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Measurement of the $b \to \tau^- \overline{\nu}_\tau$ X Branching Ratio and an Upper Limit on $B^- \to \tau^- \overline{\nu}_\tau$

ALEPH Collaboration[1]

Abstract

Using 1.45 million hadronic Z decays collected by the ALEPH experiment at LEP, the $b \to \tau^- \overline{\nu}_\tau$ X branching ratio is measured to be $2.75 \pm 0.30 \pm 0.37\%$. In addition an upper limit of 1.8×10^{-3} at 90% confidence level is placed upon the exclusive branching ratio of $B^- \to \tau^- \overline{\nu}_\tau$. These measurements are consistent with SM expectations, and put the constraint $\tan\beta/M_{H^\pm} < 0.52\ \mathrm{GeV}^{-1}$ at 90% confidence level on all Type II two Higgs doublet models (such as the MSSM).

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1 Introduction

The decays of b hadrons to final states involving τ^- leptons are particularly sensitive to new effects linked to particle mass, since they involve both a heavy quark and the heaviest lepton. Thus, whilst the branching ratio of the decay $b \to \tau^- \overline{\nu}_\tau$ X is predicted, using heavy quark effective theory (HQET), to be $2.30 \pm 0.25\%$ in the Standard Model (SM) [1], it can be an order of magnitude larger in models with two Higgs doublets (as the decay is then mediated by H^- as well as W^-). For so called Type II two Higgs doublet models (in which one doublet couples to d-type quarks and charged leptons and the other couples to u-type quarks), a measurement of this branching ratio allows one to constrain $\tan\beta/M_{H^\pm}$ [2]. Here, $\tan\beta$ is the ratio of the vacuum expectation values of the two Higgs doublets and $M_{H^\pm}$ is the mass of the charged Higgs. This class of models includes the Minimal Supersymmetric Standard Model (MSSM). The SM prediction for the $\mathrm{B}^- \to \tau^- \overline{\nu}_\tau$ exclusive branching ratio [3, 4],

$$\mathrm{B.R.}^{\mathrm{excl}}_{\mathrm{SM}} = 4.7 \times 10^{-5} (f_B/190\ \mathrm{MeV})^2 (V_{ub}/0.003)^2 \tag{1}$$

is rather imprecise because the decay constant, f_B, and the CKM matrix element, V_{ub}, are each currently uncertain by about 30%. In Type II two Higgs doublet models this branching ratio is multiplied by a factor [4]

$$[(5.28\ \mathrm{GeV}/M_{H^\pm})^2 \tan^2\beta - 1]^2 \tag{2}$$

so an experimental limit on it may further constrain such models.

This paper updates the previous ALEPH study [5] of the inclusive decay channel. An upper limit is also placed upon the exclusive channel $\mathrm{B}^- \to \tau^- \overline{\nu}_\tau$.

2 Summary of Analysis Method

A detailed description of the analysis method is given in [5]. The basic idea is to tag $b \to \tau^- \overline{\nu}_\tau$ X decays using the large missing energy associated with the two ν_τ in the decay chain $b \to \tau^- \overline{\nu}_\tau$ X , $\tau^- \to \nu_\tau X'$.

A total of 1.45 million hadronic Z decays were selected from the 1991–93 ALEPH data, using the cuts of [6]. Residual non-$q\bar{q}$ events (present at the 0.2% level) were rejected by requiring at least seven charged tracks coming from the primary vertex and a missing energy in the event of less than 50 GeV. These two cuts are 99.7% efficient for hadronic events.

As in [5], each event was divided into two halves using the plane perpendicular to the thrust axis. The missing energy, $E_{miss} = E_{beam} + E_{corr} - E_{vis}$ in each event-half was calculated, where E_{beam} is one half of the centre of mass energy and E_{vis} is the visible energy in the event-half, found using charged tracks and energy deposits in the calorimeters from photons or neutral hadrons [7]. $E_{corr} = (M^2_{same} - M^2_{oppo})/(4E_{beam})$ is a correction, not used in [5], which, based on 4-momentum conservation, approximately compensates for the fact that the true energy in each hemisphere is not precisely E_{beam} [8]. Here, M_{same} and M_{oppo} are the measured invariant masses of the hemispheres on the same and opposite sides of the event to which E_{miss} is being measured respectively. This correction reduces by 20%, the number of event-halves having large E_{miss} because of finite detector resolution.

A major source of background is $b, \bar{c} \to e^-/\mu^- \bar{\nu}$ X decays as these also give large E_{miss} . This background was reduced by rejecting event-halves containing identified $e^\pm$ or $\mu^\pm$.

A further background is event-halves having large E_{miss} as a result of finite detector resolution. As only 22% of events are $b\bar{b}$, this background was reduced by tagging $b\bar{b}$ events. This tag used the finite lifetime of b hadrons and the precision of the ALEPH vertex detector [9]. It calculated for each event-half a confidence level, α_{hemi}, that all the tracks came from the primary event vertex. The event-half opposite to that in which E_{miss} was being measured was required to satisfy $\alpha_{hemi} < 0.01$. This differs from the $b\bar{b}$ tag used in [5], which was constructed using tracks from both event-halves. Although the latter approach yields higher efficiencies, it has the disadvantage of making the results sensitive to any dependence of the tag on the missing energy in the event. The new tag selects $b\bar{b}$ events with an efficiency of 55% and a purity of 80%.

The analysis used 1.93 million Monte Carlo events, generated using JETSET 7.2 (parton shower) [10], with b and c quark fragmentation according to the parameterization of Peterson *et al.* [11]. For the exclusive analysis, an additional 8900 $b\bar{b}$ events were generated in which one of the b hadrons was required to be a $\mathrm{B}^\pm$ decaying to $\tau^\pm\ \overline{\nu}_\tau$. All events were processed using a full simulation of the ALEPH detector.

Several improvements were made to JETSET as described in Section 3.1 of [12]. Furthermore, τ^- polarization in b hadron decays is now included. This has a significant effect on the measured branching ratios: decreasing that for $b \to \tau^-\ \overline{\nu}_\tau$ X by 12% (relative) and increasing the upper limit on $\mathrm{B}^- \to \tau^-\ \overline{\nu}_\tau$ by 20%. For the decay $b \to \tau^-\ \overline{\nu}_\tau$ X , the dependence of the τ^- polarization, P_τ, on its energy, E_τ, in the b hadron rest frame, was taken from the prediction of the free quark model.[2] (As one might expect, P_τ is predicted to be negative and tends towards -1 as E_τ increases). For the decay $\mathrm{B}^- \to \tau^-\ \overline{\nu}_\tau$, the τ^- polarization is simply $+1$. The expected angular distribution of the τ^- decay products, for a given τ^- polarization, can be found in [14, 15].

3 $b \to \tau^-\ \overline{\nu}_\tau$ X Branching Ratio

Fig. 1 shows the E_{miss} spectra obtained from the 1991–93 data and Monte Carlo after the application of all cuts. (i.e. Including $e^\pm/\mu^\pm$ veto and $b\bar{b}$ tag). The histogram for the Monte Carlo has been subdivided into contributions from $b \to \tau^-\ \overline{\nu}_\tau$ X , $b, \bar{c} \to e^-/\mu^- \bar{\nu}$ X and residual background.

The $b \to \tau^-\ \overline{\nu}_\tau$ X branching ratio is measured by comparing data and Monte Carlo in the signal region $E_{cut} < E_{miss} < 30$ GeV. The cut at 30 GeV ensures that the inclusive and exclusive branching ratio measurements are statistically independent. The Monte Carlo histogram was normalized to have the same number of entries as the data, as this reduces sensitivity to the assumed efficiencies of the analysis cuts. The results are given in Table 1, where contributions from cascade decays such as $b \to \mathrm{D}_s^-$X, $\mathrm{D}_s^- \to \tau^-\ \overline{\nu}_\tau$ have been subtracted, and the quoted systematic errors are discussed below.

As the result obtained using $E_{cut} = 16$ GeV has the smallest total error, it will be taken as the best estimate of the branching ratio:

$$\mathrm{B.R.}(b \to \tau^-\ \overline{\nu}_\tau\ \mathrm{X}\ ) = 2.75 \pm 0.30 \pm 0.37\%.$$

[2]Using section 3.3e of [1], assuming quark masses of $m_b = 4.8$ GeV and $m_c = 1.42$ GeV [13], and with $\lambda_1 = \lambda_2 = 0$ (free quark model).

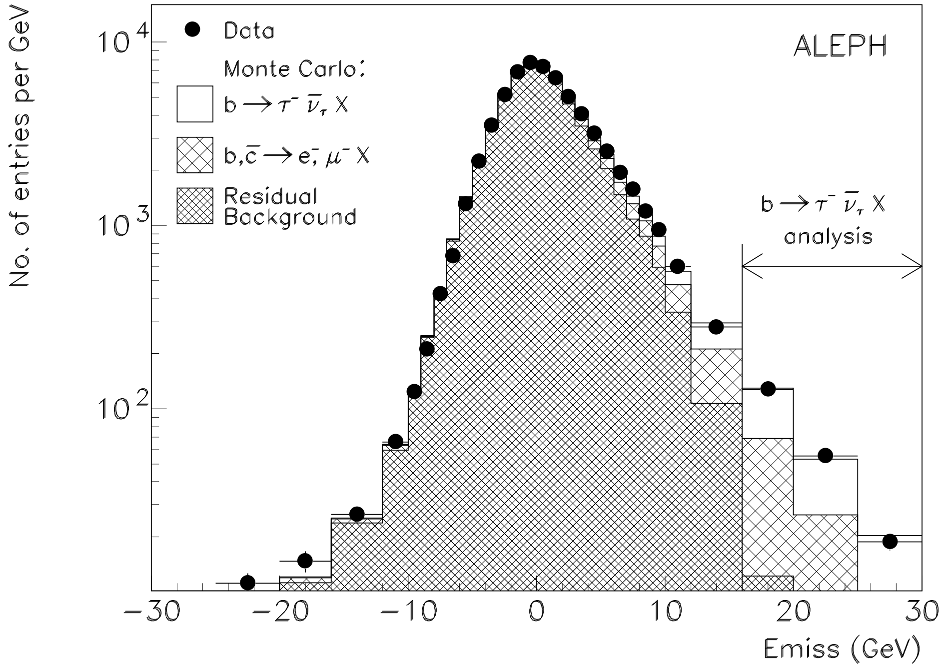

Figure 1: E_{miss} using $b\bar{b}$ tag and $e^{\pm}/\mu^{\pm}$ veto.

Table 1: Results for the $b \to \tau^- \ \overline{\nu}_\tau$ X branching ratio.

E_{cut} (GeV)	$b \to \tau^- \ \overline{\nu}_\tau$ X Branching Ratio (%)
12	$2.57 \pm 0.26 \pm 0.67$
16	$2.75 \pm 0.30 \pm 0.37$
20	$2.79 \pm 0.43 \pm 0.35$

With this choice for E_{cut} , the signal region contains an estimated 405 entries from $b \to \tau^- \ \overline{\nu}_\tau$ X , 418 from $b, \bar{c} \to e^-/\mu^- \bar{\nu}$X , and 55 other background.

The measurement of the $b \to \tau^- \ \overline{\nu}_\tau$ X branching ratio relies on a comparison of data with Monte Carlo. However, the missing energy resolution, the $e^{\pm}/\mu^{\pm}$ identification efficiency and the performance of the $b\bar{b}$ tag can all be measured using the data itself, and these measurements used to calibrate the Monte Carlo and estimate systematic errors. Table 2 shows the contributions to the systematic error on the $b \to \tau^- \ \overline{\nu}_\tau$ X branching ratio, for various choices of E_{cut} . A more detailed description of the methods used to assess these, than is given below, can be found in [5].

- The background from $b, \bar{c} \to e^-/\mu^- \bar{\nu}$X decays is primarily dependent on the assumed b fragmentation function and $b \to e^-/\mu^- \bar{\nu}$X branching ratio. These were taken from ALEPH measurements of $\langle x_b \rangle = \langle E_b \rangle / E_{beam} = 0.714 \pm 0.012$ and B.R.($b \to e^-/\mu^- \bar{\nu}$X) = $11.4 \pm 0.5\%$ respectively [12]. There is also a small dependence on the assumed fraction of D**,D$^*\pi$ in $b \to e^-/\mu^- \bar{\nu}$X . This was taken to be $21 \pm 8\%$ [16]. One can check the E_{miss} spectrum from $b, \bar{c} \to e^-/\mu^- \bar{\nu}$X decays by plotting E_{miss} for event-halves tagged as being in $b\bar{b}$ events and *requiring* the presence of $e^{\pm}/\mu^{\pm}$. This is shown in Fig. 2a. No significant difference between

Table 2: Absolute systematic errors (in percent) on $b \to \tau^- \overline{\nu}_\tau$ X branching ratio.

Systematic Effect	E_{cut} (GeV)		
	12	16	20
$\langle x_b \rangle$: 0.714 ± 0.012 [12]	∓ 0.16	∓ 0.23	∓ 0.25
$\langle x_c \rangle$: 0.487 ± 0.012 [12]	∓ 0.01	∓ 0.02	∓ 0.04
B.R.($b \to e^-/\mu^- \bar{\nu}$X): $11.4 \pm 0.5\%$ [12]	∓ 0.15	∓ 0.15	∓ 0.15
B.R.($b \to c \to e^+/\mu^+$X): $8.2 \pm 1.2\%$ [12]	∓ 0.11	∓ 0.07	∓ 0.03
D**,D$^*\pi$ in $b \to e^-/\mu^- \bar{\nu}$X : $21 \pm 8\%$ [16]	± 0.04	± 0.04	∓ 0.01
$\langle P_\tau \rangle$: -0.735 ± 0.030	± 0.01	± 0.02	± 0.02
10% change in $d\sigma/dE^*$ of ν_τ from b decay	± 0.07	± 0.07	± 0.07
B.R.(D$_s^-$ $\to \tau^- \overline{\nu}_\tau$): $3.7 \pm 2.3\%$ [17]	∓ 0.11	∓ 0.11	∓ 0.08
Effect of E_{neut} cut	± 0.07	± 0.06	± 0.06
E_{miss} resolution in $b\bar{b}$ events	± 0.59	± 0.11	± 0.04
$\mu^\pm$ identification efficiency	± 0.10	± 0.08	± 0.08
$e^\pm$ identification efficiency	± 0.10	± 0.08	± 0.07
$e^\pm$ reconstruction efficiency	± 0.05	± 0.05	± 0.05
$e^\pm/\mu^\pm$ from π^-,K$^-$ decays, γ conv., misid.	± 0.02	± 0.02	± 0.02
$b\bar{b}$ tag efficiency	± 0.04	± 0.05	± 0.05
Total Systematic Error	$\pm 0.67\%$	$\pm 0.37\%$	$\pm 0.35\%$

data and Monte Carlo is seen, which could not be explained by varying $\langle x_b \rangle$ and B.R.($b \to e^-/\mu^- \bar{\nu}$X) within the quoted errors.

- In addition to a dependence on $\langle x_b \rangle$, the efficiency of tagging $b \to \tau^- \overline{\nu}_\tau$ X decays is sensitive to two quantities not considered in [5]:

  i) The τ^- polarization. The mean polarization, $\langle P_\tau \rangle$, predicted by the free quark model is -0.735 ± 0.030, where the error is based on a comparison with heavy quark effective theory [1]. The predictions of this model were therefore scaled in accordance with this error to assess the systematic error.

  ii) Uncertainty in the energy spectrum, $d\sigma/dE^*$ of the ν_τ coming directly from the b hadron decay, in the rest frame of the b hadron. This was allowed for by distorting the shape of this spectrum by ±10%. (Justified by comparison of spectator model predictions with HQET [13]).

- The decay D$_s^-$ $\to \tau^- \overline{\nu}_\tau$ is expected to be the only other significant source of $\tau^\pm$. It is predicted to have a branching ratio of $3.7 \pm 2.3\%$, based upon WA75's measurement of the D$_s^-$ $\to \mu^- \overline{\nu}_\mu$ branching ratio [17]. Uncertainty from the $b \to$ D$_s^- X$ branching ratio is negligible.

- The E_{miss} resolution was calibrated using event-halves selected with a light quark tag (obtained by inverting the $b\bar{b}$ tag) and containing no identified $e^\pm/\mu^\pm$. These cuts together minimize the effect of semileptonic decays. The calibration applied to the Monte Carlo consisted essentially of scaling the measured neutral hadronic energy, E_{neut} , and degrading slightly the resolution on this quantity. As in [5], sensitivity to this was minimized by only using event-halves satisfying $E_{neut} < 7$ GeV in the

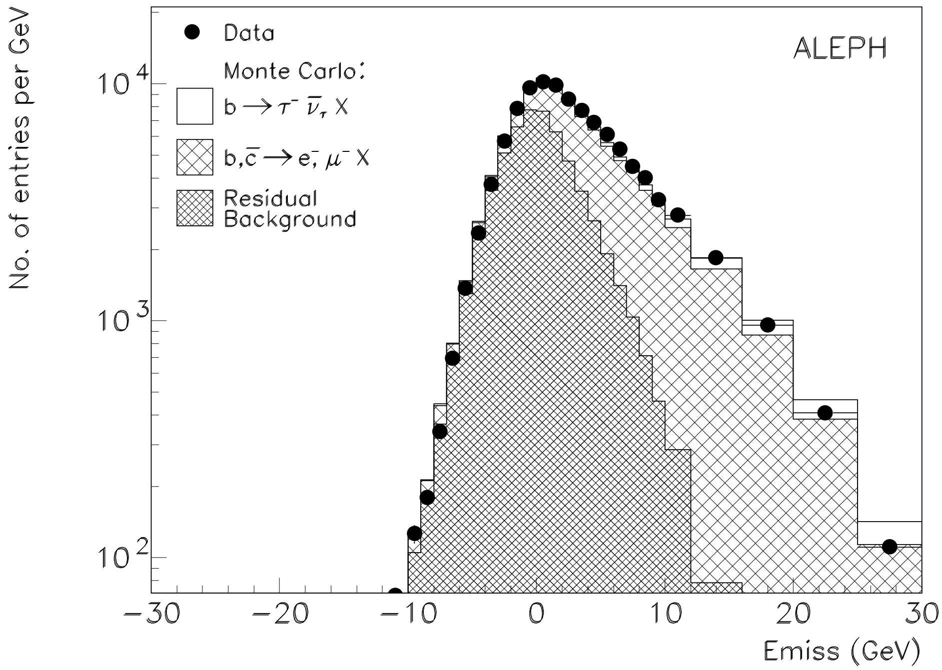

Figure 2a: E_{miss} using $b\bar{b}$ tag and *requiring* the presence of $e^{\pm}/\mu^{\pm}$.

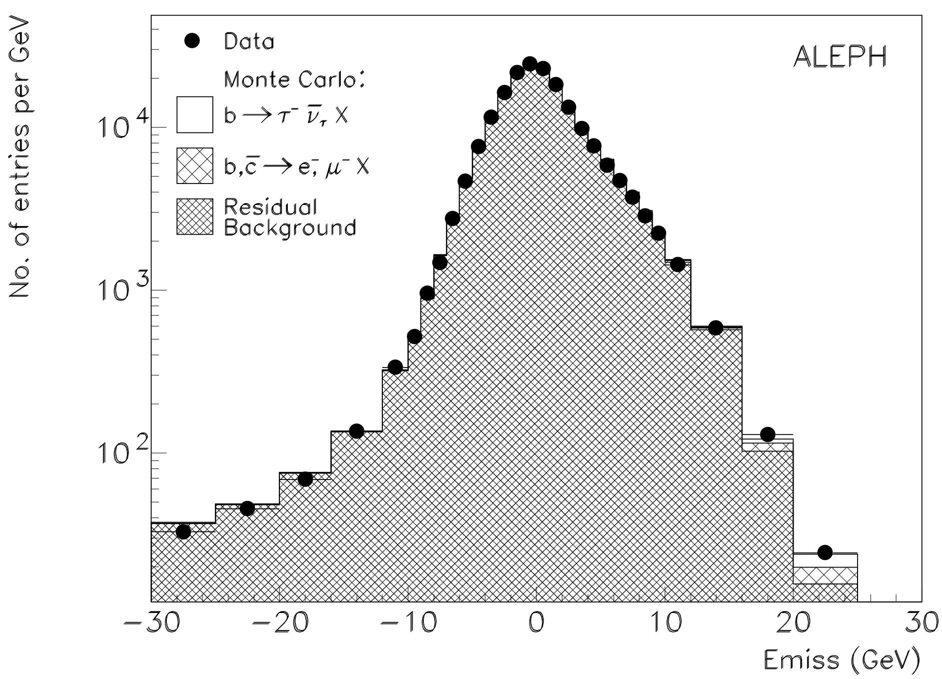

Figure 2b: E_{miss} using light quark tag and $e^{\pm}/\mu^{\pm}$ veto.

analysis. 70% of event-halves passed this cut in the data and 69% in the Monte Carlo. The difference in these two numbers was used to estimate the size of any systematic error associated with this cut. Fig. 2b shows a comparison of the resulting E_{miss} spectra in data and Monte Carlo, after this calibration and cut.

Large missing energy, E_{miss} , in event-halves, when not due to semileptonic decays, is usually caused by failure to reconstruct neutral hadronic energy, E_{neut} . Since $b\bar{b}$ events are less likely to have large E_{neut} , the E_{miss} resolution is significantly better in $b\bar{b}$ events than in light quark events. Therefore, the correction to the Monte Carlo resolution function based upon light quark tagged events will be incorrect, unless the Monte Carlo correctly simulates the relative probability of getting large E_{neut} in $b\bar{b}$ as compared to light quark events. Using the $b\bar{b}$ tag, evidence was seen that it may underestimate the latter at the 30% level, and this leads to the systematic error associated with E_{miss} resolution in $b\bar{b}$ events given in Table 2.

- The $e^{\pm}/\mu^{\pm}$ identification efficiency in the data was measured using γ conversions, $Z \rightarrow \mu^+\mu^-$ and $\gamma\gamma \rightarrow \mu^+\mu^-$ events. Tracks/events of the correct topology were selected in which one $e^{\pm}/\mu^{\pm}$ was identified, and the probability of identifying the other was measured. The resulting efficiencies are shown in Figs. 3a,b, where they are also compared with the predictions of the Monte Carlo. Occasionally, $e^{\pm}$ are not reconstructed because they emit hard Bremsstrahlung. A 10% relative uncertainty was assumed on the rate at which this process occurs [12]. The probability of event-halves failing the $e^{\pm}/\mu^{\pm}$ veto, as a result of $e^{\pm}/\mu^{\pm}$ from $\pi^{\pm}$, $K^{\pm}$ decays, γ-conversions or misidentification was measured as a function of the charged energy in the event-half using light quark tagged events (to minimize the effect of semileptonic decays). Negligible difference was seen between data and Monte Carlo, and this result was used in estimating the systematic error arising from this source.

- The performance of the $b\bar{b}$ tag was measured by comparing the number of events in which one/both event-halves were tagged. Details may be found in [9]. The efficiencies for tagging $b\bar{b}$, $c\bar{c}$ and light quark events were found to be higher in data than in Monte Carlo, by factors of 1.03 ± 0.01, 1.00 ∓ 0.05 and 1.16 ± 0.13 respectively.

4 Upper Limit on $B^- \rightarrow \tau^- \overline{\nu}_\tau$ (Exclusive)

The analysis method for $B^- \rightarrow \tau^- \overline{\nu}_\tau$ is essentially identical to that for $b \rightarrow \tau^- \overline{\nu}_\tau X$, except that event-halves with larger E_{miss} are searched for.

Two minor cuts did, however, need replacing. In the inclusive analysis, non-$q\bar{q}$ events were rejected by cutting on the charged multiplicity and missing energy of the entire event. However, when searching for event-halves with extremely large E_{miss} , these cuts result in correlations between the event-halves. For the exclusive analysis, they were therefore replaced by the requirement that the event-half opposite to that in which E_{miss} was being measured should have at least six charged tracks and a missing energy of less than 25 GeV. This change reduced the efficiency by 5%.

The resulting E_{miss} spectrum is shown for data and Monte Carlo in Fig. 4. Also shown is the expected contribution from $B^- \rightarrow \tau^- \overline{\nu}_\tau$, assuming a branching ratio of 1%. This is clearly inconsistent with the data. The numbers of entries in the region $E_{miss} > 30$ GeV of this figure are given in Table 3.

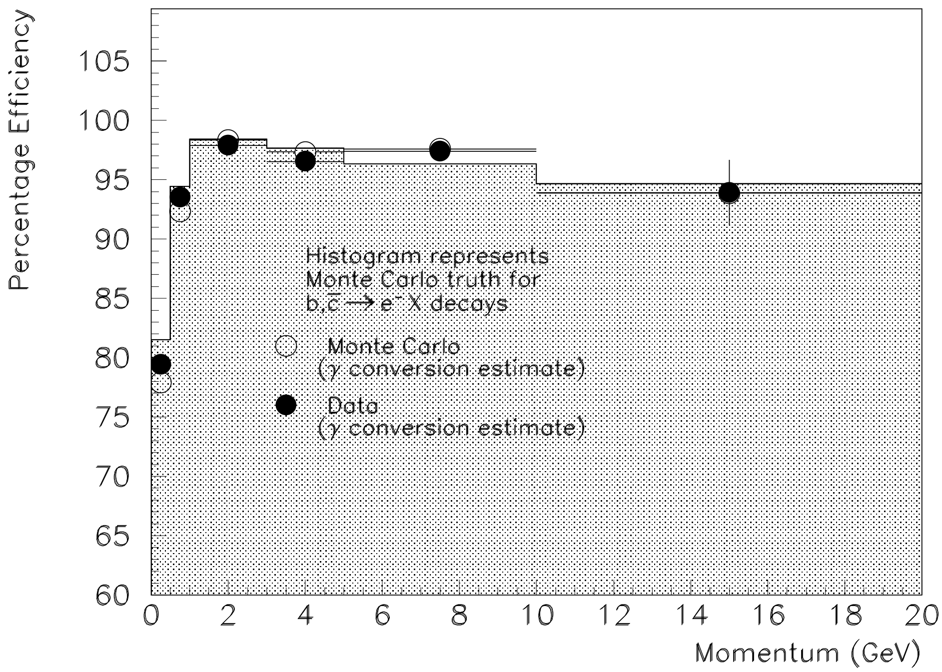

Figure 3a: $e^{\pm}$ identification efficiency as a function of momentum.

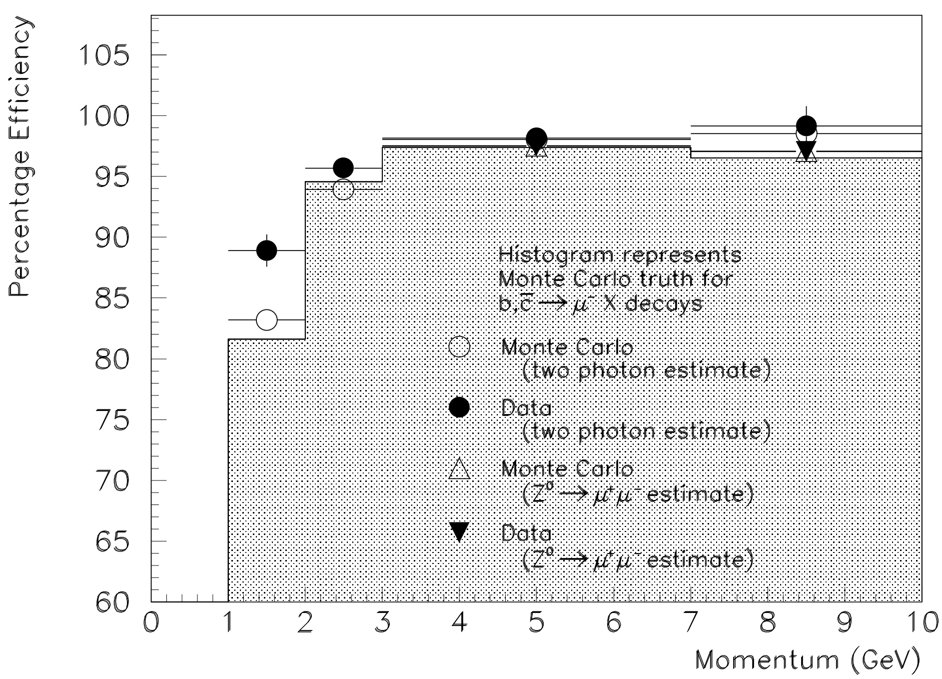

Figure 3b: $\mu^{\pm}$ identification efficiency as a function of momentum.

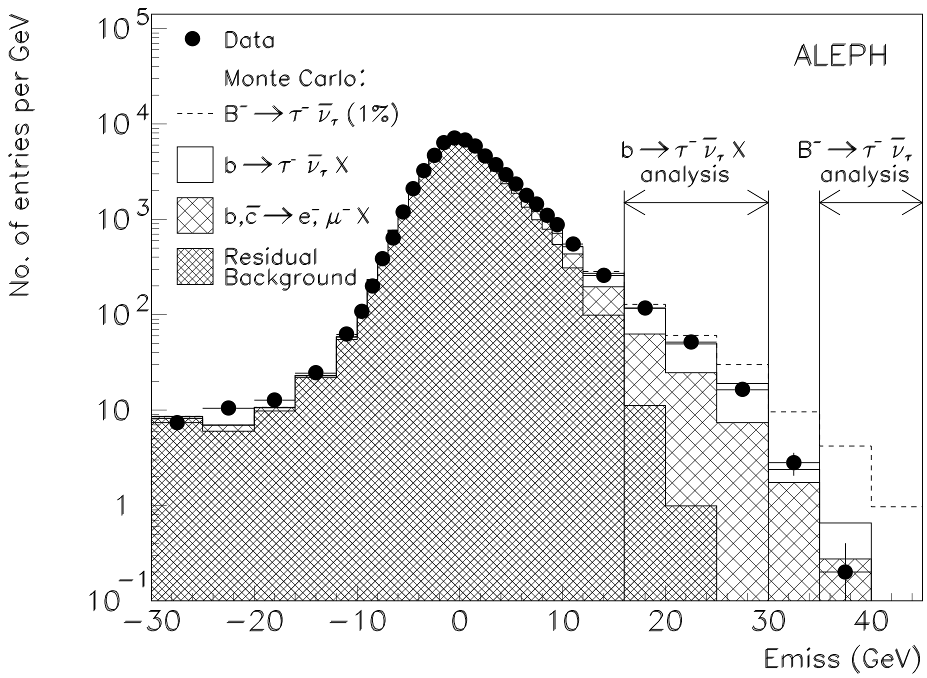

Figure 4: E_{miss} spectrum for $\mathrm{B}^- \to \tau^- \overline{\nu}_\tau$ exclusive analysis.

Table 3: Number of entries in tail of E_{miss} spectrum.

Source	Missing Energy (GeV)		
	$30 < E_{miss} < 35$	$35 < E_{miss} < 40$	$40 < E_{miss}$
Data	14	1	0
$\mathrm{B}^- \to \tau^- \overline{\nu}_\tau$ (1%)	35.8 ± 3.2	17.6 ± 2.3	4.8 ± 1.2
$b \to \tau^- \overline{\nu}_\tau$ X	3.3 ± 1.2	2.0 ± 0.9	0
$b, \bar{c} \to e^-/\mu^- \bar{\nu}$X	8.3 ± 1.9	1.4 ± 0.8	0
$\mathrm{D}_s^- \to \tau^- \overline{\nu}_\tau$	0	0	0
Residual Background	0.4 ± 0.4	0	0

An upper limit was placed on the $\mathrm{B}^- \to \tau^- \overline{\nu}_\tau$ branching ratio by comparing data and Monte Carlo in the signal region $E_{miss} > E_{cut}$. To be conservative, no background subtraction was performed. The optimum choice of E_{cut} was determined from Monte Carlo to be 35 GeV, using the optimization method described in [18]. There are two significant sources of systematic error affecting the number of $\mathrm{B}^- \to \tau^- \overline{\nu}_\tau$ decays which are found:

i) Uncertainty in the b fragmentation function. Varying this in accordance with the ALEPH measurement of $\langle x_b \rangle = \langle E_b \rangle / E_{beam} = 0.714 \pm 0.012$ [12], alters the efficiency for detecting $\mathrm{B}^- \to \tau^- \overline{\nu}_\tau$ by, for example, $\pm 8\%$ for $E_{miss} > 35$ GeV.

ii) Uncertainty in the fraction of weakly decaying b hadrons which are $\mathrm{B}^\pm$. This is assumed to be $37 \pm 3\%$ [19].

These were taken into account by convoluting a Poisson distribution with a Gaussian when calculating the upper limit. This leads to the following upper limit on the branching ratio:

$$\mathrm{B.R.}(\mathrm{B}^- \to \tau^- \ \overline{\nu}_\tau \ ) < 1.8 \times 10^{-3} \text{ at } 90\% \text{ c.l.}$$

5 Conclusions

Using the missing energy distribution of a sample of $b\bar{b}$ tagged events from which $b \to e^-/\mu^- \bar{\nu}\mathrm{X}$ decays have been largely eliminated, the inclusive branching ratio $\mathrm{BR}(b \to \tau^- \ \overline{\nu}_\tau \ \mathrm{X} \ )$ has been measured to be $2.75 \pm 0.30 \pm 0.37\%$ and a 90% confidence level upper limit of 1.8×10^{-3} has been placed on the exclusive branching ratio $\mathrm{BR}(\mathrm{B}^- \to \tau^- \ \overline{\nu}_\tau \ )$. The inclusive measurement updates the previous ALEPH result [5] and is in agreement with a recent L3 measurement of $2.4 \pm 0.7 \pm 0.8\%$ [20]. A preliminary 90% confidence level upper limit of 2.2×10^{-3} on the exclusive branching ratio has been quoted by the CLEO collaboration, using a completely different method [3].

The inclusive branching ratio measurement reported here is consistent with the SM prediction of $2.30 \pm 0.25\%$ [1], and sets the constraint

$$\tan\beta/M_{H^\pm} < 0.52 \ \mathrm{GeV}^{-1} \tag{3}$$

at 90% confidence level, on Type II two Higgs doublet models (such as the MSSM) [2]. Using equation 2, the upper limit on the $\mathrm{B}^- \to \tau^- \ \overline{\nu}_\tau$ exclusive branching ratio may be used to place a further constraint on these models:

$$\tan\beta/M_{H^\pm} < \frac{1}{5.28}\left[1 + \left(\frac{1.8 \times 10^{-3}}{\mathrm{B.R.}^{\mathrm{excl}}_{\mathrm{SM}}}\right)^{\frac{1}{2}}\right]^{\frac{1}{2}} \mathrm{GeV}^{-1} \tag{4}$$

at 90% confidence level. Here, $\mathrm{B.R.}^{\mathrm{excl}}_{\mathrm{SM}}$ is defined in equation 1. Assuming $f_B = 190$ MeV and $V_{ub} = 0.003$ would imply $\tan\beta/M_{H^\pm} < 0.51 \ \mathrm{GeV}^{-1}$. However, because of the large uncertainties on f_B and V_{ub}, the exclusive measurement is currently less constraining than the inclusive one.

Acknowledgements

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References

[1] A. Falk, Z. Ligeti, M. Neubert, Y. Nir, Phys. Lett. **B326** (1994) 145.

[2] Y. Grossman, Z. Ligeti, Phys. Lett. **B332** (1994) 373.

[3] CLEO Collab., Contribution to 27^{th} International Conference on High Energy Physics, Glasgow (1994), ICHEP94-GLS0160, CLEO-CONF 94-5.

[4] Wei-Shu Hou, Phys. Rev. **D48** (1993) 2342.

[5] D. Buskulic *et al.*, ALEPH Collab., Phys. Lett. **B298** (1993) 479.

[6] D. Decamp *et al.*, ALEPH Collab., Phys. Lett. **B231** (1989) 519, Section 3.1.

[7] D. Decamp *et al.*, ALEPH Collab., Phys. Lett. **B246** (1990) 306, Section 2.1. D. Buskulic *et al.*, ALEPH Collab., "Performance of the ALEPH detector", to be submitted to Nucl. Instrum. Methods.

[8] D. Buskulic *et al.*, ALEPH Collab., Phys. Lett. **B322** (1994) 275.

[9] D. Buskulic *et al.*, ALEPH Collab., Phys. Lett. **B313** (1993) 535.

[10] T. Sjöstrand and M. Bengtsson, Comput. Phys. Commun. **43** (1987) 367.
JETSET 7.2 User's Manual.

[11] C. Peterson *et al.*, Phys. Rev. **D27** (1983) 105.

[12] D. Buskulic *et al.*, ALEPH Collab., Z. Phys. **C62** (1994) 179.

[13] Private communication from Y. Grossman, Z. Ligeti, Y. Nir, Weizmann Institute of Science, Israel. (Based upon [1].)

[14] F. Mandl, G. Shaw, "Quantum Field Theory", Wiley publications (1984) 259.

[15] D. Decamp *et al.*, ALEPH Collaboration, Phys. Lett. **B265** (1991) 430.

[16] CLEO Collab., contribution to International Europhysics Conference on High Energy Physics, Marseille (1993), CLEO-CONF 93-19.

[17] S. Aoki *et al.*, WA75 Collab., Prog. Theor. Phys. **89** (1993) 131.

[18] D. Buskulic *et al.*, ALEPH Collab., Phys. Lett. **B313** (1993) 299.

[19] D. Buskulic *et al.*, ALEPH Collab., Phys. Lett. **B322** (1994) 441.

[20] M. Acciarri *et al.*, L3 Collab., CERN-PPE/94-068 (1994).