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Search for charged Higgs bosons and measurement of $|V_{cs}|$ in quark and lepton flavour identified events at LEP2

on behalf of the DELPHI Collaboration

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Abstract

A search for pair produced charged Higgs bosons was performed on the high energy data collected by DELPHI at LEP2. All three major final states, $\tau\nu\tau\nu$, $cs\tau\nu$ and cscs were searched for. The analyses used a combination of event shape variables, di-jet masses and jet flavour tagging. The jet flavours were identified by using life time tagging and particle identification based on the RICH detector complemented by ionisation energy loss measurements. A similar type of jet flavour tagging was also used in extracting the $|V_{cs}|$ element of the Cabibbo–Kobayashi–Maskawa (CKM) matrix in hadronic decays of the $W^{\pm}$ boson. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Identification of the quark flavour in hadronic decays of heavy bosons is of great importance for several analyses at LEP. It is needed for precise determination of the decay fractions of Z and W bosons and for background suppression in searches of new particles like Higgs bosons.

This article describes two DELPHI analyses at LEP2 using separation of sc di-jets from ud di-jets. The first is the search for $e^+e^- \to H^+H^-$ [1] and the second the measurement of $|V_{cs}|$ in W boson decays [2]. Despite the different nature of these two analyses, jet flavour tagging as a tool is used in a very similar way.

2. Jet flavour tagging

Due to their significant lifetime, the b-jets can be identified with high efficiency and purity by using secondary vertex reconstruction. Separating the lighter quark flavours: c, s, u and d, however, is much more difficult. The flavour of the primary quark is veiled in the hadronisation process but some signatures still remain and can be used for the determination of the initial quark flavour of a hadronic jet. One important tool for quark flavour identification is particle identification as the ratios of final state particle types after hadronisation depend on the initial quark flavour, as can be seen in Fig. 1. The DELPHI detector has a special emphasis on hadron identification by using Ring Imaging Cherenkov detectors (RICH) complemented by ionisation energy loss measurement. The detailed description of the DELPHI detector and its performance can be found elsewhere [3,10].

Two methods were used in the analyses described here for identifying hadronic jets originating from initial c- and s-quarks: particle identification and secondary vertex reconstruction. c- and s-jets can be tagged by high momentum

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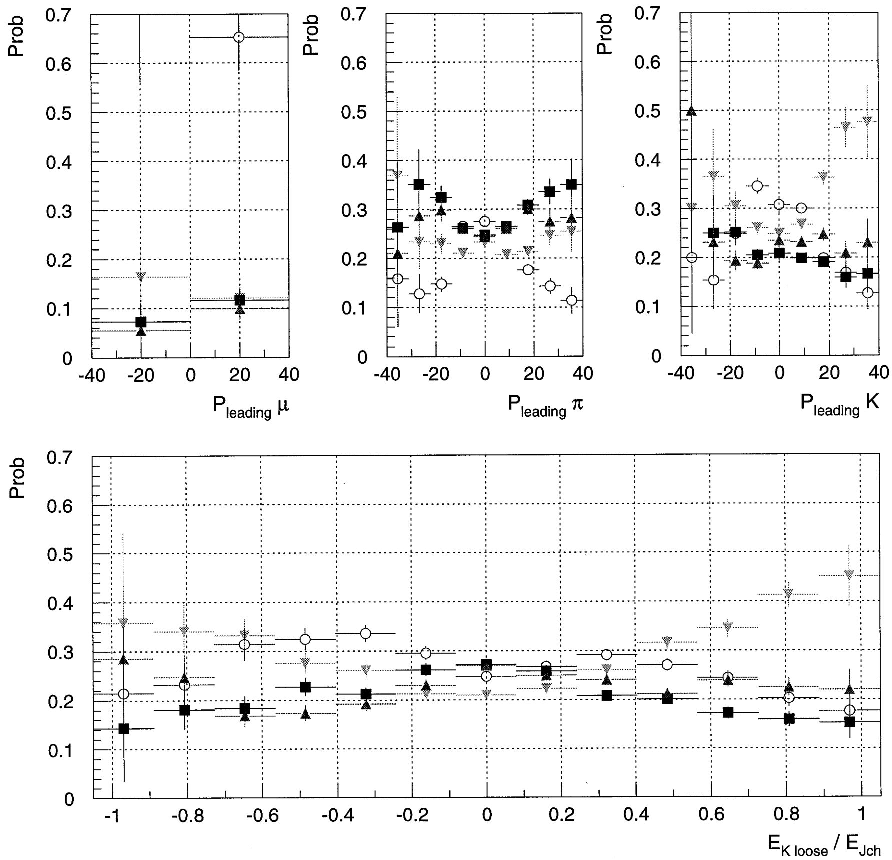

Fig. 1. The fractions of u- (up triangles), d- (filled squares), s- (down triangles) and c-jets (open dots) as a function of the momentum of the leading particle in the jet (upper plots) for leading μ (left), π (center) and K or p (right) and of the fraction of the jet charged energy taken by identified kaons and protons (lower plot). This variable is signed by the product of the tagged particle charge with the jet charge.

kaons containing the initial s-quark or an s-quark from c → s decay. As c-quarks can decay semileptonically, an identified muon in the jet can also be used for tagging (see Fig. 1). Further, c-quarks can be identified using a lifetime tag that is based on the impact parameter distribution of the particles assigned to the jet.

3. Search for charged Higgs bosons

In the Standard Model (SM), the electroweak symmetry breaking is caused by coupling to a Higgs doublet. Since no SM Higgs boson has been observed, it is interesting to investigate extensions of the model. Many of these models, e.g. supersymmetric models, include extended Higgs sectors containing charged Higgs bosons. Discovery of the charged Higgs bosons would manifest new physics beyond the SM.

Direct and indirect searches for charged Higgs bosons have been performed in several experiments, e.g. in t-quark decays at hadron colliders [4] and in rare B decays as $b \to s\gamma$ [5] or $B \to \tau\nu$. Exclusion limits from these searches are, however, model dependent. In $e^+ e^-$ collisions the $H^\pm$ pair production cross-section depends only on the $m_{H^\pm}$. This makes a model independent direct search possible.

3.1. DELPHI analysis at LEP2

Coupling of the charged Higgs boson to fermions depends on the fermion masses and for quarks on the relevant element of the Cabibbo–Kobayashi–Maskawa matrix (CKM). The heaviest allowed fermion pairs for $H^{\pm}$ masses accessible for LEP2 are $c\bar{s}$ and $\tau\bar{\nu}$. This results in three possible final states: (i) fully hadronic final state with four hadronic jets, (ii) mixed final state with two hadronic jets + $\tau\nu$ and (iii) fully leptonic final state with $\tau\nu\tau\nu$. All three channels were analysed.

In the fully hadronic channel the signal is characterised by four high multiplicity hadronic jets. The most difficult background comes from W pairs and was rejected using kinematical variables and jet flavour tagging (see Fig. 2) [1].

In the semileptonic decay channel the signal is characterised by two high multiplicity hadronic jets, one narrow jet and missing energy and momentum. The main background comes from semileptonic W pair decays and was rejected using flavour tagging, kinematical event variables and lepton identification.

Fully leptonic signal events are characterised by two narrow acoplanar jets and large missing energy and momentum. Background comes mainly from leptonic W pair decays and was rejected using different angular distributions of τ leptons signal and background events.

3.2. Results and conclusions

Data collected with the DELPHI detector at c.m.s. energies of 161, 172, 183 GeV and first part of data collected at 189 GeV, corresponding to integrated luminosities of 10, 10, 53.5 and 27 pb^{-1} respectively, were analysed. No charged Higgs signal

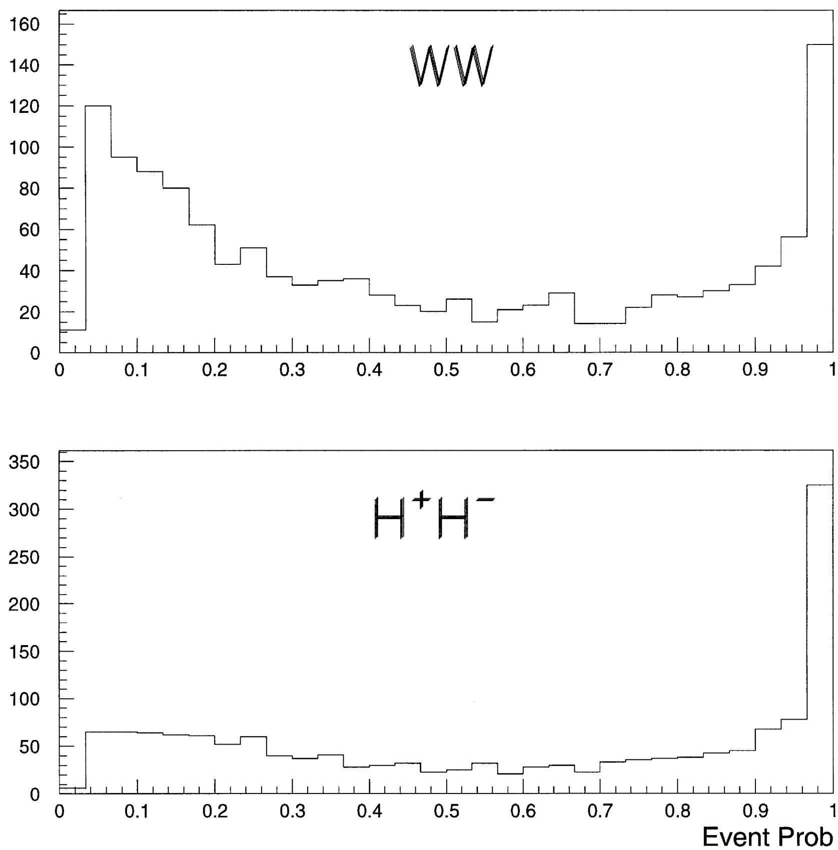

Fig. 2. Distributions of the event $c\bar{s}\,\bar{c}s$ probability for simulated WW background (upper plot) and charged Higgs boson signal (lower plot). The decays of W to ud can be seen as a high event rate at low $c\bar{s}\,\bar{c}s$ probability.

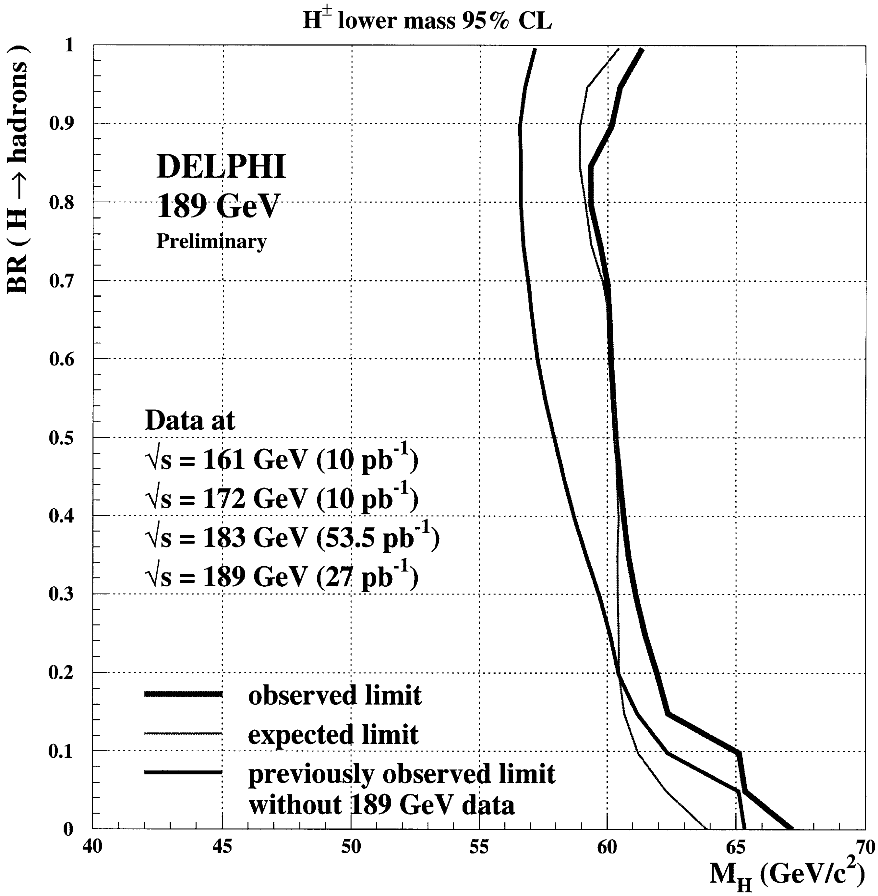

Fig. 3. Preliminary observed and expected lower mass limits for charged Higgs boson as function of the hadronic branching ratio.

was seen and a preliminary lower mass limit was set at 59.2 GeV/c^2 (see Fig. 3) [6].

Jet flavour tagging using RICH based particle identification was used for improving the background rejection. In the analysis of the fully hadronic channel which profits most from the flavour tagging, the additional background rejection power due to the cs identification was estimated to be of the order of 10%.

With more data collected in the two coming years the search at LEP2 is expected to have sensitivity for masses close to $m_{W^{\pm}}$, i.e. up to about 75 GeV/c^2. Closer to the $W^{\pm}$ mass the kinematical properties of the signal and W pair background events become more alike but the flavour compositions do not change. Therefore, the importance of the jet flavour tagging for background rejection can be expected to increase.

4. $|V_{cs}|$ measurement

In the SM the eigenstates of electroweak interaction are related to the mass eigenstates by the unitary 3×3 Cabibbo–Kobayashi–Maskawa (CKM) matrix [7,11]. The three CKM matrix mixing angles and a phase are free parameters of the SM and need to be determined experimentally. Apart from the CKM matrix elements relating heavy t-quark, $|V_{cs}|$ is known with poorest precision

Table 1
The measured values of the CKM matrix elements relating u-, d-, c-, s- and b-quarks prior to the LEP2 $|V_{cs}|$ measurements [8]

$\lvert V_{ud}\rvert = 0.9740 \pm 0.0010$	$\lvert V_{us}\rvert = 0.2196 \pm 0.0023$	$\lvert V_{ub}\rvert = 0.0033 \pm 0.0008$
$\lvert V_{cd}\rvert = 0.224 \pm 0.016$	$\lvert V_{cs}\rvert = 1.04 \pm 0.16$	$\lvert V_{cb}\rvert = 0.0395 \pm 0.0017$

as can be seen in Table 1. The most precise $|V_{cs}|$ measurement before LEP2 were obtained by combining data on branching ratios for D_{e3} meson decays with accurate values for the D lifetimes [8]. These measurements suffer from uncertainties in the hadronic form factors.

The relatively large number of W boson pairs recorded at LEP2 provides new methods to measure $|V_{cs}|$ using W boson decays. The coupling of W to a quark–antiquark pair $q_i q_j$ is proportional to the relevant CKM matrix element $|V_{ij}|$. $|V_{cs}|$ can be calculated from the hadronic and leptonic branching ratios, by inserting the values of the contributing CKM matrix elements, as follows:

$$|V_{cs}| = \sqrt{\frac{3\Gamma_l}{\Gamma_{h,0}} \frac{\mathrm{Br}(W^{\pm} \to \mathrm{had})}{(1 - \mathrm{Br}(W^{\pm} \to \mathrm{had}))} - \sum_{ij \neq cs} |V_{ij}|^2},$$

where

$$\Gamma_l = \frac{G_F M_W^3}{6\sqrt{2}\pi} = (227 \pm 1)\ \mathrm{MeV}\ \text{and}$$

$$\Gamma_{h,0} = \frac{3(1 + \alpha_s(M_W)/\pi) G_F M_W^3}{6\sqrt{2}\pi} = (707 \pm 3)\ \mathrm{MeV}.$$

A direct measurement of $|V_{cs}|$, being independent of the leptonic W couplings and α_s, can be obtained by using c and s jet flavour identification by measuring the fraction of cs final state, R^W_{cs}, in all hadronic final states in W boson decays:

$$R^W_{cs} = \frac{|V_{cs}|^2}{|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 + |V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2}.$$

4.1. DELPHI measurement of $|V_{cs}|$

A measurement was performed using data collected with the DELPHI detector at c.m.s. energies of 161, 172 and 183 GeV, corresponding to integrated luminosities of 9.93, 9.98 and 50.0 pb^{-1}, respectively. Approximately 700 W pairs were used in the analysis. The preliminary value of the hadronic branching ratio was measured to be $0.675 \pm 0.015(\mathrm{stat}) \pm 0.009(\mathrm{syst})$ and this was converted to: $|V_{cs}| = 0.98 \pm 0.07(\mathrm{stat}) \pm 0.04(\mathrm{syst})$ [2].

The direct measurement using jet flavour tagging was performed by combining hadronic jets in both fully hadronic and semileptonic WW events to di-jets with four different flavour combination hypothesis: $c\bar{s}$, $\bar{c}s$, $u\bar{d}$ and $\bar{d}u$. The other flavour combinations are Cabibbo suppressed and they were regarded as a small contribution to the $u\bar{d}$ and $\bar{d}u$ combinations. Di-jets were assigned with a probability (P_{cs}) to be cs pairs. The relative contribution of cs di-jets in all di-jets was determined by fitting the simulated P_{cs} distributions to the data (see Figs. 4 and 5). The preliminary fitted value for R^W_{cs} for 183 GeV data is $0.50^{+0.07}_{-0.05}(\mathrm{stat}) \pm 0.05(\mathrm{syst})$ and converting R^W_{cs} to $|V_{cs}|$ and combining the 161 and 172 GeV data results in: $|V_{cs}| = 1.01^{+0.12}_{-0.10}(\mathrm{stat}) \pm 0.10(\mathrm{syst})$ [2].

4.2. Results and conclusions

Combining the DELPHI $|V_{cs}|$ measurements obtained with the hadronic branching ratio method and the jet flavour identification method results in preliminary measurement: $|V_{cs}| = 0.99 \pm 0.06(\mathrm{stat}) \pm 0.05(\mathrm{syst})$. The LEP2 results improve significantly the precision of $|V_{cs}|$ measurement from the previous measurements and are in agreement with the SM prediction using unitarity constraints which is: $|V_{cs}| = 0.9737$–0.9753 [8].

Impact of the RICH based particle identification to the precision of the R^W_{cs} measurement is significant. The error of the $|V_{cs}|$ measurement with flavour tagging method based only on the lifetime tag would be $\sim 50\%$ larger than the one with particle identification included [9].

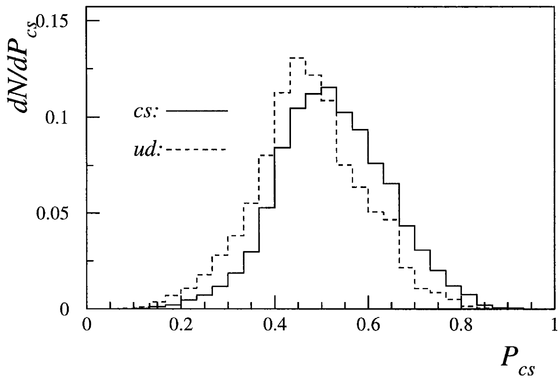

Fig. 4. Dijet P_{cs} distributions for simulated cs di-jets (full histogram) and ud di-jets (dashed histogram).

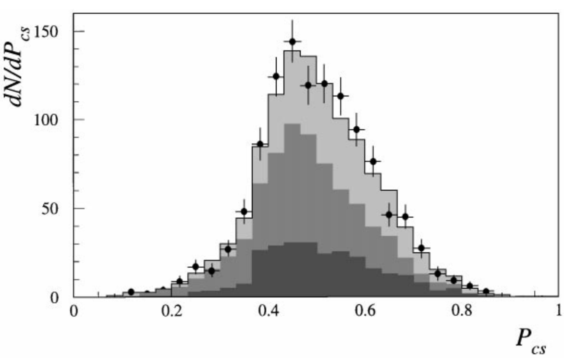

Fig. 5. The measured P_{cs} distribution (dots) with the best fit (histograms). The lightest shading stands for cs, the middle one for ud and Cabibbo suppressed decays and the darkest one for background.

With the full statistics of LEP2 the error of the $|V_{cs}|$ measurement is expected to still decrease significantly.

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