

# LHC Searches for Vector Portals and Light Dark Matter

on behalf of the ATLAS, CMS, and LHCb Collaborations

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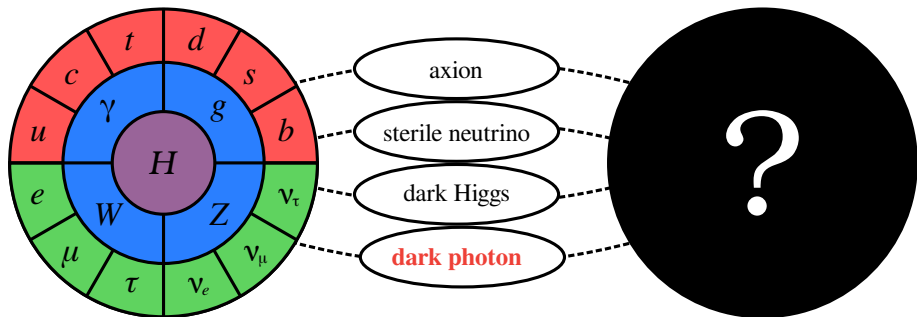


September 2, 2020



WORKSHOP ON FEEBLY-INTERACTING PARTICLES

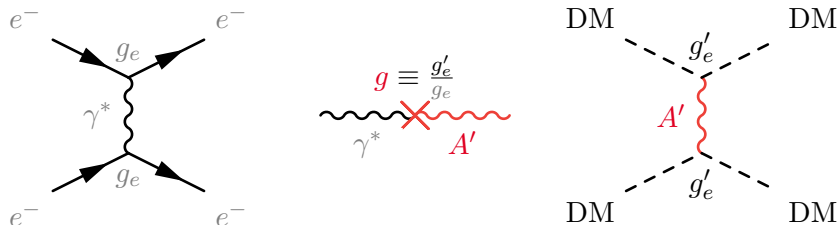
## Hidden Sector



- 1 broken  $U(1)$  gauge symmetry in dark sector
- 2 allow mixing between dark and SM hypercharge fields

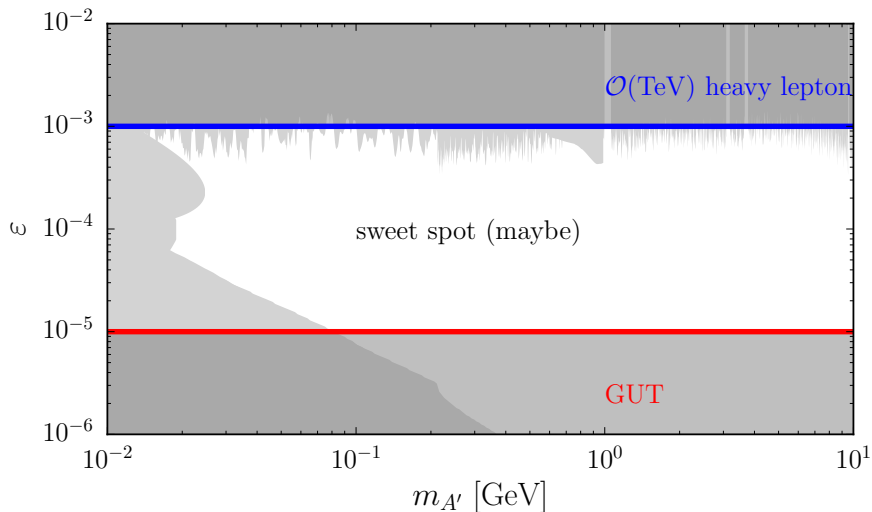
$$\mathcal{L} \supset -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m_{A'}^2}{2}A'_\mu A'^\mu + g_e J^\mu A_\mu + \varepsilon g_e J^\mu A'_\mu$$

# Dark Photons



- ① mass of the dark photon,  $m_{A'}$ , and mixing,  $\varepsilon$ , are free parameters
  - ② the dark photon couples like the photon, modified by  $\varepsilon$
  - ③ if  $m_{A'} < 2m_{\text{DM}}$  then dark photon decays visibly
- what happens if ② and ③ are relaxed?
  - require  $m_{A'}$ ,  $\varepsilon$ , 12 fermion couplings, and an invisible width
  - *dark photon limits can be recast to any general vector model*

## Parameters



† all limit plots have been produced with DARKCAST ([gitlab.com/philtten/darkcast](https://gitlab.com/philtten/darkcast))

# Properties

## ① production

- fermion annihilation
- meson decays
- electron/proton scattering

## ② lifetime

- *prompt* or *displaced*

$$\tau(\varepsilon, m_{A'}) = \frac{\hbar}{\Gamma_{A'}(\varepsilon, m_{A'})}$$

production



lifetime



decay

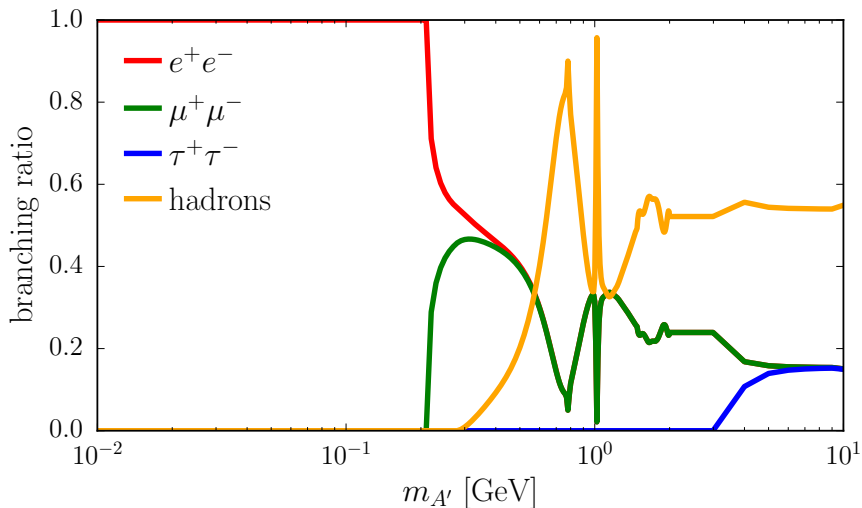
SM

SM

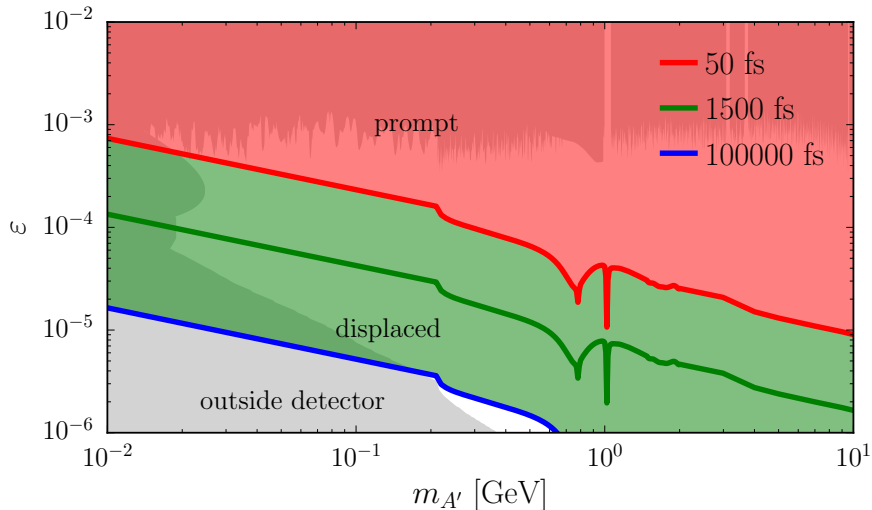
## ③ decay products

$$\text{BR}_{A' \rightarrow X}(m_{A'}) = \frac{\Gamma_{A' \rightarrow X}(\varepsilon, m_{A'})}{\Gamma_{A'}(\varepsilon, m_{A'})}$$

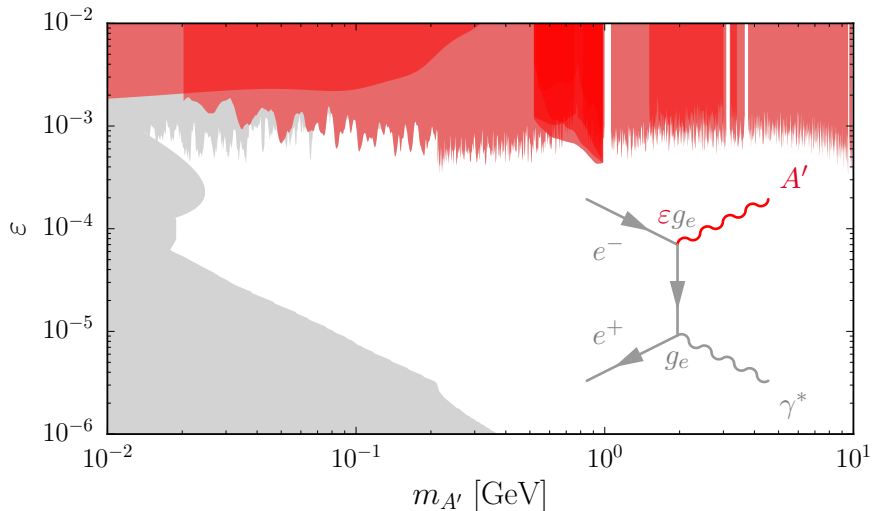
## Decay Products



## Lifetime

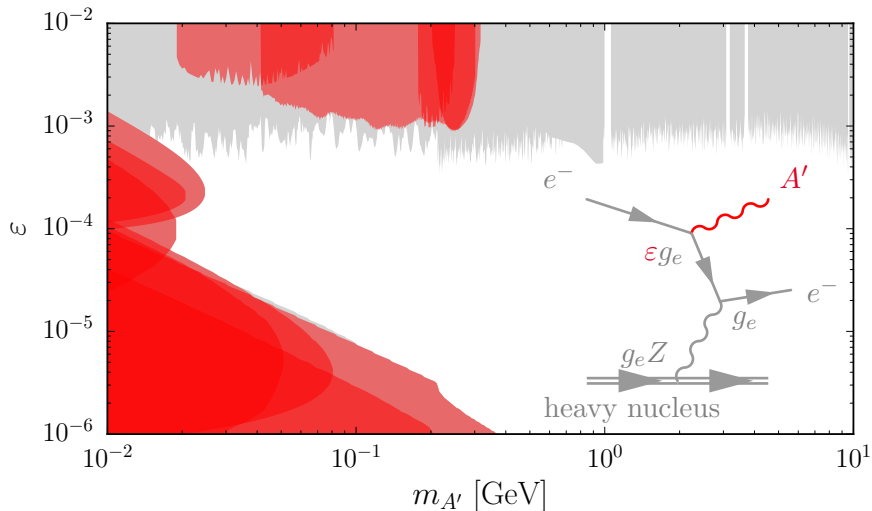


## Production: Electron-Positron Annihilation

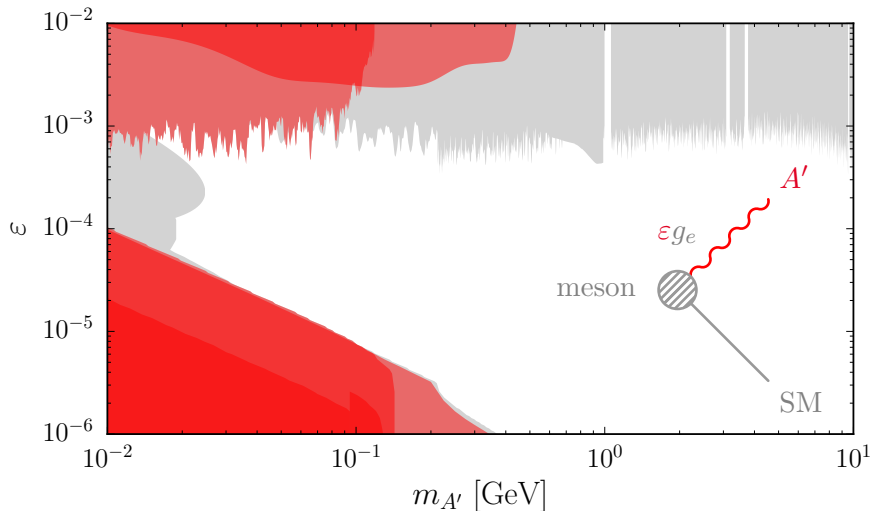




## Production: Electron/Proton Scattering



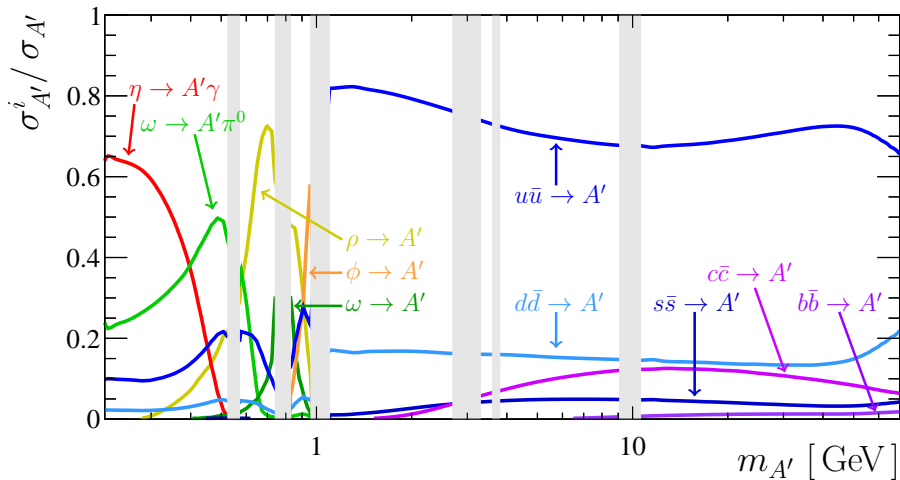
# Production: Meson Decays



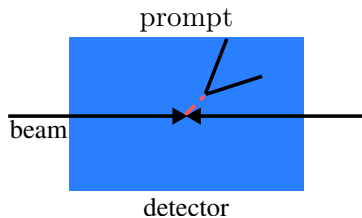
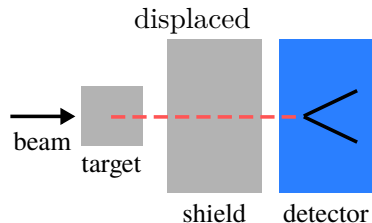
## Production: LHC

JHEP 06, 004 (2018)

- $\mu^+\mu^-$  final state for LHCb fiducial, similar for ATLAS and CMS

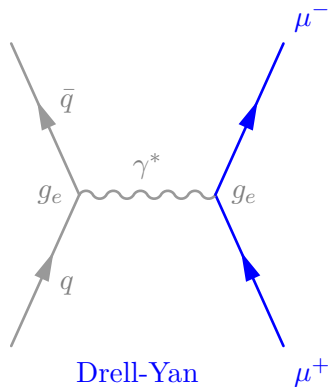
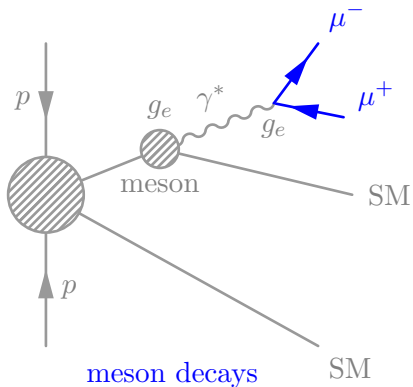


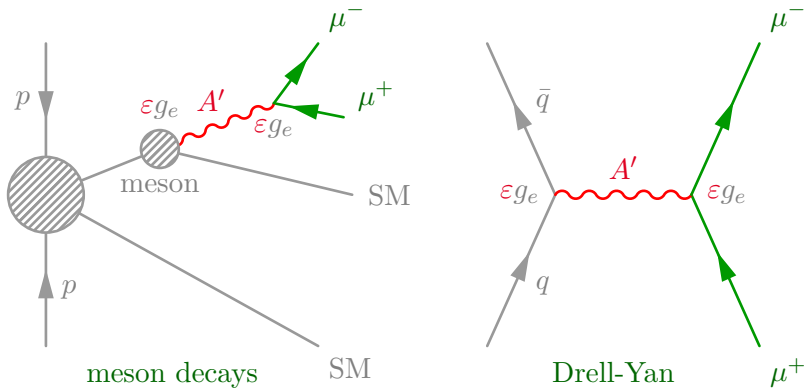
# Strategies



- sensitive to long lifetimes
  - EM background free
  - difficult to normalise
  - do both simultaneously for best of both worlds
- sensitive to shorter lifetimes
  - bump hunt on large EM background
  - normalised from sidebands

# Good Backgrounds (*prompt*)

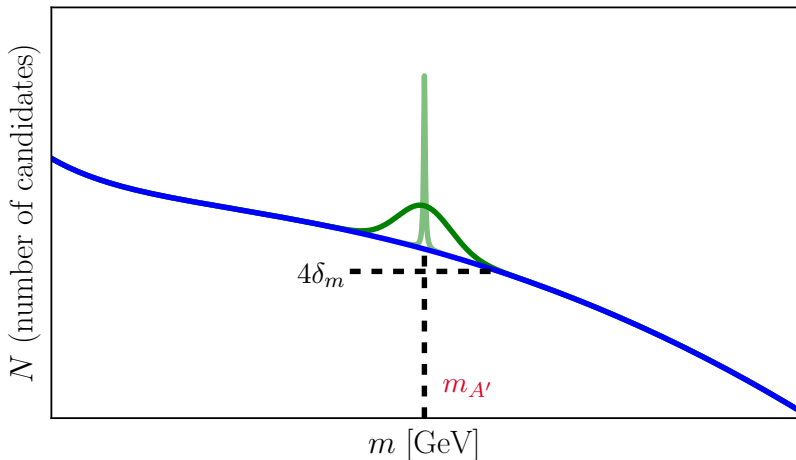


Signal (*prompt and displaced*)

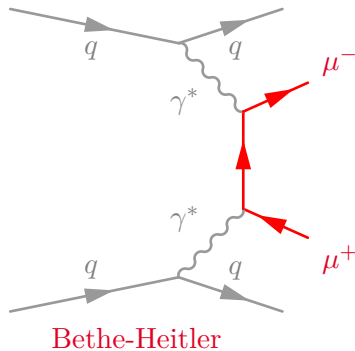
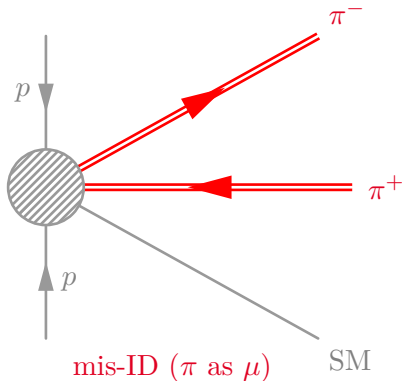
$$N_{\text{signal}} \propto \epsilon^2 N_{\text{good}}$$

# Bump Hunting

$$N_{\text{signal}} \approx \frac{\pi \varepsilon^4 m_{A'}^2}{8 \Gamma_{A'}(\varepsilon, m_{A'}) \delta_m} N_{\text{good}} \text{ per } 4\delta_m$$



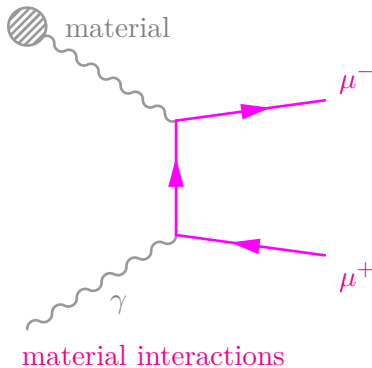
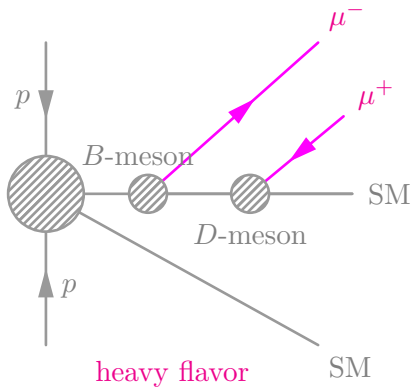
# Bad Backgrounds (*prompt*)

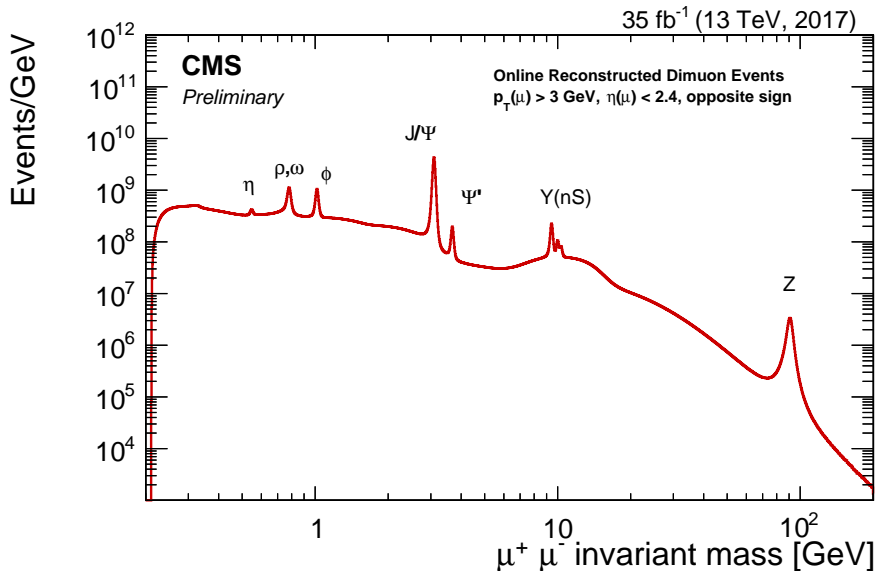


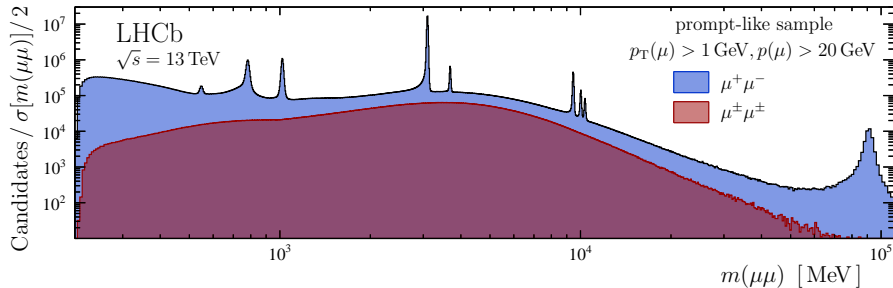
$N_{\text{signal}}$  is not proportional to  $N_{\text{bad}}$



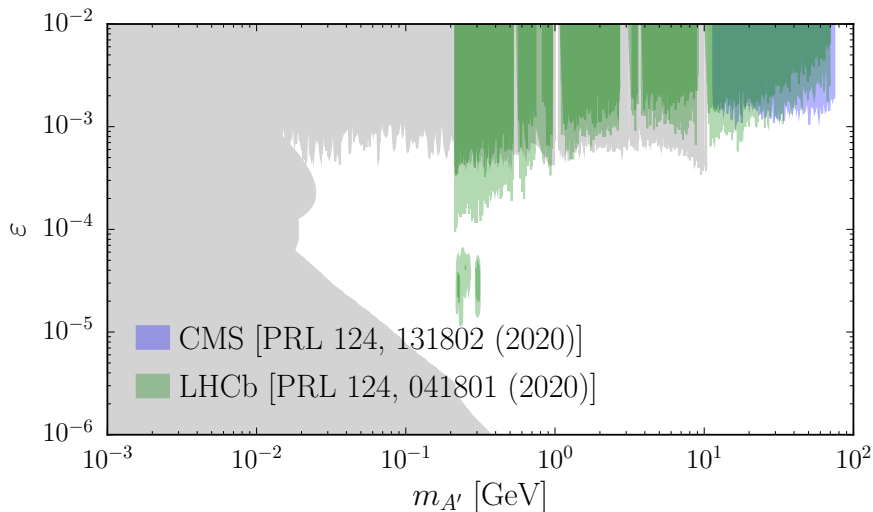
# Ugly Backgrounds (*displaced*)

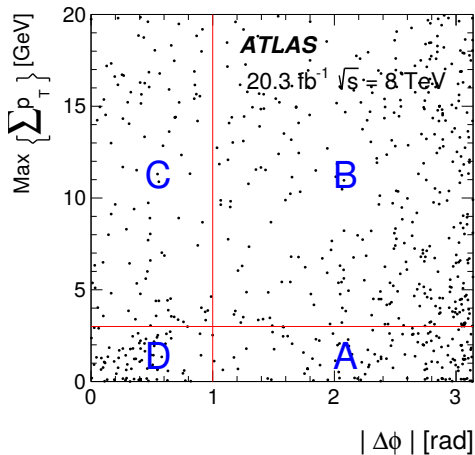
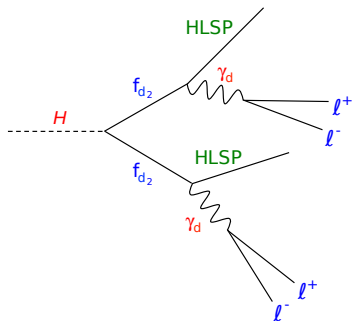




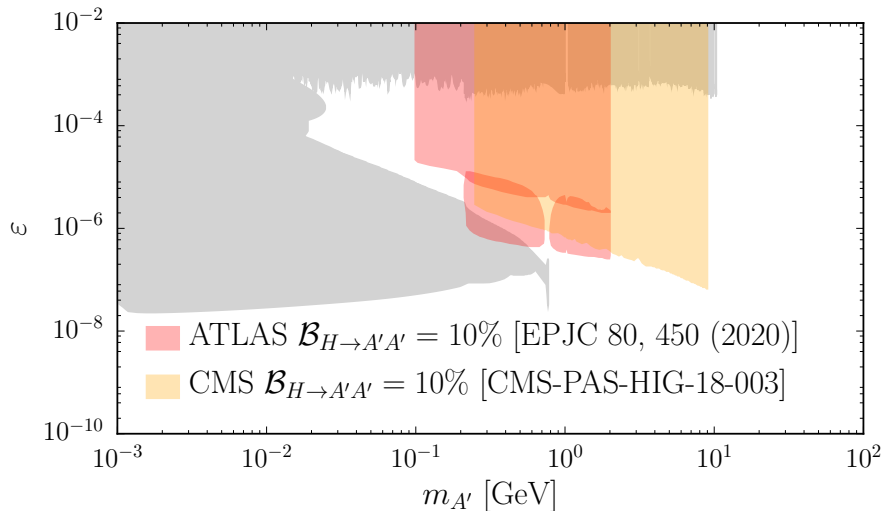


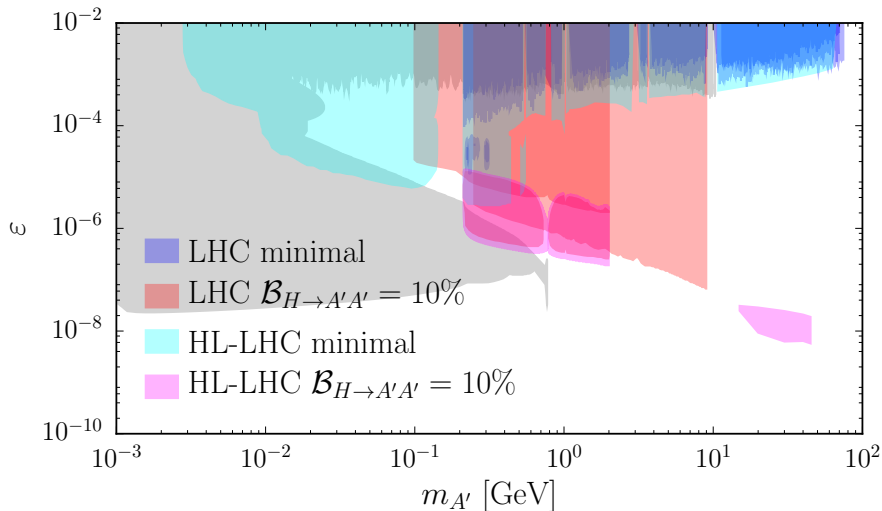
## Minimal Limits





## Higgs Limits





# Outlook

- the dark photon provides a flexible portal  
(see *e.g.* JHEP 06, 004 (2018))
- LHC has unique dark photon coverage with both  $e^+e^-$  and  $\mu^+\mu^-$
- with run 3, minimal  $e^+e^-$  will also be possible
- these searches can be recast in a multitude of ways  
(see *e.g.* arXiv:2007.03923 [hep-ex])
- data preservation is critical

Thank you!