CP Violation Measurements and Prospects with Hadronic B-Decays at LHCb

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OUTLINE

HADRONIC B-DECAYS AT LHCB

- Large b-$\bar{b}$ cross section ($284 \pm 20 \pm 49$ μb) (PLB 694(209))
- Full spectrum of B-hadrons (e.g. B^0, B_s^0, Λ_b)
- Large background: **Trigger**
- Hadronic final states: **RICH**
- Time dependent processes: **VELO**

NEUTRAL MESON MIXING

Mass states are linear combinations of flavour states

$$\begin{aligned} |B_L^{(s)}\rangle &= p|B_{(s)^0}\rangle + q|\bar{B}_{(s)^0}\rangle \\ |B_H^{(s)}\rangle &= p|B_{(s)^0}\rangle - q|\bar{B}_{(s)^0}\rangle \end{aligned}$$

These states have different mass and lifetimes

$$\begin{aligned} \Delta m_{(s)} &= m_H^{(s)} - m_L^{(s)} \\ \Delta\Gamma_{(s)} &= \Gamma_L^{(s)} - \Gamma_H^{(s)} \end{aligned}$$

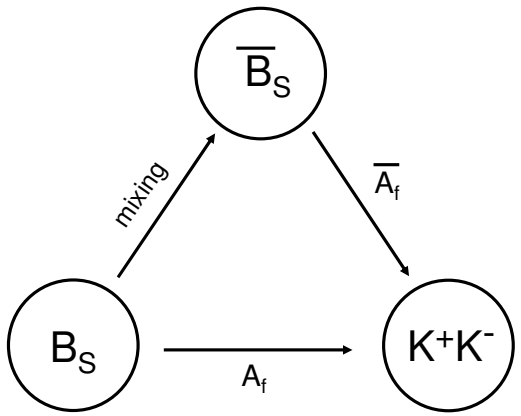
Decay amplitudes $A_f = \langle f|T|B^0_{(s)}\rangle$ and $\bar{A}_f = \langle f|T|\bar{B}^0_{(s)}\rangle$

OSCILLATION AND DECAY TO FINAL STATE f

Time dependent decay rate:

$$\Gamma_{B^0_{(s)}/\bar{B}^0_{(s)}\to f} = N \cdot \frac{e^{-\Gamma_{d,s}t}}{2}(\quad \pm \quad A_{dir} cos(\Delta m_{d,s} t)$$
$$\mp \quad A_{mix} sin(\Delta m_{d,s} t)$$
$$+ \quad cosh(\frac{\Delta\Gamma_{d,s} t}{2})$$
$$+ \quad A_{\Delta\Gamma} sinh(\frac{\Delta\Gamma_{d,s} t}{2}) \quad)$$

- A_{dir} Direct decay
- A_{mix} Oscillation and decay
- $A_{\Delta\Gamma}$ Decay rate asymmetry



CLASSIFICATIONS OF MEASUREMENTS

SPECIAL CASES

Flavour specific final state f: $A_{mix} = A_{\Delta\Gamma} = 0$ and $A_{dir} = 1$

- e.g. $B^0 \to K^+\pi^-$ and $B_s^0 \to D_s^-\pi^+$

Common final state f: A_{dir}, A_{mix} and $A_{\Delta\Gamma}$ all non-zero

- e.g. $B_s^0 \to K^+K^-$ and $B_s^0 \to D_s^\mp K^\pm$

ANALYSIS TYPES

Time integrated

- Comparing rates of decay channels

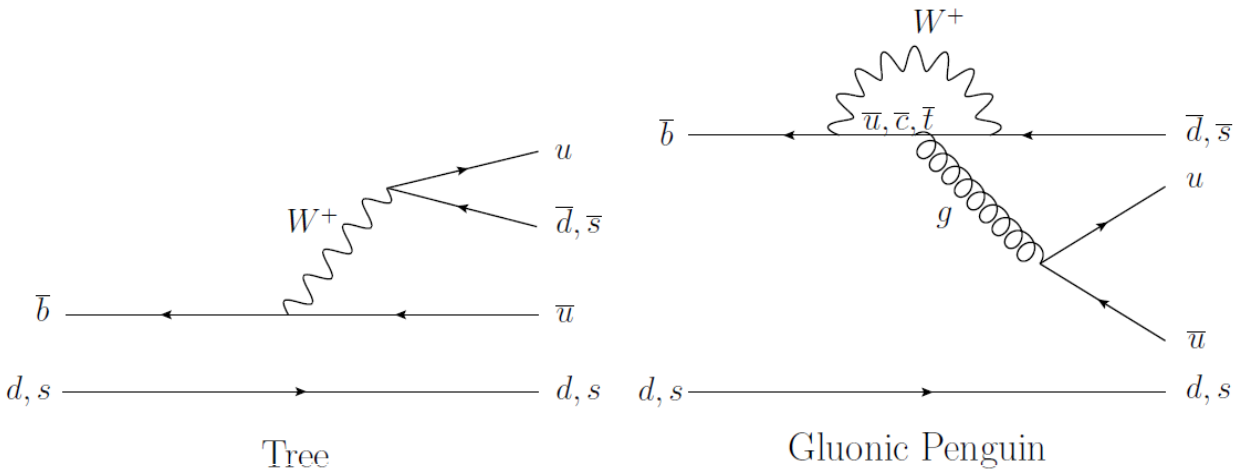
Time dependent analysis

- Fitting the time evolution

OUTLINE

$B^0, B_s^0, \Lambda_b \to h^+h^-$ DECAYS ($h = \pi$, K OR P)

Loop and Tree diagram are of similar strength
Sensitive to BSM processes



Examples of two contributing SM Feynman diagrams

EXPERIMENTAL POSSIBILITIES

- *CP* Asymmetries
- CKM angle γ
- Lifetime measurements

OUTLINE

$B^0 \to K^+\pi^-$ AND $B_s^0 \to \pi^+K^-$ *CP* ASYMMETRIES

FIRST $B \to h^+h^-$ *CP* ASYMMETRY MEASUREMENT AT LHCB

- Flavour specific final state
- Time Integrated and un-tagged analysis
- Many specific backgrounds: $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$, ...

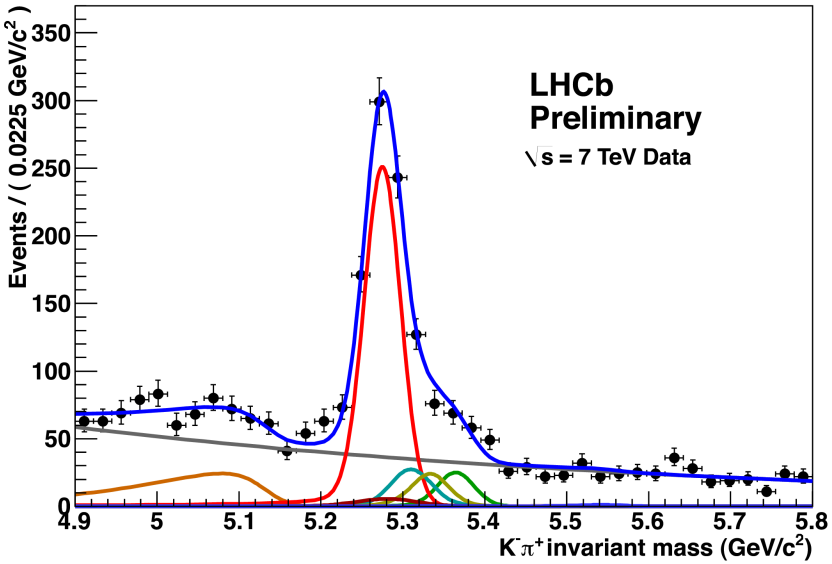
$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)}$$

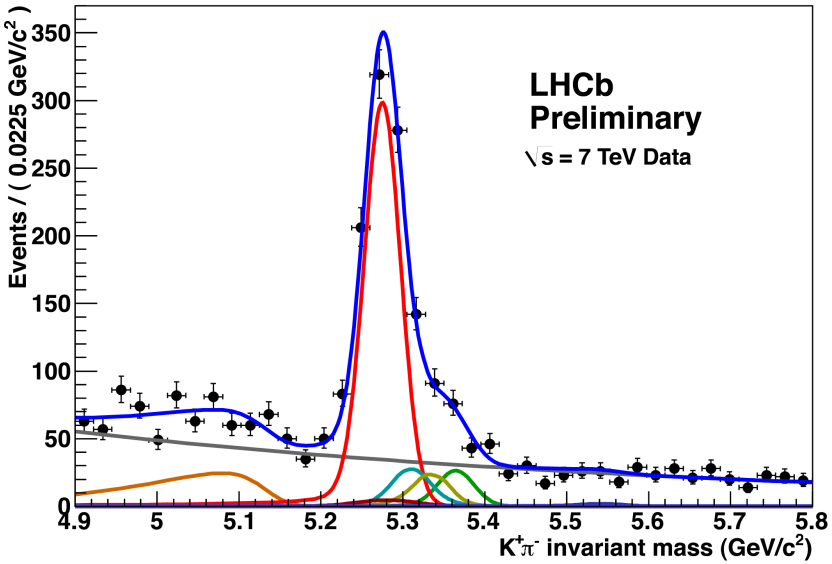
TEST OF U-SPIN SYMMETRY ($d \leftrightarrow s$)

- $A_{CP}(B^0 \to K^+\pi^-) \approx A_{dir}(B_s^0 \to K^+K^-)$
- $A_{CP}(B_s^0 \to \pi^+K^-) \approx A_{dir}(B^0 \to \pi^+\pi^-)$

RAW ASYMMETRIES

Mass fit to $B^0 \to K^-\pi^+$ (left) and $B^0 \to K^+\pi^-$ (right) (Similar for $B_s^0 \to \pi^+K^-$)





- $A_{CP}^{raw}(B^0 \to K^+\pi^-) = -0.086 \pm 0.033$
- $A_{CP}^{raw}(B_s^0 \to \pi^+K^-) = -0.15 \pm 0.19$

Measurement of Branching Ratios in preparation

FROM RAW TO PHYSICAL ASYMMETRIES

Corrections:

$$A_{CP} = A_{CP}^{raw} - A_D - \kappa \cdot A_P$$

κ is a smearing factor from the oscillation

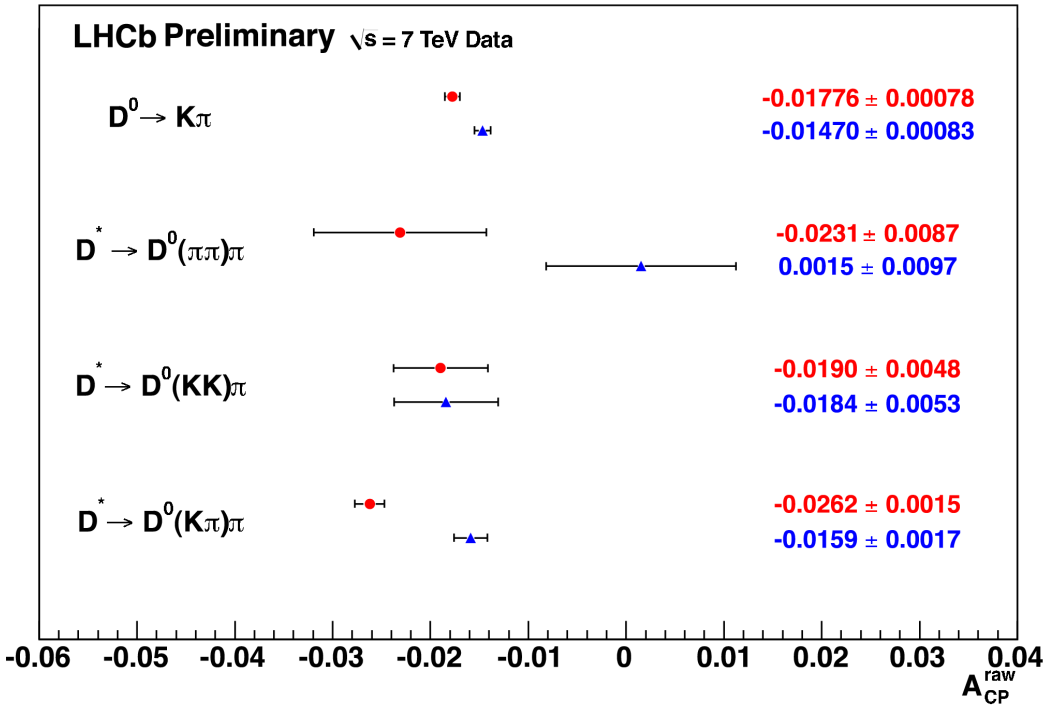
PRODUCTION ASYMMETRIES

- B^0 and B^+ share valence quark with the protons
- $A_P(B^0)$ measured from $B^\pm \to J/\psi K^\pm$
  - $A_{CP}(B^\pm \to J/\psi K^\pm)$ measured by B-factories
- B_s^0: Washed out by B_s^0 oscillations

DETECTION ASYMMETRIES

DETERMINED FROM CHARM DECAYS

- Untagged D^0 and self-tagged $D^{*\pm} \to D^0\pi^\pm$
- Measure asymmetries of D^0 to KK, $\pi\,\pi$ and Kπ



Raw asymmetries for magnetic field Up and Down

$B^0 \to K^+\pi^-$ AND $B_s^0 \to \pi^+K^-$ RESULTS

LHCB MEASUREMENTS (37 PB^{-1})

$$A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033\,(\text{stat}) \pm 0.008\,(\text{syst})$$
$$A_{CP}(B_s^0 \to \pi^+K^-) = -0.15 \pm 0.19\,(\text{stat}) \pm 0.02\,(\text{syst})$$

CURRENT WORLD-BEST MEASUREMENTS

$$A_{CP}(B^0 \to K^+\pi^-) = -0.098 \pm 0.013 \qquad (PDG)$$
$$A_{CP}(B_s^0 \to \pi^+K^-) = -0.39 \pm 0.015 \pm 0.08 \qquad (CDF)$$

DETERMINATION OF γ FROM $B \to h^+h^-$

MEASURE THE TIME DEPENDENT *CP* ASYMMETRIES

- $A_{dir}(B^0 \to \pi^+\pi^-)$, $A_{mix}(B^0 \to \pi^+\pi^-)$
- $A_{dir}(B_s^0 \to K^+K^-)$, $A_{mix}(B_s^0 \to K^+K^-)$

UNKNOWN PARAMETERS:

- CKM angle γ
- ϕ_s and ϕ_d: Weak phases (G. Cowan's talk & B-factories)
- $d^{(\prime)}$, $\theta^{(\prime)}$ hadronic parameters for $B^0 \to \pi^+\pi^-$ $(B_s^0 \to K^+K^-)$
- U-spin symmetry: $d = d^{\prime}$ and $\theta = \theta^{\prime}$ (hep-ph/9903456)

Measurement of the time-dependent asymmetries with 2011 data set

OUTLINE

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

Decay into a *CP* even final state: K^+K^-

- *CP* conserved: only accessible from B_L
- *CP* violation: mix of B_L and B_H
- SM predicts very small *CP* violation

Lifetime distribution, without initial flavour (B_s^0 or $\bar{B}_s^0$) discrimination:

$$\Gamma(t) \propto \left[(1 - A_{\Delta\Gamma})\, e^{-\Gamma_L t} + (1 + A_{\Delta\Gamma})\, e^{-\Gamma_H t}\right]$$

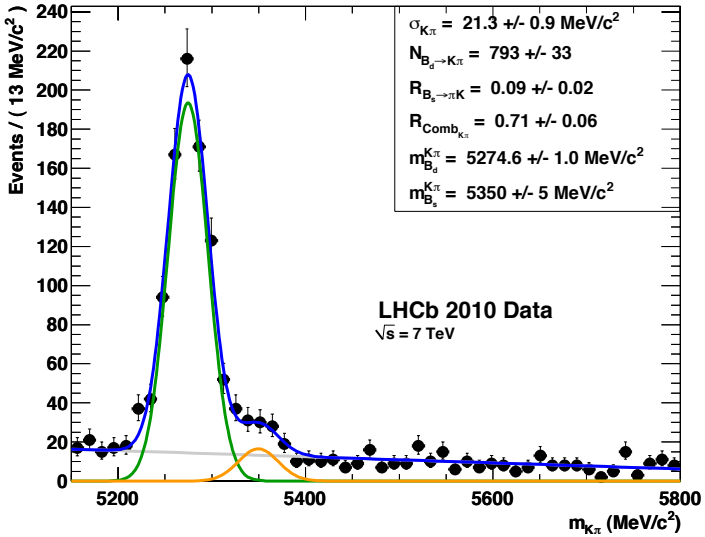
Where $A_{\Delta\Gamma}$ is defined as

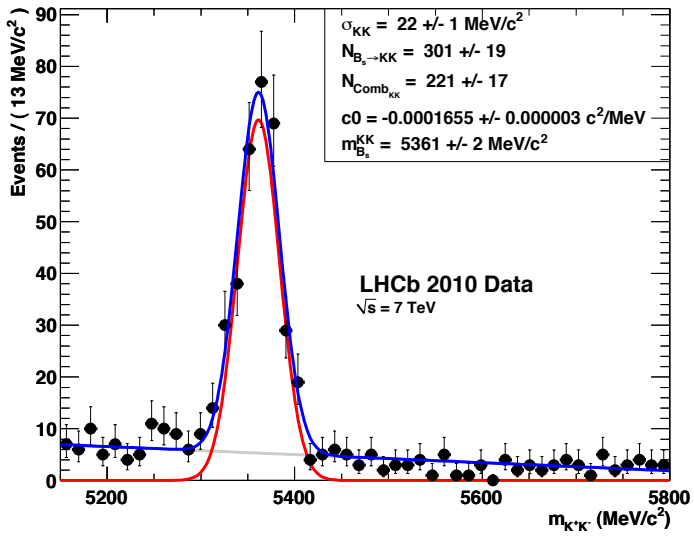
$$A_{\Delta\Gamma} = \frac{R_H - R_L}{R_H + R_L} \qquad \text{or} \qquad A_{\Delta\Gamma} = \frac{2Re(\lambda_f)}{1+|\lambda_f|^2}, \qquad \lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$$

METHOD: $B_s^0 \to K^+K^-$ LIFETIME MEASUREMENT

Experimental Challenge

- The event selection introduce a lifetime bias
- Two different analysis methods used





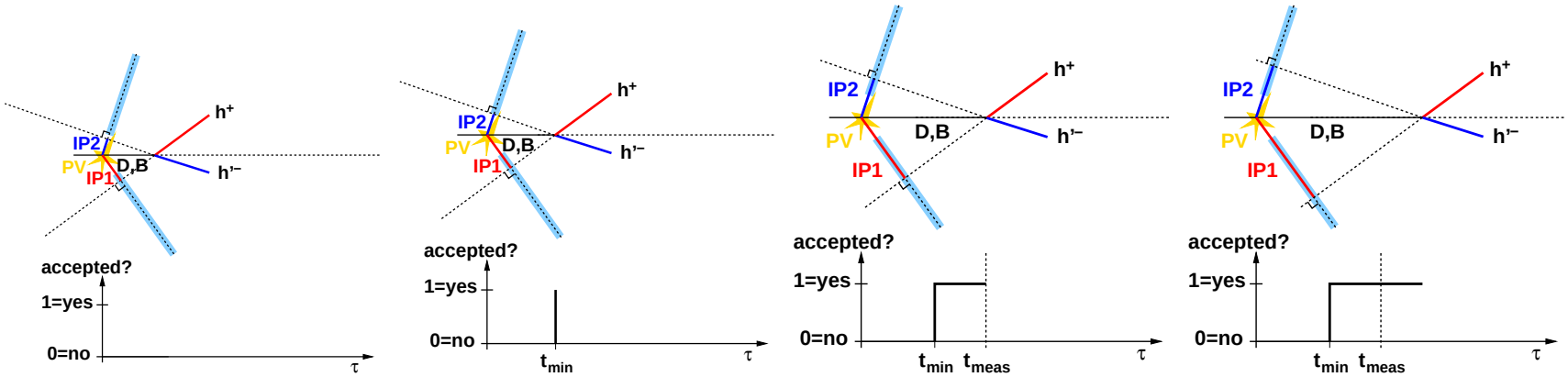
RELATIVE LIFETIME MEASUREMENT

- Compare to kinematically similar $B^0 \to K^+\pi^-$
- Acceptance cancel in the ratio

ABSOLUTE LIFETIME MEASUREMENT

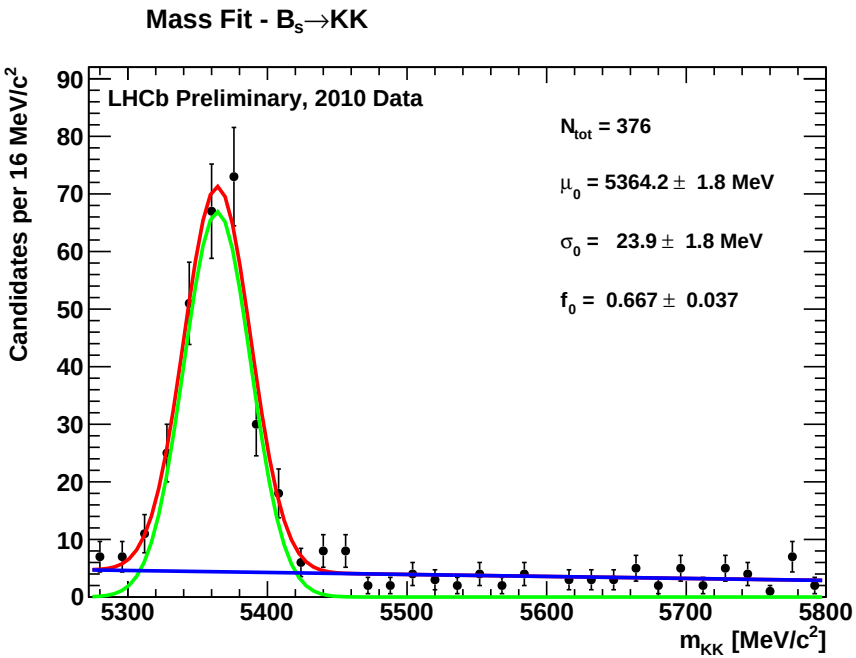
DATA DRIVEN ANALYSIS

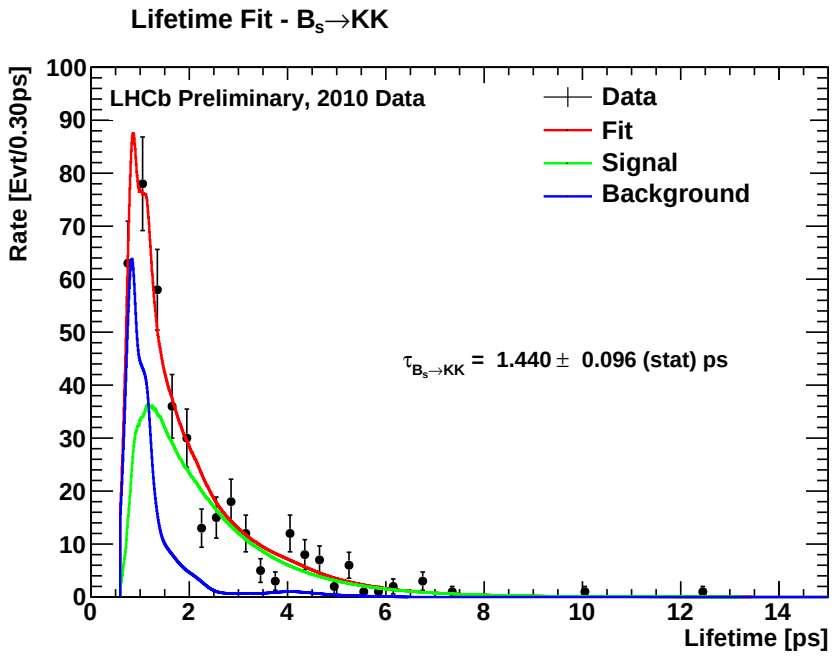
- The acceptance function is determined per event
  - Triggger and Selection re-run for all hypothetical lifetimes
  - The step function is parametrised by the parameter t_{min}



see V.V. Gligorov's Talk for further details

RESULTS: $B_s^0 \to K^+K^-$ LIFETIME





$$\hat{\tau}_{B_s^0 \to K^+K^-} = 1.440 \pm 0.096\,(\text{stat}) \pm 0.010\,(\text{syst})\ \text{ps}$$

$$\hat{\tau}^{CDF}_{B_s^0 \to K^+K^-} = 1.58 \pm 0.18\,(\text{stat}) \pm 0.02\,(\text{syst})\ \text{ps}$$

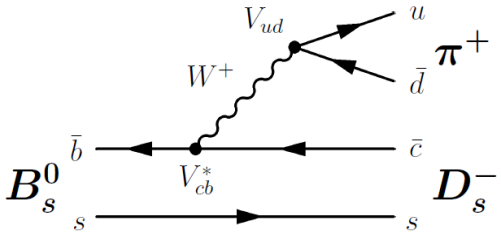
$$\hat{\tau}^{SM}_{B_s^0 \to K^+K^-} = 1.390 \pm 0.032\ \text{ps}$$

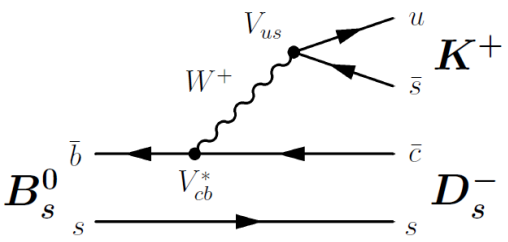
Publication in preparation

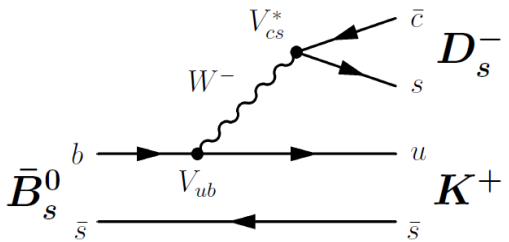
OUTLINE

γ FROM TREE DOMINATED DECAYS

Insensitive to loop processes (c.f γ from $B \to h^+h^-$ decays)







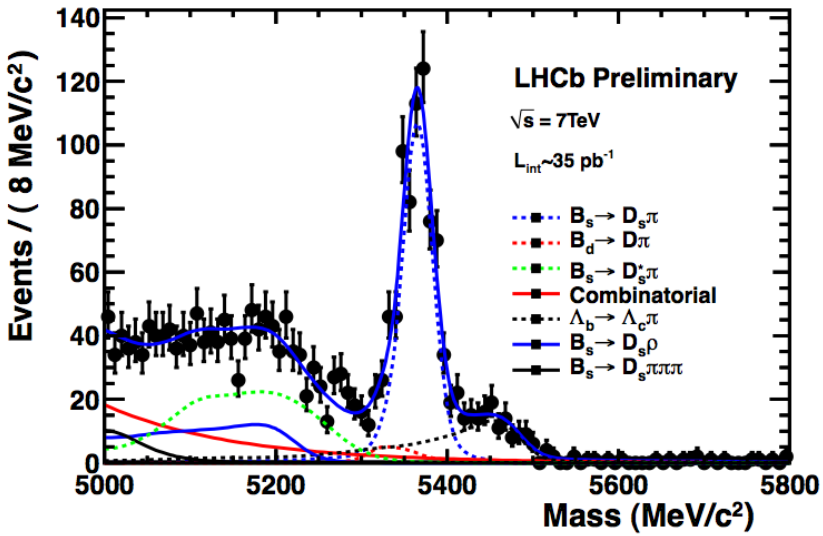
TIME DEPENDENT ANALYSIS

$B_s^0 \to D_s\pi$: Flavour specific - Measure $\Delta\Gamma_s$ and Δm_s
$B_s^0 \to D_sK$: Common final state - Measure A_{dir} and A_{mix}

Measurement of γ with 2011/12 data set

TOWARDS A MEASUREMENT OF γ

Measurements of branching ratios (LHCb-CONF-2011-008/013/024)



HADRONISATION RATIO OF B^0 AND B_s^0

- Measured from ratios of $B^0 \to D^- K^+$ and $B^0 \to D^- \pi^+$ to $B_s^0 \to D_s^- \pi^+$
- Important for B_s^0 branching ratio measurements, e.g. $B_s^0 \to \mu^+ \mu^-$
  (see J. Albrecht's talk)

$$f_s/f_d = 0.245 \pm 0.017\,(\text{stat}) \pm 0.018 \pm (\text{syst}) \pm 0.018\,(\text{theory})$$

result from semi-leptonic decays in preparation

OUTLINE

SUMMARY

- LHCb has a rich program of studying hadronic B decays
- Many interesting measurements are not included in this talk, e.g.
  - Time-integrated measurements of γ (GWL and ADS)
  - γ from Dalitz analysis
  - $B \to hhh$ Dalitz analysis
- Promising results already from 2010 Data, e.g.
  - A_{CP} from $\mathrm{B}^0 \to \mathrm{K}^+\pi^-$ and $\mathrm{B}_s^0 \to \pi^+\mathrm{K}^-$
  - Effective lifetime of $\mathrm{B}_s^0 \to \mathrm{K}^+\mathrm{K}^-$
  - Hadronisation ratio f_d/f_s
- Expect many world-best measurements from 2011 data