Ref.TH.3387-CERN

HIGGS BOSONS AND HEAVY FLAVOURS AT LEP

K.J.F. Gaemers

CERN -- Geneva

and

Institute for Theoretical Physics
University of Amsterdam

ABSTRACT

The production of Higgs particles together with heavy onia states in e^+e^- collisions is considered. If the mass of the top-quark is large enough, the production rate for TH may be observable.

Ref.TH.3387-CERN
9 August 1982

The standard $SU(2) \times U(1)$ model of electroweak interactions predicts charged and neutral intermediate bosons with masses of ~ 80 GeV and ~ 90 GeV, respectively. The model needs symmetry breaking in order to generate these as well as other masses. In the simplest version of the model this symmetry breaking is achieved by introducing a doublet of scalar Higgs fields. Eventually one neutral Higgs boson is left after symmetry breaking.

Many processes have been proposed in order to look for the existence of this Higgs boson. A survey of many possibilities can be found in Refs. 1), 2). In hadron-hadron collisions, gluon-gluon fusion may be an important production mechanism for Higgs bosons. Another mechanism is the production of virtual Z and $W^\pm$ bosons (through the Drell-Yan mechanism) which decay subsequently into real (on-shell) intermediate bosons and Higgses ^{3), 4)}. Higgs production together with a large p_T Z boson has been discussed in Ref. 5). All these proposals do not give a signature for Higgs production that will be easily distinguished from the enormous hadronic background.

One may expect to see cleaner signals in e^+e^- annihilation. Here several reactions have also been studied. In Ref. 1), the production of Higgs bosons by bremsstrahlung off a J/ψ particle is considered. This reaction, although it leads to the same final state as that considered here, proceeds through a different mechanism. At the Z peak a promising signal is given by the decay process

$$Z \longrightarrow \mu^+ \mu^- H \quad (1)$$

which has been proposed by Bjorken ⁶⁾ and also studied by Finjord ⁷⁾. The complete production and decay has been studied in Refs. 8)-10). In Ref. 9) a discussion of possible backgrounds to the decay (1) can be found. There are mechanisms where the H is produced together with other fermion-anti-fermion pairs. These have been looked at in Refs. 8) and 11). In Ref. 8) it was found that the cross-section for

$$e^+e^- \longrightarrow q \bar{q} H \quad (2)$$

is much larger than for

$$e^+e^- \longrightarrow \mu^+ \mu^- H \quad (3)$$

Reaction (2) has the disadvantage that its signature will not be as clear as that for reaction (3).

In this letter we will look again at reaction (2), however not for free quarks which will become hadron jets eventually, but for the case where the quarks are bound into a 1^{--} vector meson like the ϕ , J/ψ , Υ , etc. This process

$$e^+e^- \longrightarrow {}^3S_1(q\bar{q}) H \quad (4)$$

which is interesting in itself will also contribute to (3) through the leptonic decay

$${}^3S_1(q\bar{q}) \longrightarrow \mu^+\mu^- \quad (5)$$

The dominant diagrams contributing to (2) and (4) are given in Fig. 1a and Fig. 1b, respectively.

In the sequel we will explicitly treat the case of the J/ψ meson. It is straightforward to modify the results so that they apply to other vector mesons.

For a calculation of the cross-section for (4) where 3S_1 is now a J/ψ , one needs (see Fig. 1) the $Ze\bar{e}$ and HZZ coupling constants which follow immediately from the standard model. One also needs the Z - J/ψ coupling. The J/ψ couples only to the vector current; the axial current coupling is absent due to parity. Since the vector current also gives the electromagnetic interaction of the J/ψ , we can express the Z - J/ψ coupling in terms of the partial decay rate $\Gamma(J/\psi \rightarrow e^+e^-)$.

In order to do this explicitly we will use the bound state formalism used in Ref. 12). The partial rate is expressed in terms of the quark charge Q_q and a parameter f related to the wave function at the origin. It is given by

$$\Gamma(V \rightarrow e^+e^-) = \frac{8\pi\alpha^2 Q_q^2 f_V^2}{M_V} \quad (6)$$

In terms of the parameter f_V we have :

$$\langle J/\psi | \bar{c} \gamma^\mu c | 0 \rangle = f_{J/\psi} M_{J/\psi} \sqrt{6} \epsilon^\mu \quad (7)$$

where ϵ^μ is the J/ψ polarization vector. If we compare the values of f^2/M for the vector mesons ϕ , J/ψ and Υ , we find that it has roughly the same value of 8 MeV for all three. In speculating about properties of the top quark and toponium vector mesons, we will use this value although it may actually mean a slight overestimate ¹³⁾.

We can now give the differential cross-section for reaction (4)

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 p \sqrt{\lambda(s, M_V^2, M_H^2)}}{s} \cdot \frac{1}{|s - M_Z^2 + i M_Z \Gamma_Z|^2} \cdot \frac{1}{|M_V^2 - M_Z^2 + i M_Z \Gamma_Z|^2} \cdot \left(1 + \cos^2 \theta + \frac{E_V^2}{M_V^2} \sin^2 \theta\right) \quad (8)$$

In this expression, E_V is the energy of the produced vector meson and p is a combination of coupling constants given by

$$p = 3 v_q^2 (v_e^2 + a_e^2) M_Z^4 M_V^2 f_V^2 (G_F \sqrt{2}) \quad (9)$$

The v 's and a are given by :

$$\begin{aligned} v_e &= (-1 + 4 \sin^2 \theta_w) / (2 \sin 2\theta_w) \\ a_e &= -1 / (2 \sin 2\theta_w) \\ v_q &= \begin{cases} (1 - \frac{8}{3} \sin^2 \theta_w) / (2 \sin 2\theta_w) & ; Q_q = +2/3 \\ -(1 - \frac{4}{3} \sin^2 \theta_w) / (2 \sin 2\theta_w) & ; Q_q = -1/3 \end{cases} \end{aligned} \quad (10)$$

The total cross-section for $J/\psi + H$ production can of course be calculated immediately from (8).

We will now discuss some of the consequences. As can be seen from (8), the cross-section contains a product of two Breit-Wigner functions. The dependence on the centre-of-mass energy is simply given by the factor $|s - M_Z^2 + i M_Z \Gamma_Z|^{-2}$, at least near the Z peak. For very large s the cross-section shows the scaling s^{-1} behaviour. The second factor $|M_V^2 - M_Z^2 + i M_Z \Gamma_Z|^{-2}$ is more interesting since it implies that if toponium exists with a mass not too far from the Z peak, it may give rise to a large cross-section.

We now give the cross-sections for ϕH , $J/\psi H$ and ΥH at the Z peak (90 GeV for $\sin^2 \theta_w = 0.22$). In Fig. 2 we show these cross-sections as a function of the Higgs mass M_H . The curves for ϕ and J/ψ almost fall on top of one another. From this Figure we see that the ΥH cross-section is of the order of 10^{-39} cm^2 for a large range of Higgs masses. The sensitivity to the Higgs mass is essentially determined by phase space here, in contrast to $\mu\bar{\mu}H$ production which shows a very strong dependence on M_H [see, e.g., Refs. 6) and 7)]. The branching ratio $B(Y \rightarrow \mu\bar{\mu}) \approx 3\%$. This means that the contribution of ΥH to $\mu\bar{\mu}H$ will be practically unobservable. A fortiori this holds for the lighter vector mesons. We will now speculate about the top quark. If the top quark and, consequently toponium (T), exists, the

toponium mass must be larger than ~ 40 GeV ¹⁴⁾. In Fig. 3, we present the TH production cross-section at the Z peak as a function of M_H for values of M_T of 40 GeV, 60 GeV and 80 GeV, respectively. The propagator effect, mentioned above, which favours heavy vector mesons, can be clearly seen. For large toponium masses, the cross-section is of the order of $\approx 10^{-37}$ cm². This corresponds to 0.01 unit in R at this energy. Even if we take into account leptonic branching ratios, this cross-section will probably lead to an observable rate. It may also be possible that the three-gluon decay mode is visible together with the decay products of the Higgs boson.

It should be mentioned finally that if the top quark mass is very large, other diagrams besides the one of Fig. 1b will contribute. In these diagrams, the Z boson produces a quark-antiquark pair and the Higgs boson radiates off the quark or antiquark, after which they bind in a vector meson. For the light quarks these contributions are unimportant as can be inferred, for example, from the results of Ref. 11). For very heavy quarks these effects are now under study ¹⁵⁾. The interference of these diagrams for unbound quarks has been studied in Ref. 16).

We see that if toponium exists and if it has a large enough mass, it may be a useful tool in the study of Higgs bosons.

REFERENCES

- 1) J. Ellis, M.K. Gaillard and D.V. Nanopoulos, Nuclear Phys. B106 (1976) 292.
- 2) M.K. Gaillard, Comments Nucl.Part.Phys. 8 (1978) 31.
- 3) H.M. Georgi, S.L. Glashow, M.E. Machacek and D.V. Nanopoulos, Phys.Rev. Letters 40 (1978) 692.
- 4) S.L. Glashow, D.V. Nanopoulos and Y. Yildiz, Phys.Rev. D18 (1978) 1724.
- 5) J. Finjord, G. Girardi and P. Sorba, Phys.Letters 89B (1979) 99.
- 6) J.D. Bjorken, 1976 SLAC Summer Institute Lectures, SLAC report SLAC-198 (1976).
- 7) J. Finjord, Phys.Scr. 21 (1980) 143.
- 8) D.R.T. Jones and S.T. Petcov, Phys.Letters 84B (1979) 440.
- 9) E. Ma and J. Okada, Phys.Rev. D20 (1979) 1052.
- 10) R.L. Kelly and T. Shimada, Phys.Rev. D23 (1981) 1940.
- 11) K.J.F. Gaemers and G.J. Gounaris, Phys.Letters 77B (1978) 379.
- 12) E.L. Berger and D.R.T. Jones, Phys.Rev. D23 (1981) 1521.
- 13) C. Quigg, International Symposium on Lepton-Photon Interactions, Fermilab (1979), and private communication.
- 14) J. Bürger, International Symposium on Lepton-Photon Interactions, Bonn (1981).
- 15) K.J.F. Gaemers, in preparation.
- 16) V. Barger, F. Halzen and W.Y. Keung, Madison preprint MAD/TH/27 (1982).

FIGURE CAPTIONS

Figure 1 : a) Diagram contributing to a $f\bar{f}H$ final state;
 b) Diagram contributing to a VH final state.

Figure 2 : Cross-sections for ϕH ; $J/\psi H$ and ΥH production as a
 function of the Higgs mass.

Figure 3 : Cross-sections for TH production as a function of the
 Higgs mass for various T masses.

Fig. I

Fig. 2

Fig. 3