

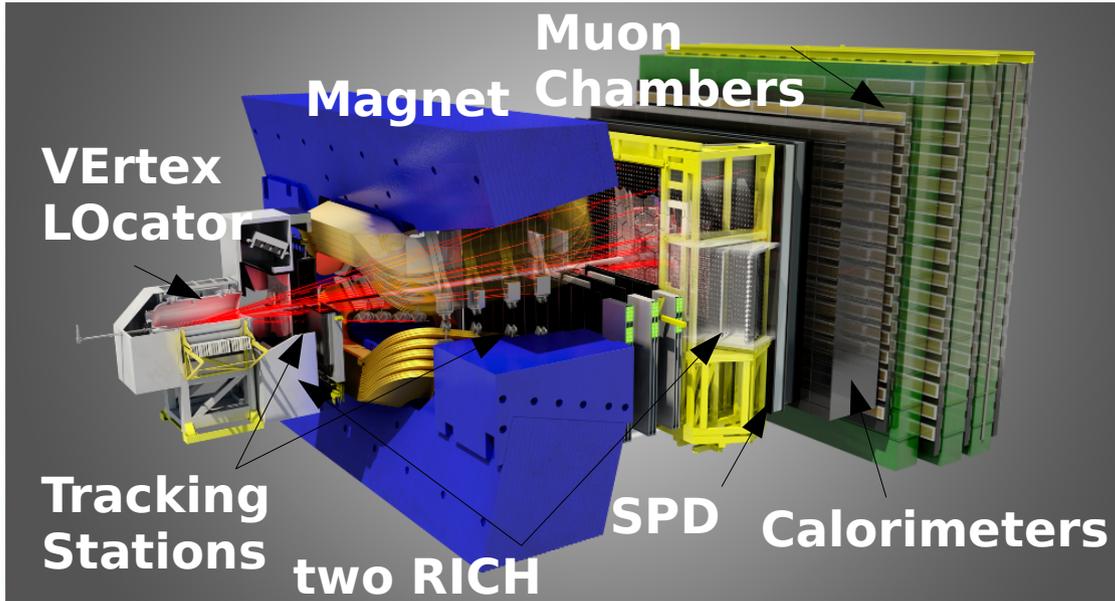
BSM Higgs: the LHCb perspective

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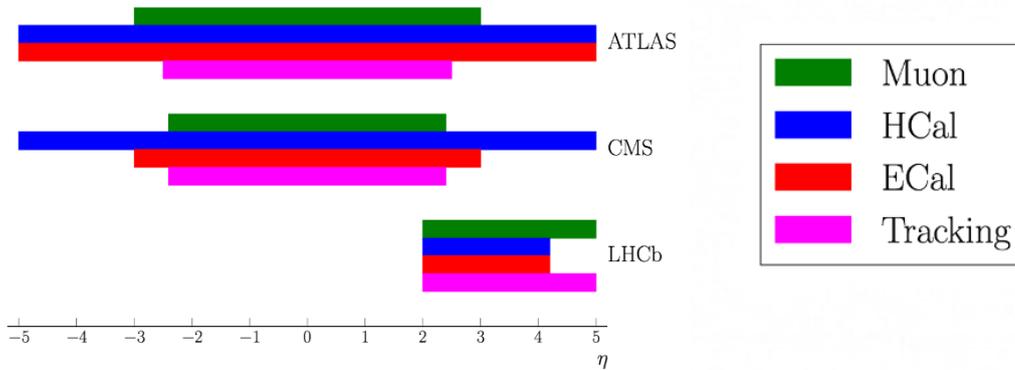
Higgs Cross Section workshop, 2017-07-13, Cern, Geneve

LHCb detector

JINST 3 (2008) S08005



- **LHCb** is a forward spectrometer ($2 < \eta < 5$) initially designed for B physics.
- It covers a **unique acceptance** within the LHC experiments ($2 < \eta < 5$).
- **Momentum resolution:** 0.4% at 5 GeV and 0.6% at 100 GeV.
- **Impact parameter resolution** of 13-20 μm at high p_T .
- **Muon ID efficiency:** 97% with 1-3% $\mu \rightarrow \pi$ mis-identification.



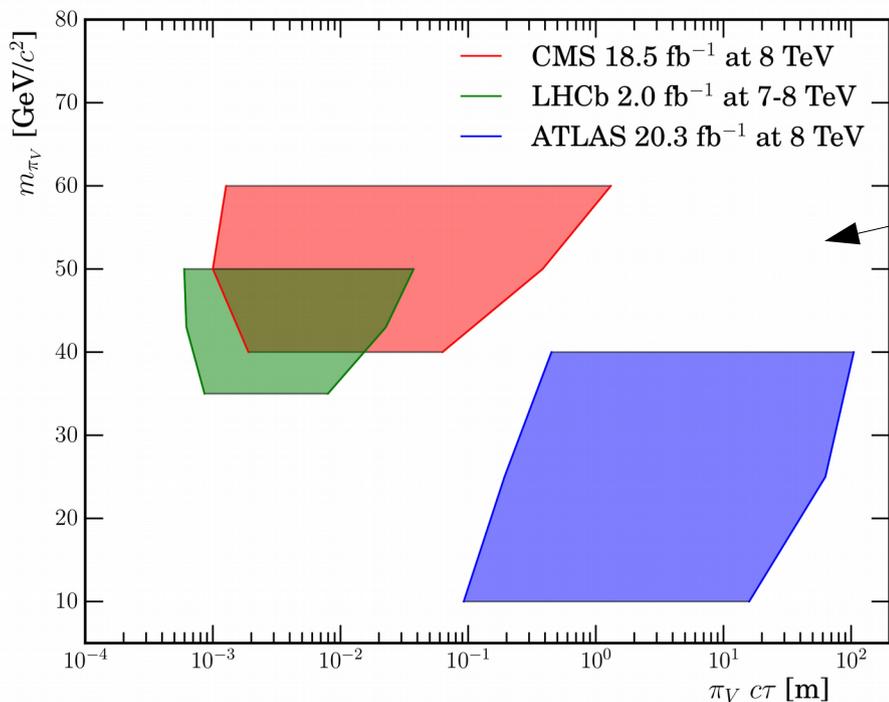
- LHCb can complement ATLAS and CMS in searches:

Low masses:
low energy threshold trigger

Low lifetimes:
excellent vertexing and boost

Higgs decaying to Long Lived Particles

- Interesting scenario where the SM Higgs (or Higgs-like particles) decays in $H \rightarrow \pi_\nu \pi_\nu$, where π_ν is a **long-lived particle with low mass**.
- Motivated by R-parity violating SUSY or Hidden Valley models.
- **At LHCb a complementary phase space with respect to other experiments is accessible.**



$m(\pi_\nu)$ and $t(\pi_\nu)$ regions where experiments are able to exclude $BF(H \rightarrow \pi_\nu \pi_\nu) < 50\%$, with $m(H) = 125$ GeV

References:

LHCb: arXiv:1705.07332

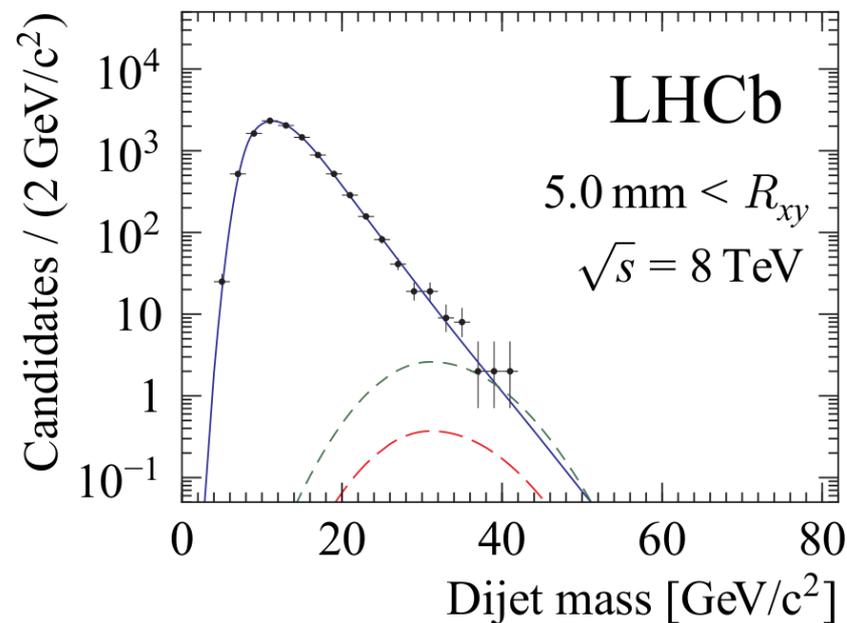
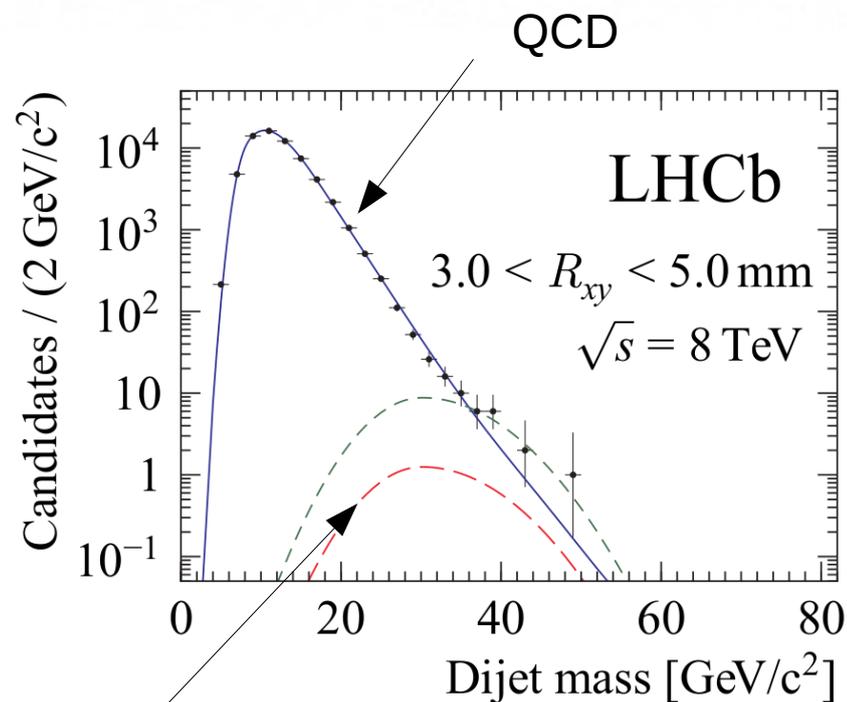
ATLAS: arXiv:1504.03634, 1501.04020

CMS arXiv:1411.6530 (1508.01522)

LLP decaying to two jets

arXiv:1705.07332

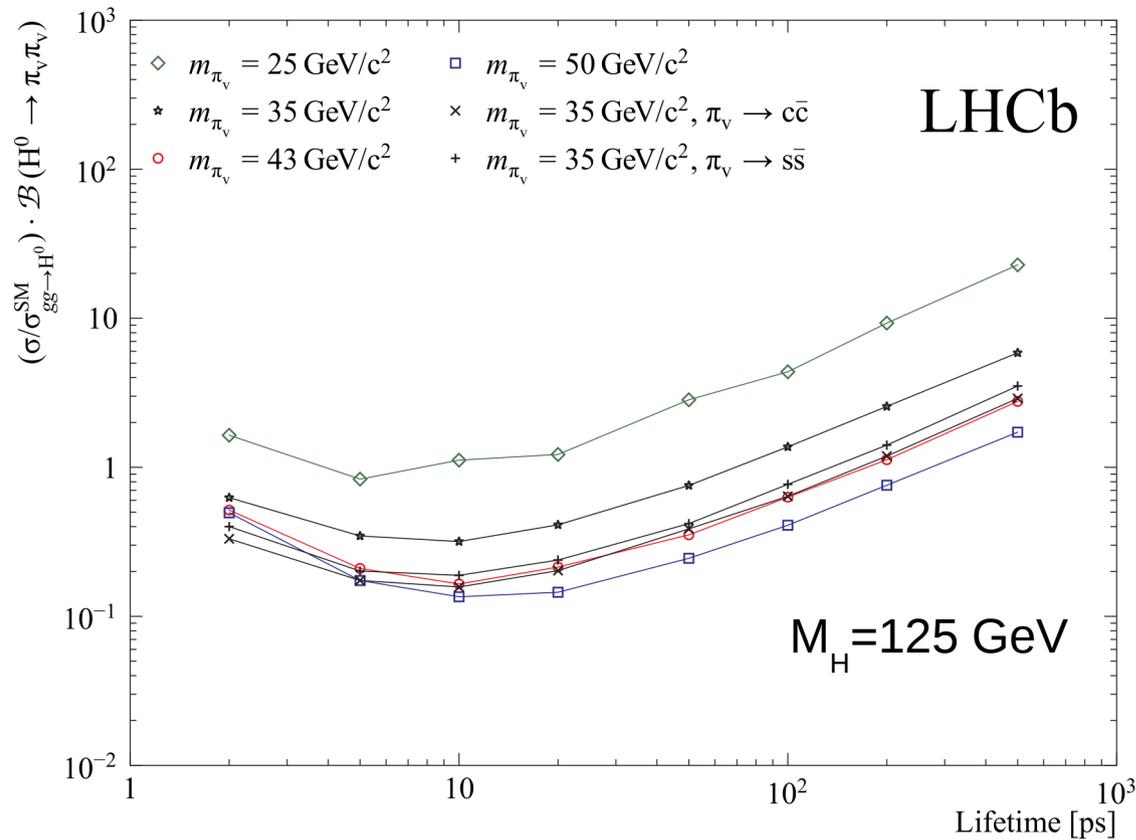
- Scenario: the SM Higgs decays to $\pi_\nu \pi_\nu$ and $\pi_\nu \rightarrow q\bar{q}$, Hidden Valley model.
- Signature: **one displaced vertex (selected by trigger) associated to two jets.**
- Material interaction veto and dijet momentum aligned with SV-PV vector to reduce background.
- The dijet invariant mass is used to set limits, in intervals of lateral displacements (R_{xy}).



LLP decaying to two jets

arXiv:1705.07332

- Limits calculated in the $25 < m(\pi_\nu) < 50$ GeV mass range and $2 < \tau(\pi_\nu) < 500$ ps lifetime range.
- Best sensitivity with $m=50$ GeV and $\tau=10$ ps.

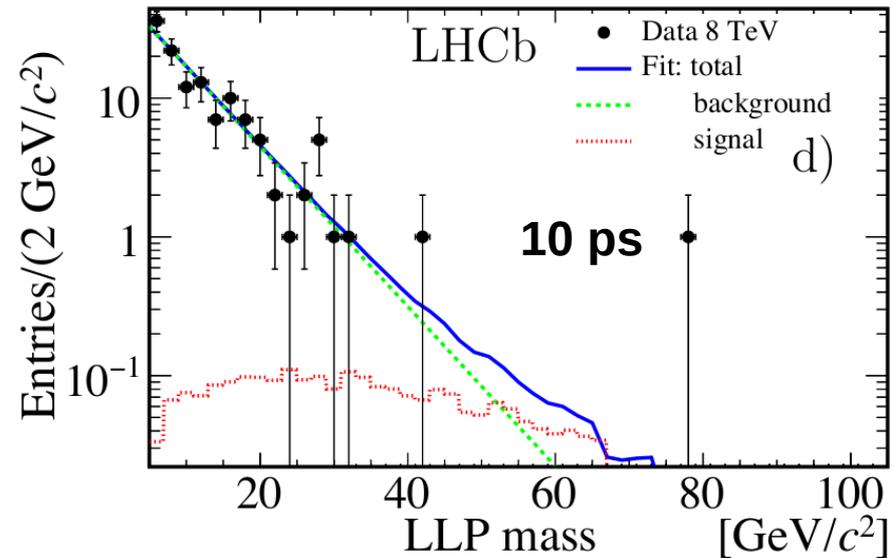
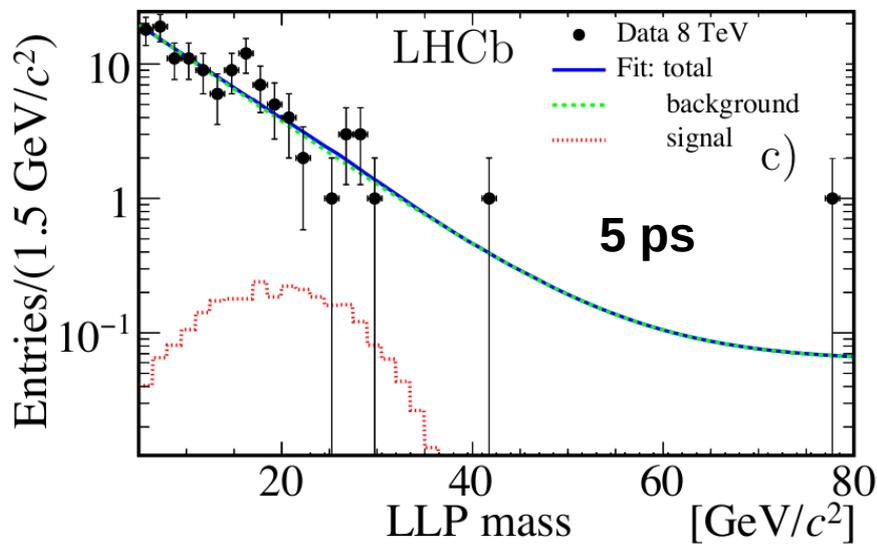


7 TeV and 8 TeV datasets
 $\rightarrow 1 \text{ fb}^{-1}$ and 2 fb^{-1}

LLP decaying semileptonically

Eur. Phys. J. C (2017) 77:224

- Model: Higgs-like particle decaying in $\pi_\nu \pi_\nu$ (Hidden Valley), with π_ν decaying semileptonically.
- Signature: **one displaced vertex associated to a high p_T (>10 GeV) isolated lepton selected by the trigger.**
- Dataset dominated by bb background, removed with tight selection and MVA.
- Fit to LLP invariant mass \rightarrow limit extraction on cross section times BF.

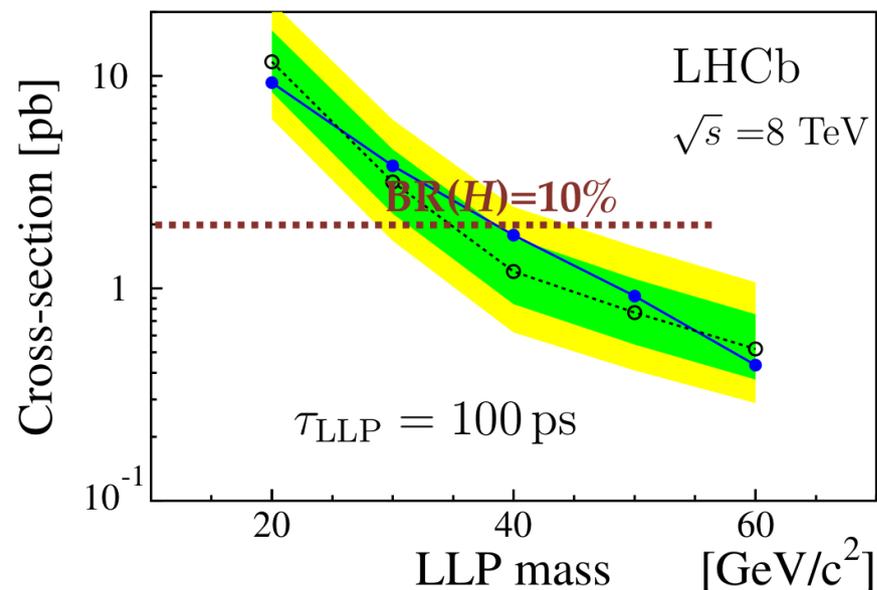
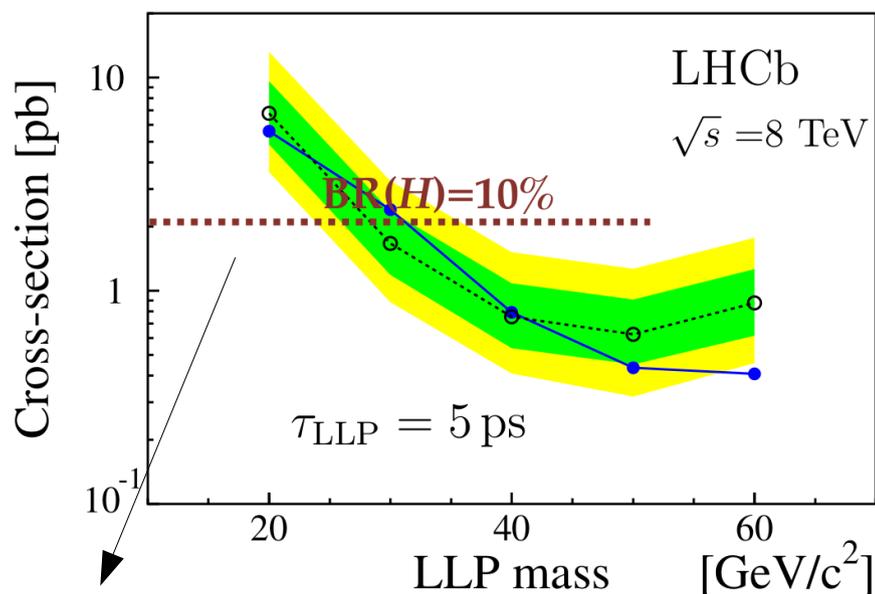


LLP decaying semileptonically

Eur. Phys. J. C (2017) 77:224

- LLP mass varied between 20-60 GeV, lifetime 5-100 ps
- Higgs mass varied in the 60-130 GeV range.

7 TeV and 8 TeV datasets
 $\rightarrow 1 \text{ fb}^{-1}$ and 2 fb^{-1}



assuming Higgs cross section $\sim 20 \text{ pb}$

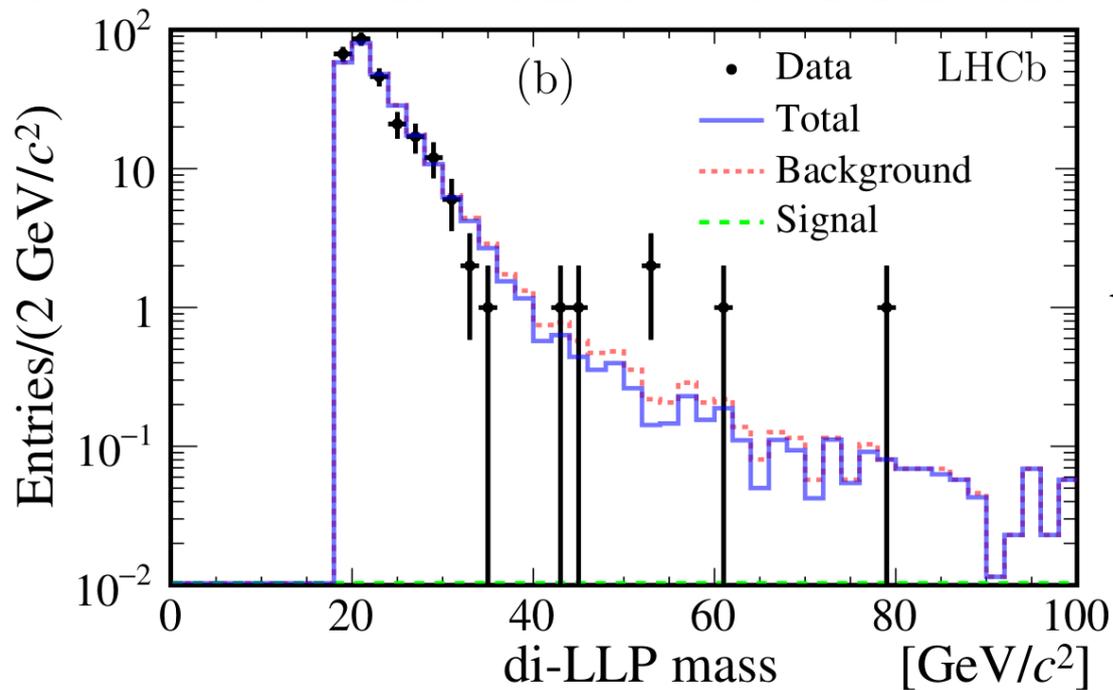
$M_H = 125 \text{ GeV}$

- Alternative model studied: RPV mSUGRA neutralino

LLP: two vertices signature

Eur. Phys. J. C (2016) 76:664

- Higgs-like particle decaying to $\pi_\nu \pi_\nu$ (Hidden Valley).
- Signature: **both π_ν decay vertices selected by the trigger.**
- Reduced acceptance with respect to single π_ν searches.
- Fit to di-LLP invariant mass \rightarrow limit extraction on cross section times BF.



Signal Model example:

$$m(H) = 114 \text{ GeV}$$

$$m(\pi_\nu) = 48 \text{ GeV}$$

$$\tau(\pi_\nu) = 10 \text{ ps}$$

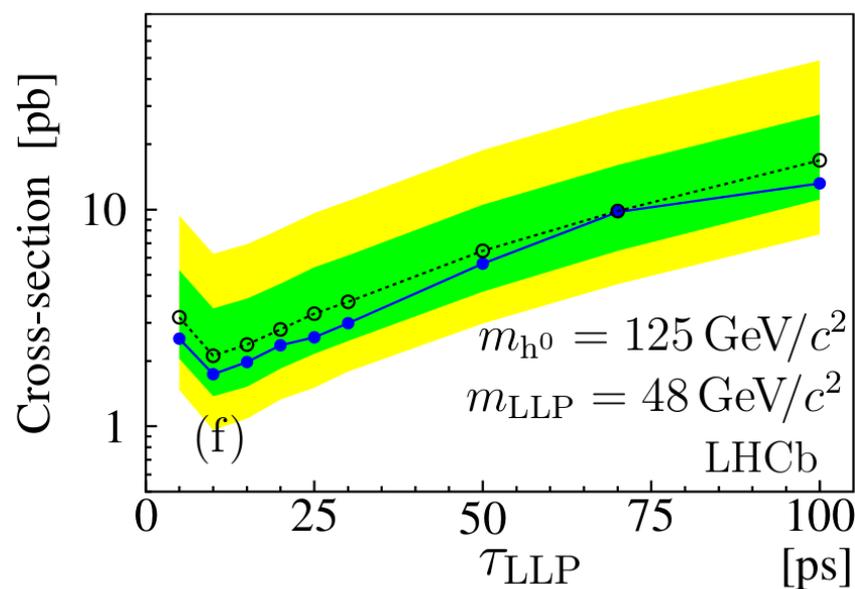
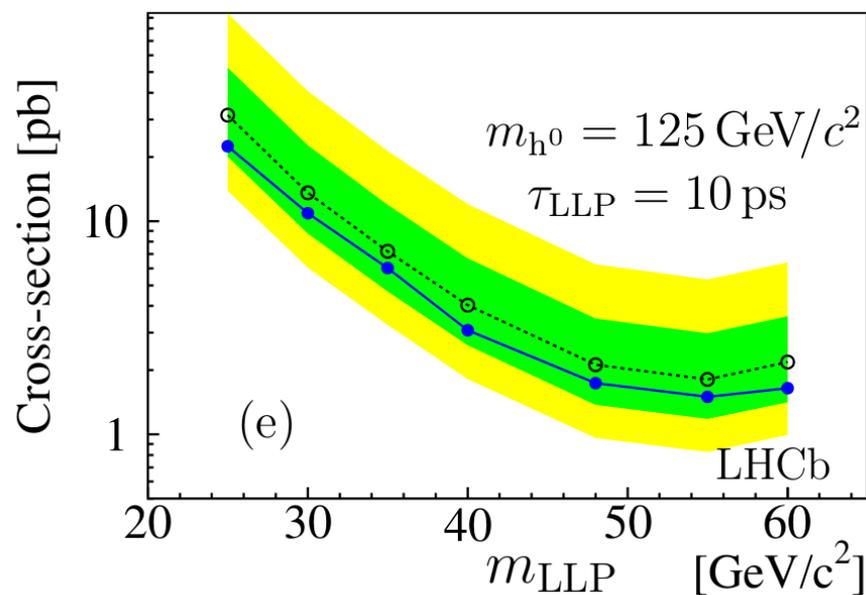
7 TeV dataset $\rightarrow 0.62 \text{ fb}^{-1}$

LLP: two vertices signature

Eur. Phys. J. C (2017) 77:224

- LLP mass varied between 25-60 GeV, lifetime 5-100 ps
- Higgs mass varied in the 80-140 GeV range.

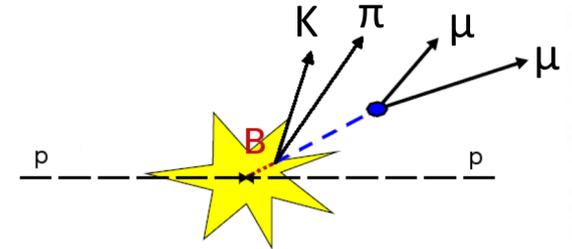
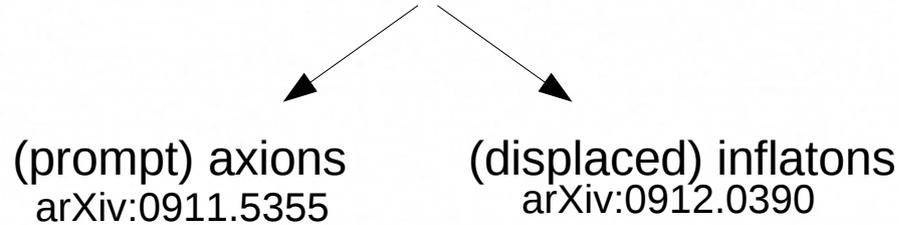
7 TeV dataset $\rightarrow 0.62 \text{ fb}^{-1}$



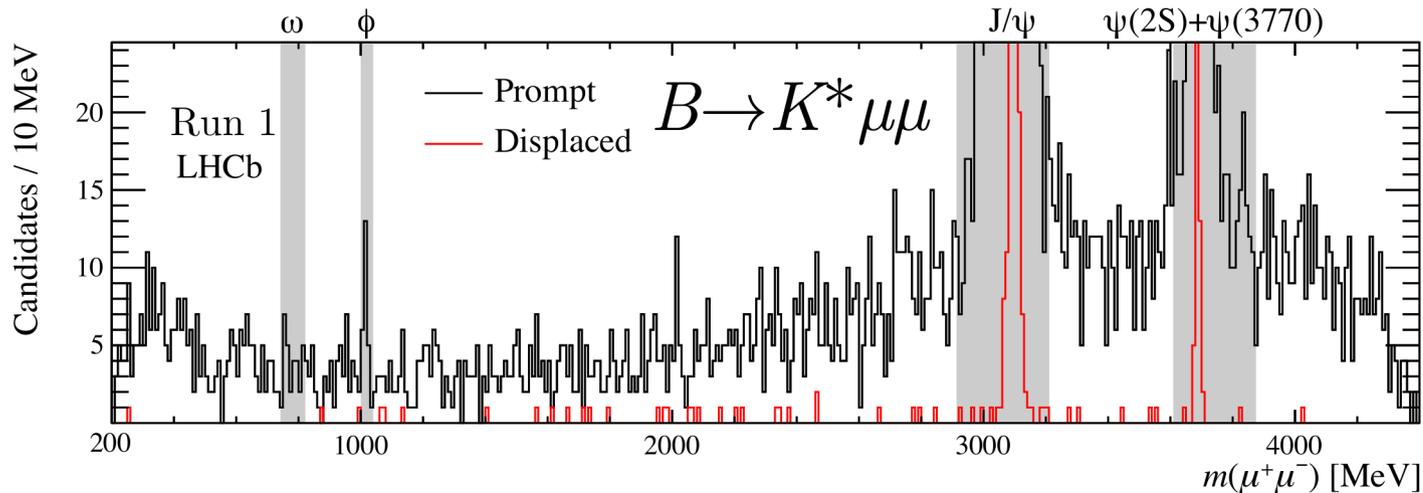
Hidden sector $\chi \rightarrow \mu\mu$ in $B \rightarrow K^{(*)} \mu\mu$

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

- New narrow scalar resonances, accessible via mixing with SM Higgs.



- Signature: $\mu\mu$ mass peak in $B \rightarrow K^{(*)} \mu\mu$ events.
- Excellent dimuon mass resolution (3 to 9 MeV) in clean B events.
- Events selected using the uBoost technique, to get efficiency flat in m_χ and τ_χ



7 and 8 TeV datasets

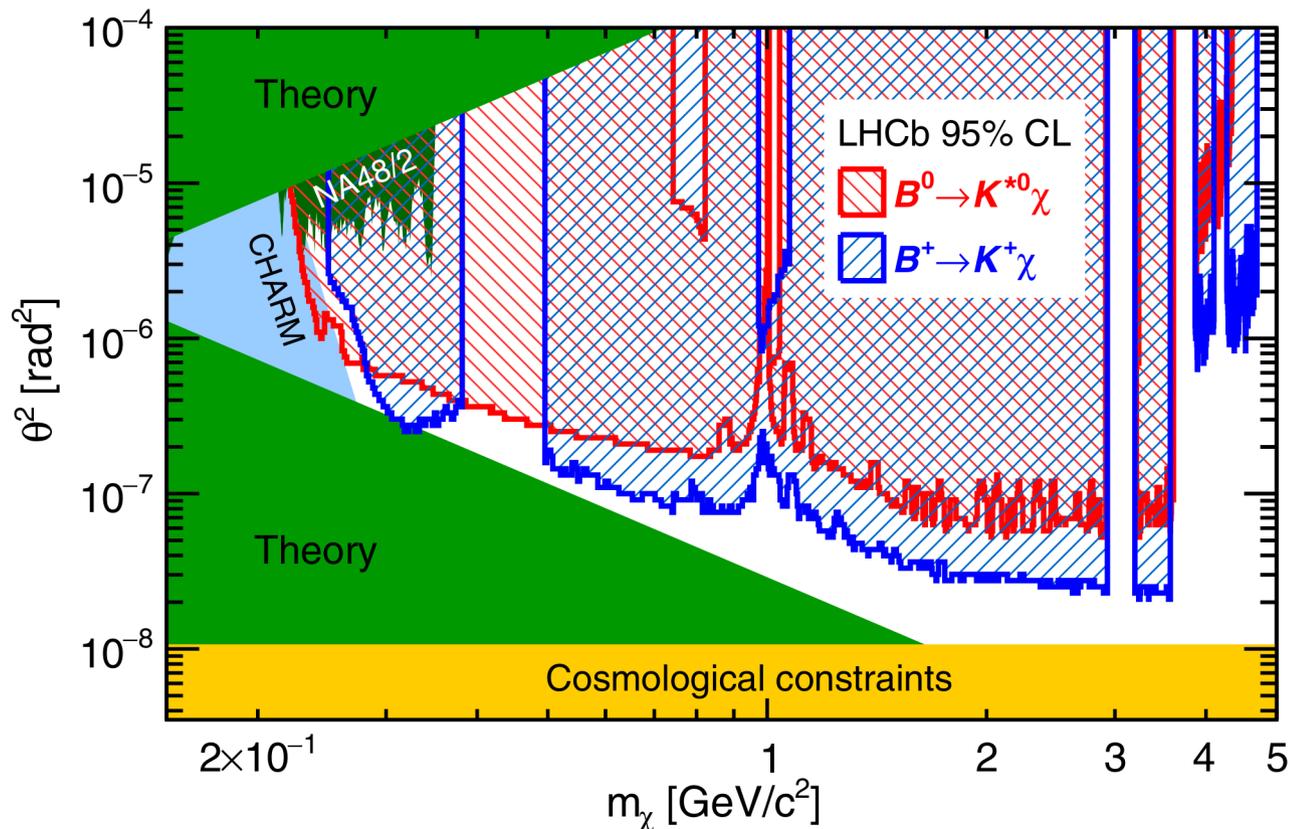
Hidden sector $\chi \rightarrow \mu\mu$ in $B \rightarrow K^{(*)} \mu\mu$

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

- Upper limits at 95% CL on $\text{BF}(K^{(*)} \mu\mu) \times \text{BF}(\chi \rightarrow \mu\mu)$
- Constraints on new scalar mixing with the SM Higgs:

$$|\chi\rangle_{\text{phys}} = \cos\theta |\chi\rangle + \sin\theta |\text{Higgs}\rangle$$

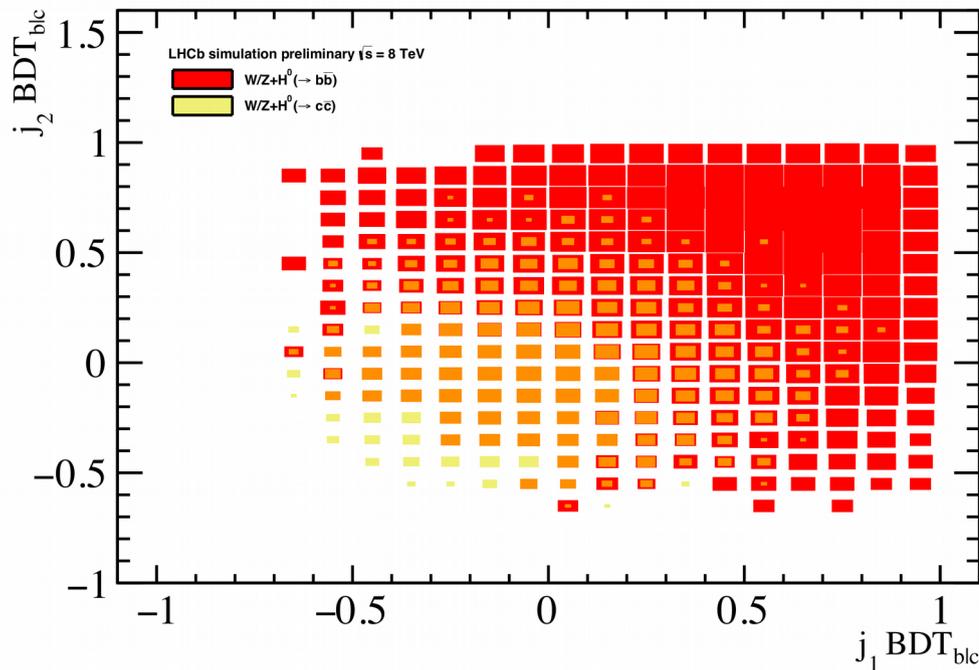
$$\text{BF}(K^{(*)} \chi) \approx 1/\theta^2$$



Direct search for $H \rightarrow cc$

LHCb-CONF-2016-006

- $H \rightarrow cc$ production can be enhanced by BSM physics (arXiv:1310.7029, 1303.1812).
- Excellent performance in jets heavy flavour tagging, thanks to the VERtEX LOcator.
- A Boosted Decision Tree is trained to separate b from c jets, BDT(b|c).
- Upper limits on $V+H(\rightarrow bb)$ and $V+H(\rightarrow cc)$ production at 95% C.L. are set using the 8 TeV dataset.
- Two heavy flavour tagged jets + one high p_T lepton are selected.



← **BDT(b|c) 2-dimensional distribution for jets from $H \rightarrow bb$ and $H \rightarrow cc$ assuming SM Yukawa couplings.**

- An additional cut, **BDT(b|c) < 0.2 for both jets**, is applied to set the $V+H(\rightarrow cc)$ limit: 0 data events selected.

Direct search for $H \rightarrow cc$

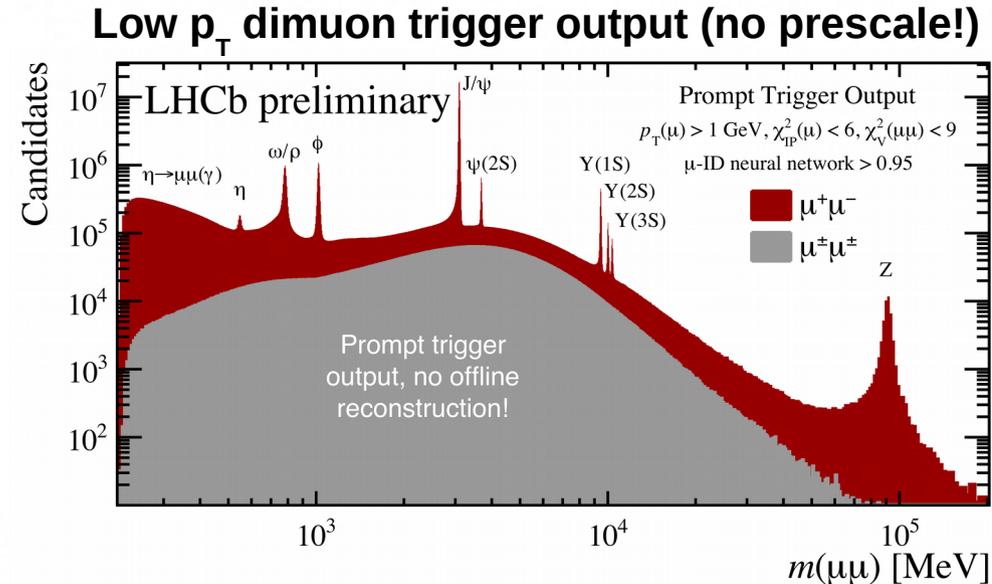
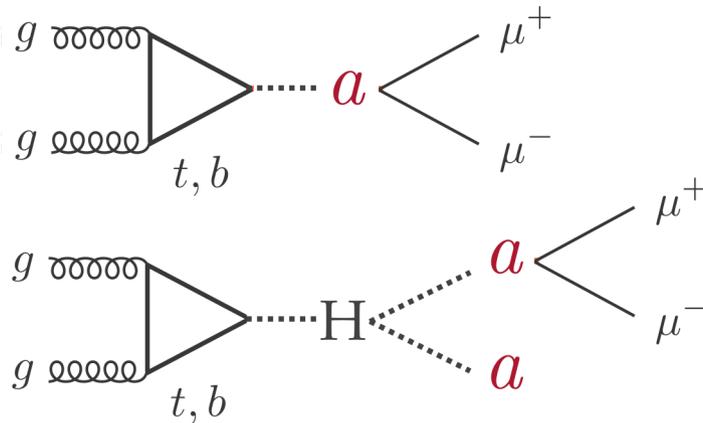
LHCb-CONF-2016-006

- The upper limit on $V+H(\rightarrow bb)$ is $50 \times \sigma_{SM}$, on $V+H(\rightarrow cc)$ $6400 \times \sigma_{SM}$
- In the high luminosity phase we expect to collect 300 fb^{-1} at 14 TeV.
- The $V+H(\rightarrow cc)$ cross section times acceptance increased of a factor 7.
- We expect to improve our di-c-jet tagging efficiency from $\sim 2\%$ (Run I) to $\sim 30\%$ (phase II Upgrade), thanks to the improved IP resolution.
- In the high-lumi phase we expect an upper limit on $V+H(\rightarrow cc)$ below 5-10 times σ_{SM} .

Reference for the limit recast at high lumi: Mike William's talk at LHCb future upgrades workshop
<https://agenda.infn.it/getFile.py/access?contribId=36&sessionId=4&resId=0&materialId=slides&confId=12253>

Future prospects

- Search for low mass CP-odd Higgs (a) in dimuon final state:



- The dimuon trigger can also be used to search for Dark Photons (arXiv:1603.08926, 1509.06765)
- Search for Lepton Flavour Violating Higgs decays: as example $\mathbf{H} \rightarrow \mu\tau}$ or $\mathbf{H} \rightarrow \mu e$
- Search for NMSSM $\mathbf{H} \rightarrow \mathbf{aa} \rightarrow \mathbf{bb} \tau\tau$ or $\mathbf{H} \rightarrow \mathbf{aa} \rightarrow \mathbf{bb} \mathbf{bb}$
- **Suggestions from experts are welcome!**



**Thanks for your
attention!**



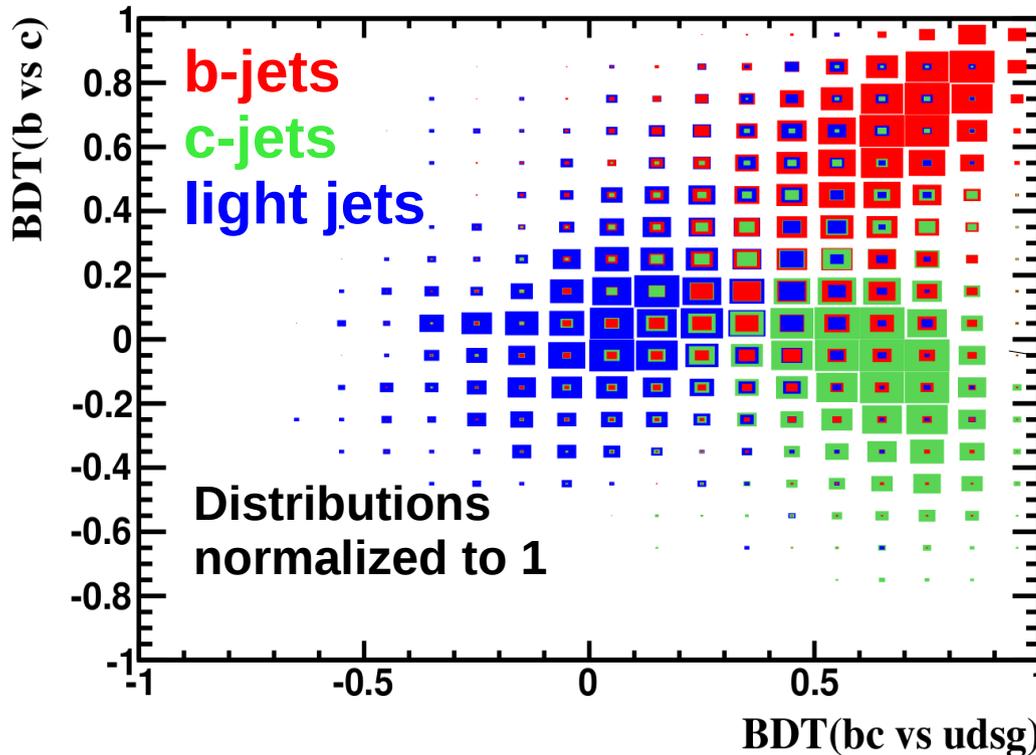
Backup slides

Jets heavy flavour identification

JINST 10 (2015) P06013

- Jets are heavy flavour tagged if one Secondary Vertex compatible with a b or c hadron decay is found with $\Delta R < 0.5$ from the jet axis.

- Two **Boosted Decision Trees** are used to identify b and c jets.



BDT(bc|udsg)
To separate **heavy flavour** jets
from **light** jets

BDT(b|c)
To separate **b-jets** from **c-jets**

**A good discrimination
power is achieved!**