Theory Ideas for LHCb: Dark Shower

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LLP search: why LHCb?

ATLAS/CMS have 20x higher luminosity,

10x larger angular coverage, and much bigger detectors

What kind of LLP signatures are easier to probe @ LHCb?

One example: dark shower signals

Dark shower signal with light/soft dark hadrons

decay hadronically within ~ m distance

Pretty generic in BSM models generating dark showers!

What's in the dark?

Standard Model

U(1)

$SU(2)_L$

$SU(3)_c$

leptons

quarks

Higgs

Hidden Sector

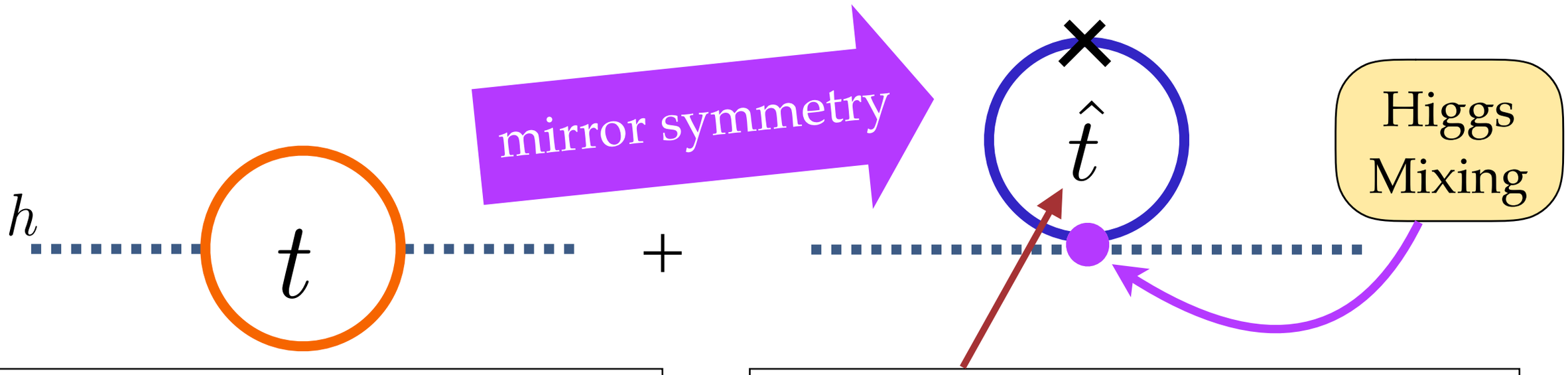
Hidden Force

dark photon?

dark QCD?

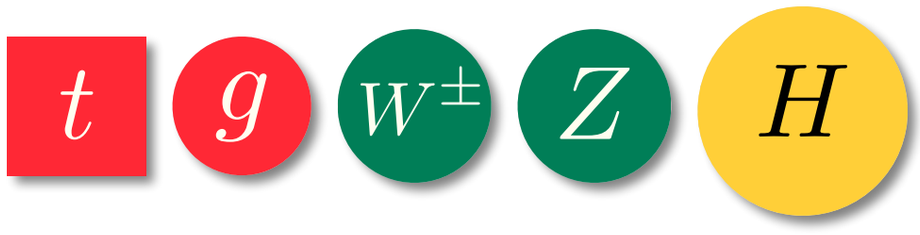
One example: **Twin Higgs**

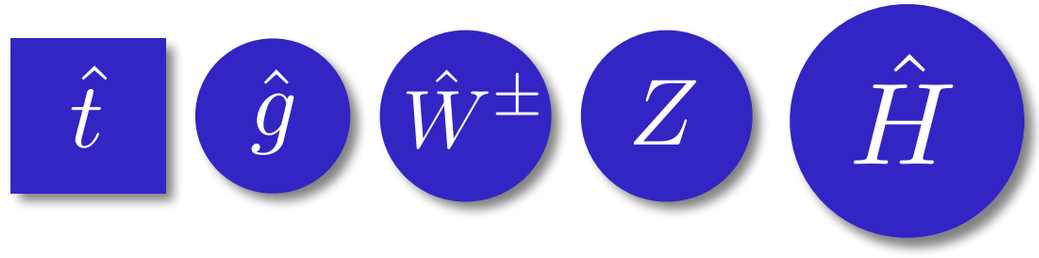
Chacko, Goh, Harnik (2005)



Top
carries SM gauge charges

Mirror top
carries **mirror gauge** charges

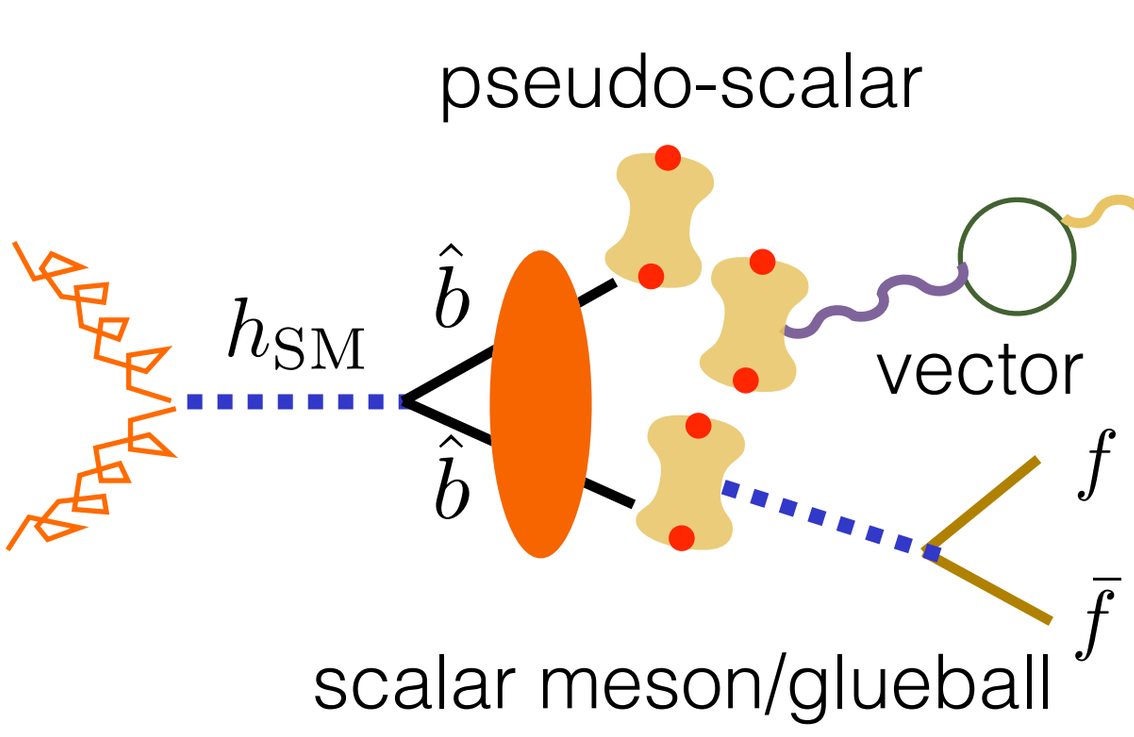




Mirror copy of the relevant particles

One example: **Twin Higgs**

Chacko, Goh, Harnik (2005)



through photon mixing

Cheng, Jung, Salvioni, YT (15′)

through Higgs portal

Craig, Katz, Strassler, Sundrum (15′)

Curtin, Verhaaren (15′)

Cheng, Jung, Salvioni, YT (15′)

Low pT final states

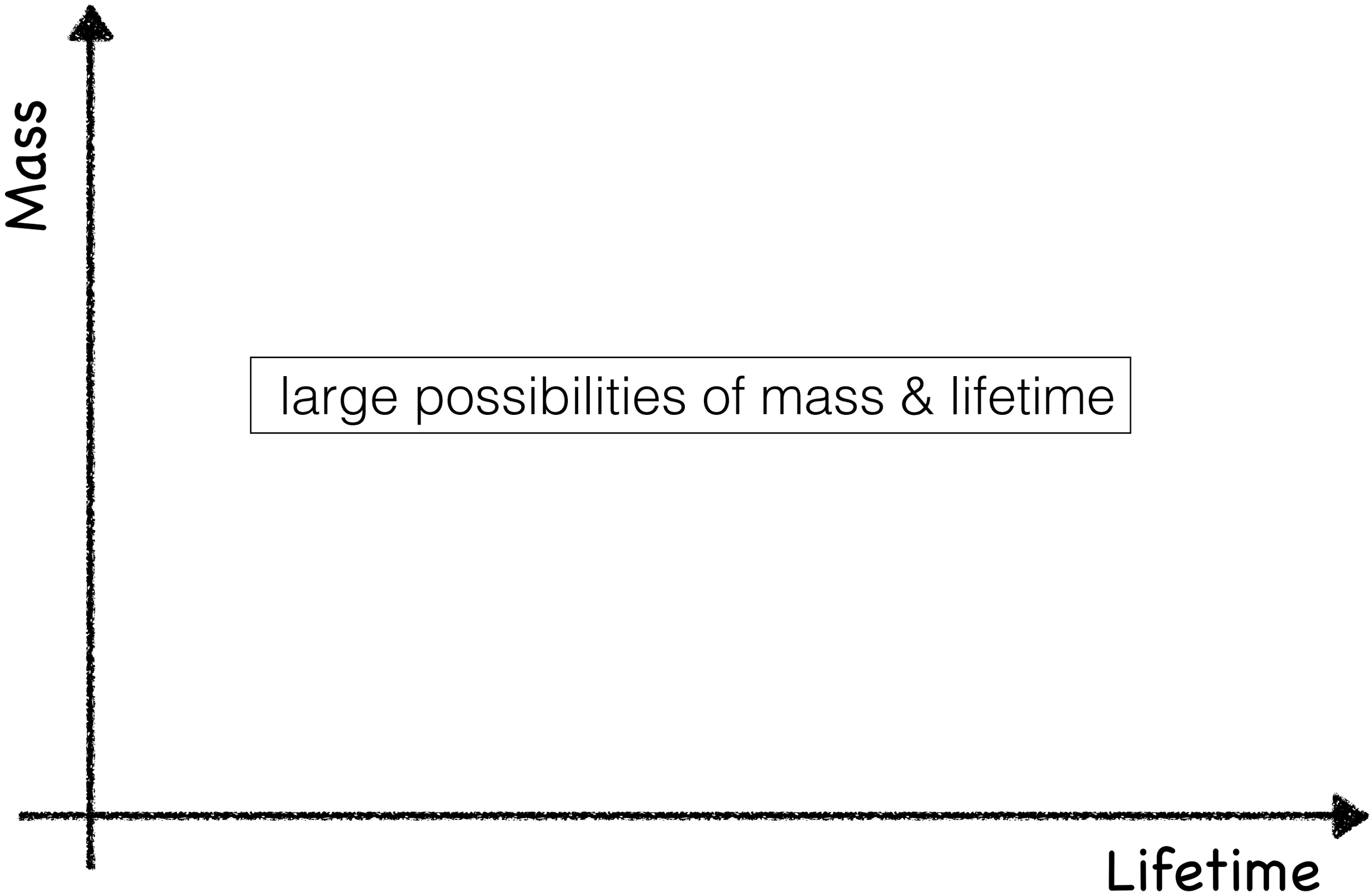
If Higgs decays into > 4 dark mesons,

each of the decay final state has pT < 10 GeV

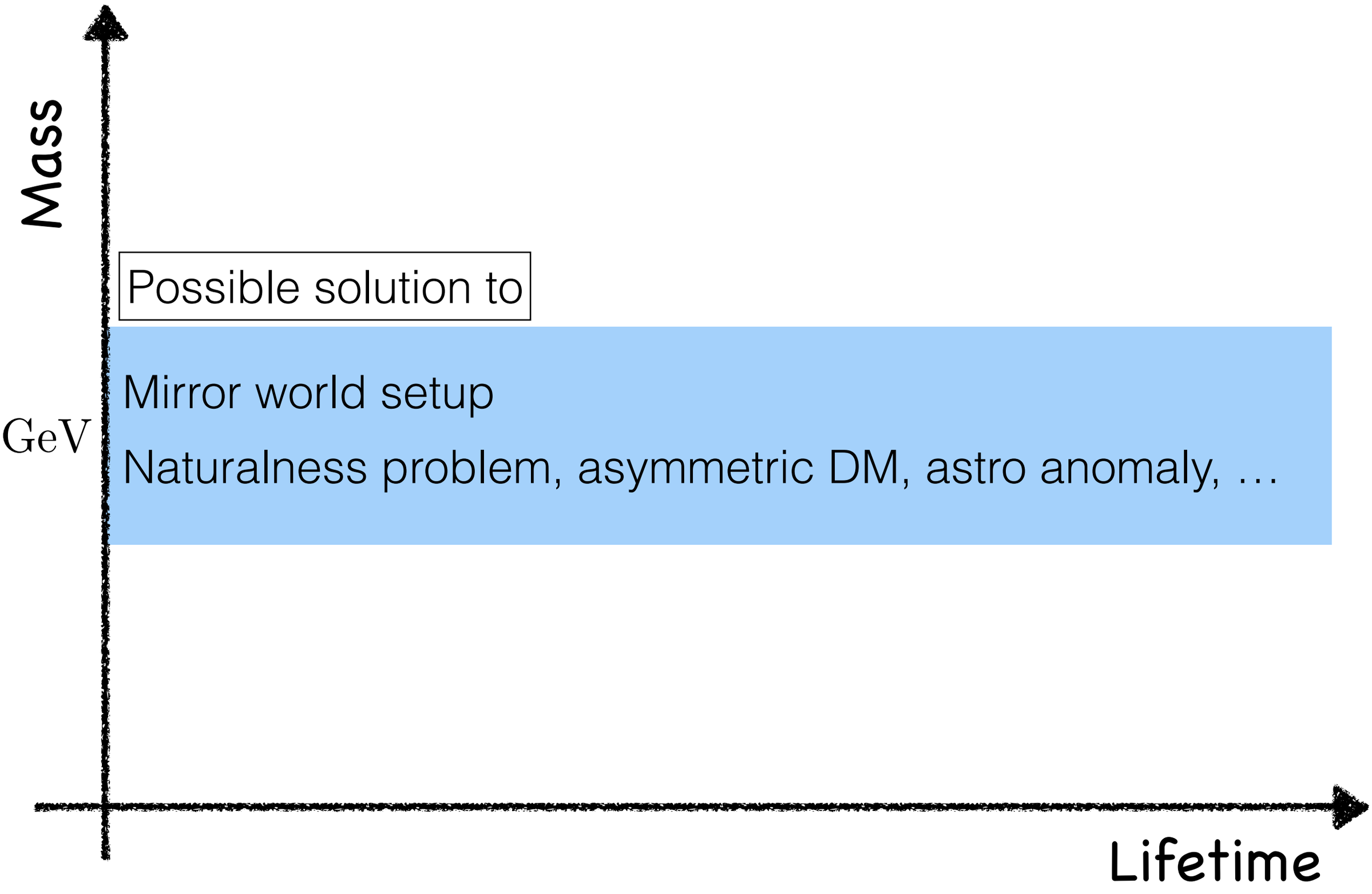
Easy to get low pT signals from dark hadrons

Not easy for ATLAS/CMS, but not a problem for the LHCb!

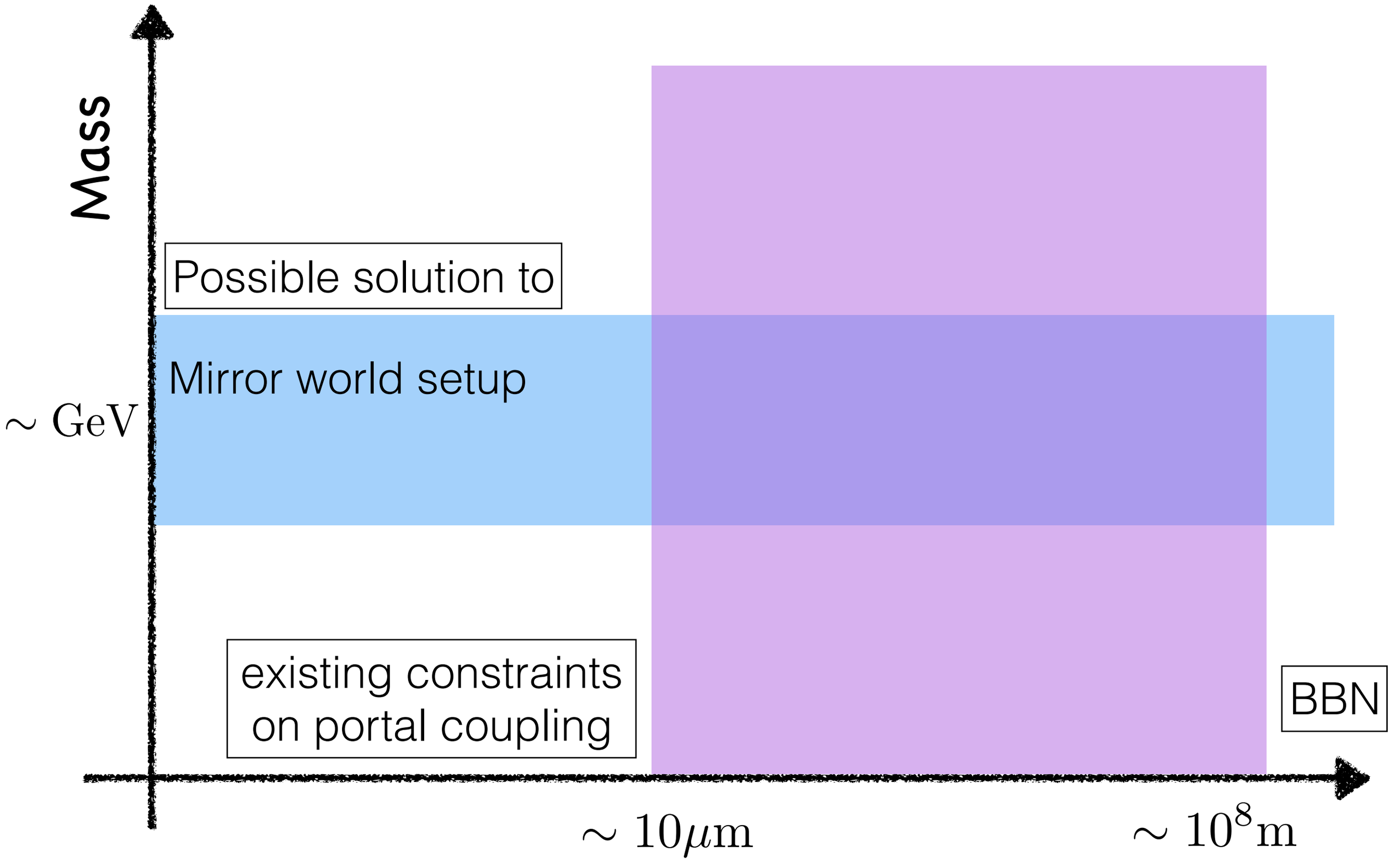
Mass / lifetime of dark mesons?



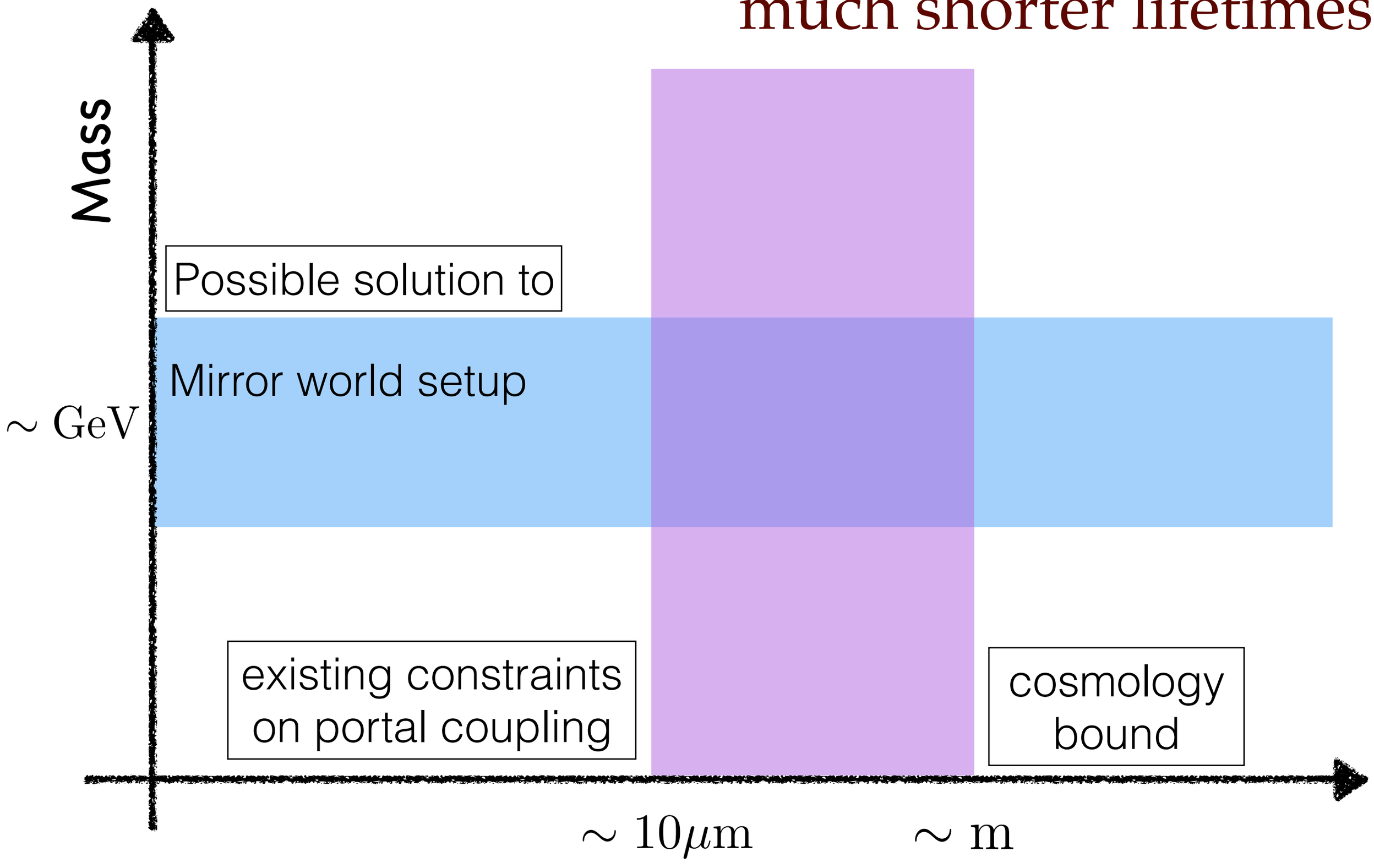
Mirror sector setup prefers ~< GeV LLP mass



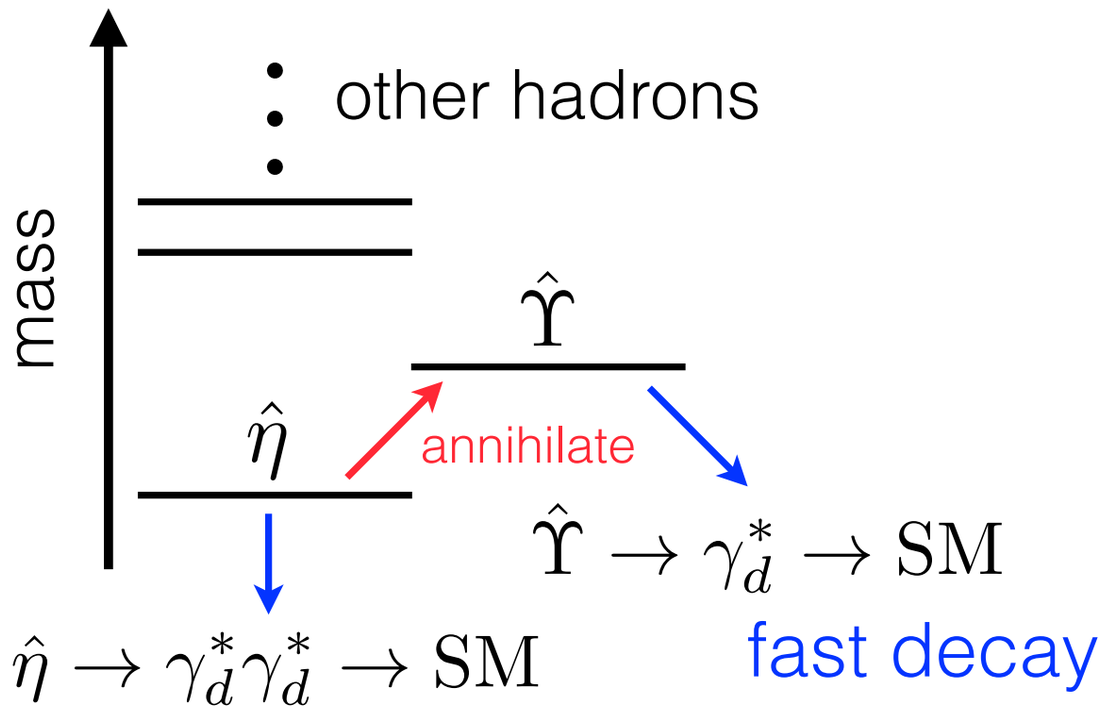
In general, lifetime can be >> LHCb size



But sometimes cosmology prefers much shorter lifetimes

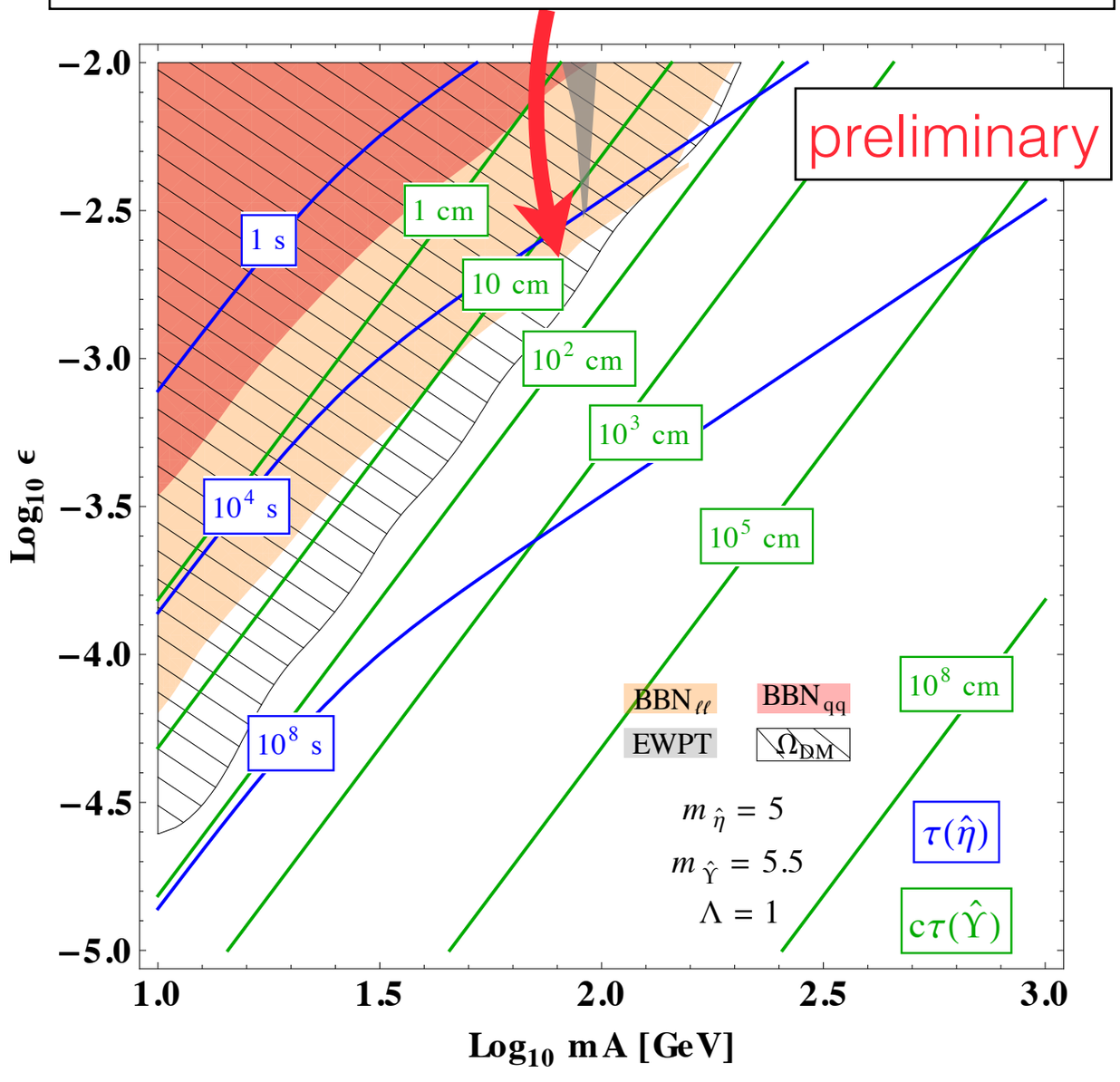


e.g., dark hadrons couple via photon mixing



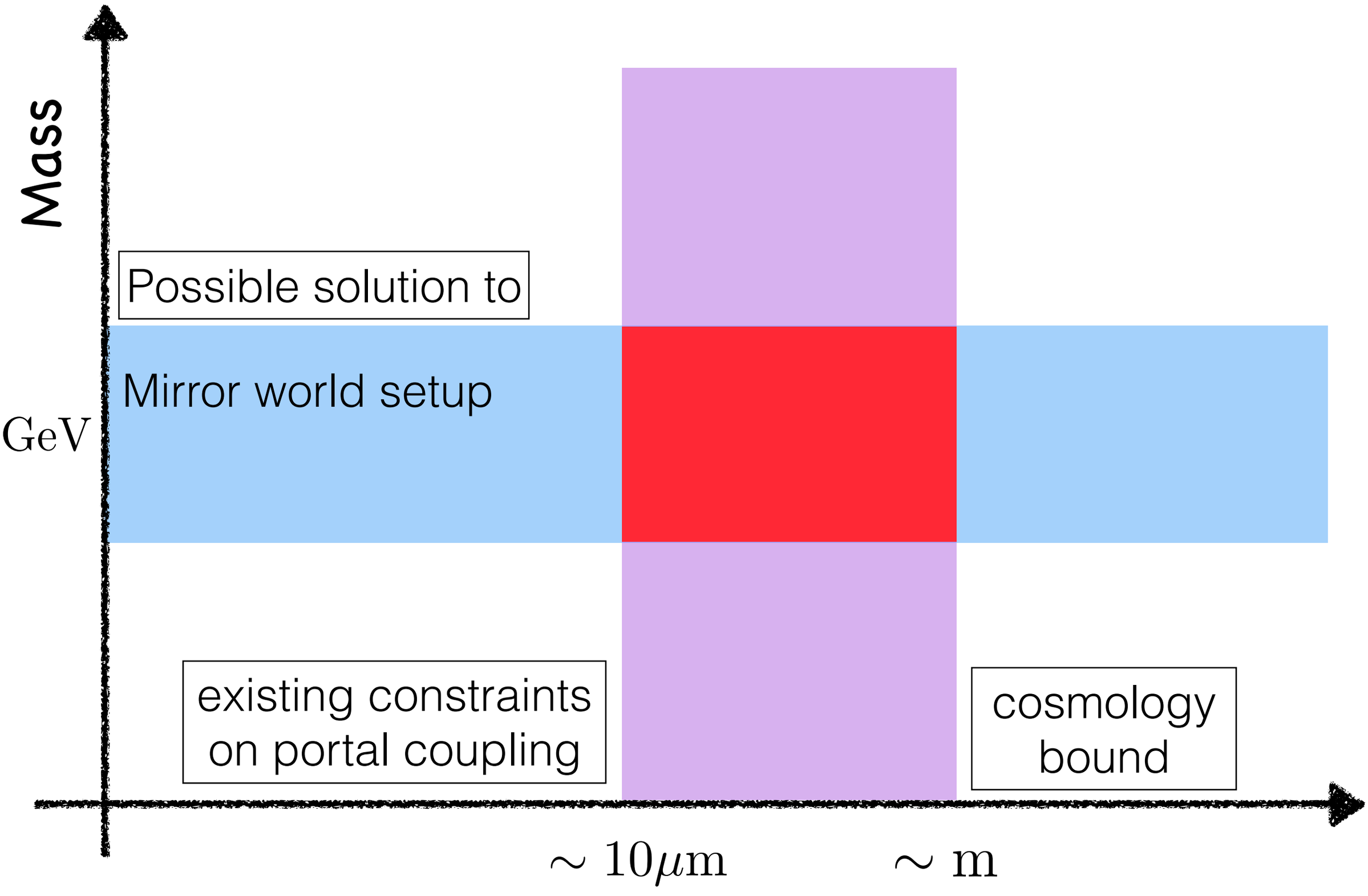
- need to annihilate the lightest state into heavier (easier to decay) states
- the heavier meson needs to decay in SM quickly while the annihilation is efficient

vector meson has a ~ m scale
upper bound on decay lifetime



Li & YT (in preparation), also see 1512.02647

LHCb VELO can be large enough



Good at constraining ~ cm scale lifetimes

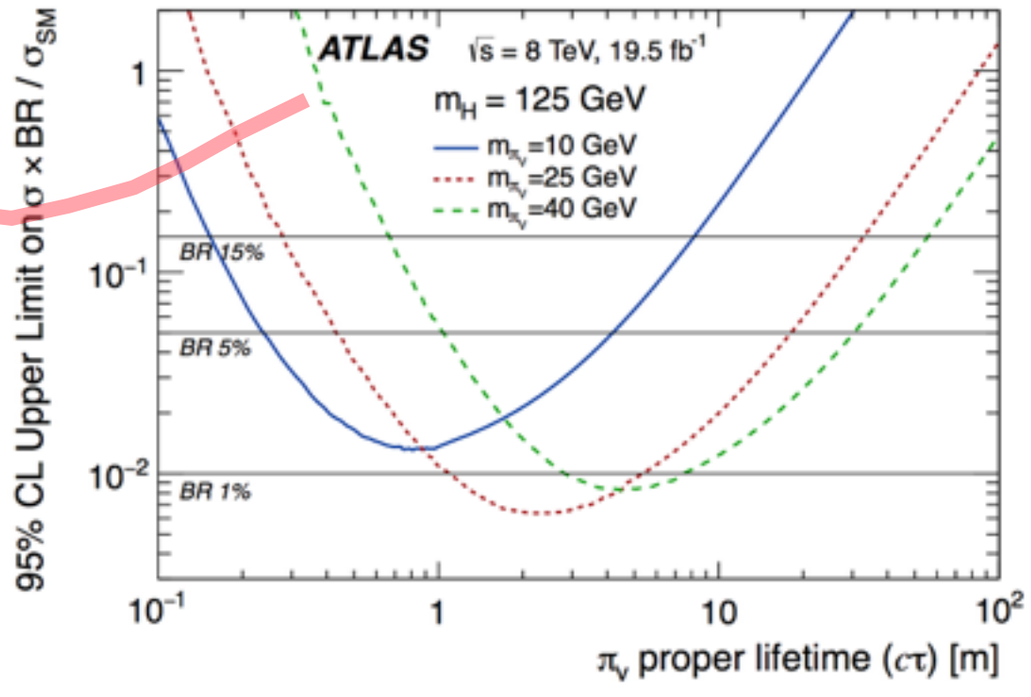
LLP to jet jet

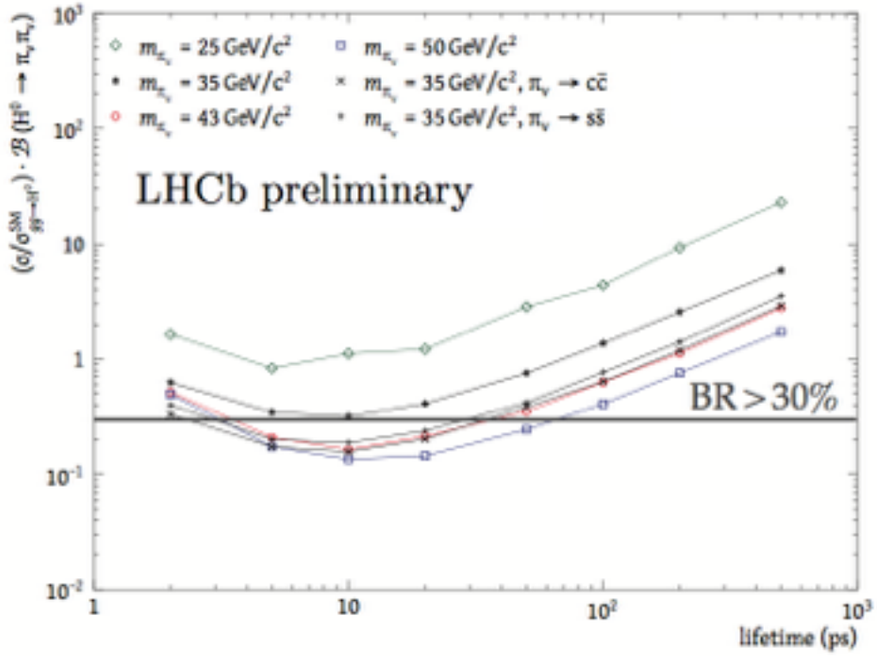
NEW

LHCb-PAPER-2016-065

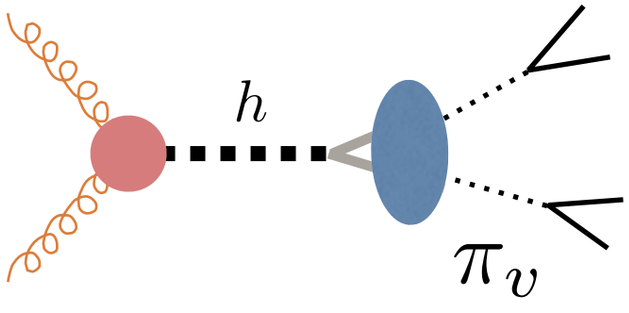
2/fb of 7 & 8 TeV data

Displaced hadronic jets ATLAS 1504.03634





~ 0.01 m



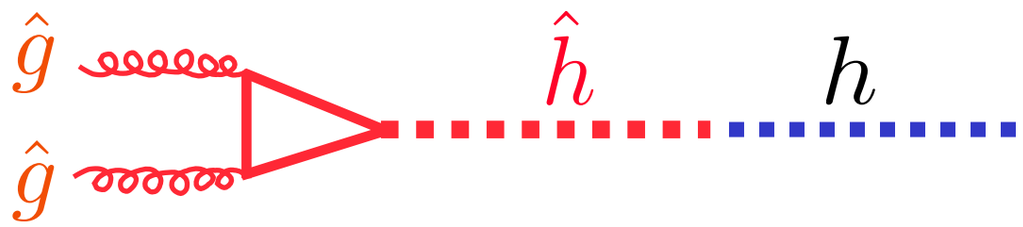
$m_{\pi_v} > 10\,\mathrm{GeV}$

Talk by Martino Borsato

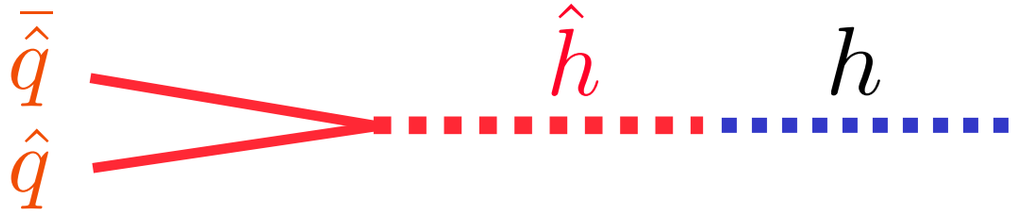
Different ``portals'' connect SM & Dark sector

Higgs portal

scalar glueball



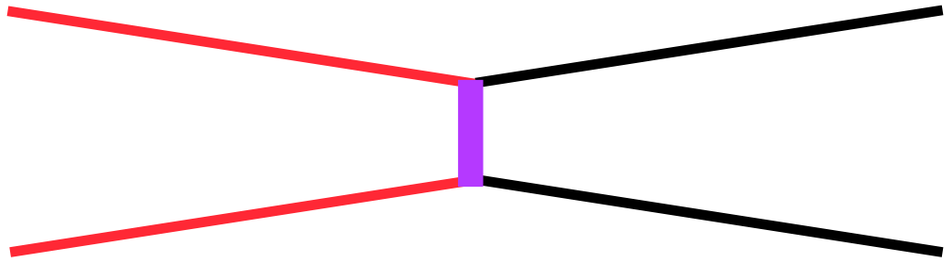
scalar meson



heavier SM fermions

colored mediator

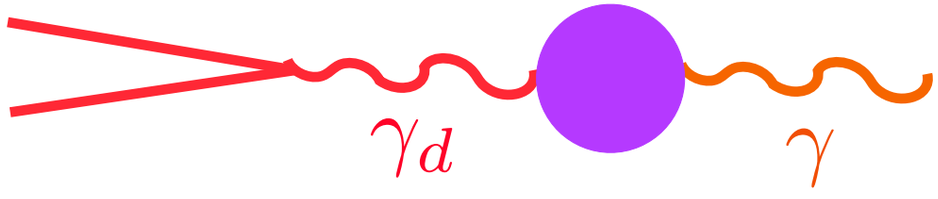
(p-)scalar meson



SM quarks

photon portal

vector meson



charged fermions (e.g., muons)

Dark hadrons can easily decay hadronically

Low mass (< 10 GeV) hadronic LLP decay is hard to search at ATLAS/CMS

In LHCb, if decay final states are hadrons that are easy to identify, such as kaons, pions, baryons,…

sub-GeV hadronic LLP decay can be achievable

Displace decay into D-mesons

Consider $D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ (9.5% Br)

$D^{0} \to K^{-}2\pi^{+}\pi^{-}$ (8% Br)

2 reconstructed D-mesons

(based on $B^0 \to D^+ D^-$ search)

1608.06620

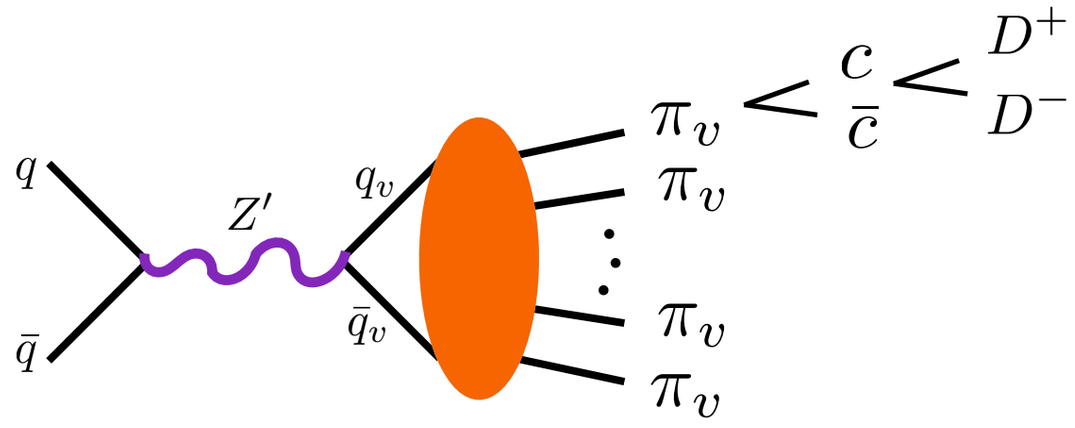
track pT > 0.1 GeV, D-meson HT > 1.8 GeV

DV p > 10 GeV, total D-meson pT > 5 GeV

$\ell > 10 c\tau_D$

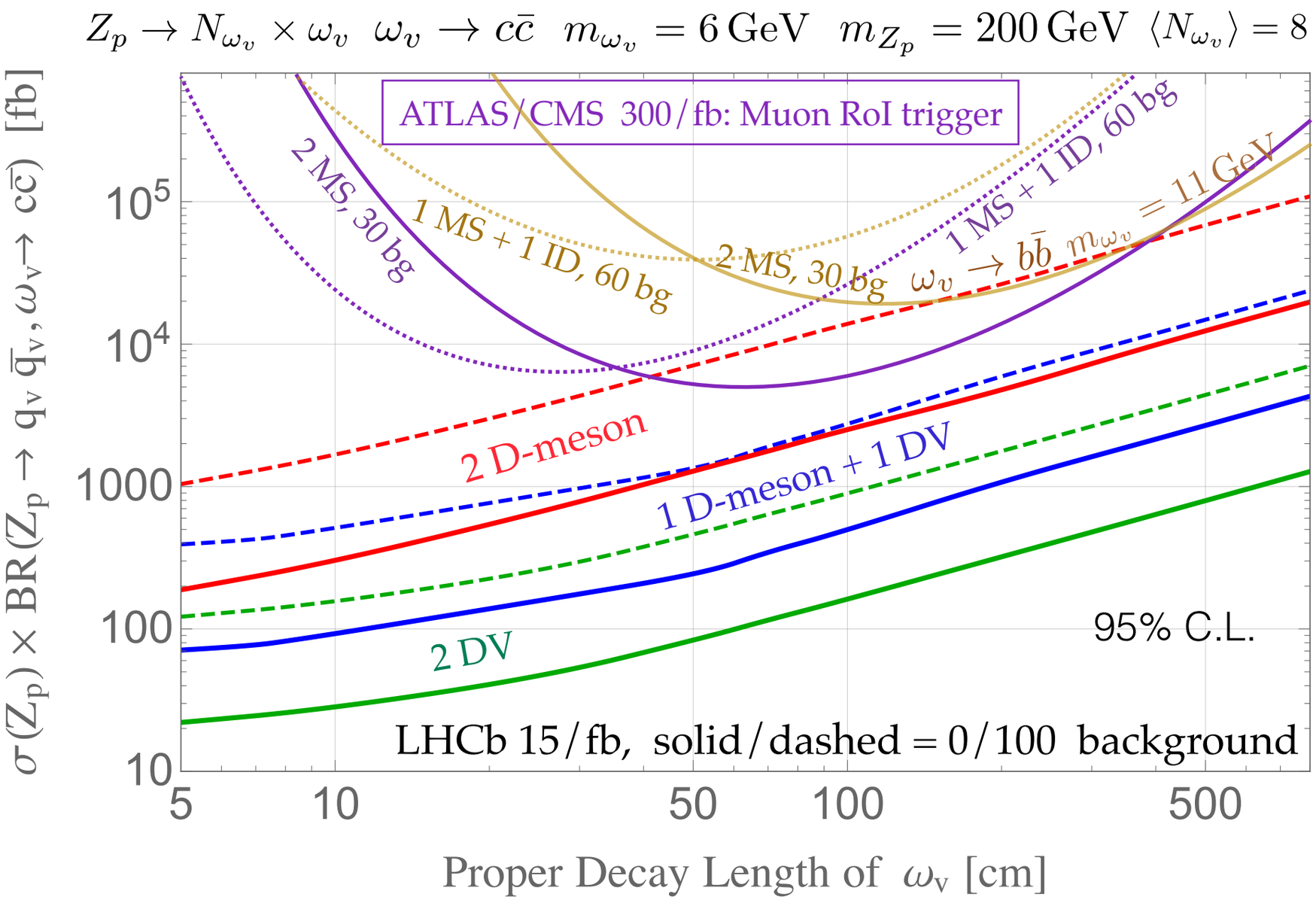
1 D-meson + 1 DV (>= 3 tracks)

2 DV (>= 3 tracks)



HV decay into D-mesons

Pierce, Shakya, YT, Zhao (2017)

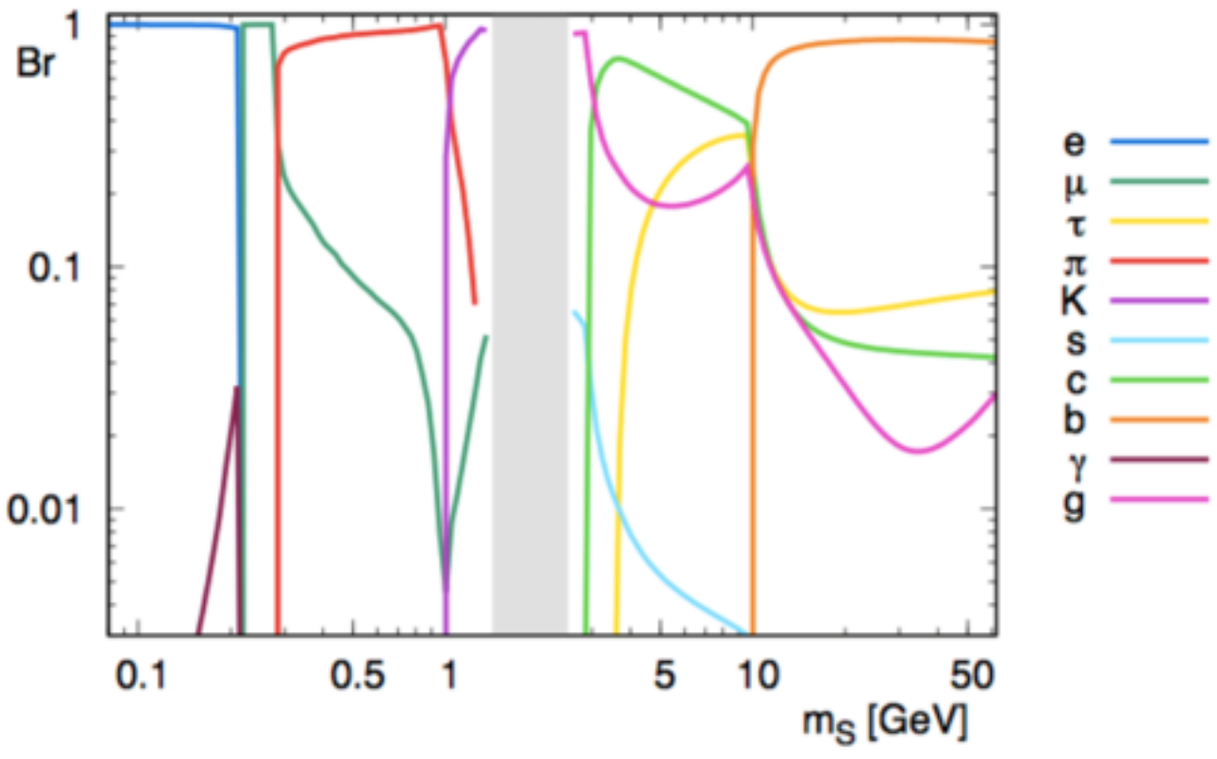


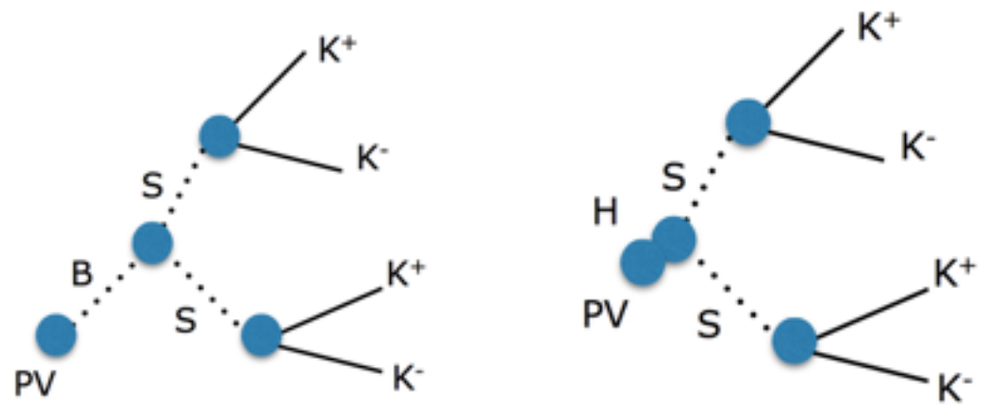
More exclusive search on the LLP decay

Shuve, Pospelov, YT, Vidal, Zurita (in progress)

different signature, but similar idea

$$-\mathcal{L}_S = \frac{\lambda_S}{4} S^4 + \frac{m_0^2}{2} S^2 + \lambda S^2 H^\dagger H$$





background can be low
with tight isolation cuts
+ mass resolution + kaon id

- Look at H or B yields for m(S)=1.2 GeV/c^2, and BR(S → K^+K^-) = 1
  - K p_T > 0.5 GeV/c and 2 < η < 5 for every kaon
  - S decay location 2 < ρ < 25 mm , z < 400 mm

    (ρ in cylindrical coordinates)