Search for a Higgs Boson Decaying into Two Photons in $\text{e}^+\text{e}^-$ Interactions at Centre-of-Mass Energy up to 202 GeV

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Outline

- Introduction
- Search for $h \to \gamma\gamma$ with the L3 detector
- Search situation at LEP and combined results
- Summary
Introduction

- SM of EW interactions has been tested successfully at LEP.
- The Higgs sector has so far not been observed.
- We are therefore free to extend it beyond the SM and search for more exotic processes.

- In this analysis: $e^+e^- \rightarrow hZ \rightarrow 2$ photons + jet or lepton pair, or missing energy.

- Data collected with the L3 detector in:
  - 1998 $\sqrt{s} = 189$ GeV $\approx 176$ pb$^{-1}$ (Published)
  - 1999 $\sqrt{s} = 192 - 202$ GeV $\approx 240$ pb$^{-1}$ (Preliminary)
  - 2000 up to $\sqrt{s} = 209$ GeV $\approx 125$ pb$^{-1}$ (and still coming in)
Higgs Decay into Photons

- The decay to $\gamma\gamma$ proceeds via charged particle loops, i.e. fermions and W bosons;

- There are models that significantly enhance the $H \rightarrow \gamma\gamma$ Branching Ratio:
  
  Purely fermiophobic models that suppress $\text{BR}(H \rightarrow f\bar{f})$, at least at tree level.
  Effective Lagrangians that include (anomalous) $H_{\gamma\gamma}$ and $HZ\gamma$ couplings.

$\text{BR}(H \rightarrow \gamma\gamma) \approx 0.1\% \rightarrow 0.2\%$
for $80 \text{ GeV} \leq m_H \leq 130 \text{ GeV}$
Fermiophobic Higgs

2HDM: A fermiophobic scenario

Type I model, can tune parameters to switch off fermion couplings.

\[ g_{hff} \propto \cos \alpha / \cos \beta \]

\[ \Rightarrow \] Setting \( \alpha = \frac{\pi}{2} \),

\( h \) becomes fermiophobic.
Higgs-Strahlung: the dominant mechanism

\[ E_{CM} = 199.6 \text{ GeV} \]
The L3 detector is optimized for measuring with high precision electrons, photons and muons:

- Electromagnetic calorimeter: BGO crystals.
- Large magnetic volume housing the whole detector;
Search Strategy

- Preselection cuts to reduce the most copious background;

- Tighter cuts for each Z decay mode: $Z \rightarrow q\bar{q}, \nu\bar{\nu}, l^+l^-$;

- Definition of a variable with high discriminant power between signal and background (e.g. Higgs reconstructed mass);

- Evaluation of a Confidence Level for every mass hypothesis; calculate a mass limit for the Higgs.
Topologies: $h^0Z \rightarrow \gamma\gamma jj$

Gives the highest sensitivity to this analysis: $BR(Z \rightarrow \text{hadrons}) \cong 70\%$

- **Signal:** two isolated photons and two jets

- **Backgrounds:**
  - $e^+e^- \rightarrow Z/\gamma^* \rightarrow q\bar{q}(\gamma\gamma)$ double ISR photons;
  - $e^+e^- \rightarrow WW, ZZ$
  - $e^+e^- \rightarrow Zee$

- **Strategy:** selection of high multiplicity hadronic events, large visible energy;
  - two isolated energetic photons, $Z \rightarrow jj$.
  - final variable: the di-photon invariant mass.

24 events data, 28.7 events MC, 45\% eff for $m_h = 95$ GeV
Topologies: $h^0Z \rightarrow \gamma\gamma\nu\nu$

$BR(Z \rightarrow \nu\nu) \approx 20\%$

- **Signal:** two well separated photons and missing energy.
- **Backgrounds:**

<table>
<thead>
<tr>
<th>2 fermion processes</th>
<th>$e^+e^- \rightarrow \nu\bar{\nu}(\gamma)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e^+e^- \rightarrow e^+e^-(\gamma)$</td>
</tr>
<tr>
<td></td>
<td>$e^+e^- \rightarrow \mu^+\mu^-(\gamma)$</td>
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<tr>
<td></td>
<td>$e^+e^- \rightarrow \tau^+\tau^-(\gamma)$</td>
</tr>
</tbody>
</table>

| 4 fermion processes  | $WW \rightarrow l\nu l\nu, ZZ \rightarrow l\nu l\nu$ |

- **Strategy:** selection of low multiplicity events and missing energy; two energetic acoplanar photons, $M_{\text{miss}} \approx M_Z$
  - final variable: the di-photon invariant mass.

3 events data, 4.3 events MC, 37% eff for $m_h = 95$ GeV
Topologies: $h^0 Z \rightarrow \gamma \gamma ll$

$BR(Z \rightarrow ll) \approx 10\%$

- **Signal:** two isolated photons + two isolated leptons:

- **Backgrounds:**
  - 2 fermion processes: $e^+ e^- \rightarrow e^+ e^- (\gamma)$
  - $e^+ e^- \rightarrow \mu^+ \mu^- (\gamma)$
  - $e^+ e^- \rightarrow \tau^+ \tau^- (\gamma)$

- **Strategy:** selection of low multiplicity events;
  - two energetic photons and two leptons, $M_{ll} \approx M_Z$.
  - final variable: the di-photon invariant mass.

5 events data, 2.5 events MC, 29% eff for $m_h = 95$ GeV
Some candidates

Typical candidate: $e^+ e^- \rightarrow \gamma\gamma qq$

$E_{\gamma_1} = 47.9$ GeV

$M_{\gamma\gamma} = 90$ GeV

$M_{jj} = 96.5$ GeV

$E_{\gamma_2} = 41$ GeV

Typical candidate: $e^+ e^- \rightarrow \gamma\gamma \nu\nu$

$E_{\gamma_1} = 54.8$ GeV

$E_{\gamma_2} = 31$ GeV
Invariant Mass Spectrum

- **Observed data**: 32 events
- **SM background**: 35.5 events
- **Potential signal**: 36.7 events

\[ m_h = 95 \text{ GeV}, \text{BR} = 1 \]
Exclusion Plot

Derivation of the exclusion plot in the assumption of SM Higgs production:

\[ M_h^{\text{obs}} > 99.2 \text{ GeV} \]
### Other Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>Search channel</th>
<th>Data</th>
<th>MC</th>
<th>Limit observed</th>
<th>Limit Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>192-209</td>
<td>qq, $\nu\nu$, $l\bar{l}$</td>
<td>8</td>
<td>8</td>
<td>102.7</td>
<td>102.0</td>
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<tr>
<td>OPAL</td>
<td>91-209</td>
<td>qq, $\nu\nu$, $l\bar{l}$</td>
<td>230</td>
<td>227.2</td>
<td>103.1</td>
<td>103.5</td>
</tr>
<tr>
<td>L3</td>
<td>189-202</td>
<td>qq, $\nu\nu$, $l\bar{l}$</td>
<td>32</td>
<td>35.5</td>
<td>99.2 (Bay. CL)</td>
<td></td>
</tr>
<tr>
<td>DELPHI</td>
<td>189-202</td>
<td>qq, $\nu\nu$</td>
<td>68</td>
<td>65.3</td>
<td>96.1</td>
<td>97.5</td>
</tr>
</tbody>
</table>

Results are preliminary!
Mass Plot

$\gamma\gamma$ mass spectrum from ADLO combination

- Observed events: 338
- Expected events: 335.5
Signal significance w.r.t. bkgd.

Signal comparison : SM, but fermion couplings = 0

Signal - like result would be less than $5\sigma = 5.7 \cdot 10^{-7}$
LEP Combination

95% CL exclusion for $\text{BR}(h \to \gamma\gamma)$

$$M_{h}^{\text{obs}} > 106.4 \text{ GeV}$$

$$M_{h}^{\text{exp}} > 105.6 \text{ GeV}$$

Photonic Higgs Search

ADLO Combined

Excluded Region

$+2 \text{ sigma expected}$

$-2 \text{ sigma expected}$

Limit $= 106.4 \text{ GeV}$

Upper Limit on $\text{BR}(h^0 \to \gamma\gamma)$
No evidence of a neutral Higgs from the SM or a fermiophobic Higgs in the data collected at LEP at $\sqrt{s} = 189$ GeV; no evidence of a Higgs in $\sqrt{s} = 192 - 202$ GeV data either.

A preliminary mass limit on a fermiophobic Higgs is set to 106.4 GeV at 95% CL.