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How to Measure the Structure of the Weak Charged Current in semileptonic b decays

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ABSTRACT

We propose a new method to measure the structure of the weak charged-current in semileptonic b -hadron decays using the energy spectrum of the neutrinos. This method allows us to distinguish experimentally between the $V-A \times V+A$, $V \times V+A$ and $V+A \times V-A$ form of the charged current interaction.

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1 Introduction

The semileptonic weak decays of hadrons containing c and b quarks are often modelled according to the so-called “spectator model”, which describes the charm and beauty hadron decays with the weak charged current at the quark level [1, 2]. This ansatz uses the assumption that the light quarks present in charm and beauty hadrons do not play an active role in the decay dynamics. Within this approach, the quark level $V-A \times V-A$ structure is assumed for the matrix element calculation of b -hadron decays. Gronau and Wakaizumi have pointed out that no experimental justification exists so far, which can exclude even the exotic $V+A \times V-A$ structure for the b -quark decay [3].

In a recent review on physics of heavy flavours [4], semileptonic decays involving $b \rightarrow c$ transitions were called the showpiece of the heavy quark effective theory (HQET) [5, 6]. This approach has the goal to obtain a systematic derivation of the properties of heavy-flavour hadrons from QCD. HQET is made in two steps. First, one considers the limit for the infinite heavy quark mass and corrects the results afterwards for the finite mass of the heavy quark. For the process $\bar{B} \rightarrow D^* l \bar{\nu}$, which is normally used to determine the V_{cb} entry in the quark mixing matrix, these finite mass corrections have been estimated and were found to be very small [7].

Beside the exotic possibility of a $V+A$ contribution in the b decay, we want to point out that the experimental data on well measured semileptonic $K^\pm$ decays, nearly completely saturated by $K^\pm \rightarrow \ell^\pm \nu \pi^0$ decay, are described with matrix elements, which are calculated from the chiral Lagrangians without any reference to the underlying quark structure (see e.g. [8]). In the decay of s quarks ($K^\pm$), the structure of the interaction is described with a matrix element of the form $V \times V-A$ instead of the $V-A \times V-A$ that one would use for the decay of a free s quark. Such a theoretical description of kaon decays requires that the underlying quark level structure is completely washed out. This can be explained with the small mass of the s quark, relative to the confinement scale. Therefore, by changing the quark content of the hadrons from s to c and b , some kind of dynamic transition must take place for the weak semileptonic hadron decays. Consequently, one might ask to which degree the semileptonic B and D hadron decays can be described with the quark level matrix elements, how these matrix elements are modified by perturbative QCD corrections and by the confinement (hadron structure) effects, and whether this can be probed experimentally.

To perform such a measurement it is necessary to find observables, which distinguish between the quark level and chiral Lagrangian form of the matrix element. The simplest effect is an energy asymmetry between the charged lepton and the neutrino in semileptonic c -hadron and b -hadron decays, which occurs because of the polarization of the virtual W , which “decays” into a lepton and a neutrino. In the case of the $K^\pm \rightarrow \pi^0 e^\pm \nu$ decay, the virtual W is unpolarized, whereas for infinitely heavy b quarks, where the $V-A \times V-A$ interaction is expected, the virtual W is 100% polarized. It is thus natural to expect that, in the case of b -hadron decays, the experimental results should be found somewhere in between these two extreme cases.

In $e^+ e^- \rightarrow b \bar{b}$ production, with one semileptonic b -hadron decay, the neutrino energy

can be obtained from the difference between the known centre-of-mass energy and the observed energy¹ as will be described below. In this paper, we show how one can use the measurement of the missing energy (the neutrino energy) to distinguish between the possible theoretical descriptions of semileptonic b -hadron decays. After a general description of the energy spectra of the charged lepton and the neutrino, we discuss the observables that are sensitive to the structure of the b -hadron decays at LEP energies. We have not studied the possibility of such a measurement at lower energies, but see no problem of principle for it, for example at the $\Upsilon(4s)$ resonance. Finally, we simulate this measurement using semileptonic b -hadron decays produced in Z^0 decays, the JETSET Monte Carlo and realistic detector resolutions. This simulation indicates that such a measurement is indeed feasible for $b\bar{b}$ events produced in hadronic Z^0 decays.

The neutrino energy spectrum from semileptonic b -baryon decays has recently been proposed as a quantity, which is sensitive to the primary b quark polarization. In ref. [9] the neutrino momentum spectrum is proposed as a particularly good method to study the b -quark polarization and, in ref. [10], the energy asymmetry between the charged lepton and the neutrino energy has been proposed as a quantity, which is sensitive to the b -baryon polarization in Z^0 decays.

2 The lepton energy spectrum and the weak charged current

For a free semileptonic b -quark decay (assuming no fragmentation, no hadronization and no QCD corrections) it is straightforward to calculate the distributions of the charged lepton and the neutrino. In such a *spectator approach* [1] of semileptonic B -meson decays, two classes of corrections must be added to these results : QCD corrections and corrections arising from the bound-state structure of the B meson. The description of the K -meson decay $K^\pm \rightarrow \pi^0 e^\pm \bar{\nu}$ is diametrically opposite to this [8].

Instead of trying to give a theoretical motivation of the above approaches, we discuss an observable that will allow us to distinguish experimentally between the predictions obtained from the assumption of the point-like mesons (*p.l.*) (as in ref [8]) and from the one with the lowest-order spectator model approach [1], that is the free-quark (*f.q.*) approximation, with the V-A (or V+A) $\times$ V-A assumption.

In the spectator approach, the matrix element for the decay $b(p_b) \rightarrow c(p_c)\ell(p_\ell)\bar{\nu}(p_{\bar{\nu}})$ averaged over spin can be written as:

$$|M_{f.q.}^b|^2 = p_b \cdot p_{\bar{\nu}} p_\ell \cdot p_c, \quad (1)$$

where $p_b, p_c, p_\ell, p_{\bar{\nu}}$ denote respectively the four-momenta of the decaying free quark b and the decay products: the c quark, the charged lepton ℓ and the (anti)neutrino $\bar{\nu}$. Similarly

¹This is especially convenient for experiments operating at the top of a resonance, as in the case of the Z^0 at LEP, where events with missing energy along the beam pipe due to initial-state photons are damped by the resonance.

for the c -quark decay, $c(p_c) \rightarrow s(p_s)\ell(p_\ell)\nu(p_\nu)$ the matrix element takes the form

$$|M_{f,q}^c|^2 = p_c \cdot p_\ell \, p_\nu \cdot p_s, \quad (2)$$

where as before p_c, p_s, p_ℓ, p_ν denote respectively the four-momenta of the decaying c quark and its decay products: the s quark, the lepton ℓ and the neutrino ν .

In the case of [8], the point-like ($p.l.$) matrix element for $K(p_K) \rightarrow \pi(p_\pi)\ell(p_\ell)\nu(p_\nu)$ reads:

$$|M_{p.l.}|^2 = p_\ell \cdot p_K \, p_\nu \cdot p_K - p_K^2 \, p_\ell \cdot p_\nu, \quad (3)$$

where again $p_K, p_\pi, p_\ell, p_\nu$ denote respectively the four-momenta of the decaying K meson and its decay products: π , charged lepton ℓ and neutrino ν . We will use this form of the matrix element also for the $B(p_B) \rightarrow X(p_X)\ell(p_\ell)\nu(p_\nu)$ decay as an extreme choice with respect to the free-quark one.

Note that even from the point of view of the Lorentz structure alone, this form of the matrix element should be applied only for the exclusive B - and D -meson decays, where there is only a single scalar meson in the final state. This decay mode constitutes at most 20% of the semileptonic B -meson decays and between 30 and 40% for D -meson decays [11], whereas for K mesons, the above decay mode saturates nearly completely the semileptonic decay channels. In the case of the $B \rightarrow D\ell\nu$ decay, this form of matrix element was indeed used in ref. [12], but clear statements on the limitation of this picture were given.

From the matrix elements defined above, we get the following well-known charged-lepton energy spectra:

$$\begin{aligned} f_{f,q}^b(x) &= x^2 \frac{(x_M - x)^2}{(1 - x)^3} ((1 - x)(3 - 2x) + (1 - x_M)(3 - x)), \\ f_{f,q}^c(x) &= x^2 \frac{(x_M - x)^2}{1 - x}, \\ f_{p.l.}(x) &= x^2 \frac{(1 - x)^2}{(1 - x_M x)}, \end{aligned} \quad (4)$$

and the neutrino energy spectra:

$$\begin{aligned} g_{f,q}^b(x) &= x^2 \frac{(x_M - x)^2}{1 - x}, \\ g_{f,q}^c(x) &= x^2 \frac{(x_M - x)^2}{(1 - x)^3} ((1 - x)(3 - 2x) + (1 - x_M)(3 - x)), \\ g_{p.l.}(x) &= x^2 \frac{(1 - x)^2}{(1 - x_M x)}. \end{aligned} \quad (5)$$

Here $x = 2E_{\ell,\nu}/M$, $E_{\ell,\nu}$ denotes the charged lepton (neutrino) energy and M the mass of the decaying b (c) quark or b hadron. Analogously, m denotes the mass of the final-state c (s) quark or c hadron and $x_M = 1 - m^2/M^2$. In all formulae the normalization is omitted.

It is easy to recognize simple relations between these spectra. In particular for the decay of b and c quarks, the electron and neutrino spectra are simply interchanged. This is due to the opposite sign of the axial-coupling of the W to the quark line in the two cases; thus, the sign of the W polarization is inverted. Due to the absence of W polarization in the case of the point-like meson decays, identical energy spectra of the charged lepton and the neutrino are predicted and a good description of K decays is obtained.

It should be realized that, because of the $V-A$ couplings of the W to leptons, the energy of the charged lepton is larger than that of the neutrino from the decay of the b quark, because the W coupling to the b quark is also $V-A$. For the decay of the c quark, where its coupling to the W is $V+A$, the neutrino should obtain more energy than the charged lepton.

In the case of point-like (and spin-zero) c and b mesons, identical energy spectra for the neutrino and the charged lepton should be observed for the $V \times V-A$ assumption. Furthermore in this case, both the spectra of the charged lepton and the neutrino are essentially the ones obtained for the neutrino in the $V-A \times V-A$ case. Therefore, also the energy difference between the charged lepton and the neutrino should be smaller than the one calculated for the free-quark decay.

The lepton energy spectra, discussed in section 3, are obtained with the appropriately modified KORALZ [13] and TAUOLA [14] Monte Carlo programs. In section 4, we discuss the results of a simulation of such an experiment at the Z^0 peak with the JETSET73 [2] Monte Carlo.

3 Observables in semileptonic b decays

The average energy of b -hadrons in Z^0 decays has been measured, using mainly the observed p and p_t spectra of electrons and muons². With the assumption of the pure $V-A \times V-A$ coupling, an average b -hadron energy of about 32 GeV, or about 70% of the beam energy, has been estimated [15].

To demonstrate the influence of the structure of the weak charged current on the charged lepton and the neutrino, we have used a fixed b -hadron energy of 32 GeV, and 36 GeV for the quark-level simulation with the modified KORALZ and TAUOLA Monte Carlo. For the simplification of the comparison, the B -meson (b -quark) and D -meson (c -quark) masses were fixed to the "pole" quark masses [16] of 4.8 and 1.45 GeV respectively. The semileptonic b decays, $b \rightarrow \ell \nu c$, are then simulated, using always the $V-A$ assumption for the leptonic side and the $V-A$, V and $V+A$ assumption for the quark side. The resulting energy spectra for the charged lepton and the neutrino for a b -hadron energy of 32 GeV are shown in figure 1a for the $V-A \times V-A$ matrix element. For the $V+A \times V-A$ matrix element the charged lepton and the neutrino spectra are simply exchanged. For the $V \times V-A$ one finds that the charged lepton and the neutrino energy spectrum are identical, and also that they are essentially identical to the neutrino energy spectrum obtained with the one for the $V-A \times V-A$ matrix element. The mean energy values of the charged lepton

²Charged leptons

and the neutrino for different b -hadron energies, with the considered matrix elements are given in table 1.

Matrix element		V-A $\times$ V-A	V $\times$ V-A	V $\times$ V-A	V+A $\times$ V-A
b energy (GeV)		32	32	36	36
$m_b(c)=4.8(1.45)$ GeV	$\langle E_l \rangle$	10.55	9.34	10.52	10.51
$m_b(c)=4.8(1.45)$ GeV	$\langle E_\nu \rangle$	9.34	9.34	10.52	11.89
$m_b(c)=5.3(2.00)$ GeV	$\langle E_l \rangle$	8.50	7.64	8.60	8.64
$m_b(c)=5.3(2.00)$ GeV	$\langle E_\nu \rangle$	7.64	7.64	8.60	9.55

Table 1: The mean energy of the charged lepton and of the neutrino obtained with the quark level decay simulation (KORALZ), respectively for the matrix elements as given by formulae (1) to (3) for V-A $\times$ V-A, V $\times$ V-A and V+A $\times$ V-A coupling.

Figure 1b shows the charged-lepton energy spectrum (thick line histogram) for the V-A $\times$ V-A coupling and a b -hadron energy of 32 GeV. The thin line shows the charged lepton spectrum, for the V+A $\times$ V-A assumption, but now with a b -hadron energy of 36 GeV; a very similar spectrum is found. The different energy spectrum for the charged lepton, due to the assumed coupling, as well as its average energy (demonstrated in table 1), can thus simply be compensated by a small change of the b -hadron energy, which in fact is within its experimental uncertainty³. This is the main reason why the charged lepton energy spectrum alone does not allow a distinction to be made between the V-A $\times$ V-A, V $\times$ V-A and the V+A $\times$ V-A assumption. However, if also the neutrino energy spectrum can be measured, a significant (more than 2 GeV) difference of the mean neutrino energy for the above extreme cases is found. The obtained neutrino energy spectra for the V-A $\times$ V-A assumption and a b -hadron energy of 32 GeV, and for the V+A $\times$ V-A assumption with a b -hadron energy of 36 GeV are shown in fig. 1c.

The different energy spectra of the charged lepton and the neutrino are the result of virtual W polarization. The difference in the energy spectra should be largest if the polarization of the W in the b -hadron rest frame is parallel to the direction of the boost in the laboratory system. If this polarization is transverse to the direction of the boost, essentially identical energy spectra should be found. For the inclusive measurement of the charged lepton and the neutrino only, the b energy and momentum is not known. However, once the energy of the W (the energy sum of the charged lepton and the neutrino) exceeds half the average energy of the b hadron (roughly 16–17 GeV at the Z^0 peak) the W should already be substantially polarized along the b direction, which can be approximated by the direction of the thrust axis of the event. Indeed one finds that the average energy

³In ref. [15] this uncertainty is calculated, using the observed charged lepton energies and the V-A $\times$ V-A matrix element assumption, to be of the order of 1 GeV. Once this assumption is released, we expect an increase in the estimated uncertainty.

of the charged lepton and of the neutrino are essentially identical for W energies smaller than half the b -hadron energy, while the energy difference becomes very large (between 3.5 to 4 GeV) for larger W energies, as demonstrated in figs. 2a and 2b. To quantify this effect, we define an energy asymmetry, which is the difference between the charged lepton energy and the neutrino energy divided by their energy sum (the W energy). The resulting asymmetry is shown in fig. 2c as a function of the W energy for the V-A, V and V+A assumption on the quark side. Large asymmetries of up to 15% are expected, which should be compared to a statistical error of a few per cent obtainable for a few thousand clean semileptonic b decays.

We have also studied the energy spectra of the charged lepton and the neutrino for different quark/hadron masses and find that the spectra change considerably. The mean energy values for masses close to the B and D hadron masses of 5.3 GeV and 2.0 GeV respectively, are also given in table 1. As expected, one finds that the relative difference between the energy of the charged lepton and the neutrino, about 13%, does not vary for different assumed quark masses.

4 Feasibility of the measurement at the Z^0 peak?

As described above, we propose to measure the neutrino energy spectrum (the missing energy) in semileptonic b -hadron decays, that is b decays with an identified electron or muon. Measurements of b -hadron decays, based on the identification of electrons and muons have become a standard technique in e^+e^- experiments, fixed-target experiments and hadron-collider experiments.

The exact knowledge of the beam energy in e^+e^- experiments allows us to extract the neutrino energy, which corresponds to the difference between the beam energy (half the Z^0 mass at LEP) and the observed jet energies. For not too hard gluon radiation, the hadronic events can be well separated into two hemispheres, defined for example by the thrust (or the sphericity) axis. Due to energy and momentum constraints, the original energy in each hemisphere has to be the beam energy. The difference between the beam energy and the visible energy in one hemisphere corresponds approximately to the energy of the neutrino produced in the semileptonic decays. Thus, the neutrino energy and momentum can be measured with an accuracy, that is essentially identical to the jet energy and momentum resolution.

The jet energy resolution that is currently the best has been obtained with the compensating calorimeter of the ZEUS experiment at HERA, with resolutions of about $18\%/\sqrt{E}$ for electrons and photons and $35\%/\sqrt{E}$ for hadronic showers [17]. Using these numbers, one obtains a jet energy resolution of about ± 3 GeV for a total energy of 91 GeV. So far little attention has been put into the accuracy of jet energy measurements at the Z^0 peak at LEP. Nevertheless, measurements of the total hadronic energy in hadronic Z^0 decays with resolutions of about ± 6 GeV have been reported by the ALEPH and L3 collaborations [18]. Using the jet energy resolutions obtained above and a simple scaling with the square root of the energy, a 45 GeV jet should be measurable with an accuracy between

± 2 GeV and ± 4 GeV.

Furthermore, systematic errors of better than 100 MeV have been estimated by all four LEP experiments for the absolute energy scale of the W -mass measurement from hadronic W decays at LEP200 [19]. Such a small energy scale uncertainty should be compared to the difference expected for the average neutrino energy, of up to 1.7 GeV, if semileptonic b -hadron decays would be described with a coupling of the form $V+A \times V-A$ instead of the $V-A \times V-A$ form.

All LEP experiments have demonstrated that Z^0 decays into a pair of b quarks, with subsequent decays into electrons or muons, can be selected with small backgrounds and good efficiency [20], using energetic electrons or muons with large transverse momenta with respect to the thrust axis of the event. In the absence of identified electrons or muons, the feasibility of a missing energy measurement in b -hadron decays to measure the branching ratio of $b \rightarrow \tau \nu X$, has already been demonstrated by ALEPH [21] and preliminarily by the L3 [22] collaboration.

The proposed experiment at LEP is based on the comparison of the charged lepton energy spectrum with the neutrino energy spectrum in inclusive semileptonic b -hadron decays. To simulate such an experiment, we have used Z^0 decays into a pair of b quarks, generated with JETSET73. Hard three-jet events are removed, with the cut that the observed invariant mass per hemisphere is smaller than 24 GeV. For the simulation of the b -hadron energy spectrum, the Peterson fragmentation function [23] with an ϵ parameter of 0.007 for the $V-A \times V-A$ coupling is used. After the removal of hard three-jet events, the average b -hadron energy is found to be 32 GeV. The average charged-lepton energy and the neutrino energy before the selection cuts are found to be 8.54 and 7.84 GeV respectively.

For the $V+A \times V-A$ case, ϵ ($= 0.0021$) was chosen such that the average energy of the charged lepton is similar to the $V-A \times V-A$ case. An average b -hadron energy of 34 GeV is obtained, and the average energy of the charged lepton and the neutrino before the selection cuts are respectively 8.1 and 9.1 GeV.

Next, the semileptonic b -hadron decays are selected using simple and standard cuts. It is required that the charged lepton has an energy above 3 GeV and a transverse momentum of more than 1 GeV with respect to the thrust axis of the event. The energy and momentum resolution of the charged lepton, typically at most a few per cent, is much smaller than the resolution of the neutrino energy and is therefore ignored in the following. The neutrino energy measurement has then been simulated using a Gaussian jet energy resolution with a sigma of ± 2 GeV and ± 4 GeV.

Figure 3a shows the expected energy spectra of the charged lepton and the extreme assumptions of the $V-A \times V-A$ and $V+A \times V-A$ matrix elements. Essentially identical spectra are found. The corresponding energy spectra for the neutrino, using a resolution of ± 4 GeV, are shown in fig. 3b. One finds that the difference in the mean energy value has been reduced, due to the selection cuts, from 1.7 GeV to about 1.1 GeV. As long as the energy resolution is Gaussian, this difference does not depend on it. Clearly, if an absolute energy scale uncertainty of the order of 100 MeV can be obtained, a difference of about 1.1 GeV should be clearly observable.

To study the dynamics of the W polarization, as has been discussed in sections 2 and 3 and shown in fig. 2c, the difference between the charged-lepton energy and the neutrino energy should be studied as a function of the W energy and mass. For such a detailed study we find from our simulations that the jet energy resolution becomes essential.

Due to the required selection cuts, used for the charged lepton, a special phase-space region of the b -hadron decays is selected and, as a consequence, a strong bias to higher energy charged leptons is introduced. If the neutrino could be measured with almost the same accuracy as the charged lepton, symmetric selection criteria on the charged lepton and the neutrino might be used. With the price of reduced statistics, the original asymmetry pattern could almost be recovered. Figure 4a shows the generated neutrino spectrum for the $V-A \times V-A$ case, with the charged lepton selection cuts, and the neutrino energy spectrum, but now smeared with a resolution of ± 2 GeV and ± 4 GeV. The distortion of the neutrino energy spectrum is strongest in the regions where the original neutrino energy was either low or high. As a consequence of the selection cuts and the energy resolution, we find that it becomes very difficult to define cuts, which allow a measurement of the energy asymmetry as function of the W energy. However, the observed W energy spectrum, which is shown in fig. 4b, appears to be quite a sensitive quantity to estimate the original b -hadron energy. Therefore, the combined information from the energy spectra of the charged lepton, the neutrino and the W should allow a study of the structure of the underlying charged-current dynamics in some detail.

5 Summary

In this paper, we have concentrated on the energy spectra of the charged lepton and of the neutrino, which depend strongly on the longitudinal W polarization in semileptonic b -hadron decays. We have shown that the energy spectra of the charged lepton and the neutrino are sensitive to details in the structure of the weak charged current. The considered $V-A$, V and $V+A$ structure on the hadron side of the semileptonic b -hadron decays represent respectively:

- the Standard Model predictions for the free b -quark decay in the infinite b -quark mass approximation,
- the experimentally confirmed matrix element used to describe the $K^\pm$ semileptonic decay, where the quark interaction is completely dominated by the hadronic structure and,
- the exotic, but experimentally not yet excluded, possibility that the b -quark decay would be described by the matrix element, used for the Standard Model prediction for a free c -quark decay.

From a simulation of the proposed experiment at the Z^0 peak, we find that such a measurement is indeed possible and that the above theoretical possibilities can indeed be distinguished experimentally, if a good jet energy resolution can be combined with a

systematic accuracy of the mean value of the missing energy measurement of better than 200 MeV.

The experimental sensitivity to an asymmetry in the transverse momenta of the charged lepton and of the neutrino is much more difficult to estimate and requires a detailed knowledge of the angular accuracy of the missing-energy measurement. However, we see no problem of principle to study also the effects of the transverse W polarization and the virtual mass distribution of the charged lepton and neutrino system.

Finally, we would like to remark that a similar analysis can be performed also for semileptonic c -hadron decays. In this case one can expect a sizeable discrepancy, due to the somewhat lower mass of the c quark, between the quark level matrix element and the experimental distributions. Such a deviation in the case of the c -hadron decays would fit nicely into the picture of a dynamic transition, when going from the semileptonic K decays, which are described by the point-like matrix element, to the heavier charm and beauty hadrons that are usually described by the free quark matrix elements.

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Figure 1: a) The energy spectra of the charged lepton and the neutrino for $V-A \times V-A$ with a b -hadron energy of 32 GeV. b) The energy spectra of the charged lepton for $V-A \times V-A$ with a b -hadron energy of 32 GeV and for $V+A \times V-A$ and a b -hadron energy of 36 GeV. c) The energy spectra of the neutrino for $V-A \times V-A$ with a b -hadron energy of 32 GeV and for $V+A \times V-A$ and a b -hadron energy of 36 GeV. (The masses for the B meson (b quark) and the D meson (c quark) were fixed to 4.8 and 1.45 GeV respectively.)

Figure 2: The energy spectra of the charged lepton and the neutrino for $V-A \times V-A$, a b -hadron energy of 32 GeV and a) the W energy between 6 GeV and 16 GeV, b) the W energy above 18 GeV, c) the energy asymmetry as a function of the W energy for $V-A \times V-A$, $V \times V-A$ and $V+A \times V-A$

Figure 3: The energy spectra of the charged lepton and of the neutrino from the JETSET73 simulation and the requirement that the charged lepton has an energy of more than 3 GeV and a p_t with respect to the thrust axis of more than 1 GeV, a) the charged lepton energy spectra for the V-A and V+A case with $\epsilon = 0.007(0.0021)$ respectively, b) the neutrino energy spectra for the V-A and V+A case with $\epsilon = 0.007(0.0021)$ respectively and a neutrino energy resolution of ± 4 GeV.

Figure 4: The energy spectra of the neutrino using the JETSET73 simulation with the $V-A \times V-A$ matrix element and the requirement that the charged lepton has an energy of more than 3 GeV and a p_t with respect to the thrust axis of more than 1 GeV, a) the generated neutrino energy spectra and with a gaussian resolution of ± 2 GeV and ± 4 GeV b) the observed W energy spectrum for the $V-A \times V-A$ and $V+A \times V-A$ matrix element with the charged lepton cuts as above and neutrino energy resolution of ± 2 GeV. The difference in the shape of the spectrum is mainly due to the shift in average b energy from 32 to 34 GeV.