Lifetime Measurements and Time Dependent CP Violation of $B \to h^+ h'^-$
IoP - Joint annual HEPP and APP conference

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Overview

Introduction

- Lifetime measurements of six different $B \to h^+ h'^-$ decay modes, $B_s^0 \to K^+ K^-$, $B_d^0 \to \pi^+ \pi^-$, $B_d^0 \to K^- \pi^+$, $B_s^0 \to \pi^+ K^-$, $\Lambda_b^0 \to p^+ K^-$ and $\Lambda_b^0 \to p^+ \pi^-$.
- Measurements of time dependent CP violation of the $B_s^0 \to K^+ K^-$ and the $B_d^0 \to \pi^+ \pi^-$ decay modes.
- $B \to h^+ h'^-$ decays are dominated by tree and penguin processes.
- Charge conjugation implied throughout this talk.
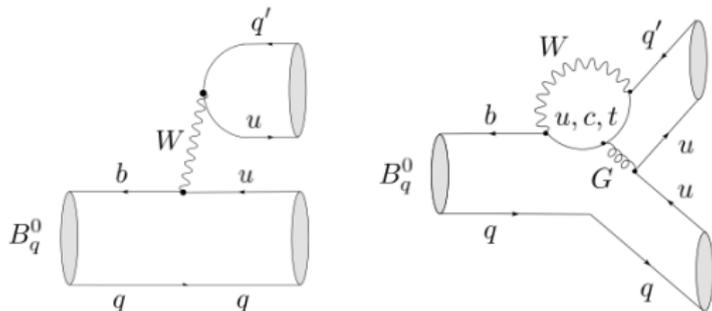
- Tree and penguin processes are of comparable size. New Physics can compete with Standard Model processes.

Motivation

- $B \to h^+ h'^-$ modes provide opportunity to perform high precision lifetime measurements.
- $B_s^0 \to K^+ K^-$ effective lifetime can be used to constrain the B_s^0 mixing phase ϕ_s.

$$\tau_{K^+K^-} = \frac{\int_0^\infty t \left\langle \Gamma(B_s(t) \to K^+K^-) \right\rangle dt}{\int_0^\infty \left\langle \Gamma(B_s(t) \to K^+K^-) \right\rangle dt}.$$

- Can be written in terms of $y_s = \Delta\Gamma_s/2\Gamma_s$ and the decay rate asymmetry $A_{\Delta\Gamma}$;

$$\frac{\tau_{K^+K^-}}{\tau_{B_s}} = \frac{1}{1-y_s^2} \left[\frac{1+2A_{\Delta\Gamma}y_s+y_s^2}{1+A_{\Delta\Gamma}y_s} \right] = 1 + A_{\Delta\Gamma}y_s + (2 - A_{\Delta\Gamma}^2)y_s^2 + \mathcal{O}(y_s^3).$$
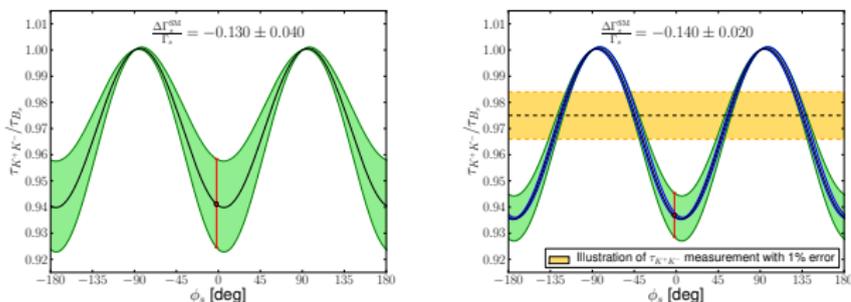
Eur. Phys. J C71 (2011) 1531 (arXiv:0705.1121):

Left plot shows dependence of $\tau_{K^+K^-}/\tau_{B_s}$ on the B_s mixing phase. Right plot shows impact of measurement with 1% uncertainty.

Motivation

- Direct and Mixing CP asymmetries can be measured by time dependent analysis of the decay channels $B_s^0 \to K^+ K^-$ and $B_d^0 \to \pi^+ \pi^-$.
- $B_s^0 \to K^+ K^-$ and $B_d^0 \to \pi^+ \pi^-$ have approximate U-spin flavour symmetry through interchange of d and s quarks. See Slide 2.
- Measurements of experimental observables of these decays can be used to extract the unitary triangle angle γ.
- Time dependent CP asymmetry for neutral B mesons decaying to a CP eigenstate f can be written as

$$A_{CP}(t) = \frac{\Gamma(B_q^0(t) \to f) - \Gamma(\overline{B_q^0}(t) \to f)}{\Gamma(B_q^0(t) \to f) + \Gamma(\overline{B_q^0})(t) \to f)}$$

$$A_{CP}(t) \approx -C_f \cos(\Delta m t) + S_f \sin(\Delta m t),$$

- where C_f is the direct CP violation, S_f is the mixing induced CP violation.

Experimental Status

- Previous analyses use 1/3 of available data sample.
- LHCb results with 1 fb^{-1} of data:
- 2011 lifetime analysis, Phys.Lett.B736 (2014) 446-454 (arXiv:1406.7204) results:
  $\tau_{B_s^0 \to K^+ K^-} = 1.407 \pm 0.016 \pm 0.007$ ps,
  $\tau_{B_d^0 \to K^- \pi^+} = 1.524 \pm 0.011 \pm 0.004$ ps,
 $\tau_{B_s^0 \to \pi^+ K^-} = 1.60 \pm 0.06 \pm 0.01$ ps.
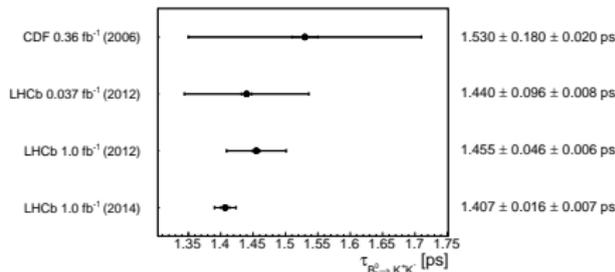
- 2011 time dependent CP violation, JHEP 10 (2013) 183 (arXiv:1308.1428v2):
  $C_{KK} = 0.14 \pm 0.11 \pm 0.03$, $S_{KK} = 0.30 \pm 0.12 \pm 0.04$.
 $C_{\pi\pi} = -0.38 \pm 0.15 \pm 0.02$, $S_{\pi\pi} = -0.71 \pm 0.13 \pm 0.02$,
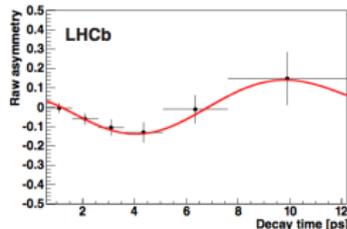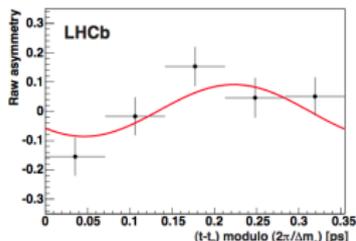
(left) $B_s^0 \to K^+ K^-$, (right) $B_d^0 \to \pi^+ \pi^-$.

Analysis

- Using the full available data sample; 3 fb^{-1} of run1 (2011 and 2012) data.
- Analysis strategy:

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            ┌───────────┐
            │ Selection │
            └───────────┘
                  │
                  ▼
      ┌───────────────────────┐
      │ Acceptance Correction │
      └───────────────────────┘
                  │
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            ┌──────────┐
            │ Mass Fit │
            └──────────┘
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  │ Lifetime Fit │  │ Asymmetry Fit  │
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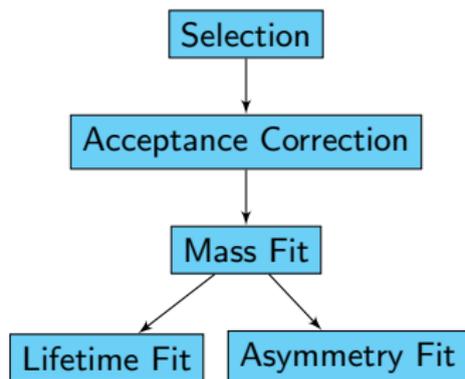
- Using same event selection for lifetime and CPV analyses.
- Events selected using multivariate analysis (MVA) methods, which removes combinatorial background, and then particle identification (PID) selections, which separate final states i.e. KK, $\pi\pi$, πK, pK and $p\pi$.
- Simultaneous fits for all final states.

Acceptance Correction

- Data driven method that determines the acceptance function on an event by event basis.
- Acceptance is either zero (rejected) or one (accepted). Shows intervals of decay time where an event is accepted based on applied cuts.
- Uses the fact that mother decay time is independent of daughter kinematics.
- Can move the primary vertex along mother momentum whilst daughter kinematics remain the same.
- The decision can be evaluated varying decay time.
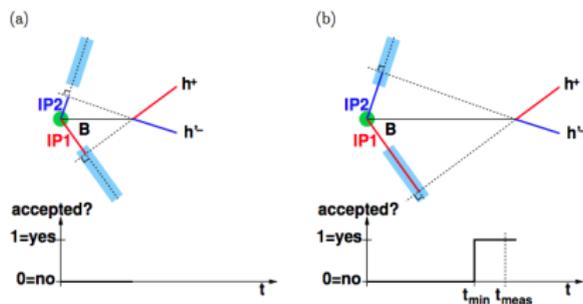
- Example: IP selection. The blue area shows where the track is accepted. In (a) IP2 is too small and in (b) it lies within the accepted region.
- CPU intensive.

MVA Selection

- Preselections applied to select $B \to h^+ h'^-$ candidates.
- The same BDT is used to remove combinatorial backgrounds for all final states.
- Trained on signal of MC12 $B_s^0 \to K^+ K^-$ and background of upper side band data under KK hypothesis, $5500 < m_B < 5800$ MeV/c^2.
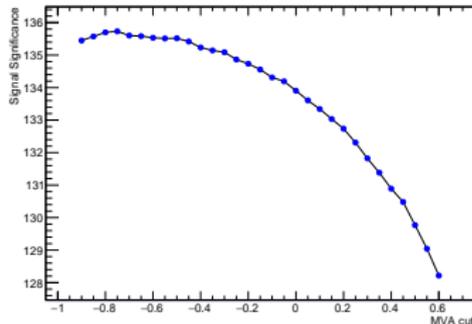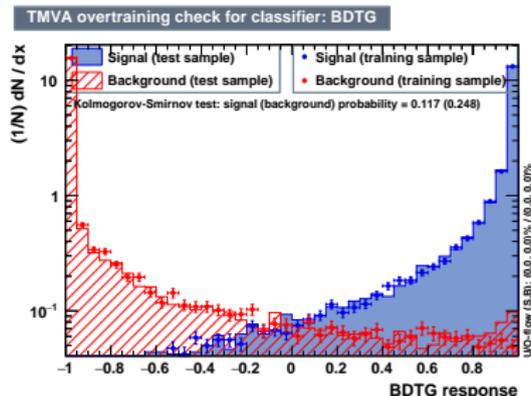

- After looking at $B_s^0 \to K^+ K^-$ signal significance ($S/\sqrt{S+B}$) decided on cut at > -0.8.
- Tight selection chosen to minimise potential systematics.

Particle Identification Selection

- $B \to h^+ h'^-$ misidentified backgrounds are a dominant source of systematics.
- Mis-id rates used to measure cross feeds between different modes.
- PID selections that gave a tolerable level of mis-ID rates were chosen.
- Example:
  (left) $B_s^0 \to K^+ K^-$ selection efficiencies vs PID selection on daughter tracks for Kaon-Pion and Kaon-Proton separation.
  (right) Misidentification rates vs PID selection on daughter tracks of $B^0 \to K^+ \pi^-$ in $B_s^0 \to K^+ K^-$.
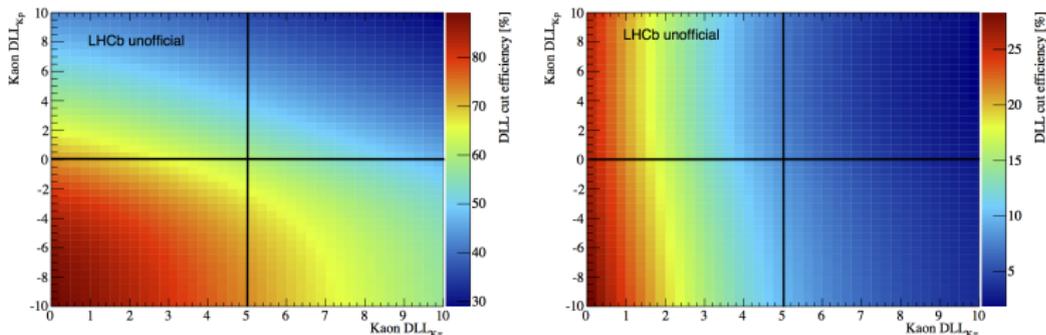

- Chose selection at (5,0), shown on figures.

Mass Distributions: *KK* 2011 and 2012 data

- Signal shape is fitted with a double crystal ball function, tail parameters extracted from MC.

- $B \to h^+ h'^-$ backgrounds misidentified from their PID assignments are fitted with templates. Shapes from MC.

- Single partially reconstructed background made up of 3-body decays that could be mis-reconstructed as signal with one lost final state particle, possibly with a single misidentification. Parameters are obtained from MC.

- The fit procedures for the $K\pi$, $\pi\pi$, pK and $p\pi$ mass spectrum are the same as the KK.
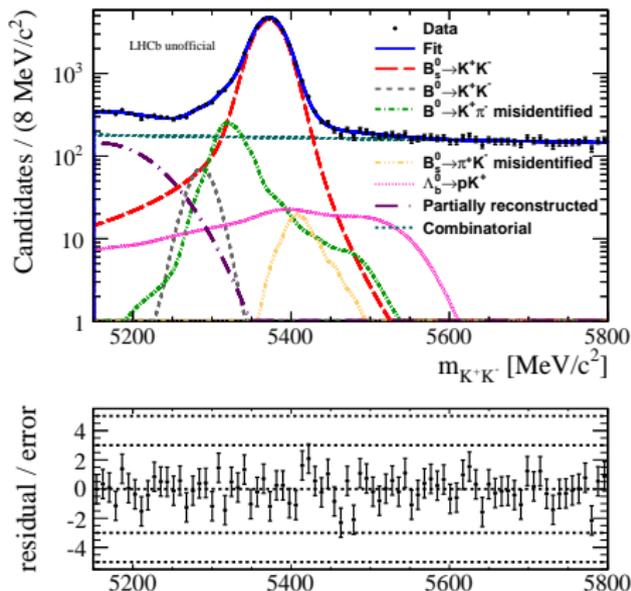
- 29514 ± 269 $B_s^0 \to K^+ K^-$ candidates (64% purity over mass range).

Mass Distributions: $K\pi$, $p\pi$, pK, 2011 and 2012 data
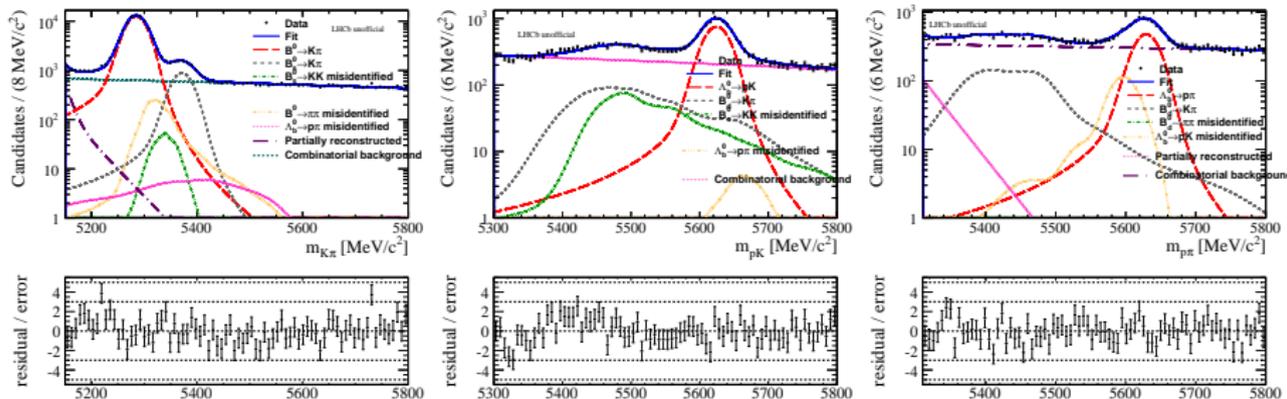
- 81908 $\pm$ 574 $B_d^0 \to K^+\pi^-$ candidates (60% purity),
- 5836 $\pm$ 417 $B_s^0 \to \pi^+K^-$ candidates (4.2% purity),
- 6339 $\pm$ 203 $\Lambda_b^0 \to p^+K^-$ candidates (22% purity),
- 4375 $\pm$ 222 $\Lambda_b^0 \to p^+\pi^-$ candidates (13% purity),
- $\pi\pi$ fit still in progress.

Lifetime Fitter

- Results on sample of $B_s^0 \to K^+ K^-$ simulated data.
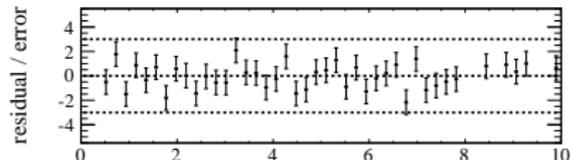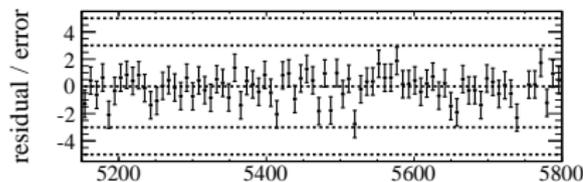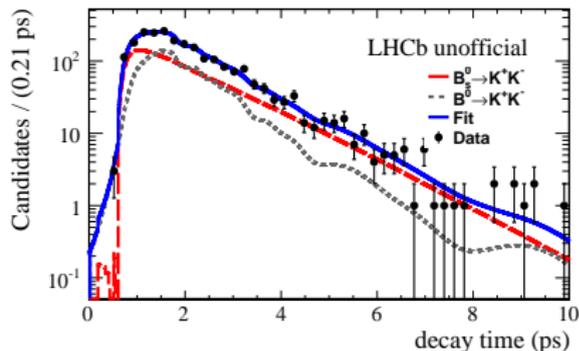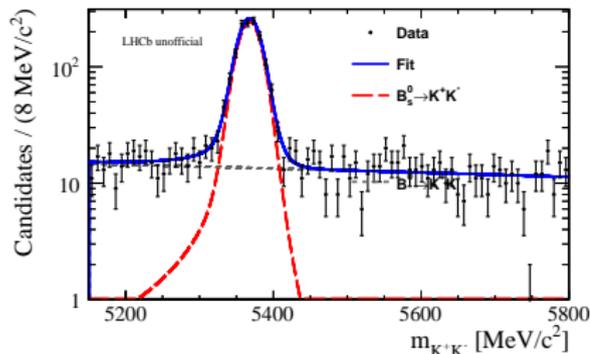
- Acceptance corrected for on this simulated data.
- Lifetime correctly recovered.

Time Dependent Asymmetry Fitter

- Time dependent asymmetry fit on simplified simulations of $B_d^0 \to \pi^+ \pi^-$.
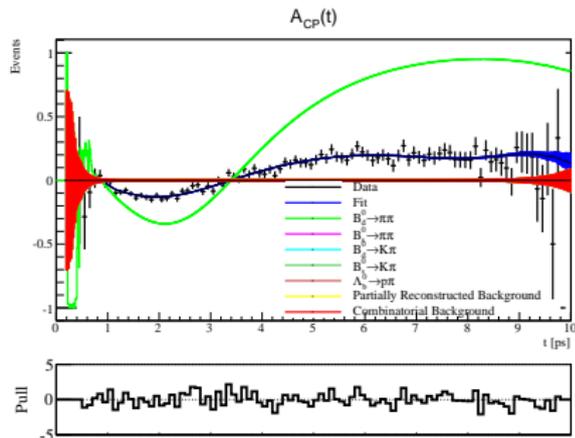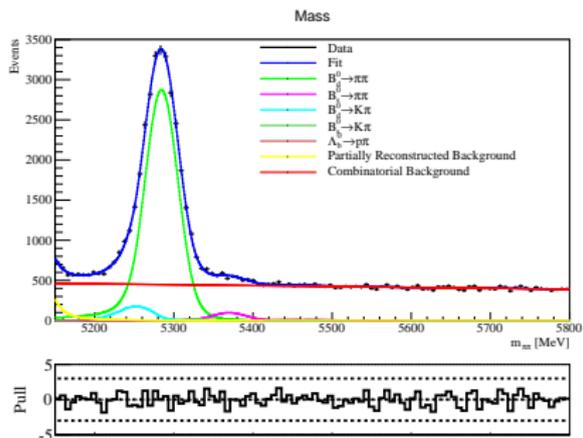
- Recovered correct values from simplified simulations.

Summary

- Performing lifetime measurements of six decay modes; $B_s^0 \to K^+K^-$, $B_d^0 \to \pi^+\pi^-$, $B_d^0 \to K^-\pi^+$, $B_s^0 \to \pi^+K^-$, $\Lambda_b^0 \to p^+K^-$ and $\Lambda_b^0 \to p^+\pi^-$.

- Time dependent CP violation in $B_s^0 \to K^+K^-$ and the $B_d^0 \to \pi^+\pi^-$ being measured.

- Using full run 1 statistics.

- The analysis is at a mature stage.

- Event selection is finalised for the six $B \to h^+h'^-$ decay modes.

- Aiming for increase on precision from run 1 with improved method and higher statistics.