Search for Dark Matter in association with an energetic photon in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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According to several astrophysical and cosmological evidences, Dark Matter (DM) accounts for about 27% of the Universe mass-energy, but its nature and properties are still largely unknown. Production at colliders is one of the possible strategies for DM detection, and it is being explored in a comprehensive effort within the ATLAS Collaboration at CERN. In this context, the Mono-$\gamma$ analysis searches for an excess of events in final states with one energetic photon and missing transverse momentum in proton-proton collisions at the Large Hadron Collider (LHC). The full Run2 data collected in 2015-2018 by the ATLAS detector, at a centre-of-mass energy of 13 TeV and corresponding to a total integrated luminosity of 139 fb$^{-1}$ is used, and the results are interpreted in terms of production of Weakly-Interacting Massive Particles (WIMPs) or Axion-Like Particles (ALPs).

Motivation

- DM production in proton-proton collisions at LHC is possible, if DM interacts with Standard Model (SM) particles.
- The production of DM particles, invisible to the detector, in association with a SM particle X (photon, $W$, $Z$, Higgs or jet) leads to a Mono-$\gamma$ signature: the visible particle recoils against undetected DM, thus producing an unbalance in the total transverse energy of the final state known as the missing transverse momentum ($E_t^\text{miss}$).
- An excess of events with high $E_t^\text{miss}$ with respect to SM expectations can be interpreted in terms of DM production.

Signal models

Two models of DM production have been considered:

- **WIMPs production**
  - Simplified DM model of DM production in an s-channel with vector or axial-vector mediator.
  - Free parameters: Mediator mass, DM mass, Mediator couplings to SM and DM sectors, Decay width, fixed to minimal value.

- **ALPs production**
  - Effective Field Theory with scale $f_a$.
  - SM Lagrangian extended with a single scalar (ALP)
  - The assumption of null coupling to photons (motivated by experimental constraints), reduces the free parameters to: Theory scale, $f_a$.
  - Coupling $c_a$ to W boson.

Analysis strategy and results

Real photon backgrounds: MC expectations are normalized to data through a background-only likelihood fit performed simultaneously in dedicated Control Regions (CRs), each enriched with a specific background.

Fake Photons backgrounds: due to jets or electrons misidentified as photons, mainly in $W/Z + jets$

Agreement between data and SM expectations, after background-only multi-bin fit (in SRE1, SRE2, SRE3, SRE4). Experimental and theoretical systematic uncertainties included as nuisance parameters of the likelihood function.

Interpretation of results

A simultaneous likelihood fit, including a signal component, is performed separately in each SR (single-bin fit) or in all SRS (multi-bin fit) and associated CRs.

**Model independent limits on the visible cross-section of new physics (single-bin fit)**

<table>
<thead>
<tr>
<th>Signal region $\sigma (\alpha \times A x s)^{\text{eff}}/[\text{fb}]$</th>
<th>$\sigma (\alpha \times A x s)^{\text{eff}}/[\text{fb}]$</th>
<th>$H_{\text{exp}}$ [fb]</th>
<th>$\sigma (\alpha \times A x s)^{\text{eff}}/[\text{fb}]$</th>
<th>$H_{\text{exp}}$ [fb]</th>
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</tr>
</tbody>
</table>

**Model dependent limits on ALP production (multi-bin fit)**

Model dependent limits on WIMP production (multi-bin fit)

Free couplings: $g_1=0.25$, $g_0=0$ (for Axial-Vector and Vector mediators or $g_1=g_0=0.1$ (0.01) for Axial-Vector (Vector) mediator.

No excess observed within uncertainties => set 95% CL limits.