Charmless hadronic two-body B decays at LHCb

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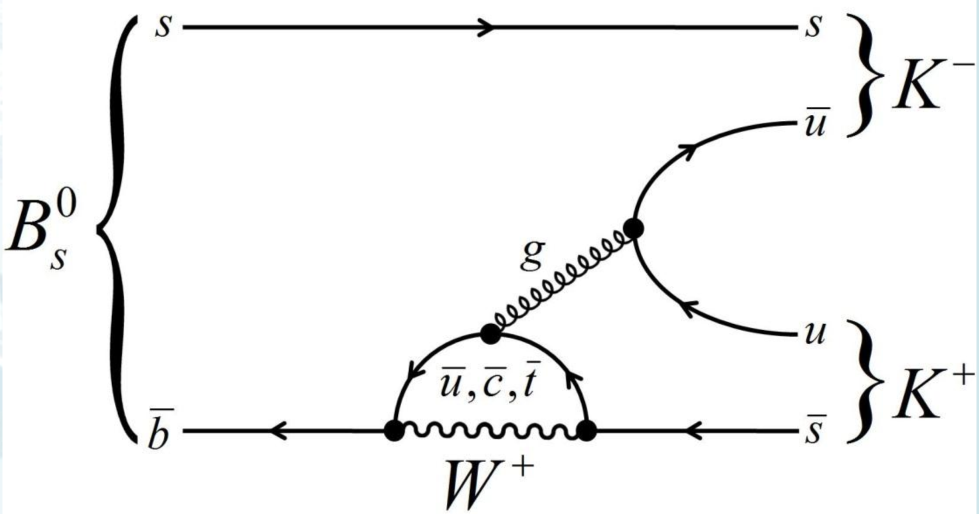
On behalf of the **LHCb** collaboration

Motivation

Charmless hadronic two-body B meson decays ($\boldsymbol{H_b \to h^+ h'^-}$) present opportunities to:

- Test the Standard Model
- Explore new physics
- Study new sources of CPV



$H_b = \{B^0, B_s^0, \Lambda_b^0\}$
$h^\pm = \{\pi^\pm, K^\pm, p^\pm\}$

Both **strong** and **electroweak** loop diagrams contribute – sensitive to new physics.

Studies presented:

- $\boldsymbol{B_s^0 \to K^+ K^-}$ **lifetime** [LHCb-CONF-2011-018]
- **Direct Charge-Parity violation in $\boldsymbol{B^0 \to K^+ \pi^-}$ and $\boldsymbol{B_s^0 \to \pi^+ K^-}$** [LHCb-CONF-2011-011]

Disentangling the decays

The $H_b \rightarrow h^+ h'^-$ spectrum contains many decays – strongly overlapped in mass and with near identical kinematics.

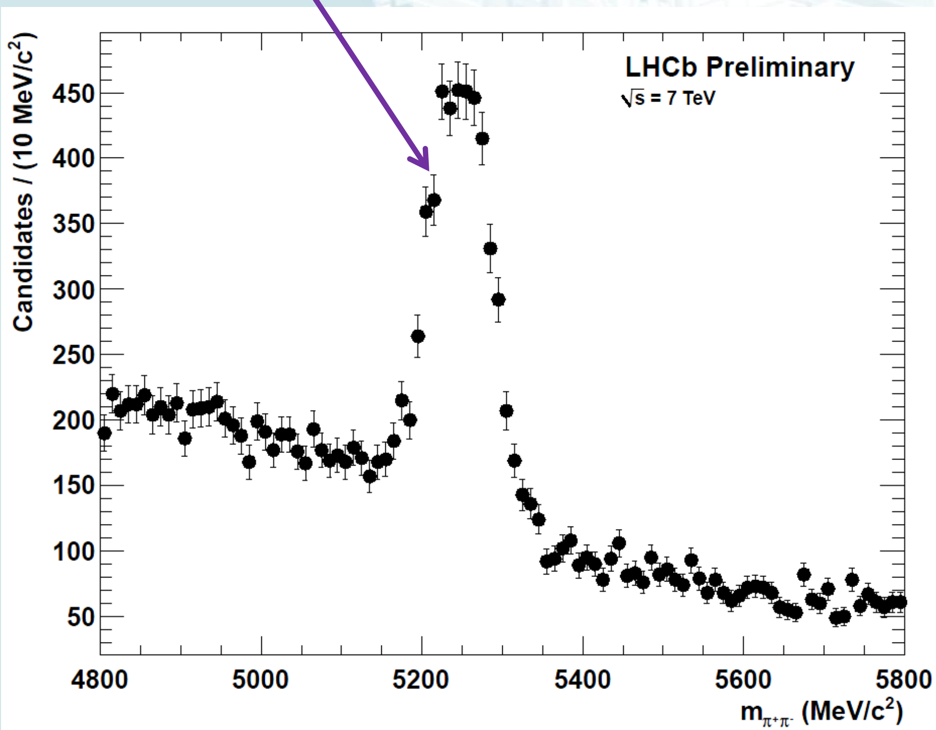
Need strong particle identification (PID) to disentangle them – provided by LHCb's Ring Imaging Cherenkov (RICH) detectors.

RICH detectors allow distinction of protons, pions and kaons.

We impose PID requirements separating out KK, Kπ and ππ final states.

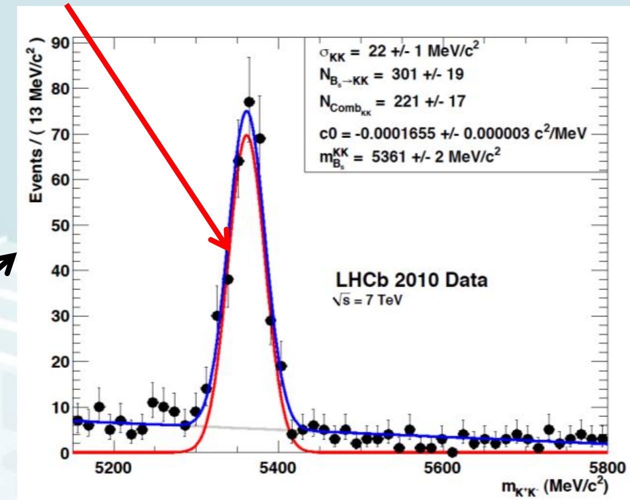
Disentangling the decays

All $H_b \to h^+h'^-$ channels overlapped

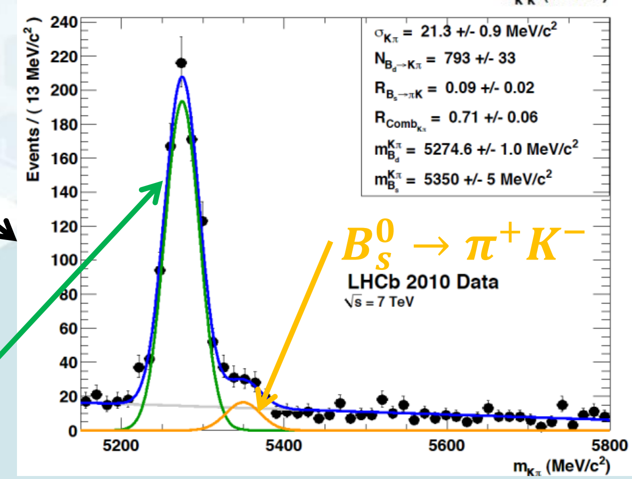


KK

$B_s^0 \to K^+K^-$



$K\pi$



$B_s^0 \to \pi^+K^-$

$B_d^0 \to K^+\pi^-$

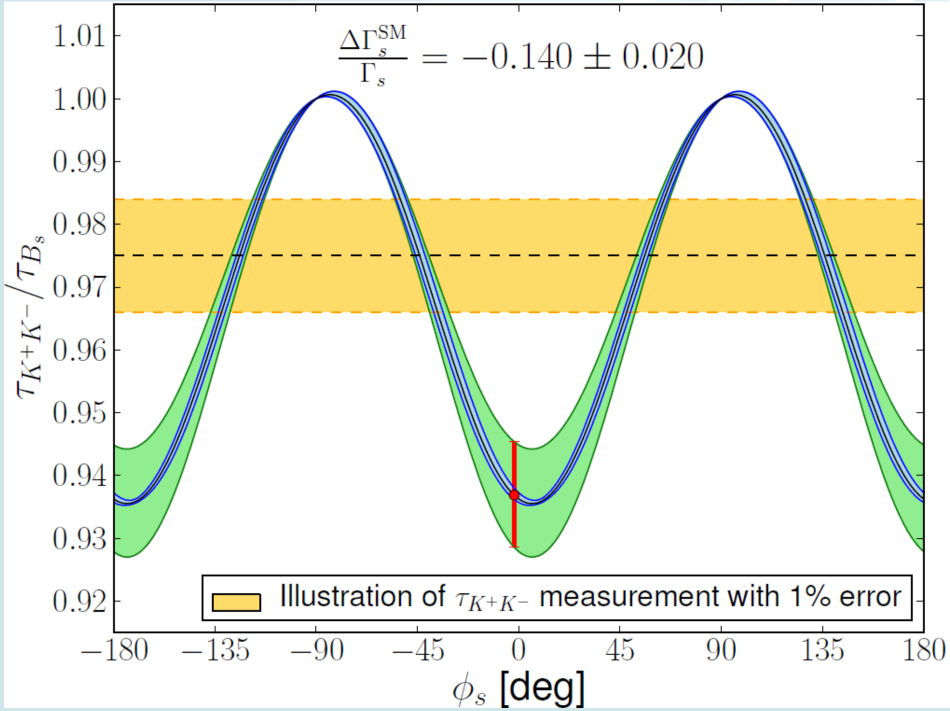
Measuring the $B_s^0 \to K^+K^-$ lifetime

Motivation

$B_s^0 \to K^+K^-$ dominated by penguin diagrams – sensitive to particles from NP in the loops

Decay rate dominated by **light** mass eigenstate: $\Gamma[f,t] = Ae^{-\Gamma_L t} + Be^{-\Gamma_H t}$

Fitting a single exponential to this gives an effective lifetime: $\tau_{K^+K^-}^{-1} = \frac{A/\Gamma_L + B/\Gamma_H}{A/\Gamma_L^2 + B/\Gamma_H^2}$



Effective lifetime related to the mixing phase ϕ_s

In the SM $\phi_s = (2.1 \pm 0.1)^\circ$

Giving:

$$\tau_{K^+K^-}(SM) = (1.390 \pm 0.032)\text{ps}$$

R. Fleischer, R. Knegjens, [arXiv:hep-ph/1011.1096].

Correcting for proper decay time acceptance

Trigger and selection accept displaced decay vertices

-> sculpts the measured proper decay time distributions

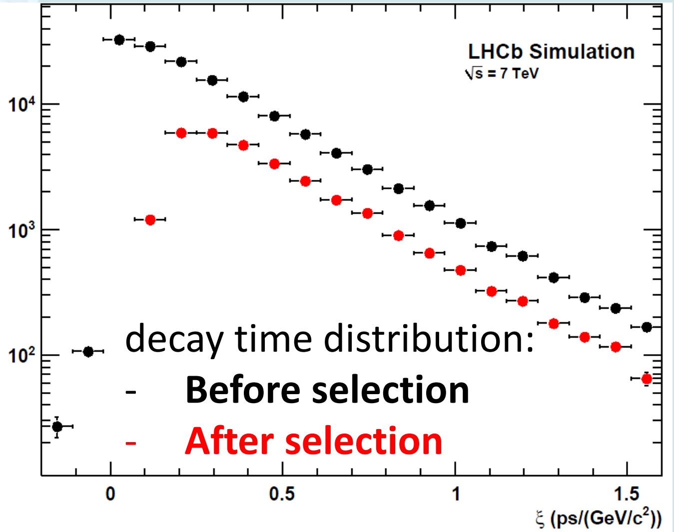
This“acceptance” must be corrected for.

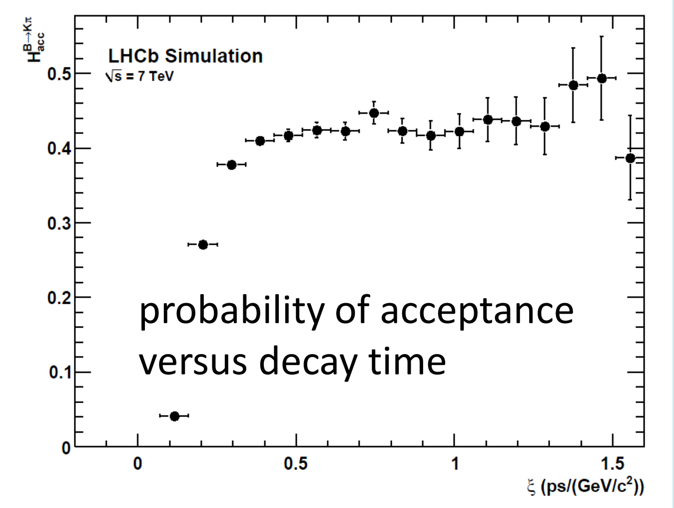
Two methods:

Relative cancels acceptance by taking ratio with kinematically similar $B_d^0 \to K^+\pi^-$

Absolute uses data-driven approach to calculate acceptance, then accounted for in the fit

Both methods **completely data-driven**, no MC input





Relative Lifetime Measurement

The measured proper time distribution:

$$F_{meas}(t) = [F_{true}(t) * G_{res}(t)] \times H_{acc}(t)$$

$B_s^0 \to K^+K^-$, $B_s^0 \to \pi^+K^-$ $B_d^0 \to K^+\pi^-$, $B_d^0 \to \pi^+\pi^-$ all have very similar kinematics and the acceptances are the same to a high precision.

$$R(t) = \frac{[F_{true}(t,\tau_1) * G_{res}(t,\sigma)] \times \cancel{H_{acc}(t)}}{[F_{true}(t,\tau_2) * G_{res}(t,\sigma)] \times \cancel{H_{acc}(t)}}$$

Which to a good approximation is:

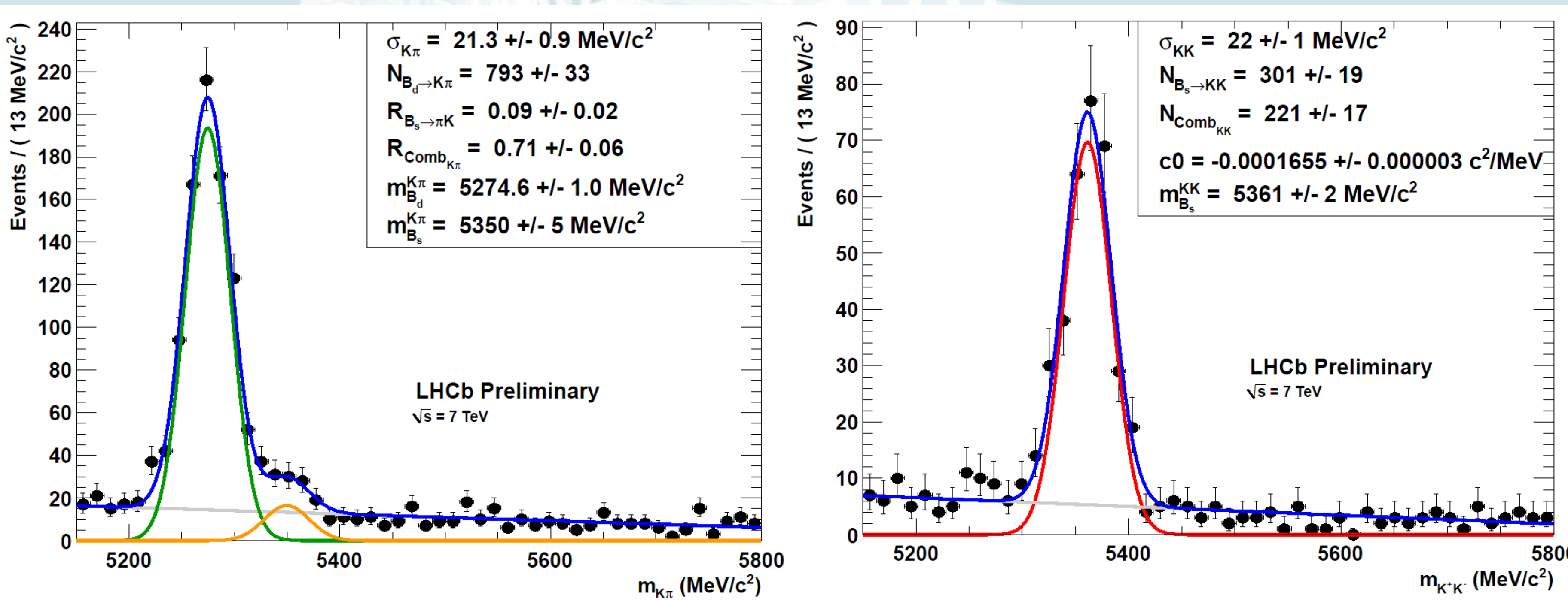
$$R(t) = Ae^{-t\left(\frac{1}{\tau_1}-\frac{1}{\tau_2}\right)}$$

$B_d^0 \to K^+\pi^-$ is used as the control mode (most abundant $H_b \to h^+h'^-$ channel) and the PDG value of its lifetime used as input to the fit.

Relative Lifetime Measurement

Outline of the method:

1) Dataset split into bins in proper decay time
2) Fits to the invariant mass spectra of the KK and Kπ final states are performed in each bin

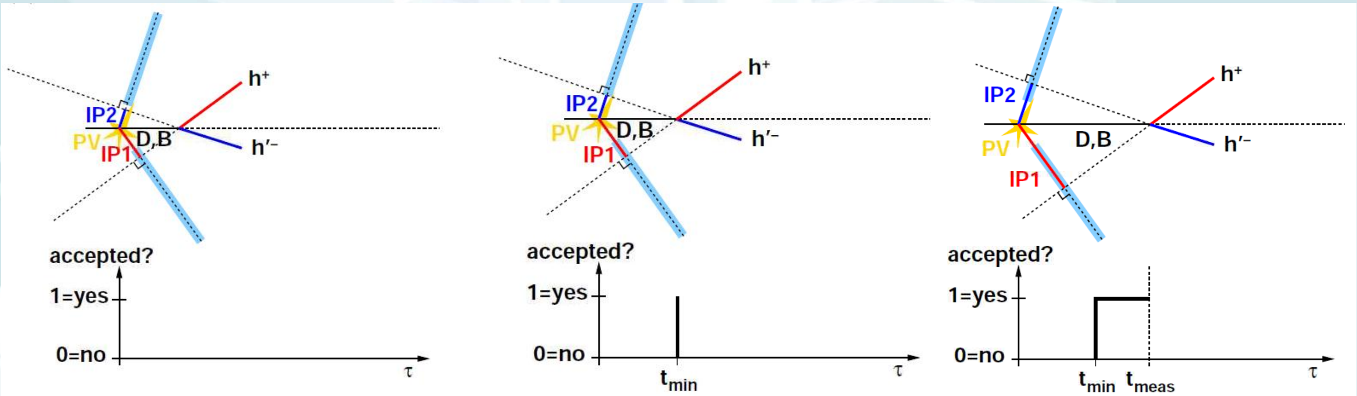


3) Yield of $B_d^0 \to K^+\pi^-$ extracted from the fit in each proper decay time bin
4) Ratio of yields of $B_s^0 \to K^+K^-$ and $B_d^0 \to K^+\pi^-$ fitted across all bins and the effective $B_s^0 \to K^+K^-$ lifetime extracted

Absolute Lifetime Measurement

Complementary approach -> determines proper decay time acceptance in a completely data-driven way:

1) Acceptance determined on a candidate-by-candidate basis
2) p-p interaction point moved along the momentum vector of the B_s



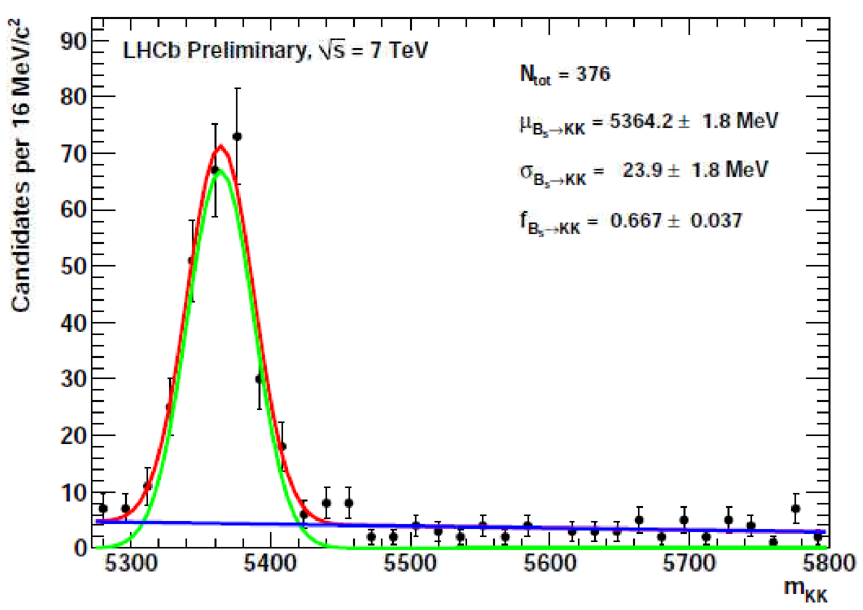
3) Selection decision evaluated for a range of hypothetical decay times in order to calculate the point where a candidate is rejected – called the "turning point"
4) Turning points, one per candidate, fed into fit to make an unbiased lifetime measurement

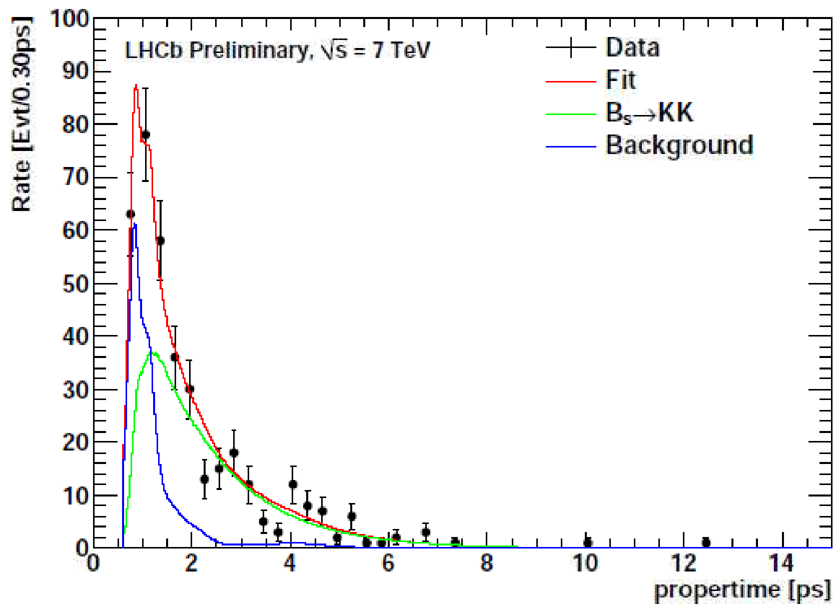
Absolute Lifetime Measurement

Mass fit determines probability candidate is signal/background

Proper decay time fit -> extract lifetime. Requires a background proper time PDF.

- No *a priori* model for background proper decay time distribution
- A sum of Gaussian kernels, one per candidate, is used to extract a non-parametric background decay time PDF from data.
- Provides a continuous, non-binned function to the fitter, applicable over a large range of statistics.





Systematic uncertainties and results

Both methods have been extensively validated and the following sources of systematic uncertainty evaluated:

- **Contamination from other $H_b \to h^+ h'^-$ channels**
- Background model
- **Acceptance correction**
- **Primary vertex association in multiple PV events**
- Proper decay time scale at LHCb
- Reconstruction acceptance

Relative and absolute results consistent within 0.5σ with same sensitivities.
Preliminary result is:

$$\boxed{\tau_{K^+K^-} = \left(1.440 \pm 0.096(\text{stat}) \pm 0.010(\text{syst})\right)\text{ps}}$$

CDF result $\tau_{K^+K^-} = \left(1.53 \pm 0.18(\text{stat}) \pm 0.02(\text{syst})\right)\text{ps}$

[*CDF Collaboration, "Measurement of the $B_s^0 \to K^+K^-$ lifetime and extraction of $\Delta\Gamma_{CP}$ and Γ_{CP}", CDF public note (unnumbered)*]

SM Prediction $\tau_{K^+K^-}(SM) = (1.390 \pm 0.032)\text{ps}$

R. Fleischer, R. Knegjens, [arXiv:hep-ph/1011.1096].

Direct Charge-Parity violation in $B^0 \to K^+\pi^-$ and $B_s^0 \to \pi^+K^-$

Direct CPV in $B^0 \to K^+\pi^-$ and $B_s^0 \to \pi^+K^-$

Current Status

$B^0 \to K^+\pi^-$

	$A_{CP}(B^0 \to K^+\pi^-)$
BaBar	$-0.107 \pm 0.016^{+0.006}_{-0.004}$
Belle	$-0.094 \pm 0.018 \pm 0.008$
CLEO	$-0.04 \pm 0.16 \pm 0.02$
CDF	$-0.086 \pm 0.023 \pm 0.009$
Average	$-0.098^{+0.012}_{-0.011}$

BaBar, arXiv:0807.4226 [hep-ex]
Belle, PRL 98 (2007) 211801
CLEO, PRL 85 (2000) 525
CDF, arXiv:1103.5762 [hep-ex]

$B_s^0 \to \pi^+K^-$

CDF with 1 fb^{-1}

$$A_{CP}(B_s^0 \to \pi^+K^-) = 0.39 \pm 0.15 \pm 0.08$$

$$A_{CP} = \boxed{A_{CP}^{RAW}} - \boxed{A_D(K\pi)} - \boxed{\kappa A_P}$$

Raw asymmetry measured in data

Instrumental $K^+\pi^-/K^-\pi^+$ asymmetry

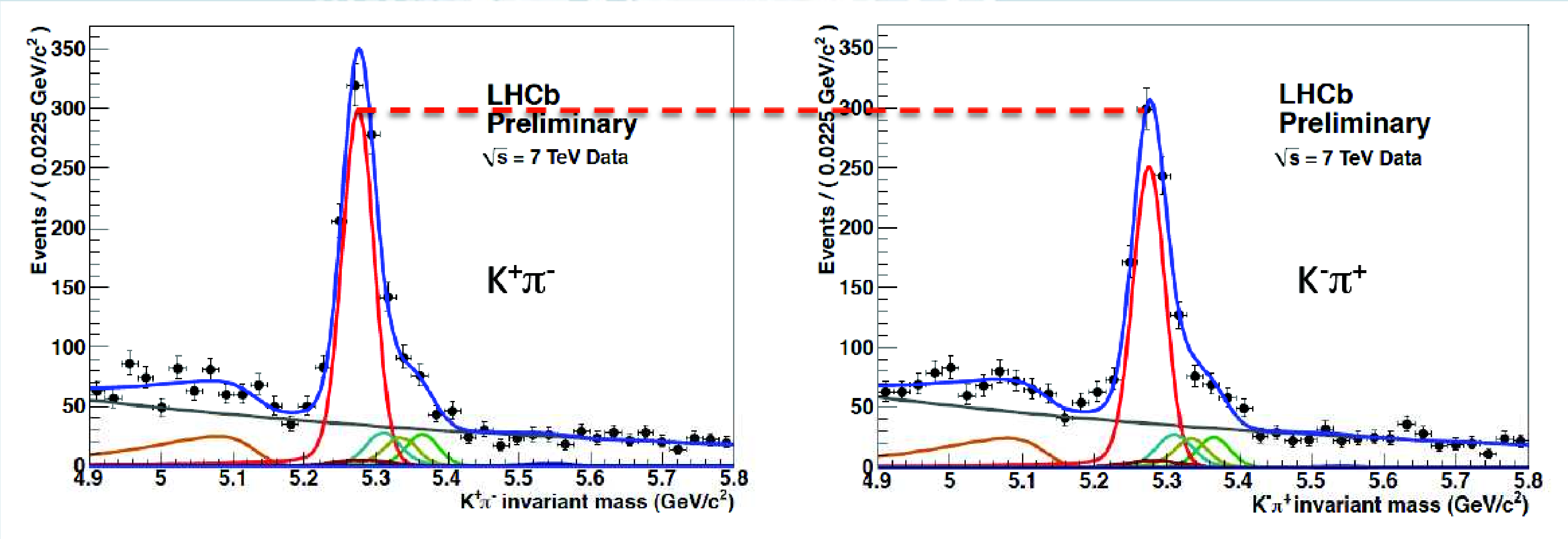
Production asymmetry

Instrumental asymmetries calculated using $D^* \to D^0(K\pi)\pi_s$, $D^* \to D^0(KK)\pi_s$, $D^* \to D^0(\pi\pi)\pi_s$ and $D^0 \to K\pi$ decays.

Production asymmetry studied using $B^+ \to J/\psi(\mu^+\mu^-)K^+$ decays.

Direct CPV in $B^0 \to K^+\pi^-$

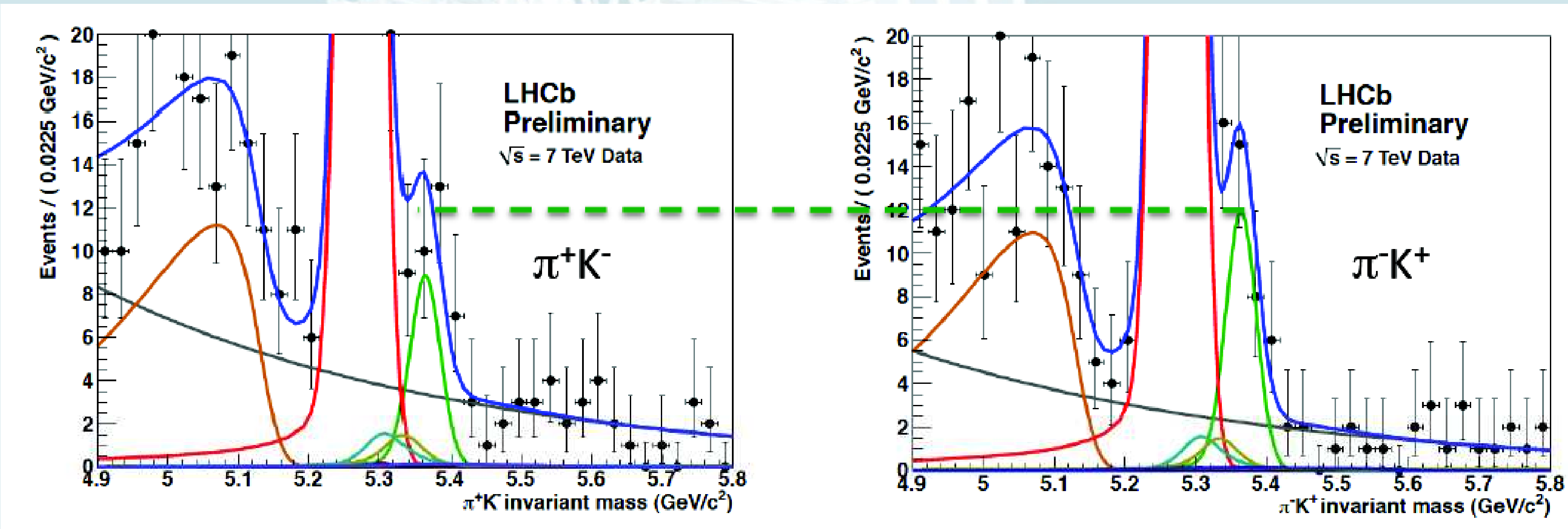
Raw CP asymmetry is -0.086 ± 0.033.



After corrections $\boldsymbol{A_{CP}(B^0 \to K^+\pi^-)}$ = **-0.074 ± 0.033 ± 0.008**.

Direct CPV in $B_s^0 \to \pi^+ K^-$

Raw CP asymmetry is 0.15 ± 0.19.



After corrections $\boldsymbol{A_{CP}(B_s^0 \to \pi^+ K^-)}$ **= 0.15 ± 0.19 ± 0.02**.

Conclusions and Outlook

Using the 37pb^{-1} p-p dataset collected in 2010:

LHCb has made the **world's best measurement of the $B_s^0 \rightarrow K^+K^-$ lifetime**

$$\boxed{\tau_{K^+K^-} = \left(1.440 \pm 0.096(\text{stat}) \pm 0.010(\text{syst})\right)\text{ps}}$$

consistent with the SM prediction and the CDF result.

And the **CP asymmetries**

$$\boxed{A_{CP}(B^0 \rightarrow K^+\pi^-) = -0.074 \pm 0.033 \pm 0.008}$$

$$\boxed{A_{CP}(B_s^0 \rightarrow \pi^+K^-) = 0.15 \pm 0.19 \pm 0.02}$$

in agreement with the world averages.

With the expected 1fb^{-1} LHCb will be able to make a $B_s^0 \rightarrow K^+K^-$ lifetime measurement with an uncertainty smaller than the SM prediction and will dominate world averages for the time-integrated asymmetries.

Backup

Acceptance cancellation