Dark sector→LHCb

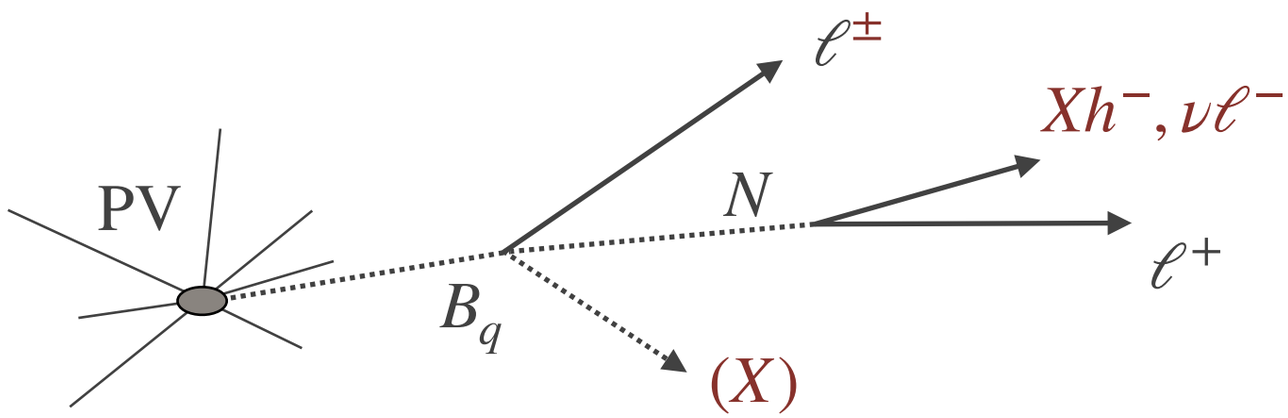
- **Dark sector** = light masses, small couplings, displaced vertices, invisible signatures

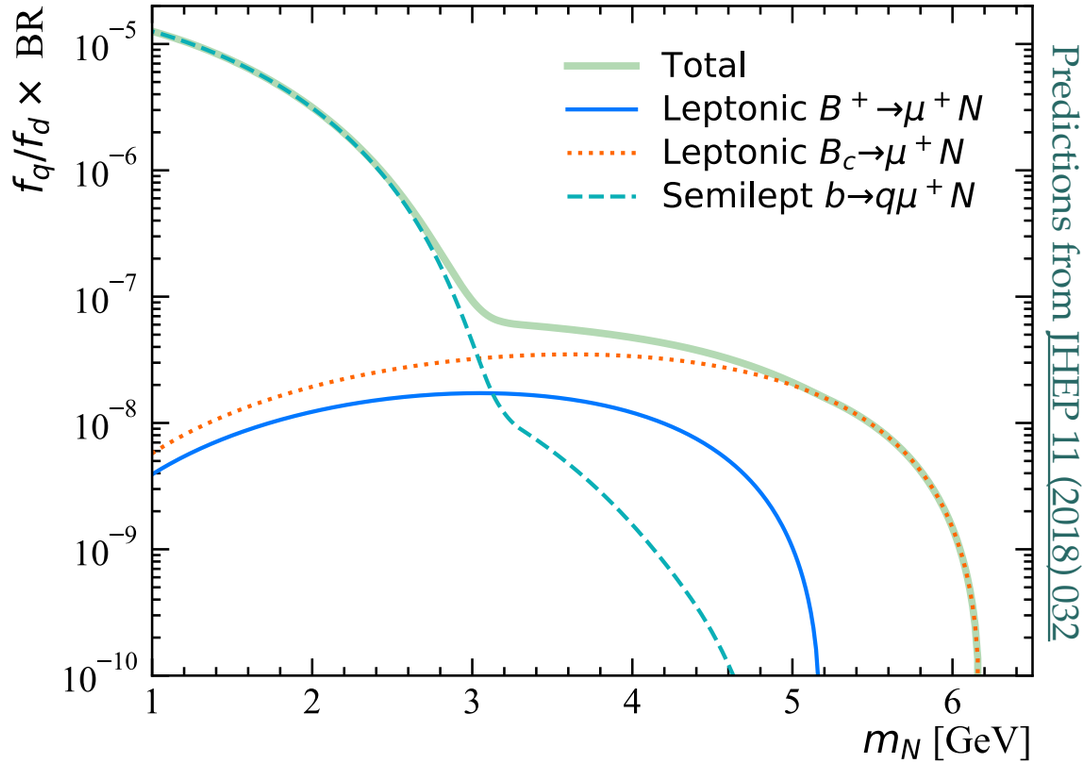
- Why searching at LHCb?
  - Huge production rates in forward LHC region
  - Precise low-p_T trigger for soft signatures
  - Real-time identification of displaced vertices (at first trigger level in the upgrade!)
  - Huge boost in forward region → increased flight distance

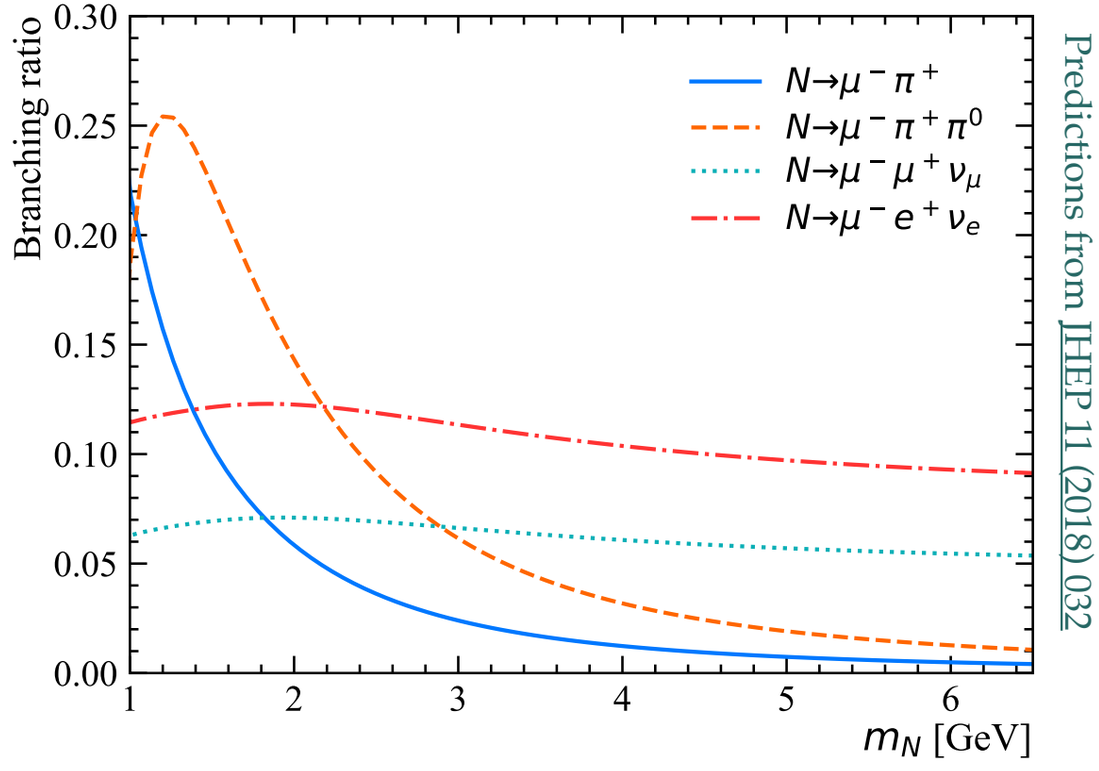
- **Heavy** neutral leptons (**GeV**)
- **Light** scalars (**GeV**)
- **Visible dark** photons

Heavy neutral leptons

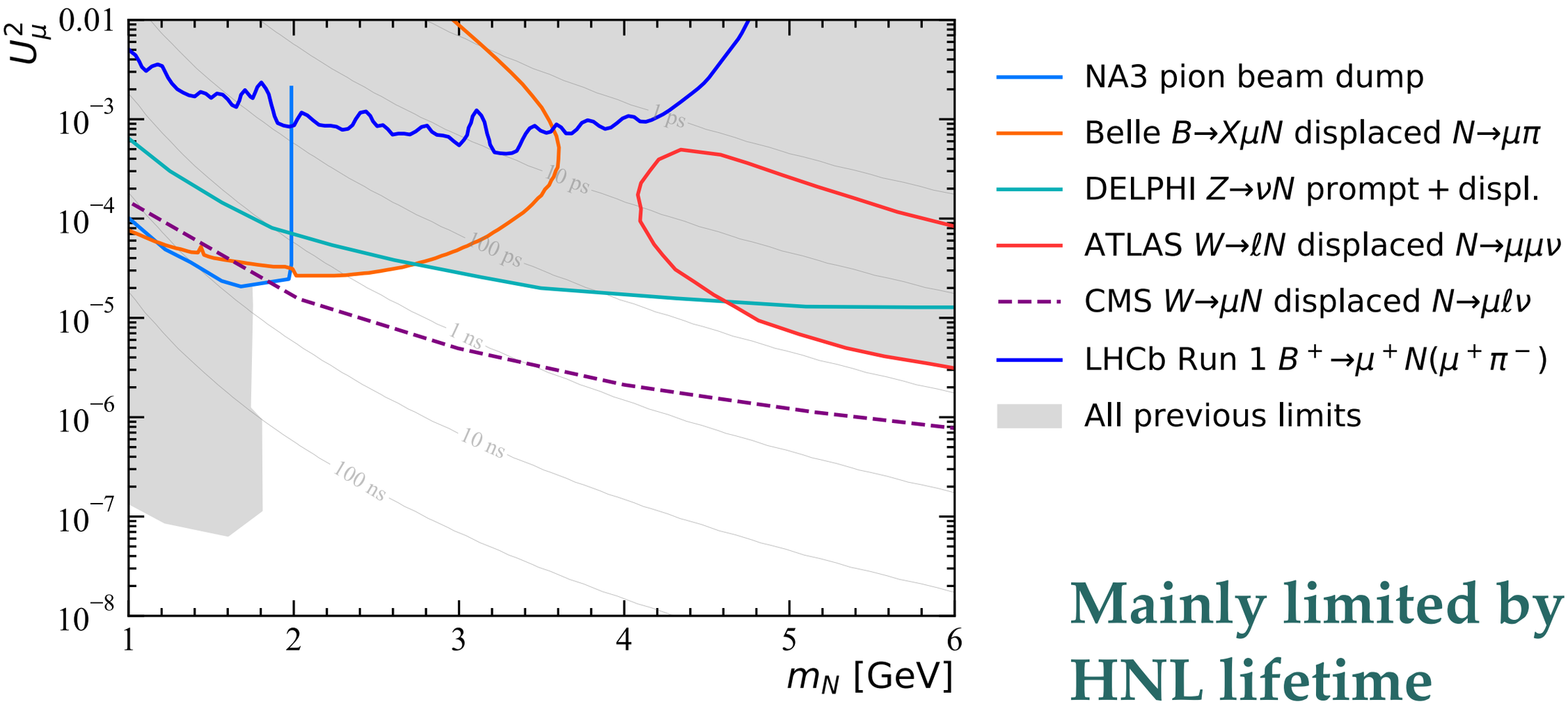
HNL in B decays







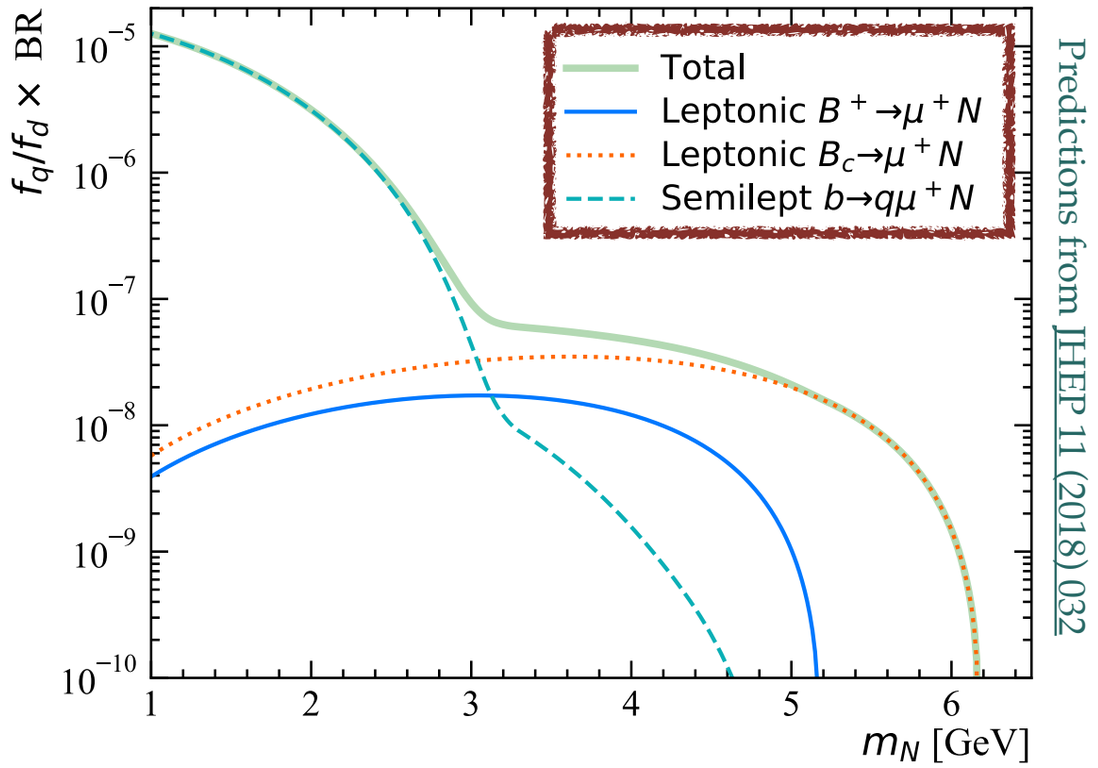
HNL searches in GeV range

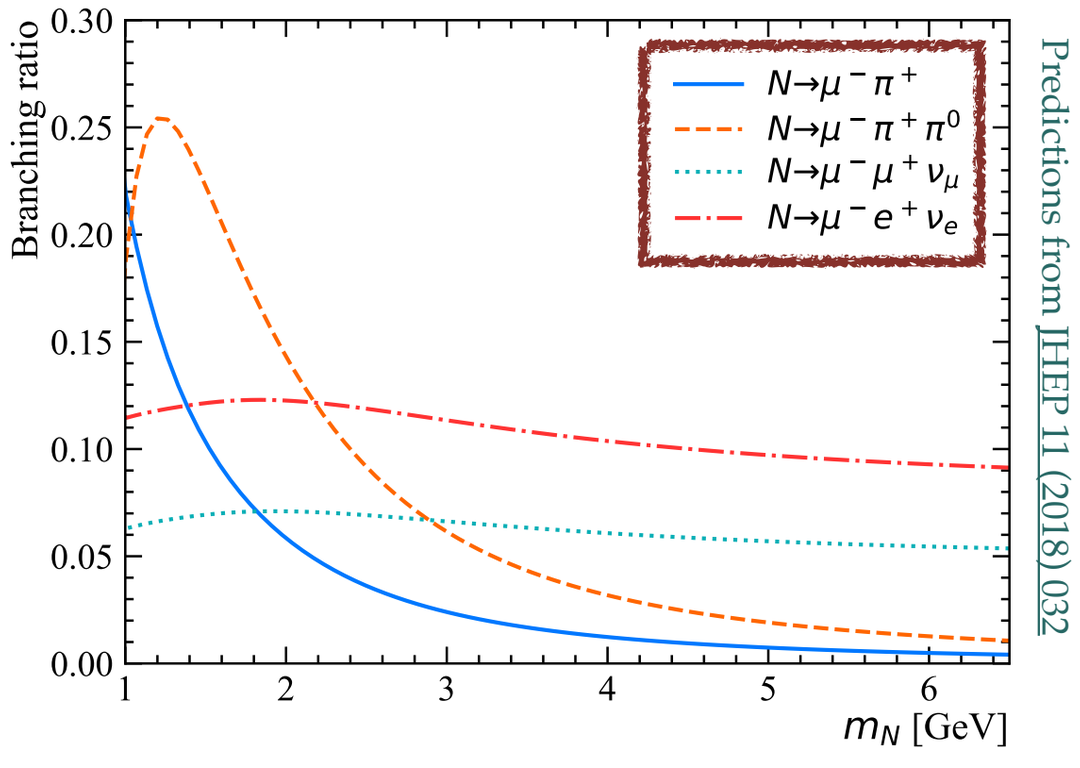


Mainly limited by HNL lifetime

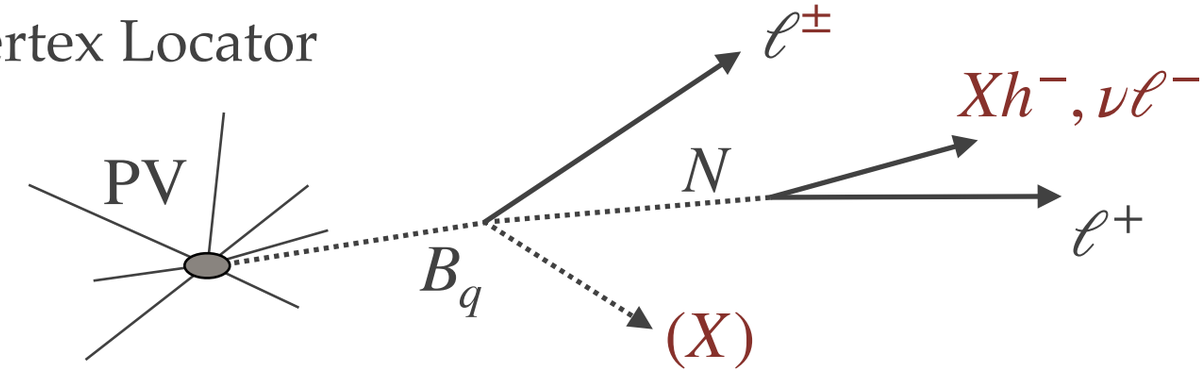
Future Prospects

B→HNL in future LHCb





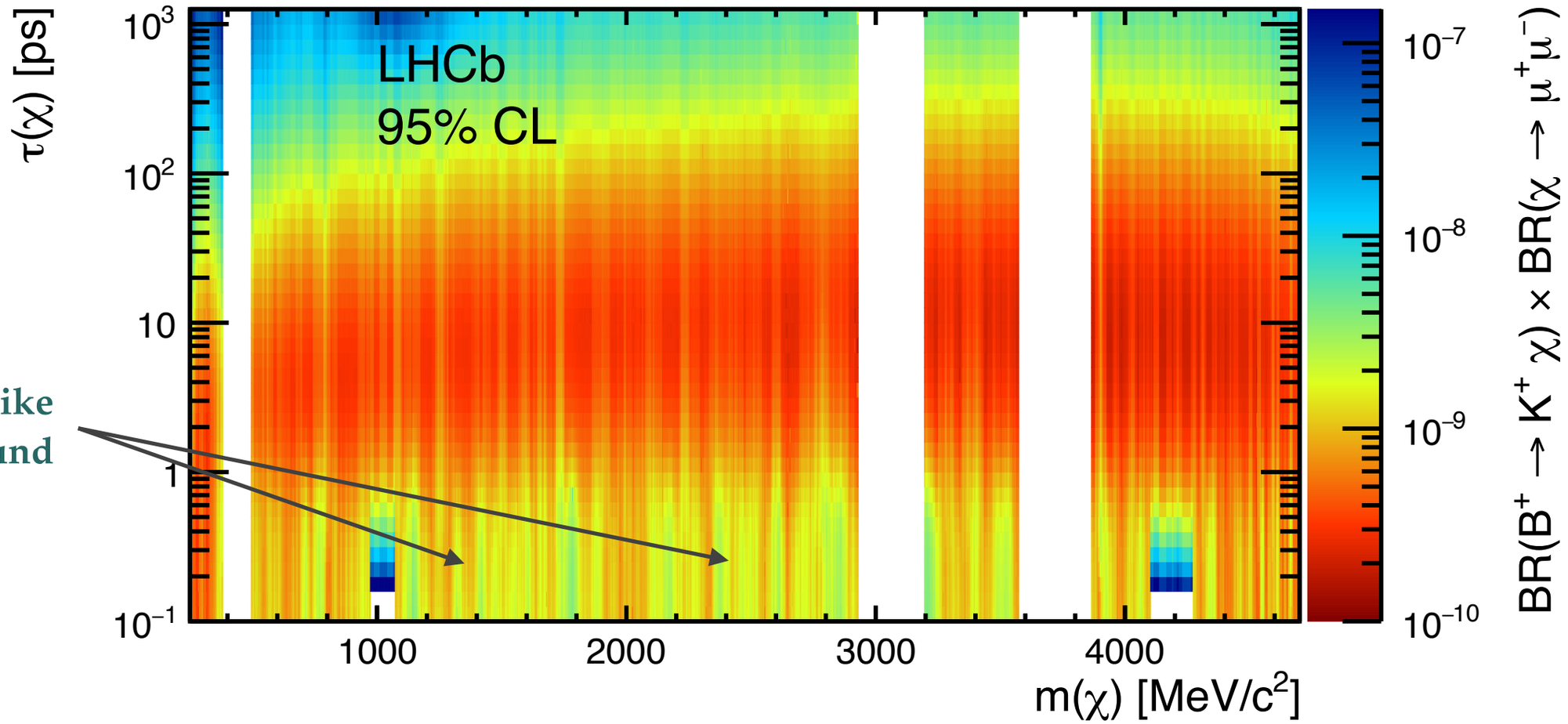
- Future LHCb strategy:
  - Include $B_c \to \ell N$ and $B_q \to X\ell N$
  - Include partially reconstructed N decays
  - Include N decays downstream of the Vertex Locator (10x longer decay time)
  - Search in all lepton flavours (also τ?)
  - Search both LNC and LNV decays



Light scalars

Light scalar from $b \to s$

Phys Rev Lett 115 161802 (2015)
Phys Rev D 95, 071101(R) (2017)

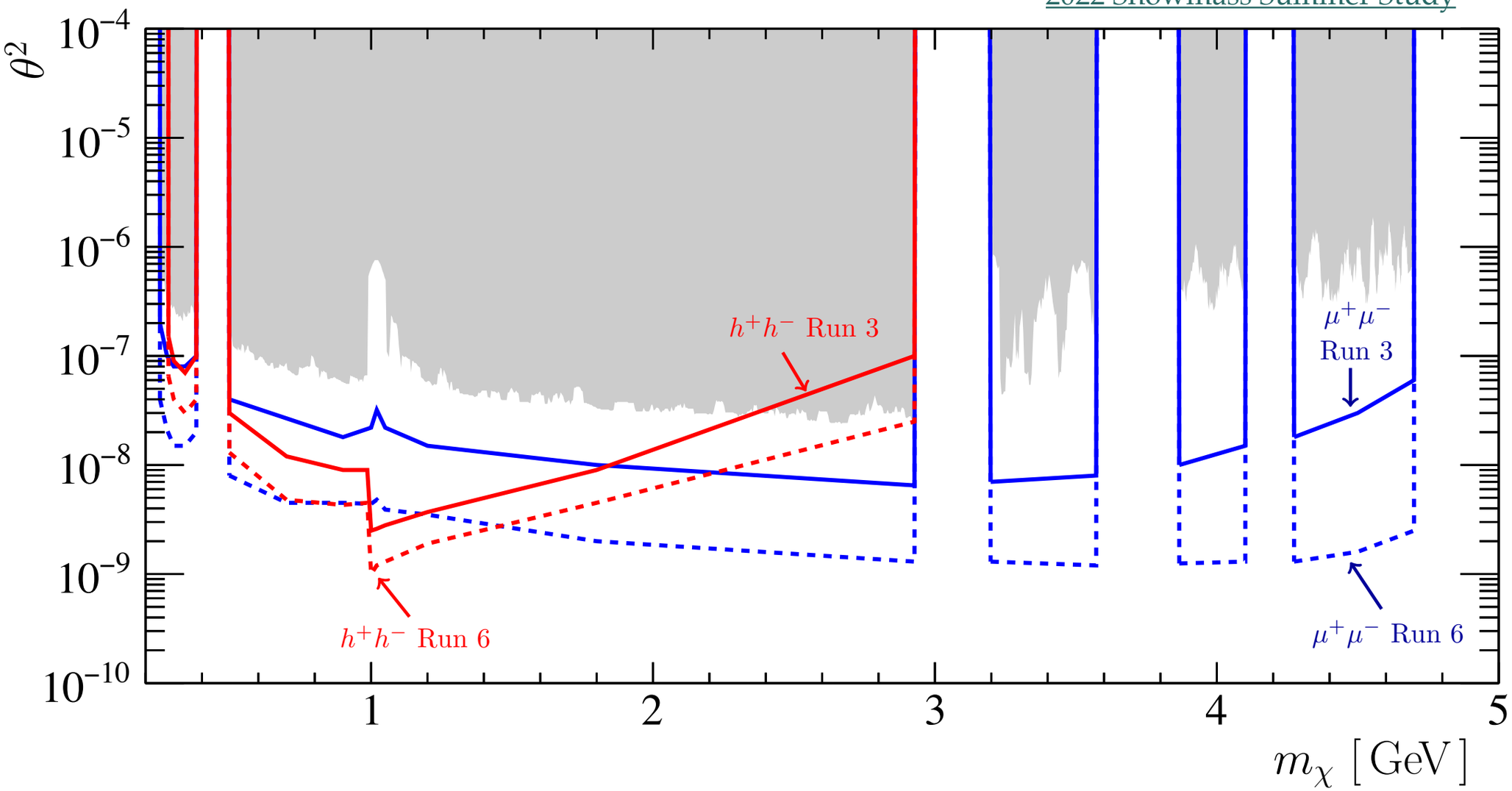


- Use peaks in reconstructed m_B and $m(\mu\mu)$ to reduce background
- Upper limits down to $\mathbf{10^{-10}}$ on $\mathrm{BR}(B^+ \to K^+ \chi) \times \mathrm{BR}(\chi \to \mu\mu)$

Future Prospects

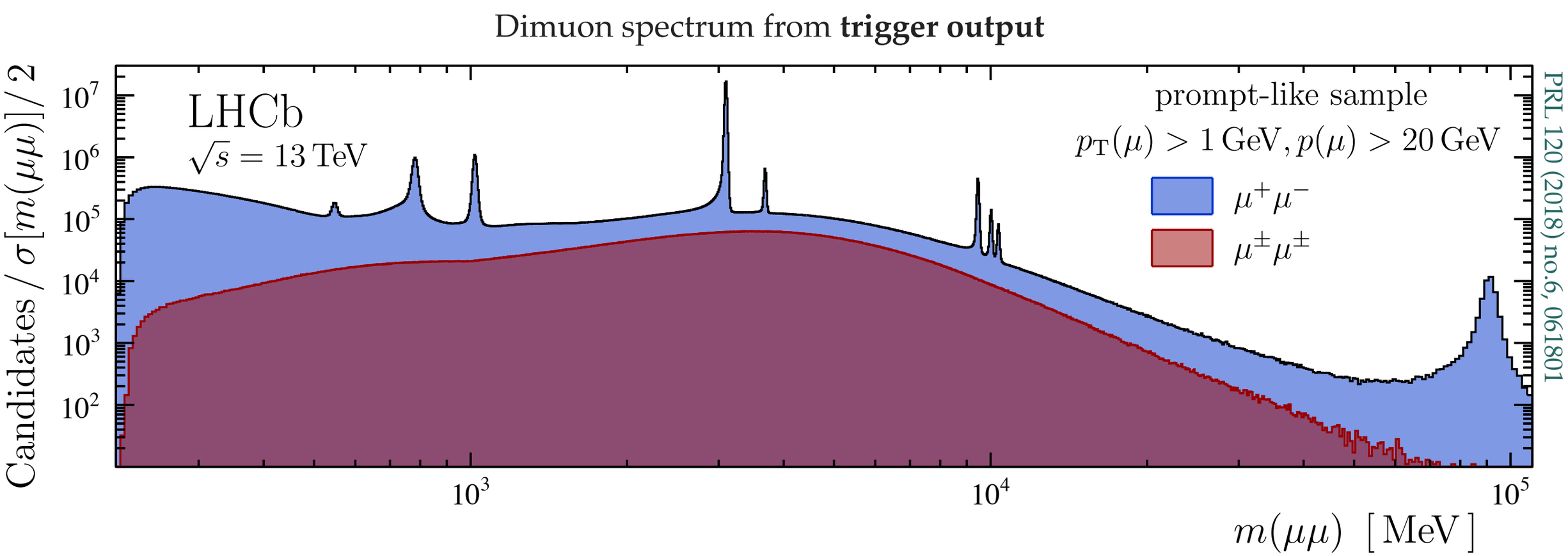
Light scalar from $b \to s$

2022 Snowmass Summer Study



Dark photons

Visible $A' \rightarrow$ LHCb



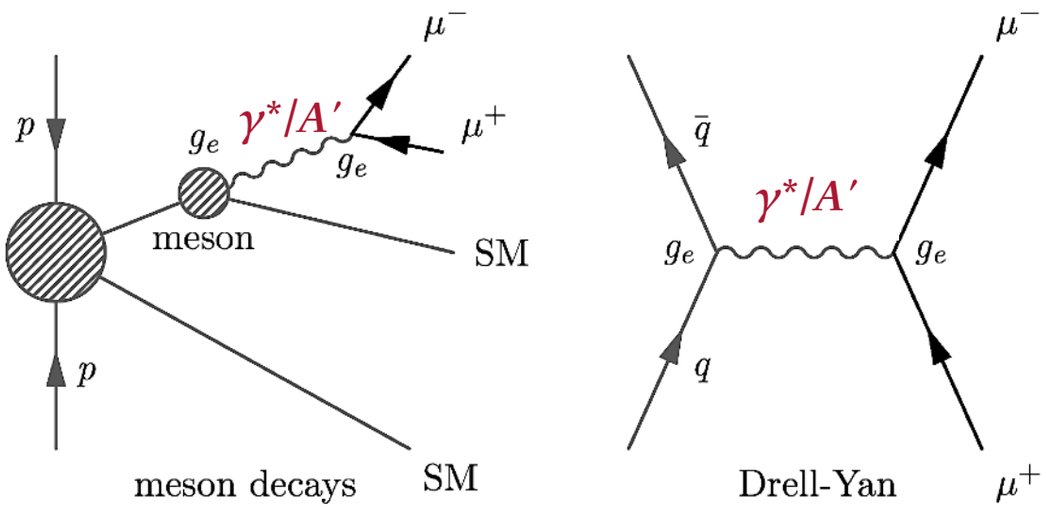
- Started inclusive $A' \rightarrow \mu^+\mu^-$ searches in Run 2
  - Leveraging the online-analysis capabilities introduced in 2015
    → no pre-scale down to threshold $2m_\mu$
  - Great prospects for upcoming upgrade

Visible $A' \rightarrow$ LHCb

PRL 120 (2018) no.6, 061801
and PRL 124 (2020) 041801

Analysis strategy:

- inherits production mode of off-shell photon
  → Can normalise to $\gamma^* \rightarrow \mu\mu$ continuum
  → just need to separate non γ^* background
  - No need for efficiencies from simulation (only if displaced vertex)



$$n_{\mathrm{ex}}^{A'}[m(A'), \varepsilon^2] = \varepsilon^2 \left[\frac{n_{\mathrm{ob}}^{\gamma^*}[m(A')]}{2\Delta m} \right] \mathcal{F}[m(A')]\, \epsilon_{\gamma^*}^{A'}[m(A'), \tau(A')]$$

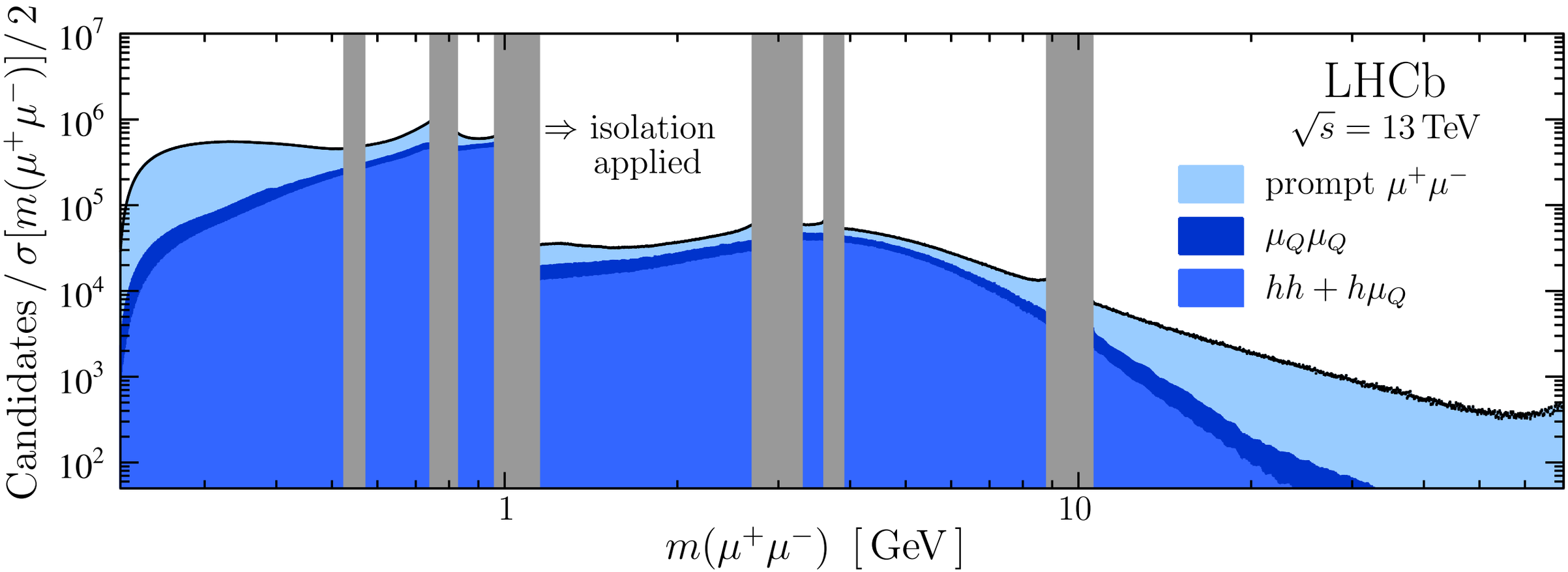
off-shell photon

phase-space

A′ / γ^* eff ratio,
ϵ**=1 for prompt**

Prompt-like $A' \to \mu^+\mu^-$

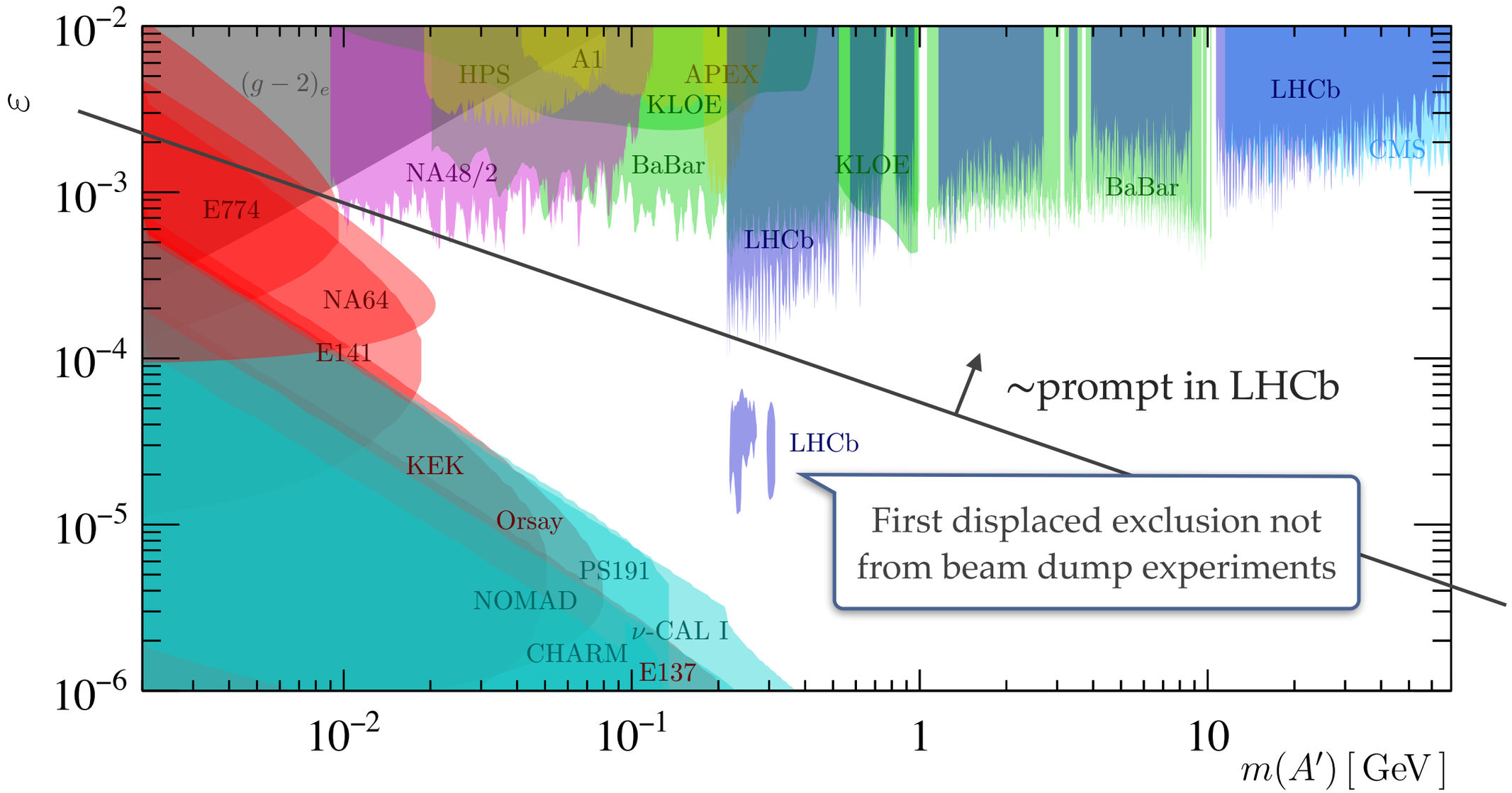
PRL 120 (2018) no.6, 061801
and PRL 124 (2020) 041801



- $O(10^7 - 10^{11}) \times \epsilon^2$ dark photons expected
  - Peak hunt on top of large background
  - Remove regions with QCD resonances
- Also displaced search at low mass (low background)

Visible A' limits

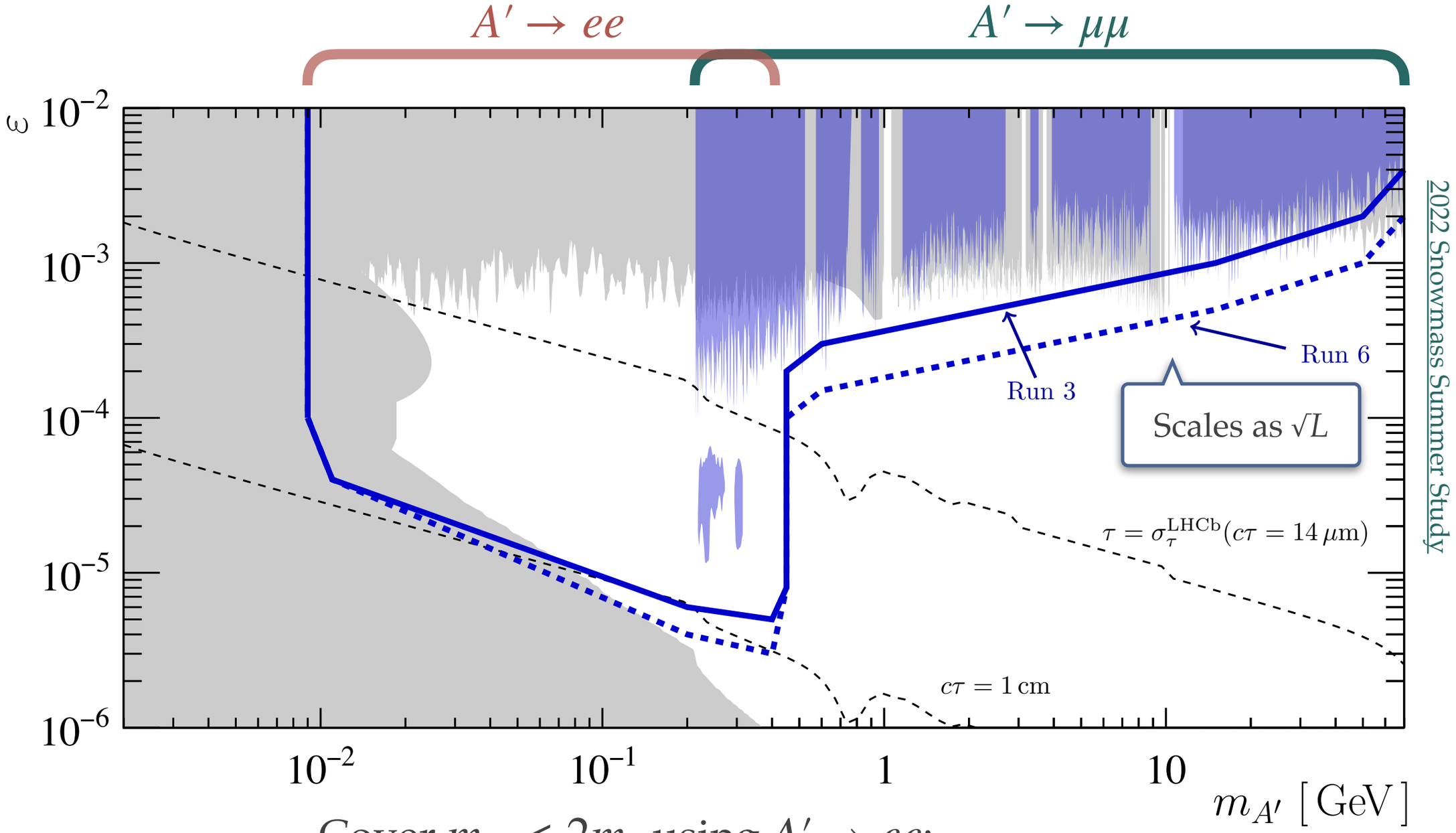
PRL 124 (2020) 041801



- Easy to recast to other vector models JHEP 06 (2018) 004

Future Prospects

Visible A' prospects



Cover $m_{A'} < 2m_\mu$ using $A' \to ee$:

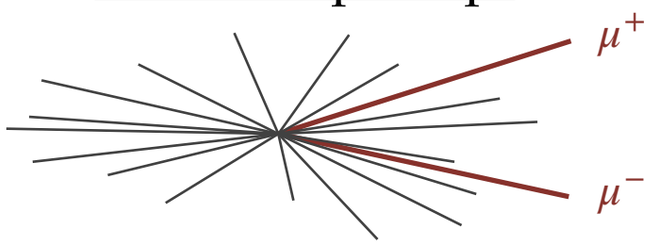
- $D^* \to D^0 A'$ (lower bkg) PRD 92 no.11, 115017 (2015)
- $\pi^0/\eta \to A'\gamma$ (higher rate) 2022 Snowmass Summer Study

Inclusive $X \to \mu^+\mu^-$ search

LHCb JHEP10(2020)156

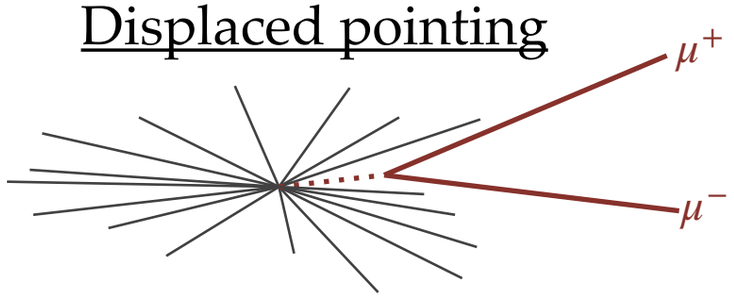
- Probe additional dark sectors in $\mu\mu$
  - Drop assumption of kinetic mixing with γ^*
  - Minimise assumptions on production mechanism (tight fiducial regions and results in kinematic bins)

Inclusive prompt

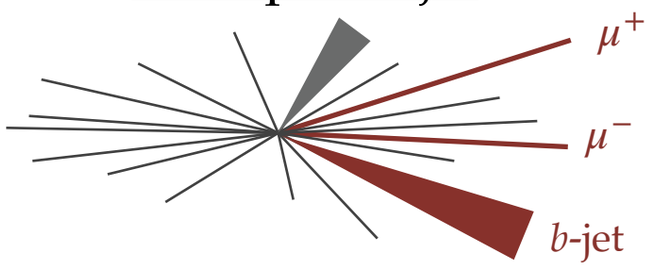


- No isolation requirements
- Non-zero width considered

Displaced pointing

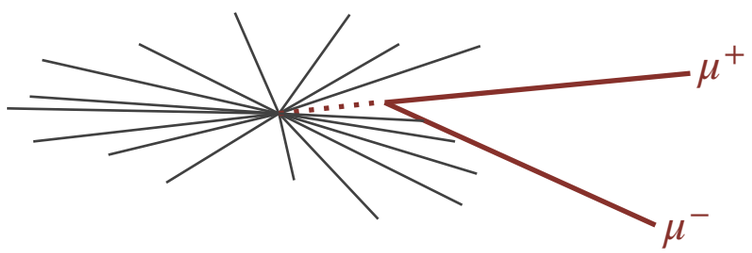


Prompt + b-jet



- Non-zero width considered

Displaced non-pointing



Inclusive $X \to \mu^+\mu^-$ search

LHCb JHEP10(2020)156