Measurement of the B_d^0 Meson Oscillation Frequency Using Lepton – Jet Charge Tagging

The L3 Collaboration

Abstract

The time-dependent B^0-$\bar{B}^0$ mixing has been studied using about two million hadronic Z decays registered by L3 in 1994 and 1995. Tagging of b quark production is performed by identifying leptons from semileptonic B decays and using the correlation between the lepton's charge and the jet charges in the two hemispheres as a signature for mixing. The proper time of the B-particle decay is measured by reconstructing the production and decay vertices. The frequency for a B_d^0 meson oscillation corresponds to the mass difference Δm_d between the two B_d^0 mass eigenstates:

$$\Delta m_d = 0.437 \pm 0.043\ (\mathrm{stat}) \pm 0.044\ (\mathrm{syst})\ \mathrm{ps}^{-1}\,.$$

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Introduction

As in the case of K-mesons, oscillations between particle-antiparticle states are expected in the system of neutral B-mesons. In the Standard Model, the mechanism causing mixing is a second order weak interaction through box diagrams. The flavour eigenstates B^0_d ($\bar{\mathrm{b}}$d) and $\bar{\mathrm{B}}^0_\mathrm{d}$(b$\bar{\mathrm{d}}$) are linear combinations of the mass eigenstates B_1 and B_2. Neglecting effects from CP violation (expected to be small), the probability to find a B^0_d decaying at proper time t, provided it was produced as $\bar{\mathrm{B}}^0_\mathrm{d}$ at $t = 0$, is given by

$$P(\bar{\mathrm{B}}^0_\mathrm{d} \to \mathrm{B}^0_\mathrm{d}) = \frac{1}{\tau} e^{-\frac{t}{\tau}} \left(\frac{1 - \cos \Delta m_d t}{2} \right)$$

where τ is the lifetime of the B-meson. A measurement of the oscillation frequency thus gives a direct measurement of the mass difference Δm_d between two physical states.

The phenomenon of B^0-$\bar{\mathrm{B}}^0$ mixing is well established by experiment. Time integrated probabilities for mixing in the B^0-$\bar{\mathrm{B}}^0$ system were first observed by the UA1 Collaboration [1], as a result of the combined B^0_d and B^0_s contribution. Mixing of B^0_d-$\bar{\mathrm{B}}^0_\mathrm{d}$ alone was measured at the Υ(4S) by ARGUS and CLEO [2]. Comparing these results with precise measurements of B^0-$\bar{\mathrm{B}}^0$ mixing at LEP [3] leads one to expect a large oscillation frequency for the B^0_s meson, which makes it difficult to measure. The time dependence of mixing for B^0_d mesons has been recently measured at LEP using different techniques [4–6, 10].

Here we present a measurement of the B^0_d oscillation frequency in which we use the jet charges of the two thrust hemispheres for tagging the flavor of B meson at its production time and the charge of the lepton from the B meson decay for tagging the flavor of B meson at its decay time. Tagging the flavor of B meson at its production time by jet charge exploits the correlation between the charge of the primordial quark and the sum of charges observed in its hemisphere. The flavor of the primordial quark (b or $\bar{\mathrm{b}}$), in turn, determines whether $\bar{\mathrm{B}}^0$ or B^0 is produced.

The proper time of the B meson decay is measured by reconstructing the production and decay vertices and estimating the B meson momentum. The method of proper time reconstruction is described in detail in [7] and [8].

The lepton–jet charge sample is selected from about two million hadronic Z decays recorded in 1994 and 1995.

Event Selection and Jet Charge Reconstruction

The cuts applied to select hadronic events and identify lepton candidates are described in [8]. In the present analysis the selected events contain one identified lepton with high momentum and high tranverse momentum. If more such leptons are found, the most energetic one is considered. Hereafter *same* side (or hemisphere) denotes the hemisphere containing this lepton.

Secondary vertex must be reconstructed in both hemispheres. Although the reconstruction of secondary vertex in the *opposite* hemisphere is not necessary for the analysis, requiring it increases the probability that the event is b-flavored from 80% to 85%. This increase in sample purity outweighs the 48% loss in efficiency as the oscillation signal becomes more pronounced and the error on the frequency smaller.

The jet charge is defined as the weighted sum of charges in one hemisphere. The hemisphere is determined by the direction of the thrust axis. In the sum

$$Q_{jet} = \frac{\sum_i w_i q_i}{\sum_i w_i} \tag{1}$$

q_i is the charge of the ith track in the hemisphere and its weight, w_i, is proportional to a power function of the longitudinal component of the track's momentum with respect to the thrust axis:

$$w_i = C \left(\vec{p} \cdot \frac{\vec{T}}{|\vec{T}|} \right)^{\kappa} . \tag{2}$$

In the hadronization process the meson that contains the primordial quark carries, on average, a large fraction of the quark's momentum. As a result, its decay products tend to be the most energetic too. This choice gives a greater weight to tracks with higher momentum and consequently to the charges originating from the meson containing the primordial quark.

In order for a track to be included in the jet charge sum, the following requirements have to be met:

- 0.5 GeV $< p_\perp <$ 50 GeV, where $p_\perp$ is the momentum measured in the r-ϕ plane,
- the track must have at least 10 hits in the TEC, with the first and the last hits being at least 20 sense wires apart, and
- the track's distance of closest approach (DCA) to the average position of collision must be less than 20 mm.

These are somewhat less stringent criteria than those used for tracks in the vertexing to ensure that as many tracks enter the sum as are reasonably likely to come from the interaction region and be assigned the correct charge. Figure 1 shows the comparison of the distribution of the number of tracks in the sum for real data and Monte Carlo events.

To obtain a good reliability, those tracks which are more likely to be assigned the wrong charge should carry a smaller weight in the sum. Coefficient C is therefore chosen to be the probability of correct track charge assignment. Since this probability decreases as the track passes nearer to the anode wire plane in the TEC, C depends on the azimuthal angle: $C = C(\phi)$. Function $C(\phi)$ is determined through studying Bhabha events.

The power κ is found in Monte Carlo studies by maximizing the probability of reconstructing the correct jet charge. The maximum is found with $\kappa = 0.4$ (see figure 2).

The reliability of the primordial quark flavor determination is further improved by taking into account the jet charge in the *same* hemisphere as well. Special care has to be taken however as the *same* hemisphere contains the lepton tagging the flavor at the instant of decay, and this can give rise to a significant correlation between the lepton charge and the jet charge. Indeed, the jet charge of the *same* hemisphere calculated in the same way as described above does exhibit a rather strong correlation with the mixing. This is due to the high momentum of the lepton from the semileptonic B^0 decay because that gives its charge a large weight in the sum (2). In order to decrease correlation, the momentum dependence of the weight is eliminated by setting $\kappa = 0$. Thus the tagging variable is

$$Q_{2jet} = Q_{same}^{\kappa=0} - Q_{opp}^{\kappa=0.4} . \tag{3}$$

Figure 3 shows the comparison of the jet charge distributions for real data and Monte Carlo events.

To increase the separation power of the method, events with small $|Q_{2jet}|$ are rejected. This way the region of low correct reconstruction probability is excluded (see figure 4(a)). The effect of this on the correct fraction and the efficiency of the reconstruction is shown in figure 5. Reliability is defined as the ratio of the number of correctly reconstructed jet charges to all, $r = N_{cor}/(N_{cor}+N_{inc})$, and efficiency as the ratio of the number of all reconstructed jet charges to the number of all reconstructed jet charges with no cut, $\epsilon = (N_{cor}+N_{inc})/N_{no\ cut}$. The cut is found by maximizing the expected statistical significance of the signal which is proportional to $(N_{cor}-N_{inc})/\sqrt{N_{cor}+N_{inc}} = (2r-1)\sqrt{\epsilon}$. The maximum is found with the cut $|Q_{2jet}| > 0.12$. This gives a reliability of 71% (72% for unmixed events and 67% for mixed events) at an efficiency of 73%.

Likelihood Function

In order to extract the oscillation frequency, an unbinned maximum likelihood fit is performed. The total likelihood of the data sample is the product of the event likelihoods:

$$\mathcal{L} = \prod_{like\ sign\ events} \mathcal{L}_{like} \prod_{unlike\ sign\ events} \mathcal{L}_{unlike}\,. \tag{4}$$

The form of the event likelihood function is different for events with like and unlike signed lepton – jet charge combination:

$$\begin{aligned}
\mathcal{L}_{like}(t) &= R^{mix}(t)(1-P^{mix}_{2jet}) + W^{mix}(t)P^{mix}_{2jet} \\
&+ R^{unm}(t)(1-P^{unm}_{2jet}) + W^{unm}(t)P^{unm}_{2jet} \\
&+ F_{cc}w_{cc}Q_{cc}(t) \\
&+ F_{uds}w_{uds}Q_{uds}(t) \\
\mathcal{L}_{unlike}(t) &= R^{mix}(t)P^{mix}_{2jet} + W^{mix}(t)(1-P^{mix}_{2jet}) \\
&+ R^{unm}(t)P^{unm}_{2jet} + W^{unm}(t)(1-P^{unm}_{2jet}) \\
&+ F_{cc}(1-w_{cc})Q_{cc}(t) \\
&+ F_{uds}(1-w_{uds})Q_{uds}(t)
\end{aligned} \tag{5}$$

where P^{mix}_{2jet} (P^{unm}_{2jet}) is the reliability of the jet charge reconstruction in b-flavored events with (without) mixing, i.e., the probability of correctly determining the charge of the primordial b or $\bar{\mathrm{b}}$ quark. $R^{mix}(t)$ ($R^{unm}(t)$) is the probability to find, at proper time t, a lepton with the "right" sign of charge (the sign expected from the primordial quark decay without mixing) in a mixed (unmixed) event. The "wrong" sign probability for mixed (unmixed) events, $W^{mix}(t)$ ($W^{unm}(t)$), is expressed as

$$\begin{aligned}
W^{mix}(t) &= F_{bl}(1-w_{bl})M_{bl}(t) \\
&+ F_{bcl}(1-w_{bcl})M_{bcl}(t) \\
&+ F_{bfk}(1-w_{bfk})M_{bfk}(t)
\end{aligned} \tag{6}$$

and

$$\begin{aligned}
W^{unm}(t) &= F_{bl}w_{bl}(D_{bl}(t)+U_{bl}(t)) \\
&+ F_{bcl}w_{bcl}(D_{bcl}(t)+U_{bcl}(t)) \\
&+ F_{bfk}w_{bfk}(D_{bfk}(t)+U_{bfk}(t))\,.
\end{aligned} \tag{7}$$

$R^{mix}(t)$ ($R^{unm}(t)$) can be obtained from equation 6 (equation 7) by exchanging w and $1-w$.

In the above equations

F_{bl}, F_{bcl}, F_{bfk}, F_{cc}, F_{uds}	are the fractions of the various types of events,
$M_{bl}(t)$, $M_{bcl}(t)$, $M_{bfk}(t)$	the probabilities of a mixed B^0 meson decaying at a reconstructed time t in various types of b events,
$U_{bl}(t)$, $U_{bcl}(t)$, $U_{bfk}(t)$	the probabilities of an unmixed B^0 meson decaying at a reconstructed time t in various types of b events,
$D_{bl}(t)$, $D_{bcl}(t)$, $D_{bfk}(t)$	the probabilities of a b-hadron other than B^0 decaying at a reconstructed time t in various types of b events,
$Q_{cc}(t)$, $Q_{uds}(t)$	the reconstructed decay time distributions of Monte Carlo c and light quark events
w_{bl}, w_{bcl}, w_{bfk}	the probabilities of finding a "wrong" sign lepton for reasons other than mixing in b-flavored events, and
w_{cc} and w_{uds}	the probabilities of a like sign event in c and light flavored events.

The indices used above refer to the following types of events:

bl	$\mathrm{b} \to \ell^-$, $\mathrm{b} \to \tau^- \to \ell^-$
bcl	$\mathrm{b} \to \mathrm{c} \to \ell^+$, $\mathrm{b} \to \bar{\mathrm{c}} \to \ell^-$ and $\mathrm{b} \to \mathrm{J}/\Psi \to \ell^+\ell^-$
bfk	$\mathrm{b} \to fake\ \ell$
cc	$\mathrm{c}\bar{\mathrm{c}}$ events
uds	light quark ($\mathrm{u}\bar{\mathrm{u}}$, $\mathrm{d}\bar{\mathrm{d}}$ or $\mathrm{s}\bar{\mathrm{s}}$) events.

The probabilities of a mixed B^0 decaying at a reconstructed time t ($M_{bl}(t)$,...) are obtained by convoluting the theoretical probability densities multiplied by the proper time reconstruction efficiency function $\epsilon(t')$ (see figure 6) with a resolution function $R(t,t')$. $R(t,t')$ describes the probability of finding an event at the measured time t if it actually occurred at time t'.

$$\begin{aligned} M_{bl}(t) &= M_{bcl}(t) = M_{bfk}(t) \\ &= f_d \int_0^\infty \frac{\epsilon(t')}{N_d} \frac{1}{\tau_d} e^{-\frac{t'}{\tau_d}} \frac{1-\cos\Delta m_d t'}{2} R(t,t')\, dt' \\ &+ f_s \int_0^\infty \frac{\epsilon(t')}{N_s} \frac{1}{\tau_s} e^{-\frac{t'}{\tau_s}} \frac{1-\cos\Delta m_s t'}{2} R(t,t')\, dt' \end{aligned} \tag{8}$$

where Δm_d and Δm_s are the oscillation frequencies of B^0_d and B^0_s mesons. The corresponding probabilities for unmixed decays ($U_{bl}(t)$,...) can be obtained from equation 8 by replacing the minus sign before $\cos\Delta m_d t'$ with a plus sign. Similarly, the probabilities of the other b-hadrons decaying at a reconstructed time t are given by

$$D_{bl}(t) = D_{bcl}(t) = D_{bfk}(t) \;=\; f_u \int_0^\infty \frac{\epsilon(t')}{N_u} \frac{1}{\tau_u} e^{-\frac{t'}{\tau_u}} R(t,t')\, dt'$$

$$+ \quad f_{\Lambda_b} \int_0^\infty \frac{\epsilon(t')}{N_{\Lambda_b}} \frac{1}{\tau_{\Lambda_b}} e^{-\frac{t'}{\tau_{\Lambda_b}}} R(t,t')\, dt' \ . \tag{9}$$

f_d, f_u, f_s and f_{Λ_b} denote, respectively, the B^0_d, $B^\pm_u$, B^0_s and b-baryon fractions in the sample of all b-hadrons. The normalization factors N_i ($i = d, s, u, \Lambda_b$) are defined by the requirements

$$\int_{-\infty}^{\infty} dt \int_0^\infty dt' \, \frac{\epsilon(t')}{N_i} \frac{1}{\tau_i} e^{-\frac{t'}{\tau_i}} R(t,t') = 1 \ . \tag{10}$$

The resolution function, $R(t,t')$, has an explicit dependence on the true decay time, t', therefore we parametrize it in 11 intervals. In each interval the resolution is parametrized with the sum of three Gaussians.

The w factors and the fractions F are determined from the Monte Carlo and listed in table 1.

source	F	w
$\mathrm{b} \to \ell$	0.854	0.004
$\mathrm{b} \to \mathrm{c} \to \ell$	0.092	0.86
fake ℓ	0.029	0.26
$\mathrm{c\bar{c}}$-events	0.018	0.38
$\mathrm{u\bar{u}}, \mathrm{d\bar{d}}, \mathrm{s\bar{s}}$-events	0.007	0.44

Table 1: Fractions F and factors w from Monte Carlo.

Fitting Procedure and Results

Nine parameters are allowed to vary in the fit to the data sample of years 94 and 95, with 8707 events in total. They are the oscillation frequency of the B^0_d meson Δm_d, the probabilities P^{unm}_{2jet} and P^{mix}_{2jet} of correctly determining the primordial quark flavor by the jet charge in unmixed and mixed events, respectively, the life times of B^0_d (τ_d), $B^\pm_u$ (τ_u), B^0_s (τ_s) and Λ_b (τ_{Λ_b}), and the Λ_b and B^0_s fractions in $\mathrm{b\bar{b}}$ events, f_{Λ_b} and f_s. The first two parameters vary freely whereas Gaussian constraints are applied to the last seven.

Figure 7 shows the fitted decay time distribution. The like sign fraction, defined as the ratio of the number of events with like sign lepton – jet charge combination to the number of all events, is plotted in figure 8 for data and the fitting function.

The central value of P^{mix}_{2jet} is set to its Monte Carlo value. Its uncertainty is estimated as follows. An analogous fit is performed with the jet charge in the *opposite* hemisphere ($Q^{\kappa=0.4}_{opp}$, cf. equation 3) as tagging variable. As $Q^{\kappa=0.4}_{opp}$ exhibits no correlation with the mixing on the *same* side, $P_{jet} = P^{unm}_{jet} = P^{mix}_{jet}$. The fit yields $P_{jet} = 0.634 \pm 0.012$, whereas the Monte Carlo value is $P^{MC}_{jet} = 0.66 \pm 0.005$. The difference between them is used as an estimate of the uncertainty of P^{mix}_{2jet}.

The central values and uncertainties for the fractions f_{Λ_b} and f_s are the same as in the dilepton fit [9]. f_d and f_u are derived assuming that $f_d = f_u$ and $f_d + f_u + f_s + f_{\Lambda_b} = 1$. The central values and uncertainties of the b-hadron life times are taken from [12]. We also impose a Gaussian constraint on the sum of the b-hadron life times weighted by their fractions, $\tau = f_d\tau_d + f_u\tau_u + f_s\tau_s + f_{\Lambda_b}\tau_{\Lambda_b}$, requiring it to be compatible with the world average value of the average b-hadron life time, $\tau = 1.549 \pm 0.02$ps [12].

Near maximal mixing is assumed for B^0_s with $\Delta m_d = 10\,\mathrm{ps}^{-1}$.

Parameter	Fit result	Constraint
Δm_d	0.437 ± 0.060 ps^{-1}	none
P_{2jet}^{unm}	0.733 ± 0.011	none
P_{2jet}^{mix}	0.679 ± 0.029	0.670 ± 0.030
τ_d	1.60 ± 0.05 ps	1.56 ± 0.06 ps
τ_u	1.64 ± 0.05 ps	1.62 ± 0.06 ps
τ_s	1.63 ± 0.10 ps	1.61 ± 0.10 ps
τ_{Λ_b}	1.11 ± 0.08 ps	1.14 ± 0.08 ps
f_{Λ_b}	0.089 ± 0.025	0.087 ± 0.029
f_s	0.101 ± 0.016	0.102 ± 0.016

Table 2: The result of the fit.

The fit results are given in table 2. The error on Δm_d includes both the statistical error and the contributions from the errors of all other fitted parameters. To obtain the statistical error, we perform a one-parameter fit of Δm_d with the other parameters fixed to their fitted values. With the purely statistical error, the result is

$$\Delta m_d = 0.437 \pm 0.043 \text{ (stat) ps}^{-1}\,.$$

The total systematic error due to the fitted parameters is calculated by subtracting in quadrature the statistical error from the error of the multiparameter fit. Its value is 0.041 ps^{-1}. The contribution of each fitted parameter to this systematic error is estimated by the shift of the fitted value of Δm_d in an eight-parameter fit in which the parameter under study is fixed to its fitted value plus its fit error. Due to correlations, the sum in quadrature of the contributions obtained this way is not equal to the total systematic error due to the fitted parameters calculated above. To illustrate the breakdown of the systematic error, we assume, for simplicity, that the contributions are not correlated and scale them so that their sum in quadrature is equal to the total systematic error above. This procedure does not affect the final errors.

Parameter	Contribution to the error [ps^{-1}]
P_{2jet}^{unm}	0.037
P_{2jet}^{mix}	0.015
f_{Λ_b}	0.004
f_s	0.001
τ_d	0.002
τ_u	0.004
τ_s	0.002
τ_{Λ_b}	0.002
total	0.041

Table 3: Estimation of the contributions to the error on Δm_d from fitted parameters. The values are scaled to yield the total systematic error if no correlation is assumed.

The contributions to the systematic error from the non-fitted, fixed parameters are estimated to be the shift of the fitted value of Δm_d in nine-parameter fits in which the parameter in question is shifted from its original value by its estimated uncertainty. The cascade decay fraction F_{bcl} is set to its Monte Carlo value in table 1. Its contribution is found by shifting its value by 15%. The oscillation frequency of the $\mathrm{B_s^0}$ meson, Δm_d, is varied between its current lower limit, 8 ps^{-1} [11], and 20 ps^{-1}. The other uncertainties are the same as those in the dilepton method [9]. Table 4 lists these contributions and their sum in quadrature.

Source of uncertainty	Variation of Δm_d [ps^{-1}]
F_{bcl}	0.002
fake ℓ fraction	0.001
$\mathrm{c\bar{c}}$ fraction	0.001
uds fraction	0.002
time resolution	0.009
B momentum	0.007
w_{bl}	0.001
w_{bcl}	0.001
w_{bfk}	0.001
w_c	0.002
w_{uds}	0.004
Δm_s	0.004
total	0.014

Table 4: Contributions to the systematic error on Δm_d from the fix parameters.

The overall systematic error is the sum in quadrature of the contributions from all sources in tables 3 and 4. The final result of the Δm_d measurement is

$$\Delta m_d = 0.437 \pm 0.043 \text{ (stat)} \pm 0.044 \text{ (syst) ps}^{-1}$$

or, in units of eV/c^2

$$\Delta m_d = (2.88 \pm 0.34 \text{ (stat)} \pm 0.29 \text{ (syst)}) \times 10^{-4} \mathrm{eV}/c^2 \ .$$

References

[1] C. Albajar *et al.*, Phys. Lett. **B 186** (1987) 247.

[2] ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. **B 192** (1987) 245;
ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. **B 324** (1994) 249;
CLEO Collaboration, J. Bartelt *et al.*, Phys. Rev. **D 50** (1994) 43.

[3] ALEPH Collaboration, D. Decamp *et al.*, Phys. Lett. **B 284** (1992) 177;
DELPHI Collaboration, P. Abreu *et al.*, Phys. Lett. **B 332** (1994) 488;
L3 Collaboration, M. Acciarri *et al.*, Phys. Lett. **B 335** (1994) 542;
OPAL Collaboration, R. Akers *et al.*, Z. Phys. **C 60** (1993) 199.

[4] ALEPH Collaboration, D. Buskulic *et al.*, Phys. Lett. **B 313** (1993) 498;
ALEPH Collaboration, D. Buskulic *et al.*, Phys. Lett. **B 322** (1994) 441.

[5] DELPHI Collaboration, P. Abreu *et al.*, Phys. Lett. **B 338** (1994) 409.

[6] OPAL Collaboration, R. Akers *et al.*, Phys. Lett. **B 327** (1994) 411;
OPAL Collaboration, R. Akers *et al.*, Phys. Lett. **B 336** (1994) 585.

[7] L3 internal note 1913.

[8] L3 Collaboration, M. Acciarri *et al.*, Phys. Lett. **B 383** (1996) 487.

[9] L3 internal note 2058 (revised).

[10] OPAL Collaboration, R. Akers *et al.*, Z. Phys. **C 66** (1995) 555.

[11] L3 Internal note 2087.

[12] Particle Data Group, Phys. Rev. D54 (1996).

List of Figures

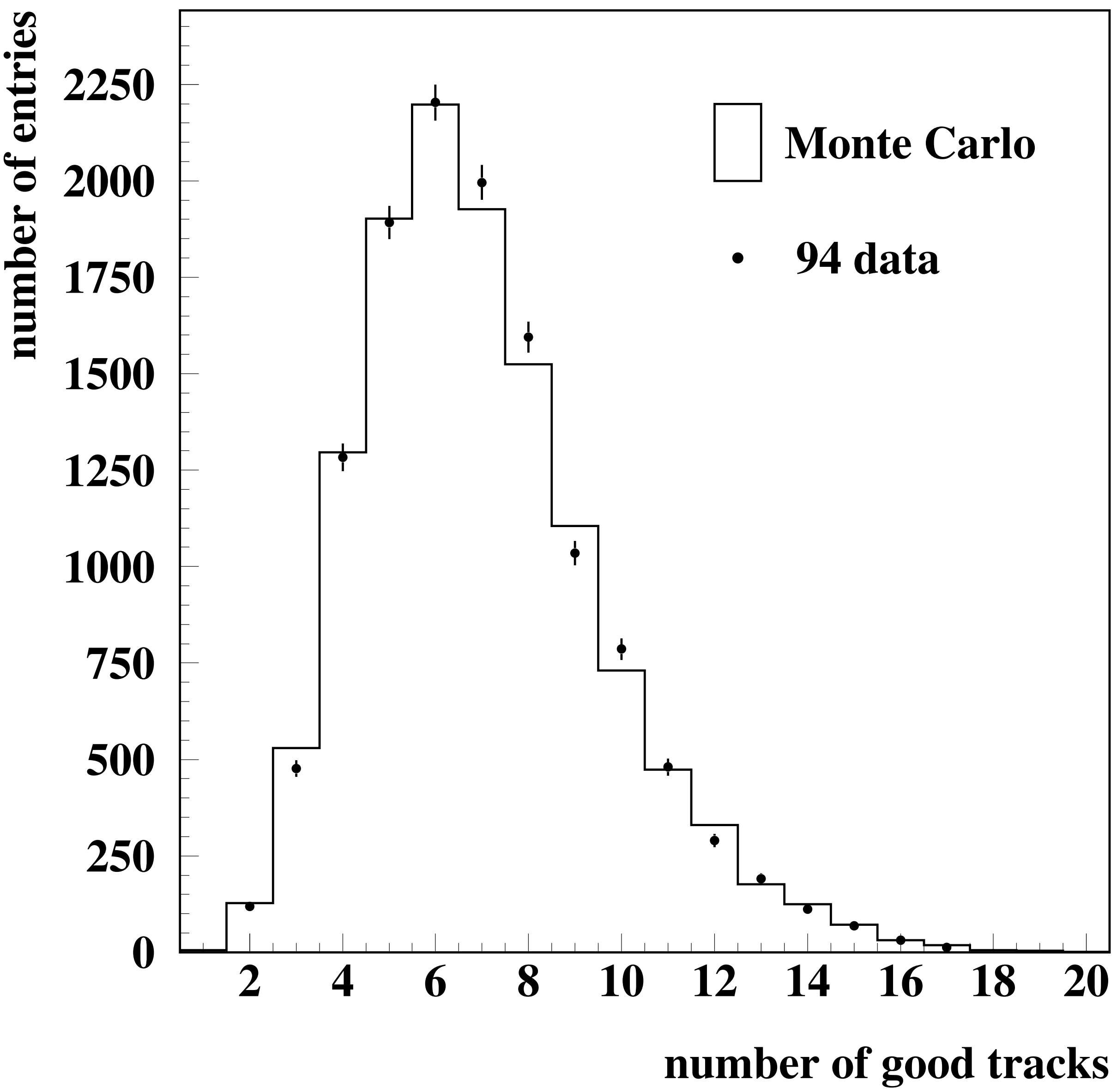

Figure 1: The distribution of the number of tracks used in the jet charge reconstruction for data and Monte Carlo. The Monte Carlo histogram is normalized to contain exactly as many events as are in the data.

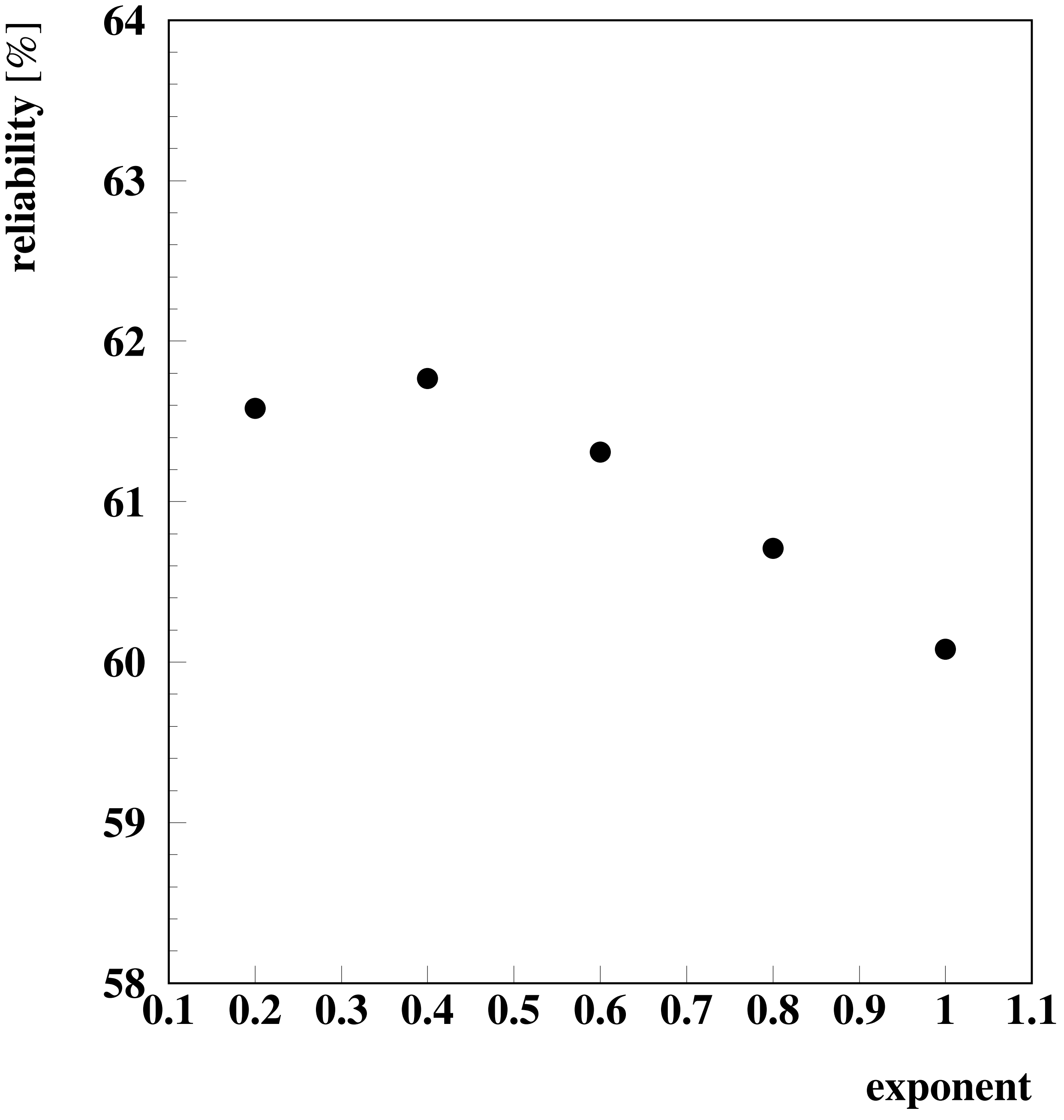

Figure 2: The probability of correct jet charge reconstruction in the *opposite* hemisphere as a function of the exponent κ in the weight (equation 2).

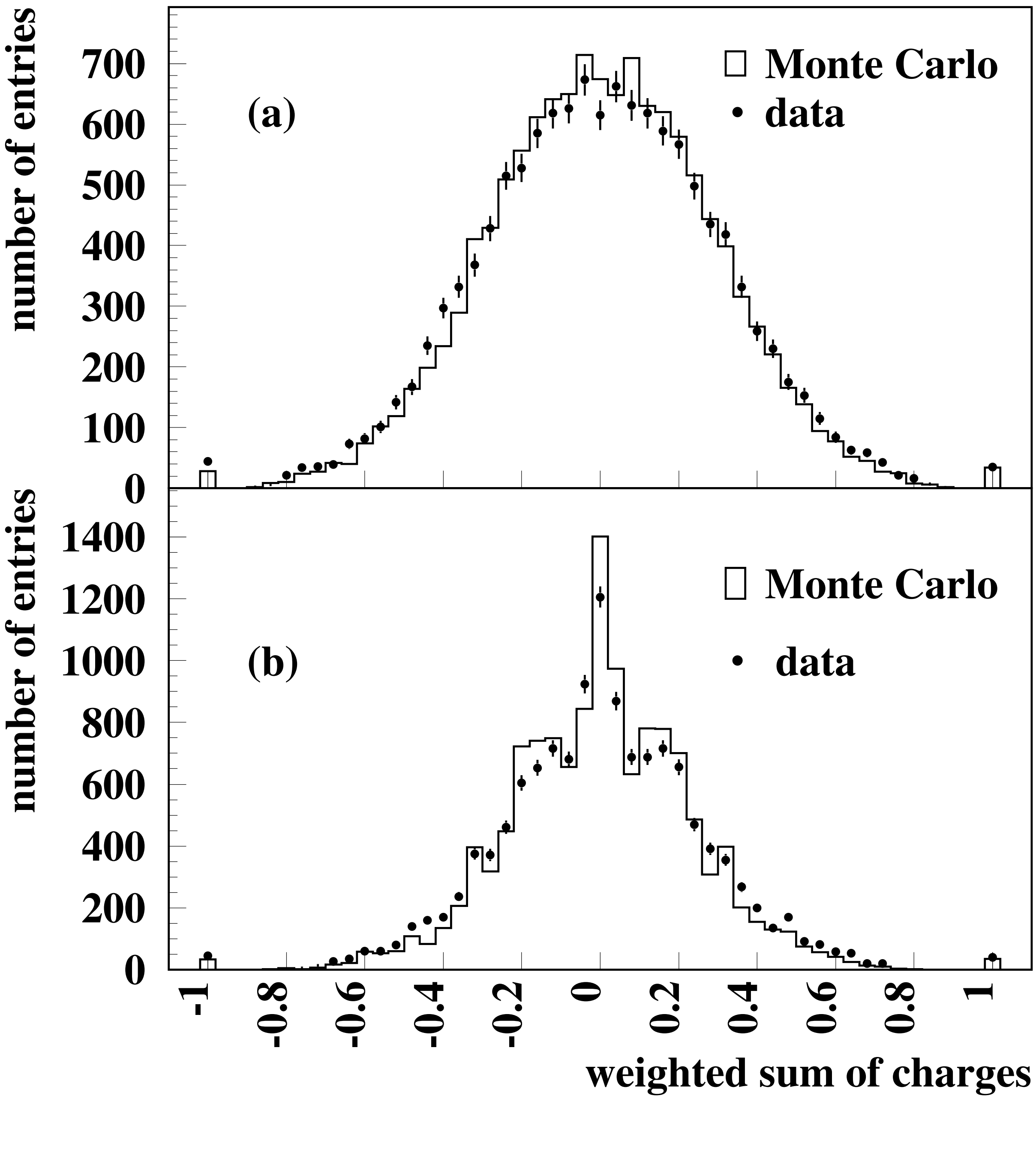

Figure 3: The distributions of the jet charge sum for data and Monte Carlo with (a) $\kappa = 0.4$ and (b) $\kappa = 0$. The Monte Carlo histograms are made to contain exactly as many events as are in the data.

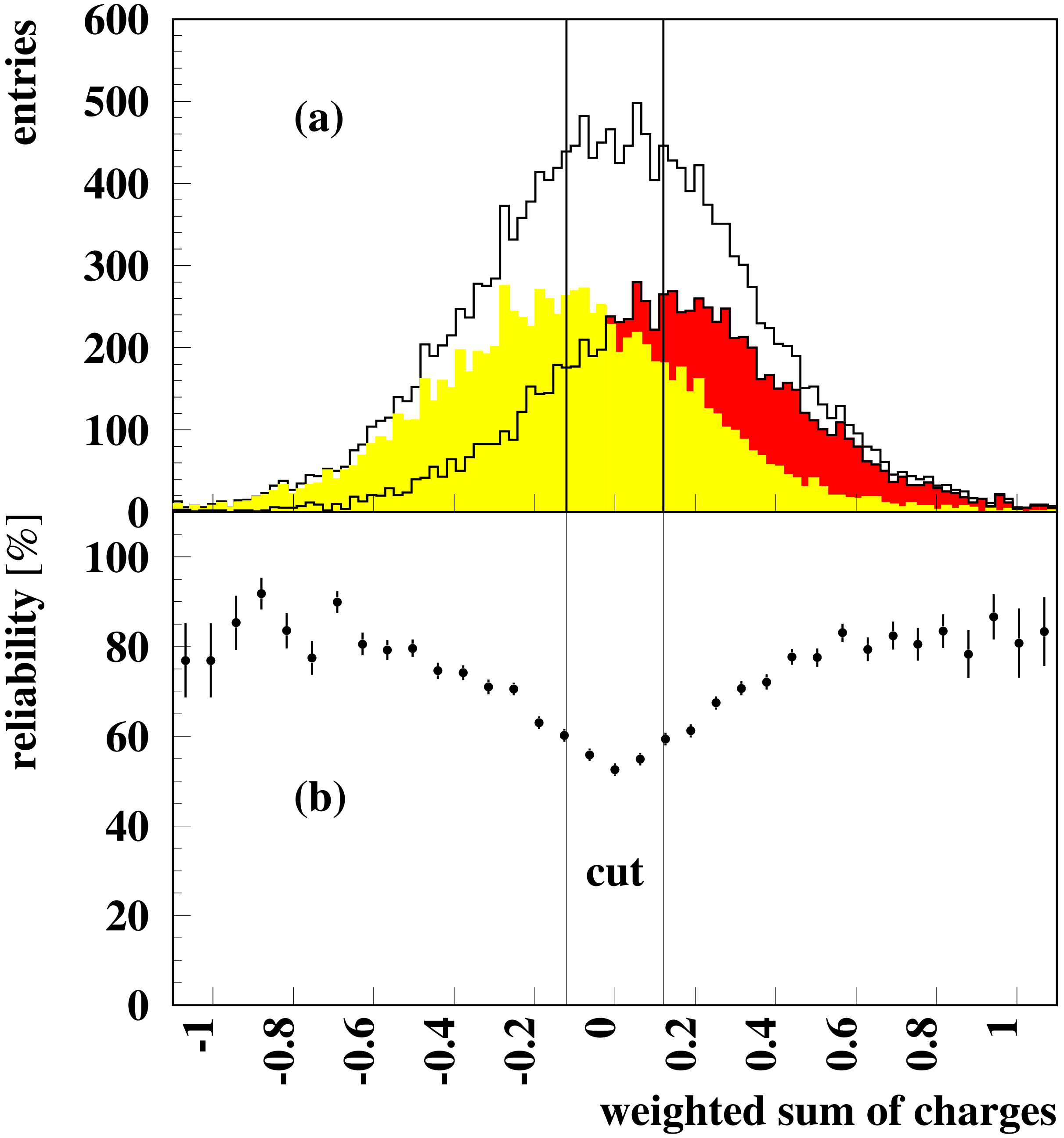

Figure 4: (a) $Q_{2jet} = Q_{same} - Q_{opp}$ for a b-quark jet (light shade) and a $\bar{\text{b}}$-quark jet (dark shade). The unshaded histogram is their sum. (b) The probability of correct jet charge reconstruction (reliability) as a function of Q_{2jet}. This probability tends to 50% at $Q_{2jet} = 0$ so the power of separation vanishes there. The two vertical lines indicate the excluded low reliability region.

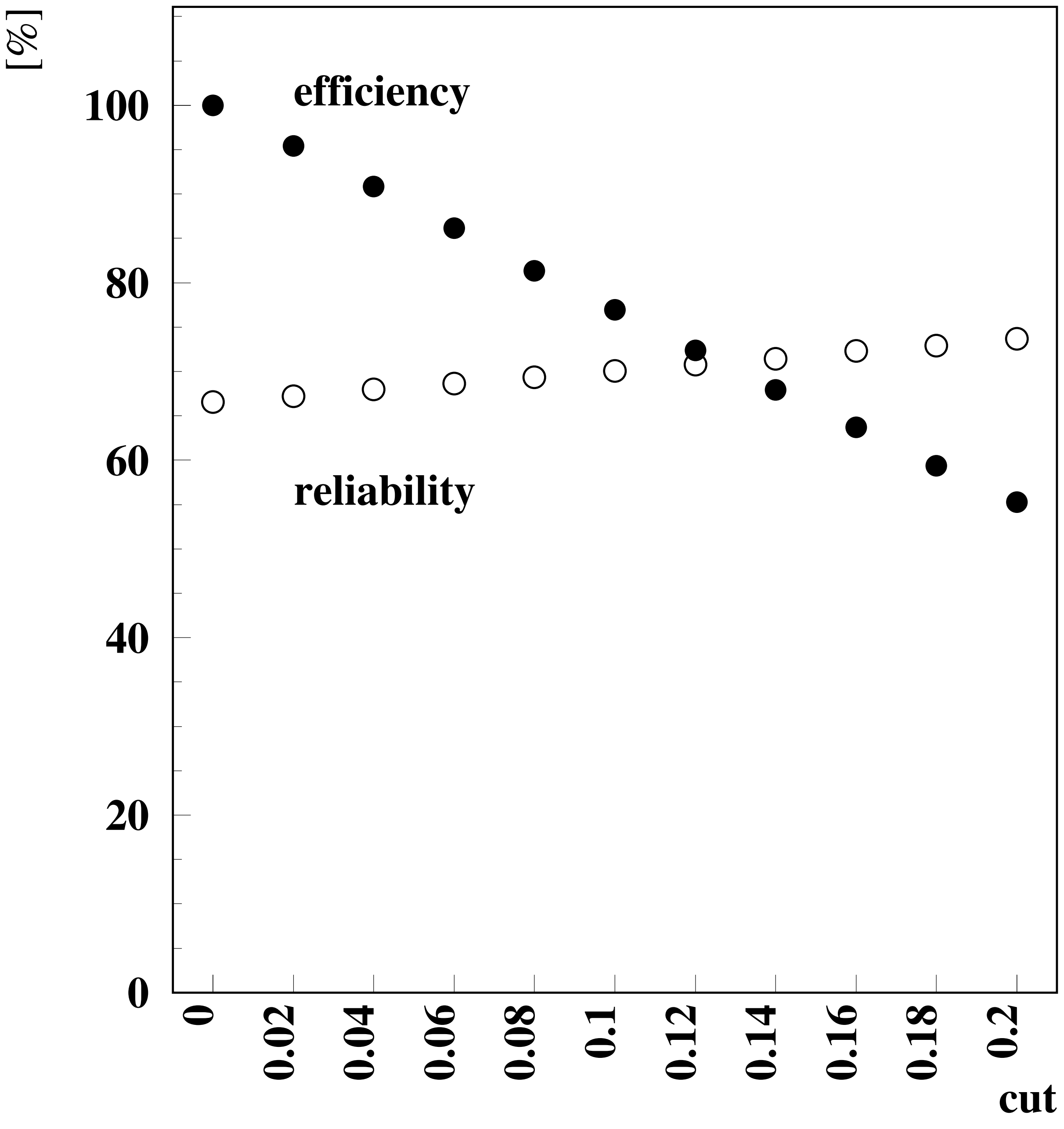

Figure 5: The reliability and efficiency of the jet charge reconstruction versus the cut on $|Q_{2jet}|$.

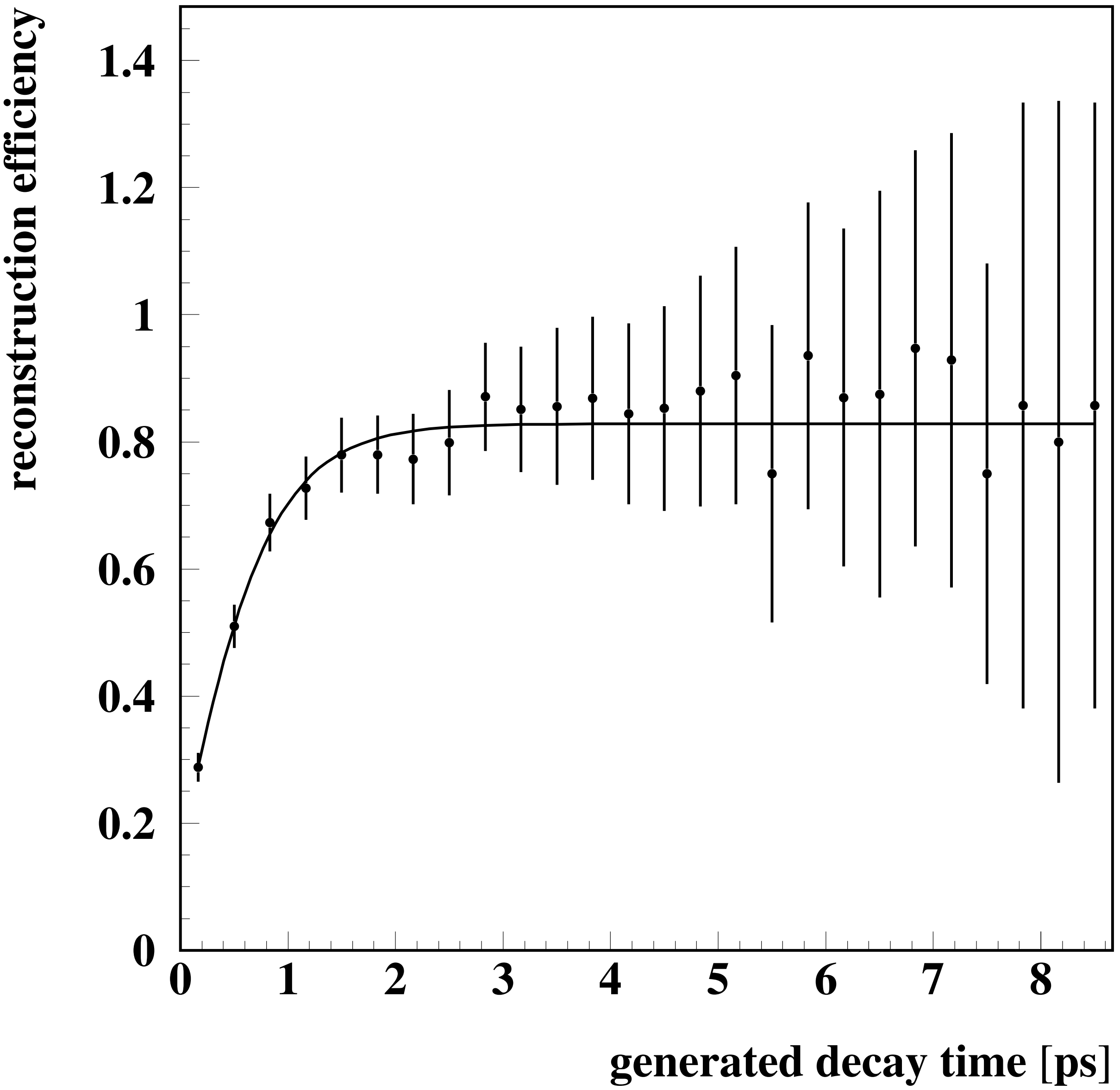

Figure 6: The time dependence of the efficiency of decay time reconstruction. The efficiency drops as the secondary vertex approaches the primary one and the ambiguity of the tracks' assignment to them increases. The solid line is the graph of the function (ϵ, see equation 8) used in the fit.

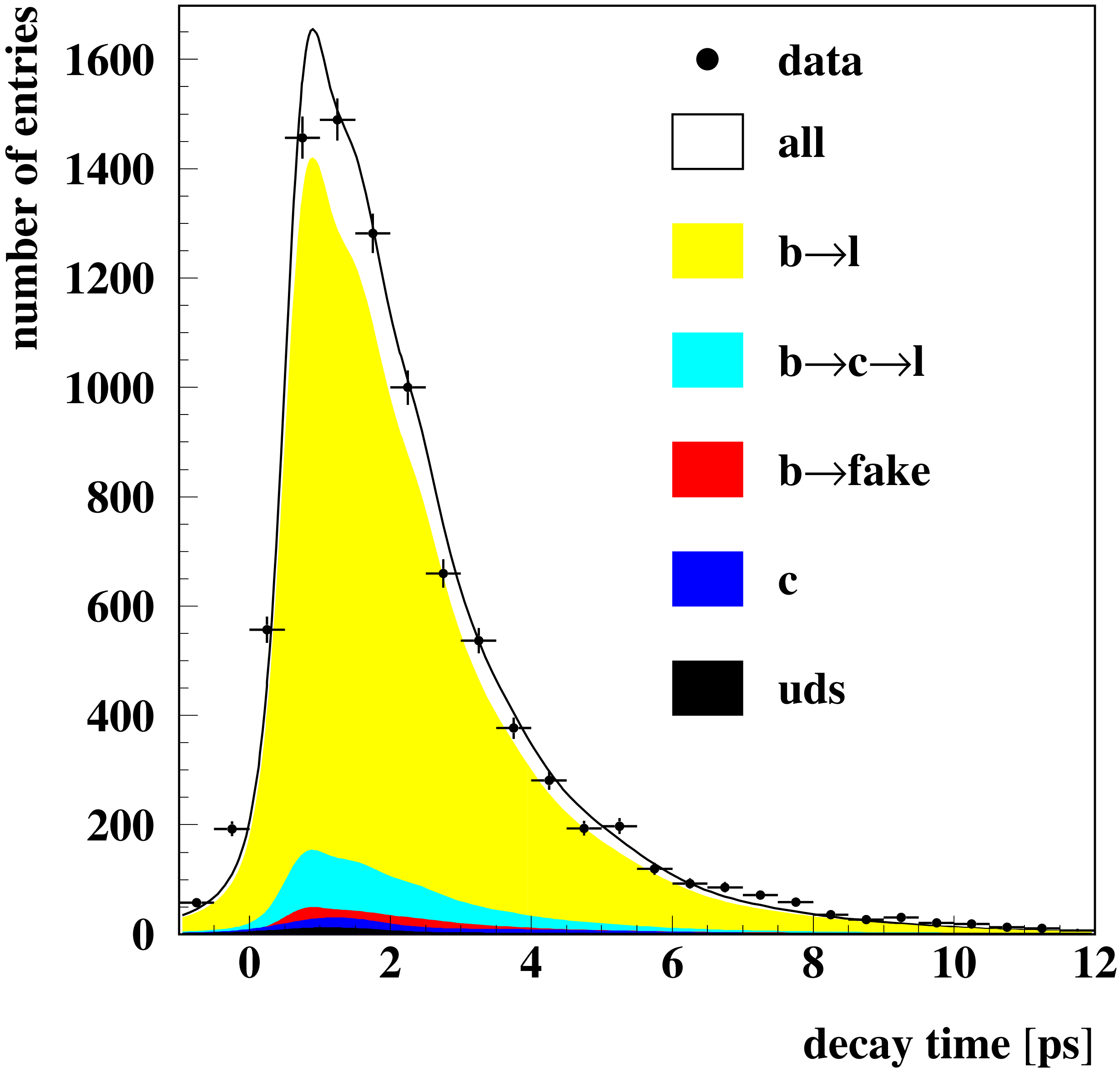

Figure 7: The distribution of the reconstructed proper decay times. The solid line is the sum of the like and unlike sign fitting functions, with the contributions from the various types of events shown in different shades.

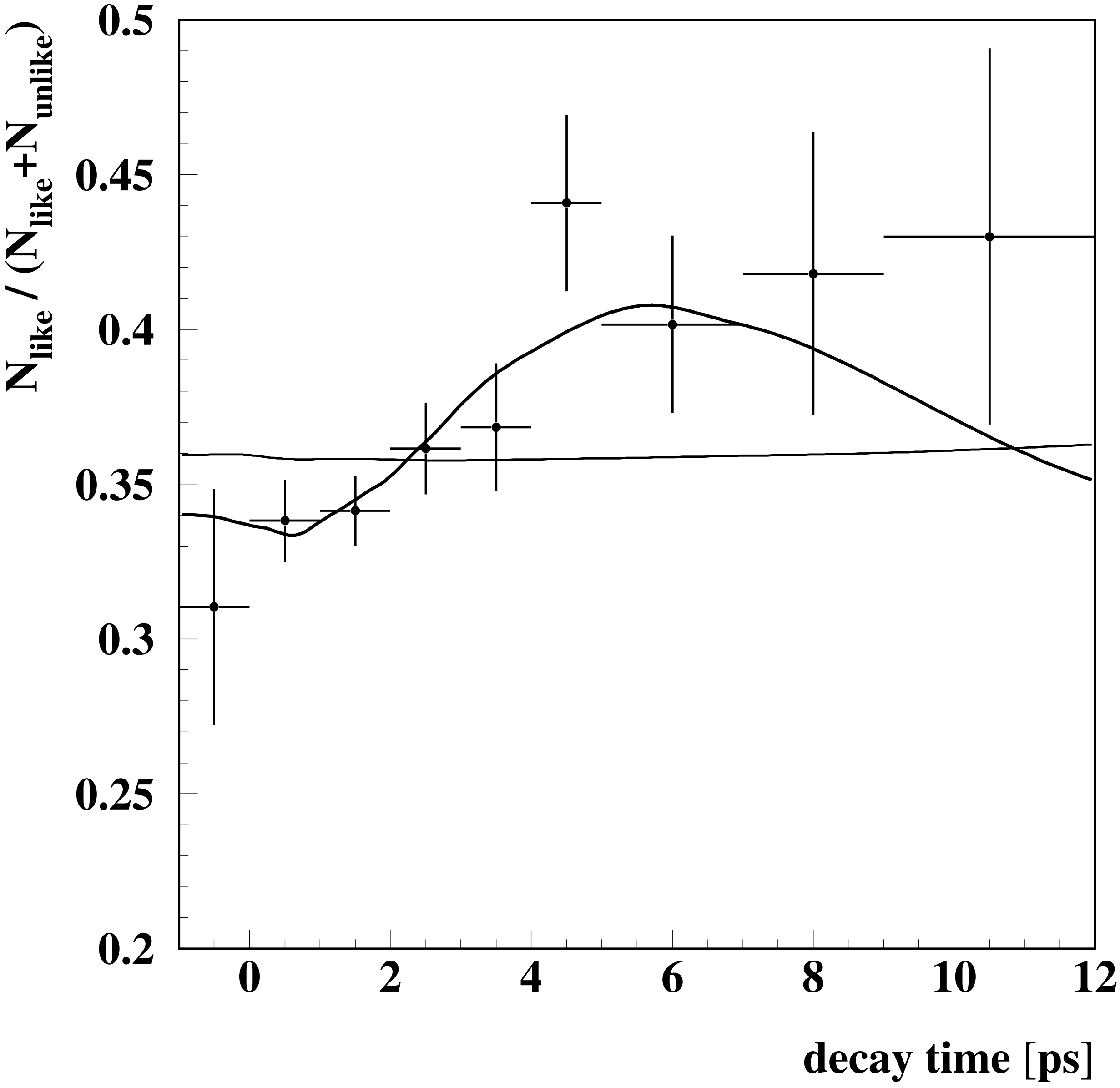

Figure 8: The ratio of events with like sign jet charge and lepton to all events. The thick curve is the same ratio for the like and the unlike sign branches of the fitting function. The nearly straight thin curve is the same, assuming time independent mixing.