Semileptonic B Mixing Measurements

IOP HEPP 2013

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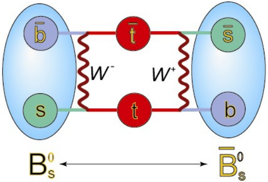
- Two flavour eigenstates $|B^0\rangle$ and $|\overline{B^0}\rangle$, of a B^0 system (B^0_d or B^0_s)
- Time-dependence of this is governed by:

$$i\frac{d}{dt}\begin{pmatrix} |B^0\rangle \\ |\overline{B^0}\rangle \end{pmatrix} = \left(\hat{M} - \frac{i}{2}\hat{\Gamma}\right)\begin{pmatrix} |B^0\rangle \\ |\overline{B^0}\rangle \end{pmatrix}$$

- Box diagram leads to off-diagonal elements M_{12} in $\hat{M}$



- Off-shell virtual states lead to off-diagonal elements Γ_{12} in $\hat{\Gamma}$
- Diagonalisation of $\hat{M}$ and $\hat{\Gamma}$ gives mass eigenstates, $|B_L\rangle$ and $|B_H\rangle$

$$|B_L\rangle = p|B^0\rangle + q|\overline{B^0}\rangle$$

$$|B_H\rangle = p|B^0\rangle - q|\overline{B^0}\rangle$$

B Mixing

- Observables governing this system are...
  - Decay width, $\Gamma_q = 1/\tau_q$, and decay width difference, $\Delta\Gamma_q = \Gamma_L - \Gamma_H$
  - Mass, m_q, and mass difference, $\Delta m_q = M_H - M_L$
  - Flavour specific asymmetries, a_{fs}^q

- Focus on the mixing frequencies Δm_s and Δm_d

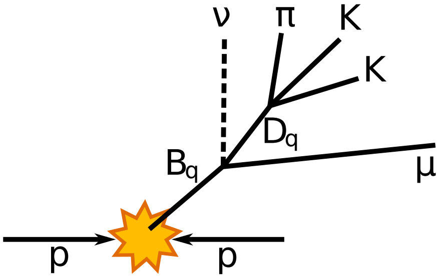
SM prediction [arXiv:1205.1444]

$$\Delta m_s = (17.3 \pm 2.6)\,\mathrm{ps}^{-1} \quad \Delta m_d = (0.543 \pm 0.091)\,\mathrm{ps}^{-1}$$

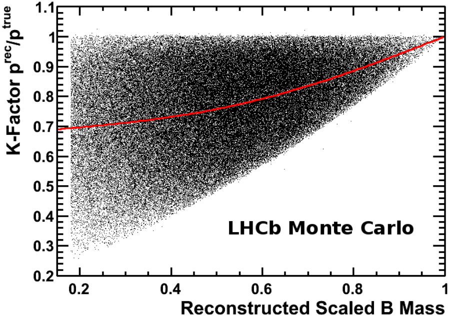
PDG averages [Phys. Rev. D 86, 010001 (2012)]

$$\boxed{\Delta m_s = (17.69 \pm 0.08)\,\mathrm{ps}^{-1} \quad \Delta m_d = (0.507 \pm 0.0040)\,\mathrm{ps}^{-1}}$$

- Aim: select $B_q^0 \rightarrow D_q^{\pm(*)}\mu^{\mp}\nu\ X^0$, where $q = s, d$ and $D_q^{\pm} \rightarrow K^+K^-\pi^{\pm}$
- Measure Δm_s and Δm_d, with a view for a future a_{fs} measurement



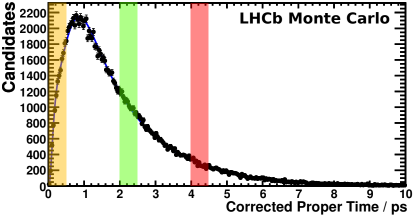
Momentum correction

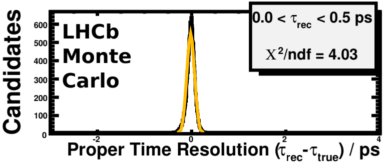


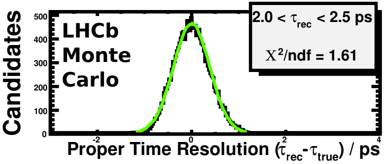
- Neutrino in decay $\rightarrow$ missing B momentum
- Momentum inversely proportional to lifetime
- Apply an average correction from MC
- $k = p^{rec}/p^{true}$ parametrised as function of B mass

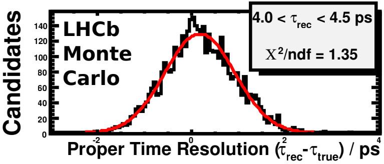
Time dependent resolution

- Resolution in bins of reconstructed time
- $\tau < 1\,\mathrm{ps}$ small vertex resolution dominates
- $\tau > 1\,\mathrm{ps}$ resolution from missing momentum dominates



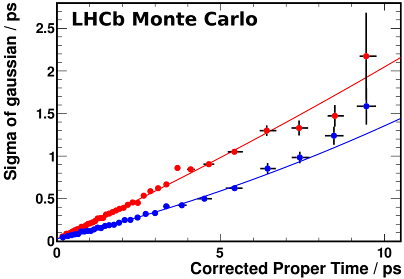


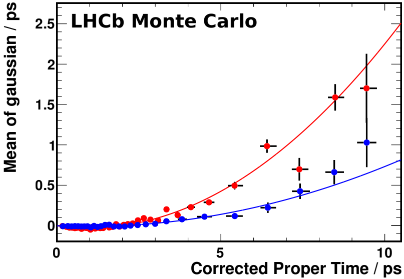




Time dependent resolution

Split by: Low scaled B mass and High scaled B mass

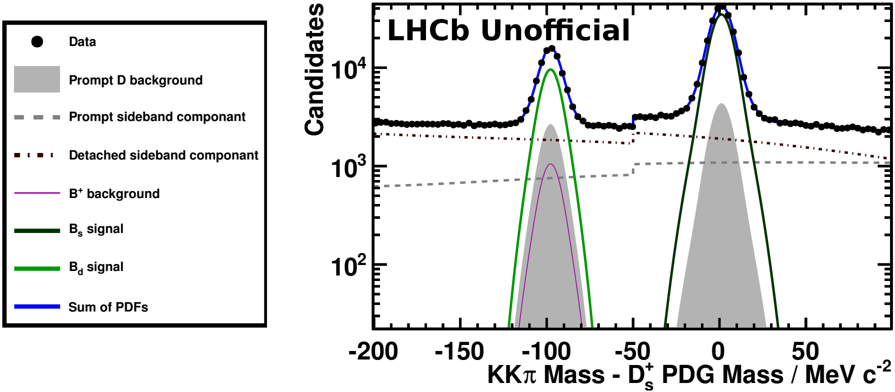




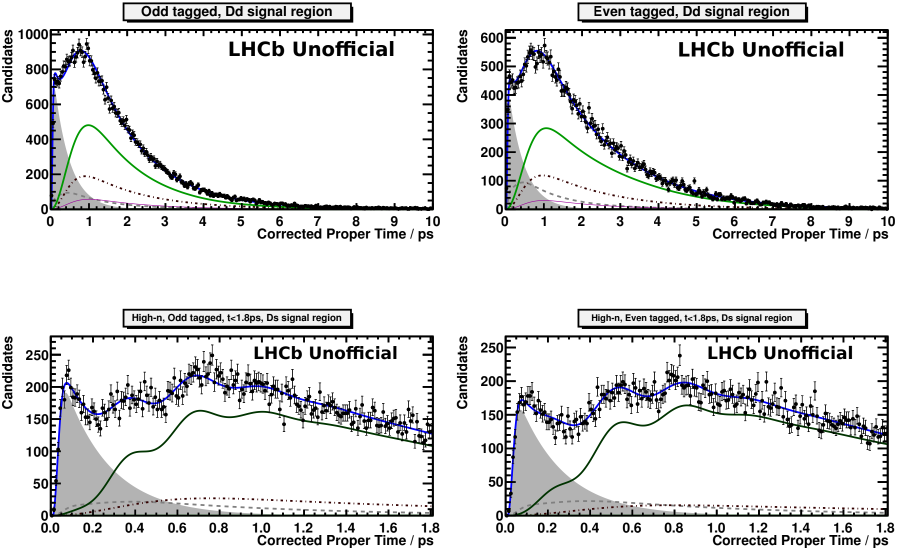
$$\Gamma_t(t) = e^{-\Gamma_q t}\left[\cosh\left(\frac{\Delta\Gamma_q t}{2}\right) \pm (1-2\omega)\cos\left(\Delta m_q t\right)\right] \otimes e^{\frac{-(\mu-t)^2}{2\sigma^2}} \times \varepsilon(t)$$

- Mixing formula smeared with Gaussian
- Acceptance function, $\varepsilon(t)$, applied after smearing
- Replace Gaussian sigma and mean with fitted quadratic dependence

- RooFit binned log likelihood fit performed in three dimensions:
  - $KK\pi$-mass
  - corrected lifetime of the B
  - B flavour tag
- Simultaneously fit in two reconstructed scaled B mass categories



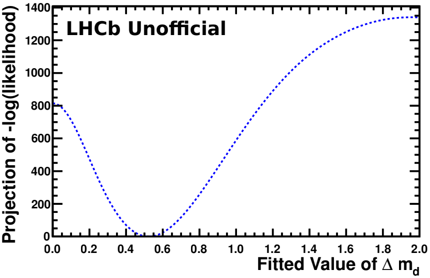
Proper Time Fit

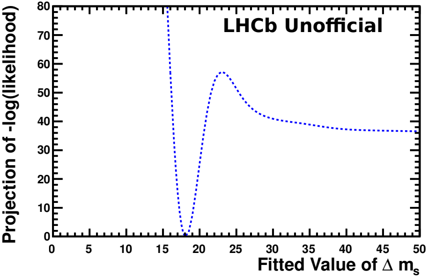


Systematics Summary

Cause of uncertainty	Systematic uncertainty	
	Δm_d / ps^{-1}	Δm_s / ps^{-1}
resolution model	0.0055	0.11
fit model	0.002	0.09
k-factor	0.0052	0.06
momentum-scale	0.0008	0.03
z-scale	0.0001	0.004
B^+ MC-fraction	0.006	n/a
total uncertainty	0.0099	0.16

Significance



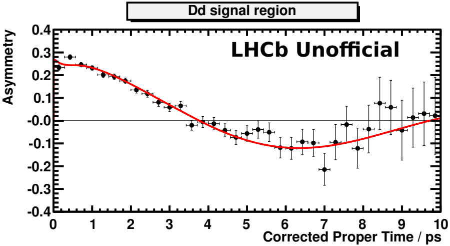


- Log-likelihoods of null hypotheses compared to nominal fit (H_1)
- Consider null hypotheses of $\Delta m \to 0$ (H_0) or $\Delta m \to \infty$ (H_0')

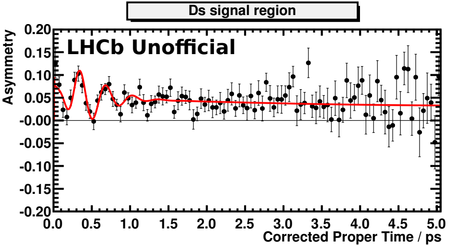
$$H_0(\Delta m_d = 0) = H_1 + 313.5 \qquad H_0(\Delta m_s = 0) = H_1 + 34.89$$

$$H_0'(\Delta m_d = 50) = H_1 + 366.9 \qquad H_0'(\Delta m_s = 50) = H_1 + 36.16$$

- Delta-log-likelihood rejects the null hypothesis by 5.9σ for Δm_s

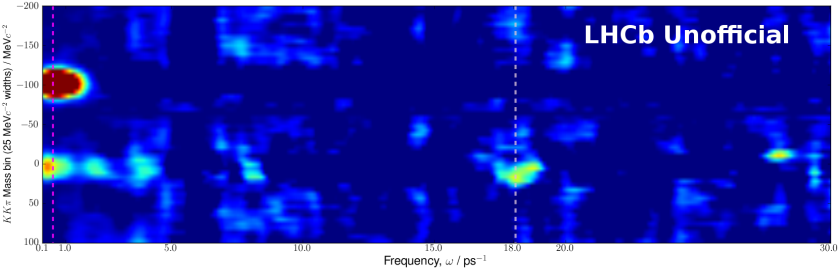


[Blinded] $\Delta m_d =$
$(0.612 \pm 0.011(\text{stat}) \pm 0.010(\text{syst}))\ \text{ps}^{-1}$



[Blinded] $\Delta m_s =$
$(18.89 \pm 0.22(\text{stat}) \pm 0.16(\text{syst}))\ \text{ps}^{-1}$

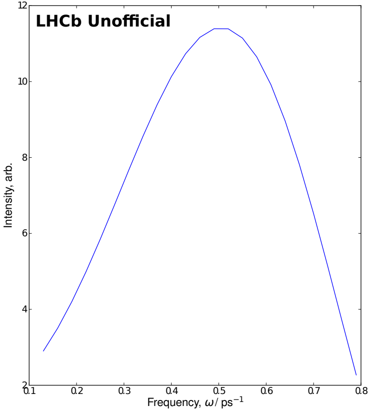
- Calculate the Fourier spectrum as a function of $KK\pi$ mass
- Interesting cross-check of method
- Δm_s and Δm_d can be extracted independent of fitter

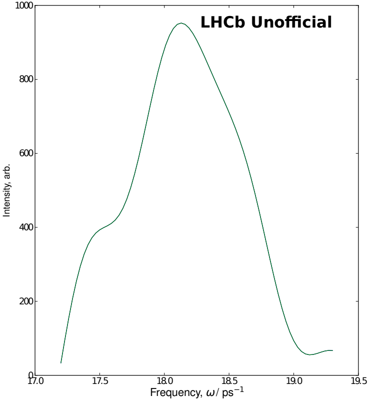


- Focus on the peaks in the Fourier spectrum from oscillations
- Use RMS as an estimate of the error

$$[\text{Blinded}] \quad \Delta m_d = (0.605 \pm 0.182(\text{rms}))\,\text{ps}^{-1}$$

$$[\text{Blinded}] \quad \Delta m_s = (19.13 \pm 0.40(\text{rms}))\,\text{ps}^{-1}$$





Conclusion

- Measured mixing frequencies Δm_d and Δm_s using RooFit

$$\text{[Blinded]} \quad \Delta m_d = (0.612 \pm 0.011(\text{stat}) \pm 0.010(\text{syst}))\,\text{ps}^{-1}$$

$$\text{[Blinded]} \quad \Delta m_s = (18.89 \pm 0.22(\text{stat}) \pm 0.16(\text{syst}))\,\text{ps}^{-1}$$

- These agree well with Fourier transform method

$$\text{[Blinded]} \quad \Delta m_d = (0.605 \pm 0.182(\text{rms}))\,\text{ps}^{-1}$$

$$\text{[Blinded]} \quad \Delta m_s = (19.13 \pm 0.40(\text{rms}))\,\text{ps}^{-1}$$

- Error several times the world average's error
- However this is a **semileptonic** decay, making this 5σ measurement fairly impressive

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