

# LHCb and Dark Matter

Philip Ilten



Massachusetts Institute of Technology



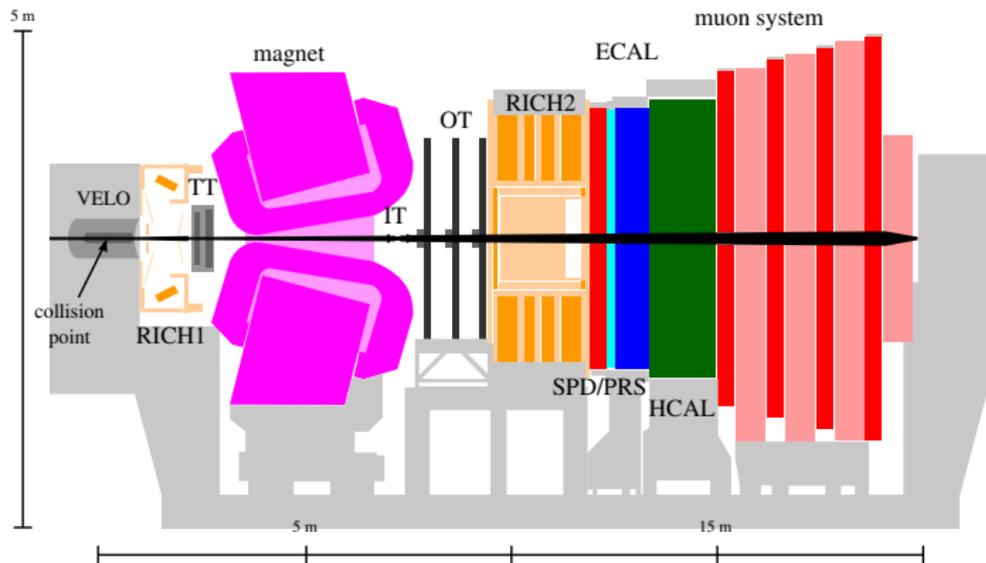
July 27, 2017

## FUTURE OF COLLIDER SEARCHES FOR DARK MATTER

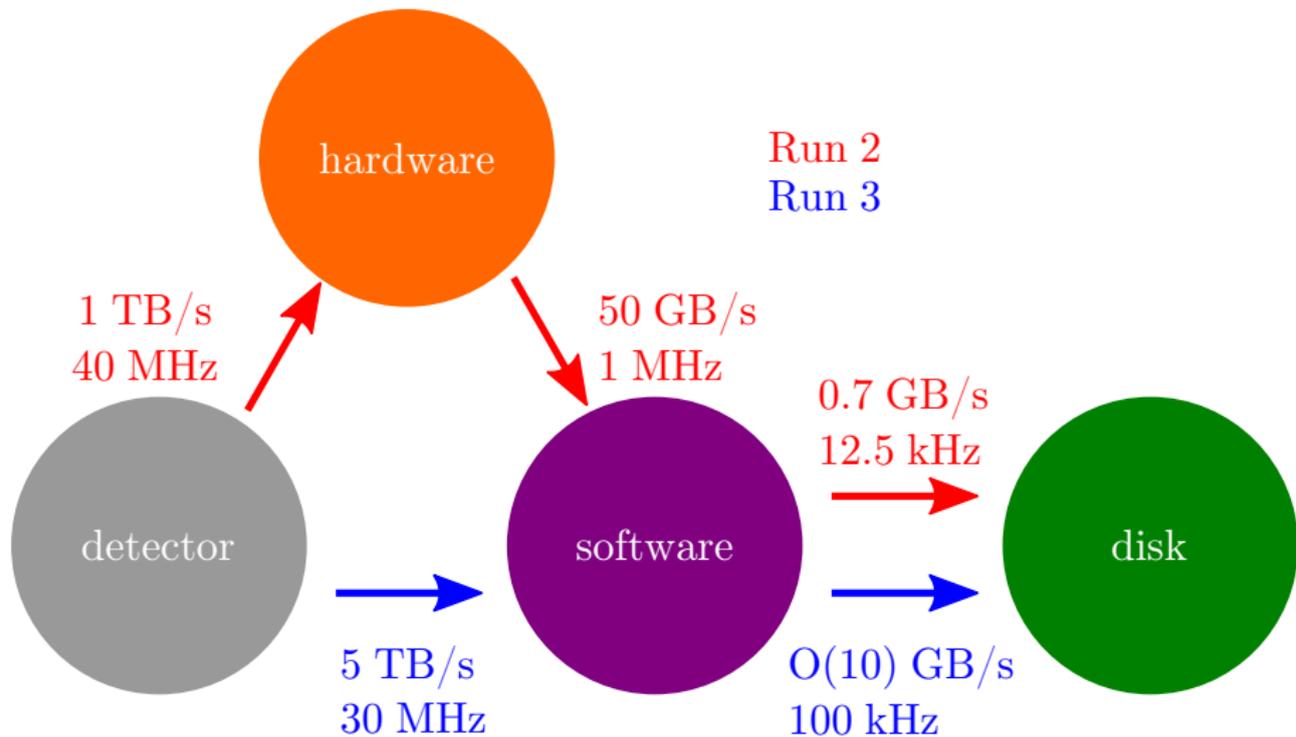
# Overview

- LHCb and current searches
- dark photon phenomenology
- dark photons at LHCb with  $D^{*0} \rightarrow D^0 A'[ee]$
- dark photons at LHCb with inclusive  $A'[\mu\mu]$

# LHCb



- momentum resolution between 0.5% at 5 GeV to 1% at 200 GeV
- mass resolution of  $\approx 0.4\%$
- impact parameter resolution of 13 – 20  $\mu\text{m}$  for tracks
- secondary vertex precision of 0.01 – 0.05(0.1 – 0.3) mm in  $xy(z)$



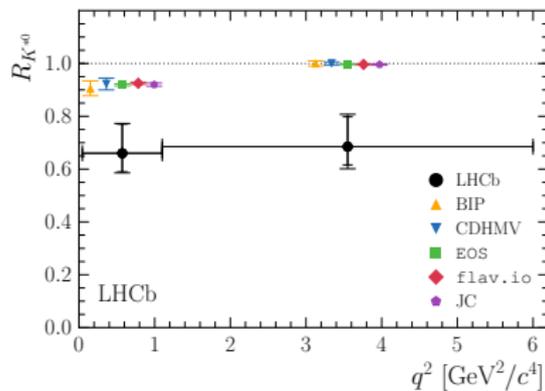
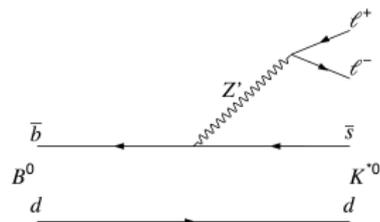
- projected luminosity per run

LHC era				HL-LHC era	
Run 1(a) 2011	Run 1(b) 2012	Run 2 2015 - 2019	Run 3 2021 - 2023	Run 4 2027 - 2029	Run 5 2031 - ?
1 fb <sup>-1</sup>	2 fb <sup>-1</sup>	5 fb <sup>-1</sup>	15 fb <sup>-1</sup>	23 fb <sup>-1</sup>	300 fb <sup>-1</sup> ?

- heavy ion and **fixed target** data
- LHCb upgrade during LS 2
  - LHCb-PUB-2014-040**
  - replacement of readouts and photo-detectors for the RICHs
  - replacement of tracking detectors
  - full software trigger**, see **LHCb-TDR-016**
    - currently limited by hardware readout at 1 MHz
    - upgrade will read out entire detector at 40 MHz

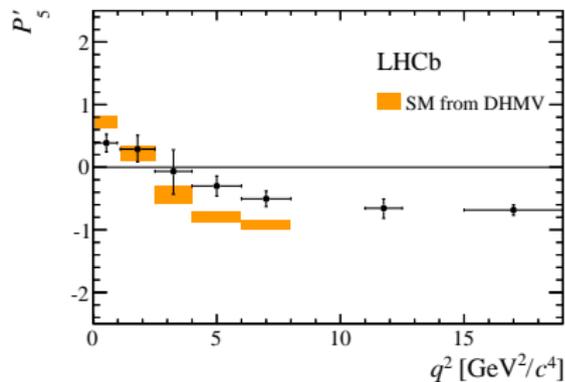
## Indirect Measurements

LHCb-PAPER-2017-013



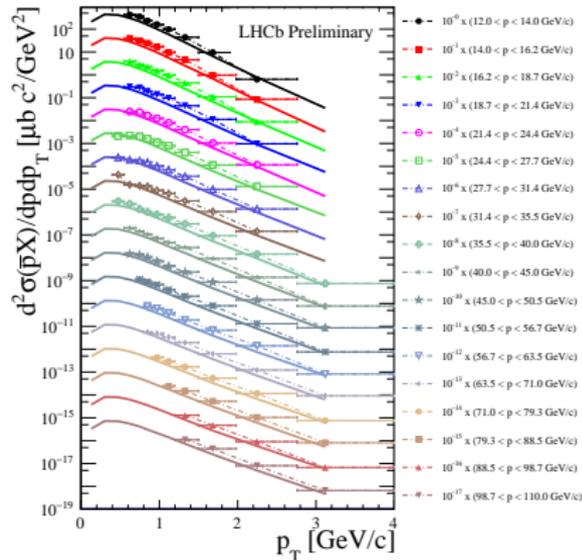
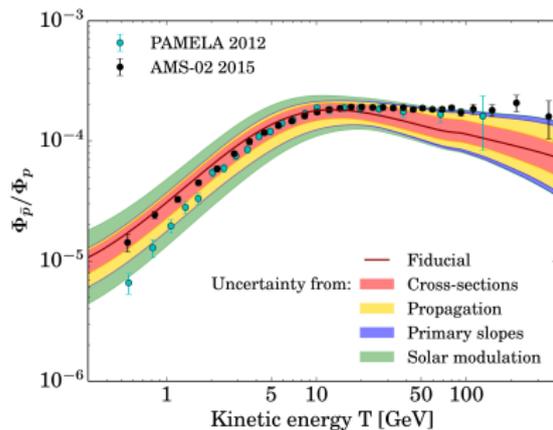
JHEP 02 (2016)

$$B^0 \rightarrow K^{*0} \mu \mu$$



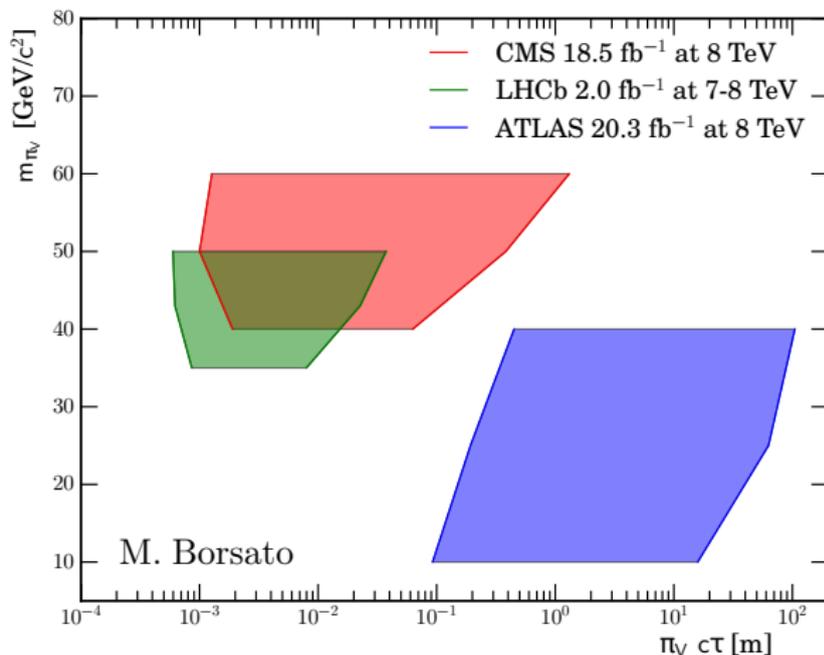
## Supporting Measurements

## LHCb-CONF-2017-002



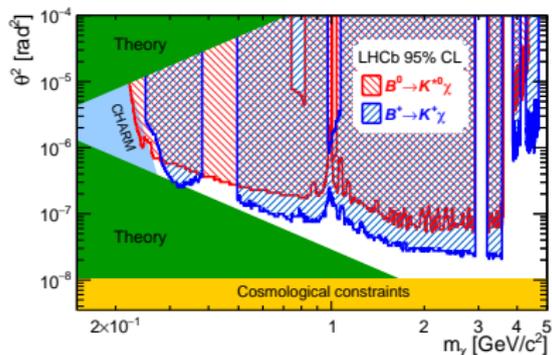
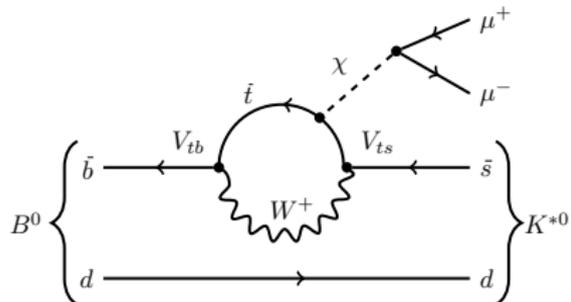
# Long Lived Particles

EPJC 75 (2015), LHCb-PAPER-2016-065,  
EPJC 76 (2016), EPJC 77 (2017)

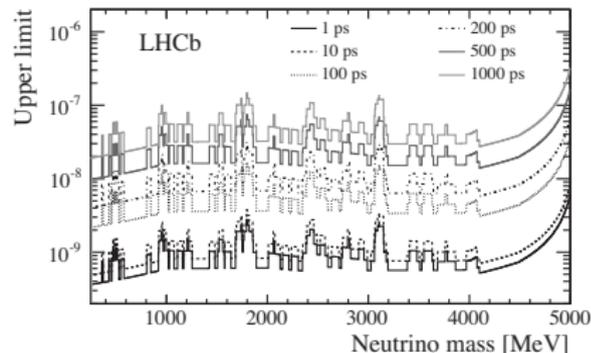
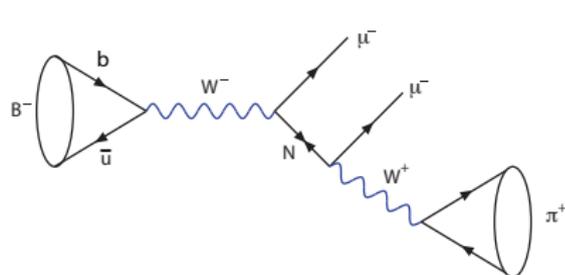


# Light Resonances

PRL 115 (2015)  
LHCb-PAPER-2016-052



PRL 112 (2014)



# Bottom Line

- *don't judge a fish by its ability to climb a tree*
- **areas where LHCb cannot compete**
  - **luminosity:**  $10\times$  less luminosity than ATLAS and CMS
  - **acceptance:** 10% for 100 GeV, 1% for 1 TeV, ...
- **areas where LHCb does well**
  - **flavor:** anything that requires PID other than pions/leptons
  - **displaced:** 50 fs lifetime resolution
  - **narrow:** 0.4% mass resolution
  - **trigger:** flexible with real time calibration and full reconstruction

# Dark Photons

# Properties

## 1 production

- electron-positron annihilation
- hadron decays
- electron scattering

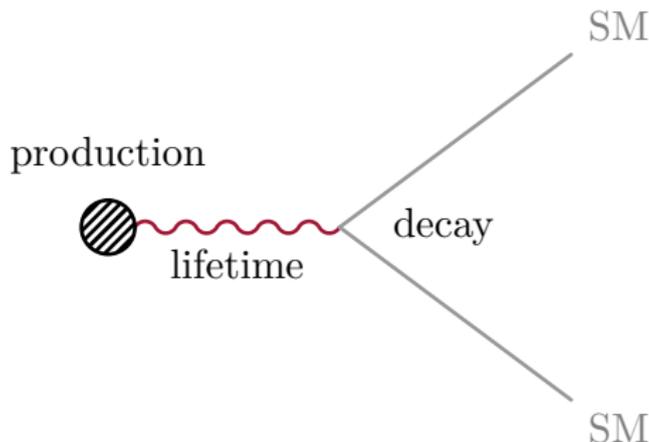
## 2 lifetime

- *prompt* or *displaced*

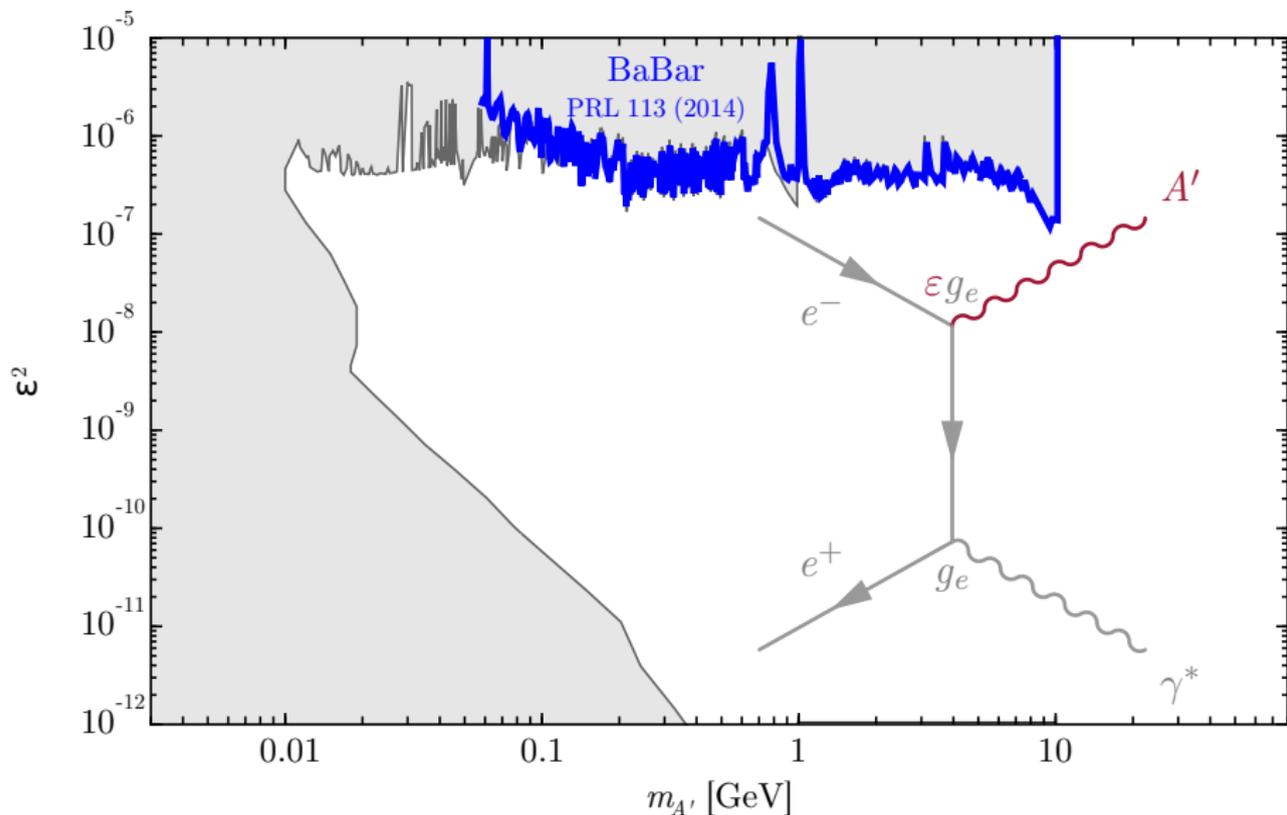
$$\tau(\varepsilon, m_{A'}) = \frac{\hbar}{\Gamma_{A'}(\varepsilon, m_{A'})}$$

## 3 decay

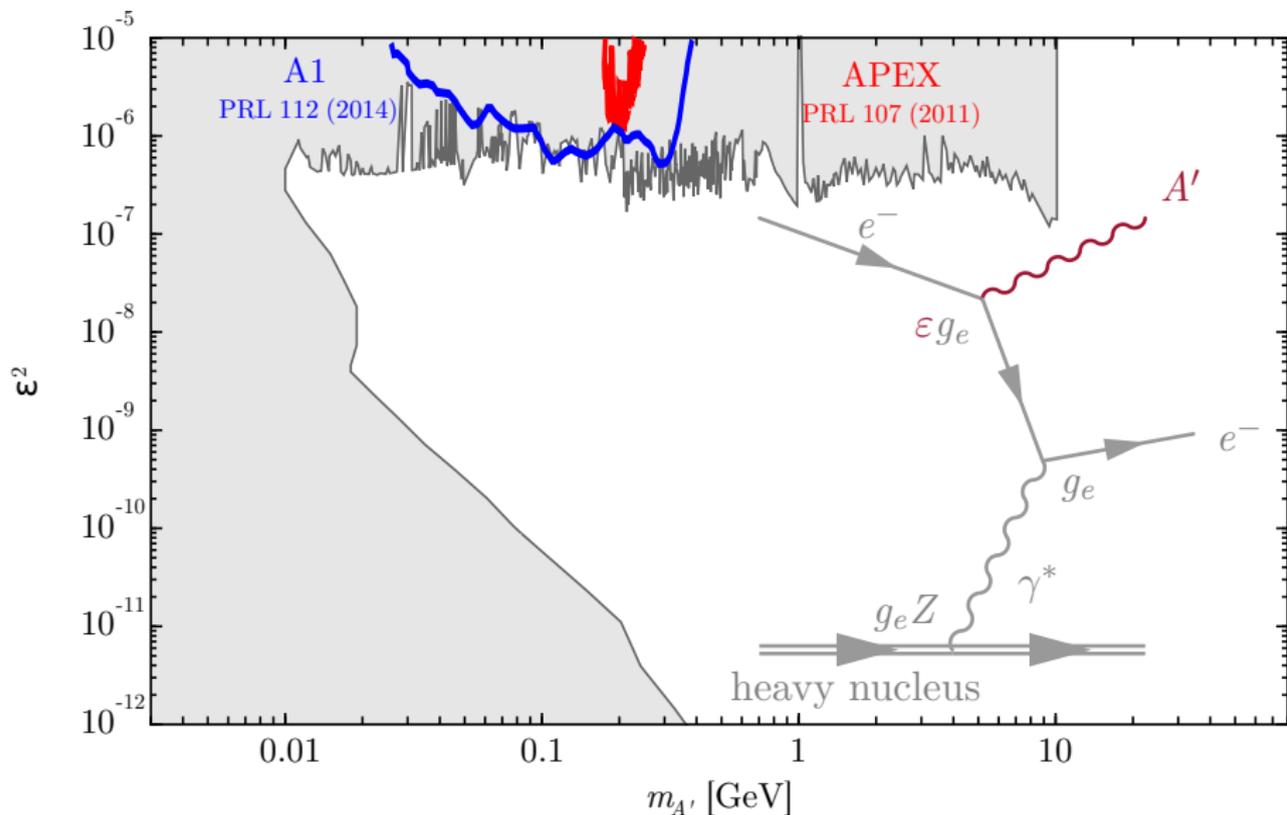
$$\text{BR}_{A' \rightarrow X}(m_{A'}) = \frac{\Gamma(\varepsilon, m_{A'})_{A' \rightarrow X}}{\Gamma_{A'}(\varepsilon, m_{A'})}$$



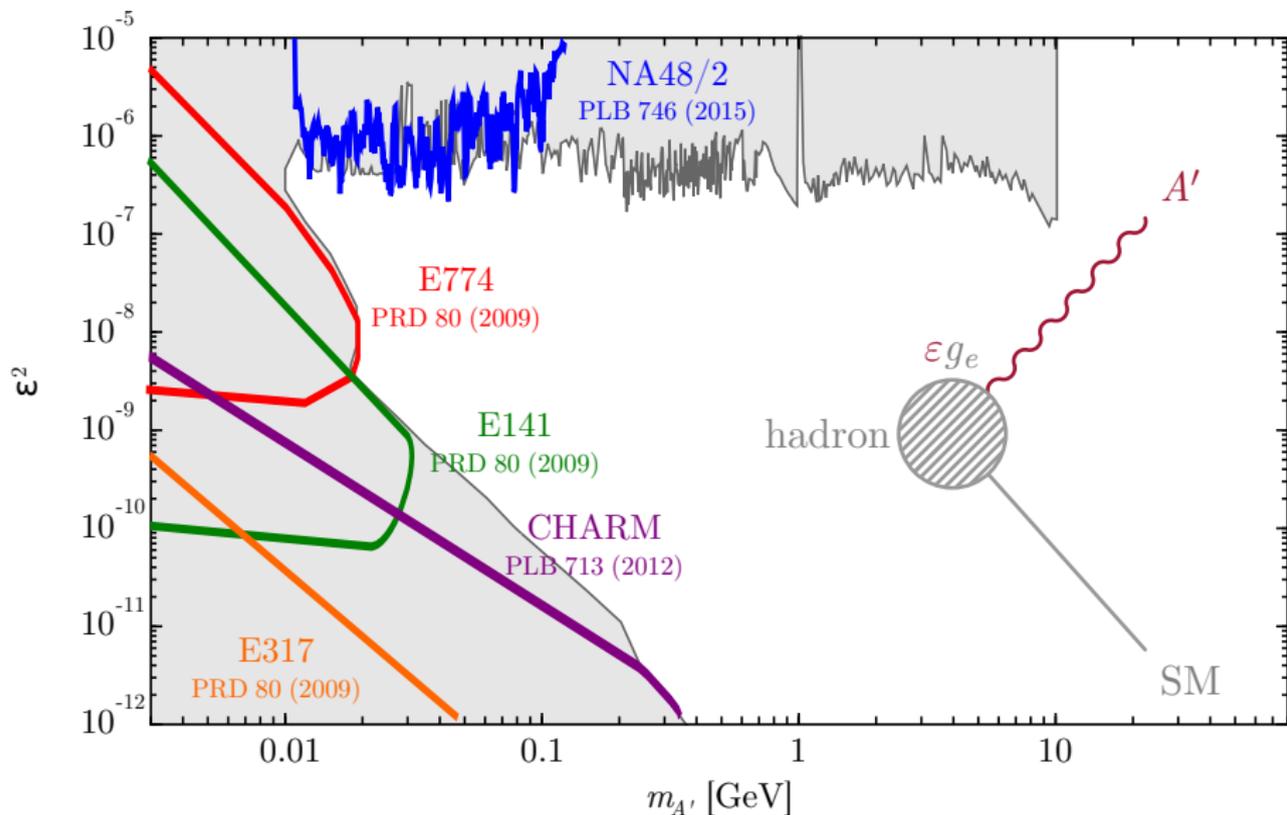
## Production: Electron-Positron Annihilation



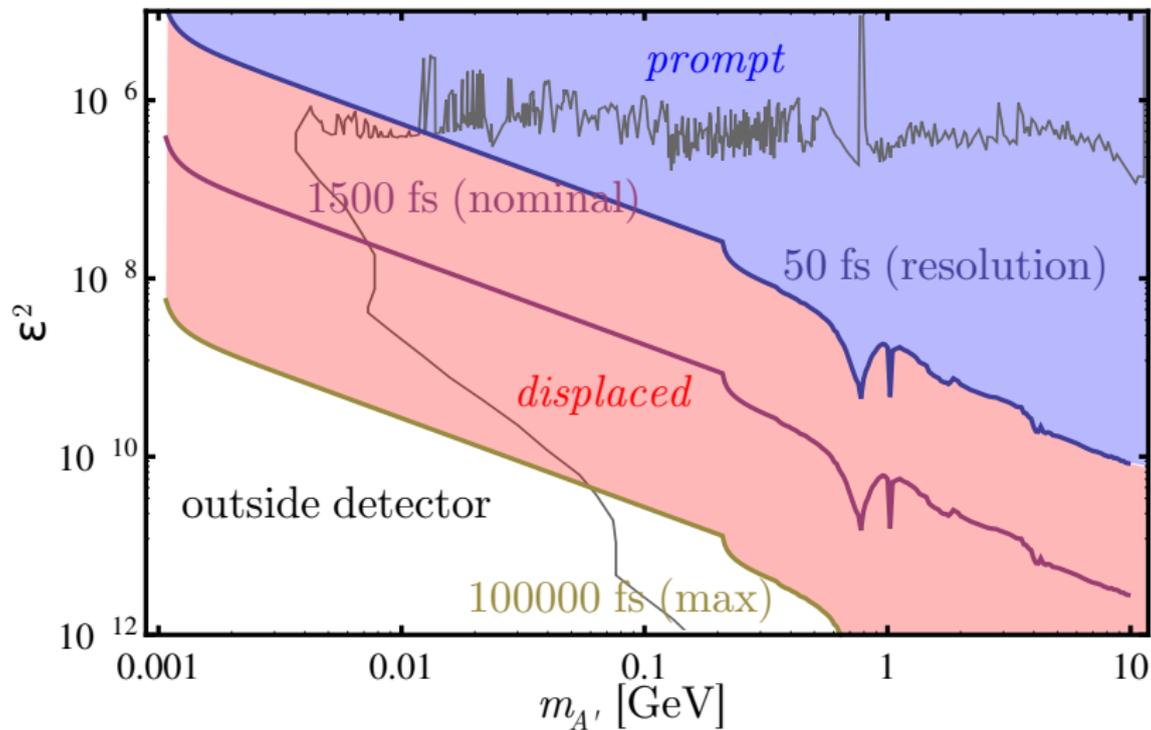
## Production: Electron Scattering



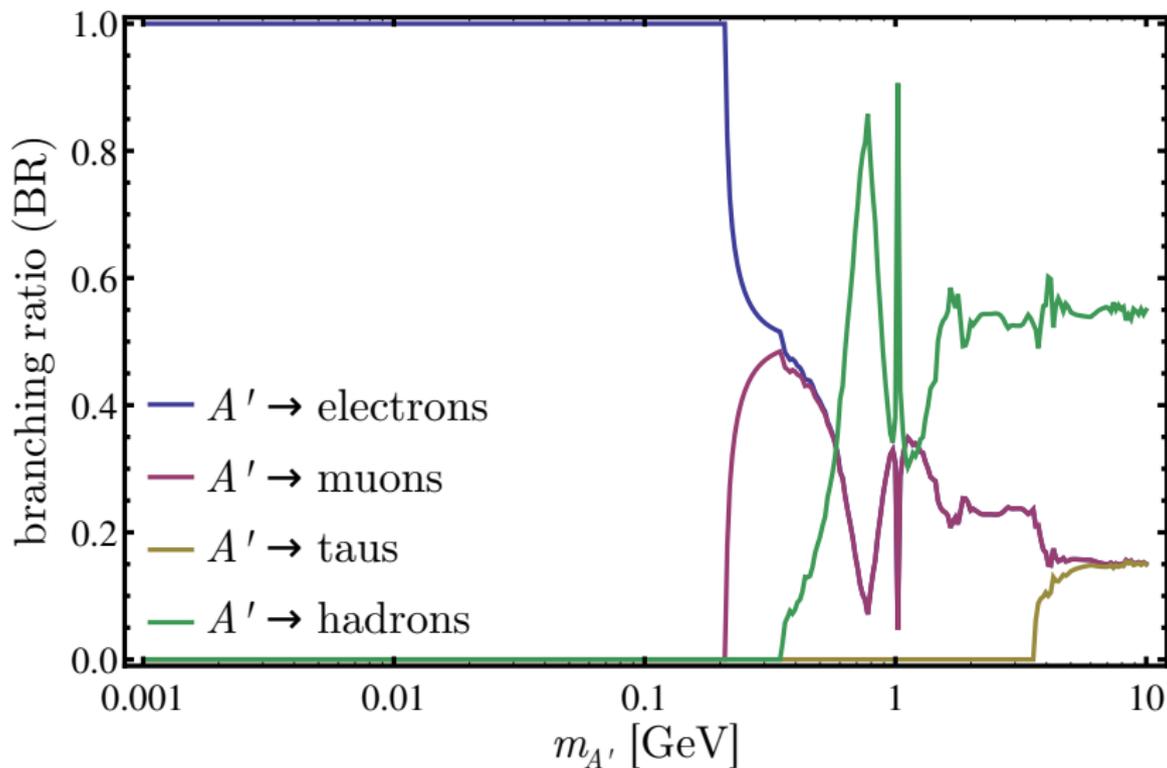
## Production: Hadron Decays



## Lifetime



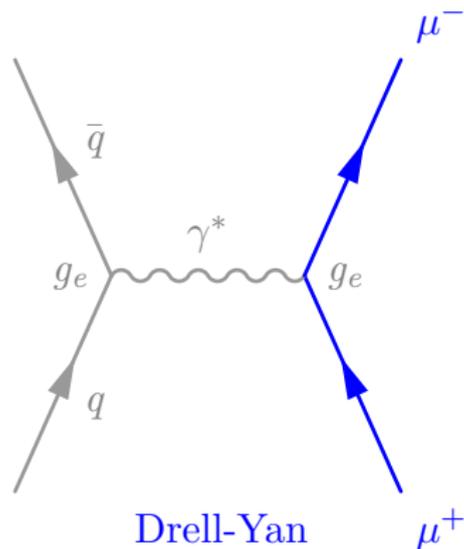
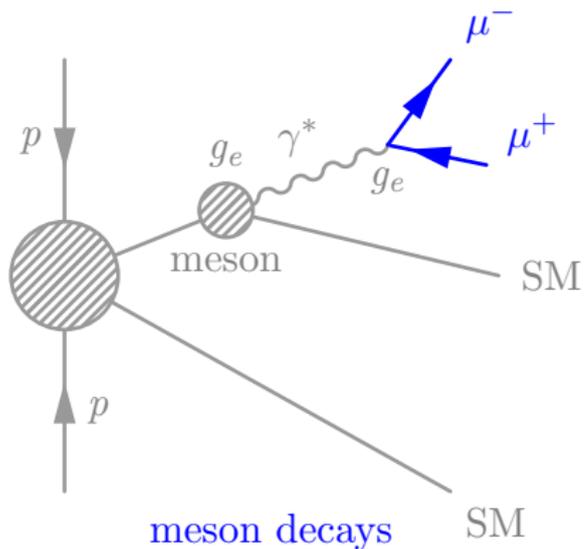
## Decay

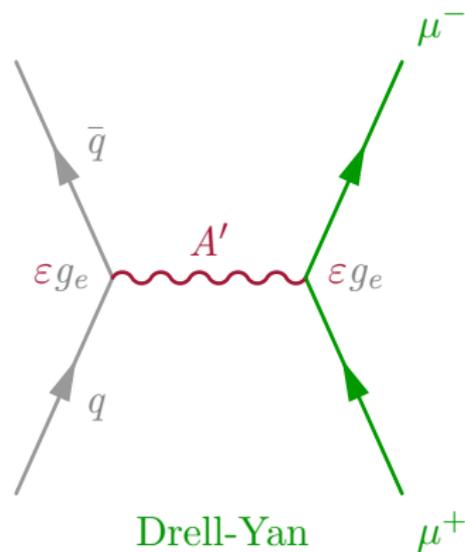
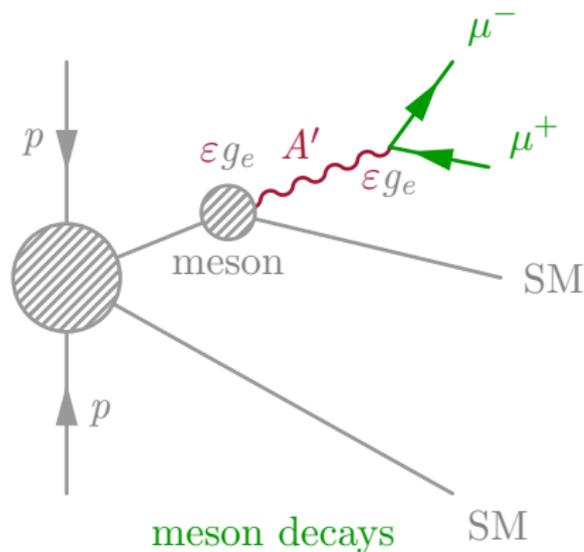


# Future Dark Photon Searches

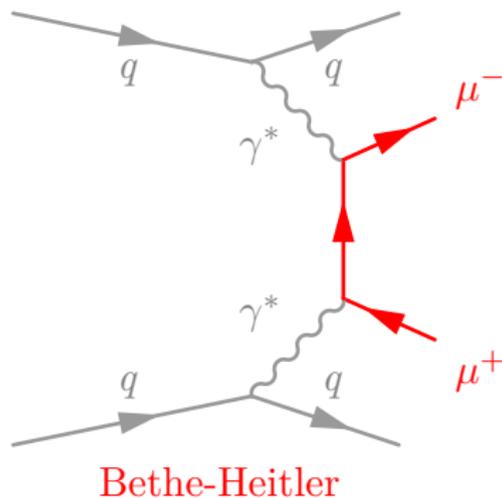
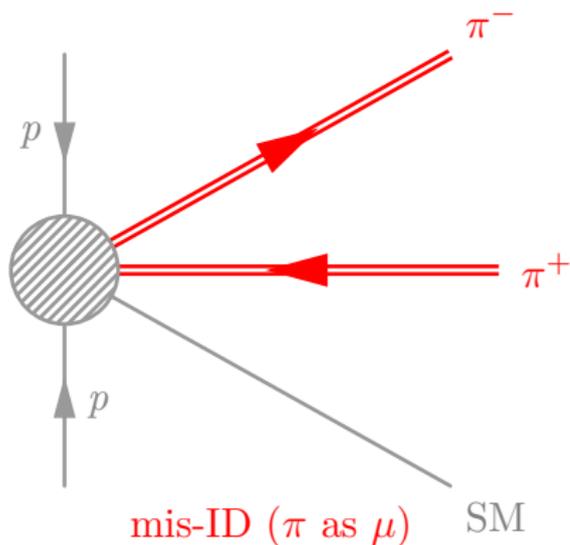
inclusive  $A'[\mu\mu]$

PRL 116 (2016): PI, Soreq, Thaler, Williams, Xue

Good Backgrounds (*prompt*)

Signal (*prompt and displaced*)

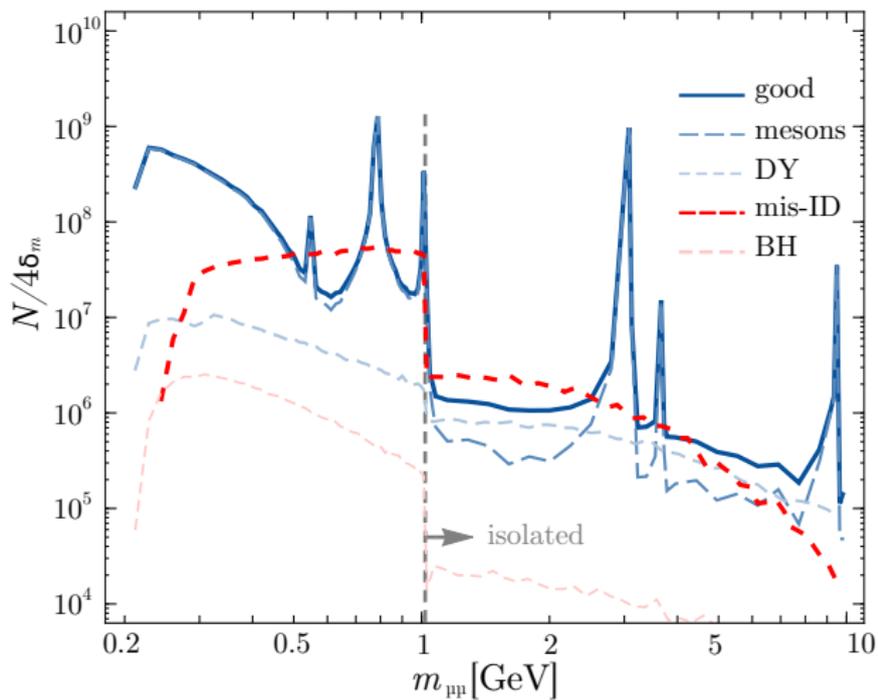
$$N_{\text{signal}} \approx \frac{\pi \epsilon^4 m_{A'}^2}{8 \Gamma_{A'}(\epsilon, m_{A'}) \delta_m} N_{\text{good}} \text{ per } 4 \delta_m, \quad \delta_m \approx 0.4\% m$$

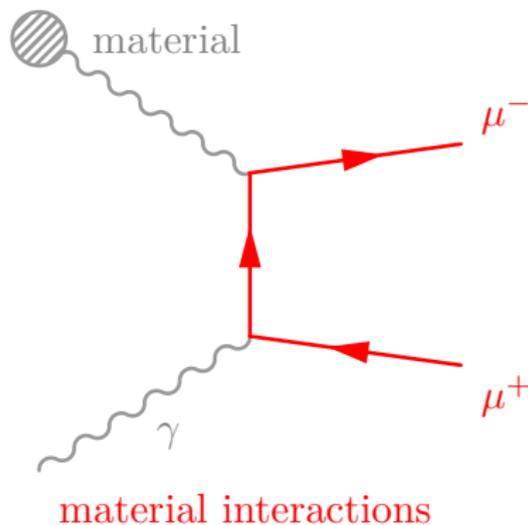
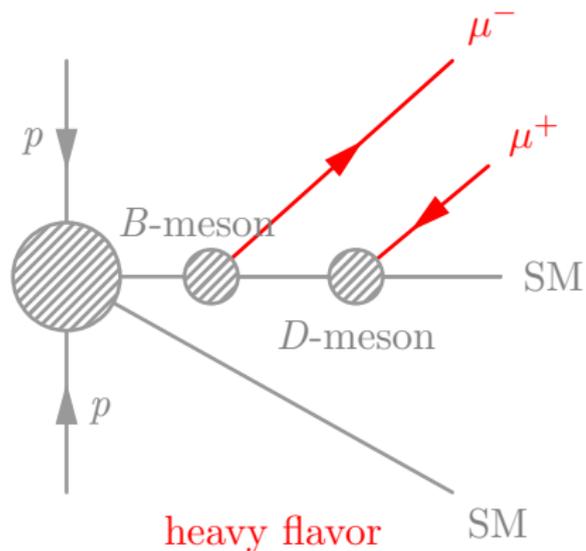
Bad Backgrounds (*prompt*)

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

LHCb **mis-ID** probability  $\approx 1$  out of 1000

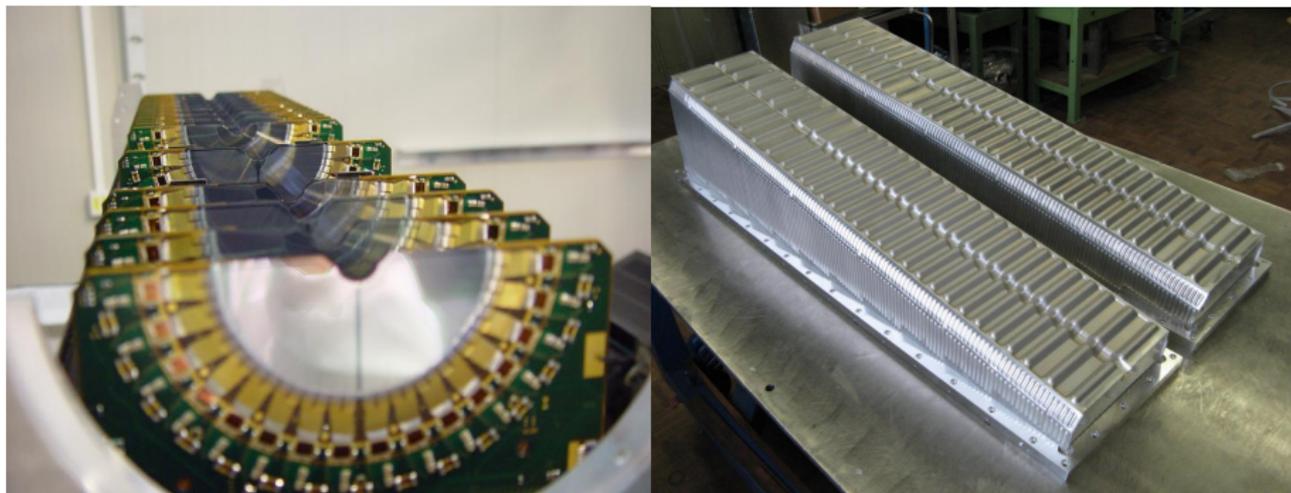
# Prompt Production



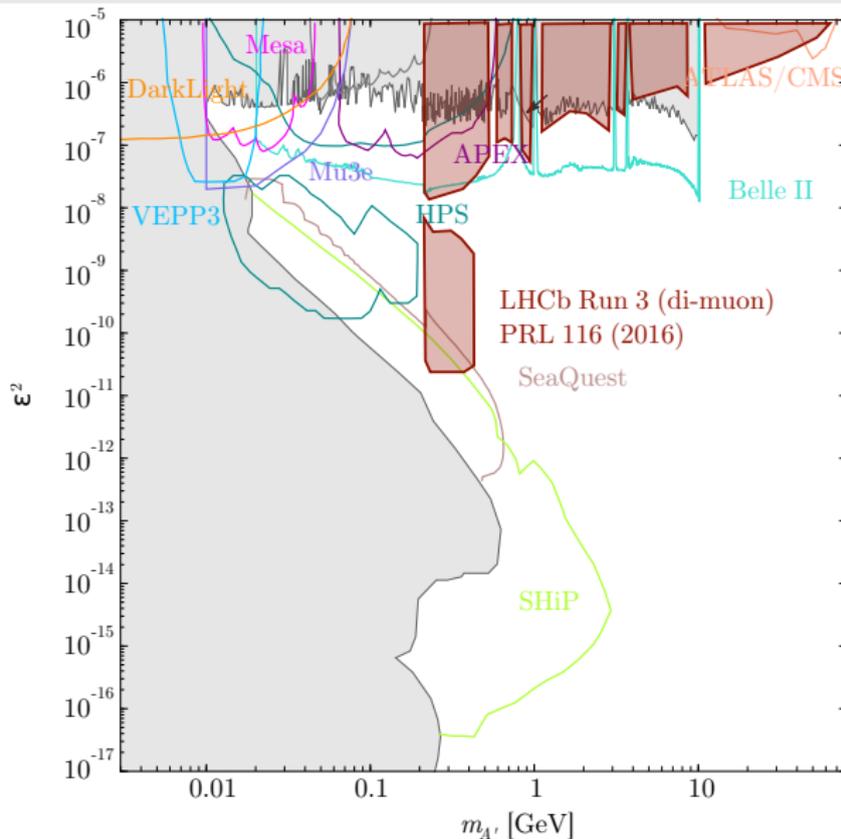
Bad Backgrounds (*displaced*)

$$N_{\text{heavy}} \approx 10000 \text{ per } 4\delta_m$$

# Material



## Reach

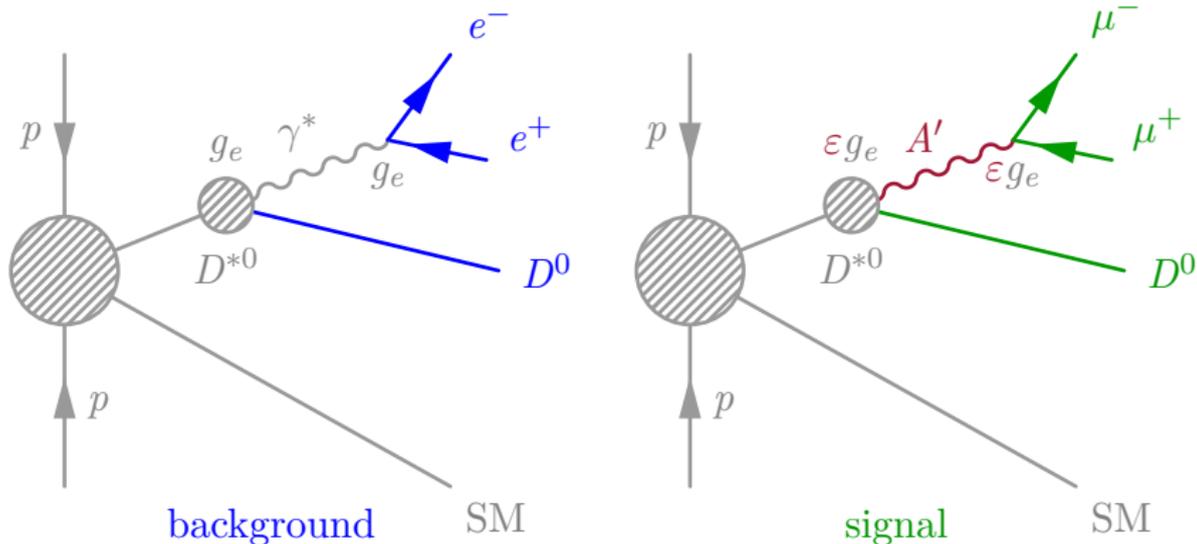


# Future Dark Photon Searches

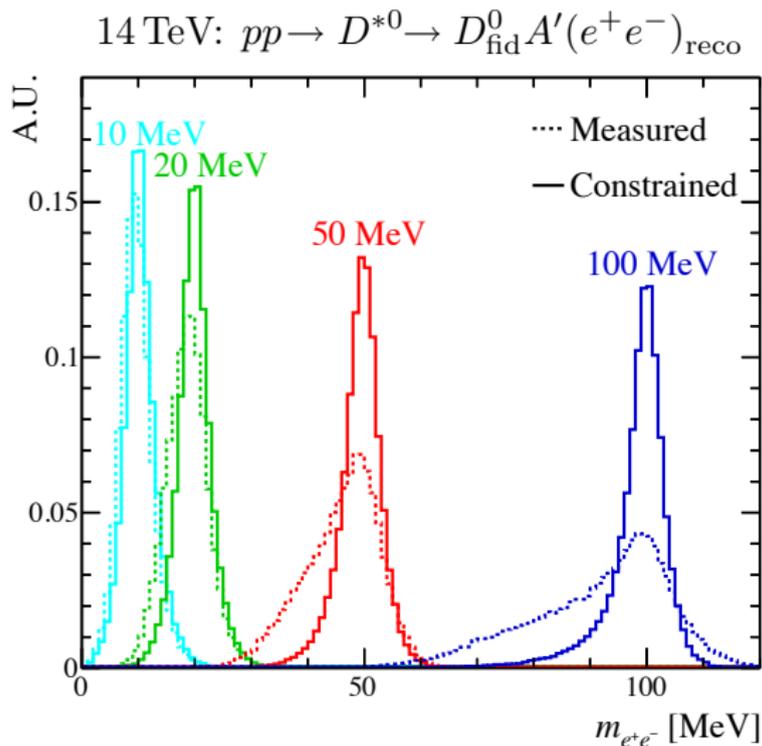
$$D^{*0} \rightarrow D^0 A'[ee]$$

PRD 92 (2015): PI, Thaler, Williams, Xue

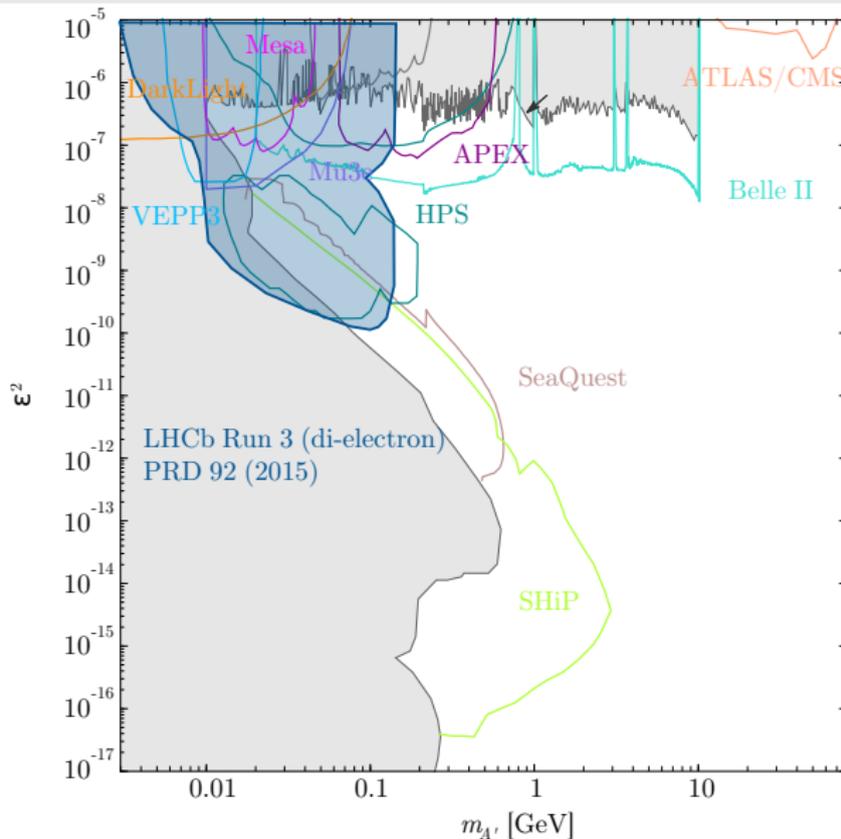
# Good Background and Signal



# Mass Resolution

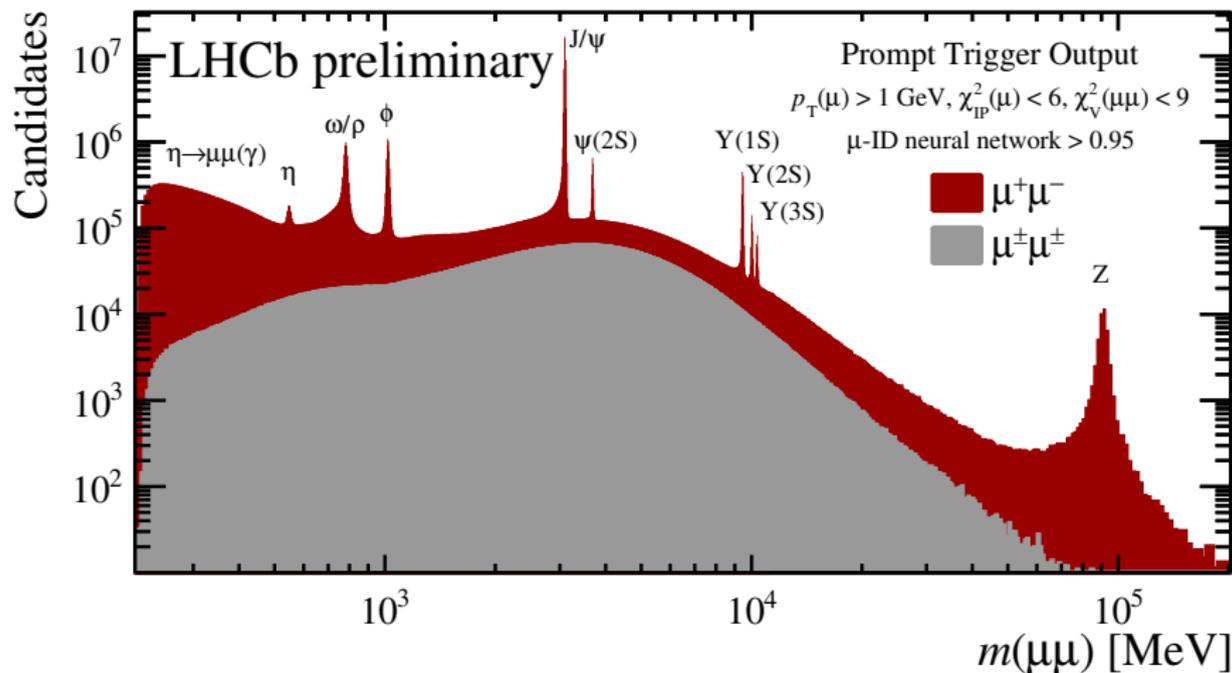


## Reach

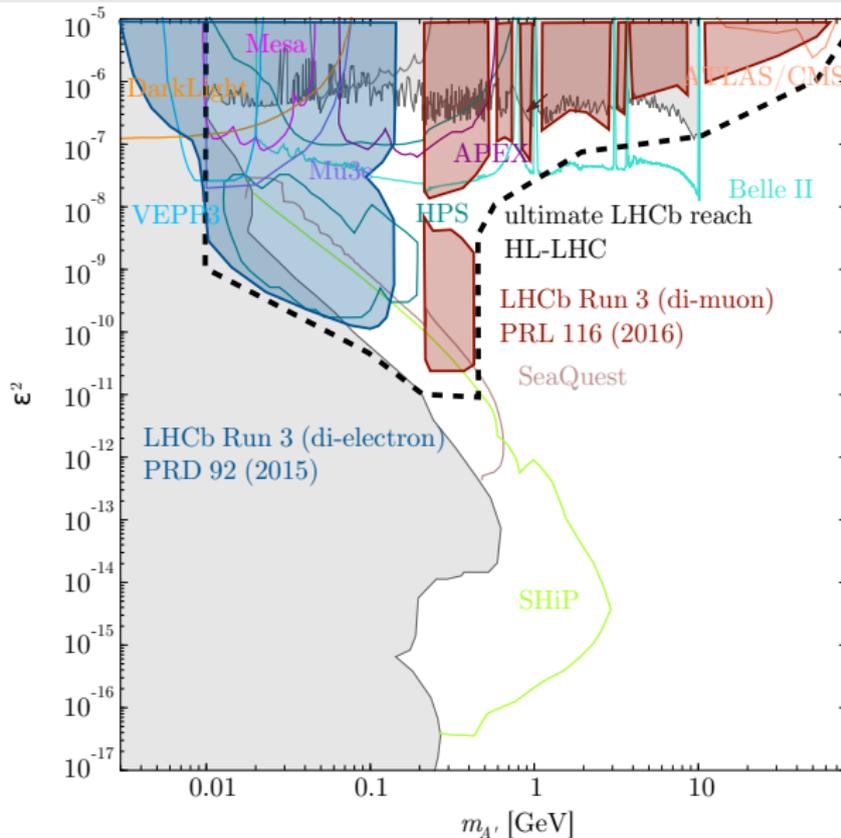


# Conclusion

## Real Data



## Full Reach



# Outlook

- LHCb has a maturing dark matter program
- inclusive  $A'[\mu\mu]$  analysis underway
  - prompt data matches predictions
  - displaced backgrounds under control
- validation of  $D^{*0} \rightarrow D^0 A'[ee]$  strategy begun
- focus on LHCb strengths for new analyses
  - **flavor**: anything that requires PID other than pions/leptons
  - **displaced**: 50 fs lifetime resolution
  - **narrow**: 0.4% mass resolution
  - **trigger**: flexible with real time calibration and full reconstruction

Thank you!