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Upper limit for the decay $B^- \to \tau^- \bar{\nu}_\tau$ and measurement of the branching ratio $b \to \tau \bar{\nu}_\tau X$

Preliminary

DELPHI Collaboration

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Abstract

Using the data sample of hadronic Z^0 decays collected by the DELPHI experiment in the 1992-1995 LEP1 period, the leptonic decay $B^- \to \tau^- \bar{\nu}_\tau$ has been studied. The analysis was done in both leptonic $\tau^- \to \ell^- \nu_\tau \bar{\nu}_\ell$ and hadronic $\tau^- \to \nu_\tau X$ decay channels. No excess was observed in data and the upper limit BR($B^- \to \tau^- \bar{\nu}_\tau$) $< 1.1 \times 10^{-3}$ at 90% confidence level was obtained. It is consistent with Standard Model expectations and puts a constraint on the ratio $tan\beta/M_{H^\pm} < 0.46$ GeV^{-1} in the framework of any type II Higgs doublet model. From the missing energy distribution, the branching ratio of $b \to \tau \bar{\nu}_\tau X$ was measured in the hadronic channel $\tau \to \nu_\tau X'$. The result, $BR(b \to \tau \bar{\nu}_\tau X\ ) = (2.52 \pm 0.23(stat) \pm 0.49(syst))\%$, is consistent with the Standard Model prediction and with previous experimental measurements.

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1 Introduction

Purely leptonic decays of charged B mesons are of interest to test the validity of the Standard Model. This decay results from the $W^{\pm}$ mediated interaction between a quark current and a leptonic current. The heavy quark b annihilates with the light antiquark $\bar{u}$ into a virtual W^- boson which decays leptonically. In the Standard Model, the width of the decay $B^- \to \tau^- \bar{\nu}_\tau$ is predicted to be

$$\Gamma^{SM}(B^- \to \tau^- \bar{\nu}_\tau) = \frac{G_F^2 f_B^2 |V_{ub}|^2}{8\pi} m_B^3 (\frac{m_\tau}{m_B})^2 (1 - \frac{m_\tau^2}{m_B^2})^2$$

where G_F is the Fermi coupling constant, $|V_{bu}|$ is the CKM matrix element, f_B is the B decay constant, m_B and m_τ are the B meson and τ lepton masses, respectively. Using the most accepted values for f_B (190 MeV) and $|V_{ub}|$ (0.003) [1], the expected branching ratio is $BR^{SM}(B^- \to \tau^- \bar{\nu}_\tau\ ) = 6 \times 10^{-5}$. However there is still a large uncertainty on this value because f_B and $|V_{ub}|$ are poorly determined at present.

Because of helicity conservation, rates are proportional to the square of the lepton mass. Purely leptonic decays to electron or muon are then expected to have small branching fractions: BR($B^- \to \mu^- \bar{\nu}_\mu$)= 2×10^{-7} and BR($B^- \to e^- \bar{\nu}_e$)= 5×10^{-12}. For this reason, these decays are far from being observed at LEP.

The partial decay width for the decay $B^- \to \tau^- \bar{\nu}_\tau$ is also sensitive to physics beyond the Standard Model. In models with two Higgs doublets (the so called type II Higgs models) the decay width can be significantly larger due to the contribution of charged Higgs bosons. In such models the branching ratio becomes [2]:

$$BR(B^- \to \tau^- \bar{\nu}_\tau) = BR^{SM} \times [(\frac{m_{B^-}}{m_{H^\pm}})^2 \tan^2\beta - 1]^2$$

where BR^{SM} is the branching ratio predicted by the Standard Model, m_{B^-} is the mass of the B^- meson, $\tan\beta$ is the ratio of the vacuum expectation values for the Higgs fields and $m_{H^\pm}$ is the mass of the charged Higgs boson.

No evidence for an enhancement relative to the Standard Model prediction has been observed by previous experimental studies at CLEO [3], ALEPH [4] and L3 [5], putting a constraint on the parameters of supersymmetric models with two Higgs doublets. The best upper limit has been obtained so far by L3: BR($B^- \to \tau^- \bar{\nu}_\tau$)$< 5.7 \times 10^{-4}$ at 90% confidence level.

At LEP1 energy, the production of B_c mesons decaying leptonically, can give a substantial contribution to the $\tau\bar{\nu}_\tau$ final state because the coupling of the virtual W involves the CKM matrix element V_{bc} instead of V_{bu}. The B_c meson has recently been observed by the CDF Collaboration [6]. Its mass and lifetime are in agreement with current expectations. Within a relative uncertainty of a factor two, the relative fraction of $\tau\bar{\nu}_\tau$ final states coming from B_c and B_u production is given by:

$$\frac{N_{B_c}}{N_{B_u}} = 1.2 \frac{f(b \to B_c)}{10^{-3}}$$

where $f(b \to B_c)$, the inclusive probability that a b quark hadronizes into a B_c meson, varies in the range $0.02\% \div 0.1\%$. [7]

The decay $b \to \tau\bar{\nu}_\tau X$, where X stands for all the other particles produced in the decay, besides the τ and the $\bar{\nu}_\tau$, represents a test of the Standard Model. The Standard Model predicts a value for the branching ratio $b \to \tau \bar{\nu}_\tau X$ of $(2.30 \pm 0.25)\%$ using Heavy Quark Effective Theory (HQET) [8, 9]. The supersymmetric extension of the Standard Model, with two Higgs doublets, predicts an enhancement for the decay $b \to \tau \bar{\nu}_\tau X$ [10, 11], as it can be mediated by H^- and W^- exchanges. An experimental measurement of this branching ratio allows thus to constrain the ratio $tan\beta/m_{H^\pm}$. Previous experimental measurements of BR($b \to \tau \bar{\nu}_\tau X$) by ALEPH [4], L3 [12] and OPAL [13] collaborations have confirmed the validity of Standard Model theoretical predictions.

In this paper, an upper limit on the exclusive branching ratio of $B^- \to \tau^- \bar{\nu}_\tau$ and a measurement of the inclusive branching ratio $b \to \tau \bar{\nu}_\tau X$ obtained in the DELPHI experiment are presented.

2 Sample selection

The data have been collected with the DELPHI detector at LEP during the 1992-1995 LEP1 running period. They contain about 3.5 million hadronic Z^0 events at the centre of mass energy 91.2 GeV. The DELPHI detector and its performance have been described elsewhere [14, 15].

The analysis uses a sample of about 7 million simulated events, which have been generated using the JETSET 7.4 (parton shower) program with b and c quark fragmentation described according to the Peterson parameterization [16]. These events have been processed through a full simulation of the DELPHI detector. For the exclusive analysis, a dedicated sample of 10000 events of B_u mesons decaying into $\tau \bar{\nu}_\tau$ has been generated and passed through the same simulation chain.

Charged track reconstruction is done with an improved version of the reconstruction program DELANA. Only tracks with impact parameters smaller than 2 cm in both $R\phi$ and z are accepted.

Electron identification has been described in [15]. In both inclusive and exclusive hadronic analyses the loose tagging procedure which has an efficiency of 80% and a misidentification probability of $\simeq$ 1.6%, has been selected. Muons have been identified by requiring at least one hit in the muon chambers (very loose tagging) [15]. The identification efficiency of this selection is 96% and the misidentification probability is $\simeq$ 5.4%.

In the leptonic channels of the exclusive analysis, instead, tighter cuts have been applied for lepton identification. They have an efficiency of 45% (70%) and correspond to a misidentification probability of 0.2% (0.45%) for electrons (muons). The momentum of the lepton is required to be greater than 2 GeV.

The probability P_E that all tracks from an event originate from a common primary vertex is used as the b-tagging variable [17]. $b\bar{b}$ events have been selected using $P_E < 0.01$ which gives an efficiency of 72% and a purity of 75%.

The cuts which have been applied to select real and simulated events samples, in both the inclusive and exclusive analyses, have been listed below:

a) the beam energy has to be compatible with the Z^0 decay (45.5 GeV $< E_{beam} <$ 45.75 GeV),

b) the standard hadronic event selection has been used [15] which requires a multiplicity of charged particles larger than seven and with a total energy greater than 15 GeV,

c) all subdetectors, needed for the analysis, have to be fully operational,

d) a two jet topology has been selected by requiring that the thrust of the event verifies: $0.85 < T < 1.00$ [18],

e) to match the acceptance of the vertex detector and to have optimal containment of the energy, the barrel region of the detector, excluding the vertical plane passing through the interaction point, has been selected by cutting on the direction of the event thrust axis: $0.1 < |\cos\theta_t| < 0.7$ [18],

f) events enriched in b quarks are selected by requiring $P_E < 0.01$ where P_E is the b-tagging event probability.

3 Upper limit of the decay $B^- \to \tau^- \bar{\nu}_\tau$

The decay $B^- \to \tau^- \bar{\nu}_\tau$ has been studied using the two main one prong decay modes of the τ lepton:

1) the leptonic channel, with a branching fraction of 35%[21], in which τ^- decays to $\ell^- \nu_\tau \bar{\nu}_\ell$ where ℓ^- is either an electron or a muon,

2) the hadronic channel, with a 65% branching fraction [21], in which τ^- decays to $h^- \nu_\tau X$, where h^- is a charged hadron and X are other hadrons (mostly π^0's that decay to two γ's).

3.1 Leptonic Channel

In the leptonic channel a lepton ℓ (μ or e) is identified using tight cuts. Furthermore it has been required that the lepton track has a positive impact parameter relative to the event primary vertex, larger than four times its measurement uncertainty in a plane perpendicular to the beam direction. The lepton has been selected in the hemisphere with the largest missing energy (this condition is verified by 90% of simulated signal events). Because of helicity conservation the ℓ^- is emitted preferentially in a direction opposite to the flight direction of the τ^-. This implies that, in the laboratory frame, the lepton ℓ^- will have an energy distribution peaked at low values. Since the standard lepton identification in DELPHI can be achieved only for $E_\ell > 2$ GeV, it is difficult to use E_ℓ as a discriminating variable (see Figure 1).

It is possible to substantially reduce the background from semileptonic decays using a fitting procedure with constraints. This approach is based on the fact that only the lepton is the final detectable particle for the searched decays, while there are multiple tracks in case of background semileptonic decays. Energy and momentum of the B meson can be reconstructed as:

$$\overrightarrow{P_{B^-}} = -\sum_{i \neq \ell} \overrightarrow{P_i}$$

$$E_{B^-} = \sqrt{s} - \sum_{i \neq \ell} E_i$$

The summation is done over all detected particles in both hemispheres of the event except the lepton ℓ taken to be a τ decay product.

The energies of all reconstructed particles E_i^{fit} are then varied, in the kinematical fit, in order to minimize their deviations from experimentally measured values

$$\chi^2 = \sum_{i \neq lepton} \frac{(E_i^{fit} - E_i^{meas})^2}{\sigma^2_{E_i^{meas}}}$$

under the constraint $E^2_{B^-} - \overrightarrow{P_{B^-}}^2 = M^2_{B^-}$.

In order to reject the background, E_{B^-} is required to be greater than 37 GeV (Figure 1).

Except the lepton, all tracks in the hemisphere are required to be consistent with the primary vertex within 3σ, in a plane perpendicular to the beam direction, and to have a momentum less than 5 GeV. The charged particles hemisphere multiplicity is required to be less than six. Since the measured lepton originates from two successive leptonic decays, an isolation criteria is applied. Defining a cone with half-opening angle of 0.5 radians around the ℓ direction, it is required that the system of particles, situated inside this cone, has a total energy less than 12 GeV and an invariant mass less than 3 GeV/c^2. The distribution of these two quantities, for both signal and background events, together with the applied cuts, are shown in Figure 1.

After having applied the selection criteria, 3 events remain in real data, 5 in the $q\bar{q}$ simulation, which has been normalized to the same luminosity, and 25 in the dedicated $B^- \to \tau^- \bar{\nu}_\tau$ simulation. This corresponds to a background rejection factor of 7410 while the efficiency to the signal is 6.5%.

3.2 Hadronic Channel

In the hadronic channel, only hemispheres with no $e^\pm$ or $\mu^\pm$ have been selected. To achieve a high rejection against semileptonic decays the cuts used for lepton identification have been lowered, corresponding to a so-called very loose criteria. The leading hadron h is identified as the track with maximum momentum which is inconsistent with the primary vertex by 4σ in a plane perpendicular to the beam direction. In order to reduce the background it is required that the hadron energy, E_h, is less than 10 GeV. Furthermore the hadron h is selected in the hemisphere with the largest missing energy (this is verified for 88% signal events). Since most of the hadronic decays are of the type $\tau^- \to \nu_\tau h^- n\pi^0$, π^0's and γ's have been selected inside a cone of half-opening angle equal to 0.5 *rad* around the direction of the charged track h^-. The energy and momentum of the B meson can be reconstructed as:

$$\overrightarrow{P_{B^-}} = - \sum_{i \neq h\pi^0\gamma/cone} \vec{P_i}$$

$$E_{B^-} = \sqrt{s} - \sum_{i \neq h\pi^0\gamma/cone} E_i$$

The summation is done over all detected particles, in both hemispheres of the event, except the hadron h and eventual π^0's and γ's situated inside the cone, taken to be τ decay products.

By analogy with the leptonic channel, the energy of all reconstructed particles have been corrected after a fit under the constraint $E^2_{B^-} - \overrightarrow{P_{B^-}}^2 = M^2_{B^-}$. In order to reject the background E_{B^-} is required to be greater than 37 GeV (Figure 2).

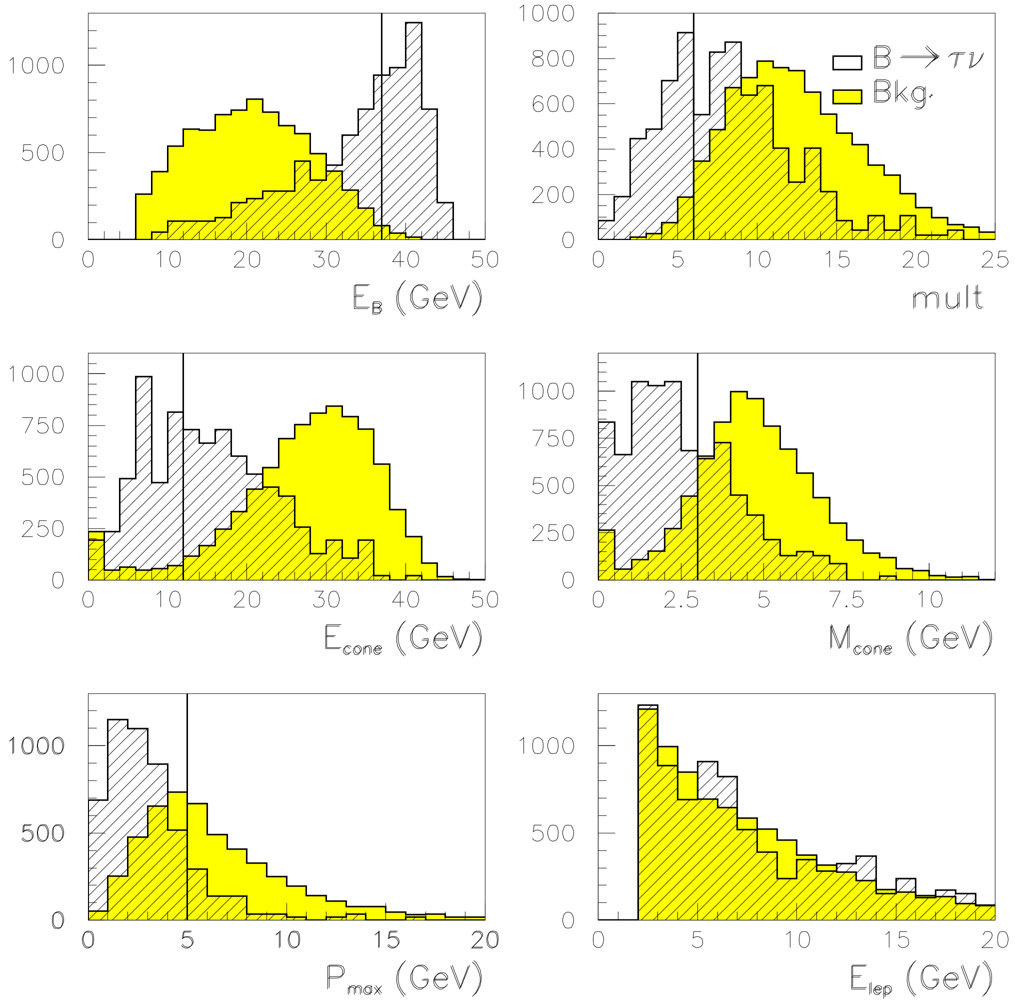

Figure 1: *Simulated signal (hatched) and background (shaded) distributions in the leptonic channel for the B meson energy, the hemisphere charged particles multiplicity, the total energy of particles inside the cone, the invariant mass of the system of particles situated inside the cone, the maximum momentum of primary particles and the lepton energy.*

Other charged tracks in the hemisphere have been required to be compatible with the primary vertex $d_{xy}/\sigma(d_{xy}) < 3$ and to have a maximum momentum of 2 GeV/c. The total neutral energy in the cone was required to be less than 4 GeV, the total energy and the invariant mass of the system of particles situated inside the cone were forced to be less than 7 GeV and 2 GeV/c^2 respectively. The hemisphere multiplicity was required to be less than eight particles.

After having applied the selection criteria, 17 events remain in real data, 20 in the $q\bar{q}$ simulation, which has been normalized to the same statistics, and 47 in the dedicated $B^- \to \tau^-\bar{\nu}_\tau$ simulation. This corresponds to a background rejection factor of 7440 while the signal efficiency is 3.2%.

3.3 Results

In both hadronic and leptonic channels there was no evidence for an excess of events in data as compared to the background estimate after having applied the selection criteria. Combining the two channels and using the Bayesian approach in case of two subchannels with background [19], to obtain the limit, the total number of events originating from $B^- \to \tau^-\bar{\nu}_\tau$ decays is found to be < 3.5 at 90% confidence level. The main sources of systematic errors have been included in the limit evaluation. They concern uncertainties affecting the b-tagging efficiency, the $\tau^- \to \ell^-\nu_\tau\bar{\nu}_\ell$ and $\tau^- \to \nu_\tau X$ branching ratio, the rate for lepton misidentification and efficiency. The largest systematic error comes from the evaluation of the probability for b quarks to hadronise into charged B^- mesons, which is 0.382 ± 0.025 [21]. However, the contribution of the systematic error to the upper limit turns out to be not significant.

The upper limit on the number of events translates to:

$$BR(B^- \to \tau^-\bar{\nu}_\tau) < 1.1 \times 10^{-3}$$

at 90% confidence level.

4 Measurement of the Branching Ratio $b \to \tau\bar{\nu}_\tau X$

The main signature of the $b \to \tau\bar{\nu}_\tau X$ $\tau \to \nu_\tau X'$ decay chain is a large missing energy originating from the production of two or three neutrinos. The main background sources come from hadronic events in which a large missing energy is due to the finite resolution of the detector and/or to semileptonic b and c decays giving high energy neutrinos. To reduce these backgrounds, an enriched sample of $b \to \tau\bar{\nu}_\tau X$ candidates has been selected in two steps. First, a sample of $Z \to b\bar{b}$ events has been obtained. Then events have been retained if they have a large missing energy and no electron or muon candidate. To achieve a high rejection against heavy flavour semileptonic decays, the cuts used for lepton identification are very loose. These cuts force the τ lepton to decay through an hadronic channel: $\tau \to \nu_\tau X'$, where X' are hadrons. Since the inclusive analysis is more sensitive to detector inefficiencies as compared to the exclusive one, the cuts e) and f) on the thrust axis polar direction have been tightened using: $0.2 < |\cos\theta_t| < 0.6$.

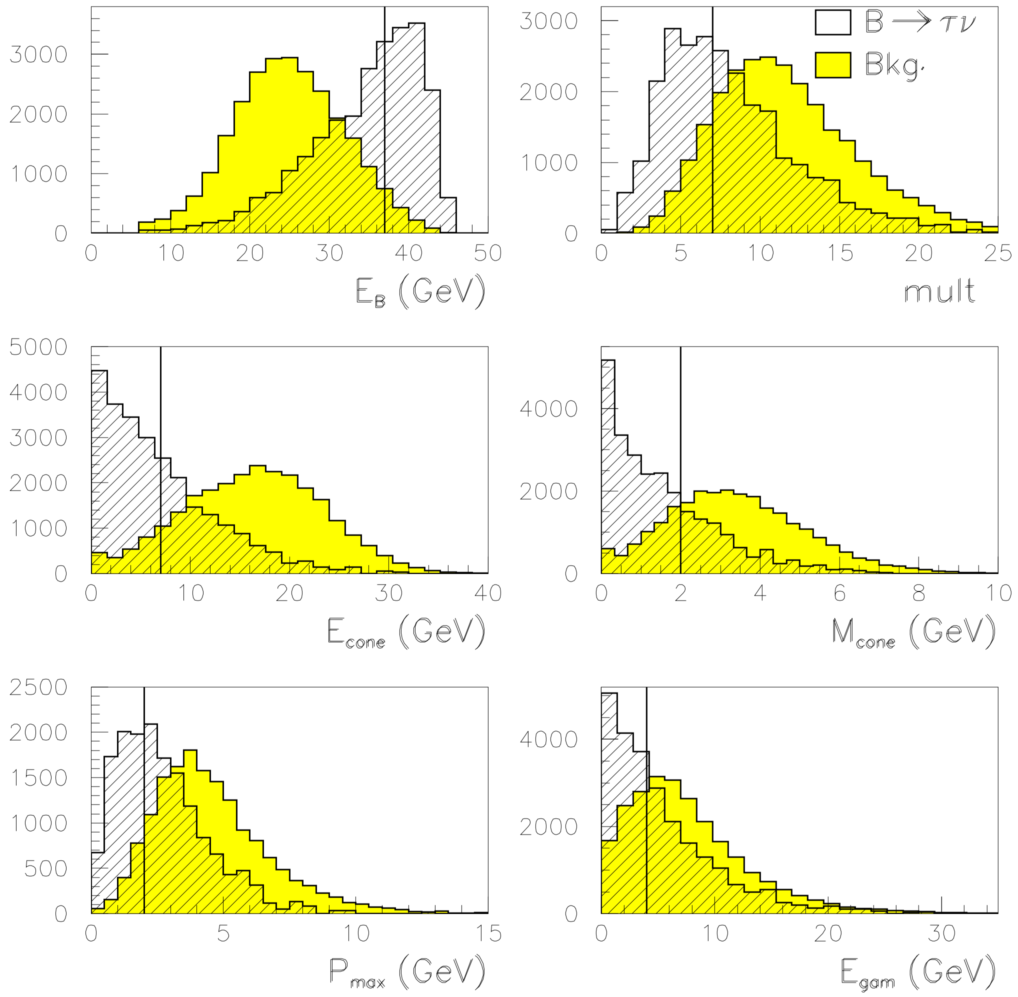

Figure 2: *Simulated signal (hatched) and background (shaded) distributions, in the hadronic channel, for the B meson energy, the charged particles hemisphere multiplicity, the energy in the cone, the invariant mass in the cone, the maximum momentum of the primary particles and the electromagnetic energy in the cone.*

4.1 Fitting procedure

In both real (RD_{bb}) and simulated (MC_{bb}) samples, each selected event has been divided into two hemispheres using the plane perpendicular to the thrust axis.

In each hemisphere the missing energy, E_{miss}, has been calculated from the expression:

$$E_{miss} = E_{beam} - E_{vis} + E_{corr}$$

where E_{beam} is one half of the centre of mass energy, $E_{corr} = (M^2_{same} - M^2_{oppo})/(4E_{beam})$ is a correction, based on 4-momentum conservation, which has a distribution peaked at 0 and a standard deviation of 1.3 GeV, and E_{vis} is the visible energy in the hemisphere:

$$E_{vis} = E_{ch} + E_{\gamma} + E_{oth} + E_{HCAL} \tag{1}$$

E_{ch}, E_{γ}, E_{oth}, E_{HCAL} are the sums, in each hemisphere, of the individual energies of charged particles, electromagnetic showers, non-photon showers in electromagnetic calorimeters and "neutral" hadronic calorimeter showers, respectively.

In order to achieve agreement between data and simulation in the energy measurement, a sample of simulated hadronic events (MC_{uds}) has been selected using the previously mentioned criteria but tagging light quarks instead of $b\bar{b}$ pairs. This was done using, in place of cut f), the condition f') defined as follows:

f') $0.6 < P_E < 1.0$, corresponding to an efficiency of 41% and a purity of 91%.

A sample of real data events (RD_{uds}) has been also selected in similar conditions.

The visible energy in the MC_{uds} sample has been parameterized as:

$$E_{vis} = c_1 \cdot E_{ch} + c_2 \cdot E_{\gamma} + c_3 \cdot E_{oth} + c_4 \cdot E_{HCAL} + c_0, \tag{2}$$

where the coefficients c_i depend on the hemisphere charged multiplicity. The evaluation of these coefficients is performed by minimizing the sum:

$$\chi^2 = \sum_{i=1}^{5} \frac{(M_i^{RD_{uds}} - M_i^{MC_{uds}})^2}{D_i^{RD_{uds}}} \tag{3}$$

In this expression, $M_i^{RD_{uds}}$ ($M_i^{MC_{uds}}$) is the i-th order central moment of the E_{vis} distribution in real data (simulated) events and D_i^{RD} is the dispersion of this distribution. After having applied this correction, there is agreement between the E_{miss} distributions obtained in real and simulated events (Figure 3). The same coefficients c_i, have been used also for the MC_{bb} sample and a corrected value of E_{vis} has been obtained.

4.2 Results

A sub-sample of $b \to \tau X$ (MC_{bb}^{btau}) events has been isolated from the simulated sample MC_{bb} by requiring that the Z^0 decays into a $b\bar{b}$ pair and that, in one hemisphere, the b decay products contain a τ lepton. The complementary sub-sample, MC_{bb}^{bkg}, contains all other possible decay modes and gives the simulation background. Figure 4 shows the hemisphere missing energy distributions, for both RD_{bb}, MC_{bb}^{btau} and MC_{bb}^{bkg}. The excess of events in data, present at high values of the missing energy, is due to the $b \to \tau\bar{\nu}_{\tau}X$ process.

The measurement of the $b \to \tau \bar{\nu}_\tau X$ branching ratio relies on a comparison between the missing energy distribution of the data sample RD_{bb} and the background simulation sample MC_{bb}^{bkg}. Figure 5 shows the distribution of the difference $RD_{bb} - MC_{bb}^{bkg}$. The shape of this distribution is consistent with that of MC_{bb}^{btau} (shaded area). The values of measured BR($b \to \tau \bar{\nu}_\tau X$) and the statistical error using different missing energy bins have been reported in Table 1. The result is stable. The bin $10 \div 40$ GeV has been chosen for the final measurement since it is the one with the lowest relative error; it gives:

$$BR(b \to \tau \nu_\tau X) = (2.52 \pm 0.23(stat))\%$$

$E_{miss}(GeV)$	BR($b \to \tau \bar{\nu}_\tau X$)	stat. err.
$-10 \div 40$	2.62%	0.32%
$-5 \div 40$	2.68%	0.31%
$0 \div 40$	2.73%	0.29%
$5 \div 40$	2.93%	0.23%
$10 \div 40$	2.52%	0.23%
$15 \div 40$	1.96%	0.29%
$20 \div 40$	1.83%	0.36%
$25 \div 40$	1.53%	0.66%

Table 1: *Measured branching ratio of $b \to \tau \bar{\nu}_\tau X$ and statistical error for different missing energy intervals*

4.3 Systematic errors

The main physics background comes from the semileptonic decays of b and c quarks to e and μ. The uncertainty on the branching ratios of these decays contribute to the systematic error. Using the latest DELPHI value for 94C data [22] $BR(b \to \ell) = (10.64 \pm 0.13(stat) \pm 0.24(syst)^{+0.43}_{-0.27}(model))\%$ and varying this branching ratio by one standard deviation the error on BR($b \to \tau \bar{\nu}_\tau X$) turns out to be 0.15%. In a similar way, the effect from the uncertainty on the cascade semileptonic branching fraction, $BR(b \to c \to \ell) = (8.32 \pm 0.29(stat) \pm 0.41(syst)^{+0.57}_{-0.69}(model))\%$ [23], has been evaluated to be 0.17%.

Furthermore, a possible difference between data and simulation on the lepton identification efficiency has to be taken into account. Using the value of 1% (3%) for μ (e) a systematic error of 0.02% (0.07%) has been obtained. Similarly, using for the uncertainty on the lepton misidentification evaluation, the values of 0.25% (0.2%) for μ (e), a systematic error on the branching ratio of 0.07% (0.06%) has been obtained.

The only significant background involving τ leptons comes from the decay $D_s \to \tau \bar{\nu}_\tau$. Using the DELPHI value of $(8.5 \pm 4.2 \pm 2.6)\%$ [24] and changing the branching ratio by one standard deviation an error on BR($b \to \tau \bar{\nu}_\tau X$) of 0.14% is got.

The difference in the b tagging purity for data and simulation is reflected in the systematic error, since the percentage of real $b\bar{b}$ events in the selected samples influences directly the value of the measured branching ratio. Having estimated this difference to be of the order of 2% this gives a systematic error of 0.07%.

The missing energy spectrum depends on the mean energy of the decaying B hadrons. This means that the uncertainty on $< x_b >$ reflects on the systematic error. Using the latest DELPHI value of $< x_b >= 0.702 \pm 0.009$ [25] the fragmentation distribution is changed in the simulation so that the mean value varies by $\pm 1\sigma$. Repeating the analysis with the new fragmentation function, a systematic uncertainty of 0.30% is obtained. Similarly the error from the value of $< x_c >= 0.49 \pm 0.02$ [25] is found to be 0.09%.

Table 2 summarizes the systematic errors on the measured branching ratio, calculated by changing the parameters described above by one standard deviation. The shape systematics accounts for the sensitivity of this measurement to the calibration of the measurement of the missing energy using a sample of events enriched in light quarks. Choosing different ways to tune the light quark simulation sample, the maximum spread (0.24%) in the variation of the extracted branching ratio has been used as systematic error. Combining all systematic contributions in quadrature a total systematic error of 0.49% is obtained.

Absolute variations of the parameters	$\Delta(\mathrm{b} \to \tau\bar{\nu}_\tau \mathrm{X})$
$BR(b \to \ell) = (10.64^{+0.51}_{-0.38})\%$	0.15
$BR(b \to \mathrm{c} \to \ell) = (8.32^{+0.76}_{-0.85})\%$	0.17
$BR(D_s \to \tau\nu) = (8.5 \pm 4.9)\%$	0.14
μ ID efficiency ($\pm 1\%$)	0.02
e ID efficiency ($\pm 3\%$)	0.07
μ misidentification ($\pm 0.25\%$)	0.07
e misidentification ($\pm 0.2\%$)	0.06
b-tagging purity ($\pm 2\%$)	0.07
$< \mathrm{x_b} >= 0.703 \pm 0.008$	0.30
$< \mathrm{x_c} >= 0.49 \pm 0.02$	0.09
shape	0.24
Total Systematic Error	0.49

Table 2: Systematic uncertainties on BR($b \to \tau\bar{\nu}_\tau X$)

5 Restriction on supersymmetric models

No indication of an enhancement of the branching ratio $B^- \to \tau^-\bar{\nu}_\tau$ has been found when compared to the Standard Model prediction. In the Type II Higgs models the branching ratio BR($B^- \to \tau^-\bar{\nu}_\tau$) is enhanced by a factor of $[(\frac{m_{B^-}}{m_{H\pm}})^2 \tan^2\beta - 1]^2$. Using the value of $m_{B^-} = 5279$ MeV [21], and $BR^{SM} = 6 \times 10^{-5}$ the following limit is obtained:

$$\frac{tan\beta}{M_{H\pm}} < 0.46\, GeV^{-1}$$

at 90 % confidence level [20].

Using the B_c contribution hypothesis [7], one gets $BR^{SM}(B_u + B_c) = \alpha \times BR^{SM}(B_u)$, where α is a factor, $1.5 < \alpha < 3.3$, which takes into account the B_c contribution in the $\tau\bar{\nu}_\tau$ final state. Using the lowest bound for α the previous limit becomes $\frac{tan\beta}{M_{H\pm}} < 0.42\, GeV^{-1}$ at 90 % confidence level.

No indication of a large enhancement of the branching ratio of $b \to \tau\bar{\nu}_\tau X$ has been found compared to the Standard Model prediction. Using HQET and including one loop QCD corrections [20], the inclusive measurement of $b \to \tau\bar{\nu}_\tau X$ translates into a constraint on the charged Higgs mass in the frame of any Type II Higgs doublet model:

$$\frac{tan\beta}{M_{H^\pm}} < 0.48\,GeV^{-1}$$

at 90 % confidence level [20].

6 Conclusions

Using 3.5 million hadronic Z^0 decays collected in the 1992-1995 LEP1 period, the purely leptonic decay $B^- \to \tau^-\bar{\nu}_\tau$ has been studied in both the leptonic $\tau^- \to \ell^-\nu_\tau\bar{\nu}_\ell$ and hadronic $\tau^- \to \nu_\tau X$ decay channels. No signal has been observed in the data and this corresponds to the following upper limit:

$$BR(B^- \to \tau^-\bar{\nu}_\tau) < 1.1 \times 10^{-3} \text{ at } 90\% \text{ C.L.}$$

This limit is consistent with Standard Model expectations of $BR^{SM} = 6 \times 10^{-5}$ and is competitive with respect to previous experimental results. Since the branching ratio of $B^- \to \tau^-\bar{\nu}_\tau$ is expected to be significantly larger in models with two Higgs doublets, the following constraint is obtained in the framework of any type II Higgs doublet model:

$$\frac{tan\beta}{M_{H\pm}} < 0.46\,GeV^{-1} \text{ at } 90\% \text{ C.L.}$$

This limit becomes slightly more stringent if one includes the possible B_c contribution, to the $\tau\bar{\nu}_\tau$ final state.

Using the observed missing energy distribution in a sample enriched in $b\bar{b}$ events but depleted in their semileptonic decays, the branching ratio:

$$BR(b \to \tau\nu_\tau X) = (2.52 \pm 0.23(stat) \pm 0.49(syst))\%$$

has been measured. This value is in agreement with the Standard Model prediction of $(2.30\pm0.25)\%$ and with previous measurements by LEP experiments (Figure 6). Including the present measurement, the LEP average becomes $(2.52 \pm 0.26\%)$. From this value a limit on $tan\beta/M_{H^\pm}$ has been obtained which is similar to the one deduced from the search for the exclusive channel $B^- \to \tau^-\bar{\nu}_\tau$ and is not influenced by the large uncertainty on f_B and $|V_{ub}|$.

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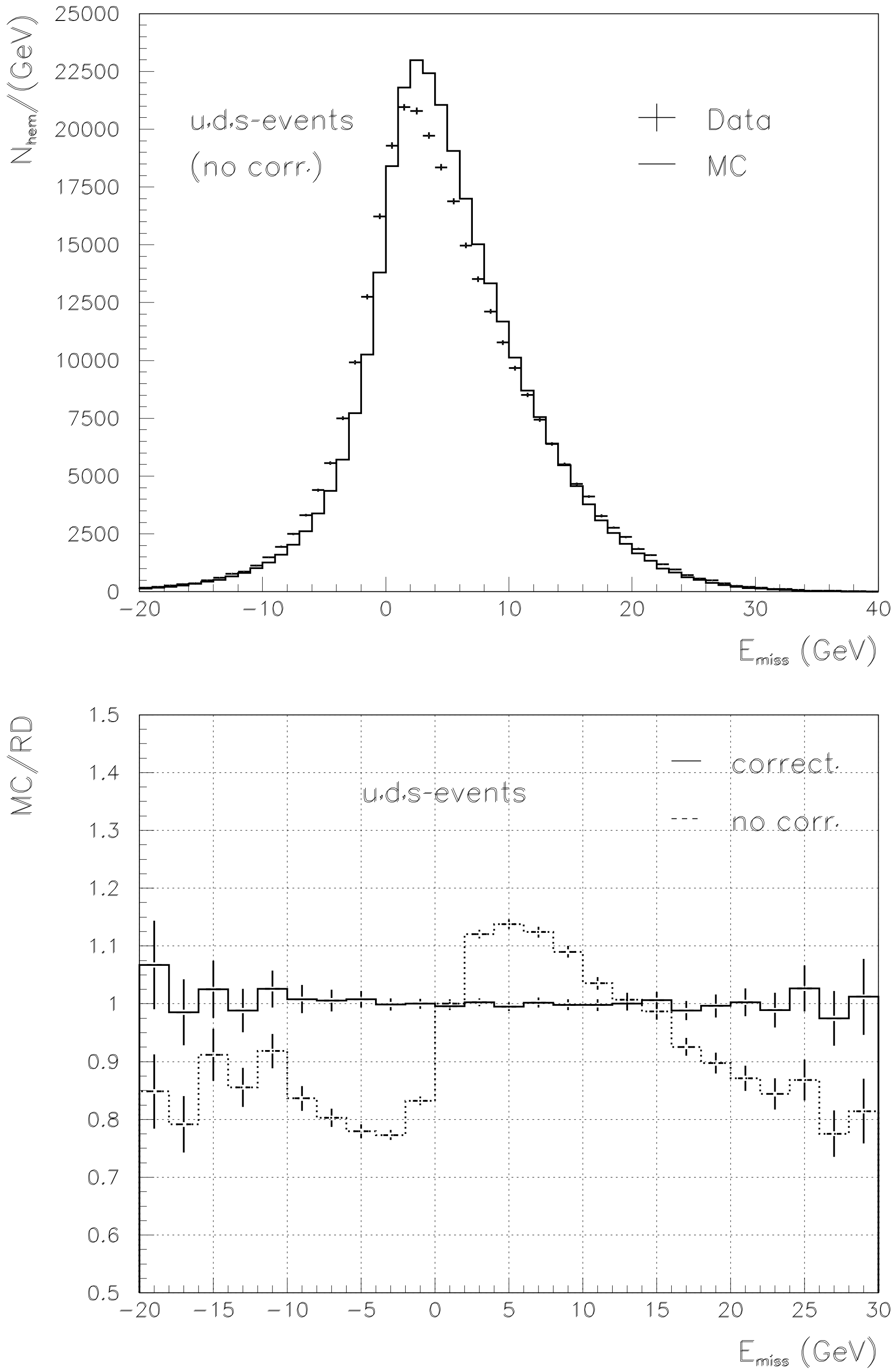

Figure 3: *Comparison between real and simulated events of the missing energy distribution. The upper plots give these distributions for events samples depleted in heavy flavours decays. In the lower plots the ratio between the two previous distributions have been compared, before and after having applied the corrections.*

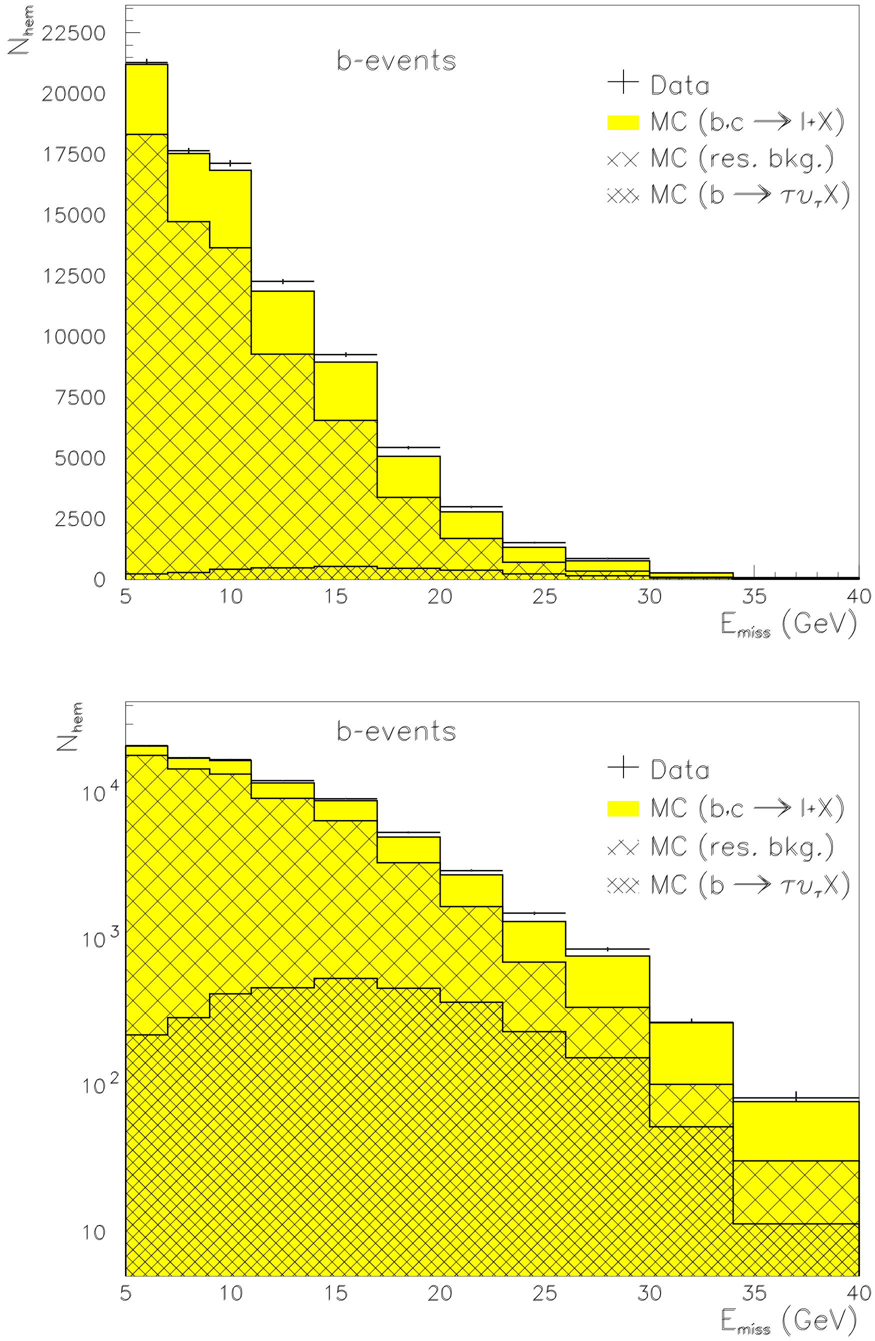

Figure 4: *Missing energy distributions for real data (dots) and Monte Carlo (shaded area) in both linear and logarithmic scale. The Monte Carlo is subdivided in simulation signal, semileptonic background and residual background*

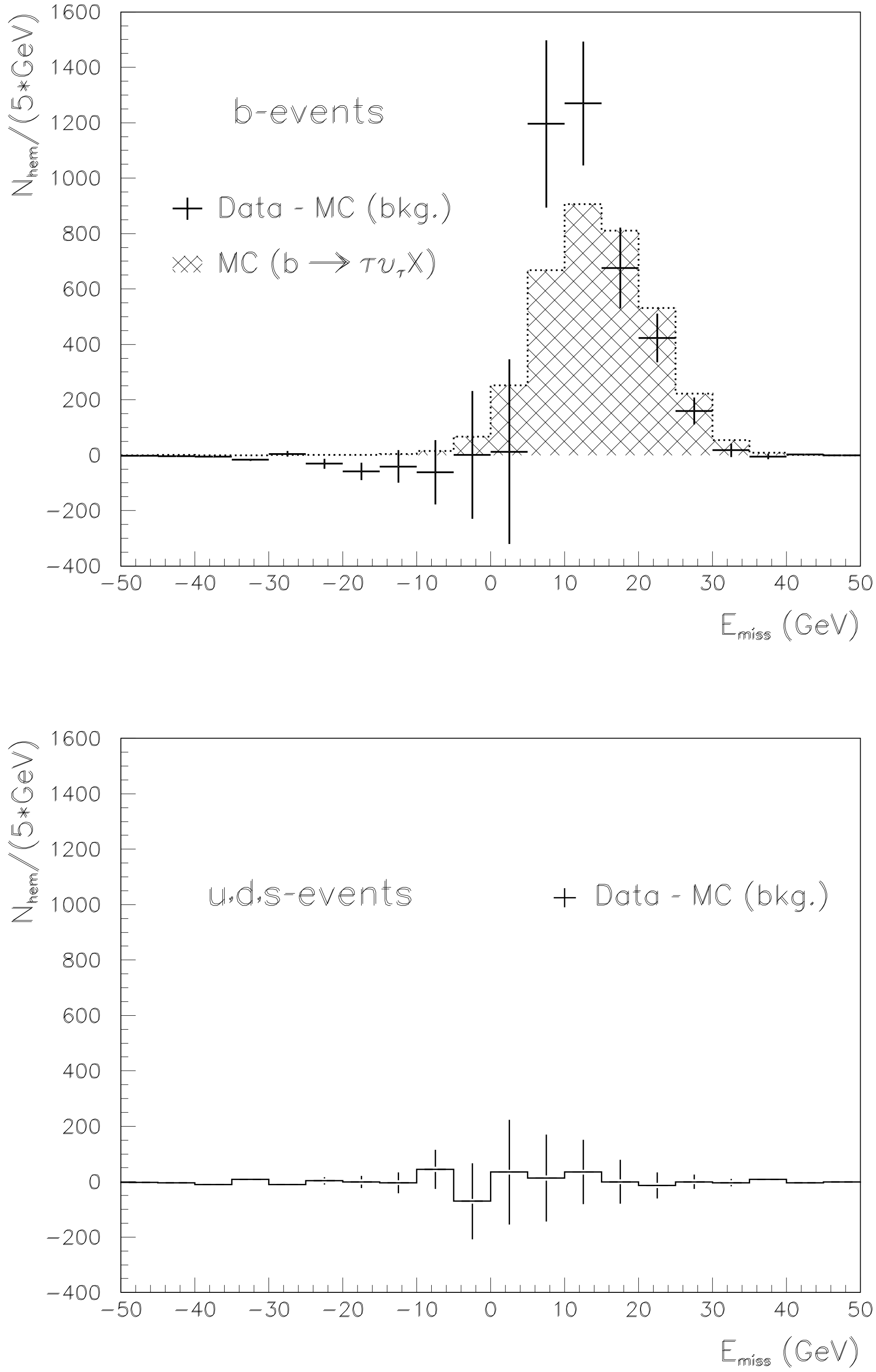

Figure 5: *Difference of missing energy distributions between real data and background simulation for both b and light quark samples. The clear excess of data in the b sample is compared with the predicted missing energy spectrum of the b to tau signal (hatched area)*

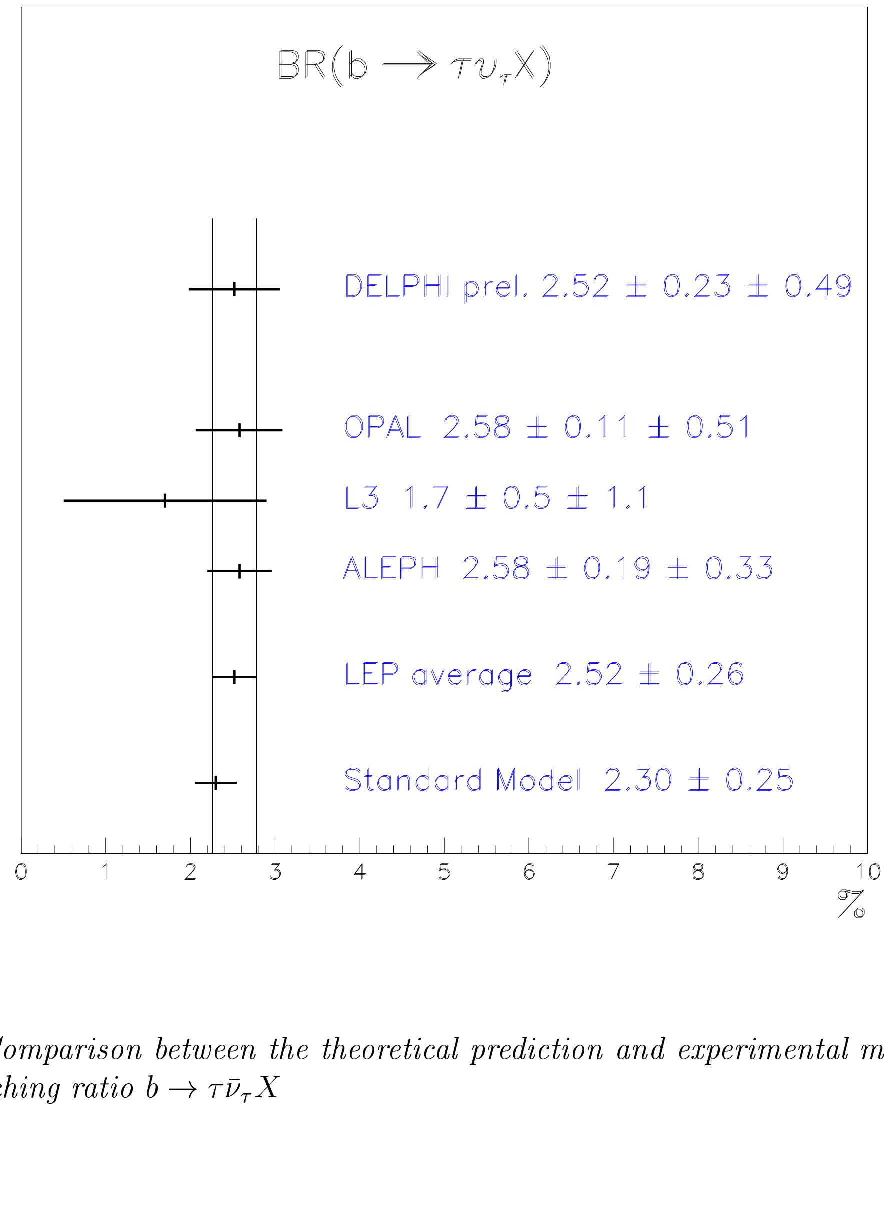

Figure 6: *Comparison between the theoretical prediction and experimental measurements of the branching ratio* $b \to \tau \bar{\nu}_\tau X$