CP violation and the $B_s^0 \to K^+K^-$ Lifetime Measurement at LHCb

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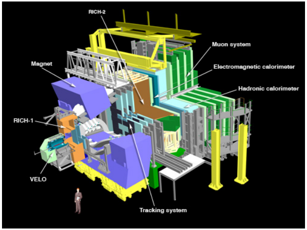
OUTLINE

THE LHCB EXPERIMENT

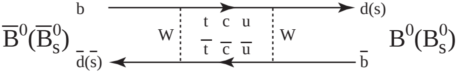
- B-physics at LHCb
  - Large $\mathrm{b}\text{-}\overline{\mathrm{b}}$ cross section ($\sim 300\,\mu\mathrm{b}$)
  - Full spectrum of B-hadrons (e.g. B^0, B_s^0, Λ_b)
  - Large background
- Data taking since March 2010
  - 2010: $\int \mathcal{L} = 37\,\mathrm{pb}^{-1}$
  - Already several world-best measurements



OUTLINE

MIXING FORMALISM

Neutral mesons mix via common states



Mass eigenstates

$$|B_L\rangle = p|B_s\rangle + q|\bar{B}_s\rangle$$
$$|B_H\rangle = p|B_s\rangle - q|\bar{B}_s\rangle$$

Time evolution: Mass and lifetime difference

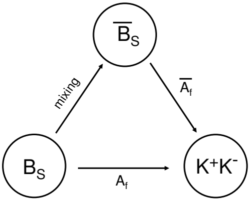
$$\Delta m = m_H - m_L$$
$$\Delta\Gamma = \Gamma_L - \Gamma_H$$

Phase shift introduced by the mixing

$$\phi_s \qquad \text{or} \qquad \beta_s$$

DECAY INTO A COMMON FINAL STATE

For $B_s^0 \to K^+K^-$ the final state is accessible from both B_s^0 and $\bar{B}_s^0$



Three sources of *CP* violation in $B_s^0 \to K^+K^-$

- Decay (A_f and $\overline{A}_f$)
- Mixing (q/p)
- Interference between mixing and decay (ϕ_s or β_s)

MASS EIGENSTATES VS. *CP* EIGENSTATES

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

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

$$\Gamma(t) = N \cdot \frac{|A_f|^2}{2} \left(1 + |\lambda_f|^2\right) \left[(1 - A_{\Delta\Gamma})\, e^{-\Gamma_L t} + (1 + A_{\Delta\Gamma})\, e^{-\Gamma_H t}\right]$$

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

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

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SM PREDICTION AND EXPERIMENTAL STATUS

The Standard Model predicts the mixing phase ϕ_s to be small

- Small *CP* violation in the B_s^0 sector.
- Decay dominated by the mostly *CP* even mass state B_L

A single exponential maximum likelihood fit gives an effective lifetime

$$\hat{\tau}_{B_s^0 \to K^+K^-} = \frac{1}{\Gamma + \frac{\Delta\Gamma}{2}} + \frac{1}{\Gamma - \frac{\Delta\Gamma}{2}} - \frac{1}{\Gamma + A_{\Delta\Gamma} \cdot \frac{\Delta\Gamma}{2}}$$

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

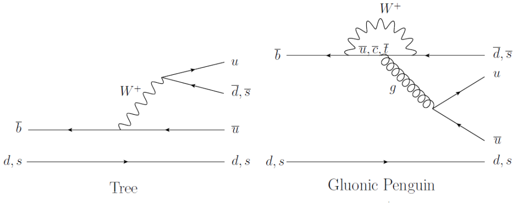
No published result exists, but a preliminary measurement has been done by CDF

$$\hat{\tau}_{B_s^0 \to K^+K^-} = 1.53 \pm 0.18\ (\mathrm{stat})\ \pm 0.02\ (\mathrm{syst})\,\mathrm{ps}$$

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

Cabbibo suppressed decays:

- Small branching ratio
- Sensitive to non-SM processes



Two contributing SM Feynman diagrams

Experimental challenges:

- Many similar final states: LHCb RICH
- Time dependent analysis: LHCb VELO
- Large hadronic background: LHCb trigger

Outline

$B_s^0 \rightarrow K^+K^-$: UNTAGGED LIFETIME MEASUREMENT

Selection:

- Geometric and kinematic cuts to maximise $\frac{S}{S+B}$
- Hard PID cuts to include only one signal class in the fit
- PID currently not used in the fit

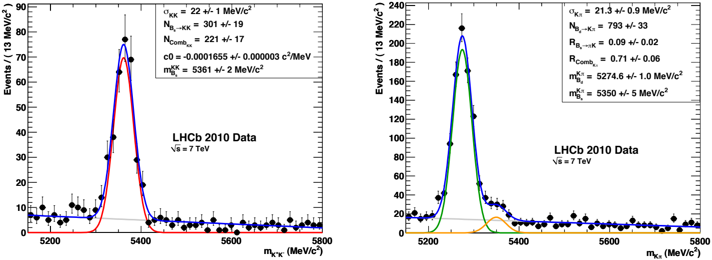
Event selection introduces a lifetime bias

- Relative measurement: Measure relative to $B^0 \rightarrow K^+\pi^-$
- Absolute measurement: Determine per-event acceptance function

$B_s^0 \to K^+K^-$: Relative Lifetime Measurement

Compare the lifetime with the kinematically similar $B^0 \to K^+\pi^-$

- Acceptance functions cancel in ratio
- Perform a simultaneous fit of the signal yields across all time bins
- Sensitive to $m_{B_s}/\tau_{B_s \to KK} - m_{B_d}/\tau_{B_d \to K\pi}$



Time-integrated fits to the $B_s^0 \to K^+K^-$ and $B^0 \to K^+\pi^-$ mass spectra

$B_s^0 \rightarrow K^+K^-$: ABSOLUTE LIFETIME MEASUREMENT

Data driven analysis - no input from Monte Carlo

- Determine per-event acceptance functions
- Derive a non-parametric background description from data

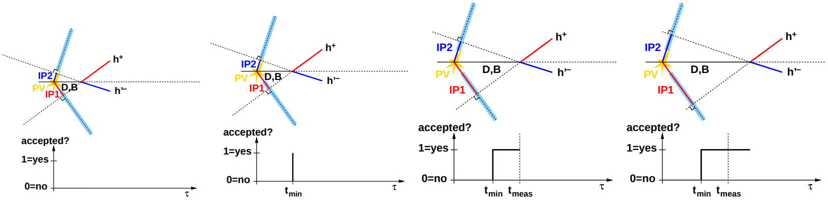
Background lifetime distribution

- Sum of Gaussian 'kernel' functions
- One per event, weighted by background probability
- Width determined by (roughly) by the local density

$B_s^0 \to K^+K^-$: Absolute Lifetime Measurement

Event-by-event acceptance function

- Move primary vertex along the B_s^0 momentum vector
- Re-run trigger and selection for each hypothetical lifetime
- Acceptance interval part of the analytical signal lifetime PDF



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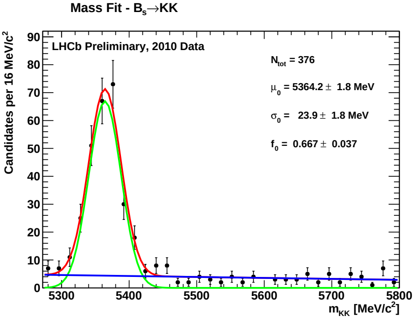
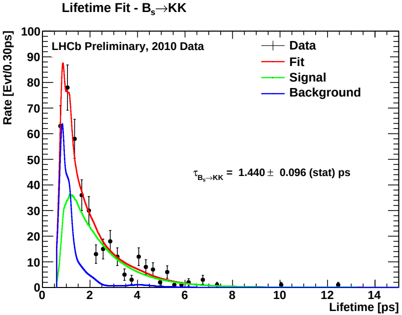
RESULTS: $B_s^0 \rightarrow K^+K^-$ LIFETIME

The results of the two methods agree





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

Summary and Outlook

- The $B_s^0 \rightarrow K^+K^-$ lifetime is a measurement of *CP* violation
- Probe for physics beyond the Standard Model
- LHCb has made a world-best measurement of the effective lifetime
- Two complete and independent analyses are presented
- The data expected in 2011/12 will allow a precision measurement

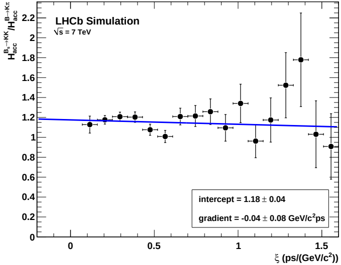
BACKUP

ACCEPTANCE CANCELLATION

Define the mass independent quantity $\xi = \frac{t}{m}$

$$R(\xi) = \frac{F_{meas}^{B_s \to KK}(\xi)}{F_{meas}^{B_d \to K\pi}(\xi)} = \frac{H_{acc}^{B_s \to KK}(\xi) \times [F_{true}^{B_s \to KK}(\xi, m_{B_s}/\tau_{B_s \to KK}) \otimes G_{res}(\xi, \sigma_{B_s \to KK})]}{H_{acc}^{B_d \to K\pi}(\xi) \times [F_{true}^{B_d \to K\pi}(\xi, m_{B_d}/\tau_{B_d}) \otimes G_{res}(\xi, \sigma_{B_d \to K\pi})]}$$

Acceptances cancel in the ratio



Ratio of $H_{acc}^{B_s \to KK} / H_{acc}^{B_d \to K\pi}$ in LHCb MC