Recent results from LHCb on charged-current decays of b-hadrons

Anna Lupato
On behalf of the LHCb Collaboration

University of Padova & INFN

EPS-HEP
Ghent, Belgium, July 10-17, 2019

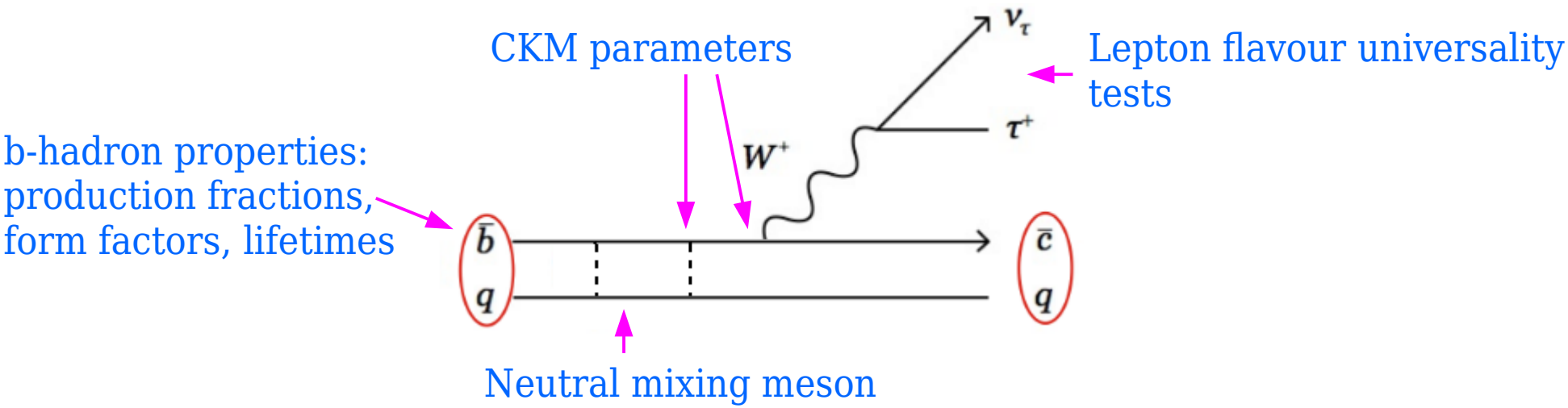
Semileptonic b-hadron decays

- High branching fractions $\mathcal{B}(B \to X l \nu) \sim 10\%$: tree-level transition mediated by a W boson in SM;
- Theoretically clean: only one hadronic current, parametrized in terms of scalar function;
- Theoretical uncertainty controllable, could be further reduced by lattice calculation improvements

- Partially reconstructed signal due to missing neutrinos.

- Large number of b hadrons produced at LHCb (B, B_s, B_c, Λ_b ...): all b-flavour hadrons
  → almost 100 million semileptonic decays in run1+2

- Semileptonic decays are good probes for:



Outline

- Precision measurement of the Λ_c,Ξ_c^+,Ξ_c^0 baryon lifetimes [LHCb-PAPER-2019-008, arXiv:1906.08350]
- Measurement of b-hadron fraction in 13 TeV pp collisions [LHCb-PAPER-2018-050, arXiv:1902.06794]
- Search for the rare decay $B^+ \to \mu^+\mu^-\mu^+\nu$ [LHCb-PAPER-2018-037, arXiv:1812.06004]
- Measurement of the relative $B^- \to D^0/D^*/D^{**0}\,\mu^-\nu$ branching fractions using B^- from B_{s2}^{*0} decays [Phys. Rev. D 99, 092009 (2019)]

Outline

- Precision measurement of the Λ_c,Ξ_c^+,Ξ_c^0 baryon lifetimes
  [LHCb-PAPER-2019-008, arXiv:1906.08350]
- Measurement of b-hadron fraction in 13 TeV pp collisions
  [LHCb-PAPER-2018-050, arXiv:1902.06794]
- Search for the rare decay $B^+ \to \mu^+\mu^-\mu^+\nu$ [LHCb-PAPER-2018-037, arXiv:1812.06004]
- Measurement of the relative $B^- \to D^0/D^*/D^{**0}\,\mu^-\nu$ branching fractions using B^- from B_{s2}^{*0} decays [Phys. Rev. D 99, 092009 (2019)]

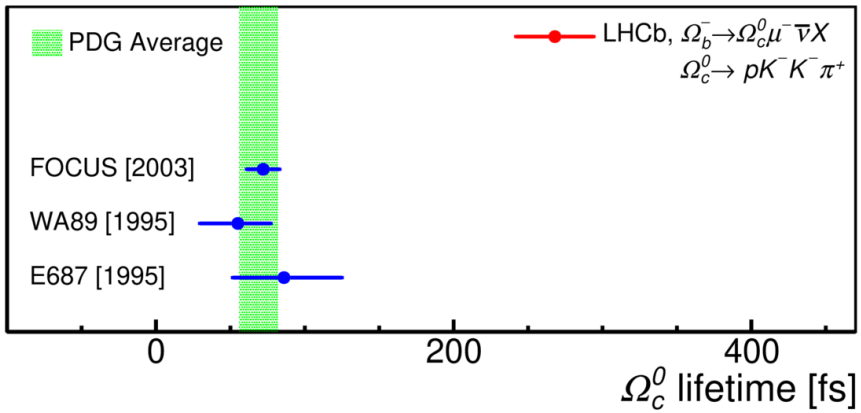
Λ_c,Ξ_c^+,Ξ_c^0 baryon lifetimes

[LHCb-PAPER-2019-008, arXiv:1906.08350]

- Measurement of lifetimes of hadrons containing b or c quarks play an important role in testing theoretical approaches that are used to perform Standard Model calculation.

- In HQET, at LO, all charm lifetimes are equal. Sizable corrections enter at $O(1/m_c^2, 1/m_c^3)$
  → Charm hadron lifetimes provide a sensitive probe of these higher order (HO) corrections

- This analysis is a followup of LHCb Ω_c^0 lifetime measurement which reports a value about 4x larger than, and inconsistent with, the WA. [PRL 121 (2018) 092003]

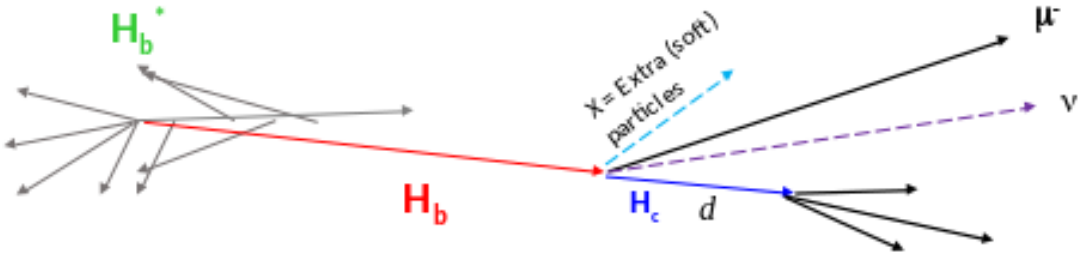


- The Λ_c,Ξ_c^+,Ξ_c^0 lifetimes were measured last almost 20 years ago

$\Lambda_c, \Xi_c^+, \Xi_c^0$ baryon lifetimes

[LHCb-PAPER-2019-008, arXiv:1906.08350]

- $r_{H_c} = \tau_{H_c} / \tau_{D^+}$
- Data sample: 3 fb^{-1} (2011+2012)
  - 3 reconstructed final states which originate from semileptonic decays
    - $\Lambda_c \to pK\pi$, $\Xi_c^+ \to pK\pi$, $\Xi_c^0 \to pKK\pi$
  - Normalization channel: $B \to D^+ X\mu\nu$, $D \to K\pi\pi$
- The signal yields have been extracted by fitting the invariant mass distributions of Λ_c, Ξ_c^+, Ξ_c^0, D^+
- The decay time of each candidate is determined as:



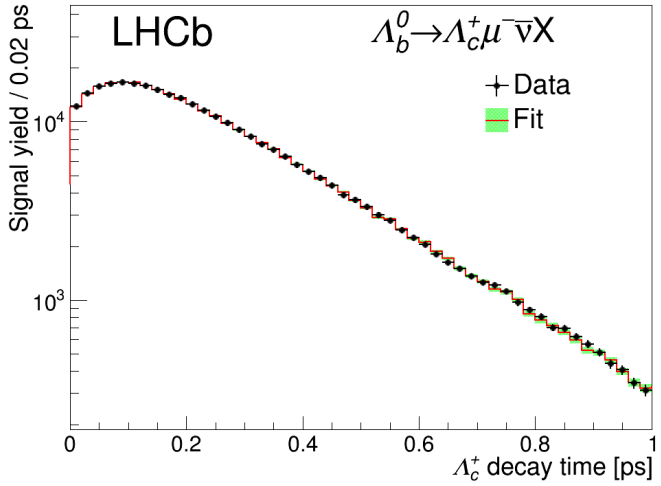
$$\tau(H_c) = d(H_c)\frac{m(H_c)}{p(H_c)}$$

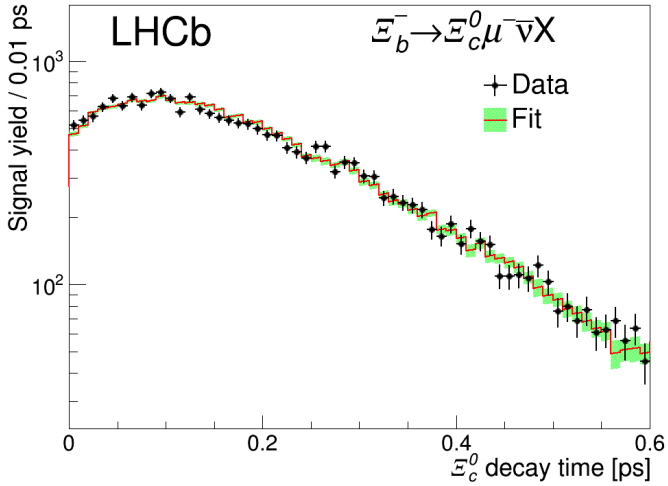
- Backgrounds in the decay time spectrum are suppressed by applying sWeights determined from $M_{inv}(H_c)$ distribution.

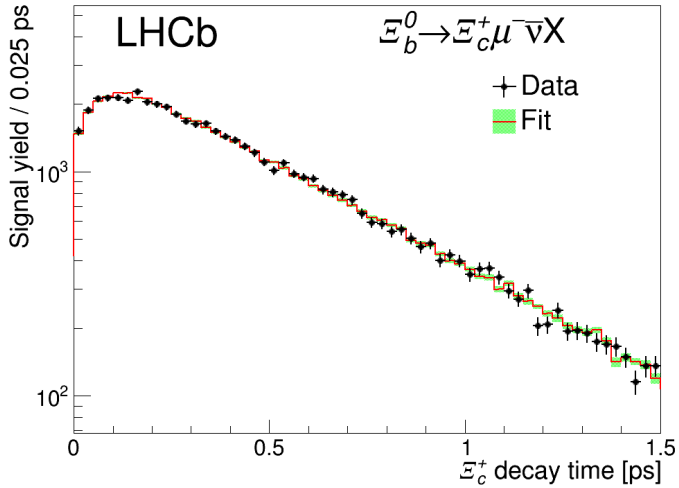
Λ_c, Ξ_c^+, Ξ_c^0 baryon lifetimes

[LHCb-PAPER-2019-008, arXiv:1906.08350]

- Simultaneous fit to D^+ and charm baryon decay time spectra







	$r(H_c) = \tau / \tau_D$	τ (fs)	τ (fs) $_{PDG}$
Λ_c^+	0.1956 ± 0.0010± 0.0013	203.5 ± 1.0 ± 1.3 ± 1.4fs	200 ± 6
Ξ_c^+	0.4392 ± 0.0034± 0.0028	456.8 ± 3.5 ± 2.9 ± 3.1fs	442 ± 26
Ξ_c^0	0.1485 ± 0.0017± 0.0016	154.5 ± 1.7 ± 1.6 ± 1.0fs	112^{+13}_{-10}

due to the uncertainty in the D^+ lifetime

- The measurements are 3-4 times more precise than the current world average
- Λ_c^+, Ξ_c^+ lifetimes consistent with the world averages
- Ξ_c^0 is ~3.3σ higher.

Outline

- Precision measurement of the Λ_c,Ξ_c^+,Ξ_c^0 baryon lifetimes [LHCb-PAPER-2019-008, arXiv:1906.08350]
- Measurement of b-hadron fraction in 13 TeV pp collisions [LHCb-PAPER-2018-050, arXiv:1902.06794]
- Search for the rare decay $B^+ \to \mu^+\mu^-\mu^+\nu$ [LHCb-PAPER-2018-037, arXiv:1812.06004]
- Measurement of the relative $B^- \to D^0/D^*/D^{**0}\,\mu^-\nu$ branching fractions using B^- from B_{s2}^{*0} decays [Phys. Rev. D 99, 092009 (2019)]

b-hadron fractions measurement @13 TeV

[LHCb-PAPER-2018-050,arXiv:1902.06794]

- Knowledge of b-hadron fragmentation fractions is essential in many aspects.
  - To allow for relating the pp production cross-section from pQCD to the observed hadrons
  - To convert the observed B_s and Λ_b production ratios at the LHC into absolute branching fractions
  - To characterize the signal (background) composition in inclusive (exclusive) b-hadron analyses
- These fractions must be determined experimentally because they are driven by strong dynamics in the non-perturbative regime.
- LHCb measured the b-hadrons production fractions in 7 TeV pp collisions [Phys. Rev. D85 (2012) 032008]

b-hadron fractions measurement @13 TeV

[LHCb-PAPER-2018-050,arXiv:1902.06794]

- The measured ratios are:

$$\frac{f_s}{f_u+f_d} \quad \frac{f_{\Lambda_b^0}}{f_u+f_d}$$

$$f_q \equiv \mathcal{B}(b \to B_q)$$
$$f_{\Lambda_b} \equiv \mathcal{B}(b \to \Lambda_b)$$

- Data sample: 1.67 fb^{-1} (2016)
- Inclusive semileptonic decays: $H_b \to H_c X\mu\nu$
- Theoretical basis: Semileptonic widths for all b hadrons are almost equal [I.Bigi et al., JHEP 09 (2011) 012] → $\Gamma_{SL}(H_b) = \Gamma_{SL}$
  - Differences predicted to be around 1% (HQE)

→ we can use the measured lifetime to relate measured yield to hadron fragmentation.

$$\frac{f_s}{f_u+f_d} = \frac{n_{\rm corr}(\bar{B}_s^0 \to D_s\mu)}{n_{\rm corr}(B \to D^0\mu) + n_{\rm corr}(B \to D^+\mu)} \frac{\tau_{B^-}+\tau_{\bar{B}^0}}{2\tau_{\bar{B}_s^0}} (1-\xi_s) - \frac{\mathcal{B}(B \to D_s K\mu)}{\langle\mathcal{B}_{SL}\rangle} \frac{\epsilon(\bar{B} \to D_s^+)}{\epsilon(\bar{B}_s^0 \to D_s^+)}$$

Corrected yields of $\bar{B}_s^0$, $\bar{B}^0$, B^-

SU(3) breaking correction $\xi_s = (-1 \pm 0.5)\%$

Subtraction of $\bar{B}^0(B^-) \to D_s^+ K\mu^-\bar{\nu}_\mu X$ contributions in $\bar{B}_s^0$ signals

$$\frac{f_{\Lambda_b^0}}{f_u+f_d} = \frac{n_{\rm corr}(\Lambda_b^0 \to H_c\mu^-)}{n_{\rm corr}(B \to D^0\mu^-) + n_{\rm corr}(B \to D^+\mu^-)} \frac{\tau_{B^-}+\tau_{\bar{B}^0}}{2\tau_{\Lambda_b^0}} (1-\xi_{\Lambda_b^0})$$

Corrected yields of Λ_b^0, $\bar{B}^0$, B^-

Chromomagnetic correction $\xi_{\Lambda_b^0} = (3 \pm 1.5)\%$

b-hadron fractions measurement @13 TeV

[LHCb-PAPER-2018-050,arXiv:1902.06794]

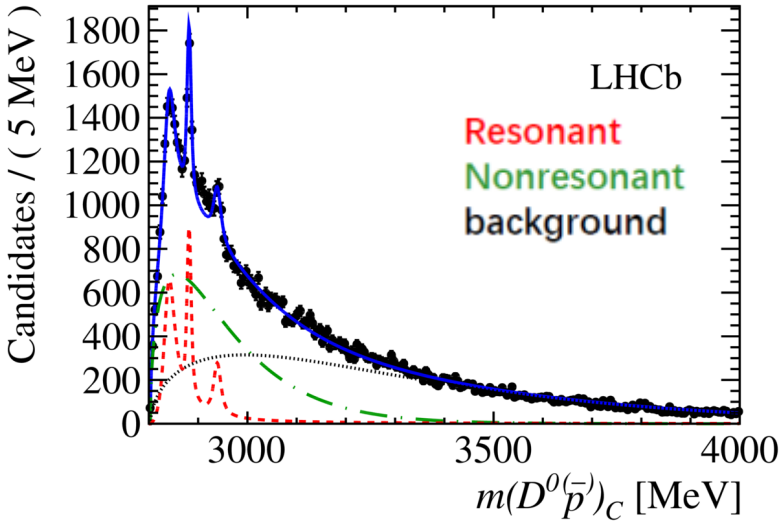
$$n_{\rm corr}(B \to D^0\mu^-) = \frac{1}{\mathcal{B}(D^0 \to K^-\pi^+)\epsilon(B \to D^0)} \times \left[n(D^0\mu) - n(D^0K^+\mu^-)\frac{\epsilon(\overline{B}{}^0_s \to D^0)}{\epsilon(\overline{B}{}^0_s \to D^0K^+)} - n(D^0p\mu^-)\frac{\epsilon(\Lambda_b^0 \to D^0)}{\epsilon(\Lambda_b^0 \to D^0p)} \right]$$

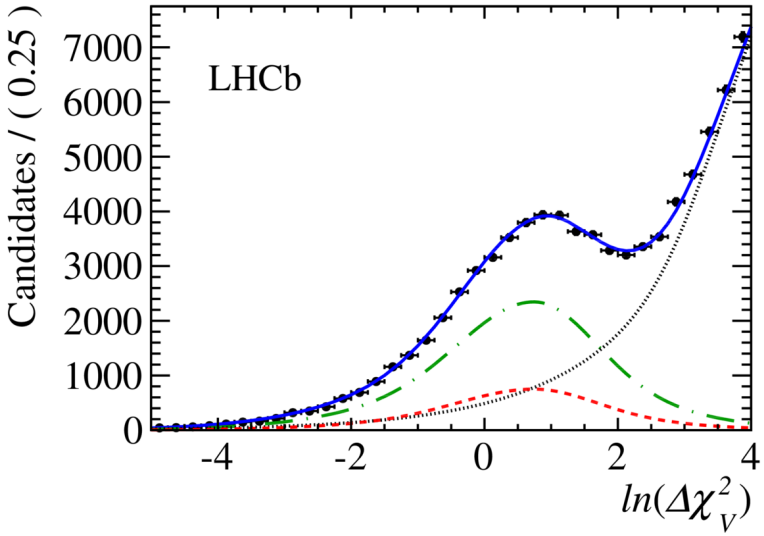
Inclusive yield

Subtracted yield of $B_s \to D^0 K X\mu\nu$

Subtracted yield of $\Lambda_b \to D^0 p X\mu\nu$

- $D^0 h X\mu\nu$ are signal for B_s and Λ_b and background for $\overline{B}{}^0$ and B^-
  - 2D Fit to
    - $m(D^0h) - m(D^0) - m(D^0)_{pdg}$ (h=K,p)
    - $\ln(\Delta\chi^2_V)$: logarithm of the vertex χ^2 difference between Dhμ and Dμ

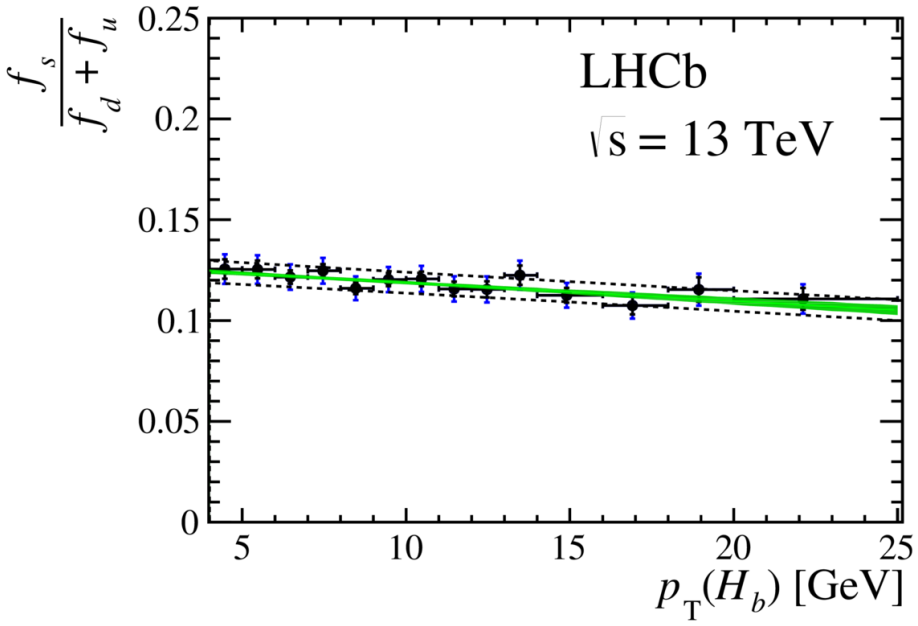


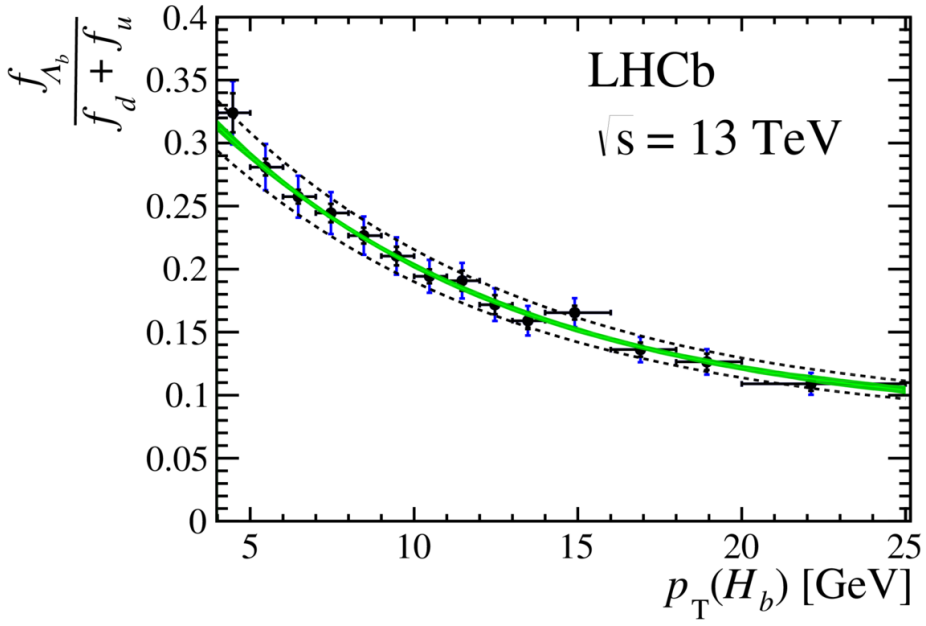


b-hadron fractions measurement @13 TeV

[LHCb-PAPER-2018-050,arXiv:1902.06794]

- Fit to data: linear χ^2 fit to p_T (charm+μ) distributions incorporating a full covariance matrix, which takes into account correlation introduced from the kaon kinematics, PID and tracking systematic uncertainties.





- Averages fractions integrated between the limits $4<p_T$ (charm+μ)<25 GeV and $2<\eta<5$

$$\frac{f_s}{f_u+f_d} = 0.122 \pm 0.006 \qquad \frac{f_{\Lambda_b^0}}{f_u+f_d} = 0.259 \pm 0.018$$

Outline

- Precision measurement of the Λ_c,Ξ_c^+,Ξ_c^0 baryon lifetimes [LHCb-PAPER-2019-008, arXiv:1906.08350]
- Measurement of b-hadron fraction in 13 TeV pp collisions [LHCb-PAPER-2018-050,arXiv:1902.06794]
- Search for the rare decay $B^+ \to \mu^+\mu^-\mu^+\nu$ [LHCb-PAPER-2018-037, arXiv:1812.06004]
- Measurement of the relative $B^- \to D^0/D^*/D^{**0}\,\mu^-\nu$ branching fractions using B^- from B_{s2}^{*0} decays [Phys. Rev. D 99, 092009 (2019)]

Search for B→ 3μν decays

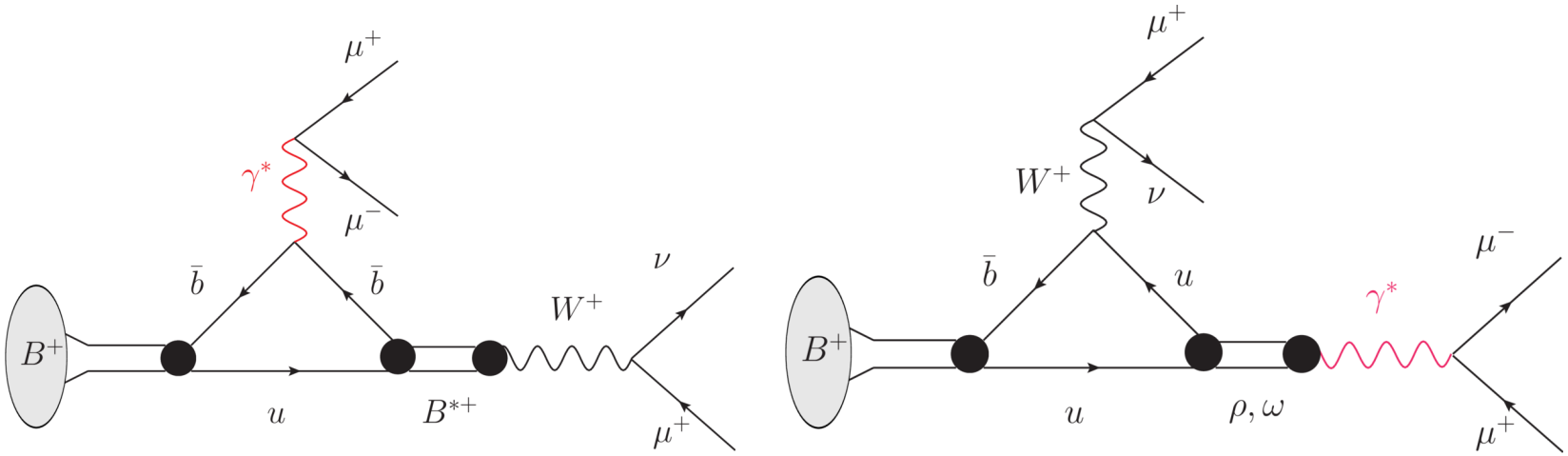
[LHCb-PAPER-2018-037, arXiv:1812.06004]

- Leptonic B^+ decays have branching fraction proportional to $|V_{ub}|^2$ and are helicity suppressed
  - Precise SM predictions and sensitive to new physics
- Measurements from BaBar and Belle in agreement with SM [PRD 92, 051102(R) (2015)] [PRD.D88 (2013) 031102]
- In LHCb, difficult to measure $B^+ \to l\nu$ because there is only 1 track
- Adding a photon decaying in two muons, $B^+ \to 3\mu\nu$ → feasible to reconstruct in LHCb
- Theoretical prediction (vector-meson dominance): $\mathcal{B}(B^+ \to 3\mu\nu) \sim 1.3 \times 10^{-7}$ [A.V.Danilina and N.V.Nikitin, PAN(2018)81,347]

Search for B→ 3μν decays

- The B+→ 3μν receives contributes from

[LHCb-PAPER-2018-037, arXiv:1812.06004]



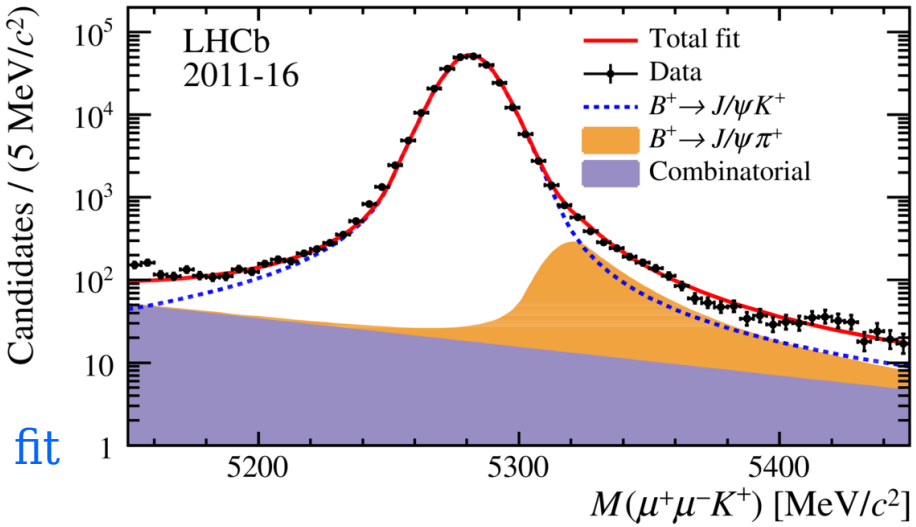
- The branching fraction is obtained by normalising to the B+→J/ψ(→ μ-μ+)K+ decays:

$$\mathcal{B}(B^+ \to \mu^+\mu^-\mu^+\nu_\mu) = \mathcal{B}(B^+ \to J/\psi\, K^+) \times \mathcal{B}(J/\psi \to \mu^+\mu^-) \times \frac{\varepsilon(B^+ \to J/\psi\, K^+)}{\varepsilon(B^+ \to \mu^+\mu^-\mu^+\nu_\mu)} \times \frac{N(B^+ \to \mu^+\mu^-\mu^+\nu_\mu)}{N(B^+ \to J/\psi\, K^+)}$$

from PDG

0.370 ± 0.003

Unbinned extended maximum likelihood fit



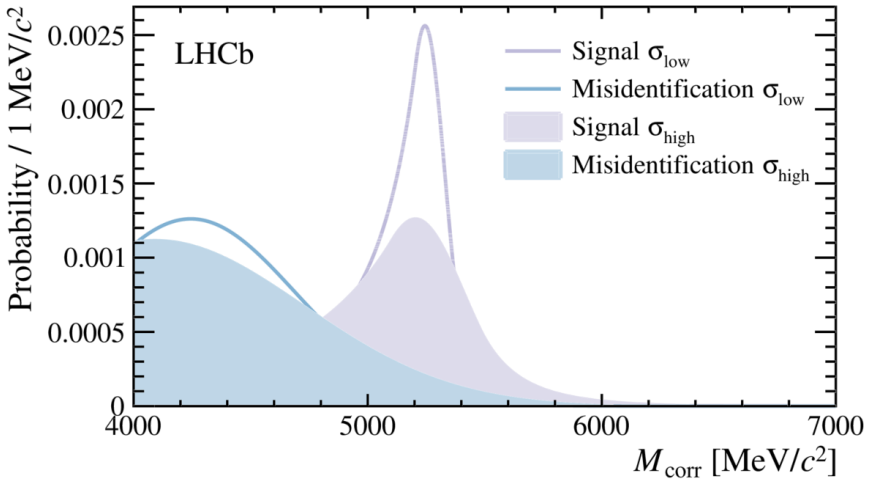
Search for B→ 3μν decays

[LHCb-PAPER-2018-037, arXiv:1812.06004]

- In order to determine $B^+ \to 3\mu\nu$ signal yields an extended maximum likelihood fit is performed to the corrected mass distribution.

$$M_{corr} = \sqrt{M^2 + |p_{T,miss}|^2} + |p_{T,miss}|$$

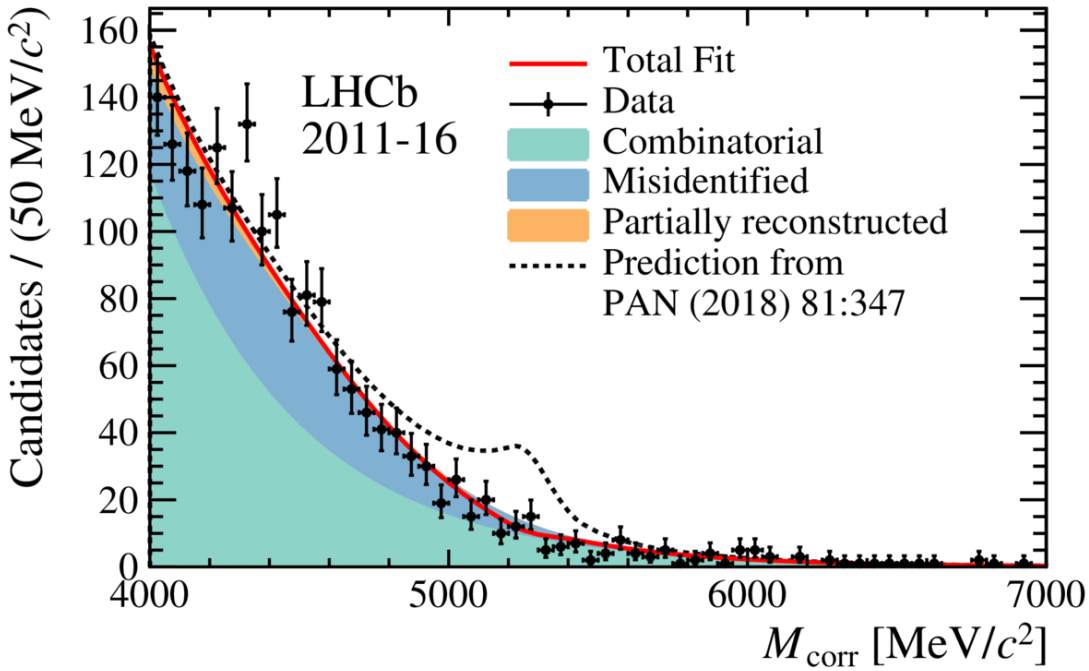
- To improve the sensitivity of the mass fit the uncertainty on primary and secondary vertices are propagated to the corrected mass and the sample is split into two:
  - high and low uncertainties on m_{corr}



Search for B→ 3μν decays

[LHCb-PAPER-2018-037, arXiv:1812.06004]

- The analyis has been performed using 4.7 fb^{-1} (2011-2012-2016)
- No significant signal is found
- A limit on the branching fraction is set 1.4 x 10^{-8} at 95% confidence level, using CL method
- Plot also shows prediction based on vector meson dominance model, which shows a tension with the measurement [A.V.Danilina and N.V.Nikitin, PAN(2018)81,347]



Outline

- Precision measurement of the Λ_c,Ξ_c^+,Ξ_c^0 baryon lifetimes [LHCb-PAPER-2019-008, arXiv:1906.08350]
- Measurement of b-hadron fraction in 13 TeV pp collisions [LHCb-PAPER-2018-050, arXiv:1902.06794]
- Search for the rare decay $B^+ \to \mu^+\mu^-\mu^+\nu$ [LHCb-PAPER-2018-037, arXiv:1812.06004]
- Measurement of the relative $B^- \to D^0/D^*/D^{**0}\,\mu^-\nu$ branching fractions using B^- from B_{s2}^{*0} decays [Phys. Rev. D 99, 092009 (2019)]

Relative $B(B^- \to D^0/D^{*}/D^{**0}\,\mu^-\nu)$

[Phys. Rev. D 99, 092009 (2019)]

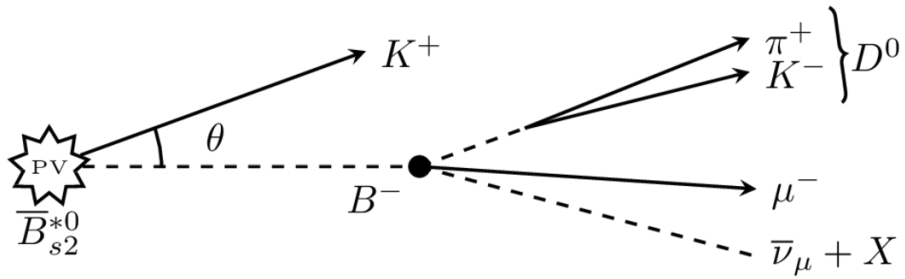
- The composition of the inclusive bottom-to-charm semileptonic rate is not fully understood
- One way to resolve this inclusive–exclusive gap is to make measurements of relative rates between different final states

$$f_{D^{**0}} = \mathcal{B}(B^- \to (D^{**0} \to D^0 X)\mu^-\bar{\nu}_\mu)/\mathcal{B}(B^- \to D^0 X\mu^-\bar{\nu}_\mu)$$

$$f_{D^{*0}} = \mathcal{B}(B^- \to D^{*0}\mu^-\bar{\nu}_\mu)/\mathcal{B}(B^- \to D^0 X\mu^-\bar{\nu}_\mu)$$

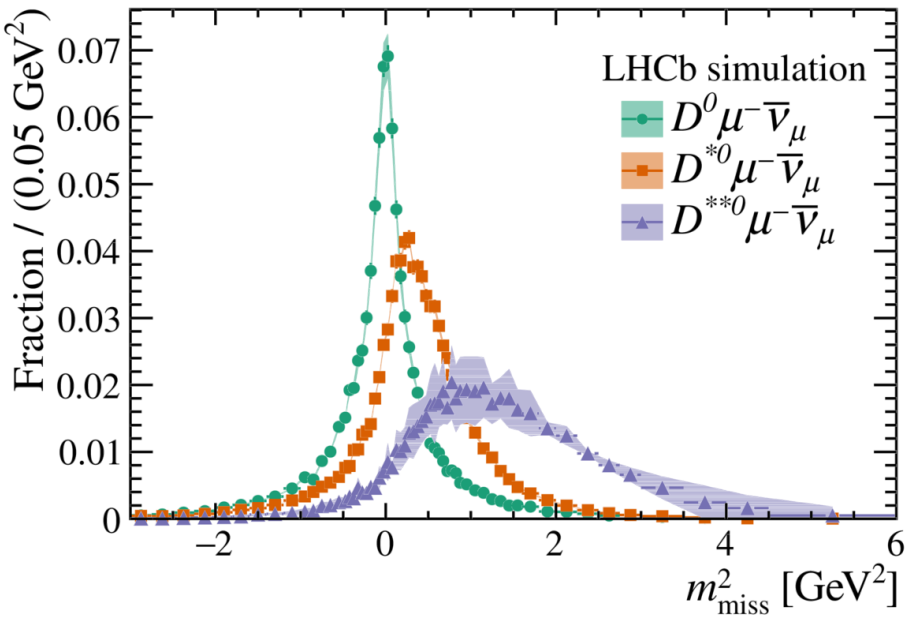
$$f_{D^0} = \mathcal{B}(B^- \to D^0\mu^-\bar{\nu}_\mu)/\mathcal{B}(B^- \to D^0 X\mu^-\bar{\nu}_\mu)$$

- NEW TECHNIQUE: use B candidate from $B_{s2}^{*0} \to BK$ to tag the B and determine its momentum → Large dataset are required ~1% of B originate from B_{s2}^{*0}



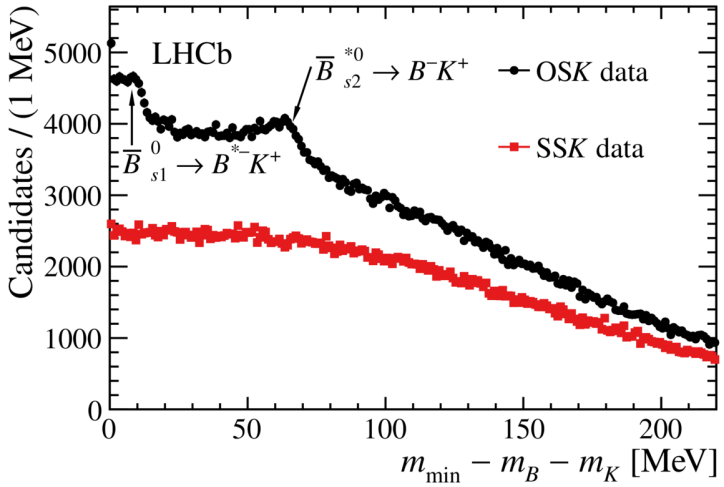
- Imposing $m(B_{s2}^{*0})=m(BK)$ → E_B can be determined up to a quadratic ambiguity →

$$m^2_{\text{miss}} = (p_B - p_{\text{vis}})^2$$



Relative $\mathcal{B}(B^- \to D^0/D^{*}/D^{**0}\,\mu^-\nu)$

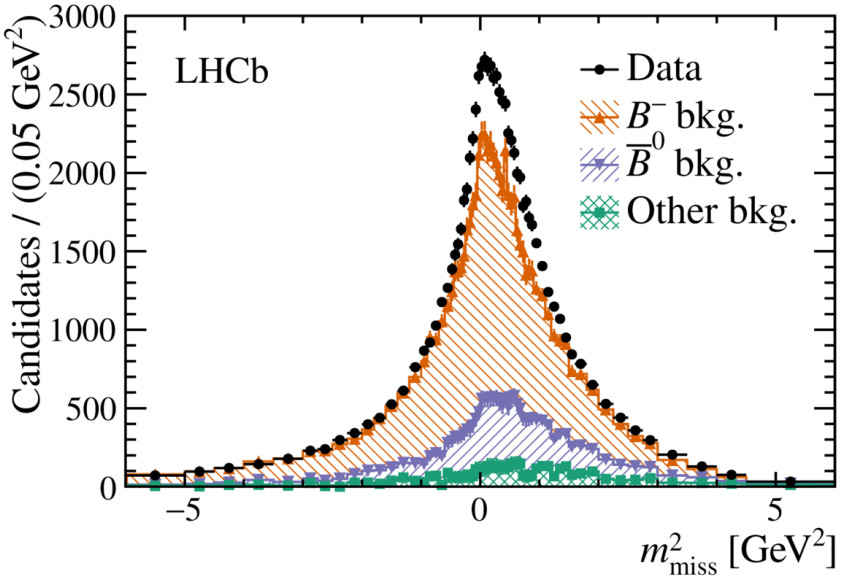
[Phys. Rev. D 99, 092009 (2019)]



- minimum mass of BK pair necessary to yield real solutions

$$m_{\rm min} = \sqrt{m_B^2 + m_K^2 + 2m_B\sqrt{p_K^2 \sin^2\theta + m_K^2}}$$

- Biggest challenge of the analysis: determine large amount of background:
  - Main background derived by B^- and B^0 not from B_{s2}^{*0} which is the 83% of the selected candidates → determined using data with same-sign K



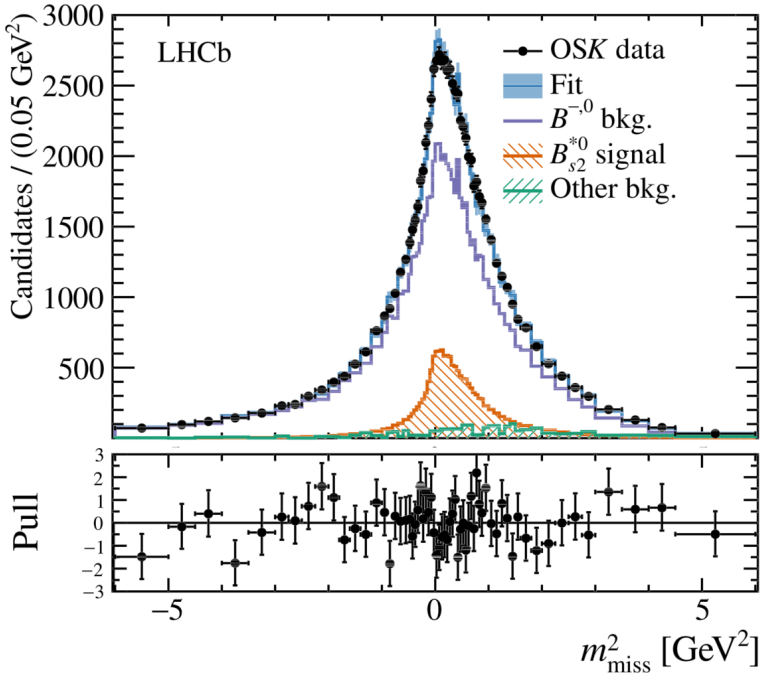
Relative $B(B^- \to D^0/D^{*}/D^{**0}\,\mu^-\nu)$

[Phys. Rev. D 99, 092009 (2019)]

- The relative branching fractions are determined from a binned template maximum likelihood fit to the missing mass distributions:

$$f_{D^0} = 0.25 \pm 0.06$$

$$f_{D^{**0}} = 0.21 \pm 0.07$$



- The results are compatible with expectations based on previous exclusive measurements [PRD,76,051101 (2007)]
- We have demonstrated that the reconstruction of the momentum of B decays with missing particles using B_{s2}^{*0} is a viable method at the LHCb experiment.

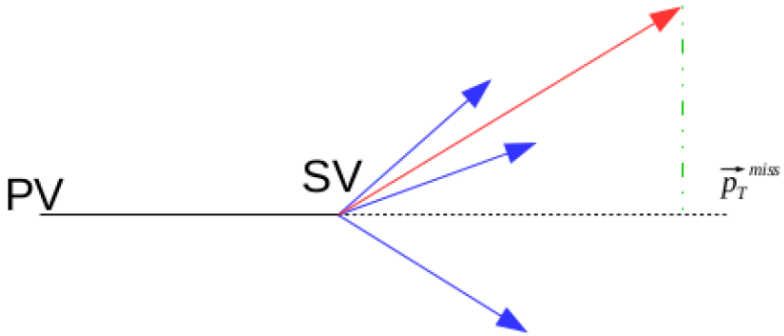
Conclusion

- Study of semileptonic B decays at LHCb are very challenging due to the missing neutrinos and no beam energy constraint.
- Semileptonic b-hadron decays have recently allowed to increase the precision on the Λ_c,Ξ_c^+,Ξ_c^0 baryon lifetimes. Ξ_c^0 is $\sim 3.3\sigma$ higher with respect to the world average.
- Using the semileptonic b-hadron decays, the b-hadron fractions measurement @13 TeV have been calculated and now it will be possible obtain the B_s and Λ_b absolute absolute branching fractions.
- A new limit on the *B* ($B^+ \to \mu^+\mu^-\mu^+\nu$) has been fixed.
- A new promising method to extract the fractions of $B^- \to DX\mu\nu$ has been tested.

Backup

Semileptonic Techniques

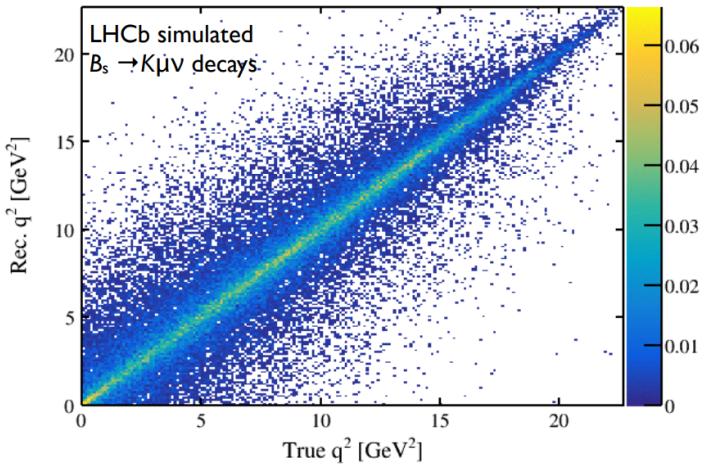
- Analysis rely on an estimation of the B kinematics
- Corrected mass: use a correction to the visible mass which contains information form the momentu carried out away by the neutrino



$$M_{corr} = \sqrt{M^2 + |p_{T,miss}|^2} + |p_{T,miss}|$$

- It is not possible to reconstruct the B momentum in the laboratory rest frame using final particles and hence constrain the kinematics of decay →
  - Approximate the B momentum in z direction:

$$(p_B)_z = (p_{B_{vis}})_z \frac{m_B}{m_{B_{vis}}}$$



  - Use a regression algorithm to pick up the solution

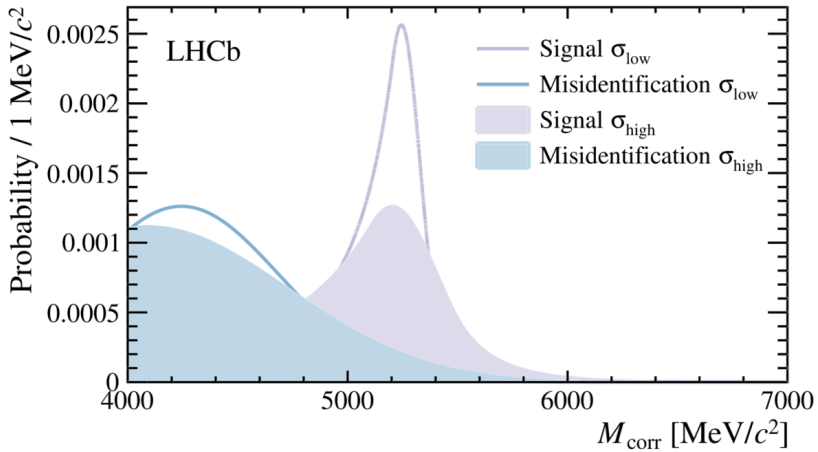
    [10.1007/JHEP02(2017)021]

- Partial reconstructed background:
  - Isolation tools to suppress charged track and neutral particles

Search for B→ 3μν decays

[LHCb-PAPER-2018-037, arXiv:1812.06004]

- Backgrounds:
  - m(μ-μ+)< 980 MeV to avoid potential background from ϕ → μ-μ+
  - Background from J/ψ and $\psi(2s)$ are removed with vetos
  - Misidentified combinations are studied on a sample of μ-μ+μ±X corrected for misidentification probability.
  - Partially reconstructed backgrounds (B → D(→ Kπμμ)μνX) are determined by simulation
- In order to determine B+→ 3μν signal yields an extended maximum likelihood fit is performed to the corrected mass distribution.

$$M_{corr} = \sqrt{M^2 + |p_{T,miss}|^2} + |p_{T,miss}|$$

- To improve the sensitivity of the mass fit the uncertainty on primary and secondary vertices are propagated to the corrected mass and the sample is split into two:
  - high and low uncertainties on m_{corr}