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Improved mass limit for the Standard Model Higgs boson using (most of) the ALEPH 1994 data

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Abstract

The reaction $e^+e^- \rightarrow HZ^*$ is used to search for the standard model Higgs boson, in a data sample corresponding to about 3,552,000 hadronic Z decays collected by the ALEPH experiment at LEP. Two candidate events were found in the $H\mu^+\mu^-$ channel compatible with the expected background from the electroweak process $e^+e^- \rightarrow l^+l^-q\bar{q}$. When interpreted as coming from the signal, these candidates correspond to Higgs boson masses of 51.5 ± 0.5 GeV/c^2 and 49.7 ± 0.5 GeV/c^2 for which more than 25 events would be expected to be selected . This results in an improved 95% C.L. lower limit on the Higgs boson mass of 62.9 GeV/c^2.

Contribution to the La Thuile and Moriond Conferences (Winter 1995).

1 Introduction

Searches for acoplanar jets accompanied by missing energy, relevant for the $H\nu\bar{\nu}$ channel, and for energetic lepton pairs in hadronic events, relevant for the Hl^+l^- channel, were carried out using the data collected by ALEPH between 1989 and 1992, corresponding to 1,233,000 hadronic Z decays. No events were found and a 95% C.L. lower limit on the Standard Model Higgs boson mass was set at 58.4 GeV/c^2 [1].

In Ref. 1, the location of the most critical cuts was determined following an optimization procedure [2] which consists in minimizing $\overline{\mathrm{N}}_{95}$, the average value of the 95% C.L. upper limit on the number of signal events produced obtained with a large number of Gedanken experiments, in the absence of any signal contribution:

$$\overline{\mathrm{N}}_{95}(x) = \frac{e^{-b(x)}}{\varepsilon(x)} \left\{ 3.00 + 4.74 b(x) + 6.30 \frac{b^2(x)}{2!} + 7.75 \frac{b^3(x)}{3!} + \ldots \right\}, \tag{1}$$

where x is the location of the cut, $\varepsilon(x)$ is the acceptance of the search for this cut determined from large signal Monte Carlo samples, and $b(x)$ is the number of background events expected when the cut is applied. This last number is determined from the background Monte Carlo distribution of the variable x obtained when all other cuts have been applied, smoothed and extrapolated so that an analytical representation of $b(x)$ is available.

Since this average upper limit depends on the absolute background level, the cuts are expected to change — namely to be tightened — as more luminosity becomes available, in a way such that the number of background events expected remains approximately constant (this would not be true if the selection efficiency varied rapidly with the cut location). This was in particular the case when the two topological searches were updated [3,4,5] with the data collected by ALEPH in 1993, corresponding to 704,000 additional hadronic Z decays. The same automatic procedure was applied again with the presently available 1994 ALEPH data — about 90% of the whole 1994 sample — corresponding to 1,615,000 hadronic Z decays, and the result is presented in this note.

2 Update of the search in the $H\nu\bar{\nu}$ channel

The update of the acoplanar jet search only consists in optimizing the cuts on the three variables $\mathrm{S}, \mathrm{A}, \eta$ with Eq. (1), as presented in Ref. 3 and accounting for the integrated luminosity collected by ALEPH in 1994:

- the sum S of the three jet-jet angles obtained when the event is forced to form three jets, designed to reject $e^+e^- \to b\bar{b}g$ events with two semi-leptonic decays;

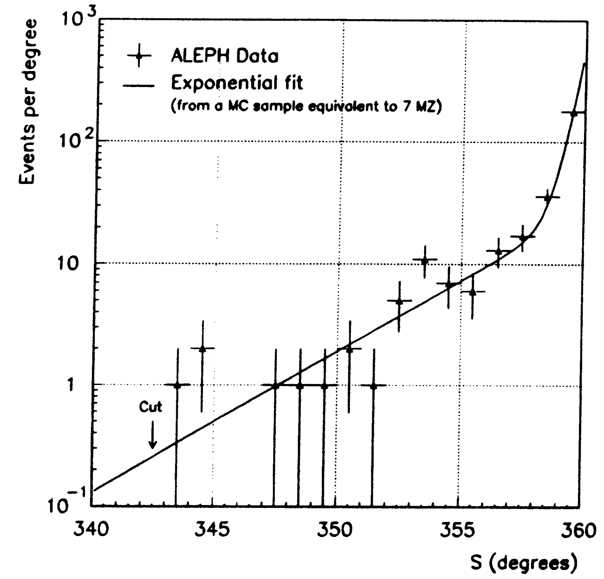


Figure 1: Distribution of S in the ALEPH data. Also indicated by a full line is the result of the (multiple) exponential fit of $db(S)/dS$, as obtained from Monte Carlo, with an absolute normalization. The 1994 cut location is indicated by an arrow.

- the angle A of the smallest cone around the total missing momentum direction containing an energy larger than 1 GeV, designed against $e^+e^- \to b\bar{b}g$ events where the energy of one jet is essentially carried away by a neutrino coming from a semi-leptonic decay, thus rendering uncertain the determination of this jet direction;

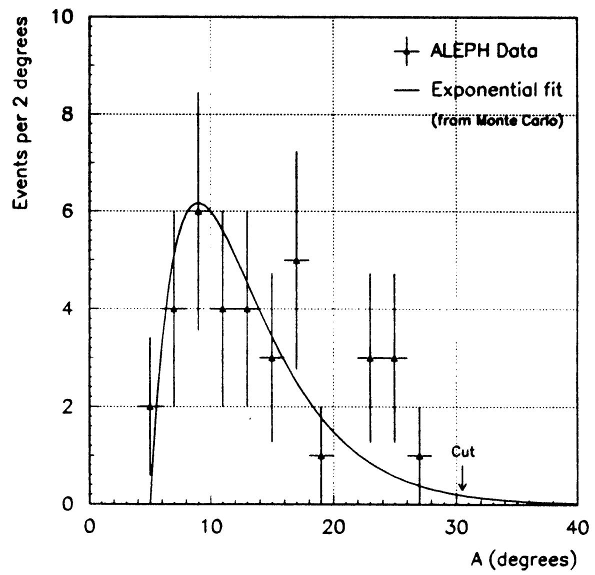


Figure 2: Distribution of A in the ALEPH data. Also indicated by a full line is the result of the (multiple) exponential fit of $db(A)/dA$, as obtained from Monte Carlo, with an absolute normalization. The 1994 cut location is indicated by an arrow.

- the acoplanarity angle η, against $e^+e^- \to q\bar{q}g$ events accompanied by a hard initial state radiation, possibly with semi-leptonic decays too.

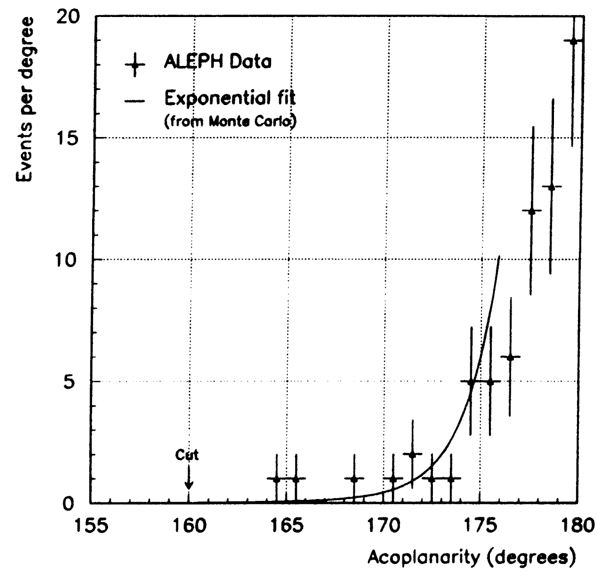


Figure 3: Distribution of the acoplanarity angle η in the ALEPH data. Also indicated by a full line is the result of the (multiple) exponential fit of $\mathrm{d}b(\eta)/\mathrm{d}\eta$, as obtained from Monte Carlo, with an absolute normalization. The 1994 cut location is indicated by an arrow.

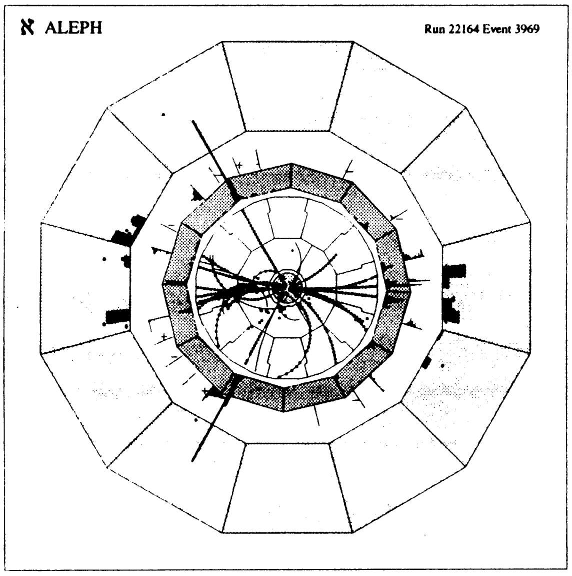
Figures 1, 2 and 3 show the distributions of these three variables when the 1994 data are included, together with the functions $\mathrm{d}b(x)/\mathrm{d}x$ ($x = \mathrm{S}, \mathrm{A}, \eta$) as obtained by fitting to decreasing exponential shapes the relevant background Monte Carlo distributions (all cuts being applied but the cut on x). It is worth noticing that the same expressions have been kept for the functions $b(x)$ since 1992. The overall normalizations are directly taken from the Monte Carlo and scale with the total integrated luminosity.

In 1992, the cuts were set respectively to $\mathrm{S} < 345°$, $\mathrm{A} > 25.8°$ and $\eta < 164°$ [1]. They became $\mathrm{S} < 343.8°$, $\mathrm{A} > 28.0°$ and $\eta < 162°$ with the inclusion of the 1993 data [3], rejecting this way two events that would have satisfied the previous year cuts (1.6 background events were expected at this point) and leading to a selection efficiency reduction of $\sim 4\%$. When the 1994 data are included, these cuts move to $\mathrm{S} < 342.5°$, $\mathrm{A} > 30.5°$ and $\eta < 160°$ which reduces the selection efficiency by another 5%. About 1.9 background events were expected to satisfy the 1993 cuts, and one event was found with $\mathrm{S} = 343.3°$, subsequently rejected by the optimized 1994 cuts.

The numbers of signal events expected to be selected by this search are given in Table 2 for different Higgs boson mass hypotheses. Since no events were found in the data, this results in a 95% C.L. lower limit on the Higgs boson mass of 61.5 GeV/c^2 (see Fig. 6) when only the $\mathrm{H}\nu\bar{\nu}$ channel is used.

3 Update of the search in the Hl^+l^- channel

The main background to the Hl^+l^- topology comes from the electroweak four-fermion process $e^+e^- \rightarrow l^+l^-q\bar{q}$. It is shown in Ref. 6 that 27.2 ± 1.7 such events were expected from this source in the ALEPH 89-93 data, of which 3.3 ± 1.4 events have a recoil mass above 40 GeV/c^2. A total of 29 events was observed, of which 3 events have a mass above 40 GeV/c^2, in agreement with the expectation. When the 1994 data are included, 55 events are observed (26 in the He^+e^- channel and 29 in the $H\mu^+\mu^-$ channel) while 51.8 ± 3.2 were expected. Among them, 11 events (7 events in the He^+e^- channel and 4 events in the $H\mu^+\mu^-$ channel) have a recoil mass above 40 GeV/c^2, while 6.3 ± 2.7 were expected. Two such events are shown in Fig. 4 and the mass distribution of the whole sample is shown in Fig. 5



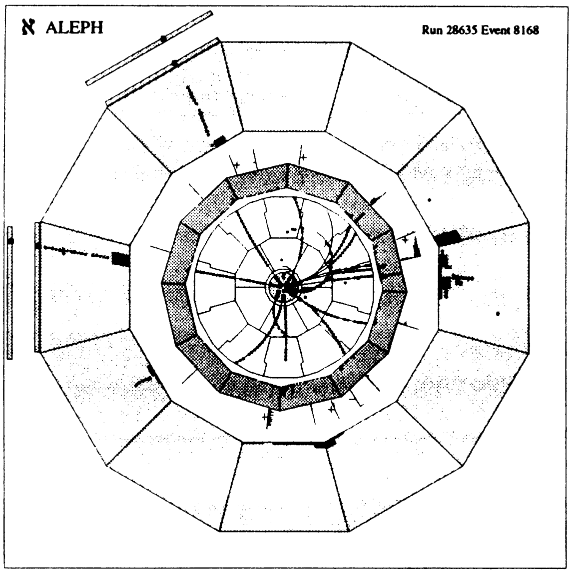


Figure 4: View of the ALEPH detector for a He^+e^- candidate with a recoil mass of 66.0 GeV/c^2 and for a $H\mu^+\mu^-$ candidate with a recoil mass of 49.7 GeV/c^2.

Given the large number of background events expected, it was noticed in 1993 that the combination of this channel with the acoplanar jets search was bound to eventually degrade the expected 95% C.L. limit obtained from the $H\nu\bar{\nu}$ channel alone. It was therefore decided [4], instead of simply removing the Hl^+l^- analysis from the combination, to strengthen its selectivity by adding a requirement on the b-quark content of the events. The cut on a new variable P_b, defined as the combined probability for the charged particles of the event to come from the main interaction point [7], was then optimized to $P_b < 0.20$ (a high b-quark content turns into a small value of the probability P_b) using the usual automatic procedure. Only one event with mass 51.5 ± 0.5 GeV/c^2 and $P_b = 0.047$ remained in the 1993 data sample.

The update of the search in 1994 consists in optimizing the cut on the b-tagging variable, which consequently moves to $P_b < 0.08$, corresponding to a selection efficiency reduction of 8.5% with respect to the 1993 analysis, and to a rejection of non-b background

Table 1: Recoil mass and b-quark content of the 11 Hl^+l^- candidates.

Event type	Recoil mass	P_b
$\mu^+\mu^-q\bar{q}$	49.7 GeV/c^2	0.004
$\mu^+\mu^-q\bar{q}$	51.5 GeV/c^2	0.047
$\mu^+\mu^-q\bar{q}$	61.8 GeV/c^2	0.112
$e^+e^-q\bar{q}$	55.2 GeV/c^2	0.159
$\mu^+\mu^-q\bar{q}$	44.2 GeV/c^2	0.217
$e^+e^-q\bar{q}$	66.0 GeV/c^2	0.354
$e^+e^-q\bar{q}$	59.8 GeV/c^2	0.378
$e^+e^-q\bar{q}$	53.2 GeV/c^2	0.378
$e^+e^-q\bar{q}$	43.2 GeV/c^2	0.453
$e^+e^-q\bar{q}$	62.9 GeV/c^2	0.644
$e^+e^-q\bar{q}$	53.9 GeV/c^2	0.883

events of 85% instead of 71% in 1993. As mentioned in Section 1, this change is necessary to keep the number of non-b background events expected at the same level (0.8 events expected) with the 1993 and with the 1994 integrated luminosities.

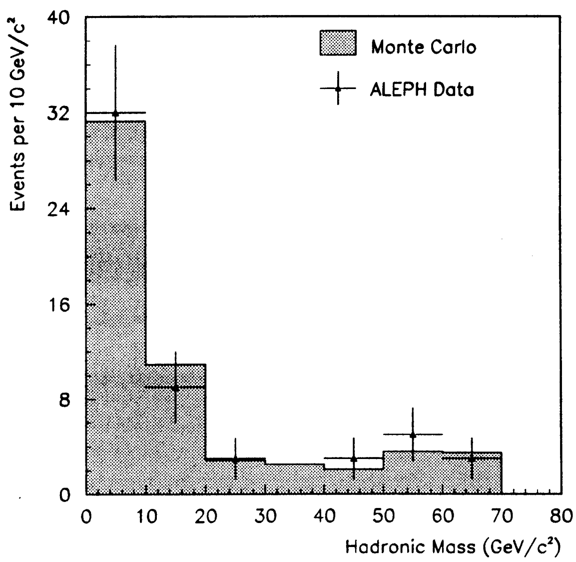


Figure 5: Distribution of the hadronic mass for $e^+e^- \rightarrow l^+l^-q\bar{q}$ Monte Carlo events, with an absolute normalization (shaded histogram), and for the ALEPH data (triangles with error bars). The mass is computed as recoiling against the lepton pair above 30 GeV/c^2, and is simply the measured mass of the hadronic system below 30 GeV/c^2.

The resulting numbers of signal events expected to be selected by this search are given in Table 2. The values of P_b for the eleven events with masses above 40 GeV/c^2 are listed in Table 1. It can be seen that only the two first events of this Table, with masses 49.7 and 51.5 GeV/c^2, are retained, while 1.4 ± 0.4 background events were expected.

4 Combined result of the search

The numbers of events expected to be selected by each of the two updated topological searches are shown in Table 2 for different Higgs boson masses.

Table 2: Number of signal events expected to be selected by the acoplanar jet search and by the energetic lepton pair search, for different Higgs boson mass hypotheses.

m_{H}	Acoplanar Jets	Lepton pairs	Total
50 GeV/c^2	20.50	5.59	26.09
55 GeV/c^2	9.95	2.82	12.77
60 GeV/c^2	4.15	1.26	5.41
65 GeV/c^2	1.40	0.46	1.86

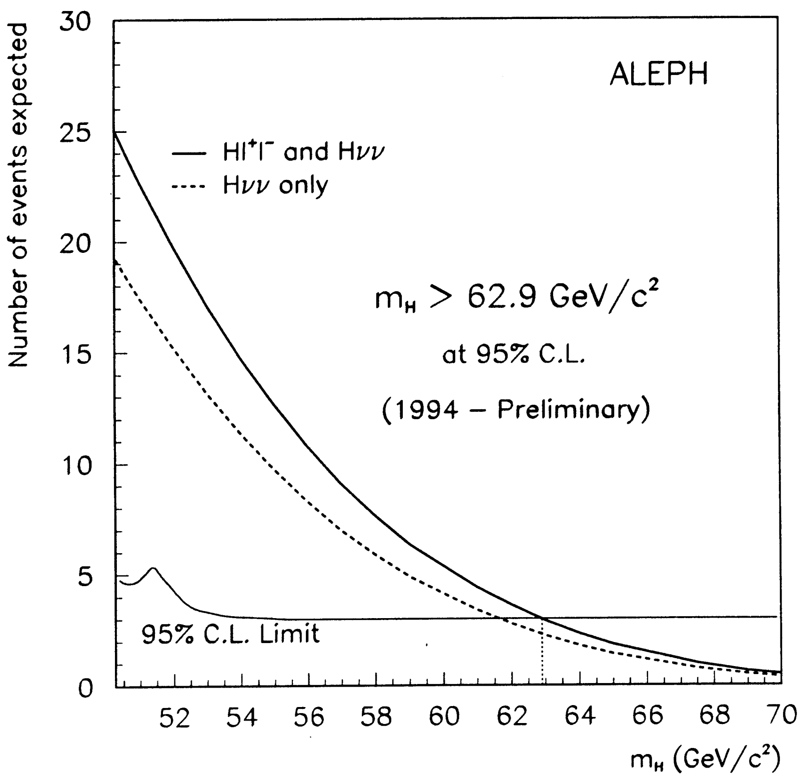


Figure 6: Number of signal events expected to be selected from the acoplanar jet search alone (dashed line) and from the combination with the leptonic channel (full line) as a function of the Higgs boson mass. Also indicated is the 95% C.L. limit on the number of events. The vertical dotted line indicates the 95% C.L. lower limit on the Higgs boson mass.

The total number of events expected, obtained by adding the two contributions and conservatively reduced by a systematic uncertainty of 2% as described in Ref. 1, is shown in Fig. 6 as a function of the Higgs boson mass. Only two events were observed in the

Hl^+l^- channel in a region where more than 25 signal events are expected. This results in an improved 95% C.L. lower limit on the Higgs boson mass of 62.9 GeV/c^2. Since about 200,000 hadronic Z decays from 1994 were not available for the analysis at the time of writing, this is to be taken as a preliminary result.

References

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