PROCEEDINGS OF SCIENCE

Prompt signature searches in CMS

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The pursuit of beyond the standard model (BSM) physics searches with prompt signatures has been a prominent aspect of the physics program at the LHC. Here we report recent results obtained by the CMS experiment on searches for dark matter (DM) and its light mediators, as well as BSM vector bosons using prompt signatures. These results benefit from the large amount of data at $\sqrt{s}$ = 13 TeV collected during the Run 2 of the LHC between 2016 and 2018, as well as the incorporation of advanced machine learning techniques and innovative data acquisition strategies. The data agree with the SM predictions in all the reported searches. Stringent or best upper limits to date are set for a variety of benchmark signal cross sections.

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1. Introduction

Prompt leptons and jets in final states are key tools in collider experiments for the direct probe of new physics. We report here the substantial progress achieved by the CMS experiment [1] that is enabled by the appreciable amount of data collected by the CMS detector during LHC Run-2, the incorporation of advanced machine learning algorithms in the event selection and particle identification, and the deployment of innovative data acquisition techniques.

2. dark Higgs (WW) + MET

The CMS Collaboration reported on a search of the dark Higgs using $s + p_{\mathrm{T}}^{\mathrm{miss}}$ signature [2], where s refers to the dark Higgs boson and $p_{\mathrm{T}}^{\mathrm{miss}}$ is the missing transverse momentum of the event. The dark Higgs s is motivated by a postulated Majorana DM particle χ that transforms under a new U(1) local gauge symmetry, yielding an additional massive spin-1 vector boson Z' [3]. This search focuses on the phase space $m_s > 160$ GeV, where the decay of the dark Higgs to a pair of W bosons becomes dominant. Two decay channels of the W boson pair, WW $\rightarrow l\nu qq$ and WW $\rightarrow l\nu l\nu$, are considered. In the former case, event selections are aided by Boosted Decision Trees (BDTs) while in the latter 3-D maximum likelihood fits are performed using the separation of two leptons ΔR_{ll}, the invariant mass of the two leptons m_{ll}, and the transverse mass of the trailing lepton and missing transverse momentum $m_{\mathrm{T}}^{l_{\min}, p_{\mathrm{T}}^{\mathrm{miss}}}$. Results are obtained from the joint fit of the distributions observed in the $l\nu qq$ and $l\nu l\nu$ channels. No significant deviation from the SM predictions is seen in either channel. Limits at 95% confidence level (CL) are set on the production cross section of the signal process, which extend the results for a broader range of the DM mass hypotheses (of 100 – 300 GeV) compared to previous searches conducted by the ATLAS experiment [4, 5]. For $m_\chi = 200$ GeV and $m_s = 160$ GeV, this work excludes $m_{Z'}$ up to ≈ 2200 GeV, while for $m_{Z'} = 700$ GeV, it excludes m_s up to ≈ 350 GeV.

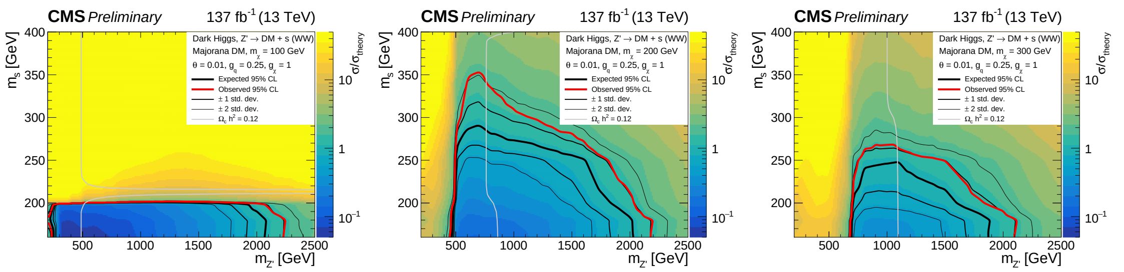

Figure 1: Observed (expected) exclusion regions at 95% CL for the dark Higgs model in the $(m_s, m_{Z'})$ plane, marked by the solid red (black) line [2]. The expected $\pm 1\sigma$ (68% CL) and $\pm 2\sigma$ (95% CL) bands are shown as the thinner black lines. The mass assumptions of χ are 100 (left), 200 (middle), and 300 GeV (right). The gray line indicates model parameters that produce exactly the observed relic density.

3. GeV-scale di-muon resonances

In LHC Run-2, the CMS experiment deployed a special high-rate strategy that could record events with two muons with transverse momenta as low as 3 GeV, sacrificing a certain amount of

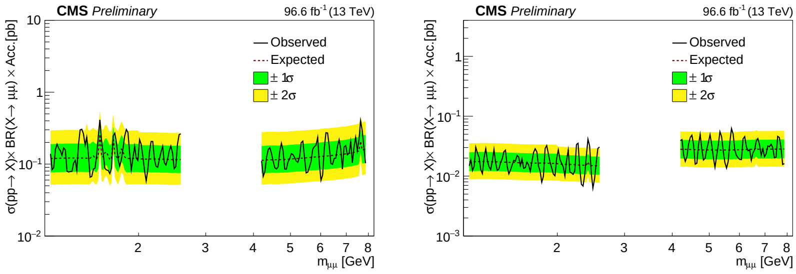

Figure 2: Expected and observed model-independent upper limits at 95% CL on the product of the signal cross section (σ), the branching fraction (B) and fiducial acceptance (A) to a pair of muons for the inclusive dimuon selection targeting the dark photon model (left) and the high-p_{T} selection targeting 2HDM+s (right) [7].

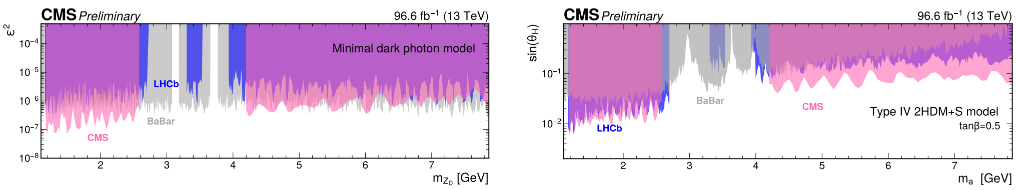

Figure 3: Observed upper limits at 90% CL (pink) on ϵ^2 in the minimal model of a dark photon (left) and $\sin(\theta_H)$ for the 2HDM+s (right) in the mass ranges of 1.1–2.6 GeV and 4.2–7.9 GeV [7]. The CMS limits are compared with the existing limits at 90% CL obtained by LHCb [11, 12] (blue) and BaBar [13] (gray).

the full event information [6]. This strategy, known as "scouting", enabled unprecedented searches by the CMS for new physics in the low-mass region of around several GeV. Using data collected with scouting triggers, CMS reported results on a search for GeV-scale dimuon resonances [7]. This search is motivated by the model of a dark photon from a new gauge field $\mathrm{U}(1)_{\mathrm{D}}$ that is kinetic mixed with the SM $\mathrm{U}(1)_{\mathrm{Y}}$ [8, 9], as well as a light pseudoscalar boson from a two Higgs doublet model with an extra complex scalar singlet (2HDM+s) [10]. Two muon identification discriminators are trained as boosted decision trees (BDTs) using data from J/ψ and Υ (1S) samples, providing $\sim$ 30% improvement to the final limits on the cross section. The results are extracted by simultaneous signal plus background maximum likelihood fits to the di-muon mass spectrum. Empirical analytic functions are used to estimate the background contribution with dedicated corrections to account for the misidentified $D^0 \to \mathrm{K}^+\mathrm{K}^-/\mathrm{K}^-\pi^+$ events, in which kaons or pions are misreconstructed as muons. Limits at 95% CL are set for a hypothetical resonance with a mass from 1.1-2.6 GeV or from 4.2-7.9 GeV, which are competitive or the world's best limits. Values of the squared kinetic mixing coefficient $\epsilon^2 > 10^{-6}$ in the dark photon model are excluded over most of the mass range of the search. Assuming the Higgs doublets vacuum expectation $\tan\beta = 0.5$, values of the mixing angle $\sin(\theta_H) > 0.08$ are excluded over most of the mass range of the search for the 2HDM+s.

4. Searches for high-mass resonances

CMS also reported new results on searches for new TeV-scale resonances. The signature of three well-separated hadronic jets is used for the first time by a collider experiment to probe the decay of singly-produced new resonances either directly to the 3-body final state or through a

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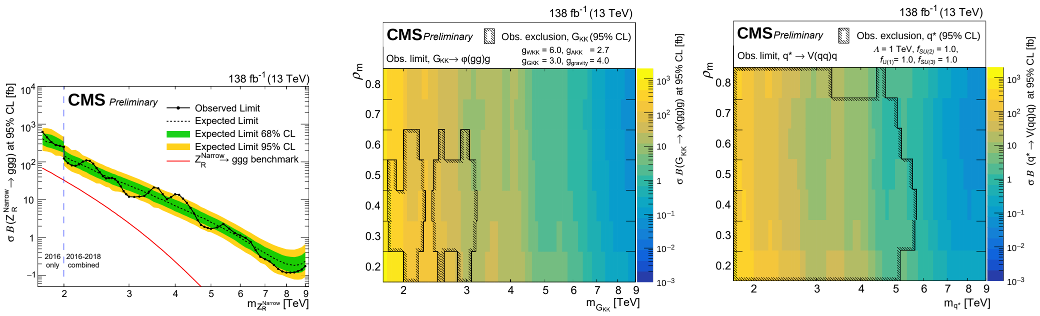

Figure 4: Observed limits at 95% CL on σB for the Z_R (left), G_{KK} (middle) and q^* (right) models [14]. The legend shows the model parameters for the chosen benchmark [23, 24], and their corresponding mass exclusion ranges are depicted with areas inside the black hatched contours.

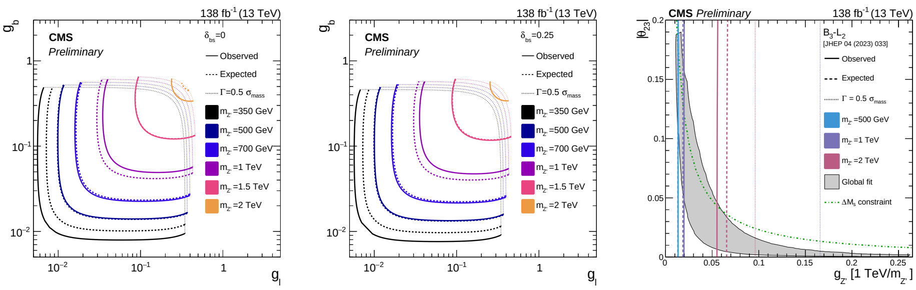

Figure 5: exclusion limits at 95% CL in the $|g_b| - |g_l|$ plane for the lepton-flavor-universal model (left and middle) and in the $|\theta_{23}| - |g_{Z'}|$ plane for the $B_3 - L_2$ model (right) [15].

cascade [14]. Limits have been established for the 3-body or the cascade decay with the initial and intermediate resonance mass ratio between 0.3 and 0.8 of a new resonance. Results are interpreted in the context of a new right-handed boson Z_R decaying to three gluons, a Kaluza–Klein gluon G_{KK} decaying via an intermediate radion to three gluons (ggg), and an excited quark (q*) decaying via a vector boson to three quarks (qqq).

Results on another search for high-mass dimuon resonance produced in association with one or more b quark jets are also reported [15]. Model-independent limits are derived on the number of signal events with exactly one or more than one b quark jet and interpreted in a lepton-flavor-universal model with a new Z$'$ boson as well as a specific $B_3 - L_2$ model that is constructed to accommodate possible contributions to $b \to sll$ transitions beyond the SM. This is the first dedicated search for this signal process at the LHC that yields the most stringent constraints to date for the models considered.

5. Conclusions

The CMS Collaboration has been actively working on addressing the fundamental questions of physics with prompt signatures. Our recent progress in searches for dark matter, as well as other beyond the standard model physics signatures are reported. Significant improvements are anticipated, driven by more data, an improved detector, and technological advancements in data taking and analysis during the LHC Run 3.

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