Accuracy of B^0-$\bar{B}^0$ mixing and B^0 lifetime measurements at Hera-B

Peter Kreuzer
University of California, Los Angeles, USA

Abstract

This article presents an estimate of the expected accuracy Hera-B should reach in the measurement of time-dependent oscillations of neutral B^0 mesons. The full reconstruction of about 3700 $B^0 \to J/\psi K^{*0} \to l^+l^-K\pi$ events per year, together with lepton, kaon and charge tagging should allow the determination of Δm_d with a relative error of about 4.0% after two Hera-B running years. A similar estimate for the B^0 meson lifetime measurement accuracy yields a relative error on the B^0 proper lifetime of about 1.5%. Both results will improve the existing world averages.

1 Introduction

The accurate determination of Standard Model parameters is presently one of the main issues in high energy physics. The mixing factor Δm_d which characterizes B^0 oscillations is coupled to the CKM-parameter $|V_{td}|^2$. Hence the accuracy of $|V_{td}|$ is related to the error of a Δm_d measurement. The most sensitive measurements of Δm_d are obtained through time dependent studies. If one neglects the effects of CP non-conservation and the decay rate difference $\Delta\Gamma_d$ between the "long-lived" and "short-lived" B^0 under study, the probabilities for a B^0 meson with a given initial flavor (B or $\bar{B}$)[1] to decay with the same flavor (unmixed) or to undergo mixing before it decays are given by the following distributions:

$$P_u(t) = \frac{\Gamma}{2}\, e^{-\Gamma t}\,[1 + \cos(\Delta m_d\, t)] \quad (1)$$

$$P_m(t) = \frac{\Gamma}{2}\, e^{-\Gamma t}\,[1 - \cos(\Delta m_d\, t)] \quad (2)$$

The $B^0 \to J/\psi\, K^{*0} \to l^+l^-K\pi$ decay mode is a good choice for mixing measurements at Hera-B because it can be triggered with the J/ψ-trigger used for the "golden channel" $B^0 \to J/\psi\, K_S \to l^+l^-\pi^+\pi^-$.

The time-dependent observation of B oscillations requires the determination of

(a) the proper time of the B meson decay

(b) the production (B or $\bar{B}$) and decay (B or $\bar{B}$) flavors of the B meson

If the B decays can be fully reconstructed, the effect of the energy (or momentum) resolution on the decay time resolution is negligible and the main contribution to the decay time resolution

[1] For convenience, B is now used for B^0 .

is the decay length resolution. At Hera-B , the vertex resolution in the silicon vertex detector should reach $\sigma_z \approx 500\mu m$ and the expected boost of the B meson is $\gamma\beta \approx 20$. Therefore, the decay time resolution can be computed as :

$$\frac{\sigma_t}{t} = \frac{\sigma_z}{\gamma\beta \cdot c\tau} = 5.5\,\% \tag{3}$$

This resolution will only have a little influence on the accuracy of a B^0 - $\bar{B}^0$ mixing measurement, because σ_t is very small compared to $\frac{1}{\Delta m_d}$.

The b flavour at the B decay is given by the reconstruction of the decay. The determination of the production flavor of the B meson requires flavor-tagging of the "second B" in the event. As tagging is never perfect, one has to account for dilution effects such as mixing of the tagging B, wrong charged particles or wrong tags due to particle misidentification. The tagging efficiencies from the Hera-B proposal [1] for lepton, kaon and charge tags are presented in Table 1.

Table 1: *Tagging efficiencies and dilution factors*

TAG	**Lepton**	**Kaon**	**Charge**
Efficiencies :			
ϵ (tag found)	16.1 %	46.0 %	96.4 %
ϵ_c (correct)	11.5 %	31.3 %	56.0 %
ϵ_w (wrong)	4.6 %	14.7 %	40.4 %
Dilution :			
$D = \frac{\epsilon_c - \epsilon_w}{\epsilon}$	0.43	0.36	0.16

The determination of Δm_d is achieved through the fit of a measured mixing assymetry function. The main factor affecting the statistical accuracy of Δm_d is the number of reconstructible B decays per Hera-B running year in a given channel. An estimate of this number for the $B^0 \to J/\psi\, K^{*0} \to l^+l^- K\pi$ channel is presented in section 2. In section 3, the simulation of the mixing analysis is described and the results on the estimated Δm_d accuracy are given. Finally, a similar estimate on the B^0 lifetime measurement accuracy is presented.

Similar measurements have been achieved at the various LEP experiments. However, none of them are based on fully reconstructed B events, which leads to a substantial increase of systematic errors from lifetimes and fractions of individual B hadron species, as well as from the parametrization of the b fragmentation function.

2 Signal-reconstruction efficiency

The only difference between the $B^0 \to J/\psi\, K^{*0} \to l^+l^- K\pi$ decay channel and the Hera-B "golden channel" is the $K^{*0} \to K\pi$ decay versus the $K_S \to \pi^+\pi^-$ decay. Therefore, all the trigger and reconstruction efficiencies [1] except the K^{*0} reconstruction efficiency are the same in the two channels[2]. A summary of all the factors used in the signal-reconstruction efficiency estimation is given in Table 2.

The K^{*0} reconstruction efficiency is estimated separately. It mainly depends on the kaon identification capability of the RICH detector. This is simulated using the momentum-dependent

[2]This is a conservative choice. One expects better B reconstruction efficiency in the $J/\psi\, K^{*0}$ channel, since the B forms a 4-track decay vertex.

Table 2: $B^0 \to J/\psi\, K^{*0} \to l^+l^- K\pi$ *reconstruction efficiency*

	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
Branching ratios	$5.056 \cdot 10^{-5}$	$5.056 \cdot 10^{-5}$
Trigger	0.637	0.325
Lepton tracking	0.837	0.757
K^{*0} **reconstruction**	0.540	0.540
J/ψ **and B reconstr.**	0.941	0.679
Decay kinematics	0.799	0.799
Secondary vertex	0.690	0.690
Overall efficiency	$\mathbf{7.552 \cdot 10^{-6}}$	$\mathbf{2.514 \cdot 10^{-6}}$

kaon detection efficiency curve [1] shown in Figure 1; the probability to identify a kaon with less than 35 GeV is set to 90% and for higher momenta it drops according to a Gaussian distribution. A 5% probability to misidentify a pion as a kaon is also assumed. The thresholds for pions (3.5 GeV), kaons (12.5 GeV) and protons (23.4 GeV) correspond to the lower bound of 20 detected photons. If a kaon doesn't make sufficient light, identification is made by excluding pions. The resulting overall kaon detection efficiency is $\epsilon_K = 72\,\%$. Considering geometrical acceptances for kaons and pions (88 % each) and a 10 % probability for kaons to decay before the RICH detector, one obtains a K^{*0} reconstruction efficiency of 54 %.

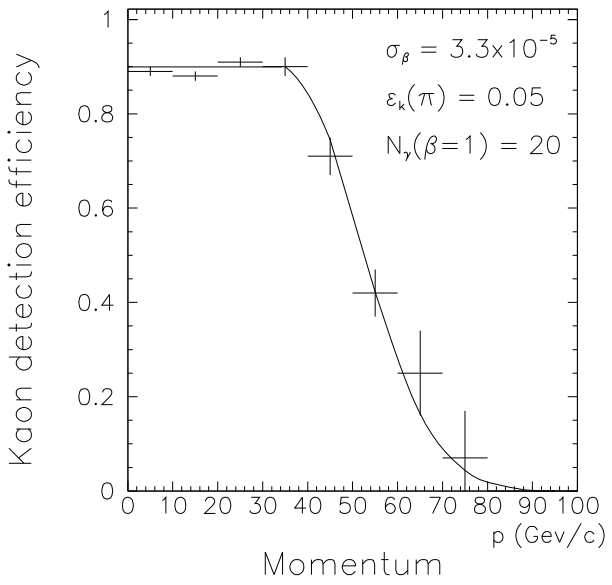

Figure 1: *Momentum dependence of the kaon detection efficiency for a fixed pion fake rate of* $\epsilon_K(\pi) = 5\,\%$. *The number of detected photons was set to the pessimistic case of 20. Above 35 GeV, the points where fitted with a Gaussian distribution.*

The number of estimated reconstructible B decays per year is extracted from Table 2;

the overall efficiency for the electron and muon channels together is $\epsilon_{RECO} = 9.948 \cdot 10^{-6}$. At Hera-$B$, one running year is expected to produce about $3.7 \cdot 10^8$ $b\bar{b}$ pairs, therefore the corresponding number of reconstructible $B^0 \to J/\psi\, K^{*0} \to l^+l^- K\pi$ decays is

$$N_{\mathrm{B}^0} \approx \textbf{3700 events/ year}$$

3 Accuracy of a Δm_d measurement

This study is achieved using a fast Monte-Carlo simulation. For every decay, a decay time is generated and smeared with the resolution given in (3). The "candidate" is then mixed according to equations (1) and (2) and the tagging efficiencies from Table 1 are introduced. The proposed mixing asymmetry measurement for a given time-bin (t) is the difference between the number of mixed ($n_m(t)$) and unmixed ($n_u(t)$) "candidates" divided by the sum. Using equations (1) and (2) one can easily show that

$$A(t) = \frac{n_m(t) - n_u(t)}{n_m(t) + n_u(t)} = -\, D_T \cos(\Delta m_d\, t) \tag{4}$$

where D_T is the overall tagging dilution factor due to wrong tags[3]. The result of the simulation and the fit using A(t) are shown in Figure 2. The relative error on Δm_d extracted from the fit

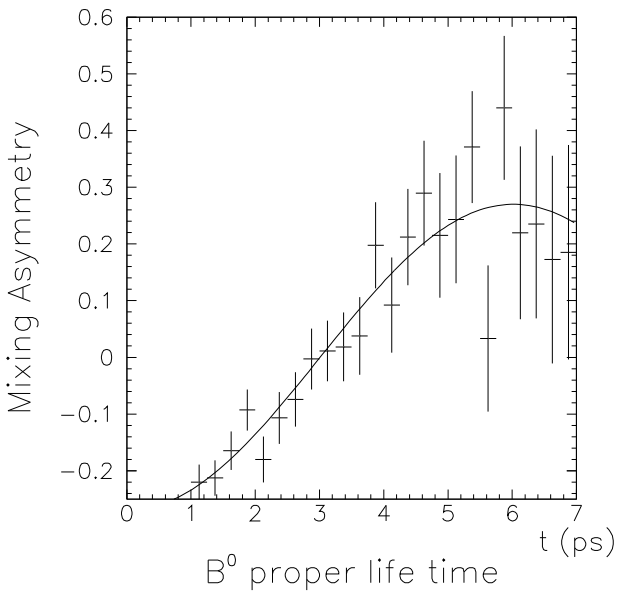

Figure 2: *Asymmetry distribution fitted with* $A(t) = -\, D_T \cos(\Delta m_d\, t)$ *for an input of 7400 events (2 Hera-B running years). The decay length cut corresponds to* $t_0 \geq (0.7) \cdot \tau_{B^0}$. *The extracted values from the fit are* $\Delta m_d = 0.5219\, ps^{-1}$ *and* $\delta(\Delta m_d) = 0.02081\, ps^{-1}$.

[3]The overall dilution factor D_T is a combination of dilution factors from the various taggs. Their individual contribution given in Table 1 is included in the Monte-Carlo simulation, but D_T is left as a free parameter in the fit to extract Δm_d.

for 1 Hera-B running year (3700 reconstructed B events) is

$$\frac{\delta\,(\Delta m_d)}{\Delta m_d} = \frac{0.02689}{0.5252} \;\approx\; \mathbf{5.5}\,\% \tag{5}$$

After two running years (7400 reconstructed B events), this relative error decreases to **4.0** %. The actual world average [2] has a higher relative error ($\frac{\delta\,(\Delta m_d)}{\Delta m_d} \approx \frac{0.031}{0.474} = 6.5\,\%$).

It is important to note that no background effects have been included in the present simulation. Nevertheless, the expected capability of Hera-B to fully reconstruct B^0 decay's should limit the systematic errors compared to LEP results.

4 Accuracy of a B^0 lifetime measurement

The HQE model predicts small lifetime differences between charged and neutral B mesons: $\frac{\tau_{B^-}}{\tau_{B^0}} = 1 + 0.05 \cdot \frac{f_B^2}{(200MeV)^2}$. Precise lifetime measurements are necessary to check this model. In order to estimate how accurately Hera-B can measure the lifetime τ_{B^0} in the $B^0 \to J/\psi\, K^{*0} \to l^+l^-K\pi$ channel, a similar simulation to the mixing study is used. In this case, no tagging is required, and the lifetime is extracted from an exponential fit to the decay-time distribution (Figure 3). The obtained accuracy after two Hera-B running years is

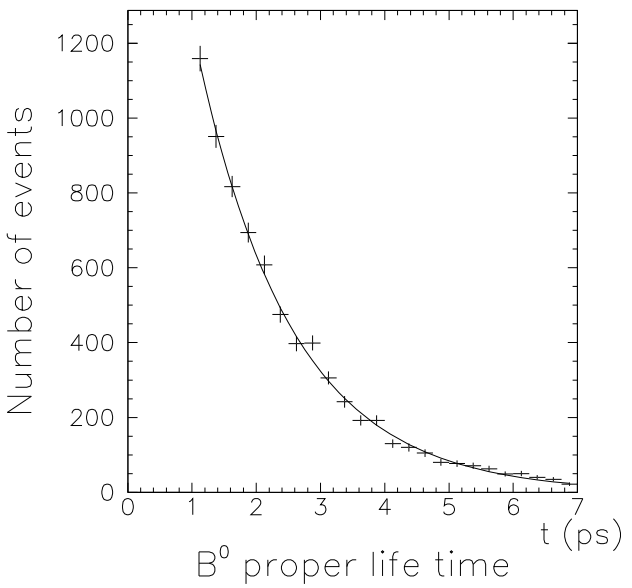

Figure 3: *Lifetime distribution fitted with an exponential for an input of 7400 events. The extracted values from the fit are* $\tau_{B^0} = 1.48522\,ps$ *and* $\delta(\tau_{B^0}) = 0.02246\,ps$.

$$\frac{\delta\,(\tau_{B^0})}{\tau_{B^0}} \;\approx\; \mathbf{1.5}\,\% \tag{6}$$

Again, no background effects have been included in this simulation. In comparison, the existing world average [2] on τ_{B^0} is given with an accuracy of ($\frac{\delta\,(\tau_{B^0})}{\tau_{B^0}} \;\approx\; \frac{0.06}{1.56} = 3.8\%$).

5 Conclusion

The simulation has shown that Hera-B will be able to measure accurately both Δm_d and τ_{B^0} (4.0% and 1.5% accuracy respectively after 2 running years) using the $B^0 \to J/\psi\, K^{*0} \to l^+l^-K\pi$ decay mode. The accuracy estimates indicate an improvement of the existing world averages. Mixing studies in additional channels like semi-leptonic decays could further enhance the statistics and therefore improve the measurement accuracy.

6 References

[1] The Hera-B collaboration, Proposal, DESY-PRC 94/02, May 1994;
[2] R.M. Barnett et al. (Particle Data Group), Phys. Rev. D54, 1 (1996).