EXOTICA SEARCHES AT THE CMS EXPERIMENT

F. SANTANASTASIO
(ON BEHALF OF THE CMS COLLABORATION)
University of Maryland, Department of Physics - John S. Toll Physics Building, College Park, MD 20742-4111, United States of America

This paper presents the results of searches for various new physics phenomena in proton-proton collisions at $\sqrt{s} = 7$ TeV delivered by the LHC and collected with the CMS detector in 2010. While the sensitivity of these early searches varies, in many cases they set the most stringent limits on these new physics phenomena. These results demonstrate good understanding of the detector and backgrounds in a variety of channels, which is a fundamental component of successful searches in view of the much larger data sample expected to be delivered by LHC in 2011 and beyond.

1 Introduction

The standard model (SM) of particle physics has been extremely successful in describing all phenomena at the highest attainable energies thus far. Yet, it is widely believed to be only an effective description of a more complete theory, which supersedes it at higher energy scales. Many theoretical extensions of the SM have been proposed in the past decades, which usually predict the existence of new particles. Examples of such conjectured particles are the Z' and W' bosons, fourth generation fermions, supersymmetric particles, leptoquarks, excited quarks, gravitons, and many others. Past experiments at the Fermilab Tevatron collider, and previously at the CERN SPS, HERA, and LEP colliders, have performed estensive searches for signs of such new physics. In absence of a positive signal, lower limits on the masses of such new particles have been set. With its higher centre-of-mass (CM) energy of 7 TeV, the proton-proton Large Hadron Collider (LHC) at CERN can produce particles with masses larger than the current limits, thus extending the search for new physics in an unexplored territory.

This paper presents the results of searches for various new physics phenomena [a] in proton-proton collisions at $\sqrt{s} = 7$ TeV delivered by the LHC and collected with the Compact Muon Solenoid (CMS) [1] detector in 2010. For the majority of these searches the full dataset has been used, corresponding to an integrated luminosity of almost 40 pb^{-1}. The results are presented in different sections, depending on the phenomenology of the new physics scenario: search for new heavy resonances are presented in Section 2; compositeness models are discussed in Section 3; searches for signs of the existence of extra dimensions are described in Section 4; finally, search for long-lived particles and for other exotic final states are presented in Section 5, followed by a brief summary in Section 6.

[a] Searches for Supersymmetry at CMS are not discussed in this paper. These results can be found in other proceedings of this conference.

2 New Heavy Resonances

2.1 *Dilepton and Diphoton Resonances*

Many models of new physics and extensions of the SM predict the existence of narrow resonances, possibly at the TeV mass scale, that decay to a pair of charged leptons (such as Z' bosons) or to lepton and neutrino (such as W' bosons). Also the Randall-Sundrum (RS) model of extra dimensions foresees the existence of Kaluza–Klein graviton excitations (G_{KK}) decaying to a pair of charged leptons or pair of photons. The CMS Collaboration has searched for such narrow resonances in the invariant mass spectrum of dimuon/dielectron [2] and diphoton [3] final states, as well as in the transverse mass spectrum of electron+neutrino [4] and muon+neutrino [5] final states. The spectra are consistent with standard model expectations in both the bulk and the tails of the aforementioned distributions. Figure 1 shows the 95% confidence level (CL) upper limits on the cross section of Z'/G_{KK} (W') production, obtained combining the dielectron (electron+neutrino) and dimuon (muon+neutrino) channels. A Z' (W') with SM-like coupling can be excluded below 1.14 (1.58) TeV. Model-independent lower limits on the Z' mass have also been reported in Ref. [2] as a function of the couplings of the Z' to fermions in the annihilation of charge 2/3 and charge -1/3 quarks. In the diphoton channel, limits are derived on the cross section for the production of RS gravitons, and hence on the parameters of the warped extra dimension model. For values of the coupling parameter ranging from 0.01 to 0.1, graviton masses below 371 to 945 GeV are excluded at the 95% CL.

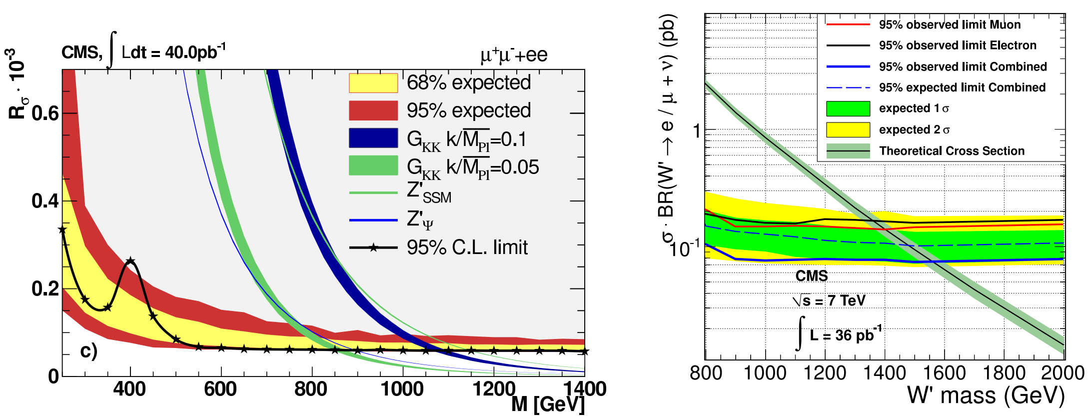

Figure 1: (Left) Upper limits as a function of resonance mass, on the Z' cross section relative to standard model Z boson production, obtained combining dielectron and dimuon final states. (Right) Upper limits as a function of the resonance mass, on the W' cross section for the individual electron+neutrino and muon+neutrino channels, and their combination.

2.2 *Leptoquarks*

The standard model has an intriguing but ad hoc symmetry between quarks and leptons. In some theories beyond the SM, such as SU(5) gran unification, Pati–Salam SU(4), and others, the existence of a new symmetry relates the quarks and leptons in a fundamental way. These models predict the existence of new bosons, called leptoquarks. The leptoquark (LQ) is coloured, has fractional electric charge, and decays to a charged lepton and a quark with unknown branching fraction β, or a neutrino and a quark with branching fraction $(1-\beta)$. Constraints from experiments sensitive to flavour-changing neutral currents, lepton-family-number violation, and other rare processes favour LQs that couple to quarks and leptons within the same SM generation, for LQ masses accessible to current colliders. Searches for pair-production of first and second generation scalar LQs have been performed in the eejj [6], $e\nu$jj [8], and $\mu\mu$jj [7] channels. The dominant backgrounds for these searches arise from the SM production of Z/γ+jets, W+jets and $t\bar{t}$ events. The reconstructed variable S_{T}, defined below[b] has a large signal-to-background discrimination power, and it is used to select LQ candidate events. Figure 2 (left) shows the exclusion limits at 95% CL on the first generation leptoquark hypothesis in the β versus LQ mass plane for the eejj and eνjj channels, and their combination. First generation scalar LQ masses below 384 GeV (340 GeV) are excluded at 95% CL for $\beta = 1$ ($\beta = 0.5$). In the $\mu\mu$jj channel, a 95% CL lower limit on the second generation scalar LQ mass is set at 394 GeV assuming $\beta = 1$.

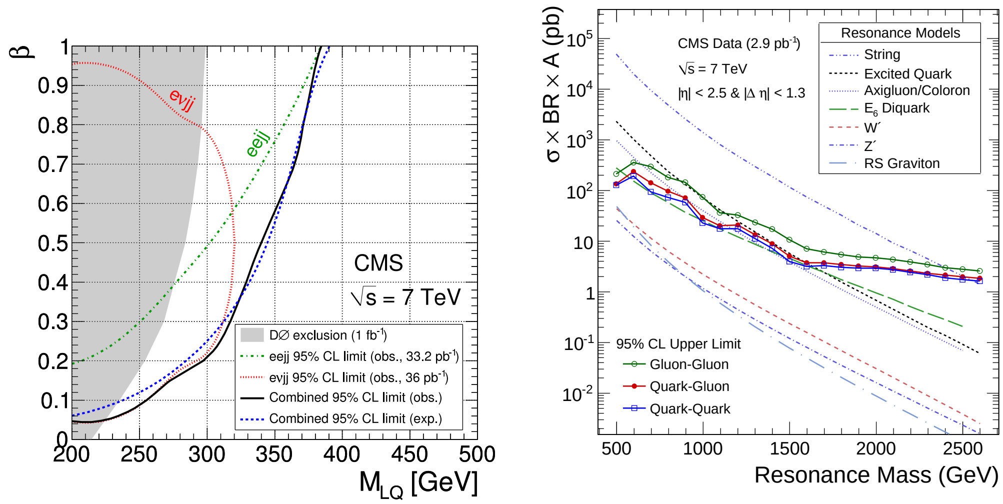

Figure 2: (Left) Exclusion limits at 95% CL on the first generation LQ hypothesis in the β versus LQ mass plane. The shaded region is excluded by the current D0 limits, which combine results of eejj, eνjj, and $\nu\nu$jj decay modes. (Right) 95% CL upper limits on signal cross section for dijet resonances of type gluon-gluon, quark-gluon, or quark-quark, versus dijet resonance mass, compared to theoretical predictions for various new physics models.

2.3 Dijet Searches

In the standard model, point like parton-parton scatterings in high energy proton-proton collisions can give rise to final states with energetic jets. At large momentum transfers, events with at least two energetic jets (dijets) may be used to confront the predictions of perturbative Quantum Chromodynamics (QCD) and to search for signatures of new physics. The new physics could manifest itself via the direct production of a new massive particle that then decays into a dijet final state (quark-quark, quark-gluon, or gluon-gluon resonances), and/or the rate of dijet events could be enhanced through a new force that only manifests itself at very large CM energies (contact interactions). Complementary search strategies have been pursued by the CMS experiment in the dijet channel: search for narrow resonances in the dijet mass spectrum[9], search for narrow resonances and contact interactions using the dijet centrality ratio variable[10], and search for contact interactions using dijet angular distributions[11]. The first two analyses were performed with the early 3 pb^{-1} of proton-proton collisions at $\sqrt{s} = 7$ TeV, and they are now being updated with more data. Figure 2 (right) shows the 95% CL upper limits on signal cross section versus dijet resonance mass, compared to theoretical predictions for various new physics models. String resonances, with mass less than 2.50 TeV, excited quarks, with mass less than 1.58 TeV, and axigluons, colorons, and E_6 diquarks, in specific mass intervals, have been excluded at 95% CL. Using measurements of dijet angular distributions over a wide range of

[b]In the eejj and $\mu\mu$jj channels, S_{T} is defined as the scalar sum of the transverse momenta of the two leading (in p_{T}) charged leptons and jets. In the eνjj channel, S_{T} is defined as the scalar sum of the transverse momentum of the electron, the missing transverse energy ($\not{E}_{\mathrm{T}}$), and the two leading jets.

dijet invariant masses, a lower limit on the contact interaction scale for left-handed quarks of $\Lambda^+ = 5.6$ TeV ($\Lambda^- = 5.6$ TeV) for constructive (destructive) interference is obtained at the 95% CL.

2.4 Fourth Generation of Fermions and $\mathrm{t\bar{t}}$ *Resonances*

Recently, there has been renewed interest in extensions of the SM predicting a fourth generation of massive fermions. Theoretical works have also shown that indirect bounds on the Higgs boson mass can be relaxed, and an additional generation of quarks may possess enough intrinsic matter and anti-matter asymmetry to be relevant for the baryon asymmetry of the Universe. Driven by this motivation, a search for pair production of heavy bottom-like quarks (b′) in trileptons and same-sign dilepton final states [12], arising from the decay chain $\mathrm{b'\bar{b}'} \rightarrow \mathrm{tW^-\bar{t}W^+} \rightarrow \mathrm{bW^+W^-\bar{b}W^-W^+}$, has been performed at CMS. The total branching ratio for these channels is 7.3% and the very small expected SM background comes mainly from $\mathrm{t\bar{t}}$ events. No events are found in the signal region defined in the analysis, and the b′ mass range from 255 to 361 GeV has been excluded at the 95% CL.

The CMS experiment has also performed a model-independent search for new massive neutral bosons (such as Z′) decaying via a top-antitop quark pair [13]. The event reconstruction and selection is optimized for the production of top quarks close to rest, with well separated decay products. The analysis focuses on decay channels of the $\mathrm{t\bar{t}}$ system that include a single isolated electron or muon. No significant deviation from SM expectations is found in the $\mathrm{t\bar{t}}$ mass spectra obtained from eight independent data samples, categorized by lepton type, multiplicity of jets and number of b-tagged jets. Upper limits on the production cross section times branching fraction, $\sigma_{\mathrm{Z'}} \times \mathrm{BR}(\mathrm{Z'} \rightarrow \mathrm{t\bar{t}})$, of the order of 25, 7, and 4 pb^{-1} for invariant masses in the region $m_{\mathrm{Z'}} = 0.5$, 1, and 1.5 TeV, respectively, are set. These results are competitive with the current limits from the Tevatron, particularly at high mass values.

3 Compositeness Models

A fundamental question in the standard model (SM) of particle physics is the source of the mass hierarchy of the quarks and leptons. A commonly proposed explanation for the three generations is a compositeness model in which the known leptons and quarks are bound states of either three fermions, or a fermion-boson pair. The underlying substructure of these new bound states implies a large spectrum of excited states. Novel strong contact interactions (CI) couple excited fermions (f^*) to ordinary quarks and leptons (f) and can be described with the effective lagrangian $\mathcal{L}_{\mathrm{CI}} \propto (\jmath^\mu \jmath_\mu)/\Lambda^2$, where Λ is the compositeness scale, and $\jmath_\mu$ is the fermion current.

3.1 Excited Leptons

A search for the associated production of a lepton (ℓ) and an oppositely charged excited lepton (ℓ^*) is performed [14]. The final state contains two leptons and a photon, $\ell\ell\gamma$, arising from the decay $\ell^* \rightarrow \ell\gamma$, where ℓ is either an electron or a muon. The SM backgrounds containing misidentified electrons or photons are estimated using data-driven methods. The maximum reconstructed invariant mass among the two possible lepton-photon combination, $\mathrm{M}_{\ell\gamma}^{\mathrm{max}}$, is used to discriminate between signal and SM backgrounds. No excess of events is found in the $\mathrm{M}_{\ell\gamma}^{\mathrm{max}}$ spectra above the SM expectation in the electron or muon channel. Figure 3 (left) shows the region excluded at 95% CL in the $\Lambda - \mathrm{M}_{\ell^*}$ parameter space for the $\mu\mu\gamma$ channel, where M_{ℓ^*} is the excited lepton mass. A similar exclusion is obtained in the $\mathrm{ee}\gamma$ channel.

The CMS experiment has performed a search for anomalous production of highly boosted Z bosons in the dimuon decay channel arising from the decays of new heavy particles[15]. The search is optimized for the detection of excited quark production and decay via $q* \rightarrow qZ \rightarrow q\mu\mu$, with no explicit requirement on the jet recoiling against a high transverse momentum Z. Figure 3 shows the dimuon p_T spectrum from data compared to the simulation of excited quark signals. The results are consistent with background-only expectations. Limits are derived on excited quark production in the plane of compositeness scale Λ versus mass for two scenarios of production and decay: one assuming excited quark transitions via SM gauge bosons only, and one including also novel contact interaction transitions from new strong dynamics. The q^* mass limits at 95% CL with contact interactions are more sensitive than previous searches in scenarios where the coupling to gluons is suppressed relative to the electroweak gauge bosons, ruling out masses below 1.17 TeV in the extreme case when this coupling is zero.

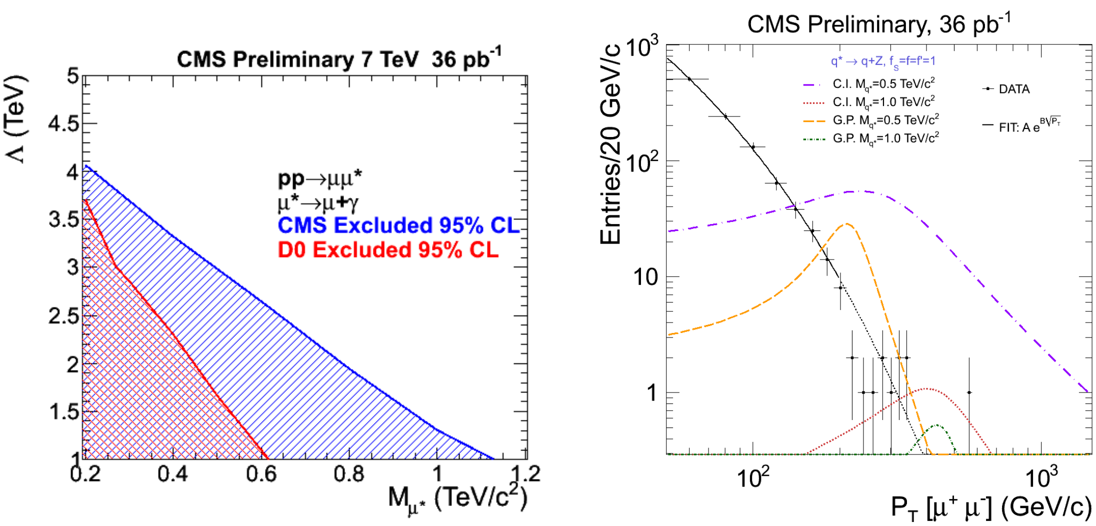

Figure 3: (Left) Exclusion at 95% CL in the $\Lambda - M_{\ell^*}$ parameter space for the $\mu\mu\gamma$ channel. (Right) The dimuon p_T spectrum distribution from data with a background parametrization overlaid. Various excited quark signals are shown, corresponding to different production mechanisms (gauge interaction and contact interaction) and different q^* masses.

4 Extra Dimensions

Compact large extra dimensions (ED) are an intriguing proposed solution to the hierarchy problem of the SM, which refers to the puzzling fact that the fundamental scale of gravity $M_{Pl} \sim 10^{19}$ GeV is so much higher than the electroweak symmetry breaking scale $\sim 10^3$ GeV. In the ADD model[c], the SM is constrained to the common 3+1 space-time dimensions, while gravity is free to propagate through the entire multidimensional space. The gravitational flux in 3+1 dimensions is effectively diluted by virtue of the multidimensional Gauss's Law. In this framework, the fundamental Planck scale can be lowered to the electroweak scale, thus making production of gravitons possible at the LHC. Some of the experimental signatures of the existence of such extra dimensions are discussed below.

[c] The original proposal to use ED to solve the hierarchy problem was presented by Arkani-Hamed, Dimopoulos, and Dvali (ADD).

4.1 Diphoton and Dimuon Channels

Search for virtual-graviton contributions in the diphoton [16] and dimuon final state have been performed at CMS. Figure 4 displays the diphoton (left) and dimuon (right) invariant mass distribution for the observed data, the backgrounds, and the ADD signal. The ADD signal, differently from the searches discussed in Section 2.1, would not appear as a narrow peak but as an overall excess of events at high values of invariant mass. In both $\gamma\gamma$ and $\mu\mu$ channels, the data is found to be consistent with SM expectations. New lower limits on the effective Planck scale in the range of 1.6–2.3 TeV at the 95% CL are set, depending on the number of extra dimensions and the theoretical conventions used to describe the virtual-graviton production.

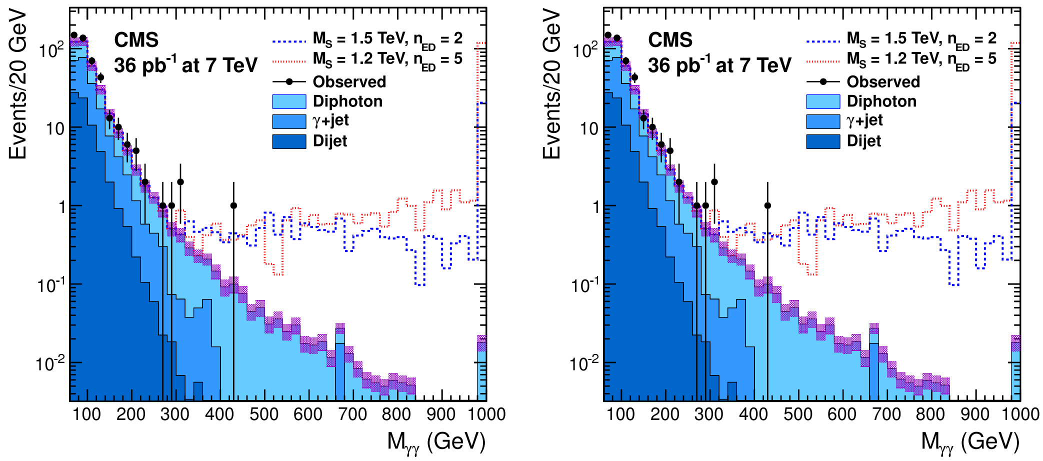

Figure 4: (Left) (Right)

4.2 Mono-jet Final State

4.3 Microscopic Black Holes

5 Long-Lived Particles and Other Exotic Signatures

6 Summary

Table 1: CAPTION

Acknowledgments

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