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Measurements of BR($b \to \tau^- \bar{\nu}_\tau X$) and BR($b \to \tau^- \bar{\nu}_\tau D^{*\pm} X$) and Upper Limits on BR($B^- \to \tau^- \bar{\nu}_\tau$) and BR($b \to s \nu \bar{\nu}$)

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Abstract

Using the LEP I ALEPH data (1991-1995) the branching ratio BR($b \to \tau^- \bar{\nu}_\tau X$) is found to be (2.41±.21±.34)% using a missing energy technique. A complementary measurement using two leptons in the final state gives ($3.94 \pm .67 \pm^{+.62}_{-.56}$)%. Combined together this leads to (2.72±.20±.27)%. The branching ratio BR($b \to \tau^- \bar{\nu}_\tau D^{*\pm} X$) is measured to be (0.94±.32±.37)% and the following limits are established : BR($B^- \to \tau^- \bar{\nu}_\tau$) $< .16\%$ and BR($b \to s \nu \bar{\nu}$) $< 7.7 \times 10^{-4}$ both at 90% CL. BR($b \to \tau^- \bar{\nu}_\tau X$) and BR($B^- \to \tau^- \bar{\nu}_\tau$) allow to set a constraint on the charged Higgs mass in the frame of any type II Higgs doublet model : $\tan\beta / M_{H^\pm} < .46\ \mathrm{GeV}^{-1}$ at 90% CL.

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1 Introduction

The $b \to \tau$ transitions are interesting as they involve heavy fermions in both initial and final states. They are sensitive to any new mediating heavy boson like a charged Higgs [1, 2] which should enhance $BR(b \to \tau^- \bar{\nu}_\tau X)$ and $BR(B^- \to \tau^- \bar{\nu}_\tau)$ relative to the SM predictions [3]. In such case also the production of D mesons in the final state will be enhanced to the detriment of D^*[4]. Similarly the process $b \to s\nu\bar{\nu}$ is also sensitive to new heavy physics [5]. This work updates the measurement of $BR(b \to \tau^- \bar{\nu}_\tau X)$ and $BR(B^- \to \tau^- \bar{\nu}_\tau)$ using a missing energy technique [6]; with the same method the $BR(b \to \tau^- \bar{\nu}_\tau D^{*\pm} X)$ is measured and a first limit on $BR(b \to s\nu\bar{\nu})$ is set. $BR(b \to \tau^- \bar{\nu}_\tau X)$ is also measured independently using modes with two leptons and both $BR(b \to \tau^- \bar{\nu}_\tau X)$ results are combined.

2 Measurements using the missing energy

2.1 Summary of the Method

All the processes studied here give at least two νs leading to a large missing energy in the corresponding hemisphere of the $Z \to b\bar{b}$ decay. The background is due to events with $b, c \to e/\mu\nu X$ and those with large E_{miss} due to the finite resolution of the detector. It is reduced by applying a $b\bar{b}$ lifetime tag [7] to the opposite hemisphere and vetoing the identified e/μ in the hemisphere where E_{miss} is measured. Details of this method can be found in [8, 6]. When not specified the analysis is the same as [6]. The analysis uses 3.6 million hadronic Z decays, 3.5 million hadronic Monte Carlo events together with dedicated fully simulated samples of $b \to \tau^- \bar{\nu}_\tau X$, $B^- \to \tau^- \bar{\nu}_\tau$ or $b \to s\nu\bar{\nu}$ events.

As in [8, 6] an E_{miss} calibration is applied to the Monte Carlo to make data and Monte Carlo E_{miss} distributions match in samples enriched in $Z \to u\bar{u}, d\bar{d}, s\bar{s}$ leading to an attenuation of the neutral hadronic energy by .89. A cut $E_{neu} < 7$ GeV is used as in [8, 6]. This calibration has been cross-checked with a calibration done in a $Z \to \tau^+\tau^-$ sample: this gives an additional confidence in it.

2.2 Measurement of $BR(b \to \tau^- \bar{\nu}_\tau X)$

$BR(b \to \tau^- \bar{\nu}_\tau X)$ is measured through the counting of the entries in the missing energy bin [16,35] GeV. Two samples called A and B are built by applying the $b\bar{b}$ tag in the opposite hemisphere and a e/μ veto for A and a tag [9] for B in the hemisphere the E_{miss} is measured. The extraction of $BR(b \to \tau^- \bar{\nu}_\tau X)$ proceeds through a fit where the input quantities are: 4 E_{miss} bins between 16 and 35 GeV for the samples A and B and the measurement of $< x_b >$ [10] and $BR(b \to e/\mu\nu X)$ [11]. The fitted quantities in the fit are : $BR(b \to \tau^- \bar{\nu}_\tau X)$, $< x_b >$ and $BR(b \to e/\mu\nu X)$. The fit gives χ^2=9.9 for 7 d.o.f. and the fitted values are found to be in reasonable agreement with external measurements (see table 1). The E_{miss} distributions for samples A and B can be seen on figure 1 a) and b). The error on $BR(b \to \tau^- \bar{\nu}_\tau X)$ includes statistics and systematics coming from all the sources present in the fit. The purely statistical part is obtained by redoing the fit when $< x_b >$ and $BR(b \to e/\mu\nu X)$ are fixed. It is found to be .21%.

The advantage of this fit compared to a direct extraction is that thanks to the sample B an anti-correlation between $< x_b >$ and $BR(b \to e/\mu\nu X)$ is found and allows a reduction

Quantity	Fit result	Ext. meast
$BR(b \to \tau^- \bar{\nu}_\tau X)$	2.41±.34 %	-
$< x_b >$	.708 ±.012 %	.705 ±.007 ±.013 % [10] with $BR(b \to D^{**})$=21%
$BR(b \to e/\mu\nu X)$	11.19 ±.21 %	11.11 ±.23 % [11]

Table 1: Results of the fit with the errors, compared to external measurements.

of the systematical error. As a consistency check the fit can be redone by removing the constraint on either $< x_b >$ or $b \to e/\mu\nu X$. The results are found to stay consistent. The choice of the lower cut in E_{miss} (=16 GeV) has been optimized to give the smallest total error.

The systematical errors are evaluated by varying the external measurements by 1 σ and redoing the same fit. The results are shown in table 2. New sources are added compared to [6]: 1) the Λ_b are measured to be polarized $P(\Lambda_b) = -.31^{+.22}_{-.19} \pm .08$ [12]. This shifts $BR(b \to \tau^- \bar{\nu}_\tau X)$ by .06%±.05%. 2) The different calibration schemes lead to an error of 0.06%. The final result is (2.41±.21±.34)%.

Source	Error in %
$< x_b >$=.705 ±.007 ±.013 % [10]	.22
$BR(b \to e/\mu\nu X)$=11.11 ±.23 % [11]	.06
$BR(b \to c \to e/\mu\nu X)$=7.78±.37%[11]	.02
$BR(D_s^\pm \to \tau^\pm \nu_\tau)$=5.7±2.3%[13]	.12
$BR(b \to D^{**})$=21 ±8 %[14]	.05
$< x_c >$=.487±.08±.08 [15]	.01
$b \to e/\mu\nu X$ decay modelling	.04
$b \to \tau^- \bar{\nu}_\tau X$ decay modelling	.06
$< P_\tau >$=-.706±.030 [3]	.02
$P(\Lambda_b) = -.31^{+.22}_{-.19} \pm .08$ [12]	.06
$b\bar{b}$ tag performances	.05
μ-id efficiency	.06
e-id reco.+efficiency	.10
E_{miss} in $b\bar{b}$	.10
cut E_{neu}<7 GeV	.06
E_{miss} calibration procedures	.06
Total systematics	.34

Table 2: Summary of the systematical errors for $BR(b \to \tau^- \bar{\nu}_\tau X)$.

2.3 Measurement of $BR(b \to \tau^- \bar{\nu}_\tau D^{*\pm} X)$

A $D^{*\pm}$ selection is performed, looking for $D^{*\pm} \to D^0 \pi^+_{soft}$ followed by $D^0 \to K^- \pi^+ \pi^- \pi^+$, $D^0 \to K^- \pi^+$,$D^0 \to K^- \pi^+ \pi^0$ and $D^0 \to K^0_S \pi^+ \pi^-$ selected by kinematical cuts. The D^0 tracks are required to vertex at at least 2 σ from the reconstructed primary vertex. This ensures an enrichment in $Z \to b\bar{b}$ and no $b\bar{b}$ tag is applied on the opposite hemisphere. It is also required to have an additional track h incompatible with the primary vertex, with opposite charge relative to π_{soft} and lying in a cone $|\cos(h, D^0)| > .85$ [16]. The same method is applied as above with e/μ veto but no $b\bar{b}$ tag. The branching ratio is extracted by counting the events in the E_{miss} bin [12,30] GeV (see figure1 c). 62 $b \to \tau^- \bar{\nu}_\tau D^{*\pm} X$, 58 $b, c \to e/\mu\nu X$ and 40 background events are estimated from Monte Carlo. The same sources of systematics as for $BR(b \to \tau^- \bar{\nu}_\tau X)$ are considered. The resulting branching ratio is extracted to be $(0.94 \pm .32 \pm .37)\%$.

2.4 Upper limits on $BR(B^- \to \tau^- \bar{\nu}_\tau)$ and $BR(b \to s\nu\bar{\nu})$

These analyses use the same event selection and bin [35,50] GeV in E_{miss} energy as optimized in [6]. The number of events in this bin (see Table 3) take into account the uncertainties from the systematics in the $BR(b \to \tau^- \bar{\nu}_\tau X)$ fit. The E_{miss} distributions can be seen on Figure 1 c) and d). To be conservative the limits on the processes are estimated

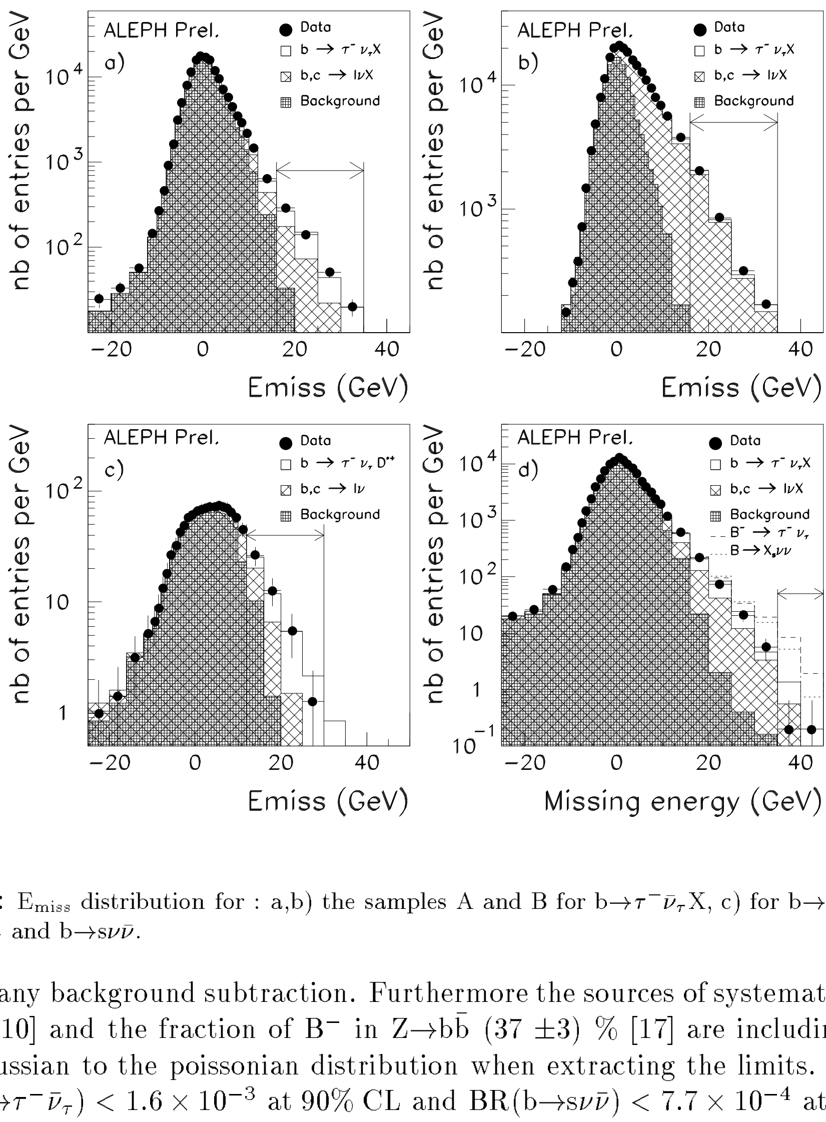

Figure 1: E_{miss} distribution for : a,b) the samples A and B for $b \to \tau^- \bar{\nu}_\tau X$, c) for $b \to \tau^- \bar{\nu}_\tau D^{*\pm} X$. d) for $B^- \to \tau^- \bar{\nu}_\tau$ and $b \to s\nu\bar{\nu}$.

without any background subtraction. Furthermore the sources of systematics coming from $< x_b >$ [10] and the fraction of B^- in $Z \to b\bar{b}$ (37 $\pm$3) % [17] are including by convoluting a gaussian to the poissonian distribution when extracting the limits. The results are $BR(B^- \to \tau^- \bar{\nu}_\tau) < 1.6 \times 10^{-3}$ at 90% CL and $BR(b \to s\nu\bar{\nu}) < 7.7 \times 10^{-4}$ at 90% CL. [1]

[1]assuming η=-.5, η being the equivalent of the Michel parameter for the $b \to s\nu\bar{\nu}$ decay [5].

Source	30< E_{miss} <35	35< E_{miss} <40	40< E_{miss}
Data	28.	1.	1.
BR($B^-\to\tau^-\bar{\nu}_\tau$) (=1%)	72.8 ±6.1	35.4 ±4.4	9.6 ±3.4
BR($b\to s\nu\bar{\nu}$) (=.3%)	54.0 ±4.8	19.2 ±3.5	4.0 ±2.8
BR($b\to\tau^-\bar{\nu}_\tau X$)	6.6 ±2.2	4.0 ±3.1	0.
$b,c\to e/\mu\nu X$	15.9 ±4.5	2.8 ±2.2	0.3 ±.4
Other Backgrounds	.8 ±.6	0.	0.

Table 3: Numbers of entries in the E_{miss} bins for $B^-\to\tau^-\bar{\nu}_\tau$, $b\to s\nu\bar{\nu}$ and the background processes.

3 Measurement of BR($b\to\tau^-\bar{\nu}_\tau X$) Using Dilepton Events

An alternative analysis to measure BR($b\to\tau^-\bar{\nu}_\tau X$) using a sample of dilepton events has been developed. Details of this analysis can be found in [18]. The analysis uses the 1992 to 1995 data yielding to a total of 3,250,000 hadronic events, together with 2 million Monte Carlo events. The e/μ identification is performed as in [9].

The signature used to tag the signal events is a pair of leptons (e,μ) of **opposite sign in a jet**, one coming from the τ decay and the other from the charm. The separation of the signal from the background events is achieved using the different kinematic properties of the various categories of events. A multivariate analysis using a Neural Network (NN) technique is used to obtain the best discriminating power.

The main background consists on dileptons coming from two successive decays : $b\to\ell$ for ($\ell = e,\mu$) followed by the cascade decay of the b quark following a semileptonic decay $(b\to c\to\ell)_D$. To determine the BR($b\to\ell\bar{\nu}_\ell X$) $\times$ BR$(b\to c\to\ell)_D$ product, the semileptonic branching ratio has been fixed to the LEP average value BR($b\to\ell\bar{\nu}_\ell$ X)= (11.11±0.23)% [11] and the $(b\to c\to\ell)_D$ fraction has been measured by fitting the output of a NN optimized to separate this kind of background. Another important background

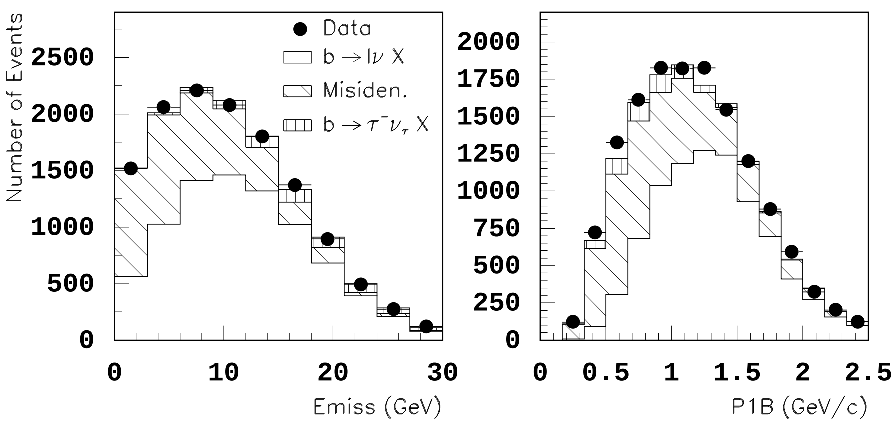

Figure 2: Data and normalized Monte Carlo distributions for the missing energy of the leptonic hemisphere and the momentum of one lepton boosted to a reference system approximating the rest system of the b hadron using the amount of signal obtained from the fit.

consists of leptons from light hadron decays or hadrons misidentified as leptons; a control sample of *same sign* dileptons within the same jet has been used to check the reliability of the description of the Monte Carlo for these events. Variables with high discriminating power to separate signal from background have been selected as input to the NN; among these are the momentum of the leptons boosted to a reference system approximating the rest frame of the b hadron, the missing energy in the hemisphere of the jet and the invariant mass of the leptonic pair. The good agreement between data and Monte Carlo distributions is examplified in Figure 2; the overall normalization of the MC to the data is done by scaling the number of hadronic events selected, without introducing any other free parameter.

System. Effect	$\Delta(\mathrm{b}\to\tau)$
BR($\mathrm{b}\to\ell$) $\times$ BR($\mathrm{b}\to\mathrm{c}\to\ell)_{\mathrm{D}}$=.91%, 2.5%variation	$\mp$0.4
$<\mathrm{x_b}>= 0.714\pm 0.013$ [15]	$^{-0.1}_{+0.3}$
D** Fraction Increased up to 20% [19]	$\pm$ 0.1
BR($\mathrm{b}\to\bar{\mathrm{c}}\mathrm{s}$) = 5 ± 0.9% [13]	$\mp$ 0.17
BR($\tau\to\ell$) = 17.65 ± 0.24% [13]	$\mp$ 0.06
BR($\mathrm{c}\to\ell$) = 9.8 ± 0.5% [20]	$\mp$ 0.08
τ Polariz.=-.735, 100% variation.	$\pm$ 0.2
Lepton ID Eff. [15]	$\pm$ 0.1
$\mathrm{E_{miss}}$ calibration	$\pm$ 0.2
Total Systematic Error	$^{+0.61}_{-0.56}$

Table 4: Systematic uncertainties on BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$)measured with dileptons.

The value of the BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$) branching ratio is obtained by fitting the output neuron distribution for the overall data sample to the sum of the different Monte Carlo distributions. The result obtained when using the overall data sample is BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$)= (3.94$\pm$.67(stat)$\pm^{+.62}_{-.56}$(syst))%; the confidence level of the fit is 0.7. Figure 3 shows the output neuron distribution for Real Data (1992+93+94+95) and normalized 92 MC, using the BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$) branching ratio obtained from the fit.

Some consistency checks have been performed : 1) Figures obtained with three subsamples of dielectrons ($\mathrm{e}^\pm,\mathrm{e}^\mp$), dimuons ($\mu^\pm,\mu^\mp$) and ($\mathrm{e}^\pm,\mu^\mp$) pairs are checked to be consistent to each other. 2) BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$) obtained when fitting the *missing energy* distribution instead of the output of the NN is 4.1 $\pm$0.9(stat.). 3) An alternative NN fed only with *charged track* information gives BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$) =4.6 $\pm$0.9(stat.). The main sources of systematic uncertainty on BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$) are presented in Table 4.

4 Combining the two BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$) measurements

The results from the $\mathrm{E_{miss}}$ and the dileptons techniques are combined taking into account correlated sources of error. The fit gives a χ^2=2 and the combined branching ratio is found to be : BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$) = (2.72$\pm$.20$\pm$.27)%.

5 Summary

Using 3.6 Million hadronic Z decays the following branching ratios have been measured using a missing energy technique : BR($\mathrm{b}\to\tau^-\bar{\nu}_\tau\mathrm{X}$)= (2.41$\pm$.21$\pm$.34)% and

BR(b$\rightarrow\tau^-\bar{\nu}_\tau$D$^{*\pm}$X)= (0.94$\pm$.32$\pm$.37)%. Using dileptons in the final state BR(b$\rightarrow\tau^-\bar{\nu}_\tau$X) is independently measured to be BR(b$\rightarrow\tau^-\bar{\nu}_\tau$X)= (3.94$\pm$.67$\pm^{+.62}_{-.56}$)%. They are combined to give : BR(b$\rightarrow\tau^-\bar{\nu}_\tau$X)= (2.72$\pm$.20$\pm$.27)%. These results are in agreement with the Standard Model predictions, the two L3 inclusive measurements : BR(b$\rightarrow\tau^-\bar{\nu}_\tau$X)= (2.4$\pm$.7$\pm$.8)% [21], BR(b$\rightarrow\tau^-\bar{\nu}_\tau$X)= (1.7$\pm$.5$\pm$1.1)% [22] and the OPAL measurements [16] : BR(b$\rightarrow\tau^-\bar{\nu}_\tau$X)= (2.58$\pm$.11$\pm$.51)%, BR(b$\rightarrow\tau^-\bar{\nu}_\tau$D$^{*\pm}$X)= (1.04$\pm$.38$\pm$.32)%. The inclusive measurement puts a constraint on the charged Higgs mass in the frame of any Type II Higgs doublet model : $\tan\beta/M_{H^\pm} < .46$ GeV^{-1} at 90% CL. On an other hand an upper limit is put on the exclusive channel : BR(B$^-\rightarrow\tau^-\bar{\nu}_\tau$)$< 1.6\times10^{-3}$ at 90% CL. Finally a first limit on the process b$\rightarrow$s$\nu\bar{\nu}$ concurrently with B$^-\rightarrow\tau^-\bar{\nu}_\tau$ is found to be BR(b$\rightarrow$s$\nu\bar{\nu}$)$<$ 7.7×10^{-4} at 90% CL.

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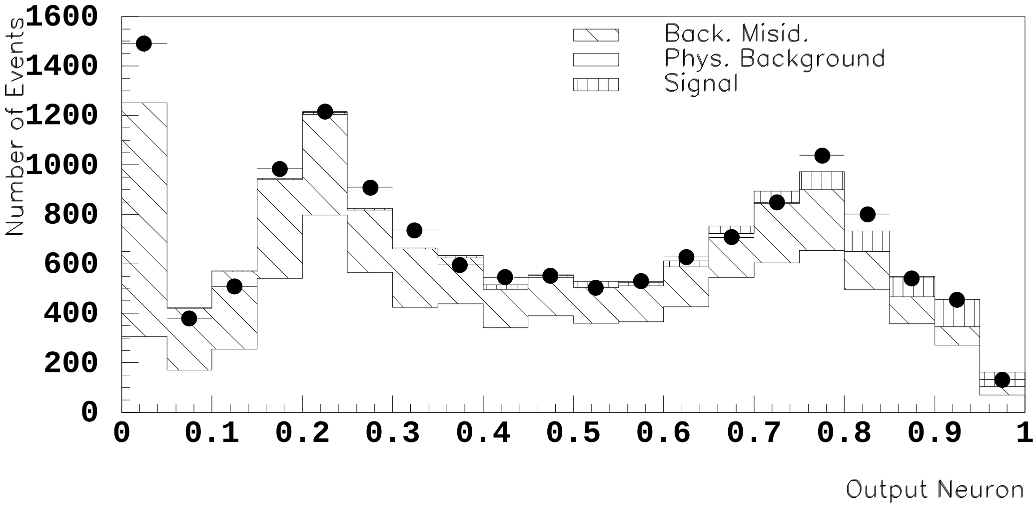

Figure 3: Output neuron distributions for the Real Data and MC, using the BR($b \to \tau^- \bar{\nu}_\tau X$) = (3.94 ± 0.67)% (value obtained in the fit).