Joint Annual Meeting of the
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Semileptonic decays at LHCb

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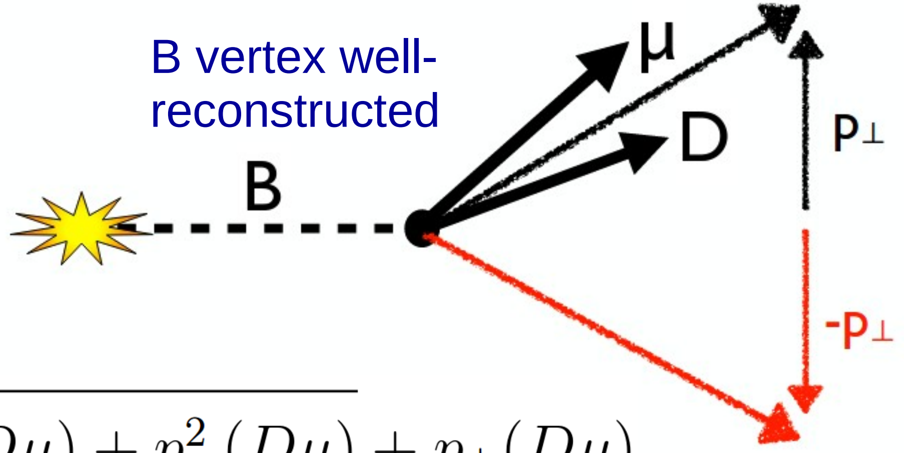
Semileptonic decays

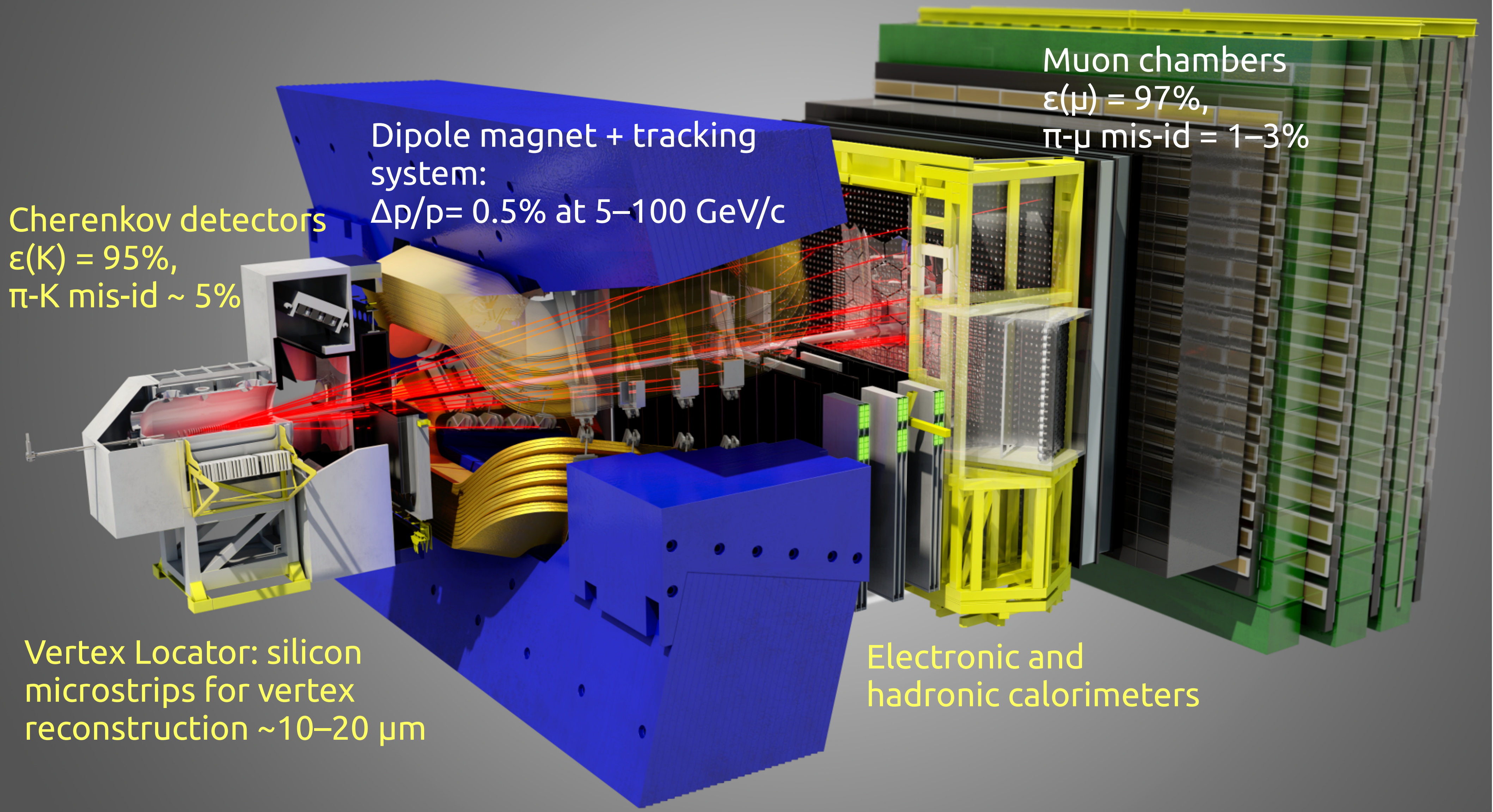
- Broad spectrum of measurements: cross-sections, lifetimes, lepton universality, CKM matrix elements, mixing and CP violation…
- Large statistics (including baryons) → potential for high precision
- Decays with (at least) a unreconstructed particle: the neutrino
- Partially reconstructed decay → missing momentum to reconstruct the B hadron
  - At LHCb, standard to correct for missing momentum via proxy variables, e.g. corrected mass



$$m_{\rm corr} = \sqrt{m^2(D\mu) + p_\perp^2(D\mu)} + p_\perp(D\mu)$$

The LHCb detector

10-50k reconstructables B mesons per second



Outline

Very broad and diverse program at LHCb, will only present two recent results

- Measurement of the flavour-specific B_s^0 lifetime and of the D_s^- lifetime

arXiv:1705.03475, accepted by PRL

- Measurement of the $B^0 \to D^* \tau\nu$ branching fraction for a test of lepton flavour universality

LHCb-PAPER-2017-017 and 027 in preparation

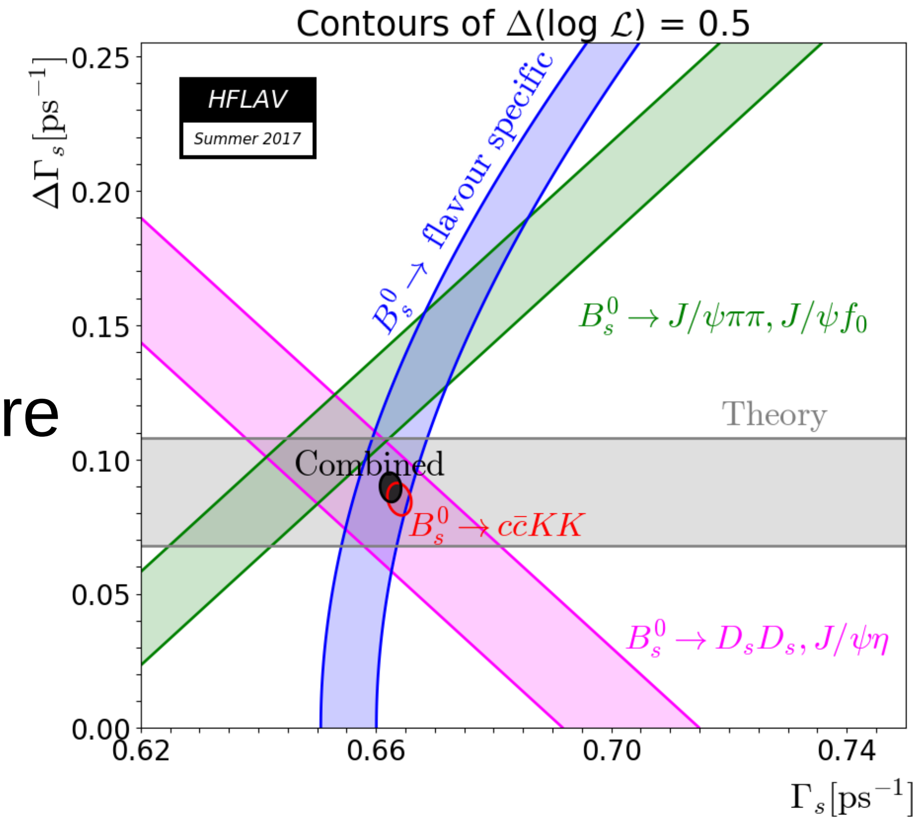
B^0_s flavour-specific lifetime

- Goal: measure the *flavour-specific* lifetime of the B^0_s in the decay $B_s^0 \rightarrow D_s^{(*)-} (\rightarrow K^+K^-\pi^-X)\, \mu^+ \nu$

$$\tau_s^{\mathrm{fs}} = \frac{1}{\Gamma_s}\left[\frac{1+(\Delta\Gamma_s/2\Gamma_s)^2}{1-(\Delta\Gamma_s/2\Gamma_s)^2}\right]$$

- Precise measurements of B and D lifetimes can be used to predict SM-values of different observables via theories such as HQE

- Use $B^0 \rightarrow D^{(*)-} (\rightarrow K^+K^-\pi^-X)\, \mu^+ \nu$ as a normalisation channel to measure the decay-width differences
  - $\Delta(B) = 1/\tau_{FS}(B_s^0) - \Gamma(B^0)$
  - $\Delta(D) = \Gamma(D_s^-) - \Gamma(D^-)$



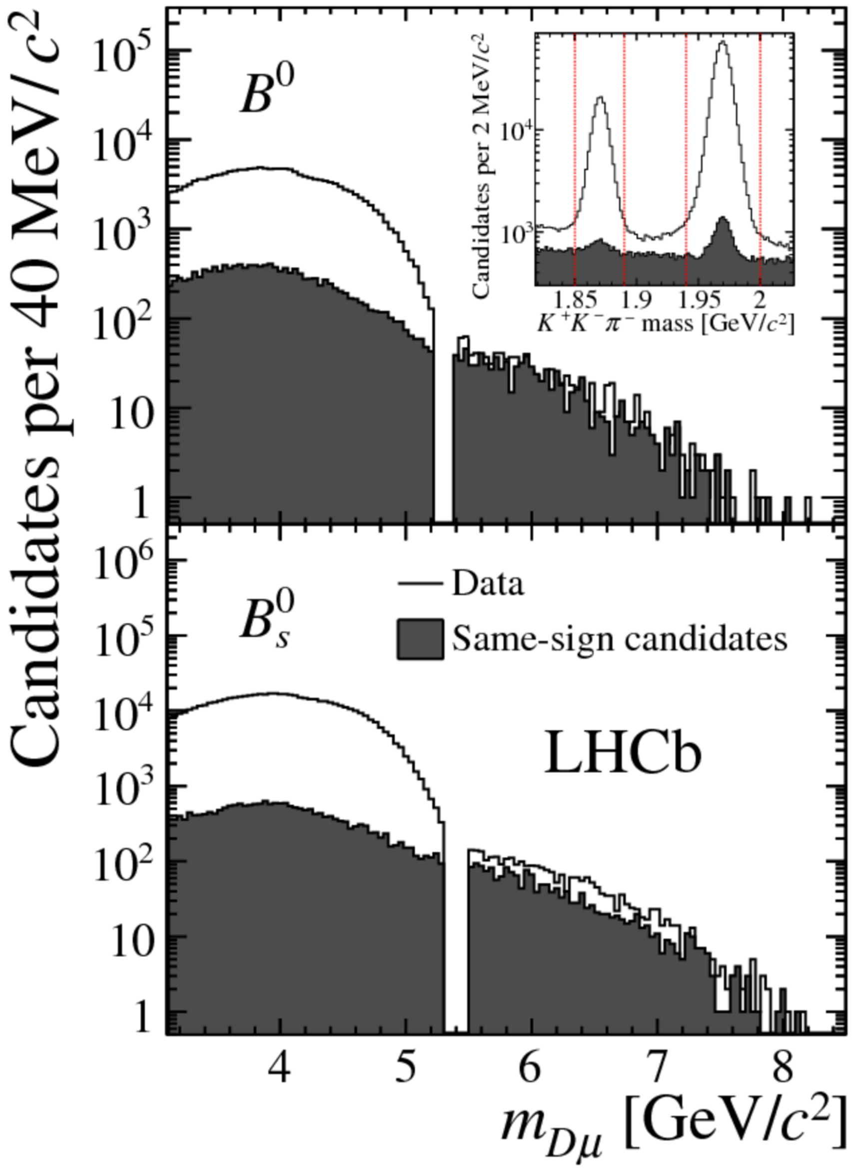
Analysis strategy

Similar strategy for Δ(D) and Δ(B) measurements:

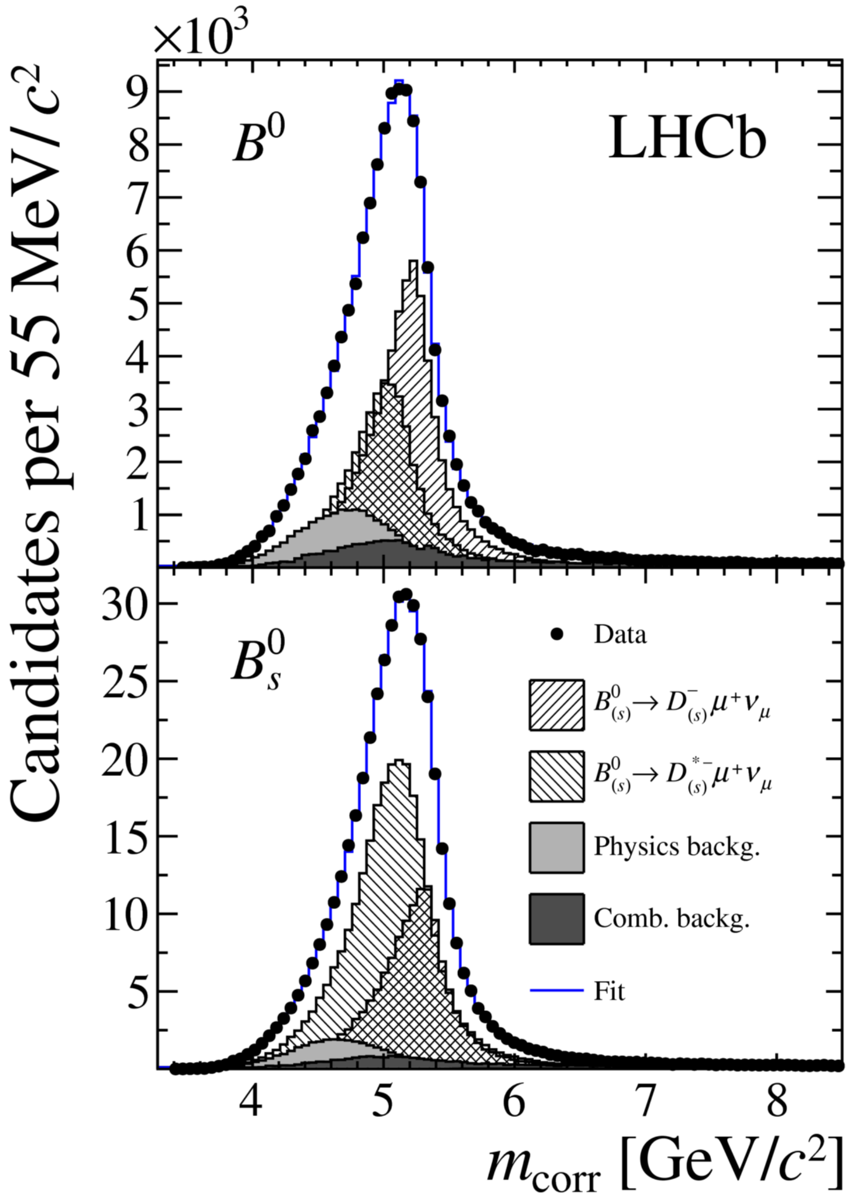
- ✔ Suppress differences in acceptance between B_s^0 and B^0 samples
- ✔ Determine the sample composition
  - ✔ Description of background and signal is crucial for
    1. Correction for missing momentum
    2. Decay-time acceptances
- ✔ Correct the observed decay time for missing momentum
- ✔ Measure the B_s^0 and B^0 yields in bins of decay time
- ✔ Fit the ratio of the yields to measure Δ(D) & Δ(B)

Event selection

- LHCb 2011-12 sample, restricted to single muon trigger
- Combine single muon with opposite-sign $D_{(s)}^- \to KK\pi$
  - Signal
  - $b \to X$ (physics bkg)
  - Combinatorial bkg
- Tune PID, momenta, track/vertex quality to make same-sign and signal candidate similar at high m(Dμ) mass
- Use same-sign to model combinatorics



Fit of sample composition



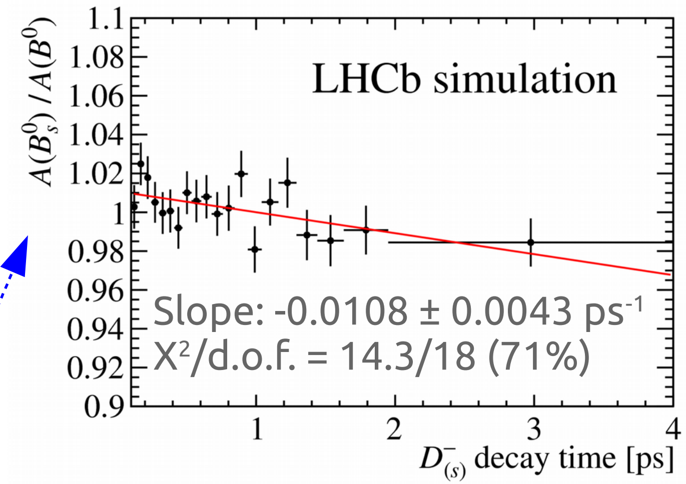
- B^0 fit fractions compatible with prediction and previous measurements
  - ➔ Validates the method

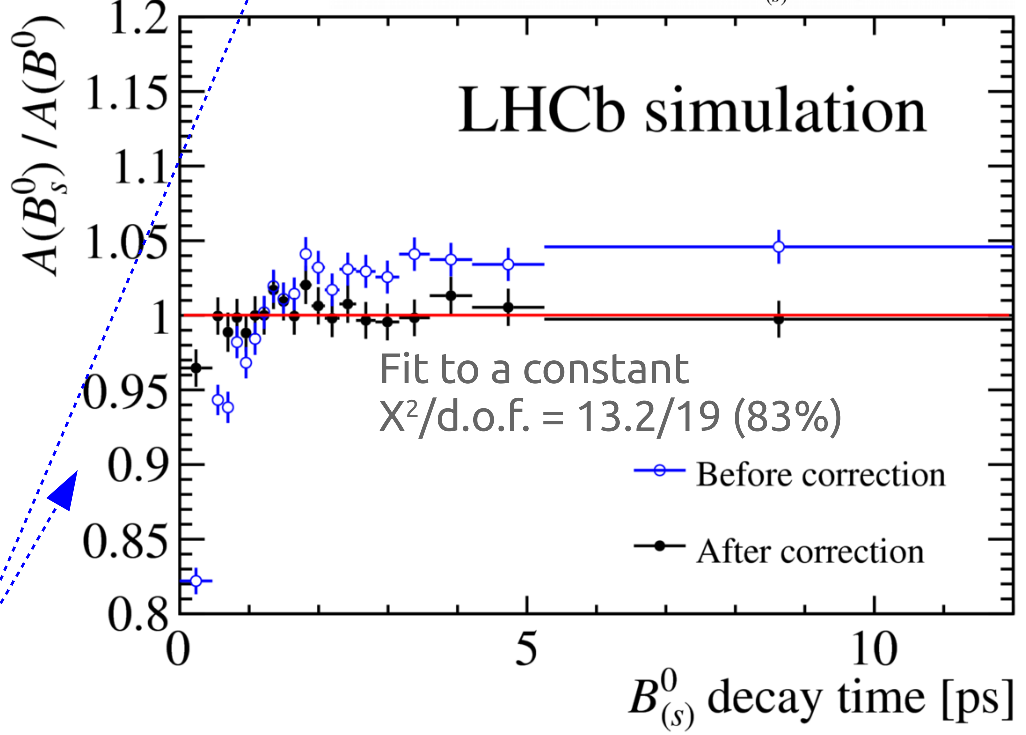
- B_s^0 fit fractions different from simulation
  - ➔ Correct simulation for the rest of the analysis

$$m_{\text{corr}} = \sqrt{m^2(D\mu) + p_\perp^2(D\mu)} + p_\perp(D\mu)$$

Measurement of Δ(D) and Δ(B)

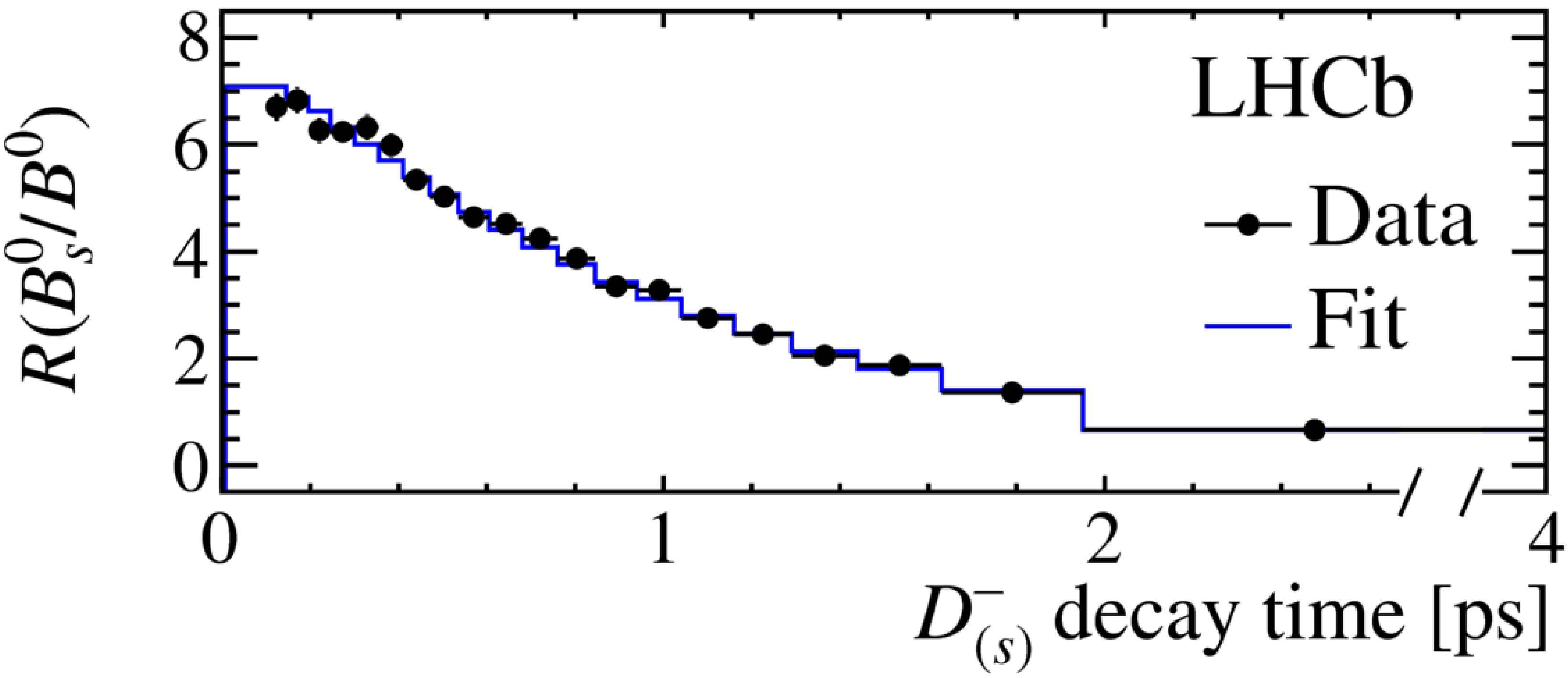
- Samples split in 20 decay-time bins
- Mass fit performed in each bin with simplified model to extract yields
- Consider experimental effects (from simulation):
  - Correction for missing momentum [Δ(B) only]
  - Decay-time resolution
  - Ratio of acceptances
- Fit the ratio for each decay-time bin





Ratios of time-dependent acceptances

$\Delta(D)$ and D_s^- lifetime results



$\Delta(D) = \Gamma(D_s^-) - \Gamma(D^-) = 1.0131 \pm 0.0117$ (stat.) $\pm\ 0.0065$ (syst.) ps^{-1}

$\tau(D_s^-) = 506.4 \pm 3.0$ (stat.) $\pm\ 1.7$ (syst.) $\pm\ 1.7$ (ref.) fs

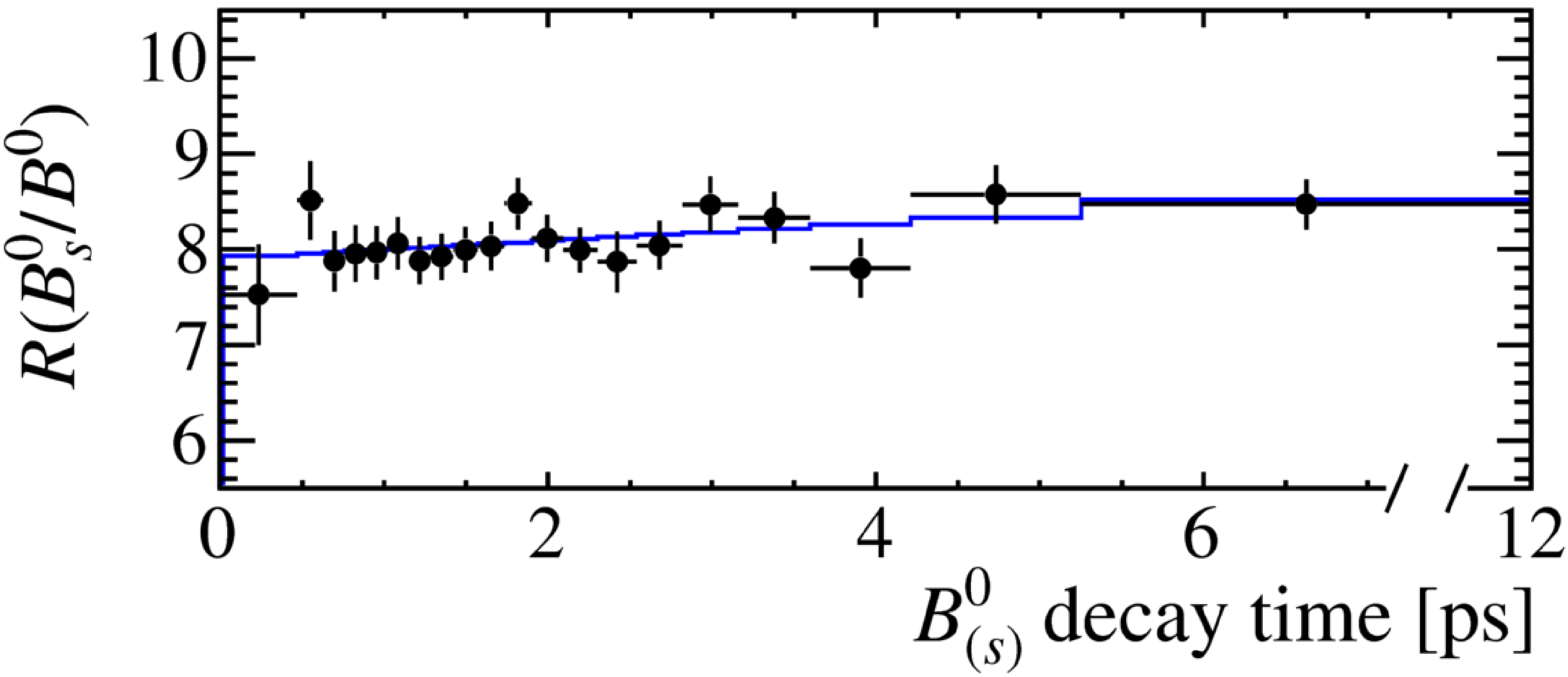
Phys. Rev. Lett. 95 (2005) 052003

Chin. Phys. C40 (2016) 100001

World's best (FOCUS): 507.4 ± 5.5 ± 5.1 fs
World's average: 500 ± 7 fs

Improved by factor 2!

$\Delta(\mathcal{B})$ and B_s^0 lifetime results



$\Delta(B) = 1/\tau_{FS}(B_s^0) - \Gamma(B^0) = -0.0115 \pm 0.0053$ (stat.) ± 0.0041 (syst.) ps^{-1}

$\tau_{FS}(B_s^0) = 1.547 \pm 0.013$ (stat.) ± 0.010 (syst.) ± 0.004 (ref.) ps

Phys. Rev. Lett. 114 (2015)

Phys. Rev. Lett. 113 (2014) 172001

D0: $1.479 \pm 0.010 \pm 0.021$ ps

LHCb: $1.535 \pm 0.015 \pm 0.014$ ps

15% more precise than LHCb world's best

Lepton Flavour Universality in B decays

- SM → Same coupling between gauge bosons and e, μ or τ
  - Branching ratios of semileptonic decays with e, μ or τ differ only for phase space and helicity-suppressed contributions
  - LFU violation would be a clear sign of BSM physics

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B}^0 \to D^{(*)+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{(*)+}\mu^-\bar{\nu}_\mu)}$$

- At LHCb, R(D*) already measured in the muonic mode **$\tau \to \mu\nu\nu$**, with **$B^0 \to D^* \mu\nu$** as norm. channel
- This measurement → hadronic mode **$\tau \to \pi\pi\pi\nu$**, with **$B^0 \to D^* \pi\pi\pi$** as norm. channel
  - Same final state, but needs some BRs as external inputs

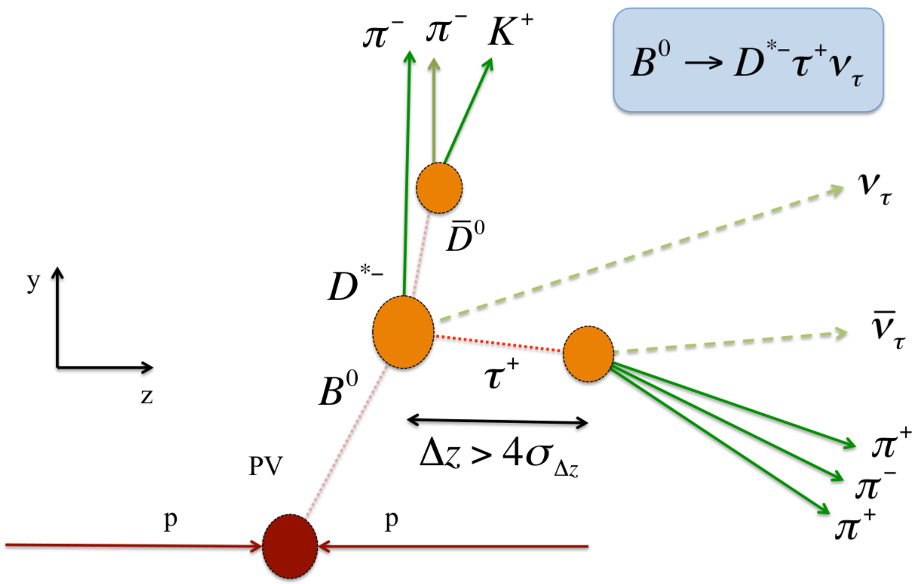
More on lepton flavour universality Friday morning (talks 401, 402 & 403)

Detached vertex method

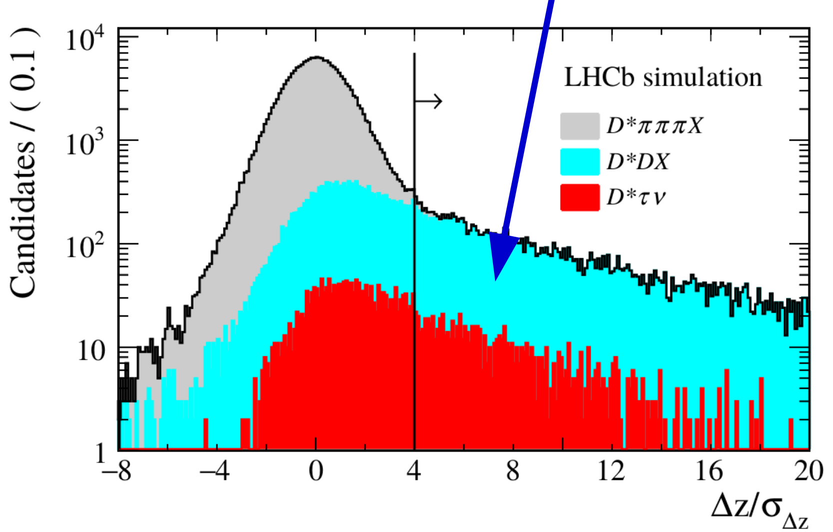
- Most abundant background consists of B decays into D*3πX

$$\frac{\mathcal{B}(B^0 \to D^* 3\pi + N)}{\mathcal{B}(B^0 \to D^* \tau \nu)_{SM}} \sim 100$$

- Good precision in tau vertex reconstruction allows to require the tau to be sufficiently downstream wrt to the B
  - Background reduced by 3 orders of magnitude
  - 35 % signal efficiency



Double charm background becomes the main offender



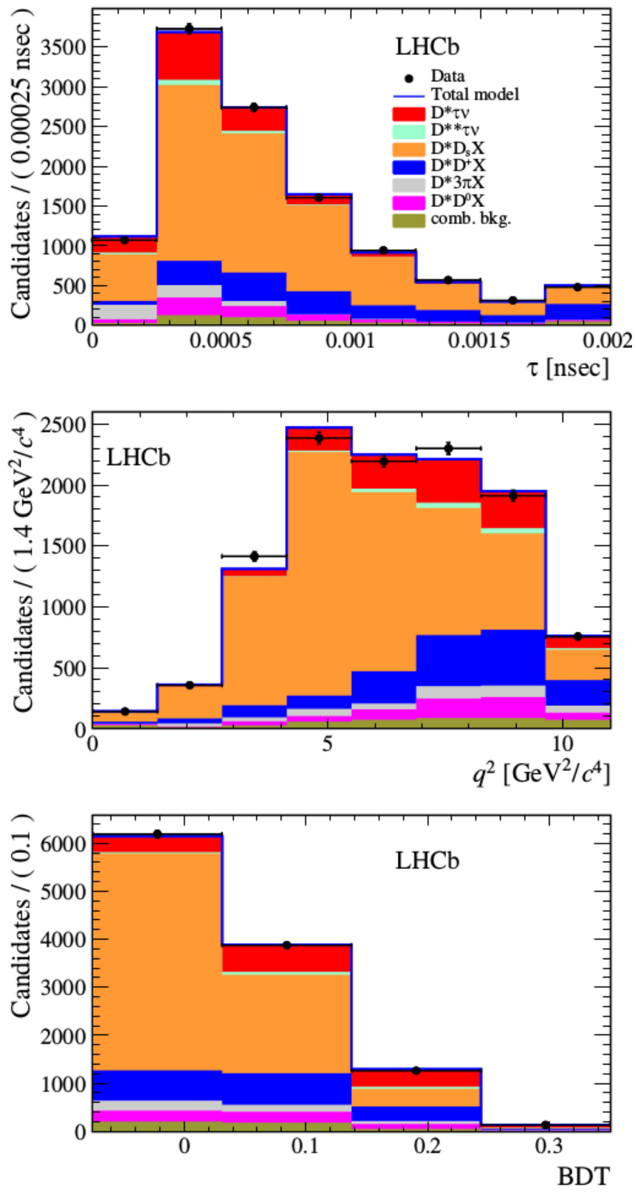
3-dimensional fit

- Extract the signal yield → extended maximum likelihood 3-dimensional fit using templates in:
  - **q^2** (squared momentum of the τ-ν system)
  - **3π decay time**
  - A **BDT output** (BDT with partial reconstruction variables and isolation criteria to discriminate double-charm decays from signal)
- 1300 ± 85 candidates give a BR of

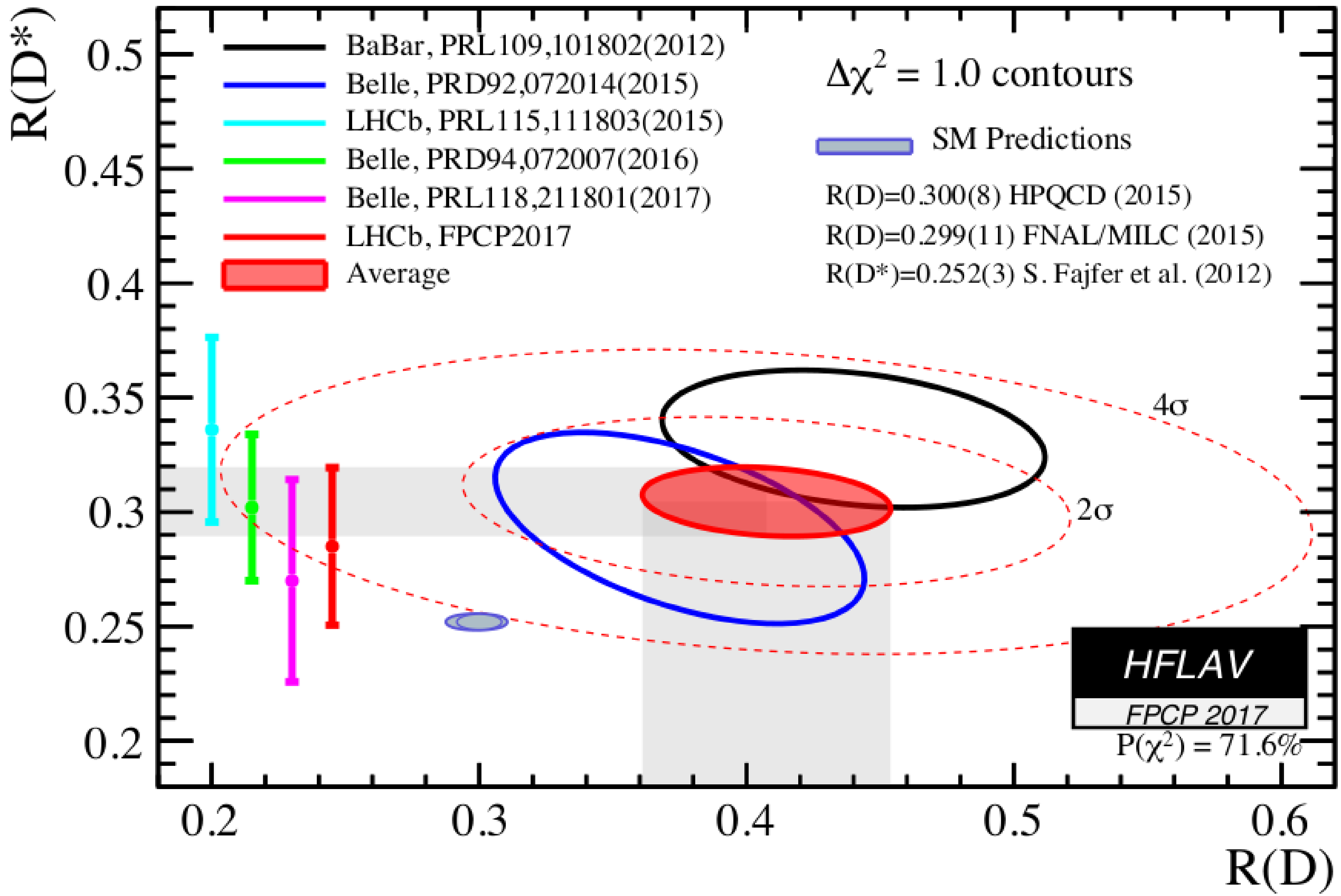
$$Br(B^0 \to D^{*-}\tau^+\nu_\tau) = (1.39 \pm 0.09_{stat} \pm 0.12_{syst} \pm 0.06_{ext})\%$$

PDG2017 = (1.67 ± 0.13)%

New naive average = (1.56 ± 0.10)%



$\mathcal{R}(D^*)$ summary



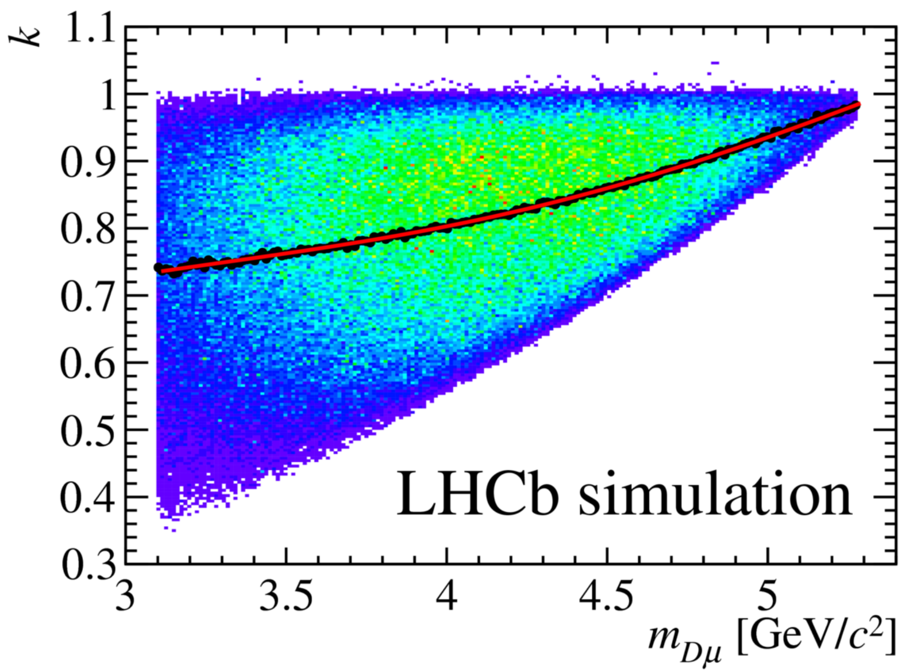
Summary

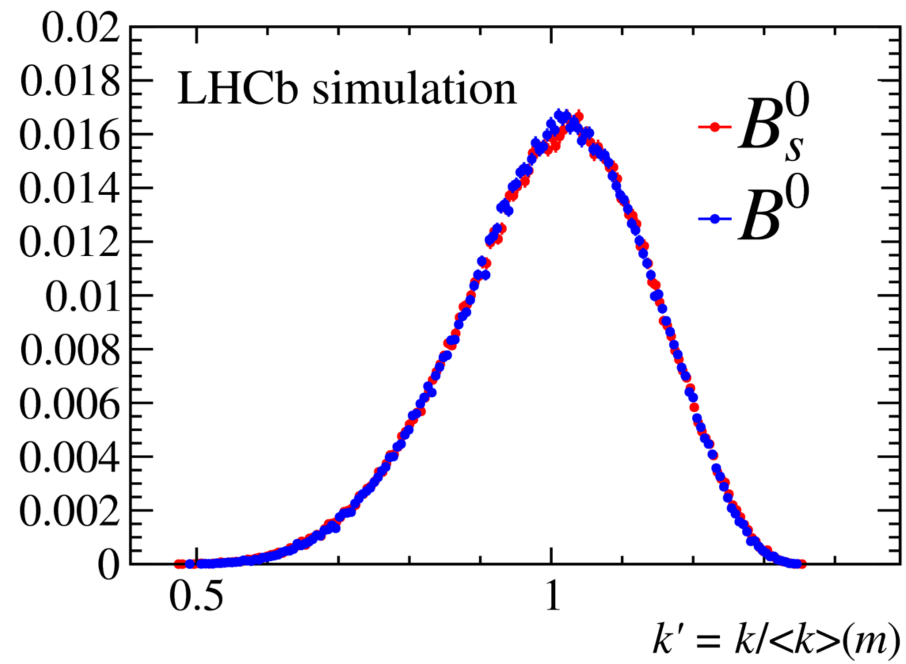
- Novel data-driven method for competitive B-lifetime measurement using semileptonic decays
  - Method potential can extend well beyond lifetime: BFs, form factors, etc.
- 15% improvement in B_s^0 and 2x in D_s^- lifetime
- Possible to reconstruct hadronic tau decays very precisely at LHCb
- New measurement of R(D*) with smallest statistical error
  - Compatible with both SM prediction and present WA

BACKUP

Momentum correction for Δ(B) determination

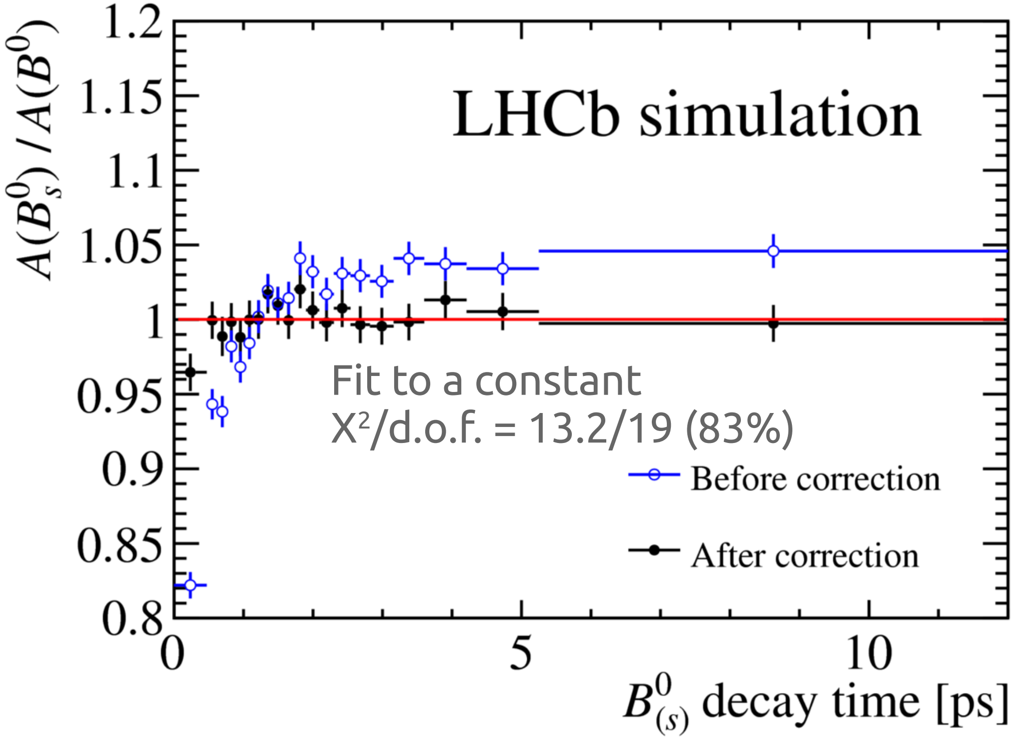
- Unlike Δ(D) measurement, decay time needs to be corrected for missing momentum, with *k-factor method*
  - Measure k = p(Dμ) / p_{true}(B) in simulation w.r.t. Dμ mass
  - Use average value of k for correcting decay time in data
  - Remaining correction enters in the time fit as resolution





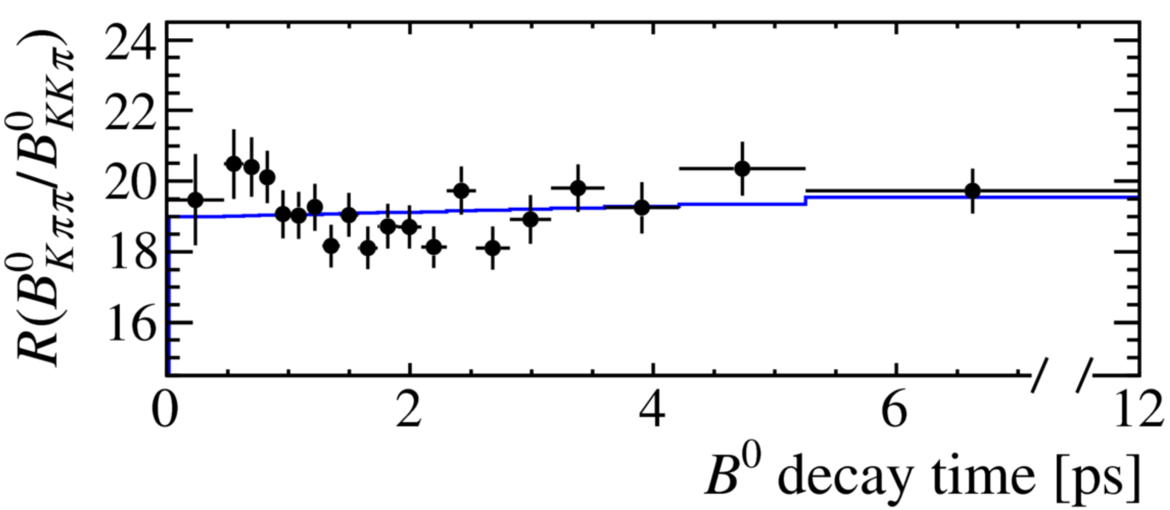
B decay-time acceptance reweighing

- Selection favours decays with close B and D vertices, i.e. small D decay time → different time-acceptances $\tau(D^-) \sim 2\,\tau(D_s^-)$
  - Correct by applying an event-by-event weight w on one sample, $w = \exp[\Delta(D)\, t_D]$
  - Ratio compatible with uniform distribution → will neglect in the fit



Null-tests

- By using a control sample of $B^0 \rightarrow D^{(*)-} (\rightarrow K^+\pi^-\pi^- X)\ \mu^+ \nu$ as signal and the same reference channel, we probe $\Delta'(B) = \Gamma(B^0) - \Gamma(B^0) = 0$ and $\Delta'(D) = 0$
- Results are compatible with zero and thus validate the method
  - $\Delta'(B) = (-4.1 \pm 5.4) \times 10^{-3}\ ps^{-1}$
  - $\Delta'(D) = (-19 \pm 10) \times 10^{-3}\ ps^{-1}$

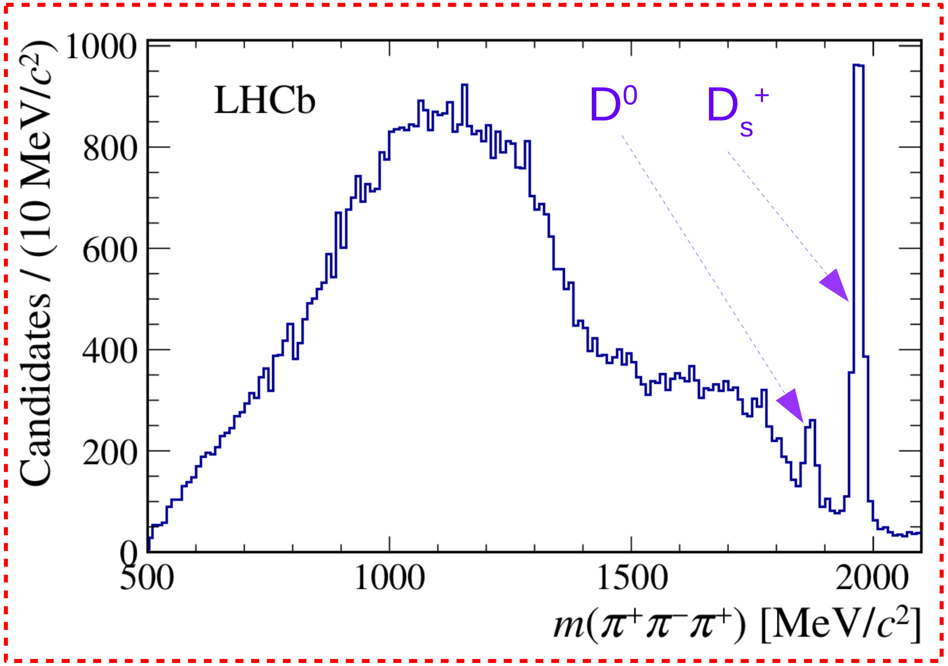


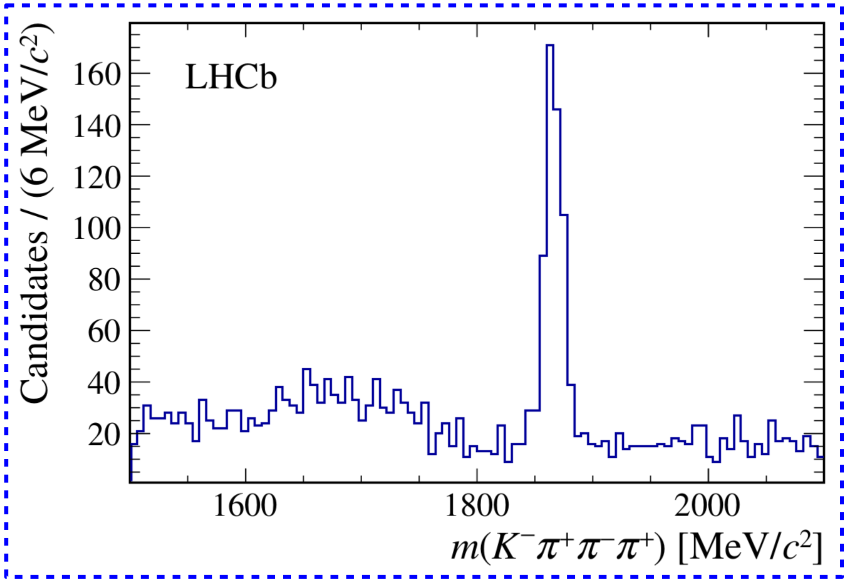
Systematic uncertainties

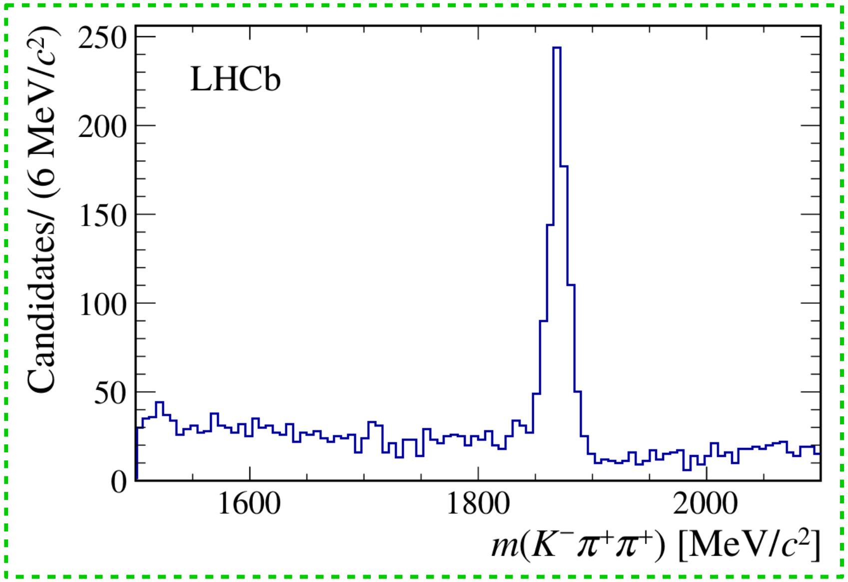
- Systematic uncertainties stay under control and below the statistical uncertainty

	$\sigma[\Delta_\Gamma(D)]$ [ps^{-1}]	$\sigma[\Delta_\Gamma(B)]$ [ps^{-1}]
Fit bias	0.0004	0.0009
Decay model of $B_s^0 \to D_s^{*-}\mu^+\nu$	0.0005	0.0025
Sample composition	0.0007	0.0005
$f_s/f_d(p_T)$	0.0018	0.0028
Decay-time acceptance	0.0049	0.0004
Decay-time resolution	0.0039	0.0004
Feed-down from B_c^+ decays	–	0.0010
Total systematic	0.0065	0.0041
Statistical	0.0117	0.0053

Control channels of double-charm bkgs







- $\pi\pi\pi$ invariant mass, at an early stage of the selection
- $D^0 \rightarrow K\pi\pi\pi$ peak: anti-isolation cut
- $D^+ \rightarrow K\pi\pi$ peak : anti-PID cut

Channels used to check data and MC agreement and correct MC if needed