Study of the weak charged hadronic current in b–decays

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Abstract

The properties of jets associated with identified semileptonic and hadronic b–decays are studied. The observed difference between the semileptonic and hadronic b–decays is used to measure the charged particle multiplicity of the hadronic weak charged current in b–decays to be 2.76±0.07(stat.)±0.13(syst.). Using a JETSET74 simulation for the hadronisation of the weak charged hadronic current good agreement with the data is obtained if 30±16% of the primary produced mesons are light flavored tensor (L=1) mesons.

submitted to the EPS conference Brussels 95

1 Introduction

The decays of b–hadrons are often described with the spectator model [1], where a b–quark is assumed to decay into a charm quark and a virtual W. The observed momentum spectra of the charged leptons [2] and the neutrinos [3] in semileptonic b–decays (b$\rightarrow$ c$\ell\nu$) are well described by this model.

Hadronic b–decays, (b$\rightarrow$ c$\overline{\mathrm{u}}$d and b$\rightarrow$ c$\overline{\mathrm{c}}$s), with a branching ratio of more than 76% are less well understood and only a few percent of the hadronic b–decays have been reconstructed. For the few identified decays a considerable fraction of tensor mesons (L=1) has been seen [4].

Using the spectator model ansatz, one could expect that the properties of the hadronic system, associated to the virtual W are essentially independent from the charm system in the b–decay. According to this picture, any difference between jets with semileptonic– and hadronic b–decays can thus be attributed to the weak charged hadronic current at the mass of the b–quark. Such a comparison of b–flavored jets, performed with the L3 detector, is described in the following.

The L3 detector consists of a central tracking chamber, a high resolution electro magnetic calorimeter composed of BGO crystals, a cylindrical array of scintillation counters, a uranium and brass hadron calorimeter with proportional wire chamber readout, and a precise muon spectrometer. These detectors are installed in a 12 m diameter solenoid which provides a uniform field of 0.5 T along the beam direction. A detailed description of the L3 detector can be found elsewhere [5]. More than a million hadronic Z^0 decays, collected between the 1991 and 1993 data taking period, are preselected, using the selection described in [6]. For this study only the events with a center of mass energy with $\pm$ 0.5 GeV around the Z^0 mass are analyzed.

To ensure that the events are well measured, the following additional selection criteria are used:

- The visible energy in each hemisphere, defined by the thrust axis of the event, has to be larger than 10% of the beam energy and the polar angle θ_{H} of the momentum vector sum of all calorimeter clusters, associated to each hemisphere has to fulfill the condition $|\cos\theta_{\mathrm{H}}| < 0.7$.
- If the visible energy of the event is smaller than 70% of the beam energy, the missing transverse energy of the event has to be larger than 50% of the beam energy or larger than the missing longitudinal energy.
- The number of charged tracks has to be larger than 4 and at least three tracks each with a transverse momentum with respect to the beam of more than 150 MeV and a distance of closest approach smaller than 1 mm have to be found in at least one hemisphere.
- To remove events with hard gluon jets, it is required that the invariant mass per hemisphere, calculated from the calorimetric clusters, is less than 25 GeV and that the energy sum of all calorimeter clusters with $|\cos\theta| > 0.74$ is smaller than 5 GeV.

With these criteria 473k hadronic events are selected in the data and 420k events in the Monte Carlo. The hadronic Monte Carlo events are simulated using JETSET73 [7] and a GEANT based description of the L3 experiment [8].

2 Selection of b–flavored jet samples

High p and p_t inclusive electron and muon candidates are used to select b–flavored events and the jets which contain semileptonic b–decay candidates.

2.1 Selection of inclusive electron candidates

Electron candidates are selected with the following criteria:

- The energy of a cluster E_{BGO} in the barrel BGO calorimeter (with the polar angle θ $|\cos\theta| < 0.72$) has to be larger than 3 GeV. The HCAL energy associated to this cluster has to be smaller than 2 GeV.
- It is further required that between 10 and 40 crystals are associated to the BGO–cluster and that more than 95% of the energy is deposited in the central 9 crystals.
- One track has to point to this BGO–cluster. It is required that the difference between the azimuthal angle estimated from the shower center and the estimated track impact point to the BGO calorimeter is smaller than 4 mrad + 8 mrad/E_{BGO} (in GeV).
- The measured p_t with respect to the beam direction from the track is consistent (within 3 σ) with the p_t measurement from the BGO calorimeter.

With this selection 7367 electron candidates with a p_t of more than 1.4 GeV are selected. The purity for jets with correctly identified semileptonic b–decays using this selection is found to be 78.7$\pm$2.1% [9], with a background of 15% from light flavored events.

2.2 Selection of inclusive muon candidates

Muon candidates are selected using the following criteria:

- Tracks found in the barrel muon system have to be reconstructed in at least two out of the three ϕ–layers and one out of the two possible z–chamber layers.
- The distance of closest approach to the event vertex, extrapolated taking the errors due to multiple scattering into account has to be smaller than 100 mm in the $x - y$ plane. This distance has also to be smaller than three times the estimated distance error due to the multiple scattering in the calorimeters.

- The measured $\mu^{\pm}$ momentum has to be between 4 GeV and 35 GeV.

With this selection 13607 muon candidates with a p_t of more than 1.4 GeV are selected. The purity for jets with correctly identified semileptonic b–decays is found to be 69.6±1.3% [9], with a background of 21% from light flavored events.

2.3 Selection of inclusive hadronic b–decays

Using the above selection for $b\overline{b}$ events with electrons and muons, the hemispheres with lepton candidates define the jets with semileptonic b–decays. The visible energy distribution of jets opposite to the ones with the lepton candidates is shown in figure 1. To reduce the background from semileptonic b–decays a visible energy of more than 40 GeV is required; these jets are the candidate jets with hadronic b–decays. With this selection, the purity of jets with correctly identified hadronic b–decays is found to be 75.4±1.2% for the electron tagged events and 70.2±0.8% for the muon tagged events.

3 The charged multiplicity of the hadronic W current

The properties of the weak charged hadronic current in b–decays are extracted from the differences between jets which are identified as containing a hadronic or a semileptonic b–decay. With the assumption that the hadrons which are associated with the jet fragmentation and the cascade charm–decays are similar for the semileptonic and the hadronic b–decays, any difference between the two types of b–decays is related to the properties of the weak charged hadronic current. In the following the average charged multiplicity of the weak charged current is measured.

Figure 2a shows the multiplicity distributions of tracks for the data in hemispheres with an identified electron excluding the electron track and in hemispheres opposite to the jet with the electron candidate, the jets with hadronic b–decays. The same distributions for the events tagged with muon candidates are shown in figure 2b. A clear difference is observed for jets which contain hadronic and semileptonic b–decay candidates. The average charged jet multiplicity, corrected for the tracking efficiency for the electron and muon tagged events in the data and in the Monte Carlo are given in table 1; for the jets which contain the lepton candidate one track is subtracted.

The observed track multiplicity for hemispheres with a charged lepton in the data and in the Monte Carlo simulation are shown in figure 3a and for hadronic b–decay candidates in figure 3b. The distributions expected from signal and background events in the Monte Carlo are also shown. The multiplicity in the data is for all jet classes slightly higher than in the Monte Carlo. As can be seen from table 1, after correcting for the average tracking efficiency, the charged multiplicity of the selected jets is 3–4% higher in the data than in the Monte Carlo. This difference is found to be similar for the jets with semileptonic or hadronic b–decay candidates. It is slightly higher for the selected jets than for the average jets, where the average track multiplicity in the data is 2% higher than in the Monte Carlo. This difference is probably related to an inaccurate simulation of the tracking efficiency. An error of 3% is therefore assigned to the estimated tracking efficiency, which has been estimated to be 89±3%. As the charged W multiplicity is obtained from the difference between the two types of jets in the data, the discrepancy between the data and the Monte Carlo is only relevant for the background correction which is obtained from the Monte Carlo.

	lepton side −1 track			hadron side		
event type	data	MC	purity	data	MC	purity
electron $p_t > 1.4$ GeV	7.58±0.04	7.20±0.04	0.79	9.57±0.05	9.32±0.07	0.75
muon $p_t > 1.4$ GeV	7.61±0.03	7.38±0.03	0.70	9.64±0.04	9.24±0.05	0.70

Table 1: Observed average charged multiplicity of jets (tracking efficiency corrected) in the data and in the Monte Carlo for high p_t electron and muon tagged b–flavored events.

In order to extract the multiplicity for the weak charged hadronic current the observed difference between jets, which are candidates for hadronic– and semileptonic b–decays has to be corrected for the tracking efficiency, background and the bias introduced due to the lepton and hadron jet selection. The changes from the raw multiplicity difference between jets with hadronic– and semileptonic b–decay to the final result for the hadronic W current for electron and muon tagged events are given in table 2.

The first number is the multiplicity difference, ΔN_{charge}, corrected only for the tracking efficiency. In a second step ΔN_{charge} is corrected for backgrounds from light flavor jets. For this correction the Monte Carlo is used. The error introduced due to the slight disagreement between the data and the Monte Carlo for the track multiplicity is included in the systematic error due to the efficiency uncertainty.

Finally the bias of the method, introduced by the selection of hadronic and semileptonic b–decays using high p and p_t leptons, is corrected. This bias is obtained by applying the used method to the Monte Carlo without background. It is found that the lepton selection method results in a value for the charged multiplicity of the hadronic W current, which is 0.1 units smaller than the originally generated hadronic W multiplicity. The systematic error associated to this bias correction is obtained from the corresponding statistical error in the Monte Carlo.

The average charged multiplicity of the hadronic W from the two measurements is:

2.76±0.07(stat.)±0.13(syst.)

The measured average charged multiplicity for the electron tagged events is 2.5 sigma (statistical error only) lower than the one for the muon tagged events. A possible source of this discrepancy could be related to an inaccurate background description of the Monte Carlo for the fragmentation of light flavored jets. No statistical significant source for this difference has been identified from a variation of the electron and muon selection criteria. However, it is found that with a stronger cut against gluon radiation, removing events which have a hemisphere with a mass larger than 15 GeV instead of 25 GeV, more consistent results for the W multiplicity of 2.70±0.13 and 2.85±0.11 are obtained for the electron and the muon tagged events respectively.

	Electrons		Muons	
type	data	MC	data	MC
raw ΔN_{charge}	1.99±0.07	2.12±0.07	2.03±0.05	1.86±0.05
background correction	2.47±0.11	2.63±0.07	2.82±0.09	2.62±0.06
result (bias correction)	2.57±0.11	2.726±0.004	2.92±0.09	2.726±0.004
Systematic errors				
tracking efficiency (0.89±0.03)	0.08	–	0.09	–
b,c decay systematics	0.04	–	0.04	–
MC $b \to \ell\nu X$ stat. (bias corr.)	0.07	–	0.06	–
b–decay purity error	0.08	–	0.07	–
"two jet" definition	0.13	–	0.07	–
total error	0.19	–	0.15	–

Table 2: The difference for the charged track multiplicity for jets with semileptonic (the track from the lepton is subtracted) and hadronic b–decays in the data and in the Monte Carlo are given for different the different corrections with the statistical errors are given. The estimated contributions to the systematic errors are also given.

As the statistical errors are not small enough to distinguish between statistics and systematics, the difference of the result given in table 2 and the one from the harder two jet event selection is included in the systematic error as given in table 2. Other contributions to the systematic error for the multiplicity measurement are listed in table 2. The uncertainties from the simulation of c– and b–hadron decays and the uncertainties in the tracking efficiency are correlated for the electron and muon tagged events. The systematic uncertainties related to the background corrections, the b–flavored purity, the bias of the method (estimated for 100% b–purity) and the definition of the "two jet" system are independent for the two selections.

The combined result of 2.76±0.07(stat.)±0.13(syst.) charged particles in the hadronic W current from b–decays can be compared with the charged particle multiplicity in semileptonic τ decays, with an average of 1.455±0.013 charged hadrons for the hadronic W current [10]. Such an increase is expected due to the higher mass[1] of the virtual W in b–hadron decays.

In a more quantitative analysis one can compare this measurement with expectations from JETSET74 [11] with a fragmentation of the W$\to q\overline{q}$ system. From this phase space simulation of hadronic W–decays with a fragmentation of the quarks one finds that an average of 3.04 charged hadrons is associated to the weak charged hadronic current using the default parameter settings. This number is found to be essentially identical for the W decay into $\overline{u}d$ and into $\overline{c}s$ quarks. The number of charged tracks in the data is 1.85 standard deviations lower. The charged multiplicity for the $q\overline{q}$ system can be lowered if the production of tensor mesons (L=1) is enabled as shown in figure 4. Good agreement of this model with the data is obtained if 30±16% of the produced hadrons are tensor mesons. As can be seen from figure 4, the production rate of vector mesons with respect to scalar mesons is found to be less important for the charged hadron multiplicity.

[1] From a Monte Carlo study of b–decays one finds an average mass of the hadronic system recoiling against the charmed hadron of about 2.3 GeV.

The production of a large rate of tensor mesons in hadronic b–decays can be expected as tensor mesons are also observed in the hadronic W current in τ and charm decays [10]. The observed fractions of resonant multi pion states in exclusive measurements of weak b–hadron decays [4] are in good agreement with our measurement.

4 Summary

The structure of jets, associated to hadronic and semileptonic B–hadron decays has been studied in an inclusive way. From the comparison of the semileptonic– and hadronic of weak b–decays, the average charge multiplicity of the weak hadronic current in b–decays and the momentum spectrum of the associated particles has been measured. The average charged hadron multiplicity, associated to the weak charged hadronic current is found to be **2.76±0.07(stat.)±0.13 (syst.)**. This is about one unit higher than the multiplicity of the hadronic W current in τ decays with an average of 1.455±0.013 charged hadrons.

The data are in good agreement with the JETSET74 phase space simulation of weak hadronic b–decays if a considerable fraction of 30±16% tensor mesons (L=1) is produced in the hadronisation of the weak charged current.

References

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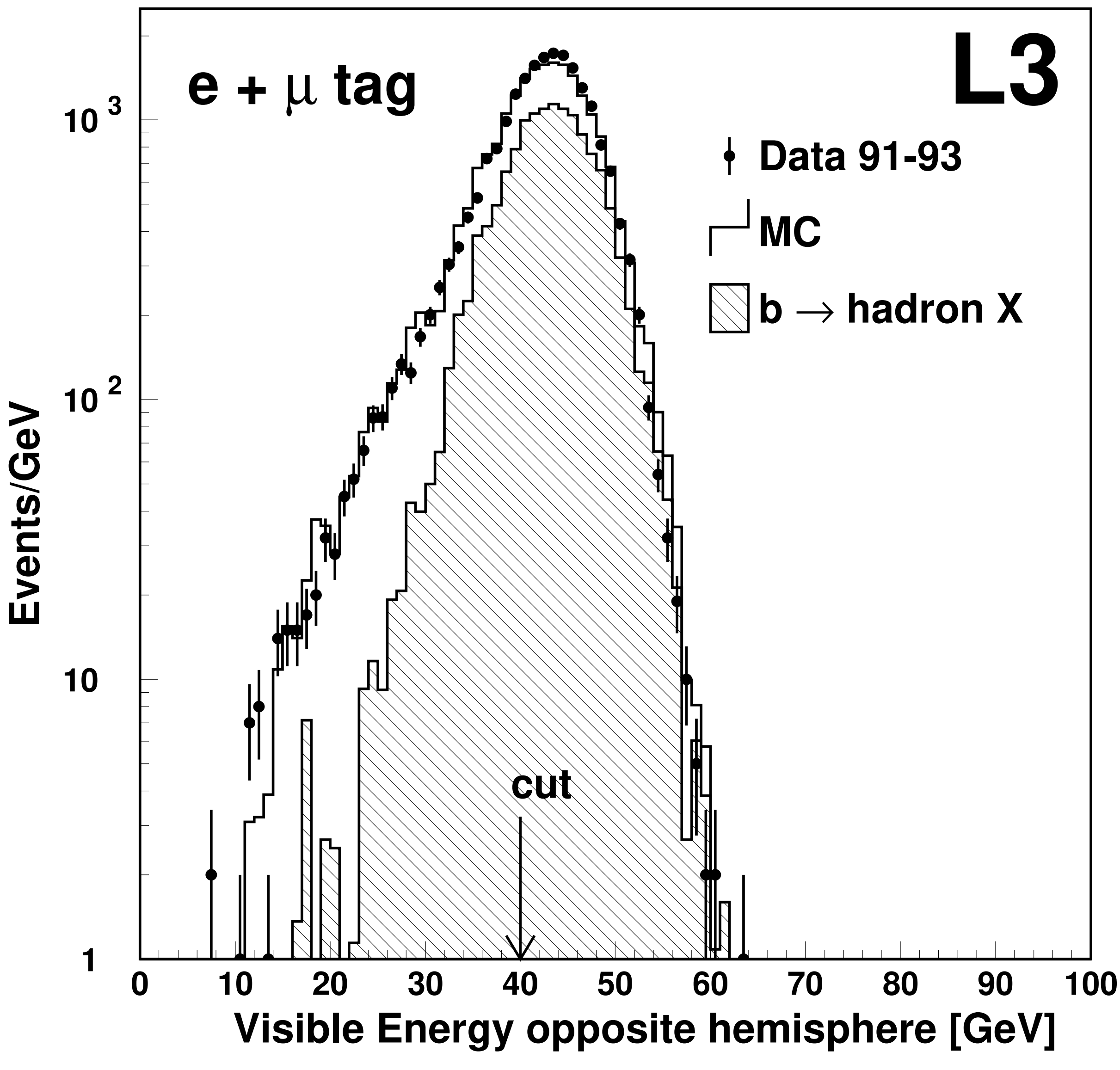

Figure 1: Energy distribution of the jets opposite to the lepton tagged jet. The data are shown with error bars, the histogram shows the Monte Carlo expectation with the full detector simulation.

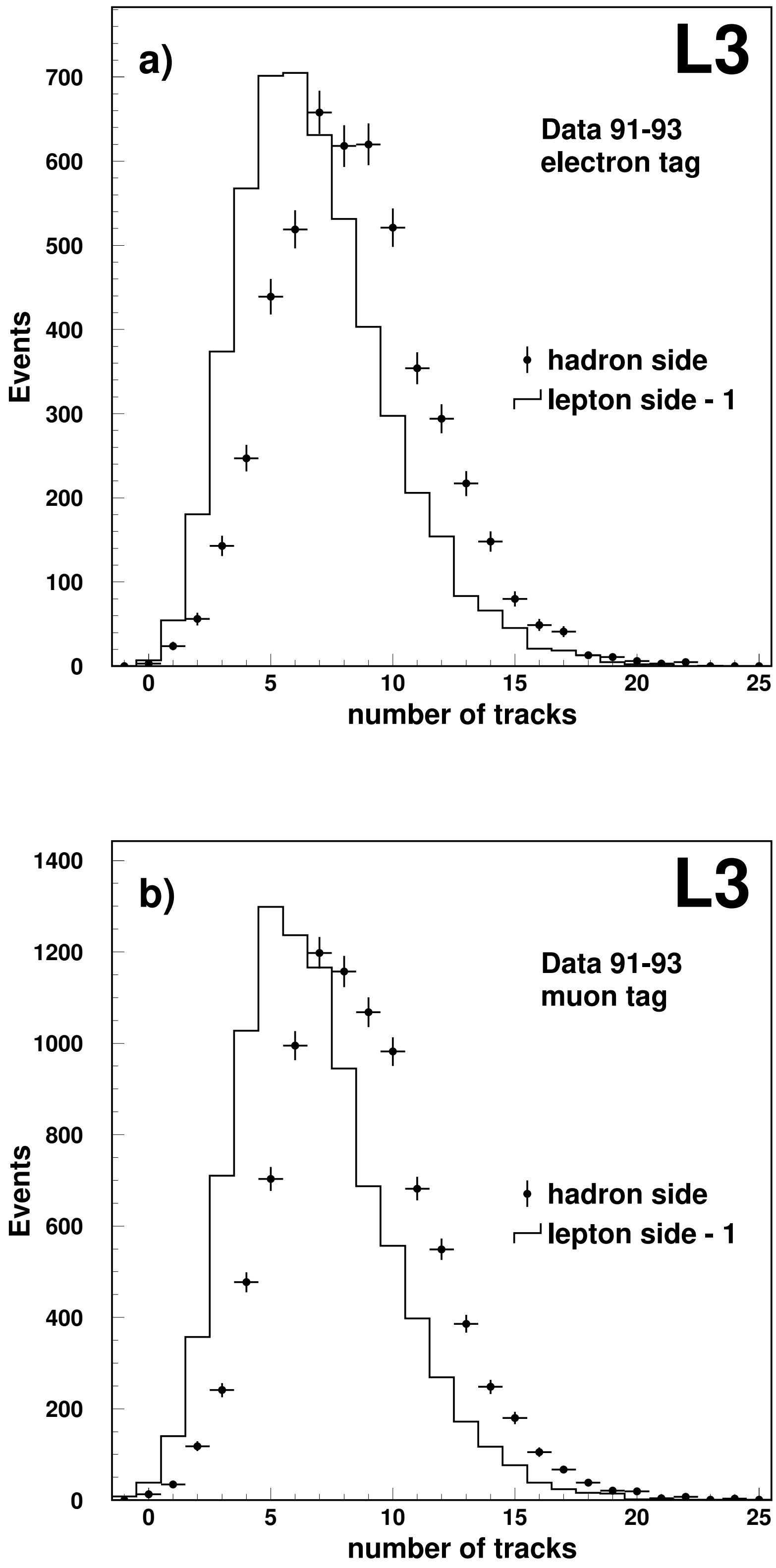

Figure 2: Comparison of the charged multiplicity for the lepton side (the lepton is subtracted) and the hadron side in the data, (a) is for electron tagged events and (b) for muon tagged events.

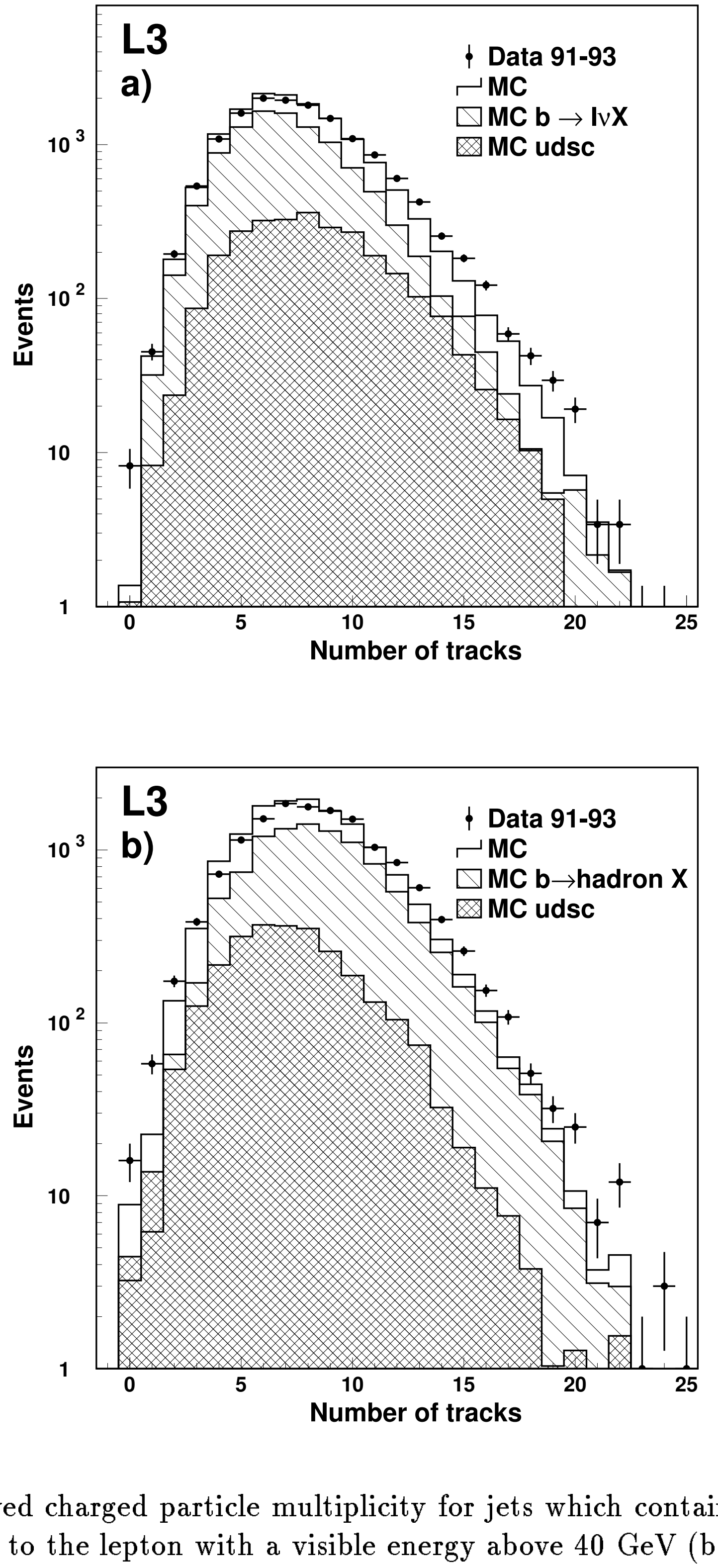

Figure 3: The observed charged particle multiplicity for jets which contain the lepton (a) and for the ones opposite to the lepton with a visible energy above 40 GeV (b).

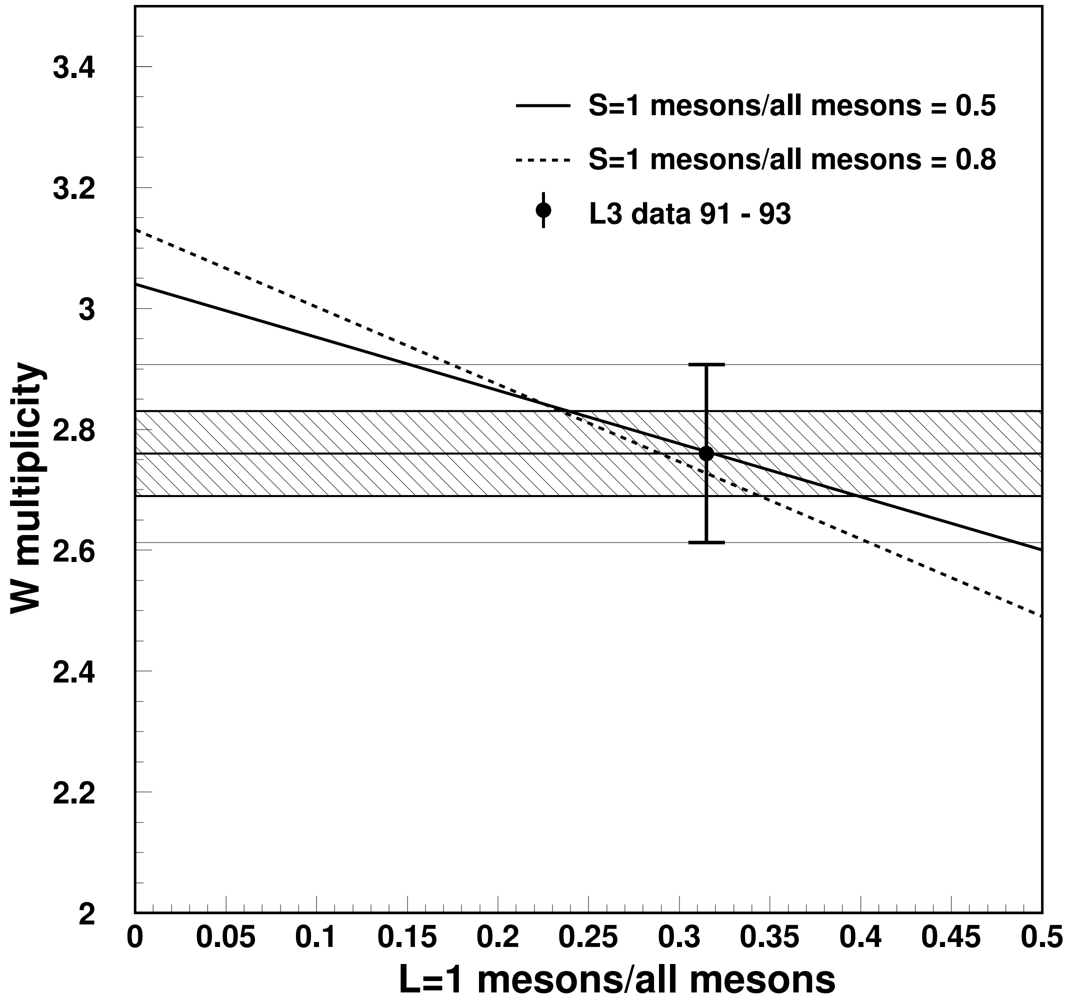

Figure 4: Comparison of the measured weak charged current multiplicity in the data and the JETSET 7.4 fragmentation model, as a function of the production probability of tensor mesons (L=1) with respect to all mesons. The two straight lines show the variation of the charged multiplicity for different probabilities to produce vector meson (S=1).