

Dark photon searches with the ATLAS detector at the LHC

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Many extensions to the Standard Model (SM) introduce a hidden or dark sector (DS) to provide candidates for dark matter in the universe and an explanation to astrophysical observations such as the positron excess observed in the cosmic radiation flux. This hidden sector could arise from an additional $U(1)_d$ gauge symmetry. ATLAS has searched for the gauge boson of the DS, which could be a massless or massive dark photon that either kinetically mixes with the SM photon or couples to the Higgs sector via some mediators. If dark photons decay in turn to SM particles with a significant branching ratio, we could either observe measurable deviations in some particular Higgs boson decay channels or new exotic signatures that would be accessible at the Large Hadron Collider (LHC) energies.

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1. Introduction

Several models propose exotic Higgs boson decays as evidence of new physics. Potential decay modes are essential to study the dark sector and its components. This proceeding summarizes two searches for dark photons based on data collected by ATLAS [1] at a 13 TeV center-of-mass energy during the 2015 and 2016 periods of the LHC [2] Run 2, corresponding to a luminosity of 36 fb^{-1} .

2. Models for dark photon searches

Dark sectors are scenarios in which the new physics structure appears somehow disentangled from the SM. In such scenarios, portals generated by quantum mechanics propagate interactions between dark and SM sectors. ATLAS has performed the following searches:

- Scalar portal (H): Add a dark singlet (ϕ/S) that spontaneously breaks $U(1)$ and mixes with the SM Higgs boson (through the Higgs mixing parameter k).

$$V_0(H, S) = -\mu^2 |H|^2 + \lambda |H|^4 - \mu_S^2 |S|^2 + \lambda_S |S|^4 + k |S|^2 |H|^2. \quad (1)$$

- Vector portal (A): Add a $U(1)'$ group whose massive "dark" gauge boson ($A'/Z_d/\gamma_d$) mixes kinetically with the SM photon (through the kinetic mixing parameter ϵ).

$$\mathcal{L} \supset -\frac{1}{4} \hat{B}_{\mu\nu} \hat{B}^{\mu\nu} - \frac{1}{4} \hat{Z}_{D\mu\nu} \hat{Z}_D^{\mu\nu} + \frac{1}{2} \frac{\epsilon}{\cos\theta} \hat{Z}_{D\mu\nu} \hat{B}^{\mu\nu} + \frac{1}{2} m_{D,0}^2 \hat{Z}_D^\mu \hat{Z}_{D\mu}. \quad (2)$$

3. Dark photon searches with the ATLAS detector

ATLAS has searched for low mass (γ_d) and high mass (Z_d) dark photons from different physics processes with masses up to 60 GeV. Two main categories have been considered in this proceeding:

3.1 Higgs boson decays to beyond-the-SM light bosons in four-lepton events

Existing measurements constrain the non-SM branching ratio of the Higgs boson to less than 30% at 95% confidence level (CL). Due to the extremely narrow decay width of the SM Higgs boson and given the possible "portal" it provides, the addition of even a small coupling to a new light state could open up sizeable new decay modes. This search considers a Higgs boson ($m_H = 125 \text{ GeV}$) decays to four leptons ($l = e$ or μ) via an intermediate state which contains one or two on-shell, promptly decaying bosons: $H \rightarrow ZX/XX \rightarrow 4l$, where X is a new vector boson Z_d (Figure 1) or pseudoscalar a with mass between 1 and 60 GeV [3].

The search for $H \rightarrow ZX \rightarrow 4l$ is performed in an X mass range between 15 GeV and 55 GeV, while the $H \rightarrow XX \rightarrow 4l$ search is done for $15 \text{ GeV} < m_X < 60 \text{ GeV}$ considering $4e$, $2e2\mu$, and 4μ final states and for $1 \text{ GeV} < m_X < 15 \text{ GeV}$ considering only the 4μ final state, respectively.

The main backgrounds of this study are estimated from simulation of $H \rightarrow ZZ^* \rightarrow 4l$ and di-boson production via $ZZ^* \rightarrow 4l$. Figure 2 shows two- and four-lepton mass distributions for the data, the SM backgrounds and three signal points for the $H \rightarrow ZZ_d \rightarrow 4l$ model where the signal strength corresponds to a branching ratio $\beta(H \rightarrow ZZ_d \rightarrow 4l) = \frac{1}{3}\beta(H \rightarrow ZZ^* \rightarrow 4l)$. Figure 2 also shows the distributions from the $H \rightarrow XX \rightarrow 4l$ signal corresponding to an expected yield normalized to $\sigma(pp \rightarrow H \rightarrow Z_d Z_d \rightarrow 4l) = \frac{1}{10} \sigma_{SM}(pp \rightarrow H \rightarrow ZZ^* \rightarrow 4l)$. Figure 3 shows 95% CL upper bounds on the effective Higgs mixing parameter $k' = k \times m_H^2 / |m_H^2 - m_S^2|$ and on ϵ .



Figure 1: Exotic Higgs boson decays to four leptons induced by intermediate dark vector bosons via (left) the hypercharge portal through ϵ and (right) the Higgs portal through k , where S is a dark Higgs boson [3].

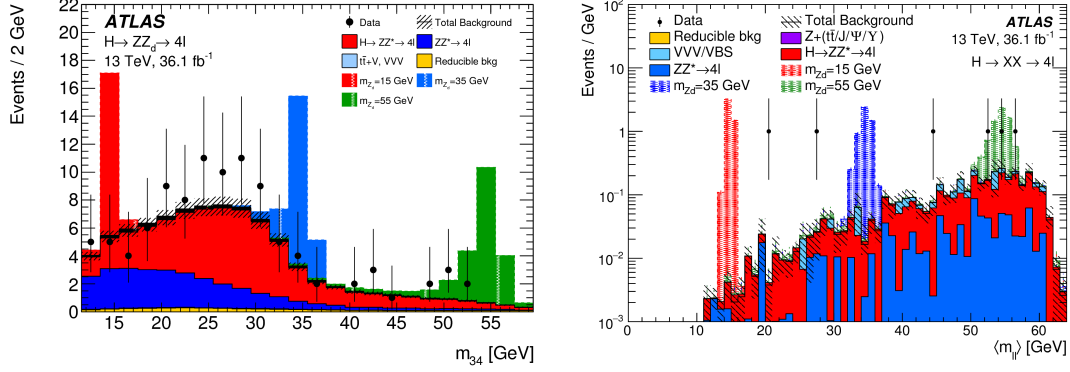


Figure 2: Left: distribution of m_{34} for data and background events in the mass range $m_{4l} \in [115, 130]$ GeV after the $H \rightarrow ZZ \rightarrow 4l$ selection. Right: distribution of $\langle m_{4l} \rangle = \frac{1}{2} (m_{12} + m_{34})$ for events selected in the $H \rightarrow XX \rightarrow 4l$ analysis for $15 \text{ GeV} < m_X < 60 \text{ GeV}$ [3].

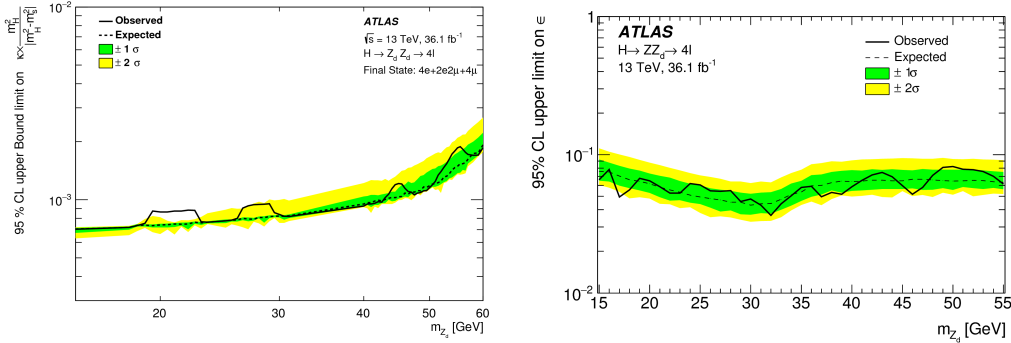


Figure 3: 95% CL upper bounds on k' and ϵ as a function of m_{Z_d} [3].

3.2 Light long-lived neutral particles decaying into collimated leptons or light hadrons

This search investigates the case where DS and SM couple via a vector portal, in which a γ_d mixes kinetically with the SM photon and decays into SM leptons and light quarks [4]. The lifetime of the γ_d is determined through the kinetic mixing term (ϵ) which can vary between 10^{-11} and 10^{-2} . For a small ϵ value, the γ_d has a long lifetime, so that it decays at a macroscopic distance from its production point. The FRVZ model [5, 6] is the benchmark of this search. Figure 4 shows the two processes considered, where the dark photons are expected to be produced with large boosts due to their small mass, resulting in collimated groups of leptons (μ) or light hadrons (h) in a jet-like structure, referred to hereafter as dark-photon jets (DPJs). Two main channels are considered: the μ DPJ– μ DPJ channel, with cosmic rays muons as the main background, and the h DPJ– h DPJ

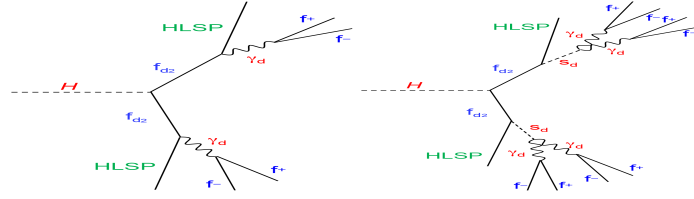


Figure 4: Dark fermion f_{d2} decays into a hidden lightest stable particle (HLSP) and a γ_d (left) or a dark scalar s_d that in turn decays into a pair of dark photons (right). Then γ_d decays into SM fermions [4].

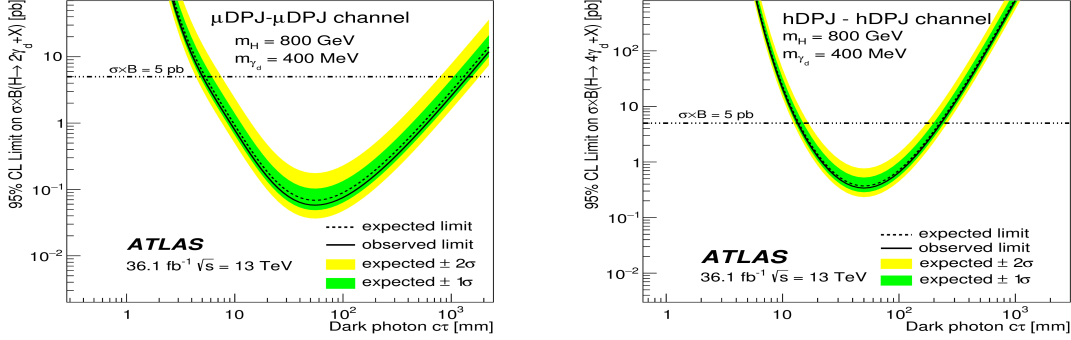


Figure 5: 95% CL upper limits on $\sigma \times B$ for the processes $H \rightarrow 2\gamma_d + X$ (left) and $H \rightarrow 4\gamma_d + X$ (right) [4].

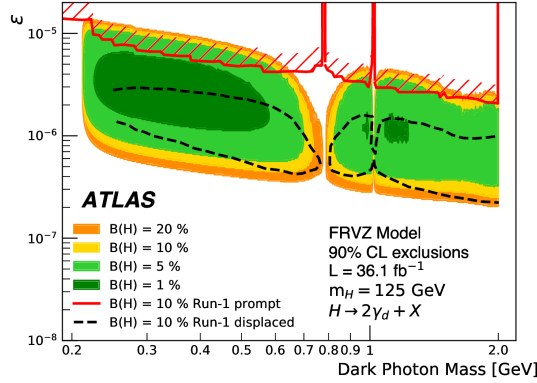


Figure 6: Run 1 and partial Run 2 combined results assuming branching ratios from 1% to 20% [4].

channel, where multi-jet production is the main background. Figure 5 shows upper limits at 95% CL on the cross-section times branching fraction in the two channels. This search results in an exclusion region at 90% CL for $H \rightarrow 2\gamma_d + X$ as a function of the γ_d mass and ϵ (Figure 6).

4. Conclusion

The dark photon searches with the ATLAS detector at the LHC resulted in no significant excess of events above SM background predictions. Upper limits at 95% CL are set on model-independent fiducial cross-sections and on the Higgs boson decay branching ratios to vector and pseudoscalar bosons in two benchmark models. Limits on the production cross-section times branching fraction as a function of the proper decay length of γ_d are reported.

References

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