Overview of LHCb results

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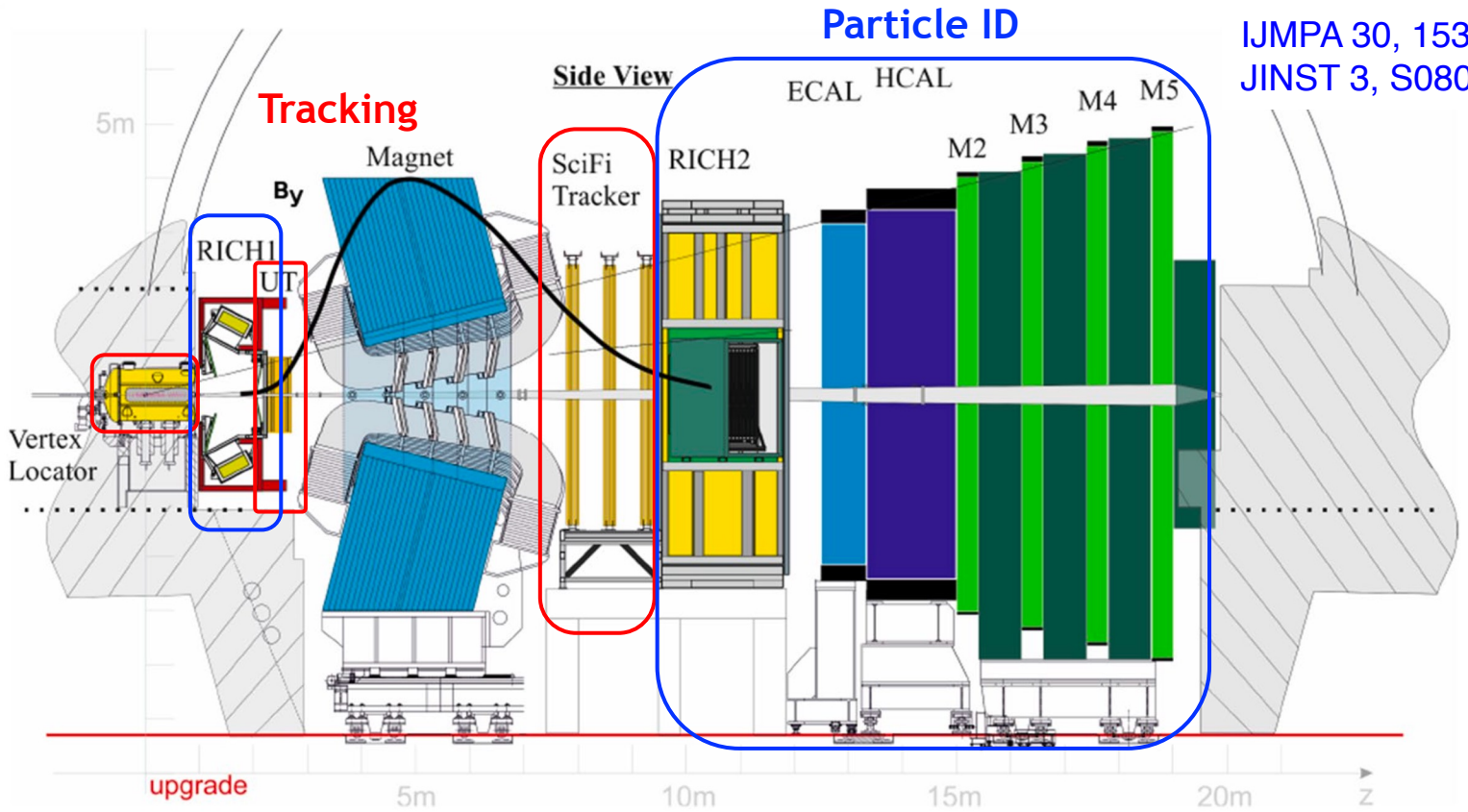
VU Amsterdam and Nikhef

on behalf of the LHCb collaboration

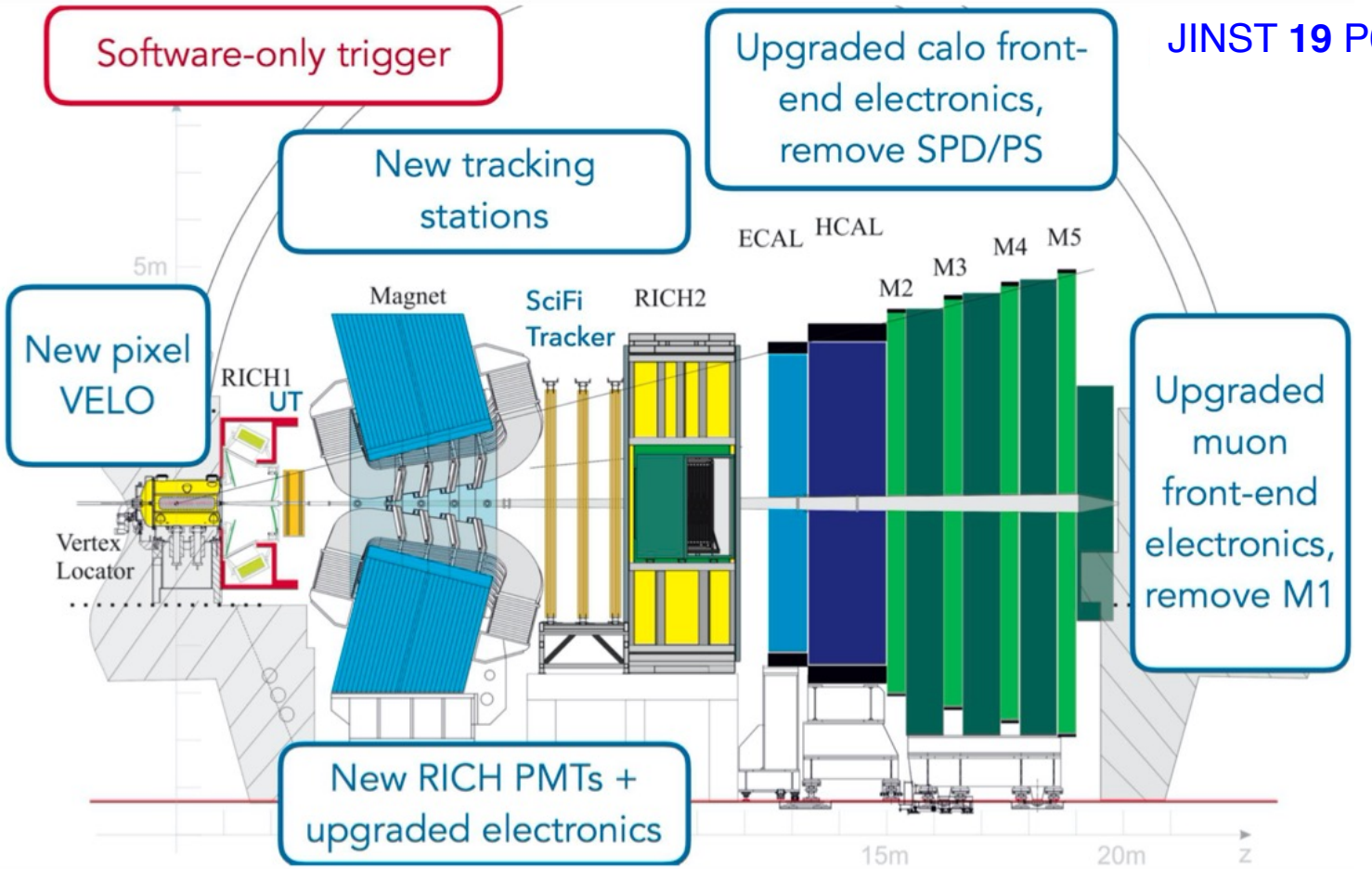
LLP2024: Fourteenth workshop
of the Long-Lived Particle Community
Tokyo, July 1st, 2024

LHCb detector



- Forward spectrometer, designed as the *b*-physics experiment at the LHC
- Precise vertex reconstruction with VELO
- Powerful $p/K/\pi$ separation using RICH detectors
- Coverage complementary to ATLAS and CMS in p_{T} and η
- **Unique sensitivity for light Long-lived Particles (LLPs) in O(GeV) range**

Upgraded LHCb

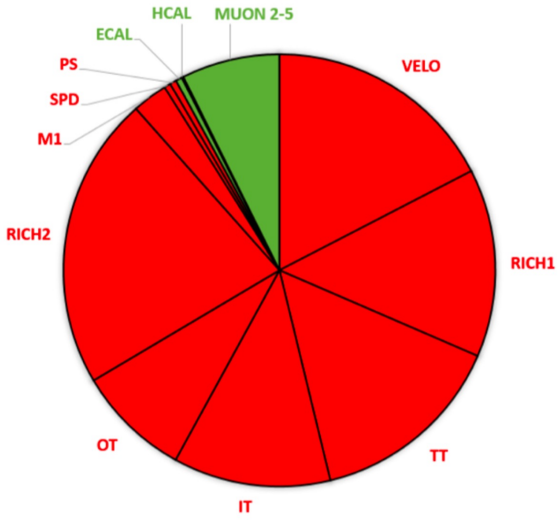


JINST **19** P05065

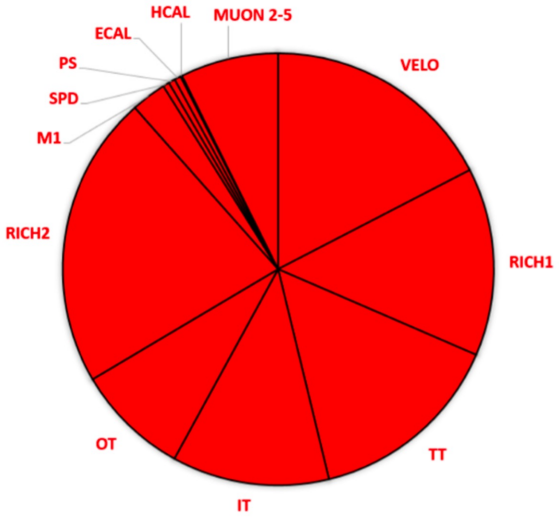
Major detector upgrade for Run 3 and 4

targeting x5 larger instantaneous luminosity compared to Run 1 and 2

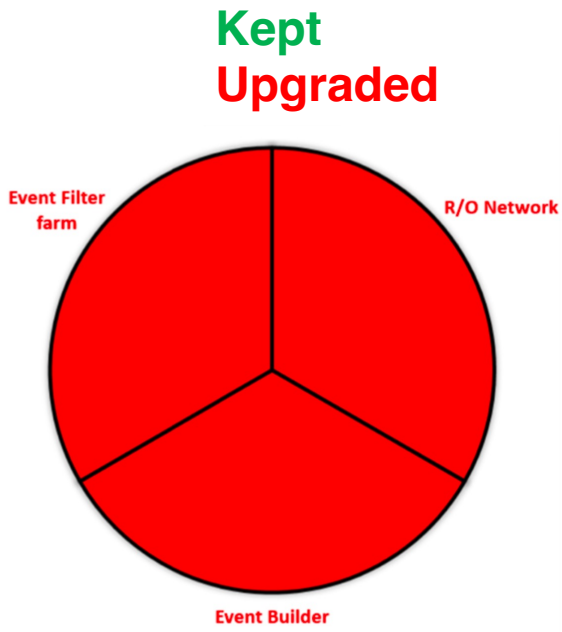
Upgraded LHCb



Detector channels



R/O electronics

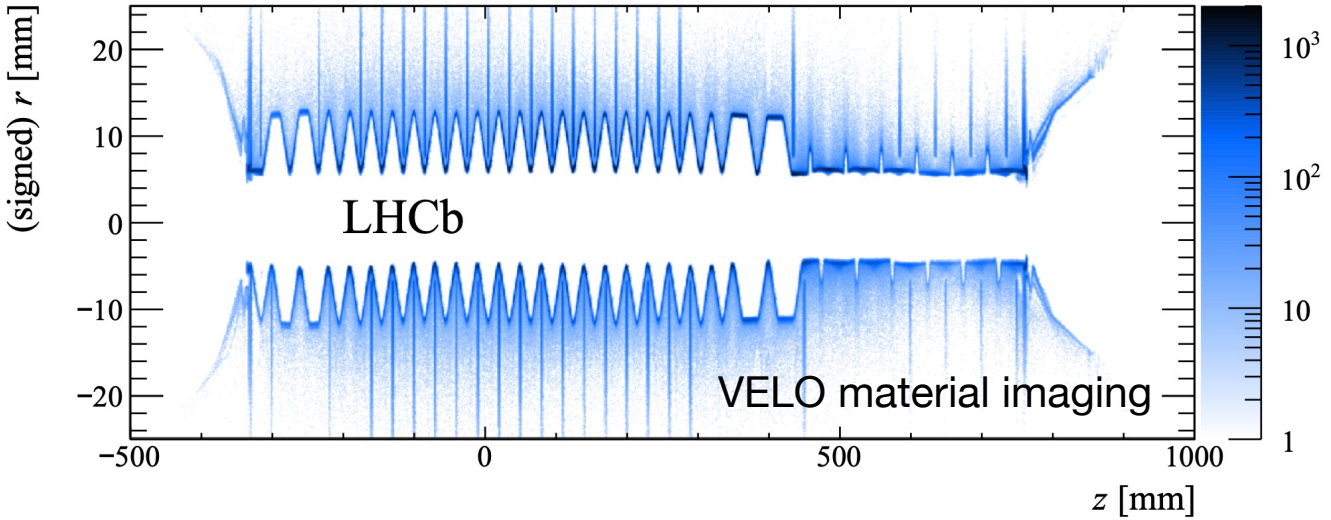


DAQ

- Most of electronics replaced
- No hardware trigger, read-out at 30 MHz
- **Fully software online trigger on GPUs**
- Allows much increased sensitivity for LLP searches with dedicated triggers

LLP searches at LHCb

- **So far focused on signatures within VELO volume**



JINST 13 (2018) 06, P06008

- Displacement of ~20 cm

  **decays of B-mesons with $\tau = 1.5\ ps$ correspond to displacement of $O(mm)$*

- Thin VELO envelope (RF foil) - background dominated by
  - heavy flavor decays at *r < 5 mm*
  - material interactions at *r > 5 mm*
- Precise material veto thanks to beam-gas imaging

- **Can be extended to downstream region**

LLP searches at LHCb

Displaced leptons

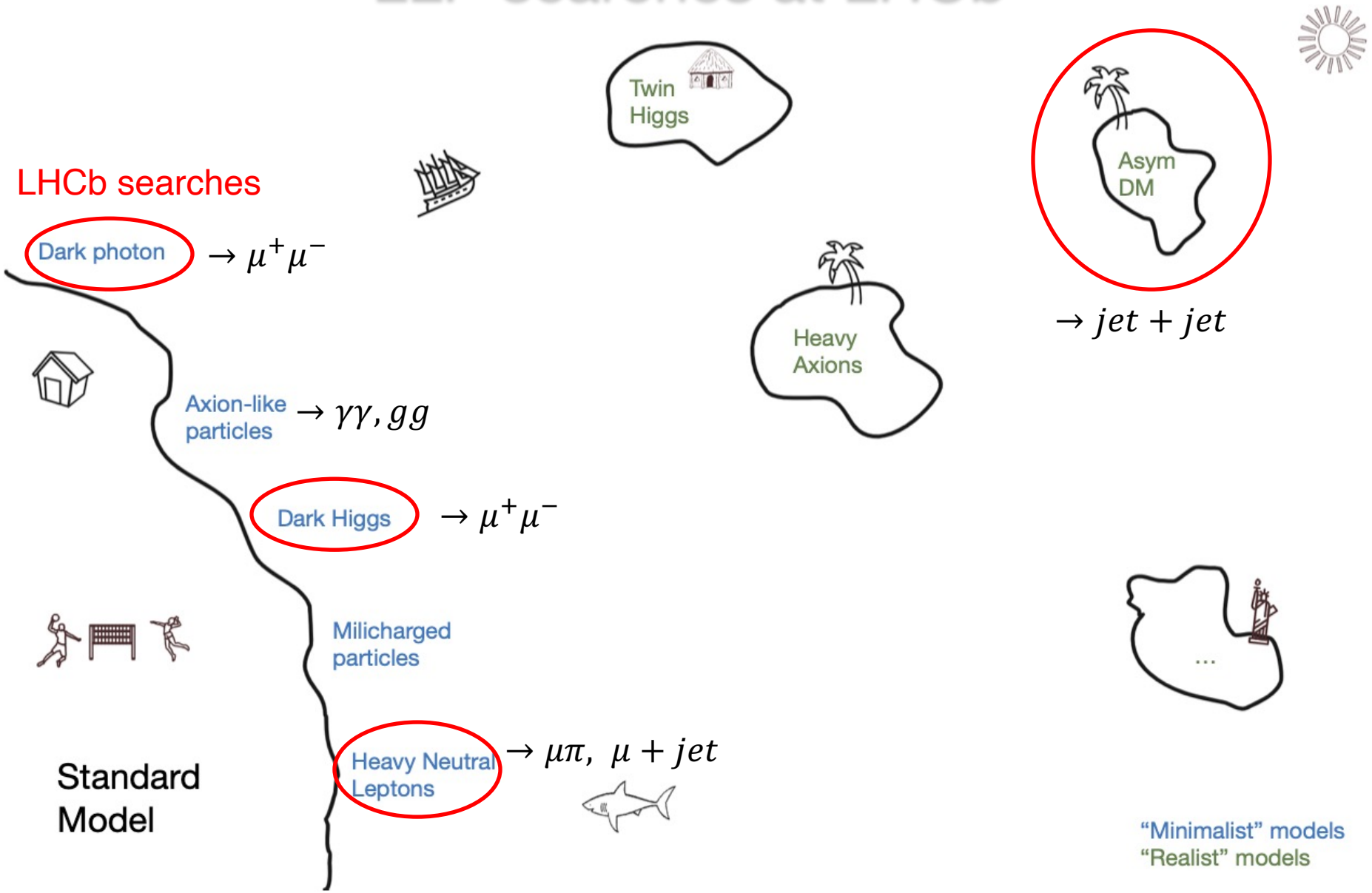
• Dark photon	PRL 120 (2018) 061801, PRL 124 (2020) 041801
• Low-mass dimuon resonances	JHEP 10 (2020) 156
• (heavy) LLPs decaying to $e^{\pm}\mu^{\pm}\nu$	EPJC 81 (2021) 261
• Majorana neutrino	PRL 112 (2014) 131802
• Light boson from $b \to s$ decays	PRL 115 (2015) 161802, PRD 95 (2017) 071101

Displaced jets

• HNL in $W^{\pm} \to \mu^{+}\mu^{\pm} jet$	EPJC 81 (2021) 248
• LLP $\to$ *jet jet*	EPJC 77 (2017) 812
• LLP $\to \mu +$ *jets*	EPJC 77 (2017) 224

expecting more results with Run 1-2 data

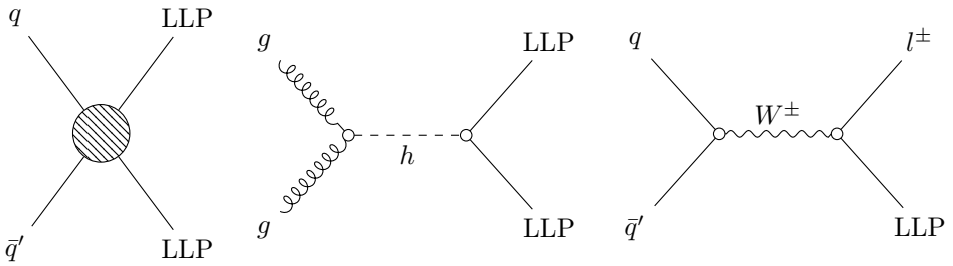
LLP searches at LHCb



stolen from seminar by S. Knapen

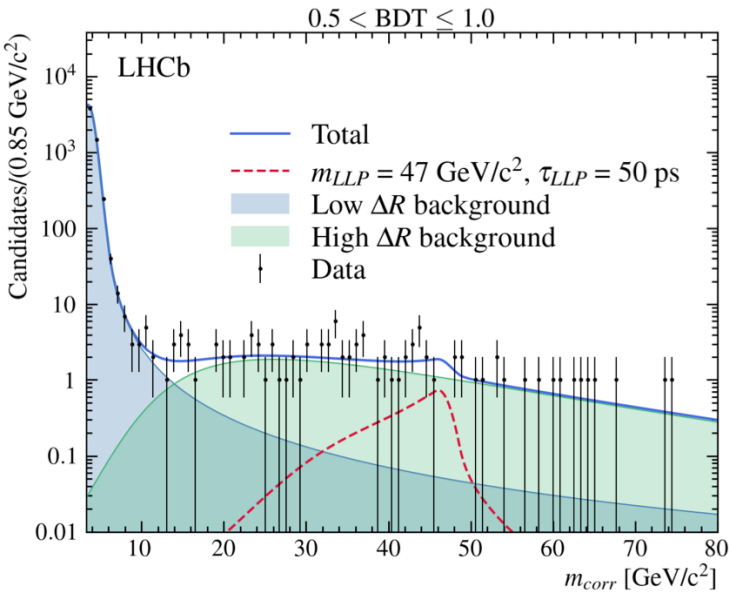
LLPs decaying to $e^{\pm}\mu^{\mp}\nu$

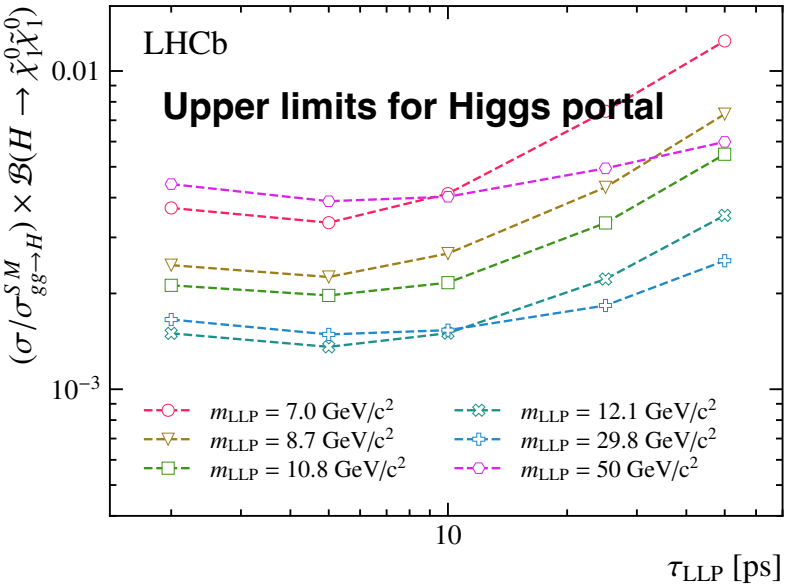
- Production mechanisms



- Analysis with full Run 2 data
- LLP masses down to 7 GeV
- *Correcting mass* to flight direction: a proof-of-concept analysis
- Simultaneous fit to corrected mass and lifetime

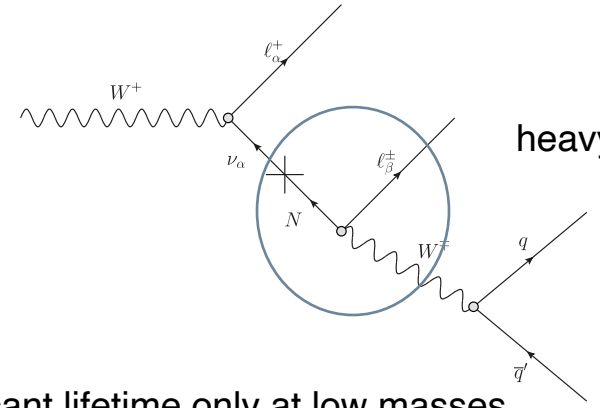
EPJC 81 (2021) 248





HNL in $W^{\pm} \to \mu^{+}\mu^{\pm} jet$

- Search neutral leptons can be found in W decays

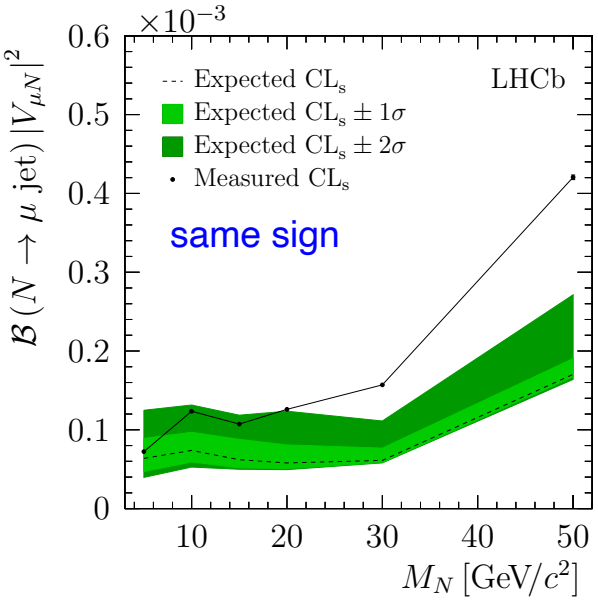


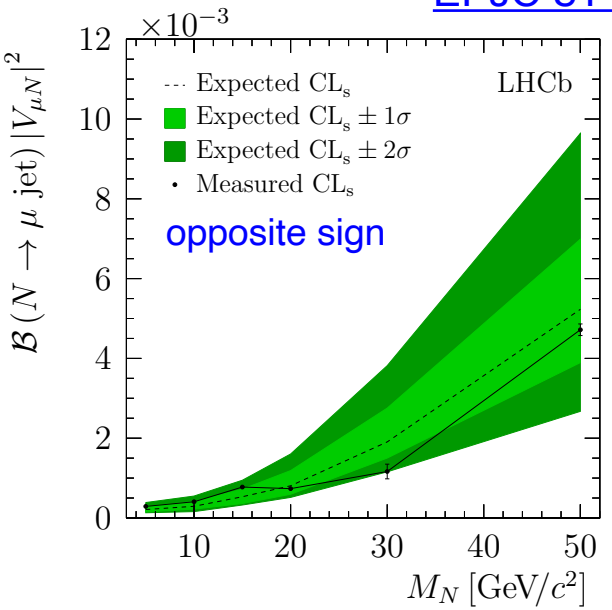
heavy neutrino decay to $\mu^{\pm} jet$

*HNL is expected to have significant lifetime only at low masses

- Upper limits for both ***same*** and ***opposite sign*** muons using Run 1 data set

EPJC 81 (2021) 248

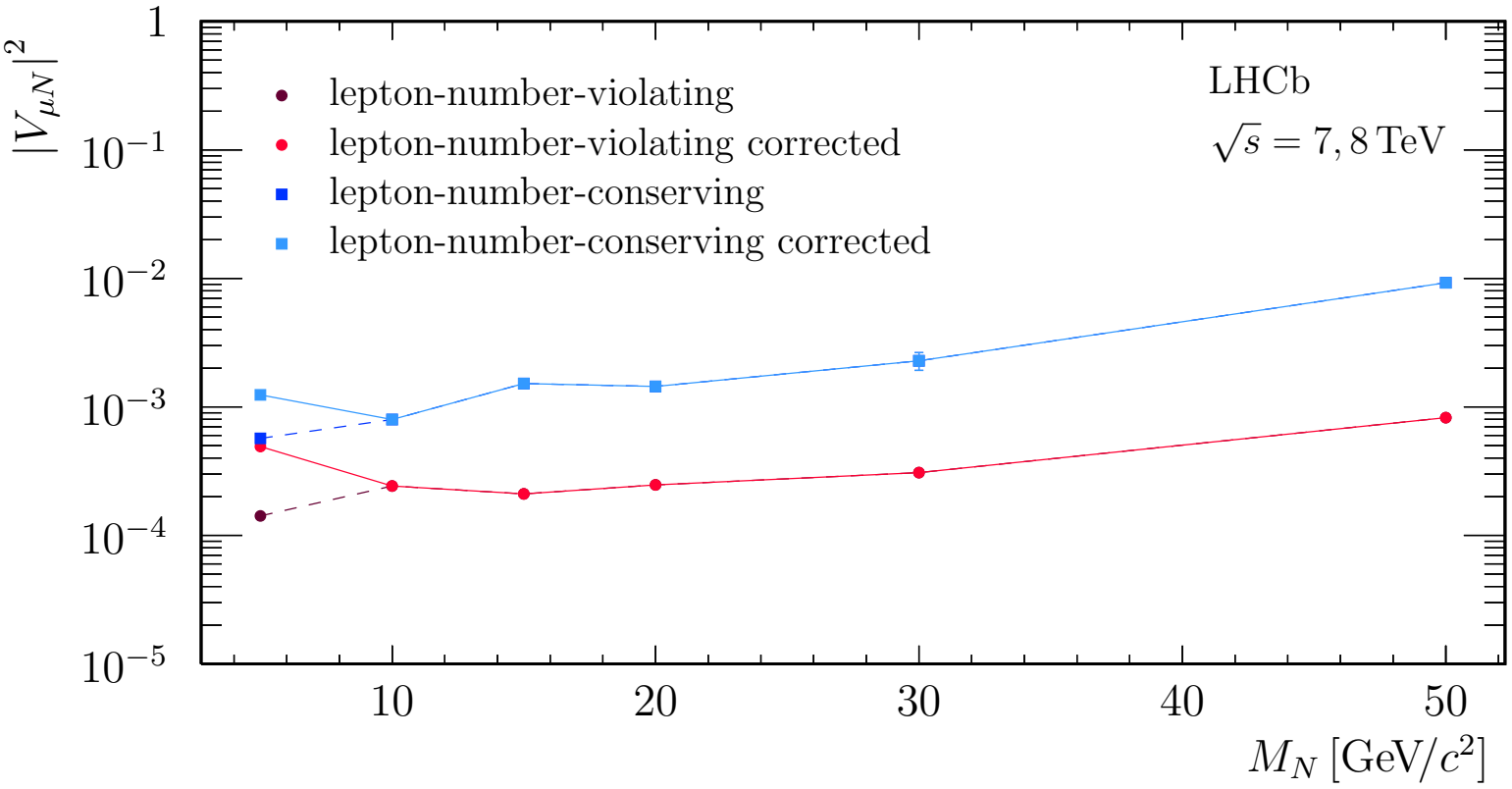




HNL in $W^{\pm} \to \mu^{+}\mu^{\pm} jet$

- Upper limits on mixing with muon neutrino - $|V_{\mu N}|^2$

EPJC 81 (2021) 248



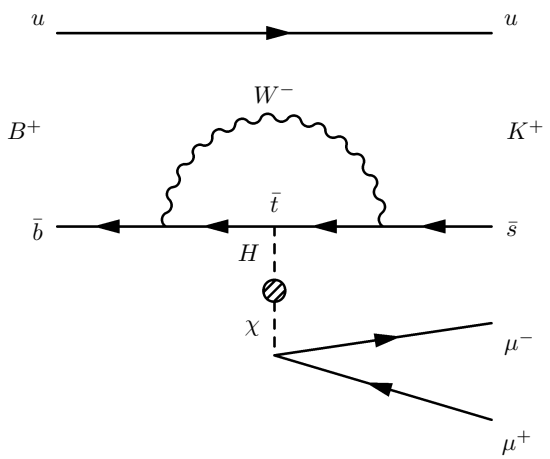
- Lifetime corrections at low masses
- Not very competitive with ATLAS, CMS and DELPHI searches

JHEP 10 265 JHEP 01 122 Z. Phys. C74 57

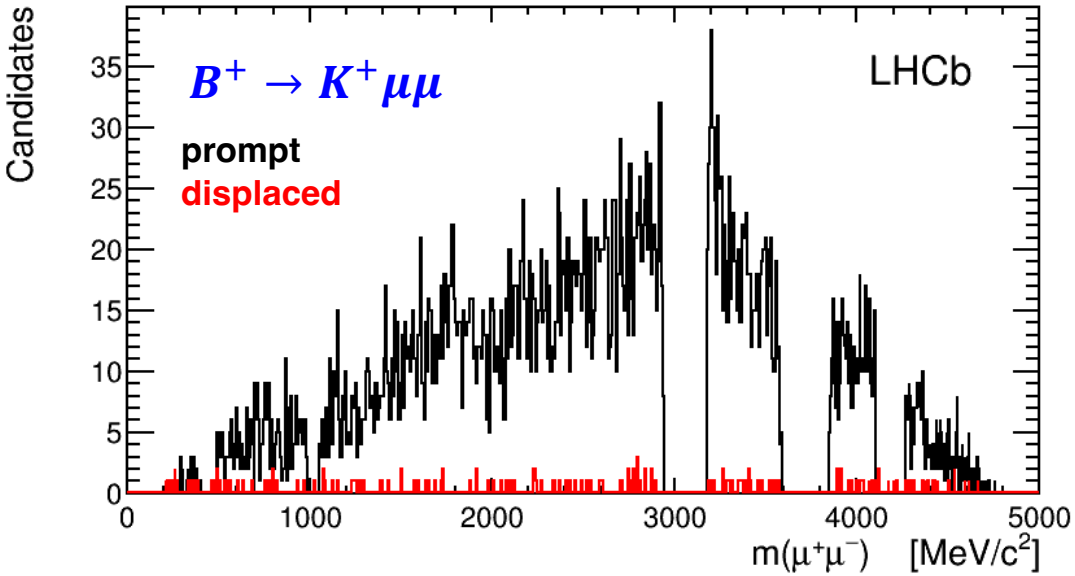
Light boson in $b \to s$ decays

- Light boson can contribute to $b \to s\mu\mu$ penguin decays

PRL 115 (2015)161802
PRD 95 (2017) 071101



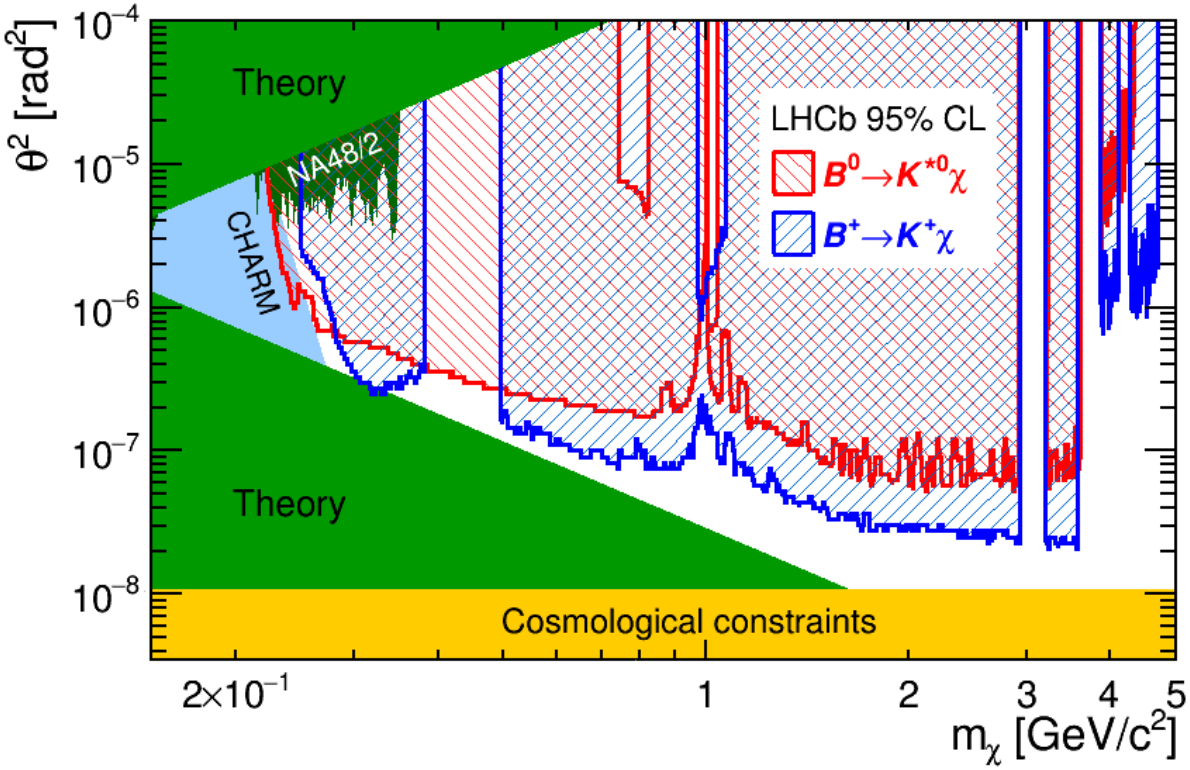
- LHCb has world's largest sample of $b \to s\mu\mu$ decays
- Study of di-muon spectrum



Light boson in $b \to s$ decays

PRL 115 (2015)161802
PRD 95 (2017) 071101

- Search for a narrow di-muon peak
- Displacement of muon pair is considered
- Upper limits on mixing with SM Higgs

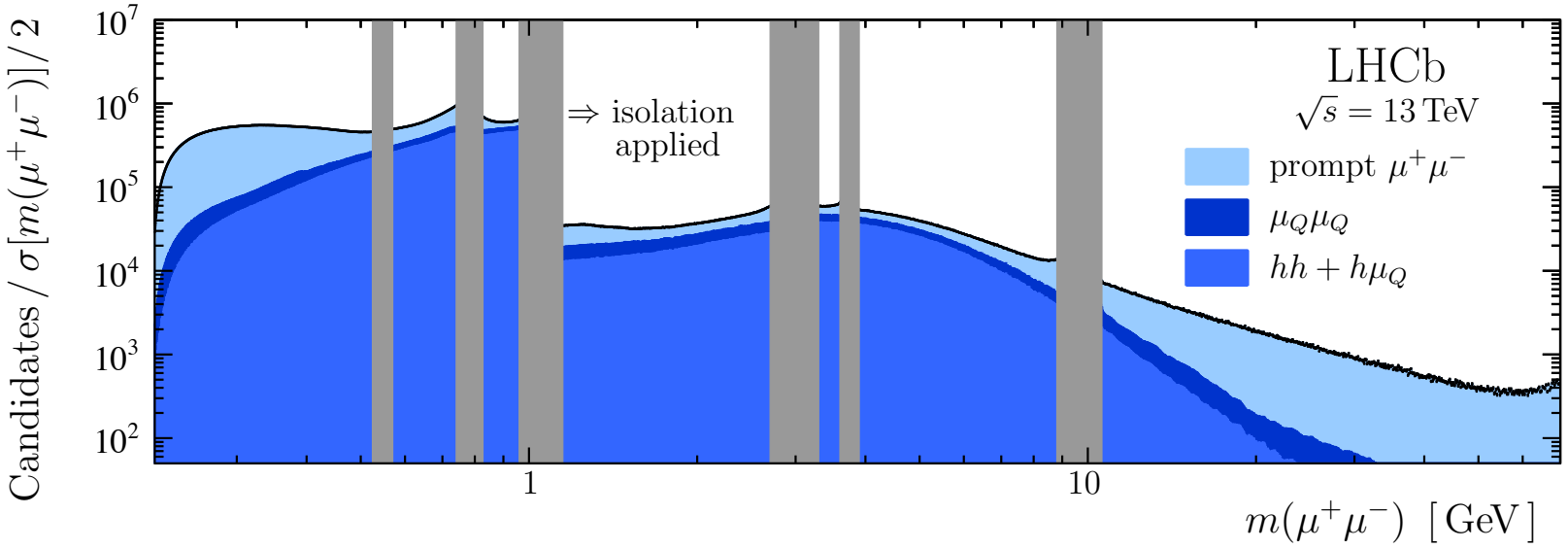


- **World's best upper limits below $2m_\tau$**
- Sensitivity will be further improved in Run 3 thanks to tracking for *very* long-lived particles

Dark photons in di-muon spectrum

- Light dark photon can appear in a mixing with off-shell photon
  - large fraction in forward region, low p_T
- Normalized to off-shell photons
  - No need for efficiencies (for prompt search)

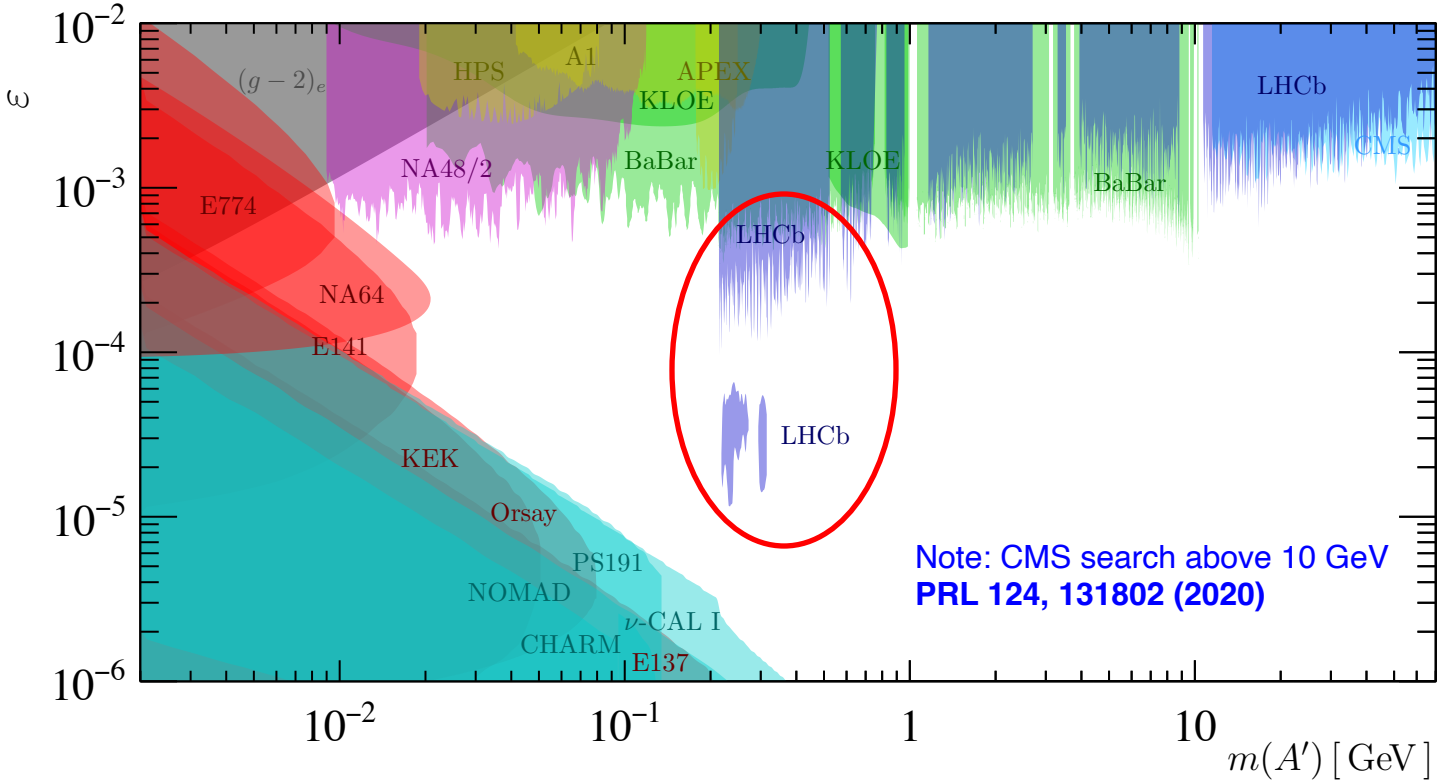
PRL 124 (2020) 041801



- Bump hunt analysis
- Regions of SM resonances removed
- Search for **both prompt and displaced** signatures using Run 2 data

Dark photons in di-muon spectrum

PRL 124 (2020) 041801



- World's best upper limits for inv. mass range of **~200-700 MeV (prompt)**
- First displaced search not from beam-dump experiments
  - explored invariant mass range: **214-350 MeV**
- Re-casted to other models
- Can be extended with di-electron search at very low masses in D^*, π^0 *or* η *decays*

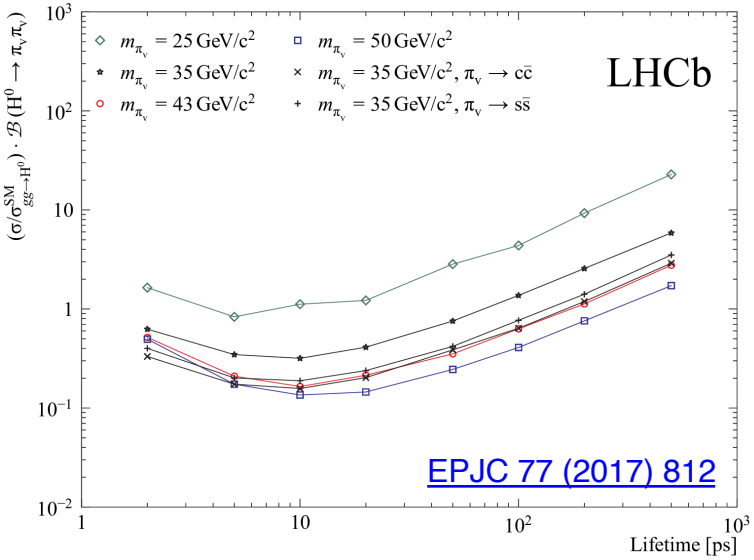
Searches of LLPs decaying to jets

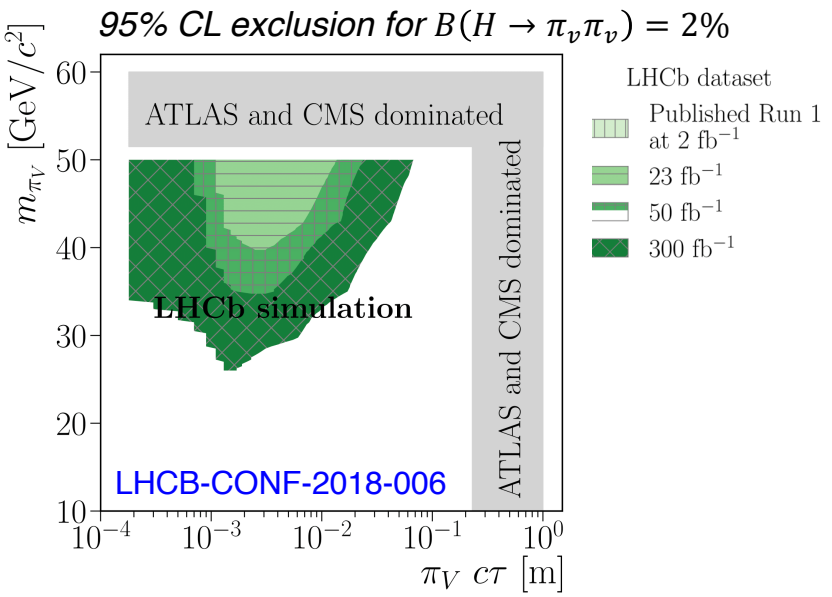
Signature: single displaced vertex with two (*b*-) jets

EPJC 77 (2017) 812

Model: Hidden Valley dark pions produced through Higgs portal

- Analysis in bins of R_{xy} - radial distance to the beam axis
- Invariant mass range explored: 25-50 GeV
- Upper limit for lifetimes range 2-500 ps
- Complementary limits to ATLAS and CMS



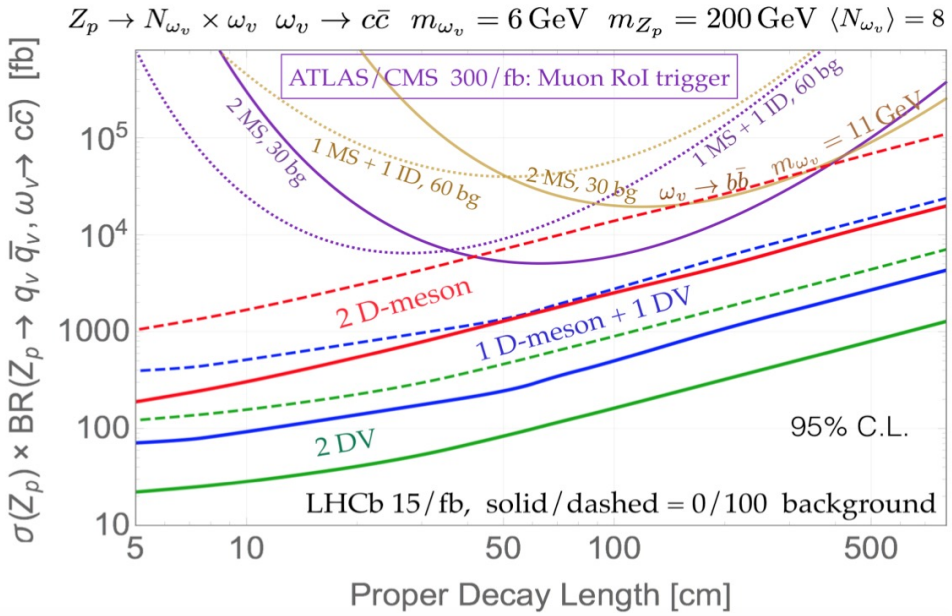


- Can be pushed to lower masses in Run 3 using jet substructure

LHCB-CONF-2018-006

LLP / ALP decays to light hadrons

- Access to low masses O(GeV)
- Unique sensitivity by using charged hadron ID from RICH
- Complicated **mixture of heavy flavor background**
- Several searches suggested:
  - Model-independent search for $H \to SS, S \to K^+K^-$
    LHCb projections: JHEP 01 (2020) 115
  - Dark hadrons via decays to *D*-mesons / displaced vertices
    LHCb projections: PRD 97 (2018) 9, 095033

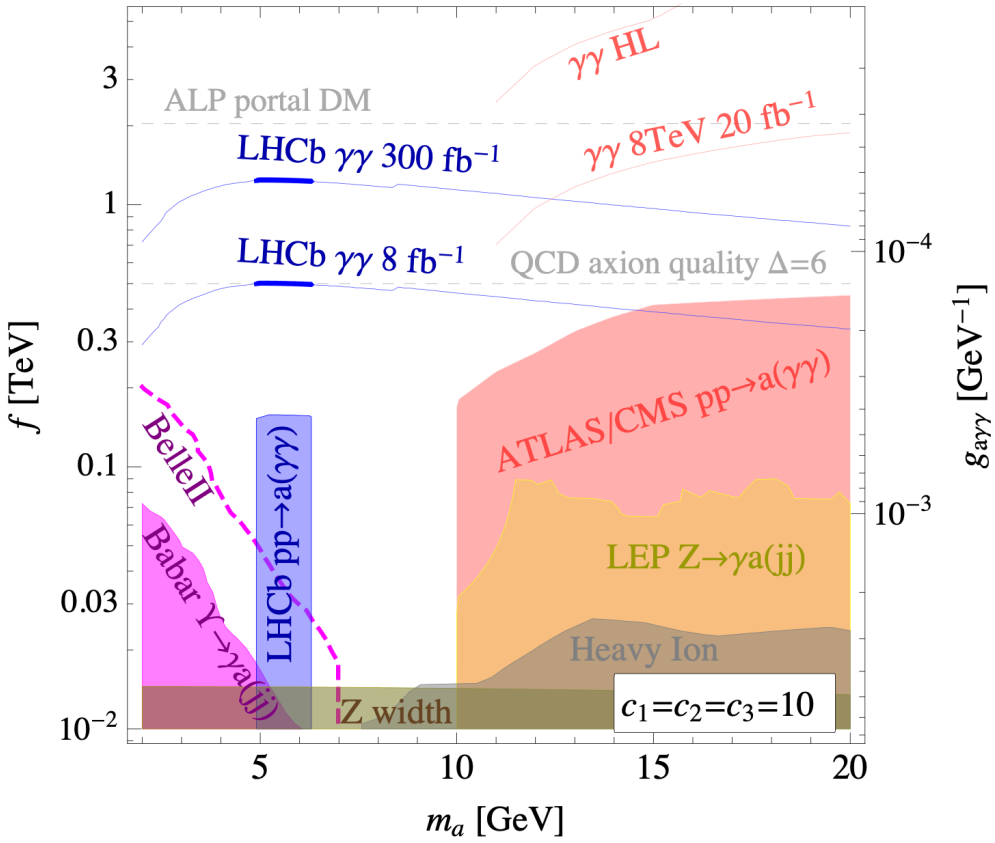


- **Not yet explored at LHCb**

Di-photons: ALP search

- ALPs can be produced and detected via $gg \rightarrow ALP \rightarrow \gamma\gamma$
- Light ALPs with **mass of O(GeV)** are not accessible by ATLAS and CMS
- LHCb has already provided best limits in narrow mass window using *(small)* open data set for $B_s^0 \rightarrow \gamma\gamma$

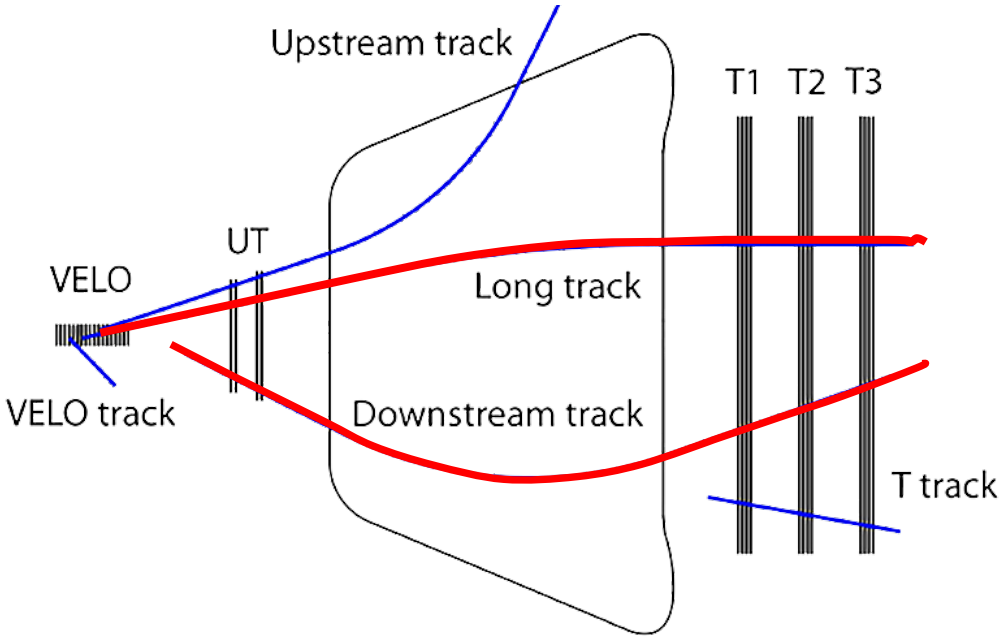
JHEP 1901 (2019) 113



Expecting much better sensitivity in broader mass range using Run 2 data set

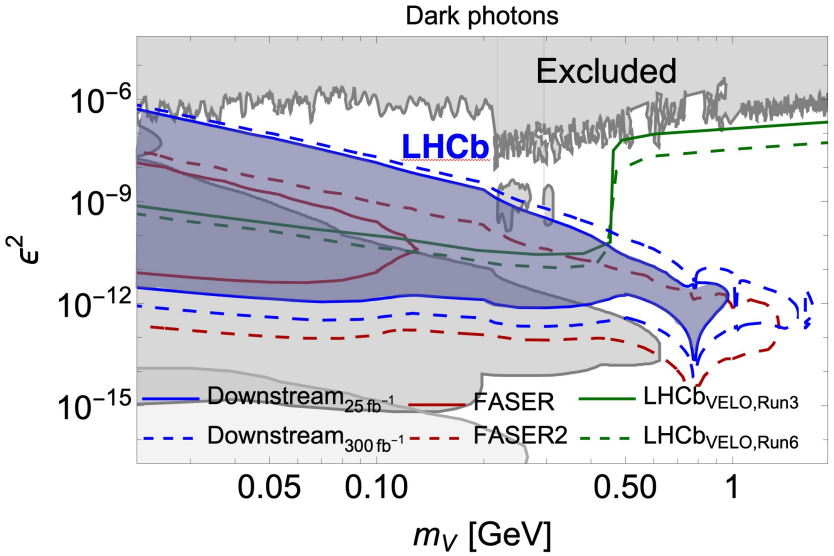
LLPs in Run 3

Tracking for *very* long-lived particles



- **Physics track types supported in online trigger:**
  - Long
  - Downstream (new in Run 3)
  - special cases for T-tracks (new in Run 3)

EPJC 84 (2024) 6, 608



- Access to lifetimes up to *10ns*
- New sensitivity for New Physics searches

strong competitor to FASER2

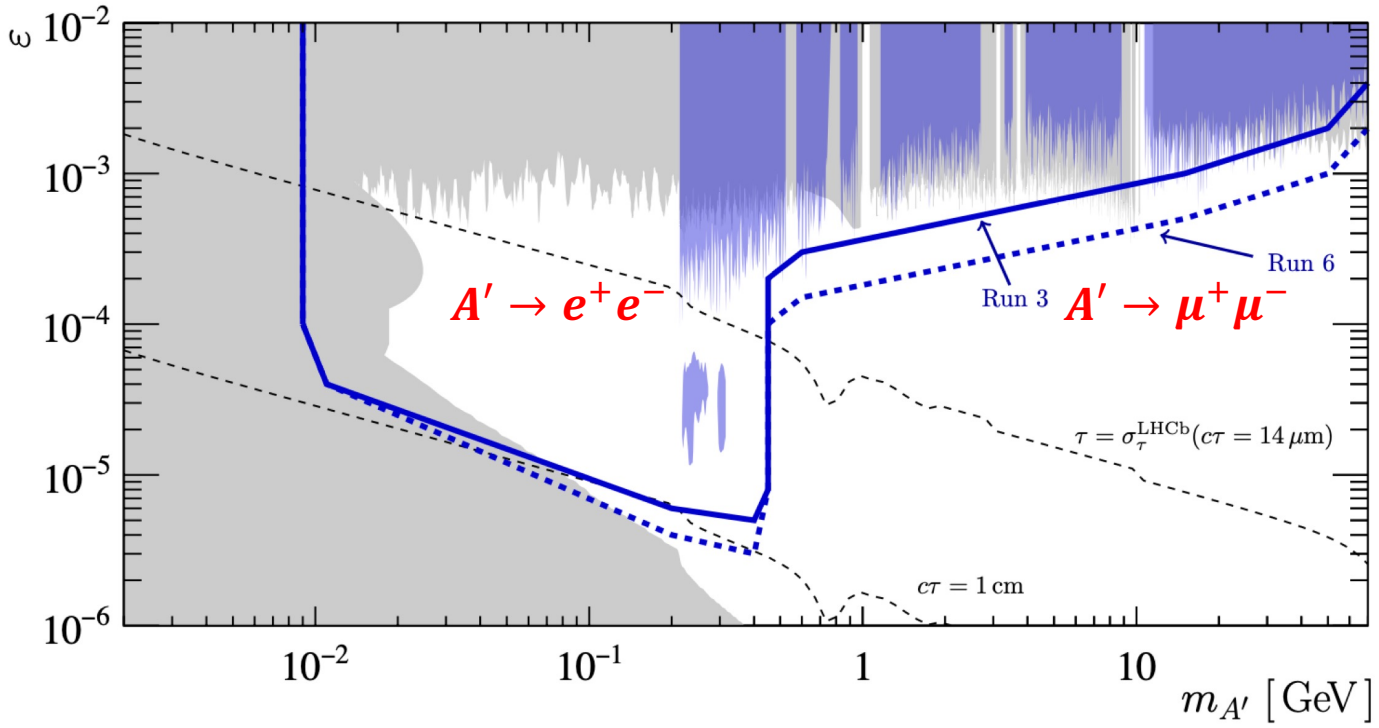
**in optimistic scenario*

see dedicated talk by I. Sanderswood

Dark photons: new muon and electron ID

- Better tracking-based **muon ID** - massive improvement at low momentum
  - can be / going to be further improved with NNs
- Monotonic and fast Lipsitz NN for **electron ID**

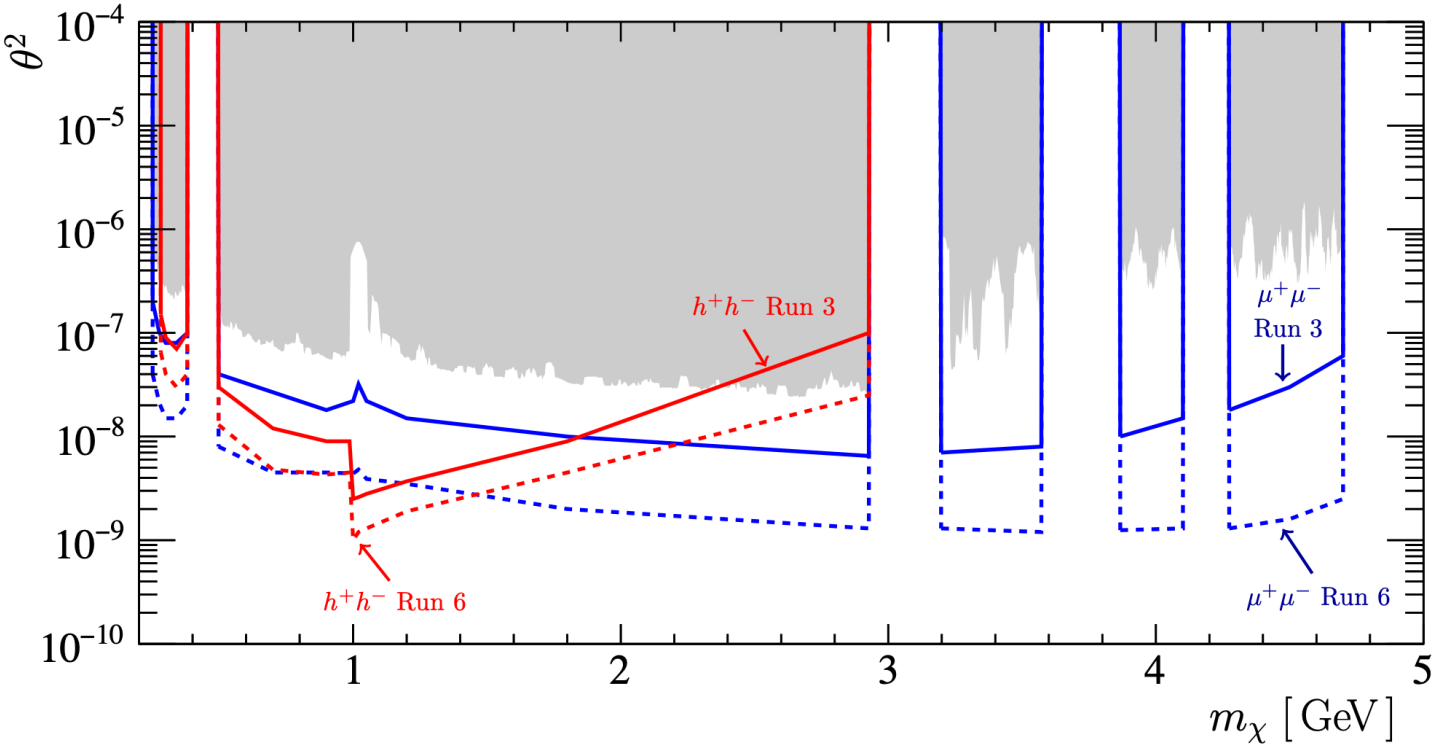
arXiv:2203.07048



- Much smaller mis-id for both muons and electrons
- **Expecting greatly improved sensitivity at very low masses**

Dark scalar from *b*-decays: prospects

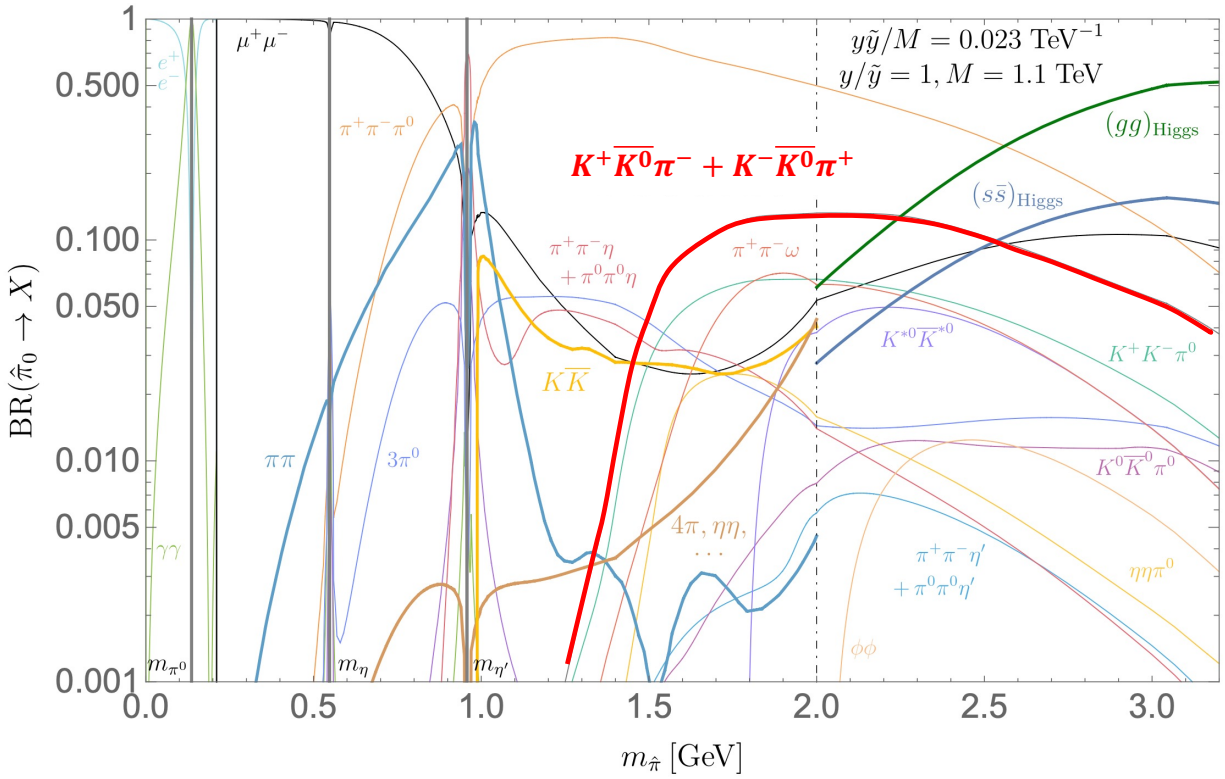
arXiv:2203.07048



- Expecting great improvements for **di-muon mode** in Run 3 thanks to
  - larger stats
  - better muon ID
  - tracking for long-lived particles
- To be followed by studying hadronic modes

Light dark pions through hadronic decays

CERN-TH-2021-150



- Results with **hadronic searches for light dark pions** (and ALPs) are limited
- Complicated behavior of BR for exclusive modes wrt inv. mass
- $K_S^0 K\pi$ **mode is promising,** especially in Run 3:
  - relatively flat and large at the same time,
  - greatly **improved K_S^0 reconstruction efficiency** in Run 3

STEALTH white paper

arXiv.2105.12668

Unleashing the full power of LHCb to probe Stealth New Physics

Editors: M. Borsato[1], X. Cid Vidal[2], Y. Tsai[3 4], C. Vázquez Sierra[5], J. Zurita[6]

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Abstract

In this paper we describe the past, present and future potential of LHCb to find Stealth physics. This refers to Beyond the Standard Model signatures with excellent theory motivation and not falling in the category of "flavor physics". Examples of these signatures include Long-Lived particles, light resonances or hadronic final states where particle identification can play an important role. We will describe why LHCb is very well equipped to discover this kind of physics at the Large Hadron Collider, and provide good examples of well motivated theoretical models that can be probed with great detail at the experiment.

Contents

Summary

- LHCb made several searches for **dark photon**, **HNLs**, **dark scalar** from *b*-decays using Run 1-2 data set, based on *displaced muon signature*
- *Hadronic* and *di-photon* signatures, so far, remain to be explored with Run 2 and 3 data

- Greatly improved sensitivity thanks to new online GPU trigger with:
  - new lepton ID (both muons and **electrons**)
  - tracking for **very long-lived particles**
  - larger statistics

  and has capabilities to attack more complex signatures with dedicated trigger

- **Expecting lots of powerful new searches with Run 3 data**