# **Dark matter at LHCb?**

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On behalf of the LHCb collaboration



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## The priority of Dark Matter searches

• The hidden-sector paradigm



# The priority of Dark Matter searches

• The hidden-sector paradigm



#### • 4 portals: 4 new particles(11 'benchmark searches') arXiv:1901.09966

- Dark photon
- Higgs-like particle
- Sterile neutrino
- Axion-like particle: to photons, gluons, or fermions

## Dark photons, A'



- Minimal model parameterised by  $m_{A'}$ , and mixing strength,  $\varepsilon$
- $\gamma^*$  and A' production/decay kinematics identical

$$n_{A'} \propto \varepsilon^2 n_{\gamma^*} \epsilon$$

- LHCb  $\sigma(\tau) = 50 \, \text{fs: 'prompt' vs 'displaced' signatures}$
- $\epsilon$ : A'/ $\gamma^*$  efficiency ratio
  - 1 in prompt case
  - Non-trivial in displaced case due to photon conversion veto

## Dark photons, A' PRL 124 041801 Prompt signature:



- Since 2015: full reconstruction in the trigger JINST 14 PO4013
- Avoids need to downscale data-rate, even at dimuon threshold
- Updated to include all available Run 2 pp data

# Dark photons, A' arXiv:JINST 13 PO6008 Displaced signature:

- A' radial flight distance > 5 mm: ~ no prompt background
- Background from photon conversions in the first detector layers
- Special beam-gas runs: high-precision material map to veto
- Use simulation to find relative  $A'/\gamma^*$  decay-time inefficiency



# Dark photons, A' arXiv:PRL 124 041801 Constraints on kinetic-mixing strength:



- First non-fixed-target constraint from displaced signature search
- Framework to 're-cast' A' limits to other searches JHEP 06 004

## What's next for dark photons?



Spotlight in parameter space:

- $10^{-5} < \epsilon < 10^{-3}$ : 1-2 loop mixing for a SM-like dark force
- 10 MeV < m < 400 MeV: velocity-dependent dark matter self-interactions

Run 3: explore 'golden' region with  $D^* \rightarrow D^0(A' \rightarrow e^+e^-)$  PRD 92 115017

## Generalising dark-photon searches JHEP 10 156

- Non-minimal models require a more general approach
  - Connection may not be kinetic mixing: no  $\gamma^*$  normalisation
  - Potentially extended dark sector: relax selection criteria



- No isolation requirements
- Non-zero width considered



Non-zero width considered





Displaced (non-prompt source)



## Generalising dark-photon searches JHEP 10 156

## Consider $m(\mu^+\mu^-)$ for the four signatures:



# Generalising dark-photon searches JHEP 10 156

## Search results:

• Eff. + lumi. → model-independent limit for each search:



- Constrain models producing a low-mass  $\mu^+\mu^-$  resonance
  - Use prompt search to constrain 2HDM + complex scalar singlet



- World-best upper limit on mixing angle with SM Higgs,  $\theta_H$ 

## **Opening more portals:**

- HLPs: dark-scalar hunt with  $B \rightarrow K^{(*)}\chi(\mu^+\mu^-)$  PRD 95 071101
- ALPs: Untapped search in  $B \rightarrow K^{(*)}a(hadrons)$
- In Run 3 (first high-energy collisions on Tuesday!), LHCb will yield more: arXiv:2203.07048



• Creative array of generic long-lived particle searches:

- 
$$X \rightarrow e^{\pm} \mu^{\mp} \nu$$
: EPIC 81 261  
-  $X \rightarrow \mu^{\pm} jet$ : EPIC 81 258  
-  $X \rightarrow \mu^{+} \{u, c\} \{\overline{d}s\overline{b}\}$ : EPIC 82 3



10/14

## New acceptance for LLP searches EPJC 80 1177

Post-Run 3 (2022-2025) step-change in sensitivity requires new acceptance

 $\Rightarrow$  CODEX-b: a new detector in the LHCb cavern

- Compact and low-cost
- Accessible & low-background location
- Transverse to beam: complementarity
- LHCb-integration to authenticate signals



## New acceptance for LLP searches EPJC 80 1177

Consider a dark scalar ("Higgs-like particle)



- Reach ultimate limit of silicon tracker length
- CODEX-b, or other creative proposals, necessary to achieve sensitivity step-change

## New acceptance for LLP searches EPJC 80 1177

CODEX-b demonstrator planned for operation during Run 3

- Scaled down detector: 2 x 2 x 2 m<sup>3</sup>; only 9 RPC planes
  - Confirm backgrounds under control
  - Demonstrate reconstruction and LHCb integration
- Collab. crystallising; procurement progress; build beginning



## In summary

### Past success

- Unique ability to trigger low-p<sub>T</sub>, low-mass signatures
- Dark-photons: a high-impact proof-of-principle

## Wide-ranging potential

- Explore all hidden-sector portals and generic LLP signatures
- The particular value of Run 3

## Future promise

- A programme that reaches to the HL-LHC era
- ... and beyond