We show how the $W$ boson polarization in the process of associated $W^\pm H$ production at the Large Hadron Collider (LHC) can be used to constrain anomalous $WWH$ couplings. We first calculate the spin density matrix for the $W$ to linear order in the anomalous couplings, which are assumed to be small. We then evaluate angular asymmetries in the decay distributions of leptons produced in the decay of the $W$ and show how they can be used to measure the individual elements of the polarization tensor. We estimate the limits that can be placed on the anomalous $WWH$ couplings at a future run of the LHC.

1. Introduction
After the discovery of the Higgs boson with a mass of around 125 GeV, several measurements at the Large Hadron Collider (LHC) indicate that its couplings are consistent with those predicted by the standard model (SM). However, a complete confirmation that the Higgs boson $H$ discovered at the LHC is indeed the Higgs boson of the SM will require precise determination of all the couplings of $H$, including Higgs self-couplings. A simplistic analysis, usually adopted in the interpretation of Higgs data, attempts to measure the ratio $\kappa$ of the coupling to that in the standard model. In this procedure, the so-called $\kappa$ framework, the forms of the interactions assumed are the same as in the SM at tree level. An attempt to introduce more general tensor forms of couplings is not permitted by the present accuracy of the experiments. However, in future experiments at higher luminosities, it is hoped that such general forms of couplings will be constrained. This could include measurement of differential cross sections, which would be highly
data intensive. Alternatively, one could measure partial cross sections, or angular or energy asymmetries of final state particles.

An interesting additional variable which we consider in this work is the polarization of the $W^\pm$ produced in association with the Higgs. Measurement of polarization of a heavy particle requires the observation of decay distributions of the particle. Again one can construct appropriate asymmetries from the kinematical distributions of the decay particles. In particular, charged leptons distributions in the decay of the $W$ would enable the measurement of $W$ polarization parameters, which in turn would constrain the strengths of the tensor structures of the $WWH$ interactions.

$W$ polarization has been discussed recently in the context of polarized top decays and diboson resonances at the LHC [1], and earlier in the context of various single, pair and associated $W$ production processes [2]. For details of the formalism in the context of LEP experiments, see [3]. $Z$ polarization has been studied in the context of new physics at $e^+e^-$ colliders [4, 5].

$W$ helicity fractions, which measure the degree of longitudinal or transverse polarizations, have been measured in top decay $t \rightarrow bW$ at the LHC from the polar-angle distributions, integrated over the azimuthal angle [6]. These correspond to the diagonal elements of the $W$ production spin-density matrix. In what follows, we also consider measurement of the off-diagonal density-matrix elements [7–11] through angular asymmetries of the leptons produced in $W$ decay.

$W$ and $Z$ polarization in associated Higgs production has been studied recently in [12], with which our work has considerable overlap. While [12] contains expressions for $W$ spin density matrices which we obtained independently, their analysis deals with hadronic decay of the vector bosons, whereas we concentrate on leptonic decay of the $W$. While the hadronic branching ratios are larger, it is not possible to determine the charge of the jets. On the other hand, though the branching ratio of $W$ into leptons is smaller, greater precision is possible, as well as charge discrimination is available.

The $WWH$ vertex for a process $W^{++} \rightarrow W^+ H$ may be written in a model-independent way as

$$\Gamma_{\mu\nu} = g m_W \left[ a_W g_{\mu\nu} + \frac{b_W}{m_W^2} (q_{\mu} k_{\nu} - g_{\mu\nu} q \cdot k) + \frac{\tilde{b}_W}{m_W^2} \epsilon_{\mu\alpha\beta} q^\alpha k^\beta \right],$$  \hspace{1cm} (1)$$

where $q$ is the incoming $W^*$ momentum and $k$ is the outgoing $W$ momentum, and $\nu$, $\mu$ are their respective polarization indices. $g$ is the weak coupling
constant, and \( a_W = 1 \) in the SM at tree level. \( b_W \) and \( \tilde{b}_W \) which are vanishing in the SM at tree level, are anomalous couplings, taken to be complex form factors. An analogous vertex for the process \( W^- \rightarrow W^- H \) may also be written. While the first two terms would arise from terms in an effective Lagrangian and are invariant under CP, the \( \tilde{b}_W \) term would correspond to a CP-violating term in the Lagrangian. The anomalous couplings could arise at one or more loops in the SM, or in extensions of the SM, with heavy particles (the top quark, \( W, Z \) and \( H \) in the SM, or other additional particles in SM extensions) occurring in the loops, and coupling to the Higgs boson. However, we will not be concerned here with predictions of any specific model.

2. Helicity amplitudes and density matrix

We consider the process \( pp \rightarrow W^\pm H X \) at the LHC, which at the partonic level proceeds via the process \( q\bar{q}' \rightarrow W^* \rightarrow W^\pm H \), where \( q \) and \( q' \) are quarks. After calculating the helicity amplitudes for the process in the presence of anomalous \( WWH \) couplings, we evaluate the production density matrix elements for the spin of the \( W \) at the partonic level and consequently for a hadronic initial state, to linear order in the anomalous couplings. We further examine how each of these polarization tensor elements may be measured from various angular asymmetries of charged leptons produced in the decay of the \( W \), and also estimate the sensitivity of these measurements for an assumed integrated luminosity of the experiment.

To calculate the helicity amplitudes for the production process in the quark-antiquark c.m. (centre-of-mass) frame,

\[
\begin{align*}
    u(p_1) + \bar{d}(p_2) &\rightarrow W^+(k) + H,
\end{align*}
\]

where \( u \) and \( d \) are respectively up-type and down-type quarks of any generation, we make use of the following representation for the polarization vectors of the \( W \):

\[
\begin{align*}
    \epsilon^\mu(k, \pm) &\equiv \left(0, \mp \frac{\cos \theta}{\sqrt{2}}, -\frac{i}{\sqrt{2}}, \pm \frac{\sin \theta}{\sqrt{2}}\right), \\
    \epsilon^\mu(k, 0) &\equiv \left(\frac{|\vec{k}|}{m_W}, \frac{E_W \sin \theta}{m_W}, 0, \frac{E_W \cos \theta}{m_W}\right)
\end{align*}
\]

where \( E_W \) is the energy of the \( W \) and \( \vec{k}_W \) its momentum, with polar angle \( \theta \) with respect to the direction of the \( u \) quark taken as the \( z \) axis.
The nonzero helicity amplitudes in the limit of massless quarks are given by

\[ M(-, +, -) = -g^2 V_{qq'} m_W \frac{\sqrt{s}}{2} \left[ a_W - (b_W + i\beta_W \hat{b}_W) \frac{\sqrt{s} E_W}{m_W^2} \right] \frac{(1 + \cos \theta)}{(s - m_W^2)} \]  

(5)

\[ M(-, +, 0) = -g^2 V_{qq'} \sqrt{\frac{s}{2}} E_W \left[ a_W - b_W \frac{\sqrt{s}}{E_W} \right] \frac{\sin \theta}{(s - m_W^2)} \]  

(6)

\[ M(-, +, +) = -g^2 V_{qq'} m_W \frac{\sqrt{s}}{2} \left[ a_W - (b_W - i\beta_W \hat{b}_W) \frac{\sqrt{s} E_W}{m_W^2} \right] \frac{(1 - \cos \theta)}{(s - m_W^2)} \]  

(7)

where \( \sqrt{s} \) is the total energy in the parton c.m. frame, \( \beta_W = |\vec{k}_W|/E_W \), and \( V_{qq'} \) is the appropriate element of the Cabibbo-Kobayashi-Maskawa matrix, and the first two entries in \( M \) correspond to helicities \(-1/2\) and \(+1/2\) of the quark and anti-quark, respectively.

The helicity amplitudes for the \( W^- \) production process

\[ d(p_1) + \bar{u}(p_2) \rightarrow W^-(k) + H \]  

(8)

are also given by eqns. (5)-(7), with the first two entries in \( M \) denoting the helicities of the \( d \) and \( \bar{u} \), and \( \theta \) representing the angle between \( W^- \) and \( d \). Here it is assumed that the same couplings \( a_W, b_W \) and \( \hat{b}_W \) occur in the process \( W^-* \rightarrow W^- H \) as in \( W^+* \rightarrow W^+ H \), as in an effective field theory approach [12].

In terms of the helicity amplitudes, the spin-density matrix for \( W \) production is defined as

\[ \rho(i, j) = \sum_{h_q, h_{\bar{q}}} M(h_q, h_{\bar{q}}, i) M(h_q, h_{\bar{q}}, j)^*, \]  

(9)

the sum and average being over initial helicities \( h_q, h_{\bar{q}} \) of the quark and anti-quark, respectively, and also over initial colour states, not shown explicitly. The diagonal elements for \( i = j \) would correspond to production probabilities with definite \( W \) polarization labelled by \( i = j \) as applicable, for example, in the study of helicity fractions. However, in the description of \( W \) production followed by decay, where measurement is made on the decay products, the full density matrix description, which includes off-diagonal elements, is needed. This is because a full description requires multiplying the helicity amplitudes
for production with the helicity amplitudes for decay in a coherent fashion
(see, for example, [13]).

The density matrix elements derived from the helicity amplitudes (5)-(7),
to linear order in the couplings $b_W$ and $\tilde{b}_W$, setting $a_W = 1$ are as follows.

\[
\rho(\pm, \pm) = \frac{g^4}{12} \frac{m_W^2 \hat{s}}{4(\hat{s} - m_W^2)^2} |V_{qq'}|^2 (1 \mp \cos \theta)^2 \left[ 1 - 2(Re b_W - \beta_W Im \tilde{b}_W) \frac{\sqrt{\hat{s}} E_W}{m_W^2} \right]
\]
(10)

\[
\rho(0, 0) = \frac{g^4}{12} \frac{E_W^2 \hat{s}}{2(\hat{s} - m_W^2)^2} |V_{qq'}|^2 \sin^2 \theta \left[ 1 - 2Re b_W \frac{\sqrt{\hat{s}}}{E_W} \right]
\]
(11)

\[
\rho(\mp, 0) = \frac{g^4}{12} \frac{\hat{s} m_W E_W}{2 \sqrt{2}(\hat{s} - m_W^2)^2} |V_{qq'}|^2 \sin \theta (1 \pm \cos \theta)
\]
(12)

\[
\times \left[ 1 - Re b_W \sqrt{\hat{s}} \frac{(E_W^2 + m_W^2)}{E_W m_W^2} - i Im b_W \sqrt{\hat{s}} \beta_W E_W \frac{m_W^2}{E_W} \mp i \beta_W \tilde{b}_W \sqrt{\hat{s}} E_W \frac{m_W^2}{E_W} \right]
\]
(13)

\[
\rho(\mp, \pm) = \frac{g^4}{12} \frac{m_W^2 \hat{s}}{4(\hat{s} - m_W^2)^2} |V_{qq'}|^2 \sin^2 \theta \left[ 1 - 2(Re b_W \pm i \beta_W Re \tilde{b}_W) \frac{\sqrt{\hat{s}} E_W}{m_W^2} \right]
\]
(14)

This density matrix, integrated over an appropriate kinematic range, can be used to determine the linear and tensor polarization components defined by [13]

\[
P_x = \frac{1}{(\sqrt{2} \sigma)} [\sigma(+, 0) + \sigma(0, +) + \sigma(-, 0) + \sigma(0, -)]
\]
(15)

\[
P_y = \frac{i}{(\sqrt{2} \sigma)} [\sigma(+, 0) - \sigma(0, +) - \sigma(-, 0) + \sigma(0, -)]
\]
(16)

\[
P_z = \frac{1}{\sigma} [\sigma(+, +) - \sigma(-, -)]
\]
(17)

\[
T_{xy} = \frac{i \sqrt{6}}{(4 \sigma)} [\sigma(+, -) - \sigma(-, +)]
\]
(18)

\[
T_{xz} = \frac{\sqrt{3}}{(4 \sigma)} [\sigma(+, 0) + \sigma(0, +) - \sigma(-, 0) - \sigma(0, -)]
\]
(19)

\[
T_{yz} = \frac{i \sqrt{3}}{(4 \sigma)} [\sigma(+, 0) - \sigma(0, +) + \sigma(-, 0) - \sigma(0, -)]
\]
(20)

\[
T_{xx} - T_{yy} = \frac{\sqrt{6}}{(2 \sigma)} [\sigma(+, -) + \sigma(-, +)]
\]
(21)
\[ T_{zz} = \frac{\sqrt{6}}{(6\sigma)}[\sigma(+,+) + \sigma(-,-) - 2\sigma(0,0)], \quad (22) \]

where \( \sigma(i,j) \) is the integral of \( \rho(i,j) \), and \( \sigma \) is the production cross section,
\[
\sigma = \sigma(+,+) + \sigma(-,-) + \sigma(0,0). \quad (23)
\]

3. Leptonic asymmetries

Obtaining spin information of the \( W \) requires measurements to be made on the decay products of the \( W \). Using leptonic decays is more convenient than using hadronic decays because charge identification is difficult, if not impossible, for that latter case. Expressions may be obtained for the decay-lepton distribution in the \( W \) production process by combining the relevant production-level density matrix elements with appropriate decay density matrix elements and integrating over the appropriate phase space. As mentioned before, a full measurement of the lepton distribution would require a very large number of events. It is more economical to use integrated angular asymmetries, which utilize all relevant events. We therefore adopt this approach and define different angular asymmetries of the charged lepton.

Following [5], we define angular asymmetries of the lepton arising from \( W \) decay, evaluated in the rest frame of the \( W \), which isolate various elements of the polarization tensor:

\[
A_x = \frac{\sigma(\cos \phi^* > 0) - \sigma(\cos \phi^* < 0)}{\sigma(\cos \phi^* > 0) + \sigma(\cos \phi^* < 0)}, \quad (24)
\]

\[
A_y = \frac{\sigma(\sin \phi^* > 0) - \sigma(\sin \phi^* < 0)}{\sigma(\sin \phi^* > 0) + \sigma(\sin \phi^* < 0)}, \quad (25)
\]

\[
A_z = \frac{\sigma(\cos \theta^* > 0) - \sigma(\cos \theta^* < 0)}{\sigma(\cos \theta^* > 0) + \sigma(\cos \theta^* < 0)}, \quad (26)
\]

\[
A_{xy} = \frac{\sigma(\sin 2\phi^* > 0) - \sigma(\sin 2\phi^* < 0)}{\sigma(\sin 2\phi^* > 0) + \sigma(\sin 2\phi^* < 0)}, \quad (27)
\]

\[
A_{xz} = \frac{\sigma(\cos \theta^* \cos \phi^* < 0) - \sigma(\cos \theta^* \cos \phi^* > 0)}{\sigma(\cos \theta^* \cos \phi^* > 0) + \sigma(\cos \theta^* \cos \phi^* < 0)}, \quad (28)
\]

\[
A_{yz} = \frac{\sigma(\cos \theta^* \sin \phi^* < 0) - \sigma(\cos \theta^* \sin \phi^* > 0)}{\sigma(\cos \theta^* \sin \phi^* > 0) + \sigma(\cos \theta^* \sin \phi^* < 0)}, \quad (29)
\]

\[
A_{x^2-y^2} = \frac{\sigma(\cos 2\phi^* > 0) - \sigma(\cos 2\phi^* < 0)}{\sigma(\cos 2\phi^* > 0) + \sigma(\cos 2\phi^* < 0)}, \quad (30)
\]
The direction of the quark momentum is defined as the $z$ axis, and the $x$ axis chosen to that the $W$ lies in the $xz$ plane. Using these axes, the angles $\theta^*$ and $\phi^*$ are the polar and azimuthal angles of the decay lepton, defined in the rest frame of the $W$.

It may be observed that since the sign of the triple vector product of the beam direction, the $W$ momentum direction and the lepton momentum direction determines the sign of $\sin\phi^*$, the asymmetries $A_y$, $A_{xy}$, $A_{yz}$ which are linear in $\sin\phi^*$ are measures of this triple vector product. These asymmetries are therefore odd under naive time reversal operation $T_N$, which is simply reversal of all momentum and spin directions. Hence these asymmetries would be either proportional to the $T$-odd parameter $\tilde{b}_W$, or proportional to the $T$-even coupling $b_W$, but to satisfy unitarity and the CPT theorem, proportional only to its imaginary part. This will be seen in the numerical expressions or asymmetries which follow later on.

4. Numerical results

To start with, we have evaluated the production spin density matrix elements after integrating over the parton distribution functions as well as the final-state phase space. We do not restrict ourselves to any particular decay mode of the Higgs, but assume that full identification is possible. In practice, one would have to apply kinematic cuts for lepton identification, elimination of backgrounds, etc., as also take into account the Higgs detection efficiency, which will require a more refined analysis.

We use the MMHT2014 parton distributions [14] with factorization scale chosen as the square root of the partonic c.m. energy. For the two cases of $W^+$ and $W^-$ production, though the partonic level cross sections and density matrices have the same expressions, the parton densities corresponding to the initial states are different. Hence the numerical results are different.

The results for the density matrices for $W^+$ production and $W^-$ production are shown respectively in Table 1 and Table 2.

The total cross section for $W^+$ production has the expression

$$\sigma = (720.4 - 5271 \text{Re } b_W) \text{ fb.} \quad (32)$$

and that for $W^-$ production the expression

$$\sigma = (471.8 - 3420 \text{Re } b_W) \text{ fb.} \quad (33)$$
Table 1: Production spin density matrix elements for the $W^+$ (in units of fb) for the SM and the coefficients of various couplings in each matrix element

| Matrix Element | SM | Re$b_W$ | Im$b_W$ | Re$b_W$ | Im$b_W$ |
|----------------|----|---------|---------|---------|---------|
| $\sigma(\pm, \pm)$ | 165.8 | $-1757$ | 0 | 0 | $\mp 1273$ |
| $\sigma(0, 0)$ | 388.7 | $-1757$ | 0 | 0 | 0 |
| $\sigma(\pm, \mp)$ | 82.91 | $-878.6$ | 0 | $\pm i636.8$ | 0 |
| $\sigma(\pm, 0)$ | 201.6 | $-1792$ | $-i863.7$ | $\pm i1046$ | $\mp 1046$ |
| $\sigma(0, \pm)$ | 201.6 | $-1792$ | $i863.7$ | $\mp i1046$ | $\mp 1046$ |

Table 2: Production spin density matrix elements for the $W^-$ (in units of fb) for the SM and the coefficients of various couplings in each matrix element

| Matrix Element | SM | Re$b_W$ | Im$b_W$ | Re$b_W$ | Im$b_W$ |
|----------------|----|---------|---------|---------|---------|
| $\sigma(\pm, \pm)$ | 110.2 | $-1140$ | 0 | 0 | $\mp 817.1$ |
| $\sigma(0, 0)$ | 251.5 | $-1140$ | 0 | 0 | 0 |
| $\sigma(\pm, \mp)$ | 55.10 | $-570.0$ | 0 | $\pm i408.5$ | 0 |
| $\sigma(\pm, 0)$ | 132.6 | $-1144$ | $-i531.7$ | $\pm i651.2$ | $\mp 651.2$ |
| $\sigma(0, \pm)$ | 132.6 | $-1144$ | $i531.7$ | $\mp i651.2$ | $\mp 651.2$ |

The total cross section for $W^+$ production could put a limit on $\text{Re } b_W$ of $2.28 \times 10^{-4}$ with an integrated luminosity $L = 500 \text{ fb}^{-1}$, and of $1.61 \times 10^{-4}$ with $L = 1000 \text{ fb}^{-1}$. The corresponding limits using cross section for $W^-$ production are $2.84 \times 10^{-4}$ and $2.01 \times 10^{-4}$. Measurement of the cross section using only electron and muon decay modes of the $W^+$ assuming branching ratios of 10.71% and 10.63% respectively, we can therefore set a limit of $4.93 \times 10^{-4}$ on the coupling $\text{Re } b_W$ for $L = 500 \text{ fb}^{-1}$, and $3.49 \times 10^{-4}$ for $L = 1000 \text{ fb}^{-1}$. The corresponding numbers for $W^-$ are respectively $6.15 \times 10^{-4}$ and $4.35 \times 10^{-4}$.

The leptonic asymmetries corresponding to the different polarizations in $W^+$ production and decay, in an obvious notation, are given by

$$A_x = -0.594 + 0.933 \text{ Re } b_W$$
$$A_y = 3.08 \text{ Re } \tilde{b}_W$$
$$A_z = 2.60 \text{ Im } \tilde{b}_W$$
$$A_{xy} = -0.563 \text{ Re } \tilde{b}_W$$
$$A_{xz} = 1.24 \text{ Im } \tilde{b}_W$$
\[ A_{yz} = 1.08 \text{Im} b_W \]  
\[ A_{x^2-y^2} = 0.0733 - 0.240 \text{Re} b_W \]  
\[ A_{zz} = -0.116 - 0.849 \text{Re} b_W \]  

The corresponding asymmetries in $W^-$ production and decay are

\[ A_x = -0.596 + 0.820 \text{Re} b_W \]  
\[ A_y = 2.93 \text{Re} \tilde{b}_W \]  
\[ A_z = 2.65 \text{Im} \tilde{b}_W \]  
\[ A_{xy} = -0.551 \text{Re} \tilde{b}_W \]  
\[ A_{xz} = 1.31 \text{Im} \tilde{b}_W \]  
\[ A_{yz} = 1.01 \text{Im} b_W \]  
\[ A_{x^2-y^2} = 0.0744 - 0.230 \text{Re} b_W \]  
\[ A_{zz} = -0.112 - 0.814 \text{Re} b_W \]  

In order to evaluate the 1-$\sigma$ limit $C_{\text{limit}}$ on a coupling $C$ which can be obtained from the asymmetries, assuming one coupling to be nonzero at a time, and an integrated luminosity $L$, we use the expression

\[
C_{\text{limit}} = \sqrt{1 - A^2_{\text{SM}}} \frac{1}{|A - A_{\text{SM}}| \sqrt{\sigma_{\text{SM}} L}},
\]  

where $A$ is the asymmetry for unit value of the coupling $C$. For $W^+$ production, for integrated luminosities of 500 fb$^{-1}$ and 1000 fb$^{-1}$, we obtain the limits shown in Table 3.

The corresponding limits from $W^-$ production and decay are shown in Table 4.
| Asymmetry | Coupling | Limit (in $10^{-3}$) \( (L = 500 \text{ fb}^{-1}) \) | Limit (in $10^{-3}$) \( (L = 1000 \text{ fb}^{-1}) \) |
|-----------|----------|----------------------------------|----------------------------------|
| \( A_x \) | \( \text{Re } b_W \) | 3.1 | 2.2 |
| \( A_y \) | \( \text{Re } \tilde{b}_W \) | 1.2 | 8.3 |
| \( A_z \) | \( \text{Im } \tilde{b}_W \) | 1.4 | 0.96 |
| \( A_{xy} \) | \( \text{Re } b_W \) | 6.4 | 4.5 |
| \( A_{xz} \) | \( \text{Im } \tilde{b}_W \) | 2.8 | 2.0 |
| \( A_{yz} \) | \( \text{Im } b_W \) | 3.3 | 2.4 |
| \( A_{x^2-y^2} \) | \( \text{Re } b_W \) | 15 | 11 |
| \( A_{zz} \) | \( \text{Re } b_W \) | 4.2 | 3.0 |

Table 3: 1-\( \sigma \) limits which could be obtained from various leptonic asymmetries in \( W^+ \) production and decay, with integrated luminosities of 500 and 1000 \( \text{fb}^{-1} \).

| Asymmetry | Coupling | Limit (in $10^{-3}$) \( (L = 500 \text{ fb}^{-1}) \) | Limit (in $10^{-3}$) \( (L = 1000 \text{ fb}^{-1}) \) |
|-----------|----------|----------------------------------|----------------------------------|
| \( A_x \) | \( \text{Re } b_W \) | 4.4 | 3.1 |
| \( A_y \) | \( \text{Re } \tilde{b}_W \) | 1.5 | 1.1 |
| \( A_z \) | \( \text{Im } \tilde{b}_W \) | 1.7 | 1.2 |
| \( A_{xy} \) | \( \text{Re } b_W \) | 8.1 | 5.7 |
| \( A_{xz} \) | \( \text{Im } \tilde{b}_W \) | 3.6 | 2.5 |
| \( A_{yz} \) | \( \text{Im } b_W \) | 4.4 | 3.1 |
| \( A_{x^2-y^2} \) | \( \text{Re } b_W \) | 19 | 14 |
| \( A_{zz} \) | \( \text{Re } b_W \) | 5.4 | 3.9 |

Table 4: 1-\( \sigma \) limits which could be obtained from various leptonic asymmetries in \( W^- \) production and decay, with integrated luminosities of 500 and 1000 \( \text{fb}^{-1} \).
5. Conclusions

It is important to obtain complete information about the Higgs boson discovered at the LHC, including the tensor form of the couplings. A proposal to measure form and magnitude of the coupling of the Higgs boson to a pair of $W$ bosons through the polarization data of the $W$ is investigated here. The polarization density matrix elements of the $W$ can be measured through certain angular asymmetries of the charged lepton produced in $W$ decay, and we have studied the sensitivity of these asymmetries to the anomalous couplings $b_W$ and $\tilde{b}_W$ defined in eqn. (1). Our results for $W^+$ and $W^-$ are shown in tables 3 and 4.

We see that a high degree of accuracy could be obtained in the measurement of the $WWW$ anomalous couplings from the measurement of the $W$ polarization parameters through suitable angular asymmetries of leptons assuming an integrated luminosity of 500 fb$^{-1}$. There is considerable improvement, as expected, if the luminosity is increased to 1000 fb$^{-1}$. The 1-$\sigma$ limits in most cases are of the order of a few times $10^{-3}$. A full-scale analysis using an event-generator coupled with appropriate cuts relevant to the decay channels of the Higgs would be able to refine the actual sensitivities that we have obtained. It would also be profitable to combine the results from $W^+$ and $W^-$ production processes, which would improve the accuracy.

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