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A Search for an Unexpected 97 GeV Higgs Signal at 189 GeV in Four-Jet Events with a Linear Discriminant Analysis

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Abstract

At 183 GeV an interesting excess of events was unexpectedly observed at around 97 GeV/c^2 in the $e^+e^- \to HZ$ four-jet channel, It motivated new searches for such a Higgs signal in the data taken at a center of mass energy of 189 GeV. The present work deals with a selection based on a Linear Discriminant Analysis. At the working point of the cut analysis, corresponding to 12.1 Monte Carlo background events for 60 pb^{-1} of integrated luminosity, the present analysis has an efficiency of 53.2% which is 12% higher than the standard cut selection efficiency. For 170.3 pb^{-1}, 31 candidates are observed while 30.6 background events are expected from standard model processes. No significant peak is observed at 97 GeV.

1 Introduction

The branching ratio of the Standard Model Higgsstrahlung process into the four jet channel is about 64%. Events are characterised by two b quarks from the Higgs decay, (jets 3 and 4) and two quark jets from the Z decay(jets 1 and 2). The signature of the signal is therefore four jets with at least two jets having a high b content [1, 2]. The main backgrounds are $q\bar{q}(\gamma)$, WW and $ZZ(^*)$. At 189 GeV, the cross-sections for these processes are respectively 96.8 pb, 16.62 pb and 2.77 pb. After application of all the cuts the backgrounds from $q\bar{q}(\gamma)$ and $ZZ(^*)$ processes remain of equal importance.

2 Monte Carlo samples, b tagging, event selection

2.1 Monte Carlo Samples

The present analysis is based on the Monte Carlo samples listed in table 1. Ten thousand HZ signal events with $M_H = 97$ GeV/c^2 have been generated with the HZHA02 program [3]. The $q\bar{q}(\gamma)$ and $ZZ(^*)$ backgrounds were generated with PYTHIA [4] while the WW events were simulated with the KORALW generator for CC03 diagrams [5] taking a W mass of 80.35 GeV/c^2.

Table 1: Summary of the Monte Carlo samples for Standard Model Background processes

Process	Number of events
$e^+e^- \to q\bar{q}(\gamma)$	299,978
$e^+e^- \to W^+W^-$	124,993
$e^+e^- \to ZZ(^*)$	24,997

2.2 b tagging

Jet b tagging is performed on the basis of a 6-variable Neural Network [6].It has been described in Ref [7] and has been used for the $e^+e^- \to HZ \to b\bar{b}q\bar{q}$ channel analyses at lower center of mass energies $\sqrt{s}$= 161, 172 [8] and 183 GeV [9]. The first two variables are based on lifetime; the third on the transverse momentum of identified leptons and the last three on jet-shape properties. These quantities are described as follows:

- The $\mathcal{P}_{uds}$ jet probability to be a uds quark based on the track impact parameters;
- $\Delta\chi^2$, the difference in χ^2 obtained by fitting tracks at both the primary and secondary vertices compared to that obtained assuming that all tracks come from the primary vertex;
- p_T the lepton transverse momentum with respect to the jet axis;
- $\mathcal{S}_b$, the jet boosted sphericity calculated in the jet reference frame;
- The jet charged track multiplicity divided by the logarithm of the jet energy;
- $\sum p_T^2$: the sum of the tranverse momentum squared of each energy flow particle with respect to the jet axis.

As several improvements have been made for the 189 GeV Monte Carlo, the neural network retrained on the new Monte Carlo (version 4.5.5) has been used. The neural network output are quoted as η_i, i being the jet number(3,4 for the Higgs jets),(1,2 for the Z jets).

2.3 Event Selection

Hadronic events are selected by requiring at least 8 good charged tracks carrying more than 10% of the centre-of-mass energy. To reject events where the photon escapes detection along the beam pipe, the missing longitudinal momentum is required to be less than $1.5 \times (M_{vis} - 90.)$ where $\mathrm{M_{vis}}$, in GeV/c^2, is the total visible mass of the event. To reject electromagnetic jets (hard Bremsstrahlung photons clustered with other tracks), the electromagnetic energy in a cone of one degree around any energy flow particle in any jet must be less than 80% of the jet energy. The events are then clustered into four jets using the Durham algorithm. Events with y_{34}, the maximum y_{cut} value giving a four jet event, smaller than 0.004 are rejected. Each jet should have at least one charged track. At this preselection level, 1790 events are selected in the data while 1912.5 are expected from background processes($1294.9WW + 526.0qq + 91.6ZZ$). The analysis follows the standard HZ analysis in the four-quark channel except for the pairing where the present selection attributes to the Higgs the two more b-like jets while the two other jets are assumed to come from the Z decay.

2.4 The Linear Discriminant Analysis Variables

With the above selection, a Linear Discriminant Analysis with the stepwise method [10] has been optimized to separate the signal from the background. The latter was composed with the three backgrounds $q\bar{q}(\gamma)$, WW and $ZZ(^*)$ in the ratio of their cross-sections at the preselection level. The optimum was found with eleven variables, as increasing the number of variables to twenty did not improve the performances.These variables are listed in table 2 with their discriminating power.

The linear combination of these variables determined by the Linear discriminant analysis is as follows:

$$\begin{aligned} U \;=\;& 0.1943 * sumnn - 0.6293 * cosmin + 0.352 * y_{34} + 2.405 * max\_n34 \\ & -0.005396 * jas + 2.07 * pr\_n34 + 0.5824 * min\_n34 - 0.4173 * bap2 \\ & +1.067 * bed - 0.02139 * yg1 + 0.01588 * xmjm2 - 1.389 \end{aligned} \tag{1}$$

The variation of the Standard Model expected background with the efficiency of a 97 GeV/C^2 Standard model Higgs is displayed in figure 1. The cut on the linear discriminant variable U has been adjusted in order to get the same background of 12.1 for a luminosity of 60 pb^{-1}, its corresponds to a value of 0.54. The efficiency so obtained is 53.2%, which is 12% larger than the value obtained with the cut analysis. [2]

Table 2: List of the eleven variables with their discriminating power

Name	variable description	discriminating power
SUMNN	$\sum(\eta_i)$	0.3815
COSMIN	$min(cos\theta_{ij} + cos\theta_{kl})$	0.2338
Y34	y_{34} being the maximum	0.1466
	ycut value giving a four jet event	
MAX_N34	$maximum(\eta_3, \eta_4)$	0.3625
JAS	the sum of the four smallest interjet angles	0.0169
PR_N34	$(1. - \eta_3)(1. - \eta_4)$	0.33
MIN_N34	$minimum(\eta_3, \eta_4)$	0.3609
BAP2	boosted aplanarity of jet 2	0.0091
BED	event broadening	0.1564
YG1	charged track multiplicity with	
	rapidity greater than 1.6 in jet 1	0.0014
XMJM2	third lowest jet mass	0.0184

2.5 Data sample

The data sample of 170.3 pb^{-1} corresponds to the official selection at 189 GeV. In figure 2, the linear discriminant variable U obtained in the data at the preselection level is compared with the distribution expected for the Monte Carlo background. While the number of events agree fairly well, the predicted distribution is slightly shifted compared to the data.
After the cut on U at 0.54, 31 events are selected in the data for 30.6 expected(7.0WW+11.6qq+12.0ZZ) as displayed in figure 3. In the data taken at C.M. energy of 183 GeV, 9 events were clustered in the Higgs mass range 90-105 GeV/c^2 while 1.9 events were expected for Standard Model processes without Higgs production [1]. The number of events corresponding to the production of a Standard Model Higgs of 97 GeV/c^2 mass with the luminosity of 59 pb^{-1} was 0.092 in this mass window. Interpreting the excess of 7.1 events as a 97 GeV/c^2 Higgs signal would suggest a cross-section 77 times higher than the Standard Model one. In the 189 GeV C.M. energy data, the Standard Model cross-section has increased by a factor 5 and the lumi-

nosity by a factor of 2.9, yielding a factor of 15 in sensitivity. The number of events for a 97 GeV/c^2 Higgs in the same mass range is 1.7. The 95% upper limit on an excess of events is 7.3 (7 events observed, 6.7 expected from backgrounds), which allows an upper limit on the cross-section times the branching of

$$\frac{\sigma \times BR}{(\sigma \times BR)_{SM}} < 4.3$$

at 95% confidence level.

3 Conclusion

A search for a 97 GeV/c^2 unexpected Higgs signal has been performed at 189 GeV. The data are consistent with Standard Model processes: for an integrated luminosity of 170.3 pb^{-1}, 31 events are observed while 30.6 events are expected from the Monte Carlo backgrounds. No excess is seen in the mass range where events were clustered in 1he 183 GeV data.

References

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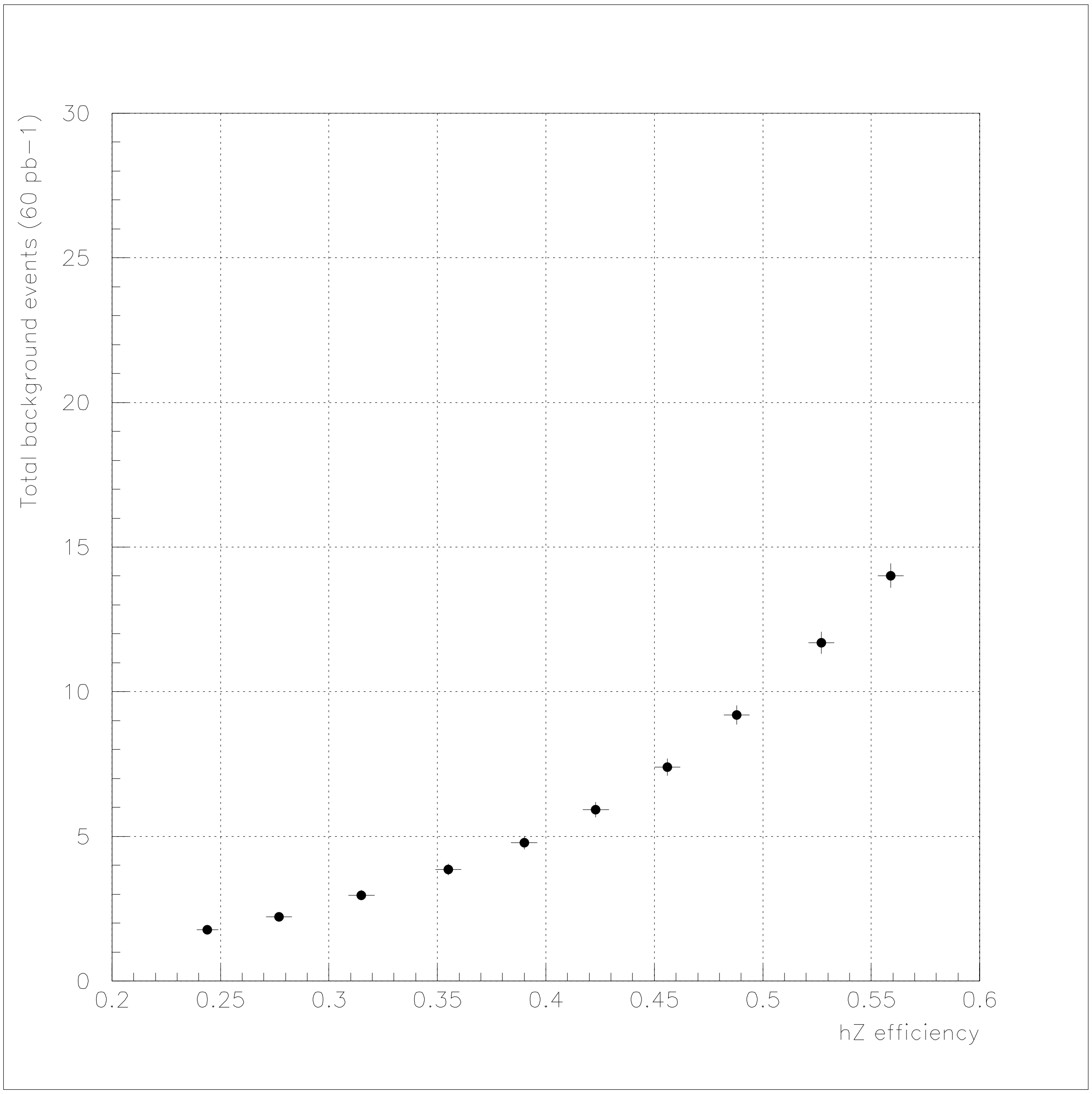

Figure 1: Number of expected background events from Standard Model processes for 60 pb^{-1} versus detection efficiency for a $97 GeV/c^2$ Standard Model Higgs

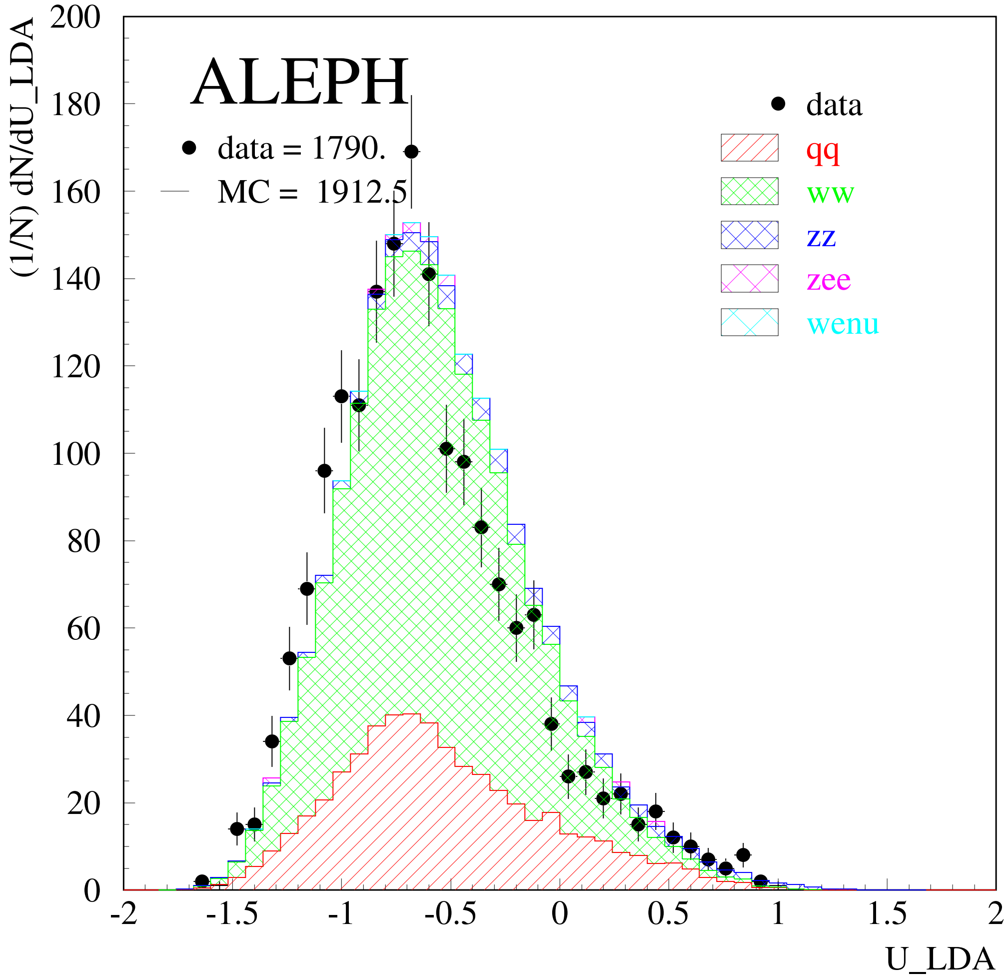

Figure 2: Comparison of the linear discriminant variable U obtained in the data with the expected Monte-Carlo background

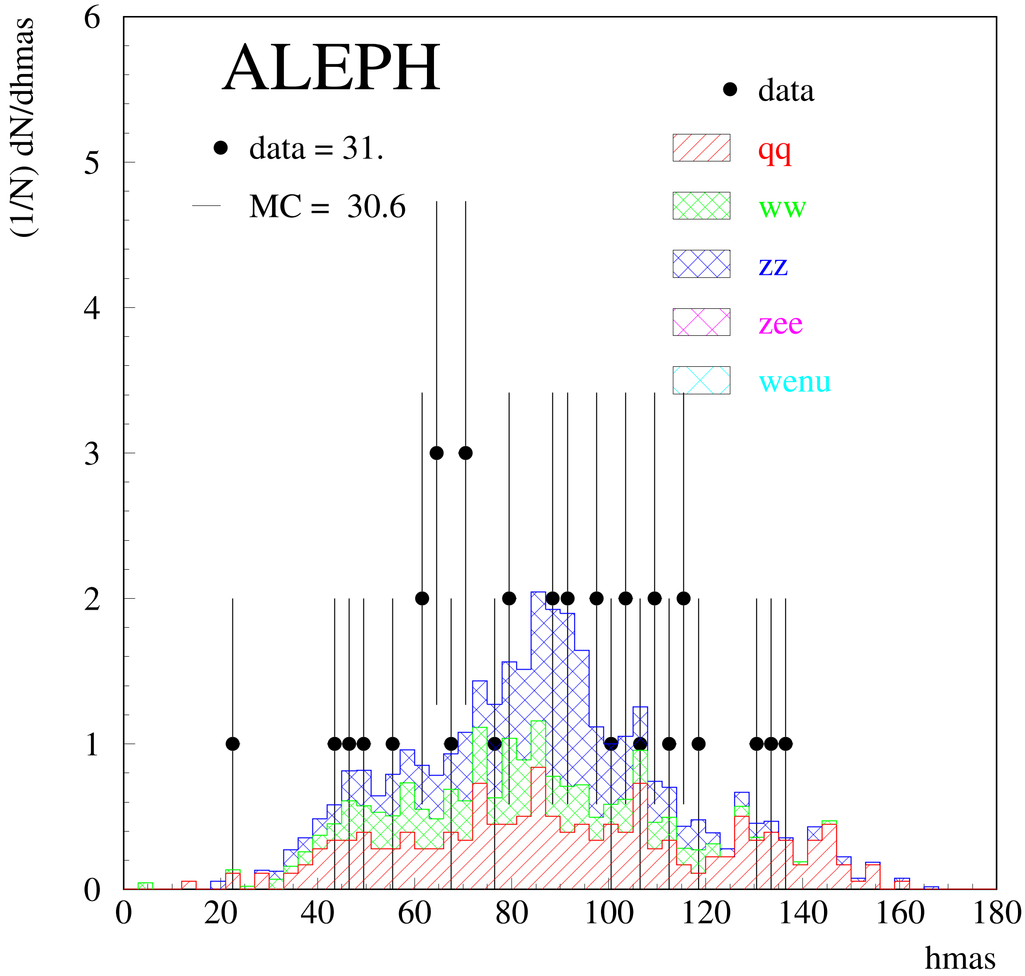

Figure 3: Comparison of data and expected Monte Carlo after the full selection