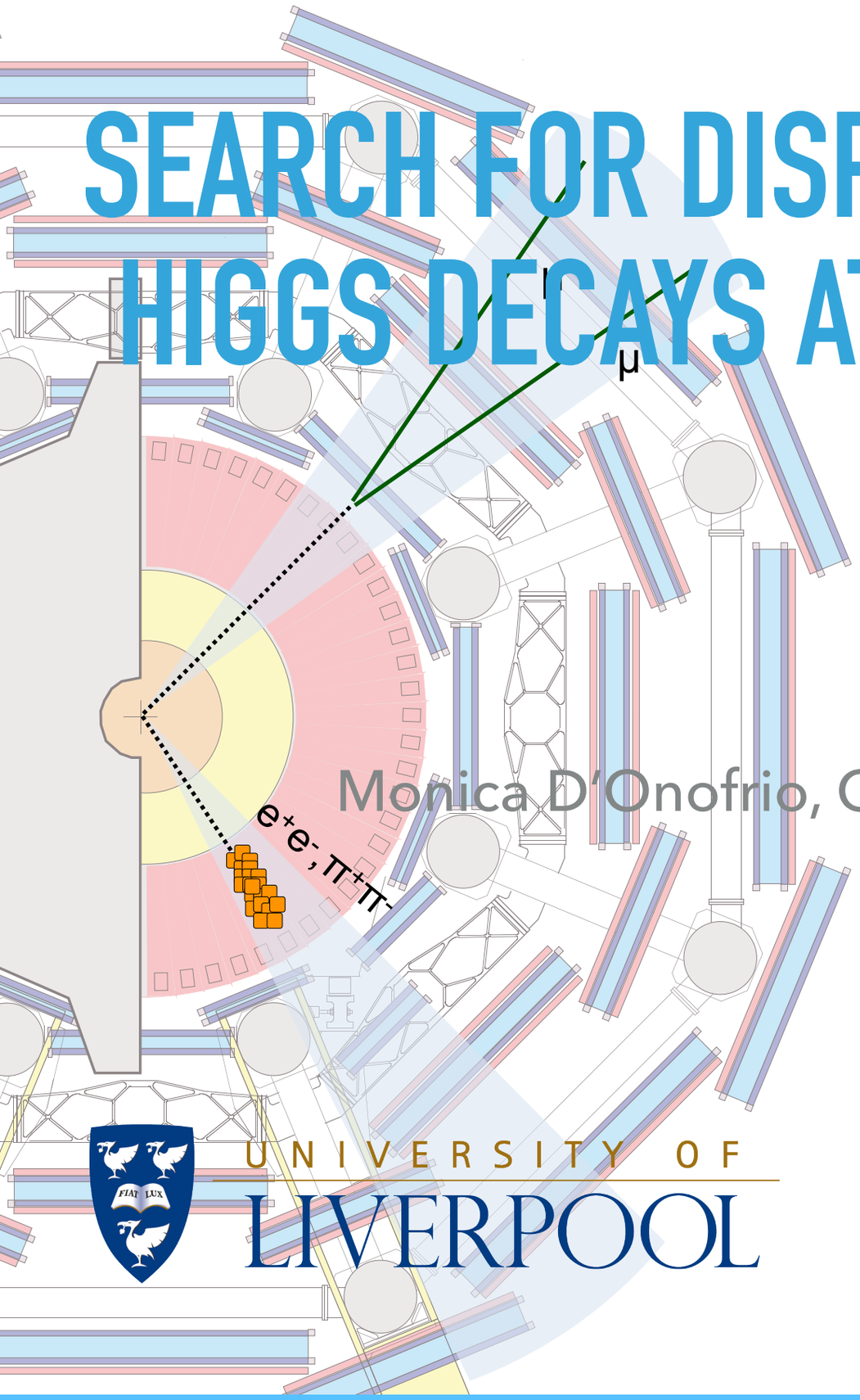

SEARCH FOR DISPLACED DARK PHOTONS IN HIGGS DECAYS AT THE ATLAS EXPERIMENT

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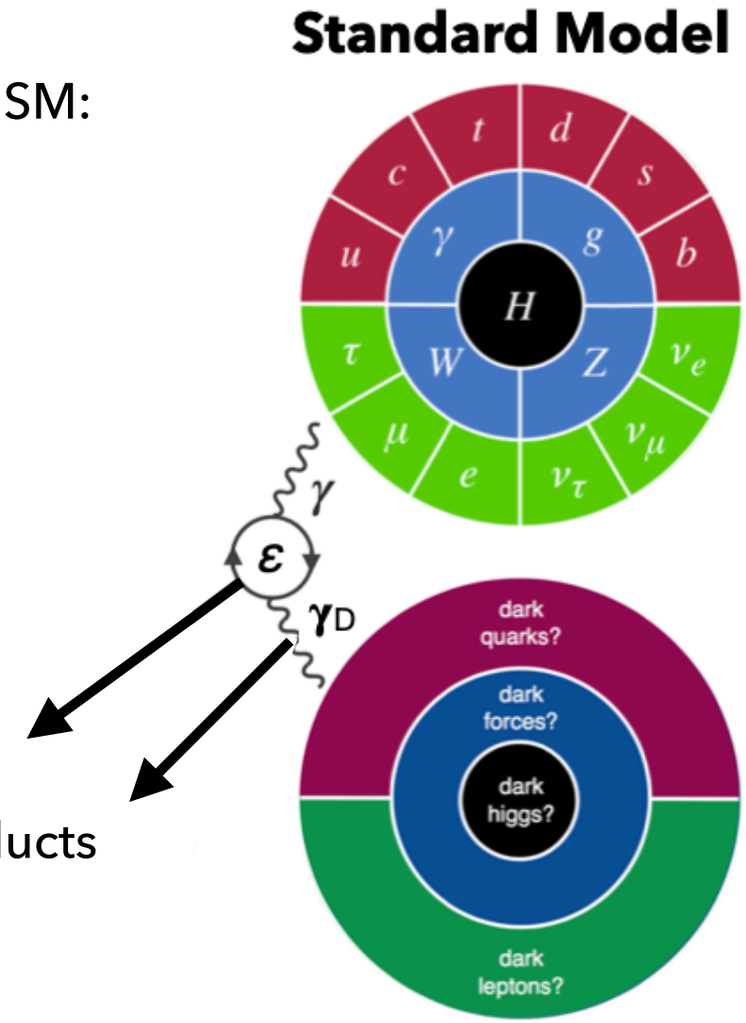
Dark Photons

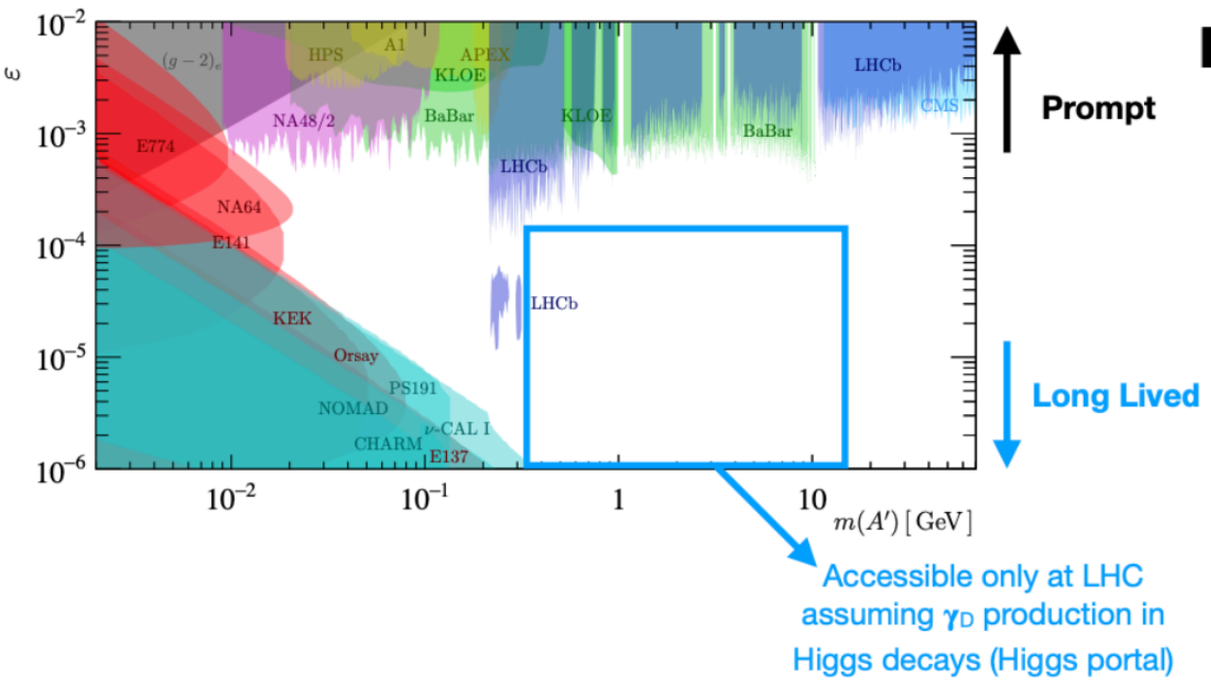
Dark sector weakly coupled to the SM:

- two free parameters:
  - dark photon mass $m_{\gamma d}$
  - kinetic mixing parameter ε

small $\varepsilon \rightarrow$ long-lived γ_d

small $m_{\gamma d}$ collimated decay products





- Vector portal:
  - no direct coupling to SM particles
  - new U(1) gauge invariance
  - kinetic mixing of SM photon and dark photon

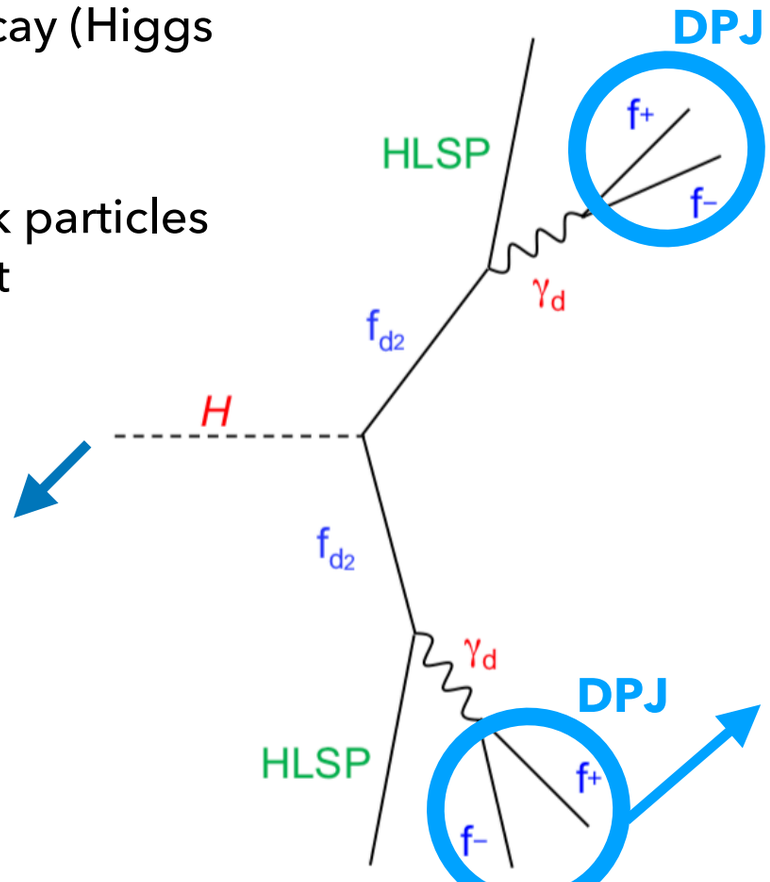
$$Dark - QED\ U(1)$$
$$\mathcal{L} \propto \epsilon e \gamma_d^\mu J_\mu^{em}$$

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

- Long Lived Particles (LLPs) @ LHC:
  - decaying in the detector volume → e.g ATLAS γ_d from Higgs Decays
  - very long lived, forward detector: e.g FASER (complementary coverage)

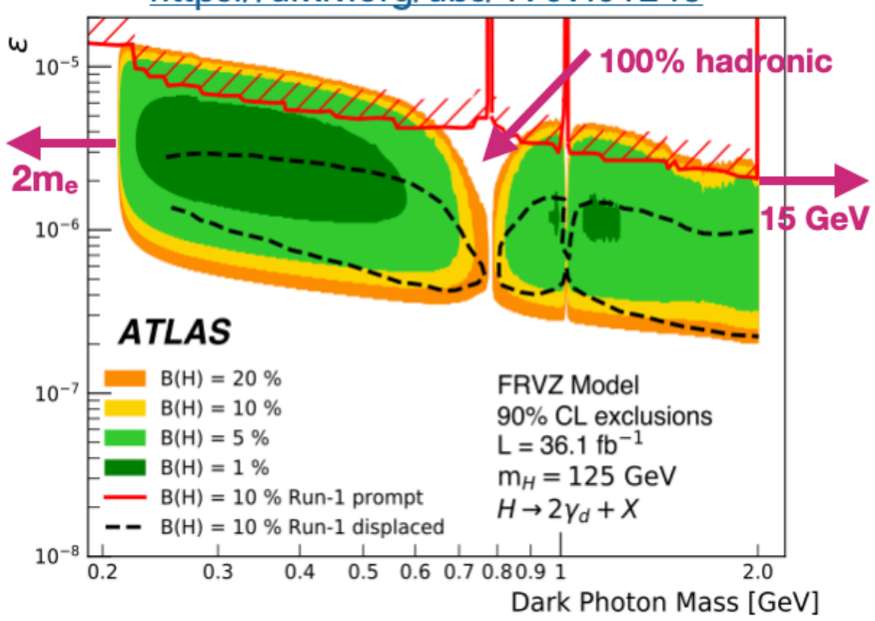
Displaced Dark Photon Jets Analysis

- γ_D from SM-like Higgs boson decay (Higgs portal models)
- assume a BR of the Higgs to dark particles around 10% to evade the current constraints
- first time exploiting Higgs associated W production (WH) and vector boson fusion (VBF)
- earlier results only considered gluon gluon Fusion (ggF)



- We consider the FRVZ benchmark model, which implies the presence of other dark sector particles
- the analysis is sensitive also to generic decays through dark scalars of the Higgs boson
- very unconventional topology: two collimated structures of leptons or light hadrons: Dark Photon Jets (DPJ)

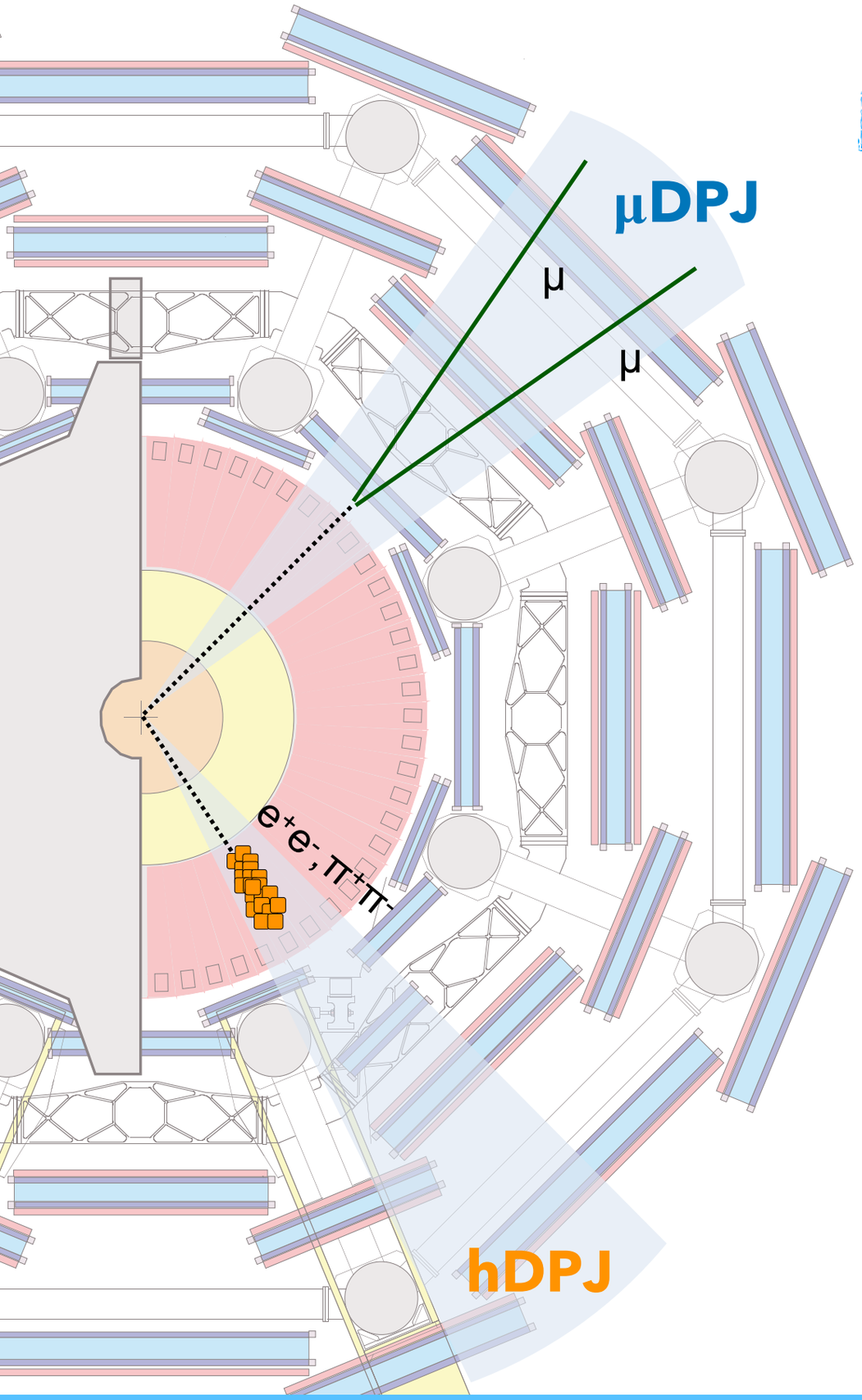
2015-2016 dataset analysis
https://arxiv.org/abs/1909.01246



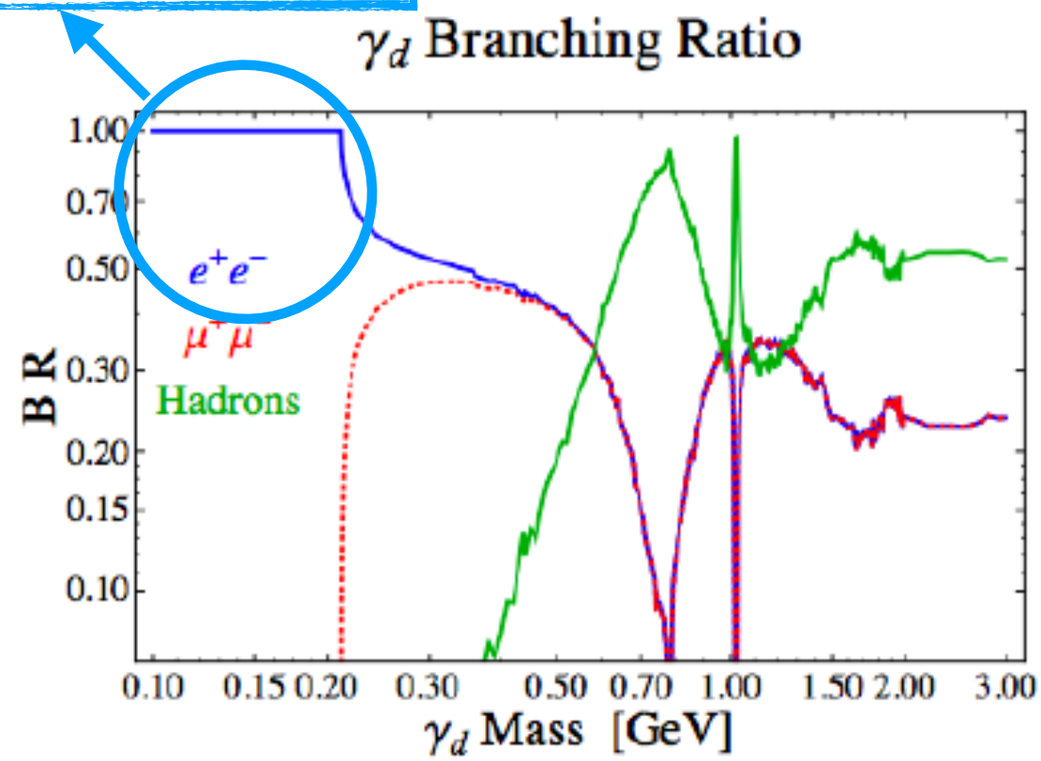
full Run-II analysis (2015-18 dataset):

- ggF: exclusion on γ_D muonic decays
- WH: focus on γ_D decays to e/h: aim for a first exclusion
- extend mass coverage: $2\ m_e < m_{\gamma d} < 15\ GeV$
- improve hadronic DPJ selection with a convolutional neural network (CNN) tagger

Dark Photon Jets in ATLAS

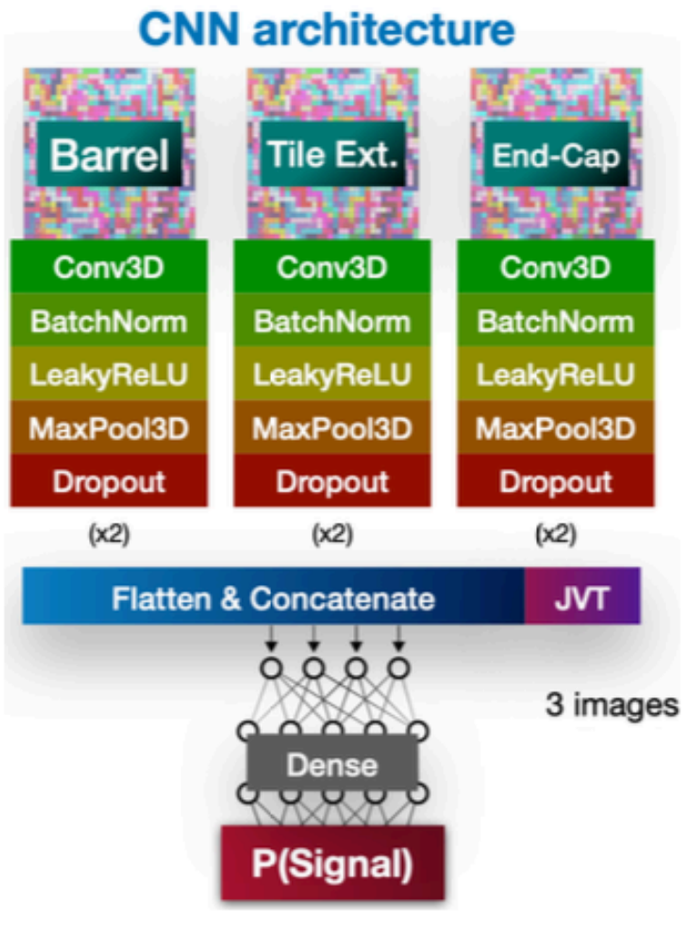


$m_{\gamma d} < 2m_{\mu}$ → 100% decay to $e^+ e^-$

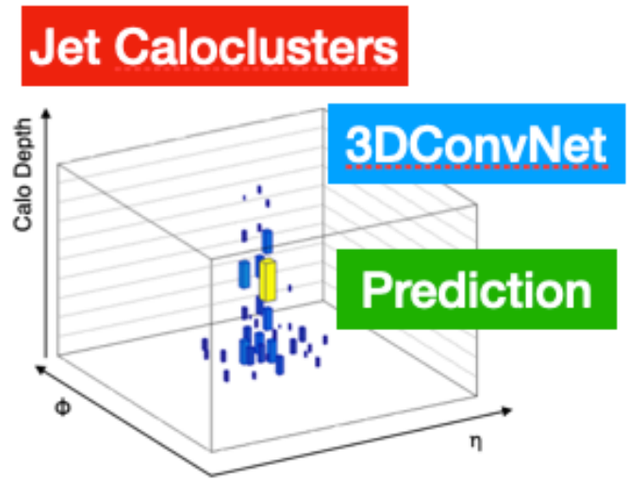


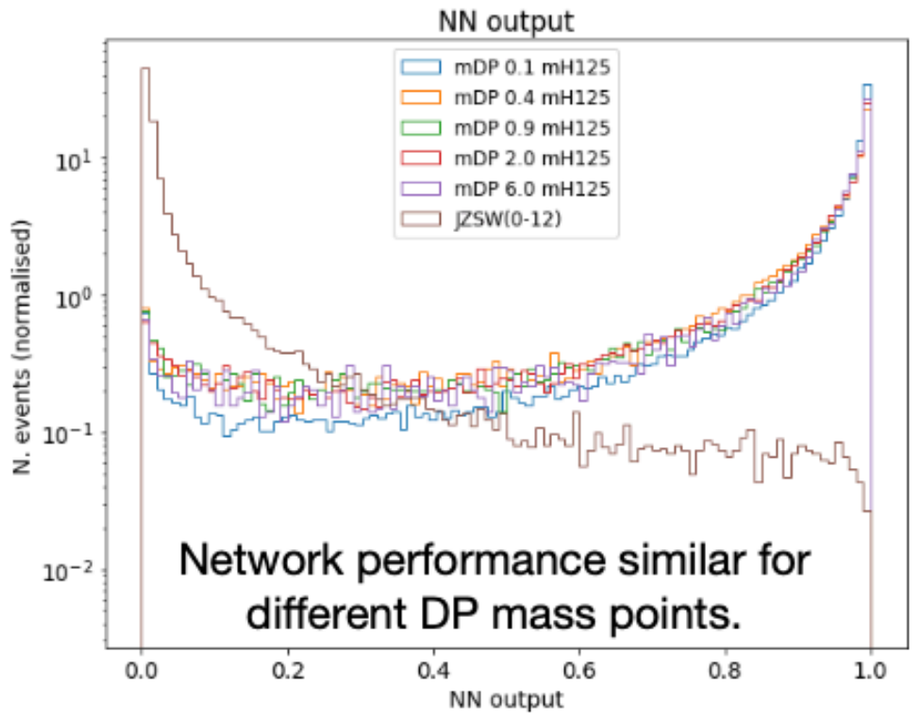
- **μDPJ**:
  - Collimated muon bundle in the Muon Spectrometer (MS) with no matching jets and tracks in the ID
- **hDPJ**:
  - low Electromagnetic Fraction jets, without associated tracks in the Inner Detector (ID) and narrower than ordinary jets

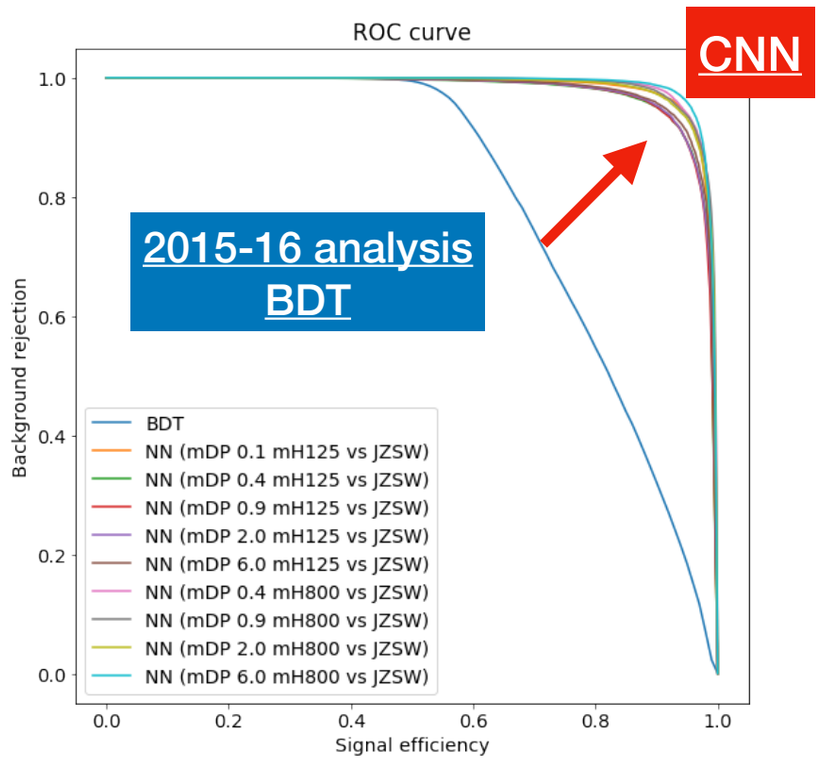
Displaced DPJ: CNN tagger



- From each jet three 3D images are produced
- 3D images are η-ϕ-Calo_layer maps (around the jet axis) of caloclusters associated to the jet
- network trained using ggF signal and multi-jet background samples
- same performances in separating WH signal and V+jets background





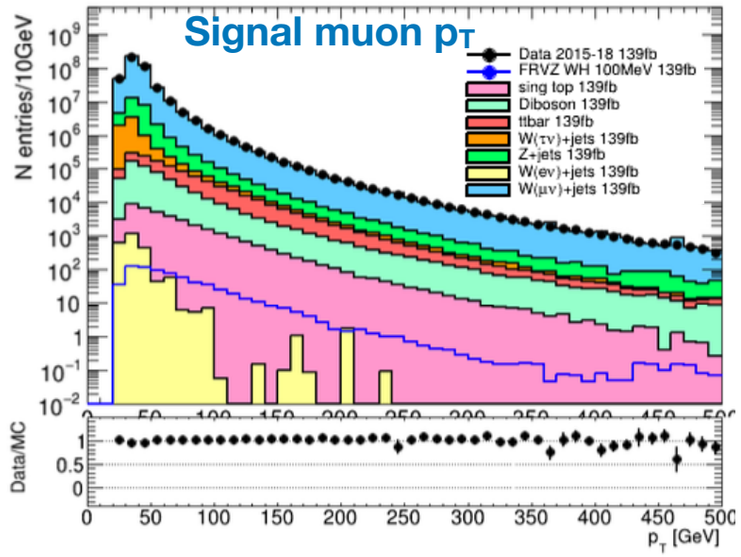


WH analysis strategy

WH Preselection

- exploit single lepton triggers high efficiency
- W/Z+Jets dominant Bkg (~98%)
- Good Data/MC agreement

Initial
Single Lepton Trigger
$NJets(p_T > 30\ \text{GeV}) \leq 3$
B-jet Veto
$N_{Leptons} == 1$
$m_T > 30\ \text{GeV}$
$E_T^{miss} > 40\ \text{GeV}$



Per DPJ type & number selection

- reconstruct either both or only one γ_d
- ggF sensible to muonic decays via the 2μDPJ
- WH focus on decays to e/h → hDPJs
- cuts on DPJ constituents

- Exactly 1 reco DPJ → 1hDPJ
- 2 reco DPJ → 2hDPJ / hDPJ-μDPJ

recover sensitivity from having 1hDPJ channel and also possibility to combine results → orthogonal selection

Bkg Estimate & Results

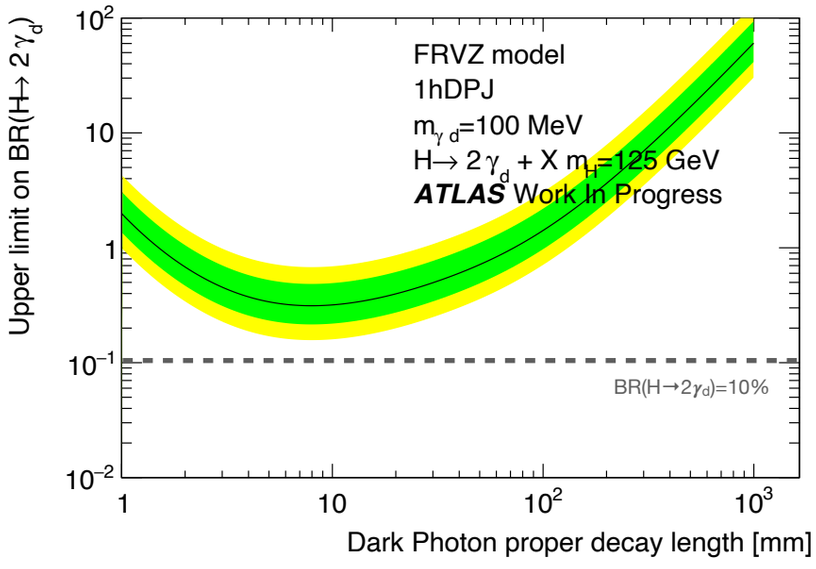
- ABCD Method:
  - Signal VS residual V+Jets
  - other SM Bkg negligible
- Results & Interpretation

- Fully Data-driven estimate
- residual V+jets background events factorised in the plane of two uncorrelated variables
- plane is divided in four regions A,B,C,D
- region A is the signal region
- expected number of bkg events in A: $N_A = N_D \times N_B / N_C$

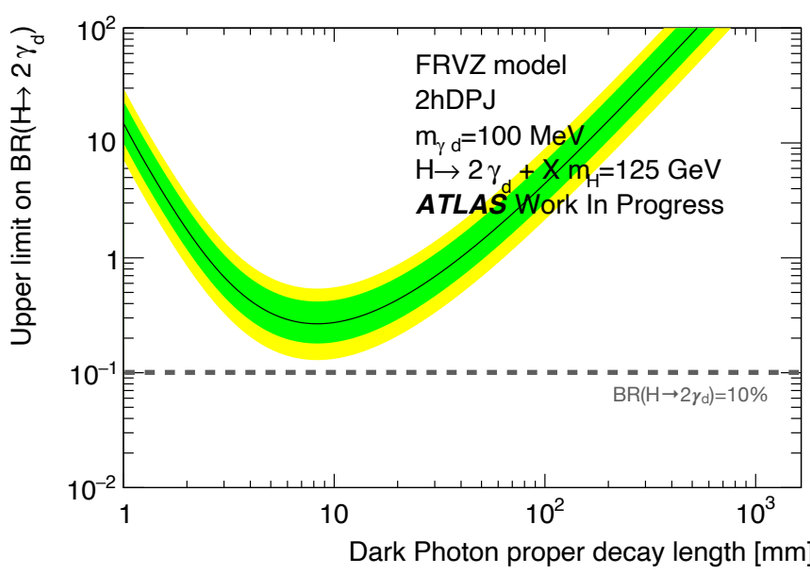
Background Estimation & very Preliminary Limits

- limits vs cτ, ABCD simultaneous fit with 36fb^{-1} Analysis Systematics
- for 1hDPJ and 2hDPJ channels showing 100 MeV DP mass point → $m_{\gamma d} < 2m_{\mu}$, 100% decay to electrons

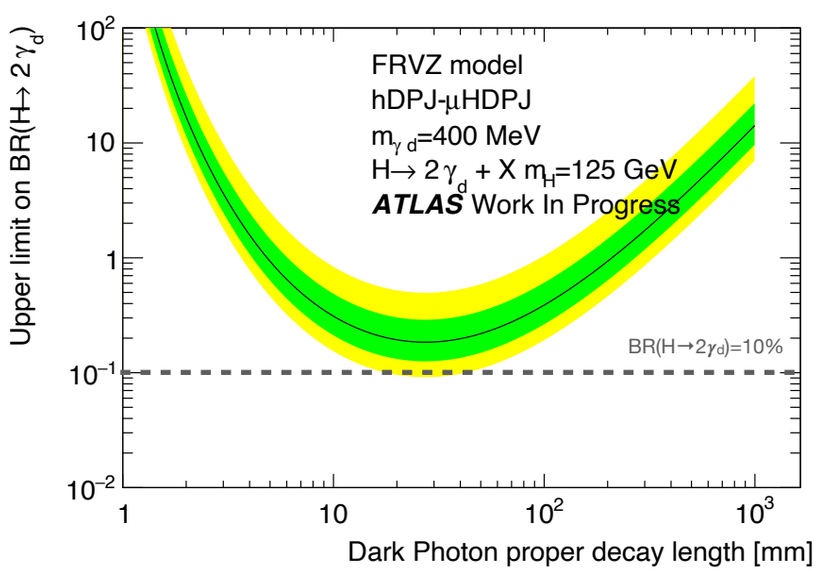
1hDPJ



2hDPJ



hDPJ-μDPJ

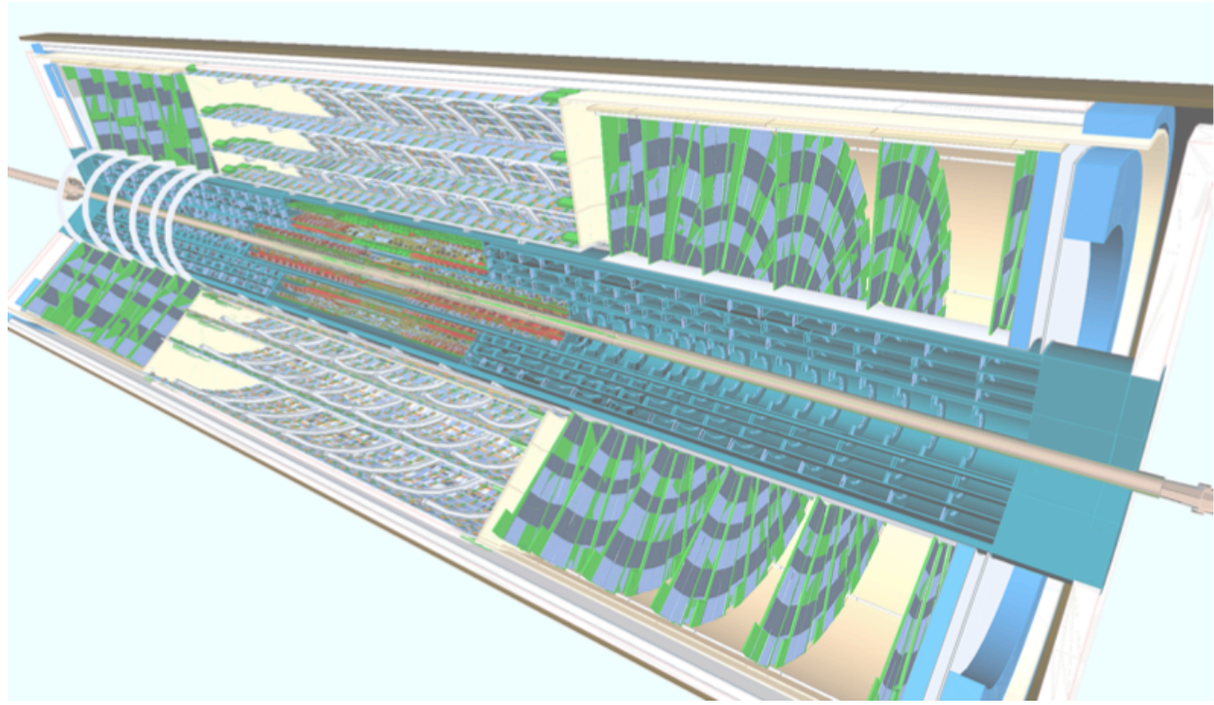


- very preliminary limits → **first exclusion for fully hadronic channels**
  - this is crucial for plane regions which would otherwise remain uncovered by the muonic channels exclusion
  - e.g $2m_e < m_{\gamma d} < 2m_{\mu}$ or near hadronic resonances
  - WH analysis 1hDPJ and 2hDPJ channels can be combined with ggF 2hDPJ channel

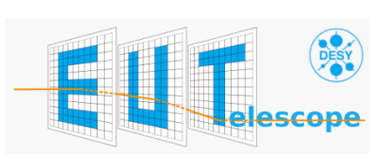
will combine results from WH fully hadronic channels to the ggF ones

Qualification Task

- ITk: ATLAS HL-LHC upgrade inner tracker:
  - all-silicon tracker
  - will have to cope with increased occupancy and radiation damage:
    - number of interactions per bunch crossing μ = 200 (from current μ = 50)
    - peak instantaneous luminosity of $7.5 \cdot 10^{34}$ cm^{-2} s^{-1} and a foreseen total of 4000 fb^{-1} in 10 years

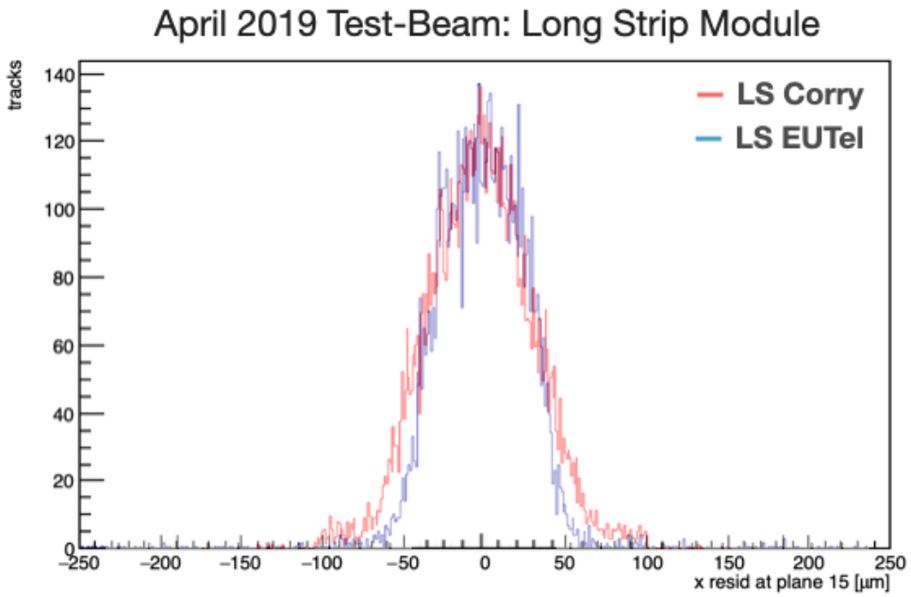


- worked in the ITk strip testbeam group:
  - contributed to the transition to a new data reconstruction framework with a first comparison of the performances for ITk strip barrel modules



The Maelstrom for Your Test Beam Data

  - plan: keep working in the group on the reconstruction of Endcap modules with the new framework



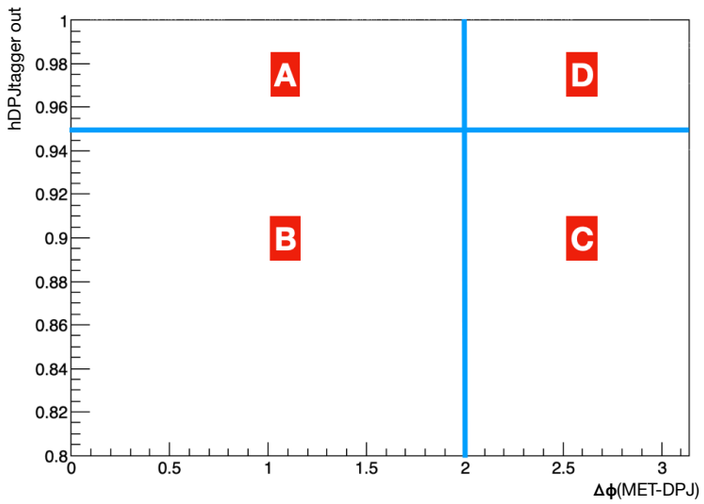
Conclusion & next steps

This Year:

- currently based at DESY, will move back to Liverpool in September
- finished my qualification task to become an ATLAS author:
  - ITk strip detector for HL-LHC ATLAS upgrade
- Plans:
  - aim at release analysis results in the summer: ggF+WH analysis joint paper

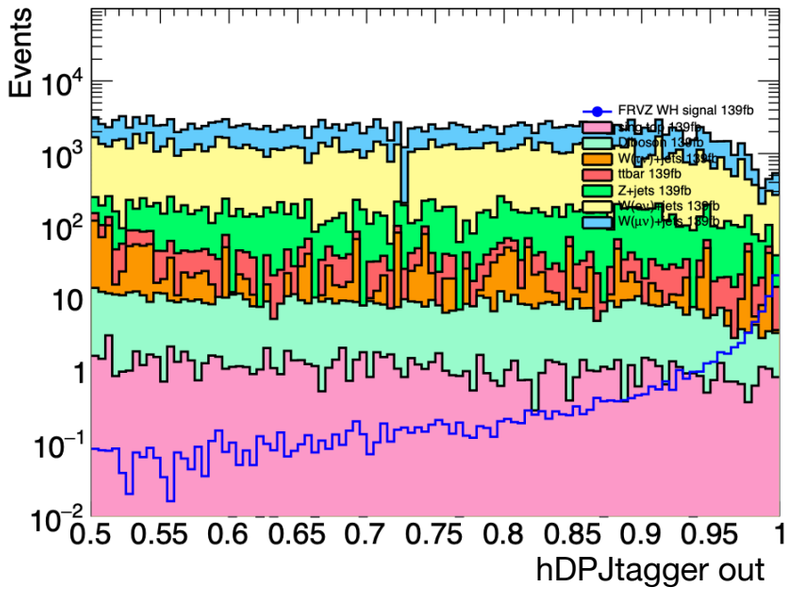
BACKUP

ABCD Background Estimation



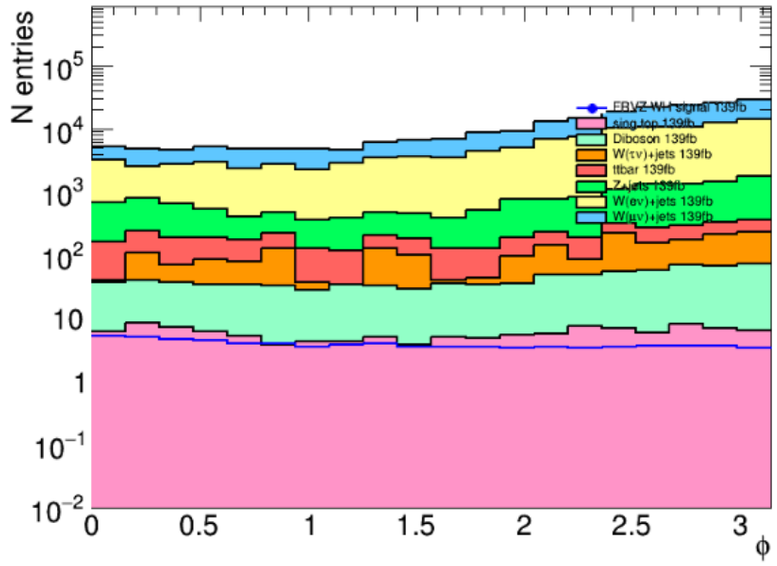
- Fully Data-driven estimate
- residual V+jets background events factorised in the plane of two uncorrelated variables
- plane is divided in four regions A,B,C,D
- region A is the signal region
- expected number of bkg events in A: $N_A = N_D \times N_B / N_C$

hDPJ Tagger output



Preselection +
1hDPJ +
hDPJ tagger >0.5

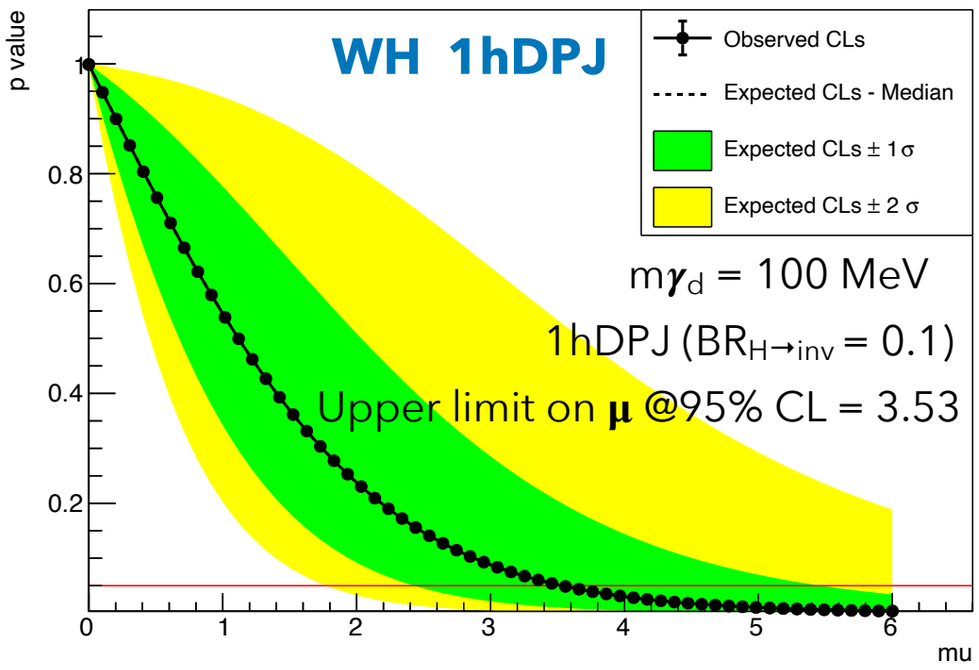
|Δϕ(MET-DPJ)|

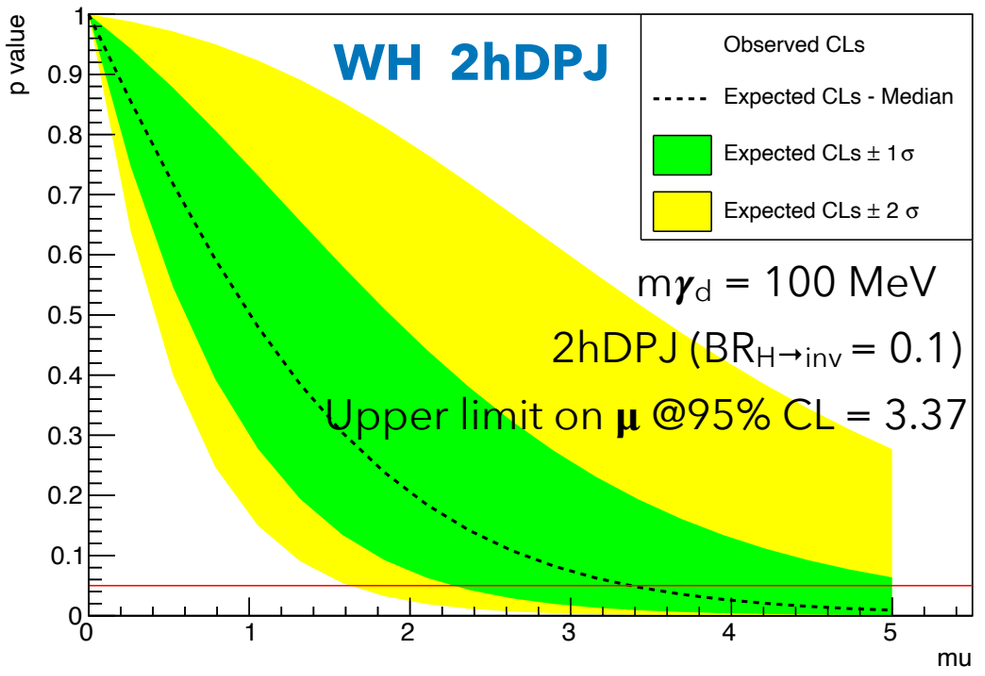


- Most powerful tool to separate Signal and V+jets bkg (Y axis is Log)
- hDPJ tagger output (1hDPJ and hDPJ-μDPJ channels)
- min[hDPJ tagger out] used in the 2hDPJ channel

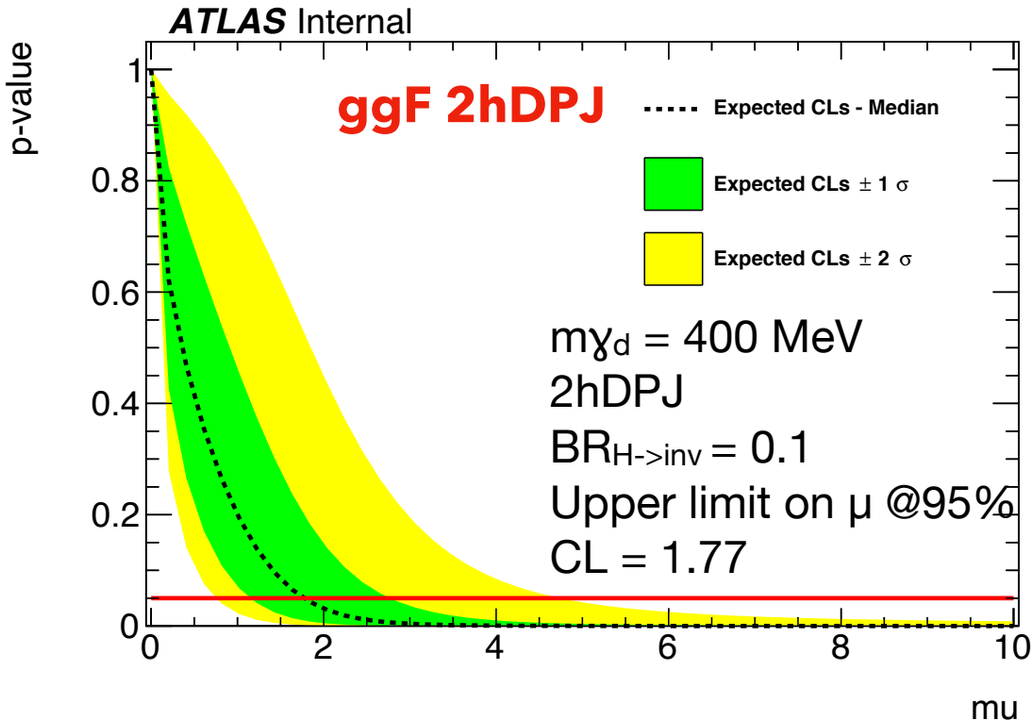
- Uncorrelated w.r.t hDPJ tagger output (<2% correlation factor)
- provides good separation (Y axis is Log)
- |Δϕ(MET-DPJ)| used for 1hDPJ channel
- min(|Δϕ(MET-DPJ)|) for 2hDPJ and hDPJ-μDPJ channels

ggF + WH combination





- WH analysis sensitivity in 1hDPJ and 2hDPJ channels competitive w.r.t ggF 2hDPJ channel (despite ~100 times smaller Xsec)
- WH 1hDPJ and 2hDPJ channels are orthogonal (possibility to combine) to each other, and also w.r.t to ggF 2hDPJ
- combining the results to obtain a first limit for fully hadronic decays of the Dark Photon:
  - this is crucial for plane regions which would otherwise remain uncovered by the muonic channels exclusion
  - e.g $2m_e < m_{\gamma d} < 2m_\mu$ or near hadronic resonances



1hDPJ Channel

- WH Preselection
- M_T> 120GeV
- Exactly one reco DPJ
- hDPJ selection:
  - Jet Cleaning: LooseBadLLP
  - tile gap noise cut
  - timing cut (|t|≤4ns)
  - width cut
- **Residual V+Jets Background estimated with ABCD plane:**
  - hDPJtagger output && Δϕ[MET-DPJ]

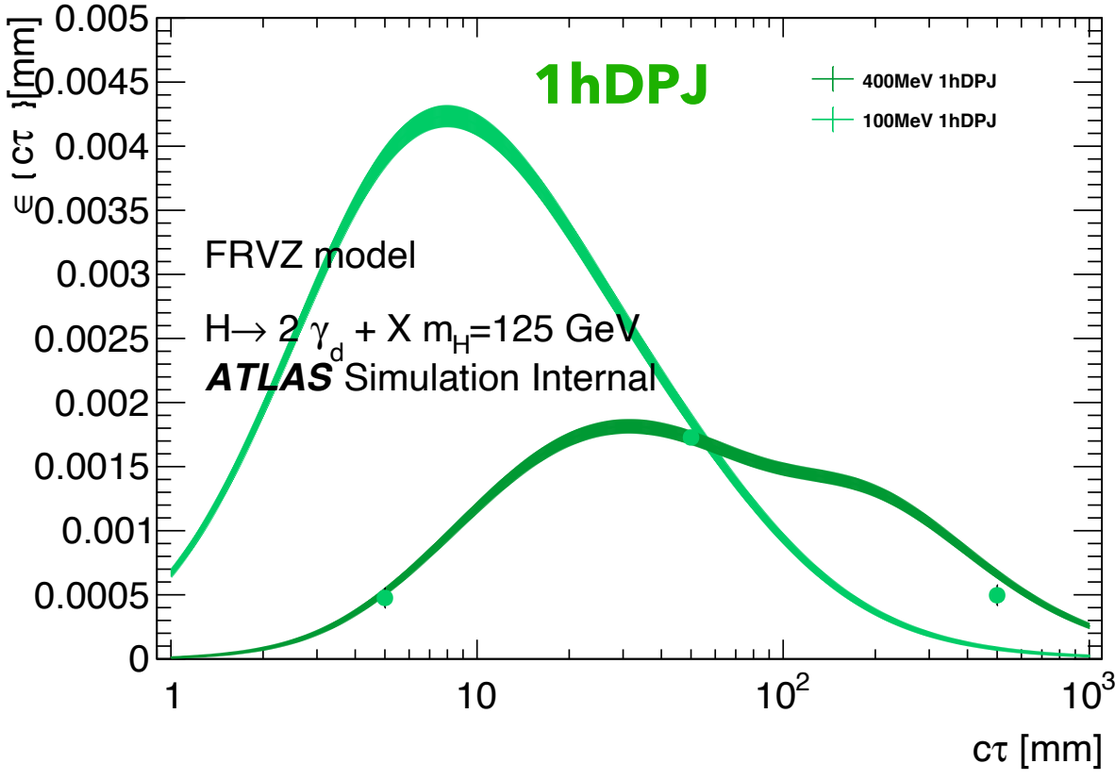
2hDPJ Channel

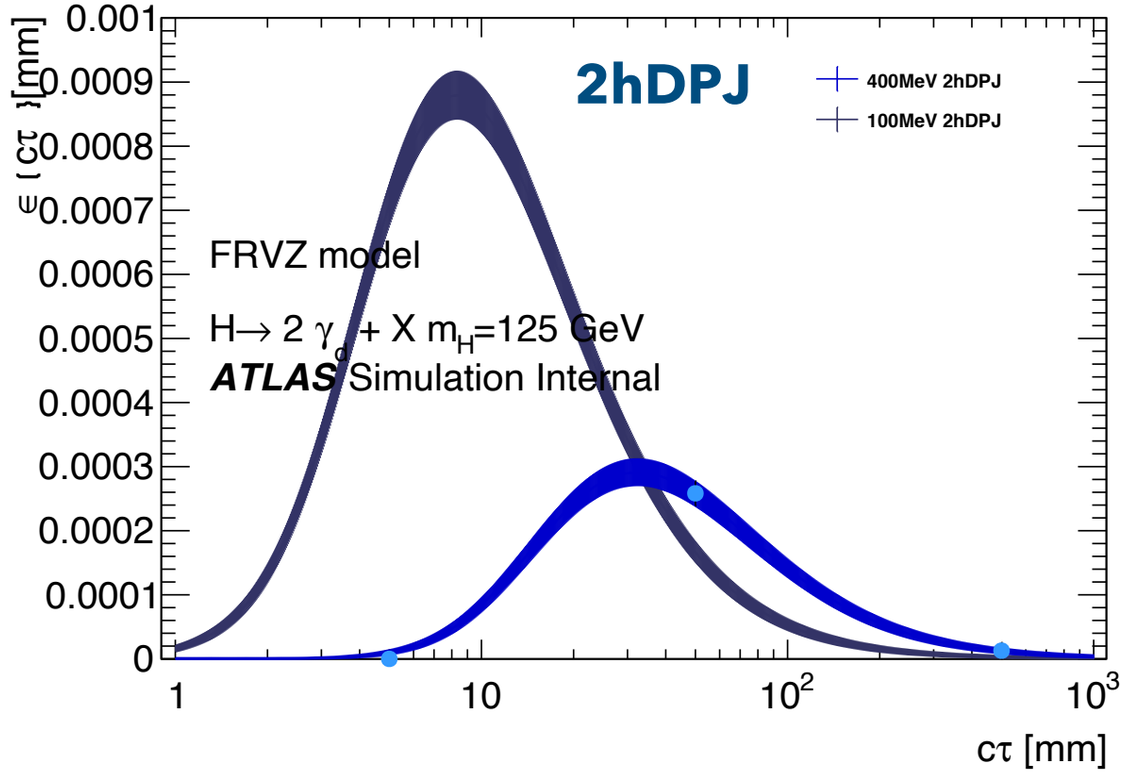
- WH Preselection
- ≥ 2 reco DPJ
- hDPJ selection:
  - Jet Cleaning: LooseBadLLP
  - tile gap noise cut
  - timing cut (|t|≤4ns)
  - width cut
- **Residual V+Jets Background estimated with ABCD plane:**
  - min(hDPJtagger output) && min(Δϕ[MET-DPJ])

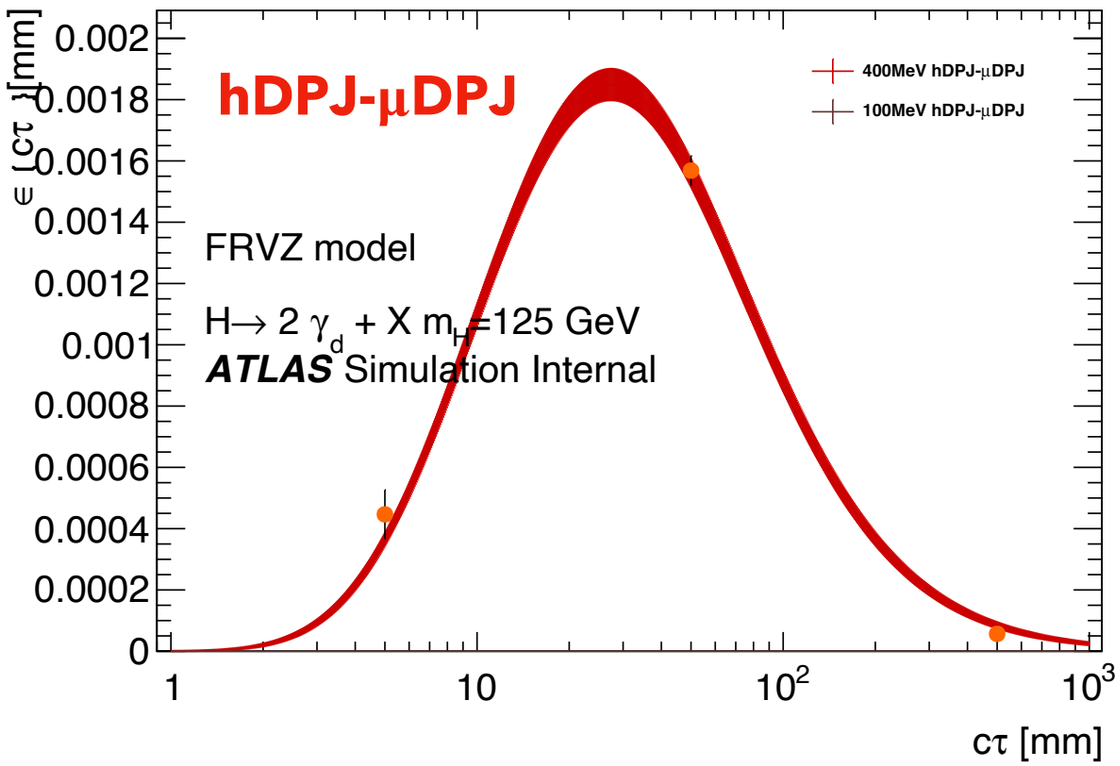
hDPJ-μDPJ Channel

- WH Preselection
- ≥ 2 reco DPJ
- μDPJ constituents selection:
  - veto muons with 1≤|η|≤1.1
  - veto Combined Muons
- hDPJ selection:
  - Jet Cleaning: LooseBadLLP
  - tile gap noise cut
  - timing cut (|t|≤4ns) && width cut
- **Residual V+Jets Background estimated with ABCD plane:**
  - hDPJtagger output
  - min(Δϕ[MET-DPJ])

Lifetime Reweighting







- Plots showing εxA for the signal samples as a function of cτ for the 3 analysis channel: 1hDPJ, 2hPDJ, hDPJ-μDPJ
- good agreement within statistical for the validation samples
- plots shown for 100MeV and 400MeV samples