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An Updated Measurement of the b Charge Separation in a Lepton-tagged Sample

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Abstract

This note gives an update of the b charge separation from leptons that was presented in ALEPH note 92-188. The new measurement is based on the p_t exclusive lepton definition and uses the 1990 - 1992 data.

1 Introduction

In the b [1] and hadronic charge asymmetry studies [2], based on a jet charge method, $\sin^2\theta_W^{eff}$ is extracted from measurement of the average charge flow between the forward and backward hemisphere. For the hadronic charge asymmetry the relationship for example is given by:

$$\langle Q_{FB}\rangle = C_{acc}\,\mathcal{A}_e\,\frac{2\cdot\Sigma_f\delta^f\,g_v^f g_a^f}{\Sigma_f((g_v^f)^2\,+\,(g_a^f)^2)} \tag{1}$$

where

$\langle Q_{FB}\rangle$ is the average charge flow as measured in the data,
C_{acc} is the correction for the experimental polar angle acceptance,
$\mathcal{A}_e$, the left-right asymmetry for electrons, is used to extract $\sin^2\theta_W^{eff}$,
$\Sigma\delta^f\,g_v^f g_a^f$ contains the typical charge separations, δ^f, for the different quark flavours. The couplings g_v^f and g_a^f also contain a weaker relationship to $\sin^2\theta_W^{eff}$.

For the b asymmetry [1] in the impact parameter-tagged sample a similar relationship can be written down.
This measurement is motivated by the fact that the error on the b charge separation due to fragmentation uncertainties in the Lund Monte Carlo is about 14.5 %, which corresponds to a substantial error on $\sin^2\theta_W^{eff}$ measurement.

The measurement of the b charge separation, in the high p, p_t lepton sample, is based on the lepton-signed hemisphere charge, which is defined as:

$$Q_{lH} = -q_l\cdot Q_H^{opposite}. \tag{2}$$

The lepton is selected to be a high p, p_t lepton, where for the calculation of the p_t, the p_t **exclusive** definition has been used. The jet charge in the opposite hemisphere, $Q_H^{opposite}$, is reconstructed using:

$$Q_H = \frac{\sum_{i=1}^{n} q_i \, |p_i^l|^\kappa}{\sum_{i=1}^{n} |p_i^l|^\kappa}, \qquad (3)$$

where q_i and p_i^l are the charge and the longitudinal momentum w.r.t. the thrust axis of track i and κ is a weighting parameter.

2 Lepton Selection and Sample composition

The lepton selection is based on [3] and has been carried out using the LEPTAG package[4].
The leptons are required to have a:

$$p > 3\,GeV/c, p_t^{excl.} > 1.5\,GeV/c. \qquad (4)$$

Figure 1 shows that a p_t in the range 1.5-1.7 minimises the total error on the b charge separation measured.
The sample composition has been evaluated using the CALPOIDS fits [5] for the 1990, 1991 data. For the 1992 the corresponding fit is not available yet. At present the flavour composition of the 1992 data is assumed to be the same as in the 1991 data. A cross-check was made by running the 1991 CALPOIDS fit on the 1992 data, this yielded a flavour composition that is virtually identical to the one obtained for the 1991 data. Equivalently a cross-check on the legitimacy of this, figures 2,3 compare the p and p_t of the leptons in the 1991 and 1992 data.
It should be noted that that due to the change in the dE/dx definition in 1992 (see figure 4), some shift in the background fractions in the electron sample may be expected, once this information is incorporated into the fit. Similarly, the muon analysis for the fit needs to be finalised also entailing some changes, which are expected to be at a smaller scale.
The flavour composition has been evaluated using the ISGW and Altarelli models. The differences in the predicted flavour fractions are quite small, as at a high p_t cut the samples are dominated by primary b decays. For the extraction of the b charge separation the average of the two predictions is used. The difference in predicted flavour composition is covered by the systematic error. (For the evaluation of the systematic error see section 4.)
The flavour composition of the samples is given in table 1.

3 Extraction of the charge separation for b quarks

The lepton-signed hemisphere charge has been measured in the 1990, 1991 and 1992 electron and muon samples separately. The background subtraction is done using a straight means method. The resulting lepton-signed hemisphere charge in the b-sample, $\langle Q_{lH} \rangle_b$, is subsequently transformed into the b charge separation, δ^b using:

$$\delta^b = 2 \cdot \langle Q_{lH} \rangle_b / (1 - 2\chi), \qquad (5)$$

where χ is the probability that the B^0 mixed before decaying. The value of χ is the present LEP average as given by the LEP electro-weak working group [6]:

$$\chi = 0.115 \pm 0.011. \tag{6}$$

As the two asymmetry measurements [1][2] use slightly different thrust axis definitions and have a different cut on the polar angle of the thrust axis, the effect of this on the lepton-signed hemisphere charge has been evaluated by calculating it under the two conditions (see table 2).

Table 3 compares the δ^b's obtained by measurements under the two given conditions. The errors quoted are statistical only. In column 4 the difference is given in terms of the number of sigmas. Changing from the charged thrust axis to the energy flow thrust axis requires a tightening of the polar angle cut down to 0.85. In case of the b asymmetry with jet charge, where the VDET is used, a polar angle cut of 0.8 is used based on the acceptance of VDET. In changing from polar angle cut of 0.9 that can be used for charged tracks to 0.8 results in a loss of approximately 18 % of the events. Hence a shift in δ^b of 42.4 % of a sigma is allowed. If this allowed shift is subtracted from the one observed, approximately 0.2 sigma remain (see column 5 of table 3) which can be explained by the fact that in some fraction of the cases the thrust axis is rotated somewhat when going from the charged to the energy flow definition. In conclusion, the two measurements are compatible[1]. From a statistics point of view it is preferable to use charged thrust definition which allows a cut at 0.9.

4 Error calculation

In the error calculation, that has been done for the background subtraction, the electrons and muons have been treated separately, as the background fractions and the background charges are different for the two samples.

The errors on the b charge separation due to the various uncertainties have been estimated using simply the derivatives, starting from the equation:

$$\delta^b = \frac{(\langle Q_{lH}^{meas.}\rangle - f_c \cdot Q_c - \Sigma f^i_{fake} \cdot Q^i_{fake})}{(f_b - f_{bc})} \cdot \frac{2}{(1-2\chi)} \tag{7}$$

where $i = uds, c, b$.

The measured lepton-signed hemisphere charge is corrected for the different backgrounds, i.e. the fraction of the background times its particular charge is subtracted. The background sources are primary charm decay (f_c, Q_c) and any source of fake leptons, such as decays in flight, misidentified hadrons, photon conversions, etc., in light quark, charm or bottom events (f^i_{fake}, Q^i_{fake} ; $i = uds, c, b$).

The fractions f_b and f_{bc} are defined as follows:

$$f_b = fraction(b \to l) + fraction(b \to \tau \to l) + fraction(b \to W \to \bar{c} \to l) \tag{8}$$

[1]When finalising the measurement of the b charge separation it maybe desirable to do some last cross-check on this point of the thrust axis definition.

or in words f_b is sum of all genuine leptons in b events where the lepton carries the same sign charge as the decaying b-quark. And

$$f_{bc} = fraction(b \rightarrow c \rightarrow l) \tag{9}$$

which yields a lepton with a charge opposite to that of the decaying b quark. The statistical error is obtained using:

$$d\delta^b = \frac{1}{(f_b - f_{bc})} \cdot \frac{2}{(1-2\chi)} \cdot d\langle Q_{lH}^{meas.}\rangle \tag{10}$$

The errors on δ^b due to the errors on the charges have been calculated using:

$$d\delta^b = \frac{f_c}{(f_b - f_{bc})} \cdot \frac{2}{(1-2\chi)} \cdot dQ_c \tag{11}$$

$$d\delta^b = \frac{f^i_{fakes}}{(f_b - f_{bc})} \cdot \frac{2}{(1-2\chi)} \cdot dQ^i_{fakes}, \tag{12}$$

where $i = uds, c, b$.
For the error calculation on the fractions the constraint that all the fractions must add up to one has been taken into account. This can be done by re-writing the formula for the extraction of δ^b as:

$$\delta^b = \frac{\langle Q_{lH}^{meas.}\rangle - \Sigma_{bg} f_{bg} \cdot Q_{bg}}{(1 - 2 \cdot f_{bc} - \Sigma_{bg} f_{bg})} \cdot \frac{2}{(1-2\chi)} \tag{13}$$

where $bg = c, fakes(uds), fakes(c), fakes(b)$.
When then subsequently taking the derivatives with respect to the f_{bc} or one of the background fractions one obtains:

$$d\delta^b = \frac{2 \cdot \langle Q_{lH}\rangle_b}{(1 - 2 \cdot f_{bc} - \Sigma_{bg} f_{bg})} \cdot \frac{2}{(1-2\chi)} \cdot df_{bc} \tag{14}$$

for the fraction of cascades and

$$d\delta^b = \frac{(\langle Q_{lH}\rangle_b - Q_{bg})}{(1 - 2 \cdot f_{bc} - \Sigma_{bg} f_{bg})} \cdot \frac{2}{(1-2\chi)} \cdot df_{bg} \tag{15}$$

for the background fractions respectively.
Finally the error due to the uncertainty on the mixing parameter χ is evaluated using:

$$d\delta^b = \frac{4 \cdot \langle Q_{lH}\rangle_b}{(1-2\chi)^2} \cdot d\chi \tag{16}$$

The charges for c → l and for events with fake leptons in uds, c or b events have been extracted from the (HVFL02 and) HVFL03 Monte Carlo samples. The errors on these charges are taken to be **max**(statistical error, 14.5%), 14.5 % being the error obtained on the charge separations due to the uncertainties in the LUND fragmentation parameters.
The amount by which the respective fractions have been varied is given in table 4.

In the final evaluation of the systematic error the following considerations have been taken into account:

- the fractions f_{bc} and f_c are obtained simultaneously from a fit to the lepton p, p_t plane and are therefore correlated. The errors due to these two sources have been added linearly.
- The estimate of the fractions of fakes in uds, c, b events rely on the same modelling of the fakes leptons. Again the errors from these sources have been added linearly.
- The errors are evaluated for electrons and muons separately. The systematic error for the combined lepton sample is obtained by weighting the two errors with the statistical significance of the measurements in the two samples.

Finally the error due to the uncertainty on the mixing on the lepton-side is added separately. This yields a final measurement of δ^b as presented in table 5a, which shows that the b charge separation in the lepton-tagged sample has been measured to 4.8 % (at $\kappa = 1.0$). This is to be compared to the uncertainty on the Lund prediction of 14.5 %. The measurement in the sample, where the thrust axis is calculated using charged tracks only and a $\cos(\theta_T)$ cut at 0.9, has the obvious slight advantage on the statistical error. As at present the the error from the mixing probability competes with the statistical one, and in the leading track approximation the measurement is the statistics dominated, the statistical advantage is interesting.

A break-down of the systematic error for the selection criteria set I at $\kappa = 1.0$ and for the selection criteria set II at $\kappa = 0.5$ are given in table 6. Table 7 gives a break-down of the measured b charge separation for the different years of data taking.

A few systematics checks have been carried out. Figure 5 shows the measurement of the b charge separation for electrons and muon separately as well as the combined lepton measurement as a function of p_t. The electron and muon measurements are compatible over the p_t range studied. The electron measurement is fairly constant against p_t, whereas the muons possibly show an indication of a trend.

The δ^b as extracted at the different κ values from data sets I and II is compared in figure 6 (top). Both data samples display the same behaviour with κ. The measured δ^b values (table 5a) are compared with the ones predicted by the HVFL03 Monte Carlo (see figure 6 (bottom plot)). Again the data and the Monte Carlo show the same behaviour.

These numbers are to be combined with the measurements obtained from the newly developed $\bar{\delta}$-method [7], where an error due to the uncertainty on the mixing probability is avoided altogether. In conclusion a combined measurement will lead to a determination of δ^b to approximately 3.3 %.

References

[1] A. Halley et al., A Preliminary Measurement of $sin^2\theta_W^{eff}$ from $A_{FB}^{b\bar{b}}$ in the 1992 Lifetime Tagged Heavy-Flavour Sample, Contribution to the EPS in Mar seille..

[2] D. Decamp, *et al.* (ALEPH Collab.), Phys. Lett. B 259 (1991) 377.

[3] D. Abbaneo et al., ALEPH 92-101, "Lepton and Jet definitions for the Lepton Paper".

[4] P. Colrain et al. , ALEPH 92-150, "The BTAGDST: A Data Set for Heavy Flavour Analyses based on the Mini-DST".

[5] A. Falvard et al., ALEPH 93-30, "Production and Semileptonic Decays of Heavy Quarks at the Z."

[6] LEP Electroweak Working Group, "Updated Parameters of the Z^0 Resonance from Combined Preliminary Data of the LEP Experiments", informal note for the EPS conference in Marseille.

[7] A. Halley, ALEPH note 93-XX

Table 1: lepton composition.

Process	1990 electrons	1991/1992 electrons	1990 muons	1991/1992 muons
b → l	0.887	0.882	0.811	0.806
b → c → l	0.052	0.051	0.053	0.053
c → l	0.032	0.040	0.035	0.043
fakes, uds events	0.019	0.016	0.057	0.056
fakes, c events	0.002	0.003	0.013	0.015
fakes, b events	0.008	0.008	0.031	0.027

Table 2 difference in thrust axis definition and polar angle cut

	hadronic Q_{FB}	b quark Q_{FB}
based on	charged tracks	energy flow objects
polar angle cut on the thrust axis	0.9	0.8
definition	**set I**	**set II**

Table 3: b charge separations as a function of κ.

κ	set I	set II	Difference	Remaining difference
0.5	0.1490 ± 0.0040	0.1466 ± 0.0042	0.585 σ	0.16 σ
0.7	0.1771 ± 0.0049	0.1737 ± 0.0052	0.673 σ	0.25 σ
1.0	0.2141 ± 0.0064	0.2099 ± 0.0068	0.636 σ	0.21 σ
1.5	0.2591 ± 0.0085	0.2532 ± 0.0092	0.667 σ	0.24 σ
∞	0.3434 ± 0.0173	0.3345 ± 0.0189	0.492 σ	0.07 σ

Table 4: variation on the event fractions.

fraction	variation electrons	variation muons
f_{bc}	15 %	15 %
f_c	15 %	15 %
f_{fakes}^{uds}	50 %	25 %
f_{fakes}^{c}	50 %	25 %
f_{fakes}^{b}	50 %	25 %

Table 5a: Measurement of δ^b (set I).

κ	δ^b
0.5	$0.1490 \pm 0.0040 \pm 0.0038 \pm 0.0043$ (4.7%)
0.7	$0.1771 \pm 0.0049 \pm 0.0043 \pm 0.0051$ (4.7%)
1.0	$0.2141 \pm 0.0064 \pm 0.0054 \pm 0.0061$ (4.8%)
1.5	$0.2591 \pm 0.0085 \pm 0.0069 \pm 0.0074$ (5.1%)
∞	$0.3434 \pm 0.0173 \pm 0.0100 \pm 0.0098$ (6.5%)

Table 5b: Measurement of δ^b (set II).

κ	δ^b
0.5	$0.1466 \pm 0.0042 \pm 0.0038 \pm 0.0042$ (4.8%)
0.7	$0.1737 \pm 0.0052 \pm 0.0043 \pm 0.0050$ (4.8%)
1.0	$0.2099 \pm 0.0068 \pm 0.0054 \pm 0.0060$ (5.0%)
1.5	$0.2532 \pm 0.0092 \pm 0.0069 \pm 0.0072$ (5.4%)
∞	$0.3345 \pm 0.0189 \pm 0.0100 \pm 0.0096$ (7.0%)

Table 6a: Break-down of the systematic error on δ^b. Selection criteria set I, $\kappa = 1.0$

source	$d\delta^b$ electrons	$d\delta^b$ muons
f_{bc}	0.0042	0.0042
f_c	0.0004	0.0004
f_{uds}^{fakes}	0.0016	0.0008
f_c^{fakes}	0.0001	0.0006
f_b^{fakes}	0.0001	0.0004
$f_{bc} + f_c$	0.0046	0.0046
$\Sigma fakes$	0.0018	0.0018
Q_c	0.0011	0.0013
Q_{uds}^{fakes}	0.0011	0.0019
Q_c^{fakes}	0.0003	0.0008
Q_b^{fakes}	0.0003	0.0009
total systematic error	0.0052	0.0056
error for two lepton samples combined: 0.0054		

Table 6b: Break-down of the systematic error on δ^b. Selection criteria set II, $\kappa = 0.5$

source	$d\delta^b$ electrons	$d\delta^b$ muons
f_{bc}	0.0029	0.0029
f_c	0.0003	0.0003
f_{uds}^{fakes}	0.0009	0.0006
f_c^{fakes}	0.0000	0.0003
f_b^{fakes}	0.0001	0.0002
$f_{bc} + f_c$	0.0032	0.0032
$\Sigma fakes$	0.0010	0.0011
Q_c	0.0013	0.0015
Q_{uds}^{fakes}	0.0008	0.0013
Q_c^{fakes}	0.0002	0.0006
Q_b^{fakes}	0.0001	0.0004
total systematic error	0.0037	0.0040
error for two lepton samples combined: 0.0038		

Table 7a: Measured b charge separation for the different years. Conditions set I at κ =1.0.

year	δ^b electrons	δ^b muons
1990	0.1879 ± 0.0264	0.2187 ± 0.0239
1991	0.2188 ± 0.0188	0.2219 ± 0.0168
1992	0.2266 ± 0.0124	0.2031 ± 0.0109

Table 7b: Measured b charge separation for the different years. Conditions set II at κ = 0.5.

year	δ^b electrons	δ^b muons
1990	0.1319 ± 0.0167	0.1620 ± 0.0157
1991	0.1547 ± 0.0124	0.1399 ± 0.0110
1992	0.1554 ± 0.0080	0.1388 ± 0.0073

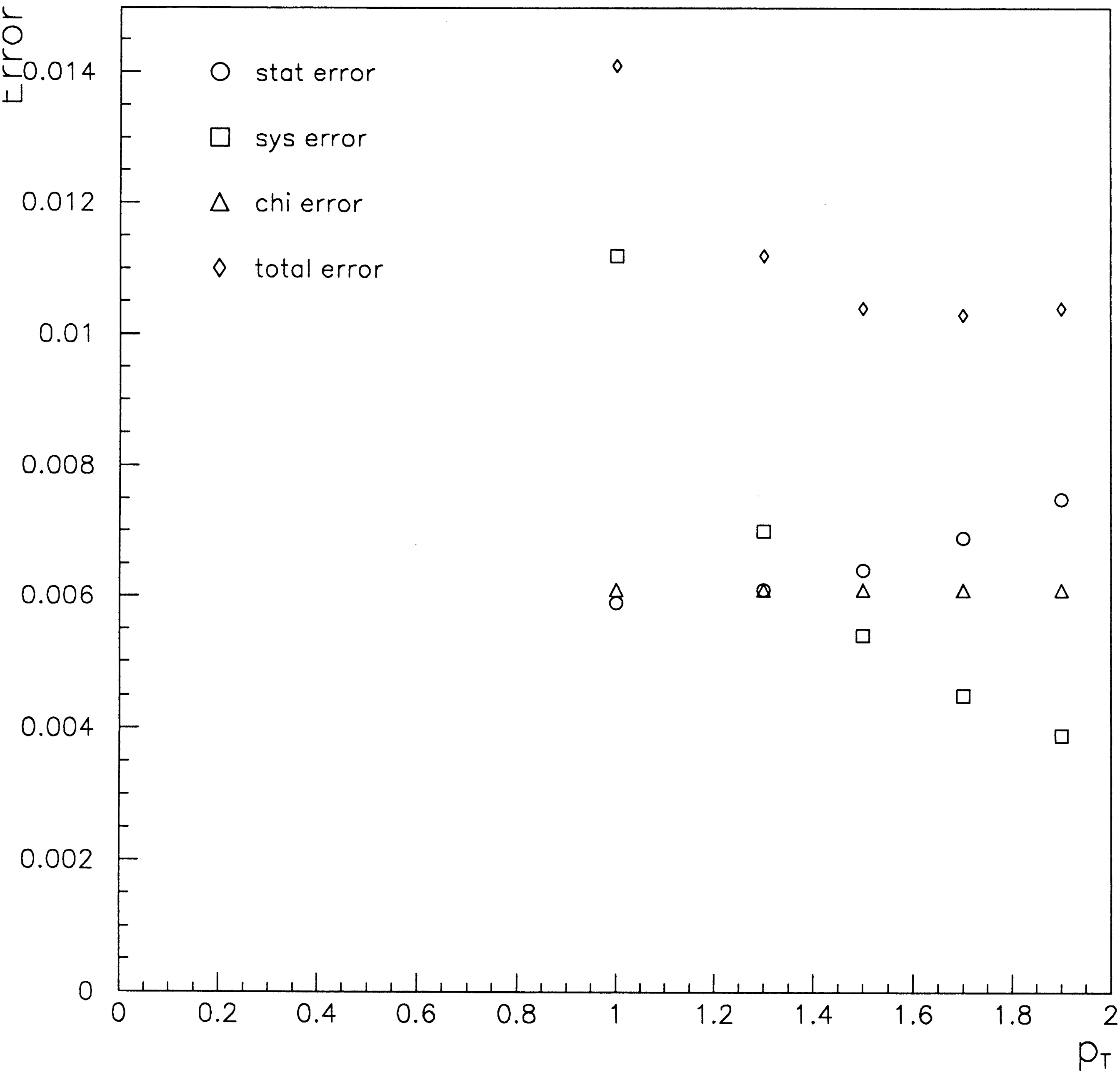


Figure 1: *Error on the b charge separation as a function of the p_t cut on the lepton, combining the electron and muon samples. The open circles indicate the statistical error, the open squares the systematic error (excluding mixing), and the open triangles the error from the mixing parameter χ. The total error is represented by the open diamonds.*

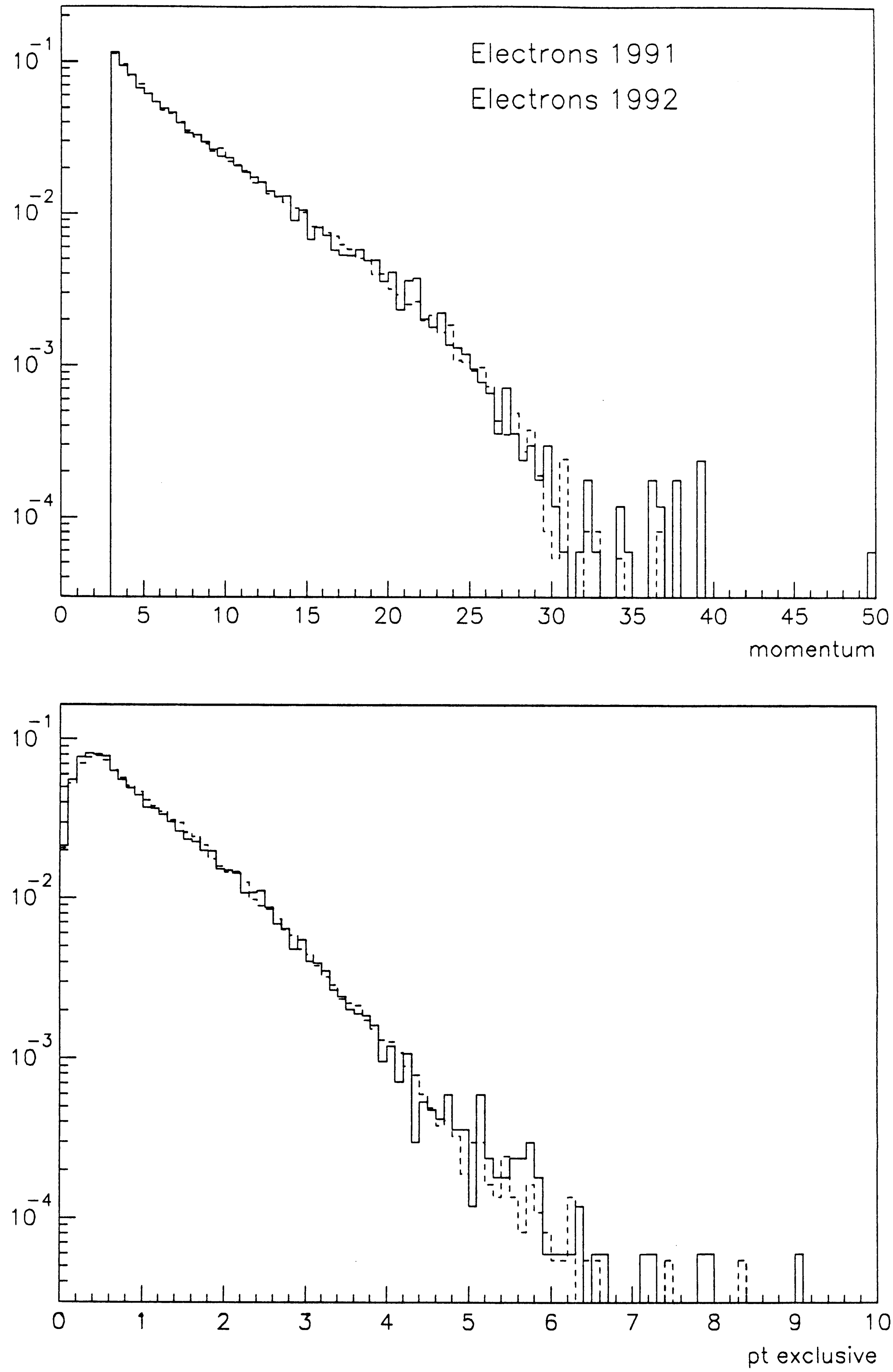


Figure 2: *a) Momentum (top) and transverse momentum spectrum (bottom) for electrons. The solid line represents the 1991 data, the dashed line the 1992 data.*

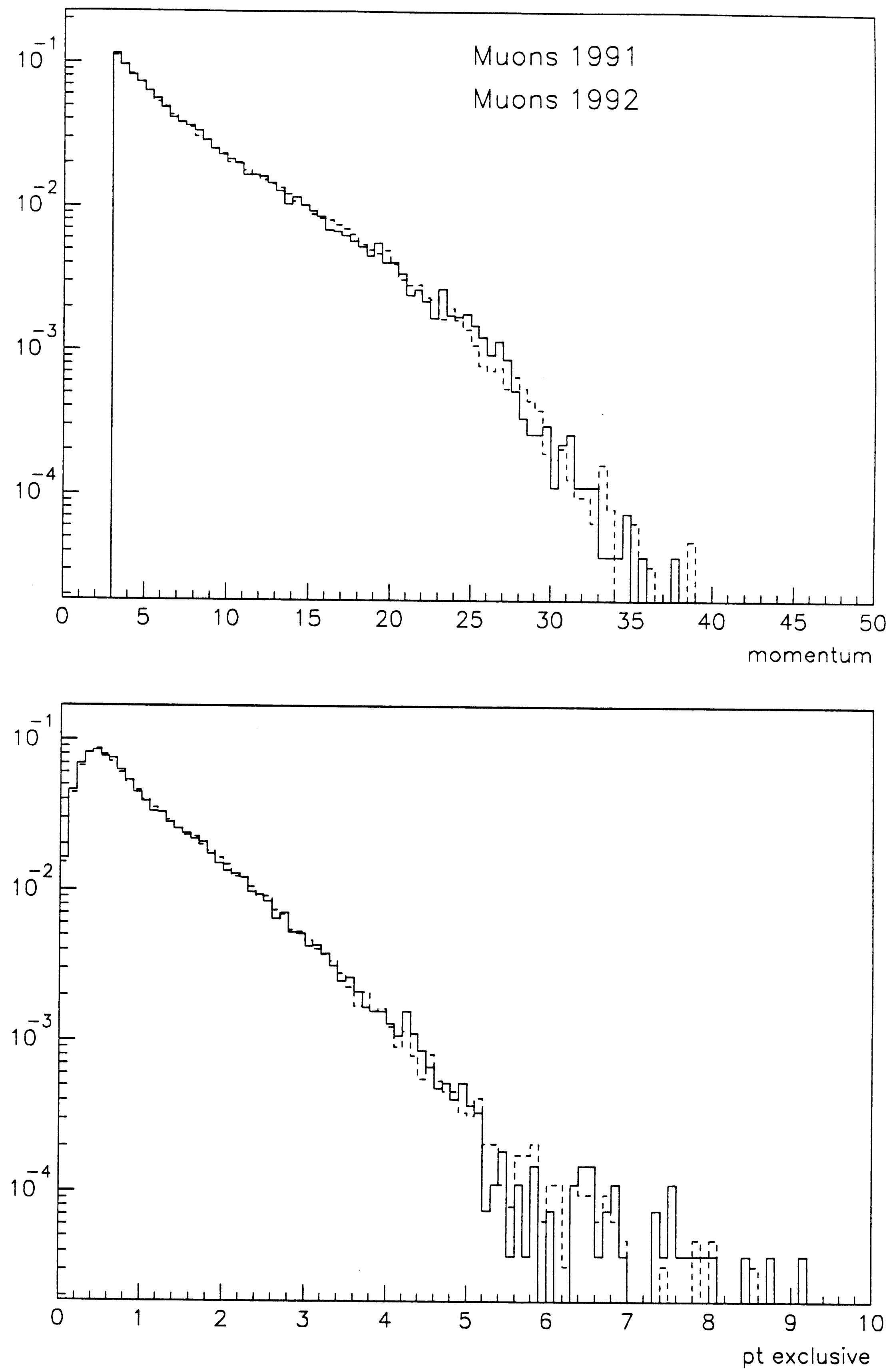


Figure 3: *b) Momentum (top) and transverse momentum spectrum (bottom) for muons. The solid line represents the 1991 data, the dashed line the 1992 data.*

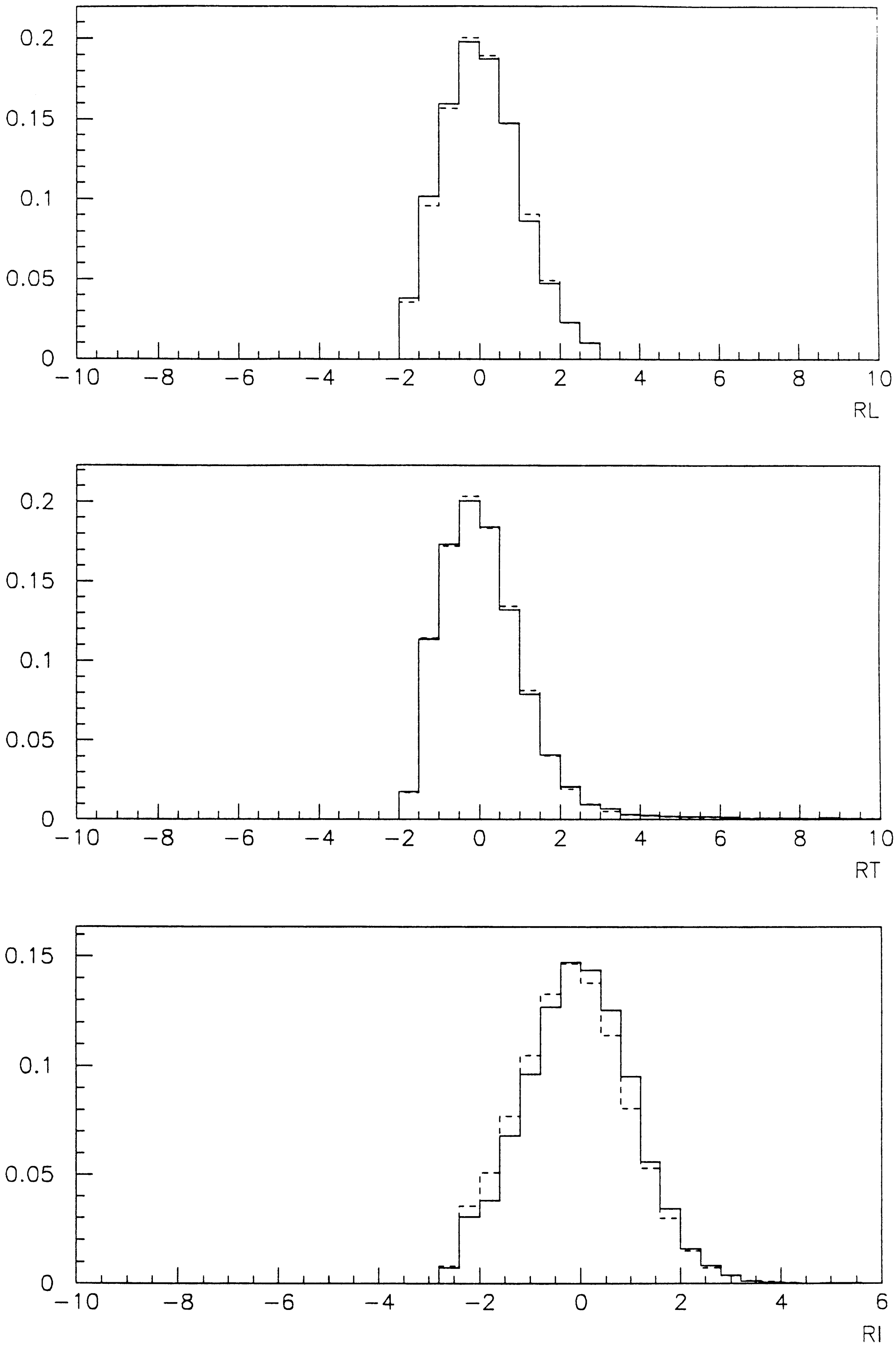


Figure 4: *Electron estimators, for the longitudinal shower profile (top), the transverse shower profile (centre) and for the dE/dx (bottom). The 1991 data are represented by the solid line, the 1992 by the dashed line. The bottom plot shows that dE/dx estimator for 1992 data is no longer centred exactly. Further studies by the lepton experts are under way.*

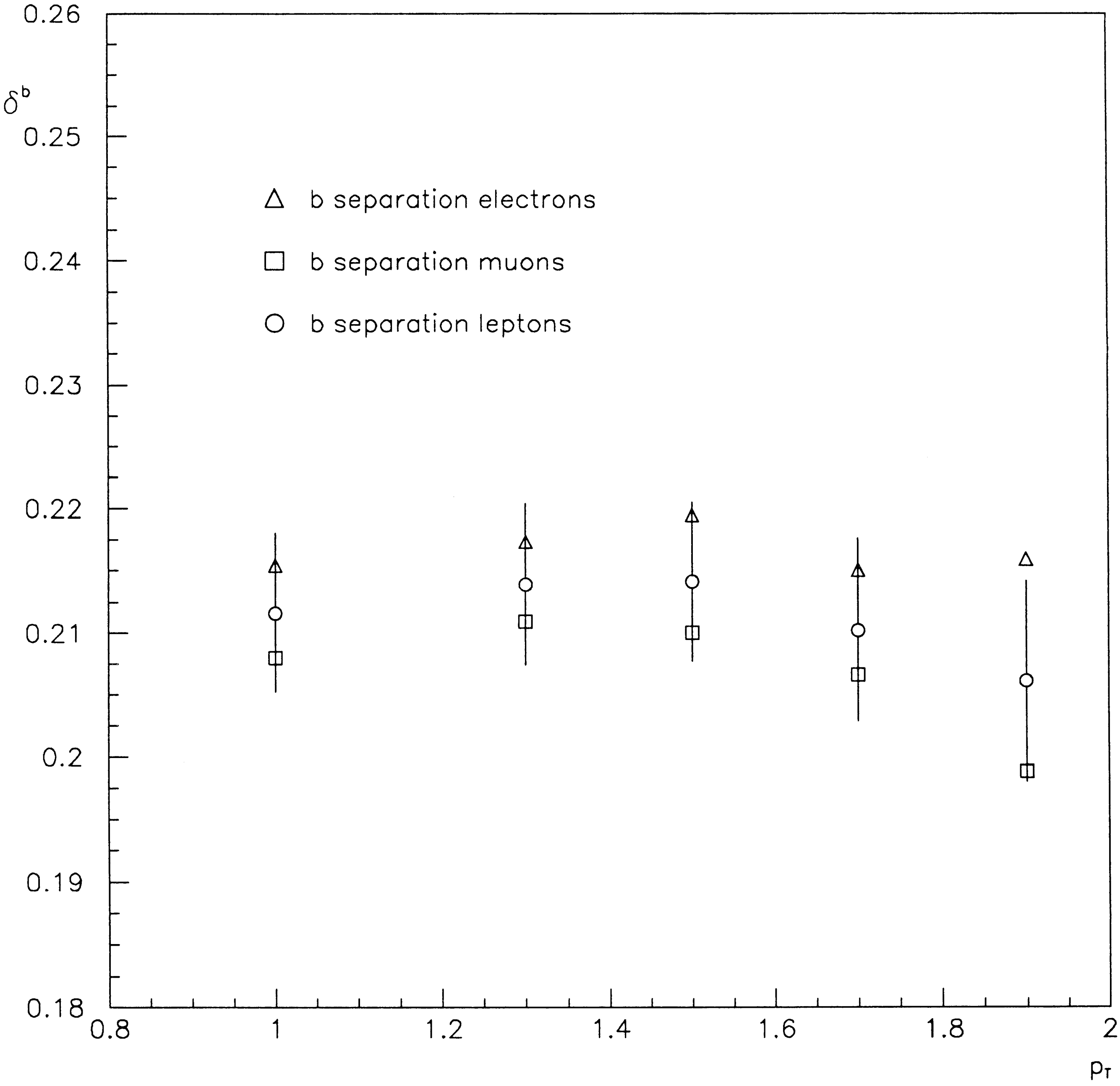
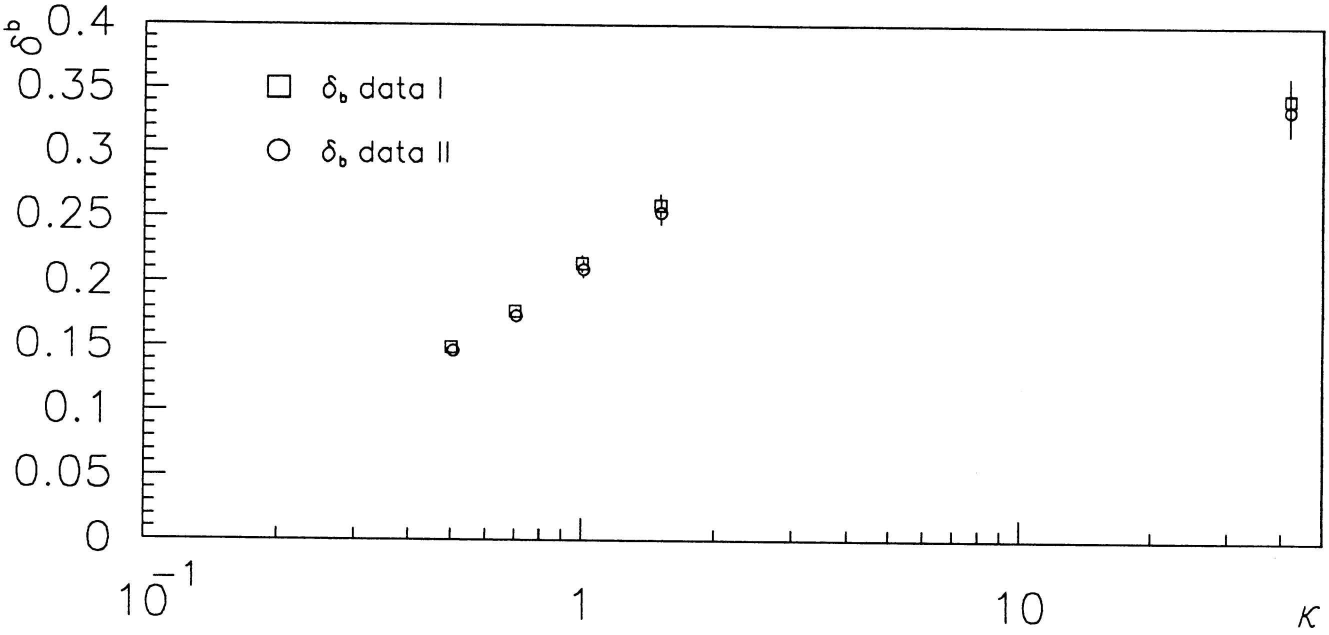


Figure 5: *b charge separation as a function of* p_t. *The open triangles shows the* δ^b *as measured in the electron sample, the open squares that measured in the muon sample. The average for the total lepton sample with the corresponding statistical error is shown by the open circles. This figure shows that the electron and muon measurements are compatible over the* p_t *range studied. It also shows that the electrons give a fairly constant measurement as a function of* p_t, *whereas the muons possibly show an indication of a trend.*



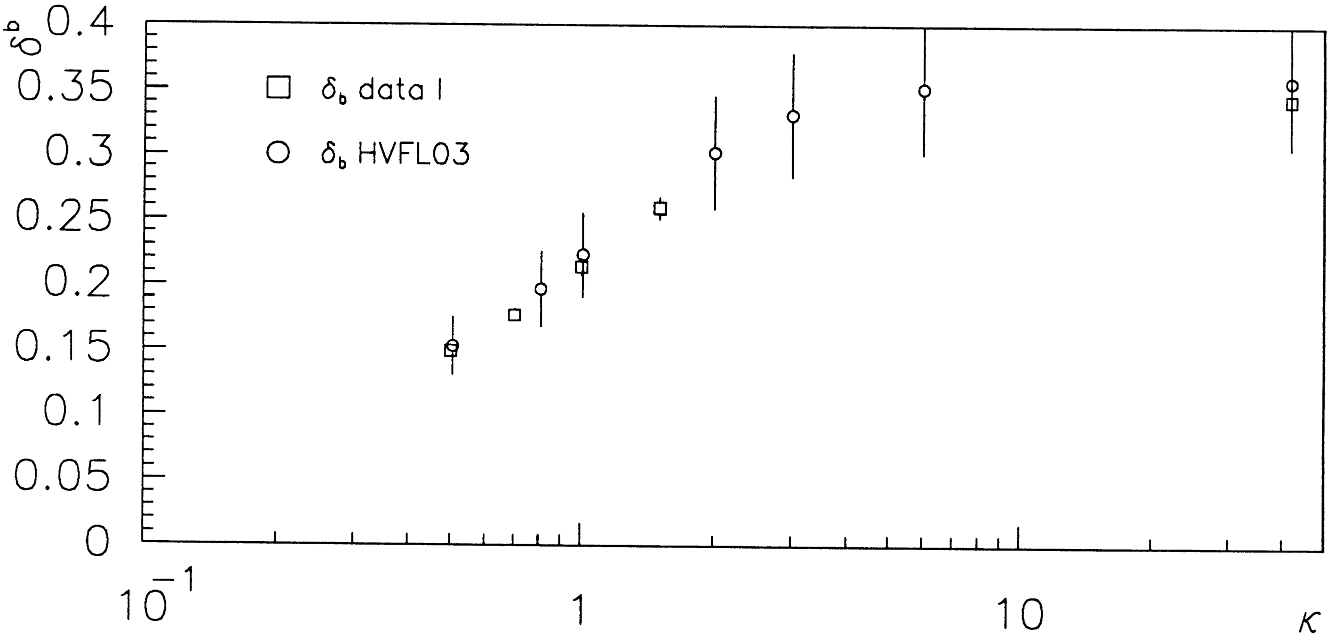


Figure 6: *Comparison of the b charge separation as measured in data sets I and II as a function of κ (top). Comparison of the b charge separation as measured in data set I with the prediction of the HVFL03 Monte Carlo (bottom).*