PROCEEDINGS OF SCIENCE

CMS searches for new physics in hadronic final states

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Many new physics models and Standard Model extensions like, additional symmetries and forces, compositeness, extra dimensions, extended Higgs sectors, supersymmetry, dark sectors and dark matter particles, are expected to manifest themselves in final states with hadronic jets. This work will present recent searches for new phenomena in such final states using the full Run II luminosity corresponding to 138 fb^{-1} collected with the CMS detector at the CERN LHC.

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1. Introduction

The Standard Model (SM) of particle physics describes the fundamental particles and their interactions. It has been tested experimentally with high precision and it has been observed good agreement with the theoretical predictions. However, it has limitations and does not provide explanation for some important phenomena in the universe. Theories of physics beyond the standard model (BSM) could resolve these open questions. The CMS experiment [1] is searching for new particles, predicted by BSM theories, analyzing data collected during RunII of LHC. In particular it will be shown the searches for new physics in hadronic final state.

2. Search for pair-produced multijet resonances using data scouting [2]

The analysis presented the search for pair produced higgsinos, gluinos, and top squarks in the R-parity violating (RPV) supersymmetric framework [4]. Three different signatures are taken into account according to the number and the type of jets in the final state, and the AK8 jets substructure: the Resolved trijets search, with a pair of 3 AK4 jets, the Boosted dijets serach, with a pair of 2 AK8 jets with 2-prong substructure, and the Boosted trijets search, with a pair of 2 AK8 jets with a 3-prong substructure. Figure 1 shows the benchmark model for the considered production and decays. The three signatures are analyzed independently, using the CMS scouting

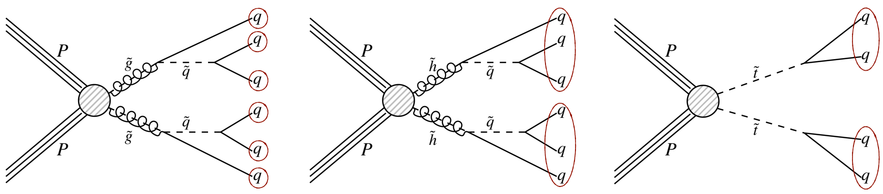

Figure 1: Benchmark models from the RPV supersymmetric for resolved trijets (left), boosted trijets (middle), and boosted dijets (right).

dataset [3] to increase the investigated phase-space region, thanks to partially reconstructed events with $H_T > 450\ GeV$. The QCD multijet backgorund is the most dominant, it is reduced thanks to several requirements, optimized for each of the three signatures. The remaining QCD background is estimated using Gaussian Processes regression [5]. Monte Carlo samples are used to estimate the resonant background, as the $t\bar{t}$ and the hadronically decaying Z/W bosons. The average jet mass distribution, for the boosted searches, and the trijet mass distribution, for the resolved search, are fitted considering different mass of the higgsinos, gluinos, and top squarks. Figure 2 shows observed and expected limits on the production cross sections, branching fraction, and acceptance for the three signatures. The trijet searches exclude RPV gluinos with mass between 70 GeV and 1.7 TeV. The boosted dijet resonance search excludes RPV top squarks with masses between 70 GeV and 200 GeV. The boosted trijet resonance excludes RPV higgsinos masses between 70 GeV and 75 GeV and between 95 GeV and 105 GeV. The most significant deviation from SM is at resonance mass of 768 GeV for the resolved search.

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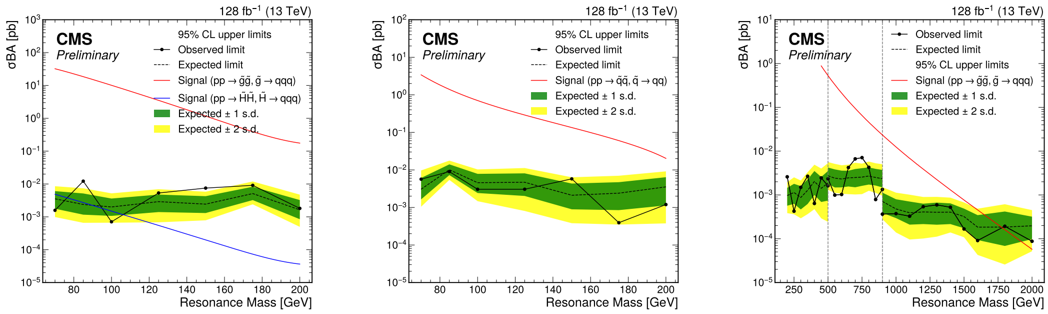

Figure 2: Observed and expected limits on the production cross sections, branching fraction, and acceptance for boosted trijets (left), boosted dijet (middle), and resolved trijets (right).

3. Search for narrow trijet resonances in proton-proton collisions [6]

This search for narrow trijet resonances and the following searches presented are performed on the full Run2 statistic of 138 fb^{-1}. It is considered the direct three body decay of a right-handed Z_R boson to gluons, both with narrow and Standard Model like width [7]. Moreover, the production of a resonance X, a Kaluza-Klein gluon [8] [9] or an excited quark q* [10], with intermediate resonance Y is investigated. The resonance mass range considered is between 1.75 TeV and 9 TeV, for the cascade decay models the ratio ρ_m between the mass of Y resonance and the mass of the X resonance is constrained between 0.2 and 0.8, to ensure the presence of 3 narrow jets in the final state. The three leading AK4 jets are reclustered into *wide-jets* to recover the energy radiated by final state gluons. The QCD multijet background is estimated with data-driven method, fitting the trijet mass m_{jjj} distribution with 3 parametric functions. Figure 3 (left) shows the trijet mass distribution. The signal is extracted using a binned maximum-likelihood fit with variable bin size approximating the m_{jjj}resolution. For the $Z_R \to ggg$ signal scenario, the current dataset does not provide sufficient sensitivity to constrain the Z_R model as shown in Figure 3 (middle and right) . For the $X \to Y(gg)g$ and $X \to Y(qq)q$ cascade decay scenarios, upper limits are estimated as function of m_X and ρ_m.

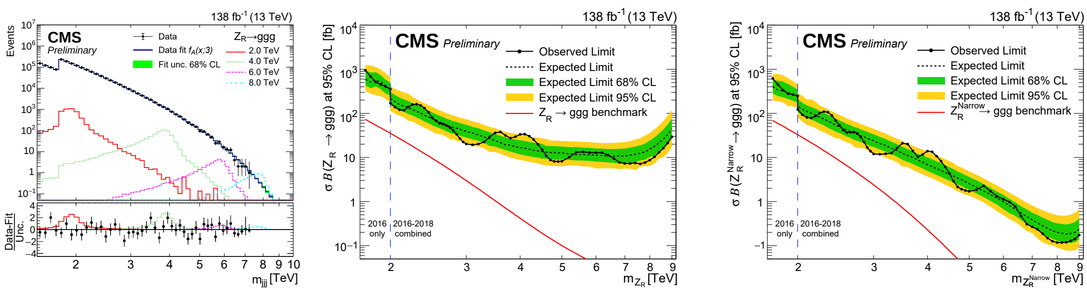

Figure 3: The trijet mass m_{jjj} distribution (left). Observed and expected limits on the production cross sections and branching fraction for the $Z_R \to ggg$ nominal (middle) and narrow (right) with scenarios.

4. Search for leptoquarks produced in lepton-quark collisions and coupling to τ leptons [11]

The analyses presented in this section and section 5 search for leptoquarks (LQs). The LQs are color-triplet bosons [12] carrying both barion and lepton number that could explain the observed deviation from the Standard Model measured in the B meson decays [13]. The LQs decay into a lepton and quark pair, for both searches it is considered the cross-generational coupling, i.e. the lepton and the quark can be from different generations. The single lepton-induced production is presented in this work. Figure 4 (left) shows the Feynman diagram of the process. The final state

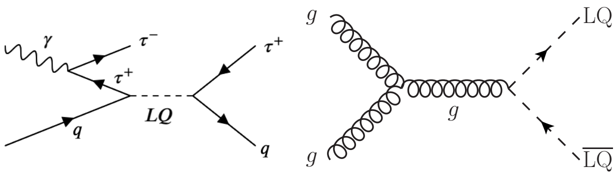

Figure 4: Feynman diagram of the lepton-induced LQ production (left) and pair production (right).

consists of a jet, missing transverse energy, and the τ lepton reconstructed through its leptonic or hadronic decays, i.e. with a muon, an electron, or hadrons in the final state. The three channel are orthogonal, since additional lepton veto is required. The main SM backgrounds with a prompt lepton in the final state are estimated from simulation and the normalization of W+jets background is extracted from data. The dominant background in the hadronic channel is the QCD multijet one. Boosted Decision Trees (BDTs) algorithms are trained for each channel to better discriminate signal from background. A maximum likelihood fit to the collinear mass, m_{coll}, distribution is performed with the signal normalization as a free parameter. The m_{coll} is reconstructed from the lepton, jet, and missing transverse energy, assuming the missing transverse energy is coming only from neutrinos from the τ lepton and it is collinear to the visible decay products. Events are categorized depending if the prompt jet is *b-tagged* or not, since LQ coupling with light quarks (u, d, s) and b quarks are considered. Figure 5 (left) shows the m_{coll} distribution for events with en electron and a *b-tagged* jet in the final state. Upper limits at 95% confidence level are set on the LQ production cross section multiplied by branching fraction as a function of LQ mass, as shown in Figure 5 (middle and right). Upper limits at 95% CL are set on the coupling strength of a LQ as a function

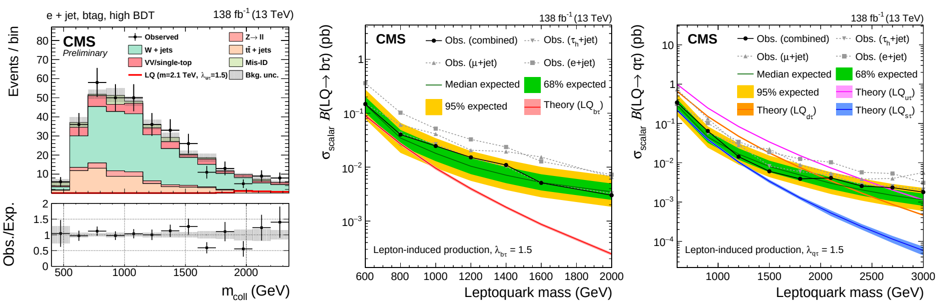

Figure 5: Collinear mass distribution for events with en electron and a *b-tagged* jet in the final state (left). Observed and expected limits on the production cross sections and branching fraction for LQ production decaying to a τ lepton, and a light-flavour quark (right) or a b quark (middle).

of the LQ mass, both for light-flavour quark and b quark couplings.

5. Search for leptoquarks decaying to muons and bottom quarks [14]

This search for pair produced LQs considers two muons in the final state and two jets from the b quarks, investigating masses of the LQs from 300 GeV to 3 TeV. Figure 4 (right) shows one Feynman diagram for the pair production of LQs. Events are selected requiring kinematic cuts on muons and AK4 jets, with at least one of the two jets *b-tagged*. A BDT algorithm is trained for each of the m_{LQ} hypotheses considered. The main SM backgrounds shapes are taken from the simulation, normalized to data at preselection in orthogonal control regions. Final selection is made with a cut-and-count approach, optimized with requirements on the BDT output with Punzi significance as figure of merit [15]. Figure 6 (left) shows the data and background event yields after the final selection, for each scalar m_{LQ} hypothesis considered. Figure 6 (right) shows the observed and expected upper limit at 95% CL on $\sigma\beta^2$, where β is the branching fraction of the LQs decay into charged lepton. LQs with masses less than 1810 GeV are excluded for $\beta = 1$.

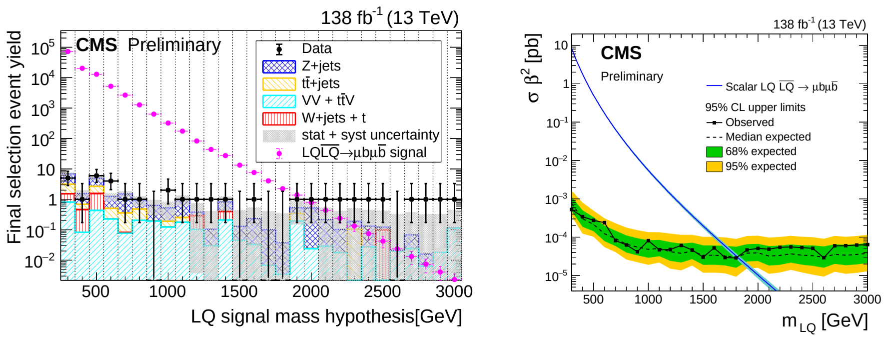

Figure 6: Data and background event yields after final selections, for each scalar m_{LQ} hypothesis (left). Observed and expected limits on the production cross sections and branching fraction for LQ production decaying to two muons and two b quarks (right).

6. Search for a high-mass dimuon resonance produced in association with b quark jets [16]

The last work presented is the search for a dimuon resonance in association with a b quark. In Figure 7 are shows two different Feynman diagrams for the Z' production, considering both coupling to a $b\bar{b}$ pair or to a $s\bar{b}$ pair.

Events are categorized according to the multiplicity of *b-tagged* jet, with one of more tagged jets. The main SM backgrounds are suppressed requiring at least one tagged jet and minimum threshold on the invariant mass of muon and b-jet. The search is performed by simultaneously fitting the unbinned $m_{\mu\mu}$ distributions, the background distribution can be modeled with Bernstein polynomials, or exponential, or power-law functions. The signal distribution is parameterized as the sum of a Gaussian with a double sided Crystal Ball and a common resolution width σ_{mass} and the fit is performed in $\pm 10\sigma_{mass}$ window. The width of the resonance is assumed to be narrow, this assumption is ensured by restricting the search to the regions of parameter space where the Z' width

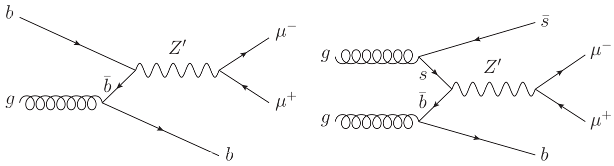

Figure 7: Two Feynman diagrams for the Z' production, considering both coupling to a $b\bar{b}$ pair (left) or to a $s\bar{b}$ pair (right), and decaying to two muons and at least one b jet.

does not exceed half of the dimuon mass resolution. The results are used to set model-independent limits at 95% confidence level (CL) on the number of signal events, as shown in Figure 8 (left), taking into account different hypotheses of f_{2b}, i.e. fraction of signal events with $N_b > 1$. Results are also interpreted in terms of a lepton flavor-universal (LFU) model and the exclusions are set on coupling strengths, as shown in Figure 8 (middle). Constraints are also set on a specific Z' model (B3-L2) [17], taking into account $b \rightarrow s l^- l^+$ transitions beyond the standard model. Most of the allowed parameter space is excluded for a Z' boson with $350\ GeV < m_{Z'} < 500\ GeV$, but large regions of the parameter space are also excluded at higher masses, as shown in Figure 8 (right).

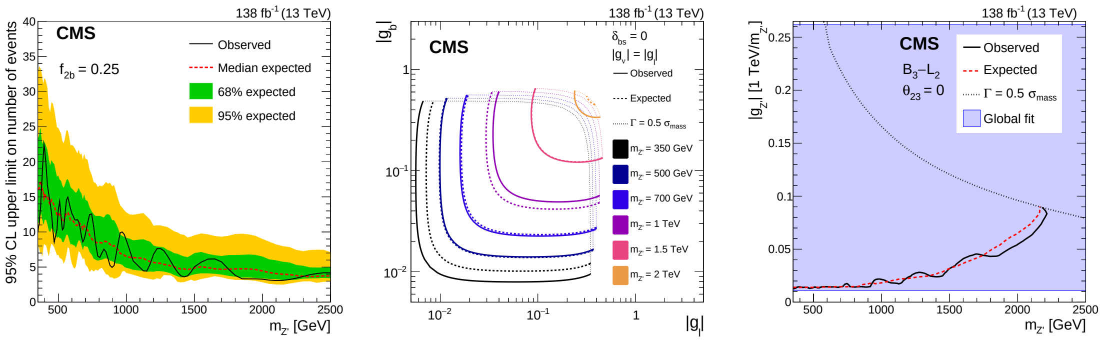

Figure 8: Observed and expected limits at 95% CL on the number of events for model-independent search (left). Exclusions limits on coupling strengths for LFU model (middle).Constraints on a specific Z' model (B3-L2) (right).

7. Conclusions

It has been presented recent results on the searches for new physics in hadronic final states at the CMS experiment at LHC. New selection and background modeling techniques has been used to improve the results, allowing to set exclusion limits on different models. The CMS experiment will continue working on the searches, analyzing the new RunIII data, and improving the analysis techniques.

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