

Search for extra-dimensions, $t\bar{t}$ resonances, 4th generation and leptoquark signatures at the LHC

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Abstract

The searches for extra-dimensions, top resonances, 4th generation quarks and leptoquark signatures are presented. The results are based on proton-proton collision data at $\sqrt{s} = 7$ or 8 TeV, corresponding to various integrated luminosities. No signal of physics beyond the Standard Model has been observed so far.

1 Introduction

In this paper are presented a selection of searches of new physics beyond the Standard Model performed by the ATLAS¹ and CMS² collaborations, with proton-proton collision data recorded in 2011 and 2012 at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV. Physics models covered by this paper are various, from extra-dimensions searches to black holes, dark matter, high mass resonances involving top quarks, 4th generation quark and leptoquarks searches. SuperSymmetry and other exotic physics searches are discussed in other proceedings of the Moriond EWK 2013 conference.

2 Large extra-dimensions searches

The search for large compactified extra-dimensions (EDs), as proposed by the Arkani-Hamed, Dimopoulos and Dvali (ADD) model³, is motivated by the solve of the hierarchy problem of the SM which refers to the large difference between the electroweak scale ($M_{EWK} \sim 1$ TeV) and the gravity scale ($M_{planck} \sim 10^{16}$ TeV). In the ADD model, the gravity propagates into a 3+1+ n dimension space, where $n \geq 2$ is the number of EDs, while the Standard Model particles are confined into a 3+1 dimension space. In this framework the gravitational flux is diluted in this multidimensional space and the effective Planck scale M_D can be reduced to a scale similar to M_{EWK} and gravitons can be produced at the LHC. Several experimental signatures indicating the presence of EDs have been studied by the ATLAS and CMS collaboration.

2.1 Graviton production searches

Since the graviton is able to propagate in the extra-dimensions, the first type of signature indicating the presence of EDs is a large amount of missing transverse energy (\cancel{E}_T). The final state jet+ \cancel{E}_T has been studied by the ATLAS experiment with a sample of pp data at $\sqrt{s} = 8$ TeV corresponding to 10 fb^{-1} ⁴. The offline event selection requires a large amount of \cancel{E}_T , one

⁴Only the most recent analyses are discussed here. Several analyses are then intentionally not discussed in this proceeding.

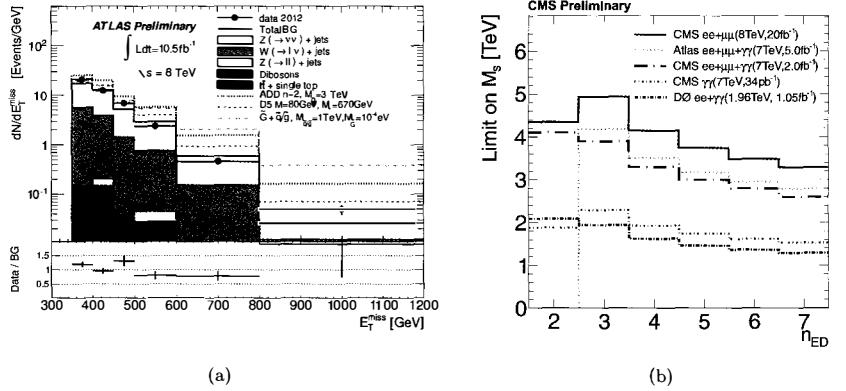


Figure 1: (a) \cancel{E}_T spectrum of events selected in a jet+ \cancel{E}_T final state by the ATLAS experiment (b) summary of limits on M_S as a function of n , for several experiments and data samples.

high- p_T jet and no additional lepton in the event. Several filters are applied to reject beam-related backgrounds, cosmic rays and anomalous electronic-noise events. Fig. 1.a shows the \cancel{E}_T spectrum for the selected events. The number of observed events in the data is in good agreement with the SM expectations and lower limits are set on the ADD model variable M_D , as a function of n : values of M_D are excluded below 3.88 ($n = 2$) to 2.58 ($n = 6$) TeV at 95% CL..

Other studies have been performed by looking for an excess of data at high dilepton masses, indicating the presence of gravitons decaying into a lepton-antilepton pair. The CMS collaboration studied both ee and $\mu\mu$ decay channels with $\sqrt{s} = 8$ TeV pp data corresponding to a total integrated luminosity of 20 fb^{-1} . Events are selected by requiring the presence of two well-identified, opposite charge, same flavor, isolated leptons. Since no excess at high masses has been noticed in both channels, limits are set on M_S , related to M_D by the formula $M_S = 2\sqrt{\pi} [\Gamma(n/2)]^{1/(n+2)} M_D$. Fig. 1.b illustrates a summary of the lower limits set on M_S by several experiments for $n \in [2, 7]$.

2.2 Black holes

A consequence of the presence of extra-dimensions is the production of microscopic black-holes in pp collisions at the LHC. The experimental signature of a microscopic black hole is a large transverse energy carried by physical objects (charged leptons, jets, photons or invisible particles). Such signatures have been studied by the CMS collaboration with 3.7 fb^{-1} of pp collisions data at $\sqrt{s} = 8$ TeV. The $S_T = \sum p_T(\text{objects})$ variable is used to separate black hole candidate events from SM backgrounds dominated by QCD multijet production, for several physical object multiplicities. As shown in Fig. 2.a, data are in agreement with the SM expectations and lower limits are set on black hole masses for several theoretical models (Fig. 2.b).

2.3 Dark matter interpretations

An interesting feature of the graviton production searches is their sensitivity to the production of dark matter particles χ , also called WIMPs : instead of a graviton, a pair of WIMPs is produced in association with a jet or a photon. Therefore the monojet/monophoton results presented in section 2.1 can be interpreted as limits on the effective theory cut-off mass scale M_* and as limits on the WIMP-nucleons scattering cross section. Several $q\bar{q}\chi\chi$ interaction

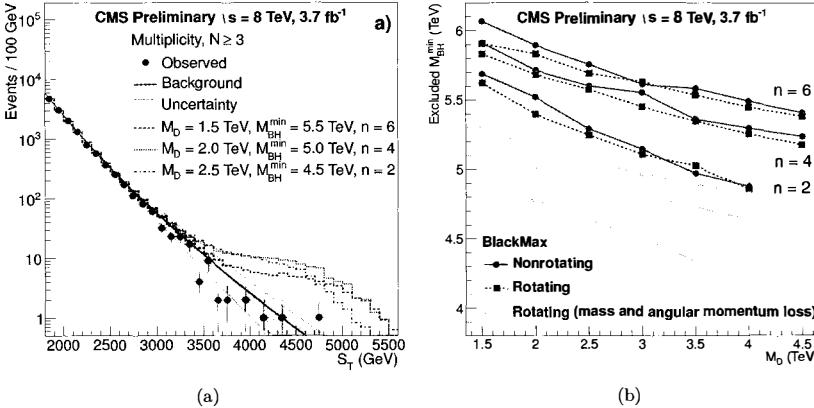


Figure 2: (a) S_T spectrum for an object multiplicity $N = 3$. Black points correspond to data, blue line to SM backgrounds and dotted lines to black holes signal for several benchmarks (b) lower limits on black hole masses for different theoretical models.

operators, spin-dependent or spin-independent have been considered. Fig. 3 shows the upper limit on WIMP-nucleon inelastic cross section, for several experiments. One can notice that limits from collider experiments are the most stringent for low χ masses and are complementary to dedicated experiments.

2.4 Contact interaction energy scale interpretation

The study of dilepton signatures allows the experimentalists to probe also the presence of contact interaction. Since no excess in data has been observed (see section 2.1), lower limits are set on the contact interaction energy scale Λ by the ATLAS experiment¹⁹ with a data sample of 5 fb^{-1} at $\sqrt{s} = 7$ TeV. Values of Λ are excluded below 13.9 TeV at 95% C.L. for constructive interferences while destructive interferences are excluded for $\Lambda < 10.2$ TeV at 95% C.L..

3 Searches for top resonances

3.1 $\bar{t}t$ resonances at high masses

Several searches for high masses $\bar{t}t$ resonances, produced by the decay of a high mass Z' boson or a Kaluza-Klein gluon, have been performed by the ATLAS and CMS collaboration with pp collision data at $\sqrt{s} = 7$ TeV corresponding to 5 fb^{-1} in both semileptonic and full hadronic channels^{10,11,12,13}. No evidence of beyond Standard Model $\bar{t}t$ resonances have been seen so far with $\sqrt{s} = 7$ TeV data. The most stringent limits have been set in the semileptonic channel (Table 1).

model	narrow Z' ($\Gamma = 1\% M_{Z'}$)	wide Z' ($\Gamma = 10\% M_{Z'}$)	KK gluon
ATLAS	$0.5 < M < 1.7$ TeV	n/a	$0.7 < M < 1.9$ TeV
CMS	$0.5 < M < 1.5$ TeV	$0.5 < M < 2.0$ TeV	$1 < M < 1.82$ TeV

Table 1: More stringent exclusion limits on Z' and KK gluon masses from the search for $\bar{t}t$ resonances set by ATLAS and CMS.

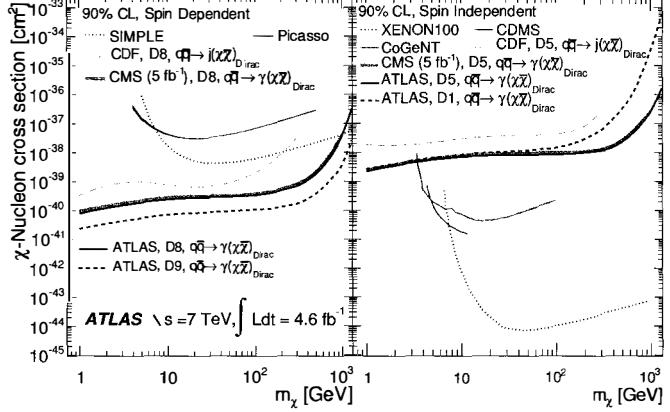


Figure 3: Limits on WIMPS-nucleon scattering cross section for several experiments, for a spin dependent interaction (right) and spin-independent interaction (left).

3.2 *top+jet resonances at high masses*

The ATLAS collaboration performed a search for top+jet resonances, produced by the decay of a high mass W' boson, in association with another top quark. The pp collision data at $\sqrt{s} = 7$ TeV are used [11]. The search has been performed in the semileptonic channel. No excess of data has been observed in the reconstructed visible W' mass spectrum and limits were set on the W' cross section production, for different coupling benchmarks. For a unity left-handed coupling, W' are excluded for masses below 500 GeV at 95% C.L..

4 Searches for 4th generation signatures

The discovery of the SM Higgs boson and related studies significantly disfavor the existence of a chiral 4th generation quark family. However, some other models are not ruled out and can still be probed by collider experiments.

4.1 5/3e up quark signature

The CMS experiment performed a search for 4th generation up quark with an electric charge 5/3e ($T_{5/3}$) with a sample of pp data at $\sqrt{s} = 8$ TeV corresponding to 20 fb^{-1} [12]. A $T_{5/3}$ decays into a W boson and a top quark. The presence of a pair of $T_{5/3}$ can then be probed into events containing two same sign leptons from the two W bosons produced by one $T_{5/3}$ and the corresponding top quark, and at least 5 jets with $p_T > 30$ GeV. The $H_T = \sum p_T(\text{leptons, jets})$ variable is used to select signal events, by requiring $H_T > 900$ GeV. Fig. 4 shows the H_T spectrum for data, SM backgrounds and a 600 GeV $T_{5/3}$ signal. No significant excess has been observed in the data and a lower limit has been set on the $T_{5/3}$ mass. At 95% C.L., 5/3e charged 4th generation up quarks are excluded for masses below 700 GeV.

4.2 *Vector-like up quark signature*

A model of vector-like 4th generation up quark (VL-up quark) pair production has been probed by the ATLAS collaboration with $\sqrt{s} = 8$ TeV data with one VL-up quark decaying into a top

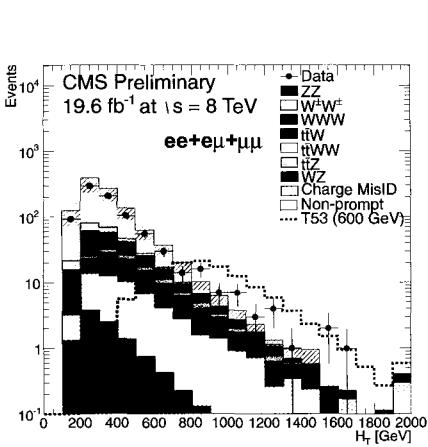


Figure 4: H_T distribution for data (black points), SM backgrounds (colored areas) and a 600 GeV $T_{5/3}$ signal.

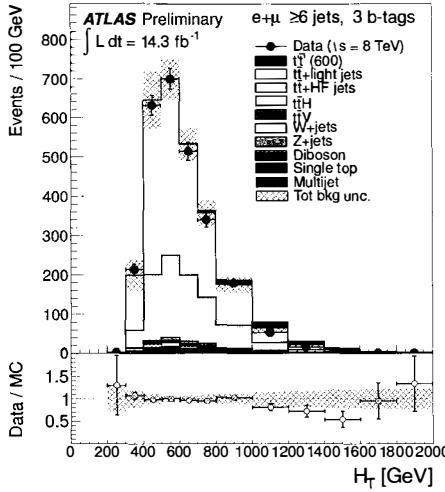


Figure 5: Scalar sum of transverse energies of lepton, E_T and jets in the final state. Data are indicated by black points, signal by the red filled area and SM background expectations by white and colored areas.

quark and one SM Higgs boson $H \rightarrow bb$ while the second VL-up quark decays into a W (Z or H) boson and a b (t) quark¹⁷. The semileptonic channel (1 charged lepton, large E_T , at least 6 jets with at least two of them tagged as jets from b quarks) has been studied, by looking for a excess of data in the $H_T = \sum p_T(\text{leptons}, E_T, \text{jets})$ distribution. As shown on Fig. 5, data are in agreement with the SM expectations and the existence of weak isospin singlet (doublet) VL-up quarks is excluded at 95% C.L. for masses below 640 (730) GeV.

4.3 Excited down-quark signature

The ATLAS collaboration also performed a search for excited down quarks (b^*)¹⁷ with pp data at $\sqrt{s} = 7$ TeV. The theoretical model used imply a chromomagnetic interaction between a b-quark and a gluon, producing a b^* decaying into a top quark and a W boson. Both semileptonic (1 electron or muon, E_T , 3 jets) and dileptonic (2 electrons or muons, E_T , one jet) channels have been studied. No excess with respect to SM expectations has been noticed and limits were set on the b^* mass, for several couplings benchmarks. For a unity left-handed couplings, b^* are excluded for masses below 870 GeV.

5 Summary of leptoquark searches at $\sqrt{s} = 7$ TeV

An intriguing feature of the Standard Model is the symmetry between the number of quarks and lepton families. Several theories beyond the Standard Model (SU(5), grand unification theories, ...) predict the existence of new bosons, the leptoquarks (LQ), carrying a fractional electric charge, a color charge, and decaying into a lepton and a quark. Constraints from Flavor Changing Neutral Currents measurements significantly constraint a leptoquark to decay into a quark and a lepton of the same generation. The branching fraction β of a LQ decay into a charged lepton and a quark is a free parameter of the model.

Searches for a pair production of scalar LQs of 1st, 2nd and 3rd generation have been performed by both ATLAS and CMS experiments^{18,19,20,21,22,23} with pp collision data at $\sqrt{s} = 7$

TeV corresponding to an integrated luminosity of 5 fb^{-1} . In all LQ decay channels, for all LQ generation, the data have been found to be compatible with SM expectations. The most stringent limits at 95% C.L. set on leptoquark masses by the ATLAS and CMS collaborations are summarized in Table 2.

	$\beta = 1$	$\beta = 0.5$	$\beta = 0$
LQ1 $\rightarrow eq(\nu_e q)$	830	640	n/a
LQ2 $\rightarrow \mu q(\nu_\mu q)$	840	650	n/a
LQ3 $\rightarrow \tau b(\nu_\tau b)$	538	n/a	450

Table 2: Most stringent lower limits set on scalar leptoquark masses in GeV. β is the branching fraction of a leptoquark decaying into a charged lepton and a quark.

6 Conclusion

Various models of physics beyond the Standard Model have been probed in various final states, and no evidence of new physics has been seen so far, with data collected by the ATLAS and CMS experiment at $\sqrt{s} = 7 \text{ TeV}$ or $\sqrt{s} = 8 \text{ TeV}$. Limits were set on key observables of the different models. Further searches for new physics signatures are still ongoing with the full dataset recorded with $\sqrt{s} = 8 \text{ TeV}$, corresponding to an total integrated luminosity of 20 fb^{-1} .

A complete list of results published by the ATLAS and CMS experiments can be found in the corresponding public twiki pages [1](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults), [2](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO).

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