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Search for Charged Higgs Bosons in e^+e^- Collisions at $\sqrt{s} = 183 - 202$ GeV

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Abstract

A search for pair produced charged Higgs bosons was performed in the high energy data collected by the DELPHI detector at LEP II at centre-of-mass energies from 183 GeV to 202 GeV. The three different final states, $\tau\nu\tau\nu$, $c\bar{s}\tau\nu$ and $c\bar{s}\bar{c}s$ were considered. New methods were applied in the rejection of wrong hadronic jet pairings and for the tau identification, where a discriminator based on tau polarisation and polar angles was used. No excess of data compared to the expected Standard Model processes was observed and the existence of a charged Higgs boson with mass lower than 75.0 GeV/c^2 is excluded at 95% confidence level.

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1 Introduction

The existence of a charged Higgs boson doublet is predicted by several extensions of the Standard Model. Pair production of charged Higgs bosons occurs mainly via s-exchange of a photon or a Z boson. In two-doublet models, the couplings are completely specified in terms of the electric charge and the Weinberg angle, θ_W, and therefore the production cross section depend only on the charged Higgs boson mass. Higgs bosons decay predominantly to the heaviest fermions kinematically allowed, which in the case of charged Higgs bosons at LEP energies can be either a $\tau\nu_\tau$ pair or a cs-quark pair. In order to ensure that the results are model independent the decay branching fraction to leptons and quarks has been treated as a free parameter in the analyses described in this paper.

A search for pair-produced charged Higgs bosons was performed based on the data collected by DELPHI during the LEP runs at centre-of-mass energies from 183 GeV to 202 GeV. The results reported here supersede those obtained in an earlier analysis of the DELPHI data limited to the 183 GeV runs [1]. Similar searches have been performed by the other LEP experiments [2].

A new technique was developed to improve the discrimination against the hadronic W decays in the search for $H^\pm$ candidates. Improved methods using the τ polarisation and boson production angles in the leptonic channel were used for rejection of W background.

2 Data Analysis

The energies and the integrated luminosities of the analysed data samples are summarised in Table 1. The DELPHI detector and its performance have already been described in detail elsewhere [3, 4].

Signal samples were simulated using the PYTHIA generator [5]. The background estimates from the different Standard Model processes were based on the following event generators: PYTHIA for $q\overline{q}(\gamma)$, KORALZ [6] for $\mu^+\mu^-$ and $\tau^+\tau^-$, BAFO [7] for e^+e^- and EXCALIBUR [8] for four-fermion final states. Two-photon interactions were generated with TWOGAM [9] for hadronic final states, BDK [10] for electron final states and BDKRC [10] for other leptonic final states.

Standard DELPHI criteria were used for particle quality cuts.

In all three analyses the final background rejection was performed by using a likelihood technique. For each of the N discriminating variables, the fractions $F_i^{HH}(x_i)$ and $F_i^{bkg}(x_i)$ of respectively H^+H^- and background events corresponding to a given value x_i of the i^{th} variable, were extracted from a sample of simulated background and H^+H^- events with equal populations. The signal likelihood was computed as the normalised product of these individual fractions, $\prod_{i=1,N} F_i^{HH}(x_i)/(\prod_{i=1,N} F_i^{HH}(x_i) + \prod_{i=1,N} F_i^{bkg}(x_i))$.

2.1 The leptonic channel

The signature for $H^+H^- \rightarrow \tau^+\nu_\tau\tau^-\overline{\nu}_\tau$ is large missing energy and momentum and two acollinear and acoplanar jets containing either a lepton or one or a few hadrons. Tighter requirements, than in the other analysed channels for good running of the most important sub-detectors were used in this analysis in order to ensure good quality of the tracks. This results in slightly smaller integrated luminosities than in the other two channels (see Table 1).

2.1.1 Event preselection

To select leptonic events a total charged particle multiplicity between 2 and 6 was required. All particles in the event were clustered into jets using the LUCLUS algorithm [5] ($d_{join} = 6.5$ GeV/c^2) and only events with two reconstructed jets both containing at least one charged particle and at least one jet with only one charged particle were retained. Events with the invariant mass of either of the jets more than 3 GeV/c^2 were rejected.

The leading track of each jet, i.e. the particle with the highest momentum, was required to satisfy $\mid \cos\theta_l \mid < 0.98$. In order to reject background events where the jets are back-to-back, and radiative return events with a photon along the beam pipe, the event acoplanarity was required to be less than 13° if both leading tracks are in the barrel region (25° in other case), the total energy component transverse to the beam direction, E_t, was required to be greater than $0.08\sqrt{s}$ ($0.1\sqrt{s}$) and the total transverse momentum, P_t, to be greater than $0.04\sqrt{s}$. Also events with a total energy detected within 30° around the beam axis of more than $0.1\sqrt{s}$ or an acollinearity of more than 150° were rejected.

Additional cuts were applied to reject W's decaying directly to an electron or a muon and a neutrino. If the τ jet was identified as an electron it had to have a momentum below $0.13\ \sqrt{s}$ and an electromagnetic energy below $0.14\ \sqrt{s}$. For muons the momentum had to be below $0.13\ \sqrt{s}$. If a τ decay candidate particle was not identified as either a muon or an electron, it was considered as a hadron.

2.1.2 Final background rejection

After these selections most of the remaining background is $W^+W^- \rightarrow \tau^+\nu_\tau\tau^-\overline{\nu}_\tau$ events. Events from both the H^+H^- signal and the W^+W^- background have similar topologies and due to the presence of missing neutrinos in the decay of each of the bosons it is not possible to reconstruct the boson mass. Two important differences, however, were used in order to discriminate the signal and the WW background: the boson polar angle and the τ polarisation.

Assuming that the ν_τ has a definite helicity, the polarisation of tau leptons originating from heavy boson decays is determined entirely by the properties of weak interactions and the nature of the parent boson. The helicity configuration for the signal is $H^- \rightarrow \tau^-{}_R\nu_{\tau R}$ ($H^+ \rightarrow \tau^+{}_L\overline{\nu}_{\tau L}$) and for the $W^\pm$ boson background it is $W^- \rightarrow \tau^-{}_L\nu_{\tau R}$ ($W^+ \rightarrow \tau^+{}_R\overline{\nu}_{\tau L}$) resulting in ${P_\tau}^H = +1$ and ${P_\tau}^W = -1$. The angular and momentum distributions depend on polarisation and it is possible to build estimators of the τ polarisation to discriminate between the two contributions.

The τ decays were classified into the following categories: electron, muon, π, $\pi + n\gamma$, 3π and others. The information on the τ polarisation was extracted from the observed kinematic distributions of its decays products, e.g. angles and momenta. These estimators are equivalent to those used at LEP I [11]. For charged Higgs bosons masses close to the threshold, the boost of the bosons is relatively small and the τ energies are similar to the τ's from Z^0 decays (40–50 GeV).

A likelihood to separate the signal from the background was built using four 'independent' variables: the estimators of the τ polarisation and the boson polar angle of both τ's. The distribution of that likelihood for data and expected backgrounds and signal is shown in Fig 1.

2.2 The hadronic channel

In the fully hadronic decay channel, each charged Higgs boson is expected to decay into a $c\bar{s}$ pair, producing a four-jet final state. The two sources of background in this channel are the $q\bar{q}gg$ QCD background and fully hadronic four-fermion final states. As the significance of the Z^0Z^0 pairs for the analysis is negligible compared to the W^+W^- pairs, the four-fermion sample is referred to as W^+W^- in the rest of the paper.

2.2.1 Event preselection

Events were clustered into four jets using the Durham algorithm [12]. The particle quality requirements and the first level hadronic four-jet event selection followed in this analysis were the same as for the DELPHI neutral Higgs analysis [13].

In order to reject more effectively three jet like QCD background events a cut on the Durham clustering parameter $y_{4\to3}$ value for transition from four to three jets was required to be greater than 0.003. Events with clear topology of more than four jets were rejected by adding a cut on the $y_{5\to4}$ value for transition from five to four jets at 0.010 because of their worse di-jet mass resolution after forcing them into four jets.

Energy-momentum conservation was imposed by performing a 4-C fit on these events and the difference between the two di-jet masses for each jet pairing is computed. A 5-C fit, assuming equal boson masses, is applied in order to improve the resolution on the di-jet mass M_{jj}. The di-jet combination giving the smallest χ^2 was selected for the mass reconstruction. Events for which the χ^2 per degrees of freedom of this combination exceeded 5 or the difference of the masses computed after the 4-C fit exceeded 10 GeV/c^2 were rejected.

2.2.2 Final background rejection

The major contribution in the selected sample of the W^+W^- events with reconstructed mass below 75 GeV/c^2 is due to picking a wrong di-jet pairing. These wrongly paired events are characterised by larger difference between the masses of the two di-jets, i.e. the two boson candidates. As the true initial quark-antiquarks pairs are connected by a QCD colour field, in which the hadrons are produced in the fragmentation process, the wrongly paired events can also be identified using a method of colour connection reconstruction [14].

The colour connection reconstruction method is based on the fact that in the rest frame of the correct initial quark antiquark pair the hadrons that are produced in this colour string should have vanishing transverse momenta relative to the quark antiquark pair axis. This could be distorted by hard gluon emission but these events are suppressed with the $y_{5\to4}$ Durham parameter cut. When boosted into a rest frame of a wrong quark pair the transverse momenta of the particles relative to the quark quark axis are larger. The correct pairing is found by calculating the sum of transverse particle momenta in each of the three possible pairing hypotheses. The pairing chosen using the colour connection reconstruction is compared to the pairing chosen using the minimisation of χ^2 of the 5-C kinematical fit. The output of this comparison, p_t-veto, is binary information: agreement or disagreement.

The production polar angle of the positively charged boson discriminates between W^+W^- and Higgs pairs. This angle is reconstructed as the polar angle of the di-jet with higher charge where the jet charge is calculated as a momentum weighted sum of the charges of the tracks in the jet. The distribution of this variable allows the discrimination of the signal against the wrongly paired W^+W^- events and QCD events even though in these cases it is not the true boson production angle.

The charged Higgs boson is expected to couple predominantly to $c\bar{s}$ in its hadronic decay mode. Therefore the QCD and W^+W^- backgrounds can be partially suppressed by selecting final states consistent with being $c\bar{s}\bar{c}s$. A flavour tagging algorithm has been developed for the study of multiparton final states [15]. This tagging is based on nine discriminating variables: three of them are related to the identified lepton and hadron content of the jet, two depend on kinematical variables and four on the reconstructed secondary decay structure. The finite c lifetime is exploited to distinguish between c and light quark jets, while the c mass and decay multiplicity, is used to discriminate against b jets. Furthermore s and c jets can be distinguished from u and d jets by the presence of an identified energetic kaon. The responses for the individual jets are further combined into an event $c\bar{s}\bar{c}s$ probability.

The four variables described above: di-jet pair mass difference, di-jet momentum polar angle, event $cscs$ probability and the p_t-veto, were combined to form an event anti-WW likelihood function separating W^+W^- events from H^+H^- events. The response of this likelihood also discriminates H^+H^- from the QCD background events.

QCD background events differ also kinematically from pair-produced bosons [16]. In order to reject the QCD background more effectively the following additional variables were used in the anti-QCD likelihood: the product of the minimum jet energy and the minimum di-jet angle $\min(E_{jet}) \cdot \min(\alpha_{jets})$ and the event acoplanarity.

The reconstructed mass distribution for data and simulated backgrounds and signal after anti-QCD and anti-WW cuts is shown in Fig 2.

2.3 The semileptonic channel

In this channel one of the charged Higgs bosons decays into a $c\bar{s}$ quark pair, while the other decays into $\tau\nu$. Such an event is characterised by two hadronic jets, a τ candidate and missing energy carried by the neutrinos. The dominating background processes are QCD $q\bar{q}\gamma$ events and semileptonic decays of W^+W^-.

2.3.1 Event preselection

At least eight charged tracks were required to be reconstructed for an event to be considered in the analysis. The energy of charged particles had to exceed 0.15 $\sqrt{s}$, and the total energy had to be greater than 0.30 $\sqrt{s}$. After clustering into two jets using the Durham algorithm, the acollinearity was required to be greater than 7°. Events were also required to have no neutral particles with energy above 40 GeV and the energy detected in a cone of around the beam axis of 20° (30°) half aperture to be less than 0.20 $\sqrt{s}$ (30 $\sqrt{s}$). Furthermore, the angle between the total momentum of the detected particles and the beam axis had to be greater than 20°. The thrust value of the event had to be below 0.95. After clustering into three jets using the Durham algorithm, the clustering distance $y_{3\to2}$ was required to be greater than 0.003.

The jet with the smallest charged particle multiplicity was treated as the τ candidate and if more than one of the jets had the same number of charged particles, the one with smallest energy was chosen. The τ jet candidate was required to have no more than seven particles, of which no more than three charged. The invariant mass of the τ jet was required to be smaller than 2 GeV/c^2. As in the leptonic analysis, the τ candidate was classified according to its decay mode into the following classes: e, μ, π, $\pi + n\gamma$, 3π and others. An electron was required to have momentum below 0.13 $\sqrt{s}$ and electromagnetic energy below 0.14 $\sqrt{s}$ and a muon to have momentum below 0.13 $\sqrt{s}$.

2.3.2 Final background rejection

The mass of the decaying bosons M_{jj} was reconstructed using a constrained fit requiring energy and momentum conservation with known beam energy and equal masses of the two bosons. The three components of the momentum vector of the ν_τ from the W and the magnitude of the τ momentum were treated as free parameters, reducing the number of degrees of freedom in the fit from 5 to 1.

Separate likelihood functions were defined to distinguish the signal events from the QCD background and from the W^+W^- background, in a manner similar to that used for the other channels described above.

To define the event anti-QCD likelihood, the polar angle of the total momentum, the logarithm of the clustering distance, defined as the $y_{3\to 2}$ value of the Durham algorithm, the product of the τ jet energy and the smallest of the angles between the τ jet and one of the other jets and, finally, a function of the cs probability of the di-jet (defined for the di-jet as for the whole event in the hadronic analysis), were used as discriminating variables.

For the event anti-WW likelihood the variables used included the reconstructed polar angle of the negatively charged boson (where the charge was taken to be that of the leading charged particle from the τ jet), the angle between the W boson and the τ in the W rest frame, the τ polarisation estimator (different for each decay channel as in the leptonic analysis) and the cs probability of the hadronic di-jet.

The reconstructed mass distribution for data and simulated backgrounds and signal after anti-QCD and ant-WW cuts is shown in Fig 3.

3 Results

3.1 Selection efficiencies and uncertainties

The number of real data and background events and the estimated efficiencies for these selections for different $H^\pm$ masses are summarised in Table 1 for the three final states.

Uncertainties in the expected background and in the signal efficiency are accounted for. Minor contributions to these uncertainties are due to uncertainties in the luminosity measurement and cross-section estimates of the generated Monte Carlo samples. The major part of the background and signal efficiency uncertainties in the leptonic channel is due to the finite simulation statistics available. Largest contribution in the semileptonic and hadronic analyses is due to uncertainty in the normalization of the Zee background as well as the differences in the response of the likelihood variables in data and simulation. The combined error estimates are included in Table 1.

Table 1: *Integrated luminosity, observed number of events, expected number of background events and signal efficiency for different energies (75 GeV/c^2 signal mass for the leptonic channel and 70 GeV/c^2 signal mass for the hadronic and semileptonic channels).*

$\sqrt{s}$	Channel	Lumin. pb^{-1}	Data	Expected Bkg.	Signal eff. %
183	$cscs$	53.00	65	64.89±7.0	28.2±2.1
189	$cscs$	158.0	194	205.09±20.0	29.9±1.9
192	$cscs$	25.890	33	33.26±4.0	28.4±2.0
196	$cscs$	76.91	91	98.27±10.0	28.4±2.0
200	$cscs$	84.28	99	105.34±11.0	28.6±2.0
202	$cscs$	41.10	43	50.67±6.0	28.6±2.8
189	$cs\tau\nu$	153.8	82	79.63±7.9	29.6±1.2
192	$cs\tau\nu$	24.88	18	13.74±1.4	31.5±1.2
196	$cs\tau\nu$	73.47	46	40.87±4.1	32.1±1.2
200	$cs\tau\nu$	82.93	41	46.96±4.7	30.9±1.2
202	$cs\tau\nu$	40.00	22	22.81±2.3	30.8±1.2
183	$\tau\nu\tau\nu$	47.042	6	4.69±0.5	33.4±1.9
189	$\tau\nu\tau\nu$	153.808	15	15.05±1.5	32.4±1.3
192	$\tau\nu\tau\nu$	24.53	2	2.63±0.3	32.1±1.5
196	$\tau\nu\tau\nu$	72.440	7	9.39±0.8	32.1±1.5
200	$\tau\nu\tau\nu$	81.766	7	9.57±0.9	31.6±1.4
202	$\tau\nu\tau\nu$	39.437	3	4.63±0.5	31.6±1.4

3.2 Determination of the Mass Limit

No excess of events compared to the expected backgrounds was observed in any of the three different final states investigated. A lower limit for a charged Higgs boson mass was derived at 95% confidence level as a function of the hadronic Higgs decay branching ratio BR($H \rightarrow \tau\nu_\tau$). The confidence in the signal hypothesis, CL_s, was calculated using a likelihood ratio technique [17].

The background and signal probability density functions of one or two discriminating variables in each channel were used. In the hadronic and semileptonic channels the two discriminating variables were the reconstructed mass and the anti-WW likelihood while in the leptonic channel only one background discrimination likelihood was used because mass reconstruction is not possible. The distributions for the discriminating variable of signal events, obtained by the simulation at different $H^\pm$ mass values for each $\sqrt{s}$, were interpolated for intermediate mass values. The signal efficiencies were fitted with polynomial functions, to obtain the expected signal rate at any given mass.

A Gaussian smearing of the central values of the number of expected background events by their estimated uncertainties was introduced in the limit derivation program.

The results are summarised in Figure 4. Independently of the hadronic decay branching ratio a lower $H^\pm$ mass limit of $M_{H^\pm} > 75.0$ GeV/c^2 can be set at 95% confidence level.

4 Conclusion

A search for pair-produced charged Higgs bosons was performed using the full statistics collected by DELPHI at LEP at centre-of-mass energies from 183 GeV to 202 GeV analysing the $\tau\nu\tau\nu$, $c\bar{s}\tau\nu$ and $c\bar{s}\bar{c}s$ final states. No significant excess of candidates was observed and a lower limit on the charged Higgs mass of 75.0 GeV/c^2 is set at 95% confidence level.

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References

[1] P. Abreu *et al.* (DELPHI Collaboration), *Phys. Lett.* **B 460** (1999), 484.

[2] R. Barate *et al.* (ALEPH Collaboration), *Phys. Lett.* **B 450** (1999) 467;
M. Acciarri *et al.* (L3 Collaboration), *Phys. Lett.* **B 466/1** (1999) 71;
K. Ackerstaff *et al.* (OPAL Collaboration), *Phys. Lett.* **B 426** (1998), 180.

[3] P. Aarnio *et al.* (DELPHI Collaboration), *Nucl. Instr. and Meth.* **A 303** (1991), 223.

[4] P. Abreu *et al.* (DELPHI Collaboration), *Nucl. Instr. and Meth.* **A 378** (1996), 57.

[5] T. Sjöstrand, *Comp. Phys. Comm.* **82** (1994), 74.

[6] KORALZ 4.0 generator: S. Jadach, B.F.L. Ward, Z.Was, Comp. Phys. Comm. 79 (1994) 503.

[7] F.A. Berends, R. Kleiss, W. Hollik, Nucl. Phys. B304 (1988) 712.

[8] F.A. Berends, R. Pittau, R. Kleiss, *Comp. Phys. Comm.* **85** (1995), 437.

[9] S. Nova, A.Olcheski and T. Todorov, in CERN Report 96-01, Vol. 2. p.224.

[10] F.A. Berends, P.H. Daverveldt, R. Kleiss, Comp. Phys. Comm. 40 (1986) 271,285 and 309.

[11] P. Abreu *et al.* (DELPHI Collaboration), *Zeit. Phys.* **C 67** (1995) 183.

[12] S. Catani *et al. Phys. Lett.* **B 269** (1991), 432.

[13] P. Abreu *et al.* (DELPHI Collaboration), CERN/EP 99–06, to be published in *E. Phys. J.* **C** (1999).

[14] A. Kiiskinen, V. Nomokonov and R. Orava, Using colour portraits in identifying the quark-antiquark pairs in heavy boson decays , DELPHI 98-91 CONF 159.

[15] M. Battaglia, *JETAG - A Jet Flavour Tagging Package for DELPHI*, DELPHI Note in preparation.
A similar jet flavour tagging technique has been used in determination of $|V_{cs}|$ at LEP II: P. Abreu *et al.* (DELPHI Collaboration), *Phys. Lett.* **B 439** (1998), 209.

[16] P. Abreu *et al.* (DELPHI Collaboration), *E. Phys. J.* **C 2** (1998), 581.

[17] A.L. Read, *Optimal statistical analysis of search results based on the likelihood ratio and its application to the search for the MSSM Higgs boson at 161 and 172 GeV*, DELPHI 97-158 PHYS 737.

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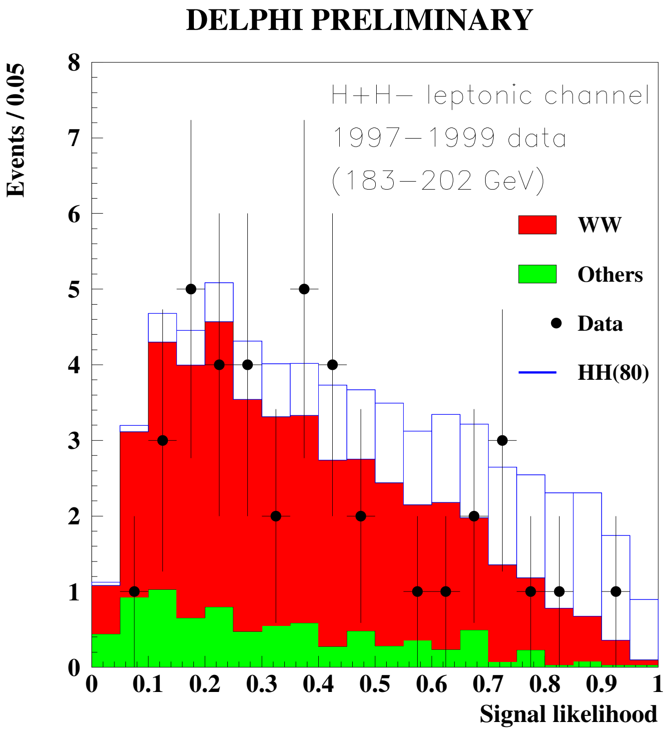

Figure 1: *Distribution of the background separating likelihood for leptonic events at 183–202 GeV. The signal histogram has been normalised to the production cross-section and 100% leptonic branching ratio.*

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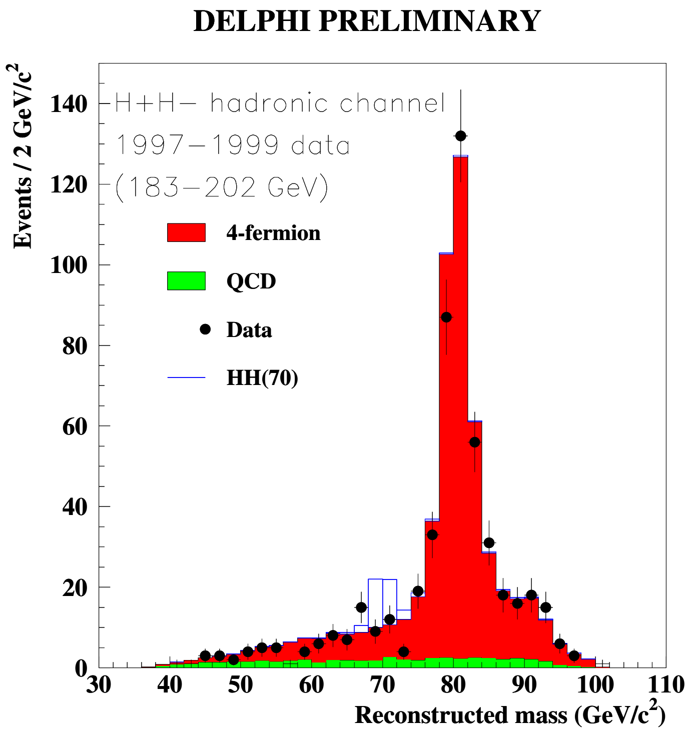

Figure 2: *Reconstructed mass distribution of hadronic events at 183–202 GeV at the final selection level. The generated* H^+H^- *signal mass is 70 GeV/*c^2 *and the signal histograms have been normalised to the production cross-section and 100% hadronic branching ratio.*

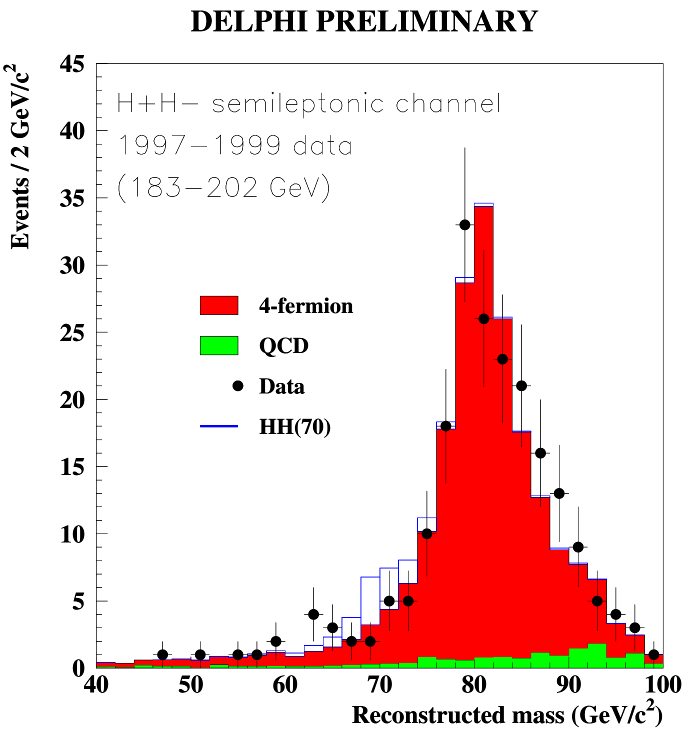

Figure 3: *Reconstructed mass distribution of semileptonic events at 183–202 GeV at the final selection level. The generated H^+H^- signal mass is 70 GeV/c^2 and the signal histogram has been normalised to the production cross-section and 50% semileptonic branching ratio.*

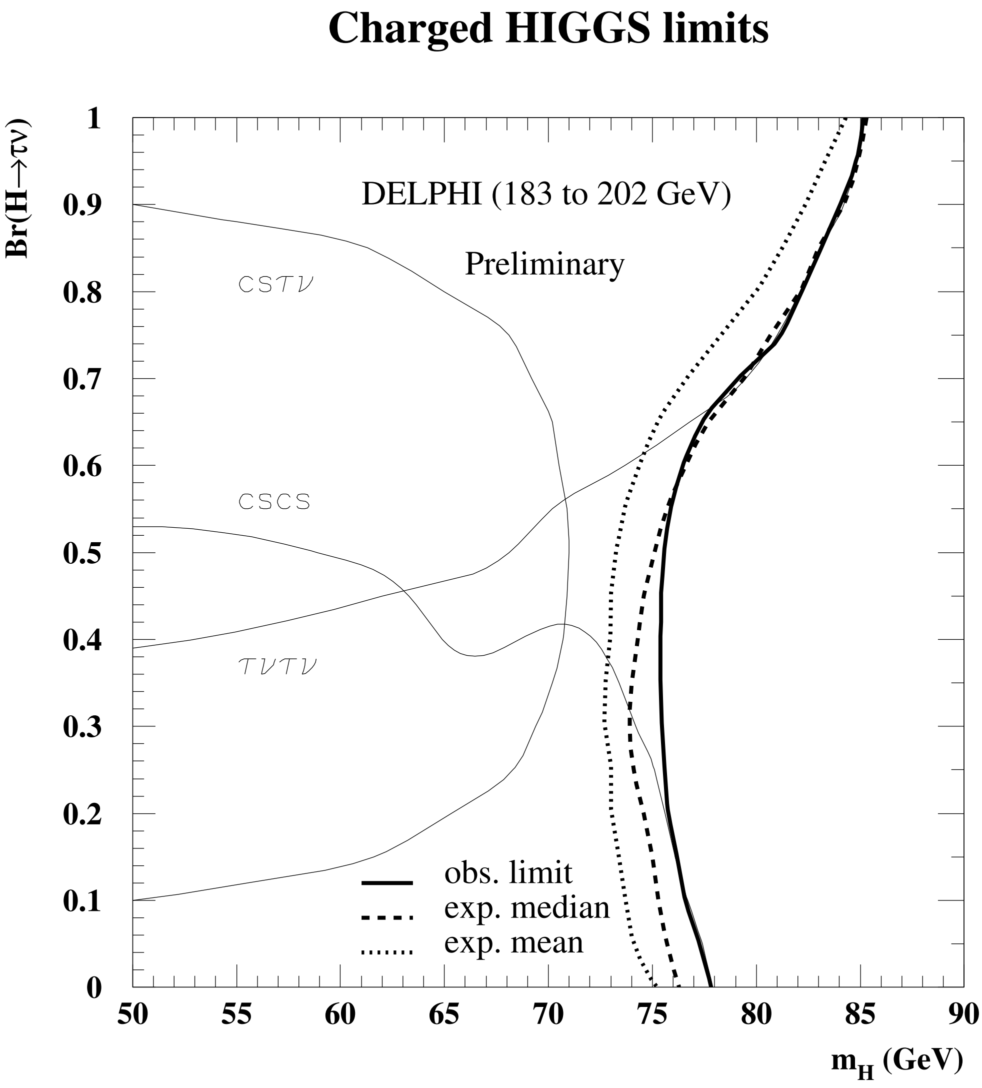

Figure 4: *The 95% confidence level observed and expected exclusion regions for* $H^{\pm}$ *in the plane* $BR(H \to \tau\nu_\tau)$ *vs.* $M_{H^\pm}$ *obtained from a combination of the search results in the hadronic, semileptonic and fully leptonic decay channels at* $\sqrt{s}$ = *183 GeV – 202 GeV. The expected mean stands for the mean of the limits obtained in all performed Gedanken experiments. The expected median is the value which has 50% of the values obtained in Gedanken experiments below and and 50% above.*