PROCEEDINGS OF SCIENCE

Search for invisibly decaying Higgs bosons

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In the last running years, the four Large Electron Positron collider (LEP) experiments collected a combined luminosity of almost 2.5 fb^{-1} at $\sqrt{s} \geq 189$ GeV. This data was searched for invisibly decaying Higgs bosons produced in association with a Z boson. The channels with electrons, muons and hadrons were investigated. None of the experiments sees hints for the production of such an invisible Higgs boson, thus each of them sets an individual lower limit on the mass at 95% confidence level. The highest of the four limits is set at 114.1 GeV. The combination of the final results has yet to be done and will increase the reach of the search.

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1. Theoretical motivation

In the Standard Model of electroweak interactions (SM), the masses of fermions and bosons are generated through coupling to the Higgs boson. Direct searches for the SM Higgs boson at LEP did not show evidence for this particle [1]. These searches assume however the Standard Model branching ratios and thus assume that the dominant Higgs decays (in the sensitive mass range) are into b-quarks.

A Higgs boson which decays dominantly into invisible particles would have escaped these direct searches. Such Higgs bosons appear in several proposed extensions of the Standard Model, e.g. models where the Higgs can decay into neutralinos [2, 3] or into fourth generation neutrinos [4] (see [5] for a more extensive list of models). It is thus worth searching for invisibly decaying Higgs bosons.

2. Experimental signatures

The search for invisibly decaying Higgs bosons assumes that they are produced in the same way as the Standard Model Higgs boson, i.e. the dominant production mechanism is the one shown in Fig. 1. In the absence of strong evidence for a signal, a lower limit on the invisible Higgs mass can be set assuming the Standard Model production cross section and a branching ratio Higgs $\rightarrow$ invisible of 100%.

The fact that the such a Higgs decays invisibly and the decay modes of the Z boson determine the experimental signatures, see Fig. 1. Events where the Z boson decays into hadrons, have jets, missing energy and momentum; Z decays into charged leptons lead to events with missing energy and momentum accompanied by the two leptons. The case where the Z decays into two neutrinos is not visible in the detector.

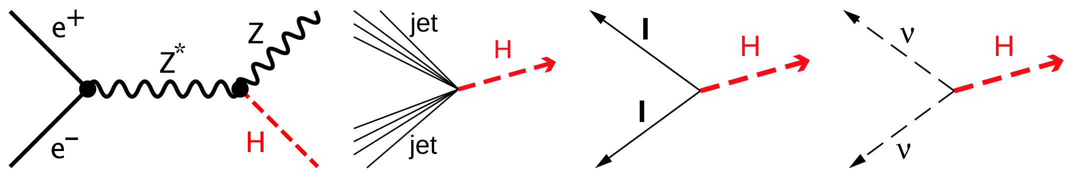

Figure 1: Feynman diagram of the Higgs strahlung process (leftmost graph) and event topologies for the three different Z decay modes into hadrons, charged leptons and neutrinos (graphs 2-4).

3. Analysis strategies

The analyses require at some stage that there are two acoplanar jets or leptons in the event, missing momentum pointing into the central region of the detector and that the visible mass is compatible with the Z mass. The missing (recoil) mass of the event is taken as the Higgs candidate mass.

A search analysis for a invisibly decaying Higgs boson typically starts with a preselection using simple variables – such as the visible energy in the event – to remove backgrounds which can be suppressed very easily while keeping the effi ciency for the signal process close to 100%. After this preselection (i.e. at very low level of the signal to background ratio), the agreement between Monte Carlo and the data is verifi ed. More cuts are now applied to further suppress backgrounds while keeping the signal effi ciency at a level of 20-50%. At this point, all experiments choose to construct a multivariate discriminant function in order to rank events according to their 'signalness'. ALEPH uses a neural network, DELPHI an iterative linear discriminant and a likelihood combination of variables is used in L3 and OPAL. Fig. 2 shows an example of a likelihood combination variable of the L3 experiment. Such a discriminant is either used to cut on (to further improve the sensitivity of the search) or to calculate confi dence levels of the presence or absence of an invisibly decaying Higgs boson [6, 7]. In other cases, the missing mass distribution or the number of selected events are used for the confi dence level calculation.

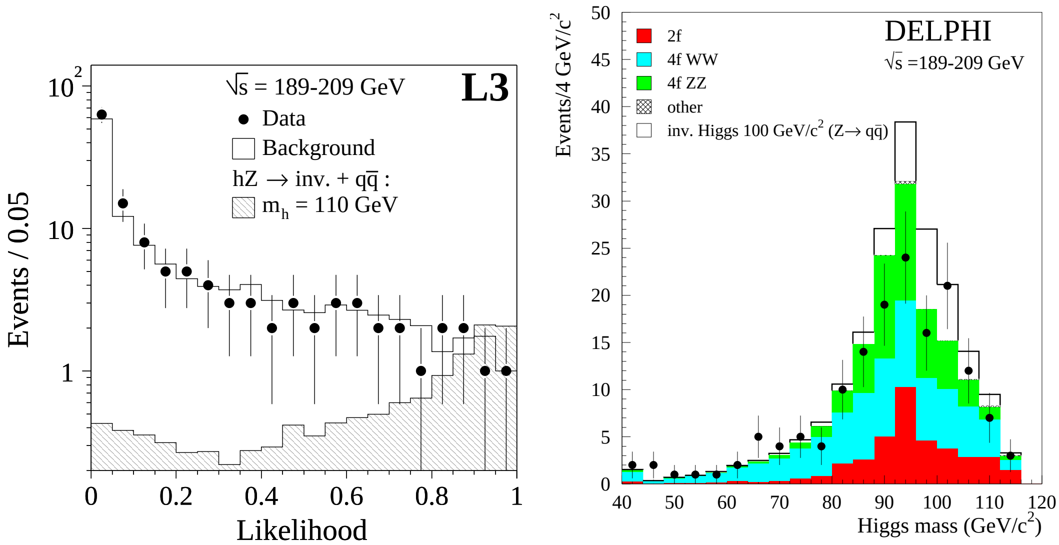

Figure 2: Final discriminant (likelihood combination) for the high mass hadronic channel selection of the L3 analysis (left) and mass distribution after final selection for the DELPHI high mass hadronic analysis (right).

4. Results

No evidence for the production of an invisibly decaying Higgs in association with a Z boson has been observed by any of the LEP experiments, thus lower limits on its mass have been set. Table 1 shows the observed lower mass limits (at 95% confi dence level) as well as those one would expect from only background in present in the data. The highest observed lower limit is set at 114.1 GeV.

The last combination of all LEP experiments' results yielded an observed lower limit of 114.4 GeV [11]. The upper limit on the production cross section as function of Higgs mass is shown in Fig 3. Note however that this combination includes results which were not fi nal.

5. Outlook

Once all four LEP experiments have fi nalized their results a combination of these will be

Experiment	Limit [GeV]		Reference
	observed	expected	
ALEPH	114.1	112.6	[8]
DELPHI	112.1	110.5	[9]
L3	112.3	111.6	[5]
OPAL	107.0	107.4	[10]

Table 1: Lower limits on the invisibly decaying Higgs mass (at 95% confidence level) observed in data and expected from background for the four LEP experiments. All results except the OPAL are final.

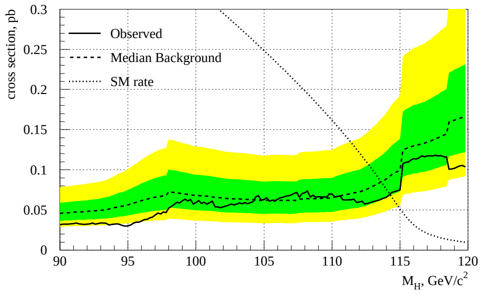

Figure 3: Upper limit on production cross section of invisibly decaying Higgs bosons (in association with a Z boson) for a combination of partially preliminary results in 2001 [11]. The lower limit on the Higgs mass is set at 114.4 GeV, i.e. where the Standard Model cross section is equal to the upper limit on the cross section.

performed and thus the sensitivity of the search extended by a few GeV. At hadron colliders such as the LHC, searches for invisibly decaying Higgs boson are diffi cult to perform, a (linear) e^+e^- collider is much more adequate to continue these searches.

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