Validation note : implementation of the ATLAS-EXOT-2019-03 analysis in the MadAnalysis 5 framework

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1 Introduction

This note describes the recasting of the analysis ATLAS-EXOT-2019-03 [1] in MadAnalysis 5 [2], that is now available in its Public Analysis Database [3], and that use the simplified fast detector simulation (SFS) [4]. This analysis is a search for new resonances decaying into a pair of jets. Many models beyond the Standard Model predict the existence of new heavy particles which could be produced in proton-proton collisions at the Large Hadron Collider (LHC), and decay to quarks and gluons, thus leading to 2 energetic jets in the detector.

The analysis use 139 fb^{-1} of data at $\sqrt{s} = 13$ TeV, collected with the ATLAS detector of the LHC between 2015 and 2018. Events are required to have at least 2 jets with a transverse momentum higher than 150 GeV. The distribution of the invariant mass m_{jj} of the 2 leading jets is examined between 1.1 and 8 TeV for local excesses relative to an estimated contribution from the Standard Model. In addition to an inclusive di-jet selection, events with jets identified as being initiated by b-quark are examined in specific regions.

The ATLAS collaboration made available substantial additional data via HEPData at `https://www.hepdata.net/record/ins1759712?version=1`, including acceptance and exclusion plots for each models, and the number of observed events and expected background with uncertainty in each m_{jj} bin.

2 Description of the analysis

2.1 Events selection

Selected events must pass a trigger that requires at least one jet with $p_T > 420$ GeV. The anti-k_t algorithm [5] with a radius parameter of 0.4 is used to group topological clusters (i.e amount of neighbouring calorimeter cells with a significant energy deposit) [6] into jets. The jet energies and angular positions are then corrected [7]. Events are rejected if any jet with $p_T > 150$ GeV is compatible with noise bursts, beam induced background or cosmic rays using the 'loose' criteria [8].

Events are required to have at least two jets with $p_T > 150$ GeV, and the azimuthal angle between the two jets $|\Delta\phi|$ must be greater than 1.0.

2.2 Signal regions

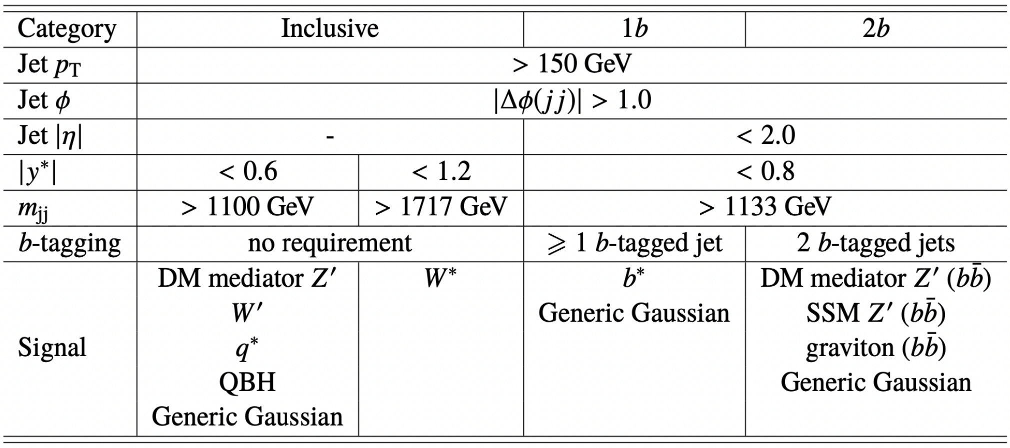
The events are classified into an inclusive region, a one-b-tagged region ($1b$) requiring at least one of the two leading jets to be b-tagged, and a two-b-tagged region ($2b$) with both of the two leading jets being b-tagged.

In the b-tagged regions, the two jets must satisfy $|\eta| < 2.0$.

A selection on the centrality $y^* = \frac{y_1 - y_2}{2}$ is made to reduce contribution from QCD processes (y_1 and y_2 are the rapidities of the leading and sub-leading jets respectively) ; a lower bound on the invariant mass m_{jj} is also required. The $|y^*|$ and m_{jj} cut values are different between the regions (Figure 1).

The identification of jets containing b-hadrons is done using a deep-learning neural network DL1r [9], at the 77 % efficiency operating point. The b-tagging efficiencies as a function of the jet p_T are represented on Figure 2. The mis-tag rate of light-flavour jets remains at the level of 1 % across the same p_T interval.

For the configuration of the detector card, I multiplied these efficiencies by a simulation-to-data scale factor, represented in function of the jet p_T on Figure 3. I have also multiplied the efficiencies by an additional factor to obtain more correct acceptance values in b-tag regions, because the simulation-to-data factors must be adapted to the simplified fast detector simulation used in MadAnalysis.



Category	Inclusive		$1b$	$2b$
Jet p_{T}	> 150 GeV			
Jet ϕ	$\lvert\Delta\phi(jj)\rvert > 1.0$			
Jet $\lvert\eta\rvert$	-		< 2.0	
$\lvert y^*\rvert$	< 0.6	< 1.2	< 0.8	
m_{jj}	> 1100 GeV	> 1717 GeV	> 1133 GeV	
b-tagging	no requirement		$\geqslant 1$ b-tagged jet	2 b-tagged jets
Signal	DM mediator Z' W' q^* QBH Generic Gaussian	W^*	b^* Generic Gaussian	DM mediator Z' ($b\bar{b}$) SSM Z' ($b\bar{b}$) graviton ($b\bar{b}$) Generic Gaussian

FIGURE 1 – Table summarizing the events selection in the different regions, with the corresponding signals tested (from [1]).

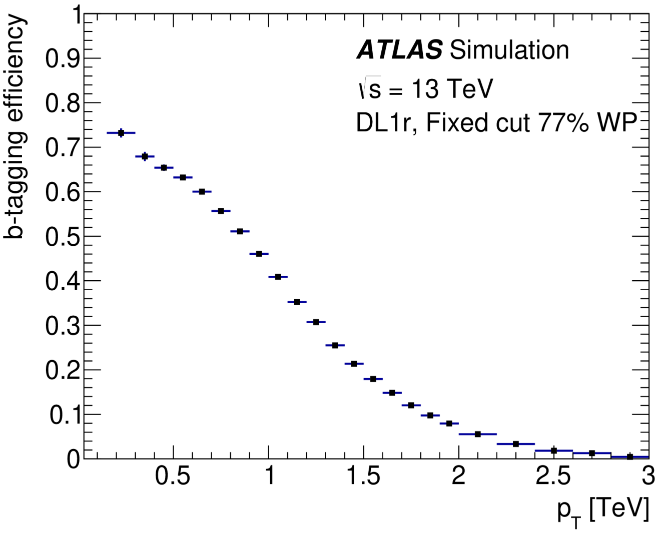


FIGURE 2 – The b-tagging efficiency as a function of jet p_T (from [1]).

3 Validation of the implementation

3.1 Generation of signal events

In the inclusive region, I consider the signals corresponding to the production of an excited quark q^* [10] and a new $W^{'}$ boson [11], respectively via $q\bar{q} \to q^* \to qg$ (q* being only u* or d*) and $q\bar{q} \to W^{'} \to q\bar{q}$.

In the 1b region, the only signal is that originating from the excited quark

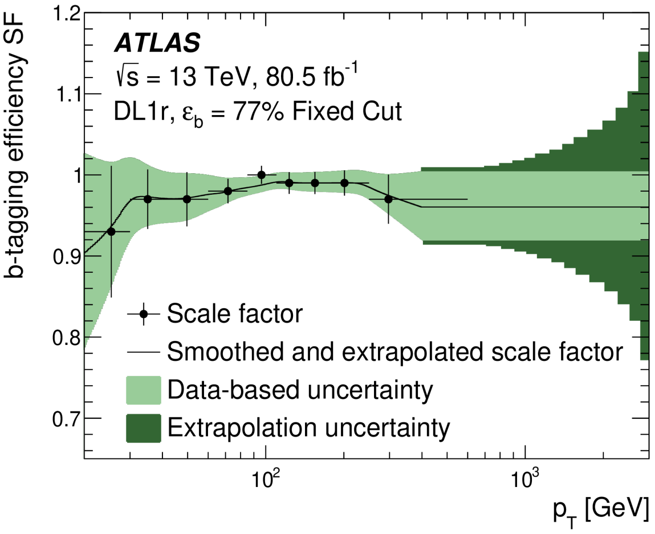


FIGURE 3 – Simulation-to-data scale factor as a function of jet p_T (from [1])

b ; I consider the process $q\bar{q} \to b^* \to bg,\ b\gamma,\ bZ,\ tW^-$. The branching ratio to the final state bg is equal to 85 % [10].

In the 2b region, I consider the signal corresponding to a sequential standard model (SSM) Z' boson decaying into $\bar{b}b$ [12].

For each of these models, I generate 20 000 events with Pythia 8 [13] for different masses of the particle, using the parameters employed by ATLAS.

For the validation, I compare the value of the acceptance that I obtained with MadAnalysis to the one from ATLAS ; finally, I compute the upper limits on cross-section for all of the processes thanks to the MadAnalysis output interpreter ma5_expert (`https://github.com/MadAnalysis/ma5_expert`), before reproducing exclusion plots.

3.2 Acceptance comparison

In Figures 4, 5, 6 and 7, I present the acceptance values I obtained with MadAnalysis respectively for the q^*, the W', the b^* and the SSM Z' signals after all the corresponding selections defined in Figure 1. On the same plot, I add the values obtained by ATLAS, and the ratio between the MadAnalysis value to the ATLAS one in the lower panels.

The agreement is excellent, especially in the Inclusive and 1b regions, with relative errors below 3 %. In the 2b region, the errors are below 15 %.

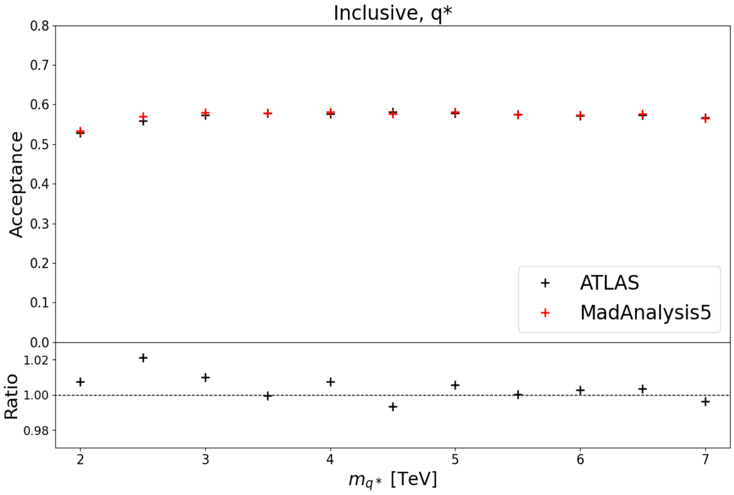


FIGURE 4 – Acceptance for the excited quark q^*

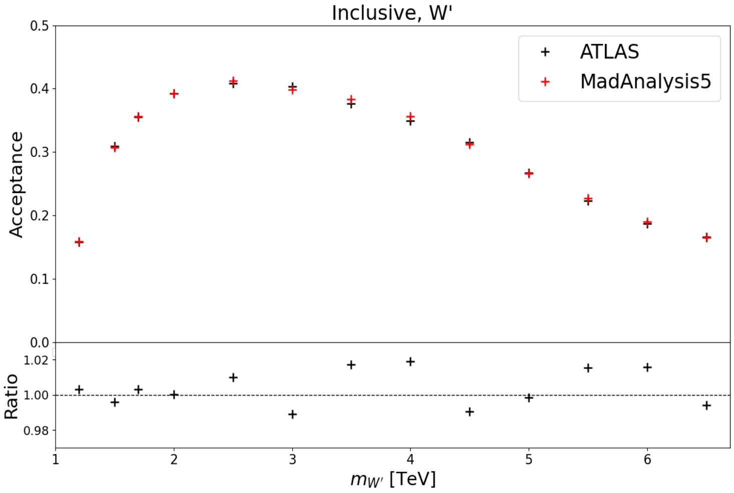


FIGURE 5 – Acceptance for the W' boson

3.3 Exclusion plots

In Figures 8, 9, 10 and 11, I reproduced in red the expected and observed exclusion limits on cross-section times acceptance times branching ratio into 2 jets $\sigma\times$ A $\times$ BR at 95 % confidence level, in function of the particle mass for the different signals. To do this, I get the number of events and expected background in each m_{jj} bins from HEPData, and I configure the

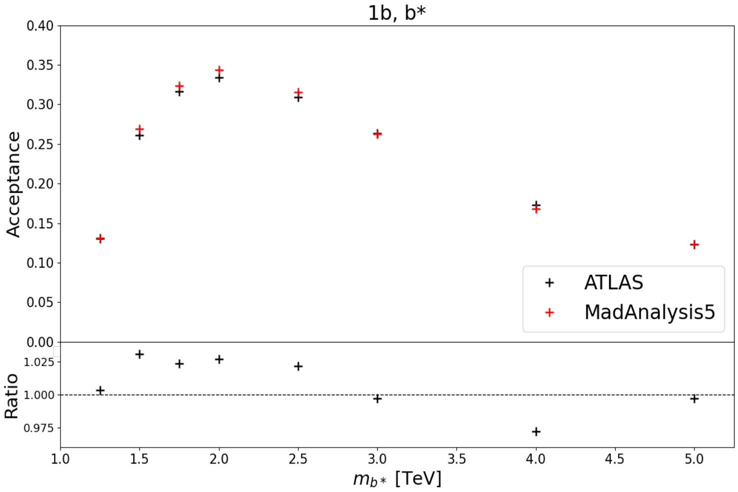


FIGURE 6 – Acceptance for the excited b-quark b^*

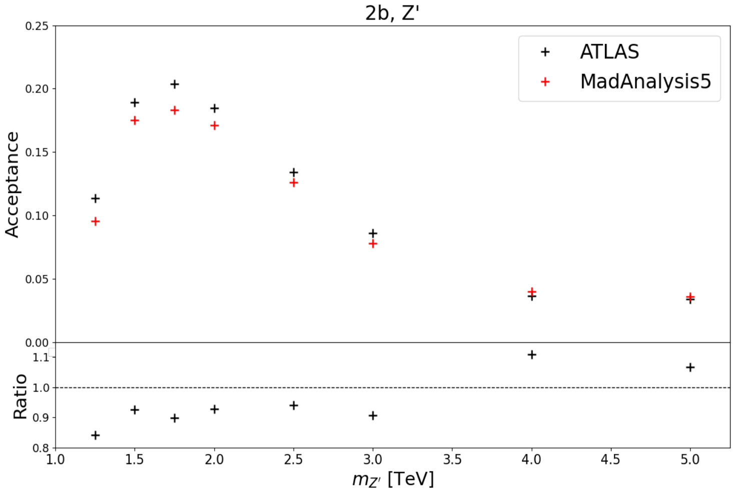


FIGURE 7 – Acceptance for the SSM Z' boson

statistical exclusion to be done by considering together all the m_{jj} bins as being decorrelated.

As for the acceptance, the agreement with the ATLAS results is very satisfying.

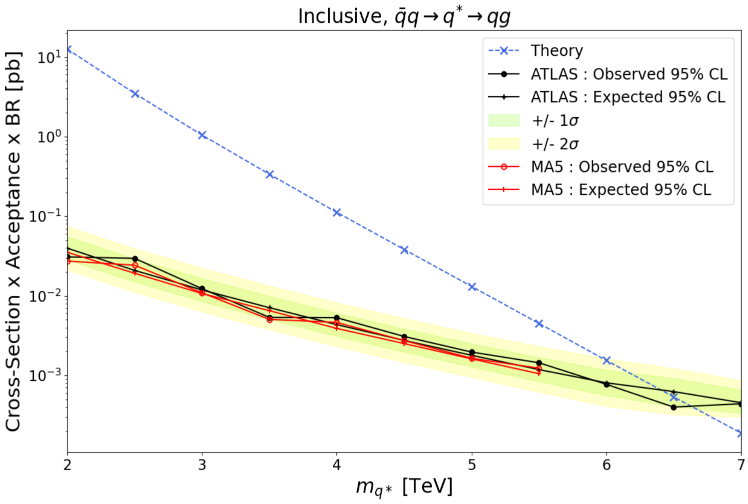


FIGURE 8 – 95% CL upper limits on $\sigma\times$ A $\times$ BR for the excited quark q^*

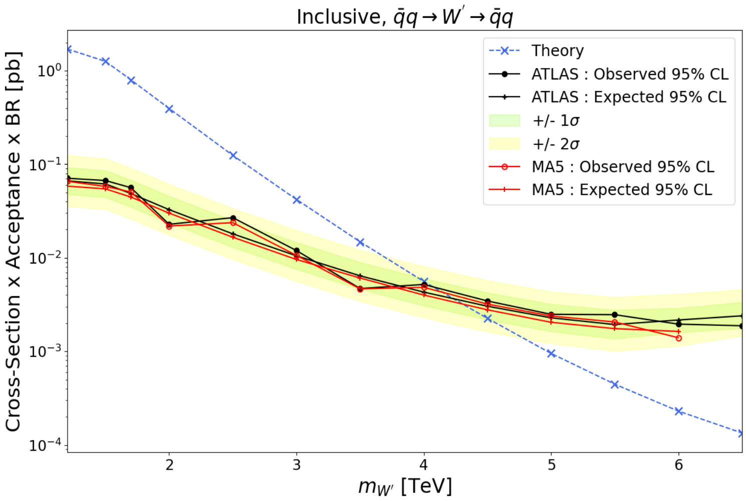


FIGURE 9 – 95% CL upper limits on $\sigma\times$ A $\times$ BR for the W' boson

4 Conclusion

I have implemented the ATLAS-EXOT-2019-03 analysis in the MadAnalysis5 framework, an analysis searching for new heavy particles decaying into quarks and gluons, forming 2 energetic jets in the final state. I have validated the implementation of the analysis by reproducing for each signal the acceptance and the excluded $\sigma\times$ A $\times$ BR values for different masses,

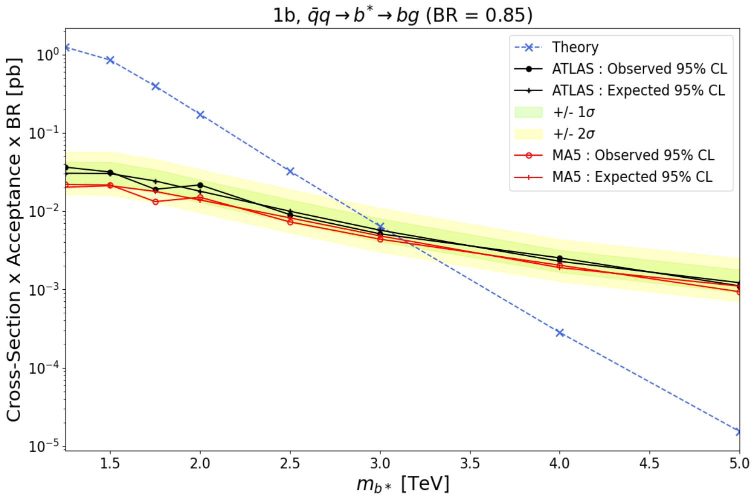


FIGURE 10 – 95% CL upper limits on $\sigma\times$ A $\times$ BR for the excited b-quark b^*

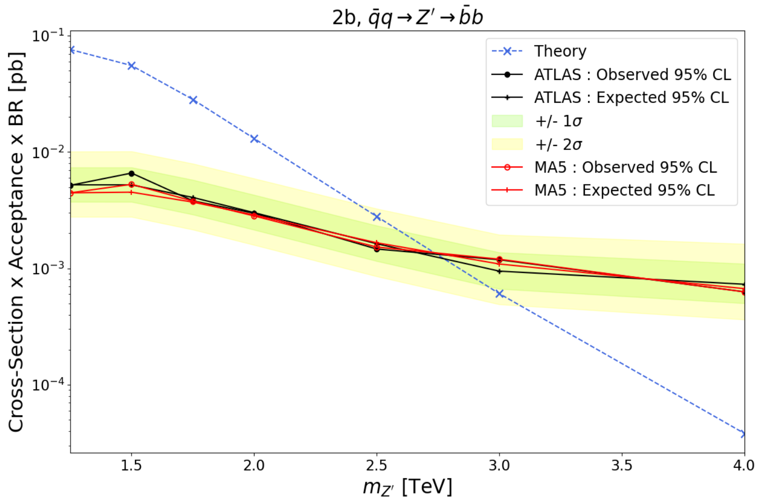


FIGURE 11 – 95% CL upper limits on $\sigma\times$ A $\times$ BR for the SSM Z' boson

which show a very good agreement with the ATLAS values. The analysis is now available in the MadAnalysis Public Analysis Database.

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