

# Searches for heavy resonances and new particles at ATLAS

Sarah Heim, On behalf of the ATLAS Collaboration

*Michigan State University, East Lansing, MI 48824, USA*

**Abstract.** We review the most recent results of searches for heavy resonances and new particles decaying to lepton, photon, jet and/or vector boson pairs. The data were produced in 2011 in 7 TeV proton-proton collisions at the LHC and recorded with the ATLAS detector. In the presented analyses, the integrated luminosities vary between 1 and 5 fb<sup>-1</sup>.

**Keywords:** resonance, heavy, dilepton, diphoton, dijet, diboson, additional gauge bosons, Randall-Sundrum graviton, technicolor, excited quarks, color octet scalars

**PACS:** 12.60.Cn,12.60.Nz,12.60.Rc,14.70.Kv,14.70.Pw,14.80.Rt,14.80.Tt

Searches for physics beyond the Standard Model (SM) can be based on specific theoretical models or more generally on different detector signatures. Analyses of dilepton, diphoton, dijet and diboson final states were conducted by the ATLAS [1] collaboration. We first discuss the surveyed final states and then implications of the observations on several new physics models.

The statistical significance of possible excesses is checked by computing the probability for the SM background to fluctuate to the observed data. Since no significant excesses are found, limits are set at the 95% confidence level on the cross-section times branching ratio as well as the masses of additional gauge bosons [2, 3], the Randall-Sundrum graviton [4], technivector mesons [5], excited quarks [6, 7], and color octet scalars [8].

## SEARCHES

The dilepton analysis [9, 10] is performed in the dielectron and dimuon channels. In the dielectron channel, in order to reduce the background from QCD multijet events and photons converting into  $e^+e^-$  pairs, the two electrons must fulfill requirements on the shapes of the showers in the calorimeters, the hits in the inner detector as well as the matching between tracks and energy clusters. In addition, the leading electron is required to have an isolated energy cluster. In the dimuon channel, in order to reject cosmics, the impact parameter as well as the distance of the muon tracks from the primary collision vertex must be small. To reject QCD multijet events, the muon tracks in the inner detector must be isolated. Only regions of the detector are used in which the alignment of the muon spectrometer is very well known, to allow for a reliable reconstruction of muons with high momenta.

The main background of the analysis is the SM Drell-Yan production of a virtual  $Z$  boson or photon. The invariant mass distribution of the electron and muon pairs is searched for resonances at masses well above the  $Z$  boson peak. No statistically



significant excess is found in  $5 \text{ fb}^{-1}$ .

In the diphoton analysis [11], events with two photon candidates are selected, including photons that convert in the inner detector producing an  $e^+e^-$  pair. Neutral hadrons are rejected by checking the shapes of the energy showers in the calorimeters. Furthermore, the energy clusters in the electromagnetic calorimeter must be isolated.

The diphoton invariant mass is calculated, and searched for peak-like excesses over the SM background, which mainly consists of SM diphoton production. No significant excess is found in  $2 \text{ fb}^{-1}$ .

In the dijet analysis [12], only events are considered that have at least two jets with transverse momenta  $p_T$  larger than 80 GeV, reconstructed using the anti- $k_t$  jet clustering algorithm [13, 14] with the distance parameter  $R = 0.6$ . Jets from new physics processes are expected to be more isotropic than SM dijet production, so the rapidity of the jets in their center-of-mass frame must be small.

For events with more than two jets, the ones with the highest  $p_T$  are selected. To estimate the SM background, the dijet invariant mass distribution is fitted with an empirical function. The fit quality is checked and the spectrum is searched for resonances. No significant excess is found in  $5 \text{ fb}^{-1}$ .

The ZZ analysis [15] consists of two channels. In the four lepton channel, events are considered that contain two pairs of isolated electrons or muons. In a second channel, events are analyzed in which one of the Z bosons decays into two quarks. Here, the final state consists of an electron or muon pair as well as a pair of jets. In both channels the pairs are required to have invariant masses close to the mass of the Z boson.

The main background in this analysis is SM ZZ production. The invariant mass of the four decay products is calculated and searched for excesses. In  $1 \text{ fb}^{-1}$ , no significant excess is seen in either channel.

In the WZ analysis [16], both the Z and the W boson are required to decay leptonically, such that the final state consists of two oppositely charged, same flavor leptons with an invariant mass close to the Z boson mass, exactly one additional lepton, and missing transverse energy.

The discriminating variable is the transverse mass of the WZ system

$$m_T^{(WZ)} = \sqrt{(E_T^Z + E_T^W)^2 - (\vec{p}_T^Z + \vec{p}_T^W)^2},$$

and the main background is SM WZ production. In  $1 \text{ fb}^{-1}$ , no significant excess is found in the transverse mass distribution.

## LIMITS

The Sequential SM [2] is a benchmark model, predicting a  $Z'_{SSM}$  boson with a higher mass but the same couplings to fermions as the SM Z boson. Searching  $5 \text{ fb}^{-1}$  of data for an excess in the dilepton mass spectrum, the obtained lower mass limit for the  $Z'_{SSM}$

boson is 2.21 TeV. Another benchmark model is the extended gauge model [3], which predicts a  $W'$  boson whose coupling to  $WZ$  is proportional to  $M_Z M_W / M_{W'}^2$ . The  $WZ$  analysis ( $1 \text{ fb}^{-1}$ ) excludes this  $W'$  boson at masses lower than 0.76 TeV.

Resonances in the dilepton, diphoton and  $ZZ$  final states could be due to Kaluza-Klein excitations of the graviton in the Randall-Sundrum (RS) model of warped extra dimensions [4]. The dilepton analysis ( $5 \text{ fb}^{-1}$ ) excludes the RS graviton with  $k/\bar{M}_{Pl} = 0.1$  for masses lower than 2.16 TeV. The diphoton analysis is in principle more sensitive, since the branching fraction for decays into diphotons is twice as large. However, a smaller dataset is used,  $2 \text{ fb}^{-1}$ , and a lower mass limit of 1.85 TeV is set. The  $ZZ$  analysis, using  $1 \text{ fb}^{-1}$ , excludes the RS graviton with  $k/\bar{M}_{Pl} = 0.1$  in the mass range 0.33 - 0.85 TeV.

Another class of models predicting new resonances is technicolor. The discussed dilepton and  $WZ$  analyses set limits in the context of the Low Scale Technicolor model [5] on the masses of the technivector mesons  $\rho_T$  and  $\omega_T$ , which are expected to be nearly degenerate. For the presented limits, the  $a_T$  meson is assumed to have a much larger mass than the  $\rho_T/\omega_T$  mesons and the mass splitting between  $\rho_T/\omega_T$  and  $\pi_T$  mesons is varied. With  $M(\rho_T/\omega_T) - M(\pi_T) = 100 \text{ GeV}$ , the dilepton search, with  $1 \text{ fb}^{-1}$  of data, results in a lower mass limit of 0.47 TeV on  $\rho_T/\omega_T$ . The  $WZ$  analysis, using the same data set, assumes a mass splitting equal to the mass of the  $W$  boson. The resulting lower mass limit is also 0.47 TeV.

Excited quarks [6, 7] are a possible manifestation of quark compositeness. The dijet analysis uses  $5 \text{ fb}^{-1}$  and sets a lower mass limit of 3.35 TeV.

Color octet scalars [8] are an example for possible exotic colored resonances decaying to two gluons. They are excluded in the dijet analysis for masses below 1.94 TeV.

## REFERENCES

1. ATLAS Collaboration, *JINST* **3**, S08003 (2008).
2. P. Langacker, *Rev. Mod. Phys.* **81**, 1199–1228 (2009).
3. G. Altarelli, B. Mele, and M. Ruiz-Altaba, *Z. Phys.* **C45**, 109 (1989).
4. L. Randall, and R. Sundrum, *Phys. Rev. Lett.* **83**, 3370–3373 (1999).
5. K. D. Lane, and E. Eichten, *Phys. Lett.* **B222**, 274 (1989).
6. U. Baur, I. Hinchliffe, and D. Zeppenfeld, *Int. J. Mod. Phys.* **A2**, 1285 (1987).
7. U. Baur, M. Spira, and P. Zerwas, *Phys. Rev.* **D42**, 815–824 (1990).
8. T. Han, I. Lewis, and Z. Liu, *JHEP* **1012**, 085 (2010).
9. ATLAS Collaboration, *ATLAS-CONF-2012-007* (2012).
10. ATLAS Collaboration, *ATLAS-CONF-2011-125* (2011).
11. ATLAS Collaboration, *Phys. Lett.* **B710**, 538–556 (2012).
12. ATLAS Collaboration, *ATLAS-CONF-2012-038* (2012).
13. M. Cacciari, G. P. Salam, and G. Soyez, *JHEP* **0804**, 063 (2008).
14. M. Cacciari, and G. P. Salam, *Phys. Lett.* **B641**, 57–61 (2006).
15. ATLAS Collaboration, *Phys. Lett.* **B712**, 331–350 (2012).
16. ATLAS Collaboration, *Phys. Rev.* **D85**, 112012 (2012).