

## Multi-photon decays of the Higgs boson at the LHC

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Many new physics scenarios predict multi-photon Higgs resonances. One such scenario is the dark axion portal model. The primary decay chain that we study is the Higgs to dark photon ( $\gamma_D$ ) pairs that subsequently decay into a photon ( $\gamma$ ) and an axion-like particle ( $a$ ). The axion-like particles then decay into photon pairs. Hence, the signal is a six-photon Higgs decay:  $h \rightarrow \gamma_D \gamma_D \rightarrow 2 \gamma 2 a \rightarrow 6 \gamma$ . However, depending on the relevant kinematics, the photons can become well-collimated and appear as photon-jets (multiple photons that appear as a single photon in the detector) or  $\xi$ -jets (non-isolated multi-photon signals that do not pass the isolation criterion). These effects cause the true six-photon resonance to appear as other multi-photon signals, such as two and four photons. We classify the mass regions where two, four, and six-photon resonances dominate. The four-photon signal is particularly interesting. These events mainly occur when the photons from the axion-like particles are collimated into photon-jets. The decay of the dark photon is then  $\gamma_D \rightarrow \gamma a \rightarrow \gamma + \gamma$ -jet, which is an apparent violation of the Landau-Yang theorem. We show that current measurements of  $h \rightarrow 2\gamma$  and searches for  $h \rightarrow 4\gamma$  at the Large Hadron Collider (LHC) can limit  $\text{BR}(h \rightarrow \gamma_D \gamma_D) < 10^{-3}$ . This model also motivates new searches for Higgs decays into six isolated photons or  $\xi$ -jets at the LHC. While there are currently no dedicated searches, we show that many of the Higgs to six isolated photons or  $\xi$ -jet events could pass two or three-photon triggers. That is, new physics could be found by reanalyzing existing data. These multi-photon signals provide excellent footing to explore new physics at the LHC and beyond.

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