NON-SUSY SEARCHES AT ATLAS

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The ATLAS detector has begun the search for new physics beyond the Standard Model (BSM) with an integrated luminosity of $\int Ldt \simeq 45$ pb^{-1} of data collected in 2010. After no significant evidence of new physics was found in the data, limits on possible signatures have been set, many of which are already more stringent than previous measurements. These proceedings review recent limits obtained on various BSM models, including excited quarks, axigluons, contact interactions, quantum black holes, heavy gauge bosons (W', Z'), gravitons, fourth-generation quarks and leptoquarks.

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1 Introduction

Over the past few decades, experimental results have consistently agreed with the observable expectations of the Standard Model (SM); yet the cause of Electroweak Symmetry Breaking (EWSB), necessary to give mass to the $W^{\pm}$ and Z^0 bosons, remains unconfirmed. In addition, the SM contains 21 arbitrary parameters, and is unable to account for the number of quark/lepton families, matter-antimatter asymmetry, or gravity. Many theories beyond the Standard Model (BSM) have been developed to address limitations of the SM. The ATLAS detector [1], located on the Large Hadron Collider (LHC) ring at CERN near Geneva, Switzerland, was especially designed to measure high-momentum particles in anticipation of new physics discoveries at the electroweak scale (~1 TeV). Signatures in the detector span a large range of final-state objects, which include electrons, photons, jets, missing transverse energy ($\not{E}_T$) and muons.

In the early months of data-taking, understanding the performance of the detector was crucial while searching for new physics processes occurring at a much higher invariant mass than available at previous experiments. ATLAS collected a total of $\simeq 45$ pb^{-1} of integrated luminosity in 2010 at a center of mass energy $\sqrt{s} = 7$ TeV, and quickly 'rediscovered' many SM physics processes, setting the stage for new physics discovery. These proceedings discuss the new physics searches performed at ATLAS according to their final-state signatures, as well as their related detector performance issues at high momentum.

Slightly different datasets were used for each analysis due to varying trigger requirements and data quality conditions of the subdetectors used to measure the final-state objects. The uncertainty on the luminosity measurement for the analyses below was 11%.

2 Searches in the dijet final state

The 2→2 scattering processes as described by QCD in the Standard Model have been well studied, and any deviation from expected behavior of dijet processes would indicate new physics. Searches were performed in both the dijet invariant mass spectrum [2], given by

$$m_{jj} = \sqrt{(E_{j_1} + E_{j_2})^2 - (\vec{p}_{j_1} + \vec{p}_{j_2})^2},$$

as well as in the angular distribution $F_\chi(m_{jj})$ of dijets, where

$$F_\chi\left(\frac{[m_{jj}^{min} + m_{jj}^{max}]}{2}\right) \equiv \frac{N_{events}(|y^*| < 0.6,\ m_{jj}^{min},\ m_{jj}^{max})}{N_{events}(|y^*| < 1.7,\ m_{jj}^{min},\ m_{jj}^{max})}\ .$$

Here, N_{events} are the number of dijet events observed within the rest-frame rapidity y^* and invariant mass ranges specified. Models studied appearing as a resonance in the dijet mass spectrum include exited quarks [3] and axigluons [4]. Other signals could also appear as a non-resonant excess of events above the dijet invariant mass distribution, such as in *qqqq* contact interactions [5] or quantum black hole (QBH) [6] models. More sensitivity to new physics may be gained by using the angular distribution, as QCD dijets are more central in the detector, while new physics signatures are more isotropic in nature. An analysis using the $F_\chi(m_{jj})$ distribution also benefits from less sensitivity to the absolute jet energy scale (JES) which is the largest systematic uncertainty for high-energy jets.

Using the calorimeter trigger and requiring high quality data in the Inner Detector (ID) and calorimeters, 36 pb^{-1} of integrated luminosity was used in the dijet analyses. Each of the two jets in the event were required to pass quality criteria ensuring that the energy deposition in the calorimeters was in-time. For the dijet resonance search, the two selected jets were additionally required to have a pseudorapidity $|\eta_j| < 2.5$, $|\Delta\eta_{jj}| < 1.3$ between them, and leading jet $p_T^{j_1} > 150$ GeV, leaving 98,651 events with $m_{jj} >$500 GeV passing all selection. In the angular distribution analysis, the additional selection required dijets to satisfy tighter rapidity ranges, with 71,402 events in data after all selection. In both the resonance and angular distribution searches, the data were found to be consistent with SM expectations. Limits were set on the models mentioned above using a modified frequentist (CL_{s+b}) approach (for $F_\chi(m_{jj})$ searches) as well as a Bayesian credibility interval approach (for m_{jj} searches). The 95% C.L. lower limits are summarized in Table 1.

Table 1: 95% C.L. lower limits on various dijet physics signatures. Units are in TeV. The limit for QBH is given for number of dimensions > 6, and the Contact Interaction limit is set on the scale of the new interaction Λ.

	m_{jj}		$F_\chi(m_{jj})$	
Model	Expected	Observed	Expected	Observed
Excited Quark	2.07	2.15	2.12	2.64
QBH	3.64	3.67	3.49	3.78
Axigluon	2.01	2.10	-	-
Contact Interaction	-	-	5.72	9.51

3 Searches in the charged dilepton, lepton with $\not\!\!E_T$ and diphoton final states

Some extensions to the SM predict massive gauge bosons (W', Z') above 1 TeV. In the Sequential Standard Model (SSM) [7], the couplings of the fermions to the W' or Z' are the same as for the SM W and Z bosons. In another string-theory-inspired model [8], an E_6 gauge group symmetry-breaking leads to 6 different Z' states: Z'_ψ, Z'_N, Z'_I, Z'_S, Z'_η and Z'_χ. Additionally, models with excited states W^* and Z^* [9] were also considered, as they have different kinematic distributions than those of the W' and Z'. Searches were performed in the dilepton channel [10] ($Z' \to e^+e^-$ and $Z' \to \mu^+\mu^-$) as well as the lepton plus $\not{E}_T$ channel [11] ($W' \to e\nu_e$ and $W' \to \mu\nu_\mu$). Similarly to the dijets searches, the invariant mass of the dileptons m_{ll} was used in order to search for Z' resonances. However, as the neutrino appears only as missing energy in the detector, only the transverse component of the mass $m_T = \sqrt{p_T^l \not{E}_T(1-\cos\phi_{l\nu})}$ could be used in W' searches. The total integrated luminosity for the W' searches was 36 pb^{-1}, while the searches for $Z' \to e^+e^-$ and $Z' \to \mu^+\mu^-$ used 39 pb^{-1} and 42 pb^{-1}, respectively.

The underlying physics process is the same regardless of the participant leptons, however, the systematic uncertainties entering the analyses are different for the electron and muon channels and are handled separately. Higher-order QCD processes are less understood at high mass, and so the background to $W' \to e\nu_e$, $W' \to \mu\nu_\mu$ and $Z' \to e^+e^-$ signals arising from jets faking electrons or mis-measuring $\not{E}_T$ was estimated based on control regions in the data. In the muon channel, the largest uncertainty came from muon momentum resolution, mainly due to misaligned Muon Spectrometer (MS) chambers which were not modeled in simulation. This was reduced by requiring that muons use combined measurements in both the ID and MS, and also pass through regions of the MS with higher geometric acceptance and better-known alignment. In both channels of the Z' search, the total systematic uncertainty was reduced by normalizing the data to the simulation in the control region $70 < m_{ll} < 120$ GeV.

After all selection criteria, 31 (16) events were observed in the $e\nu$ ($\mu\nu$) channel having $m_T > 500$ GeV, and 66 (38) events observed in the ee ($\mu\mu$) channel in the signal region $m_{ll} >$ 150 GeV. In both cases, the data agreed with SM expectations. Limits on the new physics cross sections were set using a modified frequentist approach for the W' searches and a Bayesian approach for the Z' searches. The 95% C.L. lower limits after combining the electron and muon channels are summarized in Table 2.

Table 2: 95% C.L. lower limits on various dilepton and lepton+$\not{E}_T$ physics signatures after electron and muon channels were combined. Units are in TeV.

Model	W'	W^*	Z'	Z^*	Z'_ψ	Z'_N	Z'_I	Z'_S	Z'_η	Z'_χ
Expected	1.450	1.320	1.088	1.185	0.837	0.860	0.922	0.945	0.866	0.965
Observed	1.490	1.350	1.048	1.152	0.738	0.763	0.842	0.871	0.771	0.900

Searches were also performed in the diphoton channel [12] where a Kaluza-Klein graviton resonance is predicted by the Randall-Sundrum model [13]. In this model an extra spacial dimension, characterized by its curvature k and compactification radius r_c, reduces the Plank scale $\bar{M}_{pl}$ down to the TeV scale. Because photons were reconstructed in the EM calorimeter, they had similar detector-related uncertainties as for the dielectron channel. No excess above the predicted diphoton invariant mass spectrum was found in 36 pb^{-1}, and limits on various combinations of the graviton mass ($m_{\gamma\gamma}$) and couplings ($k/\bar{M}_{pl}$) were set using a modified frequentist approach. This resulted in a 95% C.L. lower limit of 545 (920) GeV on the RS graviton mass with coupling $k/\bar{M}_{pl} = 0.02$ (0.1).

4 Searches with leptons and jets

Finally, other models predict multiple-object final-states, such as fourth generation quarks (Q_4) [14] and those involving new particles carrying both lepton and baryon number ("leptoquarks") [15]. In the decay of pairs of fourth generation quarks ($Q_4Q_4 \to W^+jW^-j \to l^+\nu jl^-\nu j$), boosted W bosons result in a final-state in which lepton-jet pairs are more collinear than in SM W pair production. A transverse "collinear mass" was constructed from lepton-jet pairs after assuming that the neutrinos were the only contributors to $\not\!\!E_T$ and by choosing $|\Delta\eta(\nu,l)|$, $|\Delta\phi(\nu,l)|$ and jet assignments which minimized the difference between the two collinear masses in the event. Together, the scalar sum of the transverse energy in the event and the collinear mass was used as a discriminant to separate new physics from the dominant top quark pair production background. In 37 pb^{-1}, no evidence for fourth generation quarks was found, and a limit of $M_{Q_4} > 270$ GeV (95% C.L.) was set using a Feldman-Cousins approach. This was the first dilepton search for an up-type fourth generation quark, as well as the first search for fourth generation quarks performed at the LHC.

Searches for leptoquarks were performed using 35 pb^{-1} of data in both the first ($eejj$ and $e\nu jj$) and second ($\mu\mu jj$ and $\mu\nu jj$) generation channels. The sum of transverse energy in the event $S_T \equiv \sqrt{p_T^{l_1} + p_T^{l_2} + p_T^{j_1} + p_T^{j_2}}$ was used to look for the presence of a new physics signal in the $llqq$ channel. Here, in order to reject background events arising mainly Z with jets, M_{ll} was found by computing the invariant mass of pairs of leptons. In the $ll\nu j$ channel, however, because the neutrino could not be fully reconstructed, only the transverse mass was used to reject the dominant W plus jets background (defined similarly as for the lepton-neutrino pair in the W' search). Choosing lepton-jet and jet-neutrino pairs which minimize the difference between the invariant mass of the lepton-jet M_{LQ} and transverse mass of the jet-neutrino M_{LQ}^T, the average $\bar{M}_{LQ}$ between them was used as a discriminant in the $l\nu qq$ channel. The data were found to be consistent with SM expectations, and using a modified frequentist approach, 95% C.L limits on the leptoquark mass were set as a function of the branching fraction β for a single leptoquark to decay to a charged lepton + jet. For first generation leptoquarks, lower limits of $M > 376$ (319) GeV for β=1.0 (0.5) were found. In the second generation, the lower limits found were $M > 422$ (362) GeV for β=1.0 (0.5).

5 Summary

ATLAS has shown that it is able to push the energy frontier to the TeV scale and search for a variety of BSM signatures in the earliest stages of LHC data, in many cases setting the world's best limits. The knowledge gained from the first round of analyses presented at Rencontres de Moriond has paved the way for future work, and ATLAS eagerly awaits more data in the hopes of discovering new physics at the LHC.

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