Production of Charged and Neutral Higgs Bosons in High Energy Lepton–Nucleon Interactions

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Abstract. We give a detailed calculation for the production of charged and neutral Higgs bosons in lepton–nucleon collisions in the framework of simple extended Weinberg–Salam models. The production cross section in the doublet–doublet models is in general much larger than that in the doublet–triplet models. In the doublet–doublet models the production cross section of neutral Higgs bosons through bremsstrahlung off heavy quarks may be by an order of magnitude larger than that of the neutral Higgs boson in the Weinberg–Salam model, and by several times smaller than that of the charged Higgs boson in the doublet–doublet models. In the HERA ep collider with \( s \approx 10^5 \text{ GeV}^2 \), there may be 1 event per 2 to 7 days for the production of a charged Higgs boson with \( m_H \approx 20 \text{ GeV} \).

1. Introduction

After the recent discovery of \( W^\pm \) and \( Z^0 \) gauge bosons, the search and study of the Higgs bosons become more prominent. Very extensive studies of Higgs bosons were carried out for the \( e^+e^- \) and \( p\bar{p} \) interactions. On the other hand, there exist only a few calculations about the production of neutral Higgs bosons in lepton–nucleon interactions [1–6]. This is because the production cross section of the latter is much smaller than the formal. However as shown by our calculations below, the production cross section of the neutral and charged Higgs bosons may become measurable in the future \( ep \) collider [7] with \( s \gtrsim 10^5 \text{ GeV}^2 \), and some experimental tests of the prediction of the standard and extended standard models on Higgs boson production in \( ep \) colliders may be realizable.

As to the charged Higgs boson production in lepton–nucleon interactions, to the knowledge of the authors, only one special case has been crudely estimated in [8]. In the Weinberg–Salam model no physical charged Higgs boson exists. Charged and neutral Higgs bosons exist in the simple, extended Weinberg–Salam models, i.e. the doublet–doublet models \((D + D \text{ models briefly})\) and the doublet–triplet models \((D + T \text{ model briefly})\). We find that in lepton–nucleon interaction at high energies the production cross section of neutral Higgs bosons in \( D + D \) models is larger than that of the neutral Higgs boson in the Weinberg–Salam model, and several times smaller than that of the charged Higgs bosons in the doublet–doublet models, and that the production cross section of \( H^+ \) in \( D + D \) model 1 [9–11] is larger than that in \( D + D \) model 2 [12].

In this paper we calculate all dominant Feynman diagrams of Higgs boson production using \( D + D \), \( D + T \) and Weinberg–Salam models, taking full account of kinematical effects and including QCD correction. Similar calculation for \( H^0 \) production in lepton–nucleon interaction has been carried out in [5] in the framework of the Weinberg–Salam model. Unfortunately, their numerical result for the process \( e + p \rightarrow \nu + H^0 + X \) is much lower than the correct one (see Sect. 3).

In Sects. 2.1 and 2.2 we give theoretical formulas for the processes \( l + N \rightarrow \nu_l + H^\pm + X \), \( l + N \rightarrow l + H^\pm + X \), \( \nu_1 + N \rightarrow 1 + H^\pm + X \) and \( \nu_1 + N \rightarrow \nu_1 + H^\pm + X \) in the framework of \( D + D \) and \( D + T \) models. In Sect. 2.3 formula for the \( H^\pm \) and \( H^0 \) bremsstrahlung off heavy quarks is given. In Sect. 3 numerical results and discussions are given.
2. Formulas for $H^{\pm,0}$ Production in Lepton–Nucleon Interactions

2.1 $H^\pm$ Production in $D + D$ Model 1

In $D + D$ model 1 [9, 11], no $W^\pm H^\mp Z^0$ coupling exists in the tree diagram. According to the assumption $\alpha < \beta \ll 1$ used in [9], the contribution from the Higgs boson $\phi^0$ is largely suppressed by the factor $\sin(\alpha - \beta)$. Neglecting the Higgs–lepton coupling the dominant contribution comes from the two interfering Feynman diagrams of Fig. 1a, (contributions from bremsstrahlung off heavy quarks being discussed in Sect. 2.3).

A straightforward and tedious calculation, neglecting all fermion masses, leads to the differential cross section for the production of $H^\pm$ in the subprocess defined by

$$1^\pm(k) + q_i(p) \rightarrow v_1(k') + H^\pm(k'') + q_i(p'),$$

$$d\sigma_{1^\pm} = \frac{m_H^2 G_F^2}{(1 + s x y)^2} \left( \frac{\sin^2(\alpha - \beta)}{(m_H^2 + s x y)^2} + \frac{\cos^2(\alpha - \beta)}{(m_H^2 + s x y)^2} \right) f(x, y, x', y'),$$

where

$$x' = \frac{-q''}{2P\cdot q'}, \quad y' = \frac{P\cdot q'}{P\cdot k'},$$

$$x = \frac{-q^2}{2P\cdot q}, \quad y = \frac{P\cdot q}{P\cdot k}.$$  \hspace{1cm} (3)

$P$, $q'$ and $q$ are, respectively, the 4-momenta of the nucleon, $H^0(h^\pm)$ and $W^\pm$ in Fig. 1a, and $\alpha$ and $\beta$ are the usual parameters in $D + D$ model. It is easy to show that $x'$ is equal to the momentum fraction of the quark $q_i$ inside the nucleon. The scaling variables defined in (3) are kinematically constrained by the relations.

$$0 < x < x' \leq 1, \quad 0 \leq y' < y \leq 1$$

$$(x' - x)(y - y') \geq m_H^2/s, \quad (s = (P + k)^2)$$  \hspace{1cm} (4)

The differential cross section for the process defined by

$$1^\pm + N \rightarrow v_1 + H^\pm + X$$

is given by

$$d\sigma_{1^\pm N} = \sum_i q_i(x', Q^2) d\sigma_{1^\pm}$$

$$dxdydy'$$

(5)

(6)

(7)

(8)

(9)

The differential cross section for the process defined by

$$v_1(N) + N \rightarrow 1^\pm + H^\pm + X$$

is related to (6) by the relation

$$d\sigma_{v_1(N)+N} = 2d\sigma_{1^\pm N}$$

(10)

since neutrino (antineutrino) has a definite initial helicity.