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Search for (singly and doubly) charged Higgses

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Abstract. Recent results on searches for singly and doubly charged Higgs bosons at LEP, Tevatron and Hera colliders are reported. These results do not show any deviation from the Standard Model expetations allowing to set lower limits on the mass of the charged Higgs bosons.

1 Introduction

Searches for charged Higgs bosons in e^+e^- collisions were performed at LEP using the data collected for the four LEP collaborations `ALEPH` [1], `DELPHI` [2], `L3` [3], and `OPAL` [4] at centre-of-mass energies from 189 GeV to 209 GeV.

Searches for pair-produced doubly charged Higgs bosons [5,6,7] and singly produced doubly-charged Higgs bosons [7,8] have been performed using e^+e^- collison data collected at LEP at centre-of-mass energies from 189 GeV to 209 GeV. Searches for same-sign multi-lepton events at LEP, Tevatron [9] and HERA [10] have been also performed in the context of the search for doubly charged Higgs bosons.

2 Searches for (singly) charged Higgs bosons at LEP

The existence of a pair of charged Higgs bosons is predicted by several extensions of the Standard Model. Pair-production of charged Higgs bosons occurs mainly via s-channel exchange of a photon or a Z^0 boson. In Two Higgs Doublet Models (2HDM), the couplings are completely specified in terms of the electric charge and the weak mixing angle, θ_W, and therefore the production cross-section depends only on the charged Higgs boson mass. In most cases, for the masses accessible at LEP energies, the $\tau^-\bar{\nu}_\tau$ and $\bar{c}s$ decay channels are expected to dominate. This is the case of the so-called type II 2HDM Models [11], where one Higgs doublet couples only to up-type fermions and the other to down-type fermions. Analyses of the three possible final states, $\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$, $c\bar{s}c\bar{s}$ and $c\bar{s}\tau^-\bar{\nu}_\tau$, have been performed by the four LEP collaborations and are described here. To avoid loss of generality, the results are combined and interpreted treating the Higgs decay branching fraction to leptons as a free parameter. An alternative set of models, type I models [12], assume that all fermions couple to the same Higgs doublet. In this case and if the neutral pseudo-scalar A is light (which is not excluded by direct searches for general 2HDM [13]) the decay to W^*A can be predominant even in the range of masses of interest at LEP (W^* is an off-shell W boson). Different techniques were developed to improve the discrimination against the dominant W^+W^- background using multidimensional estimators based on discriminant variables such as the boson production angle, jet flavour tagging or τ polarisation. The signature for $H^+H^- \to \tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ is large missing energy and momentum and two acollinear and acoplanar τ jets containing either a lepton or one or a few hadrons. Delphi [2] built a likelihood function to separate the signal from the background. It was composed of five variables: the τ polarisation likelihood of the event, the signed cosine of the polar angle of both τ's (which carries information of the boson polar angle), the acoplanarity and the total transverse momentum. The first three variables discriminated between $\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ produced from W boson and charged Higgs pairs. The last two variables had some sensitivity to the boson mass and helped in the discrimination of the remaining background from other processes. In the analysis of the $c\bar{s}c\bar{s}$ channel both charged Higgs bosons were assumed to decay into a pair of c and s quarks producing a final state with four jets. The two dominant background sources are the $q\bar{q}$ production with gluon radiation ($q\bar{q}gg$) and fully hadronic four-fermion final states. L3 analysis [3] was based on a neural network to discriminate against events compatible with a four-jet topology and those from $e^-e^+ \to q\bar{q}(\gamma)$, then a likelihood function prepared for each different Higgs boson mass was used to discriminate four-jet events compatible with charged Higgs production from the dominant background from W pair-production. Figure 1 shows the 5C mass of the pair-produced bosons before and after the cut on the final likelihoods. If at least one of the Higgs bosons decays to a W^*A pair, there are several possible topologies depending on the different boson decays. The W can decay leptonically or hadronically, and the number of jets strongly depends on the A mass and on the boson boosts. Searches at LEP were restricted to A masses

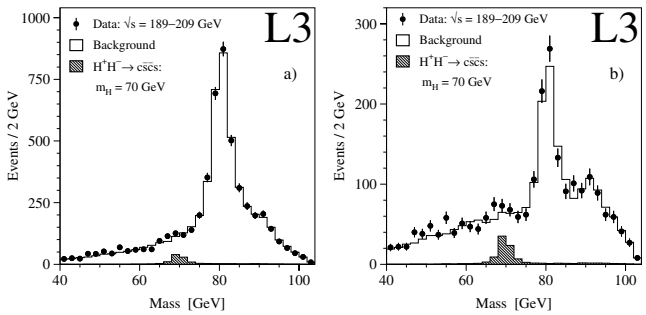

Fig. 1. Reconstructed mass spectra in the $c\bar{s}c\bar{s}$ channel for data and expected background, for events a) before, and b) after the cut on the likelihoods. The expected distribution for $M_{H^\pm} = 70$GeV and $BR(H^- \to \tau^-\bar{\nu}_\tau) = 0$ is shown in the hatched histogram

above 12 GeV/c^2, where it decays predominantly to $b\bar{b}$ Events with jets with b quark content were searched for in two topologies: events with a τ, missing energy and at least two hadronic jets and events with no missing energy and at least four hadronic jets In this way most of the possible decay chains for the W*A$\tau^-\bar{\nu}_\tau$ (first topology) and W*AW*A (second) were covered. The decay to W*A$c\bar{s}$ was neglected because its contribution is small. The DELPHI analysis used the one designed for technipion search within Technicolor models [18] as it was well suited also for these topologies and had a good performance in this search. No significant signal-like excess of events compared to the expected backgrounds was observed in any of the five final states investigated. Confidence levels were calculated using a modified frequentist technique, based on the extended maximum likelihood ratio [19]. From these confidence levels, lower limits on the charged Higgs boson mass were derived at 95% confidence level. Assuming that the branching ratio to W*A is negligible (type II models or type I with a heavy neutral pseudo-scalar) limits are set at 95% confidence level as a function of the branching ratio to leptons. The absolute DELPHI limit is 74.4 GeV/c^2 at 95% confidence level. Similar values were obtained by the other three LEP collaborations. Limits were also set within type I models for different neutral pseudo-scalar masses, $M_A > 12$ GeV/c^2 and $\tan\beta$. DELPHI results are shown in Fig. 2. The absolute limit is 76.7 GeV/c^2 at 95% confidence level.

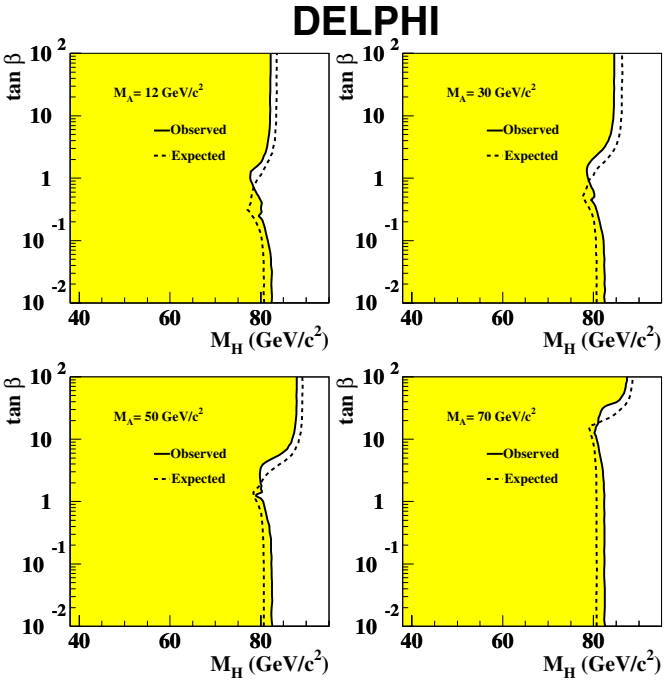

Fig. 2. The observed and expected exclusion regions at 95% confidence level in the plane of $\tan\beta$ vs. M_H in the framework of type I Two Higgs Doublet Models. These limits were obtained from a combination of the search results in all studied channels, with or without W*A decays, at $\sqrt{s} = 189$–209 GeV, for different A masses

3 Search for doubly charged Higgs at LEP, Tevatron, and Hera colliders

Doubly charged Higgs bosons ($H^{\pm\pm}$) appear in several extensions to the Standard Model [14], such as left-right symmetric models, and can be relatively light. For example, they can lead to small neutrino masses. In Supersymmetric left-right models usually the $SU(2)_R$ gauge symmetry is broken by two triplet Higgs fields, so-called left and right handed. Pair-production of doubly charged Higgs bosons is expected to occur mainly via s-channel exchange of a photon or a Z boson. In left-right symmetric models the cross-section of $e^+e^- \to H_L^{++}H_L^{--}$ is different from that for $e^+e^- \to H_R^{++}H_R^{--}$, where $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$ are the left-handed and right-handed Higgs bosons. In these models the doubly charged Higgs couples only to charged lepton pairs, other Higgs bosons, and gauge bosons, at the tree level. The dominant decay mode of the doubly charged Higgs boson is expected to be a same sign charged lepton pair, the decay proceeding via a lepton number violating coupling. As discussed in [15], due to limits that exist for the couplings of $H^{\pm\pm} \to e^\pm e^\pm$ from high energy Bhabha scattering, $H^{\pm\pm} \to \mu^\pm\mu^\pm$ from the absence of muonium to anti-muonium transitions and $H^{\pm\pm} \to \mu^\pm e^\pm$ from limits on the flavour changing decay $\mu^\pm \to e^\mp e^\pm e^\pm$, electron and muon decays are not likely. In addition, most of the models expect that the coupling to $\tau\tau$ will be much larger than any of the others. Depending on the $h_{\tau\tau}$ coupling and the Higgs mass the experimental signature is different. If $h_{\tau\tau}$ is sufficiently large, $h_{\tau\tau} \geq 10^{-7}$, the Higgs decays very close to the interaction point. DELPHI searched for pair-produced doubly charged Higgs bosons using three different analyses depending on the $h_{\tau\tau}$ coupling or, equivalently, on the mean decay length of the doubly charged Higgs boson. When the mean decay length of the Higgs boson is very small, the resulting final state consists of four narrow and low multiplicity jets coming from the interaction point. For intermediate mean decay lengths of the Higgs the topology consists of two tracks coming from the interaction point and either secondary vertices or kinked tracks. If the Higgs

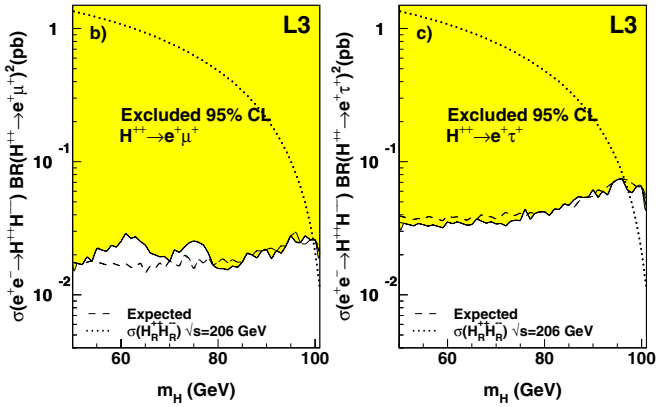

Fig. 3. Observed and expected limits on the cross section of doubly charged Higgs boson pair production times its branching ratio in a given final state as a function of m_H for the $h_{e\mu}$ and $h_{e\tau}$ channels. The expected cross section for the s-channel production of a right-handed doubly charged Higgs boson is also shown

decays outside the tracking devices the signature corresponds to stable heavy massive particles. No significant excess was observed and a lower limit on the doubly charged Higgs mass of 97.3 GeV/c^2 has been set at 95% confidence level for any value of the $h_{\tau\tau}$ coupling. L3 [7] and OPAL [5] also searched for pair production of doubly charged Higgs bosons in all possible leptonic flavours under the hypothesis that only one coupling at the time is different from zero, which implies that both doubly charged Higgs bosons in the events have the same decay mode. No evidence for $H^{++}H^{--}$ production was observed. Limits in the range of 95 GeV to 100 GeV were set depending on the decay mode considered. OPAL [8] searched for the single production of doubly-charged Higgs bosons. No evidence for the existence of $H^{\pm\pm}$ was observed. Upper limits were derived on h_{ee}, the Yukawa coupling of the $H^{\pm\pm}$ to like-signed electron pairs. A 95% confidence level upper limit of $h_{ee}, 0.071$ was inferred for $M(H^{\pm\pm}) < 160\ GeV$ assuming that the sum of the branching fractions of the $H^{\pm\pm}$ to all lepton flavour combinations was 100%. Additionally, indirect constraints on h_{ee} from Bhabha scattering where the $H^{\pm\pm}$ would contribute via t-channel exchange, were derived for $M(H^{\pm\pm}) < 2\ TeV$. L3 [7] performed also a fit of h_{ee} to the measured cross sections and forward-backward asymmetries for $\sqrt{s} = 130 - 209$ GeV setting upper limits on h_{ee} at 95% confidence level as a function of m_H. The exclusion region for $h_{ee} > 0.7$ extends to the TeV scale. Multi-electron production was studied at high electron transverse momentum [10] in positron and electron-proton collisions using the H1 detector at HERA, measuring di-electron and tri-electron yields in a data sample corresponding to an integrated luminosity of $115 pb^{-1}$ showing good overall agreement with the SM predictions. 6 events were observed with invariant mass $M_{12} > 100\ GeV$. Only one of them reulted compatible with the interpretation as $H^{\pm\pm}$ production due to their charge composition. Recently the CDF [9] experiment at Tevatron collider has reported on a search for multi-lepton production using 97.1 pb^{-1}, setting a limit of 110 GeV at 95 % in the muon sample.

4 Summary and conclusions

Searches for singly charged Higgs bosons were performed at LEP within type I and type II 2HDM models. Searches for doubly charged Higgs bosons were also performed at LEP, HERA and Tevatron colliders. No evidence for production of new particles in any of the final states investigated was oberved.

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