Higgs searches at LHCb

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On behalf of the LHCb Collaboration

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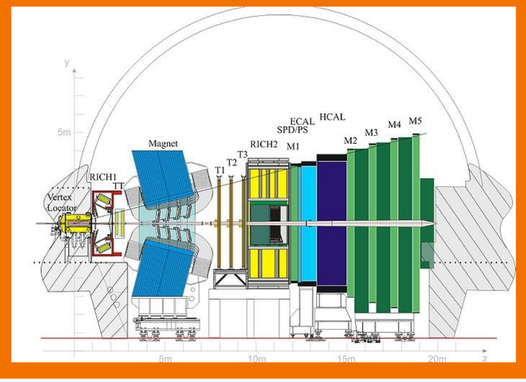
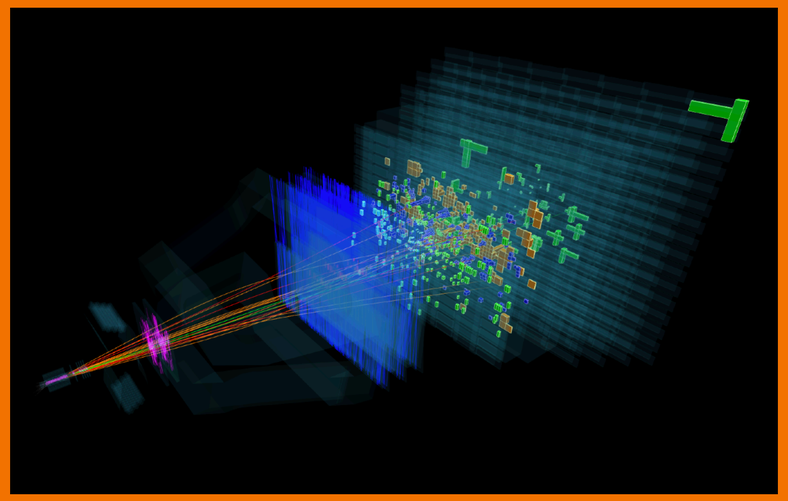
Outline

What I am going to talk about

LHCb experiment



Higgs @ LHCb



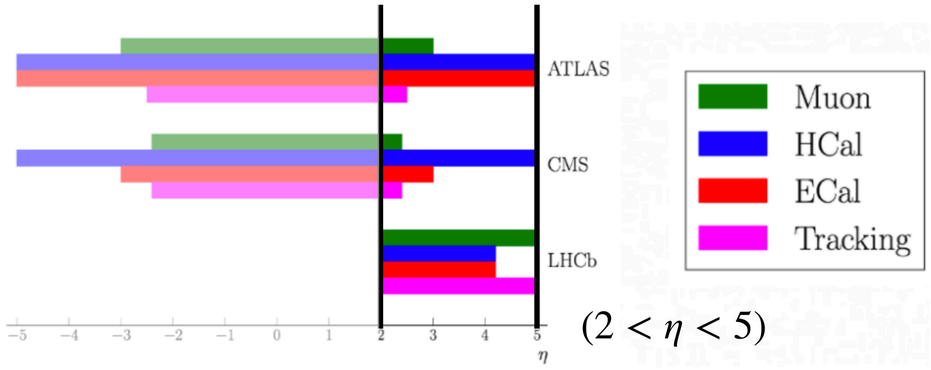
Higgs @ LHCb future upgrades

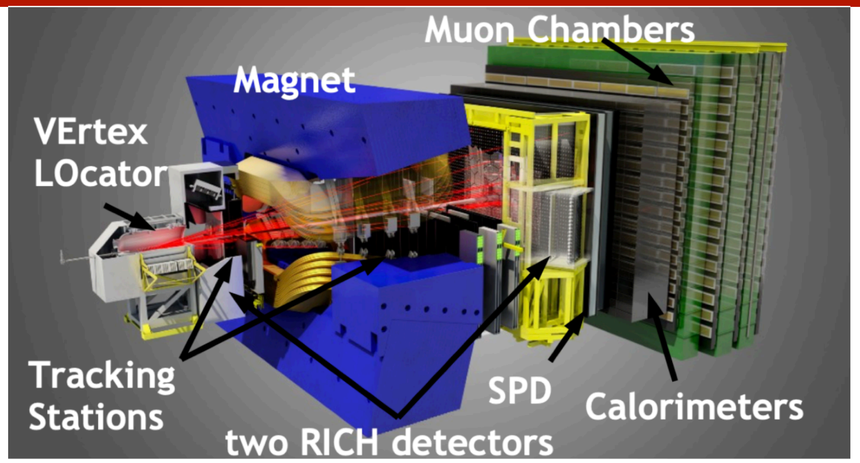
LHCb experiment

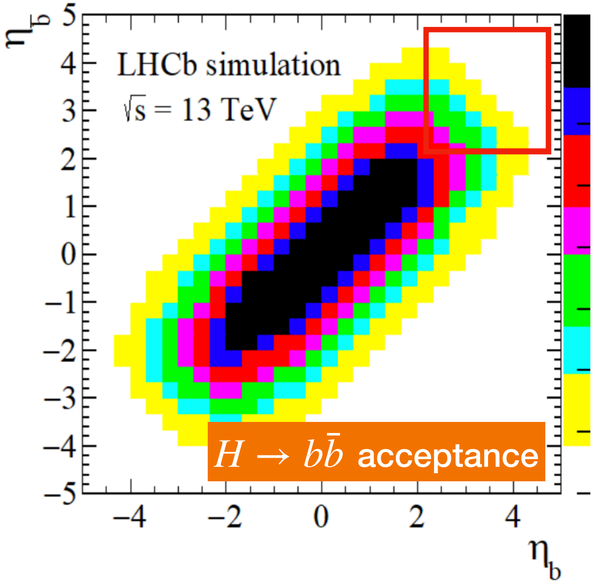
A General Purpose *Forward* Detector

JINST 3 (2008) S08005
Int. J. Mod: Phys. A 30, 1530022 (2015)
CERN-LPCC-2018-04

- LHCb, originally designed for b- and c-hadron physics, is now considered a **general purpose forward detector**
- **Excellent track momentum resolution**: 0.4% at 5 GeV and 0.6% at 100 GeV
- Very good muon and electron ID efficiency
- **Excellent vertex reconstruction helps in jets identification**: tagging of b- and c-jets with reconstruction of secondary vertices
- LHCb allows to test perturbative QCD (pQCD) predictions in a phase space $(2 < \eta < 5)$ **complementary to General Purpose Detectors** (ATLAS & CMS)
- Parton distribution functions (PDFs) and proton structure can be studied in **regions not accessible by other LHC experiments**





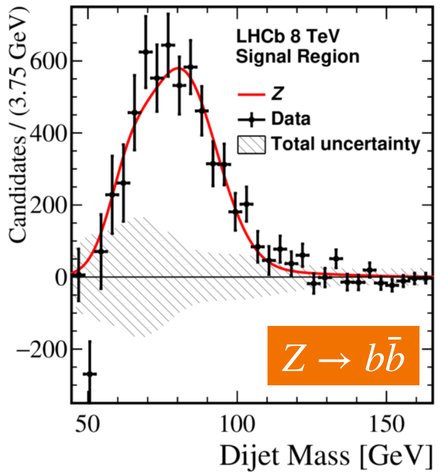


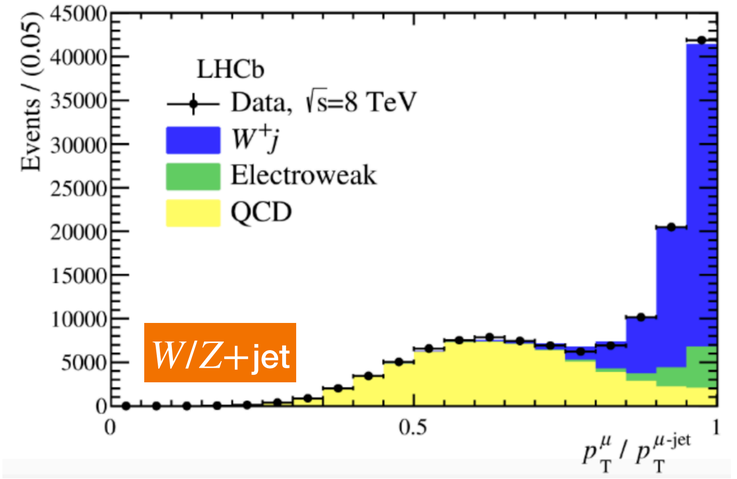
Higgs @ LHCb

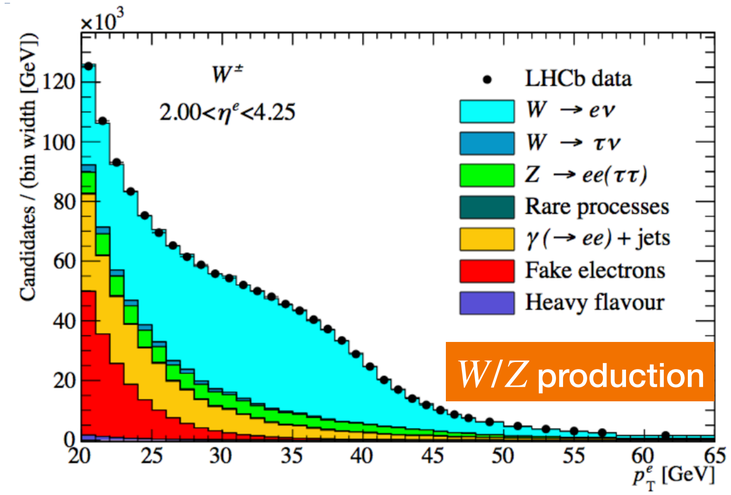
Studying high p_T physics

JHEP 10 (2016) 030
JHEP 09 (2016) 136
JHEP 05 (2016) 1-23
Phys. Lett. B776 (2018) 430

- At LHCb we can study physics at high p_T







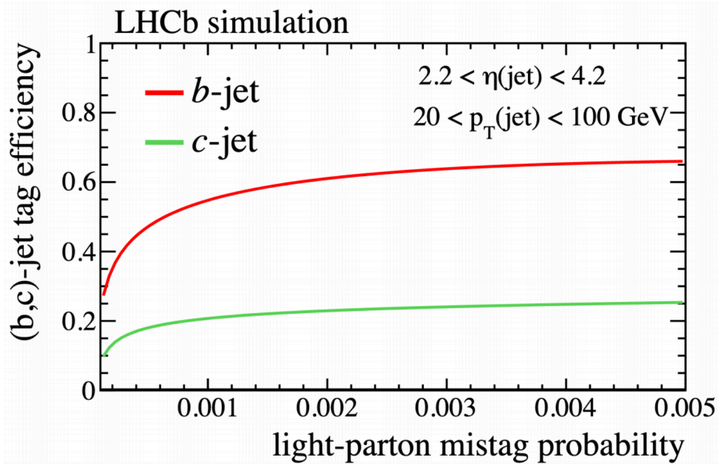
- In principle we can also study the Higgs boson, but **LHCb is limited by small acceptance and lower luminosity**
  - But we can rely on **excellent Impact Parameter** ($\sigma \sim 20$ μm) and **vertices resolution**
- Studies have been performed on Run I and Run II data:
  - "Search for $H^0 \to b\bar{b}$ or $c\bar{c}$ in association with a W or Z boson in the forward region of pp collisions"
  - "Search for lepton-flavour-violating decays of Higgs-like bosons"
  - "Search for massive long-lived particles decaying semileptonically at $\sqrt{s} = 13$ TeV
- **Ongoing studies** with Run II data
  - "Search for high mass resonances decaying to heavy flavour di-jets"

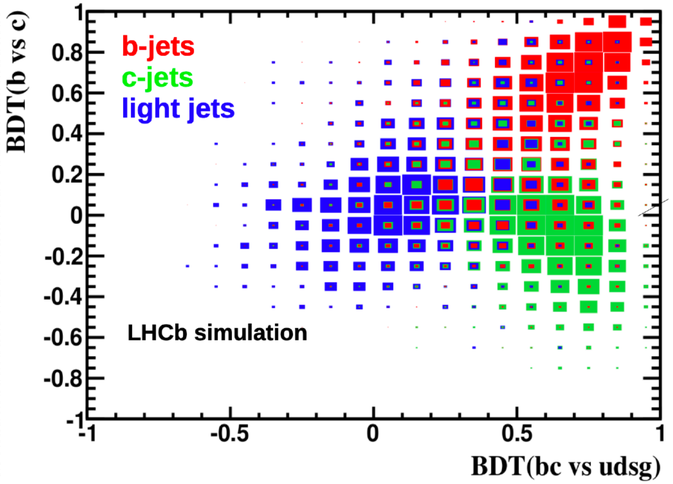
Higgs @ LHCb

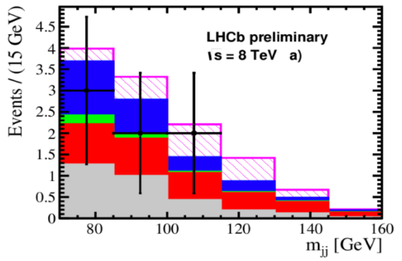
JINST 10 P06013
LHCb-CONF-2016-006

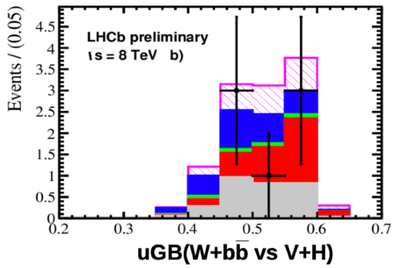
Search for $H^0 \to b\bar{b}$ or $c\bar{c}$ in association with a W or Z boson in the forward region of pp collisions

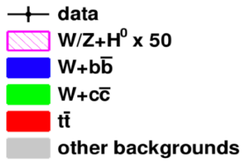
- The Higgs boson can be produced associated with a vector boson
- Search for a $b\bar{b}$ ($c\bar{c}$) + lepton signature, sensitive to WH and ZH signals, using Run I data ($\mathscr{L} \sim 2$ fb^{-1})
- Need to efficiently tag jets coming from b, c and light quarks (u, d, s, gluon)
- Jet tagging by means of Boosted Decision Trees (BDT)
- Good tagging efficiency with respect to mistag

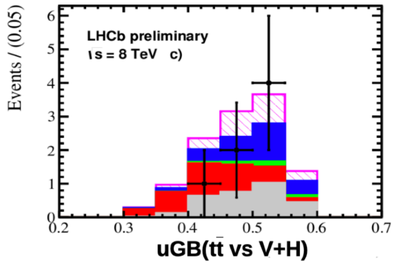


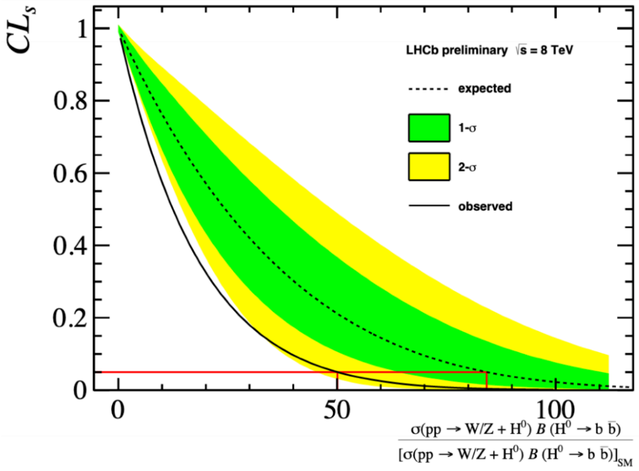












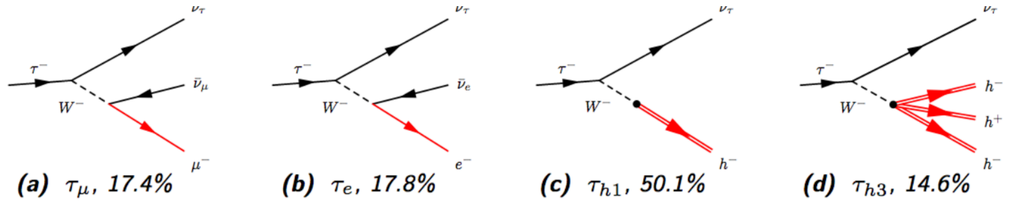
- No signals are observed, upper limits on Yukawa couplings: $y^b < 7y^b_{SM}$, $y^c < 80y^c_{SM}$

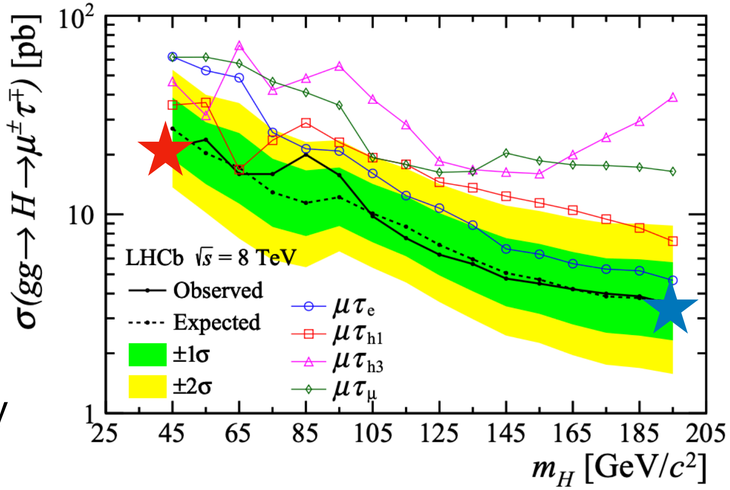
Higgs @ LHCb

EUR. PHYS. J. C78 (2018) 1008

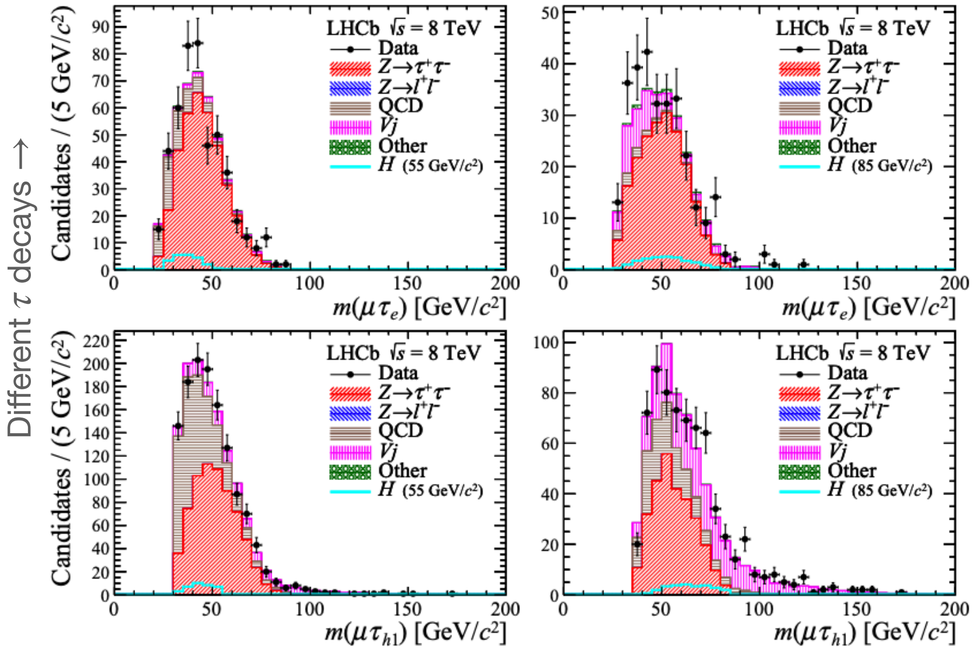
Search for lepton-flavour-violating decays of Higgs-like bosons

- Study the lepton-flavour-violating decay $H^0 \to \mu^{\pm}\tau^{\mp}$
- Higgs-like bosons are studied in the mass range $[45 - 195]$ GeV/c^2
- τ leptons are reconstructed both in leptonic and hadronic channels
- Selection is optimized with respect to mass hypothesis
- Run I data ($\mathscr{L} \sim 2$ fb^{-1}) are analyzed
- Upper limits on $\sigma \times \mathscr{B}$ are set at 95 % C.L.:
  - ★ 22 pb at $m_H = 45$ GeV/c^2
  - ★ 4 pb at $m_H = 195$ GeV/c^2
- For Higgs boson, $\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 1.7 \times 10^{-2}$
- The search provides complementary results w.r.t. ATLAS & CMS





Selection criteria →

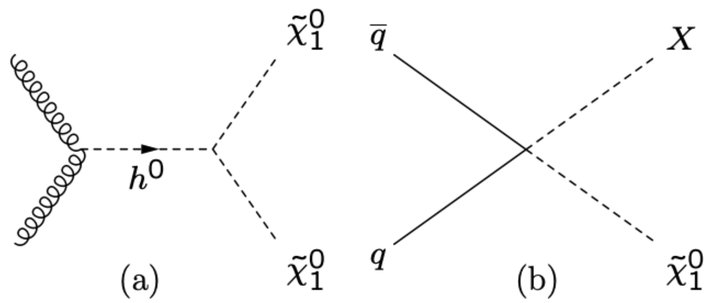


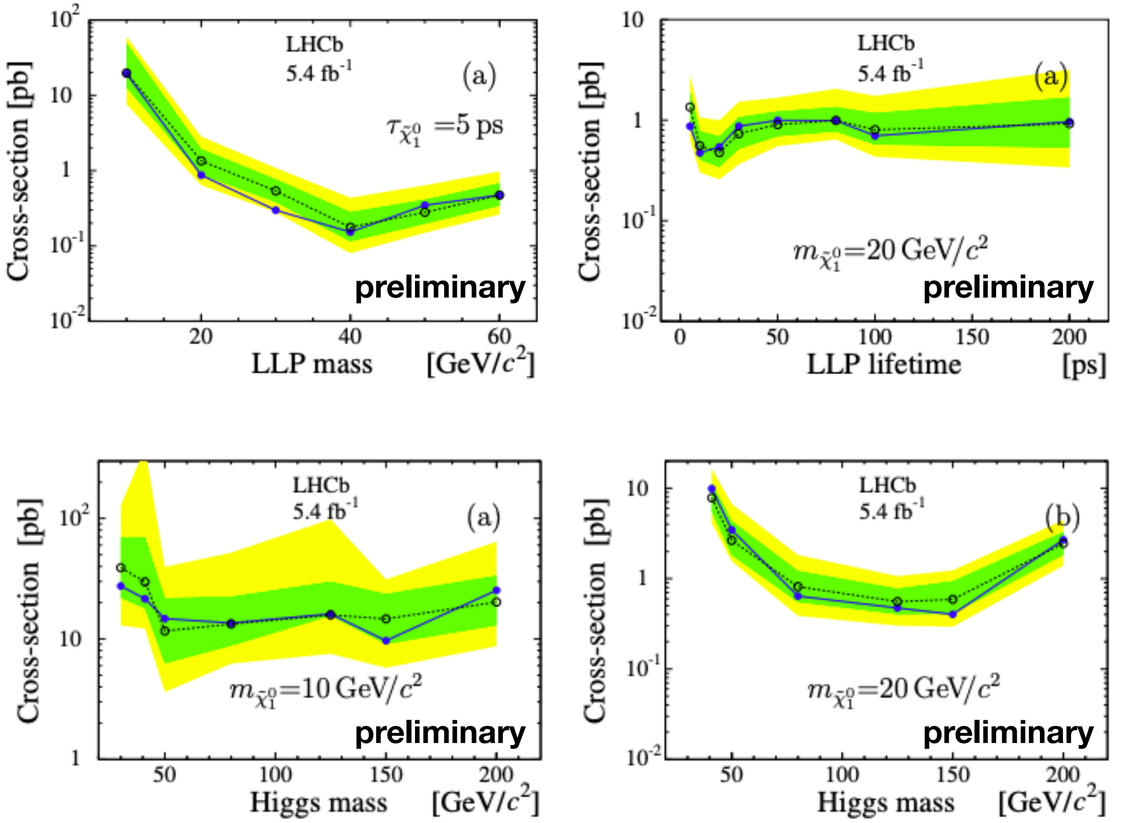
Higgs @ LHCb

NEW!
https://arxiv.org/pdf/2110.07293.pdf

Search for massive long-lived particles decaying semileptonically at $\sqrt{s} = 13$ TeV

- Search for massive long-lived particles (LLP) decaying into a muon and two quarks
- LLPs lifetimes considered range goes from 5 ps to 200 ps
- Two searches are performed:
  a. Higgs-like bosons from gluon fusion (with mass $m \in [30,200]$ GeV/c^2) decaying into 2 LLPs
  b. Direct production from quark interaction, with LLPs masses $m \in [10,90]$ GeV/c^2





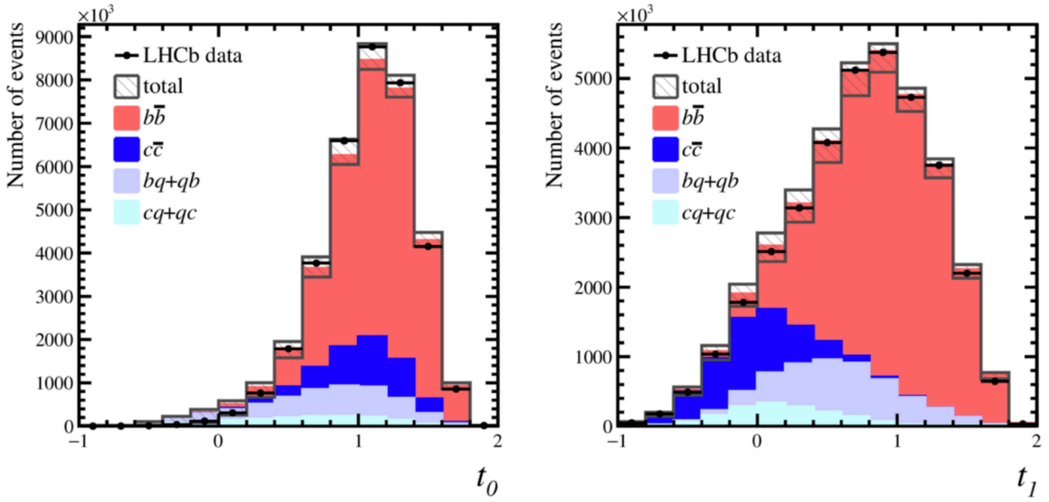
- Fit to reconstructed LLP mass → no signal found
- $95\,\%$ CL upper limits are set on $\sigma(\text{LLPs}) \times \mathcal{B}(\text{LLPs} \to q\bar{q}\mu)$ for both searches → sensitivity of the order $O(1$ pb$)$

Higgs @ LHCb

JHEP 02 (2021) 023

Search for high mass resonances decaying to heavy flavour di-jets

- The main idea is to study the inclusive decay of high mass resonances decaying to $b\bar{b}$ and $c\bar{c}$ di-jets
- It is possible to study lower invariant masses with respect to ATLAS/CMS
- QCD background has an important role in this analysis (background from $Z \to b\bar{b}$ $(c\bar{c})$ is also considered)
- **A first study has been performed to measure $b\bar{b}$ and $c\bar{c}$ differential cross sections with 2016 data**



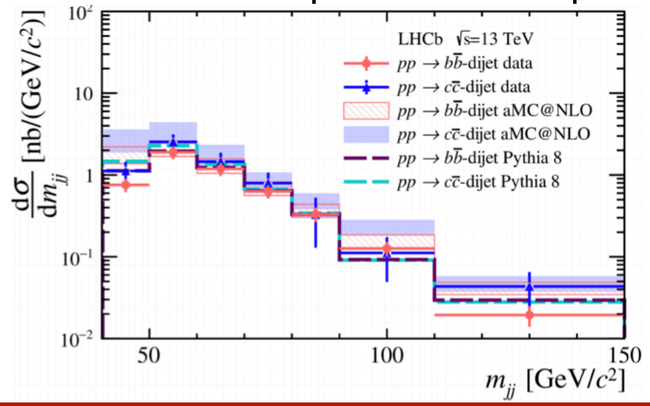
- **First measurement of $c\bar{c}$ di-jet differential cross section at a hadron collider**
- A similar approach will include high mass resonances (such as the Higgs boson) decaying to $b\bar{b}$ and $c\bar{c}$ di-jets

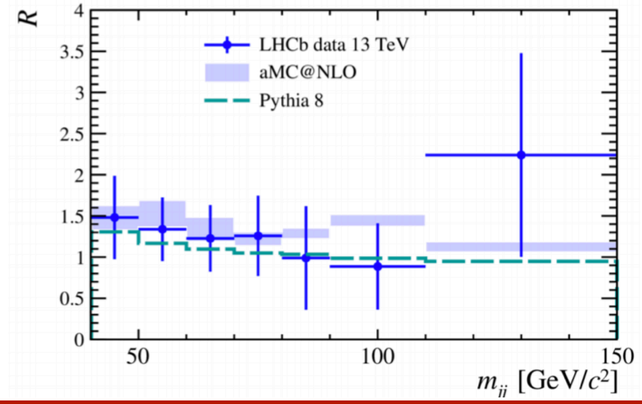
- Fit to combination of two MVA discriminators t_0 and t_1 to get flavour composition:

$$t_0 = \mathrm{BDT}_{bc|q}(j_0) + \mathrm{BDT}_{bc|q}(j_1)$$

$$t_1 = \mathrm{BDT}_{b|c}(j_0) + \mathrm{BDT}_{b|c}(j_1)$$

- The cross section ratios $R = \sigma_{b\bar{b}}/\sigma_{c\bar{c}}$ are also computed as functions of kinematic variables
- Results are compatible with expectations





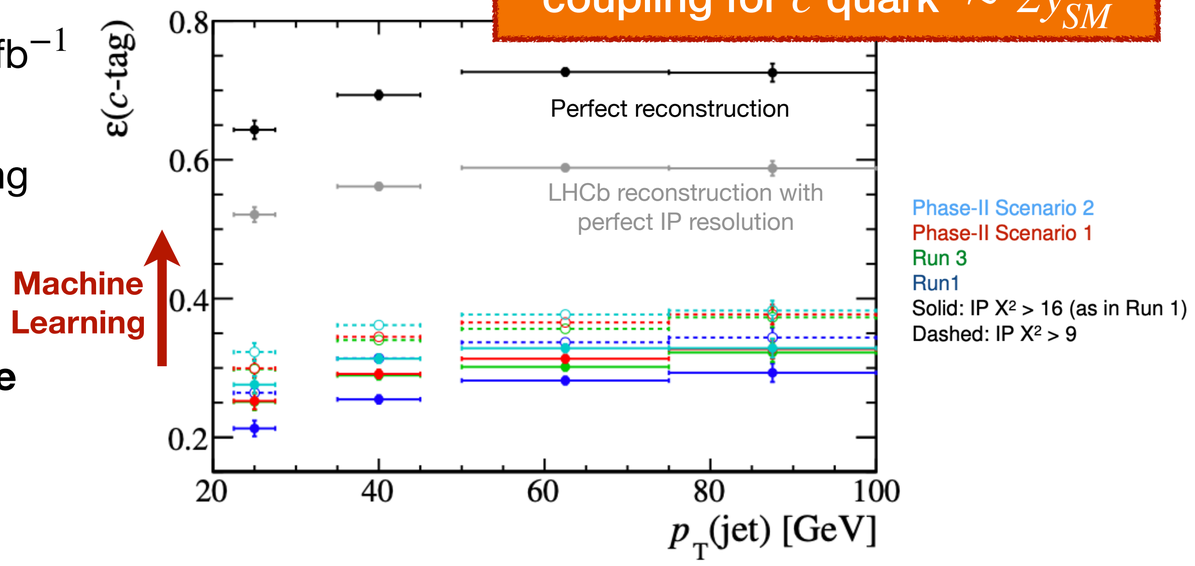
Higgs @ LHCb in future upgrades

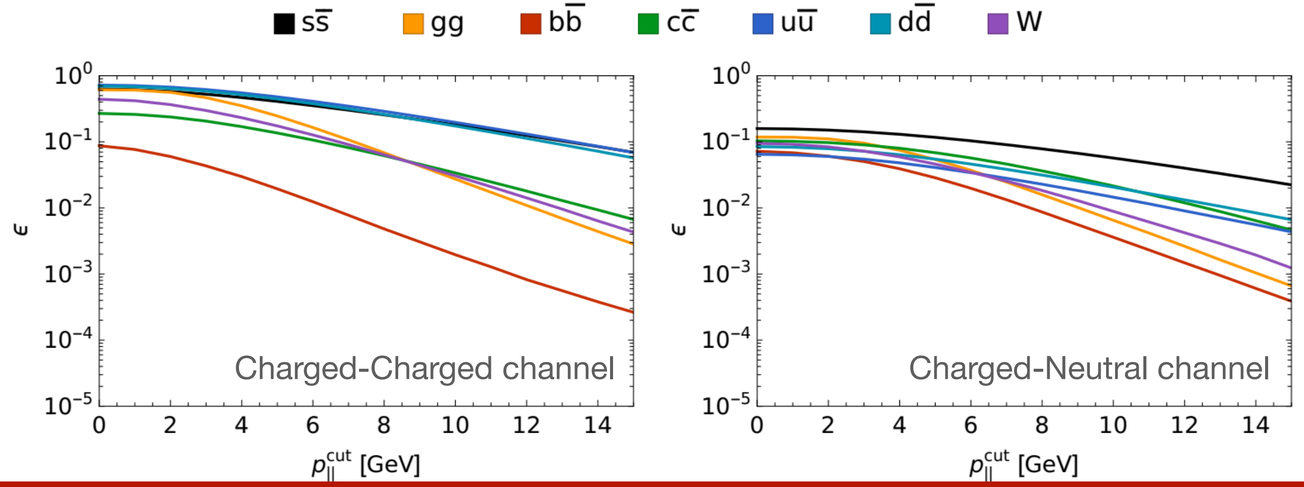
LHCB-PUB-2018-009
CERN-LPCC-2018-04

What is the future of Higgs boson studies at LHCb upgrades?

- LHCb could definitely improve its results for the process $H^0 \to c\bar{c}$:
  - Rescaling results by **increasing integrated luminosity** to 300 fb^{-1} (end of Run 5)
  - **Loosing c-tagging criteria** would allow us to get a di-jet tagging efficiency $\sim 30\,\%$ (see Thomas talk on charm tagging @ LHCb)
  - VELO-induced c-tagging efficiency (from $25\,\%$ to $30\,\%$)
  - **Better discrimination between b- and c-quarks** (e.g. **Machine Learning** algorithms, similar to CMS)

Best LHC sensitivity on Yukawa coupling for c quark $\sim 2y^c_{SM}$





- **Tagging strange jets** to constrain Yukawa coupling of the strange quark
- Strange quarks hadronize to prompt kaons
- Cut on the impact parameter d_0 to suppress heavy flavour jets
- Suppression of light jets in the Charged-Neutral channel

Conclusions

Wrap up

- LHCb is by all means a **general purpose forward detector**
- At LHCb it is possible to study high p_T physics
- **Analysis on Run I and Run II data showed that at LHCb we can study Higgs boson**
- Analysis of Run II data and future upgrades will give us really **interesting insights** on the Higgs boson, particularly for the process $H^0 \to c\bar{c}$

Stay tuned for some interesting results!

Thank you for your attention!

Backup slides

Higgs @ LHCb

Updated search for long-lived particles decaying to jet pairs

EPJC 77 (2017) 812
PRD 92 (2015) 073008
PRD 92 (2015) 012010

- A Higgs boson could decay to a pair of Hidden Valley (HV) pions, which in turn decay to $q\bar{q}$ pairs
- Search for a "displaced di-jet vertex" $\Longrightarrow$ good resolution of primary (PV) and secondary vertices (SV) is needed
- LHCb can access low lifetimes and small HV pion masses
- Run I data ($\mathscr{L} \sim 2$ fb^{-1}) are analyzed
- Different distances from PV are considered (R_{xy})
- Upper limits are set on $\sigma(gg \to H^0) \times \mathscr{B}(H^0 \to \pi_V \pi_V)$
- LHCb results are compared with ATLAS/CMS
- LHCb could explore exotic Higgs decay processes ($H^0 \to SS$) followed by a displaced decay of the scalar S