Status of LEP-wide Higgs searches

Chris Tully
Princeton

LEP working group
for Higgs boson searches
Year 2000 High-Energy Data
August 28 Combination

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Integrated Luminosity (pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>149</td>
</tr>
<tr>
<td>DELPHI</td>
<td>160</td>
</tr>
<tr>
<td>L3</td>
<td>145</td>
</tr>
<tr>
<td>OPAL</td>
<td>140</td>
</tr>
<tr>
<td>LEP</td>
<td>594</td>
</tr>
</tbody>
</table>

Investigated Higgs sectors:

- Standard Model Higgs
- MSSM Higgs
- 2HDM Charged Higgs
- Fermiophobic Higgs
- Invisible Higgs decays

LEP-wide Higgs searches
Standard Model Higgs Mass Plots

S/B definition for mass plots:

Number of expected events for a 114 GeV Higgs signal with reconstructed mass $m_H > 109$ GeV divided by the corresponding number of selected background.

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Bkgd</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>62</td>
<td>56.4</td>
<td>3.9</td>
</tr>
<tr>
<td>DELPHI</td>
<td>38</td>
<td>36.8</td>
<td>3.4</td>
</tr>
<tr>
<td>L3</td>
<td>31</td>
<td>34.7</td>
<td>2.1</td>
</tr>
<tr>
<td>OPAL</td>
<td>68</td>
<td>52.7</td>
<td>3.4</td>
</tr>
<tr>
<td>LEP</td>
<td>199</td>
<td>180.5</td>
<td>12.7</td>
</tr>
</tbody>
</table>

S/B = 0.3 @ $M_H = 114$ GeV

LEP-wide Higgs searches
### Standard Model Higgs Mass Plots

**S/B = 1.0 @ \( M_H = 114 \text{ GeV} \)**

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Bkgd</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>16</td>
<td>14.3</td>
<td>2.4</td>
</tr>
<tr>
<td>DELPHI</td>
<td>14</td>
<td>14.7</td>
<td>2.6</td>
</tr>
<tr>
<td>L3</td>
<td>11</td>
<td>9.7</td>
<td>0.7</td>
</tr>
<tr>
<td>OPAL</td>
<td>22</td>
<td>20.3</td>
<td>2.0</td>
</tr>
<tr>
<td>LEP</td>
<td>63</td>
<td>59.0</td>
<td>7.6</td>
</tr>
</tbody>
</table>

### LEP-wide Higgs searches
Standard Model Higgs Mass Plots

Excess Observed in High Mass Region $m_H > 109$ GeV

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Bkgd</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>7</td>
<td>3.3</td>
<td>1.0</td>
</tr>
<tr>
<td>DELPHI</td>
<td>5</td>
<td>5.4</td>
<td>1.3</td>
</tr>
<tr>
<td>L3</td>
<td>4</td>
<td>4.0</td>
<td>0.3</td>
</tr>
<tr>
<td>OPAL</td>
<td>11</td>
<td>9.6</td>
<td>0.9</td>
</tr>
<tr>
<td>LEP</td>
<td>27</td>
<td>22.2</td>
<td>3.6</td>
</tr>
</tbody>
</table>

$S/B = 2.0 \ @ M_H = 114$ GeV

LEP-wide Higgs searches
**Statistical Method**

Likelihood Ratio test-statistic:

\[ Q = \frac{\mathcal{L}(s + b)}{\mathcal{L}(b)} \]

Final search variables are binned and treated as Poisson counting experiments:

\[ \ln(Q) = -s_{tot} + \sum_i n_i \ln \left( 1 + \frac{s_i}{b_i} \right) \]

**For Illustrative Purposes:**

LEP-wide Higgs searches
SM Results from All Experiments

3.9σ Excess in ALEPH Data ($1 - \text{CL}_b = 6 \cdot 10^{-5}$)

LEP-wide Higgs searches
Combined SM Results

\[ -2\ln(Q) \text{ Minimum at } 114.9\text{ GeV} \]

\[ 1 - \text{CL}_b \text{ Minimum at } 2.6\sigma \text{ Significance} \]

LEP-wide Higgs searches
Consistency Checks (Experiments)

For $m_H = 114$ GeV,
ALEPH 13%
DLO 21%
ADLO 39%

DLO Mass Limit
Observed: 114.2 GeV
Median Expected: 113.8 GeV

LEP-wide Higgs searches
Background-Efficiency Curve

ADLO \( m_H = 115.0 \text{ GeV} \)

- Data: 217
- Background: 193.4
- Signal: 12.0

LEP-wide Higgs searches
SM Results from All Channels

3.2σ 4-Jet Excess in ADLO Data (1 − CL_b = 7 ⋅ 10^{-4})

LEP-wide Higgs searches
4-Jet Results from All Experiments

3.8σ 4-Jet Excess in ALEPH Data ($1 - \text{CL}_b = 7 \cdot 10^{-5}$)
2.0σ 4-Jet Excess in DLO Data ($1 - \text{CL}_b = 2 \cdot 10^{-2}$)

LEP-wide Higgs searches
Consistency Checks (Channels)

For \( m_H = 114 \text{ GeV} \),
- 4-Jet 18%
- LNT 15%
- ADLO 39%

LNT Mass Limit
- Observed: 113.3 GeV
- Median Expected: 113.1 GeV

LEP-wide Higgs searches
Combined SM Results

Observed Limit: \(112.3\) GeV
Median Expected Limit: \(114.5\) GeV

LEP-wide Higgs searches
Extended LEP Running

Improvement on Exclusion in Absence of a Higgs Signal

Expected CLs

Additional Luminosity @ 206.6 GeV (pb$^{-1}$)

(Luminosity On-Tape)

LEP-wide Higgs searches
Case 1: Accumulating Background-Only:

![Graph showing expected 1-CLb for different additional luminosity at 206.6 GeV (pb⁻¹) with markers for MH=116, 115, 114, 113 and lines indicating 3σ, 4σ, 5σ confidence levels.]

Case 2: Accumulating Background+Signal:

![Graph showing expected 1-CLb for different additional luminosity at 206.6 GeV (pb⁻¹) with markers for MH=116, 115, 114, 113 and lines indicating 3σ, 4σ, 5σ confidence levels.]

LEP-wide Higgs searches
Extended LEP Running

Road to Discovery

After Collecting 70 pb⁻¹ @ 206.6 GeV:

(Luminosity On-Tape)

LEP-wide Higgs searches
Summary of Extrapolation Results

With 75 pb\(^{-1}\) @ 206.6 GeV additional luminosity on-tape per experiment relative to the Aug 28th inputs, given what has currently been measured in the data, LEP can either:

a) 95% CL exclude up to 114 GeV, or

b) Increase the LEP-wide excess to a 3\(\sigma\) observation at 115 GeV (3.3\(\sigma\) at 114 GeV).

If after 70 pb\(^{-1}\) @ 206.6 GeV, LEP switches to 208.2 GeV running, above 100 pb\(^{-1}\) @ 208.2 GeV per experiment, LEP will have:

a) 3\(\sigma\) observation for 116 GeV, or

b) 4\(\sigma\) for 115 GeV, or

c) On road to discovery for 114 GeV.
## Summary of Standard Model Results

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Expected (GeV)</th>
<th>Observed (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>112.5</td>
<td>109.1</td>
</tr>
<tr>
<td>DELPHI</td>
<td>110.9</td>
<td>110.5</td>
</tr>
<tr>
<td>L3</td>
<td>110.2</td>
<td>108.8</td>
</tr>
<tr>
<td>OPAL</td>
<td>111.7</td>
<td>109.5</td>
</tr>
<tr>
<td>Leptons</td>
<td>108.8</td>
<td>109.9(*)</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>110.7</td>
<td>112.1</td>
</tr>
<tr>
<td>Taus</td>
<td>104.2</td>
<td>105.4</td>
</tr>
<tr>
<td>4 Jets</td>
<td>113.5</td>
<td>109.0</td>
</tr>
<tr>
<td>LEP</td>
<td>114.5</td>
<td>112.3</td>
</tr>
</tbody>
</table>

(*) Small unexcluded region below 100.7 GeV

All Results are Preliminary

LEP-wide Higgs searches
**Maximal Stop Mixing**

Mass Limits (GeV)

\[ M_h > 89.5 \quad 93.8 \]
\[ M_A > 90.2 \quad 94.1 \]

**\( \tan \beta \) Exclusion**

\[ 0.53 - 2.25 \quad 0.48 - 2.48 \]

**LEP-wide Higgs searches**
Charged Higgs Search Results

Observed (Median Expected) Limits (GeV) for $\text{Br}(H^\pm \rightarrow \tau \nu_\tau)$

<table>
<thead>
<tr>
<th>$\text{Br}=0.0$</th>
<th>$\text{Br}=1.0$</th>
<th>any $\text{Br}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>80.5 (79.8)</td>
<td>89.2 (90.9)</td>
<td>78.7 (78.5)</td>
</tr>
</tbody>
</table>

LEP-wide Higgs searches
Fermiophobic Higgs Search Results

ADLO Combined
5 September Update
Excluded Region

Photonic Higgs Search

Upper Limit on $B(h^0 \to \gamma\gamma)$

Observed Limit: 107.7 GeV
Median Expected Limit: 105.8 GeV

LEP-wide Higgs searches
Invisible Higgs decays Search Results

Observed Limit: 113.7 GeV
Median Expected Limit: 112.8 GeV

LEP-wide Higgs searches
**Recommandation**

Continue running LEP for 75 pb\(^{-1}\) @ 206.6 GeV additional luminosity on-tape per experiment relative to the Aug 28th inputs. With this data, LEP can either:

a) 95% CL exclude up to 114 GeV, or

b) Increase the LEP-wide excess to a 3\(\sigma\) observation at 115 GeV (3.3\(\sigma\) at 114 GeV).

The search results should be re-evaluated at this time.

**We all hope that what we see is the Higgs on the horizon.**