The general Two-Higgs-Doublet Model

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Description of the model

The two-Higgs-doublet model (2HDM) has been extensively studied for more than twenty years now, even though it has often been only considered as the scalar sector of some larger model, like the MSSM or some Little Higgs models for example. The general 2HDM considered here already displays by itself an interesting phenomenology that justifies its study like, for example, new sources of CP violation in scalar-scalar interactions, tree-level flavour changing neutral currents (FCNC's) due to non diagonal Yukawa interactions, or a light pseudoscalar state and unusual Higgs decays

The 2HDM considered here is based on two SU(2) doublets with the same hypercharge Y=+1. If one imposes only gauge invariance, the most general renormalisable scalar potential can be found in the reference quoted below. This potential has 6 real (mu_(1,2) and lambda_(1,2,3,4)) and four complex parameters (mu_3 and lambda_(5,6,7)). We assume the electromagnetic gauge symmetry is preserved, i.e. , that the vev's of two doublets are aligned in the SU(2) space in such a way that a single SU(2) gauge transformation suffices to rotate them to the neutral components.

The most general form for the Yukawa interactions contains two 3x3 complex Yukawa coupling matrices, noted Delta_i and Gamma_i, expressed in the fermion physical basis, i.e. in the basis where the fermion mass matrix are diagonal. Since the fermion mass matrix is
fixed, only the Gamma_i matrices, i.e. the Yukawa couplings of the second Higgs doublet, are required. We choose as free parameters the Gamma_i matrices, while the other Yukawa couplings, the Delta_i matrices, are deduced from the matching with the observed fermion masses. Conventionally, the indices of the elements of these Yukawa matrices refer to the generations of the SU(2) doublet and singlet, respectively

The 2HDM Lagrangian implemented in FeynRules is based on the Standard Model default implementation, where the scalar potential and Yukawa interactions have been modified as explained above. An important feature of this model is the freedom to redefine the two scalar fields using arbitrary "horizontal" U(2) transformations acting on the two doublets simultaneously since this transformation leaves the gauge-covariant kinetic energy terms invariant. Since a given set of Lagrangian parameter values is only meaningful for a given basis, let us take advantage of this invariance property to select the Higgs basis (by defining the additional file HiggsBasis?.fr) where only one of the two Higgs fields acquires a non-zero vev, namely H_1. Note that the Higgs basis is not univocally defined since a phase reparametrization of H_2 leaves the Higgs basis condition invariant, so that the phase of H_2 can be fixed in such a way that lambda_5 becomes real. Other basis choices can in principle be easily implemented as different extension files for the main Lagrangian file Lag.fr.

There are two independent minimization conditions for general 2HDM potential, one relating m_1 to lambda_1 and one relating m_3 to lambda_6. This reduces the number of free parameters in the most general 2HDM to ten (seven real parameters, three complex ones and three minimization conditions). Besides the usual three massless would-be Goldstone bosons, the physical spectrum also contains a pair of charged Higgs with a mass directly related to lambda_3 and m_2, so that m_2 can be directly extracted from this mass, given as an external input.

The symmetric matrix squared mass matrix for the three neutral Higgs field is diagonalized by an orthogonal matrix T which describe the relation between the physical scalar fields and the doublet neutral components. Even though this matrix is directly related to the potential parameter, it is still considered as an external input in the current implementation and must be provided by the user.

In the current implementation of the 2HDM into FeynRules, the user has to provide numerical values for all the lambda_i parameters in the Higgs basis, together with the charged Higgs mass. The other parameters of the potential, such as the \mu_i, are then deduced from these inputs. Contrary, the T matrix must be calculated externally. This, together with the change of basis required if the user wants to provide potential parameters and Yukawa coupling values in bases different from the Higgs basis, as it is often the case, can be done using the *TwoHiggsCalc?* calculator introduced for the original implementation of the 2HDM in MadGraph?. This code has been modified to produce a parameter file compatible with the present implementation. This calculator can also be used to calculate the required Higgs boson tree-level decay widths. It can be found at

?http://cp3wks05.fynu.ucl.ac.be/Calculators/TwoHiggsCalc/index.html

References

- " *CP violation* ", G. Branco, L. Lavoura and J. P. Silva, Clarandon Press, Oxford, 1999. Chapter 22.

Model files

- ?2HDM.tar.gz: This archive contains all the model files. Should be expanded in the FR model directory.
- ?HBreal.rst: Additionnal restriction file to define all parameters as being real, to be used, for example, with !CalcHEP?

Instructions

The model-file is loaded in the usual way.

Feynman gauge is not supported, only unitary gauge is available.

Examples

- ?2HDM.nb : This is an example Mathematica® notebook that loads the model and calculates Feynman rules.
- ?param_card_FR.dat : This is an example of LHA parameter file to be used with this model. It also contains the defalut values used for validation.

Validation

- ?Phase space point comparison with stock version
- ?Cross section comparison, for tau/nu_tau initial state
- ?Cross section comparison, for tau/tau initial state
- ?Cross section comparison, for tau/tau initial state (part 2)
- ?Cross section comparison, for VV initial state
- ?Cross section comparison, for VSSS external legs