Resonant Structure and Flavor-tagging in the $B\pi^\pm$ System Using Fully Reconstructed $B$ Decays

The ALEPH Collaboration

Abstract

Exclusive reconstruction of $B^{**} \rightarrow B\pi^\pm$, with a mass resolution of only a few MeV/$c^2$, is an important tool for the study of $B^{**}$ spectroscopy. Therefore, with the ALEPH detector at LEP, we have looked for resonant structure in the $B\pi$ system with a data sample of almost 500 fully-reconstructed charged and neutral $B$ mesons. We observe a narrow structure above the expected background with a mass $m_{\text{narrow}} = 5703 \pm 14$ MeV/$c^2$, and a width $\sigma_{\text{narrow}} = 28_{-15}^{+18}$ MeV/$c^2$. There is also a hint of a broader structure at lower mass. The total production rate is estimated to be $BR(b \rightarrow B^{**} \rightarrow B^{(*)}\pi)/BR(b \rightarrow B_{ud,s,d}) = (30 \pm 8)\%$.

In the same sample of reconstructed $B$’s, we have measured the efficiency and mistag rate for a $B$ flavor-tag based on the $\pi^\pm$ with the highest longitudinal momentum relative to the $B$ direction. We find a tag efficiency of (85 ± 3)\% and a mistag rate of (29 ± 3)\%, and show that this tag reproduces the expected results in $B - \bar{B}$ mixing. This tag may well supplement and cross-check other tags in CP violation and mixing studies in the $B$ system. (Please note: all results quoted are preliminary with statistical errors only.)
1 Introduction

The ability to tag the flavor of neutral $B$ mesons at production by the charge of a near-by pion has important implications for the study of CP violation and mixing in the $B^0$ system [1]. This flavor tagging ability may be enhanced by the existence of resonant structure in the $B\pi$ and $B^*\pi$ systems. The masses, widths, and decay branching ratios of these $B^{**}$ resonant states have been the subject of recent theoretical predictions, based on Heavy Quark Effective Theory (HQET), and extrapolation from the measured properties of the analogous $D^{**}$ states [2].

The first experimental results on these topics have recently come from experiments at LEP, where the $B$'s are produced in the decays $Z^0 \to \bar{b}\bar{b}$. Evidence for $B\pi$ charge correlations [3] and $B\pi$ resonant structure ([3], [4], [5]) have been observed. However, all these studies are based on the inclusive reconstruction of $B$'s. The resulting $B\pi$ mass resolution is poor (of the order of 40 MeV/$c^2$), and the assignment of tracks to the $B$ is not unambiguous.

In this note we report preliminary results based on a different, complementary approach. Charged and neutral $B$ mesons, fully reconstructed in the ALEPH experiment at LEP, are used to study $B\pi$ correlations, resonant structure, and $B^0 - \bar{B}^0$ mixing. The advantage of this approach for the study of the $B^{**}$ states is that the mass resolution is improved by about one order of magnitude compared to the previous studies, allowing the observation of narrower structure. The advantage for the study of flavor tagging and mixing is that our method corresponds much more closely to the techniques that will actually be used in future experiments on CP violation (which depend on the full reconstruction of neutral $B$ mesons). Moreover, the identity and decay proper time of the $B$ meson are accurately known, and there is a clean separation between tracks from the $B$ decay and the tracks from fragmentation.

The disadvantage of this approach with the present data sample is that the number of fully-reconstructed $B$ mesons is limited. Our results are based on about three million hadronic $Z^0$ decays, providing almost 500 reconstructed $B$'s with a purity of about 82%.

In the sections to follow we will describe the reconstruction of the $B$ decays, the selection of the associated charged $\pi$ (which we will refer to as $\pi_\pi$), and our results on the $B\pi$ mass spectrum. Then we give the efficiency and purity for tagging charged and neutral $B$'s using the charged pion with the highest value of longitudinal momentum (relative to the $B$ direction), including application to time-dependent $B - \bar{B}$ mixing. Finally, we give our conclusions.

2 $B$ Reconstruction

The analysis is based on data collected by the ALEPH detector throughout the years 1991-1994 (3.3 million hadronic $Z^0$ decays). A variety of hadronic channels is utilized to collect the fully reconstructed $B$ candidates. Most of the decays are of the form $B \to D^{(*)}\pi^\pm$, $D^{(*)}\rho^\pm$ or $D^{(*)}a_1^\pm$, but about 14% are in the modes $B \to J/\psi K$, $\psi'K$, $J/\psi K^*$ or $\psi'K^*$. Constraining the $B$ mass to its nominal value [6], the $B\pi$ invariant mass resolution varies from 2 MeV/$c^2$ to 5 MeV/$c^2$ in the $B\pi$ mass range from 5.5 GeV/$c^2$ to 5.8 GeV/$c^2$.

Additional $B$ decays are reconstructed in the channels $B^\pm \to D^{*0}\pi^\pm$ and $B^\pm \to D^{*0}a_1^\pm$, with a missing soft $\gamma$ or $\pi^0$ from the $D^{*0} \to D^0\gamma$ or $D^0\pi^0$ decay. The $B$ reconstruction is done by
scaling the mass and momentum of the $D^0$ candidate to the mass and average momentum\(^1\) of the $D^{*0}$. The resulting $B\pi$ mass resolution is $\approx 4 \text{ MeV}/c^2$ in the low mass region, similar to the fully reconstructed $B$'s.

Table 1 summarises the various contributions to the final sample consisting of a total of 474 $B$ decays. The purity of the sample is estimated to be $(82 \pm 5)\%$.

<table>
<thead>
<tr>
<th>Contributions</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully reconstructed (neutral $B$)</td>
<td>198</td>
</tr>
<tr>
<td>Fully reconstructed (charged $B$)</td>
<td>186</td>
</tr>
<tr>
<td>Reconstructed with missing soft $\gamma$ or $\pi^0$ (charged $B$)</td>
<td>90</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>474</strong></td>
</tr>
</tbody>
</table>

Table 1: The $B$ sample composition

### 3 Selection of the $\pi_{**}$

Tracks which have not been used in the reconstruction of the $B$ meson are potential $\pi_{**}$ candidates. The $\pi_{**}$ candidate track must have a momentum $> 0.2 \text{ GeV}/c$, originate from the primary vertex (with a probability $\geq 0.5\%$), and have a $dE/dx$ (if available) consistent with a pion within $\pm 3\sigma$. In addition, the track should give a low mass combination with the $B$ ($m_{B\pi} \leq 7.3 \text{ GeV}/c^2$, i.e. $2 \text{ GeV}/c^2$ above the mass of the $B$; this is mainly to avoid combinations with hard tracks from nearby gluon jets in events with more than two jets).

#### 3.1 Right-sign and wrong-sign tracks

All tracks passing the above cuts can be used to form $B\pi$ combinations. However, not all of them can have originated from a resonance decay. For a particular $B$ hadron type (e.g. $B^+$), only tracks of one sign (i.e. $\pi^-$) can come from the decay of a $B^{**}$ resonance into $B\pi$. Such tracks will be called `right-sign` tracks in the following, as opposed to the `wrong-sign` tracks where the $B\pi$ system could not have originated from the decay of a resonance (see table 2).

<table>
<thead>
<tr>
<th>right sign</th>
<th>wrong sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^-\pi^+$</td>
<td>$B^-\pi^-$</td>
</tr>
<tr>
<td>$B^0\pi^+$</td>
<td>$B^0\pi^-$</td>
</tr>
</tbody>
</table>

Table 2: Right-sign and wrong-sign combinations for all $B$ hadron types

The distinction between right-sign and wrong-sign tracks reduces the background combinations by almost a factor of 2 while having only a small effect on the signal due to $B^0 - \bar{B}^0$ mixing. Furthermore, the wrong-sign combinations can serve as a check on our estimate of the background. In particular, the wrong-sign combinations can be used to test the reliability of the simulated events and also to study the normalization of the simulated events relative to the data.

\(^1\)the momentum that the $D^{*0}$ would have if the center-of-mass decay angle of the $\pi^0(\gamma)$ was 90 degrees.
### 3.2 Discrimination of the $\pi_{s\pi}$ from fragmentation tracks

The main source of background in this study is the fragmentation pions. The selection criteria applied so far have very little discriminating power between these and the $\pi_{s\pi}$ pions. The difference between the signal pions and the fragmentation tracks comes from the hard fragmentation of the $b$ quark. Due to the hard $b$-fragmentation, the $B$ hadron takes most of the string momentum, leaving the fragmentation tracks behind. Therefore, the pion originating from a resonance decay is expected to be more forward and energetic than the fragmentation tracks. In terms of kinematic variables, the above properties are best incorporated in the pion’s component of momentum along the $B$ direction ($p_1$) and the $\cos(\theta^*)$, where $\theta^*$ is the decay angle of the pion in the rest frame of the $B^{**}$. Clearly these two variables are highly correlated. The $p_1$ distribution for the signal pions is relatively flat and extends up to about $7 \text{ GeV}/c$ (the exact value depends on the mass of the resonance), whereas the fragmentation tracks peak at rather low values of $p_1$ ($\approx 1 \text{ GeV}/c$). Similarly for the $\cos(\theta^*)$ distribution, the background tracks peak at $\cos(\theta^*) = -1$, whereas the distribution for signal pions is symmetric about $\cos(\theta^*) = 0$ due to parity conservation in the decay\(^2\).

Several algorithms using $p_1$ or $\cos(\theta^*)$ can be implemented to produce the $B\pi$ mass spectrum. The right-sign (wrong-sign) distributions presented in the following section are based on choosing the maximum-$p_1$ right-sign (wrong-sign) track (the $\text{max-}p_1$ algorithm), but it has been checked that the results are stable irrespective of the choice of algorithm. The wrong-sign distributions will be used as a control sample. The overall efficiency for the signal (after applying the $\text{max-}p_1$ algorithm) is estimated from simulation to be $(70 \pm 4)\%$.

### 4 \(B\pi\) mass spectroscopy

The $B\pi$ mass distributions for right-sign and wrong-sign combinations in the data based on the $\text{max-}p_1$ algorithm are shown in figure 1. Two important issues are the estimate of the background shapes and the normalization of these shapes to the data. These are discussed in detail below.

#### 4.1 Contributions to the mass spectrum

For a reasonable $B^{**}$ relative production rate ($25 - 35\%$), the main contribution to the $B\pi$ mass distributions should come from non-$B^{**}$ $B$ candidates ($\approx 60\%$). Another $\approx 18\%$ of combinations come from the impurity in our $B$ sample (fake $B$ events). Therefore the background shape is mainly determined from these two sources. There should also be some contribution from events where the $B^{**}$ decayed with a neutral pion or where the charged $\pi_{s\pi}$ did not pass the selection criteria and, finally, there is the expected signal.

The shape of the background from sources other than the fake $B$ events was estimated using simulated events. The distributions for right-sign and wrong-sign combinations using the $\text{max-}p_1$ algorithm are shown in figure 2. The fitted function is of the form

$$Bkg(m) = \sqrt{m^2 - m_0^2} \times p_4$$

\(^2\)some acceptance distortions are possible, but have been shown in simulation not to be significant.

\(^3\)the efficiency is a function of $m_{B\pi}$ and it rises from $68\%$ at $m_{B\pi} \approx 5.5 \text{ GeV}/c^2$ to $72\%$ at $m_{B\pi} \approx 5.7 \text{ GeV}/c^2$.
where $m_0$ is the threshold value ($= m_B + m_\pi$) and $p_4$ is a fourth-order polynomial.

The shape of the background coming from the fake $B$ events was determined using the data. For this purpose, the decay length significance cut, used for the selection of $B$ candidates, was reversed. Since all other cuts for the $B$ reconstruction remained the same it is a reasonable assumption that the $B\pi$ mass distribution of these events will be similar to the one from the fake $B$'s in the signal $B$ sample. In addition, candidates from the high mass sideband in the signal $B$ spectrum were used. The $B\pi$ mass distributions from the fake $B$ samples are shown in figure 3, fitted to functions of the same form as above. To further test any dependence of the $B\pi$ mass spectrum on the fake $B$'s, a tighter lifetime cut was also applied which increased the purity of the sample to about 90% and the results presented below remained stable.

A combination of the above two shapes with the correct weight factors was used to fit the background shapes in the data.

### 4.2 Normalizing the background shapes to the data

Another important question is how to normalize the above shapes to the data. Several normalization schemes can be used:

- Normalize the right-sign distribution in the high mass region (above 6, 6.1, 6.2 ... GeV/$c^2$) where no resonances are expected.

- Normalize to the wrong-sign distribution and use the same normalization factor for the right-sign spectrum.

- Leave the normalization as a free fit parameter when fitting for some signal.

Figure 1 shows the background shapes using the above normalization schemes superimposed on the data. All the schemes give very consistent results. This gives confidence in the reliability of the simulation events and the stability of the results which will be presented below. It can also be seen (figure 1.b) that the agreement in shape and normalization for the wrong-sign distribution is good, which is yet another test for the reliability of the background studies. In the right-sign distribution, however, there is a significant excess of events above the background curve, in the low mass region.

### 4.3 Results

An unbinned likelihood fit was used to extract the characteristics of the excess in the low mass region of the right-sign distribution. The fitting function included the background shapes, as described in the previous section, and two Gaussians since there appears to be a narrow structure at about 5.7 GeV/$c^2$ but also some excess of events below it, which may be related to the production of the narrow and wide $B^{**}$ states respectively. The fitted parameters were the means and widths of the two Gaussians ($m_{\text{narrow}}$, $\sigma_{\text{narrow}}$ and $m_{\text{wide}}$, $\sigma_{\text{wide}}$), the total area of the excess and the fractional area of the narrow structure. The fit results are (see fig. 4):

$$m_{\text{narrow}} = 5703 \pm 14 \text{ MeV}/c^2$$


Assuming that the observed signal is due to the production of $B^{**}$ states, the relative production rate for these states can be calculated to be:

$$\frac{BR(b \rightarrow B^{**} \rightarrow B^{(*)}\pi)}{BR(b \rightarrow B_{u,d})} = 30 \pm 8\%.$$ 

This production rate is based on the efficiency of the $max - p_{t}$ algorithm and the purity of our $B$ sample. It also includes an isospin efficiency factor of $2/3$ to take account of the unobserved $B^{**} \rightarrow B^{(*)}\pi^{0}$ decays.

The total area of the excess, as well as the mass and width of the narrow structure, are fairly stable. However, by looking at the errors of the other parameters, it becomes clear that the limited statistics do not allow the precise determination of them. For example, the results of the fit show that the mass and width of the wide structure together with the relative fraction between narrow and wide states are heavily correlated.

The statistical significance of the excess can be estimated from figure 1.a where the background curves are superimposed on the right-sign distribution. By restricting to the area from 5.5 $GeV/c^2$ to 5.76 $GeV/c^2$ the probability that the estimated background fluctuates to the observed 155 events is at the 3.4 $\sigma$ level. Separately for the narrow and the wide structures the corresponding statistical significances are 3.6 $\sigma$ and 2.2 $\sigma$. Clearly, the significance of the broad structure is marginal but the possible excess is at a region where the wide $B^{**}$ states are expected and therefore it may have some relevance.

5 $B$ Flavor-tagging and Mixing

Flavor-tagging is expected to play an important role in future CP violation experiments in the b-quark sector. In one class of these experiments, neutral $B$ mesons, decaying into a CP eigenstate such as $J/\psi K_{S}^{0}$, must be tagged at production as a $B^{0}$ or $\bar{B}^{0}$. CP violation will lead to an asymmetry in the $B^{0}$, $\bar{B}^{0}$ decay rates which is a sinusoidal function of proper time. In this section, we examine the use of the $max - p_{t}$ pion, associated with a fully-reconstructed $B$ meson, as a flavor tag. As an illustrative example, we show the use of this tag in time-dependent $B^{0} - \bar{B}^{0}$ mixing.

The particle which will tag the $B$ meson must satisfy the same general criteria already given in section 3. On average, 2.4 particles satisfy these criteria in the ALEPH environment for each fully-reconstructed $B$ decay. If there is more than one such track, the one with the highest longitudinal momentum, relative to the direction of the reconstructed $B$, is chosen to provide the tag (the
max – p_t track). The tagged combinations will be classified as “right-sign” or “wrong-sign” with the same convention as that already given in table 2.

An event which illustrates the use of the max – p_t flavor-tag is shown in fig. 5. The B^+, which decays into J/ψK^+, is correctly tagged by the max – p_t track, a π^-.

5.1 Tagging Charged B Mesons

In the case of our sample of 276 fully reconstructed charged B mesons, 244 have a tagging track, leading to a tagging efficiency (corrected for fake B’s):

\[ \epsilon_{\text{tag}}^{\text{charged}} = (87 \pm 3)\% \]

The asymmetry between right-sign and wrong-sign combinations, \( A_{\text{charged}}^{\text{charged}} = (N_{rs} - N_{ws})/(N_{rs} + N_{ws}) \), is shown as a function of the proper time of the B decay in fig. 6.a. Note that the resolution on the proper time is very good (\( \sigma(\text{proper time}) \leq 0.1\) ps), as the B momentum and decay length are very well determined for fully-reconstructed decays. The asymmetry depends very weakly on proper time, as expected for charged B’s (which do not undergo mixing). The small dependence comes from the different lifetime component of the fake B’s in the sample. Taking into account this effect, the formula for \( A_{\text{charged}}^{\text{charged}} \) as a function of the proper time \( t \) is:

\[ A_{\text{charged}}^{\text{charged}}(t) = \frac{A_f f_f \frac{e^{-t/\tau_f}}{\tau_f} + (1 - 2 \omega_{\text{tag}}^{\text{charged}}) f_B \frac{e^{-t/\tau_{B+}}}{\tau_{B+}}}{f_f \frac{e^{-t/\tau_f}}{\tau_f} + f_B \frac{e^{-t/\tau_{B+}}}{\tau_{B+}}} \]

where \( A_f \) is the right-sign/wrong-sign asymmetry due to the fake B’s (estimated using the fake B sample in the data; see section 4.1), \( f_f = 1 - f_B = 0.18 \pm 0.05 \) is the impurity of the B sample, and \( \tau_f \) and \( \tau_{B+} \) are the lifetimes of the fake and signal B’s, respectively. The parameter to be determined is the mistag rate \( \omega_{\text{tag}}^{\text{charged}} \) for charged B’s. Fitting for \( \omega_{\text{tag}}^{\text{charged}} \) we obtain

\[ \omega_{\text{tag}}^{\text{charged}} = (27 \pm 3)\% \]

The lifetime of the fake B’s was fixed to \( \tau_f = 1 \) ps as it is expected to be smaller than the B lifetime. Varying \( \tau_f \) from 0.5 to 1.5 ps had very little effect. The systematic effects due to changing \( A_f \) and \( f_f \) within their errors were also negligible.

5.2 Tagging Neutral B Mesons and B – \( \bar{B} \) Mixing

In our sample of 198 neutral B mesons, we find that 168 are associated with a tagging particle. Thus the tagging efficiency for neutral B’s (corrected for fake B’s) is:

\[ \epsilon_{\text{tag}}^{\text{neutral}} = (82 \pm 4)\% \]

The right-sign/wrong-sign asymmetry \( A_{\text{neutral}} \) will now have a strong proper time dependence due to mixing. This is illustrated in fig. 6.b, where \( A_{\text{neutral}} \) is plotted as a function of proper time. The fitting function now has the form:

\[ A_{\text{neutral}}(t) = \frac{A_f f_f \frac{e^{-t/\tau_f}}{\tau_f} + (1 - 2 \omega_{\text{tag}}^{\text{neutral}}) f_B \frac{e^{-t/\tau_{B0}}}{\tau_{B0}} \cos(\Delta m_B t)}{f_f \frac{e^{-t/\tau_f}}{\tau_f} + f_B \frac{e^{-t/\tau_{B0}}}{\tau_{B0}}} \]

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which includes the $\cos(\Delta m_d)$ component as expected for mixing. The mass difference $\Delta m_d$ of the CP eigenstates was left as a free parameter of the fit together with $\omega_{tag}^{ neutral}$. The fit results are:

$$\omega_{tag}^{ neutral} = (33 \pm 6) \%$$

$$\Delta m_d = 0.53^{+0.20}_{-0.16} \text{ps}^{-1}.$$

The value for $\omega_{tag}^{ neutral}$ is consistent with the corresponding mistag rate for the charged $B$’s as expected from isospin considerations [9]. The value obtained for $\Delta m_d$ is also in good agreement with the world average of $0.496 \pm 0.032 \text{ ps}^{-1} [8]$. Fixing $\Delta m_d$ to the world average value has a negligible effect on $\omega_{tag}^{ neutral}$. Finally, as in the case of the charged $B$’s above, $\omega_{tag}^{ neutral}$ is stable to changes of $\tau_f$, $A_f$ and $f_f$.

5.3 Tagging Quality Factor

To quantify the effectiveness of a given tag for CP violation studies, it is common to introduce the tag quality factor:

$$Q_{tag} = \epsilon_{tag}(1 - 2\omega_{tag})^2.$$

The amount of data necessary to reach a given statistical error in a CP asymmetry measurement will be proportional to $1/Q_{tag}$. Averaging the charged and neutral tag efficiencies and mistag rates given above, we find:

$$\epsilon_{tag} = 85 \pm 3 \%$$

$$\omega_{tag} = 29 \pm 3 \%$$

The corresponding tag quality factor is

$$Q_{tag} = 0.15 \pm 0.04.$$

This is about four times better than the corresponding tag quality factor of $\approx 0.04$ for a lepton tag in ALEPH. In any case, the $max - \pi_l$ tag can be used as an additional, independent tag, allowing both higher efficiency and the cross-checks possible with double-tags.

This tag should also work well at hadron machines for the study of CP violation in the $B$ system, such as the Tevatron Collider, HERA-B, or the LHC. However, the detailed results may differ, due to the different $b - \bar{b}$ mass spectrum.

6 Conclusions

With a data sample consisting of close to 500 fully-reconstructed $B$ mesons coming from hadronic decays of the $Z^0$, we have looked for resonant structure in the $B\pi^\pm$ system. Using the "right-sign" $max - \pi_l$ charged pion, we find in the $B\pi$ mass spectrum a narrow structure above the expected background with a mass $m_{narrow} = 5703 \pm 14 \text{ MeV}/c^2$, and a width $\sigma_{narrow} = 28^{+18}_{-14} \text{ MeV}/c^2$. There are also some hints for a broader structure of lower mass. On the whole, the results are reasonably consistent with the expectations for the production of $B^{(*)}$ states decaying into $B^{(\pm)}\pi^{\pm}$.

The total production rate for the narrow and broad structures taken together is determined to be $BR(b \rightarrow B^{(*)} \rightarrow B^{(\pm)}\pi)/BR(b \rightarrow B_{u,d}) = (30 \pm 8)\%$. However, the production fraction of the
narrow structure relative to the total structure is poorly determined. We note that our results on $m_{\text{narrow}}$, $\sigma_{\text{narrow}}$, and the total production rate are consistent with the corresponding values determined by ALEPH in the $B^{*}$ analysis based on inclusive $B$ reconstruction [5], once the mass resolution in that analysis is taken into account.

Using the same sample of reconstructed $B$'s, we have measured the efficiency and purity of a flavor-tag using a near-by pion. This technique may well play an important role in future studies of $B - \bar{B}$ mixing and CP violation in the $B$ system, as first suggested in [1]. The specific tag we have used is based on the charge of the pion with the highest longitudinal momentum, relative to the $B$ direction. A $B^0$ is tagged by a $\pi^+$, while a $\bar{B}^0$ is tagged by a $\pi^-$; a $B^+$ should be associated with a $\pi^-$, and a $B^-$ with a $\pi^+$. We find we are able to flavor-tag both charged and neutral $B$'s in this way with high efficiency $(85 \pm 3\%)$ and a reasonable mistag rate $(29 \pm 3\%)$. We have checked that this tag, when used to measure the frequency for $B - \bar{B}$ mixing, gives results consistent with the world average.

This $\text{max} - p_t$ tag, which is based on tracks in the same jet as the $B$, can be used as a tag which is independent of tags based on track(s), such as a high $p_t$ lepton, in the opposite jet. It can thus be used to increase the overall tag efficiency and/or purity, and cross-check the performance of the other tags.

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References


Figure 1: The $B\pi$ mass distributions in the data together with the expected background shapes: (a) Right-sign distribution; the three curves correspond to the three different normalization schemes described in the text, and (b) Wrong-sign distribution.
Figure 2: The $B\pi$ mass distributions in simulated events with the $max-pl$ algorithm, fitted as described in the text: (a) Right-sign combinations, (b) Wrong-sign combinations.
Figure 3: The $B\pi$ mass distributions from the fake $B$ candidates with the $max - p_l$ algorithm, fitted as described in the text: (a) Right-sign combinations, (b) Wrong-sign combinations.
Figure 4: A fit to the right-sign $B\pi$ mass distribution: the results of a two Gaussian unbinned likelihood fit, including expected background.
Figure 5: An overall $r-\phi$ view, and two close-up orthogonal views, of a flavor-tagged event. The $B^+$, which decays to $K^+J/\psi$ (with $J/\psi \rightarrow \mu^+\mu^-$), is tagged by the track with the highest $p_t$, the $\pi^-$. The error ellipses for the primary and $B$ decay vertices are indicated with $1\sigma$ ellipses.
Figure 6: Right-sign/Wrong-sign asymmetry as a function of the proper time for (a) charged $B$’s and (b) neutral $B$’s. The dashed lines are the fit results as described in the text.