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Higgs Candidates in e^+e^- Interactions at $\sqrt{s} = 206.6$ GeV

The L3 Collaboration

Abstract

In a search for the Standard Model Higgs boson, carried out on 212.5 pb^{-1} of data collected by the L3 detector at the highest LEP centre-of-mass energies, including 116.5 pb^{-1} above $\sqrt{s} = 206$ GeV, an excess of candidates for the process $e^+e^- \rightarrow Z^* \rightarrow HZ$ is found for Higgs masses near 114.5 GeV. We present an analysis of our data and the characteristics of our strongest candidates.

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1 Introduction

In the Standard Model of electroweak interactions [1], a single Higgs doublet [2] gives rise to a neutral scalar, the Higgs boson, with a mass, m_{H}, that is a free parameter of the theory. Searches in $\mathrm{e^+e^-}$ collisions for the Standard Model Higgs boson have been reported up to centre-of-mass energies of 202 GeV by L3 [3] and other experiments [4]. No evidence of a signal has been found.

Analyses of preliminary data from the four LEP experiments [5] have been combined, resulting in an indication of a Higgs signal at the highest accessible Higgs masses. In this letter we report the most significant candidates observed in the data sample collected by L3 as well as the final results of the search for the Higgs boson[1)]. The details of the analysis will be presented in a forthcoming publication.

The dominant Higgs production mode,

$$\mathrm{e^+e^-} \rightarrow \mathrm{Z^*} \rightarrow \mathrm{HZ}\ ,$$

as well as the smaller production processes through $\mathrm{W^+W^-}$ and ZZ fusion, are considered. All significant signal decay modes are investigated. Four-fermion final states from W- and Z-pair production, as well as $\mathrm{e^+e^-} \rightarrow \mathrm{q\bar{q}}\,(\gamma)$, make up the largest sources of background.

2 Data and Monte Carlo Samples

The data were collected using the L3 detector [7] at LEP in the year 2000. The integrated luminosity is 212.5 $\mathrm{pb^{-1}}$, including 116.5 $\mathrm{pb^{-1}}$ at centre-of-mass energies above 206 GeV.

Monte Carlo samples were generated and simulated as described in Reference [3]. The number of simulated events for the most important background channels is at least 100 times the number of expected events, while the number of signal events is at least 300 times the number expected with our integrated luminosity.

3 Analysis

The search for the Standard Model Higgs boson at LEP is based on the study of four distinct event topologies representing approximately 92% of the HZ decay modes: $\mathrm{q\bar{q}q\bar{q}}$, $\mathrm{q\bar{q}}\nu\bar{\nu}$, $\mathrm{q\bar{q}}\ell^+\ell^-$ ($\ell = \mathrm{e}, \mu, \tau$) and $\tau^+\tau^-\mathrm{q\bar{q}}$. With the exception of $\mathrm{HZ} \rightarrow \tau^+\tau^-\mathrm{q\bar{q}}$, the analyses for each channel are optimised for $\mathrm{H} \rightarrow \mathrm{b\bar{b}}$, since this represents about 74% of the Higgs branching fraction in the mass range of interest.

The analyses for all the channels are performed in three stages. First, a high multiplicity hadronic event selection is applied, greatly reducing the large background from two-photon processes, while at the same time maintaining a high efficiency for the Higgs signal over a broad range of masses. In a second stage, two different methods are used for the results reported here: a cut based analysis, for $\mathrm{q\bar{q}q\bar{q}}$ topology and topologies with leptons, and a neural network based analysis, for the $\mathrm{q\bar{q}}\nu\bar{\nu}$ topology. All the analyses use topological and kinematical discriminating variables, which are not strongly dependent on the Higgs mass. The neural network analysis uses as an input variable the event b-tag.

1) After we submitted this letter, we learnt of a similar paper by the ALEPH collaboration [6]

The event b-tag variable is a combination of the b-tag for each hadronic jet. A neural network [3] is used to calculate the b-tag for each hadronic jet from a discriminant based on the three-dimensional decay lengths, information on leptons in the jet, and jet-shape variables.

Finally, a discriminating variable is built for each analysis. The final discriminant for the cut based analyses is built from a combination of a b-tag variable and a Higgs mass dependent variable [3]. For the neural network based analysis, the final discriminant is a combination of the neural network output with the reconstructed Higgs mass.

The distributions of the final discriminants are computed for the data, the expected background, and signals at each value of Higgs mass hypothesis considered. Figure 1 shows the final discriminant histograms for the $q\bar{q}q\bar{q}$ and $q\bar{q}\nu\bar{\nu}$ channels for a Higgs mass assumption of 115 GeV. The four jet analysis is divided into high and low purity samples [3]. The data are plotted along with the background expectation and the expectation from a Standard Model Higgs boson. Candidates at large values of the final discriminant have small background expectations and are therefore the most significant. Strong candidates are seen in the final discriminant plots.

4 Results

By combining all the search channels, we compute the confidence level [8, 9] for the data to be compatible with signal plus background or background only. Our data indicate the most likely mass of the Higgs candidates to be 114.5 GeV. For an assumed Higgs boson of this mass, the confidence level to be consistent with a background only hypothesis is calculated to be 0.09, equivalent to 1.7 standard deviations from the background expectation. The confidence level to be consistent with signal plus background is 0.62.

Figure 2a) shows the signal-to-background ratio for all channels combined assuming a Higgs mass of 114.5 GeV. After a cut on the final discriminant, Figure 2b) displays the number of events versus the signal efficiency. The excess of data is consistent with the signal expectation. The most significant $H\nu\bar{\nu}$ event is found where 0.16 background events and 0.38 signal events are expected. This event was recorded at $\sqrt{s} = 206.6$ GeV. This event, shown in Figure 3a), presents two nearly back-to-back jets with a large amount of missing energy and very little missing momentum, compatible with the production of the Higgs and the Z nearly at rest. The visible mass is 111 GeV. Assuming a Z boson recoiling against the Higgs, the fitted mass is 114.4 GeV with a resolution of 3 GeV. The event has a high b-tag value. One jet has a very clear secondary vertex 7 mm from the primary (Figure 3b), with a large visible mass. The main sources of background for this event are double radiative production of an off-shell Z and Z pair production.

We have verified that this event is well measured. For example, Figure 4 shows the measured energy distribution for two jet events produced on the Z peak data for calibration in the year 2000 as a function of $\cos\theta_{\mathrm{thrust}}$. The energy resolution is uniform over the detector. The location of our candidate is $\cos\theta_{\mathrm{thrust}} = 0.77$ where the measured resolution is 13%. We also compared the number of charged tracks and the number of calorimeter clusters in this event to those in two jet events going into the same region of the detector. The calorimetric clusters and charged track multiplicity are in agreement with the expectation of a heavy particle decaying to hadrons.

The most significant candidate in the $q\bar{q}q\bar{q}$ channel is shown in Figure 5. It is a four jet event with each of two dijets nearly back-to-back consistent with the Higgs and Z production near threshold. One dijet has a fitted mass of 92 GeV and the other of 114 GeV. Assuming a

Z recoiling against the Higgs, the fitted mass is 114.6 GeV. The mass resolution is 4 GeV. The event has a high b-tag value. The dominant background for this event is from $b\bar{b}$ production and QCD four jet production.

5 Summary

In data collected with the L3 detector at $\sqrt{s} = 206.6$ GeV, we have observed an excess of events above background which are compatible with a Standard Model Higgs boson of mass 114.5 GeV. High-weight events are seen in different decay channels – $q\bar{q}\nu\bar{\nu}$ and $q\bar{q}q\bar{q}$ – which are characteristic of Higgs production together with a Z boson. These data from L3, together with those of other LEP experiments [5] suggest the first observation of the Higgs boson.

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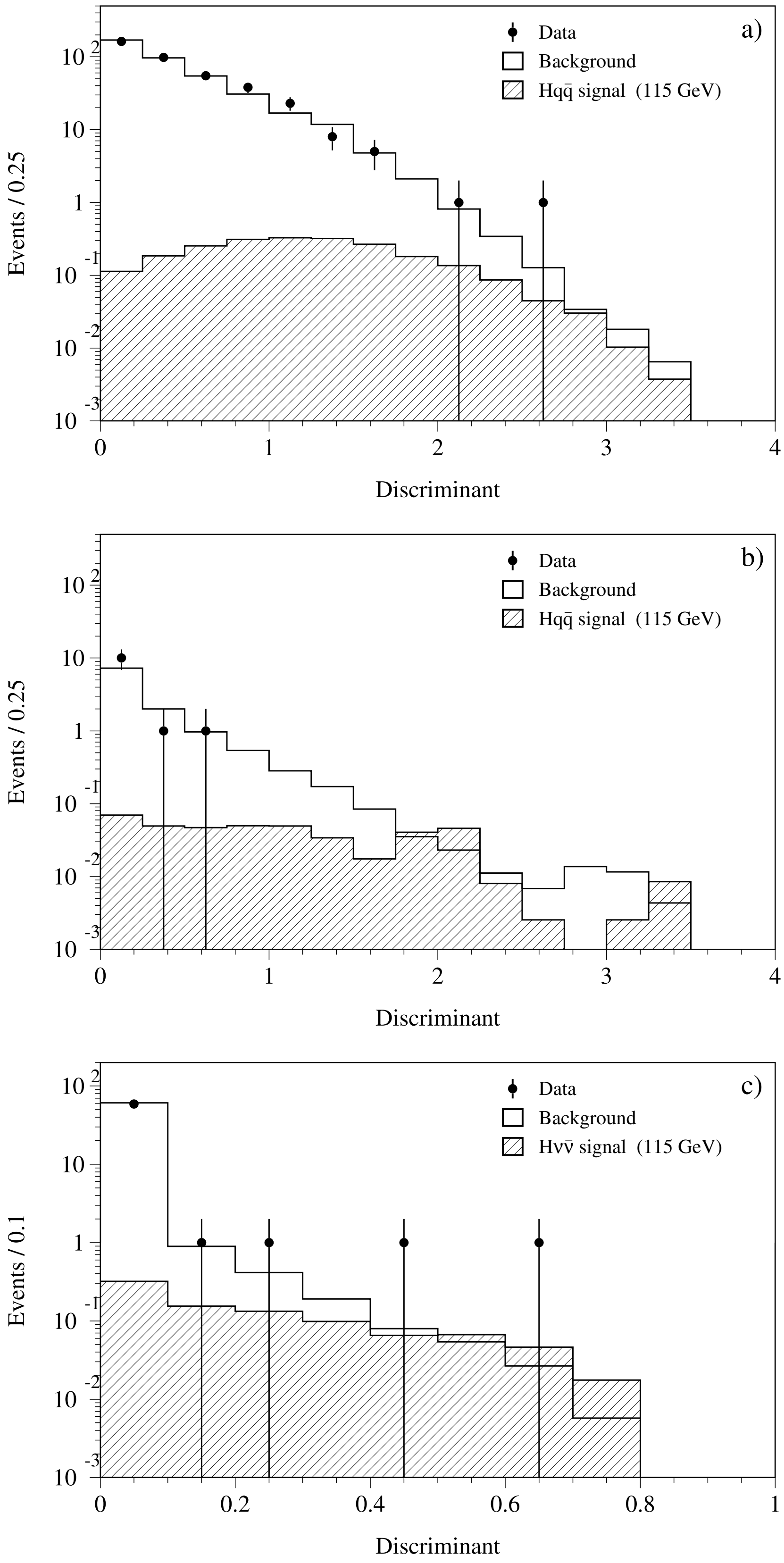


Figure 1: The final discriminant of a) the low purity four jet analysis, b) the high purity four jet analysis and c) the missing energy analysis. The expectations for a 115 GeV mass Higgs signal are superimposed.

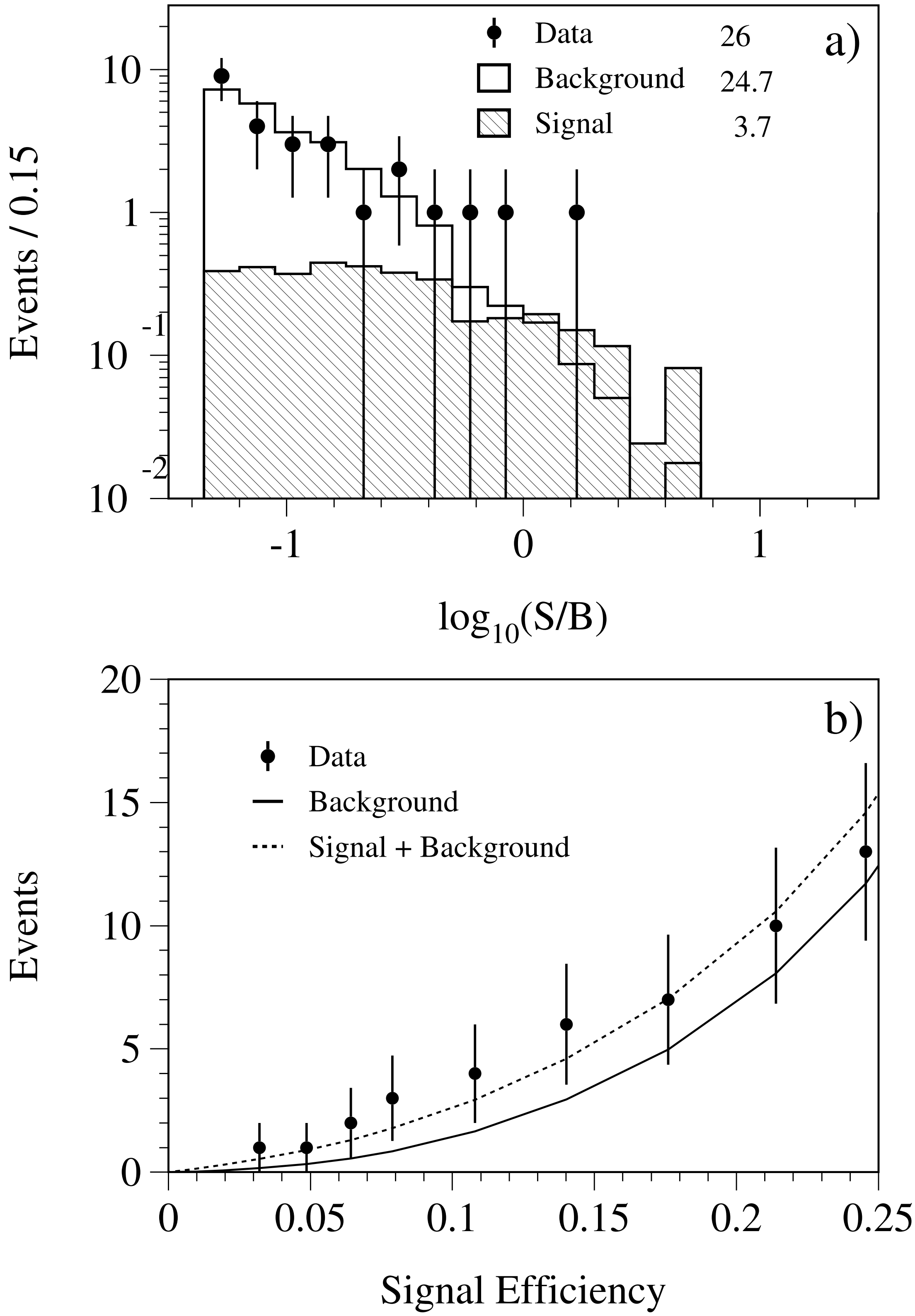
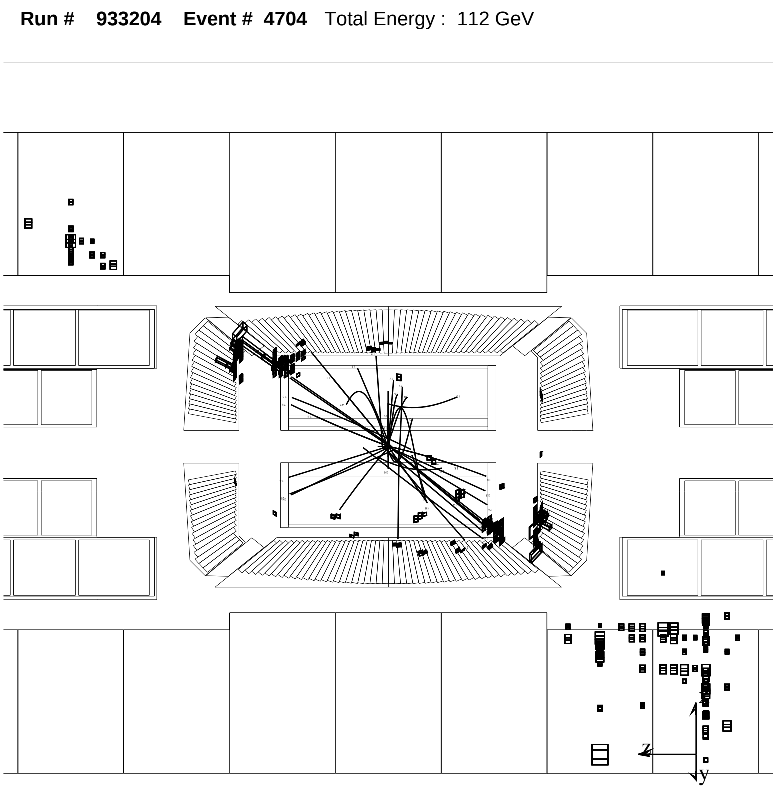


Figure 2: a) The logarithm of the signal-to-background ratio for all channels combined assuming a Higgs mass of 114.5 GeV. The total number of events is also indicated, corresponding to a signal efficiency of 31.4%. b) The number of events above a cut on the final discriminant, versus the signal efficiency.

a)



b)

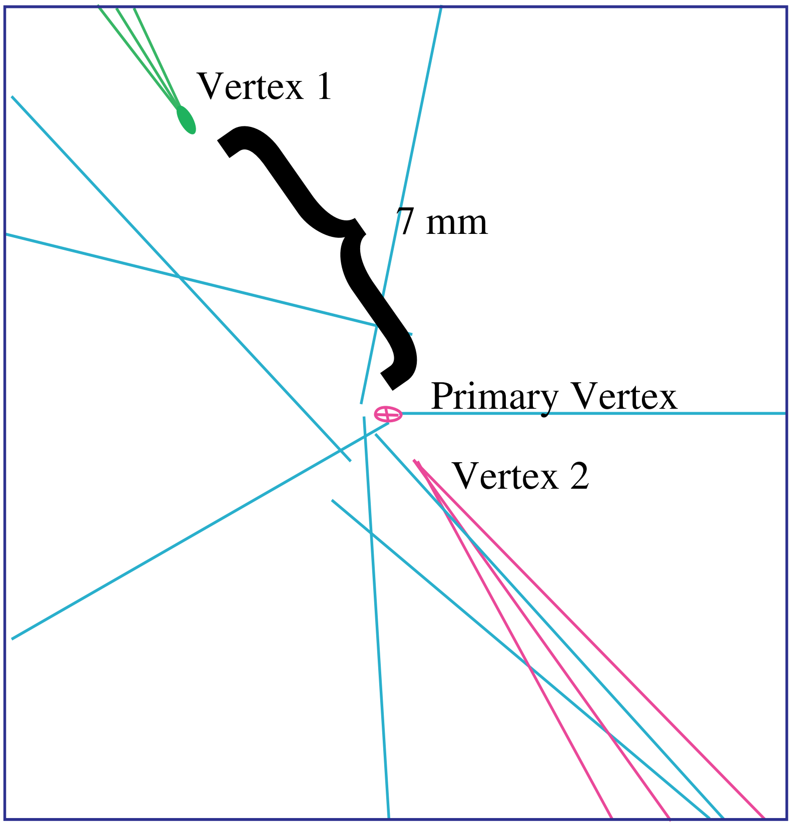


Figure 3: a) H$\nu\bar{\nu}$ Higgs candidate at $\sqrt{s} = 206.6$ GeV. b) Close-up of the vertex region of this event.

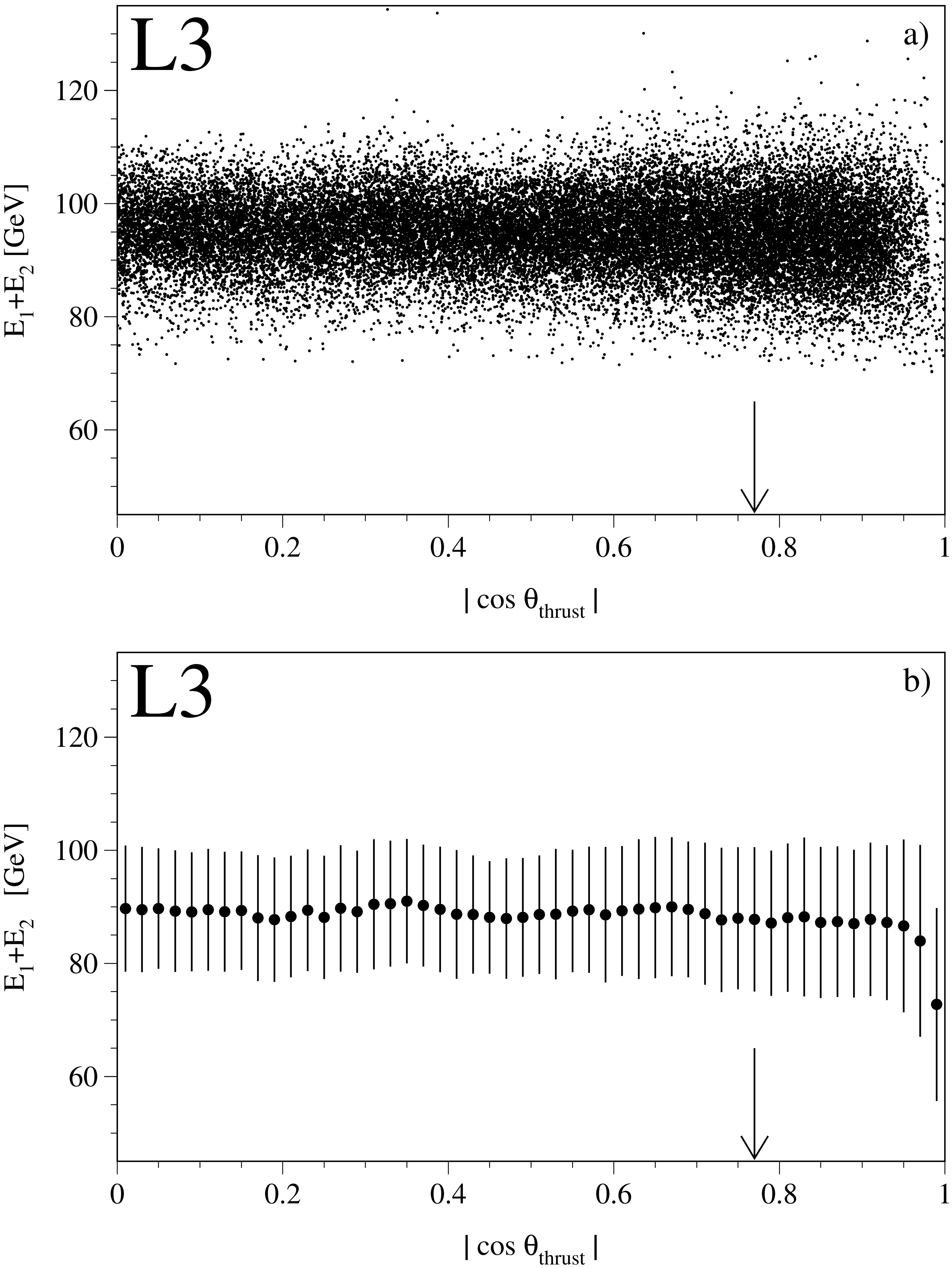


Figure 4: a) The sum of the jet energies versus $\cos\theta_{\rm thrust}$ for the Z calibration data taken in the year 2000. b) The average and r.m.s. of the same distribution. The arrows indicate the position of the $H\nu\bar{\nu}$ candidate.

Run # 928701 Event # 4738 Total Energy : 207.8 GeV

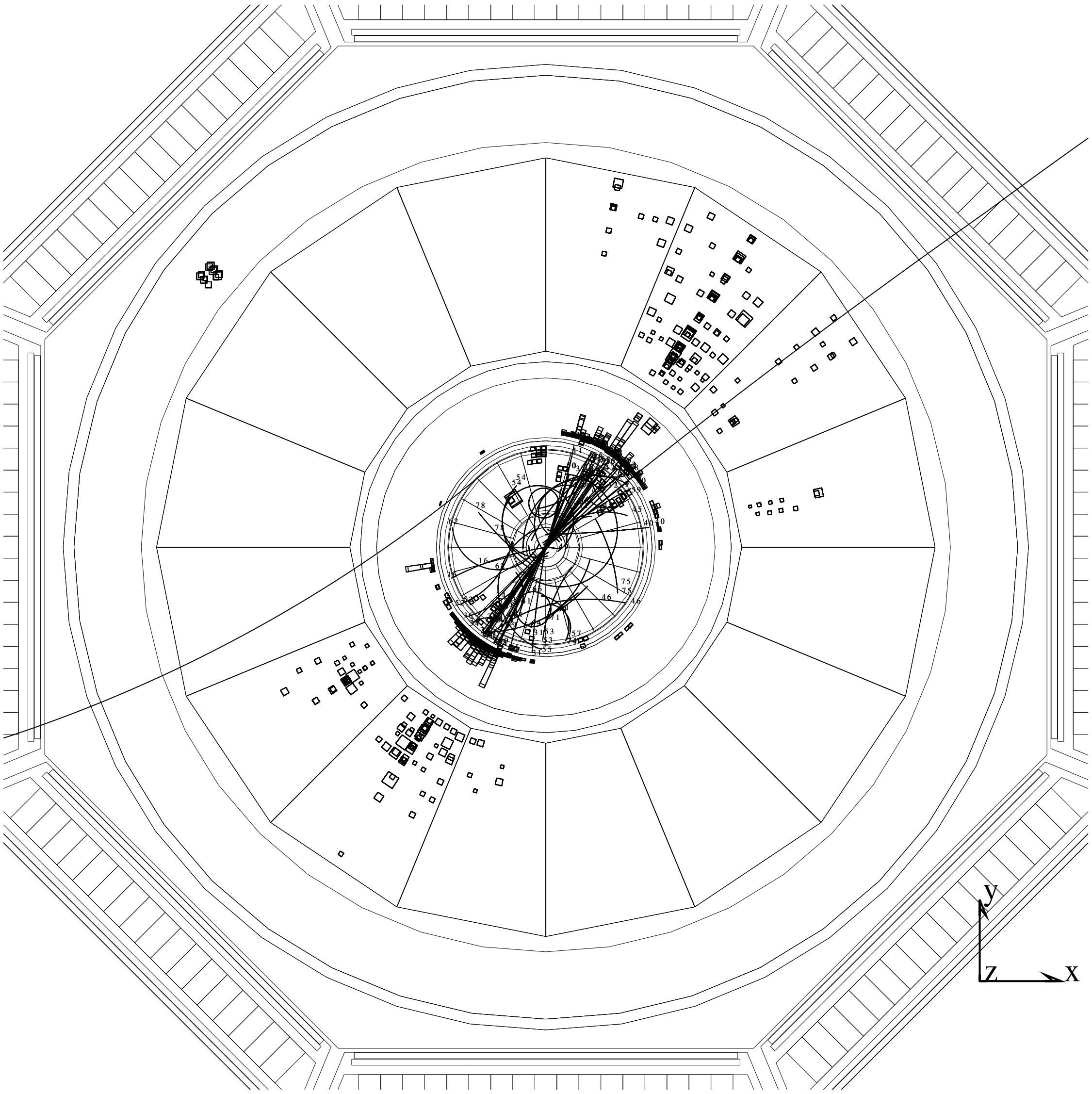


Figure 5: $Hq\bar{q}$ Higgs candidate with highest weight.