1. MOTIVATIONS

A wide range of Beyond the Standard Model (BSM) theories predict a hidden sector, weakly coupled to the visible sector.

Discovery processes with peculiar signatures:
- Lightest unstable hidden states in MeV to GeV range typically produced with large boost → highly-collimated decay products
- Decay back to SM with high branching fraction → e\(^{-}\), \(\mu^{+}\), or light hadrons in final state
- Non-negligible lifetime → displaced decay vertex with respect to primary vertex of event

2. DISPLACED LEPTON-JETS (dLJs)

Collimated jet-like structures, produced far from the primary vertex, containing pair(s) of muons, electrons, and/or light hadrons.

dLJs IN DARK PHOTON MODELS

dLJs are signatures of dark photon (\(\gamma_{d}\)) decay, the heavy gauge boson of an additional U(1). In “vector portal” models, the \(\gamma_{d}\) kinetically mix with the SM photon:

\[ \gamma_{d} \rightarrow e^{+}e^{-} + \pi^{0} \]

Smaller \(e\gamma\) yields longer \(\gamma_{d}\) lifetime. Branching ratios of the \(\gamma_{d}\) depend on its mass.

3. Categorisation of LJs into 3 types for ease of search & reconstruction:

- TYPE0: ≥2 MS tracks, no jets
- TYPE1: ≥2 MS tracks, ≥1 jet
- TYPE2: 1 jet with low EM fraction, no muons

4. dLJ RECONSTRUCTION

and dedicated TRIGGERS

Target:
- \(\gamma_{d}\) decays beyond the Inner Detector (ID) up to the Muon Spectrometer (MS)
- Muon pairs appear in spectrometer as “MShiny” tracks (no associated ID tracks)
- Tri-muon trigger: 3 MSOnly tracks, \(p_{T} > 6\) GeV (for pair of TYPE0 dLJs)
- Narrow-scan trigger: 2 MSOnly tracks in \(\Delta R > 0.5\) cone, leading \(p_{T} > 20\) GeV, sub-leading > 6 GeV (for TYPE0 and TYPE1 dLJs)

Electron/\(\gamma\) pairs appear in calorimeters as narrow isolated jets, with much less energy deposition in EM calorimeter (EMCAL) than in Hadronic Calorimeter (HCAL)

- CaloRatio trigger: jet \(p_{T} > 30\) GeV with low EM fraction of the energy (for TYPE 2 dLJs)

A LJ-finding clustering algorithm is used with \(\Delta R = 0.5\) cone (fully contains decay products).

Efficiency dependent on muons separation due to the magnetic field.

5. BENCHMARK MODELS

Falkowski-Ruderman-Volansky-Zupan (FRVZ) models:

- SM Higgs or BSM additional heavy Higgs decays to hidden sector fermions \(f_{\nu}\)
- Hidden shower ends with \(\gamma_{d}\) and Hidden Lightest Stable Particles
- \(\gamma_{d}\) produces LJs, which usually come off back-to-back

6. SEARCH STRATEGY

Two LJs are expected to be produced back-to-back in the azimuthal plane.

- All the possible combinations of pairs of LJ types are taken into account.
- If \(\geq 2\) LJs are reconstructed, the leading LJ and the farthest LJ in \(\phi\) are chosen.

7. BACKGROUND ESTIMATION

- Cosmic-ray muon energy deposits in calorimeters (for TYPE1 and TYPE2 dLJs): mis-reconstructed as jets
- QCD multi-jet production (for TYPE 2): evaluated with the ABCD method
- Beam-induced background (BIB) (for TYPE2): high-energy muon longitudinally crossing detector, with bremsstrahlung in HCAL barrel
- Cosmic muon bundles (for TYPE 0, TYPE1): mainly concentrated in barrel
- SM processes which lead to real prompt muons and muons plus jets in the final state such as W+jets, Z+jets, tt, single-top, Drell-Yan \(e^{+}e^{-}\) / \(\mu^{+}\mu^{-}\), WW, WZ, and ZZ: estimated in MC and removed by requiring muons to be non-Combined.

8. SYSTEMATIC UNCERTAINTIES

- Overall normalization of integrated luminosity
- Muon trigger efficiency using a tag and probe method with \(J_{\mu}\) from data and Monte Carlo
- CaloRatio trigger
- Close-by muon track reconstruction efficiency using a tag and probe method with \(J_{\mu}\) from data and Monte Carlo
- Effect of pile-up on \(\mathcal{F}\)
- ABCD background estimation

9. RESULTS

- Search for dLJ pairs performed using 3.57 fb\(^{-1}\) of 2015 pp data collected by ATLAS at \(\sqrt{s} = 13\) TeV.
- Starting from a general definition of dLJs, a set of selection criteria able to isolate their signature from the SM, BIB and cosmic-rays backgrounds were defined.
- Observed data consistent with the experimental background expectations.
- Results of the search used to set upper limits on non-SM Higgs boson decays to LJs according to the FRVZ2 models with a \(\gamma_{d}\) mass of 0.4 GeV.
- Limits set on the \(\alpha BR\) for Higgs → 2(3)\(\gamma\) + X as a function of the long-lived particle mean lifetime.
- SM gluon fusion production cross section is assumed for the 125 GeV Higgs boson.
- Conventional production cross section of 1.0 pb is assumed for the 800 GeV Higgs-like heavy scalar.

10. WHAT’S NEXT?

- Analysis of full 2015 + 2016 dataset (36 fb\(^{-1}\)) already ongoing, then will be extended with 2017 sample too.
- New strategies based on BDT selection have been optimised.
- Other production mechanisms of the Higgs boson will be explored, i.e. W/Z associated production.
- Better trigger performance is expected.