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Time dependent B_s mixing from lepton-kaon correlations

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Abstract

Time dependent B_s mixing has been measured with lepton-kaon correlations where the lepton tags the B_s decay and the kaon tags the b at production. It makes use of 3 millions hadronic Z decays from 91-94 data taken with the ALEPH detector. A limit of $\Delta m_s > 3.2 ps^{-1}$ has been set with this method.

1 Introduction

We describe an analysis performed to derive a limit on the time dependent $B_s - \bar{B}_s$ oscillation parameter Δm_s. For what concerns the B tagging after an eventual mixing, we rely on the lepton sign. The method to measure the B proper time is similar to that used for the dilepton analysis [1], and by S. Emery and W. Kozanecki for the Δm_d analysis [2]. The b quark charge tagging at production time uses in this analysis the sign of identified charged kaons produced on the lepton side and originating from the primary vertex (fragmentation kaons). The kaon charge is required to agree with the charge tagging done in the opposite hemisphere (lepton sign for dilepton events, jet charge for others).

The analysis has been carried out using 3.06 million hadronic Z decays collected in 91-94 using the Aleph detector.

2 Event selection, proper time determination and charge tagging

2.1 Event selection

Events containing leptons are selected as follows:

- events are required to have at least one lepton (official HEVLEP selection) with $p > 3$GeV/c and p_T (lepton excluded) > 1.25 GeV/c;
- after a clusterization with the Jade algorithm using Y_{cut} of 0.004, it is required that the event contains at least two jets;
- the lepton momentum must be less than 0.9 E_{jet};
- the charge multiplicity in the lepton jet should be ≥ 3;
- the events are splitted into two hemispheres with respect to the thrust axis and must satisfy $cos\theta_{thrust} < 0.9$;

The events are classified in double tagged events where each hemisphere contain a high p and p_T lepton and single tagged events where only one hemisphere has a lepton. With this selection the sample composition is given in table 1 for single tagged events.

Table 1: Sample composition of the single tagged lepton events

event type	fraction %	
	e	μ
$b \to l$	82.7	73.5
$b \to \tau \to l$	1.2	1.1
$b \to c \to l$	7.7	7.9
$c \to l$	6.0	6.3
$K, \pi \to \mu$	-	6.3
photon conversions	1.0	-
Misid. hadron	1.1	3.9

2.2 Proper time determination

The B charge tagging after an eventual mixing is given by the lepton charge. The B hadron proper time in the lepton hemisphere is derived as follows:

Vertexing:

The primary vertex is determined with the QFNDIP algorithm, which has been shown to minimize the effect from secondary vertices on the primary vertex reconstruction [3]. The resolutions are $\sigma_x \simeq \sigma_y \simeq 40\mu$ and $\sigma_y \simeq 10\mu$.

The QVSRCH algorithm is used to find a secondary vertex in the direction of the lepton jet, excluding the lepton itself. It tells if a charged track belongs to the primary or the secondary vertex. Then, all the tracks assigned to the secondary vertex (we ask to have found at least 2 such tracks) are vertexed with YTOPOL to form a charm track which is vertexed with the lepton to give the B track. We call call d the distance between the primary vertex and the B vertex, projected on the B track direction. We call g, the boost factor defined as follows:

$$g = \frac{M_B}{p_B \cdot c}$$

where M_B and p_B are the B mass and momentum. The B proper time is therefore

$$t = g \cdot d$$

Each of these quantities (d, g, t) are measured for each lepton hemisphere (labelled "*reco*") and compared, using the simulation, to the generated value (labelled "*true*"). The distributions of $g_{true}.(d_{reco} - d_{true})$ are fitted with three gaussians of mean M_i (ps), rms σ_i (ps) and fraction F_i to the total $(1 < i < 3)$. The results of these fits, for primary decay B leptons, are given in table 2 for four slices of the B true proper time.

Table 2: Number of leptons and result of the 3 gaussian fit to the distribution of $g_{true}.(d_{reco} - d_{true})$, for four slices of the B true proper time and before the charm distance cut. F_i,M_i and σ_i are the fraction, mean and rms of gaussian number i. In the fit we assume M_2=M_1.

Time slice (ps)	$N_{leptons}$	F_1	M_1	σ_1	F_2	σ_2	F_3	M_3	σ_3
< 0.2	4604	0.32	0.02	0.13	0.40	0.23	0.28	0.02	0.68
0.2-0.6	7732	0.34	0.01	0.11	0.33	0.28	0.33	-0.12	0.62
0.6-1.5	11454	0.33	0.02	0.11	0.30	0.25	0.37	-0.32	0.76
> 1.5	12417	0.43	0.01	0.12	0.31	0.34	0.26	-1.37	1.70

The decay length resolution depends on the true time: at large time, we observe a negative tail (third gaussian), when QVSRCH moreless ignors the B vertex and finds the C vertex close to the primary vertex.

To improve this problem of confusion between primary and secondary vertices, it is required that the charm distance to the primary vertex is at least 300 μ. After this cut, the results of the 3 gaussian fits are given in table 3 for primary decay B leptons,

The distributions of $g_{true}.(d_{reco} - d_{true})$, after cut, for primary decay B leptons, are displayed in figure 1.

The main effect of the cut on the charm vertex distance is to decrease the tail for negative $g_{true} * \Delta d$. In addition the time resolution become less dependent of the true time, $g_{true} * (d_{reco} - d_{true})$ and $\Delta g/g$ become almost uncorrelated.

Boost reconstruction:

The boost reconstruction follows exactly what has been performed for the dilepton analysis [1]. After the charm vertex distance cut, the boost resolution $\Delta g/g$ is displayed, for primary decay B leptons, in fig.2. A resolution of $\sigma = 12\%$ is obtained fitting with only one gaussian.

Table 3: Same as table 2 but after the charm distance cut.

Time slice (ps)	$N_{leptons}$	F_1	M_1	σ_1	F_2	σ_2	F_3	M_3	σ_3
< 0.2	2794	0.52	0.05	0.14	0.31	0.38	0.17	0.20	0.97
0.2-0.6	5952	0.51	0.03	0.12	0.35	0.39	0.14	0.01	1.23
0.6-1.5	9787	0.46	0.02	0.13	0.37	0.36	0.16	-0.20	1.18
> 1.5	12122	0.48	0.01	0.13	0.34	0.38	0.18	-0.51	1.63

The effect of the charm distance cut introduces a dependence of the selection efficency with t_{true} which is parametrized from the simulation and used later in the fit.

The determination of the time resolution (decay lenght and boost) and of the selection efficiency has been done independently for cascade b leptons. For reasons of simplicity it is not shown here.

2.3 Fragmentation kaon selection: b charge tagging at production time

Kaons are required to have a momentum greater than 1.5 GeV/c. The sum of the dE/dx estimators, making the assumption that a track is first a kaon then a π, is required to be negative. The fragmentation kaon is taken as the most energetic kaon at the primary vertex (QVSRCH selection). The efficiency of the kaon selection is $22.6 \pm 0.2\%$

To enrich the secondary vertex with D_s it is required that this vertex has either 0K or 2K or 1K with a charge opposite to the lepton.

To reduce the mistag rate we require also that the product of the fragmentation kaon charge by the b charge measured in the hemisphere opposite to the lepton is negative. This b charge is the lepton charge for dilepton events or the jet charge (momentum weighting with $\kappa = 0.5$) for single lepton events. With these conditions, 4436 lepton-kaon correlations are measured in the 91-94 data.

With a Monte Carlo sample of 2.03 millions of $q\bar{q}$, we determine the mistag rate to be $(20 \pm 0.02)\%$, and the fraction of B_s to be 0.158 ± 0.006 while the input MC value is 0.11. It means that requiring a fragmentation kaon enrich our sample in B_s by a factor 1.44. The sample composition is given in table 4.

Table 4: Sample composition: f_b is the fraction of B events in the total sample, f_{bc} the fraction of cascade in the B sample, f_s and f_d the fraction of B_s ad B_d in the primary B lepton sample

source	fraction
f_b	0.914
f_{bc}	0.098
f_s	0.158
f_d	0.396

3 Likelihood fit

A l^-K^- or l^+K^+ correlation is called good sign (G) and tags an unmixed event. A l^-K^+ or l^+K^- pair is called wrong sign (W) and tags a mixed event. The log-likelihood is the sum:

$$\ln L = \ln L_G + \ln Lw$$

Summing the contributions of the measured proper time bins, one can write:

$$\ln L_{G,W} = \sum N_i^{G,W} \ln D_i^{G,W}$$

where $N_i^{G,W}$ are the measured rates and $D_i^{G,W}$ are the expected time distribution probabilities:

$$D_i^{G,W} = f_b[(1-f_{bc})P_{b\to l}^{G,W}(t_m^i) + f_{bc}C_{b\to c\to l}^{G,W}] + (1-f_b)P_{bkg}(t_m^i)$$

which explicits three components, primary and cascade b decay leptons and non b (called background).

The $(b \to l)$ probabilities are:

$$P^{G,W}(t^i_m) = f_d P^{G,W}_{B_d}(t^i_m, \Delta m_d) + f_s P^{G,W}_{B_s}(t^i_m, \Delta m_s) + (1 - f_d - f_s) P^{G,W}_{B_u}(t^i_m),$$

where the label B_u means the sum of the B_u and B baryon contributions. A similar expression can be written for the cascade probabilities $C^{G,W}(t^i_m)$

For $b \to l$ we have:

$$P^{G,W}_f(t_m) = \int P^{G,W}_f(t)\, R_b(t_m, t)\, \epsilon_b(t)\, \exp^{-\frac{t}{\tau_f}}\, dt$$

where $R_b(t_m, t)$, the time resolution function, is the probability to measure t_m when the true value is t, ϵ_b is the selection efficiency, function of the true time. The index f stands for d and s.

For $b \to c \to l$ we have a similar expression:

$$C^{G,W}_f(t_m) = \int C^{G,W}_f(t)\, R_{bc}(t_m, t)\, \epsilon_{bc}(t)\, \exp^{-\frac{t}{\tau_f}}\, dt$$

The time dependence of the charge correlation is given by the expressions:

$$P^G_f(t) = \frac{1 + A_f + B_f cos(\Delta m_f t)}{2}$$

$$P^W_f(t) = \frac{1 - A_f - B_f cos(\Delta m_f t)}{2}$$

$$P^G_u(t) = \frac{1 + A_u}{2}$$

$$P^W_u(t) = \frac{1 - A_u}{2}$$

We assume that for f =d,s and u, we have:

$$C^G_f(t) = P^W_f(t)$$

$$C^W_f(t) = P^G_f(t)$$

The coefficients A and B correspond respectively to the time independent and time dependent charge correlations. The B_s and A_s parameters are determined from the Monte-Carlo for pure $B_s \to l$ events, similarly B_d and

Table 5: A_f and B_f (where f stands for u,d,s) coefficients

Flavour	B	A
B_u	0.	0.303 ± 0.018
B_d	0.396 ± 0.061	0.028 ± 0.048
B_s	$0573 \pm 0.062.$	0.032 ± 0.032

A_d are determined from a pure Monte Carlo $B_d \rightarrow l$ sample while a B_u sample is used to determine A_u.

The corresponding numbers are displayed on table 5. Lepton-kaon charge correlations are induced by several ways. If the kaon, like the lepton, originates from the same B decay, the correlation is time-independent. This is a small effect, as it can be seen from the small values of A_s and A_d. If the kaon charge is correlated to the b quark charge at production time two cases occur.

- The correlation is time independent for B which don't mix (B_u meson and b baryons). This explains the large value of A_u.
- The correlation is time dependent for B which mix. This explains the large value of the B_d and B_s parameters. For B_d mesons the production time tagging is allowed only by the opposite hemisphere charge requirement. For B_s mesons the tagging sensitivity is enlarged (larger B_s parameter) by the leading fragmentation kaon which compensates the strangess of the B_s meson.

The background (non b) is parametrized as follows:

$$P_{bkg}^{G,W} = f_{c\bar{c}} \frac{1 \pm A_{c\bar{c}}}{2} F_{c\bar{c}}(t_m^i) + f_{no.pr.} \frac{1 \pm A_{no.pr.}}{2} F_{no.pr.}(t_m^i) + f_{mis.id.} \frac{1 \pm A_{mis.id.}}{2} F_{mis.id.}(t_m^i)$$

where $f_{c\bar{c}}$, $f_{no.pr.}$, $f_{mis.id.}$ stand for the $c\bar{c}$, the non prompt and the misidentified hadron fractions. They satisfy the relation ship:

$$f_{c\bar{c}} + f_{no.pr.} + f_{mis.id.} = 1$$

The A coefficients define the asymetry parameters, while the $F(t_m^i)$ functions correspond to the measured time distributions. Both are taken from MC. The

Table 6: Fractions and charge asymmetry parameters for the backgound

$f_{c\bar{c}}$	$f_{no.pr.}$	$A_{c\bar{c}}$	$A_{no.pr.}$	$A_{mis.id.}$
0.331	0.461	0.349	−0.015	0.049

f and A values are given in table 6. To check our sample composition and time resolution functions, a fit to the time distribution is performed. It is displayed on figure 3. The lifetime fitted on data is $1.56 \pm 0.03(stat.)$ which has to be compared to the Glasgow world average value: $1.513 \pm 0.02(stat.) \pm 0.03(syst.)$.

For the data, the charge asymetry:

$$Q^i_{asy} = \frac{N^G_i - N^W_i}{N^G_i + N^W_i}$$

is computed in each time bin i. Figure 4 displays Q_{asy} versus time. The fit result with $\Delta m_s = \infty$, where only the A_u parameter is fitted is shown. The fit gives: $A_u = 0.24 \pm 0.05$ which agrees with the Monte Carlo value of table 5.

4 Setting a Δm_s limit

4.1 Method

This is performed by calculating the difference in log likelihood for any Δm_s value and the log likelihood calculated for $\Delta m_s = \infty$. It has been done with the analytic method derived by A. Roussarie [4]. Let us recall the main formulae. The average difference in log likelihood is given by:

$$\langle \Delta\mathcal{L}(\Delta m_s) \rangle = -N \sum_{i=1} P_i(\Delta m_s, \alpha^0) \ln[\frac{P_i(\Delta m_s, \alpha^0)}{P_i(\infty, \alpha^0)}]$$

where P_i are the expected time distribution probabilities ($D_i^{G,W}$ of section 2) and where the sum over good and wrong sign distributions is made, even if it is omitted for simplicity in the expressions given here. α^0 denotes the set of all parameters (fractions f, charge correlation coefficients A and B, Δm_d

and lifetimes) on which depend the charge correlation. The best estimate of these parameters is used, the same for data and simulation, to compute $\Delta\mathcal{L}(m_s)$. The statistical rms of $\Delta\mathcal{L}(\Delta m_s)$ is given by:

$$\sigma^{stat}[\Delta\mathcal{L}(\Delta m_s)] = \sqrt{N\sum_{i=1} P_i(\Delta m_s, \alpha^0)[\ln\frac{P_i(\Delta m_s, \alpha^0)}{P_i(\infty, \alpha^0)}]^2}$$

The systematical rms of $\Delta\mathcal{L}(m_s)$ originates from the fact that the best estimate of the parameters α^0 which is used, may not correspond to the true value of the data. For instance the true value of each parameter, say α_l, may differ from the used estimate α_l^0, by a systematical spread, assumed gaussian of rms σ_{α_l}. The systematic rms of $\Delta\mathcal{L}(\Delta m_s)$ which results from this parameter uncertainty is:

$$\sigma_l^{syst}[\Delta\mathcal{L}(\Delta m_s)] = N\sigma_{\alpha_l}\sum_{i=1}\frac{\partial P_i(\Delta m_s, \alpha^0)}{\partial \alpha_l}\ln[\frac{P_i(\Delta m_s, \alpha^0)}{P_i(\infty, \alpha^0)}]$$

The total systematic error is given by adding quadratically the effects of all parameters α_l:

$$\sigma^{syst}[\Delta\mathcal{L}(\Delta m_s)] = \sqrt{\sum_l [\sigma_l^{syst}\Delta\mathcal{L}(\Delta m_s)]^2}$$

The total error is:

$$\sigma^{tot} = \sqrt{\sigma_{stat}^2 + \sigma_{syst}^2}$$

and the 95 % confidence level is obtained as:

$$\Delta\mathcal{L}^{95} = \langle\Delta\mathcal{L}(\Delta m_s)\rangle + 1.645 \times \sigma^{tot}[\Delta\mathcal{L}(\Delta m_s)]$$

It has been checked extensively that these analytical computations give the same results than a fast toy Monte Carlo. They allow a faster study of the errors, more Δm_s points, and the separation of the systematical contributions of all parameters.

4.2 Results

On figure 5 is displayed the difference in Log likelihood for the data (full line), the 95 % confidence level curve obtained with the statistical error only (open circles), the 95 % confidence level curve obtained for for both statistical and systematic error (black dots). It crosses the experimental curve at a value of $\Delta m_s = 3.2 ps^{-1}$. The stars correspond to the average of experiments generated with $\Delta m_s = \infty$. In this case, the limit is $\Delta m_s = 2.7 ps^{-1}$, therefore the experimental value is slightly lucky. The systematical errors of the parameters used in the present analysis are given is table 7 and the contributions of the main systematics to the rms of $\Delta\mathcal{L}$ are shown on fig.6 (displayed is the ratio of systematical rms over statistical rms). One can see that the main systematic at low values of Δm_s is due to the correlated parameters A_u and B_d (charge correlation for non B_s) but above Δm_s =2 ps^{-1} the contribution of f_s and B_s (oscillation amplitude for B_s mesons) dominate.

Table 7: Best estimated value and assumed systematical uncertainty of each parameter. $A_{background} = A_{no.pr.} = A_{mis.id.}, f_{background} = (1 - f_b)(f_{no.pr.} + f_{mis.id.})$

parameter	value	uncertainty
$\tau_b(ps)$	1.513	± 0.037
τ_{Bd}/τ_b	1.07	± 0.060
$\tau_{B_s}(ps)$	1.54	± 0.14
f_d	0.402*.99	$\pm 0.028 * 0.99$
f_s	0.122*1.44	$\pm 0.035 * 1.44$
$f_b(1 - f_{bc})$	0.824	± 0.037
$f_b f_{bc}$	0.090	± 0.014
$f_{c\bar{c}}(1 - f_b)$	0.028	± 0.006
$f_{background}$	0.058	± 0.012
$A_{c\bar{c}}$	0.35	± 0.10
$A_{background}$	0.0	± 0.10
Δm_d	0.50	± 0.033
B_d	0.396	± 0.13
B_s	0.573	± 0.06
A_u	0.24	± 0.02

5 Conclusion

For 91-94 data, 4436 lepton - fragmentation kaon correlations have been measured. From Monte Carlo studies, this sample has a mistag rate of 20% and the enrichment in B_s is 44%. A fast new maximum likelihood technique has been derived where the Log likelihood is calculated from the time distribution probabilities using analytic formulae. A 95 % confidence limit of $\Delta m_s > 3.2 ps^{-1}$ is set. Using the lower lifetime limit for the B_s this gives a limit $x_s (\equiv \Delta m_s/\Gamma) > 4.5$.

References

[1] D. Buskulic et al. (ALEPH Collab.) ; Phys. Lett. B 322 (1994) 441.

[2] S. Emery and W. Kozanecki; Lifetime/mixing meetings, see transparencies from the ALEPH week hels in Heidelberg October 1994.

[3] B. Marx; Study of vertex reconstruction, Aleph note 93-070

[4] A. Roussarie; Lifetime/mixing meeting, see transparencies from the meeting hold November 24^{th}, 1994.

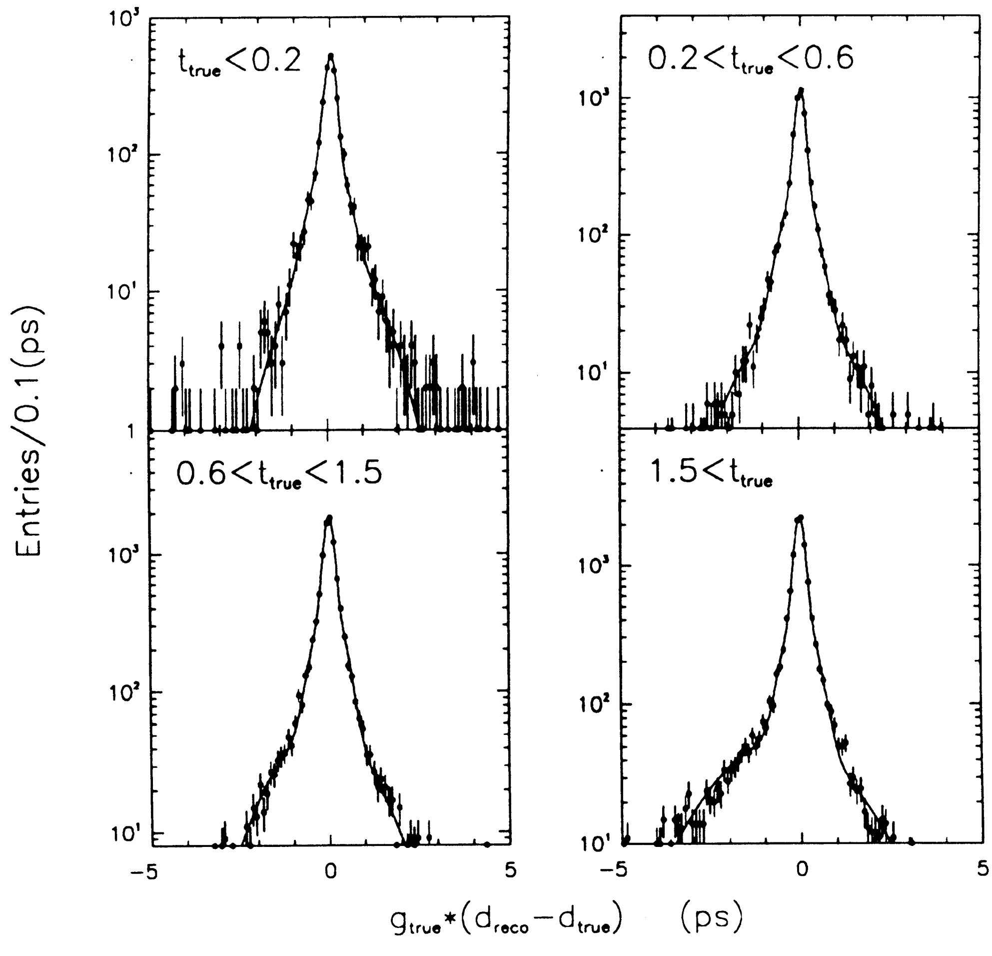

Figure 1: time resolution for different true time slices

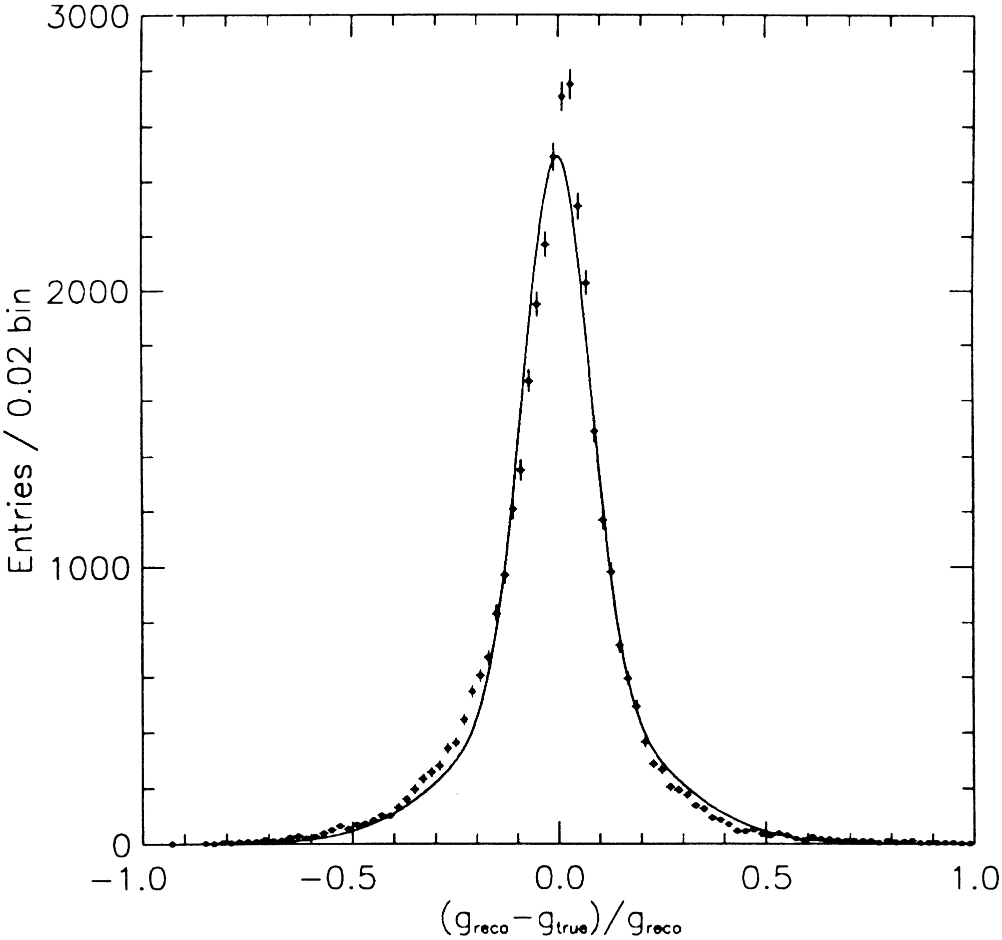

Figure 2: boost resolution

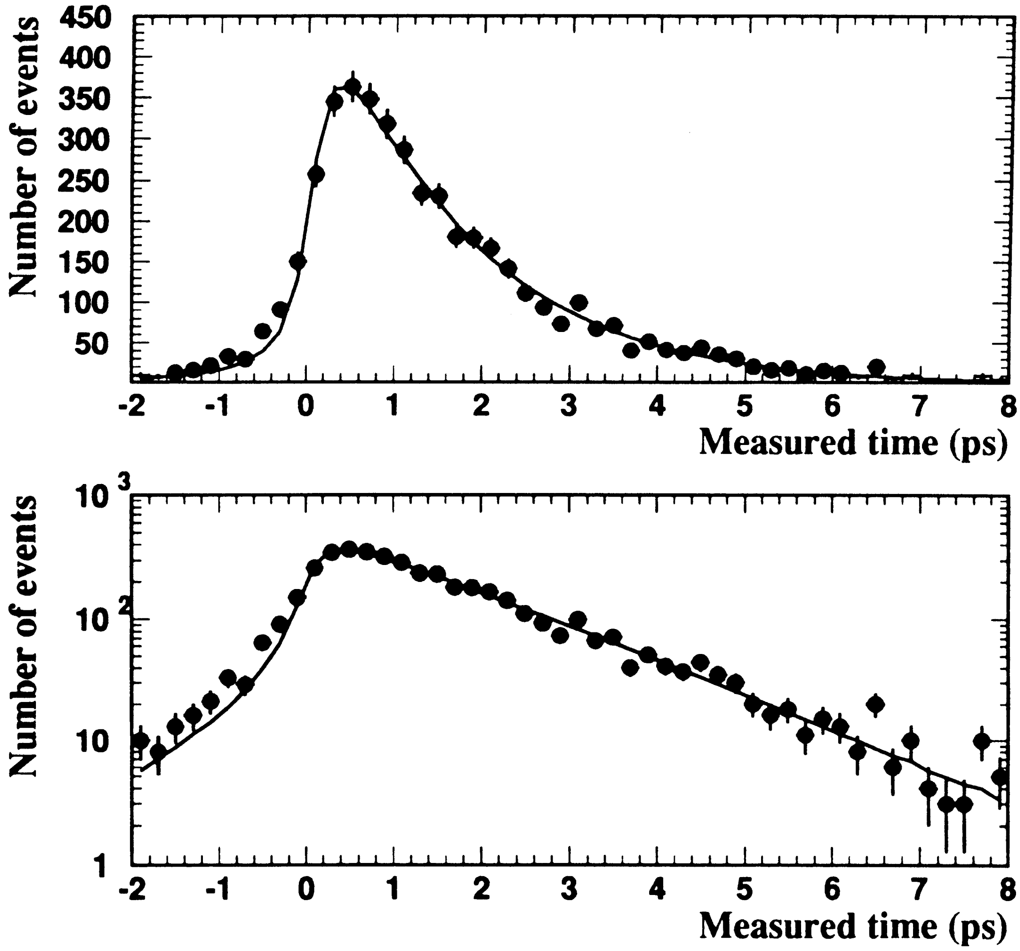

Figure 3: Lifetime fit

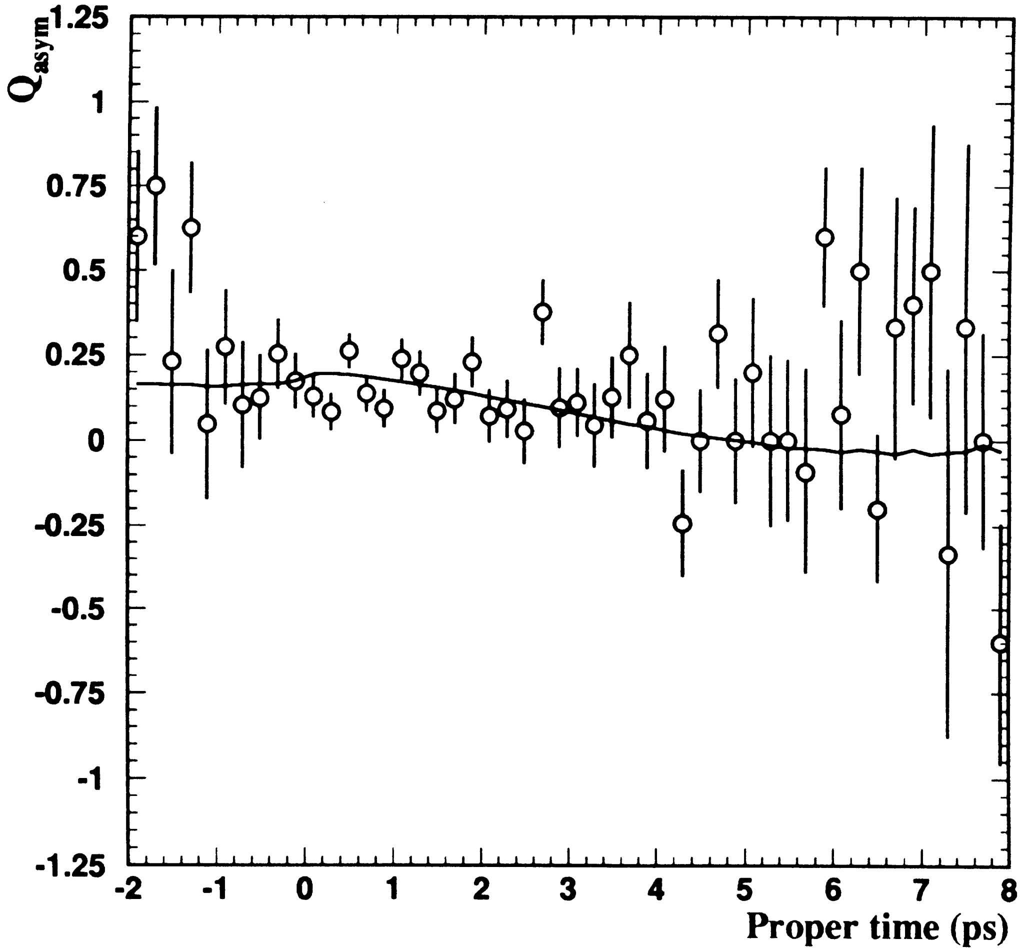

Figure 4: Charge asymetry versus time. The data points are compared to the theoritical expectation using $\Delta m_s = \infty$

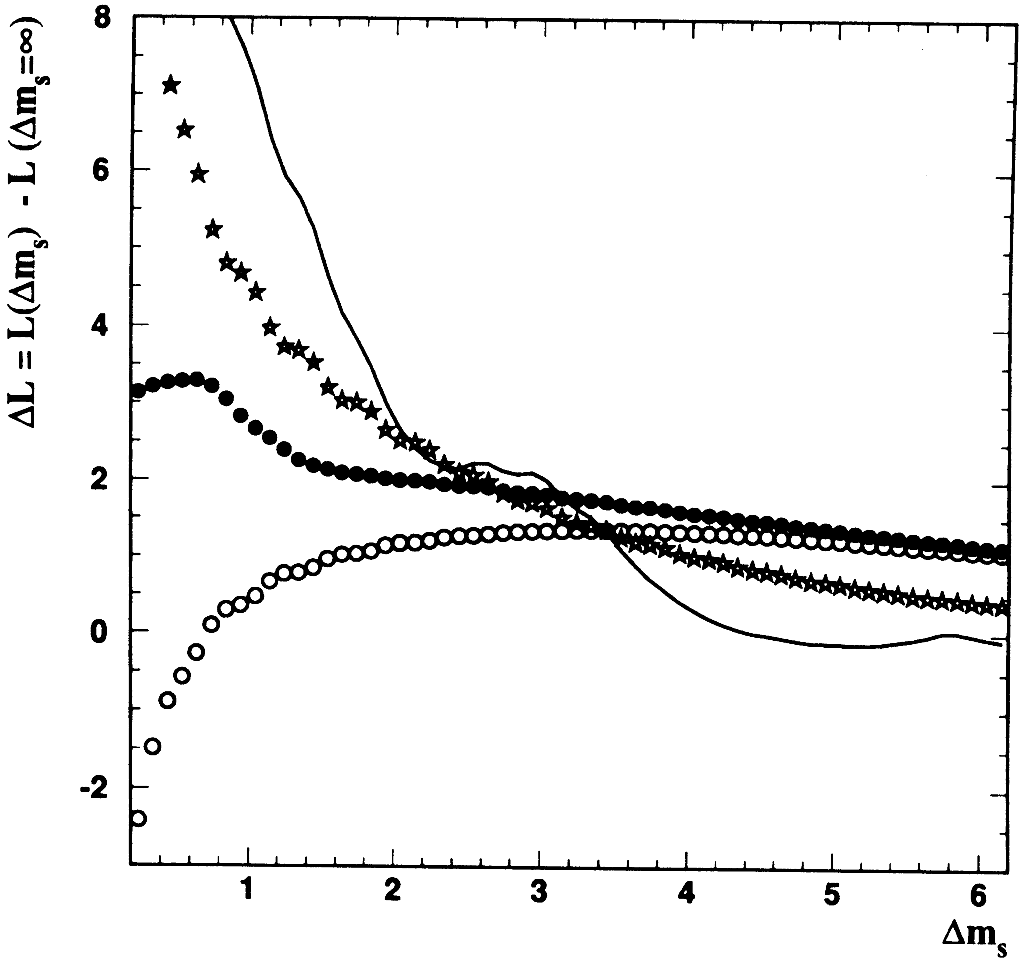

Figure 5: Log likelihood differences versus Δm_s full curve: data, open circles: $\Delta\mathcal{L}95\%$, dots: $\Delta\mathcal{L}$ 95 % C.L. limit (stat. + syst.) , stars $\Delta m_s = \infty$

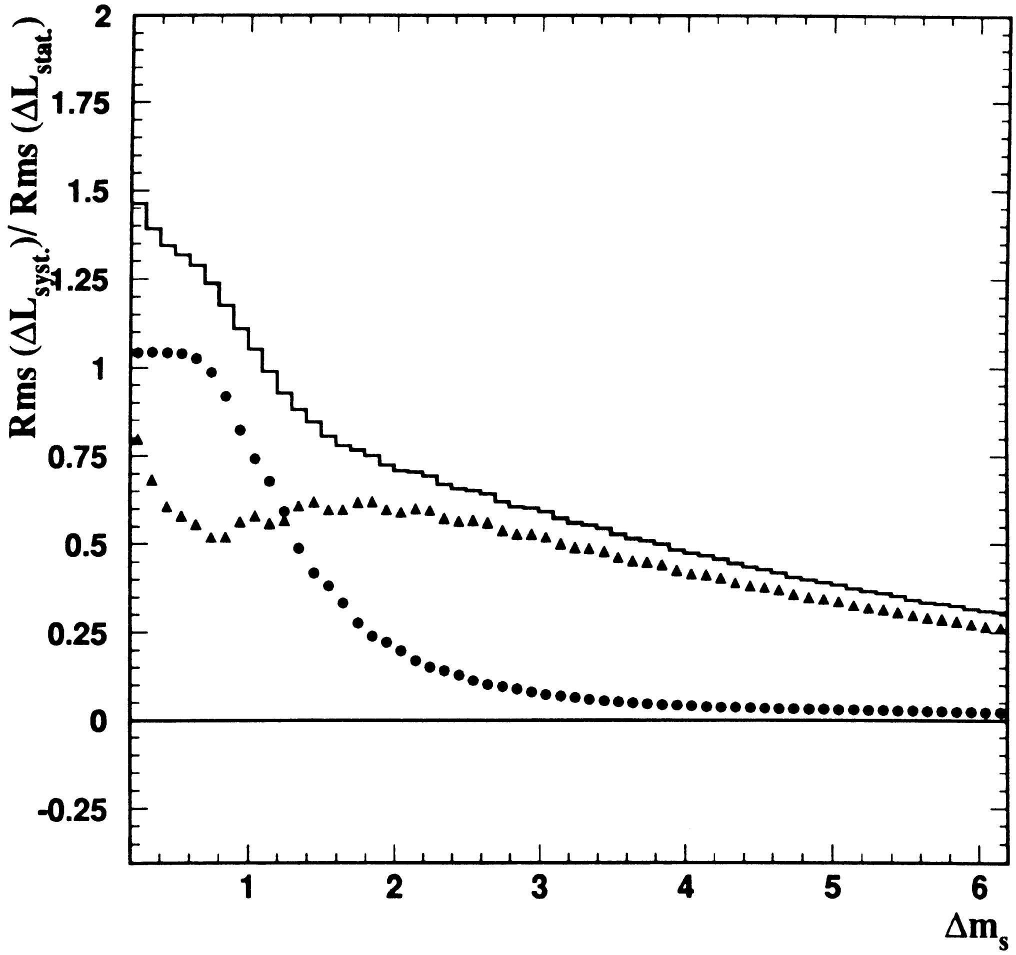

Figure 6: Ratio of the systematical rms of $\Delta\mathcal{L}$ to the statical rms versus Δm_s. Histogram: total systematics, dots: contribution of B_d,A_u, triangles: contributions of f_s and B_s.