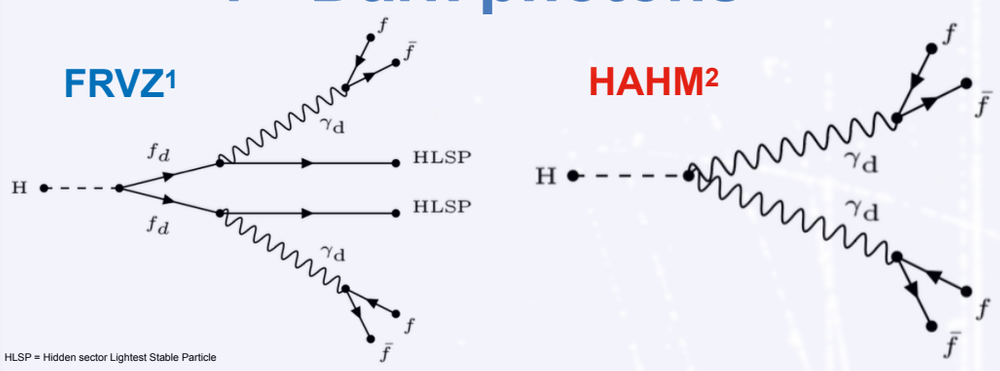
Search for long-lived dark photons in Higgs decays with the ATLAS detector and the full Run-II Data at LHC

Student: Alessandro Biondini
Supervised by: Monica D'Onofrio, Cristiano Sebastiani, Federico Meloni (DESY)

1 - Dark photons

FRVZ[1] HAHM[2]



HLSP = Hidden sector Lightest Stable Particle

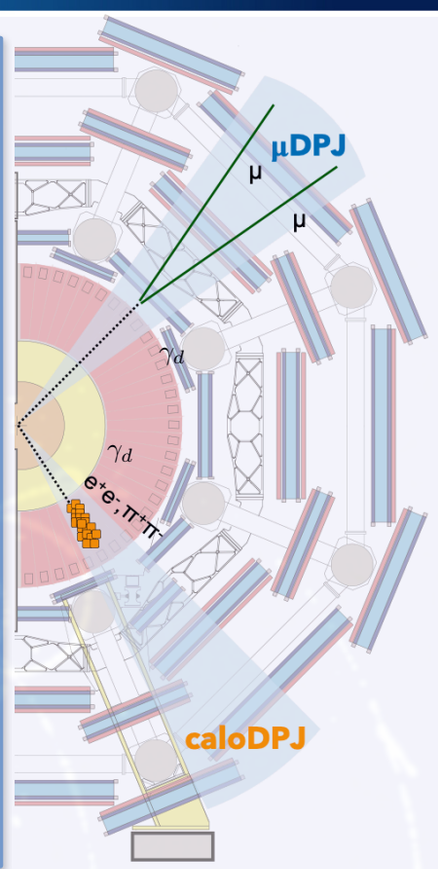
- Dark sector weakly coupled to the Standard Model (SM)
- Dark Photon (γ_D) from Higgs portal, decaying through vector portal to leptons or light hadrons
- Investigate gluon-gluon Fusion (ggF) and Higgs associated production with a W boson (WH)

$$Dark - QED\ U(1) \qquad \mathcal{L} \propto \epsilon e \gamma_d^{\mu} J_{\mu}^{em} \qquad c\tau = \frac{1}{\Gamma_{\gamma_d}^{tot}} \propto \frac{1}{\epsilon^2 m_{\gamma_d}}$$

- ε = coupling parameter between SM and Hidden Sector
- **Small $\varepsilon \rightarrow$ long lived γ_d**
- **Light and boosted LLP → Collimated pair of leptons/hadrons: "Dark Photon Jets" (DPJ)**

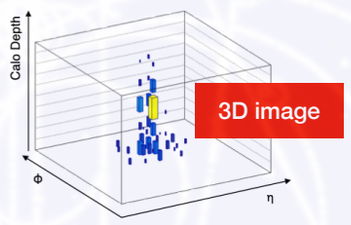
2 - DPJ Reconstruction

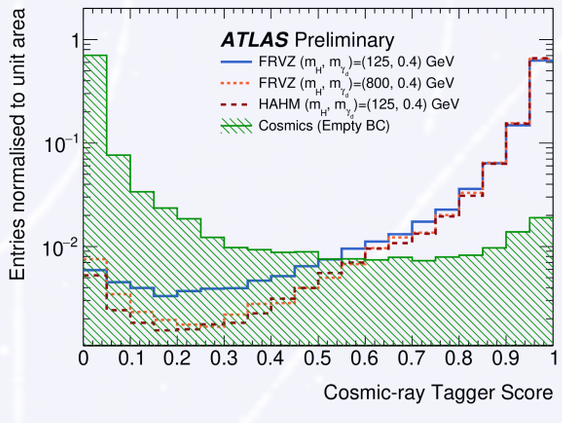
- **μDPJ**:
  - Close-by muons in the Muon Spectrometer (MS), no jets or tracks in the Inner Detector (ID)
  - Main background: cosmic-ray muons
- **caloDPJ**:
  - a.k.a cDPJ, resulting from γ_d decaying to electrons or light hadrons
  - Displaced and narrow jets with most of the energy released in the Hadronic Calorimeter (HCAL)
  - Main background: rare multijet events

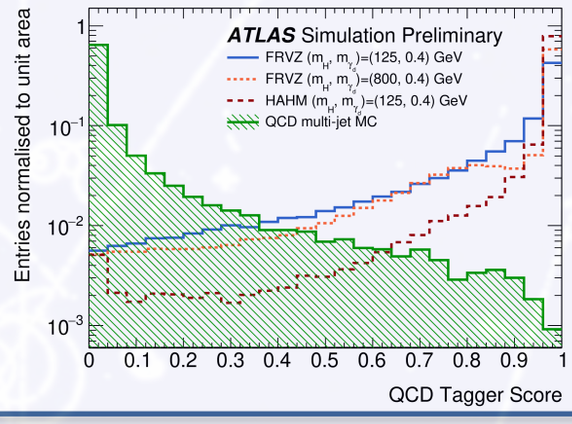


3 - Neural Network (NN) taggers for background rejection

- Cosmic-ray background: **per-muon Deep NN** (DNN) tagger exploiting timing, angular direction and impact parameter info
- Multijet background: **per-jet Convolutional NN tagger exploiting 3D images** produced using angular direction and calorimeter cluster informations
- One of the first use in ATLAS searches of a CNN based tagger trained on low-level inputs







4 - Event selection

ggF:

- Dedicated LLP triggers
- Prompt lepton veto

WH:

- Triggering on prompt lepton from *W* decay
- Missing transverse energy (E_T^{miss}) cut
- Transverse mass (m_T) cuts
- b-jet veto

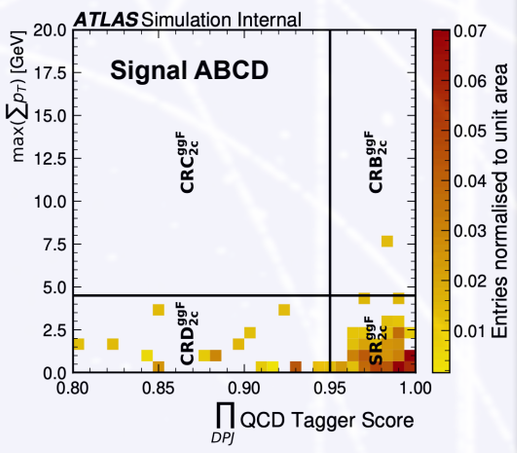
- **Per-DPJ type & number selection:**
- Specific cuts on DPJ constituents (**μ** / jets)
- Main discriminant variables: tagger score, angular distance between DPJs, isolation in the ID
- **Six orthogonal channels & signal regions:**

$SR_{2\mu}^{ggF}, SR_{2c}^{ggF}, SR_{c+\mu}^{ggF}$ $SR_{1c}^{WH}, SR_{2c}^{WH}, SR_{c+\mu}^{WH}$

5 - Background estimate

- **Multijet**: data-driven ABCD method
- **Cosmic-ray muons**: estimated in empty bunch-crossings (DNN + residuals subtracted)
- **Beam Induced Background**: reduced to negligible level

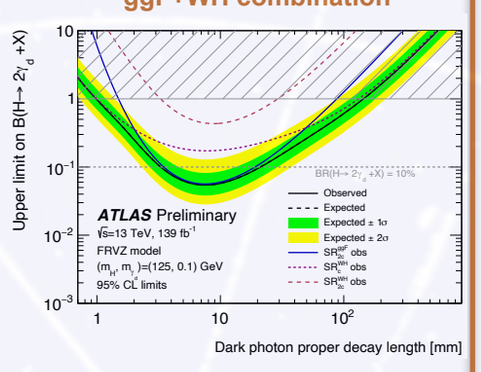
- The number of events in the signal region are estimated as:
  $N_A = N_B \times N_D / N_C$
- Background event distribution can be factorized in a plane of two uncorrelated variables

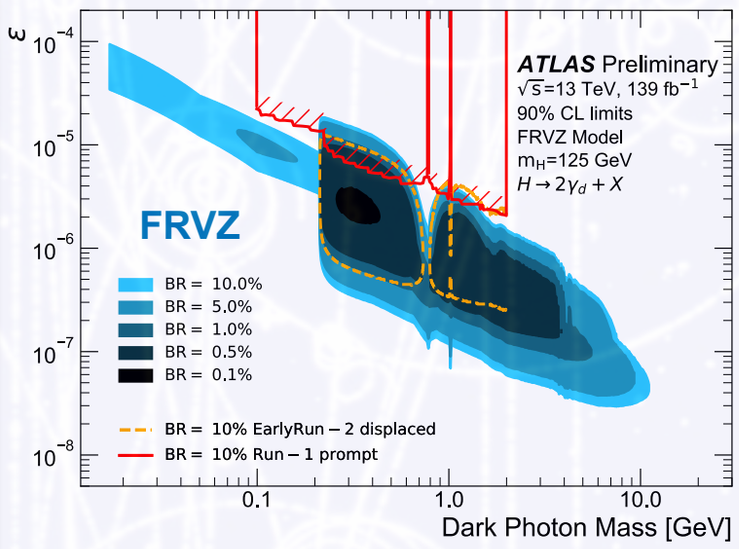


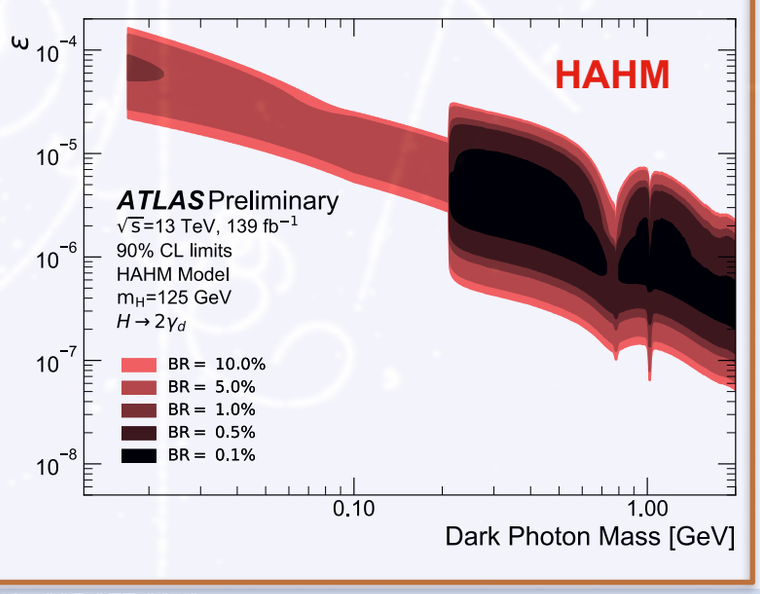
6 - Results

- **First exclusion of fully electronic decays of the γ_d** allowing to probe previously uncovered regions of the phase space: $m_{\gamma d} < 2m_{\mu}$
- **WH+ggF combination:** first search for light long-lived neutral particles deacying to collimated pairs of fermions at ATLAS exploiting the associated production mode
- **First interpretation into HAHM models**

ggF+WH combination







[1] 'Falkowski-Ruderman-Volanski-Zupan Model (FRVZ) ' - A. Falkowski, J. T. Ruderman, T. Volansky, J.Zupan - 'Hidden Higgs Decaying to Lepton Jets' - JHEP 1005:077,2010
[2] 'Hidden Abelian Higgs Model (HAHM)' - D. Curtin, R. Essig, S. Gori and J. Shelton - 'Illuminating dark photons with high-energy colliders' - JHEP 10.1007, 2015
[3] ATLAS collaboration - 'Search for light long-lived neutral particles that decay to collimated pairs of leptons or light hadrons in pp collisions at $\sqrt{s}$= 13 TeV with the ATLAS detector' - ATLAS-CONF-2022-001