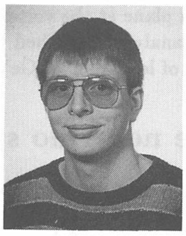
A Measurement of the V–A×V–A Structure of the Weak Charged Current in Semileptonic b-Decays and Missing Energy Measurements



Frank Behner
Institute for Particle Physics
Swiss Institute of Technology
CH-8093 Zurich

Abstract

The polarization of the W-propagator in semileptonic b decays is measured with the L3 experiment at LEP via simultaneous observation of the charged lepton and the neutrino spectrum. The polarization is seen with more than 3 standard deviations and found to be in agreement with the V–A×V–A structure. The measurement excludes the V+A×V–A polarization with more than 6 standard deviations. Furthermore, the branching ratio in $B \rightarrow \nu X$ is measured and found to be 22.7%±0.8%(stat.)±1.5%(syst.) which corresponds to a branching ratio of $B \rightarrow e\nu X$ of 10.1%±0.8%.

1 Introduction and Method

A question one likes to answer experimentally is whether b-quarks inside hadrons decay like a free particle. Such a decay can be described in a free quark or spectator model [1], with V–A×V–A coupling or with exotic V+A×V–A coupling. Another possibility would be a kaon-like decay with a V×V–A coupling where the W-propagator is depolarized due to QCD effects. The effect of the polarization of the virtuell W can be seen in the energy sharing between the charged lepton and its neutrino. In the V–A×V–A case, the neutrino spectrum is softer than the charged lepton spectrum, in the V+A×V–A the opposite is true. In the V×V–A case both leptons have the same spectrum which is then slightly softer than the charged lepton spectrum in the V–A×V–A case. If the charged lepton spectrum were only determined by the vertex structure, it would be sufficient to compare it with the predictions for the different models. Unfortunally this is not the case, because of uncertainties in the branching ratios and the b-quark and c-quark masses. A further uncertainty at the Z is the fragmentation function. It is possible to tune all parameters such that the spectrum for the charged lepton looks the same under the two extreme assumptions of the V–A×V–A and V+A×V–A case. However it is impossible to make the neutrino spectrum for the different assumptions agree at the same time [2]. The difference in the mean neutrino energy for the two extreme assumptions would be 1.7 GeV, which is obtained assuming typical values for energy, fragmentation and branching ratios. After momentum cuts on the charged lepton a difference of about 1.1 GeV still remains. If the analysis is restricted to two jet like events only, the energy of the neutrino can be defined as $E_\nu = E_{Beam} - E_{Jet}$, where the jet energy E_{jet} is defined as the total visible energy in one of the event's hemispheres separated by a plane at the vertex orthogonal to the thrust axis. E_{beam} is given by the LEP machine. In the analysis described below, two jet like events are defined as events with a mass per hemisphere of less than 25 GeV.

2 Measurement of the neutrino spectrum

Since the neutrino energy is seen as missing energy in a hemisphere as defined above, a jet energy calibration should be chosen such as to correctly reproduce the visible energy with its scale. The scale of the visible energy spectrum of data and Monte Carlo should be equal and determined separatly in a region with nearly no neutrino activity, which assures that the low energy tail is comparable. Through the calibration process all energy spectra are fitted with a Gaussian function in the bulk and high energy tail between 40 and 65 GeV, to obtain the energy scale and the resolution of jets independently of the neutrino spectrum. In the Monte Carlo a resolution of 4.6 GeV per jet is obtained for two jet like events. The expected reconstructed neutrino spectrum is then the true Monte Carlo one smeared with this resolution. The scale is fixed in the Monte Carlo such that the missing energy spectrum describes this expected spectrum. The data are then calibrated to that scale. The energy resolution in the data is found to be 4.2 GeV per jet. A statistical precision of 10 MeV for the scale is achieved by this calibration procedure. The calibration is checked and a systematic error is estimated with samples depleted and enriched in their b content. In this analysis four samples are used:

- a high x sample which requires a track with more than 60% of the beam energy and an associated calorimetric cluster with more than 50% of the beam energy, or a π^0 candidate with more than 50% of the beam energy in the electromagnetic cluster. This tag has about 7% b-purity.
- a semileptonic sample where the charged lepton candidate has to have a transverse momentum with respect to the nearest jet of 1.4 GeV. The momentum cut is 3 GeV for electrons and 4 GeV for muons. The b-purity is about 80%.
- a lifetime tag, where up to 3 high quality tracks per hemisphere which have the largest impact parameter are used to calculate a distance. This distance is the impact parameter projected on the thrust axis, weighted by the transverse momentum with respect to that axis. The sum of the two single hemisphere distances is called the total distance of the event and gives a measure of the content of long lived particles. This gives two tags:
  - the b-enriched lifetime tag with a total distance greater than 3.5 mm which has about 61% b-purity,
  - the b-depleted anti-lifetime tag with a total distance less than 0.0 mm which has about 8% b-purity.

Comparing data and Monte Carlo the uncertainty in the determination of the energy scale is estimated using again the Gaussian fit in the neutrino depleted region between 40 and 65

GeV. For the b-depleted samples the energy scales agree within 40 MeV and for the b-enriched sample within 150 MeV. The difference in the b-enriched samples could be due to differences in the charm sector or in a different flavor dependent detector response between data and Monte Carlo. Since this effect is not fully understood, 150 MeV are taken as a systematic error on the energy scale. Other error sources are the uncertainties in the tagging and the charged lepton spectrum, a summary is given in table 1.

Error Source	$\Delta E(e^{\pm})$ [MeV]	$\Delta E(\nu_e)$ [MeV]	$\Delta E(\mu^{\pm})$ [MeV]	$\Delta E(\nu_\mu)$ [MeV]
Jet Energy Calibration	–	150	–	150
Purity of b→ $X\ell\nu$ ±5%	30	150	50	120
$\ell^{\pm}$ Energy Uncertainty	100	100	100	100
Combined Error	105	235	110	215

Table 1: The dominant contributions to the systematic error for the measurement of the average charged lepton and neutrino energy.

Once the charged lepton spectrum is correctly described by a given model, the neutrino energy spectrum is also predicted. After tagging semileptonic b-decays as described above, the missing energy spectrum of the tagged hemisphere is obtained and compared with the different model predictions. For each model the fragmentation function is tuned such that the charged lepton momentum spectrum agrees between data and Monte Carlo. The average momentum is found to be 12.12±0.110±0.105 GeV for electrons and 12.11±0.070±0.110 GeV for muons, where the first error is statistical and the second is systematic. In the electron case this is 100 MeV softer than the Monte Carlo prediction and for the muons 200 MeV harder. The average electron neutrino momentum is measured to be $6.44 \pm 0.120 \pm 0.235$ GeV and the muon neutrino to be $6.08 \pm 0.120 \pm 0.215$ GeV. The difference in the average momentum between the data and the Monte Carlo is −120 MeV for the electron neutrino in the V−A×V−A case and −1020 MeV in the V+A×V−A case. For the muon neutrino, the difference is 180 MeV for V−A×V−A and −590 MeV for V+A×V−A. The kaon-like V×V−A structure is disfavored by the combined measurement of the average neutrino energy with about 2 standard deviations. To compare the full spectrum the different resolution between data and Monte Carlo has to be taken into account. Due to the agreement between the reconstructed neutrino spectrum and the Gaussian smeared spectrum, a Monte Carlo spectrum was obtained by smearing the generator spectrum with a Gaussian resolution of 4.2 GeV width. Comparing the number of events with hard neutrinos ($\geq$ 16 GeV, see table 2), the disagreement between V+A×V−A and the data is 5.7 standard deviations for the electron neutrinos and 3.7 standard deviations for the muon neutrinos. The V×V−A case is excluded by the electron neutrinos by 3.6 standard deviations while the muons neutrinos are consistent with both V−A×V−A and V×V−A [3].

3 The neutrino rate in B-decays

The branching ratio of b-decays into neutrinos and anything is also studied. This is done using lifetime-tagged b events. After subtracting the background, the branching ratio is obtained by fitting the visible energy spectrum in the range between 15 and 60 GeV with a likelihood fit. In contrast to the study above, where the presence of the neutrino was assured by the presence of a charged lepton, high hadronic background has to be subtracted. This background

		$N_{Data} - N_{MC}$		
type	N_{Data}	(V−A)×(V−A)	(V+A)×(V−A)	V×(V−A)
$b \to X e \nu_e$	518	−42 ± 29 ± 21	−241 ± 31 ± 28	−140 ± 30 ± 24
$b \to X \mu \nu_\mu$	904	85 ± 37 ± 46	−258 ± 39 ± 65	−67 ± 38 ± 54

Table 2: The difference in the number of events expected for the different models, in the bins with largest significance ($E_\nu \geq 16$GeV).

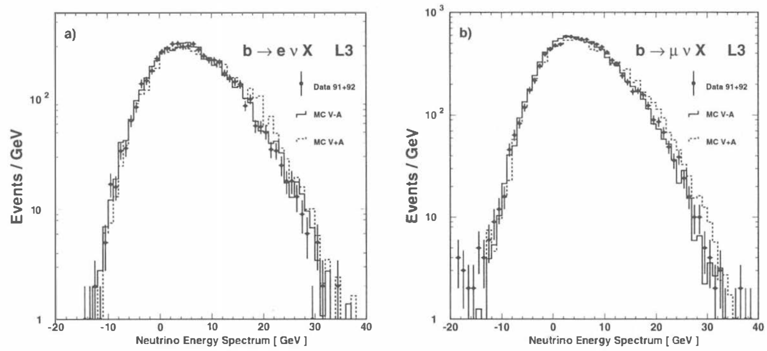


Figure 1: a) The electron neutrino spectrum compared with V−A×V−A and the V+A×V−A prediction. b) The same for the muon neutrino.

contains hadronic b-decays, decays of other flavors and detector defects. The total sample of the two jet events is used to obtain an estimate for this background directly from the data. This sample has high statistics and no bias besides the mass cut. The bias changes the b-purity from 21.7% to 22.9%. The hadronic background is then described with this sample minus the remaining semileptonic b-decays which are subtracted during the fit procedure using Monte Carlo spectra. After correction for the scale difference between the background sample and the lifetime sample, the description of the background spectrum shown in figure 2a is obtained. After a correction of the Monte Carlo lifetime tagged sample for the 150 MeV calibration bias, the shape of the neutrino in the b-enriched and in the background sample is then obtained by adding the semileptonic b-decay energy spectrum of the Monte Carlo with the ratio 1:1:0.25 for b-decays into electron, muon and tau respectively. Due to the theoretical uncertainty of the ratio $b \to \tau\nu X$ to $b \to e\nu X$, a variation of ± 0.05 for the tau neutrino fraction is taken as systematic uncertainty. To fulfill the condition that the hadronic background is the two jet sample minus the semileptonic b-decays, the visible energy spectrum is fitted in the background sample in parallel. With this method a branching ratio of $B \to \nu X$ of 22.7±0.8(stat.)±1.5(syst.)% is obtained. The best fit to the visible energy distribution in lifetime tagged events and the contribution of semileptonic b-decays is shown in figure 2b. The main systematic error sources are the purity of the lifetime tag and the energy uncertainties which were obtained from the V−A×V−A analysis.

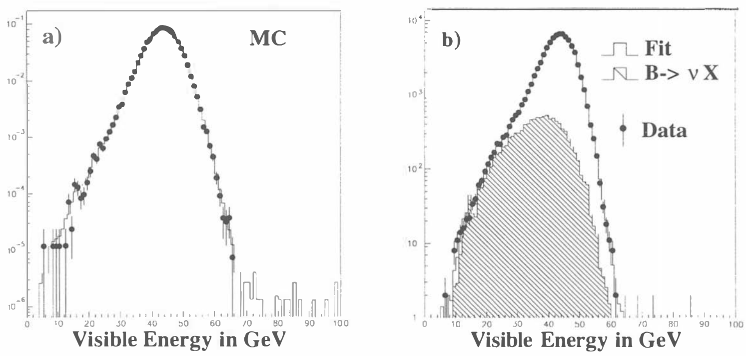


Figure 2: a) The hadronic background estimated from the two jet sample (histogram) compared with the hadronic background in the lifetime sample (dots). b) The final fitted distribution compared with the data and the neutrino content corresponding to the fitted branching ratio.

4 Conclusion

A measurement of the space-time structure of the weak charged current in semileptonic b-decays was performed. The data were found to be in good agreement with a V–A×V–A model. The exotic V+A×V–A model can be excluded with more than 6 standard deviations for the combined measurement. The polarization of the virtuell W is seen with more than 3 standard deviations significance. Furthermore the branching ratio $B\rightarrow \nu X$ was measured to be 22.7%±0.8%(stat.)±1.5%(syst.) which corresponds to a branching ratio $B\rightarrow e(\mu)\nu X$ of 10.1%±0.8%.

References

[1] G. Altarelli *et al.*, Nucl. Phys. **B208** (1982) 365.

[2] M. Dittmar and Z. Was, Phys. Lett. **B332** (1994) 168.

[3] L3 Collaboration, M. Acciarri *et al.*, CERN-PPE/95-05;