Chapter 5

ATLAS-EXOT-2016-32: an ATLAS monophoton analysis (36.1 fb^{-1})

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Abstract
We present the MadAnalysis 5 implementation and validation of the ATLAS-EXOT-2016-32 analysis, a search that targets a new physics signature featuring an energetic photon and a large amount of missing transverse momentum. The results are presented for an integrated luminosity of 36 fb^{-1} of proton-proton collisions at a center-of-mass energy of 13 TeV recorded by the ATLAS detector. This analysis has been in particular designed to search for the pair production of dark matter particles recoiling against a very energetic photon. Our implementation has been validated by comparing our cutflow predictions with those available from ATLAS.

1 Introduction

In this note, we summarize the MadAnalysis 5 [3–5] implementation of the ATLAS search for the production of dark matter in association with a hard photon [8]. This search focuses on 13 TeV LHC data and an integrated luminosity of 36.1 fb^{-1}, and the details of this anlysis is documented on
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2016-32/.

The typical dark matter models that are probed by such an analysis can be embedded in the simplified model presented in Ref. [33]. In this case, the Standard Model is supplemented by a Dirac fermionic dark matter particle that can be produced in quark-antiquark annihilations via an s-channel exchange of an axial-vector mediator. The corresponding Lagrangian reads

$$\mathcal{L} = g_\chi \bar{X}_D \gamma_\mu \gamma_5 X_D Y_1^\mu + \sum_{i,j} \left[g^A_{d_{ij}} \bar{d}_i \gamma_\mu \gamma_5 d_j + g^A_{u_{ij}} \bar{u}_i \gamma_\mu \gamma_5 u_j \right] , \tag{5.1}$$

where X_D denotes the fermionic dark matter candidate and Y_1^μ the mediator. For simplicity, we ignore flavor-violating effects and consider flavor universality, so that the new physics couplings satisfy

$$g^A_{d_{ij}} = g^A_{u_{ij}} = g_q \delta_{ij} , \tag{5.2}$$

with $i, j = 1, 2, 3$ being flavor indices. For the validation of our reimplementation, we consider the benchmark scenario defined in Ref. [8] in which the universal coupling of the mediator to quarks is set to $g_q = 0.25$ and the mediator coupling to dark matter is set to $g_\chi = 1$. The new physics setup additionally includes a dark matter mass of 10 GeV and a mediator mass of 800 GeV, which yields a mediator width of 44.01 GeV.

2 Description of the implementation

2.1 Objects

In the ATLAS-EXOT-2016-32 analysis, the signal region definition relies on photons whose transverse energy E_T^γ and pseudorapidity η^γ satisfy

$$E_T^\gamma > 10 \text{ GeV} \qquad \text{and} \qquad 1.52 < |\eta^\gamma| < 2.37 \quad \text{or} \quad |\eta^\gamma| < 1.37 . \tag{5.3}$$

Their isolation is enforced by requiring that the sum Σ_E of the energy deposits in a cone of radius $\Delta R = 0.4$ centered on the photon fullfils

$$\Sigma_E < 2.45 \text{ GeV} + 0.022 E_T^\gamma \ , \tag{5.4}$$

and that the scalar sum Σ_{p_T} of the transverse momenta of the non-conversion tracks lying in a cone of radius $\Delta R = 0.2$ centered on the photon satisfies

$$\Sigma_{p_T} < 0.05 \times E_T^\gamma \ . \tag{5.5}$$

Electron candidates are required to have a transverse momentum p_T^e and pseudorapidity η^e obeying to

$$p_T^e > 7 \text{ GeV} \qquad \text{and} \qquad |\eta^e| < 2.47 \ , \tag{5.6}$$

while the muon candidates are defined similarly,

$$p_T^\mu > 6 \text{ GeV} \qquad \text{and} \qquad |\eta^\mu| < 2.7 \ . \tag{5.7}$$

Jets are recontructed by means of the anti-k_T algorithm [15], with a radius parameter set to $R = 0.4$, and the analysis restricts itself to jet candidates with a transverse momentum p_T^j and pseudorapidity η^j fullfilling

$$p_T^j > 30 \text{ GeV} \qquad \text{and} \qquad |\eta| < 4.5 \ . \tag{5.8}$$

The missing transverse momentum vector $\mathbf{E}_T^{\rm miss}$ is defined as the opposite of the vector sum of the momenta of all reconstructed physics object candidates, and the missing transverse energy is defined by the norm of this vector,

$$E_T^{\rm miss} = |\mathbf{E}_T^{\rm miss}| \ . \tag{5.9}$$

2.2 Event Selection

Our reimplementation of the ATLAS monophoton search in MadAnalysis 5 includes all five signal regions described in the analysis (see the Table 2 in Ref. [8]). They all require to select events featuring one hard photon with an energy

$$E_T^\gamma > 150 \text{ GeV}, \tag{5.10}$$

and well separated from the missing momentum in azimuth,

$$\Delta\phi(\gamma, \mathbf{E}_T^{\rm miss}) > 0.4 \ . \tag{5.11}$$

The missing energy significance is imposed to be large,

$$\frac{E_T^{\rm miss}}{\sqrt{\sum E_T}} > 8.5\,\text{GeV}^{1/2} \ , \tag{5.12}$$

and a (loose) jet veto is finally imposed. The selected events are hence allowed to feature at most one jet that must be well separated from the missing momentum in azimuth,

$$\Delta\phi(j, \mathbf{E}_T^{\rm miss}) > 0.4 \ . \tag{5.13}$$

The five signal regions are differentiated by means of different missing energy selection criteria. Three inclusive regions SRI1, SRI2 and SRI3 are respectively defined by imposing that

$$E_T^{\rm miss} > 150 \text{ GeV}, \qquad E_T^{\rm miss} > 225 \text{ GeV} \qquad \text{and} \qquad E_T^{\rm miss} > 300 \text{ GeV}, \tag{5.14}$$

whilst two exclusive regions SRE1 and SRE2 focus on definite missing energy ranges,

$$E_T^{\rm miss} \in [150, 225] \text{ GeV} \qquad \text{and} \qquad E_T^{\rm miss} \in [225, 300] \text{ GeV}. \tag{5.15}$$

The provided validation material is however only available for the SRI1 region [8].

cuts	MA5	Official	error
Initial	1198	1198	
$E_T^{\rm miss} > 150$ GeV	$882.1(-26.37\%)$	$736(-38.56\%)$	19.85%
$p_T^{\gamma 1} > 150$ GeV and $\vert\eta\vert < 2.37$	$683.1(-22.56\%)$	$700(-4.89\%)$	-2.41%
Tight leading photon	$570.0(-16.56\%)$	$658(-6.00\%)$	-13.38%
$\Delta\phi(\gamma, E_T^{\rm miss}) > 0.4$	$568.6(-0.24\%)$	$620(-5.78\%)$	-8.30%
$E_T^{\rm miss}/\sqrt{\sum E_T} > 8.5$ GeV$^{1/2}$	$555.4(-2.32\%)$	$596(-3.87\%)$	-6.81%
$N_{\rm jet} < 2$ and $\Delta\phi({\rm jet}, E_T^{\rm miss})$>0.4	$447.6(-17.13\%)$	$461(-22.65\%)$	-2.91%
Lepton veto	$447.6(-0.00\%)$	$460(-0.21\%)$	-2.7%

Table 5.1: Comparison of the cutflow predicted by MADANALYSIS 5 with the one provided by the ATLAS collaboration.

3 Validation

3.1 Event Generation

In order to validate our reimplementation of the ATLAS analysis, we focus on the simplified model introduced above. In order to generate hard scattering signal events, we use the UFO [16] model associated with the considered simplified dark matter model [33] that has been generated with the FEYNRULES [34] and NLOCT [35] programs. We have imported this model into MADGRAPH5_AMC@NLO version 2.6.0 [1] and generated parton-level events by convoluting matrix elements at the next-to-leading order (NLO) accuracy in QCD with the NLO set of NNPDF 3.0 parton distribution functions [17]. Those events have then been showered and hadronized within the PYTHIA 8.2 environment [25], and the simulation of the detector response has been made with DELPHES 3 [2] that internally relies on FASTJET [19] for object reconstruction. We have used our MADANALYSIS 5 reimplementation to calculate the signal selection efficiencies.

3.2 Comparison with the official results

In Table. 5.1, we compare the results obtained with our implementation to the official numbers provided by the ATLAS collaboration. The discrepancy is characterized according to the measure

$$|{\rm error}| = \left|\frac{\rm MA5 - Official}{\rm Official}\right| . \tag{5.16}$$

We observe that the disagreement, on a cut-by-cut basis, is of at most 20%, and even smaller than that for most cuts. We therefore consider our analyssis as validated.

4 Summary

We have implemented in MADANALYSIS 5 the five signal regions of the ATLAS monophoton analysis of 36.1 fb^{-1} of LHC collision data at a center-of-mass energy of 13 TeV. We have validated our implementation in the context of a Dirac fermionic dark matter simplified model featuring an axial-vector mediator by comparing our predictions for the cutflow with the official one provided by ATLAS in Ref. [8]. We have found an agreement that is better than at the 20% level, so that we consider our reimplementation as validated. It is available from MADANALYSIS 5 version 1.6 onwards, its Public Analysis Database and from INSPIRE [36],

http://doi.org/10.7484/INSPIREHEP.DATA.88NC.0FER.1.