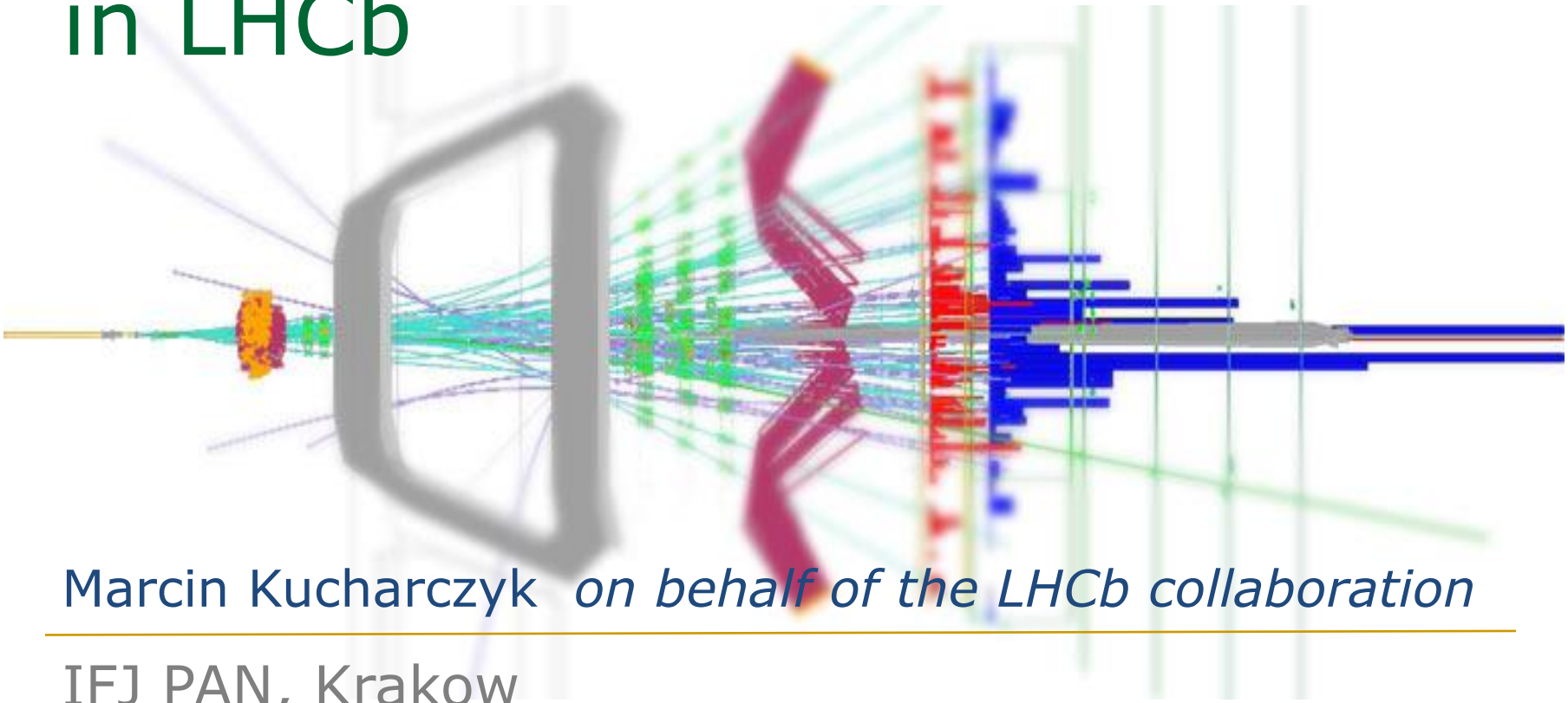
Search for long-lived particles in LHCb



Marcin Kucharczyk *on behalf of the LHCb collaboration*

IFJ PAN, Krakow

Large Hadron Collider Physics

Paris, 25-30 May 2020

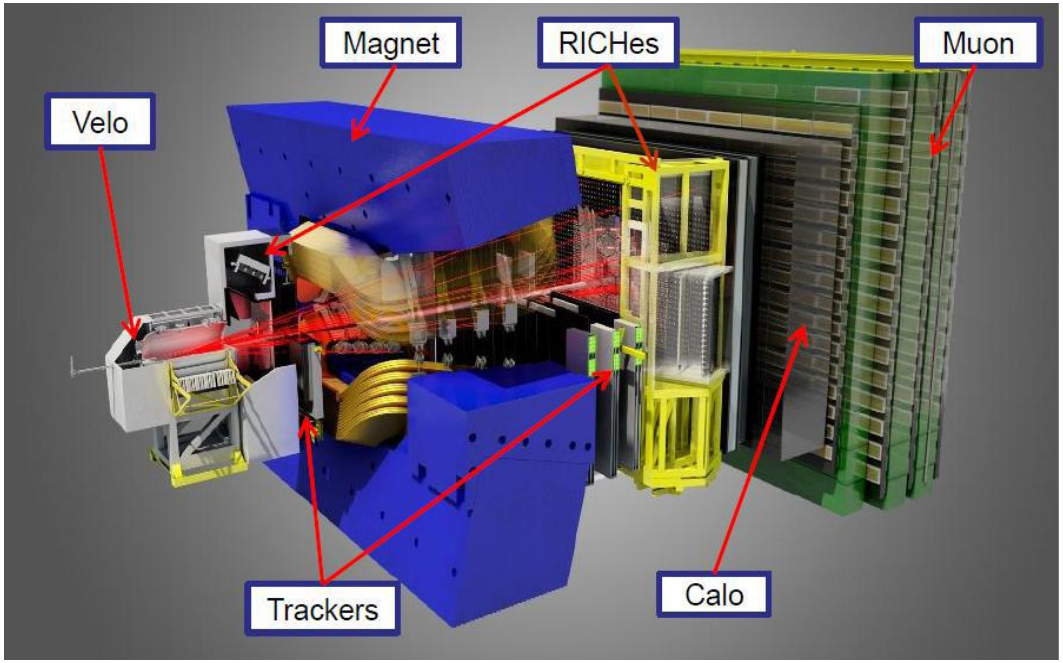
Outline

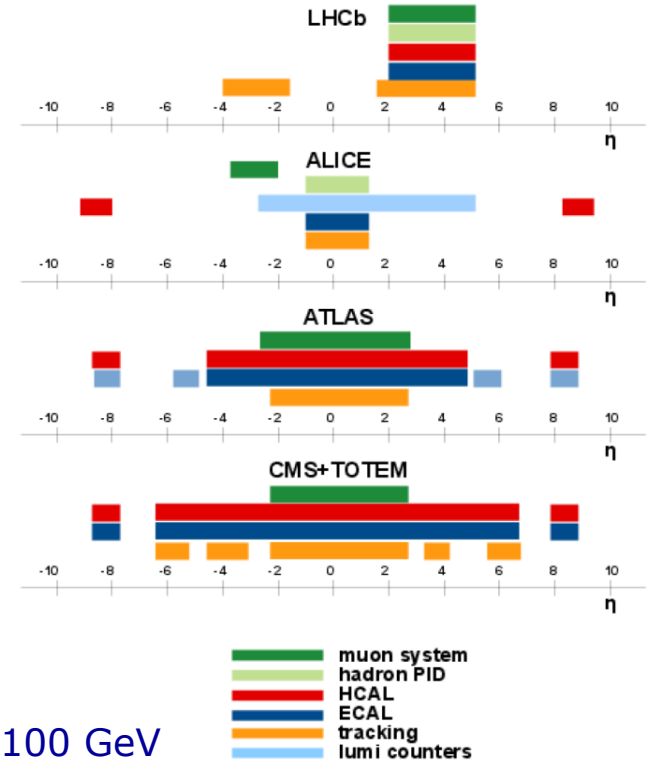
- LHCb - general purpose forward experiment
- Search for long-lived particles decaying into jet pairs
- Search for long-lived particles decaying semileptonically
- Higgs lepton flavour violating decays
- Prospects for exotic searches at LHCb
- Conclusions

LHCb detector

[Int. J. Mod. Phys. A30 (2015) 1530022]

- single arm spectrometer fully instrumented in forward region → GPD in forward region
- designed to study CP violation in *B*, but also fixed target, heavy ion physics
- precision coverage unique for LHCb: $2 < \eta < 5$





- momentum resolution between 0.4% at 5 GeV to 0.6% at 100 GeV
- impact parameter resolution of 20 μm for high-p_T tracks
- lifetime resolution: 0.2 ps for τ = 100 ps
- muon ID efficiency: 97% with 1-3% $\mu \rightarrow \pi$ misidentification

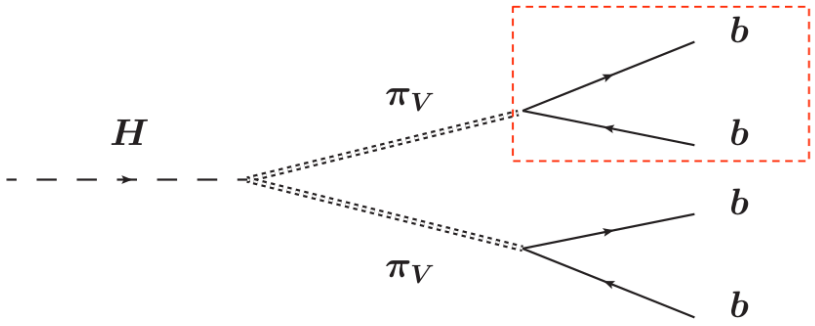
[IJMPA 30 (2015) 1530022]

Higgs decays to long-lived particles

Dark sector Higgs portal

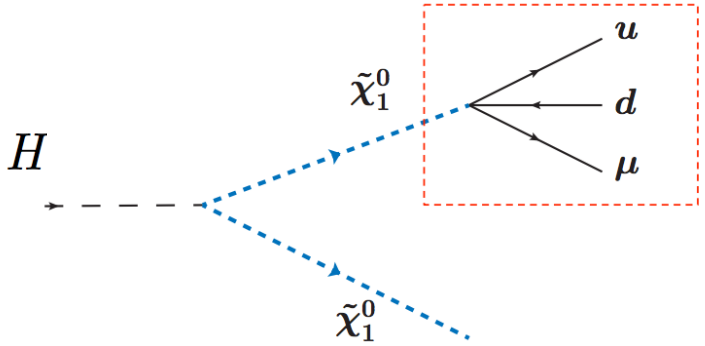
Hidden Valley sector

- 2 Hidden Valley pions decaying to jet pairs



mSUGRA with R-parity violation

- semi-leptonic decay to high p_T muon + jets



Long-lived particles decaying into jet pairs

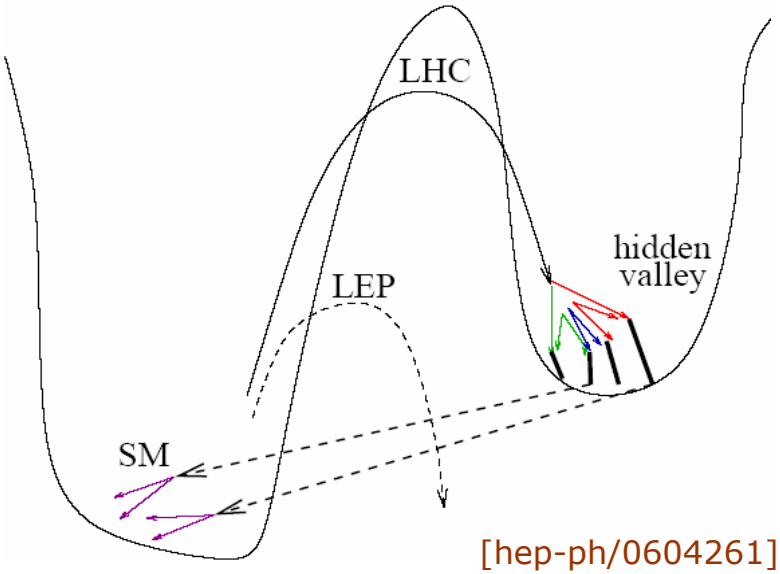
[EPJ C77 (2017) 812]

LHCb Run 1 data

- 7 and 8 TeV $\rightarrow$ 2 fb^{-1}
- simulation with Pythia 8

Single vertex with two jets

- to increase acceptance within LHCb detector
- access to $m_{n\nu} \in$ (25-50) GeV and $\tau \in$ (2-500) ps



[hep-ph/0604261]

Selection

- SV track mult. > 4, R_{xy} > 0.4 mm
- jet inputs selected by Particle Flow, IP_{tracks} > 2 mm
- jets with anti-k_T, R = 0.7, p_T > 5 GeV
- dijet alligned with the vector from PV to the displaced vertex
- material veto

Selection efficiency for signal typically 0.1 - 1%

Long-lived particles decaying into jet pairs

[EPJ C77 (2017) 812]

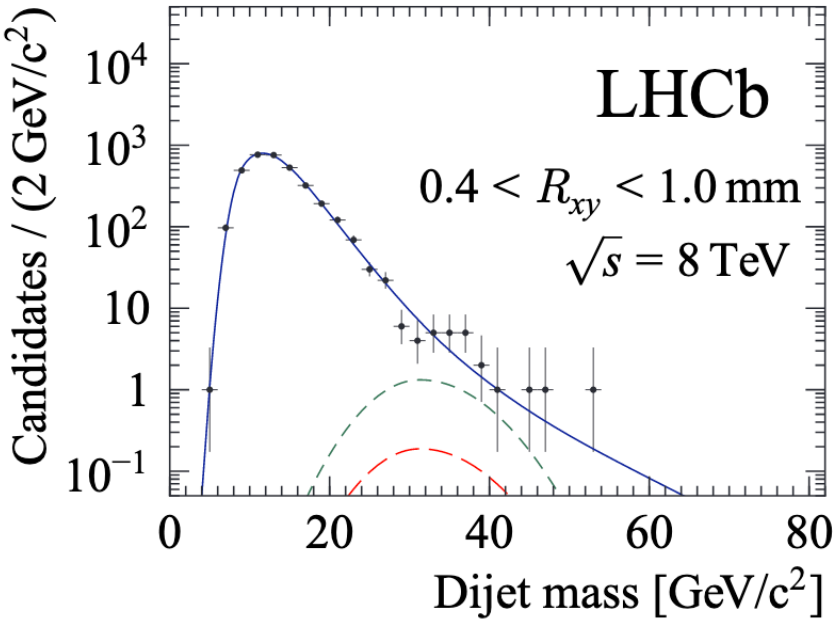
Signal yield from the fit to the dijet mass distribution

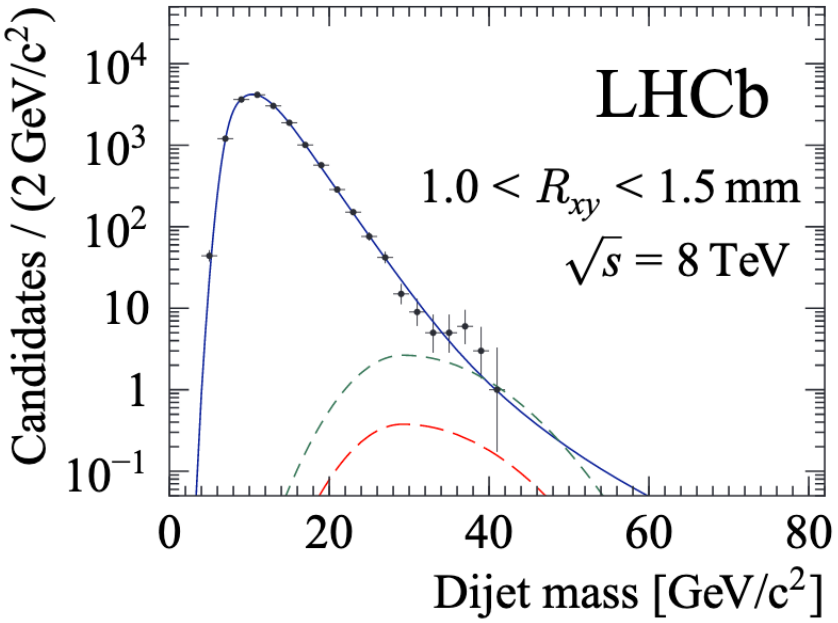
Signal → Gaussian with parameters from simulation

Background → dominated by QCD

→ displaced heavy flavor decays by Gaussian + exponential

→ small component for prompt SM dijets



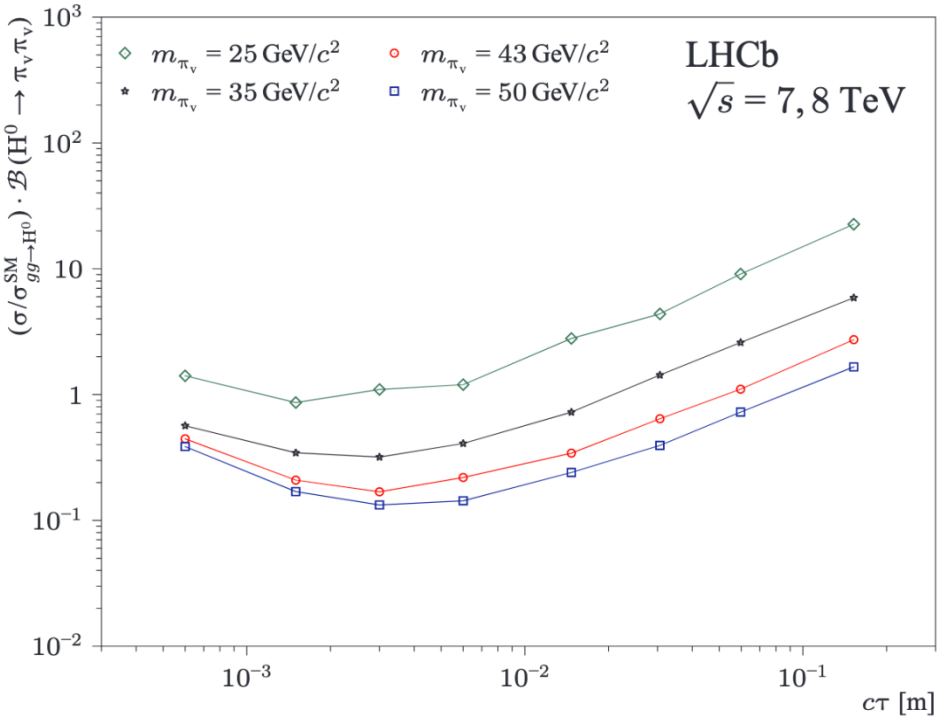


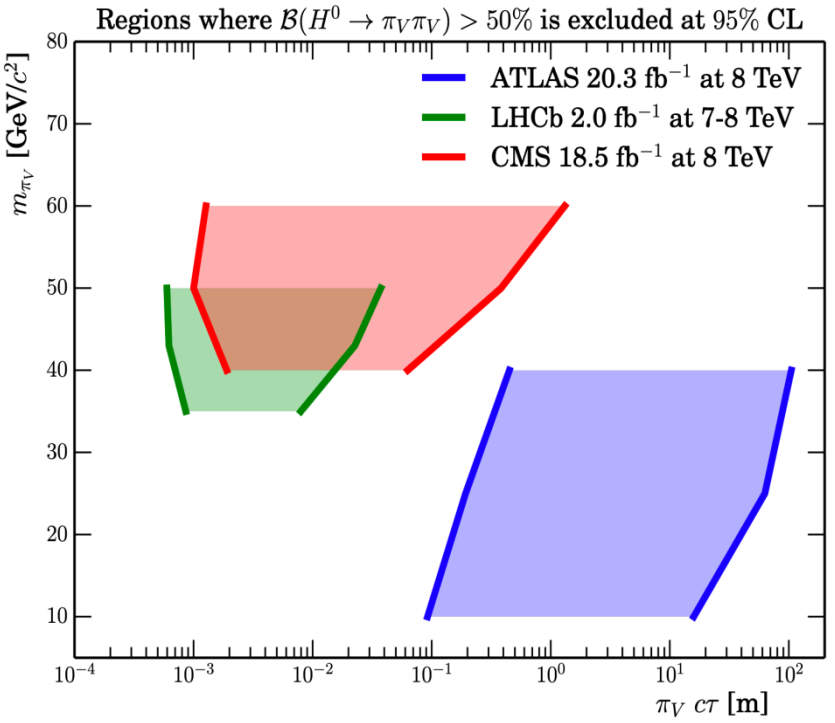
Long-lived particles decaying into jet pairs

[EPJ C77 (2017) 812]

- no significant excess of signal in the data
- upper limits on the signal strength at 95% CL set and reweighted for multiple lifetime hypotheses
- limits on $(\sigma / \sigma^{SM}_{gg\to H}) \times \mathrm{BR}(H \to \pi_V \pi_V)$

[LHCb-PAPER-2016-065]





Long-lived particles decaying semileptonically

[EPJ C77 (2017) 224]

LHCb Run 1 data

- 7 and 8 TeV → 3 fb^{-1}
- simulation with Pythia 6 and 8

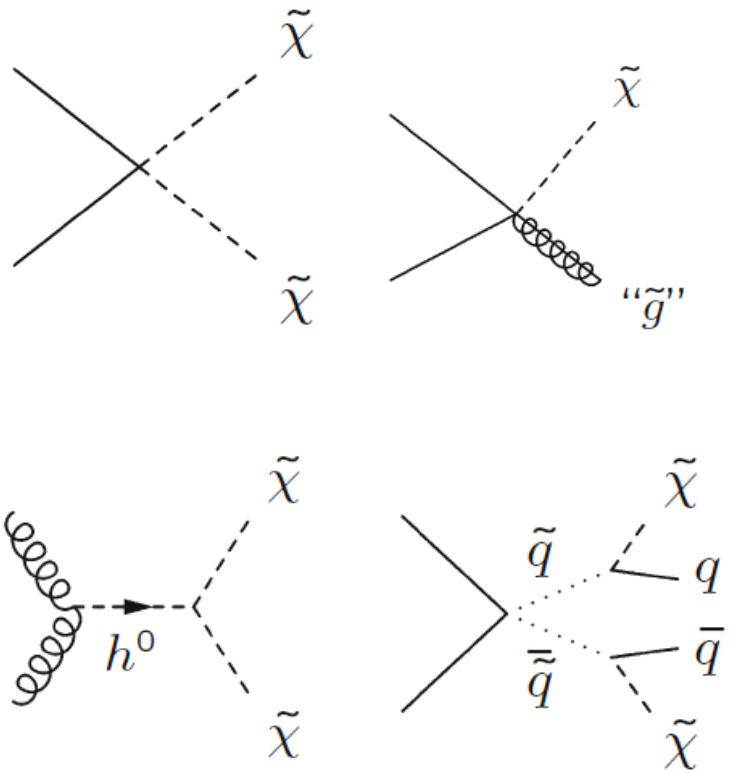
SV with high p_T muon track

- based on excellent SV reconstruction
- sensitivity range
  → *mass: 20-200 GeV*
  → *lifetime 5-100 ps*

Selection

- SV track mult. > 4, m_{SV} > 4.5 GeV, R_{xy} > 0.55 mm
- muon p_T > 12 GeV, IP_{muon} > 0.25 mm
- jets with anti-k_T, R = 0.7, p_T > 5 GeV
- material veto

LLP production mechanisms



Multivariate analysis to further discriminate signal from background

Long-lived particles decaying semileptonically

[EPJ C77 (2017) 224]

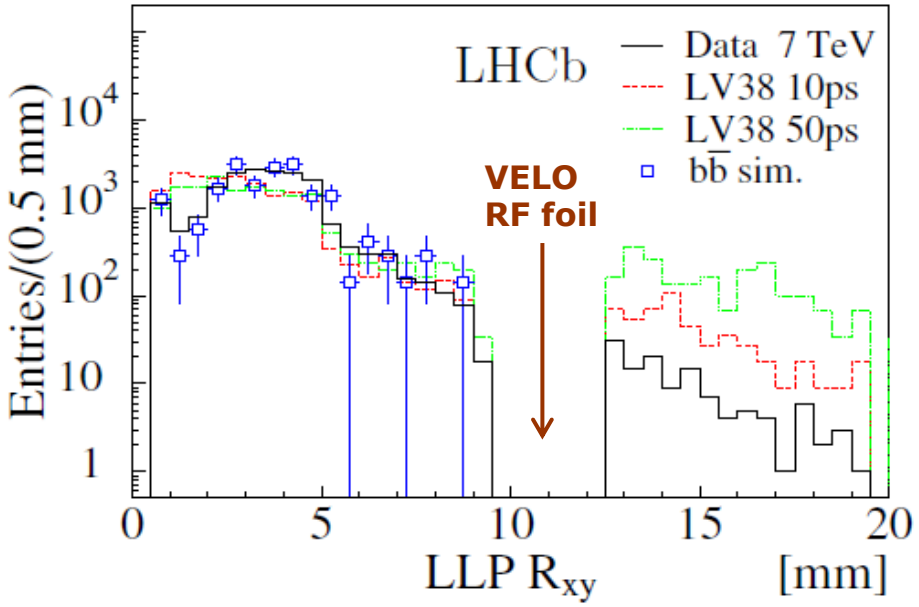
Signal yield obtained by fitting the SV mass with shape of the signal component taken from simulation

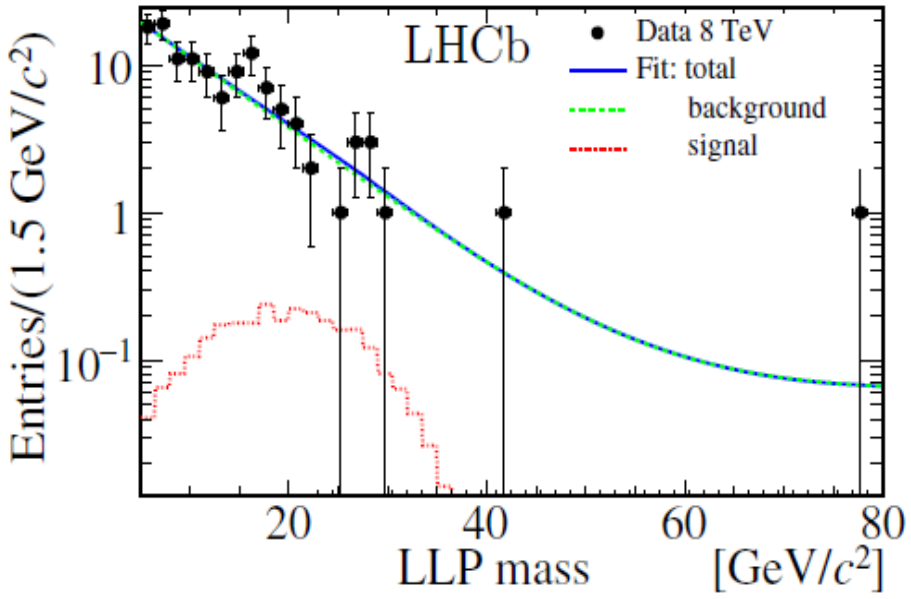
→ *several signal masses and lifetime tested*

Background dominated by $b\bar{b}$ events

→ *after multivariate filter, no simulated background survives*

→ *data-driven method adopted to determine the background templates*





Long-lived particles decaying semileptonically

[EPJ C77 (2017) 224]

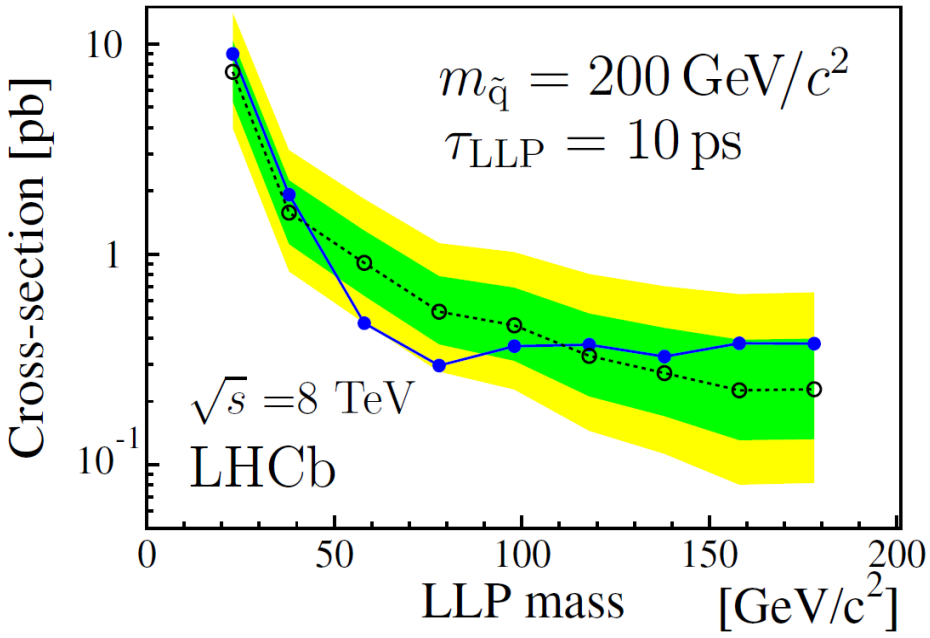
- no significant excess of signal in the data

  → *result interpreted in various models*

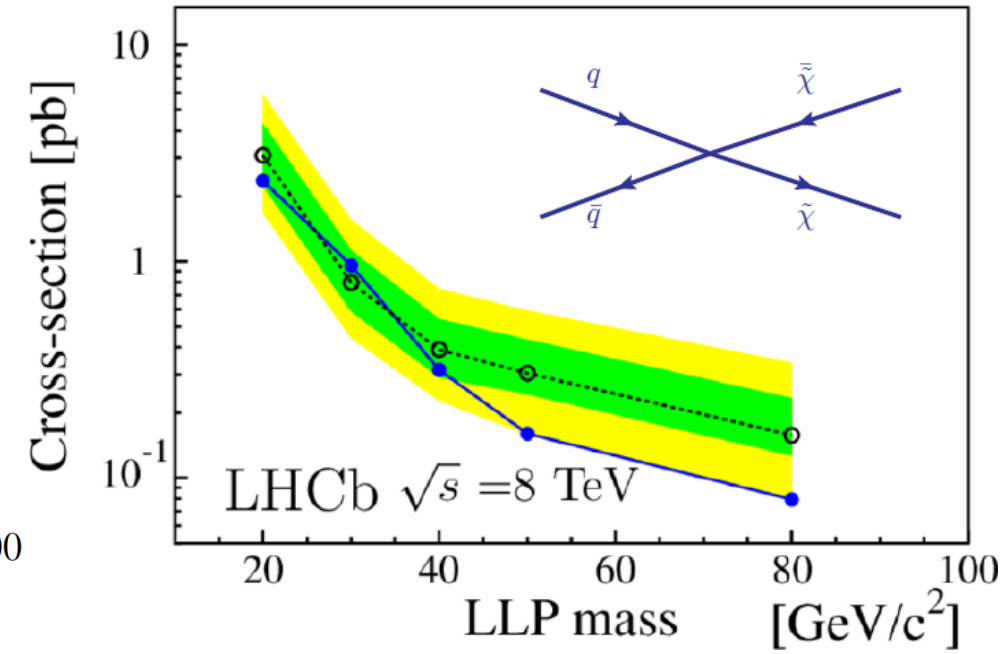
  → *several masses and lifetime hypothesis tested*

- 95% CL upper limits on cross sections

x-section × BR upper limit at 95% CL as a function of the LLP mass



x-section × BR upper limit at 95% CL for non-resonant direct double LLP production



Higgs lepton flavour violating decays

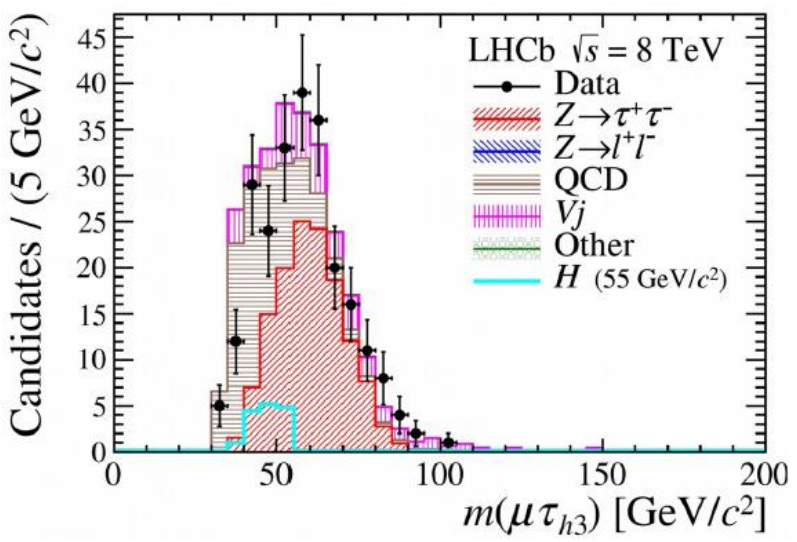
[EPJ C78 (2018) 1008]

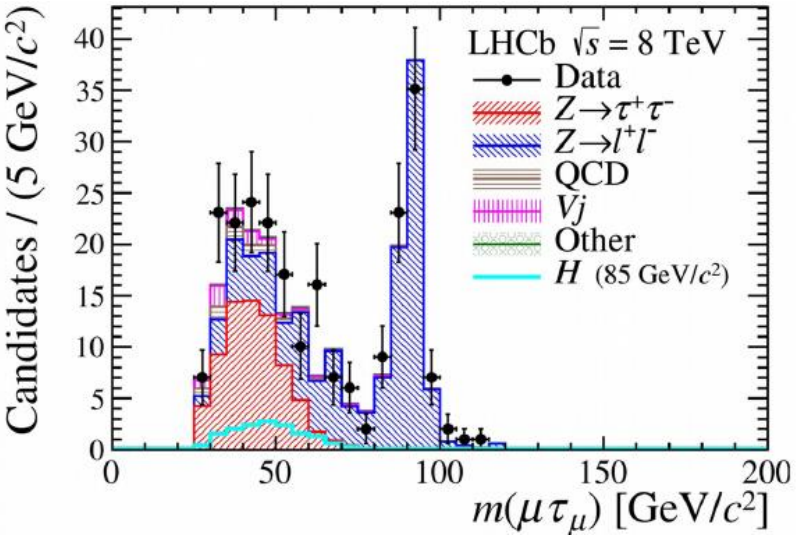
Search for LFV Higgs decay $H \to \mu\tau$

Lepton-flavour-violating decay of Higgs-like particle may indicate the presence of unknown physics

- 4 decay channels (μ, e, h, 3-h) analysed
- search performed for masses from 45 to 195 GeV.
- signature: prompt muon and displaced τ
- minimal flight distance (IP) of reconstructed candidate
- 3 different selections based on m_H vs m_Z
- background dominated by QCD, $Z \to \tau\tau$, Vj

Dataset: 8 TeV, 2 fb^{-1}





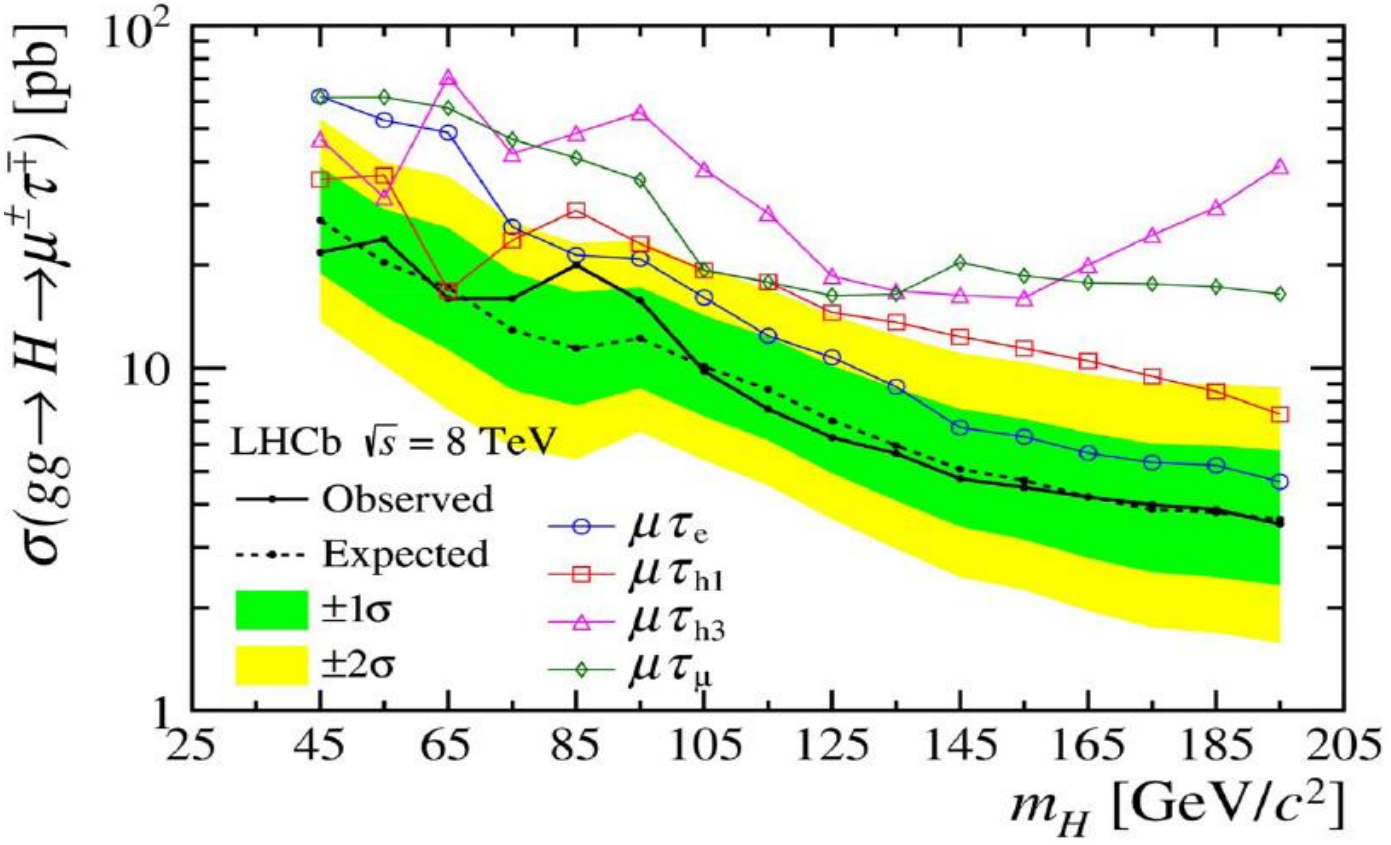
Higgs lepton flavour violating decays

[EPJ C78 (2018) 1008]

No excess found!

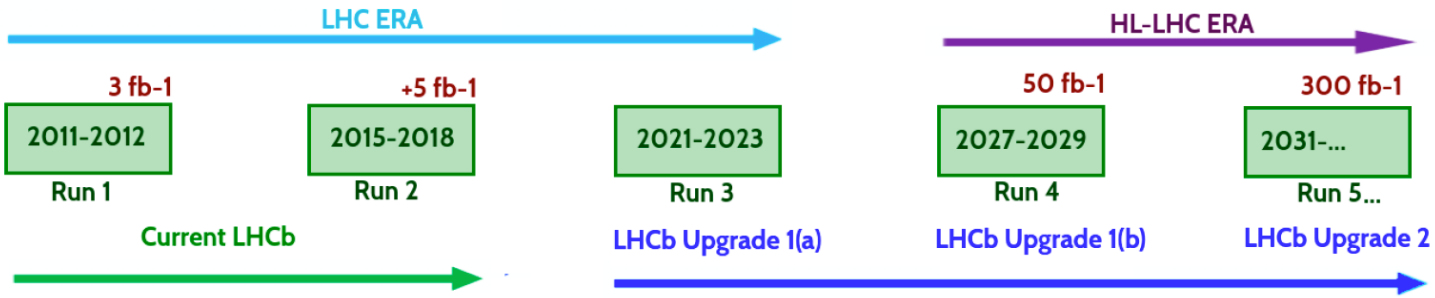
Limits on $\sigma(gg \to H \to \mu\tau)$ set for different mass hypotheses

→ for SM Higgs 95% CL limit on BR($H \to \mu\tau$) < 26%



Prospects for long-lived searches at LHCb

[arXiv:1808.08865]



$L = 4 \times 10^{32}$ cm^{-2}s^{-1}
1.1 visible interact. / xing
6 fb^{-1} collected

$L = 2 \times 10^{33}$ cm^{-2}s^{-1}
5.5 visible interact. / xing
50 fb^{-1} to be collected

$L = 2 \times 10^{34}$ cm^{-2}s^{-1}
55 visible interact. / xing
300 fb^{-1} to be collected

- upgraded VELO with pixels and live readout
- new silicon strip detector, new scintillating fibre detector
- Particle ID: new optics, new photon detectors *(multi-anode PM)*
- calorimeters: reduce PMT gain and new electronics
- muon detector: new electronics and increased granularity
- upgraded trigger all in software

  → ***no hardware trigger***

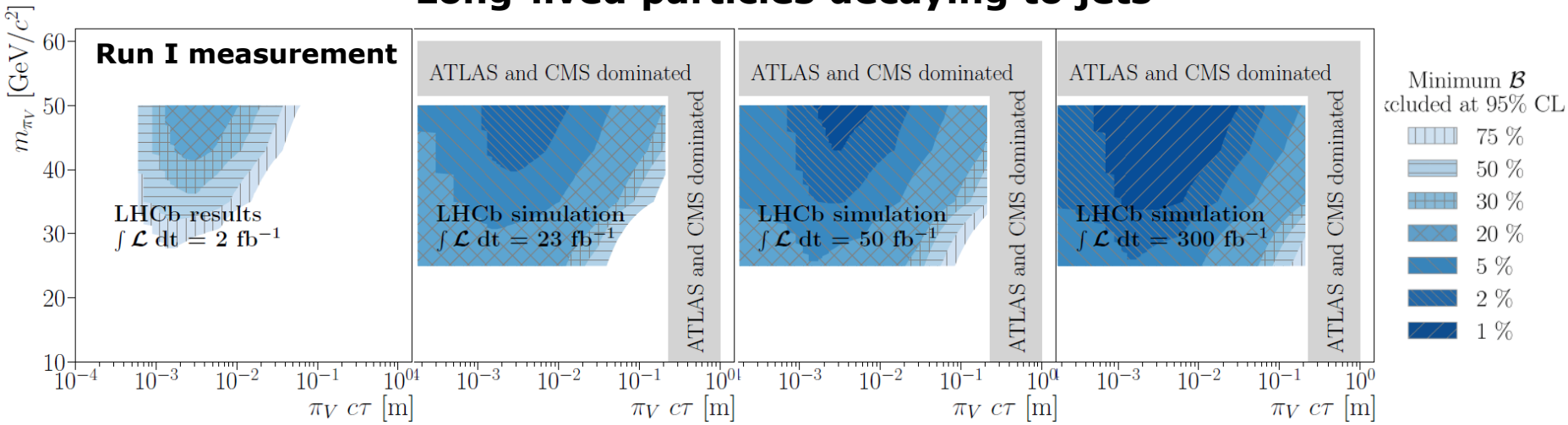
Detector with higher granularity, increased DAQ performance

Prospects for long-lived searches at LHCb

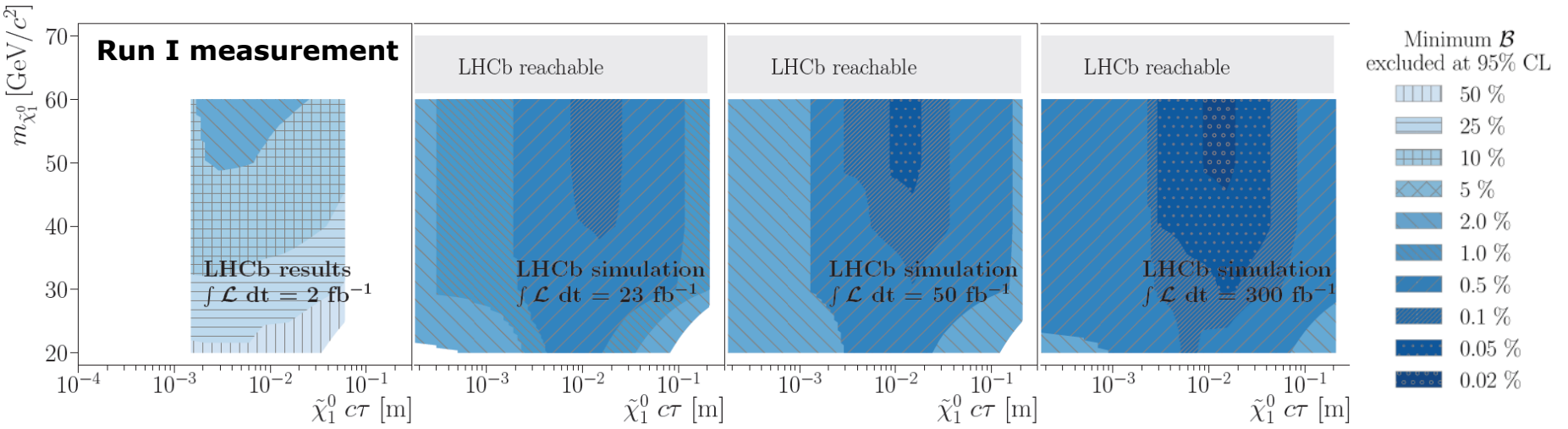
[LHCb-CONF-2018-006]

Projected from Run 1, scaled to the upgrade luminosities, conservative assumptions

Long-lived particles decaying to jets



Long-lived particles with semileptonic decay



Conclusions

LHCb has an active program to search for beyond flavour physics

- complementary phase space with respect to ATLAS and CMS

Search for Higgs exotic decays can be the portal for NP

- long-lived particles decaying semileptonically

  $\rightarrow$ *mSUGRA neutralino with RPV*

- long-lived particles decaying into jets

  $\rightarrow$ *Hidden Valley v-pion*

- LHCb can provide information on Lepton Flavour Violating Higgs decays

Strong potential in the upgraded experiment

- no bottleneck from hardware trigger
- higher luminosity