LC-PHSM-2001-055

Determination of the Higgs boson spin with a Linear e^+e^- Collider

M.T. Dova[†], P. Garcia-Abia[*] and W. Lohmann[‡]

[†] *Universidad National de La Plata, CC67, 1900 La Plata, Argentina.*
[*] *CERN* [1], *EP Division, J21300, CH–1211–Geneva 23, Switzerland*
[‡] *DESY Zeuthen, Platanenallee 6, D–15738–Zeuthen, Germany*

Abstract. The energy dependence of the production cross section of a light Higgs boson is studied at threshold and compared to the expectation of several spin assumptions. Cross section measurements at three centre-of-mass energies just above the threshold with an integrated luminosity of 20 fb^{-1} allow confirmation of the scalar nature of the Higgs Boson.

INTRODUCTION

In the Standard Model [1] particles acquire mass due to spontaneous symmetry breaking by introducing an isospin doublet of complex scalar fields. The so called Higgs mechanism [2] leads to one remnant scalar particle, the Higgs boson. Models *e.g.* in the framework of supersymmetry predict more than one neutral scalar.

A light Higgs boson is expected to be produced at an e^+e^- collider of a few hundred GeV via the Higgs-strahlung process, $e^+e^- \to Z\,H$. However, if a particle produced in association with the Z is detected, the confirmation of its scalar nature will be essential to its identification with a Higgs boson.

Here we study the production of a Standard Model Higgs boson with a mass $m_{\mathrm{H}} = 120$ GeV near the kinematic threshold. A measurement of the production cross section at three energy points with an integrated luminosity of 20 fb^{-1} each is compared with the predictions for the total cross section as function of the centre-of-mass energy for bosons of spin 0, 1 and 2 produced in association with the Z [3].

EXPERIMENTAL CONDITIONS AND DETECTOR SIMULATION

The study is performed for a linear collider operated at a centre-of-mass energies of 215, 222 and 240 GeV. The assumed data statistics correspond to an integrated

[1] On leave from the Institut für Physik der Universität Basel, Switzerland.

luminosity of 20 fb^{-1} at each energy point.

The detector used in the simulation follows the proposal presented in the TESLA Conceptual Design Report [4]. The interaction region is surrounded by a central tracker consisting of a silicon microvertex detector as the innermost part and a time projection chamber. In radial direction follow the electromagnetic and hadron calorimeters, the coils of a superconducting magnet and an instrumented iron flux return yoke. The solenoidal magnetic field is 3T. The simulation of the detector is done using SIMDET [5].

SIGNAL AND BACKGROUND PROCESSES

Events of the signal, $\mathrm{e^+e^-} \rightarrow \mathrm{Z\,H}$, are generated using PYTHIA [6] for a Higgs boson mass of 120 GeV. Only Z decays into electrons and muons are considered. For the Higgs boson all decay modes are simulated as expected in the Standard Model. The values of the cross section in the Standard Model and the expected numbers of events corresponding to a luminosity of 20 fb^{-1} are given in Table 1 at centre-of-mass energies of 215, 222 and 240 GeV. The following background

$\sqrt{s}$(GeV)	215	222	240
$\sigma(\mathrm{ZH} \rightarrow \ell^+\ell^-\mathrm{X})$	7.2	12.6	16.8
events	144	252	336

TABLE 1. The cross sections and numbers of events expected in the Standard Model for the production of a Higgs boson of $m_{\mathrm{H}} = 120$ GeV at centre-of-mass energies of 215, 222 and 240 GeV and a luminosity of 20 fb^{-1}

processes are considered: $\mathrm{e^+e^-} \rightarrow (\gamma\gamma) \rightarrow \mathrm{e^+e^-f\,\bar{f}}$, $\mathrm{e^+e^-} \rightarrow \mathrm{q\bar{q}}(\gamma)$, $\mathrm{e^+e^-} \rightarrow \mathrm{W^+W^-}$ and $\mathrm{e^+e^-} \rightarrow \mathrm{ZZ}$.

Initial state Bremsstrahlung is simulated by PYTHIA. Beamstrahlung is taken into account using the CIRCE program [7].

CROSS SECTION MEASUREMENT

The cross section determination is based on the $\mathrm{e^+e^-} \rightarrow \mathrm{Z\,H} \rightarrow \ell^+\ell^- + \text{2-jet}$ final state, where ℓ is an electron or muon. The signature is two isolated energetic electrons or muons and two jets. The identification of electrons and muons and the formation of jets are performed as described in Reference [8].

The selection efficiencies for the processes $\mathrm{e^+e^-} \rightarrow \mathrm{Z\,H} \rightarrow \mathrm{e^+e^-}$ 2-jet and $\mathrm{e^+e^-} \rightarrow \mathrm{Z\,H} \rightarrow \mu^+\mu^-$2-jet are about 50%. Each event is subject of a kinematic fit imposing energy and momentum conservation [9]. The distributions of the two jet invariant mass are shown in Figure 1 for centre-of-mass energies of 215, 222 and 240 GeV.

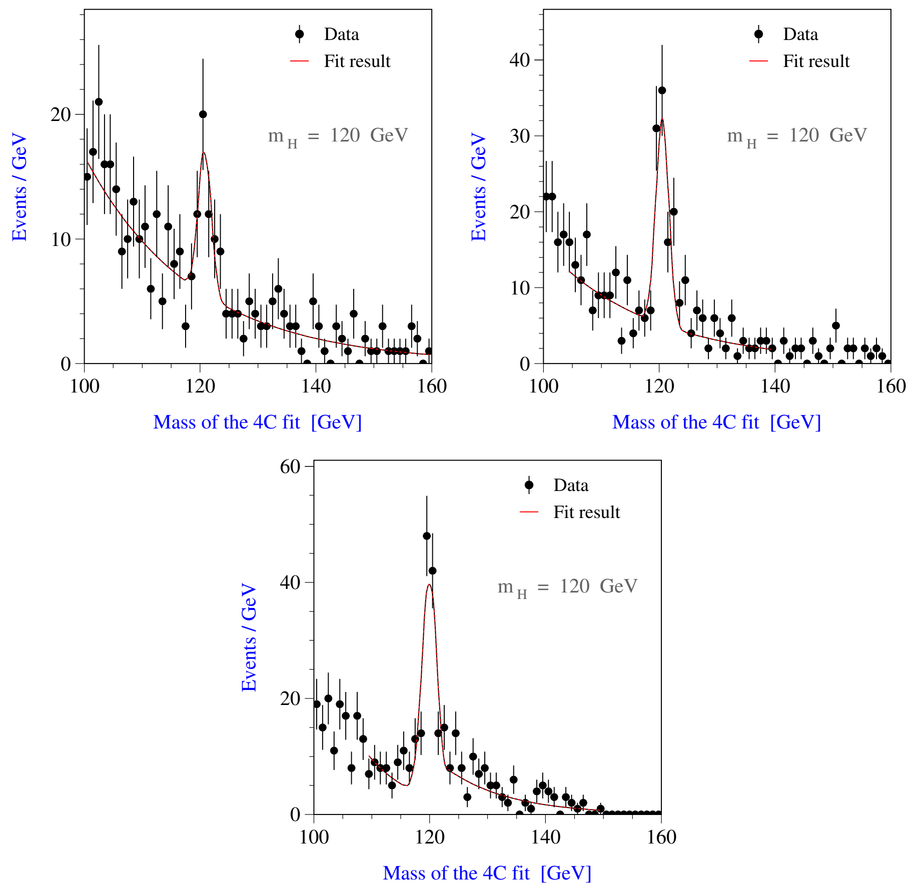

FIGURE 1. The dijet invariant mass from the ZH $\rightarrow \ell^+\ell^- q\bar{q}$ final state after a 4C kinematic fit for $\sqrt{s}$ = 215 (top left), 222 (top right) and 240 GeV (bottom).

The mass spectra are fitted with the superposition of signal and background distributions. The signal is parametrised with a gaussian and the background is fixed to the Monte Carlo expectation.

The uncertainties of the cross section measurements, $\Delta\sigma/\sigma$, range between 20% and 10% for $\sqrt{s}$ =215 GeV and $\sqrt{s}$ =240 GeV, respectively.

RESULTS

The cross sections obtained for the process $e^+e^- \rightarrow$ Z H $\rightarrow \ell^+\ell^- +$2-jet at centre-of-mass energies of 215, 222 and 240 GeV are shown in Figure 2. The results of fits using the predictions for possible models with s=0, 1 and 2 [3] with the normalisation as free parameter are also shown. These predictions include a correction for

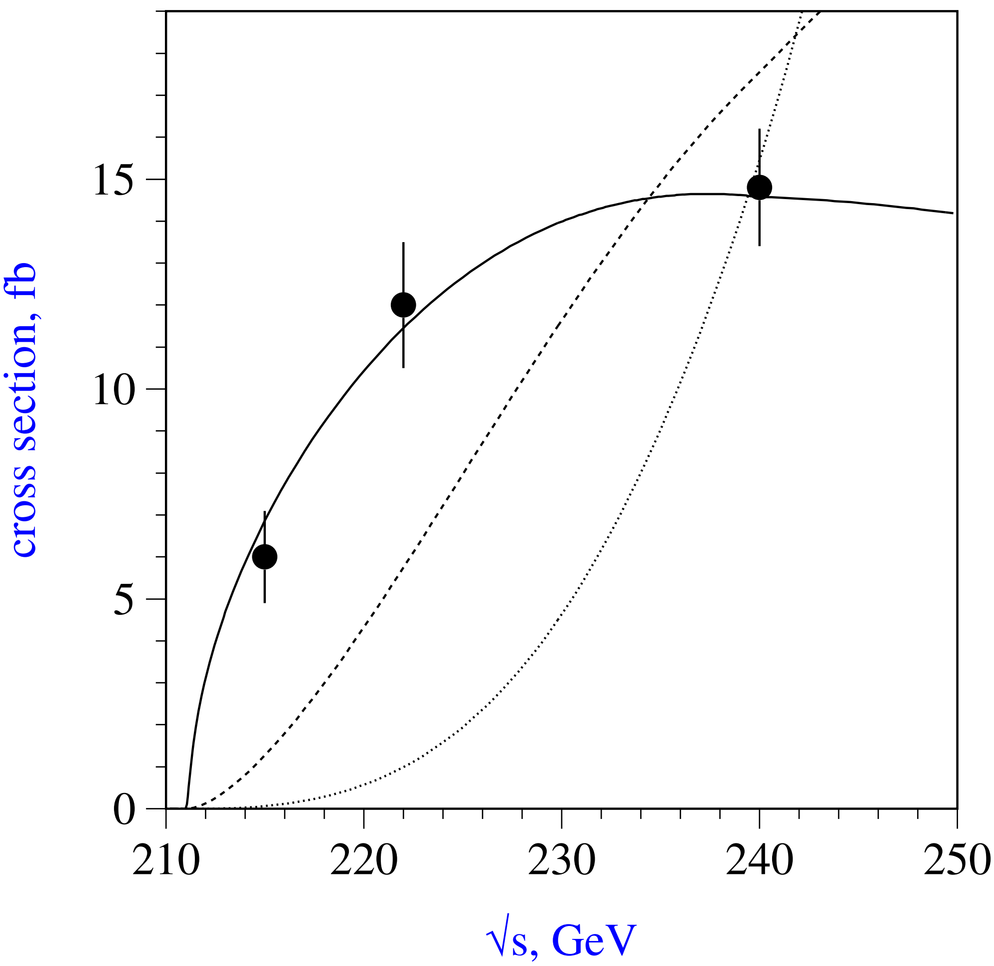

FIGURE 2. The cross sections determined at $\sqrt{s}$ = 215, 222 and 240 GeV (dots) and the predictions for s=0 (full line), s=1 (dashed line) and s=2 (dotted line).

initial state bremsstrahlung and beamstrahlung[2]. The s=0 case is clearly distinguished from the s=1 and 2 cases. The fit with the s=0 prediction has a good χ^2 probability and its normalisation factor equals to unity. The other fits have a χ^2 probability of less than 10^{-5}.

The study of the Higgs boson production just above the kinematic threshold shows that the measurement of the cross section at three centre-of-mass energy points using a luminosity of 20 fb^{-1} allows confirmation of the scalar nature of the Higgs boson. Bosons with other spins can be disfavoured[3].

ACKNOWLEDGMENTS

The Authors thank Fondation Antorchas, Argentina, for support.

REFERENCES

1. S.L. Glashow, Nucl. Phys. **22** (1961) 579; S. Weinberg, Phys. Rev. Lett. **19** (1967) 1264; A. Salam, *Elementary Particle Theory*, edited by N. Svartholm (Almqvist and Wiksell, Stockholm, 1968), p. 367.
2. P.W. Higgs, Phys. Lett. **12** (1964) 132, Phys. Rev. Lett. **13** (1964) 508 and Phys. Rev. **145** (1966) 1156 ; F. Englert and R. Brout, Phys. Rev. Lett. **13** (1964) 321; G.S. Guralnik, C.R. Hagen and T.W.B. Kibble, Phys. Rev. Lett. **13** (1964) 585.
3. D.J. Miller *et al.*, hep-ph/0102023 and LC-TH-2001-033-TESLA (2001).
4. "Conceptual Design of a 500 GeV e^+e^- Linear Collider with Integrated X-ray Laser Facility", Vol. I, editors R. Brinkmann, G. Materlik, J. Rossbach, A. Wagner, DESY 1997-048, ECFA 1997-182.
5. SIMDET V3.2, M. Pohl and H.J. Schreiber, DESY-99-030 (1999).
6. PYTHIA V6.136, T. Sjöstrand, Comp. Phys. Comm. **82** (1994) 74.
7. CIRCE V6, T. Ohl, Comp. Phys. Comm. **94** (1996) 53.
8. P. Garcia-Abia and W. Lohmann, EPJdirect **C2** (2000) 1-6, P. Garcia-Abia *et al.*, LC-PHSM-2001-054, DESY 2001.
9. V. Blobel, "Constrained Least Squares and Error Propagation", Hamburg (1997).

[2)] This correction is obtained from the ratio of the cross sections for Higgs boson production in the Standard Model with and without radiation as obtained from PYTHIA.
[3)] There are particular scenarios for s=1 and 2 [3], which show a threshold behaviour similar in shape to the s=0 one. This can be disentangled using angular information in addition.