Chapter 1

ATLAS-CONF-2016-086: an ATLAS dark matter search with b-jets and $\not{E}_T$ (13.3 fb^{-1})

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Abstract
We present the MadAnalysis 5 implementation and validation of the ATLAS-CONF-2016-086 search. This ATLAS analysis targets the production of dark matter in association with b-tagged jets and probes 13.3 fb^{-1} of LHC proton-proton collisions at a center-of-mass energy of 13 TeV. The validation of our reimplementation is based on a comparison with all the material provided by the ATLAS collaboration, as well as with a back-of-the-enveloppe expectation of a related theoretical work. By lack of public experimental information, we have not been able to validate this reimplementation more throroughly.

1 Introduction

In this note, we describe the validation of the implementation, in the MadAnalysis 5 framework [1–3], of the ATLAS-CONF-2016-086 analysis [4] probing the production of dark matter at the LHC in association with a pair of b-tagged jets originating from a bottom-antibottom quark pair at the parton level. The signature that is searched for thus consists in missing transverse energy and b-jets. The ATLAS-CONF-2016-086 analysis focuses on the analysis of an integrated luminosity of 13.3 fb^{-1} of LHC collisions at a center-of-mass energy of 13 TeV.

For the validation of our reimplementation, we have focused on a simplified dark matter model in which the Standard Model is extended by two additional fields, namely a Dirac field χ corresponding to the dark matter particle and a scalar (Φ) or pseudoscalar (A) field responsible for the mediation of the interactions of the Standard Model sector with the dark sector [5]. This scenario involves four parameters, namely the mass of the scalar mediator m_Φ (or m_A in the pseudoscalar case), the mass of the dark matter particle m_χ, the mediator coupling to the dark sector y_χ and the flavor-universal coupling of the mediator to the Standard Model y_v. In this theoretical framework, the signal that is relevant for the considered analysis arises from the process

$$pp \to \chi\bar{\chi}\, b\bar{b}\,, \tag{1.1}$$

in which the pair of dark matter particles gives rise to missing transverse energy and originates from the decay of a possibly off-shell mediator.

2 Description of the analysis

The analysis makes use of all the information present in the signal final state. It therefore requires, as a basic selection, the presence of missing transverse energy as well as of jets with some of them being b-tagged. The kinematics of the bottom-antibottom system is then used as a handle to reduce the background of the Standard Model.

2.1 Object definitions

Jets are recontructed by means of the anti-k_T algorithm [6] with a radius parameter set to $R = 0.4$. Our analysis focuses on jets whose transverse momentum p_T^j and pseudorapidity η^j fullfill

$$p_T^j > 20 \text{ GeV} \qquad \text{and} \qquad |\eta^j| < 2.8 \; . \tag{1.2}$$

Moreover, the selected jets are tagged as originating from the fragmentation of a b-quark according to a working point for which the average b-tagging efficiency is of about 60%.

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

$$p_T^e > 7 \text{ GeV} \qquad \text{and} \qquad |\eta^e| < 2.47 \; , \tag{1.3}$$

and the muon candidate definition is similar, although with slightly looser thresholds,

$$p_T^\mu > 6 \text{ GeV} \qquad \text{and} \qquad |\eta^\mu| < 2.7 \; . \tag{1.4}$$

Any jet lying within a cone of radius $\Delta R < 0.2$ of an electron is discarded, unless it is b-tagged. In this last case, it is the electron that is discarded. Any electron or muon that would then lie within a cone of radius $\Delta R < 0.4$ of a jet is finally removed from the set of jet candidates to consider.

The missing transverse momentum vector $\not{p}_T$ is defined as the opposite of the vector sum of the momenta of all reconstructed physics object candidates, and the missing transverse energy $\not{E}_T$ is then defined by its norm.

2.2 Event selection

The analysis contains a unique signal region that is defined by a requirement on the missing transverse energy,

$$\not{E}_T > 150 \text{ GeV} \; , \tag{1.5}$$

and on the number of b-tagged jets that is asked to be equal to 2. The signal being charaterized by a small jet multiplicity, events featuring a third jet with a transverse momentum greater than 60 GeV are vetoed, as events whose final state contains leptons. Moreover, the missing transverse momentum is constrained to be well separated from any jet,

$$\Delta\phi(\not{p}_T, j) > 0.4 \; . \tag{1.6}$$

In order to guarantee a full trigger efficiency, selected events are required to satisfy the so-called hyperbolic requirement on the missing energy,

$$p_T^{j_1} > 85 \text{ GeV} \qquad \text{and} \qquad \not{E}_T > \frac{\big[150 \text{ GeV}\big] p_T^{j_1} - \big[11700 \text{ GeV}^2\big]}{p_T^{j_1} - \big[85 \text{ GeV}\big]} \; . \tag{1.7}$$

The dominant component of the background, related to invisible Z-boson production in association with b-tagged jets, is reduced by requiring a large separation between the jet candidates,

$$\Delta R(j_i, j_k) > 2.8, \tag{1.8}$$

for any pair of reconstructed jets (i, k). The two b-jets are furthermore constrained to satisfy

$$\Delta\eta(b_1, b_2) > 0.5 \; , \qquad \Delta\phi(b_1, b_2) > 2.2 \qquad \text{and} \qquad \text{Imb}(b_1, b_2) \equiv \frac{p_T^{b_1} - p_T^{b_2}}{p_T^{b_1} + p_T^{b_2}} > 0.5 \; . \tag{1.9}$$

With the last requirement, one imposes a significant transverse-momentum imbalance between the two b-jets that is known to be large for typical signals.

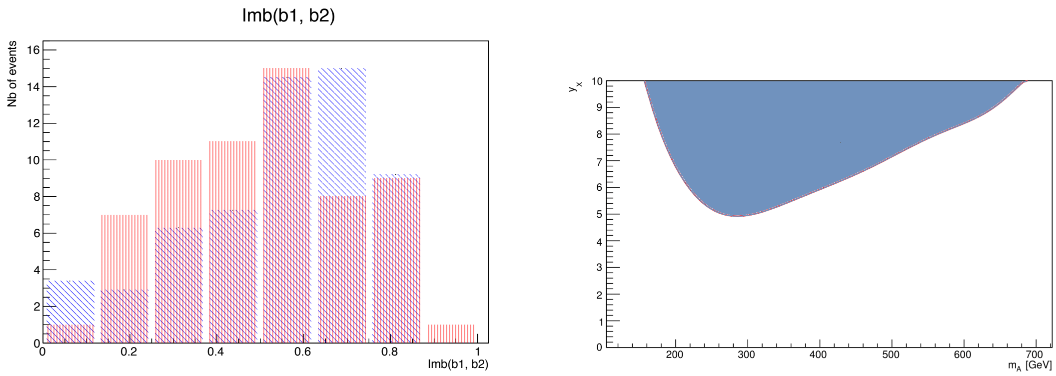

Fig. 1.1: Left: Transverse momentum imbalance when all selection criteria are applied except the one on Imb(b_1, b_2). We compare the official numbers (red) with our predictions (blue). Right: contour excluded at the 95% confidence level, presented in the parameter space of the model introduced in Ref. [13].

3 Validation

3.1 Event Generation

In order to validate our analysis, we rely on the dark matter simplified model introduced above and for which a UFO model [7] has been provided by the ATLAS collaboration. We focus on a benchmark scenario defined by

$$y_\chi = y_v = 1, \qquad m_{\Phi/A} = 20 \text{ GeV} \qquad \text{and} \qquad m_\chi = 1 \text{ GeV}. \tag{1.10}$$

We make use of MADGRAPH5_AMC@NLO version 2.6.0 [8] for hard-scattering event generation in which leading-order matrix elements are convoluted with the leading-order set of NNPDF 3.0 parton densities [9]. Those events have been showered by means of the PYTHIA 6 package [10]. Finally, the simulation of the detector response has been performed by using DELPHES 3 [11], that relies on FASTJET [12] for object reconstruction and that has been used with an appropriate tuned detector card. All necessary configuration files, most of them having been provided by ATLAS, can be found on the MADANALYSIS 5 public database webpage,

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

We have finally used our MADANALYSIS 5 reimplementation to calculate the signal selection efficiencies.

3.2 Comparison with the official results

In the left panel of Figure 1.1, we present the transverse-momentum imbalance spectrum as computed using the MADANALYSIS 5 (blue) and compare it to the official results (red). The results shown in the figure include all selection cuts but the Imb$(b_!, b_2)$ one. One obtains a fair agreement accounting for the large statistical uncertainties plaguing the simulation and about which no information has been provided by the ATLAS collaboration.

In the right panel of the figure, we consider a different new physics setup in which the dark matter mass is set to $m_\chi = 100$ GeV and the mediator coupling to the Standard Model to $g_v = 1$. We then present, in the (m_A, y_χ) plane, the parameter space region that is excluded at the 95% confidence level. We obtain a good agreement with the back-to-the-enveloppe estimations of Ref. [13].

4 Summary

We have implemented the ATLAS-CONFIG-2016-086 search in the MADANALYSIS 5 framework. Our analysis has been validated in the context of a simpified model for dark matter in which the dark matter candidate is a fermion and the mediator a boson. We have found a decent agreement with the material provided by ATLAS, which is not dramatically detailed. Due to the lack of information, the validation has been kept brief. As a fair agreement has nevertheless been obtained both with respect to the material provided by ATLAS and to an earlier theoretical work, we have considered this reimplementation as validated. It is available from MADANALYSIS 5 version 1.6 onwards, its Public Analysis Database and from INSPIRE [14],

http://doi.org/10.7484/INSPIREHEP.DATA.UUIF.89NC.

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