PROCEEDINGS OF SCIENCE

# Hidden Sector Searches in CMS

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Searches for hidden sector particles by the CMS Collaboration in proton-proton collisions recorded at the Large Hadron Collider at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV are outlined. In particular, searches for low-mass dimuon resonances targeting dark photons and for semivisible jets aiming at discovering dark QCD are presented, followed by a recent search for dark Higgs bosons decaying to two W particles. No evidence for hidden sector particles has been found, but limits have been set.

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## 1. Introduction

The standard model of particle physics (SM) needs to be embedded in an overarching theory, in order to describe phenomena like dark matter. Such a theory may contain a rich hidden sector, with couplings to SM particles that could be feeble, or strong. Heavy WIMPs (weakly interacting massive particles) have been predicted, but none have been found so far. Therefore lower mass regions are now of particular interest. Recent searches for hidden sector particles have been undertaken at the CMS experiment [1]. The analysed data, from Run 2 of the LHC, corresponding to up to 138 fb$^{-1}$ of integrated luminosity at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV were recorded between 2016 and 2018.

## 2. Low-mass dimuon resonances – dark photons

A search for low-mass dimuon resonances has been performed with a dataset of 96.6 fb$^{-1}$. A scheme called Scouting has been used to collect data with optimized efficiency in very low dimuon mass regions. The CMS trigger system has only two levels. Level-1 (L1), based on programmable hardware, has a maximum output rate of about 100 kHz. The high-level trigger (HLT) is software-based, with an output rate of the order of 1 kHz. Since the typical event size is 1 MB, the bandwidth is approximately 1 GHz. Scouting allows higher event rates, while at the same time reducing the event information, such that the standard bandwidth is kept. The entire event reconstruction is performed at the HLT. Muons with transverse momenta $p_T > 3$ GeV have been recorded. The output rate was 2 kHz compared to 0.45 kHz for standard dimuon triggers at peak LHC luminosity. The event selection required at least two opposite-charge muons with $p_T > 4$ GeV. The mass region of 2.6 to 4.2 GeV around the masses of the J/$\psi$, $\psi$(2S), and $\Upsilon$(1S) resonances was excluded. Muons are identified based on multivariate analysis (MVA) techniques, trained with J/$\psi$ and $\Upsilon$ events, using a tag and probe method. The background was estimated with same-charge probe muons. Fig. 1 (left) shows the expected and observed model-independent

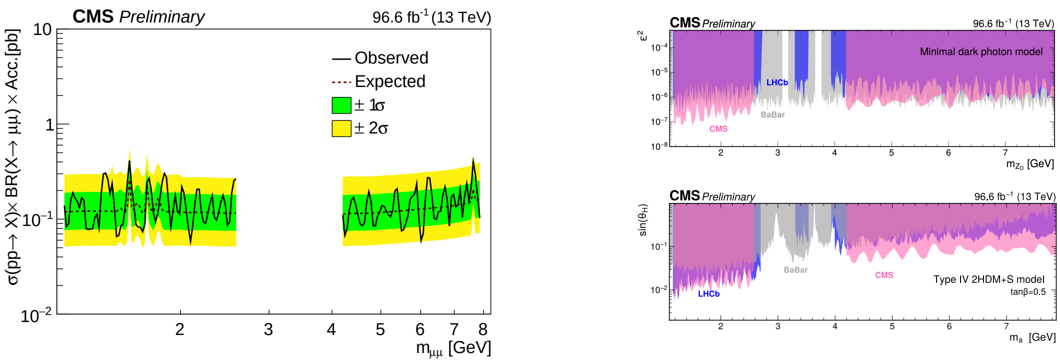


**Figure 1:** Model-independent upper limits at 95% CL on the product of the signal cross section, the branching fraction to a muon pair, and fiducial acceptance (left). Observed upper limits at 90% CL on the square of the kinetic mixing coefficient $\epsilon$ for the dark photon model (top right), and on the mixing angle $\theta_H$ for the 2HDM+S model (bottom right).

upper limits at 95% confidence level on the product of the signal cross section multiplied by the branching fraction to dimuons and the fiducial acceptance. The signal is extracted by performing simultaneous signal plus background maximum likelihood fits to the dimuon mass distribution. The upward deviations in the expected limits below 2 GeV are due to the peaking background associated with $D^0$ meson decays. The excess at 1.867 GeV may correspond to the $D^0 \to \pi^+\pi^-$ or $D^0 \to \mu^+\mu^-$ processes. An interpretation within models with a dark photon ($Z_D$) [2, 3] or a beyond-standard-model pseudoscalar ($a$) in a 2-Higgs-doublet model with an extra complex scalar (2HDM+S) [4] has also been made, resulting in limits competitive with BaBar and LHCb, or even best limits, as can be seen from Fig. 1 (right). The squared kinetic mixing coefficient $\epsilon^2$, which defines the kinetic mixing of $U(1)_D$ with $U(1)_Y$, in the dark photon model above $10^{-6}$ is mostly excluded in the mass range of the search. The sensitivity becomes better at low masses due to the larger Drell-Yan production cross section at lower energy scale. In the 2HDM+S model, the mixing angle $\sin(\theta_H)$ above 0.08 is mostly excluded in the mass range of the search with fixed $\tan\beta = 0.5$. The limits derived from this search in the low-mass region are competitive with recently reported results from LHCb [5] below the charmonium peaks and better above them.

## 3. Semivisible jets – dark QCD

A hidden sector strongly coupled to SM particles is assumed, which contains dark quarks forming stable or unstable bound states called dark hadrons. The resulting jets are expected to be wider than typical SM jets because they arise from a multi-step process: the dark quarks shower and hadronize invisibly in the dark sector, the unstable dark hadrons decay to SM quarks, and finally the SM quarks shower and hadronize visibly. An inclusive search based on event-level kinematic variables, as well as a search using a boosted decision tree (BDT) discriminator, have been performed [6]. The BDT discriminator, used to separate the signal from backgrounds, is 1 for semivisible jets, and 0 for SM jets. At the working point 0.55, the BDT variable rejects 84–88% of simulated background jets, while correctly classifying 87% of jets from the benchmark signal model. Depending on the mass of the Z′ mediator, all variations considered for dark hadron masses ($m_{dark}$) and the running coupling of the dark QCD force $\alpha_{dark}$ can be excluded. BDT-tagging of semivisible jets reduces the background by two orders of magnitude, as illustrated by Fig. 2.

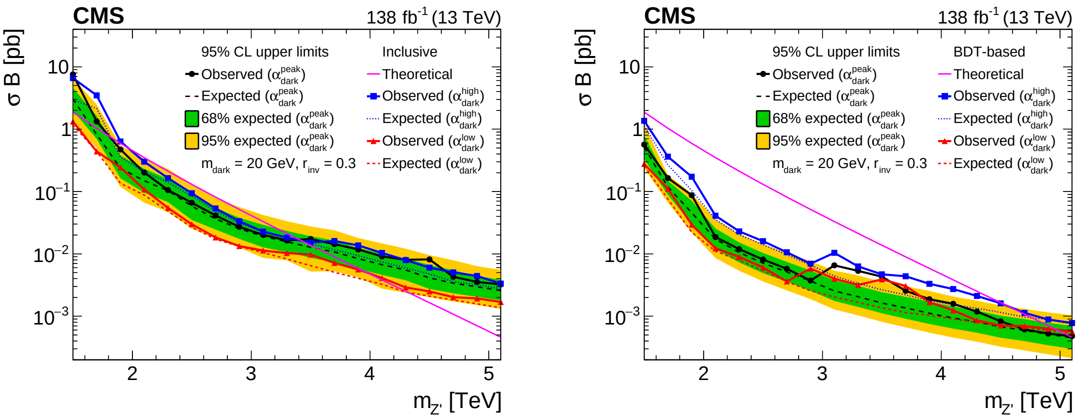


**Figure 2:** Results at 95% CL from inclusive (left) and BDT (right) searches for semivisible jets, with $r_{inv}$ denoting the fraction of stable, invisible dark hadrons.

## 4. Dark Higgs bosons in $W^+W^-$ events with transverse momentum imbalance

A simplified model containing a dark Higgs boson s, with mass above the WW threshold, and a $Z'$ mediator is assumed [7]. The event signature consists of one or two isolated leptons (electrons or muons) from the W decays and missing transverse momentum from dark matter particles. Two search channels, a dileptonic one with two leptons, and a semileptonic one, with one W decaying to a lepton, and the other one to hadronic jets has been used. Jets must not have b tags, in order to reduce background from tW and $t\bar{t}$. As can be seen from Fig. 3, for a dark matter mass of $m_\chi$ = 200 GeV and a dark Higgs boson mass $m_s$ = 160 GeV, $Z'$ masses up to 2200 GeV are excluded, whereas for $m_{Z'}$ = 700 GeV, dark Higgs boson masses smaller than 350 GeV are excluded [8]. The sensitivity weakens for $m_s > 2m_\chi$ as $s \rightarrow \chi\overline{\chi}$ starts to dominate.

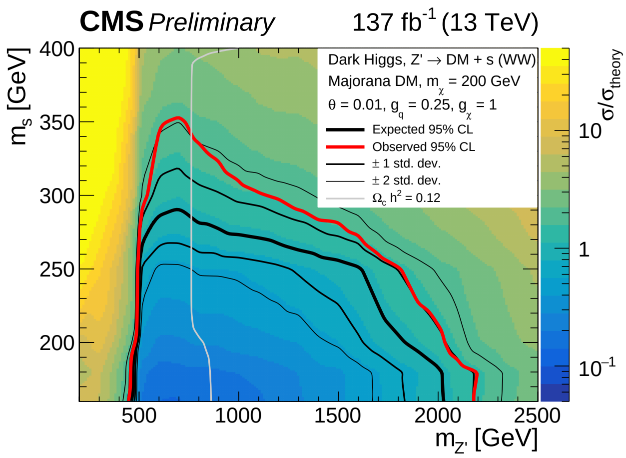


**Figure 3:** Observed (expected) exclusion regions at 95% CL for the dark Higgs model in the ($m_s$, $m_{Z'}$) plane, marked by the solid red (black) line. The expected $\pm1\sigma$ and $\pm2\sigma$ bands are shown as the thinner black lines. The gray line indicates where the model parameters produce exactly the observed relic density of cold dark matter $\Omega_c h^2 = 0.12$.

## References

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