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SEARCH FOR A NEW HEAVY RESONANCE IN FINAL STATES WITH DI-JET OR DI-b-JETS WITH THE ATLAS DETECTOR*

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A search of new heavy resonances decaying into a pair of jets in pp collisions with the ATLAS detector at LHC is reported. The dataset corresponds to an integrated luminosity of up to 139 fb^{-1} collected between 2015 and 2018 at $\sqrt{s} = 13$ TeV. No evidence of significant excess of events above the smooth background shape is observed. Upper cross-section limits for several types of signal hypotheses are provided at 95% C.L.

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1. Introduction

Searches for new particles decaying into pairs of jets have been a fundamental part of the physics programme at collider experiments for over thirty years [1]. Since new particles directly produced in pp collisions interact with the constituent partons of the proton and, consequently, can produce partons when they decay, di-jet signatures offer a simple way to search for a wide array of possible New Physics. Inclusive searches have a good sensitivity to strongly produced particle that decay into generic di-jets with large cross sections. Searches restricted to final states involving jets identified as containing a b-hadron have an increased sensitivity if the new particles preferentially decay into $b\bar{b}$, bq or bg.

This article presents a brief overview of a new resonance search in di-jet mass distribution performed by the ATLAS detector at the Large Hadron Collider (LHC). The search is comprehensively described in a published paper [2].

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2. Data samples and events selection

The analysis is based on pp collisions data at $\sqrt{s} = 13$ TeV collected by the ATLAS detector at LHC in the years from 2015 to 2018. The data were recorded under stable beam conditions while all relevant subdetectors were fully operational, and were subject to detailed quality checks. The data sample corresponds to an integrated luminosity of 139 fb^{-1} with an uncertainty of 1.7% [3].

Jets are reconstructed from topological clusters of deposits in the calorimeters with the anti-k_{t} algorithm [4] with a radius parameter of 0.4, and are required to have $p_{\mathrm{T}} > 150$ GeV. Jets containing a b-hadron are identified using a deep learning neural network, DL1r, for the first time at ATLAS. The DL1r network is based on the impact parameters of tracks and the reconstructed displaced vertices in the inner detector. The inputs of the DL1r network also include discriminating variables constructed by a recurrent neural network, which provides improvements of b-tagging by counting for the correlations between the track features. A 77% efficiency b-tagging operating point is adopted.

To maximise the sensitivities to various signal models, a selection based on half of the rapidity separation between the two leading jets, $y^* = (y_1 - y_2)/2$, is implemented. All events are classified into an inclusive category with no-b-jet tagging requirement, a one-b-tagged category ($1b$) requiring at least one of the leading two jets to be b-tagged, and a two-b-tagged category ($2b$) with both of the leading two jets being b-tagged.

Monte Carlo (MC) is used to generate a series of benchmark models: excited quarks (q^*), excited b-quarks (b^*), new heavy vector bosons (W', DM Z'), sequential standard model Z' boson (SSM Z'), excited chiral bosons (W^*), quantum black holes (QBH) and the Randall–Sundrum Graviton (G).

All analysis selections are summarised in Table I.

TABLE I

Summary of the event selection.

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	< 0.6	
m_{jj}	> 1100 GeV	> 1717 GeV	> 1133 GeV	
b-tagging	no requirement		≥ 1 b-tagged jet	2 b-tagged jets

3. Di-jet mass spectrum

The SM production of di-jet events is dominated by QCD multijet processes, which yield a smoothly falling m_{jj} spectrum. To determine the SM contribution, the sliding window fitting method is applied on the data, with a nominal fit using a parametric function

$$f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 \ln x}\,, \tag{1}$$

where $x \equiv m_{jj}/\sqrt{s}$. The background in each bin is extracted from the data by fitting in a mass window centred around that bin. The window size is chosen to be the largest possible window that satisfies the fit requirements which is BumpHunter [5] p-value > 0.01.

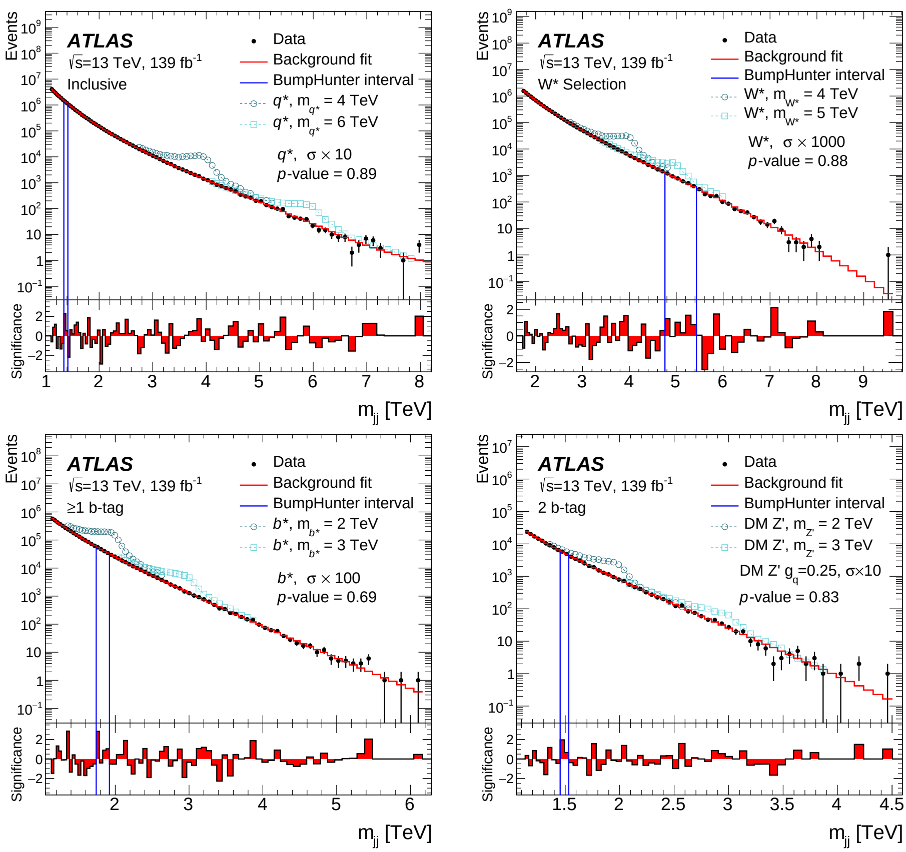

Fig. 1. Di-jet invariant mass distributions from multiple categories: inclusive di-jet with $|y^*| < 0.6$ (top left), inclusive di-jet with $|y^*| < 1.2$ (top right), di-jet with at least one b-tagged jet (bottom left) and di-jet with both jets b-tagged (bottom right). The vertical lines indicate the most discrepant interval identified by the BumpHunter algorithm, for which the p-value is stated in the figure [2].

The statistical significance of any localised excess in the m_{jj} distribution is quantified using BumpHunter test. The algorithm compares the binned m_{jj} distribution of the data to the fitted background estimate, considering contiguous mass intervals in all possible locations, from a width of two m_{jj} bins up to a half the extent of the full m_{jj} distribution. For each interval in the scan, it computes the significance of any excess found. The interval that deviates most significantly from the smooth spectrum is defined by the set of bins that have the smallest probability of arising from a Poisson background fluctuation. Figure 1 shows the observed m_{jj} distributions for the various categories and also the BumpHunter p-values of the most discrepant regions.

4. Systematic uncertainties

For the background, the statistical uncertainty on the fit results and the uncertainty on the choice of the fit function are considered. These uncertainties are estimated by fitting the pseudo-data with the nominal function and alternative parametric function. For the inclusive category, $p_1(1-x)^{p_2}x^{p_3+p_4\ln x+p_5x}$ is used as an alternative function, while for the b-tagged categories, $p_1(1-x)^{p_2+p_3x}x^{p_4+p_5\ln x}$ is used. In order to evaluate the possible biases in the function fitting strategy and the capability of the chosen function to model the data, an additional systematic uncertainty is also considered based on spurious signal tests.

The main systematic uncertainties in the MC signal samples include the modeling of the jet energy scale, jet energy resolution and b-tagging efficiency. A luminosity uncertainty of 1.7% is applied to the normalization of the signal samples. PDF uncertainties are also added which were found to be approximately 1% for most signals and reaching 4% for high-mass values.

5. Signal interpretation

Since no significant deviation from the expected background is observed, constraints on various signal models are set using a frequentist framework. Upper limits on the signal cross section times acceptance times branching ratio (times b-tagging efficiency in b-tagged categories) are extracted at 95% confidence level (C.L.), as shown in Fig. 2.

The b-tagged analysis, compared to the previous ATLAS results [6], benefits from the substantial improvements in the b-tagged identification algorithm and associated systematic uncertainties. The current and previous expected upper limits at 95% C.L. are shown in Fig. 3 as a function of the Z' mass in the DM benchmark model. A factor of up to 3.5 improvement, beyond that expected from the increase of integrated luminosity, in the expected upper limits is observed.

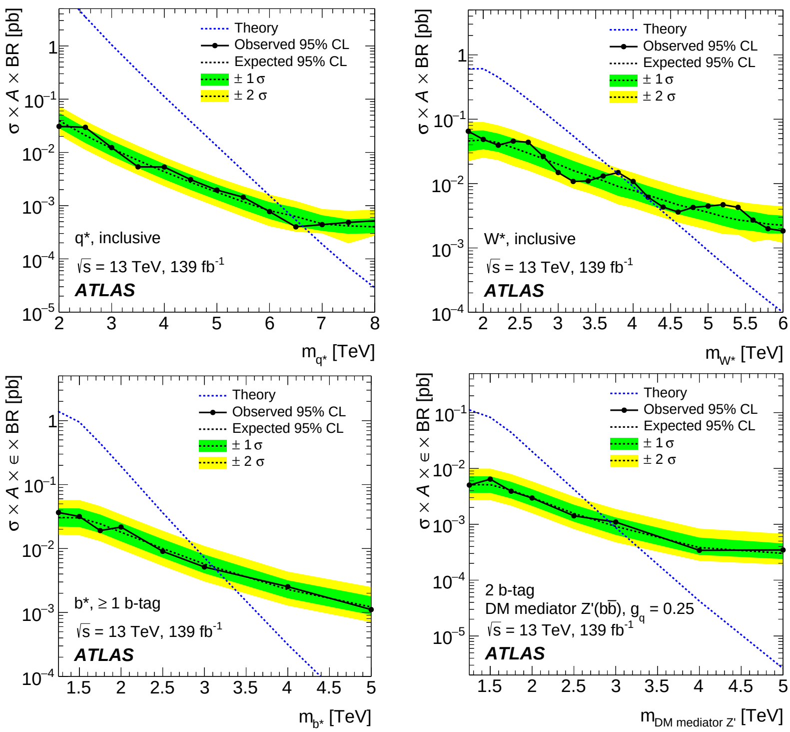

Fig. 2. The 95% C.L. upper limit on the cross section times acceptance efficiency times branching ratio (times b-tagging efficiency in b-tagged categories) as a function of signal mass for q^* (top left), W^* (top right), b^* (bottom left) and DM $Z' \to b\bar{b}$ (bottom right) signals [2].

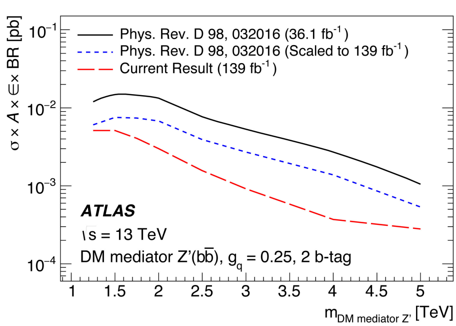

Fig. 3. The 95% C.L. expected upper limit on the cross section times acceptance times efficiency times branching ratio as a function of the DM Z' mass for the current and previous iteration of the analysis. The previous result is also scaled to the 139 fb^{-1} integrated luminosity of the current result to illustrate the analysis improvement [2].

6. Conclusion

A search for new resonances decaying into a pair of jets has been performed with di-jet events using pp collision at $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 139 fb^{-1} collected by the ATLAS detector at LHC between 2015 and 2018. No significant excess above the predicted background is observed. Constraints on various signal models are derived. The analysis with b-tagging benefits from substantial improvements in b-jet identification algorithm, resulting in an improvement in sensitivity, with respected to the previous ATLAS results, beyond that expected from the integrated luminosity increase.

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