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Dark sector searches with the ATLAS and CMS experiments

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These proceedings summarise recent searches for dark sector mediators, in particular dark photons, using $\sqrt{s}$ = 13 TeV proton-proton collision data collected by the ATLAS and CMS experiments at the Large Hadron Collider (LHC). The searches target a wide range of dark photon masses, from 0.2 to 200 GeV, as well as massless dark photons, and exploit a variety of experimental signatures. The first collider constraints for scalar dark energy are also presented.

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1. The dark sector

The nature of dark matter and dark energy are two of the most important, unsolved questions in fundamental physics. The hidden sector, or dark sector, is a hypothetical collection of fields and particles with no direct interactions with the particles of the Standard Model (SM). These dark sector particles would only couple extremely weakly to Standard Model (SM) particles through mediating particles such as dark photons, axions, or sterile neutrinos. Dark photons (γ_D, A', or Z_D) are neutral light vector gauge bosons which kinetically mix with the SM photon with a mixing strength ϵ^2. Dark photons can therefore be searched for at colliders through their decays to fermions. These new particles have been searched for at the Large Hadron Collider (LHC) using proton-proton collision data at $\sqrt{s}$ = 13 TeV collected between 2015 and 2018. The ATLAS [1] and CMS [2] collaborations have searched for dark photons in the mass range from 0.2 to 200 GeV, as well as massless dark photons, in a variety of experimental signatures. These proceedings present an overview of these recent results. The first constraints on scalar dark energy at a hadron collider are also presented.

2. Dark photon searches

2.1 Lepton jets

For masses in the range $0.2 < m_{A'} < 2.0$ GeV, the fermions (leptons) from the dark photon decays will be collimated and may be displaced in the detector depending on the lifetime of the dark photon. The ATLAS collaboration has searched for “lepton jets”, collimated groups of leptons, produced through the so-called FRVS model. In this model a cascade decay of dark photons is produced through Higgs portal production and vector portal decay [4]. Prompt and displaced Dark Photon Jets (DPJs) are reconstructed for different decays of the dark photon, either using tracks in the muon spectrometer (muon decays) or clusters of energy deposits in the calorimeter (electrons and light hadrons). No significant excess of events above the expectation from the SM background is found. The 90% exclusion regions for the Higgs boson decay as a function of the dark photon mass and kinetic mixing parameter are shown in Figure 1.

2.2 Higgs decays using ZH production

A search was performed by the CMS collaboration for a Higgs boson that is produced in association with a Z boson (ZH) that decays to an isolated photon and a massless dark photon, which is undetected [5]. The signal is distinguished from the background with the transverse mass, m_{T}[1], which has an endpoint at the Higgs mass, m_H, for the signal. No significant excess of events above the expectation from the SM background is found. The results are interpreted in terms of the massless dark photon model. An upper limit is set on the product of the ZH production cross section and branching fraction, $\mathcal{B}(H \to \mathrm{inv.} + \gamma)$, as a function of the Higgs boson mass. Assuming a SM Higgs boson, the observed (expected) upper limit on this branching fraction is 4.6 (3.6)% at 95% confidence level. These are the first limits on Higgs boson decays to final states that include an undetected massless dark photon.

[1] $m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\mathrm{miss}} E_{\mathrm{T}}^{\gamma}[1 - \cos(\Delta\phi_{\vec{p}_{\mathrm{T}}^{\mathrm{miss}},\vec{E}_{\mathrm{T}}^{\gamma}})]}$

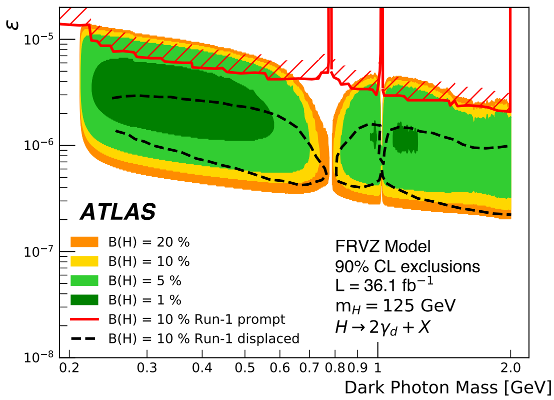

Figure 1: The 90% CL exclusion regions for the decay H$\rightarrow$ $2\gamma_d + X$ of the Higgs boson as a function of the γ_d mass and of the kinetic mixing parameter ϵ. These limits are obtained assuming the FRVZ model with decay branching fractions of the Higgs boson into γ_d between 1% and 20%, and the NNLO Higgs boson production cross sections via gluon–gluon fusion [4].

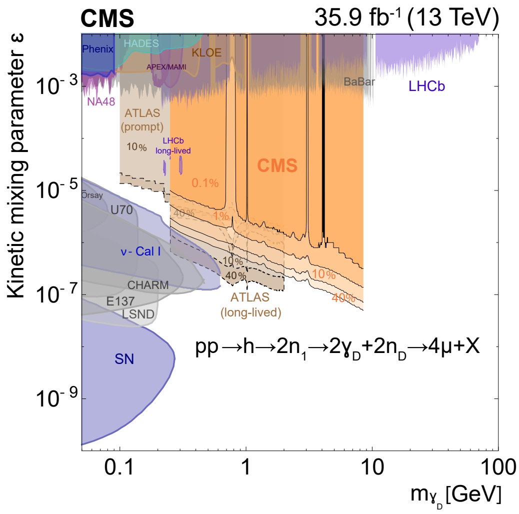

Figure 2: The 90% CL upper limits (black solid curves) in the plane (ϵ, m_{γ_D}) for the process $pp \to h \to 2n_1 \to 2\gamma_D + 2n_D \to 4\mu + X$ with m_{n_1} = 10 GeV, and m_{n_D} = 1 GeV [7]. The coloured contours for the CMS and ATLAS limits represent different values of $\mathcal{B}(h \to 2\gamma_D + X)$ that range from 0.1 to 40%.

2.3 Higgs to ZZ decays

Searches for dark photons in Higgs boson decays with two muon (or electron) pairs were performed by the ATLAS [6] and CMS [7] collaborations. In each case the two intermediate bosons are reconstructed from the lepton quadruplet. Signal regions are defined based on the invariant masses of the reconstructed bosons. No significant deviation from the predicted background is observed. The results are interpreted in terms of different benchmark dark photon models. The ATLAS search considers a hypercharge portal model and Higgs portal model, where upper limits at 95% are set on Higgs boson decay branching fractions in the benchmark models. The CMS search considers a next-to-minimal supersymmetric SM and a dark supersymmetry model that allows for non-negligible light boson lifetimes. The limits in terms of dark photon mass and ϵ are shown in Figure 2.

2.4 Resonant $\mu^{\pm}\mu^{\mp}$ production

The CMS collaboration performed a search for dark photons in pairs of oppositely charged muons [8]. In the 11.5–45 GeV mass range, the search uses data collected with so-called scouting dimuon triggers. These record events at a high rate for low transverse momentum thresholds by storing a reduced amount of trigger-level information. This greatly enhances the sensitivity to dark photons with mass below 45 GeV. No significant resonant peaks are observed, and limits are placed on dark photon masses in the ranges 30–75 and 110–200 GeV, as shown in Figure 3.

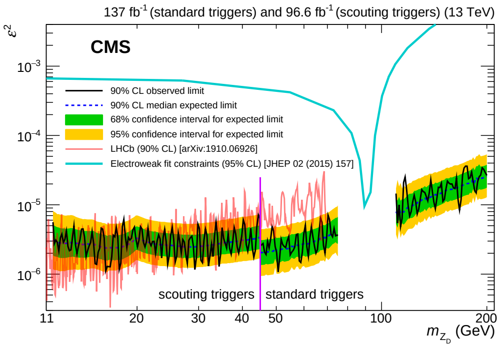

Figure 3: Expected and observed upper limits at 90% CL on ϵ^2, as a function of the dark photon mass. Results obtained using the scouting (standard) triggers are to the left (right) of the vertical purple line [8].

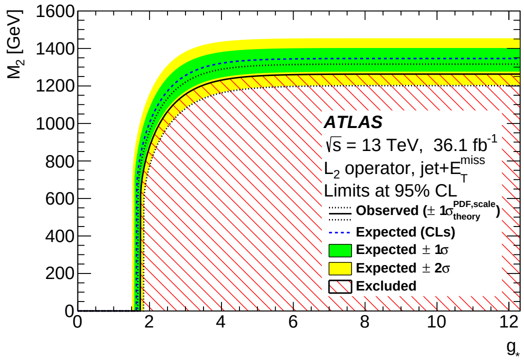

Figure 4: Exclusion plots for $\mathcal{L}_2$ on the (g^*, M_2) plane, after rescaling to take into account the EFT validity criterion [9].

3. Scalar dark energy

Dark energy is one of the potential solutions to explain the observed accelerating expansion of the universe. This has been studied for the first time at the LHC by the ATLAS collaboration [9], using an effective field theory (EFT) model implementation of the so-called Horndeski theories of scalar dark energy. The search uses events containing either a single jet or top quark pairs combined with missing transverse energy. No significant deviations from the SM expectation are observed, and limits at 95% CL are set on the least suppressed operators in the model, as shown in Figure 4.

4. Summary

These proceedings summarise recent searches for dark photons with a wide range of masses with the ATLAS and CMS experiments. The first collider constraints for scalar dark energy are also presented. These searches significantly improve the reach for dark sectors compared to previously published limits. More searches for dark sector mediators exploiting the full dataset collected between 2015 and 2018 are expected in the coming years.

References

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