Searches for new low-mass particles at LHCb

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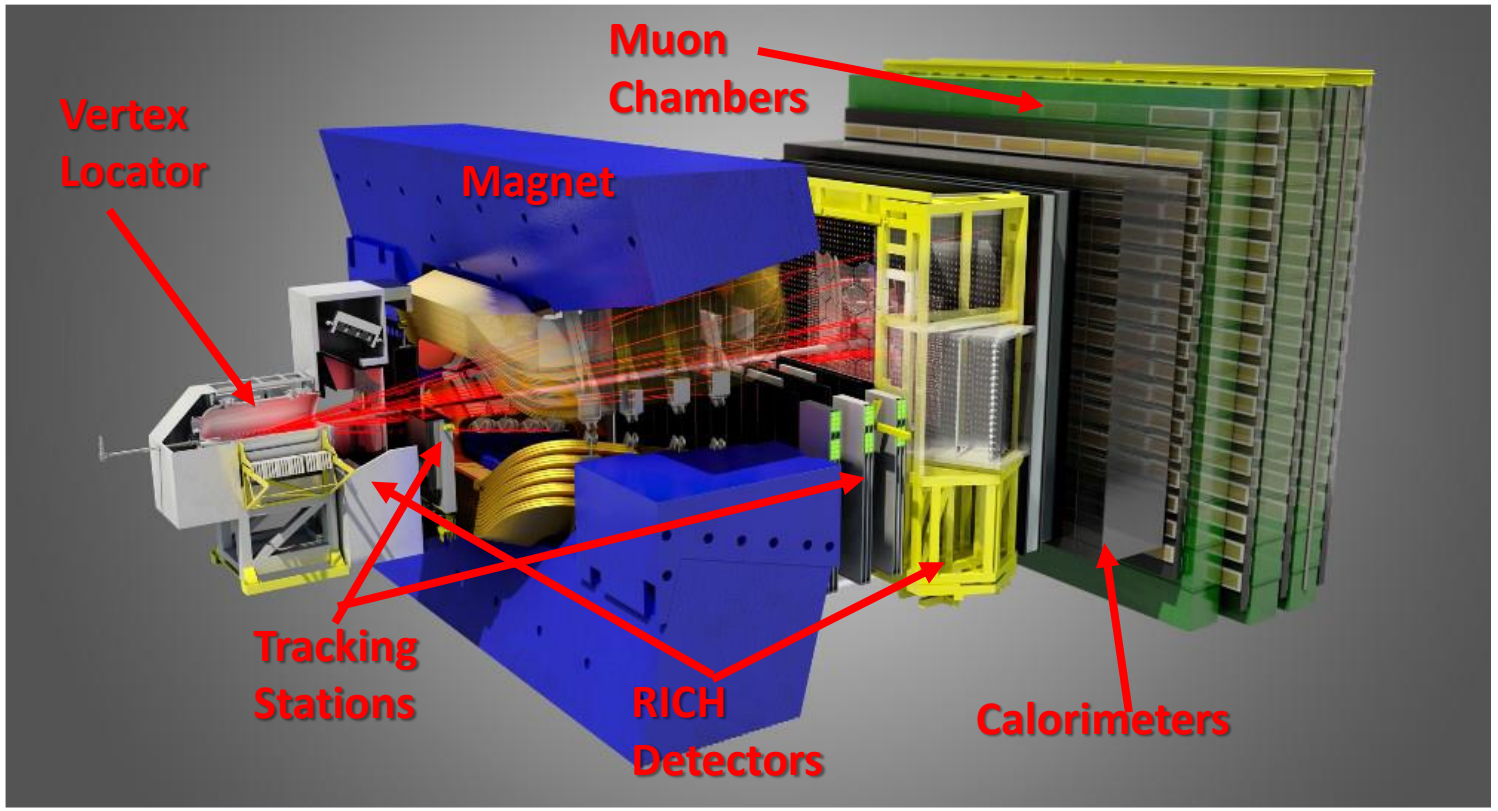
Outline

- Introduction
- Recent LHCb results on low-mass particles searches
- Summary

LHCb detector

JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

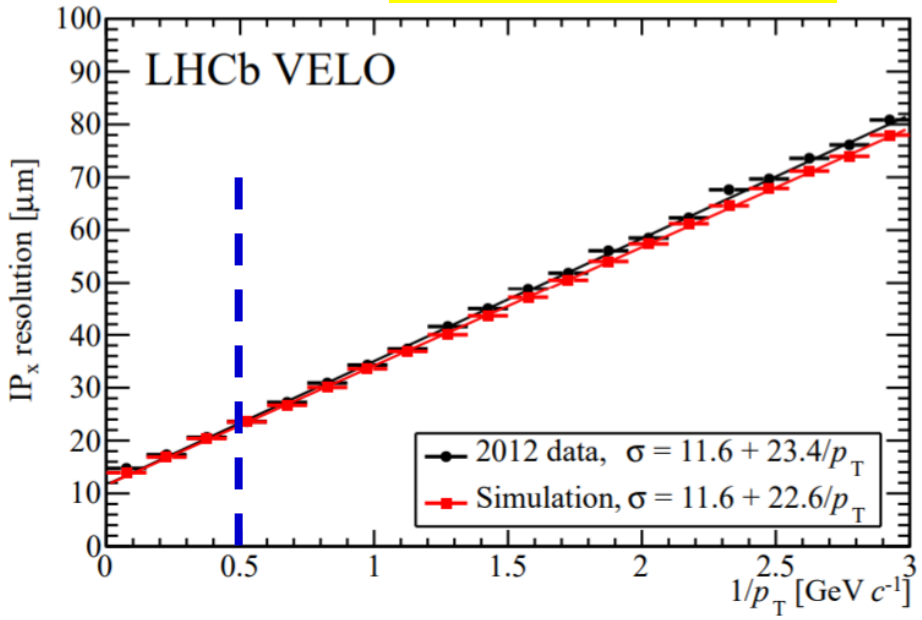


- LHCb is a forward spectrometer suited for b, c hadrons: $2 < \eta < 5$
- Momentum resolution:
  - 0.5% at 5 GeV, 1.0% at 200 GeV
- Excellent track and vertex reconstruction
- Excellent mass resolution (low masses)
- Good particle-ID separation

Vertex detector

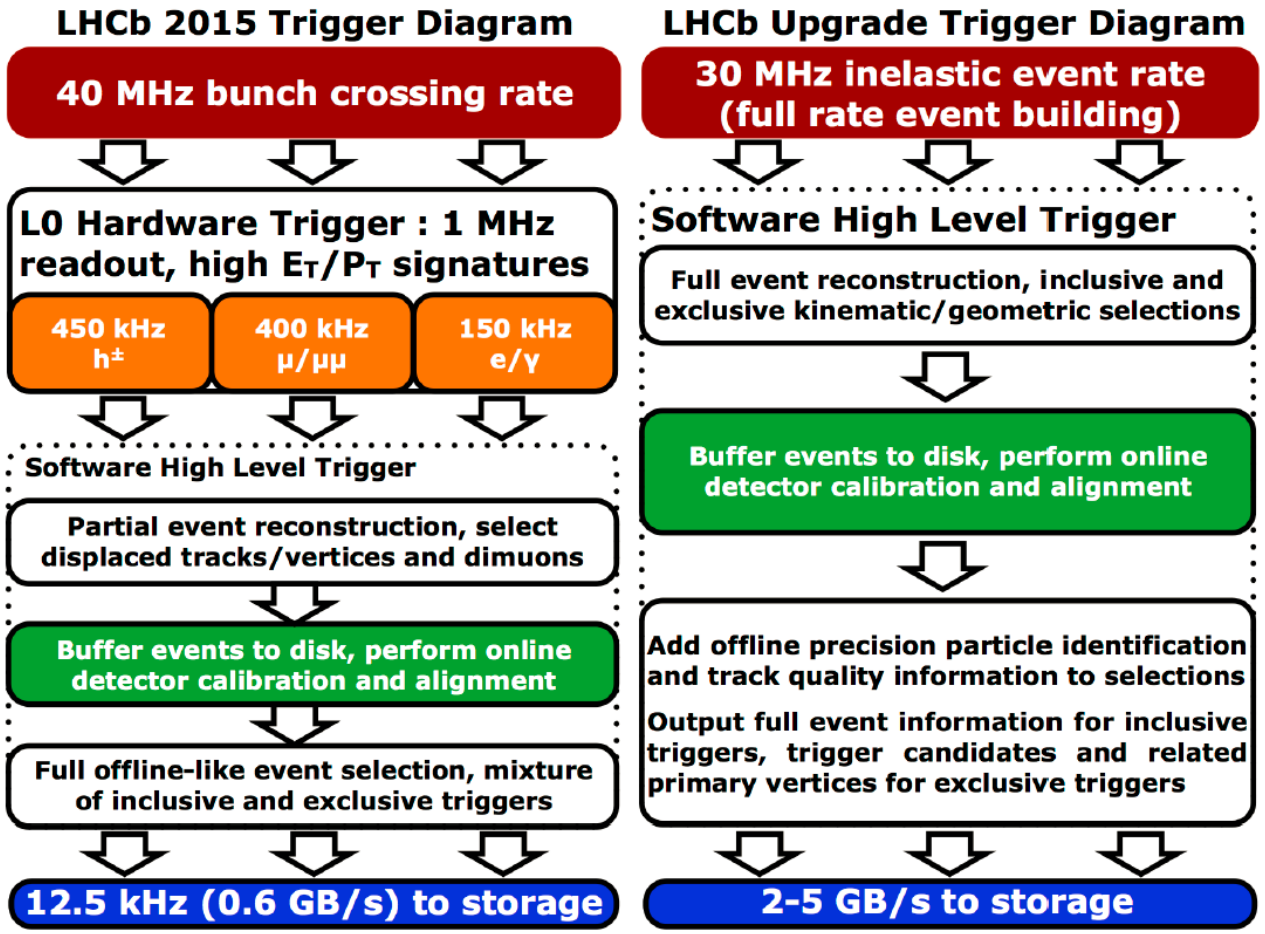
- 21 silicon strip detector stations, 8 mm from beam
  - IP resolution of $p_T > 2$ GeV/c tracks: < 20 μm
  - Typical decay time resolution: ~ 45 fs

2014 JINST 9 P09007



LHCb trigger

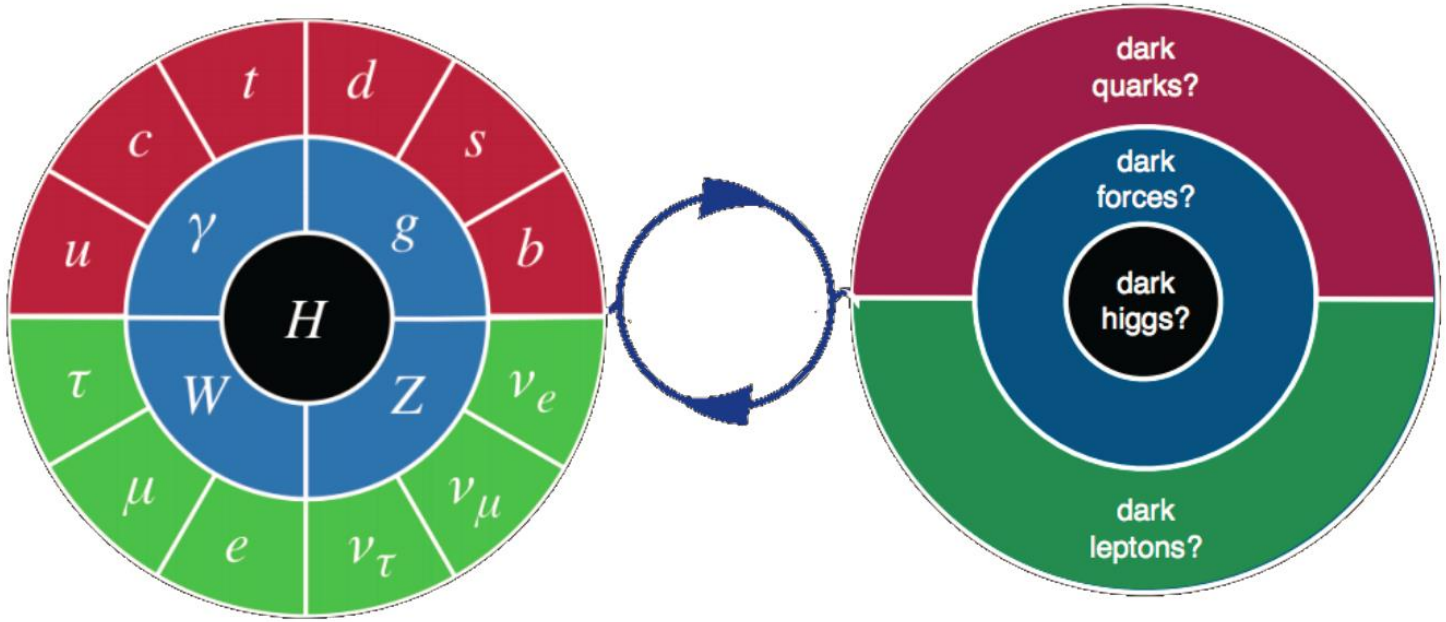
Comput. Phys. Commun. 208 (2016) 35-42
Int. J. Mod. Phys. A 30, 1530022 (2015)



- Hardware level L0
  - To be removed for Upgrade-Ia
  - Benefit for low mass searches
- Software level HLT
  - Topological trigger
  - Down to $p_T \sim 80$ MeV (μ)
- Turbo real-time analysis strategy
  - Since 2015
  - Any event part can be saved
  - Can work directly on them
  - Online μ – ID and jets in trubo

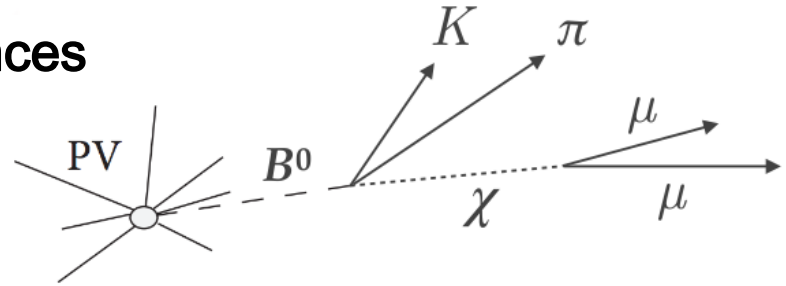
Dark sectors

- Different Dark sectors could communicate to SM through portals
- Portals generated by Quantum Mechanics between sectors that don't interact classically
- Examples of portals:
  - Vector portal (A')
  - Scalar portal (H)
  - Axion portal (a)
  - Neutrino portal (N)



Direct searches at LHCb

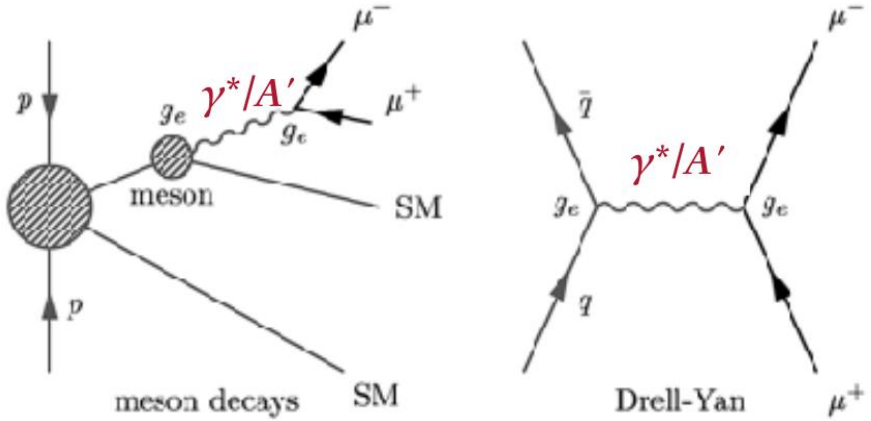
- Unique coverage complementary to ATLAS/CMS
  - Soft trigger and forward acceptance → lower masses (few GeV/ MeV for jets/leptons)
  - Excellent tracking and vertexing capabilities → lower lifetimes (~ 1 ps)
- LHCb capabilities to exploit low masses and low lifetimes:
  - Search for a di-muon resonance in $\Sigma^+ \to p\mu^+\mu^-$ decays PRL 120, 221803 (2018)
  - Search for candidates produced in B-hadron decays
  - Search for candidates produced in pp collision:
    - **Dark photons decaying into pairs of muons**
    - **Dark bosons in the mass region close to the Υ resonances**
    - **Axion-like particle (ALPs) decaying into pairs of muons**
    - Dark pions produced via SM Higgs decaying into jets



Dark photons

PRL 120, 061801 (2018)

- Search for dark photons decaying into a pair of muons
  - 2016 data, 1.6 fb^{-1}
- Kinetic mixing of dark photon (A') with off-shell photon (γ^*) by a factor of ε
  - A' inherits the production mode mechanisms from γ^*
  - $A' \to \mu^+\mu^-$ can be normalized to $\gamma^* \to \mu^+\mu^-$
  - Fully data-driven analysis: no systematics from MC
- Separate γ^* signal from background and measure its fraction
- Prompt-like search (up to 70 GeV), displaced search (214-350 MeV)
  - A' is long-lived only if the mixing factor is really small



Off-shell photon

A'/γ^* eff ratio, $\varepsilon = 1$ for prompt

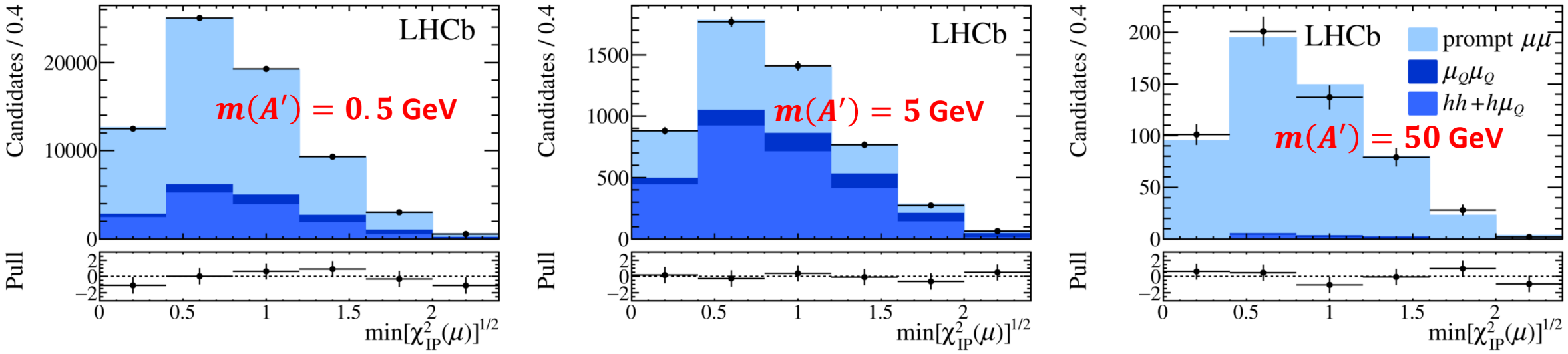
$$n_{\mathrm{ex}}^{A'}[m(A'), \varepsilon^2] = \varepsilon^2 \left[\frac{n_{\mathrm{ob}}^{\gamma^*}[m(A')]}{2\Delta m}\right] \mathcal{F}[m(A')]\, \epsilon_{\gamma^*}^{A'}[m(A'), \tau(A')],$$

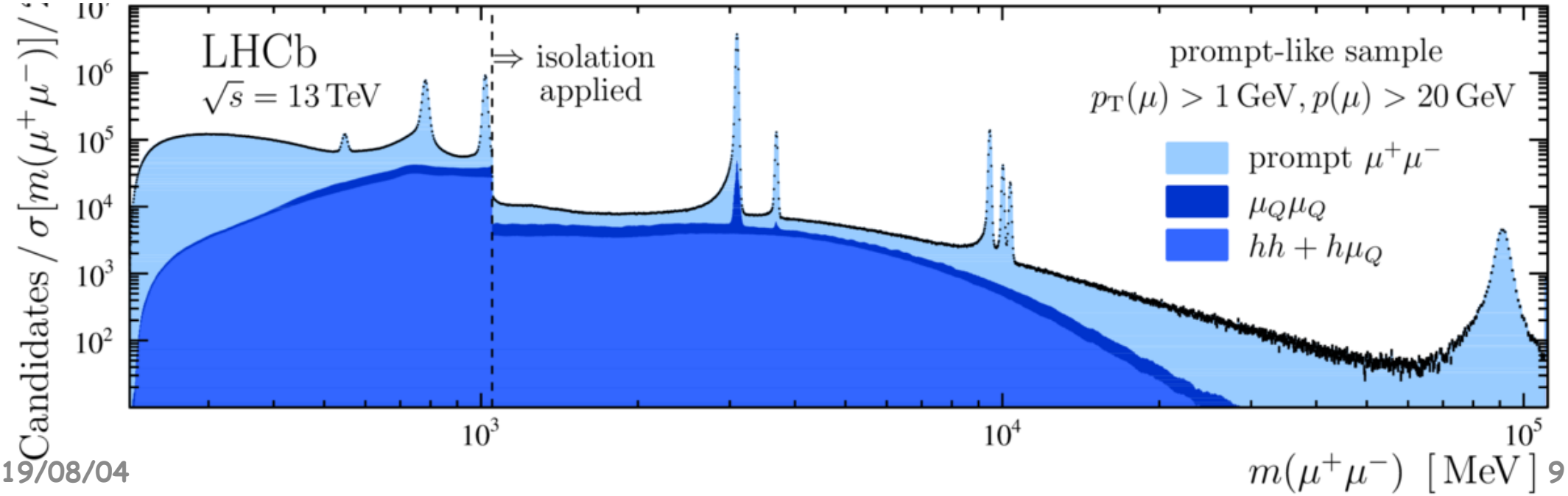
Phase-space

Dark photons

Using templates for $\min[\chi^2_{IP}]$ and χ^2_{VF}

PRL 120, 061801 (2018)

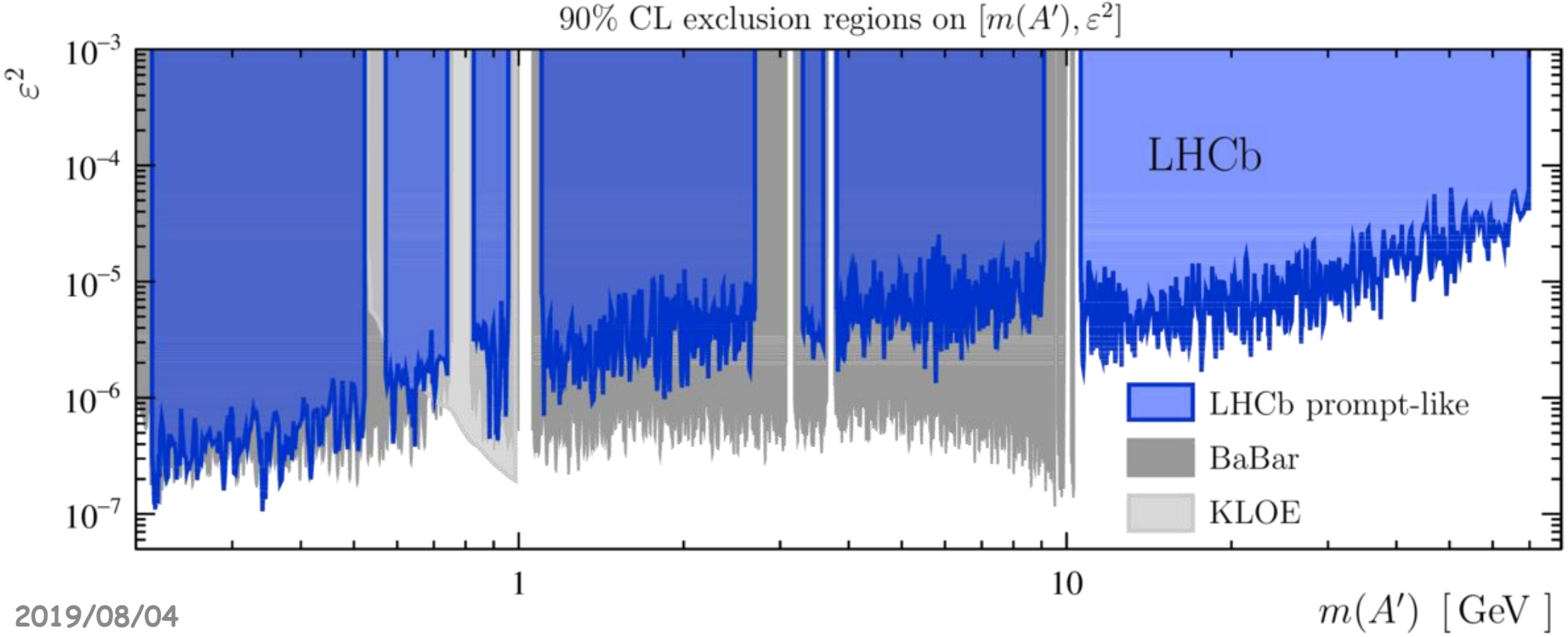




Dark photons: prompt search

PRL 120, 061801 (2018)

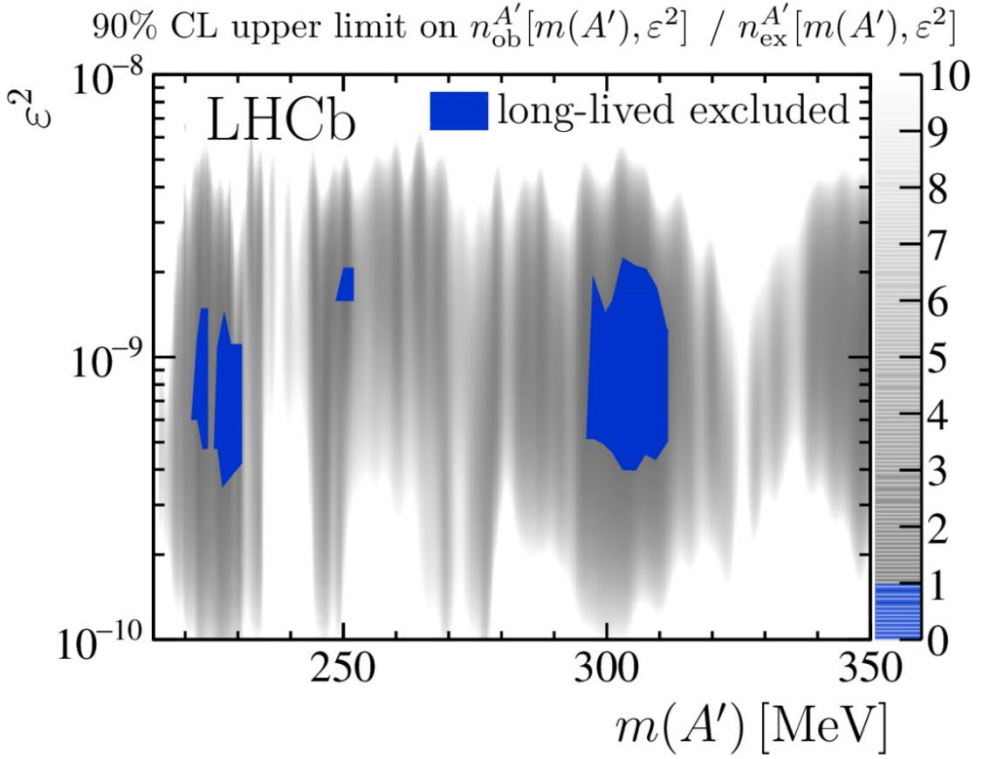
- No significant excess found: exclusion regions at 90% C.L.
- First limits on masses above 10 GeV and competitive limits below 0.5 GeV



Dark photons: displaced search

PRL 120, 061801 (2018)

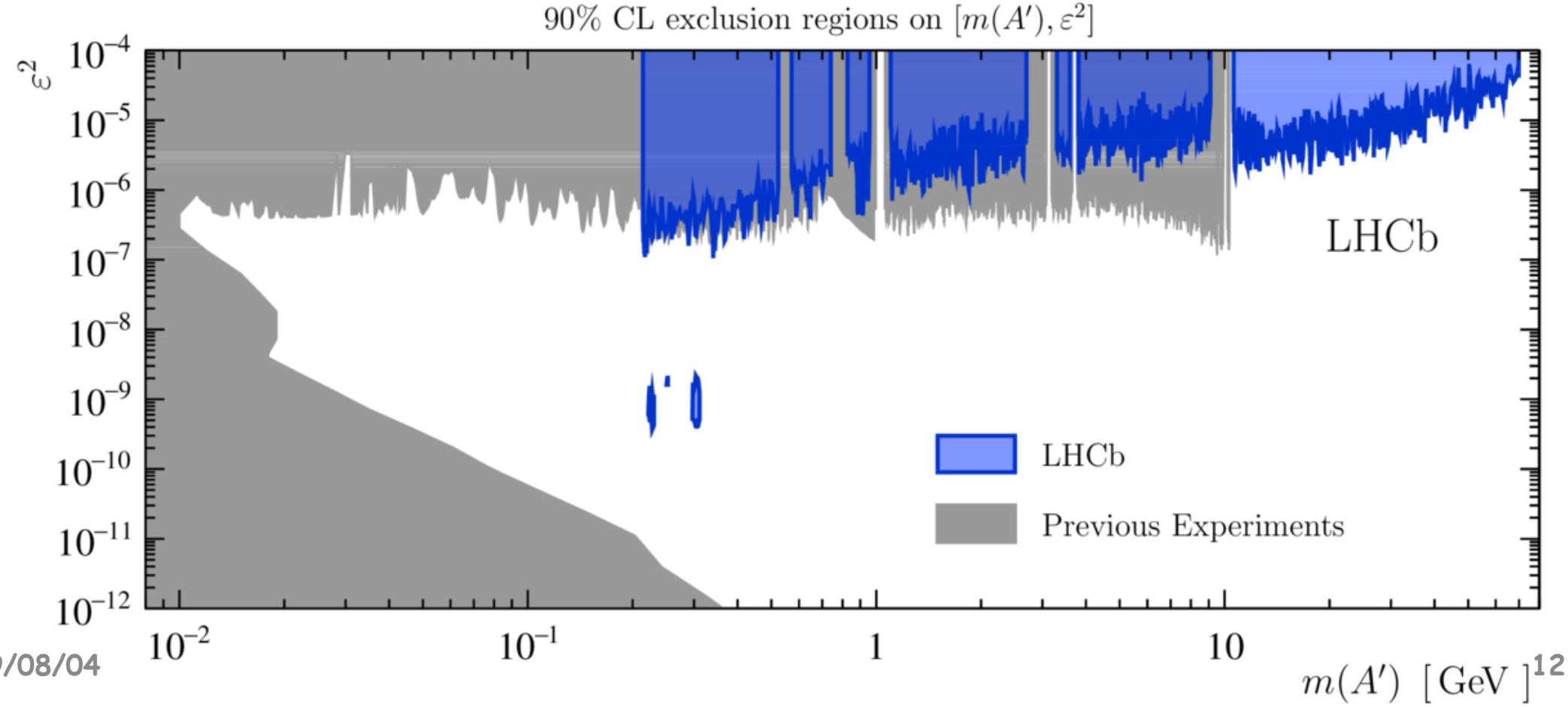
- Looser requirements on muon p_T
- Material background is mainly from photon conversions
- Isolation decision tree from $B_s^0 \to \mu^+\mu^-$
- No significant excess found:
  - Small parameter space region excluded
  - First limit ever not from beam dump



Dark photons: results

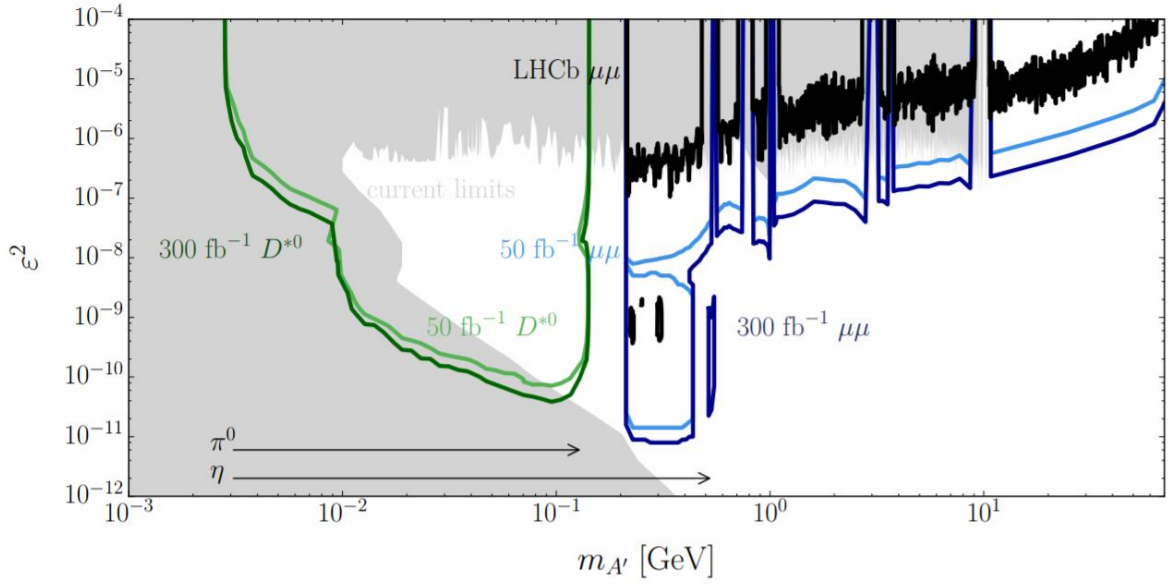
PRL 120, 061801 (2018)

- Prompt search in large range: $2m(\mu) < m(\mu\mu) < m(Z)$
- Displaced search in sensitive region: $241 < m(\mu\mu) < 350$ MeV



Dark photons: future reach

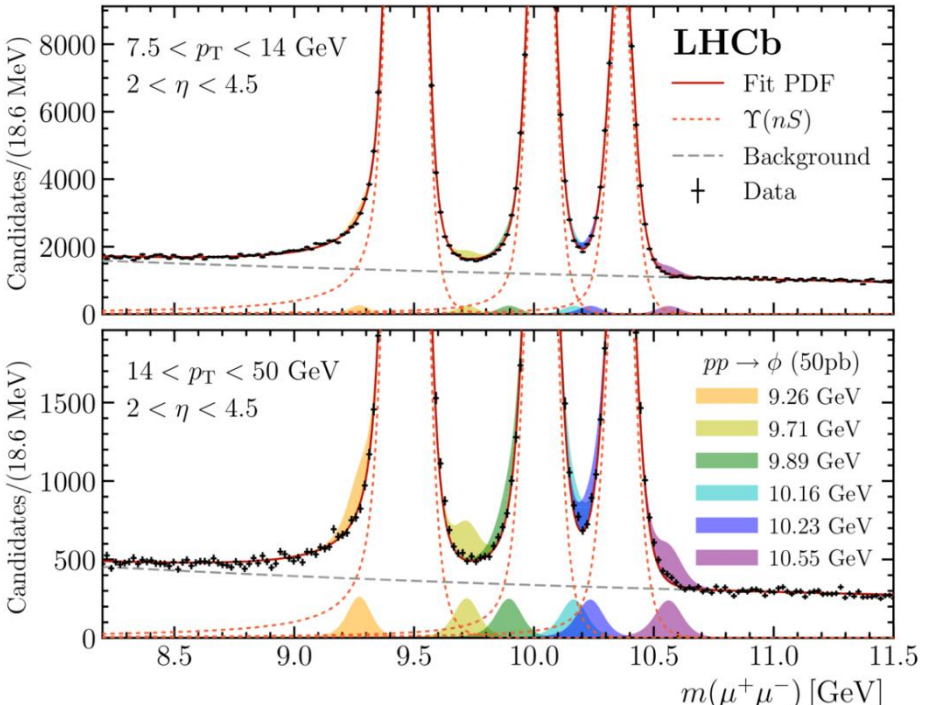
- Cover dielectron final states: $D^{*0} \to D^0 A', A' \to e^+e^-$
  - Triggerless readout in Run-3: softer final state than in di-muon mode
  - High statistics: $O(10^{10})$ $D^{*0} \to D^0\gamma$ per fb^{-1}
- Extend searches model-independently:
  - Recast in other vector models JHEP 06 (2018) 004
  - Recast in (pseudo-)scalar models arXiv:1802.02156
- Prospected reach for Run-3 and beyond: arXiv:1812.07831



Search for a dimuon resonance in Υ mass region

JHEP 08 (2018) 147

- Model independent search at LHCb using Run-1 dataset
- Inclusive scalar boson search with $m \sim 10$ GeV
  - Dimuon mass resolution: very important due to presence of Υ resonances
  - Modelling of $\Upsilon(ns)$ tails to extend mass range



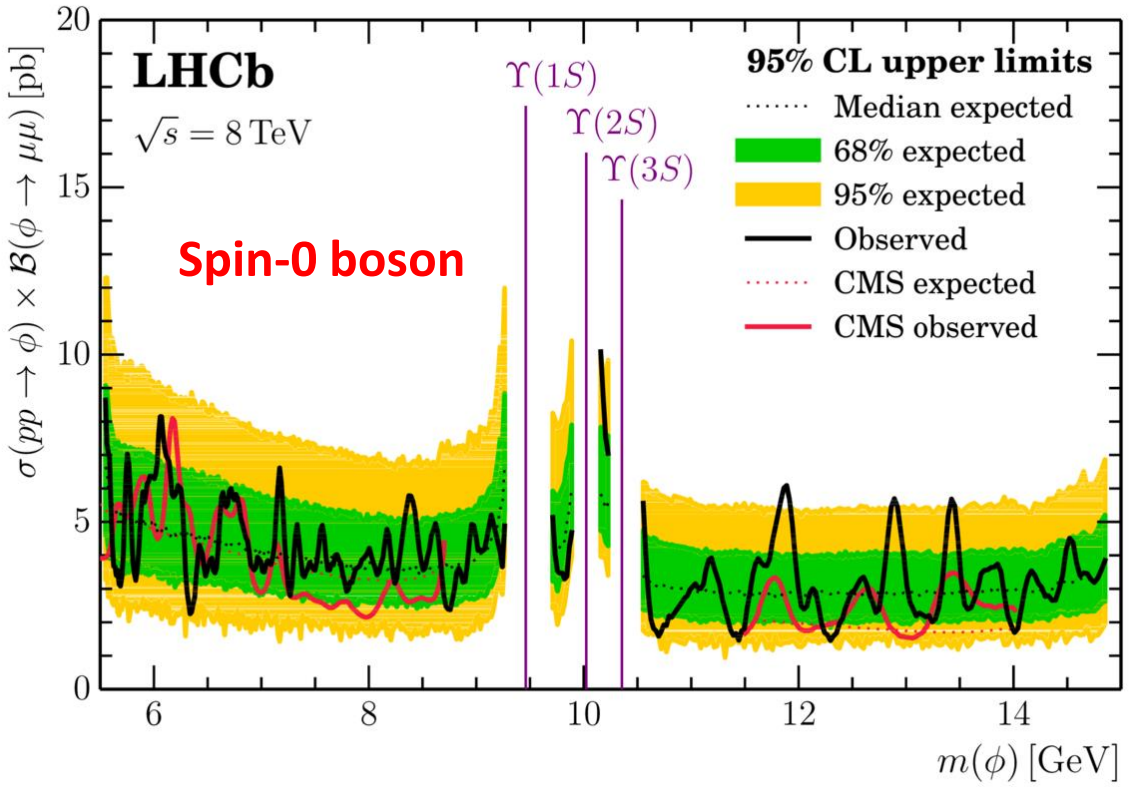
Selection:

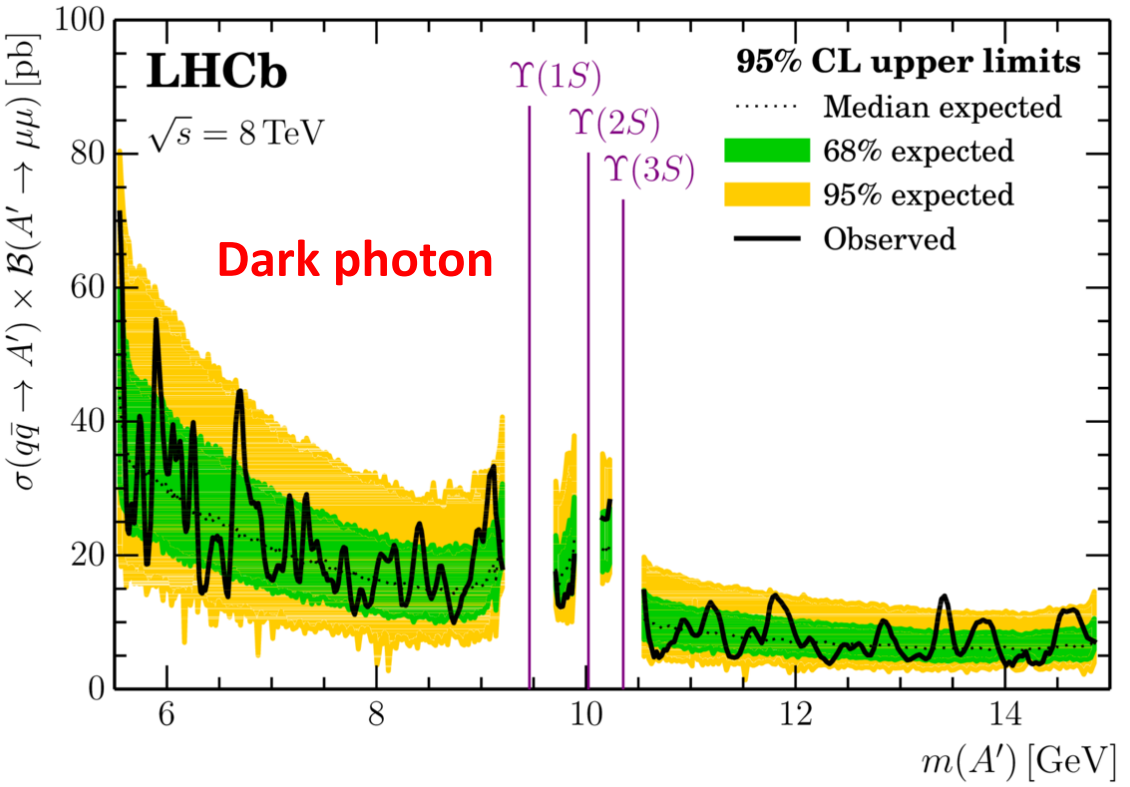
- Good quality vertex
- Prompt:
  - consistent with PV
  - proper time < 0.1 ps
- $5.5 < m(\mu\mu) < 15$ GeV

Search for a dimuon resonance in Υ mass region

JHEP 08 (2018) 147

- No excess found: results can be interpreted in different models
  - First limit near to $\Upsilon(8.7 - 11.5)$ GeV





Prospects for Axion Like Particles (ALPs)

JHEP 1901 (2019) 113

- ALPs are pseudo Nambu-Goldstone bosons associated to a Spontaneous Symmetry Breaking

$$\mathcal{L} \supset \frac{1}{2}(\partial_\mu a)^2 - \frac{1}{2}m_a^2 a^2 + \sum_{i,\mu,\nu} \frac{a}{f} c_i \frac{\alpha_i}{4\pi} F_{i,\mu\nu}\tilde{F}^{i,\mu\nu} - \frac{g^* f}{\sqrt{2}}\psi\tilde{\psi}$$

- Their mass, m_a, can be arbitrarily below the NP scale
- Coupling to the SM goes as $1/f$, while $m_{NP} \sim g * f$
  - Exploring the intensity frontier implies the energy frontier
- ALPs couple to gluons (LHC production) or photons (LHC decay)
  - Decay to gluons also possible but harder experimentally

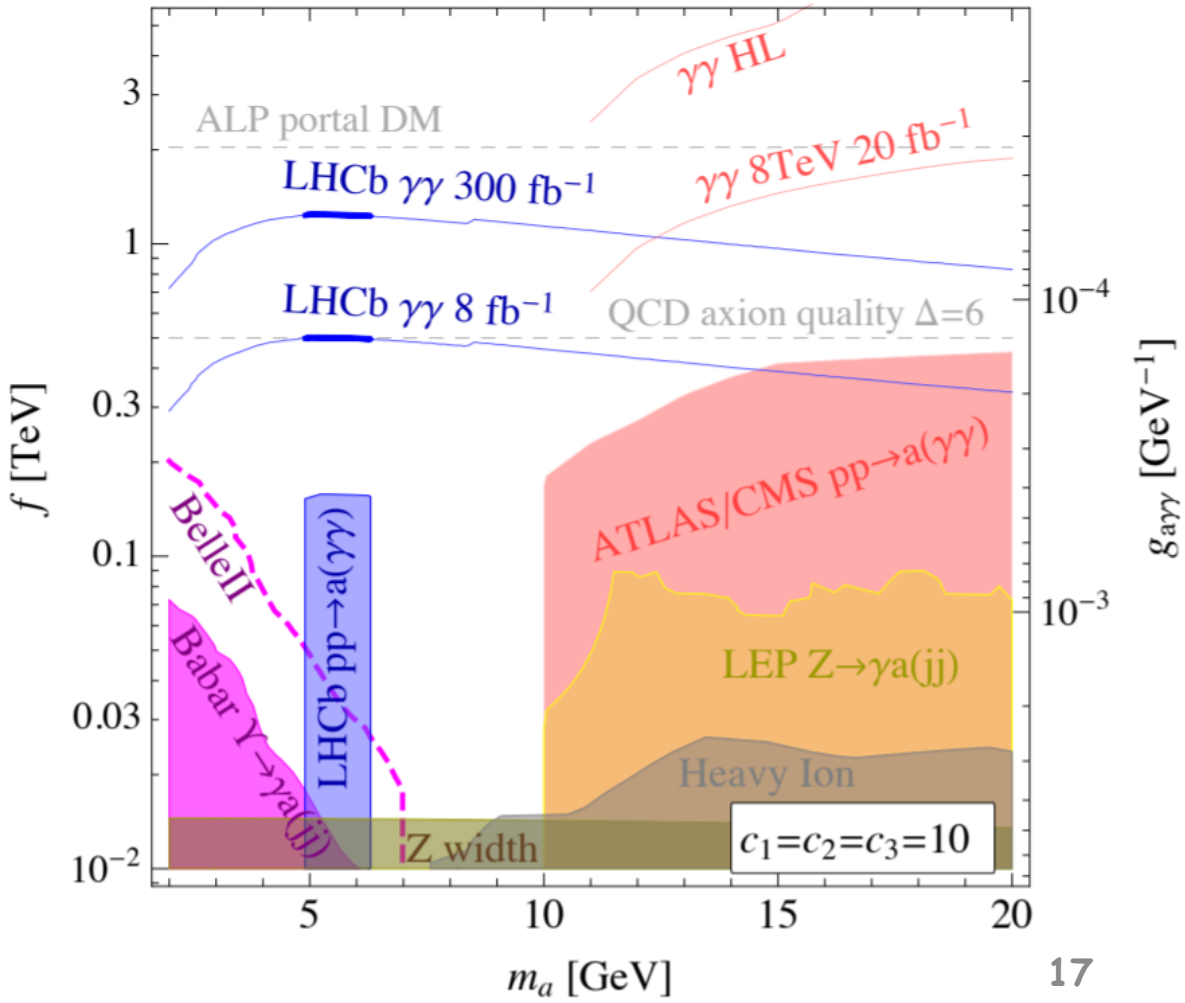
Prospects for Axion Like Particles (ALPs)

JHEP 1901 (2019) 113

- Light ALPs not reachable for ATLAS and CMS

- LHCb could cover the region between 3 and 10 GeV
  - Current best limits in mass gap done with 80 pb^{-1} of LHCb data

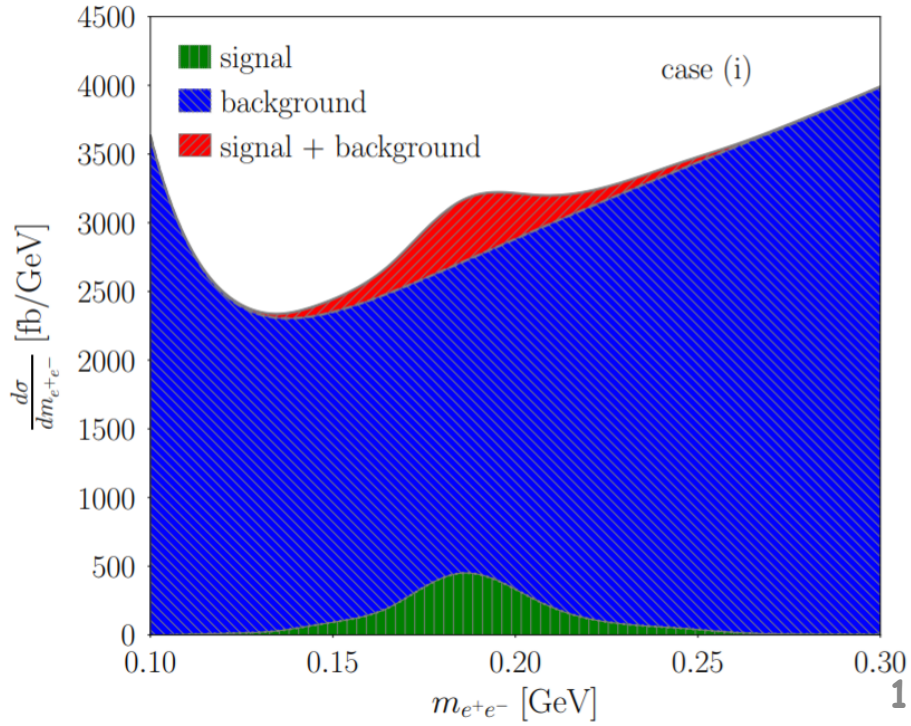
- Plan to search using 2018 LHCb data
  - Existing trigger for $B_s \to \gamma\gamma$



Prospect for True Muonium (*TM*) at LHCb

arXiv:1904.08458

- A search for the vector 1^3S_1 state (TM)
- QED predicts $\tau \sim 1.8$ ps, and mass ~ 211 MeV
  - Very low mass → off-shell γ production via $\eta \to \gamma\gamma^*$ (small BR but high σ)
  - Experimental signature → resolvable displace vertex decaying into e^+e^- pairs
- Prospect (Run-3 & beyond)
  - Assume current LHCb e^+e^- mass resolution (~ 20 MeV at 211 MeV)
  - Discovery potential at 15 fb^{-1}



Summary

- LHCb has an extensive program of searches beyond flavour physics
  - Excellent vertexing, tracking and soft trigger
  - Especially competitive for low masses and lifetimes
  - Rich variety of models and signatures can be approached

- Bright prospects for the future:
  - Software level trigger: allow softer kinematics
  - Better vertex resolution and tracking capabilities after upgrade
  - Higher luminosity

Backup