoscalar boson A and a CP-even scalar Higgs boson, and the A decays to a pair of dark matter particles.

To generate signal sample, model UFO files is provided by CMS. From the CMS genproduction gitbub repository one can retrieve the cards used for MadGraph MG5_aMC event generation for each mass point of Z'. The run card used in MadGraph MG5_aMC and proc card were retrieved from there. Also we applied some custom settings according to the mass of Z'. Some examples for a mass point $M_{Zp} = 1000$ GeV is presented in appendix A. To see full information, please look at linked github pages.

Since MadGraph MG5_aMC cannot handle the decay of standard model higgs properly, higgs decay and parton shower was handled by Pythia 8. For example, specific Pythia 8 card is used in this process. The pythia settings are then retrieved from the CMS software github repository:

- Pythia8CUEP8M1Settings and
- Pythia8CommonSettings. Also:
- The genfragment file is used.

Models studied are shown in 1. For further theoretical aspects of this model, see the paper arXiv:1402.7074

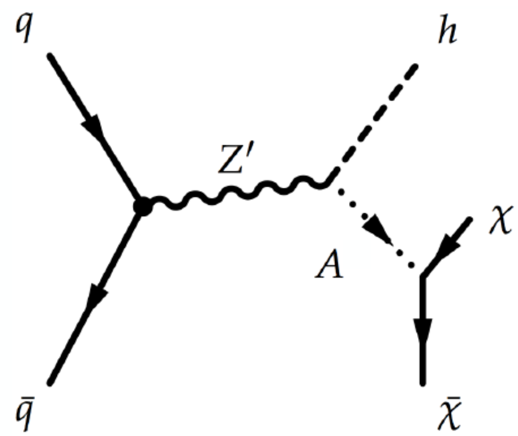

Figure 1: The Z' 2HDM model with pseudoscalar A

For detector simulation, we used `Delphes 3` with latest version of delphes card used for CMS EXO-16-037 recasting. The difference between custom card and default card is presented in appendix B. We added some lines to make nertralino not to deposit energy on calorimeter.

2 Event Selection

There are several cuts for photon identification and background rejection. We selected only diphoton mass cut where $m_{\gamma\gamma} > 95$ GeV from diphoton with asymmetric p_T threshold (30 and 18 GeV) since trigger algorithms are unknown for public.

Next we apply cut based photon identification with loose working point for Spring 2015 (Run2) 25 ns scenario. These selection is presented in CMS EXO-16-011. However, for H/E, we followed CMS EXO-16-012 selection, which is 0.1. Isolation is computed with $\Delta R = 0.3$.

Variable	Barrel Selection	Endcap Selection
H/E	<0.05	
Iso_{ch} [GeV]	< 3.32	< 1.97
ρ corrected Iso_{Neu} [GeV]	$< 1.92 + 0.14p_T + 0.000019(p_T)^2$	$< 11.86 + 0.0139p_T + 0.000025(p_T)^2$
ρ corrected Iso_{γ} [GeV]	$< 0.81 + 0.0053p_T$	$< 0.83 + 0.0034p_T$

Table 1: Value of each variable used in barrel and endcap photon identification

In addition, two more cuts are applied to enhance the signal over background discrimination and to veto events with mismeasured p_T^{miss}.

- $|\Delta\phi(\gamma\gamma,\, p_T^{miss})| > 2.1$
- $min(|\Delta\phi(jet,\, \vec{p}_T^{miss})|) > 0.5$ where jet reconstructed from the clustering of PF candidates by means of the anti-kt algorithm with a distance parameter of 0.4

After these selections, we applied kinematic selections, where $p_{T_1}/m_{\gamma\gamma} > 0.5$ and $p_{T_2}/m_{\gamma\gamma} > 0.25$, for leading photon γ_1 and subleading γ_2. Moreover we imposed diphoton mass and missing transverse momentum cut, $p_{T_{\gamma\gamma}} > 90$ GeV and $p_T^{miss} > 105$ MeV.

Finally we defined signal region (SR), $120 < m_{\gamma\gamma} < 130$ GeV and $p_T^{miss} > 105$ MeV.

3 Cut flow

Unfortunately we couldn't find out detailed cutflow. Here we present the product of acceptance and efficiency for signal in the SR for each mass point only. The error is defined as $(1 - (A \cdot \epsilon)^{MA5}/(A \cdot \epsilon)^{CMS})$ (%)

Acceptance × efficiency ($A \cdot \epsilon$)			
m_{Z_p} (GeV)	CMS EXO-16-012	MA5	Error
600	0.317 ± 0.004	0.355 ± 0.001	-11 %
800	0.399 ± 0.004	0.451 ± 0.001	-13 %
1000	0.444 ± 0.004	0.494 ± 0.001	-8.2 %
1200	0.474 ± 0.004	0.513 ± 0.001	-0.6 %
1400	0.492 ± 0.004	0.515 ± 0.001	-4.7 %
1700	0.493 ± 0.004	0.494 ± 0.001	-0.2 %
2000	0.351 ± 0.004	0.355 ± 0.001	-1.1 %
2500	0.213 ± 0.004	0.208 ± 0.001	2.3 %

4 Distributions of observables

Since missing transverse energy is important, we plotted only p_T^{miss} and $m_{\gamma\gamma}$. For this step, we made plot without normalization. For both plots from paper, the product of signal cross section and branching fraction is set to 1 fb. But we couldn't find proper values for normalization, so we presented un-normalized plots only.

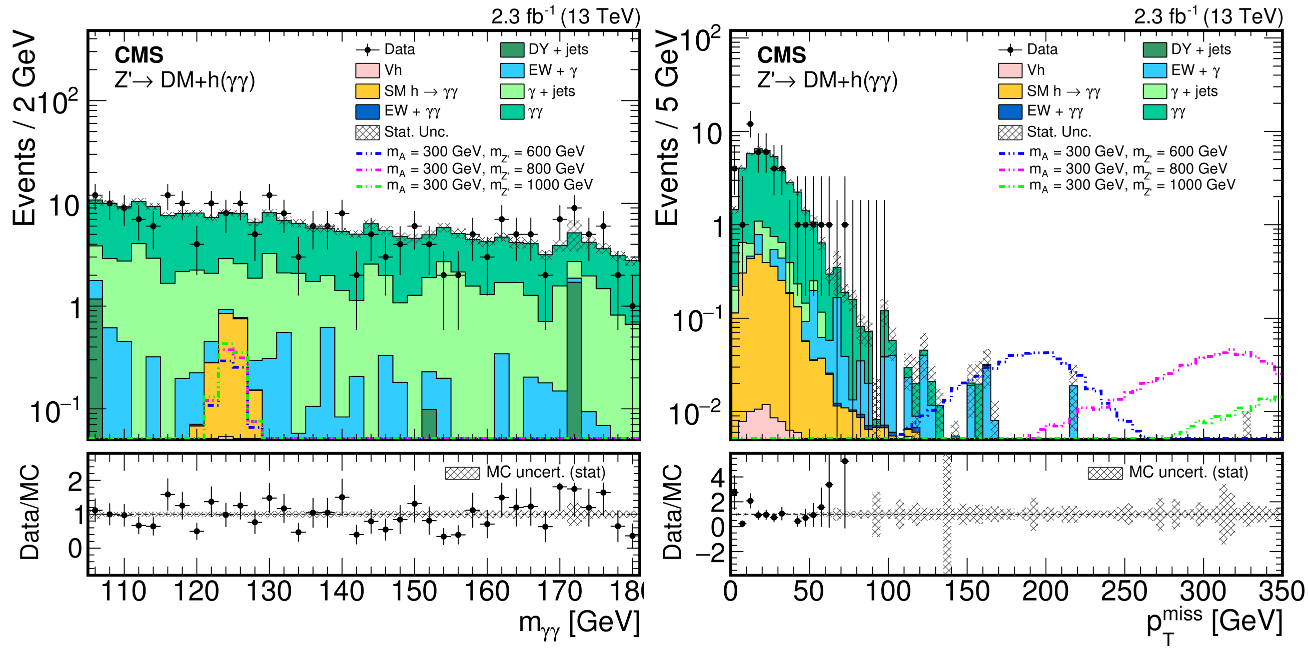

Figure 2: Distribution of $m_{\gamma\gamma}$ (left) in events passing all selection criteria except the $m_{\gamma\gamma}$ and p_T^{miss} requirement. Distribution of p_T^{miss} (right) for events passing all selection criteria including 120GeV $< m_{\gamma\gamma} <$ 130GeV except p_T^{miss} requirement. For both plots, the product of signal cross section and branching fraction is set to 1 fb.

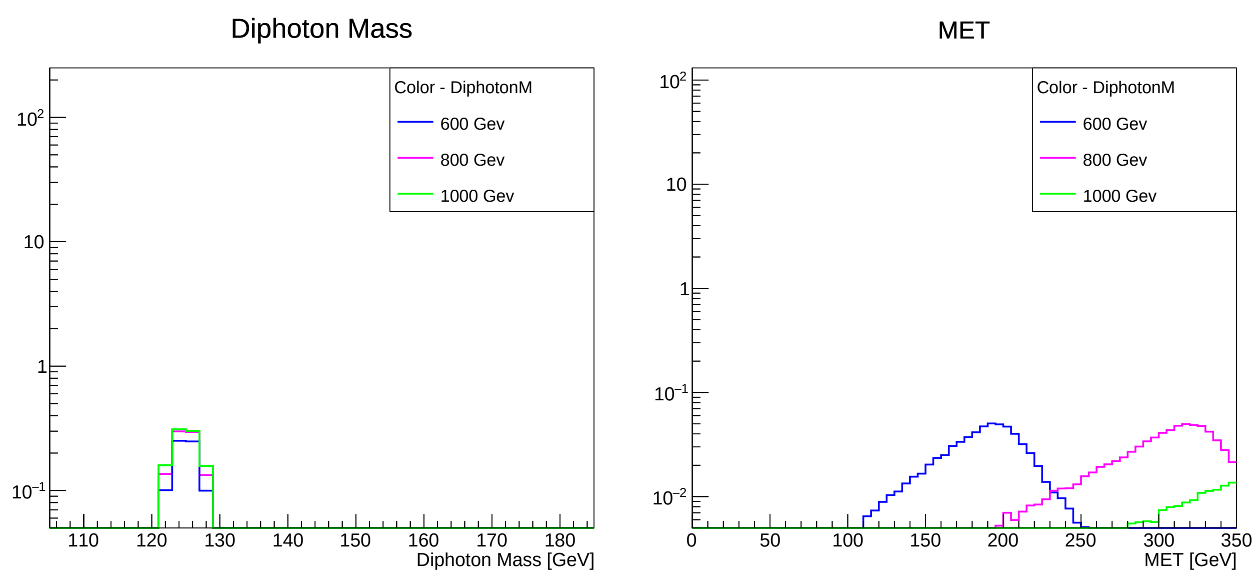

Figure 3: Distribution of $m_{\gamma\gamma}$ (left) and p_T^{miss} (right) with same requirement as CMS plots. Normalization is not properly done!

Appendices

A MadGraph MG5_aMC and Pythia 8 card settings

```
import model Zp2HDM
generate p p > Zp > h A0, A0 > n1 n1~
output Zprime_A0h_A0chichi_MZp1000_MA0300 -nojpeg

set param_card mass 32 1000
set param_card mass 26 300
set param_card mass 27 300
set param_card mass 28 300
set param_card ZpINPUTS 1 1
set param_card ZpINPUTS 2 0.8
set param_card DECAY 32 20.22504
set param_card DECAY 28 8.95228

####From the run card

 'lhapdf'  = pdlabel     ! PDF set
 263400    = lhaid      ! if pdlabel=lhapdf, this is the lhapdf number


####In the shower card
!CUEP8M1 Tune
SLHA:minMassSM=1000.
SLHA:keepSM=on
SLHA:useDecayTable = off
Main:timesAllowErrors=10000
MultipartonInteractions:expPow=1.6
MultipartonInteractions:ecmPow=2.5208
MultipartonInteractions:pT0Ref=2.4024
ParticleDecays:limitTau0=on
ParticleDecays:allowPhotonRadiation=on
ParticleDecays:tau0Max=10
Check:epTolErr=1.0000000000e-02
Tune:ee=7
Tune:pp=14


!This is for decay mode
25:m0 = 125.0
25:onMode=off
25:OnIfMatch=22 22
```

B Delphes card settings

```
######################
# MC truth jet finder
######################

module FastJetFinder GenJetFinder {
  set InputArray NeutrinoFilter/filteredParticles

  set OutputArray jets

  # algorithm: 1 CDFJetClu, 2 MidPoint, 3 SIScone, 4 kt, 5 Cambridge/Aachen, 6
      antikt
  set JetAlgorithm 6
  set ParameterR 0.4

  set JetPTMin 20.0
}

############
# Jet finder
############

module FastJetFinder FastJetFinder {
#  set InputArray Calorimeter/towers
  set InputArray EFlowMerger/eflow

  set OutputArray jets

  # algorithm: 1 CDFJetClu, 2 MidPoint, 3 SIScone, 4 kt, 5 Cambridge/Aachen, 6
      antikt
  set JetAlgorithm 6
  set ParameterR 0.4

  set JetPTMin 20.0
}

###########
# b-tagging
###########

module BTagging BTagging {
  set JetInputArray JetEnergyScale/jets

  set BitNumber 0

  # add EfficiencyFormula {abs(PDG code)} {efficiency formula as a function of
      eta and pt}
  # PDG code = the highest PDG code of a quark or gluon inside DeltaR cone
      around jet axis
  # gluon's PDG code has the lowest priority
```

```
  add EfficiencyFormula {0} { (pt >= 30.0 && pt < 130.0) * (0.124 - 1.0*10^-3*pt
      + 1.06*10^-5*pt^2 - 3.18*10^-8*pt^3 + 3.13*10^-11*pt^4) +
                              (pt >= 130.0) * (0.055 + 4.53*10^-4*pt -
                                 1.60*10^-7*pt^2) }

  add EfficiencyFormula {4} { (pt >= 30.0 && pt <205.0) * (0.40 + 1.23*10^-3*pt
     - 4.60*10^-6*pt^2 + 5.71*10^-9*pt^3) +
                              (pt >= 205.0) * (0.478 + 1.573*10^-4*pt)}

  add EfficiencyFormula {5} { (pt >= 30.0 && pt < 150.0) * (0.707 + 5.6*10^-3*pt
      - 6.27*10^-5*pt^2 + 3.10*10^-7*pt^3 - 5.63*10^-10*pt^4) +
                              (pt >= 150.0) * (0.906 - 6.39*10^-5*pt +
                                 4.11*10^-8*pt^2) }
}

#############
#    ECAL
#############

  add EnergyFraction {18} {0.0}


#############
#    HCAL
#############

  add EnergyFraction {18} {0.0}

##################
# Photon isolation
##################

module Isolation PhotonIsolation {
  set CandidateInputArray PhotonEfficiency/photons
  set IsolationInputArray EFlowFilter/eflow

  set OutputArray photons

  set DeltaRMax 0.3

  set PTMin 0.5

  set PTRatioMax 0.12
}
```