IL NUOVO CIMENTO **45 C** (2022) 126
DOI 10.1393/ncc/i2022-22126-4

Communications: SIF Congress 2021

Dark sector searches with the mono-jet signature at the ATLAS detector at the LHC

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received 31 January 2022

Summary. — This work investigates the possibility that dark matter could be produced at collider facilities, under the assumption that is weakly coupled to the ordinary matter and that it constitutes a new sector of particles (the dark sector). Under the assumption of a long-lived mediator that escapes detection in the detector, the mono-jet signature, in which high missing transverse momentum recoils against a highly energetic jet, is exploited.

1. – Motivations and dark sector signal models

The work in ref. [1] investigates the possibility that dark matter could be produced at collider facilities with the Higgs boson acting as a portal to Beyond the Standard Model (BSM) physics and with the existence of Long-Lived Particles (LLPs) foreseen. Two processes are considered: one predicted by the FRVZ (Falkowski-Ruderman-Volansky-Zupan) model [2] (fig. 1(a)), with the Higgs boson decaying into a pair of dark fermions f_d, and one (fig. 1(b)) where the Higgs boson decays into a pair of dark scalars s.

The first process results into decays into HLSPs, undetected and producing $E_{\mathrm{T}}^{\mathrm{miss}}$, and dark photons, γ_d. The latter is massive and mixes with γ via an interaction governed by the kinetic mixing parameter ε. The smaller ε, the larger the mean proper lifetime of the γ_d. The off-shell γ produced decays into a pair of light SM fermions f. Under the different m_{γ_d} hypothesis considered ($m_{\gamma_d} \in [0.2, 2]\,\mathrm{GeV}$), the γ_d can decay into a pair of electrons, muons and light hadrons with different BRs. The second model has a similar signature, with the s scalar decaying with mean proper lifetime τ_s into pairs of light SM fermions f too. Thus, according to their mean proper lifetimes, s and γ_d can be LLPs. The Higgs production mechanism considered for both the models is the gluon-gluon fusion. In the FRVZ model the scenario where the decay chain is started by a heavier Higgs-like scalar H' ($m_{H'} = 800\,\mathrm{GeV}$) is studied too. These models have been probed by various ATLAS searches [3-7] optimized for different τ regimes, looking for prompt or displaced decays of the γ_d or of the s scalar. The scenario here considered

(a) (b)

Fig. 1. – (a) Higgs decay chain predicted by the FRVZ model. The blobs represent the mixing, governed by ε, between γ_d and γ, f_d the intermediate states coupled to the Higgs, HLSP the non-interacting Hidden Lightest Stable Particle and f the SM fermions produced in the off-shell γ decay; (b) Higgs decay into a pair of dark scalar particles s, where f are the SM fermions produced in the s scalar decay.

investigates the possibility that the system is boosted by an initial state radiation jet and the LLPs (the γ_d and the s scalar) are long-lived enough to decay outside ATLAS, yielding $E_{\mathrm{T}}^{\mathrm{miss}}$, leading to a mono-jet signature which is reconstructed when an energetic jet recoils against large missing transverse momentum $E_{\mathrm{T}}^{\mathrm{miss}}$ and no other particles are detected. This work, based on the data-set collected by ATLAS [8] during Run-2 at the LHC [9], investigates the possibility that an excess of mono-jet events with respect to the SM predictions could be interpreted in terms of these dark sector models.

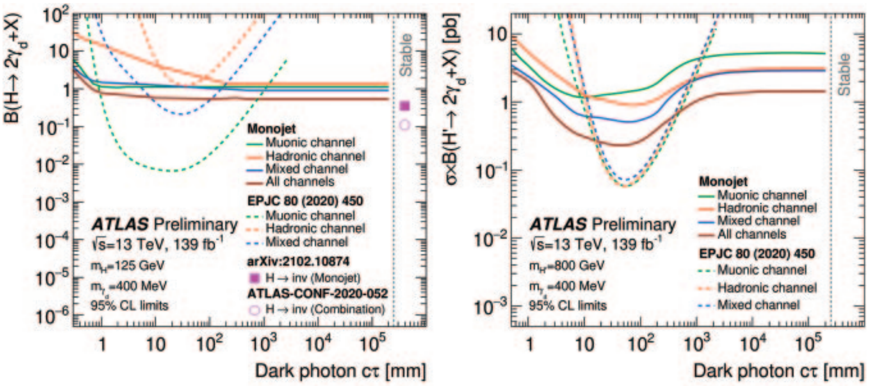
2. – The mono-jet search

The mono-jet Signal Region (SR), described more in detail in ref. [10], is defined requiring $E_{\mathrm{T}}^{\mathrm{miss}} > 200\,\mathrm{GeV}$ and the most energetic jet to have $p_{\mathrm{T}} > 150\,\mathrm{GeV}$ and $|\eta| < 2.4$. As no other particles should be detected, a lepton and γ veto is present too. Thus the dominant backgrounds are multi-jet events with badly reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$, the NCB (Non-Collisional Backgrounds) such as cosmic rays and beam induced backgrounds, and the V+Jets background. The first background is suppressed requiring at most four jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 2.8$ and $\Delta_{\phi}^{\mathrm{min}} > 0.4(0.6)$ between the direction of $E_{\mathrm{T}}^{\mathrm{miss}}$ and the closest jet for $E_{\mathrm{T}}^{\mathrm{miss}} > (\leq)250\,\mathrm{GeV}$. Residual contributions of multi-jet events and NCB are data-driven estimated. A shape fit exploiting the distribution of the total transverse momentum recoiling against hadronic activity in the events ($p_{\mathrm{T}}^{\mathrm{recoil}}$) is performed on Control Regions (CR) only to constrain the normalization of the other SM backgrounds in the SR. The fit is then performed simultaneously on CRs and SR in the background-only hypothesis, finding no excess of data over SM predictions in SR. Finally, the fit is performed under different BSM hypothesis, setting limits on the signal strengths of the models considered, providing new excluded regions in the parameters space of these models.

3. – Interpretation in terms of dark sector

Upper limits at 95% of CL on $\mathcal{B}(H \to 2\gamma_d + X)$ and on $\mathcal{B}(H' \to 2\gamma_d + X)$ for a γ_d with $m_{\gamma_d} = 400\,\mathrm{MeV}$ are reported in fig. 2(a) and fig. 2(b), respectively, as a function of τ_{γ_d} for both ref. [1] and the LLP dark-photon ATLAS dedicated search [4].

Since at small τ_{γ_d} the analysis efficiency varies for the different γ_d decay modes as the γ_d decay products have to satisfy different criteria to be reconstructed, the upper limits on $\mathcal{B}(H \to 2\gamma_d + X)$ and on $\mathcal{B}(H' \to 2\gamma_d + X)$ are reported in fig. 2(a) and fig. 2(b)

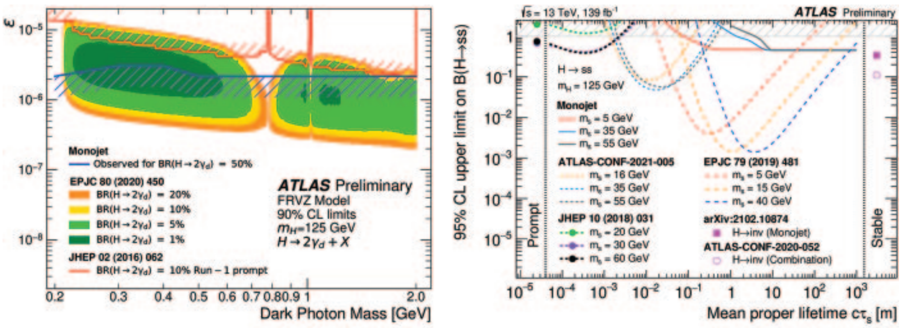


(a) (b)

Fig. 2. – Upper limits on $\mathcal{B}(H \to 2\gamma_d + X)$ ($\mathcal{B}(H' \to 2\gamma_d + X)$) in fig. (a) (fig. (b)) for a γ_d with $m_{\gamma_d} = 400\,\text{MeV}$ in the muonic (green), hadronic (orange) and mixed (blue) channels. The red line is the limit obtained in ref. [1] combining the three channels. The results of this work (solid lines) are compared to the displaced ATLAS search (dashed lines) [4] one. The mono-jet [10] search limit on $\mathcal{B}(H \to \text{inv})$ and ATLAS Run-1 and Run-2 combination results [11] are shown too.

in three separate channels: muonic, where both γ_d decay into muons; mixed, where one γ_d decays into muons and the other into quarks or electrons; hadronic, where both γ_d decay into quarks or electrons. At large τ_{γ_d} the sensitivity of this work is similar in all these channels and is complementary to the ones of ATLAS prompt [3] and displaced [4] searches. The limit on the combination of the aforementioned three channels tends to the $\mathcal{B}(H \to \text{inv})$ limit obtained in ref. [10], as expected. The results of this search are shown in fig. 3(a) at 90% of CL in the $(\varepsilon, m_{\gamma_d})$ plane with $m_{\gamma_d} \in [0.2, 2]$ GeV for a fixed $\mathcal{B}(H \to 2\gamma_d + X) = 50\%$, and are compared with the results of the prompt and displaced ATLAS analyses.

Upper limits at 95% of CL on $\mathcal{B}(H \to ss)$ are reported in fig. 3(b) as a function of τ_s



(a) (b)

Fig. 3. – (a) 90% CL exclusion contours in the $(\varepsilon, m_{\gamma_d})$ plane obtained in ref. [1] are compared to the prompt [3] and displaced [4] ATLAS searches ones; (b) 95% CL exclusion contours on $\mathcal{B}(H \to ss)$ obtained in ref. [1] shown as a function of τ_s are compared to other ATLAS searches [5-7] ones. The mono-jet [10] search limit on $\mathcal{B}(H \to \text{inv})$ and ATLAS Run-1 and Run-2 combination results [11] are also shown.

for this work and other ATLAS searches [5-7]. The sensitivities of the various searches are complementary among the several analyses for all m_s, for which different τ_s are probed by different detection techniques. This study is able to extend the current upper limits to larger τ_s assuming a $\mathcal{B}(H \to ss) \approx 50\%$.

4. – Conclusion

A reinterpretation of the ATLAS full Run-2 mono-jet search in terms of dark sector models with the Higgs boson (or a heavier mediator) acting as a portal and the existence of LLPs is given. This search probed the area of the investigated models' free parameters space with large LLPs τ that had not been probed yet. Nonetheless, for large enough τ upper limits on $\mathcal{B}(H \to ss)$ and $\mathcal{B}(H \to 2\gamma_d + X)$ are less stringent than the upper limit $\mathcal{B}(H \to \text{inv})$ obtained in ref. [10] (as can be seen in fig. 2(a) and fig. 3(b)) as in this work only $gg \to H$ is considered as Higgs production mechanism, while in [10] all Higgs production mechanisms are taken into account.

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