Search for New Particles in 2-Jet Final States in 7 TeV Proton-Proton Collisions with the ATLAS Detector at the LHC

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A search for new heavy particles manifested as resonances in two-jet final states is presented. The data were produced in $\sqrt{s} = 7\ TeV$ proton-proton collisions by the Large Hadron Collider (LHC) and correspond to an integrated luminosity of 315 nb^{-1} collected by the ATLAS detector. No resonances were observed. Upper limits were set on the product of cross section and signal acceptance for excited-quark (q^*) production as a function of q^* mass. These exclude at the 95% CL the q^* mass interval $0.30 < m_{q^*} < 1.26$ TeV, extending the reach of previous experiments.

1. Introduction

Two-jet (dijet) events in high-energy proton-proton (pp) collisions are usually described in the Standard Model (SM) by applying quantum chromodynamics (QCD) to the scattering of beam-constituent quarks and gluons. Several extensions beyond the SM predict new heavy particles, accessible at LHC energies, that decay into two energetic partons. Such new states may include an excited composite quark q^*, exemplifying quark substructure [5]; an axigluon predicted by chiral color models [5]; a flavour-universal color-octet coloron [5]; or a color-octet techni-ρ meson predicted by models of extended technicolor and topcolor-assisted technicolor [5].

The dijet invariant mass (m^{jj}) observable is particularly sensitive to such new objects. At the Fermilab Tevatron collider, 1.13 fb^{-1} of $p\bar{p}$ collision data were used to exclude the existence of excited quarks q^* with mass $260 < m_{q^*} < 870$ GeV [5]. This analysis focused on a search for the excited quarks because of the accessible predicted cross section [5] for such particles and the benchmark nature of the model that allows limits on acceptance times cross section to be set for resonant states with intrinsic widths narrower than the experimental resolution.

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2. Measurement and Exotic Search

2.1. Jet Reconstruction

Jets [1] were reconstructed in ATLAS [2] using the anti-k_T jet clustering algorithm [5] with a size parameter of $R = 0.6$. The inputs to this algorithm were 3D topological clusters of calorimeter cells seeded by cells with energy, calibrated at electromagnetic scale, significantly above the measured noise. Jet four-vectors were constructed by performing a four-vector sum over these cell clusters and calibrated by MC-derived p_T-dependent and η-dependent calibration factors. The dijet mass observable m^{jj} was computed without unfolding jets to hadrons or partons.

2.2. Event Selection

Events were required to contain at least one primary collision vertex (defined by at least five reconstructed charged-particle tracks) and at least two jets after the criteria that the leading jet $p_T^{j_1}$ and the subleading jet $p_T^{j_2}$ are larger than 80 GeV and 30 GeV respectively. The events with a poorly measured jet [6] of $p_T > 15$ GeV were vetoed to prevent from swapping between the poorly-measured jet and one of the 2 leading jets. The two leading jets were required to satisfy several quality criteria [5] and to lie outside the crack region, i.e., $1.3 < |\eta^{\mathrm{jet}}| < 1.8$. Finally, both jets were required to be within $\left|\eta^{\mathrm{jet}}\right| < 2.5$ as well as $\left|\eta^{j_1} - \eta^{j_2}\right| < 1.3$ in order to maximize the signal discovery potential illustrated in Fig. 1.

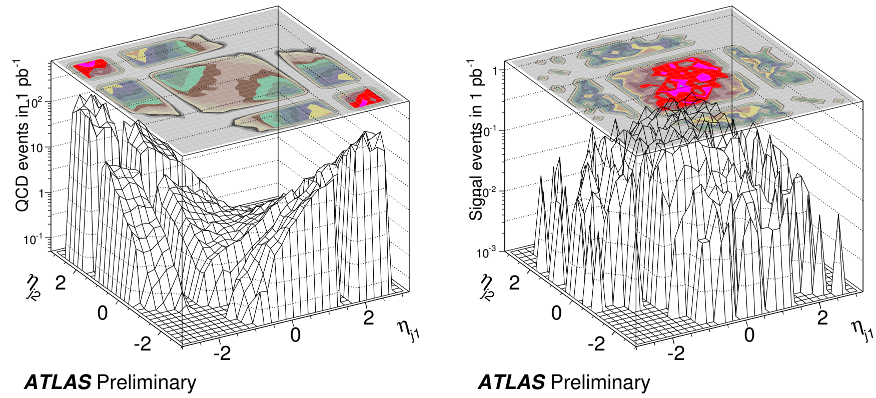


Figure 1: Surface plots describing the expected distributions of event yields in the observables η_{j_1} and η_{j_2} for dijets with $875 \leq m^{jj} \leq 1020$ GeV, a range defined by the predicted $\pm 1\sigma$ region of a 1 TeV excited quark q^*, identified in MC [left] QCD background and [middle] 1 TeV q^* signal samples.

2.3. Background Determination and Statistical Test

The background shape was determined by fitting the observed spectrum with the function [5]

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

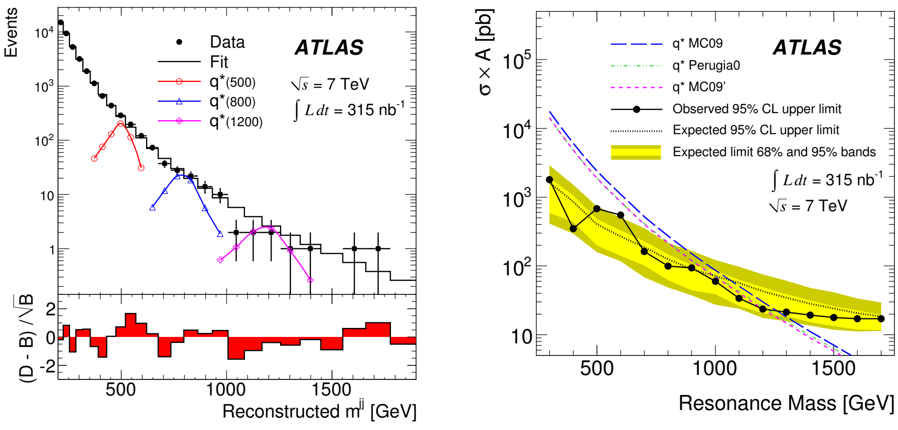
where $x \equiv m^{jj}/\sqrt{s}$ and $p_{\{1,2,3,4\}}$ are free parameters. This smooth and monotonic form of Eqn. 1 demonstrated a good agreement with QCD-predicted dijet mass distributions in pp collisions at $\sqrt{s} = 7$ TeV, as evidenced by a $\chi^2 = 27$ for 22 degrees of freedom over the dijet mass range $200 < m^{jj} < 1900$ GeV. This supported the use of Eqn. 1 to estimate the background shape in the observed m^{jj} distribution. The results of fitting the data with Eqn. 1 are shown in Fig. 2(a).

Six statistical tests of the background-only hypothesis were employed to determine the presence or absence of detectable m^{jj} resonances in this distribution: the BumpHunter [5], the Jeffreys divergence [5], the Kolmogorov-Smirnov test, the likelihood, the Pearson χ^2, and the TailHunter statistic [5]. All these tests were consistent with the conclusion that the fitted parameterization described the observed data distribution well, with p-values in excess of 51%. These observations supported the background-only hypothesis. In the absence of any observed discrepancy with the zero-signal hypothesis, a Bayesian approach was used to set 95% credibility-level (CL) upper limits on $\sigma \cdot \mathcal{A}$ for hypothetical new particles decaying into dijets with $|\eta^{\text{jet}}| < 2.5$.

2.4. Systematic Uncertainty and Limit Setting

The dominant sources of systematic uncertainty were associated with the absolute jet energy scale (JES), the background fit parameters and the integrated luminosity. The JES uncertainty was quantified as a function of p_T and η^{jet}, with values in the range $6 \sim 9\%$ [4]. The systematic uncertainty on the background determination was taken from the uncertainty on the fit parameters of Eqn. 1 to the data sample. The uncertainty on $\sigma \cdot \mathcal{A}$ due to integrated luminosity was estimated to be $\pm 11\%$ [5]. All these effects were incorporated as nuisance parameters into the likelihood function and then marginalized by numerically integrating the product of this modified likelihood, the prior in signal cross section, and the priors corresponding to the nuisance parameters to arrive at a modified posterior probability distribution.

Fig. 2(b) depicts the resulting 95% CL upper limits on $\sigma \cdot \mathcal{A}$ as a function of the q^* resonance mass after the incorporation of systematic uncertainties. The corresponding observed 95% CL excited-quark mass exclusion region



(a) (b)

Figure 2: [Left] The data (D) dijet mass distribution (filled points) fitted using a binned background (B) distribution described by Eqn. 1 (histogram). The predicted q^* signals [5] for excited-quark masses of 500, 800, and 1200 GeV are overlaid, and the bin-by-bin significance of the data-background difference is shown. [Right] The 95% CL upper limit on $\sigma \cdot \mathcal{A}$ as a function of dijet resonance mass (black filled circles). The black dotted curve shows the expected 95% CL upper limit and the light and dark yellow shaded bands represent the 68% and 95% credibility intervals of the expected limit, respectively. The dashed curves represent excited-quark $\sigma \cdot \mathcal{A}$ predictions for different MC tunes, each using a different PDF set.

was found to be $0.30 < m_{q^*} < 1.26$ TeV [3], with the expected exclusion range of $0.30 < m_{q^*} < 1.06$ TeV, using MRST2007 PDFs in the ATLAS default MC09 tune.

3. Conclusion

A model-independent search for new heavy particles manifested as mass resonances in dijet final states was conducted using a 315 nb^{-1} sample of 7 TeV proton-proton collisions recorded by the ATLAS detector. No evidence of a resonance structure was found and upper limits at the 95% CL were set on the products of cross section and signal acceptance for hypothetical new q^* particles decaying to dijets. These data exclude at the 95% CL excited-quark masses from the lower edge of the search region, 0.30 TeV, to 1.26 TeV for a standard set of model parameters and using the ATLAS default MC09 tune [5]. In the future, such searches will be extended to exclude or discover additional hypothetical particles over greater mass ranges.

References

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