The Compact Muon Solenoid Experiment
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Recent CMS Results of Searches for Physics Beyond Standard Model

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Abstract

Recent results from CMS on searches for physics beyond the Standard Model are reviewed. We present the searches performed using up to 20 fb^{-1} of data from the $\sqrt{s} = 8 \text{ TeV}$ LHC run in 2012.

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Recent CMS Results of Searches for Physics Beyond Standard Model

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Abstract

Recent results from CMS on searches for physics beyond the Standard Model are reviewed. We present the searches performed using up to 20 fb^{-1} of data from the $\sqrt{s} = 8\text{ TeV}$ LHC run in 2012.

1. Introduction

The predictions of the Standard Model (SM) describe the observed particle physics data well, the recent discoveries of Higgs boson [1–4] and the rare decay $B_s \rightarrow \mu^+\mu^-$ [5, 6] do not show deviations from the SM predictions within the present experimental uncertainties. Still, many theoretical models are considered for physics beyond SM (BSM), inspired by the ideas from the electroweak symmetry breaking, the hierarchy problem, grand unification, supersymmetry, search for dark matter particles, and others [7].

The Compact Muon Solenoid (CMS) detector is one of the two general purpose detectors located at the Large Hadron Collider (LHC). It has a 3.8 T superconducting solenoid, the all-silicon inner tracker, the crystal electromagnetic calorimeter and the brass-scintillator hadronic calorimeter, the muon system covering the pseudorapidity region $|\eta| < 2.4$, details can be found in [8, 9]. The first physics run was completed in 2012, around 5 fb^{-1} integrated luminosity was obtained at the center-of-mass energy $\sqrt{s} = 7\text{ TeV}$ and 20 fb^{-1} at $\sqrt{s} = 8\text{ TeV}$, resulting in variety of searches for BSM physics in many analyses.

2. Search for Physics beyond the Standard Model

The search for new physics at CMS has been performed in various channels for different theoretical models predicting deviations from SM. One of the important directions is the search for narrow resonances in the dilepton channels (the dimuon and dielectron ones). Many models of new physics predict the existence of narrow resonances at the TeV mass scale decaying to a pair of charged leptons [10, 11] and exotic hadron states [12], in particular, Sequential Standard Model Z'_{SSM} with SM-like couplings, the Z'_ψ predicted by grand unified theories [10], and Kaluza–Klein graviton excitations arising in the Randall–Sundrum (RS) model of a possible warped extra dimension scenario with one extra spatial dimension [13]. The recent measurement by CMS has used the data at $\sqrt{s} = 8$ TeV and integrated luminosities up to 20 fb^{-1} in both the dimuon and dielectron channels [14]. The search for resonances is based on a shape analysis of dilepton mass spectra in order to be robust against uncertainties in the absolute background level. The spectra are consistent with expectations from SM and the upper limits have been determined on the product of the cross section and branching fraction for Z' to lepton pairs relative to the SM Z boson production. The obtained upper limits on the cross section ratio

$$R_\sigma = \frac{\sigma(pp \rightarrow Z' + X \rightarrow \ell\ell + X)}{\sigma(pp \rightarrow Z + X \rightarrow \ell\ell + X)}$$

at 95% confidence level (C.L.) are shown in Fig. 1 for the two separate dilepton channels and their combination. The following 95% C.L. lower limits on the mass of Z' resonances has been determined: 2960 GeV for Z'_{SSM} and 2600 GeV for Z'_ψ . The results can be also generalized for other models [15].

CMS has also established the limits for other Z' channels: τ -lepton pair $\tau\tau$ [16], dibosons ZZ [17], $t\bar{t}$ pair [18], anomalous production of highly boosted Z bosons decaying to dimuons [19]; and W' channels: semileptonic $l\nu$ [20], diboson WZ [21] and heavy quarks $b\bar{t}$ [22].

Narrow resonances in the dijet channel have been studied and the upper limits at the 95% C.L. on the resonance cross section have been determined (Fig. 2 left plot). By comparing these generic limits with theoretical predictions for the cross section of several models of

Fig. 1: 95% C.L. limits for the product of Z' cross section and branching ratios in different channels: $\mu^+\mu^-$, e^+e^- , and combined l^+l^- , from left to right.

new particles, CMS sets specific lower limits on the mass of string resonances, excited quarks, axigluons, colorons, s8 resonances, E_6 di-quarks, W' and Z' bosons, and RS gravitons up to 1–5.1 TeV [23].

CMS has performed a search for signals from the production of right-handed W_R bosons and heavy neutrinos N_ℓ ($\ell = e, \mu$), that arise naturally in the left-right symmetric extension to SM [24], no excess over expectations from SM processes was observed [25]. For models with an exact left-right symmetry, and assuming that either N_e or N_μ is the only right-handed neutrino accessible at LHC energies, CMS has excluded the region in the two-dimensional parameter (M_{W_R}, M_{N_ℓ}) space that extends beyond $M_{W_R} = 2.5$ TeV. Assuming degenerate neutrino masses for all neutrino flavors, and combining the 8 TeV electron and muon channel results, exclusion in the (M_{W_R}, M_{N_ℓ}) mass plane extending to $M_{W_R} = 2.8$ TeV was obtained (Fig. 2 middle plot). Combining the 7 and 8 TeV data for the muon channel only, and assuming that N_μ is light enough to be produced at the LHC, CMS has excluded right-handed W_R boson up to mass $M_{W_R} = 2.9$ TeV.

One of the most spectacular predictions of theories with the low-scale quantum gravity is an opportunity of microscopic black hole production in proton-proton collisions at the LHC energies. Such models are motivated mainly by the puzzling large difference between the electroweak scale (~ 0.1 TeV) and the Planck scale ($M_{\text{Pl}} \sim 10^{16}$ TeV), known as the hierarchy problem. CMS has released a new analysis at $\sqrt{s} = 8$ TeV with 12 fb^{-1} [26] to search for the black hole production in a model with n large, flat, extra spatial dimensions (ADD model) [28]. The events with the large total transverse en-

Fig. 2: Obtained limits in the search for new physics: limits for masses of narrow dijet resonances, heavy neutrino and right-handed W_R boson, and minimum masses of black holes as a function of the reduced Planck scale.

ergy have been analyzed for the presence of multiple energetic jets, leptons, and photons, which are typical signals of evaporating semiclassical and quantum black holes. New indicative limits have been found excluding semiclassical black holes with masses below 4.3 to 6.2 TeV, see Fig. 2 (right) for the minimum black hole mass excluded at 95% C.L. as function of the reduced Planck scale for various BlackMax black hole models [29] without the stable remnant and a number of extra dimensions of $n = 2, 4, 6$. The results of the analysis could be also suitable for other models in which heavy objects appear and decay to final states with a large scalar sum of objects' transverse energies of the order of several TeV. Signatures of extra dimensions were also searched for in the mass spectrum for diphotons [30], dimuons [31] and dielectrons [32], setting the 95% C.L. limits for the string scale M_s up to 4.94 TeV.

Leptoquarks carrying both baryon and lepton numbers are predicted by many SM extensions, such as grand unification theories, technicolor and composite models. CMS has published recent results for the search of the pair-produced second-generation scalar leptoquarks in the events with at least two jets and two possible leptonic channels: either two charged leptons ($\mu\mu jj$) or a charged lepton and significant missing transverse energy ($\mu\nu jj$). The second generation scalar leptoquarks with masses less than 1070 (785) GeV have been excluded for $\beta = 1(0.5)$, where β is the branching fraction of a leptoquark to a charged lepton and a quark [33]. There was observed a small excess in the data in the second channel, but still it is within the calculated systematic and statistical uncertainties, therefore a higher-

Fig. 3: Distributions on the scalar sum of transverse momenta of four objects S_T for $\mu\mu jj$ and $\nu\nu jj$ channels, and the obtained 95% C.L. limits for second-generation scalar leptoquarks.

than-expected cross-section upper limit is visible for small values of β in the right plot of Fig. 3.

CMS also put limits for new resonances decaying to ZZ and WW states [34, 35], leptonic decays of W' bosons [36], dark matter particles [37, 38], long-lived neutral or charged particles [39–41]. Studies beyond two generations of quarks included searches for anomalous $t\bar{t}$ production [42], and vector-like quarks [43–45].

Many other searches for deviations from SM were carried out in CMS, see Fig. 4 for the graphical summary of the obtained limits on the masses and scales for various BSM models [46].

3. Conclusions

Excellent performance of LHC and CMS has provided a large dataset of pp collisions, 5 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$ and 20 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$. In the search for new physics the experiment has managed, in particular, to exclude new particles in the 2–3 TeV range in the dilepton channels and 5 TeV for dijets, allowing to improve the limits imposed by the previous studies [46].

Further efforts should increase the precision of measurements and give the answers for some burning questions from the theoretical point of view. The analysis of the whole dataset taken in 2012, and the planned transition to the full design LHC center-of-mass energy of 13–14 TeV can provide answers for, at least, some of these questions, and there is also a chance to discover new unexplained features of high-

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