



## Searches for Exotic Higgs-like boson decays at LHCb



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on behalf of  
**the LHCb**  
Collaboration



**EPS-HEP 2019, Ghent, 12/7/2019**

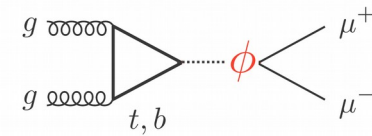
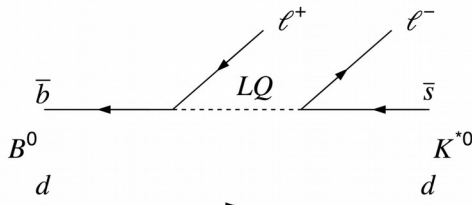
# Introduction

Quest for  
New Physics

Indirect searches

Both approaches  
followed by LHCb

Direct searches

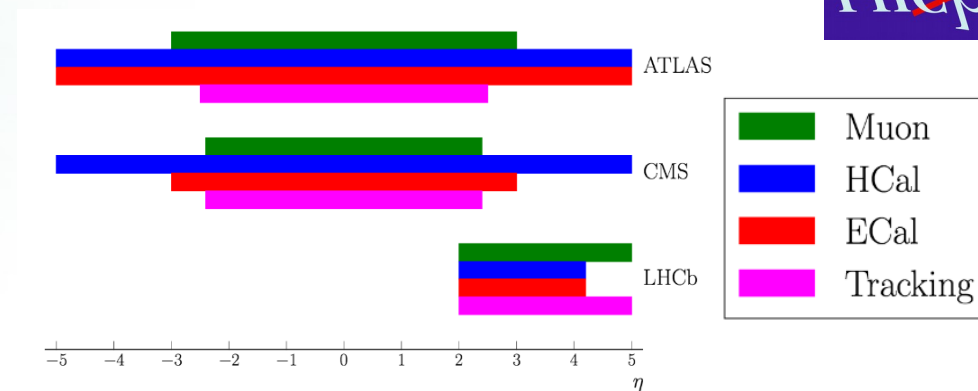
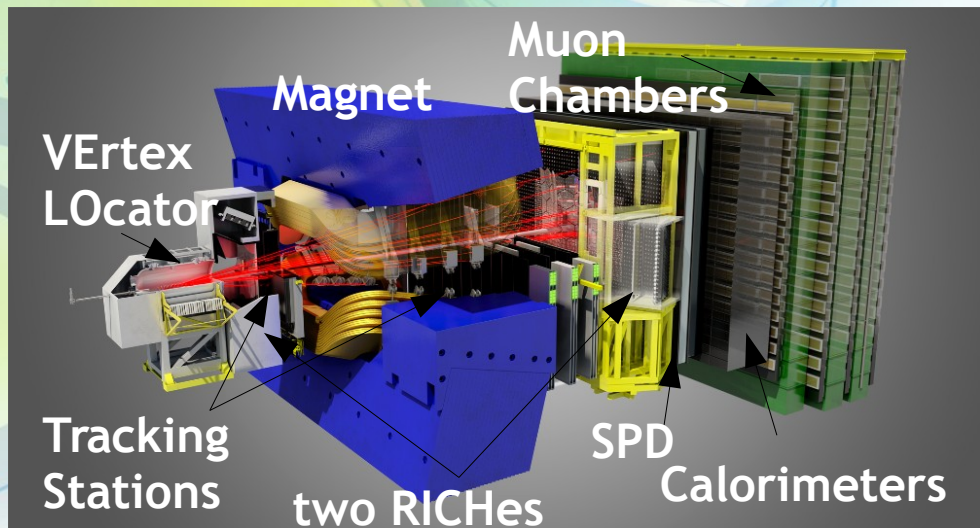


- e.g. hints of flavour anomalies:
- $b \rightarrow s$  transitions
  - Lepton flavour universality violation

- Dark Photons and Higgs-like resonances (**Carlos talk**)
- Exotic Higgs decays (**this talk!**)

# LHCb detector

JINST 3 (2008) S08005



- **Momentum resolution:** 0.4% at 5 GeV and 0.6% at 100 GeV.
- **Excellent vertex reconstruction:** IP resolution =  $(15+29/p_T)$   $\mu\text{m}$
- **Lifetime resolution:** 0.2 ps for  $\tau = 100$  ps
- **Muon ID efficiency:** 97% with 1-3%  $\mu \rightarrow \pi$  mis-identification.

**Forward acceptance ( $2 < \eta < 5$ )**  
**+ low energy threshold trigger (e.g  $p_T^\mu > 1.5$  GeV)**

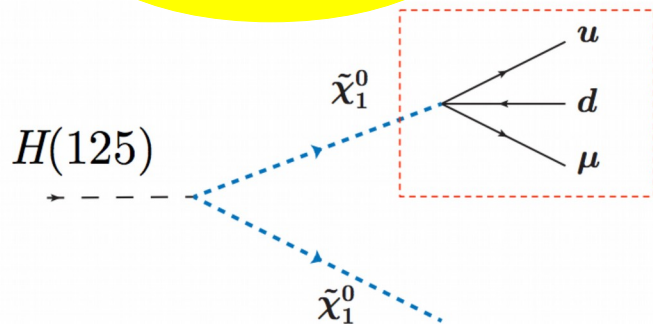
**Complementarity with ATLAS and CMS in direct searches!**

# Higgs decays to Long Lived Particles

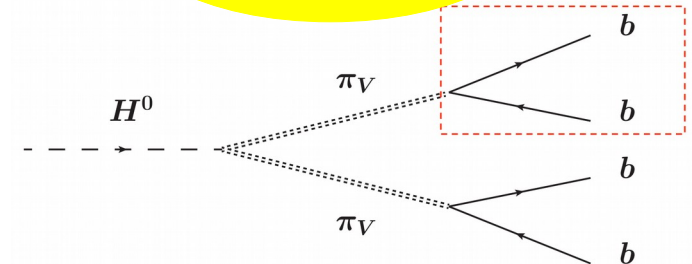
- Higgs: portal to dark sector

Two models considered

R-parity violating  
neutralinos  
(mSUGRA)



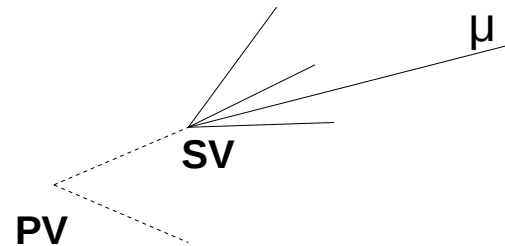
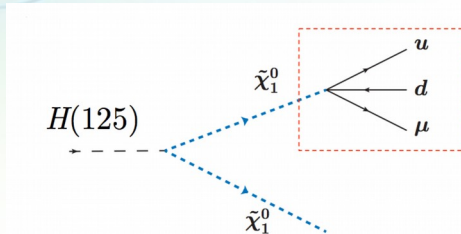
Hidden valley  
pions



# Long Lived Particles decaying semileptonically

Eur. Phys. J. C77 (2017) 224

- **Event topology:** secondary vertex (SV) with a high  $p_T$  muon track.



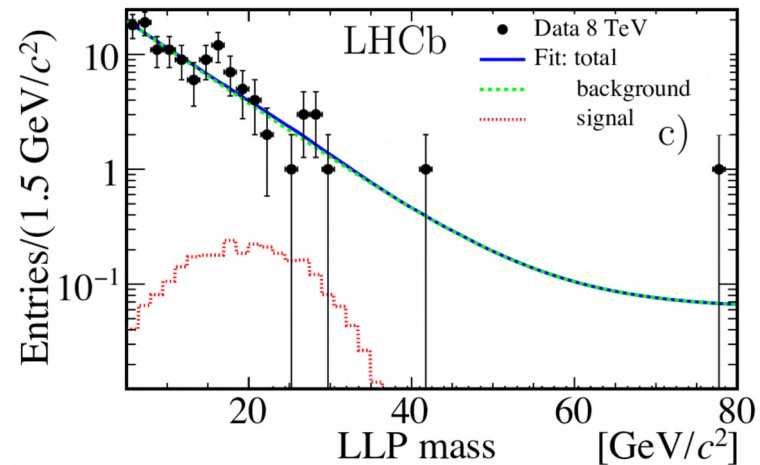
- **Dataset:** full Run I  $\rightarrow 3 \text{ fb}^{-1}$

- **Selection:**

- 4-tracks SV,  $m(\text{SV}) > 4.5 \text{ GeV}$ ,  $R_{xy} > 0.55 \text{ mm}$
- $p_T(\text{muon}) > 12 \text{ GeV}$ ,  $\text{IP}(\text{muon}) > 0.25 \text{ mm}$
- Multi-layer Perceptron to further discriminate signal from background

- **Background:** dominated by  $b\bar{b}$  events, characterized using simulation.

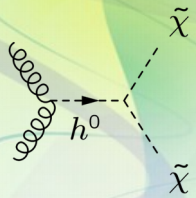
- Signal yield is obtained by fitting the SV mass distribution  $\rightarrow$  Several signal masses and lifetime are tested



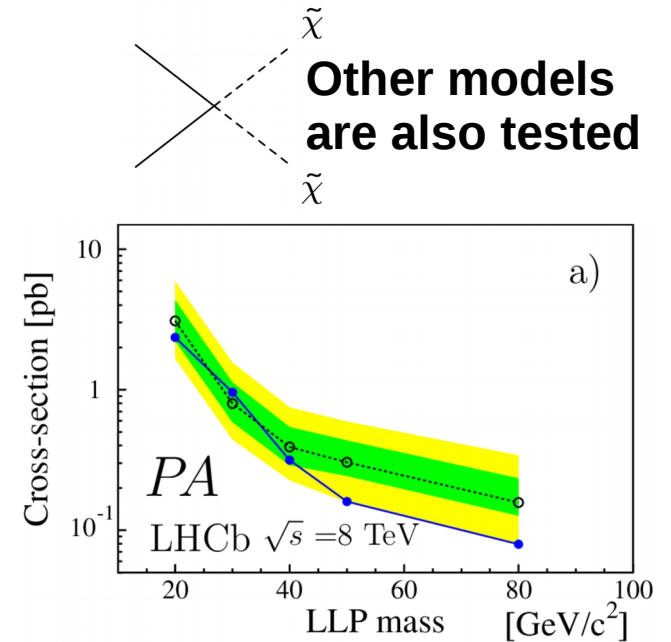
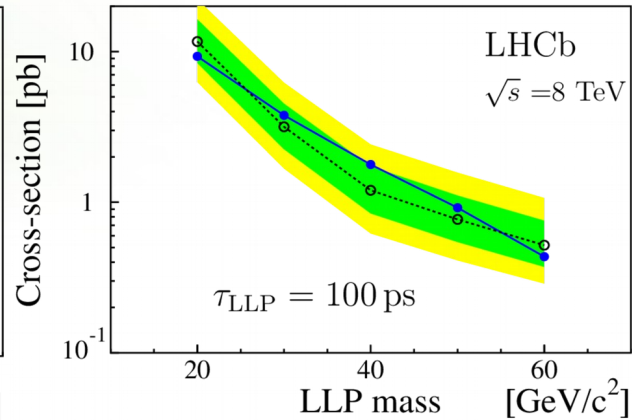
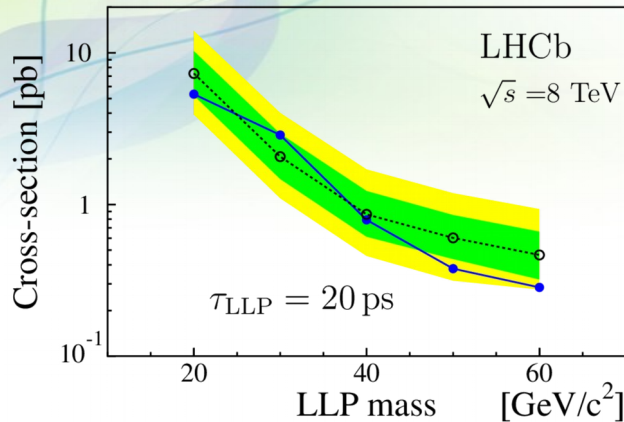
# Long Lived Particles decaying semileptonically

Eur. Phys. J. C77 (2017) 224

- 95% Confidence Level (CL) upper limits on cross sections are set with the CLs method.
- Several masses and lifetime hypothesis are tested.



## Higgs to neutralinos



# Long Lived Particles decaying to jet pairs

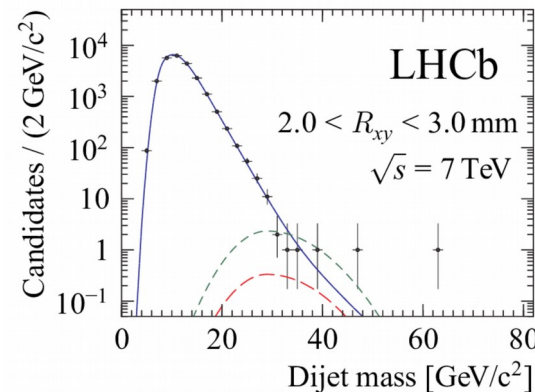
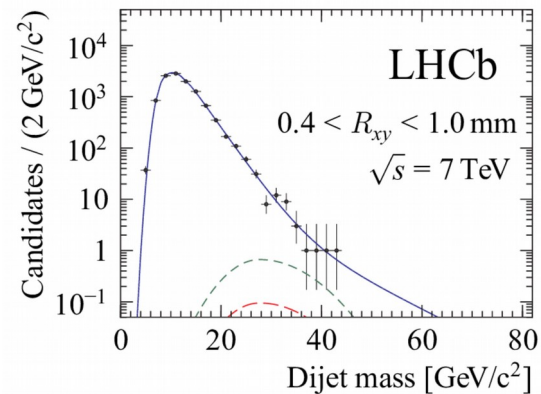
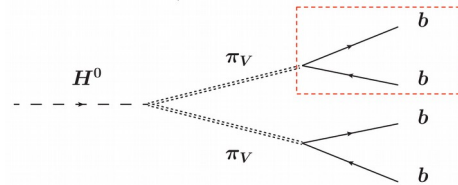
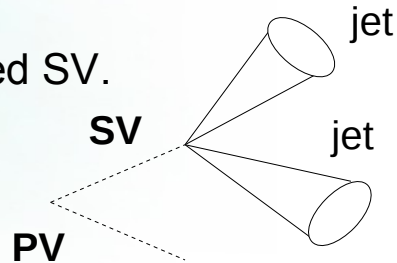
Eur. Phys. J. C77 (2017) 812

- **Event topology:** two jets associated to a displaced SV.

- **Dataset:** full Run I  $\rightarrow 3 \text{ fb}^{-1}$

- **Selection:**

- 4-tracks SV,  $R_{xy} > 0.4 \text{ mm}$
- Jet inputs selected by Particle Flow,  $\text{IP}(\text{tracks}) > 2 \text{ mm}$
- Jets clustered with anti-kt,  $R=0.7$ ,  $p_T(\text{jet}) > 5 \text{ GeV}$

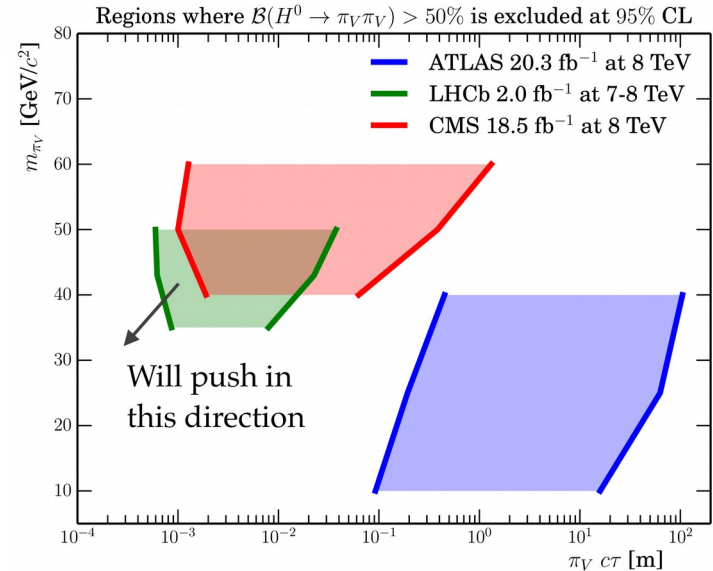
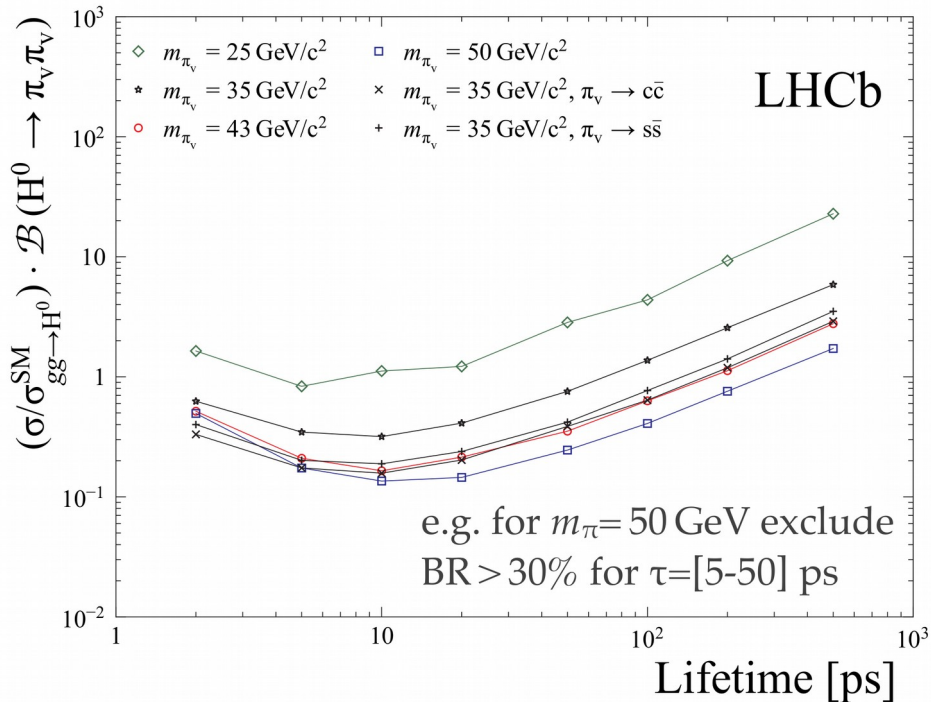


- Signal events ( $\pi_\nu \rightarrow bb$ ) generated with Pythia 8.
- Signal event yield is obtained by fitting the dijet mass distribution.
- Fits are performed in several bins of displacement from beam axis  $R_{xy}(\text{SV})$

# Long Lived Particles decaying to jet pairs

Eur. Phys. J. C77 (2017) 812

- 95% CL upper limits with the CLs method are set on  $\frac{\sigma(gg \rightarrow H)}{\sigma_{SM}(gg \rightarrow H)} \cdot BR(H \rightarrow \pi_V \pi_V)$
- Several  $\pi_V$  masses and lifetime hypothesis are tested.



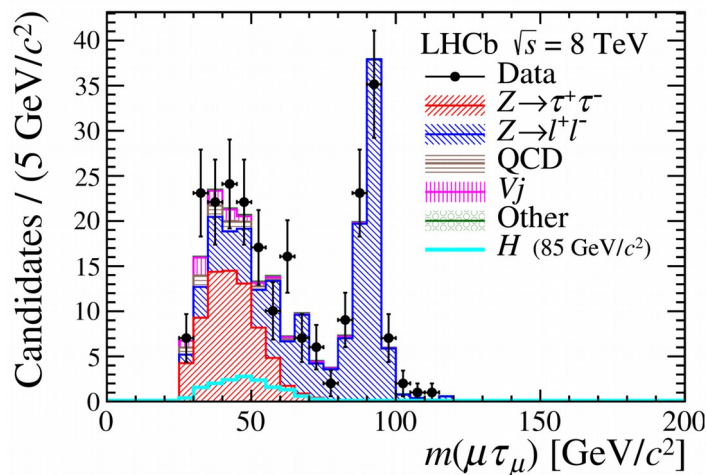
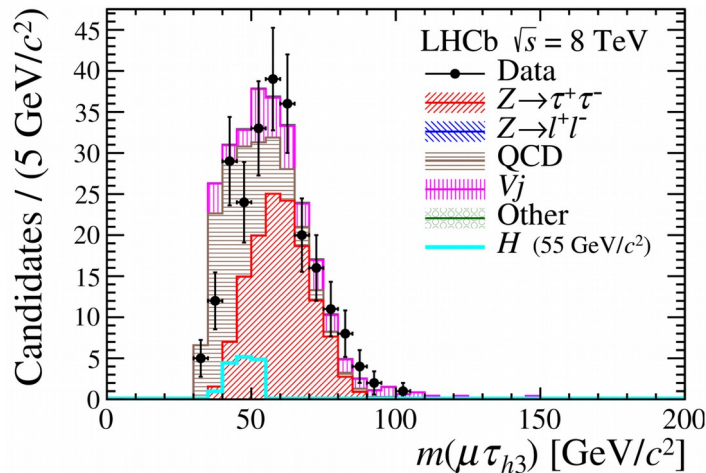
Competitive limit with ATLAS and CMS despite factor 10 less luminosity.



# Higgs lepton flavour violating decays

Eur. Phys. J. C78 (2018) 1008

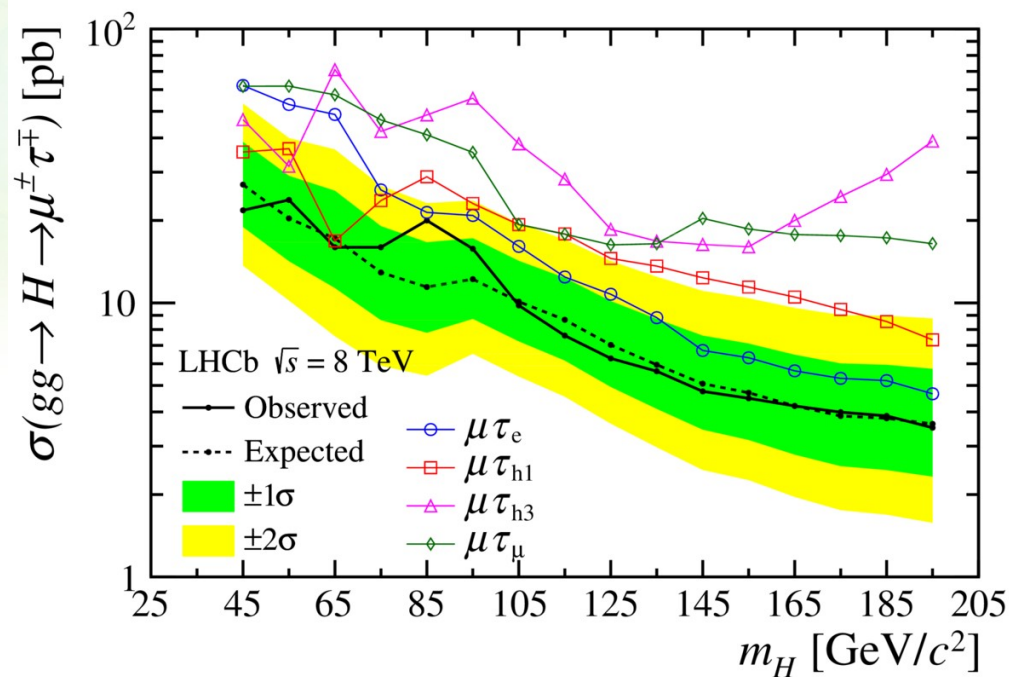
- Search for **LFV Higgs decay**  $H \rightarrow \mu\tau$
- **Signature:** prompt muon and displaced tau decay.
- **Dataset:** 8 TeV,  $2 \text{ fb}^{-1}$
- Tau is reconstructed in 4 different decay channels:
  - muon
  - electron
  - hadron
  - 3-hadrons
- Background is estimated from simulation and theoretical cross sections. Main contribution is given by  $Z \rightarrow \tau\tau$ .



# Higgs lepton flavour violating decays

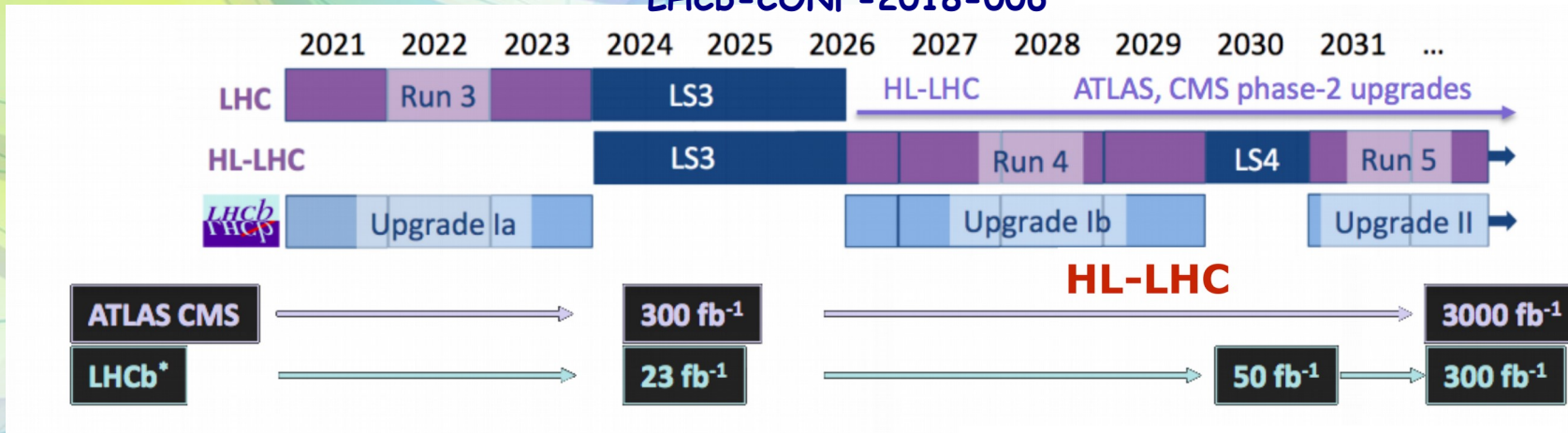
Eur. Phys. J. C78 (2018) 1008

- Limits on  $\sigma(gg \rightarrow H \rightarrow \mu\tau)$  are set with different mass hypothesis
- For SM Higgs 95% CL limit of **BR(H  $\rightarrow \mu\tau$ )<26%**



# Prospects for LLP searches at LHCb upgrades

LHCb-CONF-2018-006



**Sensitivity is extrapolated starting from Run I results and assuming:**

- Conservative assumptions for HLT trigger and material interactions.
- Optimistic assumption on pile-up (rely on jet reconstruction).
- Removal of L0 hardware trigger (100% L0 efficiency).

		2011		2012	
	$\pi_\nu$ mass	10 ps	100 ps	10 ps	100 ps
$\pi_\nu \rightarrow b\bar{b}$	25 GeV/c <sup>2</sup>	0.45	0.097	0.46	0.111
$\pi_\nu \rightarrow b\bar{b}$	35 GeV/c <sup>2</sup>	0.80	0.176	0.83	0.224
$\pi_\nu \rightarrow b\bar{b}$	43 GeV/c <sup>2</sup>	0.73	0.190	0.77	0.222
$\pi_\nu \rightarrow b\bar{b}$	50 GeV/c <sup>2</sup>	0.49	0.141	0.54	0.171
$\pi_\nu \rightarrow c\bar{c}$	35 GeV/c <sup>2</sup>	1.35		1.35	
$\pi_\nu \rightarrow s\bar{s}$	35 GeV/c <sup>2</sup>	1.30		1.19	

**Run I efficiency**

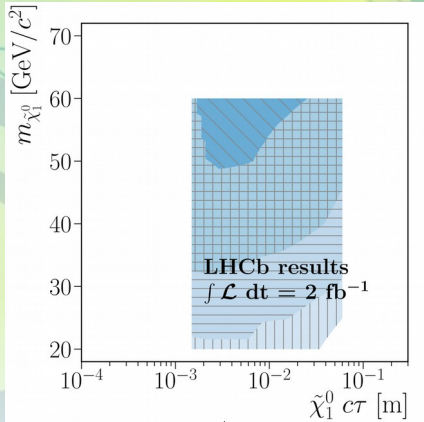
## Upgrade extrapolation

$c\tau_{\pi_\nu}$ (mm)	Efficiency (%)	$m_{\pi_\nu}$ (GeV/c <sup>2</sup> )			
		25	35	43	50
3	Acceptance	26.8	21.2	17.4	14.6
	Total	0.9	1.7	1.5	1.1
30	Acceptance	16.1	15.1	13.7	12.3
	Total	0.2	0.4	0.4	0.3

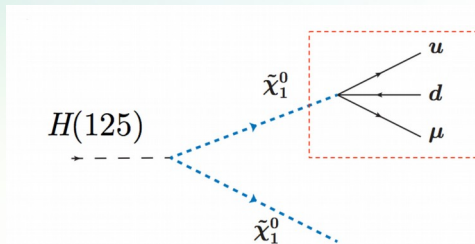
# Prospects for LLP searches at LHCb upgrades

LHCb-CONF-2018-006

## Run I measurement



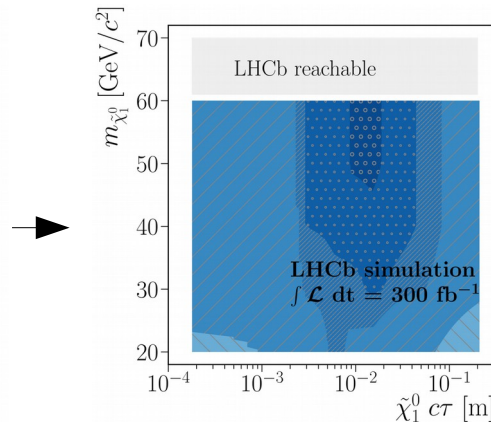
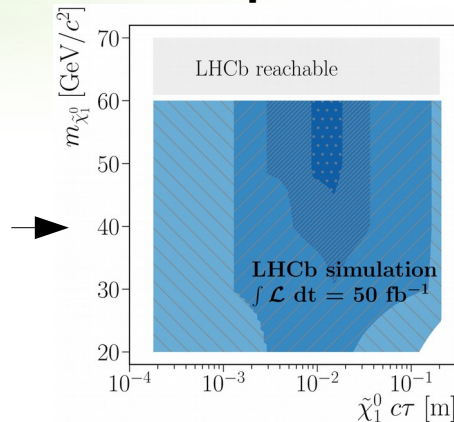
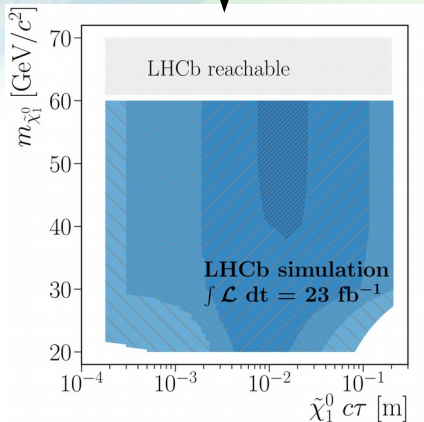
## mSUGRA neutralino



Minimum  $\mathcal{B}$   
excluded at 95% CL

- 50 %
- 25 %
- 10 %
- 5 %
- 2.0 %
- 1.0 %
- 0.5 %
- 0.1 %
- 0.05 %
- 0.02 %

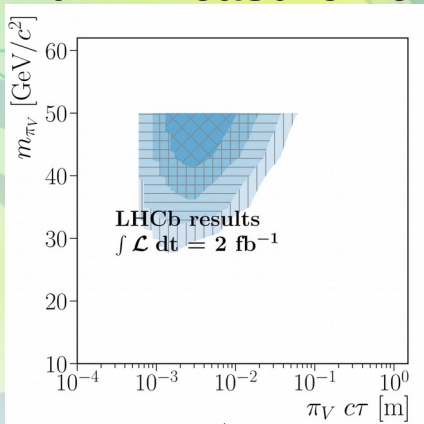
## Extrapolations



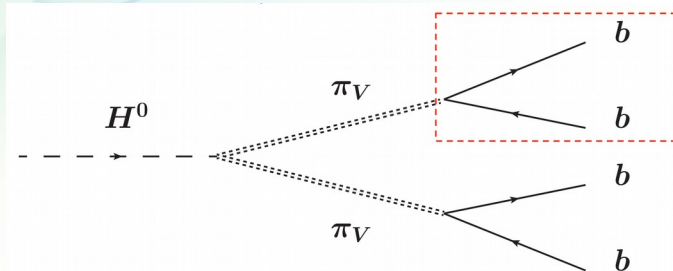
# Prospects for LLP searches at LHCb upgrades

LHCb-CONF-2018-006

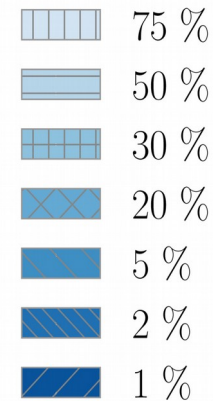
## Run I measurement



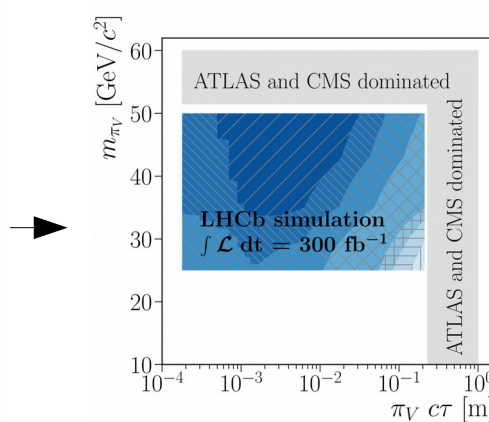
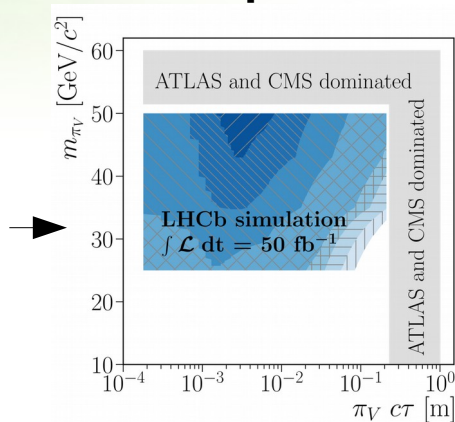
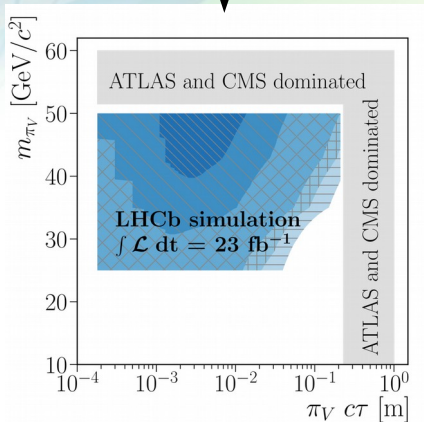
## Hidden valley pion



Minimum  $\mathcal{B}$   
excluded at 95% CL



## Extrapolations



# Conclusions

- LHCb is the game of NP direct searches, in a complementary phase space with respect to ATLAS and CMS.
- **Search for Higgs exotic decays** can be the portal for NP.
- LHCb can provide information on **Lepton Flavour Violating Higgs decays**.
- **Strong LLP programme**, it will improve in the future and with the **next upgrades**.
- **Stay tuned for Run II results!**



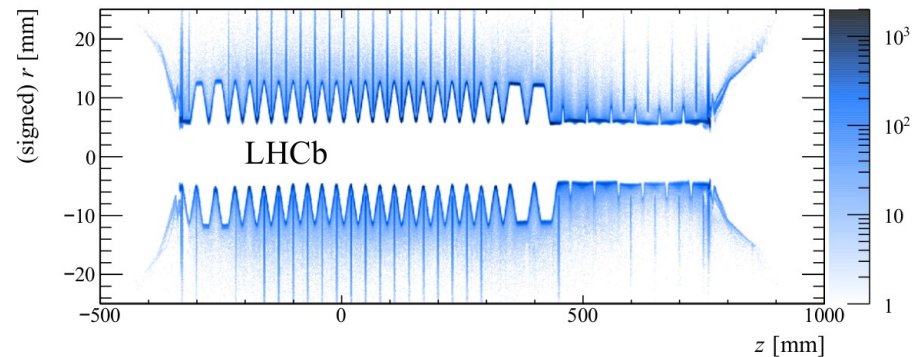
# Backup

# VErtex LOcator material

ArXiv:1803.07466

- **Map of VELO** material, including VELO silicon stations and RF foil.
- Mapped through hadron interactions with material in **beam-gas events** rather than near the pp collision region.
- SV associated to these interactions are reconstructed.
- **Fundamental to veto material interactions in LLP searches.**

## Reconstructed SVs



## RF foil map

