DELPHI 97-107 CONF 89
28 July, 1997

Measurement of Branching Ratio of $b \to \tau \nu_\tau X$

Preliminary

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Abstract

Using the DELPHI detector at LEP, the branching ratio BR($b \to \tau \nu_\tau X$) has been measured using Z^0 hadronic decays from LEP1 data. The analysis relies mostly on missing energy and b-tagging. This measurement is consistent with Standard Model expectations and puts a constraint of $tan\beta/M_{H^\pm}$ in the framework of any type II Higgs doublet models.

Paper submitted to the LP'97 Conference
Hamburg, July 28 - August 1st

1 Introduction

The decay of $b \to \tau\nu_\tau X$, where X stands for all the other particles produced in the decay besides the τ and the ν_τ, represents a test of the Standard Model which contains the present knowledge of the elementary particles and their interactions. The Standard Model predicts a value for the branching ratio $b \to \tau\nu_\tau X$of $(2.30 \pm 0.25)\%$ using Heavy Quark Effective Theory (HQET) [1] [2]. The supersymmetric extension of the Standard Model with two Higgs doublets predicts for the decay $b \to \tau\nu_\tau X$a branching ratio of (10-20)% [3] [4], as the decay is mediated by H^- and W^-. An experimental measurement of this branching ratio allows thus to constrain the quantity $tan\beta/M_{H^\pm}$, where $tan\beta$ is the ratio of the vacuum expectation values of the two Higgs doublets and $M_{H^\pm}$ is the mass of the charged Higgs. Previous experimental measurements of BR($b \to \tau\nu_\tau X$) at ALEPH [5], L3 [6] and OPAL [7] detectors confirm the validity of Standard Model theoretical predictions.

The main signature of the $b \to \tau\nu_\tau X$, $\tau \to \nu_\tau X'$ decay chain is the large missing energy associated with the production of the two or three neutrinos. The main sources of background are hadronic events which have a large missing energy due to the finite resolution of the detector and/or semileptonic b and c decays to electrons and muons with highly energetic neutrinos. To reduce these backgrounds an enriched sample of $b \to \tau\nu_\tau X$ candidates was selected in two steps. First, a sample of $Z \to b\bar{b}$ events was obtained. The events were then required to have large missing energy and no electron or muon candidates. This cut forces the τ to decay in the hadronic channel $\tau^- \to \nu_\tau h$, where h are hadrons. Section 2 describes the selection cuts in more details.

In this paper the results on measurement of the inclusive $b \to \tau\nu_\tau X$ branching ratio in DELPHI experiment are presented.

2 Sample selection

The data were collected with the DELPHI detector at LEP during the 1994 running period, at center of mass energy at the Z^0 peak. They contain about 1.7 million hadronic Z^0 events at the centre of mass energy 91.2 GeV.

The DELPHI detector and its performance has been described elsewhere [8][9].

The analysis used a sample of about 3 millions Monte Carlo events, which were generated by JETSET 7.4 (parton shower), with b and c quark fragmentation according to the Peterson parameterization [11], and processed through a full simulation of the DELPHI detector.

The charged track reconstruction was done with the new DELANA method. Only tracks with impact parameters smaller than 2 cm in both $R\phi$ and z axes were accepted.

In order to reject background associated with $b \to \ell\nu_\ell$ and $c \to \ell\nu_\ell$, ℓ being e or μ, only hemispheres with no $e^\pm$ or $\mu^\pm$ were selected. To achieve a high veto efficiency for this background the cuts used for the lepton identification were very loose. Electron identification has been described in [9]. In our analysis it was selected the loose tagging that has an efficiency of 80% and a misidentification probability of $\simeq 1.6\%$. Muons were identified requiring at least one hit in the muon chambers (very loose tagging) [9]. The identification efficiency of this muon selection is 96% and the misidentification probability is $\simeq 5.4\%$.

As the b-tagging variable, the probability P_E that all tracks from an event originate from a common primary vertex was used [12]. $b\bar{b}$ events were selected using $P_E < 0.01$ which gives an efficiency of 82% and a purity of 81%.

The following cuts have been used to select our sample of hadronic events with a good energy reconstruction and with a $b\bar{b}$ topology. The cuts were applied both at the real data and the simulation samples.

a) Beam energy compatible with Z^0 decay - $45.5 < E_{beam} < 45.75 GeV$

b) Standard hadronic event selection [9]
- Charged particle multiplicity > 7
- Total charged energy $> 15\ GeV$

c) Standard detector quality selection

d) Barrel region
- $|\cos\theta_{THR}| < 0.6$ where θ_{THR} is the polar angle of the thrust axis [10]

e) Two jet topology
- $0.85 < Thrust < 1.00$ [10]

f) Avoid detector inefficiency region around $\theta = 90^o$
- $|\cos\theta_{THR}| > 0.2$

g) No e or μ
- Absence of $e^{\pm}$ selected as described above with energy $>$ 2 GeV
- Absence of $\mu^{\pm}$ selected as described above with energy $>$ 2 GeV

h) B tagging
- $P_E < 0.01$ where P_E is the event probability

3 Fitting procedure

For both our real data RD_{bb} and simulation MC_{bb}, each selected event was divided into two hemispheres using the plane perpendicular to the thrust axis. The number of hemispheres selected in RD_{bb} (MC_{bb}) was 116224 (212585) respectively.

For each hemisphere it was calculated the missing energy E_{miss}, defined as

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

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

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

Here E_{ch}, E_γ, E_{oth}, E_{HCAL} are the sums, for each hemisphere, of charged tracks energy, electromagnetic energy, energy of non-photons showers in electromagnetic calorimeters and "neutral" hadronic calorimeter showers, respectively. Figure 1 shows the hemisphere energy distributions for the four different contributions.

In order to achieve a better agreement between data and Monte Carlo, a sample of hadronic events MC_{uds} was simulated with exactly the same selection cuts a) to g), but tagging light quarks rather than $b\bar{b}$. This was done using, instead of cut h), the cut h') defined as followed:

h') Light quark tagging
- $0.6 < P_E < 1.0$ (efficiency 41%, purity 91%)

A sample of real data RD_{uds} with selection cuts a) to g) and with light quark tag h') was also selected for the calibration. The numbers of hemispheres selected was 169693 and 339209 for RD_{uds} and MC_{uds} respectively.

The visible energy of the MC_{uds} was 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 coefficients c_i are dependent from the hemisphere charged multiplicity, and are defined separately for every hemisphere with definite charged multiplicity. The calculation of the coefficients c_i is performed by minimizing the sum

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

Here $M_i^{RD_{uds}}$ ($M_i^{MC_{uds}}$) is the i-th order central moment of the E_{vis} distribution for the real data (Monte Carlo) events and D_i^{RD} is the dispersion of the distribution of the $i-$degree of E_{vis}. After this correction we have precise agreement between real data and Monte Carlo E_{miss} distribution shapes (Figure 2). The coefficients c_i for each charged multiplicity were applied to the MC_{bb} sample and the new value of E_{vis} was calculate.

4 Measurement of the branching ratio of $b \to \tau\nu_\tau X$

A sub-sample of $b \to \tau X$ (MC_{bb}^{btau}) events has been obtained from the simulated sample MC_{bb} requiring that the Z^0 decays into a $b\bar{b}$ pair and that in one hemisphere the b decays to τ. The complementary sub-sample MC_{bb}^{bkg} = MC_{bb} - MC_{bb}^{btau} contains all the other possible decays and constitute the simulation background. Figure 3 shows the hemisphere missing energy distributions, for both RD_{bb}, MC_{bb}^{btau} and MC_{bb}^{bkg}. The excess of data present at high missing energy values is due to the $b \to \tau\nu_\tau X$process.

The measurement of the $b \to \tau\nu_\tau X$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 4 shows the distribution of the difference $RD_{bb} - MC_{bb}^{bkg}$. As it is seen from the figure, the shape of this distribution is consistent with that of MC_{bb}^{btau} (shaded area). Table 1 shows the values of measured BR($b \to \tau\nu_\tau X$) and the statistical error using different missing energy bins. The result is quite stable in all energy bins, except for the last one, where the statistic is too low for a good measurement. The bin $10 \div 40 GeV$ was chosen for our final measurement since it is the one with the lowest relative error. We have thus:

$$BR(b \to \tau\nu_\tau X) = 2.60 \pm 0.30(stat)\%$$

$E_{miss}(GeV)$	BR($b \to \tau\nu_\tau X$)	stat. err.
$-10 \div 40$	2.67%	0.42%
$-5 \div 40$	2.71%	0.40%
$0 \div 40$	2.73%	0.38%
$5 \div 40$	2.64%	0.33%
$10 \div 40$	2.60%	0.30%
$15 \div 40$	2.38%	0.33%
$20 \div 40$	2.46%	0.37%
$25 \div 40$	1.90%	0.72%

Table 1: *Measured branching ratio of $b \to \tau\nu_\tau X$ and statistical error for different missing energy intervals*

5 Systematic error

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 our systematic error. Using the latest DELPHI value for 94C data [13] $BR(b \to \ell) = (10.92 \pm 0.19)\%$ and changing this branching ratio by 1σ we obtain an error in BR($b \to \tau\nu_\tau X$) of 0.06%. From $BR(b \to c \to \ell) = (8.62 \pm 0.36)\%$ a systematic error of 0.06% was calculated in the same way.

Furthermore it should be taken in account the slight disagreement between data and simulation for the lepton identification efficiency: using the value of 1% (3%) for μ (e) we get a systematic error of 0.02% (0.07%) respectively. Similarly using for lepton misidentification the values of 0.25% (0.2%) for μ (e) we obtain a systematic error on our branching ratio of 0.07% (0.06%) respectively.

The only significant background involving τ leptons comes from the decay $D_s \to \tau\nu$. The uncertainty on this branching ratio gives us a systematic error. Using the L3 value of $(7.4 \pm 3.7)\%$ [14] and changing the branching ratio by 1σ we get an error on BR($b \to \tau\nu_\tau X$) of 0.11%.

The difference in the b tagging purity for data and simulation is reflected in the systematic error, since the percentage of real $b\bar{b}$ in the selected samples influences the branching ratio. Estimating this difference to be of the order of 2% we obtain 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 our systematic error. Using the latest DELPHI value of $< x_b > = 0.702 \pm 0.009$ [15] we obtain 0.55%. This constitutes the main contribution of the total systematic error. Similarly the error from the value of $< x_c > = 0.49 \pm 0.02$ [15] was found to be 0.15%.

Table 2 summarizes the systematic errors on our branching ratio, calculated changing the parameters described above by 1σ. The shape systematic accounts for the sensibility of our measurements to the light quark calibration. Choosing different ways to tune the light quark simulation sample we calculate the error as the maximum spread in the branching ratio. This spread turned out to be 0.23%.

Systematic Effect	Δ(b $\rightarrow \tau\nu$X)
$BR(b\rightarrow\ell) = (10.92 \pm 0.19)\%$	0.06
$BR(b\rightarrow$ c $\rightarrow\ell) = (8.62 \pm 0.37)\%$	0.06
$BR(D_s\rightarrow\tau\nu) = (7.4 \pm 3.7)\%$ [14]	0.11
μ ID efficiency = 1%	0.02
e ID efficiency = 3%	0.07
μ misidentification = 0.25%	0.07
e misidentification = 0.2%	0.06
b-tagging purity = 2%	0.07
$< \mathrm{x_b} >= 0.703 \pm 0.008$ [15]	0.55
$< \mathrm{x_c} >= 0.49 \pm 0.02$ [15]	0.15
shape	0.23
Total Systematic Error	0.65

Table 2: Systematic uncertainties on BR($b \rightarrow \tau\nu_\tau X$)

6 Conclusion

Using 1.4 million Z^0 decays we have measured the branching ratio:

$$BR(b \rightarrow \tau\nu_\tau X) = 2.60 \pm 0.30(stat) \pm 0.65(syst)\%$$

The value is in good agreement with Standard Model prediction [1] of $2.30 \pm 0.25\%$ and with previous measurements at LEP experiments (Figure 5). No indication of a large enhancement of the branching ratio was found compared to the Standard Model prediction. This measurement puts a constraint on the charged Higgs mass in the frame of any Type II Higgs double model:

$$\frac{tan\beta}{M_{H\pm}} < 0.50\, GeV^{-1}$$

at 90 % confidence level [16][17].

Acknowledgments

We thank Y. Grossman of Stanford Linear Accelerator, for converting our measurement of the $b \rightarrow \tau\nu_\tau X$branching ratio into an upper limit on $tan\beta/M_{H\pm}$. We wish to express our gratitude to the CERN accelerator division for the excellent performance of the LEP machine.

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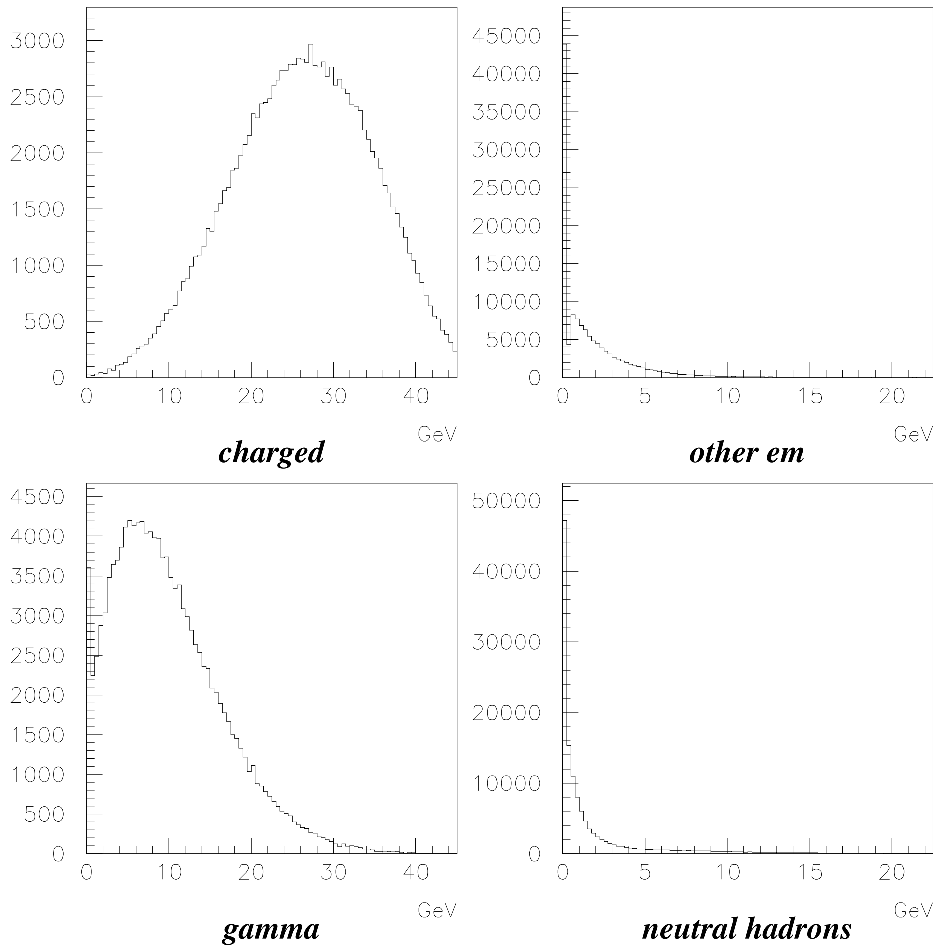


Figure 1: *Charged hemisphere energy, photon energy, non photon showers energy in electromagnetic calorimeters and neutral hadronic calorimeter showers energy contribution in the selected hemispheres*

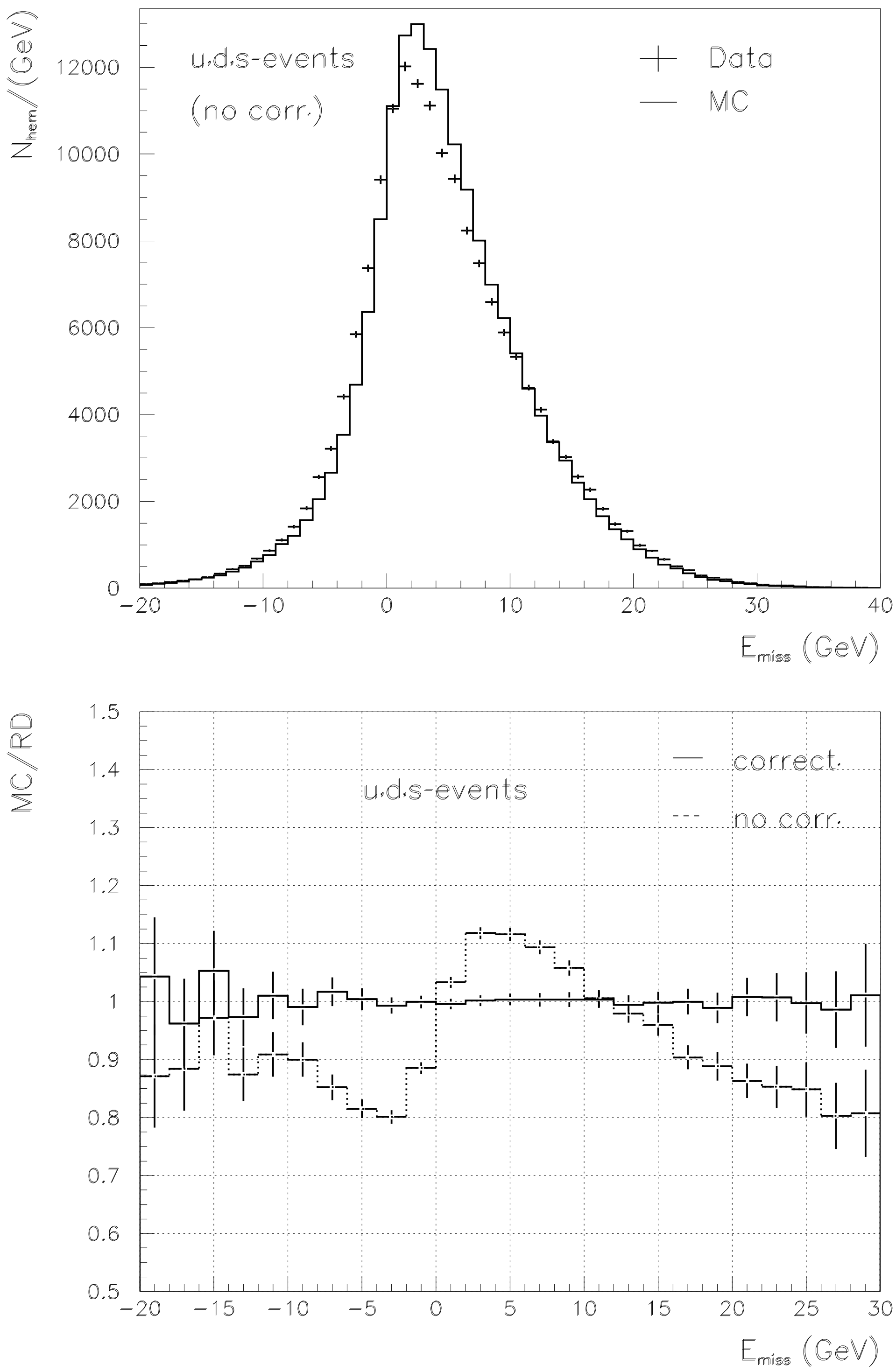


Figure 2: *Fine tuning of simulation using light quark sample*

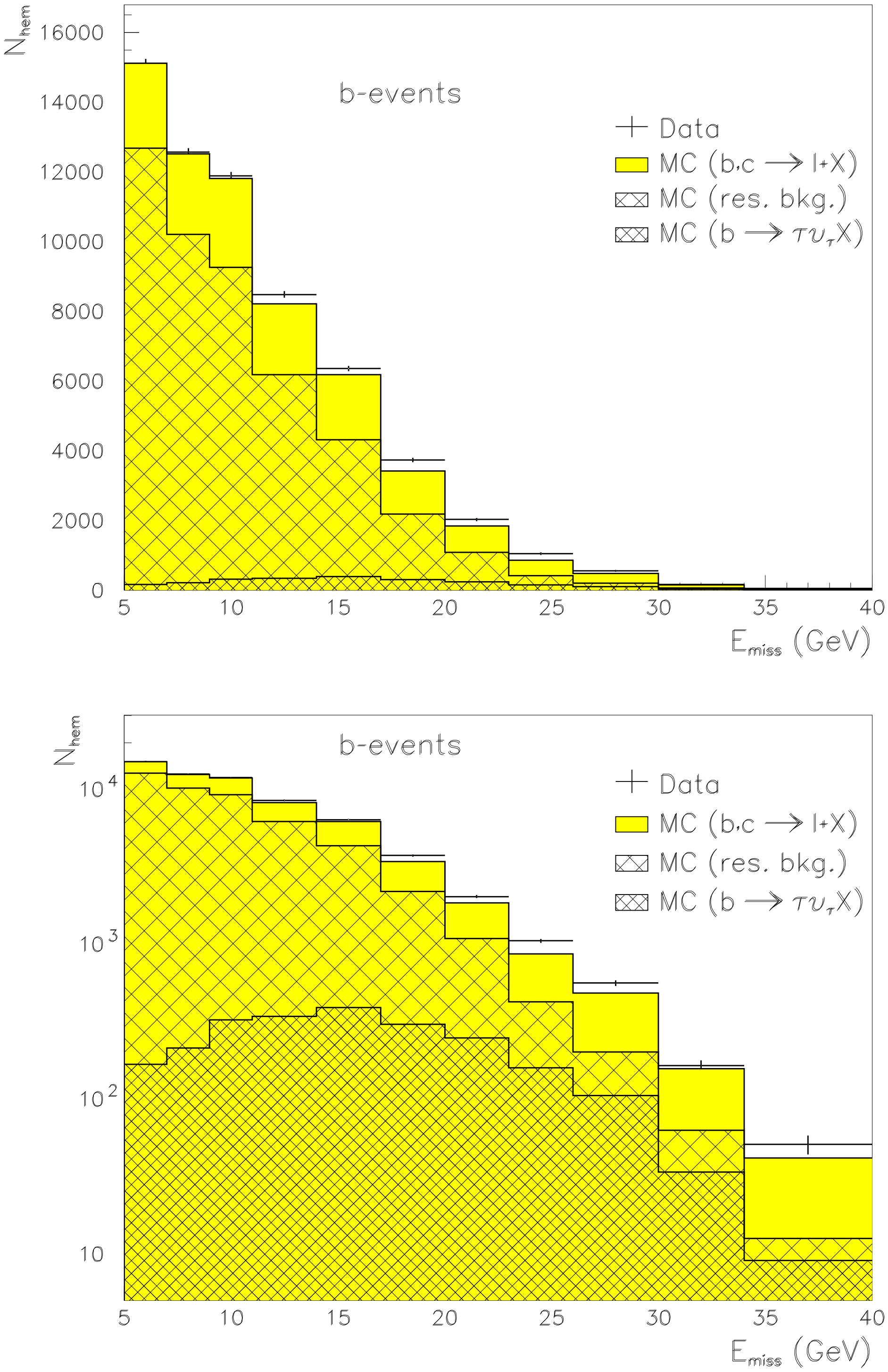
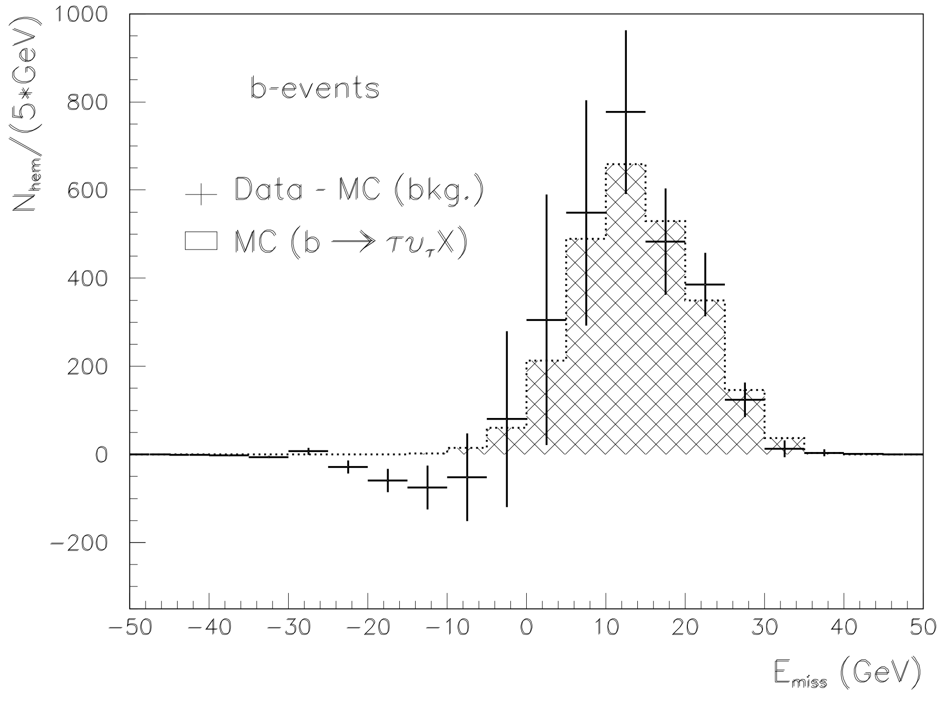


Figure 3: *Missing energy distributions for real data (dots) and Monte Carlo (shaded area) in both linear and logarithmic scale. The Monte Carlo is subdivided in simulation signal, semileptonic background and residual background*



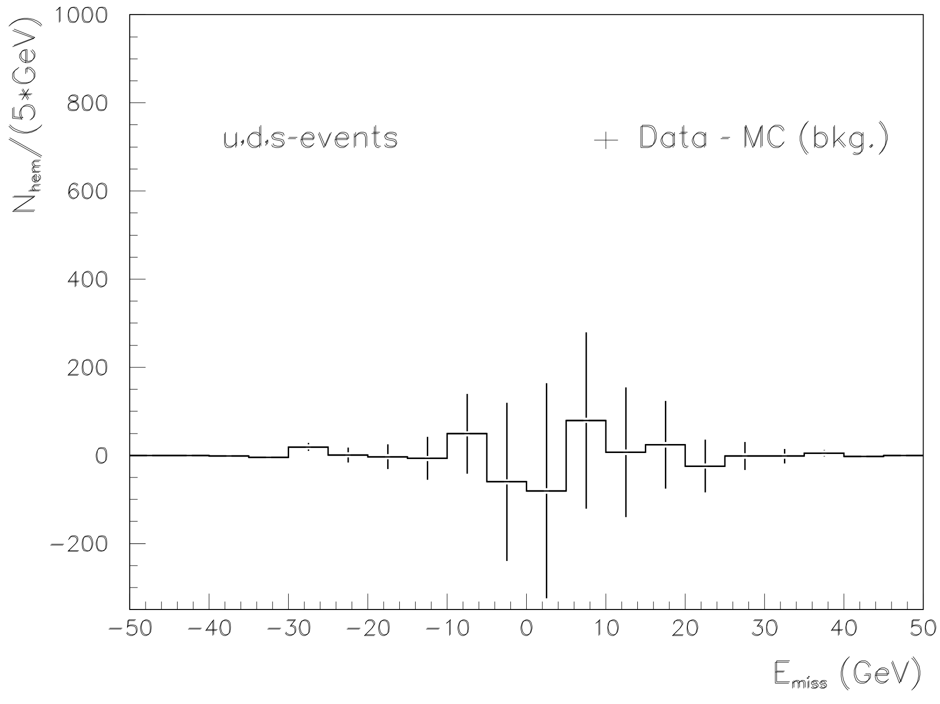


Figure 4: *Difference of missing energy distributions between real data and background simulation for both b and light quark sample. The clear excess of data in the b sample is compared with the predicted missing energy spectrum of b to tau signal (shaded area)*

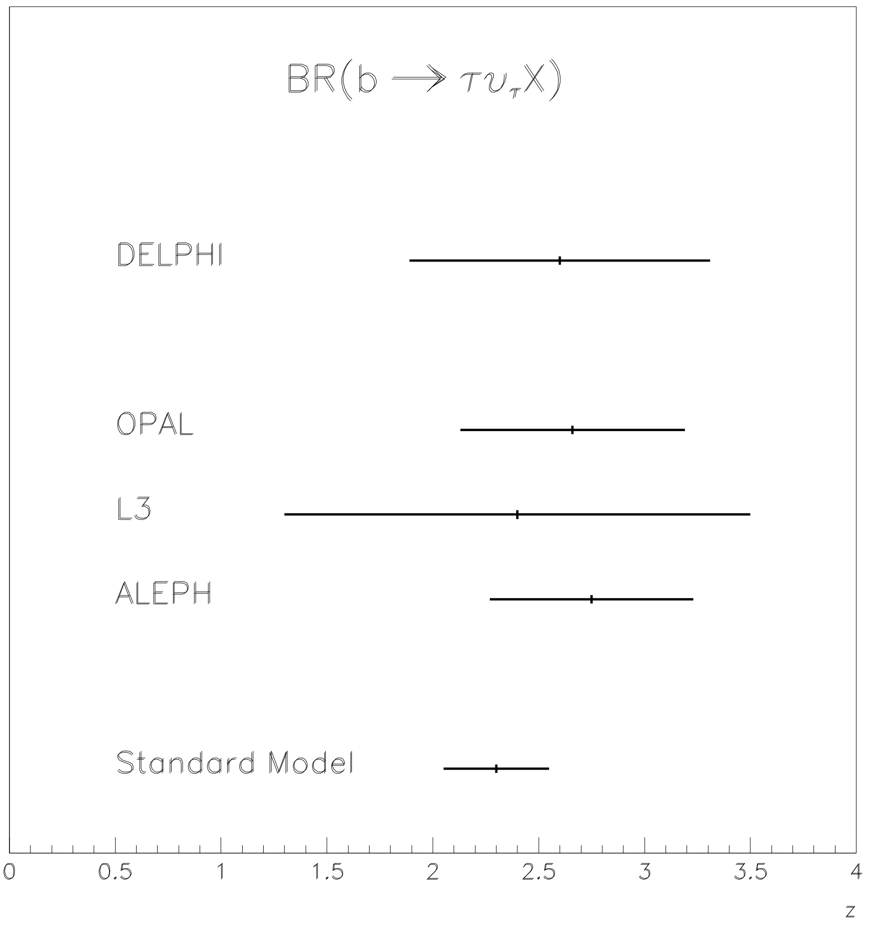


Figure 5: *Comparison between theoretical prediction and other experiment measurements branching ratios in percentage*