# SEARCH FOR DARK PHOTONS IN HIGGS DECAYS AT THE ATLAS EXPERIMENT

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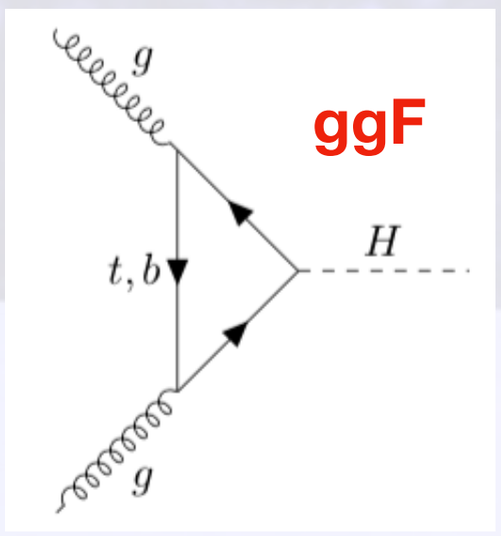
# Dark photons in Higgs decays

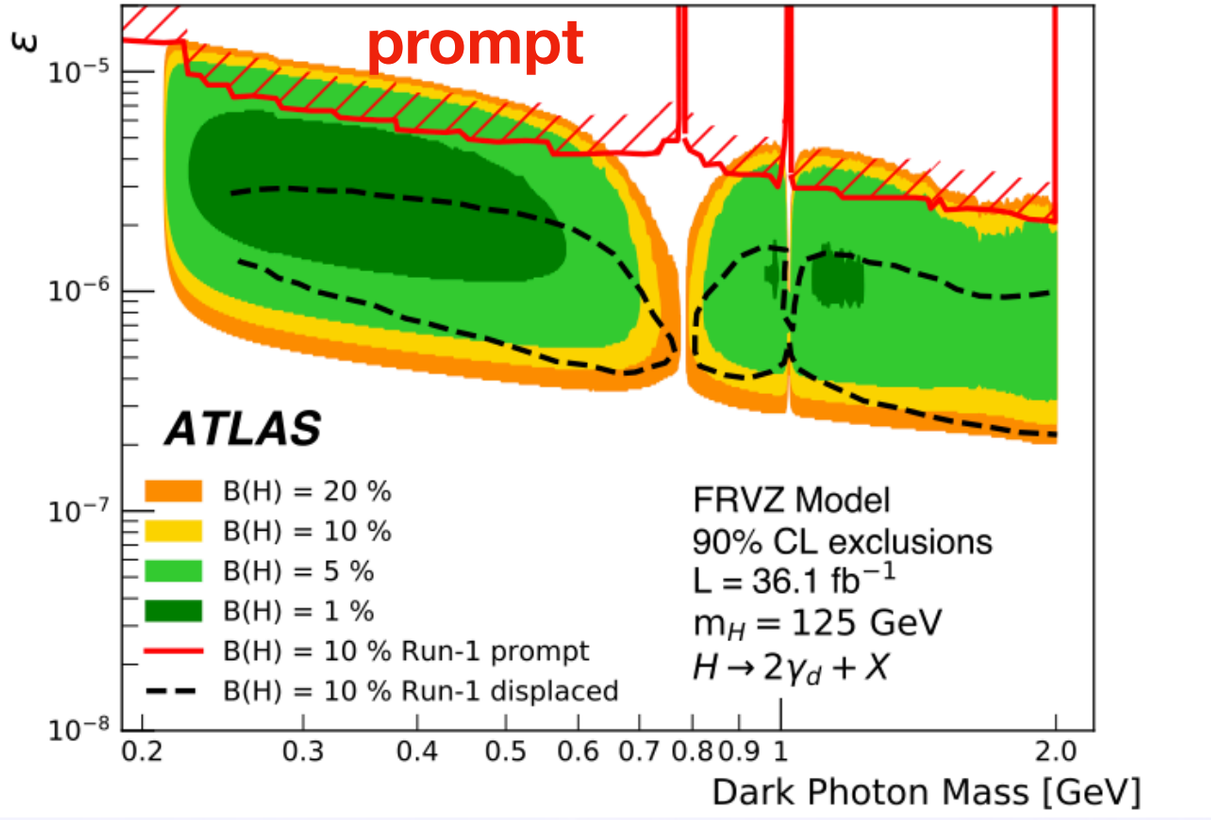
- Dark sector weakly coupled to the SM might exists and manifest through new particles as "dark photons" ($\gamma_D$);
- $\gamma_D$ mixes kinetically to SM particles with one parameter $\varepsilon$;
- $\gamma_D$ might have masses MeV-GeV range and mix kinetically to SM particles through the $\varepsilon$ parameter (coupling):
  - **small $\varepsilon$ → Long Lived $\gamma_D$.**
- Production: directly from Drell-Yan (e.g. @ LHCb) or from Higgs decays (@ATLAS and CMS):
  - **signature: highly collimated decay products (Lepton-Jets) from Higgs;**
  - rate depends on the BR ($H \to \gamma_D \gamma_D$), could be up to 25% (current BR of Higgs invisible decay).

$$c\tau = \frac{1}{\Gamma^{\text{tot}}_{\gamma_d}} \propto \frac{1}{\epsilon^2 m_{\gamma_d}}$$



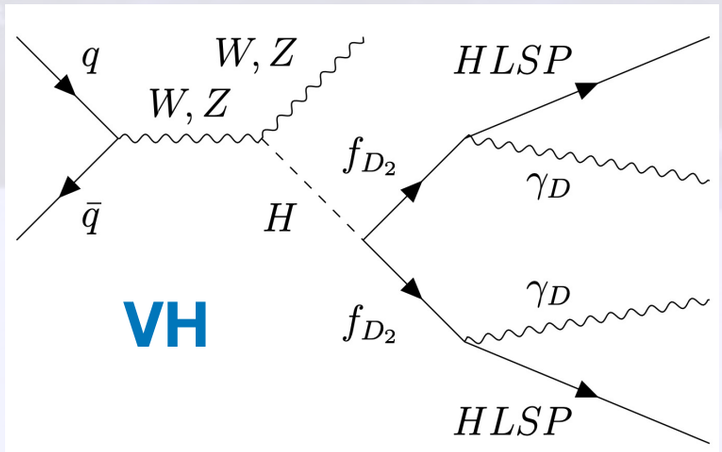

**$H \to \gamma_D \gamma_D + X$**

https://arxiv.org/abs/1909.01246



# Displaced lepton jets analysis: WH channel

- My work: **extend the coverage using associate production V(=W,Z) + Higgs;**
- WH is 2.5% of Higgs production:
  - also requiring W →$l\upsilon$ (Branching Fraction ~10% for each flavour);
  - **single lepton triggers (μ/$e$) high efficiency;**
- Past months activities:
  - major work on the reconstruction software to optimise it for the signature of interest;
  - studies on the WH event selection and optimisation (in progress);
  - studies of major background using MC simulation:
    - top-pair production and W+jets.

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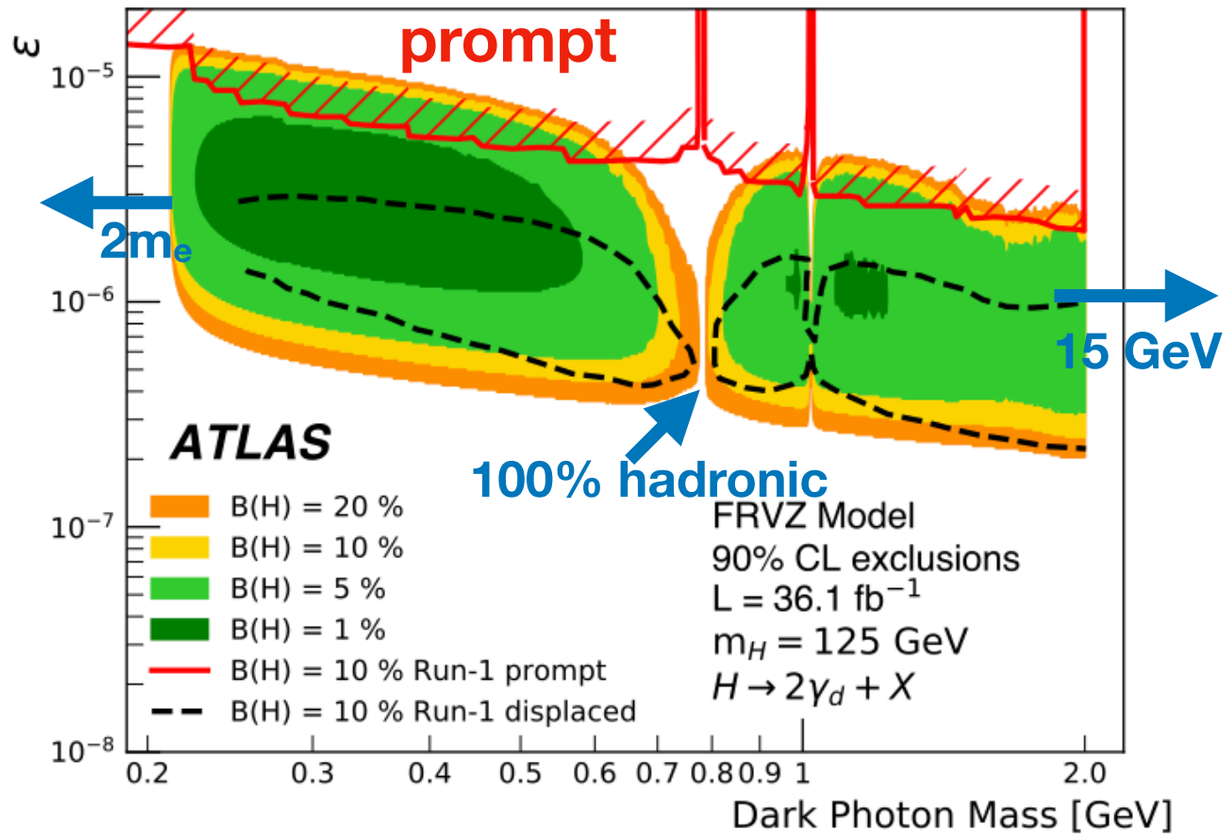
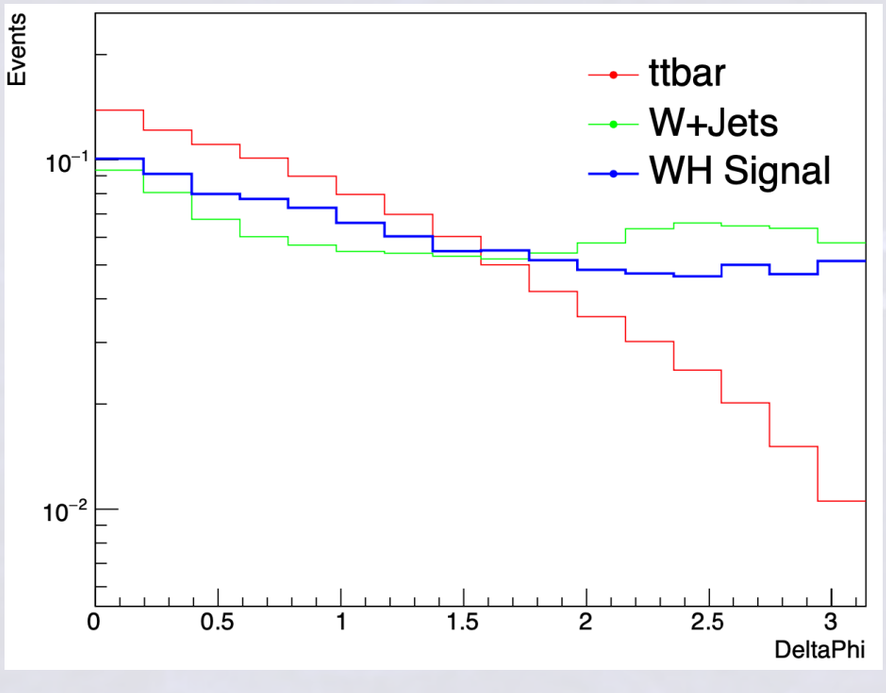
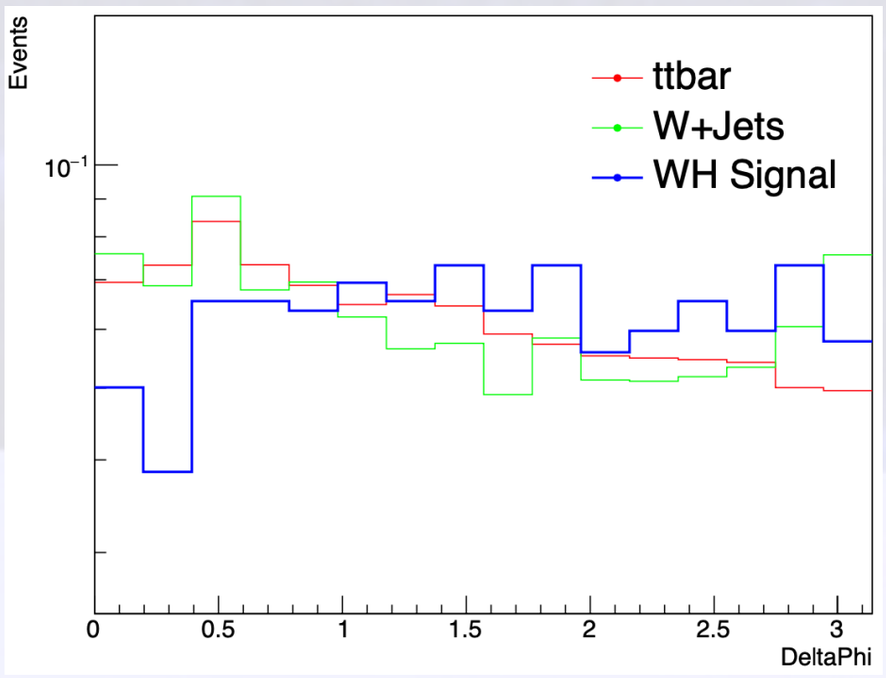


# Displaced lepton jets analysis: WH channel

- MIN [$\Delta\phi$ (MET-Jet)]




- $\Delta\phi$ (LJ-LJ)




- Basic selections applied:
  - Leading lepton ($e$ or $\mu$) pT > 27 GeV;
  - Missing $E_T$ > 50 GeV;
  - Transverse mass (mT) > 30 GeV;
  - Number of jets (with Pt over 30 GeV) < 3;
  - two or more Lepton-Jets.
- Top-pair and W+jets events reduced but still dominant over signal;
- Several kinematic variables being considered for further optimisation.
- MIN [$\Delta\phi$ (MET-Jet)]: minimum of the angular distances between the Missing $E_T$ and a Jet in the event;
- $\Delta\phi$ (LJ-LJ): angular distance between two LJ.

| WH, H → $\gamma_D$ $\gamma_D$ + X | N events in 139 fb-1 |
|---|---|
| ttbar | 14862 |
| W+jets | 5078 |
| WH signal | 174 |

# Conclusions and next steps

This Year (not only working on the analysis):

- moved to DESY in September for the next 2 years;
- outreach activities for high school students;
- started my qualification task to became an ATLAS author:
  - ITk strip detector for HL-LHC ATLAS upgrade;
  - reconstruction and analysis of test-beam data from ITk barrel and endcap modules;
- attended important international conferences:
  - ATLAS EXOTICS Workshop;
  - LHC Long Lived Particle Community Workshop.

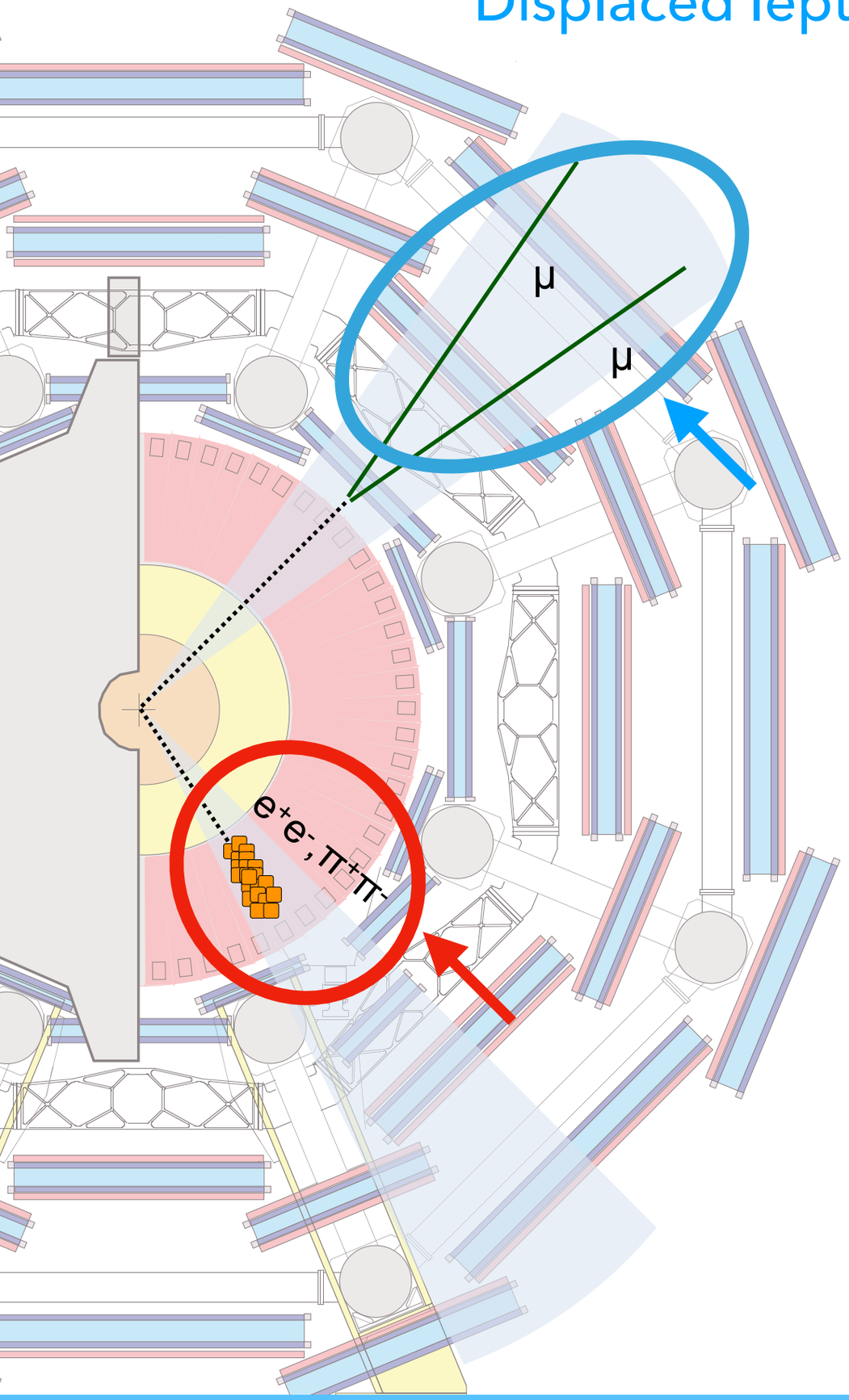
Plans:

- aim to have first results at the end of 2020;
- full publication by the end of 2021.

# THANK YOU FOR YOUR ATTENTION

# BACKUP

# Displaced lepton jets in the ATLAS detector

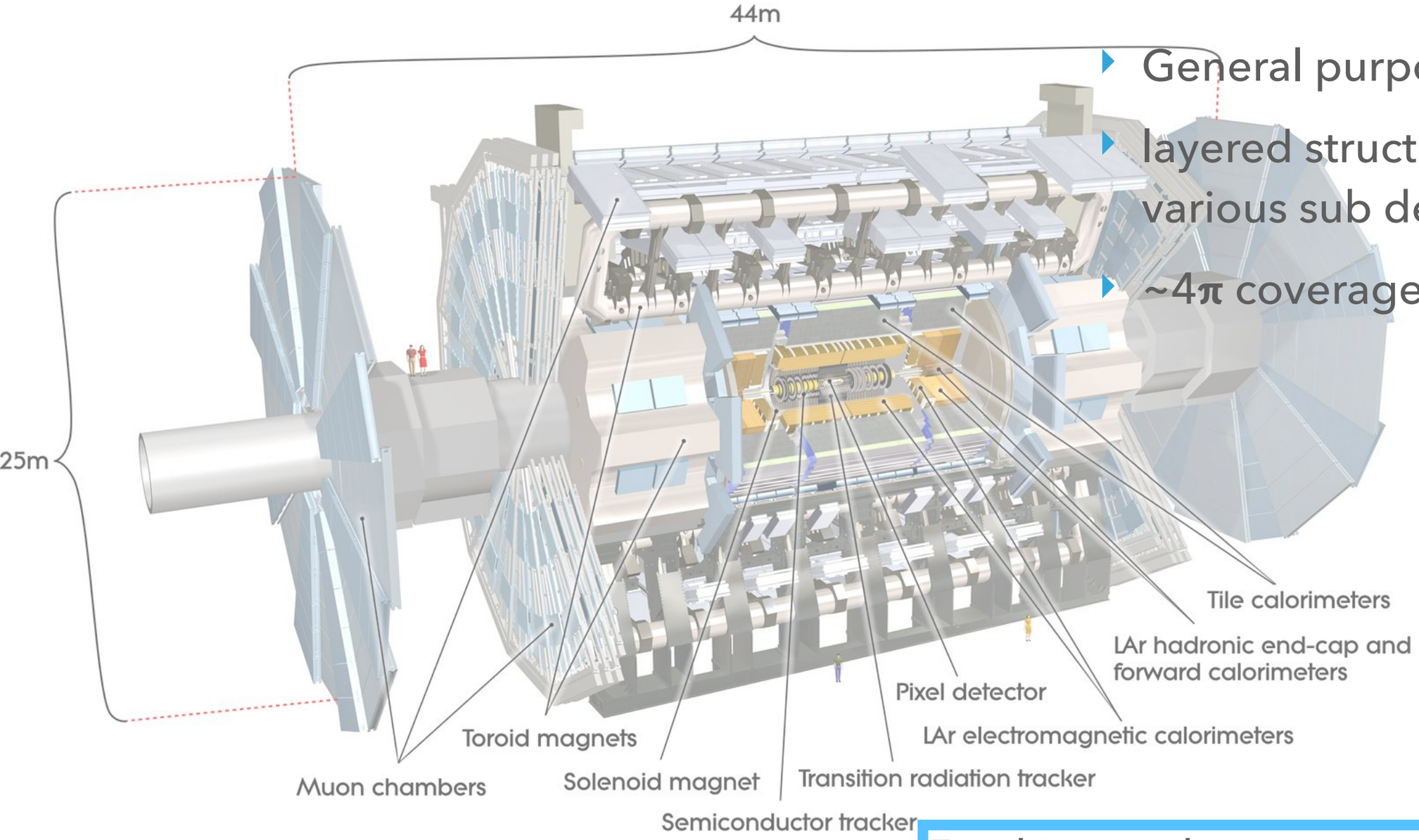



- Muonic Lepton Jets: collimated muon bundle in the MS with no tracks in the ID.
- Hadronic Lepton Jets: Low $E_{ECAL}/E_{HCAL}$ jets with no tracks in the ID.

**Three possible combinations (for $H \rightarrow 2\gamma_D$):**

- **μLJ-μLJ;**
- **μLJ-hLJ;**
- **hLJ-hLJ**

# The ATLAS detector




- General purpose detector;
- layered structure with various sub detectors;
- ~4π coverage.

For this search:

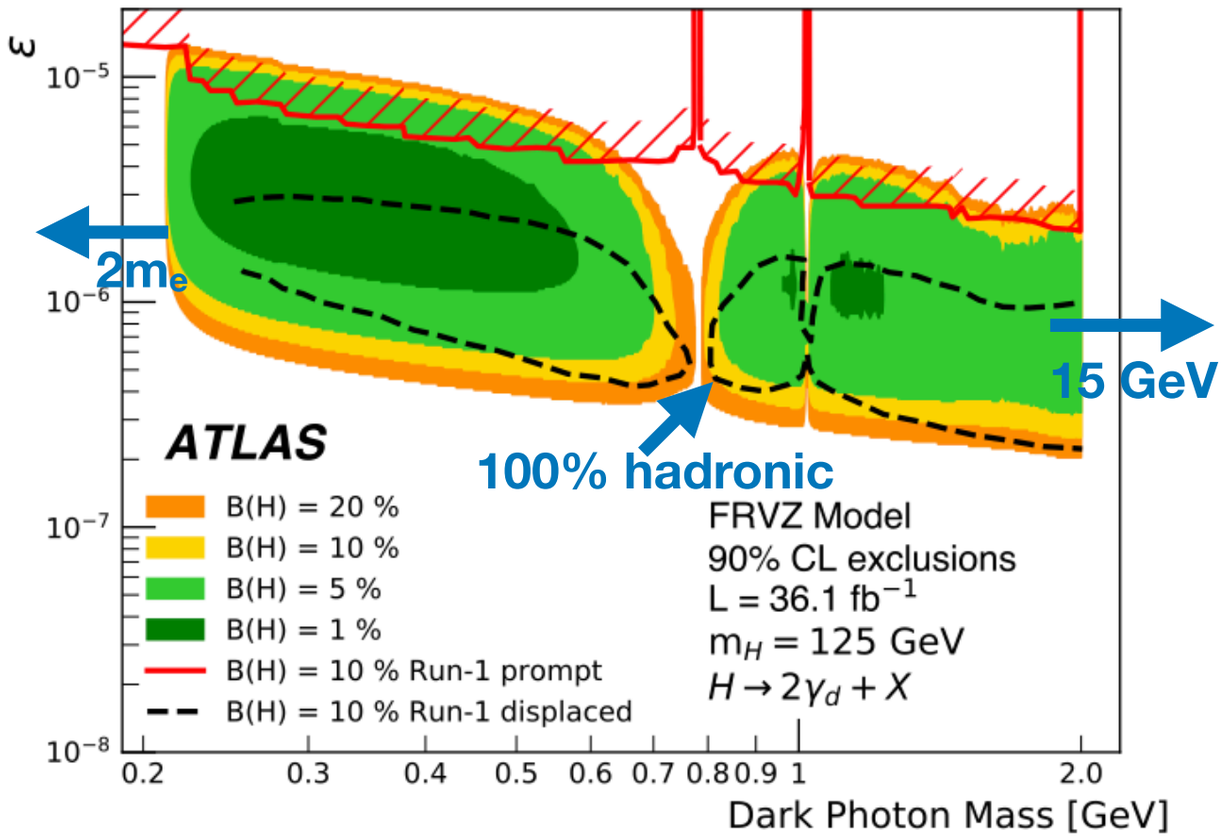
- Interested in displaced objects;
- informations from Electromagnetic (ECAL) and Hadronic calorimeter (HCAL);
- informations from muon system.

# Displaced Lepton-Jets analysis: status and plans for full Run-II analysis

Results for 2015-2016 dataset (36 $fb^{-1}$) provide exclusion only for ggF Higgs production and muonic LJs.

Overcome early Run-II limitations: ggF (used for early Run-II results) accounts for 88% of Higgs production, but dedicated triggers (low efficiency) → WH is 2.5% of Higgs production, **but single lepton triggers (high efficiency)**;

https://arxiv.org/abs/1909.01246




**Full Run-II**:

- **2015-2018 dataset: $\mathscr{L}$ = 139 $fb^{-1}$;**
- **extend search down to $2m_e$ and up to 15 GeV;**
- **ggF+VH (+VBF later) channels combination;**
- **set limit also for the hadronic channel;**
- **CNN (trained using 3D jet-images) for LJ clustering.**

# Signal and background studies: samples used

**WH signal:**

- DSID: 312539, mH=125 GeV, $m_{\gamma D}$ = 400 MeV, $c\tau$ = 50 mm, mfd2= 5 GeV, mHLSP = 2 GeV;

**W+Jets BKG (W→$\mu\upsilon$):**

- DSID:3641[56-69]; Sherpa_221_NNPDF30NNLO_Wmunu; MAXHTPTV500-1000;

**ttbar samples:**

- DSID:410472, ttbar_dilep;

**Data18 samples:**

- ~ 1.8 M events;

# WH selection: WIP

- Primary vertex in the event (hasPV == 1);
- Single lepton trigger (as of now: OR between):
  -HLT_e24_lhmedium_L1EM20VH
  -HLT_mu20_iloose_L1MU15,
  -HLT_e26_lhtight_nod0_ivarloose,
  -HLT_mu26_ivarmedium;
- Number of SignalLeptons == 1;
- Number of Jets (with Pt >= 30GeV) <= 3;
- W transverse mass mT > 30 GeV;
- MET > 50 GeV.

**BR(H→2$\gamma_D$) = 100%**

**20% signal efficiency!**

## WH signal sample

| Events after each cut: WH signal | Raw Events | Efficiency (RAW events) | Events (139 fb$^{-1}$) | Efficiency (weighted events) |
|---|---|---|---|---|
| Events | 89998 | - | 22488 | - |
| Primary Vertex | 89998 | 100% | 22488 | 100% |
| Trigger | 34001 | 37.8% | 8450 | 37.6% |
| NJets (Pt>30GeV) <= 3 | 32018 | 35.6% | 7946 | 35.3% |
| N_SignLept==1 | 27083 | 30.0% | 6731 | 29.9% |
| Mt CUT | 25039 | 27.8% | 6224 | 27.7% |
| MET CUT | 17161 | 19.1% | 4276 | 19.0% |

# Dark photons in Higgs decays

- Hidden sector weakly coupled with SM;
- no direct coupling to SM - new U(1) gauge invariance;
- $\gamma_D$ mixes kinetically to SM particles with one parameter $\varepsilon$;
- $m_{\gamma D}$ ranges from MeV to GeV scale;
- **small $\varepsilon$ → Long Lived $\gamma_D$ ;**
- **highly collimated decay products ($m_{\gamma D}$ << mH) → Lepton-Jets.**

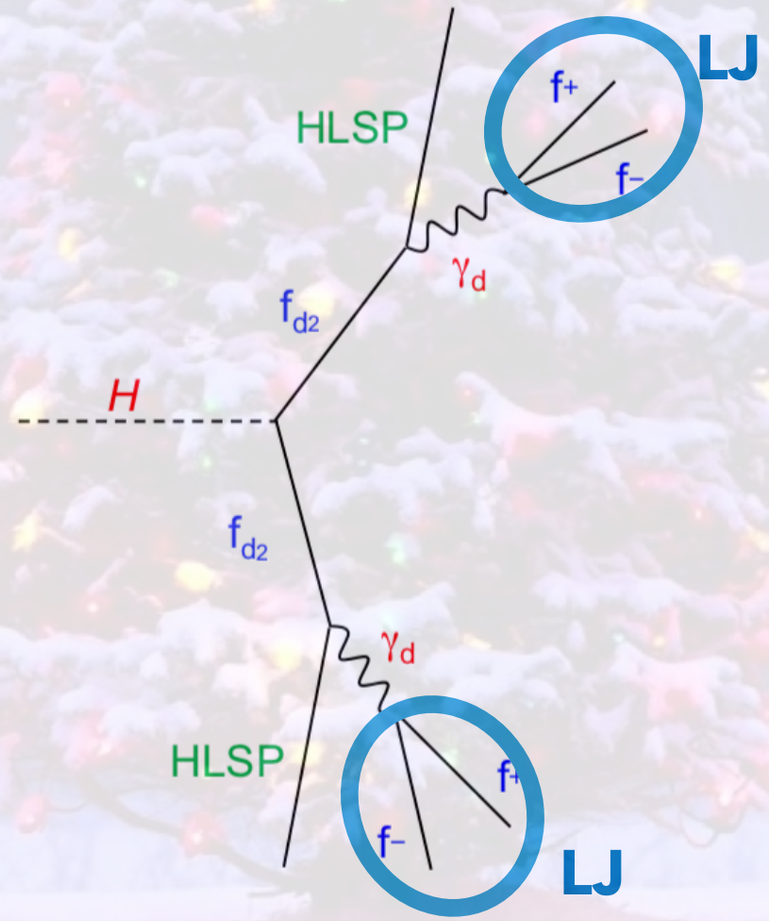
Dark-QED U(1)

$$\mathcal{L} \propto \epsilon e \gamma_d^\mu J_\mu^{em}$$

$$c\tau = \frac{1}{\Gamma_{\gamma_d}^{\text{tot}}} \propto \frac{1}{\epsilon^2 m_{\gamma_d}}$$

- Benchmark model: FRVZ model: arXiv:1002.2952 ;
- $\gamma_D$ from Higgs decay;
- Higgs production:
  - gluon gluon Fusion (ggF): already used;
  - **Higgs associate production (VH): NEW channel**
  - Vector Boson Fusion (VBF) : NEW channel

**Branching fraction H→inv upper limit is 25%, plenty of space for exotics Higgs decays involving dark photons.**




OTHER MODELS IN PROGRESS