Search for charged Higgs bosons at LEP at the DELPHI experiment

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(on behalf of the DELPHI Collaboration)
In two-doublet models, the cross-section depends only on the charged Higgs boson mass.
Data set:

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (GeV)</th>
<th>182.7</th>
<th>188.7</th>
<th>191.6</th>
<th>195.5</th>
<th>199.5</th>
<th>200.5</th>
<th>205.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated luminosity (pb$^{-1}$)</td>
<td>50.0</td>
<td>153.8</td>
<td>24.5</td>
<td>72.4</td>
<td>81.8</td>
<td>39.4</td>
<td>74.0</td>
</tr>
</tbody>
</table>
The leptonic channel

- The signature for $H^+ H^- \rightarrow \tau \nu \tau \nu$ is large missing energy and momentum and two acollinear and acoplanar jets containing either a lepton or a collimated jet with a few hadrons.

- Event selection:
  - Leptonic preselection.
  - Tau identification.
  - Angular and energy cuts.
  - Final cuts.

- Final background rejection:
  - $W^+ W^- \rightarrow \tau \nu \tau \nu$ is the dominant background after all cuts.
  - This background and the signal have similar topologies.
Two important differences were used to discriminate the signal and the WW background.

**The tau polarisation:**
- $P^H_{\tau} = +1 \quad P^W_{\tau} = -1$
- The angular and momentum distributions depend on polarisation.
- It is possible to build estimators of the tau polarisation to discriminate between the contributions.

**Boson polar angle:**
- H → s-channel.
- W → s-channel and t-channel. W angle distribution peaks to low angles.

A likelihood to separate the signal from the background is built using the estimators of the tau polarisation and the polar angle of both taus, the event acoplanarity and the transverse momentum.
Likelihood distribution in the leptonic channel

DELPHI PRELIMINARY

H+H− leptonic channel
1997–1999 data
(183–202 GeV)

Events / 0.05

Signal likelihood
The hadronic channel

- In this channel both charged Higgs bosons are expected to decay into a cs pair, producing a four-jet final state.

- Event selection:
  - Hadronic preselection.
  - Four-jet topology.
  - Compatible with being produced by two equal mass particles.

- Final background rejection:
  - Anti-QCD likelihood
    - The product of the minimum jet energy and the minimum di-jet angle.
    - The event acoplanarity.
- Anti-WW likelihood
  - di-jet pair mass difference.
  - di-jet momentum polar angle.
  - **cs tagging probability.** A flavour tagging algorithm has been developed for the study of multiparton final states.

- **Colour connection reconstruction method for jet pairing.** In the rest frame of the correct initial quark antiquark pair of hadrons that are produced in this colour string, the transverse momentum with respect to the quark antiquark pair axis should vanish.
Reconstructed mass distribution in the hadronic channel
The semileptonic channel

Those events are characterised by two hadronic jets, a tau candidate and missing energy carried by the neutrinos.

Event selection:
- anti $\gamma \gamma$ cuts.
- Anti-QCD cuts.
- Events clustered into three jets with one of them compatible with a tau candidate.

Final background rejection:
- Anti-QCD likelihood.
  - The polar angle of the total momentum.
  - The logarithm of the clustering distance (to pass from three to two jets).
  - The product of the tau energy and the smallest of the angles between the tau jet and one of the other jets.
  - cs tagging probability.
Anti-WW likelihood.

- The reconstructed polar angle of the negatively charged boson.
- The angle between the W boson and the tau in the W rest frame.
- The tau polarisation estimator.
- cs tagging probability.
Reconstructed mass distribution in the semileptonic channel

DELPHI PRELIMINARY

H+H+ semileptonic channel
1997–1999 data
(183–202 GeV)

Events / 2 GeV/c^2

Reconstructed mass (GeV/c^2)
2000 data

DELPHI preliminary

H⁺H⁻ hadronic channel
year 2000 data

- 4-fermion
- other
- Data
- H⁺H⁻ (75)

H⁺H⁻ semi-leptonic channel
year 2000 data

- 4-fermion
- other
- Data
- H⁺H⁻ (75)

H⁺H⁻ leptonic channel
year 2000 data

- 4-fermion
- other
- Data
- H⁺H⁻ (80)
Results

- Good agreement between the data and the expected background is found.

- Total sample:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Data</th>
<th>Expected Background</th>
<th>Signal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSCS</td>
<td>672</td>
<td>684.7</td>
<td>28-30</td>
</tr>
<tr>
<td>CSTV</td>
<td>268</td>
<td>276.5</td>
<td>29-32</td>
</tr>
<tr>
<td>TVTV</td>
<td>52</td>
<td>54.7</td>
<td>32-33</td>
</tr>
</tbody>
</table>
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 mass was derived at 95% C.L. as a function of the leptonic Higgs decay B.R. The C.L. was calculated using a likelihood ratio technique.

- The Background and the signal p.d.f. of one (leptonic) or two (hadronic and semileptonic) discriminant variables in each channel were used.
  - Leptonic $\rightarrow$ likelihood.
  - Hadronic and semileptonic $\rightarrow$ reconstructed mass and anti-WW likelihood.
Charged Higgs Limit

DELPHI (189 to 208 GeV)

Preliminary

<table>
<thead>
<tr>
<th>BR(H→τν)</th>
<th>Observed</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85.0</td>
<td>86.5</td>
</tr>
<tr>
<td>0.5</td>
<td>75.4</td>
<td>75.7</td>
</tr>
<tr>
<td>0</td>
<td>76.3</td>
<td>76.5</td>
</tr>
<tr>
<td>Any</td>
<td>75.0</td>
<td>74.4</td>
</tr>
</tbody>
</table>
LEP results

Lower bounds on charged Higgs mass (GeV):

<table>
<thead>
<tr>
<th>$B(H \to \tau \nu_\tau)$</th>
<th>Observed</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>80.8</td>
<td>79.6</td>
</tr>
<tr>
<td>0.5</td>
<td>78.1</td>
<td>81.7</td>
</tr>
<tr>
<td>1.0</td>
<td>87.7</td>
<td>90.5</td>
</tr>
<tr>
<td>Any</td>
<td>77.5</td>
<td>78.8</td>
</tr>
</tbody>
</table>
Conclusions

- The search pair-produced charged Higgs bosons in the three final states \( \tau \nu \tau \nu, c \bar{s} c \bar{s} and c \bar{s} \tau \nu \) has been performed using the data collected by DELPHI experiment up to \( \sqrt{s} = 209 \text{ GeV} \).

- Limit above W mass for 100% leptonic decays.

- No evidence of charged Higgs boson production was found and new mass limits were set as a function of the decay branching fraction to leptons.

\[
M_{H^{+/-}} > 75.0 \text{ GeV} / c^2 (74.4 \text{ exp.})
\]