

PYBBWH: A program for associated charged Higgs and W boson production

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Abstract

The Monte Carlo program, PYBBWH, is an implementation of the associated production of a charged Higgs and a W boson from $b\bar{b}$ fusion in a general Two-Higgs-Doublet model for both CP-conserving and CP-violating couplings. It is implemented as an external process to PYTHIA 6. The code can be downloaded from <http://www.isv.uu.se/thepp/MC/pybbwh>.

1 Associated H^\pm and W boson production

The program, PYBBWH, is an implementation of the production of a charged Higgs boson, H^\pm , in association with a W boson. The code was developed for the research presented in [1] where details on the theory and numerical results are presented. This program is written for a general Two-Higgs-Doublet model type II. The dominant production mode at tree level occurs via $b\bar{b}$ fusion and at one-loop-level via gluon fusion. This program implements the leading order $b\bar{b}$ fusion part and the relevant Feynman diagrams are given in figure 1. By only including $b\bar{b}$ fusion this program is most suited for intermediate H^\pm masses and large $\tan\beta$.

In a general type II 2HDM the couplings relevant for this production can be specified via the Higgs mixing matrix O_{ji} in the following way

$$\begin{aligned} g_{H_i H^- W^+} &= g_{H_i H^+ W^-}^* = O_{2i} \cos\beta - O_{1i} \sin\beta + i O_{3i}, \\ g_{H_i \bar{b} b} &= O_{1i} + i O_{3i} \sin\beta. \end{aligned} \tag{1}$$

In a real 2HDM where $H_i = \{h^0, H^0, A^0\}$ the mixing matrix has the simple form

$$O_{ji} = \begin{pmatrix} -\sin\alpha & \cos\alpha & 0 \\ \cos\alpha & \sin\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{2}$$

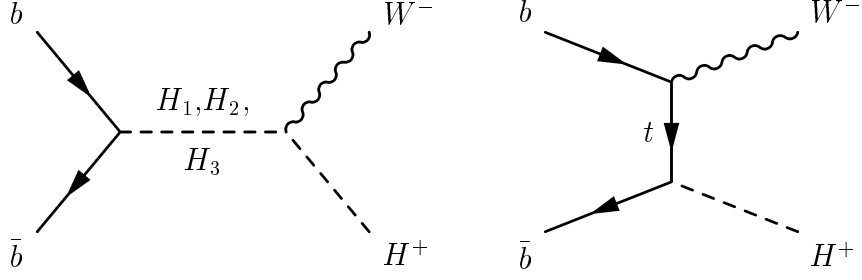


Figure 1: Feynman diagrams for $H^\pm W^\mp$ production via $b\bar{b}$ annihilation, $b\bar{b} \rightarrow H^\pm W^\mp$.

which gives purely real couplings for h^0 , H^0 and imaginary couplings for A^0 . In a general 2HDM there can be mixing between the CP-even and CP-odd Higgs states and the mixing matrix can have all elements non-zero.

Using a formalism with only diagonal propagators for the Higgs bosons¹, the differential cross-sections implemented in this program for the two processes are [2, 3]:

$$\begin{aligned} \frac{d\sigma}{dt}(b\bar{b} \rightarrow H^+W^-) &= \frac{G_F^2}{24\pi s} \\ &\left\{ \frac{m_b^2 \lambda(s, m_W^2, m_{H^\pm}^2)}{2 \cos^2 \beta} \sum_{i,j} g_{H_i H^- W^+} g_{H_j H^- W^+}^* S_{H_i} S_{H_j}^* \text{Re}[g_{H_i \bar{b} b} g_{H_j \bar{b} b}^*] \right. \\ &+ \frac{1}{(t - m_t^2)^2} [m_t^4 \cot^2 \beta (2m_W^2 + p_\perp^2) + m_b^2 \tan^2 \beta (2m_W^2 p_\perp^2 + t^2)] \\ &\left. + \frac{m_b^2 \tan \beta}{(t - m_t^2) \cos \beta} [m_W^2 m_{H^\pm}^2 - s p_\perp^2 - t^2] \sum_i \text{Re} [g_{H_i H^- W^+} + g_{H_i \bar{b} b} S_{H_i}] \right\}, \quad (3) \end{aligned}$$

$$\begin{aligned} \frac{d\sigma}{dt}(b\bar{b} \rightarrow H^-W^+) &= \frac{G_F^2}{24\pi s} \\ &\left\{ \frac{m_b^2 \lambda(s, m_W^2, m_{H^\pm}^2)}{2 \cos^2 \beta} \sum_{i,j} g_{H_i H^- W^+}^* g_{H_j H^- W^+} S_{H_i} S_{H_j}^* \text{Re}[g_{H_i \bar{b} b}^* g_{H_j \bar{b} b}] \right. \\ &+ \frac{1}{(t - m_t^2)^2} [m_t^4 \cot^2 \beta (2m_W^2 + p_\perp^2) + m_b^2 \tan^2 \beta (2m_W^2 p_\perp^2 + t^2)] \\ &\left. + \frac{m_b^2 \tan \beta}{(t - m_t^2) \cos \beta} [m_W^2 m_{H^\pm}^2 - s p_\perp^2 - t^2] \sum_i \text{Re} [g_{H_i H^- W^+}^* + g_{H_i \bar{b} b}^* S_{H_i}] \right\}, \quad (4) \end{aligned}$$

where s and t are the ordinary Mandelstam variables of the hard process and

$$\lambda(x, y, z) = x^2 + y^2 + z^2 - 2(xy + yz + zx), \quad (5)$$

¹This formalism is valid as long as the Higgs bosons are well separated in mass. If they are so close that they overlap non-diagonal propagators are needed and this program can not be used.

$$p_{\perp}^2 = \frac{\lambda(s, m_W^2, m_{H^{\pm}}^2) \sin^2 \theta}{4s}, \quad (6)$$

with θ being the polar angle in the $2 \rightarrow 2$ cms and

$$S_{H_i} = \frac{1}{s - m_{H_i}^2 + im_{H_i} \Gamma_{H_i}} \quad (7)$$

the propagators of the neutral Higgs bosons.

2 Implementation

The associated production program is implemented as an external process to PYTHIA 6. It uses the Les Houches generic user process interface for event generators [4] but it also uses PYTHIA specific routines. This means it can not be used directly together with other event generators, but after some minor changes to the code it should be possible. The code has been tested with with PYTHIA version 6.324 and the most recent version 6.413. Details on how to use an external process can be found in the PYTHIA 6 manual [5], section 9.9. In principle this is done by initiating PYTHIA with `PYINIT('USER', ' ', ' ', ' ', 0d0)`. The program does not work directly with PYTHIA 8 but it can be made to work via the Les Houches interface in PYTHIA 8.

The widths of the H^{\pm} and W bosons are included in the same way as in standard PYTHIA whenever possible, see details below. In other words the H^{\pm} and W masses vary according to Breit-Wigner distributions with mass dependent widths meaning that for each mass the decay widths are recalculated based on the open decay channels.

The program is setup for simulating LHC events as default, meaning incoming protons with 7 TeV energy. This can be changed by setting the parameters `IDBMUP` and `EBMUP` to incoming particle type and energy respectively. These parameters has to be set before `PYINIT` is called.

2.1 PYTHIA specified couplings

PYTHIA contains different SUSY simulations. The default in the PYBBWH program is to assume that one of these is used, so that the Higgs mixing angle α and $\tan \beta$ are given in `RMSS(18)` and `RMSS(5)`, respectively. The Higgs mixing matrix and the couplings used in the process generation is then calculated from α and $\tan \beta$. Some checks are performed to see if the values of `RMSS(18)` and `RMSS(5)` correspond to the Higgs-fermion couplings used in PYTHIA for Higgs decay. A warning is printed if an inconsistency is detected.

2.2 User specified couplings

If an external SUSY simulation or a general 2HDM type II is used, especially one with CP-violation, the default method can no longer be used. In this case the common block PYBBWH is used. It is defined as

```
INTEGER IPYBBWH
DOUBLE PRECISION O_M
COMMON/PYBBWH/O_M(3,3),IPYBBWH
```

where `O_M(3,3)` is the Higgs mixing matrix. `IPYBBWH` is a switch with the default value of 0, meaning `PYTHIA` specified couplings. For `IPYBBWH=1`, `O_M(3,3)` is used to calculate the couplings. Also in this case $\tan\beta$ is taken from `RMSS(5)`. The masses and widths for all Higgs particles must also be set correctly in the `PMAS` array.

Another difference between `IPYBBWH=0` and `IPYBBWH=1` is that for the former a varying width is used for the charged Higgs but for the later a fixed width, the one given by `PMAS(37,2)`, is used. This behavior is motivated since if the Higgs mixing matrix is specified in `O_M` the couplings used in `PYTHIA` to calculate the Higgs decay are probably wrong. If ones wants to use a varying width in this case this can be done by substituting the function

```
DOUBLE PRECISION FUNCTION HPWID(MHP)
```

with a new function that gives the correctly varying width. The argument given to `HPWID` is defined as

```
DOUBLE PRECISION MHP
```

and is the mass at which the width is to be calculated.

3 Download

The code can be downloaded from <http://www.isv.uu.se/thepp/MC/pybbwh>. On that web page there is also two example programs, one for `PYTHIA` specified couplings and one for User specified couplings.

4 Final comments

This code was developed for research published in [1]. The work was done in collaboration with Stefan Hesselbach and Johan Rathsman. If you use the code please cite [1] and this manual.

References

- [1] D. Eriksson, S. Hesselbach and J. Rathsman, “Associated charged Higgs and W boson production in the MSSM at the CERN Large Hadron Collider,” arXiv:hep-ph/0612198.
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